Exclusive meson production program with CLAS12 at 20+ GeV

The Next Generation of 3D Imaging
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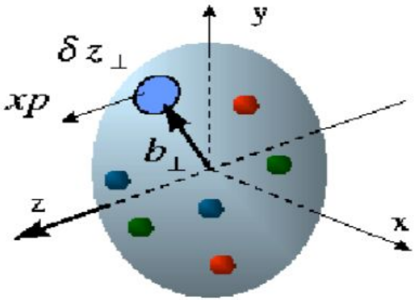
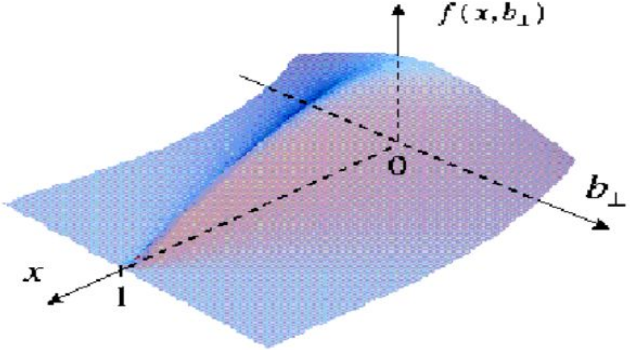
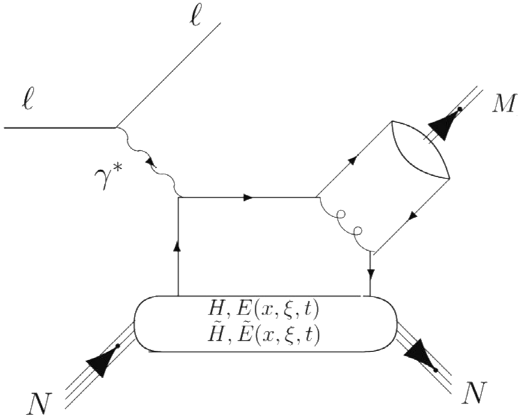
(University of Connecticut)

GPDs and exclusive meson electroproduction



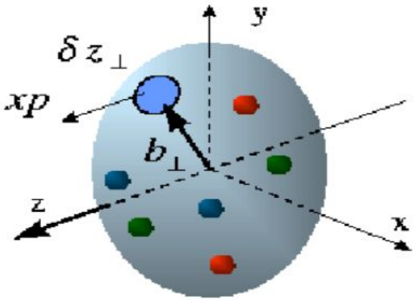


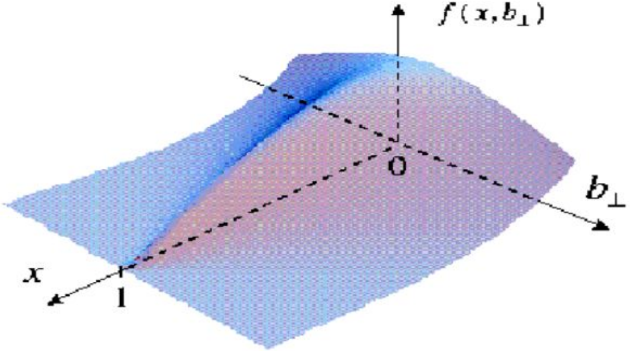
- 4 chiral-even GPDs: H, E, $\tilde{H}$, $\tilde{E}$
- 4 chiral-odd GPDs: H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$



$$\langle F \rangle = \sum_{\lambda} \int_{-1}^{1} dx \mathcal{H}_{0\lambda,\mu\lambda}(x, \xi, Q^2, t) F(x, \xi, t)$$

GPDs and exclusive meson electroproduction





- 4 chiral-even GPDs: H, E, $\tilde{H}$, $\tilde{E}$
- 4 chiral-odd GPDs: H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$

	Meson	GPD flavor composition
$\tilde{H}$, $\tilde{E}$ / H_T, $\bar{E}_T$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d$
H, E	ρ^0	$2u + d$
	ρ^+	$u - d$
	ω	$2u - d$

