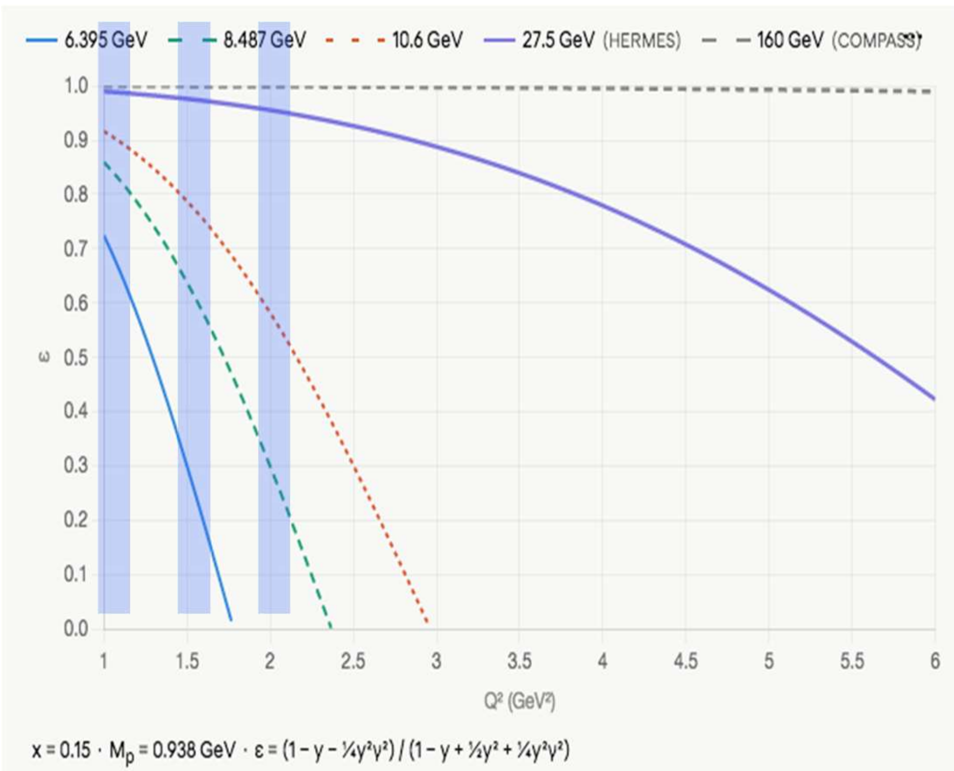
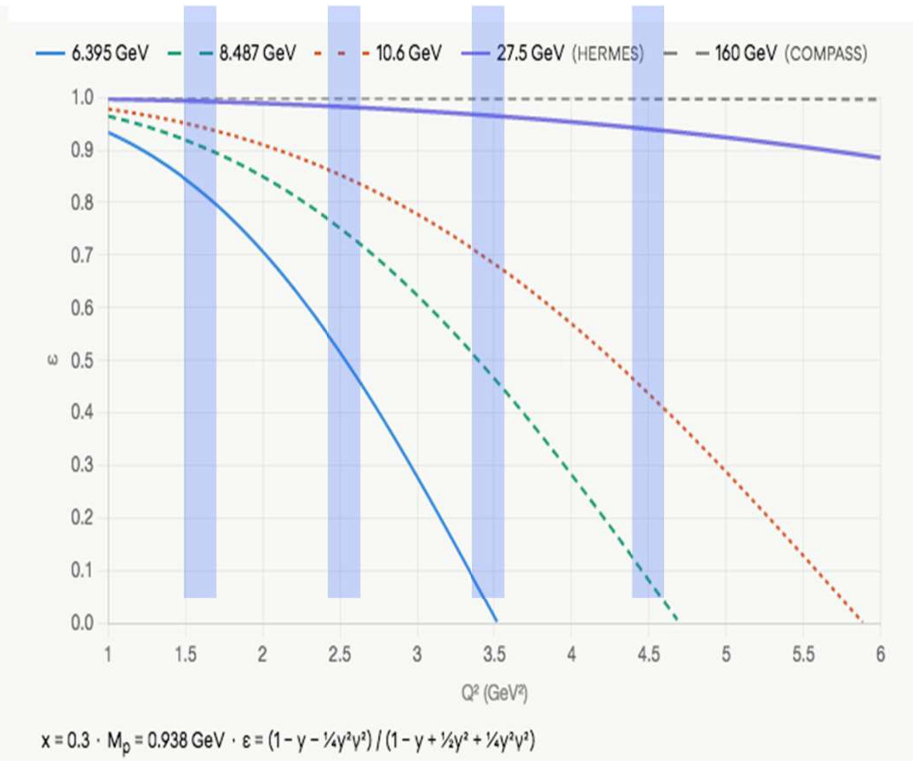
Complementarity of different experiments

Discussion session on VM data analysis H.Avakian

CLAS12 already collected data on proton for 6.4,6.5,7.5.8.5.10.2,10.6 GeV

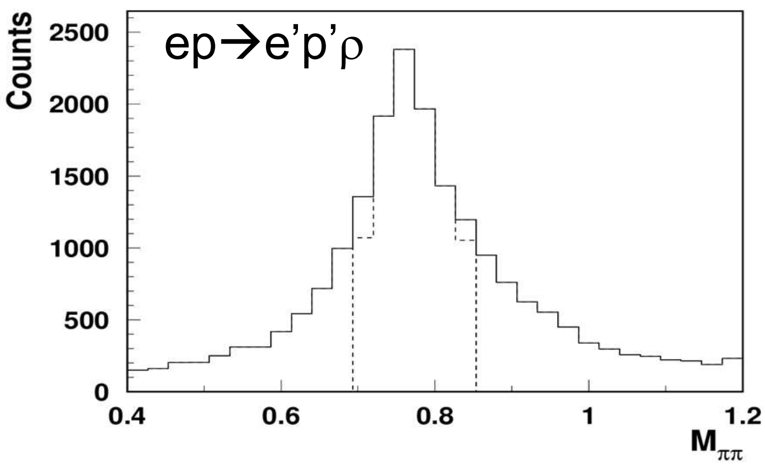


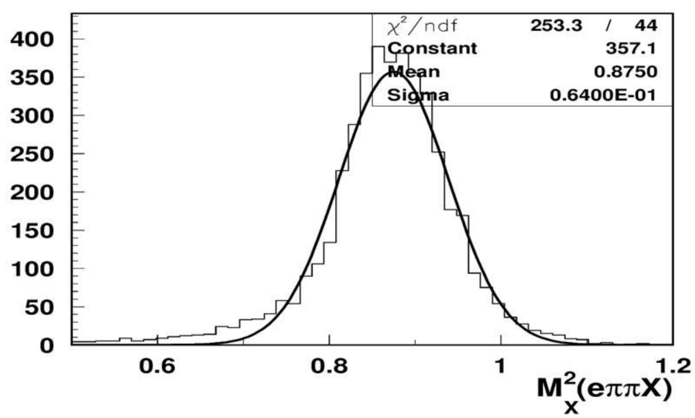


Combining SDME measurements (may need “event base” analysis) at CLAS12 and HERMES/COMPASS will be important for model independent separation of longitudinal part

Cuts on Invariant/Missing masses

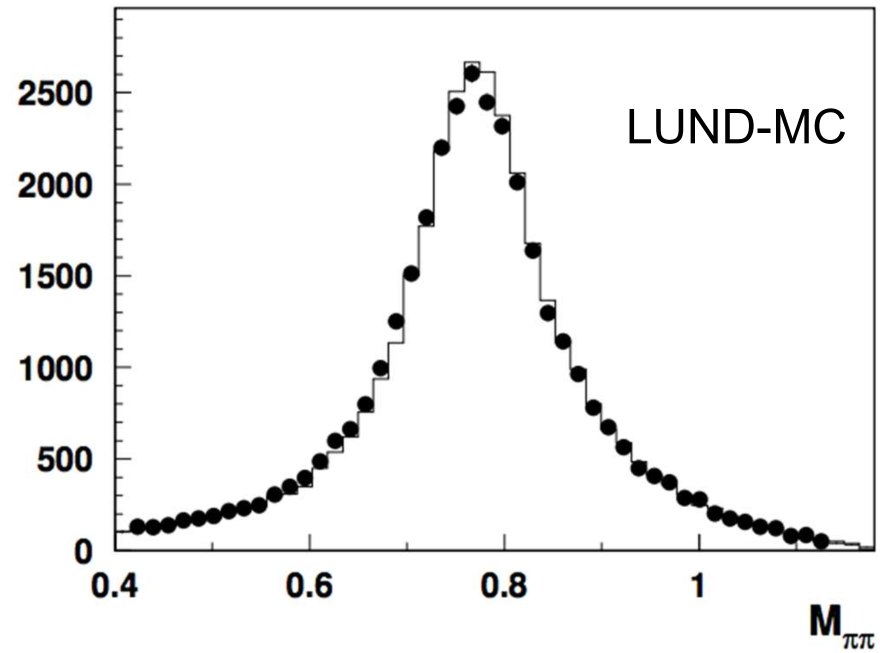
bin 0.275<x<0.325,0.05<-t<0.35 (RGA 10.2 GeV)





With proton detected and exclusivity cuts applied no major background left

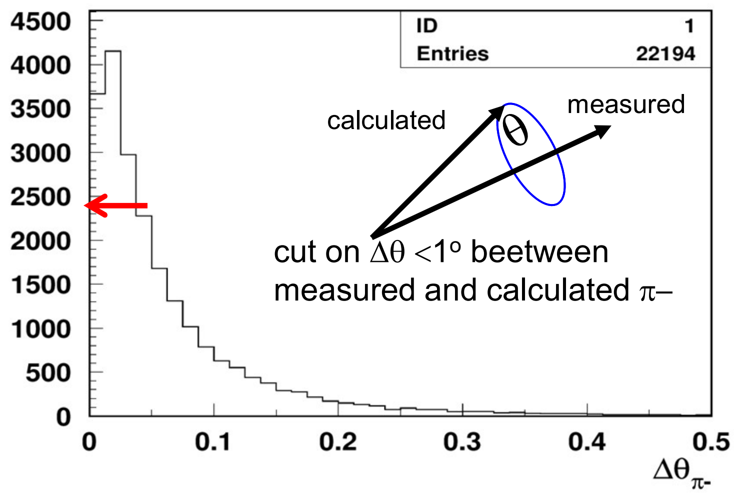
- With tight exclusivity cuts background is minor
- Wide rho peak makes problematic proper background subtraction



