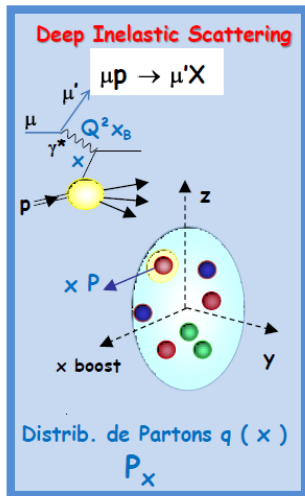# GPD Physics With Polarized Muon Beams at COMPASS-II

A. Ferrero (CEA-Saclay/IRFU/SPhN)
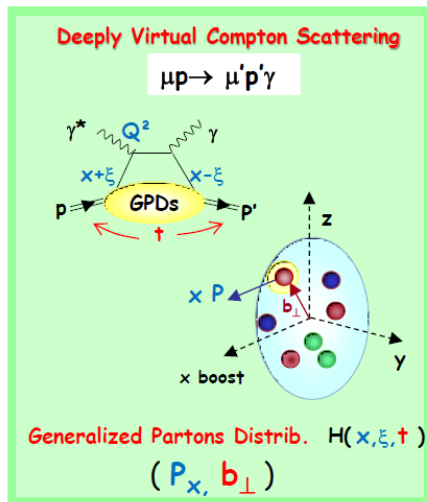
DIFFRACTION2012

Lanzarote, 11/09/2012

From PDFs to GPDs
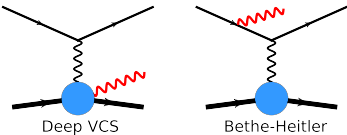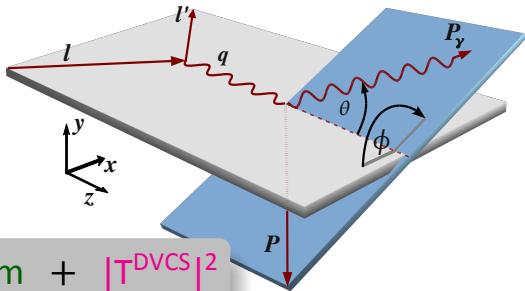

Deep Inelastic Scattering

$\mu p \rightarrow \mu'X$

Distrib. de Partons q (x)

P_x

Deeply Virtual Compton Scattering

$\mu p \rightarrow \mu'p'\gamma$

Generalized Partons Distrib. H(x,ξ,t)

$(P_x, b_\perp)$

Observation of the Nucleon Structure in 1 dimension

in 1+2 dimensions

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

Deep VCS

Bethe-Heitler

$$d\sigma \propto |T^{BH}|^2 + \text{Int. Term} + |T^{DVCS}|^2$$

$0.005 < x_{Bj} < 0.01$ $0.01 < x_{Bj} < 0.03$ $x_{Bj} > 0.03$

MC simulation for COMPASS without ECAL0

Missing DVCS acceptance w/o ECAL0
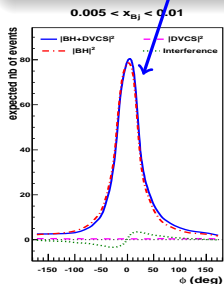
Almost pure BH
→ Ref. yield
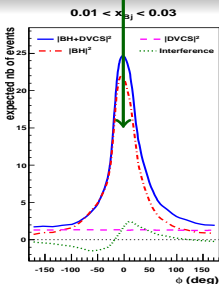
DVCS through int. term
→ Re,Im(T^{DVCS})
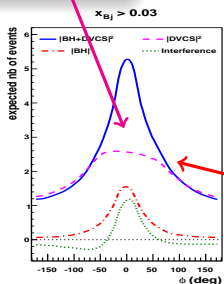
DVCS dominates
→ $d\sigma^{DVCS}/dt$ (transv. imaging)

DVCS: What Can We Learn?

