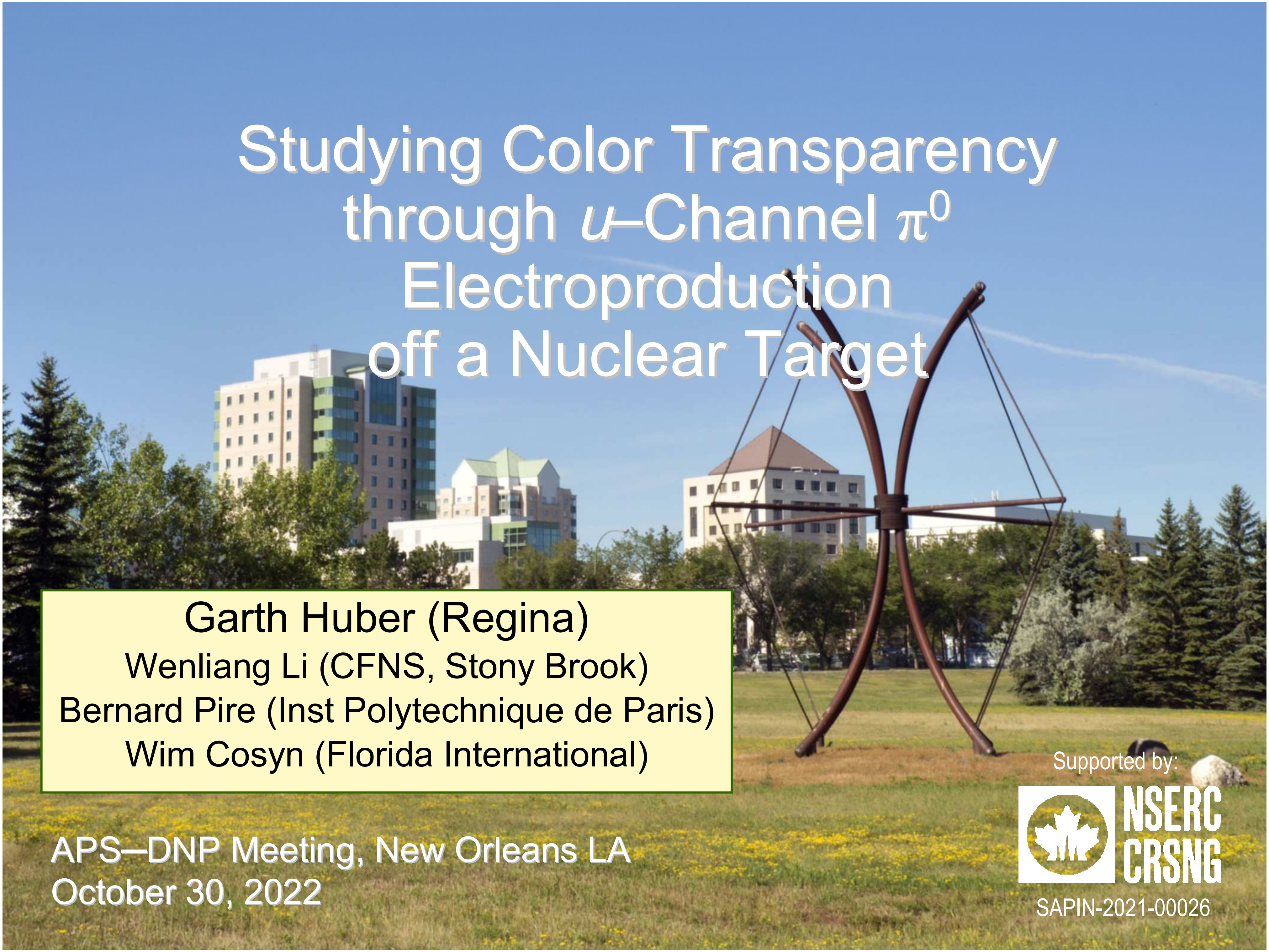

Studying Color Transparency through u–Channel π^0 Electroproduction off a Nuclear Target

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GPD–Like Model: TDA and Factorization

