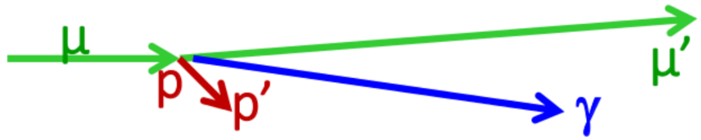
Hard Exclusive Reactions at COMPASS at CERN

Exclusive photon (DVCS) and meson (HEMP) production at small transfer for GPD studies

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



Pseudo-Scalar Meson : $\mu\ p \rightarrow \mu'\ p'\ \pi^0$

Vector Meson : $\mu\ p \rightarrow \mu'\ p'\ \rho$ or ω or ϕ ...

Nicole d'Hose - CEA Université Paris-Saclay for the COMPASS Collaboration

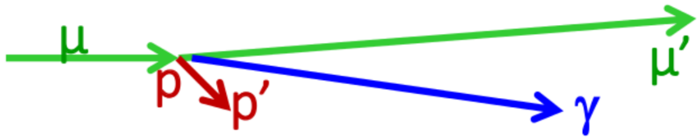
CENTER *for* NUCLEAR FEMTOGRAPHY

CNF Generalized Parton Distributions and Global Analysis

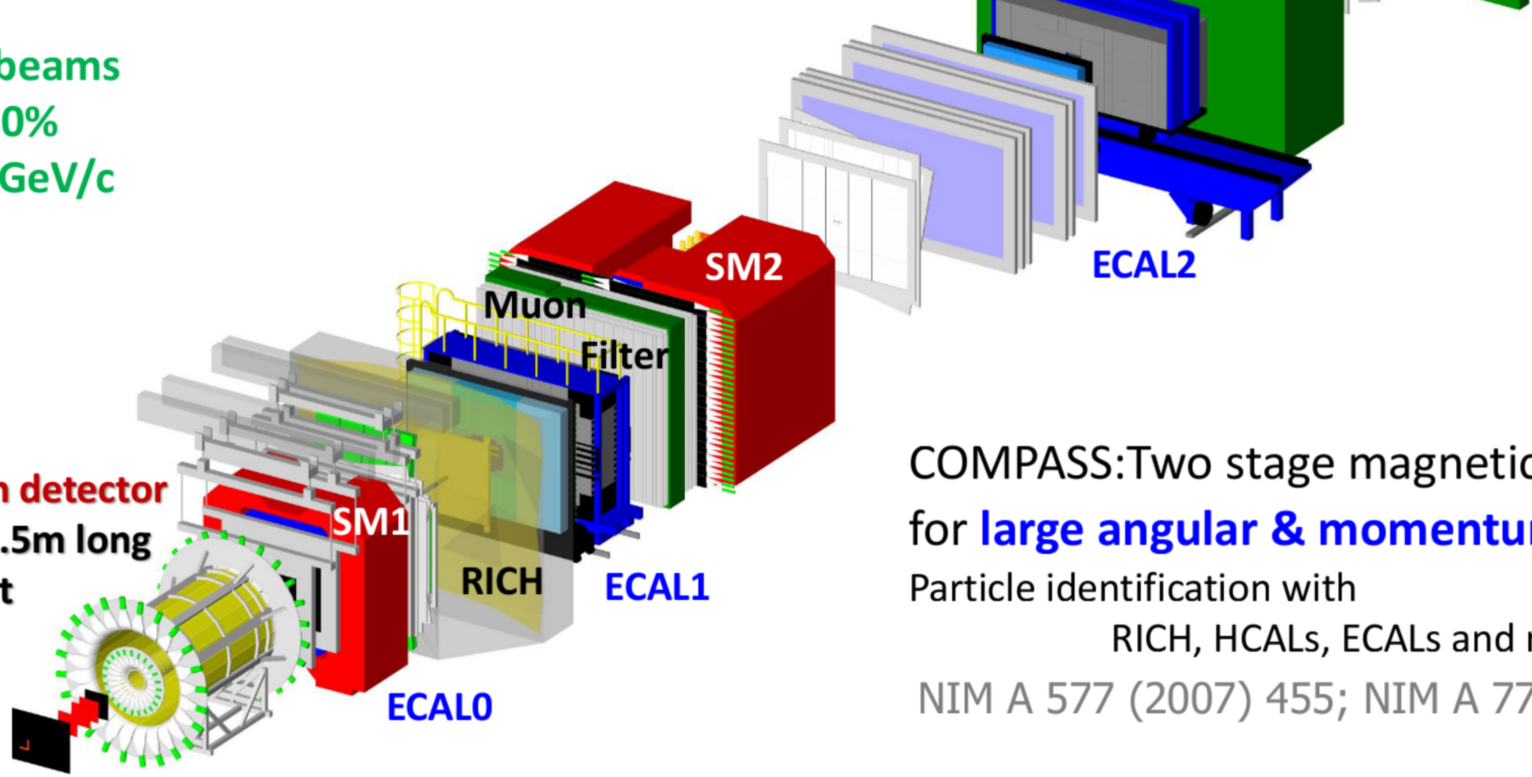
12–14 Jun 2023

Measurement of exclusive cross sections at COMPASS

DVCS : $\mu\ p \rightarrow \mu'\ p'\ \gamma$ at small transfer

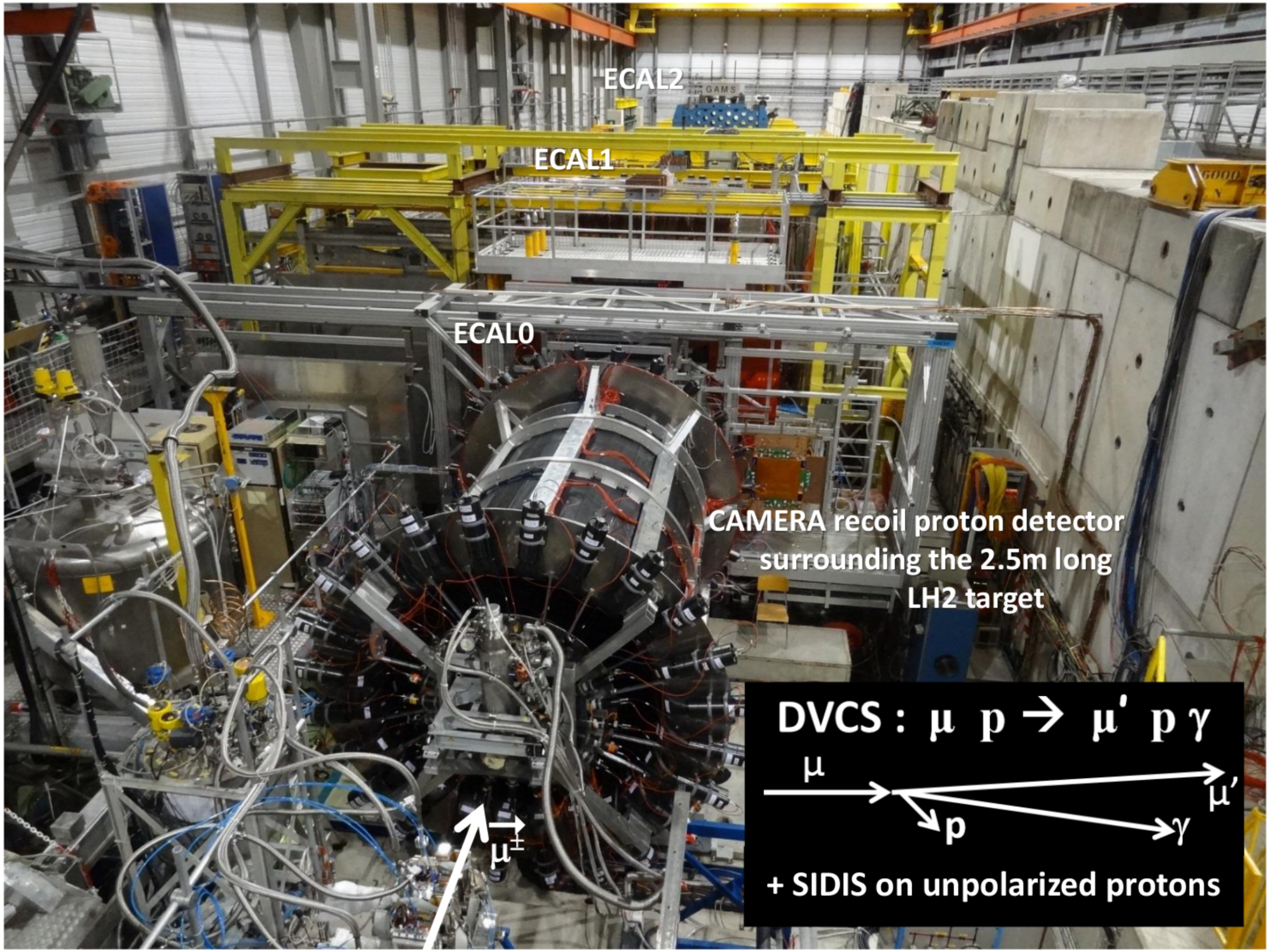


Both $\overleftarrow{\mu}^+$ and $\overrightarrow{\mu}^-$ beams
Polarisation ~ ±80%
Momentum 160 GeV/c



CAMERA recoil proton detector
surrounding the 2.5m long
LH2 target

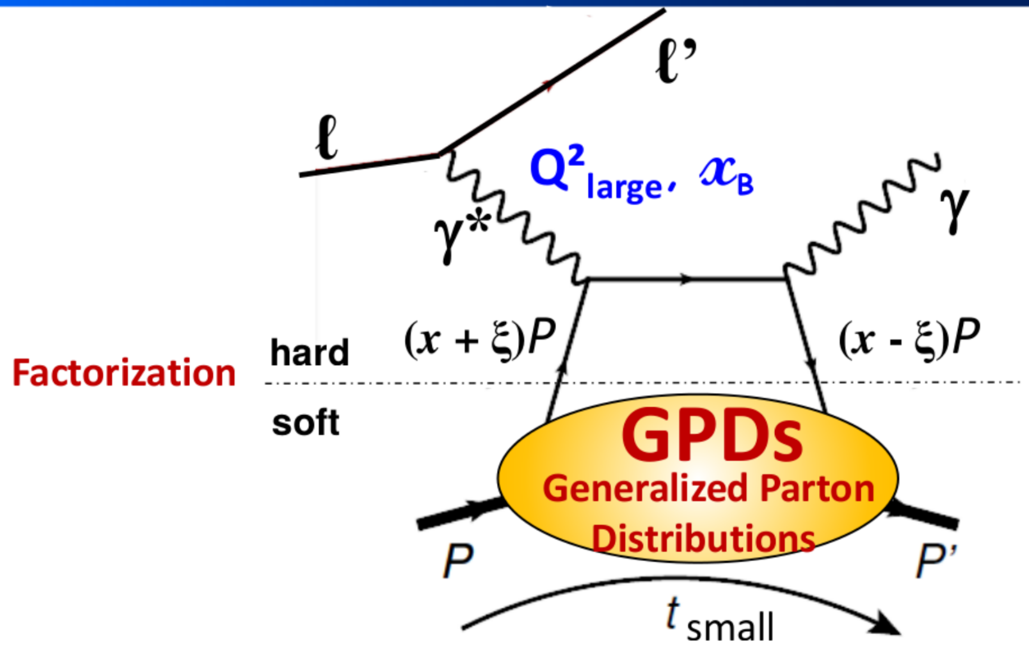
COMPASS:Two stage magnetic spectrometer
for **large angular & momentum acceptance**
Particle identification with
RICH, HCALs, ECALs and muon filters
NIM A 577 (2007) 455; NIM A 779 (2015) 69



