COMPASS: A Facility to study QCD

COMMON
MUON and
PROTON
APPARATUS for
STRUCTURE and
SPECTROSCOPY

Long Term Plans ≥2012:

Proposal submitted to CERN Scientific Comittee yesterday, 17-05-2010

- ✓ Test of Chiral Perturb. theory through Primakoff exp. with π, K beam and spectroscopy
- ✓ **Transv. Spatial Distrib. GPDs with DVCS and DVMP with μ beams**
- ✓ Strange PDF and Transv. Mom. Distrib. with SIDIS simultaneously with the GPD program
- ✓ **Transv. Mom. Distrib. with Drell-Yan with π and in far future $\bar{p}$, K**

GPD study at COMPASS

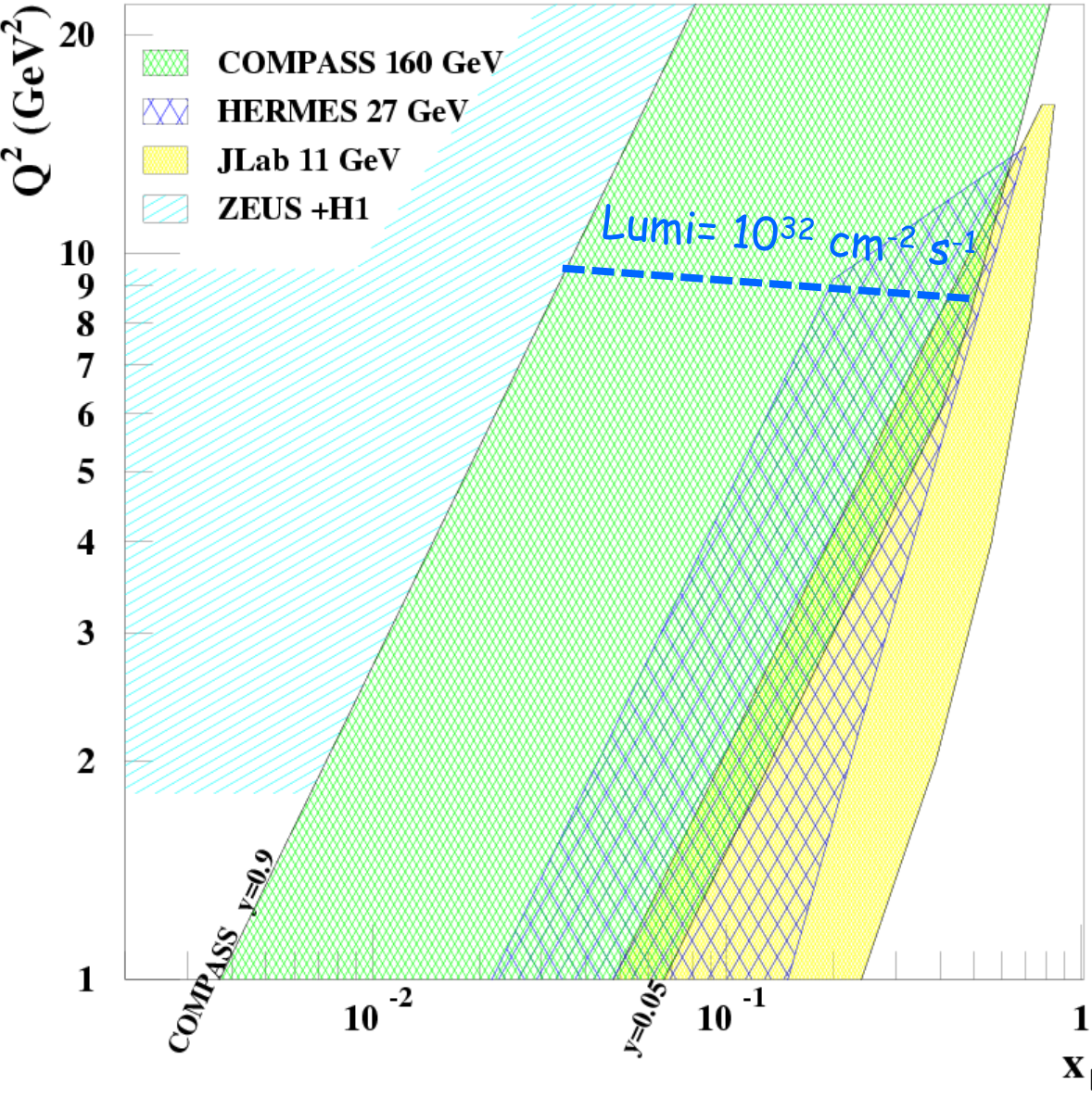
GPDs investigated with Hard exclusive photon and meson production

- ✓ Kinematic domains and Observables
- ✓ Simulations and Projections
  - the t-slope of the DVCS cross section …… LH_2 target + RPD……phase 1
    → transverse distribution of partons
  - the Beam Charge and Spin Sum and Difference and Asymm…….phase 1
    → Re T^{DVCS} and Im T^{DVCS} for GPD determination
  - the Transverse Target Spin Asymm……polarised NH_3 target + RPD……phase 2
    → angular momentum of partons
- ✓ A first look of exclusive single photon events with RPD in 2008-2009

HARDWARE UPGRADES:

- Muon Trigger
- The new Liquid Hydrogen Target and the Recoil Proton Detector
- Upgrades of Electromagnetic Calorimetry ECAL1-2 + a New ECAL0
- Trackers

What makes COMPASS unique?

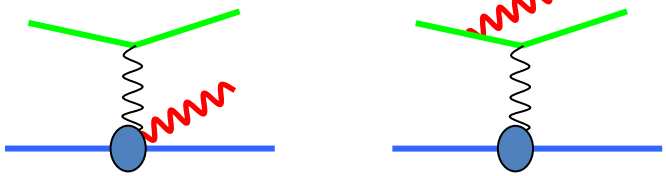


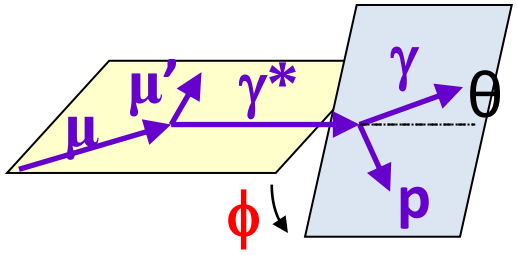
CERN High energy **muon** beam

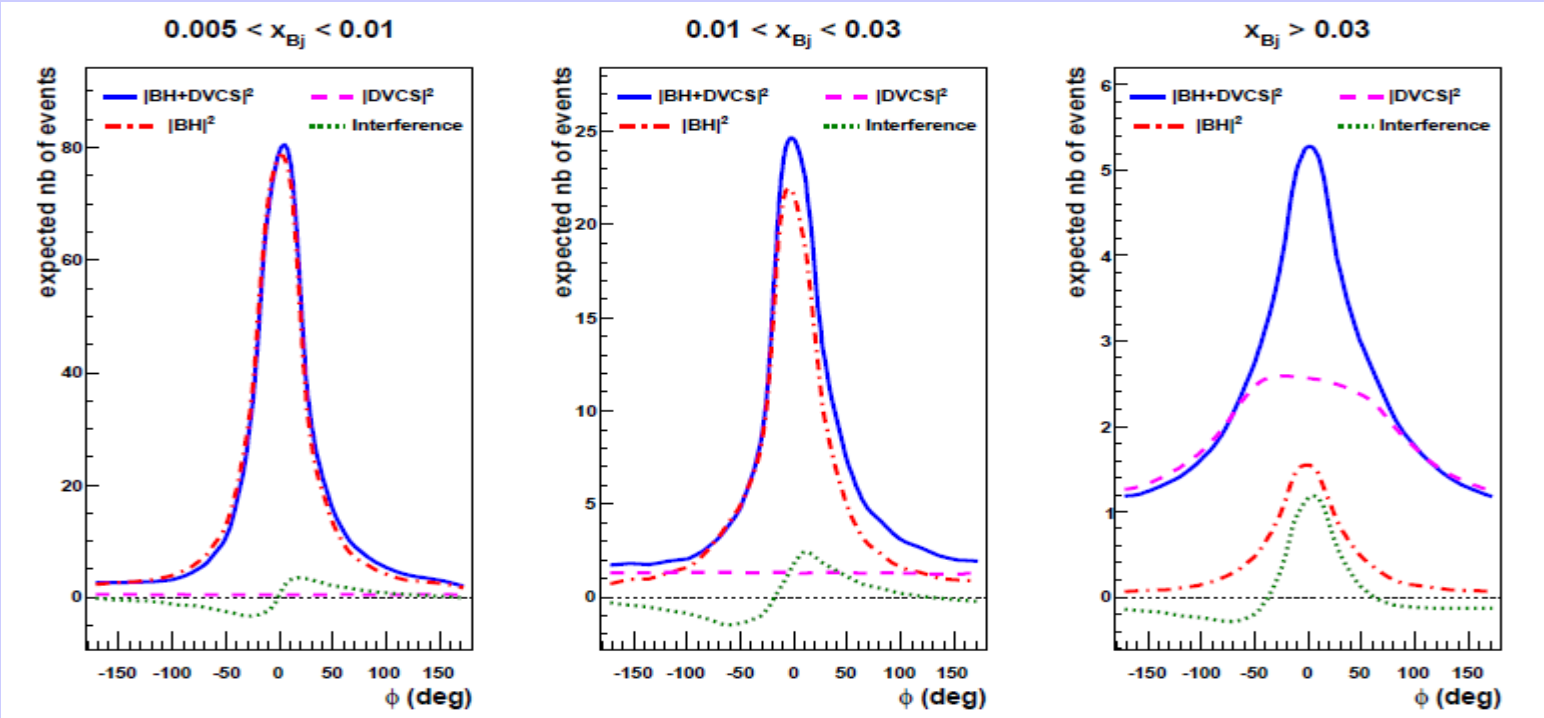
- ✓ 100 - 190 GeV
- ✓ μ^+ and μ^- available
- ✓ 80% Polarisation with opposite polarization

