DVCS Program at COMPASS-II

COMPASS

GPD 2010

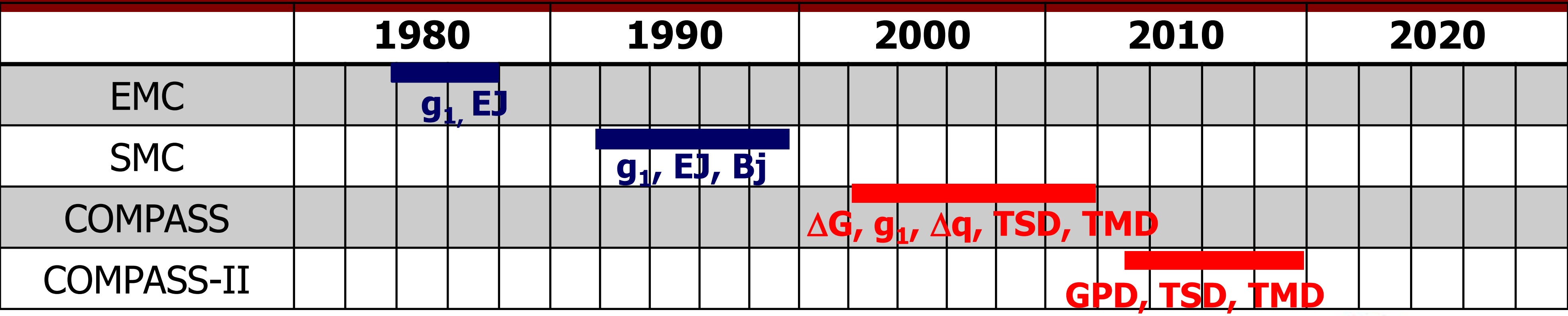
Trento , October 2010

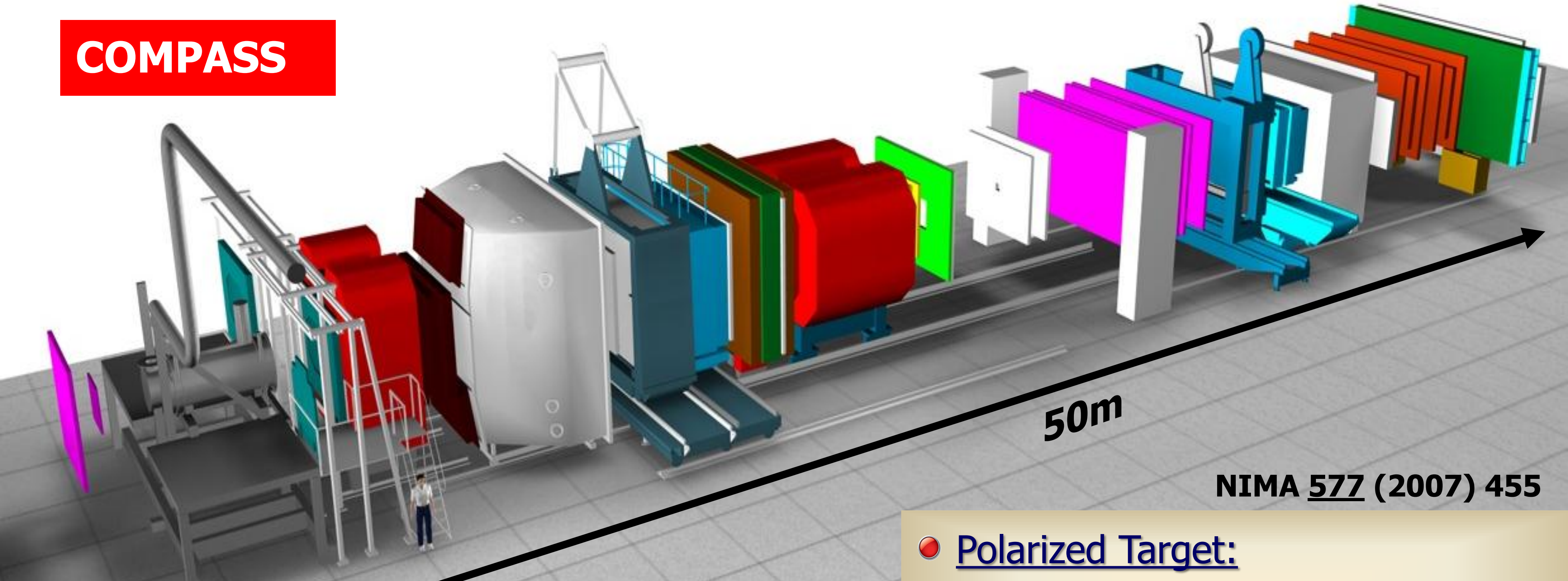
Horst Fischer*

ALU Freiburg

* on behalf of the COMPASS collaboration

Polarized DIS & SIDIS Experiments @ CERN



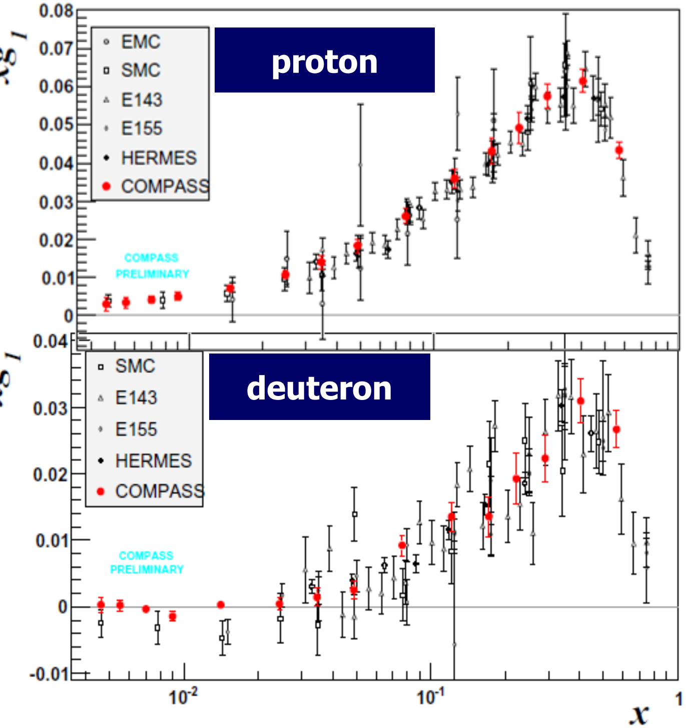


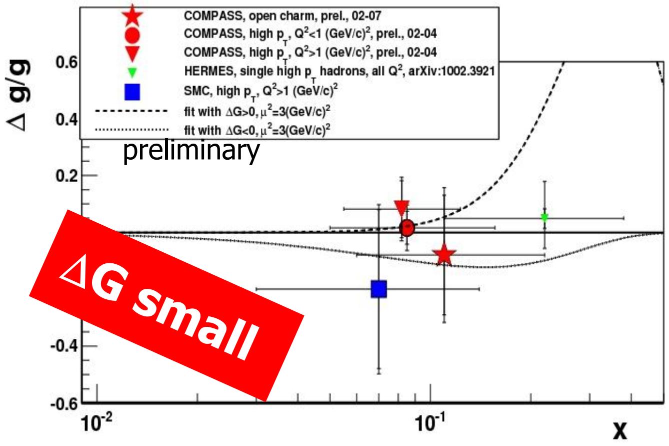
- Polarized μ Beam: 160 GeV/c, P_{Beam}=80%
  - with choice of μ^+,μ^- 50…280 GeV/c

- Polarized Target:
- 2002 – 2006: ^{6}LiD P_T= 0.5
- 2007, 2010, (2011): NH_3 P_T= 0.8

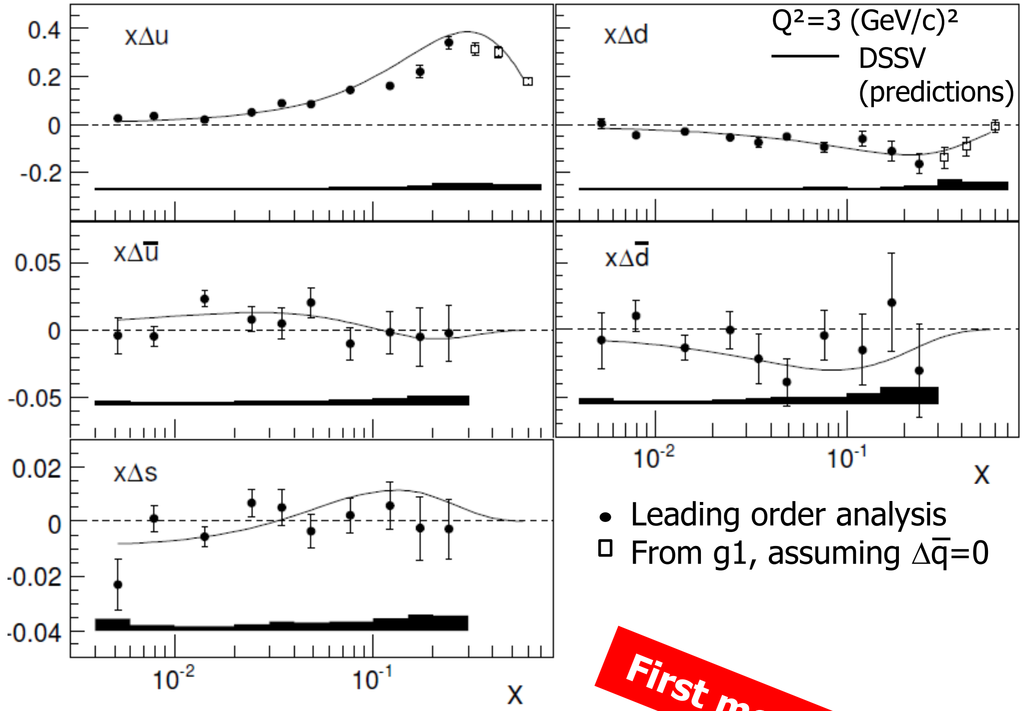
Highlights from COMPASS

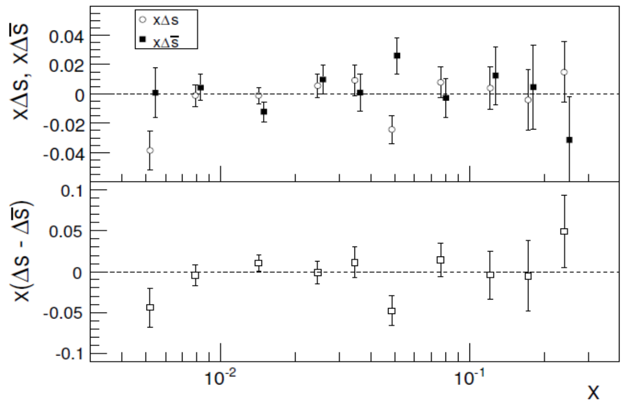
Long. Target Polarization





ΔG small





First measurement of $\Delta\bar{s}$

Highights from TSD and TMD measurements

- **H. Wollny (Thursday)**

Content of Proposal for COMPASS-II

DVCS & HEMP Measurements
Transverse Imaging
Beam charge & spin sum,
difference and asymmetry
GPD H, later GPD E

Drell-Yan Measurements
Sivers PDF
Boer Mulders PDF
Test of factorization approach

Upgrade existing

COMPASS Spectrometer

@ CERN/SPS

PDFs and Fragmentation
s(x), Kaon FF

Pion and Kaon Polarizability
Chiral Perturbation Theory

Proposal submitted to CERN (2010-05-17)

Recommendation to approve the Experiment by SPSC to RB (2010-09-29)

