Could A Fixed-Target ExpeRiment at the LHC (AFTER@LHC) be part of COMPASS future ?

Jean-Philippe Lansberg
IPN Orsay, Université Paris-Sud

COMPASS Collaboration Meeting, September 20, 2013

thanks to M. Anselmino (Torino), R. Arnaldi (Torino), S.J. Brodsky (SLAC), V. Chambert (IPNO), J.P. Didelez (IPNO), E.G. Ferreiro (USC), F. Fleuret (LLR), B. Genolini (IPNO), C. Hadjidakis (IPNO), C. Lorcé (IPNO),A. Rakotozafindrabe (CEA), P. Rosier (IPNO), I. Schienbein (LPSC), E. Scomparin (Torino), U.I. Uggerhøj (Aarhus) and R. Ulrich (KIT)

Part I

Why a new fixed-target experiment for High-Energy Physics now ?

Decisive advantages of Fixed-target experiments

- Fixed-target experiments offer specific **advantages** that are still nowadays **difficult to challenge by collider experiments**

Decisive advantages of Fixed-target experiments

- Fixed-target experiments offer specific **advantages** that are still nowadays **difficult to challenge by collider experiments**
- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain ($x_F \equiv \frac{p_z}{p_{z\,\max}}$)
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will,
  - polarising the target.

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on July 14, 2006

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on July 14, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,
the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,
the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,
the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity, yet without pile-up
- with virtually no limit on particle-species studies (except top quark)

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,
the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity, yet without pile-up
- with virtually no limit on particle-species studies (except top quark)
- with modern detection techniques

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

> k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
>
> **pg 22. of the Strategy Update Brochure**

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity, yet without pile-up
- with virtually no limit on particle-species studies (except top quark)
- with modern detection techniques

AFTER@LHC would definitely be a **unique** experiment

Part II

A fixed-target experiment using the LHC beam(s): AFTER@LHC

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E^{\gamma}_{CM} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma^{Lab}_{CM} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E^{\gamma}_{CM} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

[Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]

Generalities

- pp or pA collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
    - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
    - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
    - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]
- Good thing: small forward detector $\equiv$ large acceptance
- Bad thing: high multiplicity $\Rightarrow$ absorber $\Rightarrow$ physics limitation

Backward physics ?

- Let's adopt a novel strategy and look at **larger angles**

Backward physics ?

- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  · reduced multiplicities at large(r) angles
  · **access to partons with momentum fraction $x \to 1$ in the target**
  · last, but not least, the beam pipe is in practice
  not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$

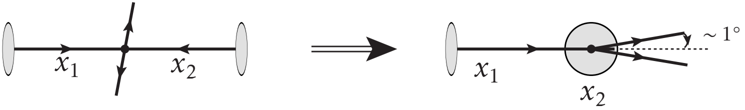
Backward physics ?

- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  - · reduced multiplicities at large(r) angles
  - · **access to partons with momentum fraction $x \to 1$ in the target**
  - · last, but not least, the beam pipe is in practice

    not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$

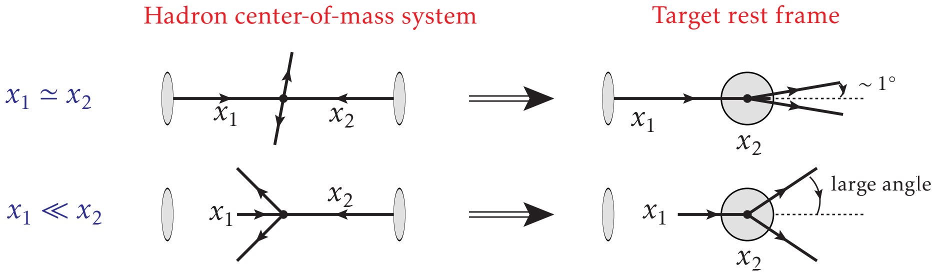
Hadron center-of-mass system — Target rest frame

$x_1 \simeq x_2$



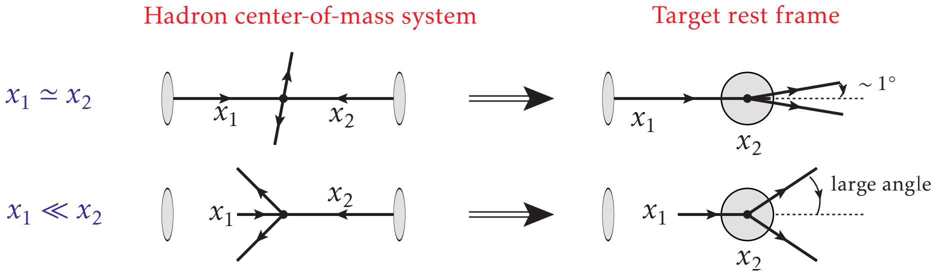
Backward physics ?

- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  - · reduced multiplicities at large(r) angles
  - · **access to partons with momentum fraction $x \to 1$ in the target**
  - · last, but not least, the beam pipe is in practice not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$



Backward physics ?

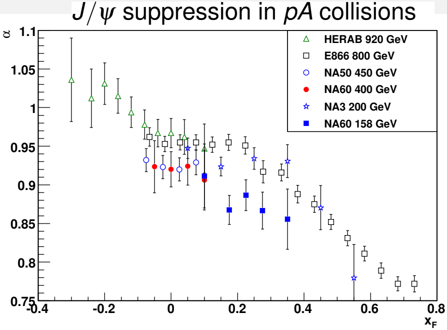
- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  - · reduced multiplicities at large(r) angles
  - · **access to partons with momentum fraction $x \to 1$ in the target**
  - · last, but not least, the beam pipe is in practice
    not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$



backward physics = large-x_2 physics

First systematic access to the target-rapidity region ($x_F \to -1$)

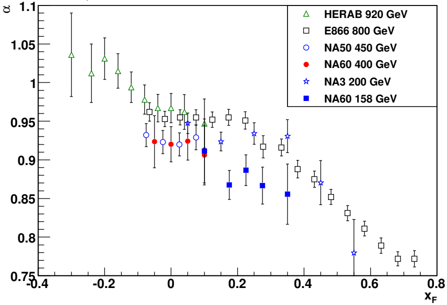
First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1

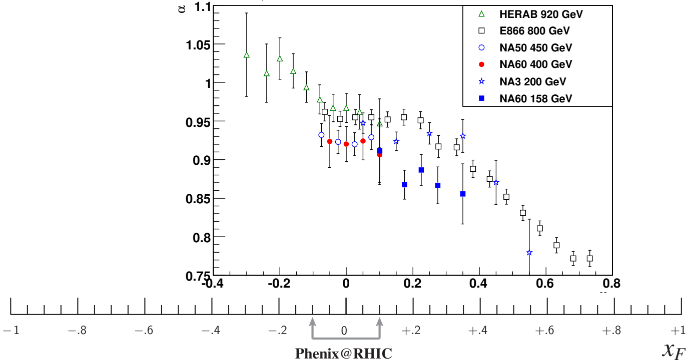
First systematic access to the target-rapidity region ($x_F \to -1$)

J/ψ suppression in pA collisions



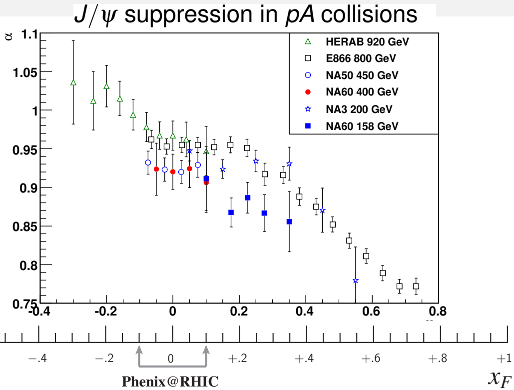
- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3

First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$

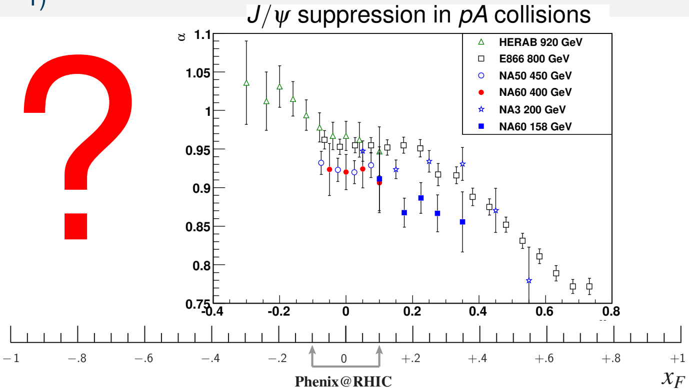
First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$

First systematic access to the target-rapidity region ($x_F \to -1$)

?



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$
- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \;\Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

The beam extraction

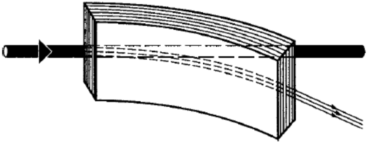
★ The LHC beam may be extracted using "Strong crystalline field" **without any decrease in performance of the LHC !**

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131

The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
without any decrease in performance of the LHC !

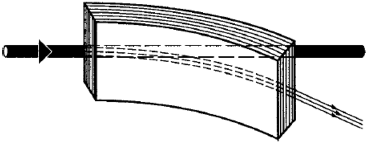
E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



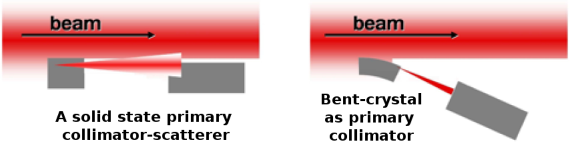
The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



★ Illustration for collimation

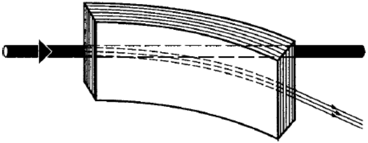


The beam extraction

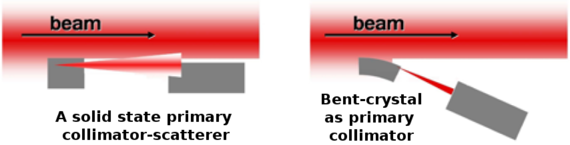
★ The LHC beam may be extracted using "Strong crystalline field"

without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



★ Illustration for collimation



★ Tests will be performed on the LHC beam:

LUA9 proposal approved by the LHCC

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ \mathrm{s}^{-1}$

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathscr{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathscr{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\int\mathcal{L}$ (pb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**26**	**260**
Liq. H_2	0.07	1	**20**	**200**
Liq. D_2	0.16	2	**24**	**240**
Be	1.85	9	**62**	**620**
Cu	8.96	64	**42**	**420**
W	19.1	185	**31**	**310**
Pb	11.35	207	**16**	**160**

Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, . . .)

