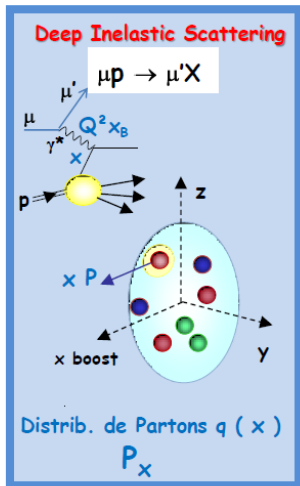# GPD study and DVCS measurements at COMPASS-II
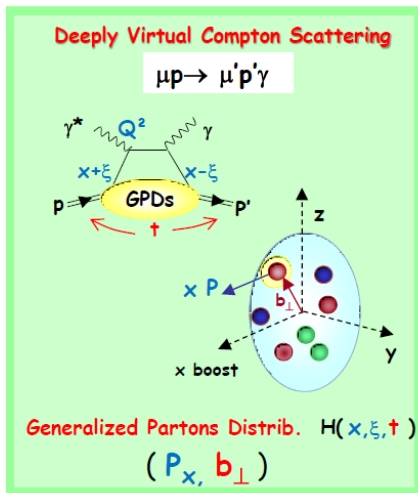
A. Ferrero (CEA/Saclay)

Photon2011

Spa, 23-27 May 2011
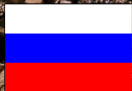
From PDFs to GPDs

Deep Inelastic Scattering

$\mu p \to \mu' X$

μ'

μ

γ^* Q^2 x_B

x

p

z

$\times P$

x boost

y

Distrib. de Partons q (x)

P_x

Deeply Virtual Compton Scattering

$\mu p \to \mu' p' \gamma$

γ^* Q^2 γ

$x+\xi$ $x-\xi$

p GPDs P'

t

z

$\times P$

b

x boost

y

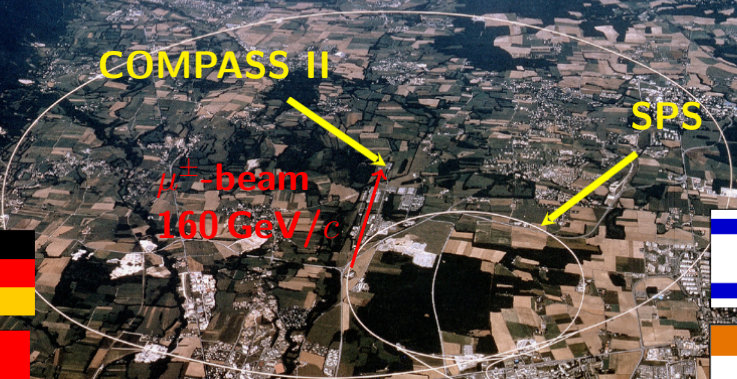Generalized Partons Distrib. $H(x, \xi, t)$

