Backward angle production of ω and ϕ mesons in Hall C

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Exclusive Meson Production Workshop, Jefferson Lab, January 22, 2015.

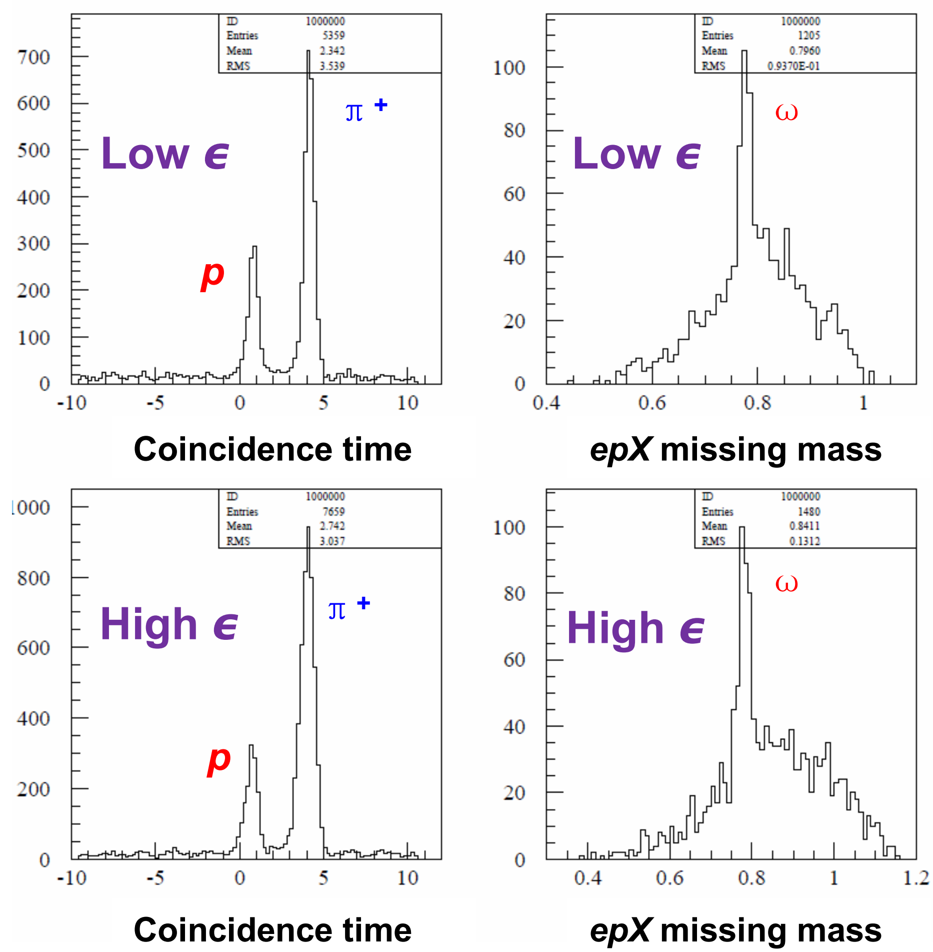
Fpi-2 (E01-004) Experiment in Hall C

Hall C logbook

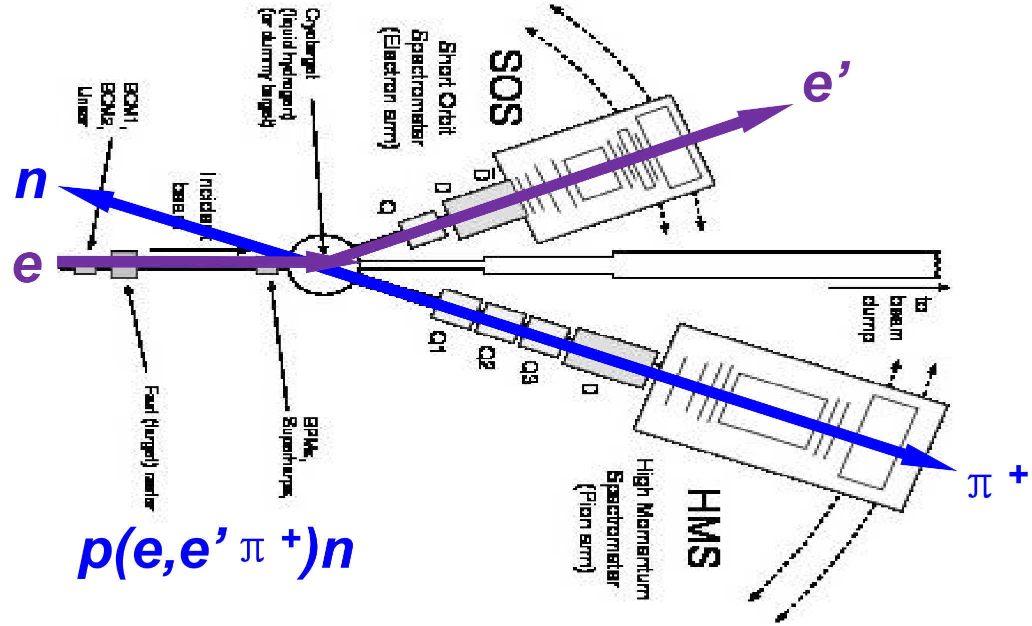
2003/07/25 08.56

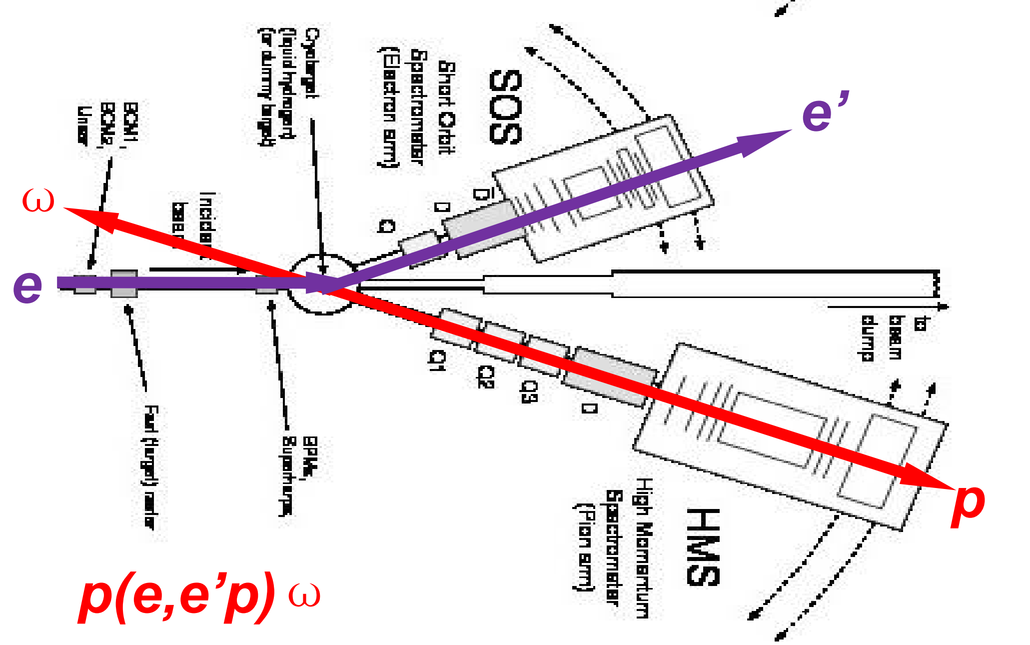
- **Fpi-2 (E01-004) ran in 2003**
  - Electric form factor of charged π through exclusive π^+ production
  - Spokespersons: **Garth Huber, Henk Blok, Dave Mack**
  - Standard Hall C HMS (hadron) and SOS (e^-) configuration
- Primary reaction for Fpi-2
  - ***p(e, e' π^+)n***
- Along with π^+ data, we obtained "for free"
  - ***p(e,e' p)X***
- Kinematics coverage
  - ***W*= 2.21 GeV, *Q^2*=1.6 and 2.45 GeV^2**
  - Two ϵ settings for each Q^2