- Will explore the intermediate x_{Bj} region
- Uncovered region between ZEUS+H1 and HERMES+Jlab before new colliders are available
- Transverse structure at $x \sim 10^{-2}$ essential input for phenemenology of high-energy pp collision

Contributions of DVCS and BH at 160 GeV







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

Deeply Virtual Compton Scattering

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

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

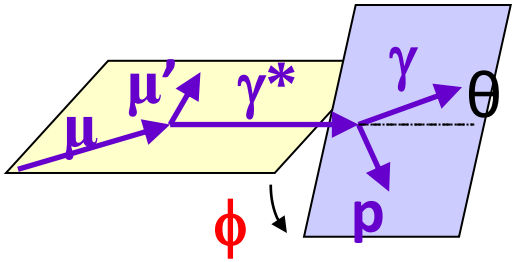
Phase 1: DVCS experiment to constrain GPD H

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

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto c_0^{Int} + c_1^{Int}\cos\phi \quad \text{and} \quad c_{0,1}^{Int} \sim \mathcal{R}e(F_1\mathcal{H})$$

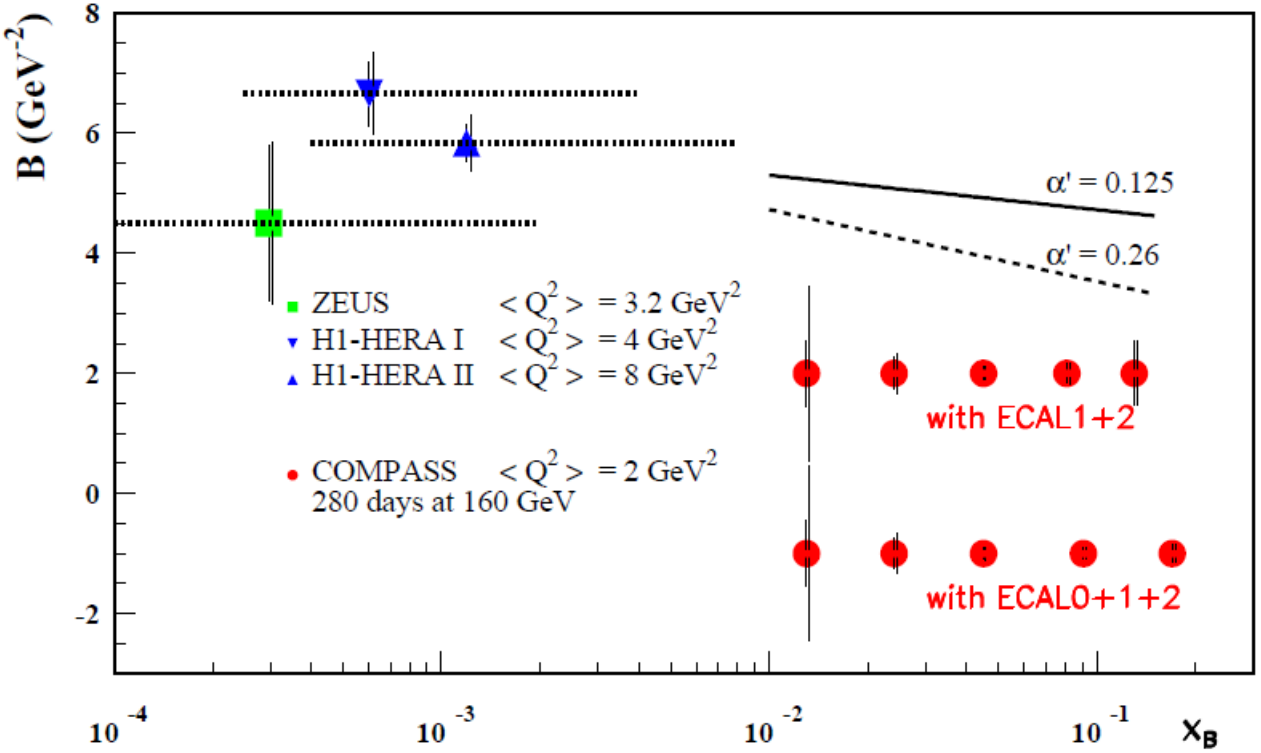
$$\mathcal{S}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto d\sigma^{BH} + c_0^{DVCS} + s_1^{Int}\sin\phi \quad \text{and} \quad s_1^{Int} \sim Im(F_1\mathcal{H})$$

Using $\mathcal{S}_{CS,U}$ and integration over ϕ and BH subtraction → $d\sigma^{DVCS}/dt$ → *transverse imaging*



Transverse imaging at COMPASS

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



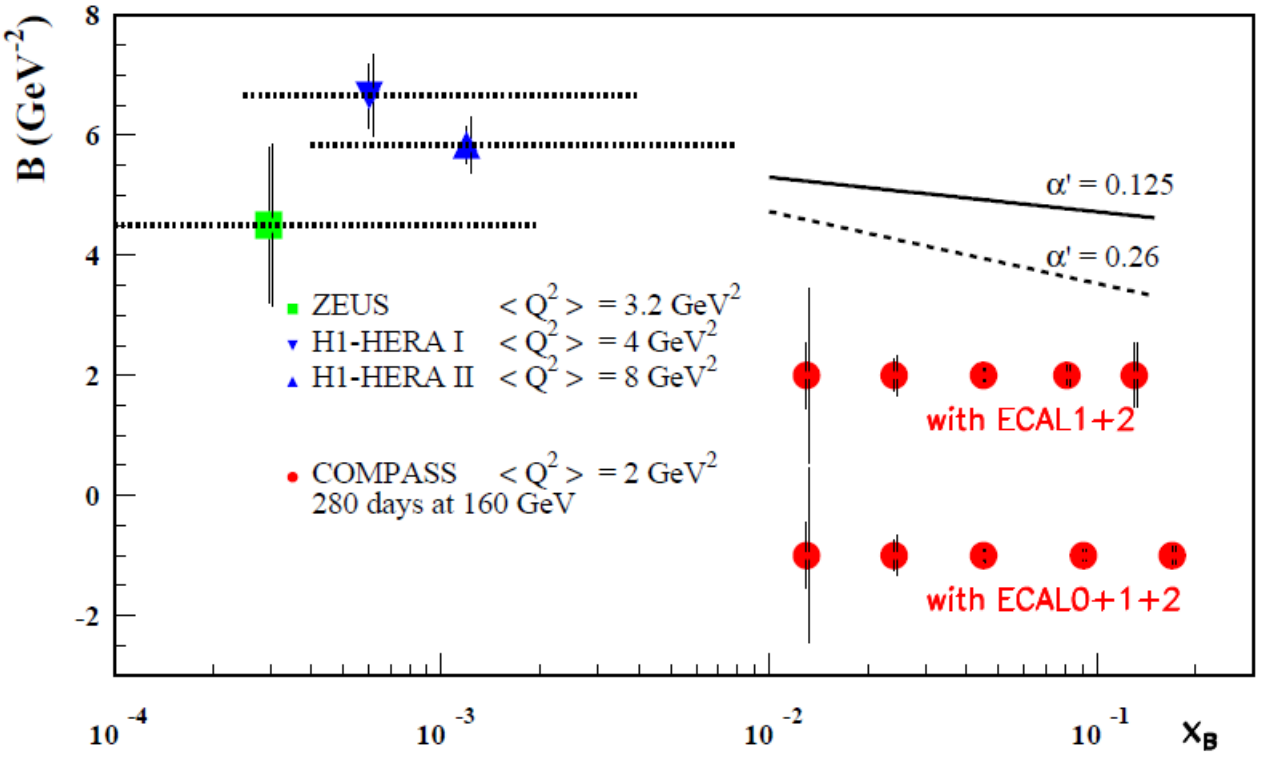
2 years of data
160 GeV muon beam
2.5m LH_2 target
$\varepsilon_{global} = 10\%$