Data taking can start 2013

CERN-SPSC-2010-014/SPSC-P-340

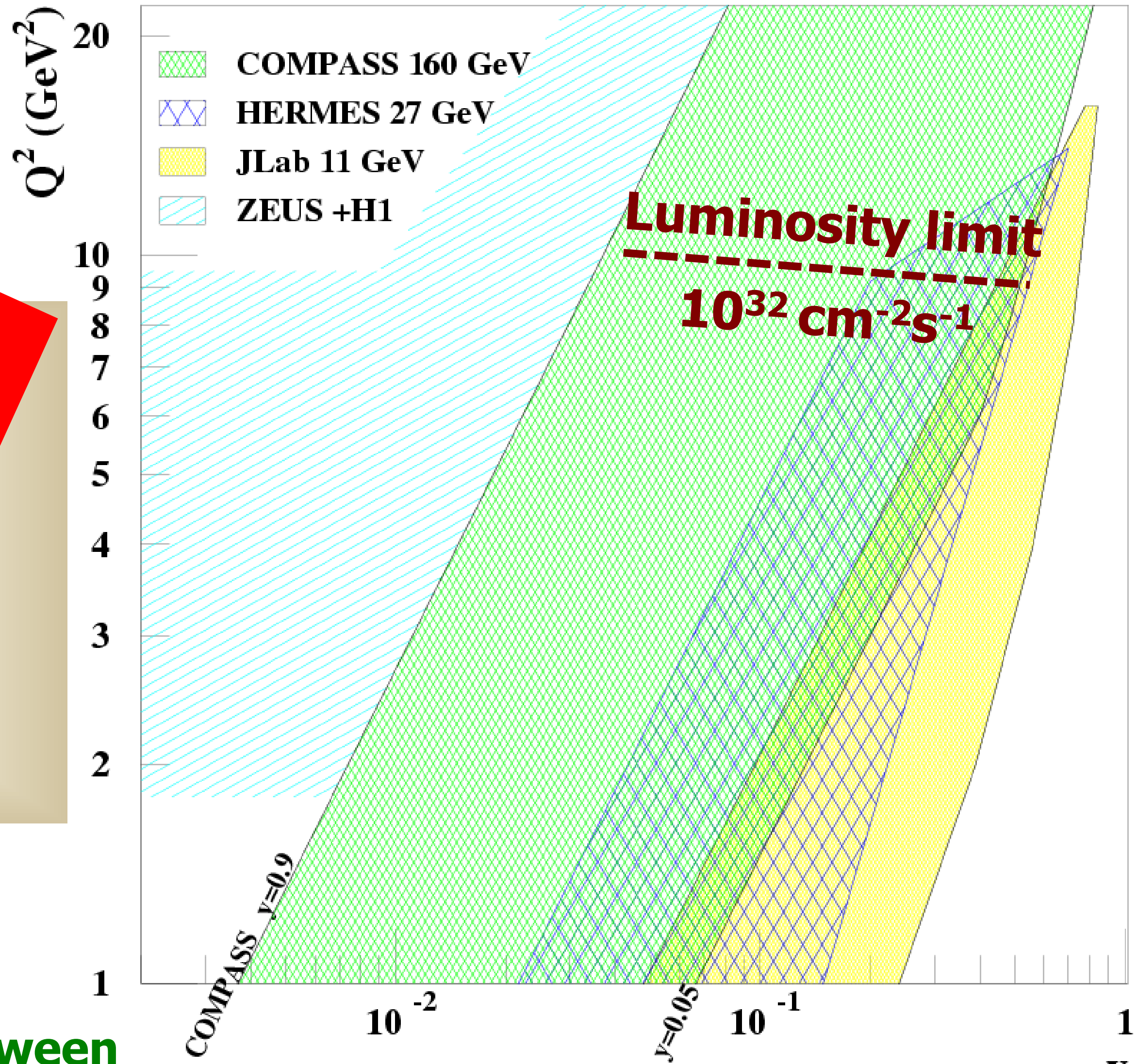
Why COMPASS-II @ CERN / SPS

- μ^+ and μ^- beam
  changeover within < 1h
- momentum: 100 - 190 GeV/c
- 80% Polarization
- μ^+ and μ^- with
  opposite polarization

Why COMPASS-II @ CERN / SPS

Unique Feature of COMPASS-II @ CERN/SPS

- μ^+ and μ^- b… changeover wi…
- momentum: 100 - 190 G… c
- 80% Polarization
- μ^+ and μ^- with opposite polarization

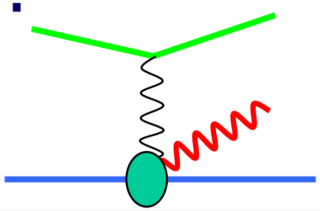


- Explore uncovered region between ZEUS/H1 and HERMES+Jlab

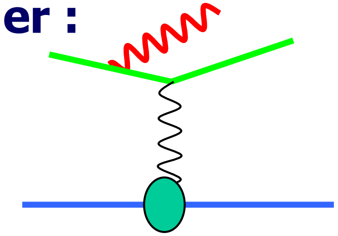
COMPASS: intermediate x_{Bj} region

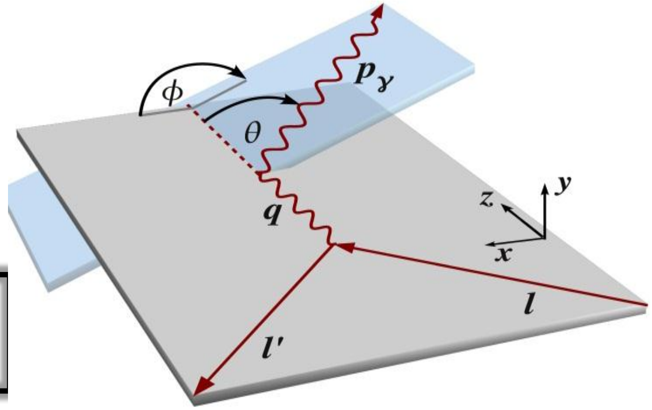
Bethe-Heitler & DVCS Cross Sections at 160GeV

DVCS :

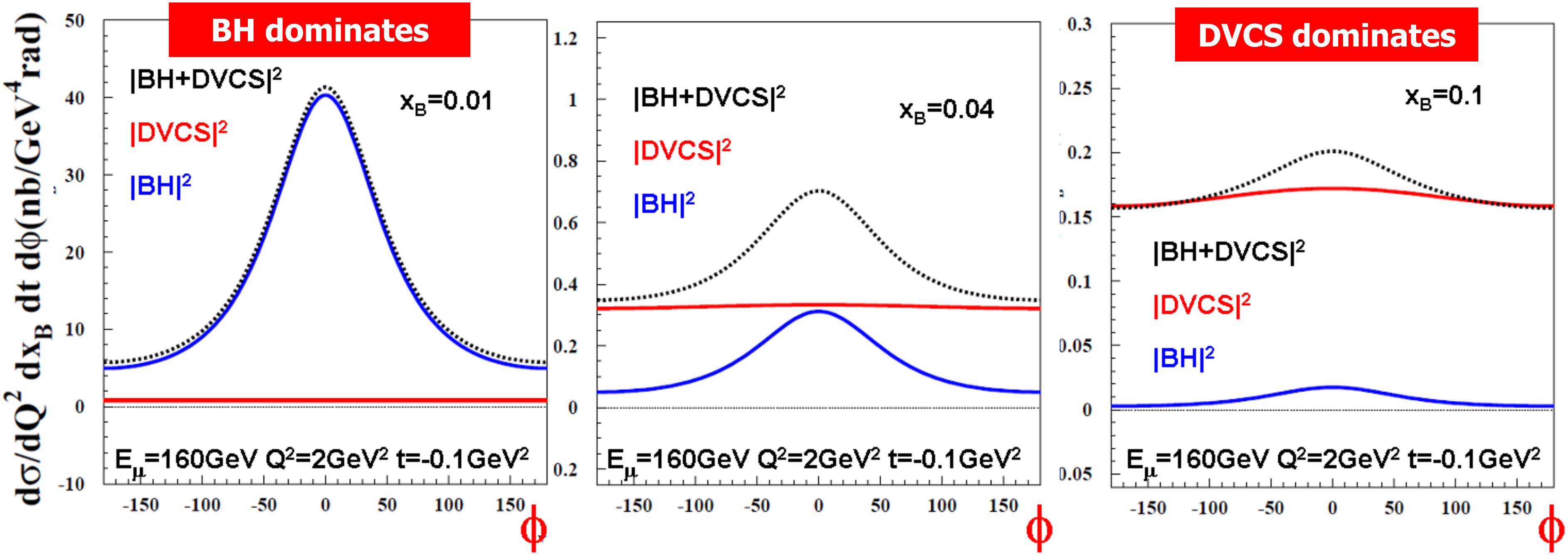


Bethe-Heitler :



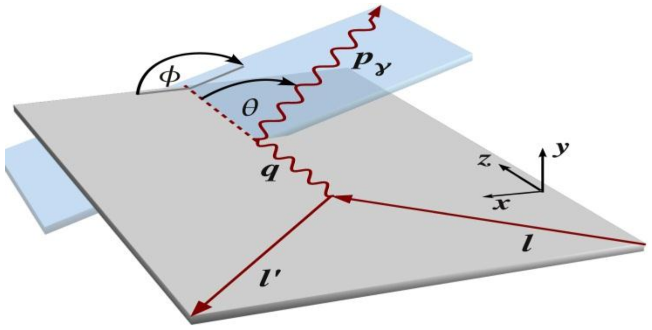


$$d\sigma \ \alpha \ |T_{DVCS}|^2 + |T_{BH}|^2 + \text{Interference Term}$$



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

Cross Section & Angular Dependence

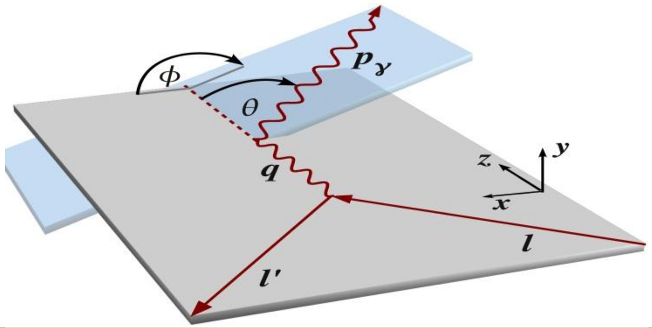


$$d\sigma_{(\mu p\to\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol} + e_\mu a^{BH}\mathcal{Re}\,T^{DVCS} + e_\mu P_\mu a^{BH}\,Im\,T^{DVCS}$$

- $d\sigma^{BH} = \frac{\Gamma(x_B,Q^2,t)}{P_1(\phi)P_2(\phi)}(c_0^{BH} + c_1^{BH}\cos\phi + c_2^{BH}\cos 2\phi)$ ← **Known (good for reference)**
- $d\sigma^{DVCS}_{unpol} = \frac{e^6}{y^2Q^2}(c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi)$
- $d\sigma^{DVCS}_{pol} = \frac{e^6}{y^2Q^2}(s_1^{DVCS}\sin\phi)$
- $a^{BH}\mathcal{Re}\,T^{DVCS} = \frac{e^6}{xy^3tP_1(\phi)P_2(\phi)}(c_0^{Int} + c_1^{Int}\cos\phi + c_2^{Int}\cos 2\phi + c_3^{Int}\cos 3\phi)$
- $a^{BH}\,Im\,T^{DVCS} = \frac{e^6}{xy^3tP_1(\phi)P_2(\phi)}(s_1^{Int}\sin\phi + s_2^{Int}\sin 2\phi)$

