GPD @ COMPASS

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On behalf of the COMPASS collaboration

GPDs as a Continuation of COMPASS

- COMPASS two-leg program

  I) Nucleon (mainly polarized) structure
  - ΔG *via* Open Charm or High p_T production. . .

    $\Rightarrow 1/2 = \Delta\Sigma/2 + \Delta G + L = J_q + J_g$
  - . . .Polarized PDFs

    $\Rightarrow$ Inclusive DIS
  - . . .Transversity DF and TMD DFs

    $\Rightarrow$ Transversely polarized target
  - . . .
  - Diffractive production of vector mesons

  II) Hadron spectroscopy
  - Search for exotics *via* PWA
  - χ-PT test *via* Primakoff *i.e* $\pi(\mu)p \rightarrow \pi(\mu)p\gamma$

    $\Rightarrow$ Exclusivity

    $\Rightarrow$ Electromagnetic calorimetry

$\Rightarrow$ Hard exclusive processes (DVCS and HEMP), constraining GPDs,
obvious candidates for future of COMPASS

How significantly can COMPASS contribute ?

- Unique features :
  - μ^+ and μ^- beams polarized with opposite polarizations
  - $\sqrt{s}$: HERA > COMPASS > eNC@FAIR > HERMES > JLAB

  ⇒ Complementarity

- Monte Carlo simulations ⇒ Expectations

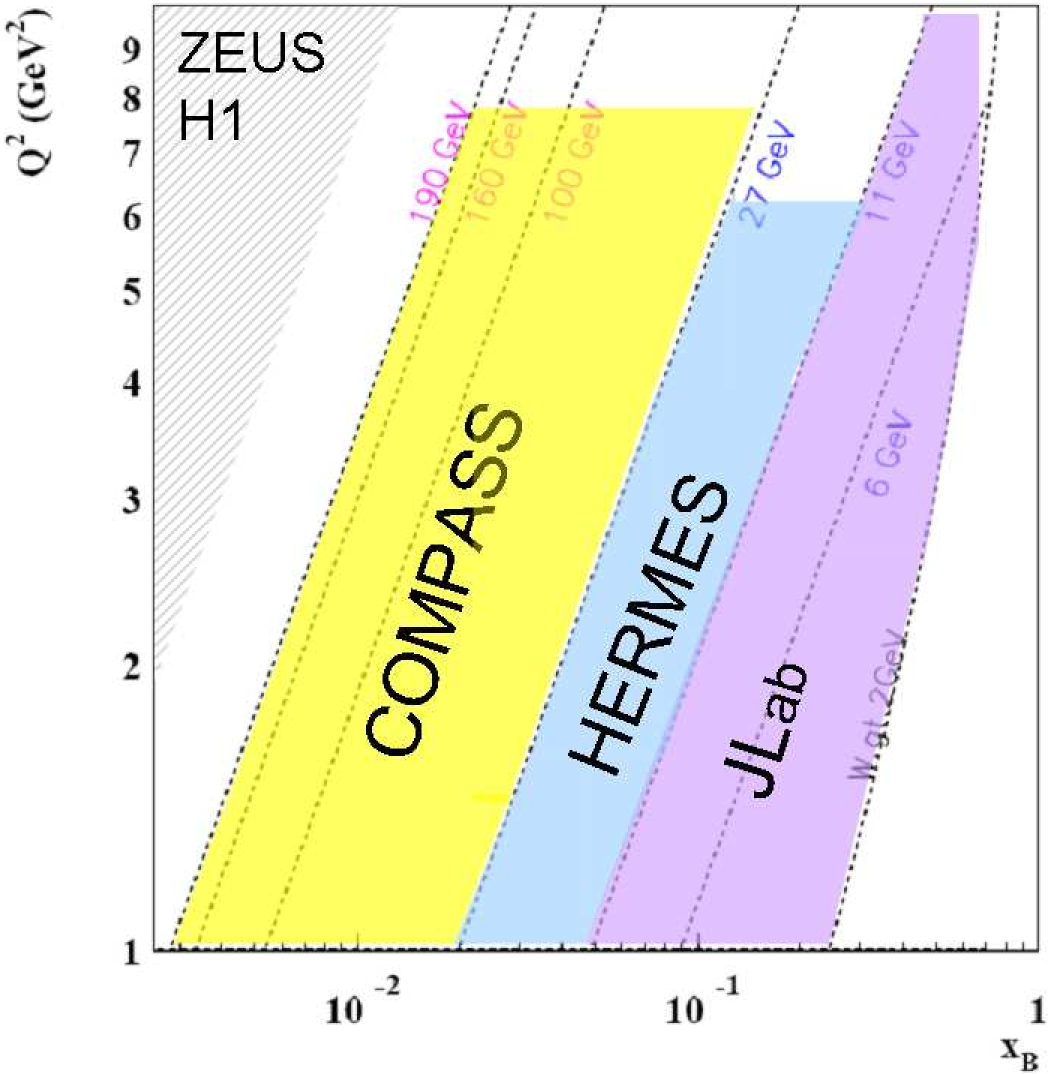
  ⇒ LoI submitted to CERN SPS Steering Committee (SPSC)

  `COMPASS Medium and Long Term Plans, CERN-SPSC-2009-003 (SPSC-I-238)`

  ⇒ Proposal to be submitted to SPSC in September 2009

- Feasibility
  - Vector mesons off transversely polarized protons in 2007
  - New equipment / Improvements
  - Test Run

What makes COMPASS unique ?



- CERN SPS muon beam 100÷190 GeV
  $\sqrt{s}$ 14÷20 GeV
  $\Rightarrow$ Kinematical domain $10^{-2} < x < 10^{-1}$
- 2.5m LH_2 target
  $\Rightarrow \mathcal{L} = 10^{32} cm^{-2} s^{-1}$
  $\Rightarrow$ Q^2 up to 8 GeV^2 for DVCS
- $\mathcal{L} \times 4 \Rightarrow Q^2$ up to 12 GeV^2

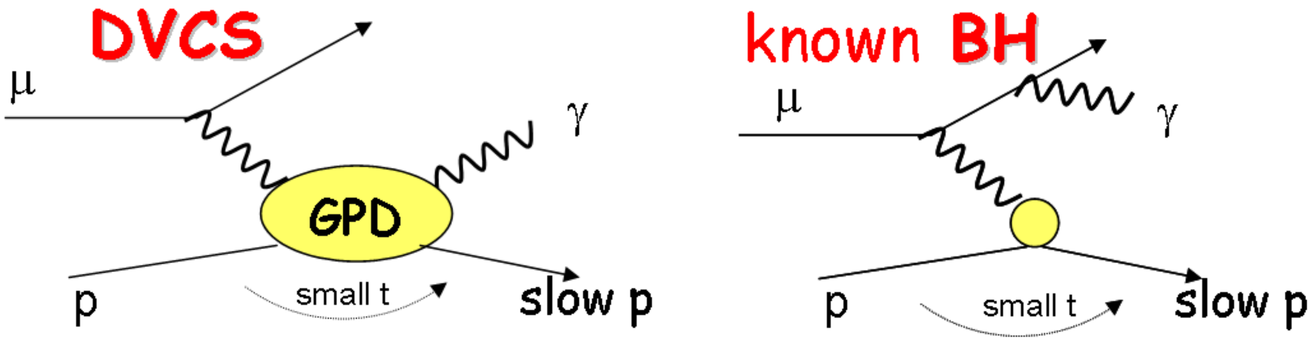
– eNC@FAIR $\sqrt{s} = 14$ GeV (2020 ?)
  $\mathcal{L} = 4\,10^{32} cm^{-2} s^{-1}$

- $\mu^{\pm}$ w/ opposite P $\simeq \pm 80\%$

DVCS *vs.* HEMP

1. Exclusive meson production
   - *Factorization is valid for long. photons only (typically Q^2 >4*
2. Exclusive single photon
   - *Kinematical domain of validity more favorable*

