Exclusively produced ρ^0 asymmetries on the deuteron and future GPD measurements at COMPASS

C. Schill (Universität Freiburg)

on behalf of the COMPASS collaboration

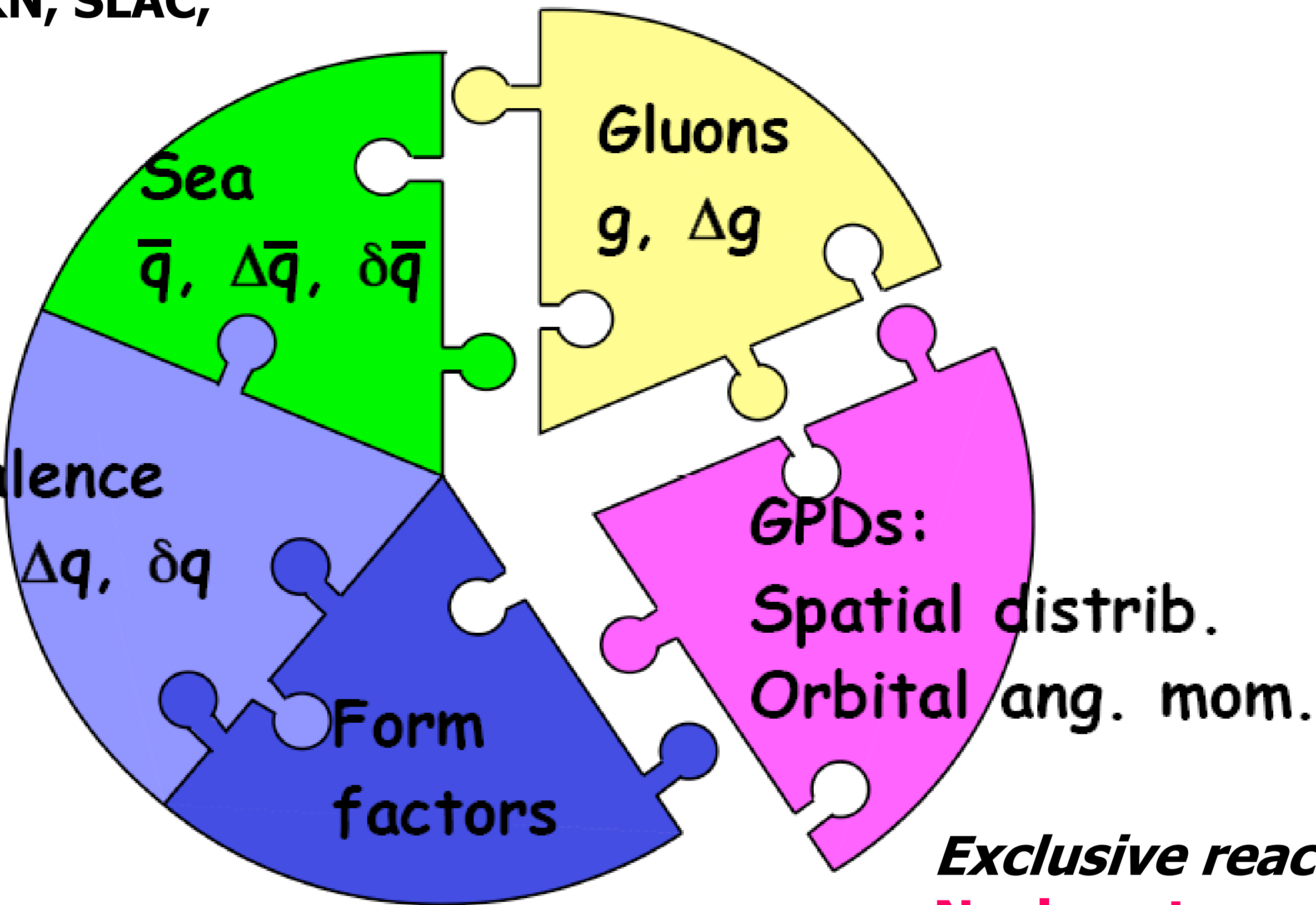
- **Physics motivation**
- **Results on exclusive ρ^0 production**
- **Future Experimental Realisation**

Transversity 2008, Ferrara

The nucleon puzzle

Deep inelastic scattering
At DESY, CERN, SLAC, JLab

Semi-inclusive reactions

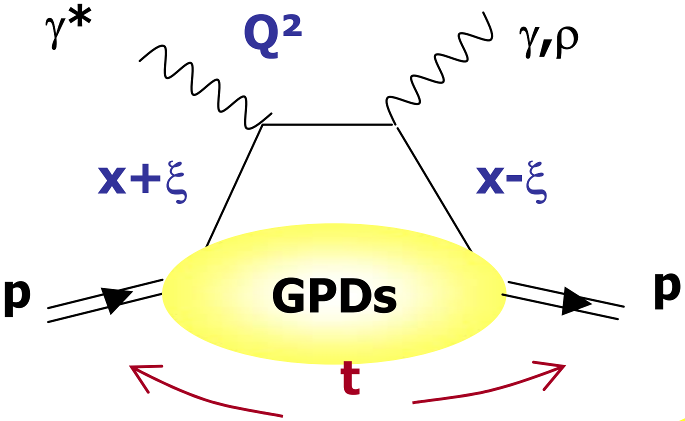


Exclusive reactions
Nucleon tomography

Elastic scattering

Generalized Parton Distributions: Coherent description of the nucleon

μp→ μpγ (μpρ)



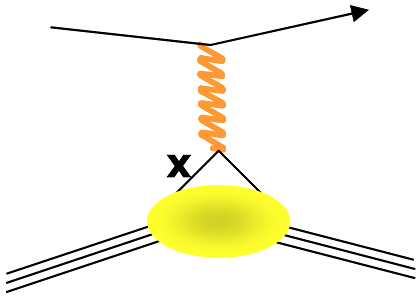
x: longitudinal quark momentum fraction ≠ x_{Bj}

2ξ: longitudinal transferred momentum fraction: $\xi = x_{Bj}/(2-x_{Bj})$

t: momentum transfer squared to the target nucleon (Fourier conjugate to the transverse impact parameter r)

