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

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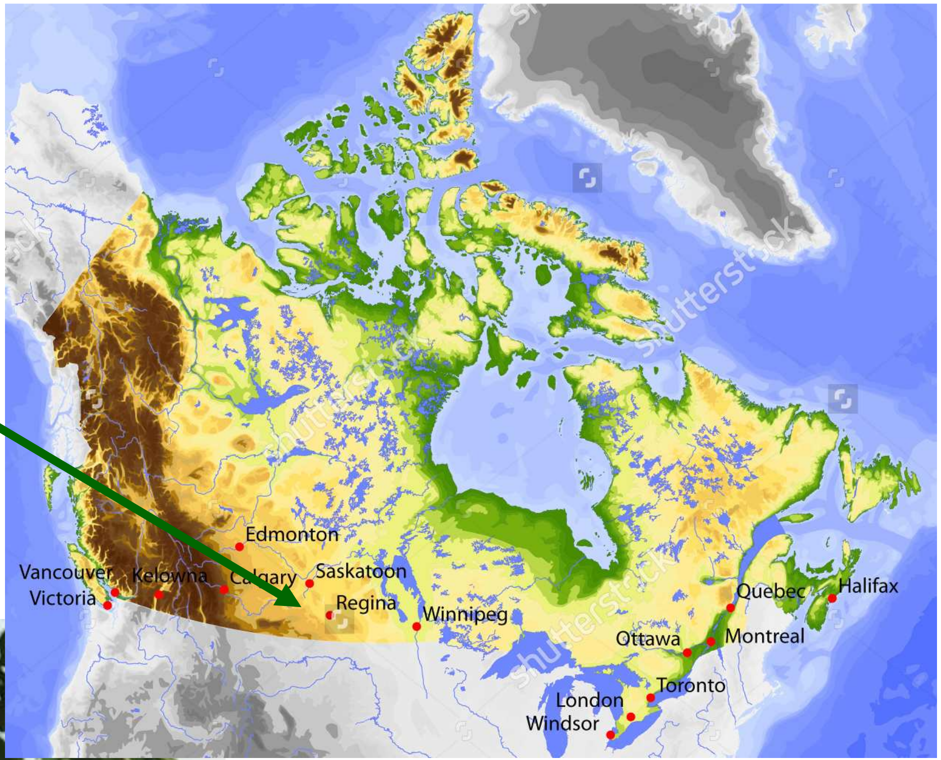

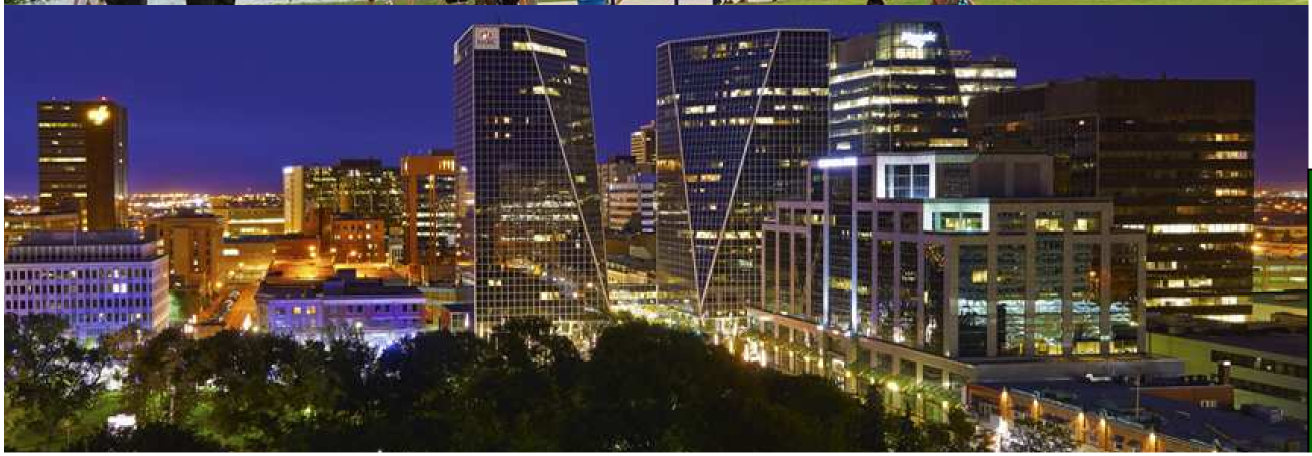

Regina is named after Queen Victoria, and is capital of the province of Saskatchewan

- **Founded 1974**
- **16,501 students, incl. 2,024 Grad Students (Sept 2019)**
- **Physics Dept. offers B.Sc., M.Sc. and Ph.D. degrees**

Jefferson Lab Fπ Collaboration

Physical Review Letters (in press), arXiv: 1910.00464

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

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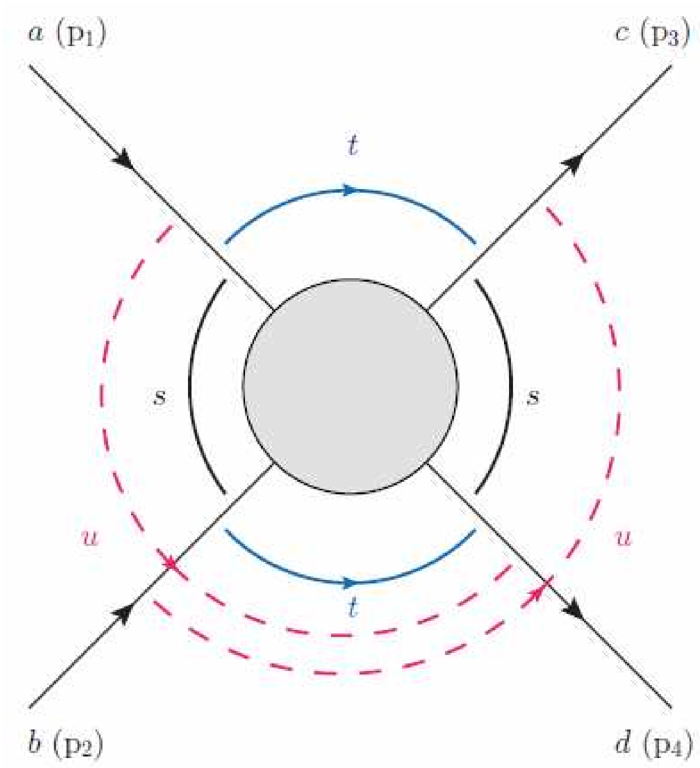


$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

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

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

s: invariant mass of the system

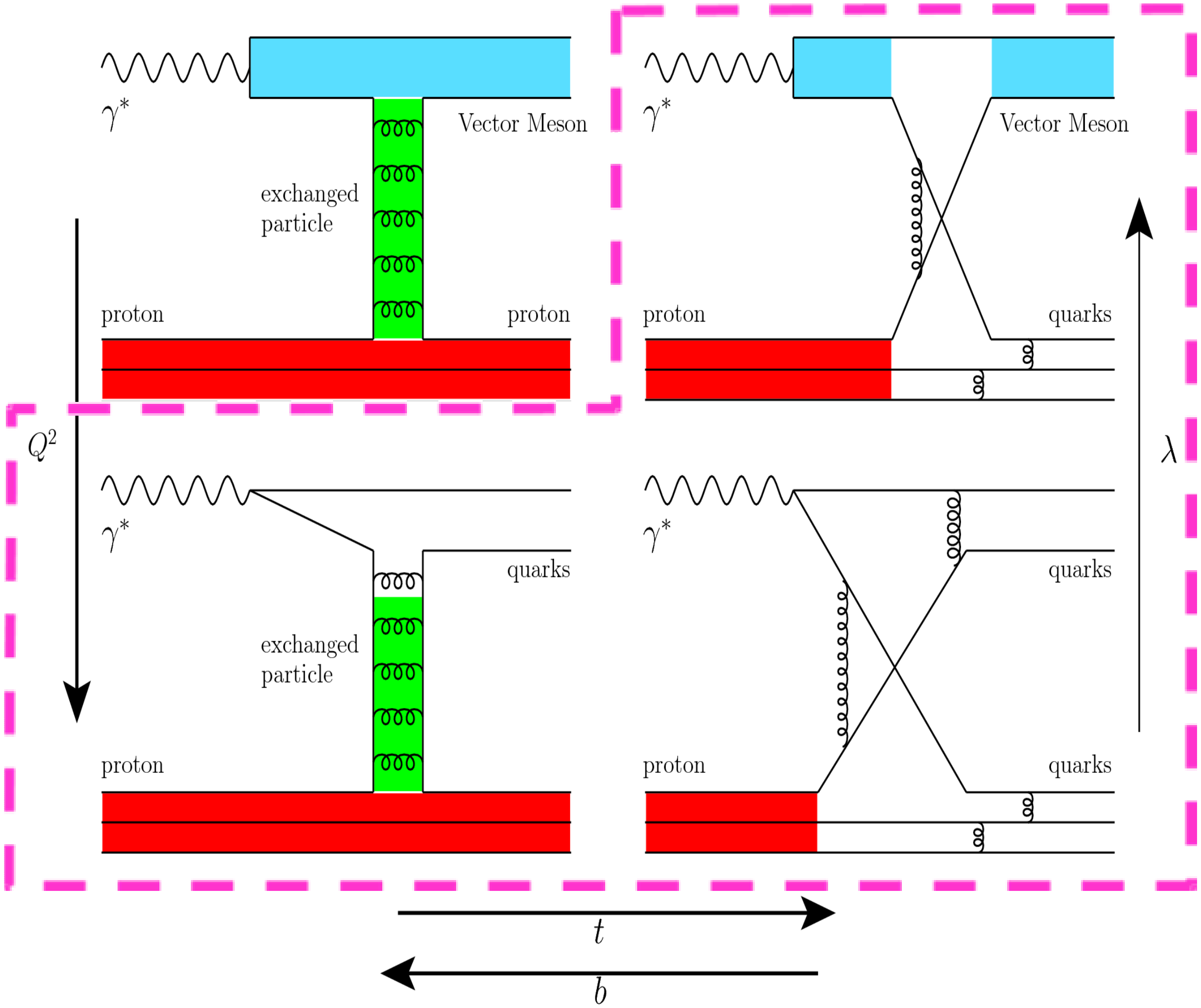
t: Four–momentum–transfer squared between **target before and after interaction**

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 meson go**

Evolution of Proton Structure



Evolution of the Proton Structure

- Physics observables
  - ***t*, *W* (*s*), *Q*²**, ***x*** (t, W (s), Q^2, x)
- *x* Evolution:
  - 0.2–0.3 valence quark distribution pronounced
- *W* Evolution:
  - Above resonance region
- **Q^2 Evolution**
  - **Wavelength of γ^* probe**
- ***t* Evolution**
  - **Impact parameter** $\left(b \sim 1/\sqrt{-t}\right)$
- What about ***u***?
  - **Baryon exchange processes**

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

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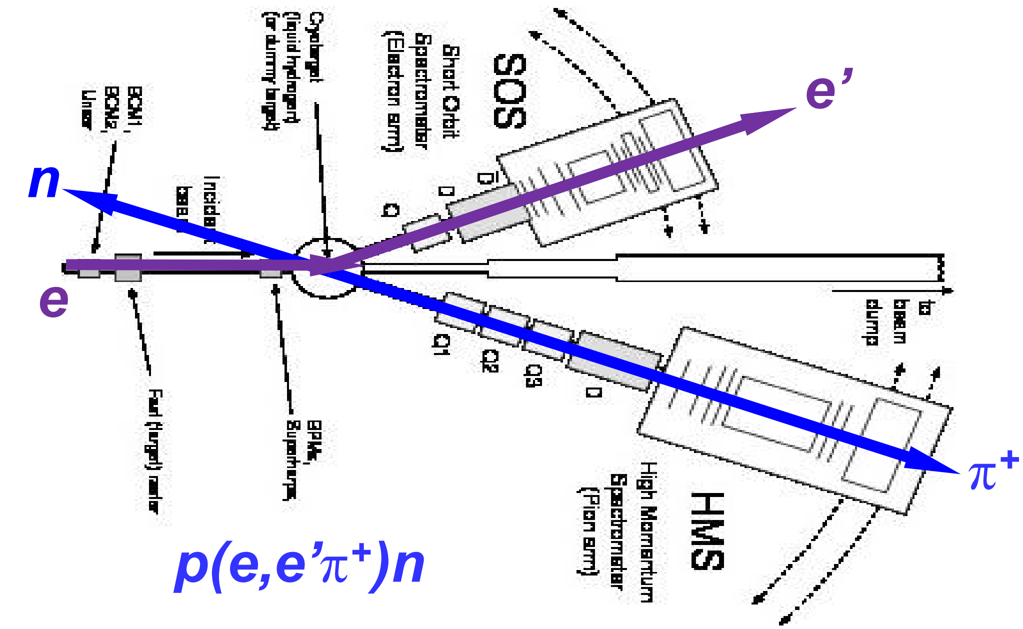
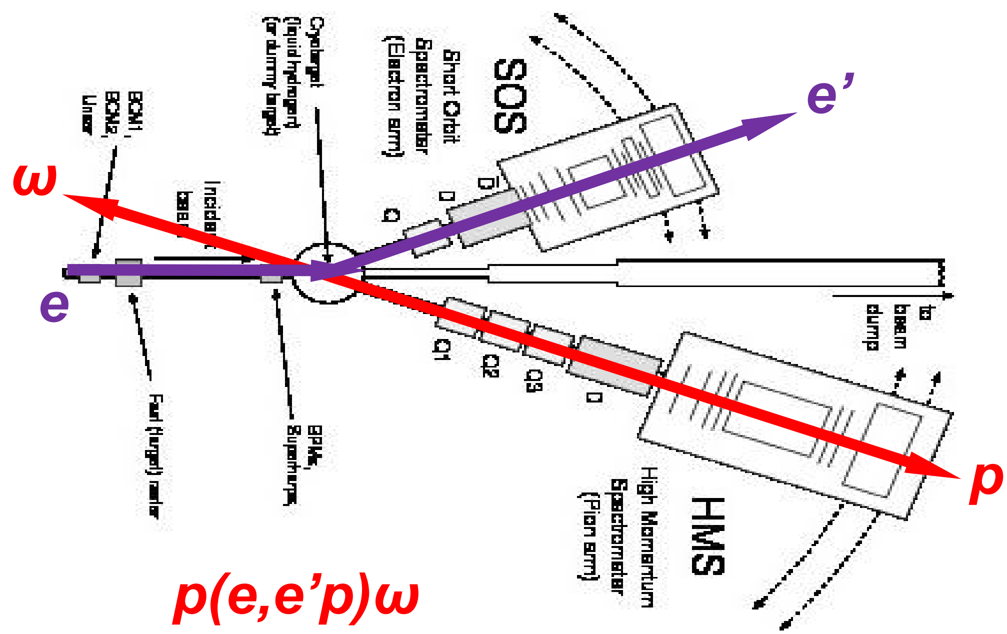


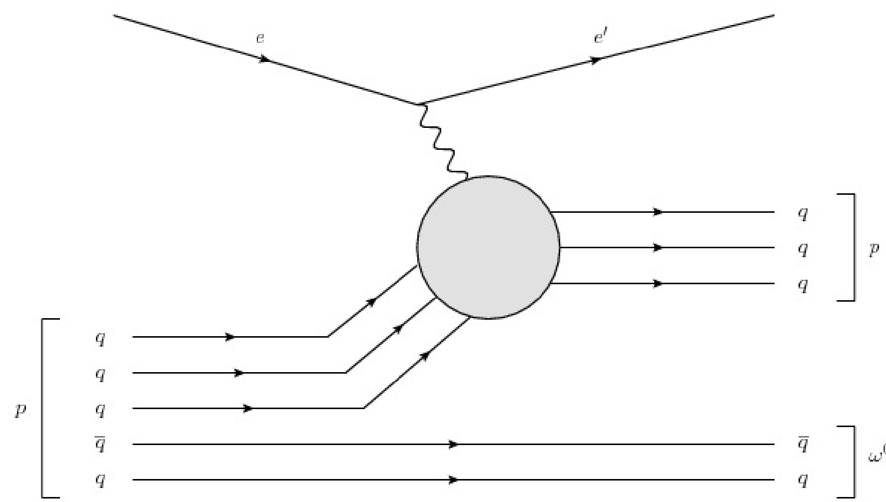


HMS is along q–vector ($p_{\gamma*}$)