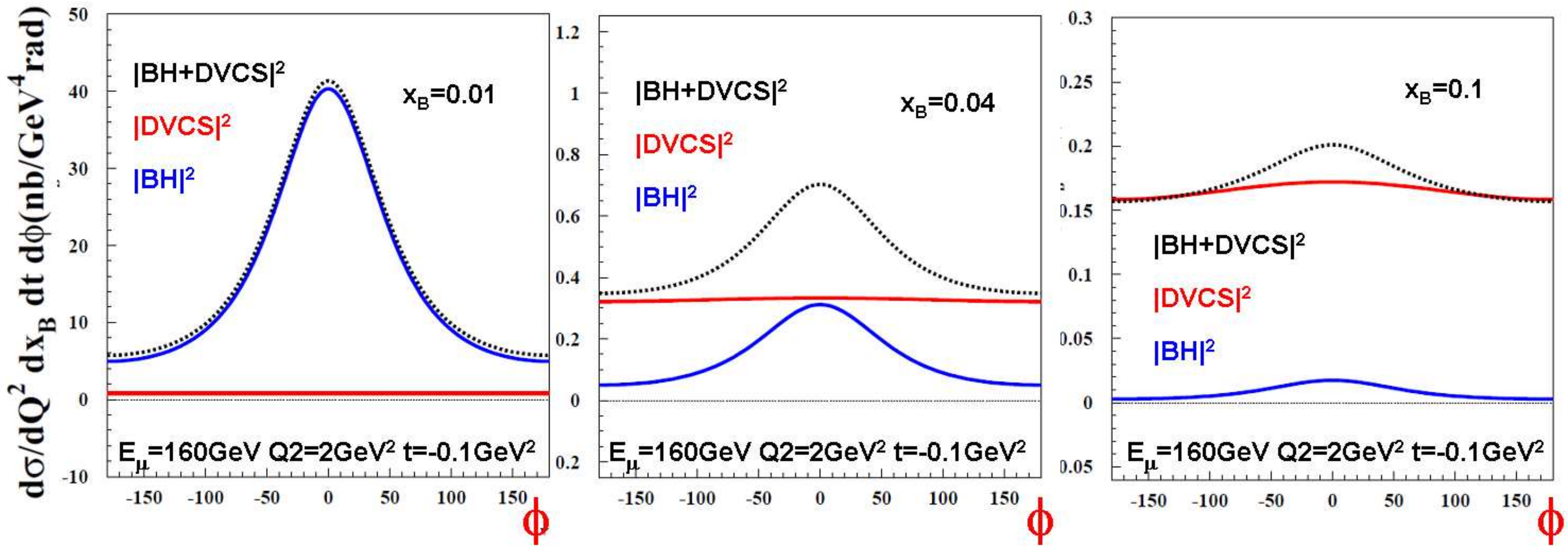
   ⇒ Optimisation of the experimental setup on DVCS



- $$\sigma \propto |DVCS|^2 + |BH|^2 + Interference\ term$$

DVCS *vs.* BH

- At fixed Q^2 and x, DVCS/BH increases w/ beam energy
- $E = 160$ GeV, $Q^2 = 2$ GeV^2, $|t| = 0.1$ GeV^2



BH dominates	BH $\simeq$ DVCS	DVCS dominates
Excellent reference	*DVCS boosted by interference*	$\Rightarrow$ *Easy* $d\sigma^{DVCS}/dt$

DVCS + BH with $\mu^{+\downarrow}$ and $\mu^{-\uparrow}$

- $d\sigma^{\mu p \to \mu p \gamma} = d\sigma^{BH}(cos\phi, cos2\phi, cos3\phi, cos4\phi) + d\sigma^{DVCS}(cos\phi, cos2\phi, P_\mu sin\phi)$

$$+ A^{INT}(cos\phi, cos2\phi)\ (e_\mu\,[c_1 cos\phi\,\Re\mathcal{A}(\gamma^*_T) + c_2 cos2\phi\,\Re\mathcal{A}(\gamma^*_L) + \ldots]$$

$$+ e_\mu P_\mu\ [s_1 sin\phi\,\Im\mathcal{A}(\gamma^*_T) + s_2 sin2\phi\,\Im\mathcal{A}(\gamma^*_L)]\,)$$

- Beam Charge and Spin Difference $\mathcal{D}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow})$
  keeping even terms, allows to determine the real parts of $\mathcal{A}(\gamma^* p \to \gamma p)$
  - In terms of Fourier coefficients of : A. Belitsky, D. Müller, A. Kirchner Nucl. Phys. B629 (2002)
    $c_0^{\mathcal{I}} + c_1^{\mathcal{I}} cos\phi + c_2^{\mathcal{I}} cos2\phi + c_3^{\mathcal{I}} cos3\phi$
- Beam Charge and Spin Sum $\mathcal{S}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow})$
  keeping odd terms, allows to determine the imaginary parts.
  - $s_1^{\mathcal{I}} sin\phi + s_1^{\mathcal{I}} sin2\phi$

  integrating and subtracting BH yields :
  - c_0^{DVCS}

Transverse Imaging

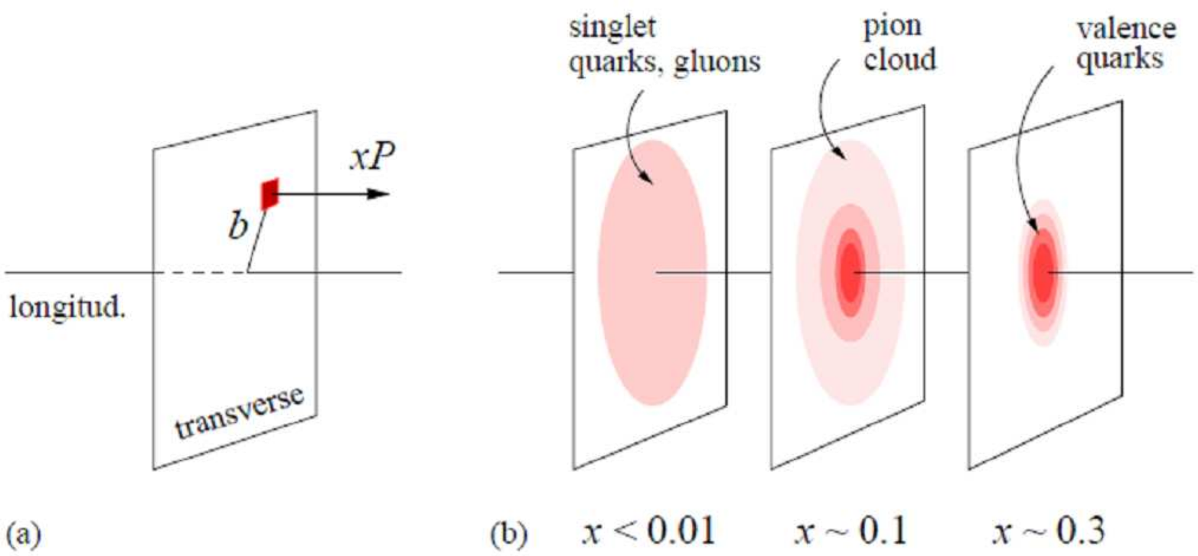
- $\mathcal{S}_{U,CS}$ and integration over ϕ cancel the interference term
- BH calculable (*from QED and measured proton FFs*) : subtracted

