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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- spin dependent fragmentation functions ΔD_q^h
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near future:
flavor decomposition!

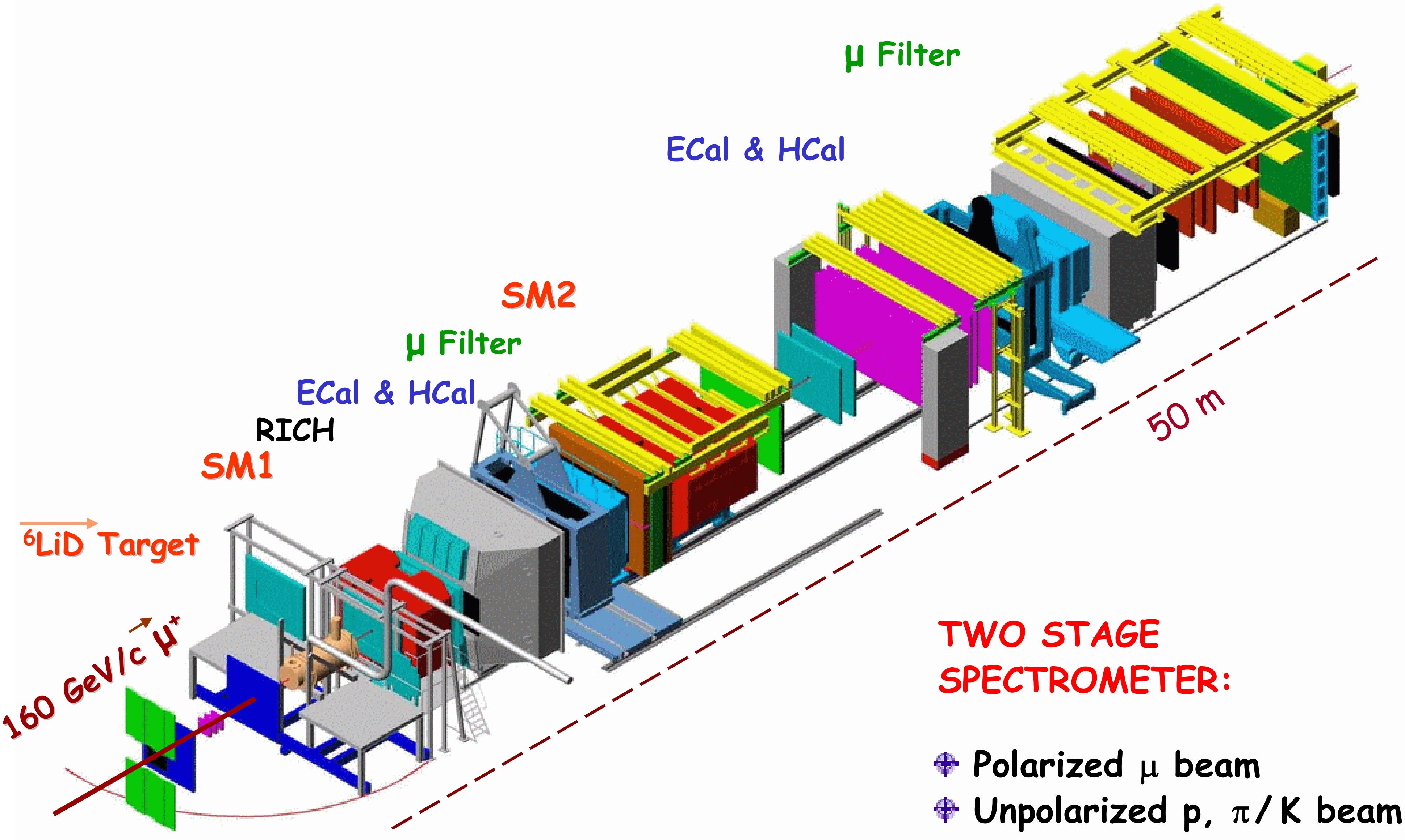
nucleon spectroscopy

- 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%	

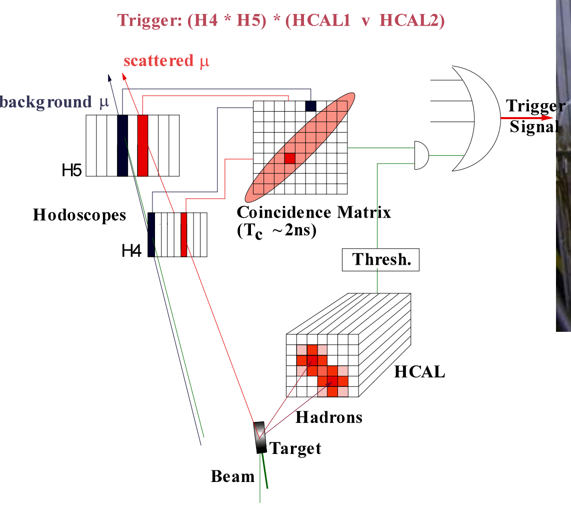
The COMPASS Spectrometer @ CERN



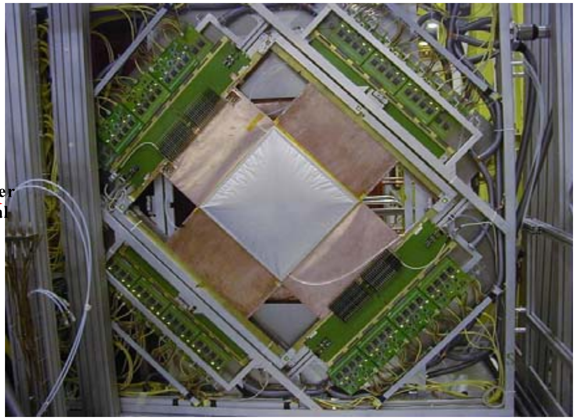
TWO STAGE SPECTROMETER:

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

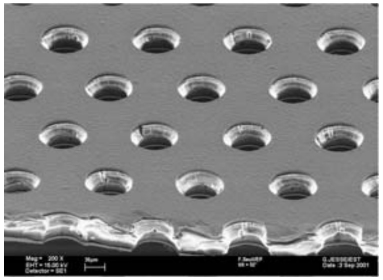
Many new technologies for tracking and PID



Trigger-System

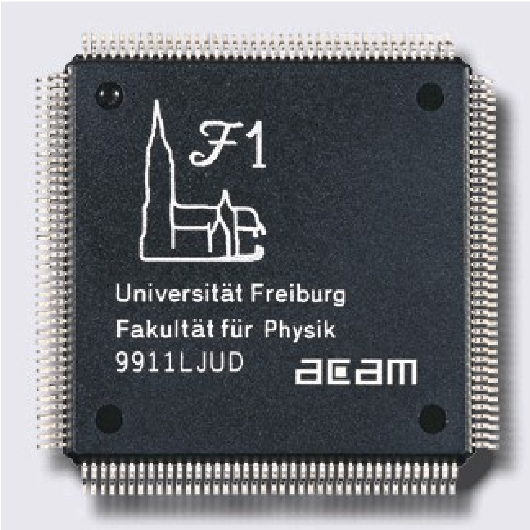


MicroMegas

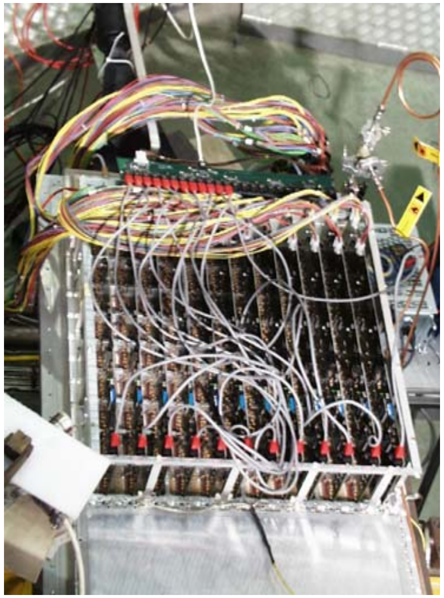


GEM

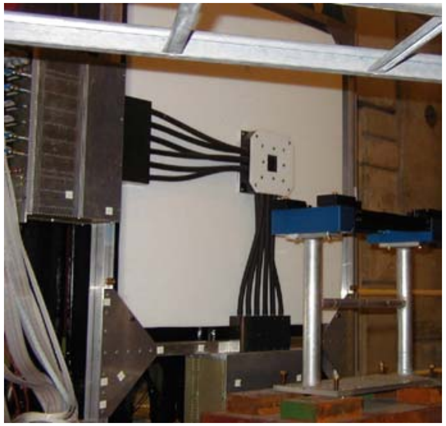
Straws



Readout electronics



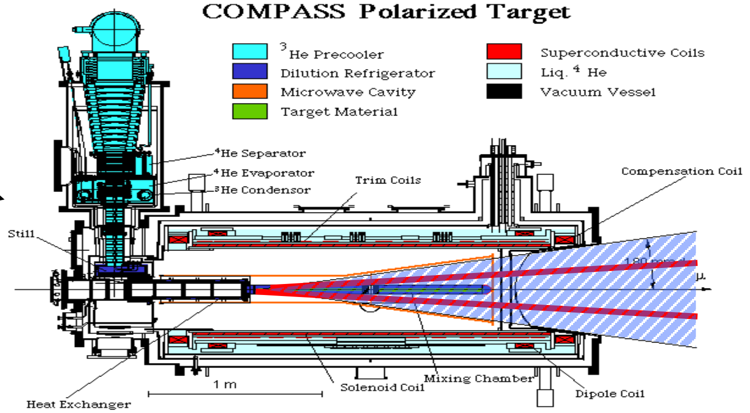
RICH readout



Scintillating fiber trackers

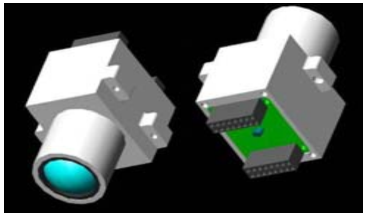
COMPASS upgrades for 2006

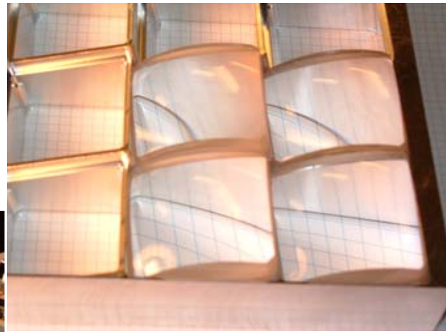
New solenoid magnet:
acceptance 70 mrad → 180 mrad