Q^2=2.45 GeV^2



t-Channel π^+ vs u-Channel ω^0 Production





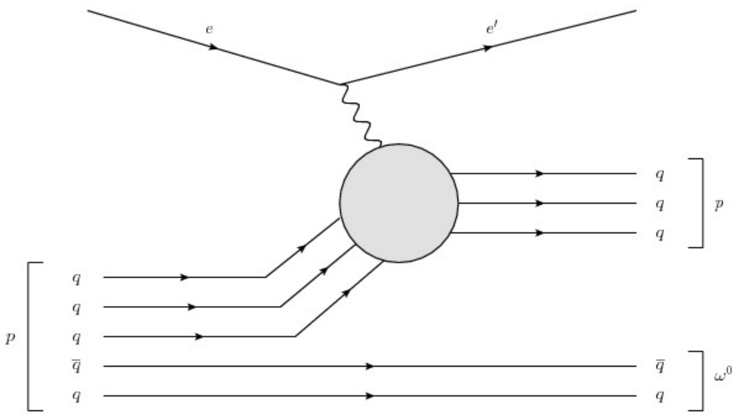
- HMS along the q-vector ($p_{\gamma*}$)
  - $p_{\pi+}$ is parallel to $p_{\gamma*}$
  - p_{ω} is anti-parallel to $p_{\gamma*}$

- Shared kinematics:

E_{beam} GeV	ϵ	$P_{\rm SOS}$ GeV/c	$\theta_{\rm SOS}$ deg	$P_{\rm HMS}$ GeV/c	θ_q deg	$\theta_{\rm HMS}$ deg
$Q^2_{nominal}$ = 1.6 GeV^2 $W_{nominal}$ = 2.21 GeV						
3.778	0.328	-0.79	43.09	2.931	-9.53	-10.53 -12.53
4.702	0.593	-1.65	25.73	2.931	-13.28	-13.28 -10.58 -16.28
$Q^2_{nominal}$ = 2.45 GeV^2 $W_{nominal}$ = 2.21 GeV						
4.210	0.270	-0.77	51.48	3.336	-9.19	-10.59 -12.19
5.248	0.554	-1.74	29.43	3.336	-13.61	-13.61 -10.61 -16.61

u-Channel ω^0 Production Kinematics

Christian Weiss: "A proton being knocked out of a proton"



$$\gamma^*(q) + p(p_1) \to \omega(p_\omega) + p(p_2)$$

$$s = (p_1 + q)^2 = (p_\omega + p_2)^2$$

$$t = (p_2 - p_1)^2 = (p_\omega - q)^2$$

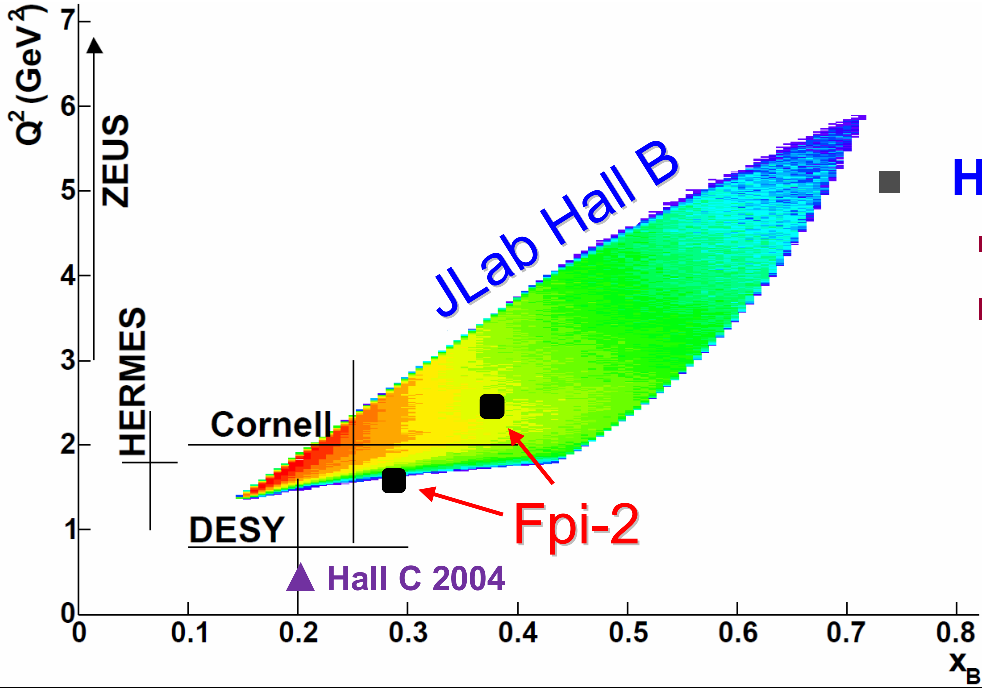
$$u = (p_\omega - p_1)^2 = (p_2 - q)^2$$

E_{beam} GeV	ϵ	$\theta_{\text{HMS}} - \theta_q$ deg	x	P_ω GeV/c	$\theta_{\omega q}$ deg	$-t$ GeV^2/c^2	$-u$ GeV^2/c^2	θ^*_ω	θ^*_p
		$Q^2_{nominal}$ = 1.6 GeV^2		$W_{nominal}$ = 2.21 GeV					
3.778	0.330	−0.9	0.2855	0.311	8.8	4.014	0.088	176.0	-3.8
		−3.0		0.367	24.3		0.129	167.4	-12.7
4.702	0.593	0.0	0.2855	0.304	0.1	4.014	0.082	180.0	0.0
		2.7		0.357	-22.9		0.121	-168.4	11.4
		−3.0		0.367	24.6		0.129	167.2	-12.6
		$Q^2_{nominal}$ = 2.45 GeV^2		$W_{nominal}$ = 2.21 GeV					
4.210	0.270	−1.4	0.3796	0.431	10.5	4.742	0.184	173.4	-6.8
		−3.0		0.491	20.8		0.242	165.4	-14.5
5.248	0.554	0.0	0.3796	0.415	0.0	4.742	0.170	180.0	0.0
		3.0		0.490	20.7		0.241	-165.2	14.3
		−3.0		0.491	-20.7		0.241	165.3	-14.3

