8th Workshop of the APS Topical Group on Hadronic Physics

GHP 2019

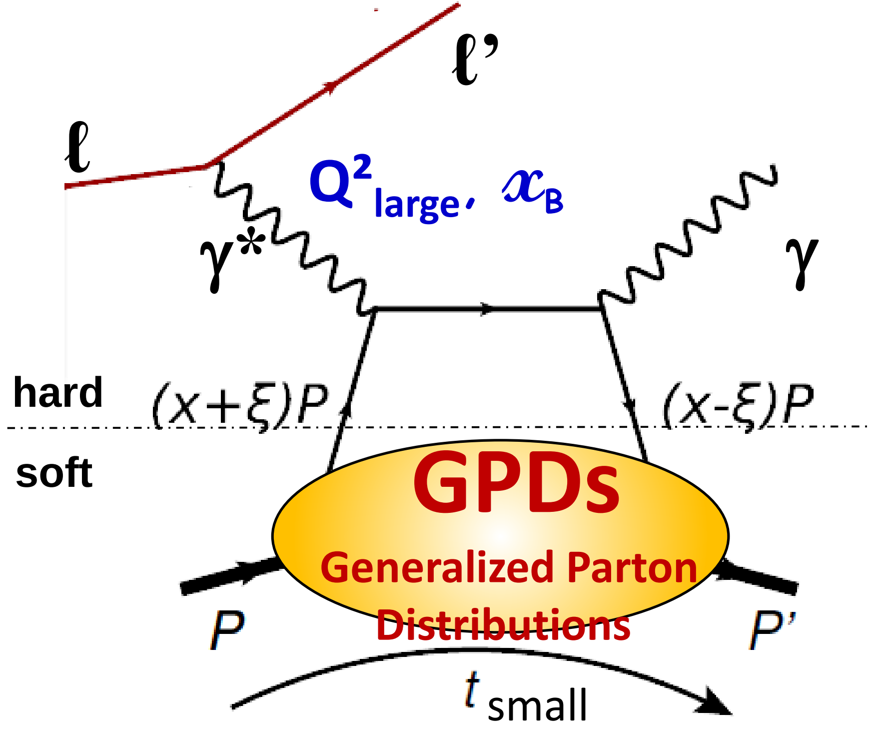
APRIL 10-12, 2019 • DENVER, CO

# GPD at COMPASS at CERN

## 1- DVCS
## 2- HEMP


Nicole d’Hose – CEA – Université Paris-Saclay

# Deeply virtual Compton scattering (DVCS)




**D. Mueller** *et al*, Fortsch. Phys. 42 (1994)
**X.D. Ji**, PRL 78 (1997), PRD 55 (1997)
**A. V. Radyushkin**, PLB 385 (1996), PRD 56 (1997)

DVCS: **ℓp→ ℓ’ p’ γ**
the golden channel
because it interferes with
the Bethe-Heitler process

also meson production
**ℓp→ ℓ’ p’ π, ρ, ω** or **ϕ** or **J/ψ...**

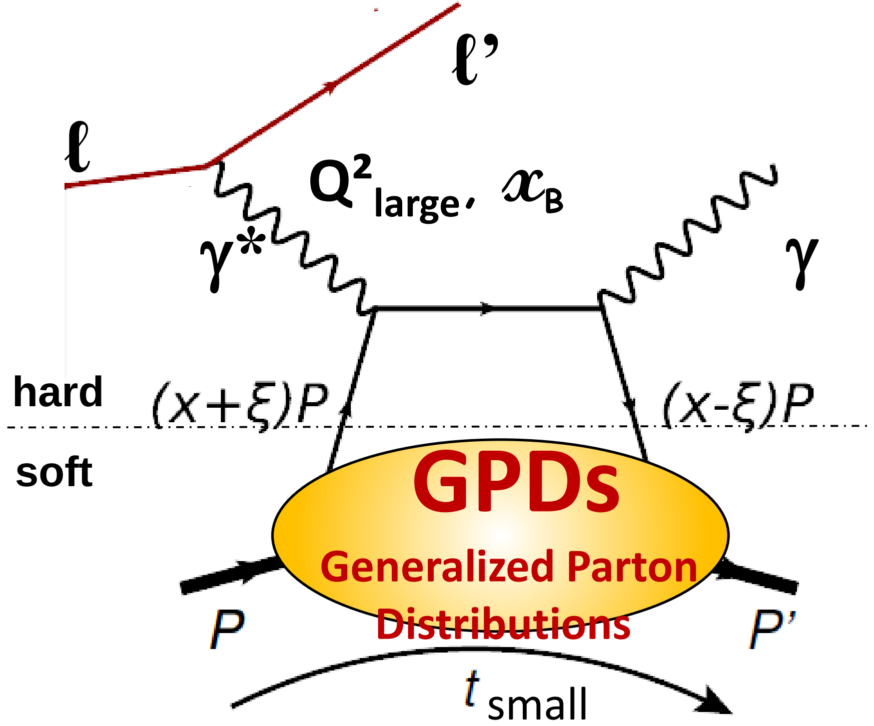
The GPDs depend on the following variables:

- x: average long. momentum
- ξ: long. mom. difference
- t: four-momentum transfer
  related to $b_\perp$ via Fourier transform

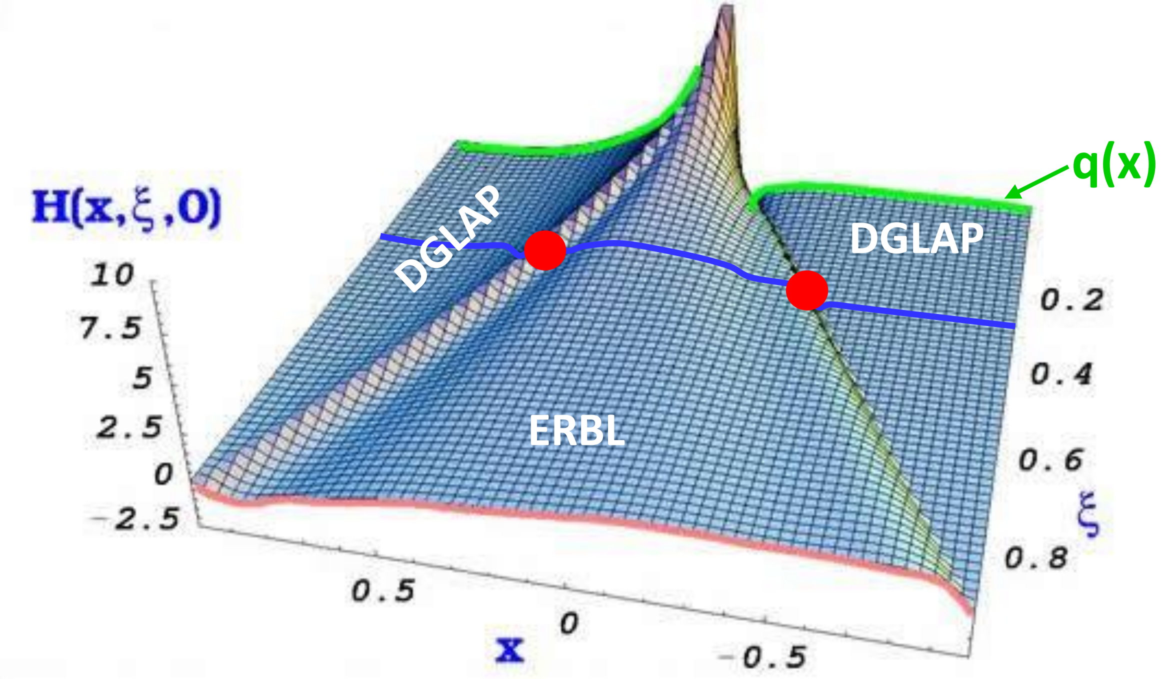
The variables measured in the experiment:

$E_\ell$, $Q^2$, $x_B \sim 2\xi/(1+\xi)$,
t (or $\theta_{\gamma^*\gamma}$) and ϕ (ℓℓ’ plane/γγ* plane)

# Deeply virtual Compton scattering (DVCS)




From Goeke, Polyakov, Vanderhaeghen, PPNP47 (2001)




The amplitude DVCS at LT & LO in $\alpha_S$ (GPD **H**) :

Real part | Imaginary part

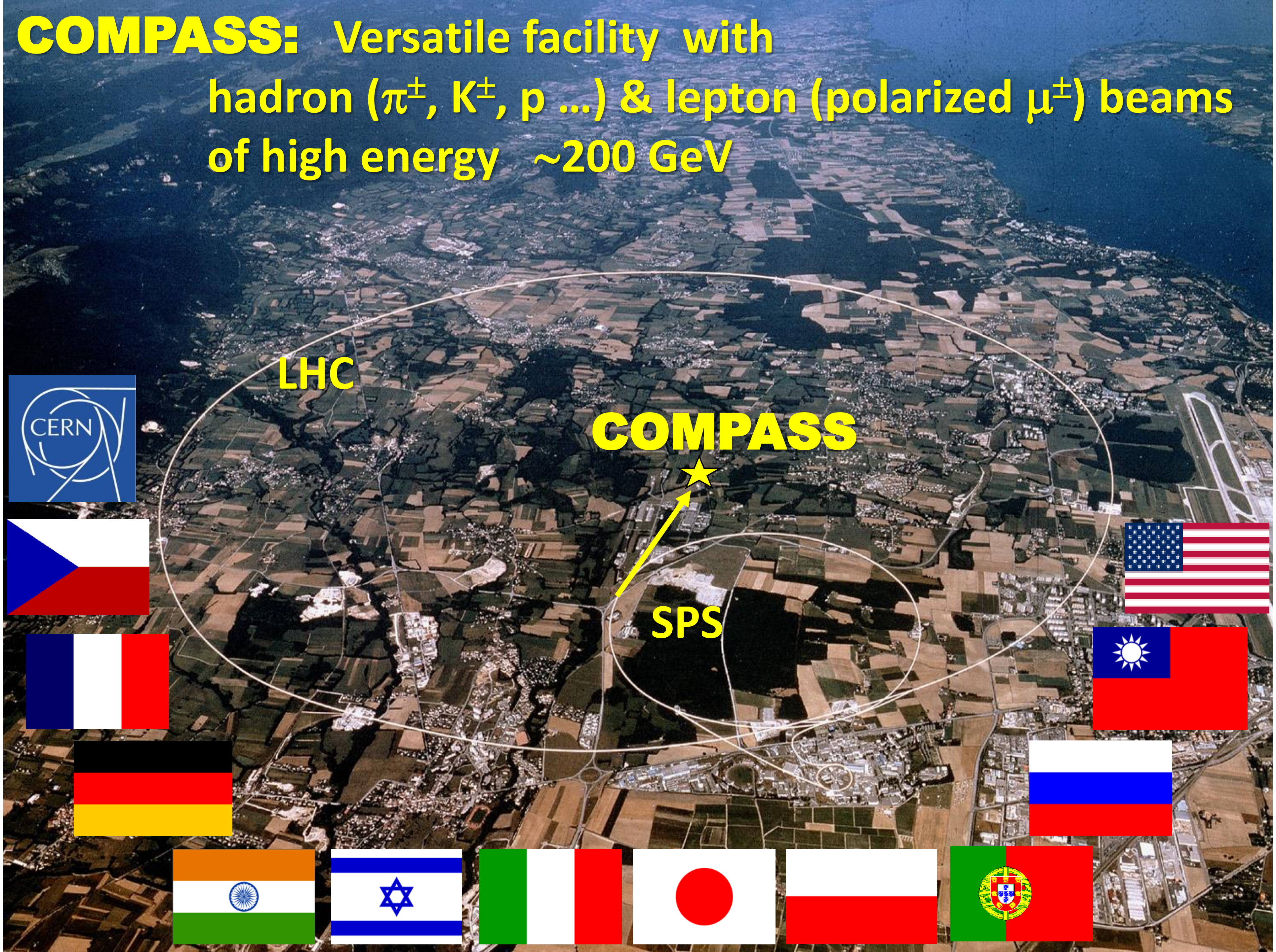
$$\mathcal{H} \underset{t,\,\xi\ \text{fixed}}{=} \int_{-1}^{+1} dx\, \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx\, \frac{H(x,\xi,t)}{x-\xi} - i\,\pi\, H(x \pm \xi, x, t)$$

In an experiment we measure

Compton Form Factor $\mathcal{H}$

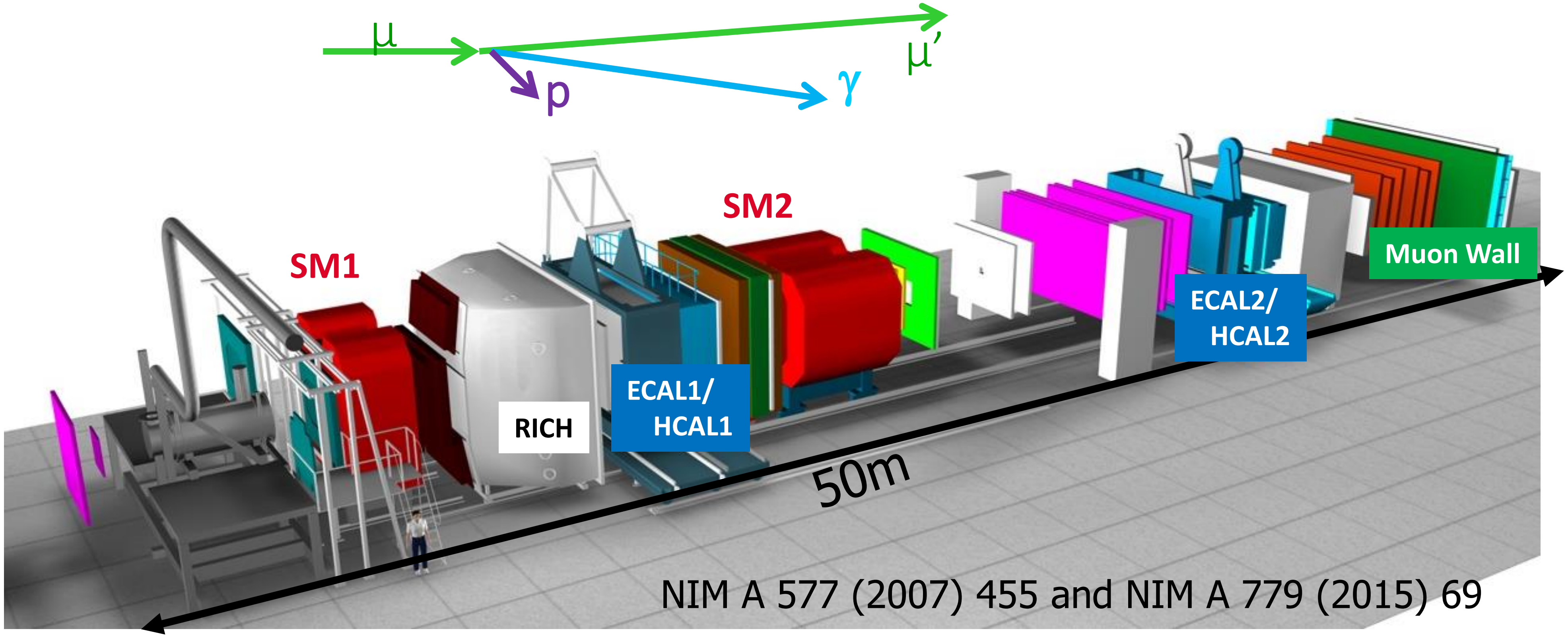
$$\mathcal{R}e\mathcal{H}(\xi,t) = \int dx\, \frac{Im\mathcal{H}(x,t)}{x-\xi} + D(t)$$

