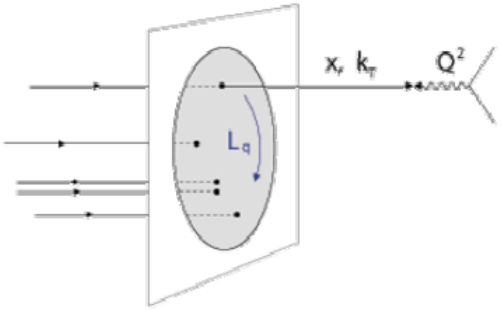
DVCS with COMPASS-II

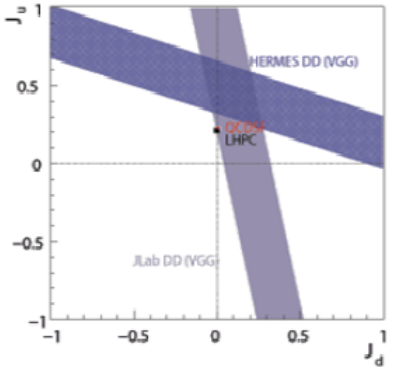
Nicole d'Hose (CEA-Saclay)
On behalf of the COMPASS Collaboration

INT Workshop INT-12-49W

Orbital Angular Momentum in QCD

February 6 - 17, 2012



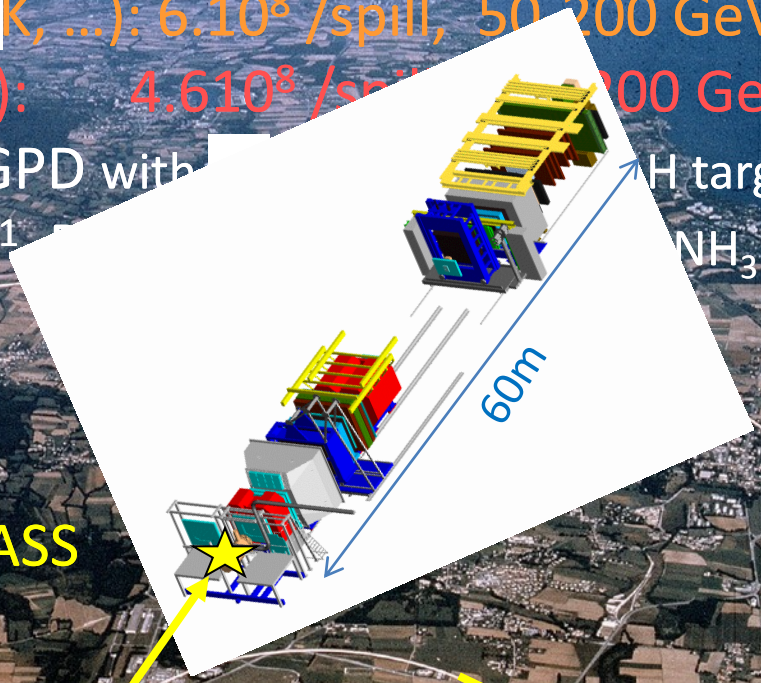


SPS proton beam: 2.6 10^{13}/spill of 9.6s each 48s, 400 GeV/c

- Secondary hadron beams (π, K, …): 6.10^{8} /spill, 50-200 GeV/c
- Tertiary muon beam (80% pol): 4.6$10^{8}$ /spill, 100-200 GeV/c

-> Luminosity ~ 10^{32} cm^{-2} s^{-1} GPD with H target

~1.2 10^{32} cm^{-2} s^{-1} NH_3 target



LHC

COMPASS

SPS

CNGS
Gran Sasso
732 kms

high energy beams, broad kinematic range, large angular acceptance

COMPASS-II: A Facility to study QCD

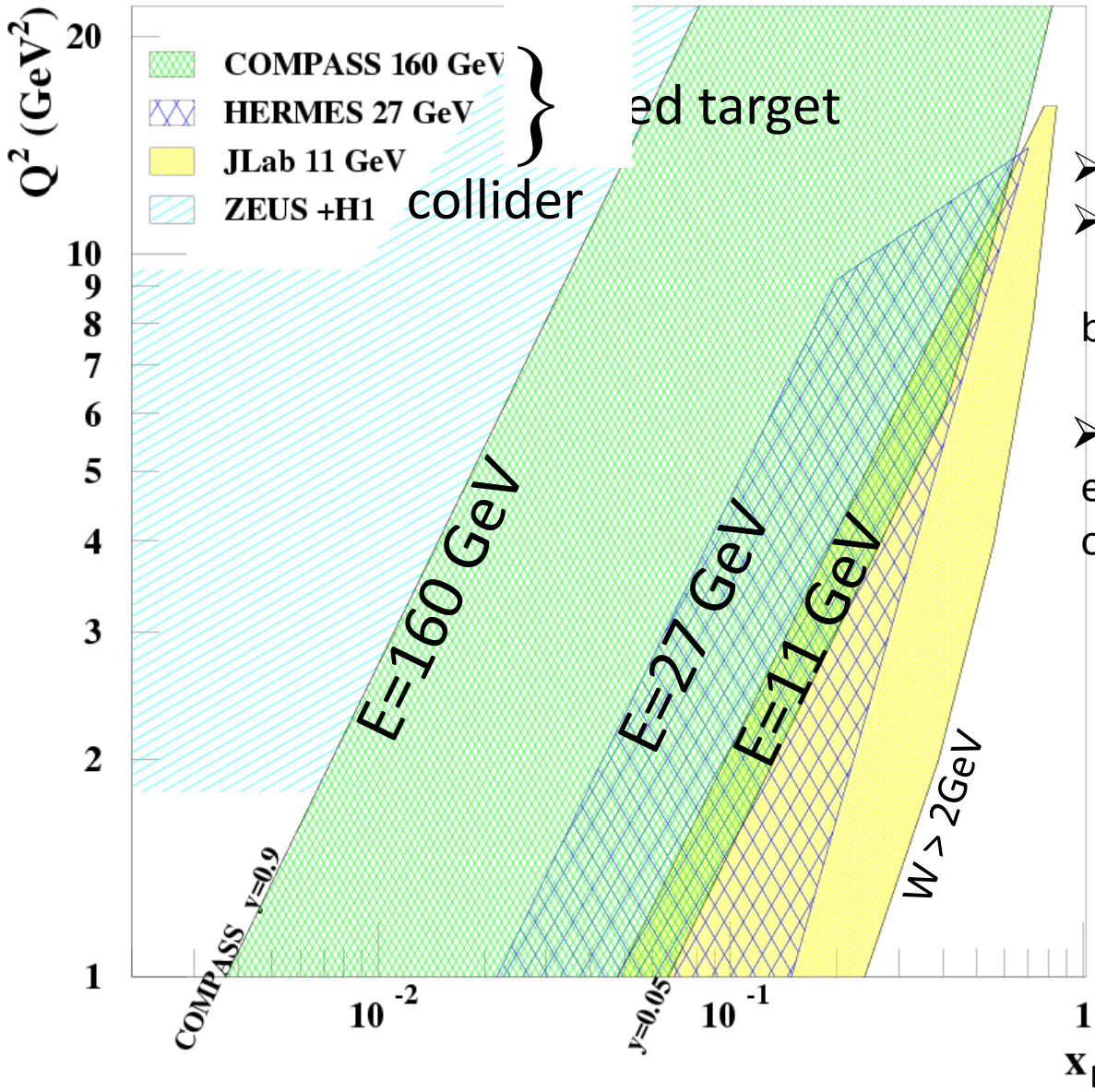
COMMON
MUON and
PROTON
APPARATUS for
STRUCTURE and
SPECTROSCOPY

COMPASS-II has been recommended by SPSC (29 sept 2010) and approved by the Research Board (1rst dec 2010)

- ✓ Primakoff with π, K beam ➔ Test of Chiral Perturb. Theory — **2012**
  + Pilot Run of DVCS with μ beams
- ✓ Drell-Yan with π beams ➔ Transverse Momentum Dependent PDFs — **2014**
- ✓ DVCS & DVMP with μ beams ➔ Transv. Spatial Distrib. with GPDs — **2015+16**