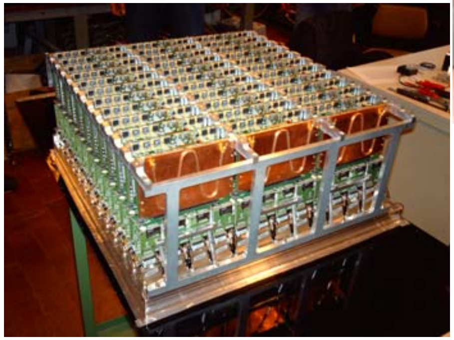


RICH upgrade

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







Other important upgrades:

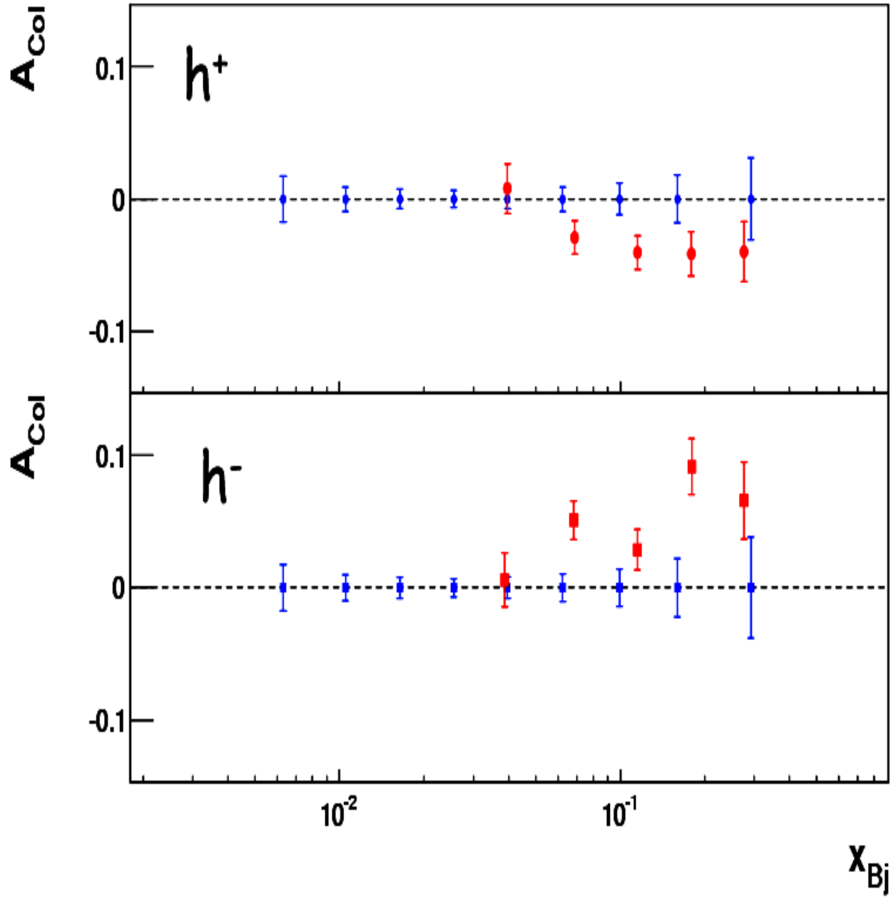
- Large Drift Chamber
- RICHWall
- Full ECAL coverage
- trigger

Expected statistics from 2006 run

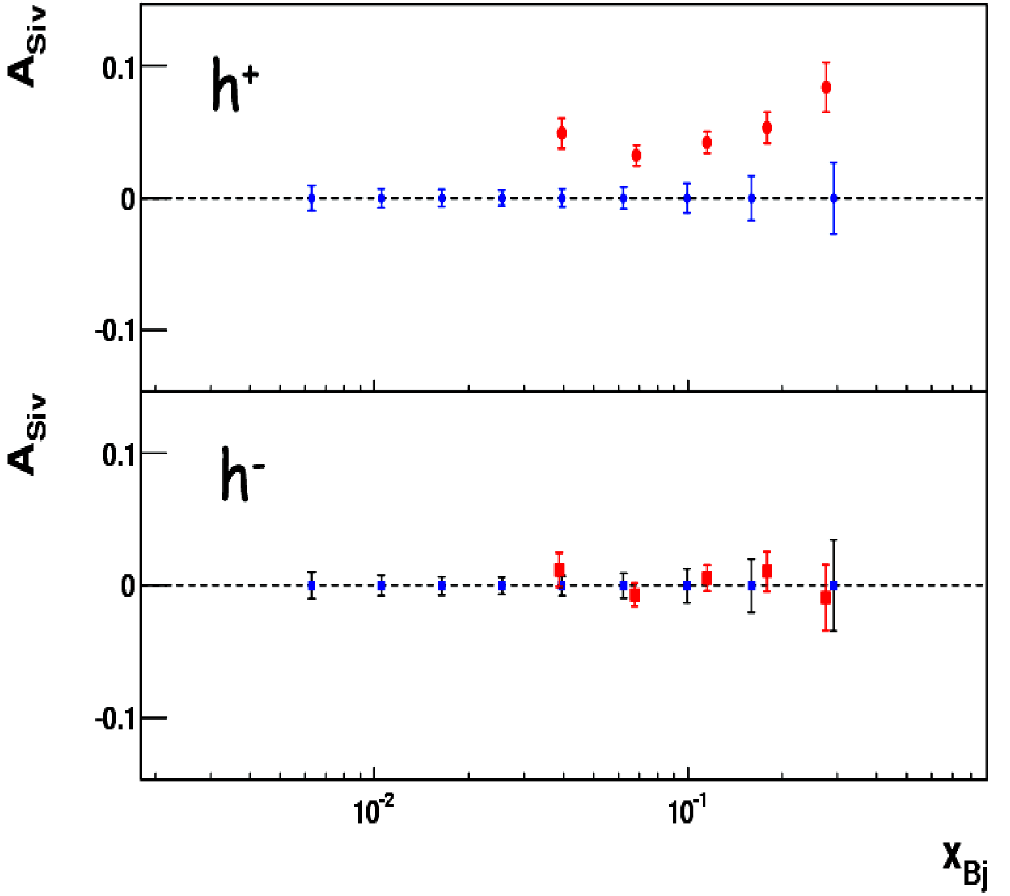
Collins and Sivers Asymmetries

Collins/Sivers: Transverse running with NH3 in 2006

Collins



Sivers



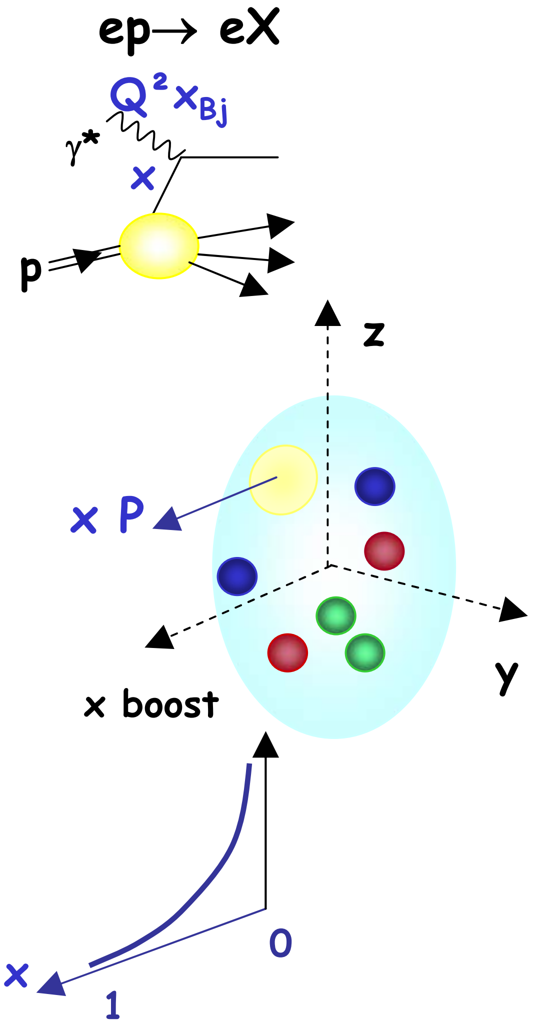
COMPASS proj.