# COMPASS: Versatile facility with hadron ($\pi^{\pm}$, $K^{\pm}$, p …) & lepton (polarized $\mu^{\pm}$) beams of high energy ~200 GeV



# The DVCS experiment at COMPASS

**DVCS :** $\mu\ p \rightarrow \mu'\ p\ \gamma$



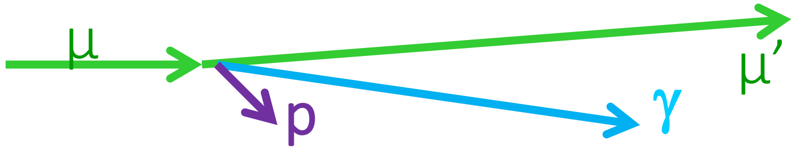

Two stage magnetic spectrometer for **large angular & momentum acceptance**

Particle identification with:

- Ring Imaging Cerenkov Counter
- Electromagnetic calorimeters (**ECAL1** and **ECAL2**)
- Hadronic calorimeters
- Hadron absorbers

# The DVCS experiment at COMPASS

**DVCS :** $\mu\ p \rightarrow \mu'\ p\ \gamma$




New equipements:

➢ **2.5m LH2 target**

➢ **4m ToF Barrel CAMERA**

24 inner & outer scintillators separated by ~1m

1 GHz SADC readout, 330ps ToF resolution

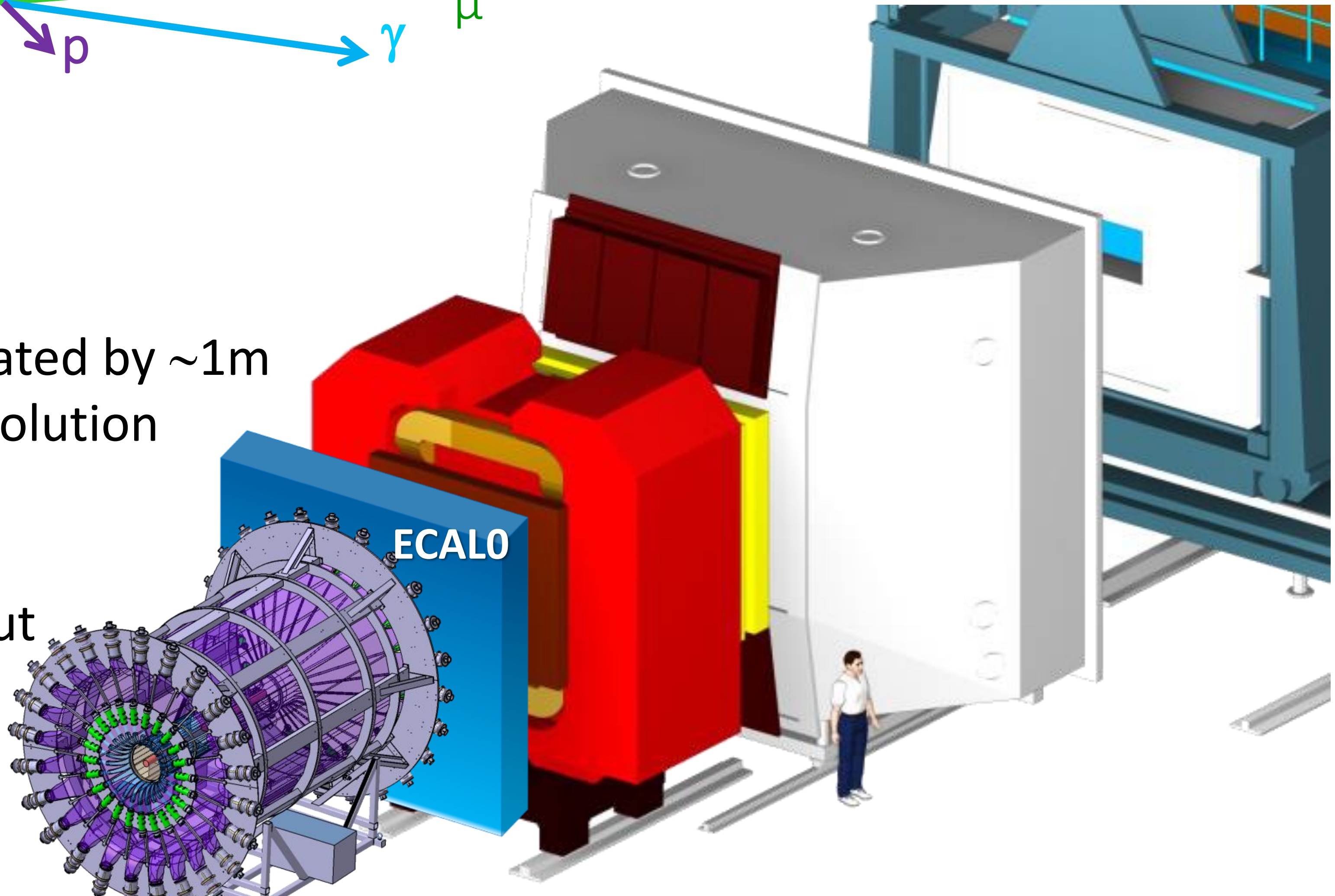
➢ **ECAL0 : 2 × 2 m2**

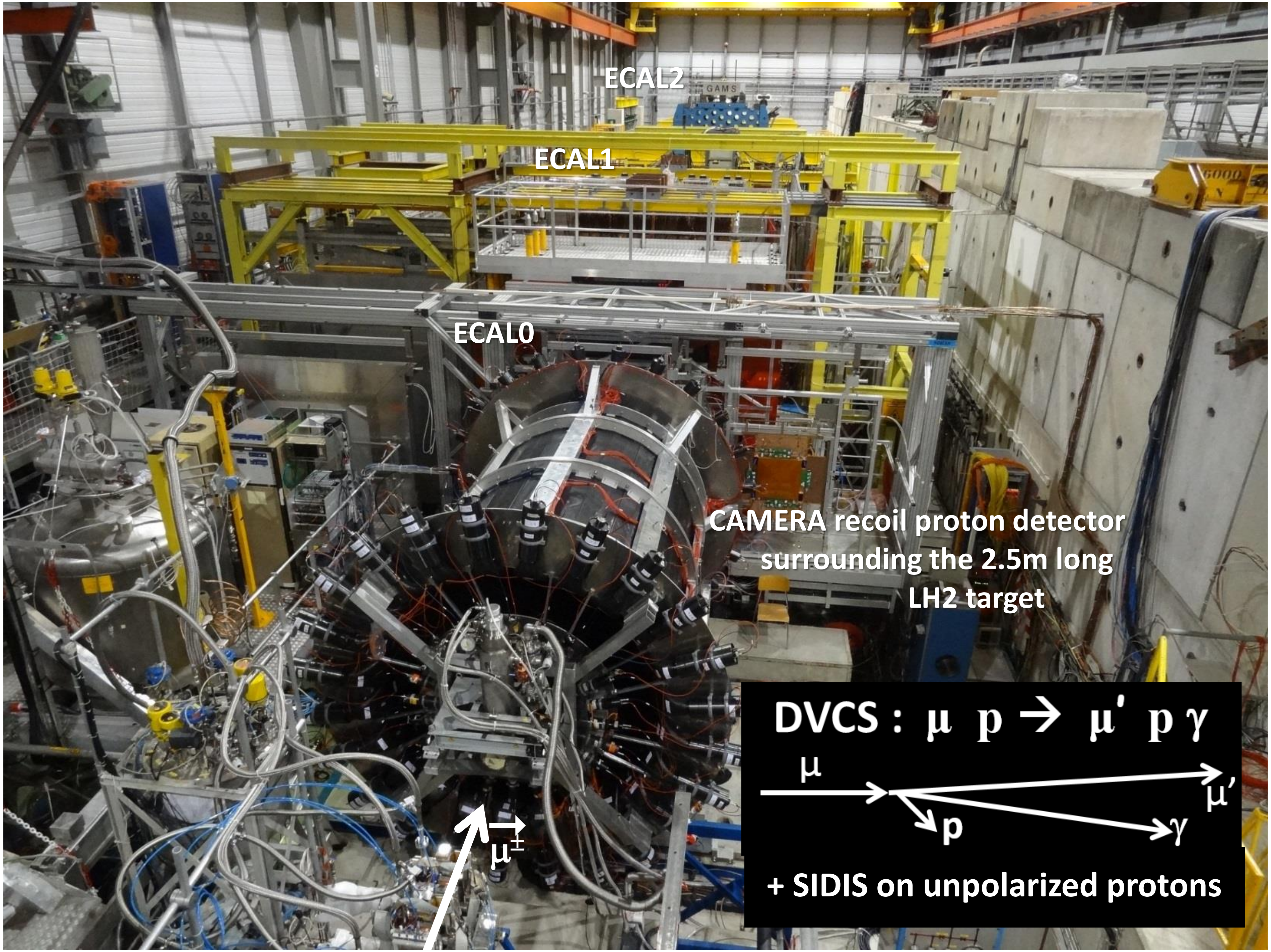
Shashlyk modules + MAPD readout

one module is made of

9 cells ($4 \times 4\ cm^2$)

= 194 modules or 1746 cells






2012: 1 month pilot run

2016 -17: 2 x 6 months data taking

# COMPASS 2012 Selection of exclusive evts with recoil detection

Comparison between the observables given by the spectro or by CAMERA

$x_{Bj} > 0.03$ $10 < \upsilon < 32$GeV
with $\pi^0$ contamination

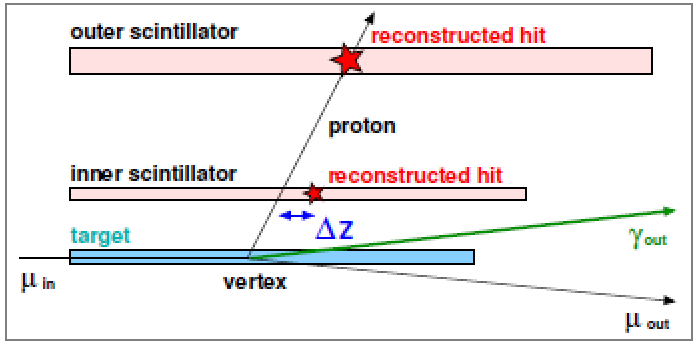
## DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$

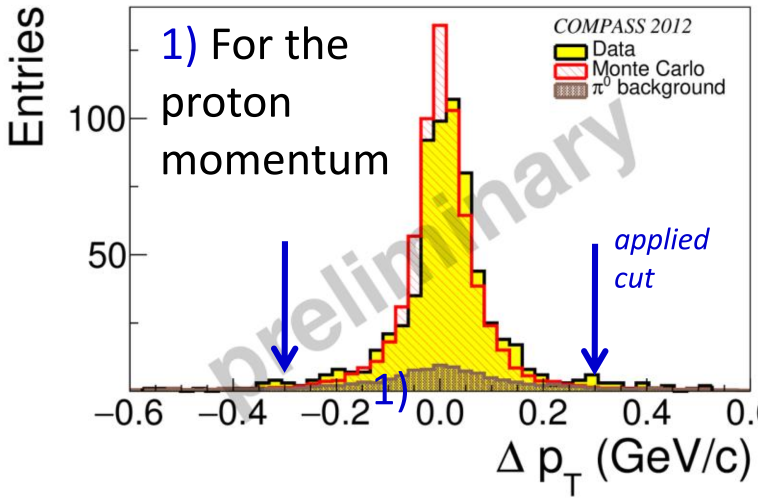
1) $\Delta p_T = p_T^{cam} - p_T^{spec}$

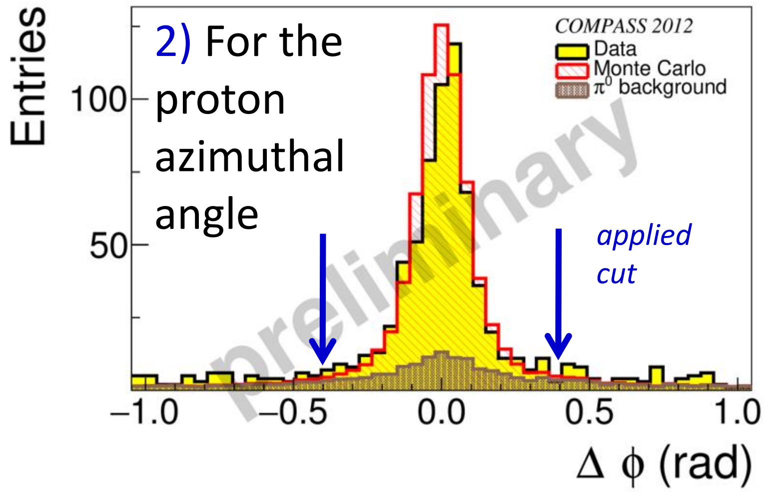
2) $\Delta \varphi = \varphi^{cam} - \varphi^{spec}$

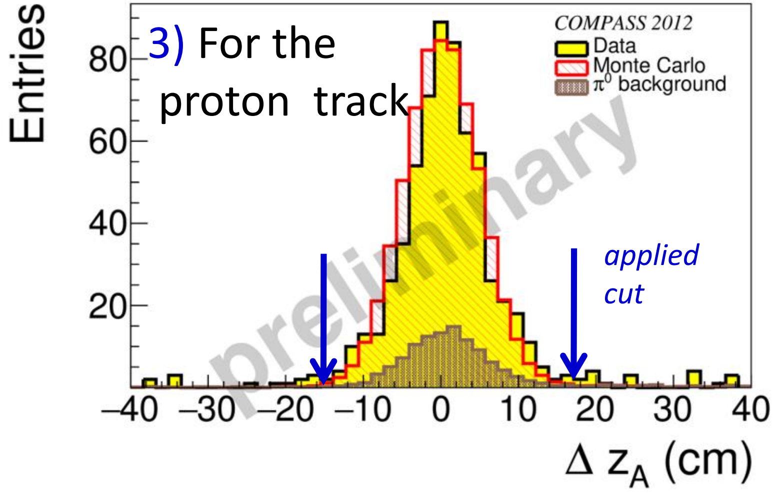
3) $\Delta z_A = z_A^{cam} - z_A^{Z_B \text{ and vertex}}$

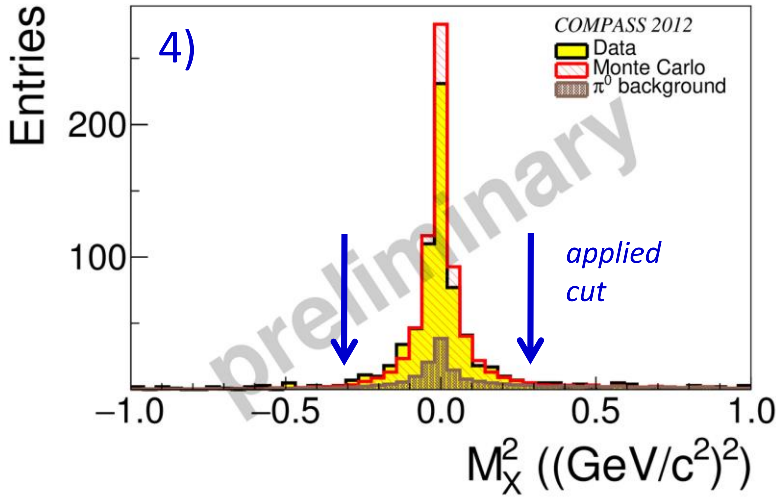
4) $M^2_{X=0} = (p_{\mu_{in}} + p_{p_{in}} - p_{\mu_{out}} - p_{p_{out}} - p_{\gamma})^2$



# COMPASS 2012 $\pi^0$ background estimation

$\pi^0$ are one of the main background sources for excl. photon events.