$\Rightarrow\ d\sigma^{DVCS}/dt \simeq e^{-\mathcal{B}|t|}$

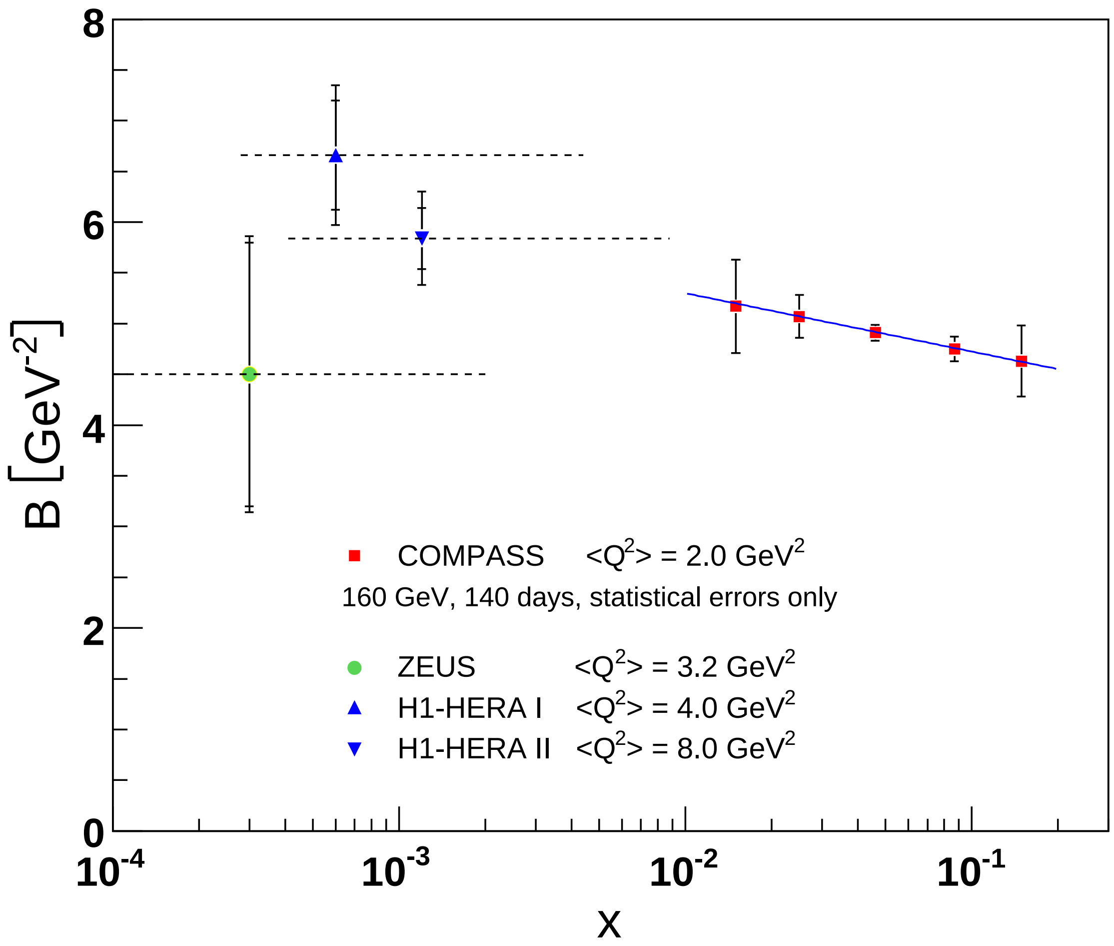
- Interpretation of GPD in the coordinate space

  M.Burkardt, Phys.Rev. D62 071503 (2000) ; J.P.Ralston and B.Pire, hep-ph : 0110075

  M.Diehl, Eur.Phys.J C 25 (2002)
- Impact parameter distribution $\mathcal{B}(x) \simeq 1/2\left\langle b_\perp^2\right\rangle(x)$



Transverse Imaging @ COMPASS



- $d\sigma^{DVCS}/dt \simeq e^{-\mathcal{B}|t|}$
- FFS model with Ansatz
  $\mathcal{B} = b_0 + 2\alpha' ln(x_0/x)$
  $\alpha' = 0.125$ GeV^{-2}
- 160 GeV, 2.5m LH_2 target
  140 days w/ global $\epsilon = 10\%$
  $\Rightarrow \int \mathcal{L}dt \simeq 1.2 fb^{-1}$
  $\mathcal{S}_{U,CS}$ ϕ integrated and

ZEUS = arXiv :0812.2517

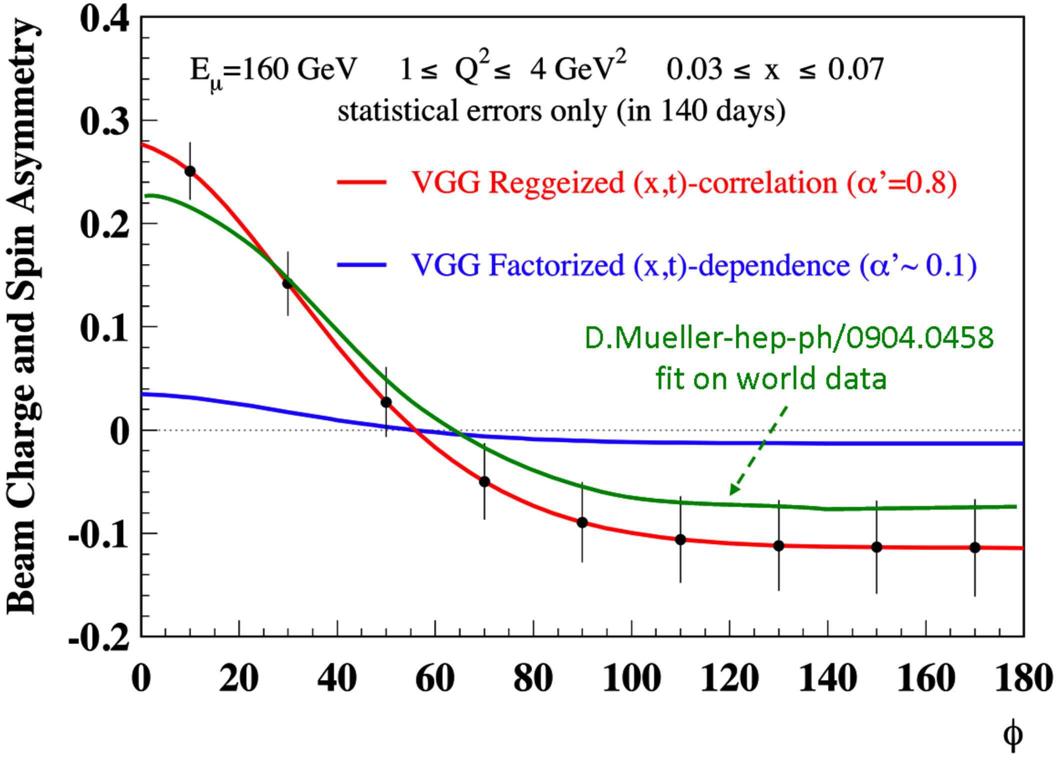
H1 = Eur. Phys. JC 44 (2005), Phys.Lett. B 659(4) (2008)

BCSA

- Neglecting higher twists, gluons :

$$\mathcal{D}_{U,CS} \propto c_0^{\mathcal{I}} + c_0^{\mathcal{I}} \, cos(\phi) \qquad \mathcal{S}_{U,CS}(\phi) \propto s_1^{\mathcal{I}} \, sin(\phi)$$