p_2,q large
p_1,p_ω small
$-t \to$ maximum

$\theta^*_\omega \approx 180^\circ$
$\theta^*_p \approx 0$
$-u \to$ minimum

Exclusive ω electro-production data

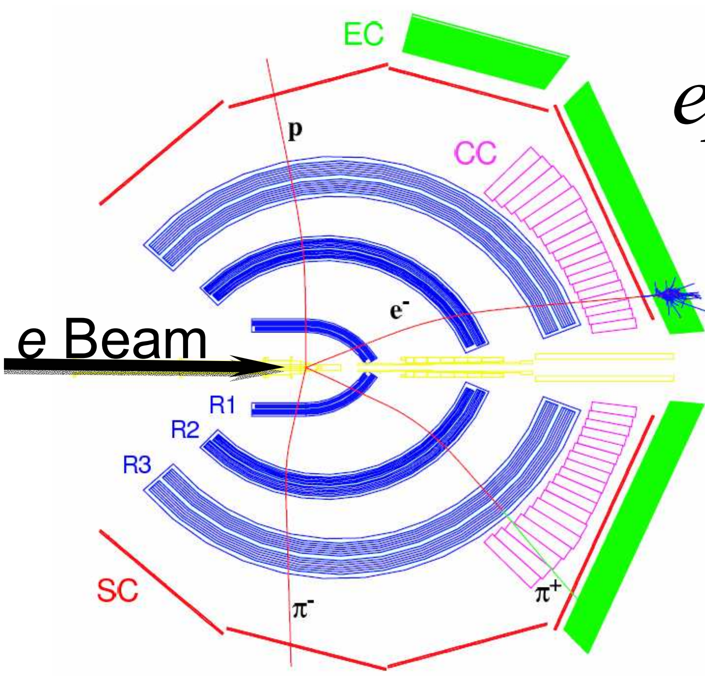


- **Hall B data:**
  - Wide coverage
  - Highest –*t*

	Q^2 GeV^2	*W* GeV	*x*	*-t* GeV^2
HERMES (Airapetian et al., 2014)	> 1	3-6.3	0.06-0.14	< 0.2
DESY (Joos et al., 1977)	0.3-1.4	1.7-2.8	0.1-0.3	< 0.5
ZEUS (Breitweg et al., 2000)	3-20	40-120	~0.01	< 0.6
Cornell (Cassel et al., 1981)	0.7-3	2.2-3.7	0.1-0.4	<1
JLab Hall C (Ambrozewicz et al., 2004)	~0.5	~1.75	0.2	0.7-1.2
JLab Hall B (Morand et al., 2005)	1.6-5.1	1.8-2.8	0.16-0.64	<2.7
JLab Fpi-2 (under analysis now)	1.6, 2.45	2.21	0.29, 0.38	4.0, 4.74

High -*t* Data from CLAS Hall B (2005)

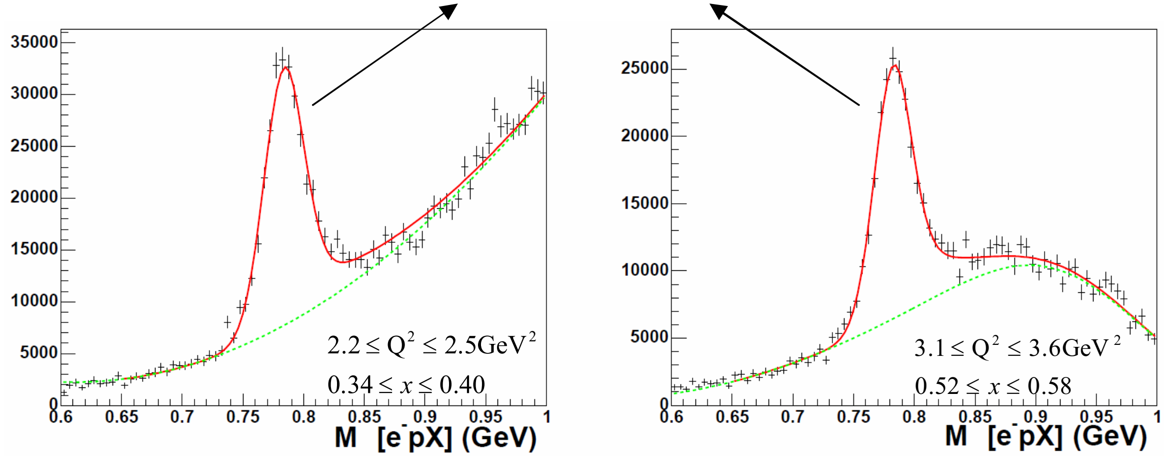
Morand et al., Eur. Phys. J. A 24, 445 (2005).



$$ep \rightarrow ep\omega$$

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

$\omega(782\text{MeV})$



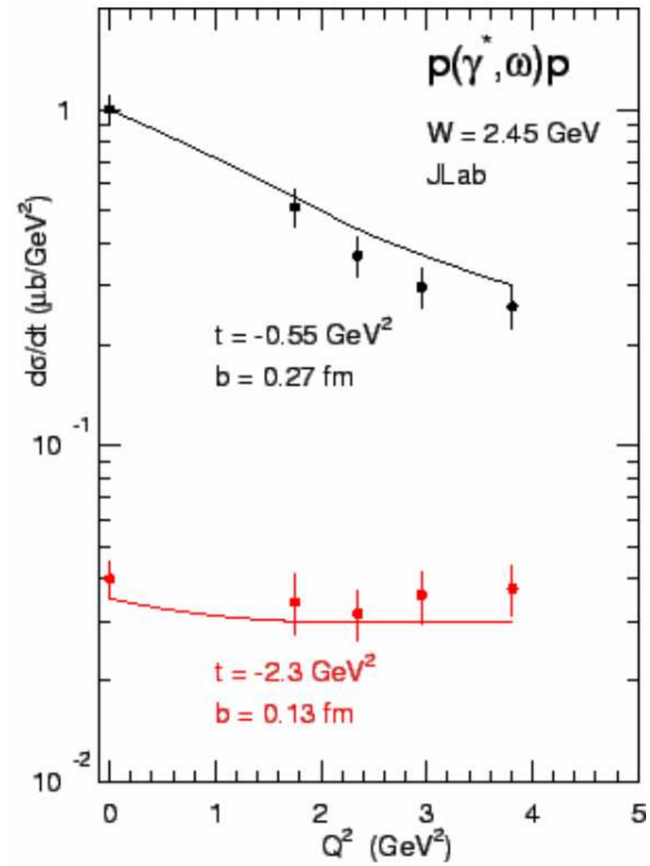
Missing mass reconstruction e^-pX

- Hall B Experiment **e1-6**
  - Oct 2001 – Jan 2002
  - Beam energy: 5.754 GeV
- Kinematic coverage:
  - *W* : 1.8-2.8 GeV
  - Q2: 1.6-5.1 GeV^2
  - **-*t* : < 2.7 GeV^2**
  - *x*: 0.16-0.64
- Event selection:

  $$ep \rightarrow ep\pi^+X$$

- Reconstructed e^-pX missing mass consistent with the ω mass
- Data published in 2005:
  - Morand et al., Eur. Phys. J. A 24, 445 (2005).