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

Elastic Form Factors

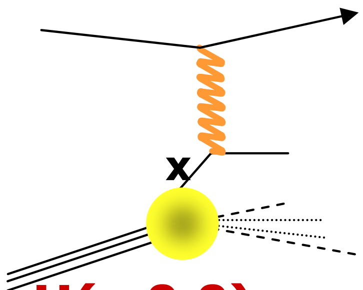


$\int H(x,\xi,t)dx = F(t)$

Ji's sum rule

$2J = \int x(H+E)(x,\xi,0)dx$

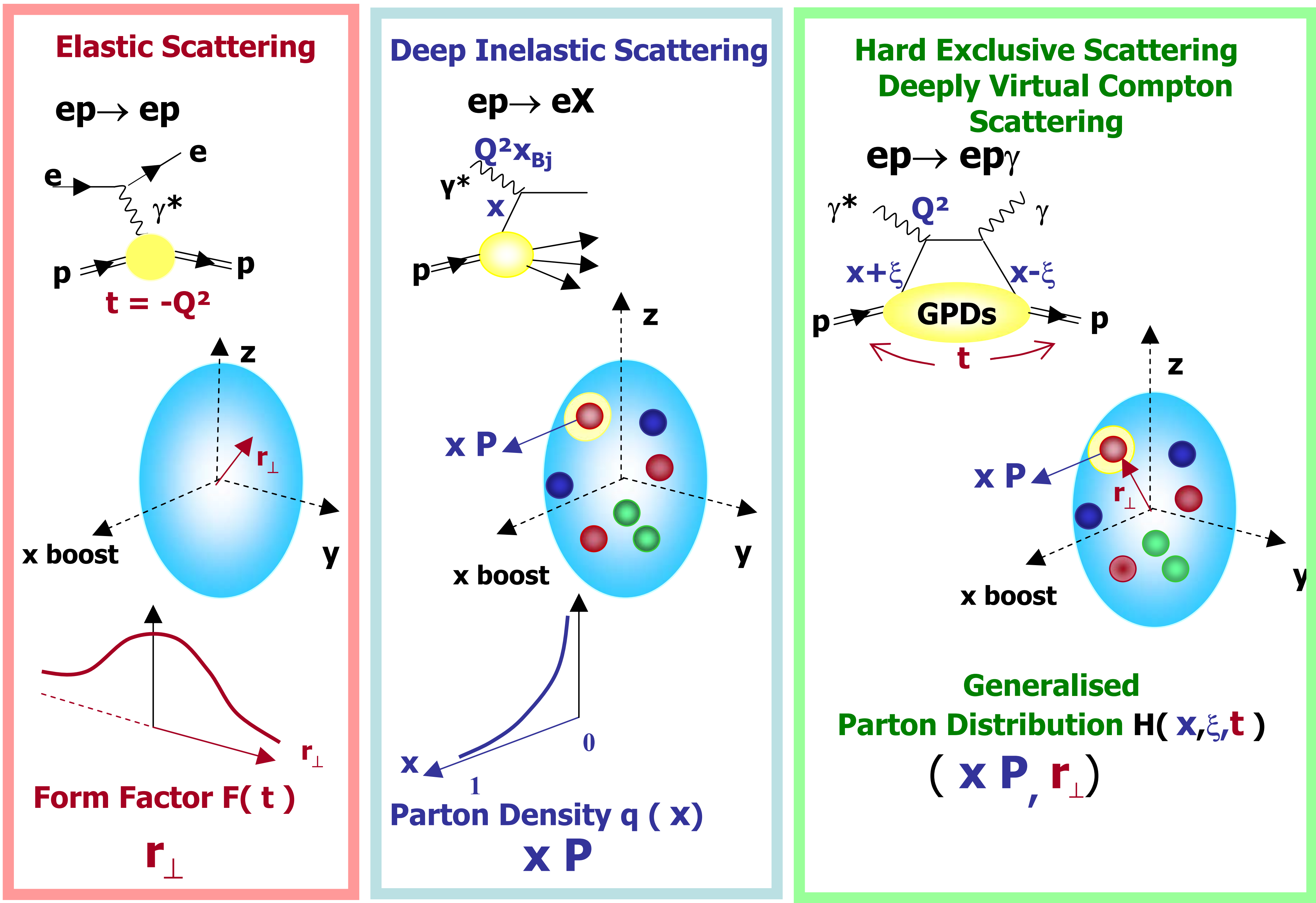
"ordinary" parton density



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

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

GPDs - a 3-dimensional picture of the nucleon structure

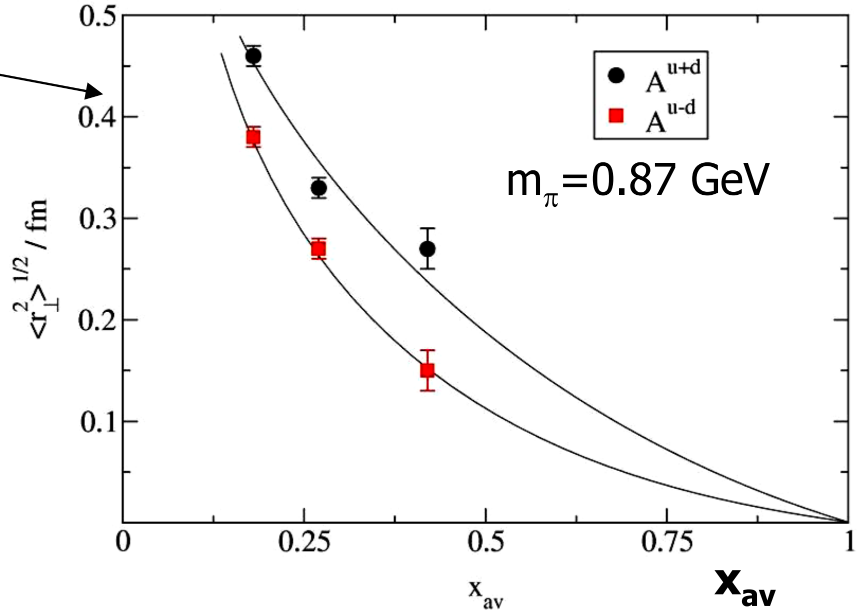


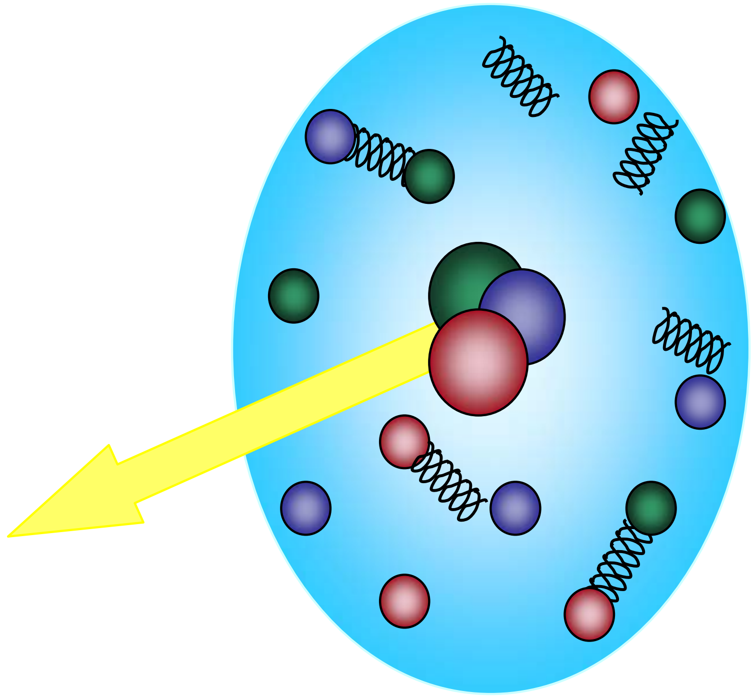
Hints on the 3-D nucleon picture ($x\,P_x, r_\perp$)?

Lattice calculation (unquenched QCD):

Negele *et al.*, NP B128 (2004) 170
Göckeler *et al.*, NP B140 (2005) 399

- **fast parton close to the N center**
  = small valence quark core
- **slow parton far from the N center**
  = widely spread sea q and gluons





COMPASS: The QCD Facility to study GPDs

Timeline

- *now:* COMPASS with polarized target
  - Complete analysis of ρ^0 production
  - Other channels: ϕ, …
  - GPD E/H investigation with the transversely polarized target

- *2010-2015:* Generalized Parton Distributions
  with recoil detector, calorimeter, liquid H_2 and D_2 target

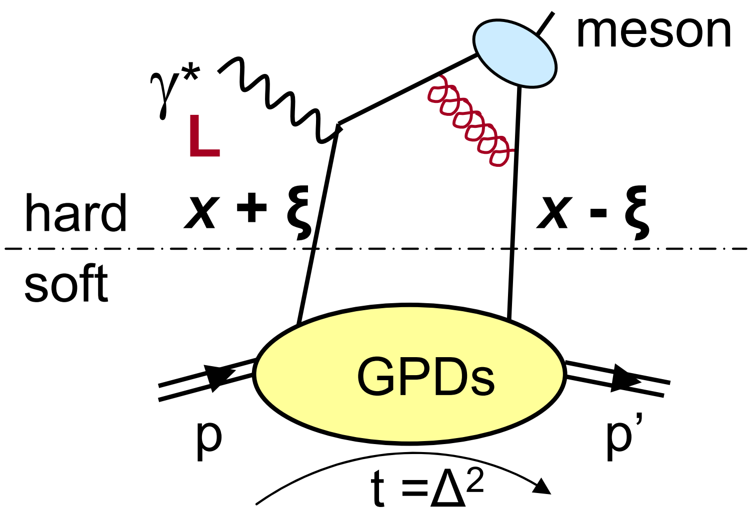
Polarized muon beam: E_π=110 GeV $\rightarrow$ E_μ=100 GeV

$P(\mu^+) = -0.8$ $\quad 2 \cdot 10^8$/spill

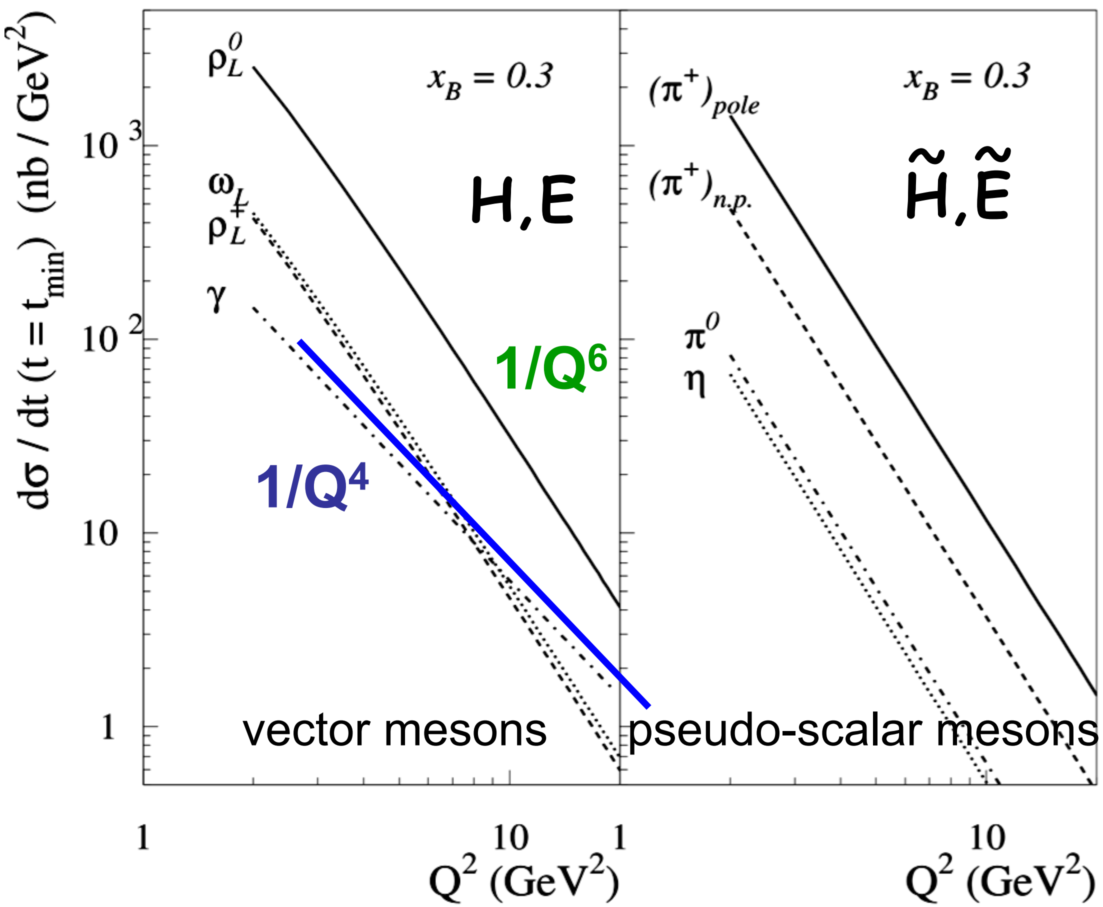
$P(\mu^-) = +0.8$ $\quad 2 \cdot 10^8$/spill

Maximize muon flux

Hard Exclusive Meson Production (ρ,ω,φ…,π,η…)



Scaling predictions:



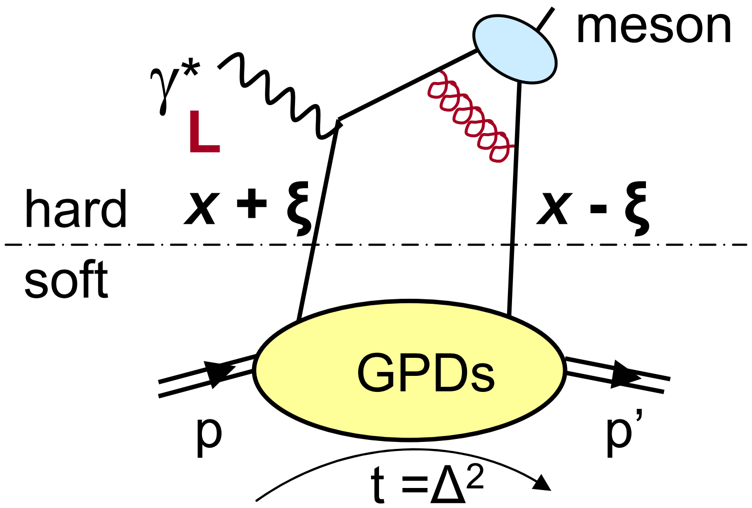
Collins et al. (PRD56 1997):

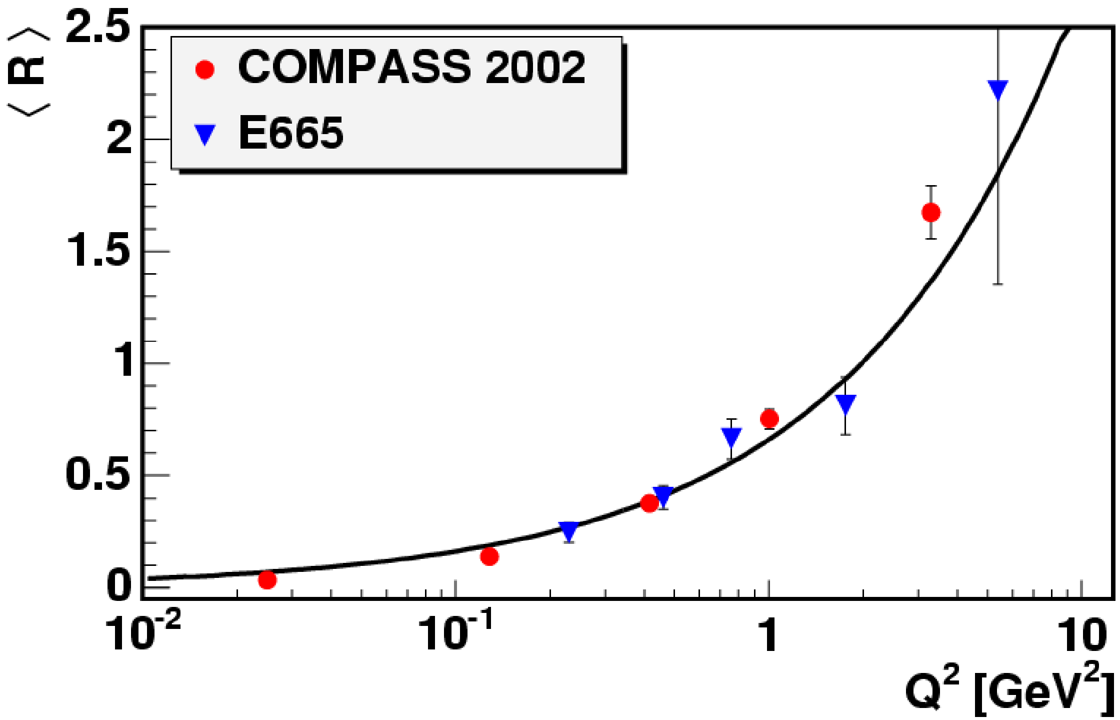
1. factorisation applies only for γ^*_L

2. $\sigma_L > \sigma_T$ for large Q^2

ρ^0 largest cross section, first COMPASS results

Hard Exclusive Meson Production (ρ,ω,ϕ…,π,η…)