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

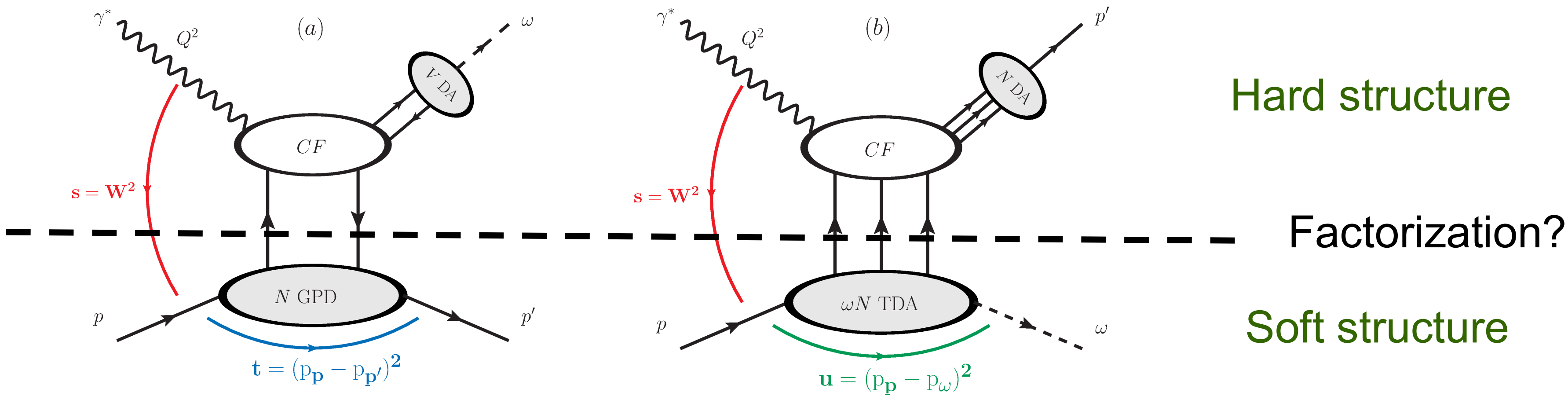
p(e,e'p)ω **Exclusive channel**

- 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.**

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

- **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 $\Delta^u_T \approx (p_\omega - p_1)_T$

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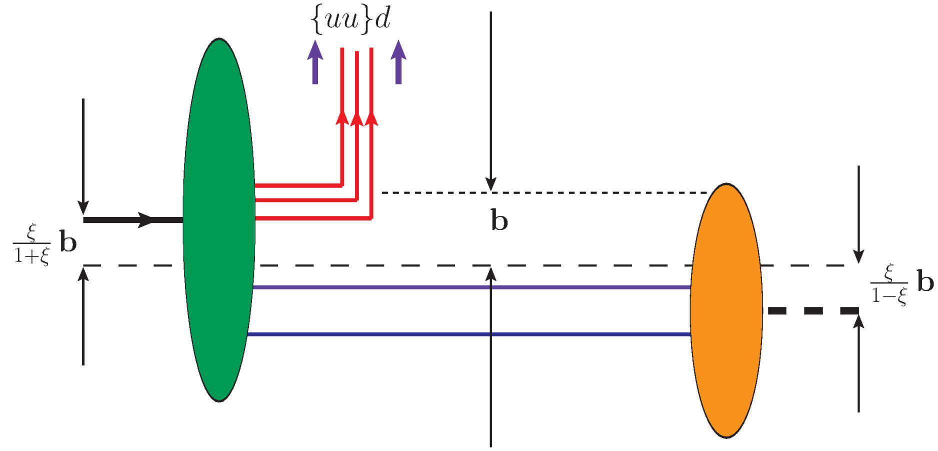
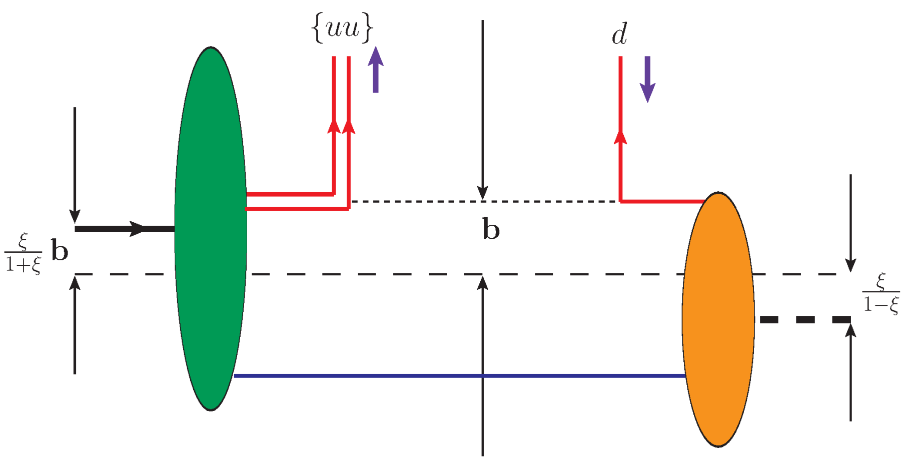
Impact parameter Interpretation of TDA

- After integrating over one momentum fraction x_i, the three exchanged quarks can be treated as an effective diquark+quark pair
- Impact picture then looks very much like that for GPDs



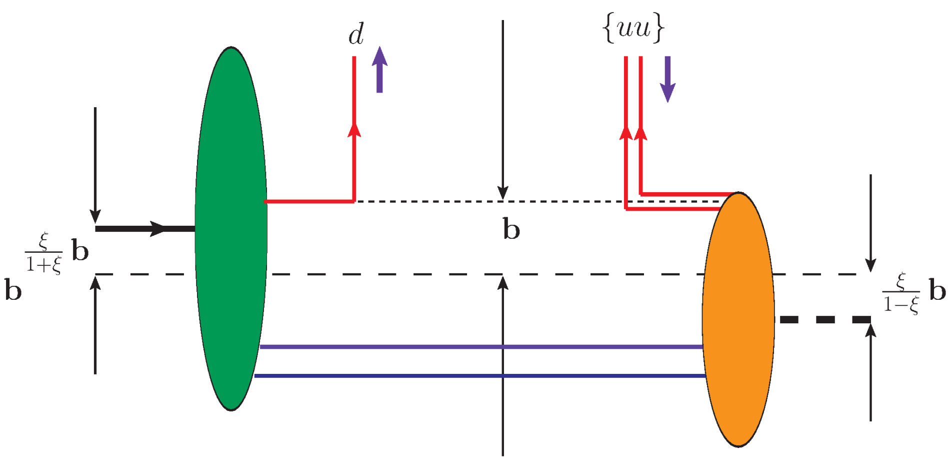
$\text{ERBL}: \quad x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$

$\longrightarrow$ All 3 quark momentum fractions x_i positive



$\text{DGLAP I}: \quad x_3 = w_3 - \xi \leq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$

$\longrightarrow$ One x_i negative



$\text{DGLAP II}: \quad x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \leq 0;$

$\longrightarrow$ Two x_i negative

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TDA Formalism (e.g. u–channel π^0)

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- Fourier transform of the πN transition matrix element

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

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

Factorization scale

- πN TDA invariant amplitudes (**eight TDAs at leading twist**)

$$H^{\pi N}_{s.f.} = \{V^{\pi N}_{1,2}, A^{\pi N}_{1,2}, T^{\pi N}_{1,2,3,4}\}$$

- Factorizing out the u–dependence:

meson to nucleon transition form factor

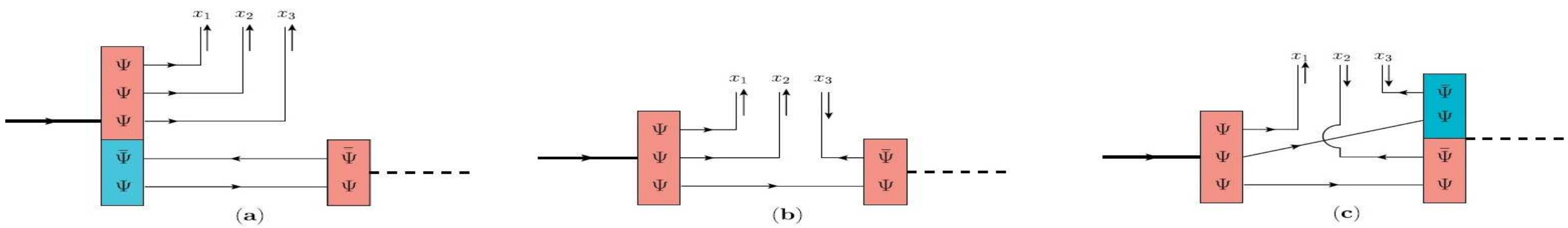
$$H^{\pi N}(x, \xi_u, \Delta^2) = H^{\pi N}(x_i, \xi_u) \times \boxed{G(\Delta^2)} \qquad \boldsymbol{\Delta^2 = u}$$

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

Partonic Interpretation of TDA

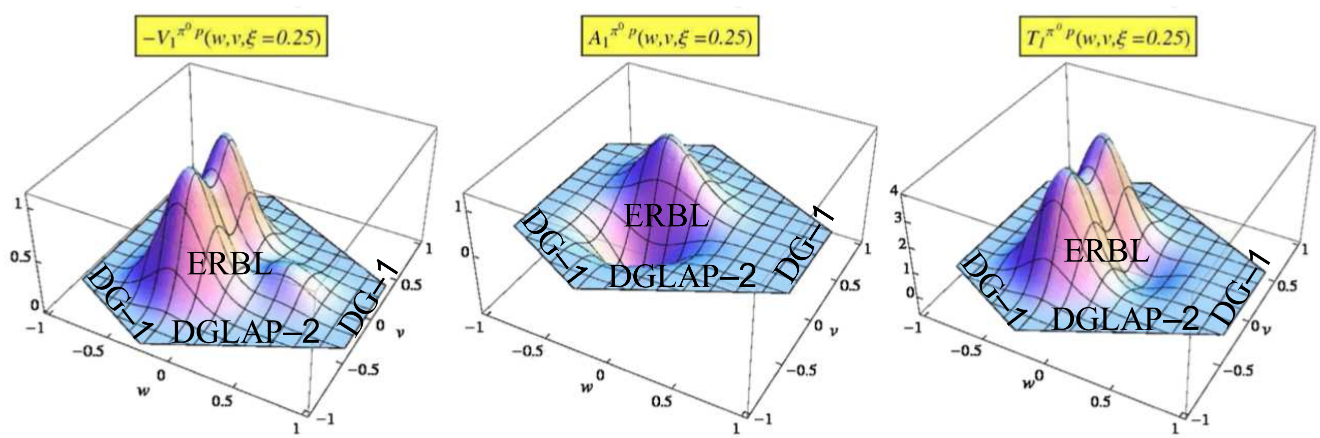
Main reactions of interest to date:

- 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)
b) Minimal Fock states of baryon & meson (DGLAP–1) region
c) Quark sea contribution to meson wf (DGLAP–2)



$v = (x_1 - x_2)/2$
$w = (x_3 - x_1 - x_2)/2$

$\pi^0 p$ 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

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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

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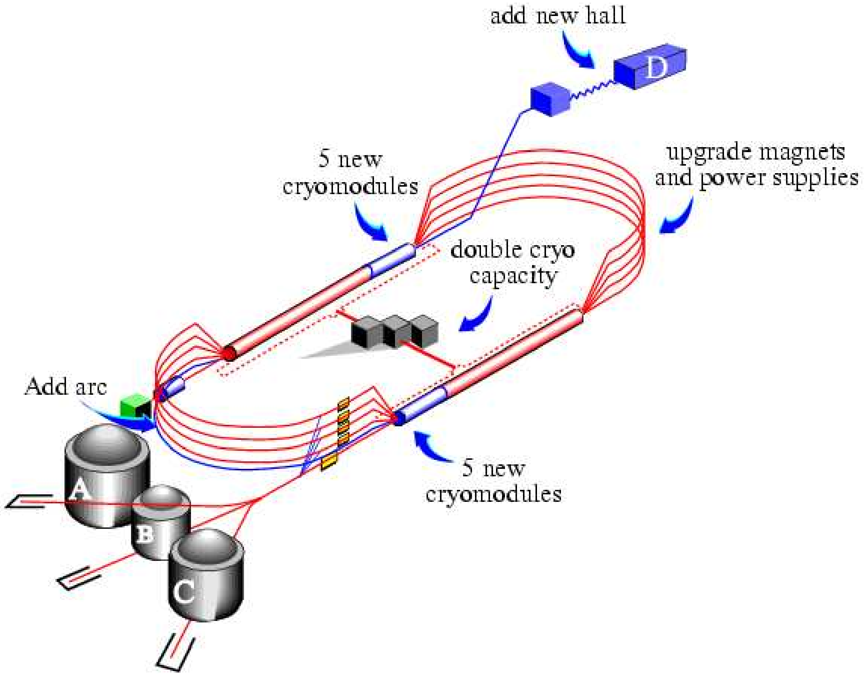
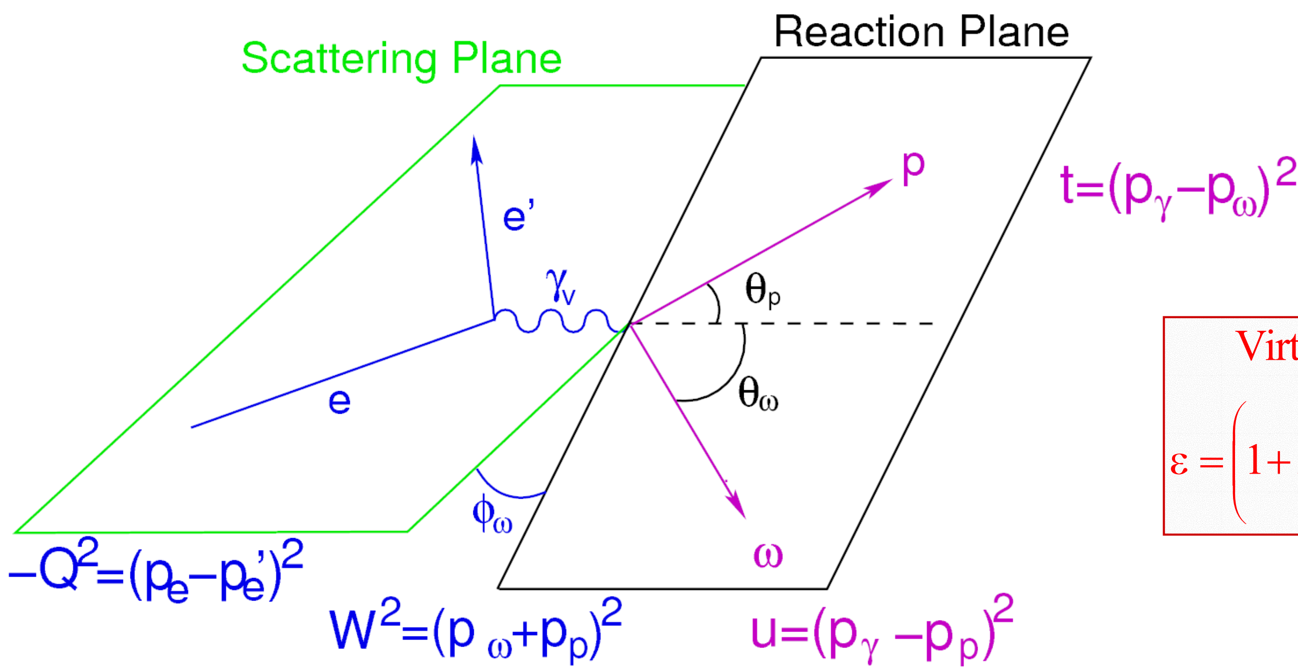


Two 1.5 GHz Superconducting Linear Accelerators provide electron beam for Nucleon & Nuclear structure studies.