HERMES Prel. results

Measurement of GPDs at COMPASS

GPD – 3-D picture of the partonic nucleon structure

Deep Inelastic Scattering

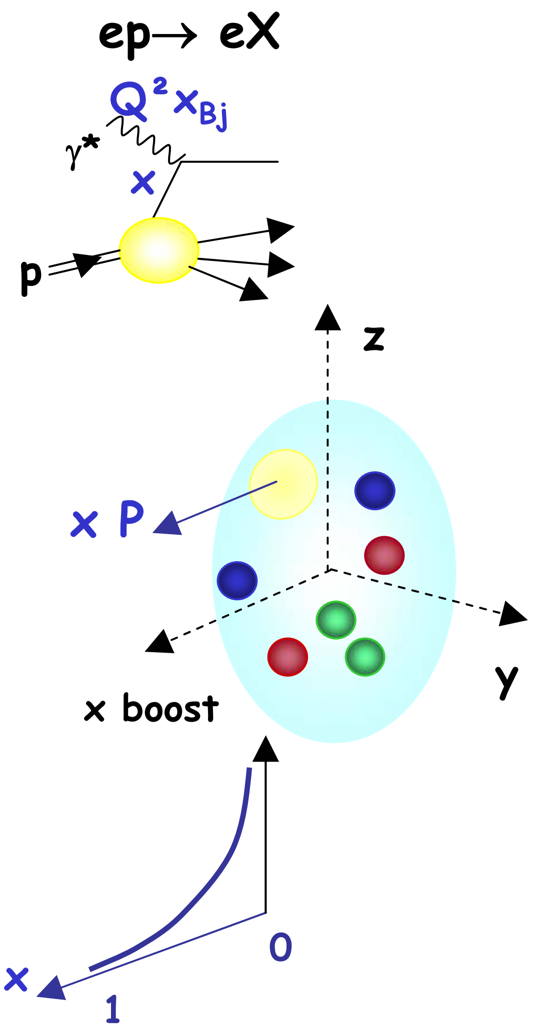


Parton Density q (x)

P_x

GPD – 3-D picture of the partonic nucleon structure

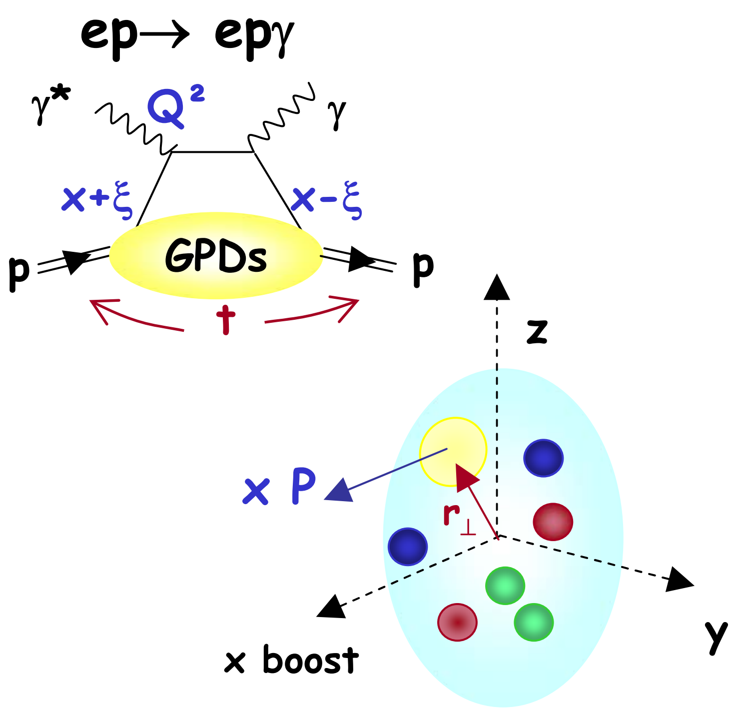
Deep Inelastic Scattering



Parton Density q (x)

P_x

Hard Exclusive Scattering
Deeply Virtual Compton Scattering



Generalized

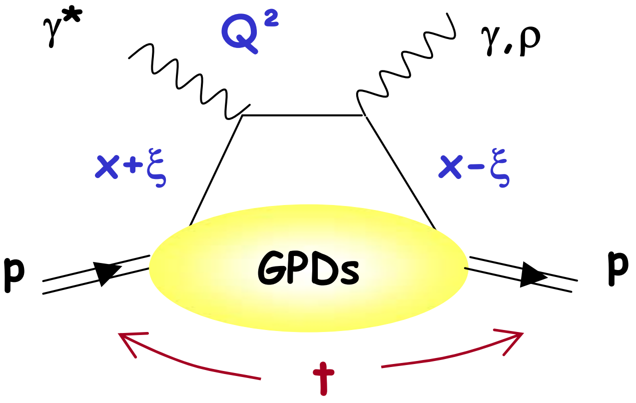
Parton Distribution H(x,ξ,t)

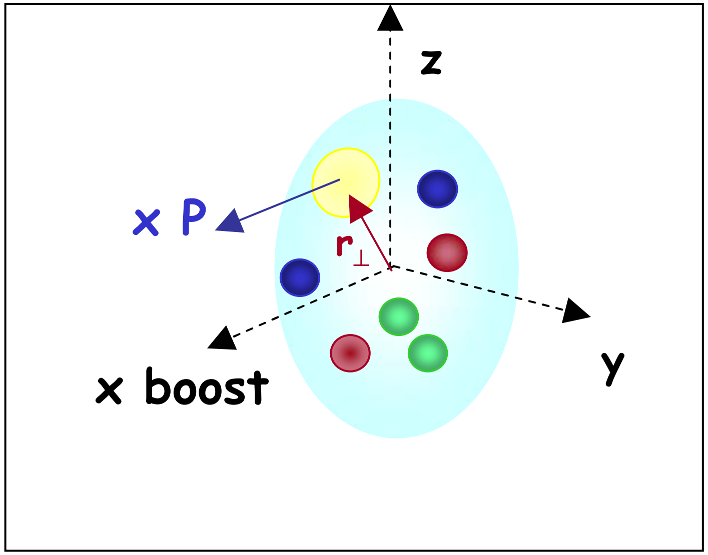
(P_x, $r_{y,z}$)

Burkardt, Belitsky, Müller, Ralston, Pire

Generalized Parton Distributions

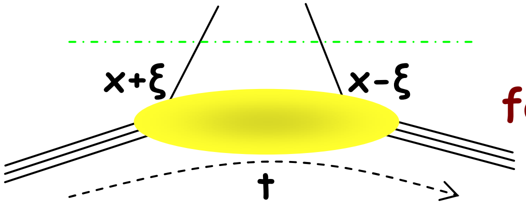
$\mu p \to \mu p \gamma \quad (\mu p \rho)$





- 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

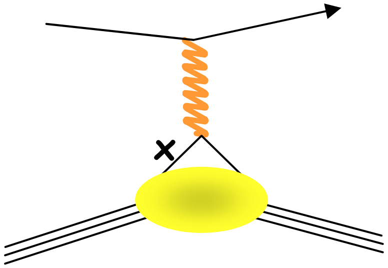
Models:

Parametrization

Fit of Parameters to the data

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

Elastic Form Factors



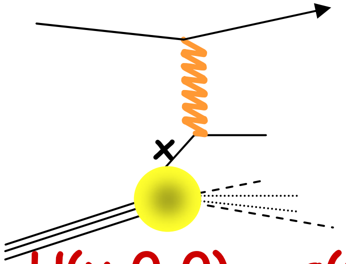
$\int H(x,\xi,t)dx = F(t)$

Ji's sum rule

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

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

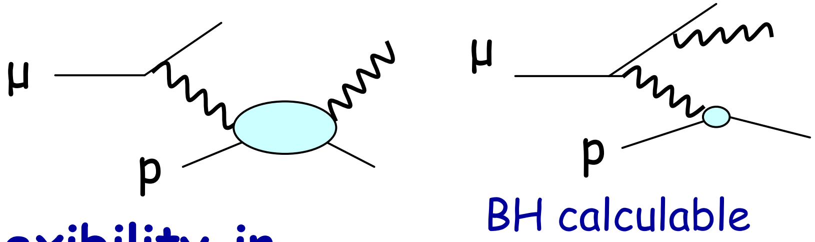
"ordinary" parton density



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

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

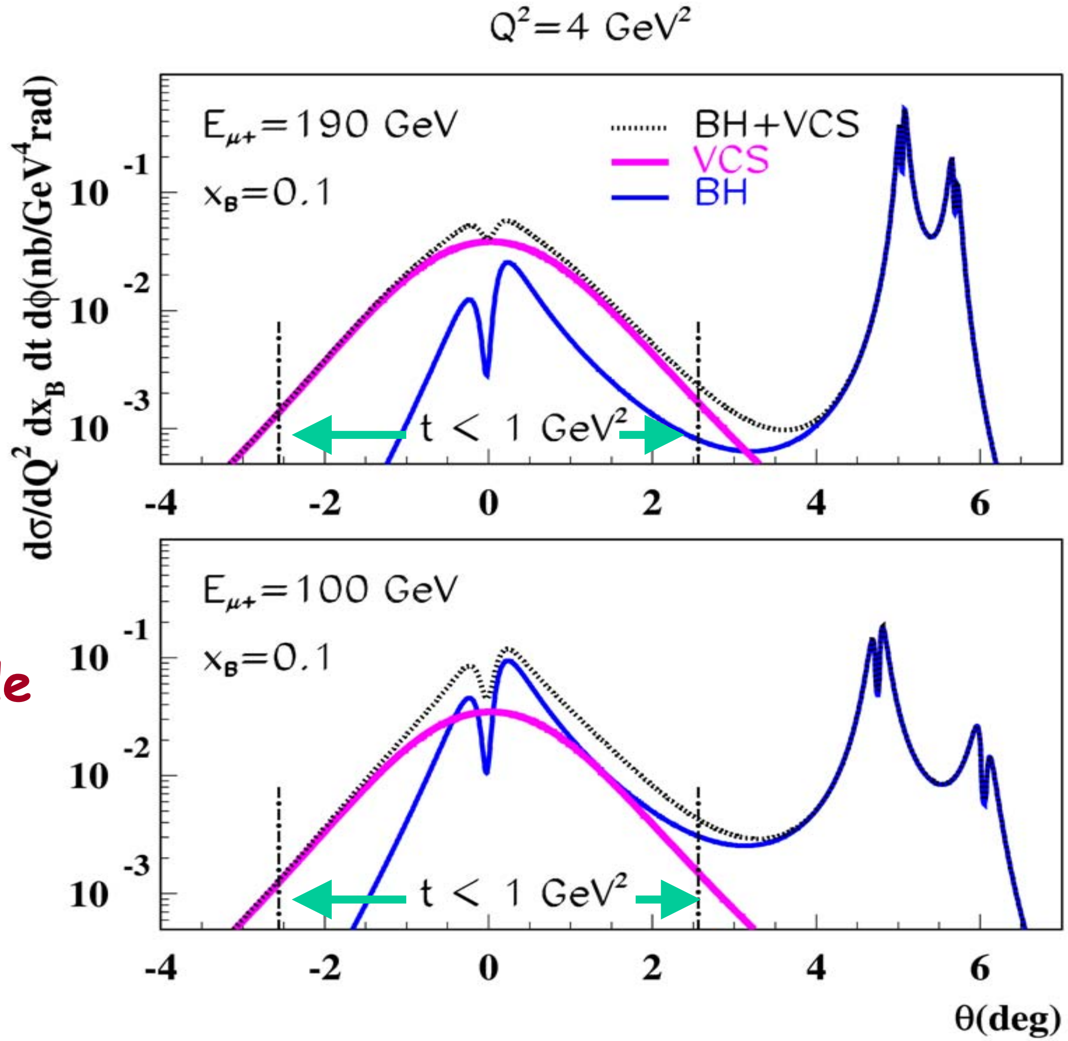
DVCS and Bethe Heitler

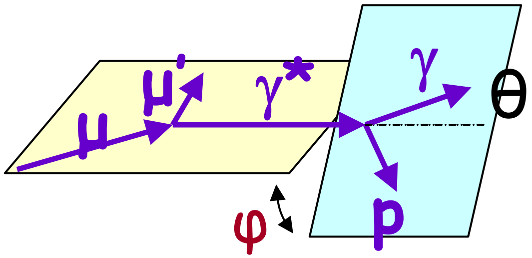


Advantage of flexibility in selection of muon beam energy at COMPASS:

- 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)

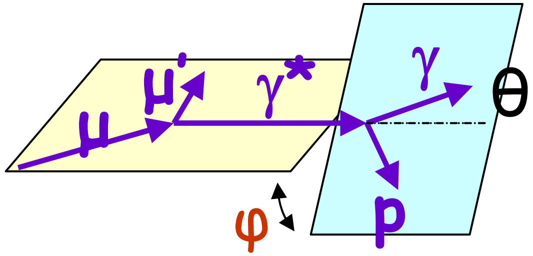
$$A^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\,\pi\, H(x=\xi,\xi,t)$$

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

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

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

$\times$ cos nφ $\times$ sin nφ



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

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

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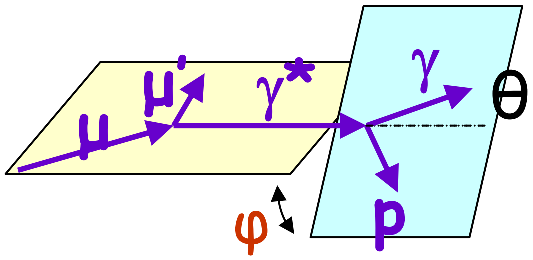
$$+\ \cancel{e_\mu\, a^{BH}\, \mathcal{R}e\, \mathcal{A}^{DVCS}} \quad + e_\mu\, P_\mu\, a^{BH}\, \mathcal{I}m\, \mathcal{A}^{DVCS}$$

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



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

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

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

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

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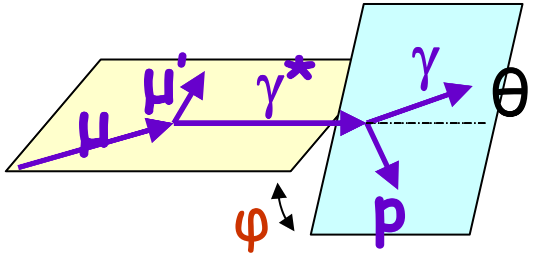
$$+ \, e_\mu \, a^{BH} \, \mathcal{R}e \, \mathcal{A}^{DVCS} \quad \cancel{+ \, e_\mu \, P_\mu \, a^{BH} \, \mathcal{I}m \, \mathcal{A}^{DVCS}}$$

