Prospects for a DVCS measurement at COMPASS

Eva-Maria Kabuß,
Institut für Kernphysik,
Mainz University
on behalf of the COMPASS collaboration

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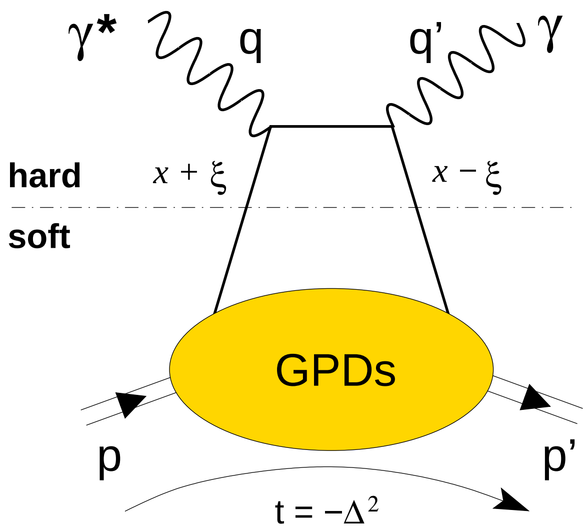
- **Physics motivation**
- **DVCS at COMPASS**
- **Observables**
- **Experimental challenges**
- **Test results**

Generalised parton distributions



Factorisation for
Q^2 large, $t < 1$ GeV^2

- **generalised parton distributions for quarks** $H^f, E^f, \widetilde{H}^f, \widetilde{E}^f(x,\xi,t)$
- **limits:**

$$\begin{aligned} q(x) &= H(x,0,0) && \text{normal PDF} \\ F(t) &= \int \mathrm{d}x\, H(x,\xi,t) && \text{elastic form factor} \end{aligned}$$

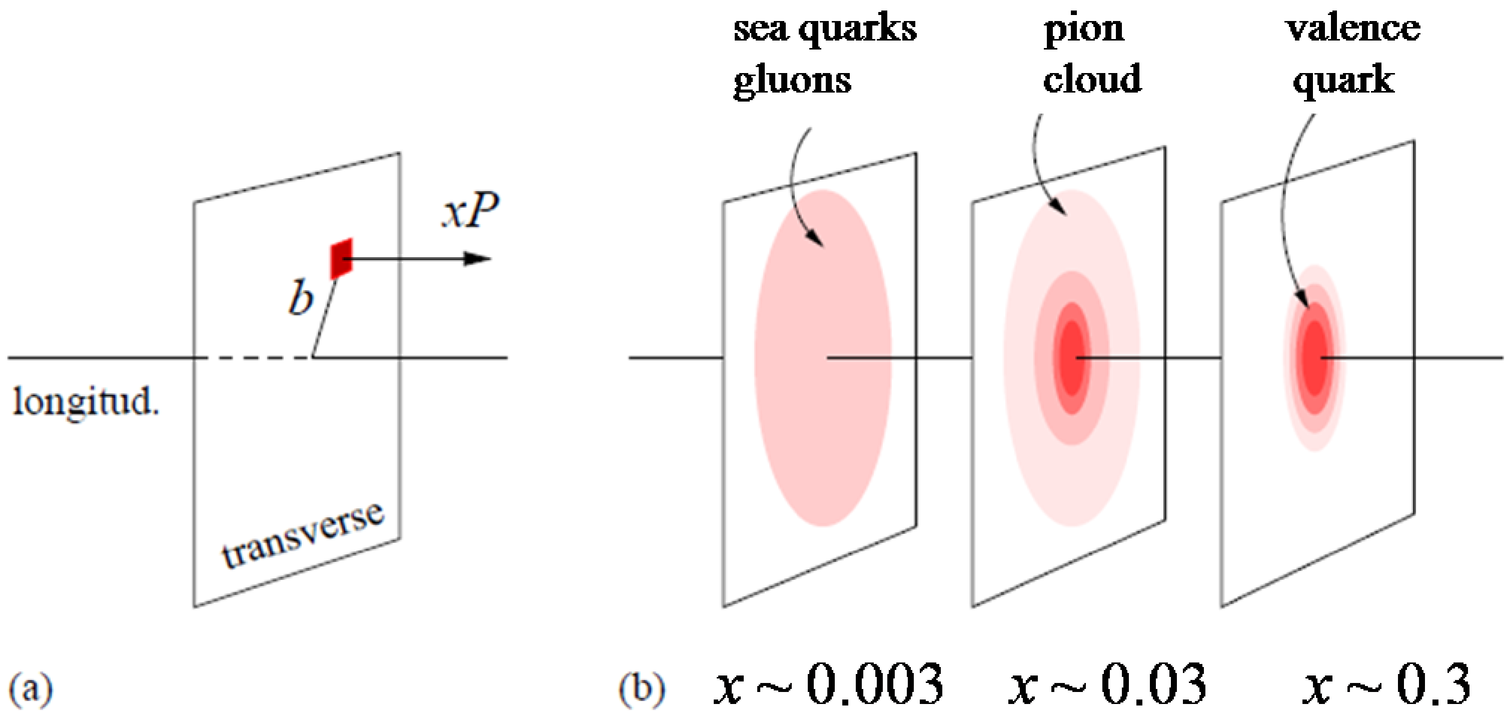
- **Ji's sumrule**

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

J^f: total angular momentum contribution of quark f

Nucleon tomography

- GPDs allow simultaneous measurement of longitudinal momentum and transverse spatial structure



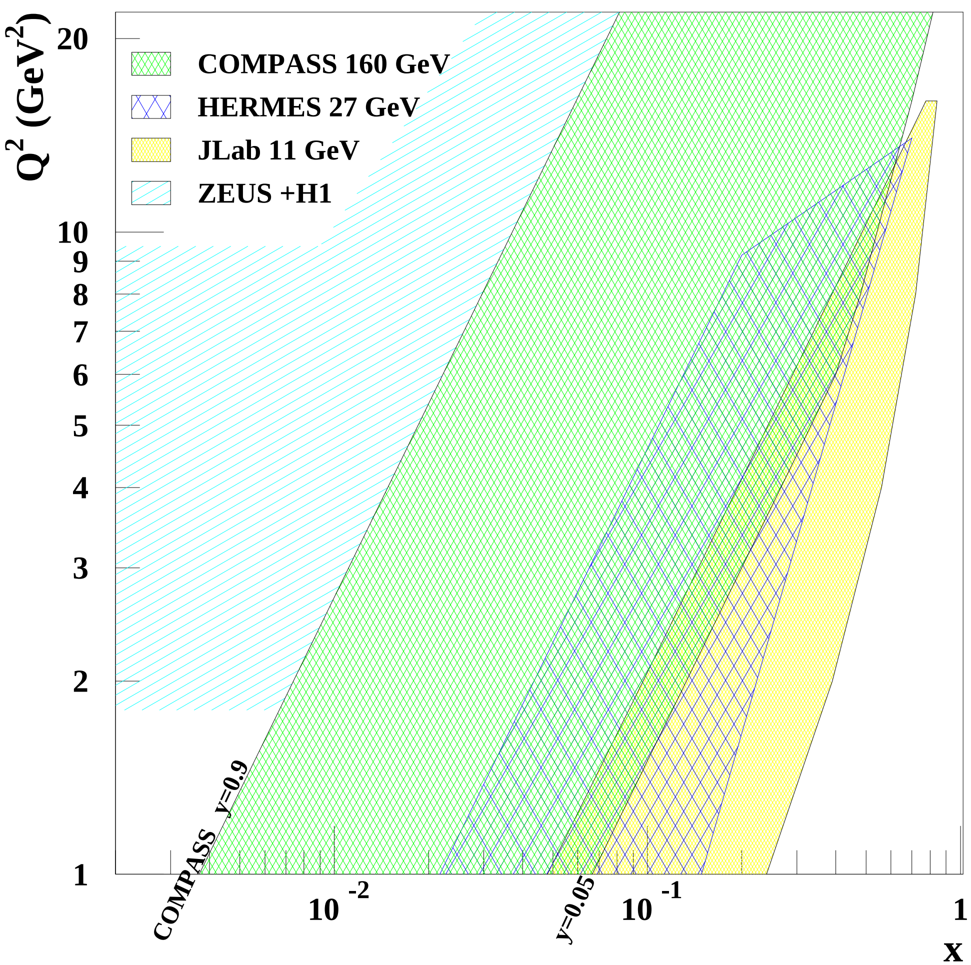
- for $\xi \to 0$: $t = -\boldsymbol{\Delta}_\perp^2$ purely transverse and

$$q^f(x, \boldsymbol{b}_\perp) = \int \frac{\mathrm{d}^2\boldsymbol{\Delta}_\perp}{(2\pi)^2} e^{-i\boldsymbol{\Delta}_\perp \cdot \boldsymbol{b}_\perp} H^f(x, 0, -\boldsymbol{\Delta}_\perp^2)$$

- $\boldsymbol{b}_\perp$ distance to center of momentum (b in figure is $\boldsymbol{b}_\perp$)

Why GPDs at COMPASS?

