The SHMS and the Hall C L/T Separated (SI)DIS Program

Thia Keppel

Hampton University / Jefferson Lab

Deep Inelastic Scattering 2009

April 2009

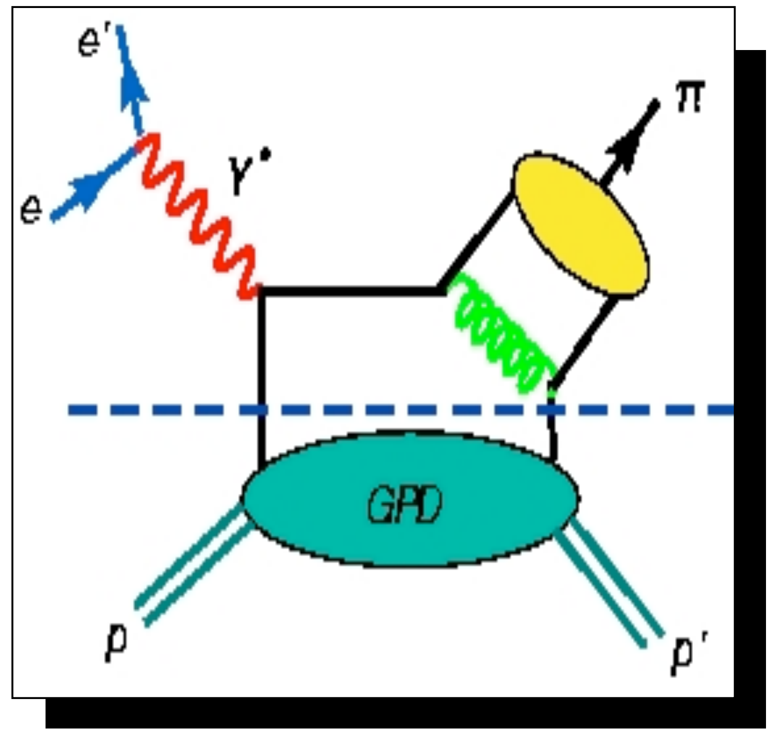
Hall-C 12 GeV Experiments

	Title	Spokespersons
12-06-101	Measurement of the Charged Pion Form Factor to High Q^2	G. Huber, D. Gaskell
12-06-104	Measurement of the Ratio R = sigma_L/sigma_T in Semi-Inclusive DIS	R. Ent, P. Bosted, H. Mkrtchyan
12-06-105	Inclusive Scattering from Nuclei at x > 1 in the quasi-elastic and deep-inelastic regimes	D. Day, J. Arrington
12-06-121	A Path to "Color Polarizabilities" in the Neutron: A Precision Measurement of the Neutron g_2 and d_2 at High Q^2 in Hall C	B. Sawatzky, T. Averett, W. Korsch, Z.E. Meziani
12-07-105	Scaling Study of the L-T Separated Pion Electroproduction Cross-Section at 11 GeV	T. Horn, G. Huber
12-06-107	The Search for Color Transparency at 12 GeV	D. Dutta, R. Ent
12-06-110	Measurement of the Neutron Spin Asymmetry A1n in the Valence Quark Region Using an 11 GeV Beam in Hall C	X. Zheng, J.P. Chen, G. Cates, Z.E. Meziani
12-07-101	Hadronization in Nuclei by Deep Inelastic Electron Scattering	B.E. Norum, J.P. Chen, H. Lu, K. Wang
12-07-102	Precision Measurement of the Parity-Violating Asymmetry in DIS off Deuterium Using baseline 12-GeV Equipment in Hall C	P. Reimer, X. Zheng, K. Paschke
12-09-011	Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV	T. Horn, P. Markowitz
12-09-017	Transverse Momentum Dependence of Semi-Inclusive Pion Production	P. Bosted, R. Ent, H. Mkrtchyan
12-07-106	The A-Dependence of J/Psi Photoproduction near Threshold	E. Chudakov, P. Bosted, J. Dunne
12-09-006	The Neutron Electric Form Factor at Q2 up to 7 (GeV/c)2 from the Reaction 2H (→e, e′ →n)1H via Recoil Polarimetry	B.. Anderson, J. Arrington, S. Kowalski, R. Madey, B. Plaster, A. Semenov
12-09-001	GEp/GMp with an 11 GeV electron beam	E. Brash, C. Perdrisat
12-09-002	Precise Measurement of π −/π+ Ratios in Sem-Inclusive Deep Inelastic Scattering Part I: Charge Symmetry Violating Quark Distribution	K. Hafidi, D. Dutta

15 total

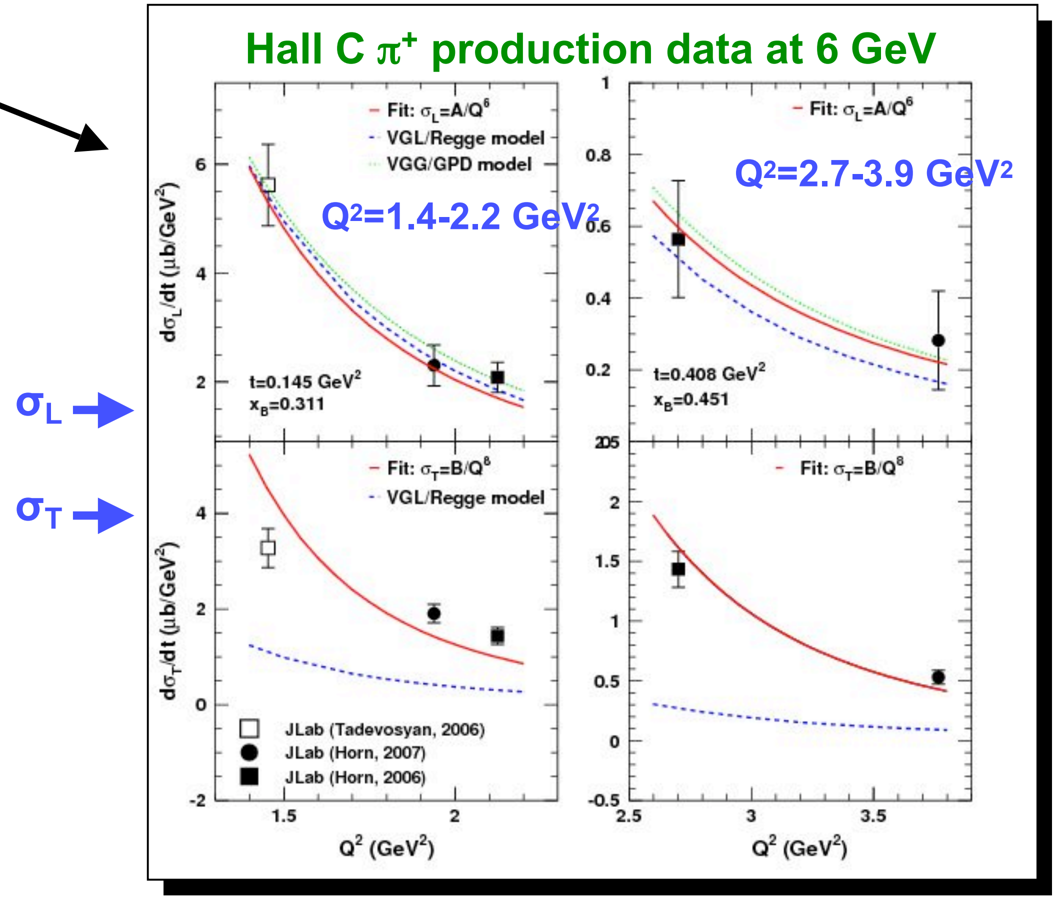
Deep Exclusive Factorization

- The kinematic regime where hard-soft factorization applies allows access to physics contained in GPDs,….
  - No single criterion for the applicability, but tests of necessary conditions can provide evidence that the Q^2 scaling regime has been reached
- One of the most stringent tests of factorization is the Q^2 dependence of the π electroproduction cross section
  - σ_L scales to leading order as Q^{-6}
  - σ_T scales as Q^{-8}
  - As Q^2 becomes large: $\sigma_L >> \sigma_T$
  - In nuclei, onset of color transparency
- Factorization theorems for meson electroproduction have been proven rigorously only for longitudinal photons *[Collins, Frankfurt, Strikman, 1997]*
  - Dominance of σ_L is important as it contains the GPD to be extracted



Q^2 dependence of σ_L and σ_T

- σ_L is consistent with the Q^{-6} QCD, BUT $\sigma_L >> \sigma_T$ and $\sigma_T \sim Q^{-8}$ are not fulfilled