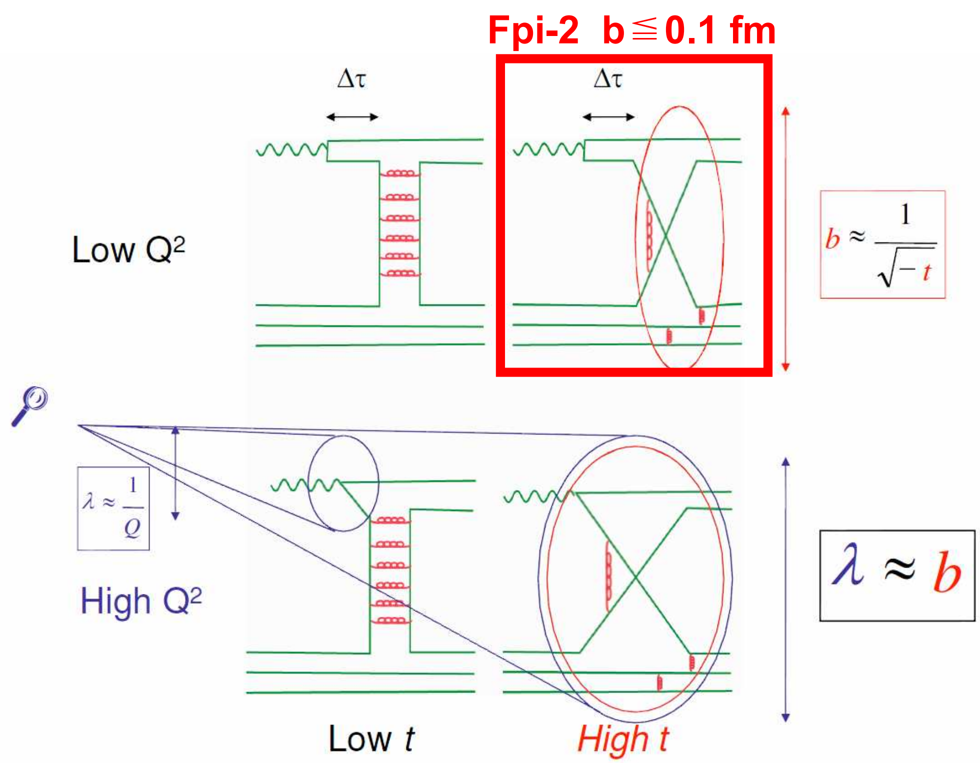
High -*t* Data from CLAS Hall B (2005)



L. Morand et al., Eur. Phys. J. A 24, 445 (2005).
https://www.jlab.org/Hall-B/public/hight_vmweb.html

Hall B & Fpi-2 kinematics comparison

	W (GeV)	*x*	Q^2 (GeV²)	**-*t* (GeV²)**	**-*u* (GeV²)**
Hall B	1.8-2.8	0.16-0.64	1.6-5.1	**< 2.7**	**> 1.68**
Fpi-2	2.21	0.29	1.6	**4.01**	**0.08-0.13**
		0.38	2.45	**4.72**	**0.17-0.24**

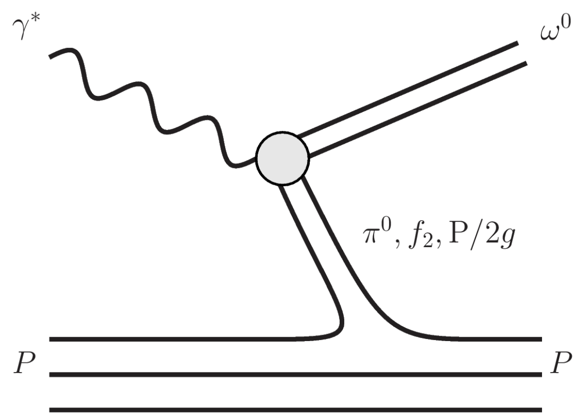


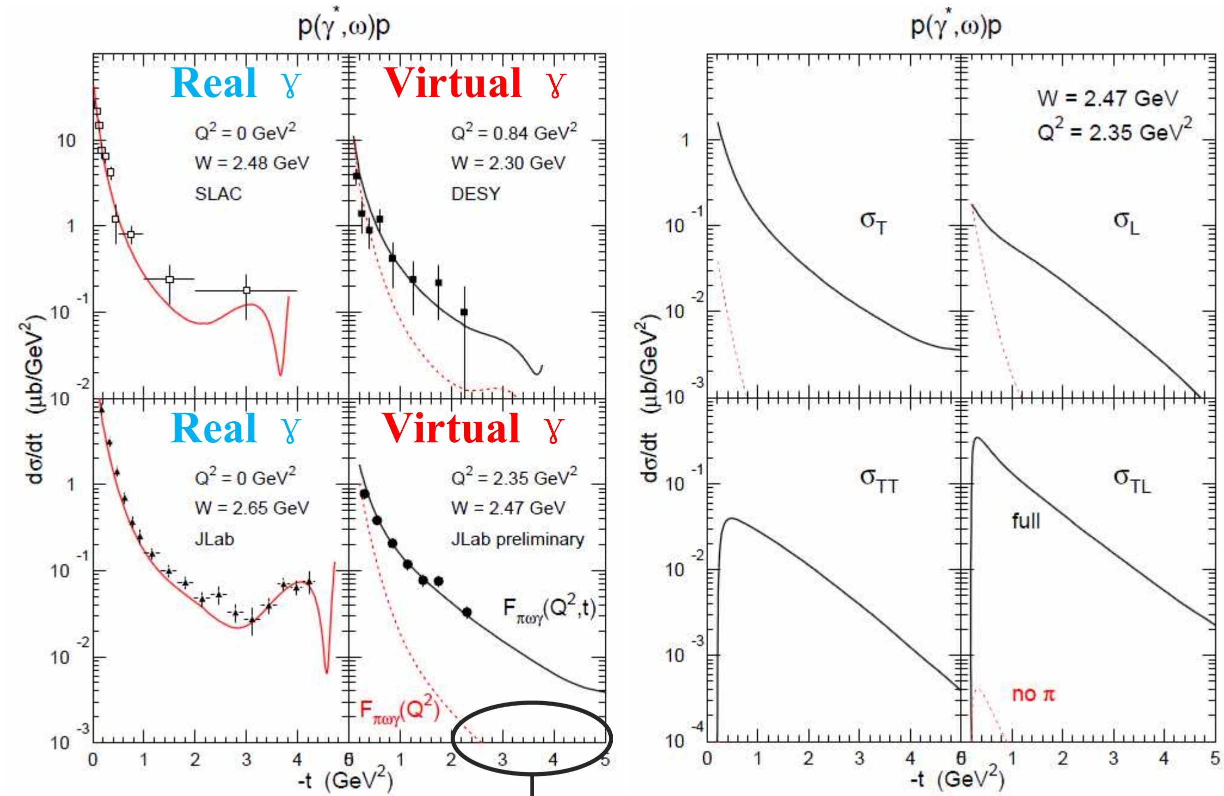
Main Conclusions:

- **Observation:** Q^2 independent cross section at high -*t*
- **Interpretation:** Virtual photon is more likely to couple to a point-like object as -*t* increases

Regge Model by JM Laget

Produced vector meson	Exchanged Regge trajectories
ρ	σ, f_2, P/2g
ω	π^0, f_2, P/2g
ϕ	P/2g