Two possible case:

- **Visible** (both $\gamma$ detected ➔ subtracted)

  the DVCS photon after all exclusivity cuts is combined with all detected photons below the DVCS threshold: 4,5,10 GeV in ECAL0, 1, 2

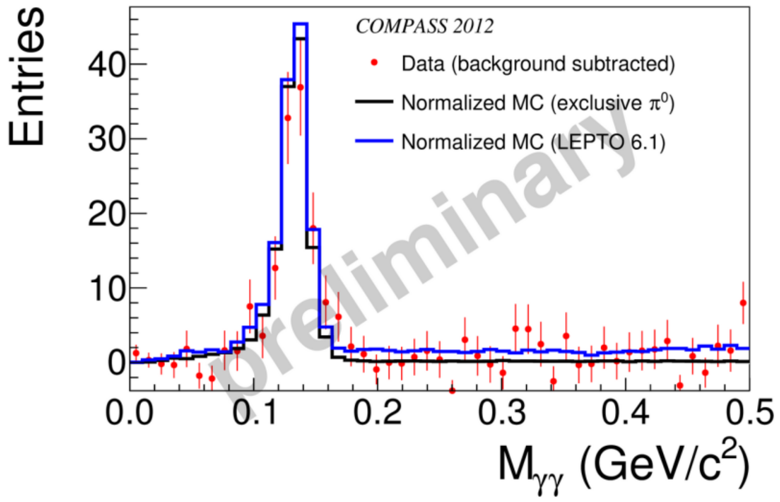
- **Invisible** (one $\gamma$ lost ➔ estimated by MC)

  ➢ **Semi-inclusive LEPTO 6.1**

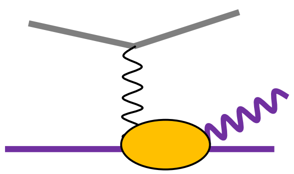
  ➢ **Exclusive HEPGEN $\pi^0$** (Goloskokov-Kroll model)

Comparing the two components to the data allows the determination of their relative normalisation. The sum of the 2 components is normalized to the visible $\pi^0$ contamination in the $M_{\gamma\gamma}$ peak

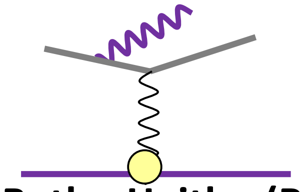
Visible leaking $\pi^0$ in the data



# COMPASS 2012 DVCS cross section at E$\mu$=160 GeV

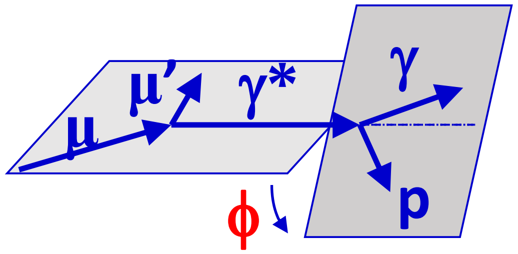


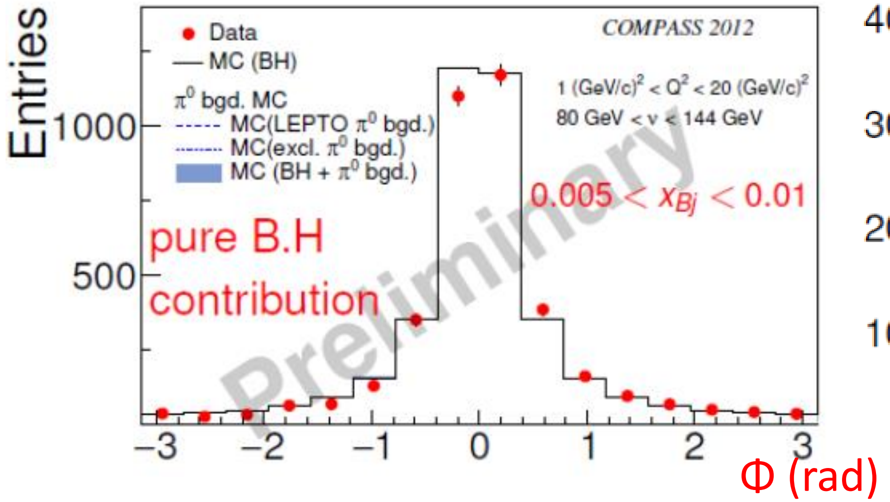
DVCS

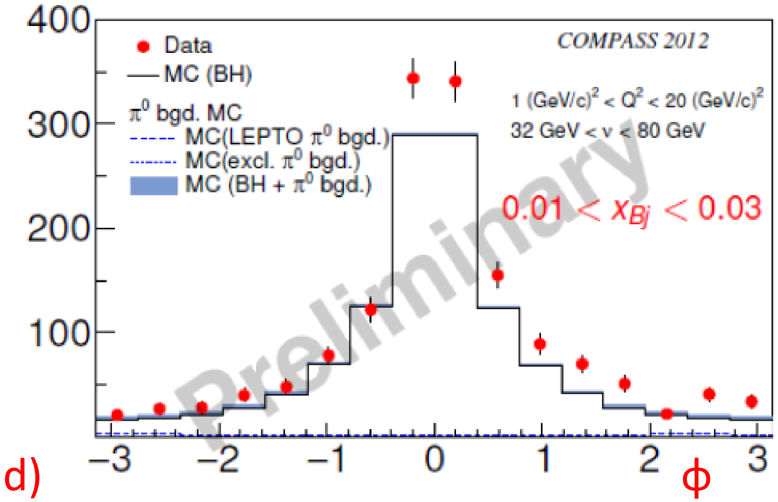


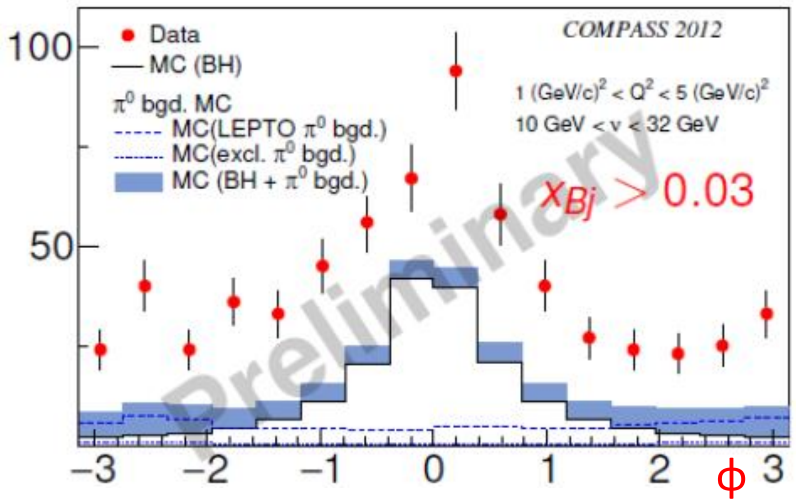
Bethe-Heitler (BH)

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



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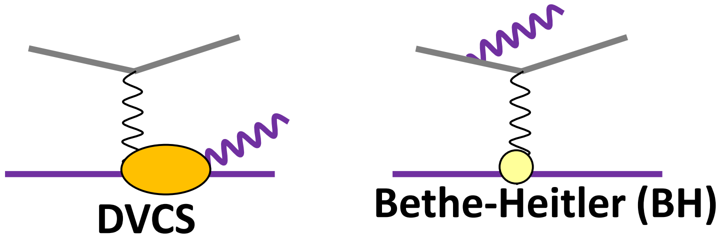
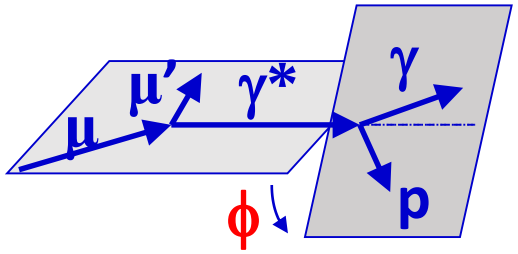
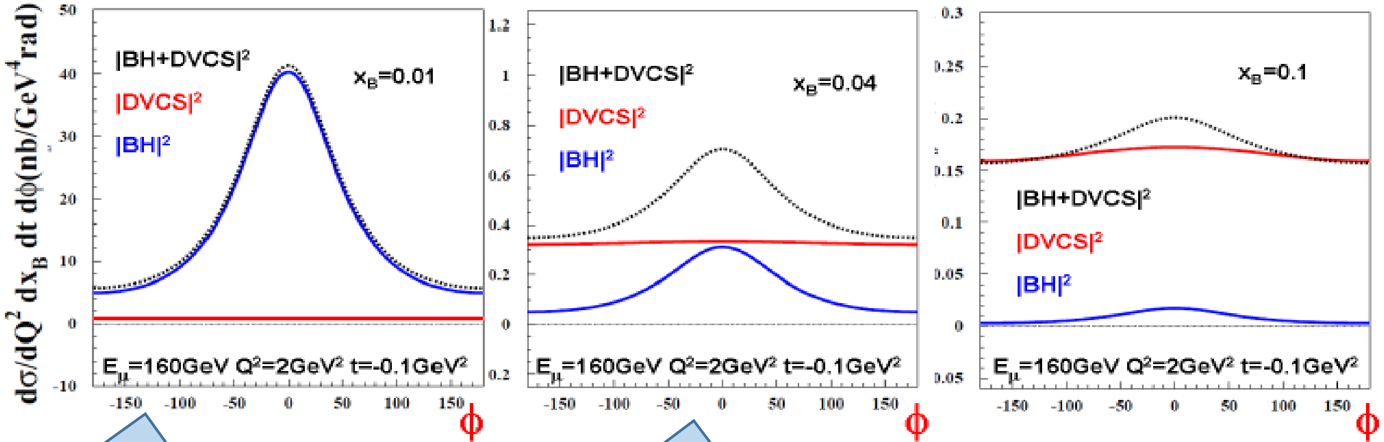



$d\sigma \propto |T^{BH}|^2$ + Interference Term + $|T^{DVCS}|^2$



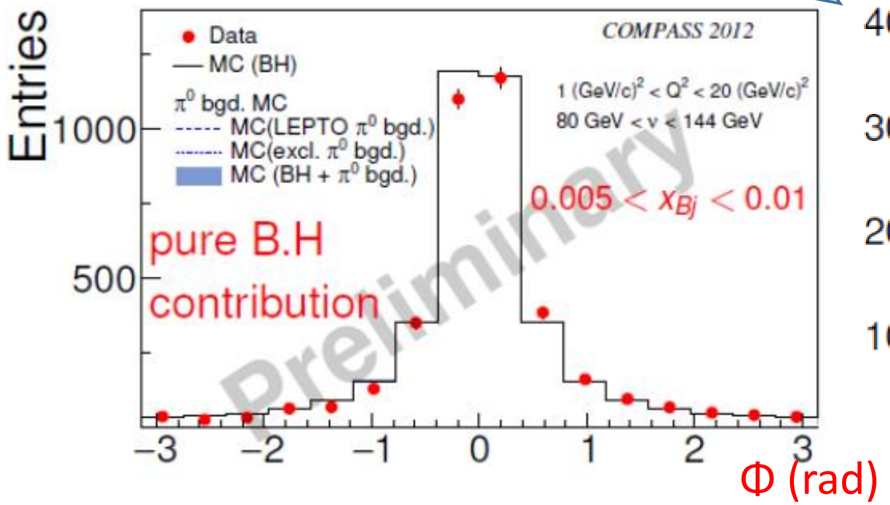

BH dominates
Reference yield

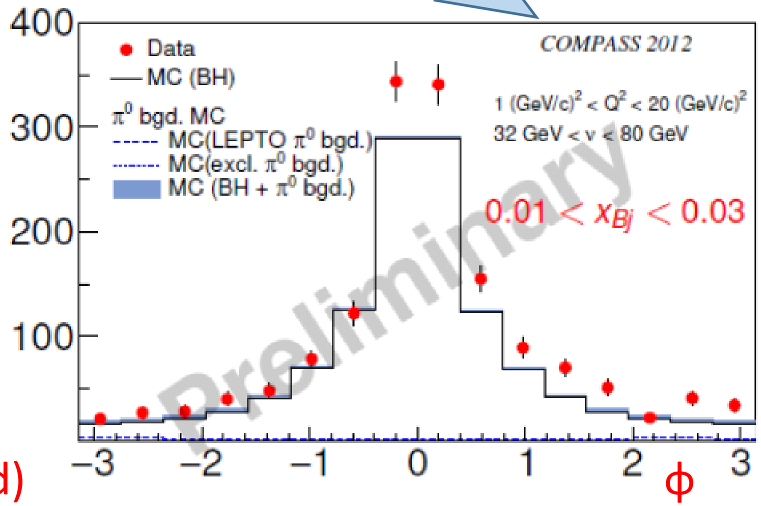
DVCS ampl. via interference

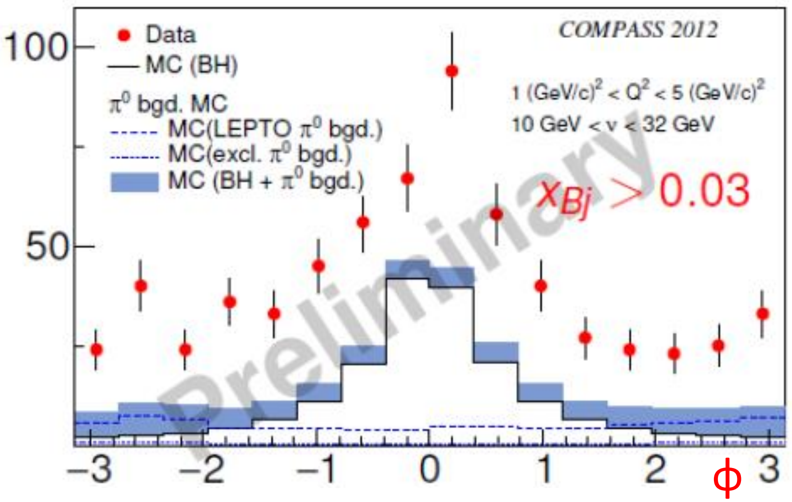
Jlab, HERMES,
H1, COMPASS

DVCS dominates - Study of $d\sigma^{DVCS}/dt$

Only for H1, ZEUS, COMPASS



# COMPASS 2012 DVCS cross section at Eμ=160 GeV

**when BH is not dominant**

At COMPASS using polarized positive and negative muon beams:

$$S_{CS,U} \equiv d\sigma^{\overleftarrow{+}} + d\sigma^{\overrightarrow{-}} = 2[d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + \mathrm{Im}\, I]$$

$$= 2[d\sigma^{BH} + c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi + s_1^{I}\sin\phi + s_2^{I}\sin 2\phi\,]$$