$(P_x, b_\perp)$

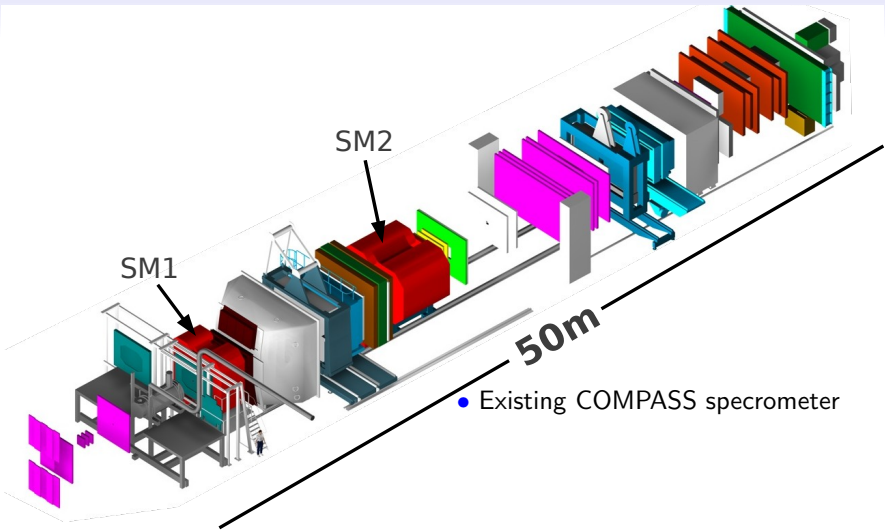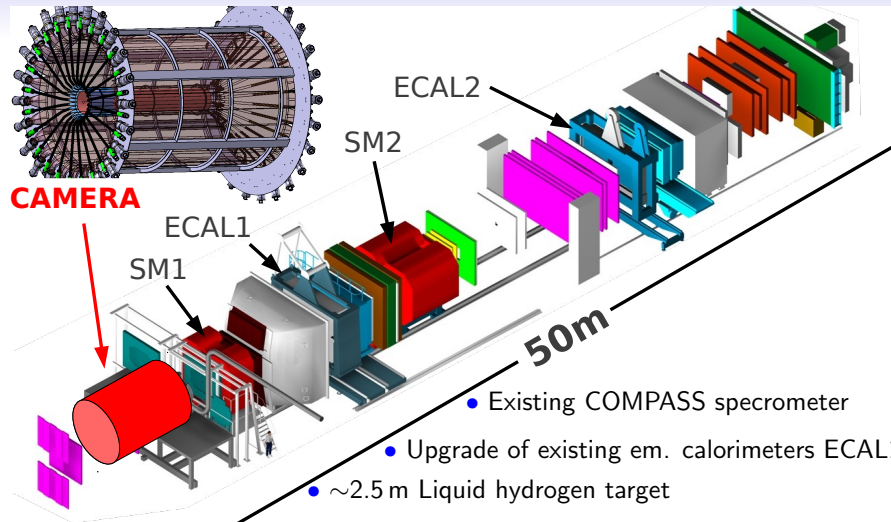**Observation of the Nucleon Structure**

in 1 dimension

in 1+2 dimensions

COMPASS-II will start in 2012

230 physicists, 10 countries + CERN, 25 institutes

COMPASS II

SPS

μ^+-beam
160 GeV/c

SM2

SM1

50m

- Existing COMPASS specrometer

- Existing COMPASS specrometer
- Upgrade of existing em. calorimeters ECAL1&2

CAMERA

ECAL2

SM2

ECAL1

SM1

50 m
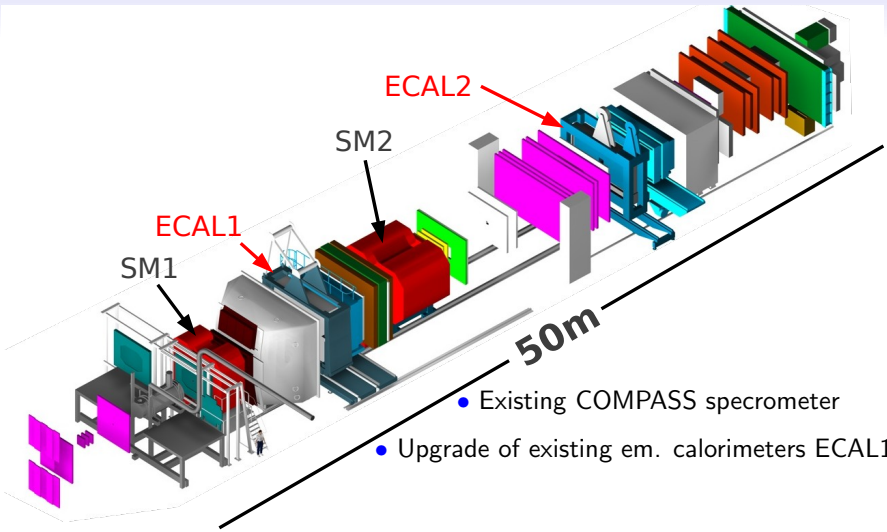
- Existing COMPASS spectrometer
- Upgrade of existing em. calorimeters ECAL1&2
- ∼2.5 m Liquid hydrogen target
- ∼4 m Recoil proton detector (CAMERA)

