Hadron Propagation and Color Transparency at 12 GeV E12-06-107

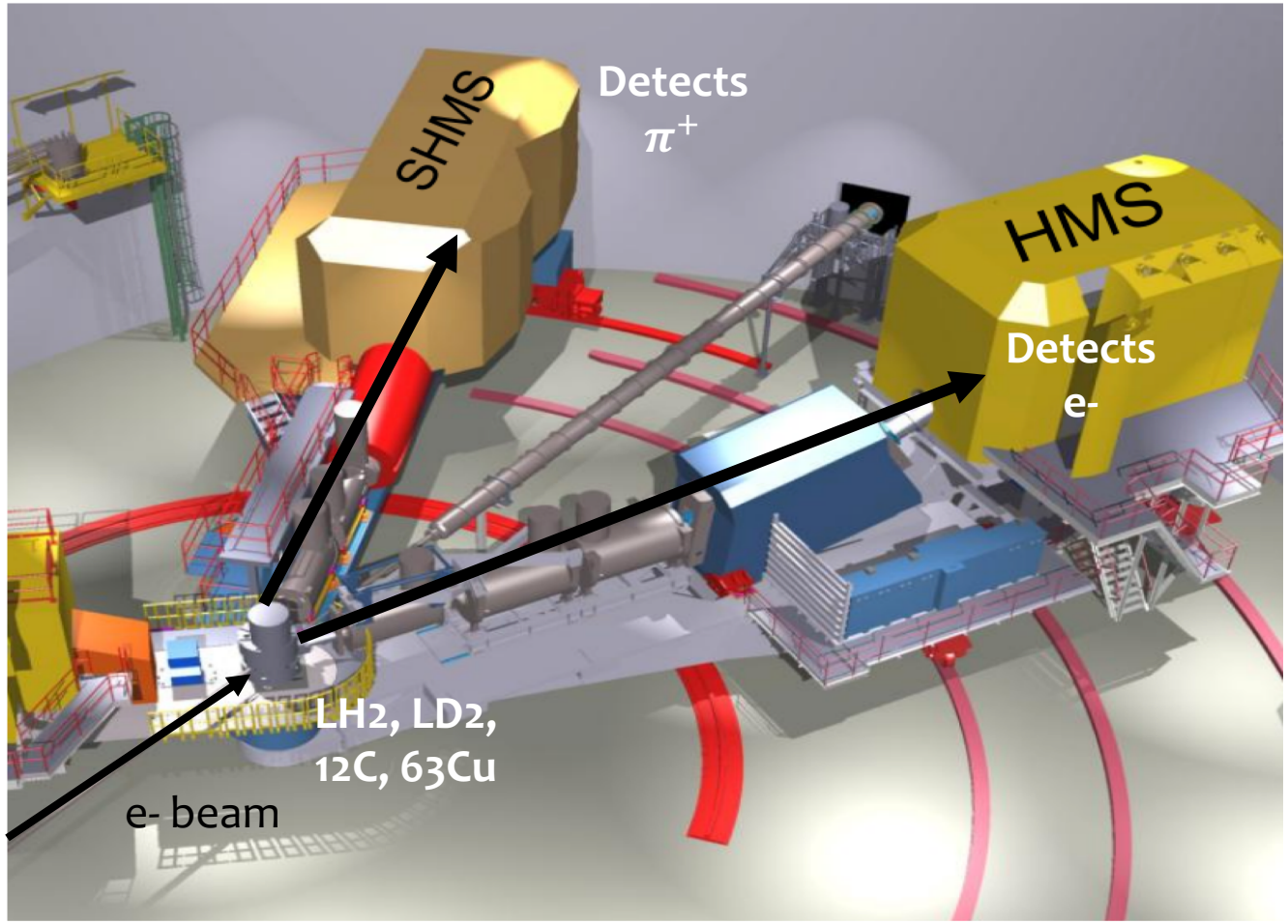
Holly Szumila-Vance
On behalf of Carlos Ayerbe Gayoso & Dipangkar Dutta

Hall C Collaboration Meeting
January 2024

Jefferson Lab

Outline

- Introduce color transparency (CT)
- Recent proton results
- Running next year in Hall C: pions!



Nuclear transparency

Probability knocked out proton in scattering to be deflected or absorbed.

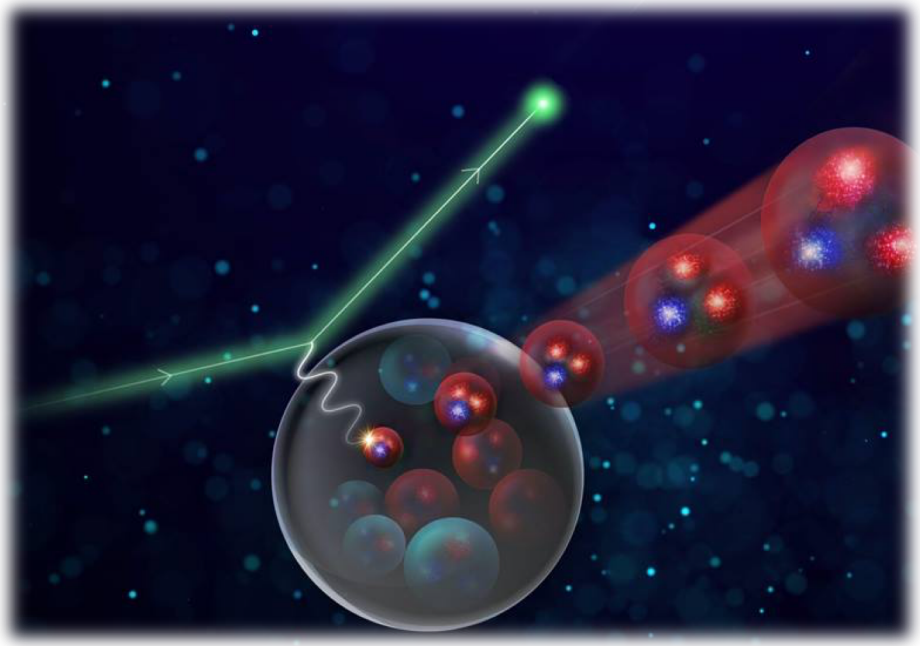
Ratio of cross-sections for exclusive processes from nuclei and nucleons is the Transparency.

$$T_A = \frac{\sigma_A}{A\,\sigma_N}$$

σ_A (nuclear cross section)

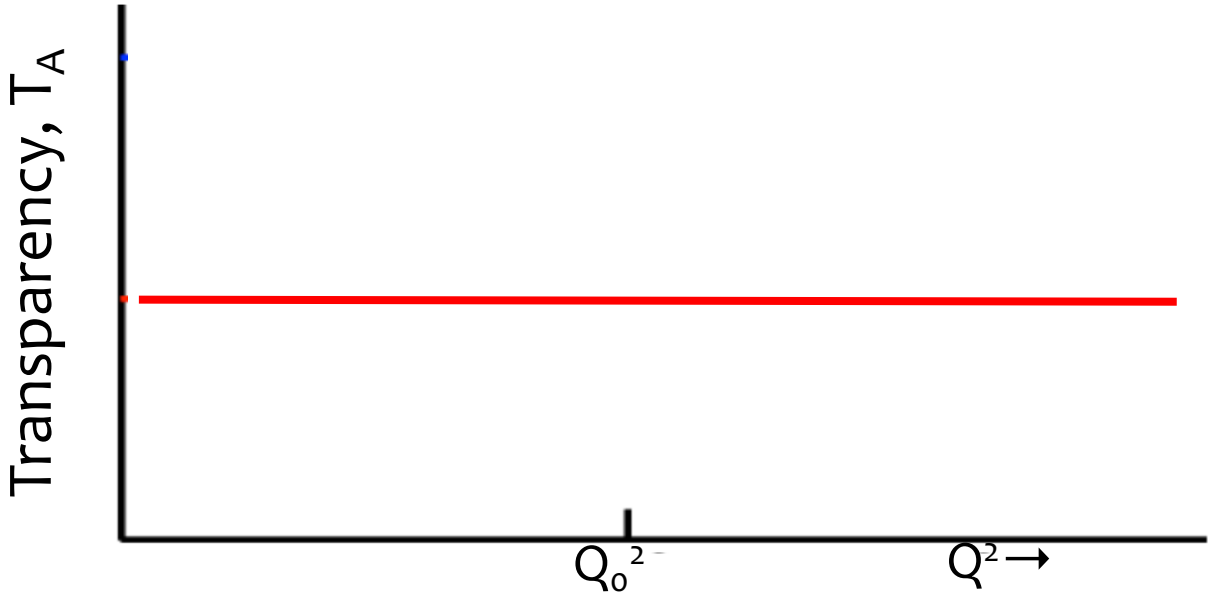
σ_N (free nucleon cross section)

$$\sigma_A = \sigma_N\, A^{\alpha}$$



Transparency is momentum independent (in the strongly interacting hadronic picture)

$$T_A = \frac{\sigma_A}{A\ \sigma_N}$$

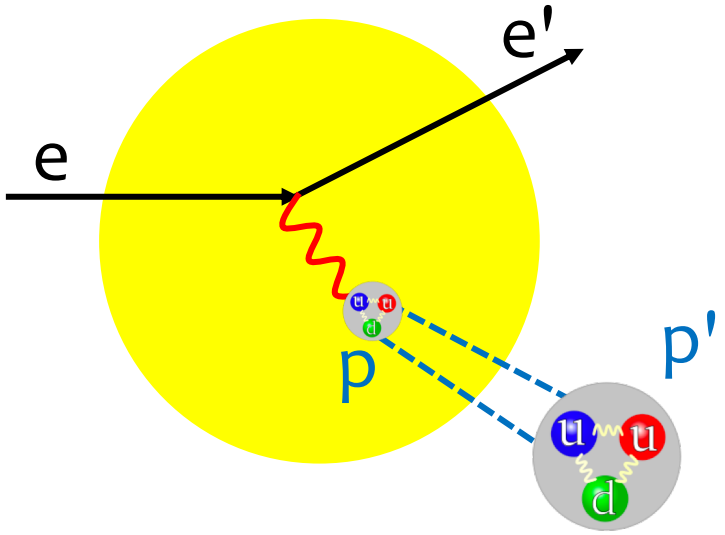


$$\sigma_A = \sigma_N\ A^{\alpha}$$

- scattering cross section
- Glauber multiple scattering
- Correlations and Final State Interaction (FSI) effects

Color transparency is a fundamental prediction of pQCD

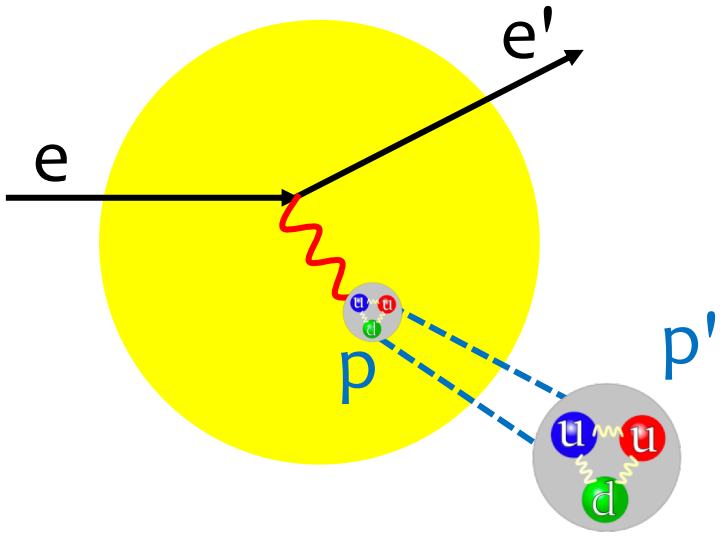
Introduced by
Mueller and Brodsky, 1982



Vanishing of final state interactions of hadrons with nuclear medium in exclusive processes at high momentum transfer

