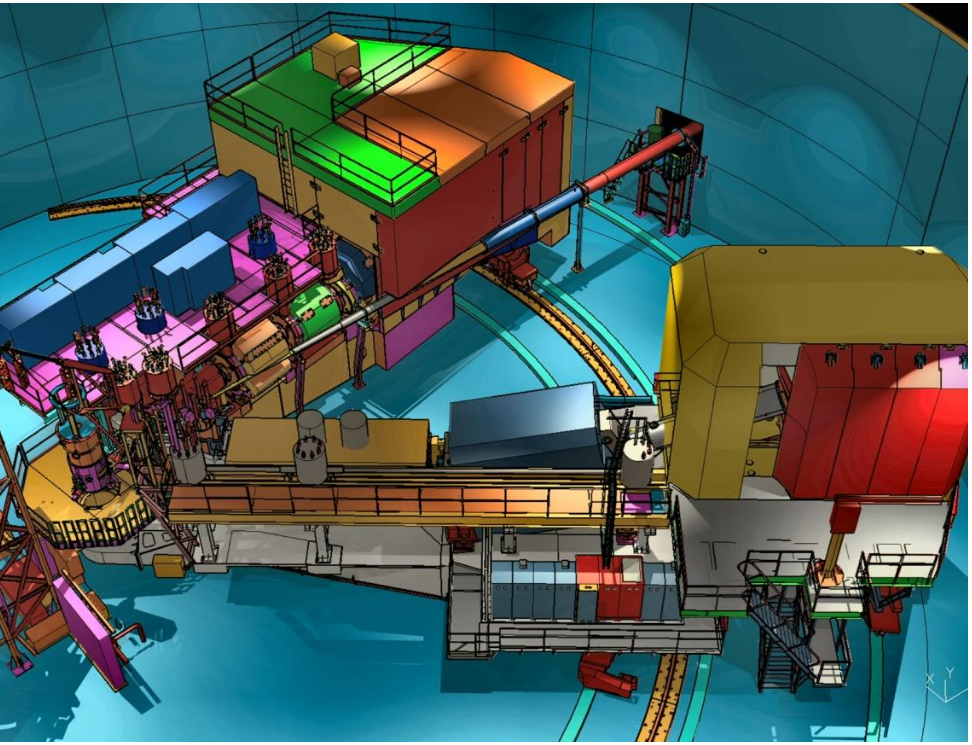
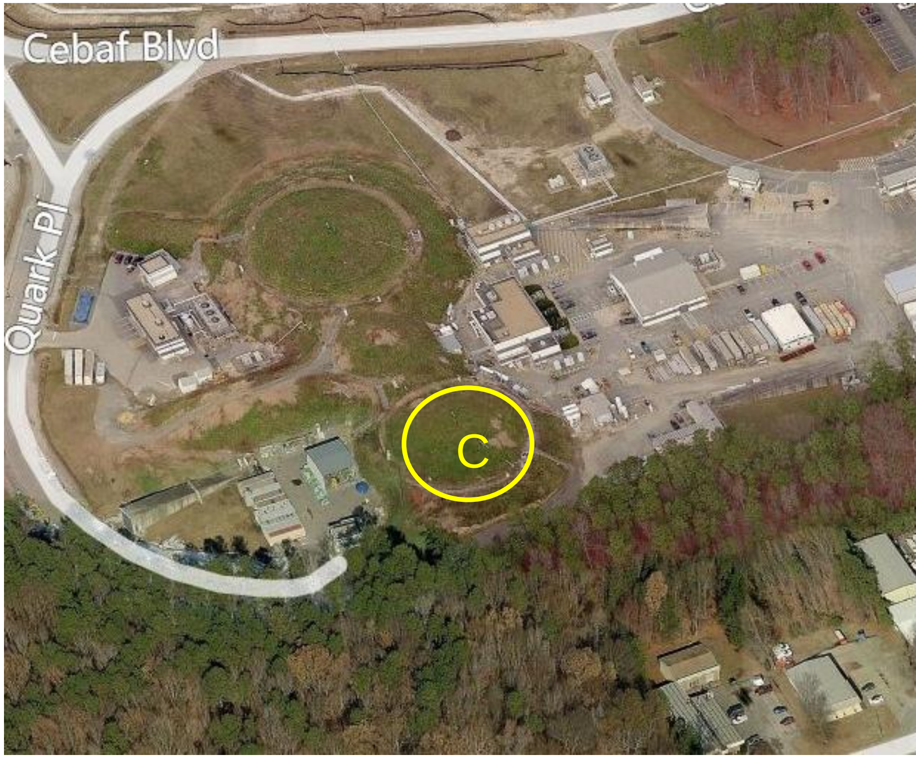
JLab Hall C 12 GeV Upgrade

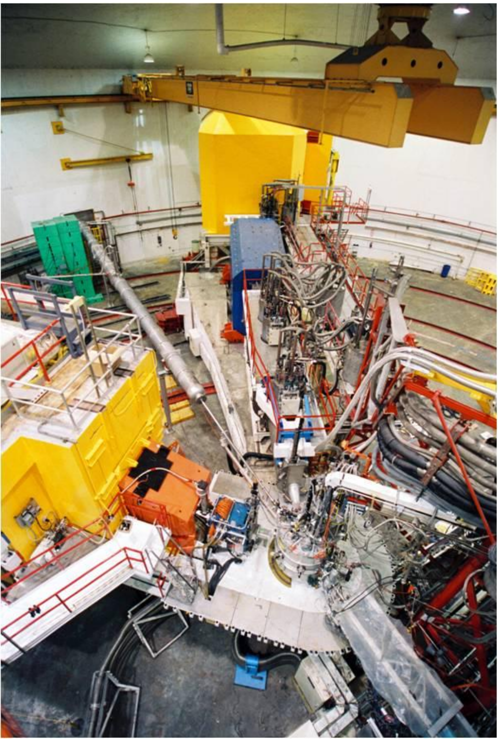
The Fourth Workshop on Hadron Physics in China and Opportunities in US, July 16-20, 2012

Stephen A. Wood Hall C

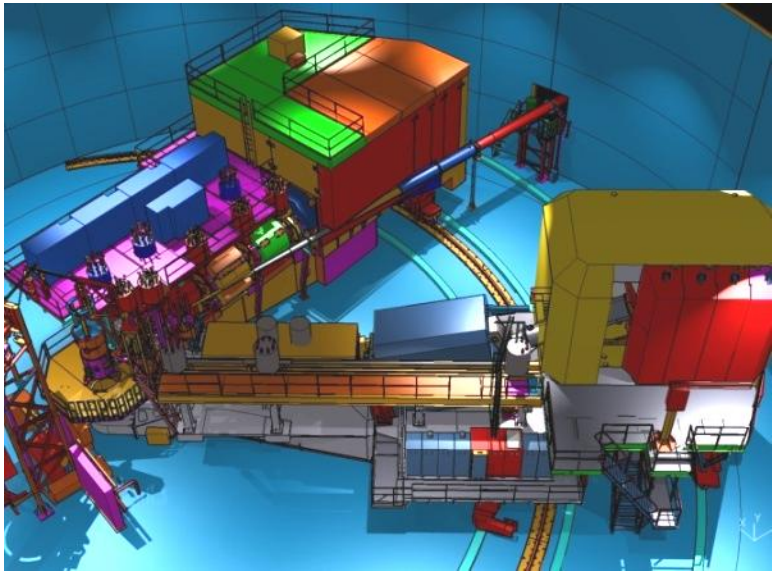




Outline



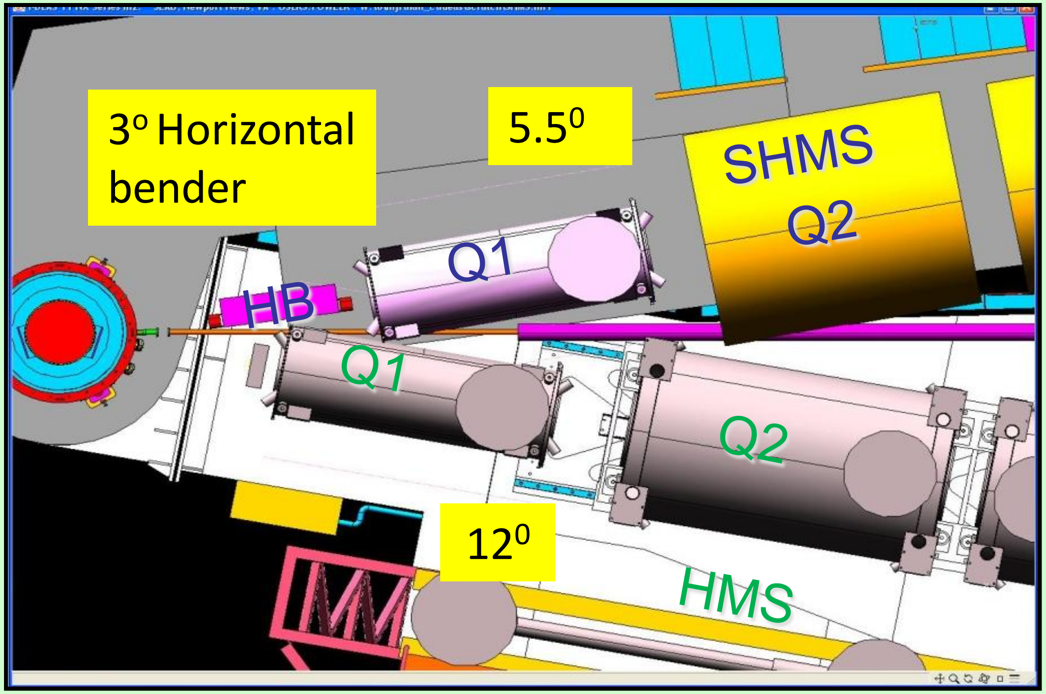
- Hall C equipment overview
- Hall C 12 GeV physics program
  - Structure functions
  - Semi-inclusive reactions/SIDIS
  - Exclusive reactions
  - Nuclear effects
- Future directions
- Hall C startup plans



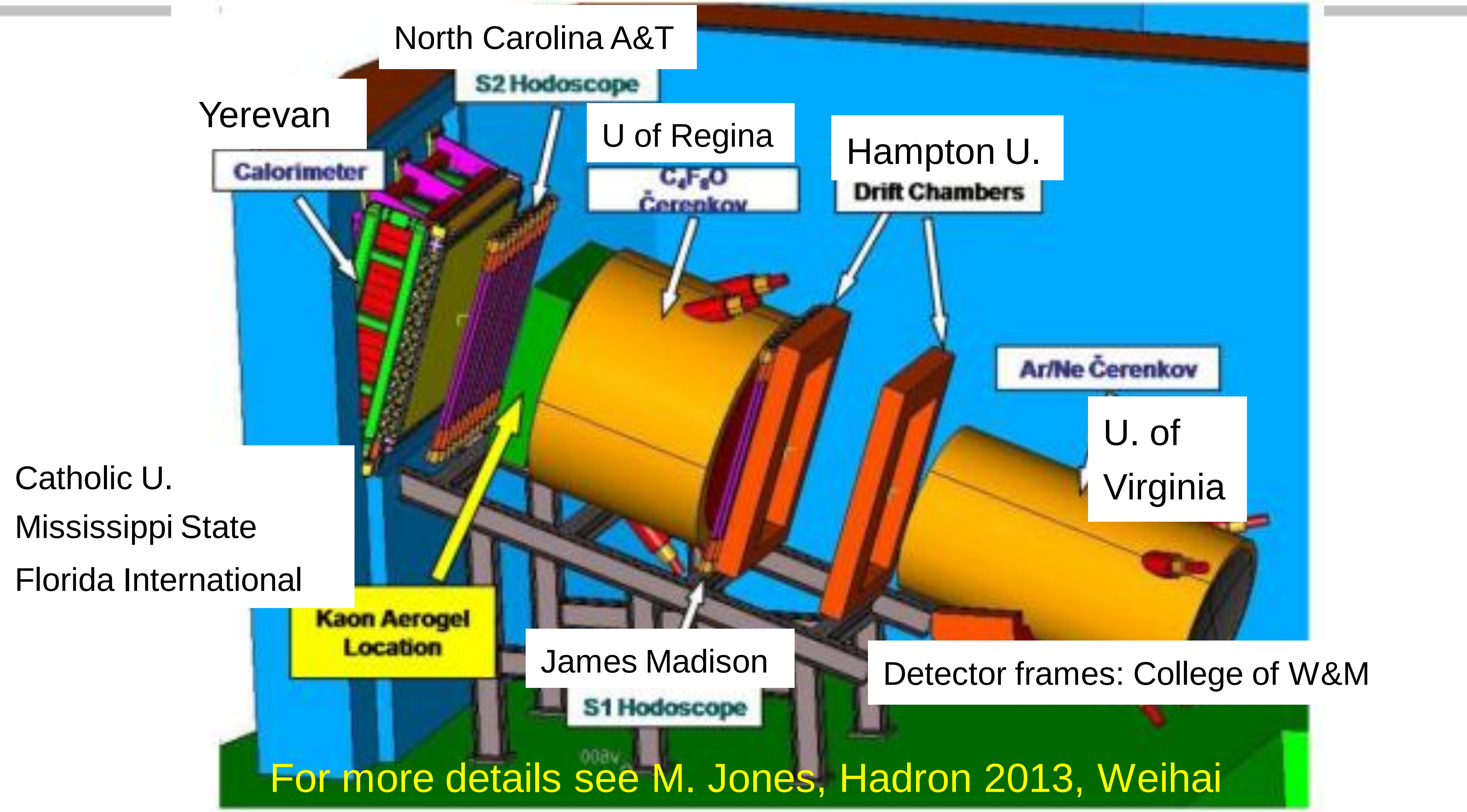
Hall C after 12 GeV Upgrade

- Beam Energy: 2 – 11 GeV/c
- Super High Momentum Spectrometer (SHMS)
  - Horizontal Bender, 3 Quads, Dipole
  - P $\rightarrow$ 11 GeV/c
  - dP/P 0.5 – 1.0x10^{-3}
  - Acceptance: 4msr, 30%
  - $5.5° < \theta < 40°$
  - Good e^-/π^- $e^+/\pi^+/K^+/p$ PID
- High Momentum Spectrometer (HMS)
  - P $\rightarrow$ 7.5 GeV/c
  - dP/P 0.5 - 1.0x10^{-3}
  - Acceptance: 6.5msr, 18%
  - $10.5° < \theta < 90°$
  - Good e^-/π^- $e^+/\pi^+/K^+/p$ PID
- Minimum opening angle: 17°

- Well shielded detector huts
- Ideal facility for:
  - Rosenbluth (L/T) separations
  - Exclusive reactions
  - Low cross sections (neutrino level)



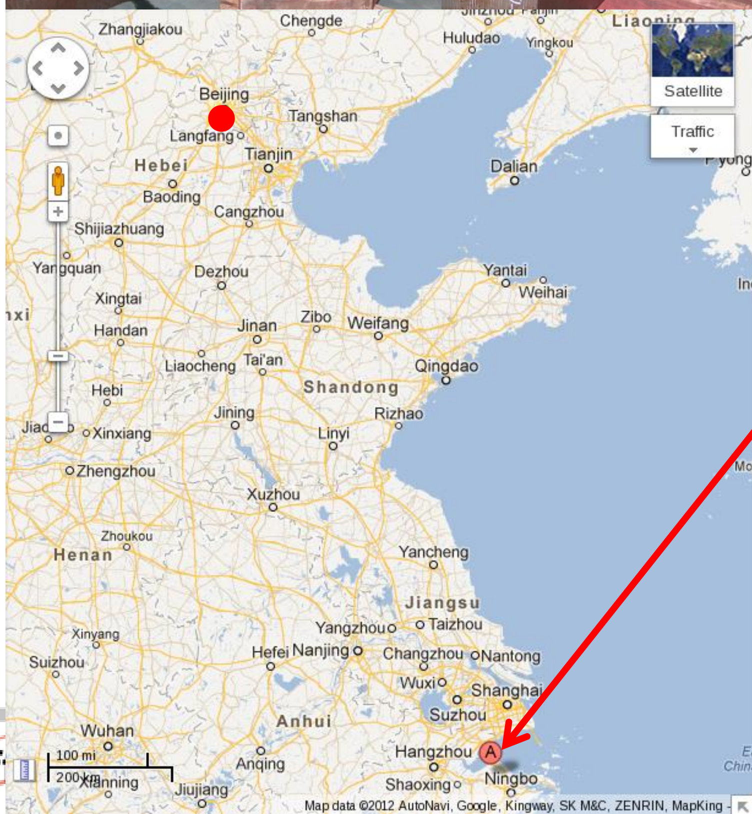
SHMS Detectors



http://hepg.sdu.edu.cn/THPPC/conference/weihai2011/Program.html

Main SHMS steel structure pieces at JLab

SHMS dipole yoke steel



Ningbo Jansen Mechanical Corp.