SIDIS (with GPD prog.) ➔ Strange PDF, Frag. Funct. and Transv. Mom. Dep. PDFs

Kinematic domain (Q^2, x_B) for GPDs



COMPASS unique for GPDs

CERN High energy muon beam

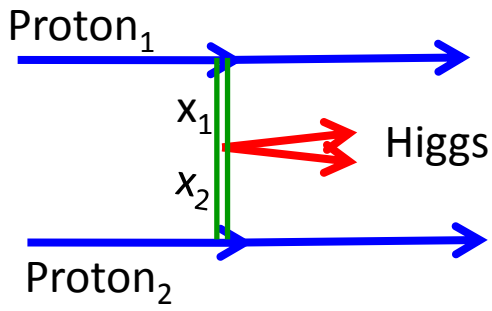
✓ 100 - 190 GeV

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

before new colliders may be available

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

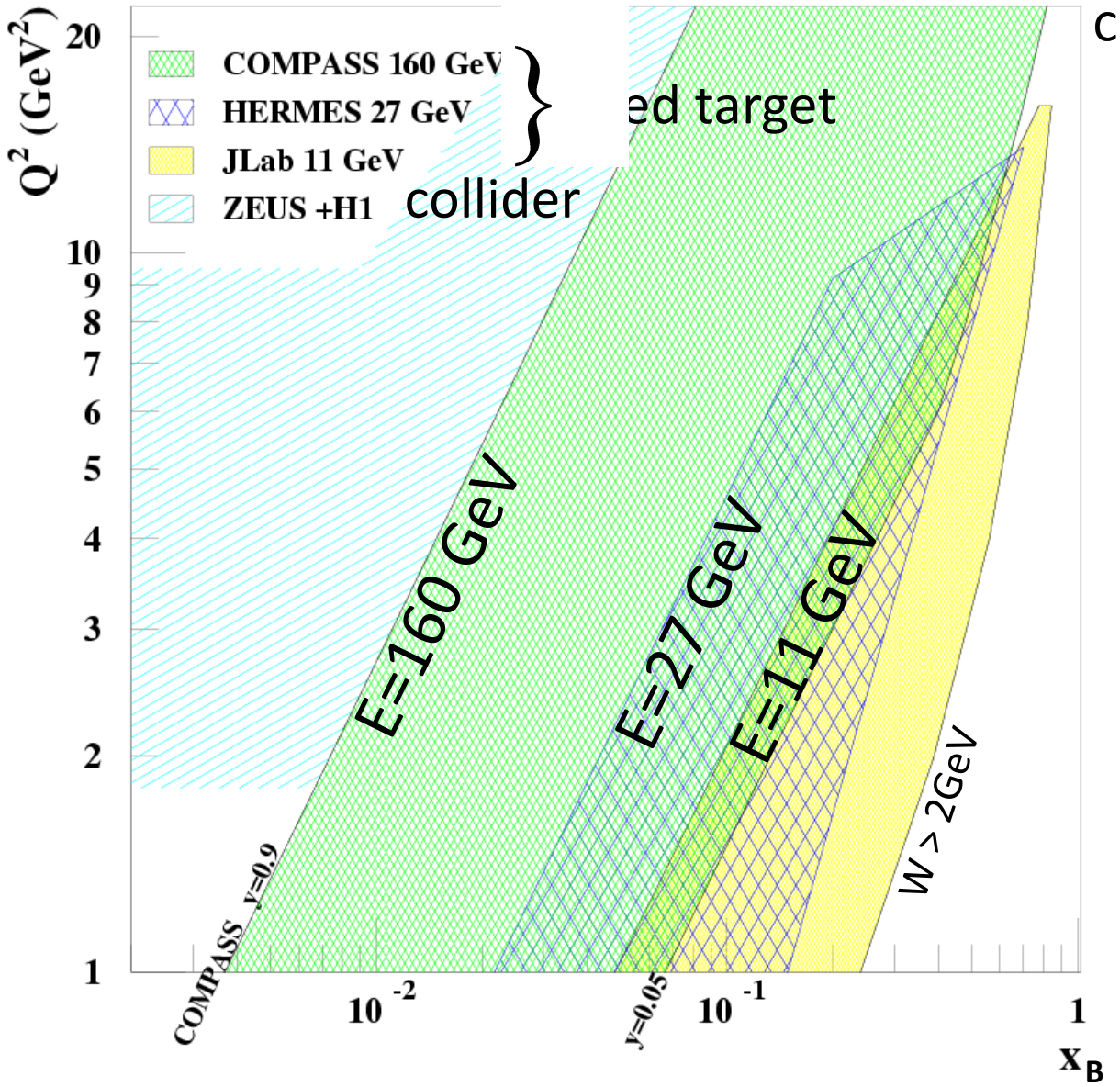
essential input for phenemenology of high-energy pp collision (LHC)



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

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

Kinematic domain (Q^2, x_B) for GPDs



COMPASS unique for GPDs

CERN High energy muon beam

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

with opposite polarization

- ✓ $4.6\ 10^8\ \mu^+$

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

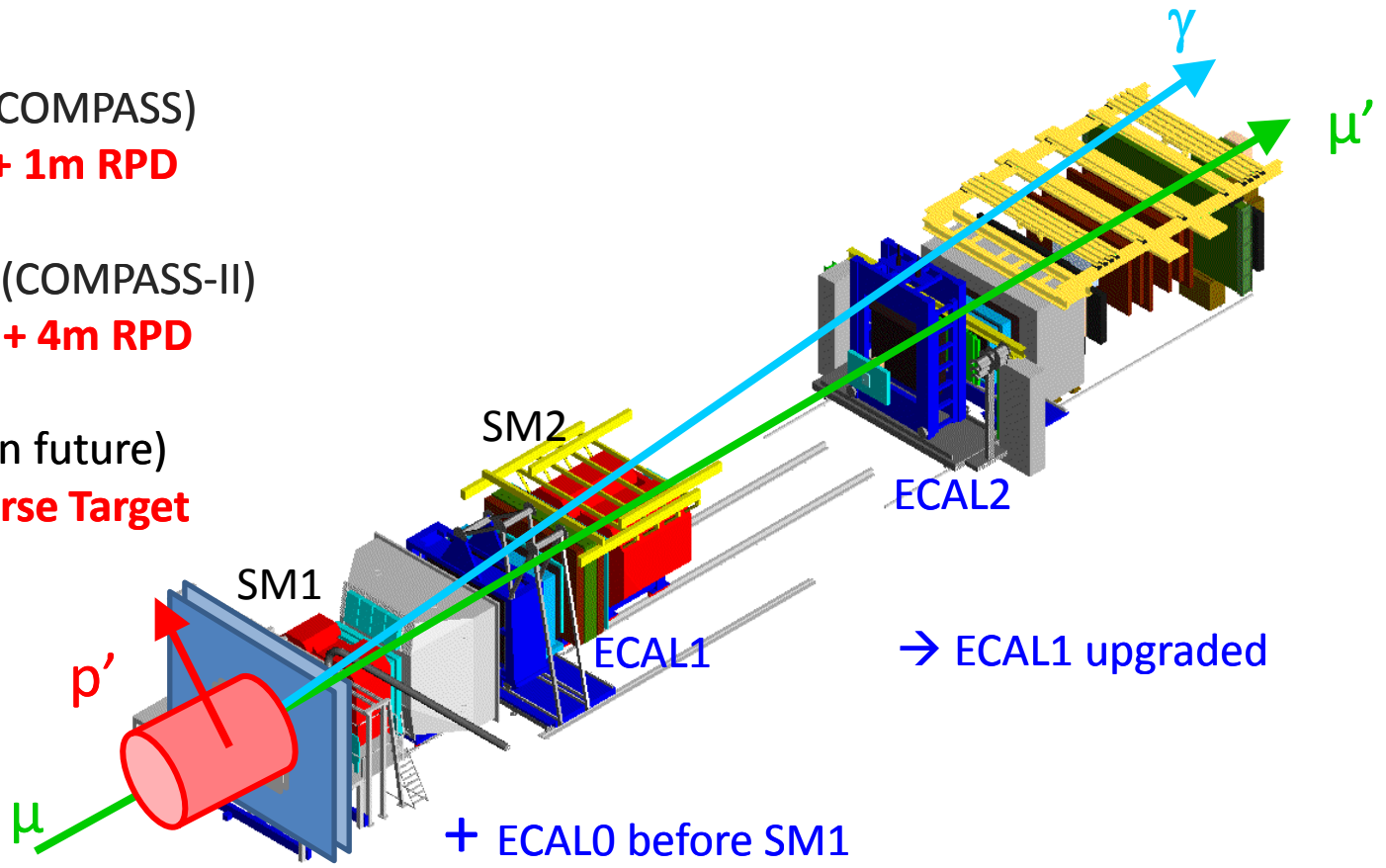
Experimental requirement for exclusive measurement