Collins et al. (PRD56 1997):

1. factorisation applies only for γ^*_L

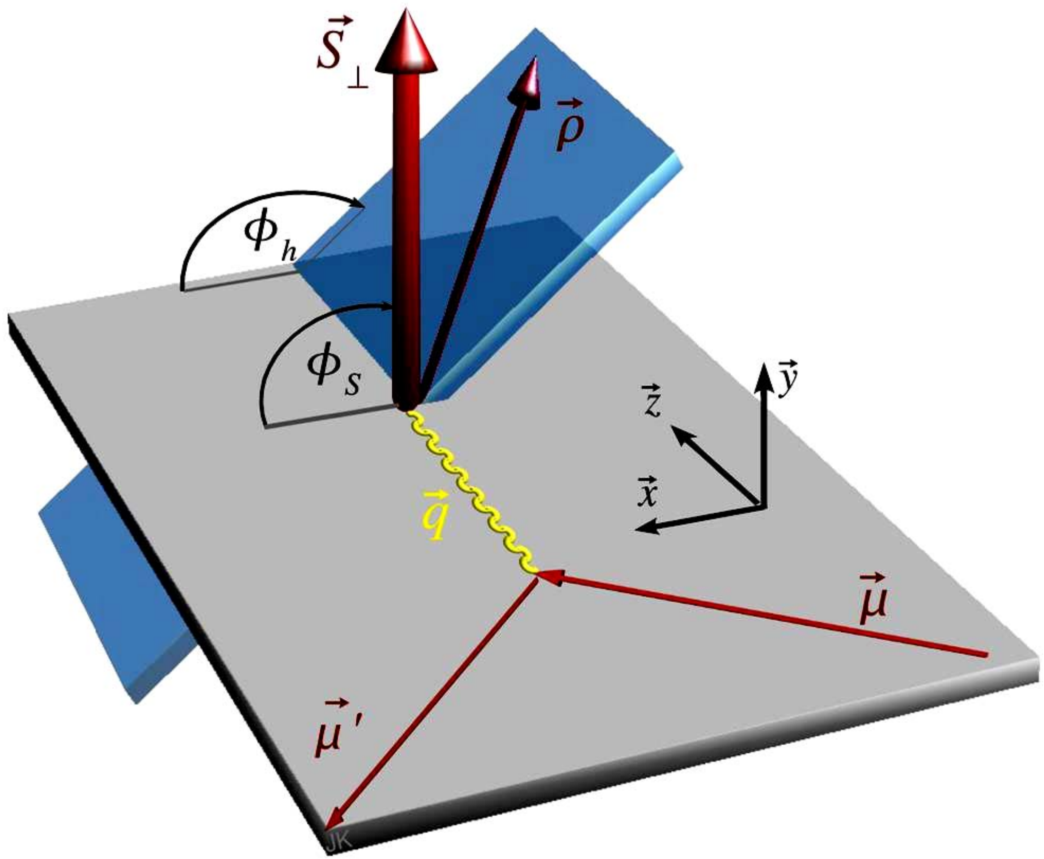
$R=\sigma_L/\sigma_T$

2. $\sigma_L > \sigma_T$ for large Q^2

ρ^0 largest cross section, first COMPASS results

Hard Exclusive ρ^0 Production

Transverse Target-Spin asymmetry $A_{UT}(\phi_h - \phi_S)$ depends linearly on GPD E.

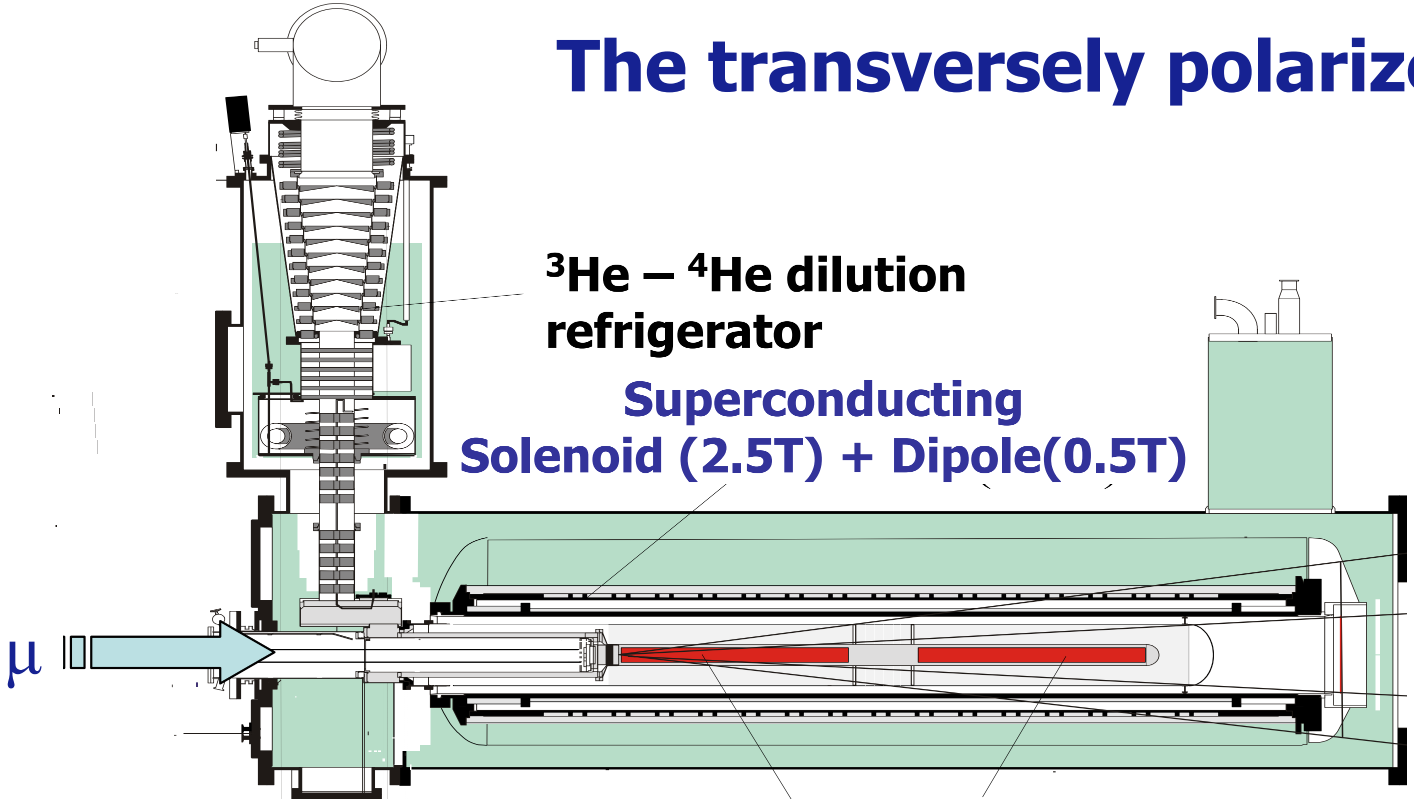


Goeke, Polyakov, Vanderhaeghen, Prog. Part. Nucl. Phys. 47 (401-515) 2001

$$A_{UT}(\phi_h - \phi_S) = \frac{d\sigma(\phi_h - \phi_S) - d\sigma(\phi_h - \phi_S + \pi)}{d\sigma(\phi_h - \phi_S) + d\sigma(\phi_h - \phi_S + \pi)}$$

$$= A_{UT}^{\sin(\phi_h - \phi_S)} \cdot \sin(\phi_h - \phi_S)$$

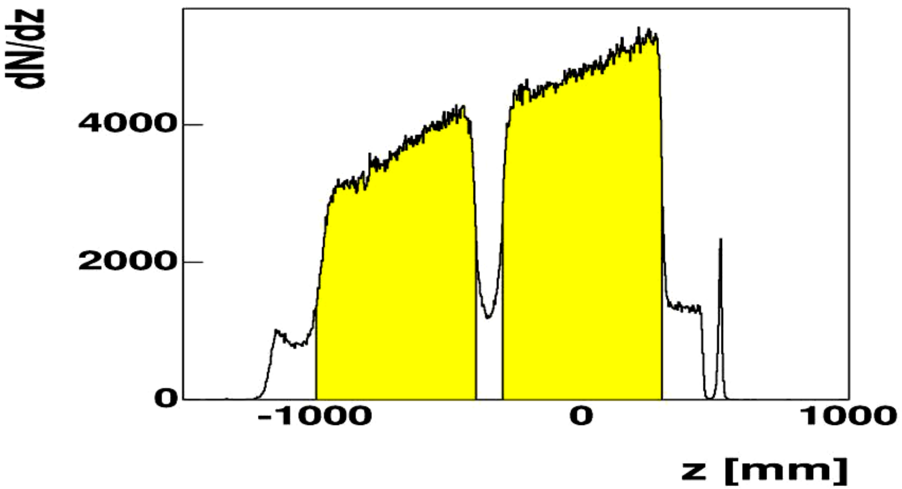
The transversely polarized ^{6}LiD-Target



