Exclusive Backward–Angle Meson Electroproduction – Unique access to *u*–channel physics

Garth Huber
Wenliang (Bill) Li*
** Now at College of William and Mary*

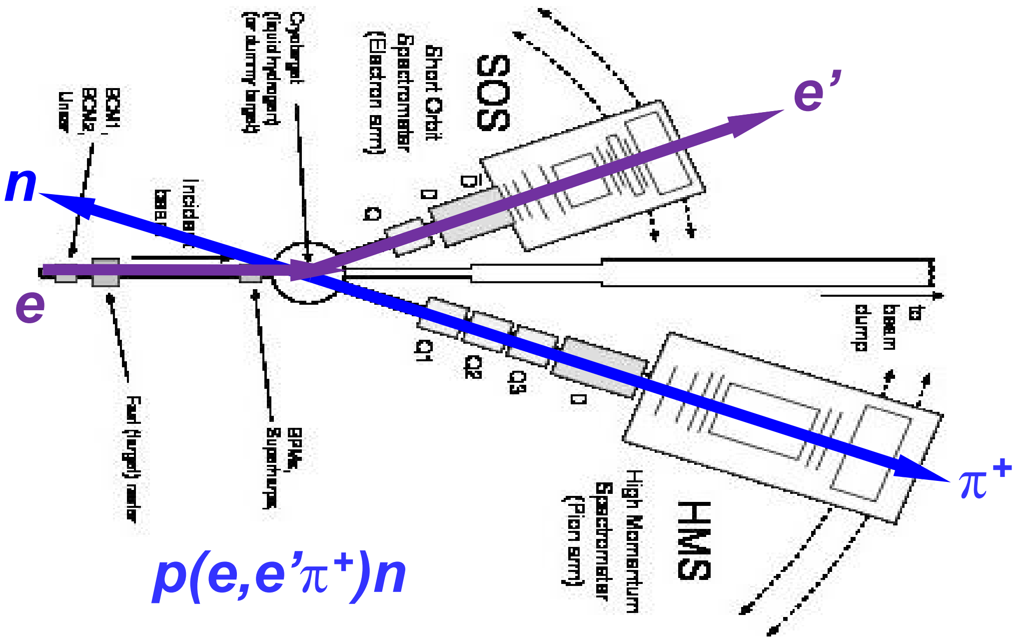
University of Regina

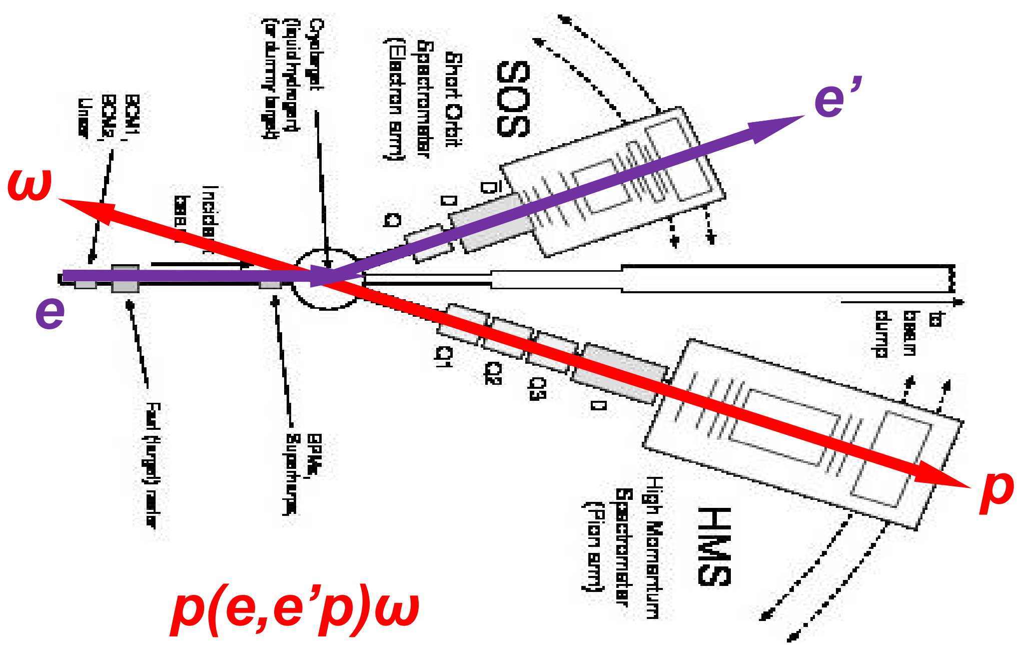
GHP 19 Workshop
Denver, CO
April 12, 2019

Supported by:
NSERC CRSNG
SAPIN-2016-00031

t–Channel π^+ vs u–Channel ω Production

Garth Huber, huberg@uregina.ca



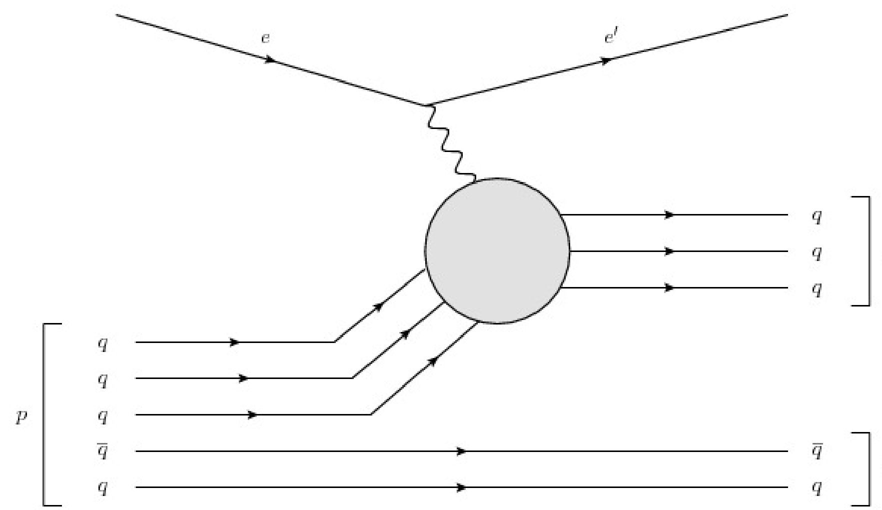


HMS is along *q*–vector (p_{γ^*})

- $p_{\pi+}$ is parallel to $p_{\gamma*}$ (forward)
- p_{ω} is anti–parallel to $p_{\gamma*}$ (backward)

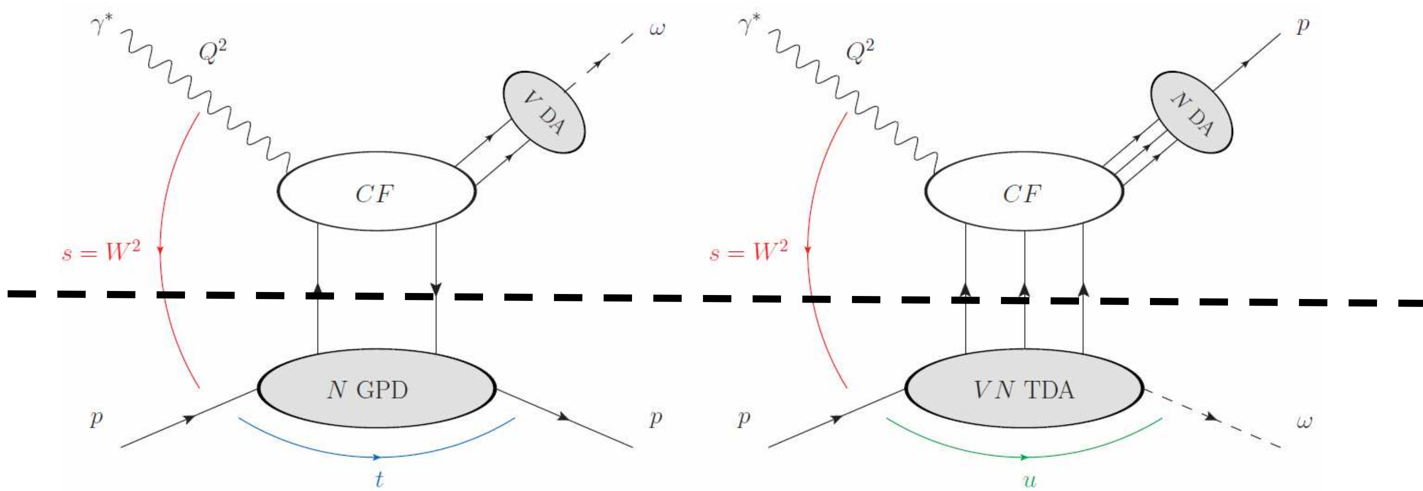
***p(e,e'p)ω* Exclusive channel**

- Full kinematic reconstruction of final state.
- Do not detect any part of decayed ω.



Mark Strikman: Knocking the proton out of the proton process.

GPD–Like Model: TDA and Factorization



***t*–channel (Forward)** ***u*–channel (Backward)**

- **Baryon to Meson Transition Distribution Amplitude (TDA)**
  - Extension of collinear factorization to backward angle regime. Further generalization of the concept of GPDs.
  - TDAs describe the transition of nucleon to 3–quark state and final state meson. *[gray oval of plot b]*
  - A fundamental difference between GPDs and TDAs is that TDAs are defined as hadronic matrix elements of 3–quark operator, while GPDs involve quark–antiquark operator.
  - **Can be accessed experimentally in backward angle meson electroproduction reactions.**

Garth Huber, huberg@uregina.ca

Skewness in Backward Angle Regime

- **Forward angle kinematics,** $-t \sim -t_{min}$ and $-u \sim -u_{max}$, in the regime where handbag mechanism and GPD description may apply, Skewness is defined in usual manner:

$$\xi_t = \frac{p_1^+ - p_2^+}{p_1^+ + p_2^+}$$ where $p_{1,2}$ refer to light cone + components

in $\gamma^*(q) + p(p_1) \rightarrow \omega(p_\omega) + p'(p_2)$

- **Backward angle kinematics,** $-u \sim -u_{min}$ and $-t \sim -t_{max}$, Skewness is defined with respect to *u*–channel momentum transfer in TDA formalism

$$\xi_u = \frac{p_1^+ - p_\omega^+}{p_1^+ + p_\omega^+}$$

- GPDs depend on x, ξ_t and $t=(\Delta^t)^2=(p_2-p_1)^2$

  TDAs depend on x, ξ_u and $u=(\Delta^u)^2=(p_\omega-p_1)^2$

- Impact parameter space interpretation of TDAs is similar to GPDs, except one has to Fourier transform with respect to $\Delta^u_T \approx (p_\omega - p_1)_T$

Garth Huber, huberg@uregina.ca

TDA Formalism (e.g. u–channel π^0)

- Fourier transform of the πN transition matrix element

$$4\mathcal{F}\langle \pi_\alpha(p_\pi)|\widehat{O}_{\rho\tau\chi}(\lambda_1 n, \lambda_2 n, \lambda_3 n)|N_\iota(p_1)\rangle$$

$$= \delta(x_1 + x_2 + x_3 - 2\xi_u)\sum_{s.f.}(f_a)_\iota^{\alpha\beta\gamma}\, s_{\rho\tau,\chi}\, H_{s.f.}^{\pi N}(x_1, x_2, x_3, \xi_u, \Delta^2; \mu_F^2)$$

Factorization scale

- πN TDA invariant amplitudes (**eight TDAs in total**)

$$H_{s.f.}^{\pi N} = \{V_{1,2}^{\pi N}, A_{1,2}^{\pi N}, T_{1,2,3,4}^{\pi N}\}$$

- Factorizing out the u–dependence:

meson to nucleon transition form factor

$$H^{\pi N}(x, \xi_u, \Delta^2) = H^{\pi N}(x_i, \xi_u) \times G(\Delta^2) \qquad \Delta^2 = u$$

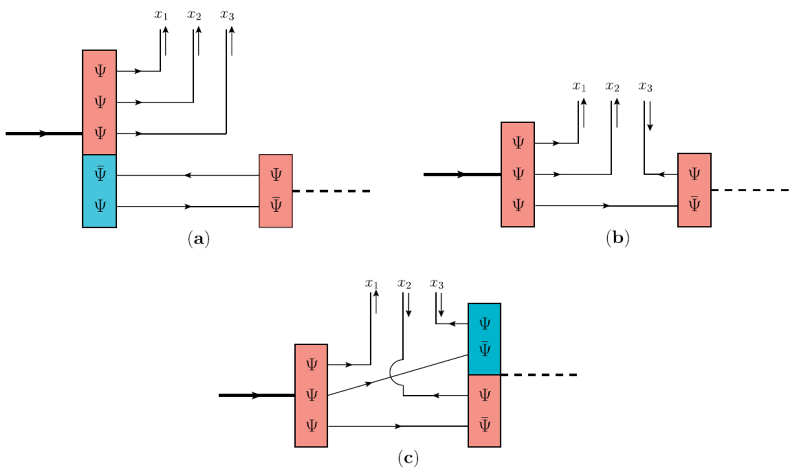
J.P. Lansberg, B. Pire, K. Semenov–Tian–Shansky, L. Szyamanowski, Phys. Rev. D **85** (2011) 054201

Garth Huber, huberg@uregina.ca

Partonic Interpretation of TDA

Main reactions of interest to date:

- Backward angle exclusive π^0, π^+, ρ, ω, φ production
- Backward angle DVCS

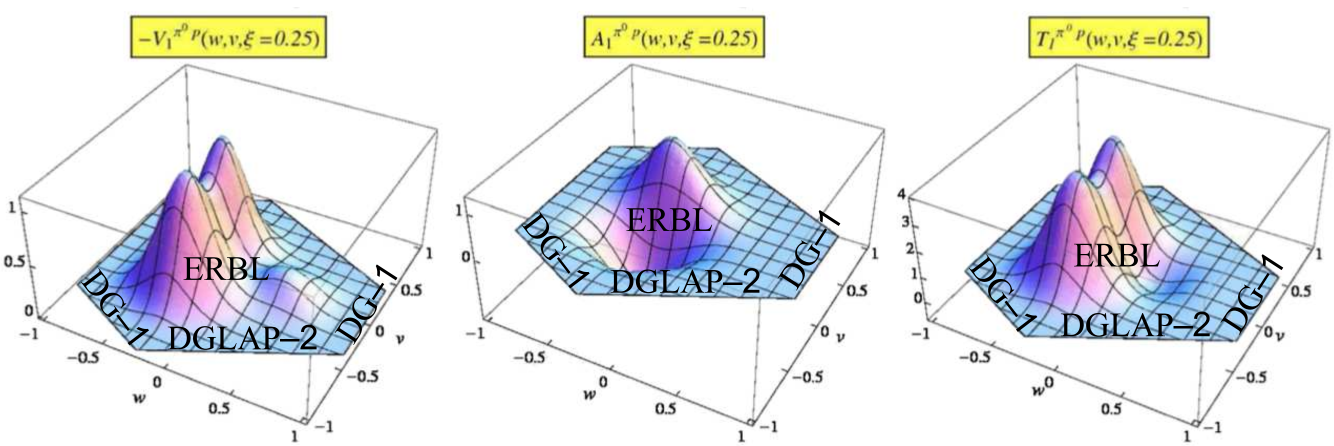


Interpretation of πN TDAs in light–cone quark model

a) Quark sea contrib to baryon wf (ERBL region)
- All 3 quark momentum fractions x_i positive

b) Minimal Fock states of baryon & meson (DGLAP–1) region
- One x_i negative

c) Quark sea contrib to meson wf (DGLAP–2)
- Two x_i negative



$\pi^0 p$ TDAs (CZ): **Vector** **Axial–Vector** **Tensor**

Model based on spectral representation w/ CZ sol for DA as input (function of quark–diquark coord)

