Future Muon- & Pion-Nucleon scattering at CERN

QCD-N '06

Horst Fischer
Universität Freiburg

on behalf of the
COMPASS Collaboration

GPDs Boer-Mulders, Sivers & Transversity from Drell Yan

Physics Goals of COMPASS

Contribute to the understanding of the non-perturbative physics of the nucleon

nucleon spin structure

- Gluon Polarization $\Delta G/G$
- **Transverse spin structure functions on p and d-Target**
- **Sivers on p and d-Target**
- Inclusive Asymmetries (low x)
- Flavor dependent polarized quark helicity densities $\Delta q(x)$
- spin dependent fragmentation functions ΔD_q^{Λ}
- Diffractive VM-Production

nucleon spectroscopy

- Primakoff-Reactions
  - polarizability of π and K
- glueballs and hybrids
- charmed mesons and baryons
  - semi-leptonic decays
  - double-charmed baryons

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- Inclusive Asymmetries (low x)
- Flavor dependent polarized quark helicity densities Δq(x)
- spin dependent fragmentation functions ΔD_q^h
- Diffractive VM-Production

near future: flavor decomposition!

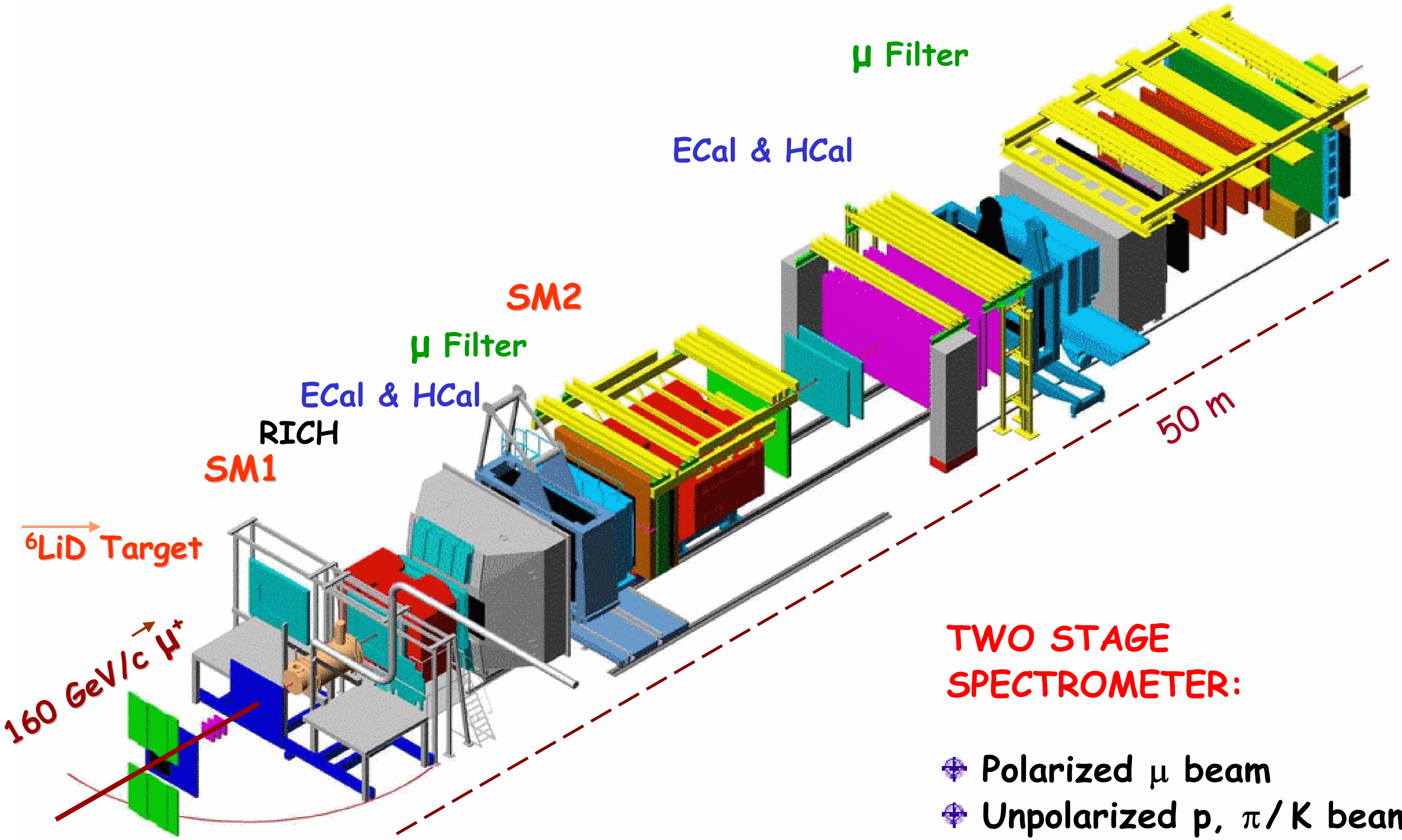
nucleon spectroscopy

- Primakoff-Reactions
  - polarizability of π and K
- glueballs and hybrids
- charmed mesons and baryons
  - semi-leptonic decays
  - double-charmed baryons

COMPASS - Fixed Target Experiment at CERN

		Muons	Hadrons (p, π/K)
Beam:	Intensity:	$2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)	$2 \cdot 10^8$ μ^+/spill
	momentum:	160 GeV/c	100 – 270 GeV/c
	polarization:	-80%	

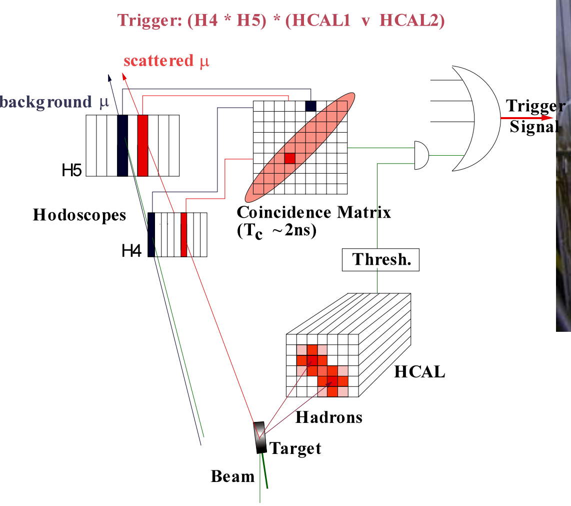
The COMPASS Spectrometer @ CERN



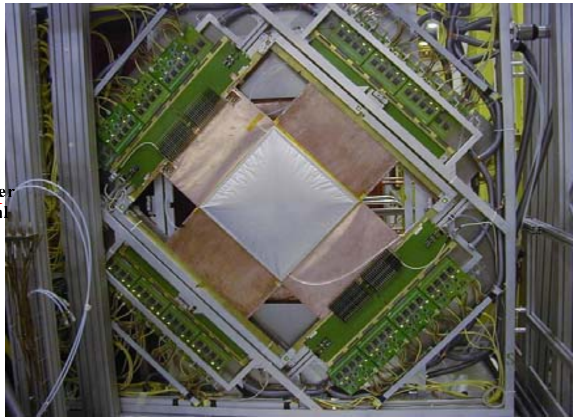
TWO STAGE SPECTROMETER:

- Polarized μ beam
- Unpolarized p, π/K beam
- Polarized target
- Particle identification

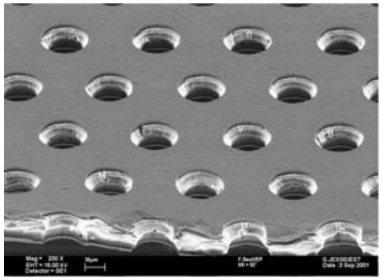
Many new technologies for tracking and PID



Trigger-System

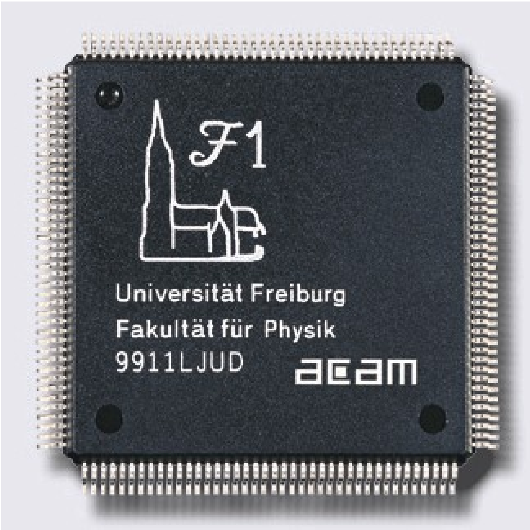


MicroMegas

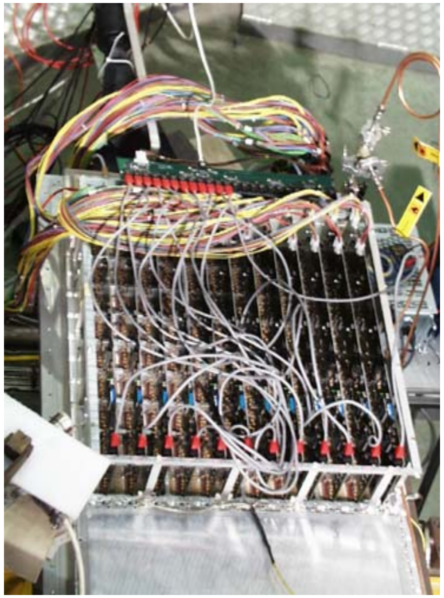


GEM

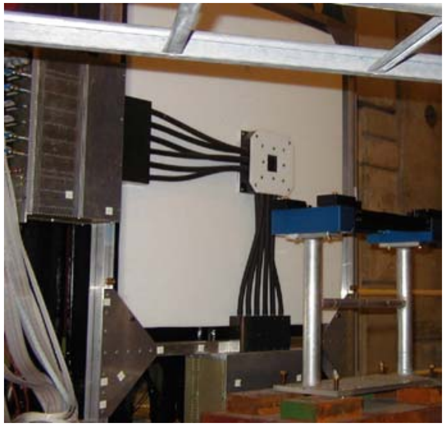
Straws



Readout electronics



RICH readout

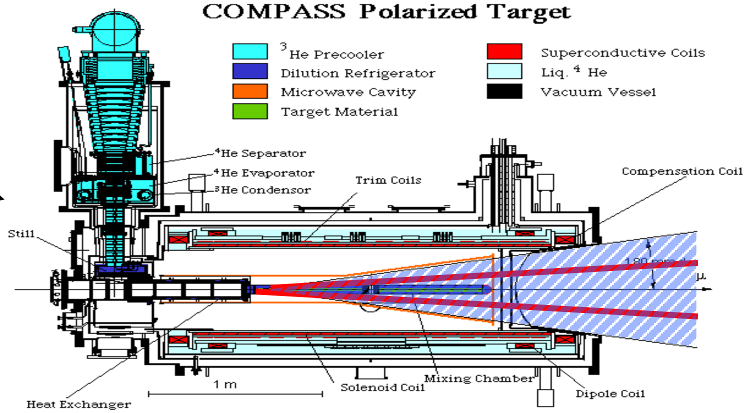


Scintillating fiber trackers

COMPASS upgrades for 2006

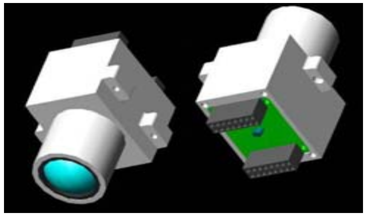
New solenoid magnet:

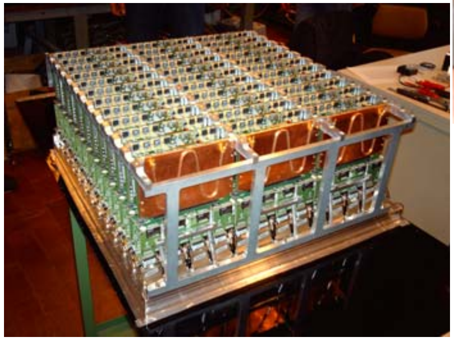
acceptance 70 mrad → 180 mrad



RICH upgrade

- Central region: MAPMT system
  - More photons
  - Improved S/N
- Outer region: sampling ADC
  - Improved S/N





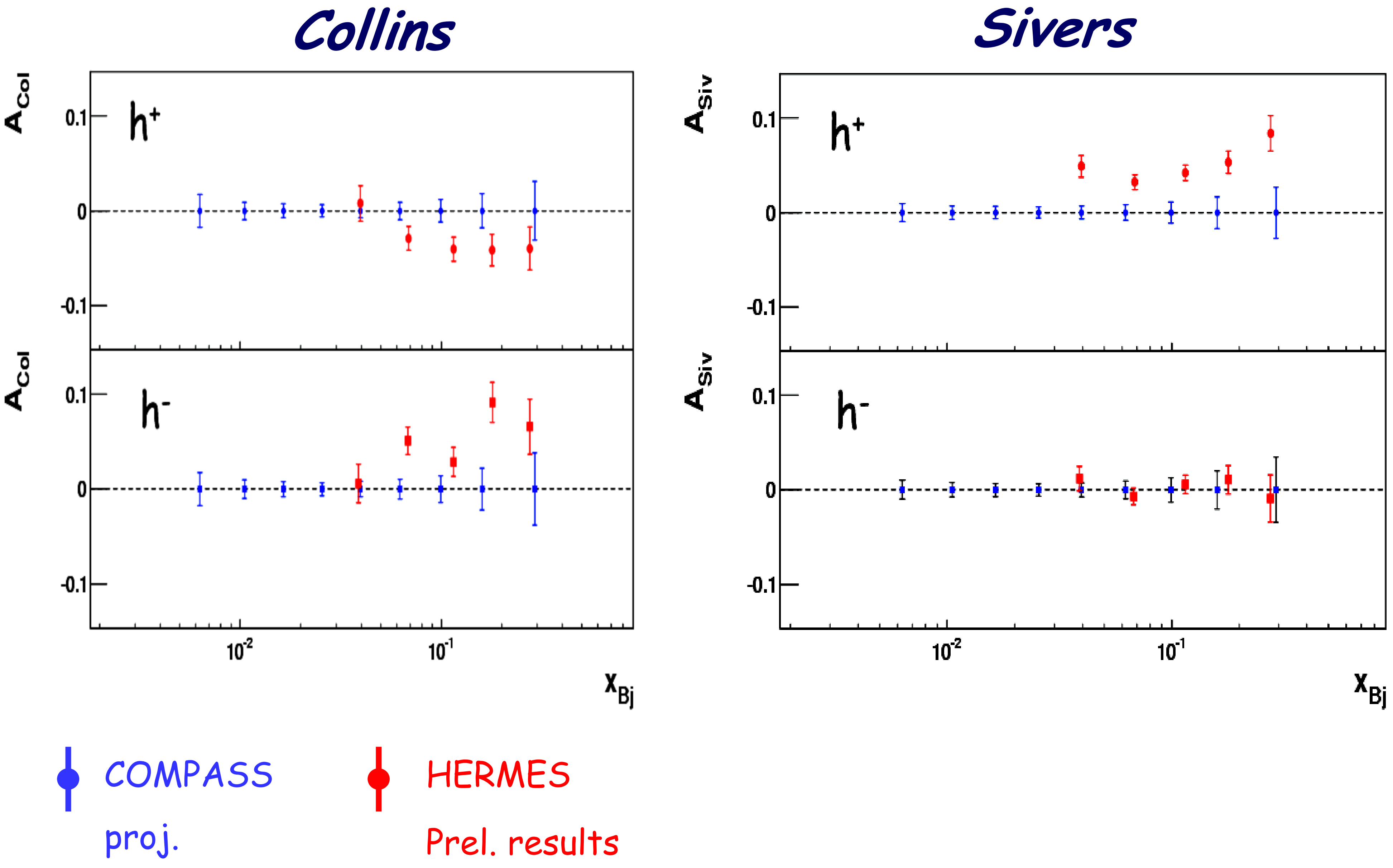
Other important upgrades:

- Large Drift Chamber
- RICHWall
- Full ECAL coverage
- trigger

Expected statistics from 2006 run

Collins and Sivers Asymmetries

Collins/Sivers: Transverse running with NH3 in 2006

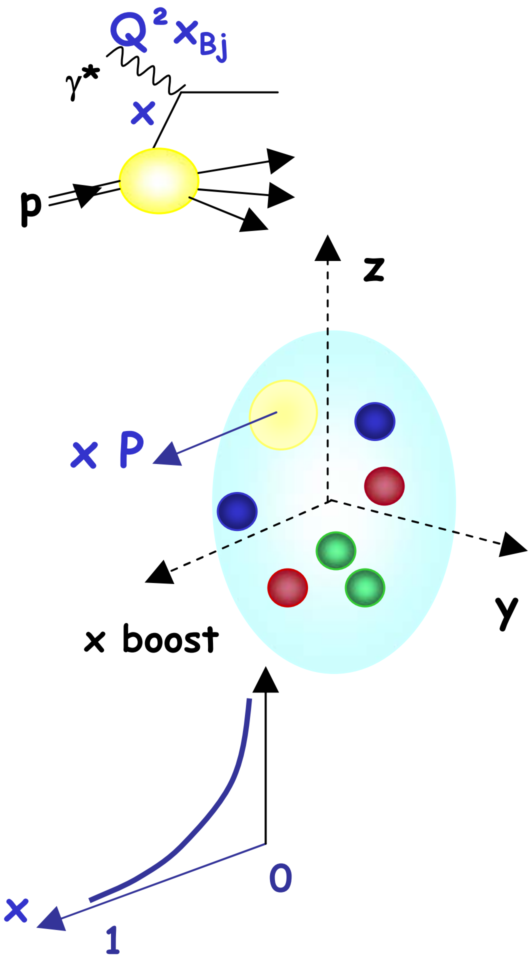


Measurement of GPDs at COMPASS

GPD – 3-D picture of the partonic nucleon structure

Deep Inelastic Scattering

ep→ eX

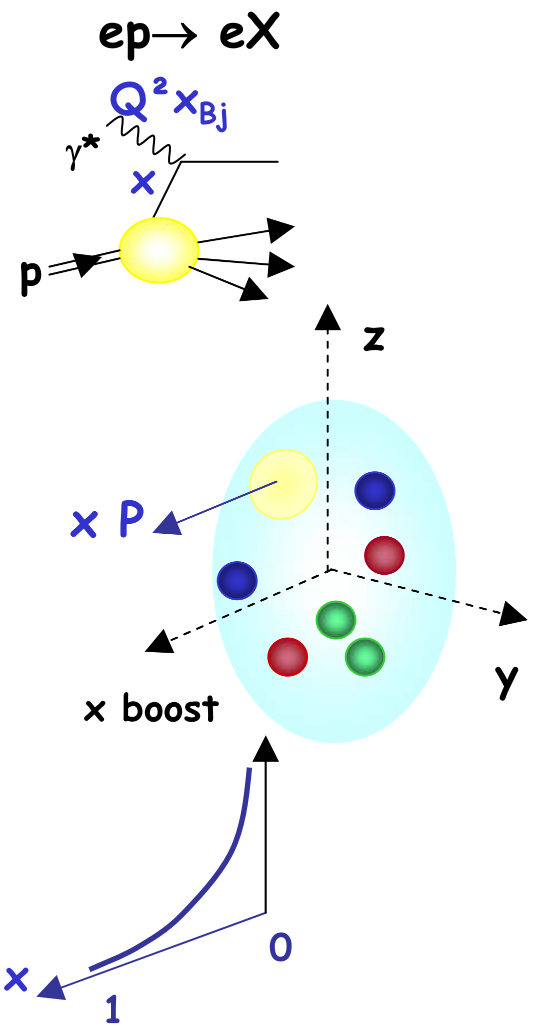


Parton Density q (x)

P_x

GPD – 3-D picture of the partonic nucleon structure

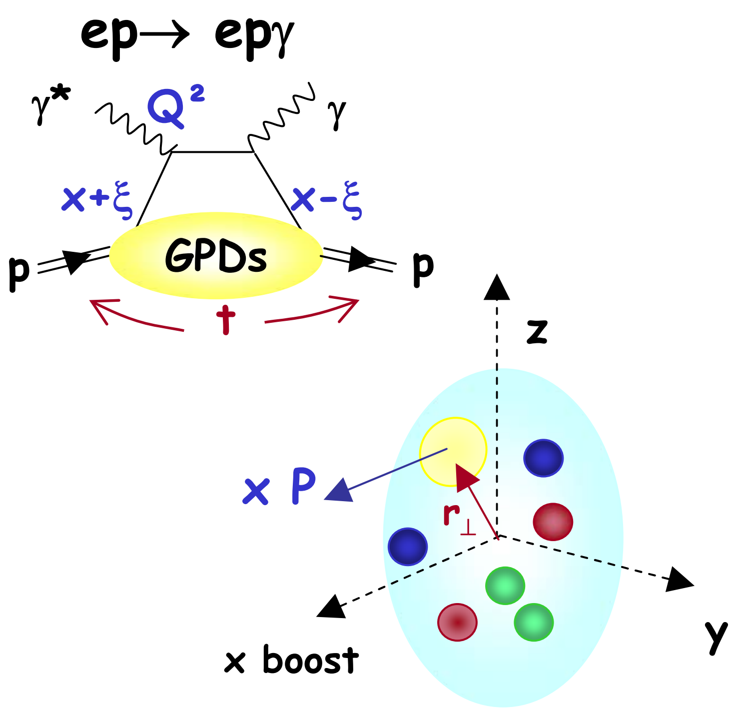
Deep Inelastic Scattering



Parton Density q (x)