Twist 2 | **Twist 3** | **Twist 2 gluon**

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:**

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

$$c_0^{DVCS+BH} + c_1^{DVCS+BH}\cos\phi + c_2^{DVCS+BH}\cos 2\phi)$$

$$s_1^{Int}\sin\phi + s_2^{Int}\sin 2\phi$$

$$\frac{d\sigma}{d|t|}$$

$$\mathcal{Im}(F_1\mathcal{H})$$

- **Beam Charge & Spin Difference:**

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

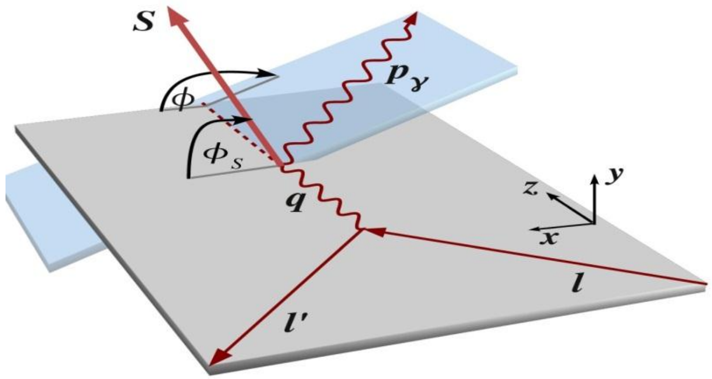
$$s_1^{DVCS}\sin\phi$$

$$c_0^{Int} + c_1^{Int}\cos\phi + c_2^{Int}\cos 2\phi + c_3^{Int}\cos 3\phi$$

$$\mathcal{Re}(F_1\mathcal{H})$$

Observables (Phase 2) – polarized Target

$$d\sigma_{(\mu p\to\mu p\gamma)}(\phi,\phi_S) = d\sigma_U(\phi) + S_T\, d\sigma_T(\phi,\phi_S)$$



- Beam Charge & Spin Sum:

$$S_{CS,T} = \left\{d\sigma^{+\leftarrow}(\phi,\phi_S) - d\sigma^{+\leftarrow}(\phi,\phi_S+\pi)\right\} + \left\{d\sigma^{-\rightarrow}(\phi,\phi_S) - d\sigma^{-\rightarrow}(\phi,\phi_S+\pi)\right\}$$

- Beam Charge & Spin Difference:

$$\mathcal{D}_{CS,T} = \left\{d\sigma^{+\leftarrow}(\phi,\phi_S) - d\sigma^{+\leftarrow}(\phi,\phi_S+\pi)\right\} - \left\{d\sigma^{-\rightarrow}(\phi,\phi_S) - d\sigma^{-\rightarrow}(\phi,\phi_S+\pi)\right\}$$

- Lepton-Charge-Averaged Unpolarized Cross-Section:

$$\Sigma_{unpol} = \tfrac{1}{2}\left[\left\{d\sigma^{+\leftarrow}(\phi,\phi_S) + d\sigma^{+\leftarrow}(\phi,\phi_S+\pi)\right\} + \left\{d\sigma^{-\rightarrow}(\phi,\phi_S) - d\sigma^{-\rightarrow}(\phi,\phi_S+\pi)\right\}\right]$$
$$+ \tfrac{1}{2}\left[\left\{d\sigma^{+\leftarrow}(-\phi,\phi_S) + d\sigma^{+\leftarrow}(-\phi,\phi_S+\pi)\right\} + \left\{d\sigma^{-\rightarrow}(-\phi,\phi_S) - d\sigma^{-\rightarrow}(-\phi,\phi_S+\pi)\right\}\right]$$

$$\mathcal{A}^{S}_{CS,T} = \frac{S_{CS,T}}{\Sigma_{unpol}}$$

$$\mathcal{A}^{\mathcal{D}}_{CS,T} = \frac{\mathcal{D}_{CS,T}}{\Sigma_{unpol}}$$

COMPASS-II - DVCS & HEMP Program

|P_{Beam}|=0.8

Phase 1 : Beam: $\mu^{+\leftarrow}$, $\mu^{-\rightarrow}$ Target: unpolarized LH_2

- constrain **GPD H** with a measurement of DVCS and HEMP
- Beam Charge & Spin Sum $\mathcal{S}_{CS,U}$
- Beam Charge & Spin Difference $\mathcal{D}_{CS,U}$, $\mathcal{A}_{CS,U} = \frac{\mathcal{D}_{CS,U}}{\mathcal{S}_{CS,U}}$

|P_{Target}|=0.9
f=0.17

Phase 2: Beam: $\mu^{+\leftarrow}$, $\mu^{-\rightarrow}$ Target: polarized NH_3

- Will be subject to an addendum to the proposal
- Constrain **GPD E** with a measurement of DVCS and HEMP
- Beam Charge & Spin Sum Asymmetry $\mathcal{A}^{\mathcal{S}}_{CS,T} = \frac{\mathcal{S}_{CS,T}}{\Sigma_{unpol}}$
- Beam Charge & Spin Difference Asymmetry $\mathcal{A}^{\mathcal{D}}_{CS,T} = \frac{\mathcal{D}_{CS,T}}{\Sigma_{unpol}}$

Projections

- Unpolarized Target (COMPASS-II, Phase 1)
- Beam Charge and Spin Sum, Difference and Asymmetry
- … for DVCS and HEMP

Input for Projections

- **Naturally polarized μ Beam with 160 GeV/c momentum** → P_{Beam}**=80%**
- **48 s SPS cycle with 9.6 s spill duration**
- **beam intensity 4.6 x 10^8 μ^+/spill** **= 9.6 x 10^6 μ^+/s (DC)**
- **3 times smaller intensity for μ^-**

- **data taking: 280 days → 70 days μ^+, 210 days μ^-**

- **Target:** **a) 2.5m liquid Hydrogen** → $\mathcal{L}$ **= 1 x 10^{32} $cm^{-2}s^{-1}$**

  b) 1.2m NH_3 (polarized) → $\mathcal{L}$ **= 3.4 x 10^{32} $cm^{-2}s^{-1}$**

  P_{target}**=90%, dilution factor f=0.17**

- **New recoil-proton detector**
- **ECAL1** (40…150mrad)**, ECAL2** (0…40mrad) **+ new ECAL0** (150…300mrad)
- **Global efficiency ε=0.1** (SPS, COMPASS, tracking, photon)

Parametrization of GPDs

Predictions based on different models

- **Factorisation:** **$H(x,\xi,t) \propto q(x)\,F(t)$**

- **Regge motivated t dependence:** **x-t correlation**

  Core of fast partons, meson cloud at larger distance

  $H(x,\xi,t) \propto q(x)\exp(-B|t|)$

  Ansatz: $B = \frac{1}{2}\langle b_\perp^2 \rangle = B_0 + 2\alpha' \ln \frac{x_0}{x}$ (α' slope of Regge trajectory)

  Valence quarks: $\alpha' \sim 1$ GeV^{-2} from form factors

  Gluons: α' small

$S_{CS,U}$ - Transverse imaging

No Modell dependence

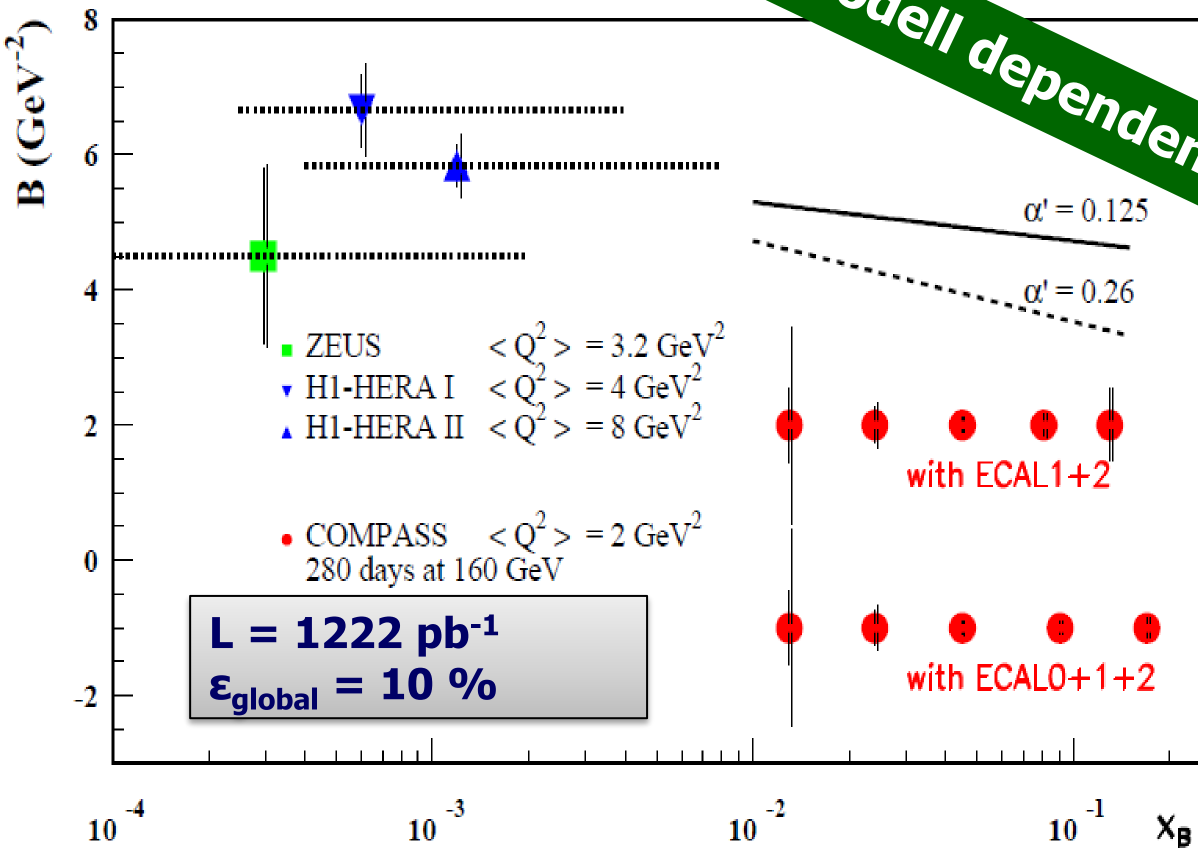
- Using $S_{CS,U}$
- Integrating over ϕ
- Subtracting BH

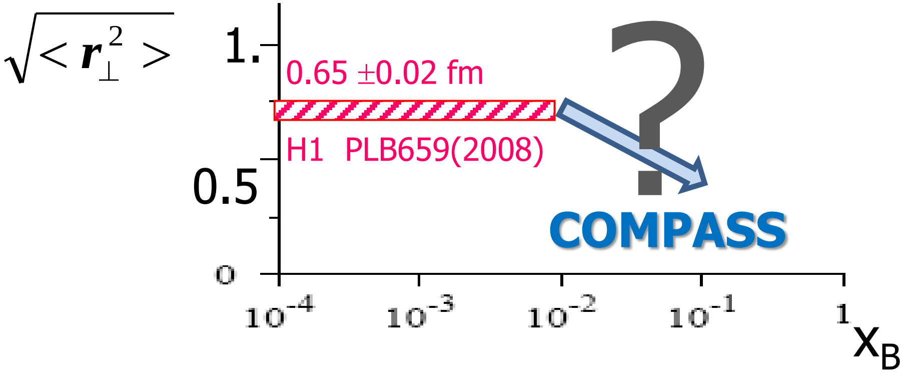
$$\frac{d\sigma}{d|t|} \propto e^{-B|t|}$$

