Hard Disintegration of the Nucleon Pair in Past, Present, and Future Tenses

Ronald Gilman
Rutgers University, New Jersey, USA
and
Jefferson Lab, Newport News, VA, USA

Probing Microscopic Structure of the Lightest Nuclei in Electron Scattering at JLab Energies and Beyond
Trento, Italy 25-30 July 2005

Plan

- Review of photo-disintegration data vs. theory
  - No real detail on theory or experiment
- Interest in hard photodisintegration: high energy, high momentum transfer regime in which quark based theories might apply
  - But also interested in "breakdown" of hadronic theories, so coverage starts at 200 - 300 MeV
  - Not covered: EFT, baryo-synthesis, p_y^n problem

A Note on Breakdown

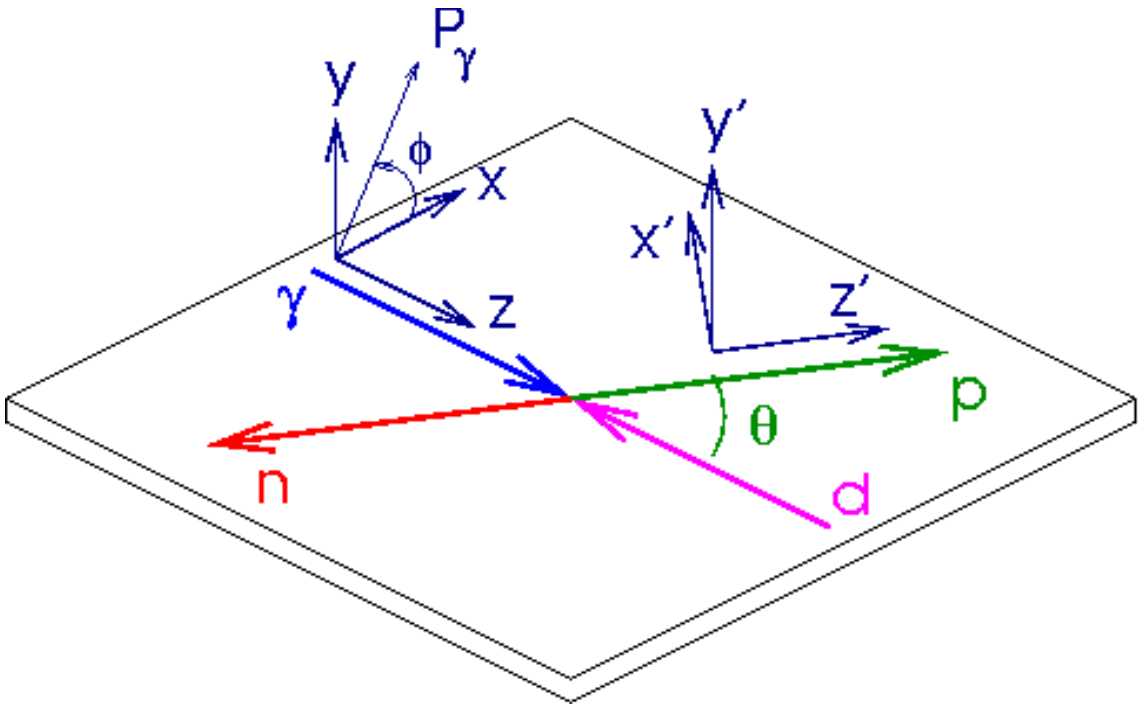
- I consider the "breakdown" of hadronic theories to be a matter of practice – the ability to construct a theoretically acceptable microscopic conventional theory that agrees well with data
- Stan Brodsky has claimed it is a matter of principle: hidden color components in the deuteron cannot be reproduced in hadronic theory