P_x

Hard Exclusive Scattering
Deeply Virtual Compton Scattering



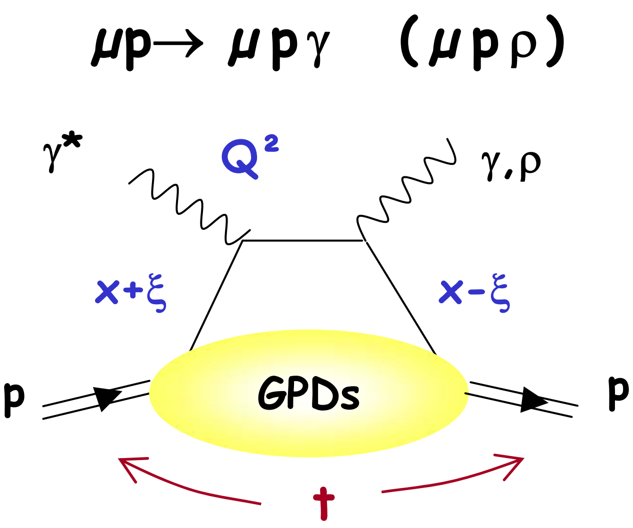
Generalized

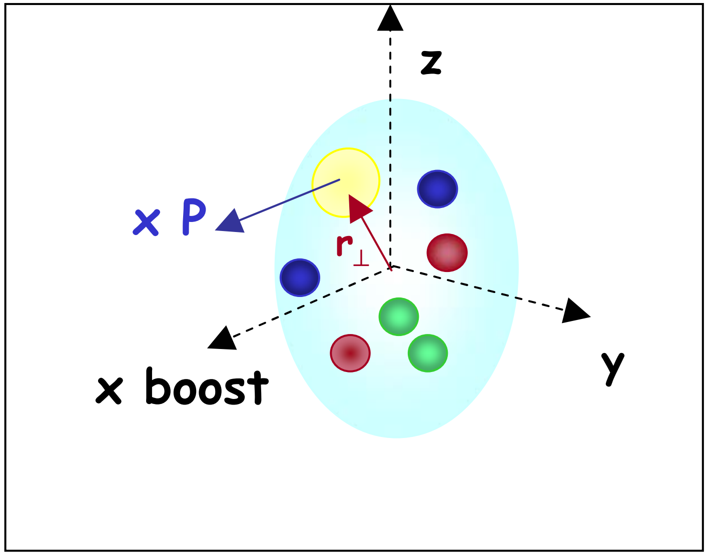
Parton Distribution H(x,ξ,t)

(P_x, $r_{y,z}$)

Burkardt, Belitsky, Müller, Ralston, Pire

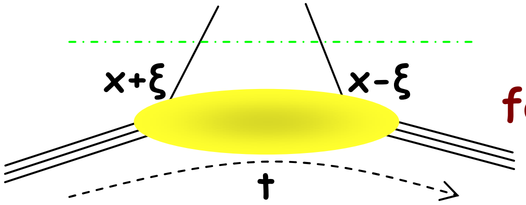
Generalized Parton Distributions





- GPDs depend on 3 variables:
  - x: longitudinal quark momentum fraction $\neq x_{Bj}$
  - 2ξ: longitudinal momentum transfer: $\xi = x_{Bj}/(2-x_{Bj})$
  - t: momentum transfer squared to the target nucleon (fourier conjugate to the transverse impact parameter r)
- Deep Virtual Compton Scattering
  - GPD: $H, \tilde{H}, E, \tilde{E}$
- Hard Exclusive Meson Production
  - Vektormeson: E, H
  - Pseudoscalar: $\tilde{E}, \tilde{H}$

GPDs and Relations to Physical Observables



factorization

The observables are some integrals of GPDs integrated over x

Dynamics of partons in the Nucleon

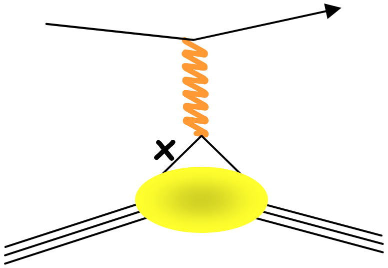
Models:

Parametrization

Fit of Parameters to the data

$H, \tilde{H}, E, \tilde{E}(x,\xi,t)$

Elastic Form Factors



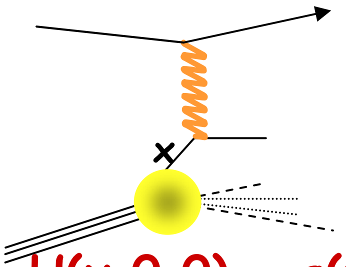
$\int H(x,\xi,t)dx = F(t)$

Ji's sum rule

$$2J_q = \int x(H^q+E^q)(x,\xi,0)dx$$

$$1/2 = 1/2\ \Delta\Sigma + L_q + \Delta G + L_g$$

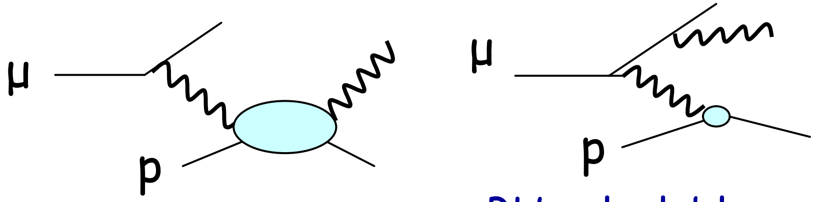
"ordinary" parton density



$H(x,0,0) = q(x)$

$\tilde{H}(x,0,0) = \Delta q(x)$

DVCS and Bethe Heitler

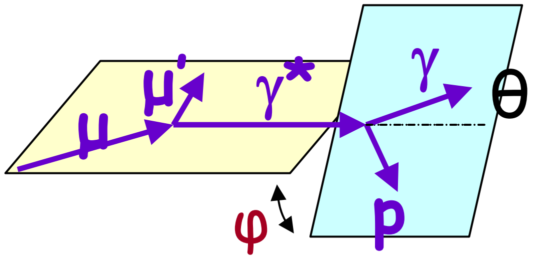


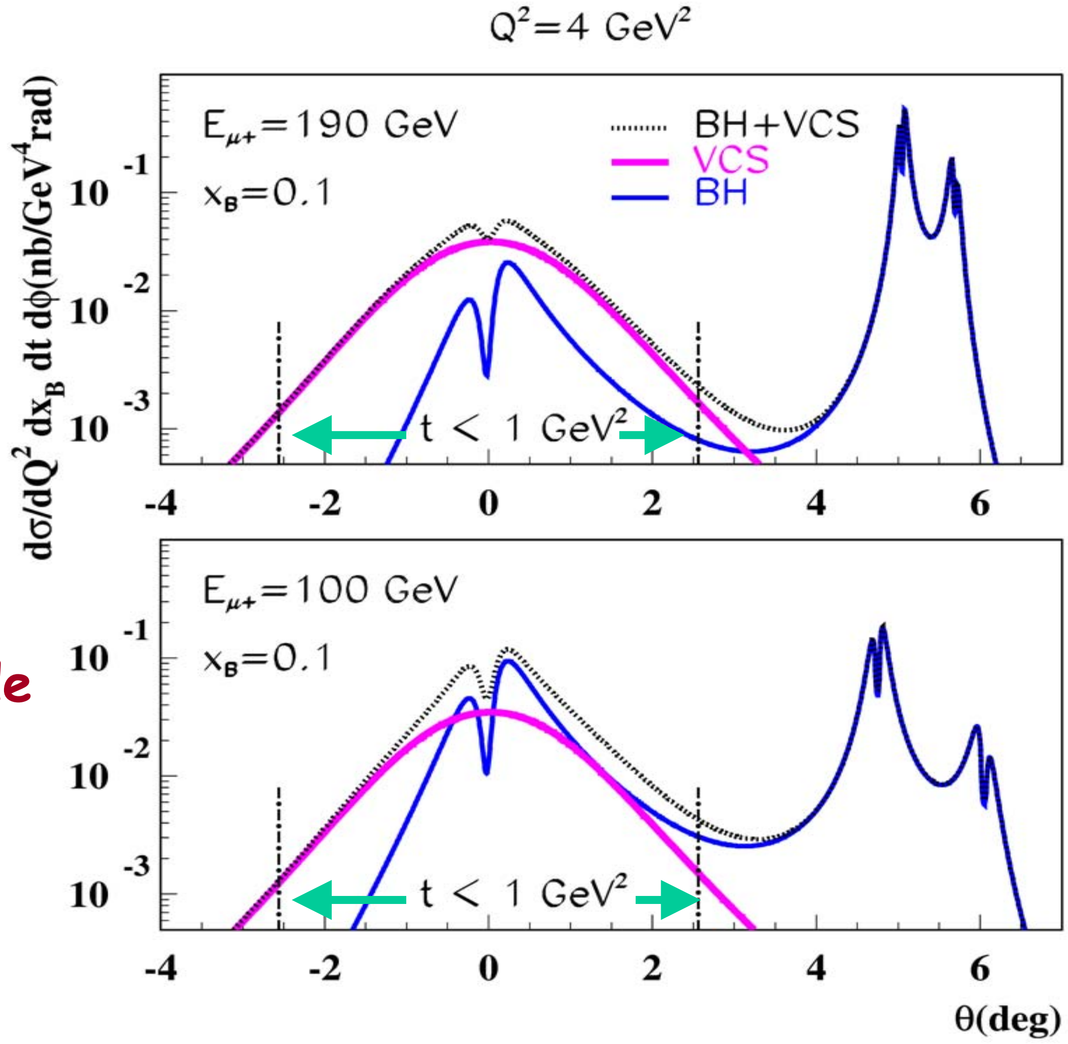
BH calculable

Advantage of flexibility in selection of muon beam energy at COMPASS:

- Higher energy: DVCS >> BH
  ⇒ DVCS Cross section

- Smaller energy: DVCS ≈ BH
  ⇒ Interference term will provide the DVCS amplitude





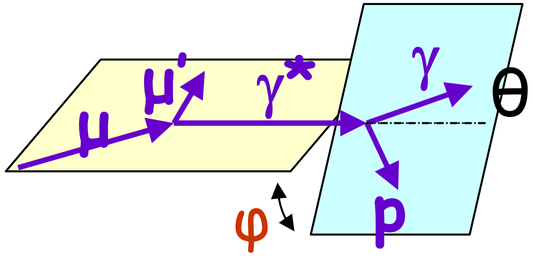
Advantage of $\overleftarrow{\mu}^{+}$ and $\overrightarrow{\mu}^{-}$ for DVCS (+BH)

$$\mathcal{A}^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

t, $\xi \sim x_{Bj}/2$ fixed

$$d\sigma_{(\mu p \to \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}$$
$$+ e_\mu\, a^{BH}\, \mathcal{R}e\, \mathcal{A}^{DVCS} + e_\mu P_\mu\, a^{BH}\, \mathcal{I}m\, \mathcal{A}^{DVCS}$$

