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

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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 ($x_F \equiv \frac{p_z}{p_{z_{\text{max}}}}$)
  - achieving **high luminosities** with dense targets,
  - **varying** the atomic mass of the target almost at will,
  - **polarising** the target.
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.
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
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.*
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**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
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]
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- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

**Benefit of the fixed target mode:** boost:
\[ \gamma_{\text{Lab}} = \sqrt{s}^2 m_p \approx 60 \]

Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM:
\[ (p_z^{CM}, E_{\gamma}^{CM} = p_T^{CM}) \]
\[ (E_{\text{Lab}}^{z, p}, E_{\text{Lab}}^{p}) = (\gamma^{\gamma} \beta^{\gamma} \gamma^{\beta} \gamma^{\beta} \gamma) (p_T^{0}) \]
\[ p_z^{LRab} \approx 60 p_T^{!} \]

[A 67 MeV \( \gamma \) from a \( \pi^0 \) at rest in the CM can easily be detected.]

Angle in the Lab. frame:
\[ \tan \theta = \frac{p_T^{CM}}{p_z^{LRab}} \Rightarrow \theta \approx 1^\circ. \]

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

The entire forward CM hemisphere (\( y_{CM} > 0 \)) within \( 0^\circ \leq \theta_{LRab} \leq 1^\circ \) \([y_{CM} = 0 \Rightarrow y_{LRab} \approx 4.8]\)

Good thing: small forward detector \equiv large acceptance

Bad thing: high multiplicity \Rightarrow absorber \Rightarrow physics limitation

J.P. Lansberg (IPNO, Paris-Sud U.)
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    \( (p_{z,CM} = 0, E_{CM}^\gamma = p_T) \)
A bit of kinematics with the 7 TeV proton beam

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    \end{pmatrix} = \begin{pmatrix} \gamma & \gamma \beta \\
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$\gamma_1 \sim \gamma_2$

Hadron center-of-mass system

Target rest frame
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In the Hadron center-of-mass system, $x_1 \sim x_2$.

In the Target rest frame, $x_1 \ll x_2$.
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\begin{align*}
  x_1 &\approx x_2 \\
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`backward physics = large-x_2 physics`
First systematic access to the target-rapidity region

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

$J/\psi$ suppression in $pA$ collisions

- $x_F$ systematically studied at fixed target experiments up to $+1$
First systematic access to the target-rapidity region

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\( J/\psi \) suppression in \( pA \) collisions

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- PHENIX @ RHIC: \(-0.1 < x_F < 0.1\) \([\text{could be wider with } \Upsilon, \text{ but low stat.}]\)
- CMS/ATLAS: \(|x_F| < 5 \cdot 10^{-3}\); LHCb: \(5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}\)
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The target-rapidity region: the uncharted territory

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- If we measure $\Upsilon(b\bar{b})$ at $y_{\text{cms}} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_{\Upsilon}}{\sqrt{s}} \sinh(y_{\text{cms}}) \simeq -1$
The beam extraction

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★ Illustration for collimation

A solid state primary collimator-scatterer

Bent-crystal as primary collimator
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★ Tests will be performed on the LHC beam:
LUA9 proposal approved by the LHCC
Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8 \, p^+ s^{-1}$
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$$\mathcal{L} = \Phi_{\text{beam}} \times N_{\text{target}} = N_{\text{beam}} \times (\rho \times \ell \times N_A)/A$$

[\ell: \text{target thickness (for instance 1cm)}]
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<table>
<thead>
<tr>
<th>Target</th>
<th>$\rho$ (g.cm$^{-3}$)</th>
<th>A</th>
<th>$\mathcal{L}$ (µb$^{-1}$s$^{-1}$)</th>
<th>$\int \mathcal{L}$ (pb$^{-1}$yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol. H$_2$</td>
<td>0.09</td>
<td>1</td>
<td>26</td>
<td>260</td>
</tr>
<tr>
<td>Liq. H$_2$</td>
<td>0.07</td>
<td>1</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Liq. D$_2$</td>
<td>0.16</td>
<td>2</td>
<td>24</td>
<td>240</td>
</tr>
<tr>
<td>Be</td>
<td>1.85</td>
<td>9</td>
<td>62</td>
<td>620</td>
</tr>
<tr>
<td>Cu</td>
<td>8.96</td>
<td>64</td>
<td>42</td>
<td>420</td>
</tr>
<tr>
<td>W</td>
<td>19.1</td>
<td>185</td>
<td>31</td>
<td>310</td>
</tr>
<tr>
<td>Pb</td>
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</tr>
</tbody>
</table>
1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, ...)