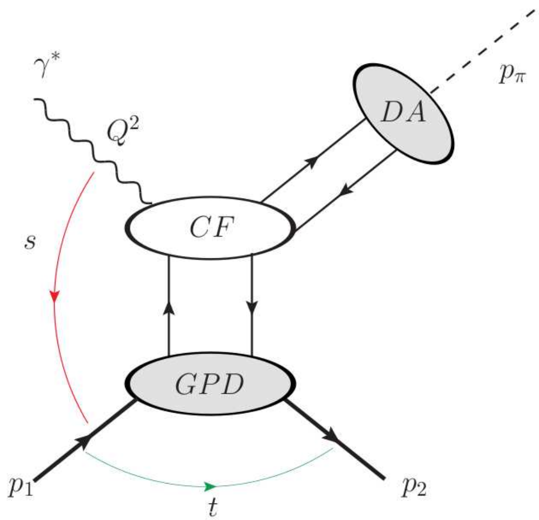


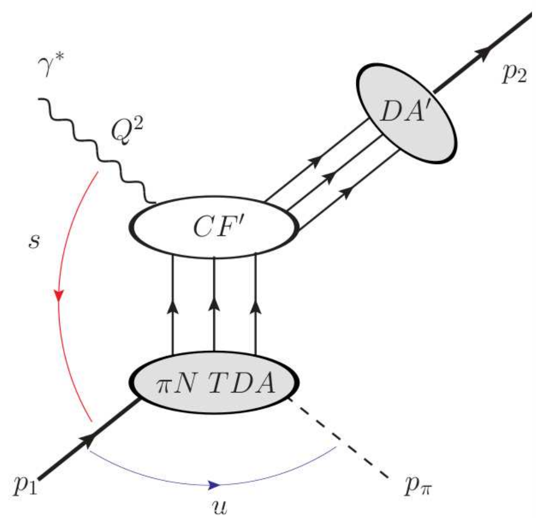
J. M. Laget, Phys. Rev. D 70, 2004

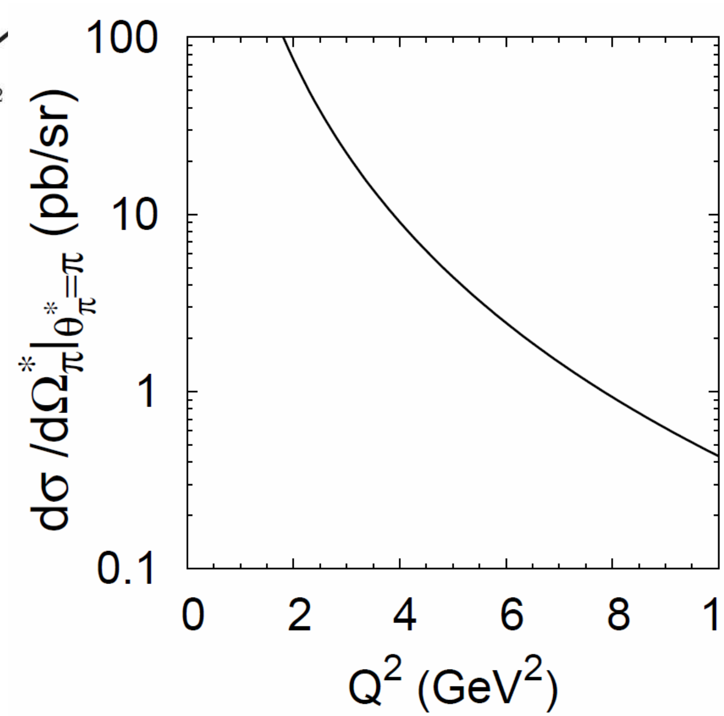
No data yet,
Fpi2 kinematics Q^2=2.45, *W=2.21, -t=4.7*

- "The determination of the (Q^2) dependency against the momentum transfer *t* of the longitudinal and the transverse parts of the **various meson electro-production channels must be actively pursued in the JLab energy range**"
- The model should be applicable also to Fpi-2 kinematics.

Further motivation: Transition Distribution Amplitude (TDA)



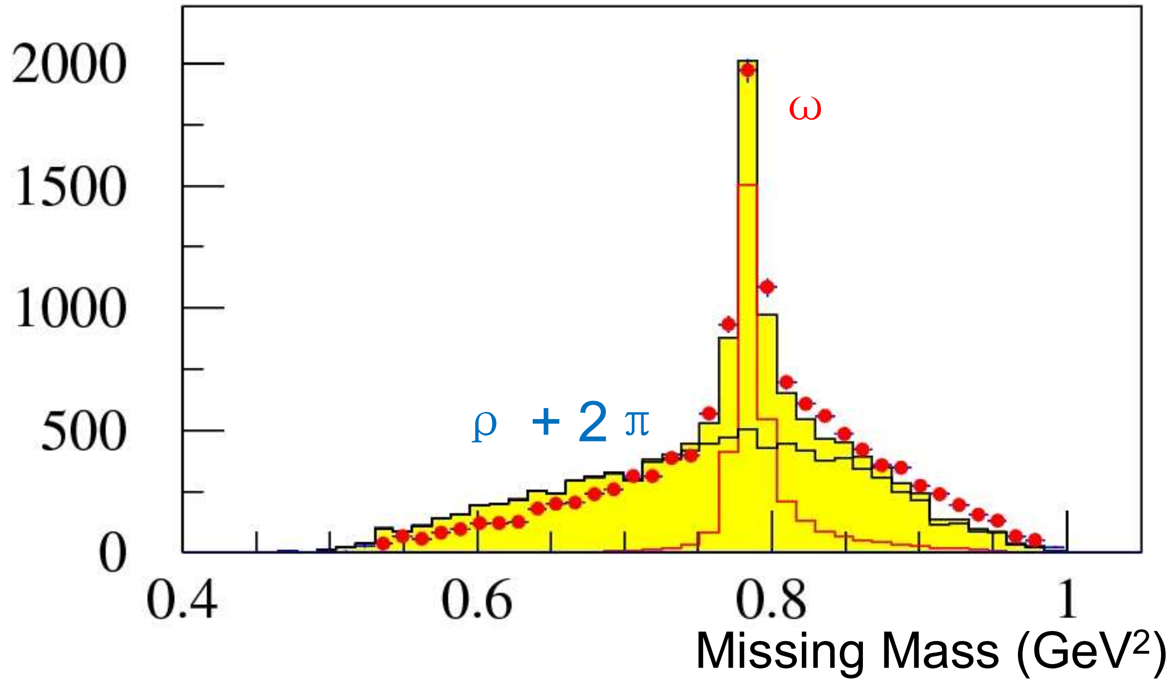




Lansberg, et al., Phys. Rev. D **77**, (2008)

- TDA backward angle analog of GPD
- Interaction of Interest: ***u*-channel π production**
- Extension of the TDA model to describe the backwards vector meson production
- Publications:
  - Lansberg, et al., Phys. Rev. D **77**, (2008)
  - Pasquini, *et al.,* Phys.Rev. D80 (2009)
  - Lansberg, *et al.,* arXiv:0709.2567 [hep-ph] CPHT-PC141.0907

Fpi-2 Data Analysis



Background Removal:

- Assigned ω yield is loosely correlated with assumed shape of background underneath peak.
- Still investigating whether better approach is to fit a polynomial (Morand) or model background via MC (Ambrozewicz).
- Possible Mechanisms:
  - ρ^0
  - 2π phase space, σ

MC Physics Generator Question

- In our Monte Carlo simulations, the ρ,ω,φ event generators typically assume a "diffractive" production mechanism of the form

$$\frac{d\sigma_{uns}}{dt} = \sigma_0 (1+\varepsilon R) \left(\frac{m_V{}^2}{Q^2 + m_V{}^2} \right)^2 b_V e^{-b_V |t - t_{\min}|}$$

$$\text{where } R = \frac{d\sigma_L}{d\sigma_T} = c_0 \left(\frac{Q^2}{m_V{}^2} \right)^{c_1}, \sigma_0 = f(W), b_V = f(c\Delta\tau_V)$$

- Parameterizations of this form give $d\sigma/dt$ which fall monotonically with $-t$, and dramatically under-predict our backward angle cross-sections.