$\times \cos n\varphi$ $\quad$ $\times \sin n\varphi$



$P_{\mu+} = -0.8$ $P_{\mu-} = +0.8$

Advantage of $\overleftarrow{\mu}^{+}$ and $\overrightarrow{\mu}^{-}$ for DVCS (+BH)

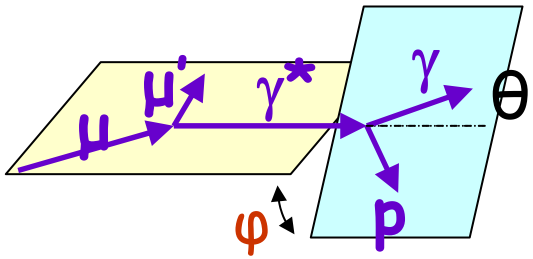
$$A^{DVCS}_{(\mu p\to\mu p\gamma)} = \int_{-1}^{+1} dx\,\frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx\,\frac{H(x,\xi,t)}{x-\xi} - i\,\pi\,H(x=\xi,\xi,t)$$

t, $\xi \sim x_{Bj}/2$ fixed

$$d\sigma_{(\mu p\to\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}$$

$$+\, e_\mu\, a^{BH}\, \mathcal{Re}\, A^{DVCS} \qquad +\, e_\mu\, P_\mu\, a^{BH}\, \mathcal{Im}\, A^{DVCS}$$

$\times \cos n\varphi$ $\qquad$ $\times \sin n\varphi$



$P_{\mu+}=-0.8$ $P_{\mu-}=+0.8$

$$\sigma^{\overleftarrow{\mu}+} + \sigma^{\overrightarrow{\mu}-} \sim H(x=\xi,\xi,t)$$

Advantage of $\overleftarrow{\mu}^{+}$ and $\overrightarrow{\mu}^{-}$ for DVCS (+BH)

$$A^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\,\pi\, H(x=\xi,\xi,t)$$

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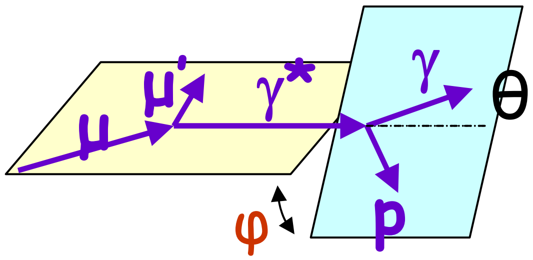
$$d\sigma_{(\mu p\to\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}$$

$$+\, e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS} + e_\mu P_\mu\, a^{BH}\, \mathcal{I}m\, A^{DVCS}$$

$\times \cos n\varphi$ $\quad$ $\times \sin n\varphi$

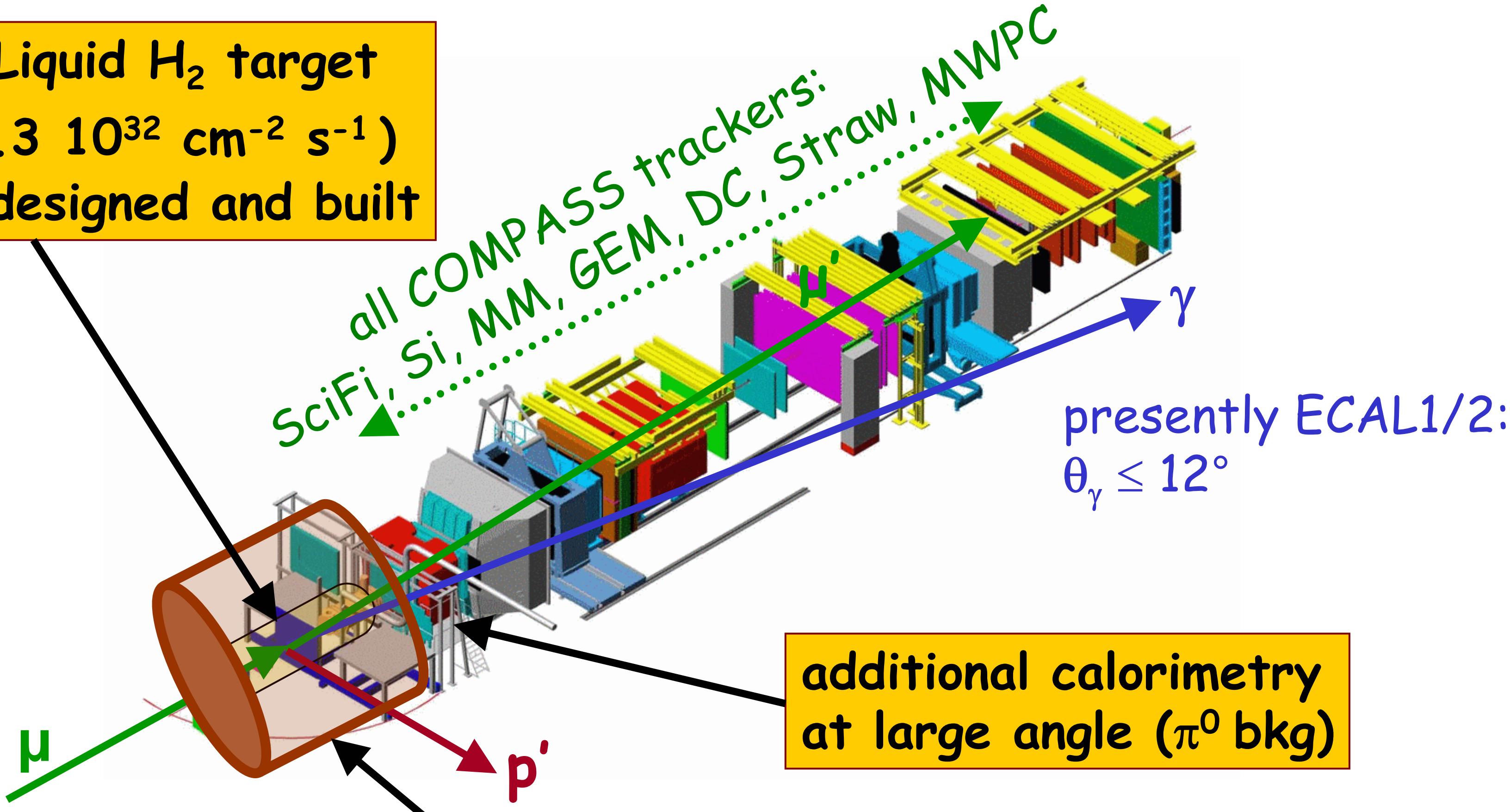


$P_{\mu+}$=-0.8 $P_{\mu-}$=+0.8

$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\overrightarrow{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

Experimental Setup: Target & Detektor

2.5 m Liquid H_2 target
($\mathcal{L}$ = 1.3 10^{32} cm^{-2} s^{-1})
- to be designed and built



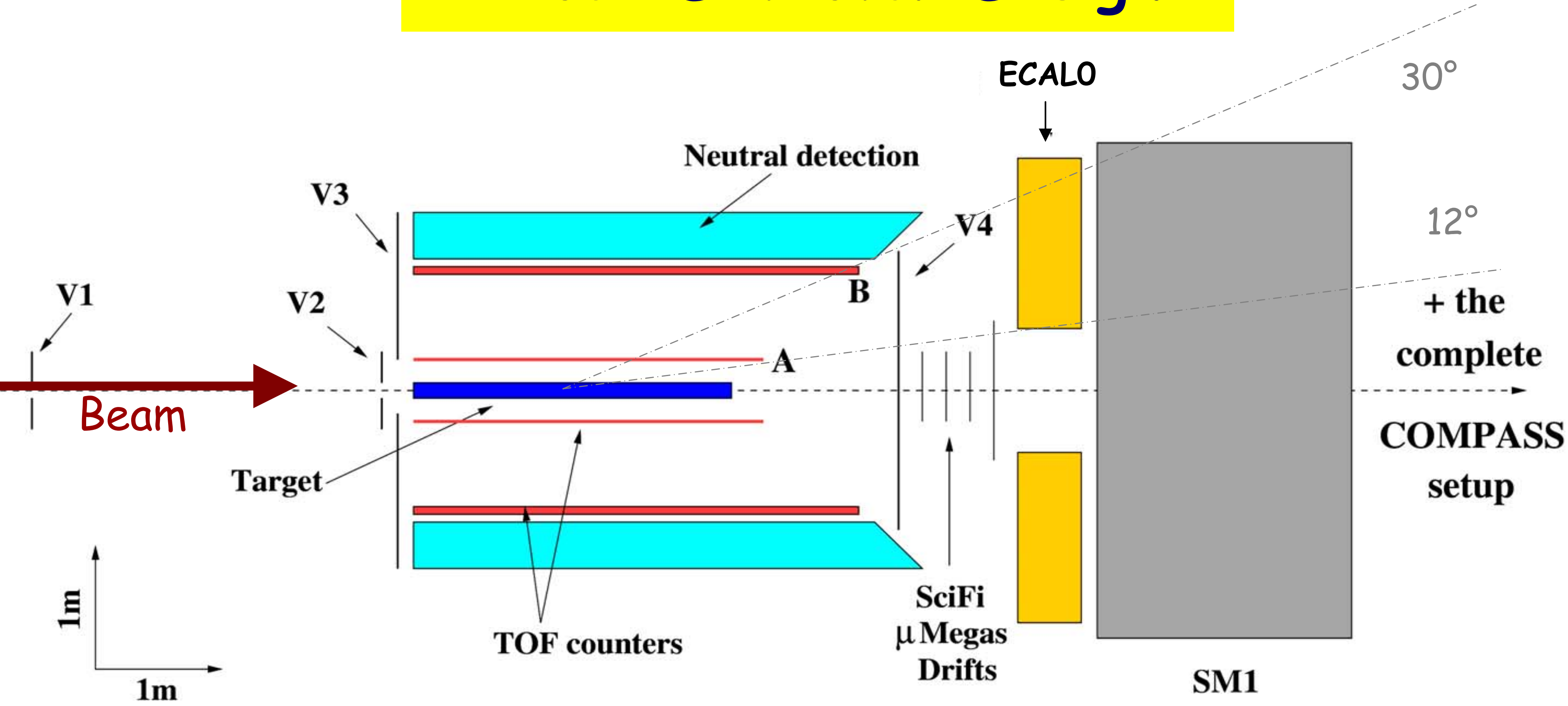
additional calorimetry at large angle (π^0 bkg)

Beam:

Energy:	100 GeV
Intensity:	$2 * 10^8$/spill
Polarization:	$P(\mu -) = +0.8$
	$P(\mu +) = -0.8$