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

Stat~$\sqrt{(N_{BH}+N_{DVCS})}/N_{DVCS}$
Syst~3% N_{BH}/N_{DVCS}

Transverse imaging at COMPASS

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



ansatz at small x_B inspired by Regge Phenomenology:

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

$\alpha' = 0.125$ GeV^{-2} (FFS model)

α' slope of Regge traject

with the projected data we can determine :

- B with an accuracy of 0.1 GeV^{-2}
- α' with an accuracy $\geq 2.5\,\sigma$
  if $\alpha' \geq$ **0.26** with ECAL1+2
  if $\alpha' \geq$ **0.125** with ECAL0+1+2

Transverse imaging at COMPASS

$B(x_B) = \frac{1}{2} \langle r_\perp^2(x_B) \rangle$

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

Transverse size of the nucleon

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

Quark-Dipole Model
Regge Phenomenology

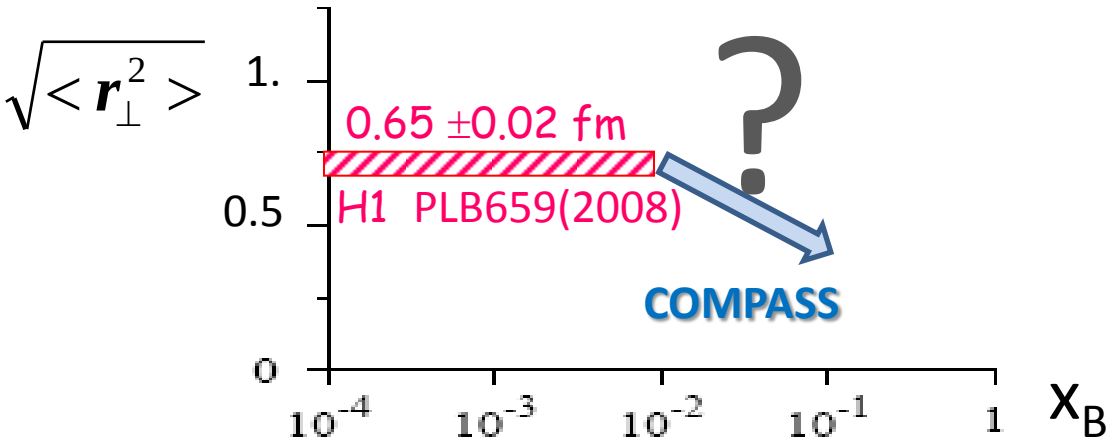
related to $\frac{1}{2} \langle b_\perp^2(x_B) \rangle$

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

Impact Parameter Representation

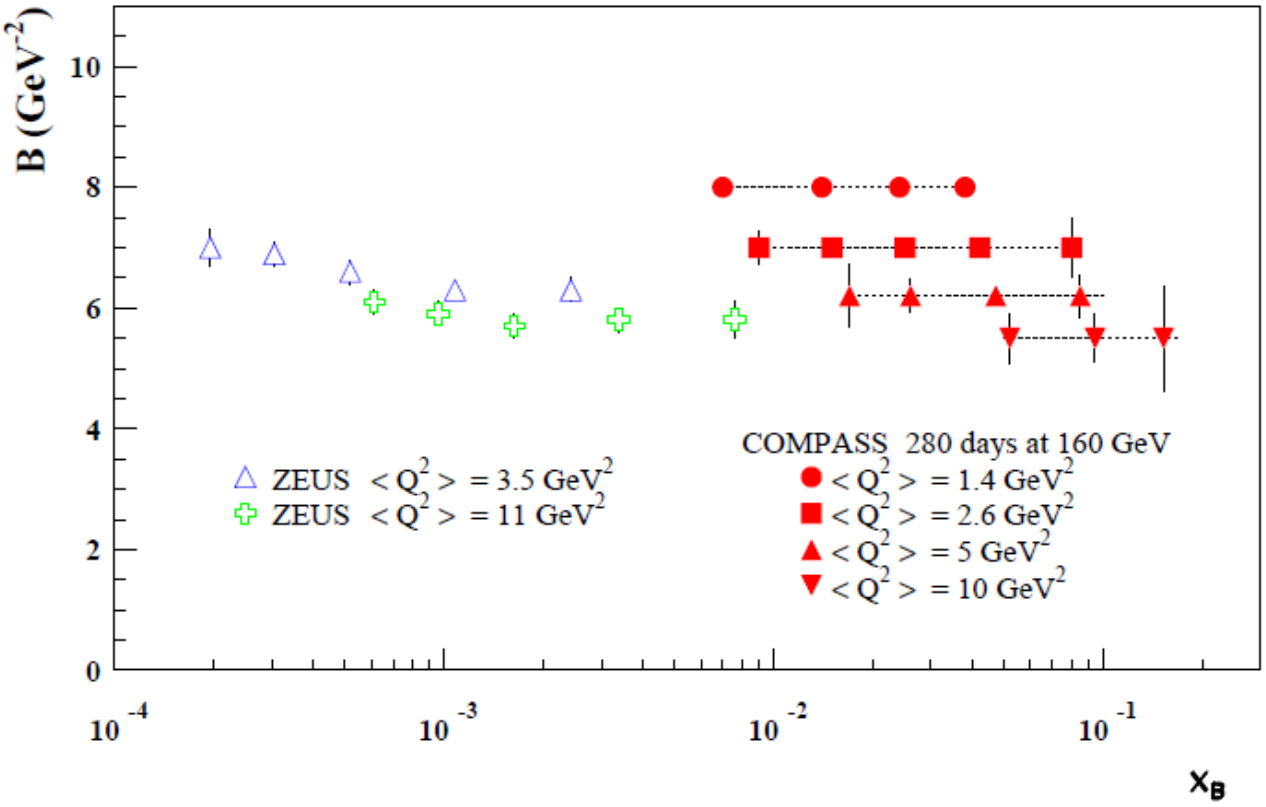
$q(x, b_\perp) \leftrightarrow H(x, \xi=0, t)$

Parametrisation with Reggeized (x,t) correlation



Transverse imaging at COMPASS

$d\sigma_{\rho VMP}/dt \sim \exp(-B|t|)$



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

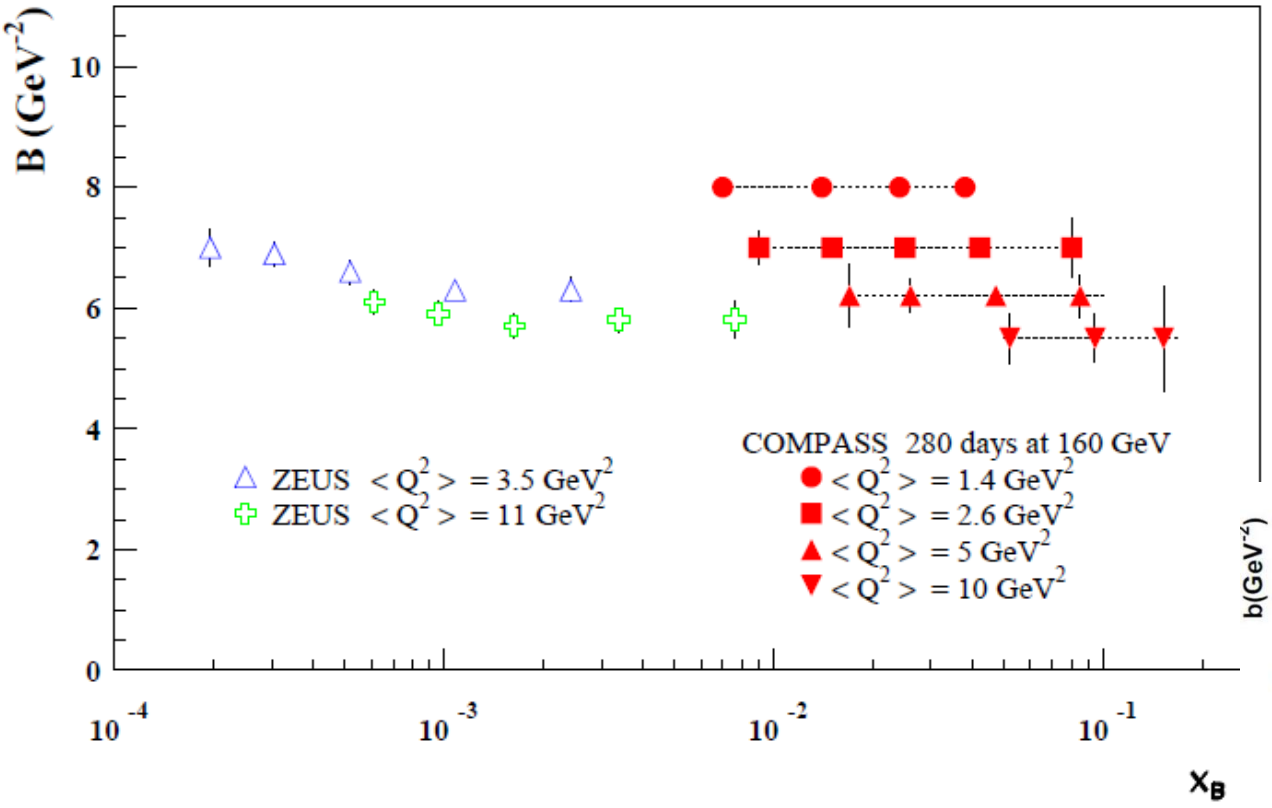
ρVMP model developed by Sandacz
Renormalised according Goloskokov and Kroll prediction