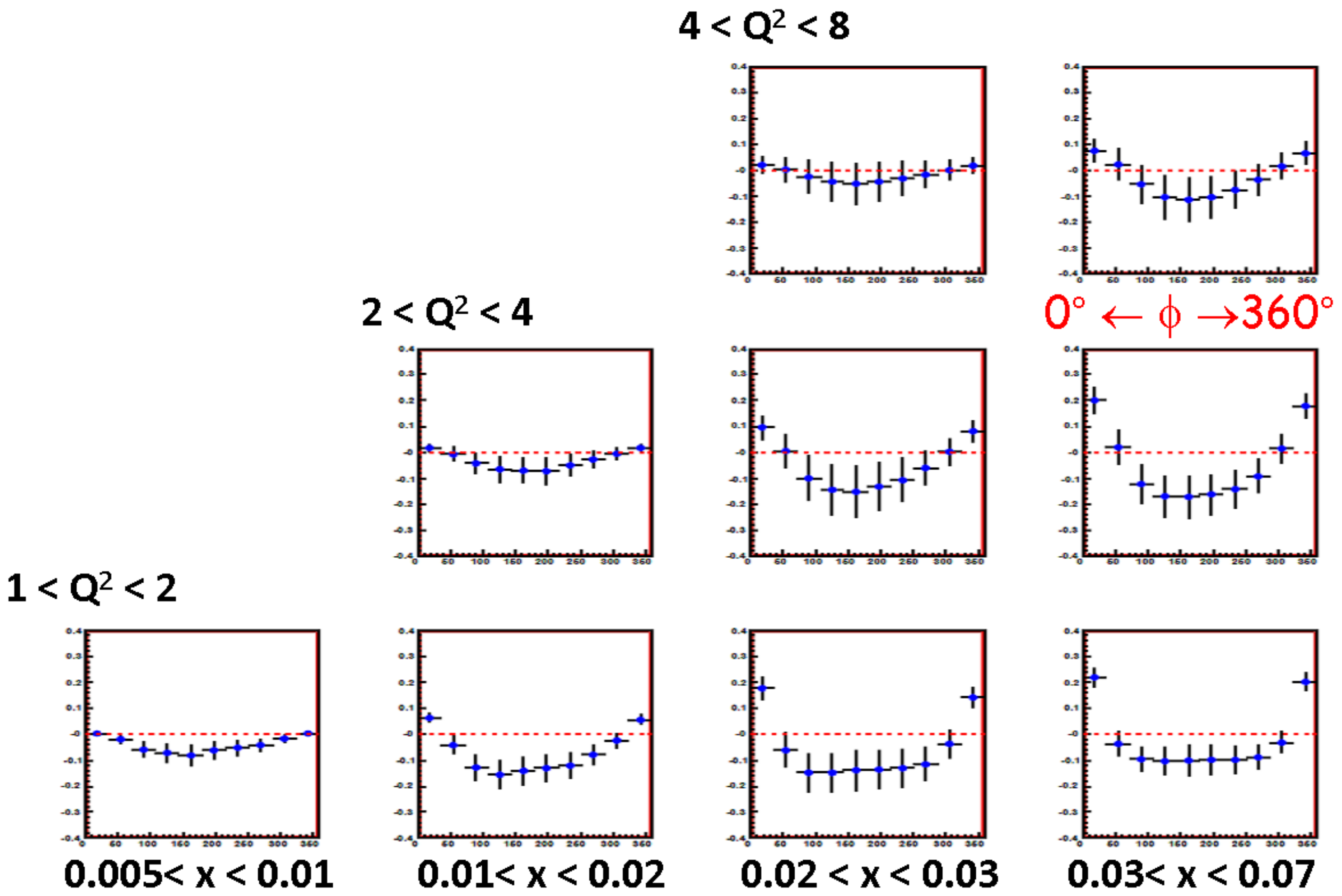
With $c_{0,1}^{\mathcal{I}} \simeq \Re(F_1 \mathcal{H})$ $\qquad s_1^{\mathcal{I}} \simeq \Im(F_1 \mathcal{H})$



- $BCSA = \mathcal{D}_{U,CS} / \mathcal{S}_{U,CS}$
- 160 GeV, 2.5m LH_2 target
  140 days w/ global $\epsilon = 10\%$
  $\Rightarrow \int \mathcal{L}dt \simeq 1.2 fb^{-1}$

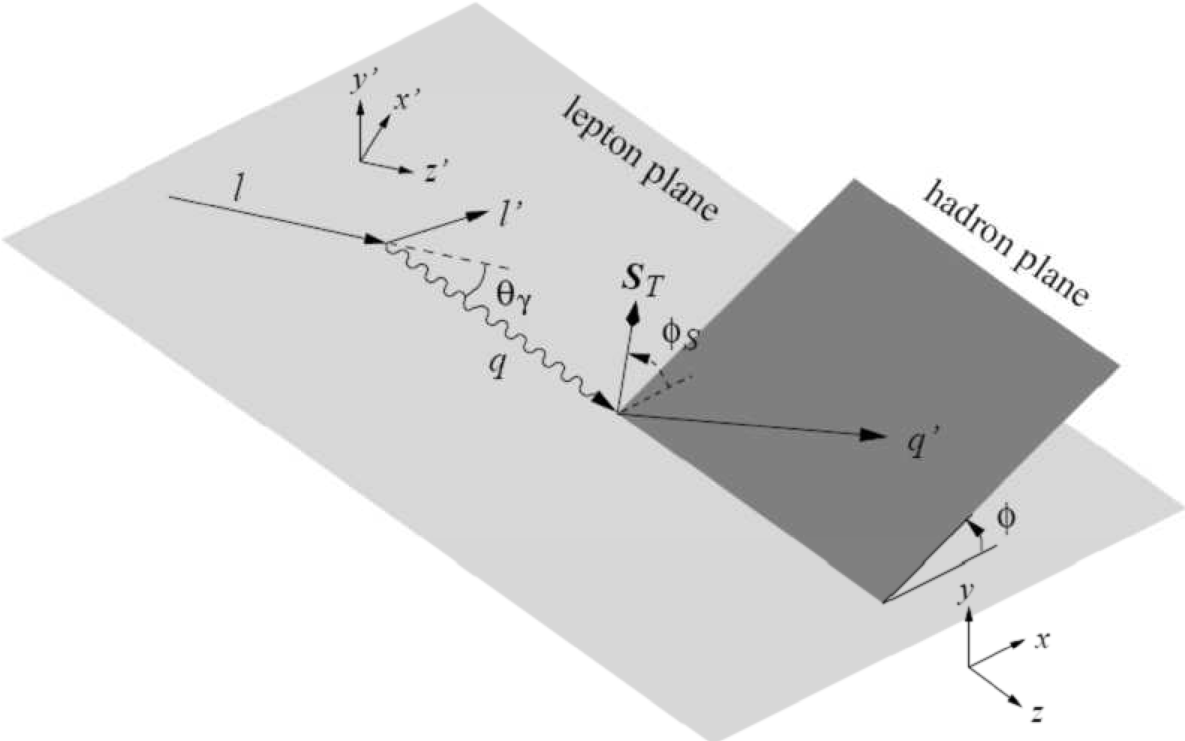
BCSA in bins of x and $Q2$

- Kinematical domain of the interference regime split in 9 (x, Q^2) bins
  VGG Reggeized (x,t)-correlation $(\alpha' = 0.8)$



Transversely polarized target

◦ Azimuthal asymmetry in ϕ and ϕ_S



$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \Im(F_2\mathcal{H} - F_1\mathcal{E})\, sin(\phi-\phi_S)\, cos(\phi)$$

◦ Simulations in progress. . .