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

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

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





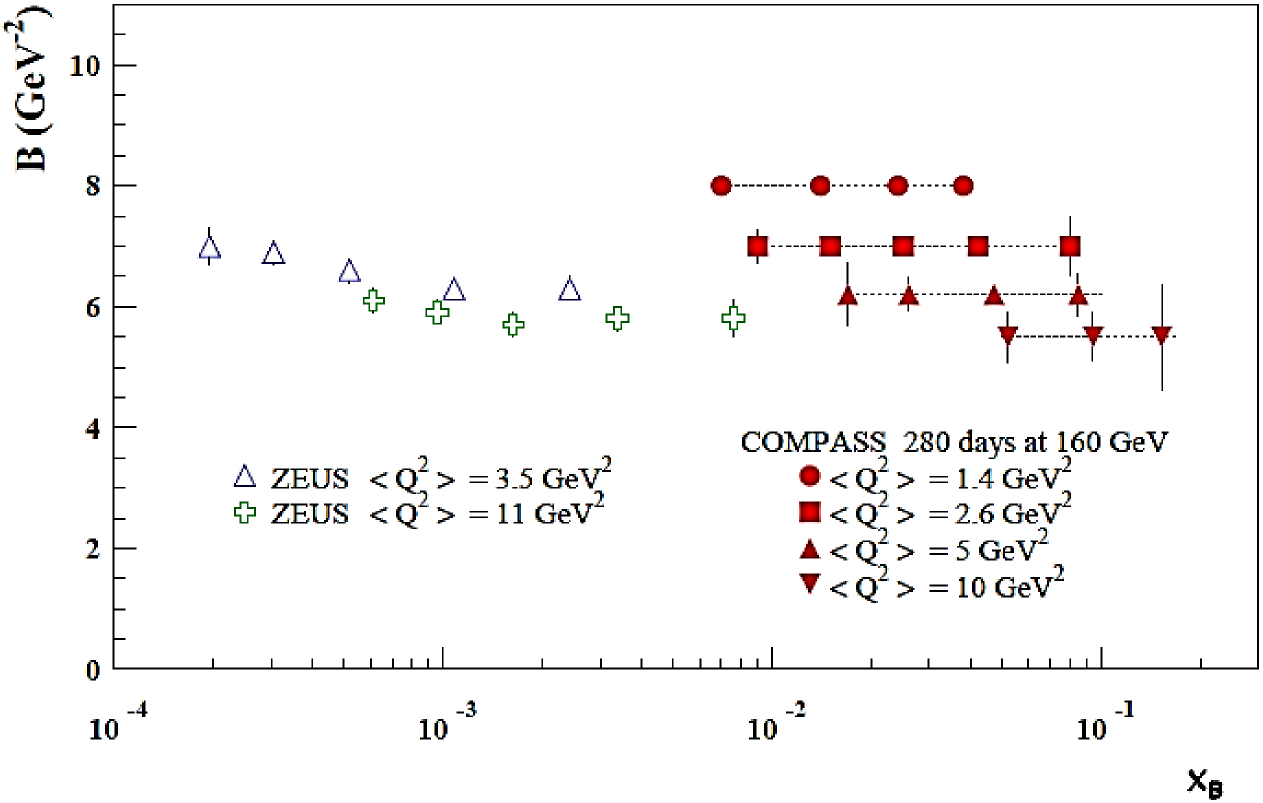
measure α' with accuracy >2.5 σ

for: α' > 0.26 (with ECAL 1+2)

α' > 0.125 (with ECAL 0+1+2)

Complementary: Hard Exclusive ρ^0 Production

$$\frac{d\sigma_{\rho VMP}}{d|t|} \propto e^{-B|t|}$$



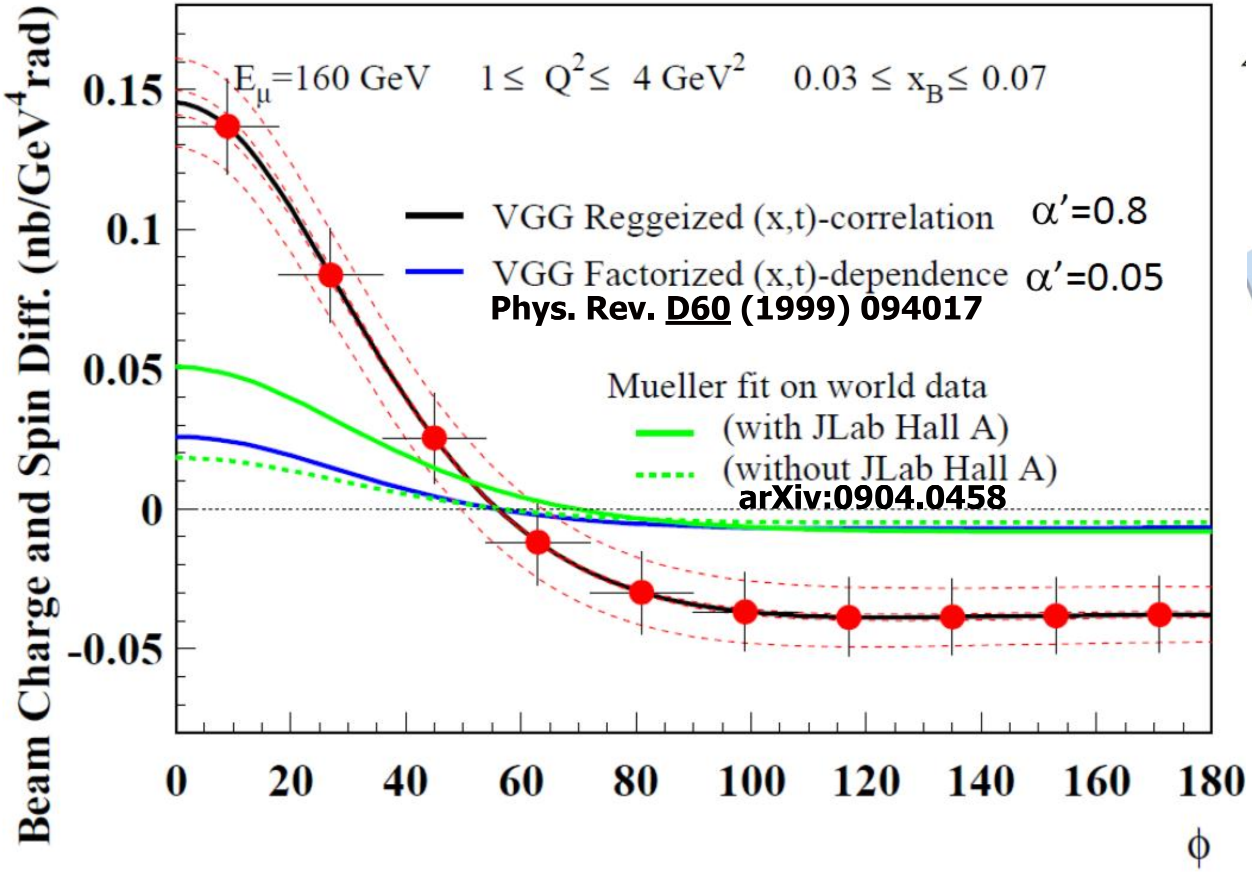
Sensitive to the nucleon size
+ the transverse size of the meson

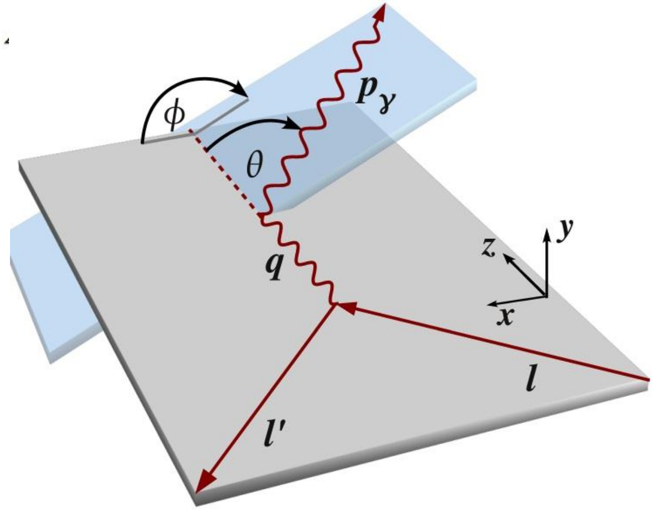
- **Q^2= 1 GeV^2 B ~ 8 GeV^{-2}**
- **Q^2= 10 GeV^2 B ~ 5.5 GeV^{-2}**

ρVMP model developed by A. Sandacz
- Normalized according Goloskokov and Kroll

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

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





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 Difference $\mathcal{D}_{U,CS}$

