Exploring fundamental questions of

NUCLEON STRUCTURE
with
GENERALIZED PARTON DISTRIBUTIONS

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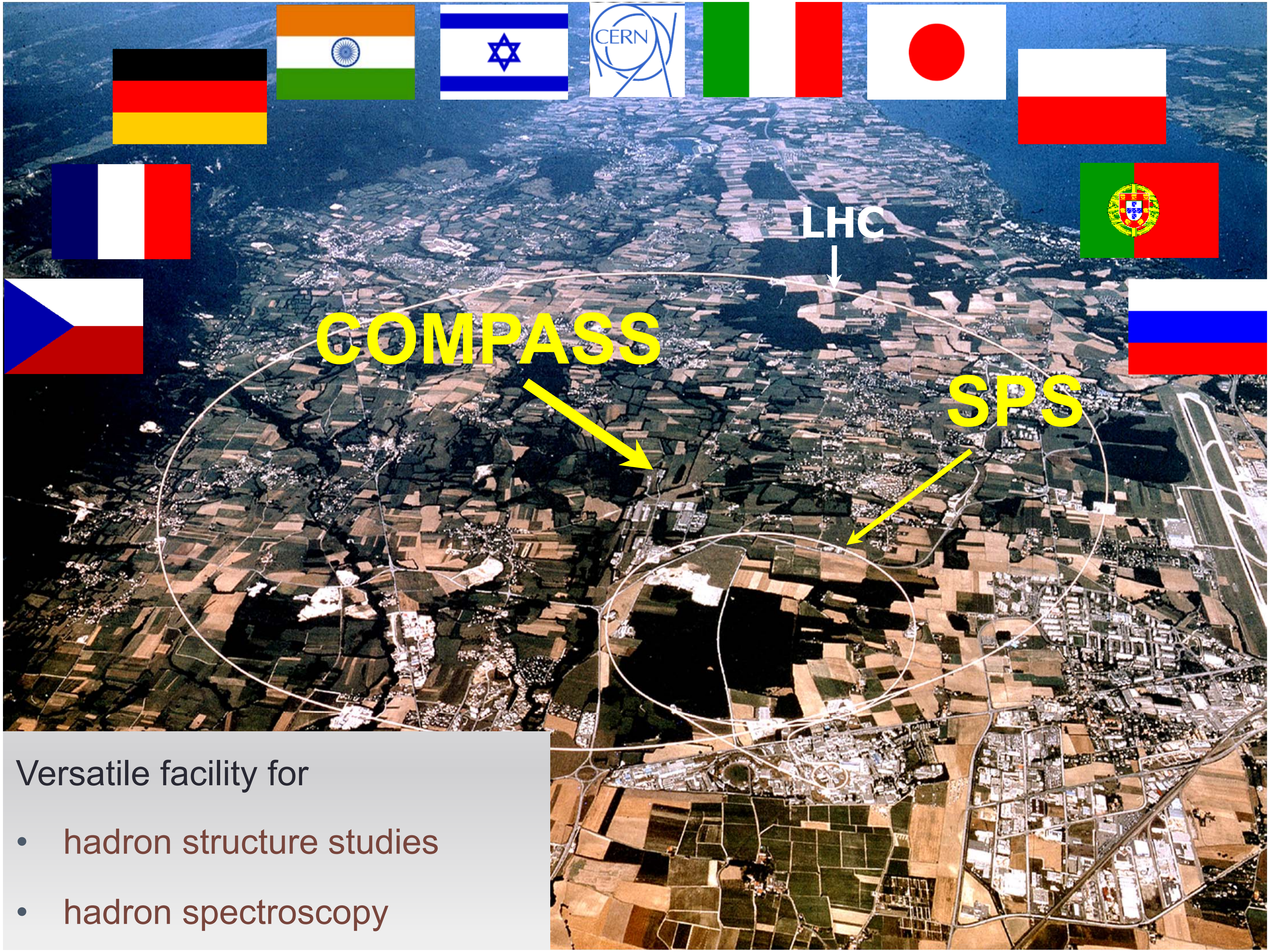
16.9.2012 – Corfu Summer School

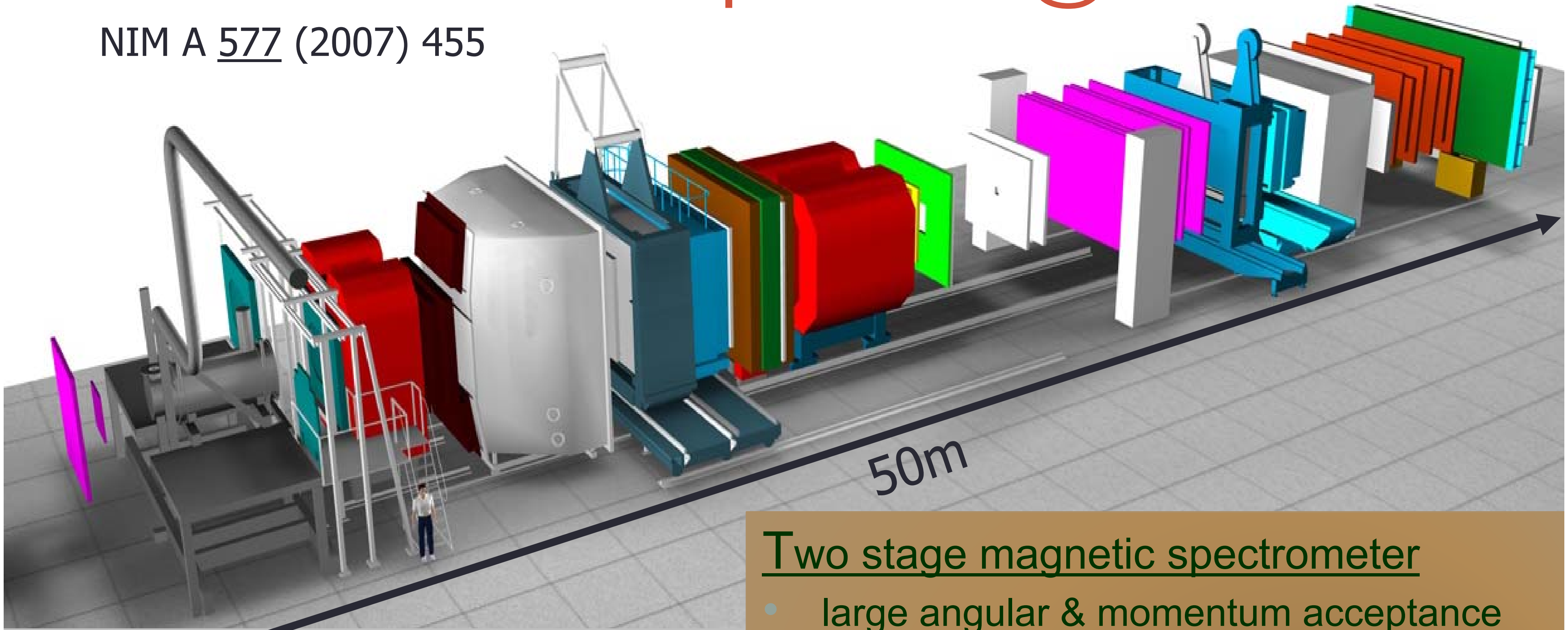


Versatile facility for

- hadron structure studies
- hadron spectroscopy

The COMPASS Experiment @ CERN

NIM A 577 (2007) 455



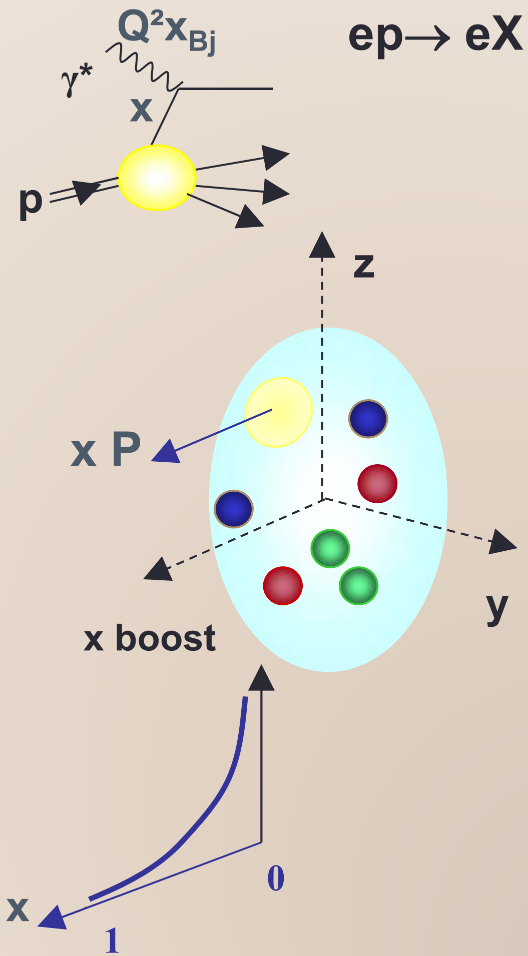
- μ^+, μ^- or hadron (p, K, p) beam
  - changeover within < 1h
- momentum: 100 - 200 GeV/c
- 80% polarization
- μ^+ & μ^- with opposite polarization

Two stage magnetic spectrometer

- large angular & momentum acceptance
- Particle identification
  - Ring Imaging Cerenkov Counter
  - Electromagnetic calorimeters
  - Hadronic calorimeters
  - Hadron absorbers