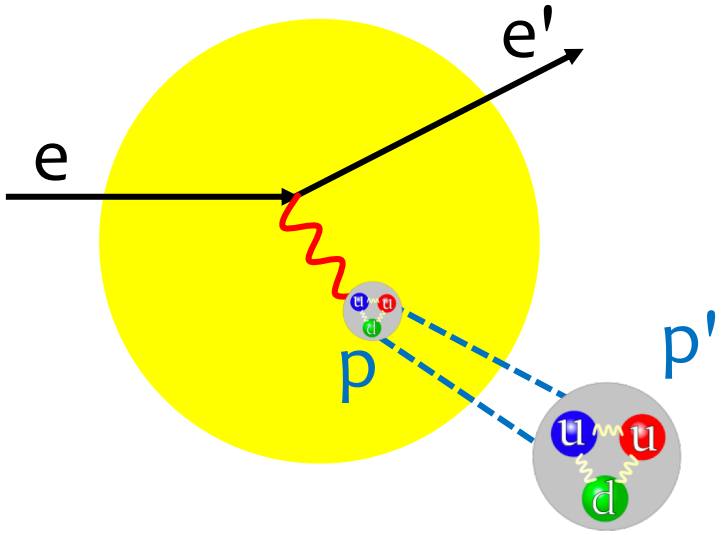
Color transparency is a fundamental prediction of pQCD

Quantum mechanics:
Hadrons fluctuate to small transverse size (*squeezing*, transferred momentum)



Color transparency is a fundamental prediction of pQCD

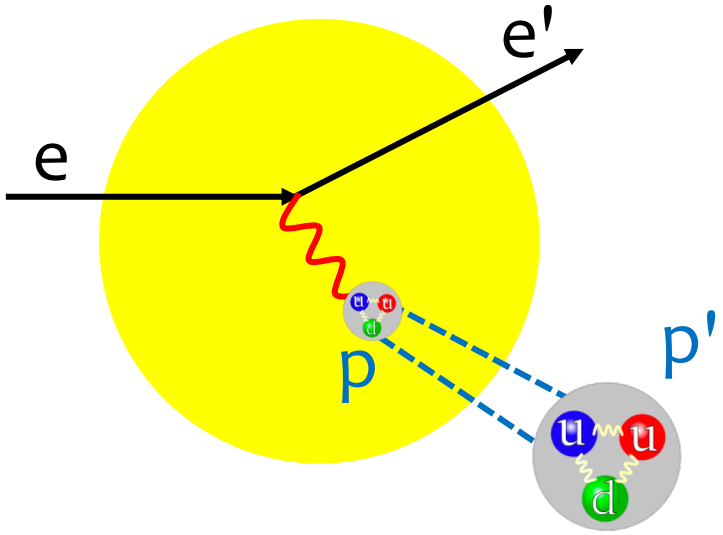
Quantum mechanics:
Hadrons fluctuate to small transverse size (*squeezing*, transferred momentum)



Relativity:
Maintains this small size as it propagates out of the nucleus (*freezing*, transferred energy)

Color transparency is a fundamental prediction of pQCD

Quantum mechanics:
Hadrons fluctuate to small transverse size (*squeezing*, transferred momentum)

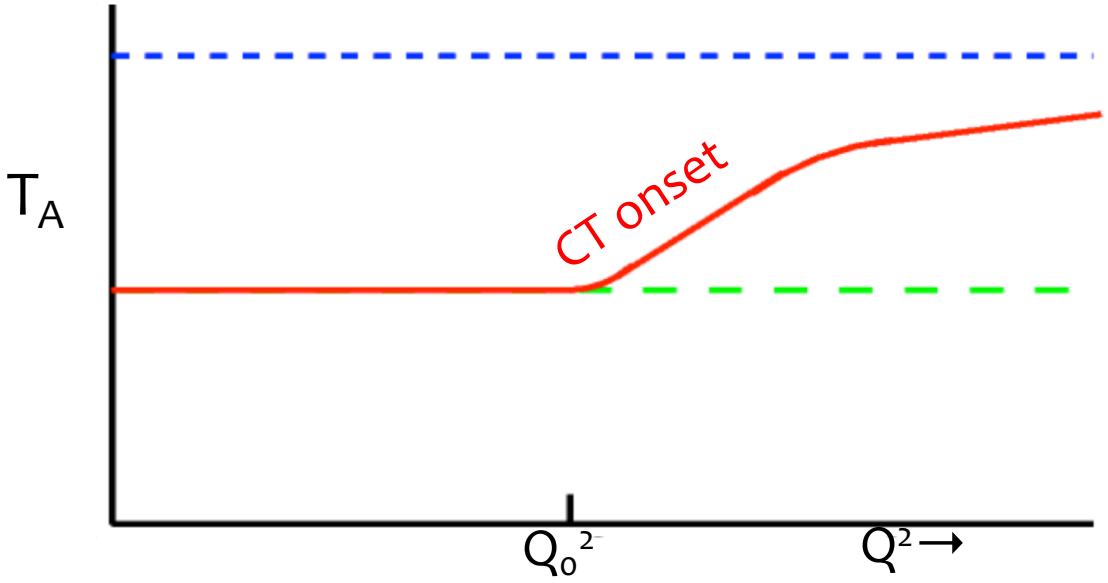


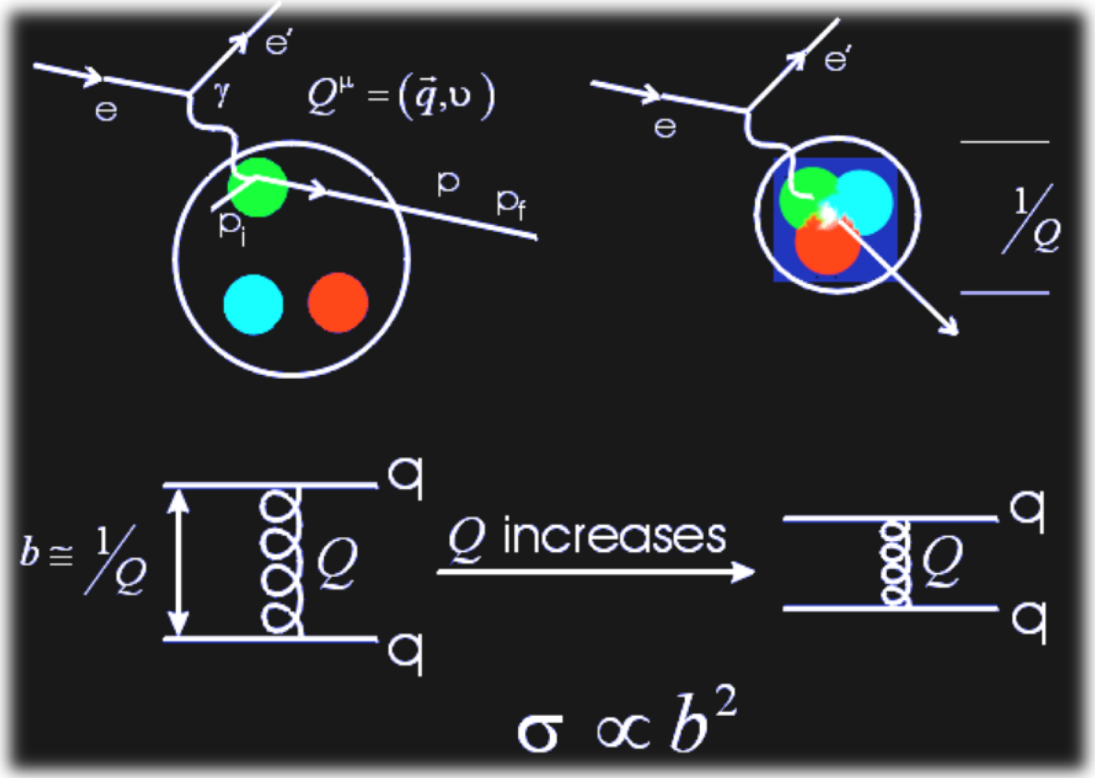
Relativity:
Maintains this small size as it propagates out of the nucleus (*freezing*, transferred energy)

Strong force:
Experience reduced attenuation in the nucleus, color screened

Onset of CT indicates the transition to quark-gluon degrees of freedom

CT is unexpected in the strongly interacting hadronic picture

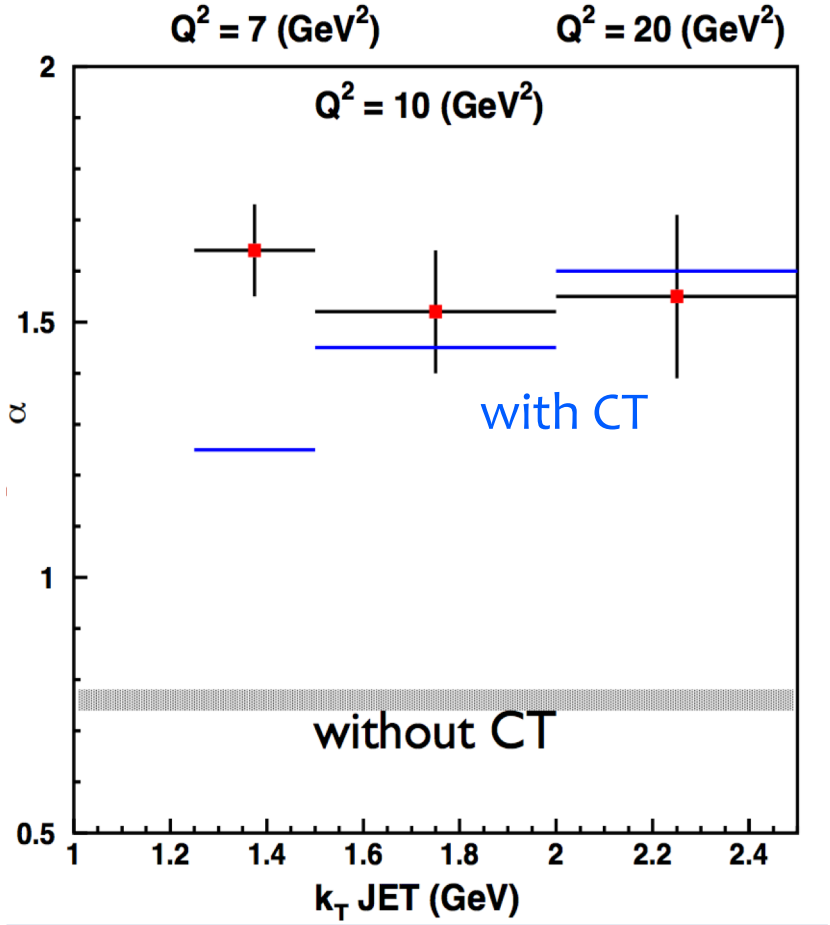




CT established at high energies

Coherent diffractive dissociation of 500 GeV/c pions on C and Pt

π + A $\longrightarrow$ 2 jets + A'



Fit to $\sigma = \sigma_0 A^{\alpha}$

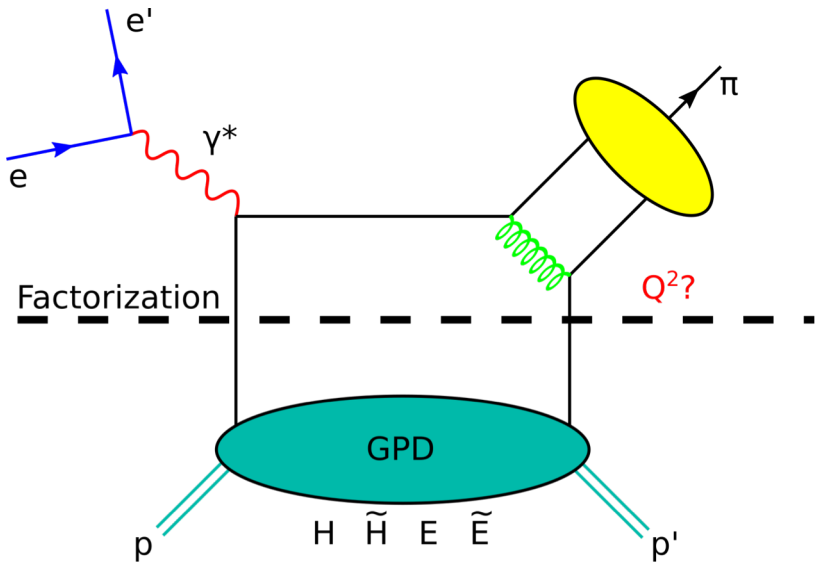
Pion-nucleus total cross section, α=1.6

CT predictions by L. L. Frankfurt, G. A. Miller, and M. Strikman, Phys. Lett. B304, 1 (1993)

Aitala et al., PRL 86, 4773 (2001)

CT is connected to other physics interpretations

GPD framework requires factorization into a hard interaction with single quark and soft part (GPDs).