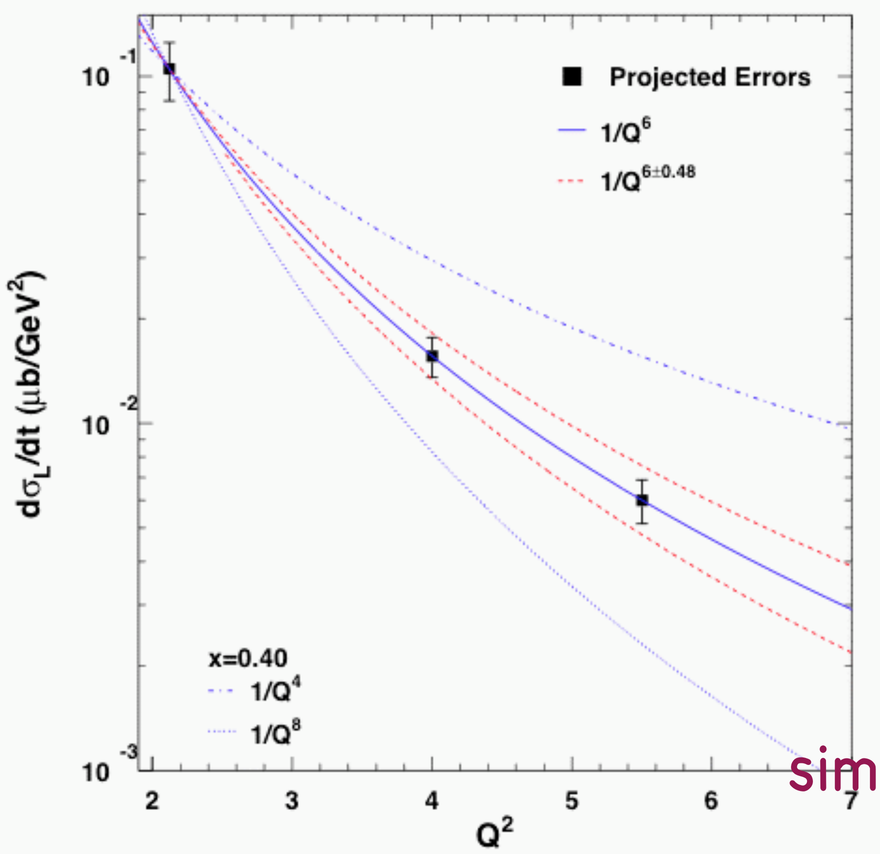


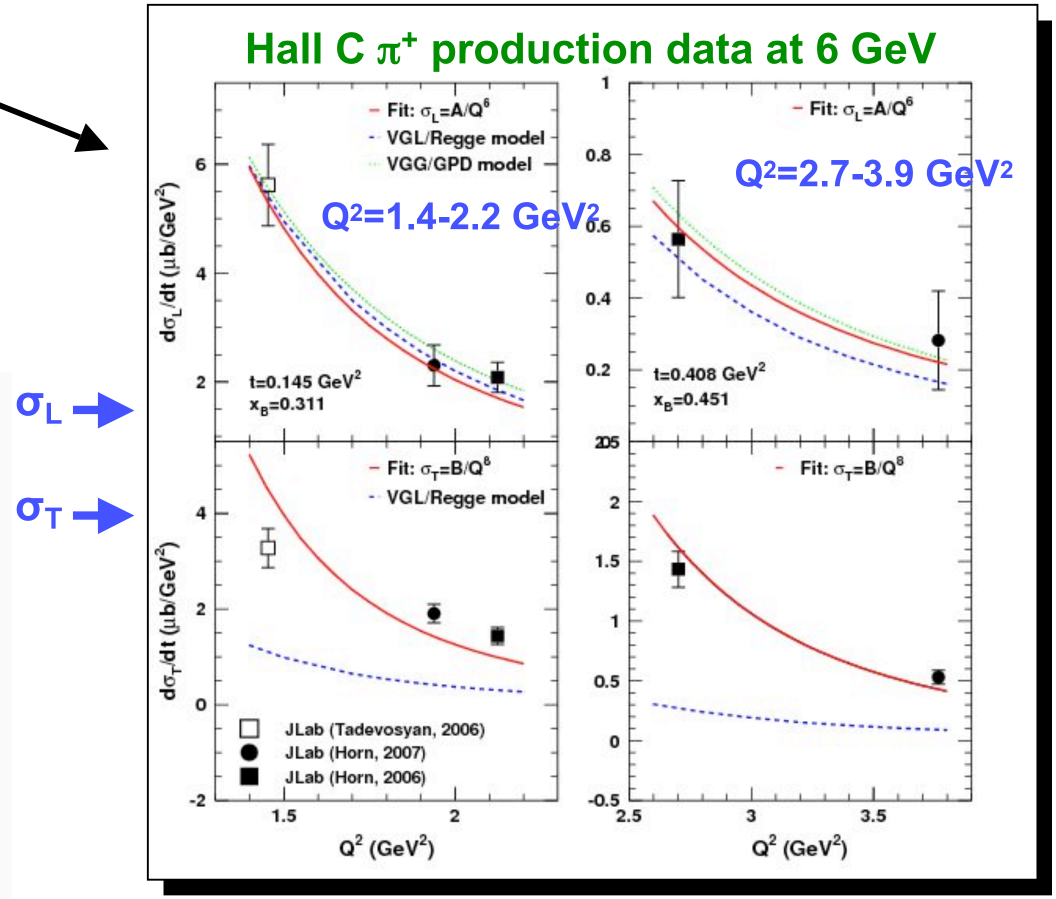
T. Horn et al., Phys. Rev. C78, 058201 (2008)

G. Huber, H. Blok, T. Horn et al., Phys. Rev. C78, 045203 (2008)

Q^2 dependence of σ_L and σ_T

- σ_L is consistent with the Q^{-6} QCD, BUT $\sigma_L >> \sigma_T$ and $\sigma_T \sim Q^{-8}$ are not fulfilled
- The onset of factorization may require an extension of the kinematic reach:





T. Horn et al., Phys. Rev. C78, 058201 (2008)

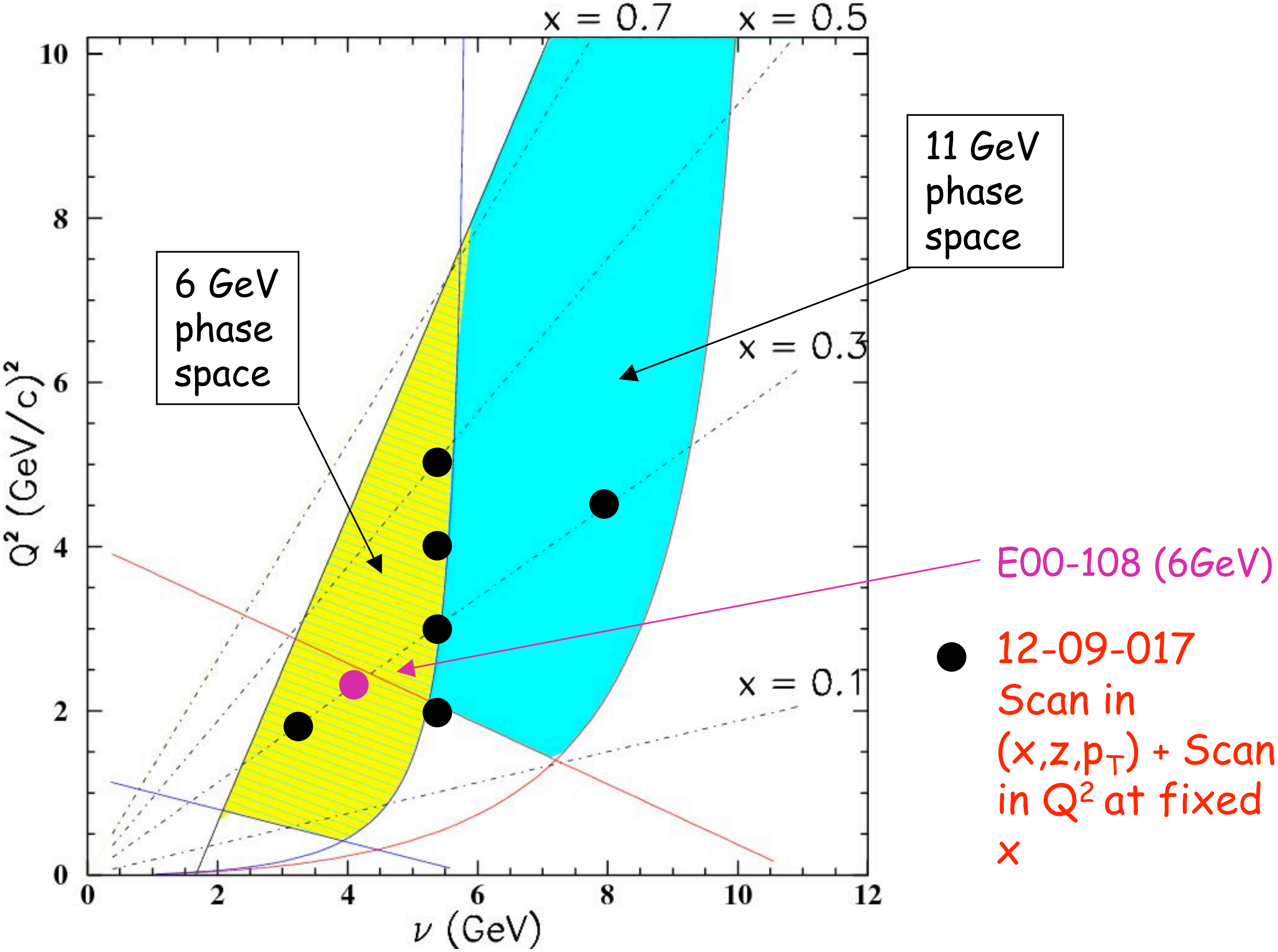
G. Huber, H. Blok, T. Horn et al., Phys. Rev. C78, 045203 (2008)

similar for kaons

Choice of Kinematics

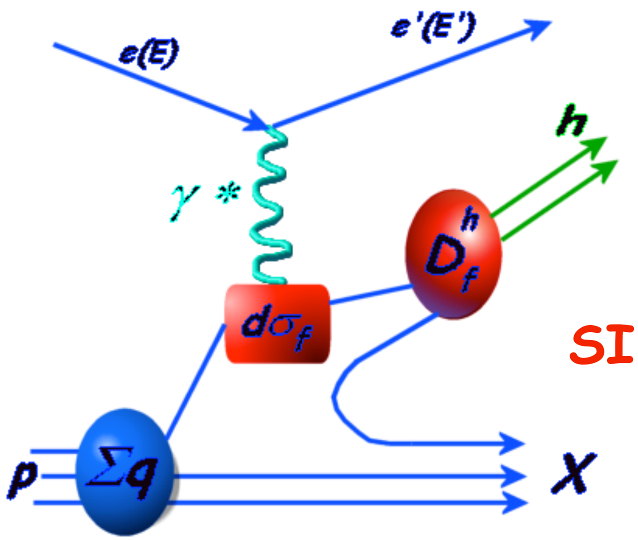
HMS + SHMS Accessible Phase Space for Deep Exclusive Scattering

Ranges bound in Q^2 by minimum electron spectrometer angle, photon angle range to search for produced meson in other spectrometer



For semi-inclusive, less Q^2 phase space at fixed x due to:
i) $M_X^2 > 2.5$ GeV^2; and ii) need to measure at both sides of Θ_γ

SIDIS – Factorization and Flavor Decomposition



SIDIS

DIS probes the sum of quarks and anti-quarks $\sum e_q^2(q+\bar{q})$

SIDIS: Detect a final state hadron in addition to scattered electron

→ Can 'tag' the flavor of the struck quark by measuring the hadrons produced: 'flavor tagging'

$$\frac{1}{\sigma_{(e,e')}}\frac{d\sigma}{dz}(ep \to hX) = \frac{\sum_q e_q^2 f_q(x) D_q^h(z)}{\sum_q e_q^2(x) f_q(x)}$$

$f_q(x)$: parton distribution function

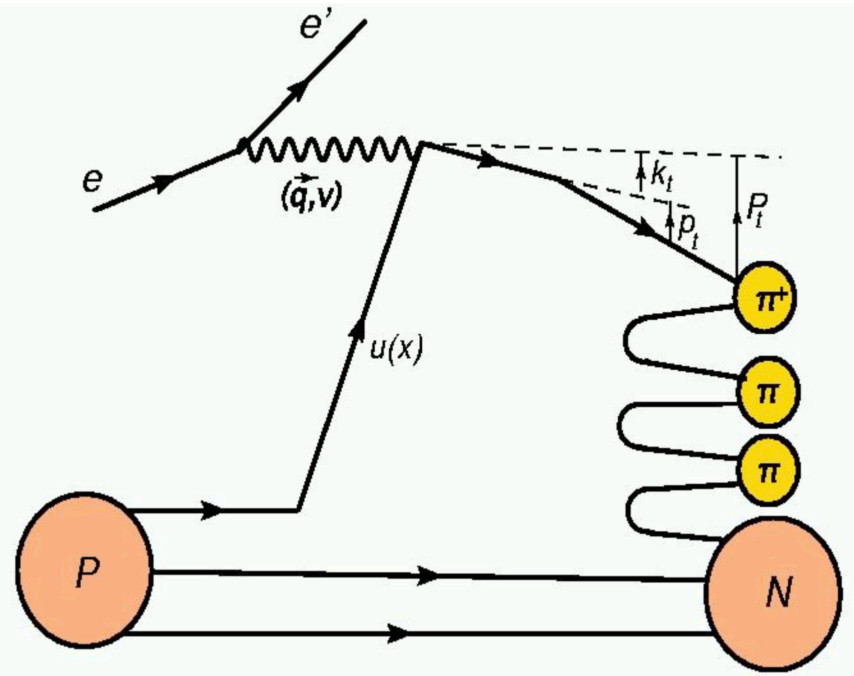
$D_q^h(z)$: fragmentation function

Measure inclusive (e,e') at same time as (e,e'h)

- Leading-Order (LO) QCD
- after integration over p_T and ϕ
- NLO: gluon radiation mixes x and z dependences

SIDIS – k_T Dependence

- Not much is known about the orbital motion of partons
- Significant net orbital angular momentum of valence quarks implies significant transverse momentum of quarks