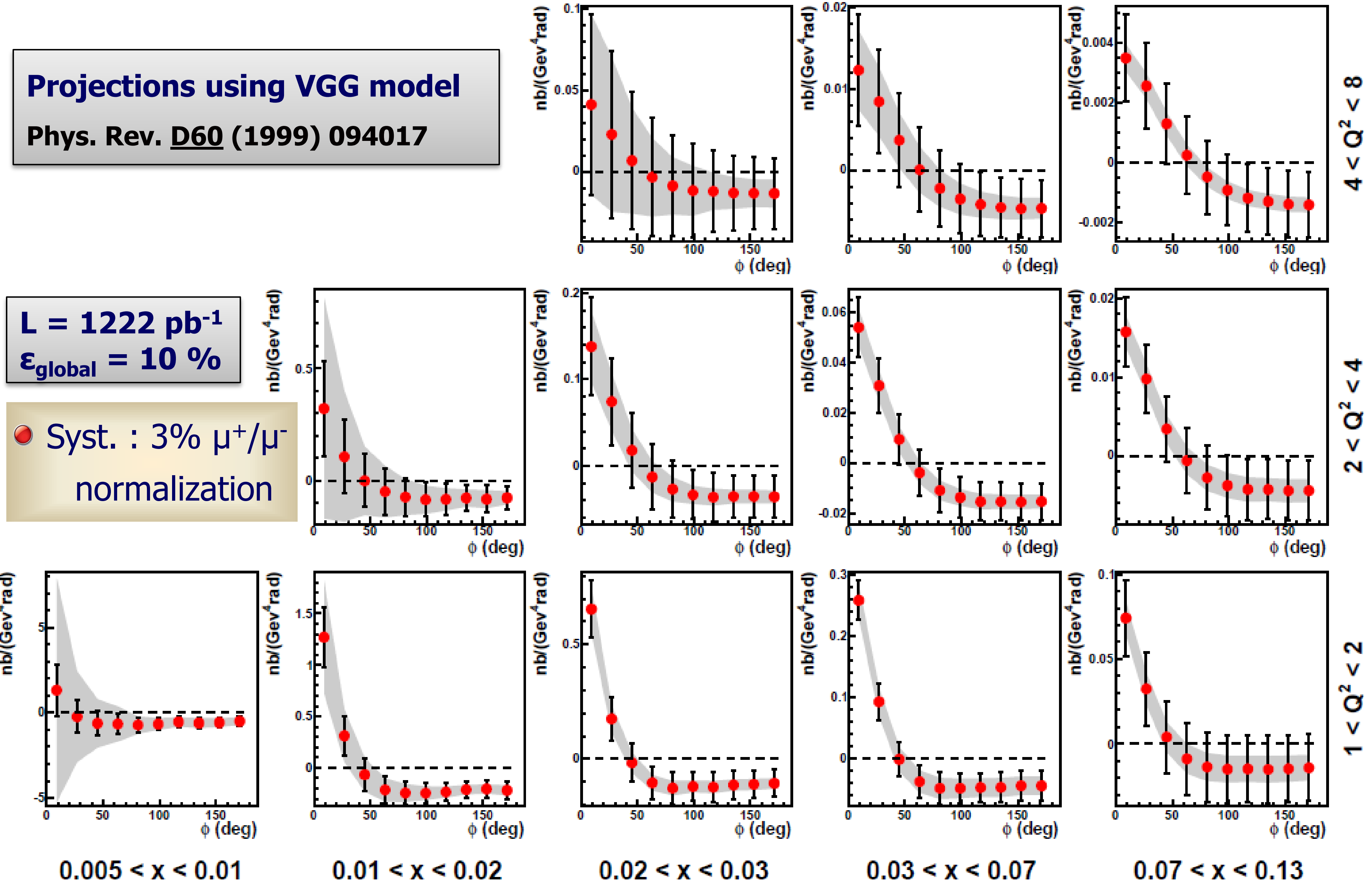
Projections using VGG model

Phys. Rev. D60 (1999) 094017

L = 1222 pb^{-1}

ε_{global} = 10 %

- Syst. : 3% μ^+/μ^- normalization



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

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

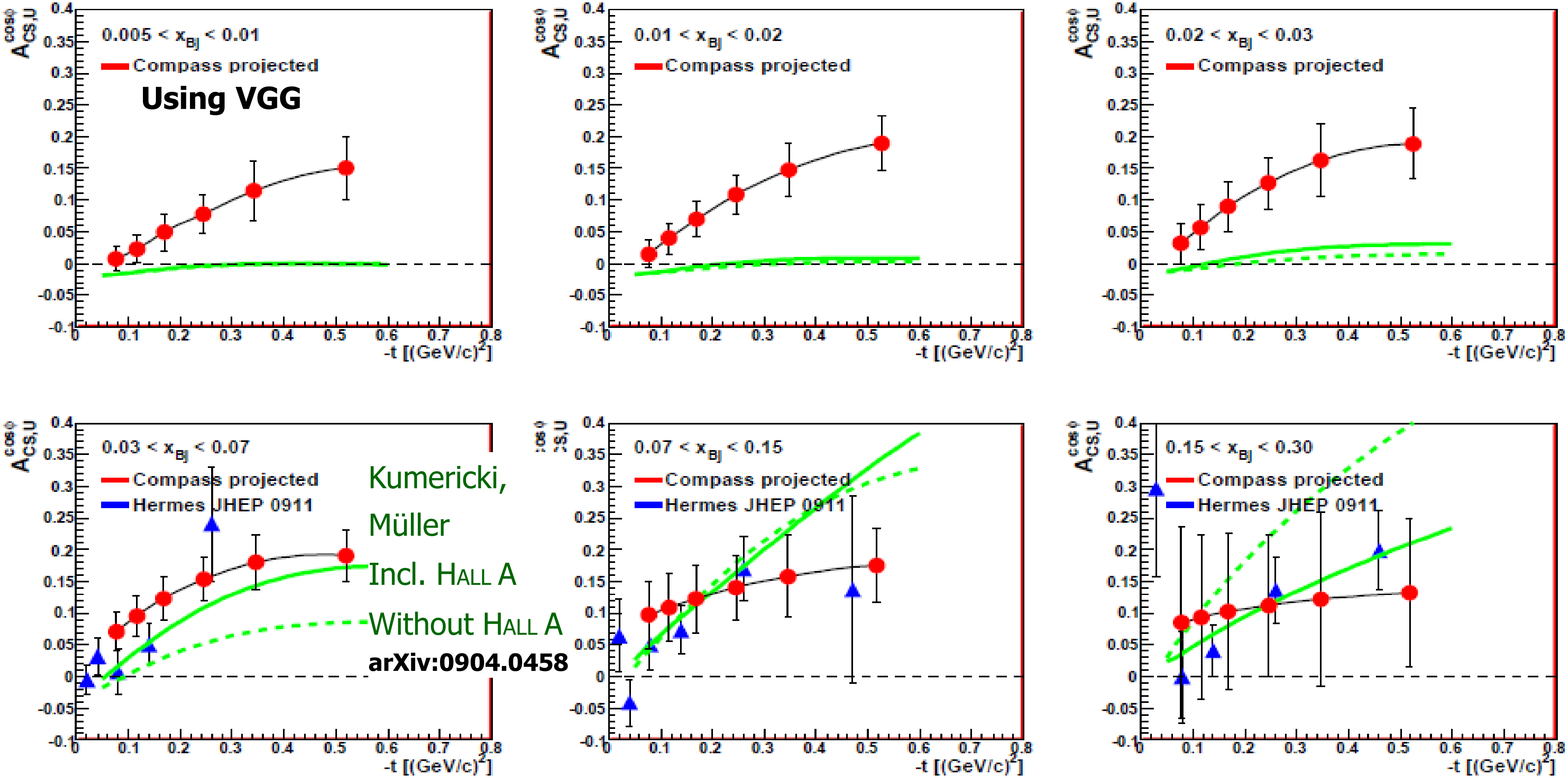
$= A_0 + A_{CS,U} \cos\phi + A_2 \cos 2\phi$

Measurement of c_1^{Int}

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

< 0 @ HERMES

Node?



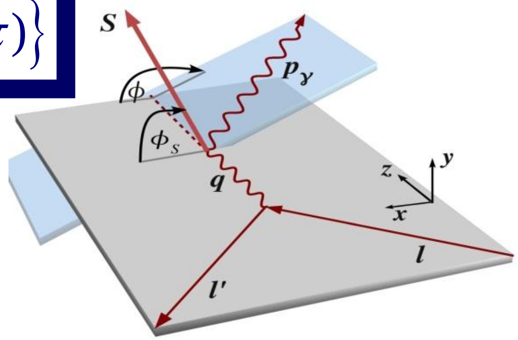
Projections

- Polarized Target (COMPASS-II, Phase 2)
- Beam Charge and Spin Sum, Difference and Asymmetry
- … for DVCS and HEMP

$\mathcal{D}_{CS,T}$ and Transverse Target Asymmetry

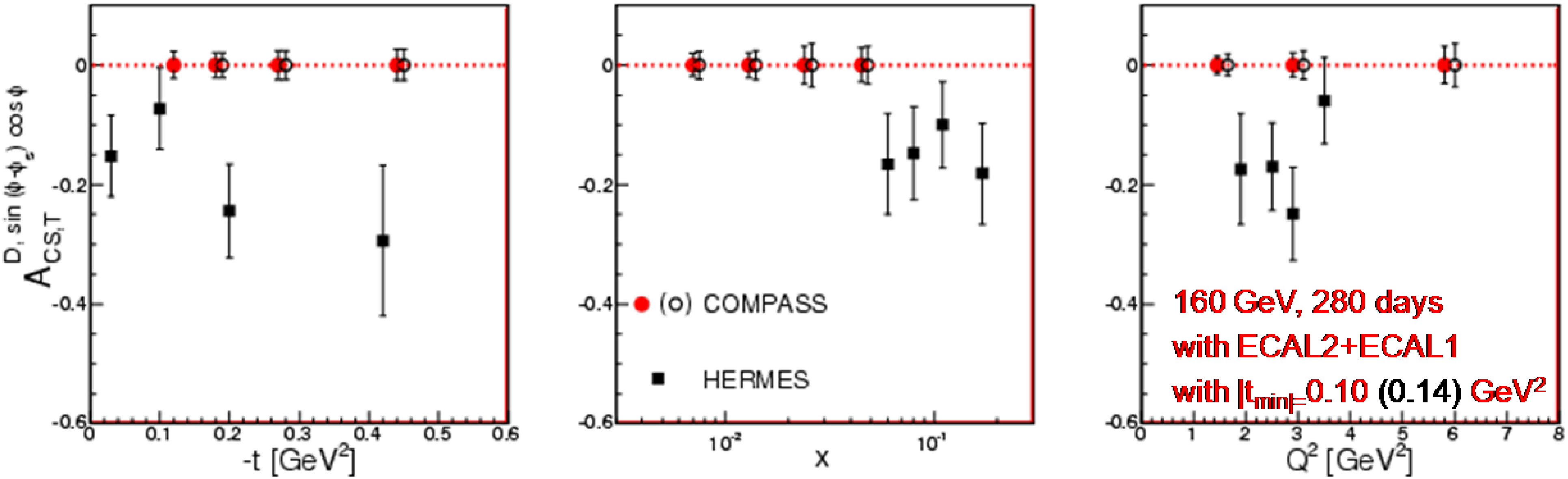
$$\mathcal{D}_{CS,T} = \{d\sigma^{+\leftarrow}(\phi,\phi_S) - d\sigma^{+\leftarrow}(\phi,\phi_S+\pi)\} - \{d\sigma^{-\rightarrow}(\phi,\phi_S) - d\sigma^{-\rightarrow}(\phi,\phi_S+\pi)\}$$

$$\mathcal{D}_{CS,T} \propto Im(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi-\phi_S)\cos\phi$$

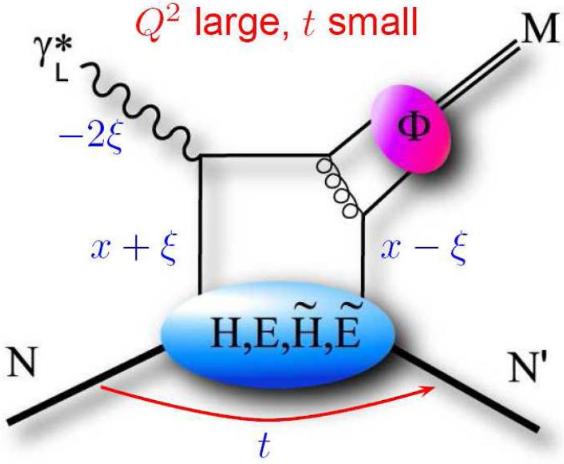


Beam: 160 GeV muon
Target: 1.2 m polarized NH_3
(P=90%, f=0.17)
2 years data taking
ε_{global} = 10 %

Constrain GPD E



Hard Exclusive Meson Production



Would allow for flavor separation:

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

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

$$H_{\phi} = -1/3\, H^s - 1/8\, H^g$$

- Vector meson production from transversely polarized target asymmetry ⇒ **E/H**

Cross section measurements:

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

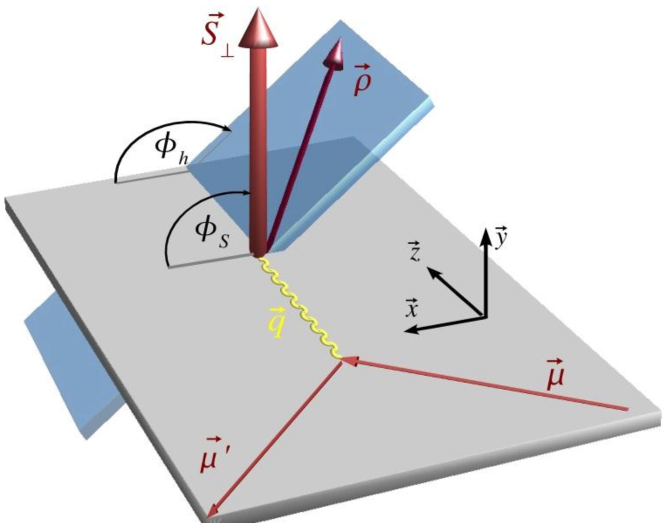
ρ : ω : ϕ ~ 9 : 1 : 2

(at large Q^2)

