JLab Few-Body Physics
Experiment

Paul Ulmer

Old Dominion University

Highlights of the First Seven Years

Users Group Annual Meeting

June 10-13, 2003

Complete or Partially Complete Experiments

Deuteron				
Elastic form factors	$A(Q)$	91-026 A	Petratos	Alexa et al., PRL 82, 1374 (1999)
		94-018 C	Kox	Abbott et al., PRL 82, 1379 (1999)
	$B(Q)$	91-026 A	Petratos	Draft prepared
	T_{20}	94-018 C	Kox	Abbott et al., PRL 84, 5053 (2000)
Photodisintegration	Cross sections	89-012 C	Holt	Bochna et al., PRL 81, 4576 (1998)
		96-003 C	Holt	Schulte et al., PRL 87, 102302 (2001)
		99-008 A	Gilman	Schulte et al., PRC 66, 042201(R) (2002)
		93-017 B	Rossi	
	Polarizations	89-019 A	Gilman	Wijesooriya et al., PRL 86, 2975 (2001)
		00-007 A	Gilman	
Photoproduction	π^-	94-104 A	Gao	Submitted for publication
	π^0	89-012 C	Holt	Meekins et al., PRC 60, 052201 (1999)
Electrodisintegration	Pol. Transfer	89-028 A	Finn	Revised draft in preparation
	^{2}H(e,e'p)	94-004 A	Ulmer	Ulmer et al., PRL 89, 062301 (2002)
	^{2}H(e,e'p)	01-020 A	Boeglin/ Ulmer	
	^{2}H(e,e'ps)	94-102 B	Kuhn	
Electroproduction	Longitudinal π^+	91-003 C	Jackson	
	π^-	97-001 B	Pivniouk	

Complete or Partially Complete Experiments

^{3}He				
Photoreactions		93-044 B	Berman	
Electrodisintegration	Extraction of G_{Mn}	95-001 A	Gao	Xu et al., PRL 85, 2900 (2000) Xu et al., PRC 67, 012201(R) (2003) Xiong et al., PRL 87, 242501 (2001)
Electrodisintegration	^{3}He(e,e'p) ^{3}He(e,e'X)	89-044 A 89-027 B	Saha Weinstein	 Internal draft
Electroproduction	Longitudinal π^+	91-003 C	Jackson	

^{4}He				
Photoproduction	π^-	94-104 A	Gao	Submitted for publication
Electrodisintegration	^{4}He(e,e'X) Pol. Transfer ^{4}He(e,e'p)^{3}H	89-027 B 93-049 A 97-111 A	Weinstein Ent Templon	 Accepted in PRL
Electroproduction	Longitudinal π^+	91-003 C	Jackson	

Deuteron Elastic Scattering

Elastic e-d Scattering

- Deuteron: $J = 1 \rightarrow J = 1$
- $L = 0,1,2 \rightarrow C0/M1/C2$ $(G_C/G_M/G_Q)$

$$\frac{d\sigma}{d\Omega} \propto A(Q) + B(Q)\tan^2\left(\frac{\theta}{2}\right) \equiv S$$

$$A(Q) = k_1 G_C{}^2(Q) + k_2 G_Q{}^2(Q) + k_3 G_M{}^2(Q)$$

$$B(Q) = k_4 G_M{}^2(Q)$$

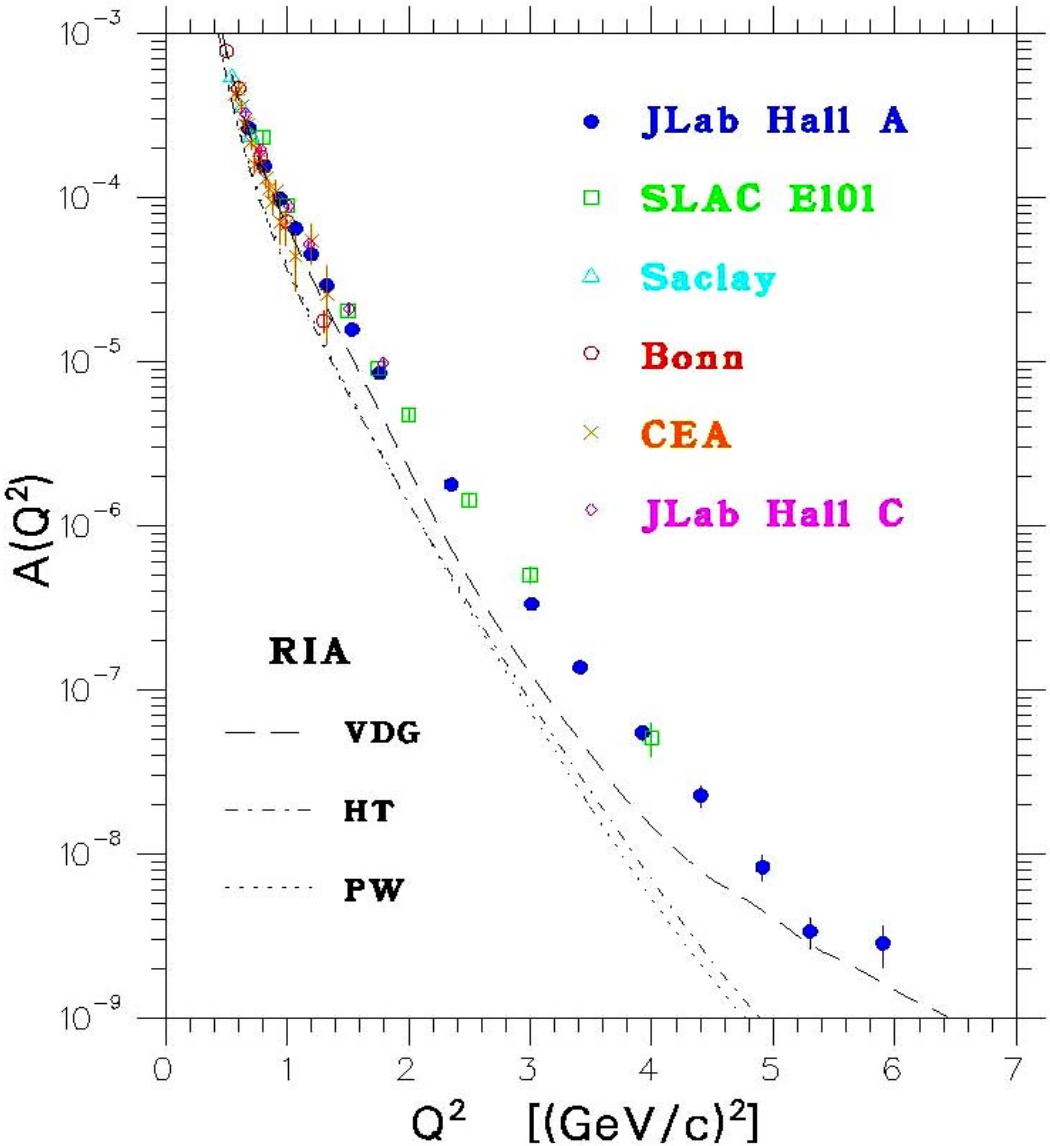
- Rosenbluth: $A\&B \rightarrow$

G_M & combination of G_C, G_Q

- Need **polarization** to separate G_C and G_Q:

$$t_{20} = -\frac{1}{\sqrt{2}\,S}\left(k_5 G_C G_Q + k_6 G_Q^2 + k_7 G_M^2\right)$$

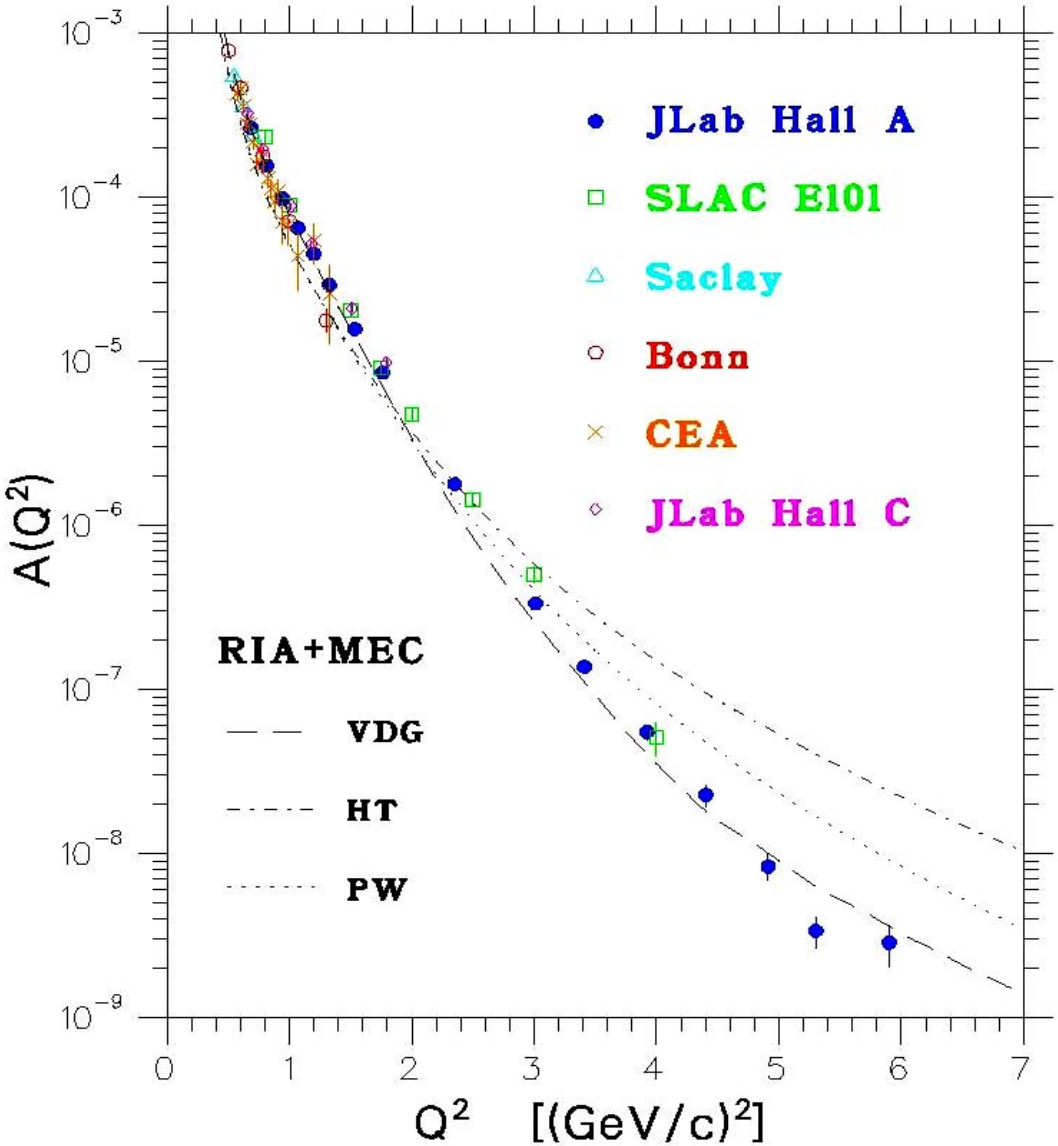
Elastic e-d Scattering – $A(Q^2)$



Data extended beyond old limit of Q^2=4 up to Q^2=6 GeV^2.

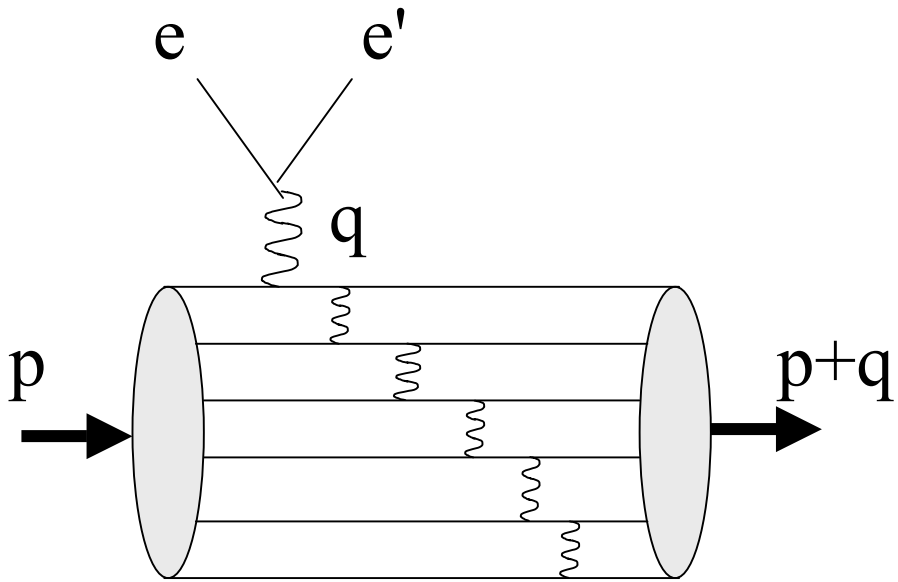
Purely nonrelativistic theories (not shown) cannot describe high Q^2 data.

Elastic e-d Scattering – $A(Q^2)$



Effect of MEC's is substantial.

Sensitive to choice of $\rho\pi\gamma$ form factor.



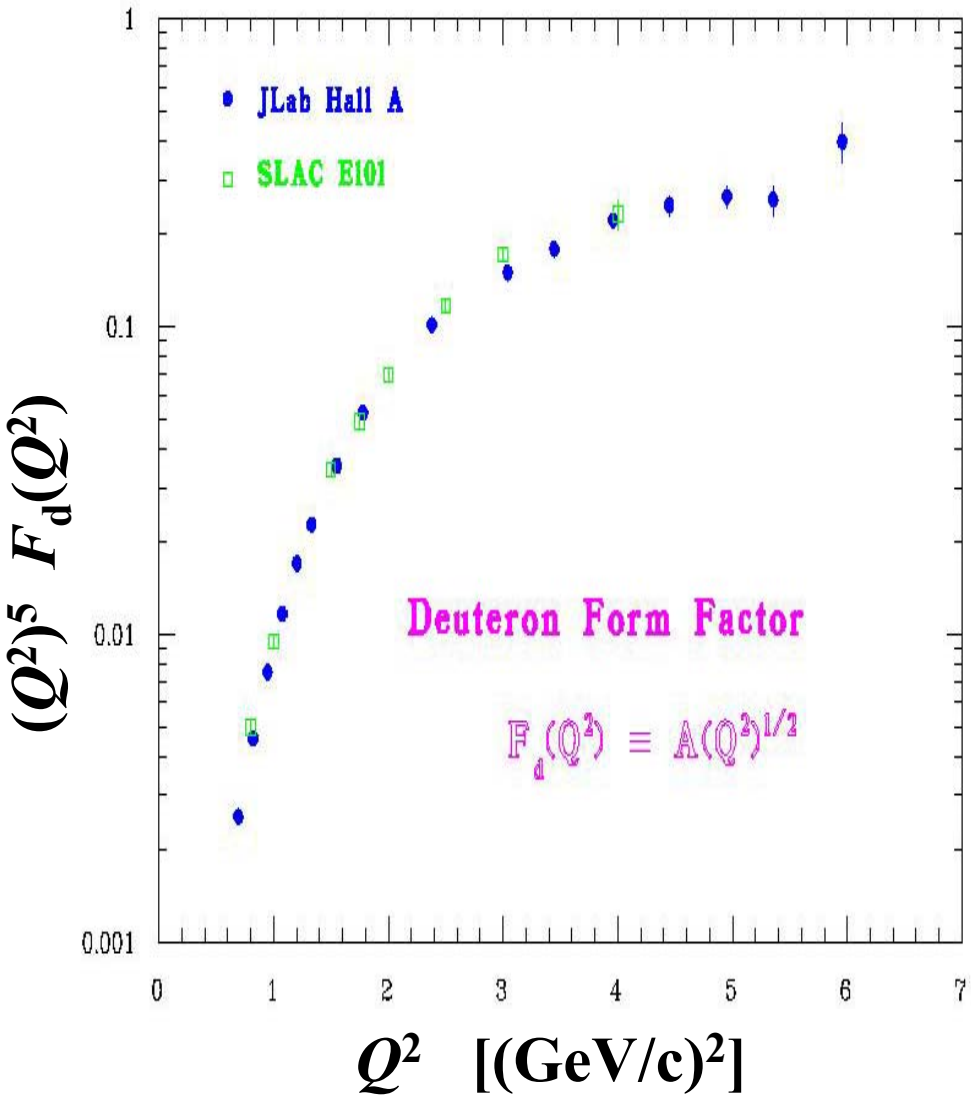
Dimensional Scaling Quark Model

$$\sqrt{A} \sim (Q^2)^{-(n-1)} \qquad n = 6 \quad \text{quarks}$$

Perturbative QCD

$$\sqrt{A} = \left[\frac{\alpha_s(Q^2)}{Q^2}\right]^5 \sum_{m,n} d_{mn} \left(\ln \frac{Q^2}{\Lambda^2}\right)^{-\gamma_n - \gamma_m}$$