2012:
1 month pilot run

2016 -17:
2 x 6 month
data taking

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 } quark longitudinal
ξ: transferred } momentum fraction

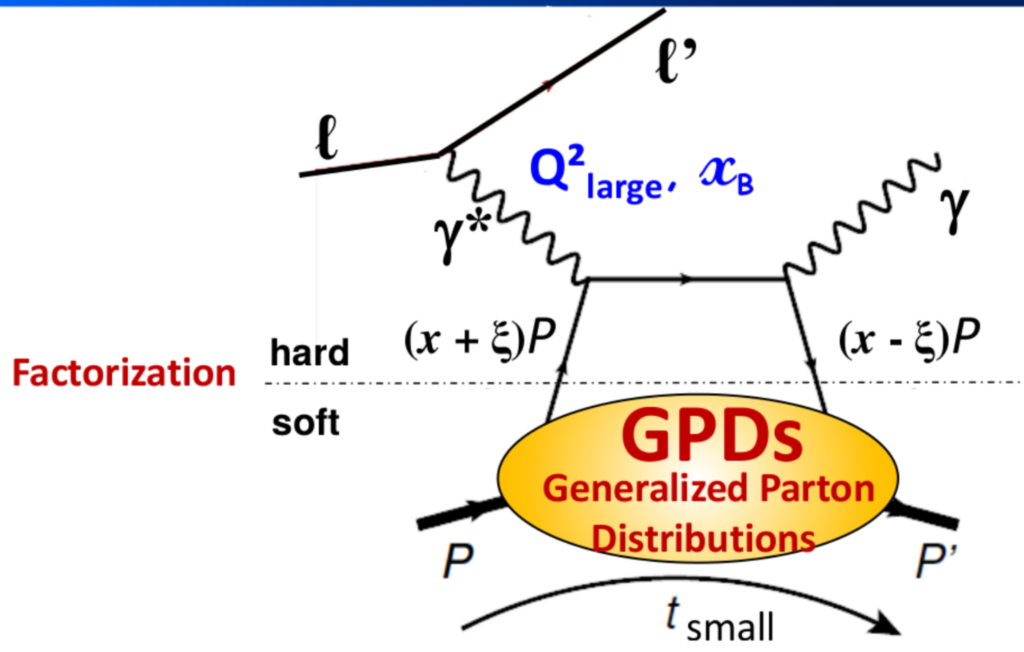
t: proton momentum transfer squared
related to $b_\perp$ via Fourier transform

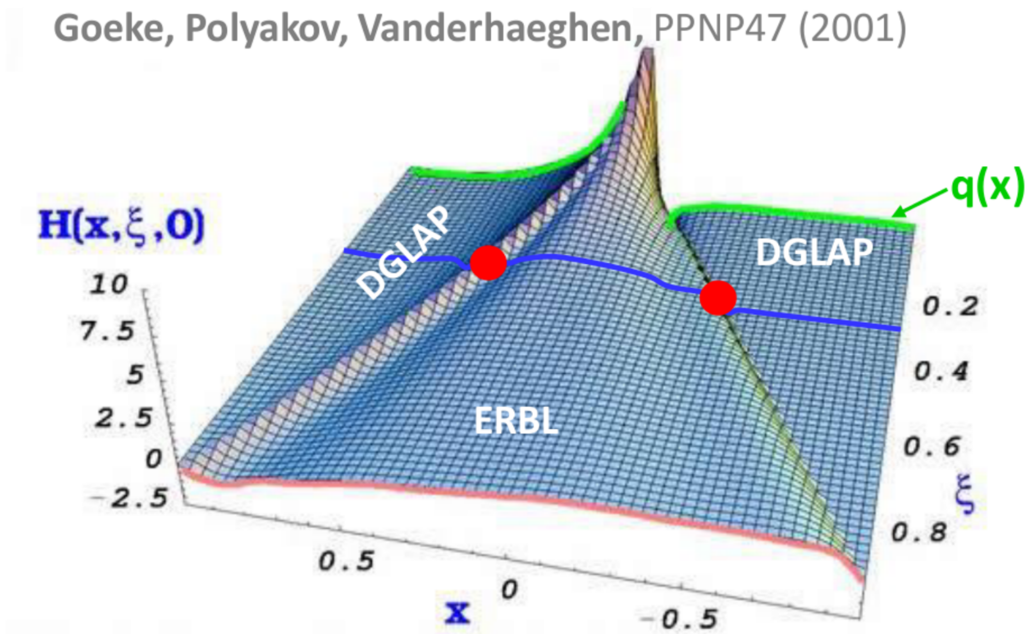
Q^2: virtuality of the virtual photon

The variables measured in the experiment:

E_ℓ, 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)





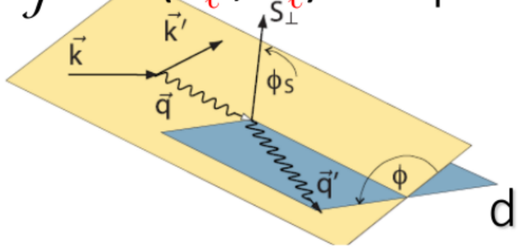
The amplitude DVCS at LT & LO in α_s (GPD **H**) : **Real part** **Imaginary part**

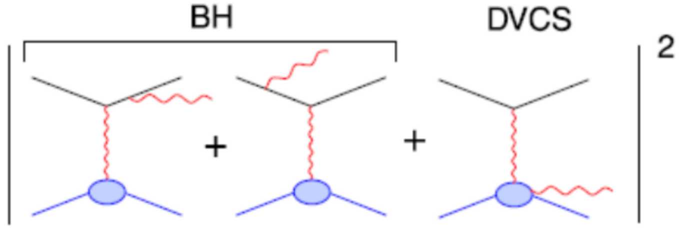
$$\underset{t,\,\xi\ \text{fixed}}{\mathcal{H}} = \int_{-1}^{+1} dx\, \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx\, \frac{H(x,\xi,t)}{x-\xi} - i\,\pi\, H(x=\pm\xi,\xi,t)$$

In an experiment we measure Compton Form Factor $\mathcal{H}$

Deeply virtual Compton scattering (DVCS)

lepton (P_ℓ , e_ℓ) and ϕ





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

$$\frac{d^4\sigma(\ell p \to \ell p \gamma)}{dx_B dQ^2 d|t| d\phi} = d\sigma^{BH} + \left(d\sigma^{DVCS}_{unpol} + P_\ell\, d\sigma^{DVCS}_{pol}\right) - \left(e_\ell \mathrm{Re}\, I + e_\ell P_\ell\, \mathrm{Im}\, I\right)$$

Well known

With unpolarized target:

Belitsky, Müller, Kirner, NPB629 (2002)

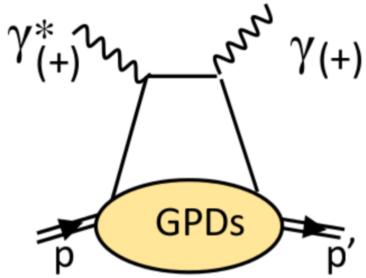
$$d\sigma^{BH} \propto c_0^{BH} + c_1^{BH}\cos\phi + c_2^{BH}\cos 2\phi$$

$$d\sigma^{DVCS}_{unpol} \propto c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi$$

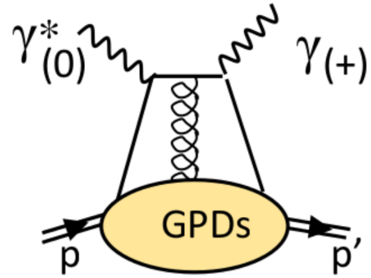
$$d\sigma^{DVCS}_{pol} \propto s_1^{DVCS}\sin\phi$$

$$\mathrm{Re}\, I \propto c_0^I + c_1^I\cos\phi + c_2^I\cos 2\phi + c_3^I\cos 3\phi$$

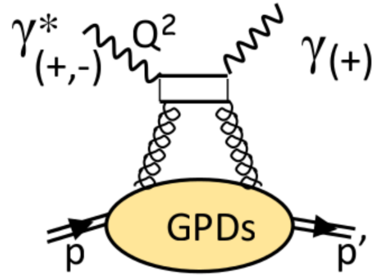
$$\mathrm{Im}\, I \propto s_1^I\sin\phi + s_2^I\sin 2\phi$$



LO,Twist-2



HT,Twist-3
suppressed by 1/Q



NLO,Twist-2
double helicity flip
suppressed by α_S

Deeply virtual Compton scattering (DVCS)

With both $\mu^{\overleftarrow{+}}$ and $\mu^{\overrightarrow{-}}$ beams we can build:

❶ **beam charge-spin sum**

$$\Sigma \equiv d\sigma^{\overleftarrow{+}} + d\sigma^{\overrightarrow{-}}$$

❷ **difference**

$$\Delta \equiv d\sigma^{\overleftarrow{+}} - d\sigma^{\overrightarrow{-}}$$

$$d\sigma^{BH} \propto c_0^{BH} + c_1^{BH}\cos\phi + c_2^{BH}\cos 2\phi$$

$$d\sigma^{DVCS}_{unpol} \propto c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi$$

$$d\sigma^{DVCS}_{pol} \propto s_1^{DVCS}\sin\phi$$

$$\mathrm{Re}\, I \propto c_0^I + c_1^I\cos\phi + c_2^I\cos 2\phi + c_3^I\cos 3\phi$$

$$\mathrm{Im}\, I \propto s_1^I\sin\phi + s_2^I\sin 2\phi$$

$$\Sigma \equiv d\sigma^{\overleftarrow{+}} + d\sigma^{\overrightarrow{-}} \rightarrow s_1^I \propto Im\,\mathcal{F}$$

and $c_0^{DVCS} \propto (Im\mathcal{H})^2$

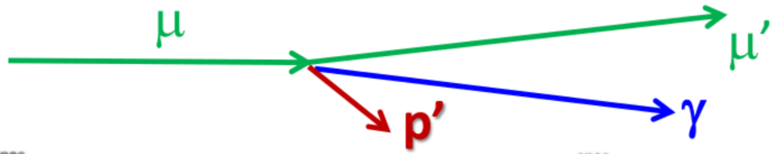
$$\Delta \equiv d\sigma^{\overleftarrow{+}} - d\sigma^{\overrightarrow{-}} \rightarrow c_1^I \propto Re\,\mathcal{F}$$

$$\mathcal{F} = F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - t/4m^2 F_2\mathcal{E} \xrightarrow{\text{for proton}} F_1\mathcal{H}$$

at small x_B
COMPASS domain

COMPASS 2016 data Selection of exclusive single photon production

Comparison between the observables given by the spectro or by CAMERA



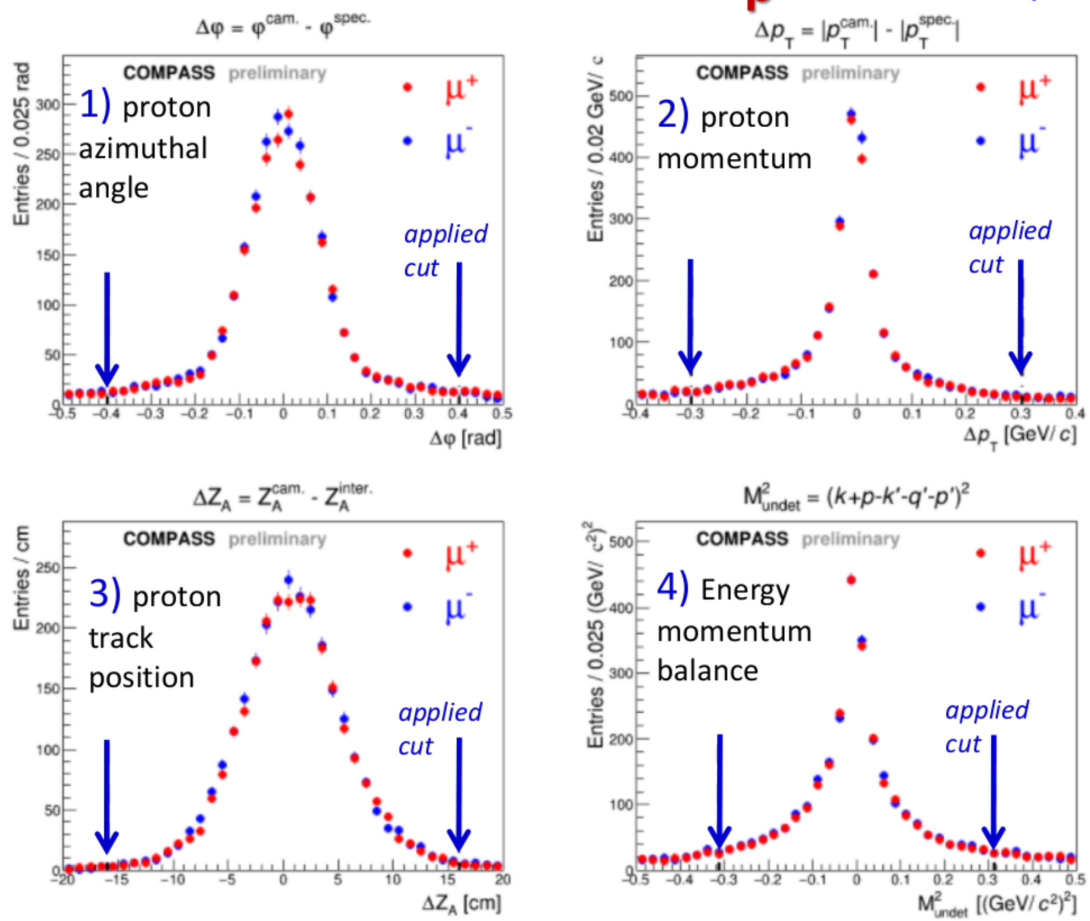
DVCS : μ p → μ' p γ

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

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

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

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



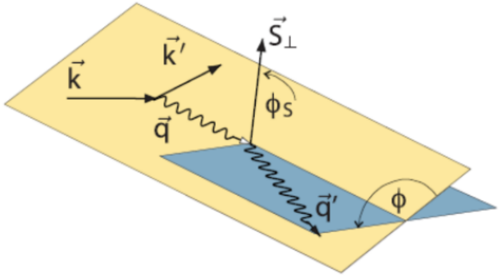
Good agreement between $\overleftarrow{\mu}^{+}$ **and** $\overrightarrow{\mu}^{-}$ yields

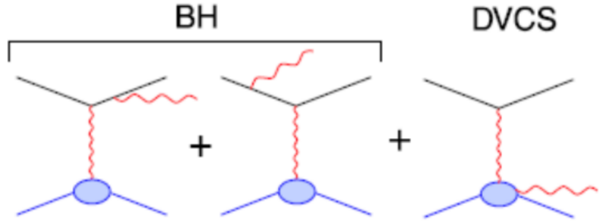
Important achievement for:

❶ $\Sigma \equiv d\sigma^{\overleftarrow{+}} + d\sigma^{\overrightarrow{-}}$ **Easier, done first**

❷ $\Delta \equiv d\sigma^{\overleftarrow{+}} - d\sigma^{\overrightarrow{-}}$ **Challenging, but promising**

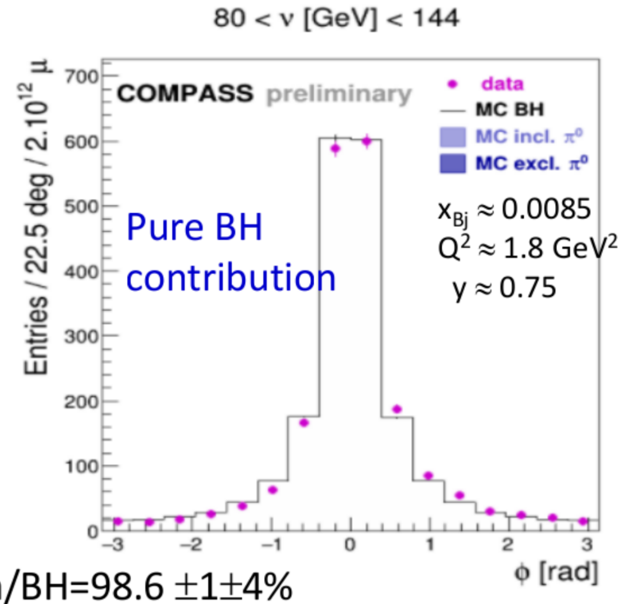
COMPASS 2016 data — DVCS+BH cross section at Eμ=160 GeV

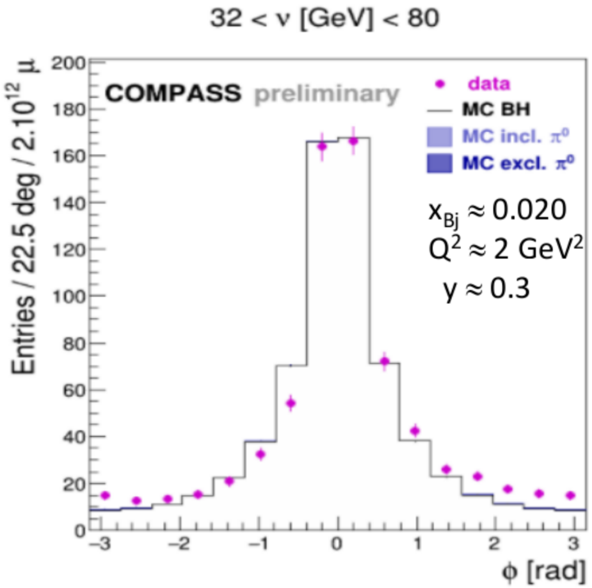


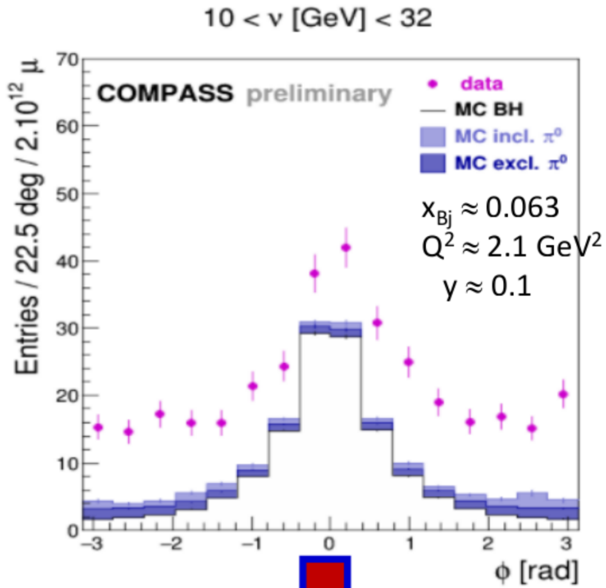


$$\Sigma = d\sigma(\overleftarrow{\mu^{+}}) + d\sigma(\overrightarrow{\mu^{-}})$$

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







Data/BH=98.6 ±1±4%

MC: BH contribution evaluated for the integrated luminosity
$\pi°$ background contribution from SIDIS (LEPTO) + exclusive production (HEPGEN)

DVCS above the BH contrib.