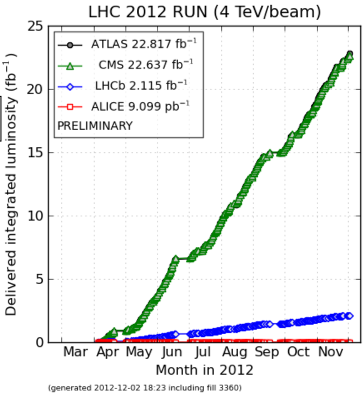
Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$

Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \mathrm{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

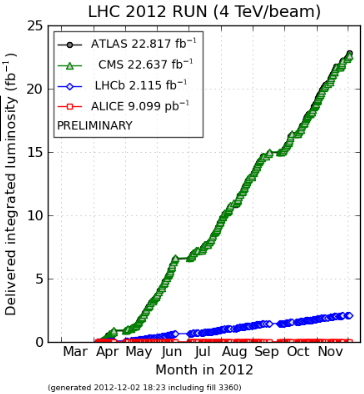


Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  · Run14dAu 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV

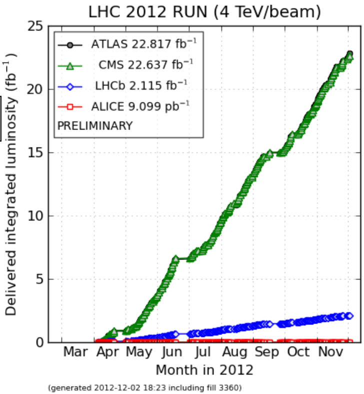


Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  · Run14dAu 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
- AFTER vs PHENIX@RHIC:
  3 orders of magnitude larger



Luminosities

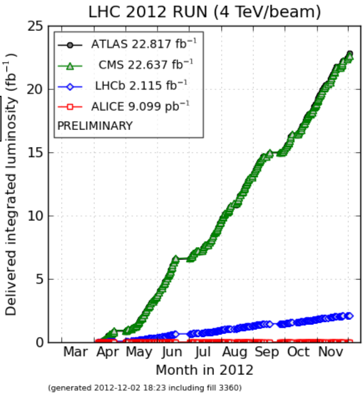
- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1}y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  - · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  - · Run14dAu 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
- AFTER vs PHENIX@RHIC:

  3 orders of magnitude larger
- Lumi for Pb runs in the backup slides

  (roughly 10 times that planned for the LHC)



A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**

A few figures on the (extracted) proton beam

- Beam loss: 10^9 $p^+ \mathrm{s}^{-1}$
- Extracted intensity: 5×10^8 $p^+ \mathrm{s}^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$

A few figures on the (extracted) proton beam

- Beam loss: 10^9 $p^+ s^{-1}$
- Extracted intensity: 5×10^8 $p^+ s^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz

A few figures on the (extracted) proton beam

- Beam loss: 10^9 $p^+\text{s}^{-1}$
- Extracted intensity: 5×10^8 $p^+\text{s}^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s^{-1} $\simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,

no pile-up !

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s^{-1} $\simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,

no pile-up !

- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h^{-1} $\times 10$ h $= 1.8 \times 10^{13} p^+$ fill^{-1}
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq 5.6\%$ of the p^+ in the beam

These protons are lost anyway !

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s^{-1} $\simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,

no pile-up !

- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h^{-1} $\times 10$ h $= 1.8 \times 10^{13} p^+$ fill^{-1}
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq 5.6\%$ of the p^+ in the beam

These protons are lost anyway !

- similar figures for the Pb-beam extraction

Part III

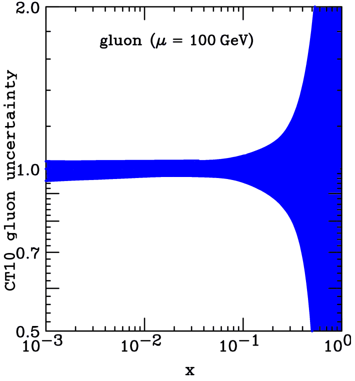
AFTER: flagship measurements

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton

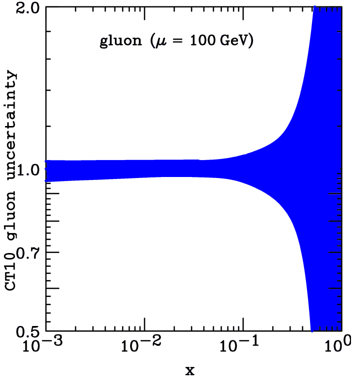
Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - Very large uncertainties



Key studies: gluons in the proton

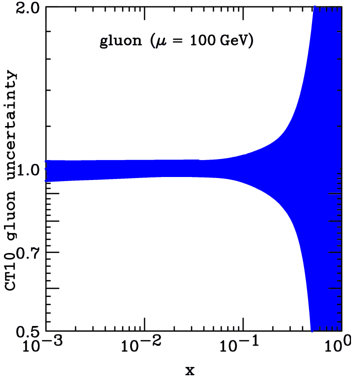
- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - Very large uncertainties



Accessible thanks gluon sensitive probes,

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - Very large uncertainties

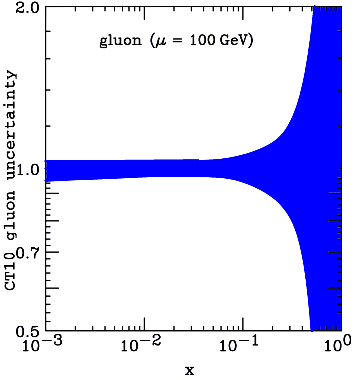


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
    - Not easily accessible in DIS
    - Very large uncertainties

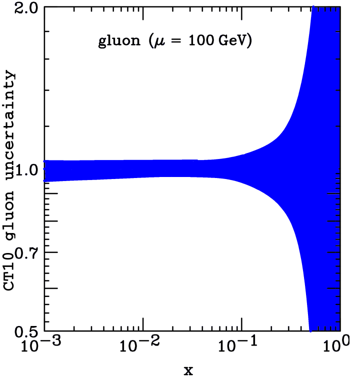


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - Very large uncertainties

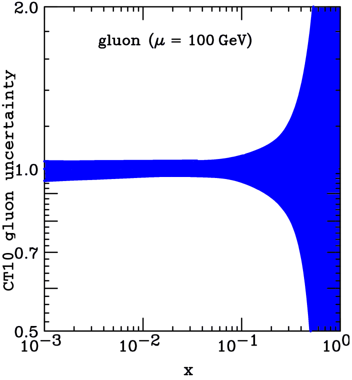


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311
- jets ($P_T \in [20, 40]$ GeV)

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - Very large uncertainties

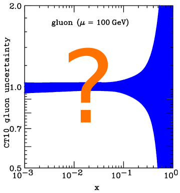


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311
- jets ($P_T \in [20, 40]$ GeV)

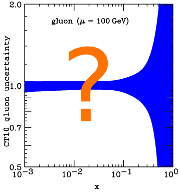
Multiple probes needed to **check factorisation**

Key studies: gluons in the neutron



Gluon PDF for the neutron unknwon

Key studies: gluons in the neutron

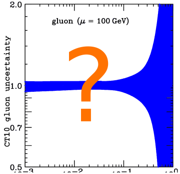


Gluon PDF for the neutron unknwon

possible experimental probes

- heavy quarkonia
- isolated photons
- jets

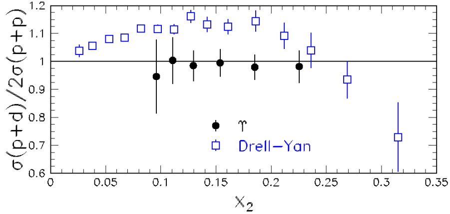
Key studies: gluons in the neutron



Gluon PDF for the neutron unknwon

possible experimental probes

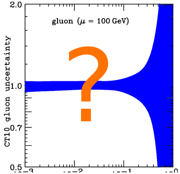
- heavy quarkonia
- isolated photons
- jets



Pioneer measurement by E866

- using $\Upsilon \to Q^2 \simeq 100$ GeV^2
- outcome: $g_n(x) \simeq g_p(x)$

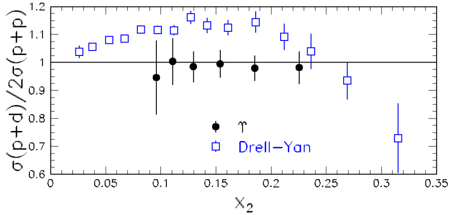
Key studies: gluons in the neutron



Gluon PDF for the neutron unknwon

possible experimental probes

- heavy quarkonia
- isolated photons
- jets



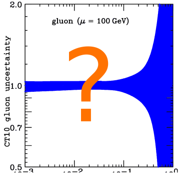
Pioneer measurement by E866

- using $\Upsilon \to Q^2 \simeq 100$ GeV^2
- outcome: $g_n(x) \simeq g_p(x)$

could be extended with AFTER

- using J/ψ, ..., $C = +1$ onia, ...
- wider x range & lower Q^2

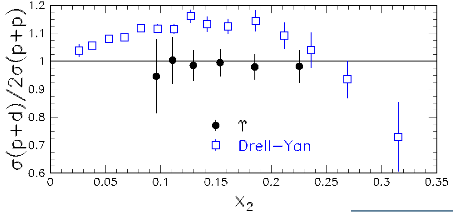
Key studies: gluons in the neutron



Gluon PDF for the neutron unknwon

possible experimental probes

- heavy quarkonia
- isolated photons
- jets



Pioneer measurement by E866

- using $\Upsilon \to Q^2 \simeq 100$ GeV^2
- outcome: $g_n(x) \simeq g_p(x)$

could be extended with AFTER

- using J/ψ, ..., $C = +1$ onia, ...
- wider x range & lower Q^2

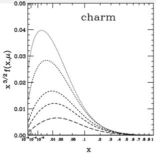
target	yearly lumi	$\mathcal{B}\frac{dN_{J/\psi}}{dy}$	$\mathcal{B}\frac{dN_{\Upsilon}}{dy}$
1m Liq. H_2	20 fb^{-1}	4.0×10^8	9.0×10^5
1m Liq. D_2	24 fb^{-1}	9.6×10^8	1.9×10^6