Color cancellation required for factorization:

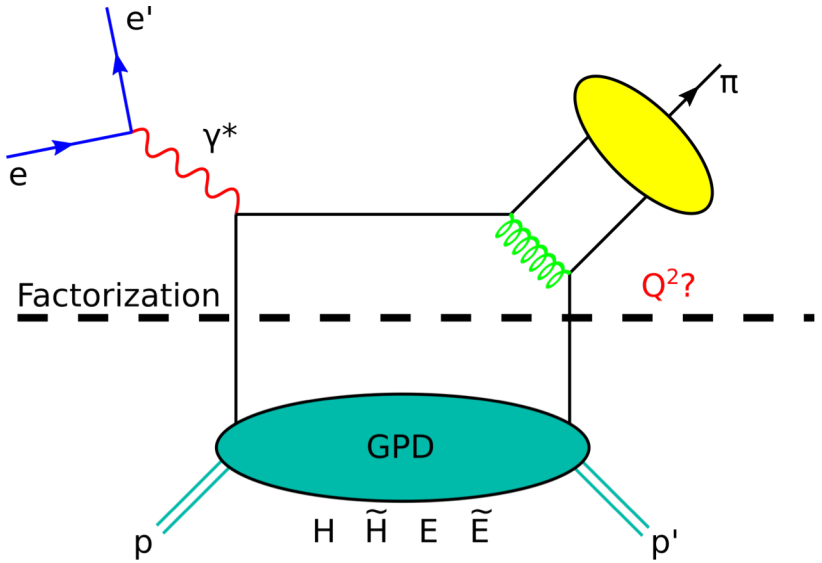
-> small size configurations

-> at high Q^2 , small size object moves through nucleus with no further interactions

L. Frankfurt and M. Strikman, Phys Rep. 160, 235 (1988).

CT is connected to other physics interpretations

GPD framework requires factorization into a hard interaction with single quark and soft part (GPDs).



Color cancellation required for factorization:

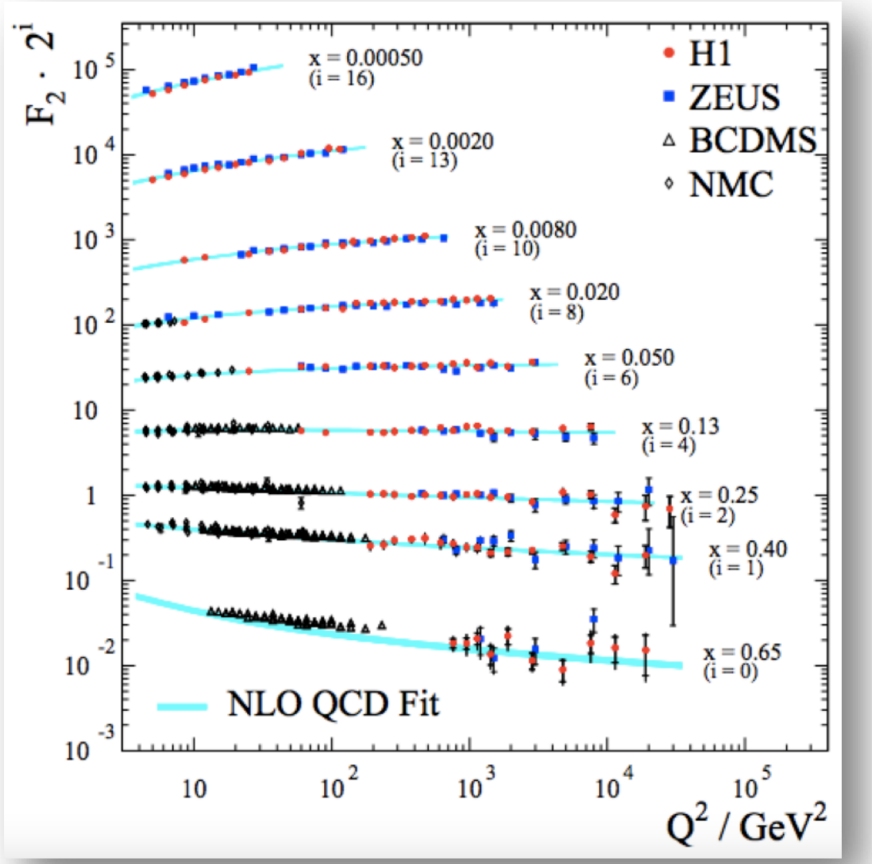
-> small size configurations

-> at high Q^2 , small size object moves through nucleus with no further interactions

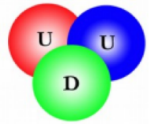
L. Frankfurt and M. Strikman, Phys Rep. 160, 235 (1988).

CT is implied by successful description of DIS.

Scaling at low x requires a suppression of interaction.



Onset of CT experiments

Baryon 

Meson 

A(e,e'p)

The Search for Color Transparency at 12 GeV

A(e,e'π^+)

2018: proton CT experiment
2021: D. Bhetuwal et al, PRL126:082301
2023: D. Bhetuwal, et al, PRC **108**, 025203

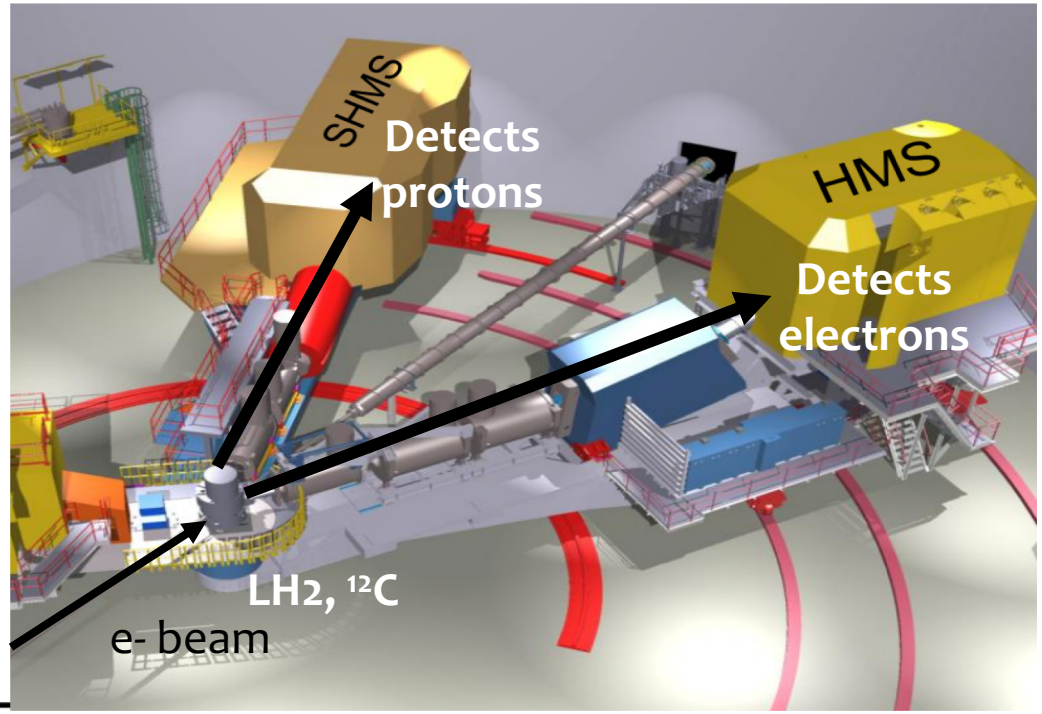
2025: pion CT scheduled to run!

→ Workshop in 2020
→ MDPI Special Issue
→ new proposal E12-23-010

Overview of the proton CT experiment

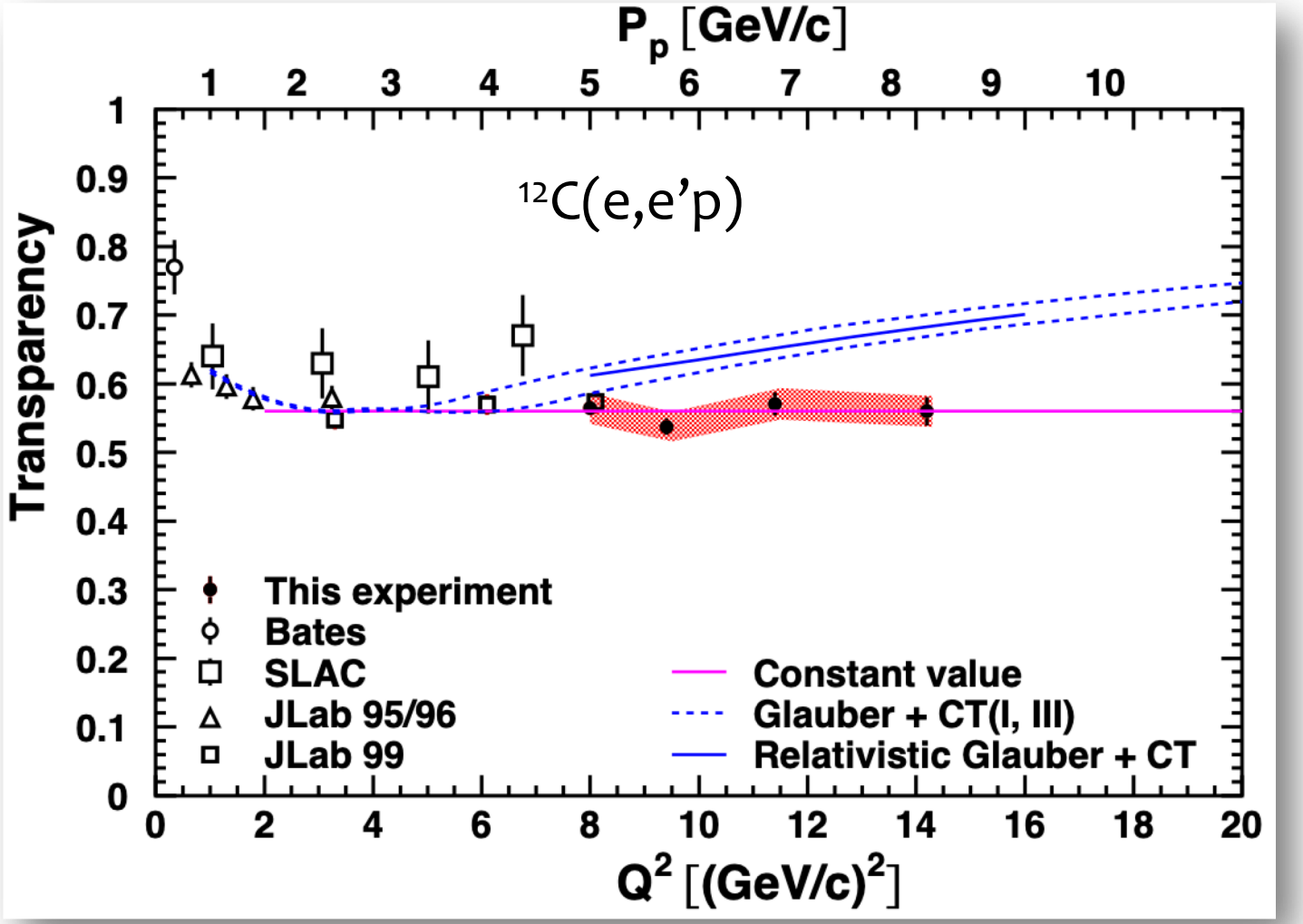
Commissioning experiment for Hall C SHMS

8.5 PAC days of running
- 10cm LH2,
- 5% r.l. carbon



	HMS		SHMS		
Q^2 (GeV/c^2)	$\theta_{e'}^{lab}$ (deg)	$p_{e'}$ (GeV/c)	θ_p^{lab} (deg)	p_p (GeV/c)	
8.0	45.1	2.125	17.1	5.030	6.4 GeV beam
9.4	23.2	5.481	21.6	5.830	10.6 GeV beam
11.4	28.5	4.451	17.8	6.882	10.6 GeV beam
14.2	39.3	2.970	12.8	8.352	10.6 GeV beam