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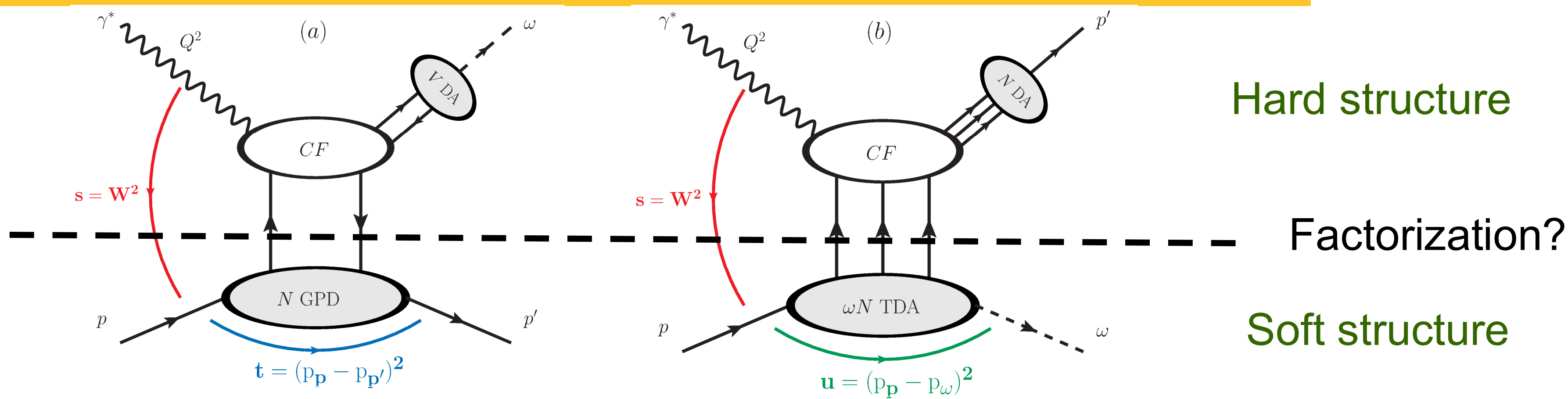

***t*–channel (Forward)** **_u_–channel (Backward)**

Baryon to Meson Transition Distribution Amplitude (TDA)

- Extension of collinear factorization to backward angle regime. Further generalization of the concept of GPDs.
- Backward angle factorization first suggested by Frankfurt, Polyakov, Strikman, Zhalov, Zhalov *[arXiv:hep-ph/0211263]*
- 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**

Skewness in Backward Angle Regime

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- **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:

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

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

- **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

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

- GPDs depend on x, ξ_t and $t=(\Delta^t)^2=(p_2-p_1)^2$
  TDAs depend on x, ξ_u and $u=(\Delta^u)^2=(p_\pi-p_1)^2$

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

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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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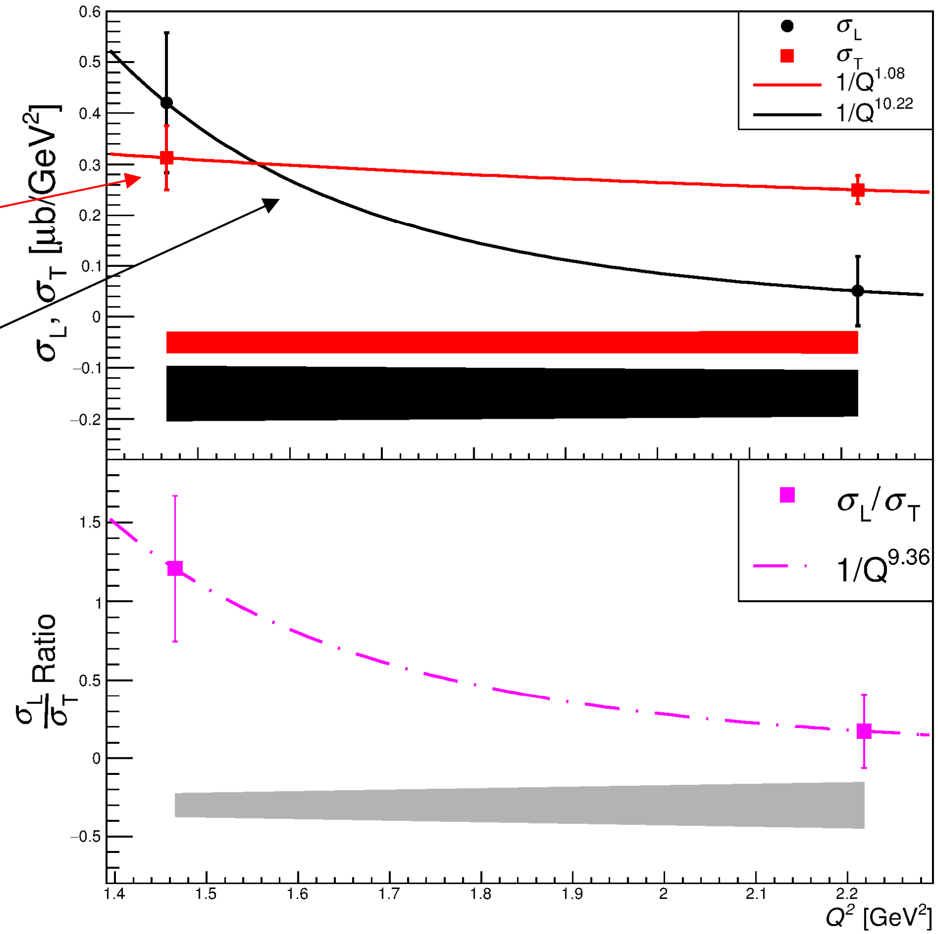
p(e,e'p)ω Q^2–Dependence from Hall C