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

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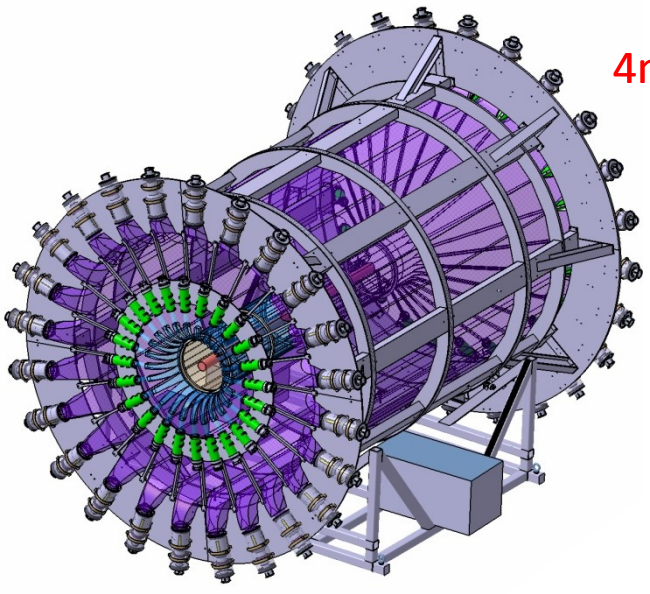
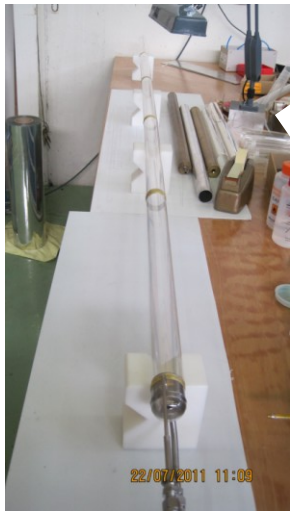


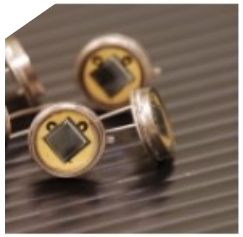
4m long ToF barrel

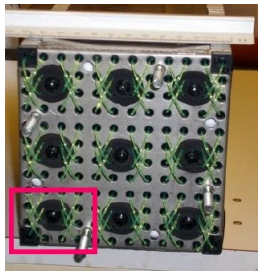
+ 1 GHz digitization of the PMT signal to cope for high rate (GANDALF boards)

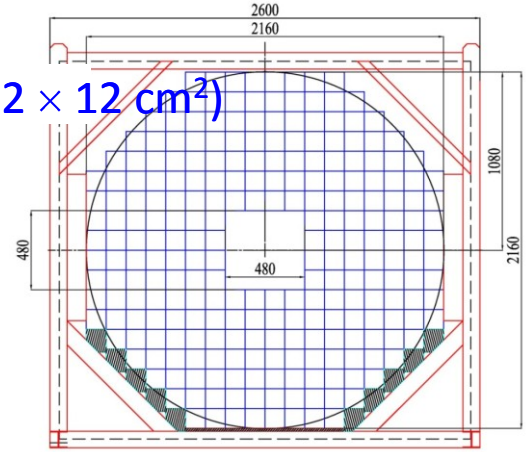


Prototype of the 2.5m long LH2 target + test of the cryostat

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

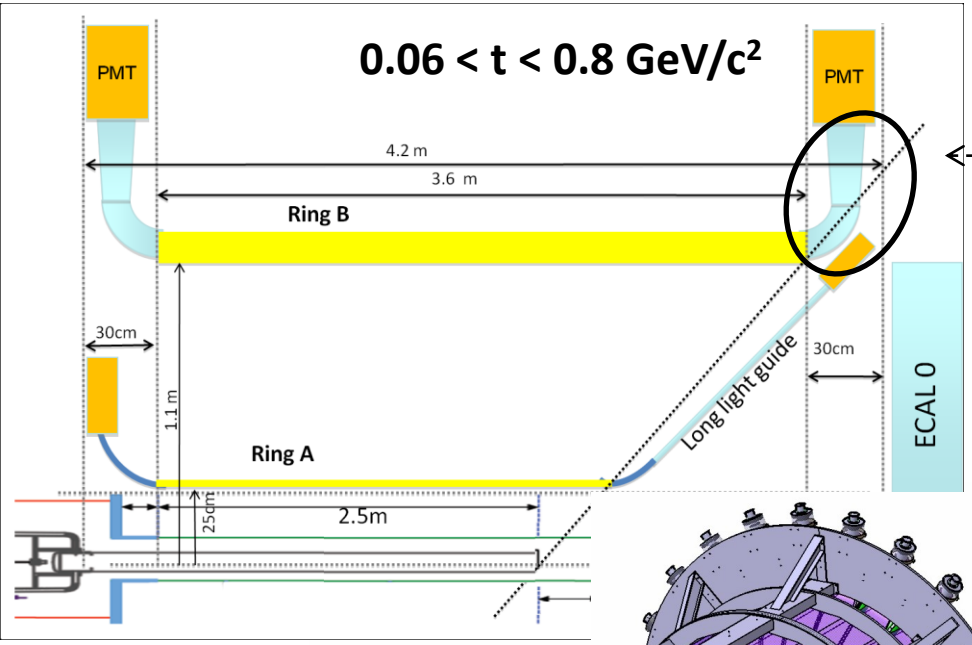


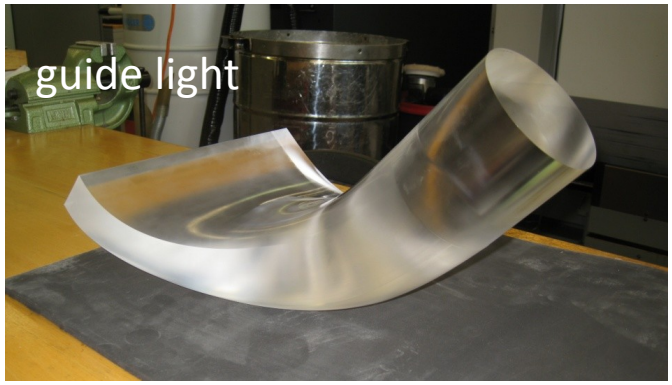




Recoil Proton Detector CAMERA

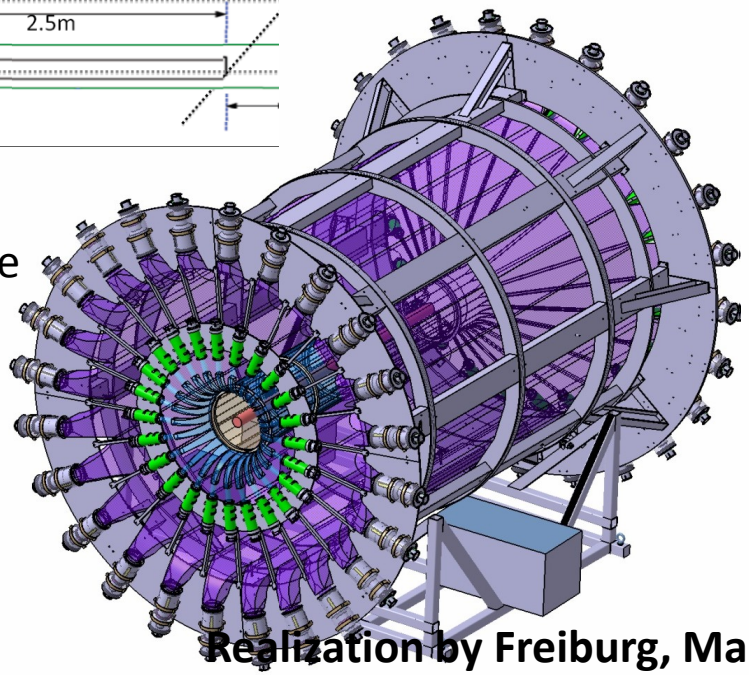
ToF between 2 rings of scintillators $\sigma(\text{ToF}) < 300\text{ps}$