Question: In the simulations needed to analyze our low $-u \rightarrow 0$ data, should we consider

$$\frac{d\sigma_{uns}}{dt} \propto b_V e^{-b_V |u - u_{\min}|} \quad ?$$

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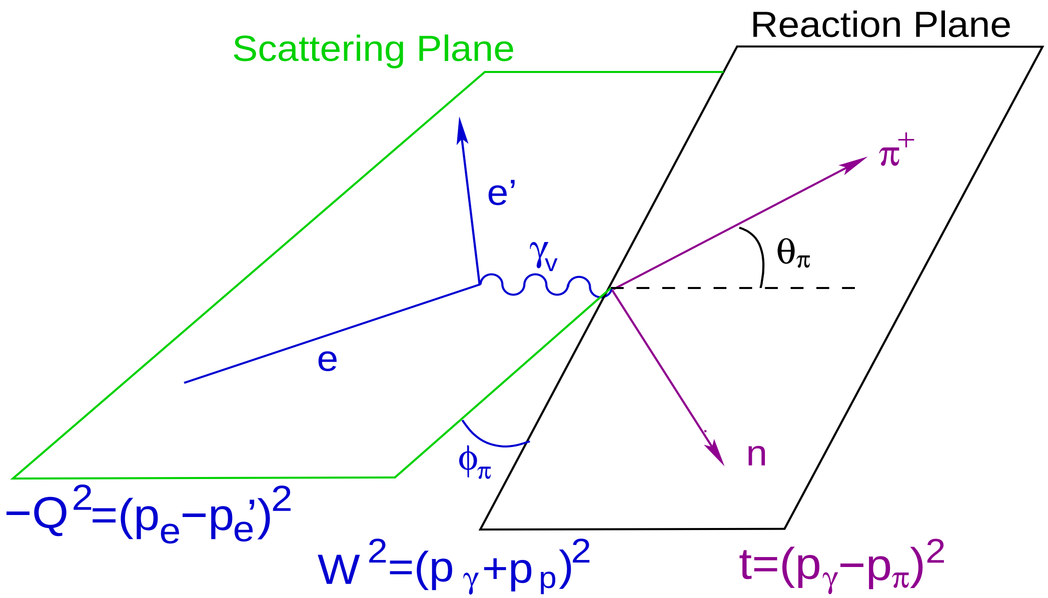
Rosenbluth Separation Method



Virtual-photon polarization:

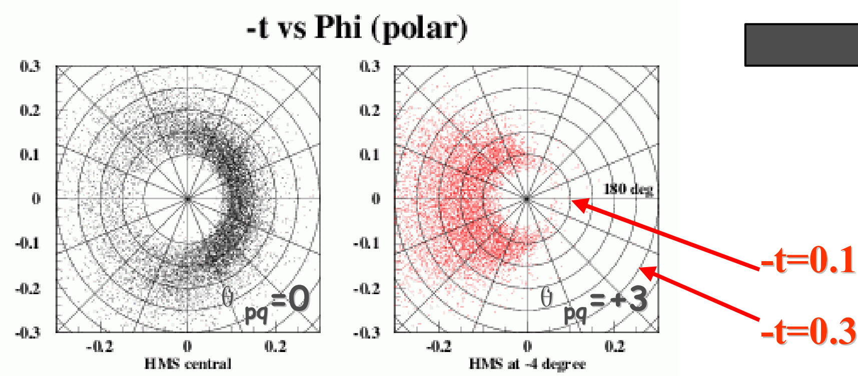
$$\varepsilon = \left(1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

$$2\pi\frac{d\sigma}{dt\,d\phi} = \varepsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

- Rosenbluth Separation method requires
  - Separate measurements are taken at different ε (virtual photon polarization)
  - Lorentz invariant physics quantities such as *Q^2, W, t, u*, remain constant
  - Beam energy, scattered e angle and virtual photon angle will change as the result, thus experiment event rates are dramatically different

Extract Response Functions through Iterative Procedure

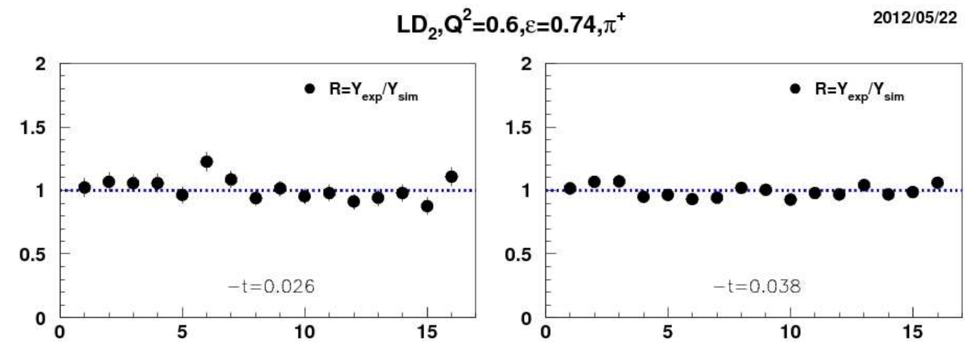
Improve ϕ coverage by taking data at multiple HMS (p) angles, $-3^o < \theta_{pq} < 3^o$.

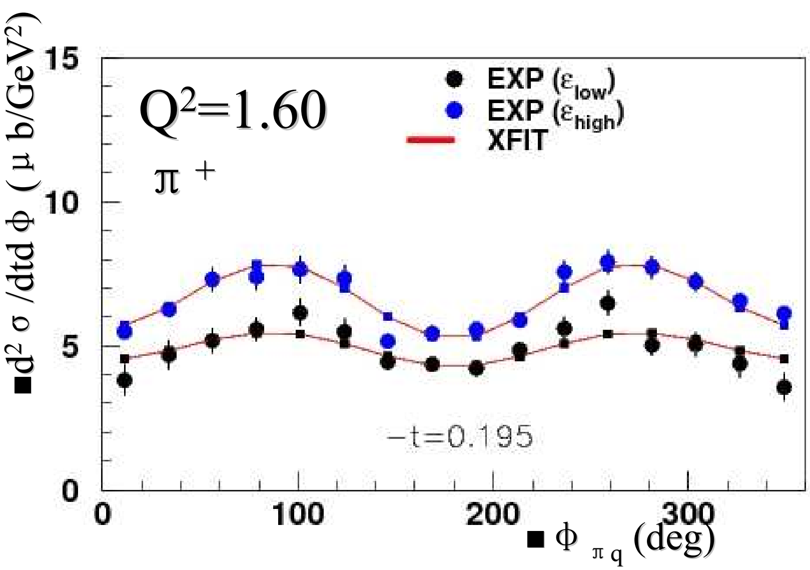


For each HMS (p) setting, form ratio:

$$R = \frac{Y_{EXP}}{Y_{SIMC}}$$

Combine ratios for HMS settings together, propagating errors accordingly.