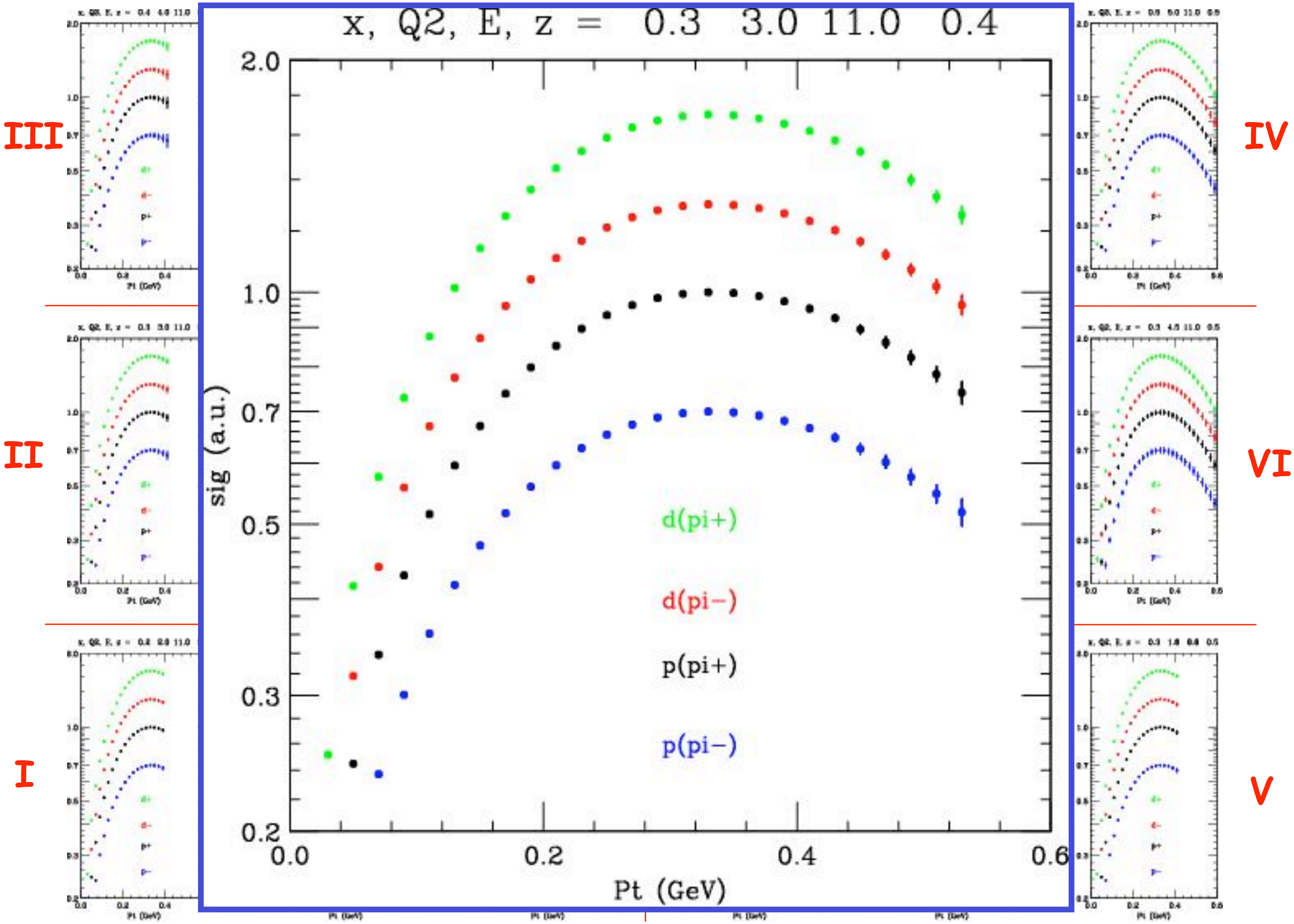


Final transverse momentum of the detected pion $\mathbf{P_t}$ arises from convolution of the struck quark transverse momentum $\mathbf{k_t}$ with the transverse momentum generated during the fragmentation $\mathbf{p_t}$.

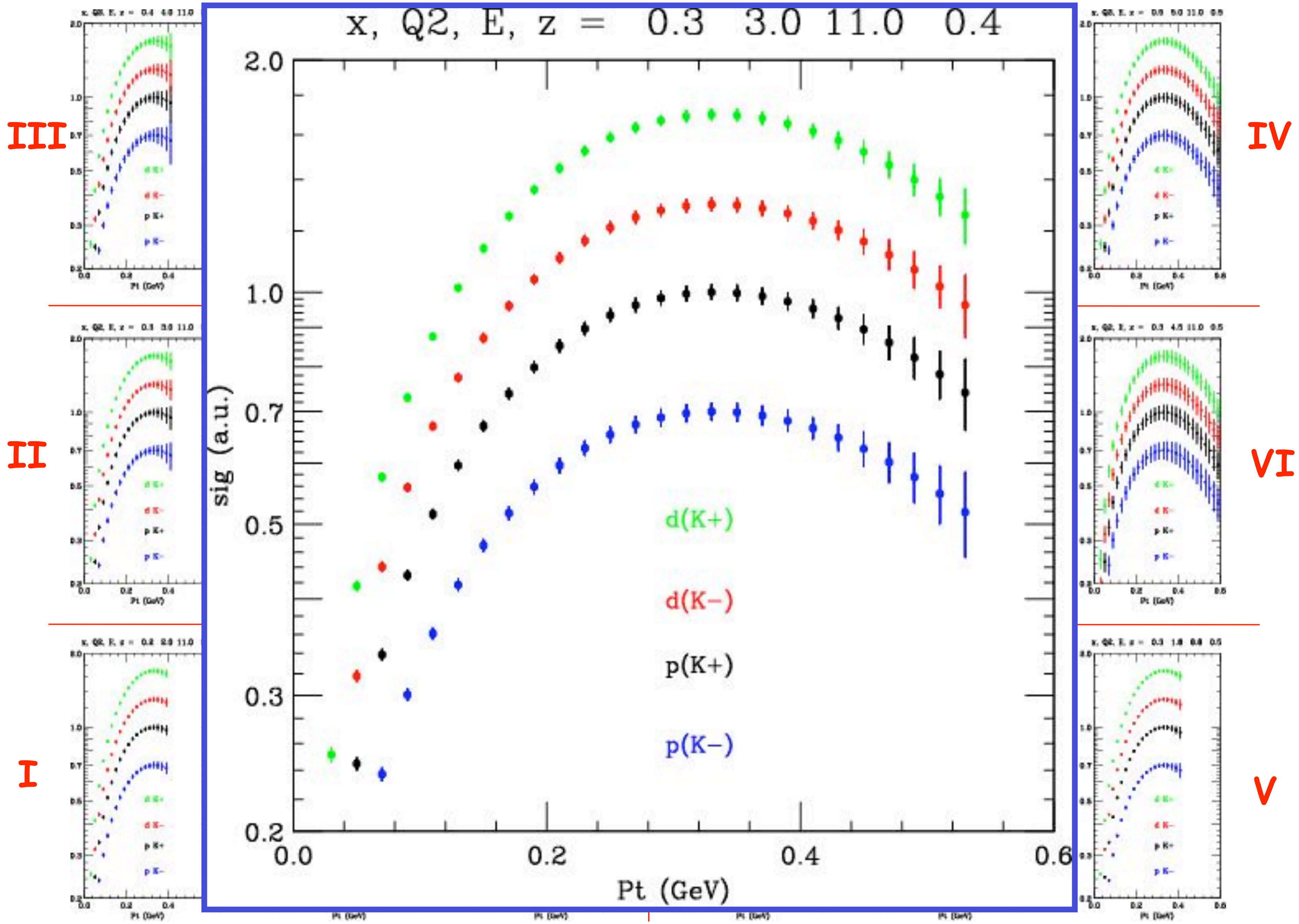
$$P_t = p_t + z\, k_t + O(k_t^2/Q^2)$$

E12-09-017: Map the p_T dependence ($p_T \sim \Lambda < 0.5$ GeV) of π^+ and π^- production off proton and deuteron targets to study the k_T dependence of up and down quarks

12-09-017 Projected Results - Pions



12-09-017 Projected Results - Kaons



$R = \sigma_L/\sigma_T$ in DIS and in $(e,e'\pi)$ SIDIS

- R_{DIS} is in the naive parton model is related to the parton's transverse momentum: $R = 4(M^2x^2 + \langle k_T^2\rangle)/(Q^2 + 2\langle k_T^2\rangle)$.

- $R_{DIS} \rightarrow 0$ at $Q^2 \rightarrow \infty$ is a consequence of scattering from free spin-$\frac{1}{2}$ constituents

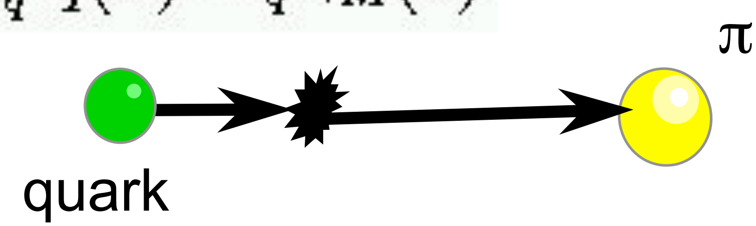
- At finite Q^2, R_{DIS} sensitive to gluon and higher-twist effects

- No distinction made up to now between diffractive and non-diffractive contributions in R_{DIS}

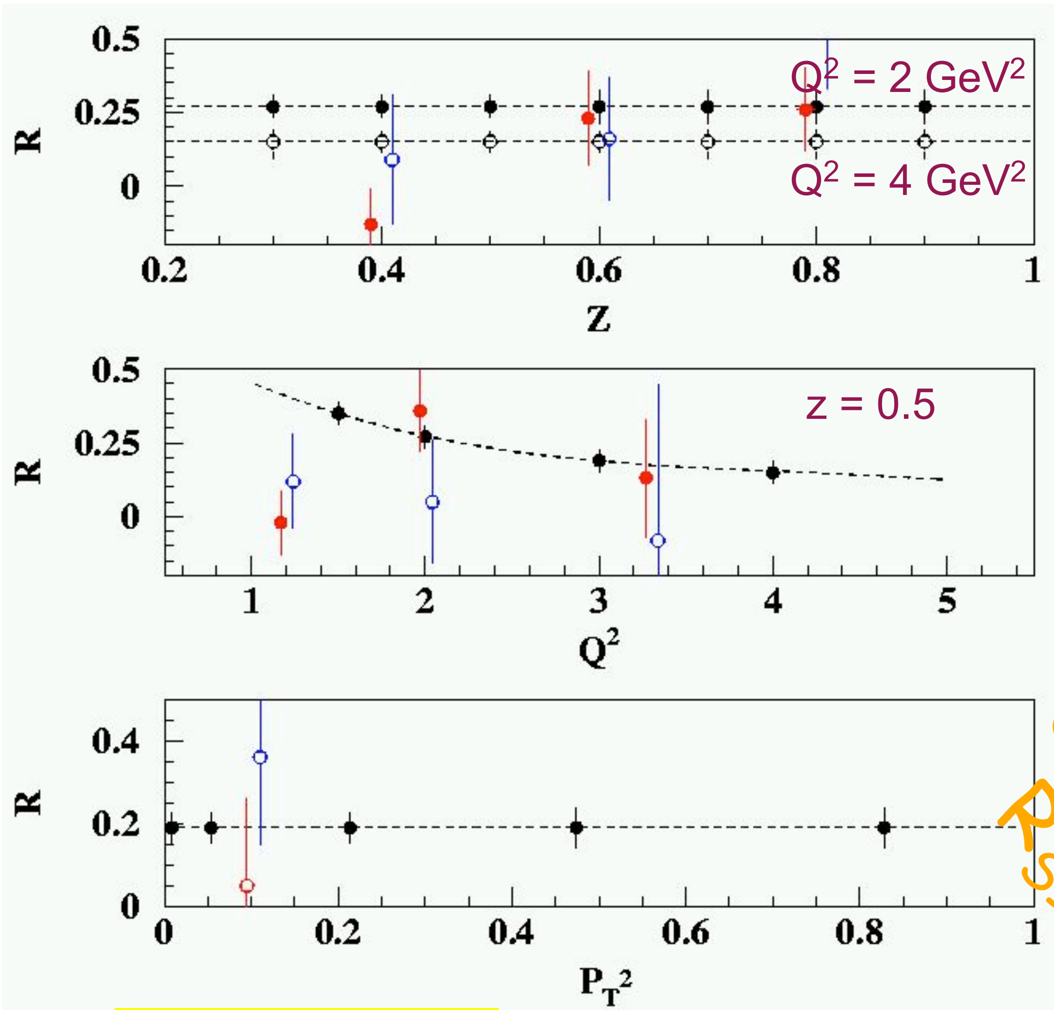
$R = \sigma_L/\sigma_T$ in DIS and in $(e,e'\pi)$ SIDIS

- If integrated over z (and p_T, ϕ, hadrons), $R_{SIDIS} = R_{DIS}$
- R_{SIDIS} may vary with z
- At large z, there are known contributions from (semi-) exclusive channels: pions originating from $\rho \rightarrow \pi^+\pi^-$
- R_{SIDIS} may vary with p_T
- Is $R_{SIDIS}^{\pi^+} = R_{SIDIS}^{\pi^-}$? Is $R_{SIDIS}^{H} = R_{SIDIS}^{D}$?
- $R_{SIDIS} = R_{DIS}$ test of dominance of quark fragmentation

$$\sum e_q^2\, q(x)\, D_{q\rightarrow M}(z)$$



$R = \sigma_L/\sigma_T$ for Pion Electroproduction



"Deep exclusive scattering" is the z → 1 limit of this "semi-inclusive DIS" process

Here, $R = \sigma_L/\sigma_T \sim Q^2$

$R_{SIDIS} \rightarrow R_{DIS}$ disappears with Q^2!