Chiral-odd GPDs

- Proton anomalous tensor magnetic moment

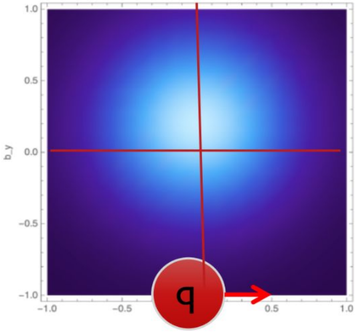
$$\kappa_T^u = \int dx \bar{E}_T^u(x, \xi, t = 0)$$
$$\kappa_T^d = \int dx \bar{E}_T^d(x, \xi, t = 0)$$

- Proton tensor charge

$$\delta_T^u = \int dx H_T^u(x, \xi, t = 0)$$
$$\delta_T^d = \int dx H_T^d(x, \xi, t = 0)$$

- Density of transversity polarized quarks in an unpolarized proton in the transverse plane

$$\delta(x, \vec{b}) = \frac{1}{2}[H(x, \vec{b}) - \frac{b_y}{m}\frac{\partial}{\partial b^2}\bar{E}_T(x, \vec{b})]$$



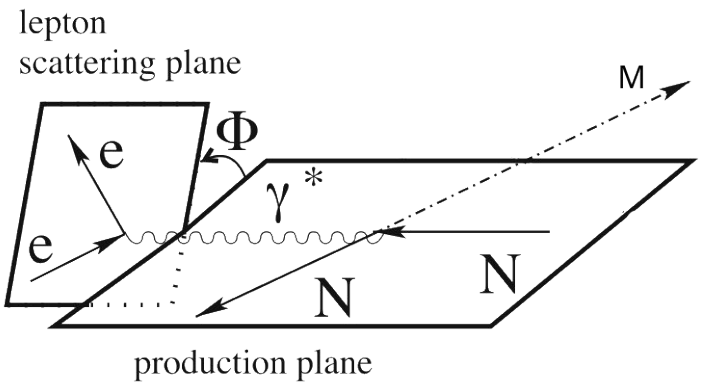
Experimental observables for exclusive meson production

$$\frac{d^4\sigma}{dQ^2\ dx_B\ dt\ d\Phi} = \Gamma(Q^2, x_B, E)$$

$$\frac{1}{2\pi}\left\{\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right.$$

$$+ \epsilon\frac{d\sigma_{TT}}{dt}\cos(2\Phi) + \sqrt{\epsilon(2\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos(\Phi)$$

$$\left. + \lambda\sqrt{2\epsilon(1-\epsilon)}\frac{d\sigma_{LT'}}{dt}\sin(\Phi)\ \right\}$$

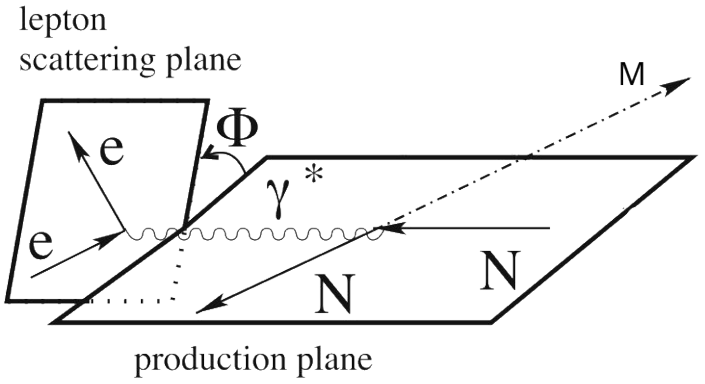


where λ is the helicity state of the incident electron beam

Experimental observables for exclusive meson production

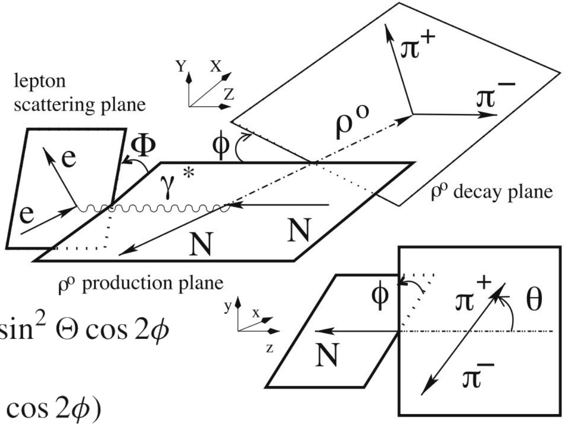
CLAS data:

Phys. Rev. C63: 065205, 2001 (φ)
Phys. Lett. B605: 256-264, 2005 (ρ^0)
Eur. Phys. J. A24: 445-458, 2005 (ω)
Phys. Rev. C78: 025210, 2008 (φ)
Eur. Phys. J. A39: 5-31, 2009 (ρ^0)
Phys. Rev. Lett. 109, 112001 (2012) (π^0)
Phys. Rev. C 95, 035207 (2017) (η)
Phys. Rev. C 95, 035206 (2017) (π^0)
Phys. Rev. C 95, 035202 (2017) (π^+)
Phys. Lett. B 768, 168 (2017) (π^0)
Phys. Lett B. 789, 426 (2019) (η)
Phys. Rev. Lett. 125, 182001 (2020) (π^+)



Vector meson production: Spin Density Matrix Elements (SDME)

$$\frac{d\sigma}{d\phi\ d\Phi\ d\Theta\ dQ^2\ dx_B\ dt} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}\left\{\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right\}\mathcal{W}^{U+L}(\Phi, \phi, \cos\Theta)$$

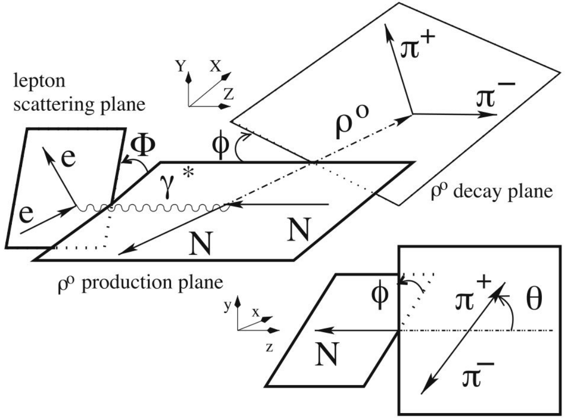


$$\begin{aligned}
\mathcal{W}^{U+L}(\Phi, \phi, \cos\Theta) &= \mathcal{W}^{U}(\Phi, \phi, \cos\Theta) + P_b\mathcal{W}^{L}(\Phi, \phi, \cos\Theta),\\
\mathcal{W}^{U}(\Phi, \phi, \cos\Theta) &= \frac{3}{8\pi^2}\Bigg[\frac{1}{2}(1 - r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00} - 1)\cos^2\Theta - \sqrt{2}\boxed{\mathrm{Re}\{r^{04}_{10}\}}\sin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

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

Vector meson production: Spin Density Matrix Elements (SDME)

$$\frac{d\sigma}{d\phi\ d\Phi\ d\Theta\ dQ^2\ dx_B\ dt} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}\left\{\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right\}\mathcal{W}^{U+L}(\Phi, \phi, \cos\Theta)$$



After simplifications from Eur. Phys. J. C (2014):