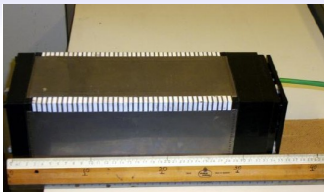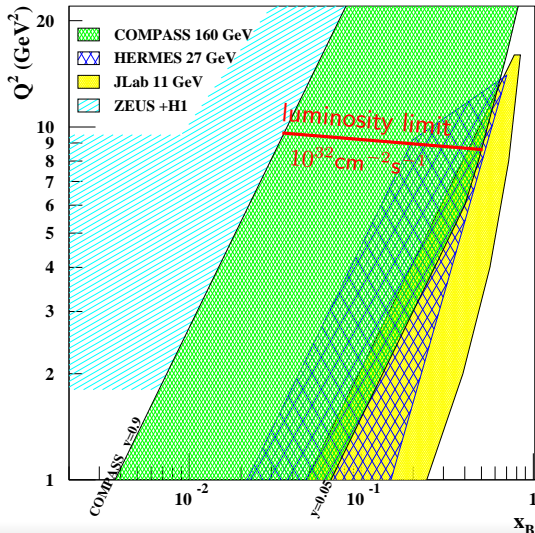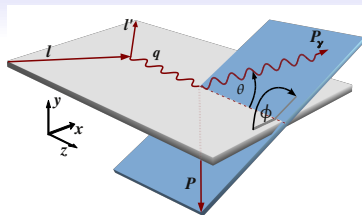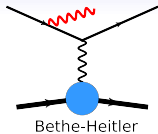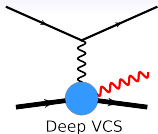# COMPASS-II @ CERN/SPS

ECAL0

ECAL1

SM1

SM2

ECAL2

50 m

- Existing COMPASS specrometer
- Upgrade of existing em. calorimeters ECAL1&2
- ~2.5 m Liquid hydrogen target

~4 m Recoil proton detector (CAMERA)

- New large angle em. calorimeter in front of SM1 (ECAL0)

- μ^+ and μ^- beams
- momentum: $100 - 190\,\mathrm{GeV}/c$
- beam polarization: $80\,\%$ opposite for μ^+ and μ^-

- coverage of intermediate x_B
  - $\rightarrow$ low x_B: **pure BH** useful for normalization
  - $\rightarrow$ high x_B: **DVCS predominance**
- $\rightsquigarrow$ **unexplored region between ZEUS+H1 and HERMES+JLab**

Figure legend: COMPASS 160 GeV; HERMES 27 GeV; JLab 11 GeV; ZEUS +H1. Axes: $Q^2\ (\mathrm{GeV}^2)$ vs x_B. luminosity limit $10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

BH and DVCS at $E_\mu = 160$ GeV

Deep VCS

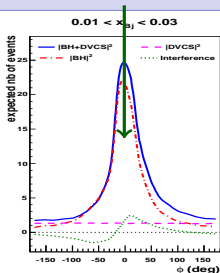Bethe-Heitler

same final state → interference
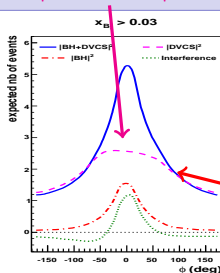
$$d\sigma \propto |T^{BH}|^2 + Int.\ Term + |T^{DVCS}|^2$$

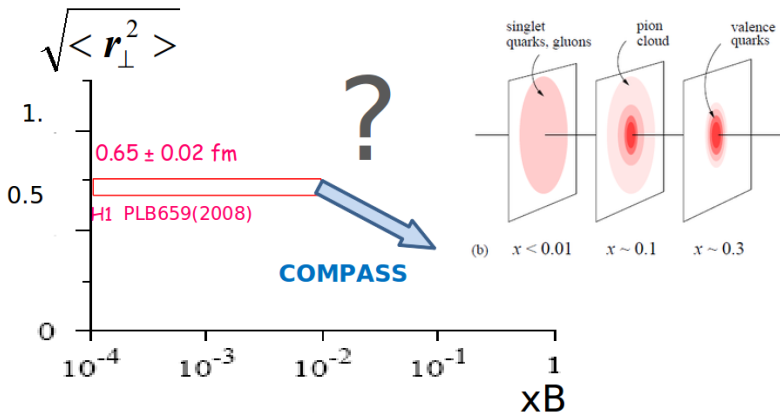$0.005 < x_{Bj} < 0.01$

$0.01 < x_{Bj} < 0.03$

$x_B > 0.03$
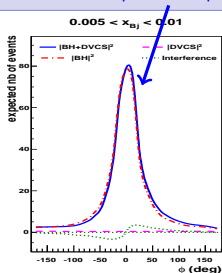
Ref. yield

Re,Im(T^{DVCS})