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



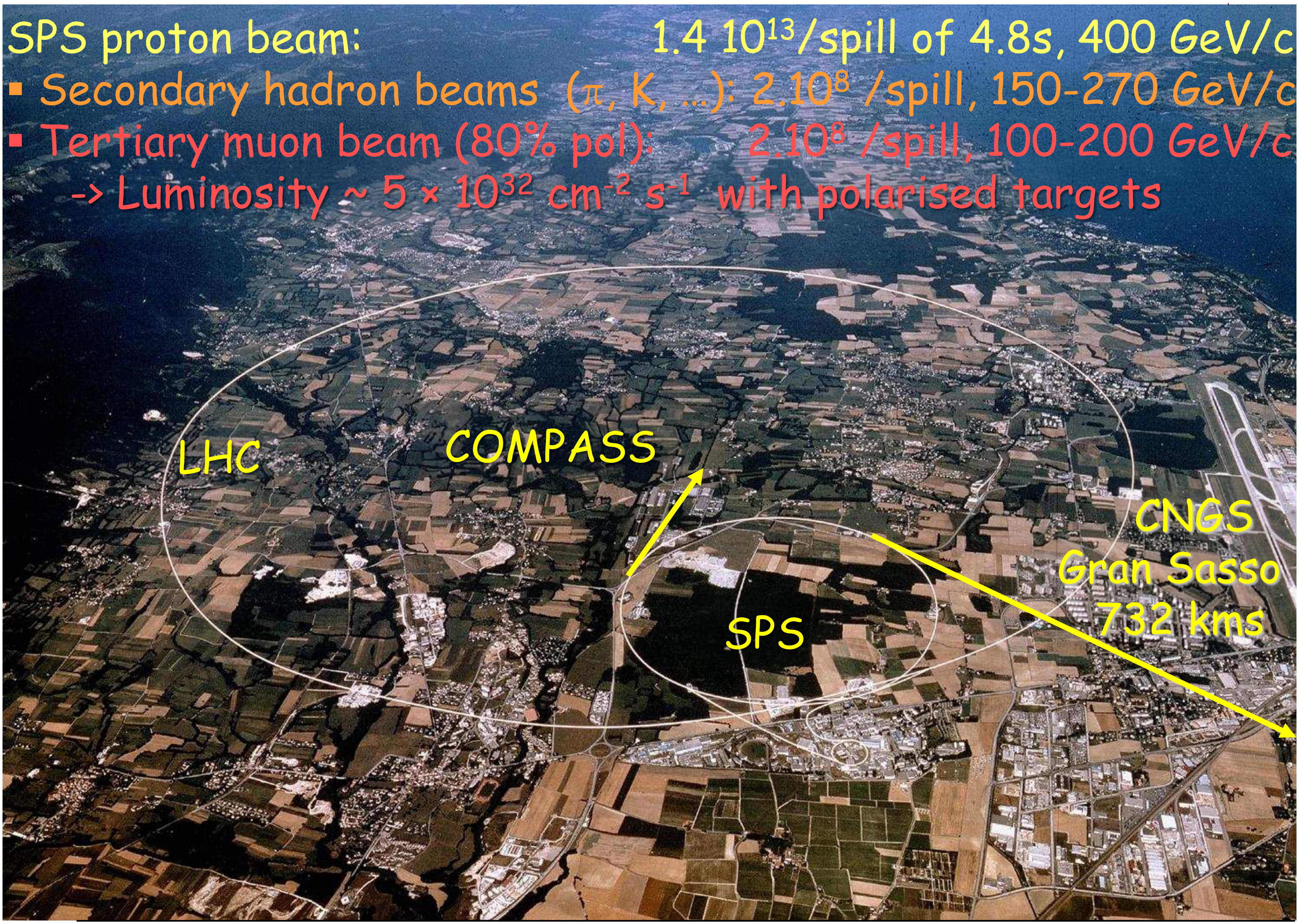
- **unique kinematic range** between HERA and HERMES/JLab
  - intermediate x_{Bj}: $\Longrightarrow$ sea and valence quarks
  - high x_{Bj} limit from acceptance
  - Q^2 up to 8GeV^2 $\Longrightarrow$ limit from cross section with $L = 10^{32}$ cm^{-2}s^{-1}

- **planned measurements:**
  - deeply virtual Compton scattering
  - deeply virtual meson production

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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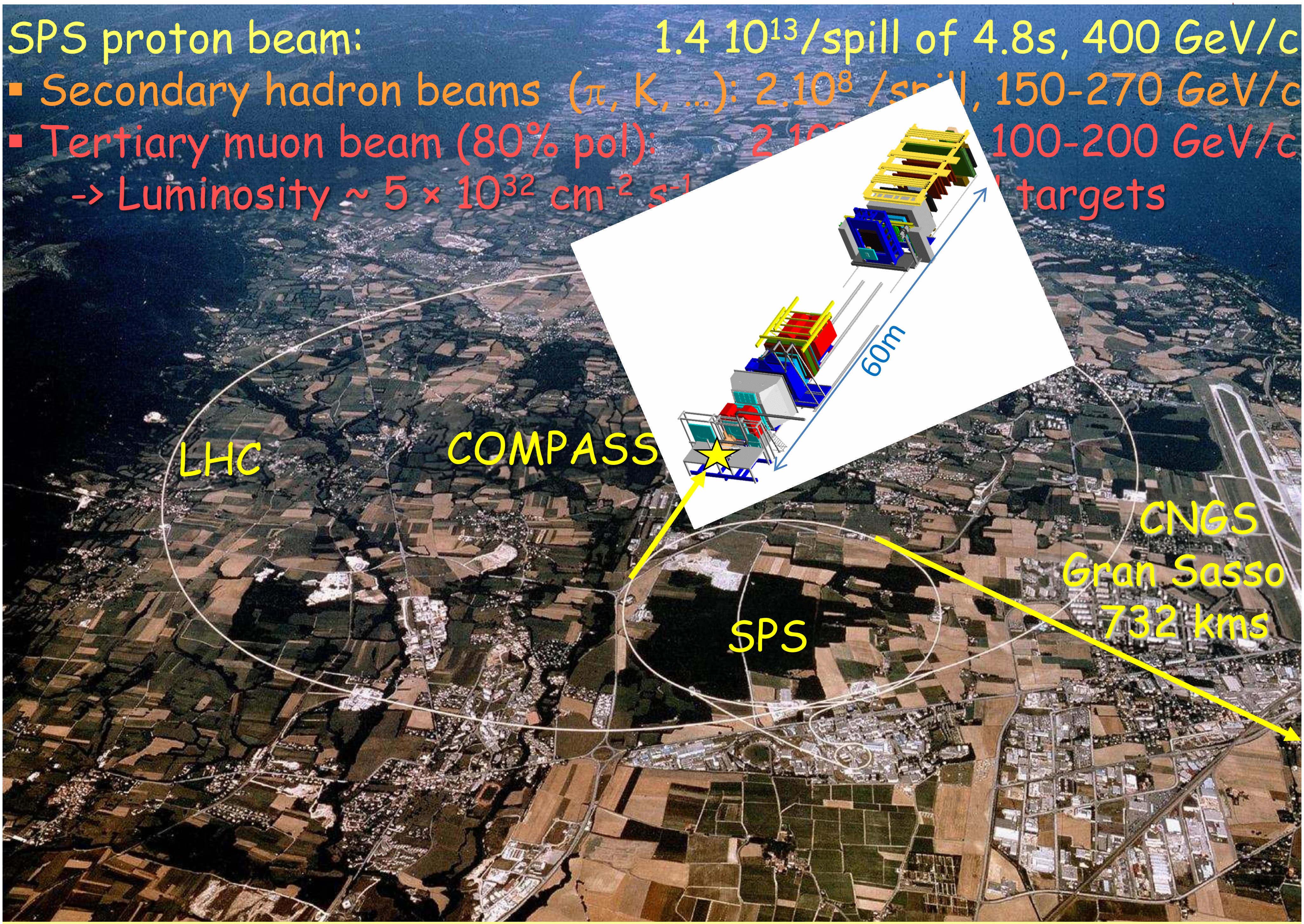
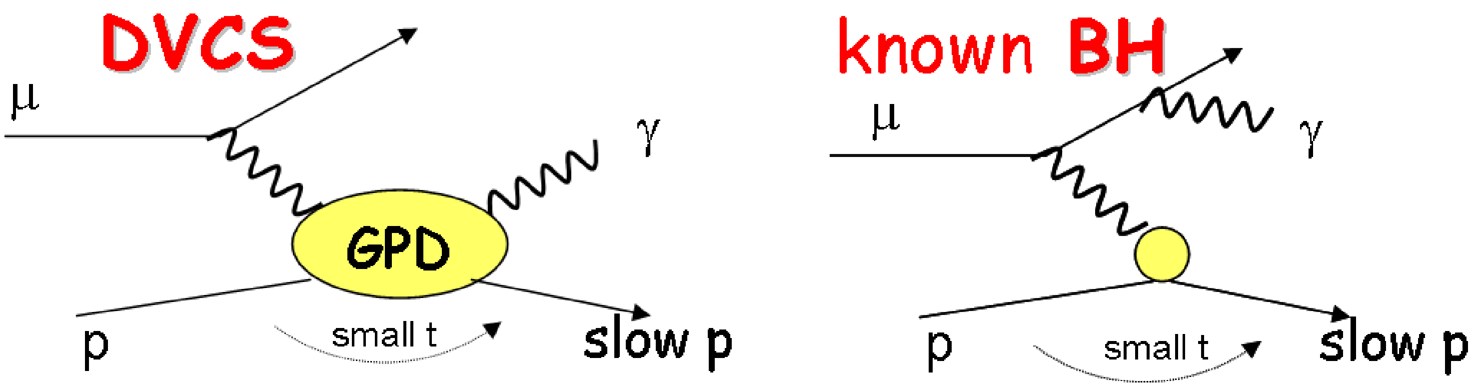


high energy beam(s), broad kinematic range, large angular acceptance

DVCS at COMPASS

- at COMPASS energies contribution from DVCS and Bethe-Heitler

$$\mu p \longrightarrow \mu \gamma p$$

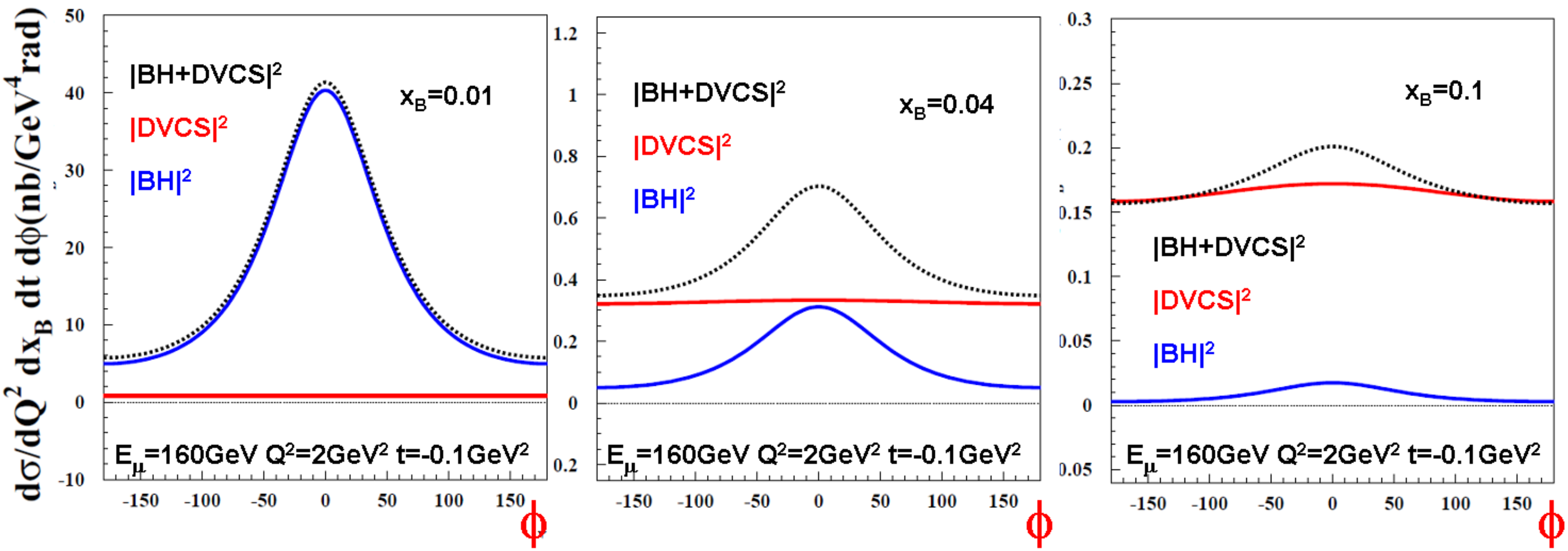


$$\mathrm{d}\sigma = \mathrm{d}\sigma^{BH} + \mathrm{d}\sigma^{DVCS} + \text{interference term}$$