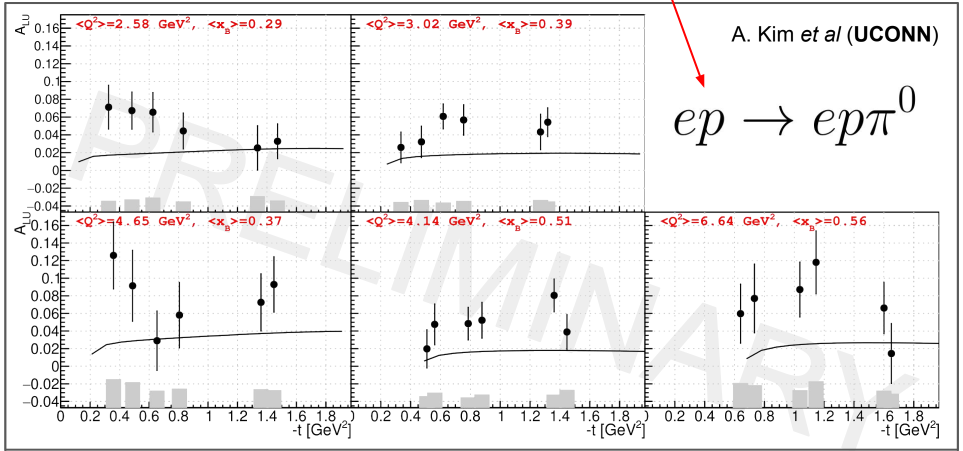
$$r^1_{00}\sigma_0 \sim \left|\bar{E}_T\right|^2$$

$$r^5_{00}\sigma_0 \sim \mathrm{Re}\left[\langle\bar{E}_T\rangle\langle H\rangle + \langle H_T\rangle\langle E\rangle\right]$$

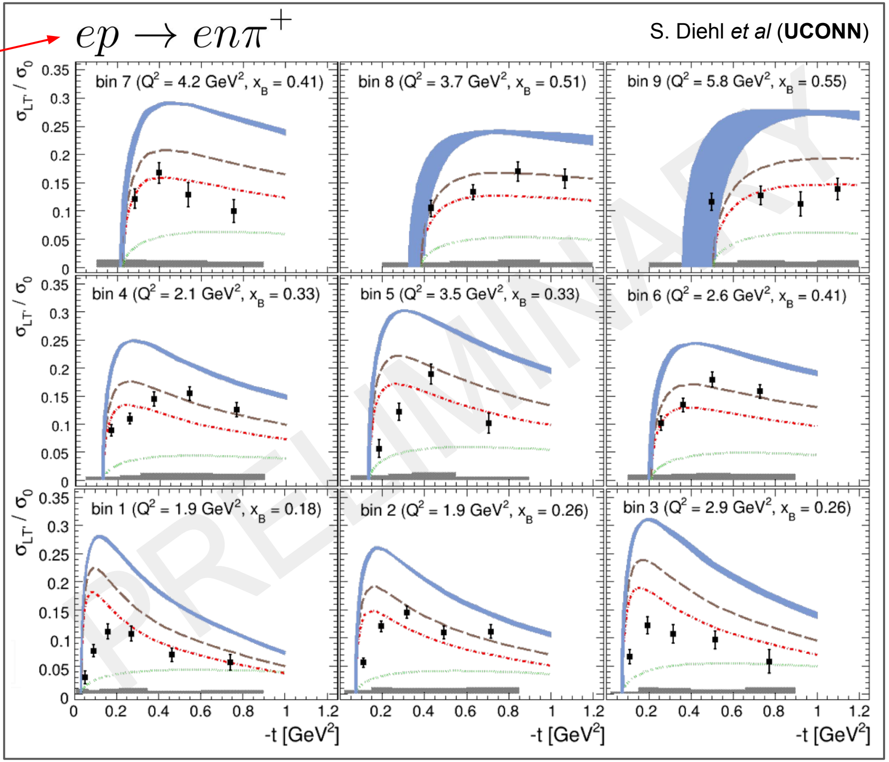
$$r^8_{00}\sigma_0 \sim \mathrm{Im}\left[\langle\bar{E}_T\rangle\langle H\rangle + \langle H_T\rangle\langle E\rangle\right]$$

Pseudoscalar meson electroproduction with CLAS12

$$\sigma_{LT'} = \xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\times$$
$$\times\ \mathrm{Im}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle + \langle\bar{E}_T\rangle^*\langle\tilde{H}\rangle\right]$$