Two 60 cm long target cells with opposite polarization

Target Polarization
≈ 50%

Dilution factor
f ≈ 0.36



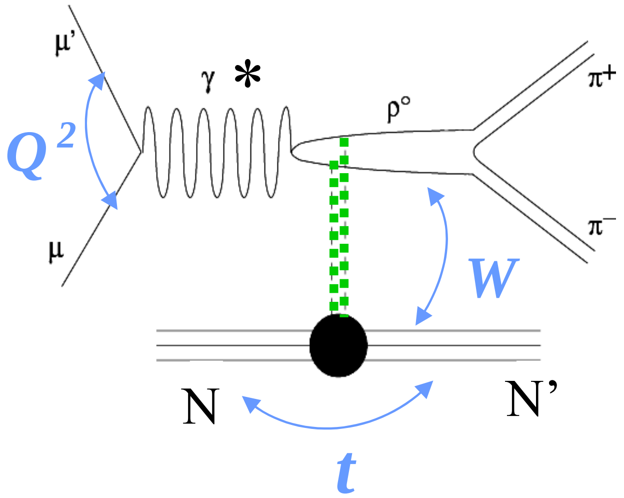
transverse

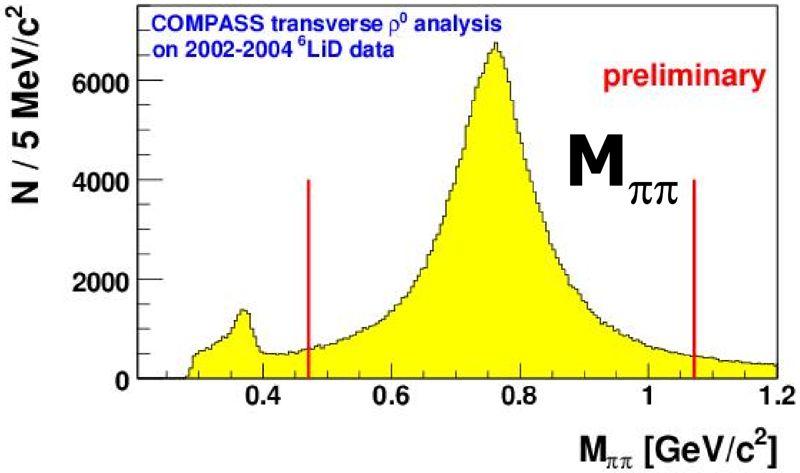
❶ ↑ ↓

❷ ↓ ↑

Reversed once a week

Selection of exclusive ρ^0 production

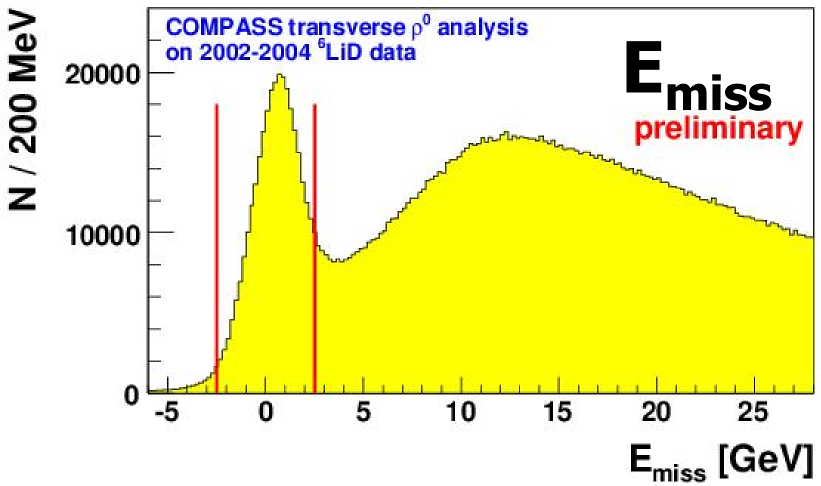




Assuming both hadrons are π

$-0.3 < M_{\pi\pi} - M_\rho < 0.3$ GeV

incoherent scattering on nucleons in ^{6}LiD polarized target

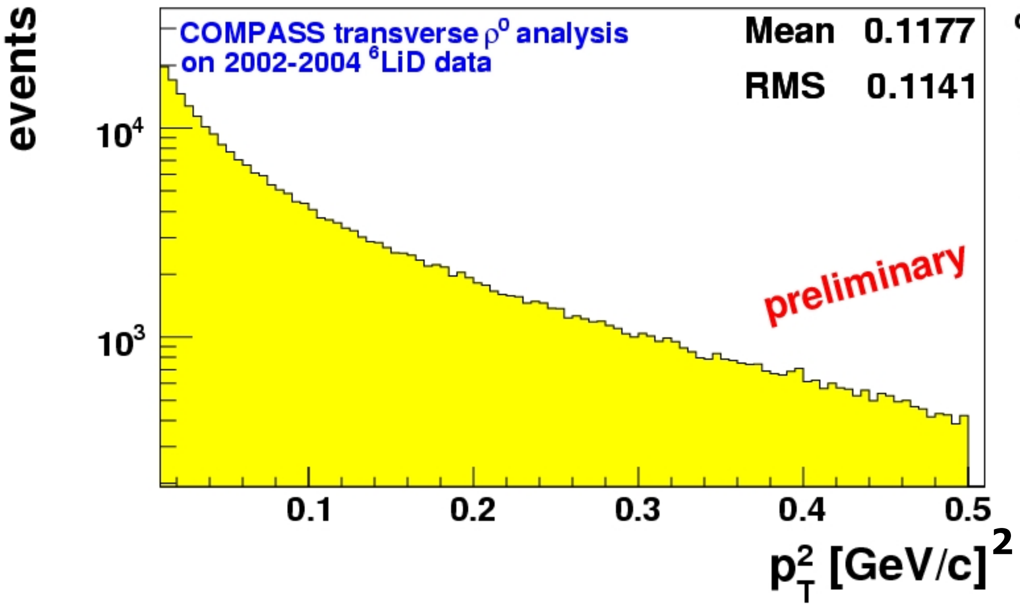


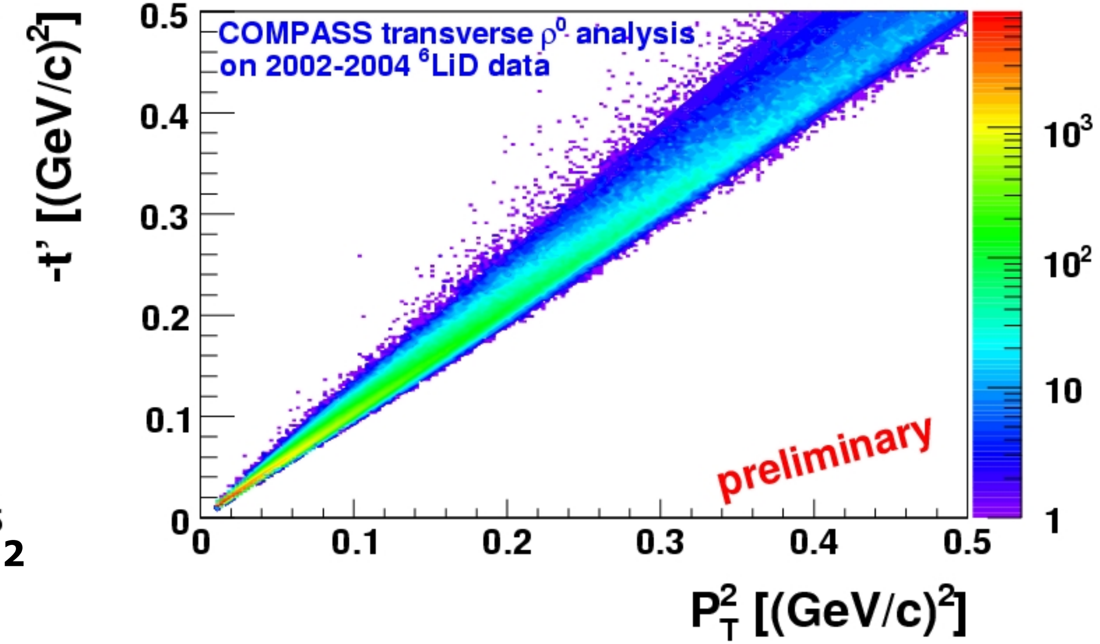
Exclusivity of the reaction

$E_{miss} = (M^2_X - M^2_N) / 2M_N$

$-2.5 < E_{miss} < 2.5$ GeV

Selection of exclusive ρ^0





minimize non exclusive background

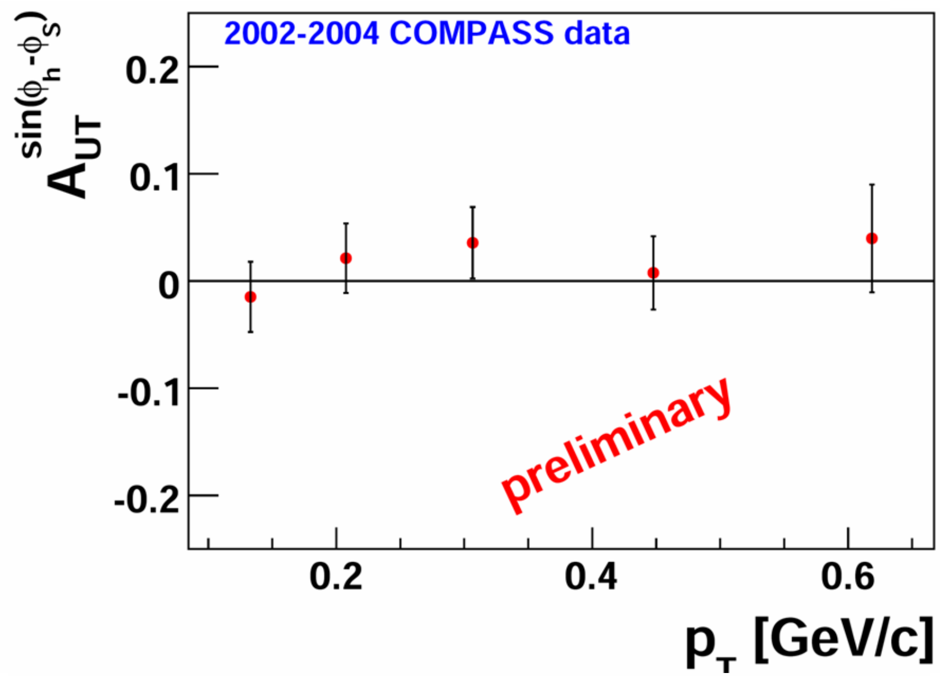
$0.01 < p_T^2 < 0.5$ (GeV/c)^2

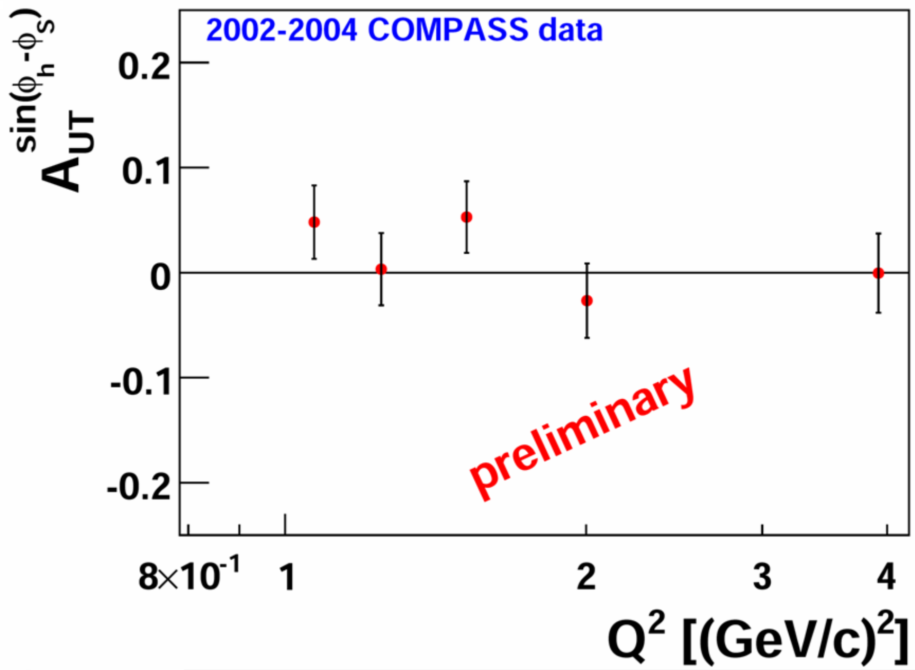
Event statistics: 270 k exclusive ρ^0

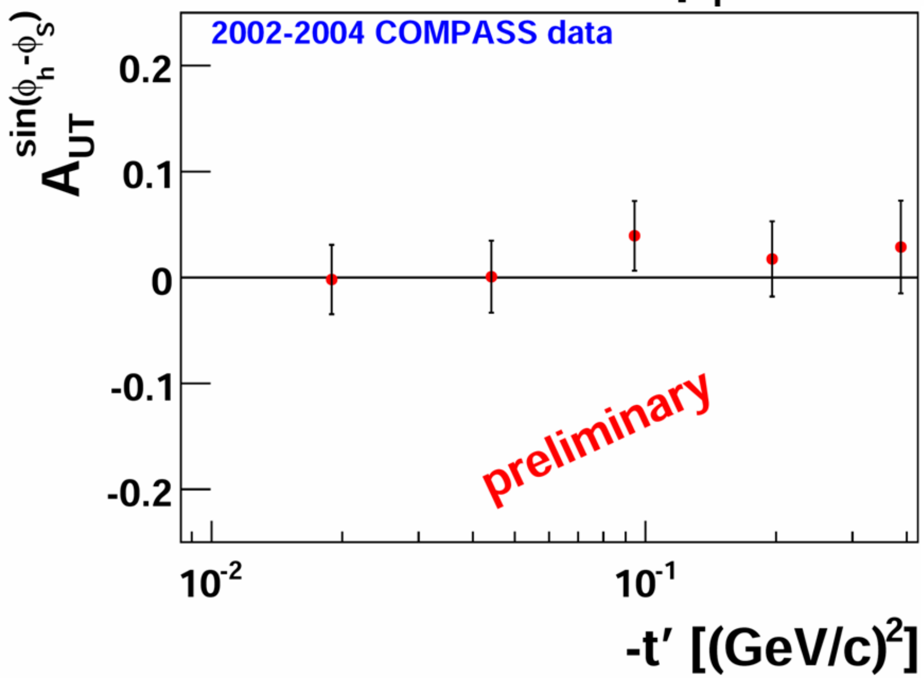
<u>work in progress:</u>

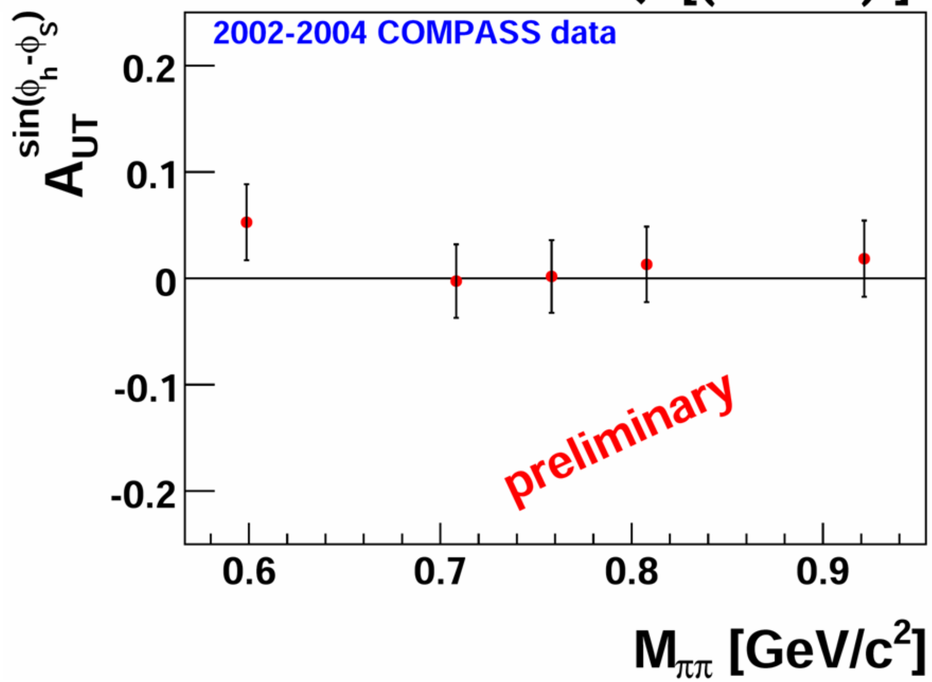
- coherent/incoherent production ($p_\perp^2$-cut)
- $\sigma_L \sigma_T$ separation (decay angle)

Results for the transverse target spin asymmetry

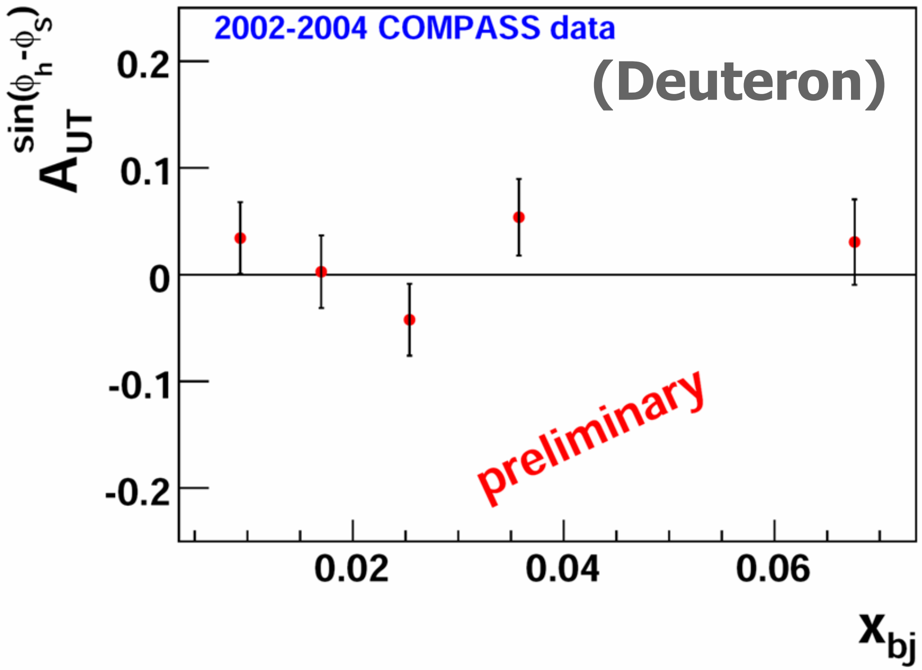








Comparison with model calculations

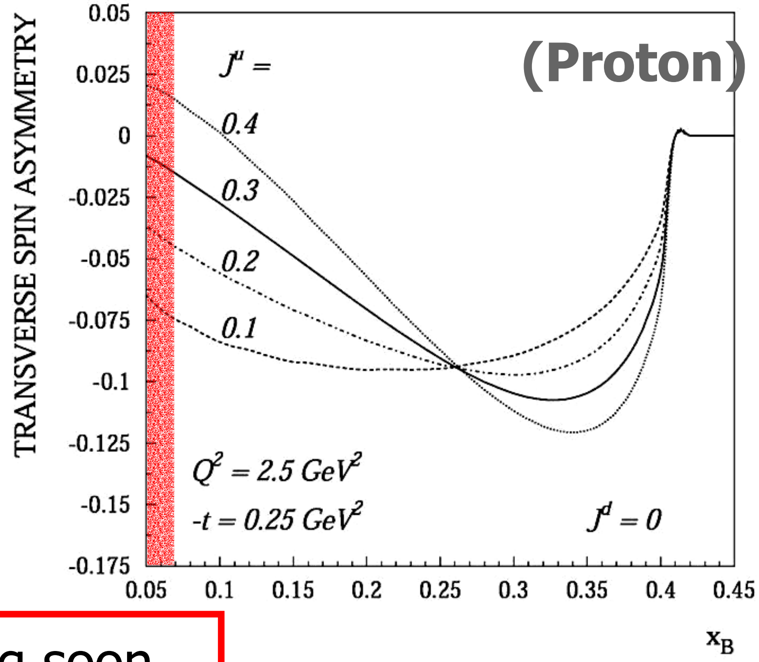


For a deuteron-target model calculations for $J^{u,d}$ still missing!

$\langle Q^2 \rangle$ = 1.93 (GeV/c)^2