Key studies

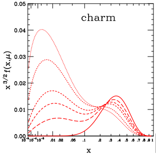
- Heavy-quark distributions (at high x_B)

Key studies

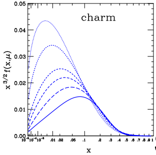
- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last



DGLAP



BHPS

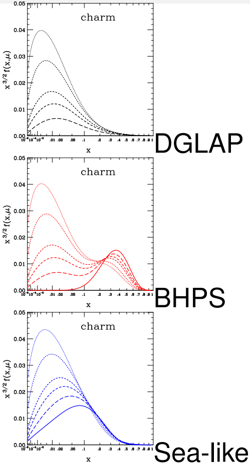


Sea-like

3 sets from CTEQ6c (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

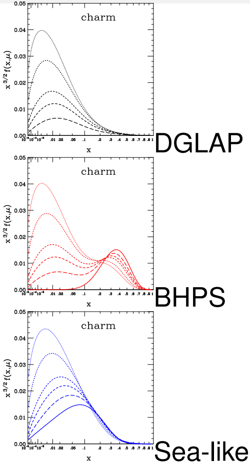


3 sets from CTEQ6c (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires



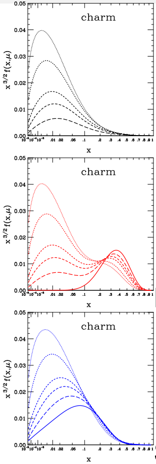
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires

  - several complementary measurements



DGLAP

BHPS

Sea-like

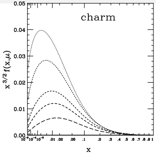
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies

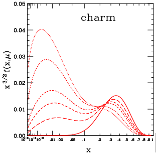
- Heavy-quark distributions (at high x_B)
    - Pin down intrinsic charm, ... at last
    - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires

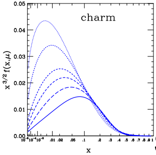
- several complementary measurements
- good coverage in the target-rapidity region



DGLAP



BHPS



Sea-like

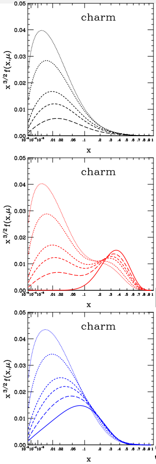
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires

  - several complementary measurements
  - good coverage in the target-rapidity region
  - high luminosity to reach large x_B



DGLAP

BHPS

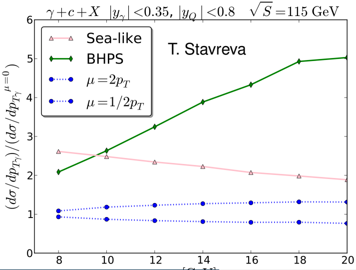
Sea-like

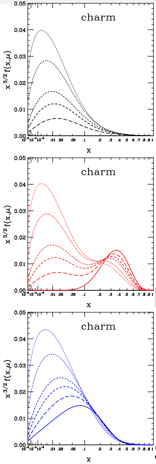
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \rightarrow 0$)

  requires
  - several complementary measurements
  - good coverage in the target-rapidity region
  - high luminosity to reach large x_B





DGLAP

BHPS

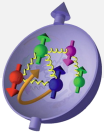
Sea-like

3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: gluon contribution to the proton spin

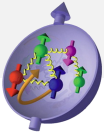
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin

Key studies: gluon contribution to the proton spin



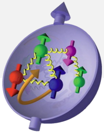
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using gluon sensitive probes

Key studies: gluon contribution to the proton spin



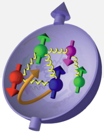
- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
    - Transverse single spin asymetries using gluon sensitive probes
    - quarkonia (J/ψ, Υ, χ_c, $\ldots$) **F. Yuan, PRD 78 (2008) 014024**

Key studies: gluon contribution to the proton spin



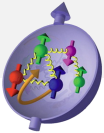
- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - *B* & *D* meson production

Key studies: gluon contribution to the proton spin



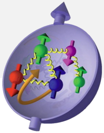
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - *B* & *D* meson production
  - γ, γ-jet, $\gamma - \gamma$ **A. Bacchetta,** ***et al.*****, PRL 99 (2007) 212002** **J.W. Qiu,** ***et al.*****, PRL 107 (2011) 062001**

Key studies: gluon contribution to the proton spin



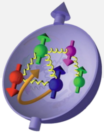
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - B & D meson production
  - γ, γ-jet, $\gamma - \gamma$ **A. Bacchetta, *et al.*, PRL 99 (2007) 212002** **J.W. Qiu, *et al.*, PRL 107 (2011) 062001**
- the target-rapidity region corresponds to high $x^{\uparrow}$
  where the k_T-spin correlation is the largest

Key studies: gluon contribution to the proton spin



- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - B & D meson production
  - γ, γ-jet, $\gamma - \gamma$ **A. Bacchetta, *et al.*, PRL 99 (2007) 212002**
    J.W. Qiu, *et al.*, PRL 107 (2011) 062001
- the target-rapidity region corresponds to high $x^{\uparrow}$
  where the k_T-spin correlation is the largest
- In general, one can carry out an extensive spin-physics program

Key studies: gluon contribution to the proton spin



- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - *B* & *D* meson production

PHYSICAL REVIEW D **86**, 094007 (2012)

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*

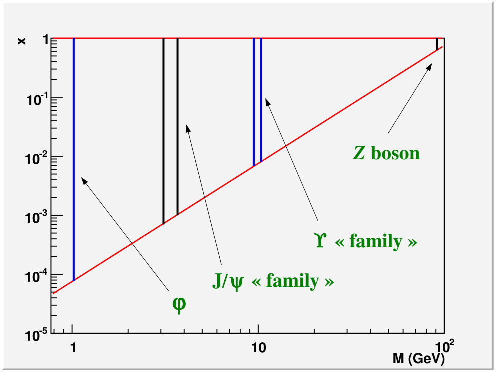
Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands

Cristian Pisano†

Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

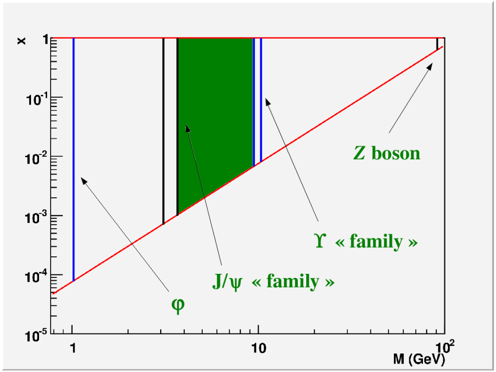
AFTER@LHC: A dilepton observatory ?

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$



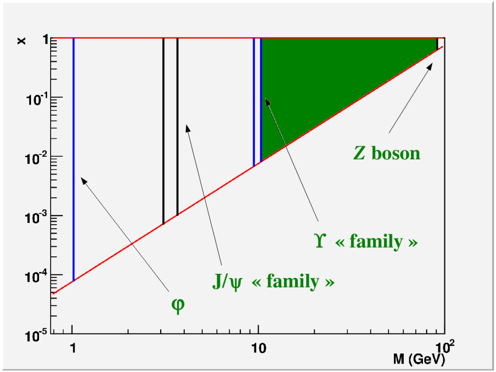
AFTER@LHC: A dilepton observatory ?

- Region in x probed by dilepton production as function of $M_{\ell\ell}$
  - Above $c\bar{c}$: $x \in [10^{-3}, 1]$
  - Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



AFTER@LHC: A dilepton observatory ?

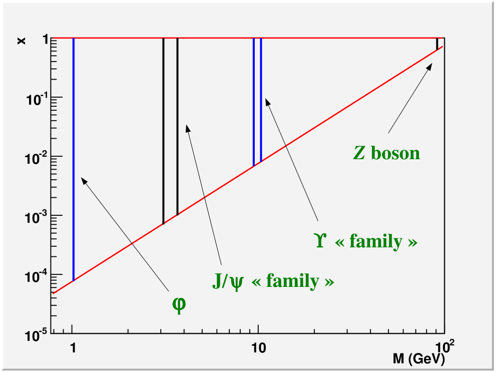
- Region in x probed by dilepton production as function of $M_{\ell\ell}$
  - → Above $c\bar{c}$: $x \in [10^{-3}, 1]$
  - → Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



AFTER@LHC: A dilepton observatory ?

- Region in x probed by dilepton production as function of $M_{\ell\ell}$
  - → Above $c\bar{c}$: $x \in [10^{-3}, 1]$
  - → Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$

Note: $x_{target}(\equiv x_2) > x_{projectile}(\equiv x_1)$
"backward" region

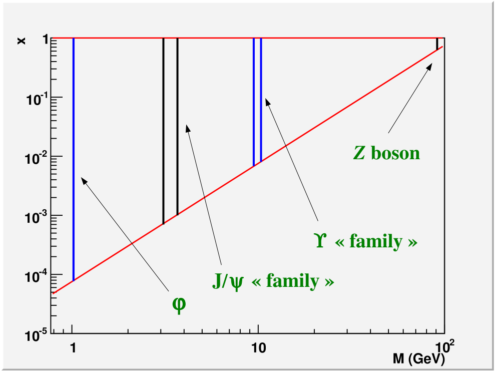


AFTER@LHC: A dilepton observatory ?