Phase 1: Polarized beam, unpol. target

$\overline{\mu'}$

$\overline{\mu}$

γ^* q q' γ

$(x+\xi)P$ $(x-\xi)P$

GPDs

P P'

t

DVCS dominance at large x_B
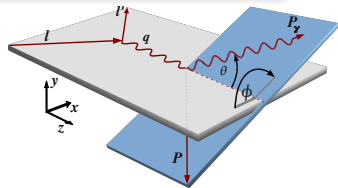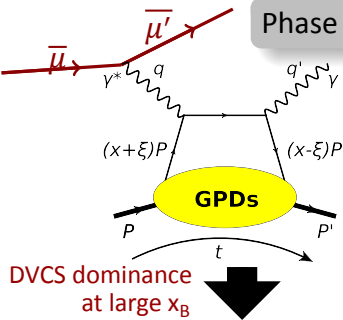
BH/DVCS interf. at intermediate x_B

x_B-dependent transv. size of nucleon

singlet quarks, gluons

pion cloud

valence quarks

longitud.

transverse

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

xP

b
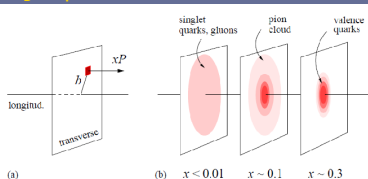
$\mathbf{r}_\perp$ parameter from slope of $d\sigma^{DVCS}/dt$

Interference between BH and DVCS

Bethe-Heitler $+$ Deep VCS $\rightarrow$ "Boost" of DVCS through int. term
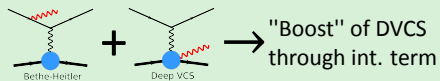
Measurement of $\mathrm{Re}\mathcal{H}(\xi, t)$ and $\mathrm{Im}\mathcal{H}(\xi, t)$ via ϕ-modulation of cross section
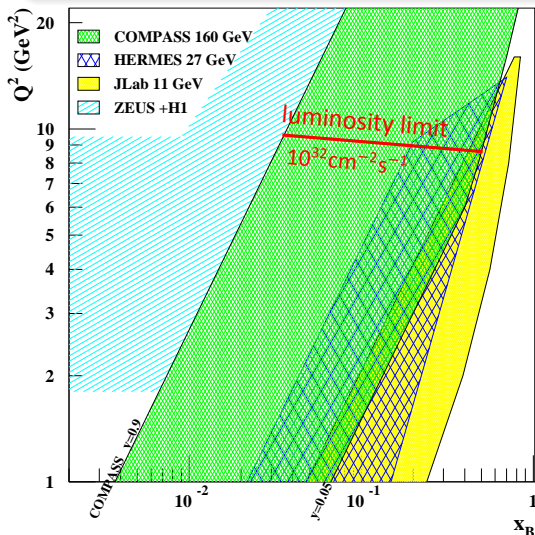
$$\mathbf{Re}\mathcal{H}(\xi, t) = P \int dx\, H(x, \xi, t)/(x - \xi)$$

$$\mathbf{Im}\mathcal{H}(\xi, t) = H(x = \xi, \xi, t)$$

Exp. constrain to GPD H
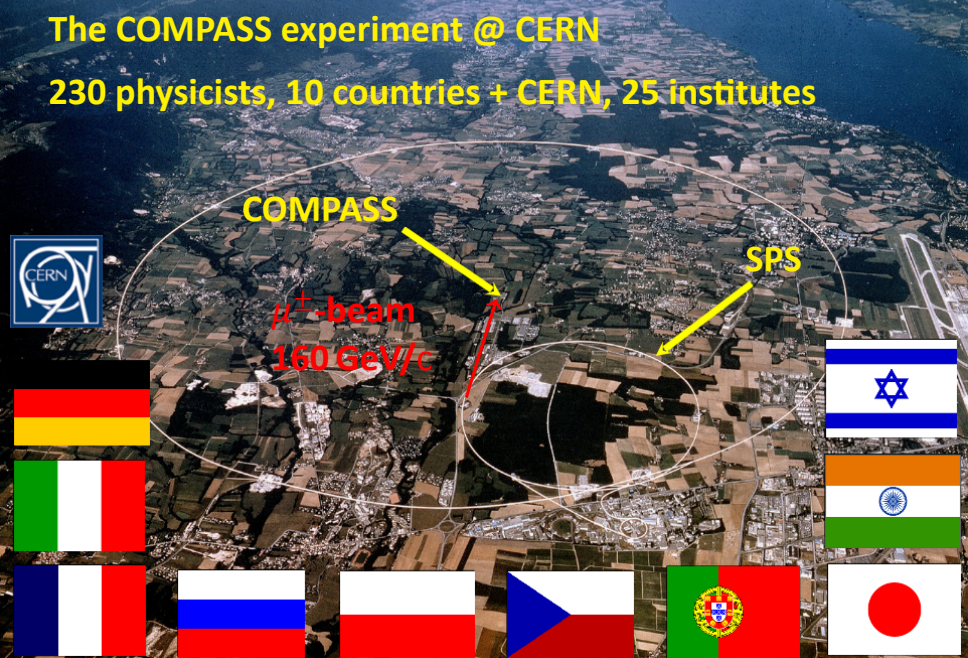
What Makes COMPASS Unique?