$\langle -t \rangle$ = 0.13 (GeV/c)^2

Model calculations for $J^{u,d}$ for the proton.

Goeke, Polyakov, Vanderhaeghen,
Prog. Part. Nucl. Phys. 47 (401-515)
2001

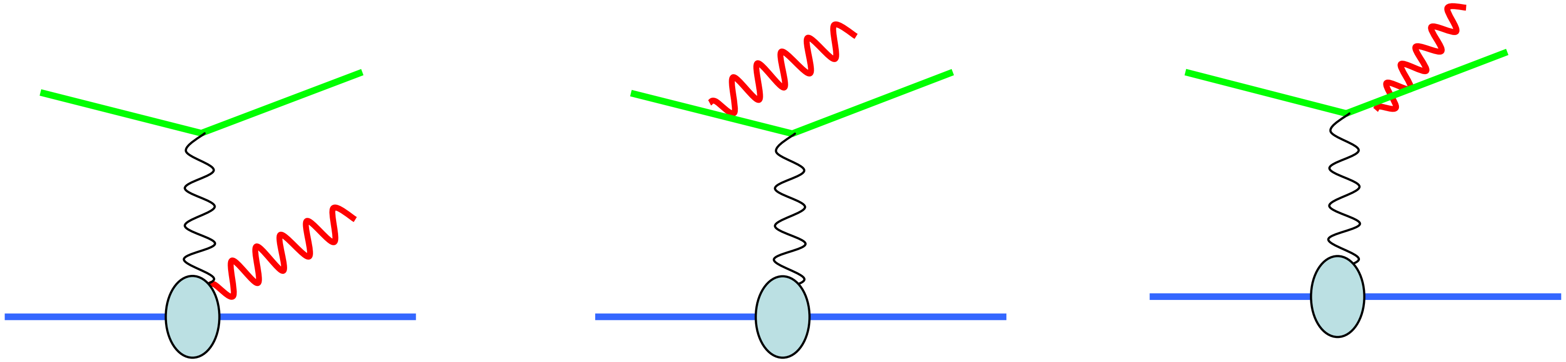


COMPASS 2007 transverse proton data coming soon…

COMPASS 2010-2015: GPD measurements

With recoil detector, calorimeter, liquid H_2 and D_2 target: DVCS & exclusive mesons

Deeply Virtual Compton Scattering:



Deeply Virtual Compton Scattering

Bethe-Heitler

DVCS Amplitude:

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

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

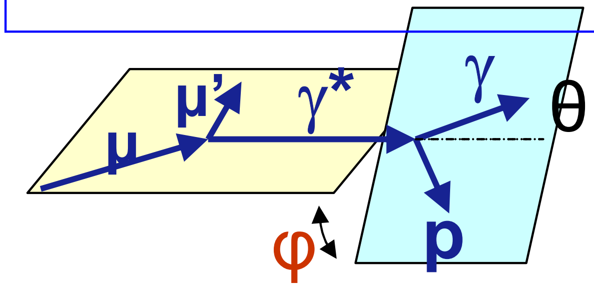
$$\mathcal{A}^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x - \xi + i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

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

$d\sigma_{(\mu p \to \mu p \gamma)} =$

$(d\sigma^{BH} + d\sigma^{DVCS}_{unpol}) + e_\mu\, a^{BH}\, \mathcal{R}e\, \mathbf{A}^{DVCS}$ $\times \cos n\varphi$

$+ P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, P_\mu\, a^{BH}\, \mathcal{I}m\, \mathbf{A}^{DVCS}$ $\times \sin n\varphi$



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

M. Diehl

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

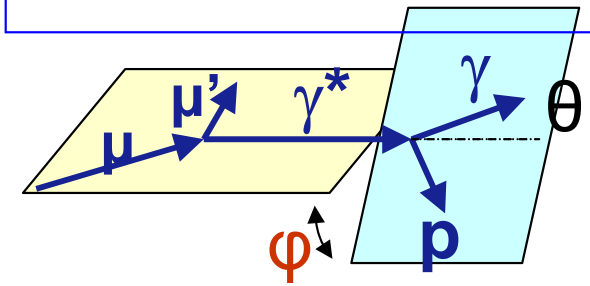
$$A^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