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

$Q^2=1$ GeV^2 $B \sim 8$ GeV^{-2}
$Q^2=10$ GeV^2 $B \sim 5.5$ GeV^{-2}

Transverse imaging at COMPASS

$d\sigma_{\rho VMP}/dt \sim \exp(-B|t|)$



2 years of data
160 GeV muon beam
2.5m LH_2 target
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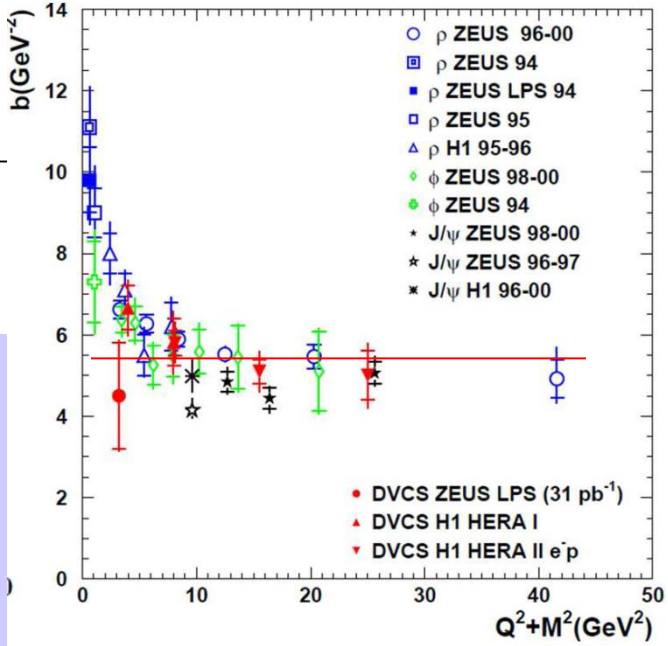


We are sensitive to the nucleon nucleon size
+ the transverse size of the meson

Q^2=1 GeV^2 B ~ 8 GeV^{-2}
Q^2=10 GeV^2 B ~ 5.5 GeV^{-2}

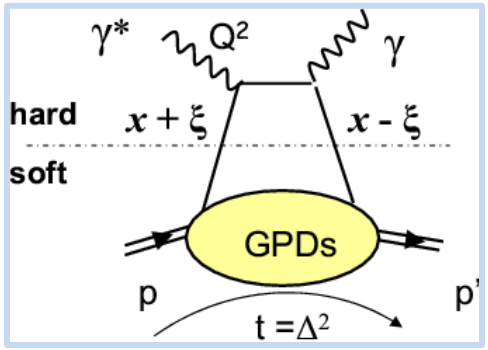
Deeply Virtual Compton Scattering

Phase 1: DVCS experiment to constrain GPD H

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

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto c_0^{Int} + c_1^{Int}\cos\phi \quad \text{and} \quad c_{0,1}^{Int} \sim \mathcal{R}e(F_1\mathcal{H})$$