- 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

W. Li, et al. PRL **123** (2019) 182501

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TDA model Comparison to Data

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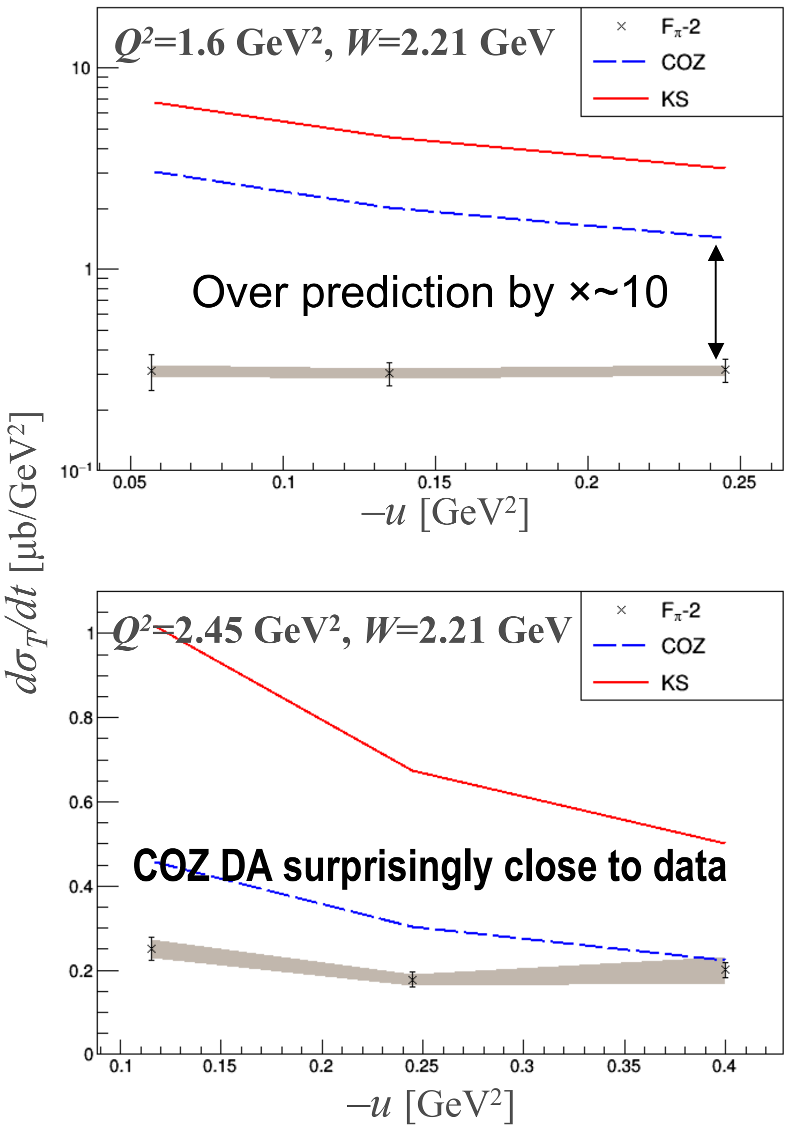
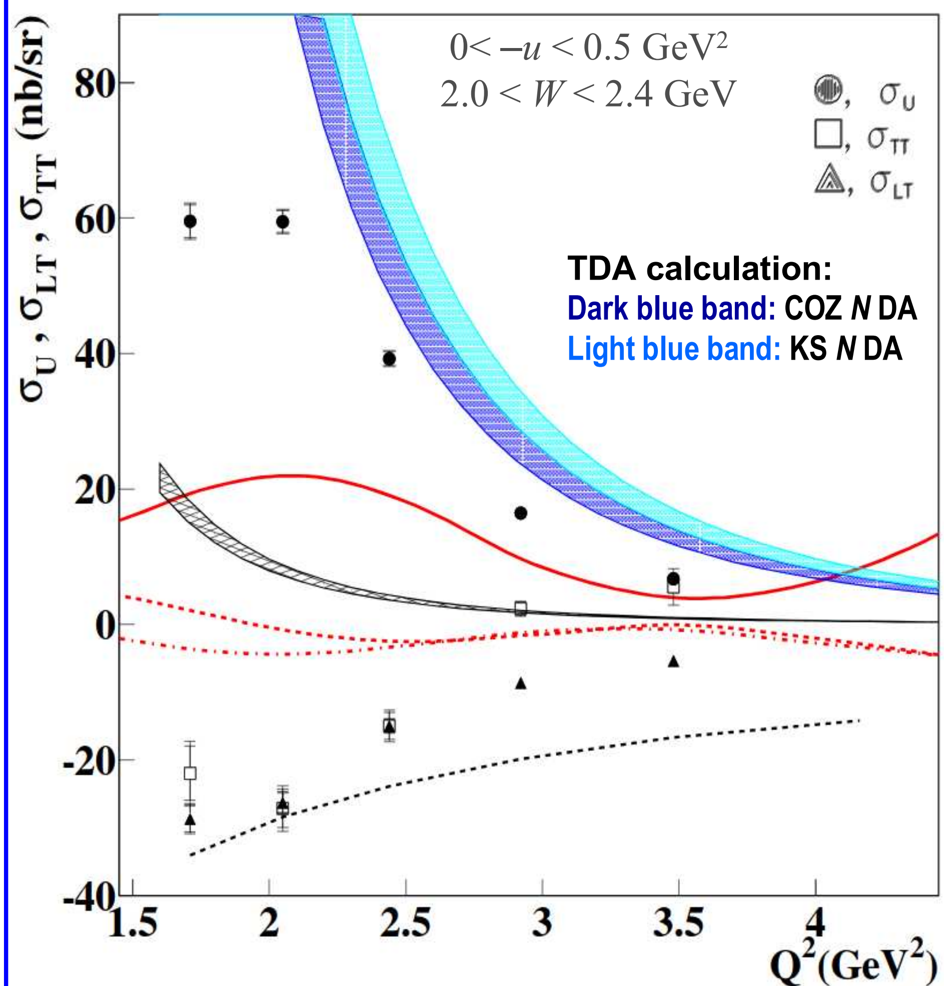