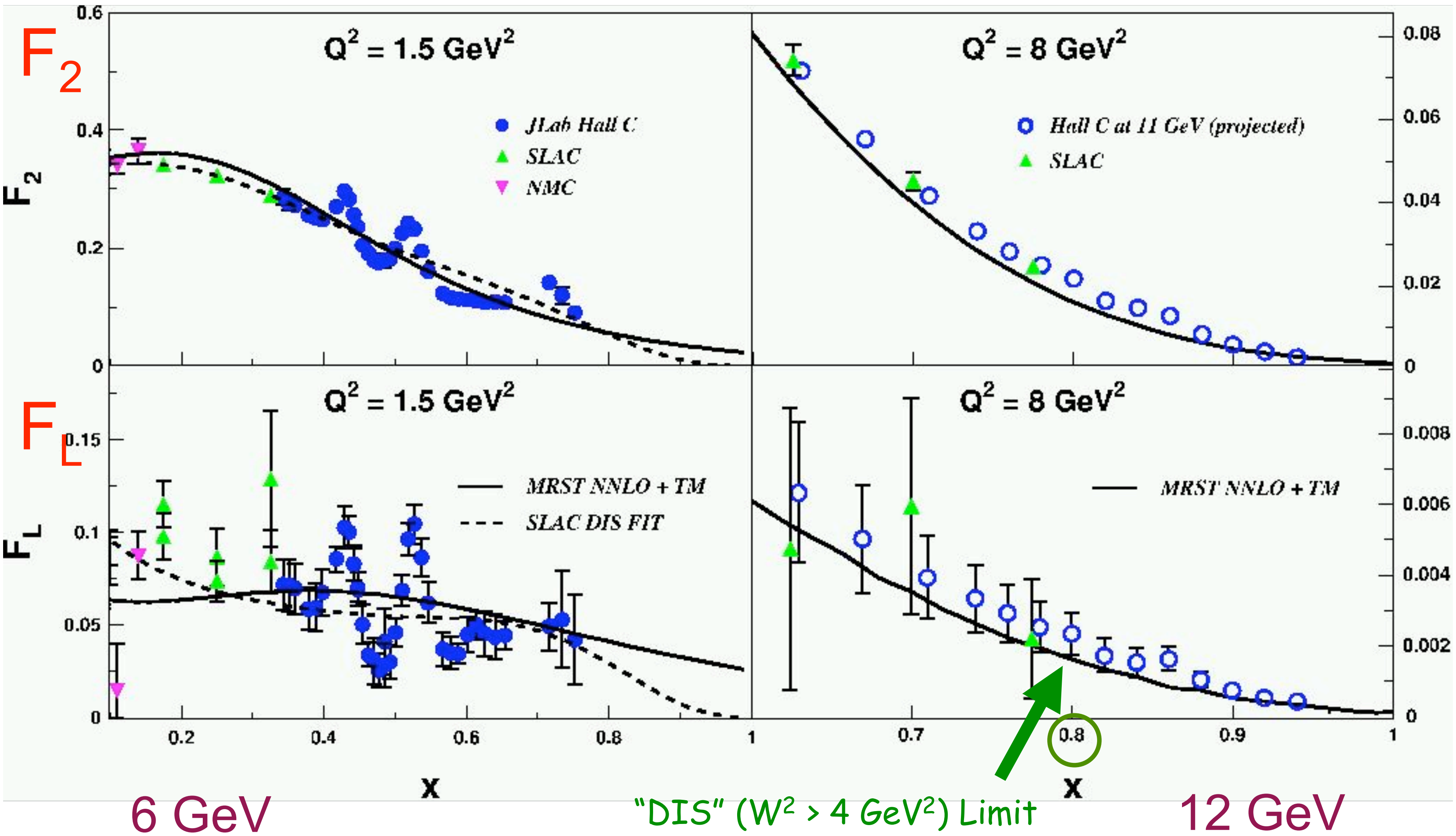
Not clear what R will behave like at large p_T

Example of 12-GeV projected data assuming $R_{SIDIS} = R_{DIS}$

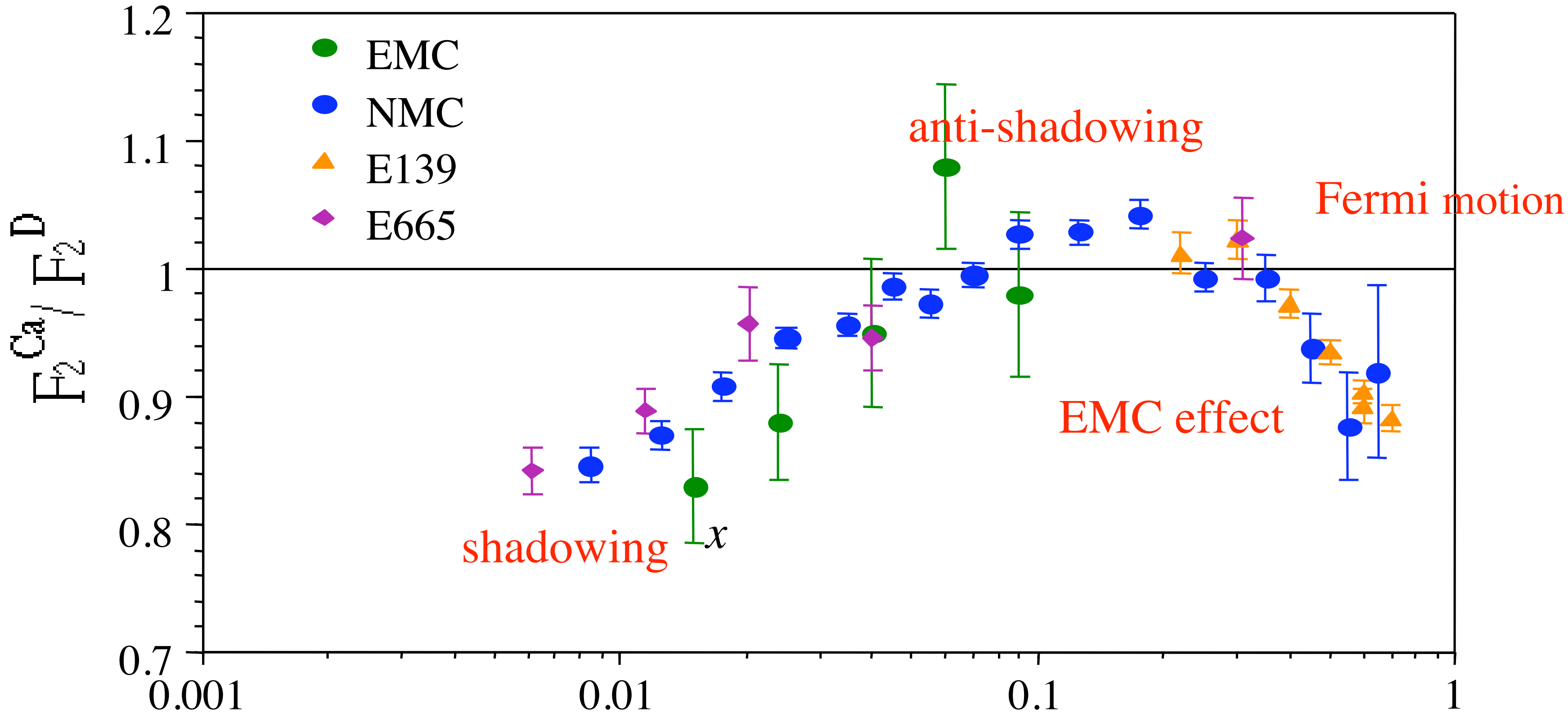
R_{SIDIS} essentially unknown!

Inclusive Structure Functions @ 12 GeV

Rosenbluth Separations up to $Q^2 \sim 12 \rightarrow R = \sigma_L/\sigma_T$



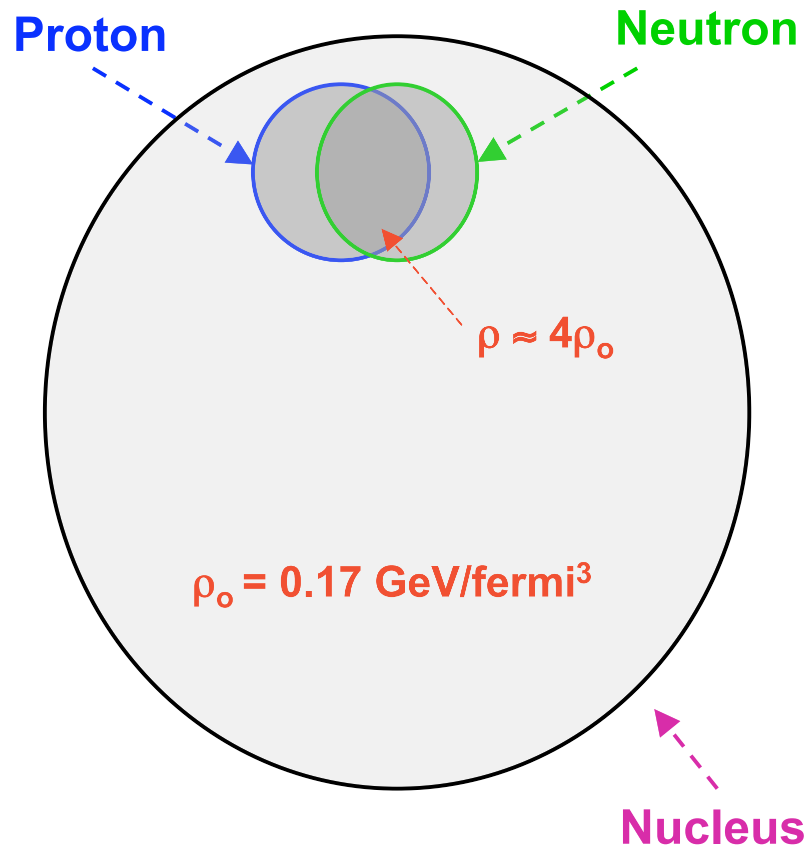
Nuclear Medium Modifications of Nucleon Structure