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

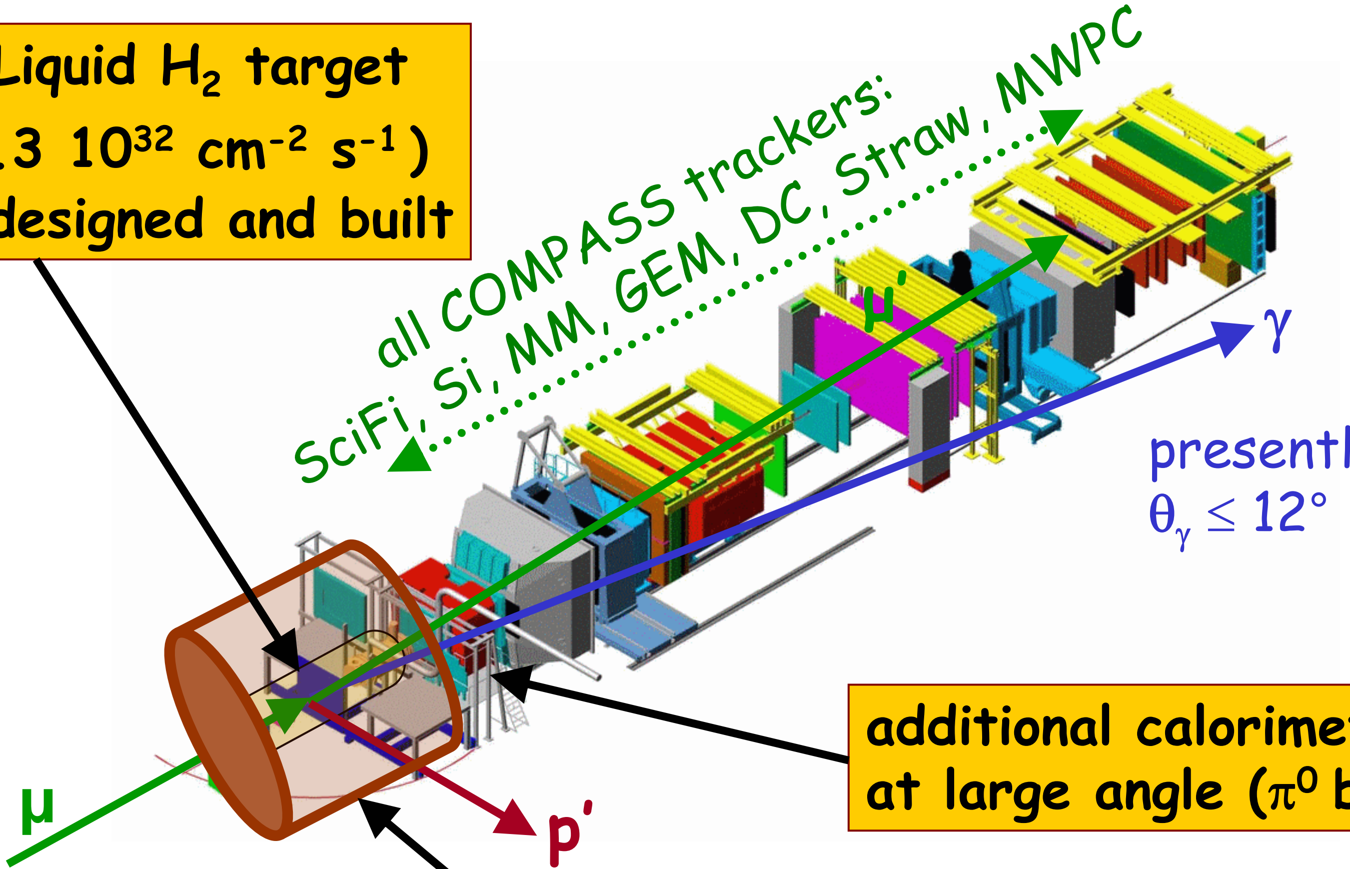


$P_{\mu+} = -0.8$ $P_{\mu-} = +0.8$

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

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



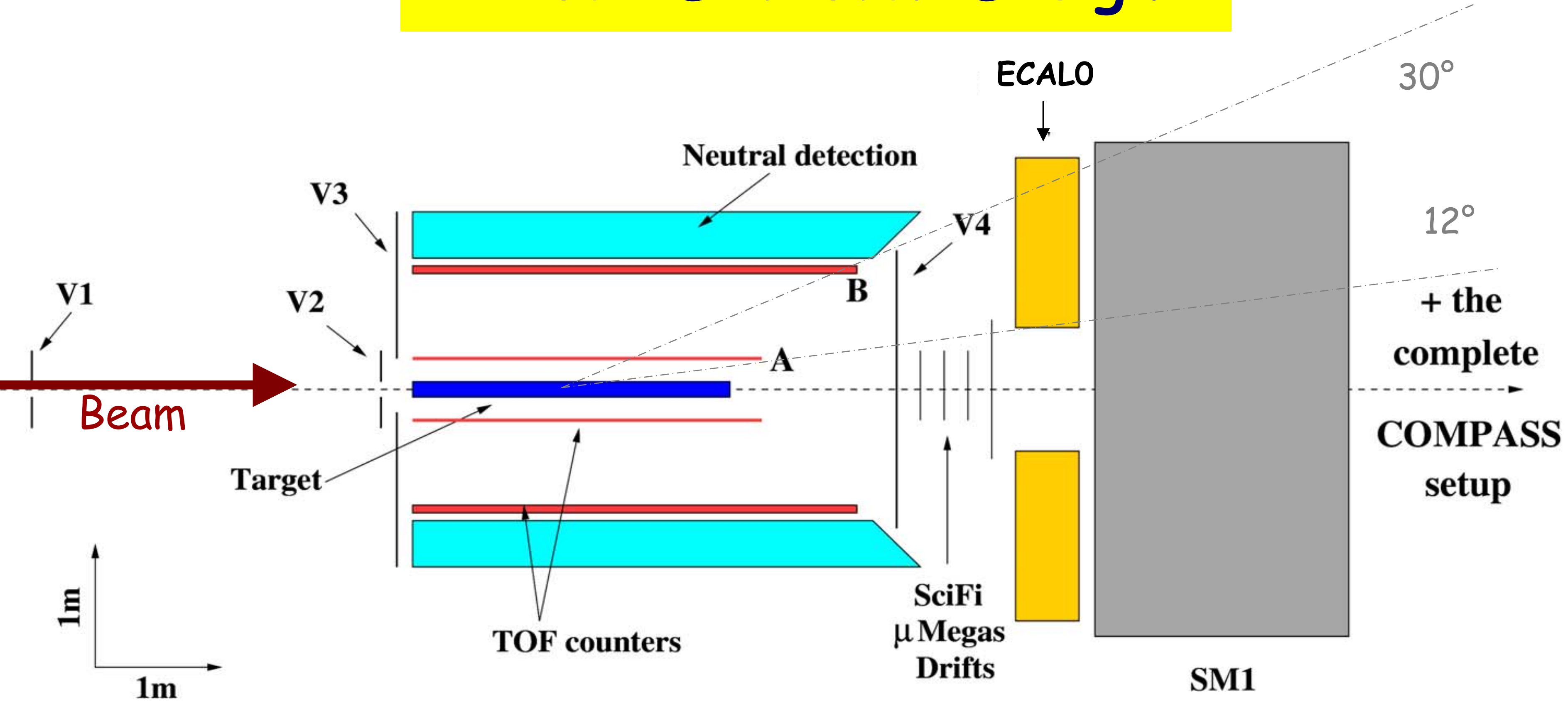
additional calorimetry
at large angle (π^0 bkg)

Recoil detector to insure exclusivity
- to be designed and built

Beam:

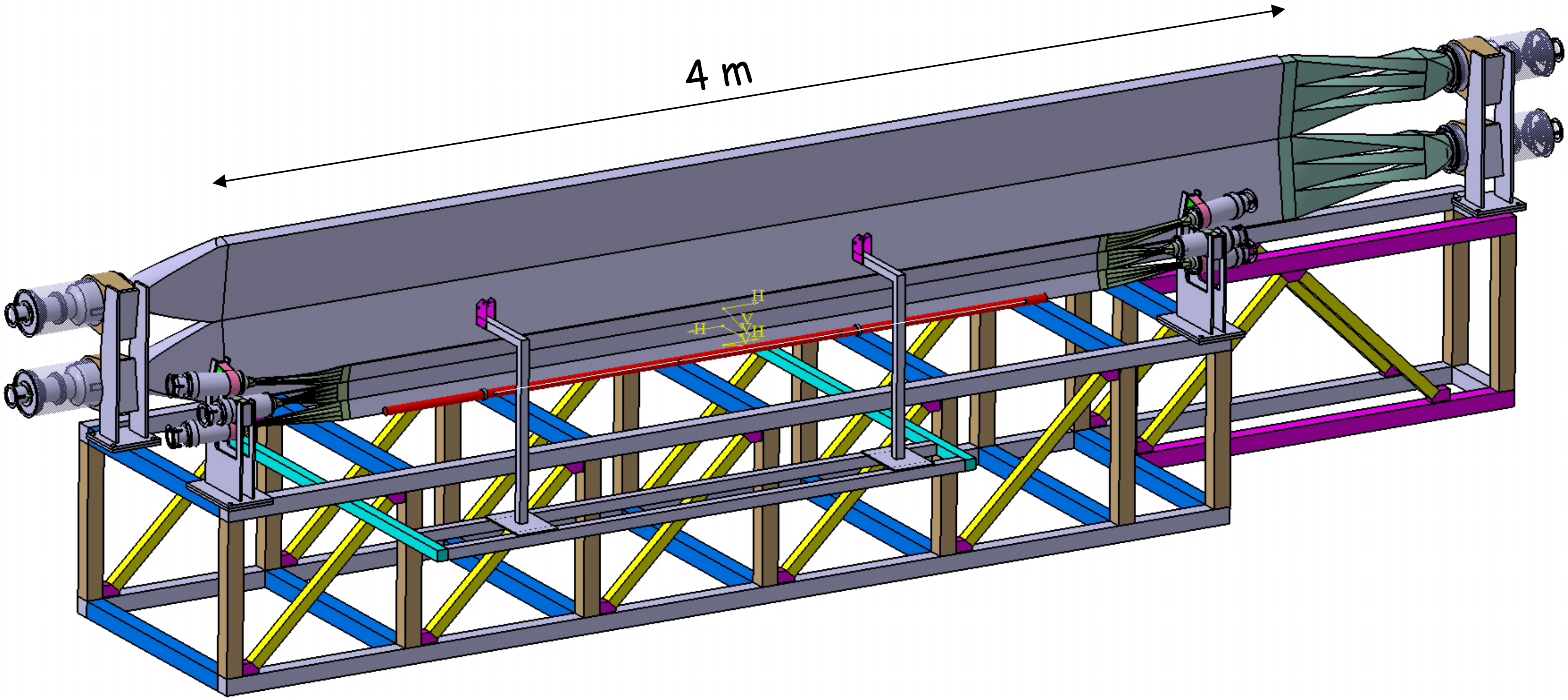
Energy:	100 GeV
Intensity:	$2{*}10^8$/spill
Polarization:	$P(\mu -) = +0.8$
	$P(\mu +) = -0.8$

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



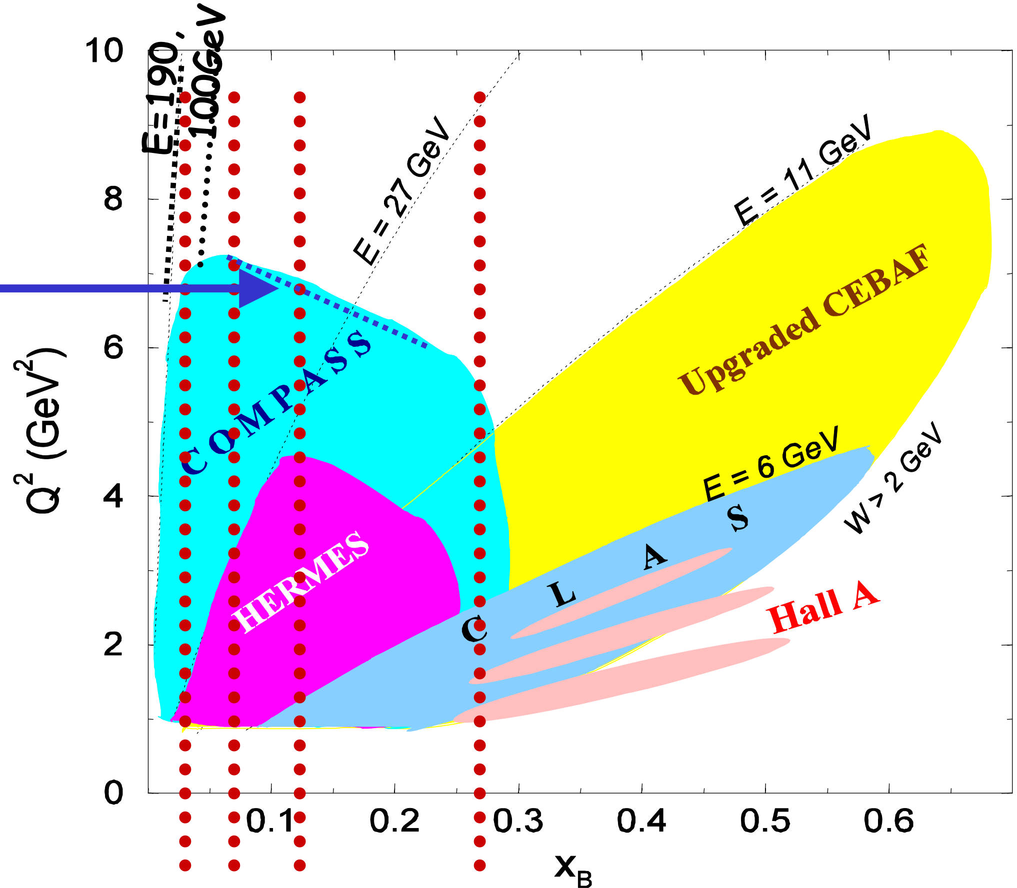
- 30° sector design
- Test at COMPASS beam this year
- Funded by EU FP6 (Bonn, Mainz, Saclay, Warsaw)

