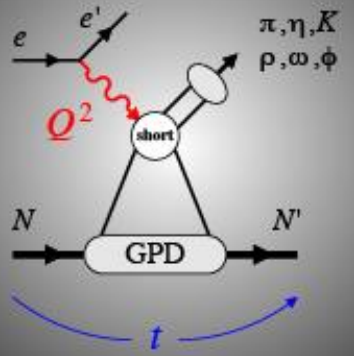
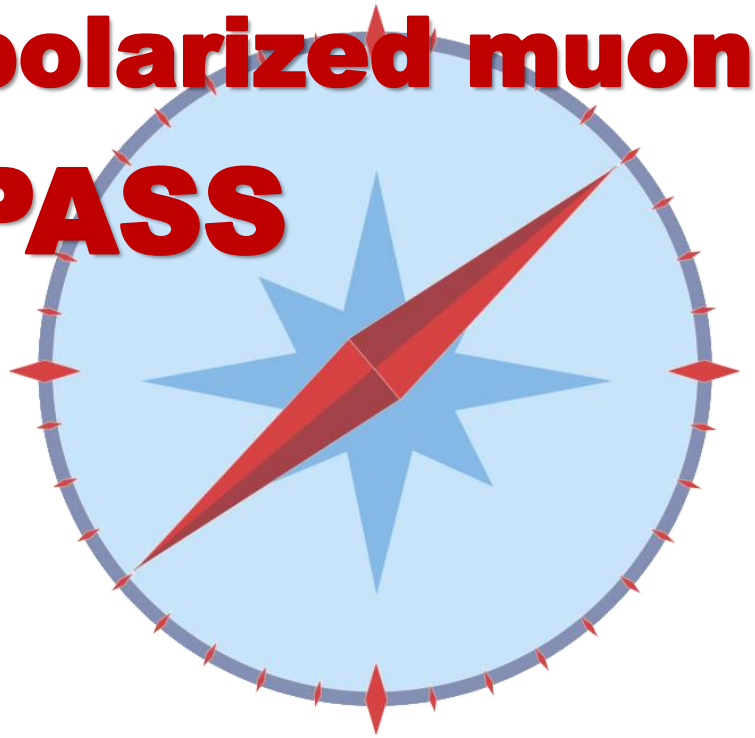


Exclusive Meson Production

with 160GeV polarized muon beams at COMPASS



Nicole d'Hose (CEA-Saclay)
On behalf of the COMPASS Collaboration
Jlab workshop, 22 January 2015

HEMP:filter of GPDs and flavors

Hard Exclusive Meson Production (HEMP):

Vector meson production $(\rho,\omega,\phi, J/\psi\ldots)$ $\Rightarrow$ **H & E**

Pseudo-scalar production $(\pi,\eta\ldots)$ $\Rightarrow$ $\tilde{H}$ **&** $\tilde{E}$

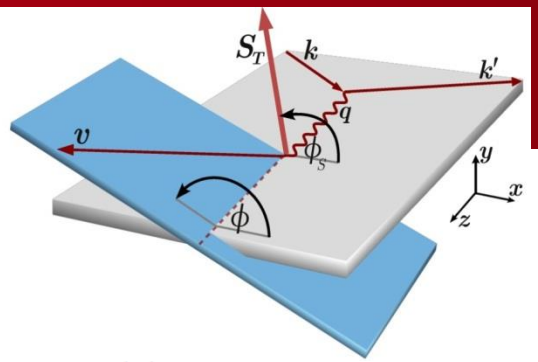
$$K\rho^0 = 1/\sqrt{2}\,(2/3\,K^u + 1/3\,K^d + 3/8\,K^g)$$

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

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

K is any of the GPDs H, E, H_T, $\overline{E_T}$

Exclusive ρ^0 production with transversely polarized target



$$\left[\frac{\alpha_{em}}{8\pi^3}\frac{y^2}{1-\varepsilon}\frac{1-x_B}{x_B}\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_{Bj}dQ^2dtd\phi d\phi_s}$$

$$= \frac{1}{2}\left(\sigma^{++}_{++}+\sigma^{--}_{++}\right)+\varepsilon\sigma^{++}_{00}-\varepsilon\cos(2\phi)\,\mathrm{Re}\,\sigma^{++}_{+-}-\sqrt{\varepsilon(1+\varepsilon)}\cos\phi\,\mathrm{Re}\,(\sigma^{++}_{+0}+\sigma^{--}_{+0})$$

$$-P_\ell\sqrt{\varepsilon(1-\varepsilon)}\sin\phi\,\mathrm{Im}\,(\sigma^{++}_{+0}+\sigma^{--}_{+0})$$

transv. polar. target

$$-S_T\left[\sin(\phi-\phi_S)\,\mathrm{Im}\,(\sigma^{+-}_{++}+\varepsilon\sigma^{+-}_{00})+\frac{\varepsilon}{2}\sin(\phi+\phi_S)\,\mathrm{Im}\,\sigma^{+-}_{+-}+\frac{\varepsilon}{2}\sin(3\phi-\phi_S)\,\mathrm{Im}\,\sigma^{-+}_{+-}\right.$$

$$\left.+\sqrt{\varepsilon(1+\varepsilon)}\sin\phi_S\,\mathrm{Im}\,\sigma^{+-}_{+0}+\sqrt{\varepsilon(1+\varepsilon)}\sin(2\phi-\phi_S)\,\mathrm{Im}\,\sigma^{-+}_{+0}\right]$$

transv. polar. target + long. Polar. beam

$$+S_T P_\ell\left[\sqrt{1-\varepsilon^2}\cos(\phi-\phi_S)\,\mathrm{Re}\,\sigma^{+-}_{++}\right.$$

$$\left.-\sqrt{\varepsilon(1-\varepsilon)}\cos\phi_S\,\mathrm{Re}\,\sigma^{+-}_{+0}-\sqrt{\varepsilon(1-\varepsilon)}\cos(2\phi-\phi_S)\,\mathrm{Re}\,\sigma^{-+}_{+0}\right]$$

σ^{ij}_{mn} for nucleon helicity / for photon helicity

interference terms:

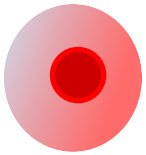
dominant LL $\quad \gamma^*_L \to \rho^0_L$

with TL $\quad \gamma^*_T \to \rho^0_L$

GPDs in exclusive ρ^0 production

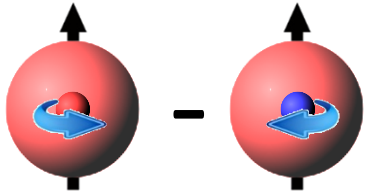
Chiral-even

$H \leftrightarrow q$



$\gamma^*_L\ p^\uparrow \rightarrow \rho^0_L\ p^\uparrow \quad L=0$

"Elusive" $E \leftrightarrow f_{1T}^{\perp}$



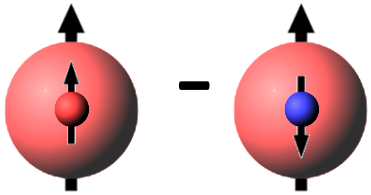
Sivers: quark k_T & nucleon transv. Spin