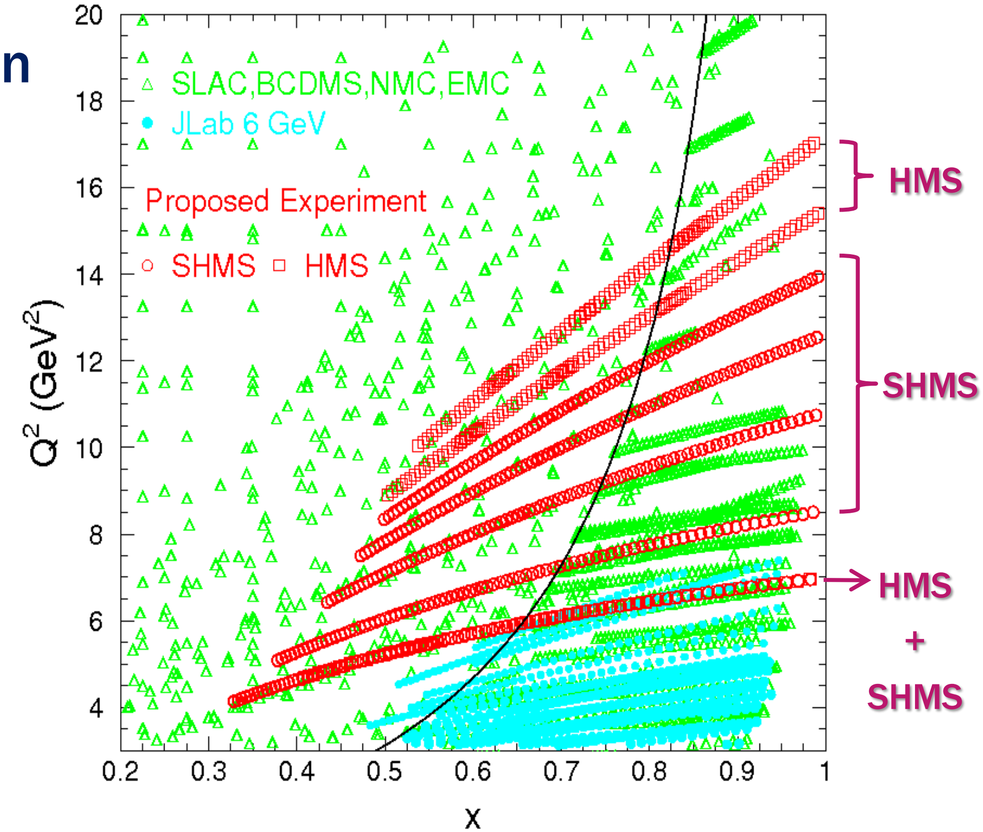
Structure Functions

E12-10-002 Precision F_2 structure function at high x

Extend proton and deuteron F_2 structure function precision measurements to larger x and Q^2 by measuring p(e,e′) and d(e,e′) cross sections in the resonance region and beyond up to Q^2 ~ 17 GeV^2 and x ~ 0.99

Need precision (~3%) data on proton and deuteron F_2 at large x to:

- **Constrain Parton Distribution Functions at large x**
- **Distinguish different mechanisms of spin-flavor symmetry breaking (d/u at large x) with precision F_2^n/F_2^d (combining with BONUS/Hall B (E12-06-113) F2n/F2d)**
- **Extend studies of local quark-hadron duality in proton and neutron F2**



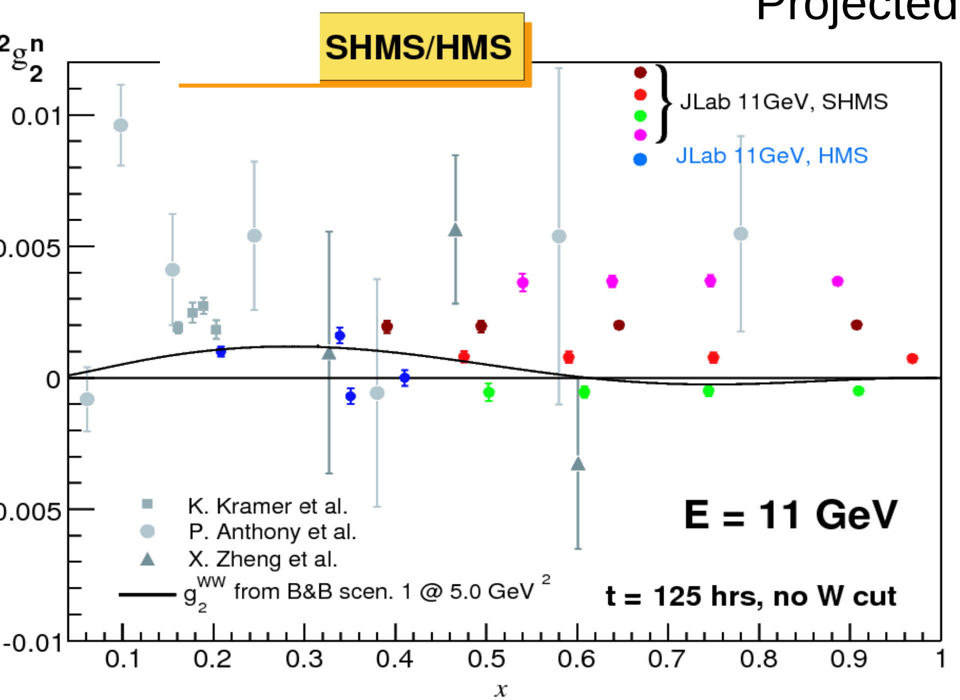
E12-06-121 Neutron g_2^n, d_2^n $^3\vec{\mathrm{He}}(\vec{e},e')$

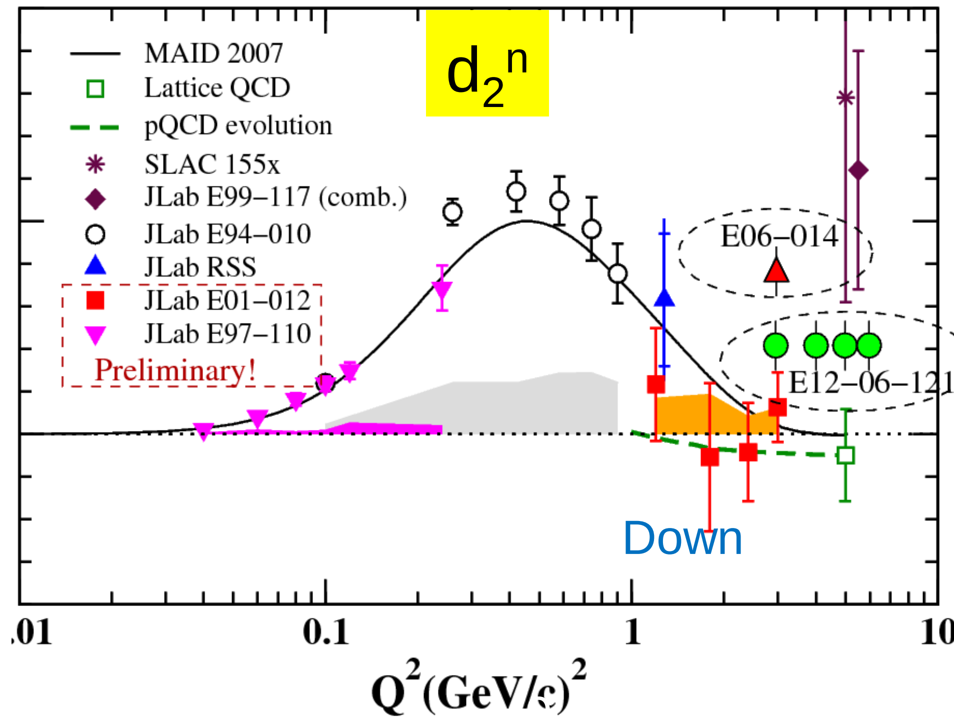
$$\Delta\sigma_{\parallel} = \sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow} \qquad \Delta\sigma_{\perp} = \sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}$$

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

Measure inclusive $\vec{n}(e,e')$ spin asymmetries for || and ⊥ target spin using ^{3}He target.

Projected Errors

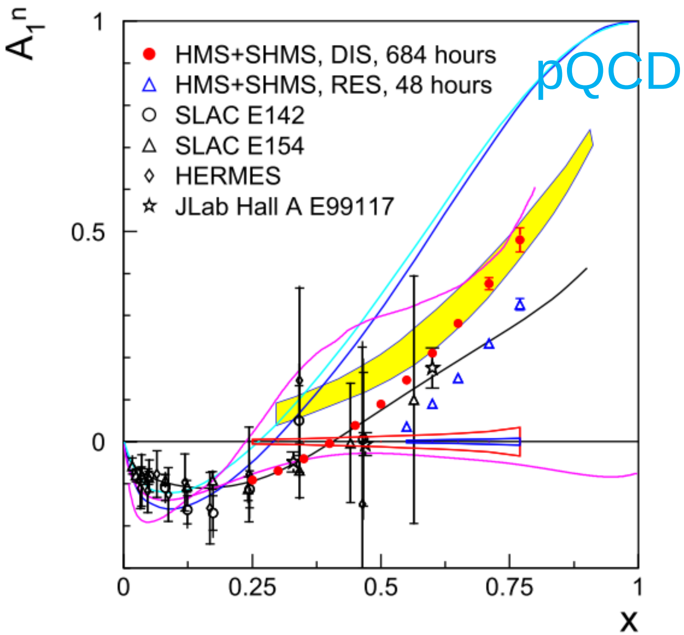




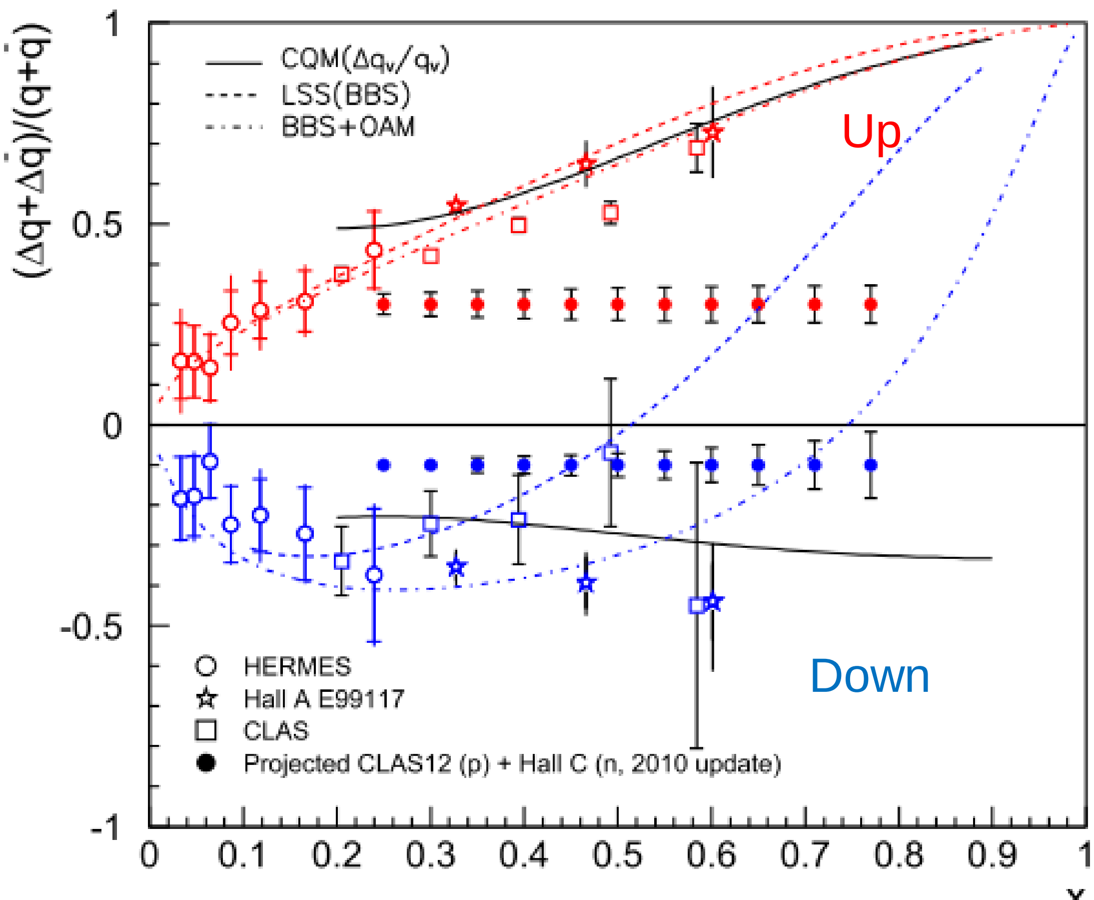
Neutron Spin Asymmetry A_{1N} in Valence Quark region

E12-06-110

$$A_1 = \frac{A_\parallel}{D(1+\eta\xi)} - \frac{A_\perp \eta}{d(1+\eta\xi)}$$



Measure inclusive $\vec{n}(e,e')$ spin asymmetries for || and ⊥ target spin using ^{3}He target.



- Combine with A_1 proton from CLAS12
- Extract the polarized PDF for up and down quarks

Semi-inclusive DIS

Semi-Inclusive Meson Production

- (e,e′) DIS probes sums of quarks and anti-quarks. $\sum e_q^2 (q(x) + \bar{q}(x))$
- By tagging DIS with mesons, gain sensitivity to quark flavours.
- At high energies the SIDIS process factorizes into a hard virtual photon-quark interaction and a subsequent quark hadronization, cross section can be decomposed as a products of quark distribution functions and fragmentation functions
- Factorization → Independence of the hard-scattering on z and hadronization/fragmentation on quark momentum x

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

$z = E_m/\nu$

$f_q(x)$: parton distribution function

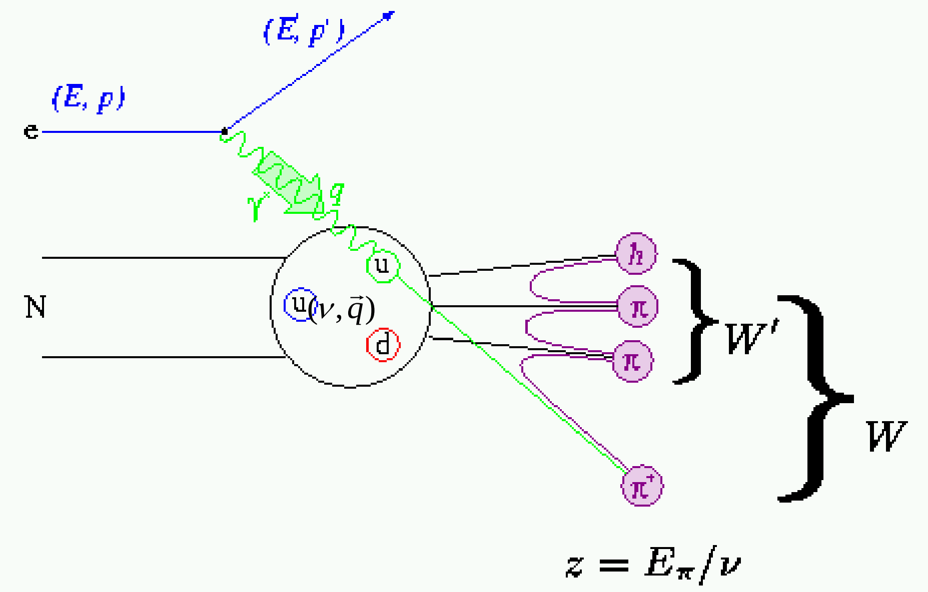
$D_q^h(z)$: fragmentation function

Semi-Inclusive DIS

SIDIS: Major part of JLab 12 GeV program.