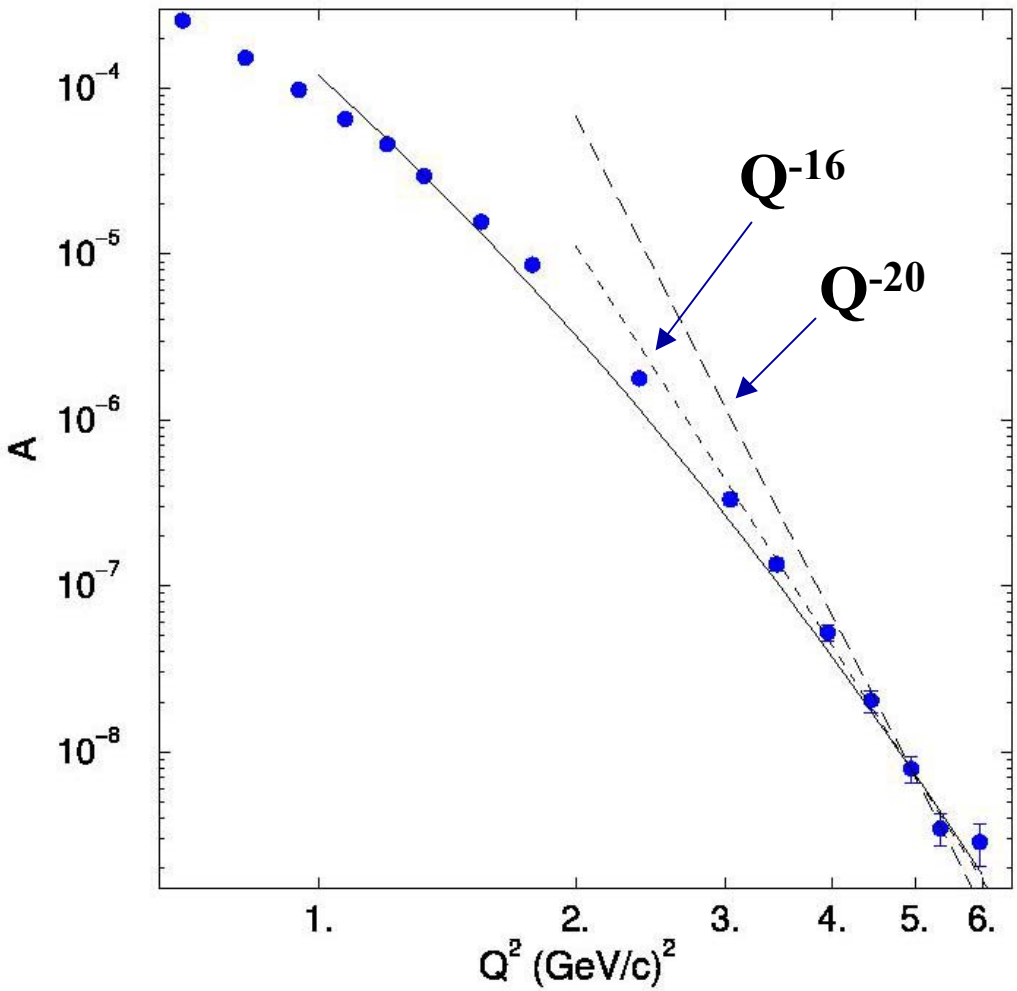
Elastic e-d Scattering – $A(Q^2)$



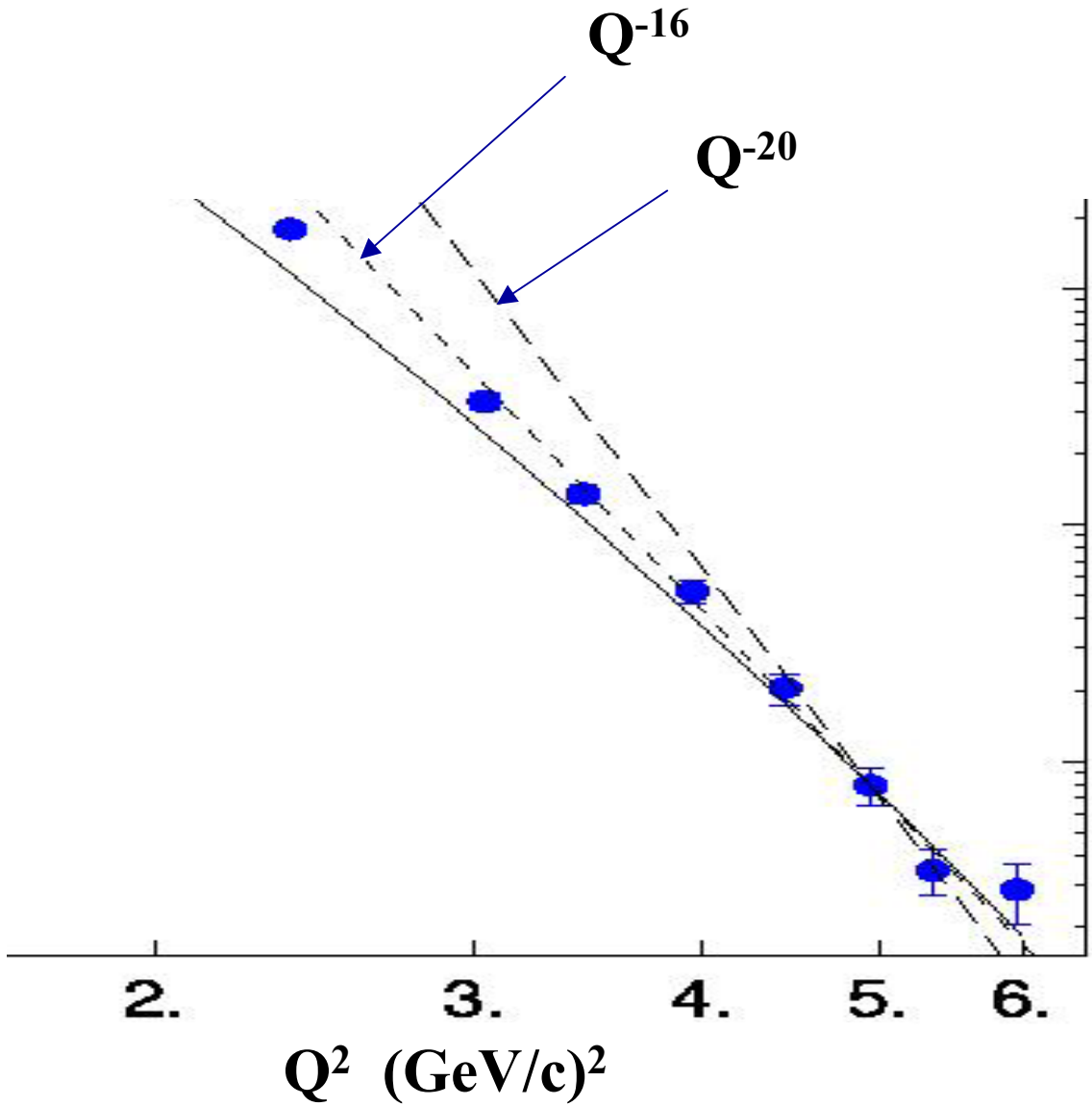
Scaling does not necessarily imply validity of pQCD.

Data appear to show scaling; however, *power* may not be quite right …

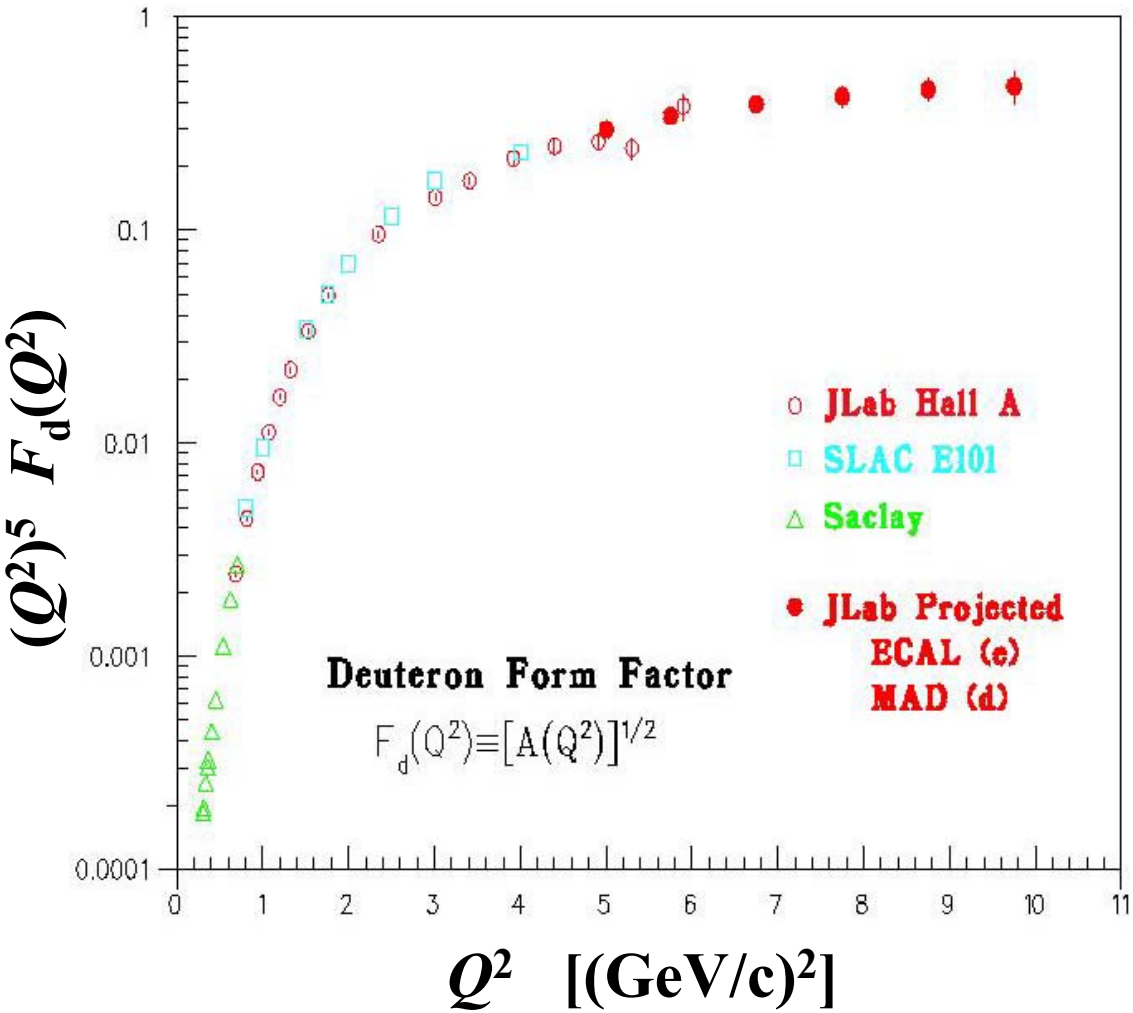
Log-Log Plot of $A(Q^2)$



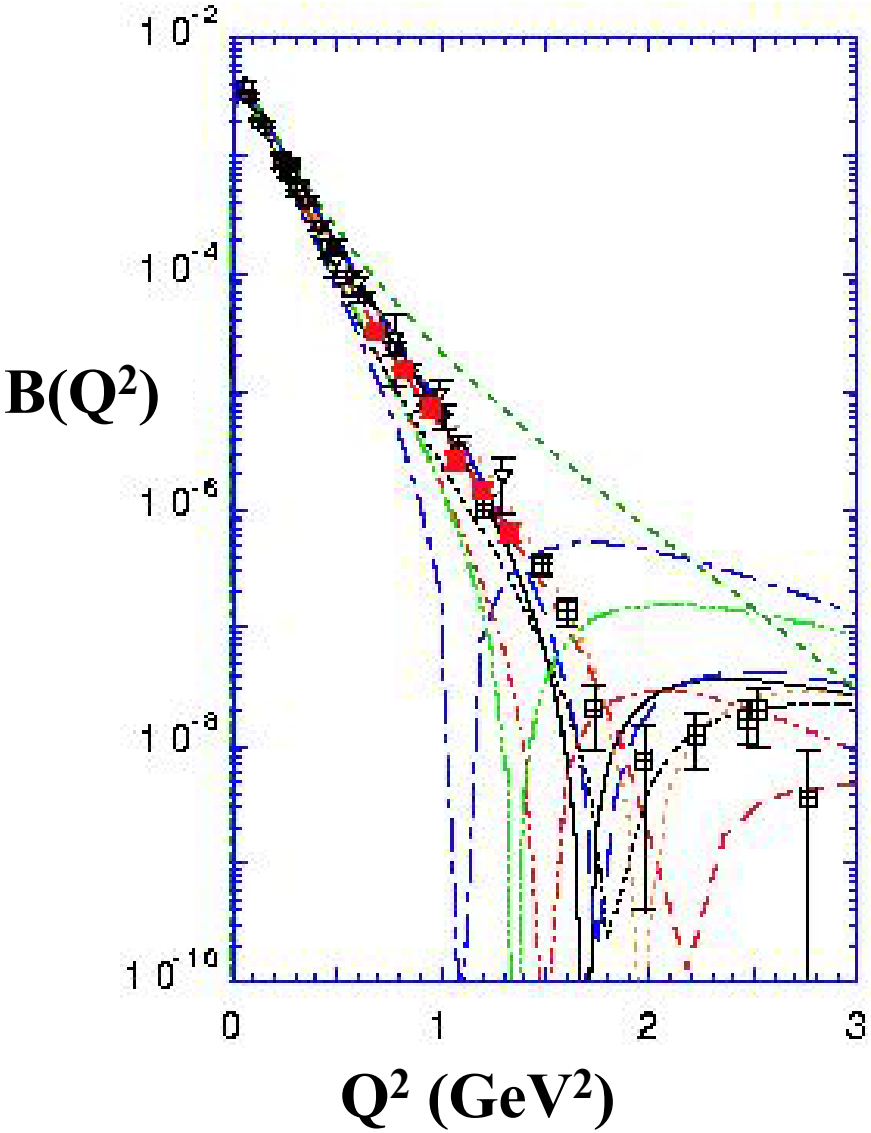
M. Garcon and J.W. Van Orden, Adv. Nucl. Phys. **26,** 293 (2001).


Q^{-16}
Q^{-20}
2.
3.
4.
5.
6.
Q^2 $(GeV/c)^2$

With 12 GeV upgrade



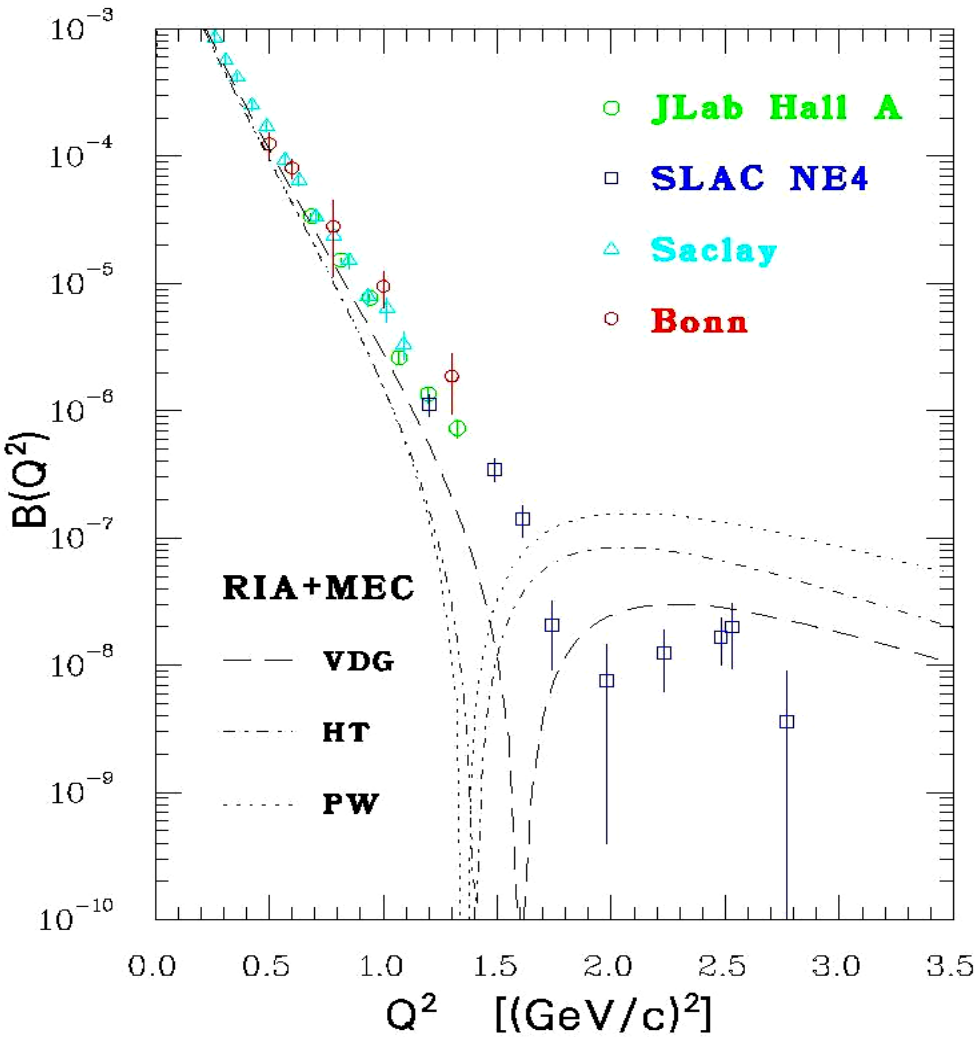
Elastic e-d Scattering – $B(Q^2)$



Minimum sensitive to details of models.

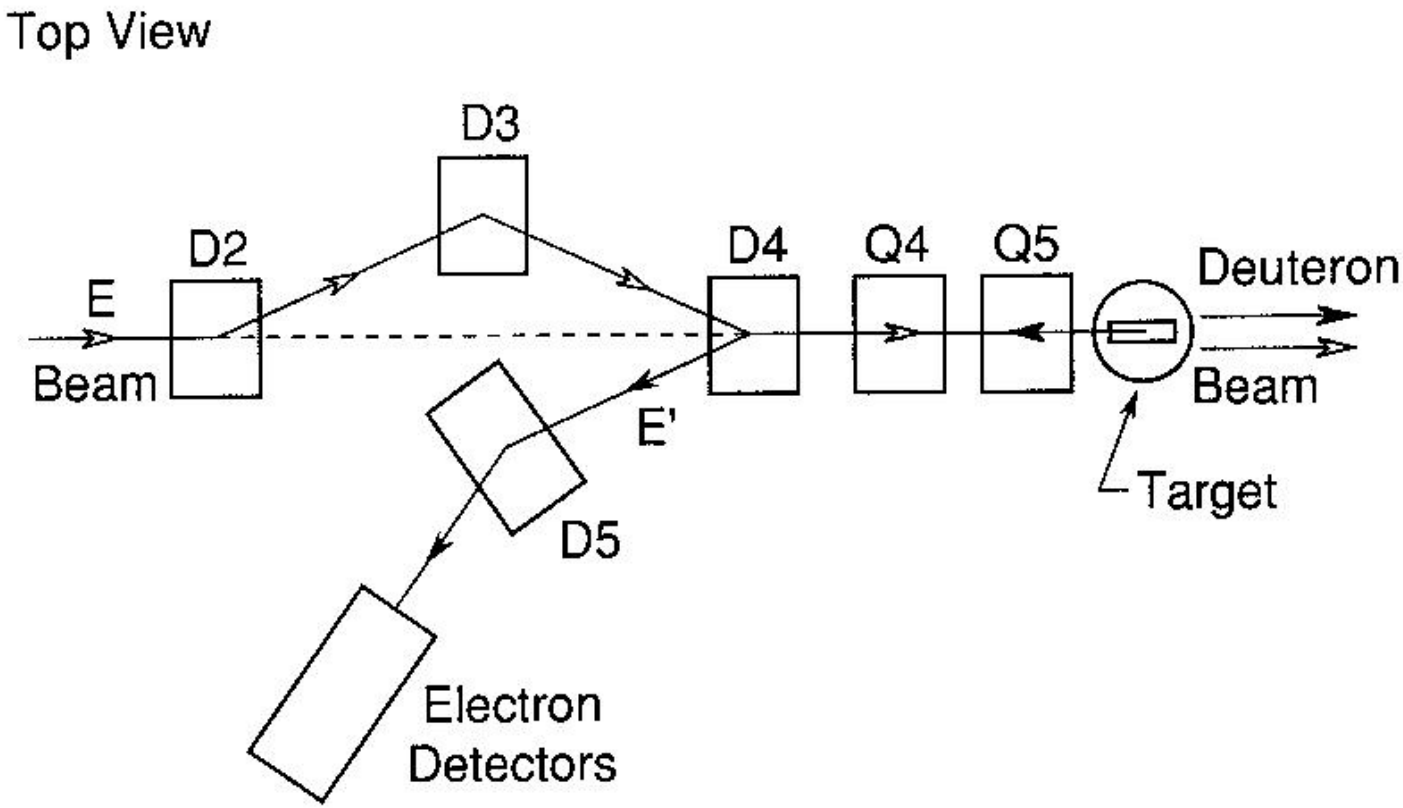
From: R. Gilman and Franz Gross, J. Phys. G **28**, R37 (2002).