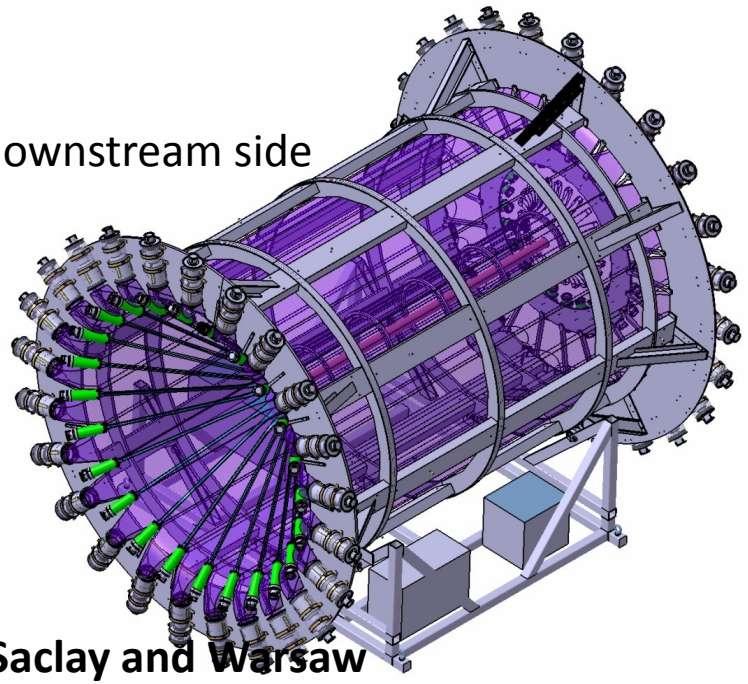


upstream side

3.90m

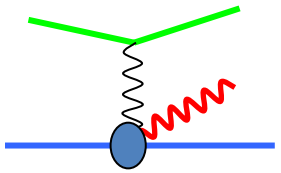


downstream side

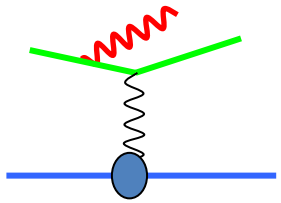


Realization by Freiburg, Mainz, Saclay and Warsaw

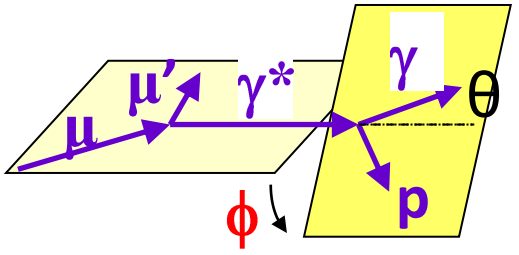
Contributions of DVCS and BH at E=160 GeV



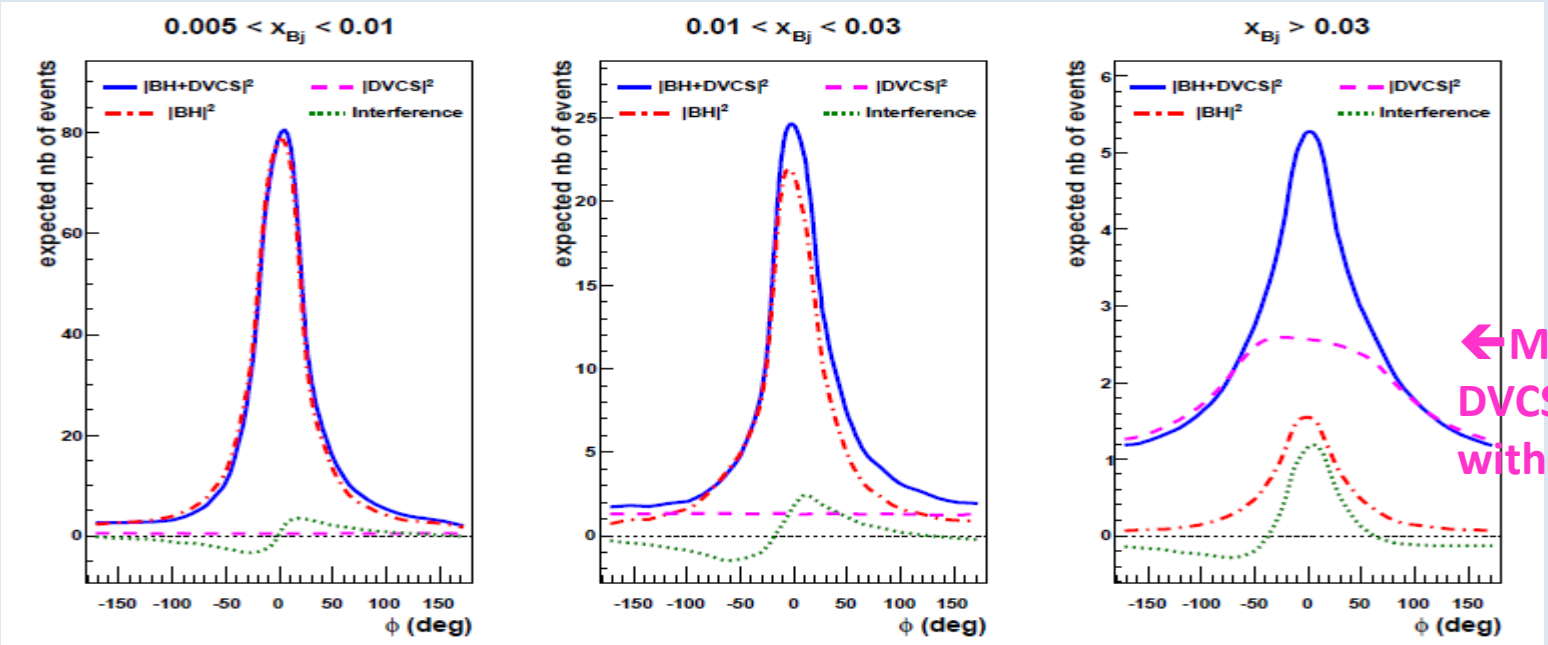
Deep VCS



Bethe-Heitler



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



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}

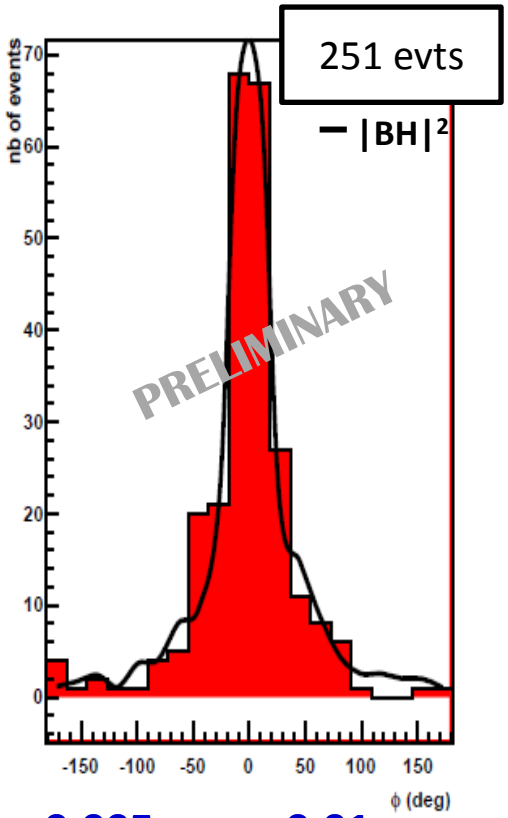
or Im T^{DVCS}

DVCS dominates

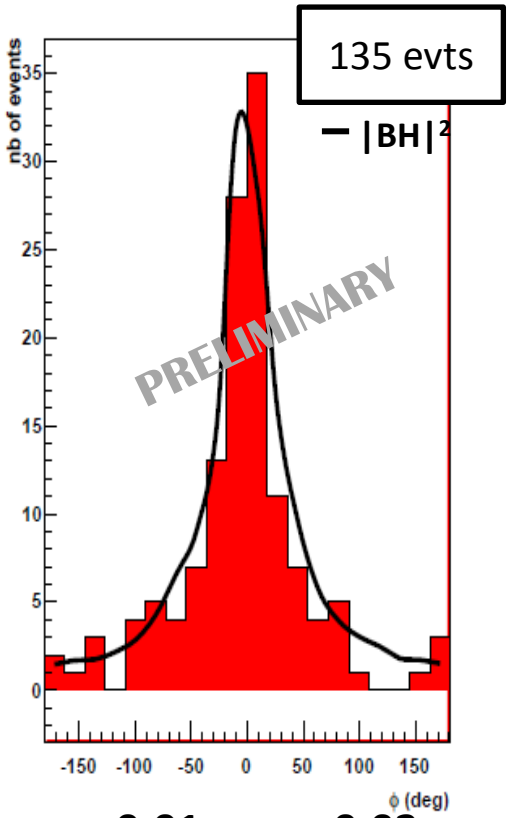
study of $d\sigma^{DVCS}/dt$

→ Transverse Imaging

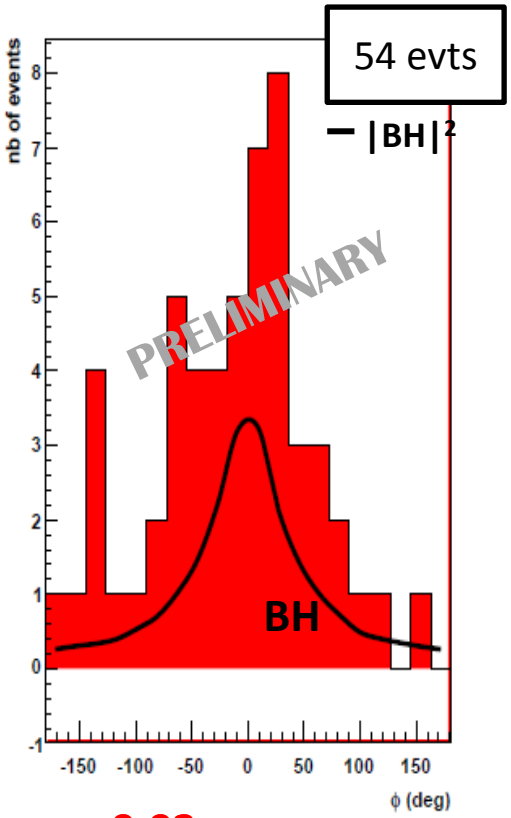
2009 DVCS test run (10 days, short RPD+target)