BH	control of experiment
DVCS	$\mathrm{d}\sigma^{DVCS}/\mathrm{d}\lvert t\rvert$
Interference	$\mathrm{Re}A^{DVCS}$ and $\mathrm{Im}A^{DVCS}$

Comparison of BH and DVCS at 160 GeV

- $Q^2 = 2\,\text{GeV}^2$, $|t| = 0.1\,\text{GeV}^2$



BH dominates, excellent reference yield

BH and DVCS compatible, access to DVCS amplitue using interference

DVCS dominates, study of $d\sigma/d|t|$, not possible at JLab

Observables

Phase 1: DVCS experiment to constrain GPD H

$$\mu^{+\downarrow}(P=-0.8),\ \mu^{-\uparrow}(P=0.8),\ \text{unpol. proton target } (\text{lH}_2)$$

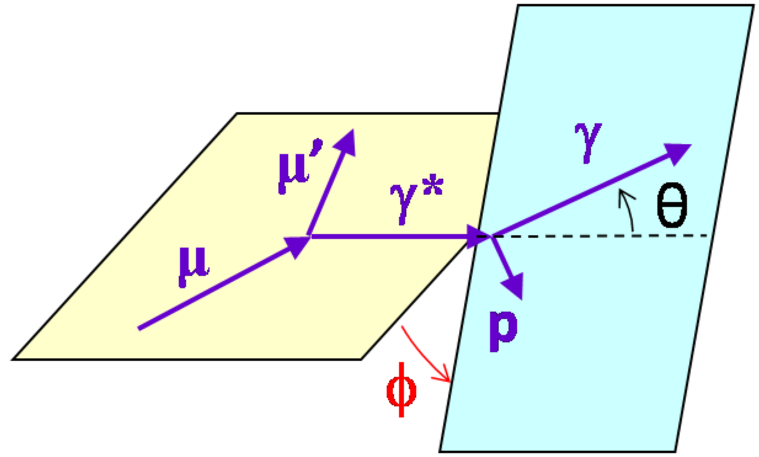
- Beam charge & Spin Sum: $\mathcal{S}_{CS,U} \equiv \mathrm{d}\sigma^{+\downarrow} + \mathrm{d}\sigma^{\downarrow}$
- Beam charge & Spin Difference: $\mathcal{D}_{CS,U} \equiv \mathrm{d}\sigma^{+\downarrow} - \mathrm{d}\sigma^{-\uparrow}$
- additionally deeply virtual meson production

Phase 2: DVCS experiment to constrain GPD E

$$\mu^{+\downarrow}(P=-0.8),\ \mu^{-\uparrow}(P=0.8),\ \text{transversely pol. proton target } (\text{NH}_3)$$

- $\mathcal{D}_{CS,T} \equiv \left(\mathrm{d}\sigma^{+\downarrow}(\phi,\phi_S) - \mathrm{d}\sigma^{+\downarrow}(\phi,\phi_S+\pi)\right) - \left(\mathrm{d}\sigma^{-\uparrow}(\phi,\phi_S) - \mathrm{d}\sigma^{+\uparrow}(\phi,\phi_S+\pi)\right)$
- $\mathcal{S}_{CS,T} \equiv \Big(\mathrm{d}\sigma^{+\downarrow}(\phi,\phi_S) - \mathrm{d}\sigma^{+\downarrow}(\phi,\phi_S+\pi)\Big) + \Big(\mathrm{d}\sigma^{-\uparrow}(\phi,\phi_S) - \mathrm{d}\sigma^{+\uparrow}(\phi,\phi_S+\pi)\Big)$
- yielding two asymmetries $\mathcal{A}^{D}_{CS,T} = \frac{\mathcal{D}_{CS,T}}{\Sigma_{unpol}}$ and $\mathcal{A}^{S}_{CS,T} = \frac{\mathcal{S}_{CS,T}}{\Sigma_{unpol}}$

Azimuthal angular dependence



- **cross section**

$$\frac{\mathrm{d}^4\sigma(\mu p \to \mu p \gamma)}{\mathrm{d}x_{Bj}\mathrm{d}Q^2\mathrm{d}|t|\mathrm{d}\phi} = \mathrm{d}\sigma$$

for 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)

BCSS and BCSD

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

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

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

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

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

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

Parametrisations of GPDs

- **predictions with different models**

  with factorisation: $H(x,\xi,t) \propto q(x)F(t)$

  with Regge motivated t dependence: x-t correlation

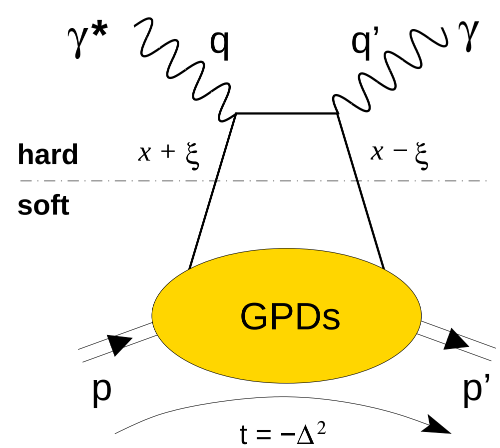
  - idea: core of fast partons, meson cloud at larger distance
    $H(x,0,t) \propto q(x)\exp(-B|t|)$
  - Ansatz: $B = 1/2\,\langle b_\perp^2\rangle = B_0 + 2\alpha' \ln\frac{x_0}{x}$
    (α' slope of Regge trajectory)
  - valence quarks: $\alpha' \sim 1$ GeV^{-2} from form factors, gluons: α' small

- **coefficients** in cross section related to **Compton form factor** $\mathcal{H}(\xi,t)$

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

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

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

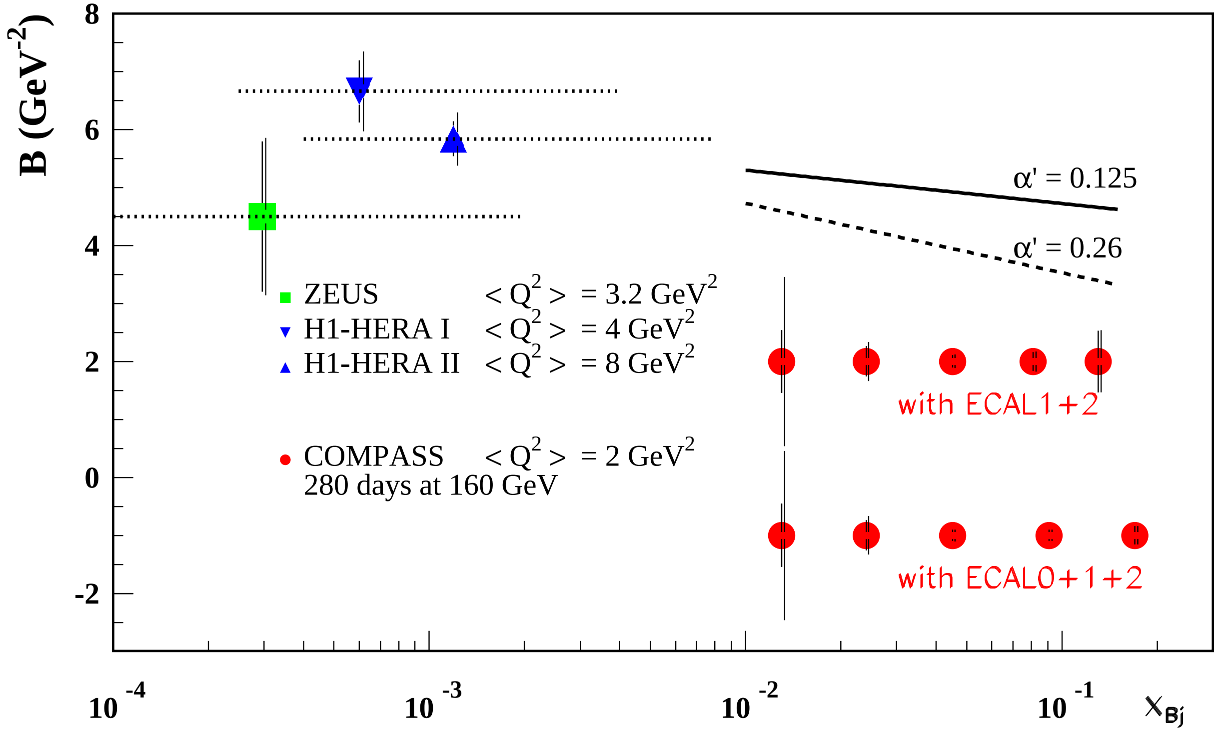


Transverse imaging

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

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

- $r_\perp$ transverse size of nucleon: $r_\perp = b_\perp/(1-x)$



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

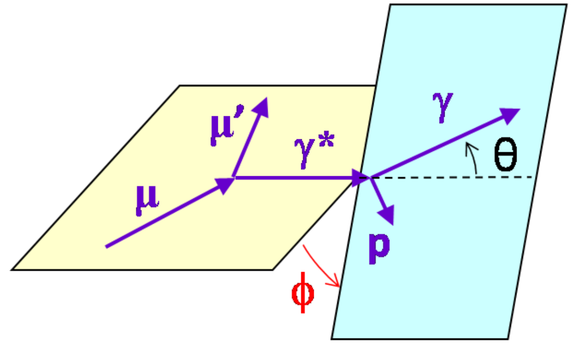
Ansatz at small x_{Bj}:
$(x \approx x_{Bj})$