Elastic e-d Scattering – $B(Q^2)$



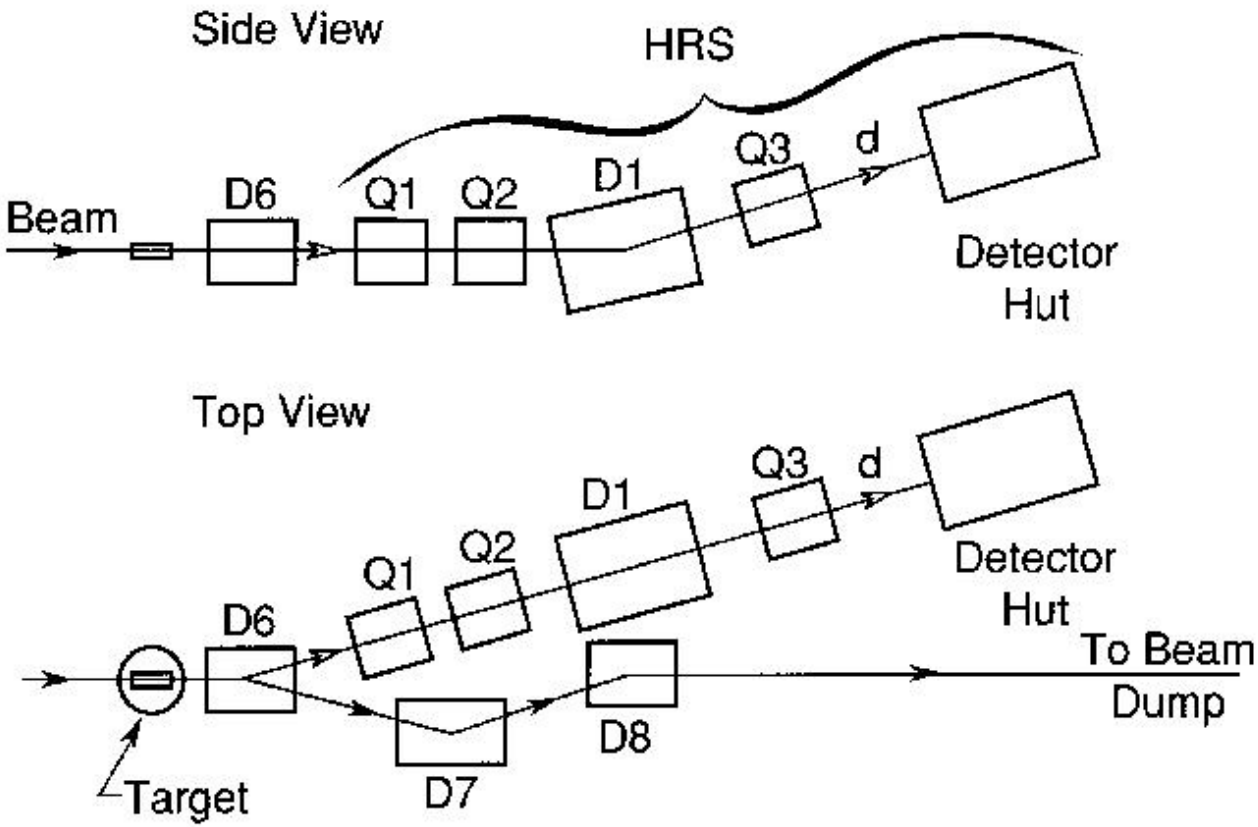
Minimum not well measured.

New JLab Proposal: $B(Q^2)$ in Hall A



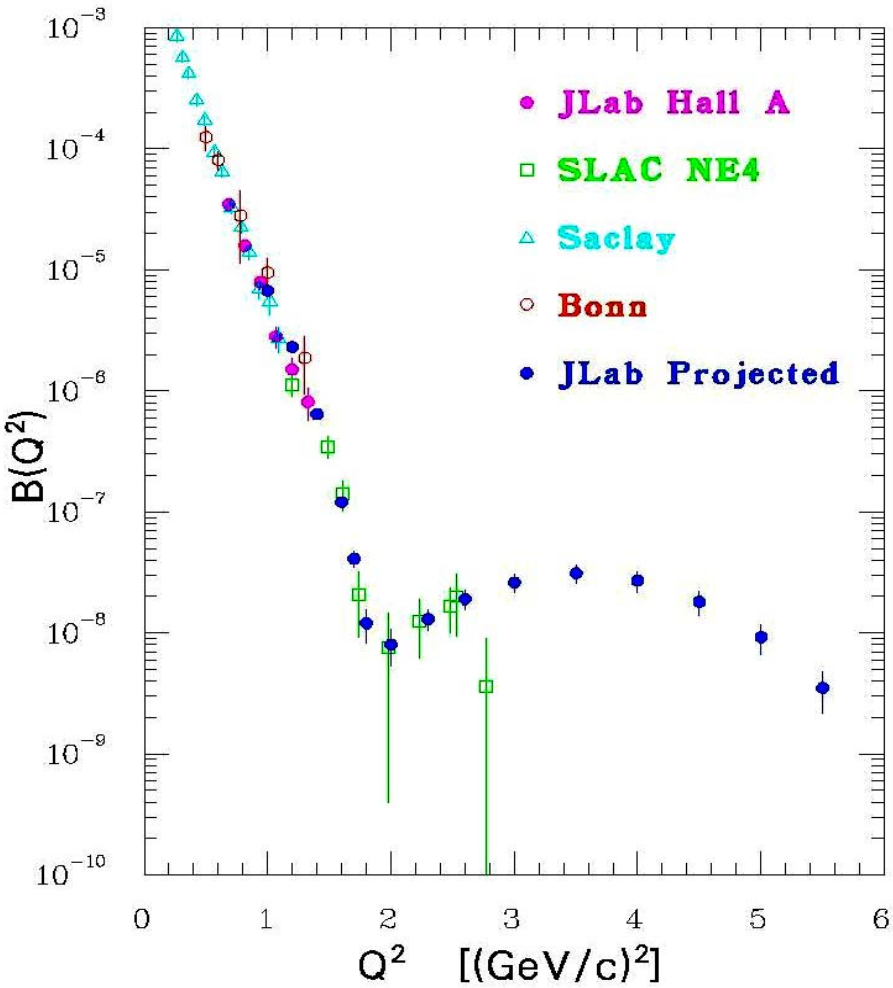
Petratos, Gomez, Beise *et al.*

New JLab Proposal: $B(Q^2)$ in Hall A



Petratos, Gomez, Beise *et al.*

New JLab Proposal

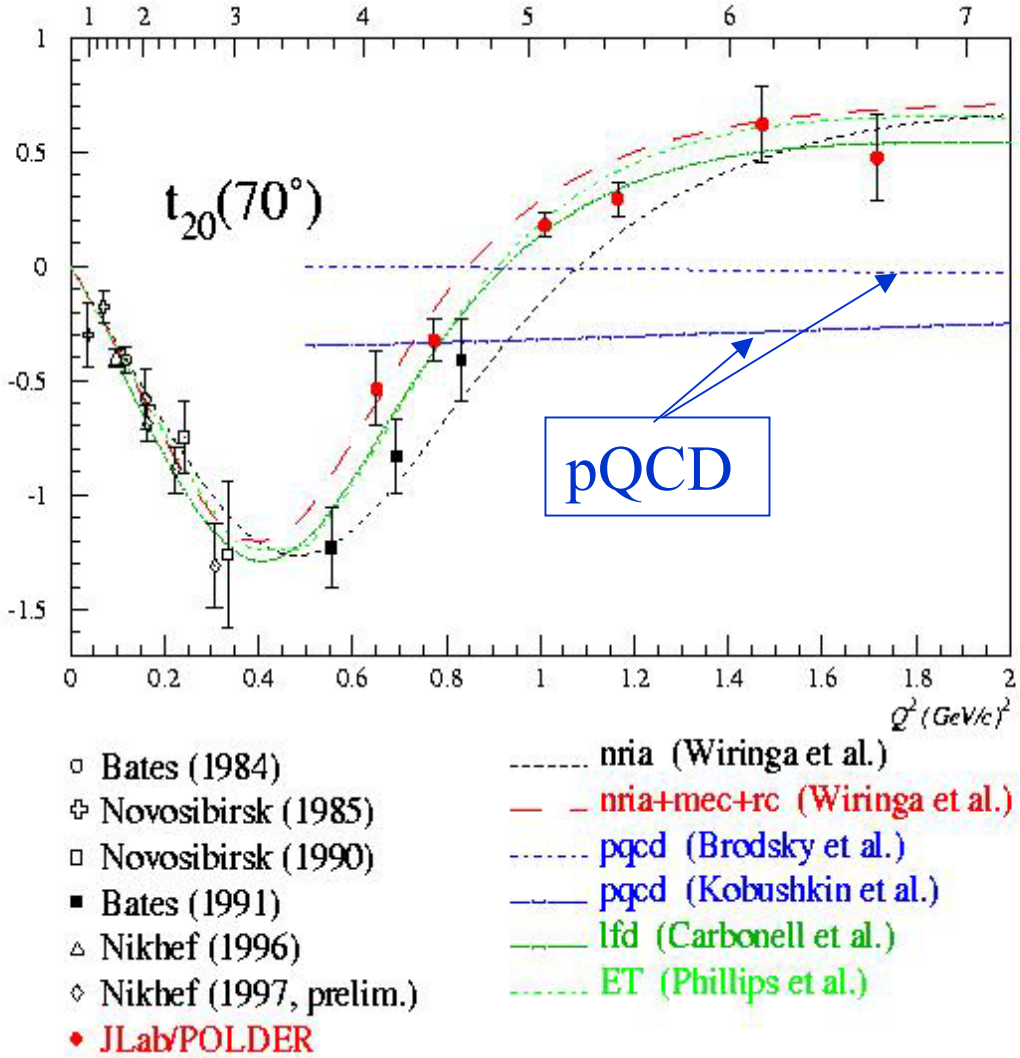


Precise measurement near minimum.

Extend to higher Q^2.

Petratos, Gomez, Beise *et al.*

Elastic e-d Scattering – T_{20}

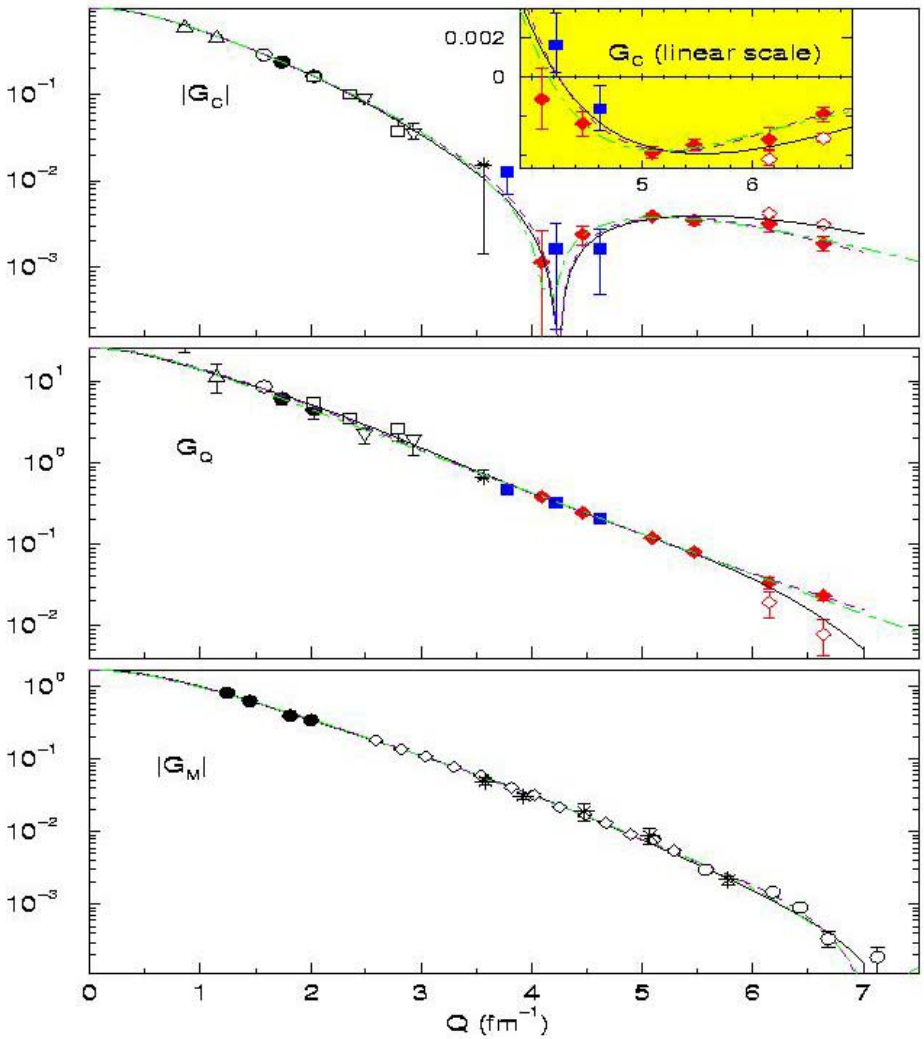


New Hall C data favor inclusion of MEC in NRIA.

pQCD evidently not valid here.

D. Abbott *et al.*, Phys. Rev. Lett. **84**, 5053 (2000).

Parameterization of Deuteron Form Factors

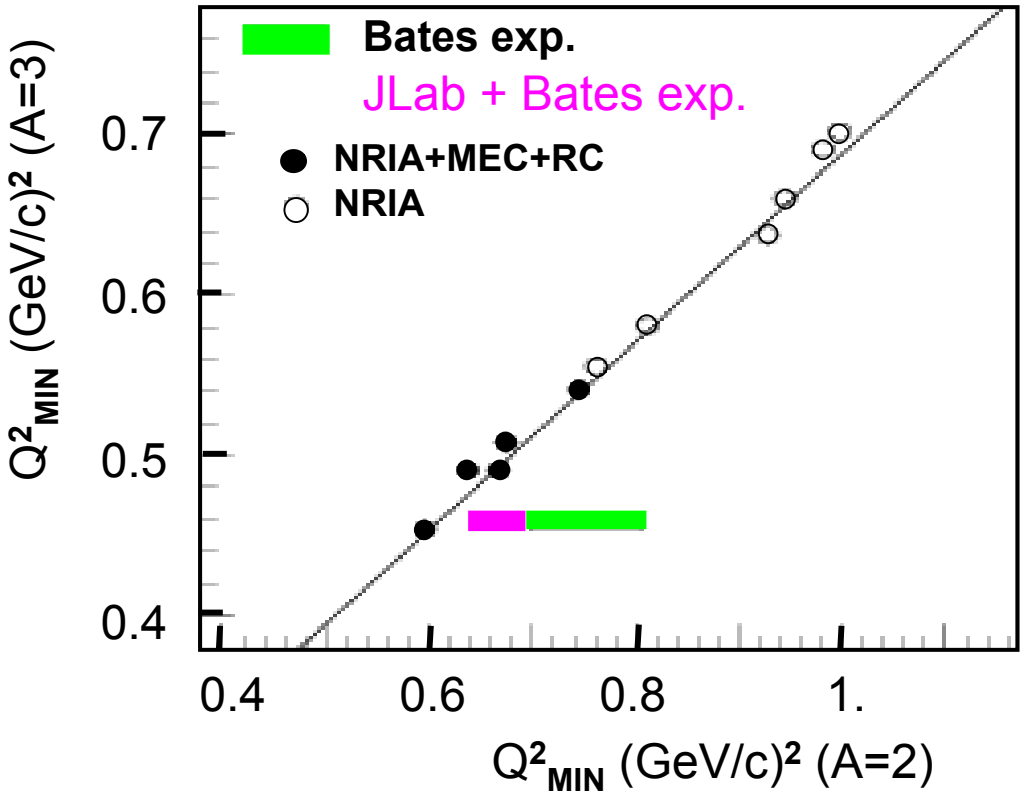


High Q JLab data shown by diamonds (♦).

D. Abbott *et al.*, Eur. Phys. Jour. A **7**, 421 (2000).

Relations between A= 2 and A= 3 (^{3}H/^{3}He) isoscalar charge form factors

(H. Henning *et al.*, Phys. Rev. C **52** (1995) R471.)