Solid line correspond to reconstructed set, using generated values in LUND-MC
Points correspond to reconstructed values
→Width is wider than resolution effects

Studies of ρ^0 impact with longitudinally polarized NH_3 target

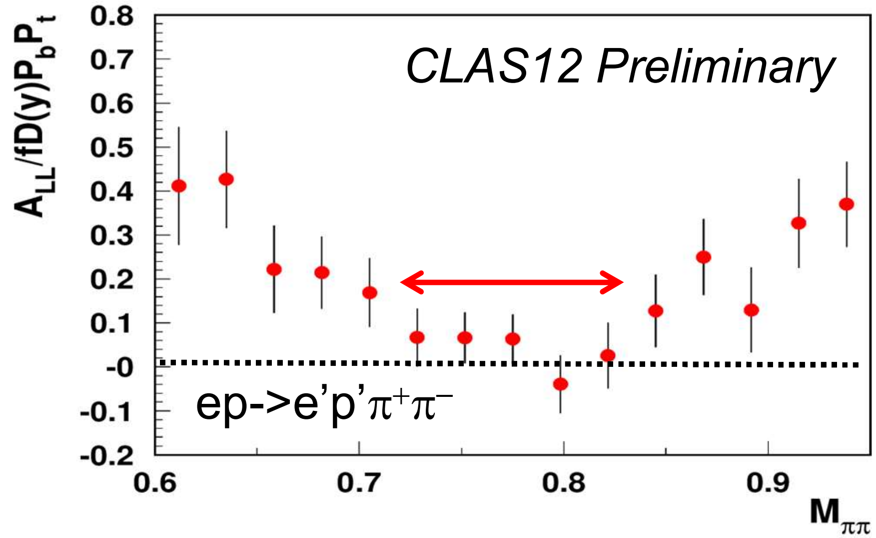
Separating exclusive dihadrons

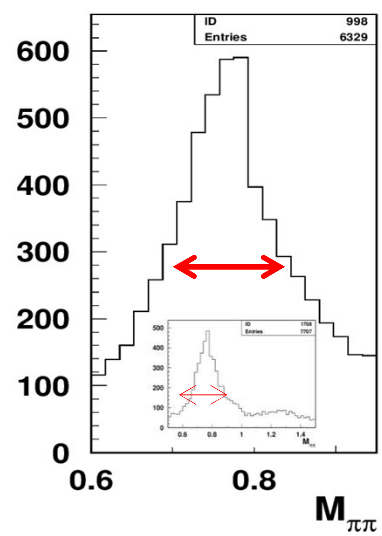


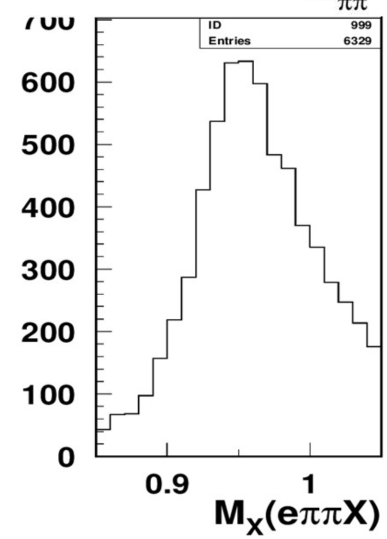
- Require the angle of negative pions is within a degree from calculated from e',p,π+ assuming exclusive e',p,π+π- event.

- Measurements of A_{LL} for ρ^0 indicate very small values (with ~10-20% bck, likely negative ~ -2-10%), and can be one of the reasons for higher A_{LL} with protons with a M_X cuts above 1.35 GeV (excluding exclusive ρ^0)

Request to theory→ evaluate the impact on $g_1(x,k_T)$ with all A_{LL}s increasing 10-20%







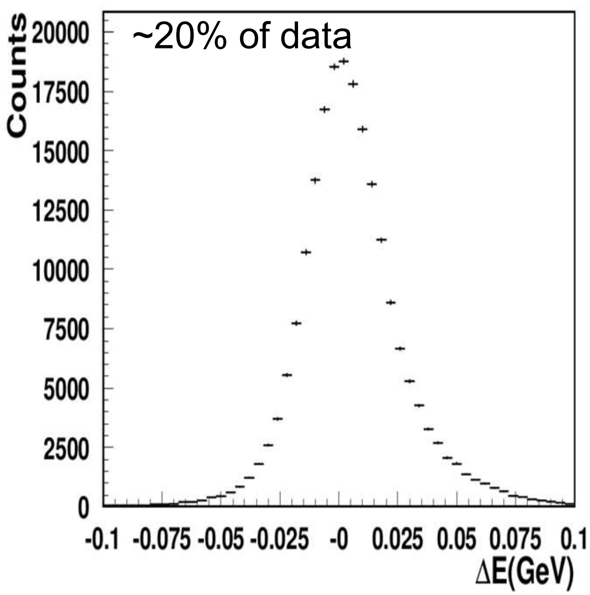
Need clear separation of hydrogen from NH_3 and diffractive exclusive ρ0s from exclusive π+π–

CLAS12 Experiments involved: Exclusive rhos

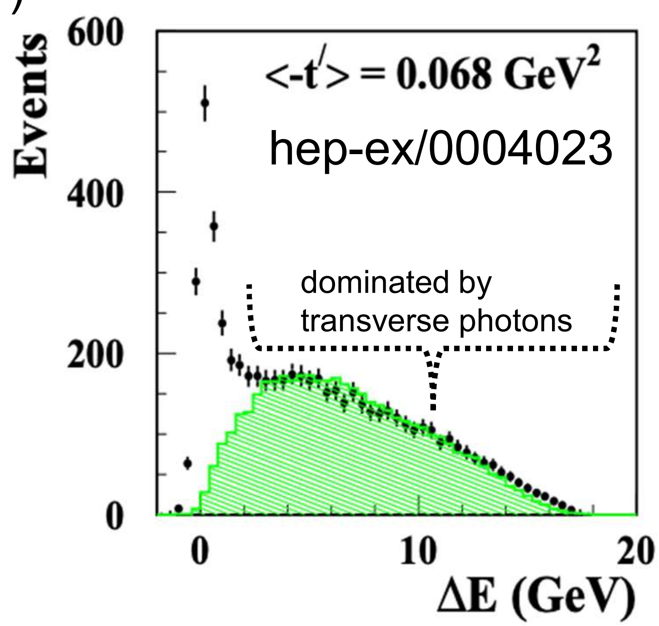
Exclusivity condition defined by the missing Energy:

$$M_X^2 = (p + q - p_{\pi^+} - p_{\pi^-})^2 \qquad E_{\text{miss}} = \frac{M_X^2 - M^2}{2M}$$

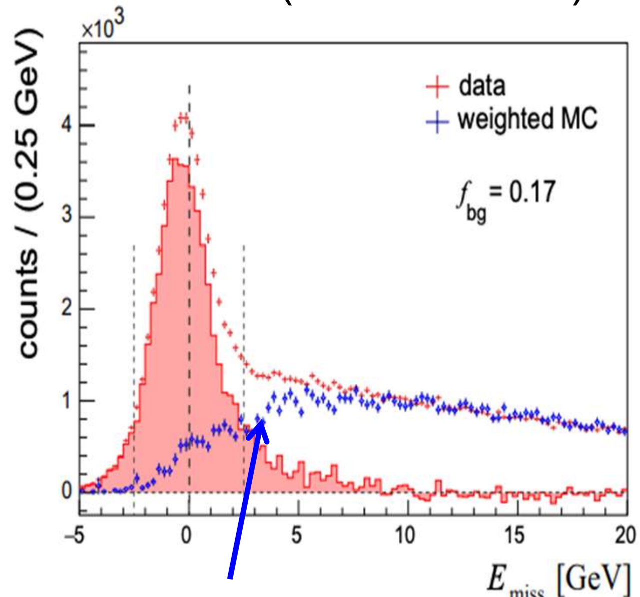
CLAS12 (width <0.1GeV)



HERMES(width ~0.6GeV)



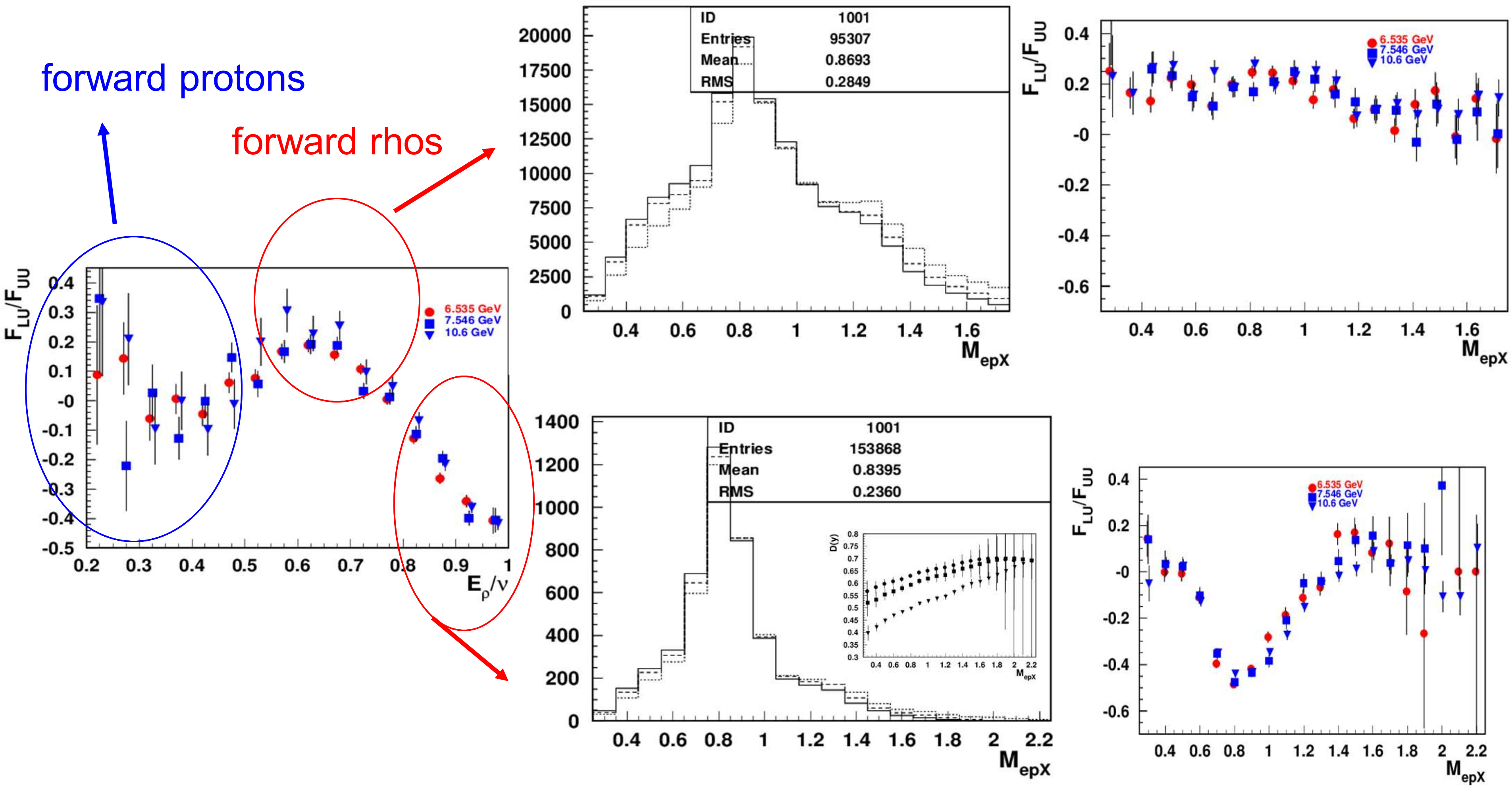
COMPASS(width ~2GeV)