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

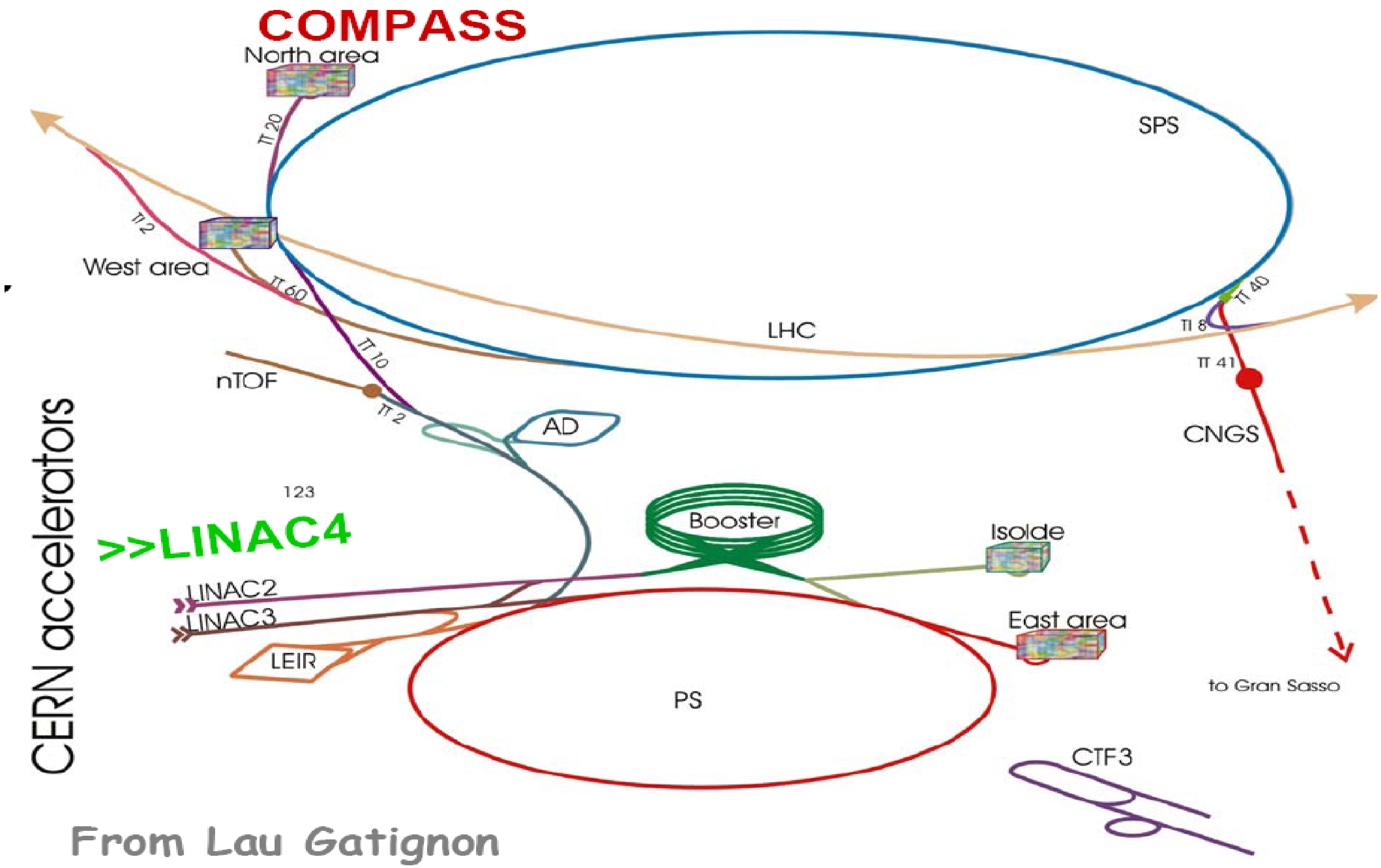


At fixed x_{Bj}, study in Q^2

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

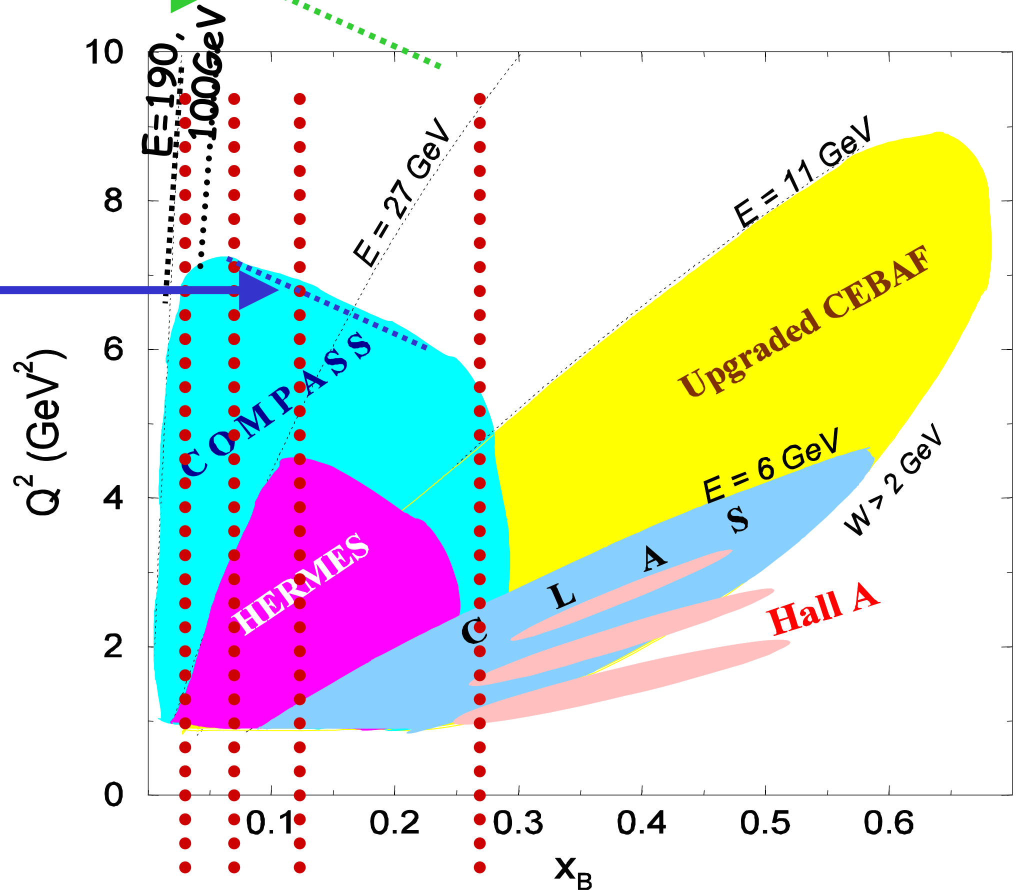
if $N_\mu \times 5$ $\Rightarrow$ $Q^2 < 17\ GeV^2$ for DVCS

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

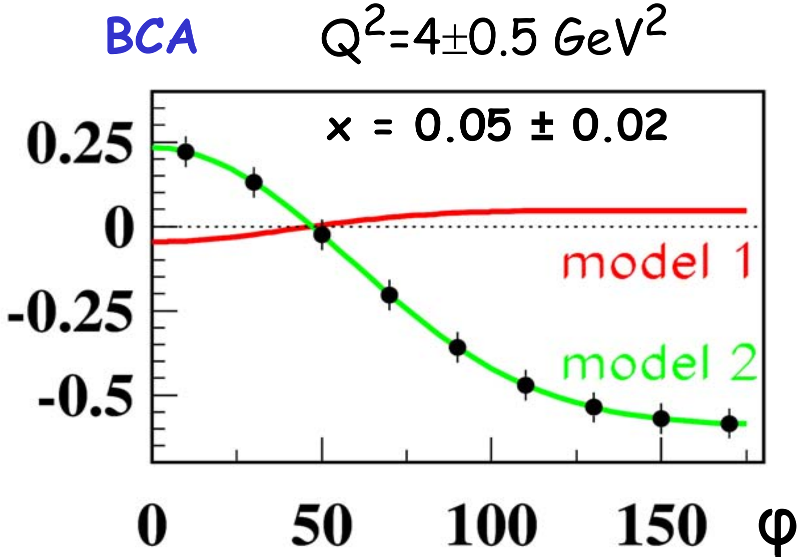
DVCS Simulations for COMPASS at 100 GeV

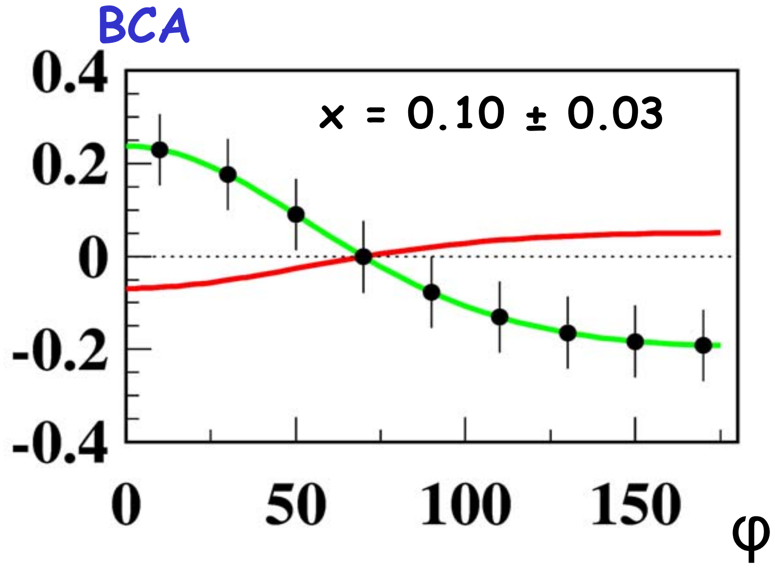
$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\overrightarrow{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