GPDs - a 3-dimensional picture of the partonic nucleon structure

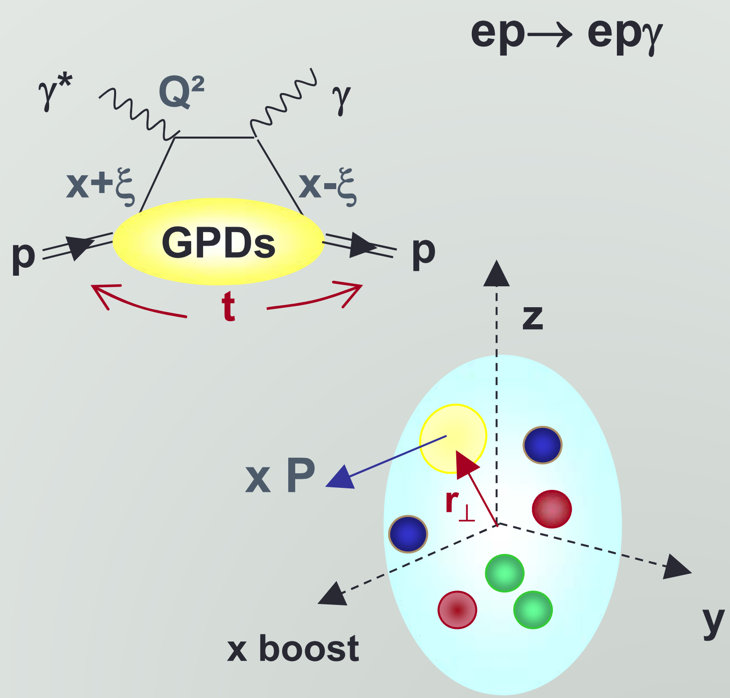
Deep Inelastic Scattering



Parton Density q (x)

P_x

Hard Exclusive Scattering
Deeply Virtual Compton Scattering



Generalized

Parton Distribution H(x,ξ,t)

$(P_{x}, r_{y,z})$

Burkard,Belitsky,Müller,Ralston,Pire

Why GPDs are promising? What can we learn from a 3D picture?

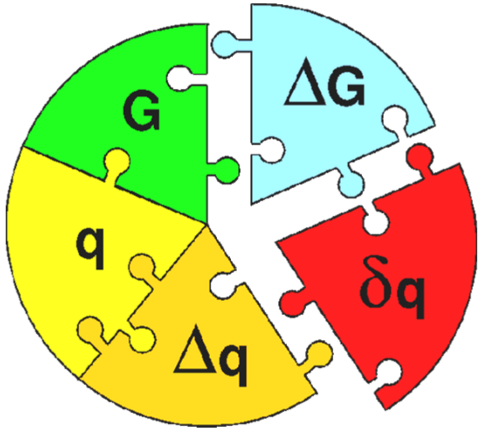
Goal: correlation between the 2 pieces of information:

-distribution of longitudinal momentum carried by the partons $\vec{p}$

-distribution in the transverse plane $\vec{r}$

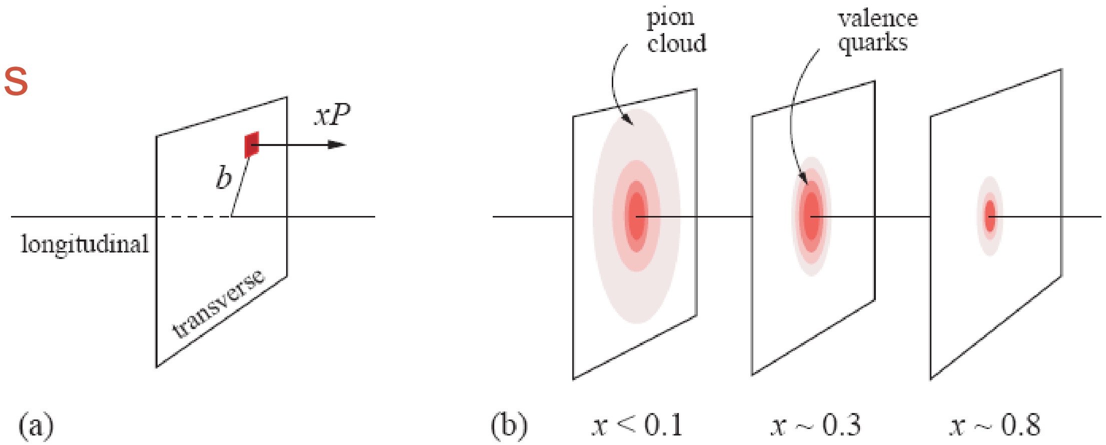
→ Implication of orbital angular momentum to the total spin of a nucleon $\vec{r} \times \vec{p}$

in the context of the *COMPASS* program

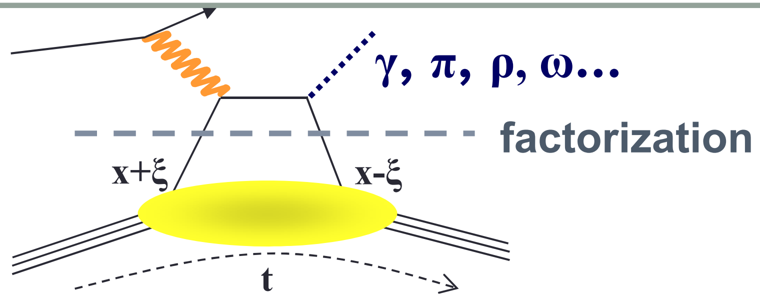


→ Knowledge of the transverse size of parton distribution

in hadron-hadron collisions such as at *LHC*, *RHIC*



GPDs and relations to the physical observables



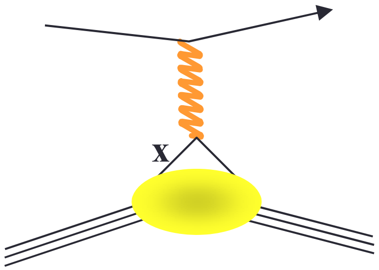
The observables are some integrals of GPDs over x

Dynamics of partons in the Nucleon Models: Parametrization

Fit of Parameters to the data

$H, \tilde{H}, E, \tilde{E}\ (x,\xi,t)$

Elastic Form Factors

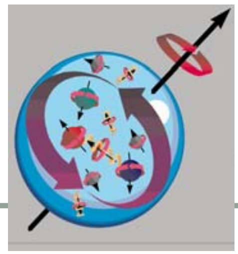


$\int H(x,\xi,t)dx = F(t)$

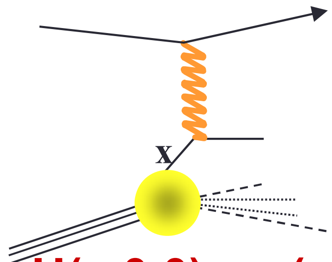
Ji's sum rule

$$2J_q = \int x(H+E)(x,\xi,0)dx$$

$$1/2 = \underbrace{1/2\ \Delta\Sigma + L_q}_{} + \Delta G + L_g$$



"ordinary" parton density



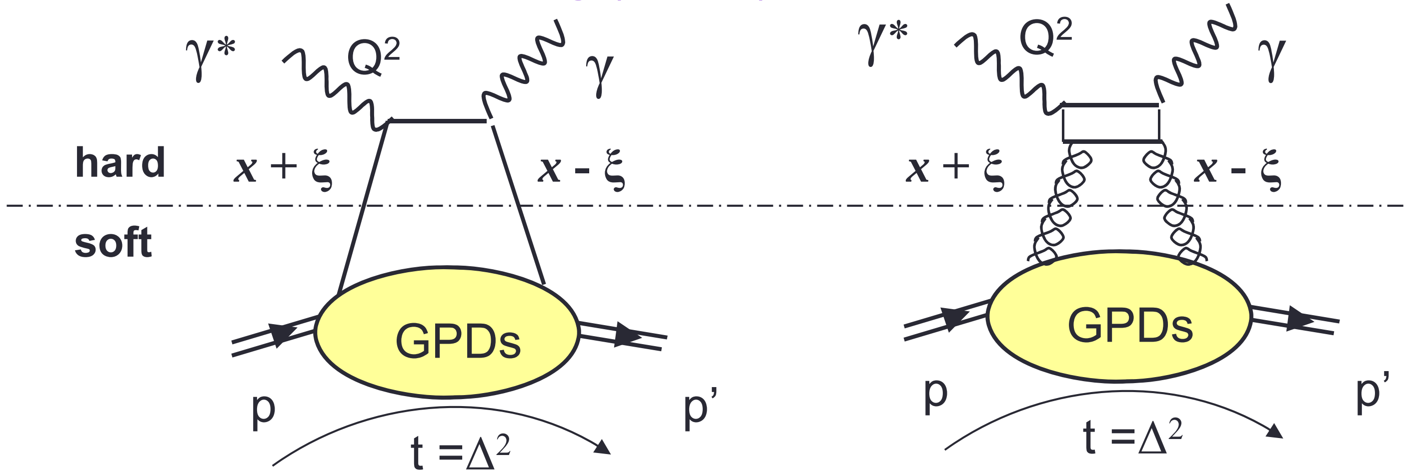
$H(x,0,0) = q(x)$

$\tilde{H}(x,0,0) = \Delta q(x)$

Necessity of factorization to access GPDs

Deeply Virtual Compton Scattering (DVCS):

