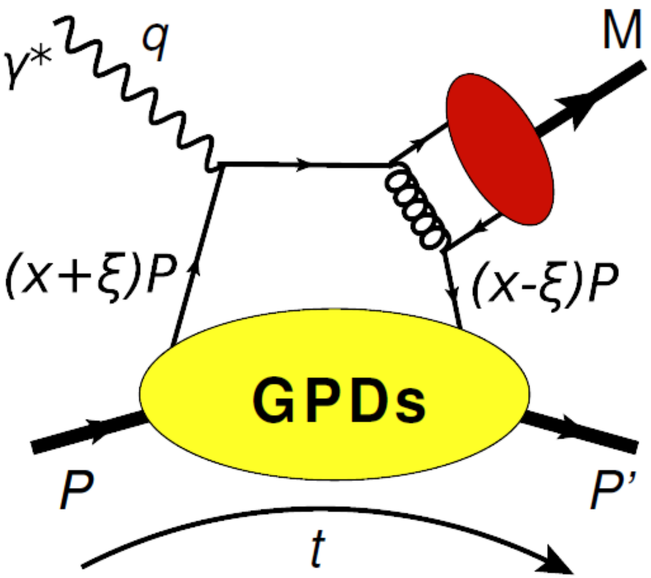
FIRST MEASUREMENTS TOWARDS GPDs WITH THE COMPASS-II EXPERIMENT AT CERN

Florian Herrmann
University of Freiburg
Baryons 2013, Glasgow



Cross section measurements:

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

ρ : ω : ϕ ~ 9 : 1 : 2

(at large Q^2)

Allows for flavor separation:

$E\rho^0 = 1/\sqrt{2}\,(2/3\, E^u + 1/3\, E^d + 3/4\, E^g)$

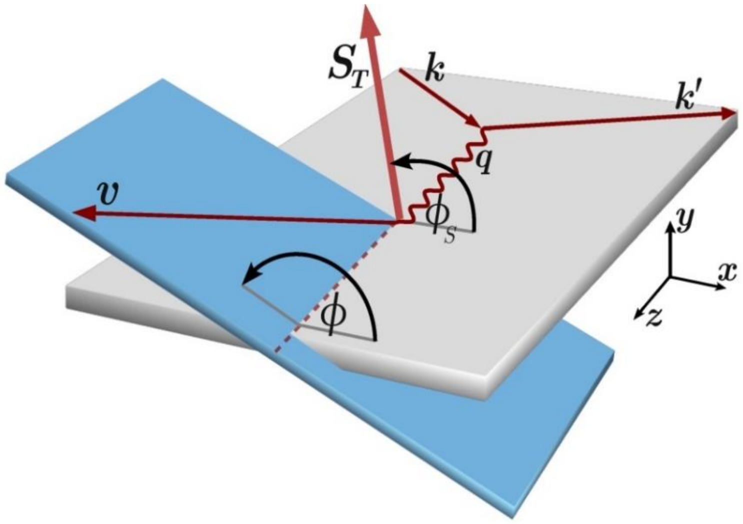
$E\omega = 1/\sqrt{2}\,(2/3\, E^u - 1/3\, E^d + 1/4\, E^g)$

$E\phi = -1/3\, E^s - 1/4\, E^g$

- Vector meson production from transversely polarized target
- Azimuthal asymmetry constrains relation of GPDs E/H

8 different asymmetries studied:

$A_{UT}^{\sin(\phi-\phi_S)}, A_{UT}^{\sin(\phi+\phi_S)}, A_{UT}^{\sin(\phi+\phi_S)}, A_{UT}^{\sin(3\phi-\phi_S)}$
$A_{UT}^{\sin(\phi_S)}, A_{LT}^{\cos(\phi-\phi_S)}, A_{LT}^{\cos(2\phi-\phi_S)}, A_{LT}^{\cos(\phi_S)}$



Allow access to Compton Form Factors

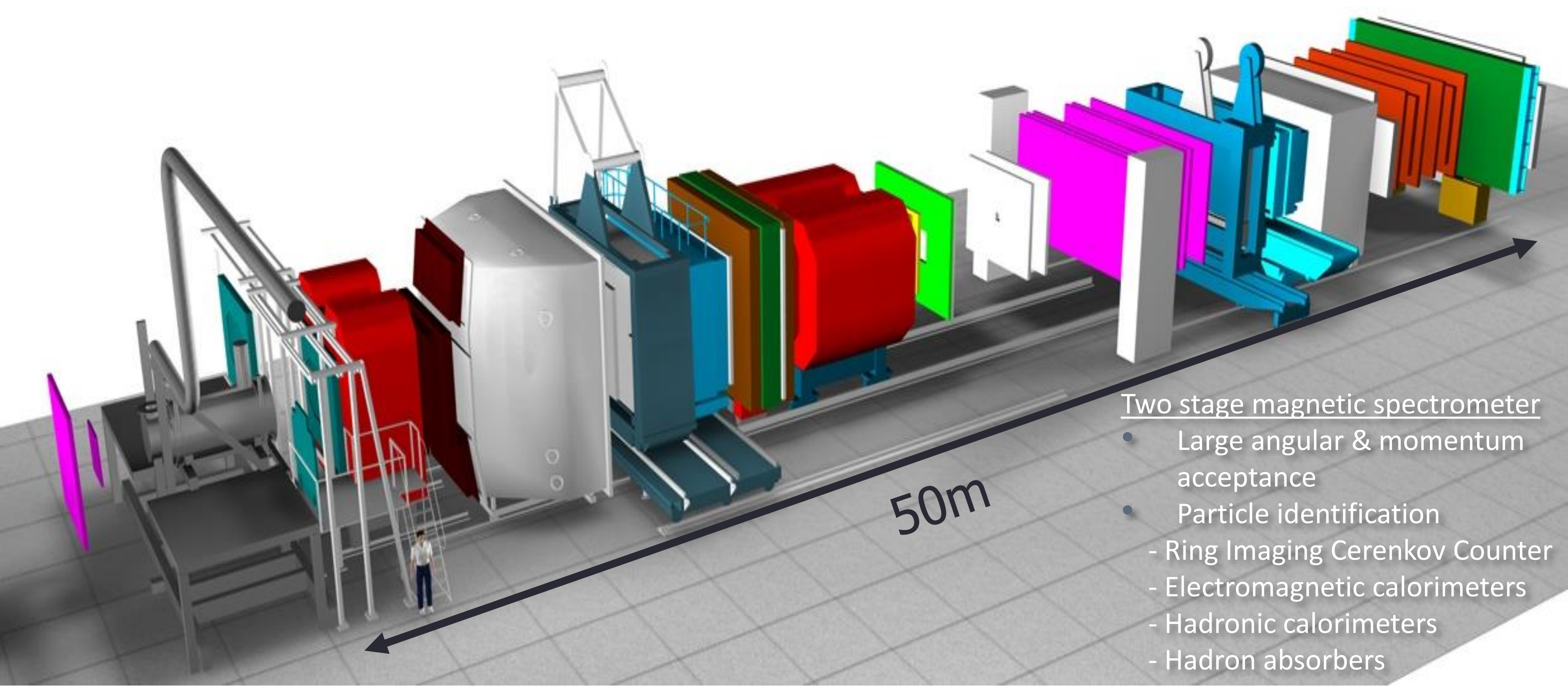
e.g. $A_{UT}^{\sin(\phi-\phi_S)} \propto \sqrt{|-t'|}\frac{\mathrm{Im}\,(\mathcal{E}^*\mathcal{H})}{|\mathcal{H}|^2}$

- $\mathcal{E}$ and $\mathcal{H}$ are are convolution integrals of hard scattering kernels and the ρ^0 distribution amplitude with GPDs $E_{q,g}$ & $H_{q,g}$
- Provide access to GPD E

Constrain total angular momentum using Ji's relation:

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

COMPASS facility



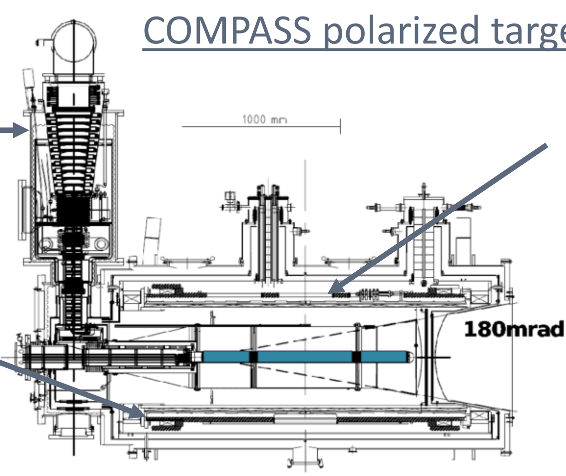
Two stage magnetic spectrometer

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

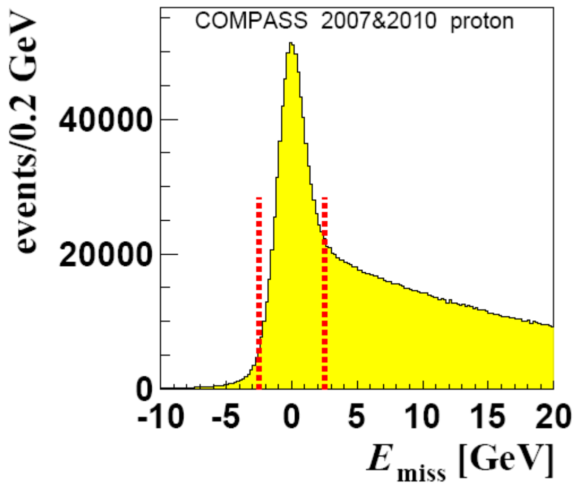
SPS M2 beam line:

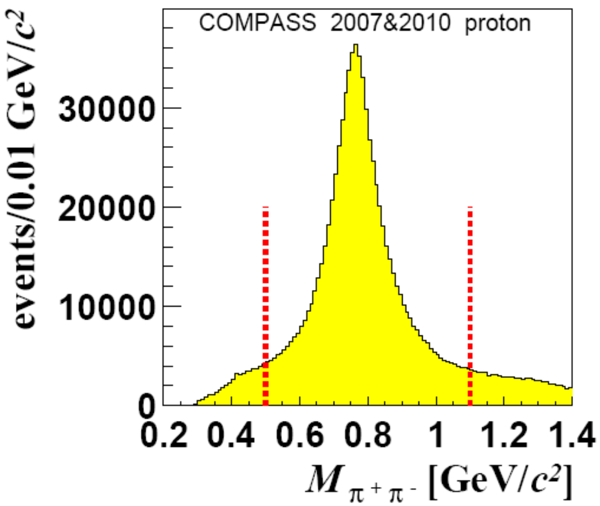
- μ^+, μ^- or hadron (p, K, pi) beam
  - changeover within < 1h
- Momentum: 100 - 200 GeV/c
- 80% polarization
- μ^+ & μ^- with opposite polarization

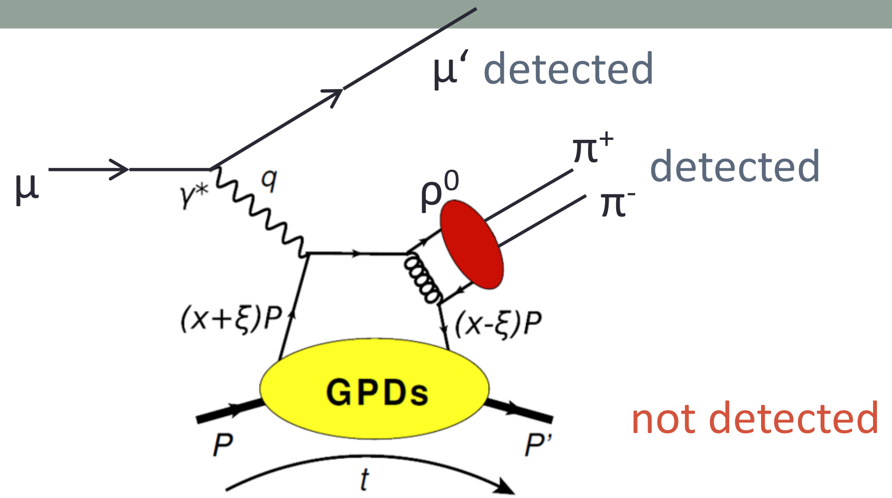
COMPASS polarized target



No recoil detector ->
Use Missing Energy Technique







Missing Energy Technique:

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

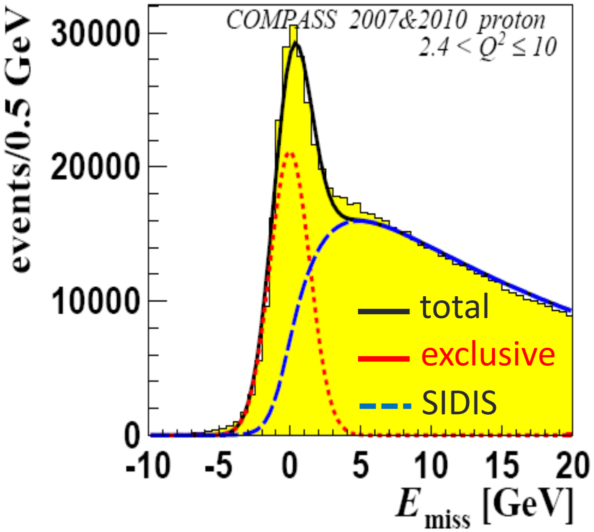
Final sample:

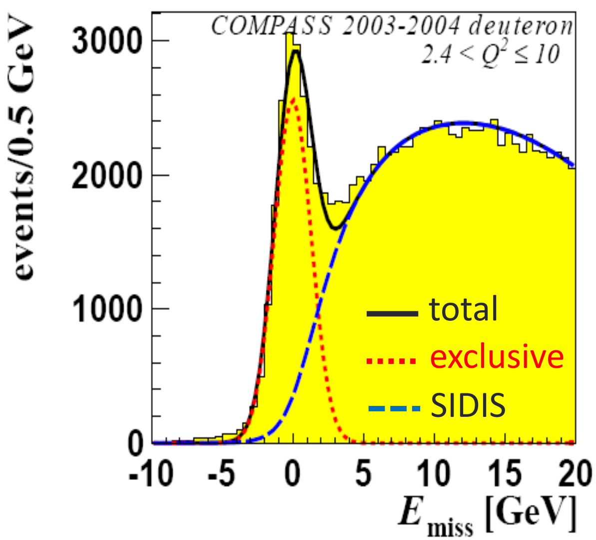
- NH_3: 797000 events
- ^{6}LiD: 97000 events