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

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

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



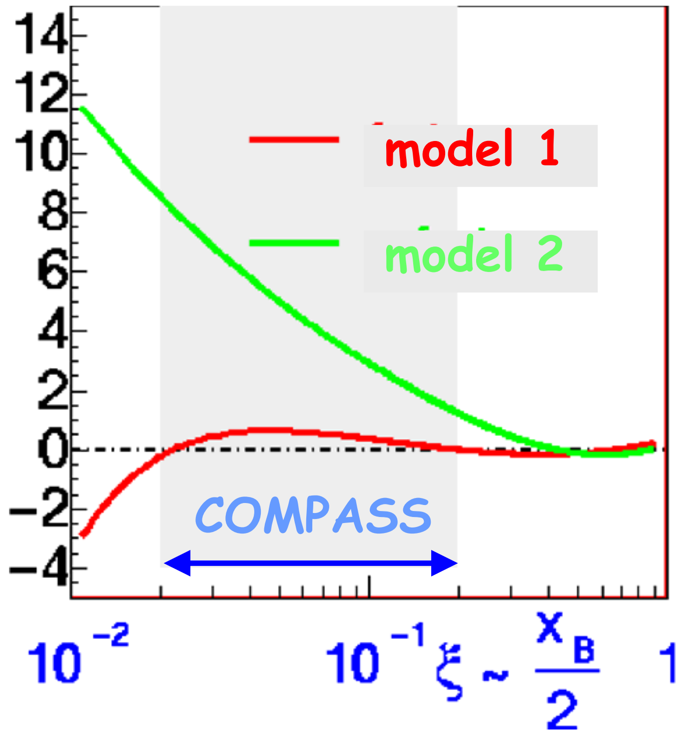


- 6 bins in Q^2 from 1.5 to 7.5 GeV^2 (1 shown)
- 3 bins in x_{Bj}=0.05,0.1,0.2 (2 shown)

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

Advantage of COMPASS kinematics

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



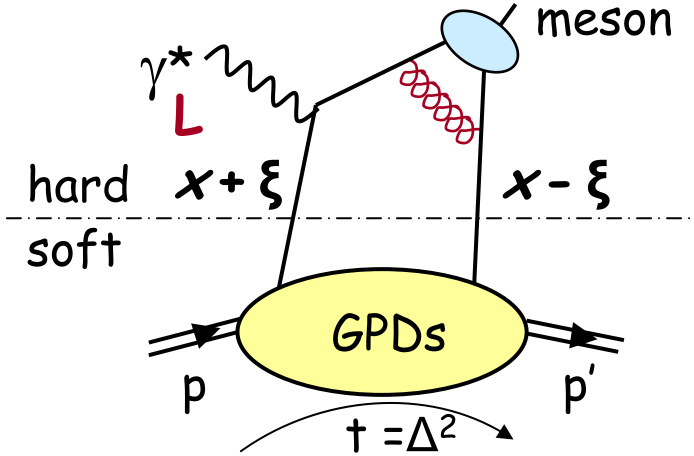
Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

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 (ρ,ω,ϕ…,π,η…)

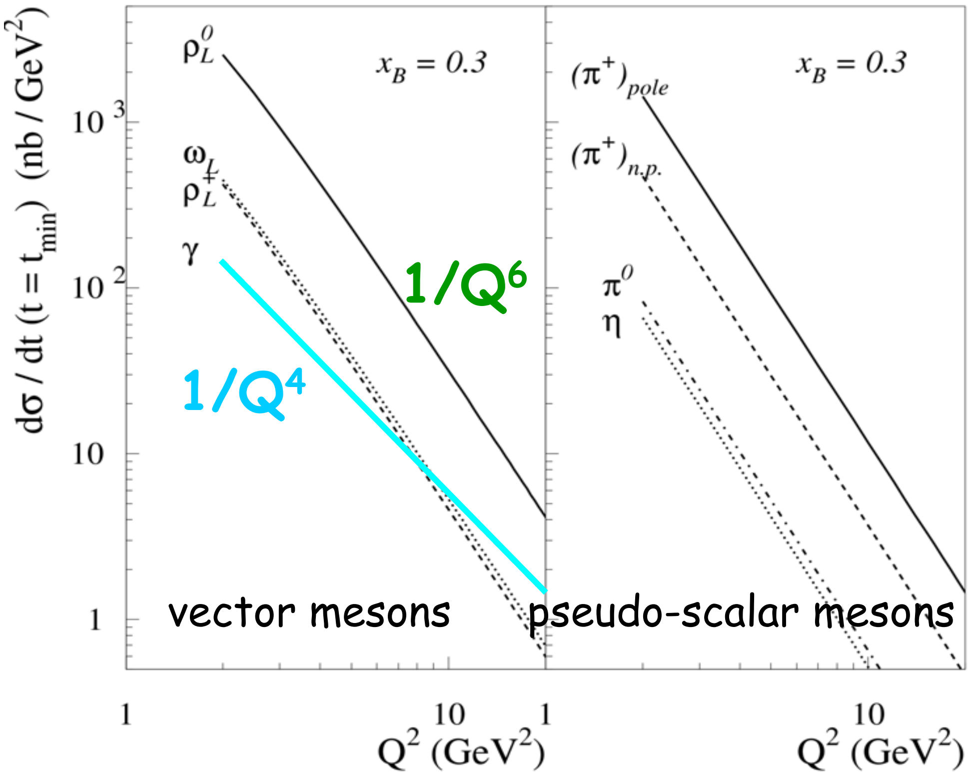


Collins et al. (PRD56 1997):

1. factorization applies only for γ^*_L

2. $\sigma_T \ll \sigma_L$

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

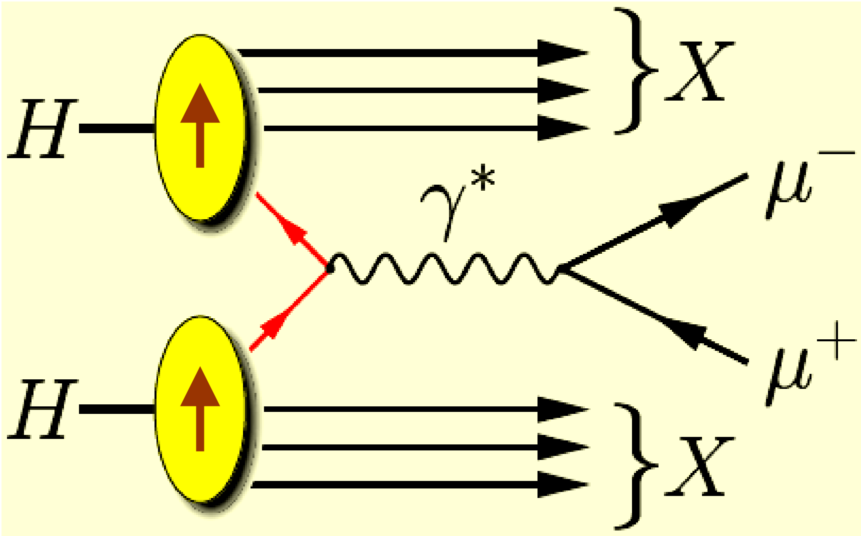
- *preliminary studies !*

Transversity from Drell-Yan

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

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

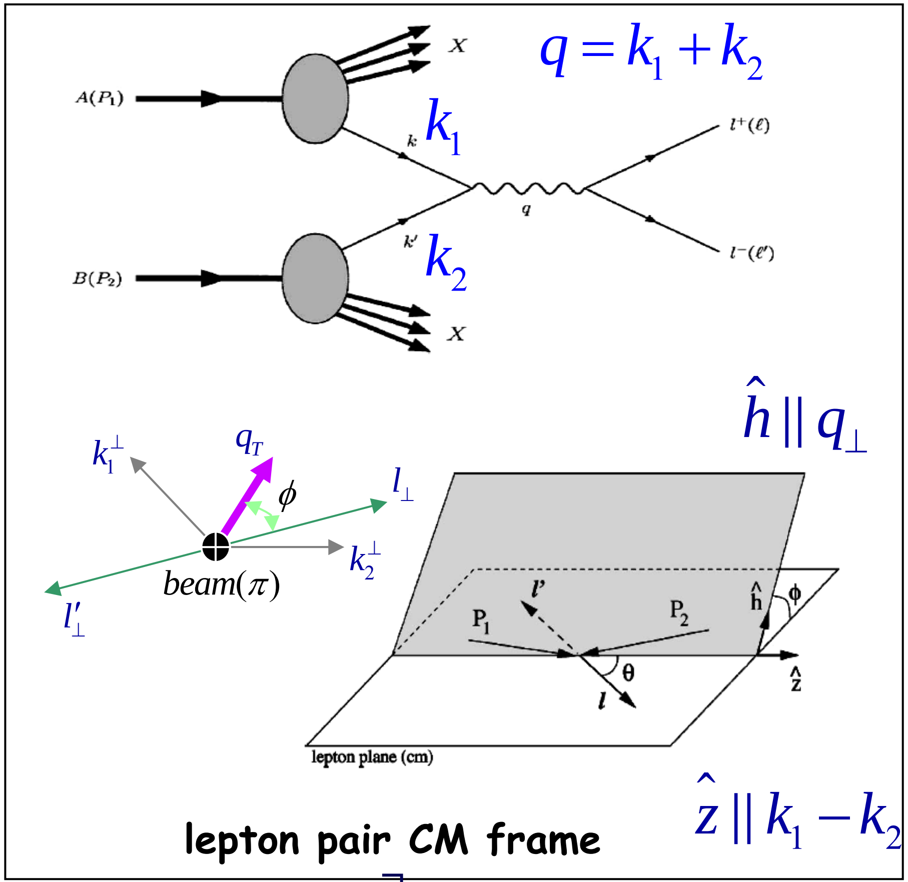
$$A_{TT} \propto \frac{\sum e_q^2 \bar{h}_{1q}(x_1) h_{1q}(x_2)}{\sum e_q^2 \bar{f}_{1q}(x_1) f_{1q}(x_2)}$$