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$

→ Above $c\bar{c}$: $x \in [10^{-3}, 1]$

→ Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



Note: $x_{target} (\equiv x_2) > x_{projectile} (\equiv x_1)$ "backward" region

→ sea-quark asymetries via p and d studies

- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)

AFTER@LHC: A dilepton observatory ?

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$

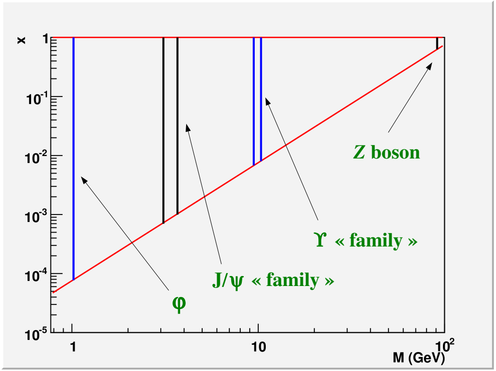
→ Above $c\bar{c}$: $x \in [10^{-3}, 1]$

→ Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$

Note: $x_{target}(\equiv x_2) > x_{projectile}(\equiv x_1)$ "backward" region

→ sea-quark asymmetries via p and d studies

- at large(est) x: backward ("easy")
- at small(est) x: forward (need to stop the (extracted) beam)



➟ To do: to look at the rates to see how competitive this will be

SSA in Drell-Yan studies with AFTER@LHC

➟ Relevant parameters for the future planned polarized DY experiments.

S.J. Brodsky, F. Fleuret, C. Hadjidakis, JPL, Phys. Rep. 522 (2013) 239
V. Barone, F. Bradamante, A. Martin, Prog. Part. Nucl. Phys. 65 (2010) 267.

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathscr{L}$ (nb^{-1}s^{-1})
AFTER	$p+p^\uparrow$	7000	115	$0.01 \div 0.9$	1
COMPASS	$\pi^\pm+p^\uparrow$	160	17.4	$0.2 \div 0.3$	2
COMPASS (low mass)	$\pi^\pm+p^\uparrow$	160	17.4	~ 0.05	2
RHIC	$p^\uparrow+p$	collider	500	$0.05 \div 0.1$	0.2
J–PARC	$p^\uparrow+p$	50	10	$0.5 \div 0.9$	1000
PANDA (low mass)	$\bar{p}+p^\uparrow$	15	5.5	$0.2 \div 0.4$	0.2
PAX	$p^\uparrow+\bar{p}$	collider	14	$0.1 \div 0.9$	0.002
NICA	$p^\uparrow+p$	collider	20	$0.1 \div 0.8$	0.001
RHIC Int.Target 1	$p^\uparrow+p$	250	22	$0.2 \div 0.5$	2
RHIC Int.Target 2	$p^\uparrow+p$	250	22	$0.2 \div 0.5$	60

➟ For AFTER, the numbers correspond to a 50 cm polarized *H* target.
➟ $\ell^+\ell^-$ angular distribution: separation Sivers vs. Boer-Mulders effects

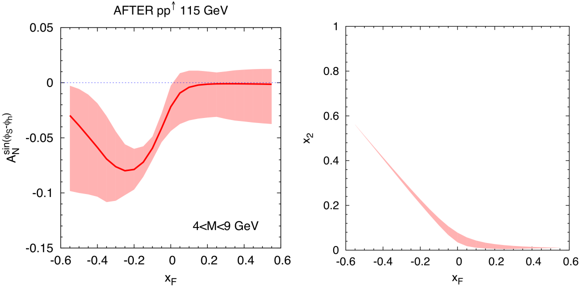
SSA in Drell-Yan studies with AFTER@LHC

➟ Relevant parameters for the future planned polarized DY experiments.

S.J. Brodsky, F. Fleuret, C. Hadjidakis, JPL, Phys. Rep. 522 (2013) 239
V. Barone, F. Bradamante, A. Martin, Prog. Part. Nucl. Phys. 65 (2010) 267.

Expe
AFT
COM
COM (low
RHI(
J–PA
PAN (low
PAX
NICA
RHIC Int.T
RHIC Int.T

expected Sivers asymmetry in
D-Y@AFTER, sign change,
no TMD evolution



M. Anselmino, ECT*, Feb. 2013 (Courtesy U. d'Alessio)

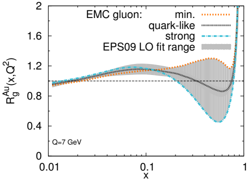
➟ For AFTER, th

➟ $\ell^+\ell^-$ angular

pA studies: large-*x* gluon content of the nucleus

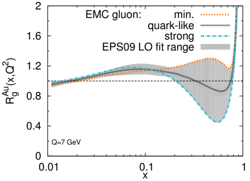
pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown
- Gluon EMC effect ?



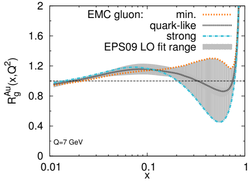
pA studies: large-*x* gluon content of the nucleus

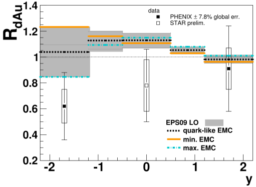
- Large-*x* gluon nPDF: unknown
- Gluon EMC effect ?
- Hint from Υ data at RHIC



pA studies: large-*x* gluon content of the nucleus

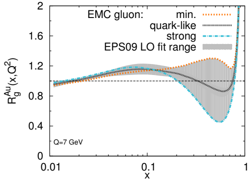
- Large-*x* gluon nPDF: unknown
- Gluon EMC effect ?
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics after 10 years of RHIC:

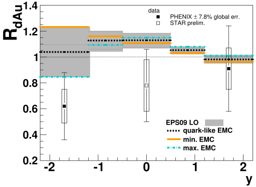


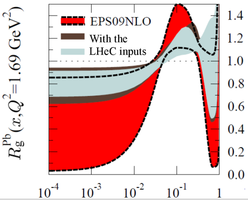


pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown
- Gluon EMC effect ?
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics after 10 years of RHIC:
- DIS contribution expected for low *x* mainly projected contribution of LHeC:

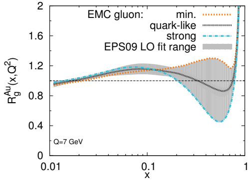


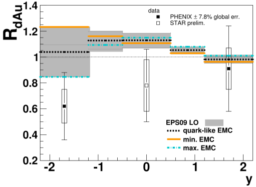


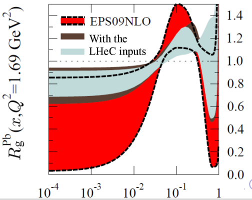


pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown
- Gluon EMC effect ?
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics after 10 years of RHIC:
- DIS contribution expected for low *x* mainly projected contribution of LHeC:
- AFTER allows for extensive studies of gluon sensitive probes in *pA*
- Unique potential for gluons at $x > 0.1$







Synergies with COMPASS

Synergies with COMPASS

- COMPASS can also definitely contribute to
  the understanding of nuclear matter effect on quarkonia

Synergies with COMPASS

- COMPASS can also definitely contribute to
  the understanding of nuclear matter effect on quarkonia

- Unique access to π-induced J/ψ production
  $\rightarrow$ last study by NA3 30 years ago!!!
  please do not overlook this ...

Synergies with COMPASS

- COMPASS can also definitely contribute to
  the understanding of nuclear matter effect on quarkonia

- Unique access to π-induced J/ψ production
  $\rightarrow$ last study by NA3 30 years ago!!!
  please do not overlook this ...

- A modern measurement of such a cross section is highly desirable

Synergies with COMPASS

- COMPASS can also definitely contribute to the understanding of nuclear matter effect on quarkonia
- Unique access to π-induced J/ψ production
  $\rightarrow$ last study by NA3 30 years ago!!!
  please do not overlook this ...
- A modern measurement of such a cross section is highly desirable
- Can be extended in 2 ways:

Synergies with COMPASS

- COMPASS can also definitely contribute to
  the understanding of nuclear matter effect on quarkonia

- Unique access to π-induced J/ψ production
  $\rightarrow$ last study by NA3 30 years ago!!!
  please do not overlook this ...

- A modern measurement of such a cross section is highly desirable

- Can be extended in 2 ways:
  - with polarised target to study the Sivers effect
    (quark or gluon: theory should tell)

Synergies with COMPASS

- COMPASS can also definitely contribute to
  the understanding of nuclear matter effect on quarkonia
- Unique access to π-induced J/ψ production
  $\rightarrow$ last study by NA3 30 years ago!!!
  please do not overlook this ...
- A modern measurement of such a cross section is highly desirable
- Can be extended in 2 ways:
  - with polarised target to study the Sivers effect
    (quark or gluon: theory should tell)
  - with different nuclear targets

Synergies with COMPASS

- COMPASS can also definitely contribute to
  the understanding of nuclear matter effect on quarkonia

- Unique access to π-induced J/ψ production
  $\rightarrow$ last study by NA3 30 years ago!!!
  please do not overlook this ...