calculable
can be subtracted

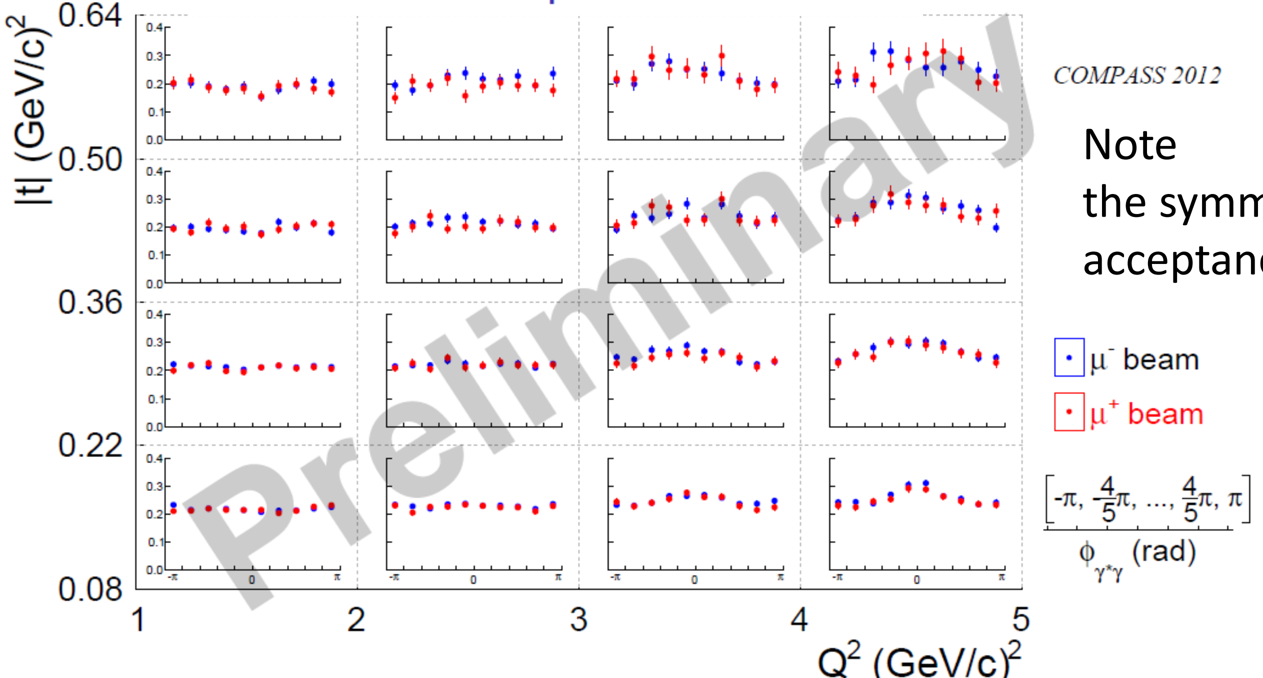
All the other terms are cancelled in the integration over $\phi$

$$\frac{d^3\sigma_T^{\mu p}}{dQ^2 d\nu dt} = \int_{-\pi}^{\pi} d\phi\, (d\sigma - d\sigma^{BH}) \propto c_0^{DVCS}$$

$$\frac{d\sigma^{\gamma^* p}}{dt} = \frac{1}{\Gamma(Q^2,\nu,E_\mu)} \frac{d^3\sigma_T^{\mu p}}{dQ^2 d\nu dt}$$

Flux for transverse
virtual photons

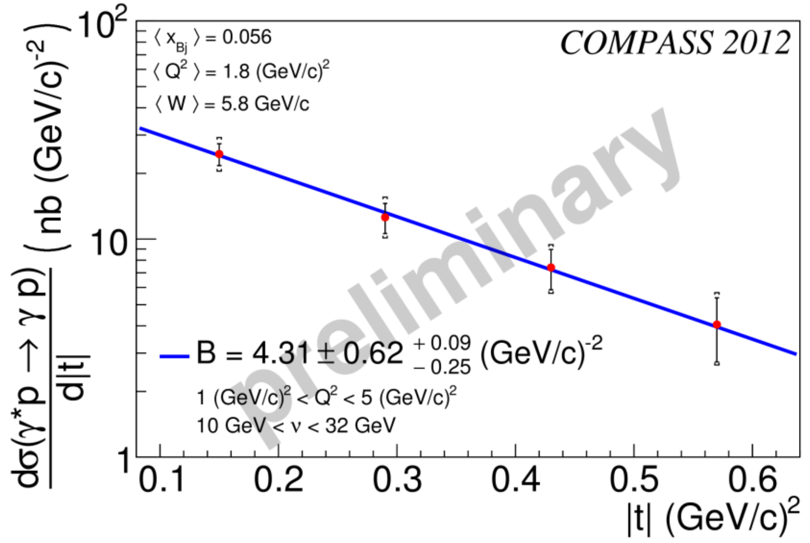
COMPASS acceptance for DVCS

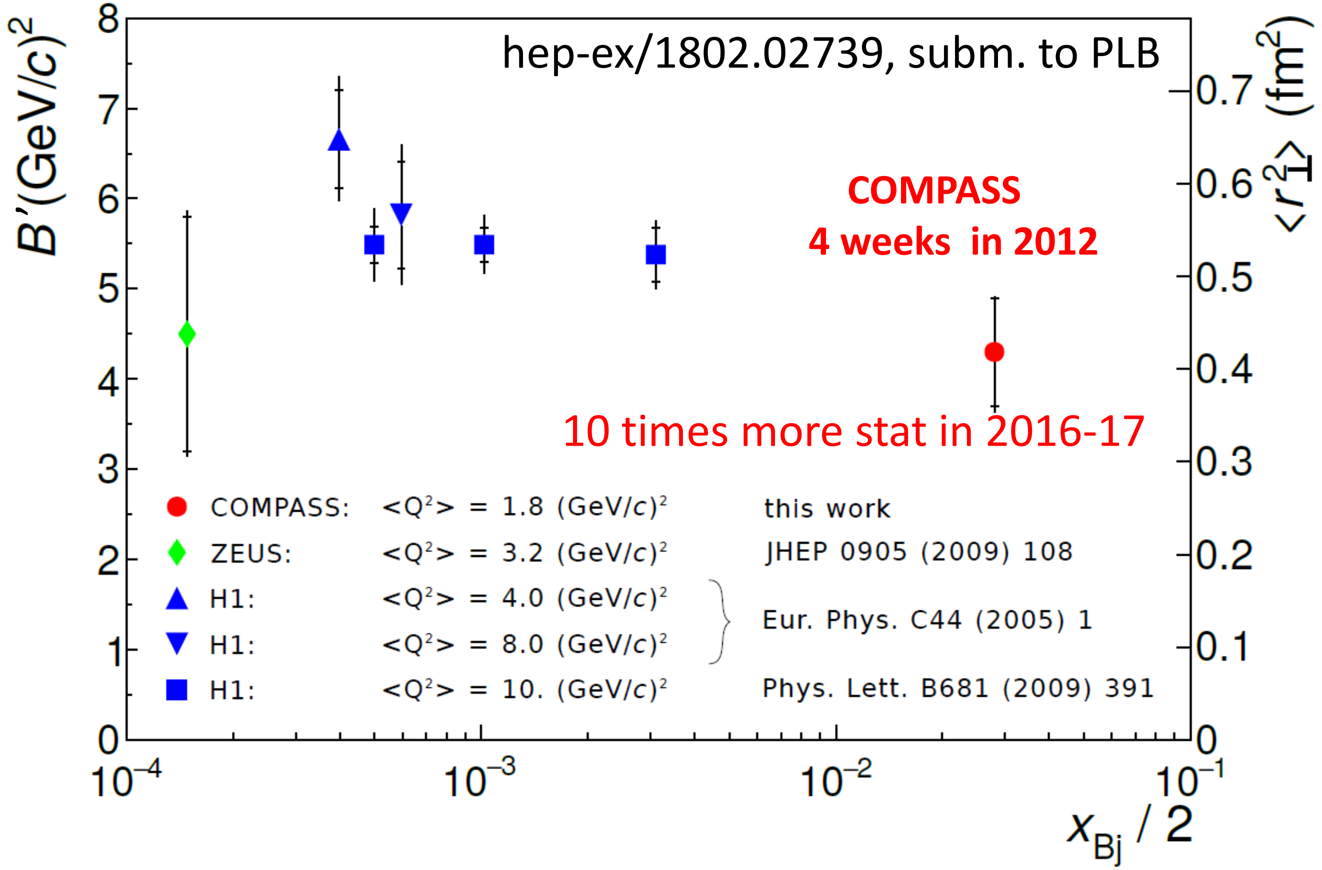


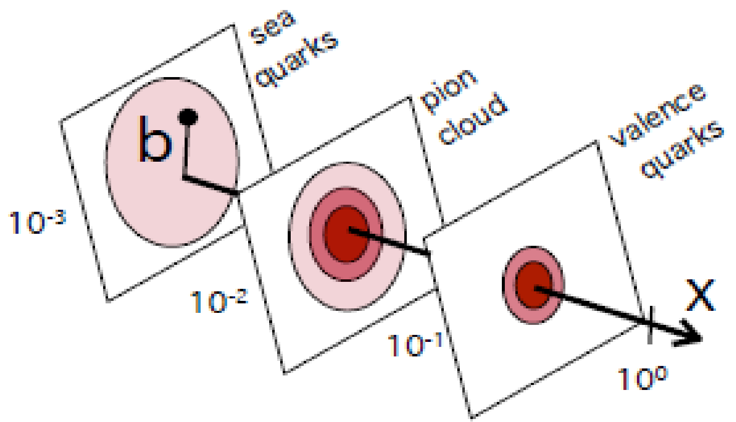

Note
the symmetric
acceptance

# COMPASS 2012 Transverse extention of partons in the sea quark range

$d\sigma^{DVCS}/dt = e^{-B'|t|} = c_0^{DVCS}$




$$B = (4.3 \pm 0.6_{\rm stat} {}^{+0.1}_{-0.3}\big|_{\rm sys})\ ({\rm GeV}/c)^{-2}$$

# COMPASS 2012 Transverse extention of partons in the sea quark range

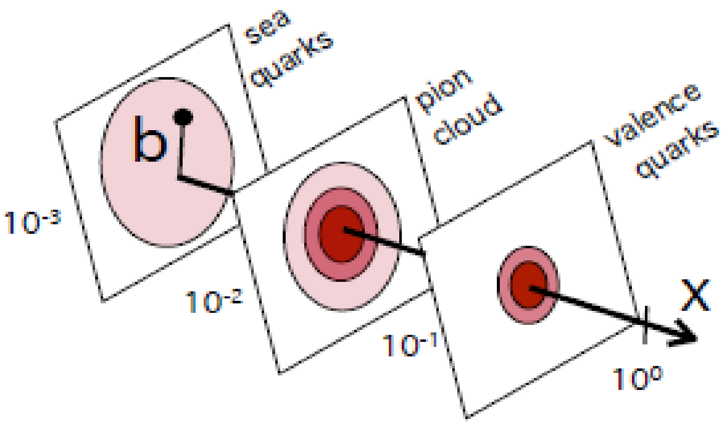
$d\sigma^{DVCS}/dt = e^{-B'|t|} = c_0^{DVCS}$

At COMPASS:
$\langle x_{Bj}\rangle=0.056$; $\langle Q^2\rangle=1.8$ GeV$^2$;
$t$ varies from 0.08 to 0.64 GeV$^2$

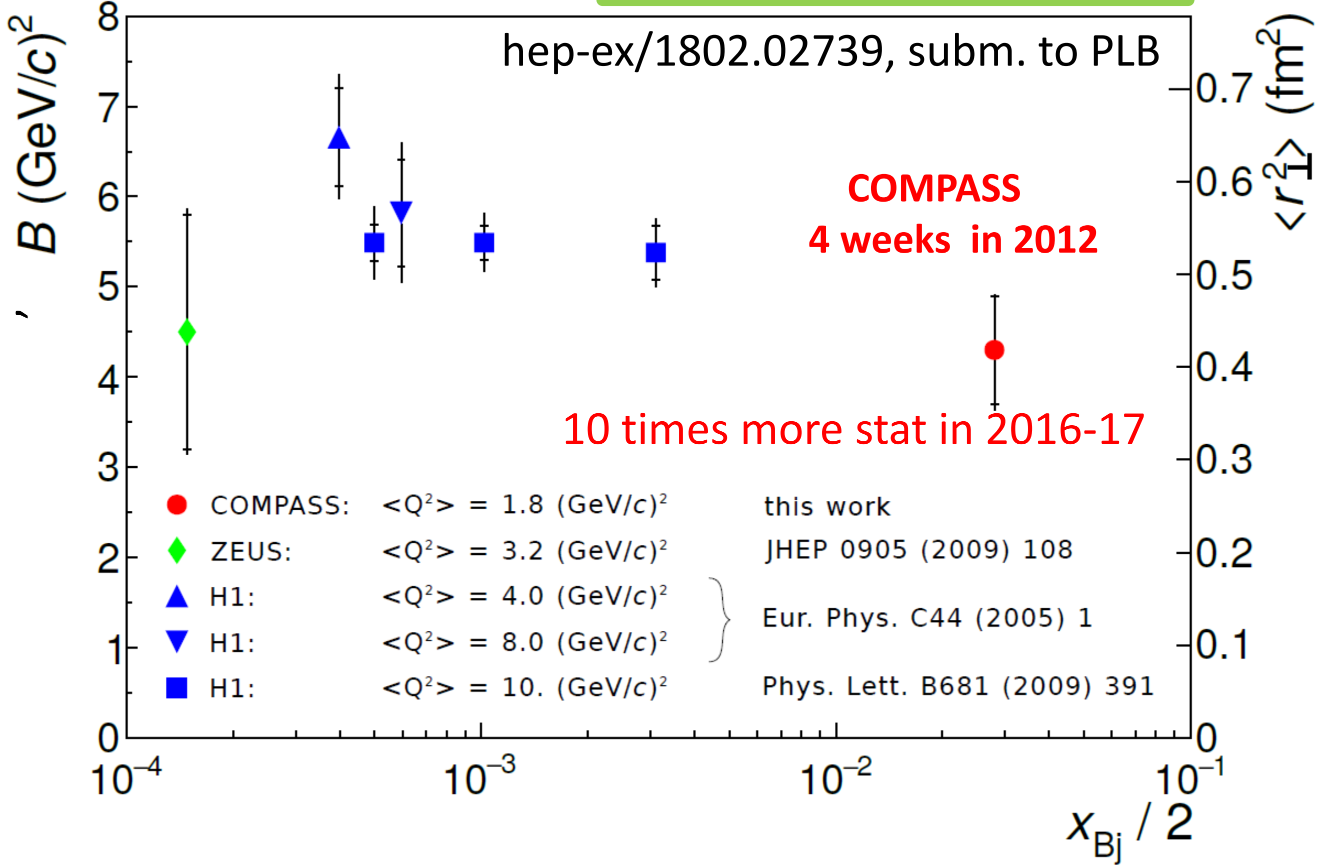
At small $x_{Bj}$ and small $t$:

$$c_0^{DVCS} \propto 4(\mathcal{H}\mathcal{H}^* + \tilde{\mathcal{H}}\tilde{\mathcal{H}}^*) + \frac{t}{M^2}\mathcal{E}\mathcal{E}^*$$

Dominance of *Im$\mathcal{H}$*
(with respect of *Re$\mathcal{H}$* and other *CFF*)




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




$$B = (4.3 \pm 0.6_{stat} {}^{+0.1}_{-0.3}|_{sys})\ (\mathrm{GeV}/c)^{-2}$$

$$\sqrt{\langle r_\perp^2\rangle} = (0.58 \pm 0.04_{stat} {}^{+0.01}_{-0.02}|_{sys} \pm 0.04_{model})\ \mathrm{fm}$$

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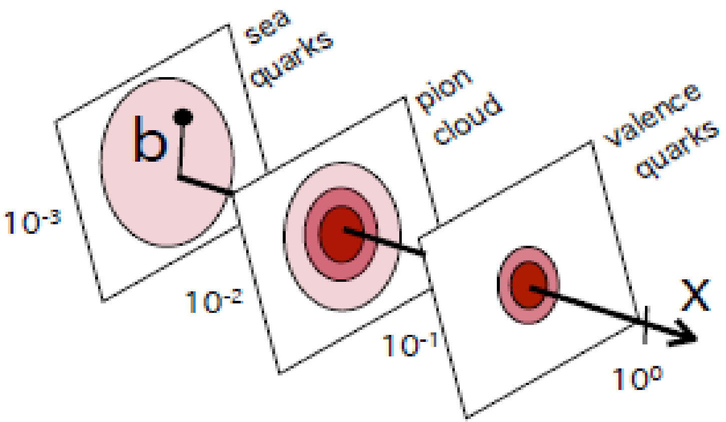