... but still strong SIDIS background

Estimate & subtract background bin-by-bin

Two examples:

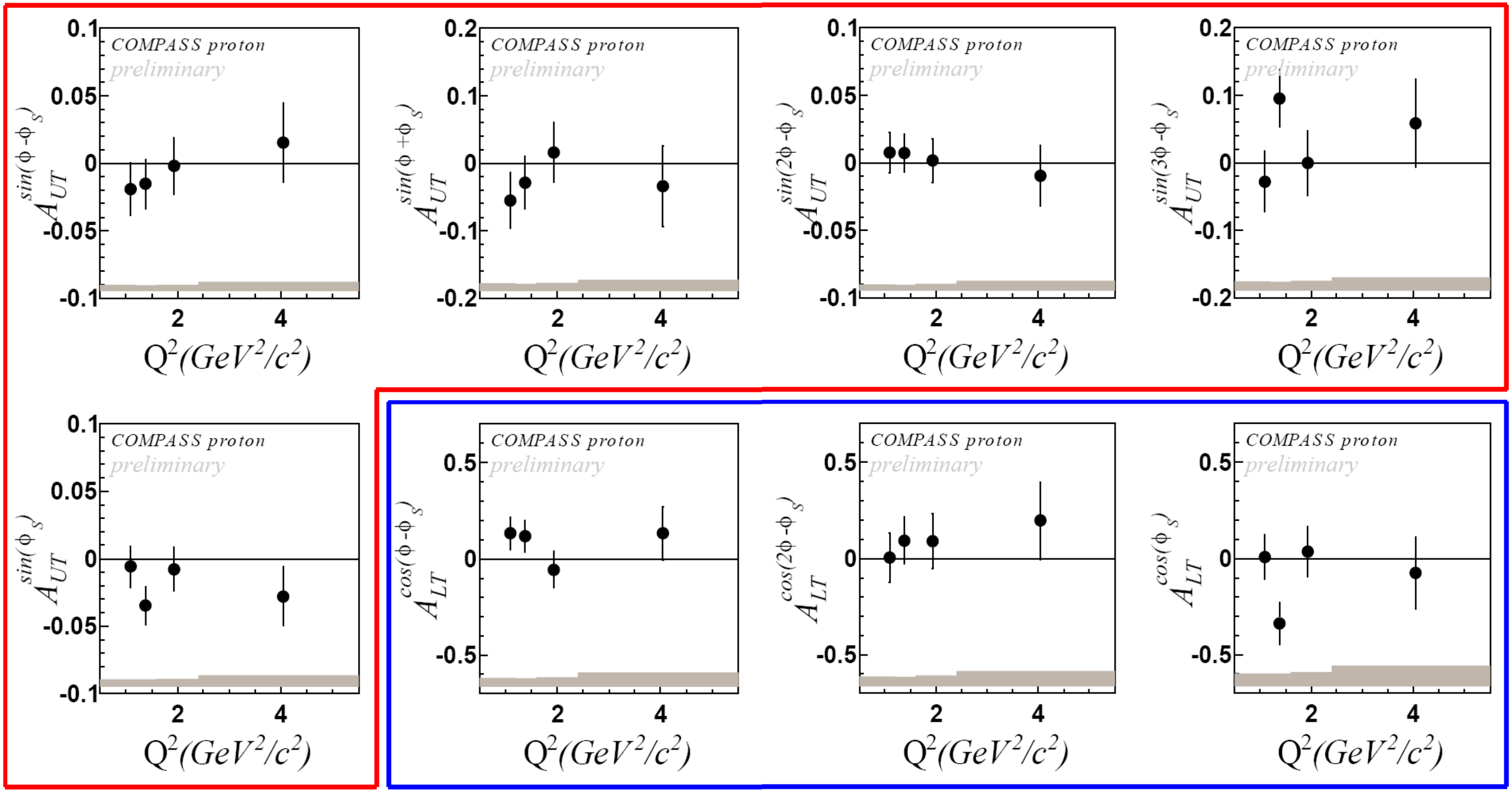




- Still 5…40% background from SIDIS (depending on target cell, x_{Bj}, Q^2, p_T^2)
- Fix shape of background using Data/MC like-sign events
- Estimate SIDIS background from fit to data
- Assume Gaussian shape for signal

Fit eight asymmetries
including corrections for dilution factor
and target polarization
by a binned max. likelihood

New Results!

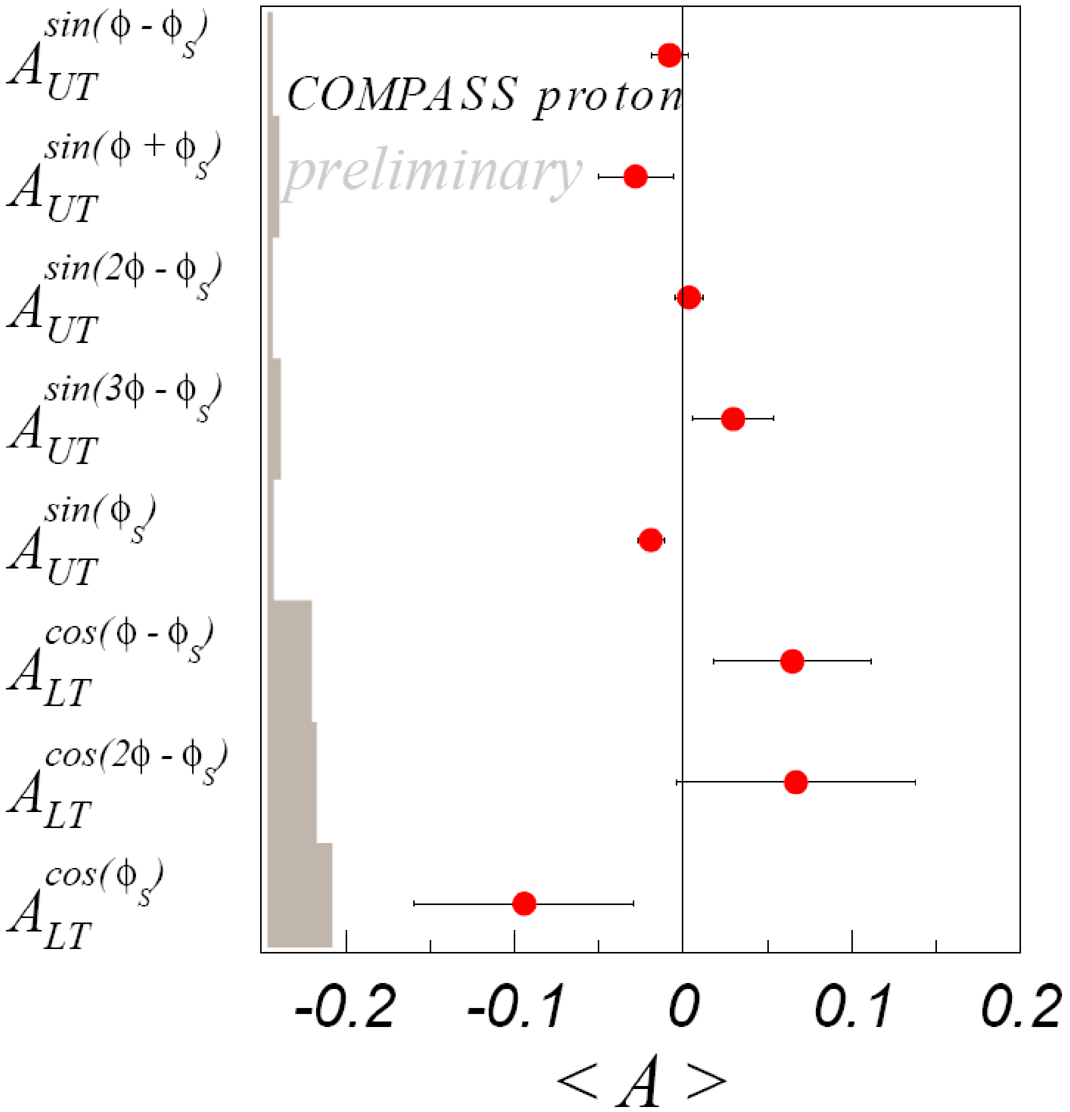


Unpolarized beam

Polarized beam

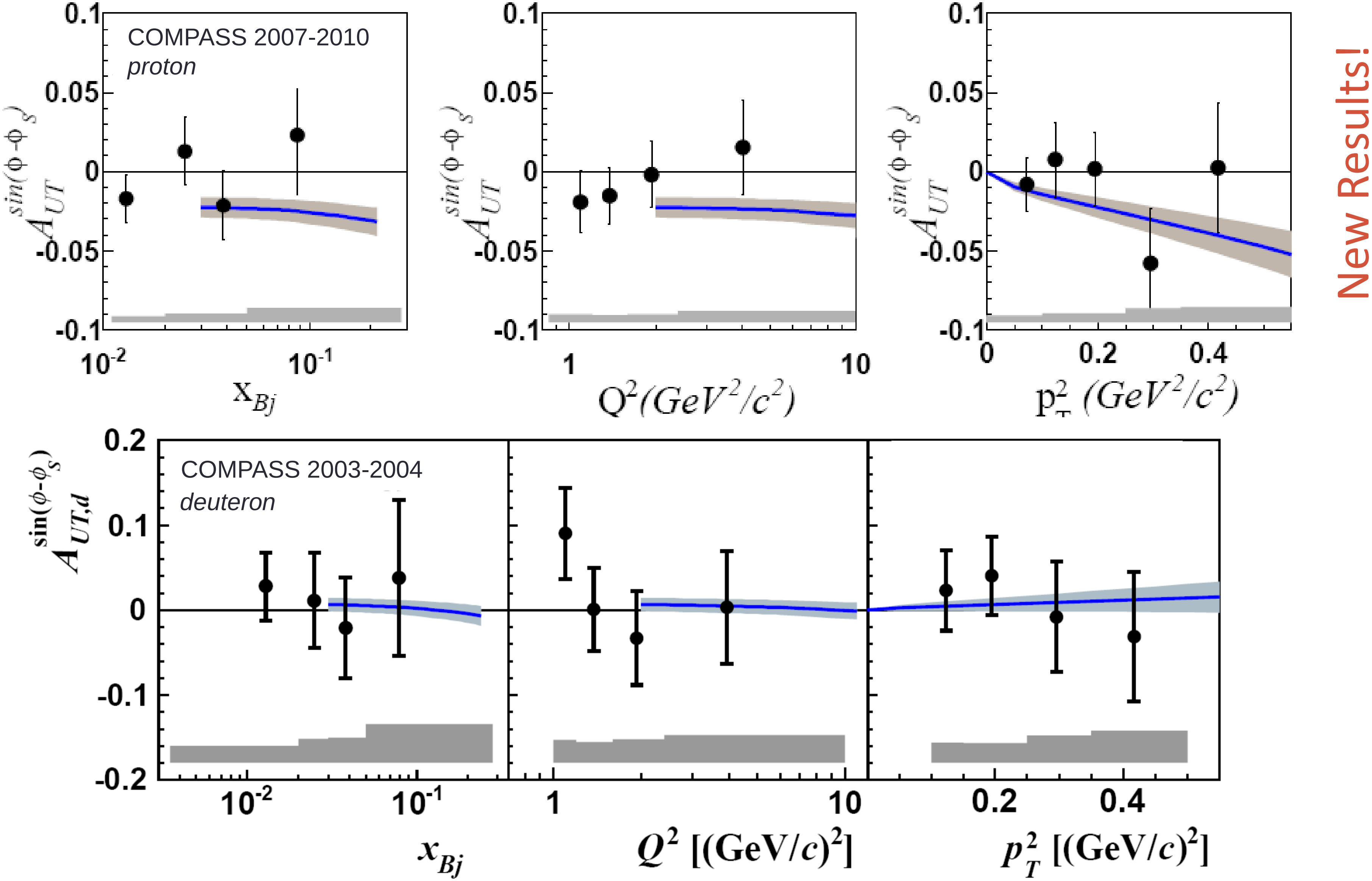
Results – mean asymmetries

New Results!



Non-zero $A_{UT}^{\sin(\phi_S)}$ may indicate non vanishing values for chiral odd GPDs!