COMPASS covers the unexplored region between collider (H1+Zeus) and low-energy fixed target (Hermes+JLab) experiments

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

- coverage of intermediate x_B
  - → low x_B: **pure BH**
    useful for normalization
  - → high x_B: **DVCS predominance**
- ⤳ **unexplored region between**
  ZEUS+H1 and HERMES+JLab
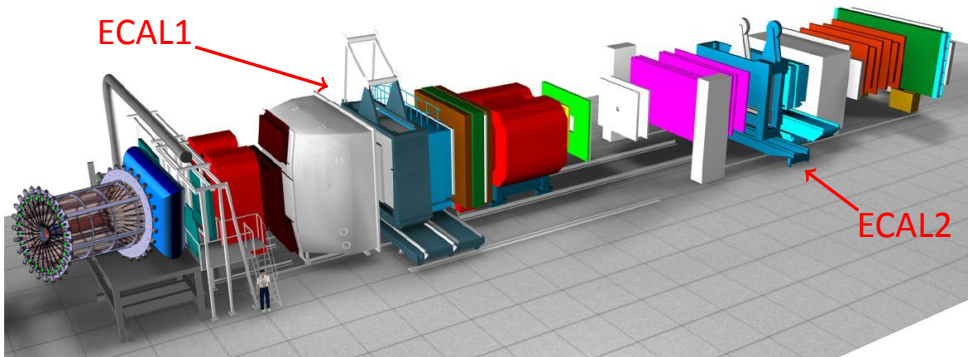
The COMPASS experiment @ CERN

230 physicists, 10 countries + CERN, 25 institutes

COMPASS

SPS

$\mu^{\pm}$-beam
160 GeV/c

The COMPASS set-up for the GPD program
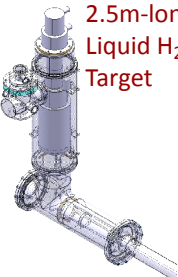

ECAL1

ECAL2

The COMPASS set-up for the GPD program

ECAL1

ECAL2

Main new equipments

2.5m-long
Liquid H_2
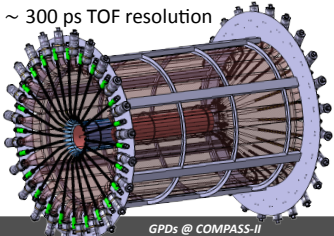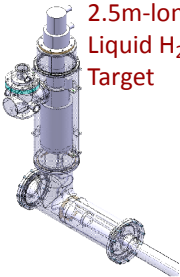Target

The COMPASS set-up for the GPD program

ECAL1

ECAL2

Main new equipments

2.5m-long Liquid H$_2$ Target

Target TOF System
24 inner & outer scintillators
1 GHz SADC readout
~ 300 ps TOF resolution

The COMPASS set-up for the GPD program

ECAL1

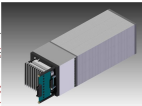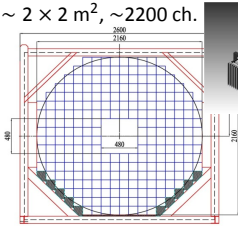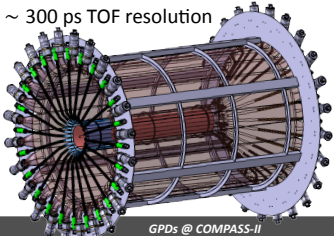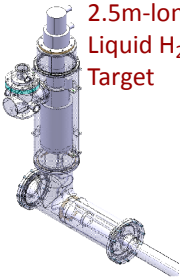ECAL2