This gives:

$$L_{H_2/D_2} \approx 20 \text{ fb}^{-1}$$

Recycling the LHC beam loss, one gets a luminosity comparable to the LHC itself!

PHENIX lumi in their decadal plan

- Run14pp $12 \text{ pb}^{-1} @ \sqrt{s_{NN}} = 200 \text{ GeV}$
- Run14 $dAu 0.15 \text{ pb}^{-1} @ \sqrt{s_{NN}} = 200 \text{ GeV}$

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)
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- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600 \, \text{s h}^{-1} \times 10 \, \text{h} = 1.8 \times 10^{13} p^+ \, \text{fill}^{-1}$
  - This means $1.8 \times 10^{13} / 3.2 \times 10^{14} \approx 5.6\%$ of the $p^+$ in the beam
  - These protons are lost anyway!
A few figures on the (extracted) proton beam

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- Extracted intensity: $5 \times 10^8 \, p^+ s^{-1}$ (1/2 the beam loss)  
- 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 $3.10^5 \, \text{km.s}^{-1}/27 \, \text{km} \approx 11 \, \text{kHz}$
- Extracted “mini” bunches:
  - the crystal sees $2808 \times 11000 \, s^{-1} \approx 3.10^7$ bunches s$^{-1}$
  - one extracts $5.10^8/3.10^7 \approx 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,
- Extraction over a 10h fill:
  - $5 \times 10^8 \, p^+ \times 3600 \, \text{s h}^{-1} \times 10 \, \text{h} = 1.8 \times 10^{13} \, p^+ \, \text{fill}^{-1}$
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \approx 5.6\%$ of the $p^+$ in the beam
    - These protons are lost anyway!
- similar figures for the Pb-beam extraction

The fixed-target experiment at the LHC
Part III

AFTER: flagship measurements
Key studies: gluons in the proton

- **Gluon distribution** at mid, high and ultra-high $x_B$ in the proton.
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- **Gluon distribution** at mid, high and ultra-high $x_B$ in the proton
  - Not easily accessible in DIS
  - Very large uncertainties
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- **Isolated photon**
**Gluon and heavy-quark distributions**

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Multiple probes needed to **check factorisation**
Key studies: gluons in the neutron

Gluon PDF for the neutron unknown

Gluon ($\mu = 100 \text{ GeV}$)
Key studies: gluons in the neutron

Gluon PDF for the neutron unknown
possible experimental probes
- heavy quarkonia
- isolated photons
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<tr>
<th>target</th>
<th>yearly lumi</th>
<th>$\mathcal{B} \frac{dN_{J/\psi}}{dy}$</th>
<th>$\mathcal{B} \frac{dN_{\Upsilon}}{dy}$</th>
</tr>
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<tr>
<td>1m Liq. H$_2$</td>
<td>20 fb$^{-1}$</td>
<td>$4.0 \times 10^8$</td>
<td>$9.0 \times 10^5$</td>
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<tr>
<td>1m Liq. D$_2$</td>
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<td>$9.6 \times 10^8$</td>
<td>$1.9 \times 10^6$</td>
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3 sets from CTEQ6c
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- **Heavy-quark distributions (at high $x_B$)**
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J.P. Lansberg  (IPNO, Paris-Sud U.)  A Fixed-Target Experiment at the LHC  September 20, 2013  16 / 27
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F. Yuan, PRD 78 (2008) 014024

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.
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AFTER@LHC: A dilepton observatory?

Region in $x$ probed by dilepton production as function of $M_{\ell\ell}$.
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**AFTER@LHC: A dilepton observatory?**

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

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

"Interesting to check the negligible $\cos^2\phi$ dependence in $pd$ compared to $\pi$ induced DY"
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Note: $x_{\text{target}} \equiv x_2 > x_{\text{projectile}} \equiv x_1$ ("backward" region)

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J.P. Lansberg (IPNO, Paris-Sud U.)
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SSA in Drell-Yan studies with AFTER@LHC

→ Relevant parameters for the future planned polarized DY experiments.