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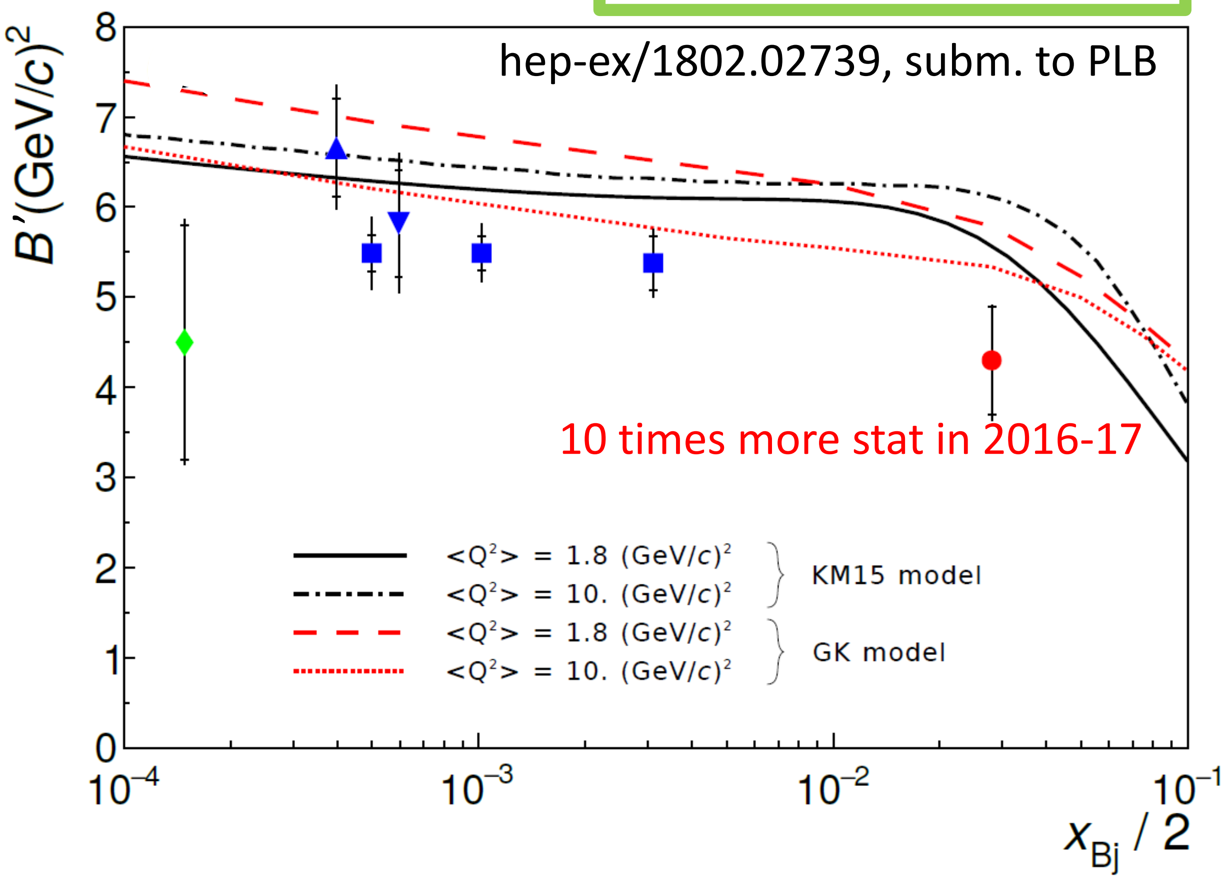


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Comparison between the observables given by the spectro or by CAMERA

**DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$**

1) $\Delta p_T = {p_T}^{cam} - {p_T}^{spec}$

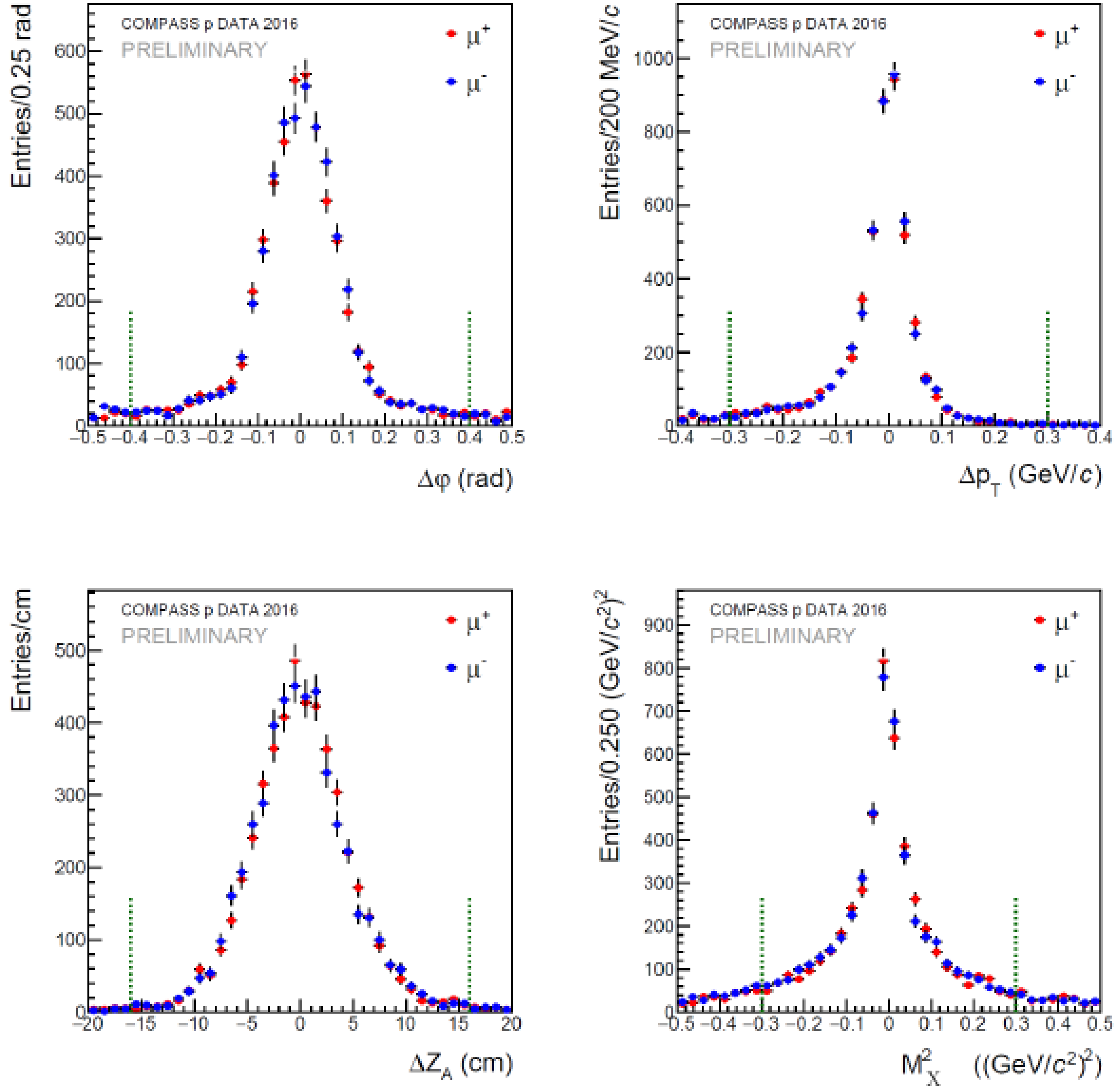
2) $\Delta\varphi = \varphi^{cam} - \varphi^{spec}$

3) $\Delta z_A = {z_A}^{cam} - {z_A}^{Z_B \text{ and vertex}}$

4) $M^2_{X=0} = (p_{\mu_{in}} + p_{p_{in}} - p_{\mu_{out}} - p_{p_{out}} - p_{\gamma})^2$

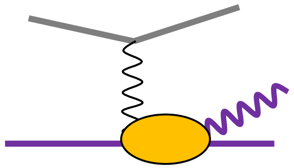
$d\sigma^{\overleftarrow{+}} + d\sigma^{\overrightarrow{-}}$ *t-slope*

$d\sigma^{\overleftarrow{+}} - d\sigma^{\overrightarrow{-}}$ *d-term*

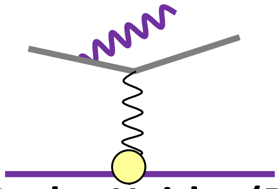


# First insight

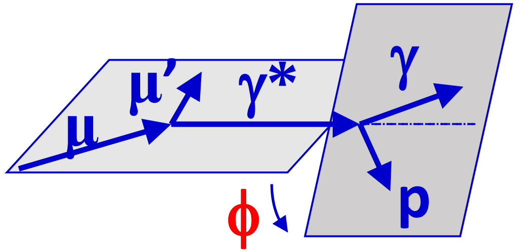
# Distributions in $\phi$



DVCS



Bethe-Heitler (BH)

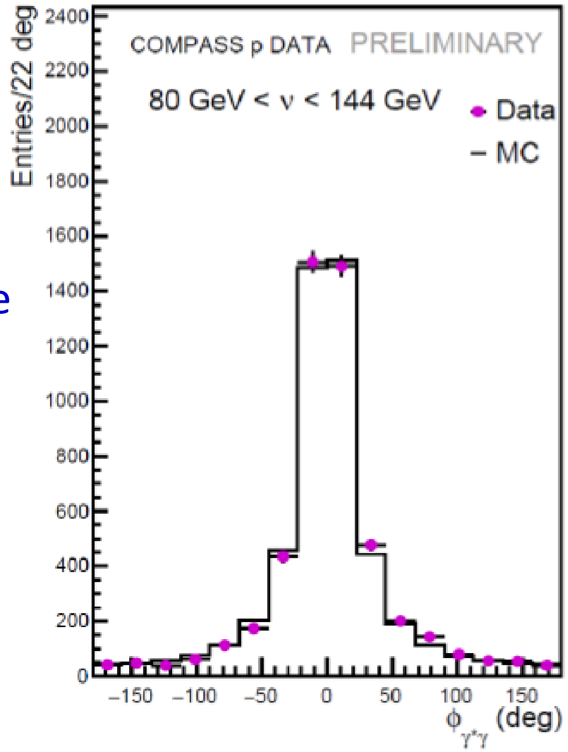



Only 1.3% of 2016-17 data

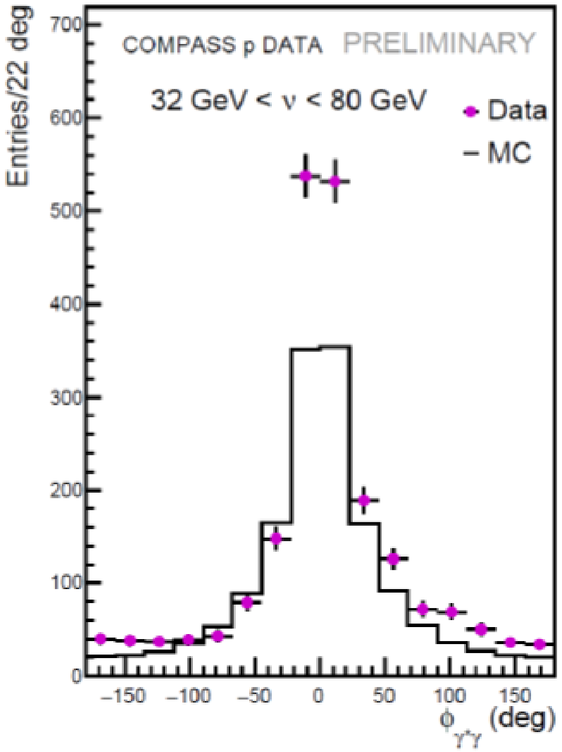
BH expected to contribute only

BH MC is normalized to this bin

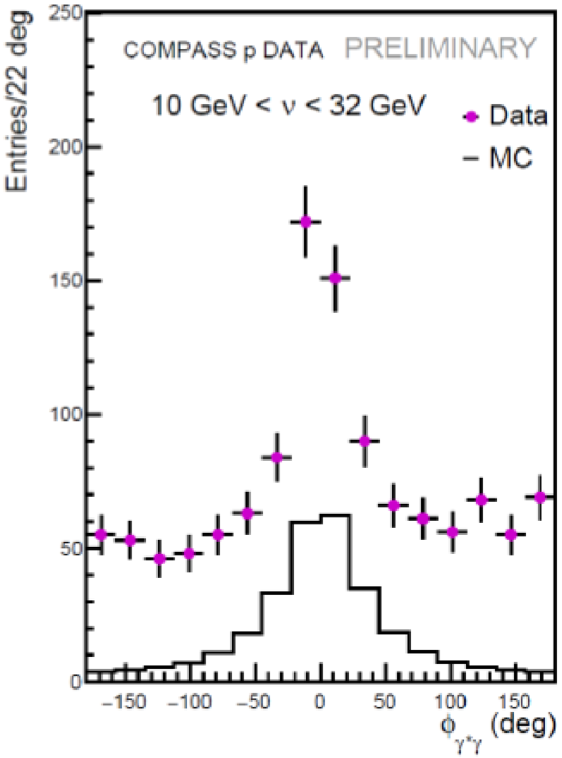
$0.005 < x_{Bj} < 0.01$




$0.01 < x_{Bj} < 0.03$




$x_{Bj} > 0.03$




No "invisible" $\pi^0$ still to be removed

a significant DVCS contribution will allow to study

$d\sigma^{DVCS}/dt = e^{-B'|t|}$

$= c_0^{DVCS}$

BLUE WATERS

*This research is part of the Blue Waters sustained-petascale computing project, which is supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois. Blue Waters is a joint effort of the University of Illinois at Urbana-Champaign and its National Center for Supercomputing Applications. This work is also part of the "Mapping Proton Quark Structure using Petabytes of COMPASS Data" PRAC allocation supported by the National Science Foundation (award number OCI 1713684 ).*

# Beam Charge and Spin Diff. @ COMPASS

$$\mathcal{D}_{CS,U} \equiv d\sigma^{\overset{+}{\leftarrow}} - d\sigma^{\overset{-}{\rightarrow}} = 2[d\sigma^{DVCS}_{pol} + \mathrm{Re}\, I] \xrightarrow{L.T.} c_0^I + c_1^I \cos\phi$$

$\mathcal{R}e\,\mathcal{H}$ **> 0** at H1

**< 0** at HERMES

Value of $x_{Bj}$ for the node?

