The GPD programm at COMPASS II

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for the COMPASS collaboration

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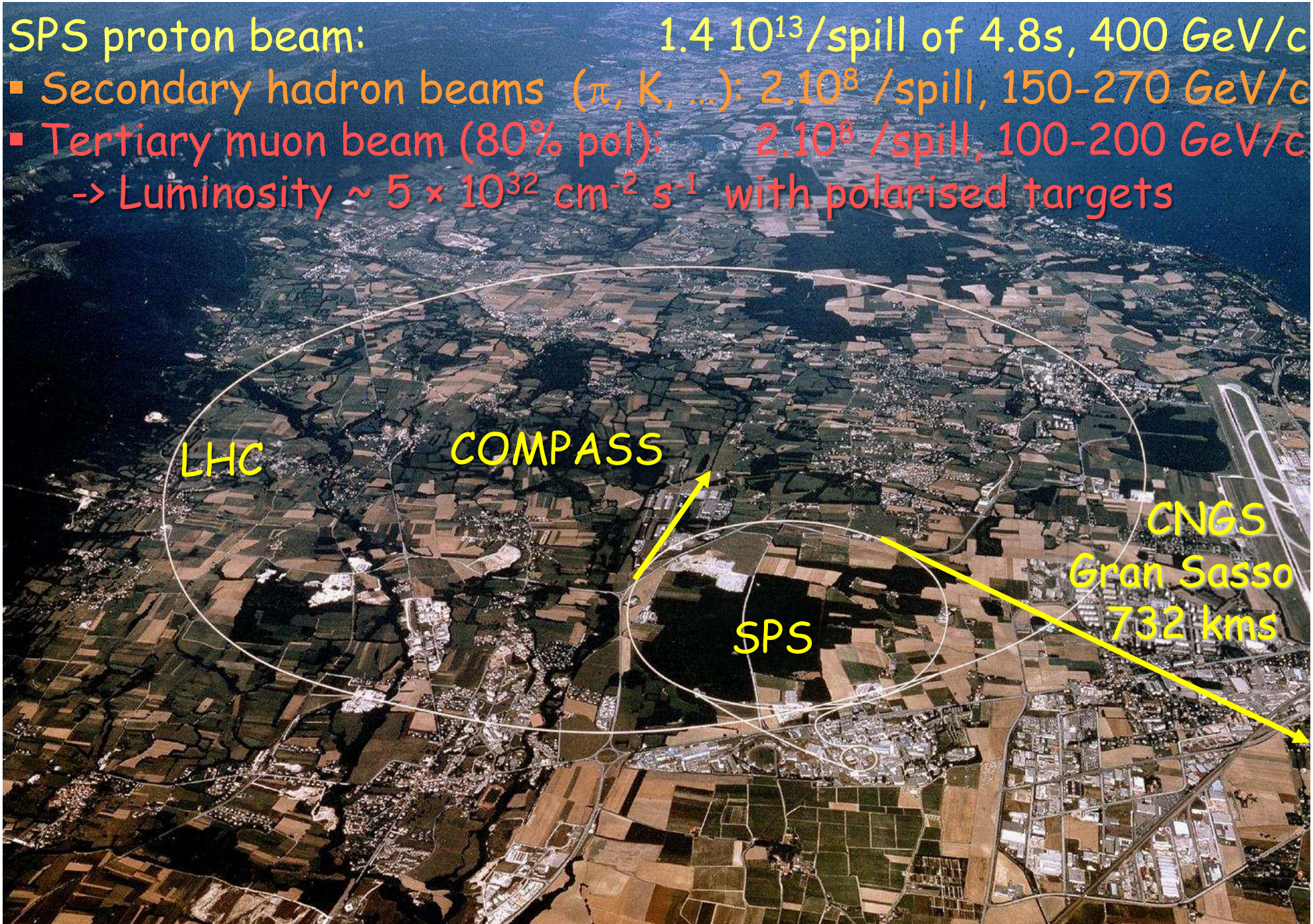
Outline

- COMPASS II proposal
- GPDs at COMPASS
- Experimental challenges
- Test measurements
- Observables and predictions
- Plans

SPS proton beam: 1.4 10^{13}/spill of 4.8s, 400 GeV/c

- Secondary hadron beams (π, K, ...): 2.10^{8} /spill, 150-270 GeV/c
- Tertiary muon beam (80% pol): 2.10^{8} /spill, 100-200 GeV/c

  -> Luminosity ~ 5 × 10^{32} cm^{-2} s^{-1} with polarised targets



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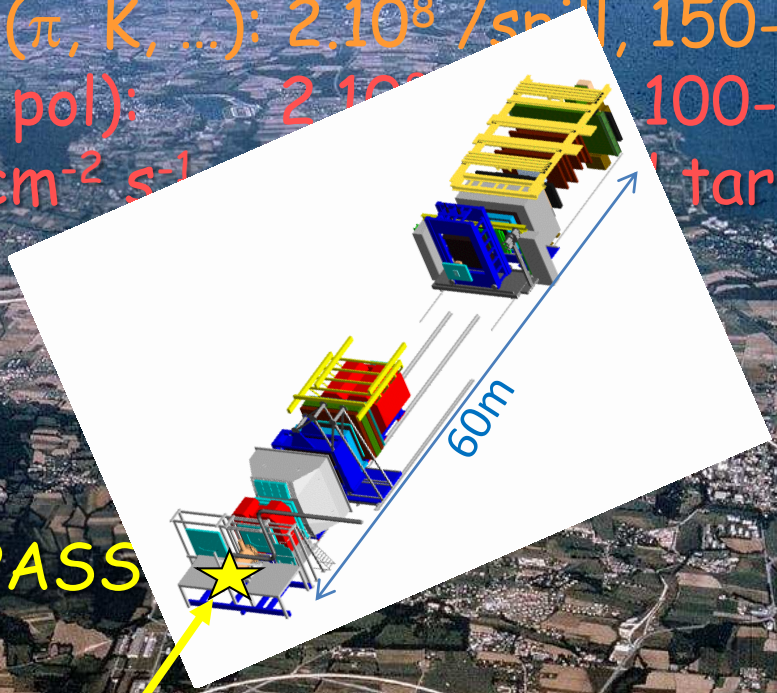


LHC

COMPASS

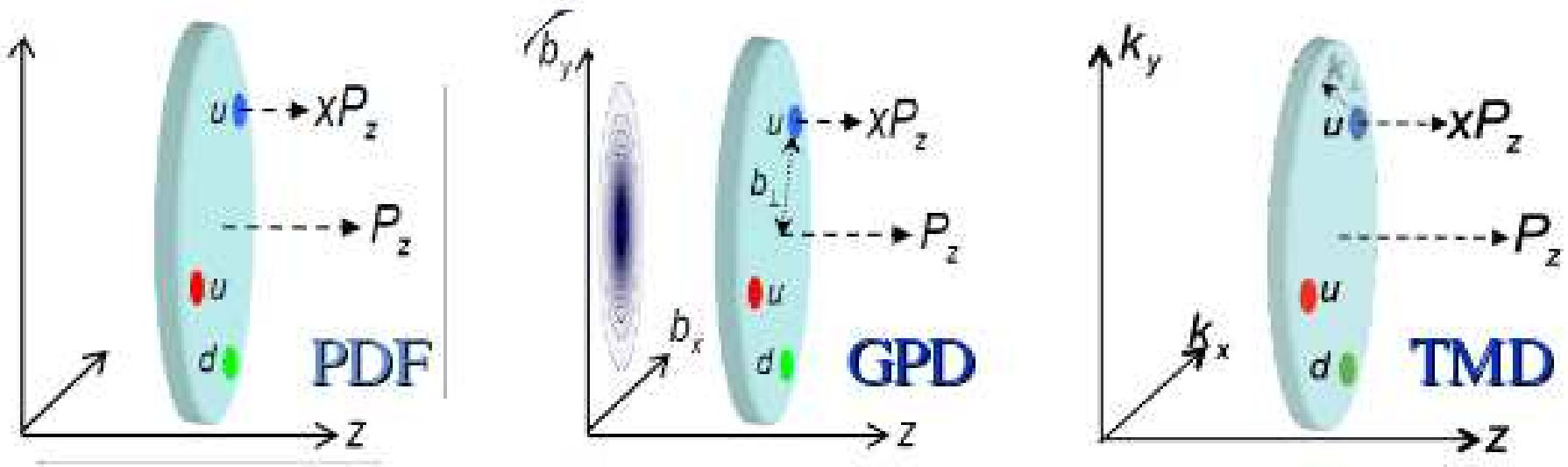
SPS

CNGS
Gran Sasso
732 kms

high energy beam(s), broad kinematic range, large angular acceptance

What we will do

Improve the 1-dimensional picture of the nucleon



Study generalised parton distributions and transverse momentum dependent distributions