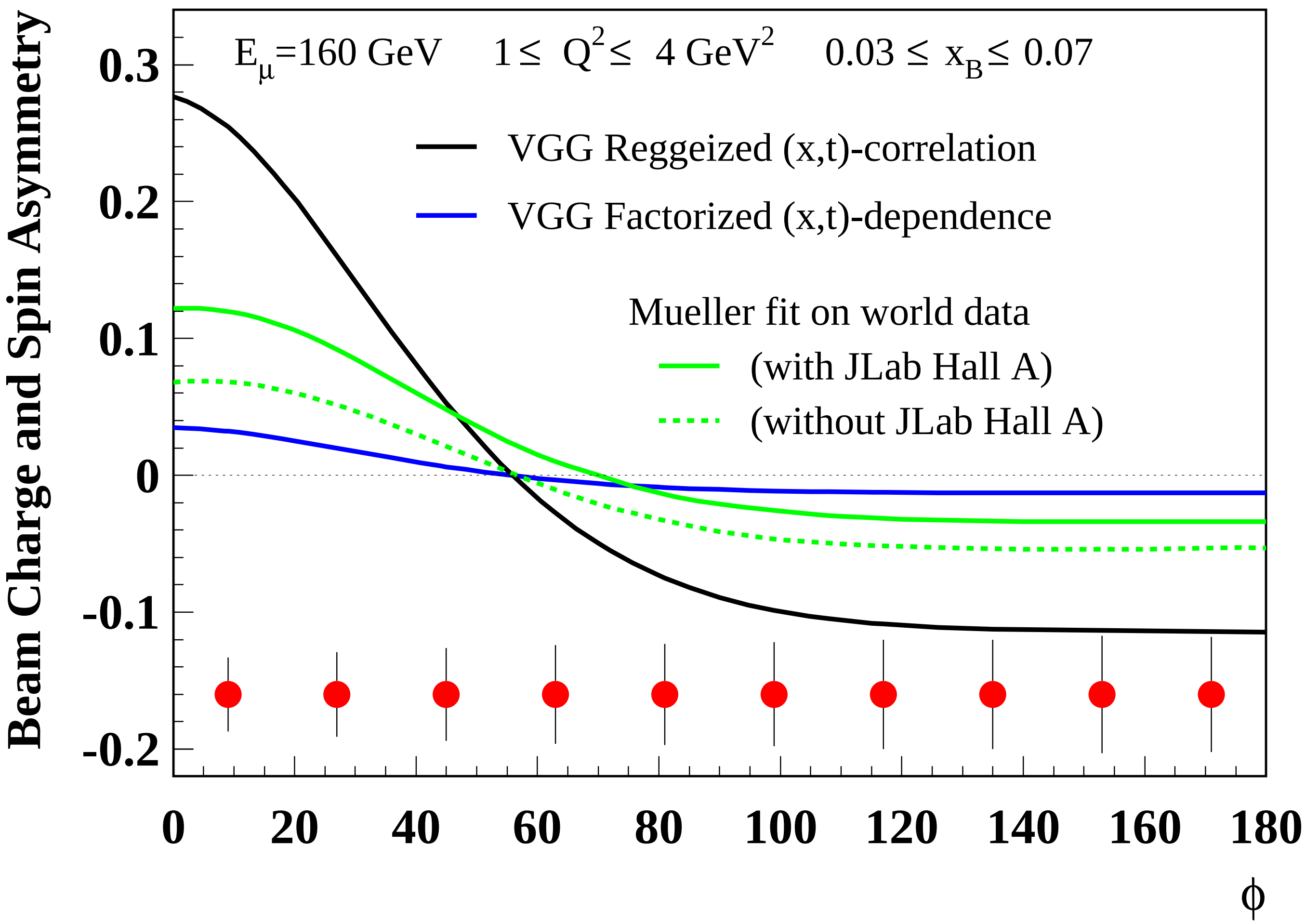
$$B(x_{Bj}) = B_0 + 2\alpha' \ln \frac{x_0}{x_{Bj}}$$

- determination of B with 0.1 GeV^{-2} accuracy, α' with 3σ acc. if $\alpha' \geq 0.16$
- no model dependence

Azimuthal dependence analysis

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

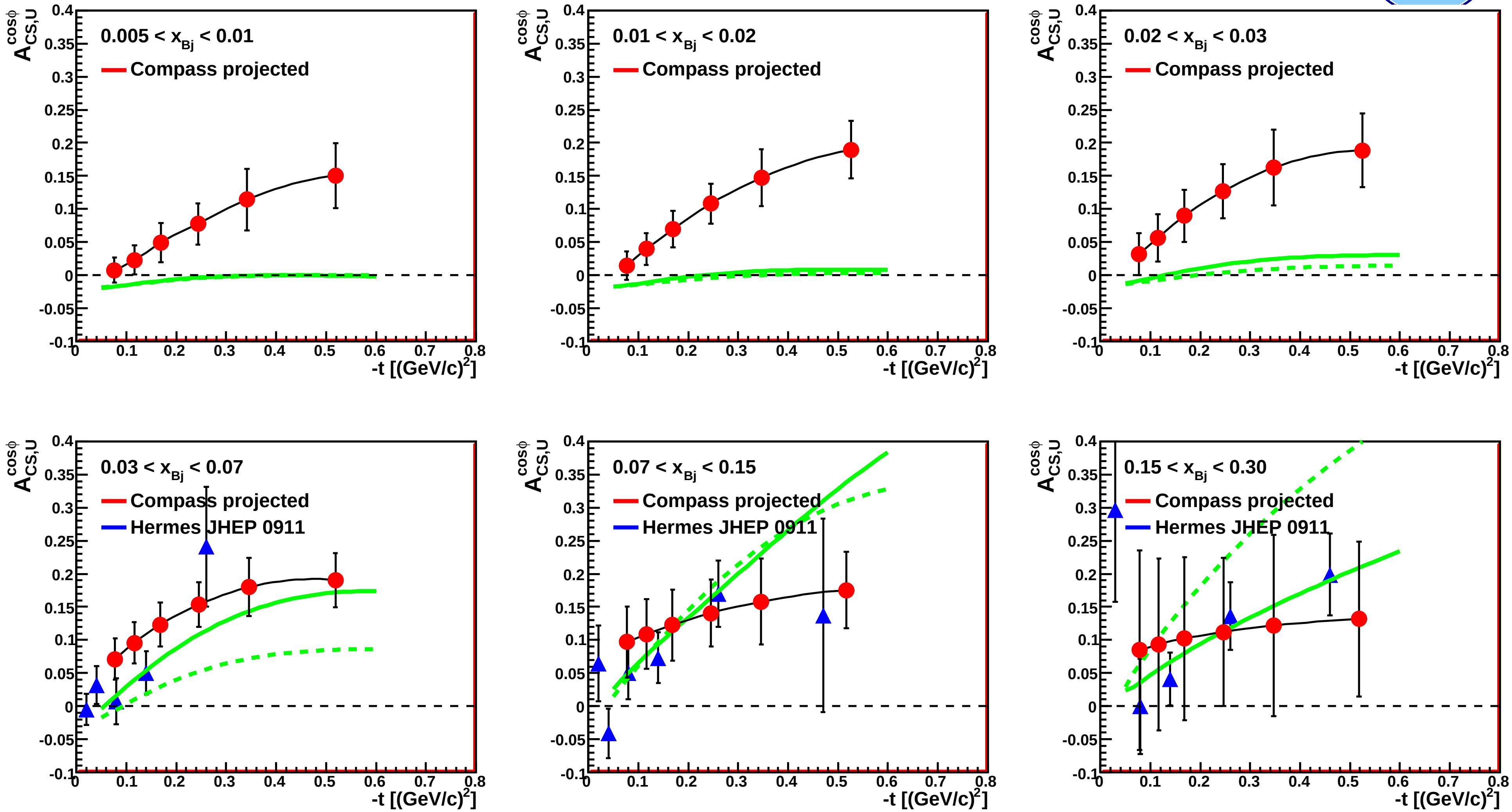




projections with
2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222$ pb^{-1}

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

Projections for $\cos\phi$ modulation



Projection with VGG model (Regge Ansatz) compared to HERMES data

Deeply virtual meson production

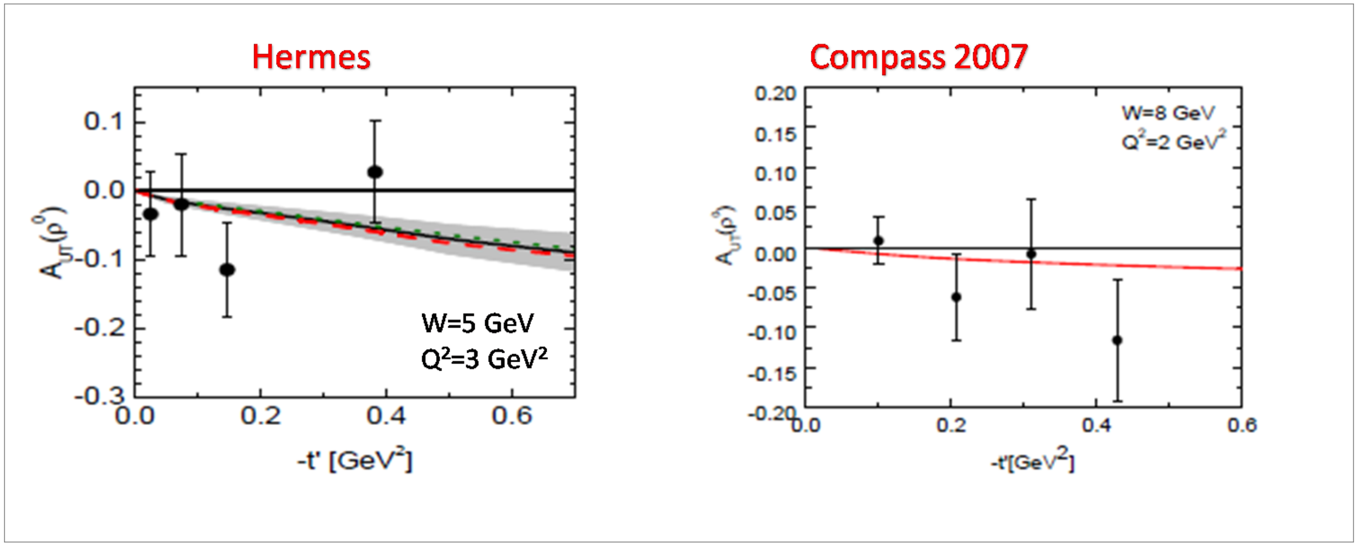
$$H_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}H^u + \frac{1}{3}H^d + \frac{3}{8}H^g\right), \quad H_\omega = \frac{1}{\sqrt{2}}\left(\frac{2}{3}H^u - \frac{1}{3}H^d + \frac{1}{8}H^g\right), \; H_\phi = -\frac{1}{3}H^s - \frac{1}{8}H^g$$

- **cross section measurement:** $\Longrightarrow \rho : \omega : \phi \approx 9 : 1 : 2$ at large Q^2

  Vector meson production (ρ, ω, Φ) $\Longrightarrow H, E$
  Pseudo-scalar production (π, η.....) $\Longrightarrow \widetilde{H}, \widetilde{E}$

