TRANSVERSITY 2011
Third International Workshop on
TRANSVERSE POLARIZATION PHENOMENA IN HARD SCATTERING
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Veli Lošinj, Croatia

ECSAC
European Centre for Science Arts and Culture

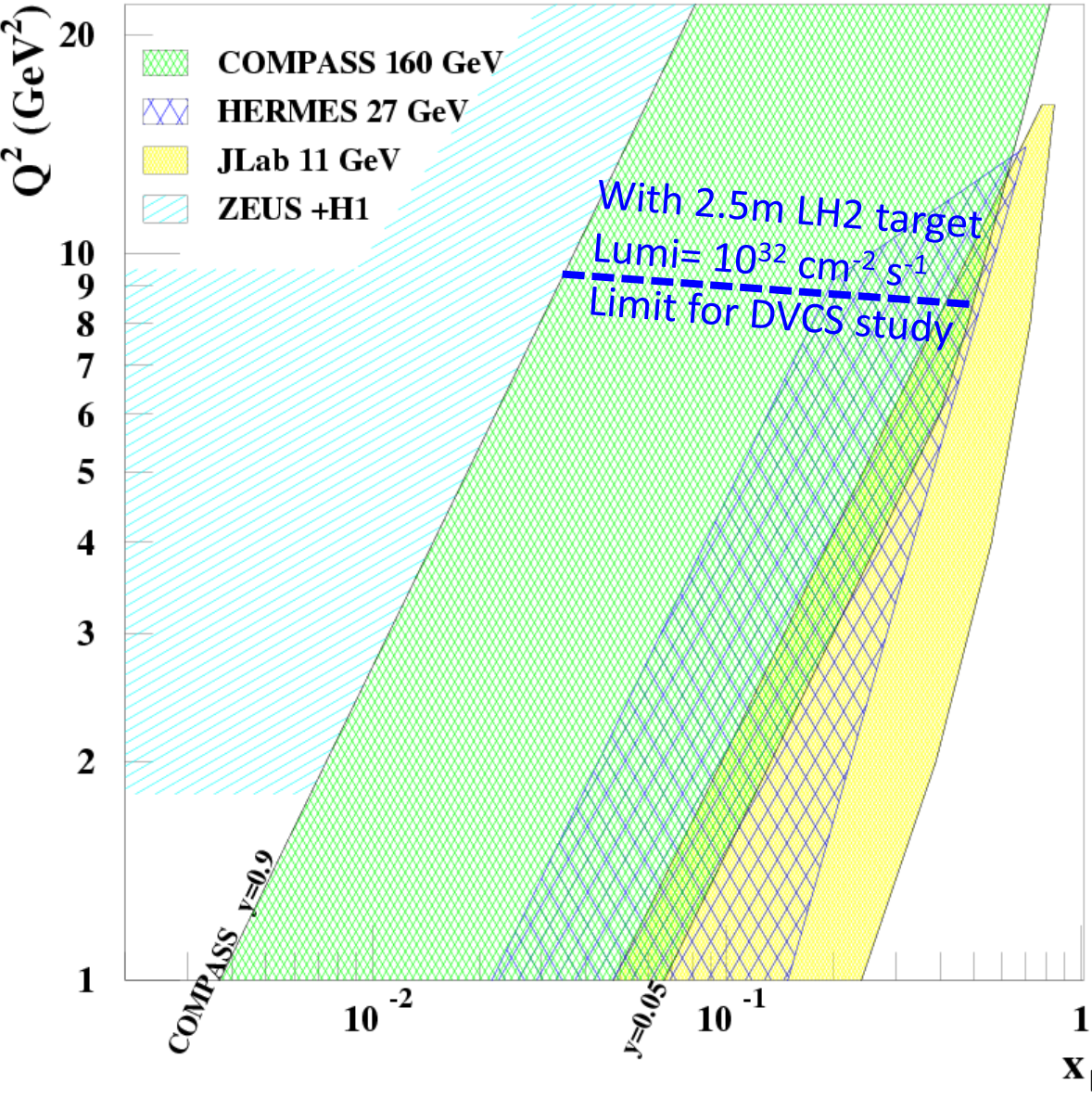
Hard Exclusive Processes at COMPASS and COMPASS II

DVCS: golden channel for GPD

HEMP: ρ^0,(ρ+,ω,ϕ,…) or π^0,…

Nicole d'Hose (CEA-Saclay)
On behalf of the COMPASS Collaboration

What makes COMPASS unique for GPD?



CERN High energy muon beam

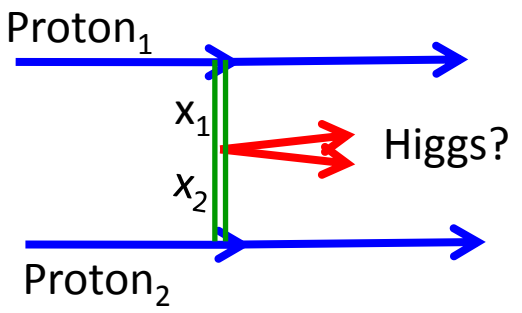
✓ 100 - 190 GeV

- Explore the intermediate x_{Bj} region
- Uncovered region between ZEUS+H1 & HERMES + Jlab

before new colliders may be available

- Transverse structure at $x \sim 10^{-2}$

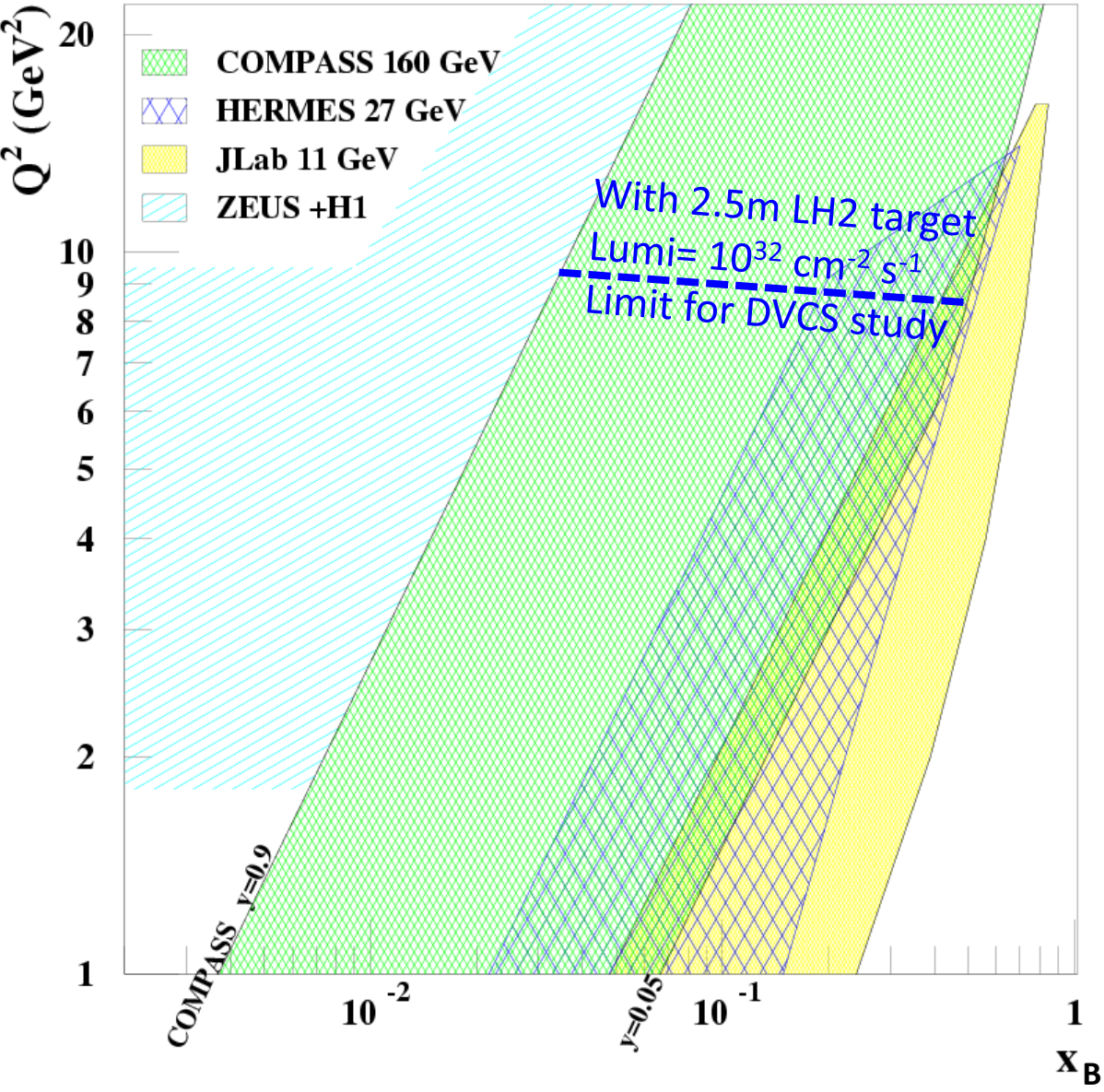
essential input for phenemenology of high-energy pp collision (LHC)



$$x_{1,2} = M_{Higgs} / \sqrt{s} \sim 10^{-2}$$

M_{Higgs} = 140 GeV and $\sqrt{s}$ =14 TeV

What makes COMPASS unique for GPD?