Nodes (Q_{Min})

This slide courtesy of S. Kox

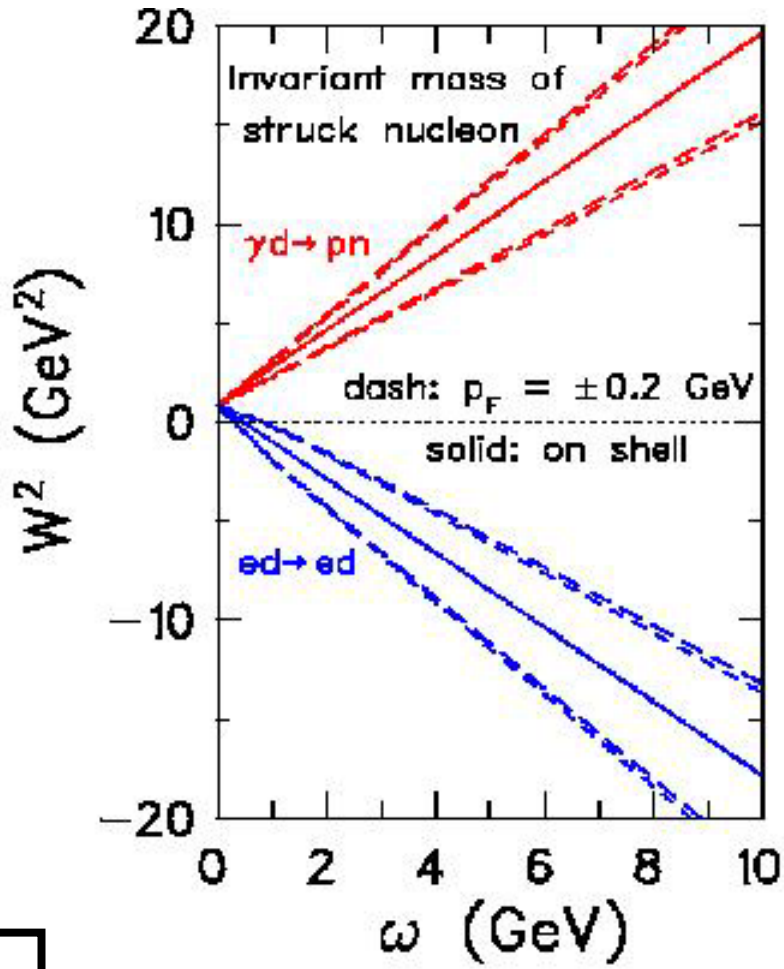
Deuteron Photodisintegration

^{2}H(e,e') elastic vs. ^{2}H(γ,p)n

- The difference between *ed* and γd is emphasized by considering the γ to strike one nucleon.
- γd: higher ω excites more resonances; average them with quarks
- *ed*: higher ω moves away from resonances

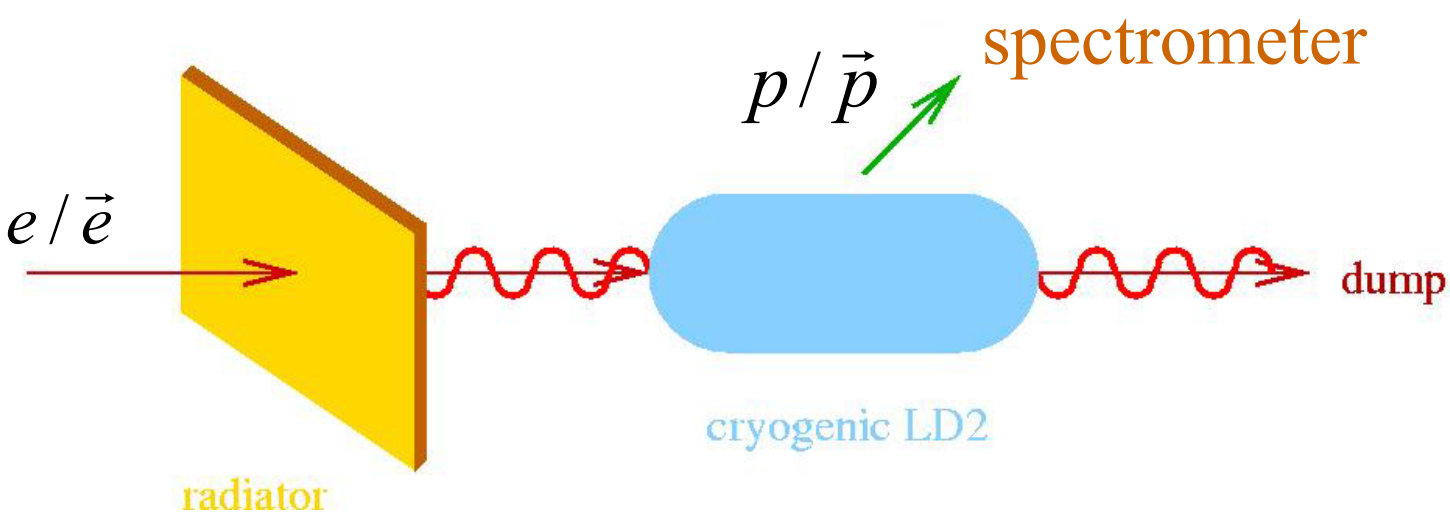
$$W_{\gamma p}^2 = 2\omega m + m^2$$

$$W_{ed}^2 = 2\omega(m - m_d) + m^2$$

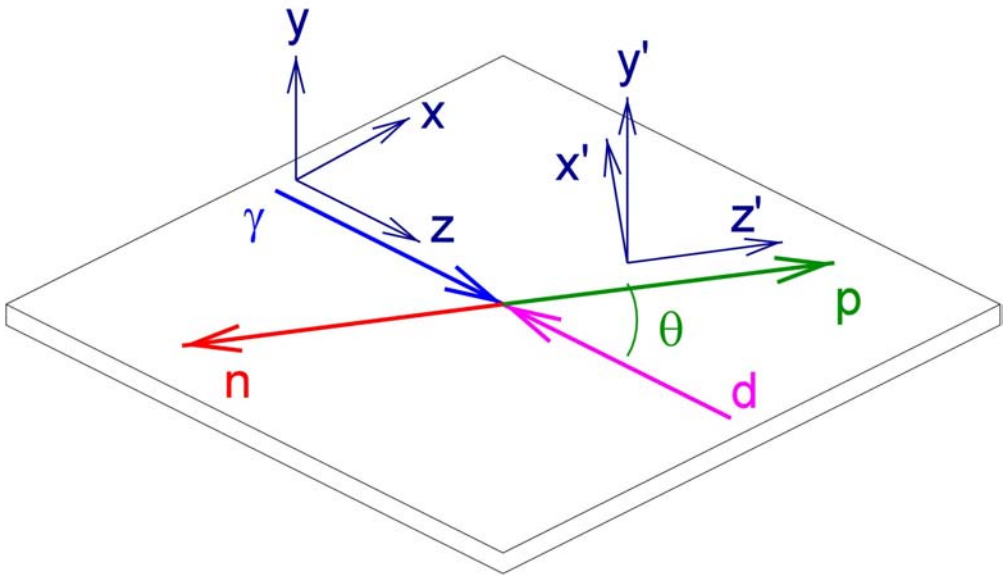


This slide and portions of others borrowed from R. Gilman.

$^2\mathrm{H}(\gamma, p)n$ and $^2\mathrm{H}(\vec{\gamma}, \vec{p})n$



Polarization Observables



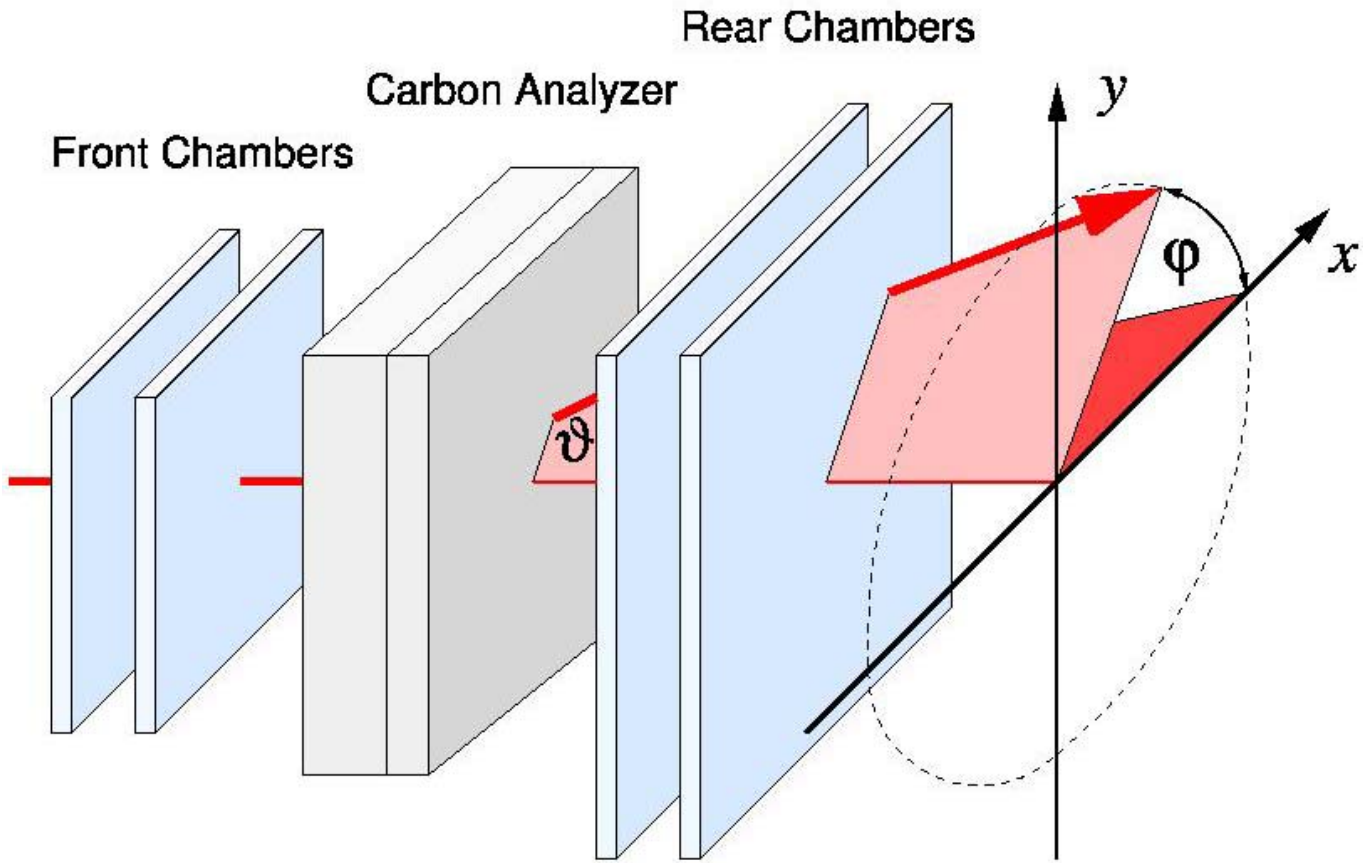
$$p_y = \frac{1}{A_y}\left(\frac{d\sigma/d\Omega_+ - d\sigma/d\Omega_-}{d\sigma/d\Omega_+ + d\sigma/d\Omega_-}\right)$$

$$\Sigma = \frac{1}{p_\gamma}\left(\frac{d\sigma/d\Omega_\perp - d\sigma/d\Omega_\parallel}{d\sigma/d\Omega_\perp + d\sigma/d\Omega_\parallel}\right)$$

Polarization Transfer:

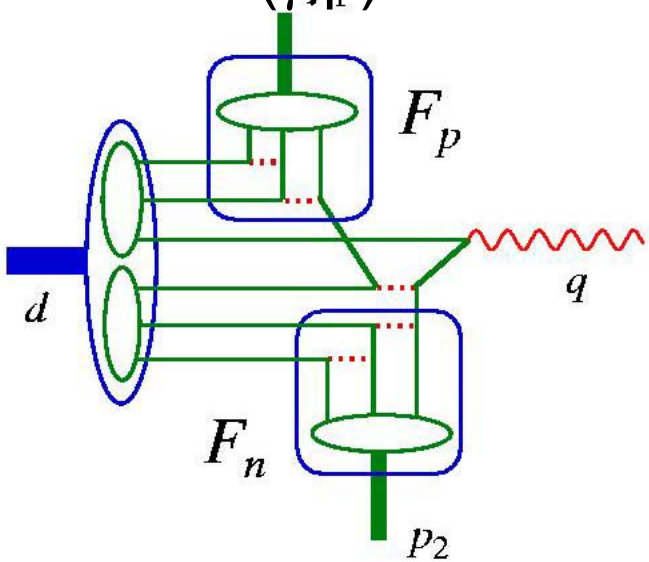
$C_{x'}/C_{z'}$

Measuring the Proton Polarization: FPP



pQCD

Typical pQCD diagram for $^2H(\gamma,p)n$



$$\text{CCR}: \quad \frac{d\sigma}{dt} = \frac{1}{t^{n-2}} f(\theta_{\text{c.m.}})$$

For d(γ, p) n

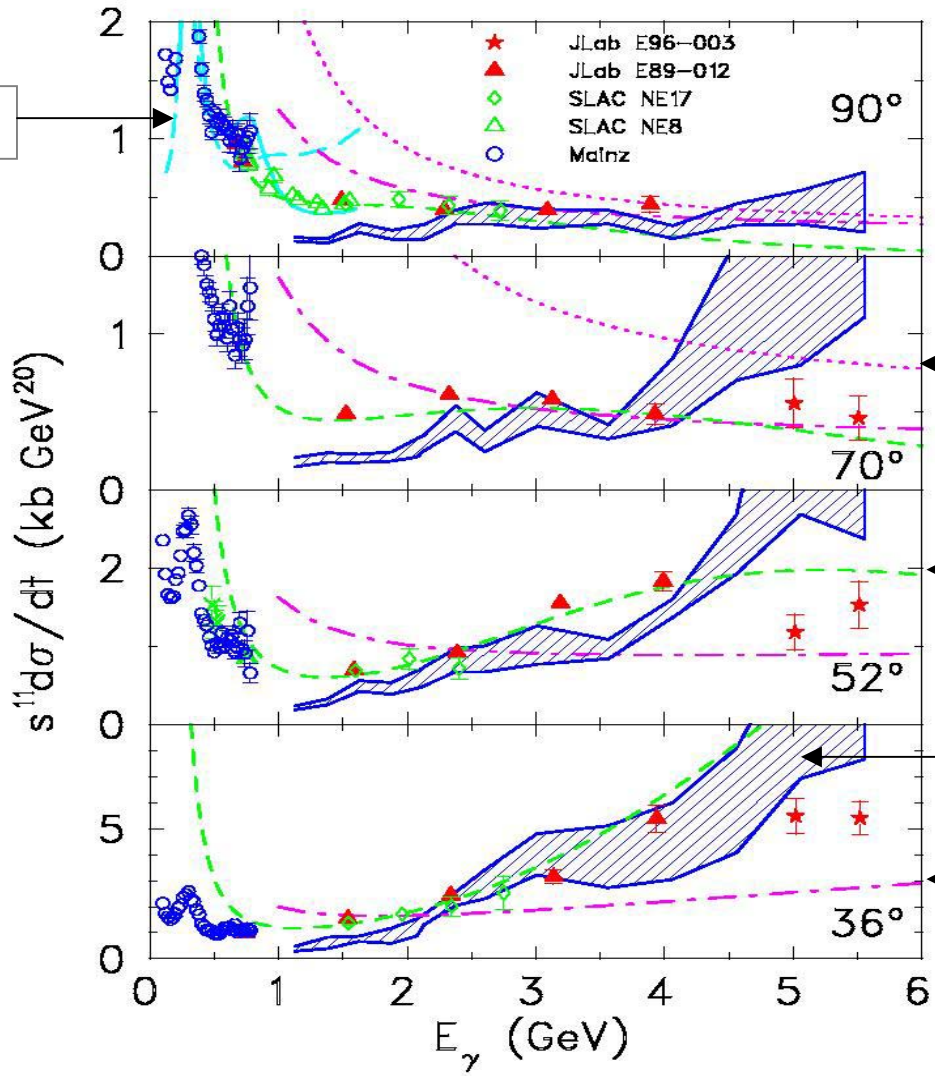
$$n = 6 + 1 + 3 + 3 = 13$$

Consequences:

Cross section scaling (CCR).

Polarizations consistent with HHC (hadron helicity conservation).

JLab Hall C, SLAC & Mainz



Lee

Brodsky/Hiller (RNA)

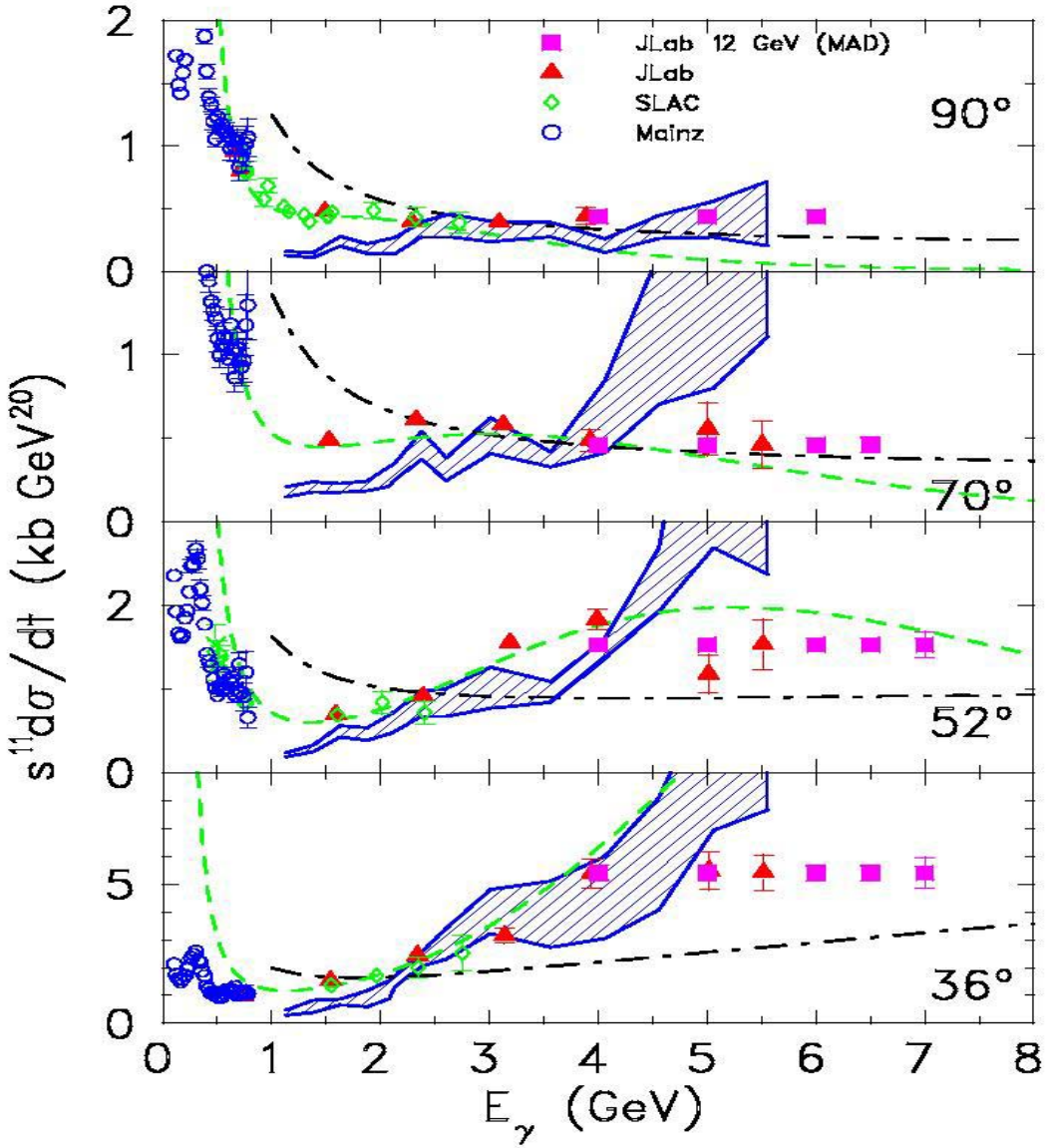
Kondratyuk/Grishina (QGS)

Frankfurt/Miller/ Strikman/Sargsian

Radyushkin

Scaling seen for p_T >1.3 GeV.