Intermediate Energy: Past Tense

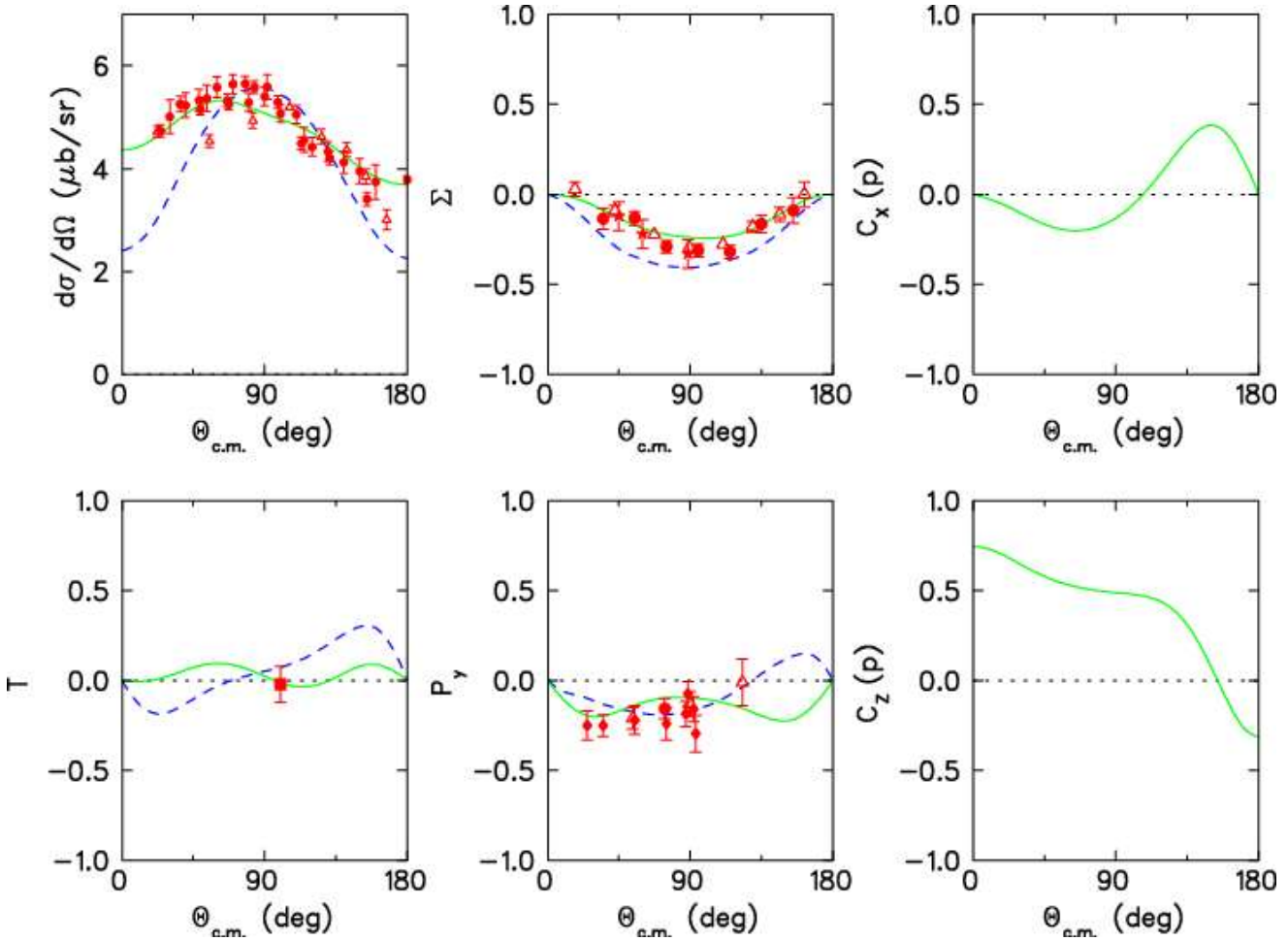
- Explosion of interest in d(γ,p)n in late 1970s / early 1980s, from large unexplained induced polarization
- Simple theories + Breit-Wigners used to extract dibaryon resonances from often poor data
- Cross sections in much better shape due to Matthews and Owens + tagged photons: Frascati, Mainz, LEGS...
- Theory improved: Schwamb and Arenhövel... but py problem remains