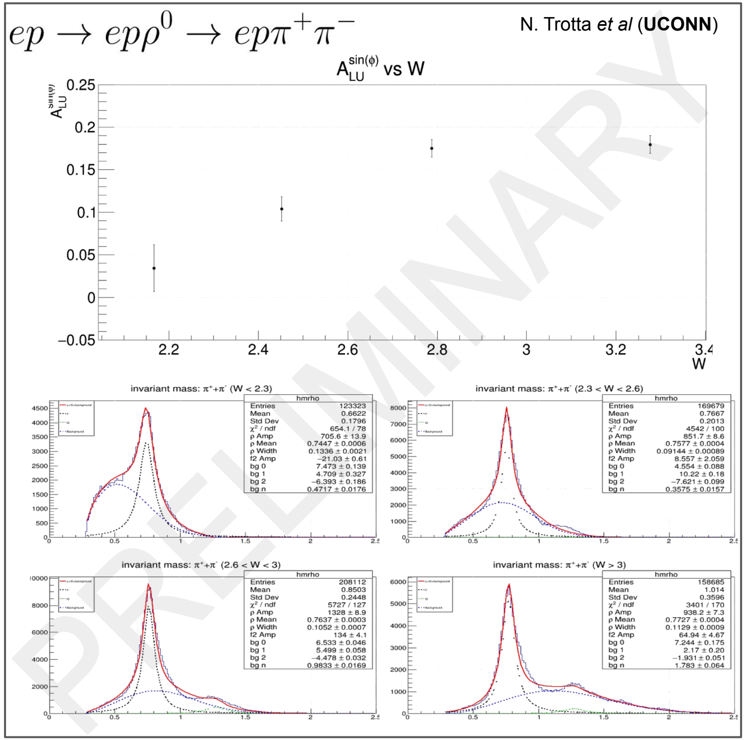
- active work on cross-section extraction by R. Johnston (MIT)

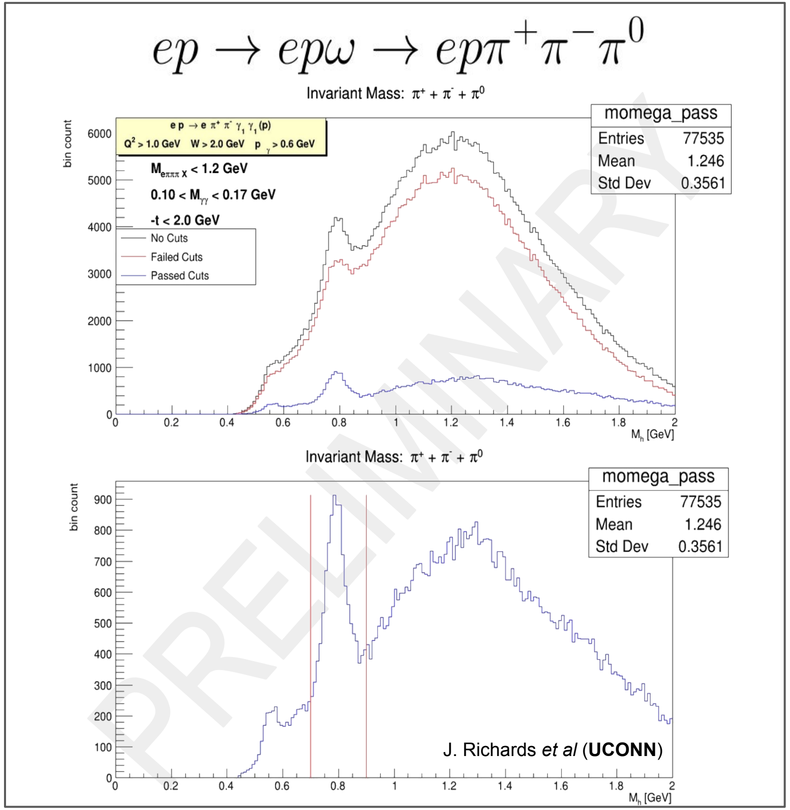


Additionally active work on η beam spin asymmetry and cross-section extraction

Vector meson electroproduction with CLAS12

$$\sigma_{LT'} \sim r^{8}_{00} \sim \; \mathrm{Im}\left[\langle H_T\rangle^{*}\langle E\rangle + \langle \bar{E}_T\rangle^{*}\langle H\rangle\right]$$