J.P. Lansberg et al., PRD **85** (2012) 054201

Garth Huber, huberg@uregina.ca

Backward Angle Collinear Factorization

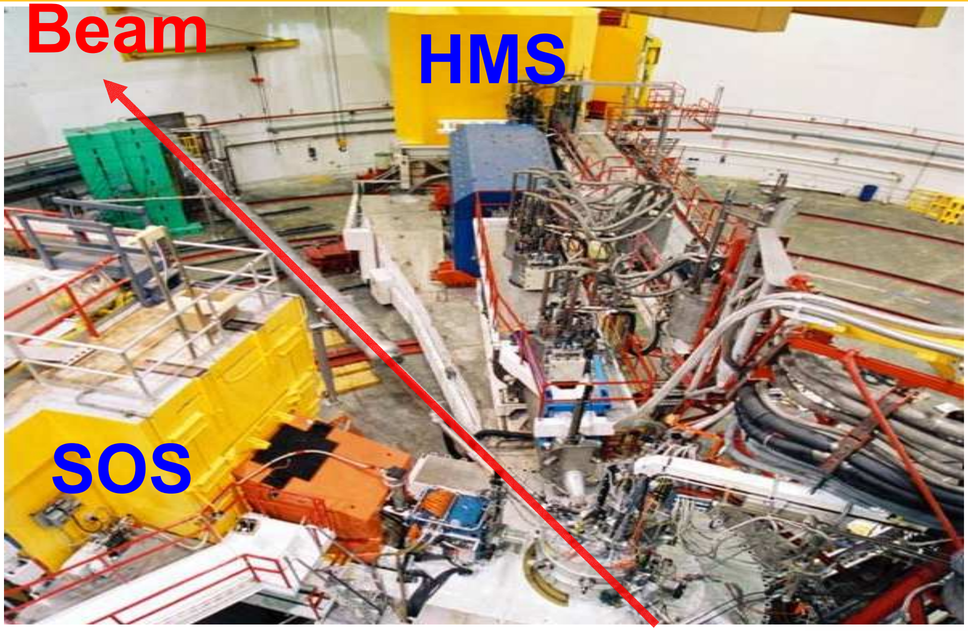
- **Kinematical regime for collinear factorization involving TDAs is similar to that involving GPDs:**
  - x_B fixed
  - $|u|$–momentum transfer small compared to Q^2 and s
  - Q^2 and s sufficiently large
- Early scaling for GPD physics occurs $2<Q^2<5$ GeV^2
  - Maybe something similar occurs for TDA physics…

Two Key Predictions in Factorization Regime:

- **Dominance of transverse polarization** of virtual photon, resulting in suppression of longitudinal cross section by at least $1/Q^2$: $\sigma_T \gg \sigma_L$
- Characteristic $1/Q^8$–scaling behavior of σ_T for fixed x_B

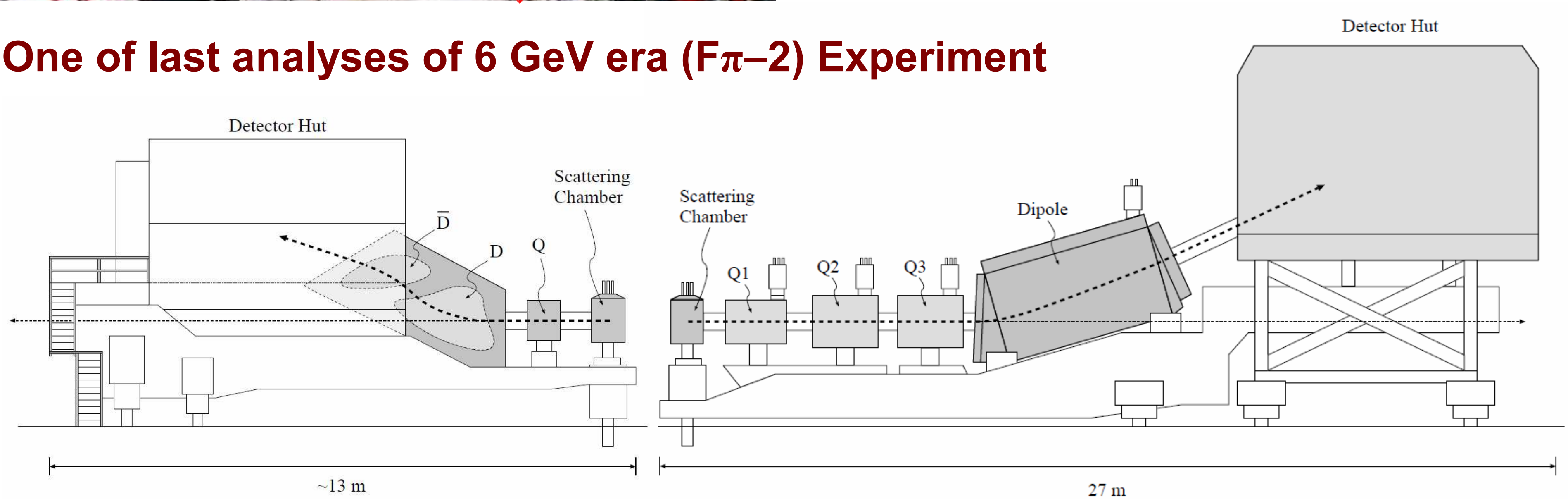
Garth Huber, huberg@uregina.ca

Jefferson Lab Hall C Experimental Setup



E_e (GeV)	ε	$-u$ (GeV²)	$-t$ (GeV²)	ξ_u	ξ_t
$\langle Q^2\rangle$=1.60 GeV² $\langle W\rangle$=2.21 GeV					
3.772	0.328	0.058 – 0.245	3.85 – 4.15	0.075 – 0.177	0.722 – 0.735
4.702	0.593				
$\langle Q^2\rangle$=2.45 GeV² $\langle W\rangle$=2.21 GeV					
4.210	0.270	0.117 – 0.400	4.48 – 4.94	0.126 – 0.256	0.748 – 0.764
5.248	0.554				

One of last analyses of 6 GeV era (Fπ–2) Experiment

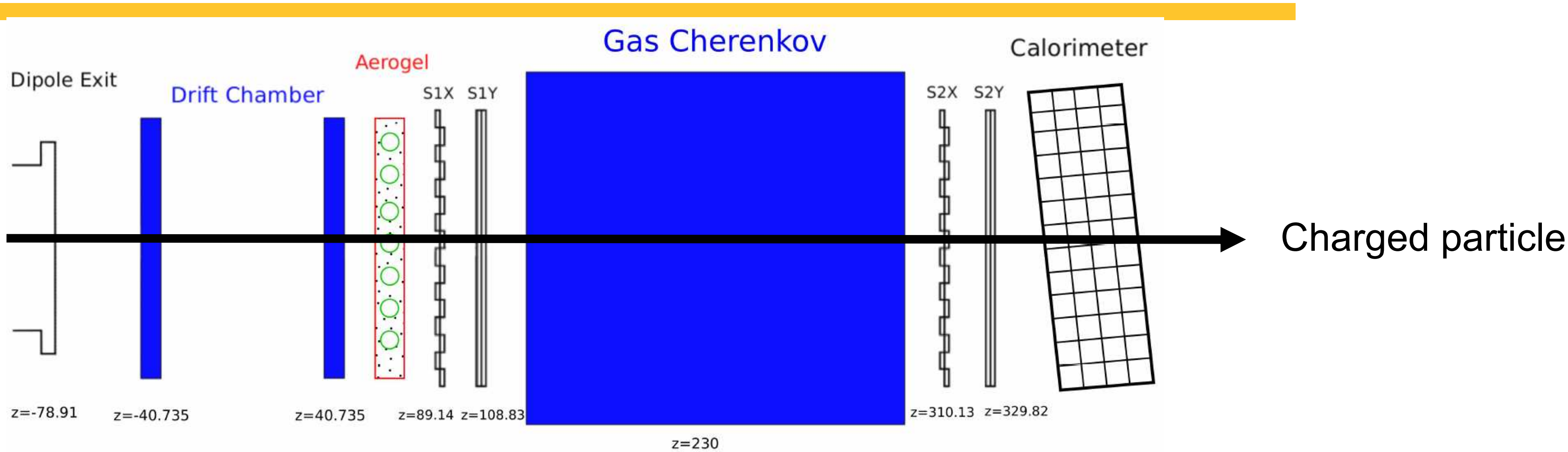


Short Orbit Spectrometer (SOS) High Momentum Spectrometer (HMS)

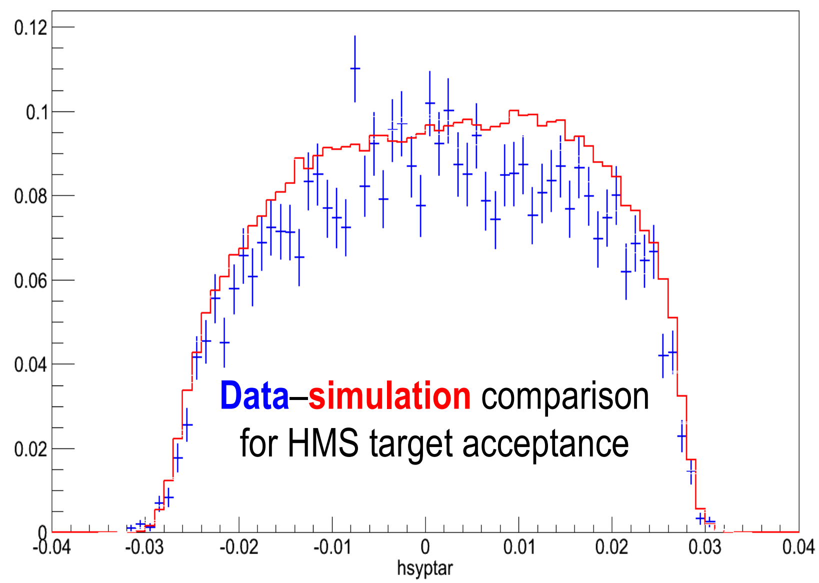
Garth Huber, huberg@uregina.ca

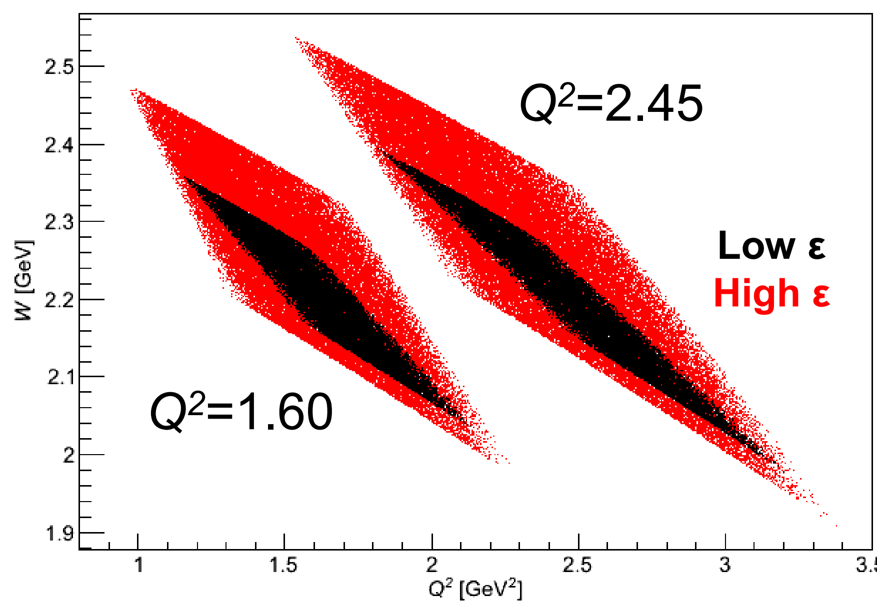
University of Regina

Experimental Setup and Acceptance



HMS focal plane detector layout, SOS is very similar
Trigger: ¾ planes of Hodoscopes





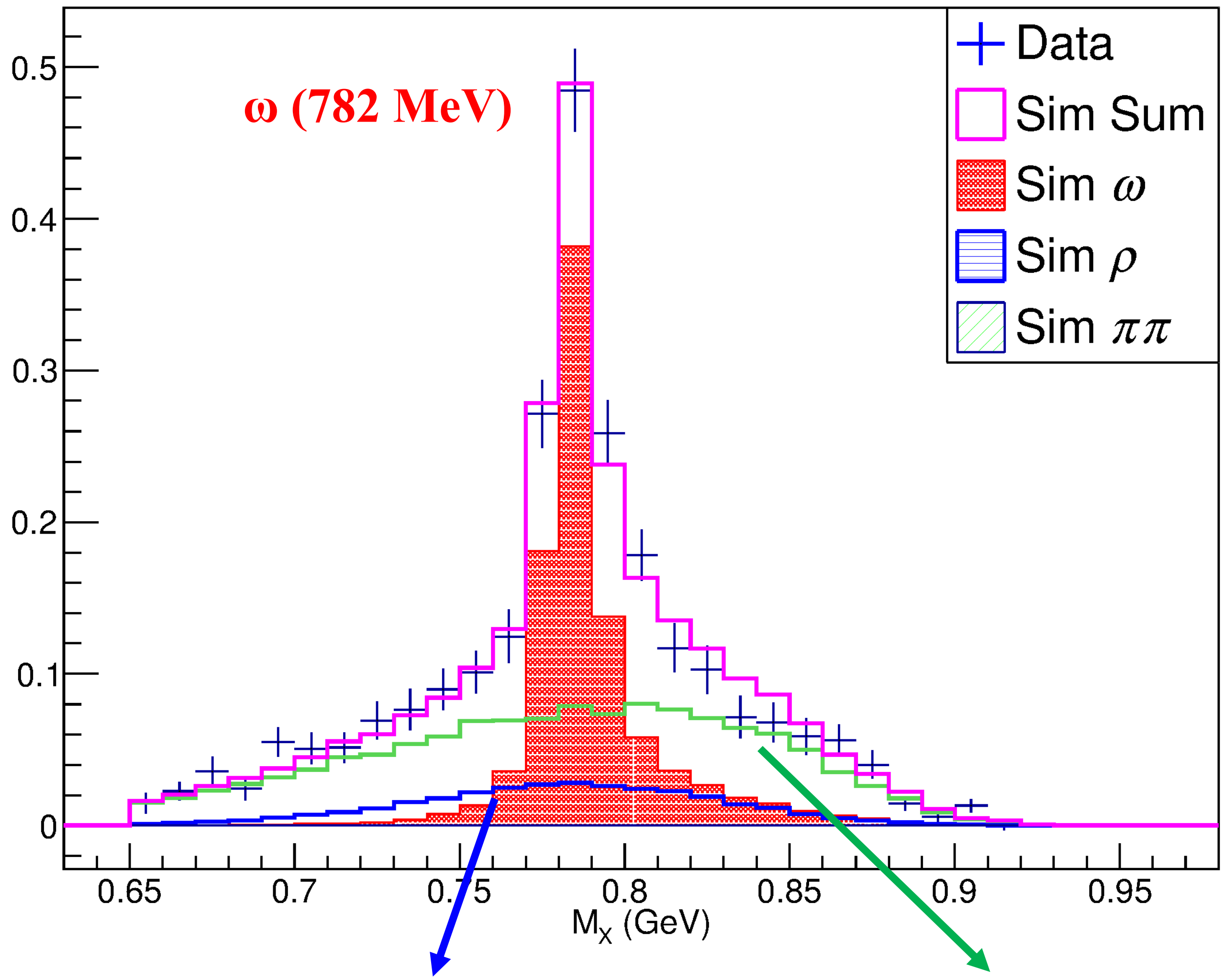
Garth Huber, huberg@uregina.ca

University of Regina

Physics Background Subtraction

University of Regina

$$M_x = \sqrt{(E_e + m_p - m_{e'} - E_p)^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_p)^2}$$