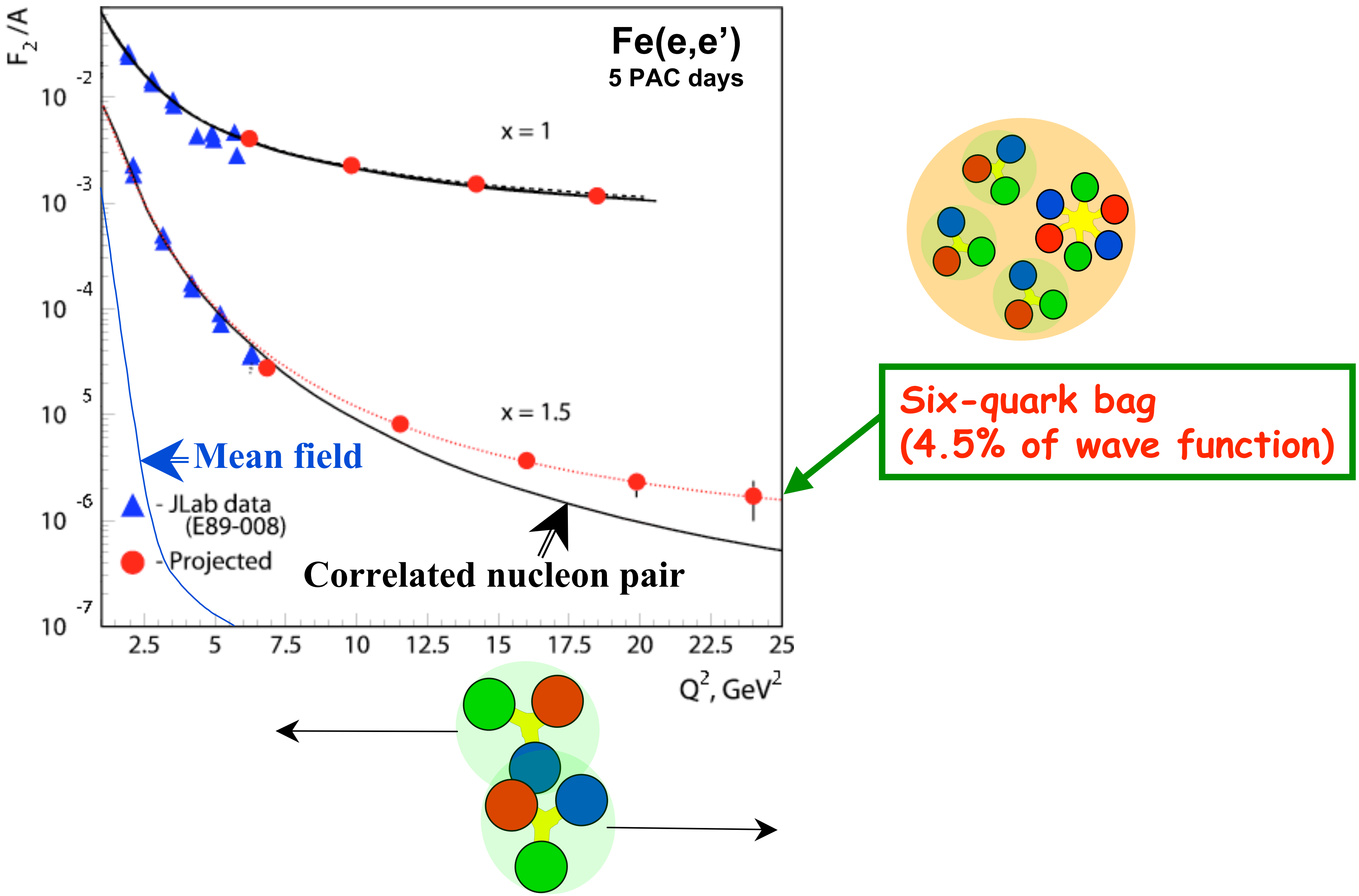
- F_2 / nucleon changes as a function of A
- No single explanation explains totality of phenomena

Nuclear Medium Effects at large x (> 1)

- A nuclear medium has an average density, ρ_o, of 0.17 GeV/fm^3.
- A typical distance for 2 nucleons participating in a short-range correlation (SRC) is ~1.0 fm → the local density can increase by a factor of ~4: this is comparable to the density of neutron stars.
- Nucleons participating in a SRC are deeply bound, i.e. their structure should be modified, like their shape or quark distributions.
- $x = Q^2/2M\nu > 1$ → can be used to select quarks inside nucleon participating in a SRC, *"superfast quarks!"*

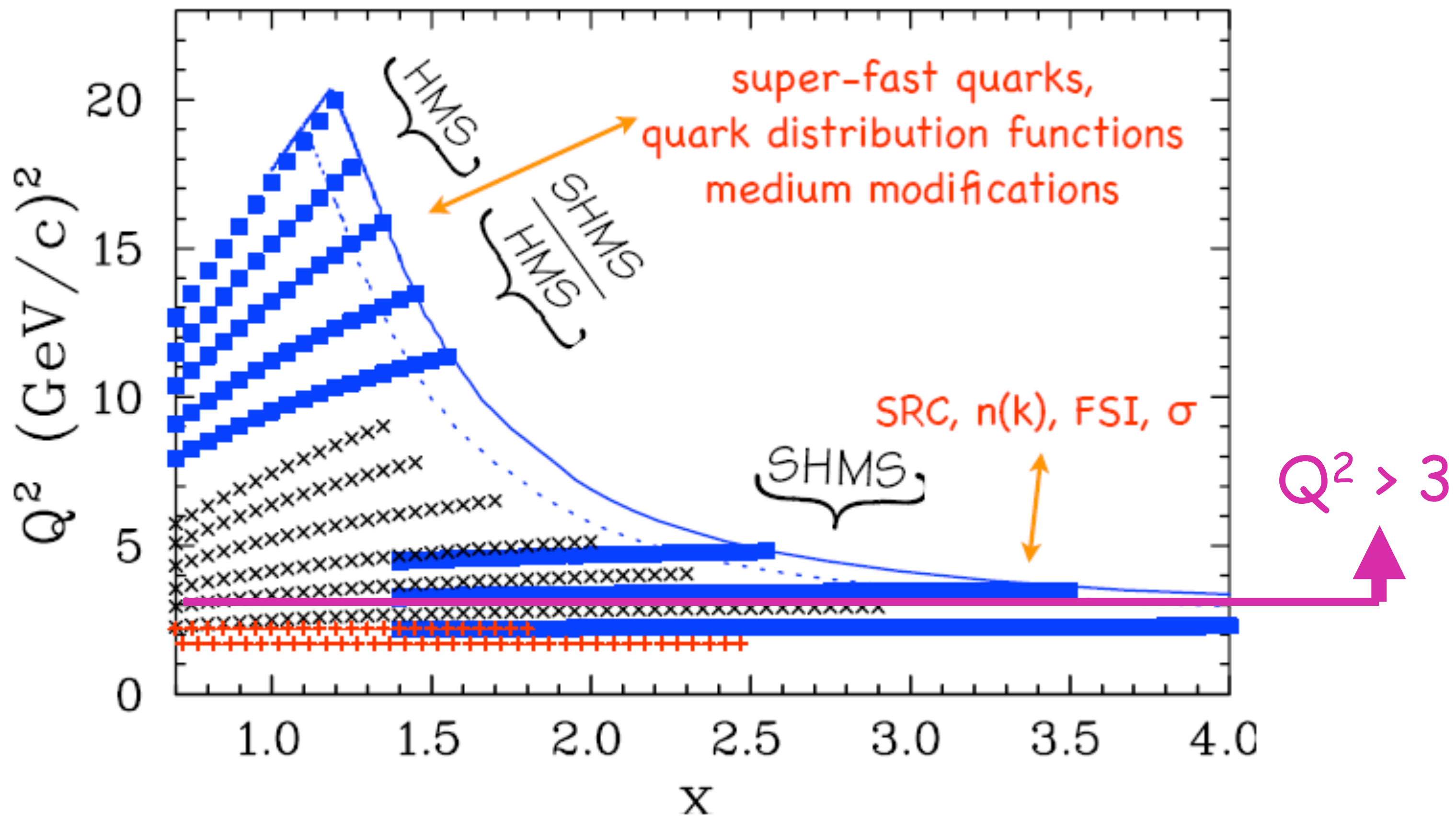


Extend Measurements on Nuclei to x > 1: *Superfast* Quarks



Scatter from nuclei in region well described by electron-quark scattering, with superfast quarks

x = momentum fraction (of nucleon) of quark

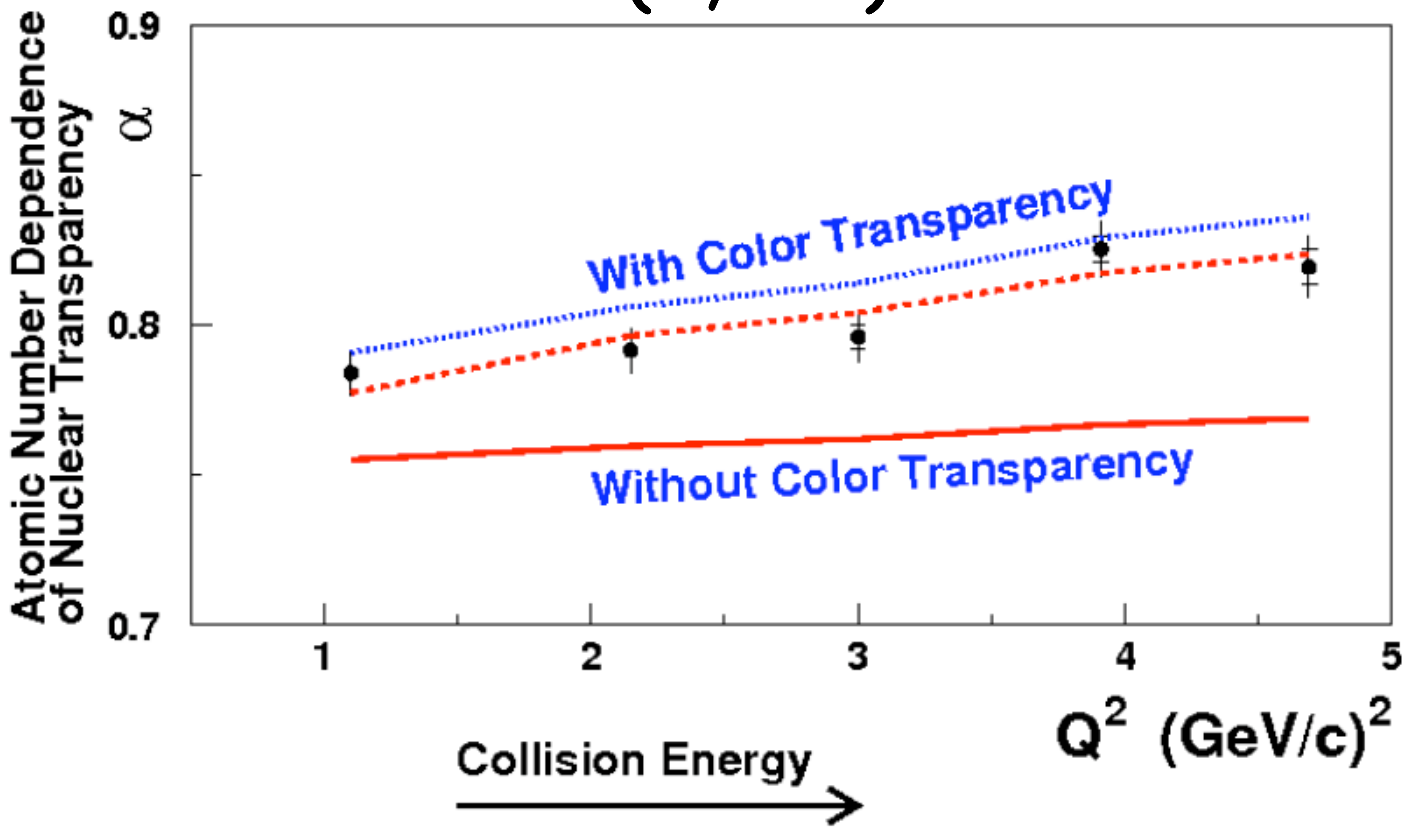


Note: $x = 3$, $Q^2 = 5$ → nucleon with 1.78+ GeV/c!
(similar for $x = 1.5$, $Q^2 = 10$)