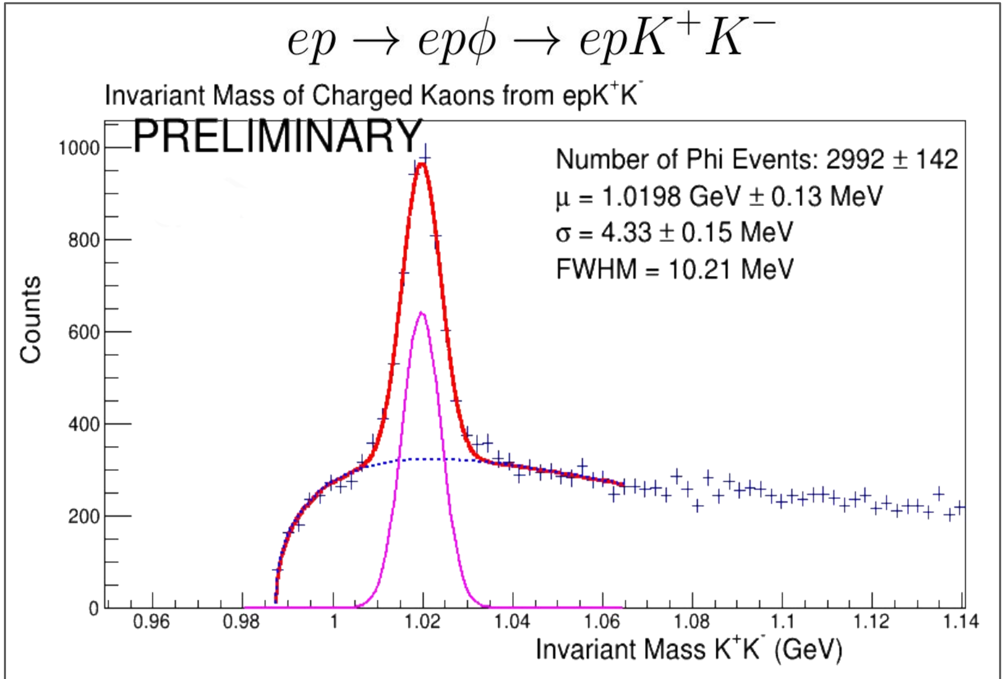


Vector meson electroproduction with CLAS12

Access gluonic GPDs:

- ϕ $(s\bar{s})$ - low $|-t|$ measurements where GPDs are relevant
- J/ψ $(c\bar{c})$ - measure the t-dependence of the differential cross section of J/ψ photoproduction*

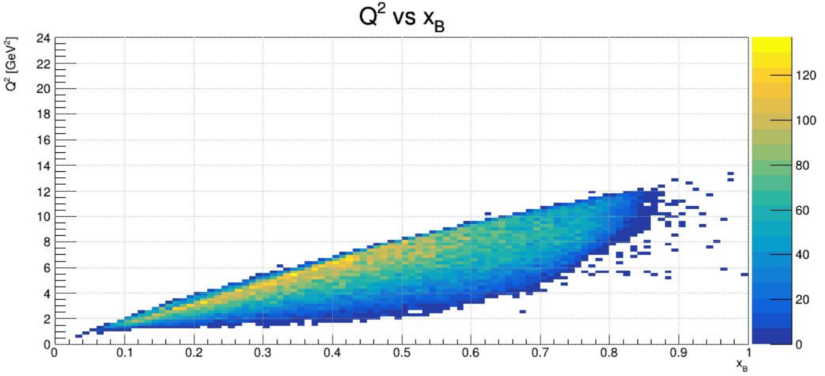
* active work on φ cross-section measurements by P. Moran (MIT)
* active work on J/ψ cross-section measurements by J. Newton (JLab)