COMPASS II - Proposal

submitted in May 2010 for 5 years of data taking in the first phase
approved in December 2010 for *initially* 3 years of data taking in 2015-2017

Generalized parton distribution (GPD)

longitudinal momentum structure plus transverse spatial structure
accessible in exclusive reaction like DVCS or DVMP

Flavour separation and fragmentation in SIDIS

strange quark distribution and fragmentation functions

Transverse momentum dependent distributions (TMD)

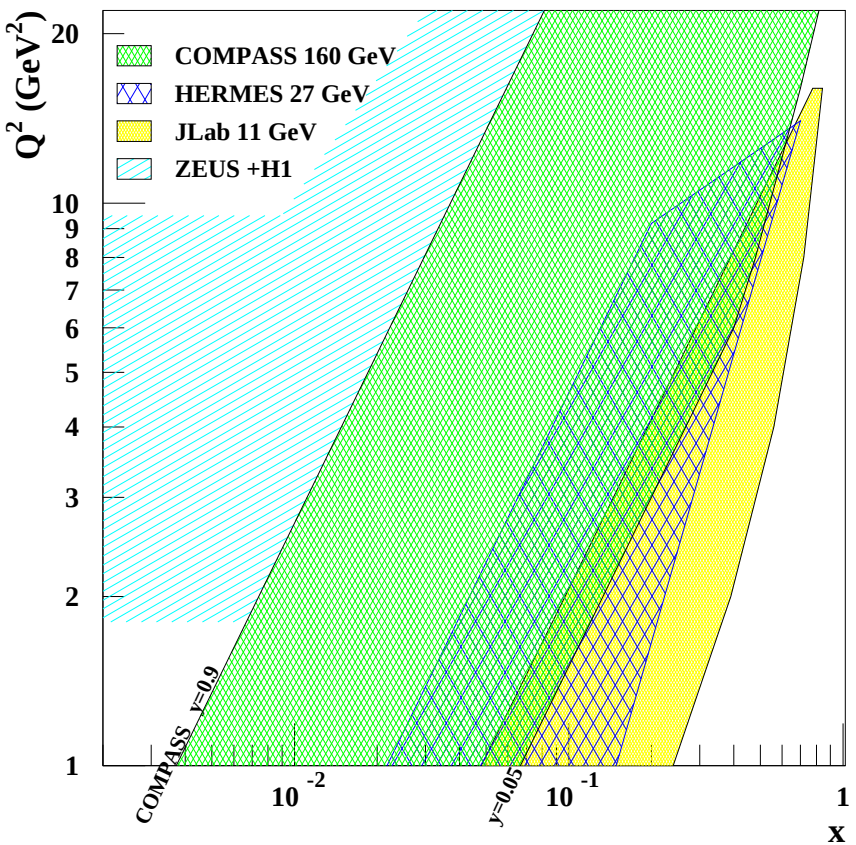
dynamic picture using intrinsic transverse momenta of partons
accessible in SIDIS and Drell-Yan processes

QCD at very low momentum transfers

pion/kaon polarisabilities, testing chiral perturbation theory,
data taken in 2012

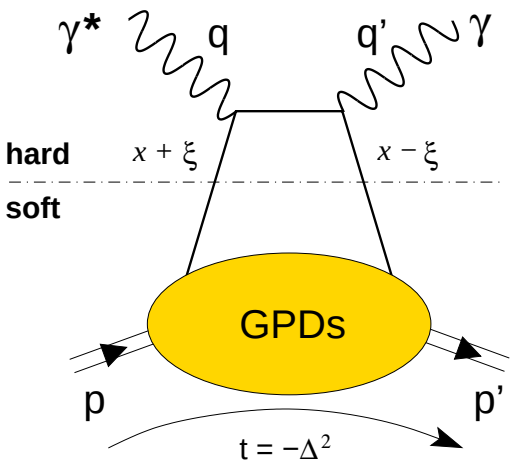
Why GPDs at COMPASS?

- **CERN high energy muon beam:**
  - 100–160 GeV, 80% polarisation
  - μ^+ and μ^- with opposite polarisation



- **unique kinematic range** between HERA and HERMES/JLab
  - intermediate x_{Bj}:
    $\Longrightarrow$ sea and valence quarks
  - high x_{Bj} limit from acceptance
  - Q^2 up to 8GeV^2
    $\Longrightarrow$ limit from cross section
    with $L = 10^{32}$ cm^{-2}s^{-1}
- **planned measurements:**
  - deeply virtual Compton scattering
  - deeply virtual meson production

Generalised parton distributions



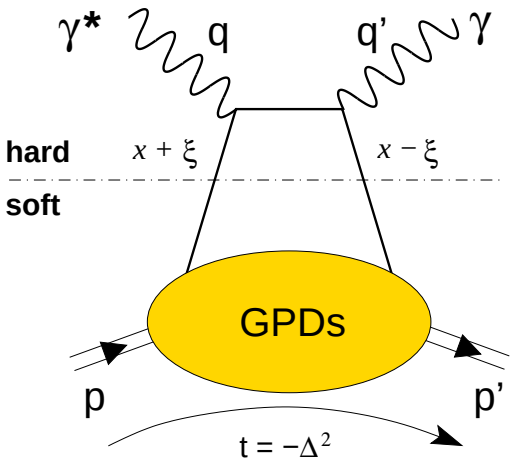
- accessible in exclusive reactions
- factorisation for Q^2 large, $|t| < 1$ GeV^2
- GPD for each quark flavour and for gluons
- depend on 3 variables: x, ξ, t with $\xi = \frac{x_{Bj}}{2-x_{Bj}}$

- 4 GPDs:

H, $\widetilde{\mathrm{H}}$	conserve nucleon helicity
E, $\widetilde{\mathrm{E}}$	flip nucleon helicity
H, E	refer to unpolarised distributions
$\widetilde{\mathrm{H}}$, $\widetilde{\mathrm{E}}$	refer to polarised distributions

- **limits**: PDFs $q(x) = \mathrm{H}(x,0,0)$ and formfactors $F(t) = \int \mathrm{d}x\, \mathrm{H}(x,\xi,t)$
- sensitivity in deeply virtual Compton scattering (DVCS) and hard exclusive meson production (HEMP)

GPDs and DVCS



- GPDs related to Compton form factors $\mathcal{H}$

$$\mathrm{Im}\,\mathcal{H}(\xi,t) \overset{\mathrm{LO}}{=} H(\xi,\xi,t)$$

$$\mathrm{Re}\,\mathcal{H}(\xi,t) \overset{\mathrm{LO}}{=} \mathcal{P}\int_{-1}^{1}\mathrm{d}x\;\mathrm{H}(x,\xi,t)\tfrac{1}{x-\xi}$$

$$\mathcal{H} = \Sigma e_f^2 \mathcal{H}^f$$

- **Ji's sumrule**

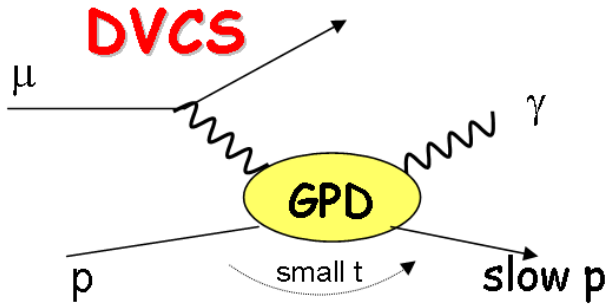
$$J^f = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1}\mathrm{d}x\;x\;\left[\mathrm{H}^f(x,\xi,t)+\mathrm{E}^f(x,\xi,t)\right]$$

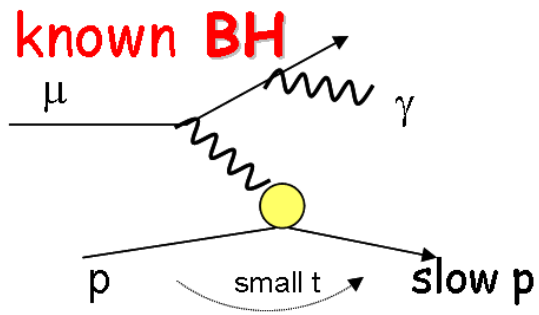
J^f: total angular momentum contribution of quark f