<table>
<thead>
<tr>
<th>Experiment</th>
<th>particles</th>
<th>energy (GeV)</th>
<th>√s (GeV)</th>
<th>x_p</th>
<th>L (nb⁻¹s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFTER</td>
<td>p+p↑</td>
<td>7000</td>
<td>115</td>
<td>0.01 ÷ 0.9</td>
<td>1</td>
</tr>
<tr>
<td>COMPASS</td>
<td>π± + p↑</td>
<td>160</td>
<td>17.4</td>
<td>0.2 ÷ 0.3</td>
<td>2</td>
</tr>
<tr>
<td>COMPASS (low mass)</td>
<td>π± + p↑</td>
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<td>~ 0.05</td>
<td>2</td>
</tr>
<tr>
<td>RHIC</td>
<td>p↑ + p</td>
<td>collider</td>
<td>500</td>
<td>0.05 ÷ 0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>J–PARC</td>
<td>p↑ + p</td>
<td>50</td>
<td>10</td>
<td>0.5 ÷ 0.9</td>
<td>1000</td>
</tr>
<tr>
<td>PANDA (low mass)</td>
<td>p + p↑</td>
<td>15</td>
<td>5.5</td>
<td>0.2 ÷ 0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>PAX</td>
<td>p↑ + p̅</td>
<td>collider</td>
<td>14</td>
<td>0.1 ÷ 0.9</td>
<td>0.002</td>
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<tr>
<td>NICA</td>
<td>p↑ + p</td>
<td>collider</td>
<td>20</td>
<td>0.1 ÷ 0.8</td>
<td>0.001</td>
</tr>
<tr>
<td>RHIC</td>
<td>p↑ + p</td>
<td>250</td>
<td>22</td>
<td>0.2 ÷ 0.5</td>
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<tr>
<td>Int. Target 1</td>
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→ For AFTER, the numbers correspond to a 50 cm polarized H target.
→ ℓ⁺ℓ⁻ angular distribution: separation Sivers vs. Boer-Mulders effects
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<tr>
<td>RHIC Int. Target 2</td>
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<td>2 ÷ 60</td>
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M. Anselmino, ECT*, Feb. 2013 (Courtesy U. d’Alessio)
$pA$ studies: large-\(x\) gluon content of the nucleus
pA studies: large-x gluon content of the nucleus

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- Gluon EMC effect?

![Graph showing EMC gluon (min., quark-like, strong) and EPS09 LO fit range with data points at RHIC.](Image)
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  - AFTER allows for extensive studies of gluon sensitive probes in pA
  - Unique potential for gluons at x > 0.1
Synergies with COMPASS

COMPASS can also definitely contribute to the understanding of nuclear matter effect on quarkonia. Unique access to $\pi$-induced $J/\psi$ production → last study by NA3 30 years ago!!!

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)
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A Fixed-Target Experiment at the LHC
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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**
  - $\gamma_{\text{lab}}^{\text{beam}} \approx 7000 \ (E_p = 7000 \text{ GeV})$
  - $E_{\gamma,\text{lab}}^{\text{max}} \approx \gamma_{\text{lab}}^{\text{beam}} \times 30 \text{ MeV} \ (1/R_{\text{Pb}} \approx 30 \text{ MeV})$
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ 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 with AFTER: photoproduction and “beyond” DY

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Fracture Fct.  
PDF  
$k_1$  
$\gamma^*$  
$k_2$  
$Q^2$  
observed hadron  
L. Trentadue, G. Veneziano, PLB 323 (1994) 201  
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Gluons in nuclei

More with AFTER: photoproduction and “beyond” DY

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

- Fracture functions
  - via Drell-Yan pair production
  - + identified hadron

- 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

L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319
Physics opportunities of a fixed-target experiment using LHC beams

S.J. Brodsky\textsuperscript{a}, F. Fleuret\textsuperscript{b}, C. Hadjidakis\textsuperscript{c}, J.P. Lansberg\textsuperscript{c,*}

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\textsuperscript{b} Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France
\textsuperscript{c} IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France

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Part IV

Conclusion and outlooks
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 $\sqrt{s} = 115 \text{ GeV}$ and $\sqrt{NN} = 72 \text{ GeV}$.

Example: precision quarkonium studies taking advantage of high luminosity (reach in $y, PT, \text{ small BR channels}$)

target versatility (nuclear effects, strongly limited at colliders)

modern detection techniques (e.g. $\gamma$ 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.
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- enlarge the physics case (cosmic rays, flavour physics, ...)