COMPASS 2016 DVCS cross section for 10 < υ < 32 GeV

At COMPASS using polarized positive and negative muon beams:

$$\Sigma \equiv d\sigma^{\overset{+}{\leftarrow}} + d\sigma^{\overset{-}{\rightarrow}} = 2[d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + \mathrm{Im}\, I]$$

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

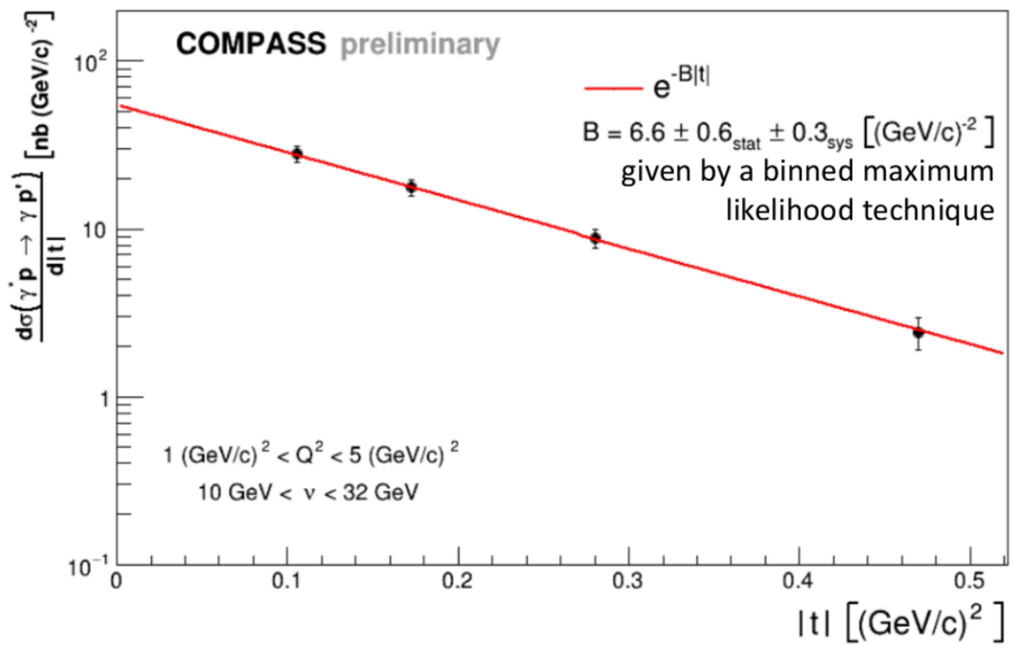
calculable
can be subtracted

All the other terms are cancelled in the integration over ϕ

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

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

Flux for transverse
virtual photons



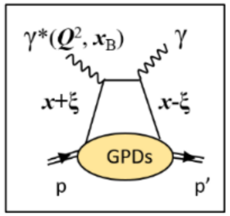
COMPASS 12-16 Transverse extention of partons in the sea quark range

$$d\sigma^{DVCS}/dt = e^{-B|t|} = c_0^{DVCS} \propto (Im\mathcal{H})^2$$

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

In the COMPASS kinematics, $x_B \approx 0.06$, dominance of $Im\mathcal{H}$
97% (GK model) 94% (KM model)

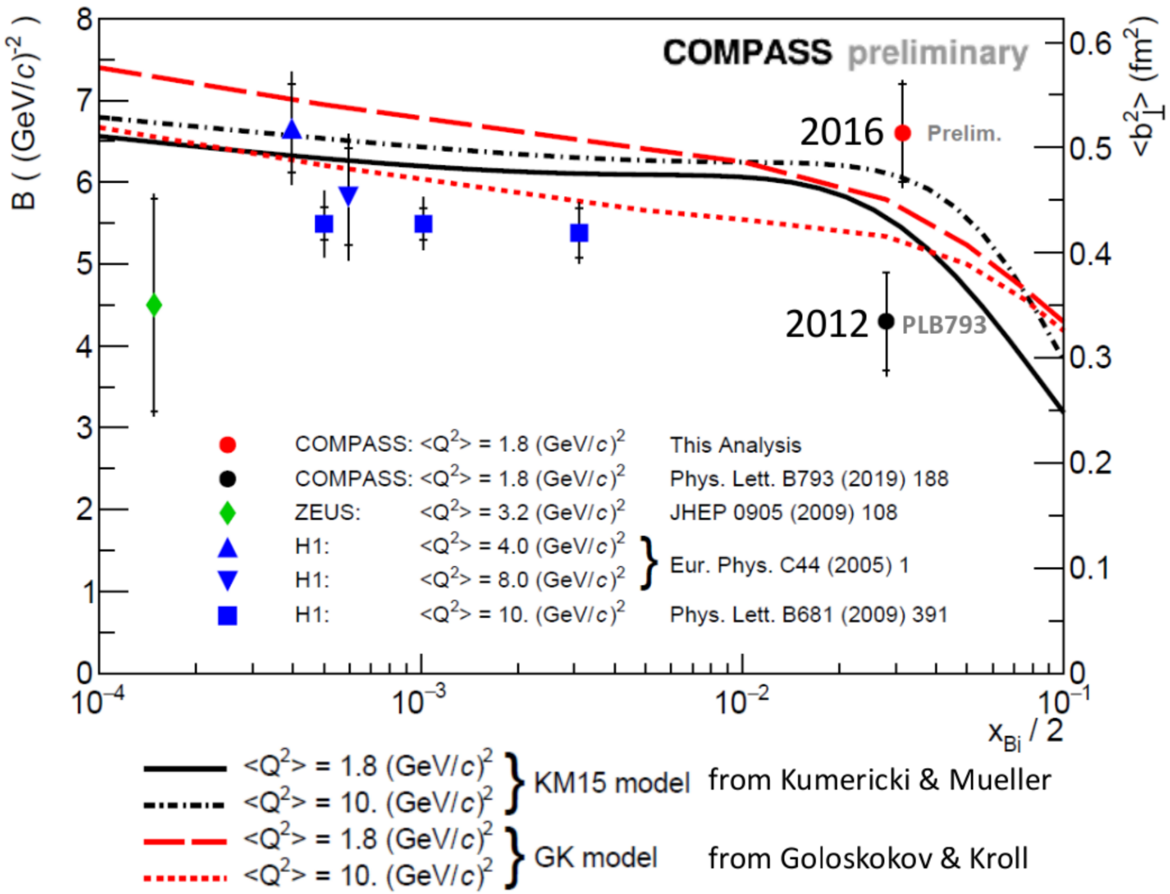
$Im\mathcal{H}$ = H (x=ξ, ξ, t)
$x = \xi \approx x_B/2$ close to 0



$$q(x, \mathbf{b}_\perp) = \int \frac{d^2\mathbf{\Delta}_\perp}{(2\pi)^2} e^{-i\mathbf{b}_\perp \cdot \mathbf{\Delta}_\perp} H_-^q(x, 0, -\mathbf{\Delta}_\perp{}^2).$$

$$\langle b_\perp^2 \rangle_x^f = \frac{\int d^2b_\perp b_\perp^2 q_f(x, b_\perp)}{\int d^2b_\perp q_f(x, b_\perp)} = -4\frac{\partial}{\partial t} \log H^f(x, \xi = 0, t)\Big|_{t=0}$$

$$\langle b_\perp^2(x) \rangle \approx 2B(\xi)$$



COMPASS 12-16 Transverse extention of partons in the sea quark range

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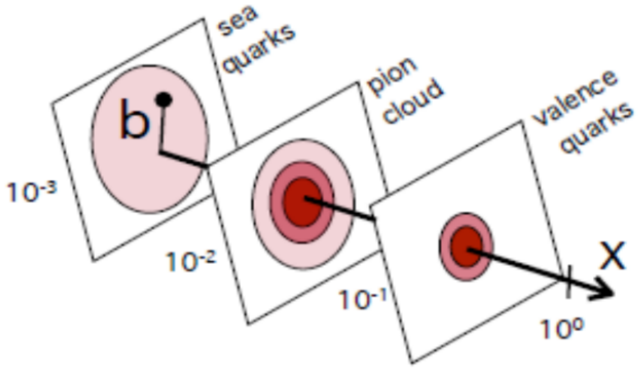
$$\langle b_\perp^2(x)\rangle \approx 2B(\xi)$$



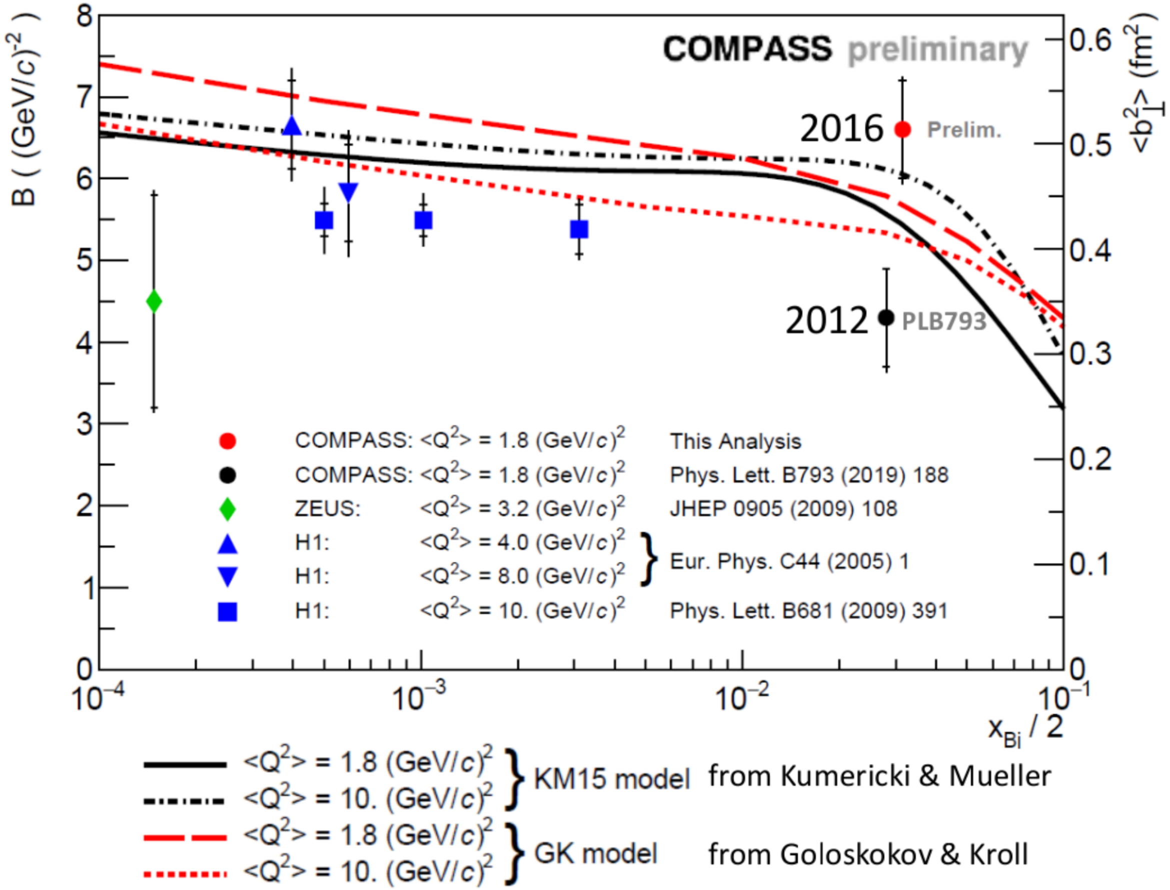
3σ difference between 2012 and 2016 data