Exclusive ρ^0 production on transversely polarized Targets



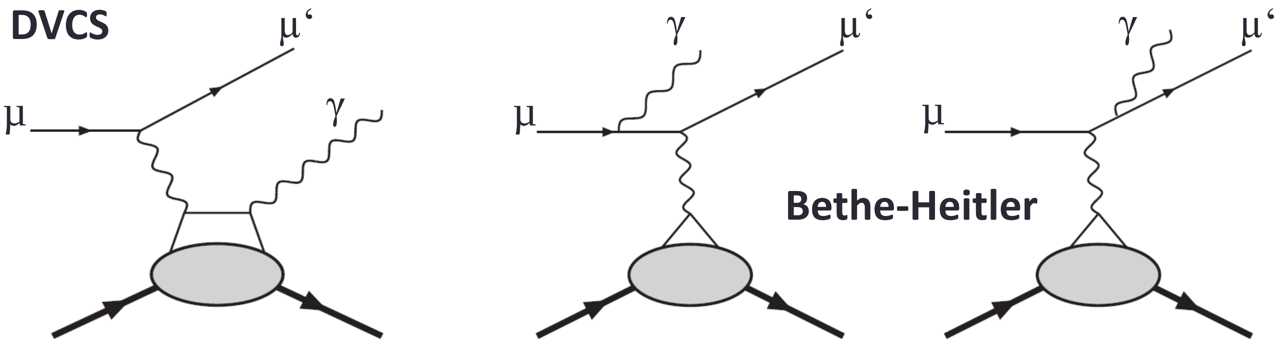
Goloskokov & Kroll EP J C50
prediction for $A_{UT}^{sin(\phi-\phi_S)}$

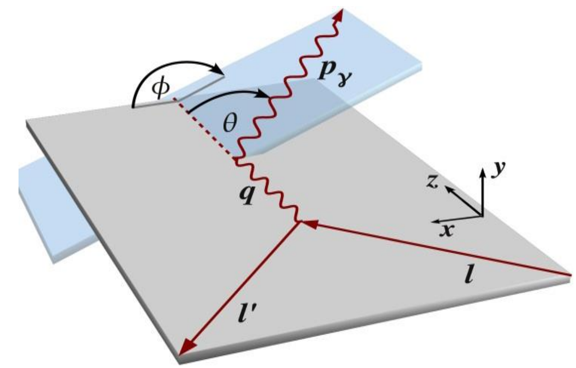
- GPDs E^u and E^d approximately cancel for ρ^0 production

Conclusions

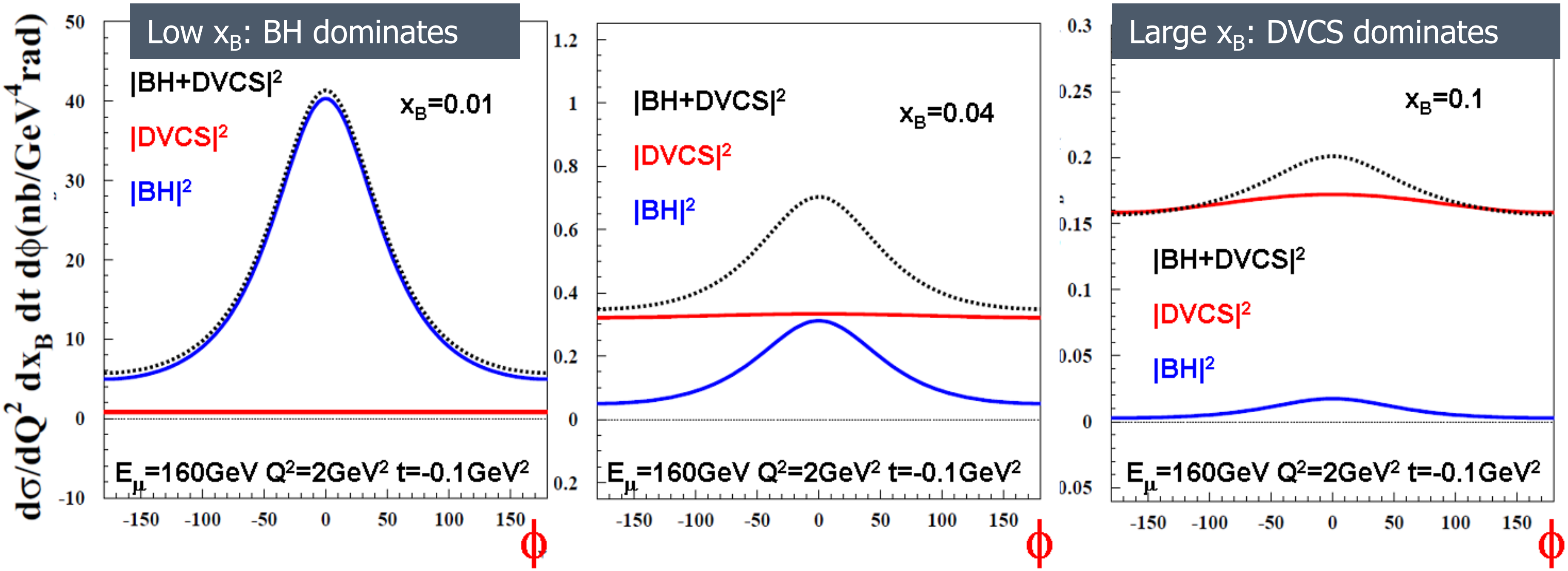
8 Azimuthal Asymmetries in polarized exclusive ρ^0 production

- Excess in $A_{UT}^{\sin(\phi_S)}$, others small & compatible with zero
- Reasonable agreement with Goloskokov&Kroll prediction for $A_{UT}^{\sin(\phi-\phi_S)}$
- May indicate **E^u and E^d cancelation**.
- Allow **access to chiral odd GPDs**





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

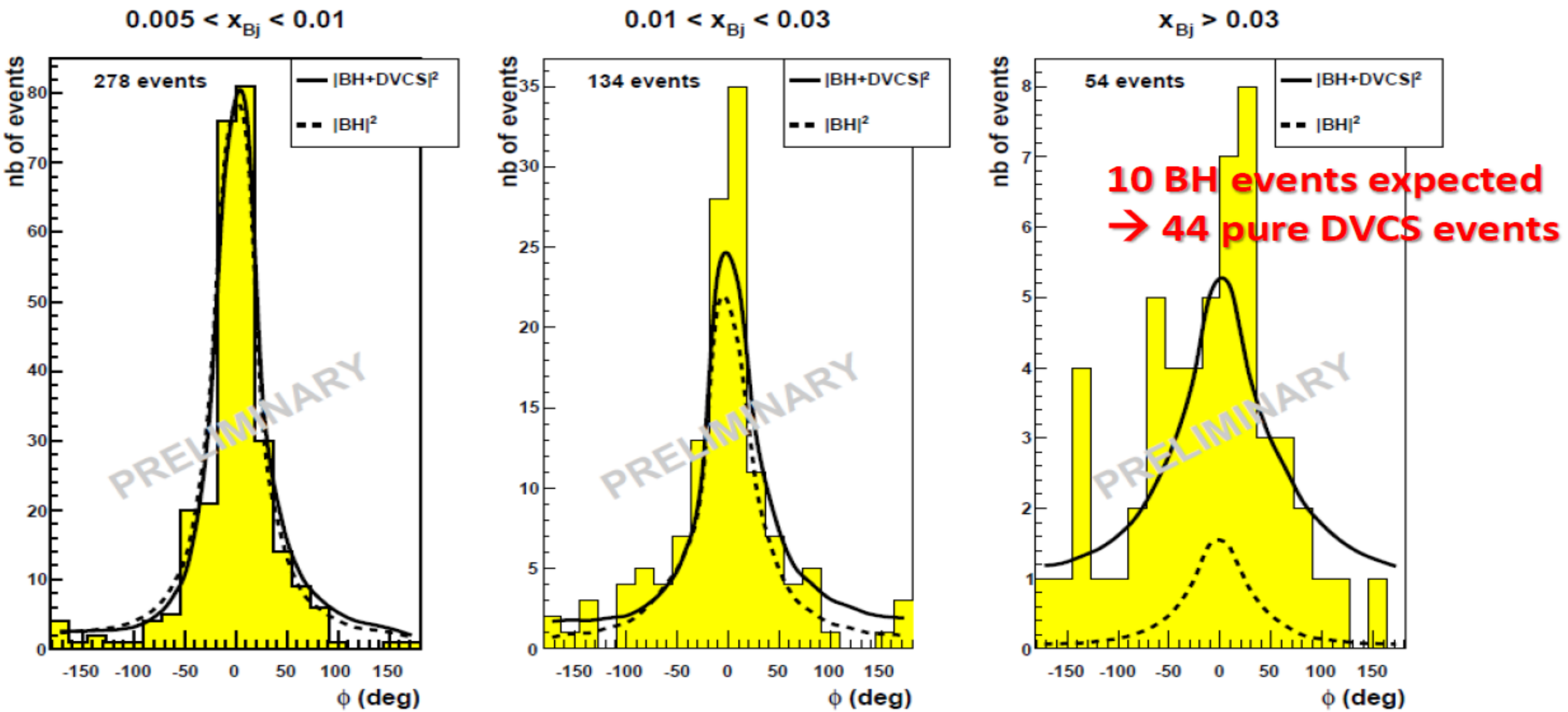


Reference yield
from almost pure BH

Study DVCS through
interference term:
Re T^{DVCS} & *Im* T^{DVCS}

Study $d\sigma^{DVCS}/dt$
Transverse Imaging

First DVCS Signal observed @ COMPASS



Detection efficiency :

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

Global efficiency :

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

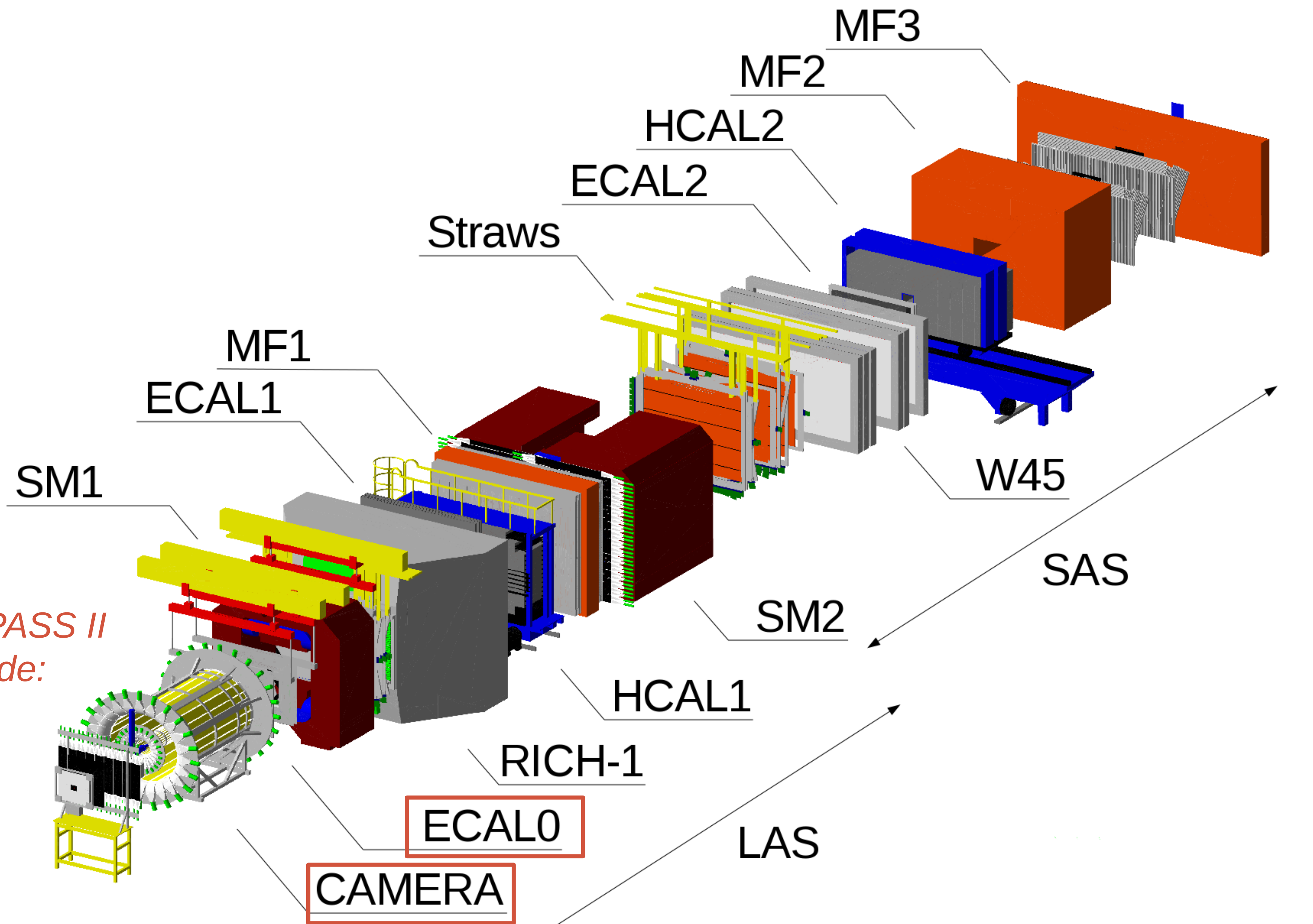
- m+p → m+p+g efficiency
- SPS & COMPASS availability
- Dead time
- Trigger efficiency

Conclusion:

Projections of errors in MC predictions are realistic!