$0.005 < x_B < 0.01$



$0.01 < x_B < 0.03$



$0.03 < x_B$

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

$\times (0.8)^4$ 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
(1 month in autumn 2012 and 2 years 2015-16)

with recoil proton detection and hydrogen target

- **→ Transverse Imaging : $d\sigma/dt$**
- **→ Constrains on the GPD H**

Deeply Virtual Compton Scattering

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

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

Phase 1: DVCS experiment to study the transverse imaging

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

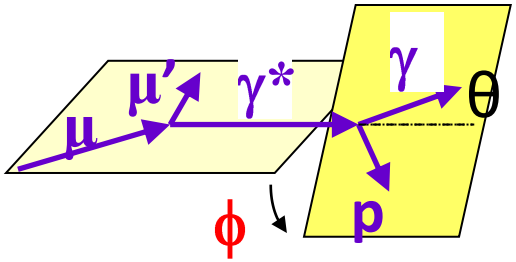
$$S_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + \Upsilon . s_1^{Int} \sin\phi$$

$\downarrow$

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

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

and integration over ϕ



Transverse imaging at COMPASS

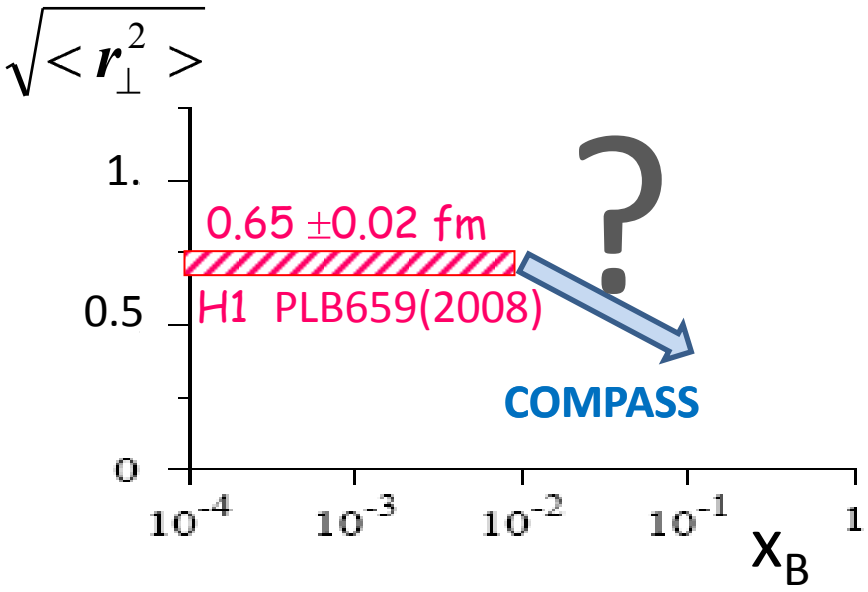
$d\sigma^{VCS}/dt \sim \exp(-B|t|)$

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

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

Transverse size of the nucleon

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

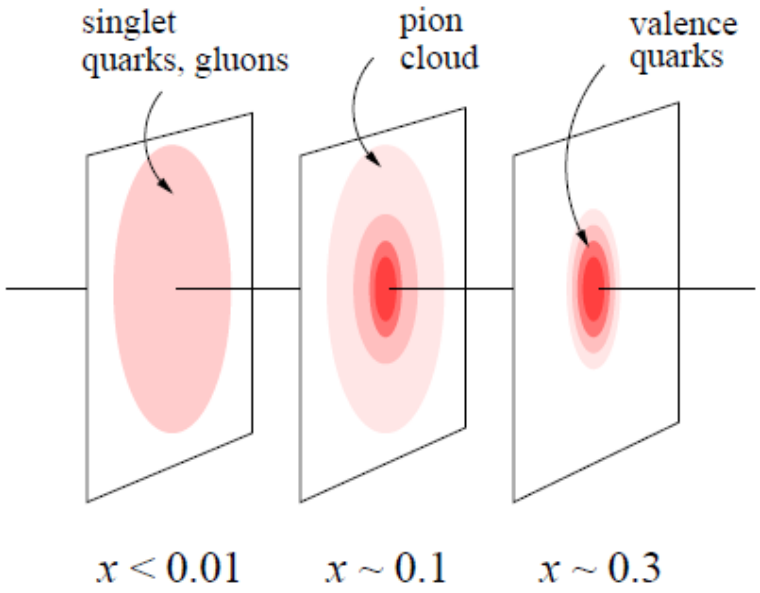


related to $\frac{1}{2} < b_\perp^2(x_B) >$

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

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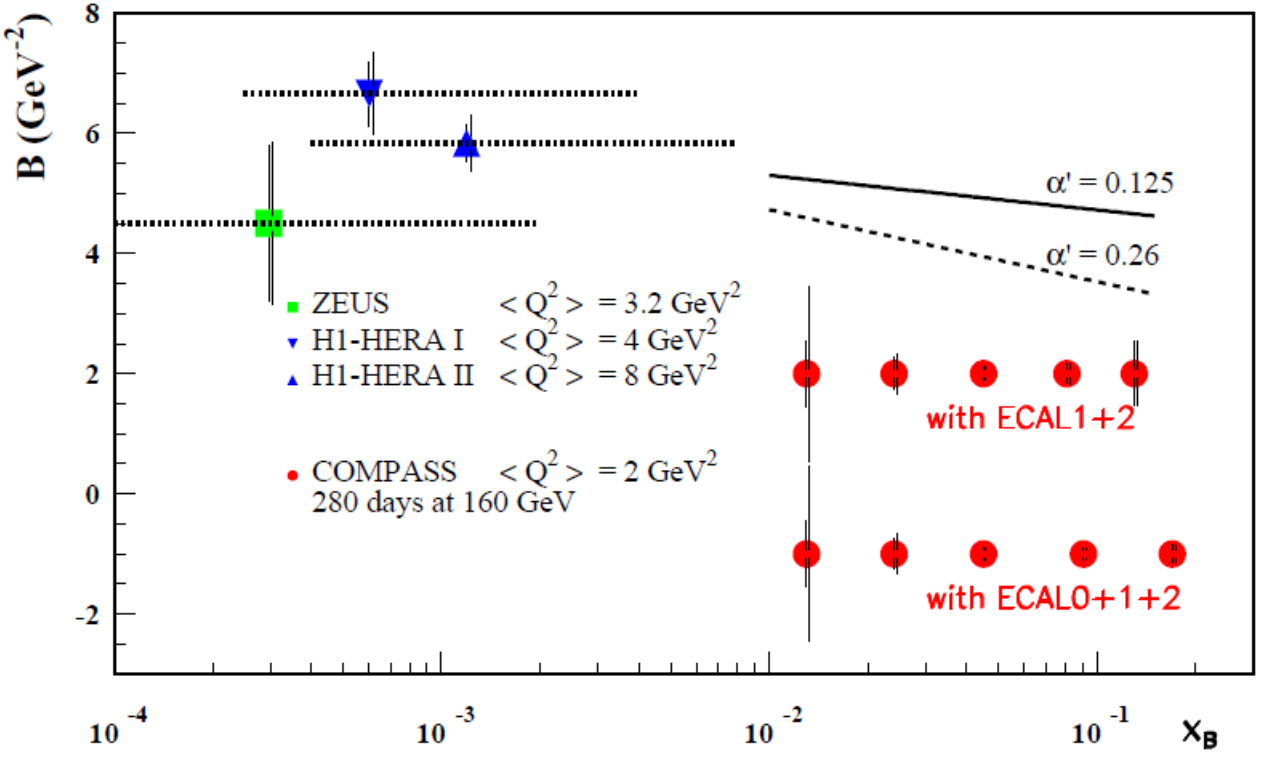