what are cosθ distributions of those?

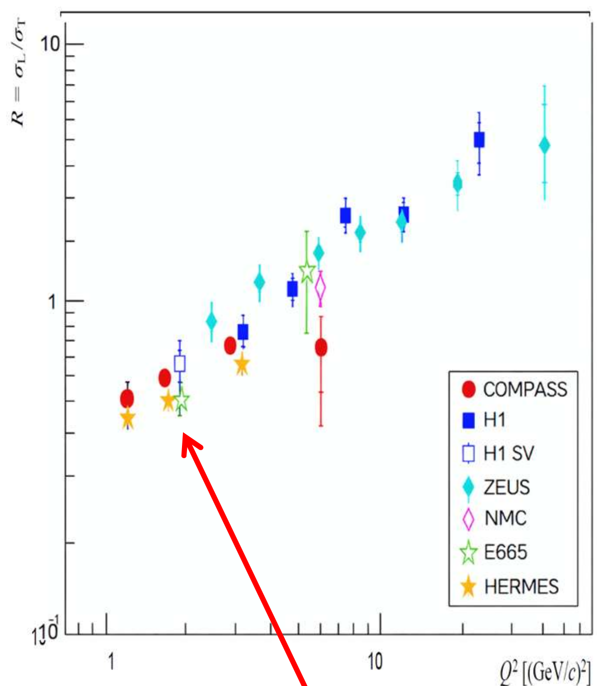
- Guarantying the "exclusivity" requires good resolutions (gets worse at higher energies)
- Subtraction procedure relays on normalization, based on exclusive limit of LUND-MC
- All distributions have tails, indicating the RC may not be negligible
- Extraction of SDMEs, will require validation in the multi-D space (significant samples)

Exclusive π+π−: missing mass dependence

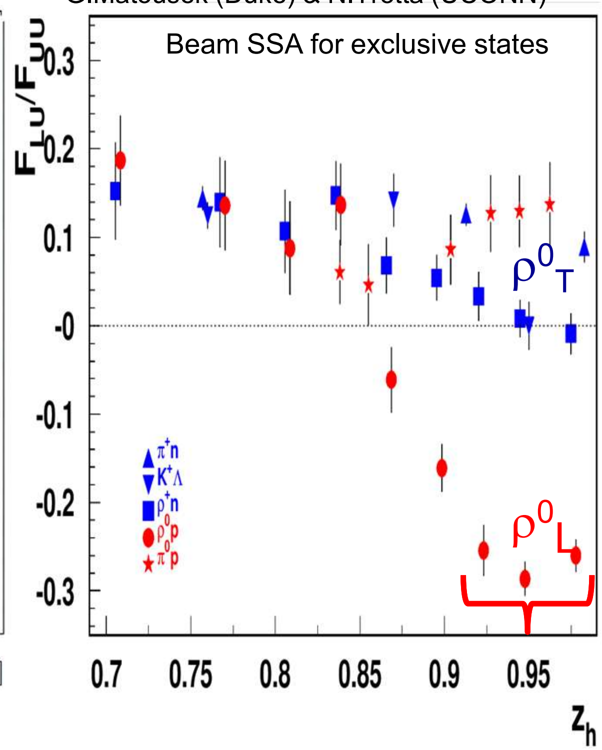


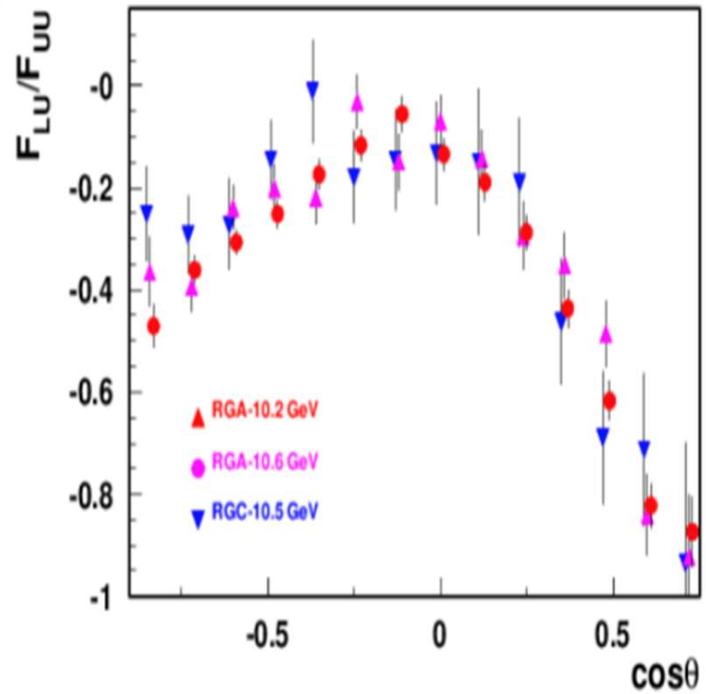
- ρs dominate both exclusive dihadron samples, contributing differently depending on z
- SSA can be used as a tool to check dominance of different dynamical contributions

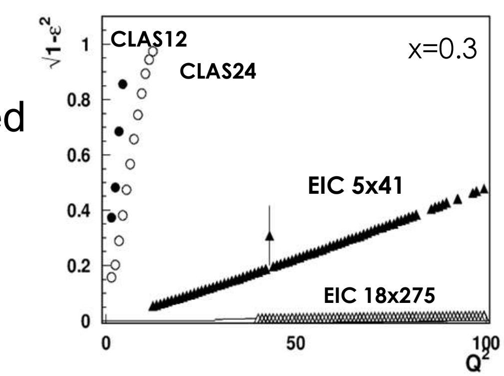
L/T photons producing T/L VMs



G.Matousek (Duke) & N.Trotta (UCONN)







L/T separation Assuming SCHC→ SSA of rho should be 0←clearly violated

To separate L and T-photon contributions detailed measurements are needed for L/T interference observables,
→ practically impossible at higher energies and large x!!!

Structure functions: case of VMs

Diehl: 0704.1565 $\gamma^*(\mu) + p(\lambda) \to \rho(\nu) + p(\sigma)$

More angles involved

$$\frac{d\sigma}{d\psi\, d\phi\, d\varphi\, d(\cos\vartheta)\, dx_B\, dQ^2\, dt} = \frac{1}{(2\pi)^2}\frac{d\sigma}{dx_B\, dQ^2\, dt}$$

$$\times\Big(W_{UU} + P_\ell W_{LU} + S_L W_{UL} + P_\ell S_L W_{LL} + S_T W_{UT} + P_\ell S_T W_{LT}\Big)$$

$$u^{\nu\nu'}_{\mu\mu'} = \tfrac{1}{2}\big(\rho^{\nu\nu'}_{\mu\mu',++} + \rho^{\nu\nu'}_{\mu\mu',--}\big)$$

beam SSA involves several dynamical contributions

$$W_{LU}(\phi,\varphi,\theta)$$

After integration over φ two terms survive

$$\cos^2\theta W^{LL}_{LU}(\phi,\theta) + \sin^2\theta W^{TT}_{LU}(\phi,\theta)$$

$$W^{LL}_{LU}(\phi) = -2\sin\phi\sqrt{\epsilon(1-\epsilon)}\,\mathrm{Im}\,u^{0\,0}_{0+}\,,$$

$$W^{LT}_{LU}(\phi,\varphi) = \sin(\phi+\varphi)\sqrt{\epsilon(1-\epsilon)}\,\mathrm{Im}\big(u^{0+}_{0+} - u^{-0}_{0+}\big)$$
$$-\sin\varphi\sqrt{1-\epsilon^2}\,\mathrm{Im}\big(u^{0+}_{++} - u^{-0}_{++}\big)$$
$$-\sin(\phi-\varphi)\sqrt{\epsilon(1-\epsilon)}\,\mathrm{Im}\big(u^{0-}_{0+} - u^{+0}_{0+}\big)\,,$$

interference of transverse and longitudinal ρ from transverse photons

$$W^{TT}_{LU}(\phi,\varphi) = -\sin\phi\sqrt{\epsilon(1-\epsilon)}\,\mathrm{Im}\big(u^{++}_{0+} + u^{--}_{0+}\big) + \sin(\phi+2\varphi)\sqrt{\epsilon(1-\epsilon)}\,\mathrm{Im}\,u^{-+}_{0+}$$
$$-\sin(2\varphi)\sqrt{1-\epsilon^2}\,\mathrm{Im}\,u^{-+}_{++}$$
$$+\sin(\phi-2\varphi)\sqrt{\epsilon(1-\epsilon)}\,\mathrm{Im}\,u^{+-}_{0+}\,.$$

Detector has acceptances in angles, and integration should account that to be interpretable by theory