Hall C focus:

- Precision Cross sections
- L/T Separated
- P_t dependence (TMD)



6 GeV experiment showed:

- Duality in (e,e'$\pi^\pm$)
- Factorization at low Q^2

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

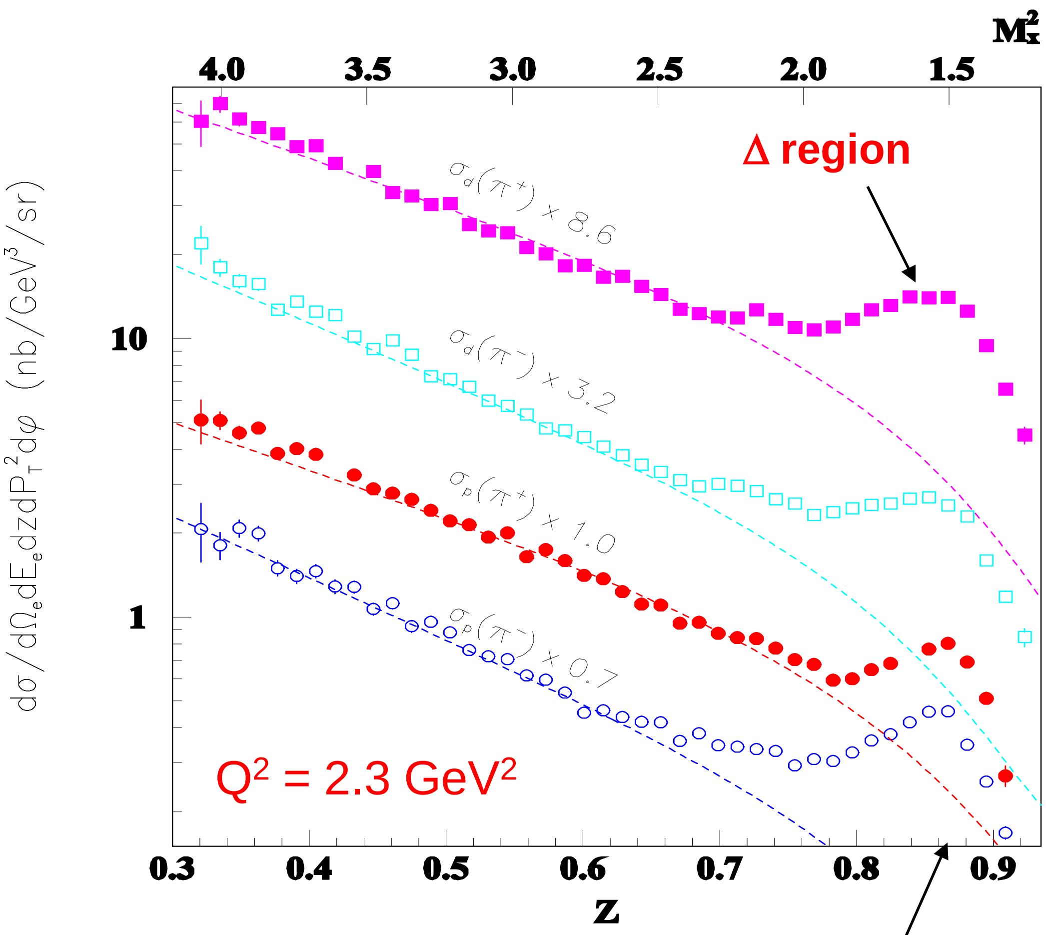
$f_q(x)$

$D_q^h(z)$

$z = E_m/\nu$

E00-108: Verifying factorization, p/d(e,e′$\pi^{\pm}$)

Z-Dependence of cross section



Phys. Rev. C 85, 015202 (2012)

($m_\Delta^2 \approx 1.5$ GeV²)

$$\sigma \sim \Sigma e_q^2 q(x)\, D_q^{\pi}(z)$$

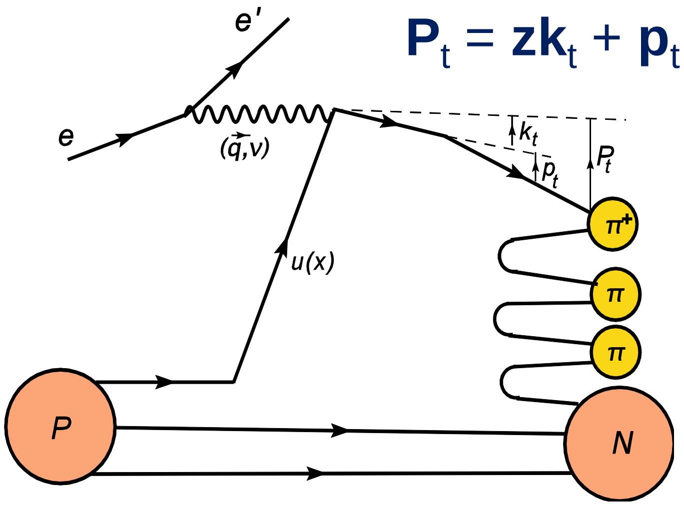
factorization

- **Good agreement between data and simple quark-parton model for z< 0.65 (assuming factorization, CTEQ5M pdfs, Binnweiss fragmentation)**
- **Excess in the data at z > 0.7 reflects the Δ resonance in unobserved fragments**
- **M_x^2 directly related to z:**

$$W'^2 = m_p^2 + Q^2 \cdot \left(\tfrac{1}{x} - 1\right)(1 - z)$$

$$\rightarrow W'^2 \equiv M_x^2 \prec (1 - z)$$

P_t dependence of SIDIS



$P_t = zk_t + p_t$

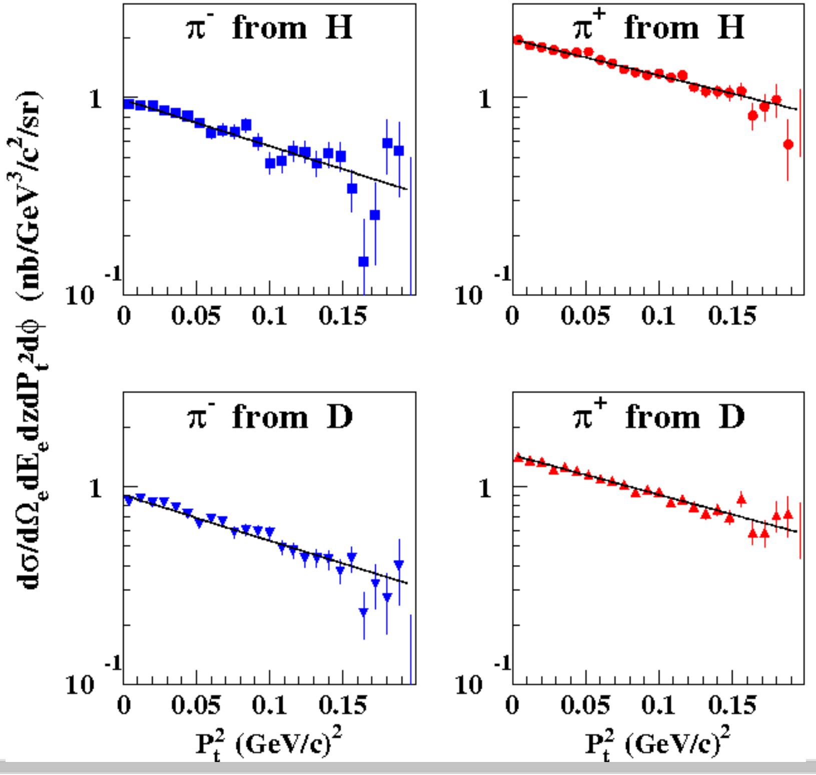
Final transverse momentum of pion P_t arises from convolving the struck quark transverse momentum k_t with transverse momentum generated during fragmentation process p_t

Assume the quark and fragmentation functions widths are Gaussian in k_t and p_t and $\langle P_t^2 \rangle = \langle z^2 k_t^2 \rangle + \langle p_t^2 \rangle$

Allow separate widths for u and d quarks, and separate widths for D^+ and D^-

$\sigma_{SIDIS} \sim \sigma_{DIS}\,(dN/dz)\; b \exp(-bP_t^2)$

$b^{\pm}_u = (z^2\mu_u^2 + \mu_{\pm}^2)^{-1}$ and $b^{\pm}_d = (z^2\mu_d^2 + \mu_{\pm}^2)^{-1}$



Quarks & Fragmentation Function Transverse Momentum

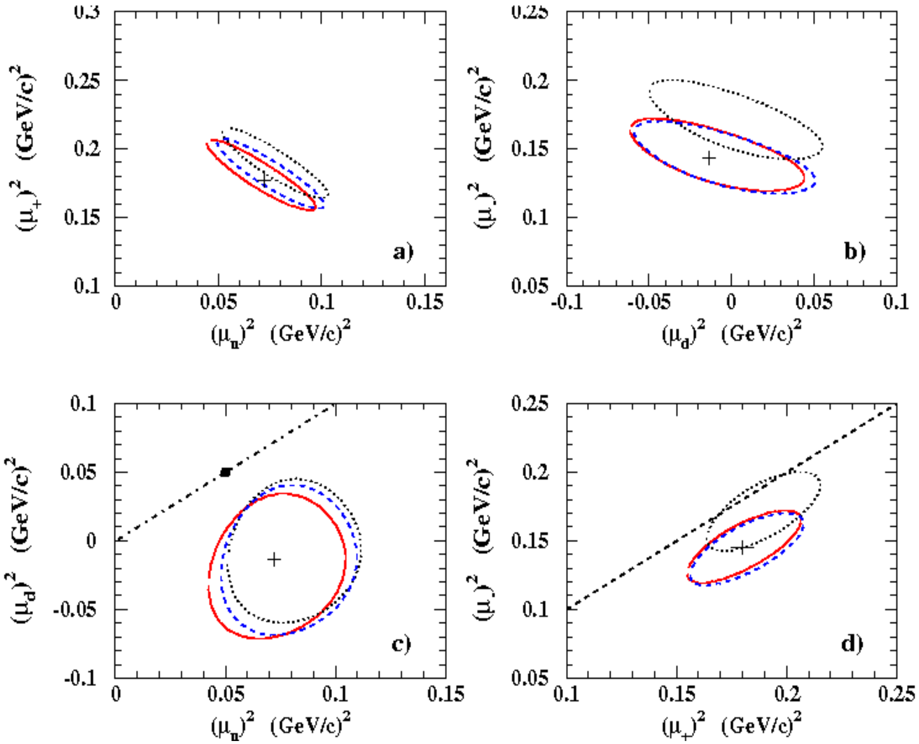
$\sigma_{SIDIS} \sim \sigma_{DIS}\,(dN/dz)\; b\, \exp(-bP_t^2)$ ➡ b ➔ $b^{\pm}_q$ ($b^{\pm}_u$ & $b^{\pm}_d$), and $b^{\pm}_q = (z^2\mu_q^2 + \mu_\pm^2)^{-1}$

$\sigma_p^{\pi+} = C[4c_1 \cdot \exp(-b^+_u P_t^2) + (d/u)(D^-/D^+)c_2 \cdot \exp(-b^-_d P_t^2)]$

$\sigma_p^{\pi-} = C[4(D^-/D^+)c_3 \cdot \exp(-b^-_u P_t^2) + (d/u)c_4 \cdot \exp(-b^+_d P_t^2)]$

$\sigma_n^{\pi+} = C[4(d/u)c_4 \cdot \exp(-b^+_d P_t^2) + (D^-/D^+)c_3 \cdot \exp(-b^-_u P_t^2)]$

$\sigma_n^{\pi-} = C[4(d/u)(D^-/D^+)c_2 \cdot \exp(-b^-_d P_t^2) + c_1 \cdot \exp(-b^+_u P_t^2)]$



Fit values:

- $D^-/D^+ = 0.43\pm0.01$; $d/u = 0.39\pm0.03$
- $\mu_u^2 = 0.07\pm0.03$ GeV^2 $\mu_d^2 = -0.01\pm0.05$ GeV^2
- $\mu_+^2 = 0.18\pm0.02$ GeV^2 $\mu_-^2 = 0.14\pm0.02$ GeV^2

Fit results for agree with HERMES D^-/D^+ (0.42), and LO GRV d/u ratio with (0.40)

Fit tends to larger k_t width for u quarks than for d ($\mu_d^2 \sim 0$)

Fragmentation width μ_+ and μ_- are similar (as predicted by Anselmino)

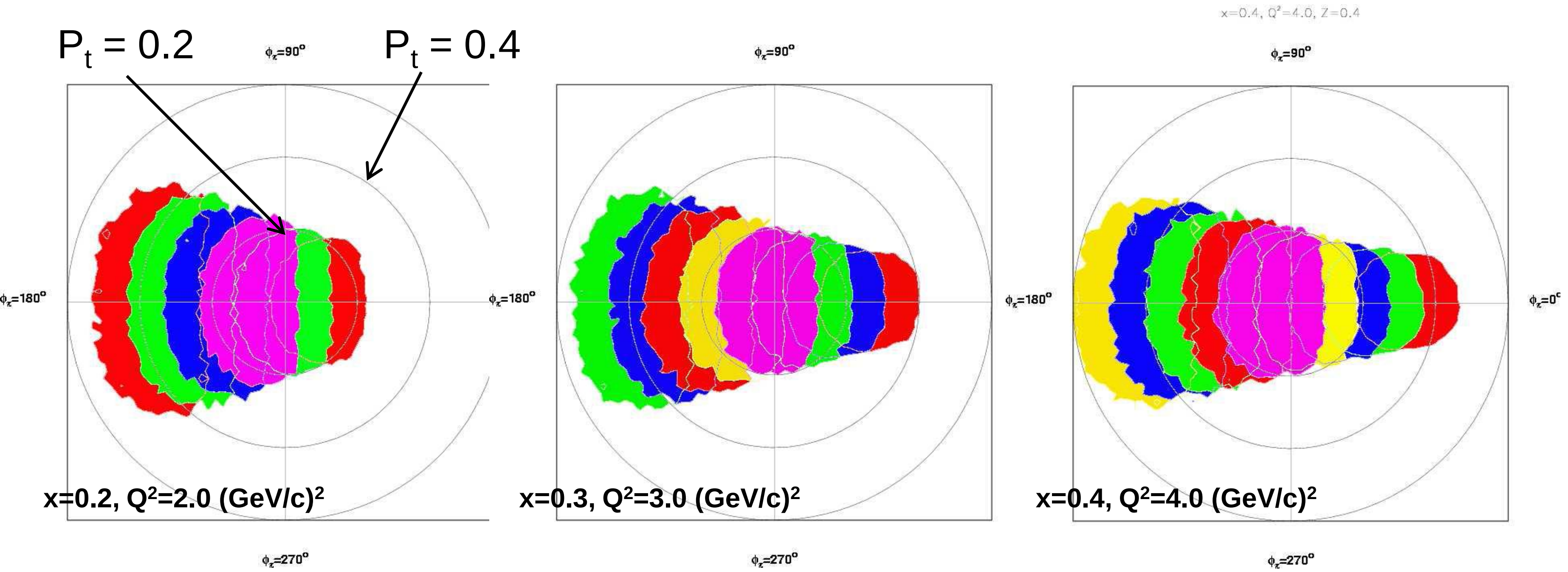
E12-09-017 TMD of SIDIS at 12 GeV

Map transverse momentum dependence of (e,e′π) over range:

$0.2 < x < 0.5$, $2 < Q^2 < 5$ GeV^2, $0.3 < z < 0.5$ and $P_t < 0.5$ GeV

Combine with CLAS12 data to constrain transverse widths of u/d quarks and fragmentation functions

Obtain some statistics on transverse momentum dependence of (e,e′K)



E12-09-017 TMD of SIDIS at 12 GeV

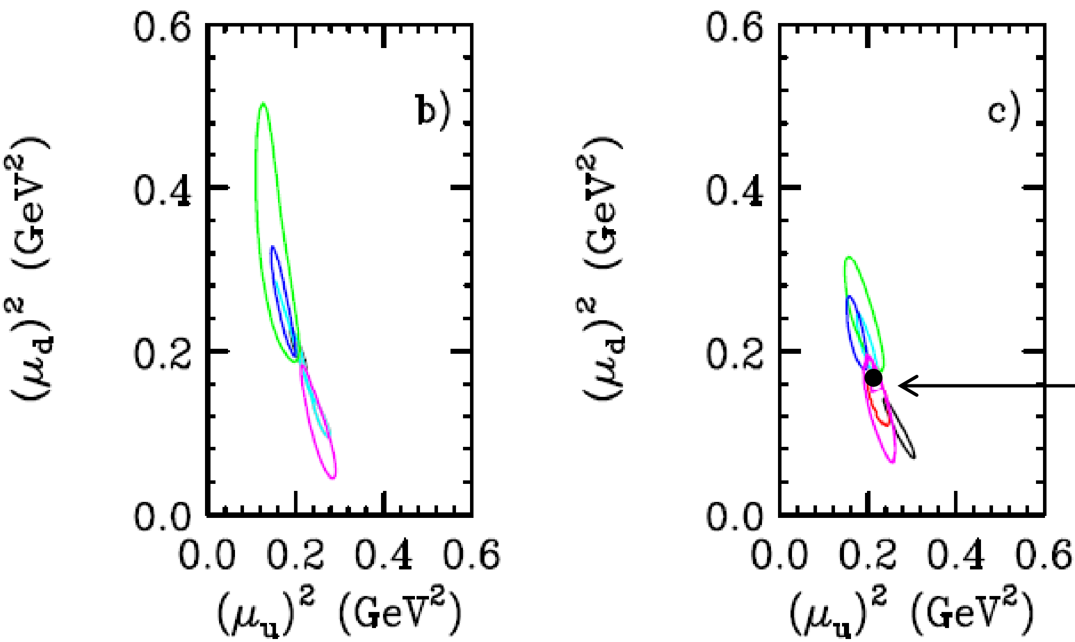
Map transverse momentum dependence of $(e,e'\pi)$ over range:

$0.2 < x < 0.5$, $1.8 < Q^2 < 5$ GeV^2, $0.3 < z < 0.5$ and $P_t < 0.5$ GeV.

Broad kinematic range will lessen assumptions in fitting P_T distributions.

Combine with CLAS12 data to constrain transverse widths of u/d quarks and fragmentation functions.

Obtain some statistics on transverse momentum dependence of $(e,e'K^+)$.

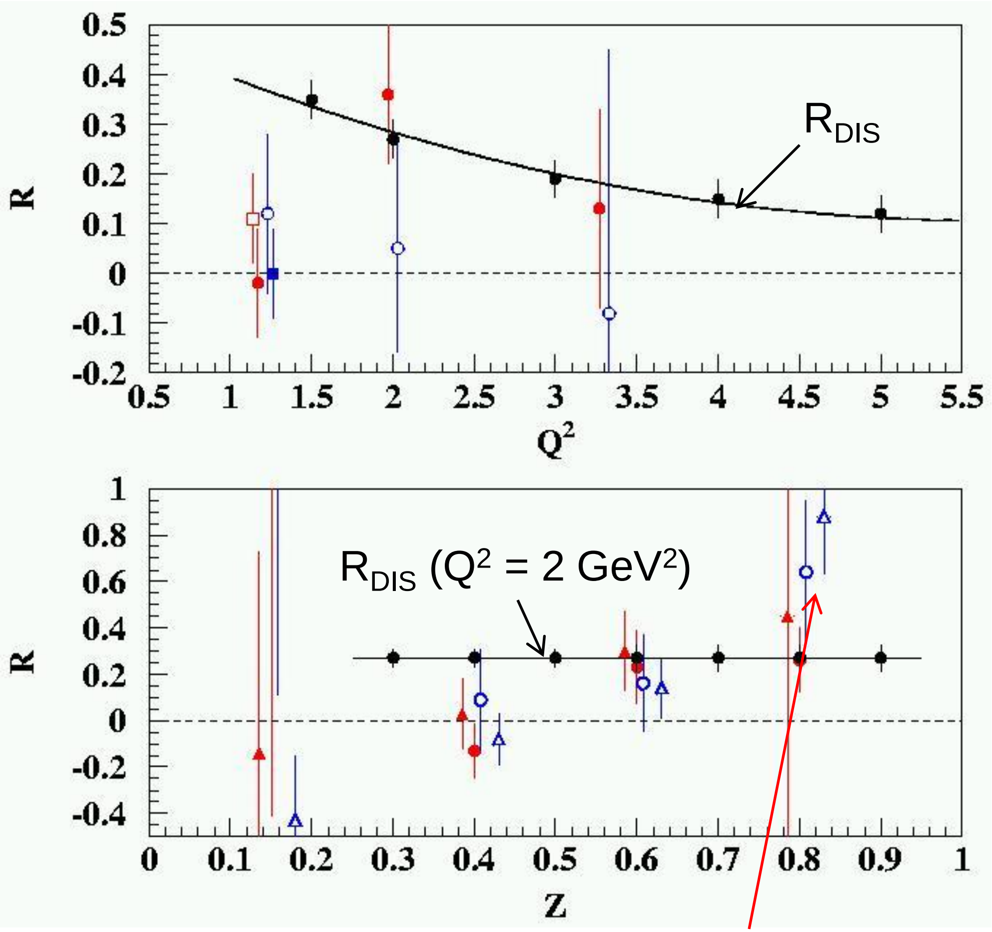


Error ellipses with and without Cahn term (azimuthal modulation) for 6 different kinematic settings

Combining all kinematics, expect ellipse of 0.02 GeV^2

E12-06-104 SIDIS $R = \sigma_L/\sigma_T$

Cornell data of 70's



R increasing as $z \rightarrow 1$?

Little known about R in SIDIS.

For z<1, expect $R \sim 1/Q^2$. But for z=1 (deep exclusive) expect $R \sim Q^2$

E12-06-104 plans z scans at $Q^2 = 2.0$ (x = 0.2) and 4.0 GeV^2 (x = 0.4)

Will cover range $Q^2 = 1.5 – 5.0$ GeV^2, with data for both H and D at $Q^2 = 2$ GeV^2

Scan P_T up to ~ 1 GeV

Also $R_{SIDIS}^{K^+}$ and $R_{SIDIS}^{K^-}$

E12-09-002 Charge Symmetry Violation Test with SIDIS

Charge Symmetry:

$m_p \sim m_n$

Energy levels mirror nuclei

p vs n scattering lengths

Charge Symmetry is assumed in parton distribution functions:

$u^p(x) = d^n(x)$

If Charge Symmetry, then $d(e,e'\pi^+)/d(e,e'\pi^-)$ depends on fragmentation functions not PDFs

Precision $N\pi^+/N\pi^-$ ratio gives $C(x) = \delta d(x) - \delta u(x)$ where:

$\delta u(x) = u^p(x) - d^n(x)$, $\delta d(x) = d^p(x) - u^n(x)$

Experiment E12-09-002:

Measure $d(e,e'\pi^-)/d(e,e'\pi^+)$ to 1% over range of kinematics

$p(e,e'\pi^+)$, $p(e,e'\pi^-)$ for further factorization tests

Requires careful control of π^+ π^- detection efficiency, radiative corrections

E12-09-002 Charge Symmetry Violation Test with SIDIS

Measure d(e,e′π^-) and d(e,e′π^+) yields $Y^{\pi-}$ and $Y^{\pi+}$

$$R^D_{meas}(x,y) = \frac{4Y^{\pi^-} - Y^{\pi^+}}{Y^{\pi^+} - Y^{\pi^-}}$$

$$D(z)(\frac{5}{2} + R^D_{meas}) + CSV(x) = B(x,z)$$

D(z) from favored/unfavored fragmentation function ratios.

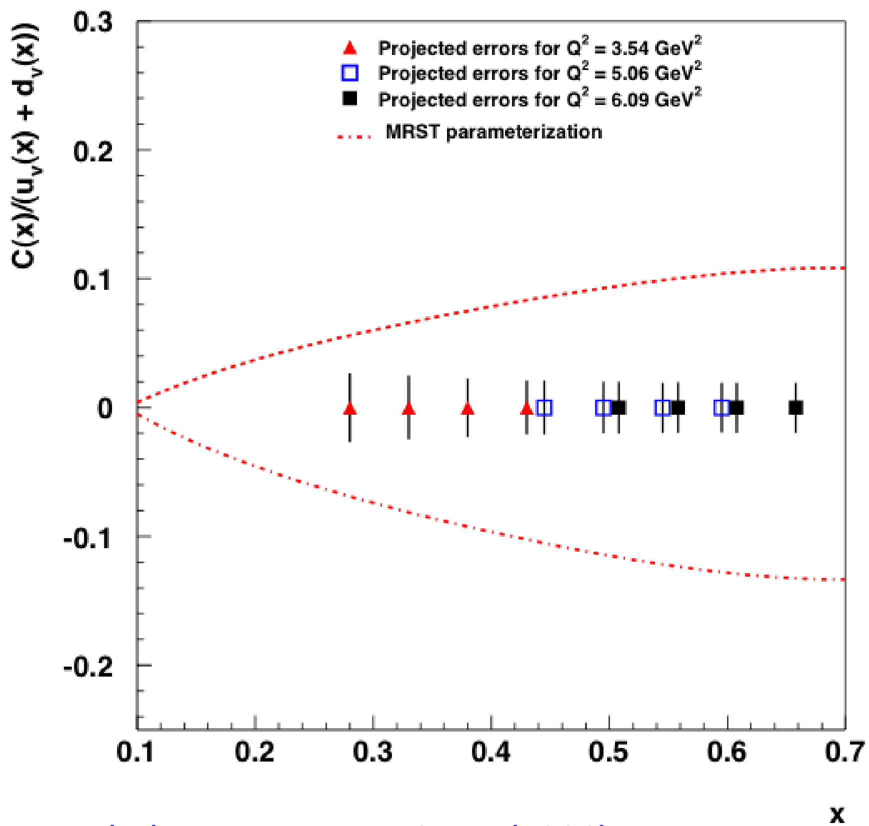
B(x,y) calculated from sea quark PDFs

$$CSV(x) = \frac{-4(\delta d - \delta u)}{3(u_v - d_v)}$$

$$\delta d = d^p(x) - u^n(x)$$

$$\delta u = u^p(x) - d^n(x)$$

Measure R(x,z) over a grid in x and z to extract D(z) and CSV(x).



Formalism of Londergan, Pang and Thomas PRD54, 3154 (1996)

Exclusive Reactions

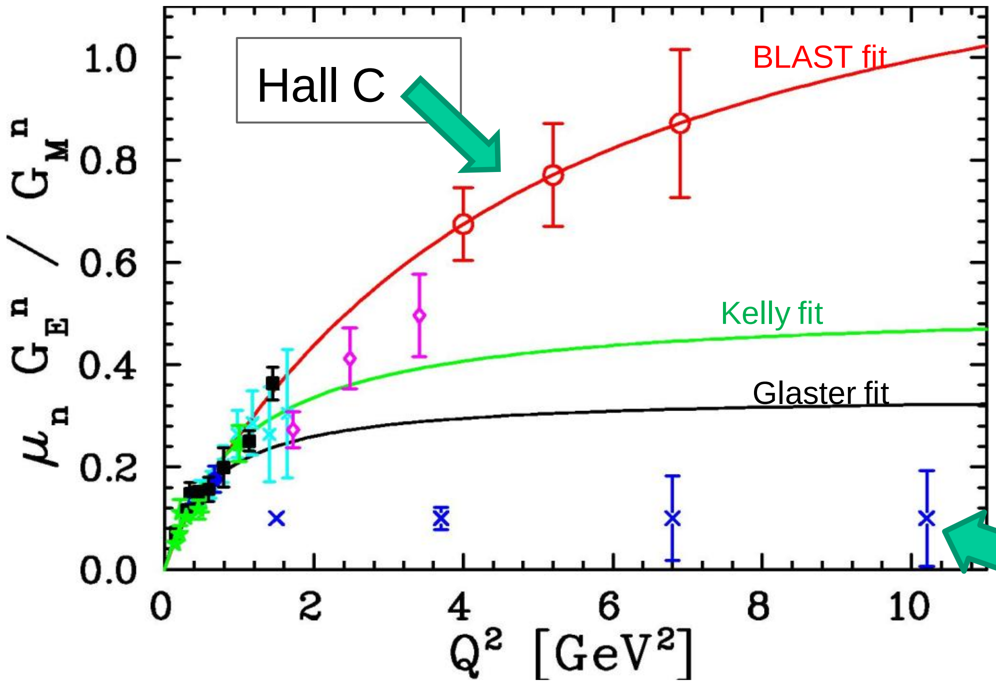
E12-11-009 Neutron Electric Form Factor

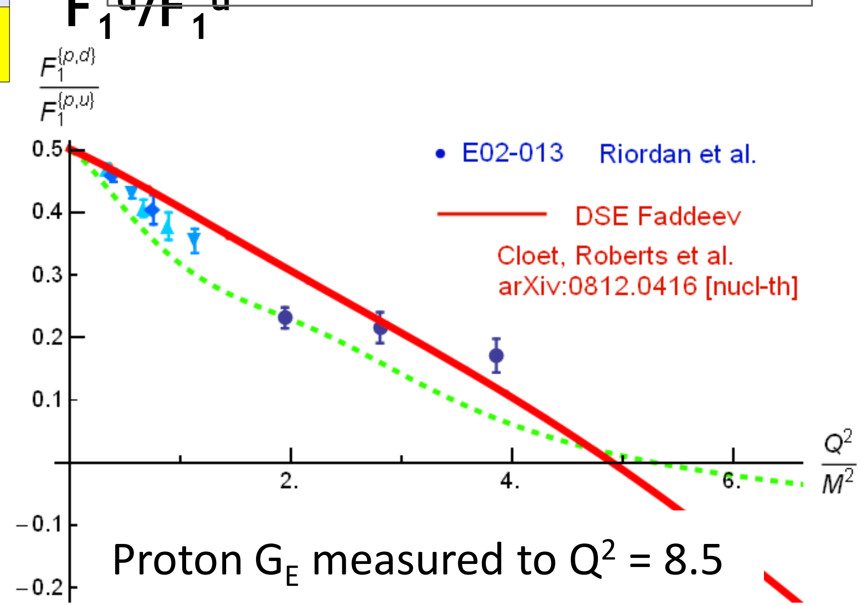
Proposal kinematics, PAC suggested two points at
$Q^2 = 6.9$ and near $Q^2 = 3.5$