Main new equipments

2.5m-long Liquid H₂ Target
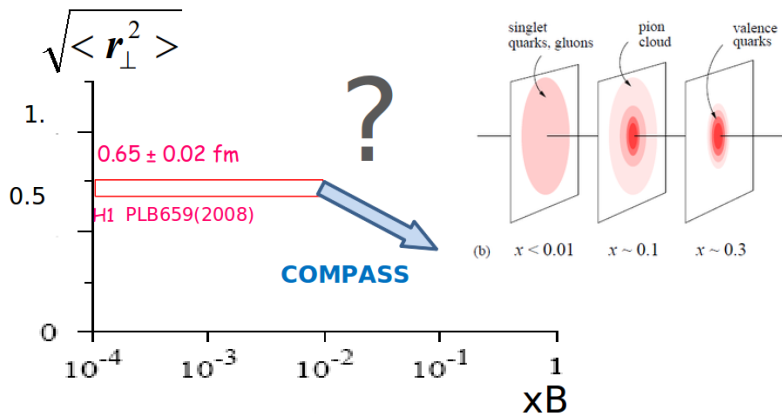
Target TOF System
24 inner & outer scintillators
1 GHz SADC readout
~ 300 ps TOF resolution

ECAL0 Calorimeter
Shashlyk modules + MAPD readout
~ 2 × 2 m², ~2200 ch.

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

x_B

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 $\rightarrow$ **$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$**
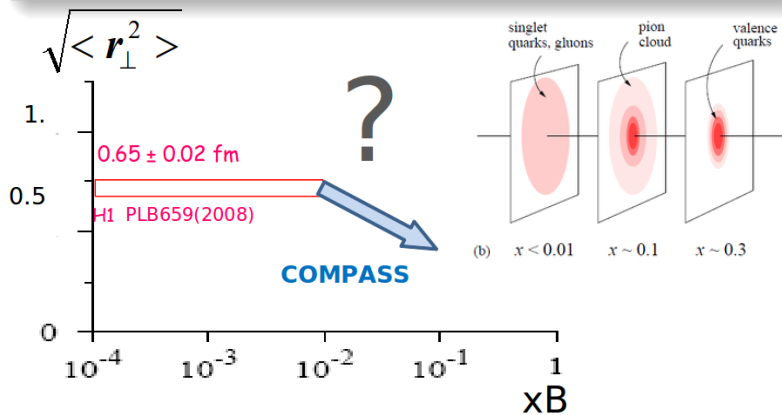
Transverse Size of the Nucleon

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singlet quarks, gluons   pion cloud   valence quarks

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COMPASS

0.65 ± 0.02 fm

H1 PLB659(2008)

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

xB

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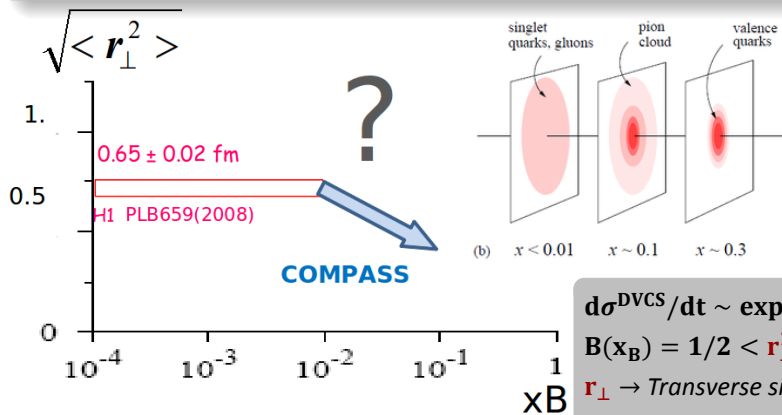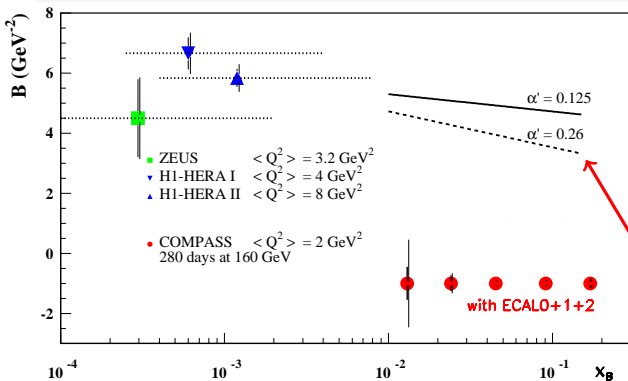
Transverse Size of the Nucleon