- **Beam energy E $\rightarrow$ 12 GeV.**
- **Beam current >100 μA.**
- **Duty factor 100%, 85% polarization.**
- Experiments in all 4 Halls can receive beam simultaneously.

Rosenbluth (L/T/LT/TT) Separation



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

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Jefferson Lab Hall C Experimental Setup

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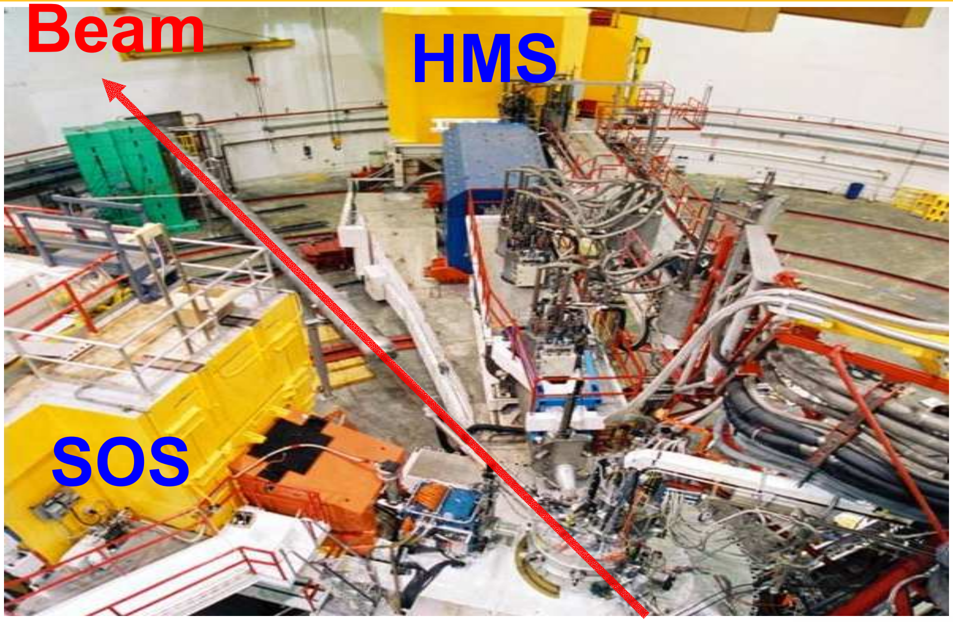
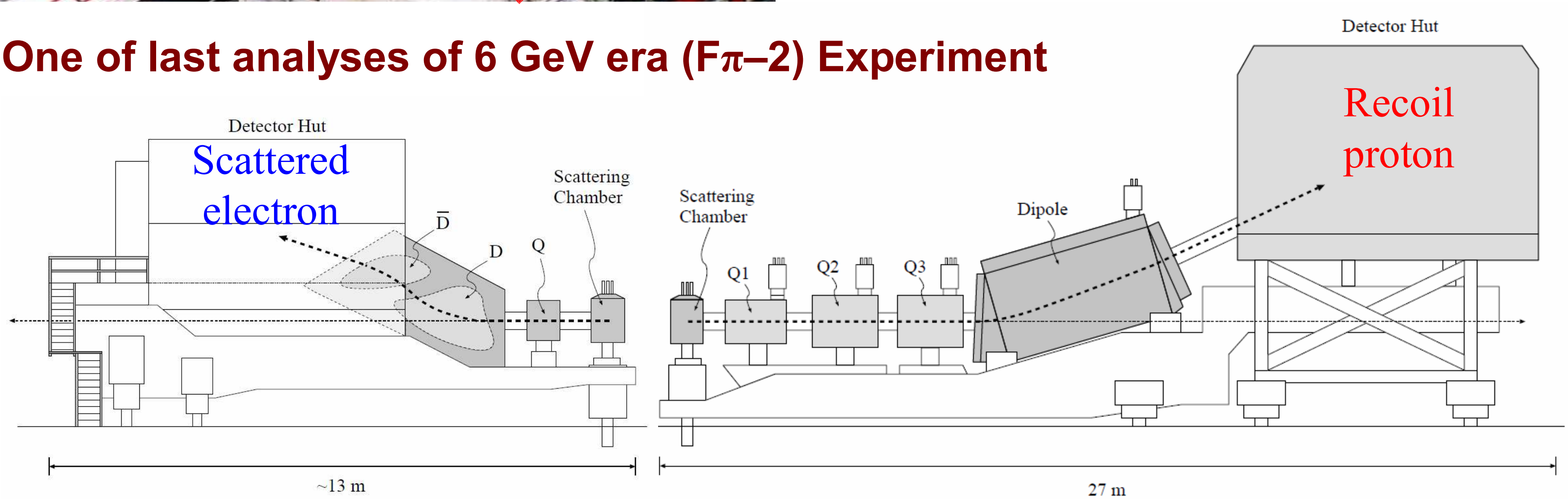


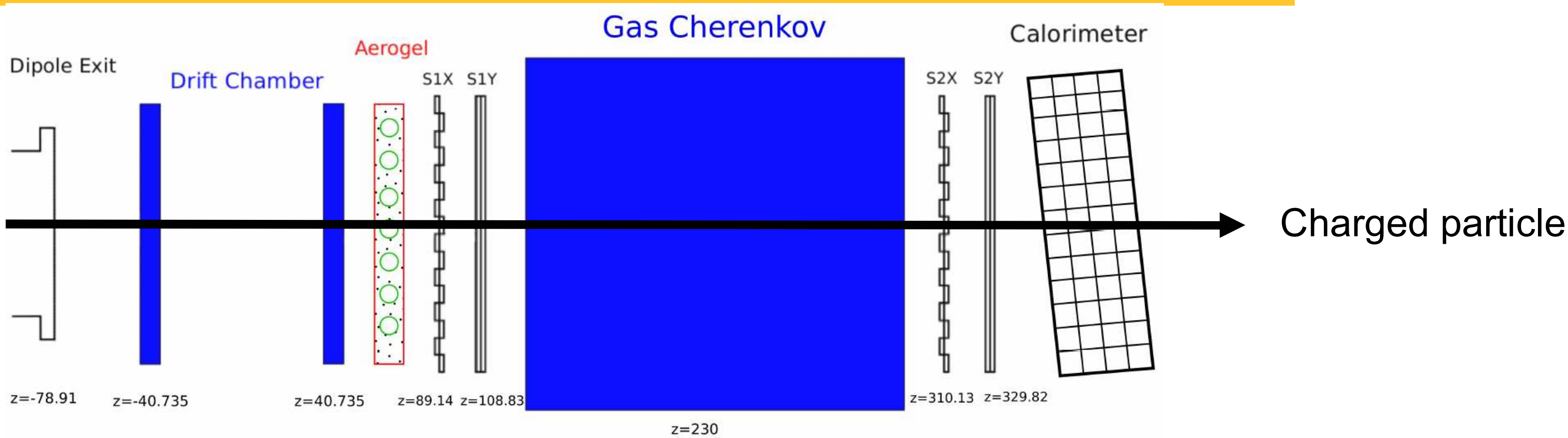
E_e (GeV)	ε	$-u$ (GeV^2)	$-t$ (GeV^2)	ξ_u	ξ_t
$\langle Q^2 \rangle$=1.60 GeV^2 $\langle W \rangle$=2.21 GeV					
3.772	0.328	0.058 – 0.245	3.85 – 4.15	0.075 – 0.177	0.722 – 0.735
4.702	0.593				
$\langle Q^2 \rangle$=2.45 GeV^2 $\langle W \rangle$=2.21 GeV					
4.210	0.270	0.117 – 0.400	4.48 – 4.94	0.126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

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

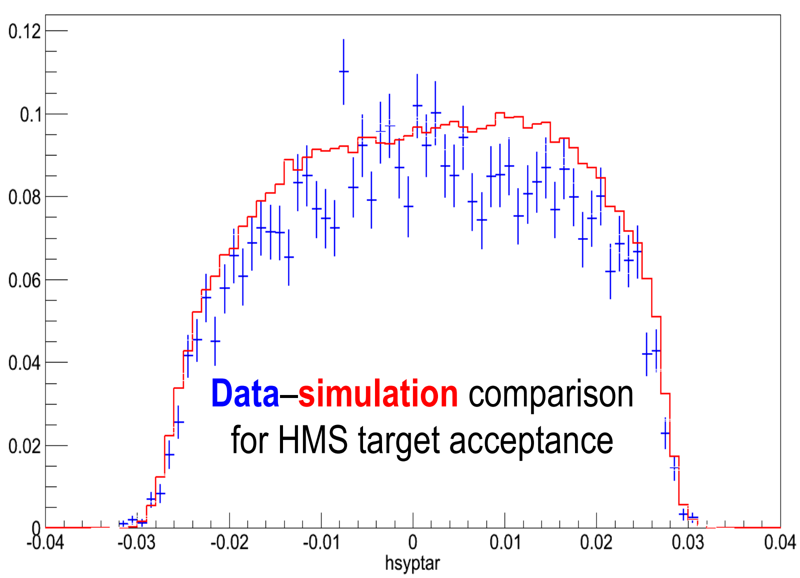


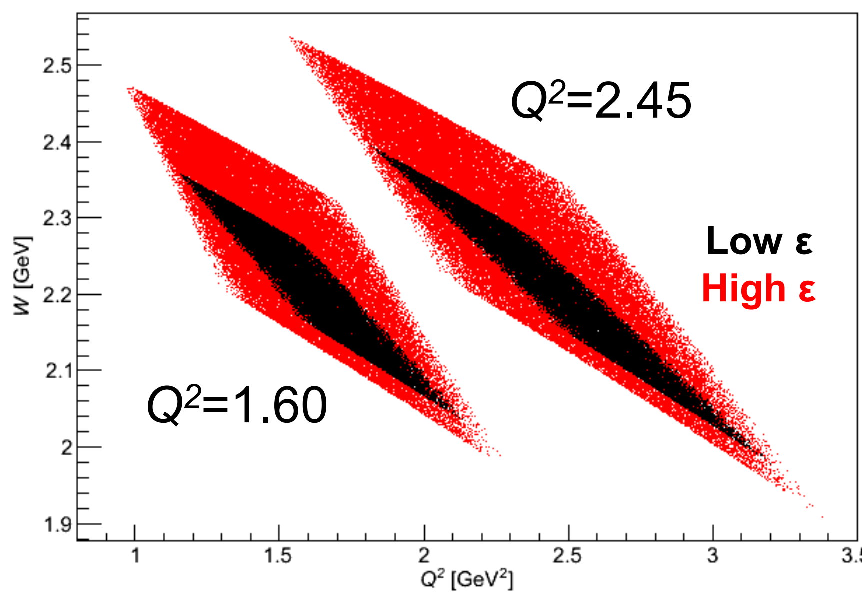
Short Orbit Spectrometer (SOS) High Momentum Spectrometer (HMS)

Experimental Setup and Acceptance



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





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Particle Identification

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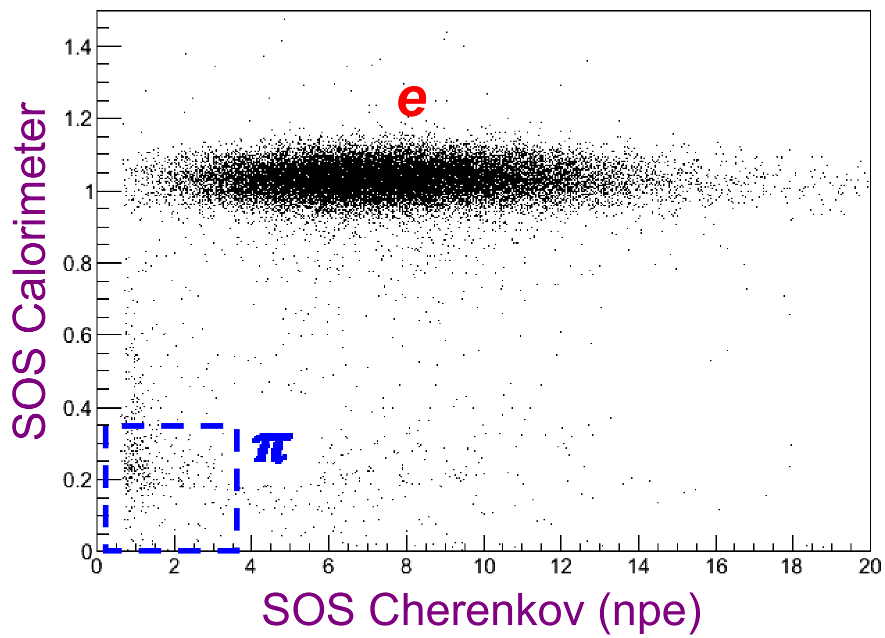
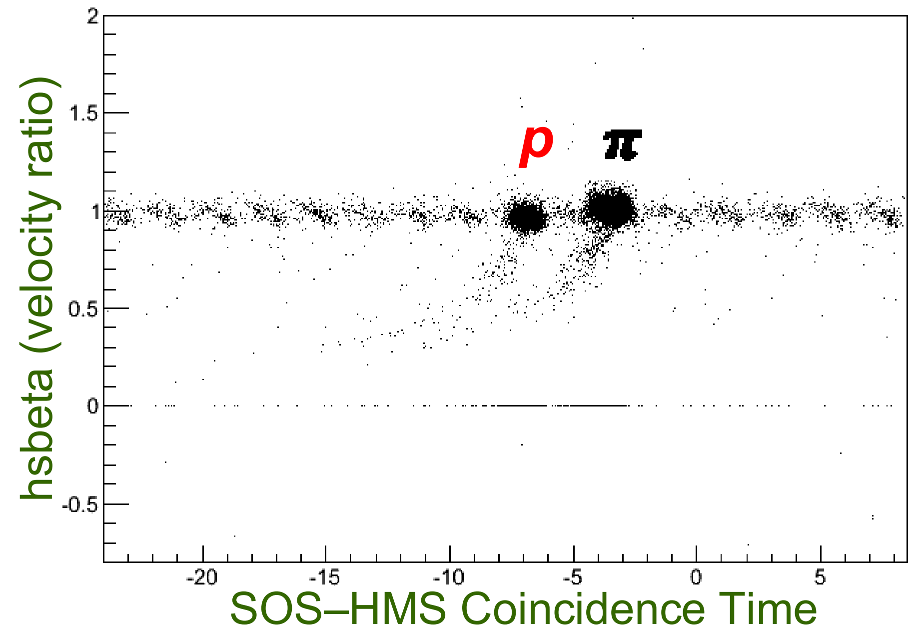