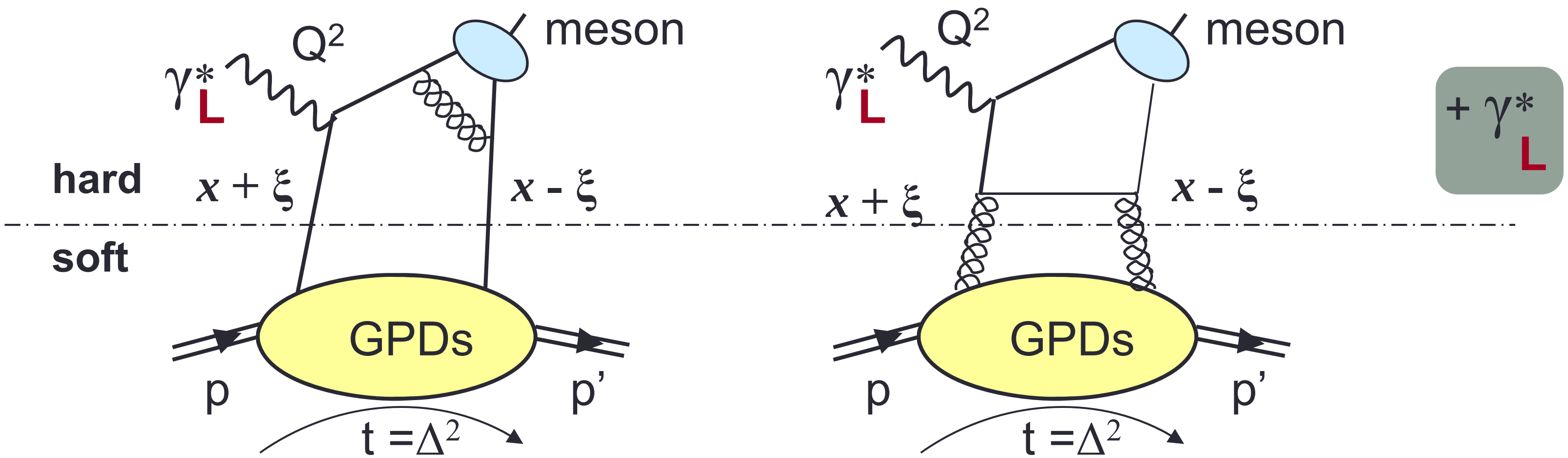
Collins *et al.*



Q² large

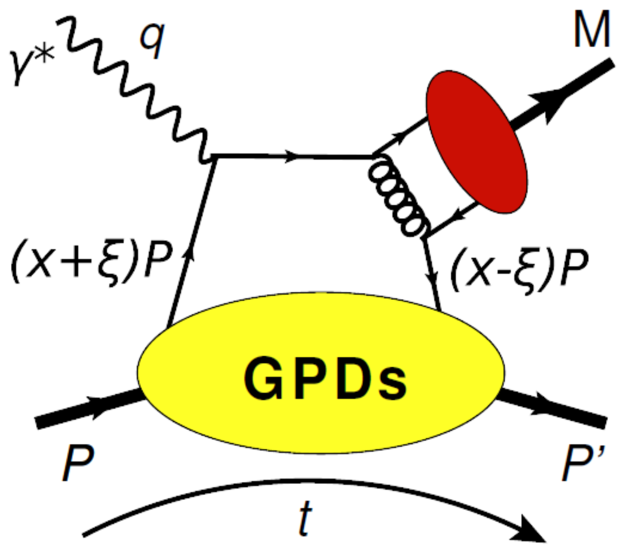
t << Q²

Hard Exclusive Meson Production (HEMP):



Quark contribution **Gluon contribution**

Hard Exclusive Meson Production



Allows for flavor separation:

$E_{\rho^0} = 1/\sqrt{2}\,(2/3\ E^u + 1/3\ E^d + 3/8\ E^g)$

$E_{\omega} = 1/\sqrt{2}\,(2/3\ E^u - 1/3\ E^d + 1/8\ E^g)$

$E_{\phi} = -1/3\ E^s - 1/8\ E^g$

- Vector meson production from transversely polarized target asymmetry $\Rightarrow$ E/H

Cross section measurements:

- Pseudo-scalar: π, η, … $\Rightarrow \tilde{H}$ & $\tilde{E}$
- Vector meson: ρ, ω, ϕ… $\Rightarrow$ H & E

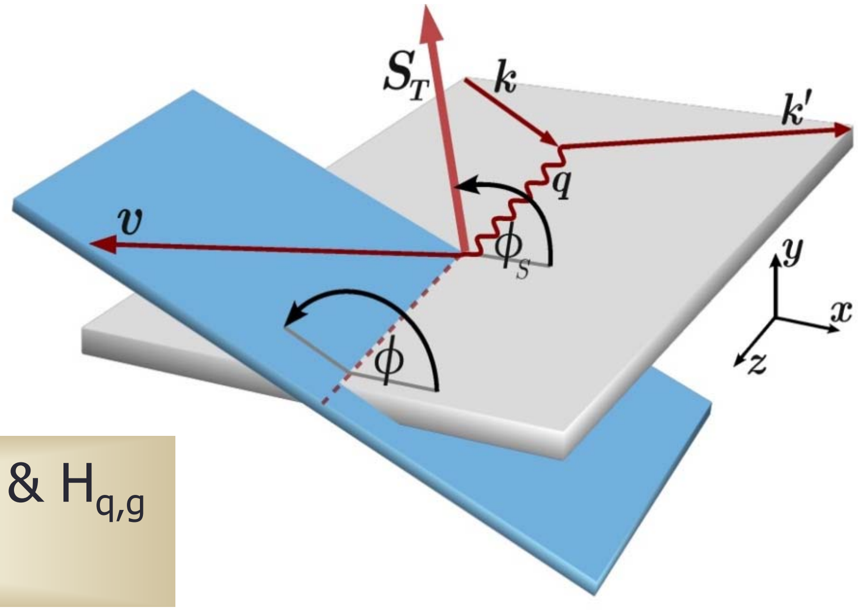
ρ : ω : ϕ ~ 9 : 1 : 2

(at large Q^2)

Presently studied at COMPASS without RPD

HEMP with polarized Target

$$A_{UT}^{\sin(\phi-\phi_S)} \propto \sqrt{|-t'|}\,\frac{\mathrm{Im}\,(\mathcal{E}^{*}\mathcal{H})}{|\mathcal{H}|^{2}}$$



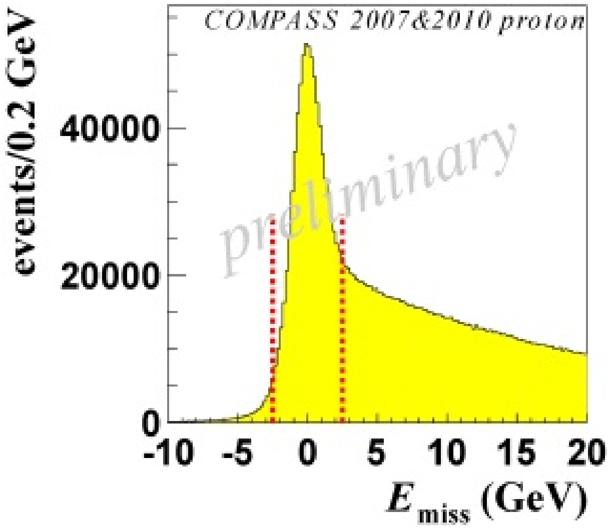
- $\mathcal{E}$ and $\mathcal{H}$ are weighted sums of GPD $E_{q,g}$ & $H_{q,g}$
- Provide access to GPD E

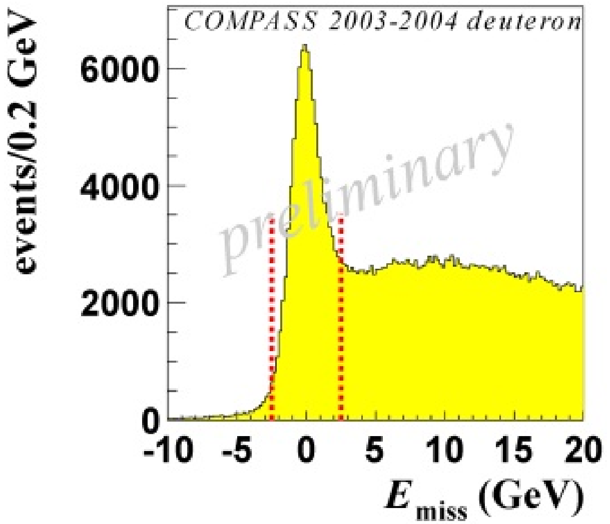
Constrain total angular momentum using Ji's relation:

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

Exclusivity Cuts

No recoil detector → assuming π and p masses





Missing Energy Technique:

$$E_{miss} = \frac{M_X^2 - M_p^2}{2M_p} = E_{\gamma*} - E_{\rho^0} + \frac{t}{2M_p}$$

- 14% contamination of diffractive dissociation (no attempt to remove it)