- **transversely pol. target asymmetries:** constraint of E/H

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



larger effects expected for ω, ρ^+

Towards GPD E

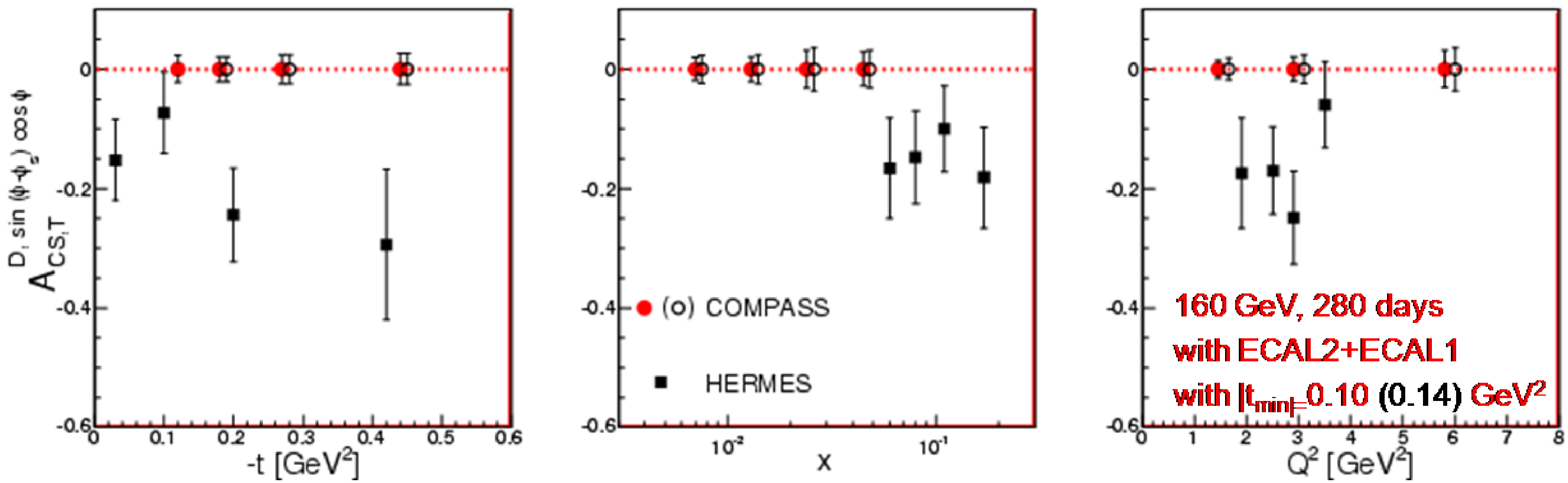
measurements with transversely polarised target

$$\mathcal{D}_{CS,T} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow})$$

$$\overset{\text{LO}}{\propto} \sin(\phi - \phi_S)(\, c^I_{0T} + c^I_{1T}\cos\phi)$$

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

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



Experimental challenges

Exclusive measurements

Phase 1:

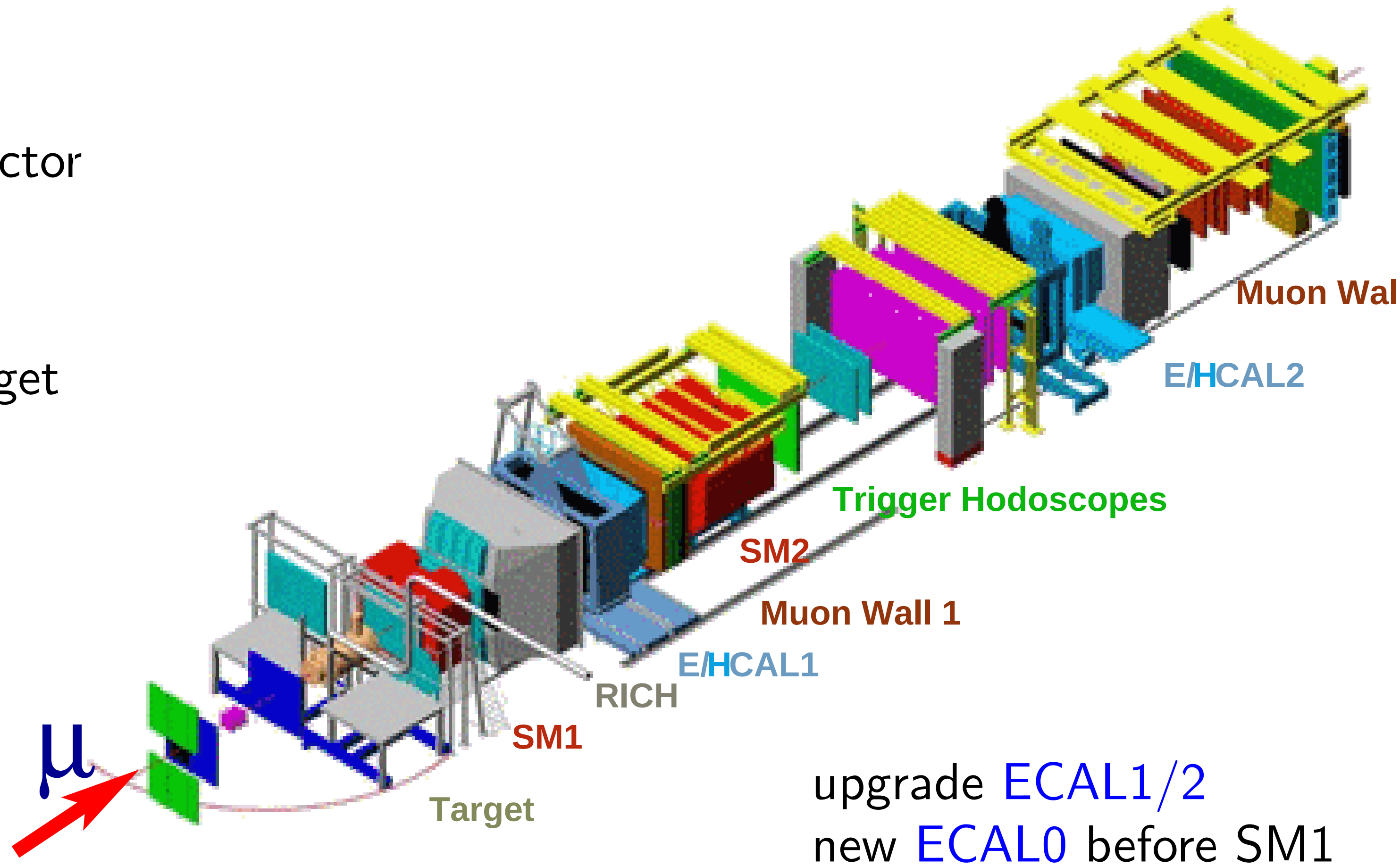
2.5 m lH_2 target
4 m long recoil detector

Phase 2:

transversely pol. target
with recoildetector

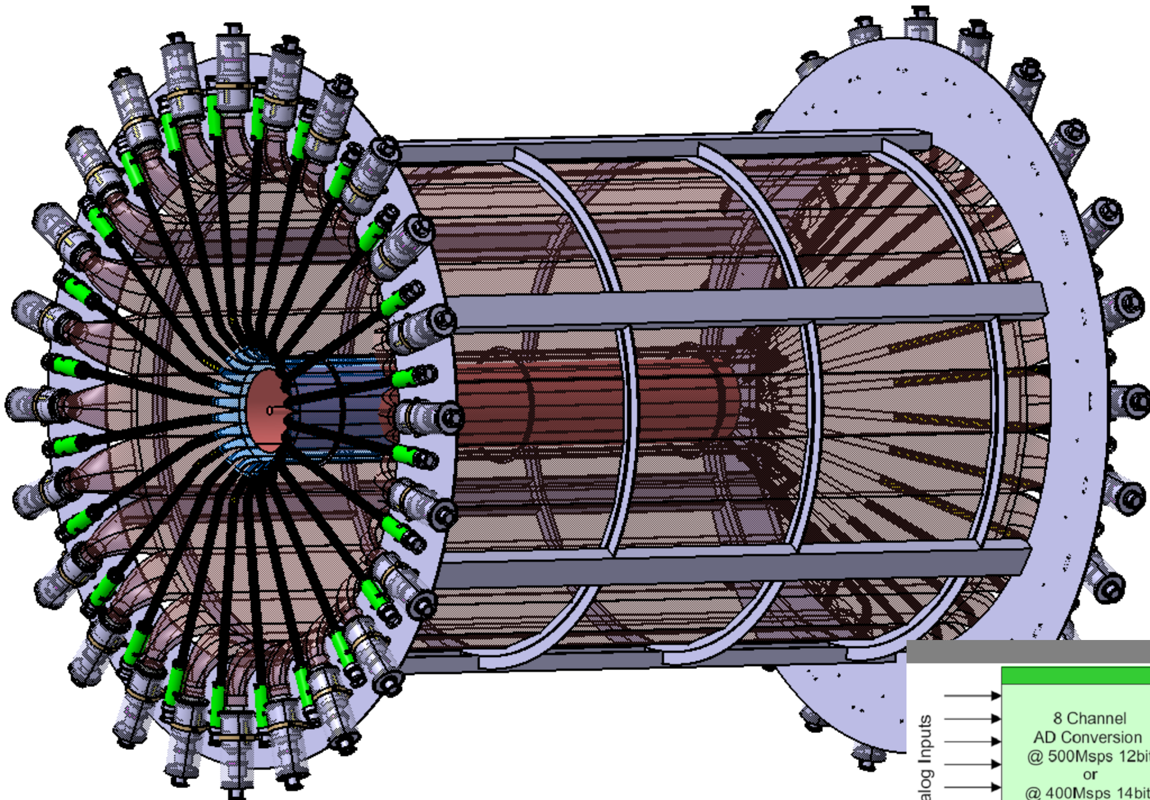
high precision
beam flux
and acceptance
determination