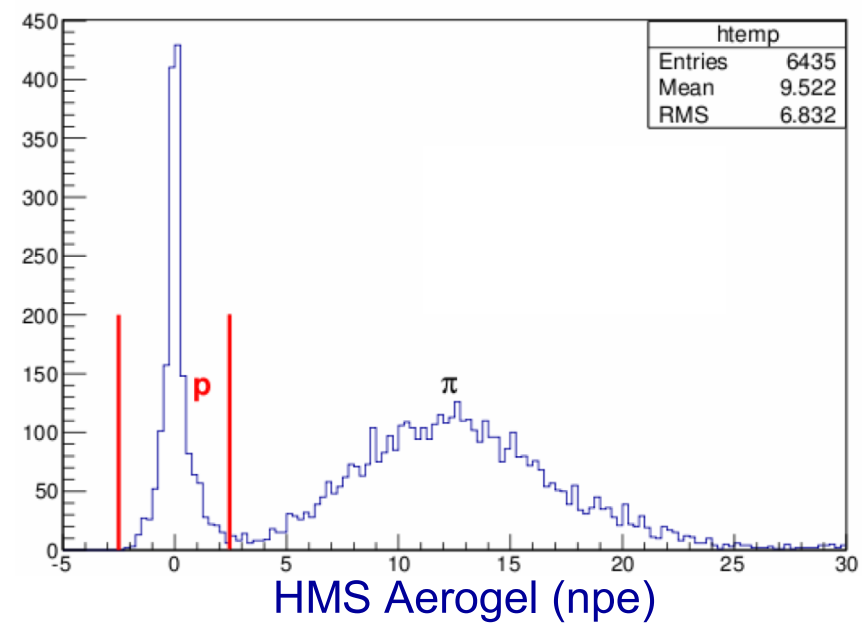
SOS: select electron

- Calorimeter cut
- Cherenkov cut

~99% efficiency

HMS: select proton

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



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Coincidence Time Selection

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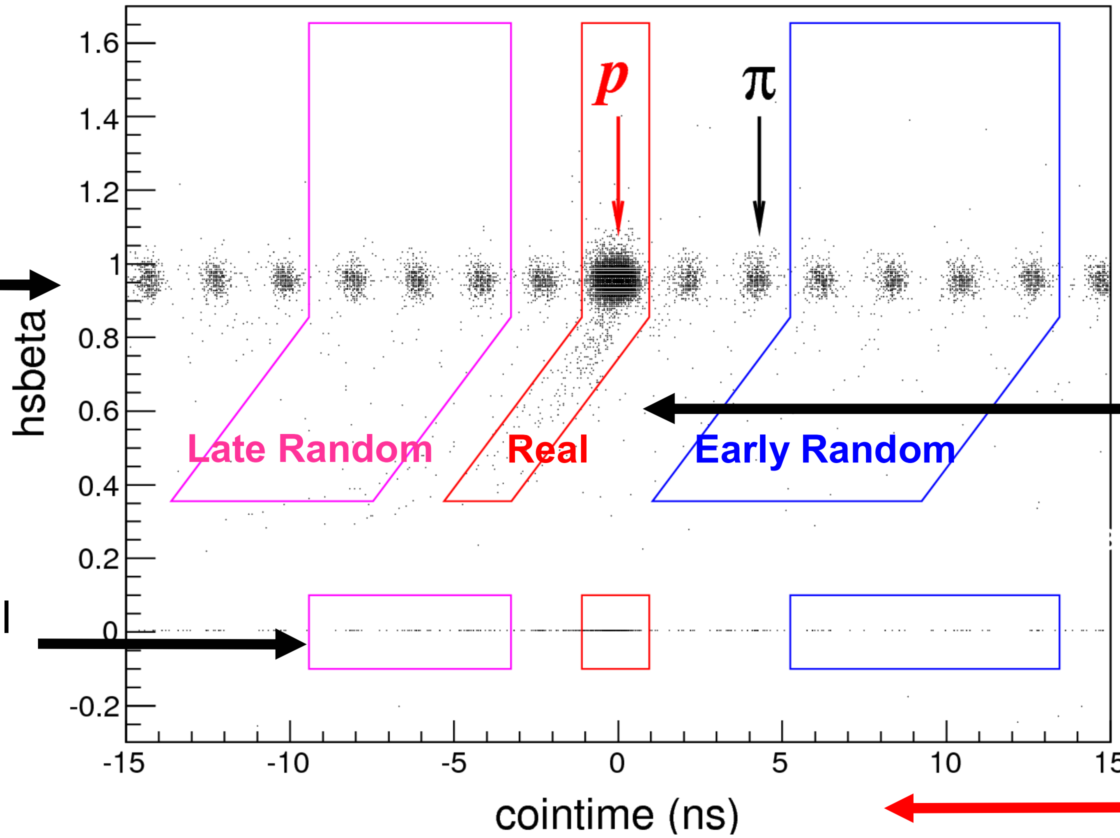
Blob: Good events

β=0: Events missing fiducial cut during reconstruction



Tail: Multiple scattering contribution

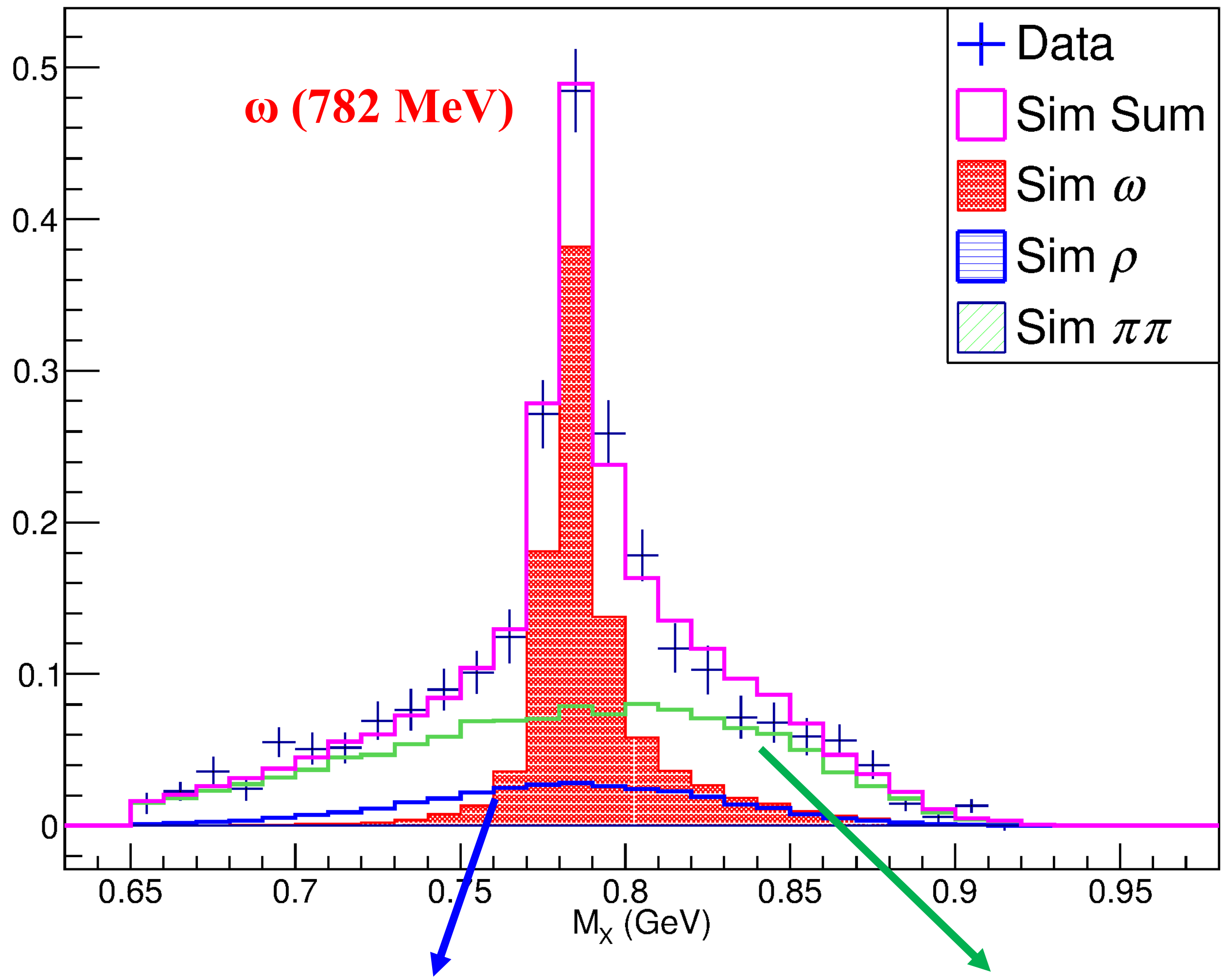
- **Random subtraction:**

$$\text{Coincidence proton} = \text{Real Events} - \left(\frac{\text{Late Random Events} + \text{Early Random Events}}{7}\right)$$

- **Missing proton due to scattering, absorption: ~7%**

Physics Background Subtraction

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



W.B. Li, GMH, et al, Phys. Rev. Lett. (2019) to appear

ρ (770 MeV)
HERMES Empirical parameterization with Soding skewness factor

2π production phase-space

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"Simple" Longitudinal–Transverse Separation

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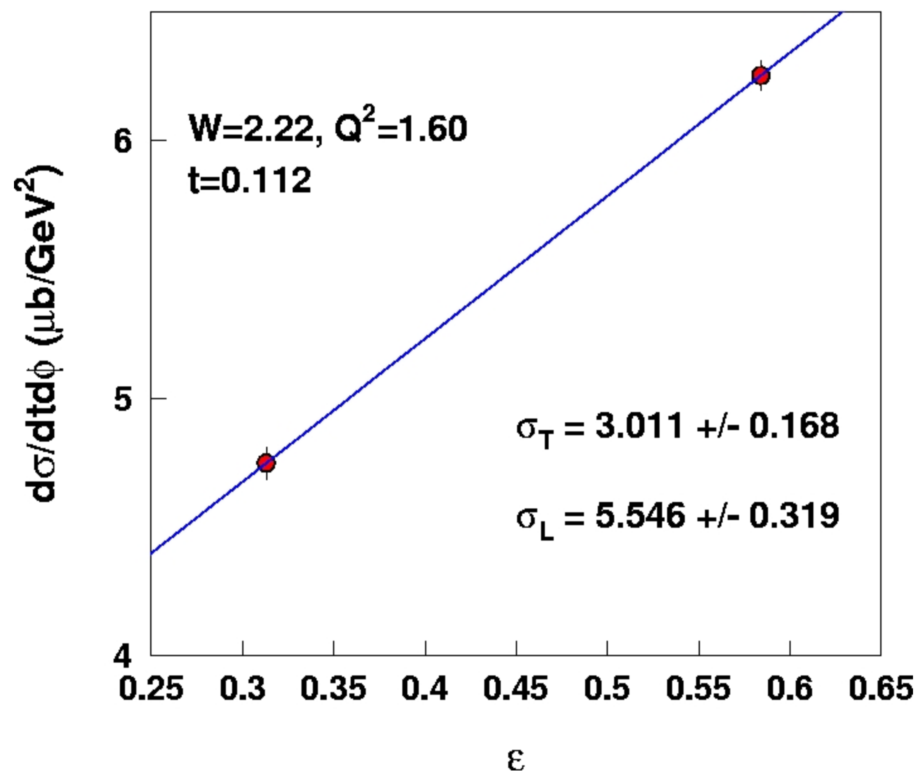
- For uniform φ–acceptance, σ_{TT}, $\sigma_{LT} \rightarrow 0$ when integrated over φ
- Determine $\sigma_T + \varepsilon\,\sigma_L$ for high and low ε in each *u*–bin for each Q^2
- Isolate σ_L, by varying photon polarization, ε



$$\varepsilon = \left[1+2(1+\tau)\tan^2(\theta/2)\right]^{-1}$$

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

"More Realistic" L/T Separation Example

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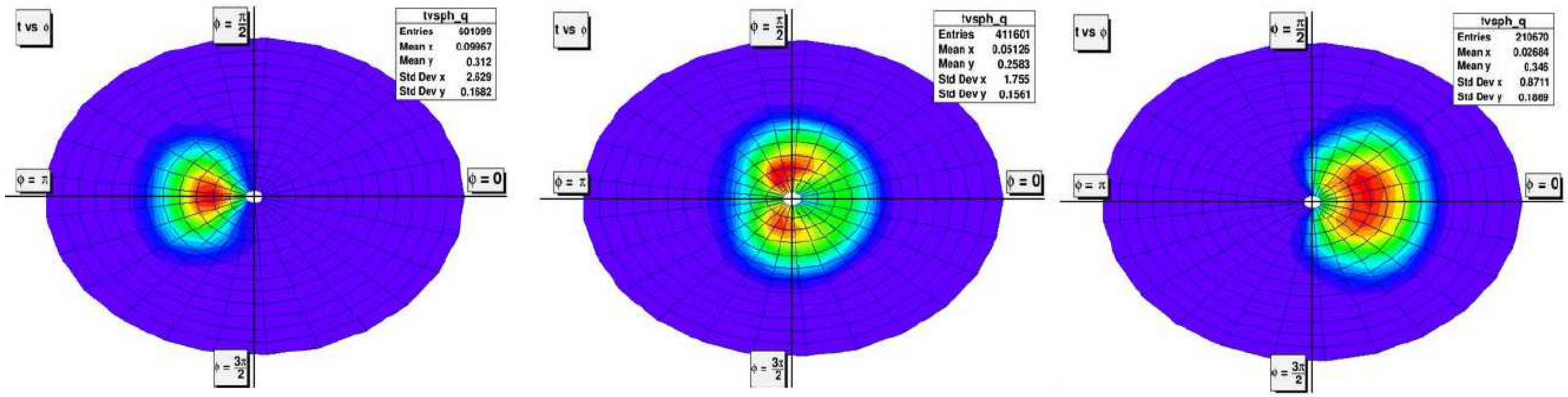
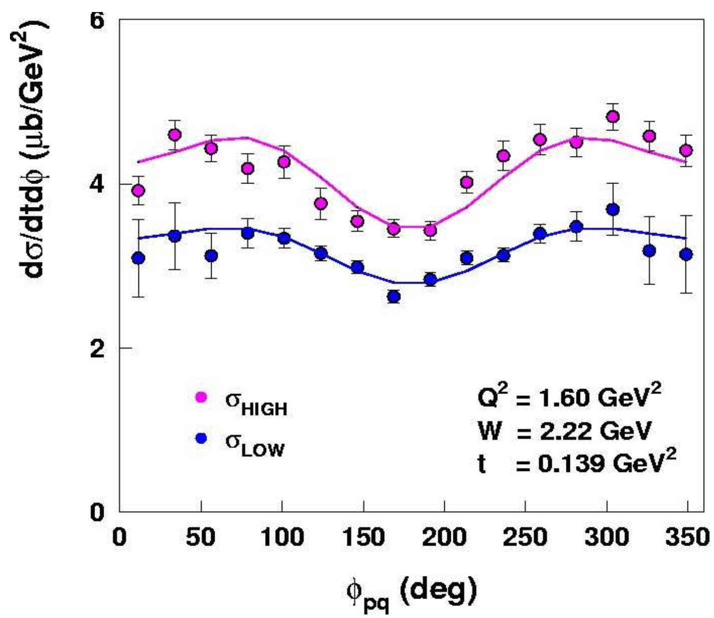
$$2\pi \frac{d^2\sigma}{dt d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)} \frac{d\sigma_{LT}}{dt} \cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$



- **Cross-Section Determination:**
  - In reality, φ acceptance not uniform
  - Must measure σ_{LT} and σ_{TT}
  - Three hadron spectrometer angles needed for full azimuthal (φ_p) coverage to determine the interference terms
- Extract σ_L by simultaneous fit using measured azimuthal angle (φ_π) and knowledge of photon polarization (ε)