2 years of data
160 GeV muon beam
2.5m LH_2 target
$\varepsilon_{global} = 10\%$

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 $B(x_B)$

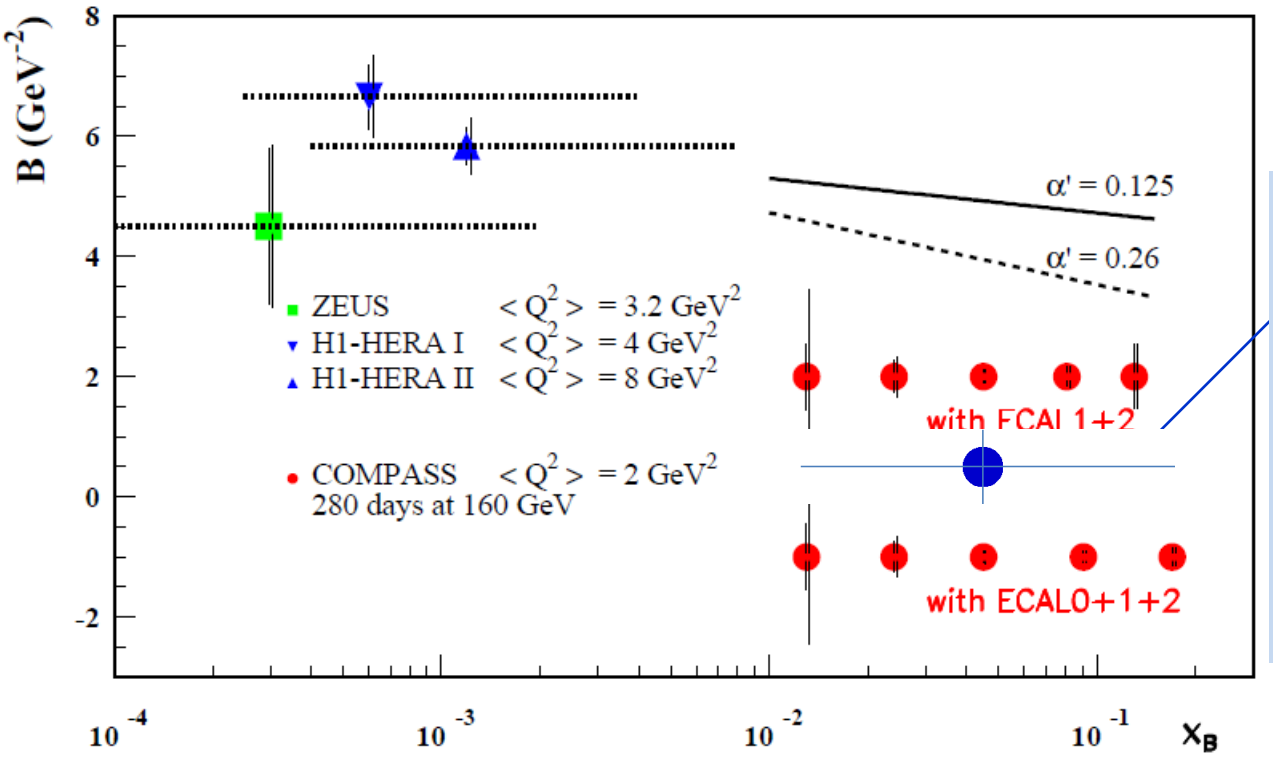
$B(x_B) = \frac{1}{2} < r_\perp^2(x_B) >$

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

Accuracy > 2.5 [illegible] $\alpha' = 0.125$ 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

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

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

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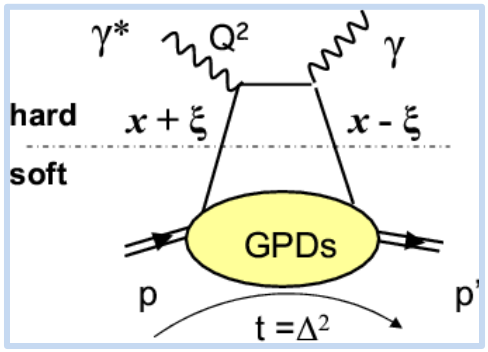


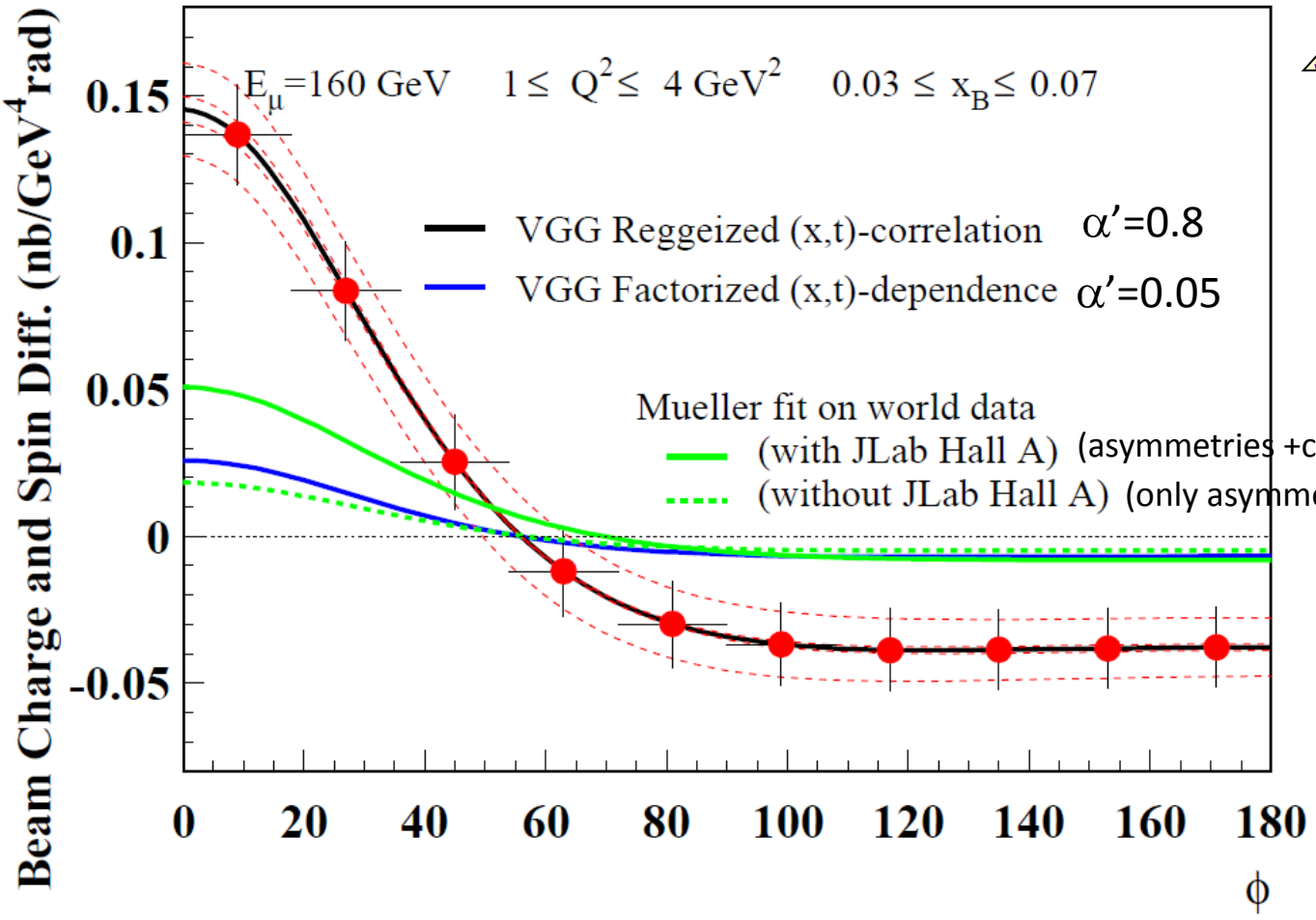
$\xi \sim x_B / (2-x_B)$

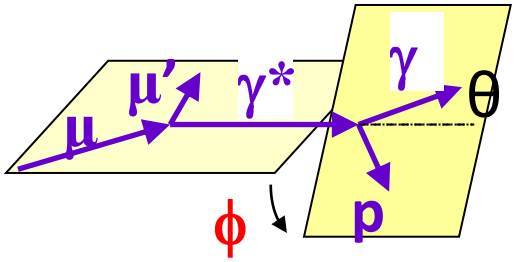
- $\mathcal{I}m\,\mathcal{H}(\xi,t) = H(x=\xi,\xi,t)$
- $\mathcal{R}e\,\mathcal{H}(\xi,t) = \mathcal{P} \int dx\, H(x,\xi,t)\,/(x-\xi)$