Hall C ω Electroproduction

W. Li, et al. PRL **123** (2019) 182501

Both data sets suggestive of early TDA scaling $Q^2 \approx 2.5$ GeV^2 !?



Hall B π^+ Electroproduction

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

Extension to Higher Q^2

- **The 6 GeV JLab Halls B,C data are qualitatively consistent with the predictions of the backward–angle factorization / TDA formalism, but they are at a too low Q^2 to be in quantitative agreement.**
  - CLAS–6 π^+ data, Hall C ω data

- **Studies of the applicability of TDA formalism are being extended in the 12 GeV era, by measuring general scaling trend of separated L/T cross sections for a variety of *u*–channel reactions**
  - 12 GeV data from Hall B
  - Hall C ρ, ω, φ data (E12–09–011)
  - Dedicated Hall C π^0 measurement (E12–20–007)

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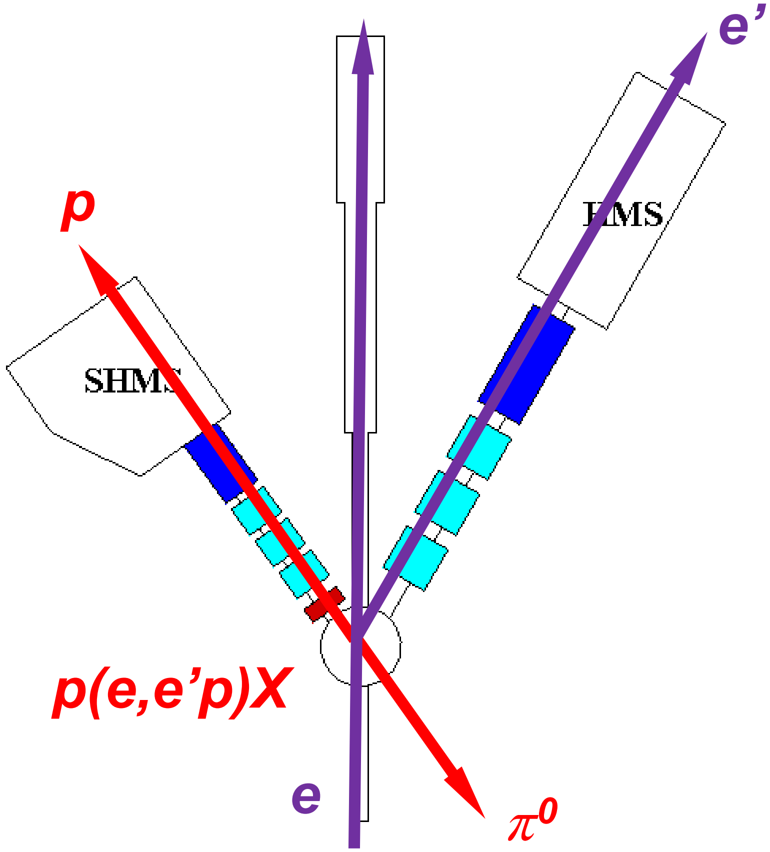
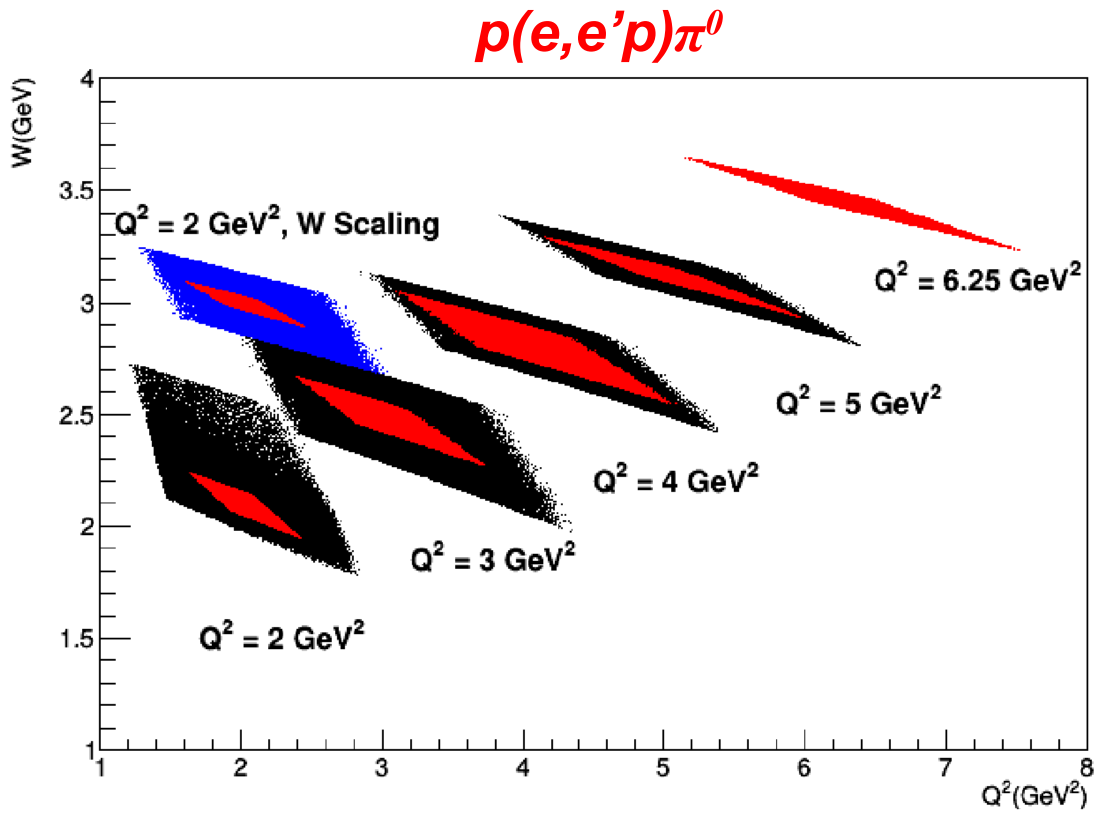
Backward Exclusive π^0 Production