DVCS dominance

MC simulation for COMPASS without ECAL0

Missing DVCS acceptance w/o ECAL0

$$\sqrt{< r_\perp^2 >}$$

0.65 ± 0.02 fm

H1 PLB659(2008)

COMPASS

singlet quarks, gluons

pion cloud

valence quarks

(b) $x < 0.01$ $x \sim 0.1$ $x \sim 0.3$

xB

Transverse Size of the Nucleon

$$\sqrt{<r_\perp^2>}$$

0.65 ± 0.02 fm

H1 PLB659(2008)

COMPASS

singlet quarks, gluons

pion cloud

valence quarks

(b) $x < 0.01$ $x \sim 0.1$ $x \sim 0.3$

$$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$$
$$B(x_B) = 1/2 < r_\perp^2(x_B) >$$
$r_\perp \to$ **Tranverse size**
  of the Nucleon

Transverse Size of the Nucleon

Beam Charge and Spin **SUM**:

$$S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu Im(I)$$

Integration over ϕ and BH subtraction $\rightarrow d\sigma^{DVCS}/dt \sim \exp(-B|t|)$

$\sqrt{<r_\perp^2>}$

0.65 ± 0.02 fm

H1 PLB659(2008)

COMPASS

singlet quarks, gluons   pion cloud   valence quarks

(b) $x < 0.01$ $x \sim 0.1$ $x \sim 0.3$

$$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$$
$$B(x_B) = 1/2 < r_\perp^2(x_B) >$$
$r_\perp \rightarrow$ **Tranverse size of the Nucleon**

xB
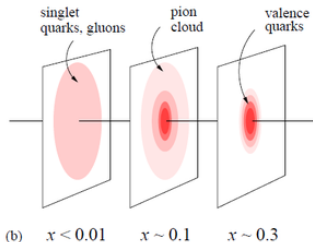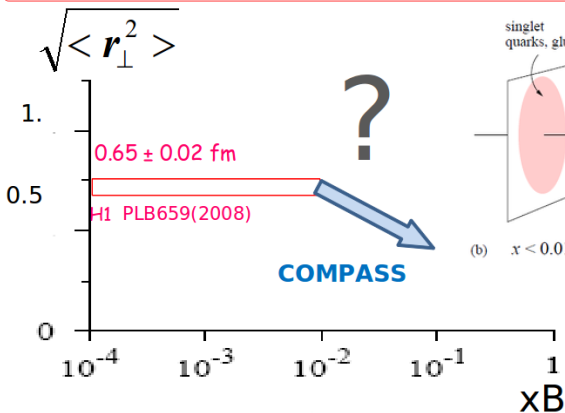
Transverse Size of the Nucleon

Beam Charge and Spin **SUM**:

$$S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu Im(I)$$

Integration over ϕ and BH subtraction $\rightarrow d\sigma^{DVCS}/dt \sim \exp(-B|t|)$

Inputs for projections:

- 160 GeV muon beam
- $L = 1222 pb^{-1}$
  2 years of data
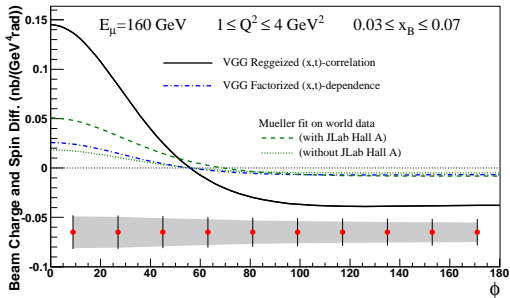 2.5 m LH$_2$ target
- $\epsilon_{global} = 10\%$