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

$\leftarrow$ 40 weeks of data

2.5 m LH$_2$ target

ϵ_{global} = 10%

L = 1222**pb^{-1}**
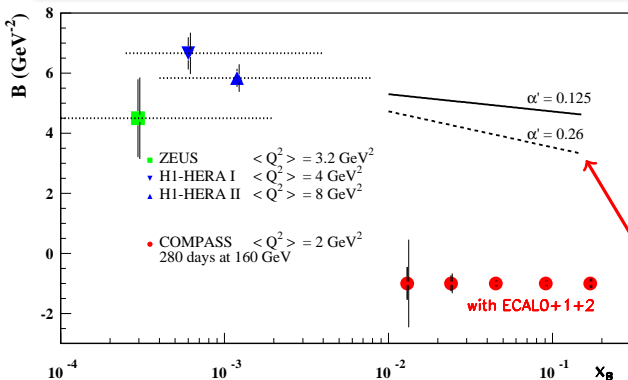
Ansatz at small x_B:
$B(x_B) \simeq B_0 + 2\alpha' \ln(x_0/x_B)$

Transverse Size of the Nucleon

Beam Charge and Spin **SUM**:

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

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

if $\alpha' > 0.125 \rightarrow$ accuracy $> 2.5\sigma$

Cross-section Difference

Beam Charge and Spin **DIFFERENCE**:

$$D_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) - d\sigma(\mu^{-\rightarrow}) \propto P_\mu d\sigma_{pol}^{DVCS} + e_\mu Re(I) \propto c_0^{Int} + c_1^{Int}\cos(\phi)$$

$$c_{0,1}^{Int} \propto Re(F_1 \mathcal{H}); \quad Re\mathcal{H}(\xi, t) = P \int dx\, H(x, \xi, t)/(x - \xi)$$
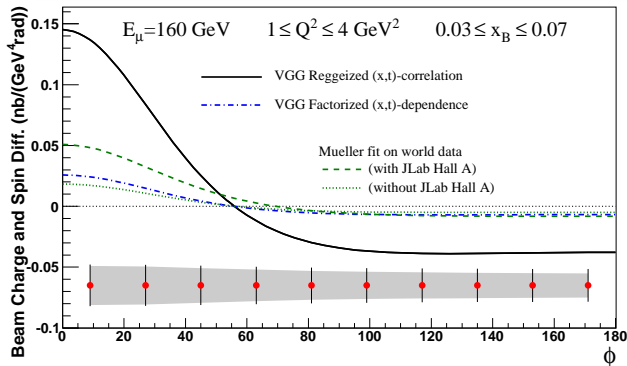
Cross-section Difference

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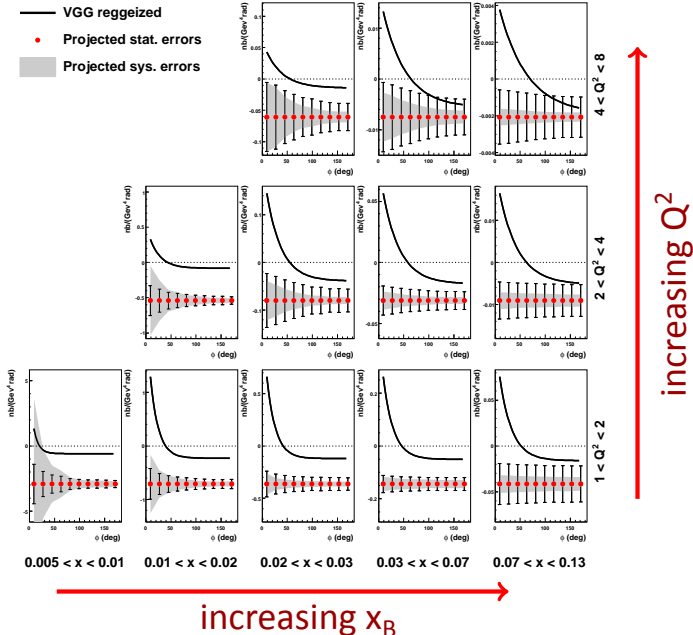