- A modern measurement of such a cross section is highly desirable

- Can be extended in 2 ways:
  - with polarised target to study the Sivers effect
    (quark or gluon: theory should tell)
  - with different nuclear targets

- $\rightarrow$ synergies with AFTER

More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions

More with AFTER: photoproduction and “beyond” DY

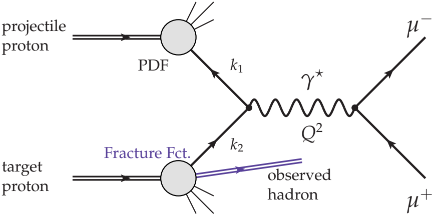
- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,\rm lab}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/R_{\rm Pb} \simeq 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
  - No pile-up

More with AFTER: photoproduction and "beyond" DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,{\rm lab}}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/R_{\rm Pb} \simeq 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
  - No pile-up
- Fracture functions

More with AFTER: photoproduction and “beyond” DY

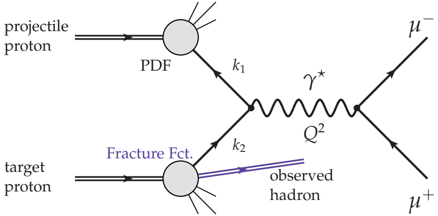
- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,{\rm lab}}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/R_{\rm Pb} \simeq 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
  - No pile-up
- Fracture functions
  - via Drell-Yan pair production + identified hadron



L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319

More with AFTER: photoproduction and "beyond" DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,{\rm lab}}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/R_{\rm Pb} \simeq 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
  - No pile-up
- Fracture functions
  - via Drell-Yan pair production
    + identified hadron

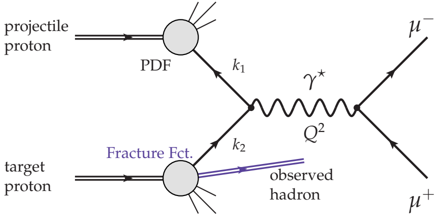


L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319

- privileged region for the identified hadron: either the projectile- or **target-rapidity region**

More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,{\rm lab}}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/R_{\rm Pb} \simeq 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
  - No pile-up
- Fracture functions
  - via Drell-Yan pair production + identified hadron

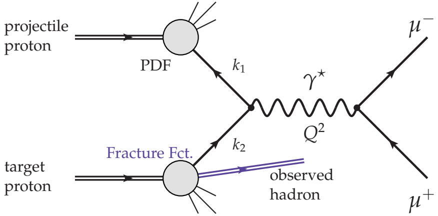


L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319

  - privileged region for the identified hadron: either the projectile- or **target-rapidity region**
  - the fixed-target mode is ideal for such studies

More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,{\rm lab}}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV ($1/R_{\rm Pb} \simeq 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV
  - No pile-up
- Fracture functions
  - via Drell-Yan pair production + identified hadron



L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319

- privileged region for the identified hadron: either the projectile- or **target-rapidity region**
- the fixed-target mode is ideal for such studies
- good prospects for fracture-function studies both with AFTER & COMPASS

More details in

Physics Reports 522 (2013) 239–255

Contents lists available at SciVerse ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

ELSEVIER

Physics opportunities of a fixed-target experiment using LHC beams

S.J. Brodsky [a], F. Fleuret [b], C. Hadjidakis [c], J.P. Lansberg [c,*]

[a] SLAC National Accelerator Laboratory, Stanford University, Menlo Park, CA 94025, USA
[b] Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France
[c] IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France

Contents

Part IV

Conclusion and outlooks

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam → 5×10^8 protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)
- LHC long shutdown (LS2 ? in 2018) needed to install the extraction system

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam → 5×10^8 protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)
- LHC long shutdown (LS2 ? in 2018) needed to install the extraction system
- Very good complementarity with electron-ion programs

Outlooks

- First physics paper Physics Reports 522 (2013) 239

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at http://indico.in2p3.fr/event/AFTER@ECTstar

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at http://indico.in2p3.fr/event/AFTER@ECTstar
- Workshop in Les Houches on 12-17 January 2014
  http://indico.in2p3.fr/event/AFTER@LesHouches
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013
  http://indico.in2p3.fr/event/LUA9-AFTER-1113

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at `http://indico.in2p3.fr/event/AFTER@ECTstar`
- Workshop in Les Houches on 12-17 January 2014
  `http://indico.in2p3.fr/event/AFTER@LesHouches`
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013
  `http://indico.in2p3.fr/event/LUA9-AFTER-1113`
- We are looking for more partners to

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013
  slides at http://indico.in2p3.fr/event/AFTER@ECTstar
- Workshop in Les Houches on 12-17 January 2014
  http://indico.in2p3.fr/event/AFTER@LesHouches
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013
  http://indico.in2p3.fr/event/LUA9-AFTER-1113
- We are looking for more partners to
  - do first simulations (we are getting ready for fast simulations)

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at http://indico.in2p3.fr/event/AFTER@ECTstar
- Workshop in Les Houches on 12-17 January 2014 http://indico.in2p3.fr/event/AFTER@LesHouches and 3-day workshop in Orsay with LUA9 on November 18-20, 2013 http://indico.in2p3.fr/event/LUA9-AFTER-1113
- We are looking for more partners to
  - do first simulations (we are getting ready for fast simulations)
  - think about possible designs

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at `http://indico.in2p3.fr/event/AFTER@ECTstar`
- Workshop in Les Houches on 12-17 January 2014
  `http://indico.in2p3.fr/event/AFTER@LesHouches`
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013
  `http://indico.in2p3.fr/event/LUA9-AFTER-1113`
- We are looking for more partners to
  - do first simulations (we are getting ready for fast simulations)
  - think about possible designs
  - think about the optimal detector technologies
  - enlarge the physics case (cosmic rays, flavour physics, ...)

Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013
  slides at http://indico.in2p3.fr/event/AFTER@ECTstar
- Workshop in Les Houches on 12-17 January 2014
  http://indico.in2p3.fr/event/AFTER@LesHouches
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013
  http://indico.in2p3.fr/event/LUA9-AFTER-1113
- We are looking for more partners to
  - do first simulations (we are getting ready for fast simulations)
  - think about possible designs
  - think about the optimal detector technologies
  - enlarge the physics case (cosmic rays, flavour physics, ...)

  Webpage: **http://after.in2p3.fr**

Synergies with COMPASS

- Single Spin Asymmetries with J/ψ: quark vs. gluon Sivers

Synergies with COMPASS

- Single Spin Asymmetries with J/ψ: quark vs. gluon Sivers
- In general, heavy-flavour production

Synergies with COMPASS

- Single Spin Asymmetries with J/ψ: quark vs. gluon Sivers
- In general, heavy-flavour production
- COMPASS expertise on secondary beams:
  "Secondary beams from 7 TeV primary protons ?"

Synergies with COMPASS

- Single Spin Asymmetries with J/ψ: quark vs. gluon Sivers
- In general, heavy-flavour production
- COMPASS expertise on secondary beams:
  "Secondary beams from 7 TeV primary protons ?"
- COMPASS expertise on polarised targets

Synergies with COMPASS

- Single Spin Asymmetries with J/ψ: quark vs. gluon Sivers
- In general, heavy-flavour production
- COMPASS expertise on secondary beams:
  "Secondary beams from 7 TeV primary protons ?"
- COMPASS expertise on polarised targets
- Study of UPC with AFTER as a prolongation of some lepton-induced-process studies with COMPASS ?

First look at Bethe-Heitler and Timelike Compton Scattering with L. Szymanowski and J. Wagner

Synergies with COMPASS

- Single Spin Asymmetries with J/ψ: quark vs. gluon Sivers
- In general, heavy-flavour production
- COMPASS expertise on secondary beams:
  "Secondary beams from 7 TeV primary protons ?"
- COMPASS expertise on polarised targets
- Study of UPC with AFTER as a prolongation of some lepton-induced-process studies with COMPASS ?

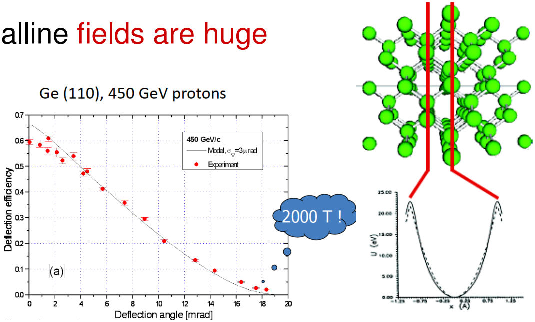
  First look at Bethe-Heitler and Timelike Compton Scattering with L. Szymanowski and J. Wagner
- The case of fracture-function studies in Drell-Yan + hadron

Part V

Backup slides

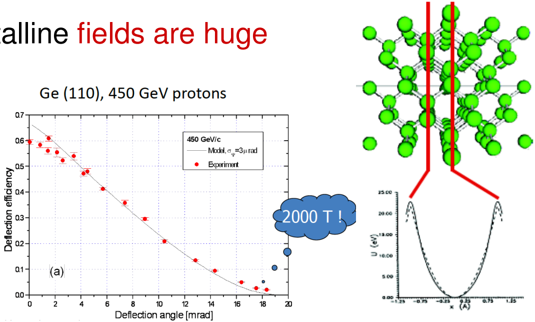
The beam extraction

- Inter-crystalline fields are huge



The beam extraction

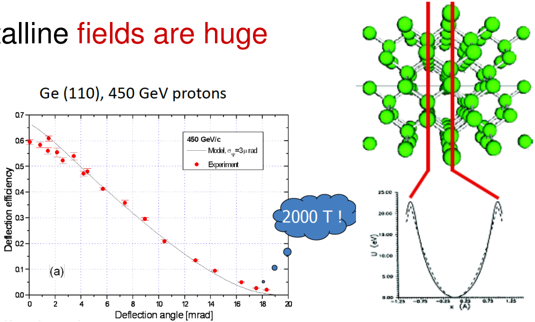
- Inter-crystalline fields are huge



- The channeling efficiency is high for a deflection of a few mrad

The beam extraction

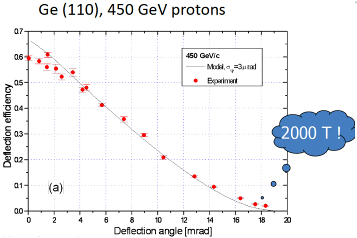
- Inter-crystalline fields are huge

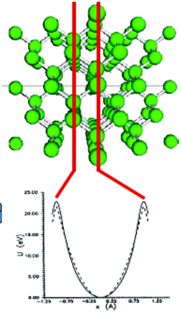


- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)

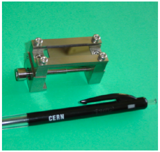
The beam extraction

- Inter-crystalline fields are huge





- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)
- Simple and robust way to extract the most energetic beam ever:



Beam extraction

- **Beam extraction @ LHC**

… there are extremely promising possibilities to extract 7 TeV protons from the circulating beam by means of a bent crystal.

… The idea is to put a bent, single crystal of either Si or Ge (W would perform slightly better but needs substantial improvements in crystal quality) at a distance of $\simeq 7\sigma$ to the beam where it can intercept and deflect part of the beam halo by an angle similar to the one the foreseen dump kicking system will apply to the circulating beam.