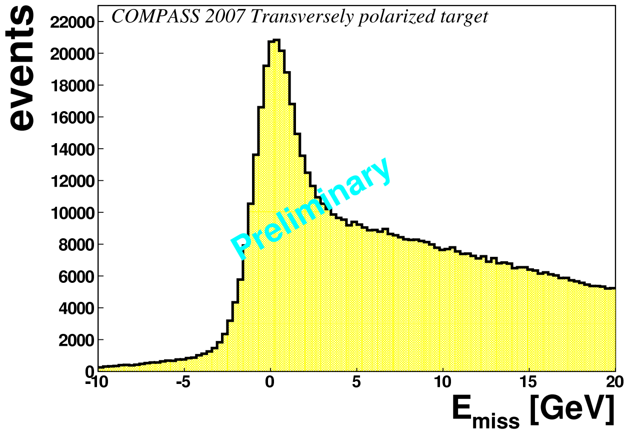
Already in COMPASS data : $\gamma^* N \rightarrow \rho N$

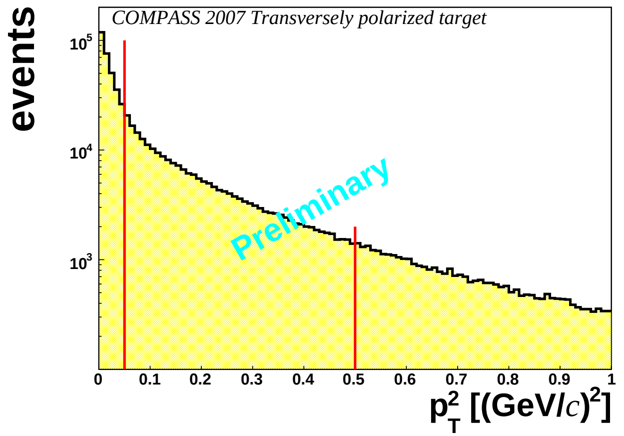
- W/o any em-calorimetry : $\gamma^* N \rightarrow \rho N$
- $A_{UT}^{sin(\phi-\phi_S)} \propto \Im(\mathcal{E}^*\mathcal{H})/\mathcal{H}^2$

$\Rightarrow$ Provided GPD H is otherwise well enough constrained, give access to GPD E.

S.V. Goloskokov, P. Kroll, Eur.Phys.J.C 2009

- Measured by fitting azimuthal modulation of exclusive ρ in incoherent diffraction

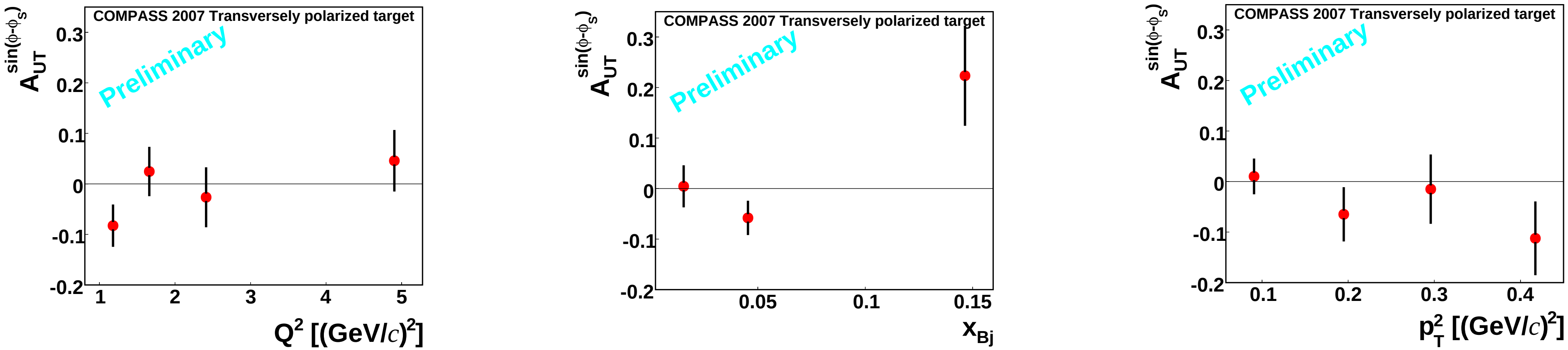




- $E_{miss} = (Missing^2 - M_p^2)/2M_p$
  -2.5 GeV $< E_{miss} <$ 2.5 GeV
- Poor precision on Missing mass
  $\Rightarrow$ *Recoil Proton Detector mandatory in any GPD dedicated data taking*
- Incoherent selected by
  0.05 GeV$^2 < p_T^2 <$ 0.5 GeV^2

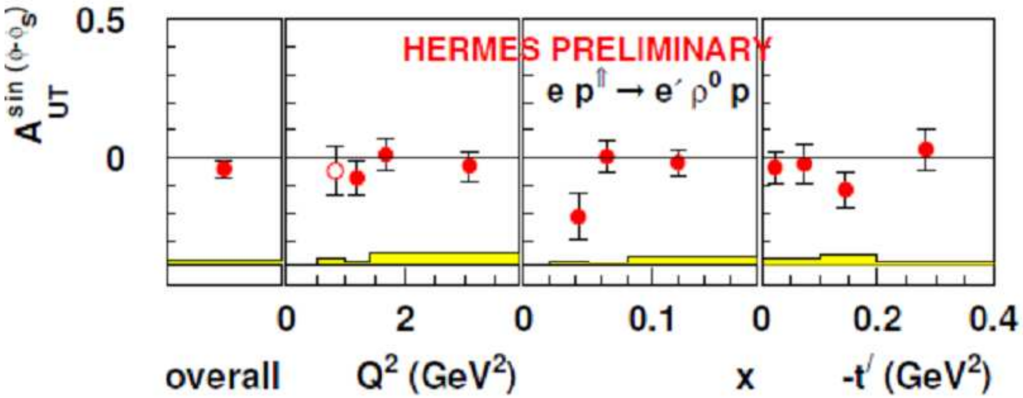
$\Rightarrow$ 35% non-exclusive left
+ 5% coherent
not yet subtracted (*will be*)

TTSA in $\gamma^* p \to \rho^o p$



- TTSA compatible w/ zero but yet compatible w/ GK prediction ($A_{UT}^{sin(\phi-\phi_S}$ = -.02)
- *Caveat* : Kinematics somewhat low (higher orders below $3 \div 4$ GeV^2). No ρ^L/ρ^T separation yet.
- New data taking w/ transverse target in 2010

with improved em-calorimetry enabling ω where higher asymmetry predicted (5 $\times$)



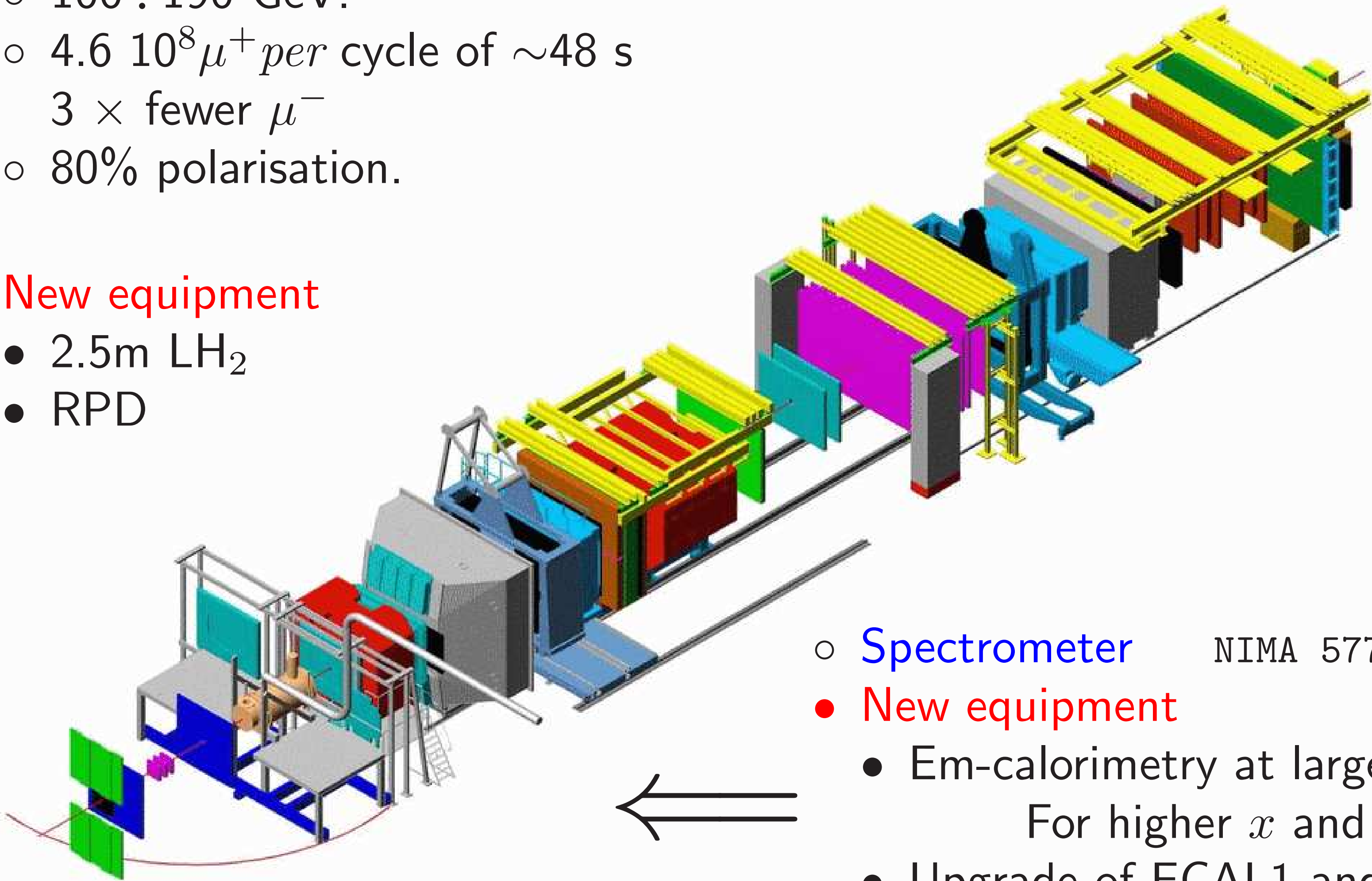
A. Rostomyan and J. Dreschler, arXiv :0707.2486 [hep-ex]