With 12 GeV upgrade



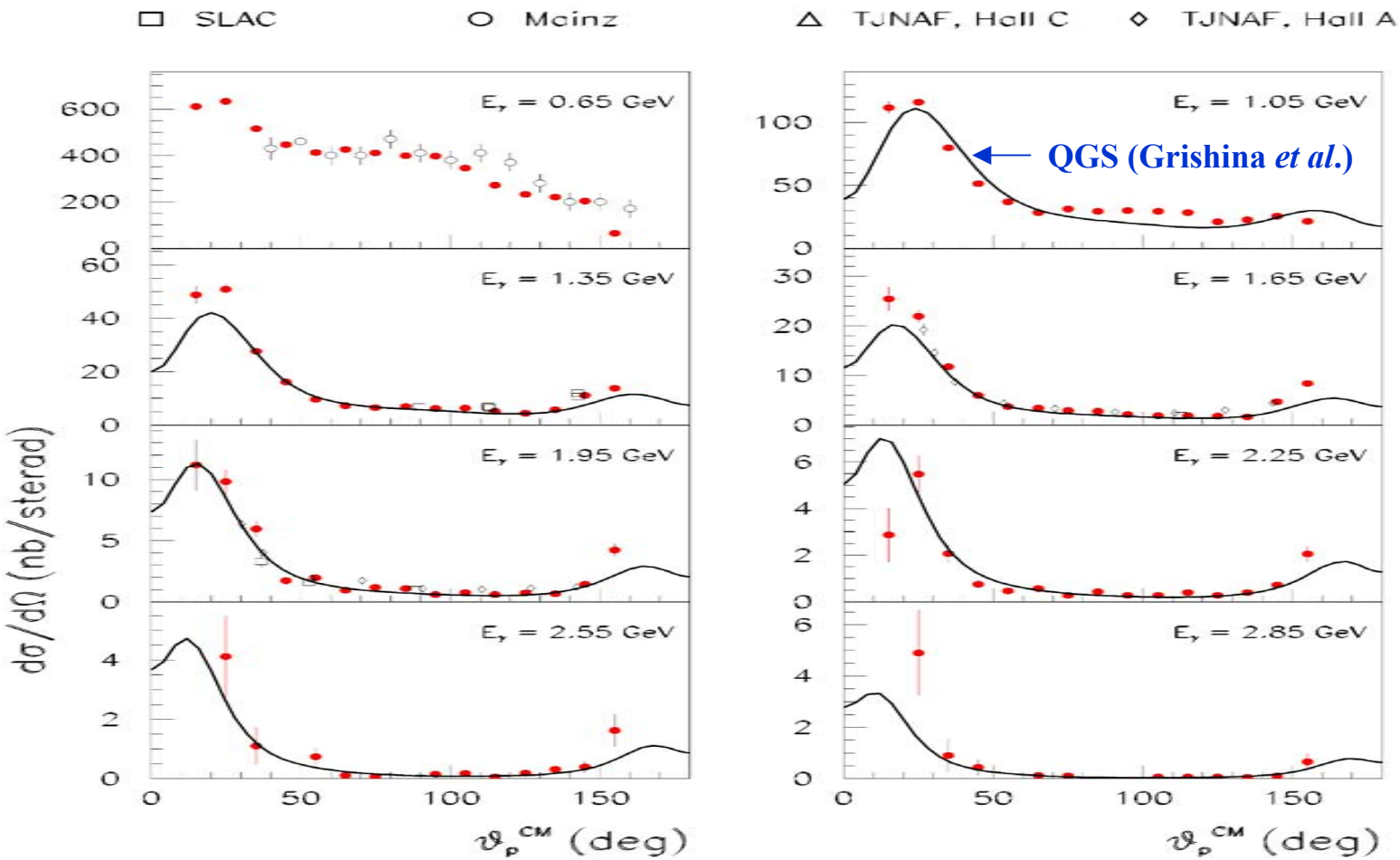
$\gamma d \rightarrow pn$ @ CLAS

complete $d\sigma/d\Omega$ *: backward-forward asymmetry*

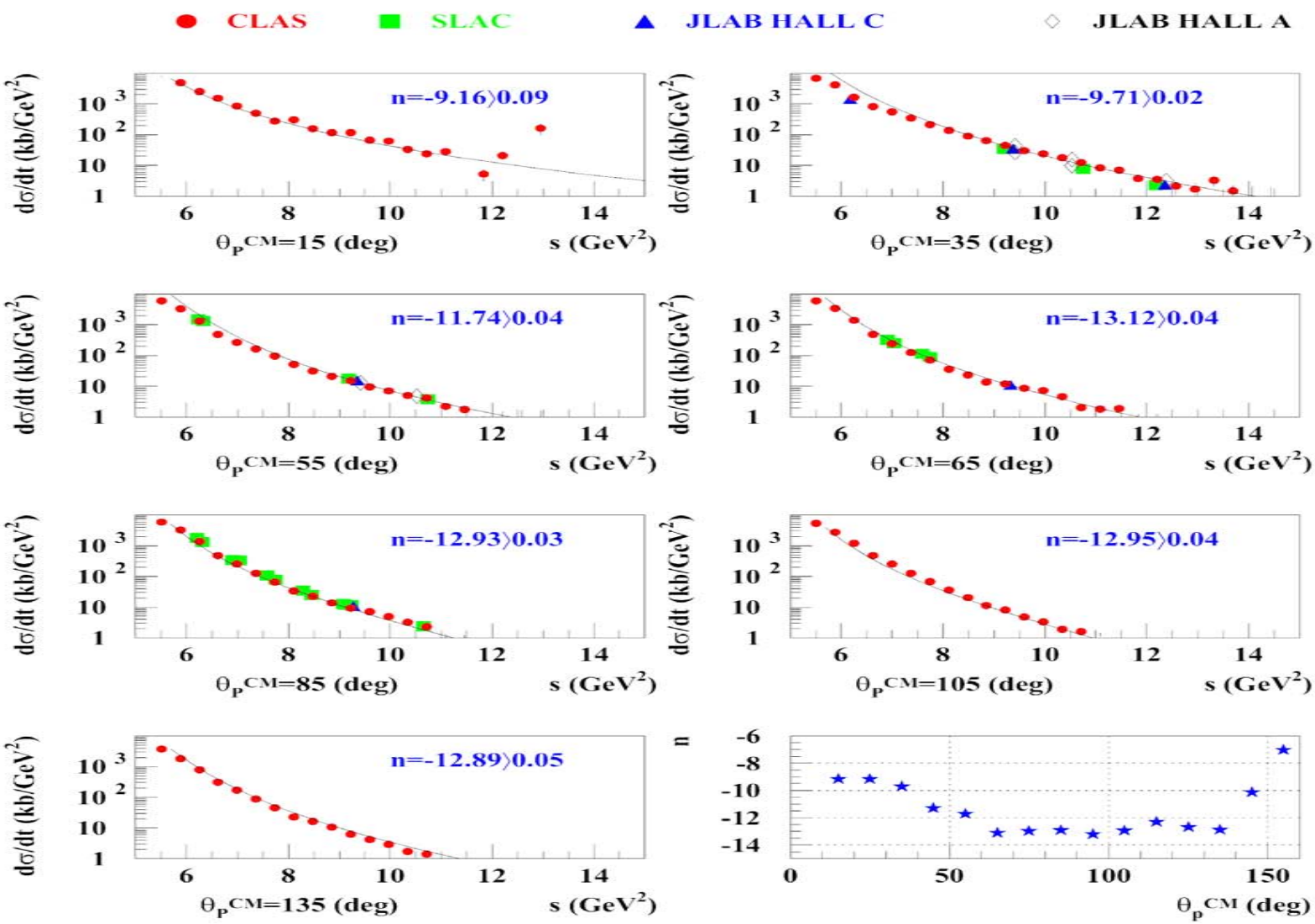
Measured Region: $0.5 \leq E_\gamma \leq 2.95$ GeV ; $15° \leq \vartheta_p^{cm} \leq 155°$

Binning: $\Delta E_\gamma = 0.1$ GeV ; $\Delta \vartheta_p^{cm} = 10°$

PRELIMINARY



$$d\sigma/dt \propto s^{-n}$$

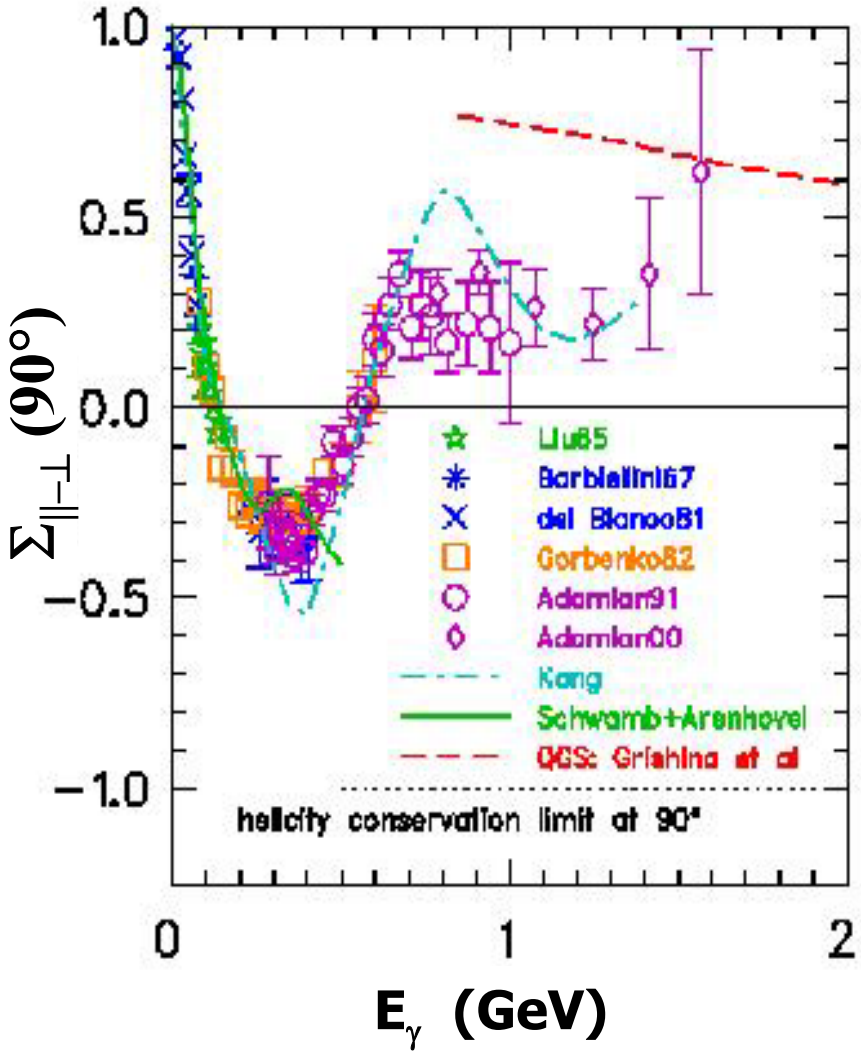


PRELIMINARY

Hall B $^2H(\gamma,p)n$ Data

- Scaling seen, but *n* values differ from CCR.
- QGS describes angular distributions well, including forward-backward asymmetry (interference between isovector & isoscalar photon amplitudes).
- QGS predicts forward minimum as well.

The Σ Asymmetry



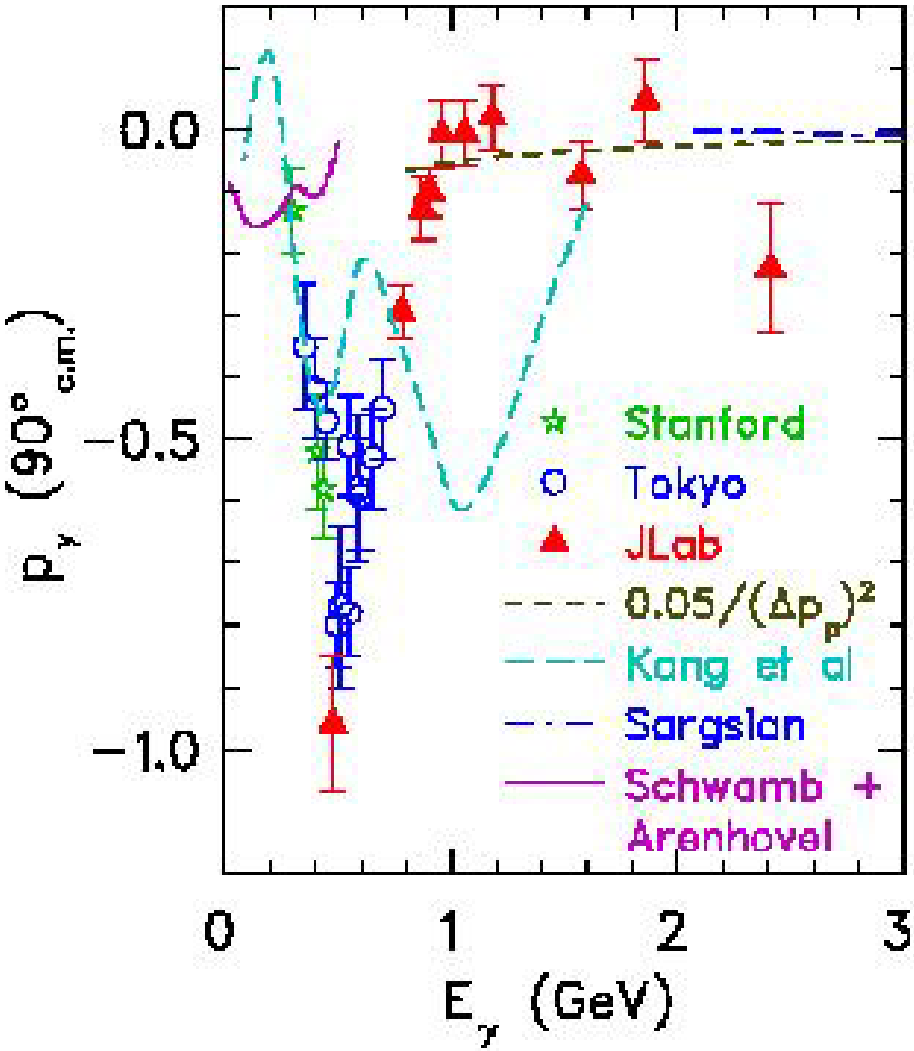
Recent Yerevan data* indicates trend away from HHC.

However, according to Grishina *et al.***, HHC → –1.0 only for isoscalar photons; **HHC → +1.0 for isovector photons.**

* F. Adamian *et al.*, Eur. Phys. J. A **8**, 423 (2000).

** V. Yu Grishina, *et al.*, nucl-th/0209076 (2002).

Induced Polarization p_y



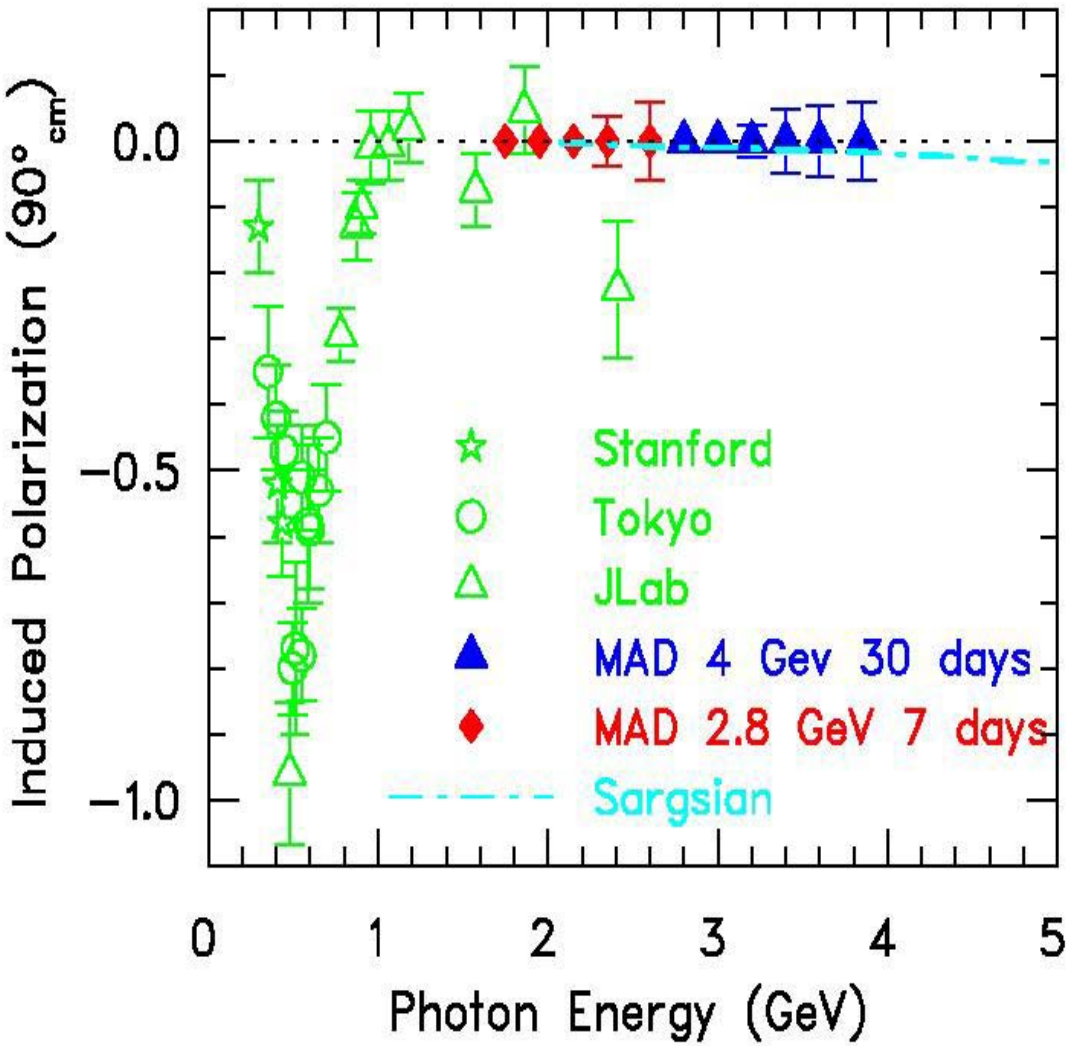
HHC→ p_y=0. Data above 1 GeV consistent with this.