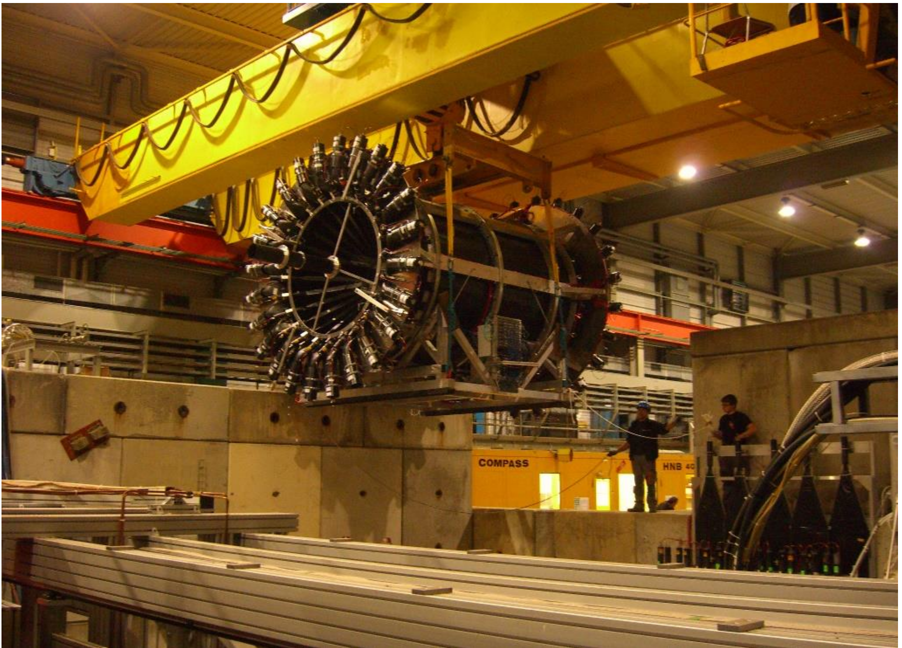
COMPASS 2012 DVCS upgrade

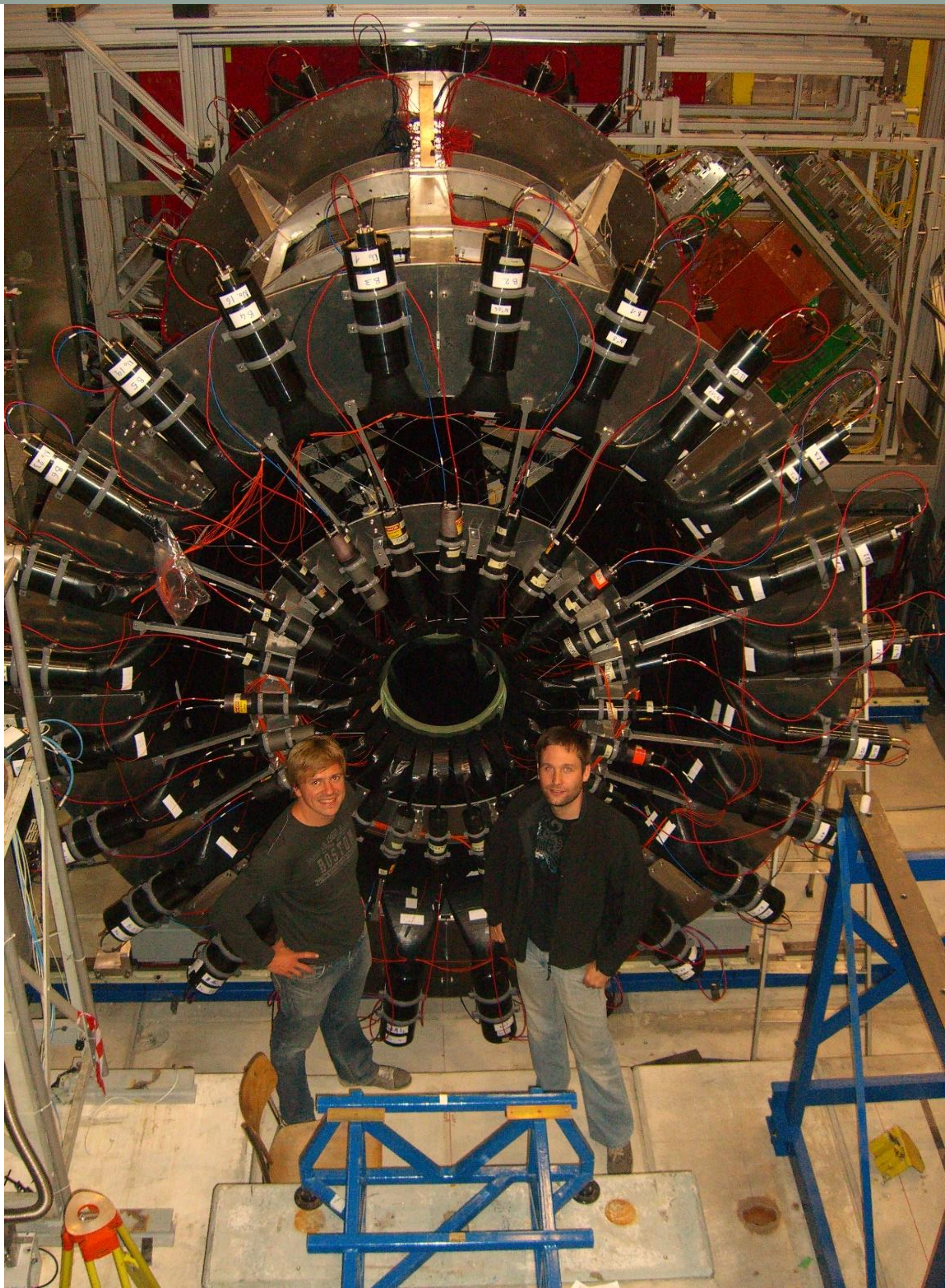
COMPASS II Upgrade:



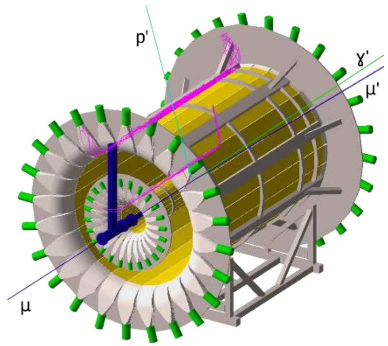
NIM A 577 (2007) 455 / CERN-SPSC-2010-014

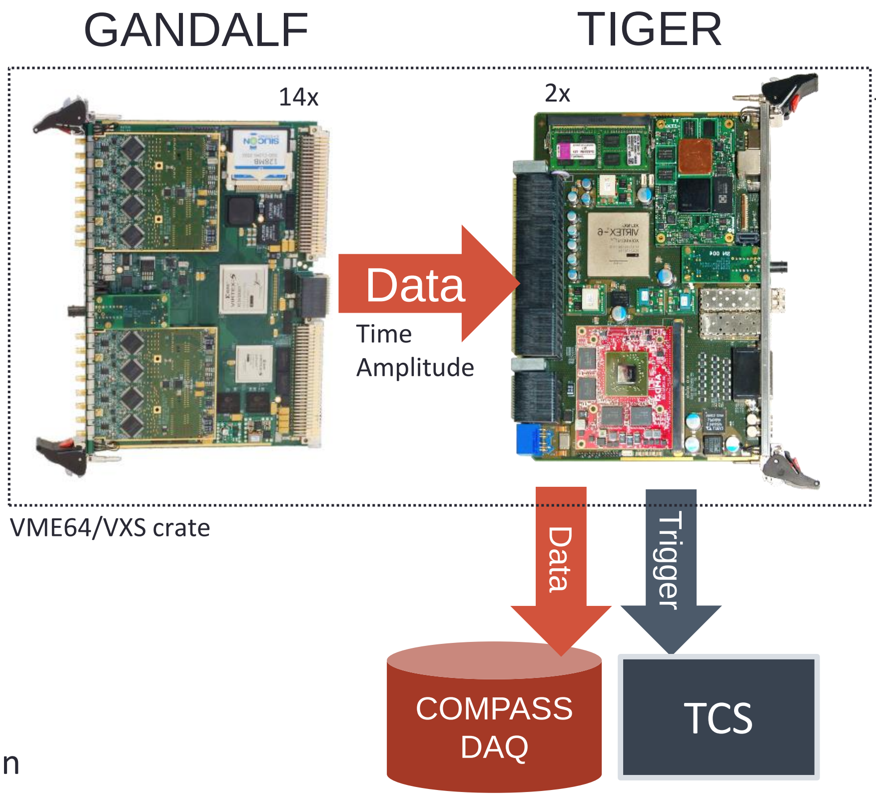
CAMERA installation

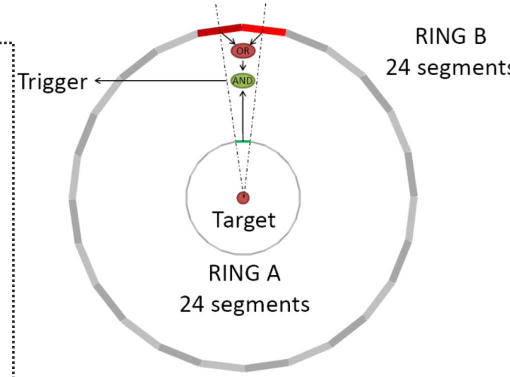




CAMERA readout and proton trigger with GANDALF and TIGER



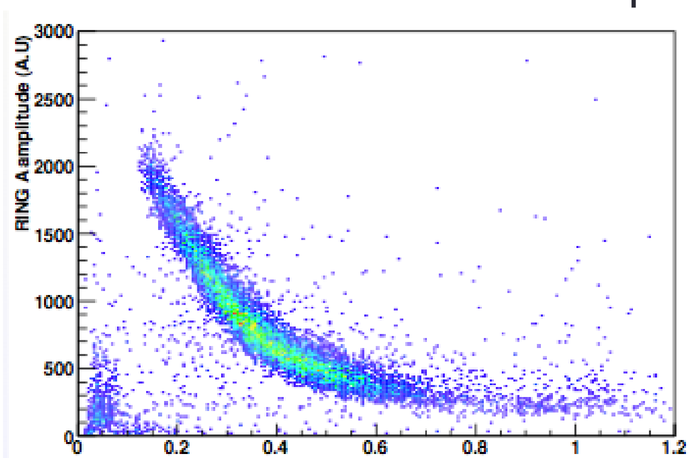


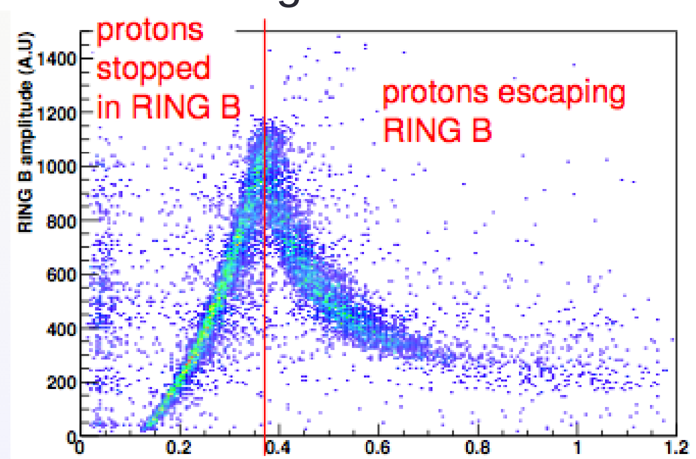


- > 1 GHz digitization of PMT signal
- > Resolution >10 ENOB
- > Real-time feature extraction
  - 1st level trigger
  - Detector signal digitization

Trigger on geometry and time:
tdiff up/down: 45ns
TOF: 0ns – 100ns

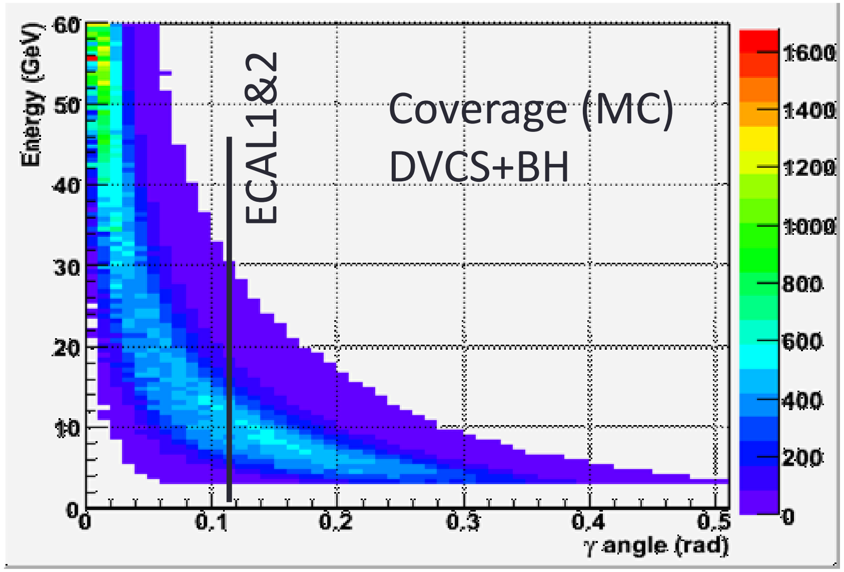
Calibration with pion beam selecting for elastic events