- unpolarised hydrogen target $\Longrightarrow$ **GPD H**
- transversely polarised target $\Longrightarrow$ **GPD E**

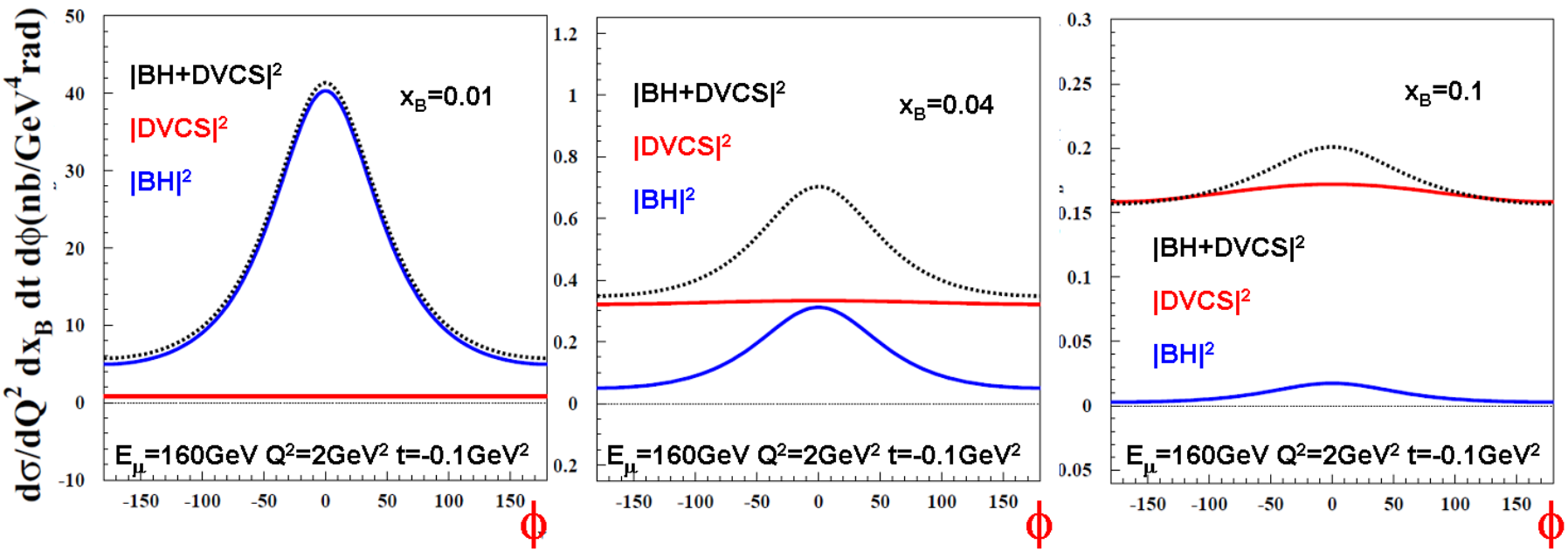
What we do measure

$$\mu^{\pm} p \longrightarrow \mu^{\pm} \gamma p$$





for COMPASS: 160 GeV, $Q^2 = 2\,\mathrm{GeV}^2/c^2$, $|t| = 0.1\,\mathrm{GeV}^2/c^2$



BH dominates, reference yield

access to DVCS amplitude via interference

DVCS dominates, study of $\mathrm{d}\sigma/\mathrm{d}|t|$,

Azimuthal dependence

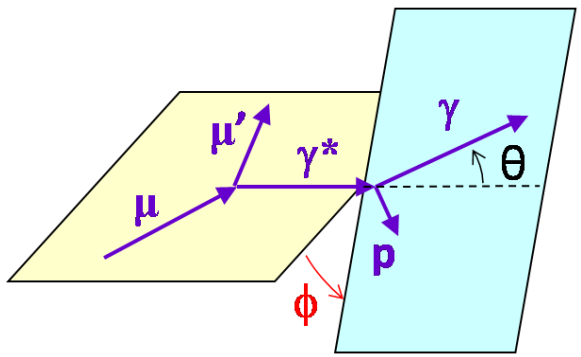
- **cross section** (polarised beam and unpolarised target)

$$\mathrm{d}\sigma = \mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS}_{unpol} + P_\mu \, \mathrm{d}\sigma^{DVCS}_{pol} + e_\mu a^{BH} \mathrm{Re}\, A^{DVCS} + e_\mu P_\mu a^{BH} \,\mathrm{Im}\, A^{DVCS}$$

- **contributions**

$$\begin{aligned}
\mathrm{d}\sigma^{BH} &\propto c_0^{BH} + c_1^{BH}\cos\phi + c_2^{BH}\cos 2\phi \\
\mathrm{d}\sigma^{DVCS}_{unpol} &\propto c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi \\
\mathrm{d}\sigma^{DVSC}_{pol} &\propto s_1^{DVCS}\sin\phi \\
a^{BH}\mathrm{Re}\, A^{DVCS} &\propto c_0^{I} + c_1^{I}\cos\phi + c_2^{I}\cos 2\phi + c_3^{I}\cos 3\phi \\
a^{BH}\,\mathrm{Im}\, A^{DVCS} &\propto s_1^{I}\sin\phi + s_2^{I}\sin 2\phi
\end{aligned}$$

Twist-2 >> (Twist-3, Twist-2 gluon)



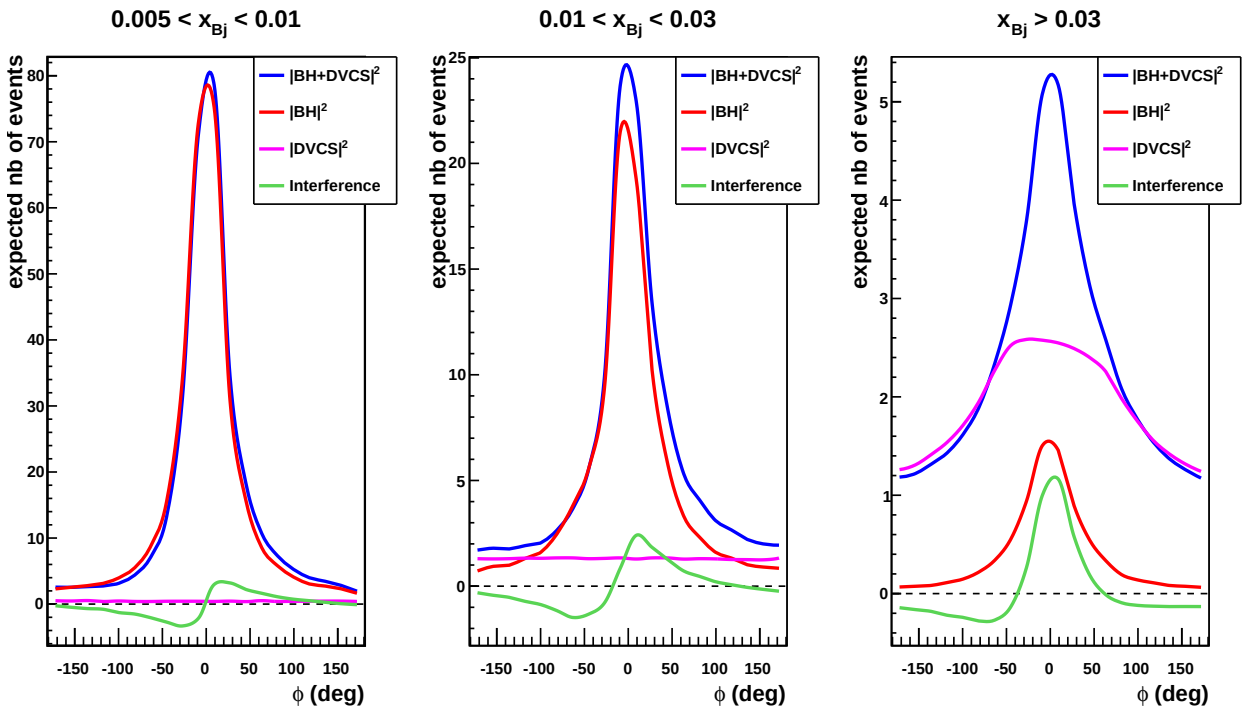
- measurement with μ^+ and μ^- yields Re(H) and Im(H)