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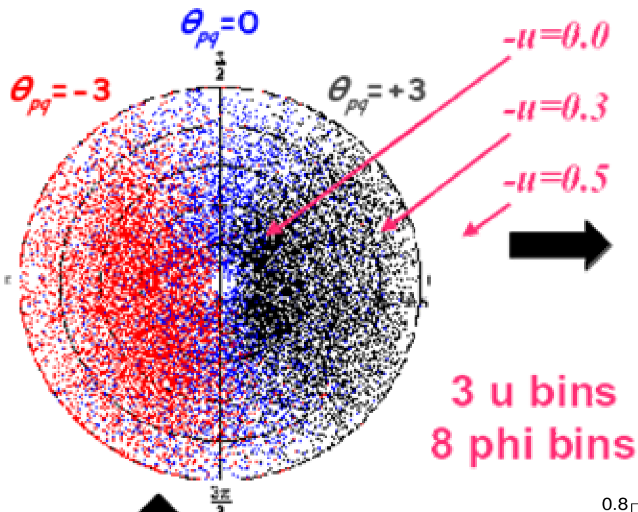
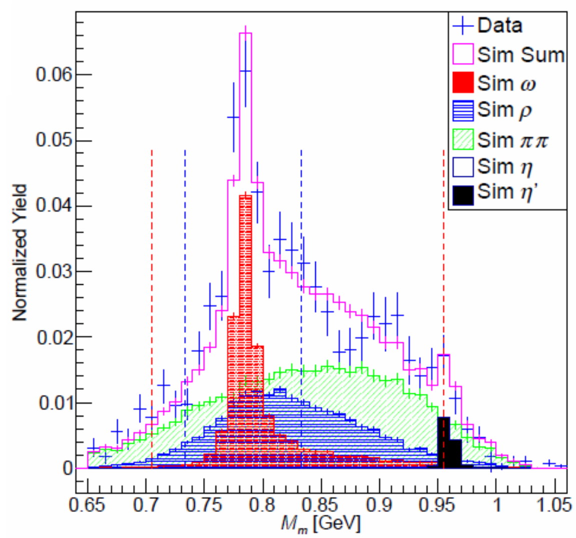
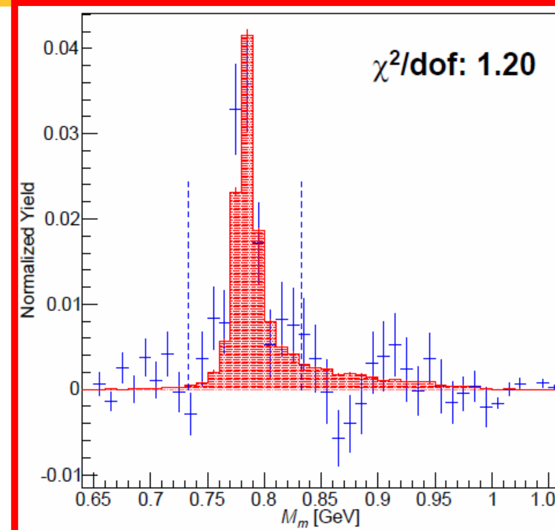
Iterative Procedure for L/T Separation

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





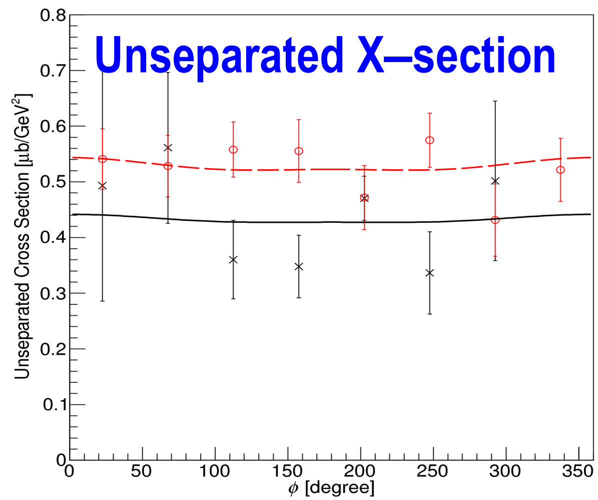


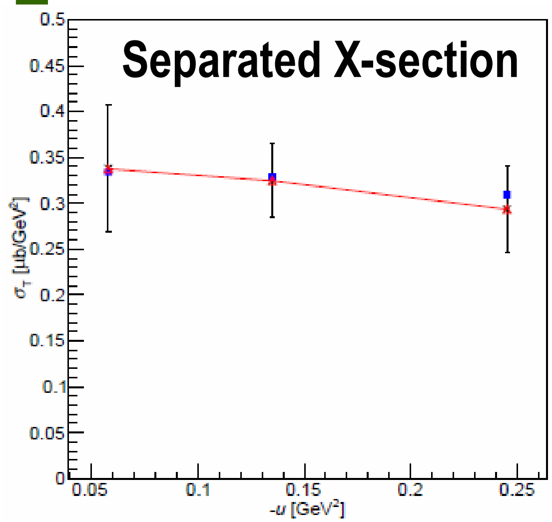
$$R=\frac{Y_{Exp}-Y_{\rho\ sim}-Y_{Xspace\ sim}}{Y_{\omega\ sim}}$$

Combine ratios for settings together, propagating errors accordingly.

$$\left.\frac{d^2\sigma}{dt d\varphi}\right|_{EXP}=R\left.\frac{d^2\sigma}{dt d\varphi}\right|_{SIMC}$$

Empirical Model





Extract L,T,LT,TT via simultaneous fit

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

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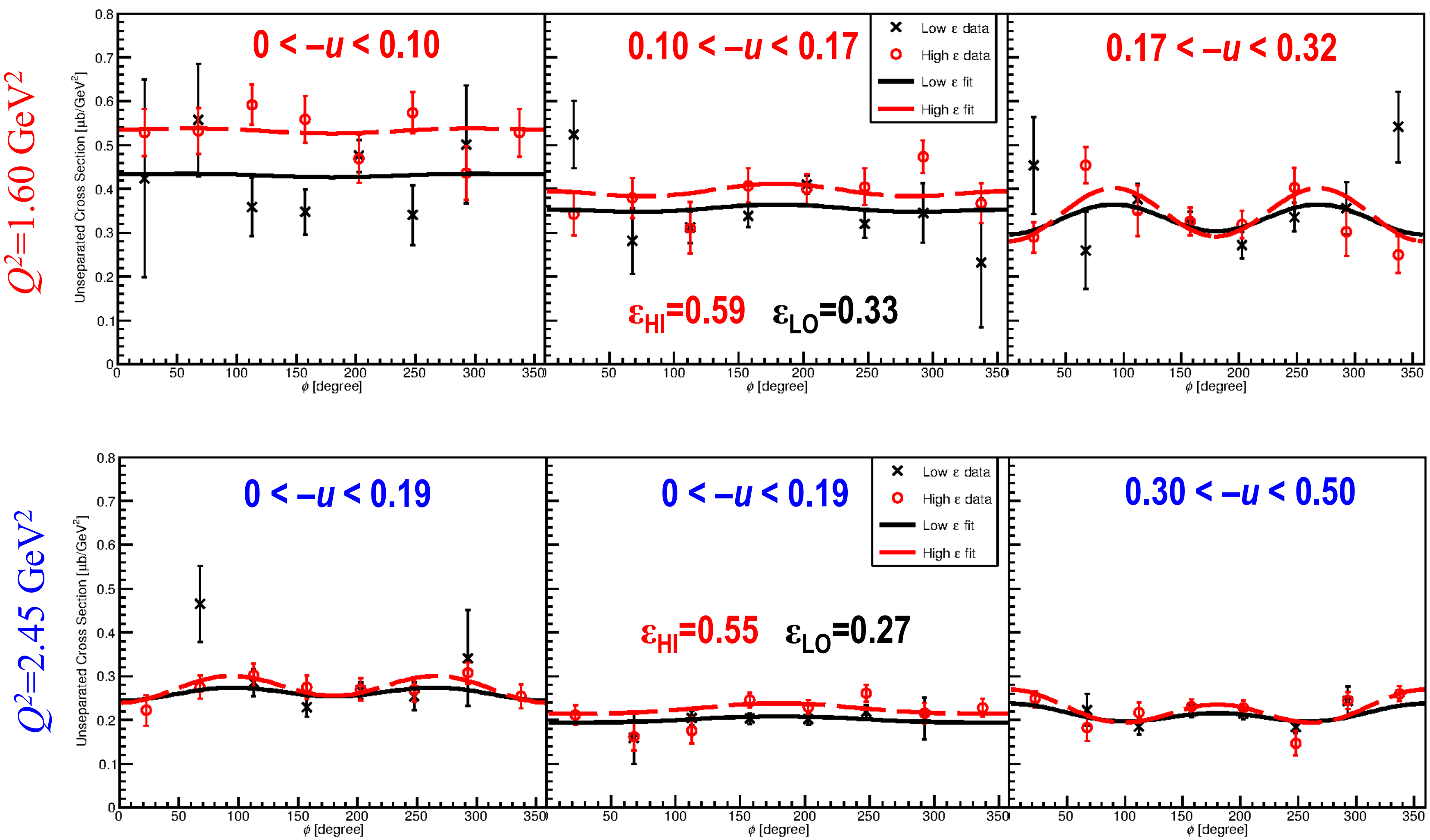
Unseparated Cross Sections

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



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

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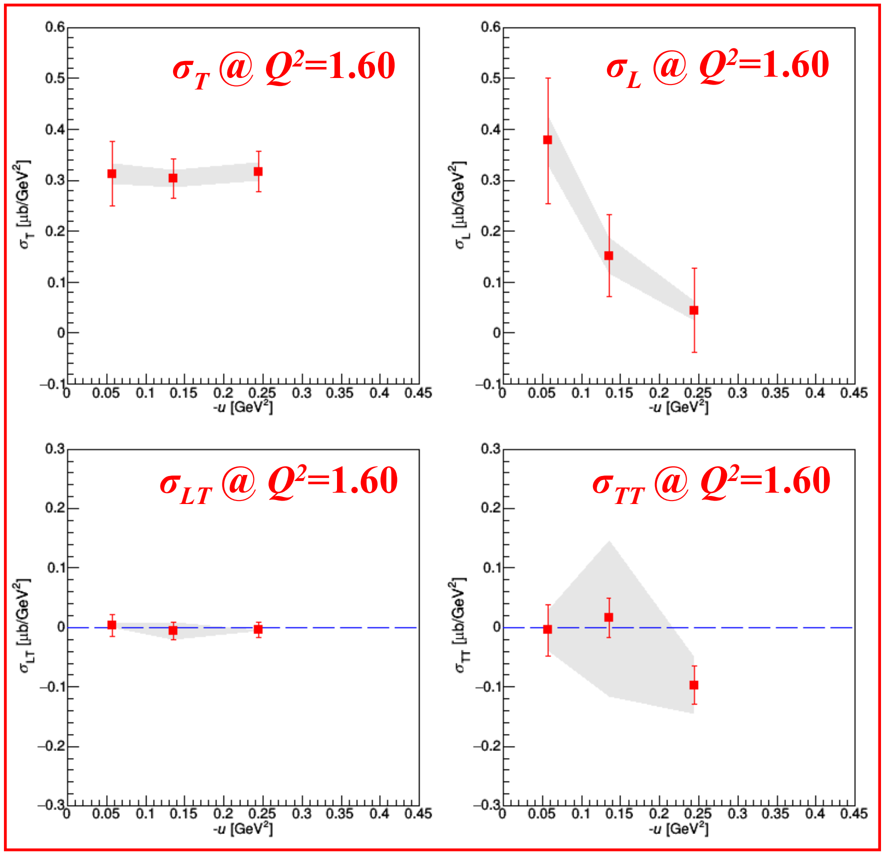

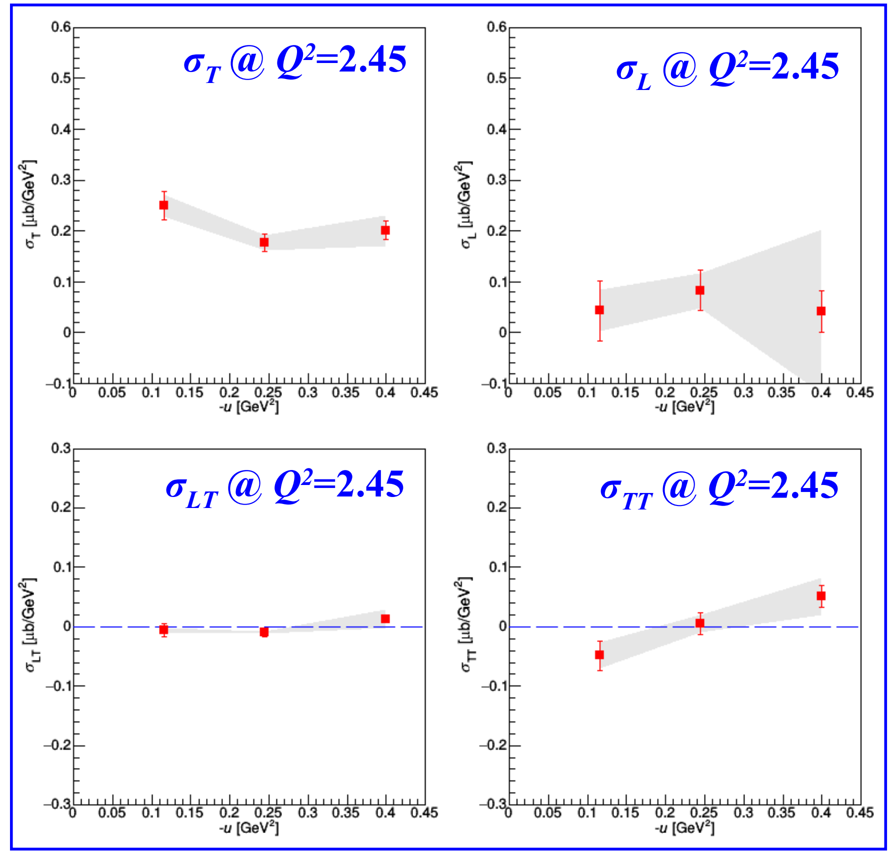

Observations:

- 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.

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)**

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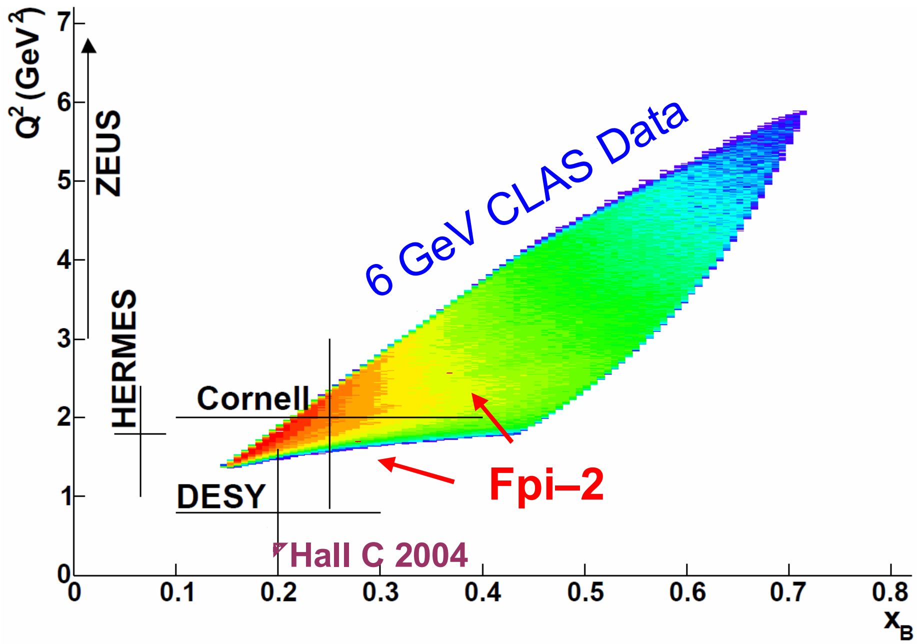
Exclusive ω Electro–Production Data



Closest data set to ours is:
L. Morand et al., [Hall B]
EPJA **24** (2005) 445

	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 (W.B. Li et al., 2019)	1.6, 2.45	2.21	0.29, 0.38	4.0, 4.74

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Backward Angle Omega Electroproduction Peak