ρ (770 MeV)

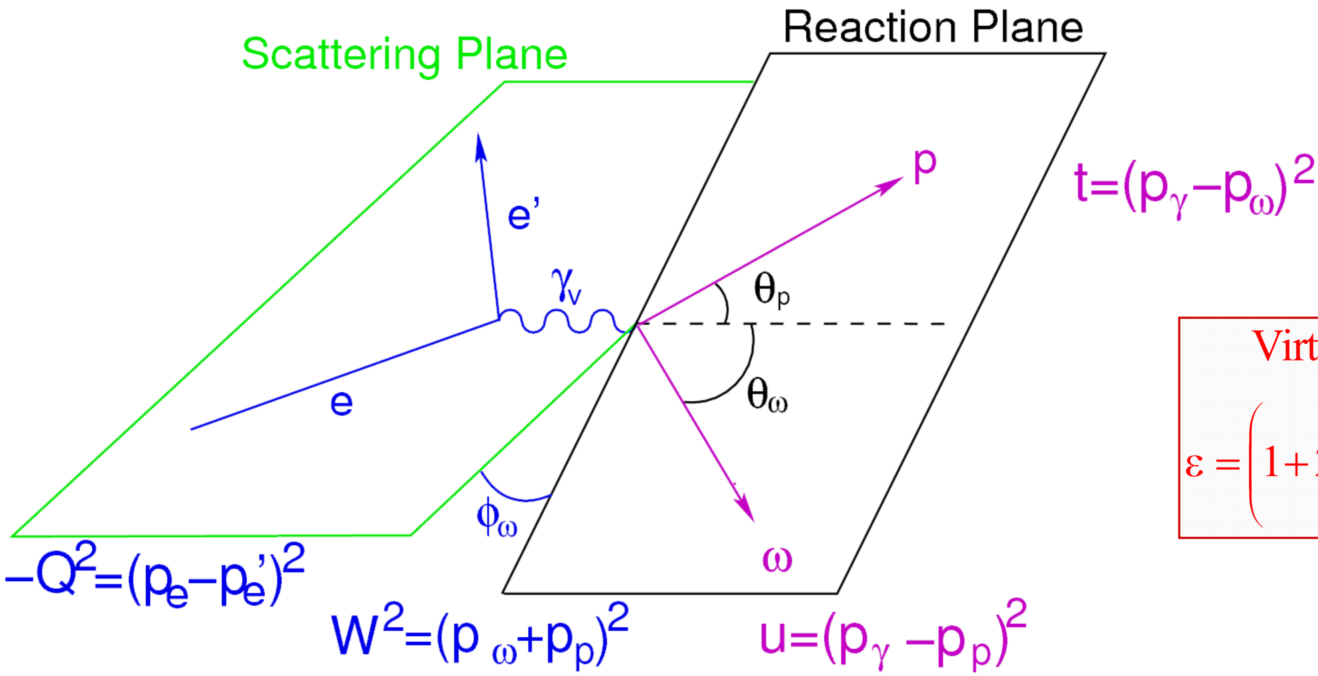
HERMES Empirical parameterization with Soding skewness factor

2π production phase-space

Garth Huber, huberg@uregina.ca

Rosenbluth (L/T/LT/TT) Separation

University of Regina



Virtual-photon polarization:

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

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

Rosenbluth Separation requires:

- Separate measurements at different ε (virtual photon polarization)
- All Lorentz invariant physics quantities: Q^2, W, t, u, remain constant
- Beam energy, scattered e' angle and virtual photon angle will change as a result, event rates are dramatically different at high, low ε

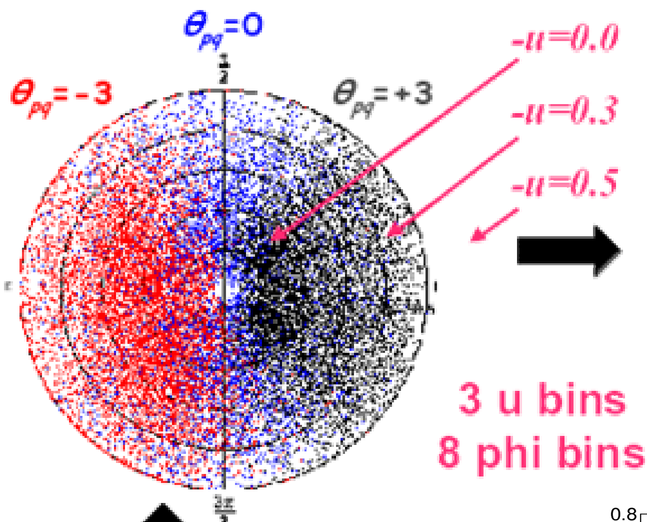
Garth Huber, huberg@uregina.ca

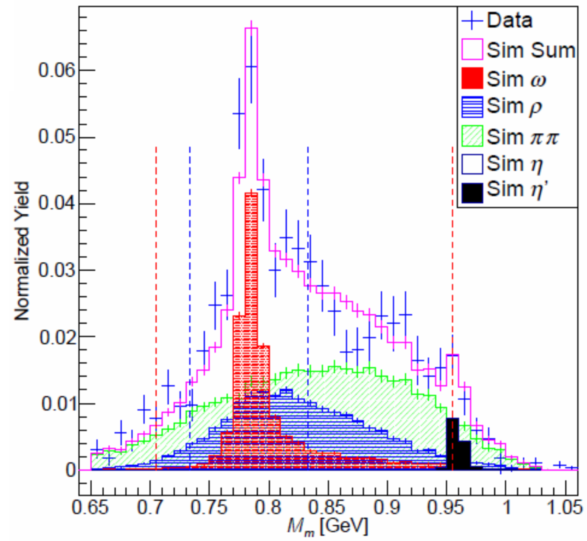
Iterative Procedure for L/T Separation

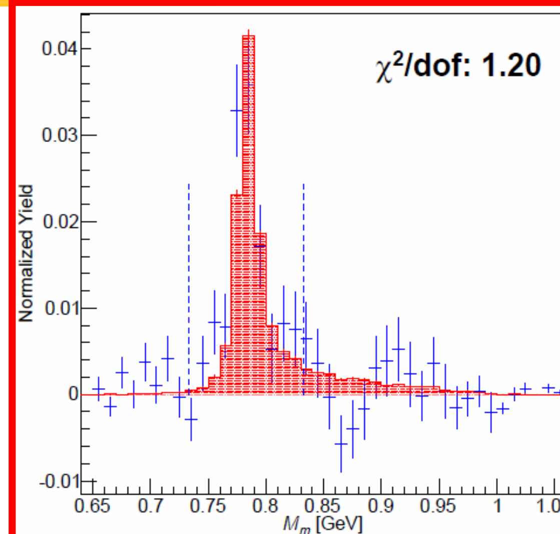
University of Regina

huberg@uregina.ca

Improve φ coverage by taking data at multiple HMS angles, $-3^{\circ}<\theta_{pq}<+3^{\circ}$.





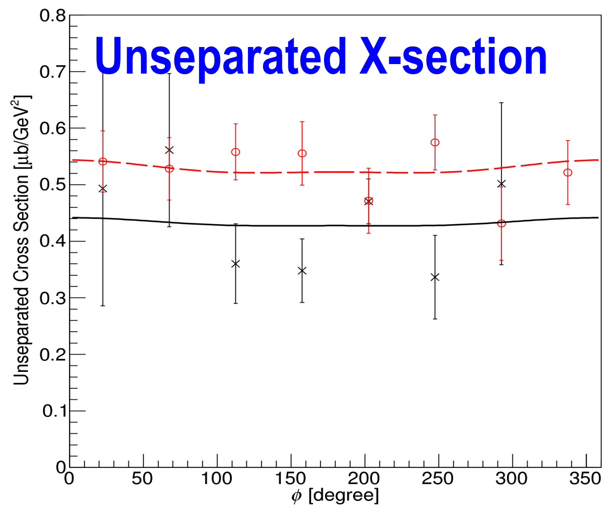


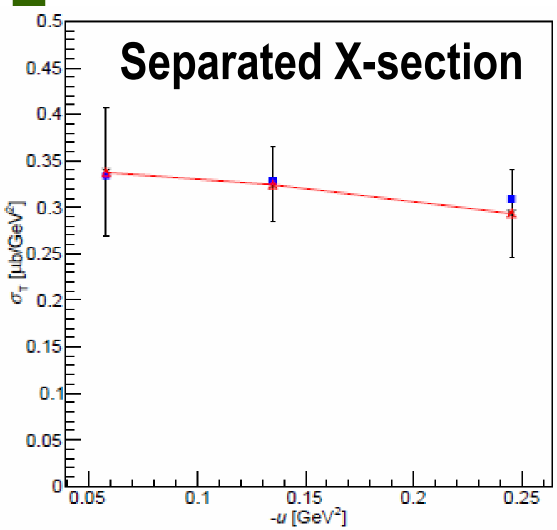
$$R=\frac{Y_{Exp}-Y_{\rho\ sim}-Y_{Xspace\ sim}}{Y_{\omega\ sim}}$$

Combine ratios for settings together, propagating errors accordingly.

$$\frac{d^2\sigma}{dtd\varphi}_{EXP}=R\,\frac{d^2\sigma}{dtd\varphi}_{SIMC}$$

Empirical Model





Extract L,T,LT,TT via simultaneous fit

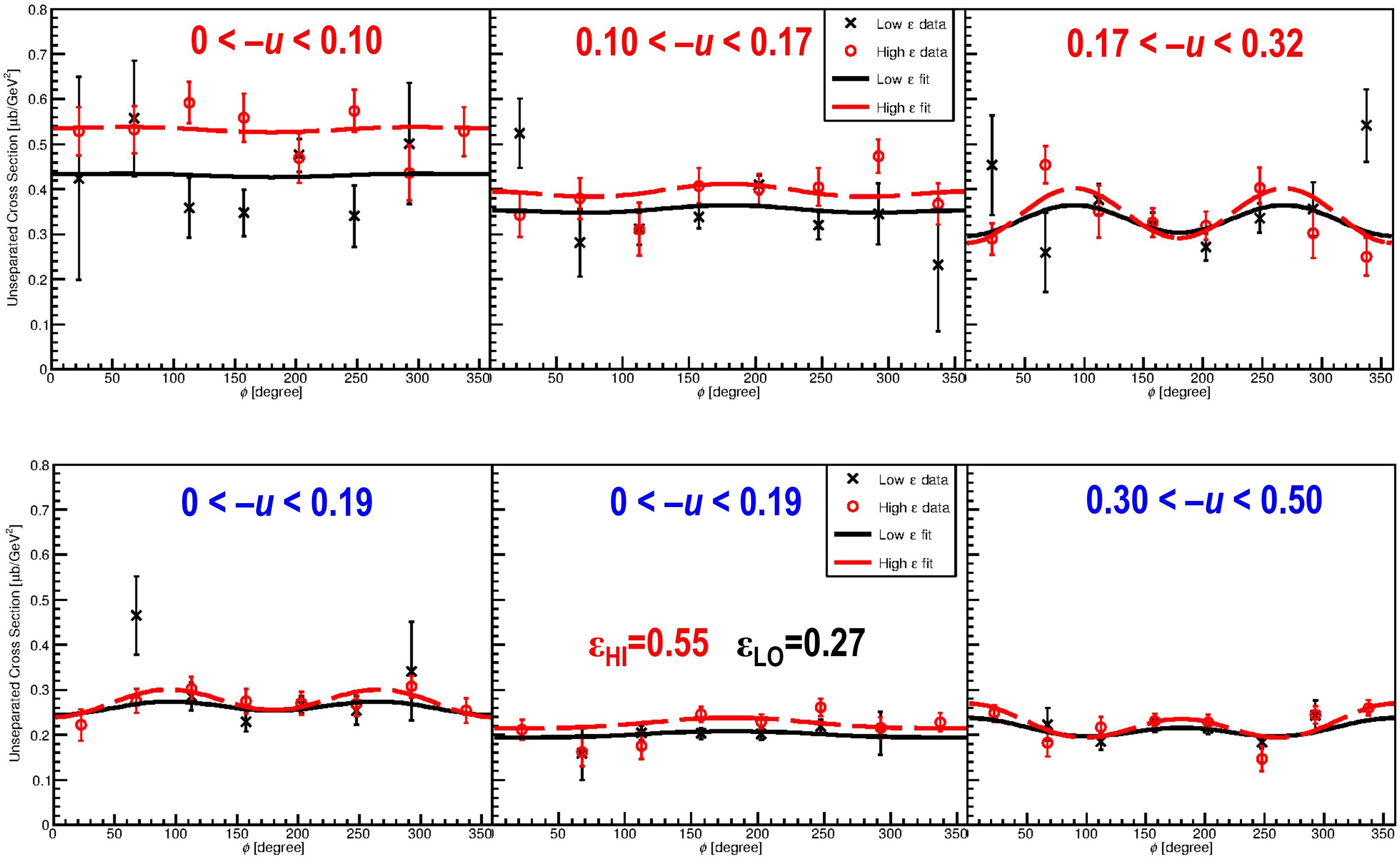
$$2\pi\frac{d^2\sigma}{dtd\phi}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