- more advanced analysis with 2016 data
- π^0 contamination with different thresholds
- binning with 3 variables (t,Q^2,ν) or 4 variables (t,ϕ,Q^2,ν)

2012 statistics = Ref

2016 analysed statistics = 2.3 × Ref

2016+2017 expected statistics = 10 × Ref



Possible next steps for DVCS

- ✓ DVCS and the sum $\Sigma \equiv d\sigma^{\overset{+}{\leftarrow}} + d\sigma^{\overset{-}{\rightarrow}}$
  - ➔ $c_0 \sim (\mathrm{Im}\mathcal{H})^2$ final conclusion using all the data sets 2012, 2016, 2017
  - ➔ $s_1 \sim \mathrm{Im}\mathcal{H}$

    constrain on $\mathrm{Im}\mathcal{H}$ and Transverse extension of partons

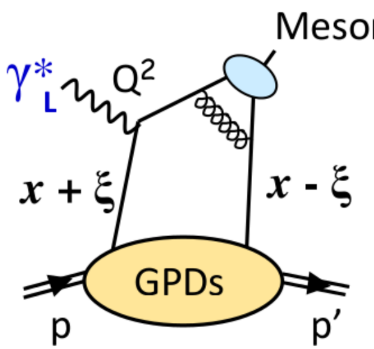
- ✓ DVCS and the difference $\Delta \equiv d\sigma^{\overset{+}{\leftarrow}} - d\sigma^{\overset{-}{\rightarrow}}$
  - ➔ c_1 and constrain on $\mathrm{Re}\mathcal{H}$ (>0 as H1 or <0 as HERMES)

    for D-term and pressure distribution

GPDs and Hard Exclusive Meson Production

Factorisation proven only for σ_L
The meson wave function
Is an additional non-perturbative term

Quark contribution



For Pseudo-Scalar Meson, as π^0

chiral-even GPDs: helicity of parton unchanged

$\tilde{H}^q(x, \xi, t)$ $\tilde{E}^q(x, \xi, t)$

+ chiral-odd or transversity GPDs: helicity of parton changed

$H_T^q(x, \xi, t)$ (as the transversity TMD)

$\bar{E}_T^q = 2\,\tilde{H}_T^q + E_T^q$ (as the Boer-Mulders TMD)

σ_T is asymptotically suppressed by $1/Q^2$ but large contribution observed
GK model: k_T of q and $\bar{q}$ and Sudakov suppression factor are considered
Chiral-odd GPDs with a twist-3 meson wave function

COMPASS 2012 - 16 Exclusive π^0 production on unpolarized proton

$\mu^\pm p \rightarrow \mu^\pm \pi^0 p$

$F\pi^0 = 2/3 F^u + 1/3 F^d$

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

COMPASS

Q^2=2.0 GeV^2

x_B=0.093

|t|~ 0.26 GeV^2

ε close to 1

8.5 < ν < 26 GeV

1 < Q^2 < 5 GeV^2

$$\frac{d\sigma_L}{dt} \propto \left|\langle\tilde{H}\rangle\right|^2 - \frac{t'}{4m^2}\left|\langle\tilde{E}\rangle\right|^2$$

$$\frac{d\sigma_T}{dt} \propto |\langle H_T\rangle|^2 - \frac{t'}{8m^2}\left|\langle\bar{E}_T\rangle\right|^2$$

$$\frac{\sigma_{TT}}{dt} \propto \frac{t'}{16m^2}\left|\langle\bar{E}_T\rangle\right|^2$$

$$\frac{\sigma_{LT}}{dt} \propto \frac{\sqrt{-t'}}{2m}\,\mathrm{Re}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

$$\left\langle\frac{d\sigma_T}{d|t|} + \epsilon\frac{d\sigma_L}{d|t|}\right\rangle = (8.2 \pm 0.9_{stat}\,{}^{+\,1.2}_{-\,1.2}|_{sys})\frac{\text{nb}}{(\text{GeV}/c)^2}$$

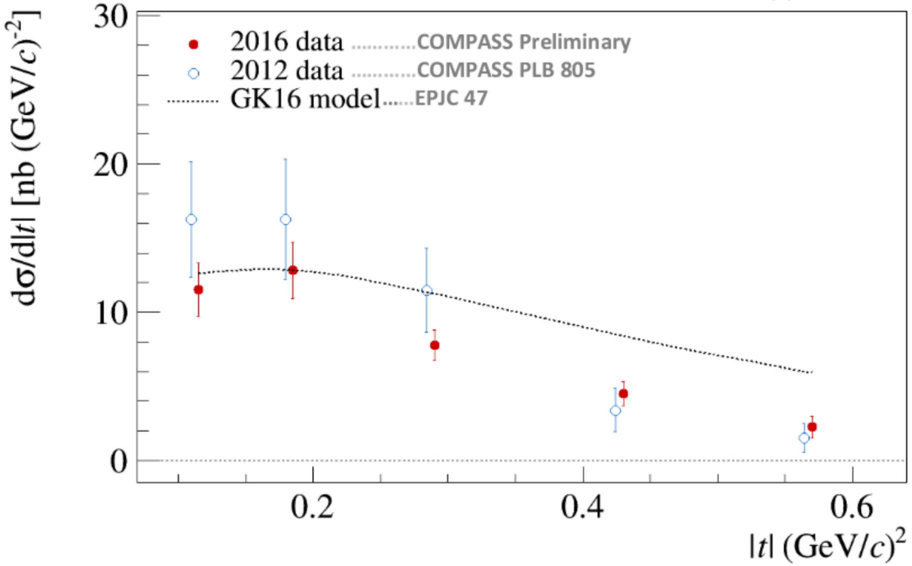
$$\left\langle\frac{d\sigma_{TT}}{d|t|}\right\rangle = (-6.1 \pm 1.3_{stat}\,{}^{+\,0.7}_{-\,0.7}|_{sys})\frac{\text{nb}}{(\text{GeV}/c)^2}$$

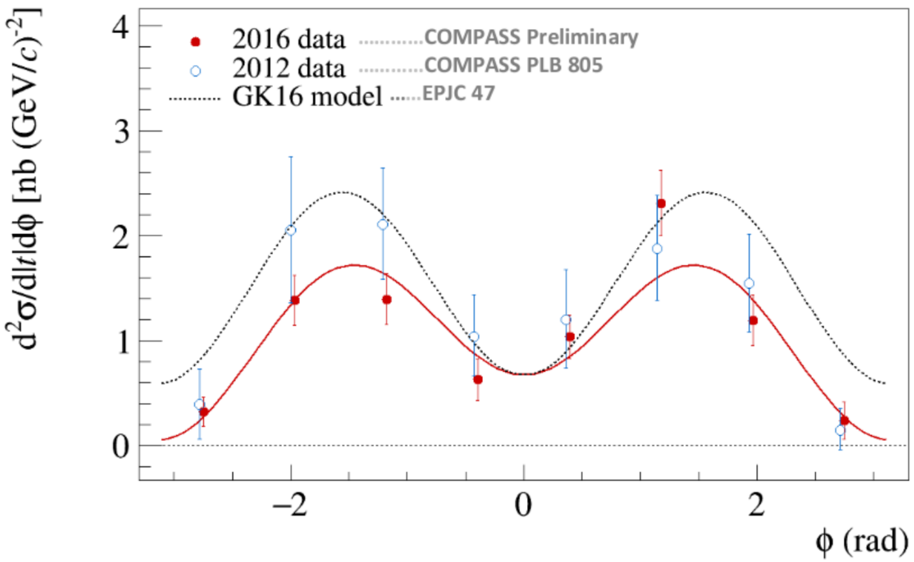
$$\left\langle\frac{d\sigma_{LT}}{d|t|}\right\rangle = (1.5 \pm 0.5_{stat}\,{}^{+\,0.3}_{-\,0.2}|_{sys})\frac{\text{nb}}{(\text{GeV}/c)^2}$$

PLB 805 (2020)

σ_{TT} large - impact of $\bar{E}_T$

σ_{LT} small but significantly positive as at CLAS





Data: **COMPASS,** PLB 805 (2020) Models: **GK** Kroll Goloskokov EPJC47 (2011) Also **GGL**: Golstein Gonzalez Liuti PRD91 (2015)

Next steps for pi0

Analysis of the 2016 data set should be completed by the end of the month

Extended kinematical domain at small and large ν to provide x_B evolution

$8.5 < \nu < 26$ GeV

6.4 ↙ ↘ 40 GeV

The 2017 data set will still increase the statistics

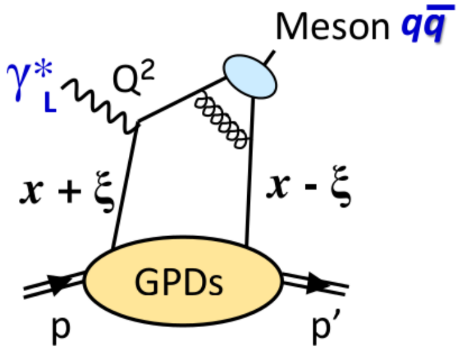
GPDs and Hard Exclusive Meson Production

Factorisation proven only for σ_L

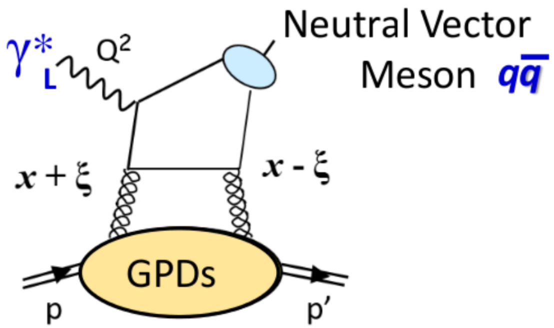
The meson wave function

Is an additional non-perturbative term

Quark contribution



Gluon contribution at the same order in α_S



For Vector Meson, as ρ, ω, φ…

chiral-even GPDs: helicity of parton unchanged

$H^q(x, \xi, t)$ $E^q(x, \xi, t)$

+ chiral-odd or transversity GPDs: helicity of parton changed

$H_T^q(x, \xi, t)$ (as the transversity TMD)

$\bar{E}_T^q = 2\,\tilde{H}_T^q + E_T^q$ (as the Boer-Mulders TMD)