$\gamma^*_L\ p^\uparrow \rightarrow \rho^0_L\ p^\downarrow \quad L=1$

Ji: $2J^q = \int x\,(H^q(x,\xi,0) + E^q(x,\xi,0))\,dx$

Chiral-odd

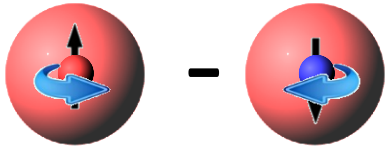
$H_T \leftrightarrow h_1$



Transversity: quark spin & nucleon transv. spin

$\gamma^*_T\ p^\uparrow \rightarrow \rho^0_L\ p^\downarrow \quad L=0$

$\bar{E}_T = 2\tilde{H}_T + E_T \leftrightarrow h_1^{\perp}$



Boer-Mulders: quark k_T & quark transverse spin

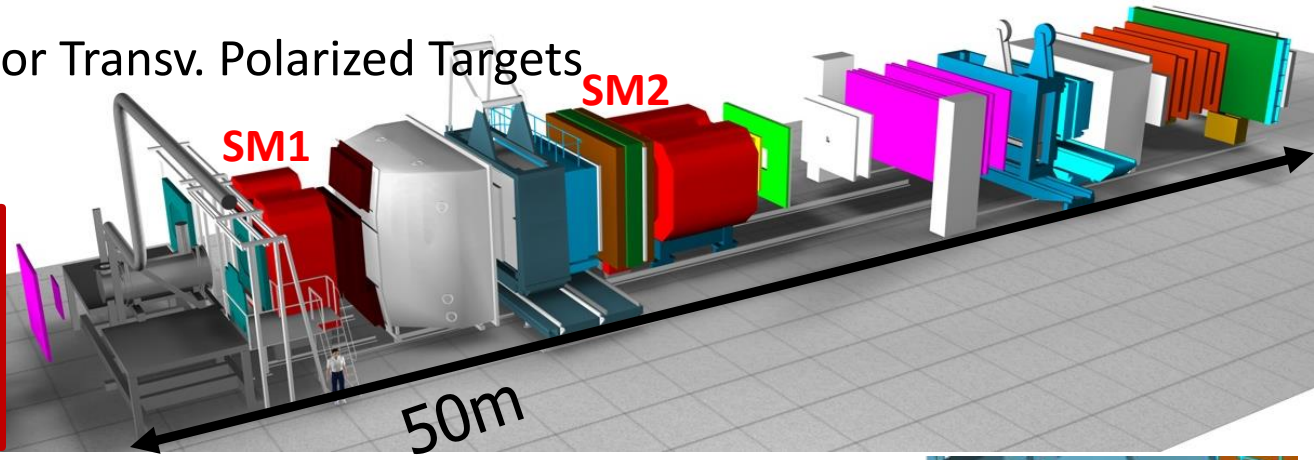
$\gamma^*_T\ p^\uparrow \rightarrow \rho^0_L\ p^\uparrow \quad L=1$

The COMPASS experiment

$\overleftarrow{\mu}$ beams with Longitudinal or Transv. Polarized Targets

SIDIS program

Polarized	Deuteron (Li^6D)	Proton (NH_3)
Long.	**2002-3-4-6**	**2007-11**
Transv.	**2002-3-4**	**2007-10**



$\overleftarrow{\mu^+}$ $\overrightarrow{\mu^-}$ beams with LH2 Target

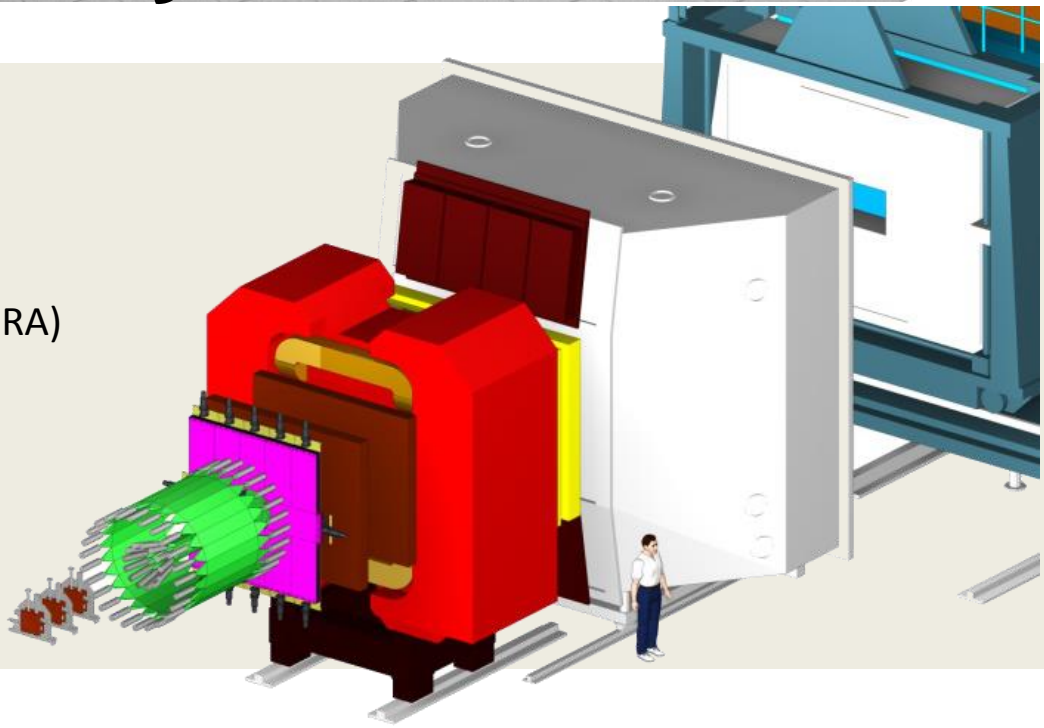
Tests in // of spectroscopy and pion polarisability

2008-9 with a 1m Recoil Proton Detector

2012 with a 4m Recoil Proton Detector (CAMERA)

2015 *Drell-Yan program for TMD*

2016-17 DVCS and HEMP program for GPD with LH2 target and CAMERA



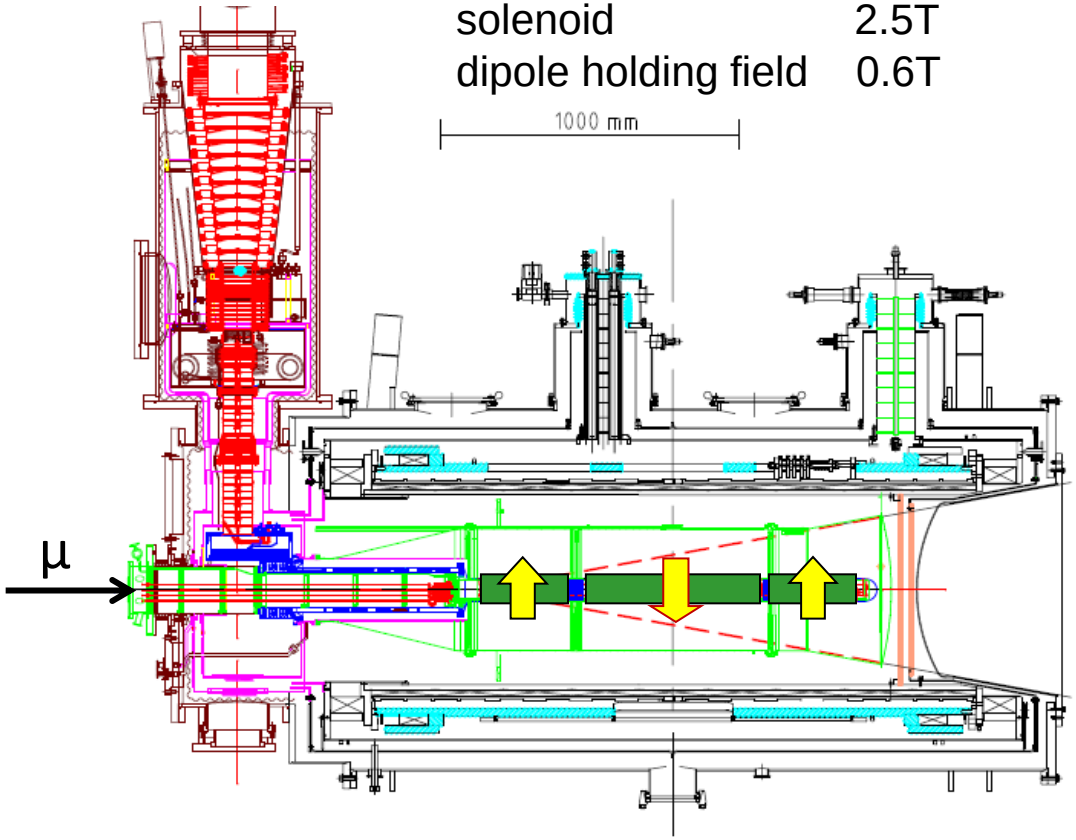
> 2020 DVCS and HEMP program for GPD with polarized target and recoil detection?