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

$d\sigma_{(\mu p \to \mu p \gamma)} =$

$(d\sigma^{BH} + d\sigma^{DVCS}_{unpol}) + e_\mu\, a^{BH}\, \mathcal{R}e\, \mathbf{A}^{DVCS}$ $\times \cos n\varphi$

$+\ P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, P_\mu\, a^{BH}\, \mathcal{I}m\, \mathbf{A}^{DVCS}$ $\times \sin n\varphi$



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

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

Diehl

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

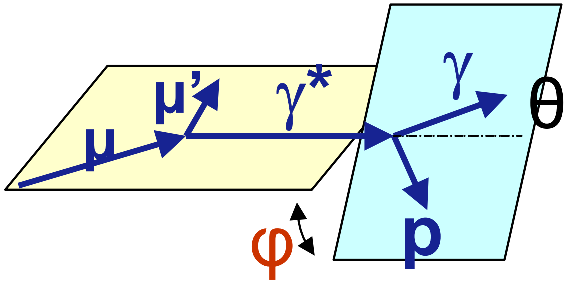
$$A^{DVCS}_{(\mu p \to \mu p \gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

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

$d\sigma_{(\mu p \to \mu p \gamma)} =$

$(d\sigma^{BH} + d\sigma^{DVCS}_{unpol}) + e_\mu\, a^{BH}\, \mathcal{R}e\, \mathbf{A}^{DVCS}$ × cos nφ

$+ P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu P_\mu\, a^{BH}\, \mathcal{I}m\, \mathbf{A}^{DVCS}$ × sin nφ



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

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

Diehl

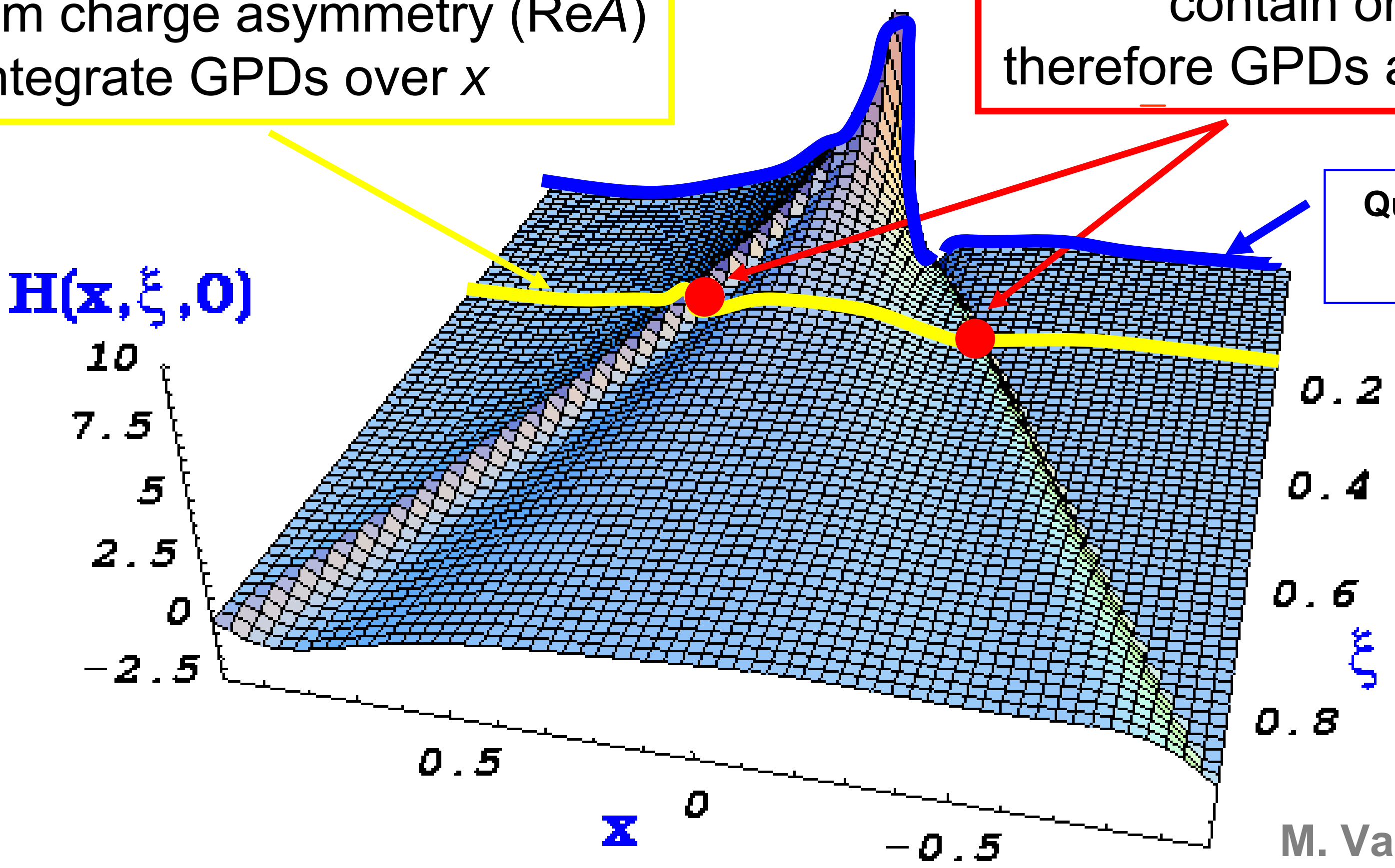
DVCS and Models of GPDs

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

Cross-section measurement
and beam charge asymmetry (Re*A*)
integrate GPDs over *x*

Beam or target spin asymmetry
contain only Im*A*,
therefore GPDs at *x* = ξ and –ξ

Quark distribution
q(x), -q(-x)



M. Vanderhaeghen

DVCS Simulations with 2 Model Variations

Double Distribution Parameterisations of GPDs
(Vanderhaeghen, Guichon, Guidal)

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

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

Model 2: **includes correlation between x and t**
considers fast partons in the small valence core
and slow partons at larger distance (wider meson cloud)

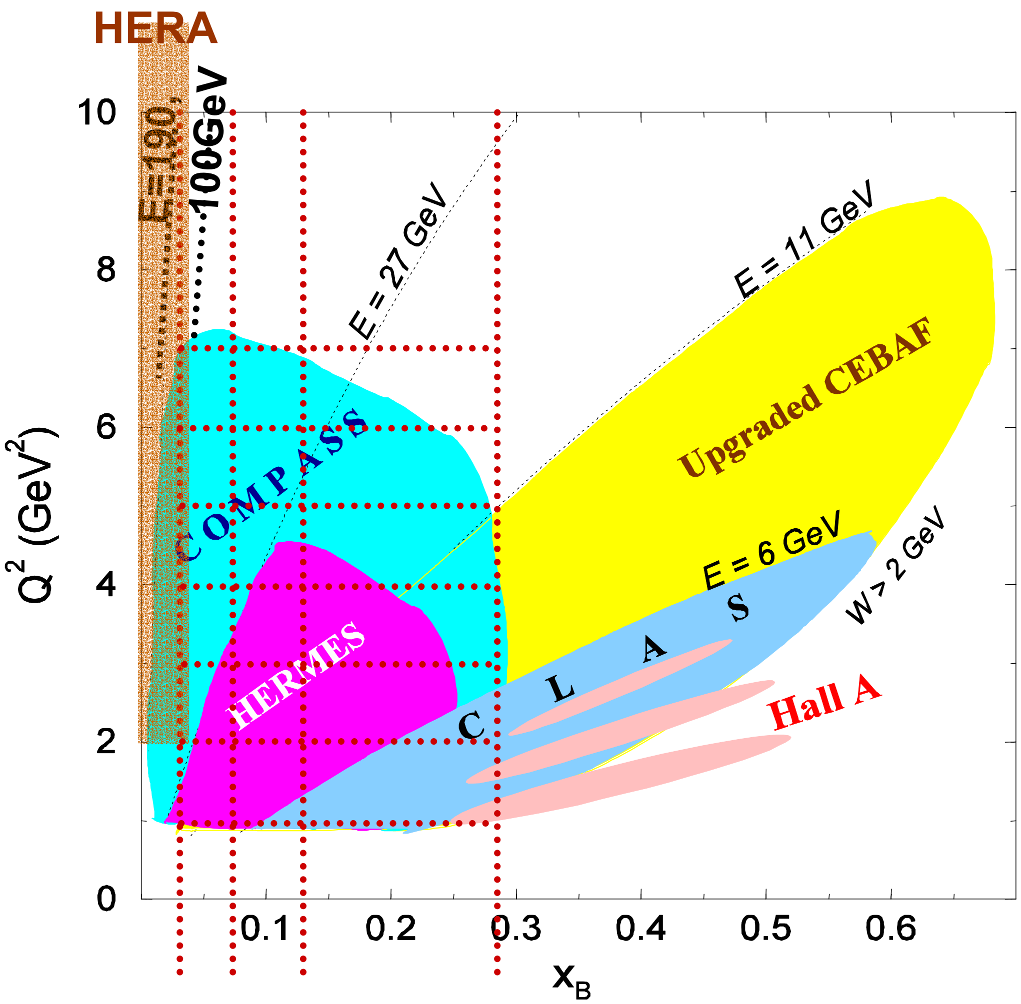
$H(x,0,t) = q(x)\,e^{t\,\langle b_\perp^2\rangle} = q(x) / x^{\alpha' t}$ **(α' slope of Regge traject.)**

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

This ansatz reproduces the
Chiral quark-soliton model: Goeke *et al.*, NP47 (2001) 401

DVCS Simulations for COMPASS at 100 GeV

- 6 bins in Q^2 from 1.5 to 7.5 GeV^2
- 3 bins in x_{Bj}=0.05, 0.1, 0.2
- Assumptions
  - L=1.3 · 10^{32} $cm^{-2}s^{-1}$
  - 150 days
  - efficiency=25%