CERN High energy muon beam

- ✓ 100 - 190 GeV
- ✓ $\mu^{+\downarrow}$ and $\mu^{-\uparrow}$ available
- ✓ 80% Polarisation

with opposite polarization

- ✓4.6 10^8 μ^+

for 2.7 10^{13} protons / SPS spill (9.6s each 48 s)

➔Lumi= 10^{32} cm^{-2} s^{-1} with 2.5m LH2 target

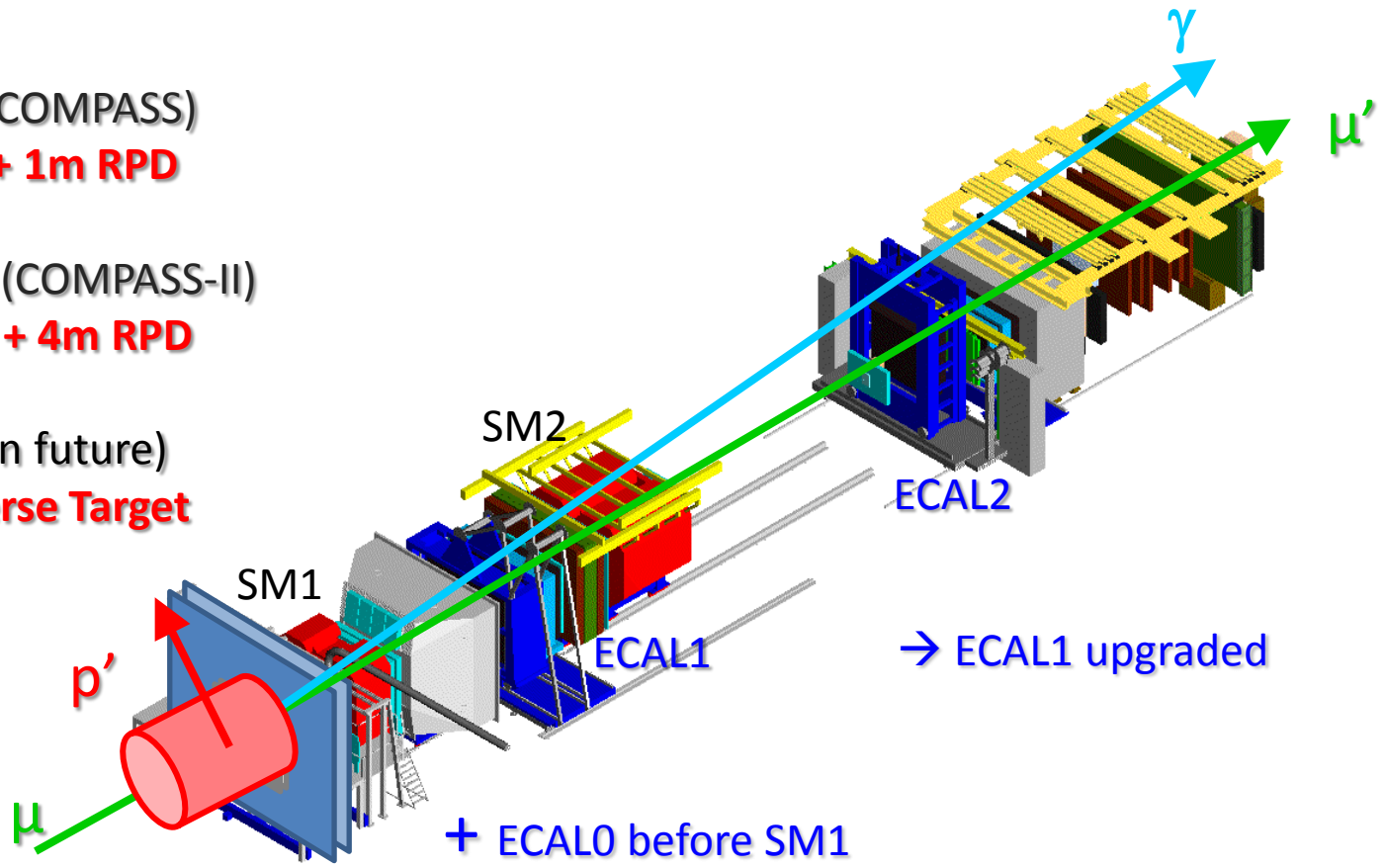
Experimental requirement for exclusive measurement

DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$

Tests in 2008-09 (COMPASS)
40cm LH2 target + 1m RPD

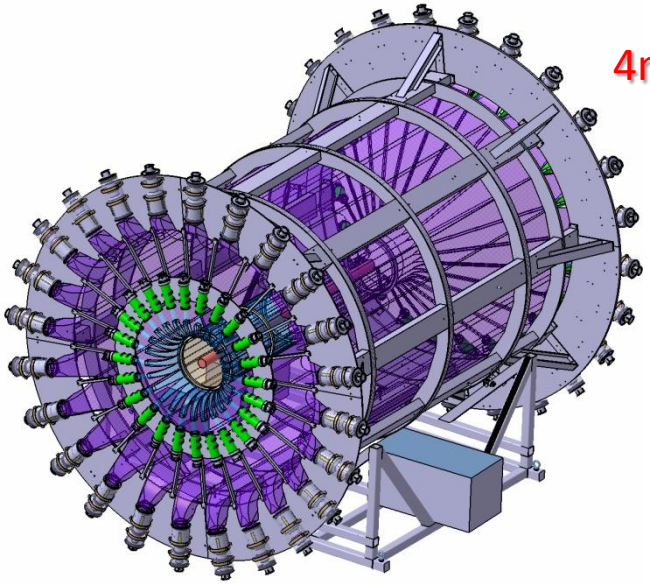
Phase 1: 2012-16 (COMPASS-II)
2.5 m LH2 target + 4m RPD

Phase 2: > 2016 (in future)
Polarised Transverse Target
integrating RPD



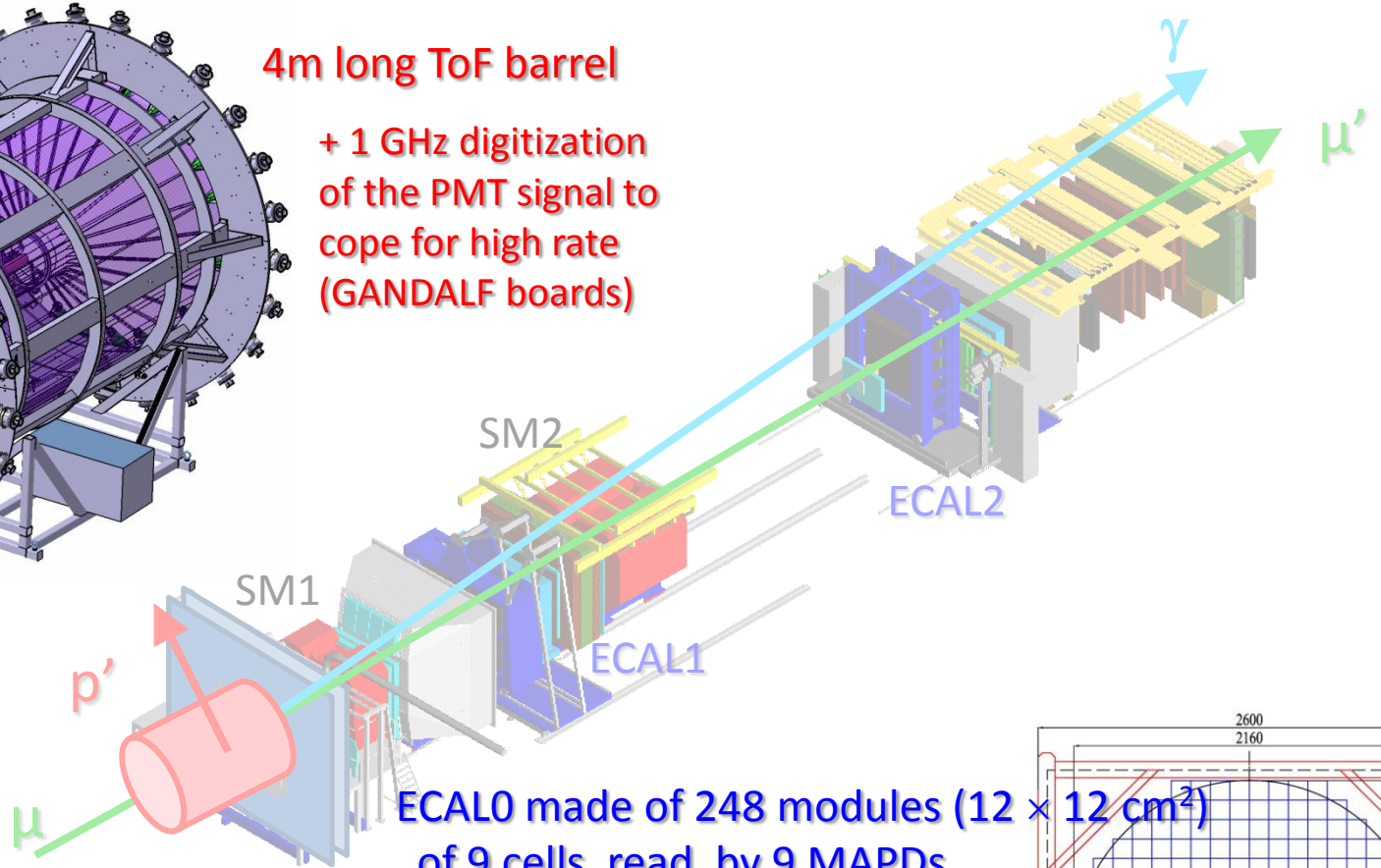
Experimental requirement for exclusive measurement

DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$

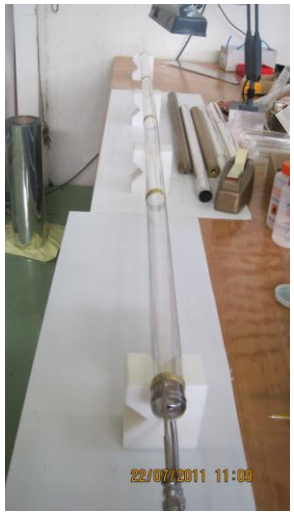


4m long ToF barrel

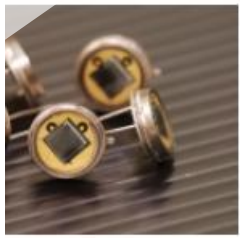
+ 1 GHz digitization of the PMT signal to cope for high rate (GANDALF boards)