The COMPASS polarized target

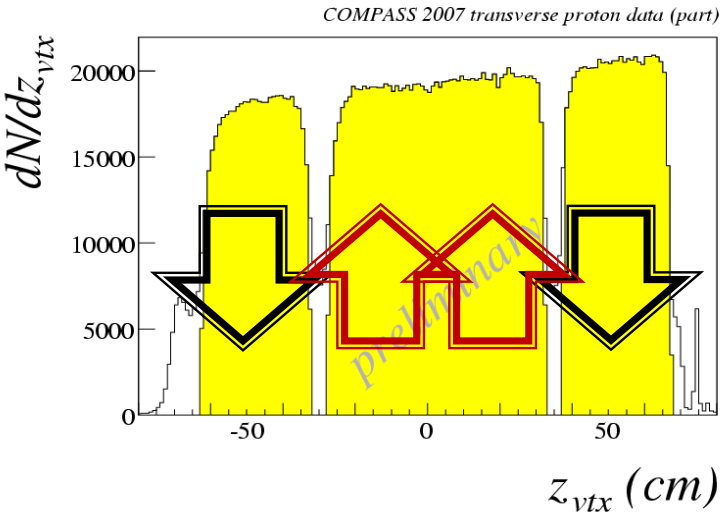
solid state target operated in frozen spin mode

^{3}He – ^{4}He dilution refrigerator (T~50mK)

solenoid	2.5T
dipole holding field	0.6T



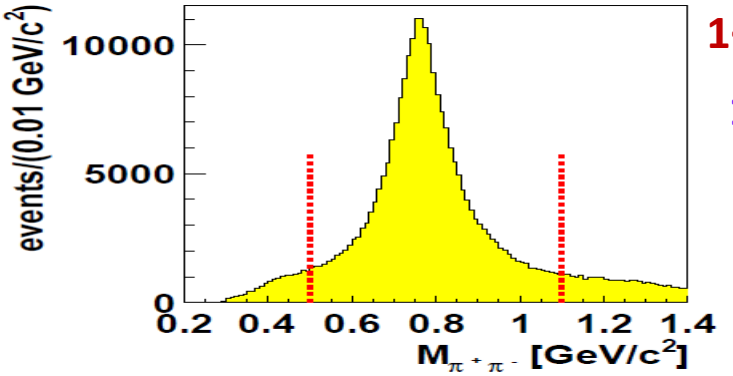
(After 2005)
3 target cells of 30, 60, 30 cm
with opposite polarization

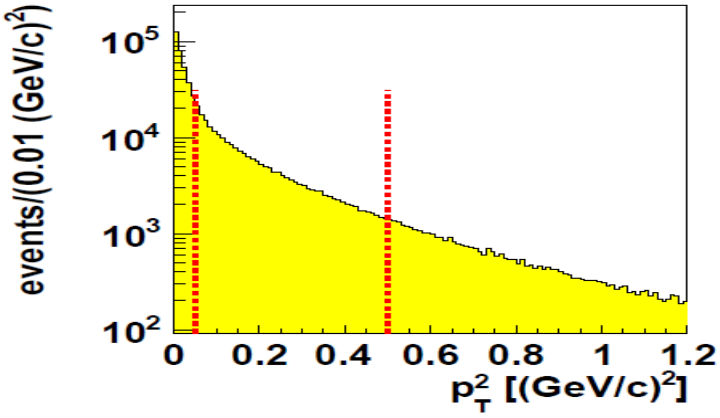


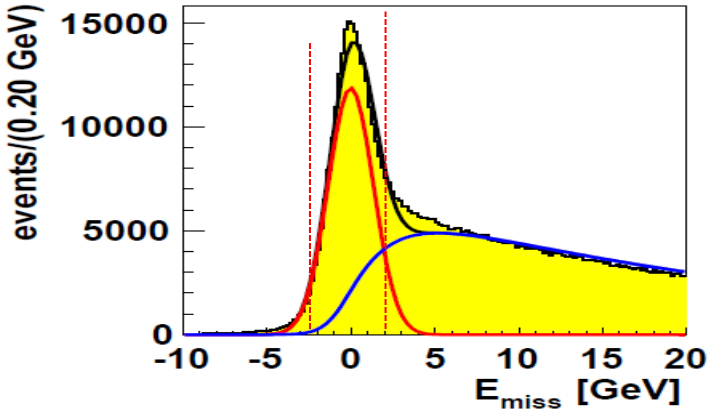
	d (^{6}LiD)	p (NH_3)
polarization	50%	80%
dilution factor for excl. ρ^0	45%	25%

Selection of Exclusive ρ° Production: μ p → μ' ρ° p

without RPD







$1< Q^2 < 10$ GeV² $0.1 < y < 0.9$ W>4 GeV $E_\rho > 15$ GeV

1- Assuming both hadrons are π

$0.5 < M_{\pi\pi} < 1.1$ GeV

To maximize the purity of the sample of ρ° / non resonant $\pi^+\pi^-$

2- Incoherent production on quasi-free protons in NH_3 polarized target

$0.05 < p_t^2 < 0.5$ GeV²

Contamination of about a 5% coherent production

3- Exclusivity of the reaction

$$E_{\text{miss}} = \frac{M_X^2 - M_P^2}{2 \cdot M_P} = E_{\gamma^*} - E_{\rho^0} + t/(2 \cdot M_P)$$

$-2.5 < E_{miss} < 2.5$ GeV

Diffractive dissociation ~12%

Does not change the asymmetry (confirmed by HERA)

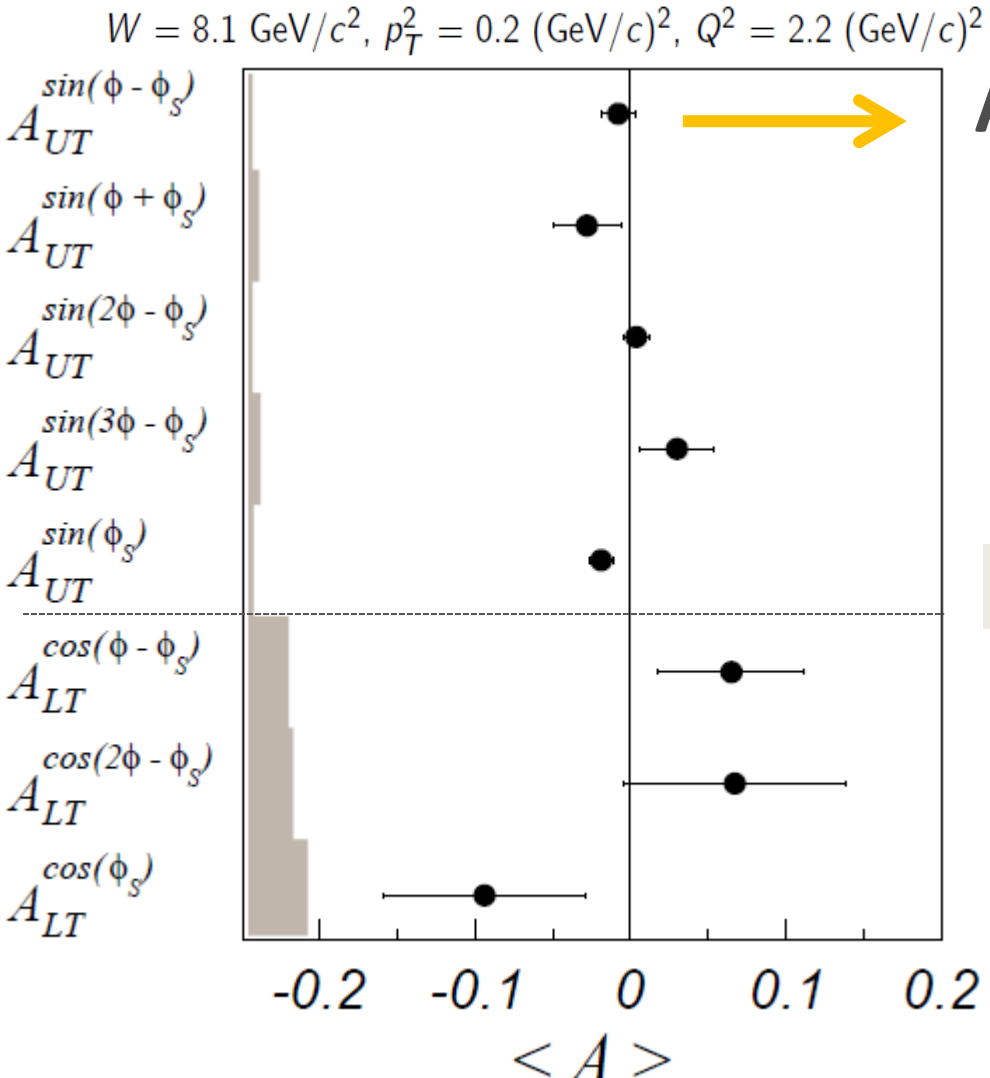
→ Background correction in every bin in:

x_{Bj}, Q^2, p_T^2, $\Phi - \Phi_S$ and cell state and polar. state

exclusive ρ^0 production with Transv. Polar. Target

$\mu\ p \rightarrow \mu'\ +\ \rho^0\ +\ p_{\text{non détecté}}$
$\hookrightarrow \pi^+\pi^-$