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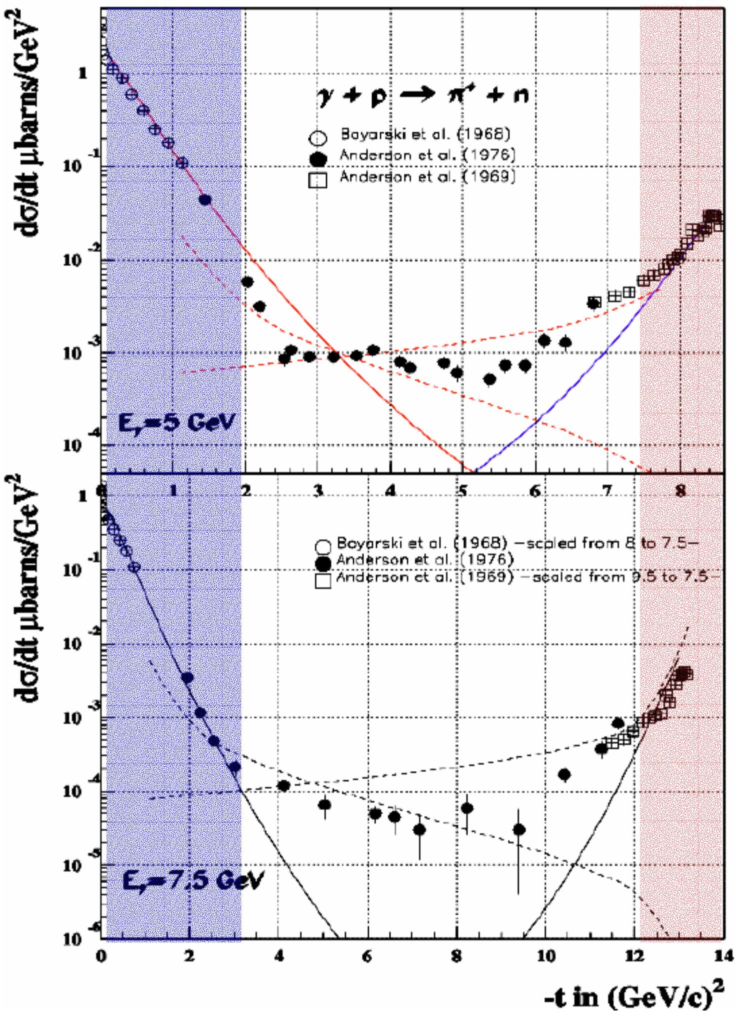
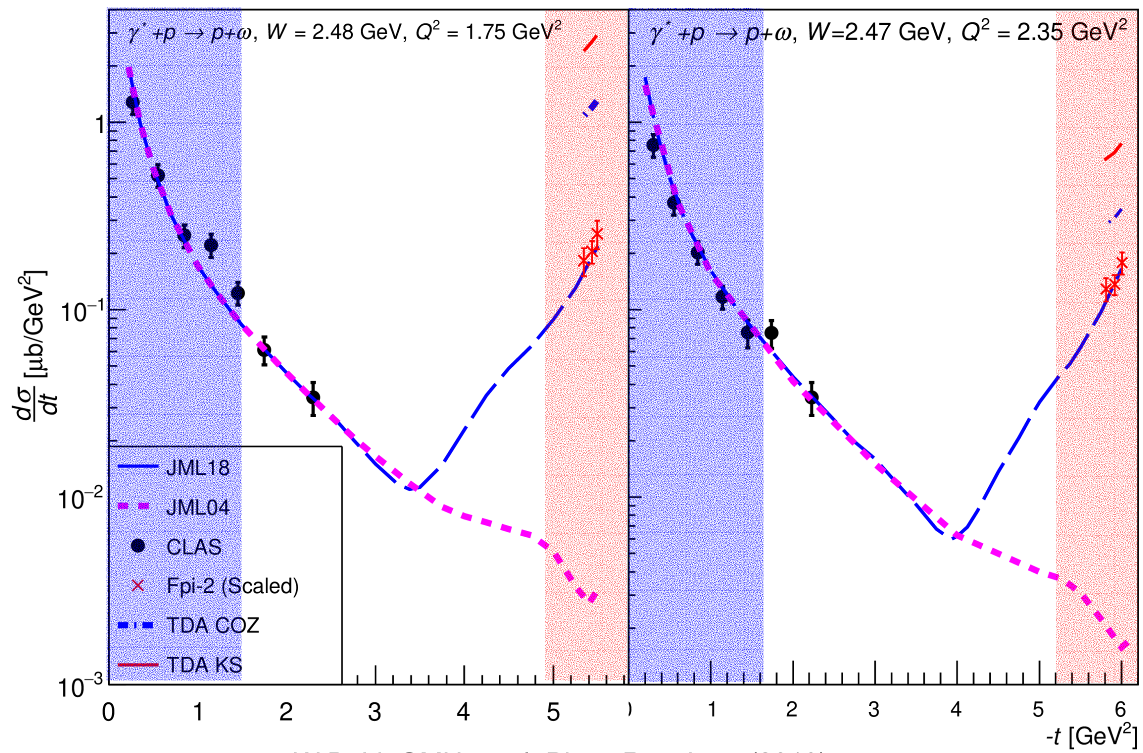
Photoproduction



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

First observation of backward angle peak in electroproduction!



W.B. Li, GMH, et al, Phys. Rev. Lett. (2019) to appear

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

	W (GeV)	x_B	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
Fπ–2	2.21	0.29	1.6	4.014	0.08 – 0.13
		0.38	2.45	4.724	0.17 – 0.24

JML Regge Model description of *u*–Peak

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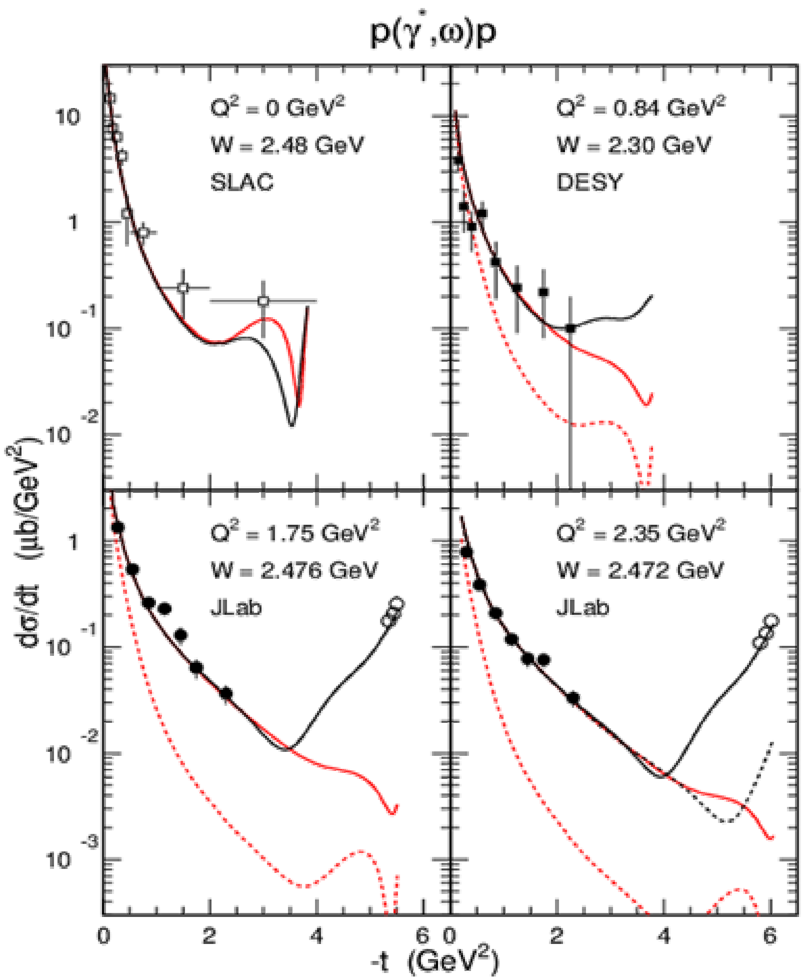
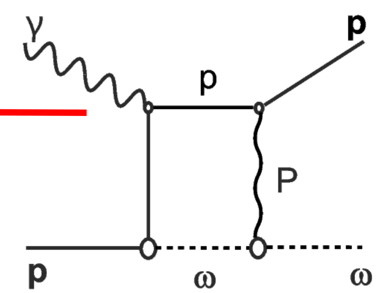


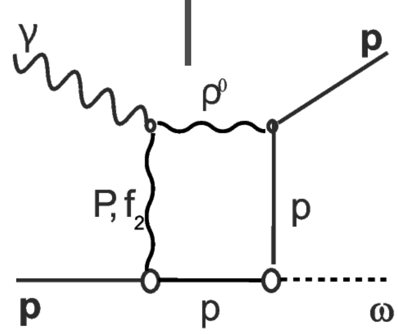
J–M Laget, Private Communication (2018)

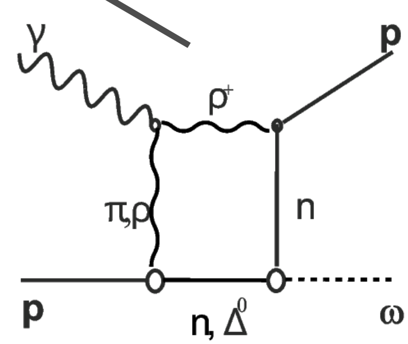
- Model provides natural description of JLab π electroproduction cross sections without destroying good agreement at Q^2=0.
  [PLB **685**(2010)146; PLB **695**(2011)1999]
- Model also consistent with magnitude and slope of backward angle ω peak.
- Would be interesting to examine L/T ratio predicted by model when full calc 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)

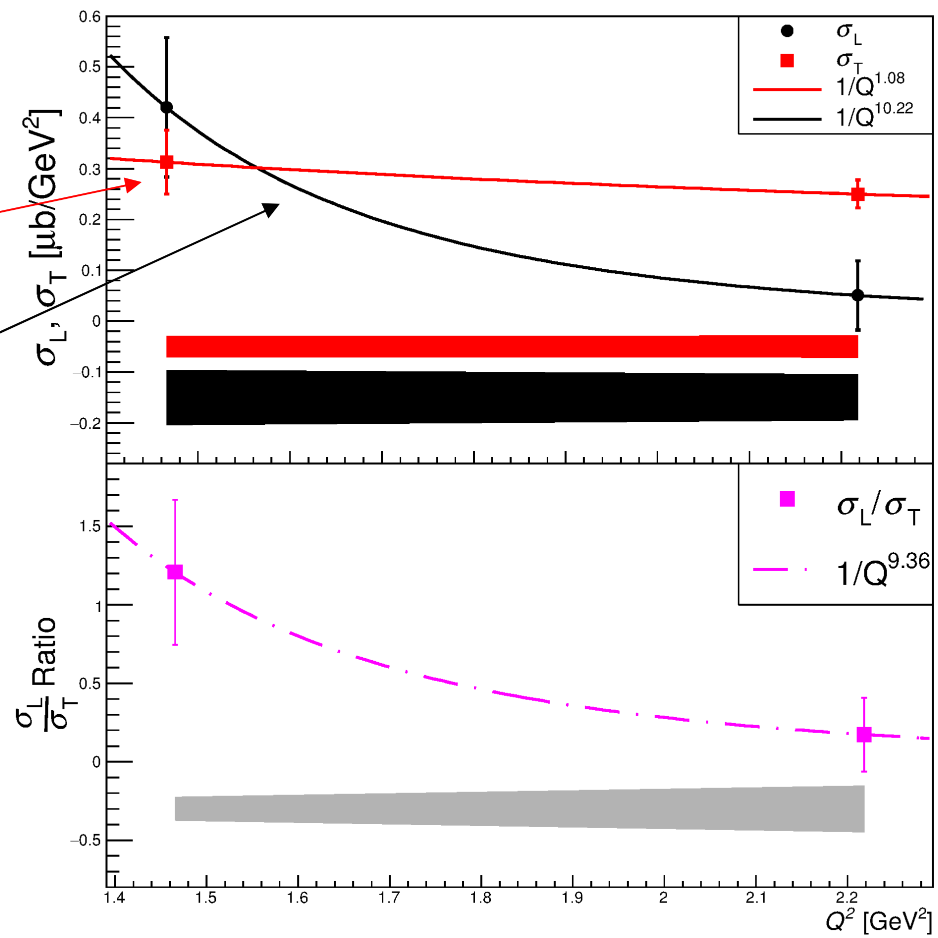




$p(e,e'p)\omega$ Q^2–Dependence

- 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

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TDA model Comparison to Data

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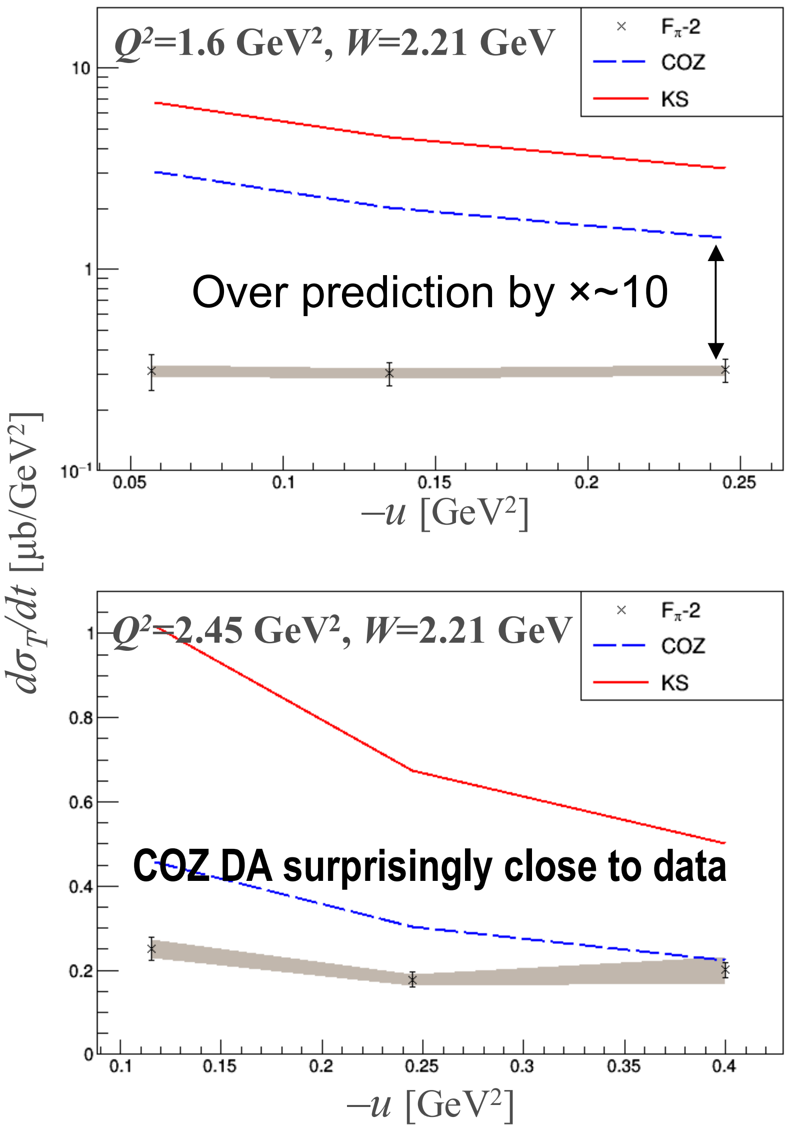
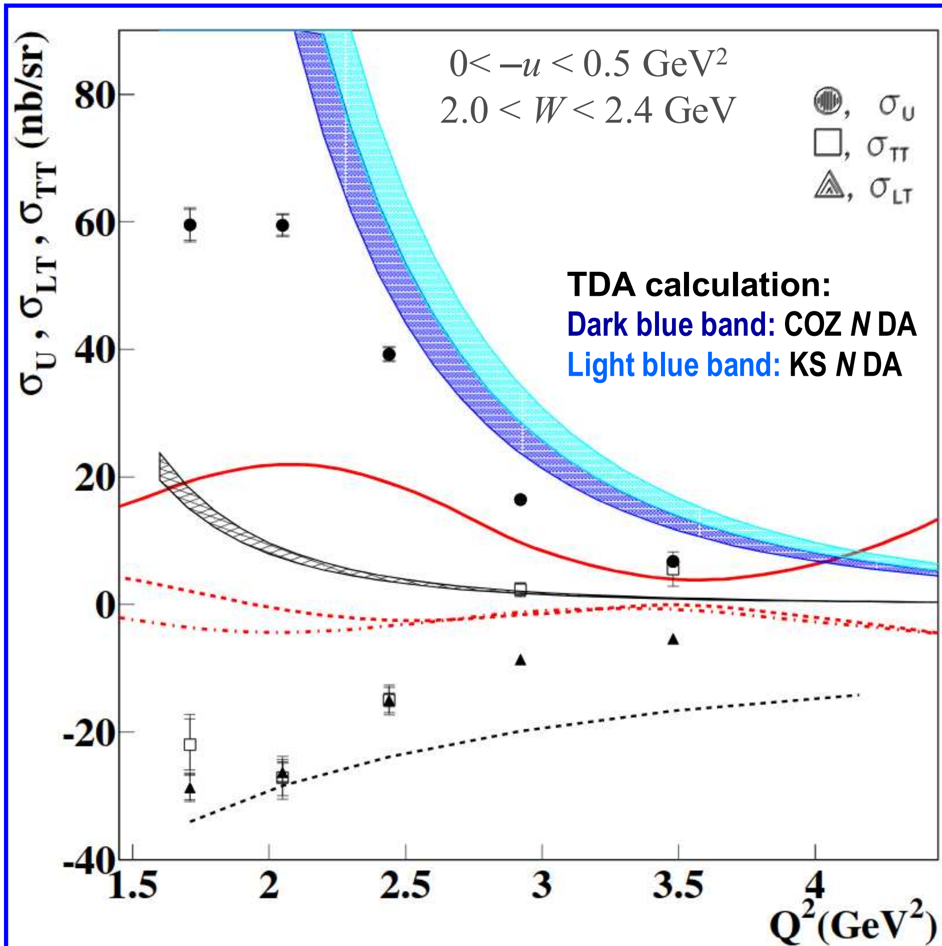