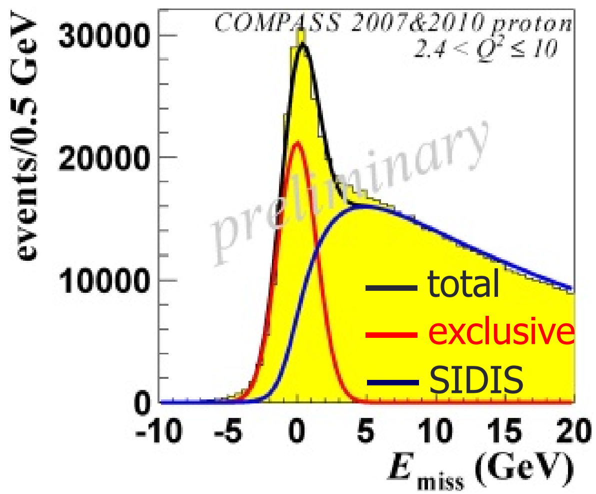
Final sample:

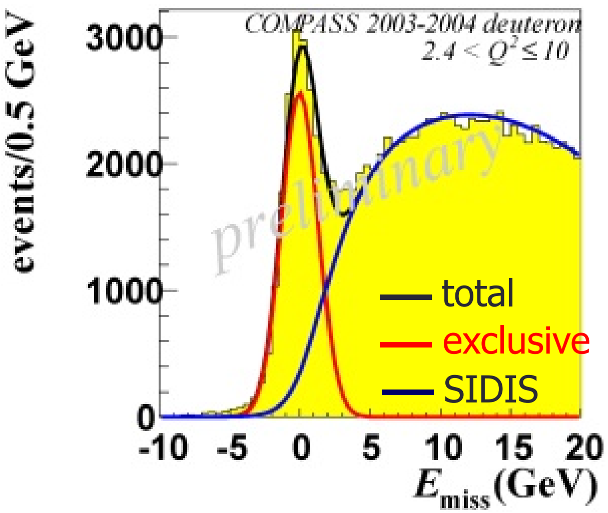
- NH_3: 797000 events
- ^{6}LiD: 97000 events

… but still strong SIDIS background

SIDIS Background Subtraction

Two examples:



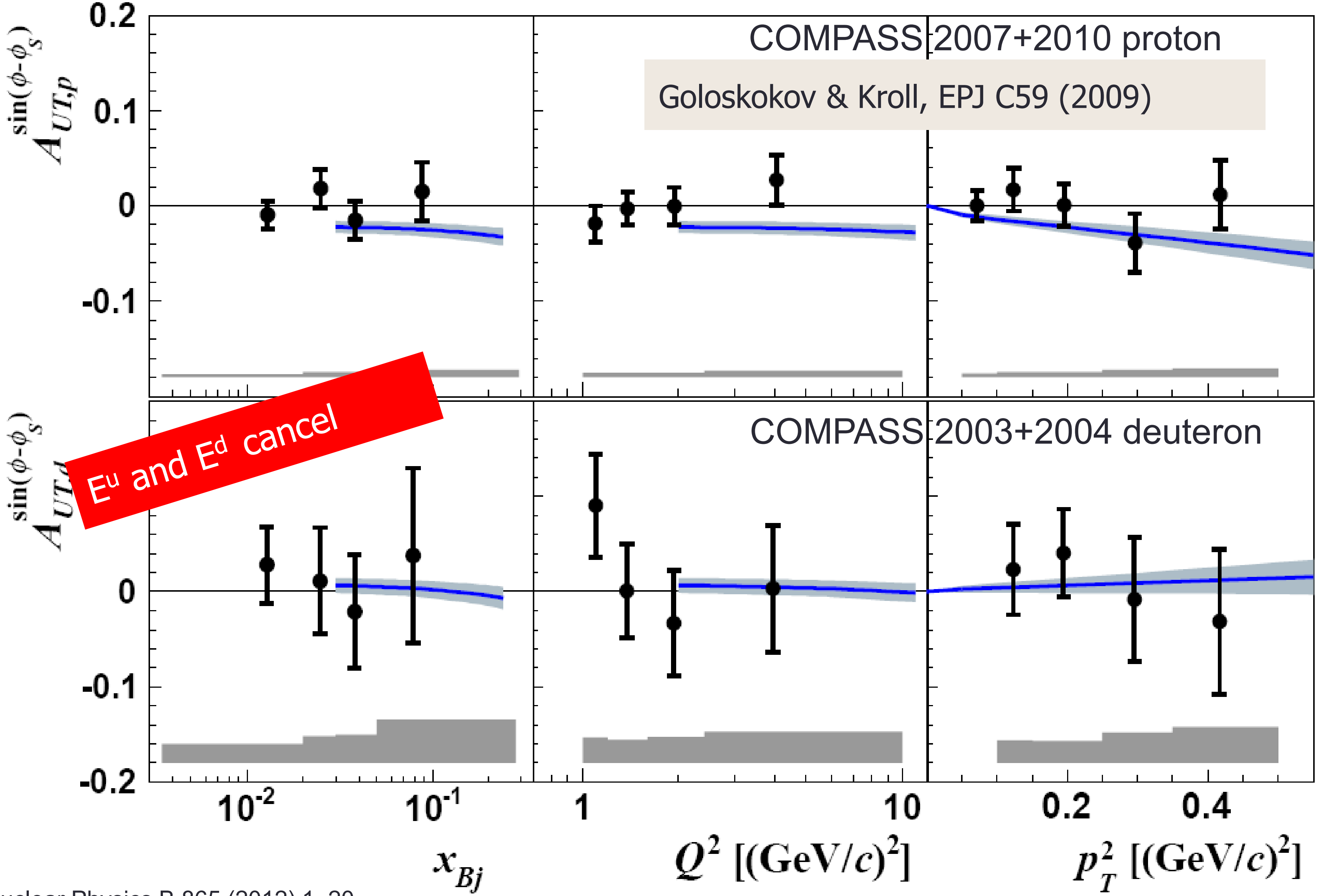


Estimate & subtract background bin-by-bin

- still 5…40% background from SIDIS (depending on target cell, $x_{Bj}, Q^2, p_T^2, \phi - \phi_S$)
- Fix shape of background using Data/MC like-sign events
- Estimate SIDIS background from fit to data
- Assume Gaussian shape for signal

$A_{UT}^{\sin(\phi-\phi_S)}$ **by a binned max. likelihood**

Exclusive ρ^0 production on transverse polarized Targets



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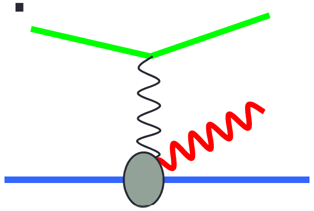
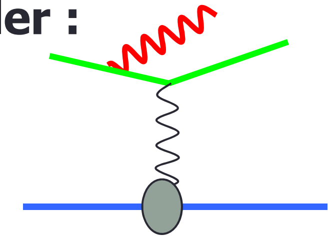
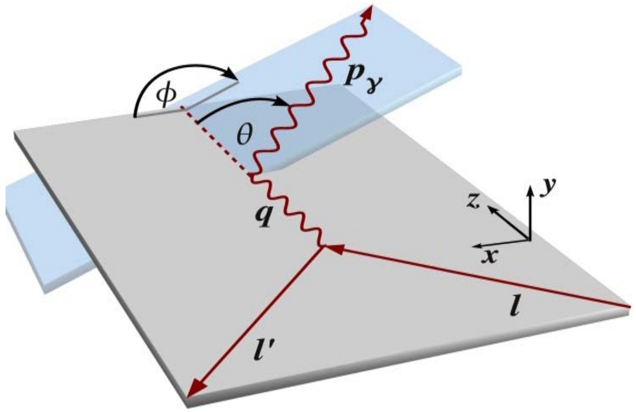
Bethe-Heitler & DVCS Cross Sections at 160GeV

DVCS :

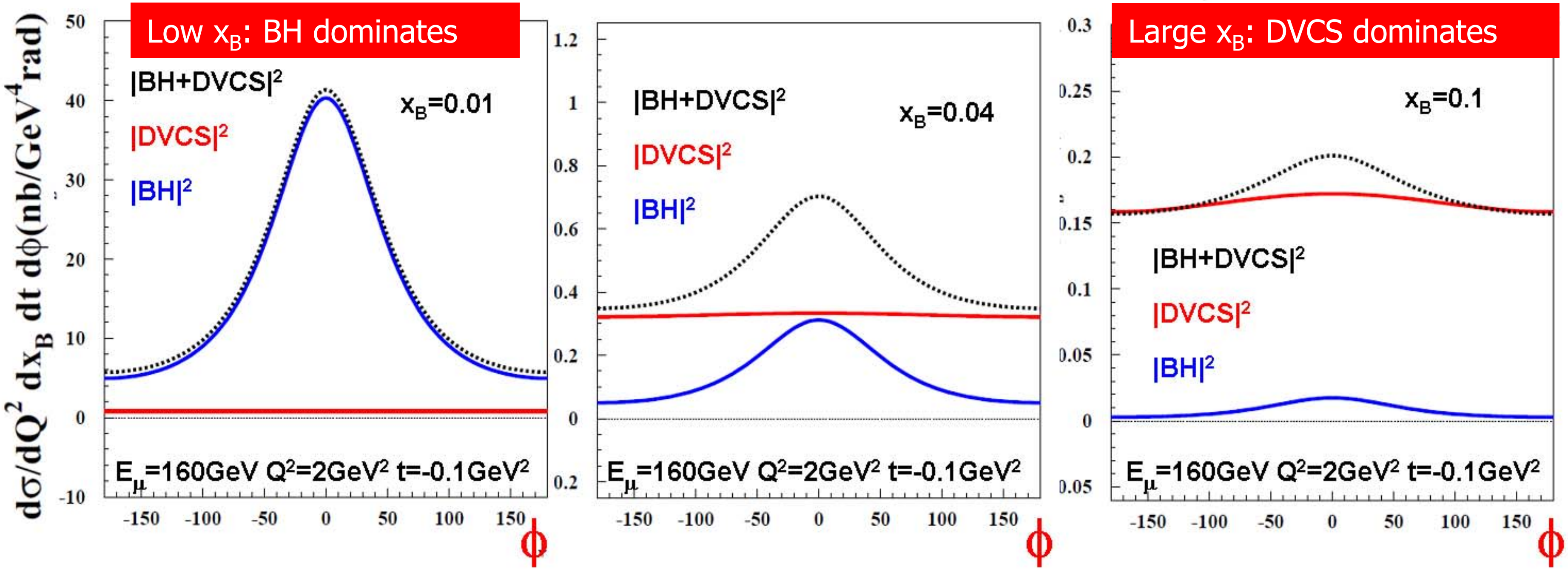


Bethe-Heitler :