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

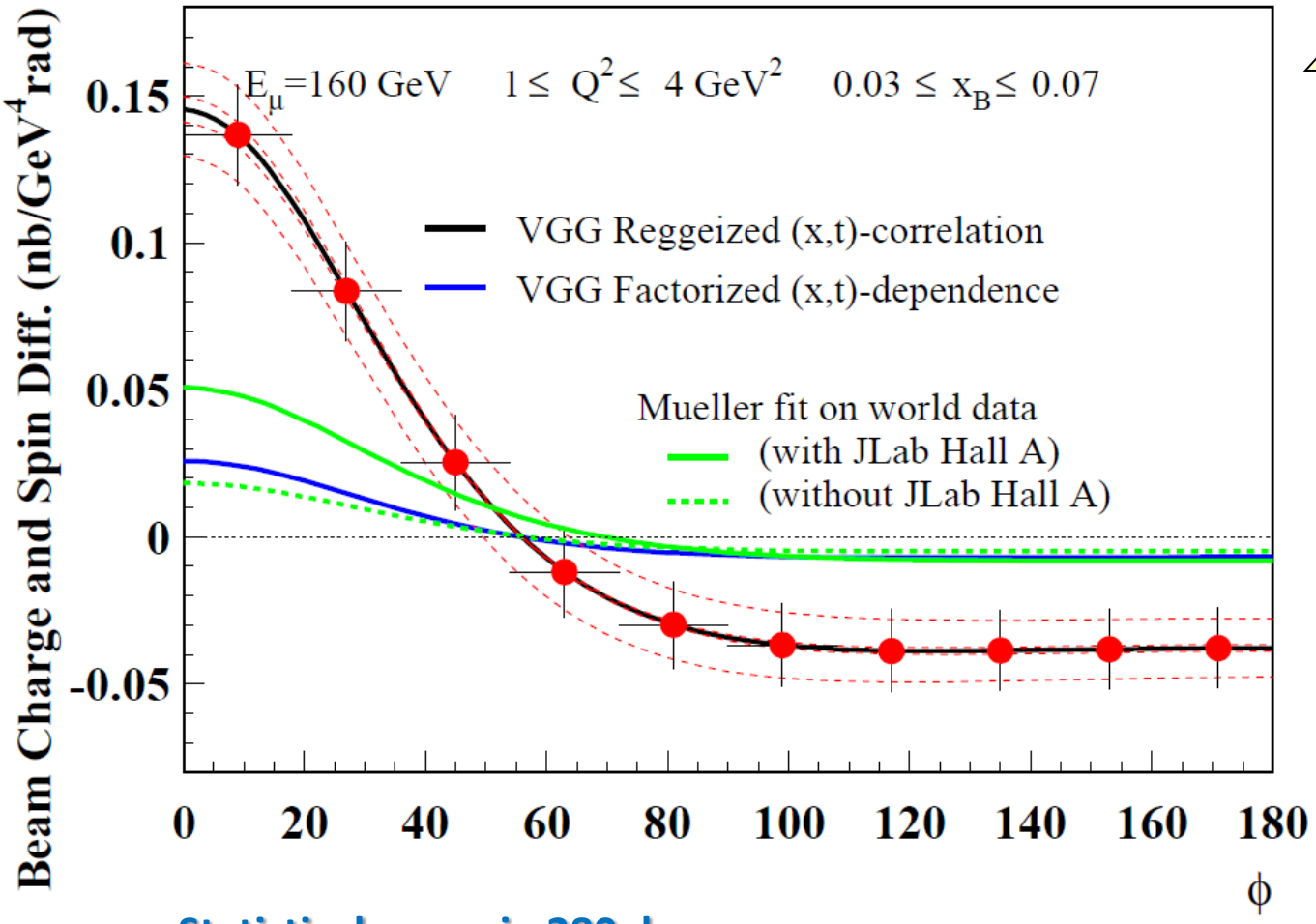


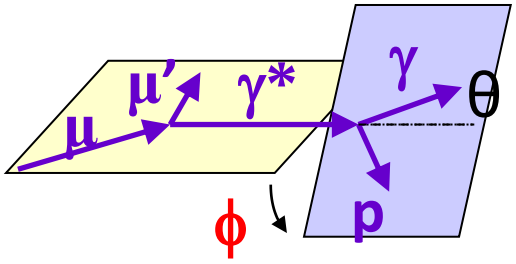
$\xi \sim x_B / (2-x_B)$

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

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%

Statistical errors in 280 days

Systematic errors for 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

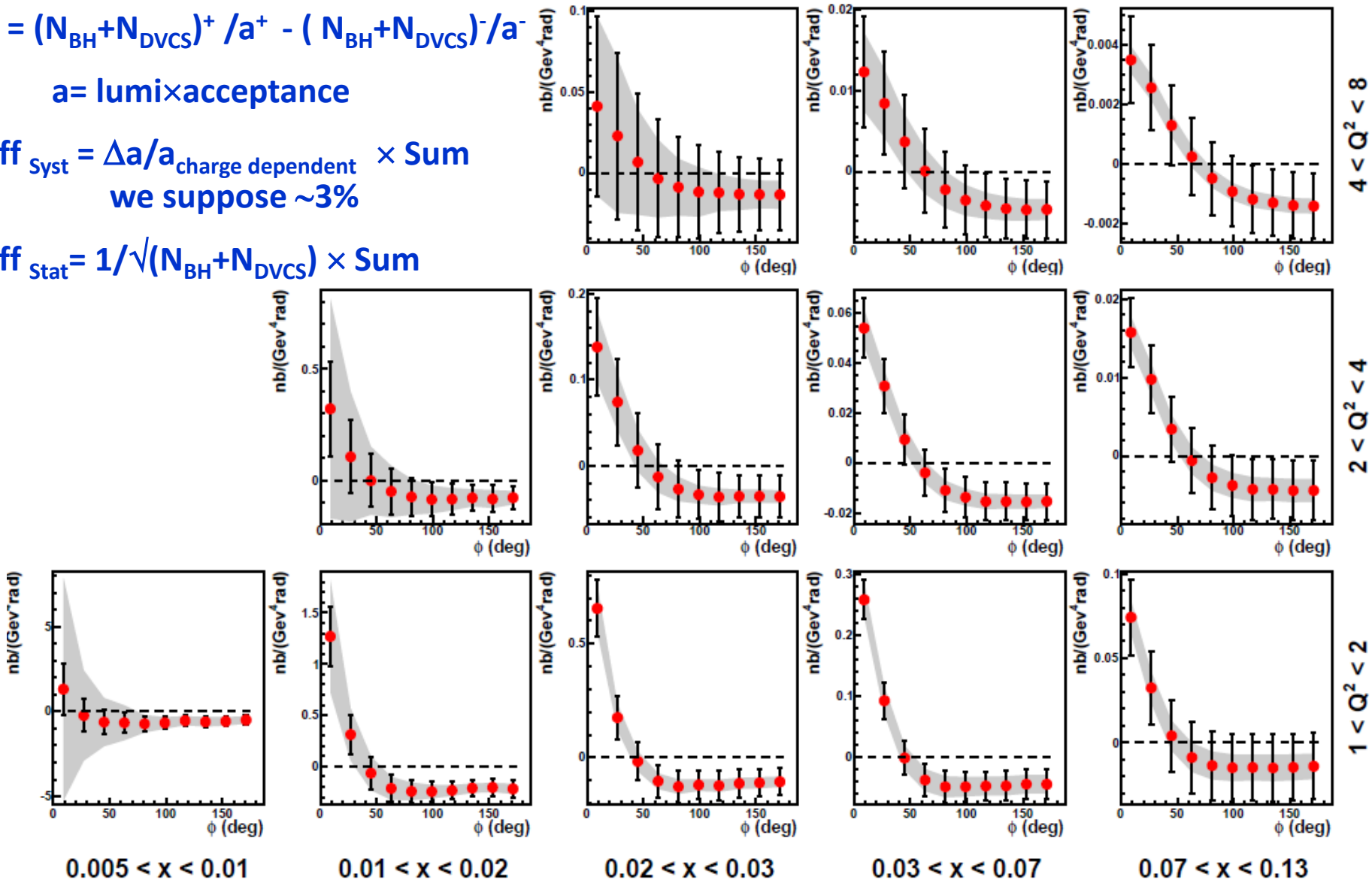
$\mathrm{Diff} = (N_{BH}+N_{DVCS})^{+}/a^{+} - (N_{BH}+N_{DVCS})^{-}/a^{-}$

a= lumi×acceptance

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

we suppose ~3%

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



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

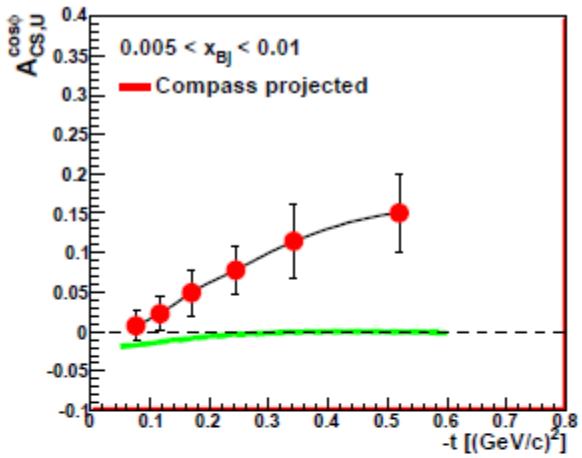
$A_{CS,U}^{\cos\phi}$ related to c_1^{Int}

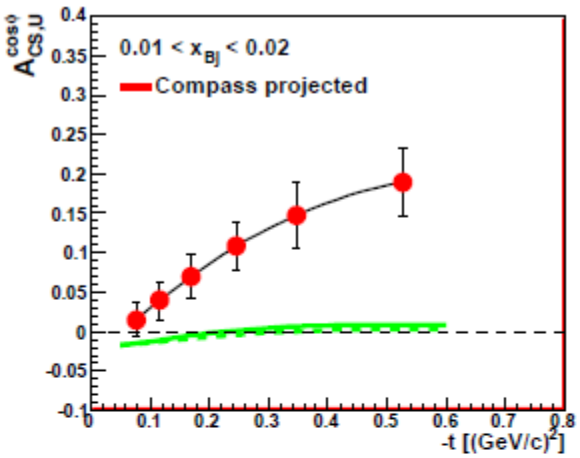
Predictions with **VGG** and **D.Mueller**

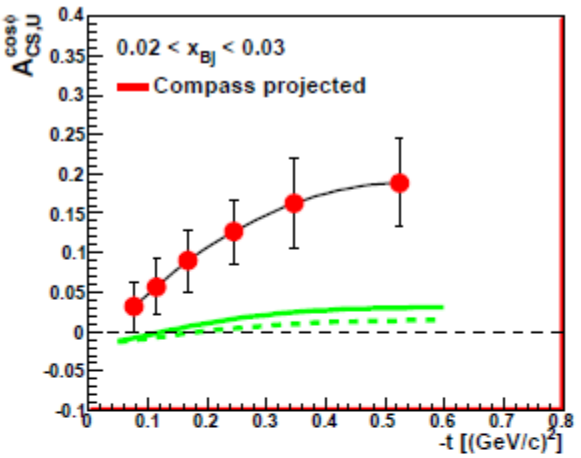
$\mathcal{R}e(F_1\mathcal{H})$ **> 0 at H1**

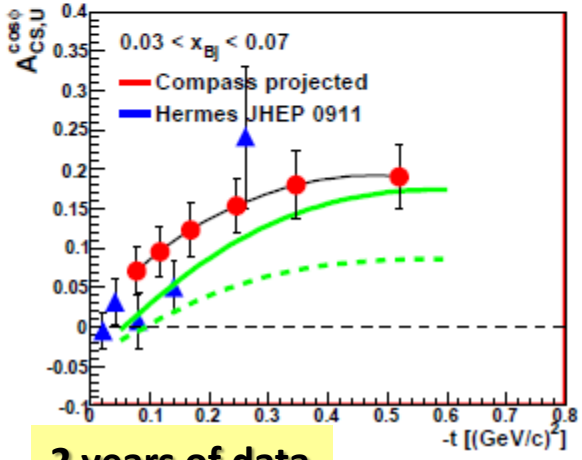
< 0 at HERMES/JLab

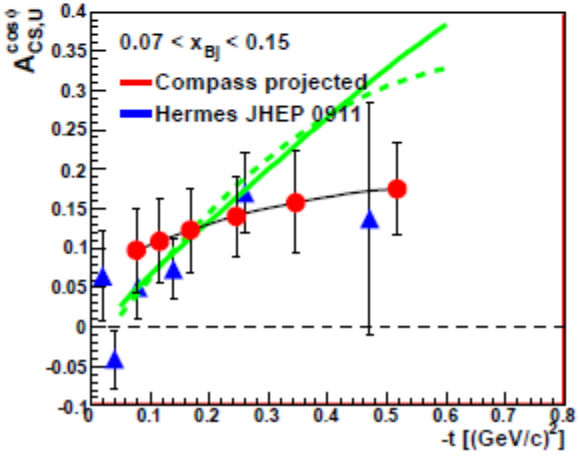
Value of x_B for the node?