Q^2 (GeV/c)^2	4.0	5.2	6.9
E_0 (GeV)	4.4	6.6	11.0
θ_e (deg)	36.3	26.3	16.8

d(e, e′n) n → Neutron Polarimeter

Present status of nucleon FF isospin separation

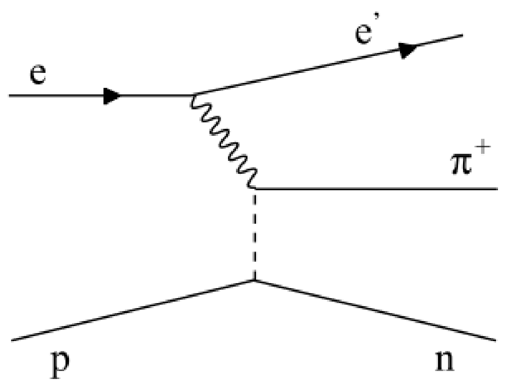




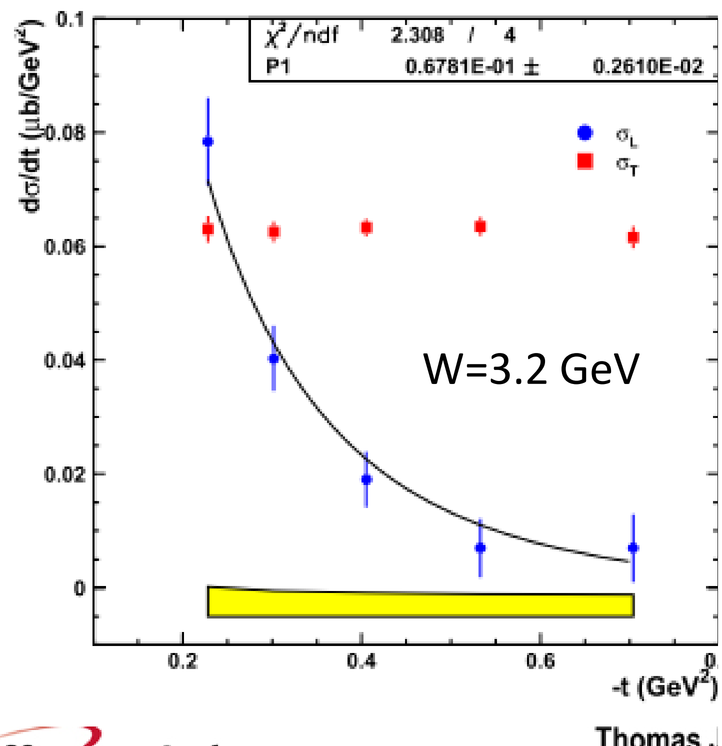
Hall A proposal at 12 GeV
using ^3He target

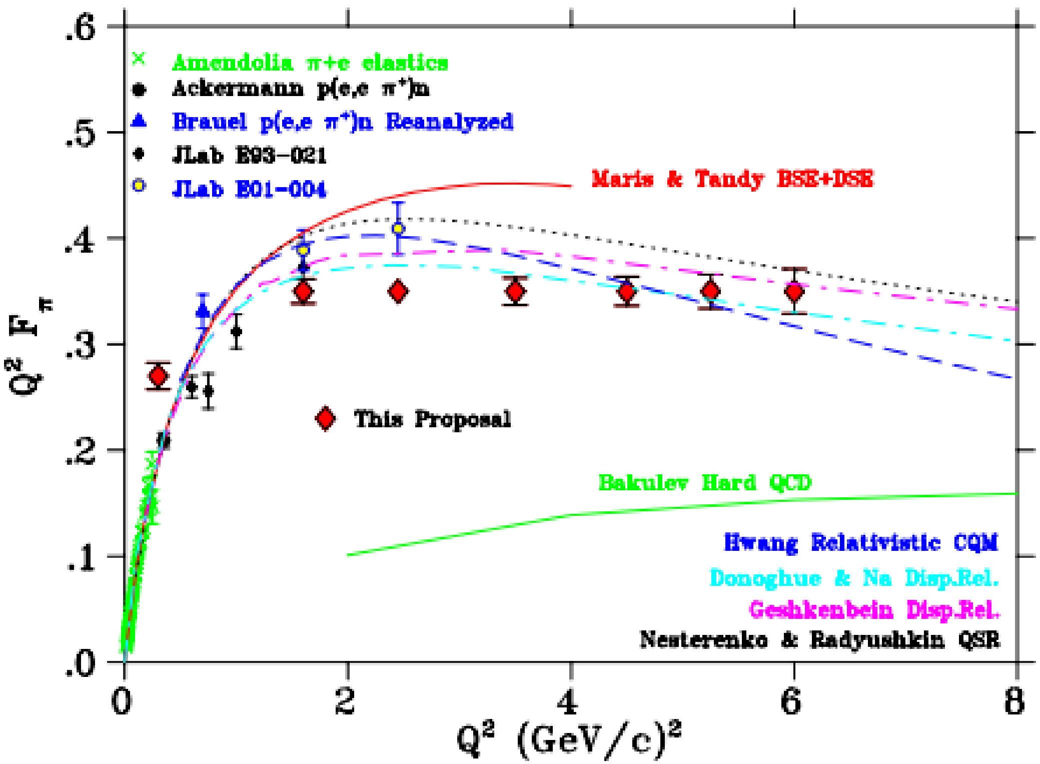
E12-06-101 Pion Form Factor

Measure exclusive $p(e,e'\pi^+)n$ as a function of t and small $\theta_{\pi q}$

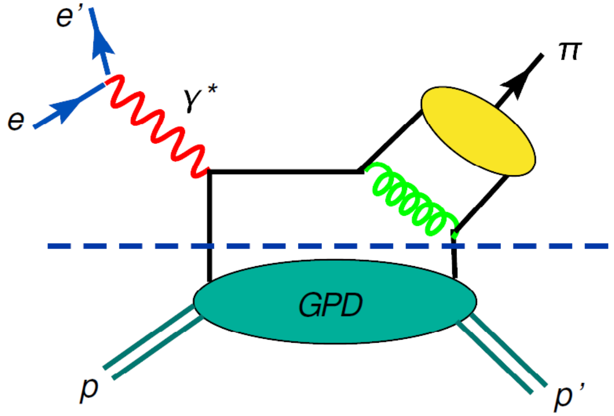


$$2\pi\frac{d^2\sigma}{dt\,d\phi} = \epsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi.$$



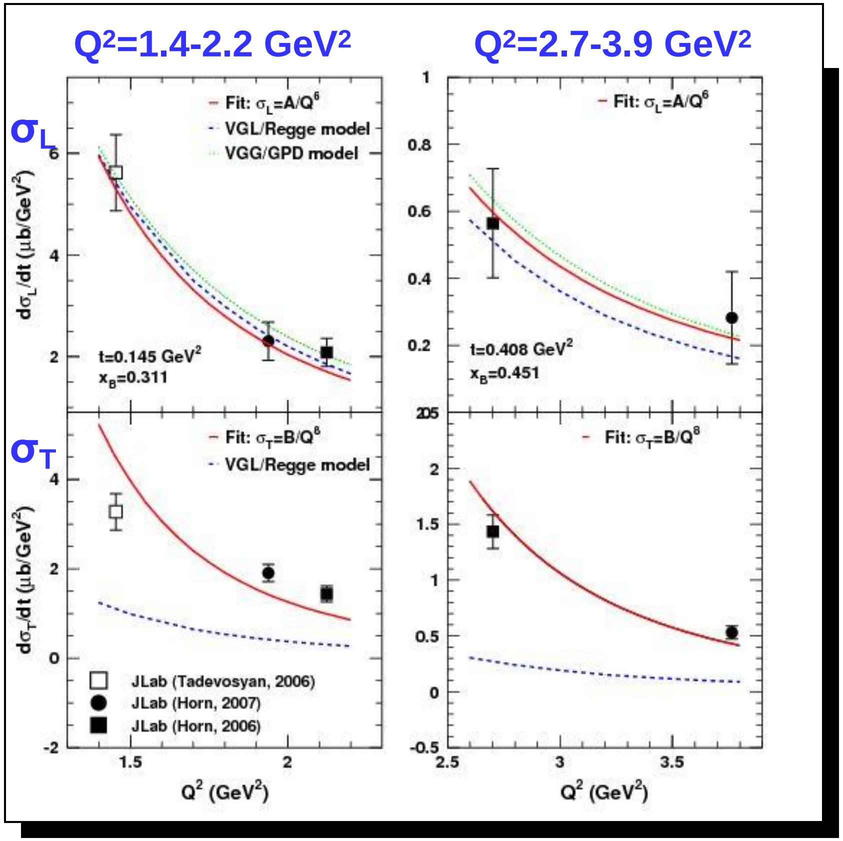


E12-07-105 Scaling of exclusive (e,e′π) cross sections



- At sufficiently high Q^2 (> 10 GeV^2), meson electroproduction should factorize into hard (quark-knockout) and soft (nucleon GPD and meson formation).
- To leading order σ_L, should scale as $1/Q^6$ and σ_T as $1/Q^8$. (At fixed x and t).
- 12 GeV experiment (E12-07-105) will extend range of scaling tests and test dominance of σ_L. ($Q^2 \rightarrow 9$ GeV^2)

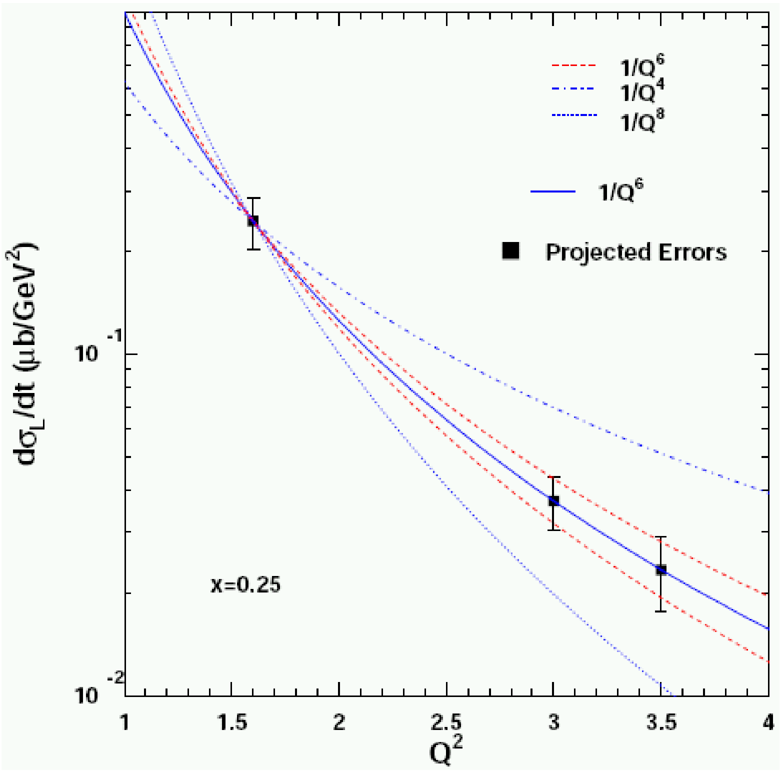
6 GeV Hall C Data

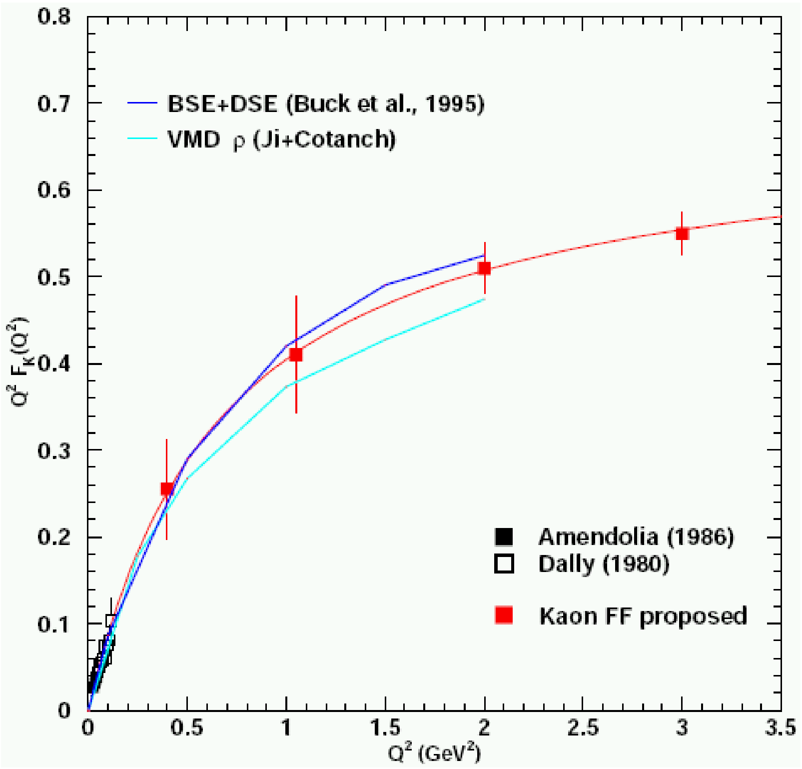


Horn et al., Phys. Rev. C. 78, 058201 (2008)

E12-09-011 L-T separated (e,e′K) at 5-11 GeV

E12-09-011: T. Horn (CUA), G. Huber (U of Regina), P. Markowitz (FIU)

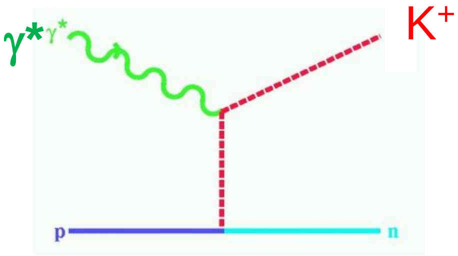




Projected errors on scaling and form factor.