Extract via simultaneous fit of L,T,LT,TT

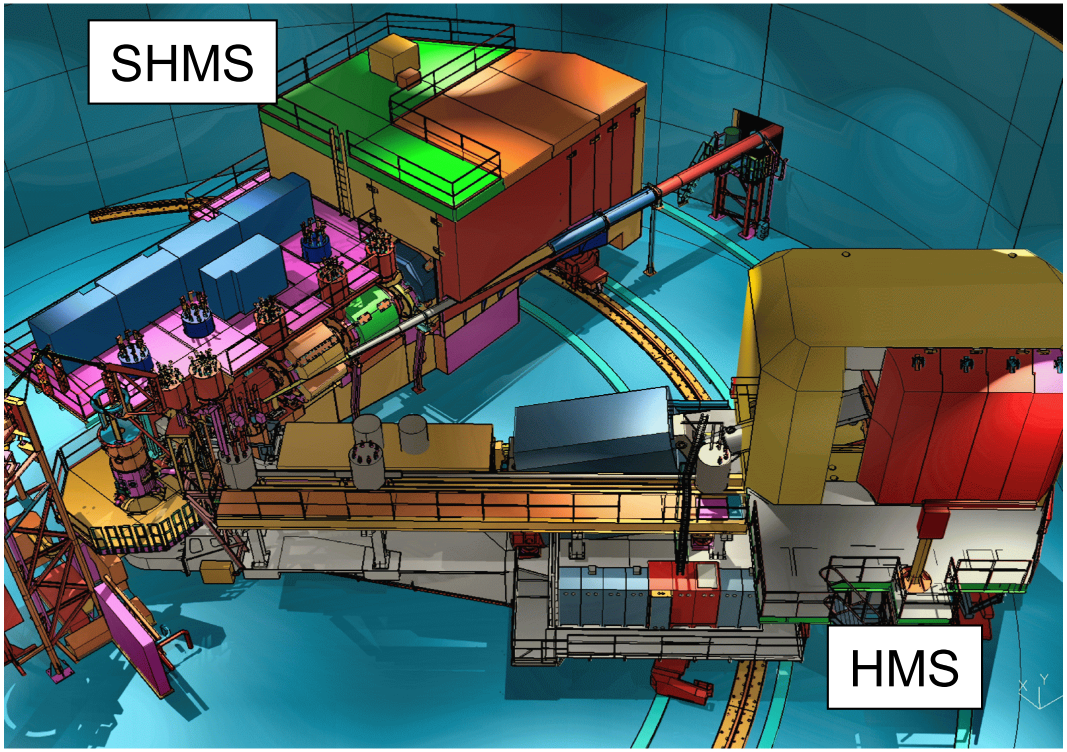
$$\left.\frac{d^2\sigma}{dtd\varphi}\right|_{EXP} = \left(\frac{Y_{EXP}}{Y_{SIMC}}\right)\left.\frac{d^2\sigma}{dtd\varphi}\right|_{SIMC}$$

$$2\pi\frac{d\sigma}{dtd\phi} = \varepsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

Fpi-2 (E01-004) *u*-channel Objectives and Timeline

- **Objectives:**
  - Obtain complete L/T/LT/TT separated cross sections for exclusive ω meson electroproduction at the kinematic limit $-t_{max}$, $-u_{min}$ for Q^2=1.60, 2.45 GeV^2, W=2.22 GeV
    - Preliminary indications are that $\sigma_T >> \sigma_L$
  - Initiate more *u*-channel meson production studies
- **Timeline**:
  - The analysis of these data are part of the Ph.D. thesis of Wenliang (Bill) Li.
  - Data have been calibrated and we are in the final stages of detector efficiency cross-checks.
  - Data analysis will continue through 2015-16, with the goal to have final separated cross sections ready by the end of 2016, and first results ready for publication in early 2017.

Jefferson Lab 12 GeV Era – Hall C Configuration



Hall C will provide 2 moderate acceptance, magnetic focusing spectrometers:

High Momentum Spectrometer:
$d\Omega \sim 6$ msr, $P_{max} = 7$ *GeV/c*
$\Theta = 10.5$ *to 80 degrees*

Super-HMS :
$d\Omega \sim 4$ msr, $P_{max} = 11$ *GeV/c*
$\Theta = 5.5$ *to 40 degrees*

- Both spectrometers provide excellent control of systematic uncertainties
- Kinematic reproducibility, well-understood acceptance

Ideal for:

- precision cross section measurements and response function separations,
  - in single arm or coincidence,
  - at high luminosity (~10^{38}/cm^{2}sec).

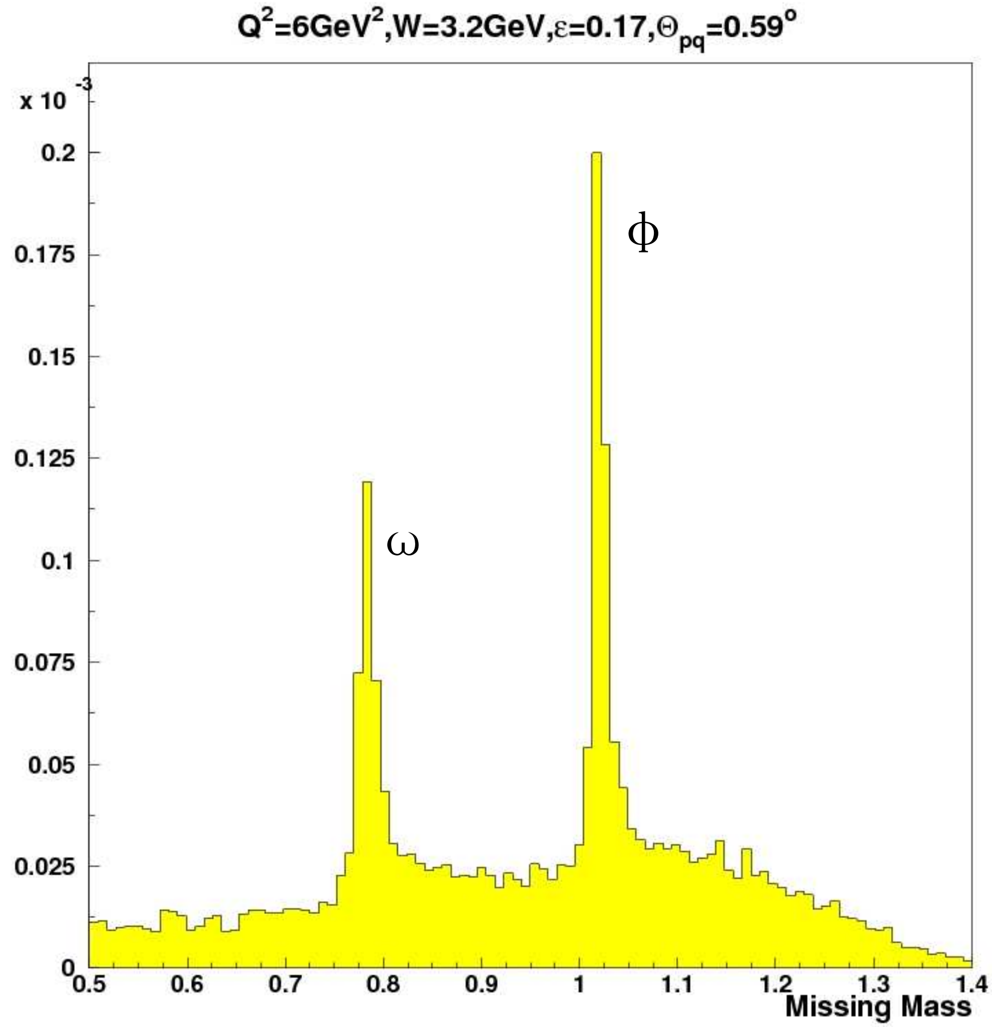
Expectations for 12 GeV Fpi-3 (E06-12-101)