Some Observables in d(γ,p)n

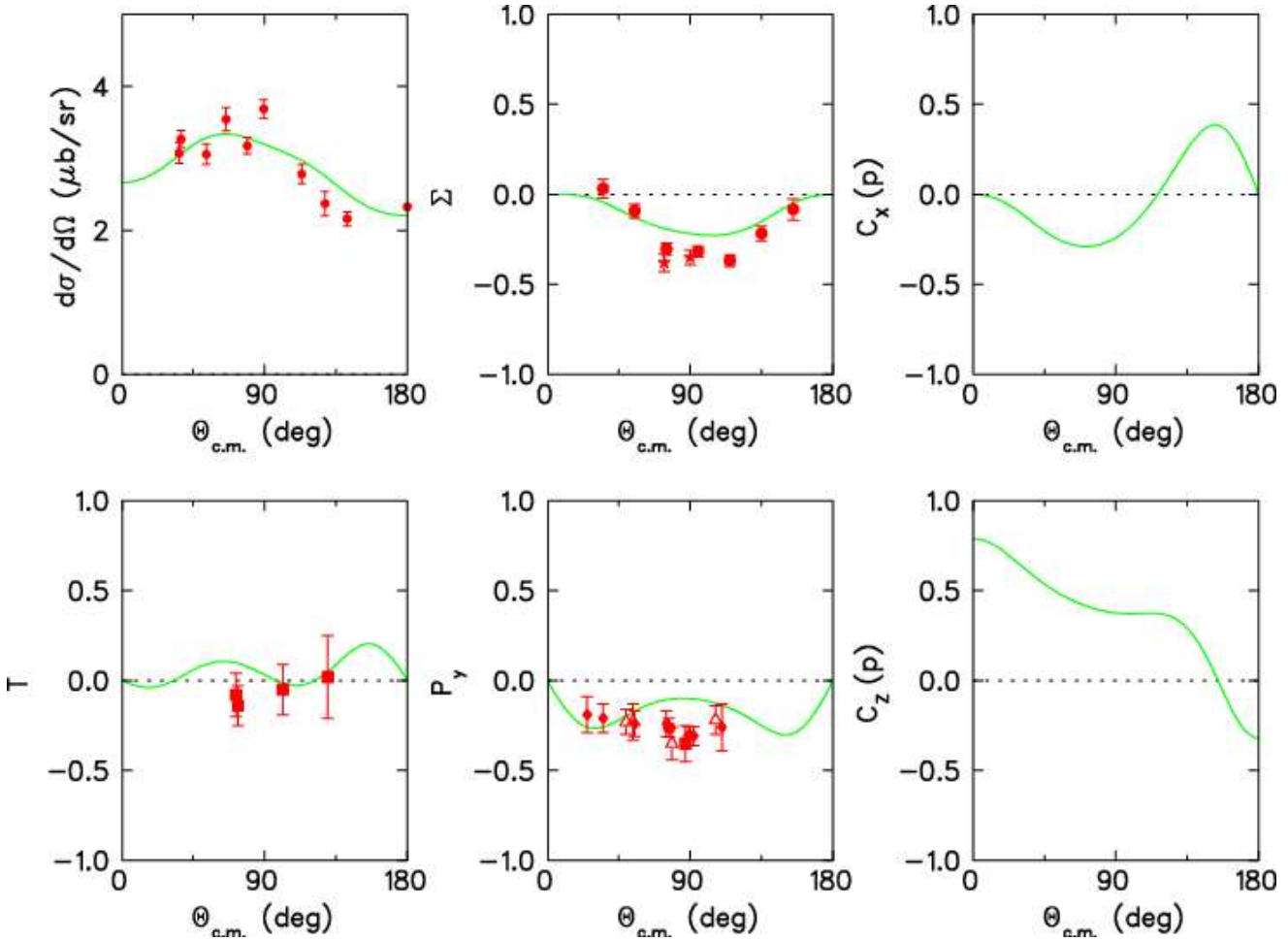
- $d\sigma/d\Omega$, Σ, T, $C_{x'}$, p_y, $C_{z'}$