Study kaon production mechanism and feasibility of

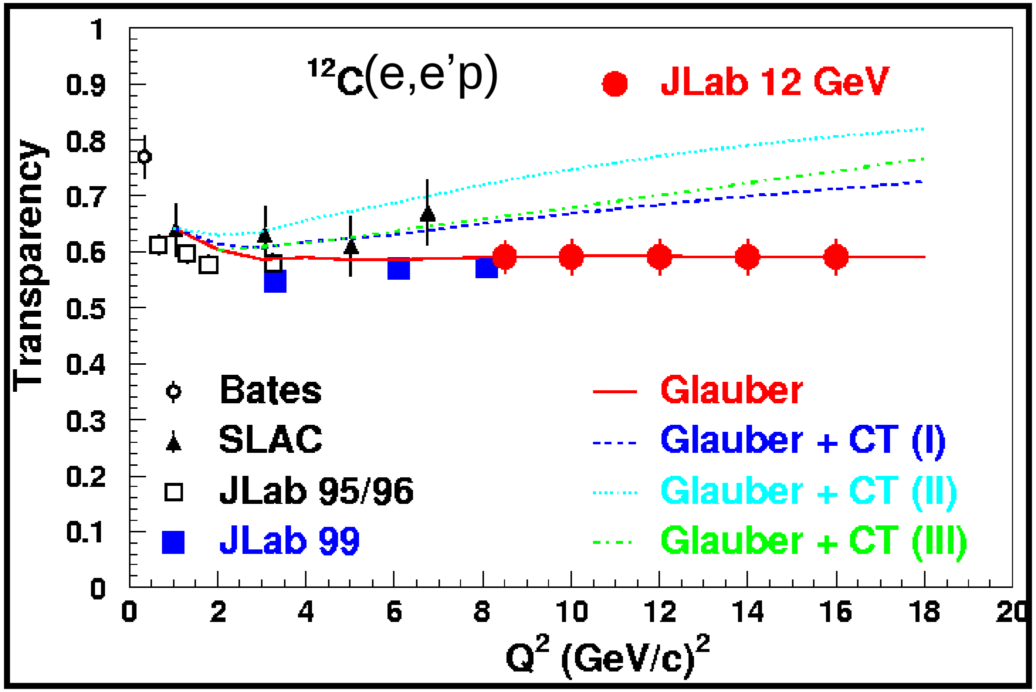
Kaon form factor extraction up to Q^2 = 3 GeV^2



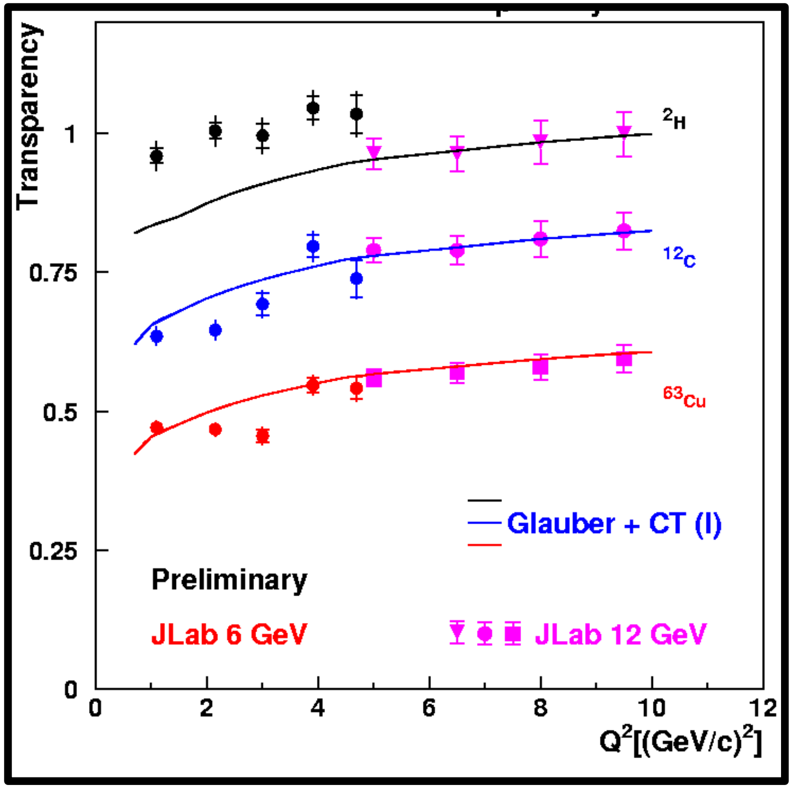
Nuclei

E12-06-107 Pion/Proton Transparency at 12 GeV

A(e,e′p) at 12 GeV (projected results)



A(e,e′π^+) at 12 GeV (projected results)



E12-06-107

EMC Effect in Light Nuclei

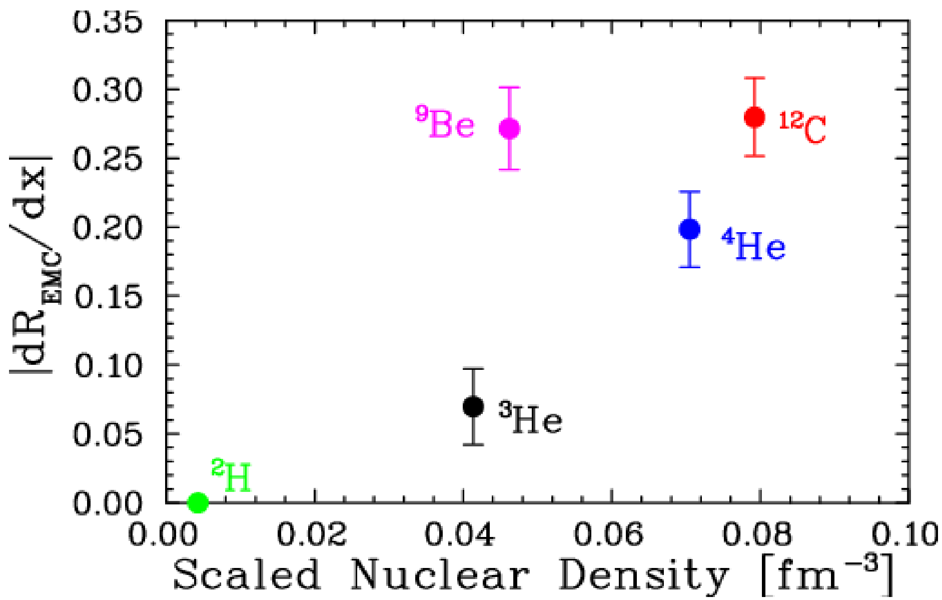
New measurement of the EMC effect in light nuclei in Hall C

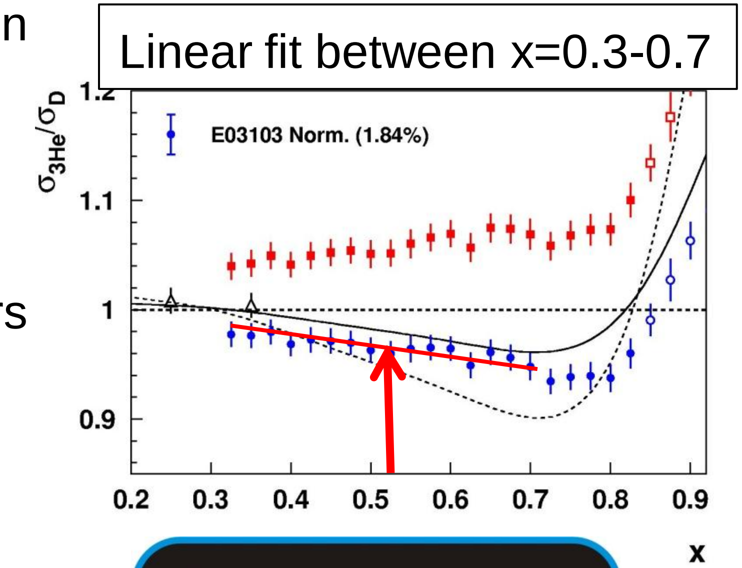
→ Both A and ρ dependent fits fail

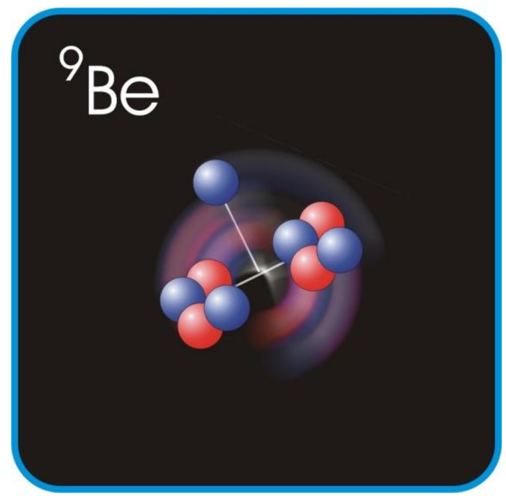
→ **Be structure suggests "local density" picture**

Cluster structure dominated by 2a+*n*

Ave. density low, but all protons in a-like clusters







12 GeV E12-10-008 (A. Daniel et.al) will measure in DIS region (higher Q^2), add broader range of nuclei and cover x = 0.1 – 1.0.

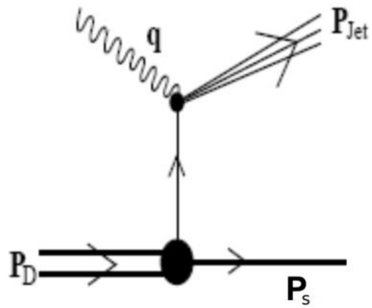
[J. Seely et al, 103:202301 (2009)]

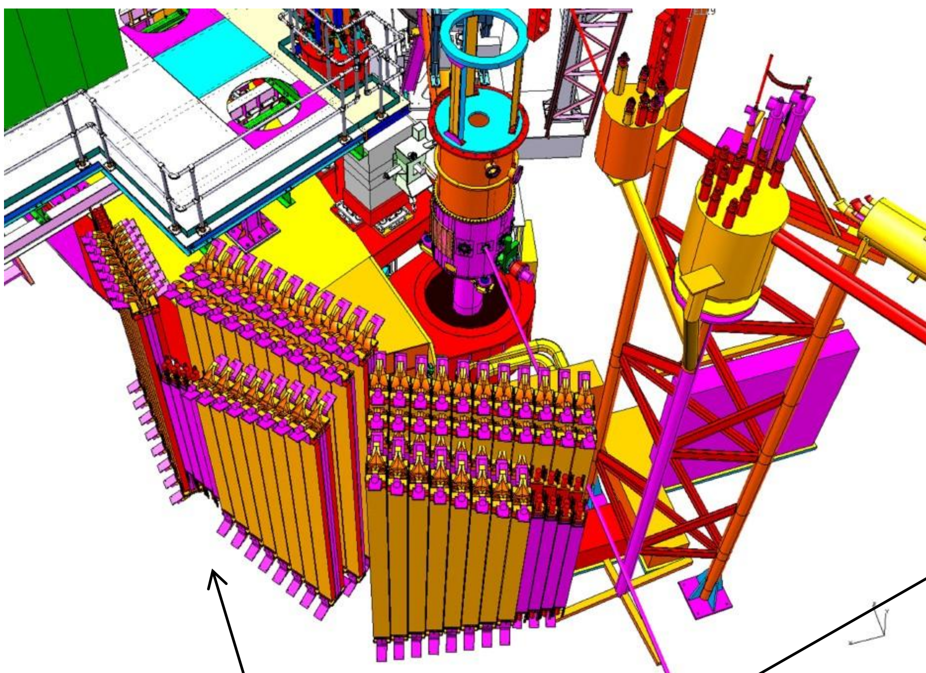
http://focus.aps.org/story/v24/st20

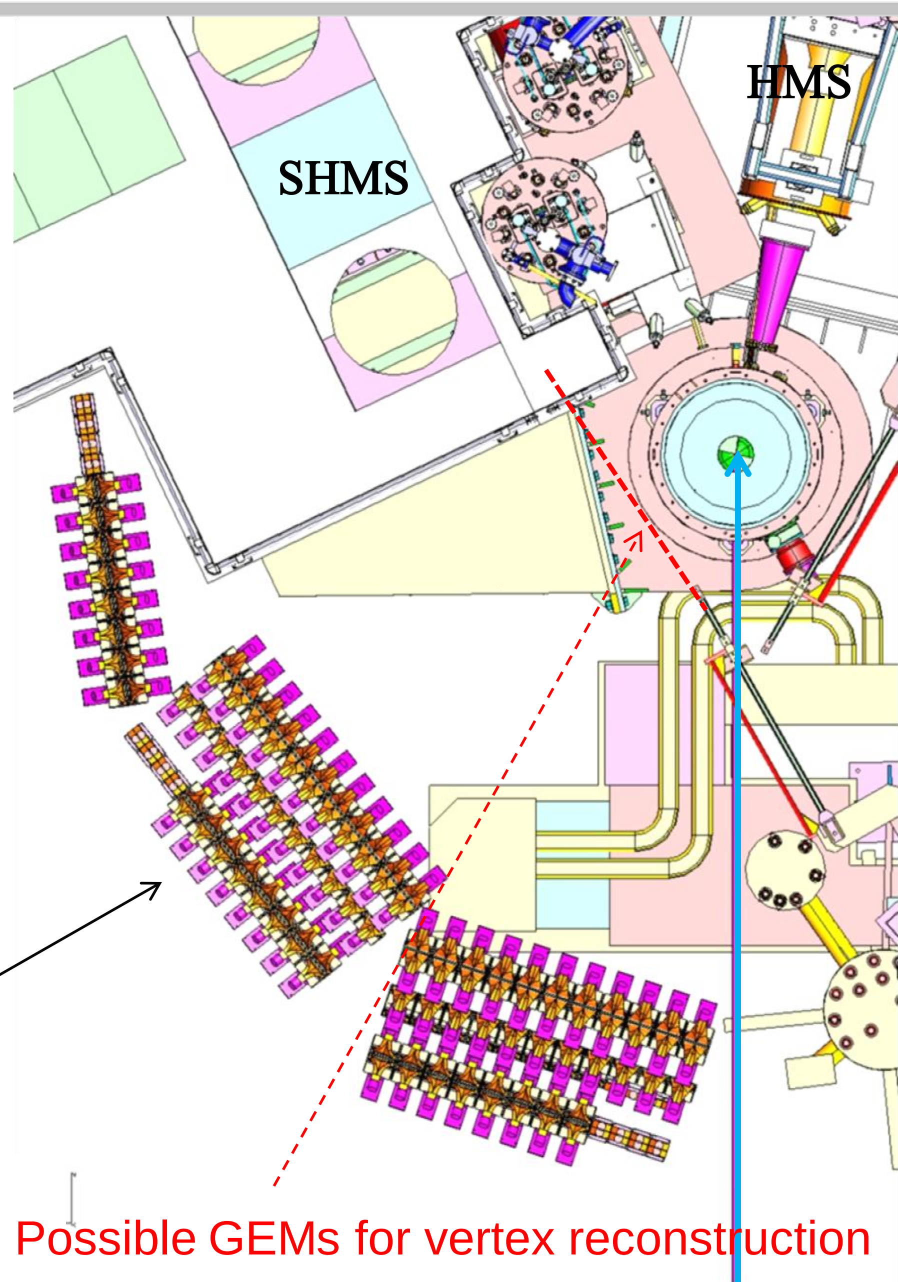
E12-11-107 Backward nucleon detector – EMC effect

$d(e, e' N_{backward})$

Detect spectator proton or neutron to tag in medium structure function on off-shell nucleon.