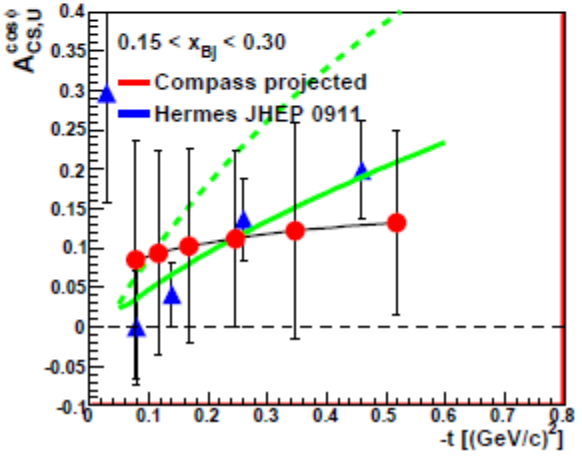












2 years of data

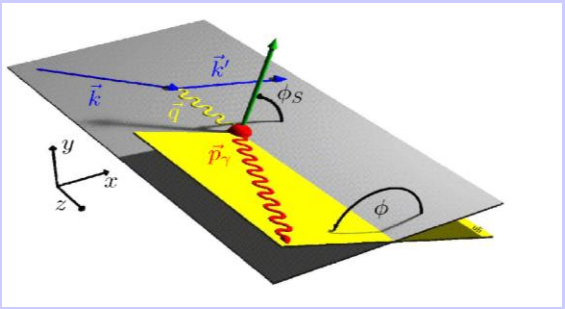
With ECAL2 + ECAL1 + ECAL0

Deeply Virtual Compton Scattering

Phase 2: DVCS experiment to constrain GPD E

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

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



the GPD E allows nucleon helicity flip

so it is related to the angular momentum

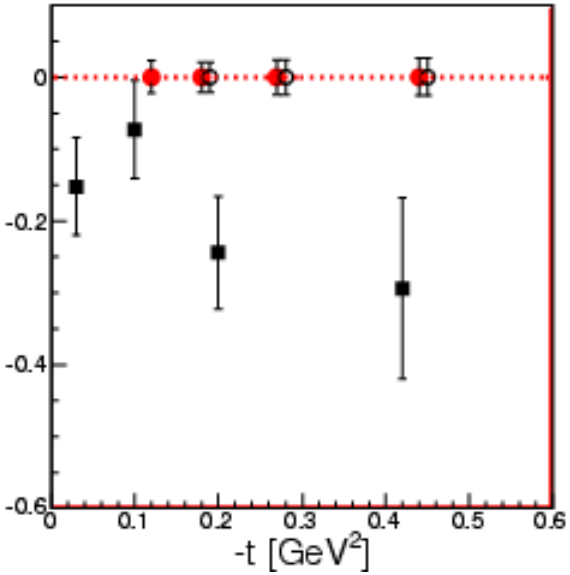
Ji sum rule: $2J_q = \int x\,(H^q(x,\xi,0) + E^q(x,\xi,0))\,dx$

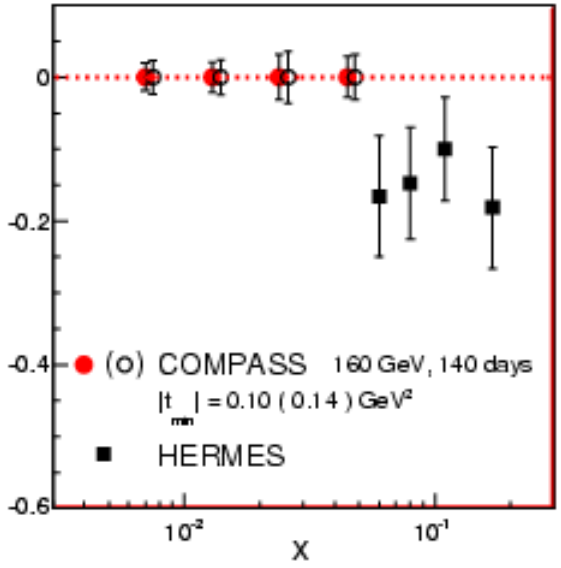
$D_{CS,T}$ and Transverse Target Asymmetry

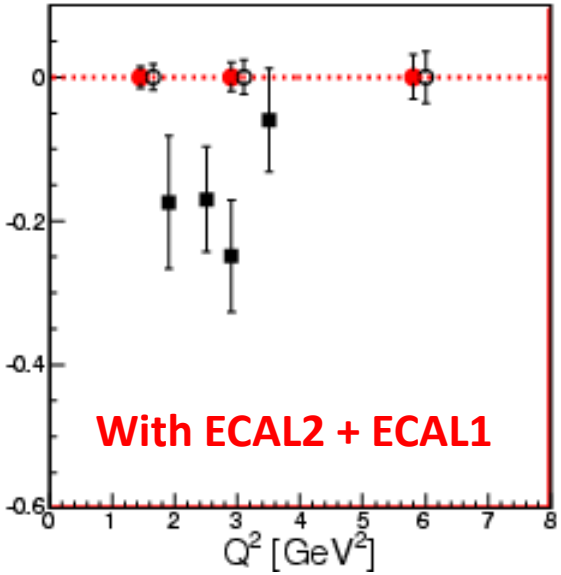
With a transversely polarized NH3 (proton) target:

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

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

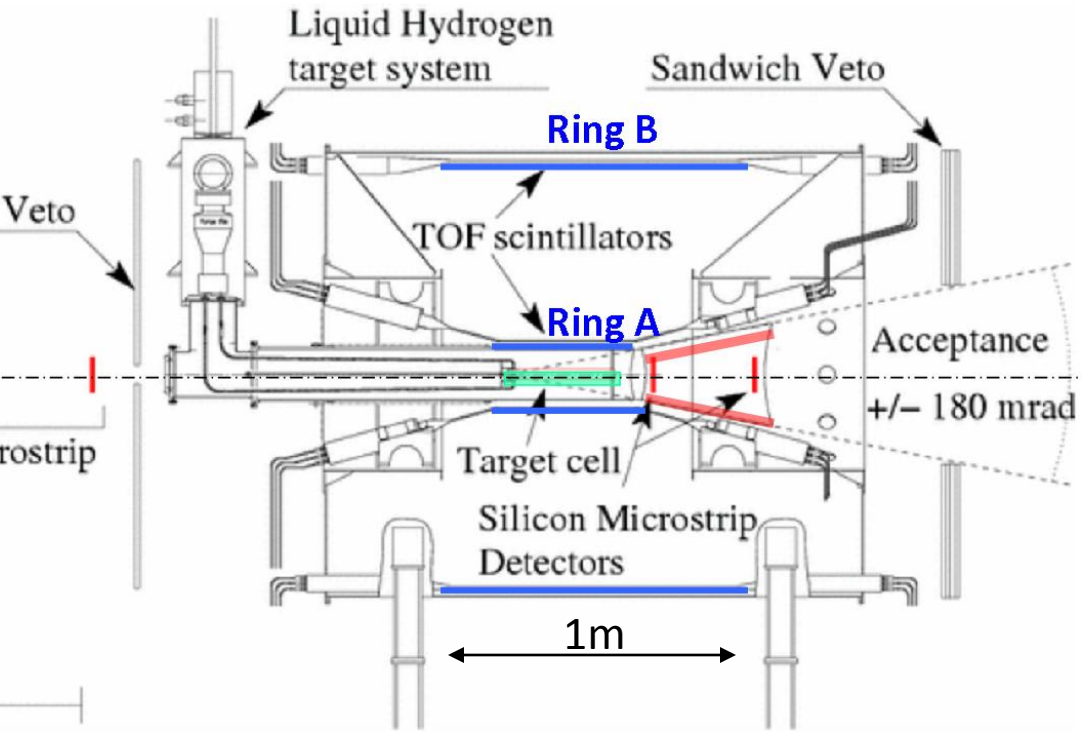


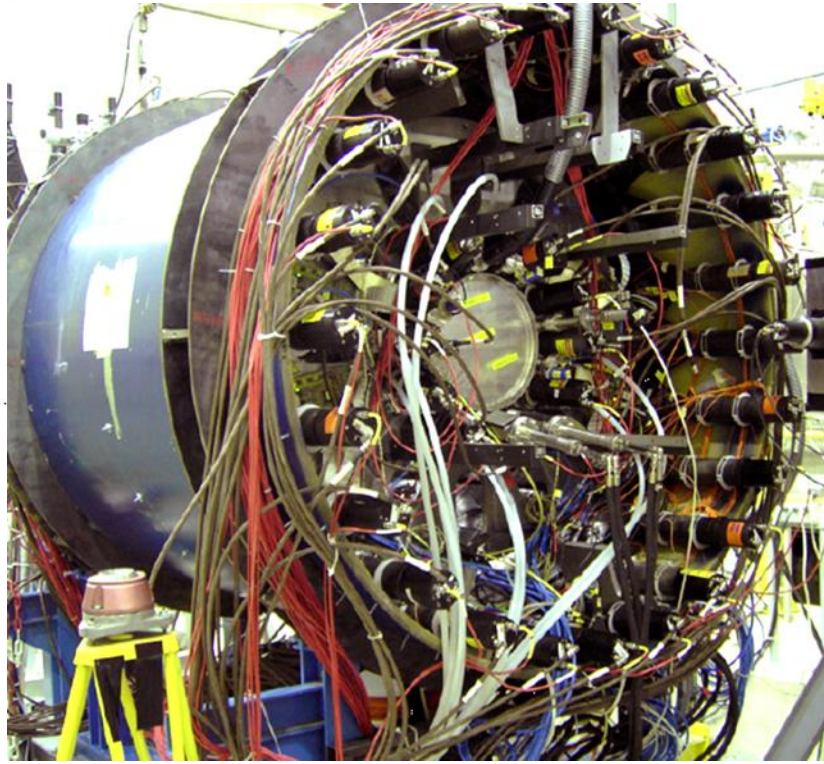




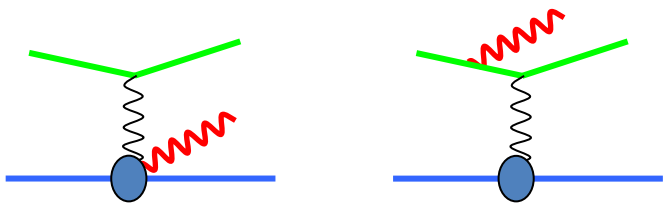
2008 - 2009 : a small 1m Recoil Proton Detector and a 40cm LH2 target

during the hadron programme



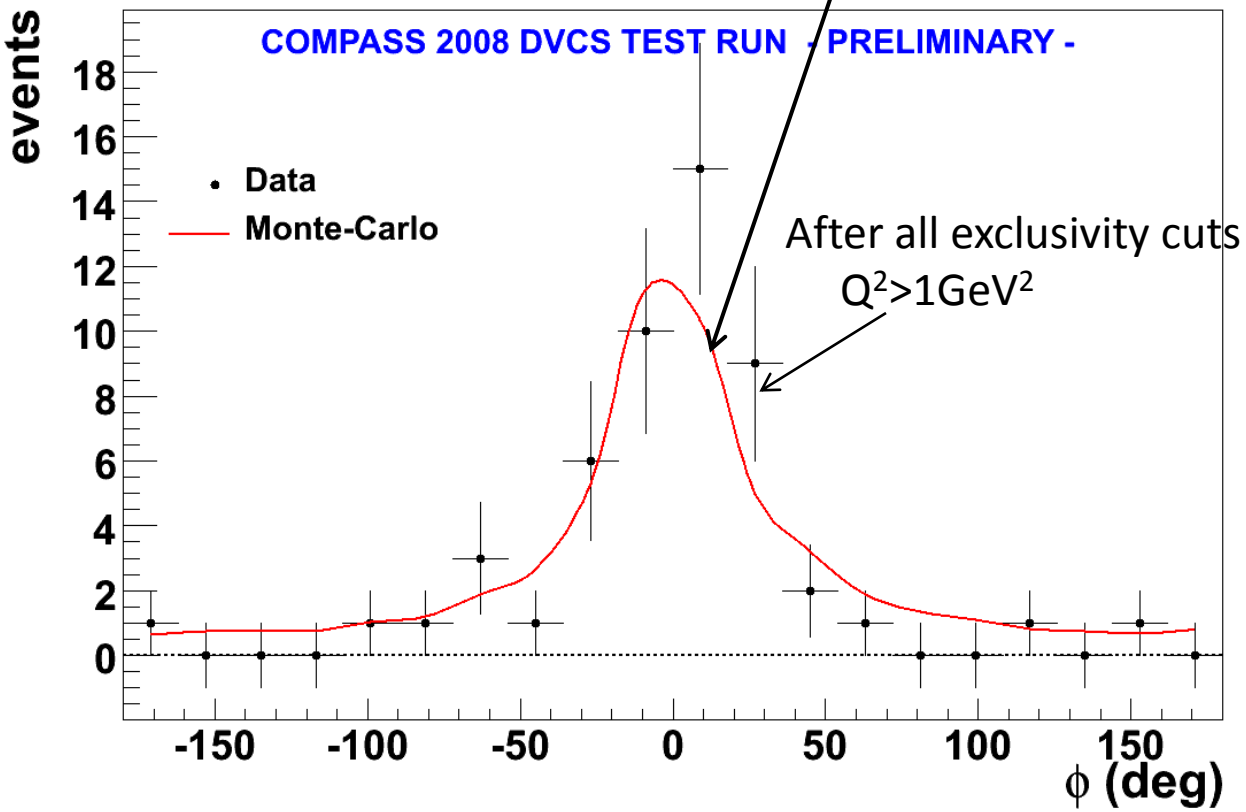


2008 test : Bethe-Heitler signal



Monte-Carlo simulation
of BH (dominant) and DVCS

➔ **Bethe-Heitler observed**



Detection efficiency :

$\varepsilon_{\mu+p\to\mu+p+\gamma} = 0.32 +/- 0.13$

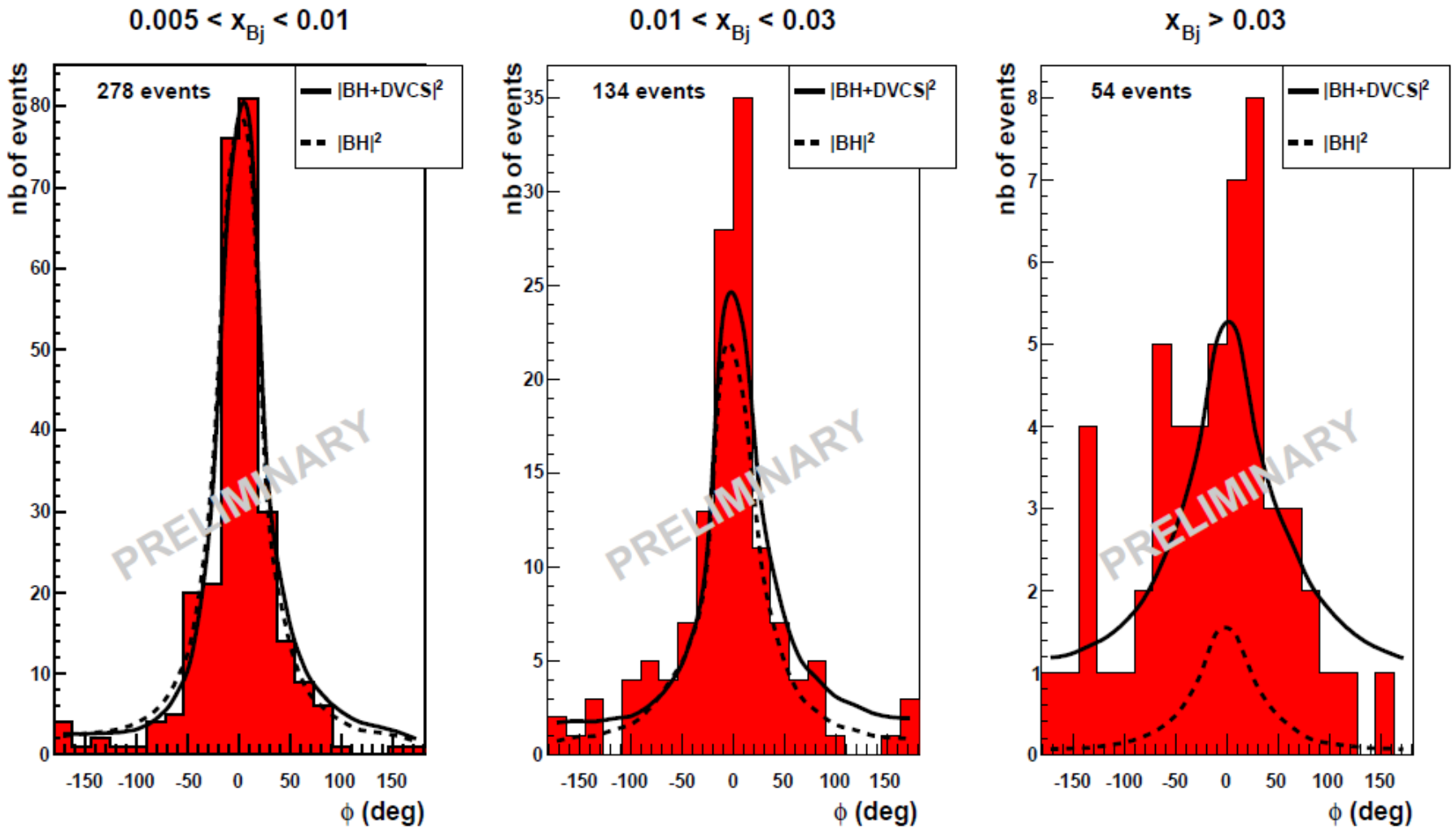
Global efficiency included also:
- SPS availability
- COMPASS Spectro availability
- Dead time
- Trigger efficiency