Note: 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

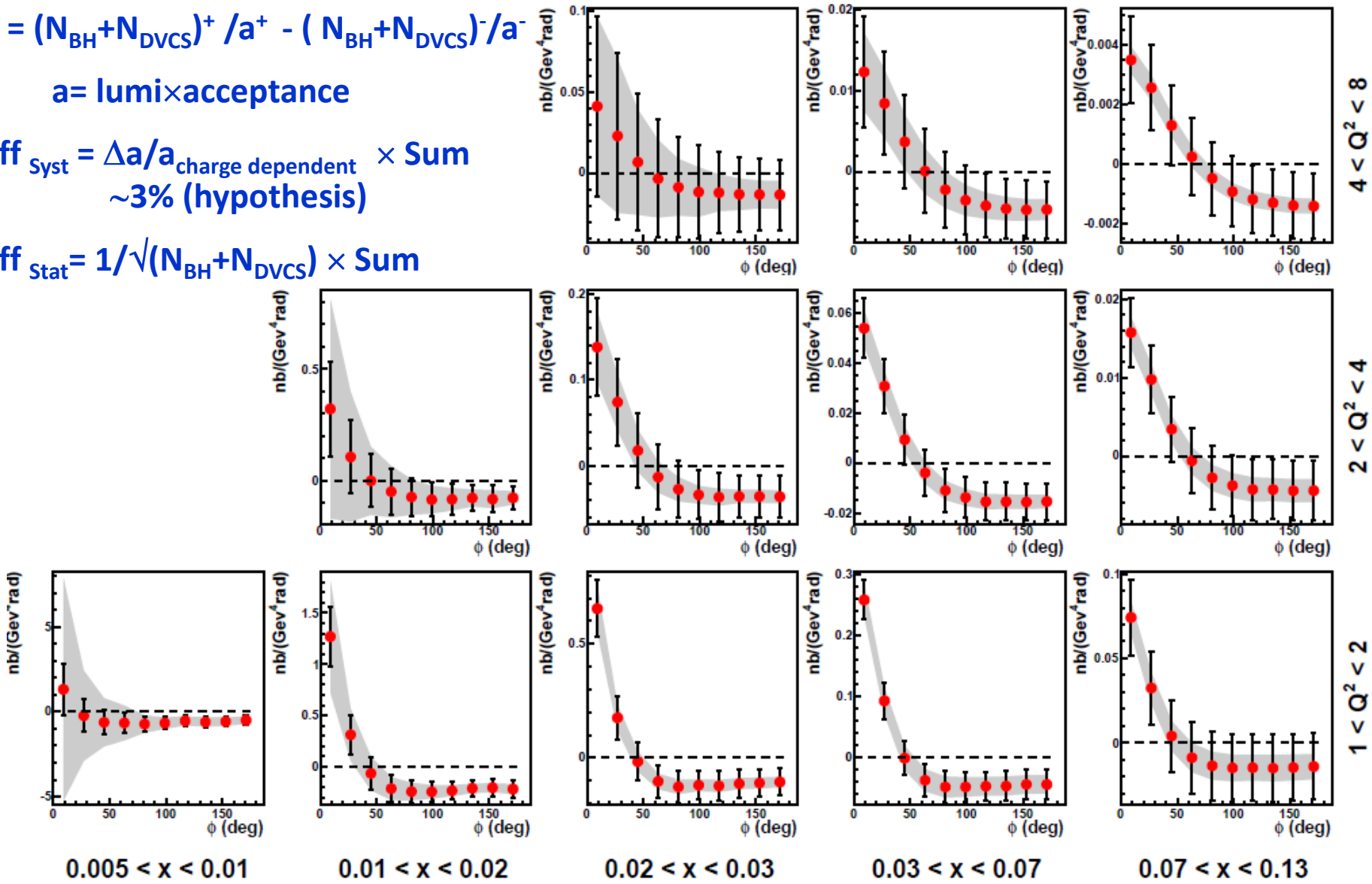
$\mathrm{Diff} = (N_{BH}+N_{DVCS})^{+}/a^{+} - (N_{BH}+N_{DVCS})^{-}/a^{-}$

a= lumi×acceptance

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

~3% (hypothesis)

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

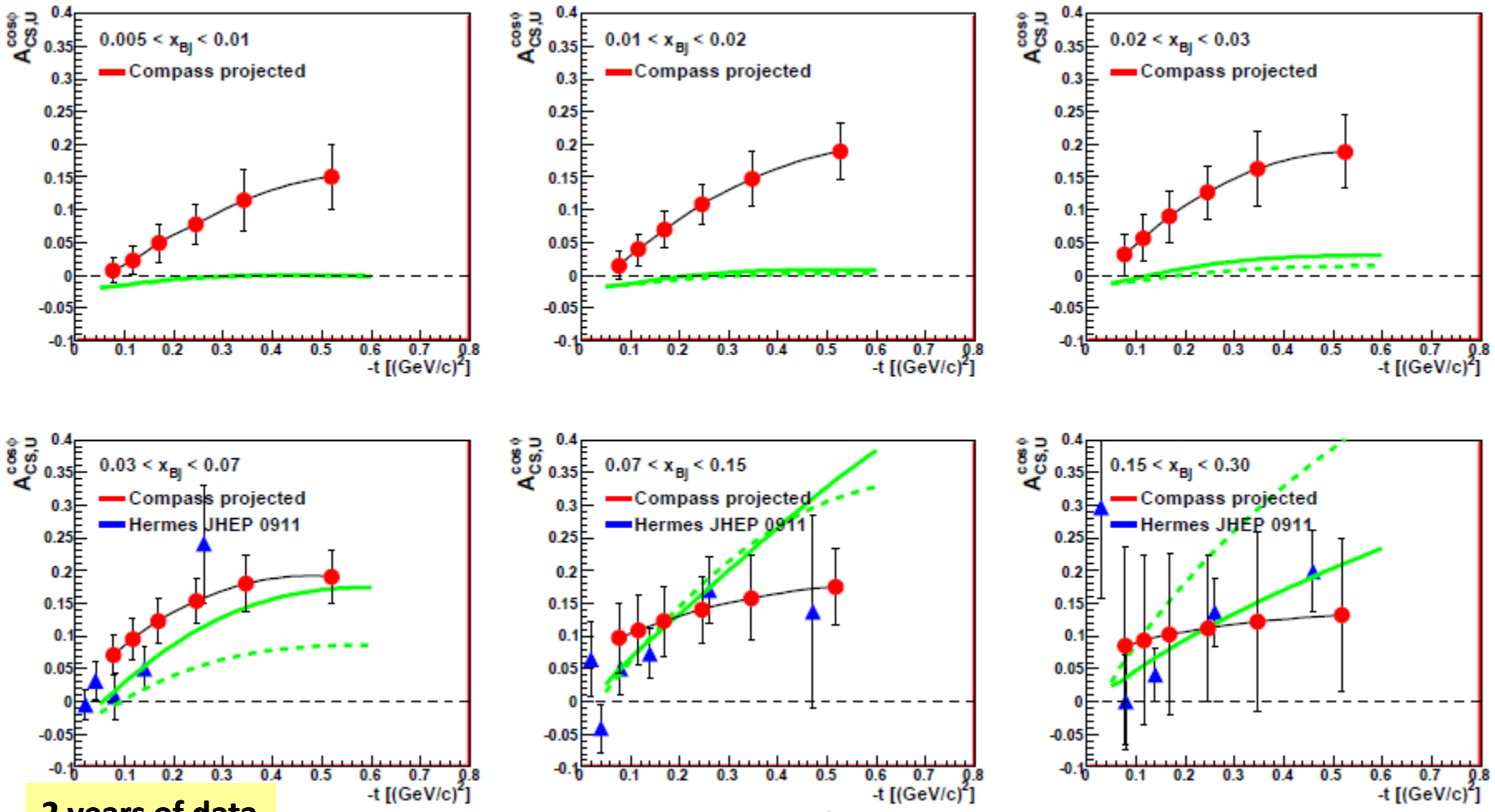


$D_{CS,U}$ [redacted] $c_0^{Int} + c_1^{Int} \cos\phi$ and $c_{0,1}^{Int}$ [redacted] $Re(F_1\mathcal{H})$