Recycled CLAS6 (Hall B) TOF detectors

Possible GEMs for vertex reconstruction

Future Facilities

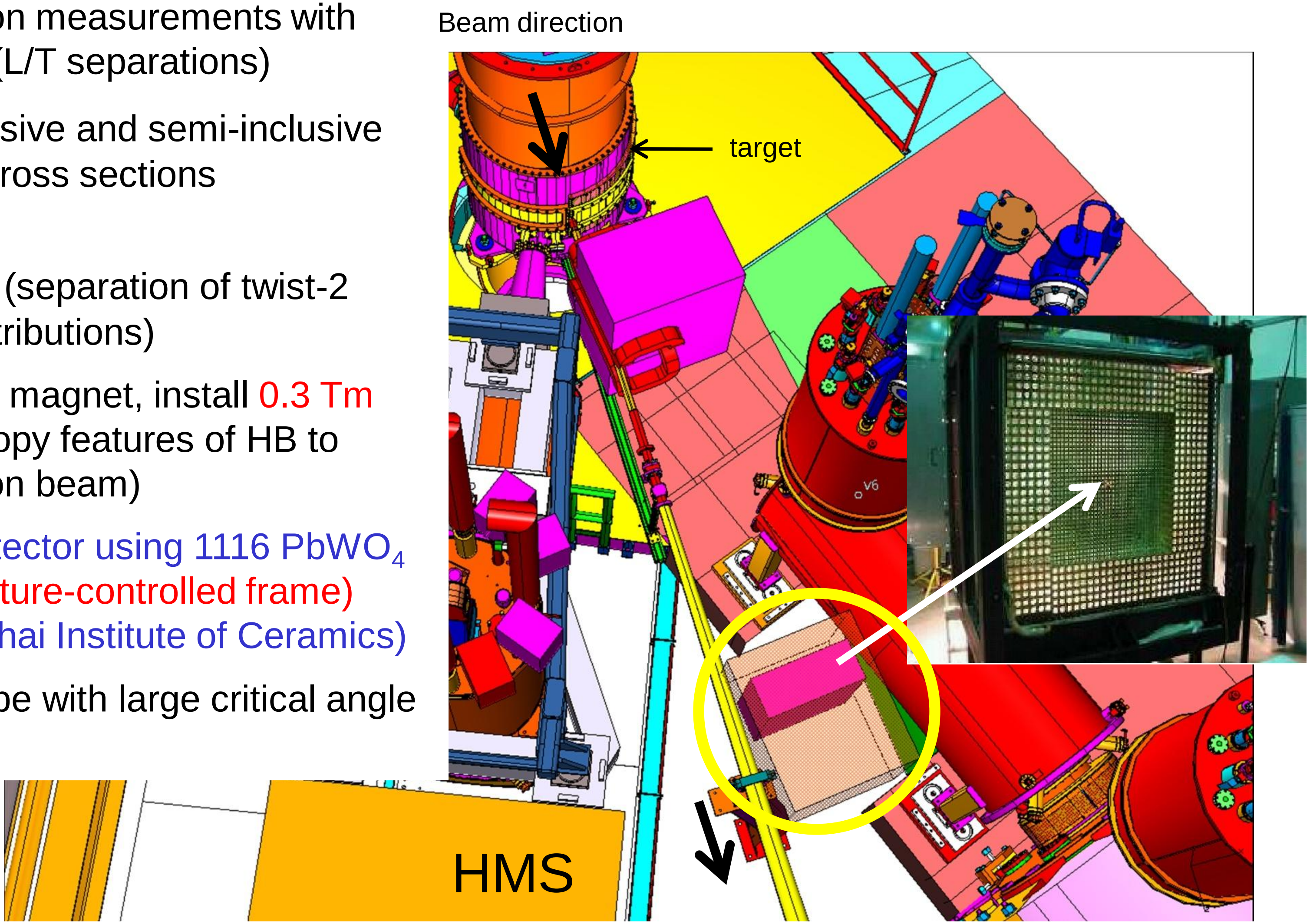
Proposed neutrals (e.g. π^0/γ) detector facility in Hall C

- Desire to augment spectrometers with capability for precision measurements with neutral final states. (L/T separations)

  p(e,e′π^0) exclusive and semi-inclusive L/T separated cross sections (PR12-11-111)

  p(e,e′γ) DVCS (separation of twist-2 and twist-3 contributions)

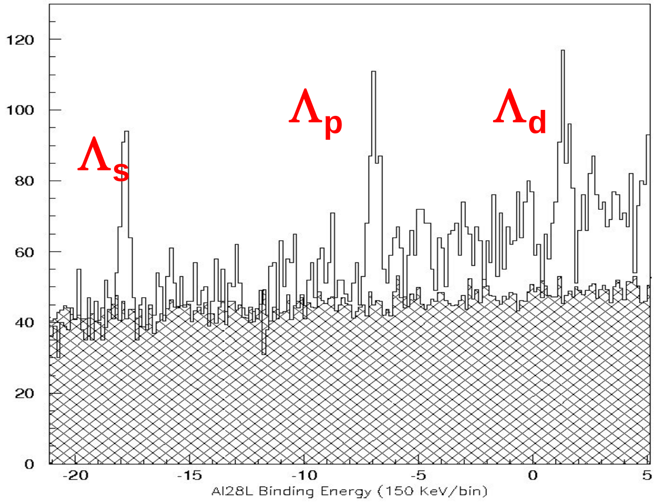
- Remove SHMS HB magnet, install 0.3 Tm sweeping magnet (copy features of HB to minimize stray field on beam)
- Add 25 msr π^0/γ detector using 1116 $PbWO_4$ blocks (with temperature-controlled frame) ($PbWO_4$ from Shanghai Institute of Ceramics)
- Dedicated beam pipe with large critical angle + shielding

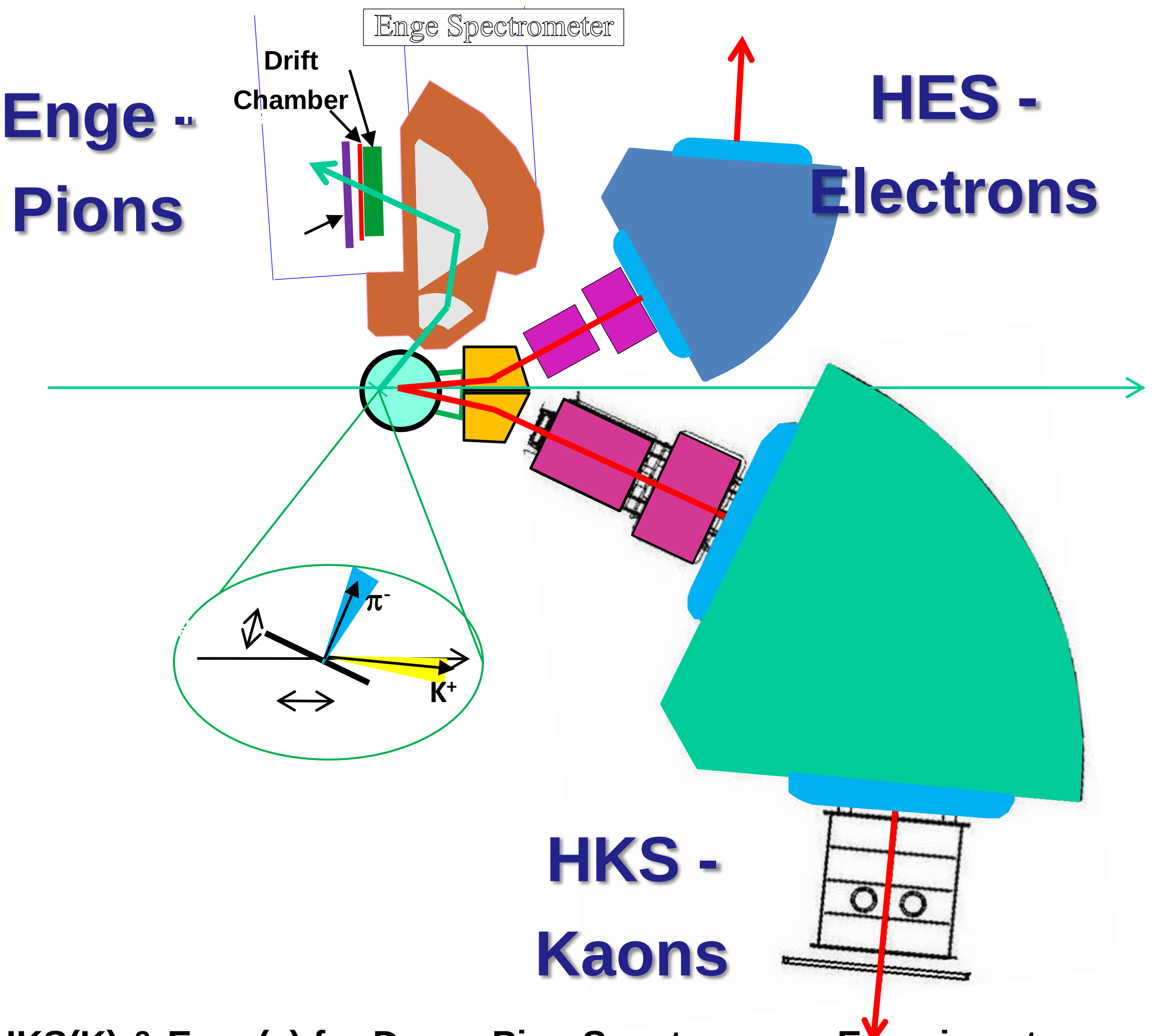


Hypernuclear Spectroscopy

See talks by L. Tang and C. Chen on past and possible future hypernuclear spectroscopy program in Hall C

$^{28}Si(e, e'K^+)^{28}{}_{\Lambda}Al$ (Hall C E01-011)



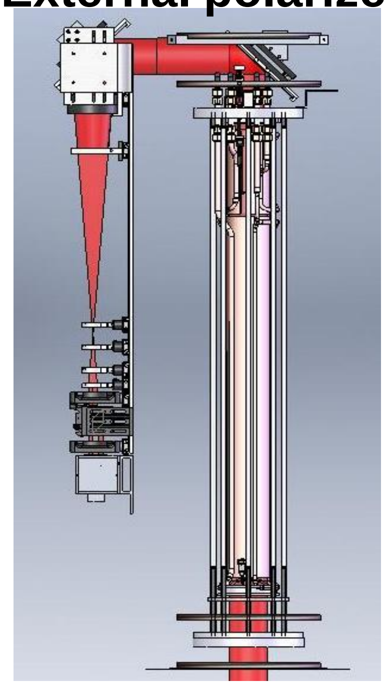


Trigger I: HKS(K) & Enge(π) for Decay Pion Spectroscopy Experiment
Trigger II: HKS(K) & HES(e') for Mass Spectroscopy Experiment

UNH/Xemed Target Loop Concept

- Compress polarized ^{3}He and deliver to aluminum target cell
- Non-ferrous diaphragm compressor achieves 3000 psi (~200 bar)
- Returns through a pressure-reducing orifice

External polarizer



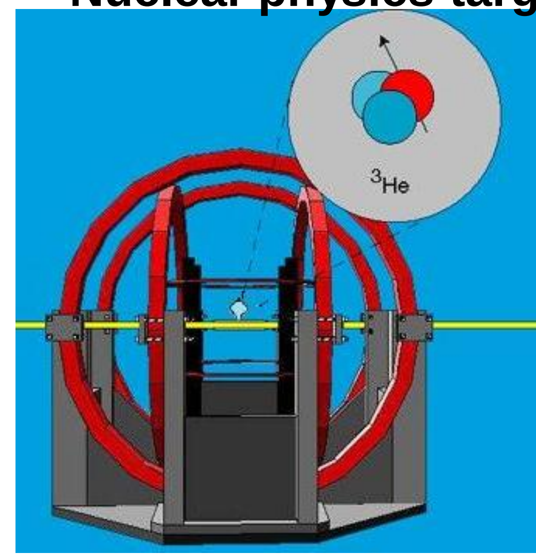
K:Rb Hybrid Spin Exchange Optical Pumping

20 Bar

Non-ferrous diaphragm compressor

200 Bar

Nuclear physics target



9 cm aluminum target cell

Cooled with LN_2 to 77K

Thickness of 0.5 g/cm^2

Recirculates at 25 SLPM

Hall C 12 GeV Startup

Approved 12 GeV Hall C proposals 1

Title	Days	Grade
Measurement of the Charged Pion Form Factor to High Q^2 (E12-06-101) *Spokespersons: G.M. Huber (huberg@uregina.ca), D. Gaskell*	52	A
Measurement of the Ratio $R = \sigma_L/\sigma_T$ in Semi-Inclusive DIS (E12-06-104) *Spokespersons: R. Ent, (ent@jlab.org) ,H. Mkrtchyan*	40	A-
Inclusive Scattering from Nuclei at x > 1 in the quasielastic and deeply inelastic regimes. (E12-06-105) *Spokespersons: J. Arrington (johna@anl.gov), D. Day*	32	A-
The Search for Color Transparency at 12 GeV (E12-06-107) *Spokespersons: D. Dutta (ddutta@jlab.org) , R. Ent*	26	B+
Measurement of Neutron Spin Asymmetry A_{1n} in the Valence Quark Region Using an 11 GeV Beam and a Polarized ^{3}He Target in Hall C (E12-06-110) *Spokespersons: J.-P. Chen, X. Zheng (xiaochao@jlab.org), Z. E. Meziani, G. D. Cates*	36	A
Neutron g_2 and d_2 at High Q^2 in Hall C (E12-06-121) *Spokespersons: B. Sawatzky (brads@jlab.org) , W. Korsch , Z.-E. Meziani, T. Averett*	29	A-
Scaling Study of the L-T Separated Pion Electroproduction Cross Section at 11 GeV (E12-07-105) *Spokespersons:. T. Horn (hornt@jlab.org) , G .Huber*	36	A-
Charge Symmetry Violating Quark Distributions via Precise Measurement of pi+/pi- Ratios in Semi inclusive Deep Inelastic Scattering (E12-09-002) *Spokespersons:K. Hafidi (kawtar@anl.gov),D. Gaskell, D. Dutta*	22	A-

Approved 12 GeV Hall C proposals 2

Title	Days	Grade
Studies of the L-T separated kaon electroproduction cross sections from 5-11 GeV (E12-09-011) *Spokespersons:T. Horn (hornt@jlab.org) , G .Huber, P. Markowitz*	40	B+
Transverse Momentum Dependence of Semi-Inclusive Pion Production (E12-09-017) *Spokespersons:R. Ent (ent@jlab.org), H. Mkrtchyan,P. Bosted*	32	A-
Precision measurements of the F_2 structure function at large x in the resonance region and beyond (E12-10-002) *Spokespersons:S.P. Malace (simona@jlab.org) , I.M. Niculescu, C. Keppel*	13	B+
Deuteron Electro-Disintegration at Very High Missing Momenta (E12-10-003) *Spokespersons: W. Boeglin (boeglin@fiu.edu), M. Jones*	21	B^+
Detailed studies of the nuclear dependence of F_2 in light nuclei (E12-10-008) *Spokespersons: A. Daniel, J. Arrington, D. Gaskell (gaskelld@jlab.org)*	23	A-
Proton Recoil Polarization in the ^{4}He(e,e'p)^{3}H, ^{2}H(e,e'p)n, and ^{1}H(e,e'p) Reactions (E)12-11-102) *Spokespersons: E. Brash , R. Ransome, G. M. Huber, S. Strauch (strauch@jlab.org)*	37	B+
In Medium Nucleon Structure Functions, SRC, and the EMC effect (PR-12-11-107) *Spokespersons:O. Hen, L.B. Weinstein (weinstei@jlab.org), S. Gilad*	40	B+
The Neutron Electric Form Factor at Q^2 up to 7 $(GeV/c)^2$ from the Reaction ^{2}H(e, e n)^{1}H via Recoil Polarimetry (E12-11-009) *Spokespersons:B. D. Anderson J. Arrington (johna@anl.gov) ,S. Kowalski, R. Madey, B. Plaster, A.Yu. Semenov*	50	B+

Timeline for Hall C Upgrade

- May 2012 Q_{weak} ended and removal (Q_{weak}+SOS) started
- Fall 2012 SHMS installation begins

Magnet	Delivery Date
Q1	Dec 2013
Dipole	Dec 2013
Q2,Q3	May, Oct 2014
3^o Horizontal Bender	Dec 2013

- Late 2013-14 Detector installation
- 2015 SHMS commissioning

Commissioning Experiments in Hall C

Early running plans – Year 1

2015: ~25 PAC days – Commissioning "Experiment"

9 days of E12-06-107 search for color transparency

A(e,e'p) only – "easy" coincidence measurement

E12-10-002 $F_2^{p,d}$ structure functions at large x

Momentum scans help understand acceptance

2 days E12-10-108 EMC Effect

Integrate light nuclei with F_2 run,

Point target helps acceptance studies.