Recent proton experiment shows no onset up to Q^2<14 GeV^2…

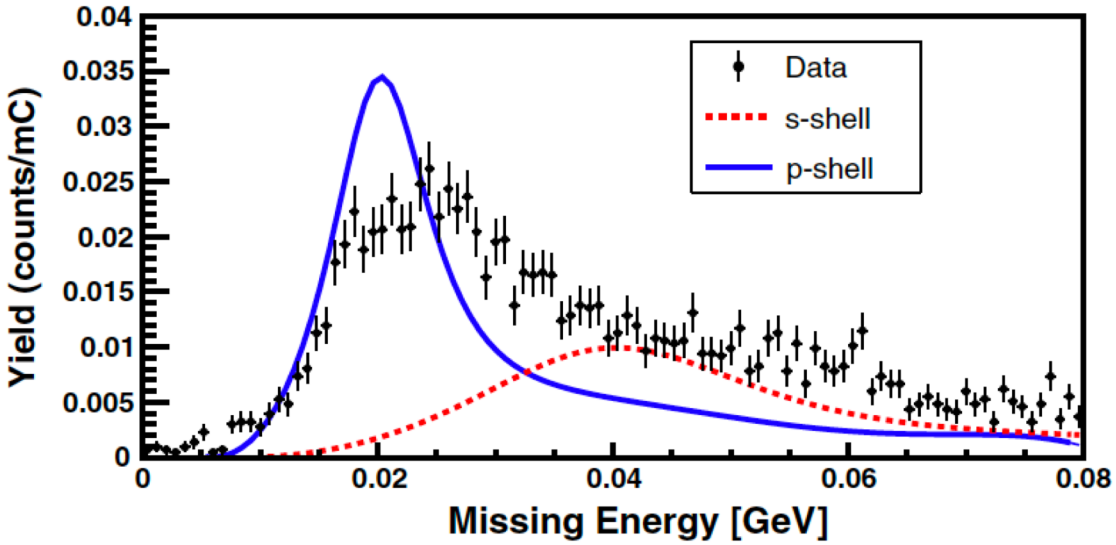


D. Bhetuwal et al, PRL126:082301 (2021)

No CT in the shell-dependent transparencies

CT predicted to be more prominent for $1s_{1/2}$ protons

Frankfurt, Nuclear Physics A515 (1990)

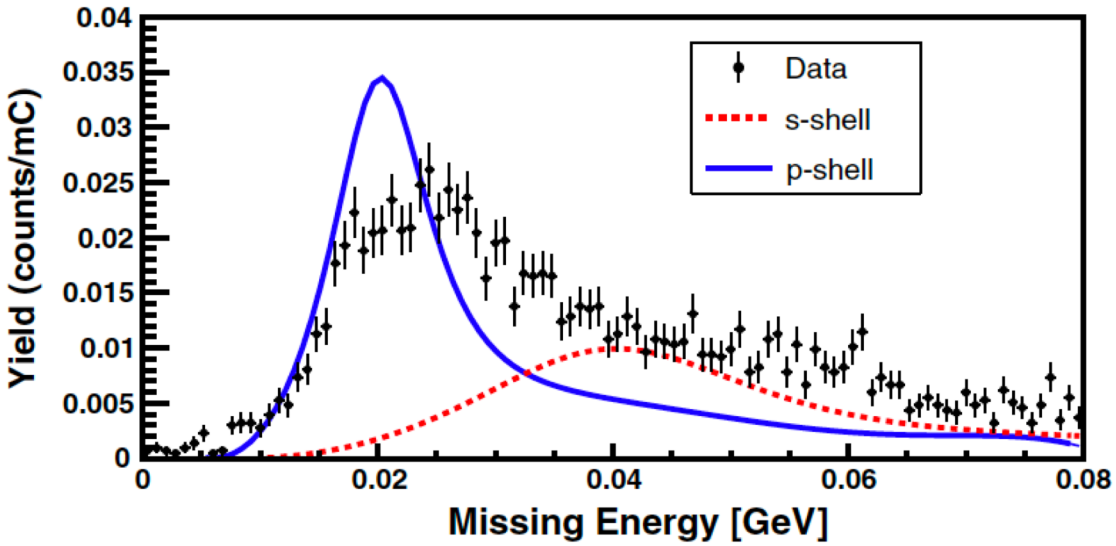


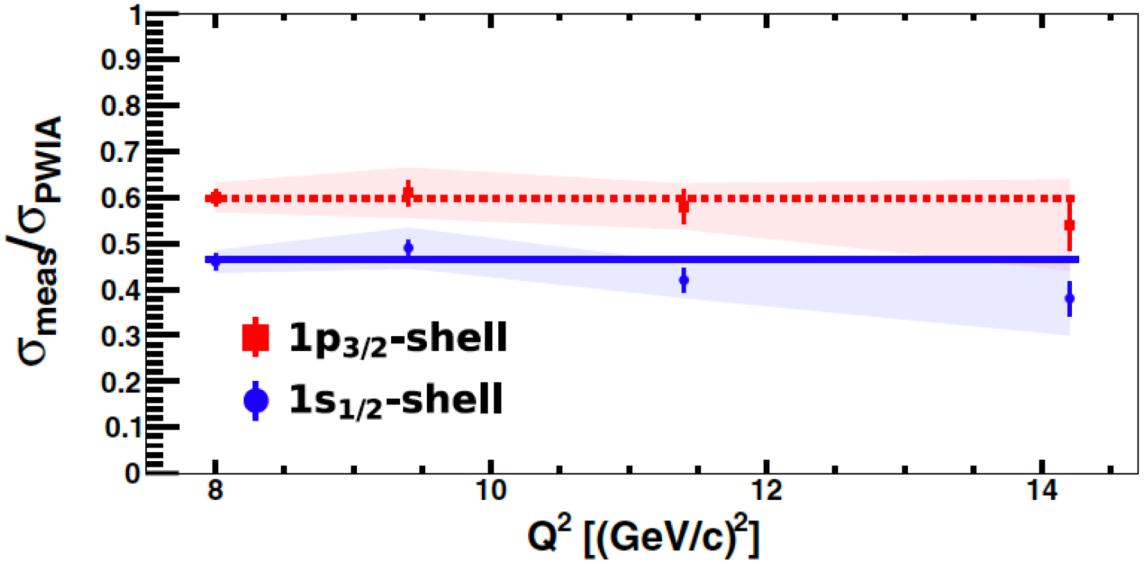
D. Bhetuwal, et al, Phys. Rev. C **108**, 025203 (2023)

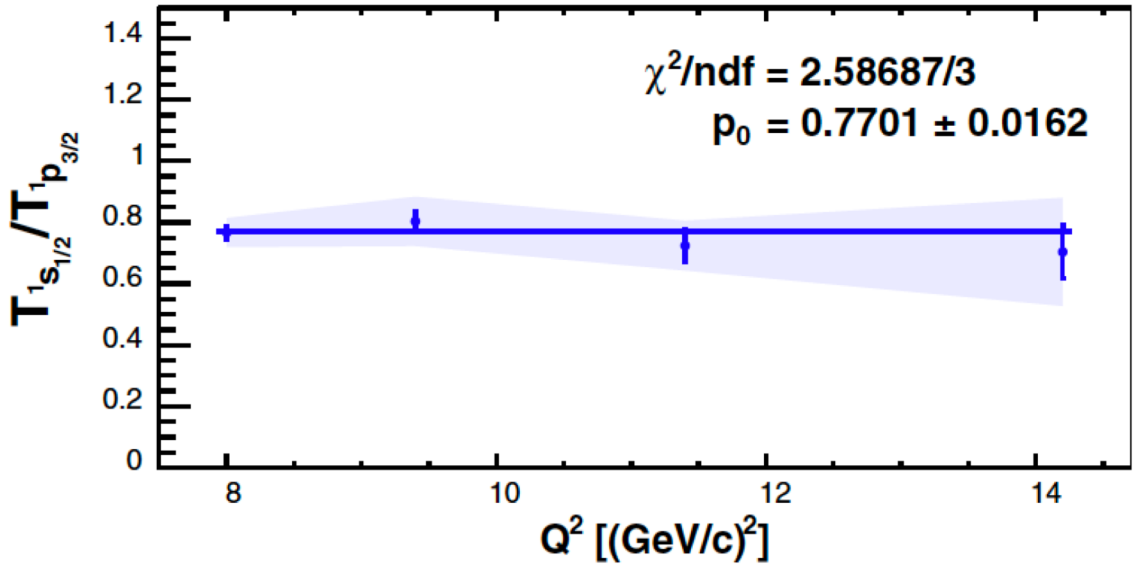
No CT in the shell-dependent transparencies

CT predicted to be more prominent for $1s_{1/2}$ protons

Frankfurt, Nuclear Physics A515 (1990)

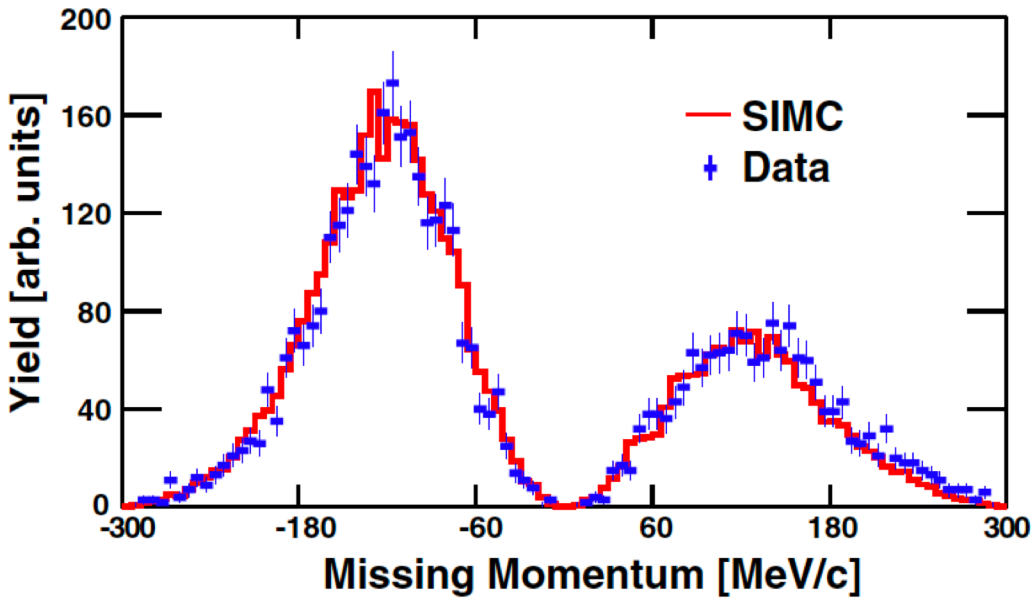






D. Bhetuwal, et al, Phys. Rev. C **108**, 025203 (2023)

No CT in the asymmetry relative to $\vec{q}$



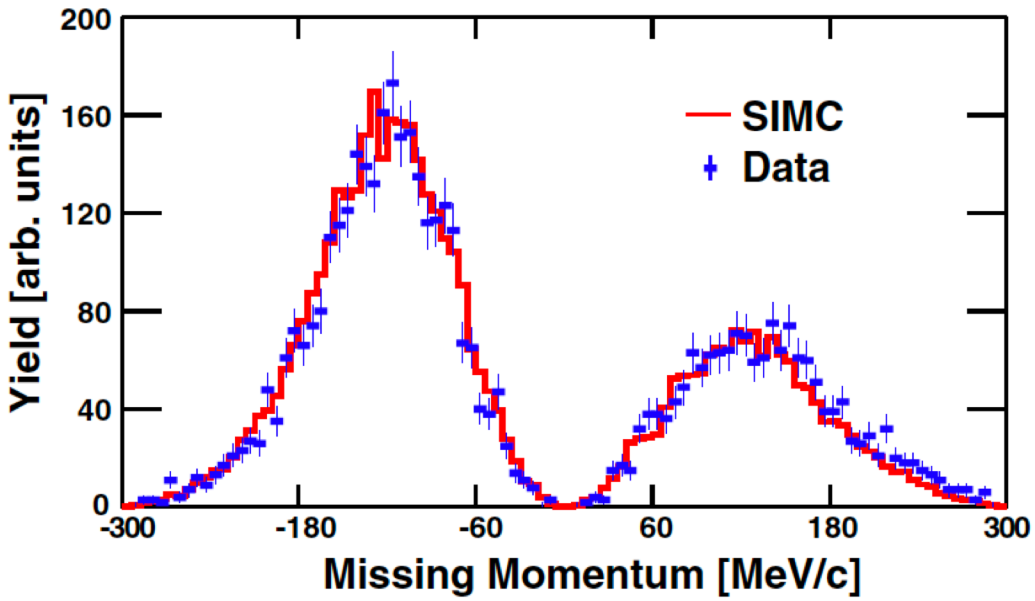
$\vec{p}_m \parallel \vec{q}$ $\quad\quad$ $\vec{p}_m \parallel -\vec{q}$

$$A_{pm} = \frac{N_+ - N_-}{N_+ + N_-}$$

CT arising from Fermi motion predicted to occur when $\vec{p}_m \parallel -\vec{q}$

Jennings and Kopeliovich PRL 70 (1993)
Bianconi et al, PLB 325 (1994)