Ansatz at small x_B: $B(x_B) = B_0 + 2\alpha' ln(x_0/x_B)$

Accuracy $\geq 2.5\sigma$ if $\alpha' > 0.125$ and full ECALs

$$\mathrm{d}\sigma_{\mu\mathbf{p}\to\mu\mathbf{p}\gamma} = \mathrm{d}\sigma^{\mathbf{BH}} + \mathrm{d}\sigma^{\mathbf{DVCS}}_{\mathbf{unpol}} + \mathbf{P}_\mu\mathrm{d}\sigma^{\mathbf{DVCS}}_{\mathbf{pol}} + \mathbf{e}_\mu\mathbf{Re}(\mathbf{I}) + \mathbf{e}_\mu\mathbf{P}_\mu\mathbf{Im}(\mathbf{I})$$

Angular Dependence of $d\sigma$

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

Combine μ^+ and μ^- data with opposite beam polarizations

Inside plot:
E_μ=160 GeV $1 \le Q^2 \le 4$ GeV^2 $0.03 \le x_B \le 0.07$

— VGG Reggeized (x,t)-correlation
-·- VGG Factorized (x,t)-dependence

Mueller fit on world data
-- (with JLab Hall A)
··· (without JLab Hall A)

y-axis: Beam Charge and Spin Diff. (nb/(GeV^{4}rad))
x-axis: ϕ

$$\mathbf{D_{CS,U} \equiv d\sigma \mu^{+\downarrow} - d\sigma \mu^{-\uparrow}}$$
$$\propto \mathbf{c_0^{Int} + c_1^{Int} cos(\phi)}$$

$$\mathbf{c_{0,1}^{Int} \propto Re(F_1 \mathcal{H})}$$
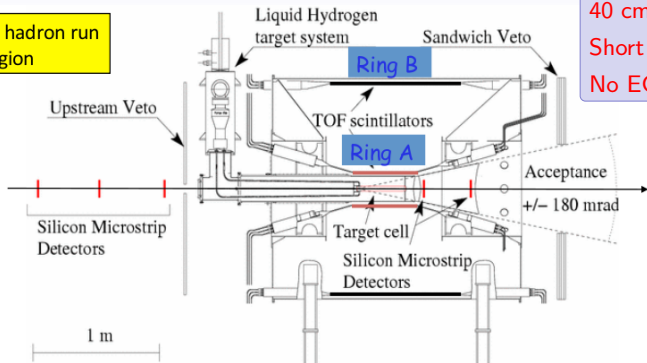
Inputs for projections:

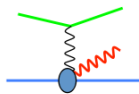- $L = 1222 pb^{-1}$
  2 years of data

- $\epsilon_{global} = 10\%$

$$\mathbf{Re\mathcal{H}(\xi, t) = P \int dx\ H(x, \xi, t)/(x - \xi)} \rightarrow \textbf{Exp. constrain to GPD H!}$$

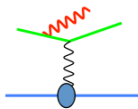Syst. error: 3% charge-dependent effect between μ^+ and μ^-

Compass hadron run
Target region

40 cm LH2 target
Short RPD
No ECAL0

Liquid Hydrogen target system
Sandwich Veto
Ring B
Upstream Veto
TOF scintillators
Ring A
Acceptance +/- 180 mrad
Silicon Microstrip Detectors
Target cell
Silicon Microstrip Detectors
1 m

DVCS

Bethe-Heitler

Selection of events :
- one vertex with µ and µ'
- no other charged tracks
- only 1 high energy photon (Δt<5ns)
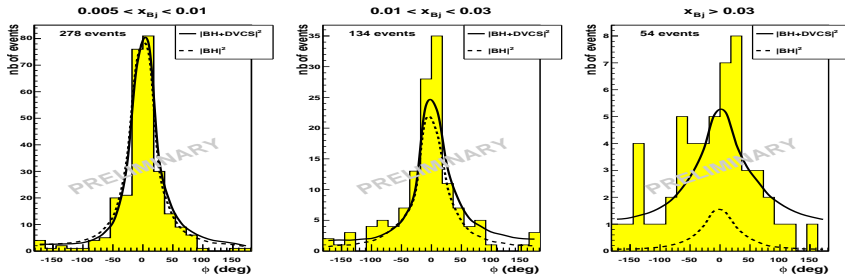- 1 proton in RPD with p < 1. GeV/c