SDMEs: different combinations in experiment

Diehl: 0704.1565 $\gamma^*(\mu) + p(\lambda) \to \rho(\nu) + p(\sigma)$

$$u^{\nu\nu'}_{\mu\mu'} = \frac{1}{2}\left(\rho^{\nu\nu'}_{\mu\mu',++} + \rho^{\nu\nu'}_{\mu\mu',--}\right)$$

$$\frac{d\sigma}{d\psi\, d\phi\, d\varphi\, d(\cos\vartheta)\, dx_B\, dQ^2\, dt} = \frac{1}{(2\pi)^2}\frac{d\sigma}{dx_B\, dQ^2\, dt} \times \left(W_{UU} + P_\ell W_{LU} + S_L W_{UL} + P_\ell S_L W_{LL} + S_T W_{UT} + P_\ell S_T W_{LT}\right)$$

$$u^{0\,0}_{++} + \epsilon u^{0\,0}_{0\,0} = r^{04}_{00} = \frac{d\sigma(\gamma^*_T \to V_L) + \varepsilon d\sigma^N(\gamma^*_L \to V_L)}{d\sigma}$$

Valuable source of info on longitudinal photon!!!

sinusoidal modulations(~0 at COMPASS)

$$\mathrm{Im}\, u^{0\,0}_{0+} = r^8_{00}/\sqrt{2}\,,$$

$$\mathrm{Re}\, u^{0\,0}_{0+} = -r^5_{00}/\sqrt{2}$$

$\longrightarrow$ Interference of $\gamma_T^* \to \rho_L$ and $\gamma_L^* \to \rho_L$

cosine modulations(huge at COMPASS)

$$\mathrm{Im}\left(u^{++}_{0+} + u^{--}_{0+}\right) = \sqrt{2}\, r^8_{11}$$ *(>0 at COMPASS/HERMES)*

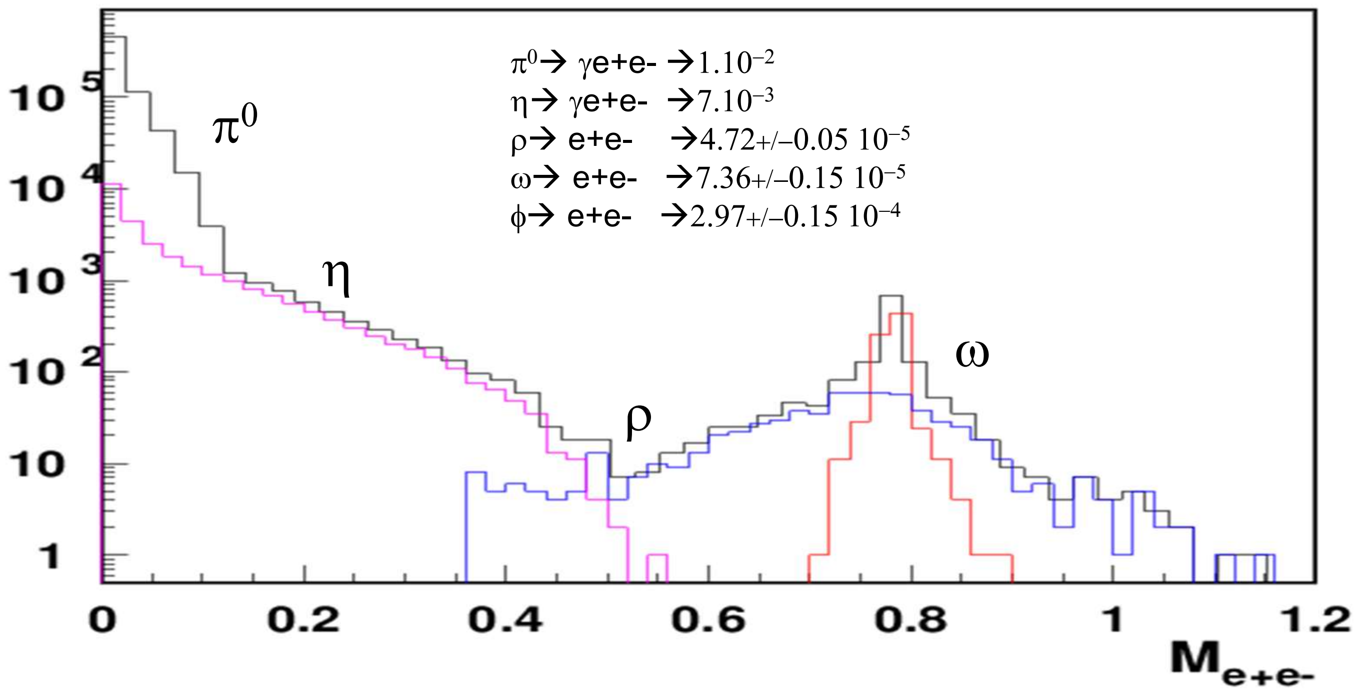
$\longrightarrow$ Interference of $\gamma_T^* \to \rho_T$ and $\gamma_L^* \to \rho_T$

$$\mathrm{Re}\left(u^{++}_{0+} + u^{--}_{0+}\right) = -\sqrt{2}\, r^5_{11}$$ *(~0 at COMPASS/HERMES)*

Using e+e- to estimate vector mesons

The invariant mass of dihadrons is contaminated by other vector mesons, with shape not changing significantly with hadronization fraction to spin-1 vs spin-0 mesons

decays of π and η are kinematically separeated from ω and ρ^0



Vector meson per electron can be independently estimated from ep$\rightarrow$e'e+e-X
Can check decay shapes changing for L-rho to $\cos^2\theta$

Measurements of exclusive rho at ZEUS

0708.1478

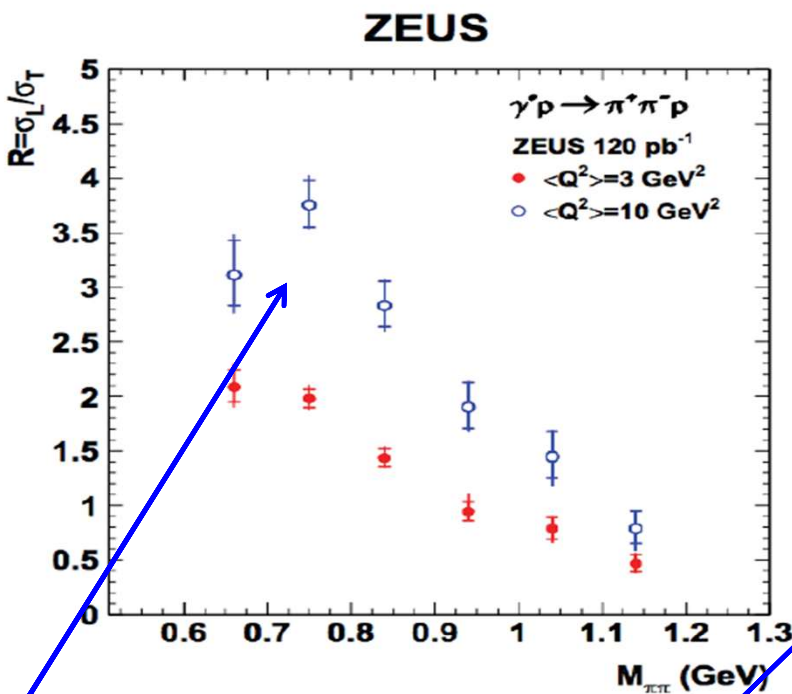
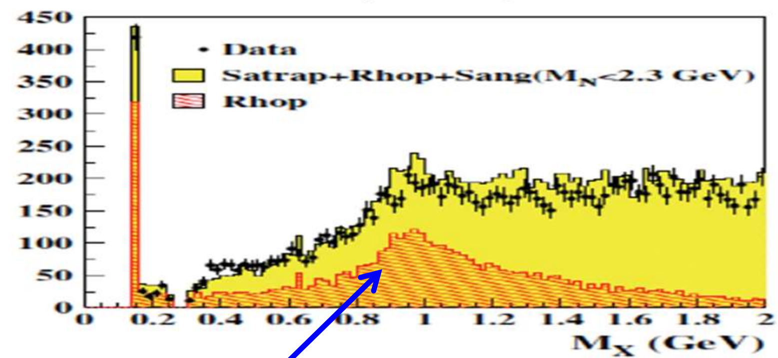
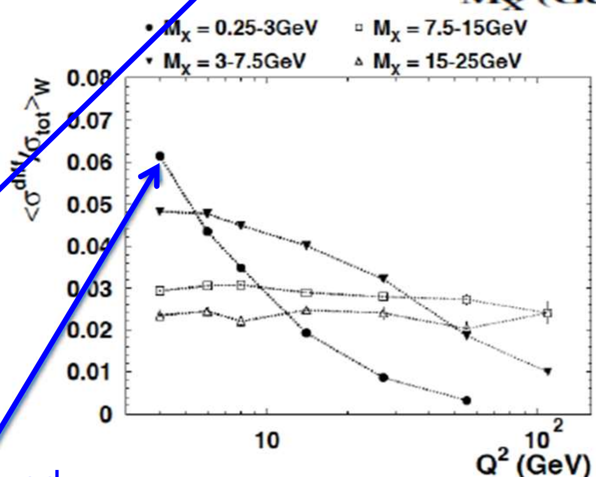


Figure 19: *The ratio R as a function of $M_{\pi\pi}$, for W = 80 GeV and for two values of Q^2, as indicated in the figure. The inner error bars indicate the statistical uncertainty, the outer error bars represent the statistical and systematic uncertainty*

ZEUS (low MX)



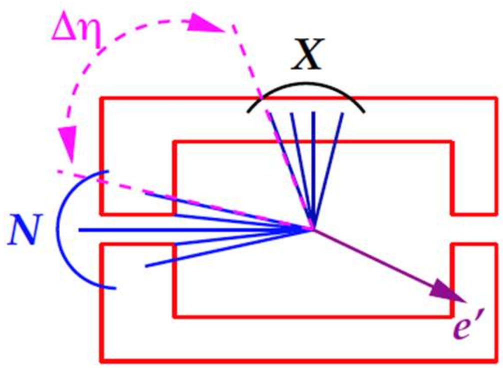


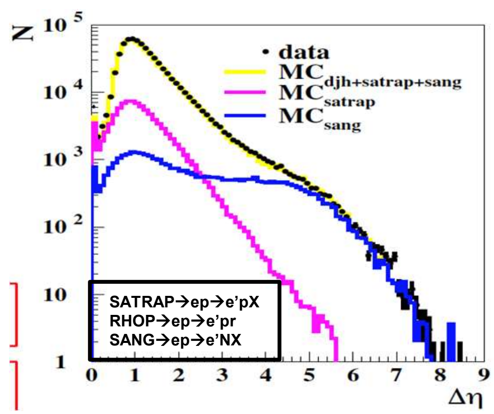
: The ratio of the diffractive cross section σ^{diff} and the total $\gamma^* p$ cross section as a function of Q^2 for different bins of M_X. To guide the eye the dotted lines ts corresponding to the same M_X values.