trigger in large
kinematic range



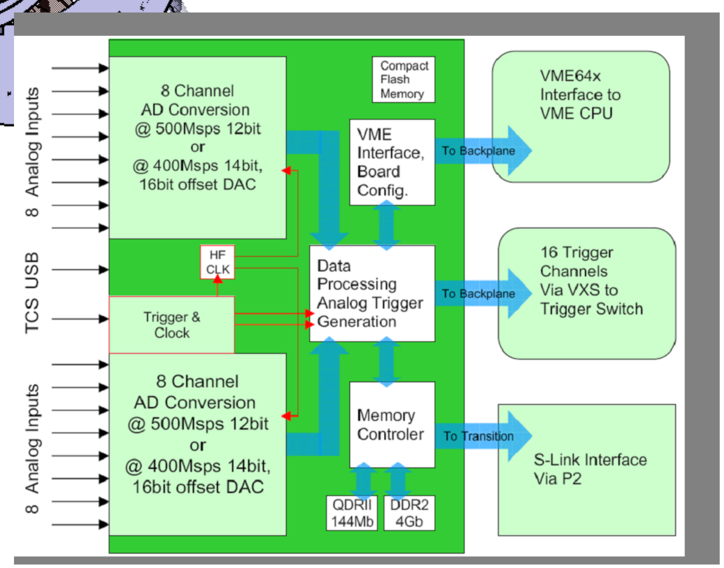
upgrade ECAL1/2
new ECAL0 before SM1

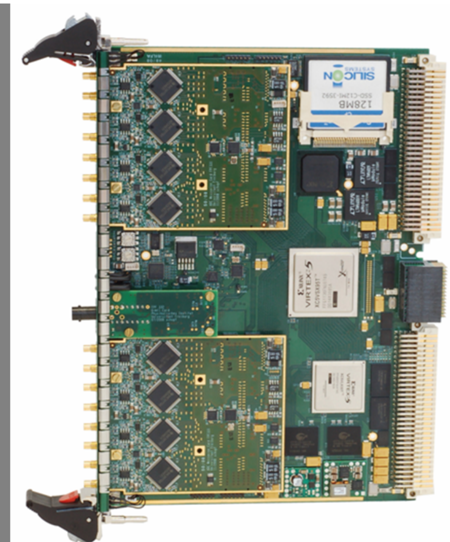
Target and recoil detector



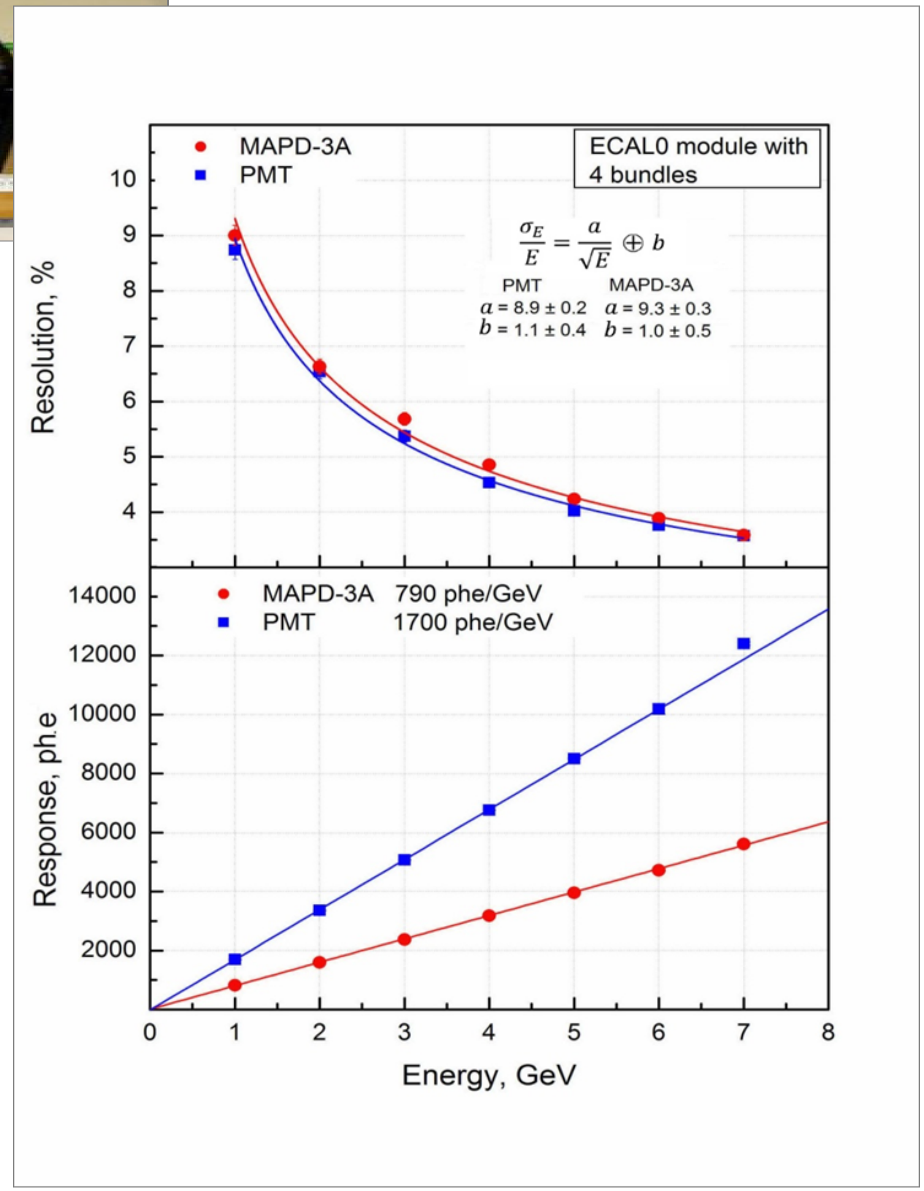
- 2.5 m **lH_2**, 40 mm diameter
- minimum thickness of cryostat and target cell
- density fluctuations $< 3\%$
- **TOF dectetor** 2 layers of scintillators
- 300 ps time resolution

- high occupancy due to δ rays
- **Gandalf Project**: 1GHz digitisation of signals to cope with high rate





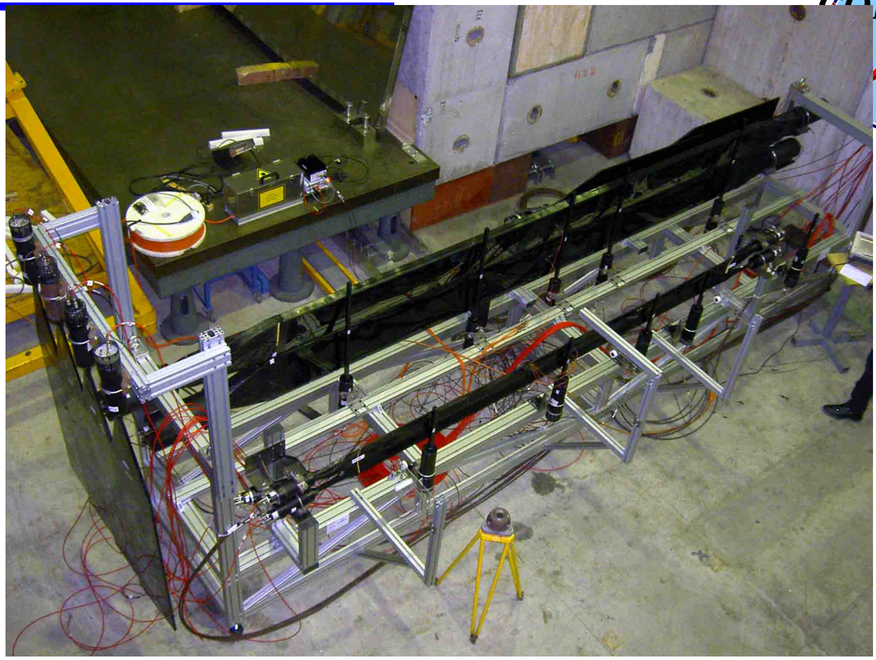
Electromagnetic calorimeter ECAL0



- Shashlik modules (length about 35 cm)
- scintillator lead sandwich
  with 15 radiation length
- light read-out with
  wave length shifting fibres
- avalanche micropixel photo diodes
  need temp. stability $\leq 0.2K$
- test at CERN T9 beam and
  at muon beam

$\Longrightarrow$ ok for GPD measurements

Test measurements



2006

- prototype of recoil detector:
  30-degree sector (4 m long)
- tested in the muon beam

  $\Longrightarrow$ spatial and time resolution

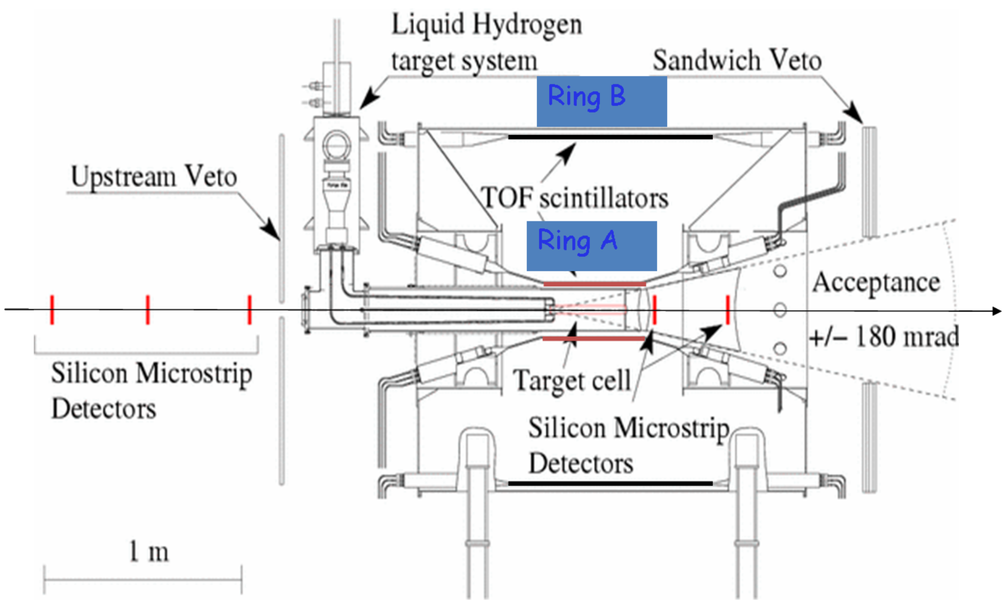
2008

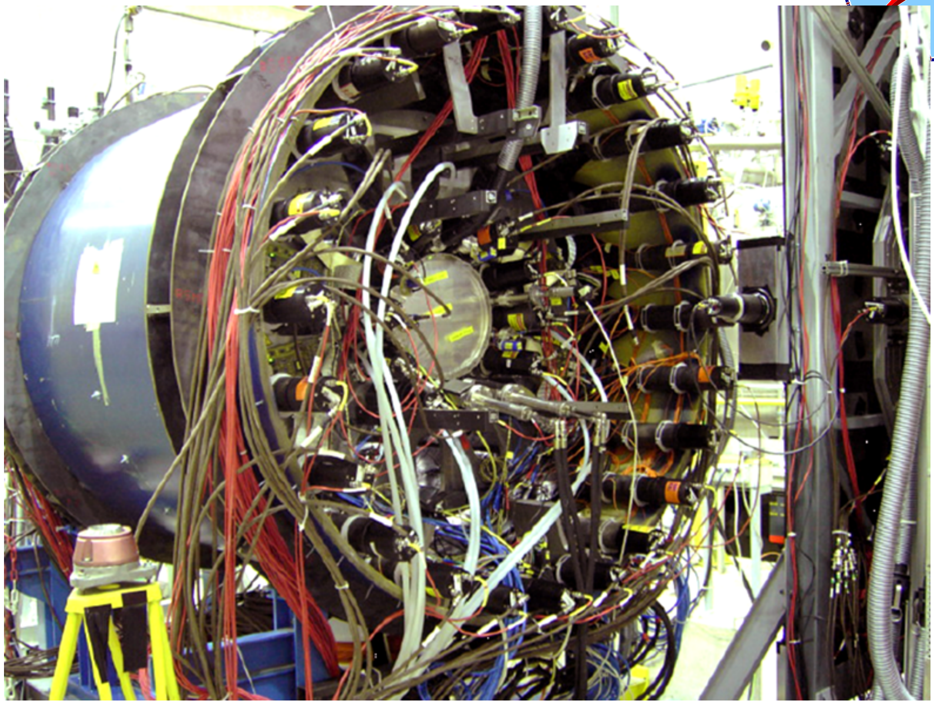
- short tex run with μ^+
  using 40 cm lH_2 target
  and 1 m long recoil detector
- only 1.5 d before shutdown for LHC to look for BH events