… ions with the same momentum per charge as protons are deflected in a crystal with similar efficiencies

Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
ELSEVIER
Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj *
Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, Aarhus C DK-8000, Denmark

Received 9 September 2004; received in revised form 6 January 2005
Available online 24 February 2005

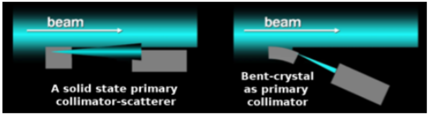
If the crystal is positioned at the kicking section, the whole dump system can be used for slow extraction of parts of the beam halo, the particles that are anyway lost subsequently at collimators.

The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS



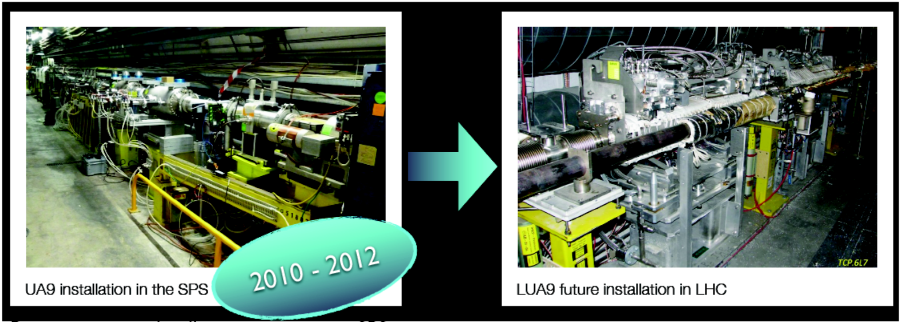
Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders



Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

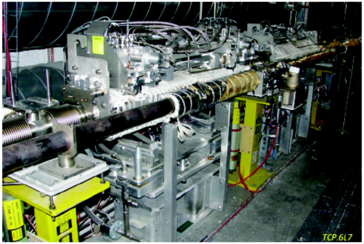
The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS

2010 - 2012



LUA9 future installation in LHC

Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 2 crystals

Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

Luminosities

- Instantaneous Luminosity:
  $\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$
  $\Phi_{beam} = 2 \times 10^5$ Pb s^{-1}, $\ell = 1$ cm (target thickness)
- Integrated luminosity $\int dt \mathcal{L} = \mathcal{L} \times 10^6$ s for Pb
- Expected luminosities with 2×10^5Pb s^{-1} extracted (1cm-long target)

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**11**
Liq. H_2	0.07	1	**8**
Liq. D_2	0.16	2	**10**
Be	1.85	9	**25**
Cu	8.96	64	**17**
W	19.1	185	**13**
Pb	11.35	207	**7**

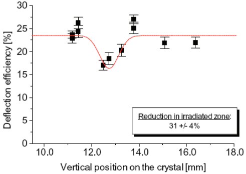
- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

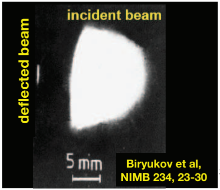
Simone Montesano - February 11th, 2013 - Physics at AFTER using the LHC beams

Crystal resistance to irradiation

- **IHEP U-70** (Biryukov et al, NIMB 234, 23-30):
  - 70 GeV protons, 50 ms spills of **10^{14} protons every 9.6 s**, several minutes irradiation
  - equivalent to 2 nominal LHC bunches for 500 turns every 10 s
  - 5 mm silicon crystal, **channeling efficiency unchanged**
- **SPS North Area - NA48** (Biino et al, CERN-SL-96-30-EA):
  - 450 GeV protons, 2.4 s spill of 5 x 10^{12} protons every 14.4 s, one year irradiation, **2.4 x 10^{20} protons/cm^2** in total,
  - equivalent to several year of operation for a primary collimator in LHC
  - 10 x 50 x 0.9 mm^3 silicon crystal, 0.8 x 0.3 mm^2 area irradiated, **channeling efficiency reduced by 30%**.
- **HRMT16-UA9CRY** (HiRadMat facility, November 2012):
  - 440 GeV protons, up to 288 bunches **in 7.2 μs**, 1.1 x 10^{11} protons per bunch (**3 x 10^{13} protons** in total)
  - energy deposition comparable to an asynchronous beam dump in LHC
  - 3 mm long silicon crystal, **no damage to the crystal after accurate visual inspection**, more tests planned to assess possible crystal lattice damage
    - **accurate FLUKA simulation of energy deposition** and residual dose

NA48 - Biino et al, CERN-SL-96-30-EA





30

S. Montesano (CERN - EN/STI) @ ECT* Trento workshop, Physics at AFTER using the LHC beams (Feb. 2013)

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, Pb*A* collisions at $\sqrt{s_{NN}} \simeq 72$ GeV

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, Pb*A* collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, Pb*A* collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations:

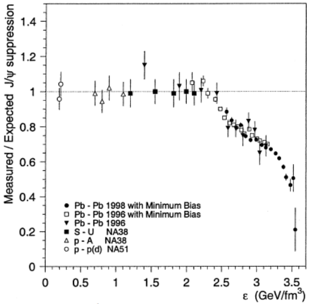


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision systems.

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, Pb*A* collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations:

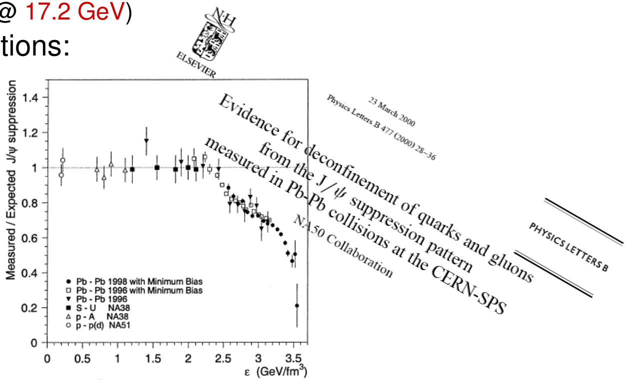


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision systems.

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_\Psi$	$N(\Upsilon)\ yr^{-1}$ $=A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0
- Unique access in the backward region

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Liq. D_2	24	9.6 10^8	1.9 10^6
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^7 1.4 10^9	1.8 10^5 7.2 10^6
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^5	1.2 10^3

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0
- Unique access in the backward region
- Probe of the (very) large *x* in the target

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also pp collisions in gg-fusion process
  - mainly because of the presence of a natural “hard” scale: m_Q
  - and the good detectability of a dimuon pair

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England
(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle $\rightarrow$ quarkonium not used anymore in global fits

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle $\rightarrow$ quarkonium not used anymore in global fits
- With systematic studies, one would restore its status as gluon probe

Accessing the large *x* glue with quarkonia

PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

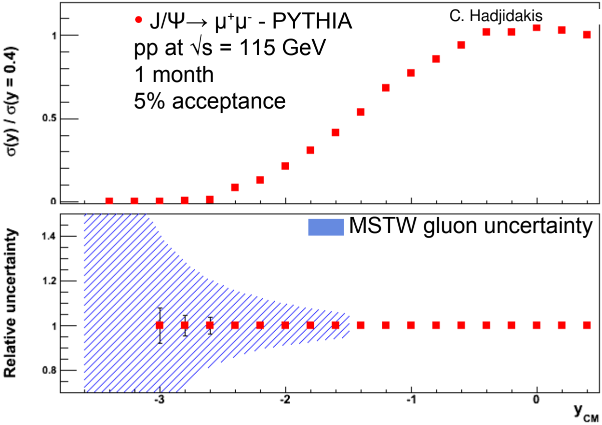
Statistical relative uncertainty
Large statistics allow to access very backward region

Gluon uncertainty from MSTWPDF
- only for the gluon content of the target
- assuming

$$x_g = M_{J/\Psi}/\sqrt{s}\, e^{-y_{CM}}$$

J/Ψ
$y_{CM} \sim 0 \rightarrow x_g = 0.03$
$y_{CM} \sim -3.6 \rightarrow x_g = 1$

Y: larger x_g for same y_{CM}
$y_{CM} \sim 0 \rightarrow x_g = 0.08$
$y_{CM} \sim -2.4 \rightarrow x_g = 1$



⇒ Backward measurements allow to access large x gluon pdf

NEW !

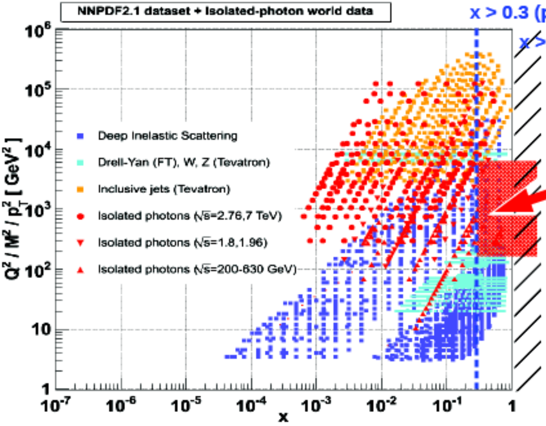
p–p

(x,Q²) map of AFTER isolated-γ

[D.d'E & J.Rojo, NPB 860 (2012) 311]

- p-p kinematics at fixed-target LHC:

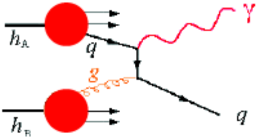
  To access x > 0.3 one needs isolated-γ with: $p_T = x_T\sqrt{s}/2 > 10\text{-}20$ GeV/c



x > 0.3 (p,Pb)

x >1 (Pb)

AFTER region: pp → γ X



[D. D'Enterria, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	1.1 10^8	2.2 10^5
1cm Cu	64	0.42	5.3 10^8	1.1 10^6
1cm W	185	0.31	1.1 10^9	2.3 10^6
1cm Pb	207	0.16	6.7 10^8	1.3 10^6
LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^7	7.5 10^4
RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^6	5.9 10^3
RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^4	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, *y* or P_T

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, y or P_T
  - Ratio ψ' over direct J/ψ measurement in *pA*

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, *y* or P_T
  - Ratio ψ' over direct J/ψ measurement in *pA*
  - not to mention ratio with **open charm, Drell-Yan,** etc ...