Test measurement in 2009

Feasibility study for detection of DVCS/BH events

Set-up

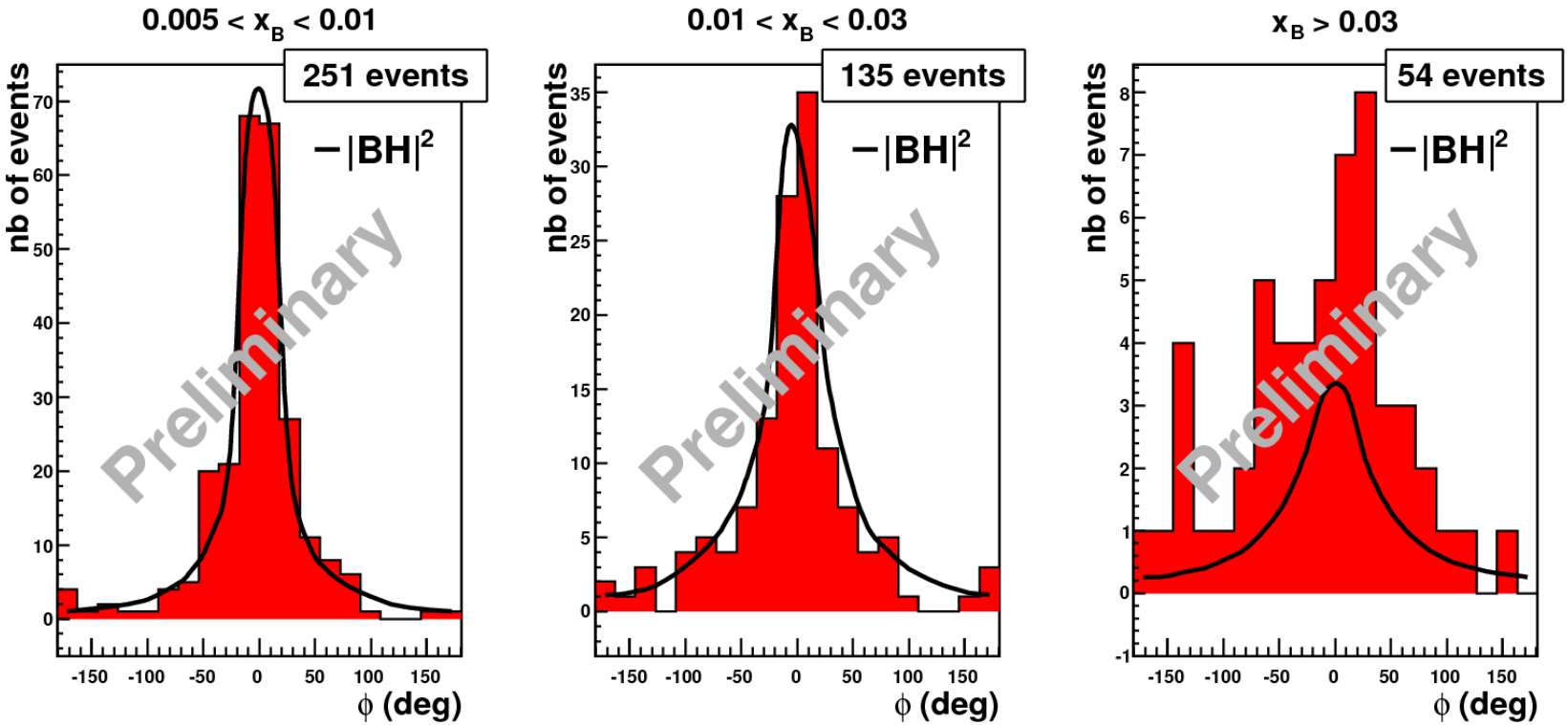
- exclusive measurements
- 40 cm long lH_2 target
- short recoil proton detector (for triggering and PID)
- two ECALs
- subset of triggers



- prediction from MC simulation (using VGG for DVCS) including detector acceptance
- low x data dominated by BH, high x data dominated by DVCS

Signal in 2009

- vertex with μ,μ', no other charged track, 1 high energy γ, proton in RPD



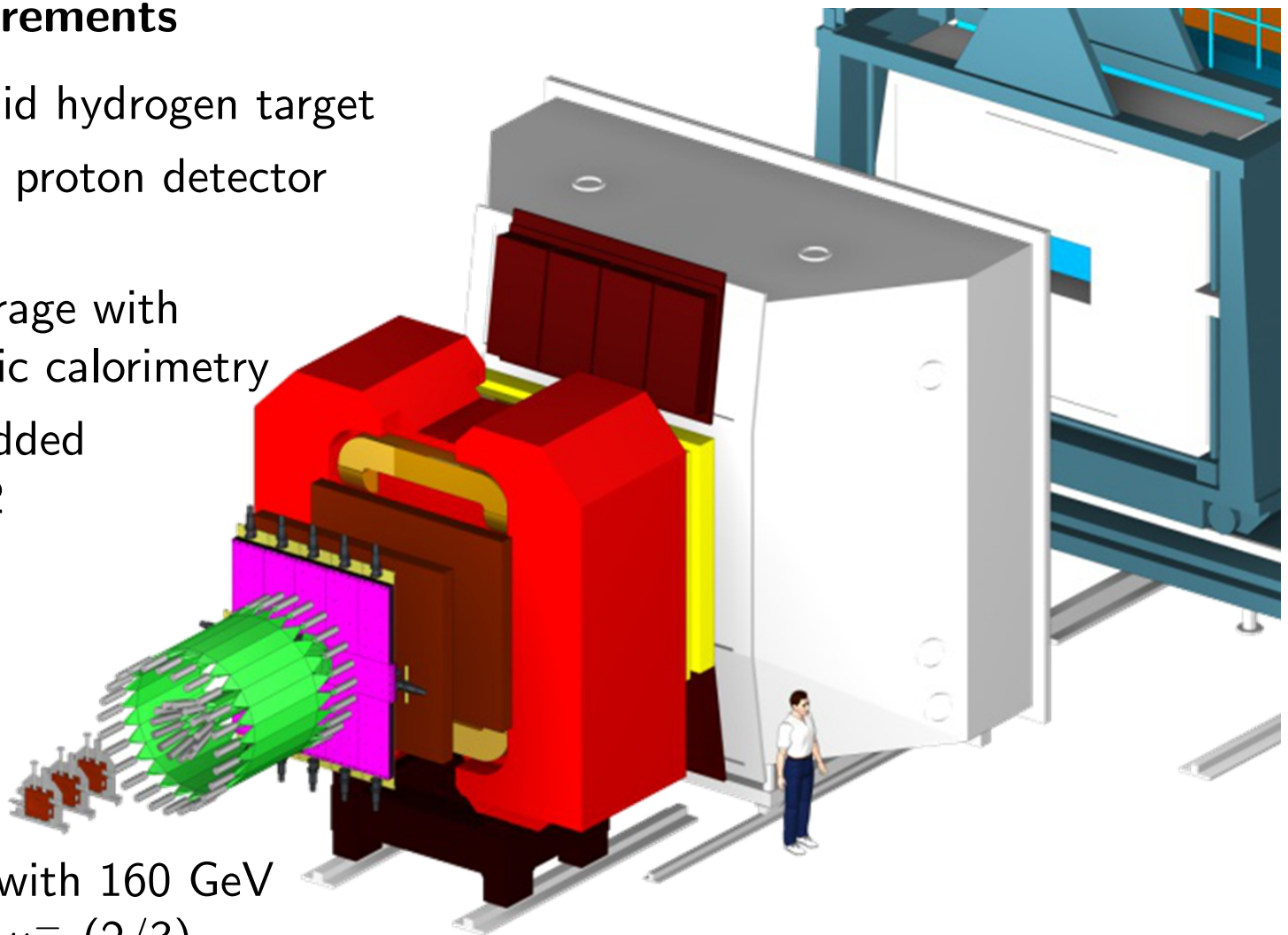
- result confirms expectations: 54 events observed with 20 from BH, excess of 34 events (2/3 DVCS, 1/3 π^0)
- shape in ϕ determined by current photon acceptance in ECAL1/2
- ECAL0 needed for more uniform acceptance in ϕ