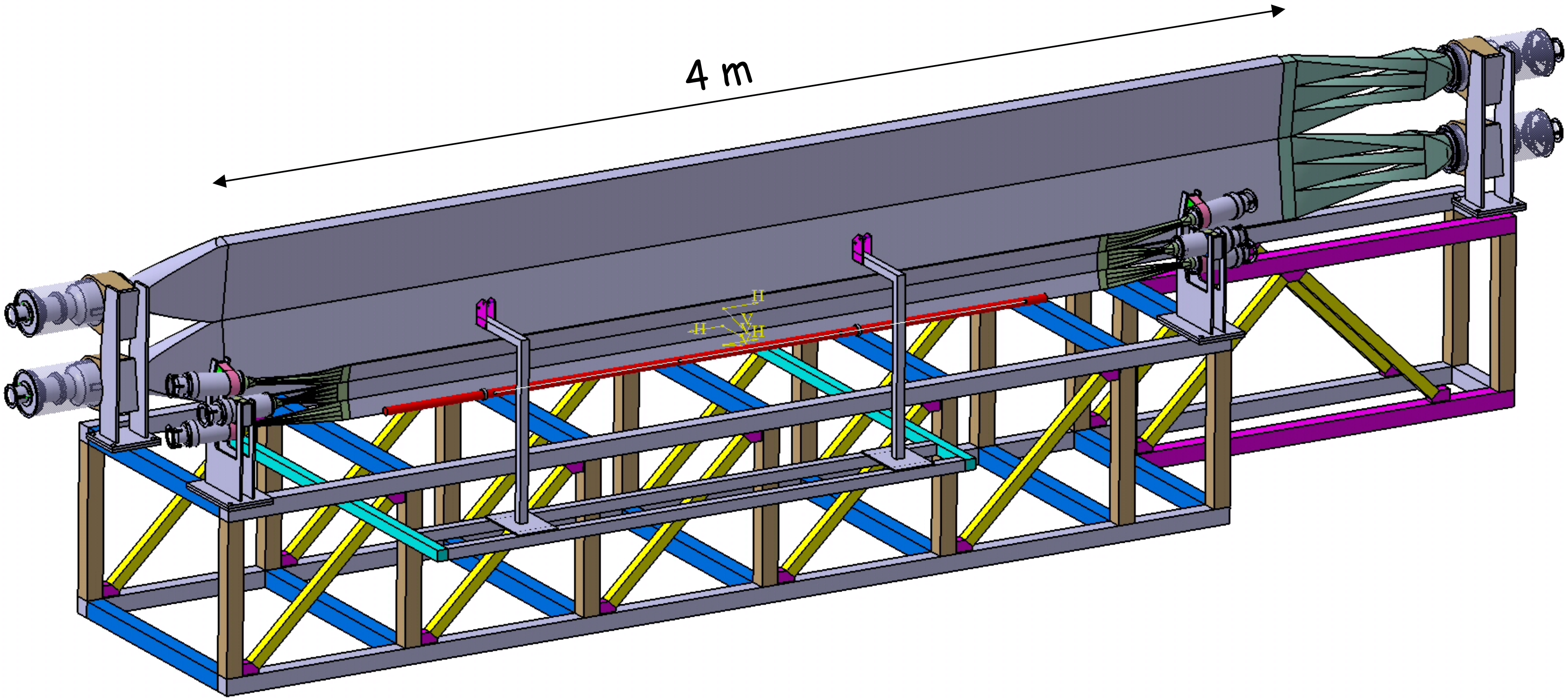
Recoil detector to insure exclusivity
- to be designed and built

Recoil Detector Design



- Detect protons of 250-750 MeV/c
  - ToF with 200 ps resolution required
  - 2 concentric barrels of 24 scintillators
  - read out at both sides, fast multi-hit ADC / wave form digitizer

Recoil Detector Prototype



- 30° sector design
- Test at COMPASS beam this year
- Funded by EU FP6 (Bonn, Mainz, Saclay, Warsaw)

Prospects: Kinematical Range

Limit for ρ (DVMP)
2 times higher Q^2

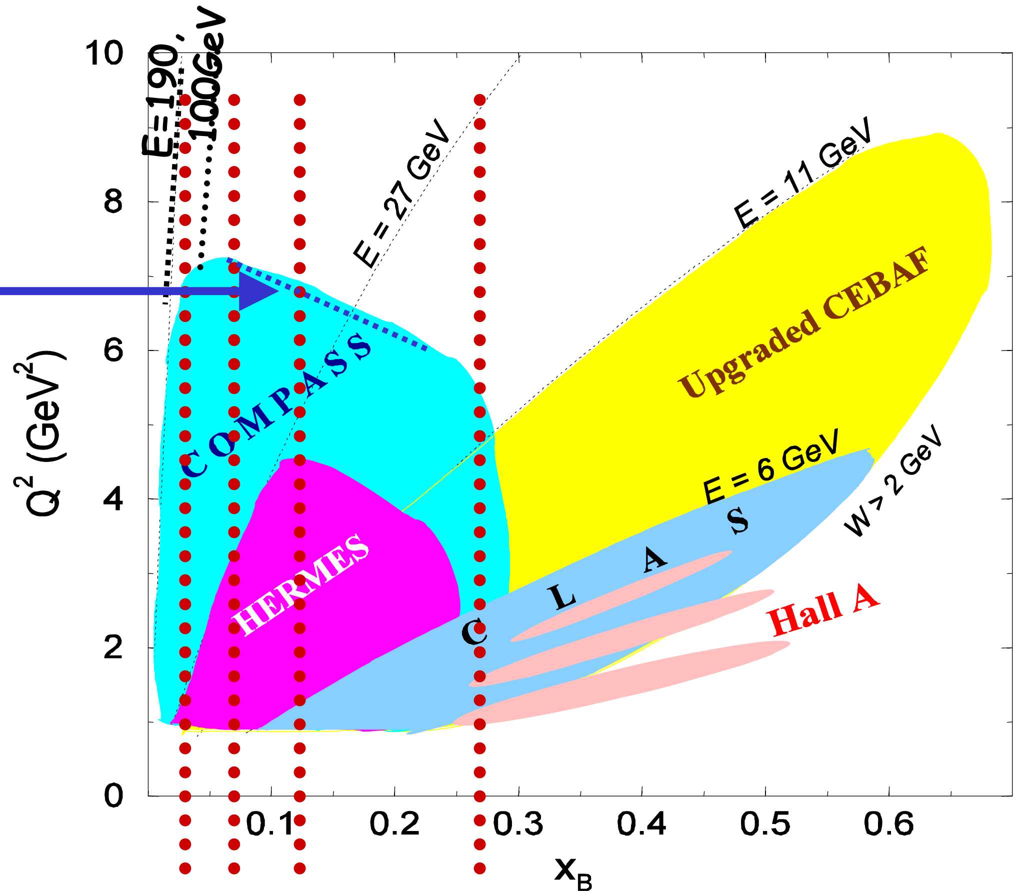
Limitation by luminosity

Today: $N_\mu = 2 \cdot 10^8 \mu$ per SPS spill

for DVCS

$\Rightarrow$ $Q^2 < 7.5\ GeV^2$

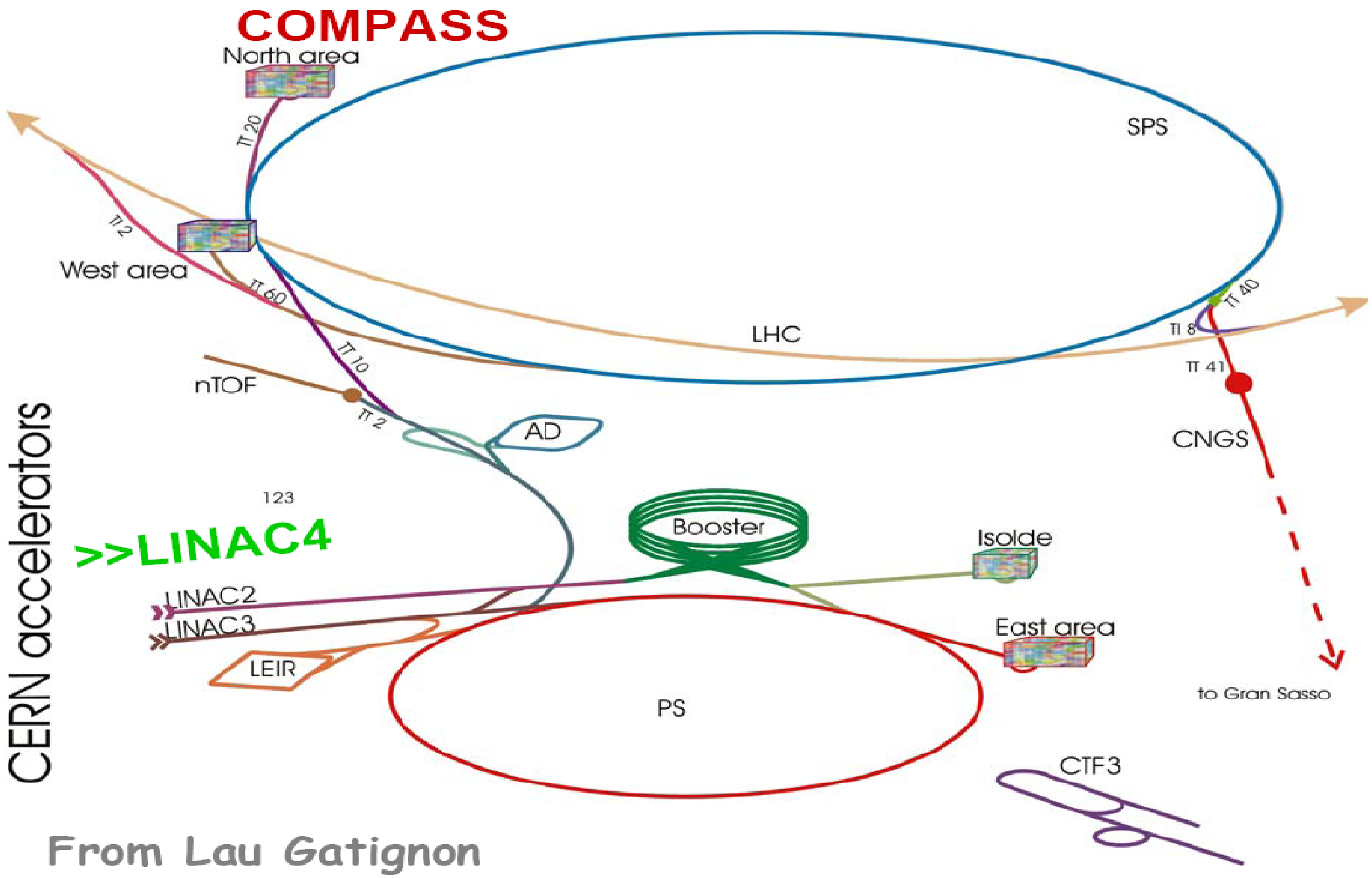
At fixed x_{Bj}, study in Q^2



μ flux at COMPASS in >2010

☹ - Sharing proton beam with CNGS

☺ - New LINAC4 → up to 10 times more protons
+ improvements on μ beam line necessary