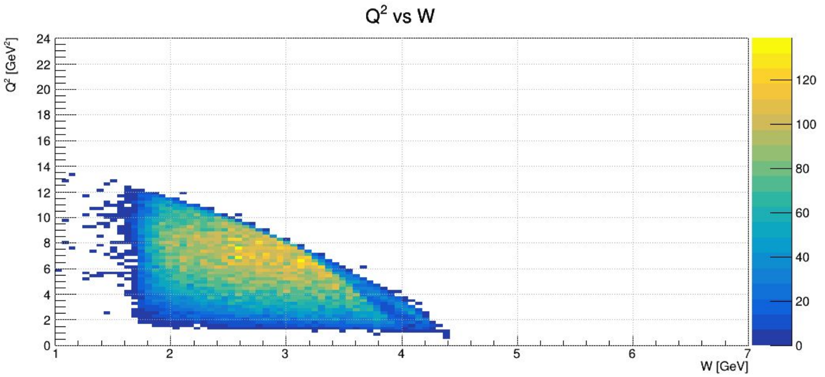


B. Clary *et al* (**UCONN**)

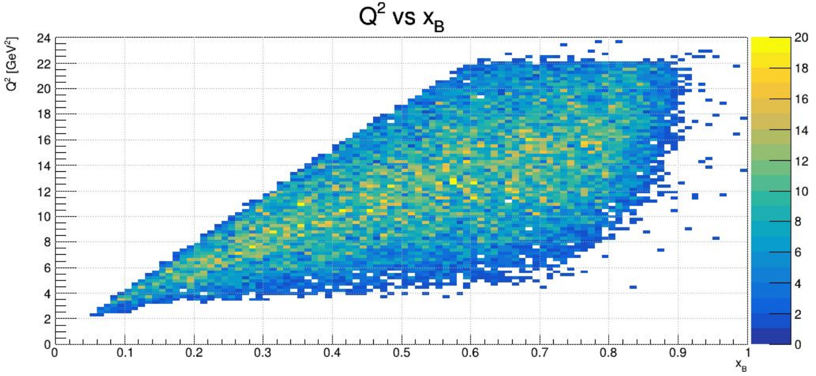
Kinematic coverage for ρ electroproduction