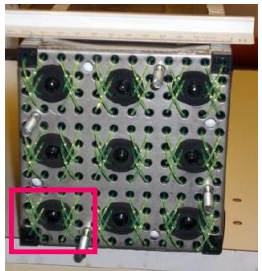


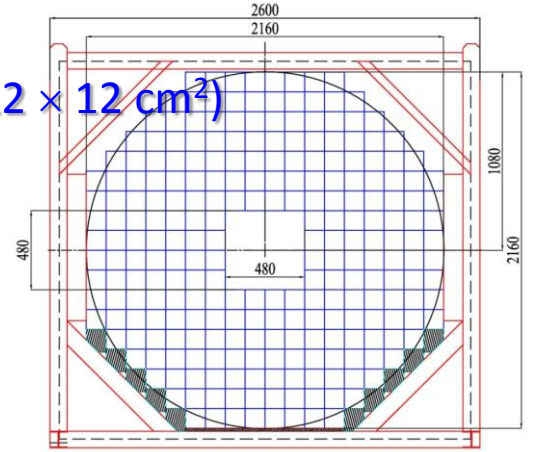
ECAL0 made of 248 modules (12 × 12 cm^2) of 9 cells read by 9 MAPDs



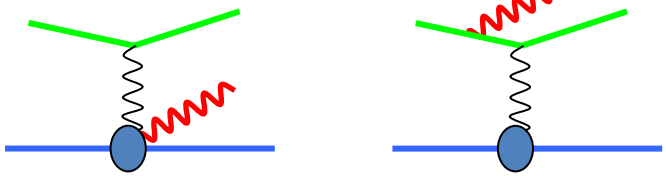
Prototype of the 2.5m long LH2 target + test of the cryostat

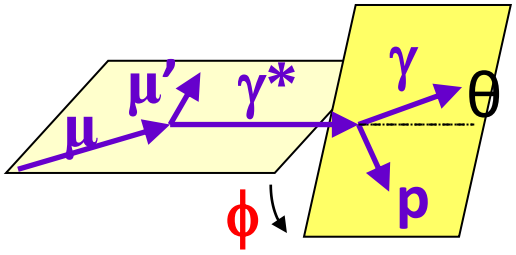




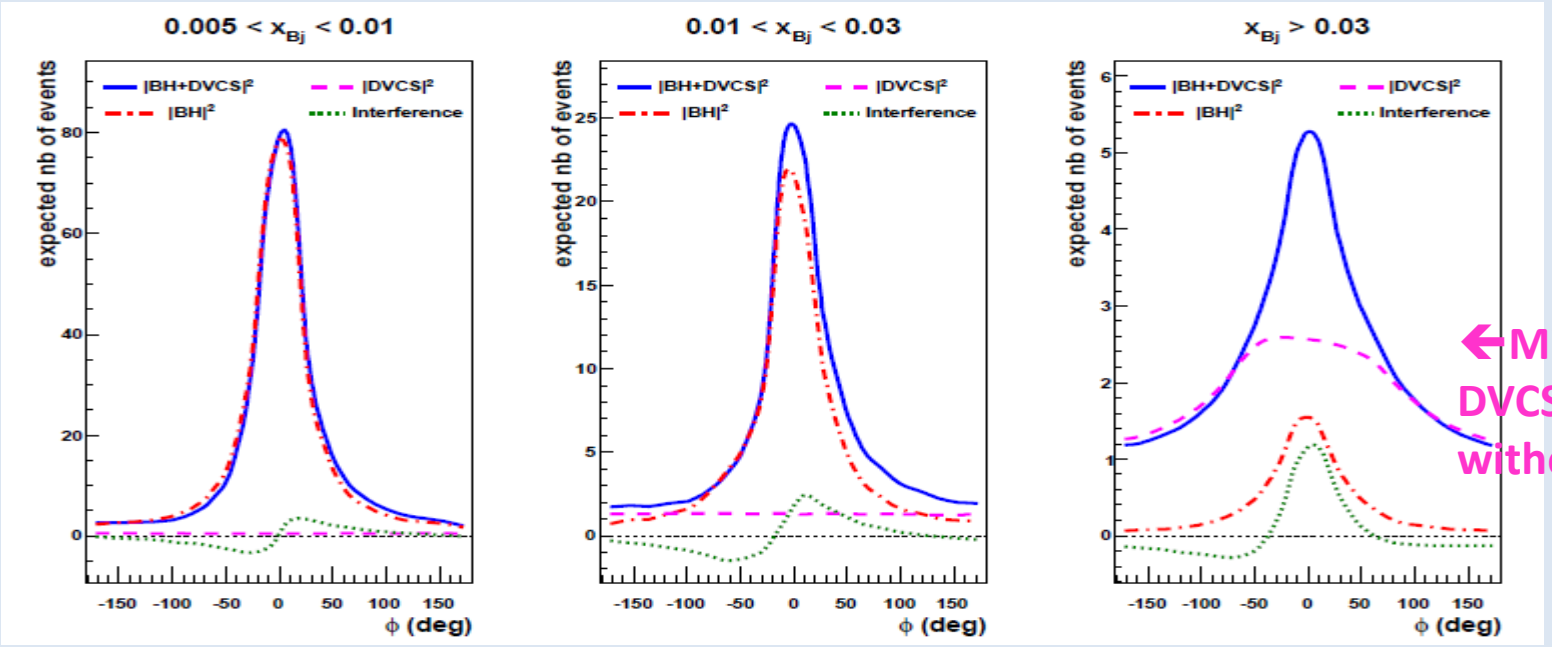


Contributions of DVCS and BH at E_μ=160 GeV





$d\sigma \alpha |T^{DVCS}|^2 + |T^{BH}|^2 + \text{Interference Term}$



Monte-Carlo Simulation for COMPASS set-up with only ECAL1+2

←Missing DVCS acceptance without ECAL0

BH dominates

excellent reference yield

study of Interference

→ Re T^{DVCS}

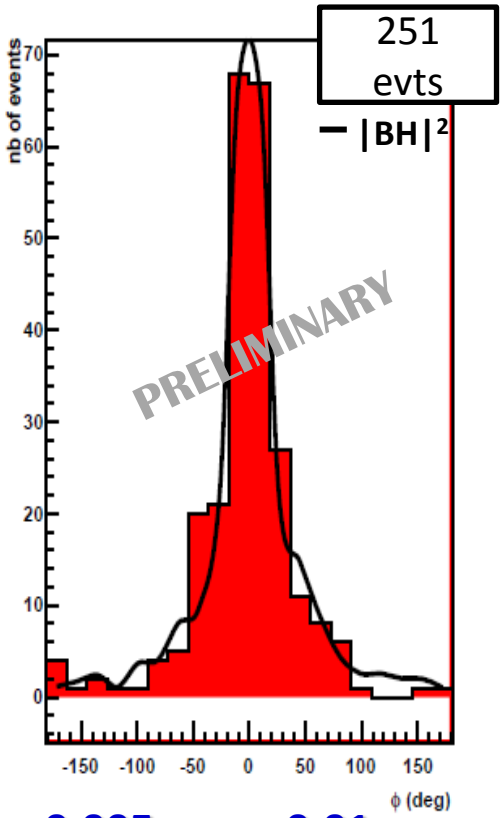
or Im T^{DVCS}

DVCS dominates

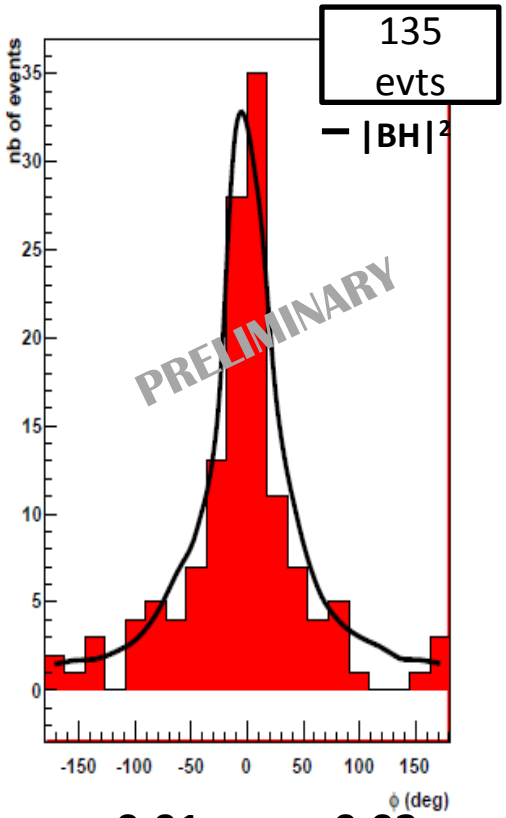
study of $d\sigma^{DVCS}/dt$

→ Transverse Imaging

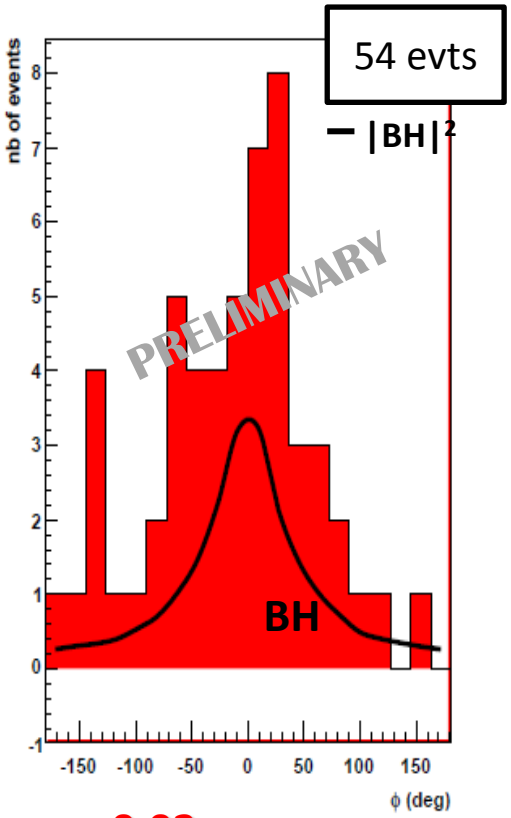
2009 DVCS test run (10 days, short RPD+target)