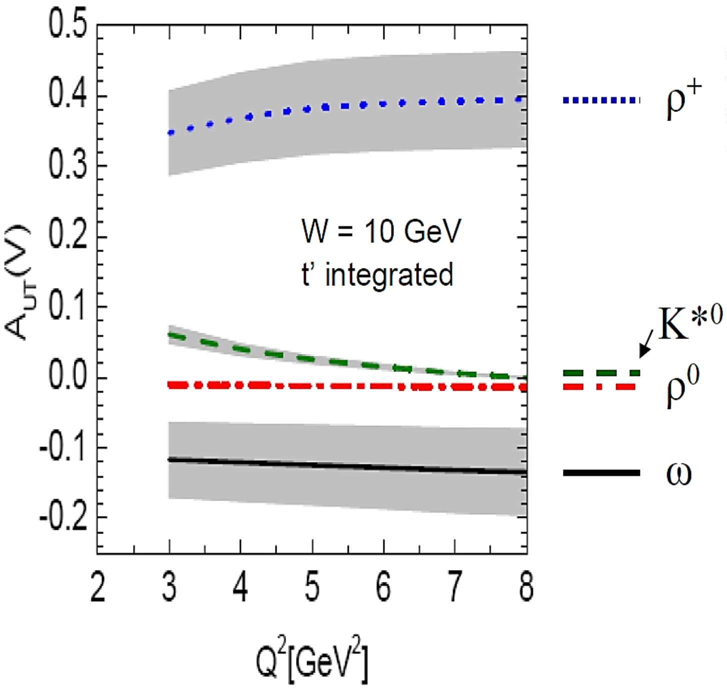
Also studied at COMPASS without RPD

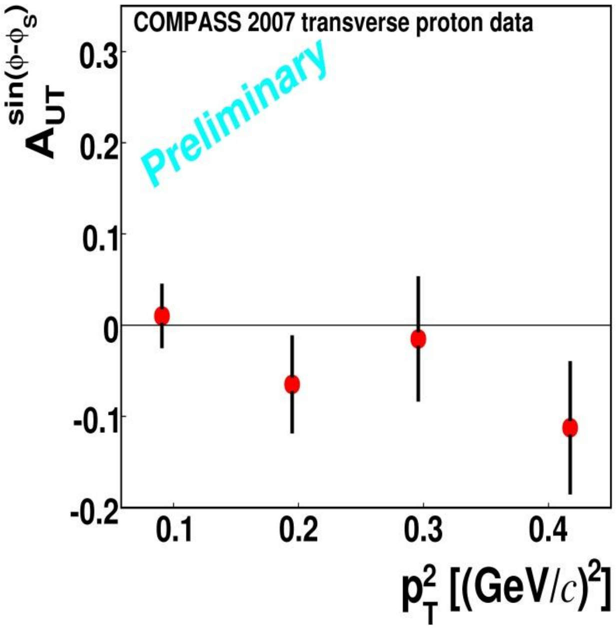
HEMP with polarized Target

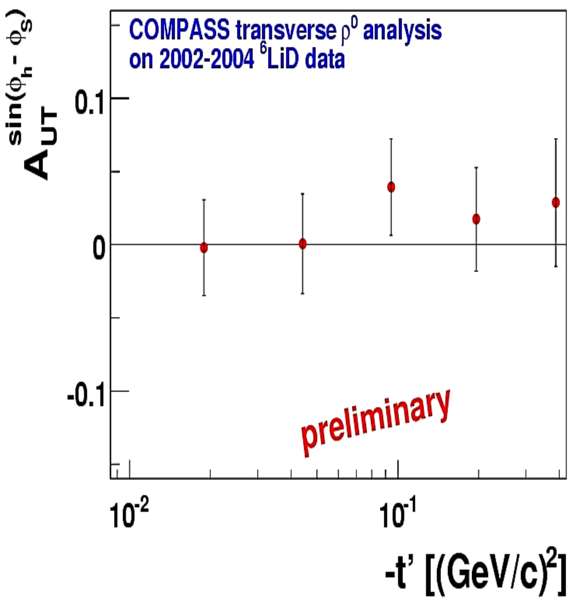
$$A_{UT}(\rho^0) \propto \sqrt{|-t'|}\,\frac{\mathrm{Im}\,(\mathcal{E}^*\mathcal{H})}{|\mathcal{H}|^2}$$



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







Goloskokov, Kroll EPJ C53 (2008) 367

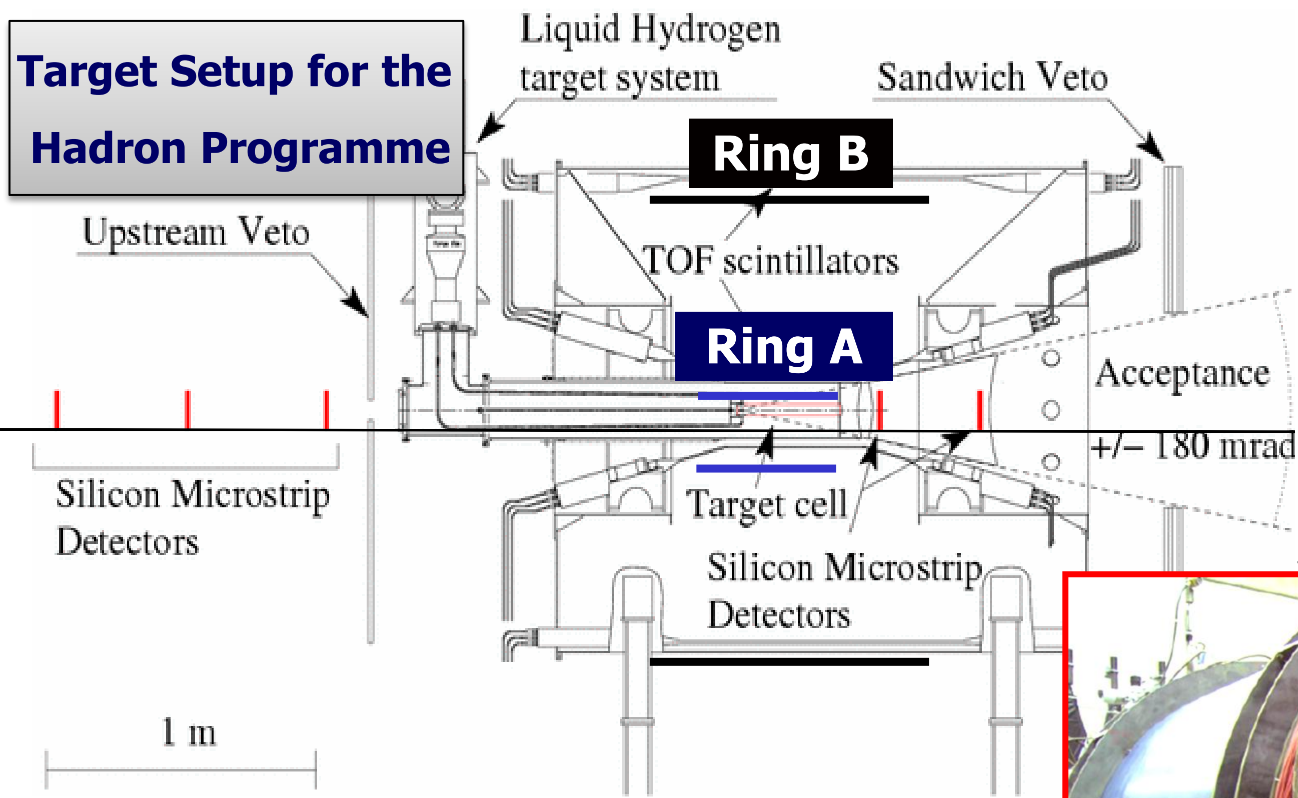
→ A. Sandacz (Thursday)

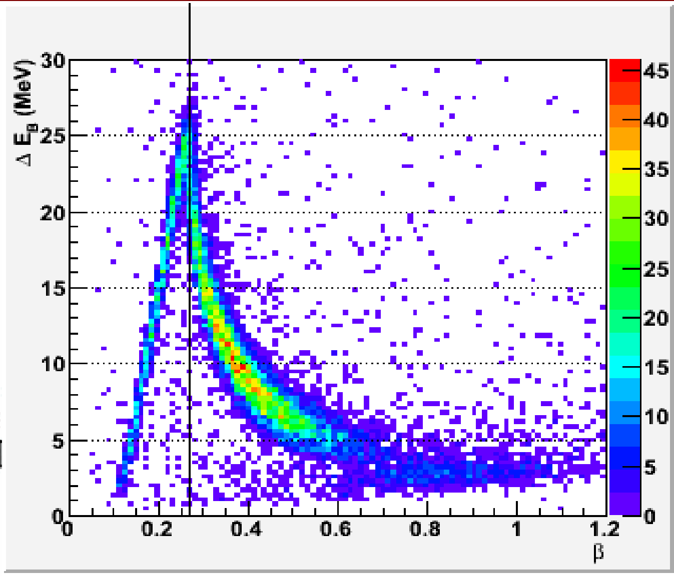
Beam Tests @ COMPASS

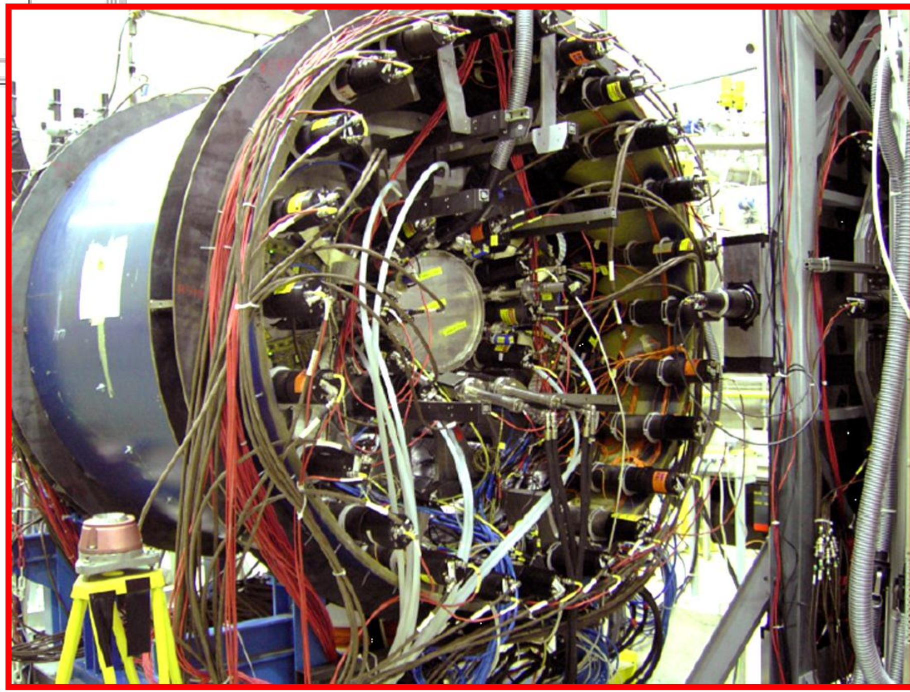
- 2008 (8 hours)
- 2009 (10 * statistics of 2008)