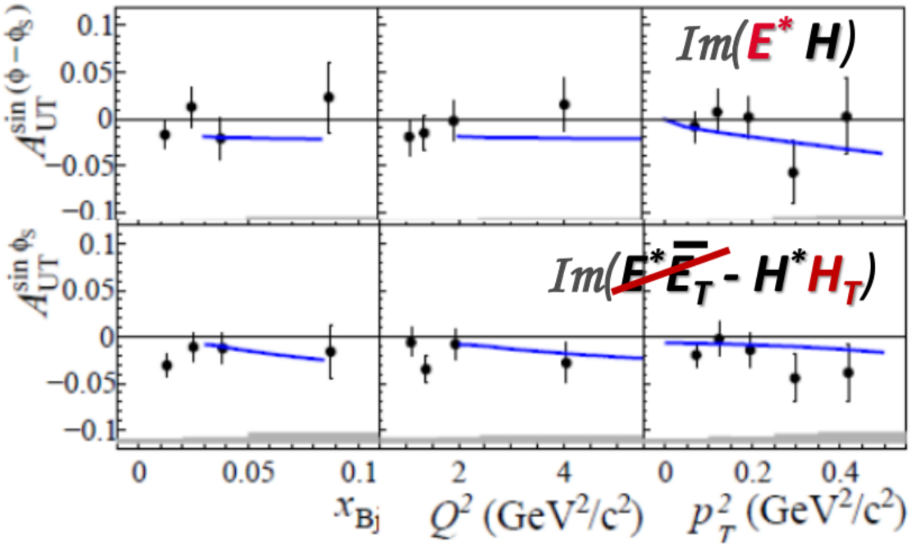
COMPASS 2010 2007 HEMP with Transversely Polarized Target without RPD

Gparity: G(π)=-1; G(ρ)=+1; G(ω)=-1

$\rho^0 \to \pi^+ \pi^-$

$$E_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u + \frac{1}{3}E^d + \frac{3}{4}\frac{E_g}{x}\right)$$

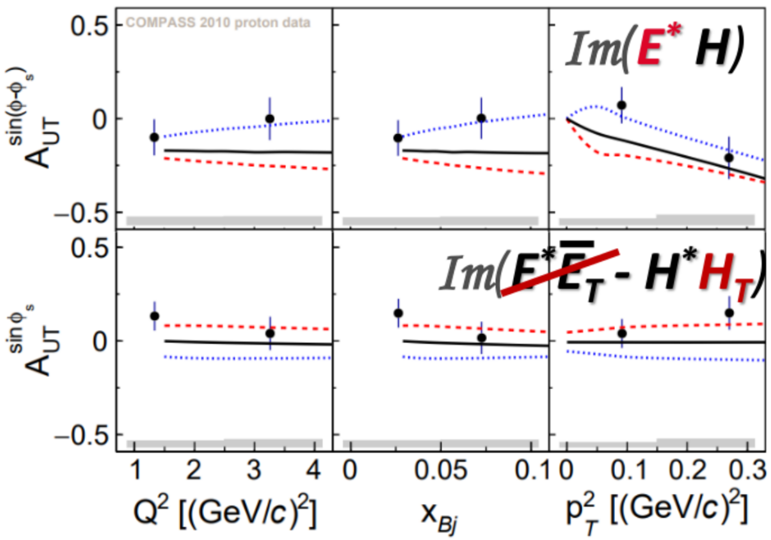
COMPASS, NPB 865 (**2012**) 1-20, PLB731 (**2014**) 19



$\omega \to \pi^+ \pi^- \pi^0$

$$E_{\omega} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u - \frac{1}{3}E^d + \frac{1}{4}\frac{E_g}{x}\right)$$

COMPASS, NPB 915 (**2017**)

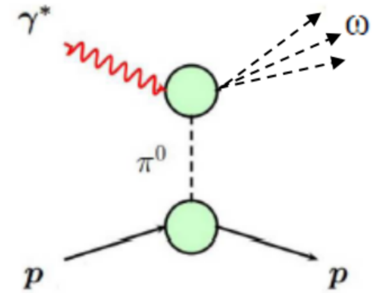


E^u and E^d of opposite sign

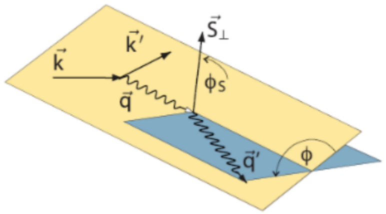
ω is more promising (see the larger scale) but there is the inherent pion pole contribution

$\Gamma(\omega \to \pi^0\gamma) = 9\times\Gamma(\rho^0 \to \pi^0\gamma)$

Same for πω FF but sign unknown



- positive πω form factor
- no pion pole
- negative πω form factor

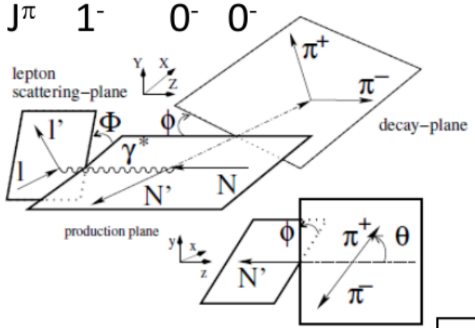


GK EPJC42,50,53,59,65,74

exclusive VM production with Unpolarised Target and SDME

$\rho^0 \rightarrow \pi^+ \ \pi^-$

$J^\pi \quad 1^- \quad 0^- \quad 0^-$



experimental angular distributions:

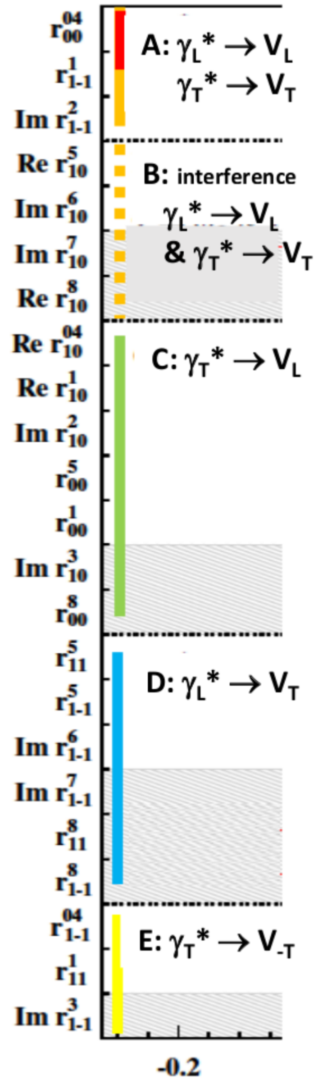
$$\mathcal{W}^{U+L}(\Phi, \phi, \cos\Theta) = \mathcal{W}^{U}(\Phi, \phi, \cos\Theta) + P_b \mathcal{W}^{L}(\Phi, \phi, \cos\Theta)$$

15 'unpolarized' and 8 'polarized' SDMEs

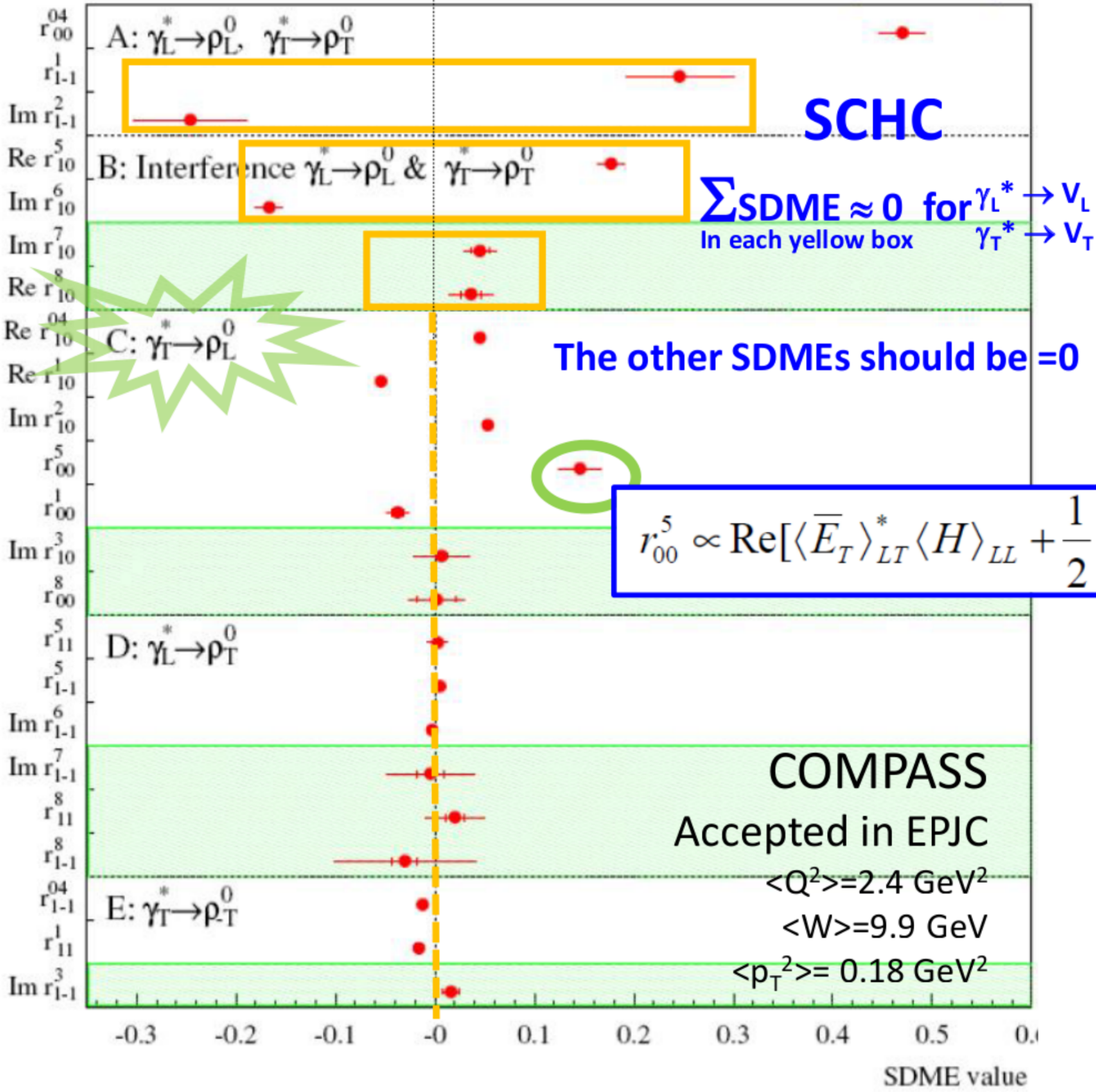
$$\mathcal{W}^{U}(\Phi, \phi, \cos\Theta) = \frac{3}{8\pi^2}\Big[\frac{1}{2}(1 - r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00} - 1)\cos^2\Theta - \sqrt{2}\mathrm{Re}\{r^{04}_{10}\}\sin 2\Theta\cos\phi - r^{04}_{1-1}\sin^2\Theta \cos 2\phi$$
$$-\epsilon\cos 2\Phi\Big(r^{1}_{11}\sin^2\Theta + r^{1}_{00}\cos^2\Theta - \sqrt{2}\mathrm{Re}\{r^{1}_{10}\}\sin 2\Theta\cos\phi - r^{1}_{1-1}\sin^2\Theta\cos 2\phi\Big)$$
$$-\epsilon\sin 2\Phi\Big(\sqrt{2}\mathrm{Im}\{r^{2}_{10}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{r^{2}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)$$
$$+\sqrt{2\epsilon(1+\epsilon)}\cos\Phi\Big(r^{5}_{11}\sin^2\Theta + r^{5}_{00}\cos^2\Theta - \sqrt{2}\mathrm{Re}\{r^{5}_{10}\}\sin 2\Theta\cos\phi - r^{5}_{1-1}\sin^2\Theta\cos 2\phi\Big)$$
$$+\sqrt{2\epsilon(1+\epsilon)}\sin\Phi\Big(\sqrt{2}\mathrm{Im}\{r^{6}_{10}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{r^{6}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)\Big],$$