$0.005 < x_B < 0.01$



$0.01 < x_B < 0.03$



$0.03 < x_B$

$\epsilon_{\mu p \to \mu' \gamma p} \approx 35\%$

$\times (0.8)^4$ for SPS + COMPASS avail. + trigger eff + dead time

$\epsilon_{global} \approx 0.14$ confirmed $\epsilon_{global} = 0.1$
as assumed for COMPASS II predictions

54 evts ≈ 20 BH
+ 22 DVCS
+ about 12 γ from π^0

Projections for Phase 1 in COMPASS-II
(test in autumn 2012 and 2 years 2015-16)

with recoil proton detection and hydrogen target

- **→Transverse Imaging : dσ/dt**
- **→Constrains on the GPD H**

Deeply Virtual Compton Scattering

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

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

Phase 1: DVCS experiment to study the transverse imaging

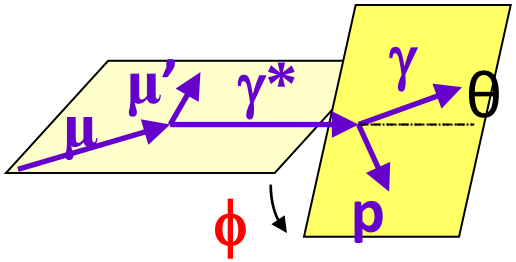
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam + unpolarized 2.5m long LH2 (proton) target

$$S_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + K.s_1^{Int} \sin\phi$$

Using $S_{CS,U}$ and BH subtraction

and integration over ϕ

$$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$$



Transverse imaging at COMPASS

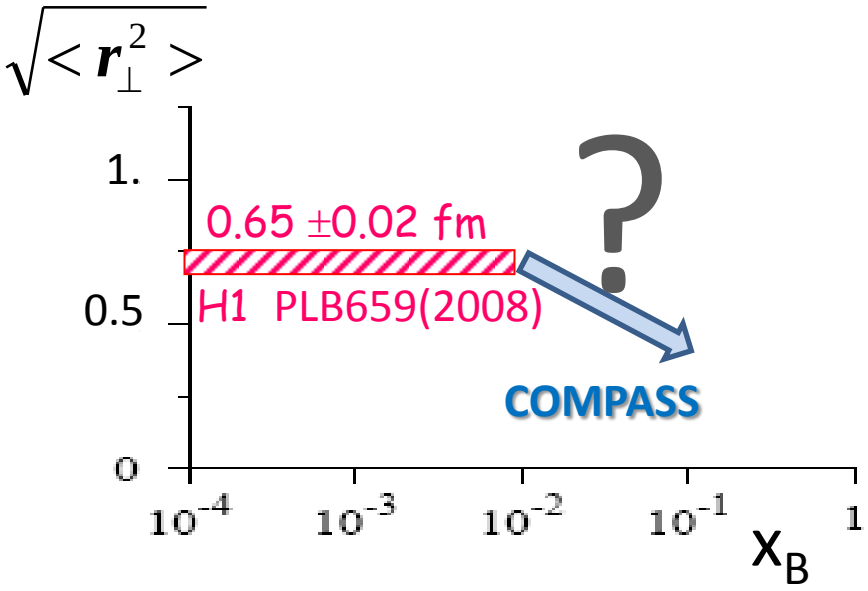
$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$

$B(x_B) = \frac{1}{2} < r_\perp^2(x_B) >$

distance between the active quark
and the center of momentum of spectators

Transverse size of the nucleon

mainly dominated by $H(x, \xi=x, t)$

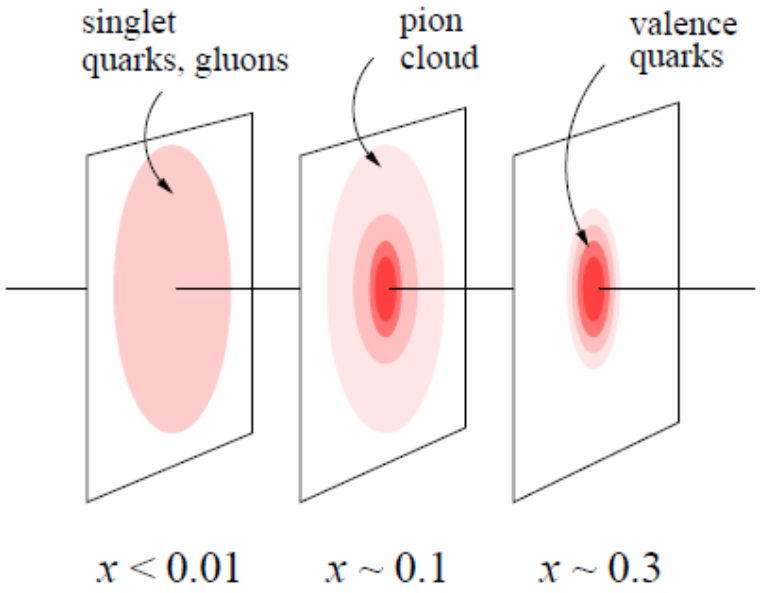


$\text{related to } \frac{1}{2} < b_\perp^2(x_B) >$

distance between the active quark
and the center of momentum of the nucleon

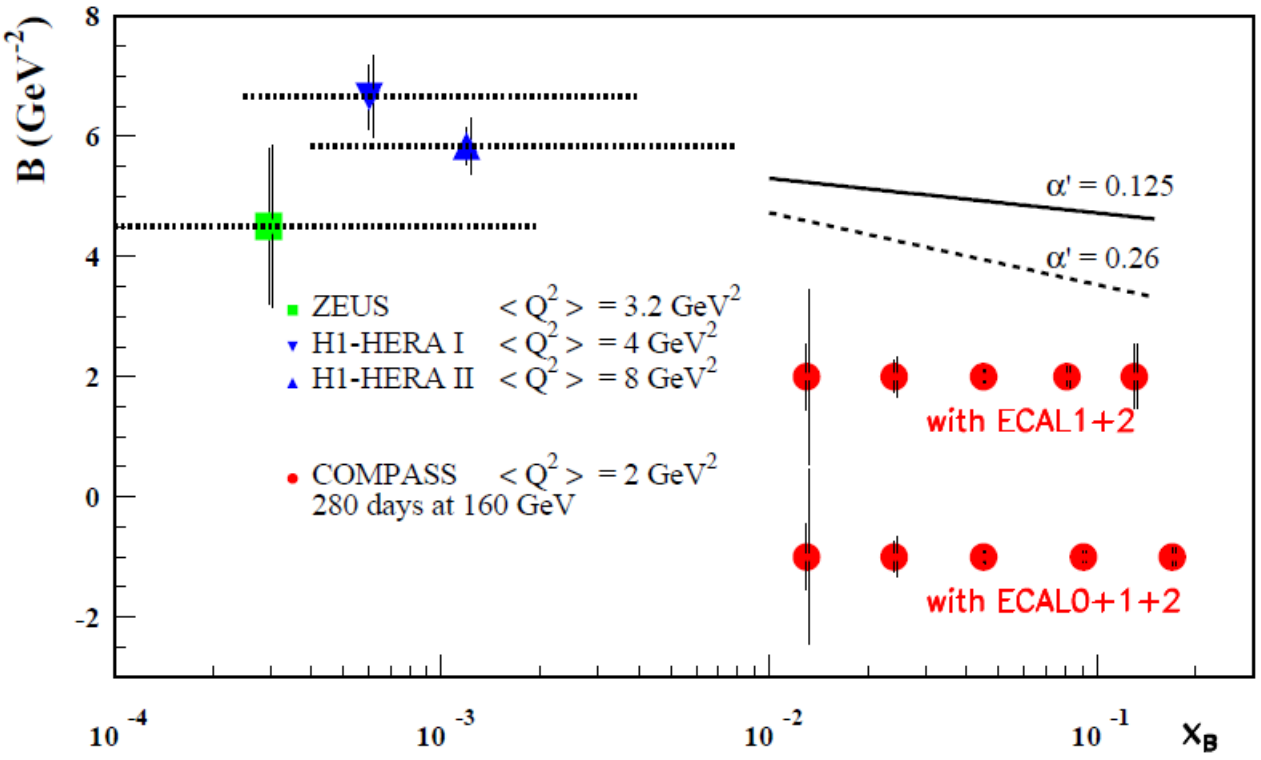
Impact Parameter Representation

$q(x, b_\perp) <-> H(x, \xi=0, t)$



Transverse imaging at COMPASS

$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$



2 years of data
160 GeV muon beam
2.5m LH_2 target
$\varepsilon_{global} = 10\%$

ansatz at small x_B
inspired by
Regge Phenomenology:

$B(x_B) = b_0 + 2\,\alpha' \ln(x_0/x_B)$

α' slope of Regge traject

without any model we can extract $B(x_B)$

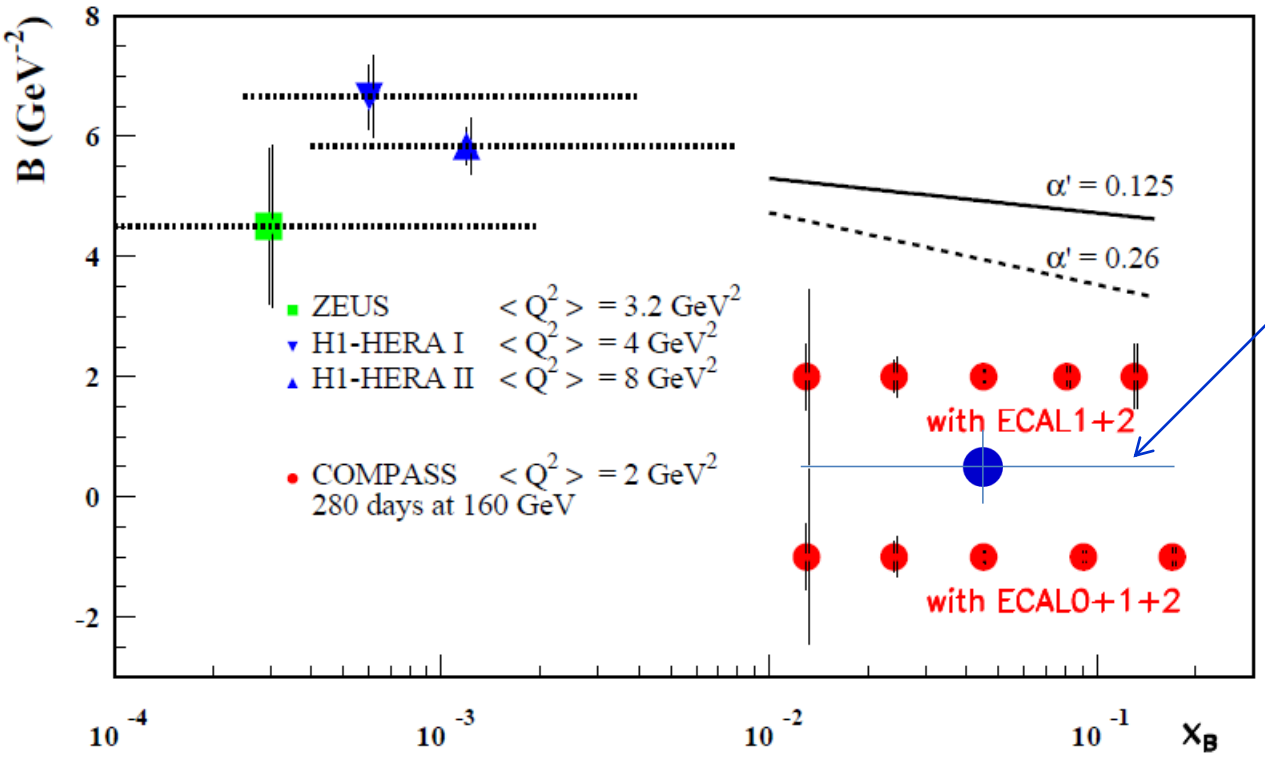
$$B(x_B) = \tfrac{1}{2} < r_\perp^2(x_B) >$$

$r_\perp$ is the transverse size of the nucleon

Accuracy > 2.5 σ if α' = 0.125 and full ECALS

Transverse imaging at COMPASS

$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$



DVCS test in 2012

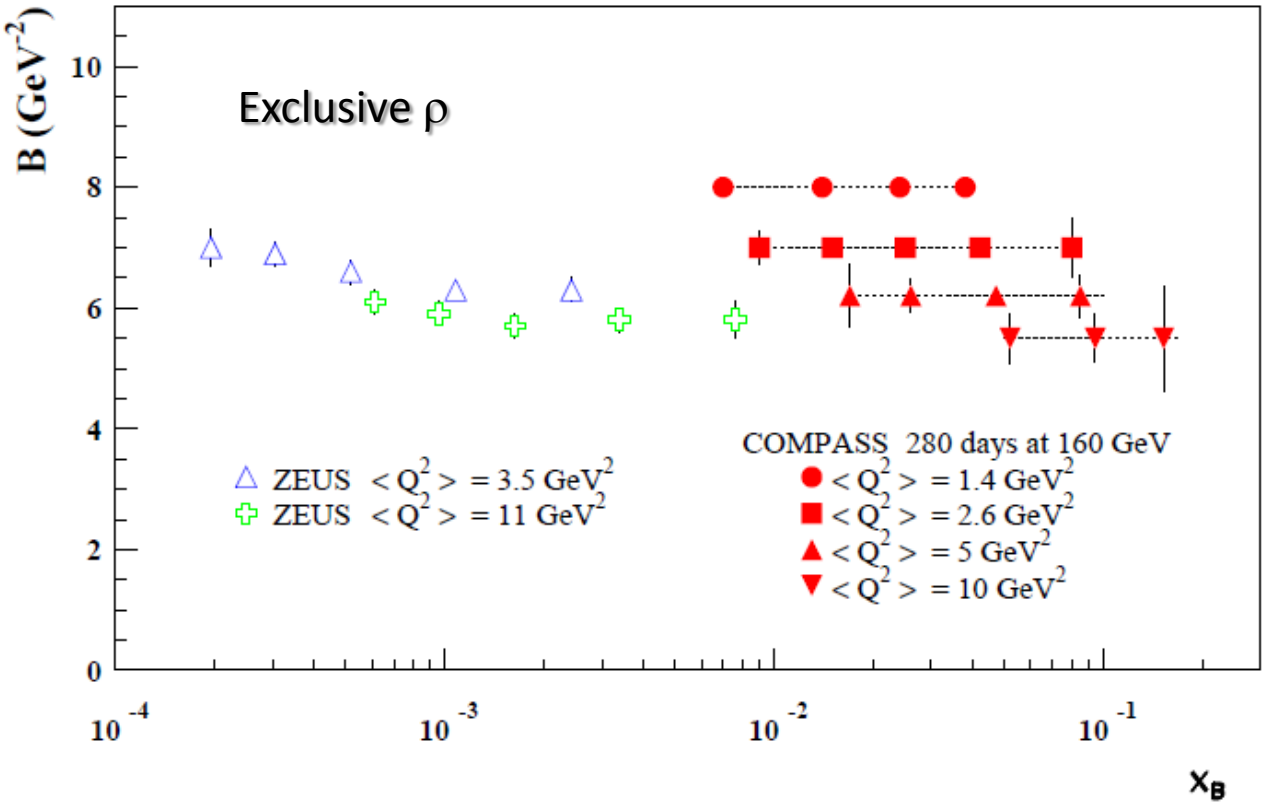
With **1 week**
Using the 4m long RPD
+ the 2.5m long LH2 target

1/40 of the complete statistics

2012: we can determine one mean value of B in the COMPASS kinematic range

Transverse imaging at COMPASS

$d\sigma^{excl.\rho}/dt \sim \exp(-B|t|)$

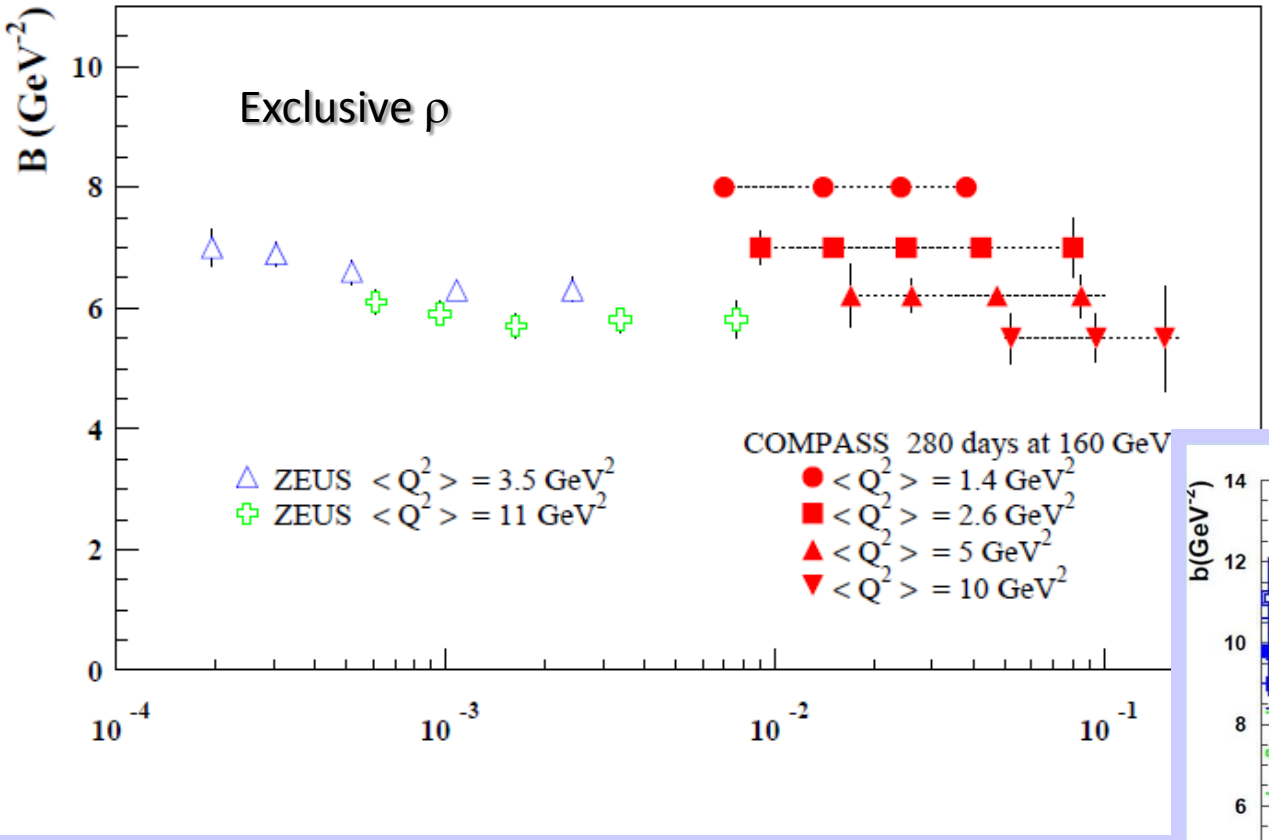


2 years of data
160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%

model developed by Sandacz
renormalised according
Goloskokov and Kroll prediction