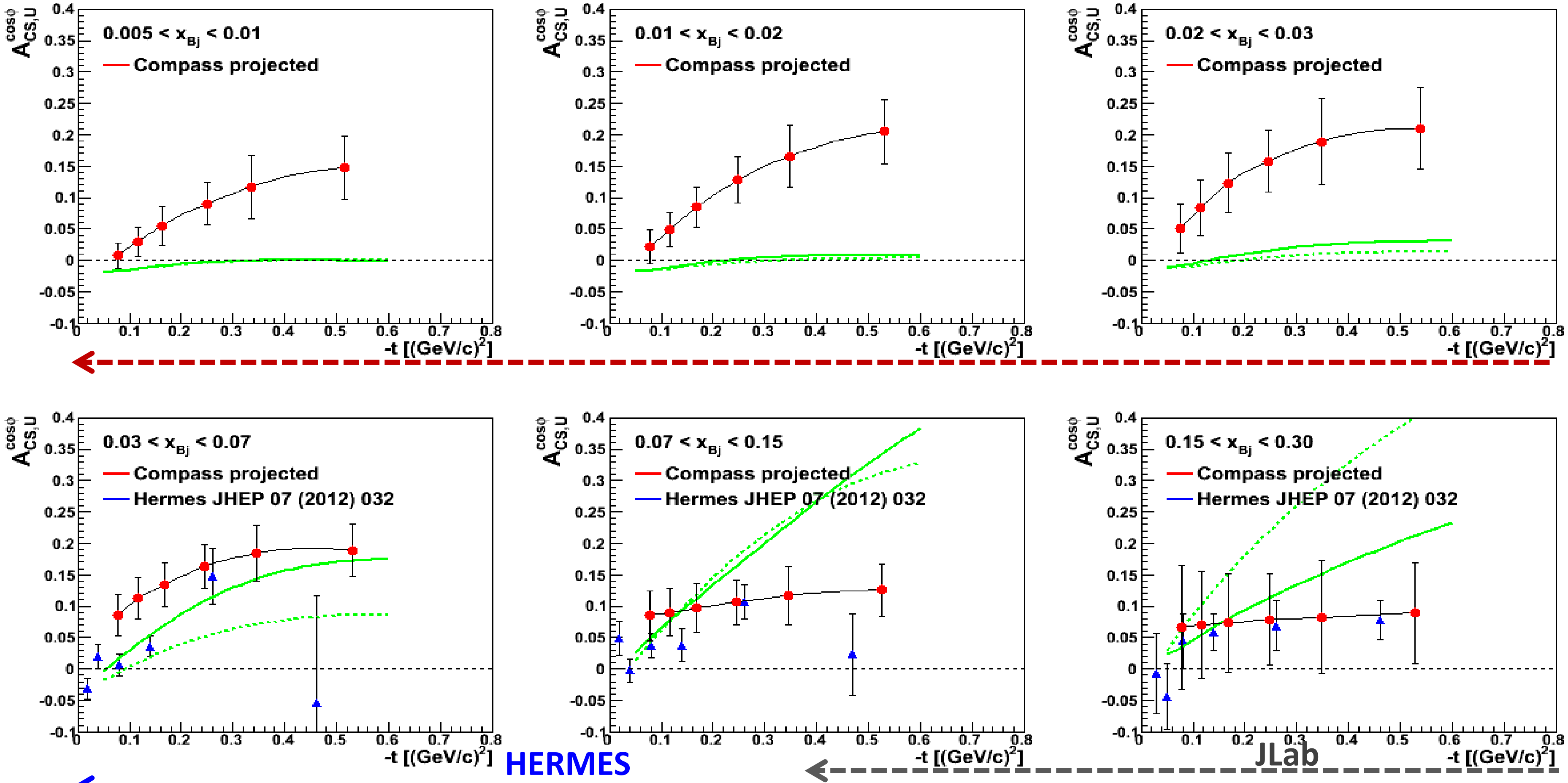
$c_1^I = Re\, F_1 \mathcal{H}$

Predictions with

**VGG**

**KM10**

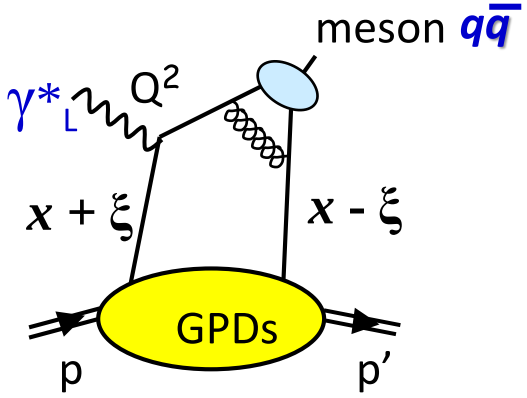
The knowledge of $Re\, F_1\mathcal{H}$ and $Im\, F_1\mathcal{H}$ is essentiel to play with the dispersion relation to extract the D-term



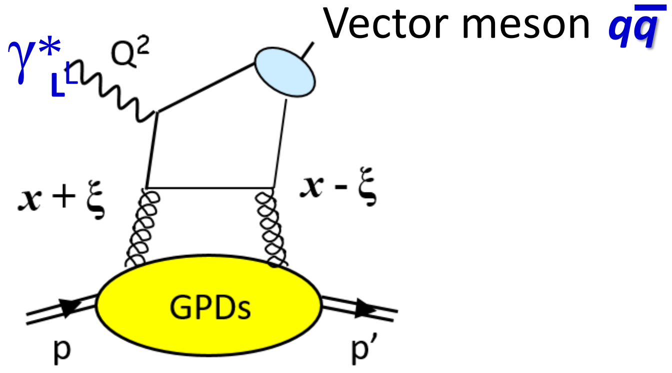

**COMPASS** 2 years of data $E\mu$= 160 GeV 1 < $Q^2$ < 8 GeV$^2$

# GPDs and Hard Exclusive Meson Production

Quark contribution




Gluon contribution at the same order in $\alpha_S$




The meson wave function
Is an additional non-perturbative term

4 chiral-even GPDs: helicity of parton unchanged

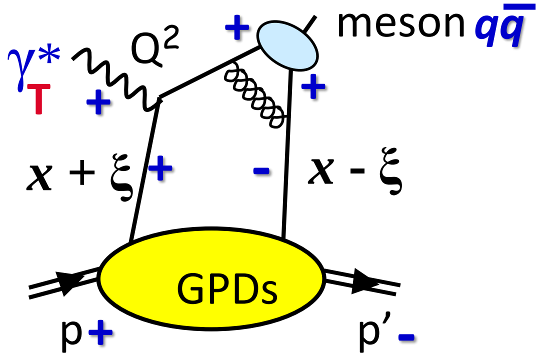
| | | |
|---|---|---|
| $H^q(x, \xi, t)$ | $E^q(x, \xi, t)$ | **For Vector Meson** |
| $\tilde{H}^q(x, \xi, t)$ | $\tilde{E}^q(x, \xi, t)$ | **For Pseudo-Scalar Meson** |

+ 4 chiral-odd or transversity GPDs: helicity of parton changed
(not possible in DVCS)

| | | |
|---|---|---|
| $H_T^q(x, \xi, t)$ | $E_T^q(x, \xi, t)$ | $\bar{E}_T^q = 2\,\tilde{H}_T^q + E_T^q$ |
| $\tilde{H}_T^q(x, \xi, t)$ | $\tilde{E}_T^q(x, \xi, t)$ | |

Factorisation proven only for $\sigma_L$
$\sigma_T$ is asymptotically suppressed by $1/Q^2$ but large contribution observed
model of $\sigma_T$ with transversity GPDs - divergencies regularized by $k_T$ of $q$ and $\bar{q}$ and Sudakov suppression factor

$\mathcal{M}_{0-,++}$ sensitive to $H_T^q$
and to a twist-3 meson wave function



# COMPASS 2012 Exclusive $\pi^0$ production on unpolarized proton

$e\, p \rightarrow e\, \pi^0\, p$

$$\frac{d^2\sigma}{dt\, d\phi_\pi} = \frac{1}{2\pi}\left[\left(\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt}\right) + \epsilon \cos 2\phi_\pi \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)} \cos \phi_\pi \frac{d\sigma_{LT}}{dt}\right]$$

$$\frac{d\sigma_L}{dt} = \frac{4\pi\alpha}{k'}\frac{1}{Q^6}\left\{(1-\xi^2)\left|\langle\tilde{H}\rangle\right|^2 - 2\xi^2 \mathrm{Re}\left[\langle\tilde{H}\rangle^*\langle\tilde{E}\rangle\right] - \frac{t'}{4m^2}\xi^2\left|\langle\tilde{E}\rangle\right|^2\right\}$$

Leading twist should be dominant

but ≈ only a few % of $\frac{d\sigma_T}{dt}$

The other contributions arise from coupling between chiral-odd (quark helicity flip) GPDs to the twist-3 pion amplitude

$$\frac{d\sigma_T}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\left[(1-\xi^2)\left|\langle H_T\rangle\right|^2 - \frac{t'}{8m^2}\left|\langle\bar{E}_T\rangle\right|^2\right]$$

$$\frac{\sigma_{LT}}{dt} = \frac{4\pi\alpha}{\sqrt{2}k'}\frac{\mu_\pi}{Q^7}\xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\mathrm{Re}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

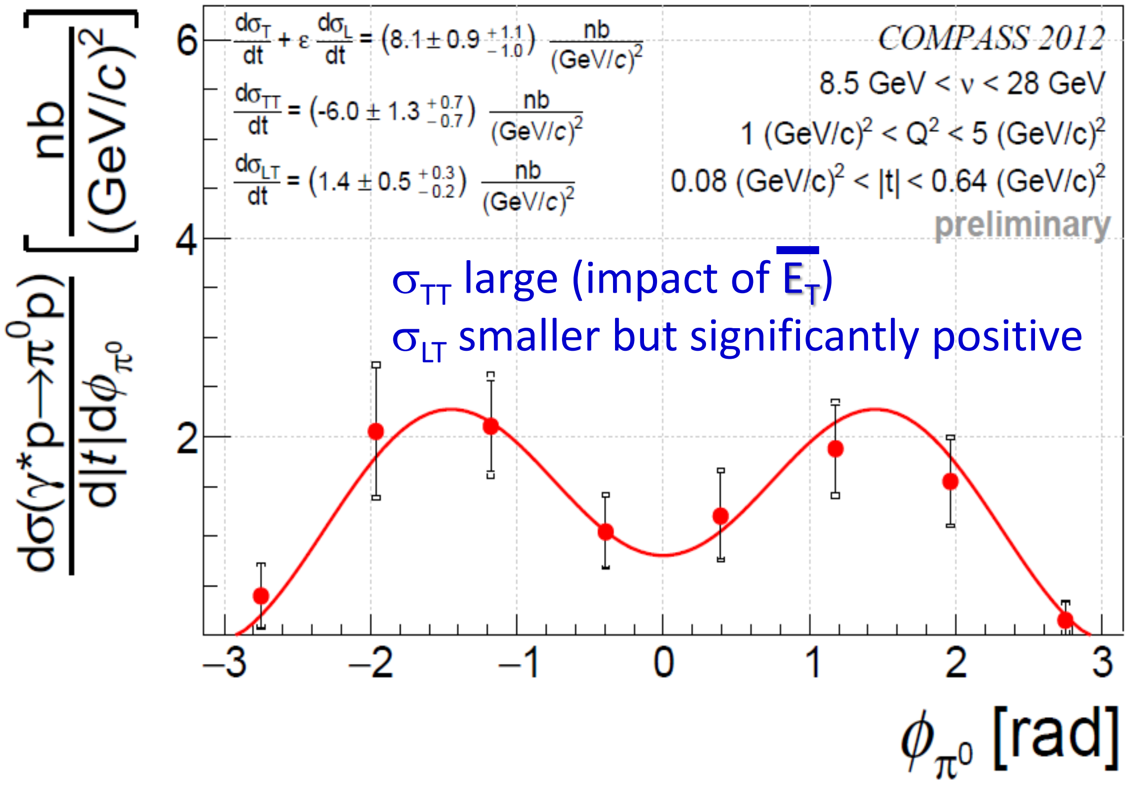
$$\frac{\sigma_{TT}}{dt} = \frac{4\pi\alpha}{k'}\frac{\mu_\pi^2}{Q^8}\frac{t'}{16m^2}\left|\langle\bar{E}_T\rangle\right|^2$$

A large impact of $\bar{E}_T$ should be clearly visible in $\sigma_{TT}$ and in the dip at small |t| of $\sigma_T$

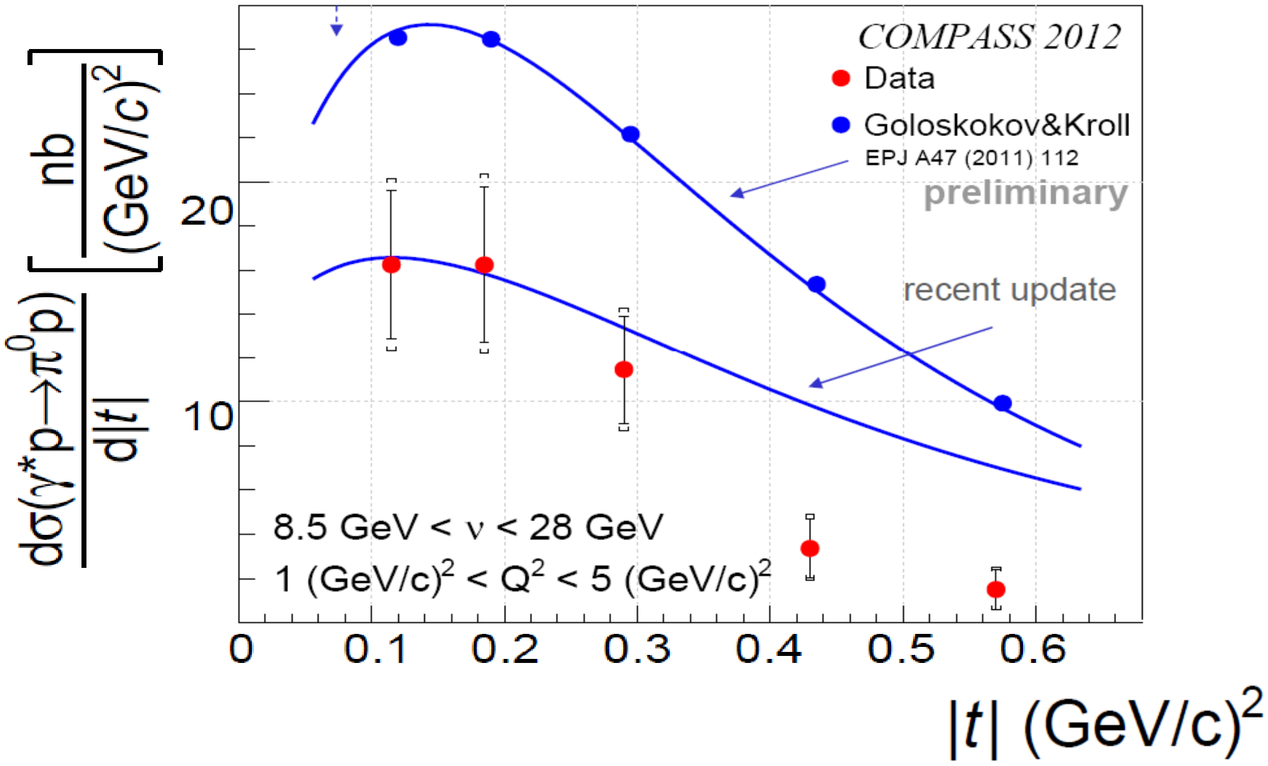
# COMPASS 2012 Exclusive $\pi^0$ production on unpolarized proton

$e\, p \rightarrow e\, \pi^0\, p$

$$\frac{d^2\sigma}{dt\,d\phi_\pi} = \frac{1}{2\pi}\left[\left(\epsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt}\right) + \epsilon\cos 2\phi_\pi \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi \frac{d\sigma_{LT}}{dt}\right]$$




A dip at small t would indicate a large impact of $\bar{E}_T$




hep-ex/1903.12030, subm. to PLB

# COMPASS 2012 Exclusive ω production on unpolarized proton

SCHC ( $\lambda_\gamma = \lambda_V$ )

SCHC implies:

- $r^1_{1-1} + \mathrm{Im}\, r^2_{1-1} = 0$

= - 0.010 ± 0.032 ± 0.047 OK

- $\mathrm{Re}\, r^5_{10} + \mathrm{Im}^6_{10} = 0$

= 0.014 ± 0.011 ± 0.013 OK

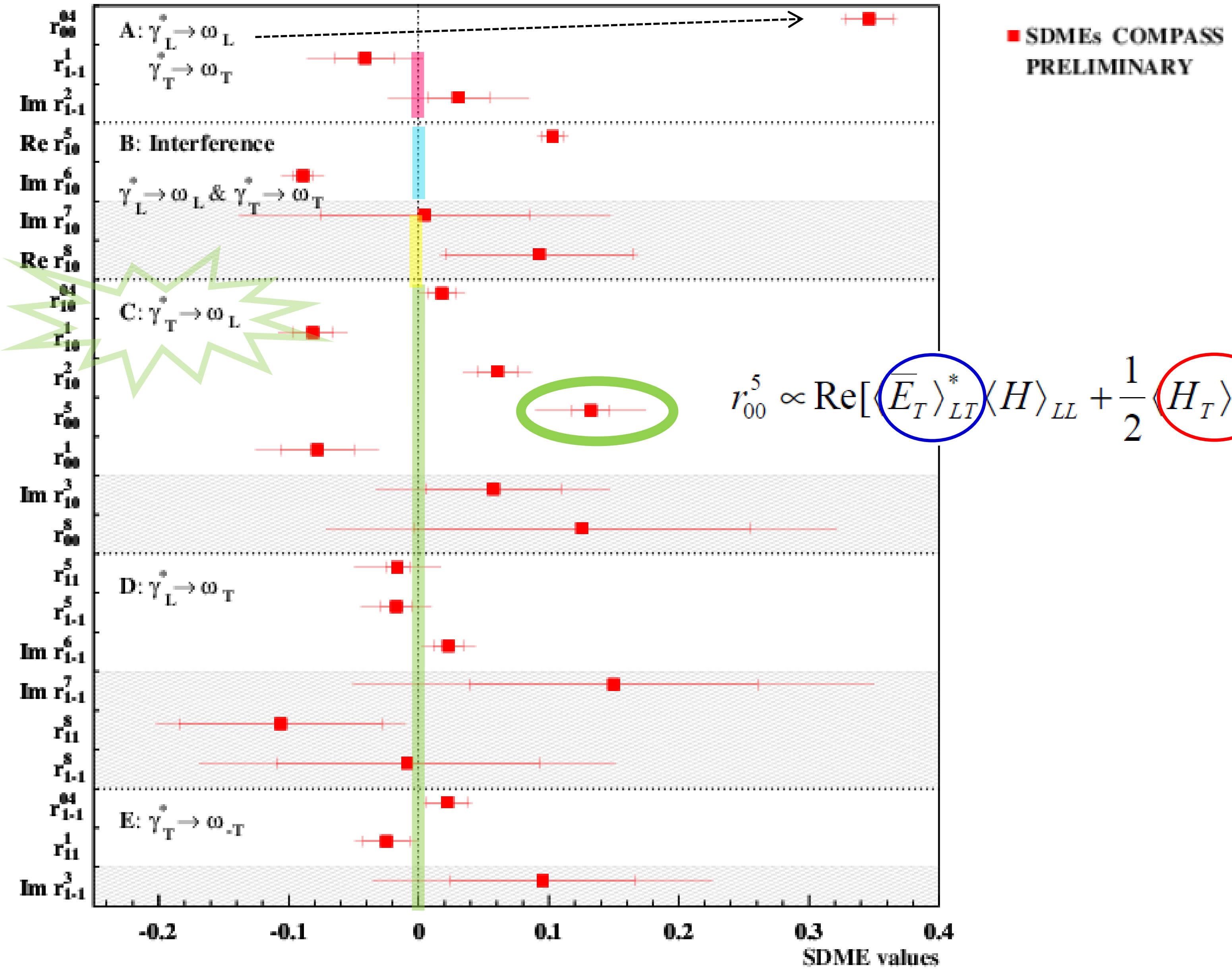
- $\mathrm{Im}\, r^7_{10} - \mathrm{Re}\, r^8_{10} = 0$

= - 0.088 ± 0.110 ± 0.196 OK

- all elements of classes C, D, E should be 0

for $\gamma^*_L \to \omega_T$ and $\gamma^*_T \to \omega_{-T}$ OK within errors

not obeyed for transitions $\gamma^*_T \to \omega_L$




$$r^5_{00} \propto \mathrm{Re}[\langle \bar{E}_T \rangle^*_{LT} \langle H \rangle_{LL} + \frac{1}{2} \langle H_T \rangle^*_{LT} \langle E \rangle_{LL}]$$

# Conclusions

**From 2016-17 data**

**sum and difference of DVCS x-sections with polarized μ+ and μ-**

➔ transverse extension of partons as a function of $x_{Bj}$

➔ Im$\mathcal{H}$(ξ,t) and Re$\mathcal{H}$(ξ,t) for D-term and pressure distribution

HEMP $\pi^0$, ρ, ω, ϕ, J/ψ ➔ universality of GPDs - transverse GPDs - flavor decomposition


**COMPASS++/AMBER starting in 2022**

Letter of Intent Draft 1.0: https://arXiv.org/abs/1808.00848

New collaborators are welcome: https://nqf-m2.web.cern.ch

**A new QCD facility**
at the M2 beam line of the CERN SPS

Letter of Intent - Draft 1.0: https://arXiv.org/abs/1808.00848

# COMPASS++/AMBER starting in 2022

| Program | Physics Goals | Beam Energy [GeV] | Beam Intensity [$s^{-1}$] | Trigger Rate [kHz] | Beam Type | Target | Earliest start time, duration | Hardware Additions |
|---|---|---|---|---|---|---|---|---|
| $\mu p$ elastic scattering | Precision proton-radius measurement | 100 | $4 \cdot 10^6$ | 100 | $\mu^\pm$ | high-pressure H2 | 2022 1 year | active TPC, SciFi trigger, silicon veto, |
| Hard exclusive reactions | GPD $E$ | 160 | $2 \cdot 10^7$ | 10 | $\mu^\pm$ | $NH_3^\uparrow$ | 2022 2 years | recoil silicon, modified PT magnet |
| Input for Dark Matter Search | $\overline{p}$ production cross section | 20-280 | $5 \cdot 10^5$ | 25 | $p$ | LH2, LHe | 2022 1 month | LHe target |
| $\overline{p}$-induced Spectroscopy | Heavy quark exotics | 12, 20 | $5 \cdot 10^7$ | 25 | $\overline{p}$ | LH2 | 2022 2 years | target spectr.: tracking, calorimetry |
| Drell-Yan | Pion PDFs | 190 | $7 \cdot 10^7$ | 25 | $\pi^\pm$ | C/W | 2022 1-2 years | |
| Drell-Yan (RF) | Kaon PDFs & Nucleon TMDs | ~100 | $10^8$ | 25-50 | $K^\pm, \overline{p}$ | $NH_3^\uparrow$, C/W | 2026 2-3 years | "active absorber", vertex det. |
| Primakoff (RF) | Kaon polarisa-bility & pion life time | ~100 | $5 \cdot 10^6$ | $> 10$ | $K^-$ | Ni | non-exclusive 2026 1 year | |
| Prompt Photons (RF) | Meson gluon PDFs | $\geq 100$ | $5 \cdot 10^6$ | 10-100 | $K^\pm$ $\pi^\pm$ | LH2, Ni | non-exclusive 2026 1-2 years | hodoscope |
| $K$-induced Spectroscopy (RF) | High-precision strange-meson spectrum | 50-100 | $5 \cdot 10^6$ | 25 | $K^-$ | LH2 | 2026 1 year | recoil TOF, forward PID |
| Vector mesons (RF) | Spin Density Matrix Elements | 50-100 | $5 \cdot 10^6$ | 10-100 | $K^\pm, \pi^\pm$ | from H to Pb | 2026 1 year | |

**Beam line unique with polarised μ+ and μ- and high intensity pion beam**

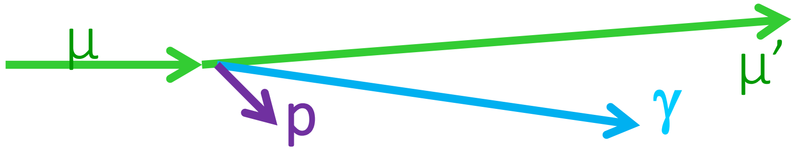
**Possible RF separated beam for high intensity antiproton and K beams**

**Versatile apparatus (Upgrade ++)**

**Proton Radius**
**Meson PDF – gluon PDF**
**Proton spin structure**
**3D imaging (TMDs and GPDs)**
**Hadron spectroscopy**
**Anti-matter cross section**

# The DVCS experiment at COMPASS

**DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$**

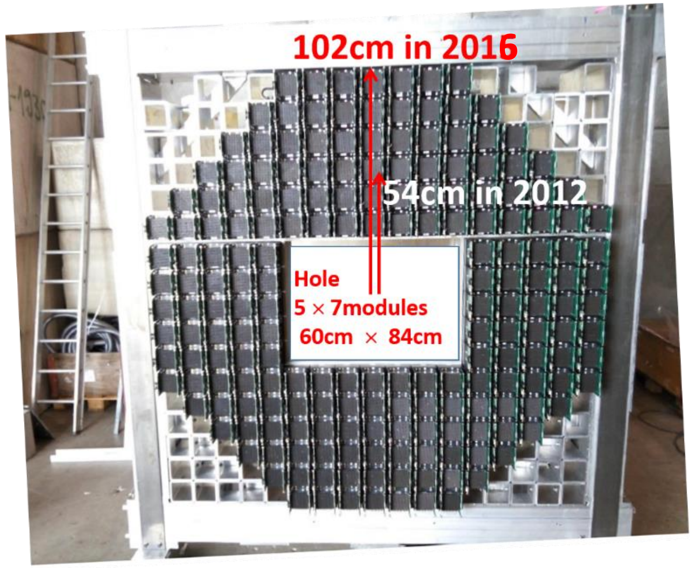



New equipements:

- **2.5m LH2 target**
- **4m ToF Barrel CAMERA**
- **ECAL0**

**CAMERA**
**L=4m**
**∅=2m**

24 inner & outer scintillators separated by about 1m
1 GHz SADC readout, 330ps ToF resolution




**ECAL0: 2 × 2 m2**

Shashlyk modules + MAPD readout
one module is made of 9 cells (4×4 cm$^2$)
= 194 modules or 1746 cells

# COMPASS 2012 Transverse extention of partons in the sea quark range

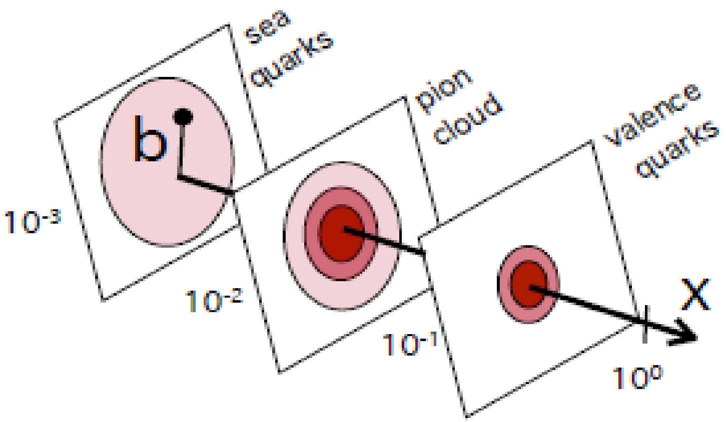
$d\sigma^{DVCS}/dt = e^{-B'|t|} = c_0^{DVCS}$

$$c_{0,\text{unp}}^{\text{DVCS}} = 2(2-2y+y^2)\mathcal{C}_{\text{unp}}^{\text{DVCS}}(\mathcal{F},\mathcal{F}^*)$$

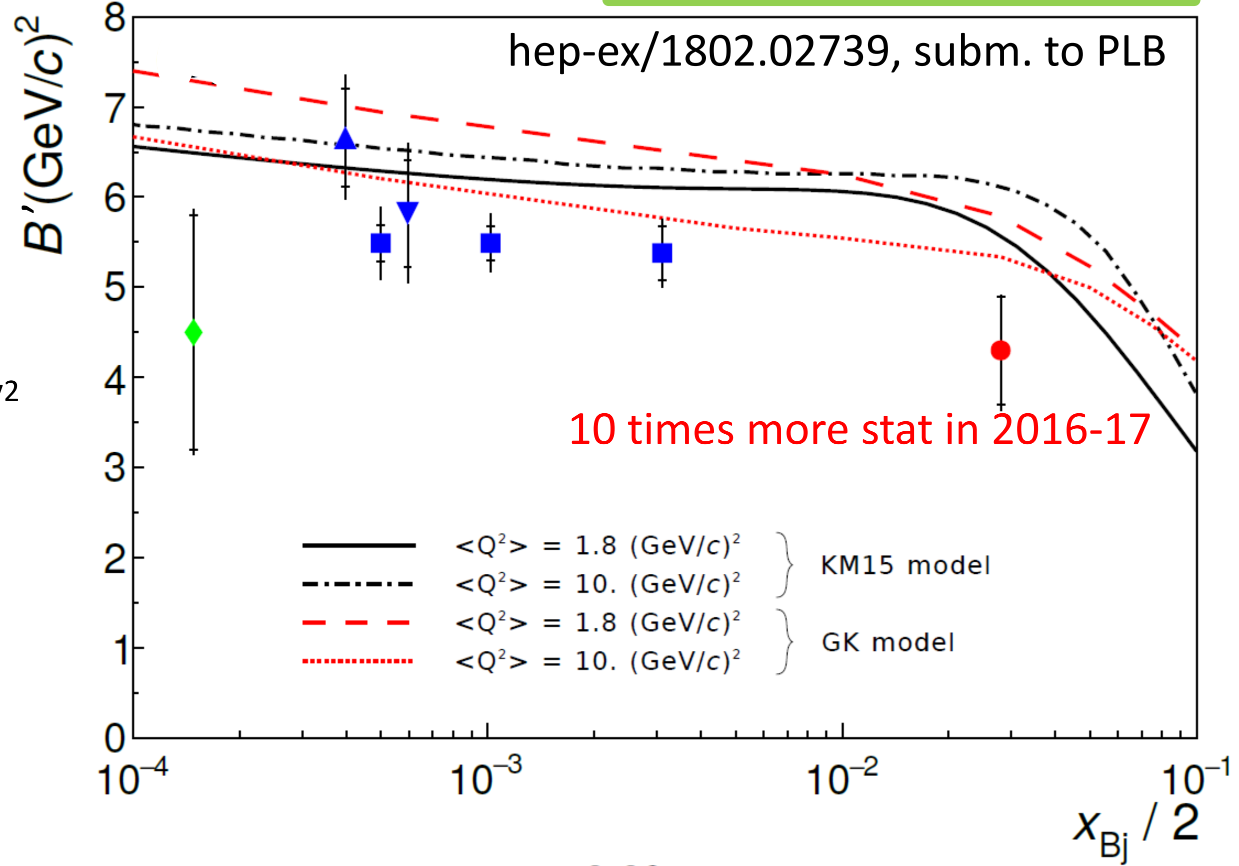
$$\mathcal{C}_{\text{unp}}^{\text{DVCS}}(\mathcal{F},\mathcal{F}^*) = \frac{1}{(2-x_B)^2}\Big\{4(1-x_B)\left(\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*\right) - x_B^2\left(\mathcal{H}\mathcal{E}^* + \mathcal{E}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{E}}^* + \widetilde{\mathcal{E}}\widetilde{\mathcal{H}}^*\right) - \left(x_B^2 + (2-x_B)^2\frac{\Delta^2}{4M^2}\right)\mathcal{E}\mathcal{E}^* - x_B^2\frac{\Delta^2}{4M^2}\widetilde{\mathcal{E}}\widetilde{\mathcal{E}}^*\Big\},$$