COMPASS: valence and sea quarks, gluons

DVCS Simulations for COMPASS at 100 GeV

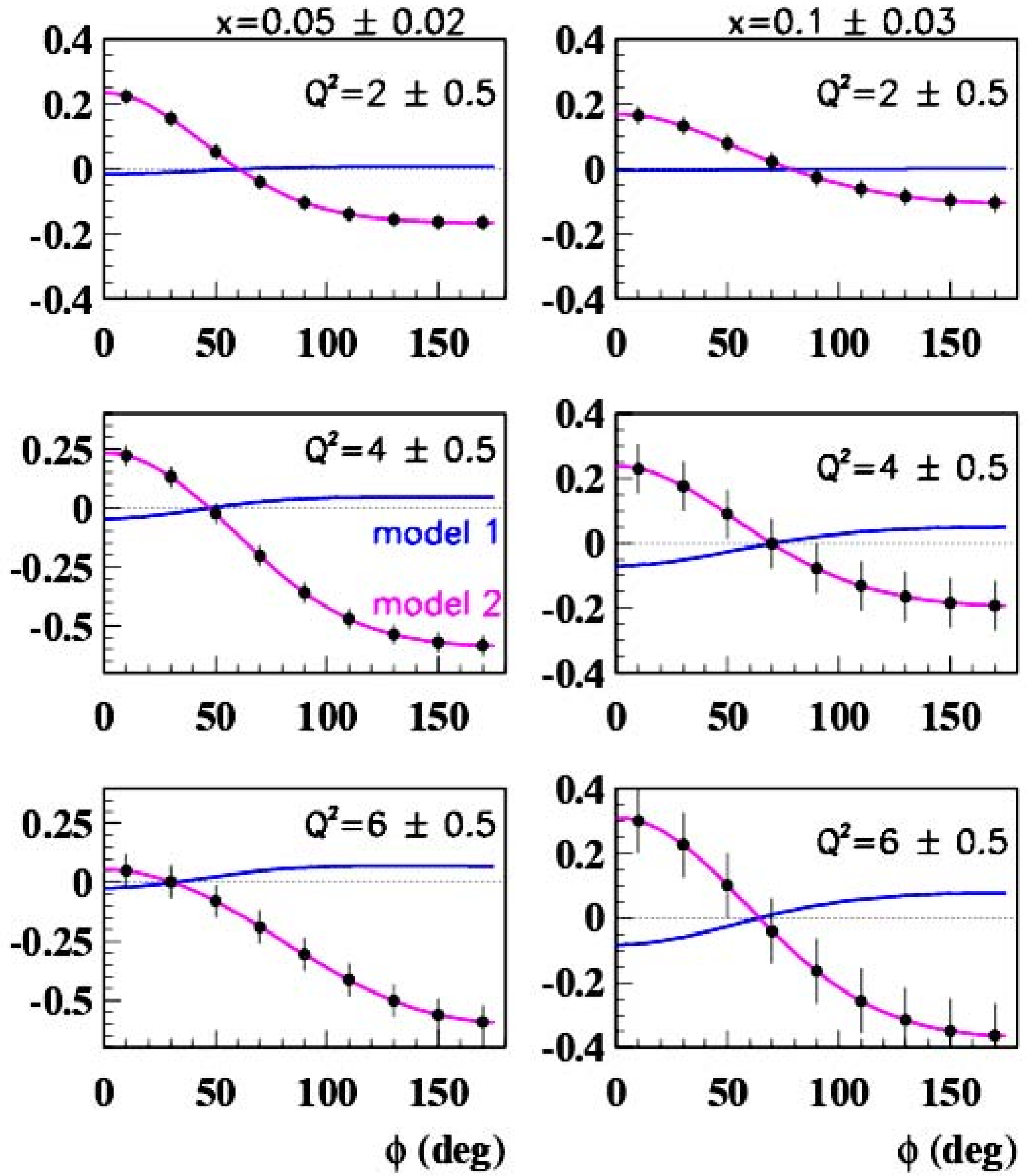
$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\overrightarrow{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

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

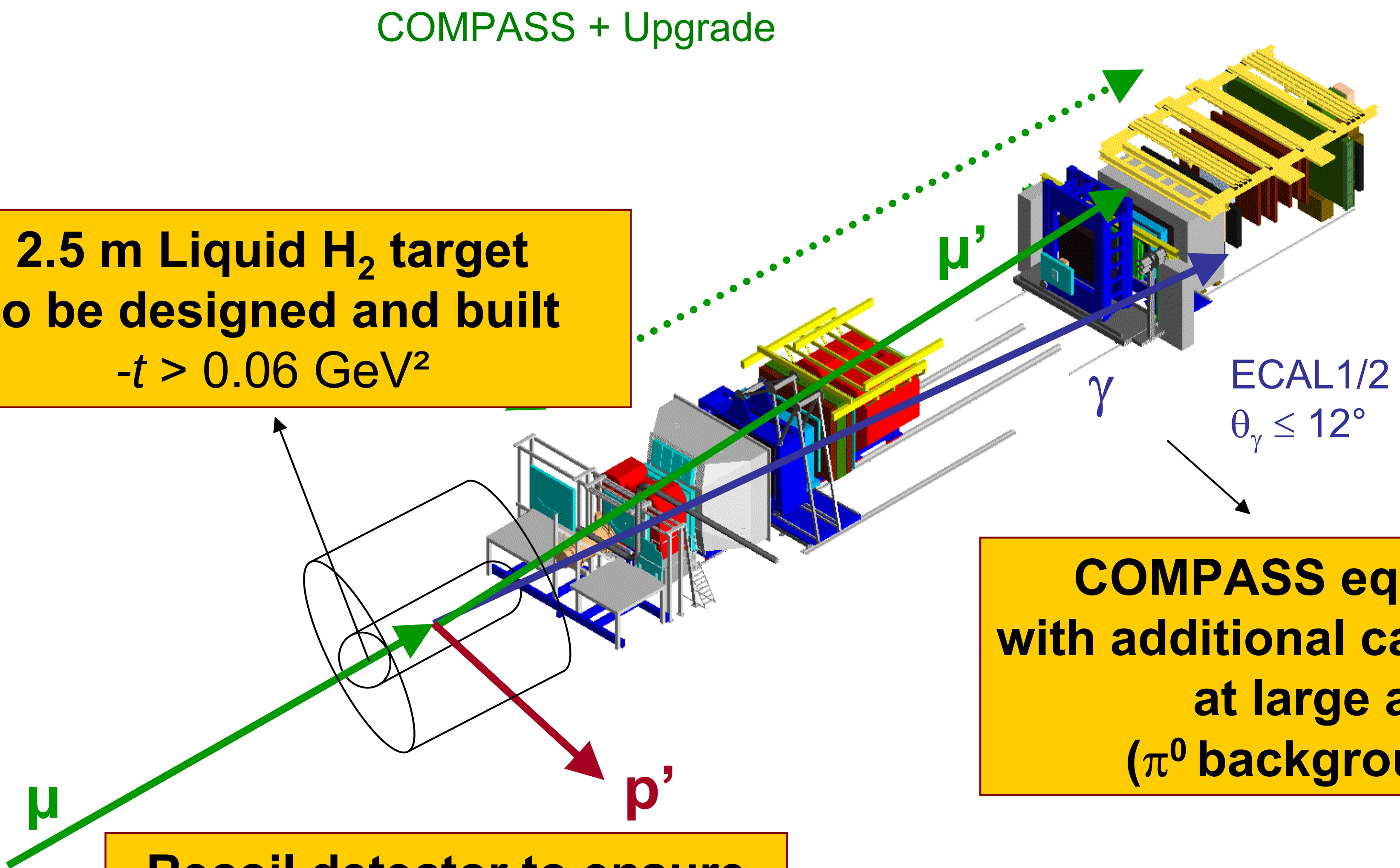
Model 2: $H(x,0,t) = q(x)\,e^{t\langle b_\perp^2\rangle}$
$= q(x) / x^{\alpha' t}$

- 6 bins in Q^2 from 1.5 to 7.5 GeV^2 (3 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%

Beam Charge Asymmetry



Experimental Setup: Target & Detektor

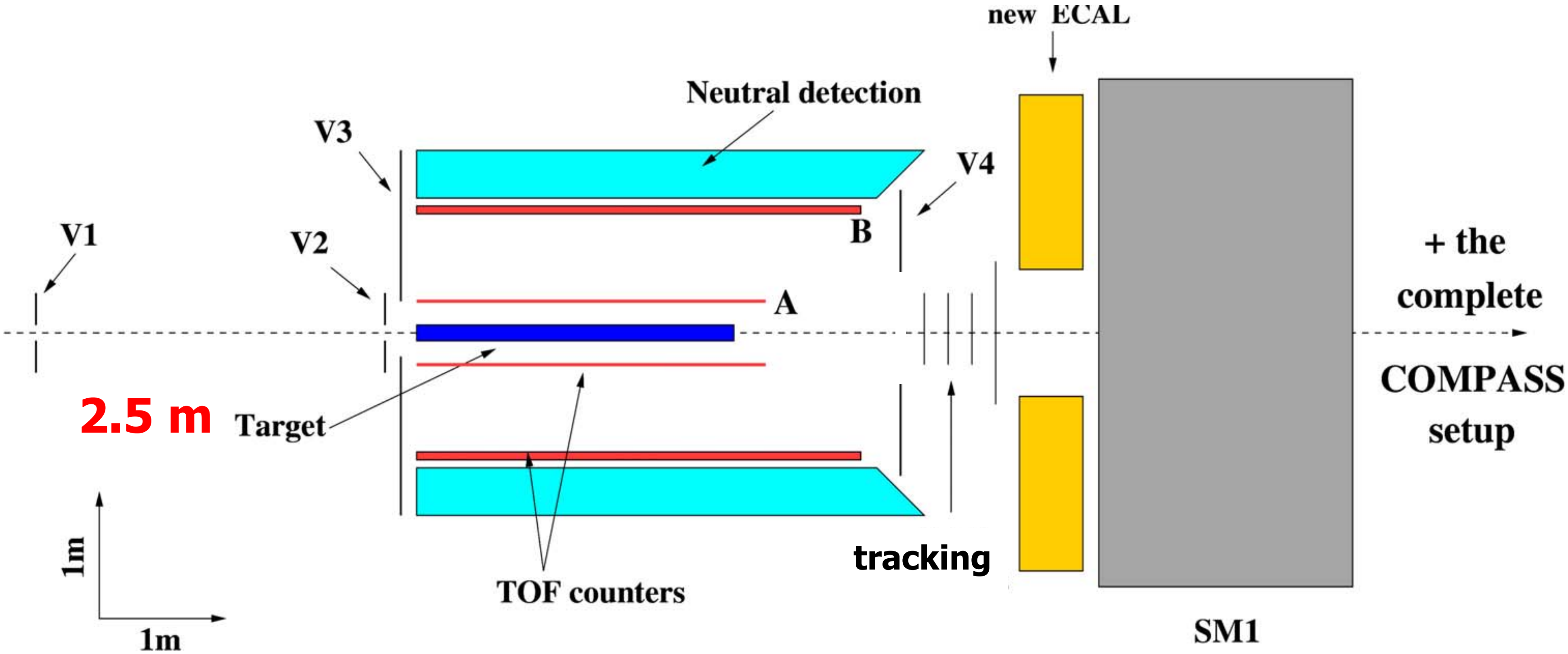


2.5 m Liquid H_2 target
to be designed and built
$-t > 0.06$ GeV²

COMPASS equipment with additional calorimetry at large angle (π^0 background)