Unseparated Cross Sections

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

Q^2=1.60 GeV^2

Q^2=2.45 GeV^2

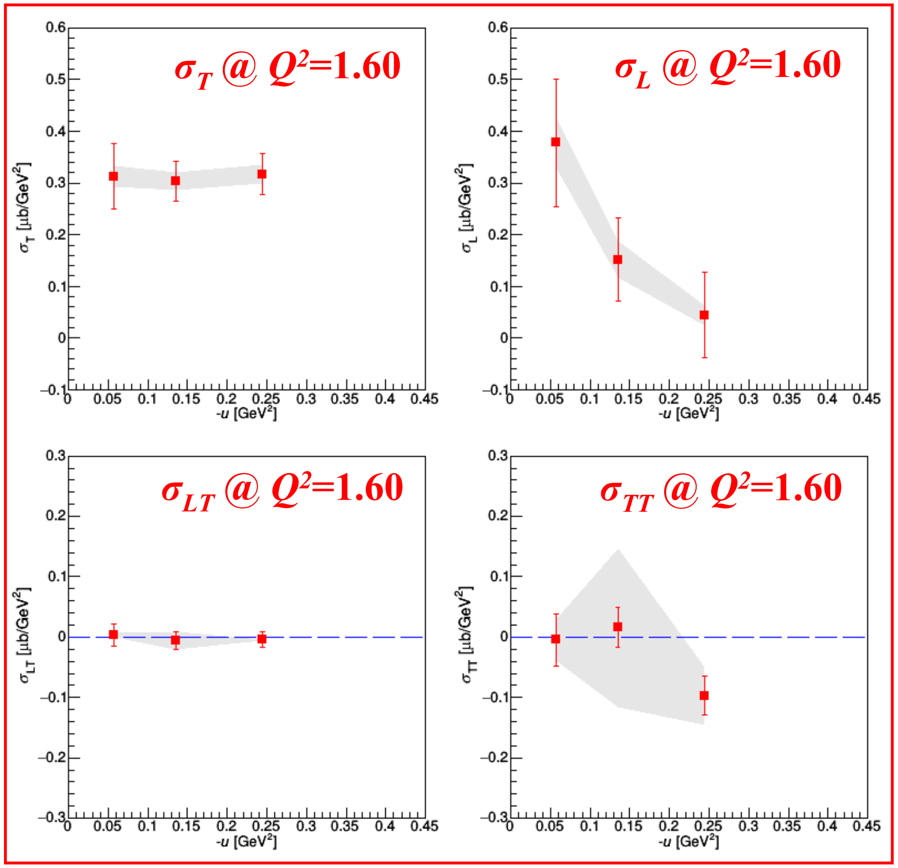


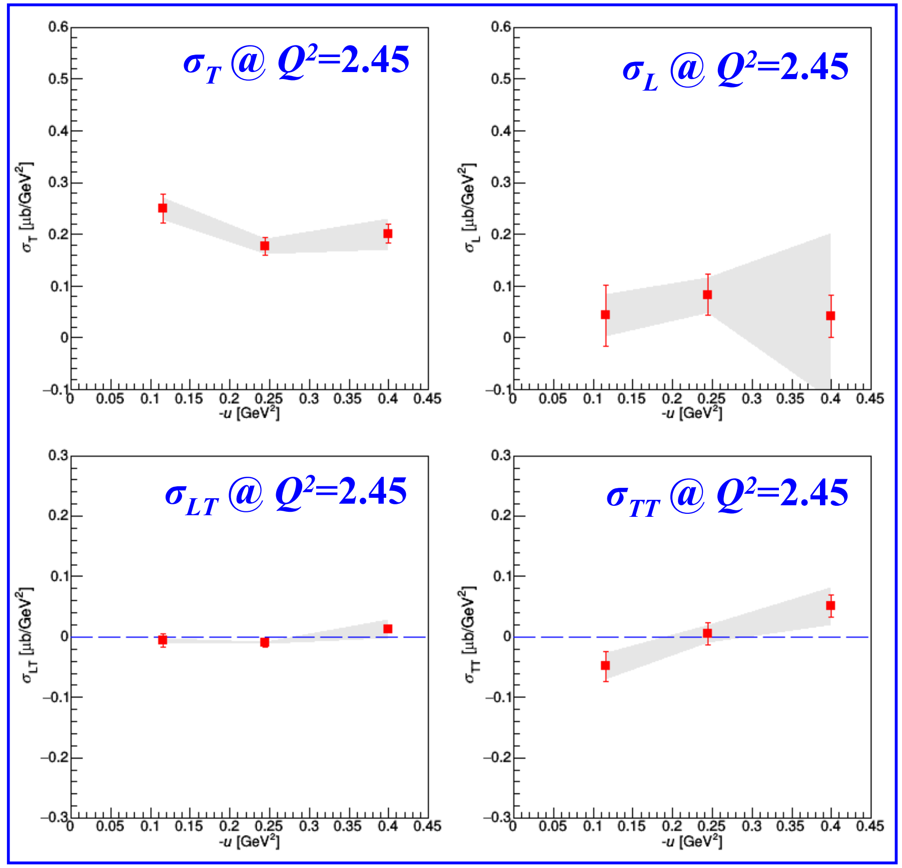
Garth Huber, huberg@uregina.ca

Separated Cross Sections $\frac{d\sigma}{dt}$ vs $-u$

University of Regina

Garth Huber, huberg@uregina.ca





Observations:

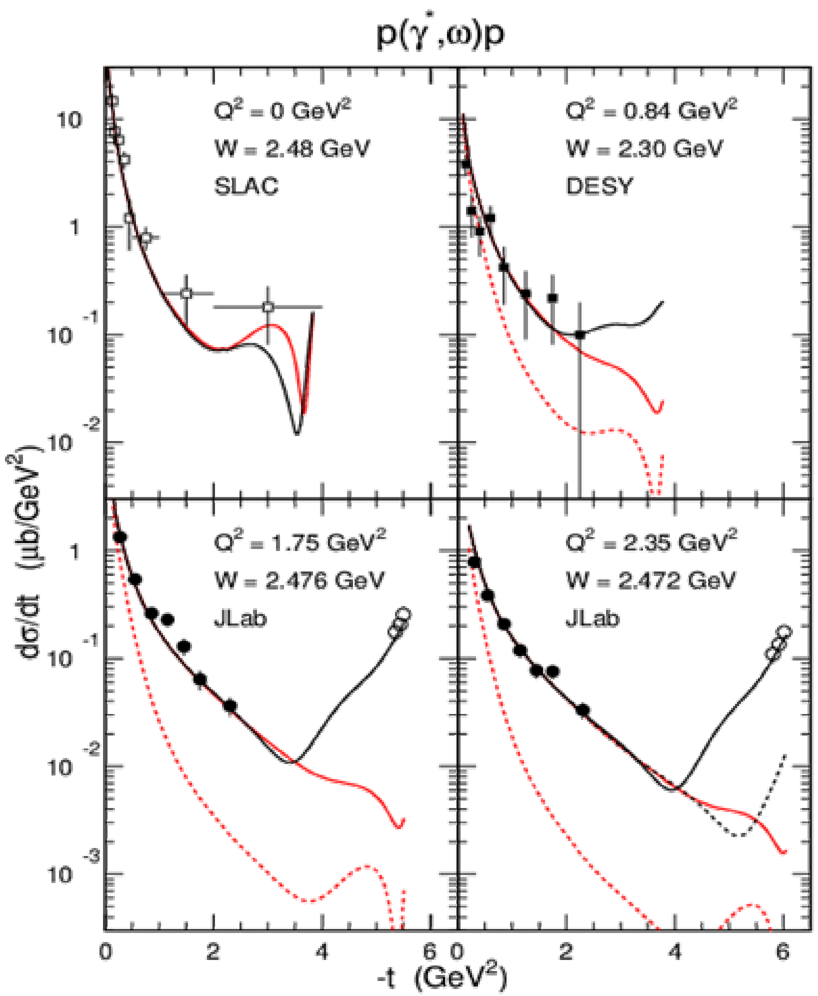
- σ_T falls slowly with $-u$; σ_L falls faster.
- σ_{LT} is very small; σ_{TT} may sign flip for different Q^2 values.

Error bars = statistical and uncorrelated syst. unc; Error bands = correlated syst. unc.

JML Regge Model description of *u*–Peak

Garth Huber, huberg@uregina.ca

University of Regina



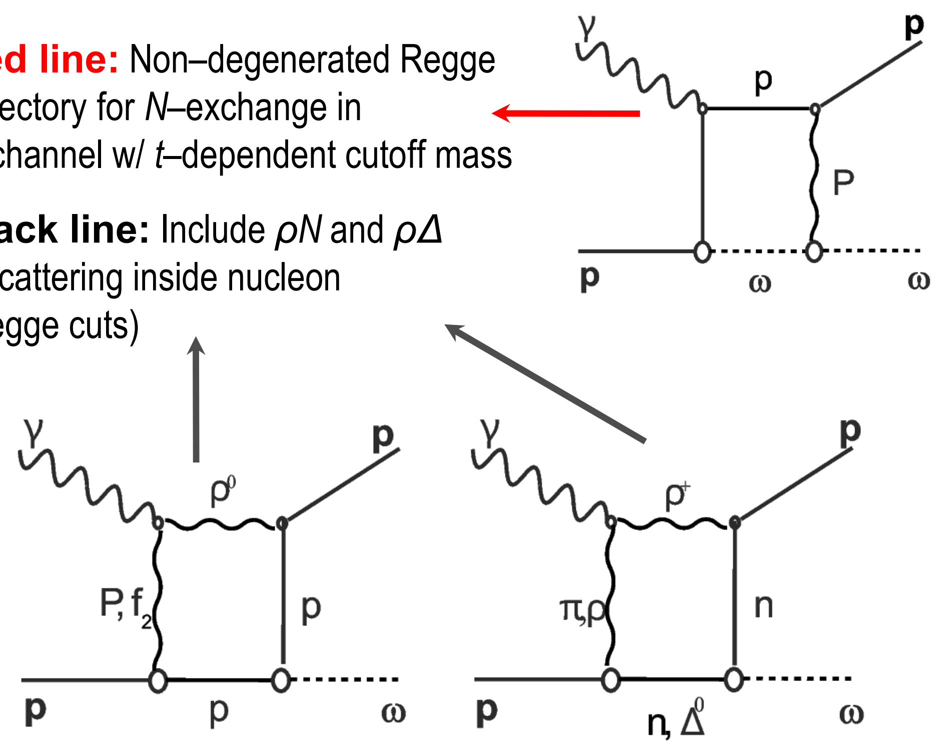
J.–M. Laget, Private Communication (2018)

- Model provides natural description of JLab π electroproduction cross sections without destroying good agreement at $Q^2=0$.

  [PLB **685**(2010)146; PLB **695**(2011)1999]
- Model also consistent with magnitude and slope of backward angle ω peak.
- Would be interesting to examine L/T ratio predicted by model when full cal available.

Red line: Non–degenerated Regge trajectory for *N*–exchange in *u*–channel w/ *t*–dependent cutoff mass

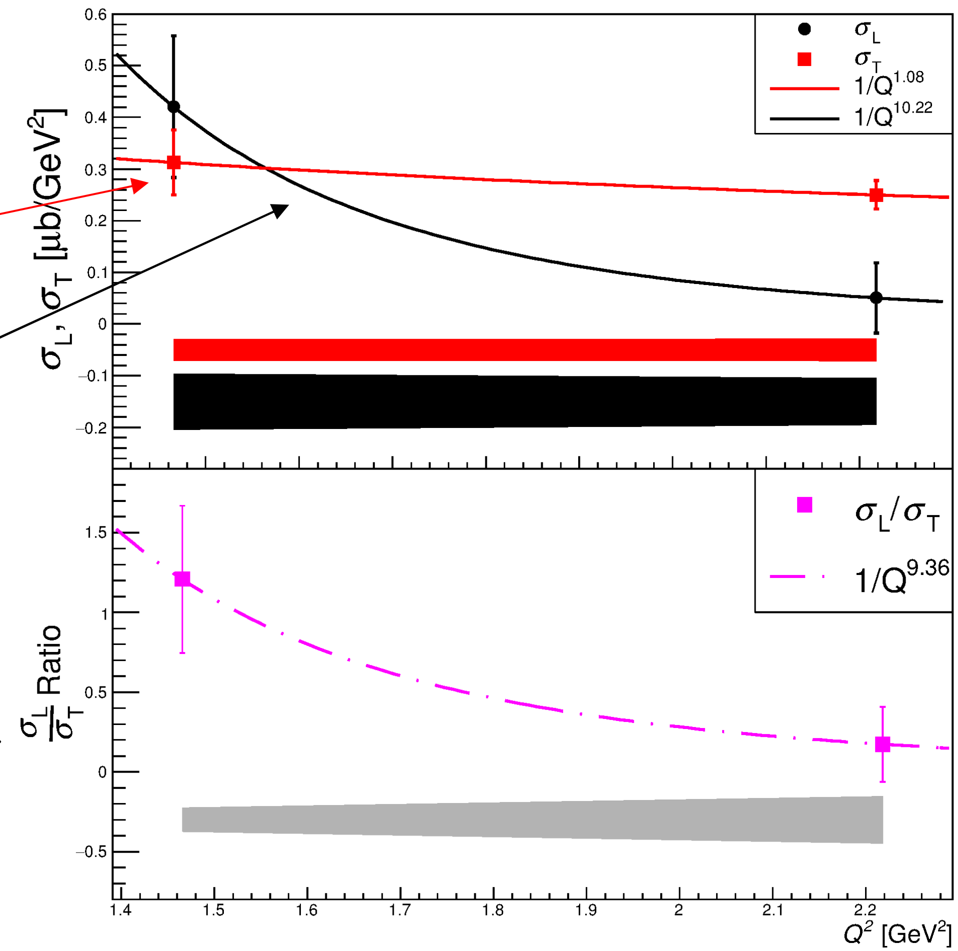
Black line: Include *ρN* and *ρΔ* rescattering inside nucleon (Regge cuts)



$p(e,e'p)\omega$ Q^2–Dependence

- To investigate Q^2–dependence, fit lowest $-u$ bin values of σ_T and σ_L to Q^{-n} function
  - σ_T appears to have a flat Q^2–dependence within measured range
  - σ_L shows much stronger decrease
- **Decreasing L/T ratio indicates the gradual dominance of σ_T as Q^2 increases.**
- Trend qualitatively consistent with prediction of TDA Collinear Factorization.