Physics of Nuclei: Color Transparency

$\sigma^A = \sigma^N A^\alpha$

$A(e,e'\pi^+)$

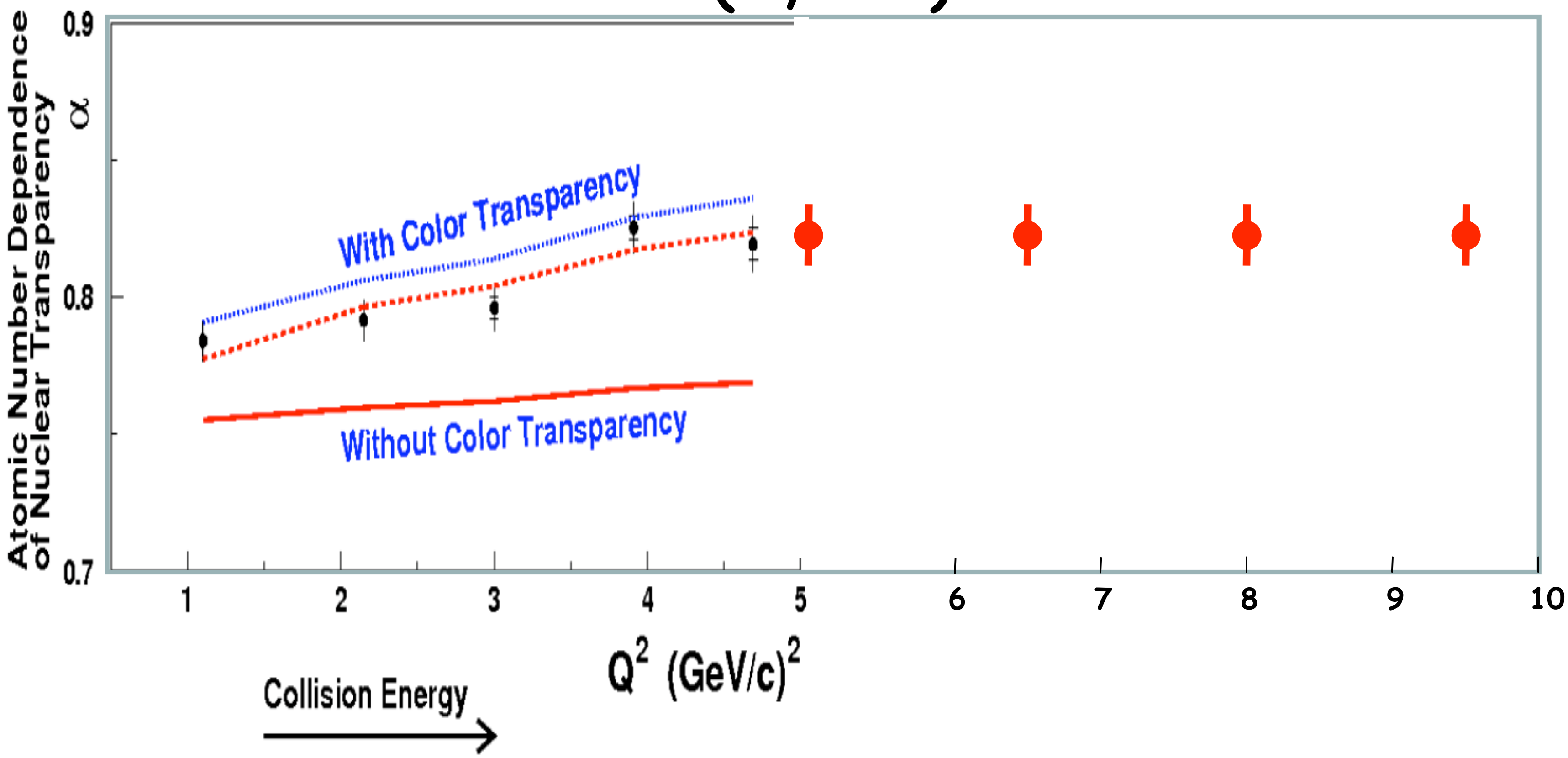


Total pion-nucleus cross section slowly disappears, or …
pion escape probability increases → Color Transparency?

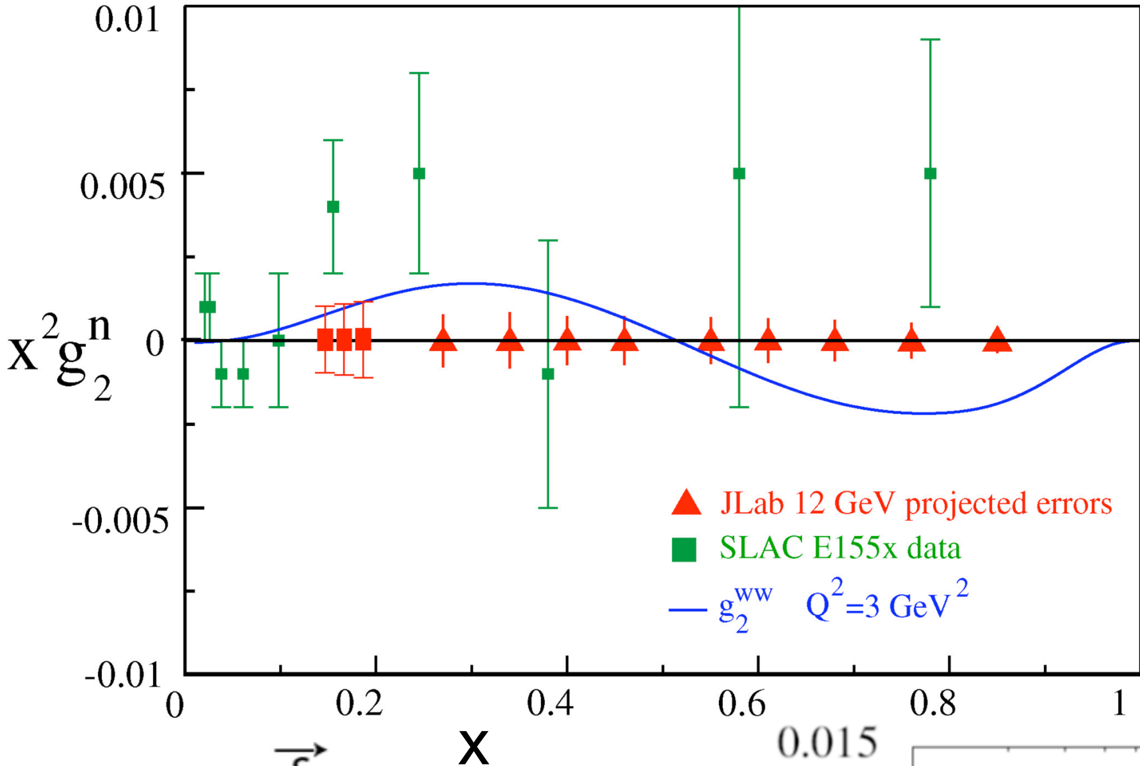
Physics of Nuclei: Color Transparency

$\sigma^A = \sigma^N A^\alpha$

$A(e,e'\pi^+)$



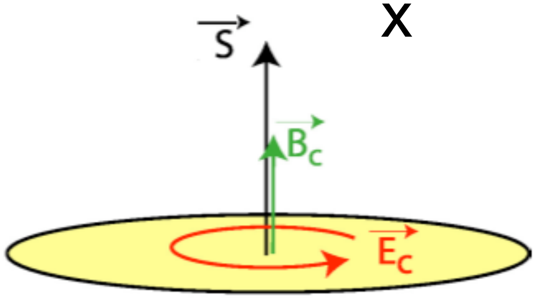
Total pion-nucleus cross section slowly disappears, or …
pion escape probability increases → Color Transparency?
→ Unique possibility to map out at 12 GeV (up to $Q^2 = 10$)



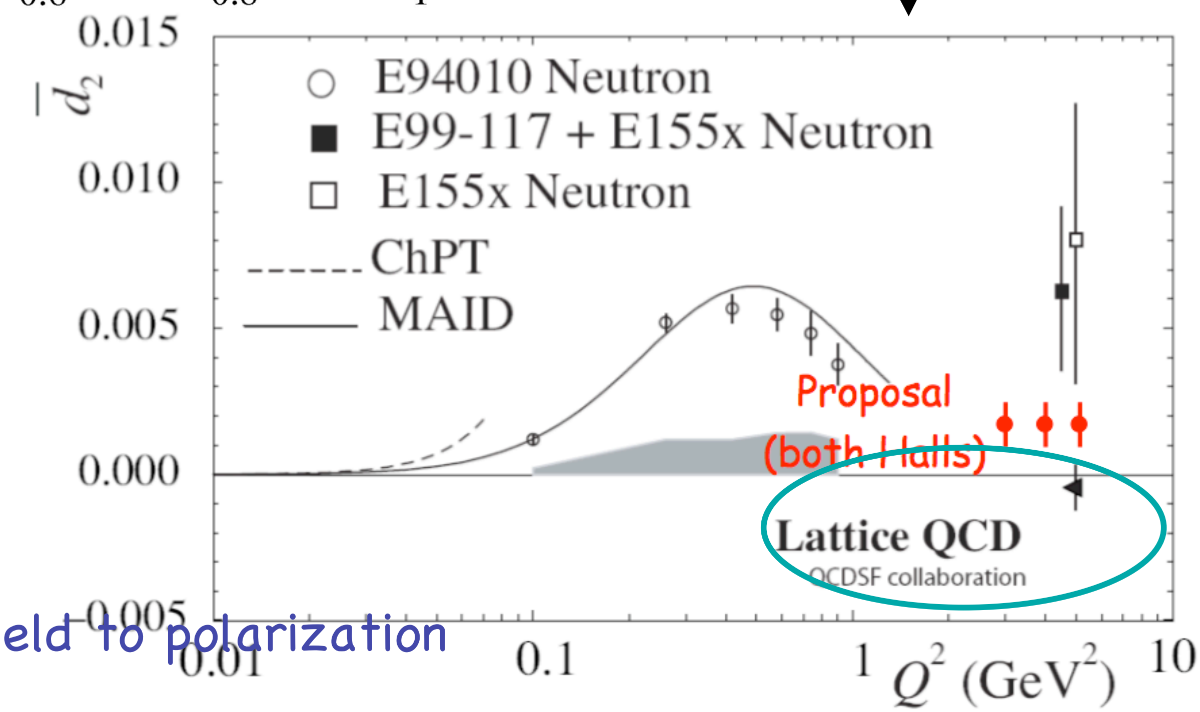
Polarized structure functions, too!

g_2 , d_2

$$d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$$



$$\chi_E^n = (4d_2^n + 2f_2^n)/3$$
$$\chi_B^n = (4d_2^n - f_2^n)/3$$



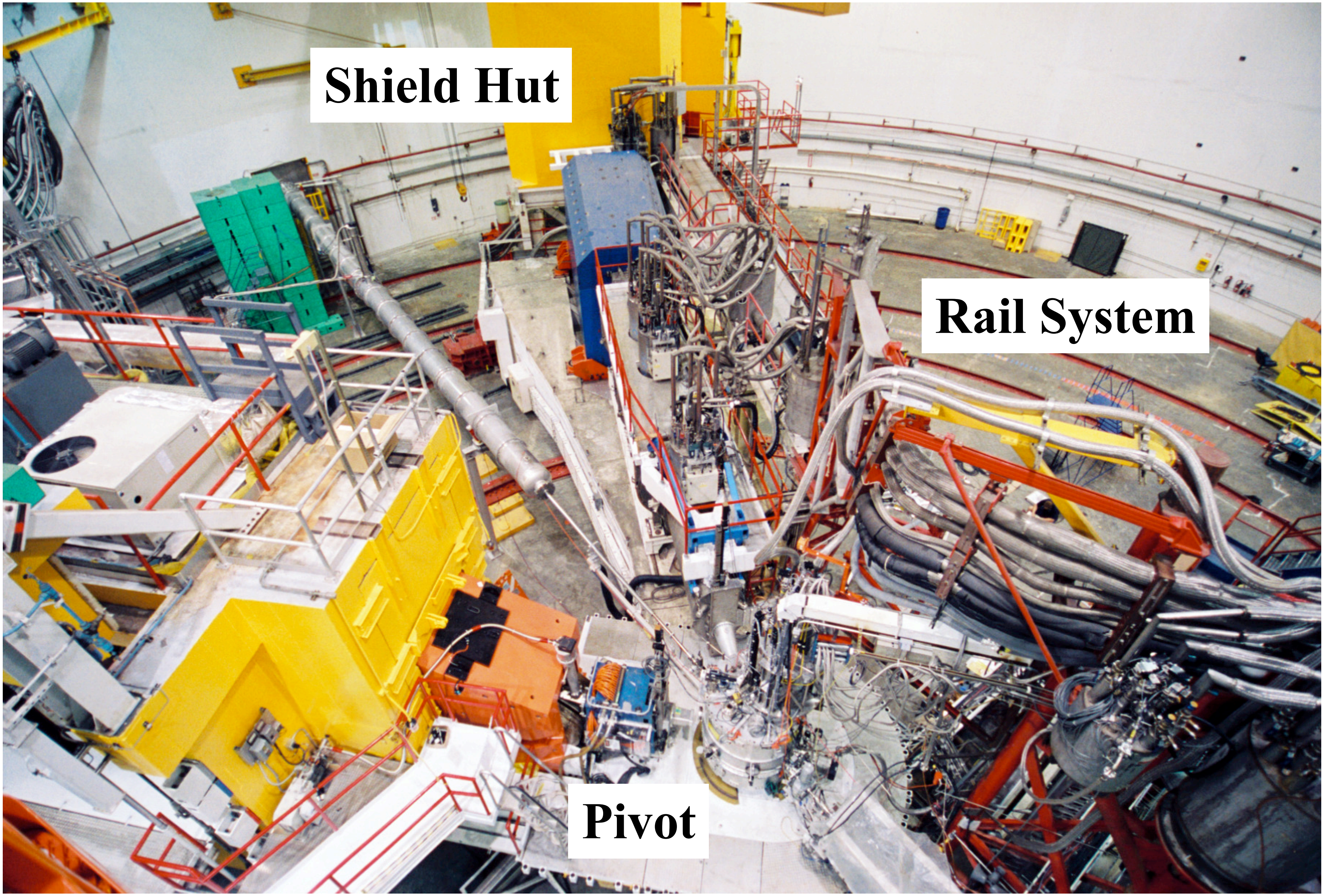
Response of the color E, B field to polarization