E12–20–007: $u \approx 0$ 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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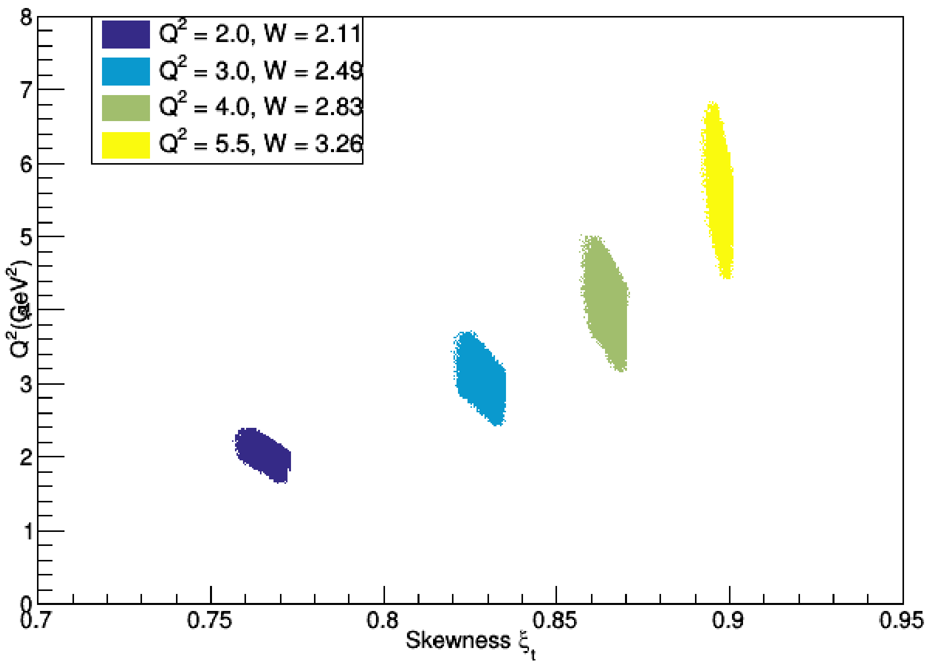
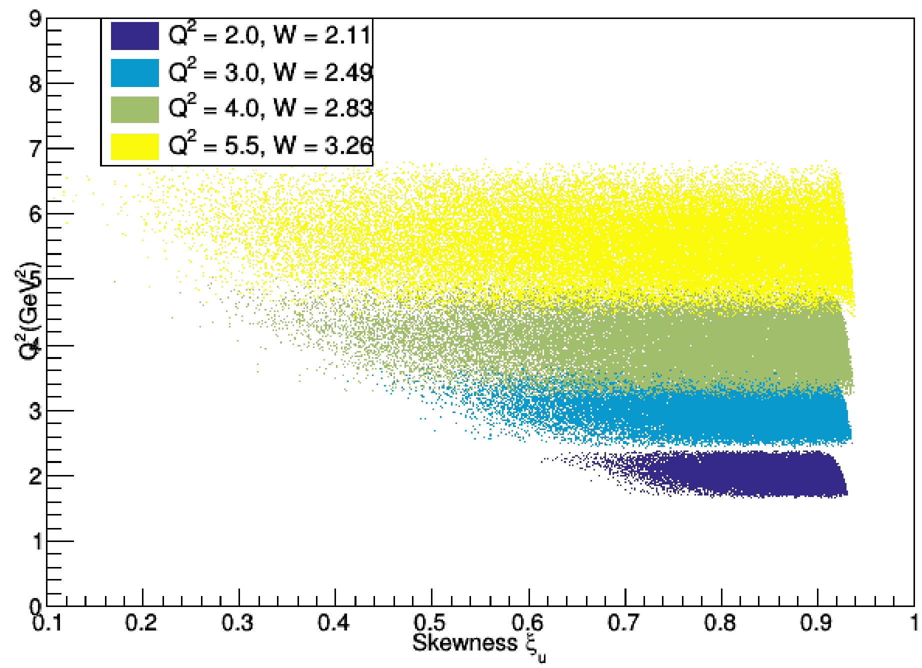
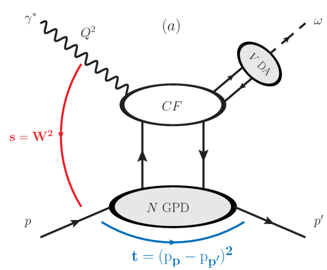
$p(e,e'p)\pi^0$ Skewness Range



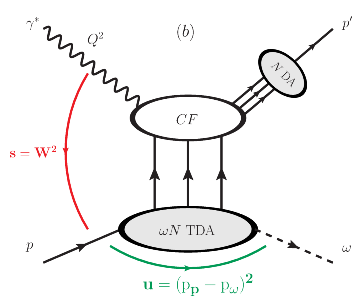




$$\xi_t = \frac{p_1^{+} - p_2^{+}}{p_1^{+} + p_2^{+}}$$

where $p_{1,2}$ refer to light cone + components

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



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

HMS and SHMS acceptance cuts, and diamond cuts applied

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CT and Backward–angle Factorization

- CT has recently been shown to not apply in C(e,e'p) up to Q^2=14 GeV^2, in contrast to CT applying already in A(e,e'π^+) at Q^2≈5 GeV^2