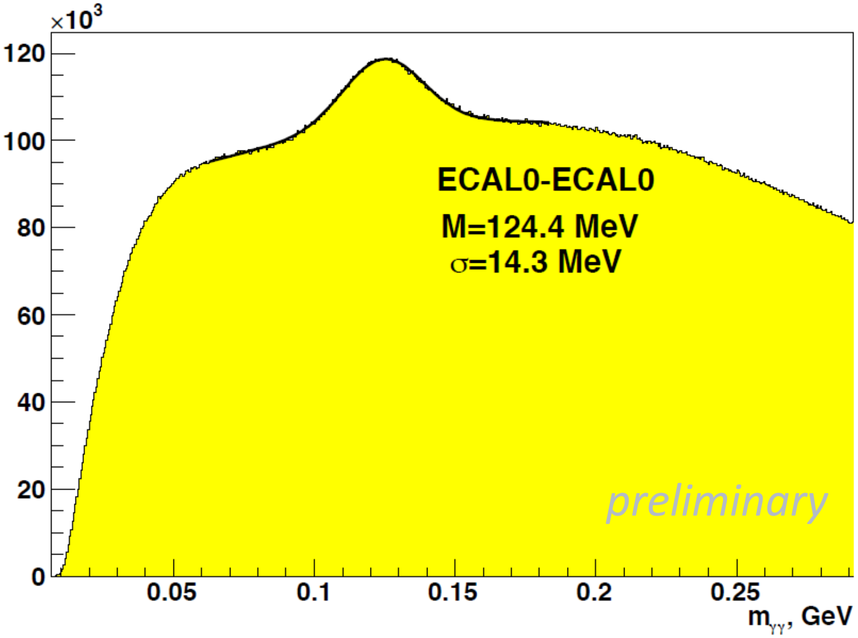


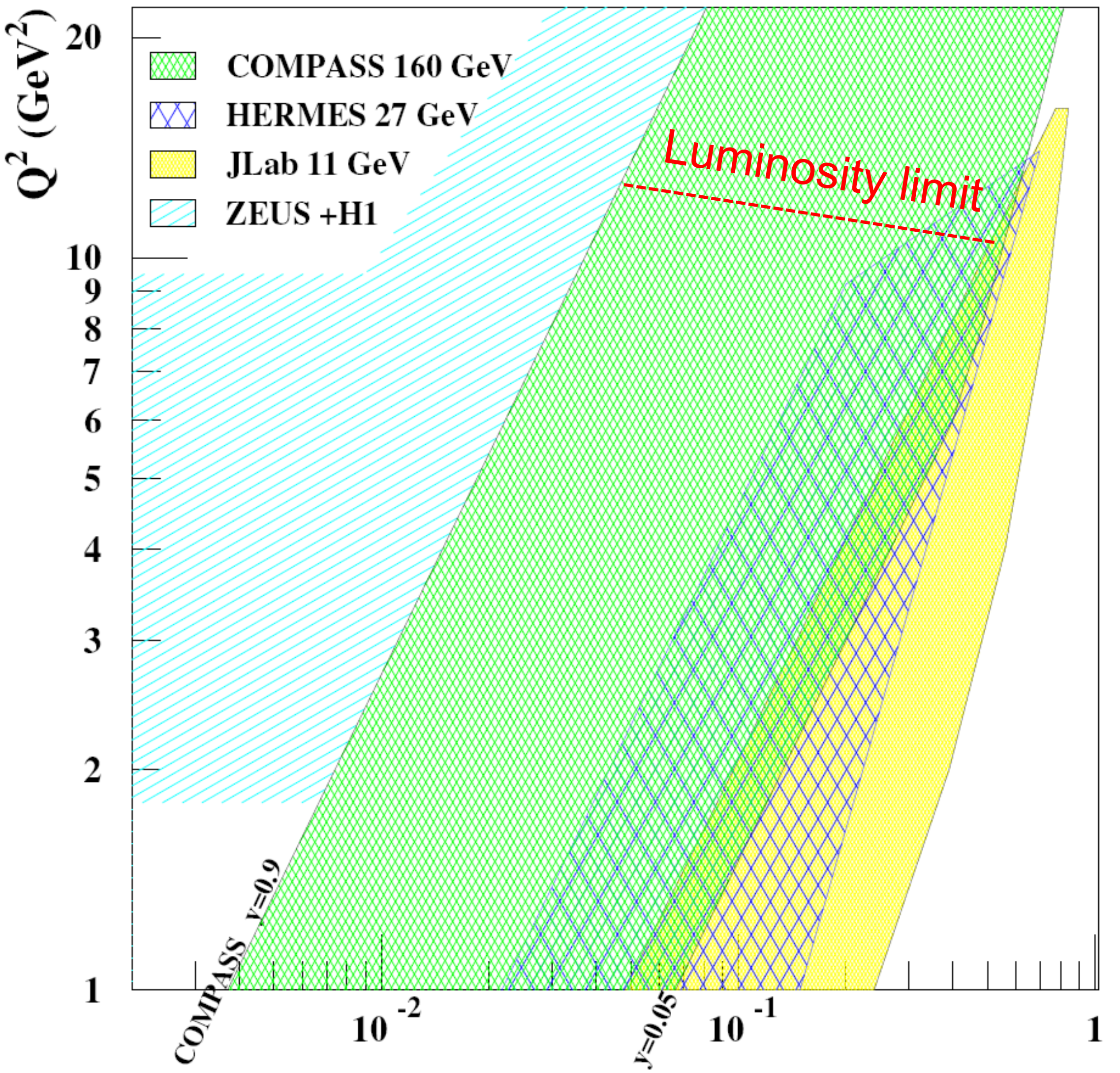
Requirements

- Photon energy range 0.2- 30 GeV
- Size: 240cm x 240cm ;
- Granularity 4x4 cm2
- Shaschlyk module with MAPD readout
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field



Reduced setup in 2012 (1/4 of total)





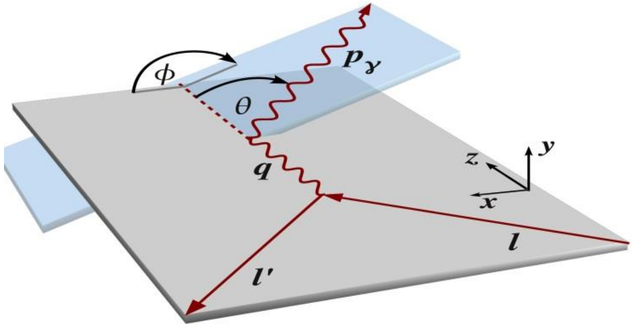
Gluon, sea and valence quarks region

- **COMPASS** will explore the intermediate x_{Bj}
- Uncovered region between ZEUS+H1 and HERMES+ JLab

Used for the following monte carlo predictions:

- polarised muon beam 160 GeV
- 48s SPS period / 9.6s spill duration
- 4.6 10^8 μ^+ per spill (1/3 for μ^-)
- 2.5m liquid hydrogen target
- $L = 10^{32}$ cm^{-2} s^{-1}
- New RPD (CAMERA)
- Extended calorimetry (ECAL0+1+2)
- $\varepsilon_{global} = 0.1$
- 280 days of data taking

Observables (Phase 1) – unpolarized Target



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

Beam Charge & Spin Sum:

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

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

MC prediction!

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

Using $S_{CS,U}$

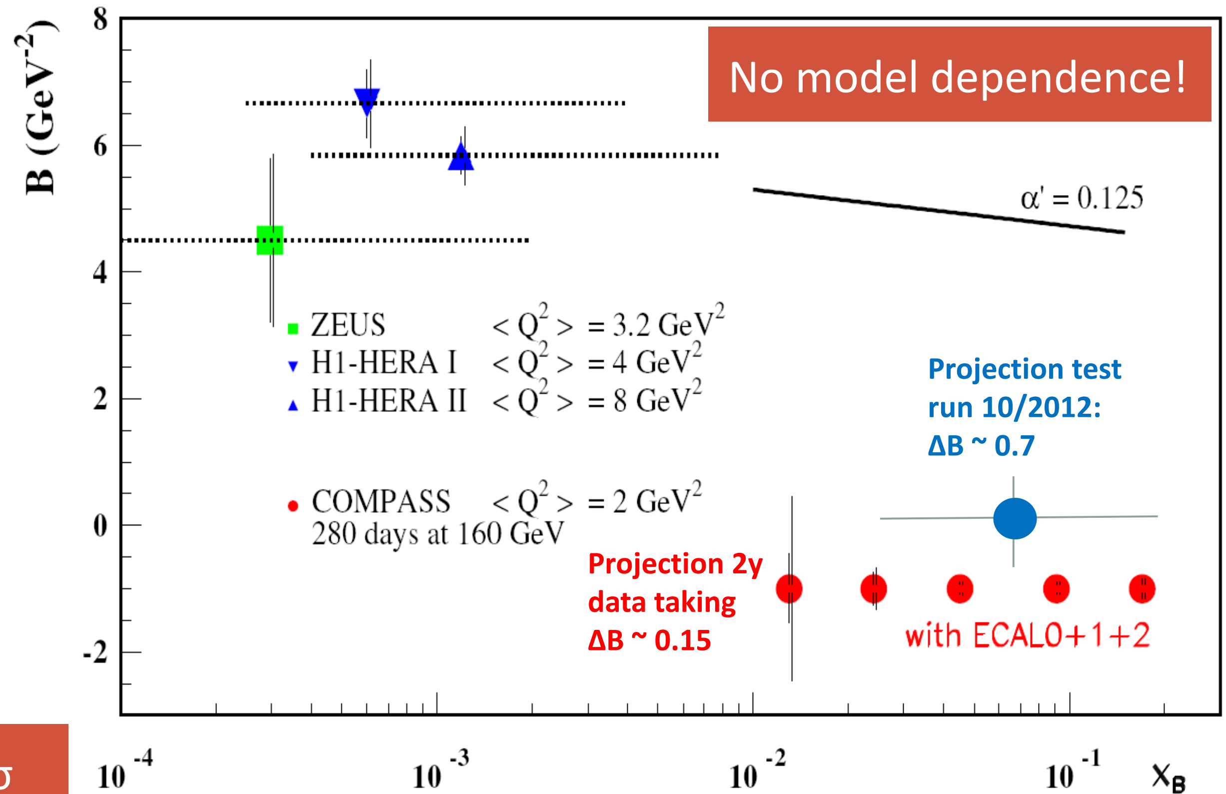
Integrating over φ

Subtracting BH

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

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

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

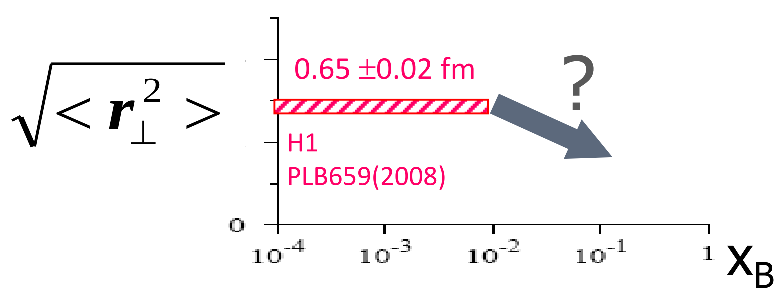


Measure α' with accuracy >2.5σ

for: α' > 0.125 (with ECAL 0+1+2)

Distance between struck quark and spectator system:

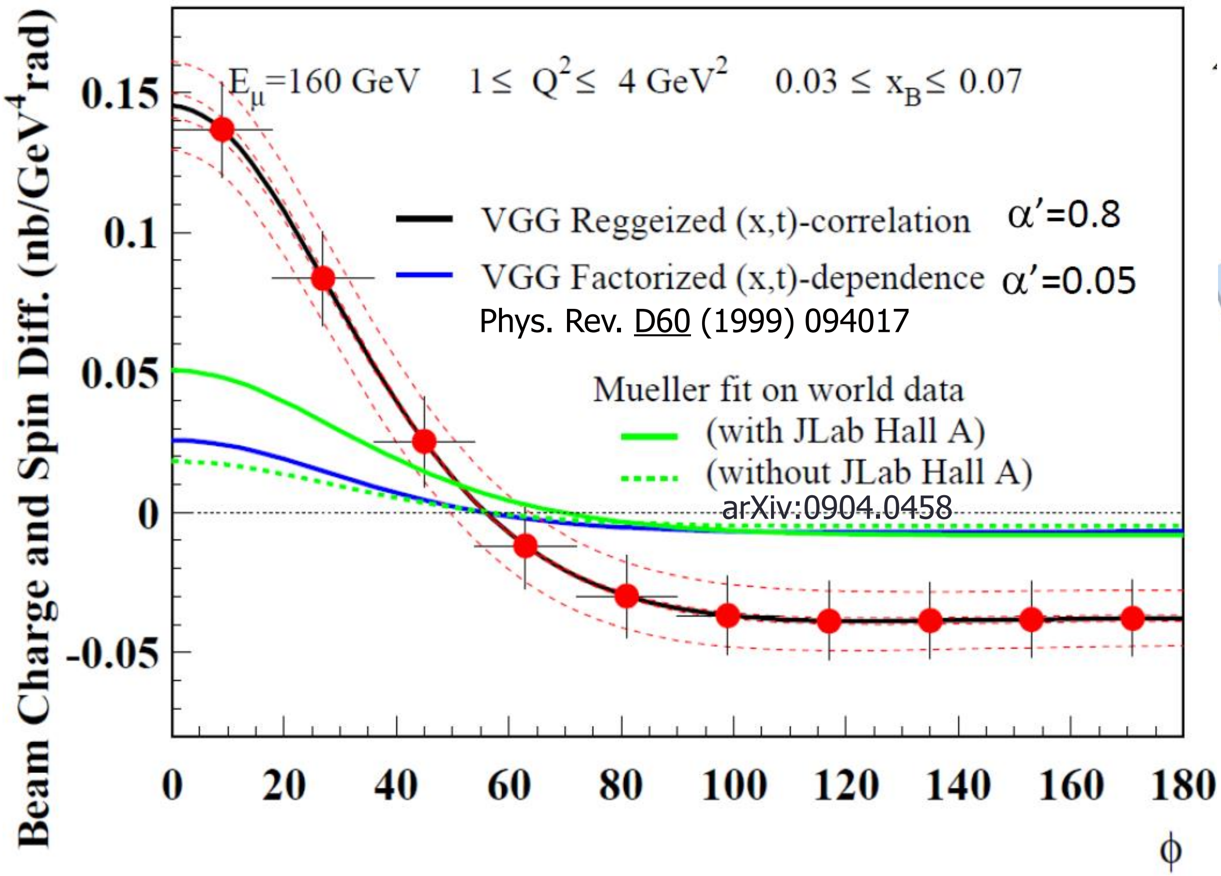
$$\langle r_\perp^2(x_B)\rangle \sim 2B(x_B)$$

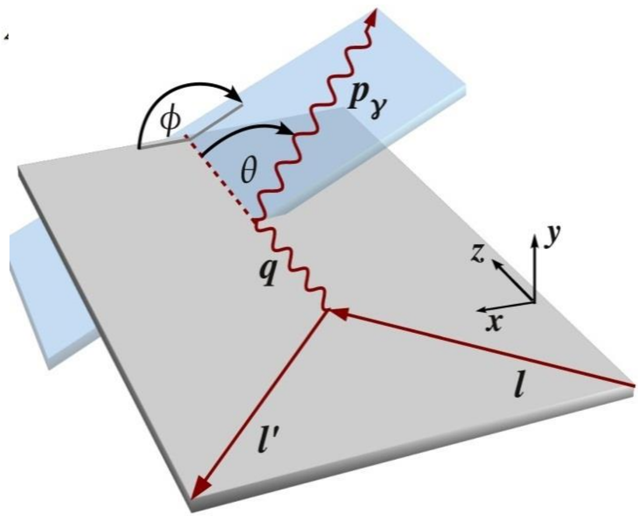


Beam Charge & Spin Difference $\mathcal{D}_{CS,U}$

MC prediction!

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





Strong constraints to GPD H!

- 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 $\mathcal{D}_{CS,U} / \mathcal{S}_{CS,U}$

MC prediction!