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

Backup slides
The beam extraction

- Inter-crystalline fields are huge

![Graph and diagram showing deflection efficiency and angle for Ge (110), 450 GeV protons.]

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:

J.P. Lansberg (IPNO, Paris-Sud U.)
A Fixed-Target Experiment at the LHC
September 20, 2013
The beam extraction

- Inter-crystalline fields are huge

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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 $\sim 7\sigma$ 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
The beam extraction: news

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)
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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:
  \[ \mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times N_A)/A \]
  \[ \Phi_{beam} = 2 \times 10^5 \text{ Pb s}^{-1}, \quad \ell = 1 \text{ cm (target thickness)} \]

- Integrated luminosity \( \int dt\mathcal{L} = \mathcal{L} \times 10^6 \text{ s for Pb} \)

- Expected luminosities with \( 2 \times 10^5 \text{ Pb s}^{-1} \) extracted (1 cm-long target)

<table>
<thead>
<tr>
<th>Target</th>
<th>( \rho ) (g.cm(^{-3}))</th>
<th>( A )</th>
<th>( \mathcal{L} ) (mb(^{-1}).s(^{-1})) = ( \int \mathcal{L} ) (nb(^{-1}).yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol. H(_2)</td>
<td>0.09</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Liq. H(_2)</td>
<td>0.07</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Liq. D(_2)</td>
<td>0.16</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Be</td>
<td>1.85</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>Cu</td>
<td>8.96</td>
<td>64</td>
<td>17</td>
</tr>
<tr>
<td>W</td>
<td>19.1</td>
<td>185</td>
<td>13</td>
</tr>
<tr>
<td>Pb</td>
<td>11.35</td>
<td>207</td>
<td>7</td>
</tr>
</tbody>
</table>

- Planned lumi for PHENIX Run15AuAu 2.8 nb\(^{-1}\) (0.13 nb\(^{-1}\) at 62 GeV)

- Nominal LHC lumi for PbPb 0.5 nb\(^{-1}\)
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 $5 \times 10^{12}$ protons every 14.4 s, one year irradiation, $2.4 \times 10^{20}$ protons/cm$^2$ in total,
  - equivalent to several year of operation for a primary collimator in LHC
  - $10 \times 50 \times 0.9$ mm$^3$ silicon crystal, $0.8 \times 0.3$ 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, $1.1 \times 10^{11}$ protons per bunch ($3 \times 10^{13}$ 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

---

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

J.P. Lansberg (IPNO, Paris-Sud U.)

A Fixed-Target Experiment at the LHC

September 20, 2013
The lead-ion beam

- Design LHC lead-beam energy: $2.76 \text{ TeV}$ per nucleon
The lead-ion beam

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- In the fixed target mode, PbA 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, PbA collisions at $\sqrt{s_{NN}} \approx 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
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- Example of motivations:

![Graph showing measured to expected J/ψ suppression vs. energy density.](image)

*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.*
A bit of kinematics with the 2.76 TeV lead-ion beam

The lead-ion beam

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AFTER, among other things, a quarkonium observatory in \( pp \)

Interpolating the world data set:

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<th>Target</th>
<th>( \int \mathcal{L} ) (fb(^{-1}).yr(^{-1}))</th>
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<td>1 m Liq. ( H_2 )</td>
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<tr>
<td>1 m Liq. ( D_2 )</td>
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<td>LHC pp 14 Tev (low pT)</td>
<td>0.05 (ALICE) ( \times 2 ) LHCb</td>
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\text{RHIC pp 200GeV} & 1.2 \times 10^{-2} & 4.8 \times 10^5 & 1.2 \times 10^3 \\
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\]

- 1000 times higher than at RHIC; comparable to ALICE/LHCb at the LHC
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AFTER, among other things, a quarkonium observatory in pp

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- 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.
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- Many **hopes** were put in **quarkonium studies** to extract **gluon PDF**
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Production puzzle \( \rightarrow \) quarkonium not used anymore in global fits
With systematic studies, one would restore its status as gluon probe
Accessing the large $x$ gluon 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
  \[ x_g = \frac{M_{J/\Psi}/\sqrt{s}}{e^{-y_{CM}}} \]