COMPASS 2007-2010,without recoil detector



$A_{UT}^{\sin(\phi - \phi_S)} \propto Im(\mathcal{E}^* \mathcal{H})$

$E\rho^0 \propto 2/3\ E^u + 1/3\ E^d + 3/8\ E^g$
Cancellation between gluon and sea contributions and **$E^{u\ val} \sim -\ E^{d\ val}$**

COMPASS, NPB865 (2012) 1-20

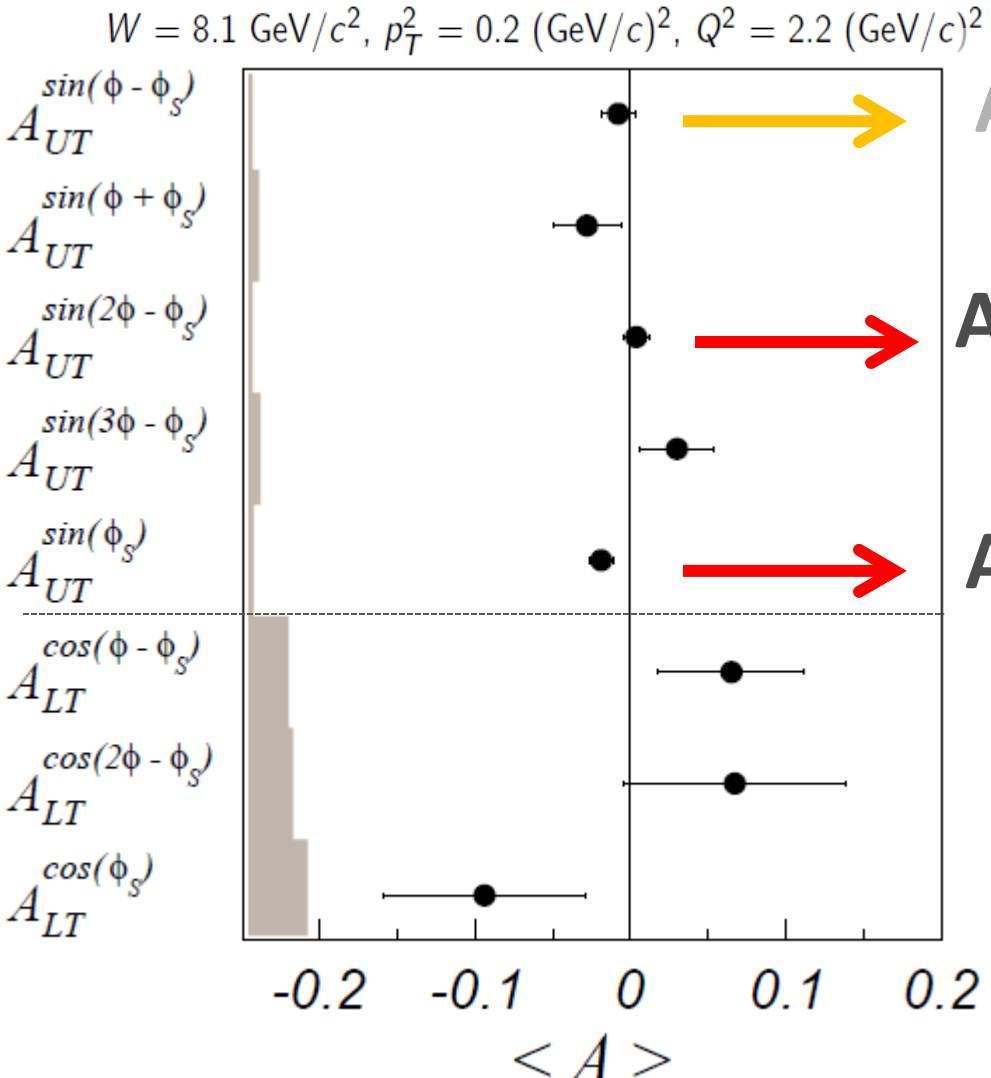
$E\omega \propto 2/3\ E^u - 1/3\ E^d + 3/8\ E^g$

ω very interesting
with also the role of the pion pole
prediction from Goloskokov and Kroll
analysis to be released

exclusive ρ^0 production with Transv. Polar. Target

$\mu\ p \rightarrow \mu' + \rho^0 + p_{\text{non détecté}}$
$\hookrightarrow \pi^+\pi^-$

COMPASS 2007-2010,without recoil detector



$A_{UT}^{\sin(\phi - \phi_S)} \propto Im(E^* H)$

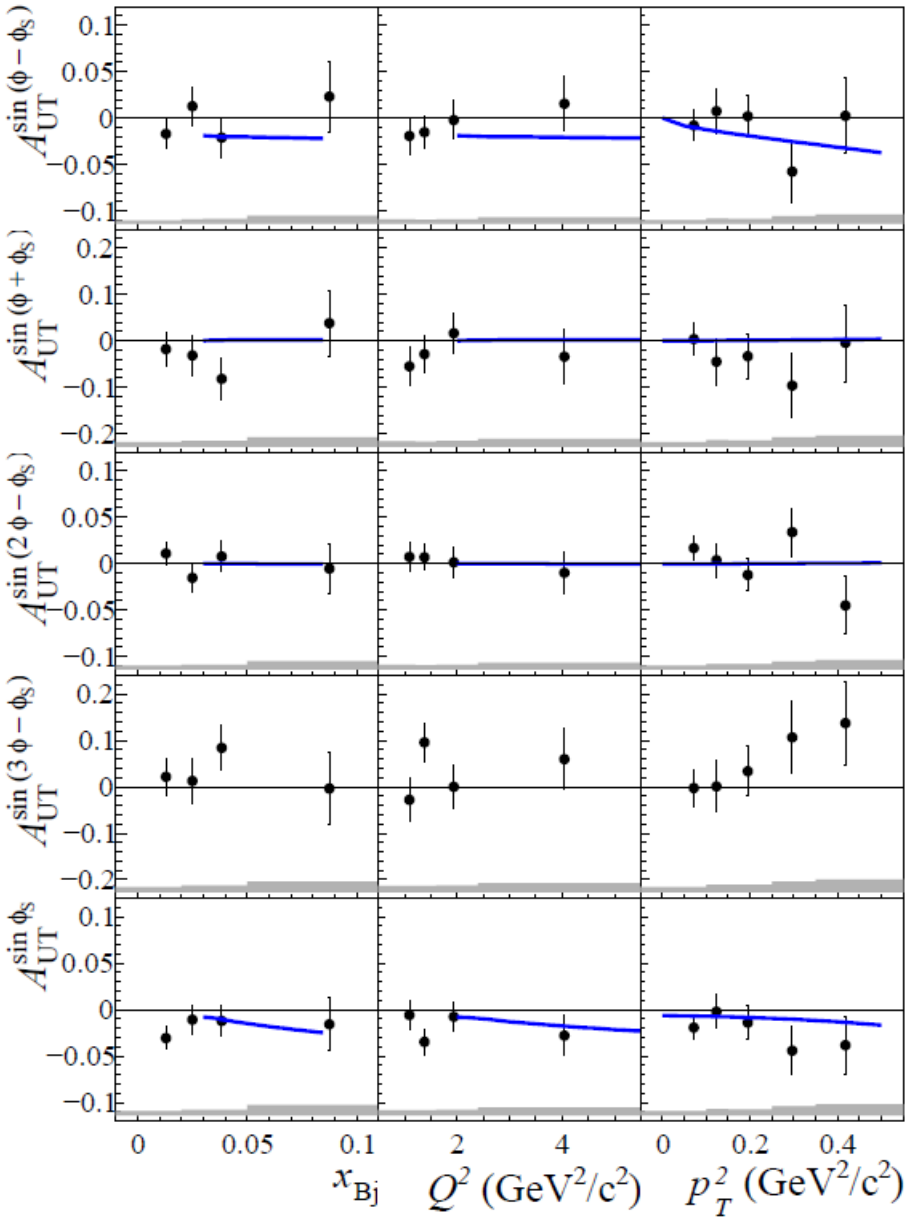
$A_{UT}^{\sin(2\phi - \phi_S)} \propto Im(E^* \bar{E}_T)$