Transverse imaging at COMPASS

$d\sigma^{excl.\rho}/dt \sim \exp(-B|t|)$



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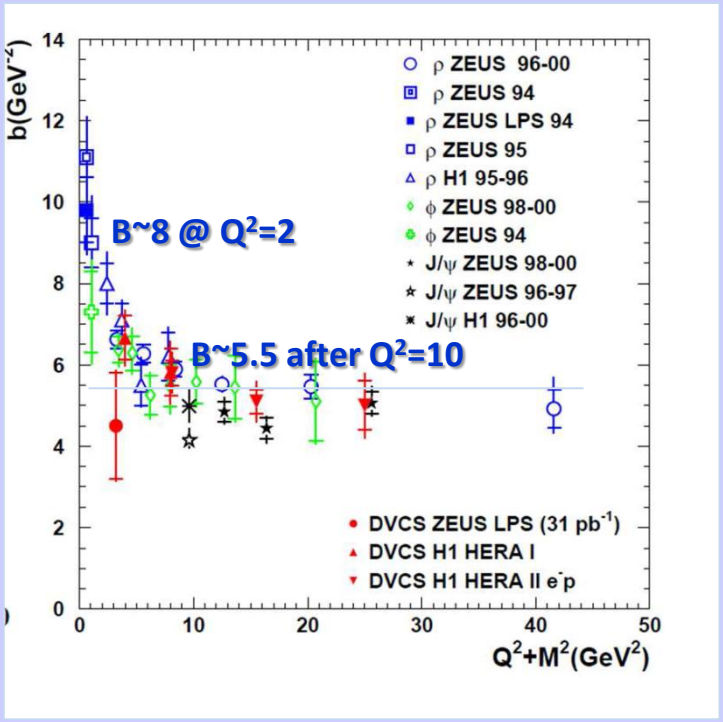

We are sensitive
to the nucleon transverse size
+ to the meson transverse size

Deeply Virtual Compton Scattering

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

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

Phase 1: DVCS experiment to constrain GPD H

with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam + unpolarized 2.5m long LH2 (proton) target

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto C_0^{Int} + C_1^{Int} \cos\phi \quad \text{and} \quad c_{0,1}^{Int} \sim \mathcal{R}e(F_1\mathcal{H})$$

$$\mathcal{S}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto d\sigma^{BH} + c_0^{DVCS} + K.s_1^{Int} \sin\phi \quad \text{and} \quad s_1^{Int} \sim \mathcal{I}m(F_1\mathcal{H})$$

Angular decomposition of **sum** and **diff** of the DVCS cross section will provide umambiguous way to separate the $\mathcal{R}e$ and $\mathcal{I}m$ of the *Compton Form Factors* from higher twist contributions

Deeply Virtual Compton Scattering

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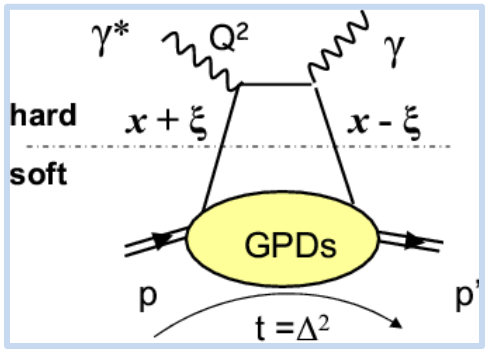


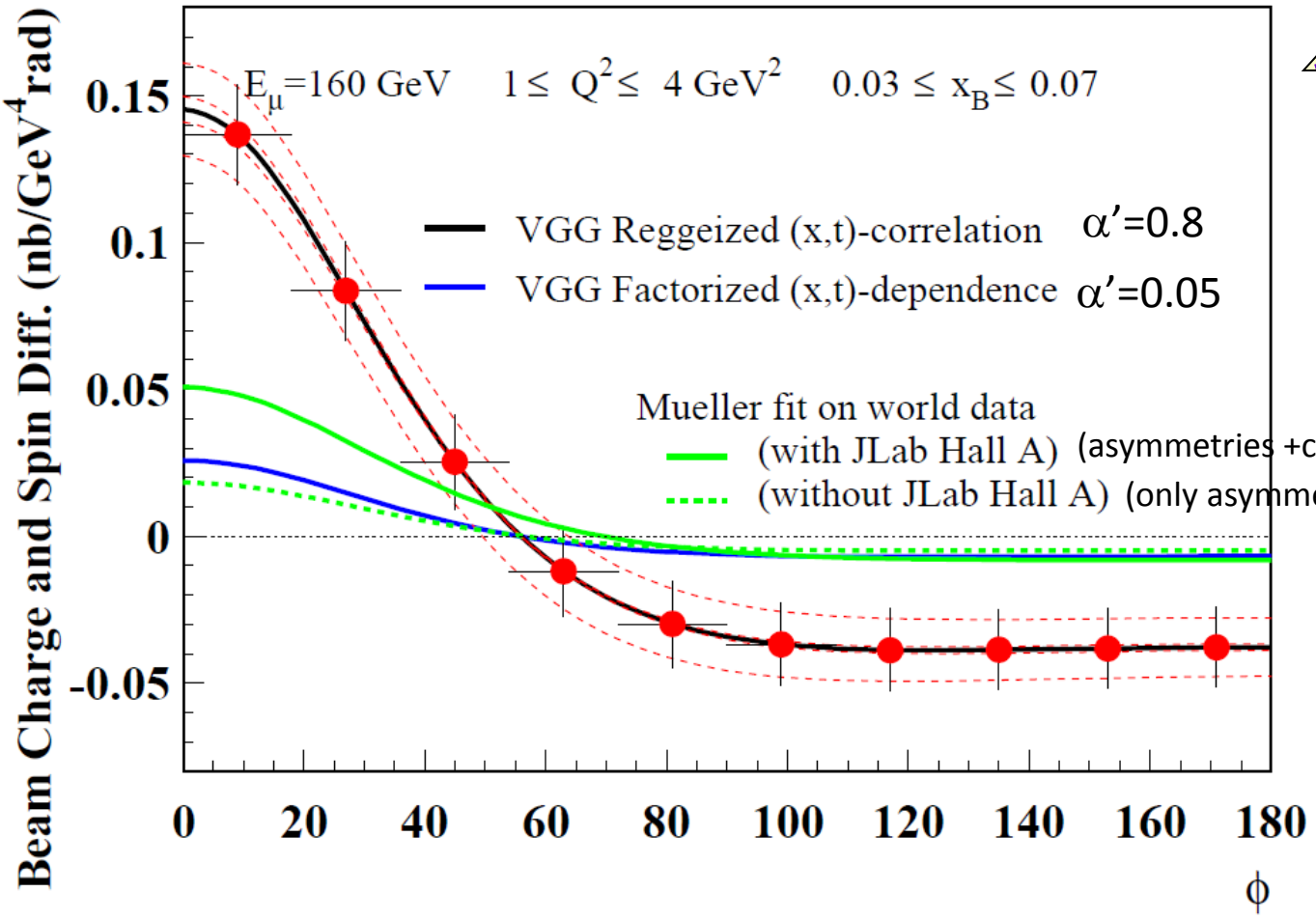
$\xi \sim x_B / (2-x_B)$

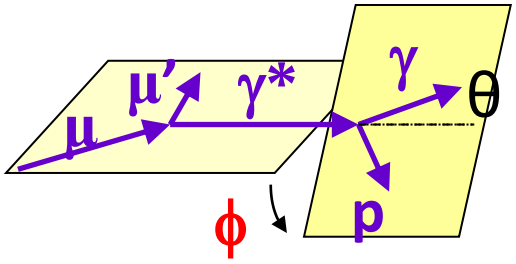
- $\mathcal{I}m\,\mathcal{H}(\xi,t) = H(x=\xi,\xi,t)$
- $\mathcal{R}e\,\mathcal{H}(\xi,t) = \mathcal{P}\int dx\, H(x,\xi,t)/(x-\xi)$

dominance of H at COMPASS kinematics

Beam Charge and Spin Difference (using $\mathcal{D}_{CS,U}$)

Comparison to different models





2 years of data
160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%

High precision beam flux and acceptance determination
Systematic error bands assuming a 3% charge-dependent effect between μ+ and μ- (control with inclusive evts, BH…)

Beam Charge and Spin Difference over the kinematic domain

Statistics and Systematics

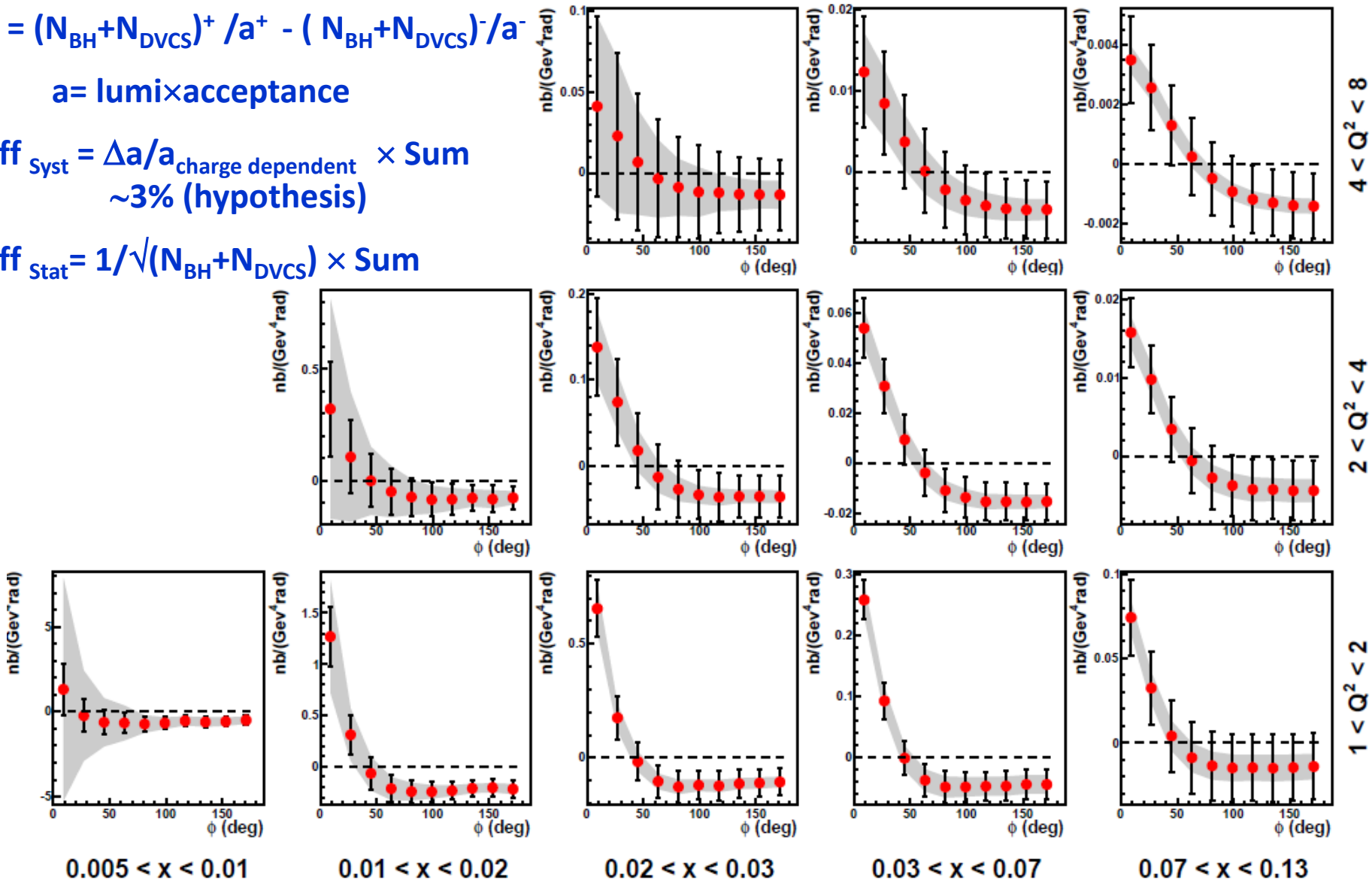
$\mathrm{Diff} = (N_{BH}+N_{DVCS})^{+}/a^{+} - (N_{BH}+N_{DVCS})^{-}/a^{-}$