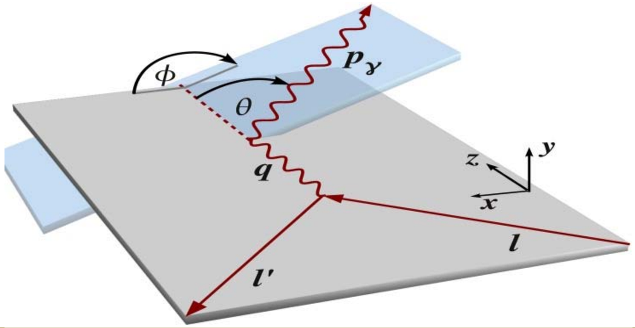


$$d\sigma \; \alpha \; |T_{DVCS}|^2 + |T_{BH}|^2 + \text{Interference Term}$$



- Reference yield from almost pure BH
- Study DVCS through interference term
  ➡ $\mathcal{R}e\, T^{DVCS}$ & $\mathcal{I}m\, T^{DVCS}$
- Study $d\sigma^{DVCS}/dt$
  ➡ Transverse Imaging

Observables (Phase 1) – unpolarized Target



$$d\sigma_{(\mu p \to \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol} + e_\mu a^{BH} \mathcal{Re}\, T^{DVCS} + e_\mu P_\mu a^{BH} \mathcal{Im}\, T^{DVCS}$$

- Beam Charge & Spin Sum:

$$\mathcal{S}_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} = 2\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu a^{BH} \mathcal{Im}\, T^{DVCS}\right)$$

- Beam Charge & Spin Difference:

$$\mathcal{D}_{CS,U} = d\sigma^{+\leftarrow} - d\sigma^{-\rightarrow} = 2\left(P_\mu d\sigma^{DVCS}_{pol} + e_\mu a^{BH} \mathcal{Re}\, T^{DVCS}\right)$$

Beam Charge & Spin Difference $\mathcal{S}_{CS,U}$ - Transverse imaging

$$\mathcal{S}_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} = 2\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu a^{BH}\, Im\, T^{DVCS}\right)$$

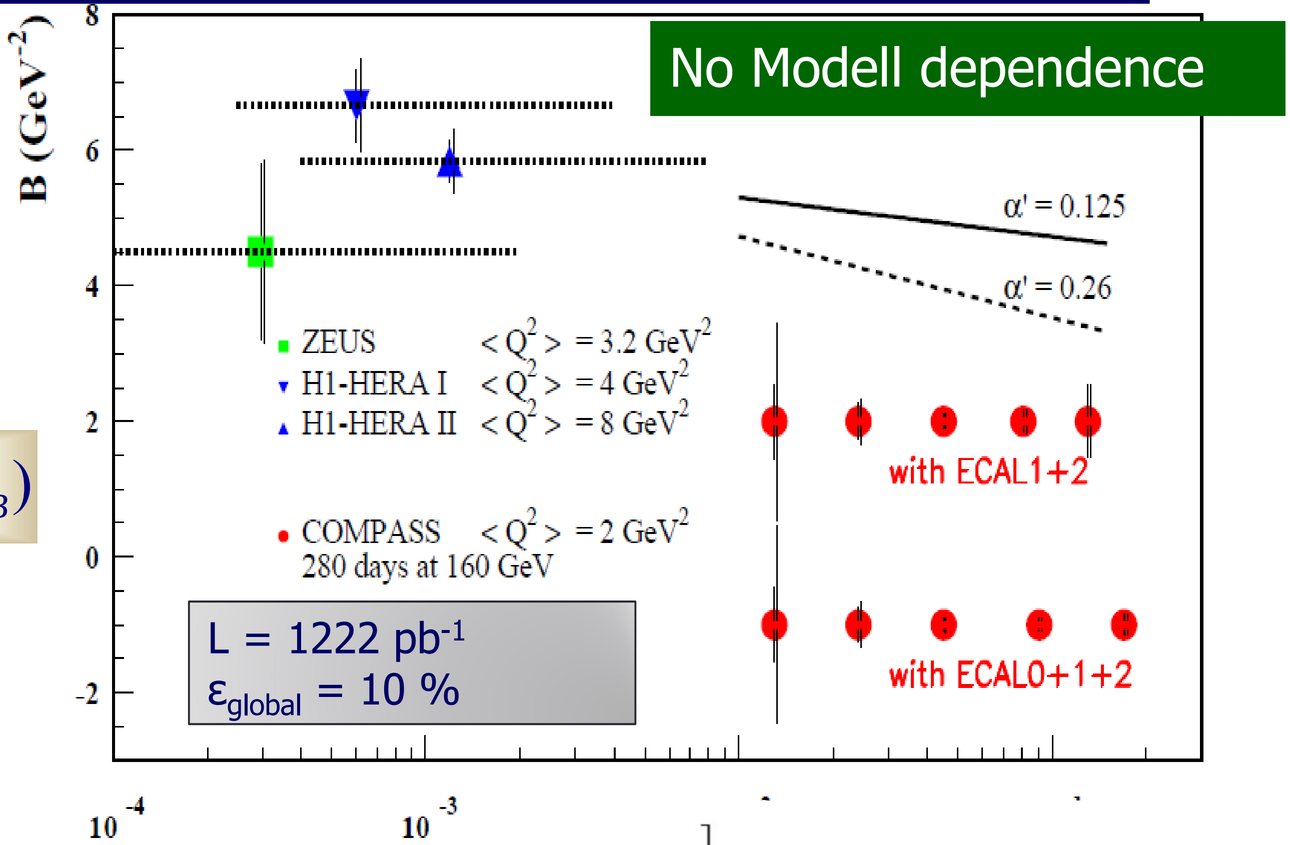
- Using $\mathcal{S}_{CS,U}$
- Integrating over ϕ
- Subtracting BH

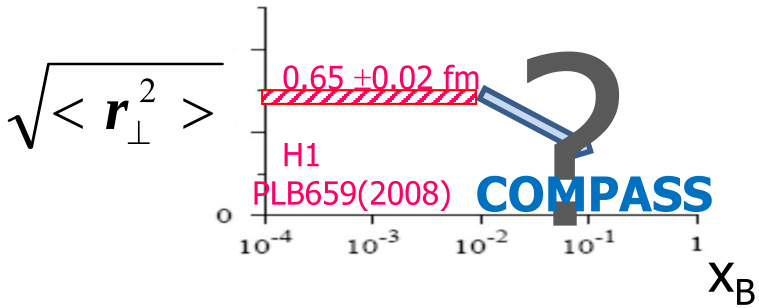
$$\frac{d\sigma}{d|t|} \propto e^{-B|t|}$$

$$\langle r_\perp^2(x_B)\rangle \sim 2B(x_B)$$

- Ansatz at small x_B:
  ($x \sim x_B$)