$A_{UT}^{\sin(\phi_S)} \propto Im(E^* \bar{E}_T - H^* H_T)$

➔ H_T should not be small

COMPASS, PLB731 (2014) 96

exclusive ρ^0 production with Transv. Polar. Target



COMPASS 2007-2010,without recoil detector
COMPASS, PLB731 (2014) 96

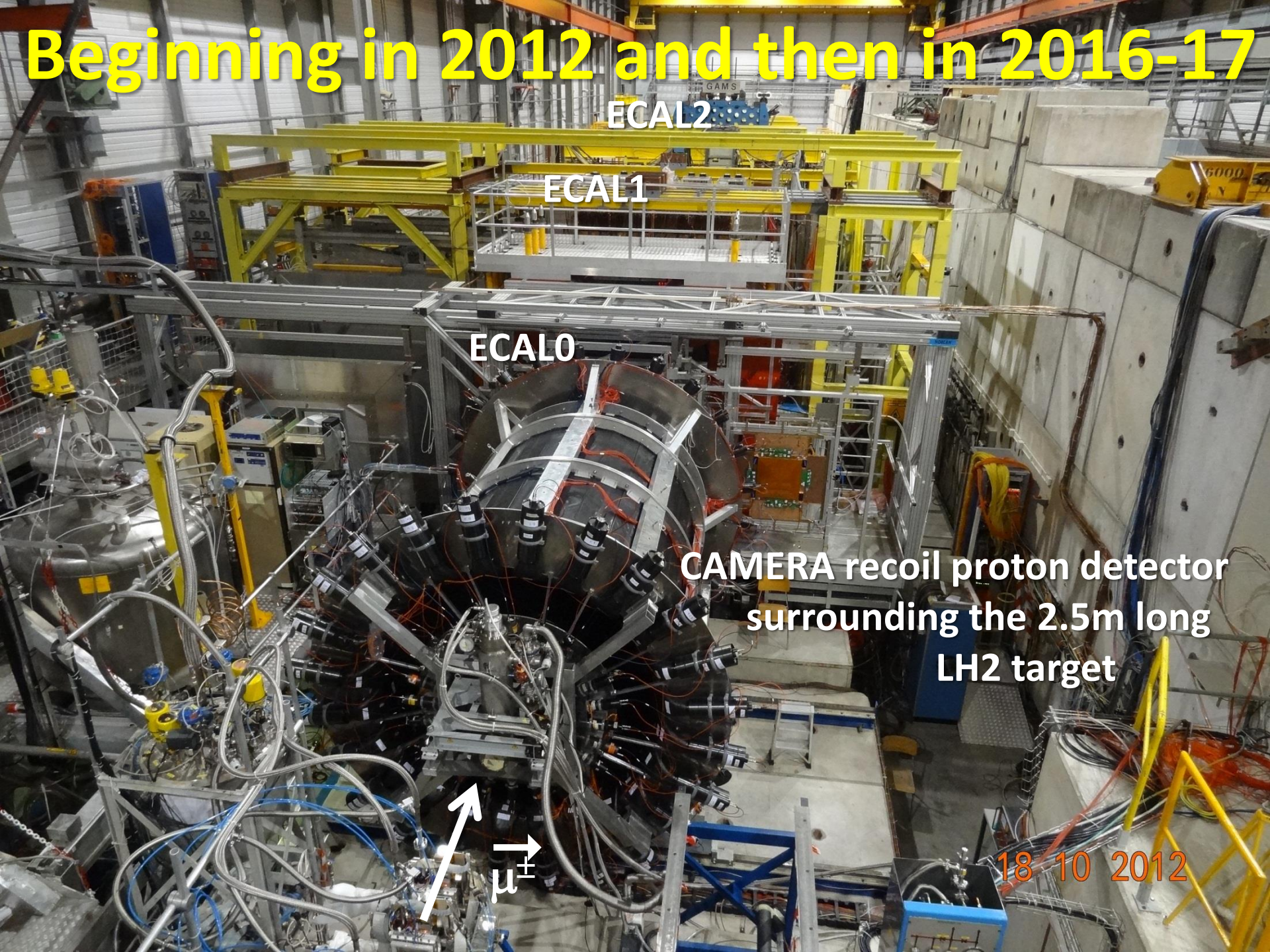
$$A_{UT}^{\sin(\phi-\phi_S)} \propto Im(\mathcal{E}^{*}\mathcal{H})$$

$$A_{UT}^{\sin(2\phi-\phi_S)} \propto Im(\mathcal{E}^{*}\bar{\mathcal{E}}_T)$$

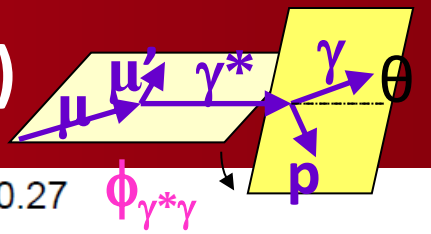
$$A_{UT}^{\sin(\phi_S)} \propto Im(\mathcal{E}^{*}\bar{\mathcal{E}}_T - \mathcal{H}^{*}\mathcal{H}_T)$$

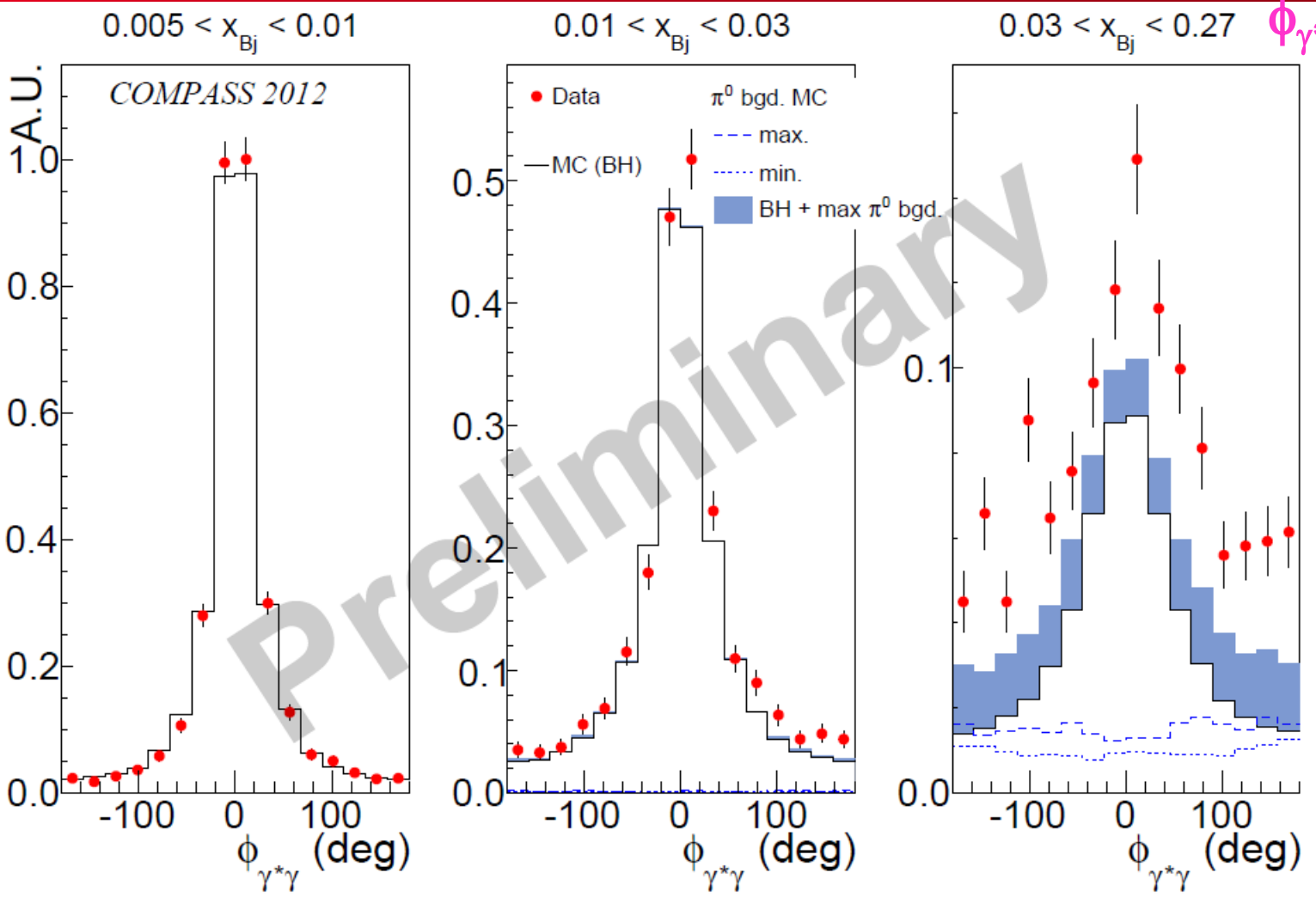
Model from Goloskokov and Kroll
EPJC74 (2014) 2725