Meson-Baryon models completely fail to describe high energy data.

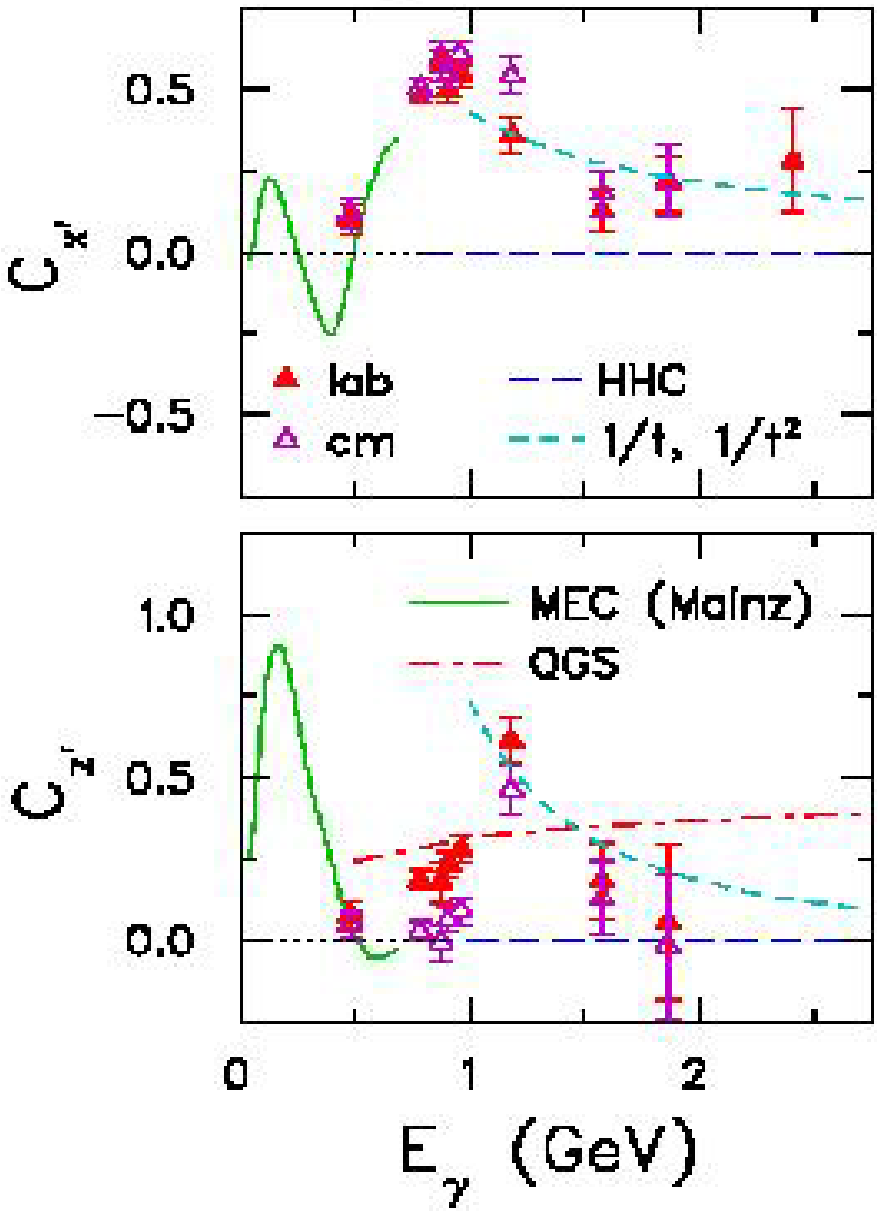
Hall A

Kharkov data not shown.

p_y with 12 GeV upgrade



Polarization Transfer

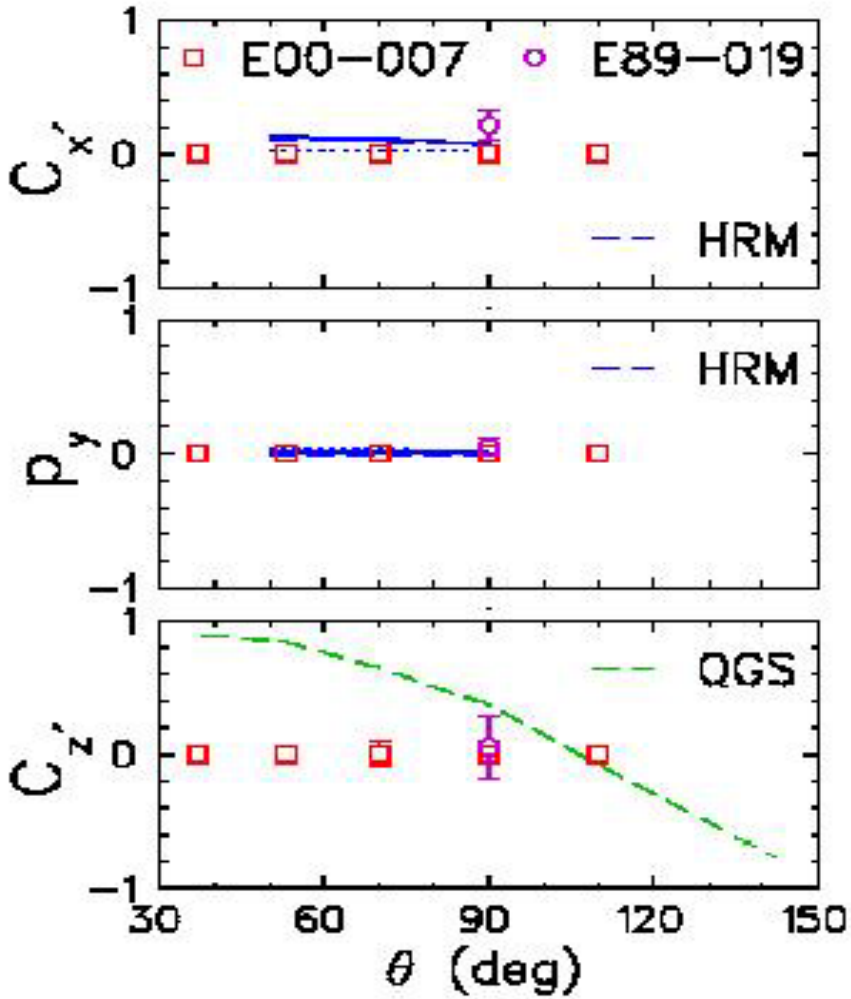


HHC→ $C_{x'}=0$ and $C_{z'}=0$.

Trend appears consistent with this, except possibly $C_{x'}$.

Hall A

More results on the way – under analysis



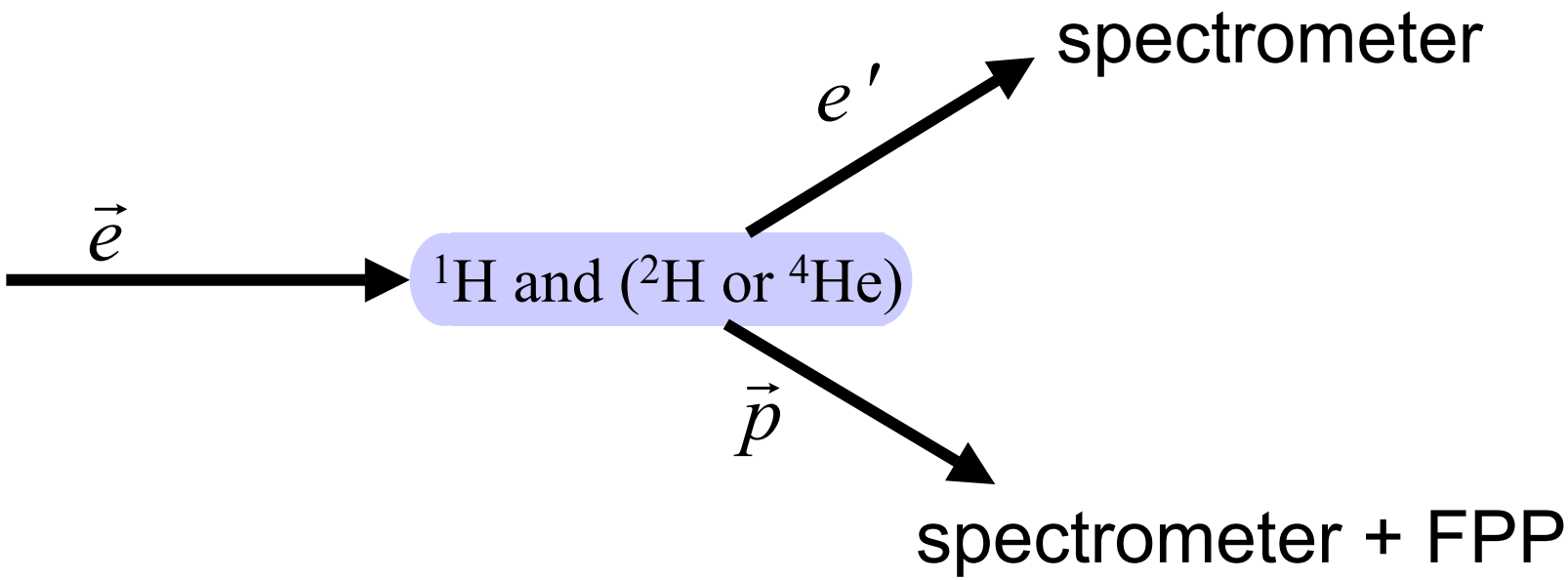
Experiment E00-007

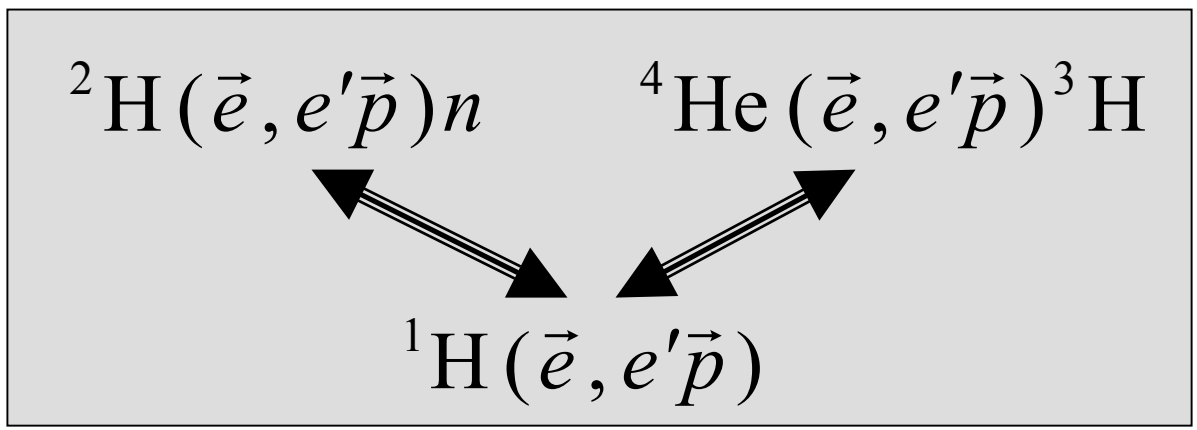
E_γ = 2 GeV

E00-007 points put at zero here; analysis to be done.

Polarization Transfer in $^{2}H(\vec{e},e'\vec{p})n$ and $^{4}He(\vec{e},e'\vec{p})^{3}H$

Polarization Transfer in Hall A





Proton Polarization and Form Factors

Free $\vec{e}\,p$ scattering*

$$I_0 P'_x = -2\sqrt{\tau(1+\tau)}\,G_E G_M \tan\left(\frac{\theta_e}{2}\right)$$

$$I_0 P'_z = \frac{e+e'}{m}\sqrt{\tau(1+\tau)}\,G_M^2 \tan^2\left(\frac{\theta_e}{2}\right)$$

$$I_0 = G_E^2 + \tau G_M^2\left[1 + 2(1+\tau)\tan^2\left(\frac{\theta_e}{2}\right)\right]$$

$$\frac{G_E}{G_M} = -\frac{P'_x}{P'_z}\cdot\frac{e+e'}{2m}\tan\left(\frac{\theta_e}{2}\right)$$

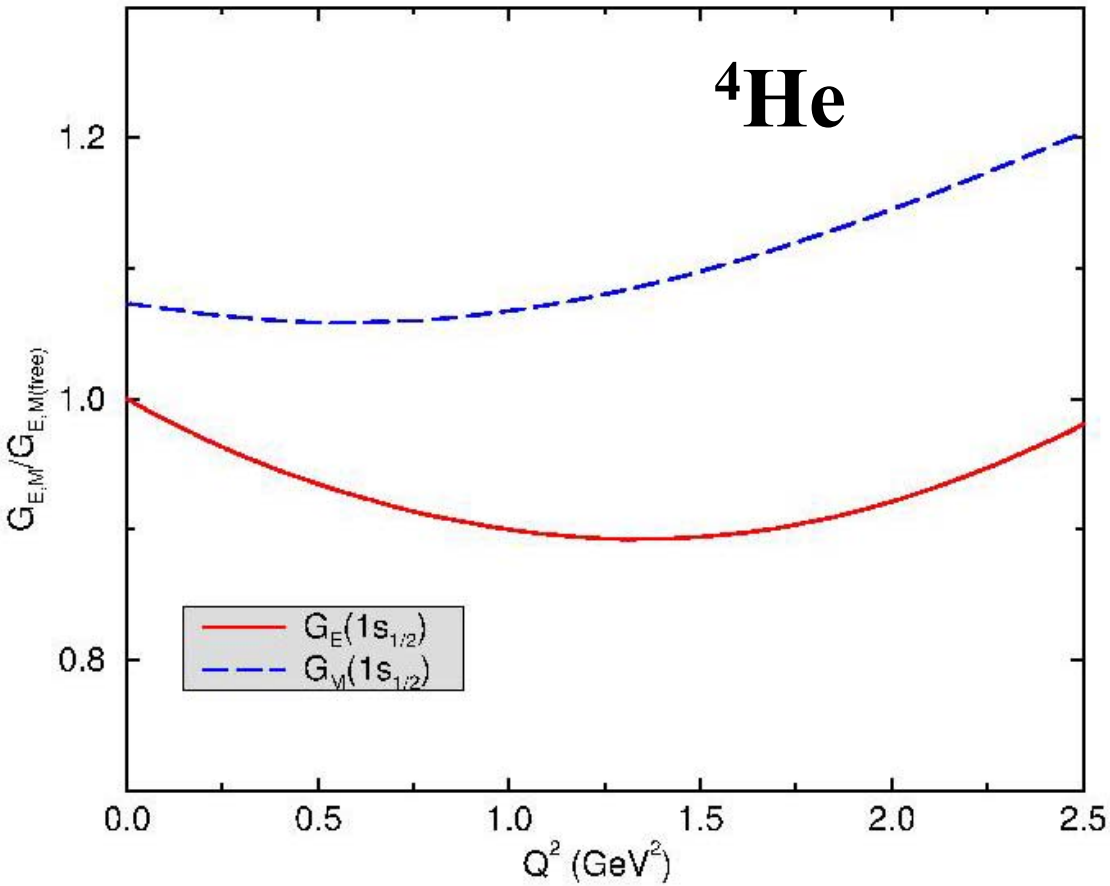
in nucleus

model assumptions

$$\frac{\tilde{G}_E}{\tilde{G}_M}$$

* R. Arnold, C. Carlson and F. Gross, Phys. Rev. C **23**, 363 (1981).

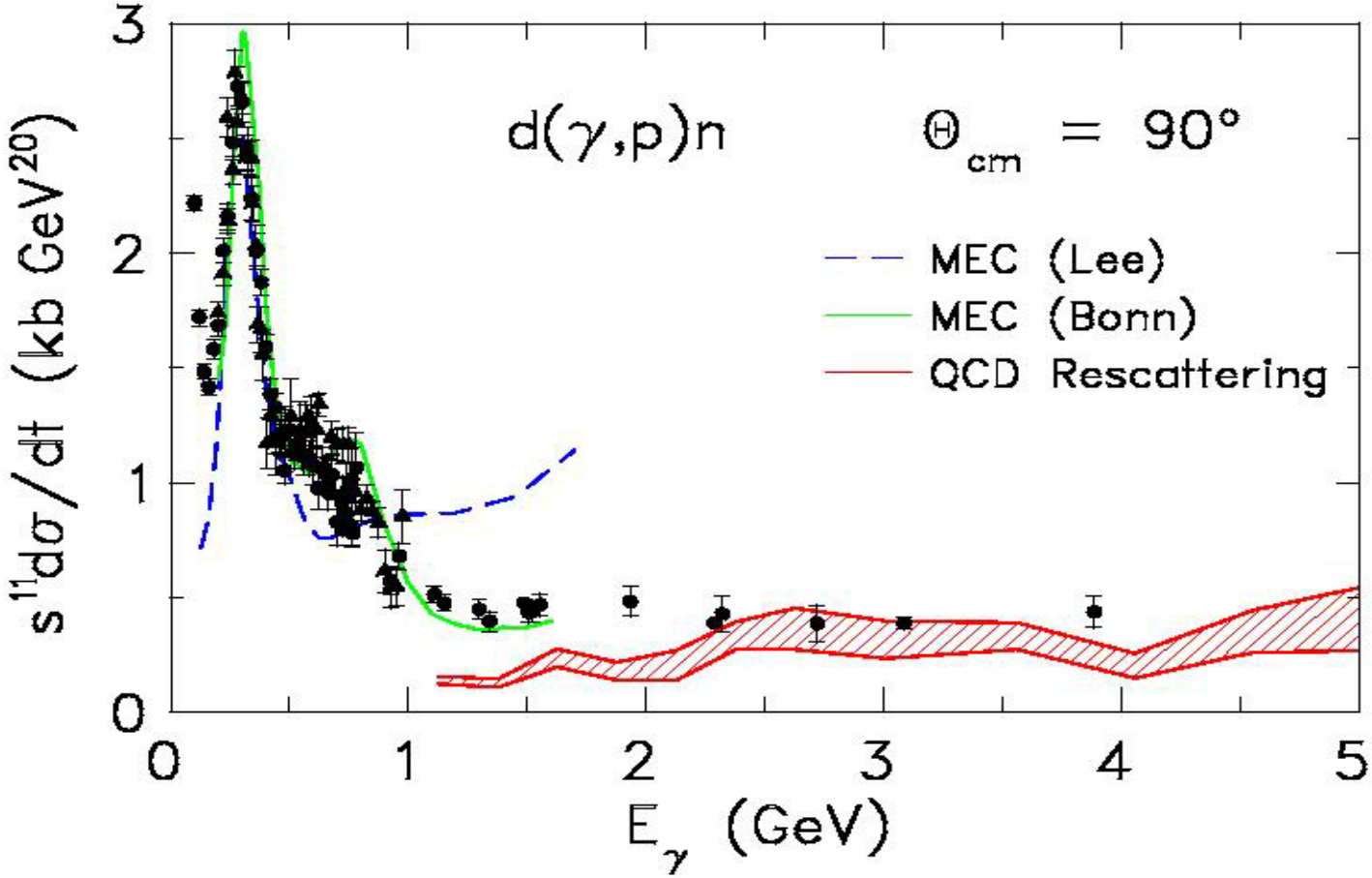
Quark-Meson Coupling Model



D.H. Lu, K. Tsushima, A.W. Thomas, A.G. Williams and K. Saito, Phys. Lett. **B417**, 217 (1998) and Phys. Rev. C **60**, 068201 (1999).