- Around rho0 mass the longitudinal photon contribution is maximized, can we claim that rho production dominates the longitudinal photon production?
- The low MX is dominated by rho0s
- At low MX the ratio ~1/Q^2 with week dependence on W and x

DDIS and rho from ZEUS

No major dependence on W for low M_X?





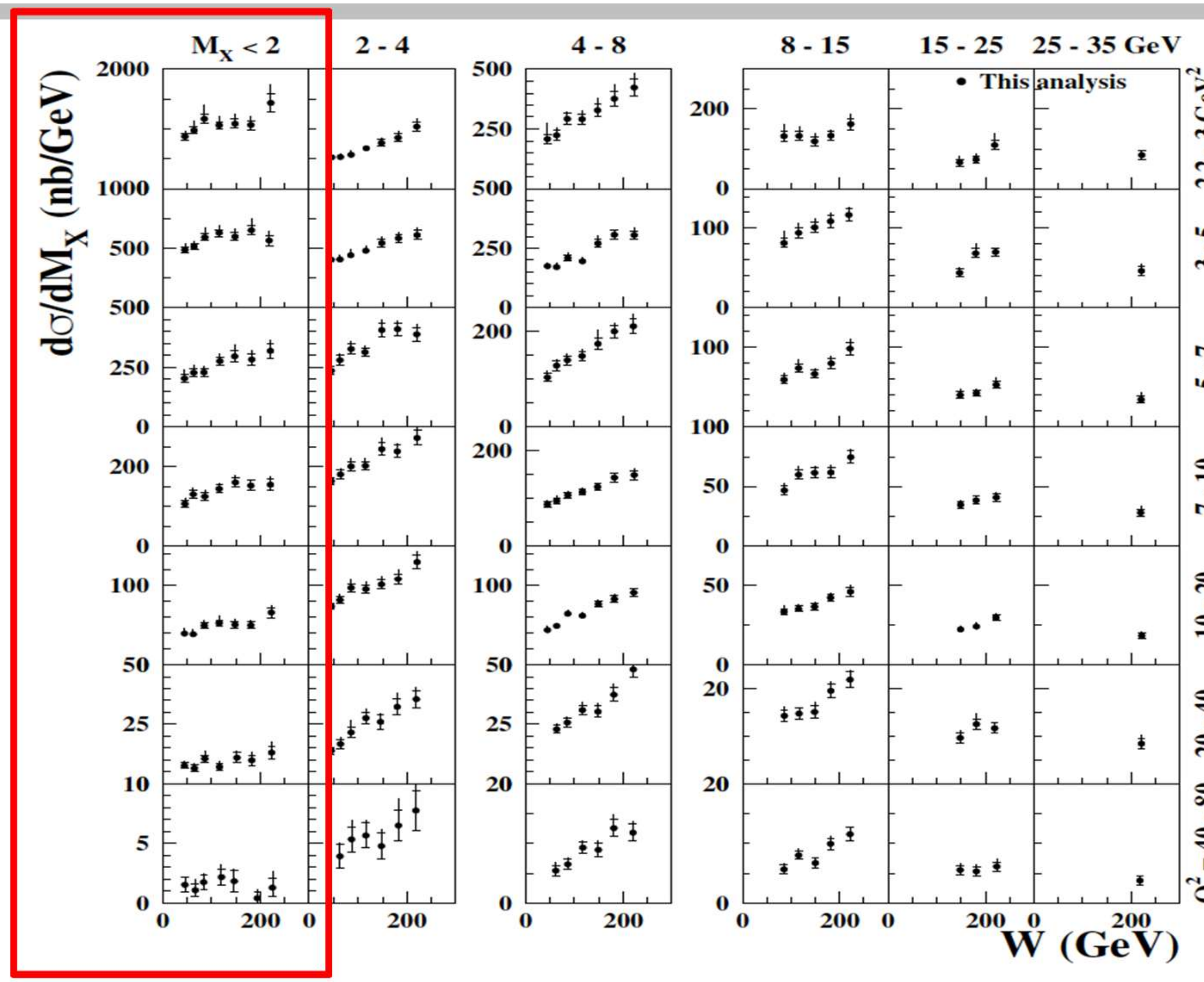
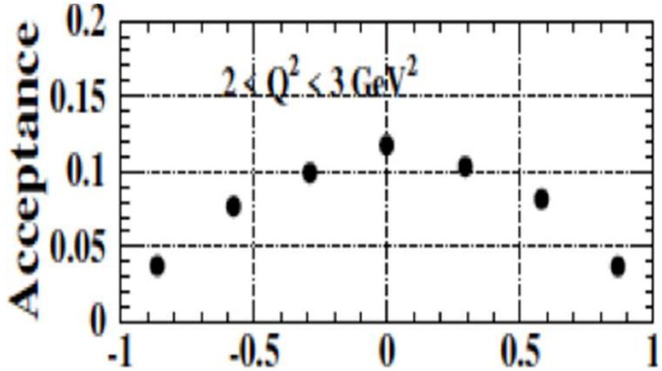
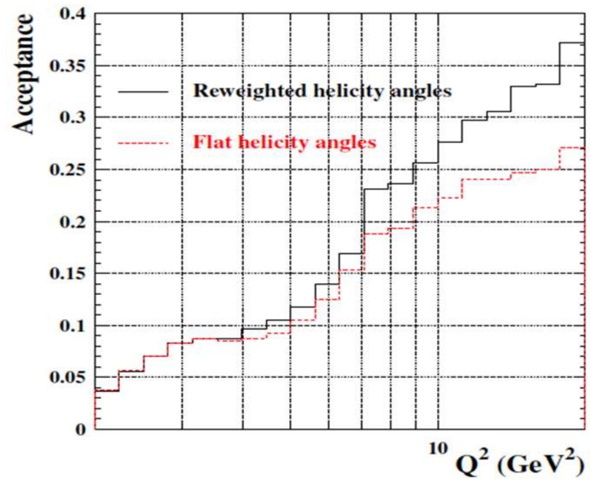


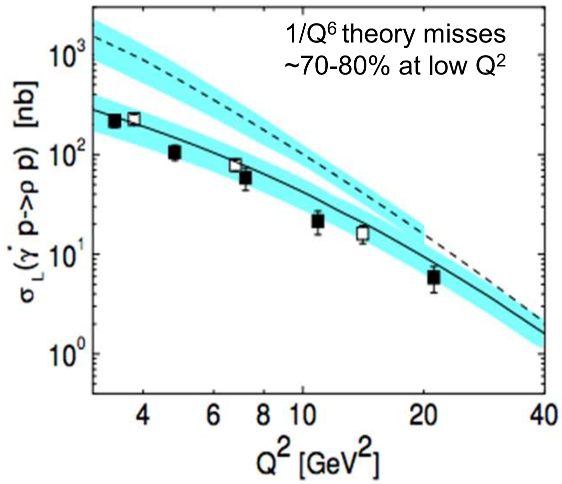
Figure 10.3: The differential cross sections $d\sigma^{diff}_{\gamma^* p \to XN}/dM_X$, $M_N < 2.3$ GeV, as a function of W for bins for M_X and Q^2. The inner error bars show the statistical uncertainties and the full bars the statistical and systematic uncertainties added in quadrature.

Impact of acceptances in cos θ

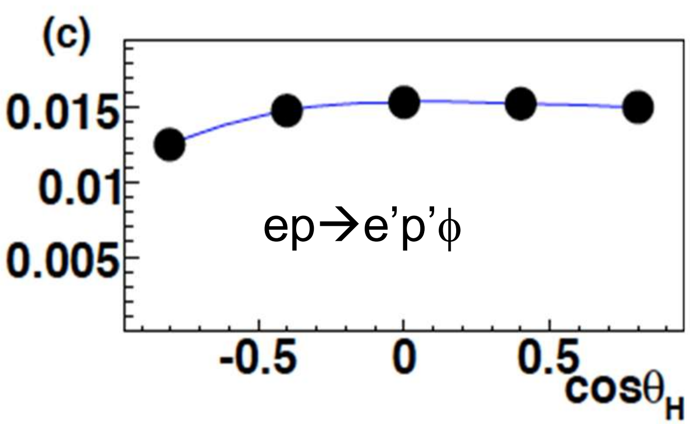
ZEUS rho (0708.1478)