$-u = -u_{min}$

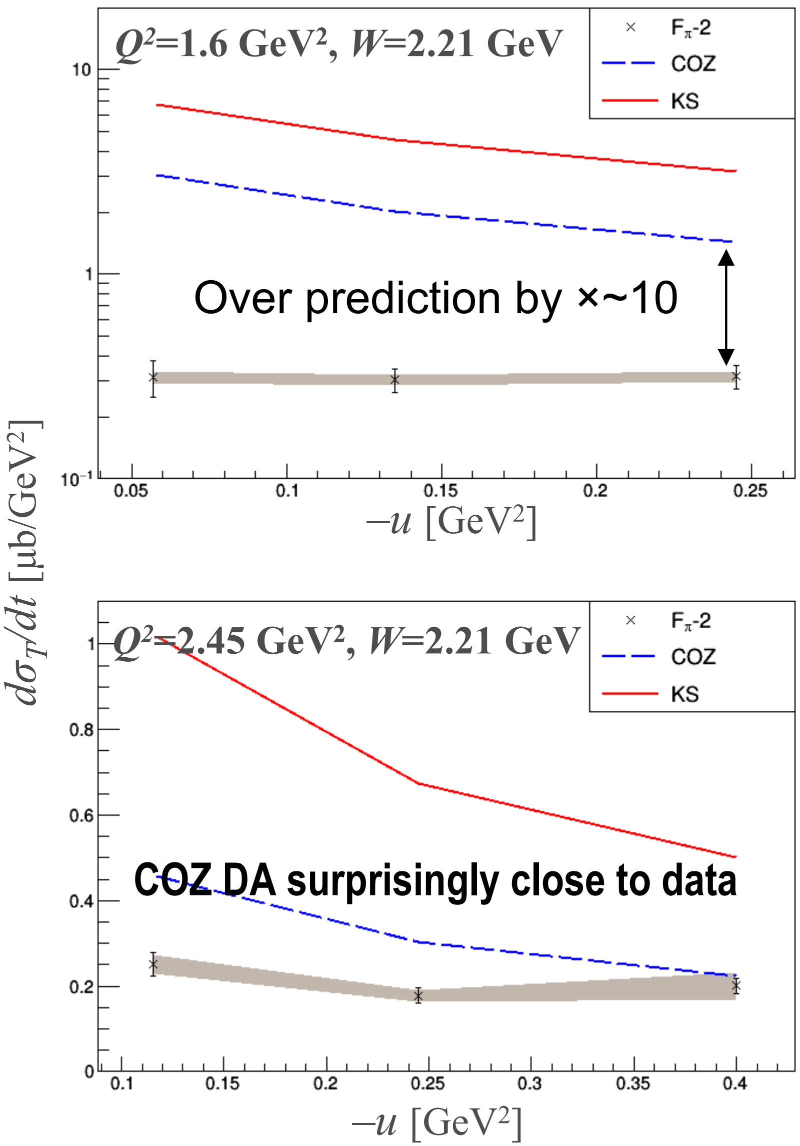


Q^2=1.47
W=2.26
$-u_{min}$=0.058

Q^2=2.23
W=2.28
$-u_{min}$=0.117

Garth Huber, huberg@uregina.ca

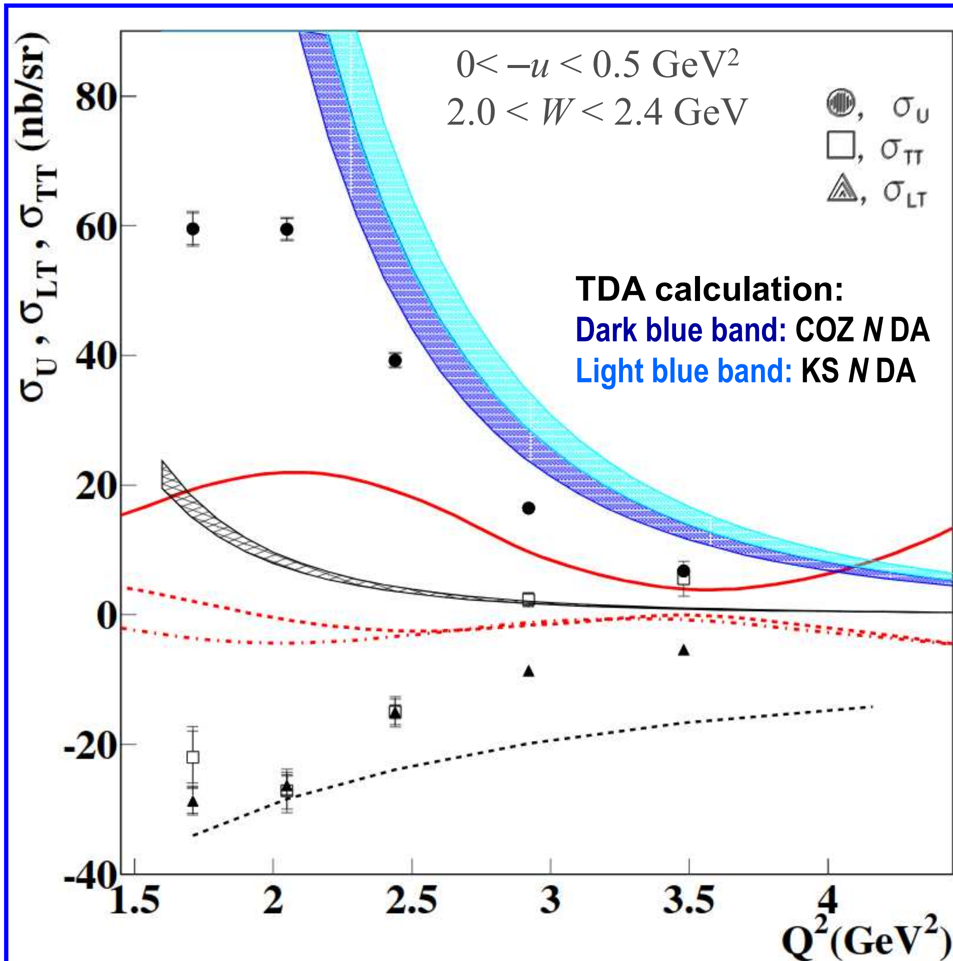
TDA model Comparison to Data



TDA calculation by B. Pire, K. Semenov, L. Szymanowski
Private Communication (2015)

Hall C ω electroproduction

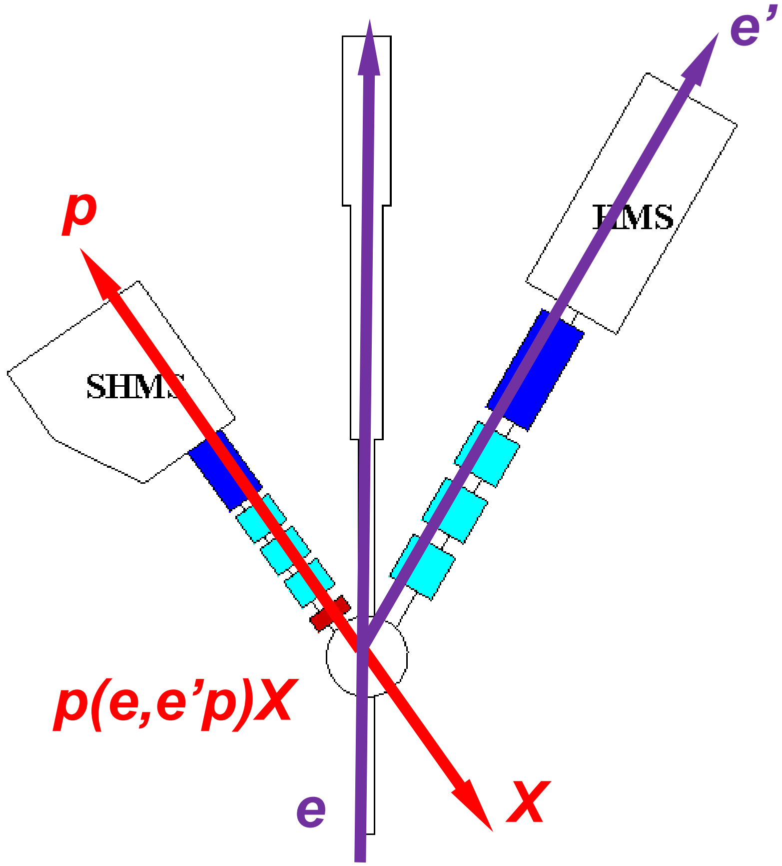
Both data sets suggestive of early TDA scaling Q^2≈2.5 GeV² !?

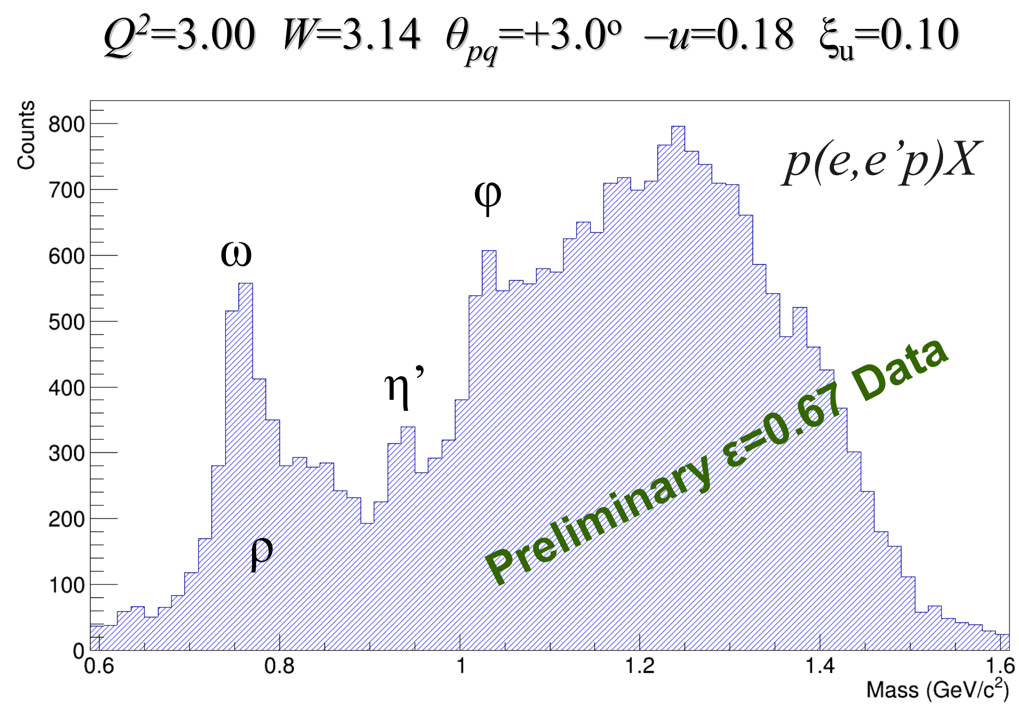


Hall B π+ Electroproduction
K. Park et al., PLB **780** (2017) 340

Garth Huber, huberg@uregina.ca

Future Backward Meson Production Opportunities





Jefferson Lab 12 GeV experiments

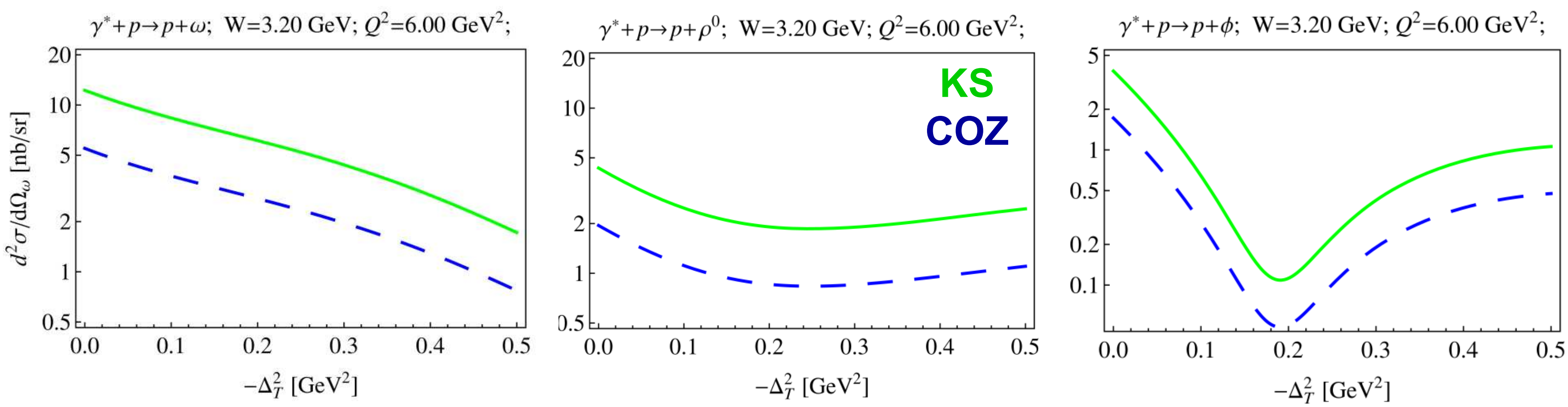
- **K^+ L/T–experiment (E12–09–011)** Spokespersons: T. Horn, G.M. Huber, P. Markowitz
  - Backward angle *(u≈0) ω, η'*, ϕ data already acquired
- **Fπ–12 experiment (E12–06–101)** L/T separations up to Q^2=6.0 GeV^2
  Spokespersons: D. Gaskell, G.M. Huber
- **LOI (2018): u≈0 π^0 production Hall C** Spokespersons: W. Li, G.M. Huber, J. Stevens
- **Large Emission Angle ϕ Experiment at CLAS: E12–12–007**
  Spokespersons: F–X Girod, M. Guidal, V. Kubarovsky, P. Stoler, C. Weiss

Garth Huber, huberg@uregina.ca

TDA Model Predictions for JLab E12-06-101

University of Regina

- **L/T–Separations over wide kinematic range will allow σ_T » σ_L and $1/Q^8$ scaling predictions to be checked with greater authority**
- u–channel φ–electroproduction particularly interesting
  - Sensitive to Strangeness content of nucleon
- Combined analysis of ρ, ω production allows one to disentangle isotopic structure of VN TDAs in non–strange sector

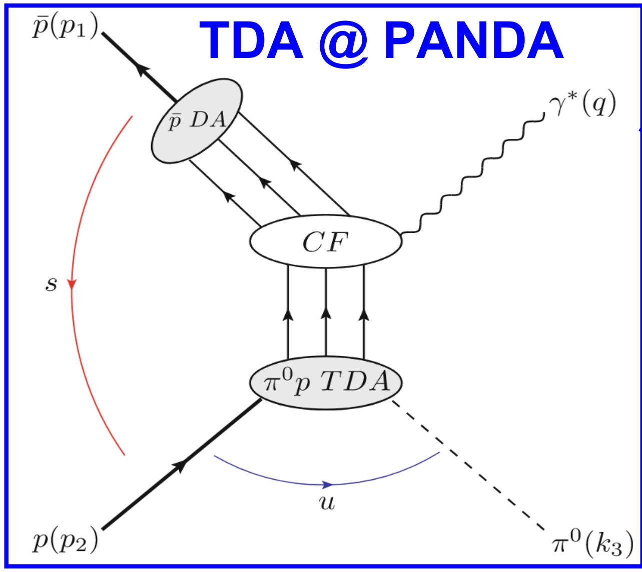


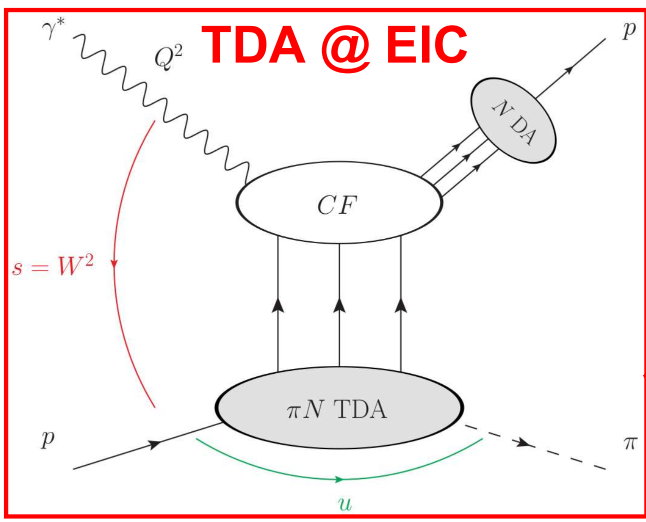
B. Pire et al., PRD 91 (2015) 094006

- At Q^2=6.0 GeV², ω predicted to remain dominant, φ production to drop rapidly with –*u*.