From Lau Gatignon

Prospects: Kinematical Range

if $N_\mu \times 5 \Rightarrow Q^2 < 17\ GeV^2$ for DVCS

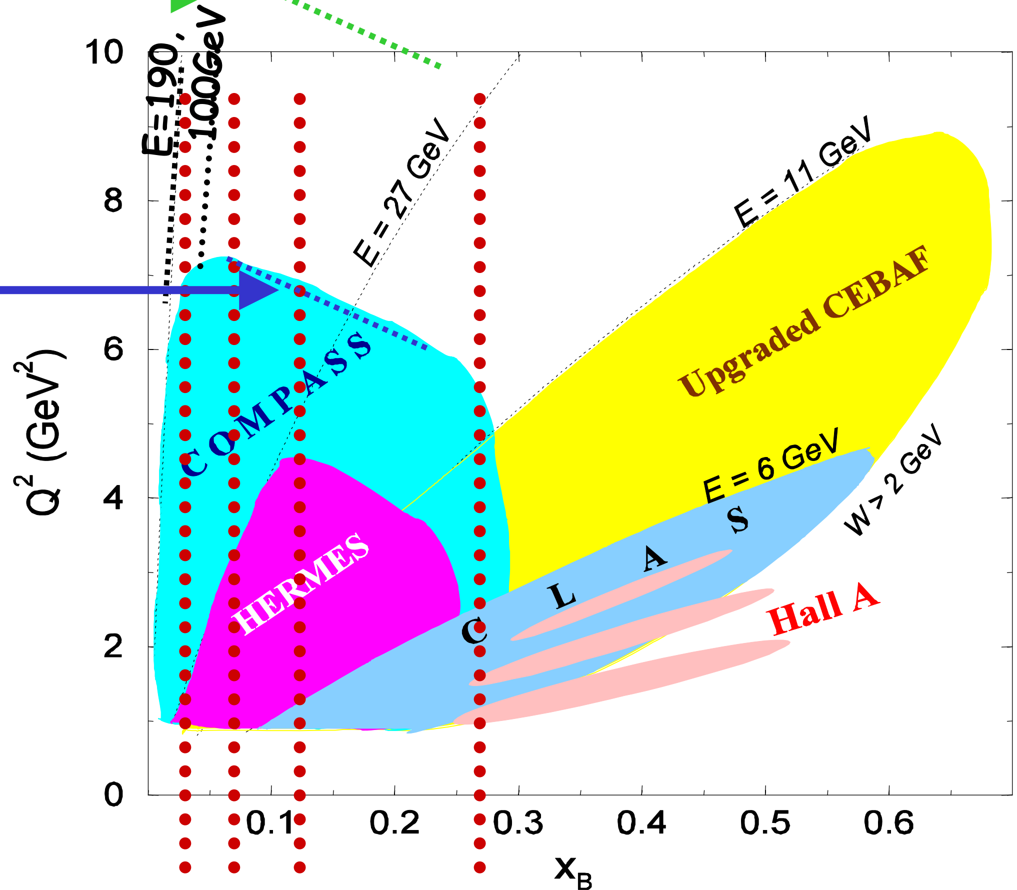
Limit for ρ (DVMP) 2 times higher Q^2

if $N_\mu \times 2 \Rightarrow Q^2 < 11\ GeV^2$ for DVCS

Limitation by luminosity

Today: $N_\mu = 2 \cdot 10^8 \mu$ per SPS spill for DVCS $\Rightarrow Q^2 < 7.5\ GeV^2$

At fixed x_{Bj}, study in Q^2



Simulations with two Models for GPDs

Use different parametrisations of GPDs

Model 1: $H(x,\xi,t) \sim q(x)\,F(t)$

Vanderhaeghen *et al.*, PRD60 (1999) 094017

Model 2: Chiral quark-soliton model: Goeke *et al.*, NP47 (2001) 401

$H(x,0,t) = q(x)\,e^{\,t\,\langle b_\perp^2\rangle} = q(x)\,/\,x^{\alpha' t}$ (α': slope of Regge trajectory)

$\langle b^2_\perp\rangle = \alpha' \ln 1/x$ transverse extension of partons in hadronic collisions

considers fast partons in the small valence core
and slow partons at larger distance (wider meson cloud)

includes correlation between x and t

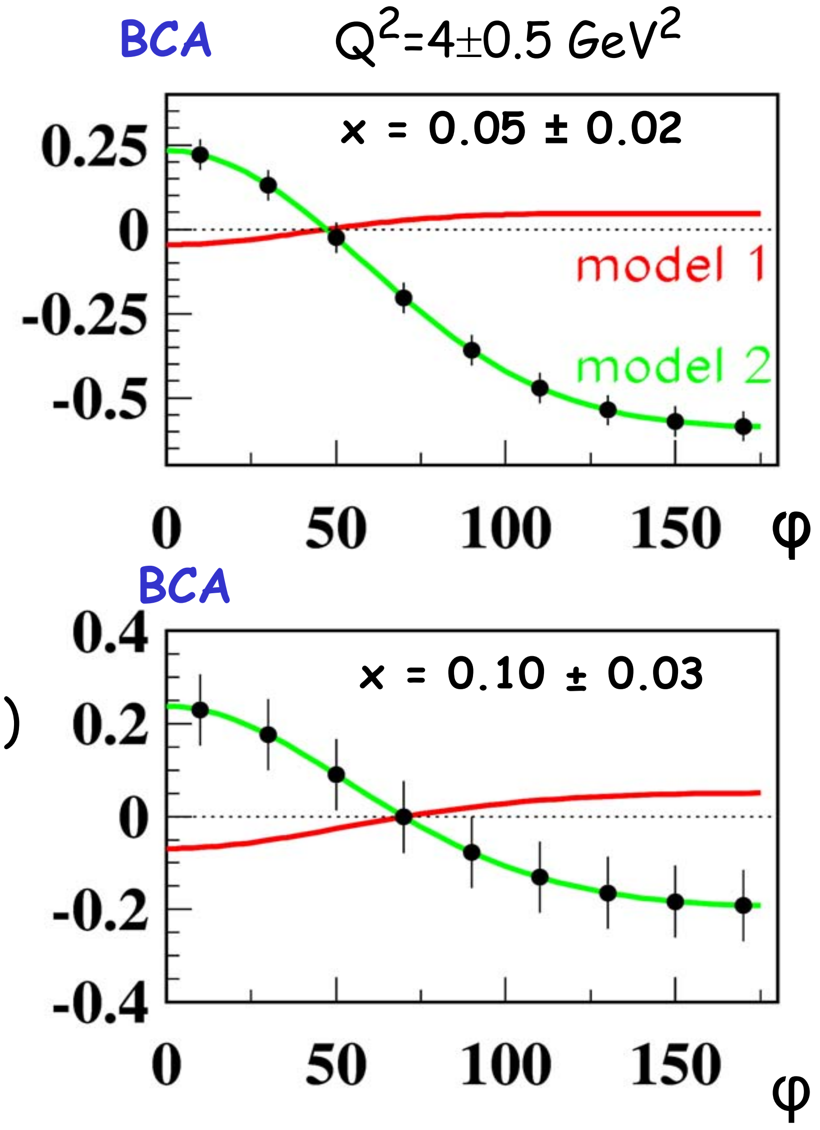
DVCS Simulations for COMPASS at 100 GeV

$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\overrightarrow{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

Model 2: $H(x,0,t) = q(x)\, e^{\,t\, \langle b_\perp^2 \rangle}$

$= q(x) / x'$

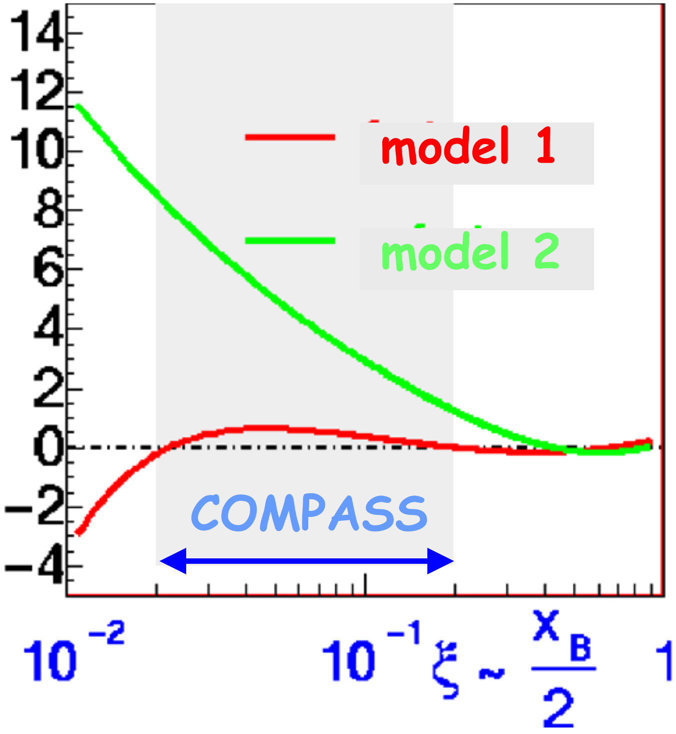


- 6 bins in Q^2 from 1.5 to 7.5 GeV^2 (1 shown)
- 3 bins in x_{Bj}=0.05,0.1,0.2 (2 shown)

- Assumptions
  - $L=1.3\ 10^{32}\ cm^{-2}s^{-1}$
  - 150 days
  - efficiency=25%

Advantage of COMPASS kinematics

$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\overrightarrow{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$



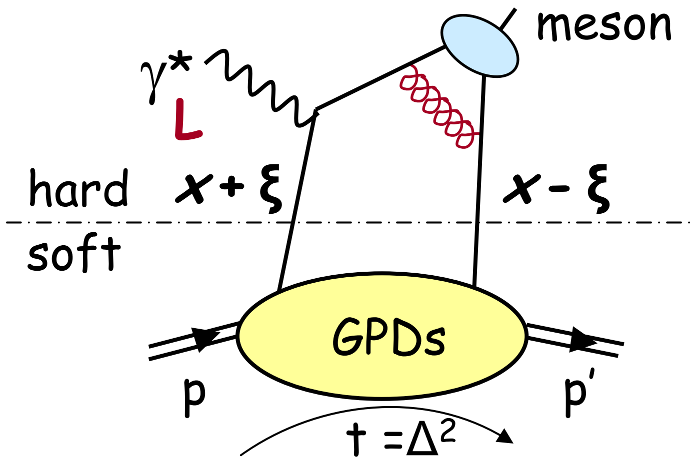
Model 1: $H(x,\xi,t) \sim q(x)\,F(t)$

Model 2: $H(x,0,t) = q(x)\,e^{t\langle b_\perp^2\rangle}$

$= q(x) / x^{\alpha' t}$

- sensitive to different spatial distributions at different x

Hard Exclusive Meson Production ($\rho, \omega, \phi \ldots, \pi, \eta \ldots$)