  $\Longrightarrow$ clear DVCS signal observed at $Q^2 > 1$ GeV^2, $x_{Bj} > 0.03$

New target region for DVCS

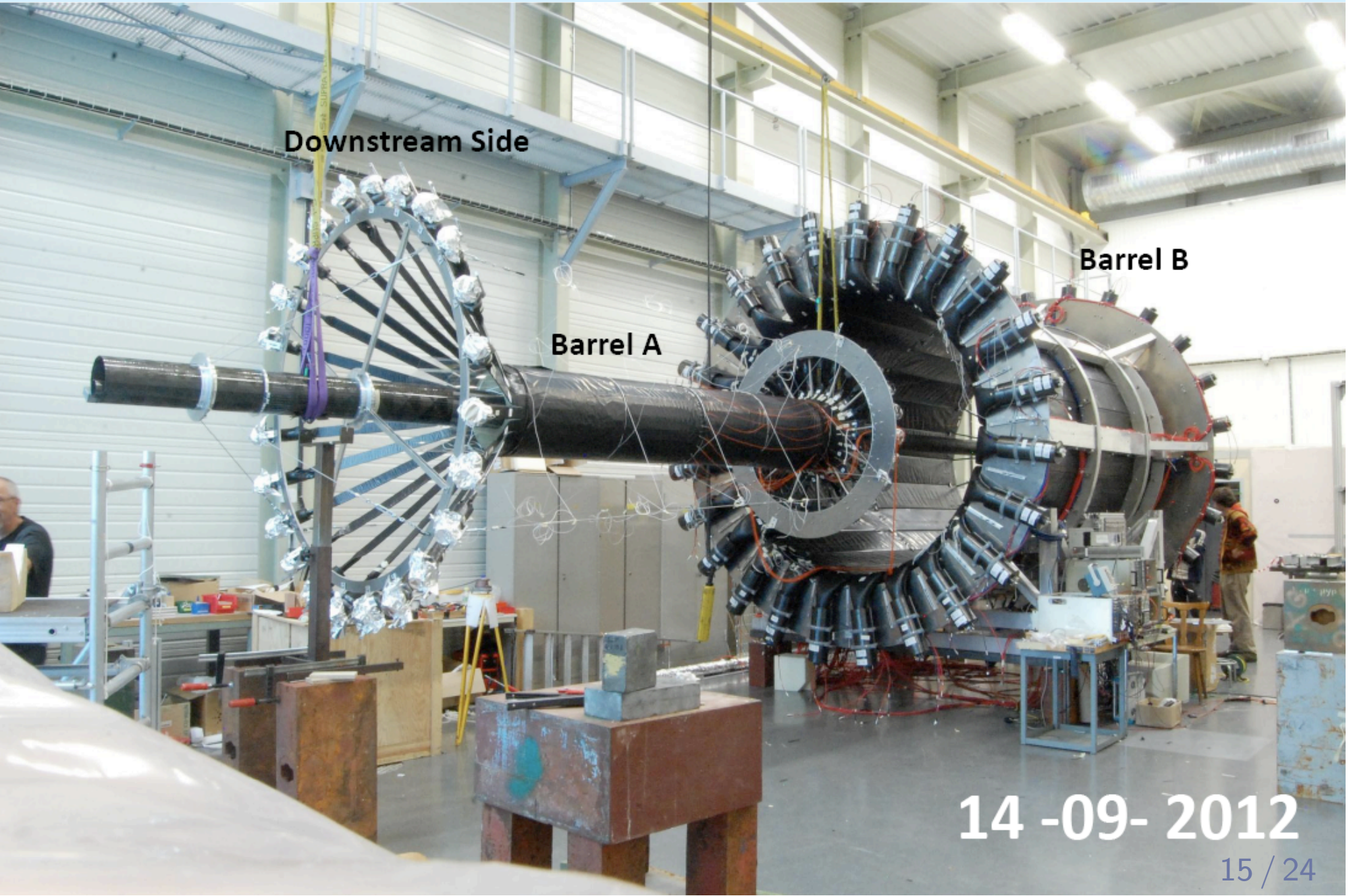
Exclusive measurements

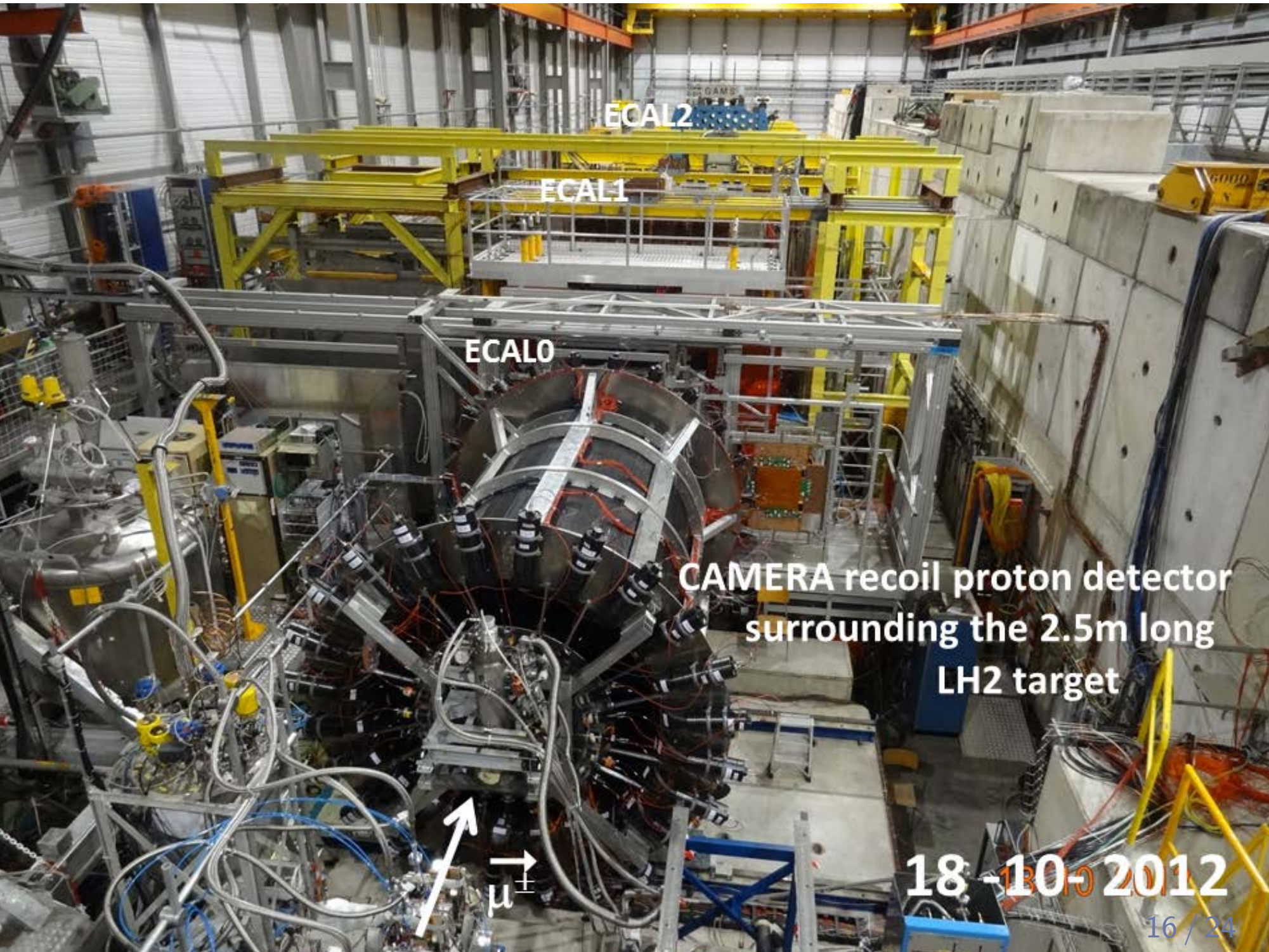
- 2.5m long liquid hydrogen target
- 4m long recoil proton detector (CAMERA)
- hermetic coverage with electromagnetic calorimetry
- new ECAL0 added partial in 2012