TTSA measured on deuteron in 2002-4, w/ lower statistics ($\times \sim 2$), equally compatible w/ 0

Spectrometer Upgrade

- Muon Beam
  - 100÷190 GeV.
  - 4.6 $10^8 \mu^+ per$ cycle of $\sim$48 s
    3 $\times$ fewer μ^-
  - 80% polarisation.

- New equipment
  - 2.5m LH_2
  - RPD

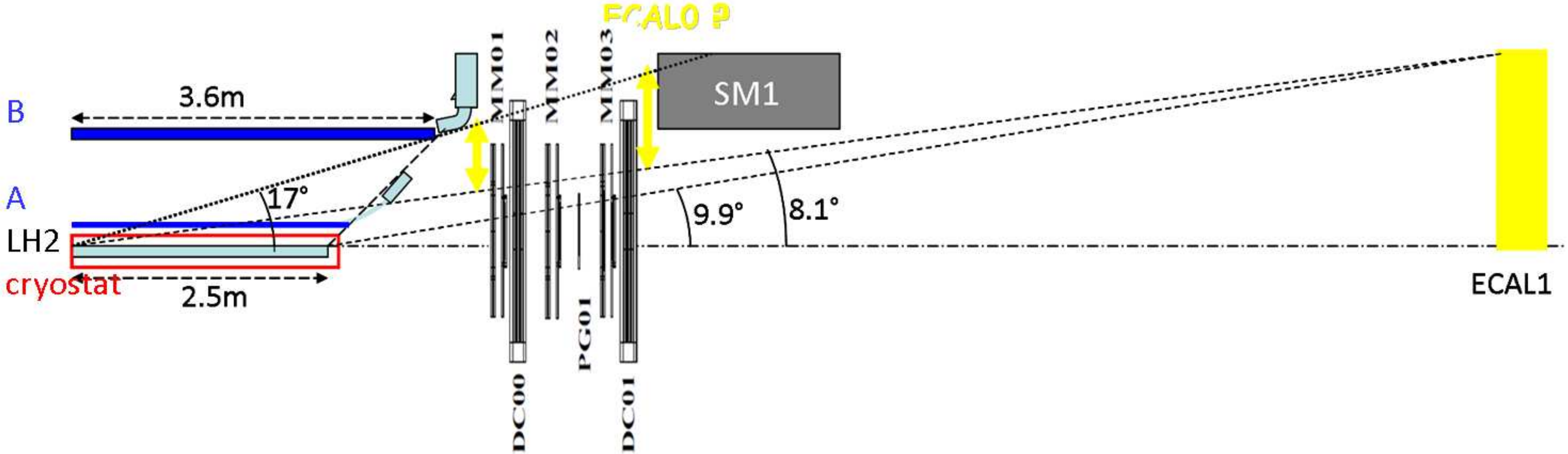


$\Longleftarrow$

- Spectrometer `NIMA 577 (2007) 455`
- New equipment
  - Em-calorimetry at large angle (ECAL0)
    For higher x and better hermeticity
  - Upgrade of ECAL1 and ECAL2

New equipment

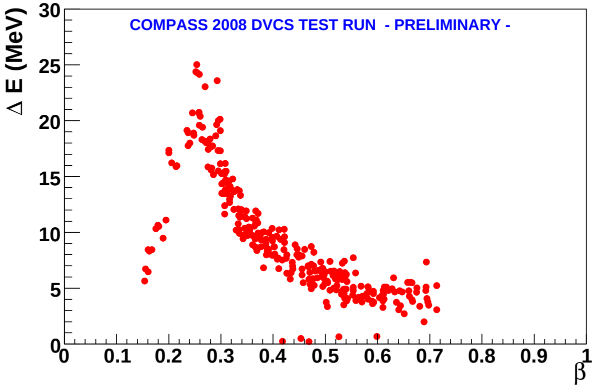
○ Long LH_2, RPD and ECAL0 projects

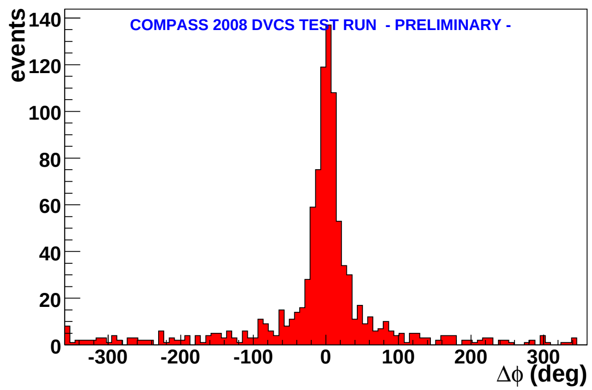


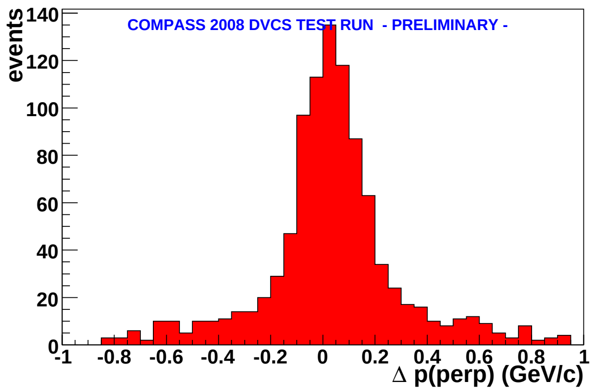
○ (for A_{UT}) Polarized target w/ thin superconducting coils
`(W.Meyer, Bochum University)`
Or RPD incorporated in present target

Test run

- Using equipment built for the hadron spectroscopy data taking
  - 40cm LH_2 *i.e. 1/6 of target planned for GPD dedicated setup*
  - RPD with proton ID and ToF. $0.06 < -t < .064$ GeV^2
  - Improved em-calorimetry