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

$Y$: 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
(x,Q^2) map of AFTER isolated-γ

p-p kinematics at fixed-target LHC:
To access x > 0.3 one needs isolated-γ with: p_T = x_T \sqrt{s/2} > 10-20 GeV/c

[ D. d'E & J. Rojo, NPB 860 (2012) 311]
AFTER: also a quarkonium observatory in \( pA \)

| Target       | \( A \) | \( \int L \) (fb\(^{-1}\).yr\(^{-1}\)) | \( N(J/\Psi) \) yr\(^{-1} \) \(
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### Heavy-flavour observatory in pA

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- not to mention ratio with **open charm, Drell-Yan**, etc ...
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- The **target versatility** of a fixed-target experiment is undisputable

- A wide rapidity coverage is needed for:
  - A precise analysis of gluon nuclear PDF: $y, pT \leftrightarrow x$
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HERA-B PRD 79 (2009) 012001, and ref. therein
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- 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
  \( (\sqrt{s_{NN}} = 72 \text{ GeV}) \)

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Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
AFTER: also an heavy-flavour observatory in \( \text{PbA} \)

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

<table>
<thead>
<tr>
<th>Target</th>
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<th>( \int \mathcal{L} ) (nb(^{-1}).yr(^{-1}))</th>
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<tr>
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The same picture also holds for open heavy flavour
What for?

Observation of $J/\psi$ sequential suppression *seems to be hindered* by

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- 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

– $J/\psi$ data in $pA$ collisions

**SPS and Hera-B**

- *J/ψ* data in *pA* collisions

![Graph showing *J/ψ* data in *pA* collisions with data points from HERA-B, E866, NA50, NA60, and NA3.](image)

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*NA 3 Z.Phys. C20 (1983)*


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

Our idea is not completely new

North-Holland

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 $B^0 \rightarrow J/\psi + K^0_S$, $B^0 \rightarrow \pi^+ \pi^-$. 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.
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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 $10^{10}$ $\bar{B}B$ 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].
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- After a year, one simply moves the crystal by less than one mm ...
Key studies: $W/Z$ production at threshold

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- Reconstructed rate are most likely between a few dozen to a few thousand / year
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$(\Xi_{cc}, \Omega^{++}(ccc), ...)$ cross sections in the central region are being calculated with the MC generator GENXICC.
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They should also be calculated for $x \to -1$ where IQ could dominate

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J.P. Lansberg (IPNO, Paris-Sud U.)
A Fixed-Target Experiment at the LHC
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**Isolated-\(\gamma\) in \(p(7\text{ TeV})-p(\text{rest}): \sqrt{s} \sim 115\text{ GeV}\)**

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

- **JETPHOX NLO**
  
  pQCD calculations:

  - p-p at \(\sqrt{s}=115\text{ GeV}\)
  - \(|y|<0.5, p_T>20\text{ GeV/c}\)
  - Isolation: \(R=0.4, E_T^{\text{had}}<5\text{ GeV}\)
  - \(\mathcal{L}\) (10 cm \(H_2\)-target) \(\sim 2\cdot10^3\text{ pb}^{-1}/\text{year}\)

  ![Graph showing the distribution of \(d\sigma/dp_T\) for isolated-\(\gamma\) events.]

  - (preliminary)

  - \(~1\text{ count}\)

**PDF: CT10 52 eigenval. (90\% CL)**

- Scales: \(\mu_i = p_T\)
- FF = BFG-II
- x-section uncertainties\(^{(a)}\) of \(\pm 150\%\)

\(^{(a)}\) \((68\%\text{CL})/(90\% \text{CL}) \sim 1.65\)
Dilute system

Non perturbative regime

$Q^2 = Q^2_s(x)$

log $(x-1)$

log $(Q^2)$

BNL-JIMWLK

$B_2(x)

log $(Q^2)$

Fixed Target @ LHC

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Fixed Target @ LHC

x \rightarrow 1

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EMC effect

Fixed Target @ LHC

DGLAP

Nuclear fermi motion
Fixed Target @ LHC

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Dilute system

\( Q^2 = Q^2_s(x) \)

\( \log (x^{-1}) \)

\( x \rightarrow 1 \quad x \gg 1 \)

DGLAP

BFKL

saturation

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EMC effect

log \( (Q^2) \)
Overall

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W/Z

log \(x^{-1}\)

log \(Q^2\)

log \(x-1\)

x \to 1

x \gg 1

Fixed Target@LHC

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