At COMPASS:
$\langle x_{Bj}\rangle=0.056$; $\langle Q^2\rangle=1.8$ GeV$^2$; $t$ varies from 0.08 to 0.64 GeV$^2$
Due to the small value of $x_{Bj}$ and $t$ it remains only:

$$c_0^{DVCS} \propto 4(\mathcal{H}\mathcal{H}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*) + \frac{t}{M^2}\mathcal{E}\mathcal{E}^*$$




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




$$B = (4.31 \pm 0.62_{\text{stat}}\ {}^{+0.09}_{-0.25}\big|_{\text{sys}})\ (\text{GeV}/c)^{-2}$$

$$\sqrt{\langle r_\perp^2\rangle} = (0.58 \pm 0.04_{\text{stat}}\ {}^{+0.01}_{-0.02}\big|_{\text{sys}})\ \text{fm}$$

# Dominance of $Im\mathcal{H}$ (with respect of $Re\mathcal{H}$ and other $\mathcal{CFF}$) at small $x_B$

Figure from Kumericki, Mueller

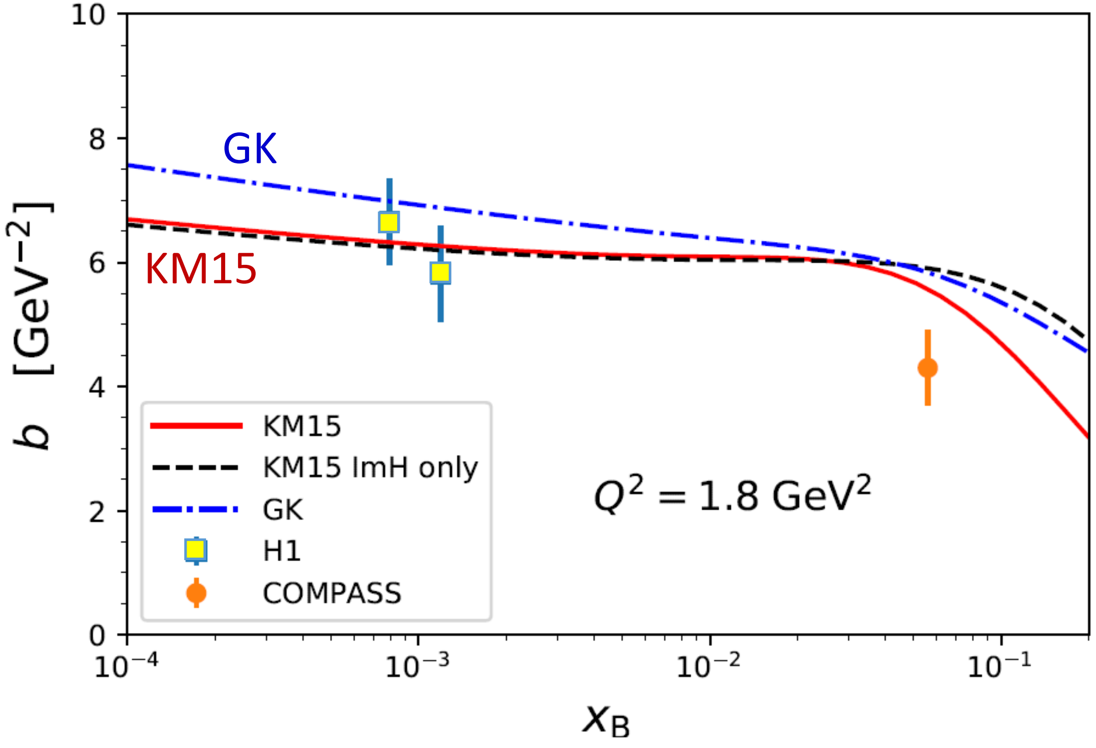
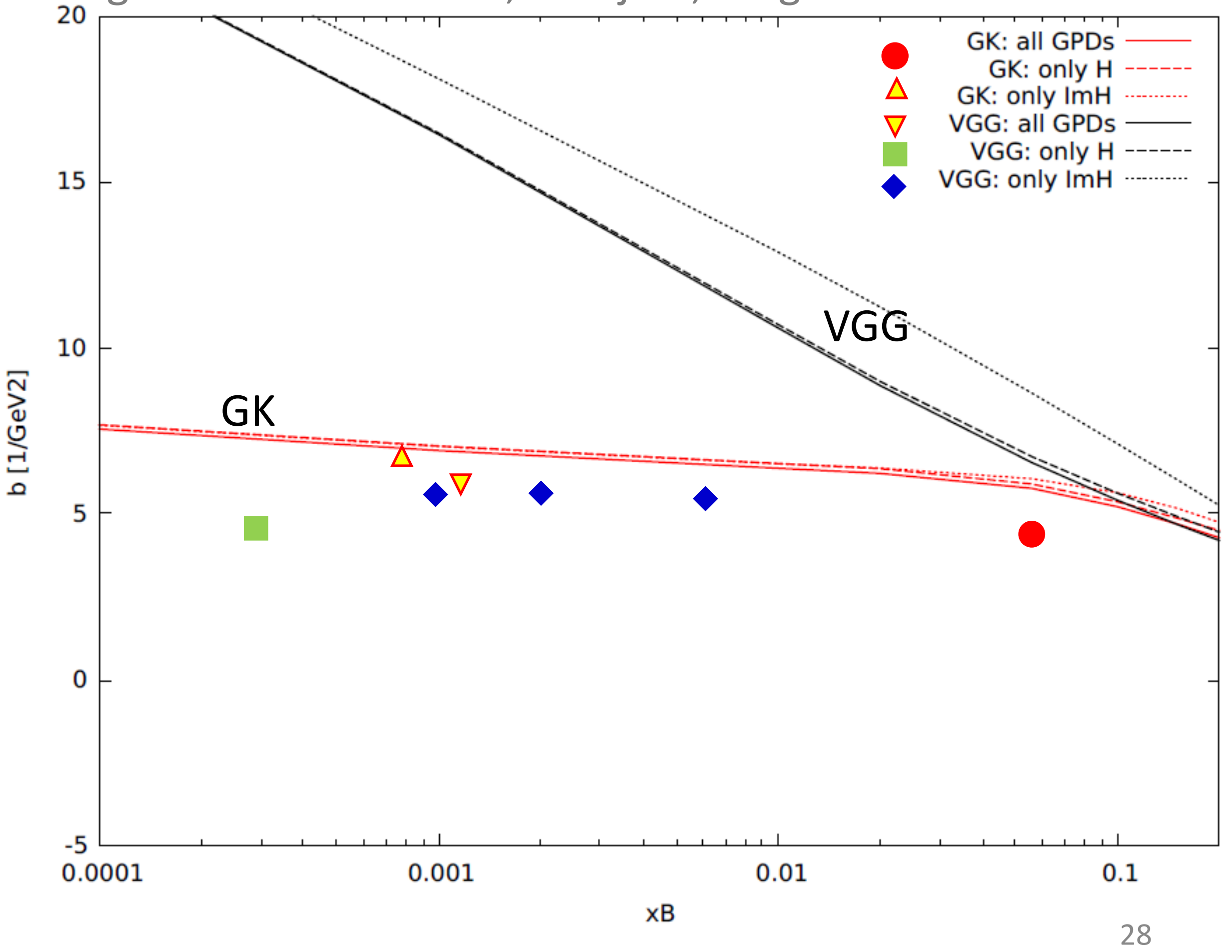
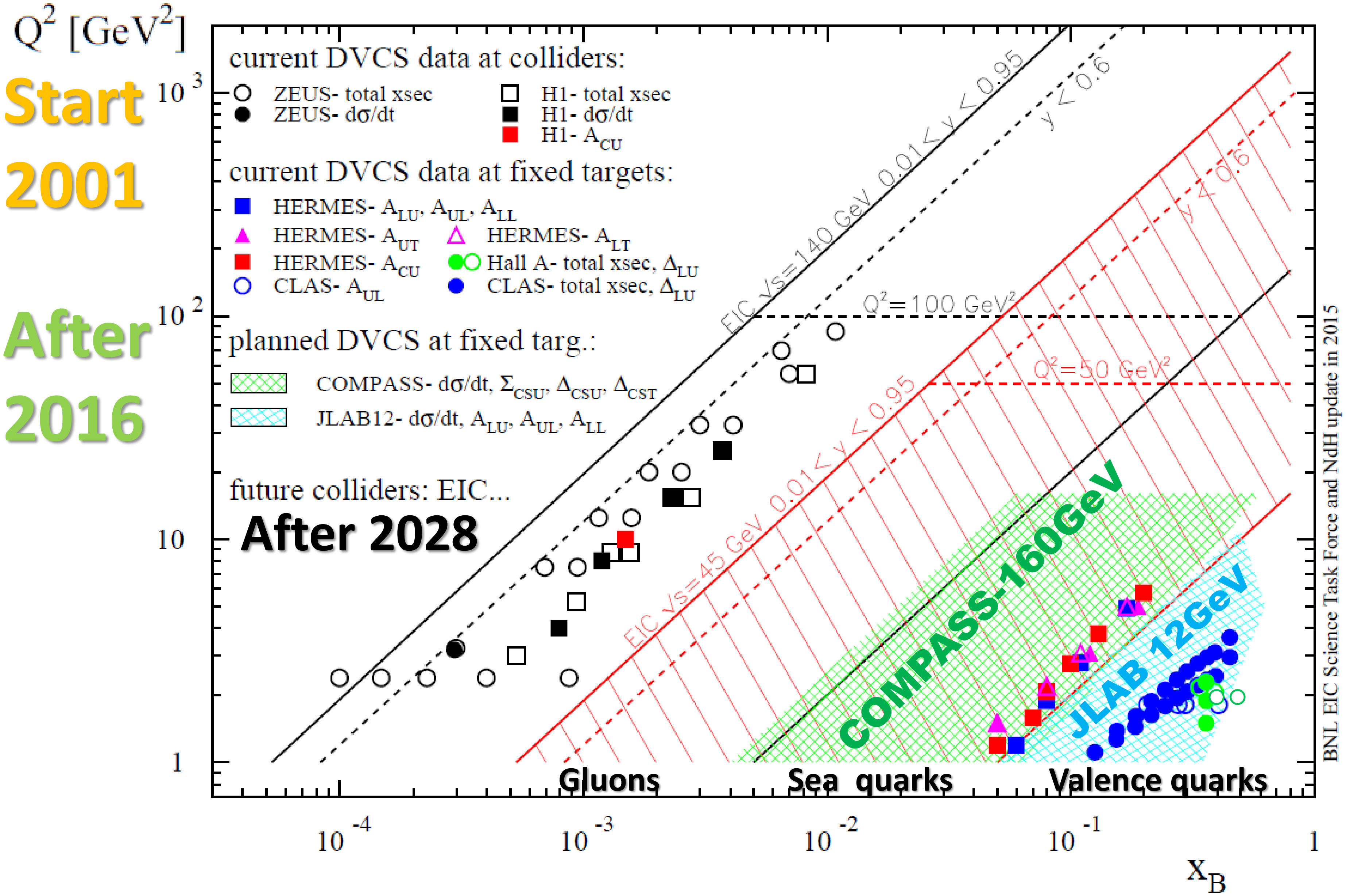
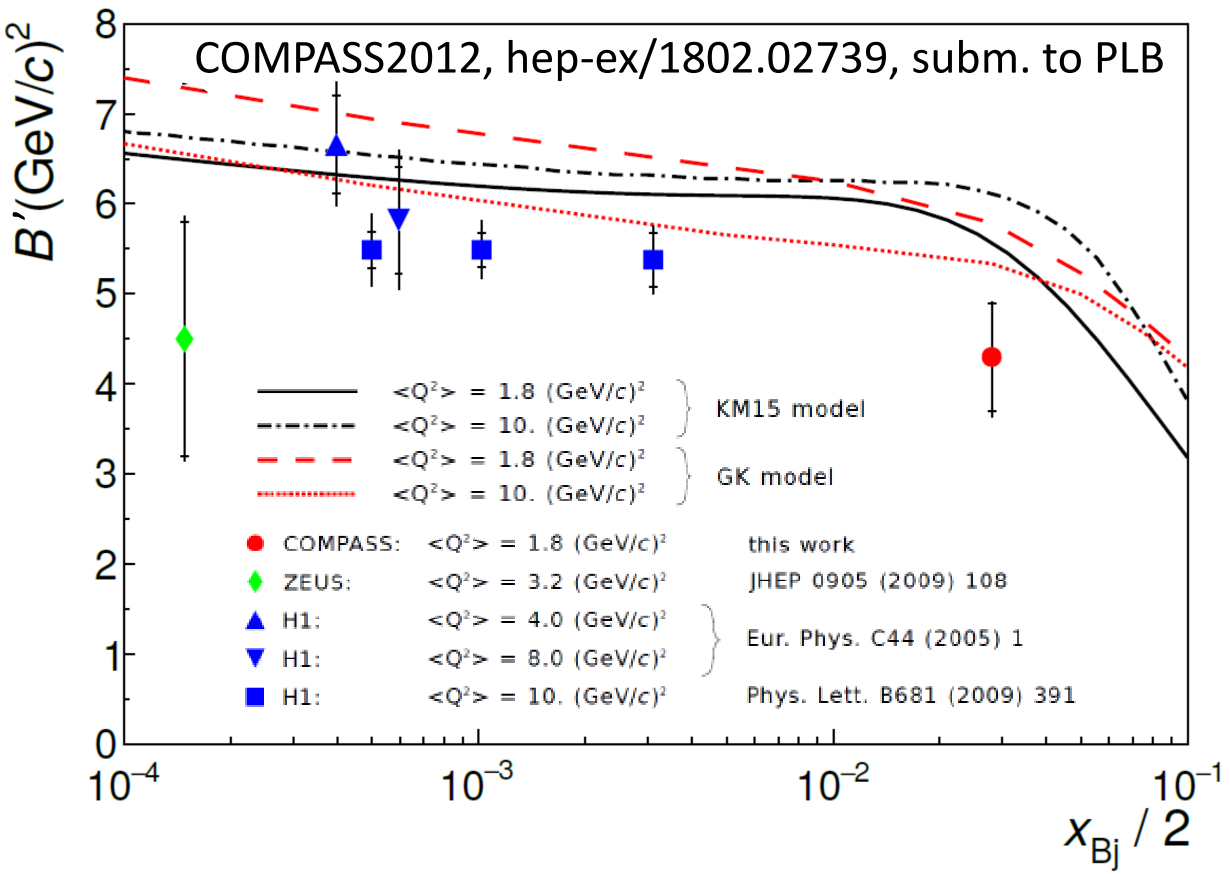



Figure from Moutarde, Sznajder, Wagner arXiv: 1807.07620



# The past and future DVCS experiments





COMPASS2012, hep-ex/1802.02739, subm. to PLB
B′(GeV/c)²
x_Bj / 2
<Q²> = 1.8 (GeV/c)²
<Q²> = 10. (GeV/c)²
KM15 model
<Q²> = 1.8 (GeV/c)²
<Q²> = 10. (GeV/c)²
GK model
COMPASS: <Q²> = 1.8 (GeV/c)² this work
ZEUS: <Q²> = 3.2 (GeV/c)² JHEP 0905 (2009) 108
H1: <Q²> = 4.0 (GeV/c)²
H1: <Q²> = 8.0 (GeV/c)²
Eur. Phys. C44 (2005) 1
H1: <Q²> = 10. (GeV/c)² Phys. Lett. B681 (2009) 391