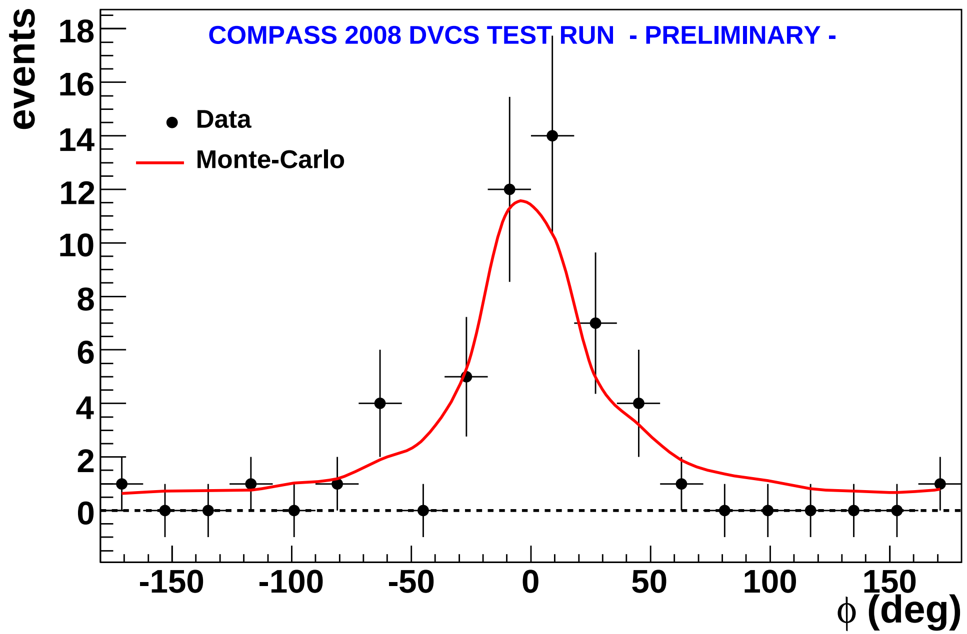


$$\Delta\phi = \phi^{miss} - \phi^{RPD}$$
$$|\Delta\phi| < 36 \text{ deg.}$$

$$\Delta p_T = p_T^{miss} - p_T^{RPD}$$
$$|\Delta p_T| < 0.2 \text{ GeV}$$

Test run : Results

◦ A single day of running ! With 1/3 nominal intensity.



◦ γ azimuthal distribution
- Exclusivity cuts
- $Q^2 > 1$ GeV^2

⇒ ∼100 BH events, $\langle x \rangle \simeq 0.014$
⇒ **Overall** efficiency = 13%

◦ Monte-Carlo simulation
of BH (dominant) and DVCS

◦ 2 weeks of measurements, w/ same conditions, planned in 2009
to get about 1000 BH and 100 (DVCS+Int).

Summary and Outlook

- TTSA of exclusive ρ^o measured in 2002-4 and 2007 : compatible w/ 0
- Transverse proton Data taking in 2010, w/ improved em-calorimetry, w/o RPD
  $\Rightarrow$ Further studies of HEMP and tests of DVCS
- Test run proves assumptions made in simulations are conservative. More tests in 2009
- Proposal to be submitted to SPSC in September 2009
  - Phase 1 : DVCS experiment in 2012 to constrain GPD H
    $\mu^{+\downarrow}$,$\mu^{+\uparrow}$ beams and Unpolarized long LH_2 target

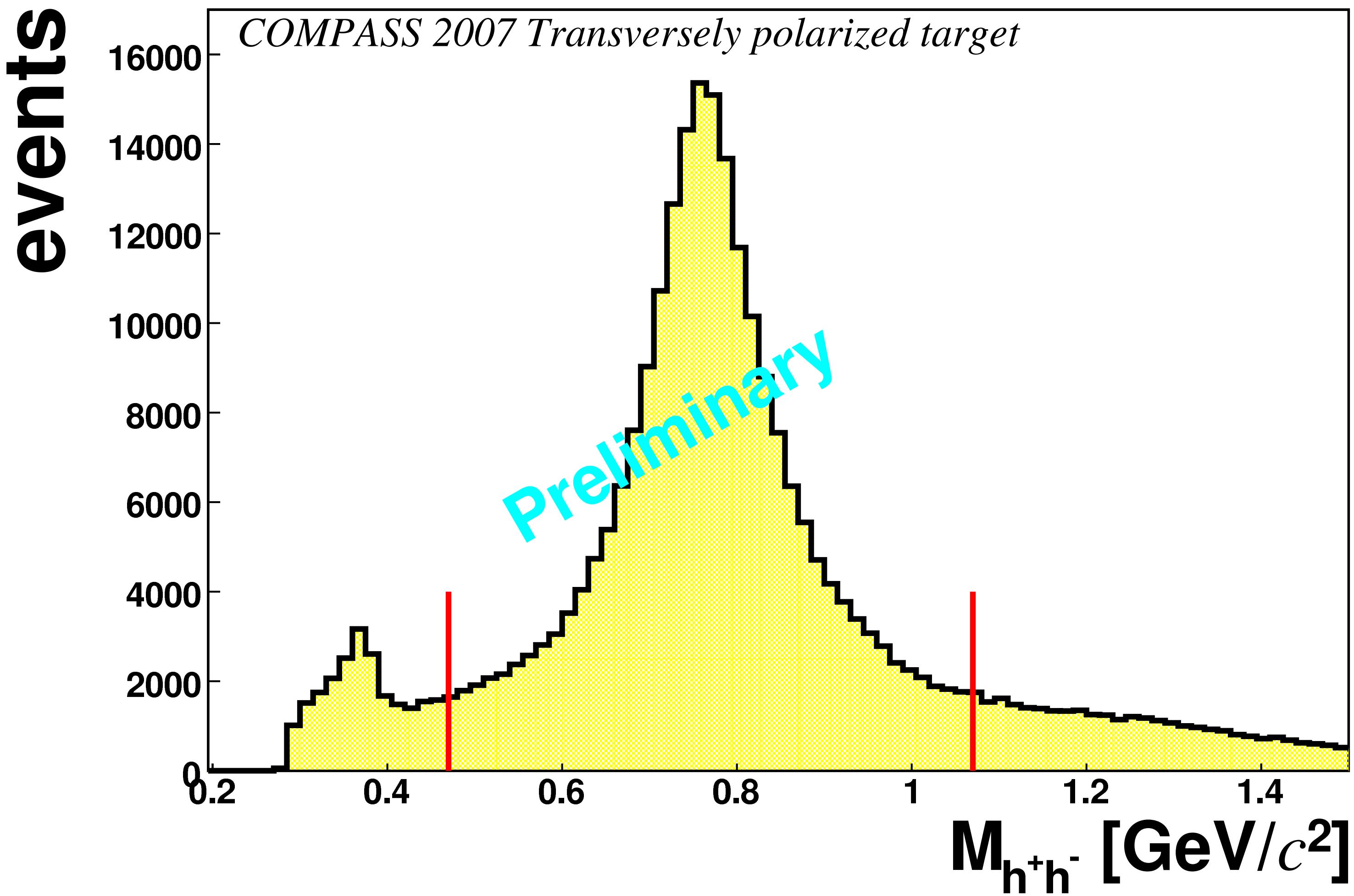
    I) $d\sigma^{DVCS}/dt\ vs.\ x \Rightarrow$ Transverse Imaging

    II) Azimuthal modulation of $\mathcal{D}_{U,CS}$ and $\mathcal{S}_{U,CS} \Rightarrow$ Constrain on GPD H
  - Phase 2 : in ~ 2014
    - μ^+ beam and Polarized proton (NH_3) target
      $\Rightarrow$ Constrain on GPD E

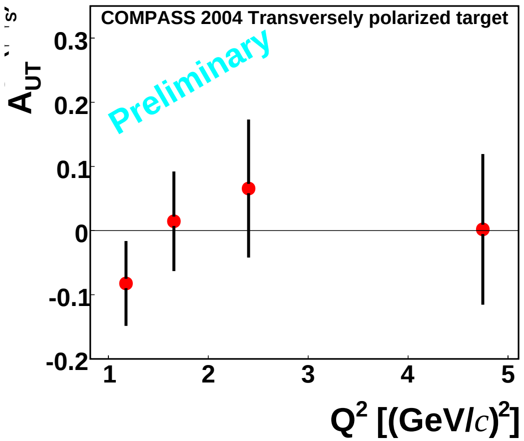
$\Rightarrow$ Accessing the intermediate x range between HERA and HERMES/JLab
A valuable set of data to further constrain GPD models.