What for ?

- The target versatility of a fixed-target experiment is undisputable

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)
- One should be careful with factorization breaking effects:

This calls for multiple measurements to (in)validate factorization

Precision heavy-flavour studies in Heavy-Ion Collisions

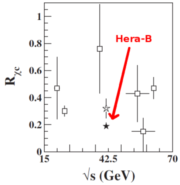
- Very precise *pp* and *pA* baselines (yields, *A* & *y* dependences)

Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise *pp* and *pA* baselines (yields, *A* & *y* dependences)
- Modern technologies to look for quarkonium excited states

Precision heavy-flavour studies in Heavy-Ion Collisions

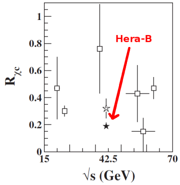
- Very precise *pp* and *pA* baselines (yields, *A* & *y* dependences)
- Modern technologies to look for quarkonium excited states



HERA-B PRD 79 (2009) 012001, and ref. therein

Precision heavy-flavour studies in Heavy-Ion Collisions

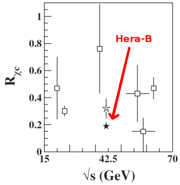
- Very precise *pp* and *pA* baselines (yields, *A* & *y* dependences)
- Modern technologies to look for quarkonium excited states
- Energy between SPS and RHIC: QGP should be formed w/o $c\bar{c}$ recombination



HERA-B PRD 79 (2009) 012001, and ref. therein

Precision heavy-flavour studies in Heavy-Ion Collisions

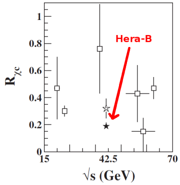
- Very precise *pp* and *pA* baselines (yields, A & y dependences)
- Modern technologies to look for quarkonium excited states
- Energy between SPS and RHIC: QGP should be formed w/o $c\bar{c}$ recombination
- Open heavy-flavour measurement down to $P_T = 0$ thanks to the boost.



HERA-B PRD 79 (2009) 012001, and ref. therein

Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise *pp* and *pA* baselines (yields, A & y dependences)
- Modern technologies to look for quarkonium excited states
- Energy between SPS and RHIC: QGP should be formed w/o $c\bar{c}$ recombination
- Open heavy-flavour measurement down to $P_T = 0$ thanks to the boost.
- Real hope of being able to look at the quarkonium sequential suppression



HERA-B PRD 79 (2009) 012001, and ref. therein

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} $= AB\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(ϒ) yr^{-1} $=AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	800	3.4 10^6	6.9 10^3
1cm Be	207.9	25	9.1 10^5	1.9 10^3
1cm Cu	207.64	17	4.3 10^6	0.9 10^3
1cm W	207.185	13	9.7 10^6	1.9 10^4
1cm Pb	207.207	7	5.7 10^6	1.1 10^4
LHC PbPb 5.5 TeV	207.207	0.5	7.3 10^6	3.6 10^4
RHIC AuAu 200GeV	198.198	2.8	4.4 10^6	1.1 10^4
RHIC AuAu 62GeV	198.198	0.13	4.0 10^4	61

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = AB$\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} =AB$\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	800	3.4 10^6	6.9 10^3
1cm Be	207.9	25	9.1 10^5	1.9 10^3
1cm Cu	207.64	17	4.3 10^6	0.9 10^3
1cm W	207.185	13	9.7 10^6	1.9 10^4
1cm Pb	207.207	7	5.7 10^6	1.1 10^4
LHC PbPb 5.5 TeV	207.207	0.5	7.3 10^6	3.6 10^4
RHIC AuAu 200GeV	198.198	2.8	4.4 10^6	1.1 10^4
RHIC AuAu 62GeV	198.198	0.13	4.0 10^4	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	800	3.4 10^6	6.9 10^3
1cm Be	207.9	25	9.1 10^5	1.9 10^3
1cm Cu	207.64	17	4.3 10^6	0.9 10^3
1cm W	207.185	13	9.7 10^6	1.9 10^4
1cm Pb	207.207	7	5.7 10^6	1.1 10^4
LHC PbPb 5.5 TeV	207.207	0.5	7.3 10^6	3.6 10^4
RHIC AuAu 200GeV	198.198	2.8	4.4 10^6	1.1 10^4
RHIC AuAu 62GeV	198.198	0.13	4.0 10^4	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ $= AB\mathcal{L}\mathcal{B}\sigma_{\Psi}$	$N(\Upsilon)\ yr^{-1}$ $= AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	**800**	**$3.4\ 10^6$**	**$6.9\ 10^3$**
1cm Be	207.9	**25**	**$9.1\ 10^5$**	**$1.9\ 10^3$**
1cm Cu	207.64	**17**	**$4.3\ 10^6$**	**$0.9\ 10^3$**
1cm W	207.185	**13**	**$9.7\ 10^6$**	**$1.9\ 10^4$**
1cm Pb	207.207	**7**	**$5.7\ 10^6$**	**$1.1\ 10^4$**
LHC PbPb 5.5 TeV	207.207	**0.5**	**$7.3\ 10^6$**	**$3.6\ 10^4$**
RHIC AuAu 200GeV	198.198	**2.8**	**$4.4\ 10^6$**	**$1.1\ 10^4$**
RHIC AuAu 62GeV	198.198	**0.13**	**$4.0\ 10^4$**	**61**

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

The same picture also holds for open heavy flavour

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and

... not well understood

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and
  ... not well understood
- the difficulty to observe directly the excited states
  which would melt before the ground states
  - χ_c never studied in *AA* collisions
  - $\psi(2S)$ not yet studied in *AA* collisions at RHIC

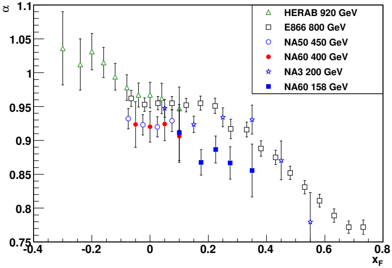
What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and
  ... not well understood
- the difficulty to observe directly the excited states
  which would melt before the ground states
  - χ_c never studied in *AA* collisions
  - $\psi(2S)$ not yet studied in *AA* collisions at RHIC
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence . . .

SPS and Hera-B

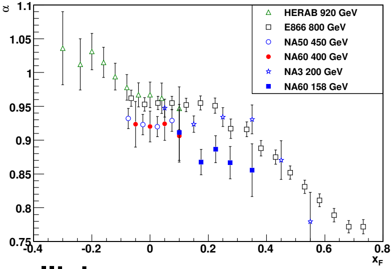
– J/ψ data in pA collisions



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

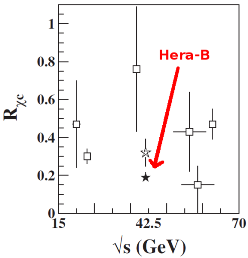
SPS and Hera-B

– J/ψ data in pA collisions



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

– χ_c data in pA collisions



HERA-B PRD 79 (2009) 012001, and ref. therein

LHB

Our idea is not completely new

Nuclear Instruments and Methods in Physics Research A 333 (1993) 125–135
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

LHB, a fixed target experiment at LHC to measure CP violation in B mesons

Flavio Costantini

University of Pisa and INFN, Italy

A fixed target experiment at LHC to measure CP violation in B mesons is presented. A description of the proposed apparatus is given together with its sensitivity on the CP violation asymmetry measurement for the two benchmark decay channels $B^0 \to J/\psi + K^0_s$, $B^0 \to \pi^+\pi^-$. The possibility of obtaining an extracted LHC beam hinges on channeling in a bent silicon crystal. Recent results on beam extraction efficiencies measured at CERN SPS based on this technique are presented.

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LHB
LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LHB
LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq 6\%$ per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} cm^{-2}s^{-1} luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions
- After a year, one simply moves the crystal by less than one mm ...

Key studies: W/Z production at threshold

- For the first time, one would study W/Z production in their threshold region $(m_{W/Z}/\sqrt{s_{AFTER}} \sim 1)$

Key studies: W/Z production at threshold

- For the first time, one would study W/Z production in their threshold region ($m_{W/Z}/\sqrt{s_{AFTER}} \sim 1$)
  - Unique opportunity to measure QCD/threshold effects on W/Z production

Key studies: W/Z production at threshold

- For the first time, one would study W/Z production in their threshold region ($m_{W/Z}/\sqrt{s_{AFTER}} \sim 1$)
  - Unique opportunity to measure QCD/threshold effects on W/Z production
  - If W'/Z' exist, their production may share similar threshold corrections to that of W/Z, but at LHC energies ($m_{W'/Z'}/\sqrt{s_{LHC}} \sim 1$?)

Key studies: W/Z production at threshold

- For the first time, one would study W/Z production in their threshold region ($m_{W/Z}/\sqrt{s_{AFTER}} \sim 1$)
  - Unique opportunity to measure QCD/threshold effects on W/Z production
  - If W'/Z' exist, their production may share similar threshold corrections to that of W/Z, but at LHC energies ($m_{W'/Z'}/\sqrt{s_{LHC}} \sim 1$?)
  - Reconstructed rate are most likely between a few dozen to a few thousand / year

Further key studies ?