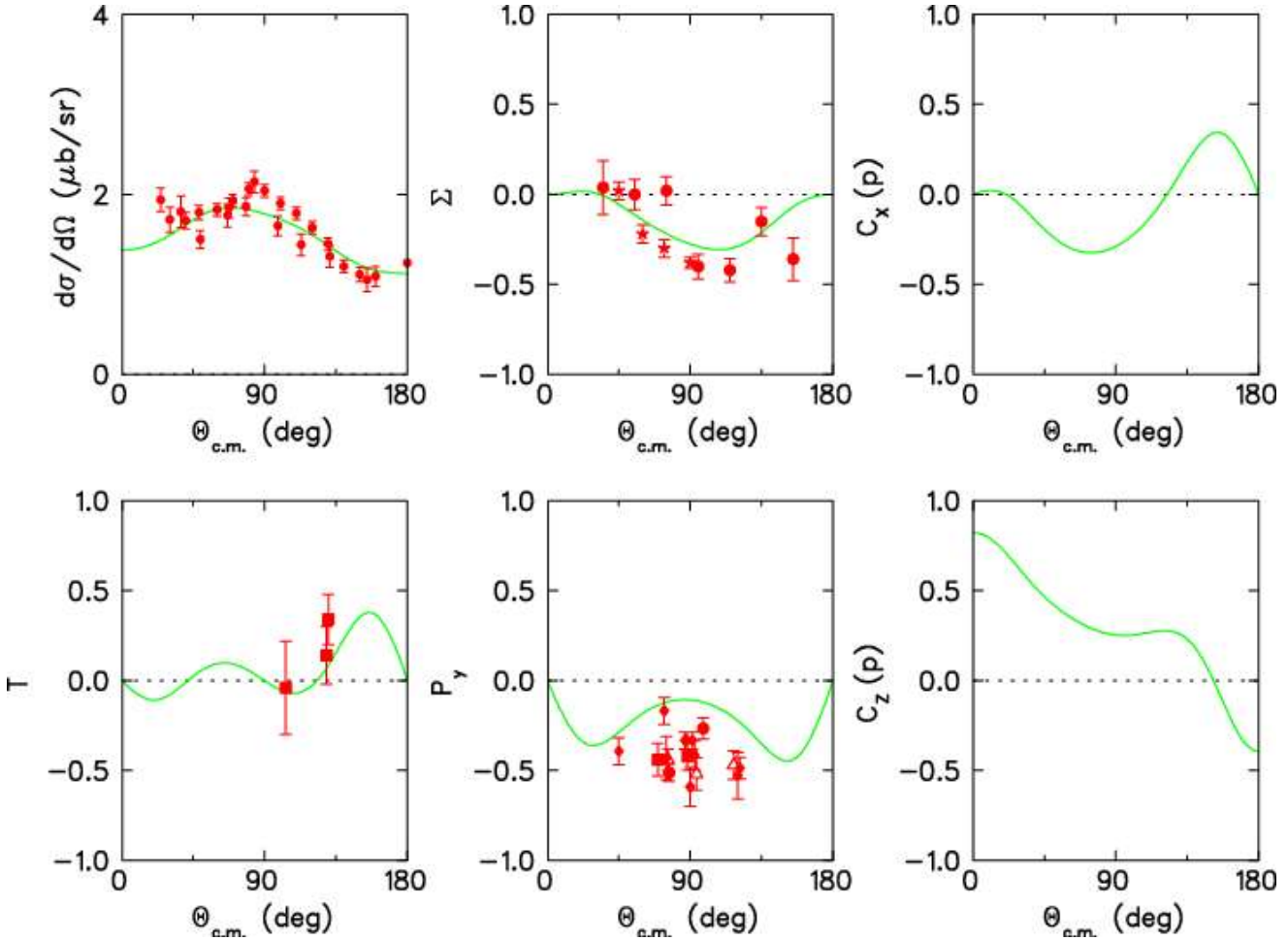
Observables at Eγ = 300 MeV



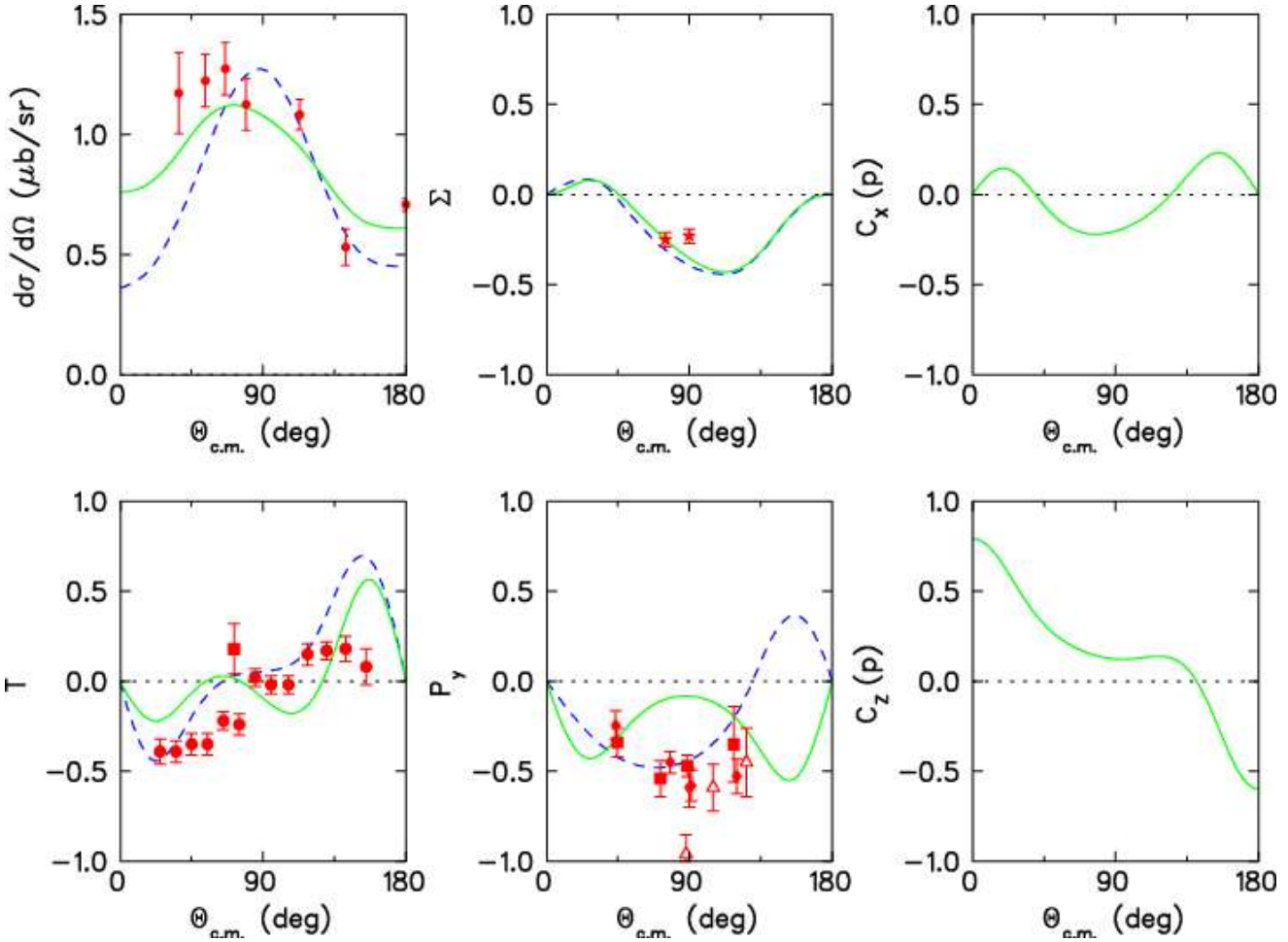
Observables at Eγ = 350 MeV



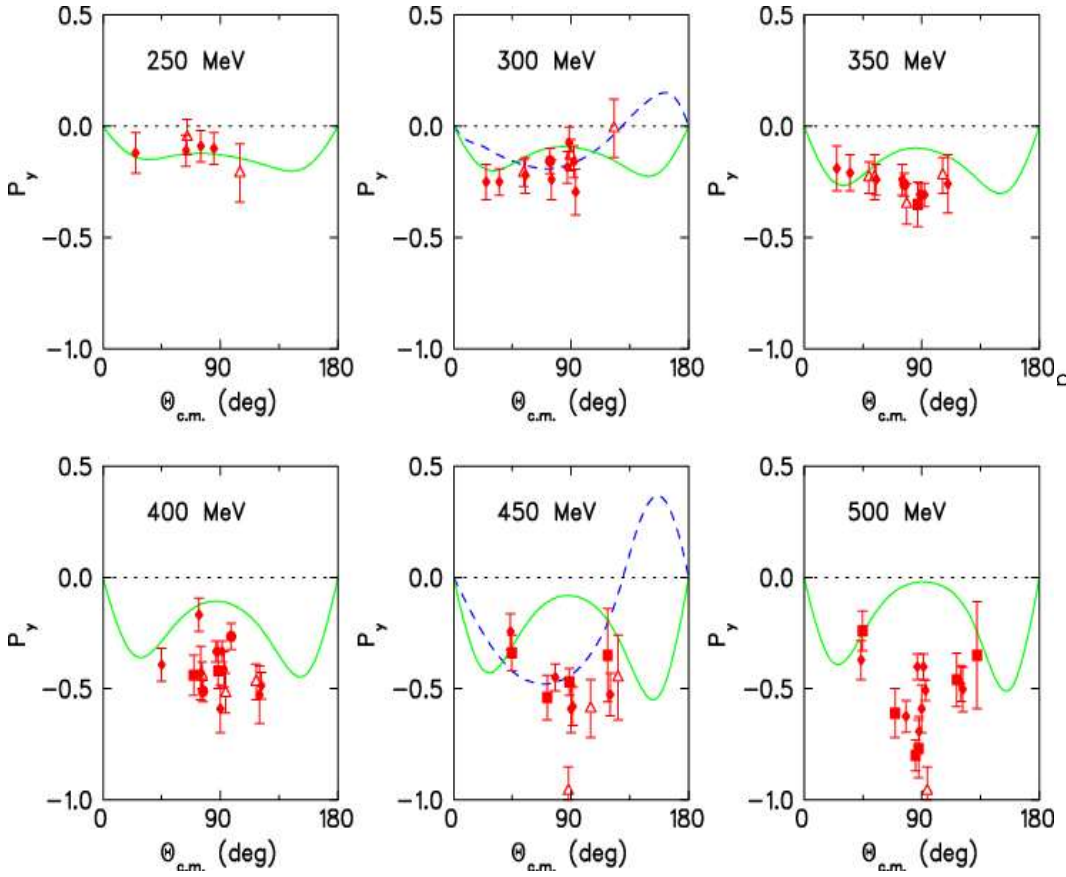
Observables at Eγ = 400 MeV

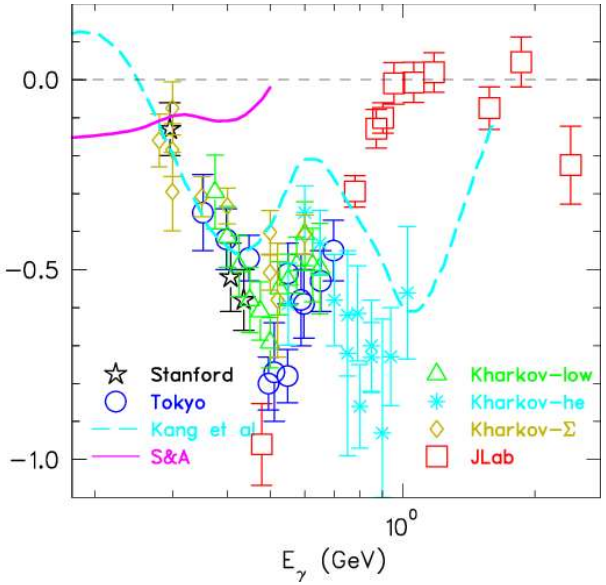