3 days of E12-10-003 d(e,e'p)

If time available

Push to lower cross sections

Early running plan – Years 2+

2016:

E12-09-017 P_t dependence of basic SIDIS cross sections

Push particle ID capabilities of SHMS

E12-09-002 Precise $\pi^+\pi^-$ ratios in SIDIS – Charge Symmetry

Detector efficiencies

E12-09-011 L/T separated p(e,e′K⁺) factorization test

Easiest L/T separation

2017:

E12-06-121 g_2^n measurements at fixed Q^2

First polarized ^{3}He target experiment in Hall C

Likely follow by E12-06-110 high x A_1^n

2018?: First Large Installation: Neutron Form Factor?

Hall C 12 GeV Era Summary

- Hall C will have two well shielded magnetic spectrometers able to exploit full beam energy, measure low cross sections with precision, LT separations
- Approved program of structure functions, SIDIS, exclusive reactions and nuclear effects (EMC, X>1, Transparency)
- Initial run plan in place
- Additions to base equipment:
    - Neutron and proton polarimeters
    - Backward nucleon detector
- Possible future facilities
    - π^0/γ detector
    - Hypernuclear program
    - High luminosity ^3He target

Backup slides

Meson Duality Experiment - E00-108

- Coincidence measurement

HMS + SOS

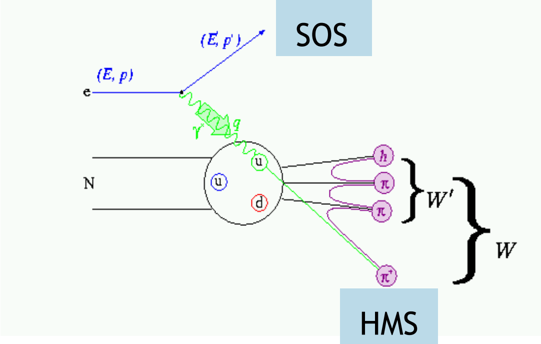
$\pi^{\pm}$

e^-

$$e + p \longrightarrow e' + \pi^{\pm} + X$$
$$e + D \longrightarrow e' + \pi^{\pm} + X$$

- 4 cm LH2 and LD2 targets
- Al (dummy) to estimate cryo target wall background
- Beam energy 5.5 GeV
- Beam current 20-70 μA

- z-dependence (z=0.3-1.0) at x=0.3, Q^2=2.3
- x-dependence (x=0.25-0.6) at z=0.55
- θ_{π} (0^o-8^o) at fixed z=0.55 and x=0.3 (P_t scan)

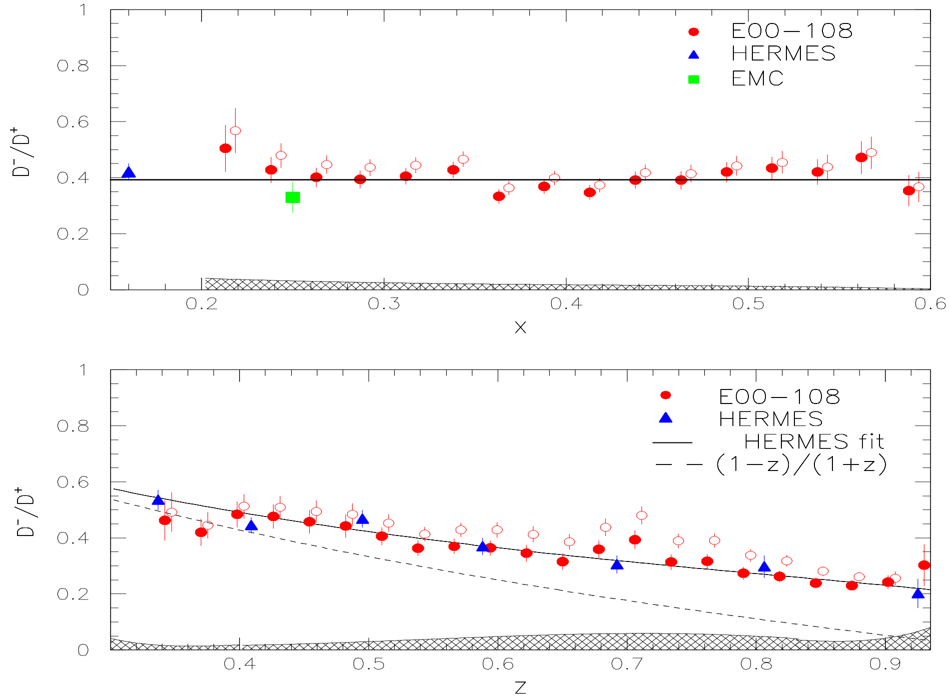


$x = Q^2/2M\nu$

$z = E_{\pi}/\nu$

Semi-inclusive $\pi^{\pm}$ electroproduction to the region M_x^2 > 1.5 GeV

D^-/D^+ from Deuteron π^+ to π^- ratio



$$\sigma_d^{\pi^+} \propto (4D^+ + D^-)(u+d)$$

$$\sigma_d^{\pi^-} \propto (4D^- + D^+)(u+d)$$

$$\frac{\sigma_d^{\pi^+}}{\sigma_d^{\pi^-}} = \frac{4D^+ + D^-}{4D^- + D^+}$$

$D^-/D^+ = (4 - r) / (4r - 1)$

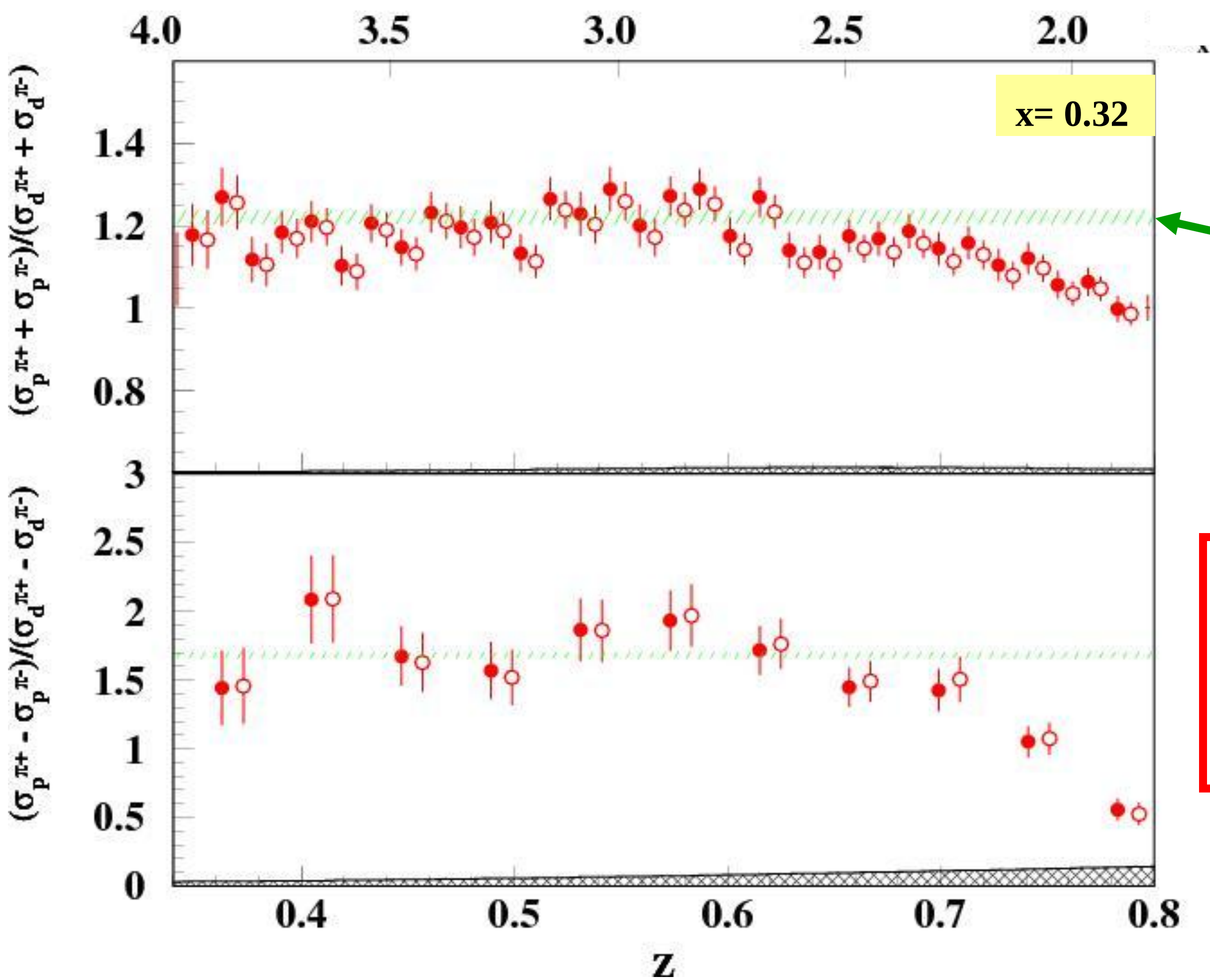
where $r = \sigma_d(\pi^+)/\sigma_d(\pi^-)$

$z = E_\pi/\nu$

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

- **Near-independence from x, as expected**
- **Results agree with HERMES & EMC**
- **The resonant contribution at z>0.8 cancel out ! (Close & Isgur)**

Verifying factorization – Cross section ratios



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

GRV & CTEQ, @ LO or NLO

Leading-Order

x-z factorization

Good description for Proton and deuteron targets for $0.4 < z < 0.65$

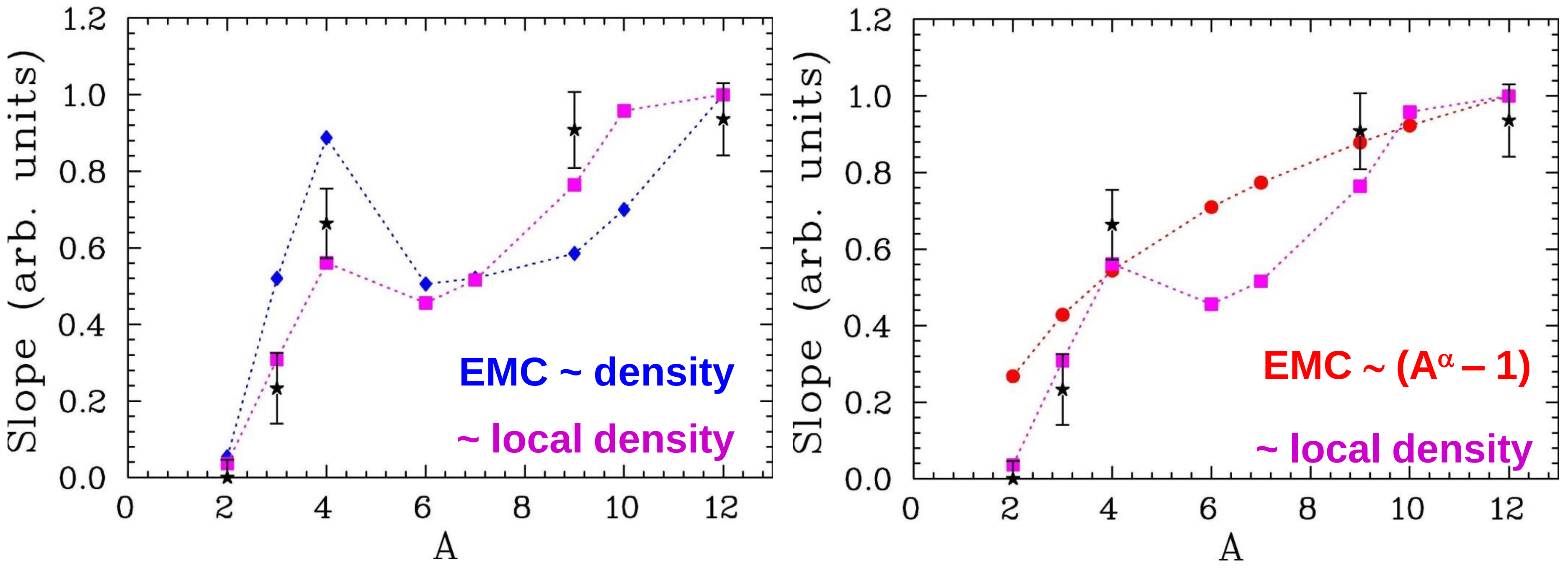
(Note: for $z = 0.65$ $M_x^2 \approx 2.5$ GeV^2)

For z<0.7 ratios are independent of z as expected from quark-model

E12-10-008 EMC Effect in Light Nuclei

12 GeV experiment that will map out A-dependence in more detail

- **Very hard to explain large ^{3}He – ^{9}Be difference in ρ-dependent fit**
- **Hard to explain large ^{3}He – ^{4}He difference in mass-dependent fit**
  - Modified fit does somewhat better, but worse for heavier nuclei
- **"Local density" works well, provides different predictions**
  - Use ab initio GFMC calc. of 2-body correlation function to calculate average nucleon 'overlap'



E12-11-107 Experimental Method

Use factorization of the d(e,e'N_S) cross section into the cross section (F_2) and the distorted momentum distribution.

Keeping the recoil kinematics fixed and measuring x-section ratios at 2 different x', the ratio is:

$$\frac{d^4\sigma}{dx_1' dQ^2 d\vec{p}_S} \Big/ \frac{d^4\sigma}{dx_2' dQ^2 d\vec{p}_S} = \left(K_1/K_2\right)\left[F_2^*(x_1',\alpha_S,p_T,Q_1^2)/F_2^*(x_2',\alpha_S,p_T,Q_1^2)\right]$$

For $x_1' \approx 0.45 - 0.6$ and $x_2' \approx 0.3$ we shall measure:

$$F_2^*(x_1',\alpha_S,p_T,Q_1^2)/F_2^*(x_2',\alpha_S,p_T,Q_1^2) = \left(\frac{d^4\sigma}{dx_1' dQ^2 d\vec{p}_S} / K_1\right) \Big/ \left(\frac{d^4\sigma}{dx_2' dQ^2 d\vec{p}_S} / K_2\right)$$

Integrating over $\theta_{pq} > 107°$ (small FSI), we'll compare the measured ratio $f(\alpha_S)$ to the BONUS results for free neutron, and to the free proton SF in d(e,e'n_S)

$$x' = \frac{Q^2}{2 p_\mu q^\mu} = \frac{Q^2}{2[(M_d - E_S)\omega + \vec{p}_S \cdot \vec{q}]}$$

x' is x-Bjorken for the moving struck nucleon

$$\alpha_s = (E_s - p_s^z)/m_s$$

$\vec{p}_s$ maps to (α_s, p_T)

E12-11-107 Experimental Method (cont.)

- Minimize experimental and theoretical uncertainties by measuring cross-section ratios

$$\frac{\sigma_{DIS}(x'_{high}, Q_1^2, \vec{p}_s)}{\sigma_{DIS}(x'_{low}, Q_2^2, \vec{p}_s)} \times \frac{\sigma_{DIS}^{free}(x_{low}, Q_2^2)}{\sigma_{DIS}^{free}(x_{high}, Q_1^2)} \times R_{FSI} = \frac{F_2^{bound}(x'_{high}, Q_1^2, \vec{p}_s)}{F_2^{free}(x_{high}, Q_1^2)}$$

FSI correction factor

x' = x from a moving nucleon

$$x'_{high} \geq 0.45$$

$$0.25 \geq x'_{low} \geq 0.35$$ No EMC is expected

$$x'_B = \frac{Q^2}{2 p_\mu q^\mu} \overset{\text{(For d)}}{=} \frac{Q^2}{2[(M_d - E_S)\nu + \vec{p}_S \cdot \vec{q}\,]}$$

$$x_B = \frac{Q^2}{2 m_N \nu}$$