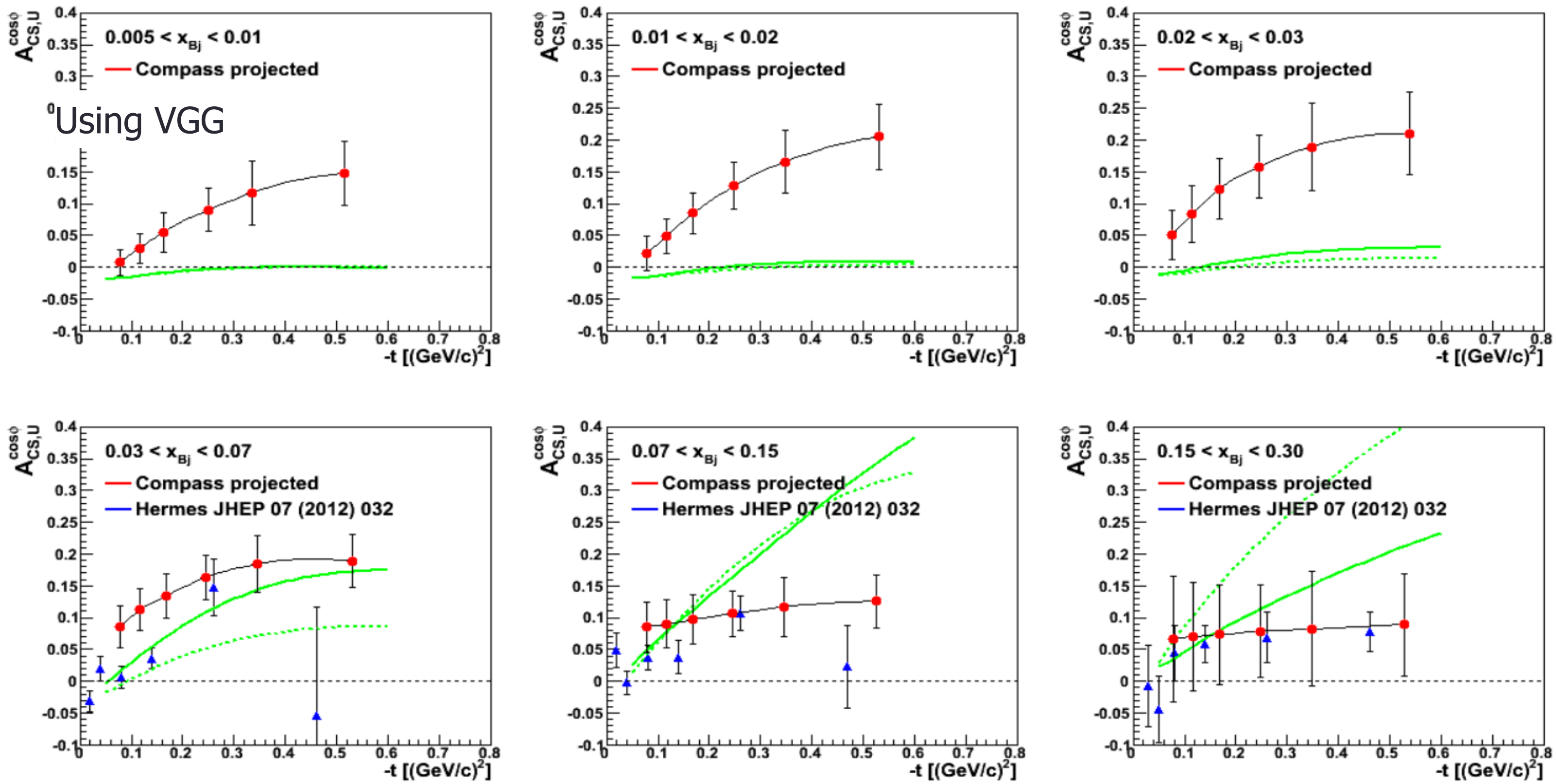
$$\text{BCSA} = \mathcal{D}_{CS,U} / \mathcal{S}_{CS,U}$$

$$= A_0 + A_{CS,U} \cos\phi + A_2 \cos 2\phi$$

arXiv:0904.0458

Mueller's fit on world data'
(with JLab Hall A)
(without JLab Hall A)

- Easier to measure than the difference as certain systematics cancel
- Less sensitive to theoretical corrections



- 2 years data taking with unpolarized target LH: study 2 dim dependence in 6 bins in xBj and 6 bins in t.
- Enough statistics for 10 bins in ϕ to do fits of azimuthal dependence

Conclusions

8 Azimuthal Asymmetries in polarized exclusive ρ^0 production

- Excess in $A_{UT}^{\sin(\phi_S)}$, others small & compatible with zero
- Reasonable agreement with Goloskokov&Kroll prediction for $A_{UT}^{\sin(\phi-\phi_S)}$
- May indicate **E^u and E^d cancelation** and **access to chiral odd GPDs**

COMPASS II, Phase 1: investigate GPDs (q,g) using HEMP & DVCS (2016-2017)

- 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 (Nucleon tomography)
- Constrain **GPD H** through ϕ dependence of $\mathcal{D}_{CS,U}$

Already built for upgrade: 4m long RPD, 2.5m LH2 target, Extended calorimetry – **operated in 2012 test run**

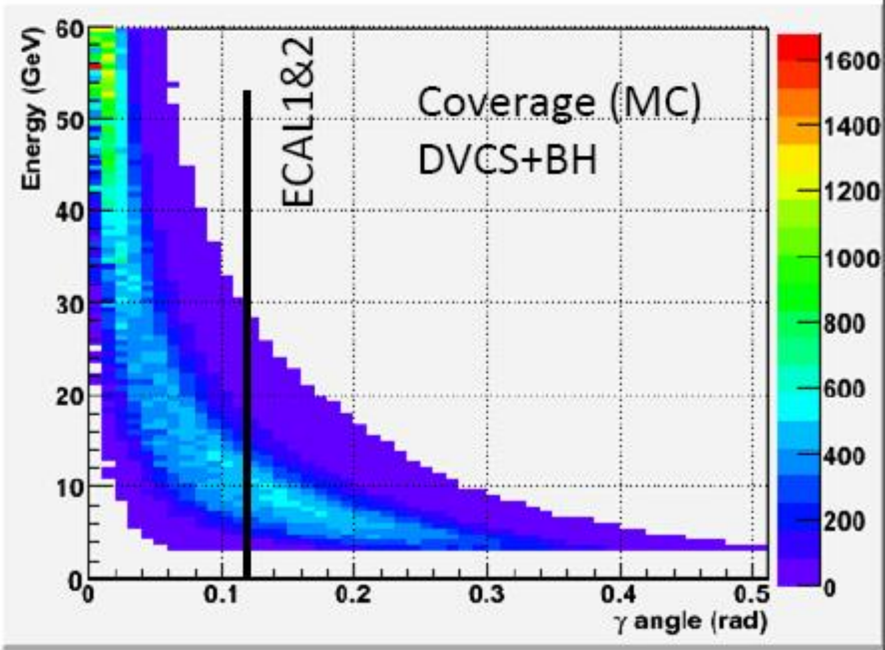
COMPASS II, Phase 2: DVCS & HEMP with transversely polarized NH_3 Target and RPD

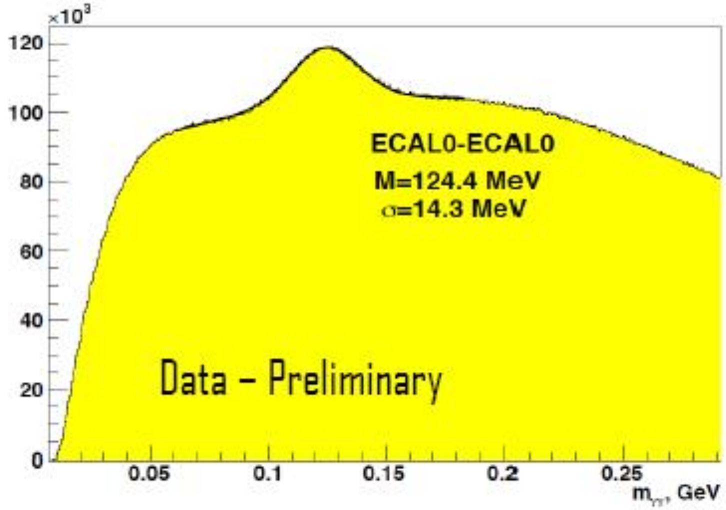
- Use knowledge of **GPD H** as input to constrain **GPD E**
- **Requires highly sophisticated recoil detection & polarized target systems**

Requirements

- Photon energy range 0.2- 30 GeV
- Size: 240cm x 240cm ;
- Granularity 4x4 cm^2
- Shaschlyk module with MAPD readout
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field.

Reduced setup in 2012 (1/4 of total)



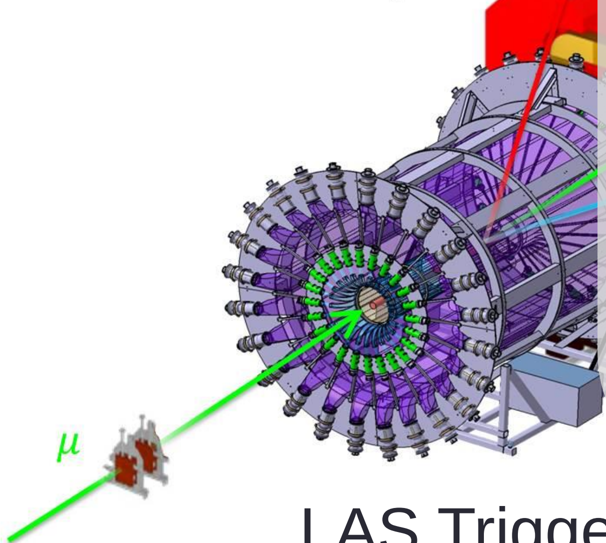


CAMERA

Target region DVCS run 2012

	SrcID
12x Gandalf	
-A and B Ring readout	820-825
	830-835
2x Gandalf	
-SciFi Dynods	840, 841
1x TIGER	
-Proton Trigger	890
1x TIGER	
-TCS and Readout	880

2xT 14xG



Finally some numbers:

120 ADC channels
600 TDC/Scaler channels

Data rate at ADCs
(CAMERA: 14 modules * 8ch * 1GHz * 12 bit)
168Gbyte/s (1,6TByte per spill)

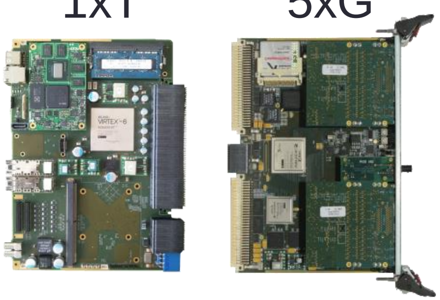
output stage: (550words * 4 * 23kHz)
45MByte/s (450 Mbyte per spill)

TCS Fibres 2 (instead of 24
SLINK ports 2 (instead of 6
6SMUX)

23 Gandalf modules
3 TIGER modules
4 VXS Backplane crate

Scintillating Fibres

1xT 5xG



5x Gandalf
-SciFi15 TDC 850,851,852
-SciFi2 TDC& 860,861
Scaler 870,871
1x TIGER
-TCS and Readout 881

LAS Trigger

2x Gandalf

Mastertimes

2x Gandalf

ADC
800

TDC
801

DVCS cross-section

Montag, 3. Juni 2013 13:59

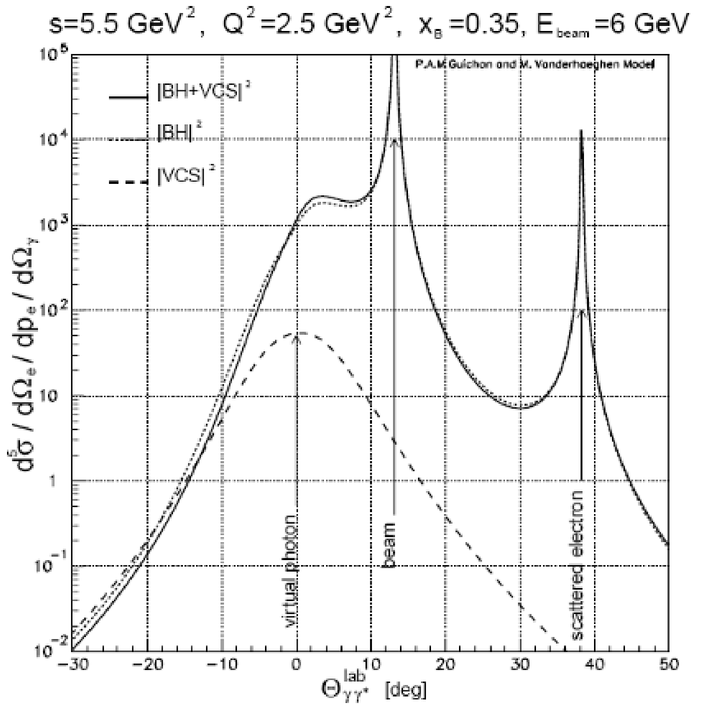


Figure 4: DVCS cross-section (target rest frame) calculated by using a model for the SPD's from P.A.M. Guichon and M. Vanderhaeghen. $\theta^{lab}_{\gamma\gamma^*}$ is the laboratory polar angle between the final photon q' and the VCS virtual photon $q = k - k'$.