2008: observation of exclusive single photon production

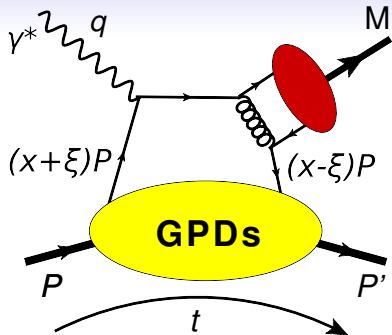confirmed $\epsilon_{global} \simeq 10\%$ assumed in simulations

2009: observation of BH and DVCS events

Comparison of MC simulation (solid & dashed lines) with data

MC yield normalized to low-x_B bin (where BH dominates)

Excess of data at $x_B > 0.03 \rightarrow$ sign for DVCS

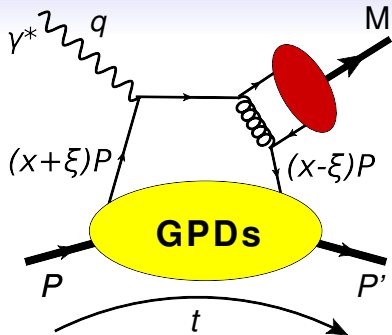# Hard Exclusive Meson Production

Cross section measurements:

- Pseudo-scalar: $\pi, \eta, .. \Rightarrow \tilde{H}$
- Vector meson: $\rho, \omega, \phi, .. \Rightarrow H$

Allow for flavour separation:

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

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

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

Hard Exclusive Meson Production

Cross section measurements:

- Pseudo-scalar: $\pi, \eta, .. \Rightarrow \tilde{H}$ & $\tilde{E}$
- Vector meson: $\rho, \omega, \phi, .. \Rightarrow H$ & E

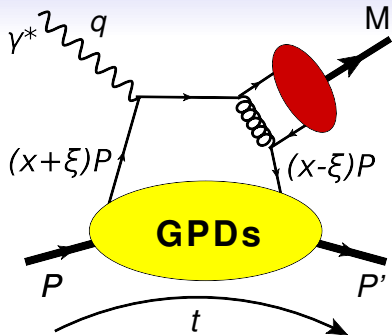Vector meson production from transversely polarized target:

- Asymmetry $\propto E/H$

Allow for flavour separation:

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

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

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

Hard Exclusive Meson Production

Cross section measurements:

- Pseudo-scalar: $\pi, \eta, .. \Rightarrow \tilde{H}$ & $\tilde{E}$
- Vector meson: $\rho, \omega, \phi, .. \Rightarrow H$ & E

Vector meson production from transversely polarized target:

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

Data without RPD collected with transv. pol. **p** and **d**:
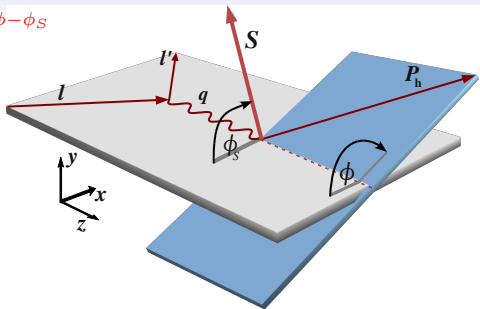
^{6}**LiD**: 2002-2004

NH$_3$: 2007 & 2010

HEMP: Transversely Polarized Target

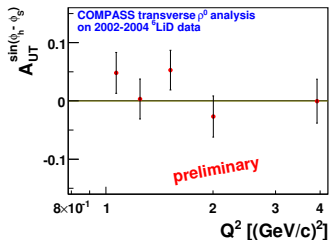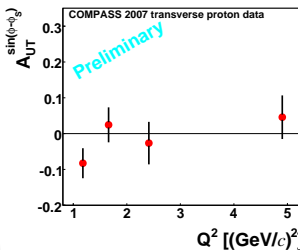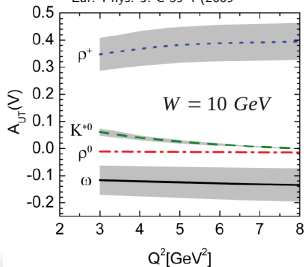Transverse target spin asymmetry: $A_{UT}^{\sin\phi-\phi_S}$