Beginning in 2012 and then in 2016-17



exclusive single photon production (2012 data)

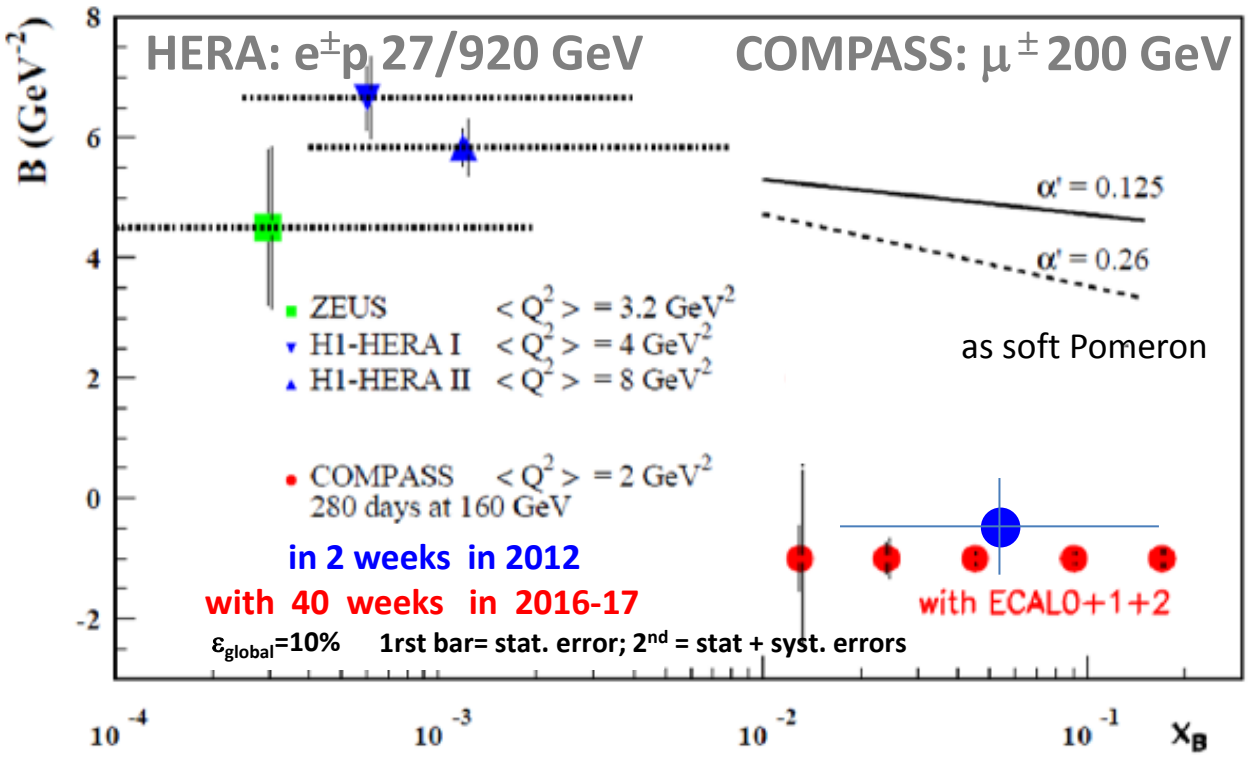




- ✓ Dominant Bethe-Heitler process clearly visible at small x_{Bj}
- ✓ π^0 background (from SIDIS and **excl. π^0**) at large x_{Bj} estimated in blue
- ✓ The data at large xBj show an excess compared to BH+Background (for pure DVCS)

Transverse imaging at COMPASS

$d\sigma^{DVCS}/dt \sim \exp(-B|t|)$

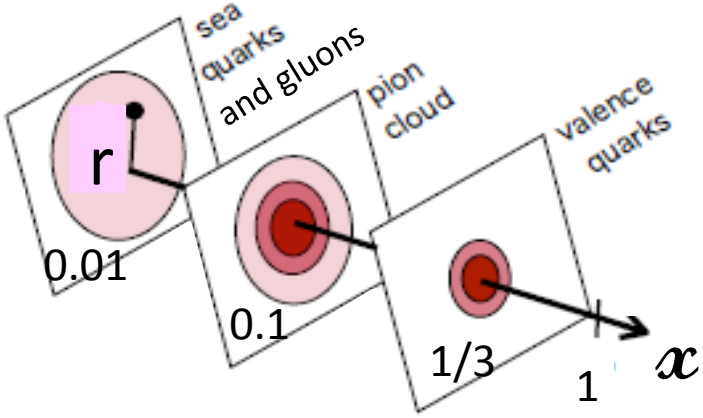


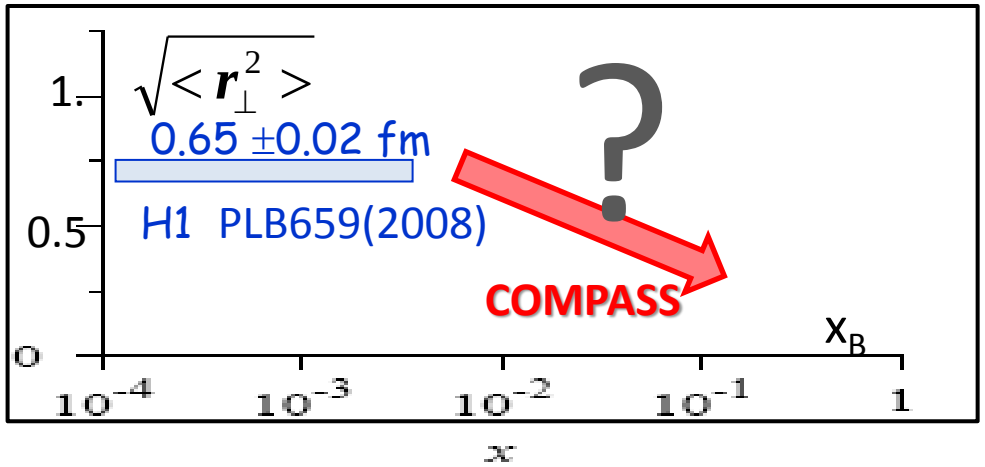
ansatz at small x_B
inspired by
Regge Phenomenology:

$B(x_B) = b_0 + 2\,\alpha' \ln(x_0/x_B)$

α' slope of Regge traject

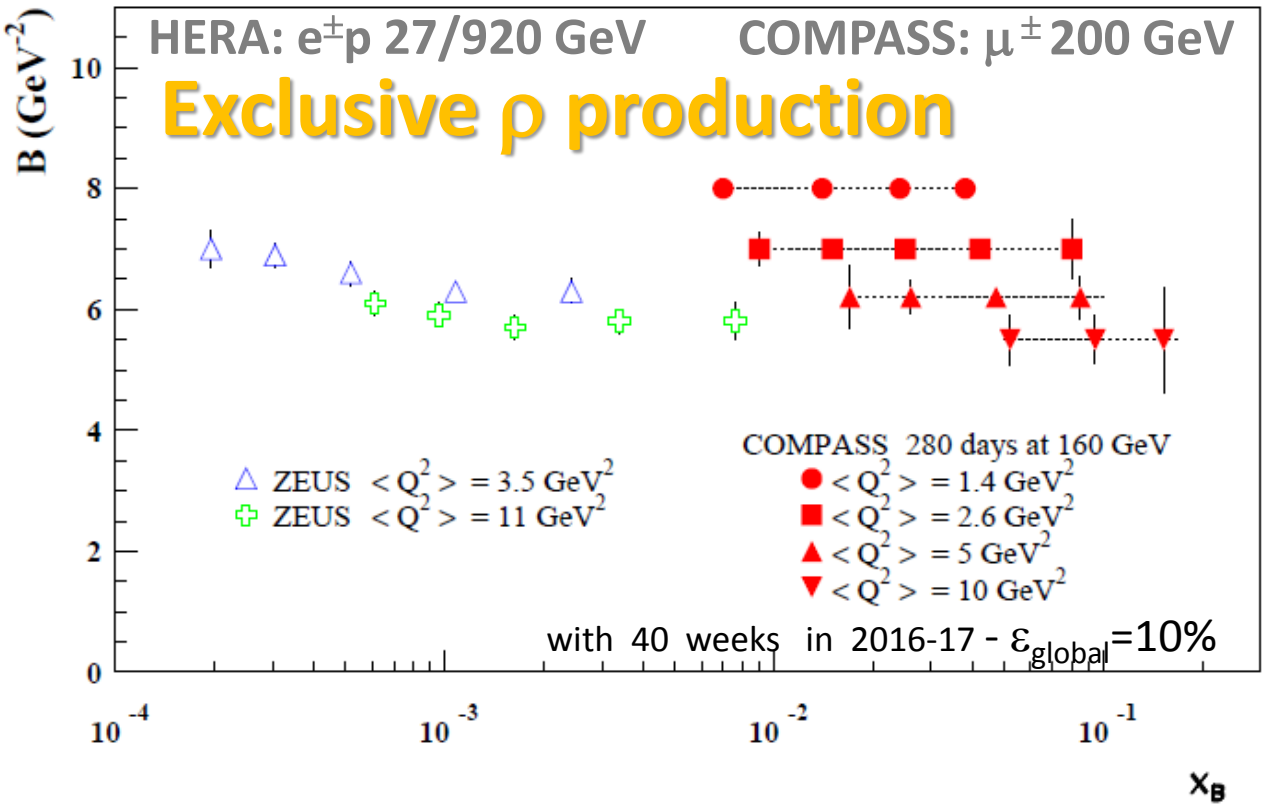
$$\langle r_\perp^2(x_B)\rangle \approx 2B(x_B)$$





Transverse imaging at COMPASS

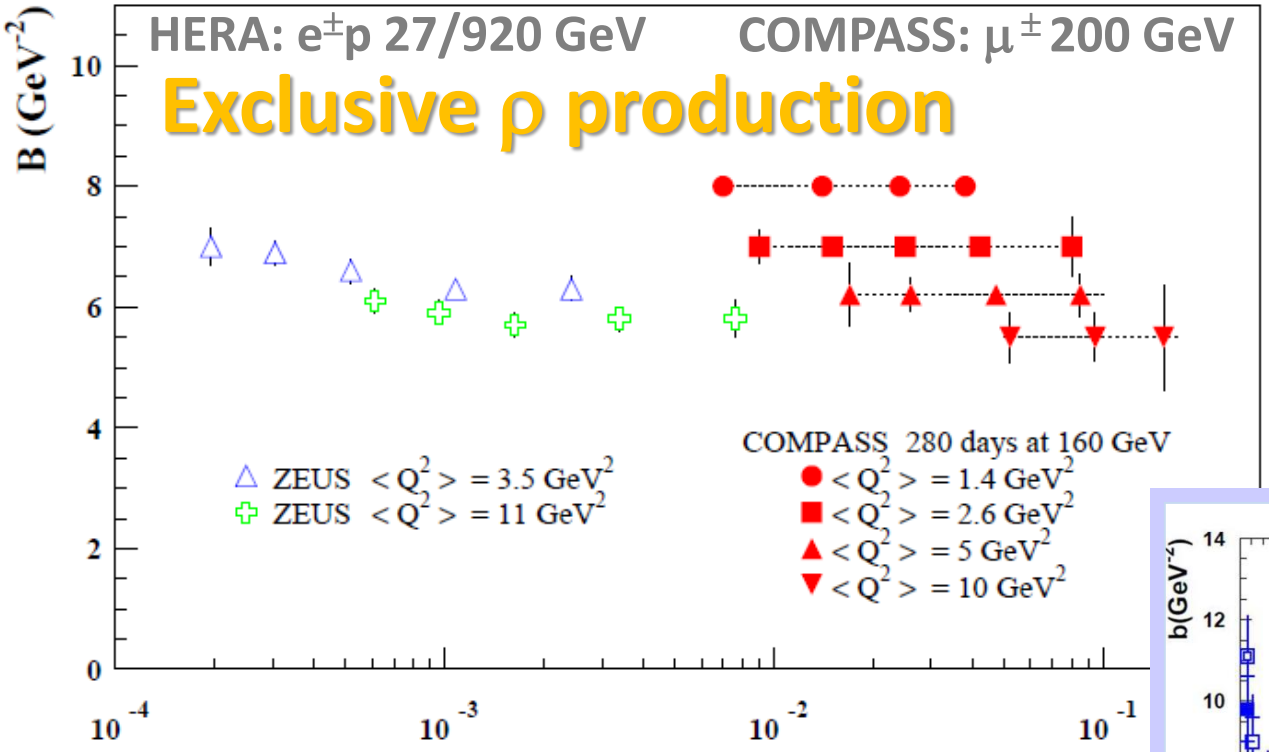
$d\sigma^{excl.\ \rho}/dt \sim \exp(-B|t|)$

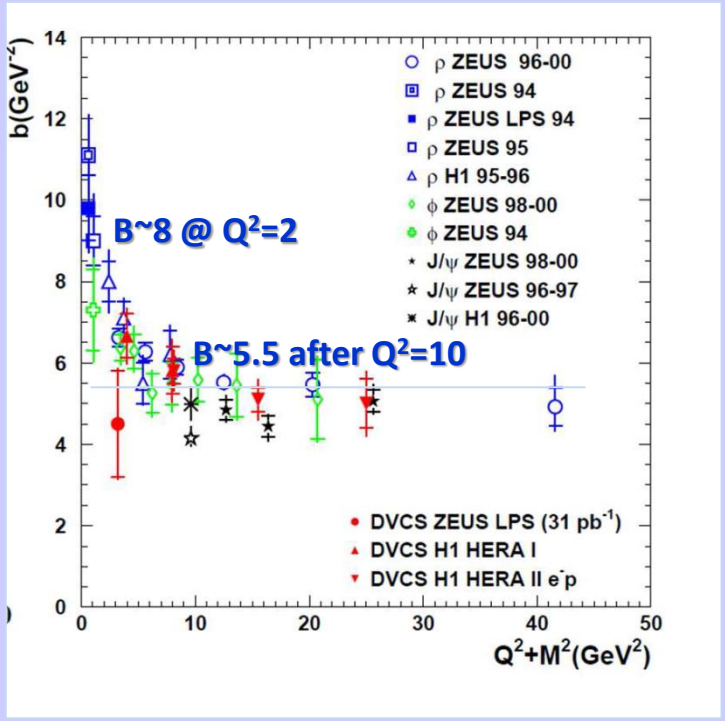


model developed by Sandacz renormalised according Goloskokov and Kroll prediction