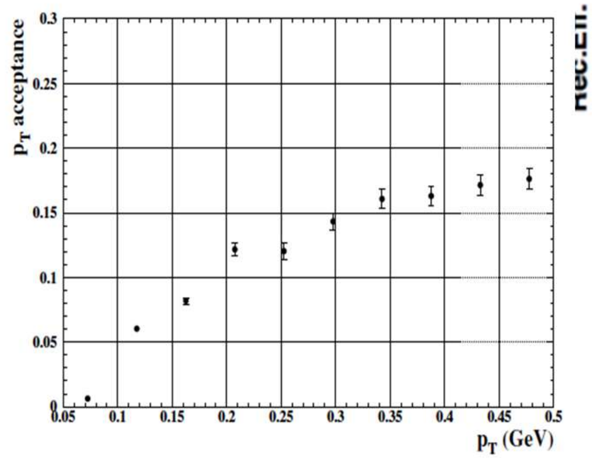


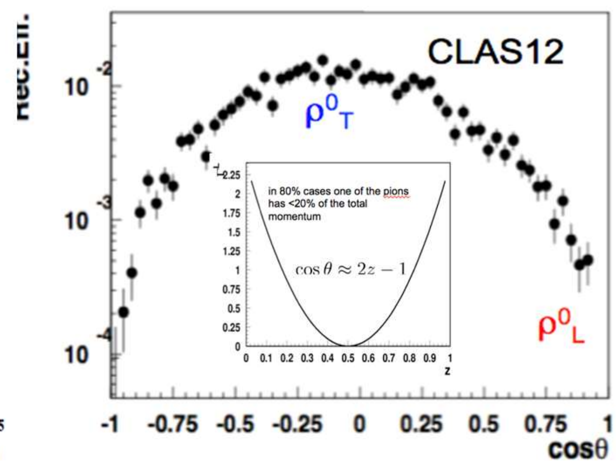




CLAS6 0803.3537







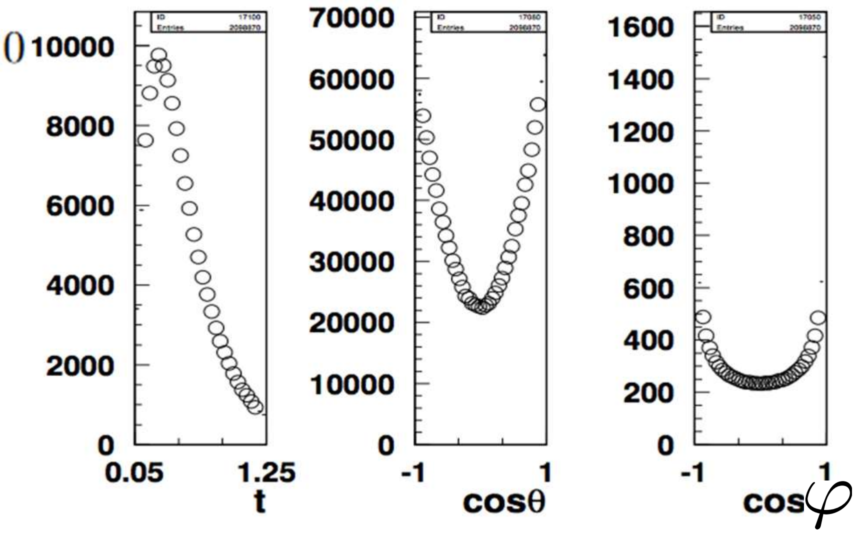
- Proper acceptance account requires fine multidimensional binning, high statistics
- ZEUS 7-bins with acceptance at $|\cos\theta|>0.8$ reducing ~2 times (integrated over t?)
- Situation even worse for electroproduction of ϕ-mesons

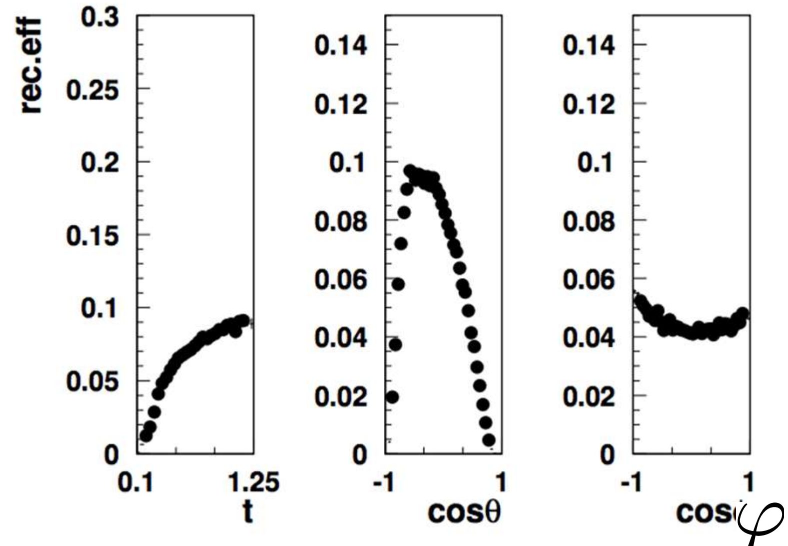
Comparing 2 MCversions for CLAS12

Generated

Reconstruction efficiencies

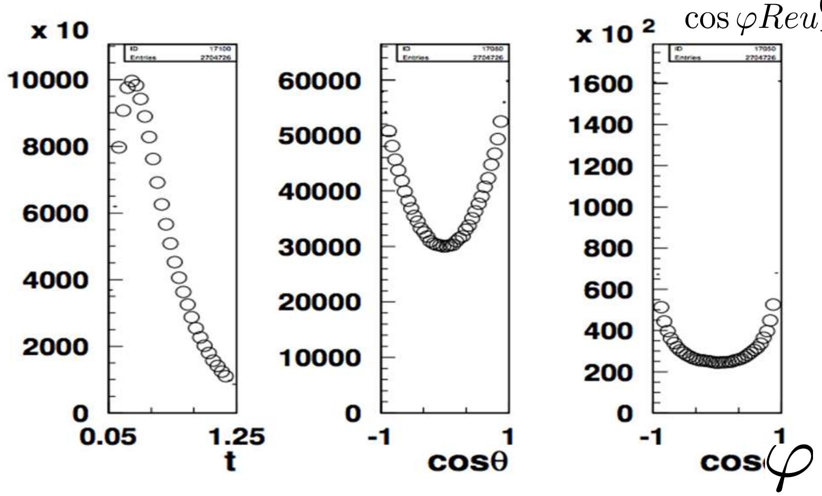
$u_{00}^{0+} = 0$

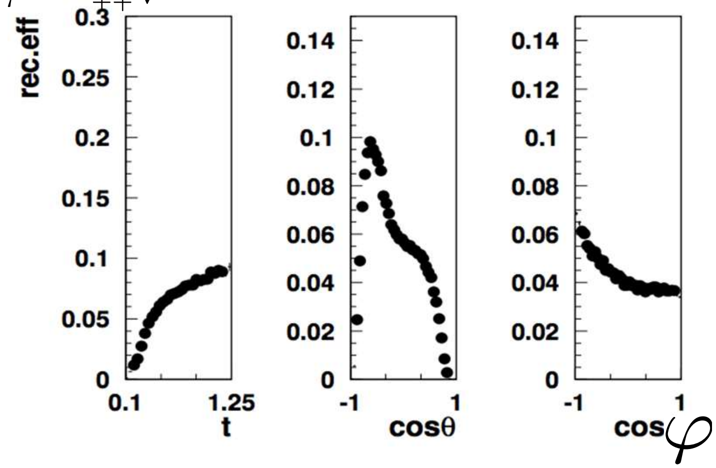




$\cos\varphi Re u_{++}^{0+} + \sin\varphi Im u_{++}^{0+} \sqrt{1-\epsilon^2}$

$u_{00}^{0+} \neq 0$

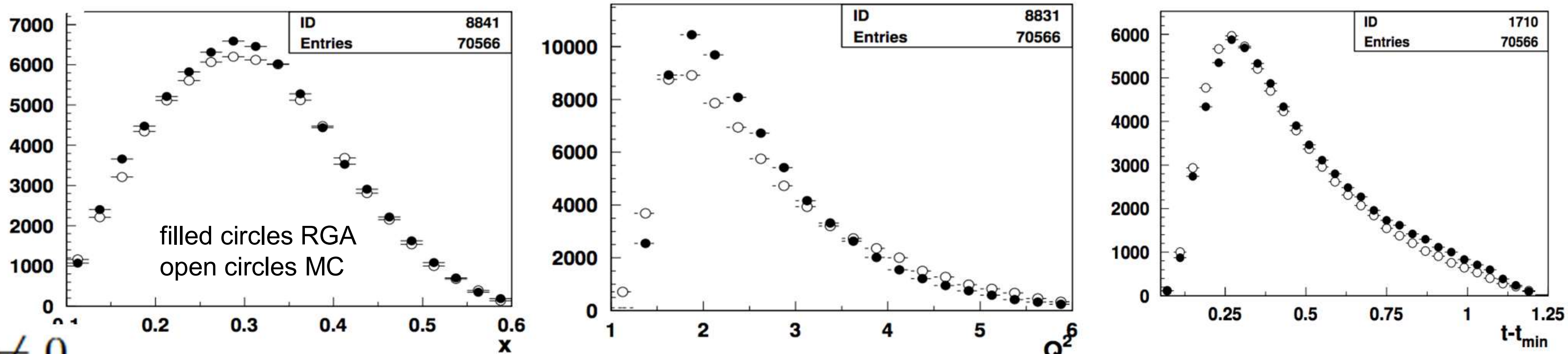




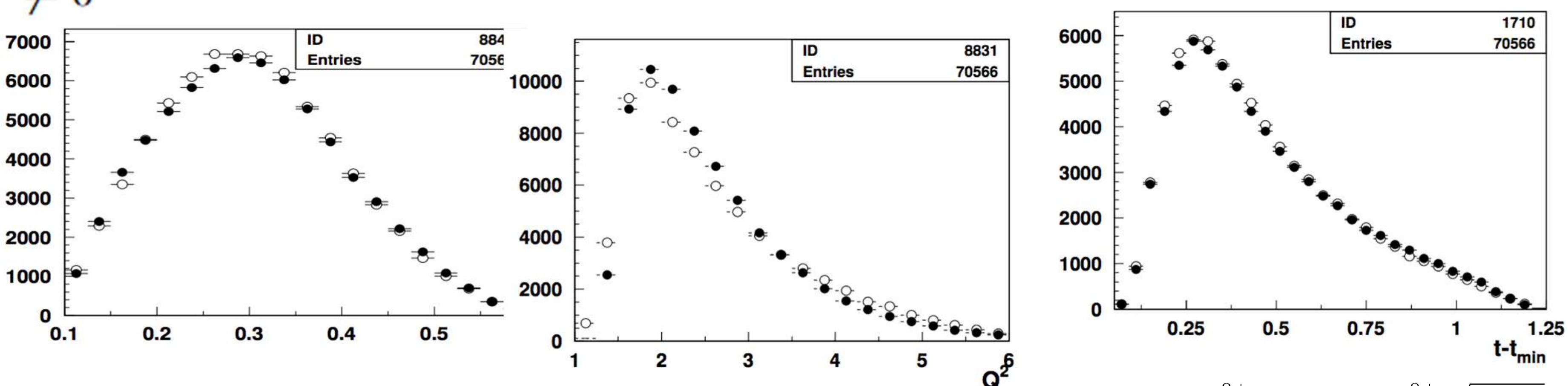
Comparing the MC with CLAS12 data (ep→e'p'ρ)

use the rho-generator-gemc-reconstruction chain to compare with CLAS12 10.6 GeV data vs 2 MC models