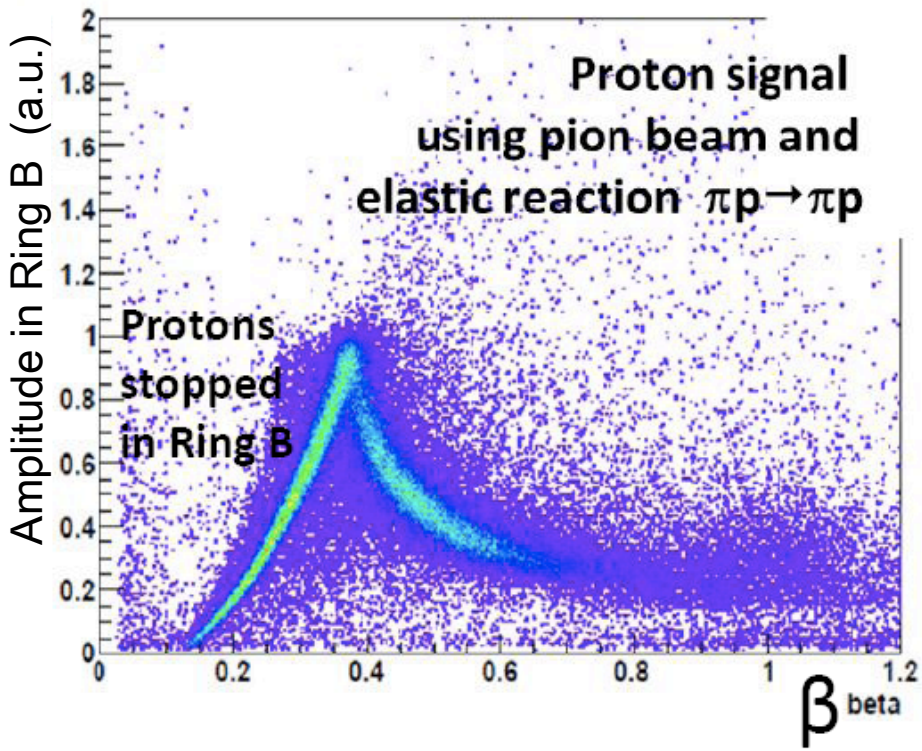
- measurement with 160 GeV μ^+ (1/3) and μ^- (2/3)
- pilot run 2012

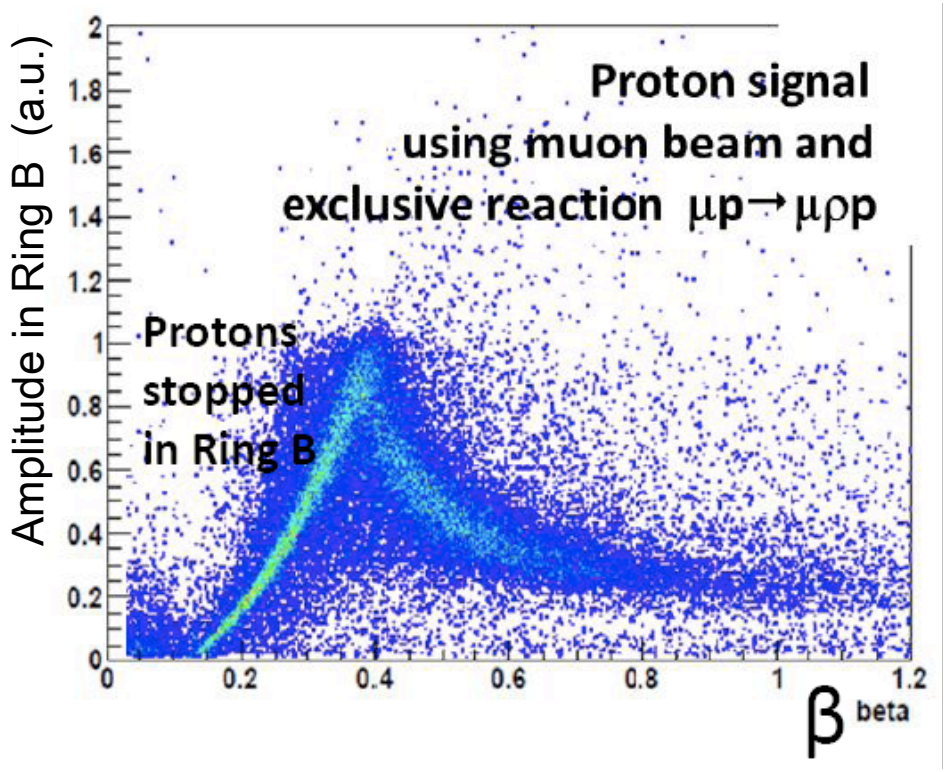
Mounting in clean area at CERN




ECAL2
ECAL1
ECAL0
CAMERA recoil proton detector
surrounding the 2.5m long
LH2 target
$\vec{\mu}^{\pm}$
18 -10- 2012

CAMERA performance





Observables

Phase 1: DVCS experiment to constrain GPD H

- Beam charge & Spin Sum:

$$\mathcal{S}_{CS,U} \equiv \mathrm{d}\sigma^{+\downarrow} + \mathrm{d}\sigma^{-\uparrow} = 2(\mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS}_{unpol} + e_\mu P_\mu a^{BH}\,\mathrm{Im}\,A^{DVCS})$$

$$\overset{\mathrm{LO}}{\propto} \mathrm{d}\sigma^{BH} + c_0^{DVCS} + s_1^I \sin\phi$$

  - integration over ϕ and subtraction of BH: $\mathrm{d}\sigma^{DVCS}_{unpol}$
  - ϕ dependence: $\mathbf{s_1^I \propto \mathrm{Im}\,(F_1 \mathcal{H})}$, F_1 Dirac form factor

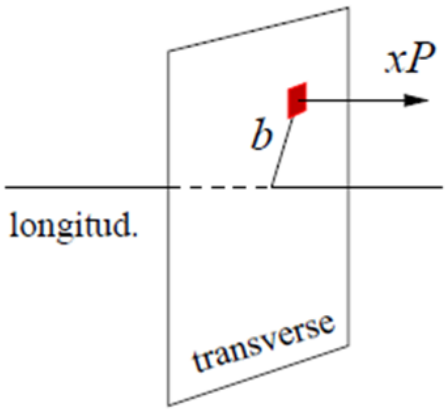
- Beam charge & Spin Difference:

$$\mathcal{D}_{CS,U} \equiv \mathrm{d}\sigma^{+\downarrow} - \mathrm{d}\sigma^{-\uparrow} = 2P_\mu \mathrm{d}\sigma^{DVCS}_{pol} + e_\mu a^{BH}\mathrm{Re}\,A^{DVCS}$$

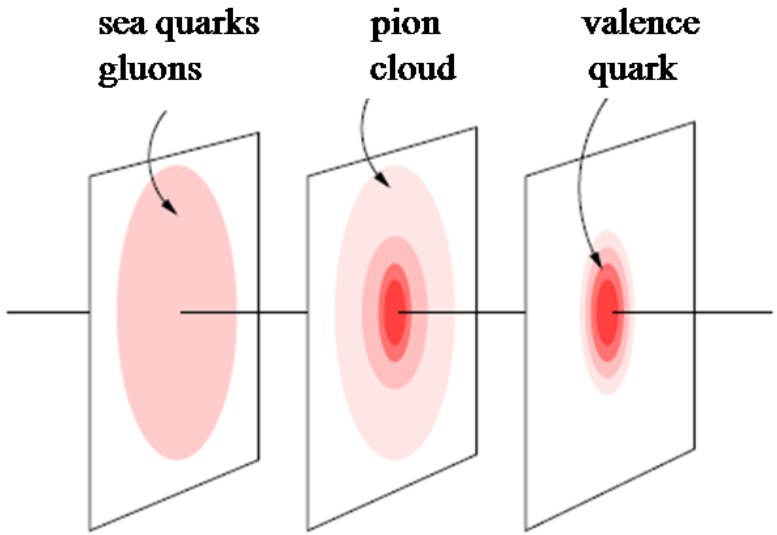
$$\overset{\mathrm{LO}}{\propto} c_0^I + c_1^I \cos\phi$$

  - ϕ dependence: $\mathbf{c_0^I, c_1^I \propto \mathrm{Re}\,(F_1 \mathcal{H})}$
  - alternatively beam charge & spin asymmetry: $\mathcal{A}_{CS,U} = \mathcal{D}_{CS,U}/\mathcal{S}_{CS,U}$

Nucleon tomography



(a)