$$\mathcal{W}^{L}(\Phi, \phi, \cos\Theta) = \frac{3}{8\pi^2}\Big[\sqrt{1-\epsilon^2}\Big(\sqrt{2}\mathrm{Im}\{r^{3}_{10}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{r^{3}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)$$
$$+\sqrt{2\epsilon(1-\epsilon)}\cos\Phi\Big(\sqrt{2}\mathrm{Im}\{r^{7}_{10}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{r^{7}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)$$
$$+\sqrt{2\epsilon(1-\epsilon)}\sin\Phi\Big(r^{8}_{11}\sin^2\Theta + r^{8}_{00}\cos^2\Theta - \sqrt{2}\mathrm{Re}\{r^{8}_{10}\}\sin 2\Theta\cos\phi - r^{8}_{1-1}\sin^2\Theta\cos 2\phi\Big)\Big]$$

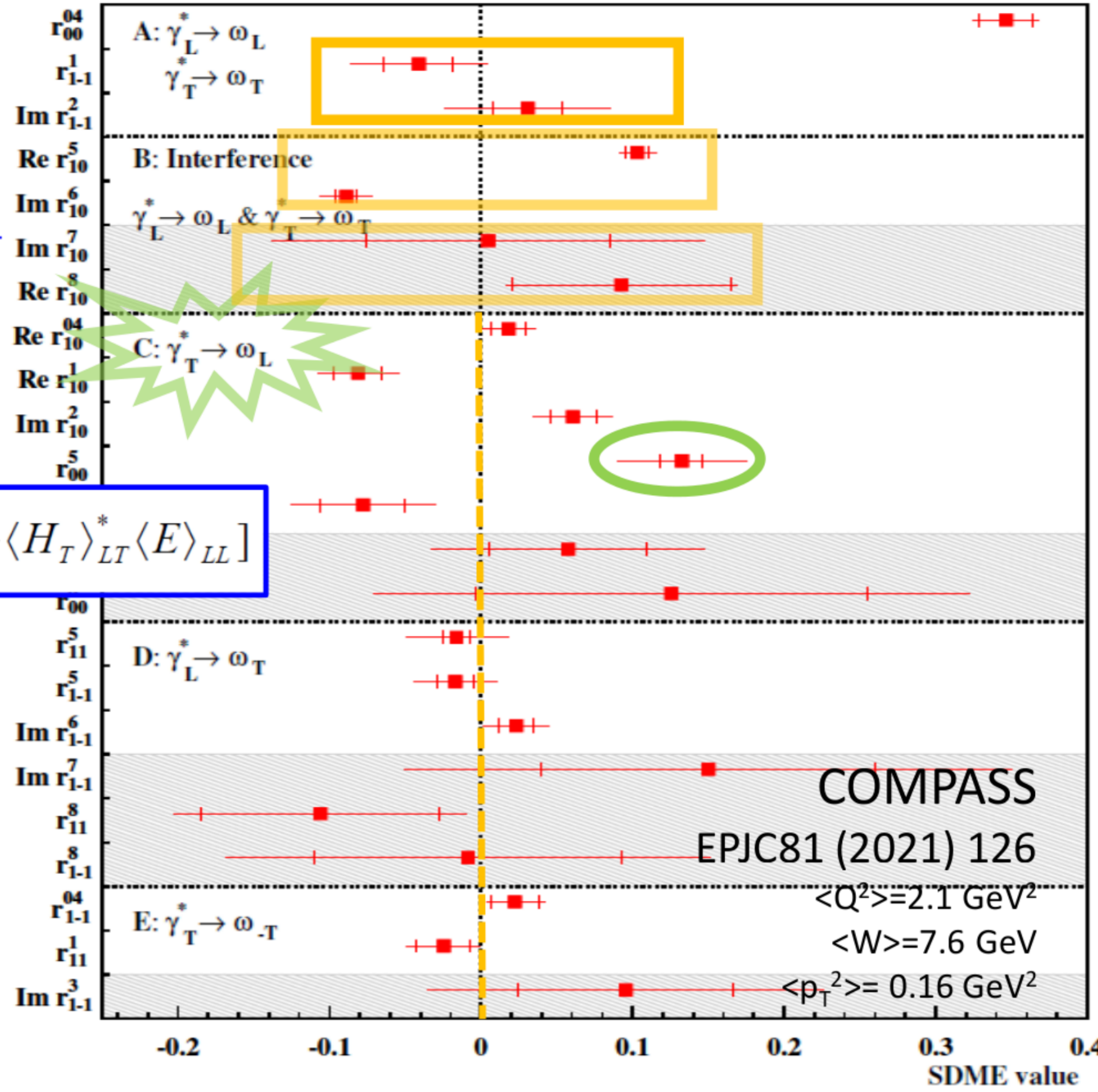
ε close to 1,
small $\mathcal{W}^L$
no L/T separation



COMPASS 2012 Exclusive ρ^0 and ω production on unpolarized proton



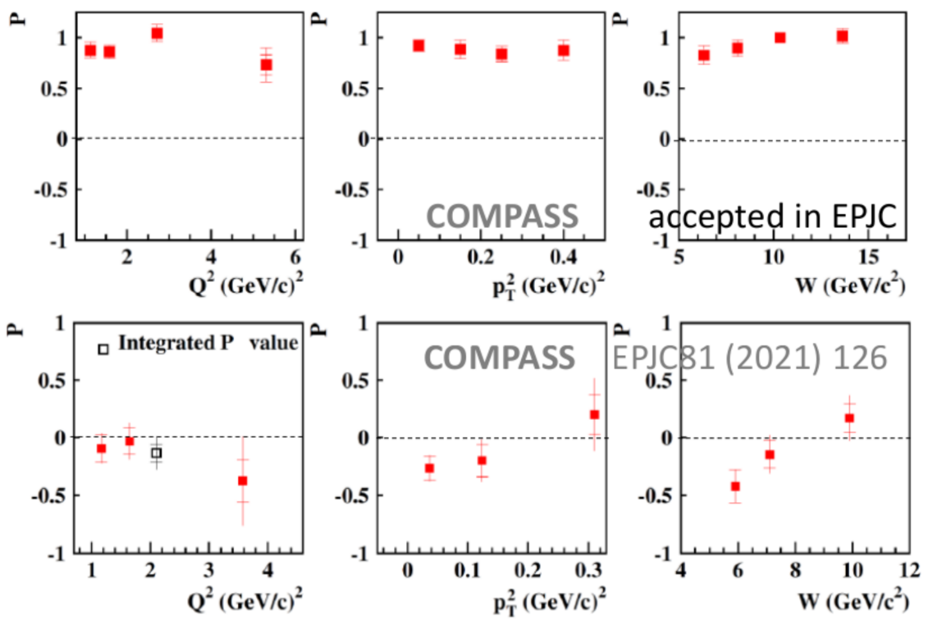
$$r^5_{00} \propto \mathrm{Re}[\langle \overline{E}_T \rangle^*_{LT} \langle H \rangle_{LL} + \frac{1}{2} \langle H_T \rangle^*_{LT} \langle E \rangle_{LL}]$$



COMPASS 2012 Comparison ω and ρ^0 production

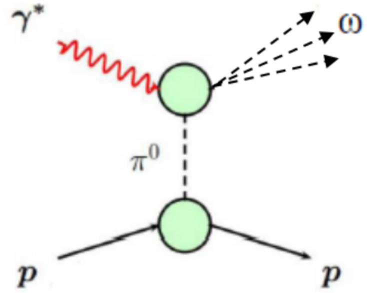
Natural (N) to Unatural (U) Parity Exchange for $\gamma_T^* \to V_T$

$$P = \frac{2r_{1-1}^{1}}{1 - r_{00}^{04} - 2r_{1-1}^{04}} \approx \frac{d\sigma_T^N(\gamma_T^* \to V_T) - d\sigma_T^U(\gamma_T^* \to V_T)}{d\sigma_T^N(\gamma_T^* \to V_T) + d\sigma_T^U(\gamma_T^* \to V_T)}$$



The pion pole exchange (UPE) is large for ω compared to ρ^0

$\Gamma(\omega \to \pi^0 \gamma) = 9 \times \Gamma(\rho^0 \to \pi^0 \gamma)$ as for π^0 Vector Meson FF



It plays an important role in ω production for:

$\gamma_T^* \to V_T$

and $\gamma_L^* \to V_T$

ρ^0: P~1 ➔ NPE dominance P~1

NPE with GPDs H, E

ω: P~0 ➔ NPE ~ UPE

UPE dominance at small W and p_T^2

UPE with GPDs $\tilde{H}, \tilde{E}$ and the dominant pion pole

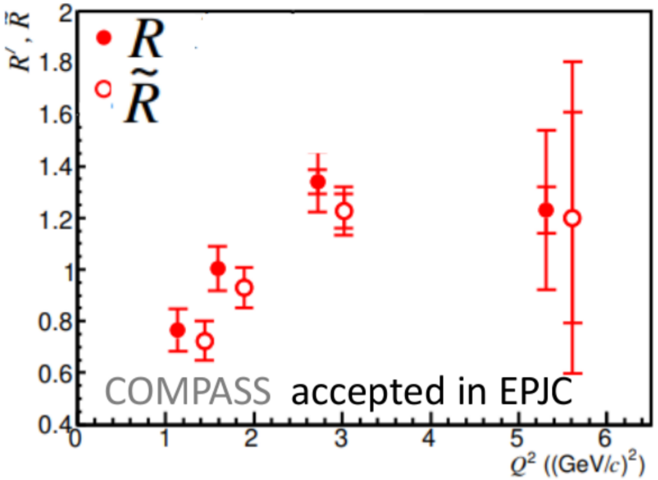
COMPASS 2012 $R = \sigma_L/\sigma_T$ for exclusive ρ^0 production

$$R = \frac{\sigma_L(\gamma_L^* \to V)}{\sigma_T(\gamma_T^* \to V)}$$

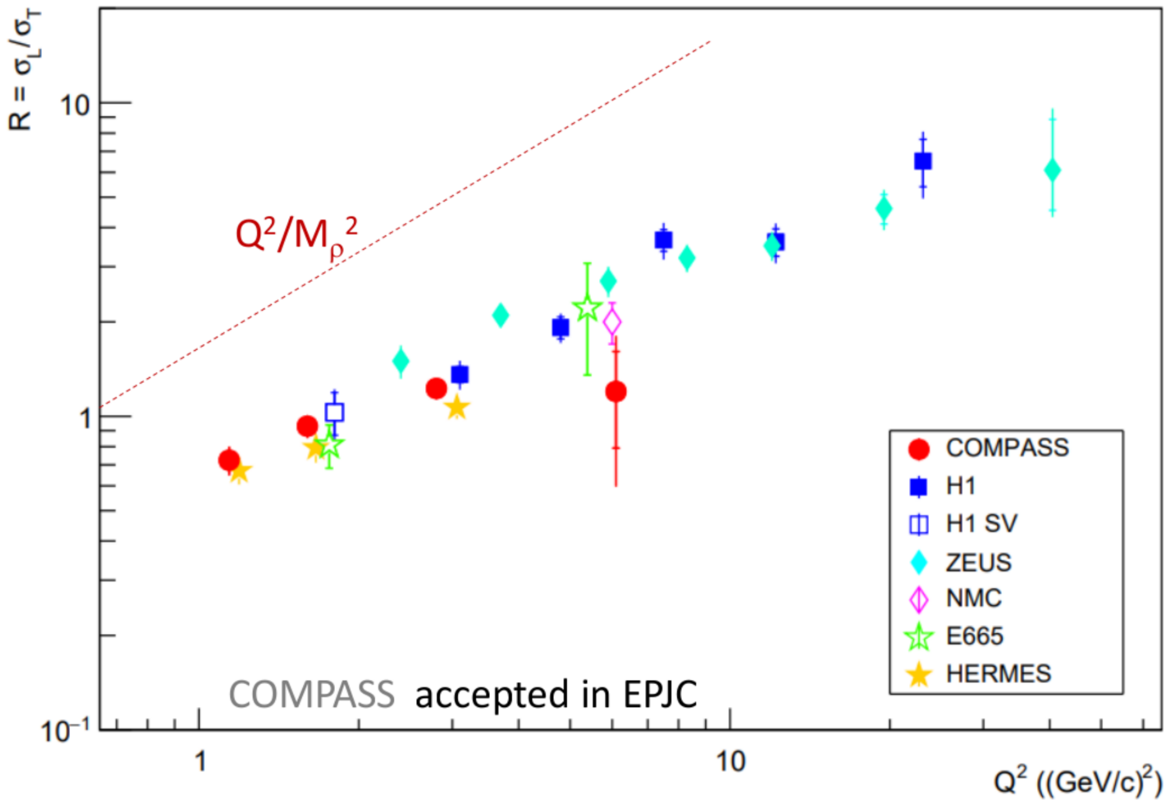
$$R = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1 - r^{04}_{00}}$$ **only if SCHC**

In COMPASS domain evaluation of **R** and

$\tilde{\mathbf{R}}$ considering violation of SCHC (and only NPE)



for all the experiments with $Q^2 > 1$ GeV^2



Deviation from the pQCD LO prediction in Q^2/M_ρ^2: QCD evolution and q_T

Transversize size effects of the meson smaller for σ_L than for σ_T

Next steps for Vector Mesons

Analysis of the exclusive ϕ production is currently in progress

(with cross section and SDMEs)

COMPASS 2016+17 Outlook for DVCS and HEMP

✓ **DVCS** and the sum $\Sigma \equiv d\sigma^{\overset{+}{\leftarrow}} + d\sigma^{\overset{-}{\rightarrow}}$

➔ c_0 and s_1 and constrain on Im$\mathcal{H}$ and Transverse extension of partons

✓ **DVCS** and the difference $\Delta \equiv d\sigma^{\overset{+}{\leftarrow}} - d\sigma^{\overset{-}{\rightarrow}}$

➔ c_1 and constrain on Re$\mathcal{H}$ (>0 as H1 or <0 as HERMES)

for D-term and pressure distribution

Importance of e^+ beam
For Jlab 20+ GeV

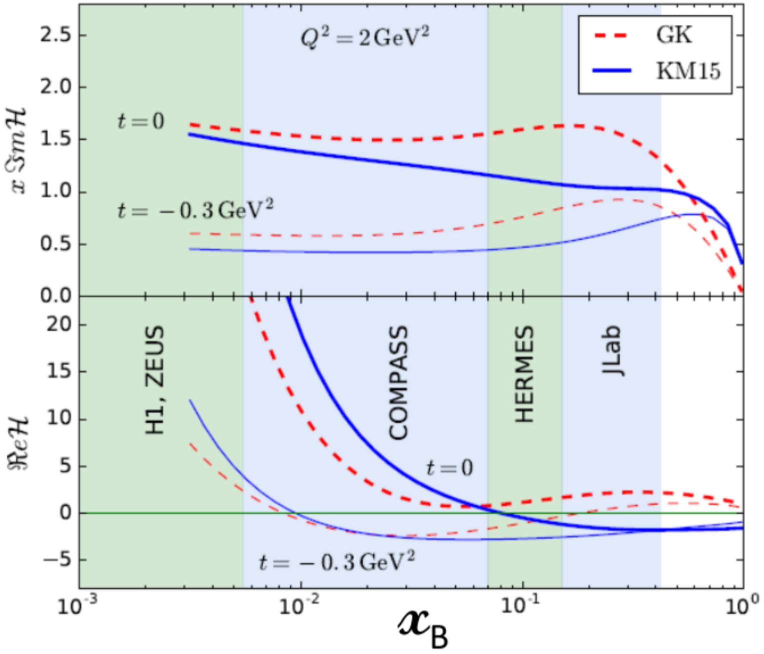
✓ On-going analysis (Cross section, SDME) for HEMP of π^0, ρ^0, ω, ϕ, J/ψ

✓ Transversity GPDs
✓ Gluon GPDs
✓ Flavor decomposition

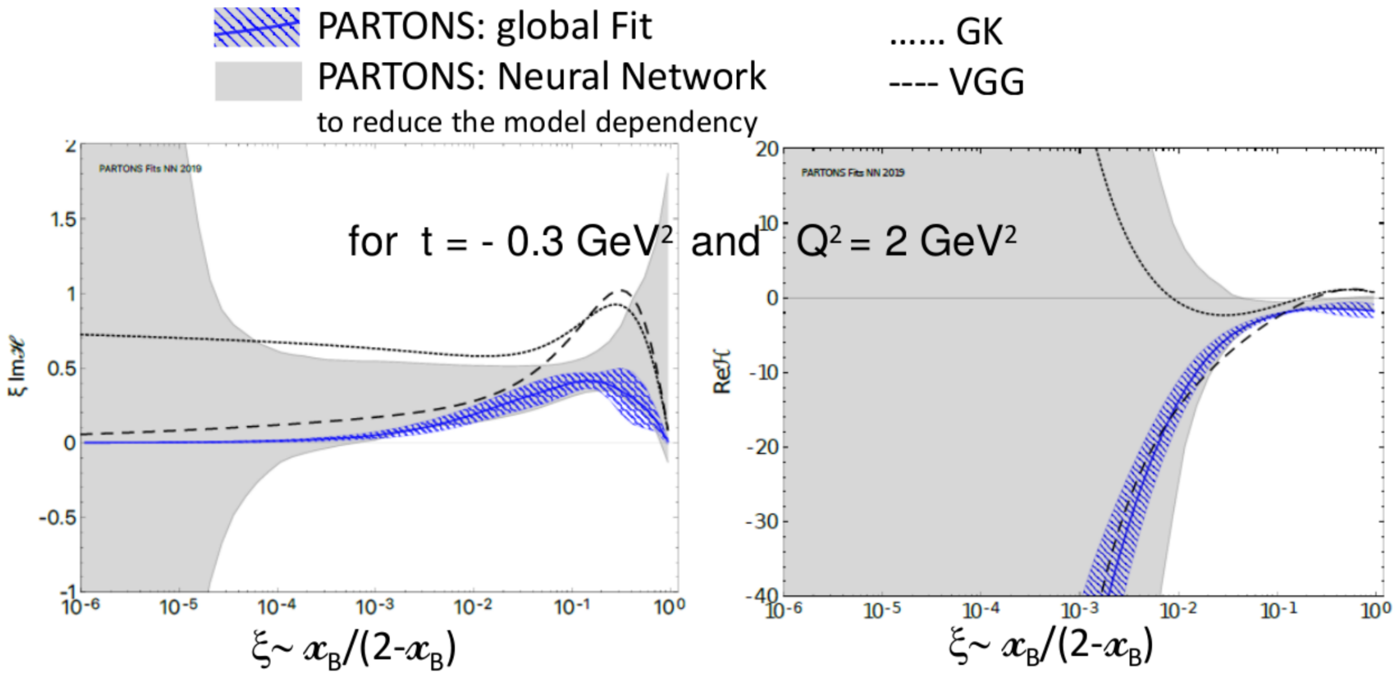
Importance of large luminosity
For DVCS, TCS, DDVCS, J/ψ …

ImH and ReH using global fits of the world data

Global Fit KM15
Compared to GK Model GK
Kumericki, Mueller, NPB (2010) 841, private com.



Global Fits using PARTONS framework
Compared to GK and VGG Models
Moutarde, Sznajder, Wagner, Eur. Phys. J. C 79 (2019) 7, 614



ReH is still poorly known (importance of DVCS with $\mu^{\pm}$ at COMPASS, $e^{\pm}$ at JLab
or TCS at JLab and EIC)