$u_{00}^{0+} = 0$



$u_{00}^{0+} \neq 0$



- With proton detected and exclusivity cuts applied no major background left
- Good agreement for distributions on relevant variables

$\cos\varphi Re u_{++}^{0+} + \sin\varphi Im u_{++}^{0+} \sqrt{1-\epsilon^2}$

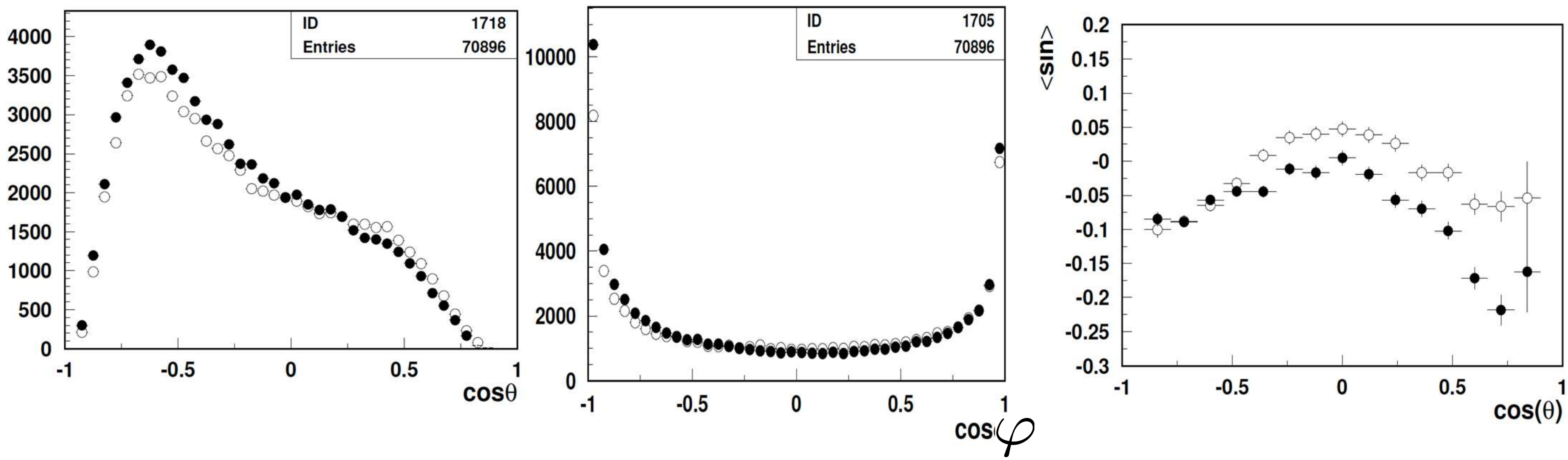
<u>10359 has additional terms in</u> $W_{LU}^{LT}(\phi,\varphi)$

<u>from interference of transverse and longitudinal rho produced by transverse photons</u>

Comparing the MC with CLAS12 data

$$u_{00}^{0+} = 0$$

CLAS12 10.6 data set vs MC



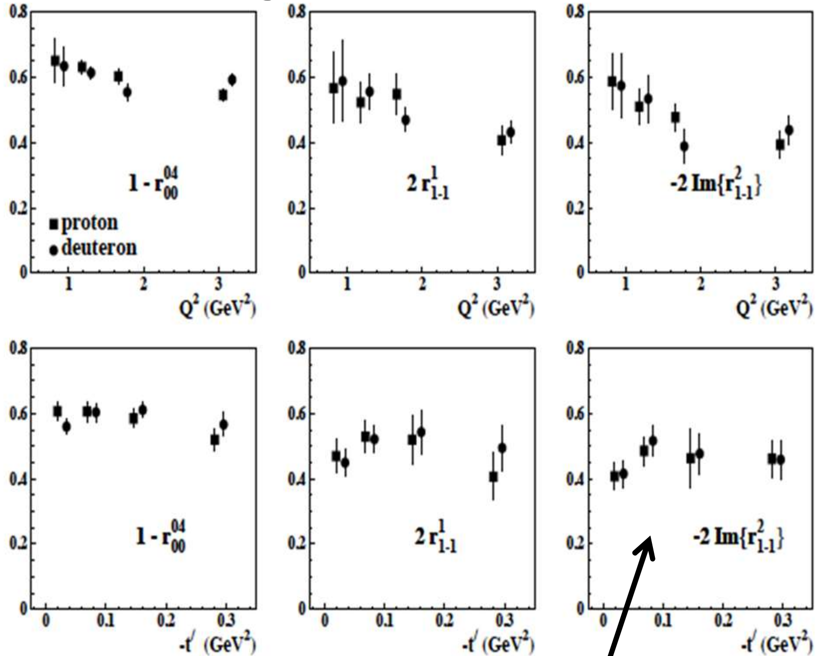
MC in terms of Helicity Structure functions: Relative contributions from longitudinal and transverse described well with Longitudinal rhos dominating ~5-6 times for Q^2~1.5

$$\int \frac{d\phi}{2\pi} \int d\varphi \, d(\cos\vartheta) \; H_{UU}(\phi, \varphi, \vartheta) = \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt}$$

$$\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} = \left(u_{++}^{00} + u_{++}^{++} + u_{++}^{--}\right) + \epsilon \left(u_{00}^{00} + 2\, u_{00}^{++}\right)$$

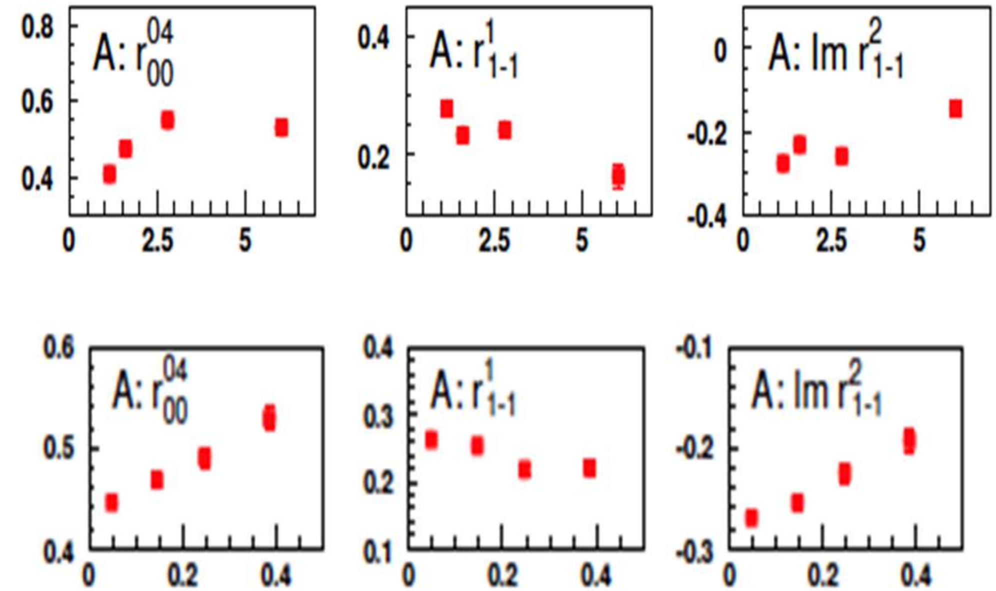
COMPASS/HERMES Measurements

HERMES $u_{++}^{00} + \epsilon u_{00}^{00} = r_{00}^{04}$



transverse part independent on t'

COMPASS $u_{-+}^{-+} = r_{1-1}^{1} - \mathrm{Im}\, r_{1-1}^{2}$



transverse part decreasing with t'

The normalized SDMEs (ratio to σ_{Total}) seem to be independent on kinematics
While average values seem to be consistent, the t-dependences of transverse dominated contributions inconsistent

Testing complementarity for different experiments using the accessible kinematics

A simple text files with 4 columns of generated Vertex and 3momentum, and reconstructed vertex and 3momentum (if available) for every relevant PID, can be used to study the potential for separation of longitudinal and transverse photon contributions

Ex of input files for a given configuration (rga-spring19,Tor-1Sol-1, bck 50nA)
/volatile/clas12/users/avakian/mc/fastmc-counts/rga10.2

```
ifarm2402.jlab.org> ll rga10.2/*txt
-rw-rw-r--. 1 avakian clas12-grp 794298858 May 27 15:40 rga10.2/pro-counts.txt
-rw-rw-r--. 1 avakian clas12-grp 733415138 May 27 15:40 rga10.2/ele-counts.txt
-rw-rw-r--. 1 avakian clas12-grp 802489418 May 27 15:40 rga10.2/pip-counts.txt
-rw-rw-r--. 1 avakian clas12-grp 727448338 May 27 15:40 rga10.2/pim-counts.txt
```

Ex. File structure for electron

Pgen	θ−gen	ϕ−gen	Z-gen	Prec	θ−rec	ϕ−rec	Z-rec
7.606	0.147	4.864	-3.747				
7.724	0.122	4.543	-4.640				
6.436	0.182	2.091	-5.268	6.409	0.183	2.087	-4.377
1.895	0.410	2.116	-1.569	1.883	0.408	2.121	-1.455
7.820	0.130	4.417	-5.156				
6.585	0.165	1.184	-4.192	6.547	0.165	1.173	-3.384
7.331	0.137	1.970	-1.048	7.275	0.138	1.967	0.786
8.079	0.111	3.892	-1.570				
7.315	0.118	5.869	-1.829				
7.956	0.126	0.875	-0.983				
7.428	0.129	3.458	-2.007				
5.645	0.269	2.495	-1.867	5.621	0.270	2.492	-1.491

Files with generated and reconstructed events for a given ID, can be used in different way, including making grids with rec.eff.