a= lumi×acceptance

$\Delta\mathrm{Diff}_{\mathrm{Syst}} = \Delta a/a_{\text{charge dependent}} \times \mathrm{Sum}$

~3% (hypothesis)

$\Delta\mathrm{Diff}_{\mathrm{Stat}} = 1/\sqrt{(N_{BH}+N_{DVCS})} \times \mathrm{Sum}$

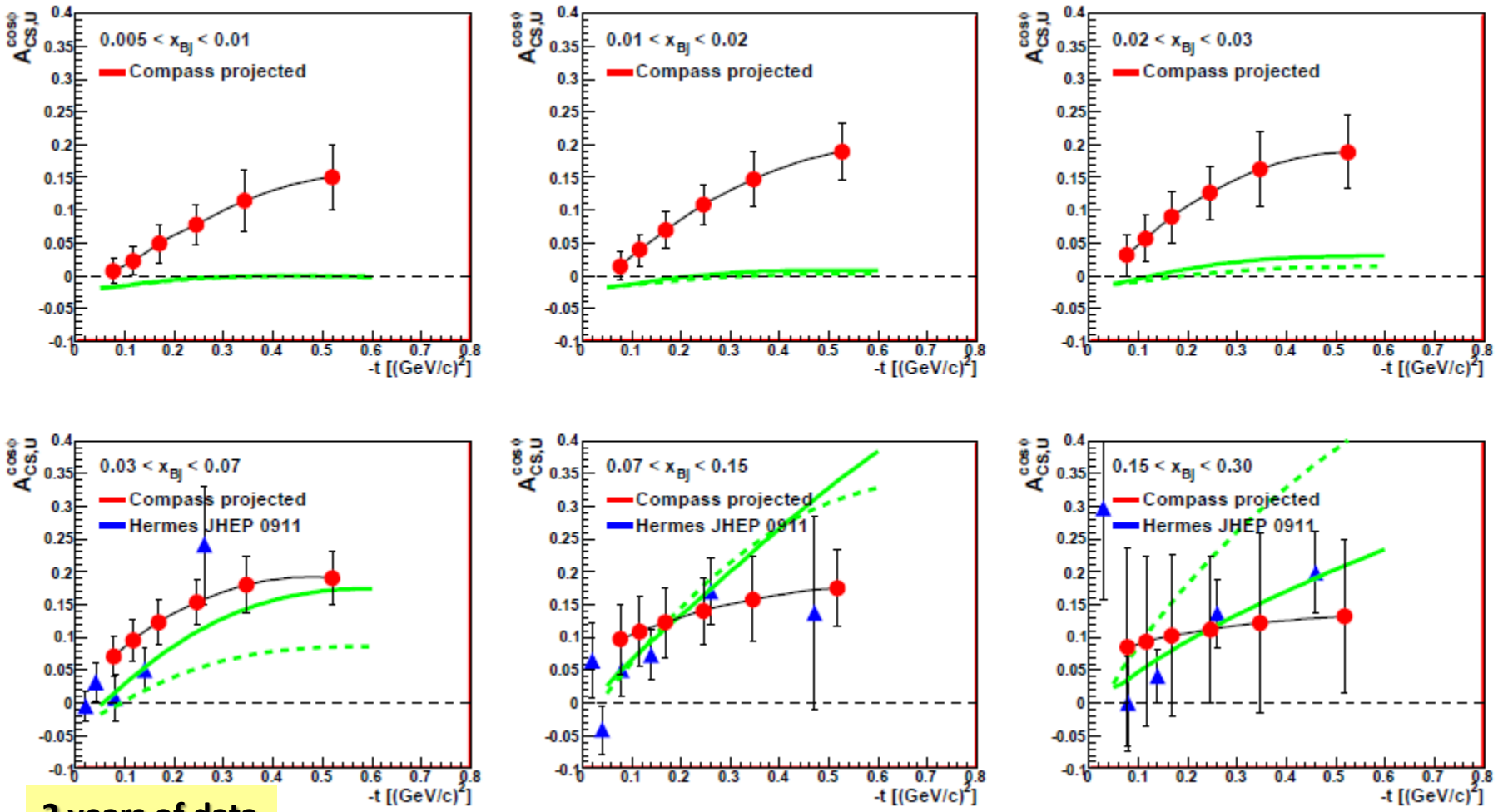


$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto C_0^{Int} + C_1^{Int}\cos\phi$ and $C_{0,1}^{Int} \sim \mathcal{R}e(F_1\mathcal{H})$

$A_{CS,U}^{\cos\phi}$ related to c_1^{Int}

Predictions with
VGG and **D.Mueller**

$\mathcal{R}e(F_1\mathcal{H})$ **> 0 at H1**
< 0 at HERMES/JLab
Value of x_B for the node?



2 years of data

With ECAL2 + ECAL1 + ECAL0

Constrains on the GPD E

on transversely polarized protons (NH3 target)

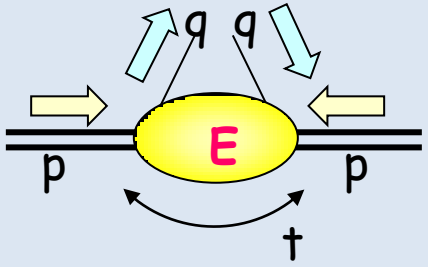
1) without recoil detection (2007 & 2010)

2) with recoil detection Phase 2 (in a future addendum)

the GPD **E** allows nucleon helicity flip

so it is related to the angular momentum

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

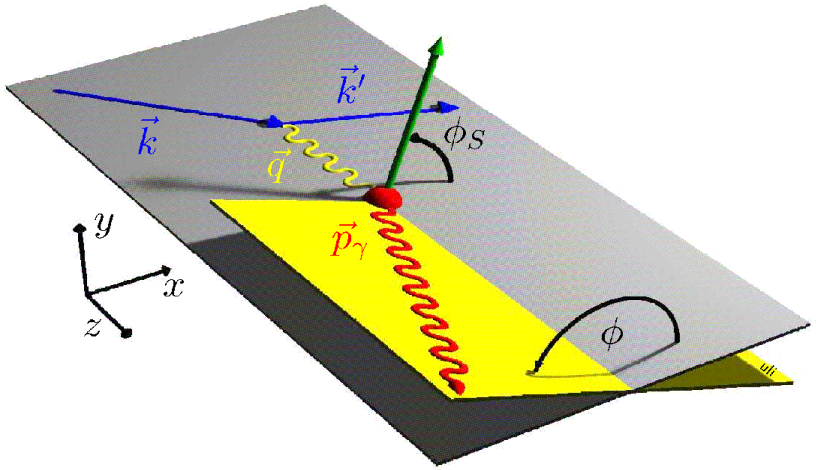


The GPD E is the 'Holy-Grail' of the GPD quest

Hard Exclusive Vector Meson Production

$$A_{UT}(\rho^0_L) \propto \sqrt{|-t'|}\, Im(\mathcal{E}^{*}\mathcal{H}) \,/\, |\mathcal{H}|^2$$

$$\times \sin(\phi - \phi_S)$$



Hard Exclusive Vector Meson Production

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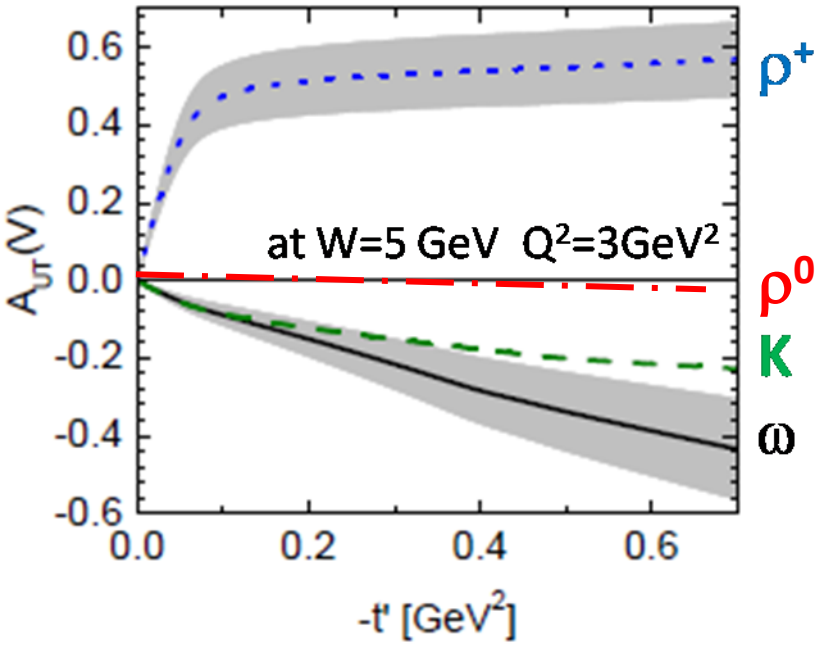