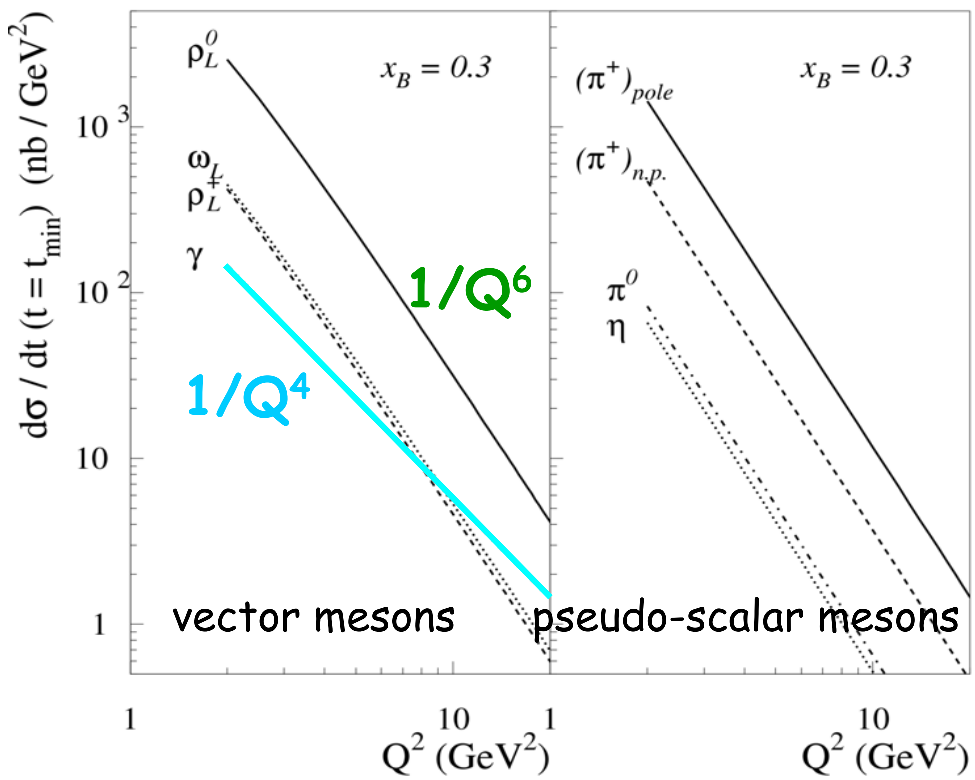


Collins et al. (PRD56 1997):

1. factorization applies only for γ^*_L

2. $\sigma_T << \sigma_L$

Scaling predictions:



ρ^0 largest production
$\rho^0 \rightarrow \pi^+ \pi^-$

present study
with COMPASS

Roadmap for GPDs at COMPASS

- ☑ **2005:** Expression of interest SPSC-EOI-005
- **2006:** Test of recoil detector prototype

➡ Proposal

- **2007-2009:** construction of
  - recoil detector
  - LH_2 target
  - ECAL0

➡ **≥2010: Study of GPDs at COMPASS**

In parallel COMPASS analysis of existing data:

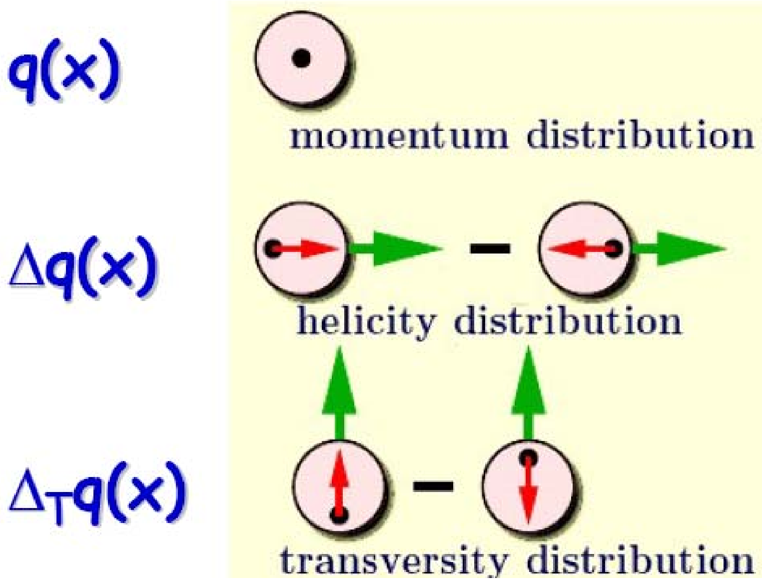
- Complete analysis of ρ, ϕ, 2π production
- GPD E/H investigations with the trans. polarized target

Boer-Mulders, Transversity and Sivers Functions from Drell Yan

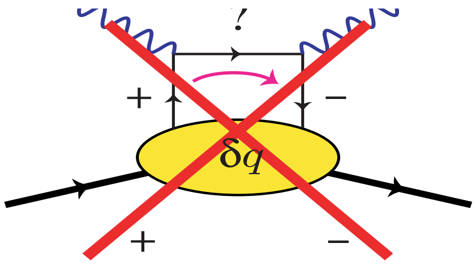
- *preliminary studies !*

Transversity

LO: 3 distribution functions necessary to describe fully the spin structure of the nucleon

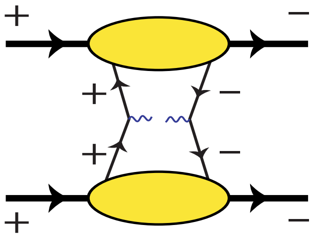


Inclusive DIS



impossible

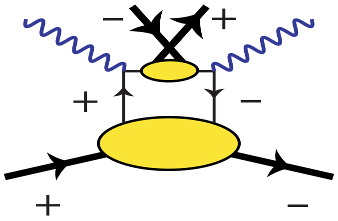
$p^{\uparrow}p^{\uparrow}\rightarrow l^{+}l^{-}X$



direct measurement

$\Sigma\Delta_T q(x)\cdot\Delta_T q(x)$

$lp^{\uparrow}\rightarrow l'hX$



convolution with spin dependent fragment. func.

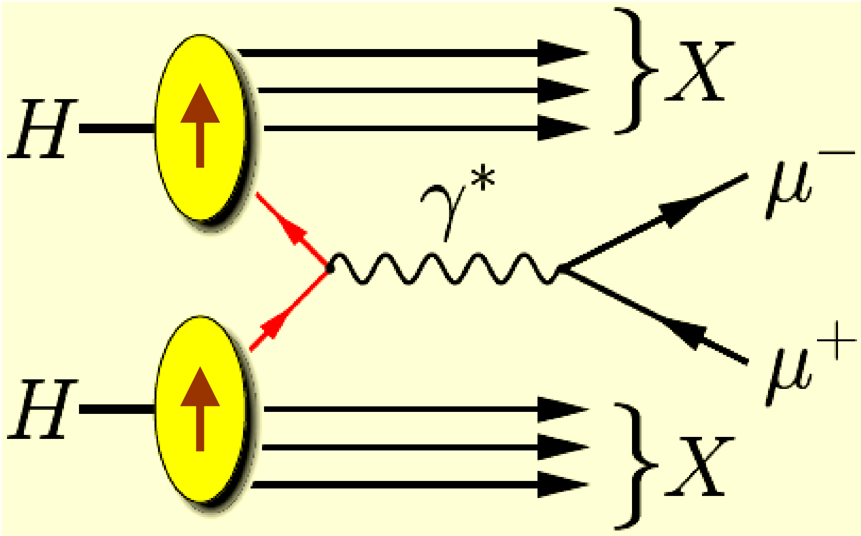
$\Delta_T q(x) \otimes FF$

Transversity from Drell-Yan

- alternative way to access transversity
- no need of any fragmention functions

- **double polarized Drell-Yan allows direct extraction of transverstiy**

$$A_{TT} \propto \frac{\sum e_q^2 \bar{h}_{1q}(x_1) h_{1q}(x_2)}{\sum e_q^2 \bar{f}_{1q}(x_1) f_{1q}(x_2)}$$



$\bar{p}^{\uparrow} p^{\uparrow} \rightarrow l^+ l^- X$ **Could become possible at GSI - experimentally challenging !**

COMPASS: transversity from $\pi^- p^{\Uparrow} \to \mu^+ \mu^- X$

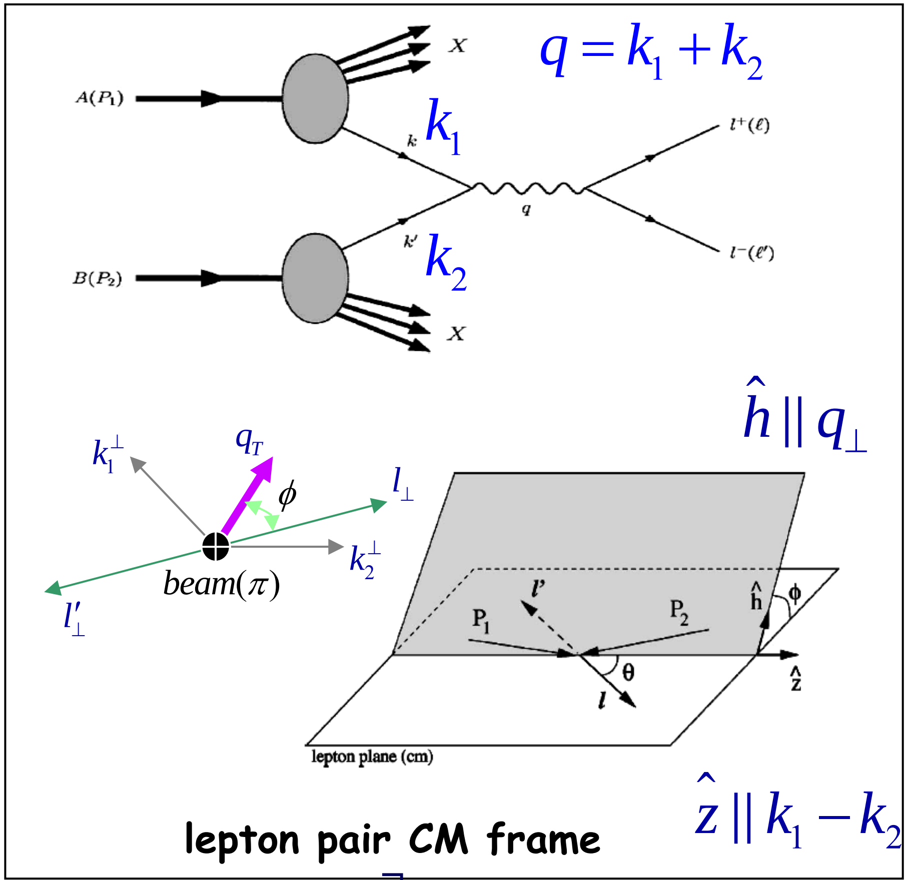
Bianconi, Radici hep-ph/0510165, hep-ph/0602103
A.Sissakian et al., Phys. Rev. D72, 054027 (2005), hep-ph/0512095

Use unpolarized Drell-Yan

$$\pi^- p \to \mu^+ \mu^- X$$

$$\hat{R} \equiv \frac{\int d^2 q_T \left[|q_T|^2 / M_\pi M_p \right] \left[d\sigma^{(0)} / d\Omega \right]}{\int d^2 q_T \sigma^{(0)}}$$

q_T weighted angular distribution
of transvese momentum of virtual photon



$$\hat{R} = \frac{3}{16\pi} \left(\gamma \left(1 + \cos^2 \theta \right) + \hat{k} \cos 2\phi \sin^2 \theta \right)$$

$$\hat{k}\left(x_\pi, x_p\right) = 8 \frac{\sum_q e_q^2 \left[\overline{h}_{1q}^{\perp(1)} \left(x_\pi\right)\Big|_{\pi^-} \cdot h_{1q}^{\perp(1)} \left(x_p\right)\Big|_p + \left(x_\pi \leftrightarrow x_p\right) \right]}{\sum_q e_q^2 \left[\overline{f}_{1q} \left(x_\pi\right)\Big|_{\pi^-} \cdot f_{1q} \left(x_p\right)\Big|_p + \left(x_\pi \leftrightarrow x_p\right) \right]}$$

How to extract transversity ?