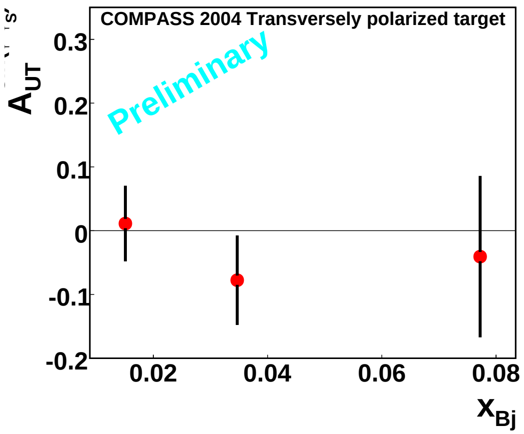
Backup

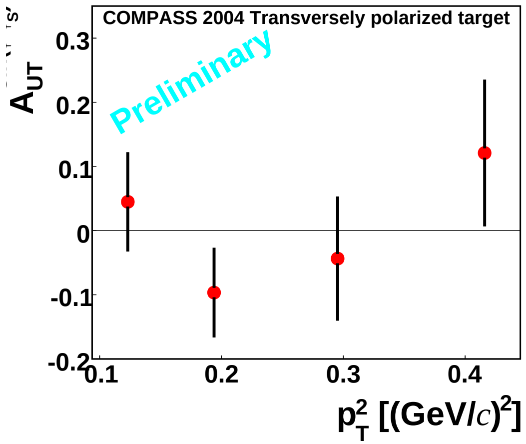
ρ Inv. Mass


COMPASS 2007 Transversely polarized target
Preliminary
events
16000
14000
12000
10000
8000
6000
4000
2000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
$M_{h^+h^-}$ [GeV/c^2]

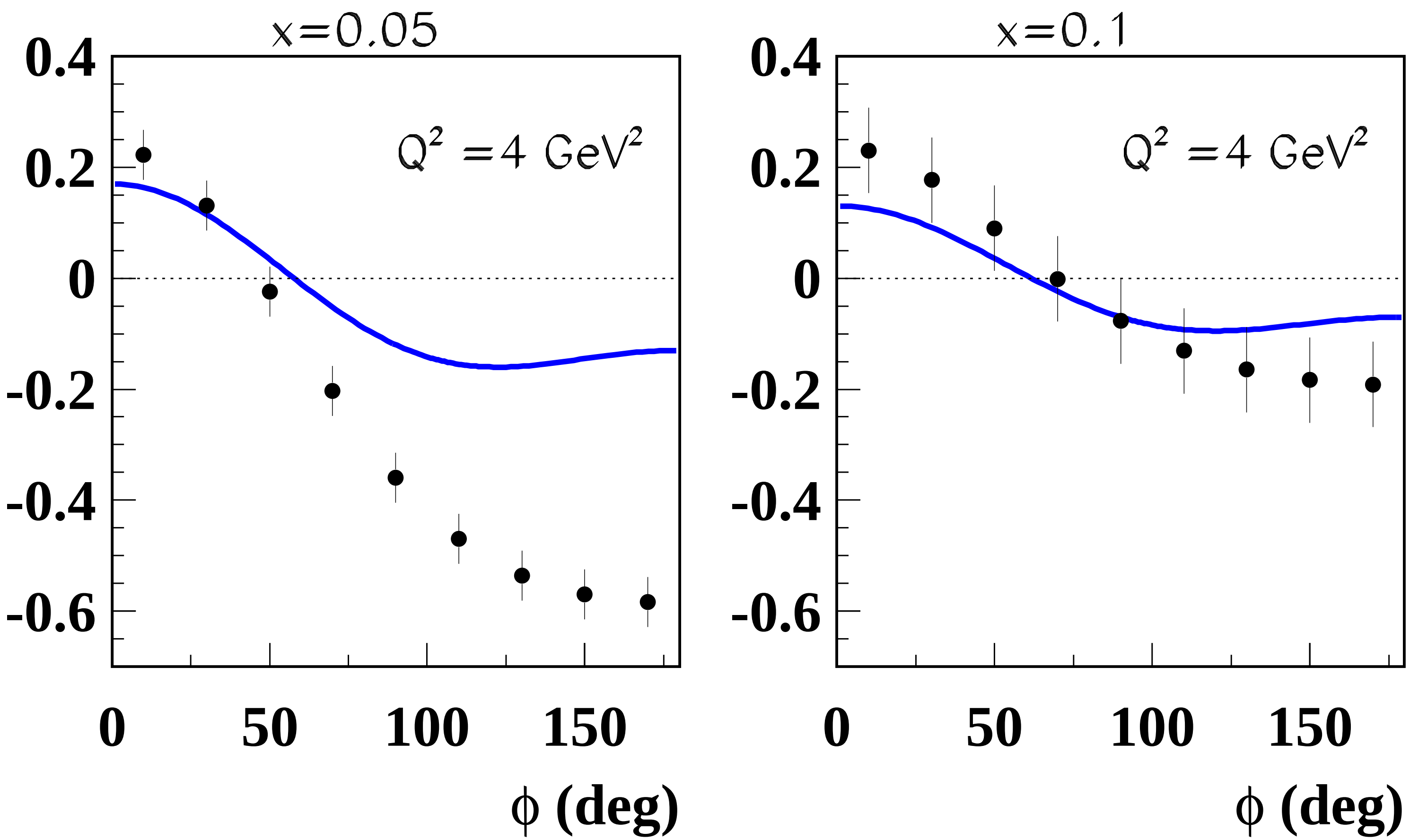
TTSA in $\gamma^* d \to \rho^o d$







Laurent Schoeffel predictions



DVCS + BH with $\mu^{+\downarrow}$ and $\mu^{+\uparrow}$

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

- Beam Charge and Spin Difference
  $\mathcal{D}_{U,CS} \equiv d\sigma(\overset{\rightarrow}{\mu^{+}}) - d\sigma(\overset{\leftarrow}{\mu^{+}}) = 2\times\left(e_\mu\, a^{BH}\,\Re(T^{DVCS}) + P_\mu\, d\sigma^{DVCS}_{pol}\right)$
  - A. Belitsky, A. Kirchner, D. Müller, Phys. Rev. D 64, 116002 (2001)
    $e_\mu : c_0^{\mathcal{I}} + c_1^{\mathcal{I}} cos(\phi) + c_1^{\mathcal{I}} cos(2\phi) + c_3^{\mathcal{I}} cos(3\phi)$ $P_\mu : s_1^{DVCS} sin(\phi)$

- Beam Charge and Spin Sum
  $\mathcal{S}_{U,CS} \equiv d\sigma(\overset{\rightarrow}{\mu^{+}}) + d\sigma(\overset{\leftarrow}{\mu^{+}}) = 2\times\left(d\sigma^{BH} + d\sigma^{DVCS}_{unpol}\right) + e_\mu P_\mu\, a^{BH},\Im(T^{DVCS})$
  - $c_0^{DVCS} + c_1^{DVCS} cos(\phi) + c_2^{DVCS} cos(2\phi)$ $e_\mu P_\mu : s_1^{\mathcal{I}} sin(\phi) + s_1^{\mathcal{I}} sin(2\phi)$