Motivation for Hall C Upgrade

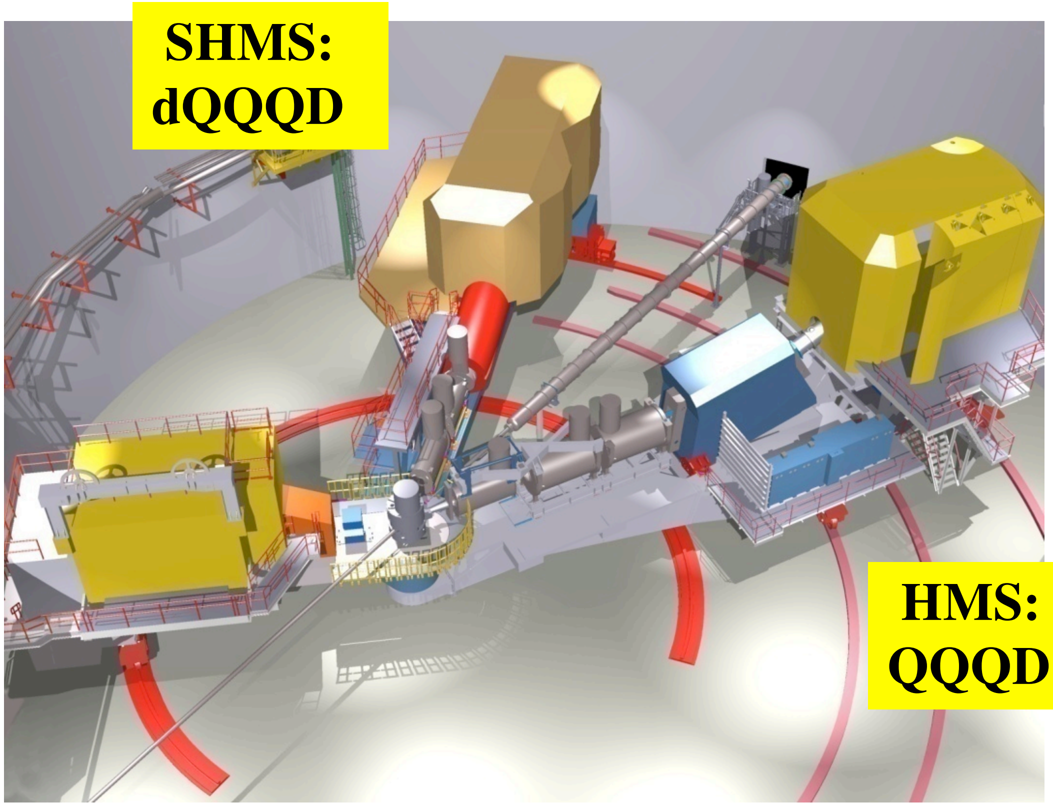
- Deep inelastic scattering at high Bjorken x
- Semi-inclusive scattering at high hadron momenta
- Polarized and unpolarized scattering on nuclei
- Pion and nucleon form factors at high Q^2

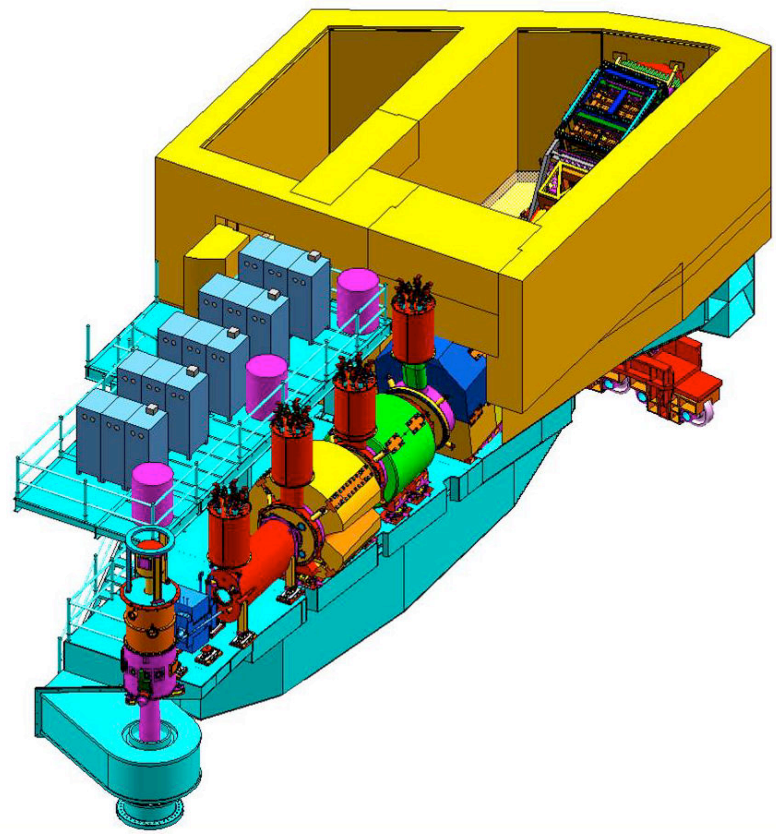
- **Highest Luminosity ($L=10^{38}$ nucleons/cm^2/s)**
- **Pair of magnetic spectrometers (SHMS + existing HMS)**
- **Detection of charged particles with highest momenta**
- **Accuracy and reproducibility**
- **Small angle capability**
- **Very good particle identification**
- **Compatibility with all target configurations**
- **Frequent momentum, angle changes**

Hall C at JLab today - with HMS (7.3 GeV)



Hall C at 12 GeV: add “Super” HMS (SHMS, 11 GeV)



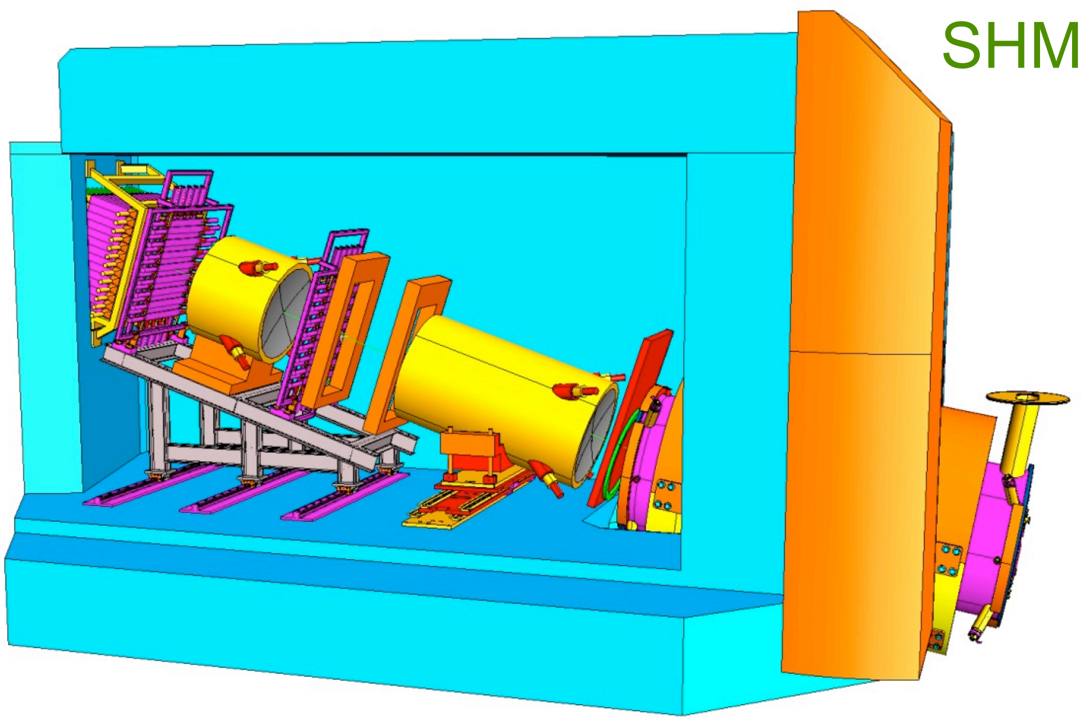


Copy main properties of HMS into SHMS design:

- Pivot and Rail System
- Point-Point Optics Design
- “Flat” Acceptances
- Shield House
- Redundancy in Detectors

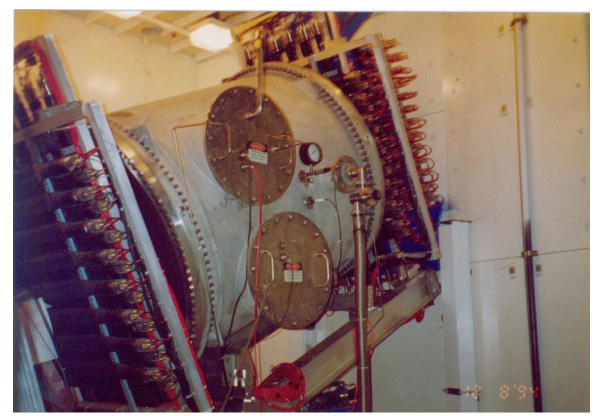
SHMS Detector System

- Noble Gas Cerenkov: e/π (or π/K) separation at high momenta
- Drift Chambers: charged particle tracking; momentum & angle measurement
- Trigger Hodoscopes: basic trigger; Time-of-Flight at low momenta; efficiency
    - 3 Planes Scintillator Paddles
    - 1 Plane Quartz Bars – insensitive to photon or low-energy background
- Heavy Gas Cerenkov: π/K separation for momenta > 3.4 GeV
- Calorimeter: e/π separation