Aus http://www2.cose.isu.edu/~mcnudust/publication/proposals/prexII.pdf

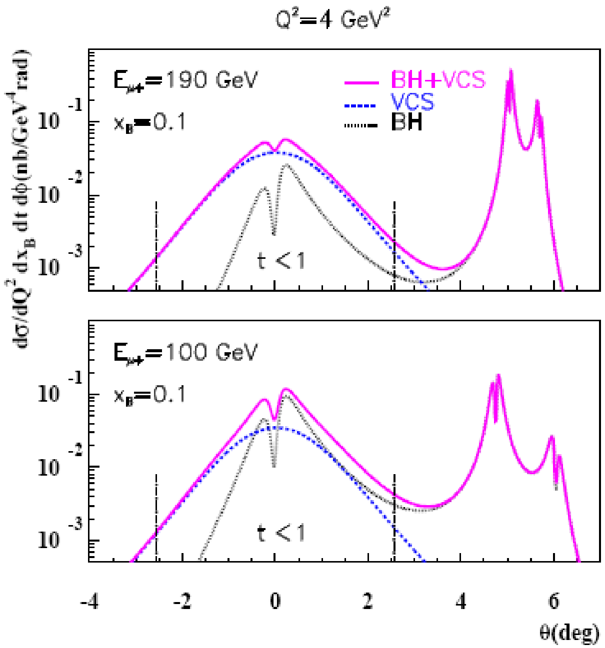
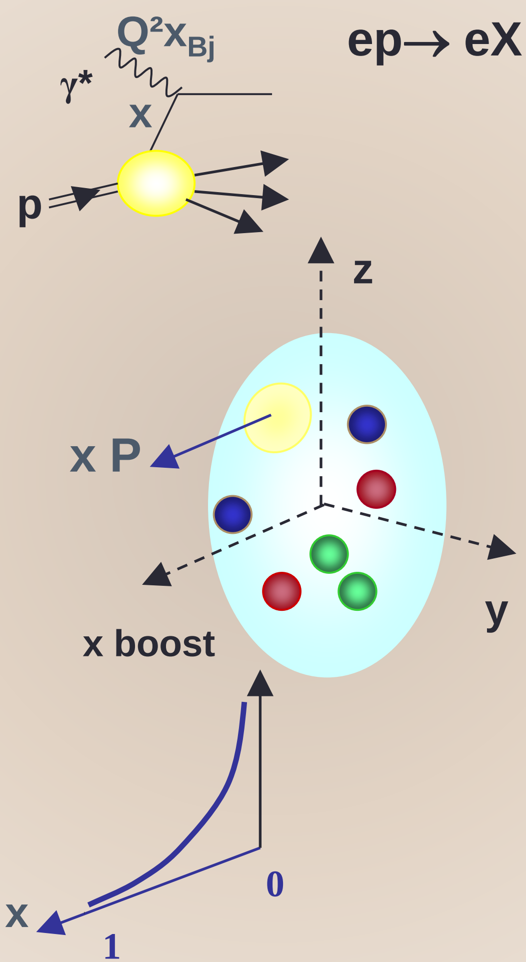


Figure 3: Cross sections for the photon leptoproduction $\mu p \rightarrow \mu p \gamma$ as a function of the outgoing real photon angle (relative to the virtual photon direction). Comparison between BH (dotted lines), DVCS (dashed lines) and the total cross sections (full lines) for 2 energies of the muon beam available at CERN: 190 and 100 GeV. The interesting domain is limited by a transfer $|t|$ smaller than 1GeV^2 i.e. θ investigating a small region around 0 degree.

Aus http://wwwcompass.cern.ch/compass/publications/2004_yellow/Body/dhose_new.pdf

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

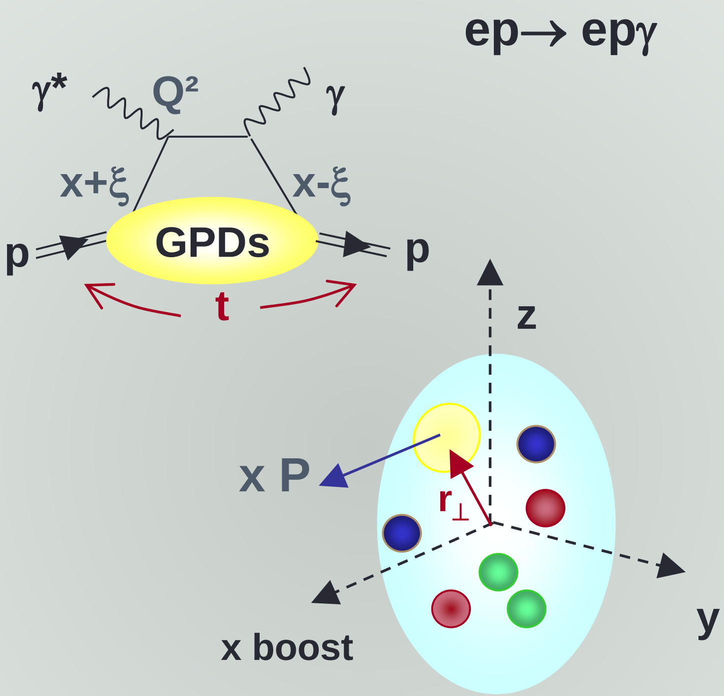
Deep Inelastic Scattering



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?

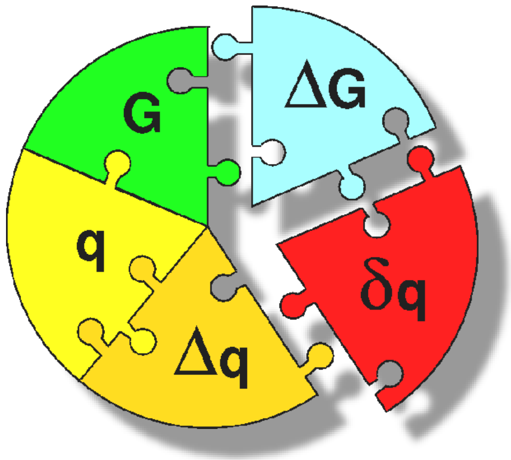
Goal: correlation between the 2 pieces of information:

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

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

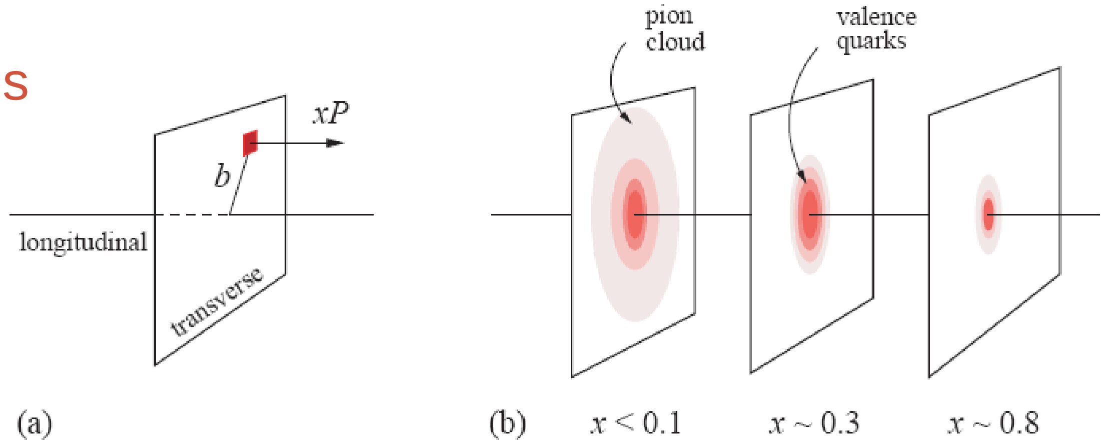
Implication of orbital angular momentum to the total spin of a nucleon $\vec{r} \times \vec{p}$

in the context of the *COMPASS* program

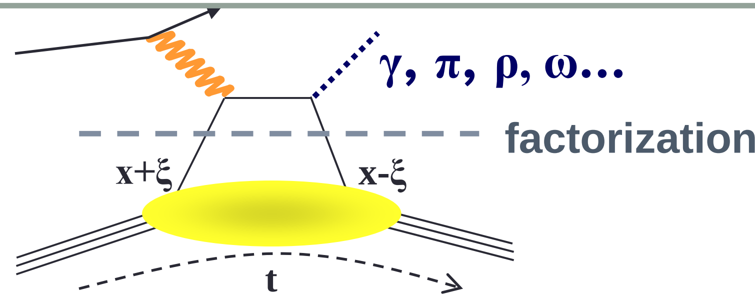


Knowledge of the transverse size of parton distribution

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

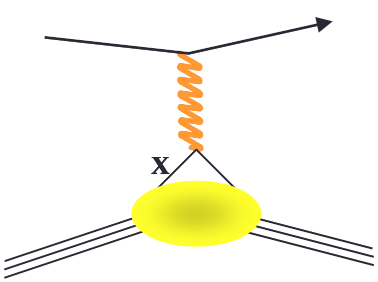
in the Nucleon Models:

Parametrization

Fit of Parameters to the data

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

Elastic Form Factors

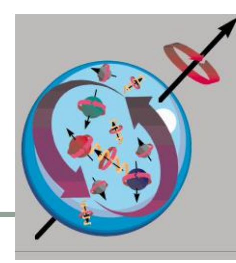


$\int H(x,\xi,t)dx = F(t)$

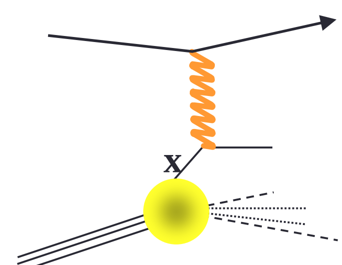
Ji's sum rule

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

$1/2 = 1/2\ \Delta\Sigma + L_q + \Delta G + L_g$



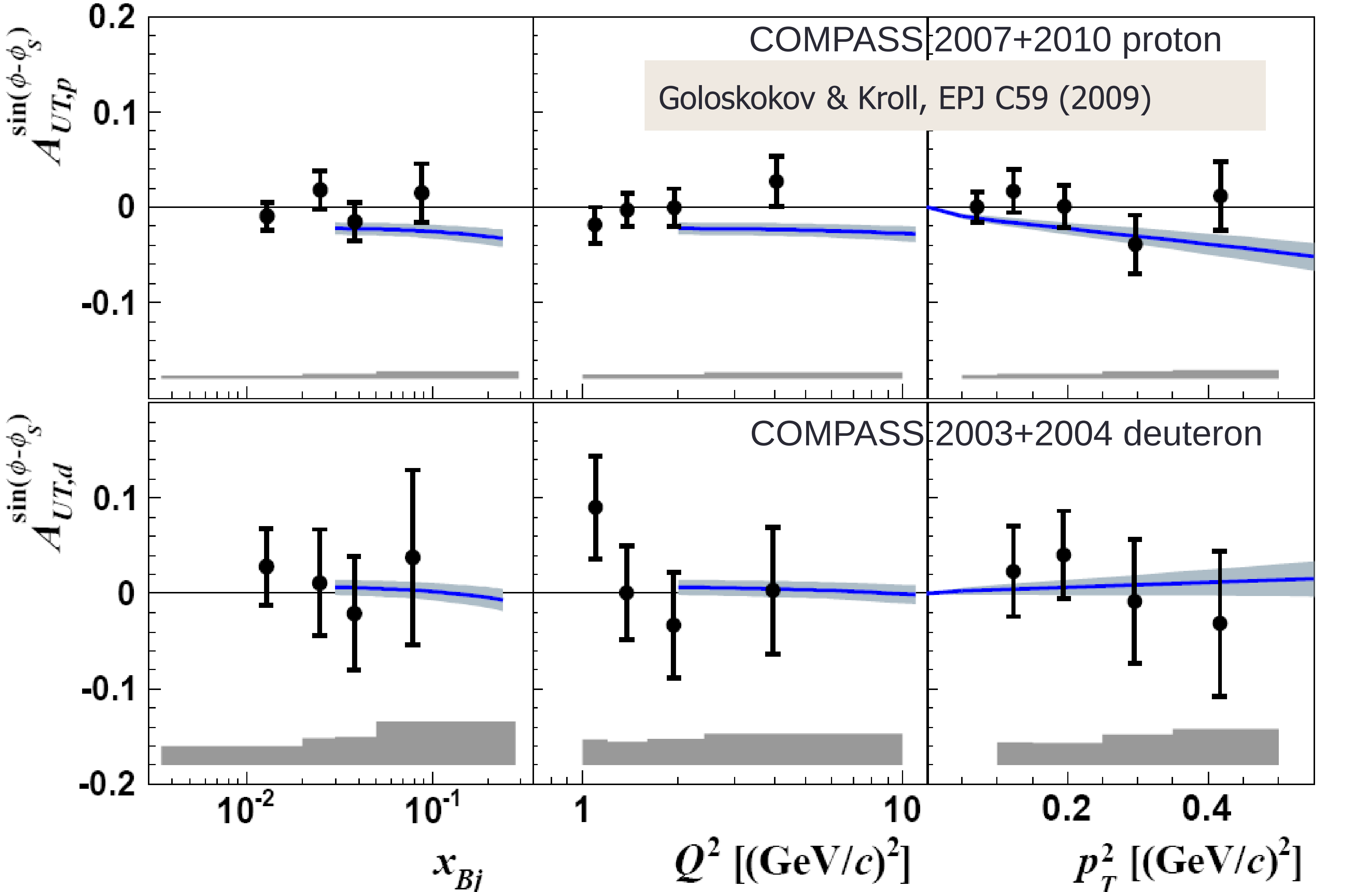
"ordinary" parton density



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

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

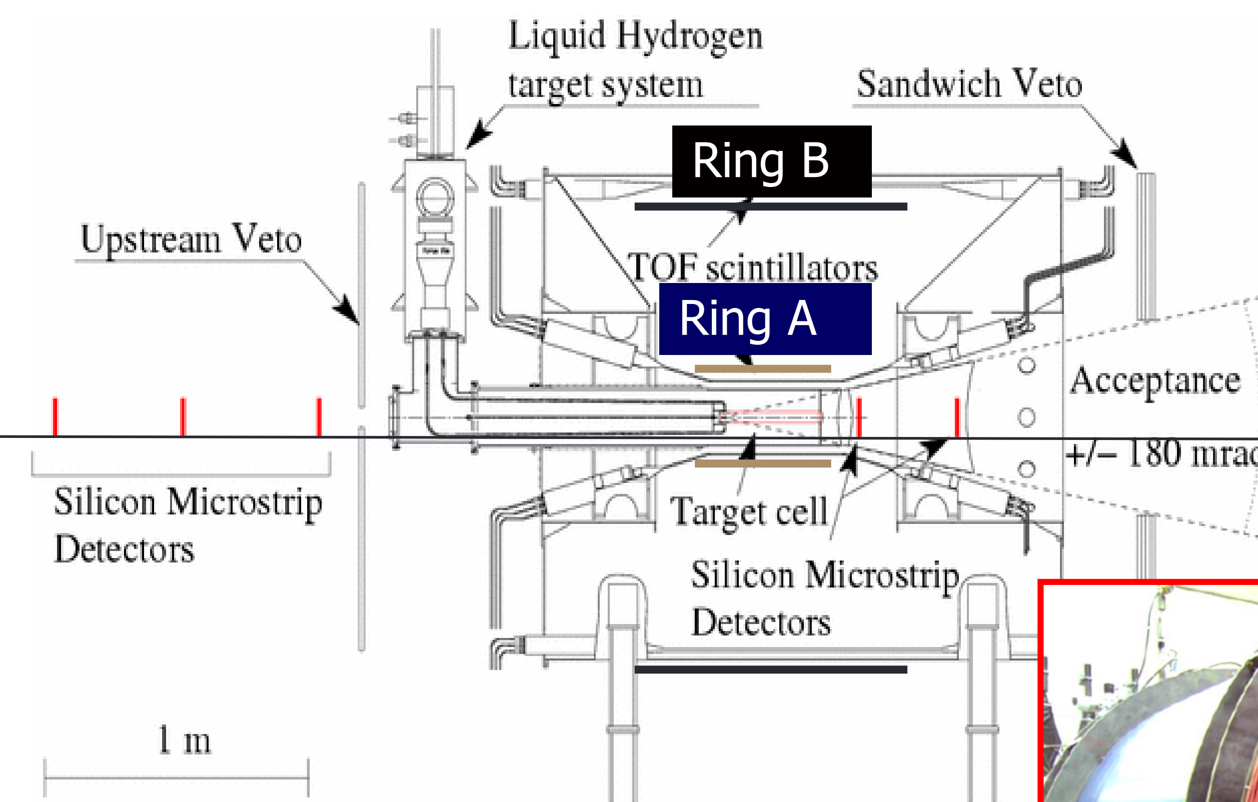
Exclusive ρ^0 production on transverse polarized Targets