TDA calculation by B. Pire, K. Semenov, L. Szymanowski
Private Communication (2015)

Hall C ω electroproduction

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



Hall B π^+ Electroproduction

K. Park et al., PLB **780** (2017) 340

Strategy for studying TDA formalism

University of Regina

- **Stage 1: Study the applicability of TDA formalism, by measuring general scaling trend of separated L/T cross sections for a variety of *u*–channel reactions**
  - CLAS–6 π^+ data, Hall C ω data from 6 GeV era (done)
  - 12 GeV data from Halls C,B (we are here)

- **Stage 2: Determine the *u*–dependence and extract the meson to nucleon transition form factor *G(u)* [slide 11] from 12 GeV data**

- **Stage 3: Extract TDAs by probing the single and double spin asymmetries for backward meson production and perform universality checks**
  - **JLab SoLID**
  - **EIC**
  - **PANDA**

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JLab Hall C – 12 GeV Upgrade

SHMS:
- 11 GeV/c Spectrometer
- Partner of existing 7 GeV/c **HMS**

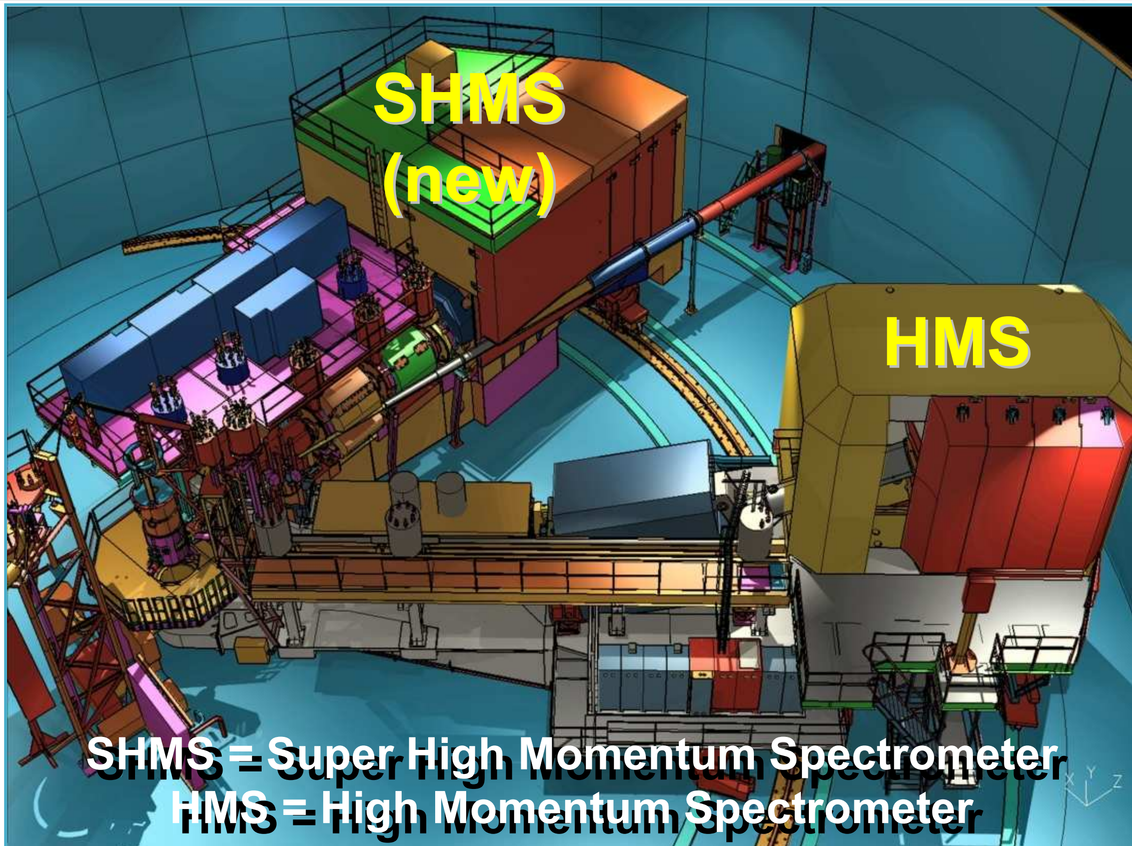
MAGNETIC OPTICS:
- Point-to Point QQQD for easy calibration and wide acceptance.
- Horizontal bend magnet allows acceptance at forward angles (5.5°)

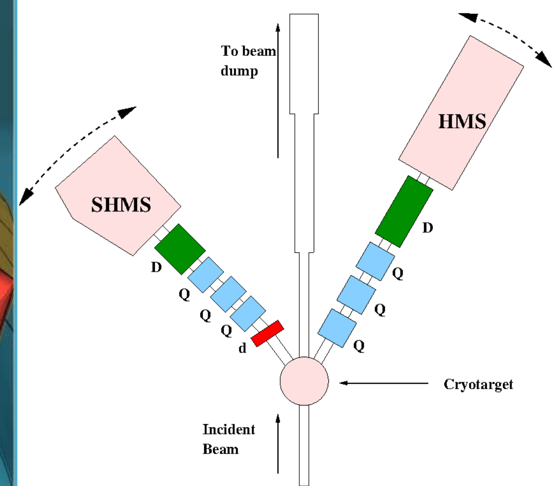
Detector Package:
- Drift Chambers
- Hodoscopes
- Cerenkovs
- Calorimeter

Well-Shielded Detector Enclosure

Rigid Support Structure
- Rapid & Remote Rotation
- Provides Pointing Accuracy & Reproducibility demonstrated in HMS

Luminosity
- ~4×10^{38} cm^{-2} s^{-1}





Upgraded Hall C has some similarity to SLAC End Station A, where the quark substructure of proton was discovered in 1968.

SHMS Small Angle Operation

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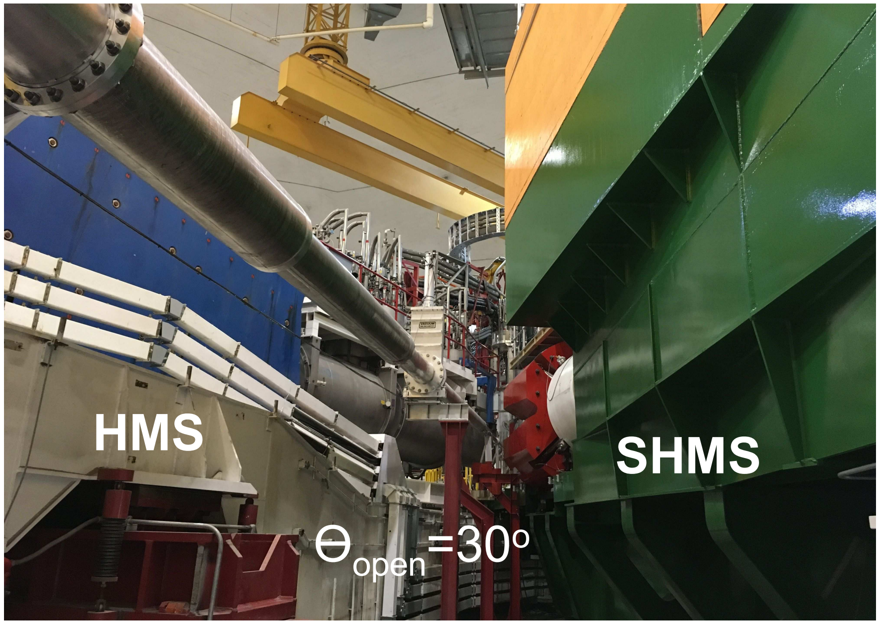
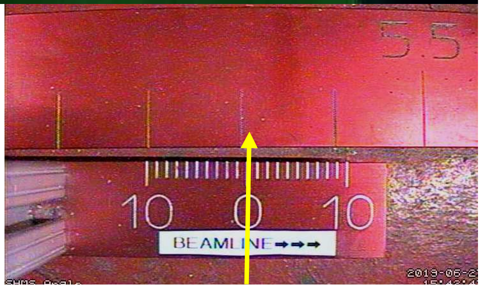
- L/T separation program requires access to hadron spectrometer angles ~5.5° with respect to beamline
- Made possible with the new SHMS

- Other kinematic settings challenge the minimum opening angle between the two spectrometers



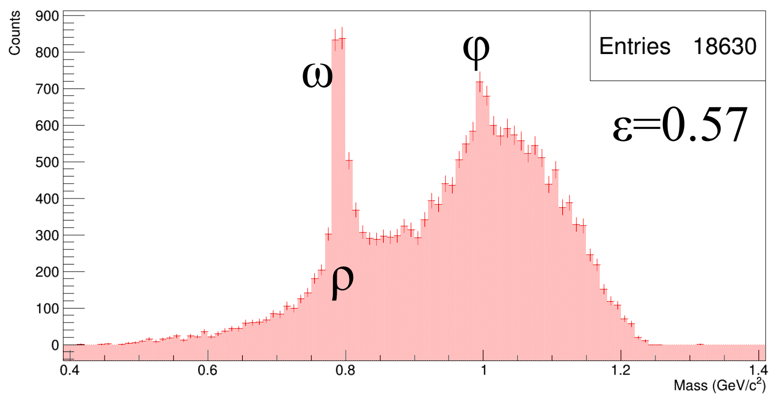


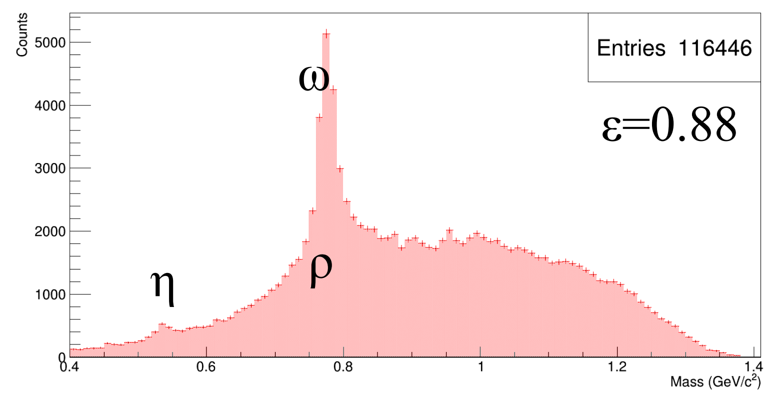
SHMS at 5.69°

Example 12 GeV data already acquired

p(e,e'p)X Online Data Analysis

Q^2=3.00 W=2.32 θ_{pq}=+3.0^o $-u$=0.15 ξ_u=0.15





K⁺ L/T–experiment (E12–09–011)

Spokespersons: T. Horn, G.M. Huber, P. Markowitz

- Data acquired fall 2018–spring 2019
- Main purpose of experiment is to acquire *t*-channel L/T–separated *p(e,e'K⁺)Λ* data for reaction mechanism and *K*⁺ form factor studies
- Abundant *u*–channel *p(e,e'p)X* data acquired parasitically
  - Will allow backward angle studies for several meson states over a wide kinematic range

Setting	Low ε data	High ε data
Q^2=0.50 W=2.40	✓	✓
Q^2=2.1 W=2.95	✓	✓
Q^2=3.0 W=2.32	✓	✓
Q^2=3.0 W=3.14	✓	✓
Q^2=4.4 W=2.74	✓	✓
Q^2=5.5 W=3.02	✓	✓

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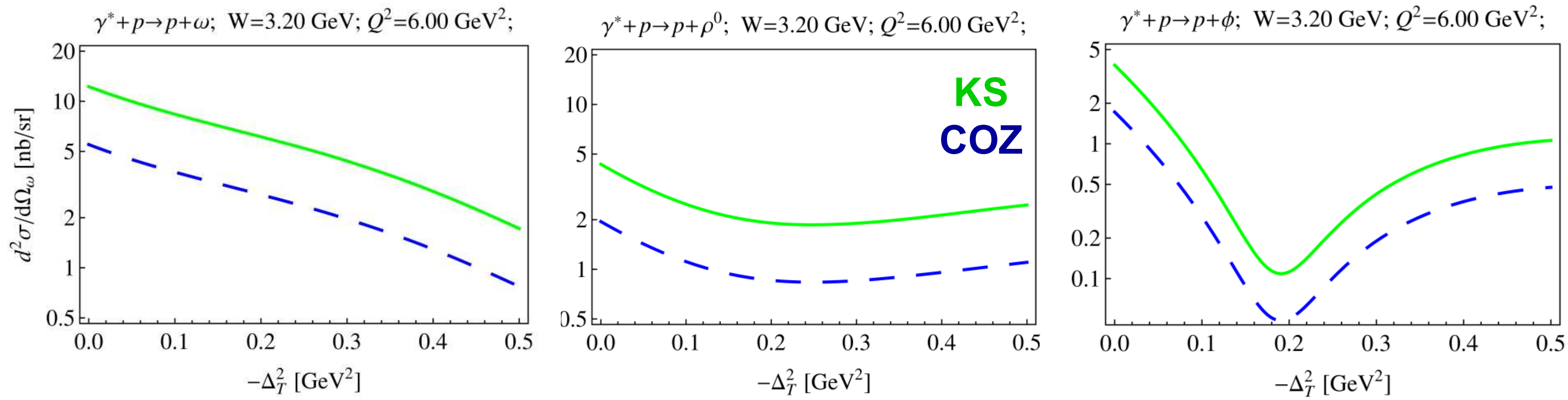
TDA Model Predictions for JLab E12–19–006

Fπ–12 experiment (E12–19–006) L/T separations up to Q^2=8.5 GeV^2

Spokespersons: D. Gaskell, G.M. Huber, T. Horn

- **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 GeV^2, ω predicted to remain dominant (unlike *t*-channel), φ to drop rapidly with –*u*.