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

- $\mathcal{E}$ and $\mathcal{H}$ are weighted sums of
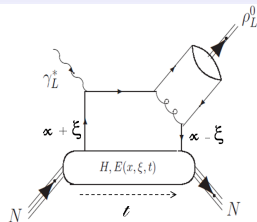
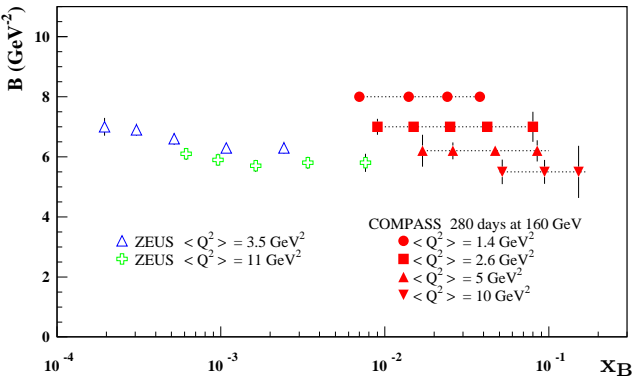 GPDs $E^{q,g}$ and $H^{q,g}$

  $\rightsquigarrow$ provide access to GPD E

Goloskokov and Kroll
Eur. Phys. J. C 59 4 (2009

Tranverse Imaging with Vector Mesons

$d\sigma^{DVMP}/dt \sim \exp(-B|t|)$ measurement @ COMPASS-II

ZEUS $<Q^2> = 3.5$ GeV^2
ZEUS $<Q^2> = 11$ GeV^2

COMPASS 280 days at 160 GeV
● $<Q^2> = 1.4$ GeV^2
■ $<Q^2> = 2.6$ GeV^2
▲ $<Q^2> = 5$ GeV^2
▼ $<Q^2> = 10$ GeV^2

Inputs for projections:

- $L = 1222 \text{pb}^{-1}$
  2 years of data
  2.5 m LH$_2$ target

- $\epsilon_{global} = 10\%$

We are sensitive to the Nucleon size + the transv. meson size
Large statistics $\rightarrow$ **B** measured as function of both x_B and Q^2
$Q^2 = 1$ GeV^2 $B \sim 8$ GeV^{-2}
$Q^2 = 10$ GeV^2 $B \sim 5.5$ GeV^{-2}

Conclusions and Outlook

$\rightarrow$ COMPASS-II will investigate quark GPDs through DVCS

- **Intermediate x_B regime** not accessible to present or planned facilities in the near future

- Two beam charges available with opposite polarizations
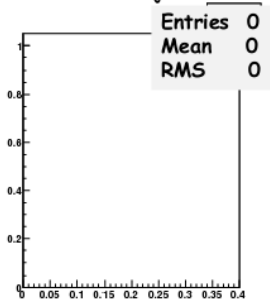 **access to real and imaginary parts of DVCS amplitude**

  Constrain **GPD H** through ϕ dependence of $\mathbf{D_{CS,U}}$ and $\mathbf{S_{CS,U}}$

- Nucleon **transversal dimension** as function of $\mathbf{x_B}$
  ("Nucleon Tomography")

$\rightarrow$ Complementary information from exclusive meson production

$\rightarrow$ In a second phase, constrain of **GPD E** by using a transversely polarized target

Backup Slides

π^0 Signal in 2009 DVCS Test Data
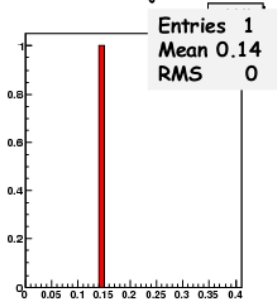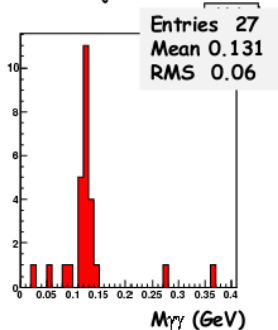

A signal around the π^0 mass is observed in the 2009 data after applying all exclusivity cuts.   The analysis work is in progress. . .