Recoil detector to ensure exclusivity to be designed and built

Recoil detector



Goals: Detect protons of 250-750 MeV/c

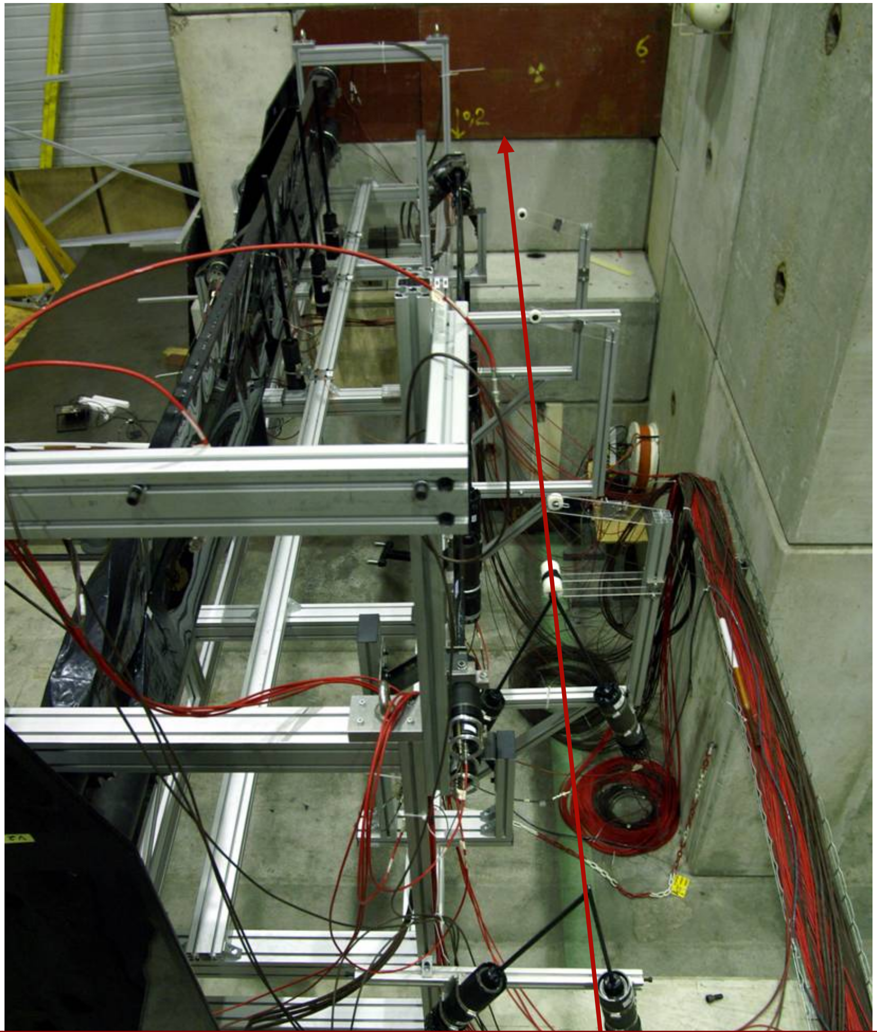
t resolution => σ_{TOF} < 300 ps

exclusivity => Hermetic detector

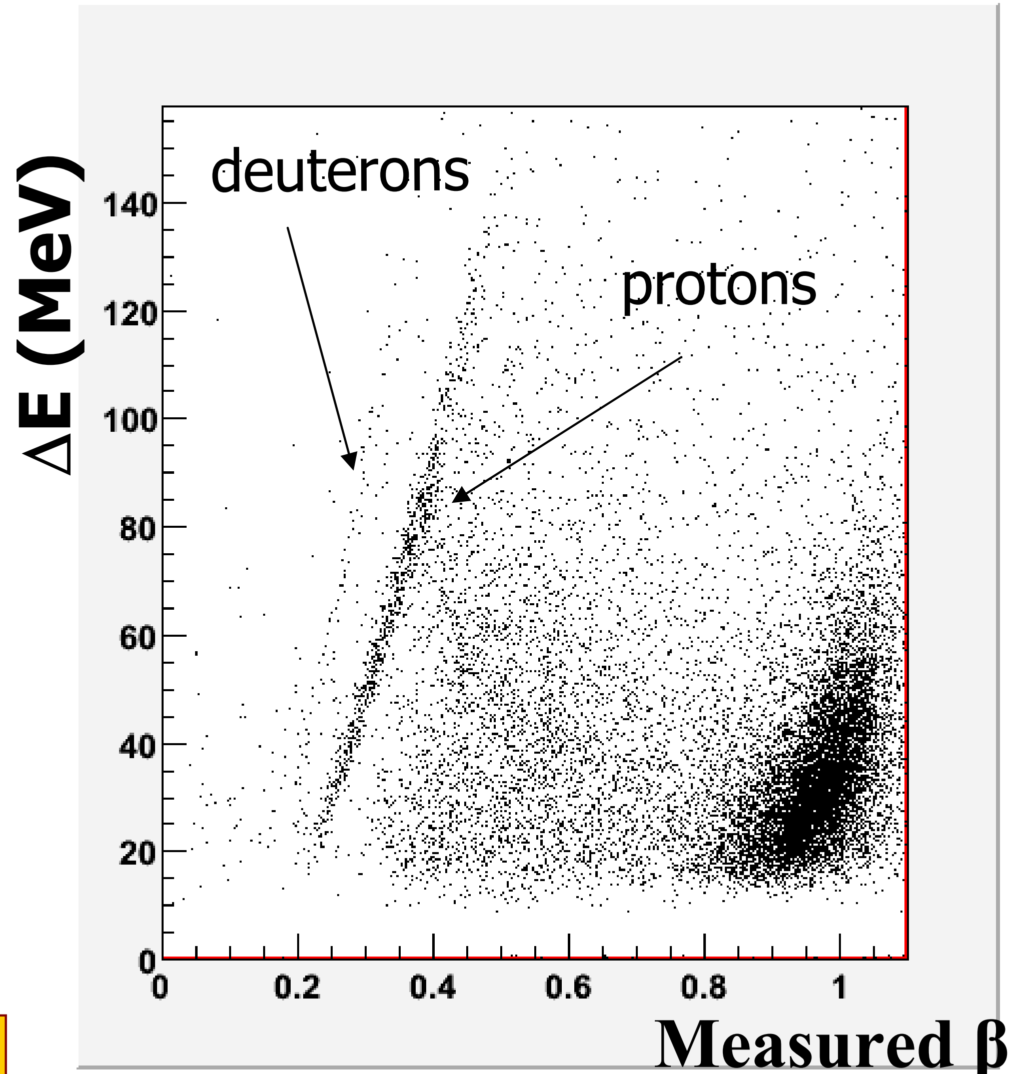
Design :

2 concentric barrels of 24 scintillators read out on both sides

Recoil detector prototype test



Fall 2006:
Test of recoil detector full size prototype at COMPASS: σ_t=310ps.
Goal: 300 ps for 10 bins in *t*

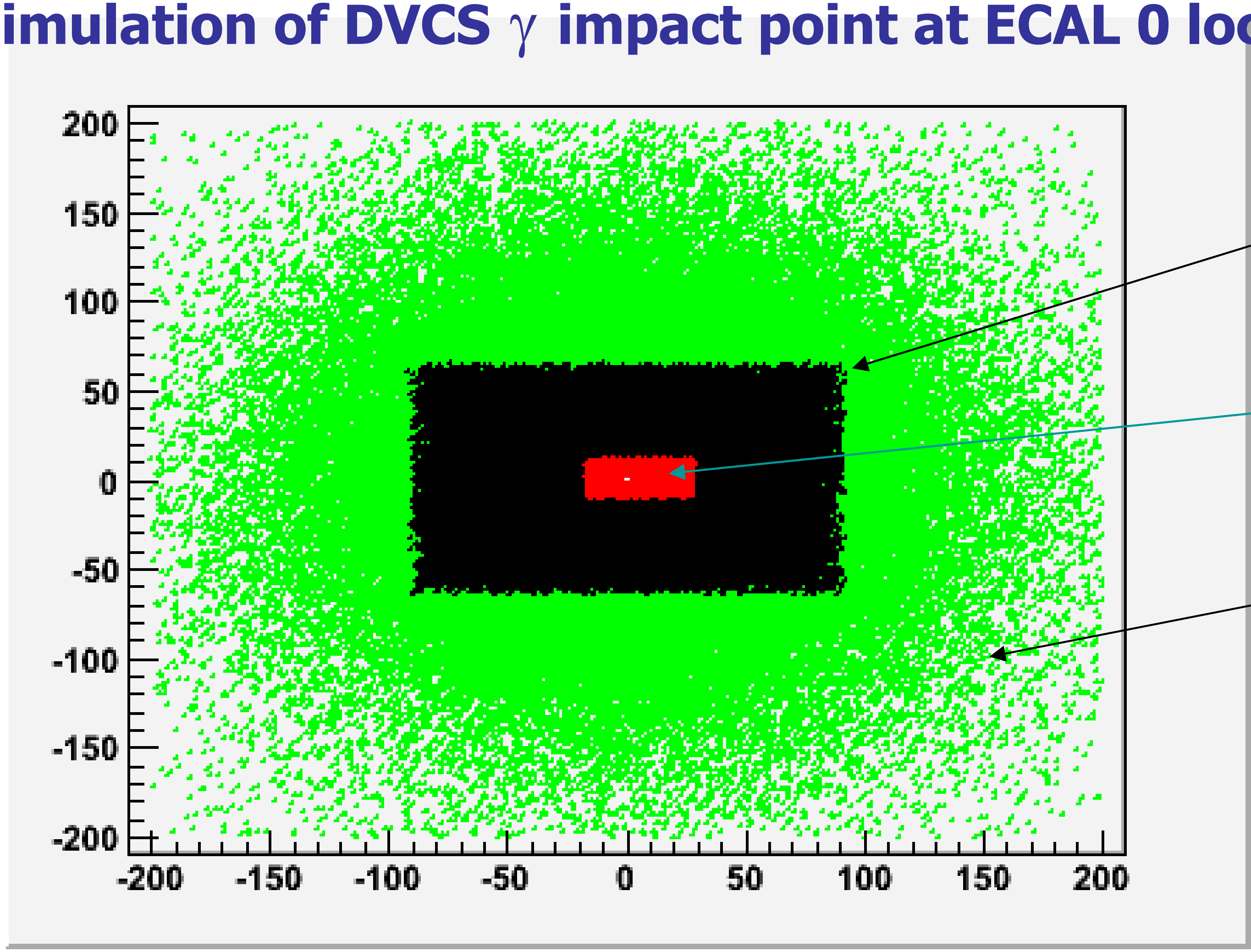


Target : 10 cm CH
Nominal beam intensity
8 hours of data

Calorimeter coverage foreseen

Goals : Detect DVCS photons & π^0

Simulation of DVCS γ impact point at ECAL 0 location



ECAL 1 (existing)

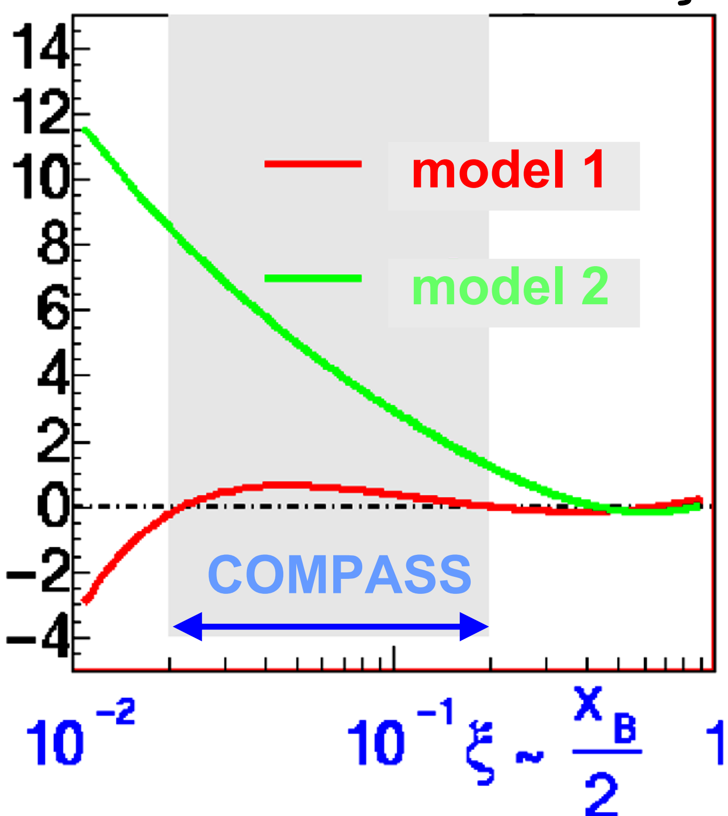
ECAL 2 (existing)

ECAL 0 To be built

Outlook for GPDs at COMPASS

- Currently: Simulations and preparation of proposal
- 2007-2009: Construction of
  - recoil detector (prototype tested)
  - LH_2 target
  - ECAL0
- 2010-2015: Study of GPDs at COMPASS
- >2014: JLab12, FAIR

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



COMPASS advantage:

sensitivity in the valence quark – sea quark region of x_{Bj}