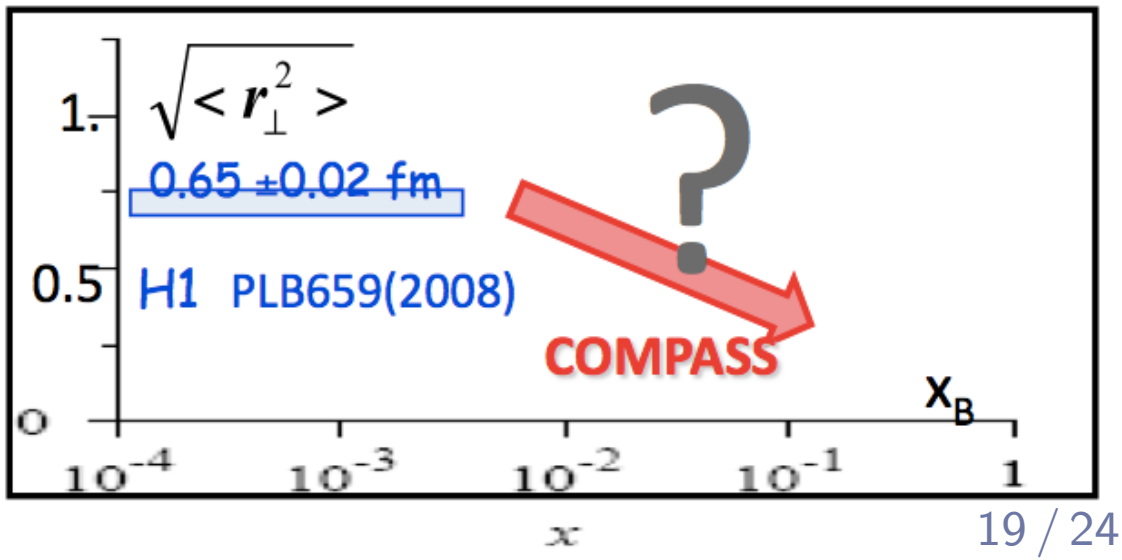
(b) $x \sim 0.003$ $x \sim 0.03$ $x \sim 0.3$

$\mathbf{b}_\perp$: distance to center of momentum

$r_\perp$: transverse size of nucleon

$r_\perp = b_\perp/(1-x)$

extraction only slightly model dependent

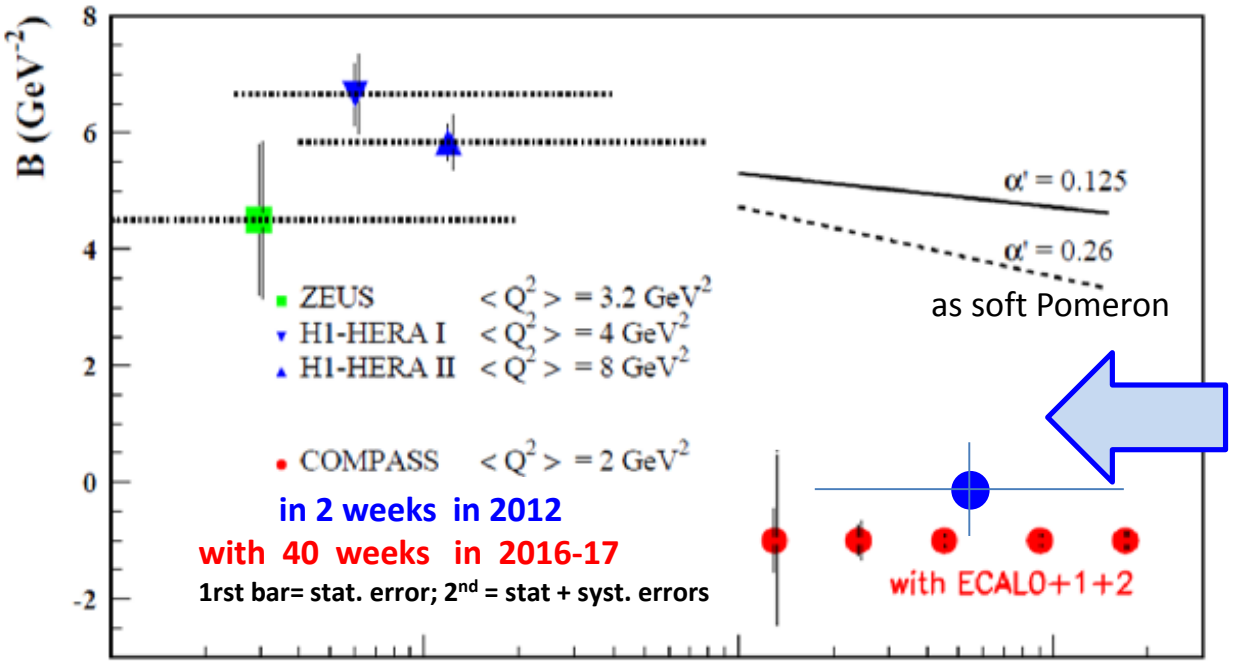


Transverse Imaging

- integration of $\mathcal{S}_{CS,U}$ over ϕ and BH subtraction yields

  $\mathrm{d}\sigma^{DVCS}/\mathrm{d}|t| \propto \exp(-B|t|)$ with $B(x) \sim 1/2\,\langle r_\perp^2(x)\rangle$

- Ansatz at small x_{Bj}: $x \approx x_{Bj}$, $B(x_{Bj}) = B_0 + 2\alpha' \ln \frac{x_0}{x_{Bj}}$



projections with
2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222$ pb^{-1}

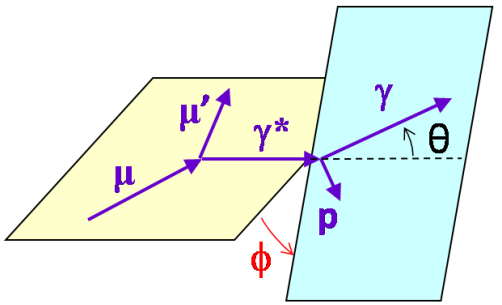
DVCS test in 2012]

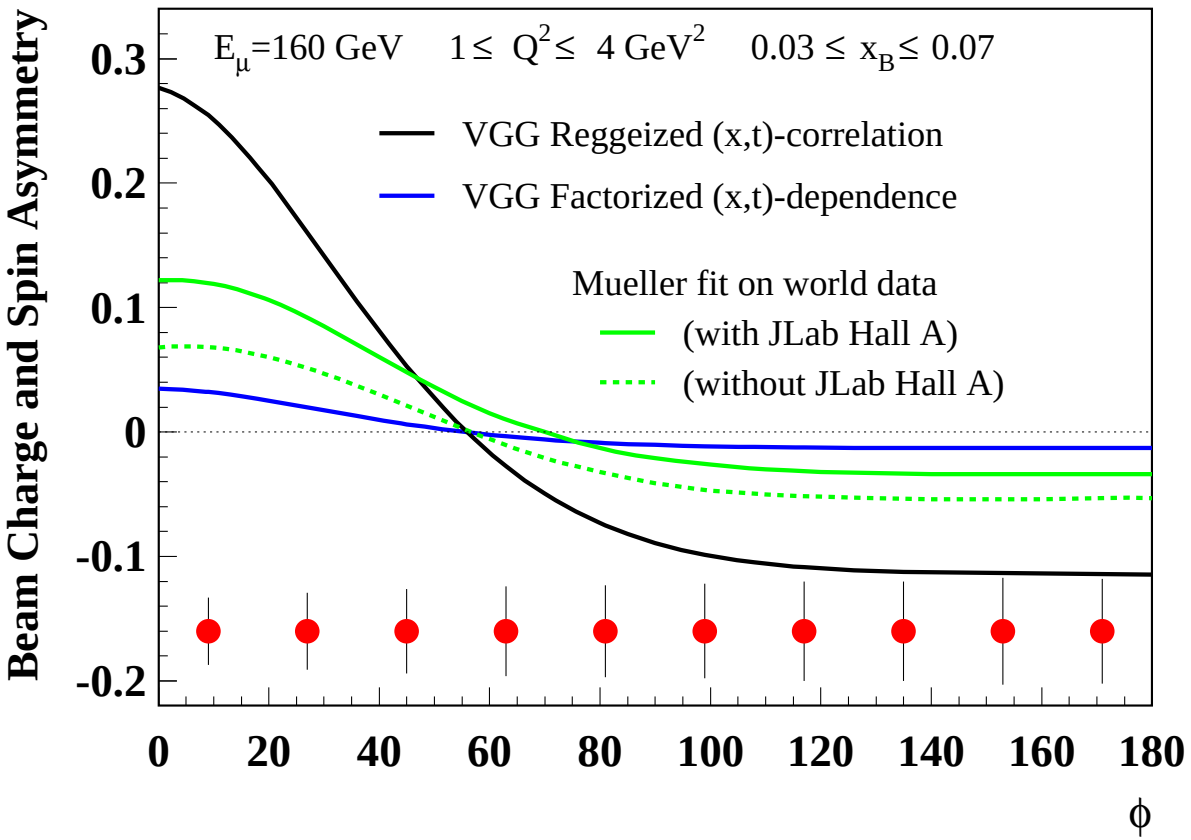
- 2012: 2 weeks data taking with nearly complete set-up

  $\Longrightarrow$ 1/20 of proposal stat.