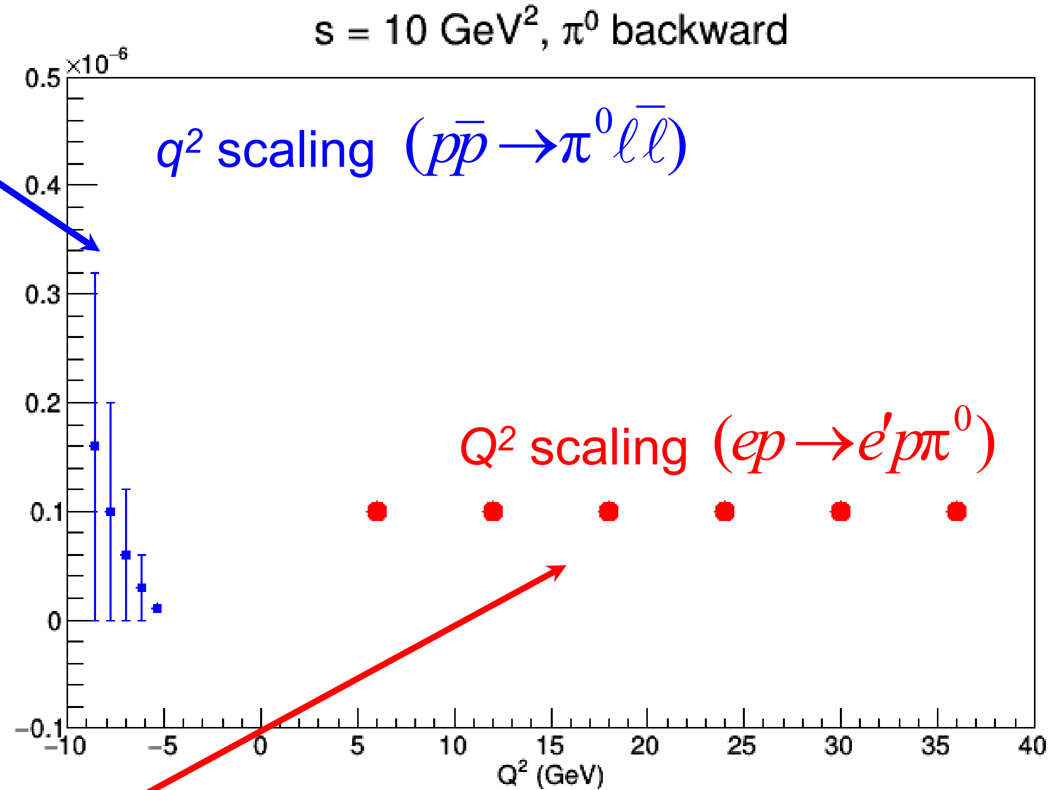
Garth Huber, huberg@uregina.ca

Future Opportunities at PANDA and EIC





PANDA Collaboration, EPJA **15**(2015)107



Same TDAs for PANDA and EIC, the ultimate universality check

Garth Huber, huberg@uregina.ca

Summary

- **New experimental technique pioneered at JLab Hall C has opened up a unique kinematic regime for study:**
  - Extreme backward angle (*u*≈0) scattering
  - Detect forward–going proton in parallel kinematics
    - Leaves "recoil" meson nearly–at–rest in target
- Possible access to **Transition Distribution Amplitudes**
  - Universal perturbative objects in *u*–channel, analogous to GPDs
  - Access to 3–quark plus sea component $\Psi_{(3q+q\bar{q})}$ of nucleon
- **J.–M. Laget Regge Model** provides natural explanation of magnitude and u–slope of observed backward angle peak
- **σ_L/σ_T separations will be essential to distinguish between alternate theoretical descriptions**

Garth Huber, huberg@uregina.ca

Jefferson Lab Fπ–2 Collaboration

University of Regina

R. Ent, D. Gaskell, M.K. Jones, D. Mack, D. Meekins, J. Roche, G. Smith, W. Vulcan, G. Warren, S.A. Wood
Jefferson Lab, Newport News, VA , USA

E.J. Brash, G.M. Huber, W. Li, V. Kovaltchouk, G.J. Lolos, S. Vidakovic, C. Xu
University of Regina, Regina, SK, Canada

H. Blok, V. Tvaskis
Vrije Universiteit, Amsterdam, Netherlands

E. Beise, H. Breuer, C.C. Chang, T. Horn, P. King, J. Liu, P.G. Roos
University of Maryland, College Park, MD, USA

W. Boeglin, P. Markowitz, J. Reinhold
Florida International University, FL, USA

J. Arrington, R. Holt, D. Potterveld, P. Reimer, X. Zheng
Argonne National Laboratory, Argonne, IL, USA

H. Mkrtchyan, V. Tadevosyan
Yerevan Physics Institute, Yerevan, Armenia

S. Jin, W. Kim
Kyungook National University, Taegu, Korea

M.E. Christy, C. Keppel, L.G. Tang
Hampton University, Hampton, VA, USA

J. Volmer
DESY, Hamburg, Germany

A. Matsumura, T. Miyoshi, Y. Okayasu
Tohuku University, Sendai, Japan

A. Sarty
St. Mary's University, Halifax, NS, Canada

K. Aniol, D. Margaziotis
California State University, Los Angeles, CA, USA

L. Pentchev, C. Perdrisat
College of William and Mary, Williamsburg, VA, USA

E. Gibson, I. Niculescu, V. Punjabi

Jefferson Lab

Hall C

Garth Huber, huberg@uregina.ca

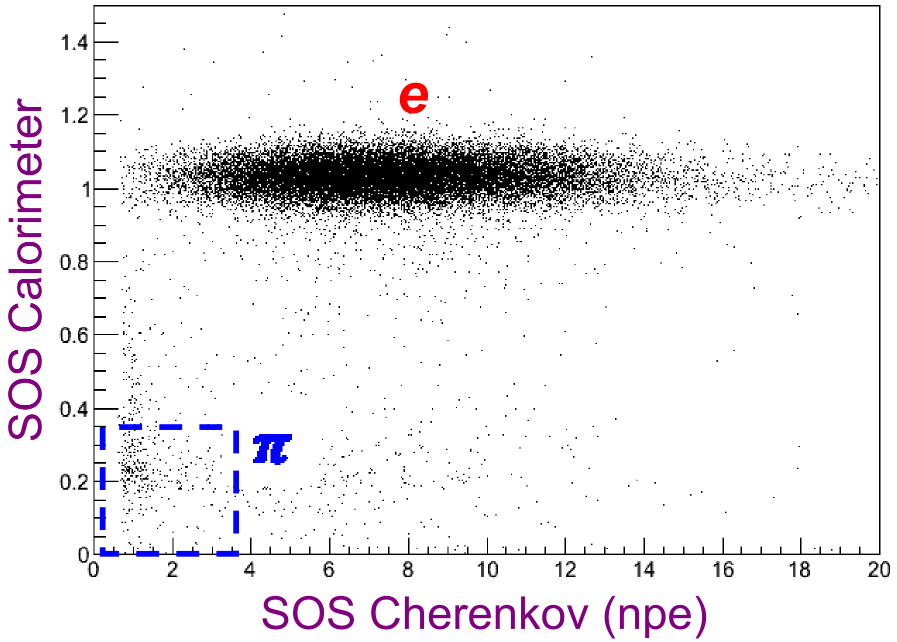
Systematic Uncertainties

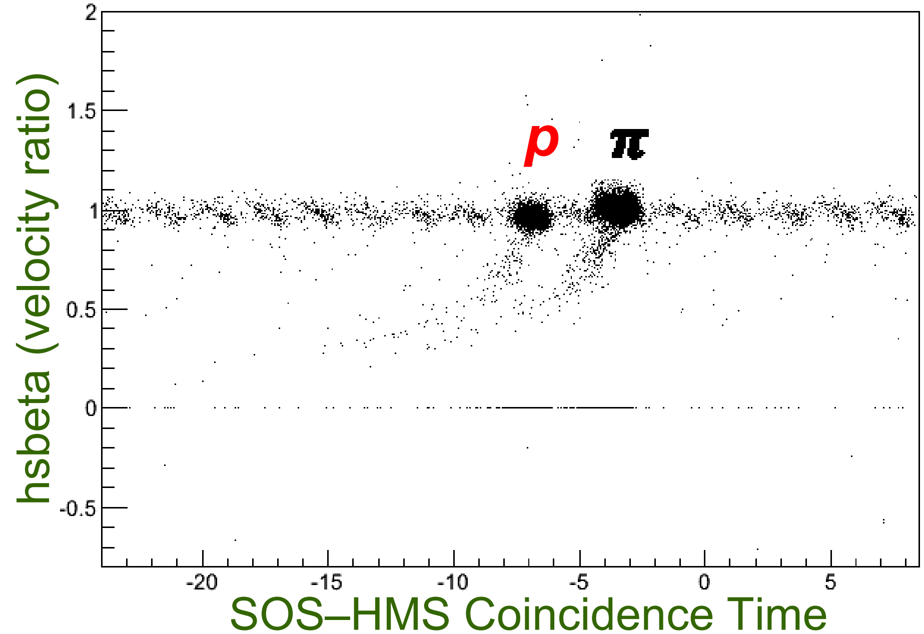
Correction	Uncorrelated (Pt-to-Pt) (%)	ϵ uncorr. u corr. (%)	Correlated (scale) (%)	Section
HMS Cherenkov			0.02	Sec. 3.6.3
HMS Aerogel			0.04	Sec. 5.3.7
SOS Calorimeter			0.17	Sec. 3.6.4
SOS Cherenkov			0.02	Sec. 3.6.3
HMS beta	0.4			Sec. 5.1.2
HMS Tracking		0.4	1.0	Sec. 5.3.3
SOS Tracking		0.2	0.5	Sec. 5.3.3
HMS Trigger		0.1		Sec. 3.7
SOS Trigger		0.1		Sec. 3.7
Target Thickness		0.3	1.0	Secs. 3.5.2, 5.3.5
CPU LT		0.2		Sec. 5.3.2.2
Electronic LT		0.1		Sec. 5.3.2.1
Coincidence Blocking			0.1	Sec. 5.3.6
$d\theta$	0.1	0.7-1.1		Ref. [3]
dE_{Beam}	0.1	0.2-0.3		Ref. [3]
dp_e	0.1	0.1-0.3		Ref. [3]
$d\theta_p$	0.1	0.2-0.3		Ref. [3]
PID		0.2		Sec. 5.1.1
Beam Charge		0.3	0.5	Sec. 3.4
Radiative Correction		0.3	1.5	Sec. 4.1.4
Acceptance	1.0	0.6	1.0	Sec. 3.8
Proton Interaction			0.7	Sec. 5.3.9
Background Fitting Limit	2.0	0.8	0.8	Secs. 6.5.3, 6.10.2
ω Integration Limit	1.7	1.0	0.3	Secs. 6.6, 6.10.2
Model Dependence	0.7			Secs. 6.2.1, 6.10.2
Total	2.9	1.7-2.0	2.6	

- Unseparated σ
  - Statistical
  - Systematic Error
    - Uncorrelated Error
    - ϵ uncorrelated u correlated
    - Scale error
- Model dependent Error to the separated (Scale error)
  - Parameterization
  - ϕ limits
  - u limits (small contribution)

Garth Huber, huberg@uregina.ca

Particle Identification

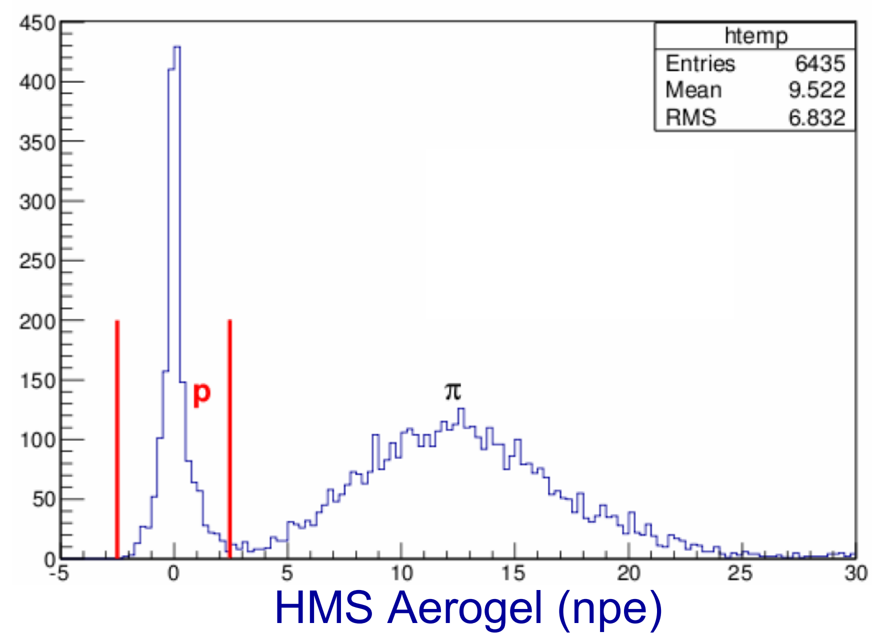




SOS: select electron
- Calorimeter cut
- Cherenkov cut

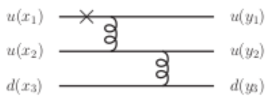
99% efficiency

HMS: select proton
- Coincidence timing cut
- hsbeta (particle velocity)
- Aerogel Cut
- Cherenkov cut: veto e^+



Garth Huber, huberg@uregina.ca

TDAs Formalism – 1

α		T_α	T'_α
1		$\frac{-Q_u(2\xi)^2[(V_1^{p\pi^0}-A_1^{p\pi^0})(V^p-A^p)+4T_1^{p\pi^0}T^p+2\frac{\Delta_T^2}{M^2}T_4^{p\pi^0}T^p]}{(2\xi-x_1-i\epsilon)^2(x_3-i\epsilon)(1-y_1)^2y_3}$	$\frac{-Q_u(2\xi)^2[(V_2^{p\pi^0}-A_2^{p\pi^0})(V^p-A^p)+2(T_2^{p\pi^0}+T_3^{p\pi^0})T^p]}{(2\xi-x_1-i\epsilon)^2(x_3-i\epsilon)(1-y_1)^2y_3}$