$$B(x_B) = b_0 + 2\alpha' \ln \frac{x_0}{x_B}$$





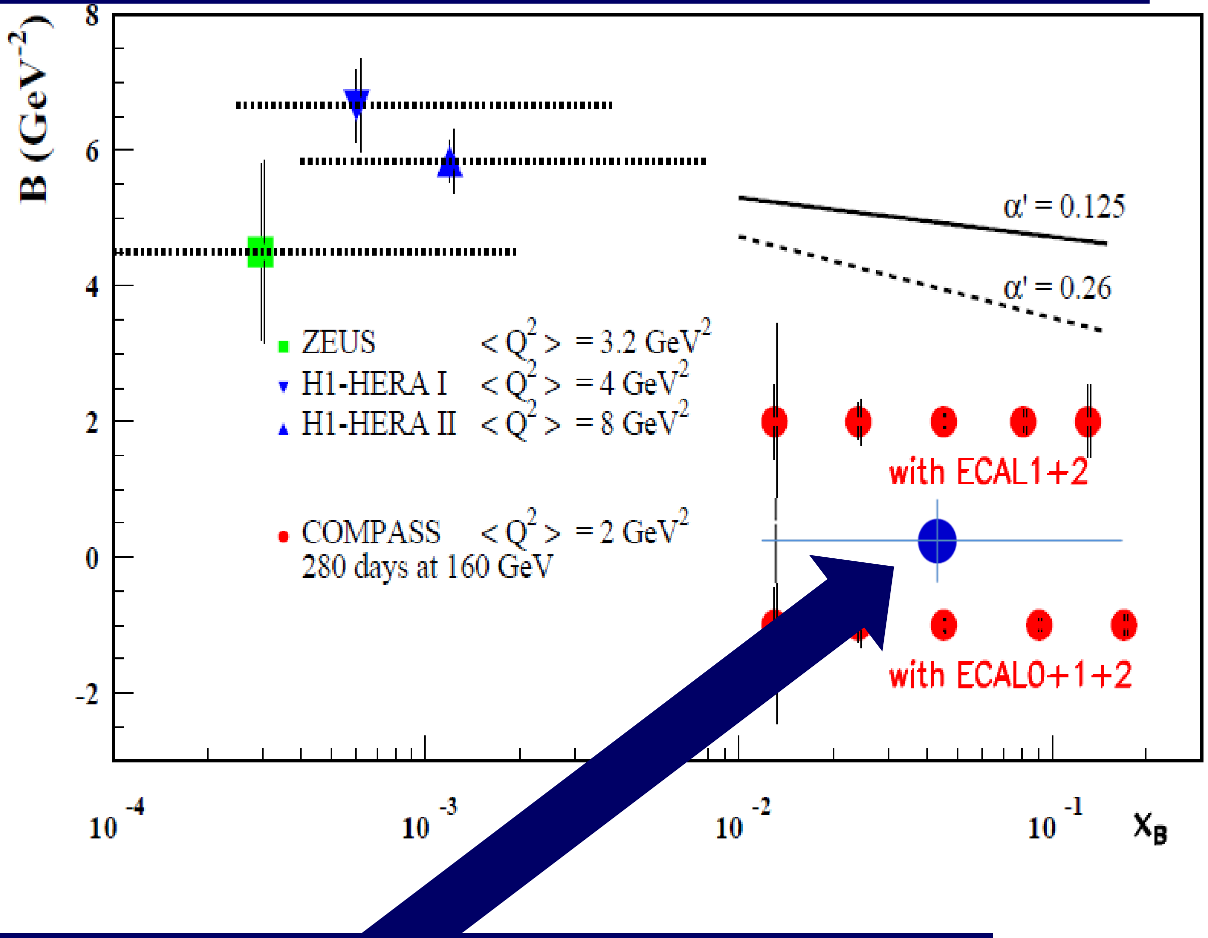
measure α′ with accuracy >2.5 σ

for: α′ > 0.26 (with ECAL 1+2)

α′ > 0.125 (with ECAL 0+1+2)

$S_{CS,U}$ - Transverse imaging - 2012

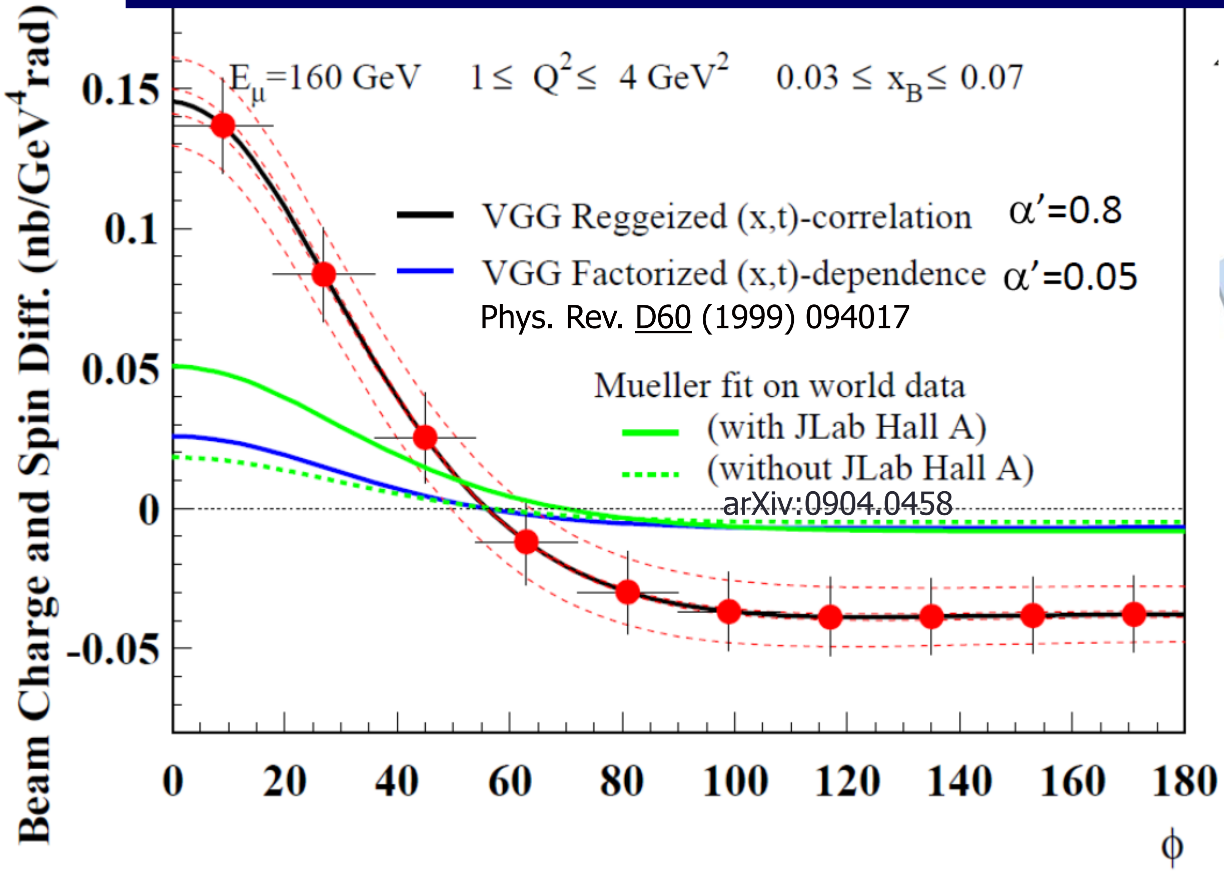
$$S_{CS,U} = d\sigma^{+\leftarrow} + d\sigma^{-\rightarrow} = 2\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu a^{BH}\, Im\, T^{DVCS}\right)$$

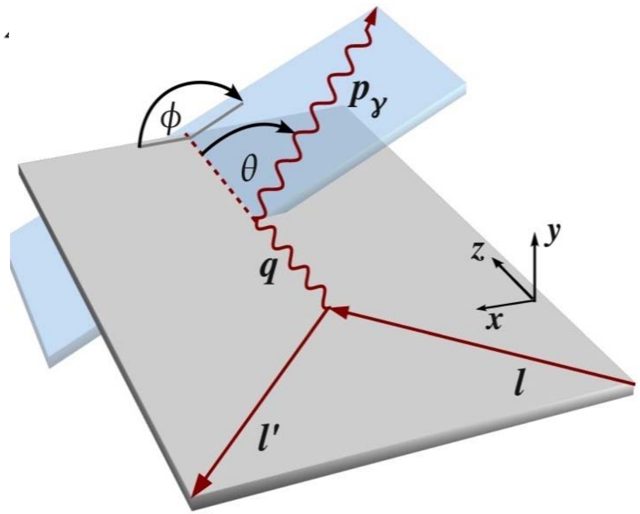


Projection for commissioning run 10/2012

Beam Charge & Spin Difference $\mathcal{D}_{CS,U}$

$$\mathcal{D}_{CS,U} = d\sigma^{+\leftarrow} - d\sigma^{-\rightarrow} = 2\left(P_\mu d\sigma_{pol}^{DVCS} + e_\mu a^{BH} \mathcal{R}e\, T^{DVCS}\right)$$