Plans for future analysis of VMs

Development of realistic MC with reasonable kinematic dependences of Helicity Structure Functions (HSFs) tested in full kinematics covered by JLab,HERMES, COMPASS

Development of the framework for AI inference of HSFs from exclusive VM data using unpolarized and polarized target data

Extraction of HSFs from CLAS12 data sets

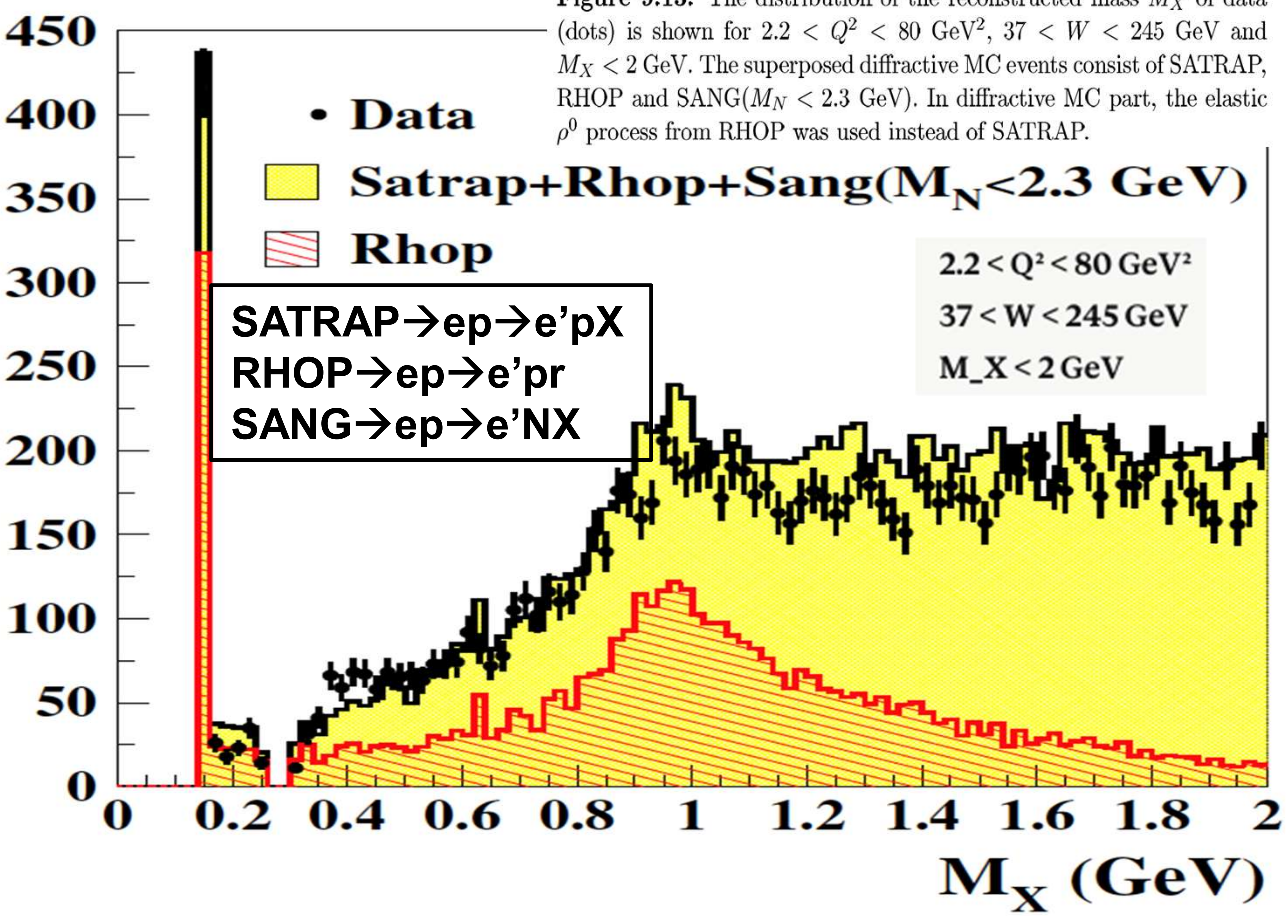
Extraction of HSFs from combined CLAS12/COMPASS (possibly HERMES) data

Store the MC generated/reconstructed event files for the configuration of the simulation/reconstruction chain used for the final analysis of VM

As a part of the preservation make public event samples for event based data analysis

DDIS and rho from ZEUS

Figure 9.13: The distribution of the reconstructed mass M_X of data (dots) is shown for $2.2 < Q^2 < 80$ GeV^2, $37 < W < 245$ GeV and $M_X < 2$ GeV. The superposed diffractive MC events consist of SATRAP, RHOP and SANG($M_N < 2.3$ GeV). In diffractive MC part, the elastic ρ^0 process from RHOP was used instead of SATRAP.



Thesis for the Degree of Doctor of Science

Measurement of the diffractive cross section in deep inelastic ep scattering using the ZEUS Forward Plug Calorimeter at HERA

Heuijin Lim

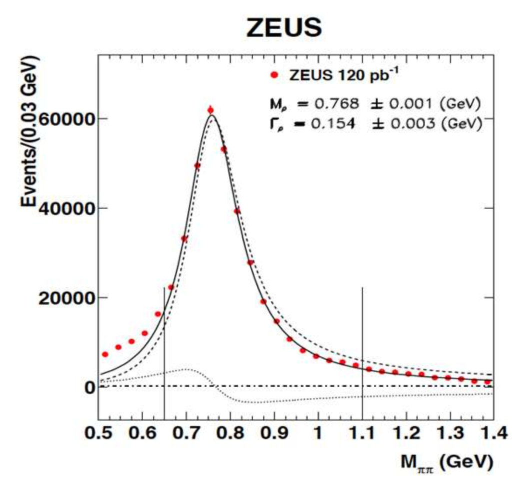


Figure 4: The $\pi^+\pi^-$ acceptance-corrected invariant-mass distribution. The line represent the best fit of the Söding form to the data in the range $0.65 < M_{\pi\pi} < 1.1$ GeV. The vertical lines indicate the range of masses used for the analysis. The dashed line is the shape of a relativistic Breit-Wigner with the fitted parameters given in the figure. The dotted line is the interference term between the non-resonant background (dash-dotted line) and the ρ^0 signal.

Is the M_X invariant mass of the hadronic system X ($\gamma^*p \to XN$) with M_N<2.3 GeV?, Why the peak at 0.9?

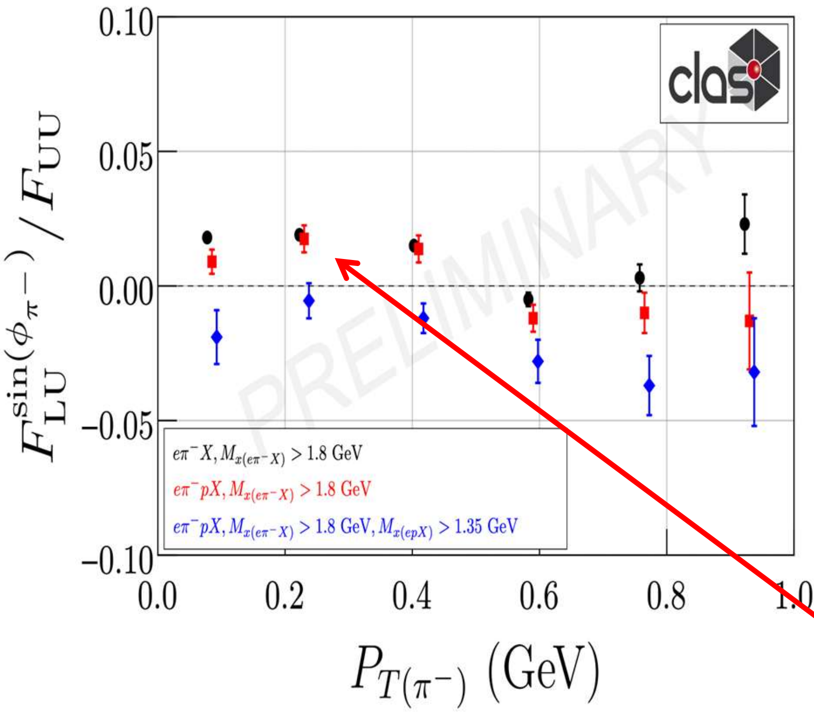
$$BW(M) = \frac{1}{\pi}\frac{\Gamma/2}{(M - M_\rho)^2 + (\Gamma/2)^2},$$

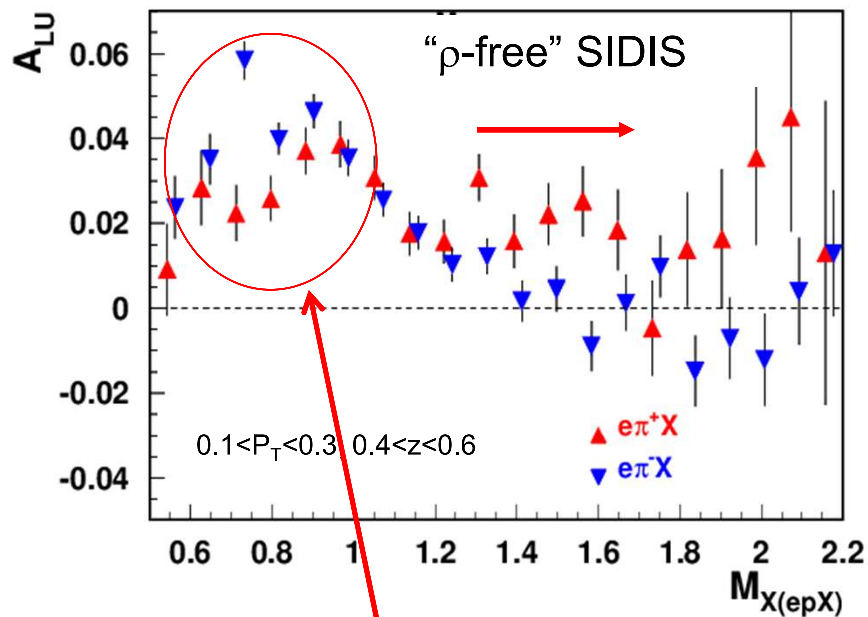
$$M_\rho \approx 0.775 \text{ GeV}, \qquad \Gamma_\rho \approx 0.149 \text{ GeV}$$

[1] In MC-SATRAP, the ρ^0 events which satisfy $|M_X - M_{\rho^0}| < 0.05 M_{\rho^0}$, are selected to be from the elastic ρ^0 processes.

why 0.05, interval will have <50% of events?

Exclusive ρ0s: impact on SIDIS SSAs





- Can change the pion SSAs, in particular at small P_T
- The same sign and size of π+ and π- SSA indicates the rho0 may be significant, subtraction will require detailed MC studies, which require proper SDMEs
- While VM contributions are ~20% in multiplicities in SSA they can be >100%
- Detection of the target proton allows to clean up the SIDIS sample from exclusive rho contributions