← 40 weeks of data

2.5 m LH_2 target

ϵ_{global} = 10%

L = 1222$\mathbf{pb^{-1}}$

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

Exp. constrain to GPD **H**

Cross-section Difference - All Bins

- **VGG reggeized**
- **Projected stat. errors**
- **Projected sys. errors**

increasing Q^2

$4 < Q^2 < 8$

$2 < Q^2 < 4$

$1 < Q^2 < 2$

0.005 < x < 0.01   0.01 < x < 0.02   0.02 < x < 0.03   0.03 < x < 0.07   0.07 < x < 0.13

increasing x_B
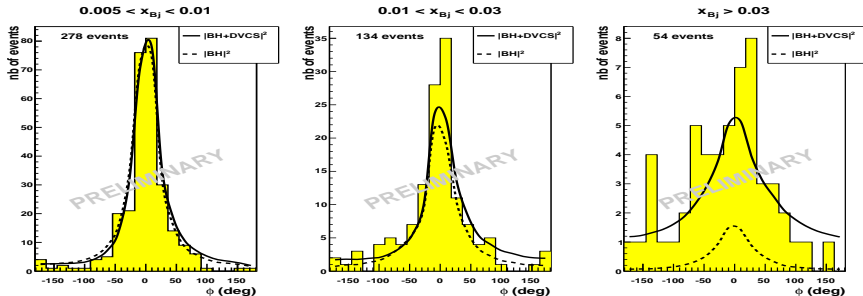
2008-9 DVCS Test - Results

2008: observation of exclusive single photon production

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

2009: observation of BH and DVCS events

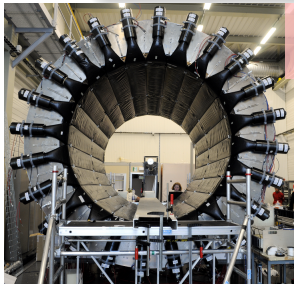Comparison of MC simulation (solid & dashed lines) with data

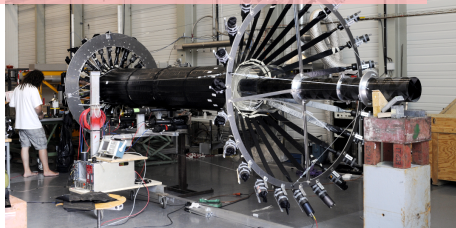*MC yield normalized to low-x_B bin (where BH dominates)*

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

A DVCS pilot run will start in October 2012

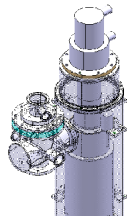> 2 weeks of beam time foreseen
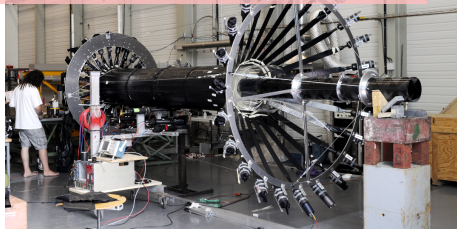
Full Proton Recoil Detector
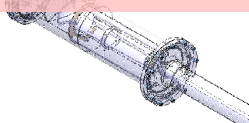
A DVCS pilot run will start in October 2012

> 2 weeks of beam time foreseen

Full Proton Recoil Detector
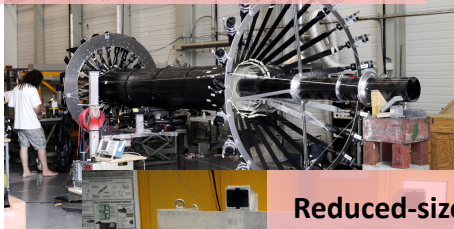
Full-size LH2 target

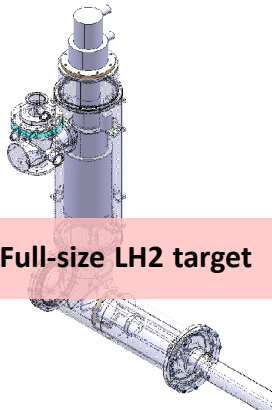A DVCS pilot run will start in October 2012
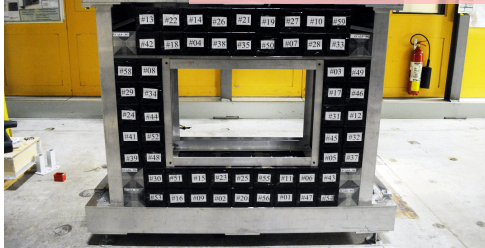
> 2 weeks of beam time foreseen