2008 & 2009 Beam Tests @ COMPASS

Target Setup for the Hadron Programme

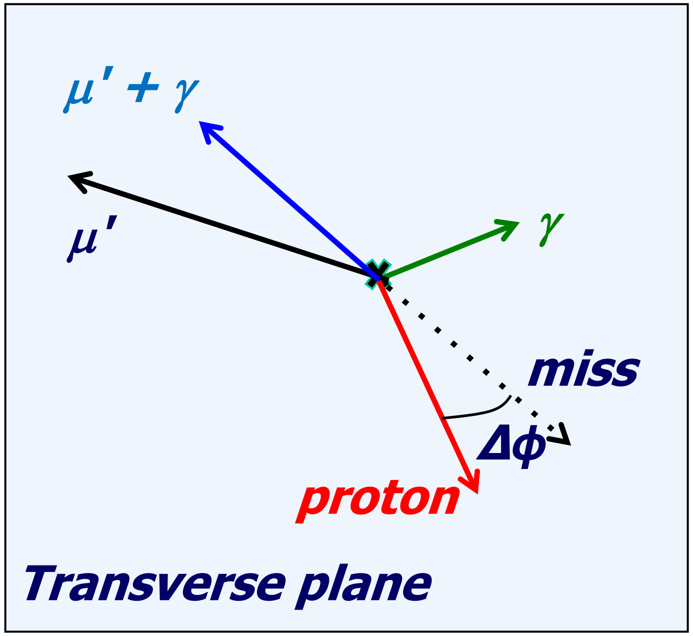


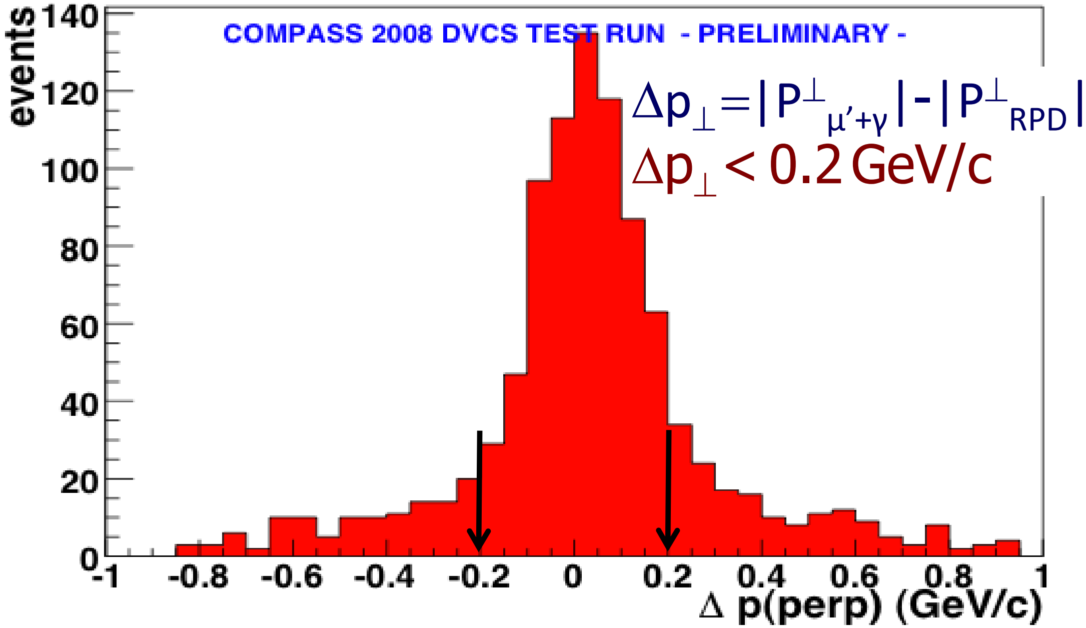


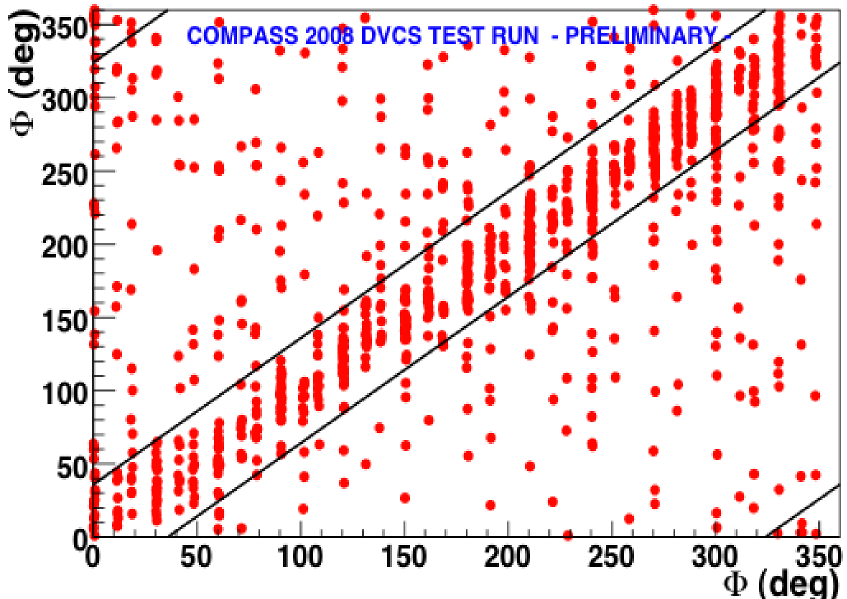


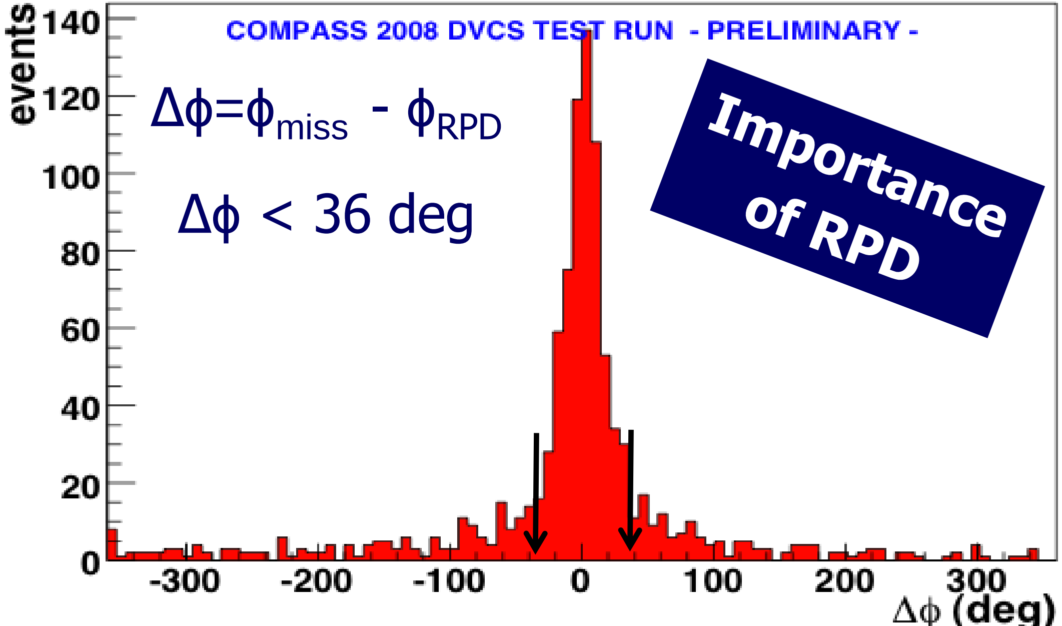
- Target : 40 cm LH2
- Recoil Detector (1m long)
- ECAL 1 & ECAL 2