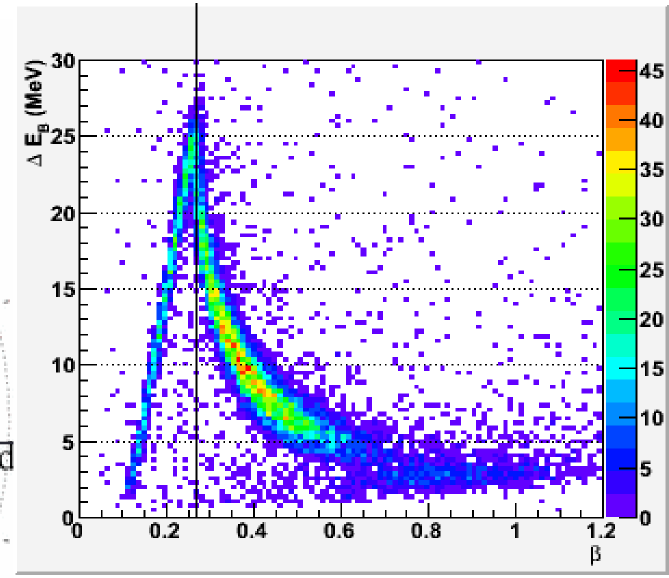


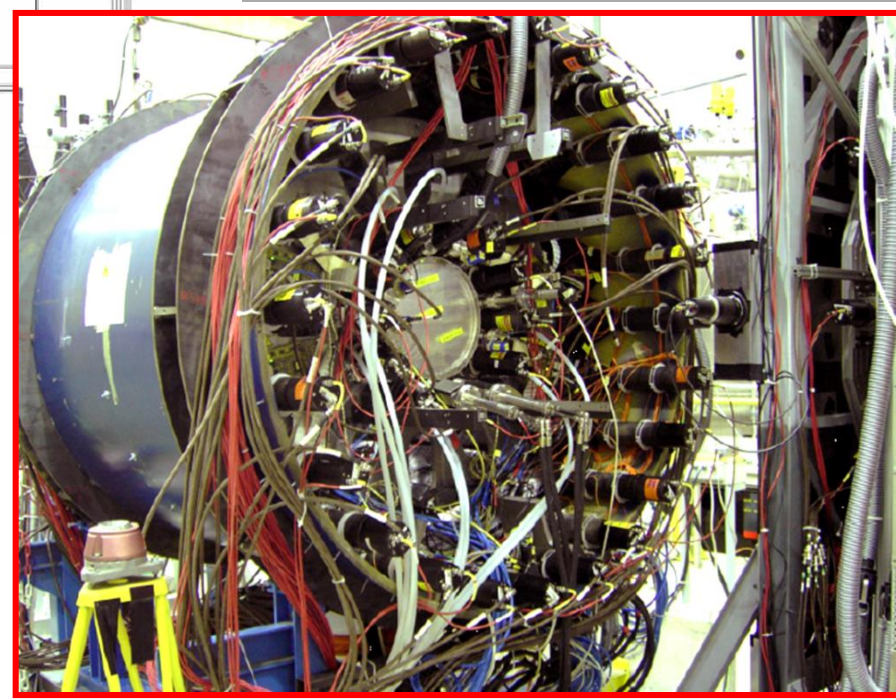
Nuclear Physics B 865 (2012) 1–20

2008 & 2009 Beam Tests @ COMPASS

Target Setup for the Hadron Programme





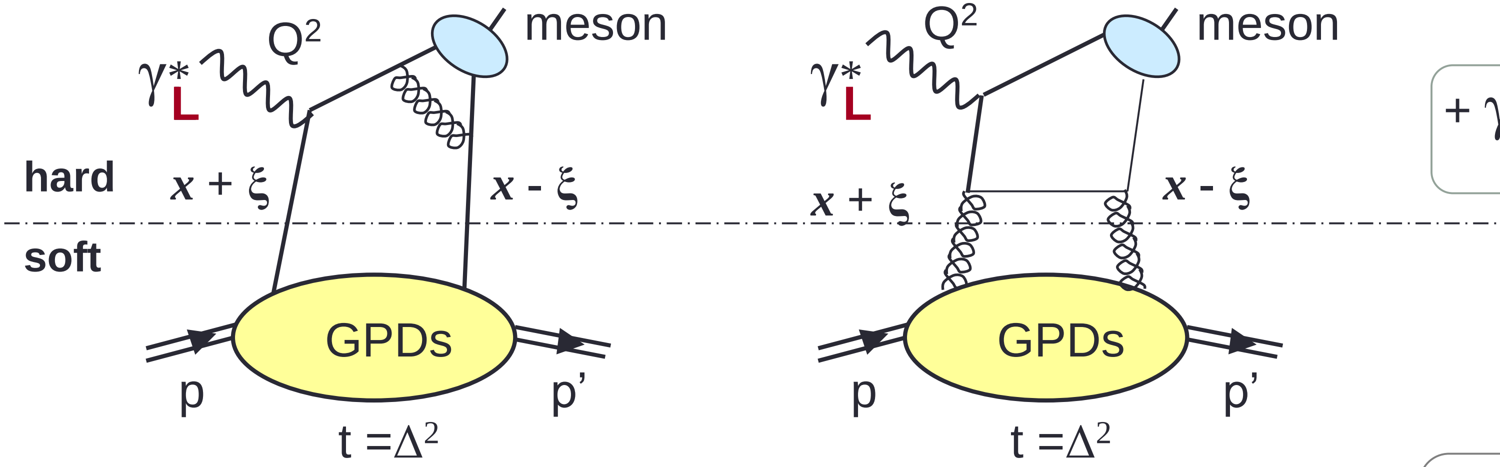


Target : 40 cm LH2

Recoil Detector (1m long)

ECAL 1 & ECAL 2

Hard Exclusive Meson Production (HEMP):

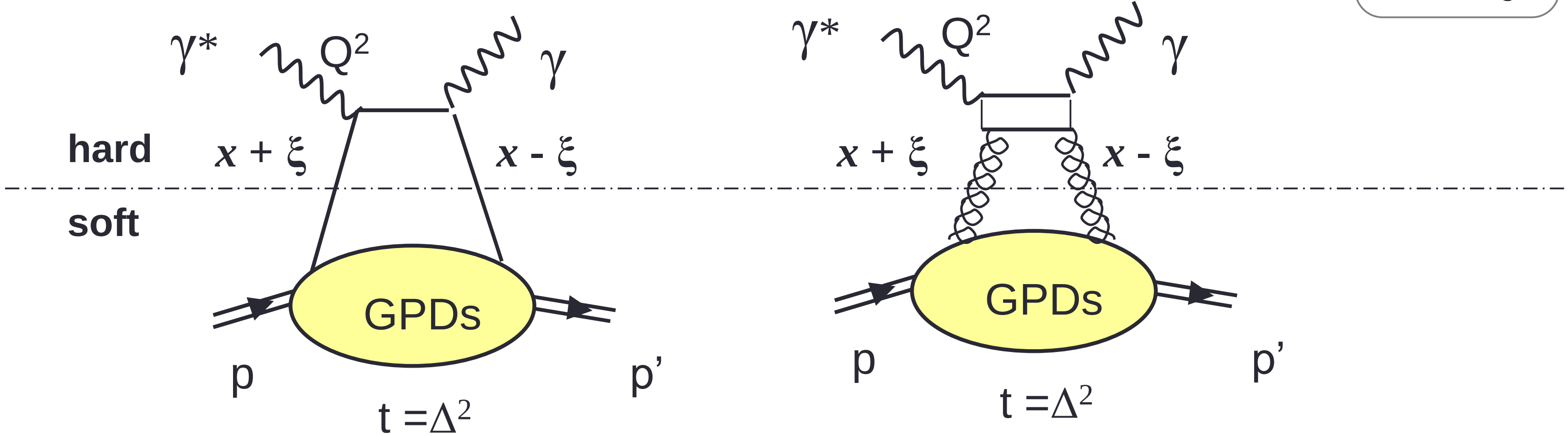


$+ \gamma^*_L$

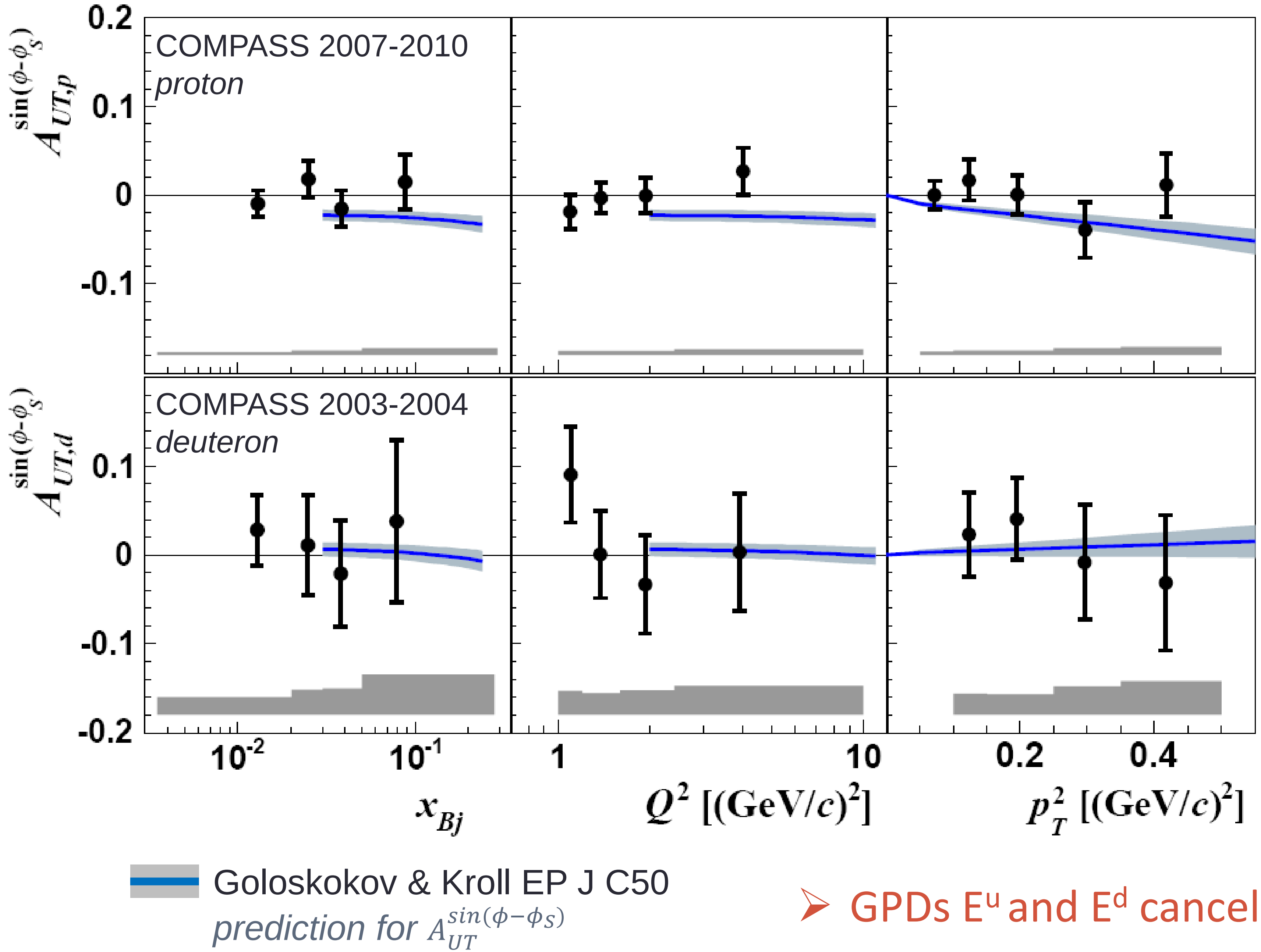
Q^2 large

$t << Q^2$

Deeply Virtual Compton Scattering (DVCS):



Quark contribution **Gluon contribution**



- GPDs E^u and E^d cancel