Observables at Eγ = 450 MeV



Induced polarization



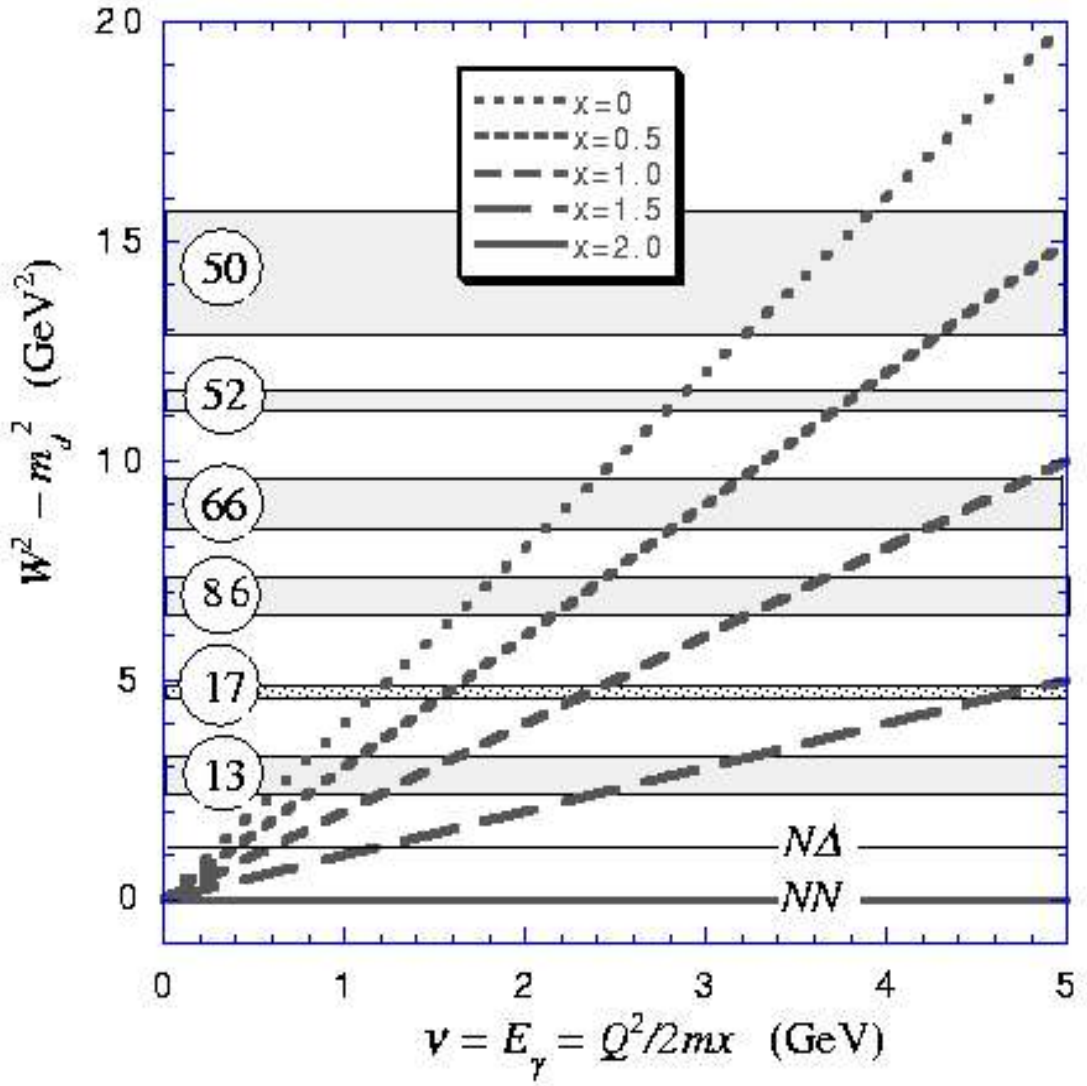


Intermediate Energy Past Summary

- Generally good theory from Schwamb and Arenhövel, based in modern NN force + relativity, but...
- The ~30 year old problem with p_y remains unresolved

Speculations

- Resonances?
- Heavy mesons?
- Multiple pions?
- ...



Intermediate Energy Future

- We have a proposal going into JLab PAC 28 (August 2005) to do systematic, precise recoil polarizations to help sort out the induced polarization problem
  - Easy but impossible to do such a thing at JLab, however the low-energy, back angle G0 proposal provides an opportunity
- LEGS is currently working on beam-target polarization measurements in pion photo-production; extension to d(γ,p)n is natural