$E\rho^0 \propto 2/3\ E^u + 1/3\ E^d + 3/8\ E^g$

$E\omega \propto 2/3\ E^u - 1/3\ E^d + 1/8\ E^g$

$E\rho^+ \propto \quad E^u - E^d \quad - 3/8\ H^g$

$\kappa^q = \int e^q(x)\ dx$

➔ $E^u \sim -E^d$

Goloskokov-Kroll: the most complete model (Q^2>3GeV² x<0.2)

with H and E for quarks and gluons

and with quark transverse degrees of freedom

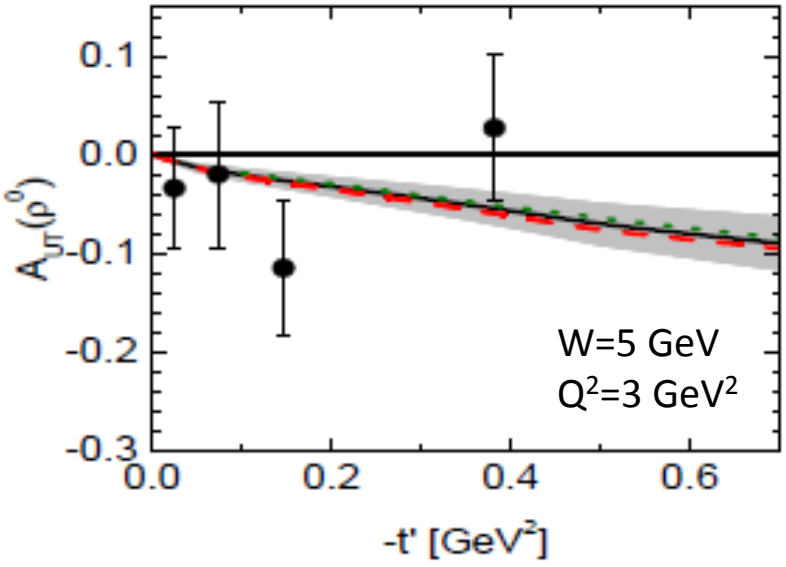
the asymptotically dominant (longitudinal) amplitude for $\gamma_L^* p \to \rho_L p$

but also the one for transversely polarized photons and vector mesons $\gamma_T^* p \to \rho_T p$

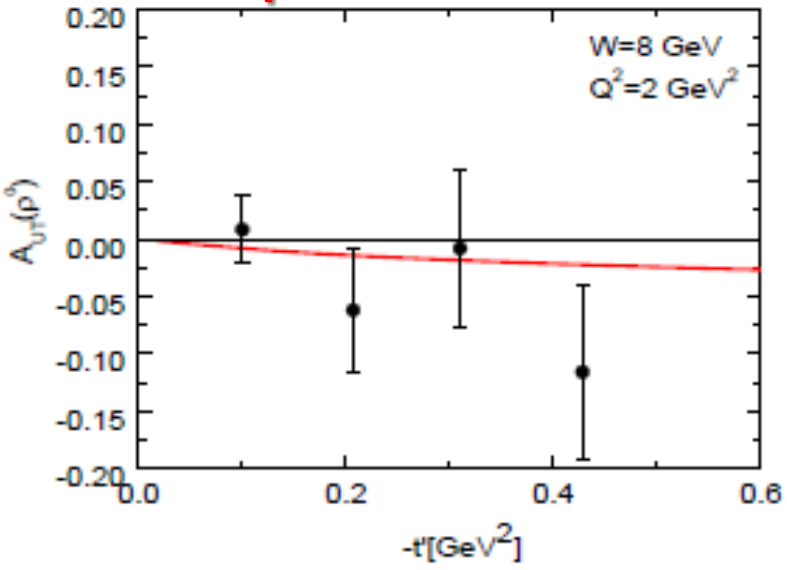
2007 results for the Transverse Target Asymmetry

$$A_{UT}(\rho^0_L) \propto \sqrt{|-t'|}\, Im(\mathcal{E}^* \mathcal{H}) / |\mathcal{H}|^2$$

Hermes



Compass 2007



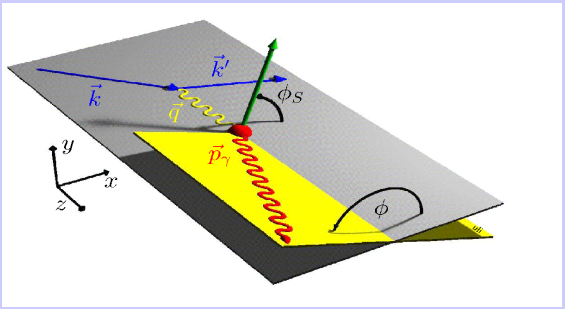
$A_{UT}(\omega)$ and $A_{UT}(\rho^+)$ should be more promising
To be completed with the analysis of 2010 data

Deeply Virtual Compton Scattering

Phase 2 (in future): DVCS experiment to constrain GPD E

with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam and **transversely** polarized NH3 (proton) target

$$\mathcal{D}_{CS,T} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow}) \propto Im(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi - \phi_S)\cos\phi$$

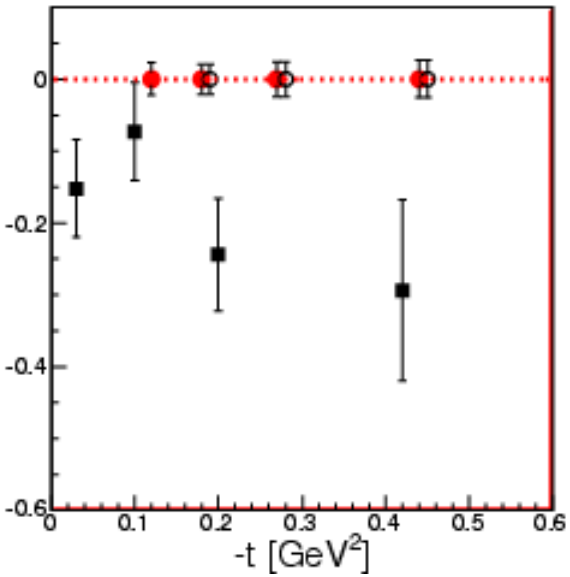


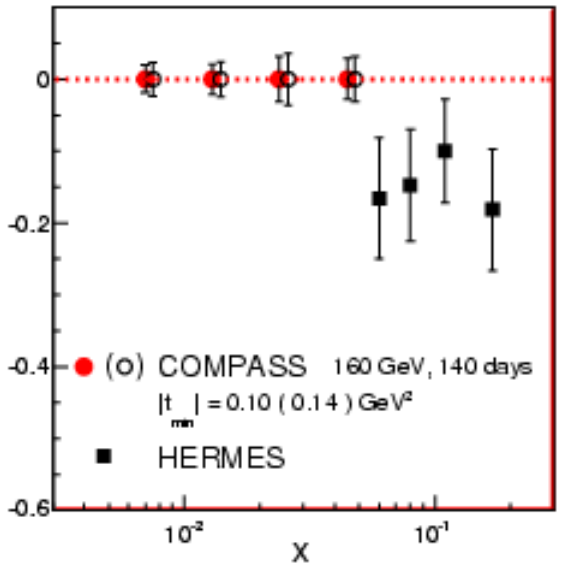
$D_{CS,T}$ and Transverse Target Asymmetry

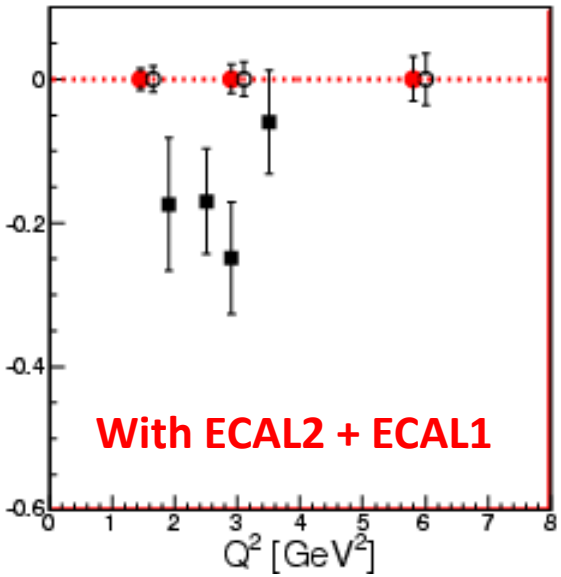
Prediction for phase 2 (in future)
With a transversely polarized NH3 (proton) target:

2 years of data
160 GeV muon beam
1.2 m polarised NH_3 target
ε_{global} = 10%

$A_{CS,T}^{\sin(\phi-\phi_s)\cos\phi}$ **related to H and E**







Summary for GPD @ COMPASS

GPDs investigated with Hard Exclusive Photon and Meson Production

$\mu^{+\downarrow}$, $\mu^{-\uparrow}$ 160 GeV

COMPASS-II 2012-16: with LH_2 target + RPD (phase 1)

- ✓ the t-slope of the DVCS and HEMP cross section
  → transverse distribution of partons
- ✓ the Beam Charge and Spin Sum and Difference
  → $\mathcal{R}e\,T^{DVCS}$ and $\mathcal{I}m\,T^{DVCS}$ for the GPD H determination
- ✓ Longitudinal contribution of Vector Meson ρ^0,ρ^+,ω → GPD H
- ✓ Total contribution of π^0 → GPDs Etilde and E_T

Using the 2007-10 data: transv. polarized NH_3 target without RPD

In a future addendum > 2016: transv. polarised NH_3 target with RPD (phase 2)

- ✓ the Transverse Target Spin Asymm
  → GPD E and angular momentum of partons

A very long and beautiful trip

« This desserves the detour.... »

And future colliders