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

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

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

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

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

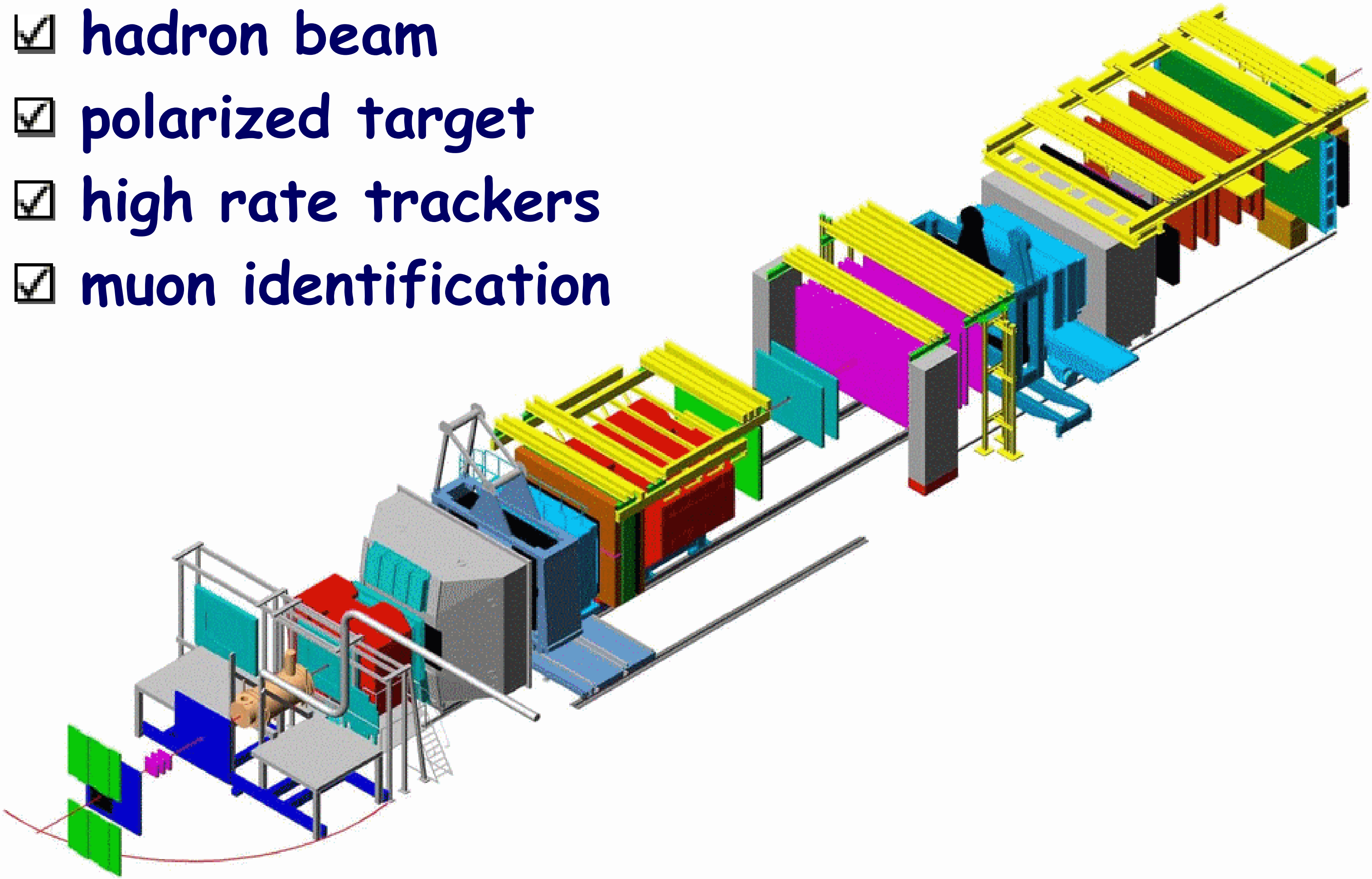
neglect s-quark, sea quark in proton, and d-quark contributions
(d-quark suppressed by $\frac{1}{4}$ due to its charge)

Boer-Mulders	Transversity	Sivers
$h_{1u}^{\perp(1)}(x) = f_{1u}(x) \sqrt{\frac{\hat{k}(x,x)\big\|_{\pi^- p}}{8C_u}}$	$h_{1u}(x) = -4\sqrt{2} \frac{\hat{A}_h(x,x)\big\|_{\pi^- p^\uparrow}}{\sqrt{C_u \hat{k}(x,x)\big\|_{\pi^- p}}} f_{1u}(x)$	$\sin(\phi - \phi_s)$

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



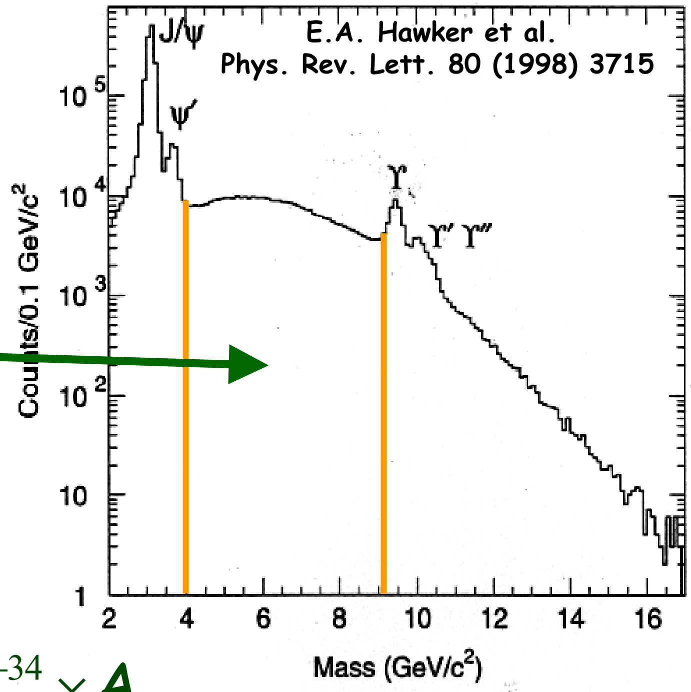
Count rate estimates

Very preliminary!

- **Beam:** $10^8\ \pi^-/s$, 100 GeV/c
- **Target:** 60 g/cm² 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:** $\sigma = 0.1\ \mathrm{nb/nucl}$
  (E. Anassontzis et al. Phys. Rev. D38 (1988) 1377)
- **Acceptance :** $A_{4\ GeV \le M_{\mu\mu} \le 9\ GeV} \cong 0.2$



- **Expected rate for DY:** $R = 8 \cdot 10^{32} \times 1 \cdot 10^{-34} \times A$

$$\cong 0.016\ \mathrm{events/s}$$

- 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	$2 \times 10^8 \mu^+$/spill (4.8/16.2s)	$4.8 \times 10^8 \pi^-$/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	$\sim 10^5$/s	$\sim 10^8$/s
charged particles/event	~ 4	~ 6

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charged particles/event	~ 4	~ 6

- **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

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

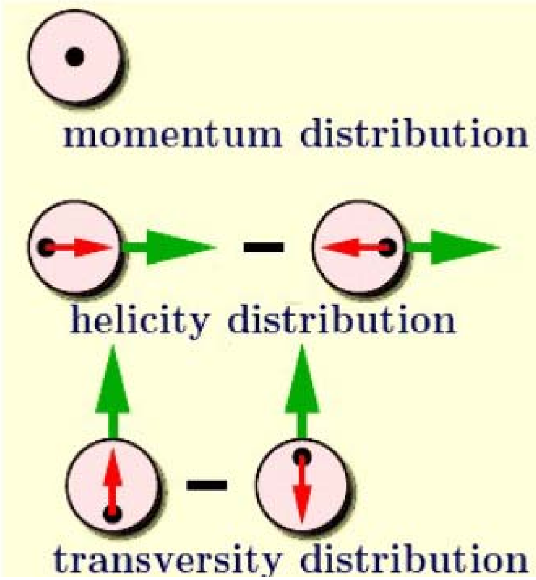
Transversity

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

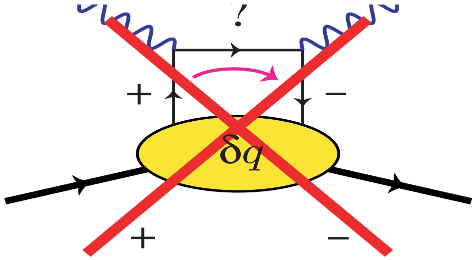
$q(x)$

$\Delta q(x)$

$\Delta_T q(x)$

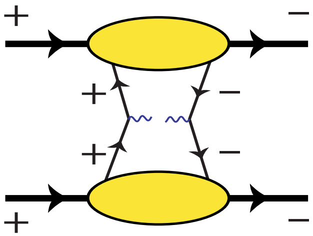


Inclusive DIS



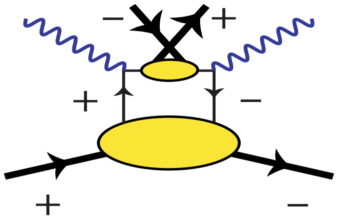
impossible

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



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

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



convolution with spin dependent fragment. func.
$\Delta_T q(x) \otimes FF$