The 12 GeV Fpi-3 experiment (Spokespersons: GH, D. Gaskell) **will also obtain "for free" backward angle (→180°) ω, ϕ.**

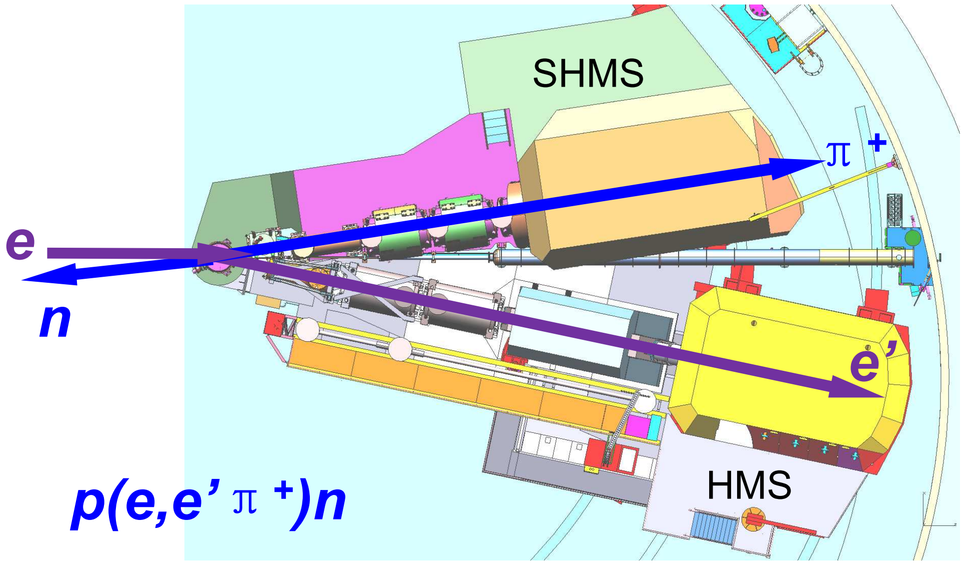
u-channel ϕ production would be very interesting, should help constrain $s\bar{s}$ in nucleon.

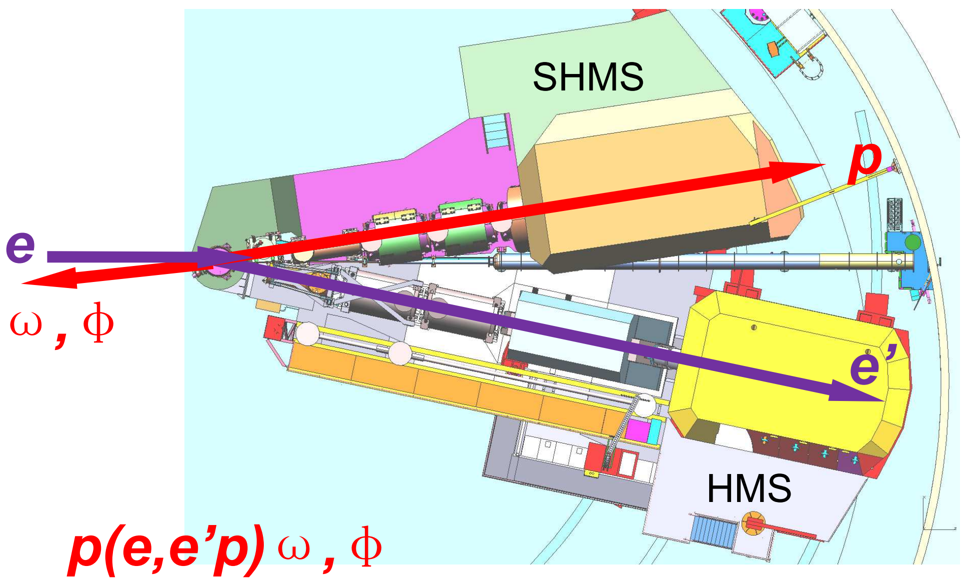
Simulation of Fpi-3 *p(e,e'p)X* acceptance for one kinematic setting.

CAUTION: Relative sizes of peaks and background are ARBITRARY!



Fpi-3 (E06-12-101) *u*-channel Kinematics





$p(e,e'p)\omega^o$ Kinematics - Approved 12 GeV				
E_{beam} (GeV)	ϵ	$-t$ (GeV^2)	$-u$ (GeV^2)	x
$Q^2_{nominal} = 1.60$ GeV^2 $W_{nominal} = 3.00$ GeV				
6.60	0.387	8.242	0.003	0.165
8.80	0.689			
9.90	0.765			
$Q^2_{nominal} = 2.45$ GeV^2 $W_{nominal} = 3.20$ GeV				
7.40	0.265	10.326	0.006	0.208
8.80	0.505			
9.90	0.625			
10.90	0.702			
$Q^2_{nominal} = 3.50$ GeV^2 $W_{nominal} = 3.10$ GeV				
7.90	0.304	10.714	0.023	0.286
9.90	0.587			
10.90	0.671			
$Q^2_{nominal} = 4.46$ GeV^2 $W_{nominal} = 3.28$ GeV				
8.80	0.224	12.814	0.031	0.311
9.90	0.404			
10.90	0.524			
$Q^2_{nominal} = 5.25$ GeV^2 $W_{nominal} = 3.20$ GeV				
8.80	0.188	13.051	0.066	0.359
9.90	0.373			
10.90	0.498			
$Q^2_{nominal} = 6.00$ GeV^2 $W_{nominal} = 3.20$ GeV				
9.20	0.177	13.774	0.093	0.391
9.90	0.298			
10.90	0.435			

Fpi-3 (E06-12-101) Analysis Priorities

- **First Priority:**
  - Pion form factor program is most highly cited Hall C work to date.
  - Fpi-3 is one of Hall C's 12 GeV flagship experiments.
  - Graded 'A' scientific priority by PAC 35.
  - Identified as "early high impact" by PAC41.
  - L/T separations require a lot of custom beam energies, data likely to be acquired in several blocks from 2018-2021.
  - Clearly, our highest priority will be to analyze the $p(e,e'\pi^+)n$ data and extract F_π for $0.3<Q^2<6.0$ GeV^2.

- **Second Priority:**
  - We are very interested in analyzing the $p(e,e'p)X$ data that will come along with the π^+ data "for free".
  - Speed of work will depend on:
    - data analysis resources (Ph.D. students, PDFs).
    - external scientific interest in these backward angle data.
  - If all goes well, we hope to publish the ω,φ data before 2025.