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

Predictions with
VGG and **D.Mueller**

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

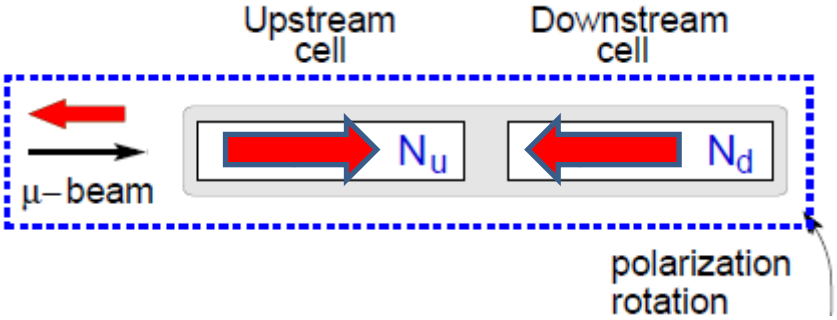


2 years of data

With ECAL2 + ECAL1 + ECAL0

Constrains on the GPD E

on transversely (and long.) polarized protons (NH3 target)

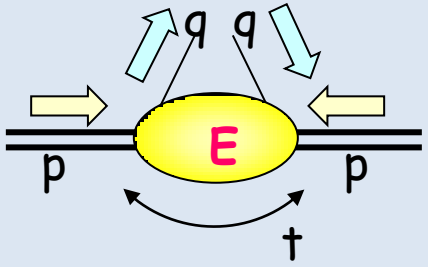


1) without recoil detection (2007 & 10)

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

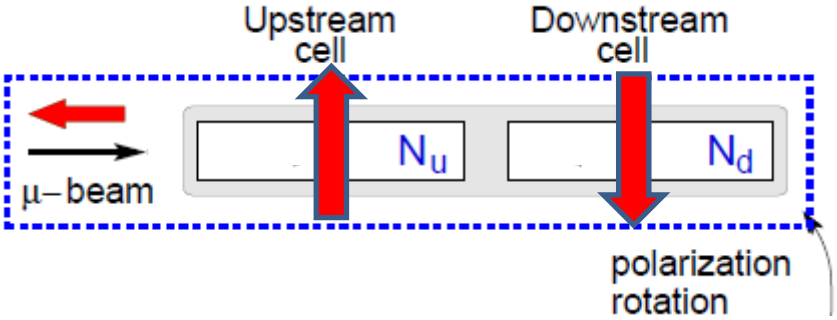


Ji sum rule: $2J_z^q = \int x\,(H^q(x,\xi,0) + E^q(x,\xi,0))\,dx$

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

Constrains on the GPD E

on transversely (and long.) polarized protons (NH3 target)

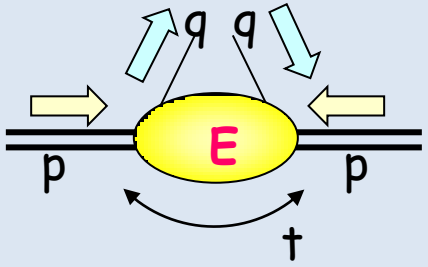


1) without recoil detection (2007 & 10)

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

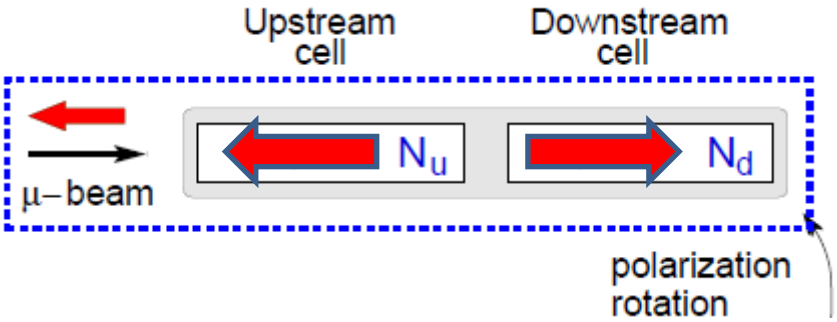


Ji sum rule: $2J_z^q = \int x\,(H^q(x,\xi,0) + E^q(x,\xi,0))\,dx$

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

Constrains on the GPD E

on transversely (and long.)
polarized protons (NH3 target)



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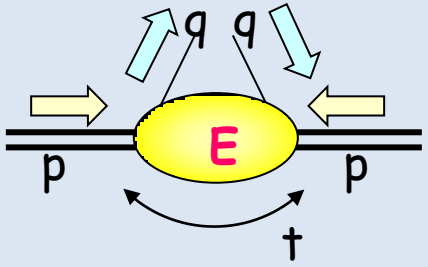

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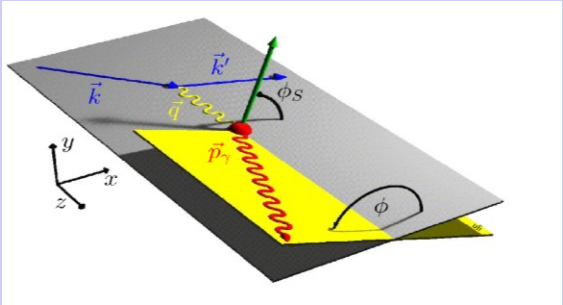
The GPD E is the 'Holy-Grail' of the GPD quest

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

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

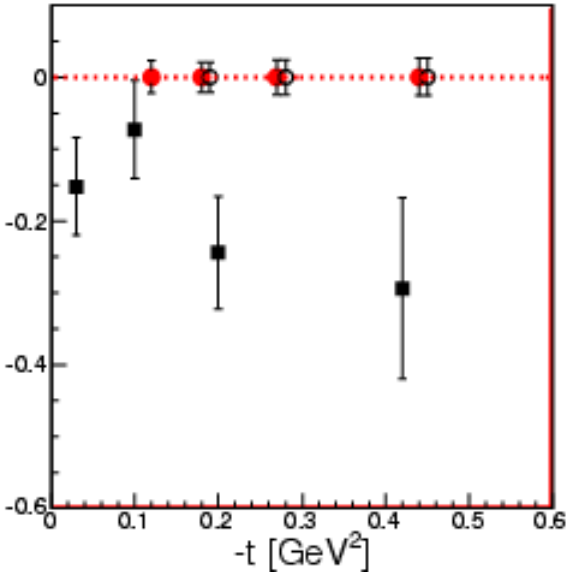


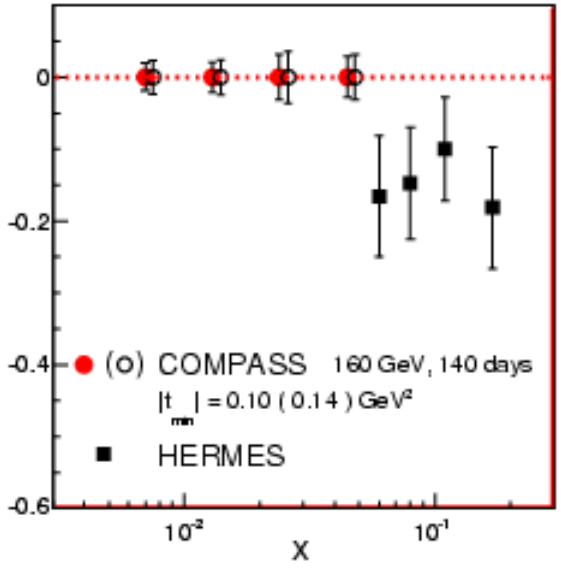
$\mathcal{D}_{CS,T}$ and Transverse Target Asymmetry

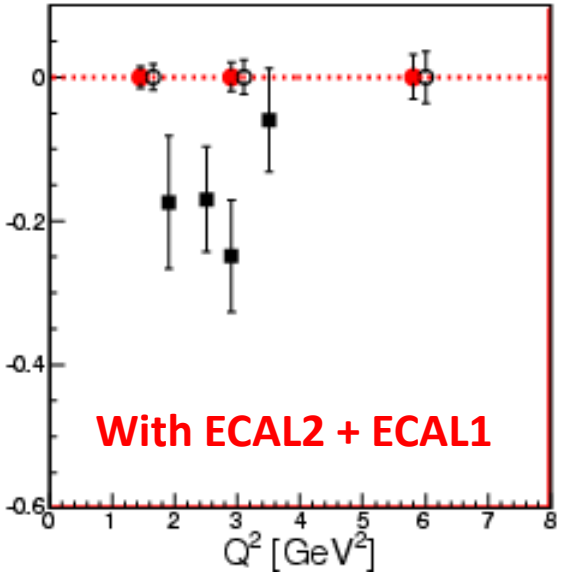
Prediction for phase 2 (in future)
With a transversely polarized NH3 (proton) target:

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 $Im\,T^{DVCS}$ for the GPD H determination
- ✓ Longitudinal contribution of Vector Meson $\rho^0, \rho^+, \omega, \Phi$ → GPD H
- ✓ Total contribution of π^0 → GPDs $\tilde{E}$ 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 voyage.... »