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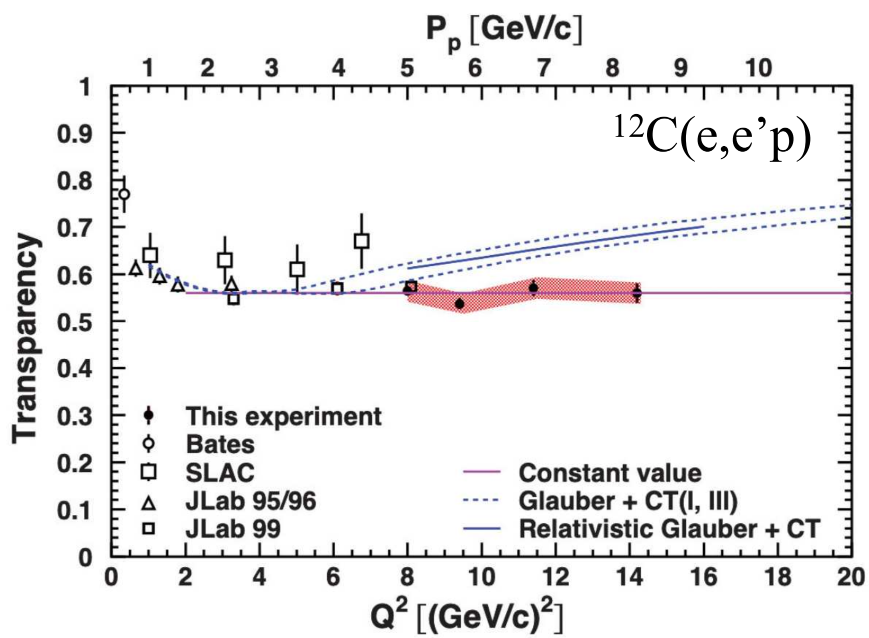
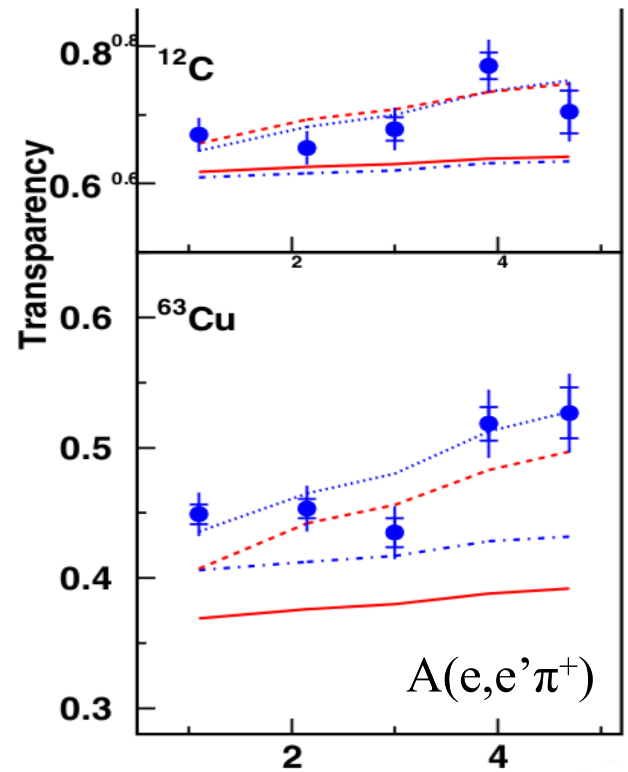
Bhetuwal et al, PRL **126** (2021) 082301



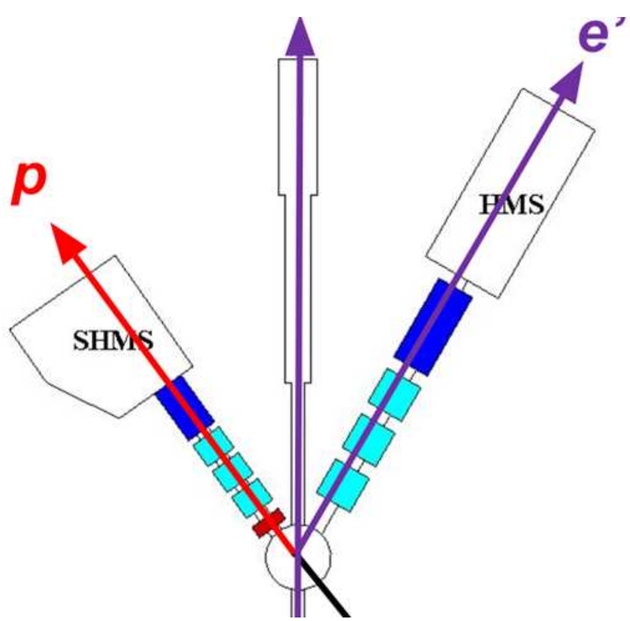


Clasie et al, PRL **99** (2008) 242502

- **Color Transparency is a co–requisite of reaching the factorization regime, and is expected to be an equally valid requirement for both forward–angle and backward–angle factorizations**

Backward–angle $A(e,e'p)\pi^0$

- Since JLab 6 GeV data are qualitatively consistent with early factorization in backward kinematics, backward–angle meson production events with a high momentum forward proton may provide an alternate means of probing Color Transparency
- Example is π^0 production, but technique extendable also to vector meson production. A short test could be attempted in E12–20–007



$A(e,e'p)\pi^0$ Kinematics E_{beam}=10.6 W=2 GeV					
Q^2 (GeV²)	e' (GeV/c, deg)	p (GeV/c, deg)	π^0 (GeV/c, deg)	t (GeV²)	u (GeV²)
3	7.3 @ 11.3°	3.9–3.6 @ 23°–30°	0.2–0.5 @ 202°–95°	–5.7 to –5.2	+0.5 to –0.1
6	5.7 @ 18.1°	5.6–5.2 @ 19°–24°	0.1–0.5 @ 196°-79°	–8.8 to –8.2	+0.6 to 0.0
10	3.6 @ 29.7°	7.7–7.3 @ 13°–16°	0.0–0.5 @ 193°–61°	–12.8 to –12.1	+0.6 to –0.1