Kinematic Constraints in Transverse Plane





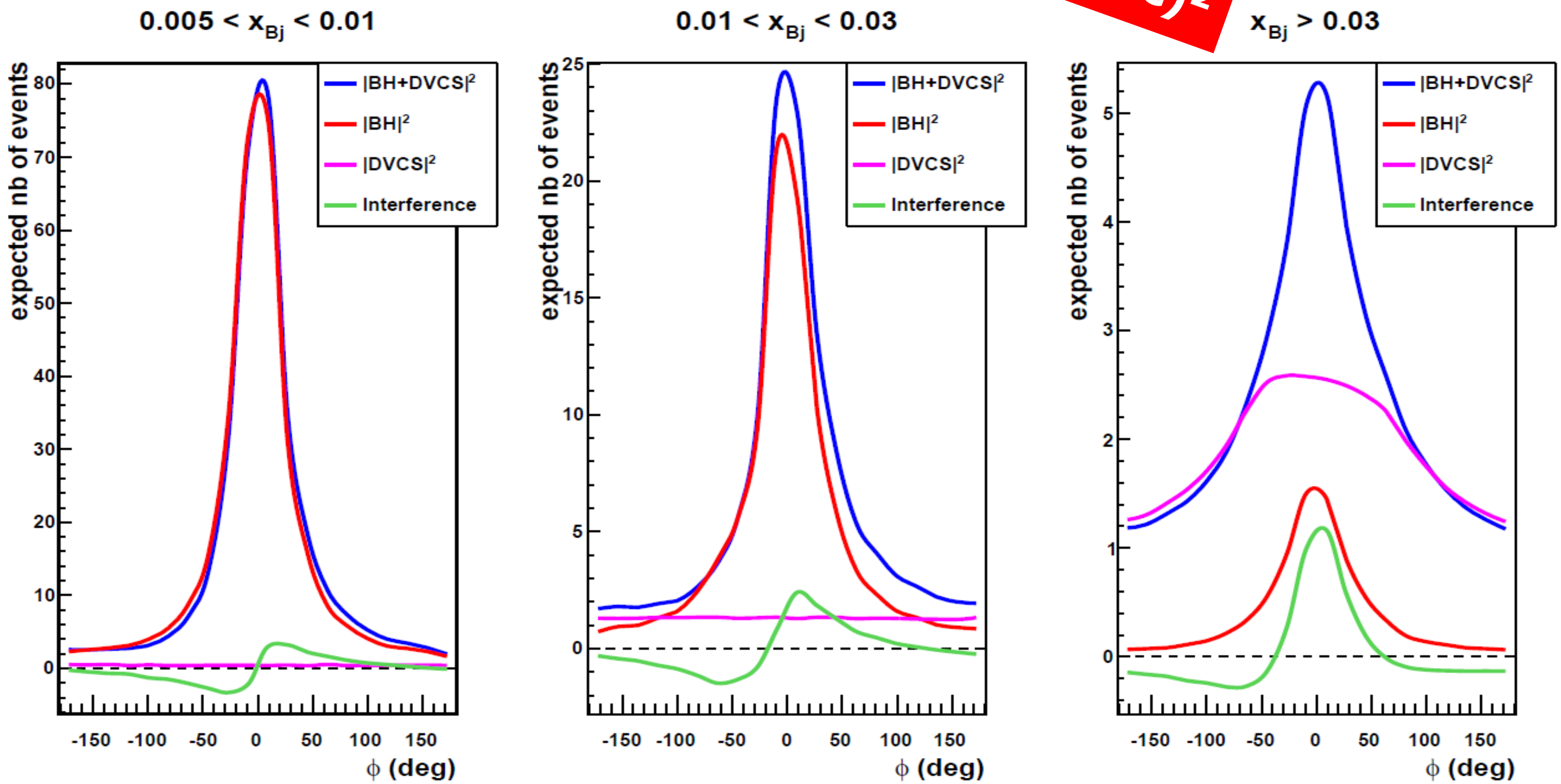




Predicions for Kinematic Binning

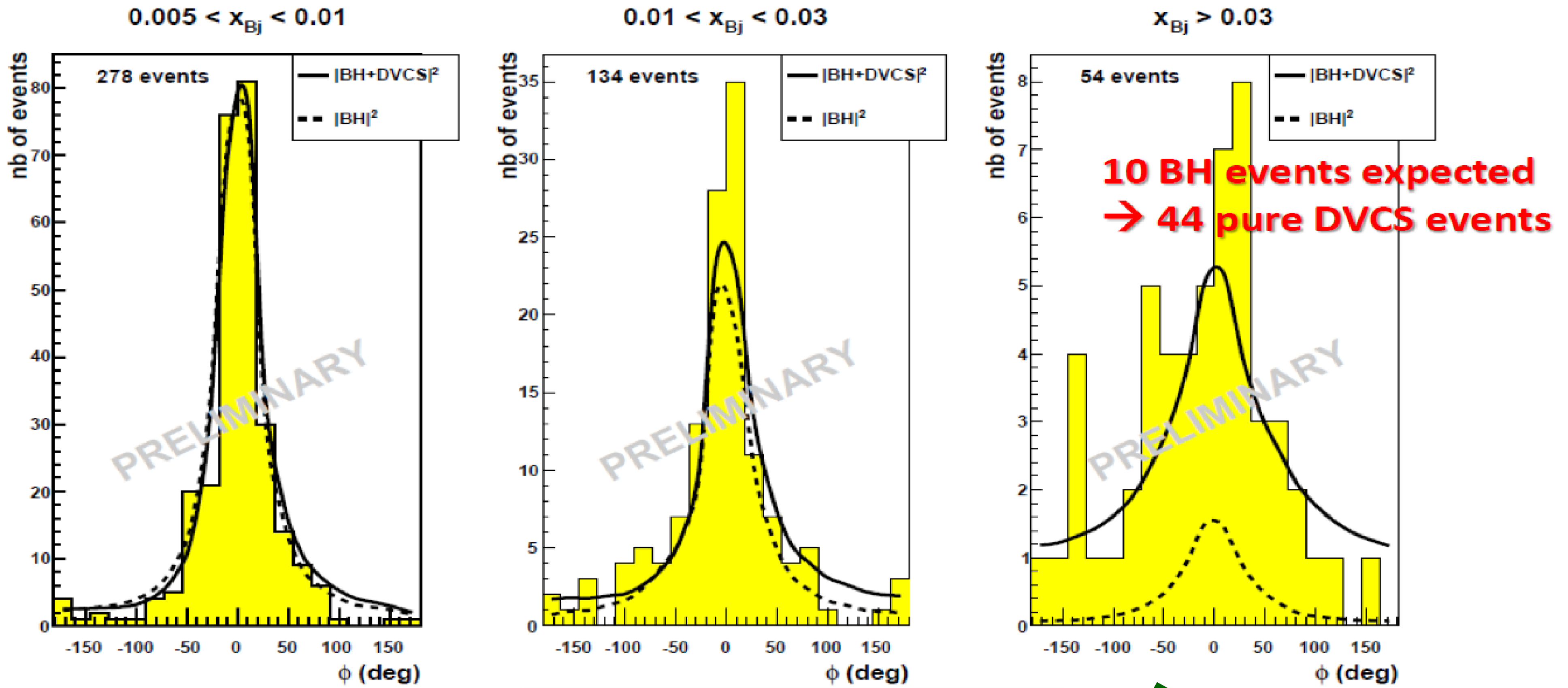
- Data taken with mostly μ^+ beam
- Predictions from MC using VGG

$Q^2 > 1\ (GeV/c)^2$



- low x → majority Bethe Heitler
- high x → dominated by DVCS

First DVCS Signal observed @ COMPASS



- Detection efficiency :

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

Projections of errors are realistic

Global efficiency :

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

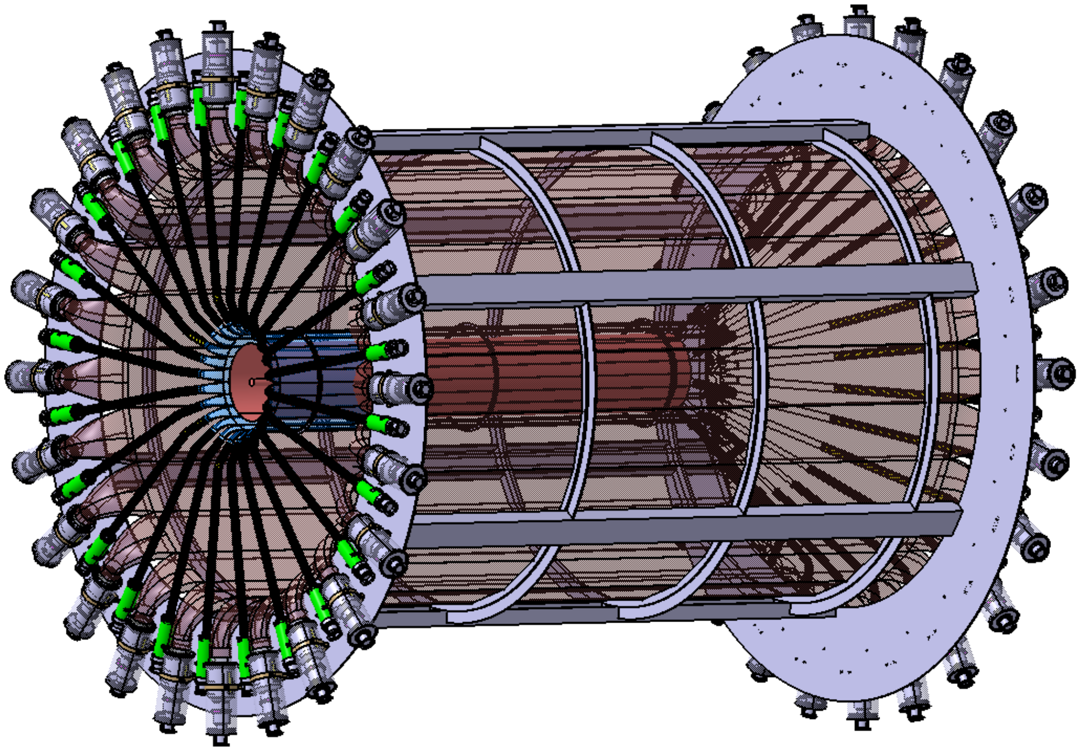
- $\mu+p \rightarrow \mu+p+\gamma$ efficiency
- SPS & COMPASS availability
- Dead time
- Trigger efficiency

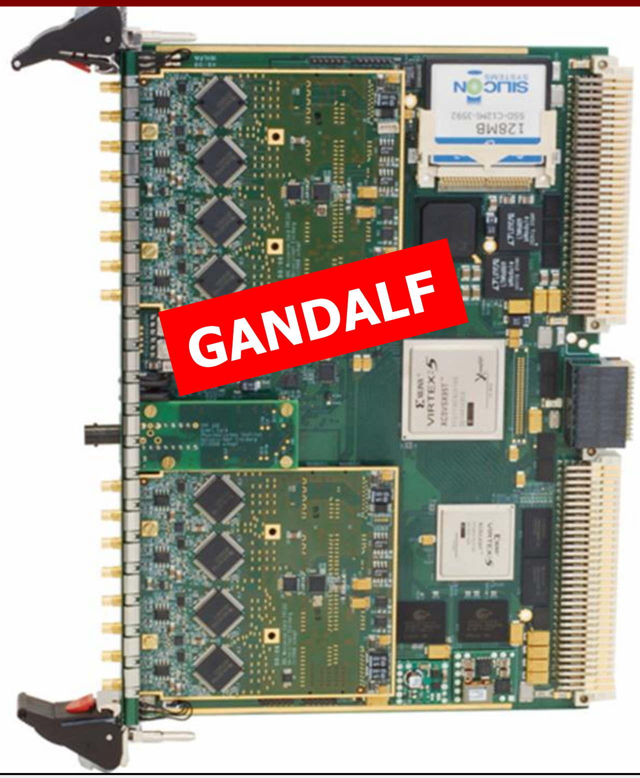
Exclusive π^0 Production
→ O. Kouznetsov

Main Detector Upgrades for COMPASS-II (DVCS/HEMP)

- Recoil-Proton Detector
- Electromagnetic Calorimeter (ECAL0)

New Target & Recoil-Proton Detector





- 2.5 m LH_2 Target; d=4 cm; $\Delta\rho/\rho<3\%$
- Min. thickness of cryostat & target walls

- 2.8/3.6 m long scintillator slabs, 2 Layers
- <300ps time resolution for TOF
- Full scale prototype tested successfully

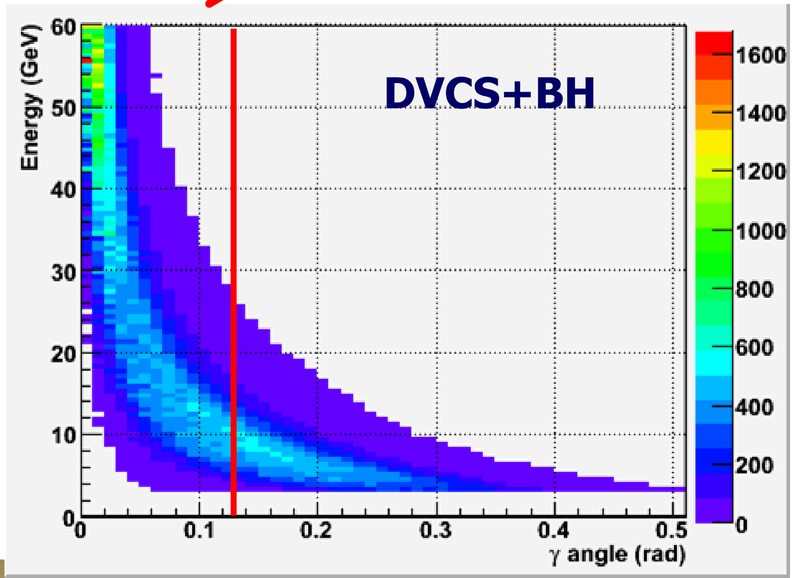
- **1 GHz digitization of PMT signal to cope for high rate**
- **Resolution >10 ENOB**
- **Self triggered**
  - **No more discriminators, meantimers, etc.**

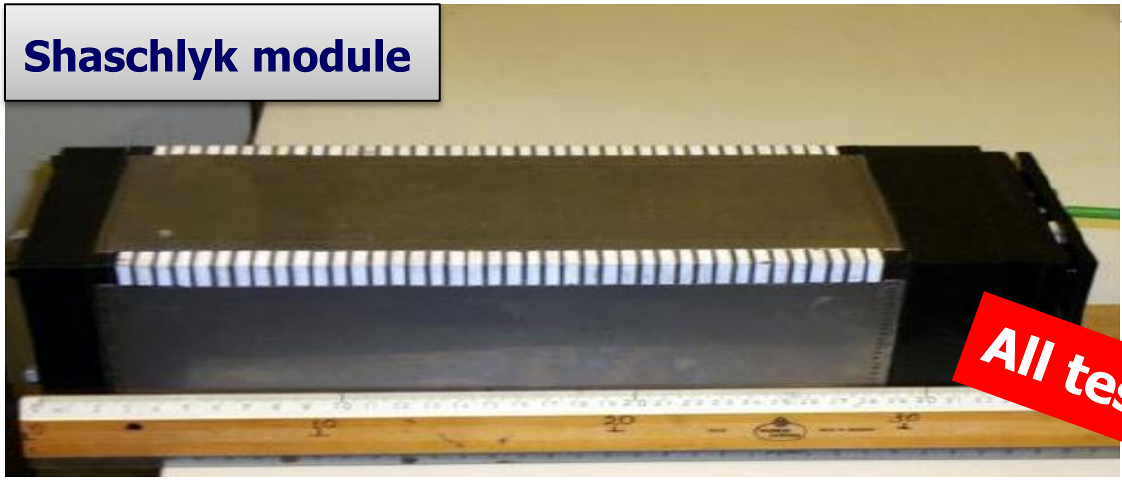
New Electromagnetic Calorimeter : ECAL0

<u>Requirements</u>

- Photon energy range 0.2- 30 GeV
- Size: 260 x 260 cm² ;
- Granularity 12 x 12 cm²
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field.

existing
ECAL1&2 →





Conclusions

Start Measurement in 2013

- **Phase 1: 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 $\mathcal{D}_{CS,U}$

- **Complementary information from hard exclusive meson production**

… 2017 ?

- **Phase 2: DVCS & HEMP with polarized NH_3 Target inside RPD**
  - Use knowledge of GPD H as input to constrain GPD E