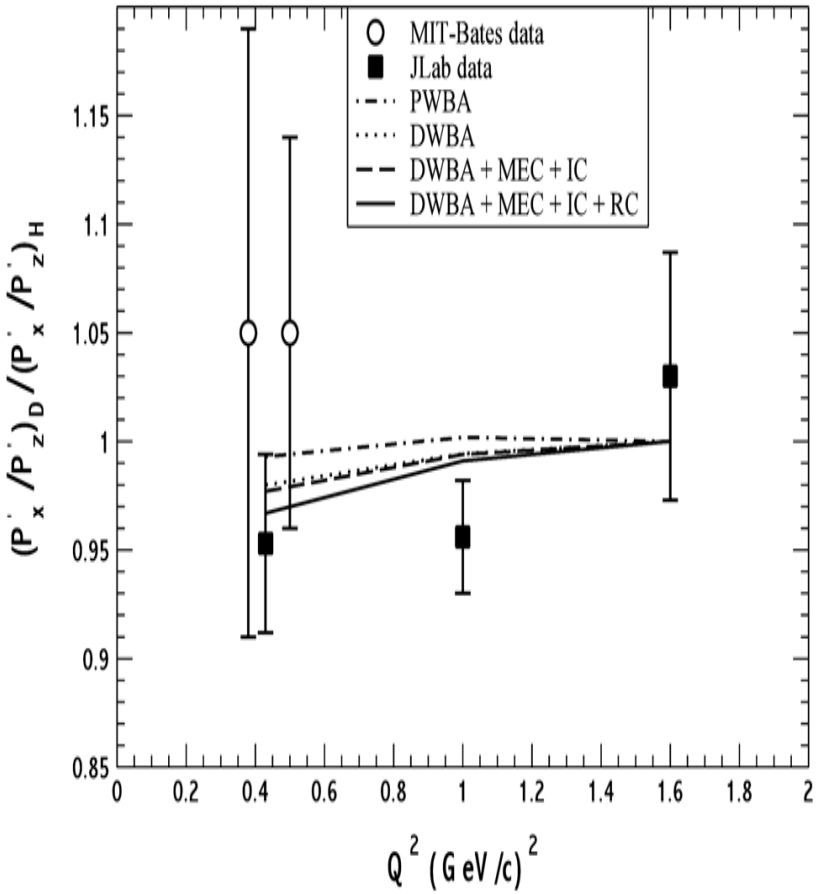
Is There a Limit for Meson-Baryon Models?

Not really but . . .



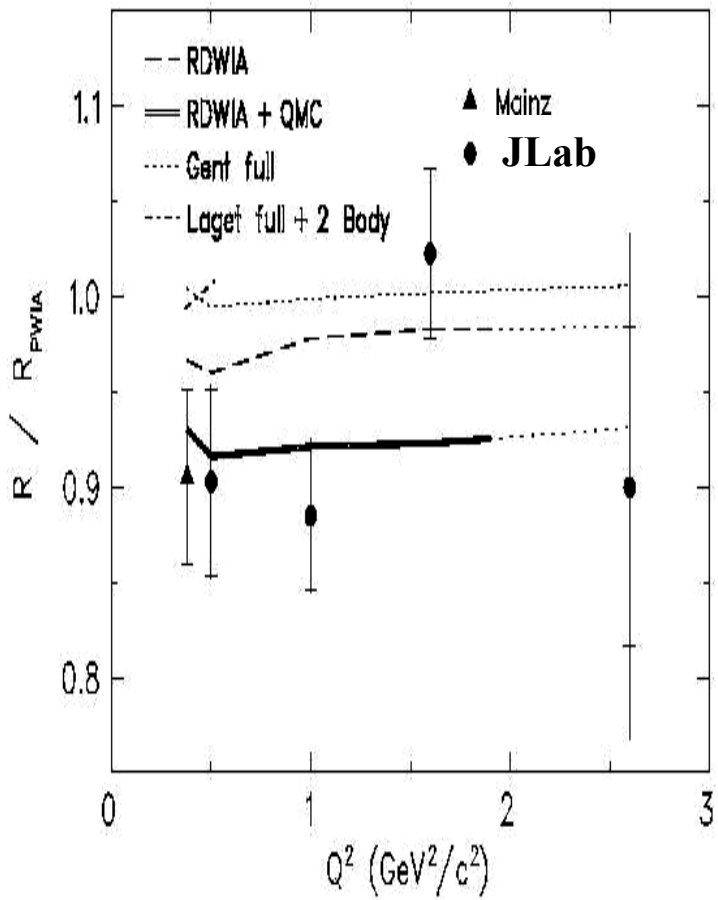
. . . there might be a more economical QCD description.

$^{2}\mathrm{H}(\vec{e},e'\vec{p})n$



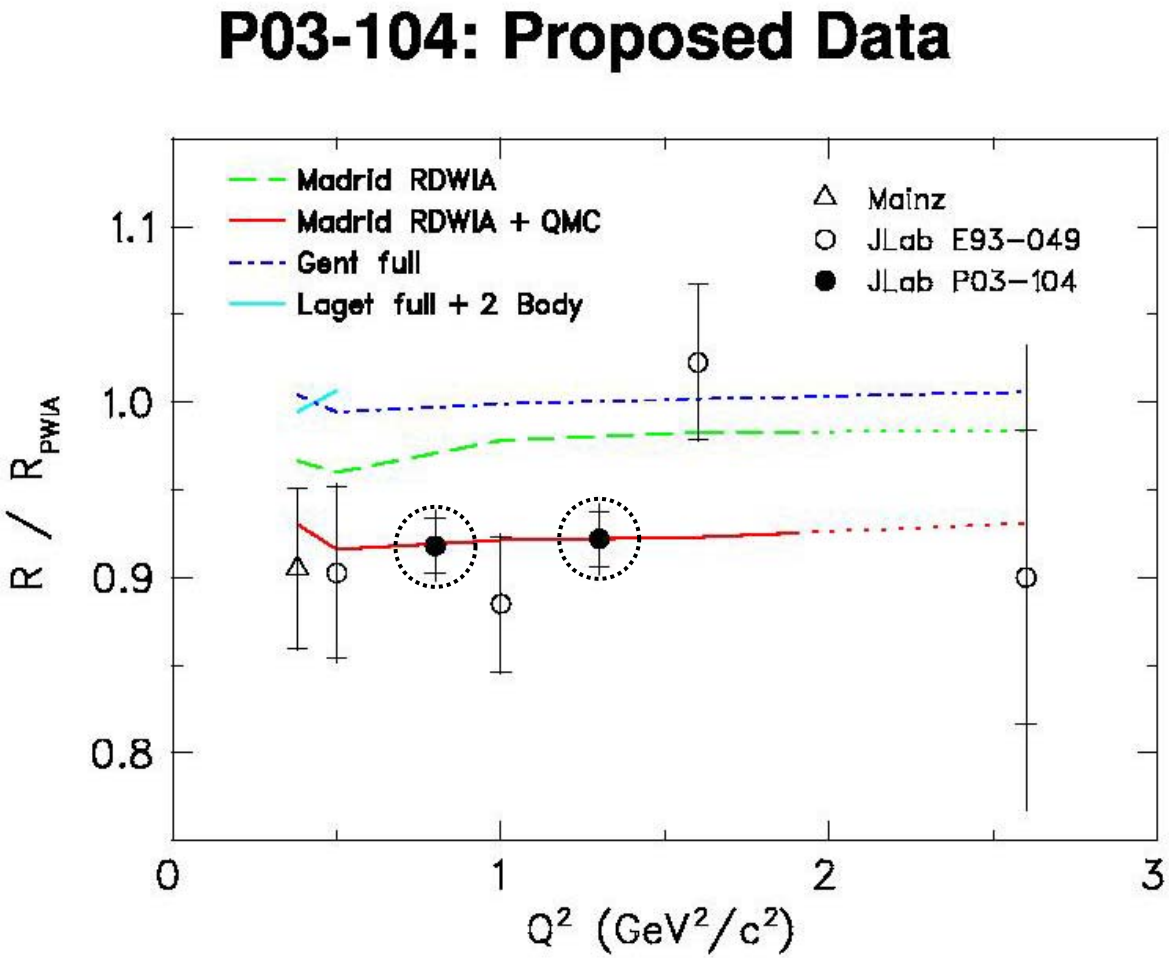
Calculations by Arenhövel

$^{4}\mathrm{He}(\vec{e},e'\vec{p})^{3}\mathrm{H}$



RDWIA calculations by Udias *et al.*

$^4He(\vec{e},e'\vec{p})$ in Hall A



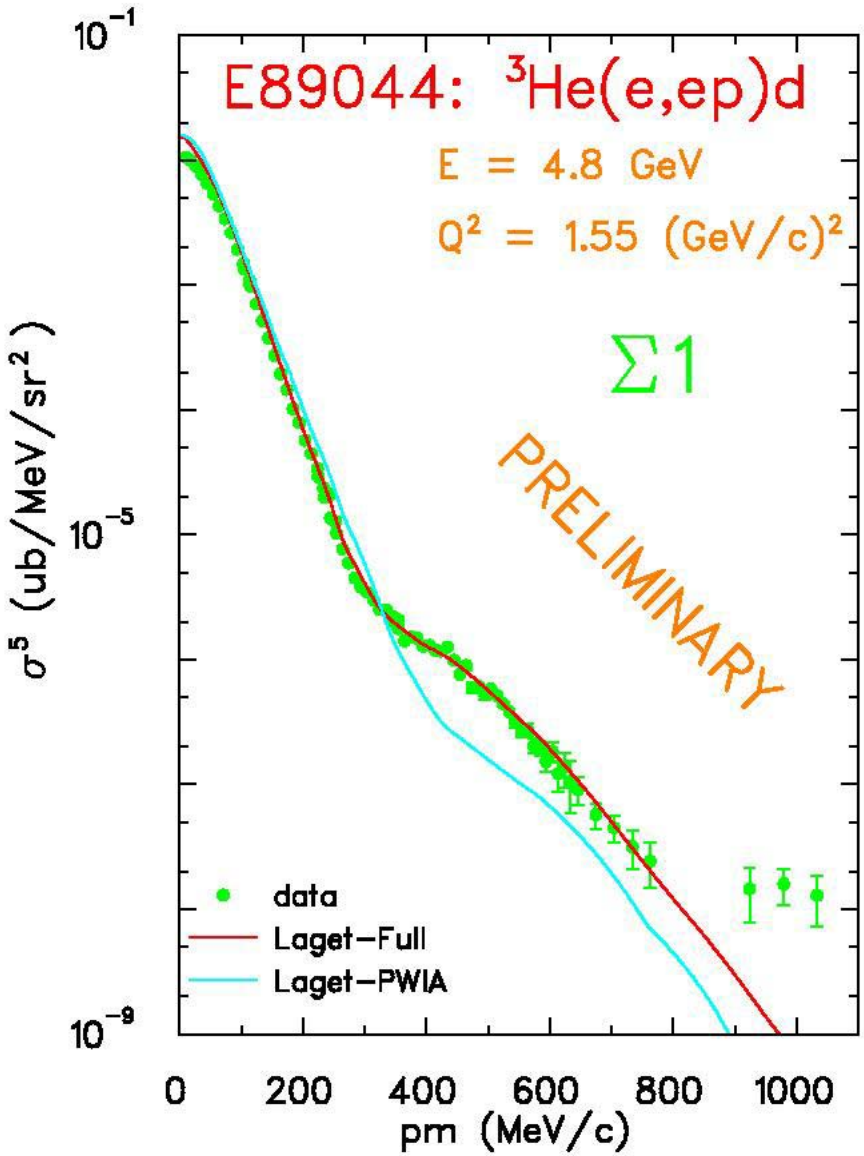
New proposal: Strauch, Ent, Ransome, Ulmer *et al.*

^{3}He Electrodisintegration

Hall A	Hall B
^{3}He(e,$e'p$)d	^{3}He(e,$e'pp$)n

Other channels measured as well.

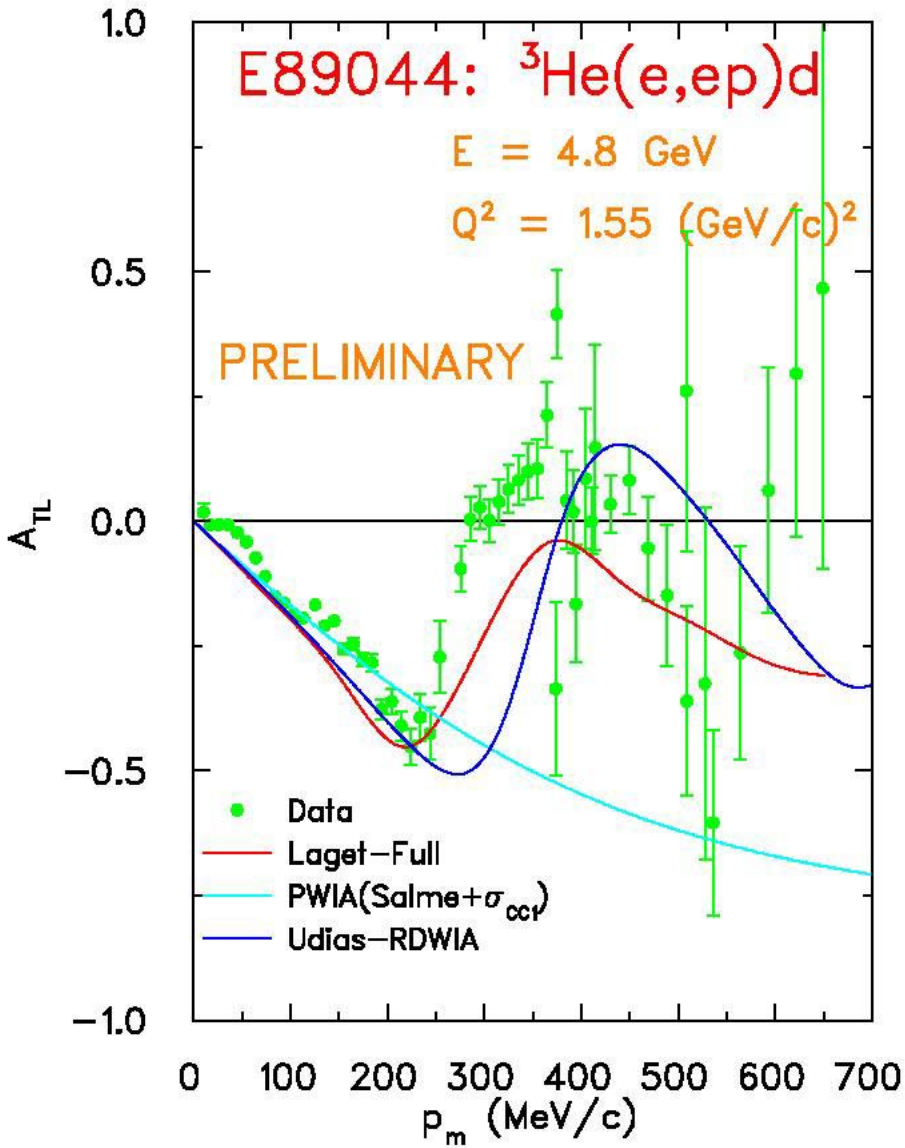
Hall A



Large effects from FSI and non-nucleonic currents.

Highest p_m shows excess strength.

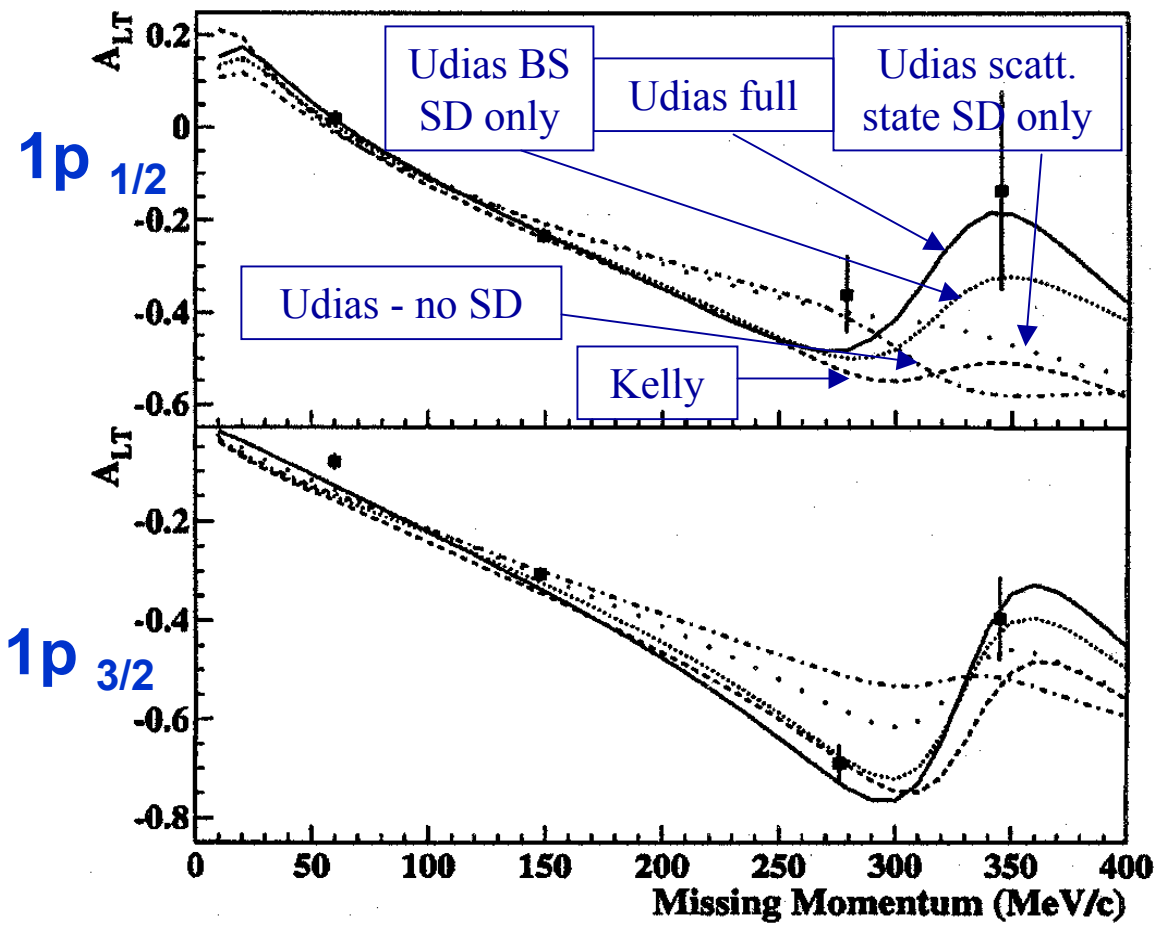
Hall A



General features reproduced but not at correct values of p_m.