2009

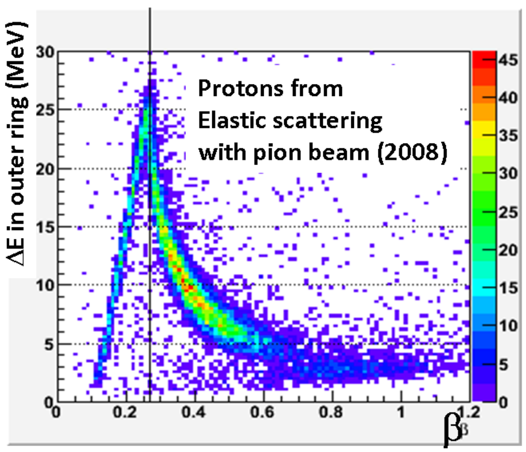
- data taking with μ^+ (8 times more stat.) and μ^- at about nominal intensity
  - measure BH events plus relative DVCS and DVMP contributions
  - comparison of μ^+ and μ^- data: μ^- flux is factor of 3 lower at 160 GeV
    $\Longrightarrow$ limitation of overall luminosity

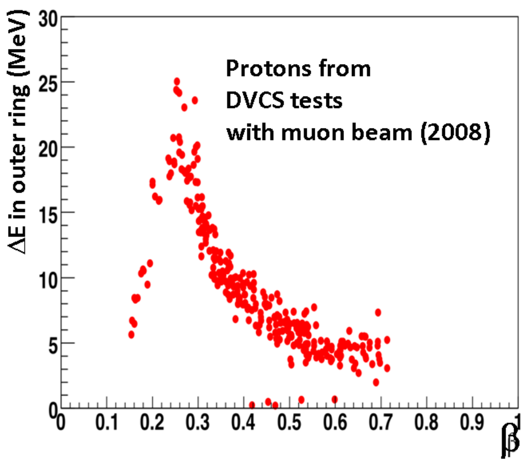
2008/2009 recoil detector



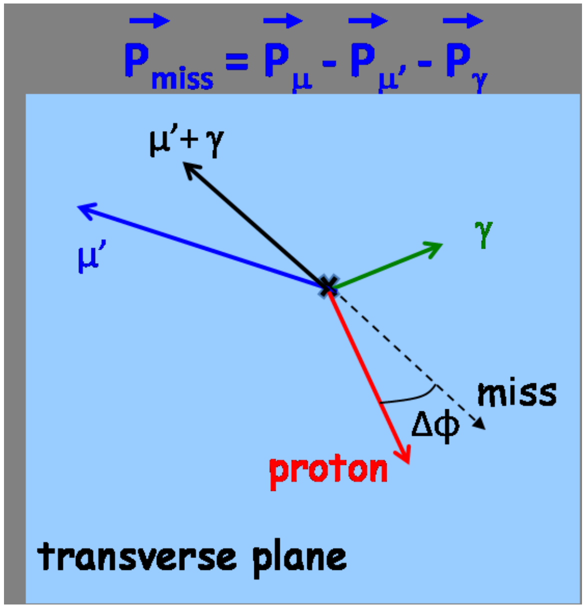


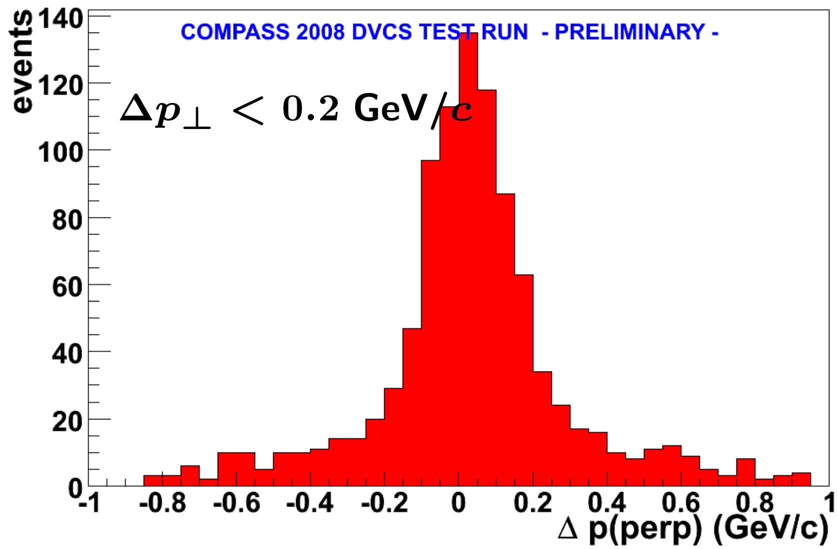
- used for triggering and proton PID
- **selection of events:**
  - vertex with μ and μ'
  - no other charged track
  - 1 high energy photon
  - proton in RPD