No CT in the asymmetry relative to $\vec{q}$

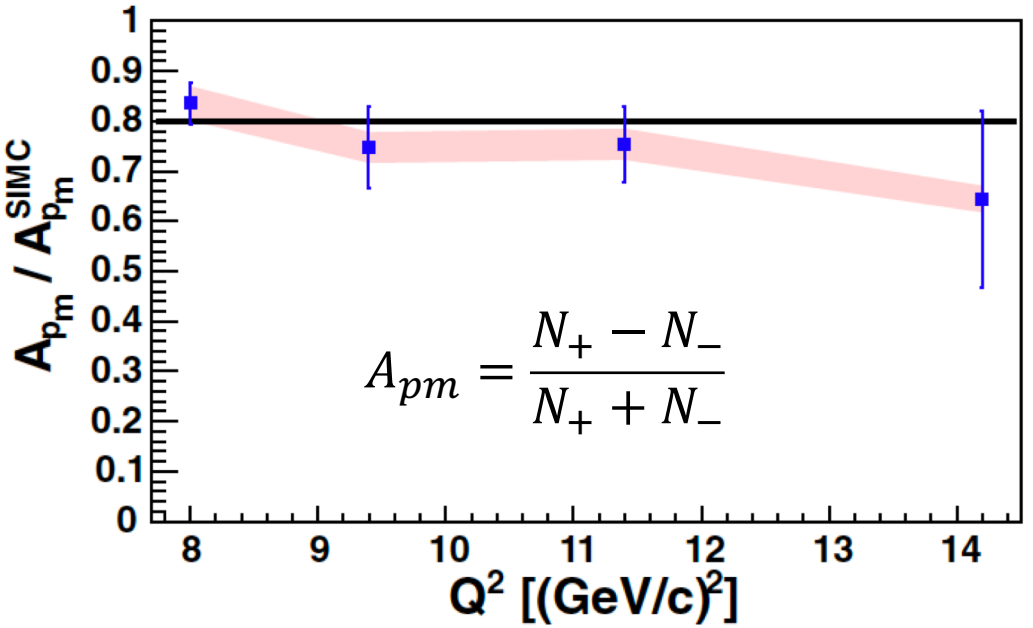


$\vec{p}_m \parallel \vec{q}$ $\quad\quad$ $\vec{p}_m \parallel -\vec{q}$

CT arising from Fermi motion predicted to occur when $\vec{p}_m \parallel -\vec{q}$

Jennings and Kopeliovich PRL 70 (1993)
Bianconi et al, PLB 325 (1994)

Studied A_{pm} in bins of missing energy and missing momentum
→ no CT-like effect observed

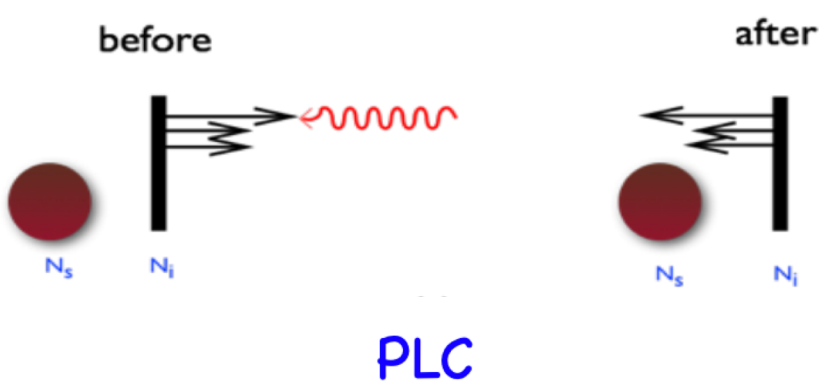


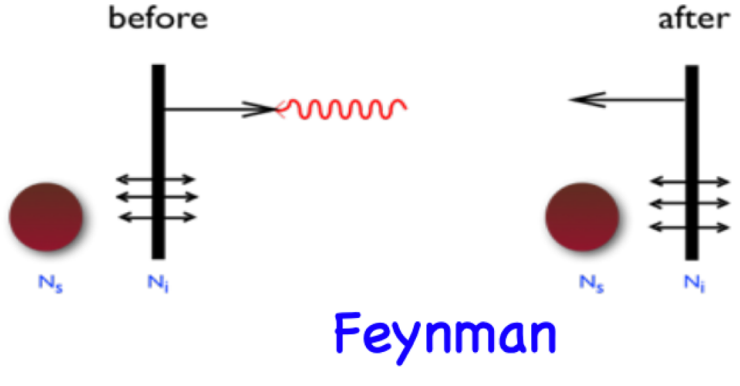
D. Bhetuwal, et al, Phys. Rev. C **108**, 025203 (2023)

(Some) interpretations

No PLC was formed (Feynman Mechanism)

G. Miller, Physics 2022
O. Caplow-Munro and G. Miller, PRC 104 (2021)

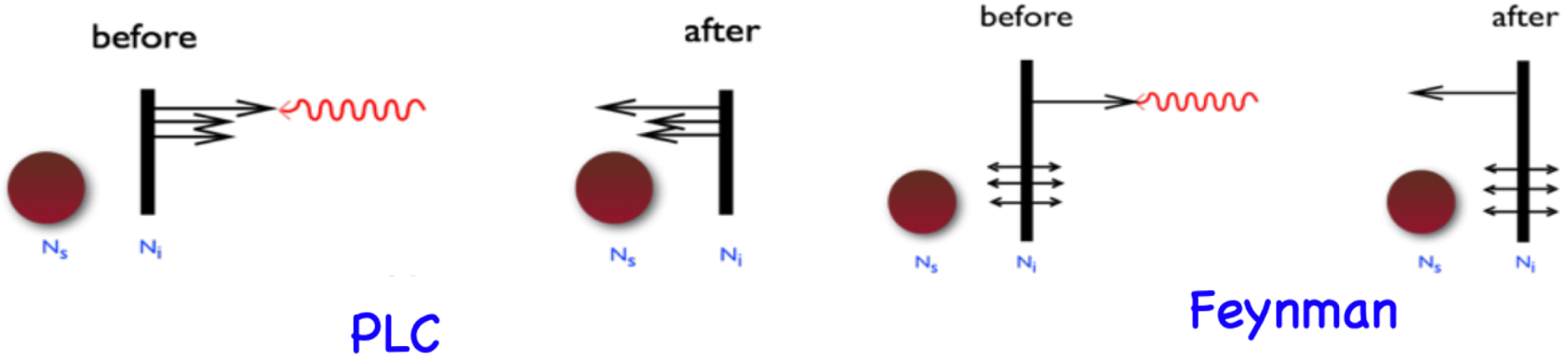




(Some) interpretations

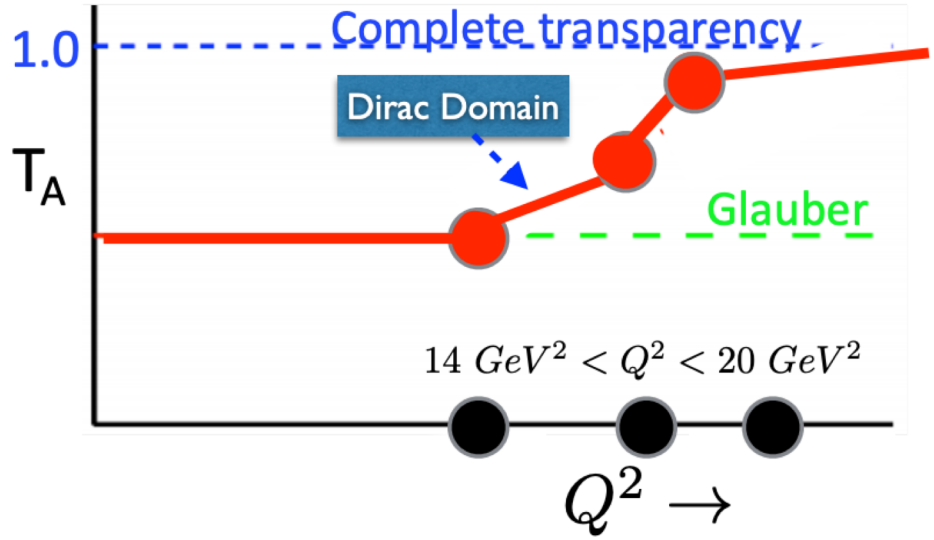
No PLC was formed (Feynman Mechanism)

G. Miller, Physics 2022
O. Caplow-Munro and G. Miller, PRC 104 (2021)



HLFQCD says we need higher Q^2

Brodsky and de Téramond, Physics 2022



Let's talk about near-term running in Hall C

A(e,e'π^+)

17.5 PAC days of running

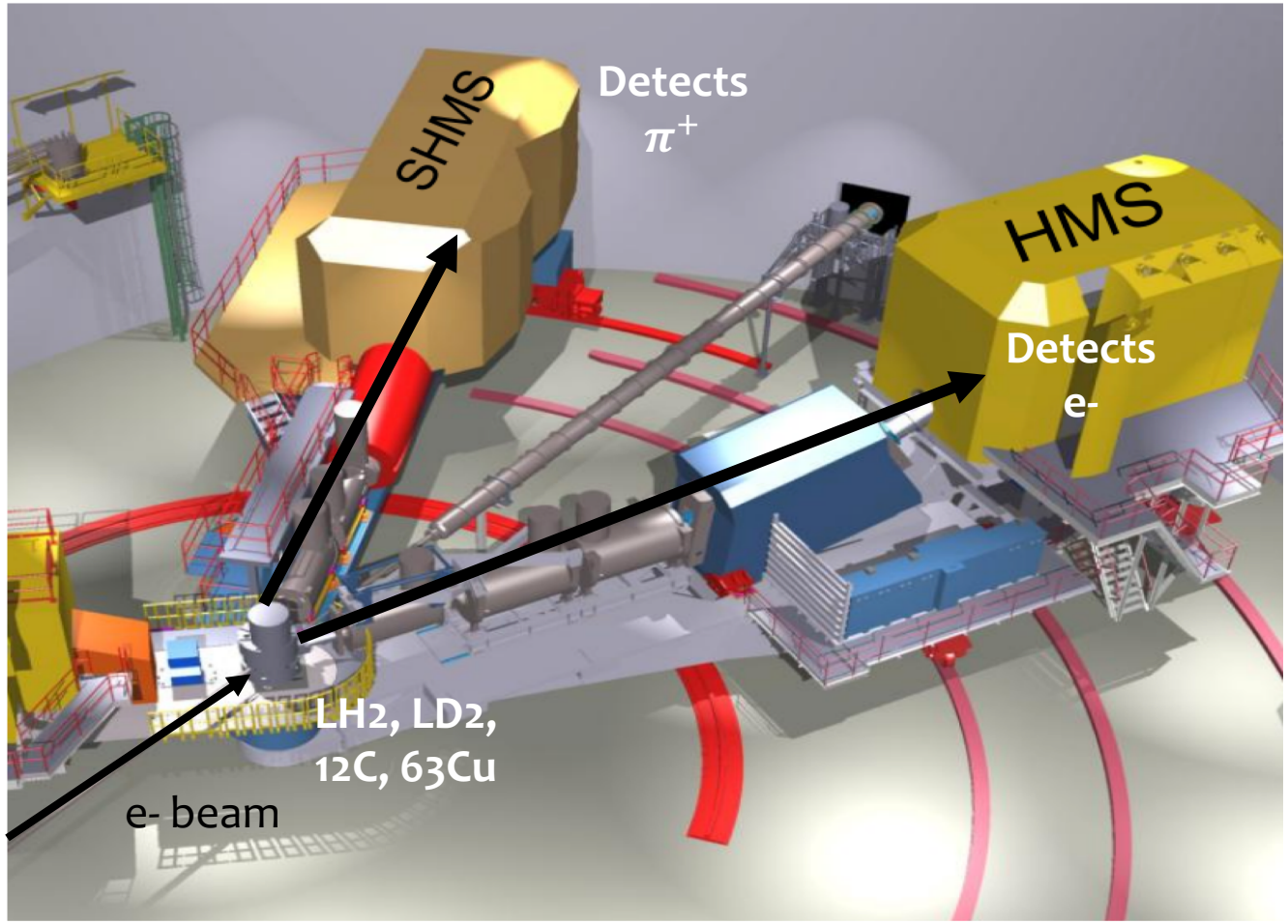
11 GeV beam

^{1}H, ^{2}H, ^{12}C, ^{63}Cu

Q^2	W	$\theta_{e'}^{HMS}$	$E_{e'}$	θ_{π}^{SHMS}	p_{π}	k_{π}
$(\mathrm{GeV/c})^2$	GeV	deg	GeV	deg	GeV/c	GeV
5.0	2.43	16.28	5.67	15.96	5.110	0.67
6.5	2.74	22.13	4.010	11.72	6.771	0.67
8.0	3.02	32.37	2.340	7.90	8.442	0.67
9.5	3.09	47.71	1.320	5.52	9.42	0.74