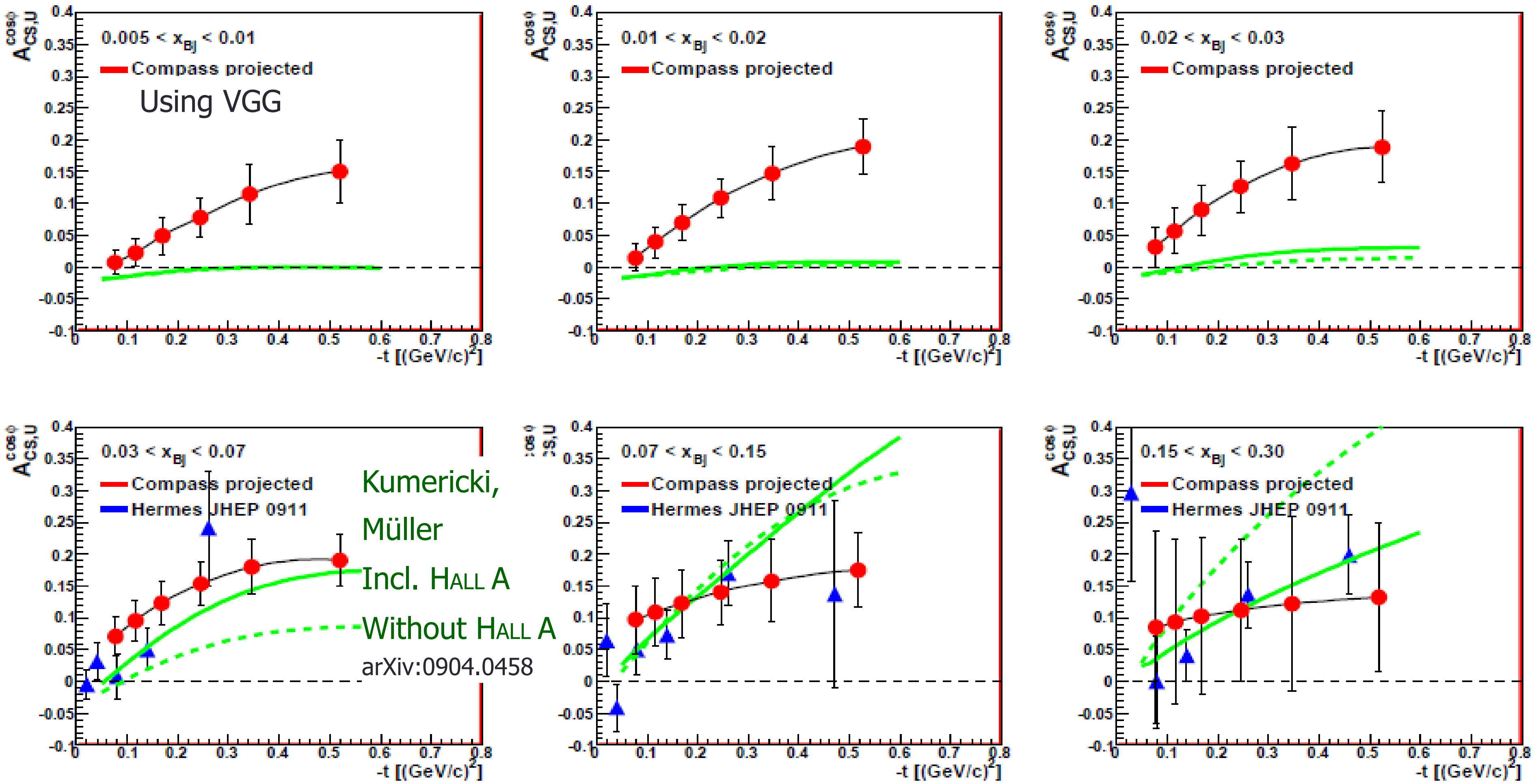
L = 1222 pb^{-1}
ε_{global} = 10 %

- Control detector acceptance and beam flux with high precision
- Error band assumes a 3% systematic uncertainty between μ^+ and μ^-
- Use inclusive events and BH for check

Beam Charge & Spin Asymmetry $\mathcal{D}_{CS,U} / \mathcal{S}_{CS,U}$

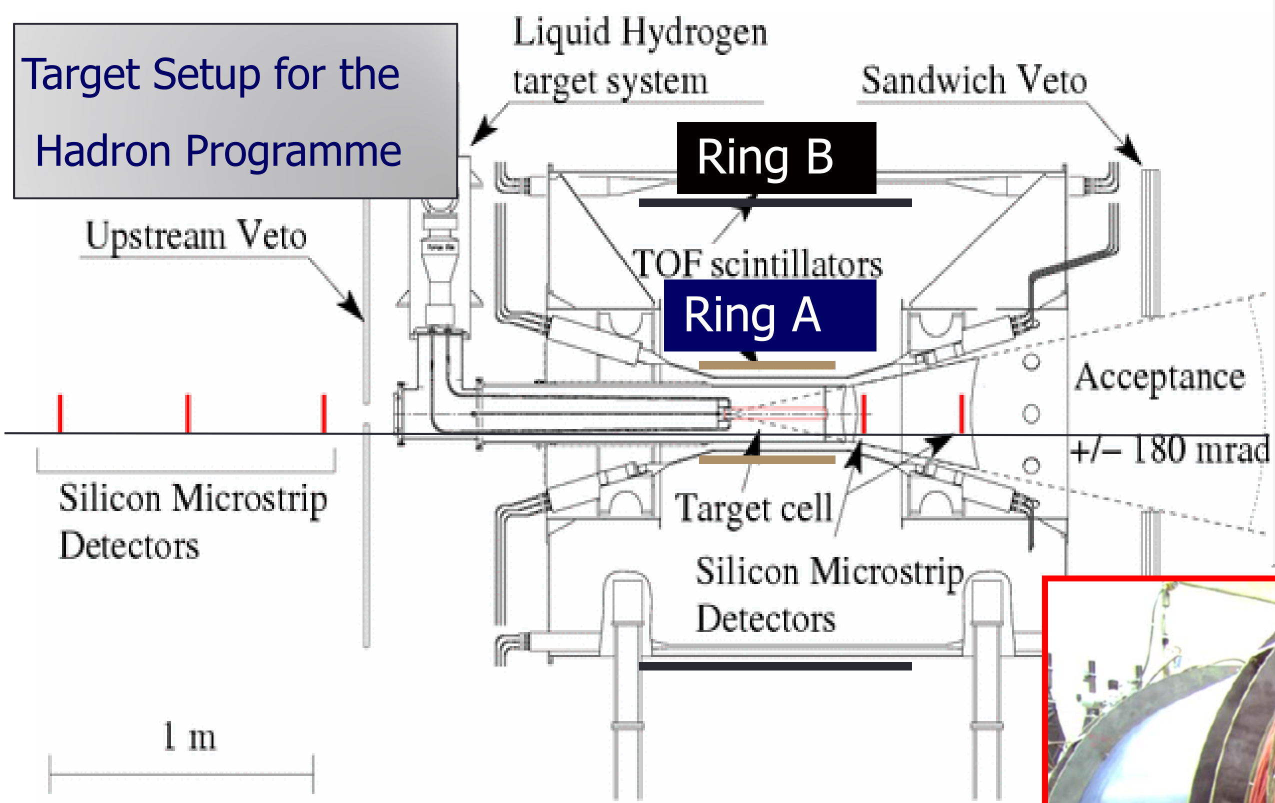
$$\text{BCSA} = \mathcal{D}_{CS,U} / \mathcal{S}_{CS,U}$$
$$= A_0 + A_{CS,U} \cos\phi + A_2 \cos 2\phi$$