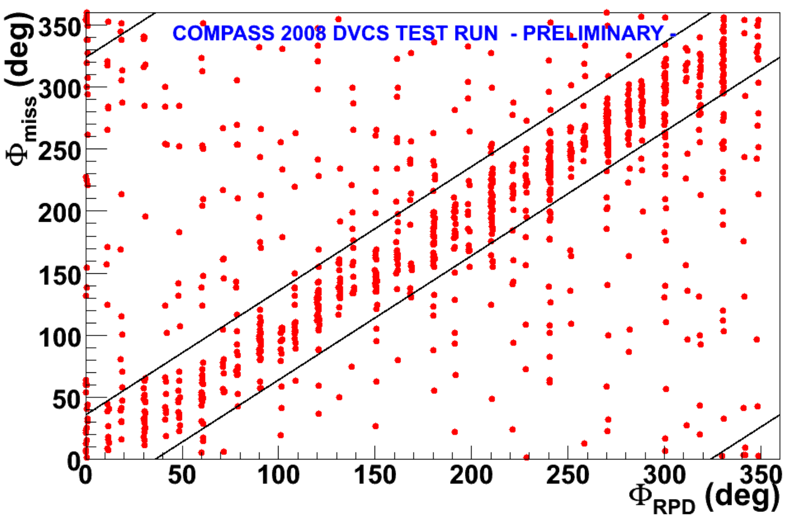


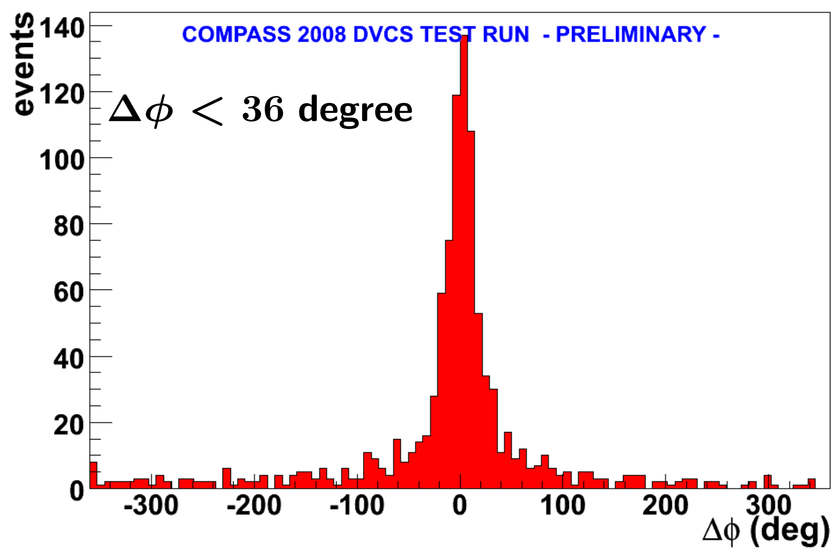


Kinematic constraints



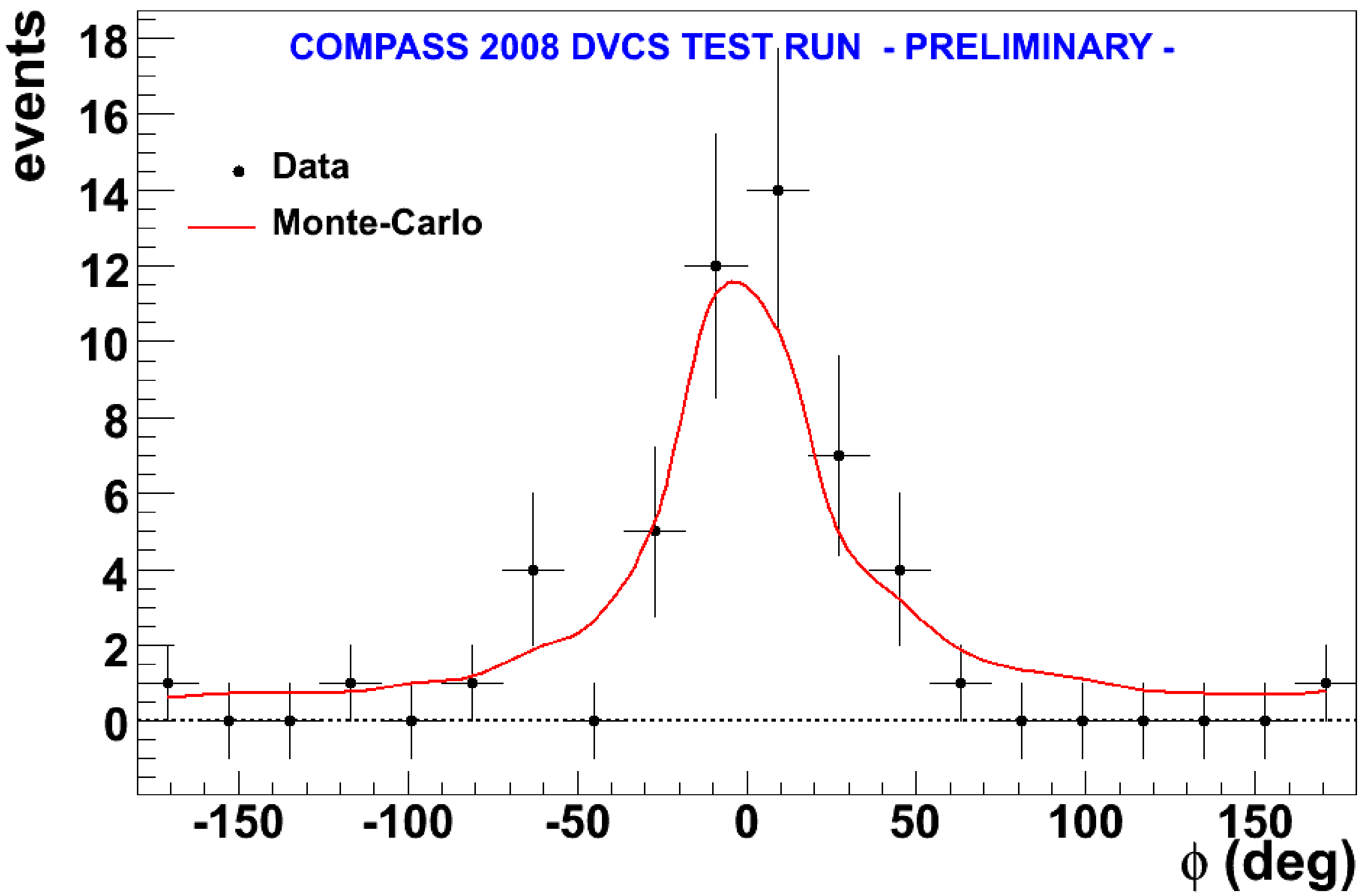






BH signal in 2008

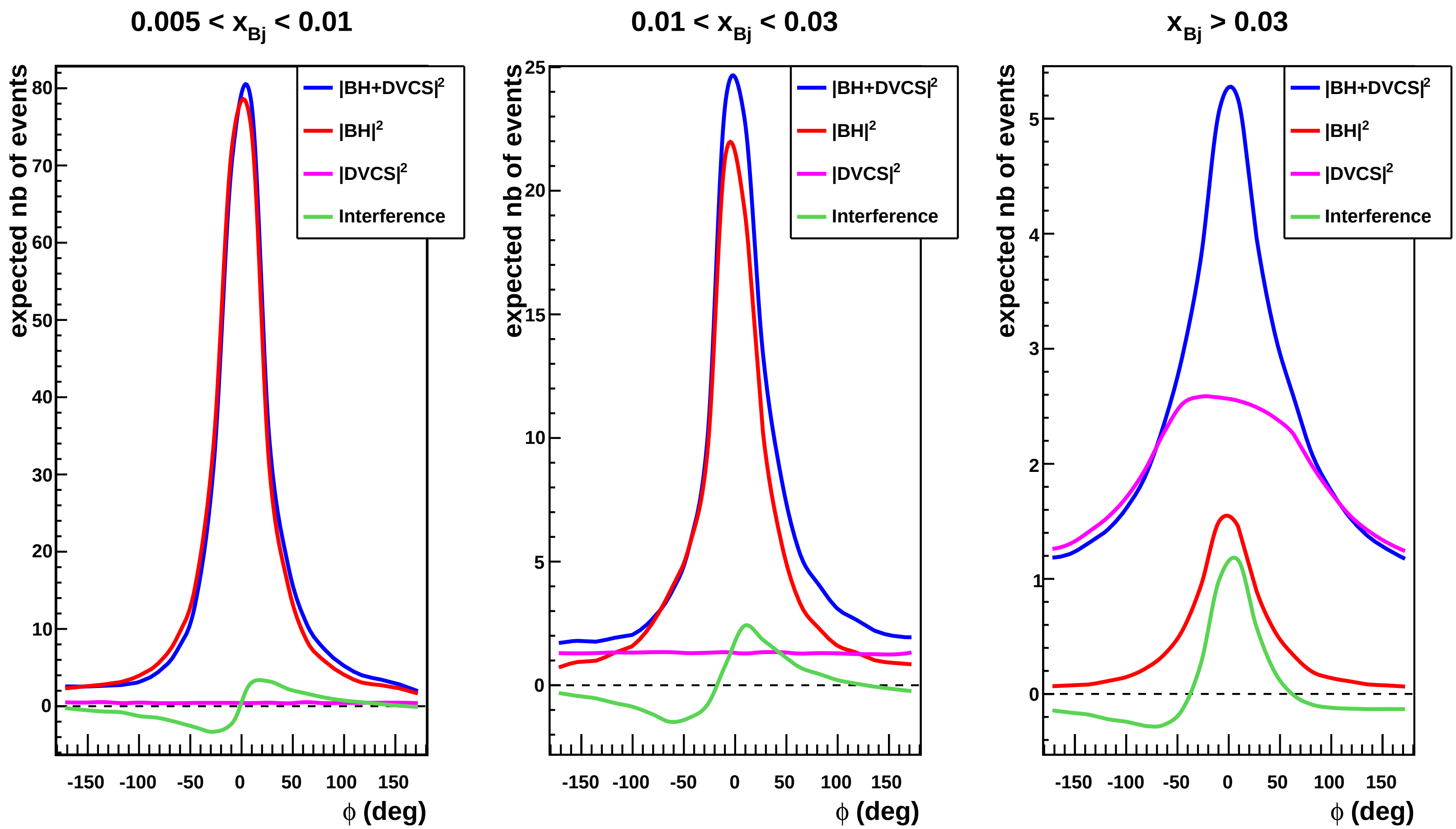
- data plus MC simulation with BH and DCVS $\Longrightarrow$ BH dominant



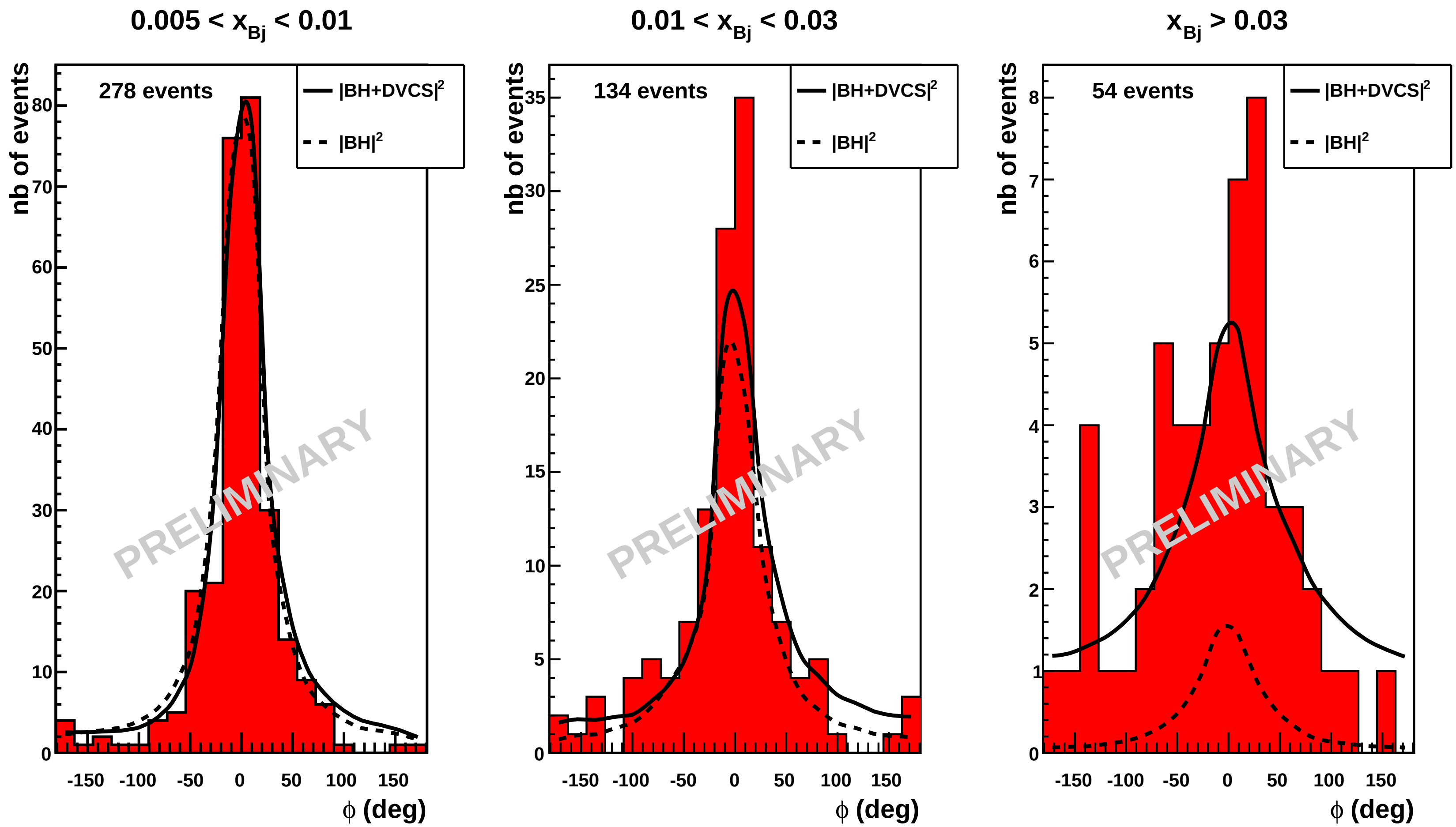
- clear BH signal for $Q^2 > 1$ GeV^2 after all cuts
- detection efficiency determined: $\varepsilon = 0.32 \pm 0.13$

Prediction 2009

- data taking with μ^+ and some μ^-, results from part of the μ^+ data
- prediction from MC simulation (using VGG for DVCS) including current detector acceptance
- low x data dominated by BH, high x data dominated by DVCS



Signal in 2009



- result confirms expectations
- 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, $x_{Bj} > 0.03$

Conclusions

- COMPASS has a great potential in GPD physics
- for exclusive measurements recoil proton detection mandatory

- Phase 1: study of GPD H with proton target planned
- liquid hydrogen target surrounded by recoil detector under design
- upgrade of electromagnetic calorimetry

- Phase 2: study of GPD E with transversely polarised NH_3 target
- transversely polarised target with recoil detector: 2 different options discussed

- Full proposal for DVCS, DY and Primakoff measurements to be submitted to SPSC in a few weeks