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Theoretical considerations

- Halls B,C 6 GeV data hint at applicability of backward–angle factorization mechanism as early as $Q^2=2.5$ GeV^2
- If this interpretation is correct, it can be confirmed by *u*–channel CT measurements such as $A(e,e'p)\pi^0$
- **Considerations:**
  - CT will not appear in the same way for backward π^0 as for the other experiments. This is because the π^0 does not originate from a point–like quark configuration, it is attached to the TDA which has no small transverse distance inside
  - Even if factorization applies, the π^0 will be subject to strong interactions in the nucleus, such as absorption, or formation of a 2π state
  - One should not insist on detecting the final meson. Rather, it would be sufficient to require $120<m_{missing}<500$ MeV. It is important to detect the high–momentum forward–going nucleon
- This new type of experiment gives rise to the intriguing idea of *"Half Color Transparency"*

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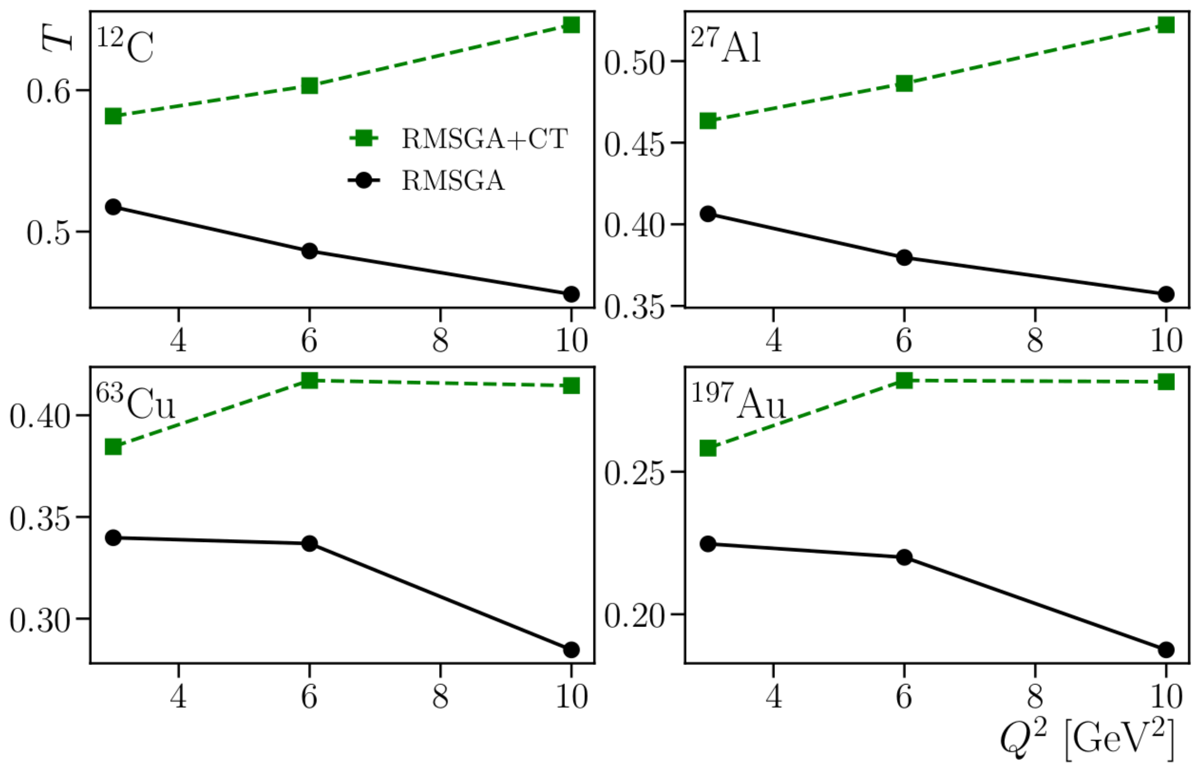
Model Estimate of Color Transparency

- **Relativisitic Multiple Scattering Glauber Approximation (RMSGA)**
- Flexible framework that treats kinematics and dynamics (nuclear wavefcn, FSI) relativisitically, and applied to wide variety of hadron–, electron–, and neutrino–induced nuclear reactions
- Transparency Ratio: $T = \sigma^{RMSGA} / \sigma^{PWIA}$
- Calculation is for Hall C kinematics on slide 11
- Clear CT effects are predicted, which set the stage for future proposal



— regular Glauber calculations

-- CT in quantum diffusion model

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Summary

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- **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
- The approach of backward angle factorization regime can be studied via u–channel CT measurements, such as A(e,e'p)π^0, across a variety of nuclei
- For more details, see our paper:

MDPI *Physics* Special Issue on JLab Color Transparency Workshop,
arXiv:2202.04470 https://doi.org/10.3390/physics4020030

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