Transverse imaging at COMPASS

$d\sigma^{excl.\ \rho}/dt \sim \exp(-B|t|)$

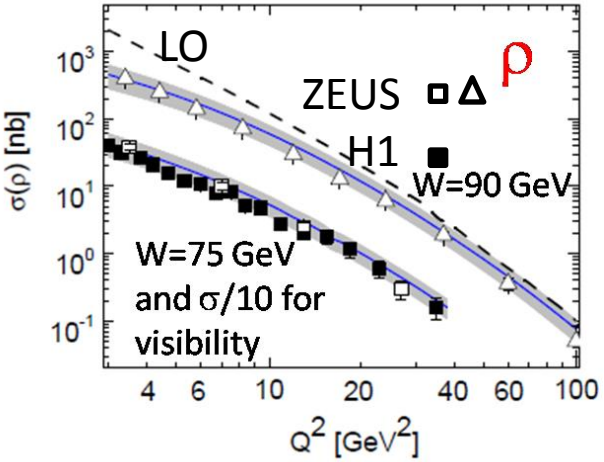


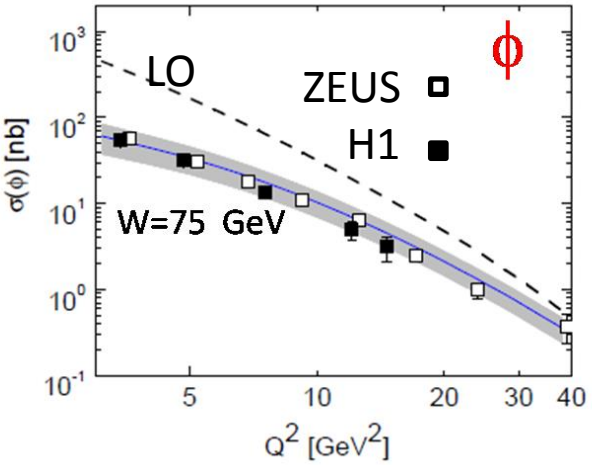


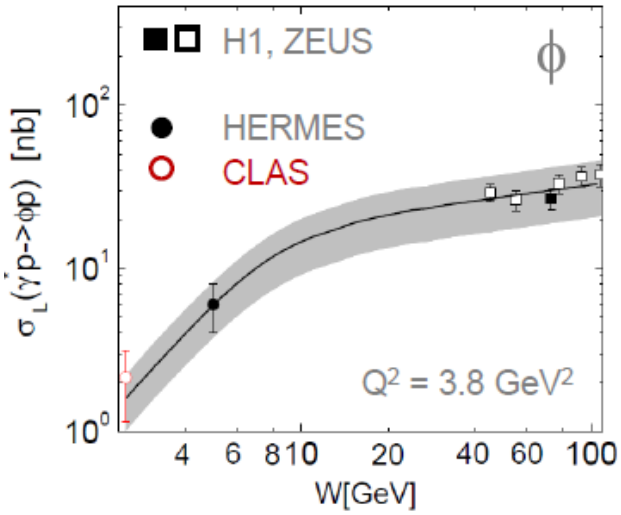
We are sensitive
to the nucleon transverse size
+ to the meson transverse size

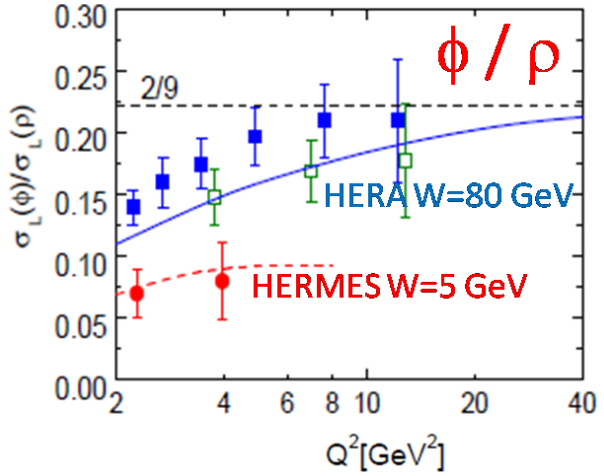
Predictions for mesons from GK model

GK model for GPDs (determined for mesons) including
dominant (longitudinal) $\gamma_L^* p \to \rho_L p$ and transv. polar. $\gamma_T^* p \to \rho_T p$
quark and gluon contributions and beyong leading twist









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

Show strong violation of $\sigma_\phi/\sigma_\rho = 2/9$ at HERA energies and low Q^2 is caused by the flavor symmetry breaking $\bar{u}(x) = \bar{d}(x) = \kappa_s s(x)$

Q^2 dependence of σ_ϕ/σ_ρ at HERA is determined by κ_s factor completely. At HERMES energies we have valence quarks contribution which gives additional suppression of σ_ϕ/σ_ρ ratio.

Outlook

ρ^0 production has been well studied **with Polarized target Li^6D (deuteron) & NH_3 (proton)**

- σ_L / σ_T and a few SDME released but not published
- A_{LL} on deuteron (2002-3 data) *EPC52 (2007) 455*
- A_{UT} on deuteron (2003-4 data) and proton (2007 data) *NPB865 (2012) 1*
- A_{UT} and A_{LT} on proton (2007-10 data)
  study of the 8 asymetries *PLB731 (2014) 96* — N evts

ω the release for the 8 asymmetries is being finalized — ~ N/30

ϕ a few analyses have been done (not released) — ~ N/10

J/ψ very few analyses done mainly at $Q^2 > 0.7$ GeV^2 (not released) — ~ N/100

40 weeks in 2016 -2017 (and 4 weeks in 2012) with LH2 target and with recoil detection

- acceptance and efficiencies will be determined with a great precision for DVCS
- use of μ+ flux and μ- flux (2.6 smaller)
- N_{proton} in 1.2m long NH_3 target / N_{proton} in 2.5m long LH2 = 1.7
- very good exclusivity (t varying from 0.07 to 1 or 2 GeV^2)

ρ^0 (a very good reference) ω ϕ J/ψ to be studied ($d\sigma/dt$, SDME)

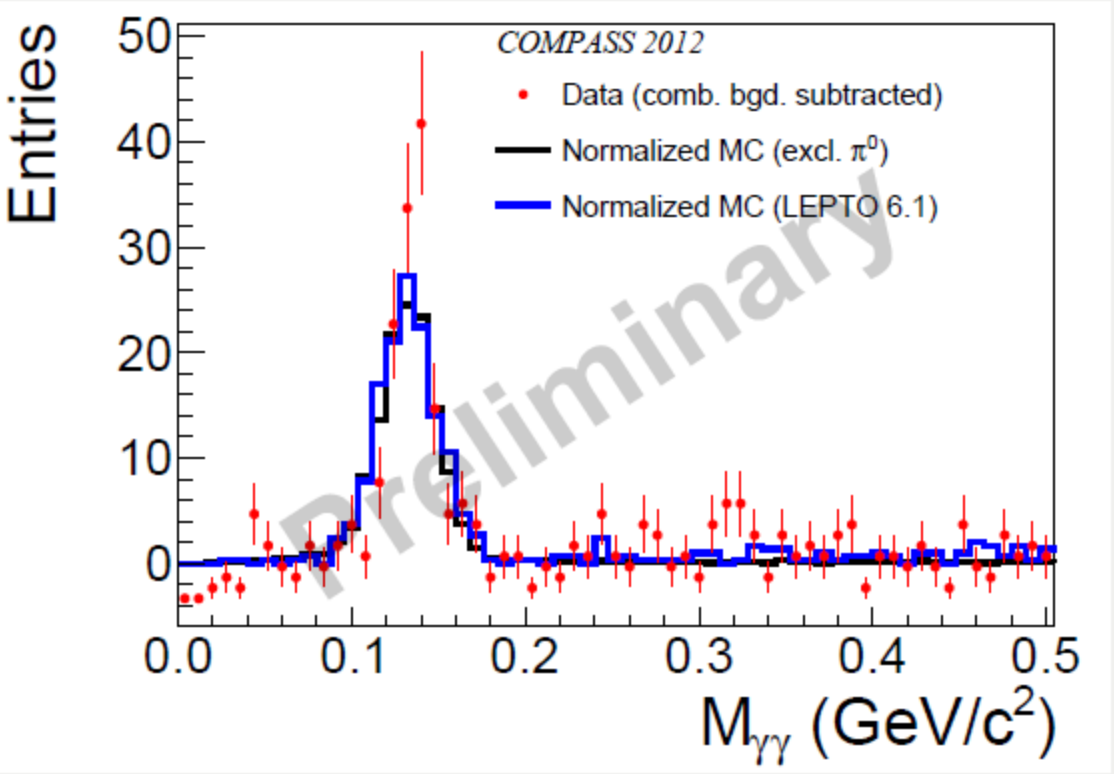
π^0 studied with DVCS but no L/T separation (ε~ 0.98 at 160 GeV)

π^0 Background Estimation

π^0s are one of the main backgroud sources for exclusive photon events

Two possible cases:

- **visible** (both γ detected, easy to reject)
- **invisible** (one γ ``lost'', only estimated with MC)



$M_{\gamma_{excl}\gamma_{bgd}}$ distribution (``Visible'' pi^0)

(combinating the exclusive γ candidate to all additional low-energy γ's)

LEPTO and HEPGEN/π^0 MC normalized to $M_{\gamma_{excl}\gamma_{bgd}}$ peak from real data