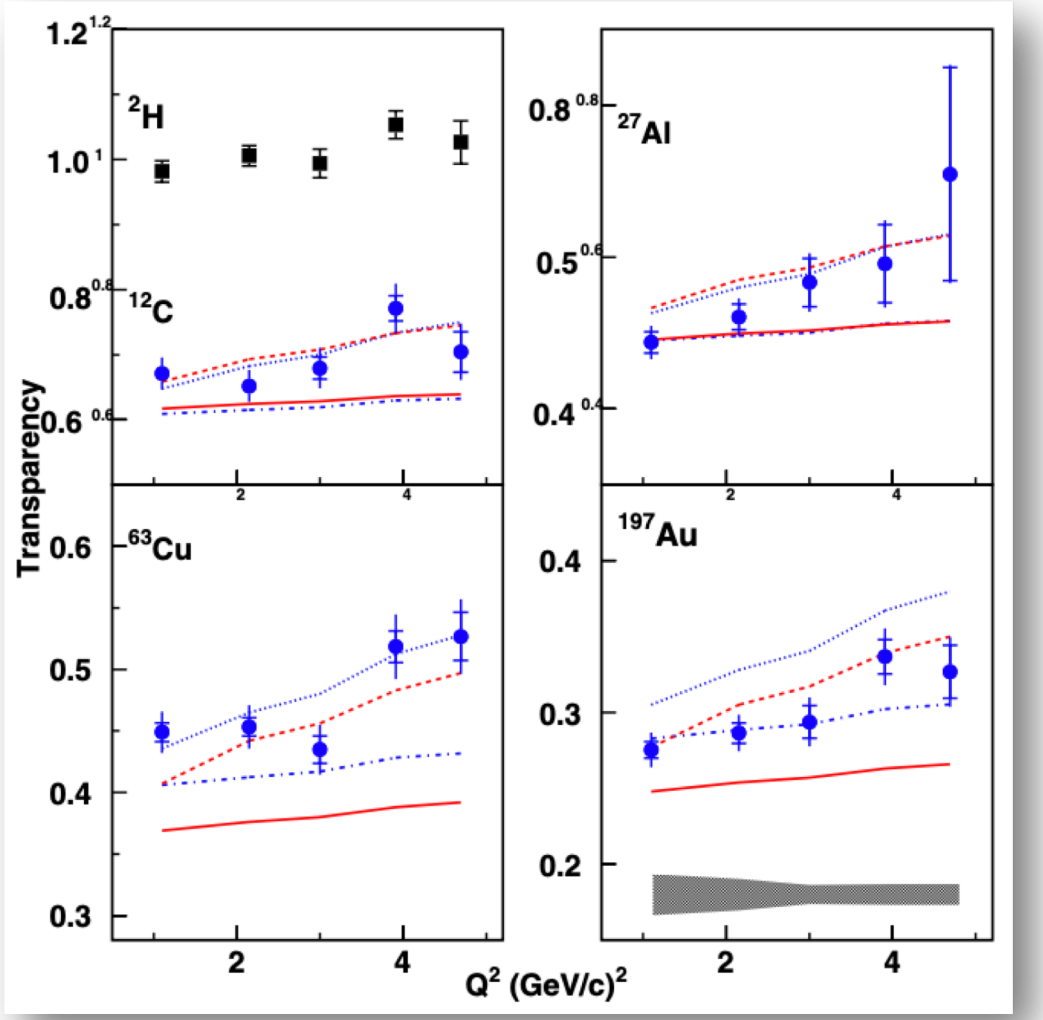
Heavy gas for π+/K+ discrimination

Noble gas with Ar



Onset for mesons observed at few GeV²

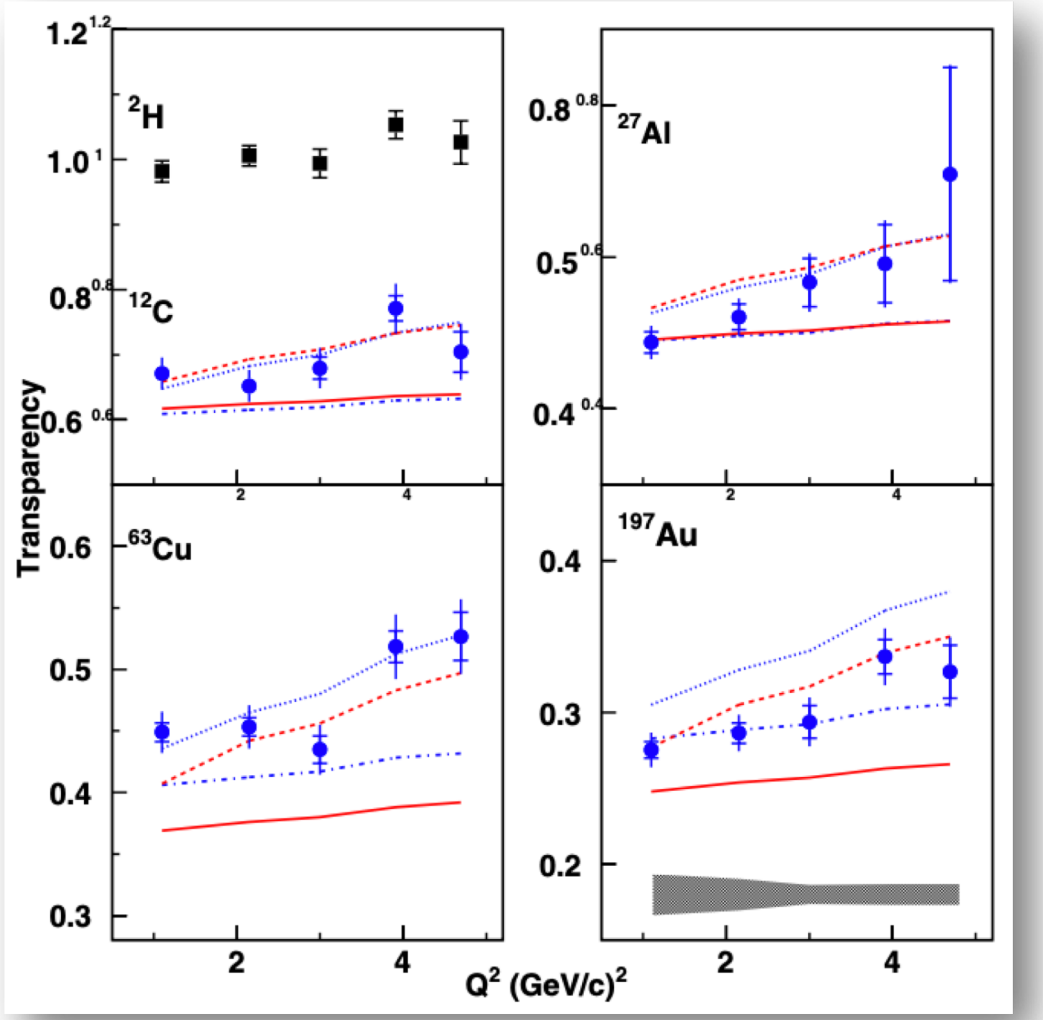
Hall C: A(e,e'π^+)



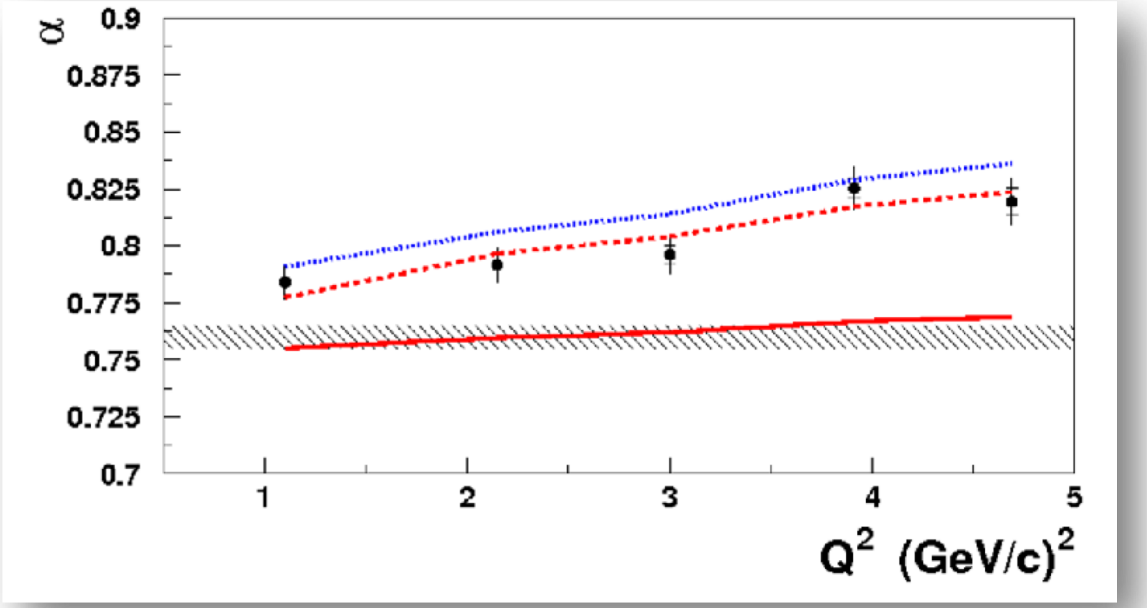
B. Clasie et al, PRL99:242502 (2007)
X. Qian et al, PRC81:055209 (2010)

Onset for mesons observed at few GeV²

A(e,e'π^+)