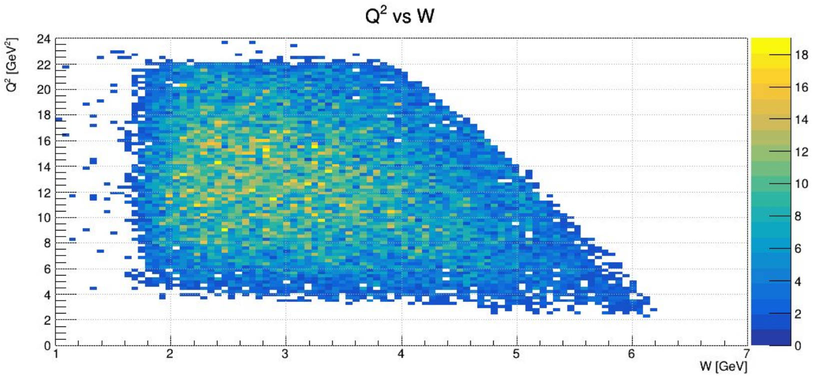
@ 10.6 GeV beam energy





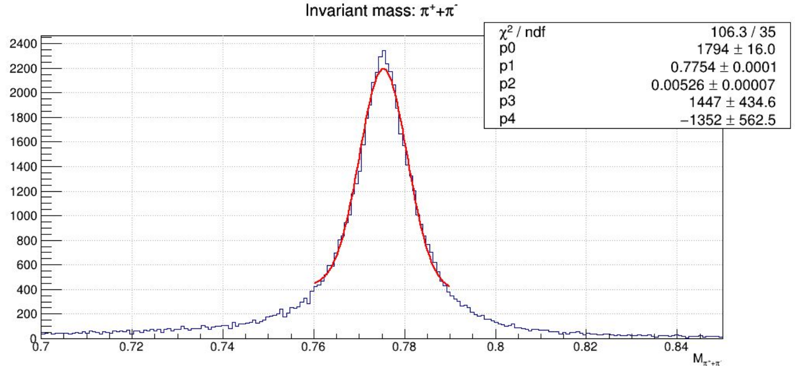
@ 22 GeV beam energy

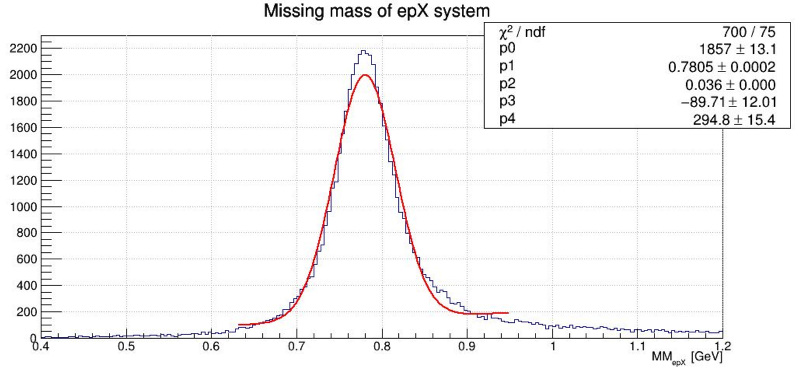




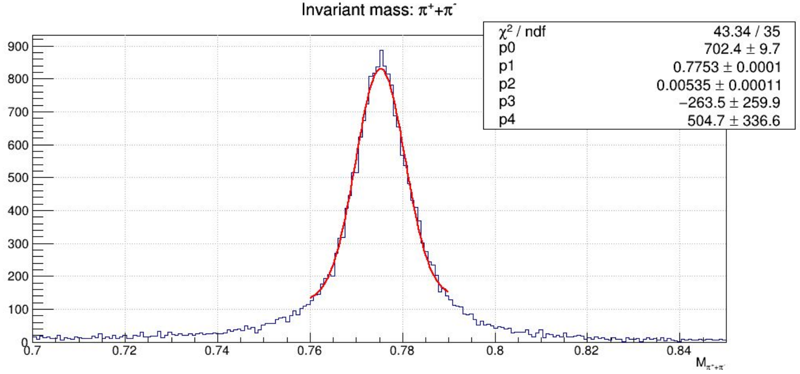
Invariant and missing masses for ϱ electroproduction

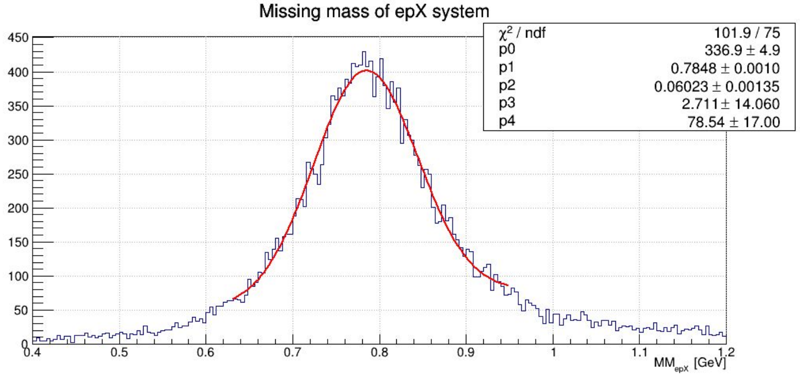
@ 10.6 GeV beam energy





@ 22 GeV beam energy





Conclusions

- CLAS spectrometer combined with 20+ GeV beam upgrade will extend ongoing 12 GeV measurements of deeply virtual meson productions channels
- The variety of reactions provide opportunity for selective access to different GPDs, as well as access to valence quark and gluonic GPDs
- High luminosity and wide kinematic coverage of CLAS spectrometer provide opportunity for multi-dimensional analysis in a wide kinematic region and allow the extraction of structure functions and spin density matrix elements from the azimuthal distributions

THANK YOU