+ use single polarized Drell-Yan $\pi^- p^\Uparrow \to \mu^+ \mu^- X$

$$\hat{A} \equiv \frac{\int d\Omega d\phi_{S2} \int d^2 q_T \left(|q_T| / M_\pi \right) \sin(\phi + \phi_{S2}) \left[d\sigma(S_{2T}) - d\sigma(-S_{2T}) \right]}{\int d\Omega d\phi_{S2} \int d^2 q_T \left[d\sigma(S_{2T}) + d\sigma(-S_{2T}) \right]}$$

ϕ_{S2} : azimuthal angle of the target spin vector S_{2T} : target spin vector

$$\hat{A}(x_\pi, x_p) = -\frac{1}{2} \frac{\sum_q e_q^2 \left[\bar{h}_{1q}^{\perp(1)}(x_\pi)\Big|_{\pi^-} \cdot h_{1q}(x_p)\Big|_p \right]}{\sum_q e_q^2 \left[\bar{f}_{1q}(x_\pi)\Big|_{\pi^-} \cdot f_{1q}(x_p)\Big|_p + (x_\pi \leftrightarrow x_p) \right]}$$

neglect s-quark, sea quark in proton, and d-quark contributions
(d-quark suppressed by $\frac{1}{4}$ due to its charge)

Boer-Mulders

$$h_{1u}^{\perp(1)}(x) = f_{1u}(x) \sqrt{\frac{\hat{k}(x,x)\Big|_{\pi^- p}}{8C_u}}$$

Transversity

$$h_{1u}(x) = -4\sqrt{2} \frac{\hat{A}_h(x,x)\Big|_{\pi^- p^\uparrow}}{\sqrt{C_u \hat{k}(x,x)\Big|_{\pi^- p}}} f_{1u}(x)$$

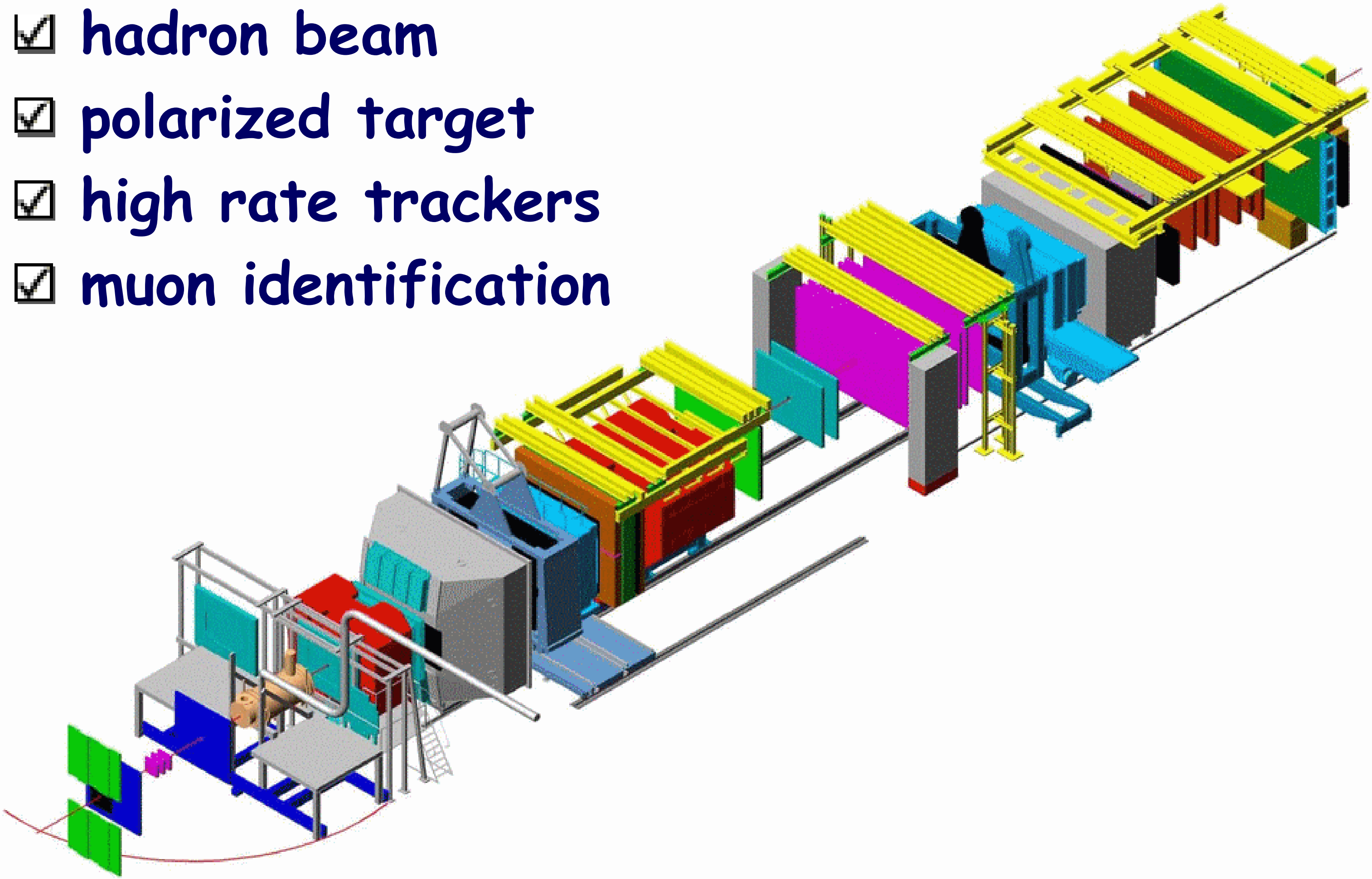
Sivers

$\sin(\phi - \phi_s)$

Single-polarized Drell-Yan

$$\pi^- p^\uparrow \rightarrow \mu^+ \mu^- X$$

- experimentally less difficult
- unique environment of COMPASS:
  - ☑ hadron beam
  - ☑ polarized target
  - ☑ high rate trackers
  - ☑ muon identification



Count rate estimates

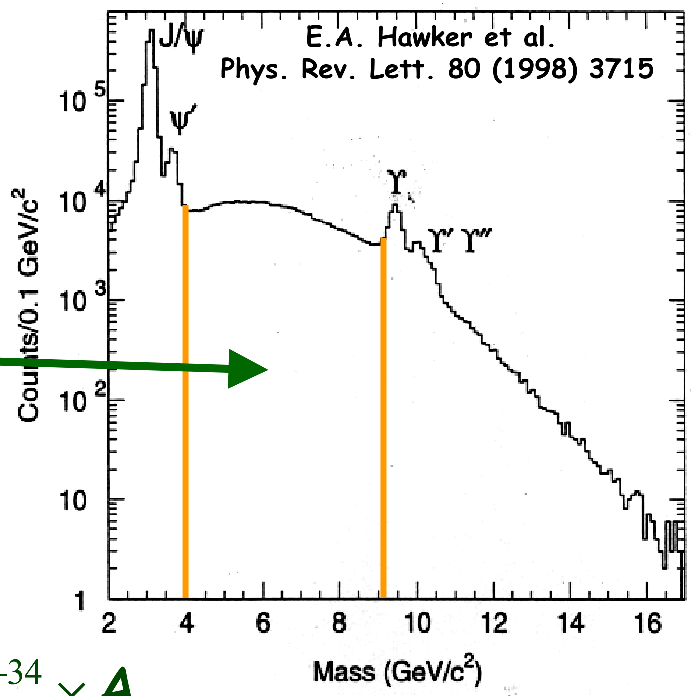
Very preliminary!

- **Beam:** $10^8\ \pi^-/s$, 100 GeV/c
- **Target:** 60 g/cm^2 NH_3
- **Luminosity:** $L = \frac{3}{17} \times 60 \times 6 \cdot 10^{23} \times 10^8$

  $\cong 8 \times 10^{32}\ cm^{-2} s^{-1}$
- **Cross section value:** $\sigma = 0.1$ nb/nucl

  (E. Anassontzis et al. Phys. Rev. D38 (1988) 1377)
- **Acceptance :** $A_{4\ GeV \leq M_{\mu\mu} \leq 9\ GeV} \cong 0.2$
- **Expected rate for DY:** $R = 8 \cdot 10^{32} \times 1 \cdot 10^{-34} \times A$

  $\cong 0.016$ events/s



- 0.08 events/spill (4000 spills/day) → 320 events/day
- Total statistics: (SPS eff=80%) 120 days → 30k/year

Comparison to present running conditions

	presently	Drell-Yan
beam	pol. μ^+ 160 GeV/c	unpol. π^- 100 GeV/c
intensity	$2\times10^8 \mu^+$/spill (4.8/16.2s)	$4.8\times10^8 \pi^-$/spill (4.8/16.2s)
pol. target	^{6}LiD 60 g/cm^2 (NH_3 60 g/cm^2 part of 2006)	NH_3 60 g/cm^2
polarization mode	longitudinal & transverse	transverse
total event rate	~10^5/s	~10^8/s
charged particles/event	~ 4	~ 6

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- **Spectrometer:**
  - high rate capability required (for trackers near the target)
  - upgrading SciFi, GEM, MicroMegas
  - no need of complete particle ID (only muon ID with muon filters)
- **Polarized target:**
  - heat load increase by x ~ 10 (0.5mW, ~ 2mW/spill)
  - running in frozen spin mode (for transverse polarization)
  - de-focused beam or better cooling efficiency to maintain polarization

Summary and Outlook

Let's start the next generation of experiments
towards the full understanding
of structure of the nucleon