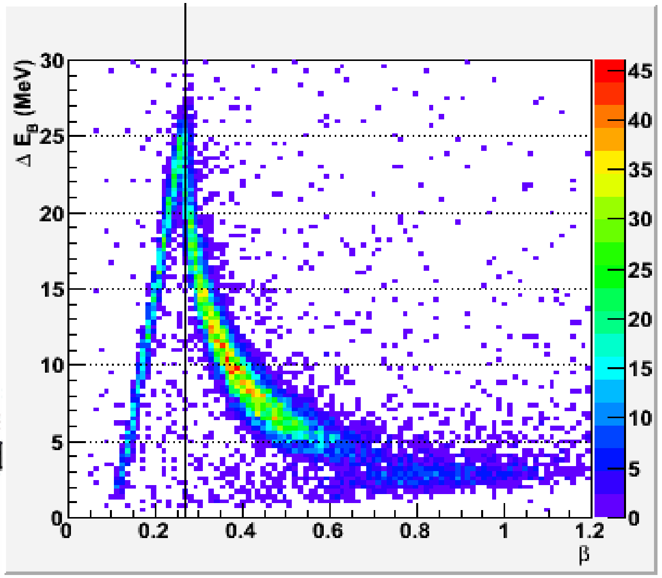
Measurement of c_1^{Int}

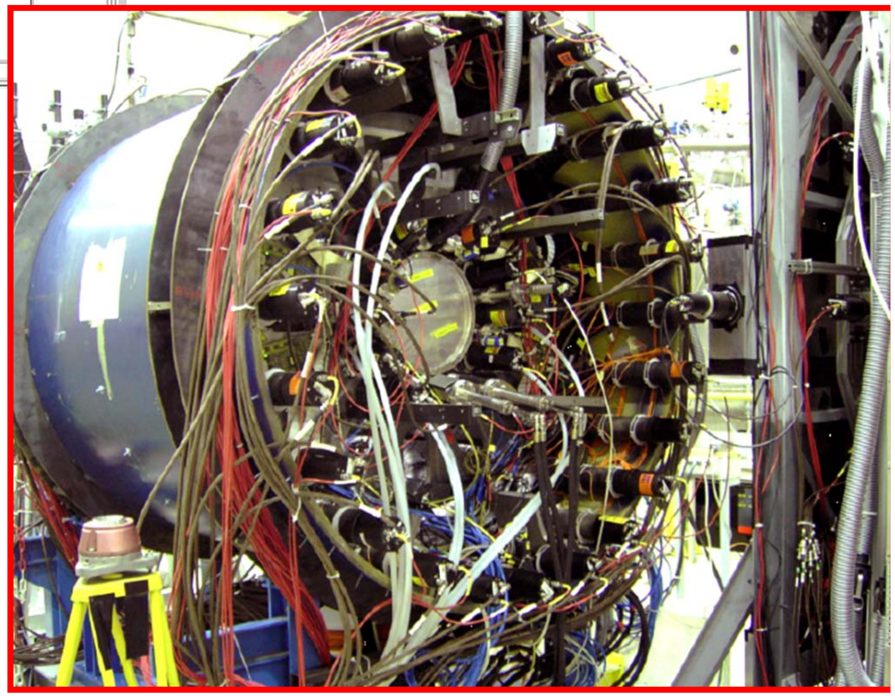


2008 & 2009 Beam Tests @ COMPASS

Target Setup for the Hadron Programme

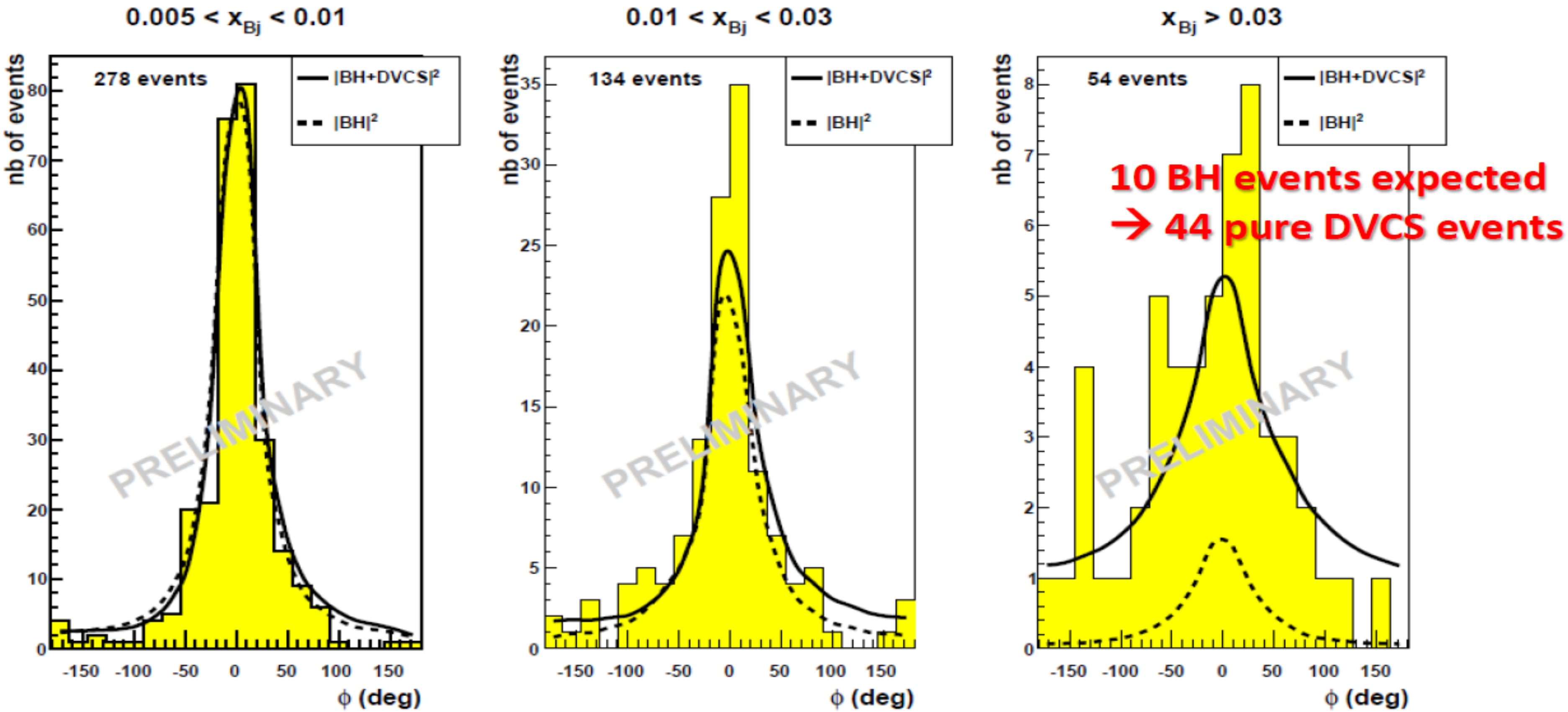






- Target : 40 cm LH2
- Recoil Detector (1m long)
- ECAL 1 & ECAL 2

First DVCS Signal observed @ COMPASS



- Detection efficiency :

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

Global efficiency :

ε_{global} = 0.13 +/- 0.05

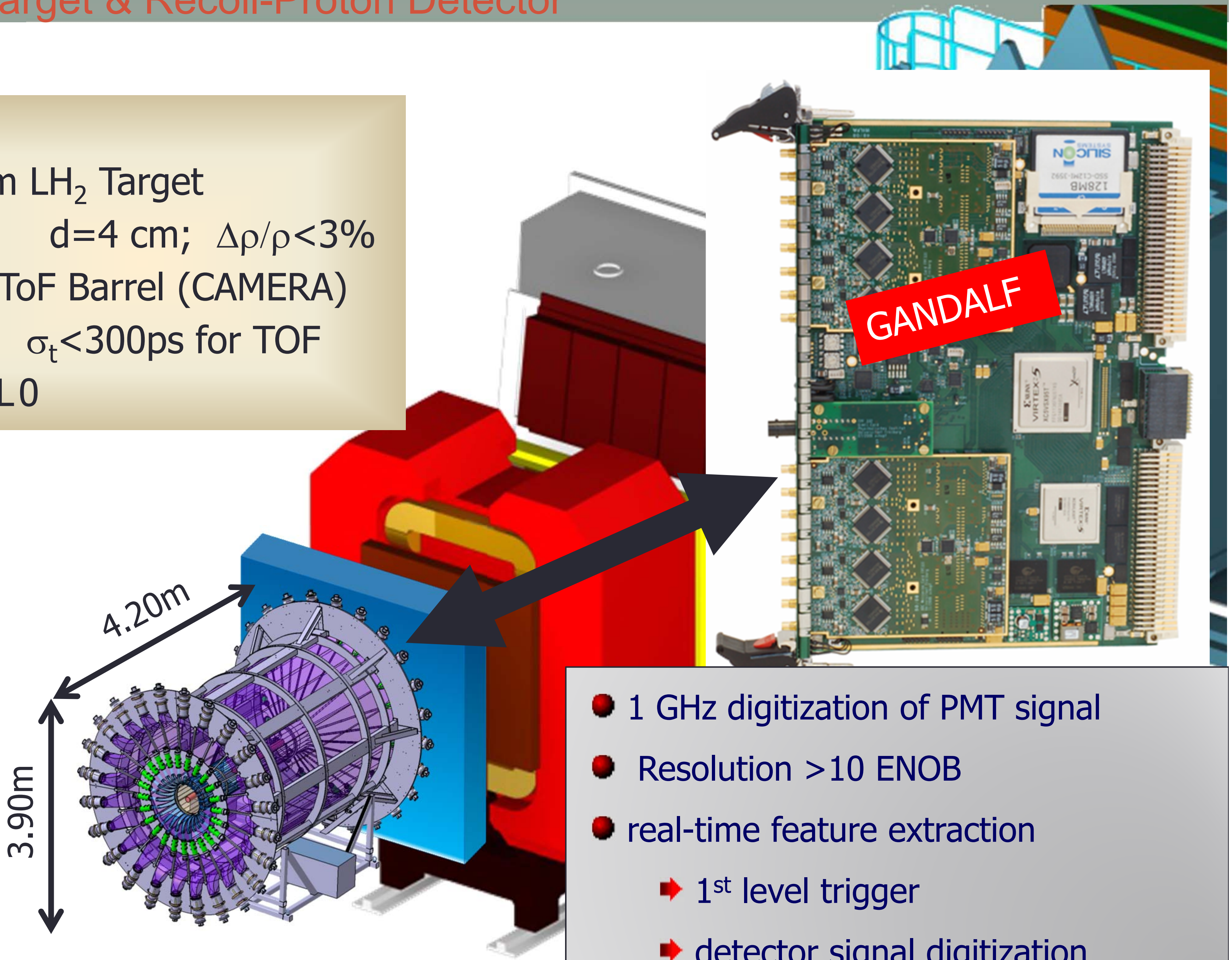
- μ+p → μ+p+γ efficiency
- SPS & COMPASS availability
- Dead time
- Trigger efficiency

Conclusion:
Projections of errors are realistic

New Target & Recoil-Proton Detector

<u>New:</u>

- 2.5 m LH_2 Target
  d=4 cm; $\Delta\rho/\rho<3\%$
- 4 m ToF Barrel (CAMERA)
  $\sigma_t<300$ps for TOF
- ECAL 0



- 1 GHz digitization of PMT signal
- Resolution >10 ENOB
- real-time feature extraction
  - 1^{st} level trigger
  - detector signal digitization

Conclusions

- Azimuthal Asymmetries in polarized exclusive ρ^0 production
  - small & compatible with zero
  - reasonable agreement with Goloskokov&Kroll prediction
  - may indicate E^u and E^d cancelation

- COMPASS II: investigate quark GPDs using DVCS
  - Covered x_B regime not accessible to any other experiment in near future
  - Frequent changes of beam charge and polarization – UNIQUE!
  - Study nucleon transversal dimension as function of x_B (Tomography)
  - Constrain GPD H through ϕ dependence of $\mathcal{D}_{CS,U}$

- Phase 2: DVCS & HEMP with polarized NH_3 Target inside CAMERA
  - Use knowledge of GPD H as input to constrain GPD E
  - Requires highly sophisticated recoil detection & polarized target systems