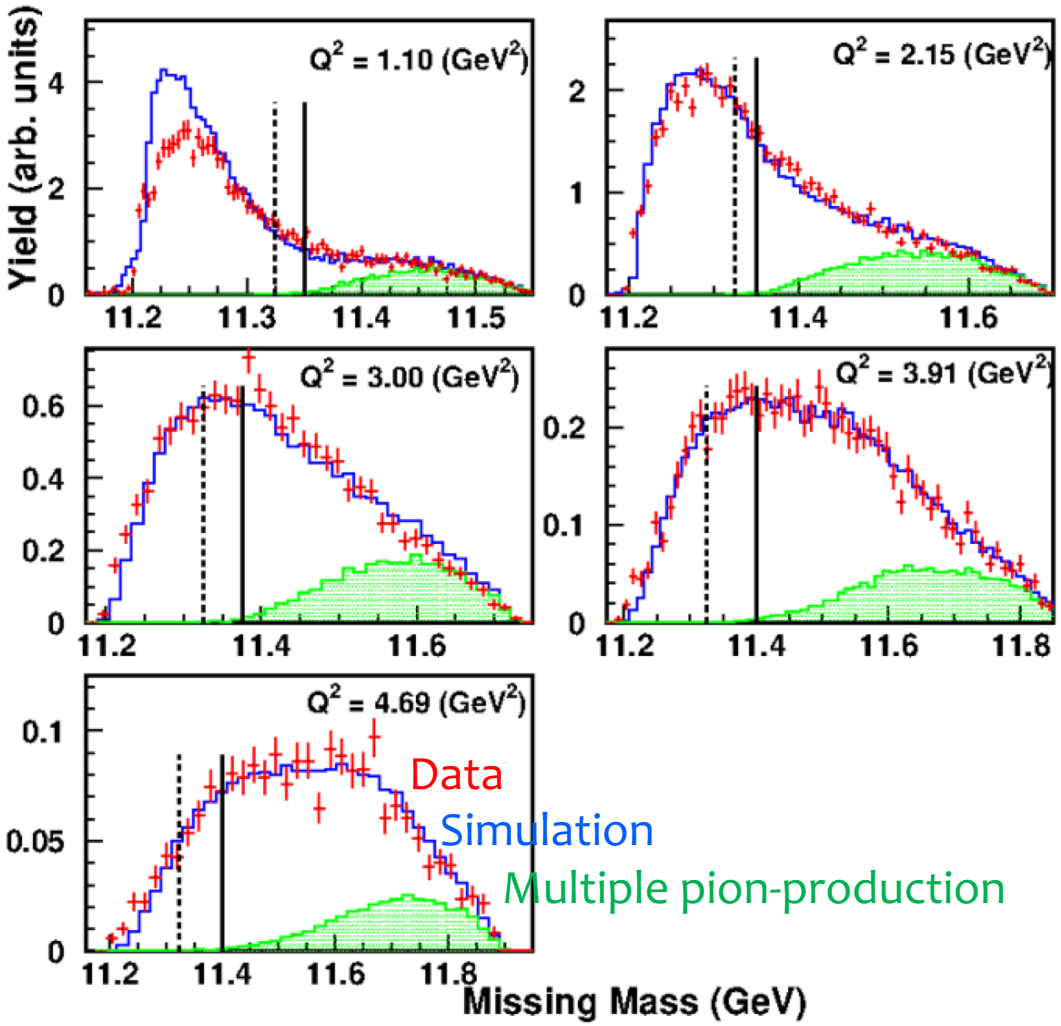


Extracted from $T = A^{\alpha-1}$



B. Clasie et al, PRL99:242502 (2007)
X. Qian et al, PRC81:055209 (2010)

Previous analysis



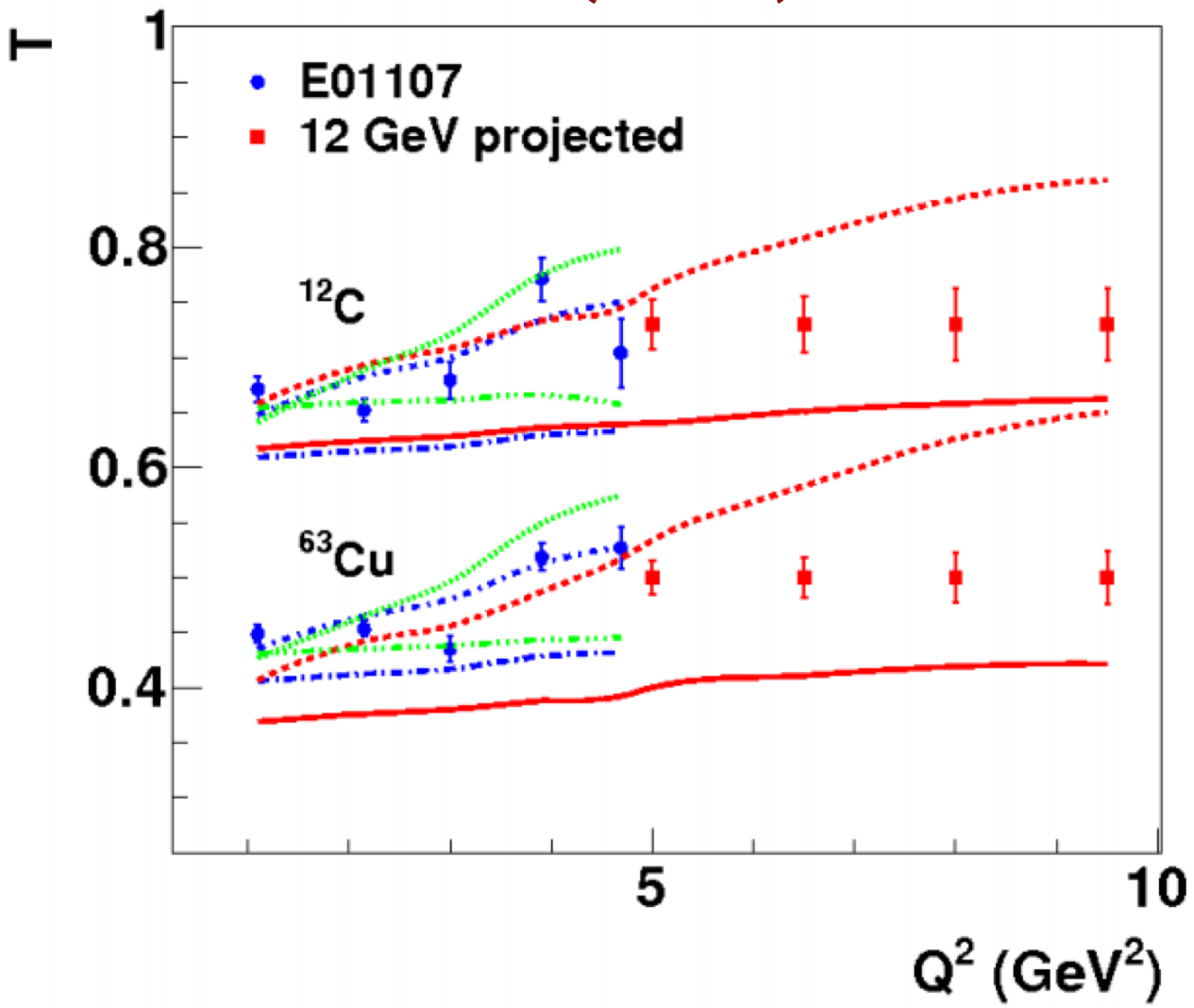
$$M_{miss} = M_{A-1} + M_{\pi}$$

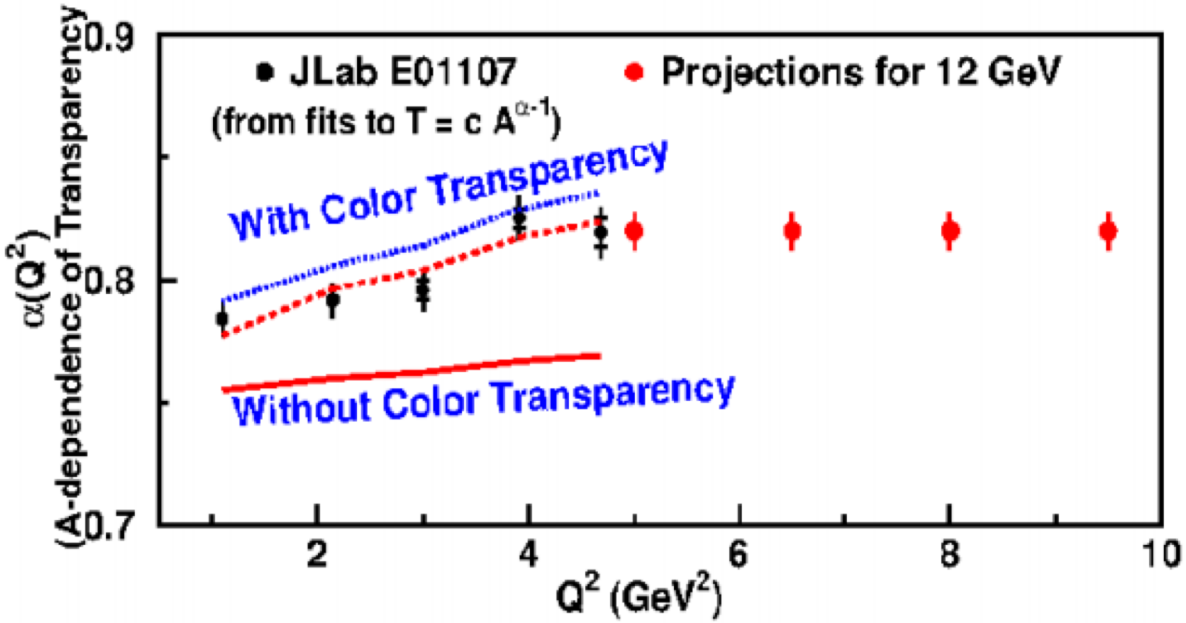
Compare A>1 yields with H(e,e'π^+), PWIA

Evaluate Q^2 and A dependence

Measure the onset over a large momentum range

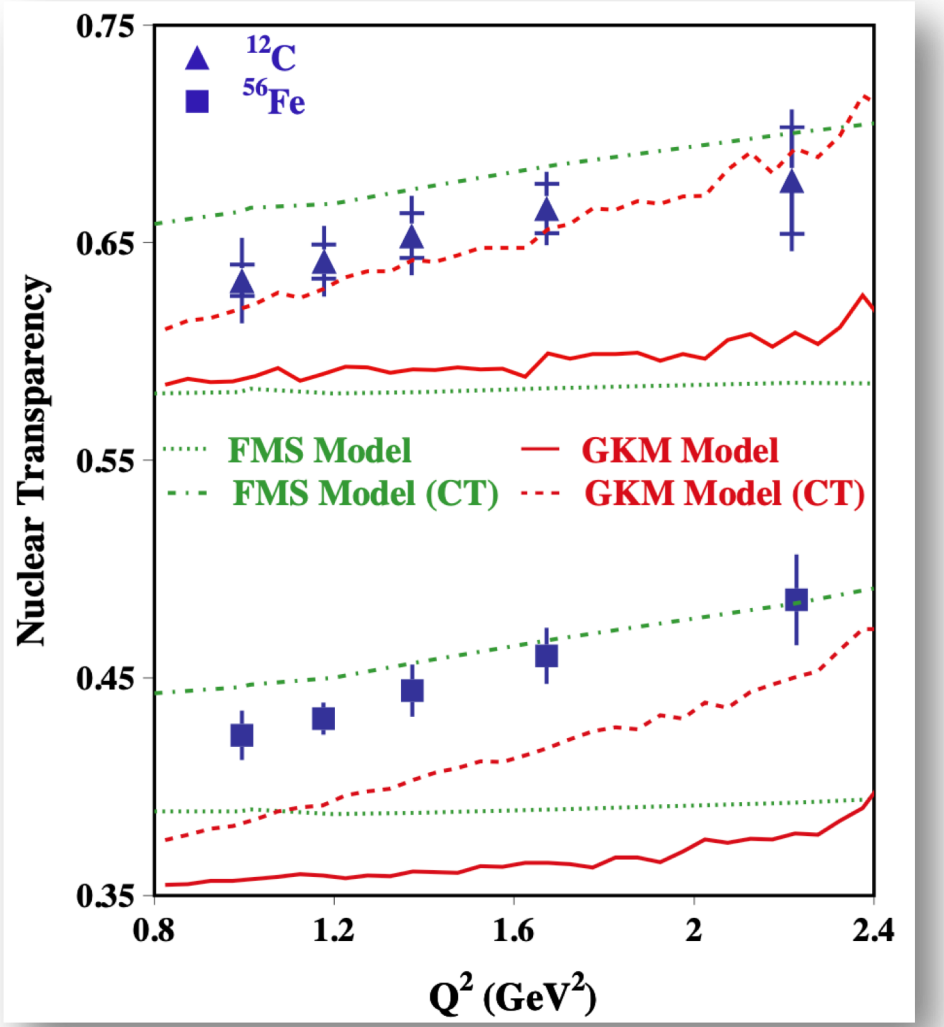
A(e,e'π^+)

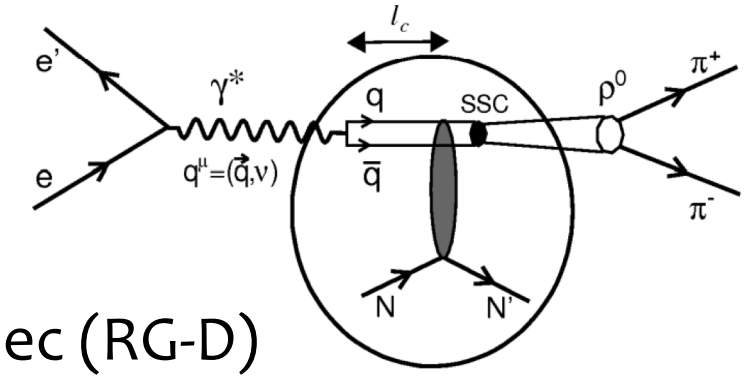




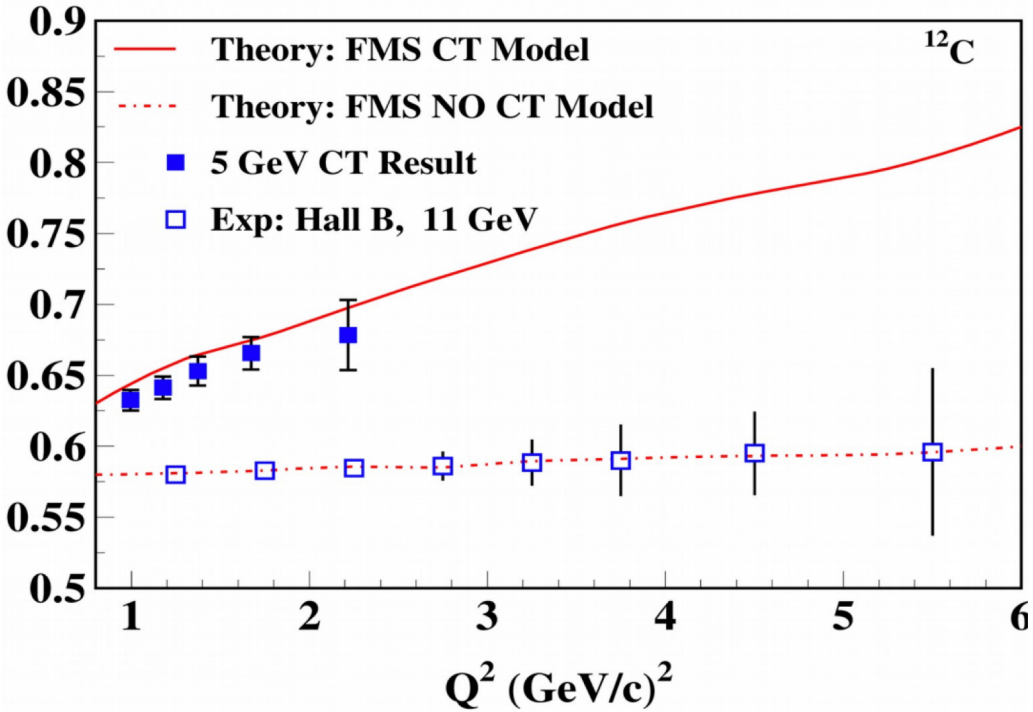
Hall B is extending rho-meson measurements