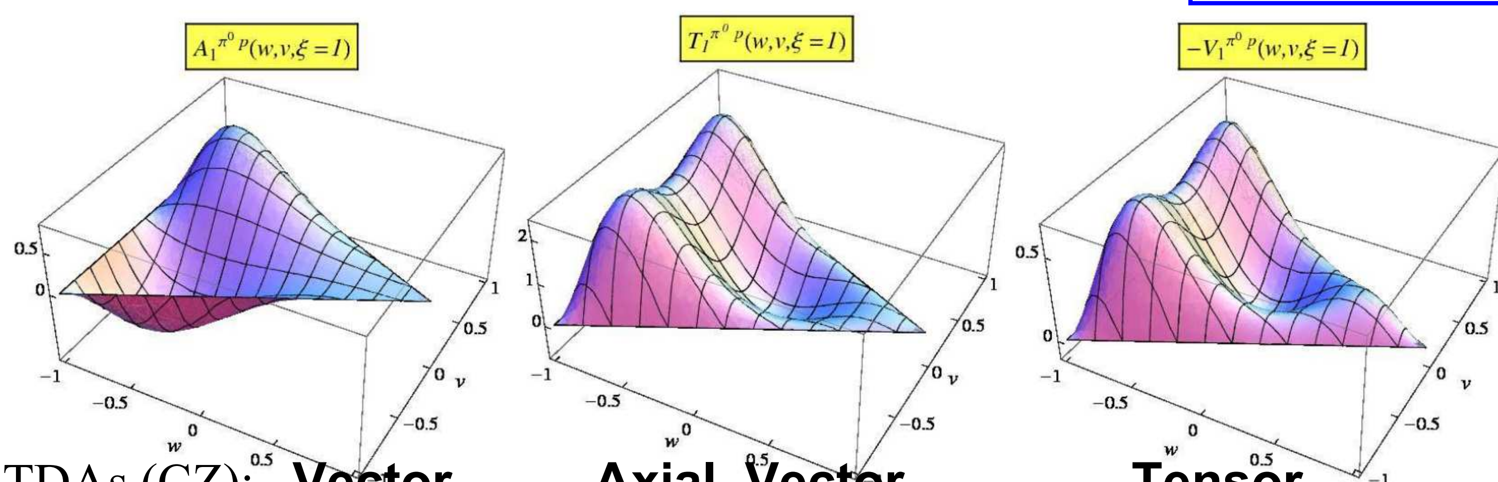
First three TDAs

$$V_1^{\pi^0 p}(x_1,x_2,x_3,\xi_u=1) = -\frac{1}{2}\times\frac{1}{4}V^P\left(\frac{x_1}{2},\frac{x_2}{2},\frac{x_3}{2}\right)$$

$$A_1^{\pi^0 p}(x_1,x_2,x_3,\xi_u=1) = -\frac{1}{2}\times\frac{1}{4}A^P\left(\frac{x_1}{2},\frac{x_2}{2},\frac{x_3}{2}\right)$$

$$T_1^{\pi^0 p}(x_1,x_2,x_3,\xi_u=1) = \frac{3}{2}\times\frac{1}{4}T^P\left(\frac{x_1}{2},\frac{x_2}{2},\frac{x_3}{2}\right)$$

Input PDF from Nucleon DA model:
- COZ (Chernak, Ogloblin, Zhitnitsky, 1989)
- KS (King and Schrajda, 1987)



$\pi^0 p$ TDAs (CZ): **Vector** **Axial–Vector** **Tensor**

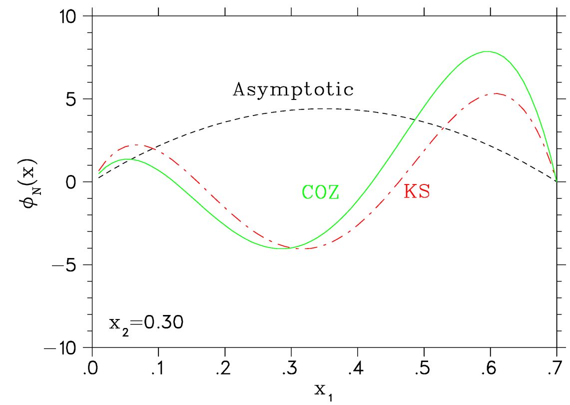
computed as functions of quark-diquark coordinates

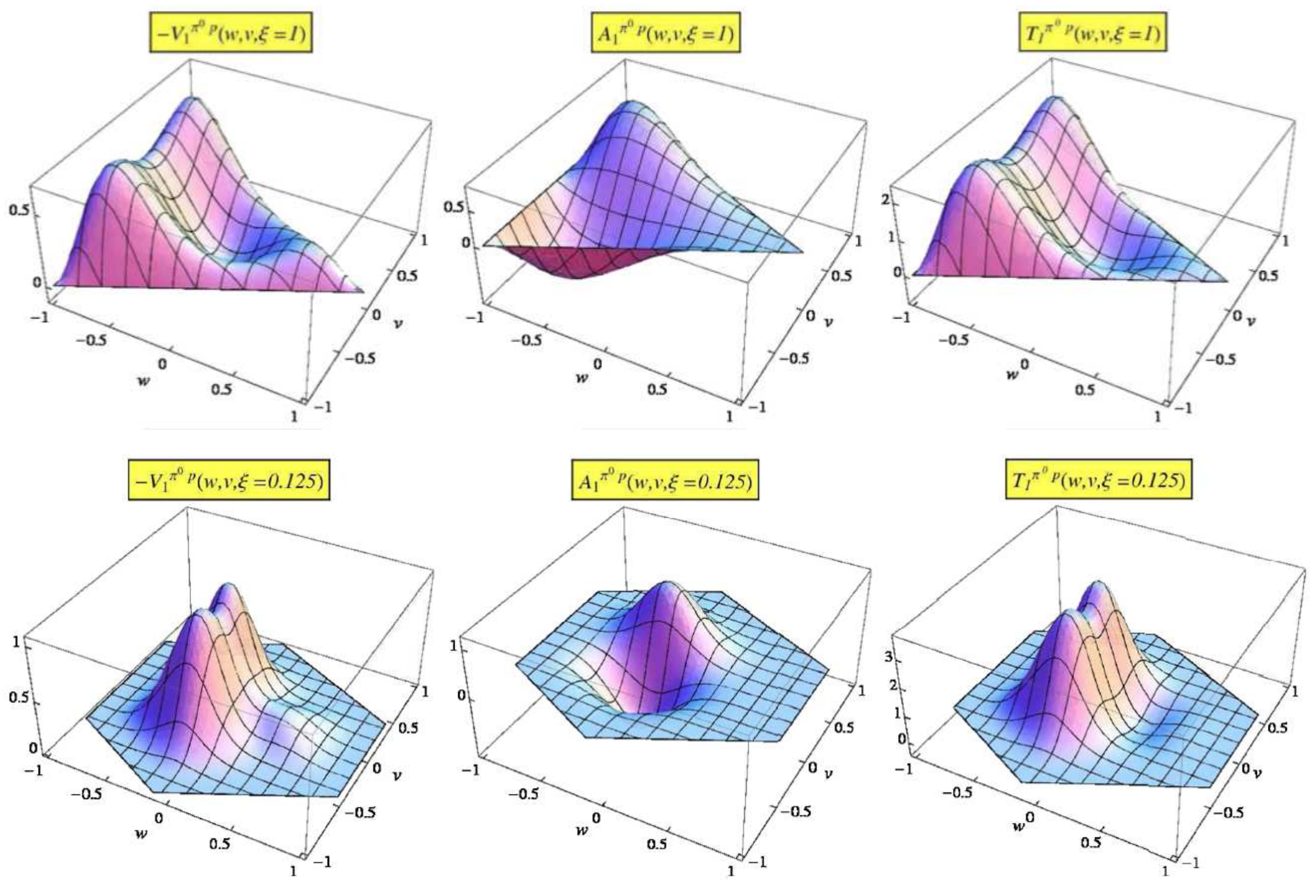
J.P. Lansberg et al., PRD **85** (2012) 054201

Garth Huber, huberg@uregina.ca

π^0p TDAs as functions of q–diquark coordinates

$$w = \xi_u - x_3;\ \ v = \frac{x_1 - x_2}{2}$$





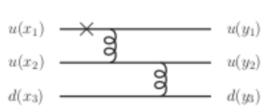
Garth Huber, huberg@uregina.ca

TDA Meson Production Cross Section

- Unpolarized exclusive π^0 production cross section:

$$\frac{d^2\sigma_T}{d\Omega_\pi} = |\mathcal{C}^2| \, \frac{1}{Q^6} \, \frac{\Lambda(s, m^2, M^2)}{128\,\pi^2 s(s-M^2)} \, \frac{1+\xi}{\xi} \left(|\mathcal{I}|^2 - \frac{\Delta_T^2}{M^2}|\mathcal{I}'|^2\right)$$

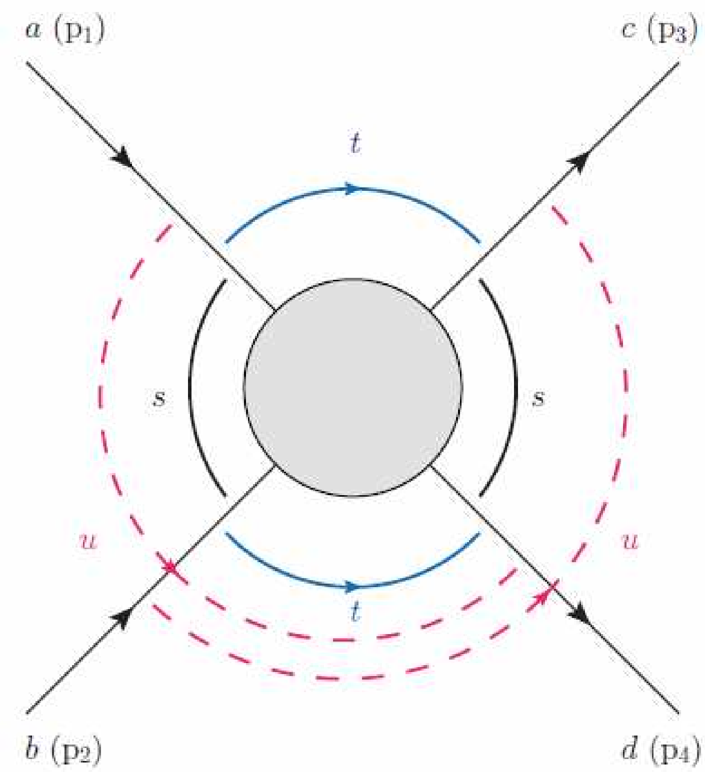
$$\mathcal{I} = \int \left(2\sum_{\alpha=1}^{7} T_\alpha + \sum_{\alpha=8}^{14} T_\alpha \right) \qquad \mathcal{I}' = \int \left(2\sum_{\alpha=1}^{7} T'_\alpha + \sum_{\alpha=8}^{14} T'_\alpha \right)$$

α		T_α	T'_α
1		$\frac{-Q_u(2\xi)^2[(V_1^{p\pi^0}-A_1^{p\pi^0})(V^p-A^p)+4T_1^{p\pi^0}T^p+2\frac{\Delta_T^2}{M^2}T_4^{p\pi^0}T^p]}{(2\xi-x_1-i\epsilon)^2(x_3-i\epsilon)(1-y_1)^2 y_3}$	$\frac{-Q_u(2\xi)^2[(V_2^{p\pi^0}-A_2^{p\pi^0})(V^p-A^p)+2(T_2^{p\pi^0}+T_3^{p\pi^0})T^p]}{(2\xi-x_1-i\epsilon)^2(x_3-i\epsilon)(1-y_1)^2 y_3}$

J. P. Lansberg, B. Pire, K. Semenov-Tian-Shansky, L. Szymananovski, Phys. Rev. D **85** (2011) 054021

Garth Huber, huberg@uregina.ca

Mandelstam variables (*s,t,u*–channels)



$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$

s: invariant mass of the system

t: Four–momentum–transfer squared between **target before and after interaction.**

u: Four–momentum–transfer squared between **virtual photon before interaction and target after interaction**

***t*-channel*: –t ~ 0*, after interaction**
- **Target: stationary,**
- **Meson: forward**
- **Measure of how forward could the meson go.**

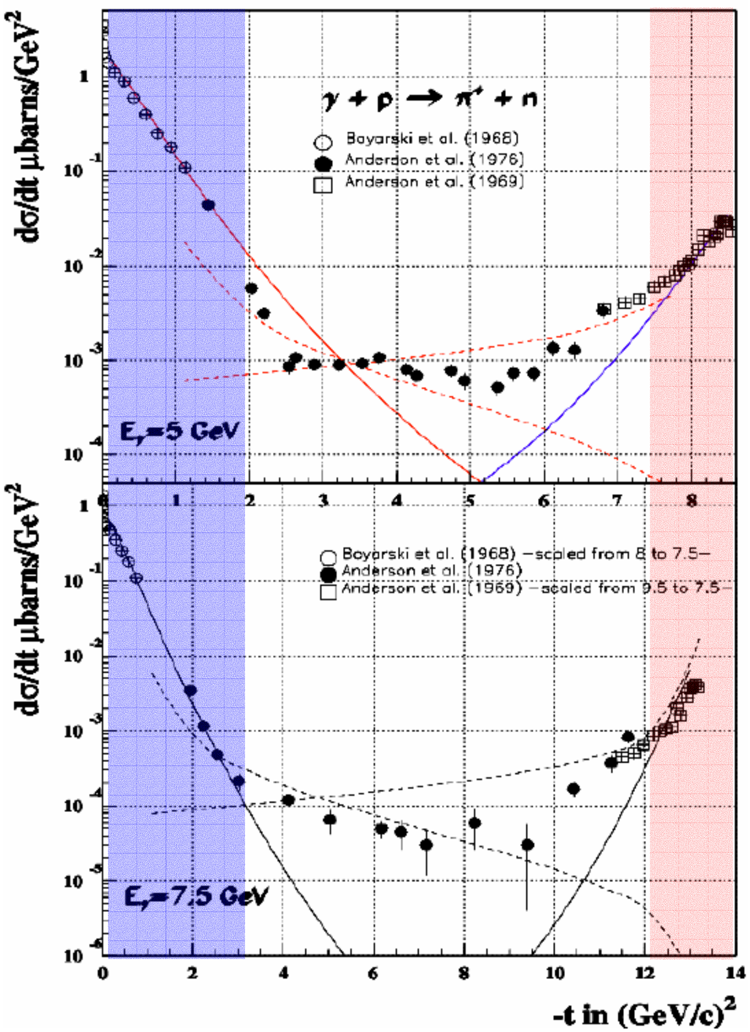
***u*-channel: *–u~0,* after interaction**
- **Target: forward**
- **Meson: stationary**
- **Measure of how backward could the the meson go**