Azimuthal dependence analysis

- analysis in bins of Q^2, x_{Bj} or t, x_{bj}
- comparison to different models



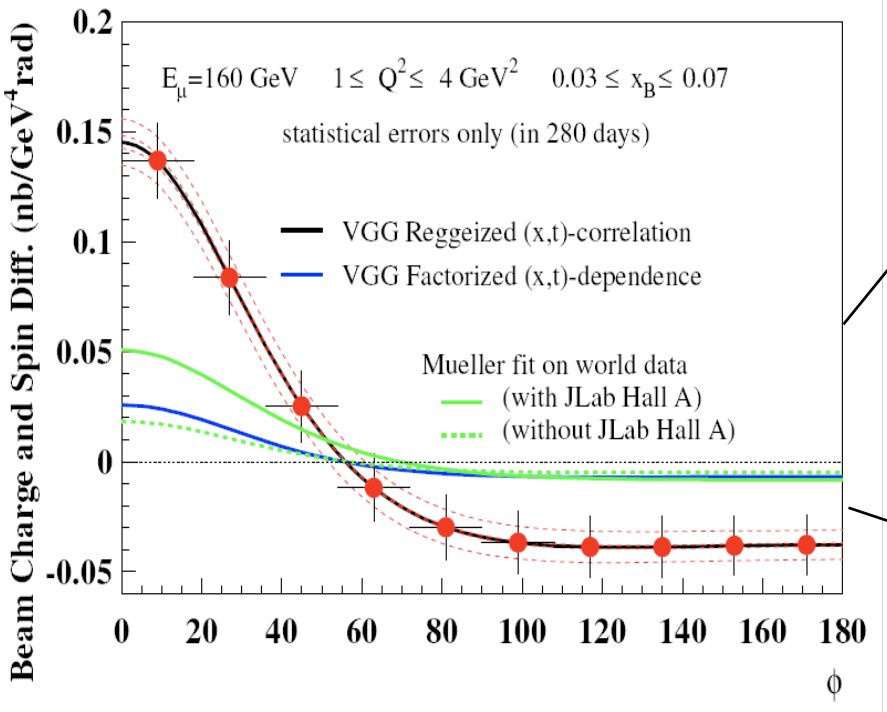


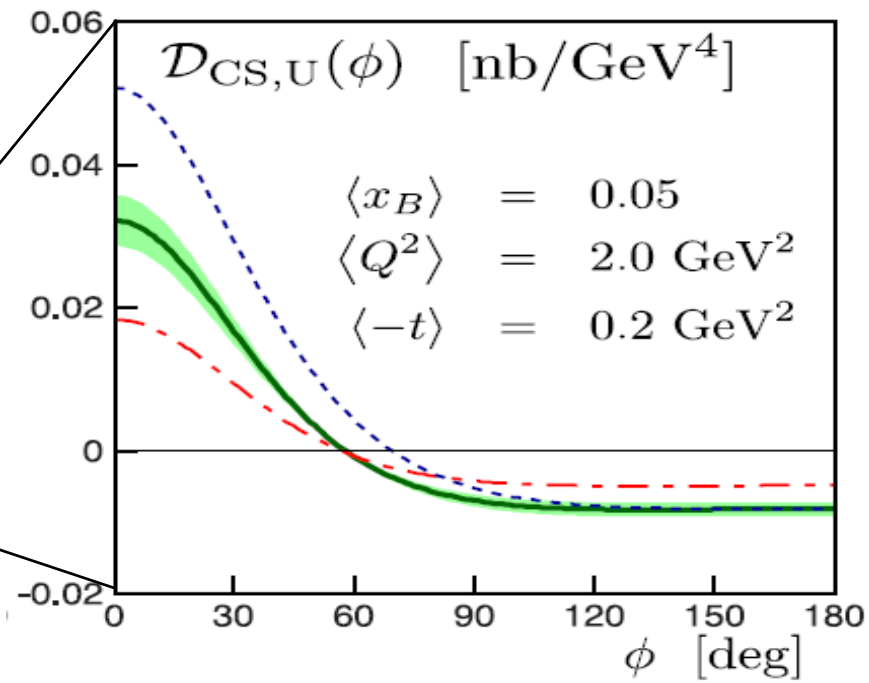
projections with
2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222\ \mathrm{pb}^{-1}$

$$\Longrightarrow \mathbf{c_1^I} \propto \mathbf{Re}(\mathbf{F_1}\mathcal{H})$$

Azimuthal dependence analysis

New predictions
by Kroll, Moutarde and Sabatié





Kroll, Moutarde, Sabatié

KM10a

KM10b

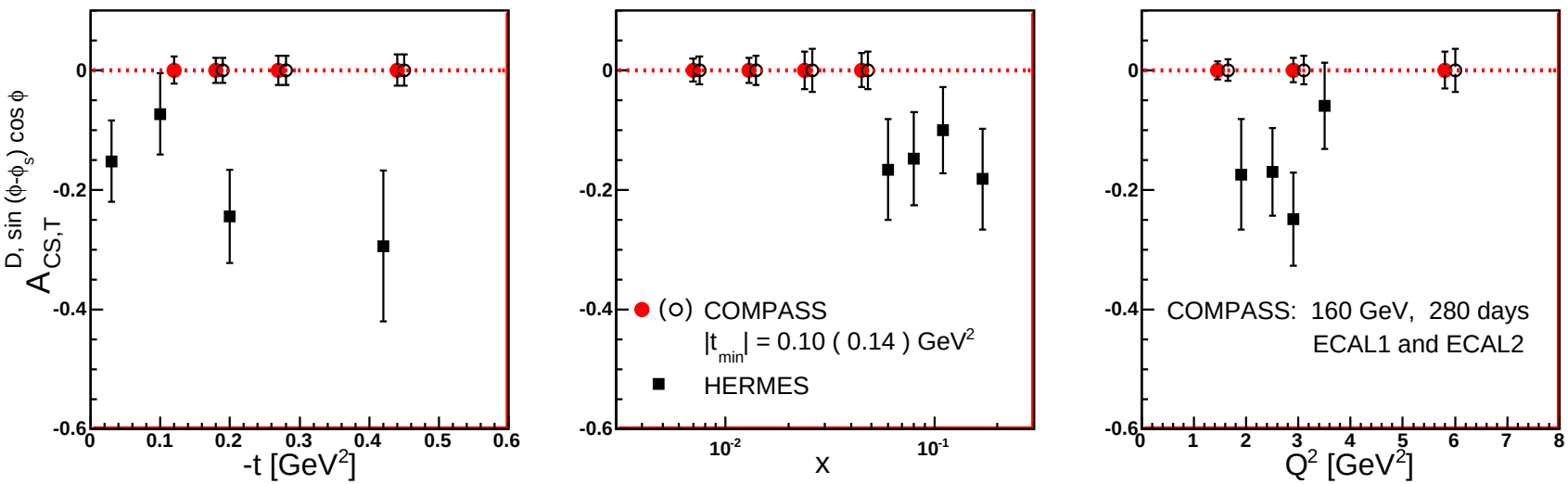
Towards GPD **E**

measurements with transversely polarised target

$$\mathcal{D}_{CS,T} \equiv \mathrm{d}\sigma_T(\mu^{+\downarrow}) - \mathrm{d}\sigma_T(\mu^{-\uparrow})$$
$$\overset{\mathrm{LO}}{\propto} \sin(\phi - \phi_S)(\, c^I_{0T} + c^I_{1T}\cos\phi)$$

$$c^I_{1T} \propto \mathrm{Im}\left((2-x)\, F_1\, \mathcal{E} - 4\,\frac{1-x}{2-x}\, F_2\, \mathcal{H}\right)$$

projections with
2 years of data
$\varepsilon_{global} = 10\%$
1.2 m pol. NH_3
target (f=0.26)



Outlook

Ongoing

- Analysis of 2012 data
- Optimisation of set-up for DVCS and HEMP measurment
- First cross section extraction possible

Future

- Long DVCS data taking in 2016/17
- Study of x_{Bj} dependence of transverse nucleon radius
- Extraction of Re(H) and Im(H) (model dependent.)
- In parallel:
  SIDIS measurements for multiplicities and TMDs
- Phase 2:
  Measurements with transverse target polarisation and recoil detector
  Extraction of GPD E to access Ji's sumrule