SHMS

HMS



SHMS Design Parameters

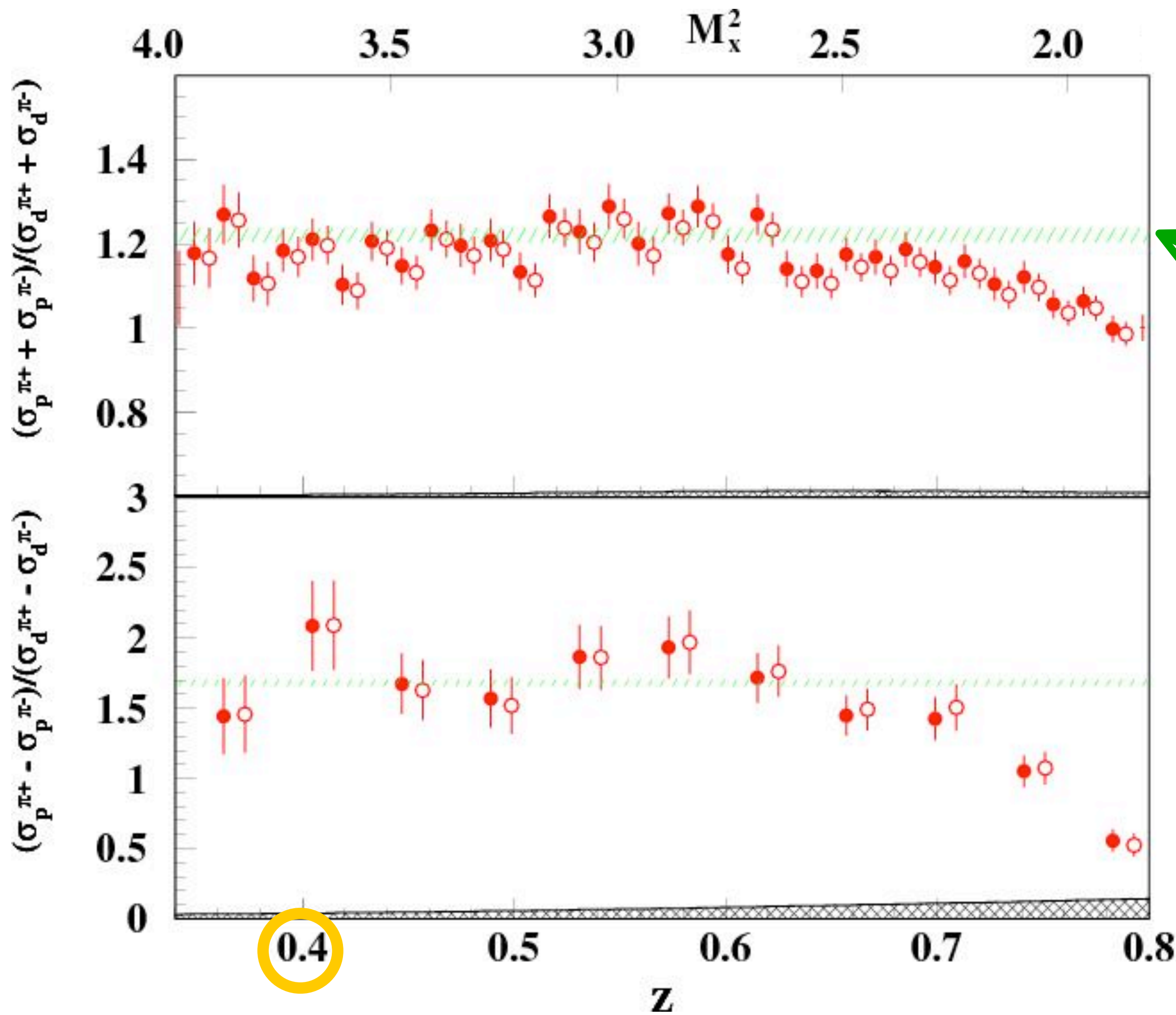
Parameter	SHMS Design
Range of Central Momentum	2 to 11 GeV/c for all angles
Momentum Acceptance δ	-10% to +22%
Momentum Resolution	0.03-0.08% (SRD: "<0.2%")
Scattering Angle Range	5.5 to 40 degrees
Solid Angle Acceptance	>4.5 msr for all angles (SRD: ">4.0 msr")
Horizontal Angle Resolution	0.5 - 1.2 mrad
Vertical Angle Resolution	0.3 - 1.1 mrad
Vertex Length Resolution	0.1 - 0.3 cm
Tracking Rate Capability	5 MHz
Beam Capability	Up to 90 μA, 11 GeV beam
Protection from	Magnetic, Cryogenic, and Fall Hazards
Angle Changes	Rapid, Remote, Reproducible

Conclusion: Hall C at 12 GeV will be well suited to exciting program of high precision inclusive, semi-inclusive cross section measurements

Thanks to Rolf Ent, Howard Fenker, John Arrington, Tanja Horn, Dave Gaskell, Zein-Eddine Meziani, Mark Jones, everyone I am forgetting….

extra slides

E00-108: Leading-Order x-z factorization



$$\sum_q e_q^2 \, q(x) \, D_{q \to M}(z)$$

GRV & CTEQ,
@ LO or NLO

Good description
for p and d targets
for 0.4 < z < 0.65

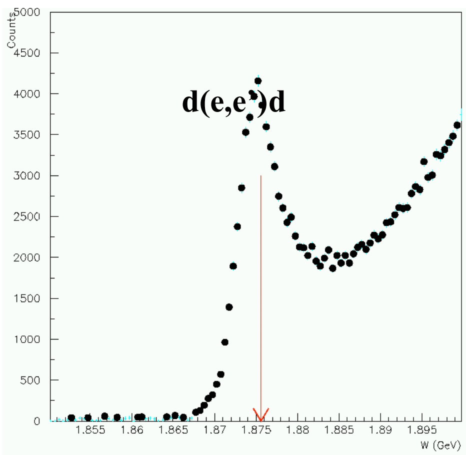
(Note: z = 0.65 ~ M_x^2 = 2.5 GeV^2)

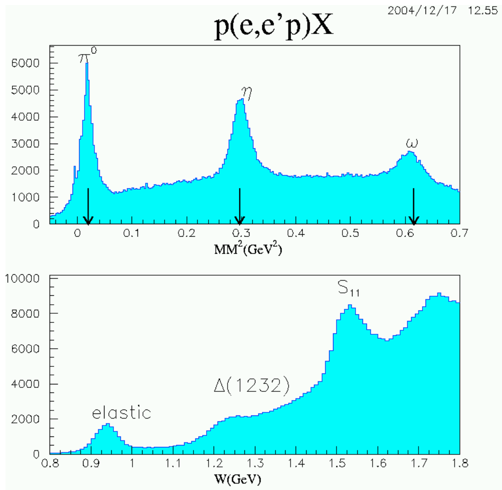
Closed (open) symbols reflect data after (before)
events from coherent ρ production are subtracted

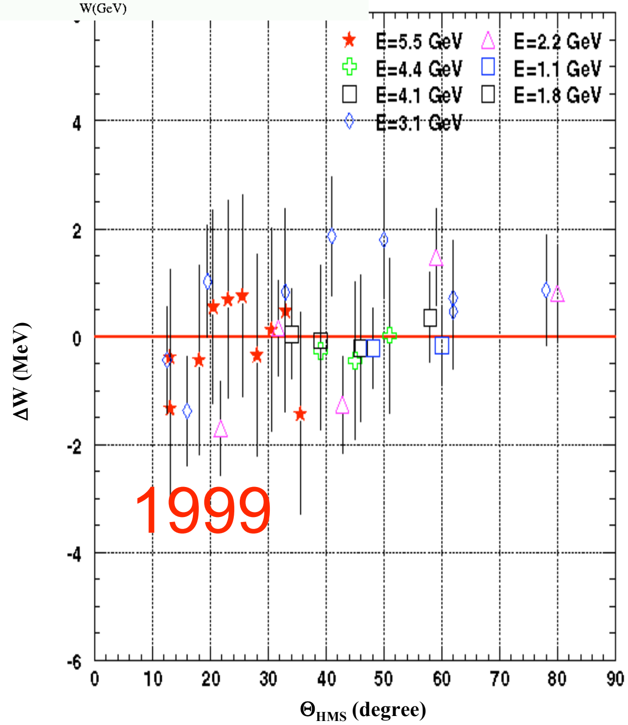
HMS Kinematic Stability

Many years of elastic data fit with one momentum offset and no angle offset

Position of elastic peak stable to < 1 MeV!







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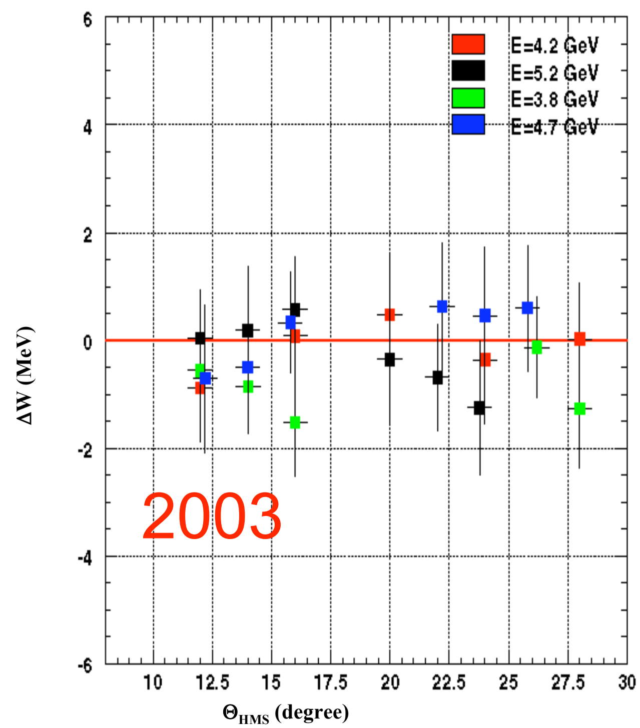
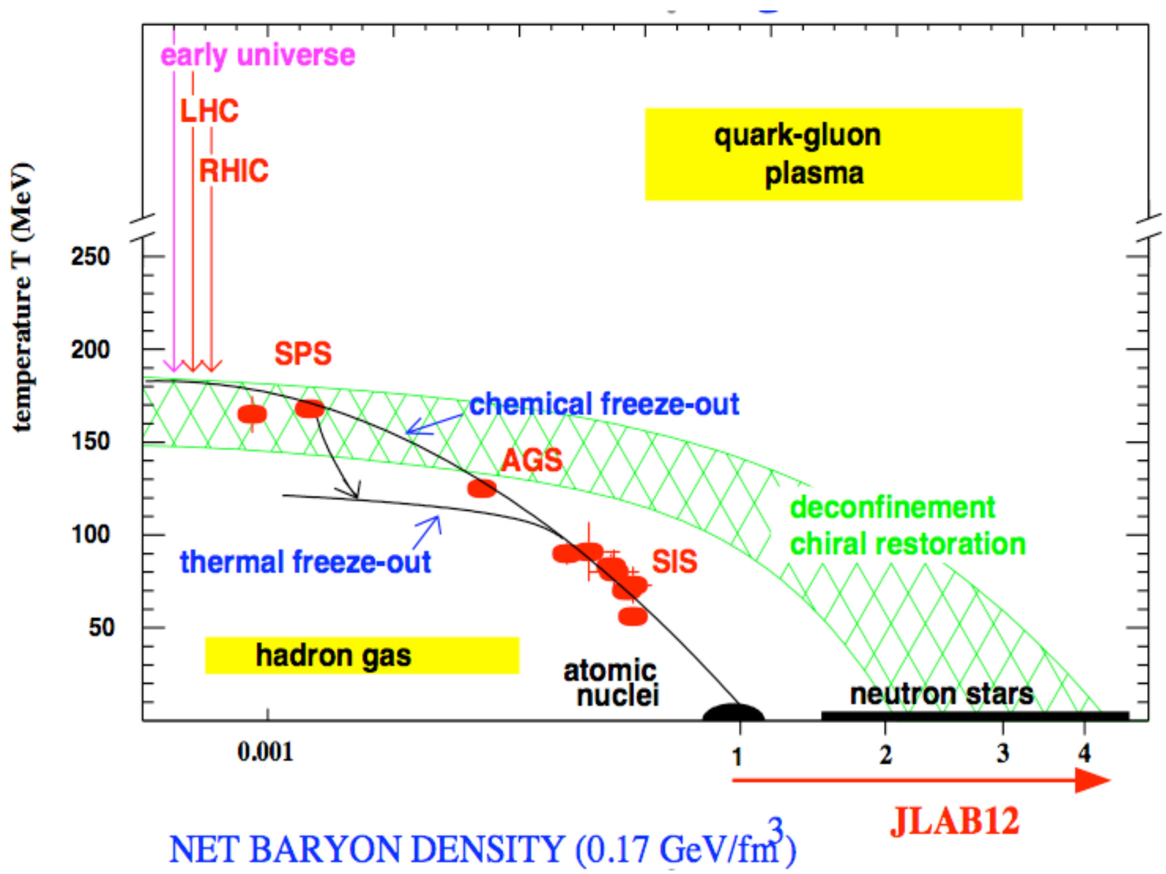


Phase Transition at High Densities

- Average nuclear densities are well below phase transition
- Short range correlations provide a small high-density component in nuclei



Low temperature high density

- Try to isolate SRCs to probe high density matter
- May be origin of EMC effect, medium modifications
- Cold, dense matter relevant to astrophysics