Full Proton Recoil Detector

Reduced-size ECAL0

Full-size LH2 target
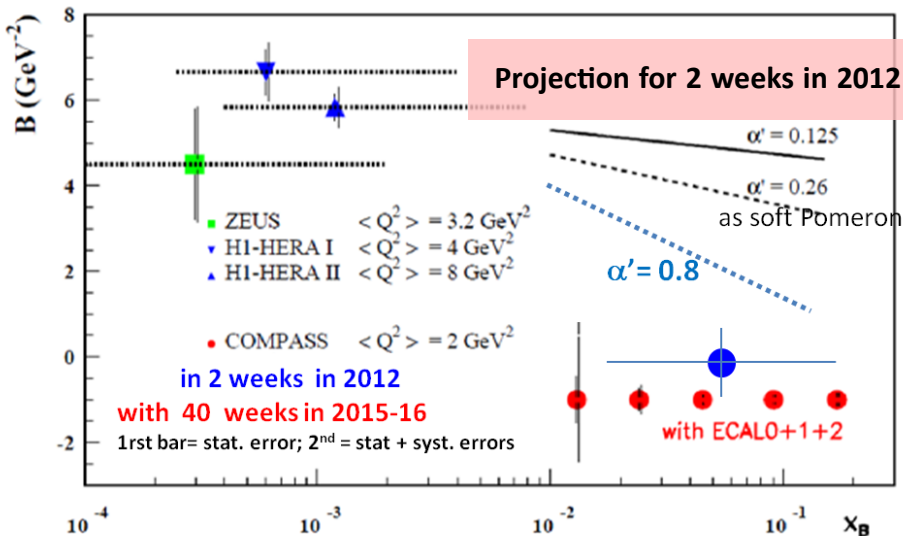
A DVCS pilot run will start in October 2012

> 2 weeks of beam time foreseen

Projection for 2 weeks in 2012

Conclusions and Outlook

→ 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
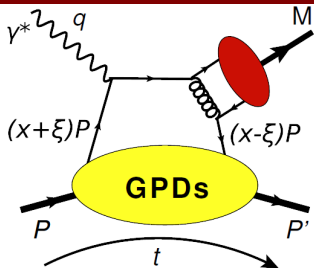 **access to real and imaginary parts of DVCS amplitude**

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

- Nucleon *transversal dimension* as function of x_B
  (``Nucleon Tomography'')

→ Complementary information from exclusive meson production
  → *See P.Sznajder talk tomorrow afternoon*

→ New pilot data to be collected starting from end of October -
  more than 2 weeks expected

→ In a second phase, constrain of *GPD E* by using a transversely
  polarized target

Backup Slides

γ^* q M

$(x+\xi)P$ $(x-\xi)P$

GPDs

P P'

t

Cross section measurements:
- Pseudo-scalar: π, η, ... $\Rightarrow$ $\tilde{\mathbf{H}}$ & $\tilde{\mathbf{E}}$
- Vector meson: ρ, ω, ϕ... $\Rightarrow$ **H** & **E**

Allows for flavor separation:

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

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

$E\phi \; = \qquad -1/3 \, E^s - 1/8 \, E^g$

$\rho : \omega : \phi \; \sim \; 9 : 1 : 2$

(at large Q^2)

Presently studied at COMPASS without RPD

- Vector meson production from

  transversely polarized target asymmetry

  $\Rightarrow$ **E/H**

γ^* q M

$(x+\xi)P$ $(x-\xi)P$

GPDs

P P'

t

Allows for flavor separation

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

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

$E\phi = -1/3 \, E^s - 1/8 \, E^g$

- Vector meson production with

  transversely polarized target asymmetry
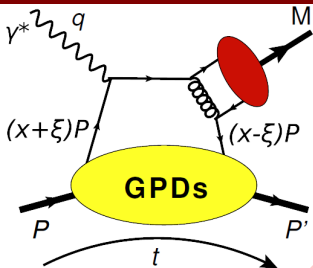
  $\Rightarrow$ **E/H**

Cross section measurements:

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

$\rho : \omega : \phi \sim 9 : 1 : 2$

(at large Q^2)

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