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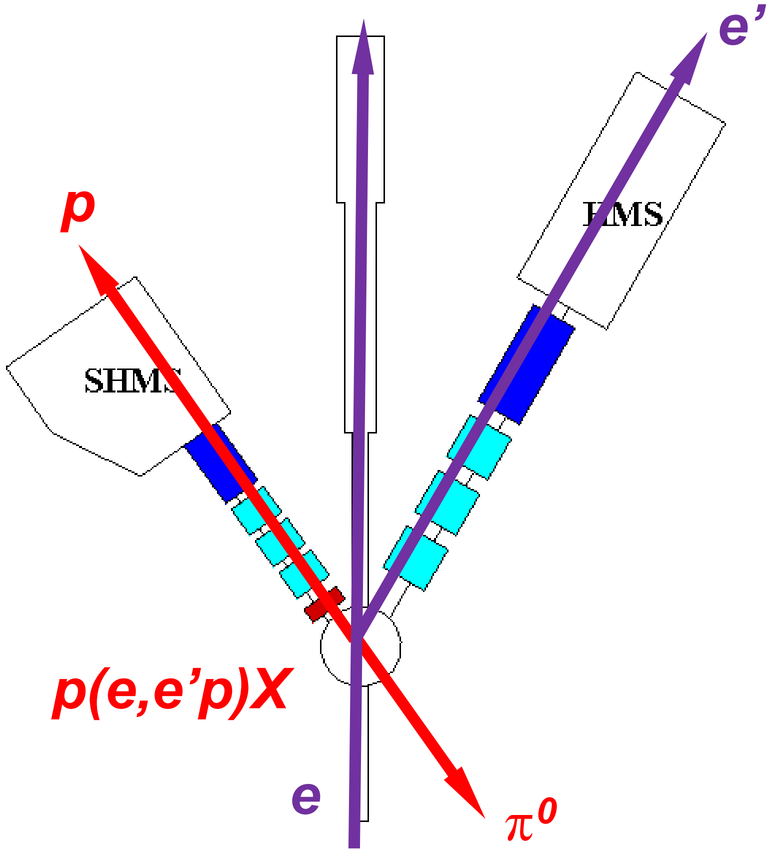
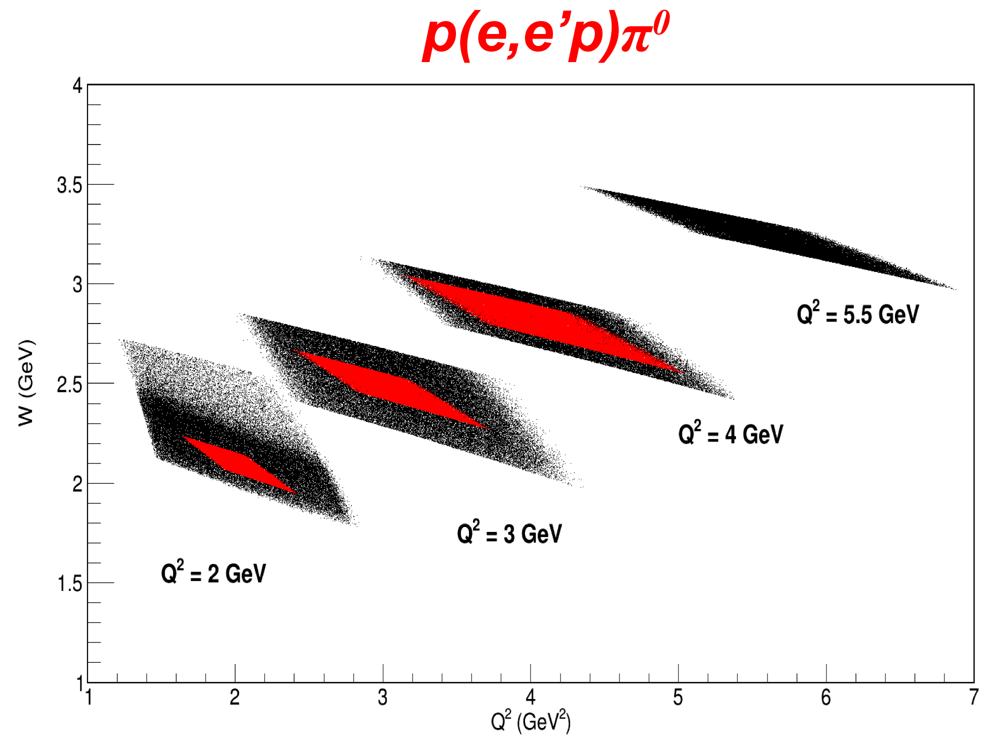
12 GeV Backward Meson Production Opportunities





LOI (2018): $u \approx 0$ π^0 production in Hall C

Spokespersons: W.B. Li, G.M. Huber, J. Stevens

Purpose: test applicability of TDA formalism for π^0 production

- Is σ_T dominant over σ_L?
- Does the σ_T cross section at constant x_B scale as $1/Q^8$?

- Kinematics overlap forward angle $p(e,e'\pi^0)p$ experiment with NPS+HMS

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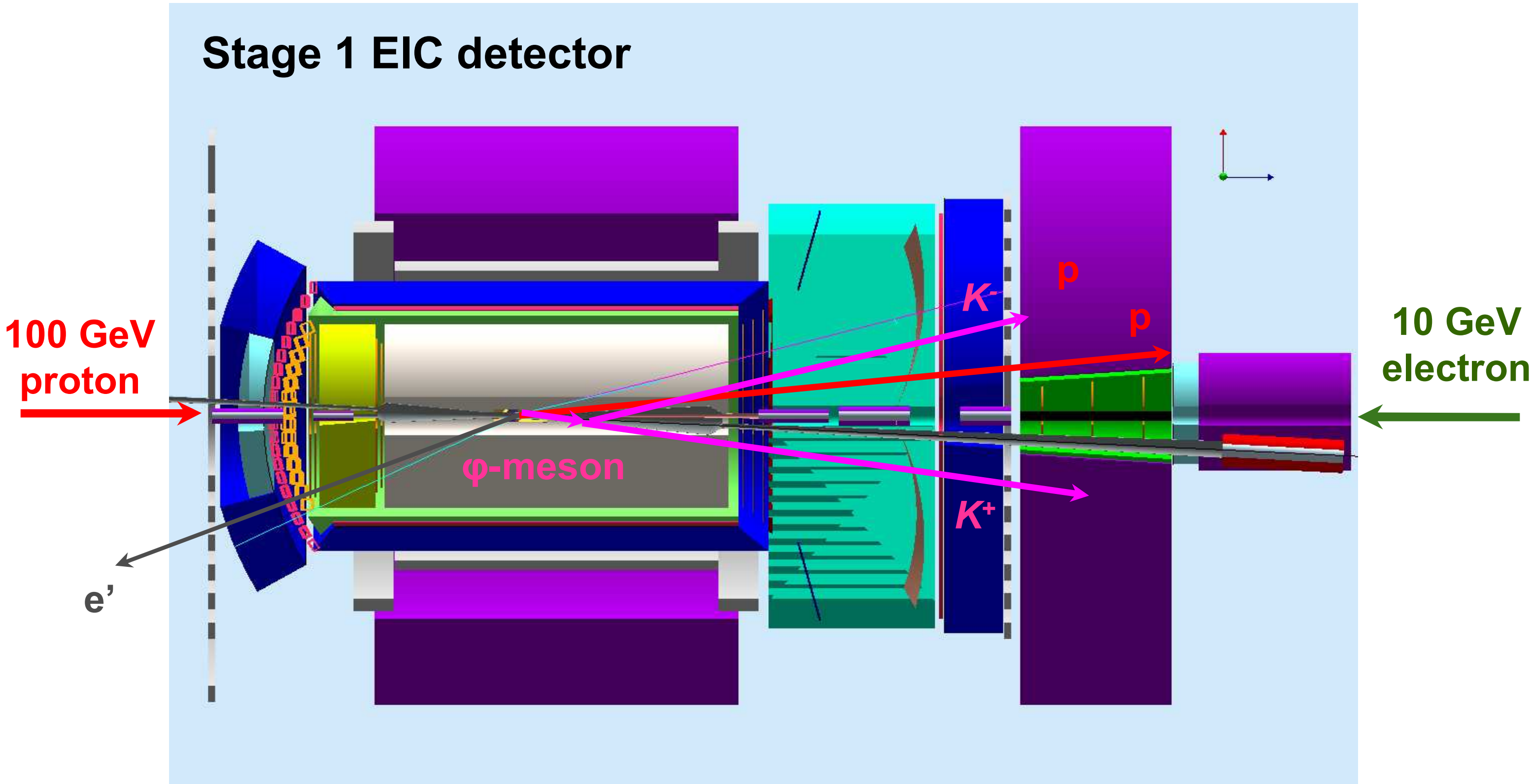
u–channel Kinematics @ EIC



Sample Kinematics for $p(e,e'p)\varphi$ at Q^2=14 GeV^2, W=5.0 GeV							
θe' (deg)	Pe' (GeV/c)	θp (deg)	Pp (GeV/c)	θφ (deg)	Pφ (GeV/c)	$-u$ (GeV^2)	x
21.3	10.26	5.5	37.8	0.1	62.9	0.32	0.37

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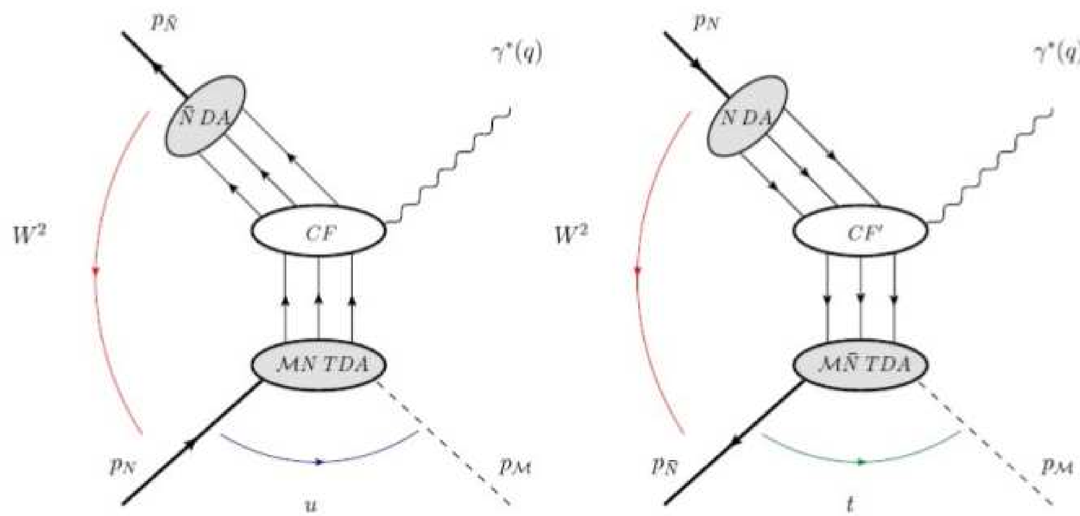
Baryon to meson TDAs at $\bar{\text{P}}$ANDA I

- $E_{\bar{p}} \leq 15$ GeV;
  $W^2 \leq 30$ GeV^2
- J.P. Lansberg et al, '12; B. Pire, L. Szymanowski, K. Semenov-Tian-Shansky '13

  πN TDAs occur in factorized description of

$$\bar{N} + N \to \gamma^*(q) + \pi \to \ell^+ + \ell^- + \pi;$$
$$\bar{N} + N \to J/\psi + \pi \to \ell^+ + \ell^- + \pi;$$

- To be done with the proton FF studies in the timelike region and heavy charmonium studies.
- Two regimes (forward and backward). C invariance $\Rightarrow$ perfect symmetry.
- Test of universality of TDAs.



Future Opportunities at PANDA and EIC

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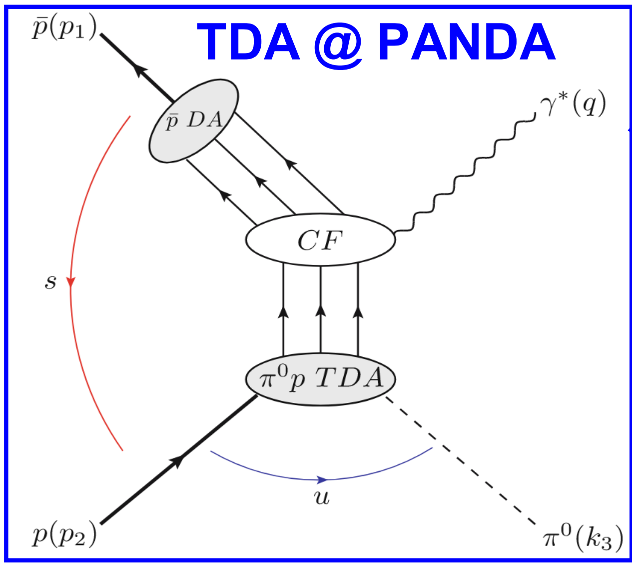
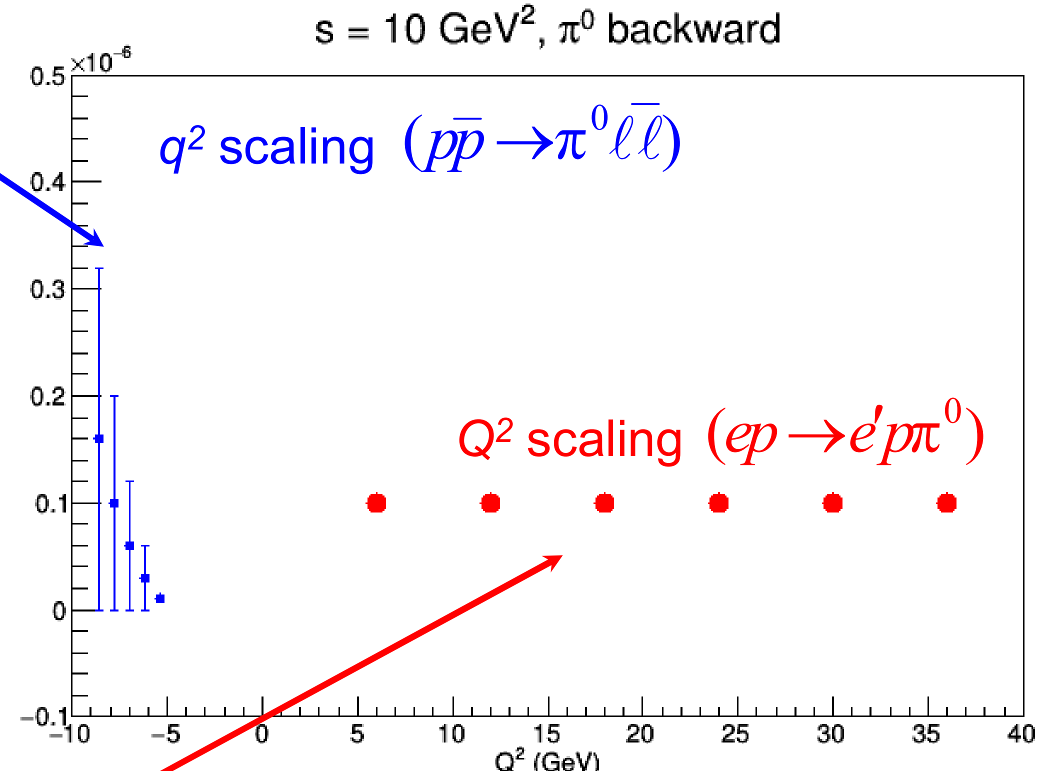
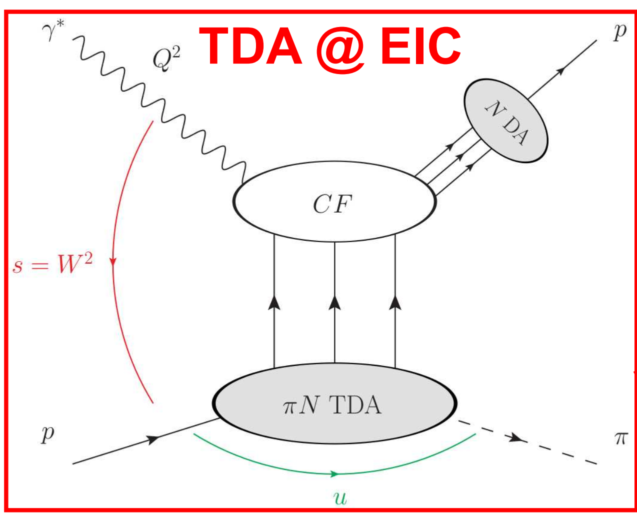
PANDA Collaboration, EPJA **15**(2015)107







Same TDAs for PANDA and EIC, the ultimate universality check

u–channel Workshop @ JLab/W&M

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

The First Backward Angle Physics Workshop at Jefferson Lab

– **Exclusive to the *u*–channel or backward angle physics**

Topics:

- **Explore Backward Photoproduction experiments**
  - **Programs at JLab D**
- **Explore Backward Electroproduction experiments**
  - **Programs at JLab A, B and C**
  - **PANDA TDA program will be invited**
- **TDA and Regge Approaches**

Tentative date: May 24th to May 26th, 2020

Summary

University of Regina

- **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**

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