(Multiply) heavy baryons:

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathscr{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathscr{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathscr{B}(b \to \Lambda_b) \times \mathscr{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathscr{B}(J/\psi \to \mu\mu) = 6\%)$

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathcal{B}(b \to \Lambda_b) \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathcal{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathscr{B}(b \to \Lambda_b) \times \mathscr{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathscr{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**
- discovery potential ? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathscr{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathscr{B}(b \to \Lambda_b) \times \mathscr{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
    $(\mathscr{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**
- discovery potential ? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)
  - Ξ_{cc}, ..., cross sections in the central region are being calculated with the MC generator GENXICC

C.H. Chang, J.X. Wang, X.G. Wu. Comput.Phys.Commun. 177 (2007) 467

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathcal{B}(b \to \Lambda_b) \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathcal{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**
- discovery potential ? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)
  - Ξ_{cc}, ..., cross sections in the central region are being calculated with the MC generator GENXICC

    C.H. Chang, J.X. Wang, X.G. Wu. Comput.Phys.Commun. 177 (2007) 467
  - they should also be calculated for $x_F \to -1$

    where IQ could dominate

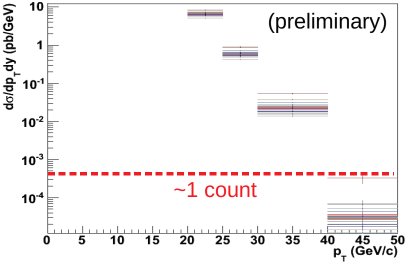
Isolated-γ in p(7 TeV)-p(rest): √s ~ 115 GeV

- p-p photon kinematics at fixed-target LHC (central rapidities):
  To access $x > 0.3$ one needs isolated-γ at: $p_T = x_T\sqrt{s}/2 > 20$ GeV/c

- JETPHOX NLO pQCD calculations:

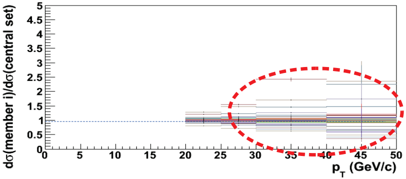
  p-p at $\sqrt{s}$=115 GeV
  $|y|<0.5$, $p_T>20$ GeV/c
  Isolation: R=0.4, $E_T^{had}<5$ GeV

  $\mathcal{L}$(10 cm H_2-target) ~ $2\bullet10^3$ pb^{-1}/year

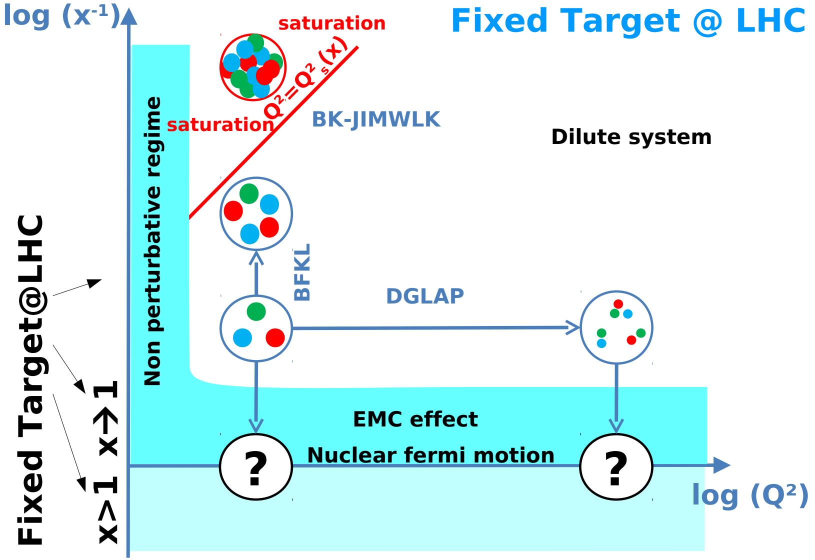


PDF: CT10 52 eigenval. (90% CL)
Scales: $\mu_i = p_T$
FF = BFG-II
x-section uncertainties(*) of ±150%

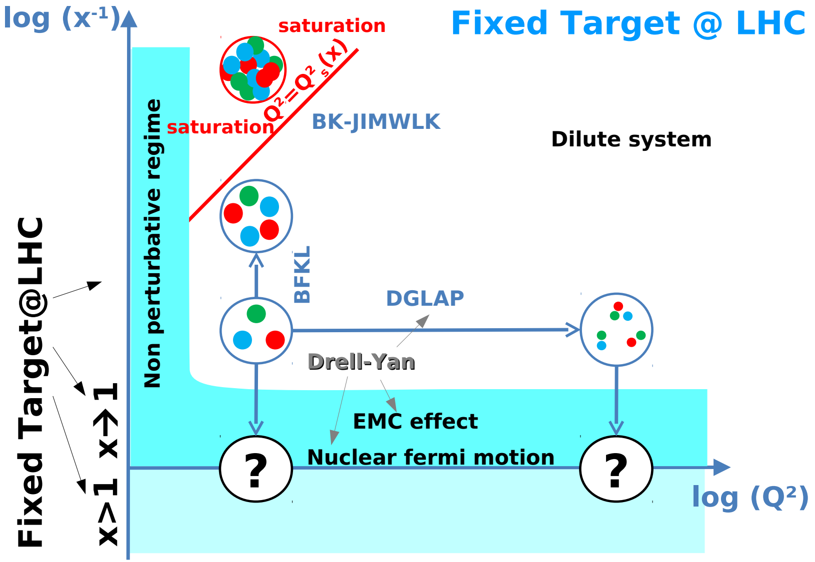
(*) (68%CL)/(90% CL) ~ 1.65



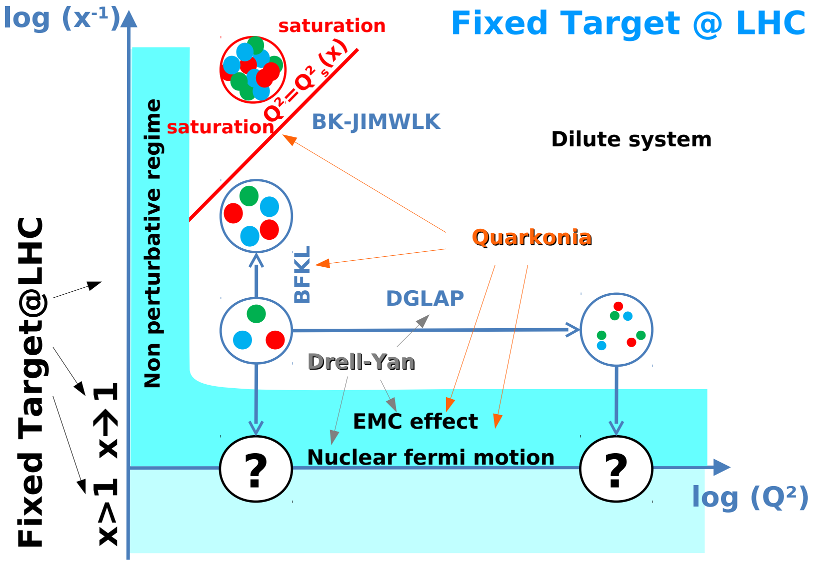
Overall


log (x^{-1})
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Fixed Target@LHC
BFKL
DGLAP
x>1 x→1
EMC effect
Nuclear fermi motion
?
?
log (Q^2)

Overall

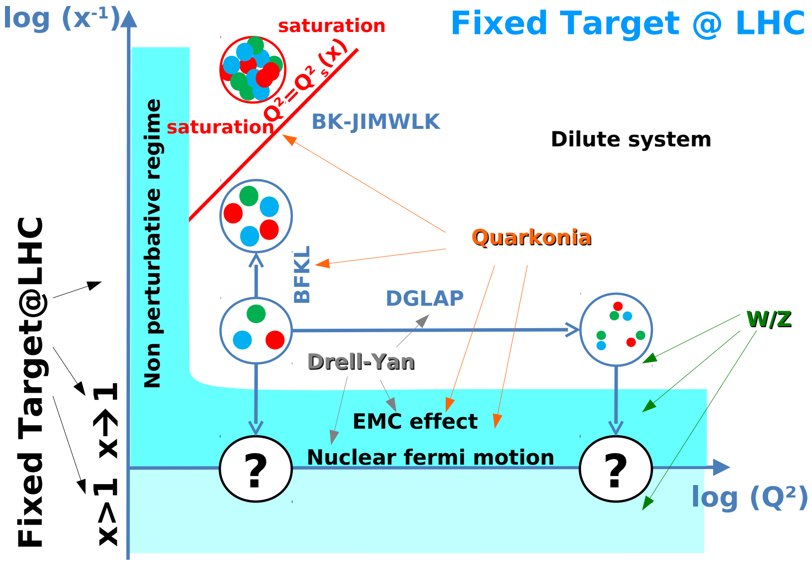

log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Fixed Target@LHC
x>1 x→1
BFKL
DGLAP
Drell-Yan
EMC effect
?
Nuclear fermi motion
?
log (Q²)

Overall

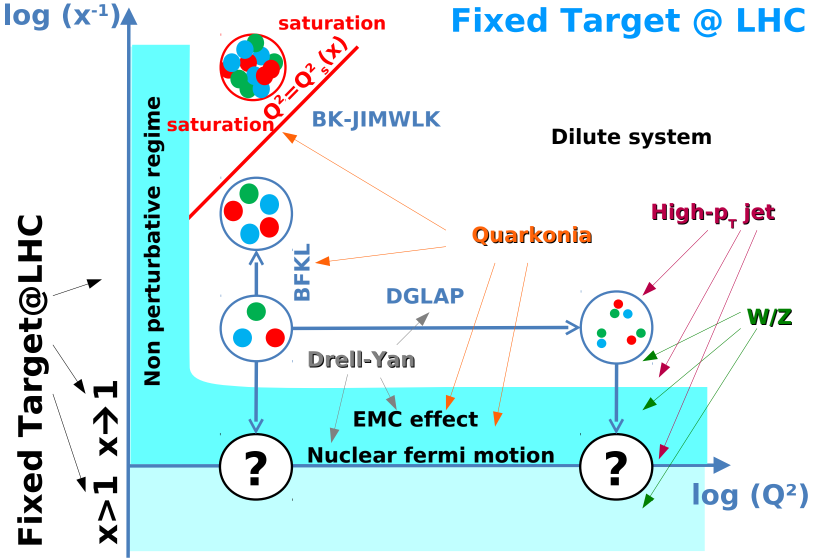


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Quarkonia
BFKL
DGLAP
Fixed Target@LHC
Drell-Yan
x>1 x→1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Quarkonia
BFKL
Fixed Target@LHC
DGLAP
W/Z
Drell-Yan
x→1
EMC effect
x>1
?
Nuclear fermi motion
?
log (Q²)

Overall



log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
High-pT jet
Quarkonia
BFKL
DGLAP
W/Z
Fixed Target@LHC
Drell-Yan
x>1 x→1
EMC effect
Nuclear fermi motion
?
?
log (Q²)