Garth Huber, huberg@uregina.ca

Backward Angle Omega Electroproduction Peak

Garth Huber, huberg@uregina.ca

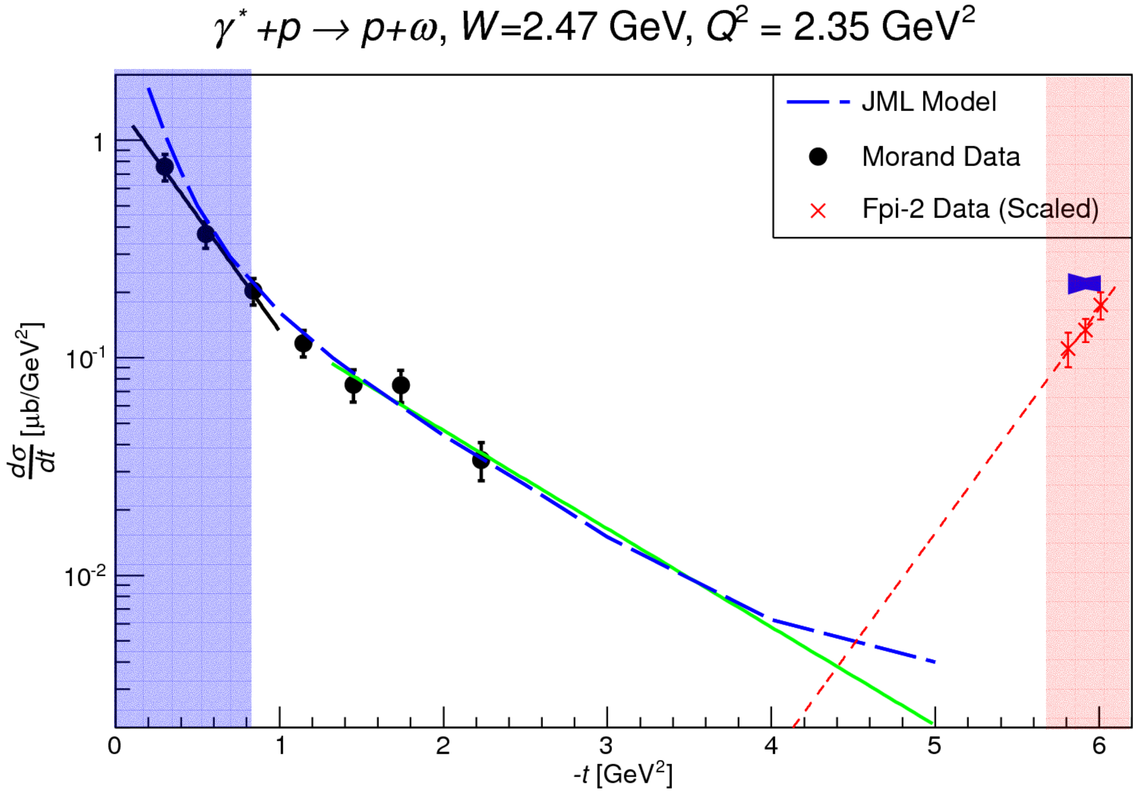
Photoproduction



M. Guidal, J.–M. Laget, M. Vanderhaeghen, PLB **400**(1997)6

First observation of backward angle peak in electroproduction!

$\gamma^* + p \rightarrow p + \omega$, W=2.47 GeV, Q^2 = 2.35 GeV^2

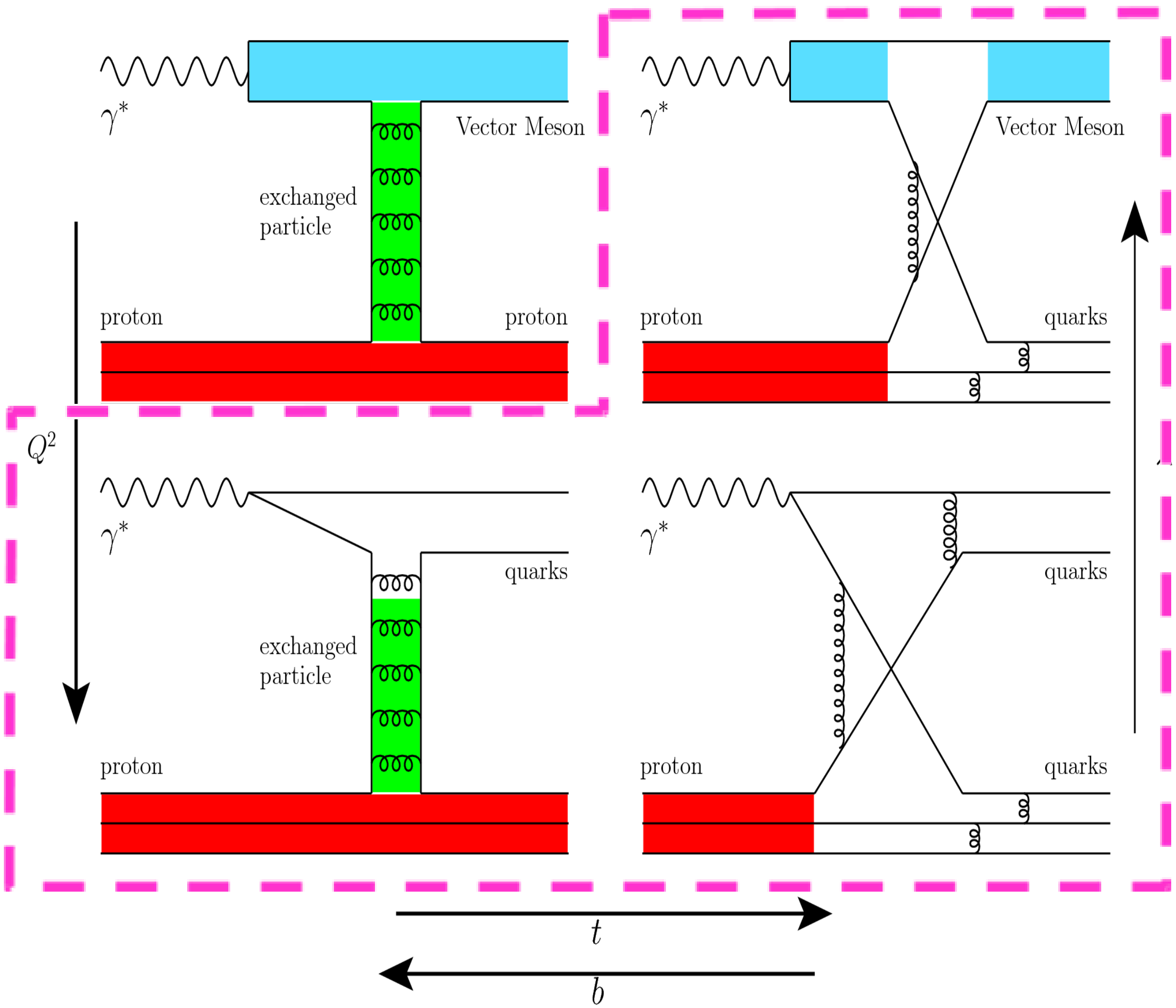


Hall C data are scaled to match kinematics of Hall B data

	W (GeV)	x_B	Q^2 (GeV^2)	$-t$ (GeV^2)	$-u$ (GeV^2)
Hall B	1.8 – 2.8	0.16 – 0.64	1.6 –5.1	< 2.7	> 1.68
Fπ–2	2.21	0.29	1.6	4.014	0.08 – 0.13
		0.38	2.45	4.724	0.17 – 0.24

Evolution of Proton Structure

Garth Huber, huberg@uregina.ca



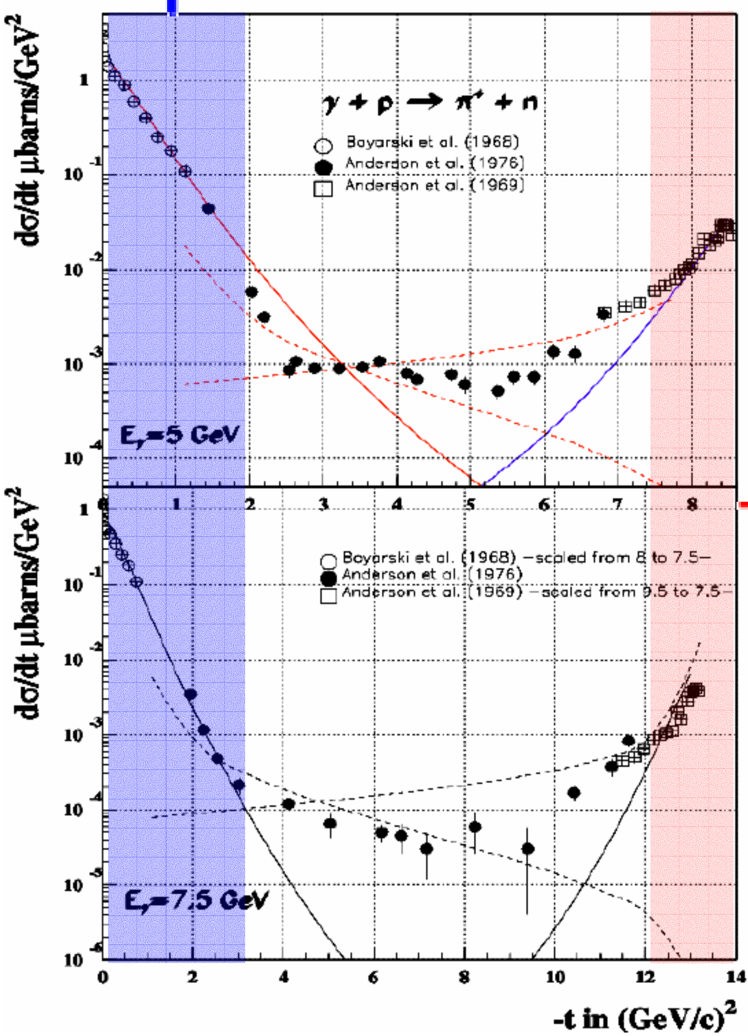
Evolution of the Proton Structure

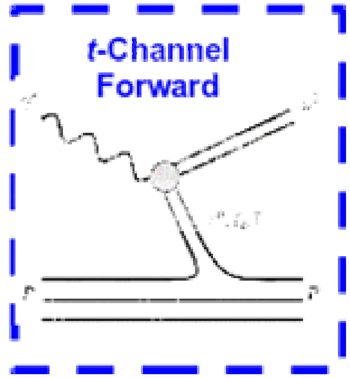
- Physics observables
  - ***t*, *W* (*s*), *Q*², *x***
- *x* Evolution:
  - 0.2–0.3 valence quark distribution is pronounced
- *W* Evolution:
  - Above the resonance region
- ***Q*² Evolution**
  - **Wavelength of the probe**
- ***t* Evolution**
  - **Impact parameter**
- What about ***u***?
  - **Physical interpretation unclear**

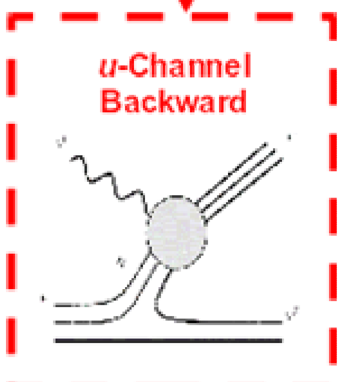
Hadronic Model: Regge Model by JM Laget

Garth Huber, huberg@uregina.ca

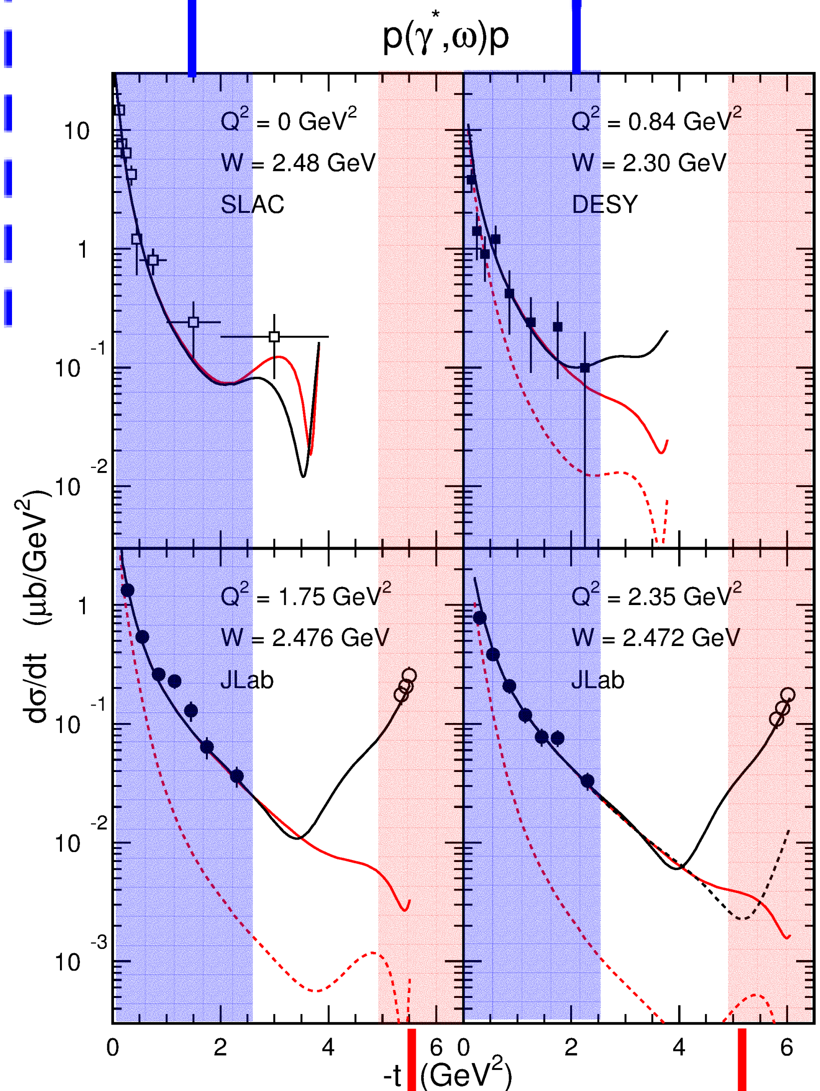
M. Guidal, J.-M. Laget, M. Vanderhaeghen, PLB **400**(1997)6







J.-M. Laget, Private Communication (2018)



Soft structure → Hard → Soft transition!

Future Opportunities

Table 8.1: Table of merit of potential opportunities of studying backward and large emission angle meson production and theory prediction availability [102, 103]. * indicates large emission angle (high $-t$) meson production experiments.

	F_π-2	F_π-12	Hall C π^0	E12-12-007*	$\overline{\text{P}}$ANDA	Regge	TDA
π^0			✓		✓		
η				✓			
ρ							
ω	✓	✓					✓
η'							
ϕ		✓		✓			✓
Facility	JLab Hall C	JLab Hall C	JLab Hall C	JLab Hall B	GSI		

Garth Huber, huberg@uregina.ca