$\Rightarrow \varepsilon_{global} = 0.13 +/- 0.05$

➔ **Projections of errors are realistic**

~ 8 times more data taken in 2009 to be shared in three x_B domains

2009 test: BH and DVCS events



10 BH events expected
→ 44 pure DVCS events

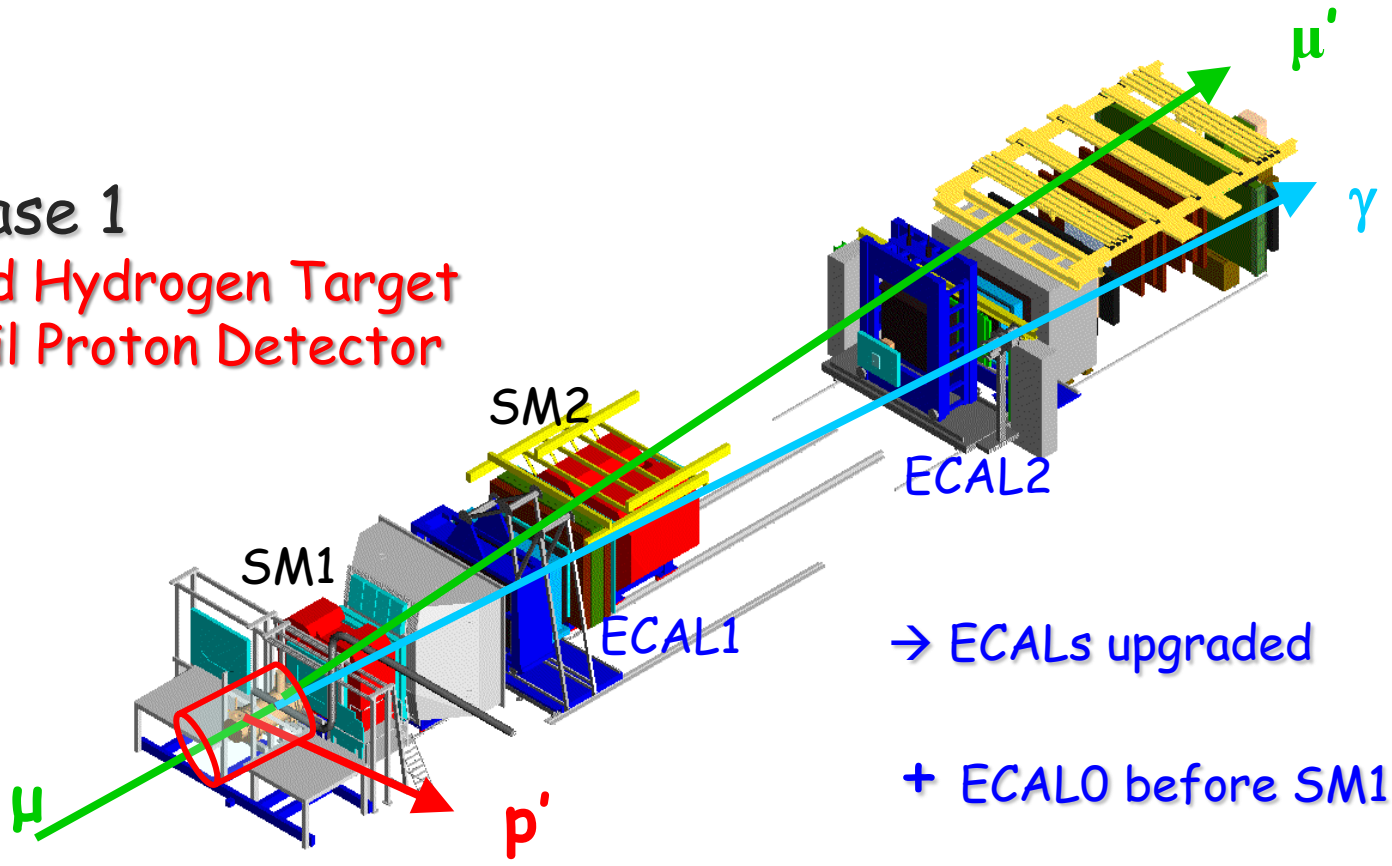
Experimental requirements for DVCS

$\mu\ p \rightarrow \mu'\ p\ \gamma$

Phase 1

~ 2.5 m Liquid Hydrogen Target

~ 4 m Recoil Proton Detector



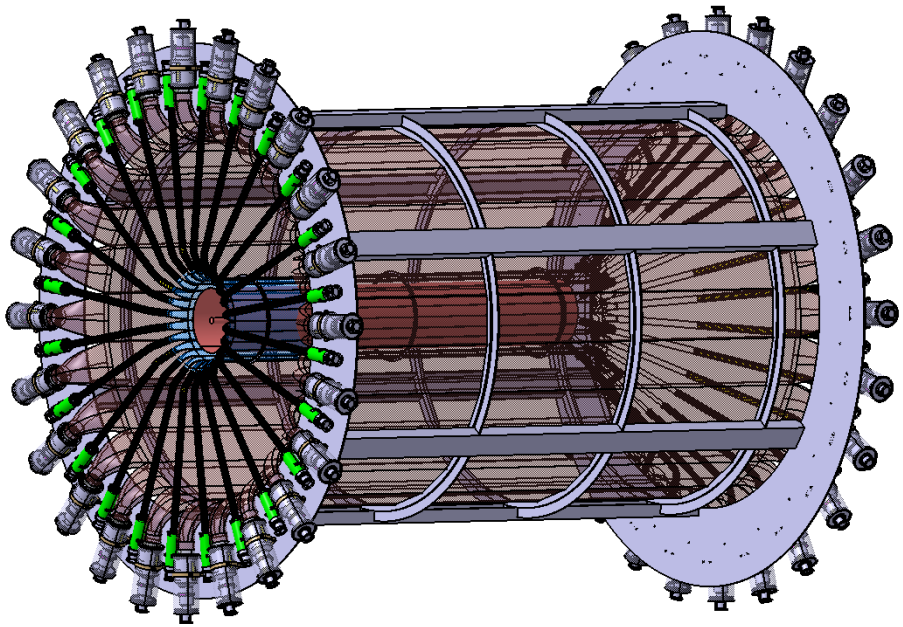
→ ECALs upgraded

+ ECAL0 before SM1

+ trigger upgrades (notably at high Q^2)

+ good tracking and identification

RPD design and its electronics

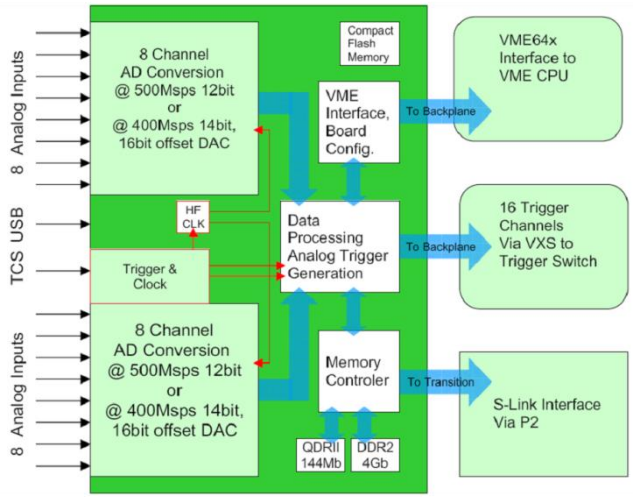


3.6 m long scintillator slabs
➔~ 300ps timing resolution

Tests made with
- MuRex (a 4m sector prototype)
- The present RPD (1m long)

Gandalf Project:

1 GHz digitalisation of the PMT signal to cope for high rate



ECAL0

ECAL0 made of

248 modules (12 × 12 cm²)
of 9 cells (towers) read by 9 AMPDs