Hall B: A(e,e'ρ⁰)





Completed running in Dec (RG-D)
Targets: deuterium, ^{12}C, ^{63}Cu, ^{120}Sn



L. El Fassi et al, PLB 712,326 (2012)
L. El Fassi, Physics 4, no. 3 (2022)

Summary

- Onset of CT is an exciting opportunity to explore the connection between hadronic and partonic degrees of freedom in nuclei

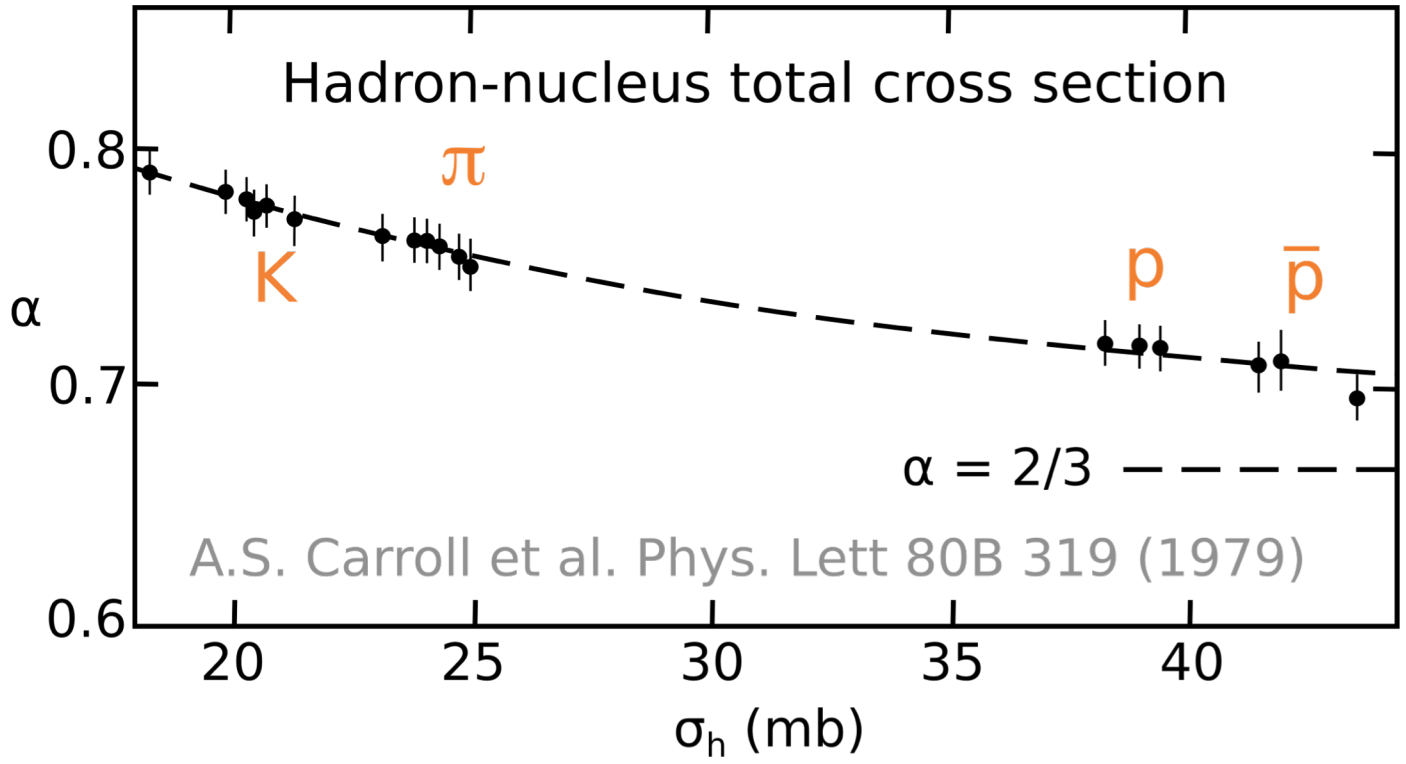
- Not observed in protons in the recent Hall C experiment

- Hall C will measure A(e,e'π^+) in 2025
  - Pion propagation in nuclear matter
  - Map onset of CT through factorization regime

Looking forward to running next year. Sign up for shifts, and join our team!

Absorption cross section is momentum independent

Hadron momenta:
60, 200, 280 GeV/c



$\sigma_A(A) = \sigma_N A^{\alpha}$

Targets of
C, Li, Al, Sn, Cu, Pb

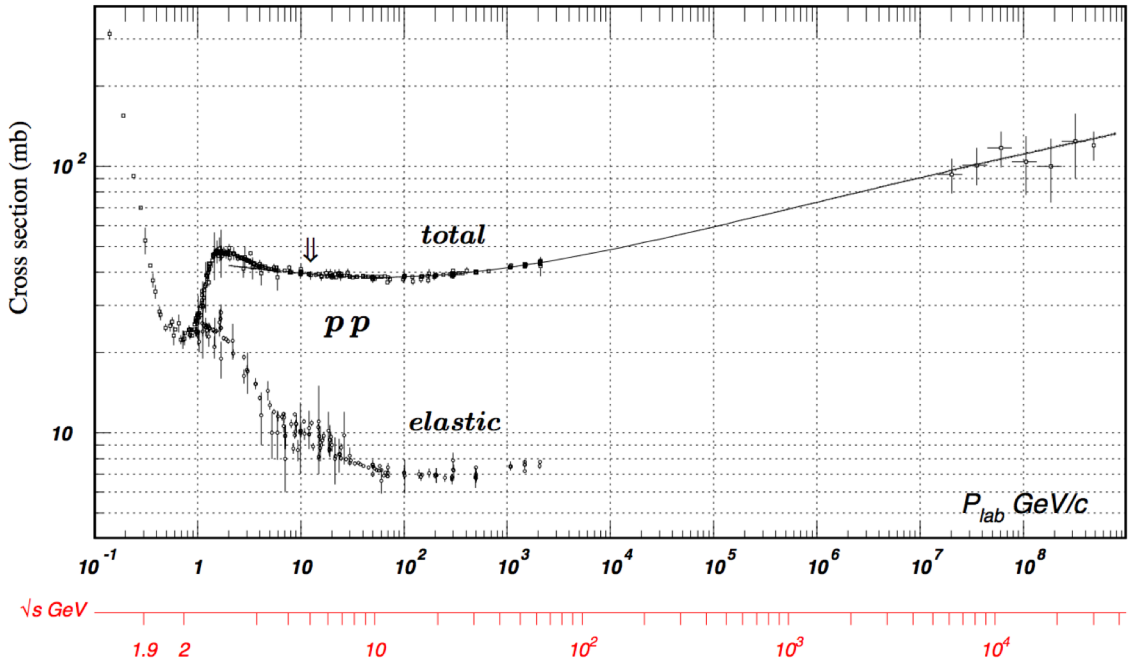
α <1 due to strong interaction nature of the probe

Tendency of $\alpha \rightarrow 2/3$ expected for opaque nucleus

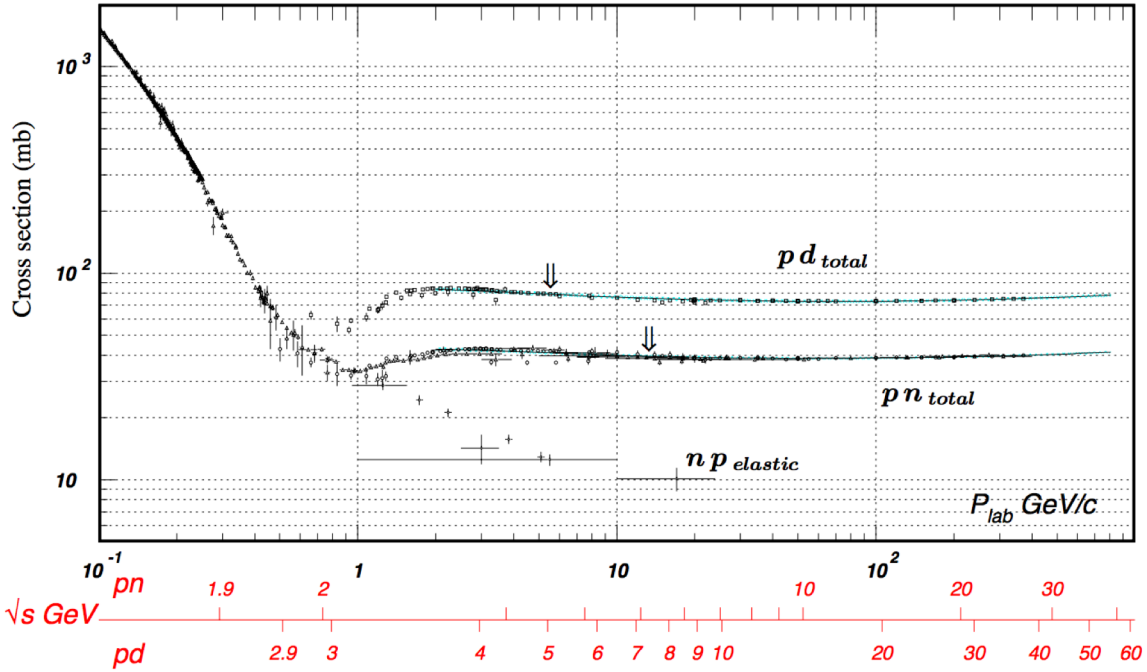
NN cross section

NN cross section is essentially energy independent

pp scattering cross section



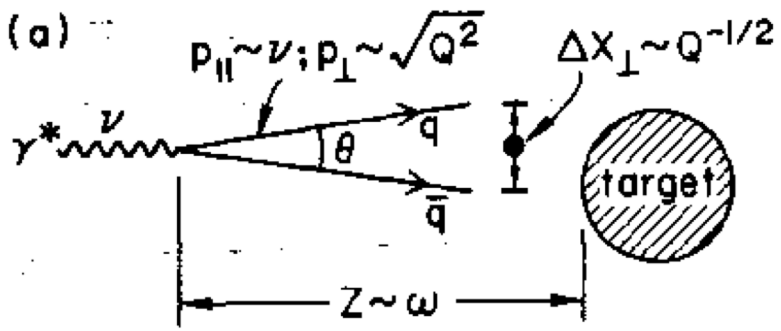
pn scattering cross section



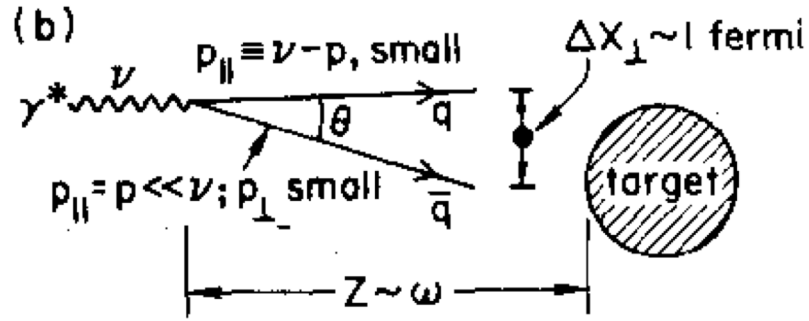
DIS picture

Small-x picture

No interaction



Interaction



Large-x picture

Interaction