$^{16}O(e,e'p)$ Q^2=0.8 GeV^2 Quasielastic

OK, not few-body.



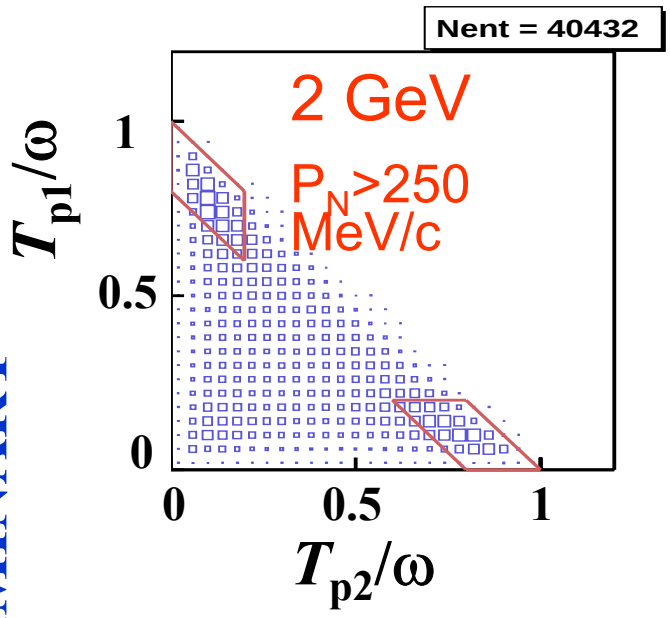
Udias *et al.*, full RDWIA calculation gives reasonable description of A_{LT}.

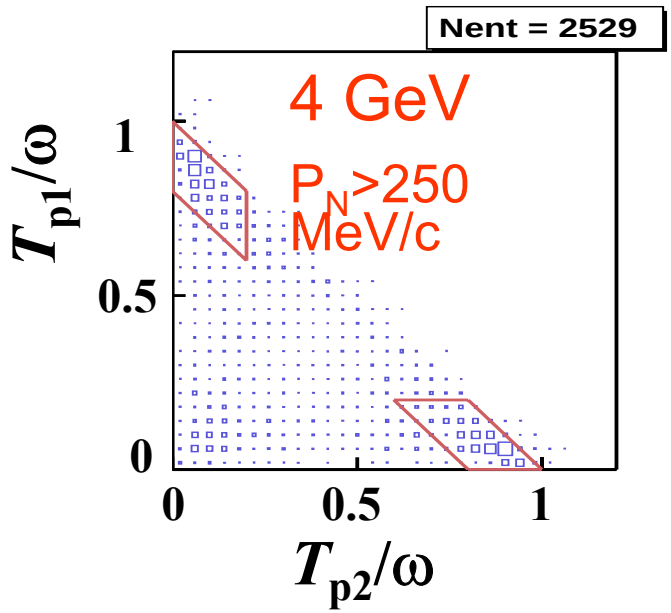
J. Gao *et al.*, Phys. Rev. Lett. **84**, 3265 (2000).

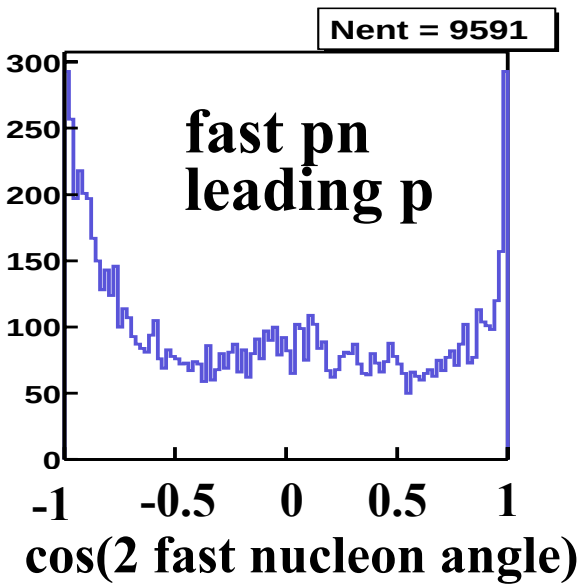
JLab Hall A

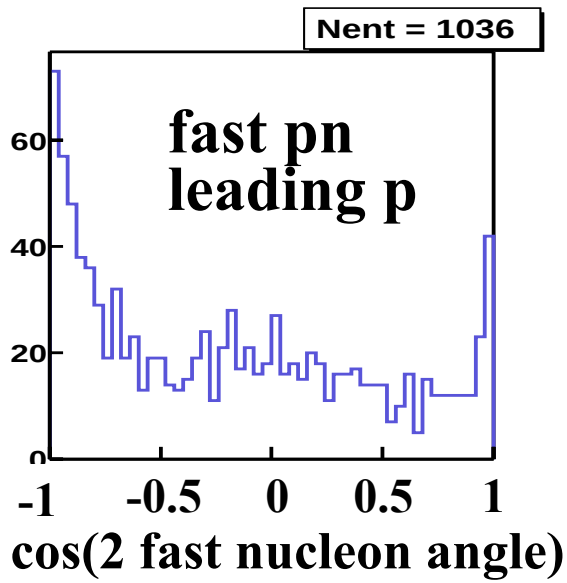
^{3}He(e,e'pp)n Hall B

PRELIMINARY





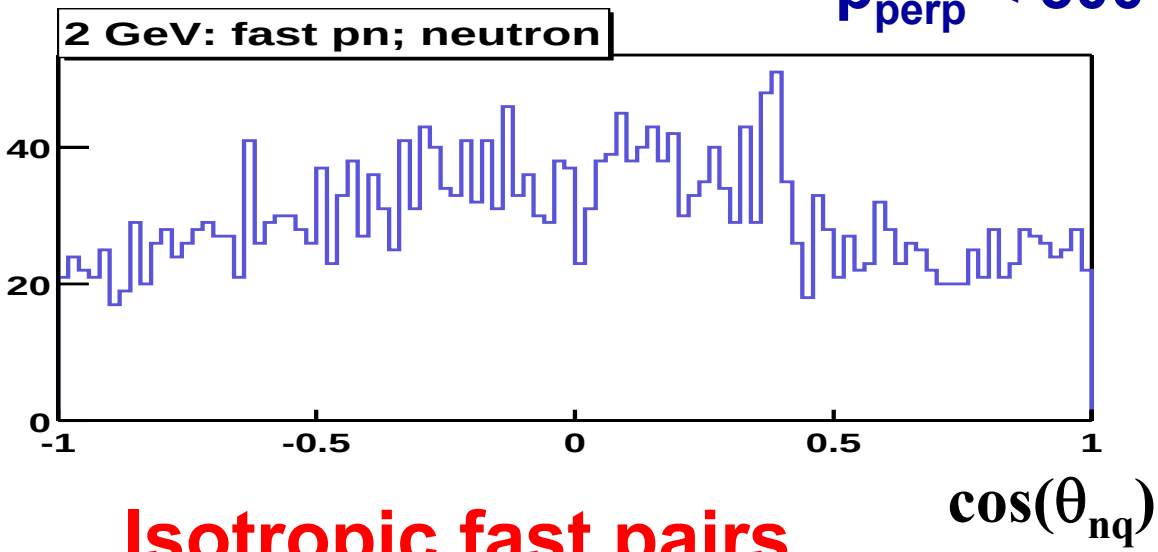




Hall B

^{3}He(e,e'pp)n 2 GeV

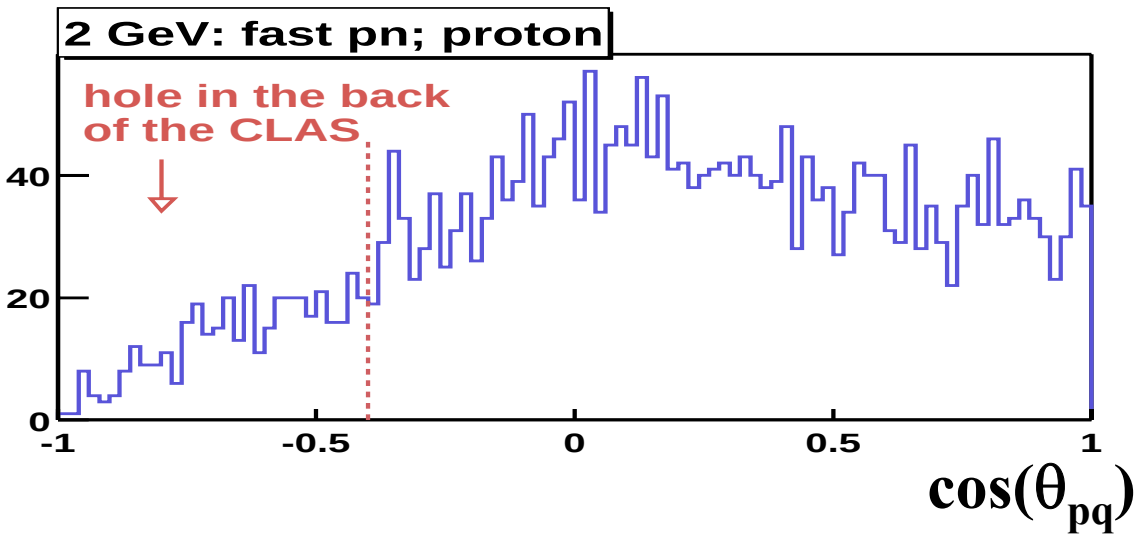
p_{perp} < 300 MeV/c



PRELIMINARY

Isotropic fast pairs

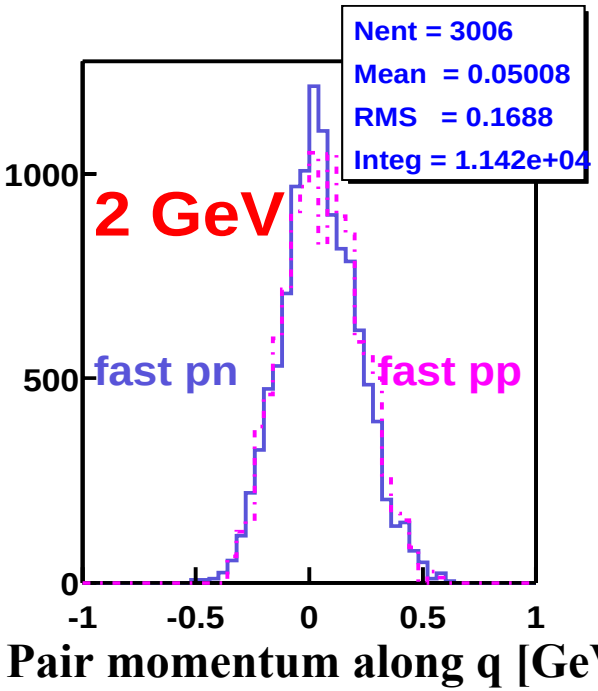
→ pair not involved in reaction.

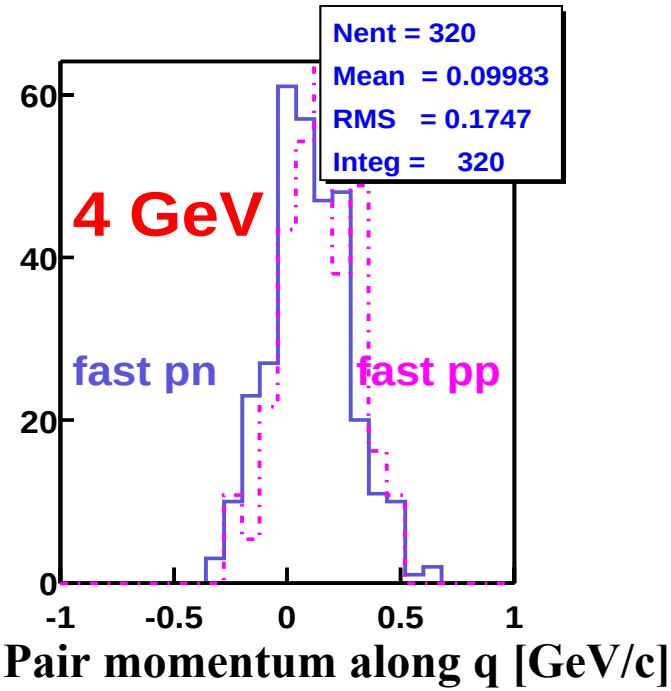


Hall B

^{3}He(e,e'pp)n

PRELIMINARY $p_{perp} < 300$ MeV/c





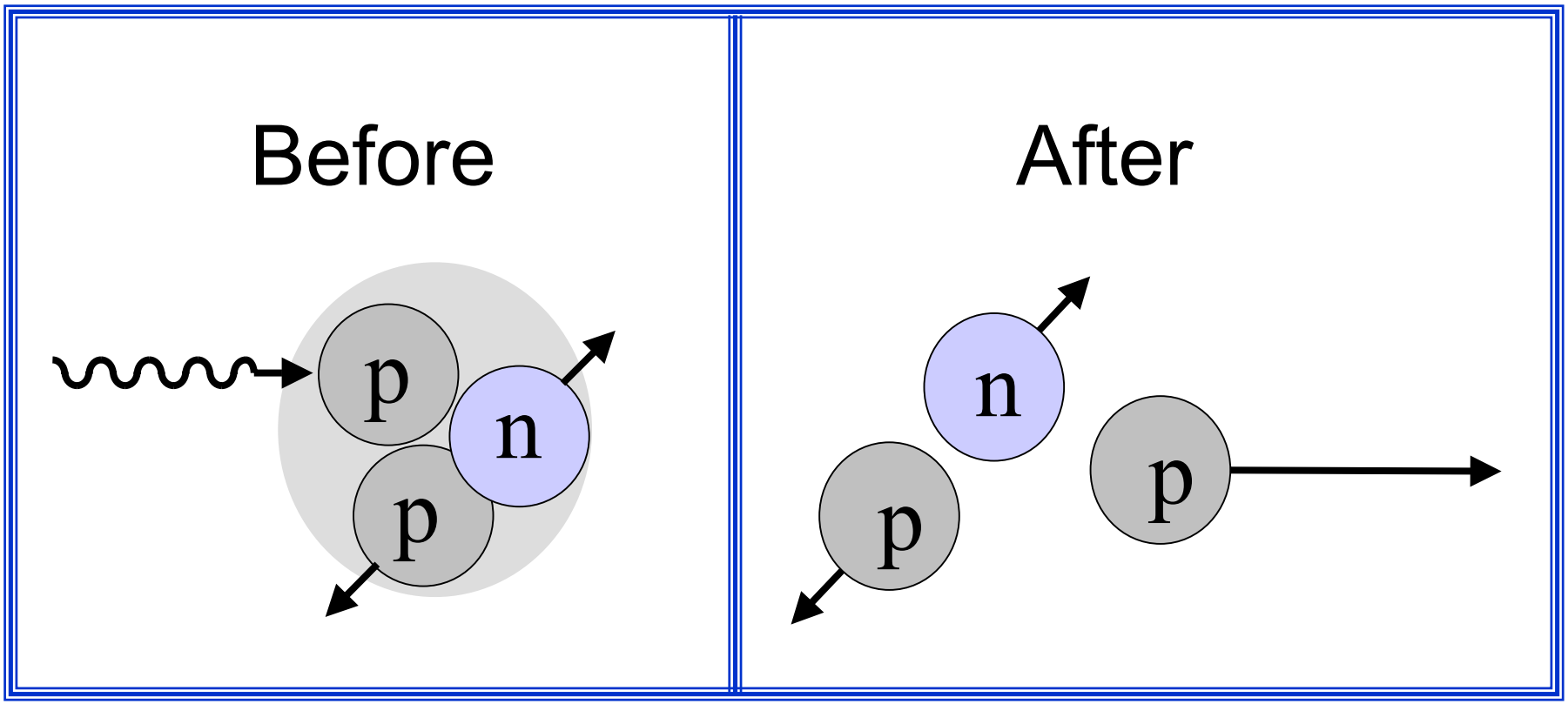
Small momentum along q

→ pair not involved in reaction.

Little Q^2 or isospin dependence.

2 GeV has acceptance corrections

Direct evidence of NN correlations



Summary

- Deuteron elastic scattering
  - *A*: Relativity important; pQCD? 12 GeV→ higher Q^2
  - *B*: More data still badly needed: proposed for Hall A
  - t_{20}: MEC's; ~~pQCD~~
- Deuteron photodisintegration
  - Cross sections: CCR? Asymmetry seen.
  - Polarizations: Consistent with approach to HHC; $C_{x'}$?
  - 12 GeV → higher E_γ

Summary, cont'd.

- Polarization transfer on ^{2}H, ^{4}He
  - Failure of DWIA calculations; evidence of MM.
- e + ^{3}He
  - Hall A: large excess high p_m strength seen
  - Hall B: direct evidence of *NN* correlations

Analysis underway for other experiments, not shown here.

For providing data slides (including some I was not able to show), thanks to:

W. Boeglin, J. Gilfoyle,
R. Gilman, S. Kox,
S. Kuhn, R. Niyazov, M. Petratos,
D. Protopopescu, B. Reitz,
P. Rossi, A. Saha, S. Strauch,
E. Voutier, L. Weinstein