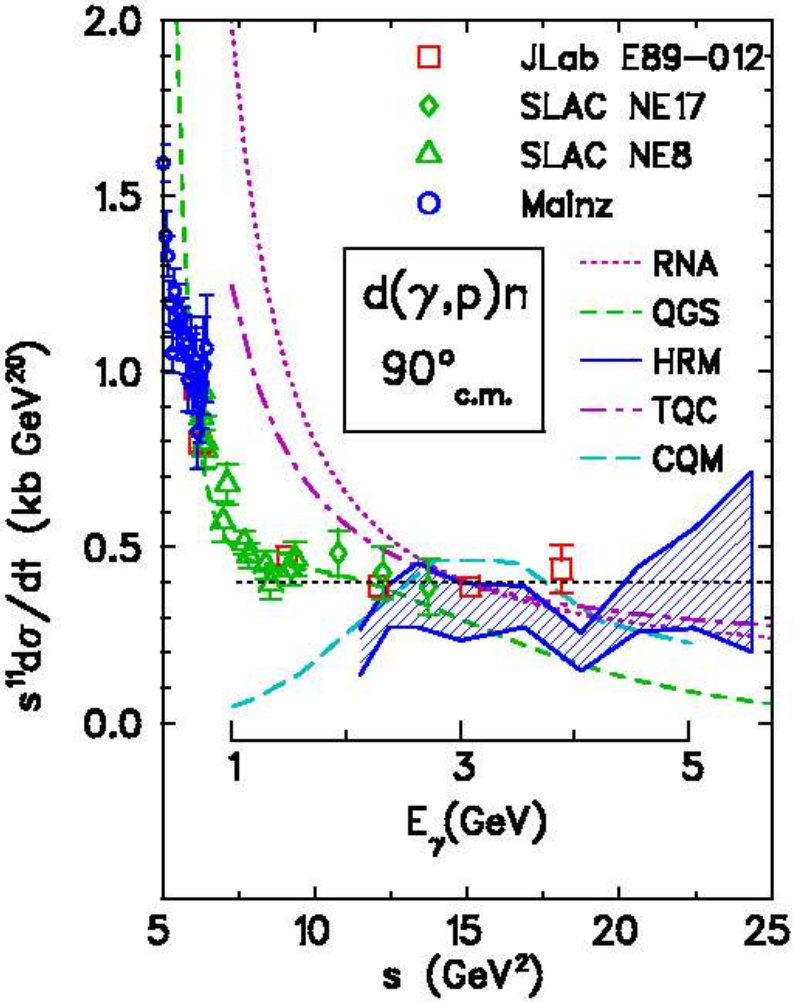
Hard Regime: Past and Present

- SLAC NE8, NE17
- JLab Hall C E89-012, E96-003
- Yerevan (Σ)
- JLab Hall A E89-019 ($C_{x'}$, p_y, $C_{z'}$), E99-008
- JLab Hall B (P. Rossi)
- JLab Hall A E00-007 ($C_{x'}$, p_y, $C_{z'}$) (X. Jiang)
- JLab Hall B: ^{3}He (S. Strauch)

- Does pQCD apply? -> Is there a good quark model? Is there a phase transition?

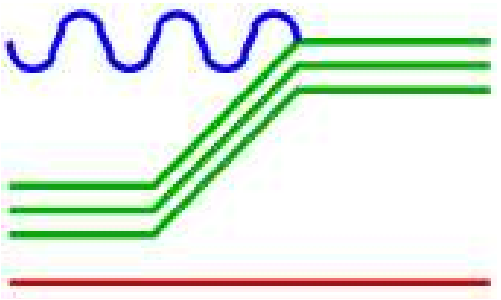
Hard Past: 90° Excitation Functions

- Cross sections fall by a factor of 30,000 from 1 – 4 GeV, ~following ``expected'' quark scaling, $d\sigma/dt \sim s^{-11}$
- Hadronic theories not satisfactory and not shown
- Most quark models normalized

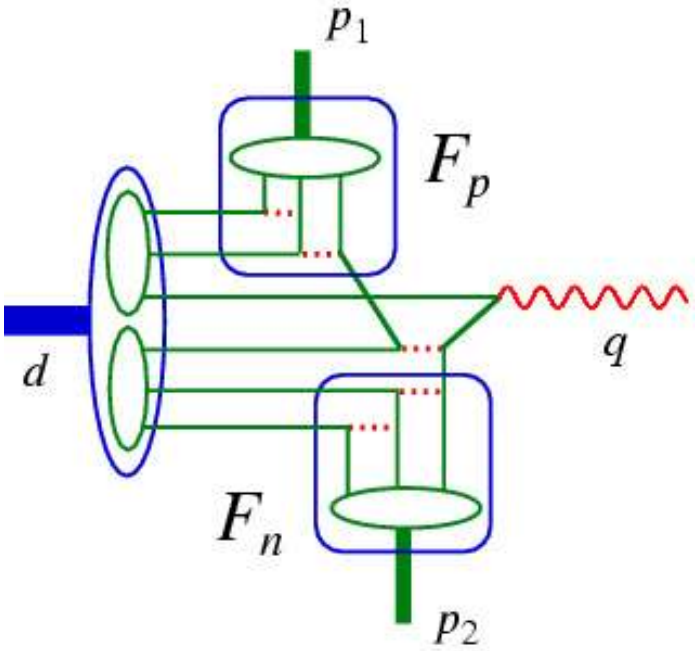


The Quark Models

- QGS: Regge phenomenology to evaluate 3-quark exchange, justified by dominance of planar diagrams

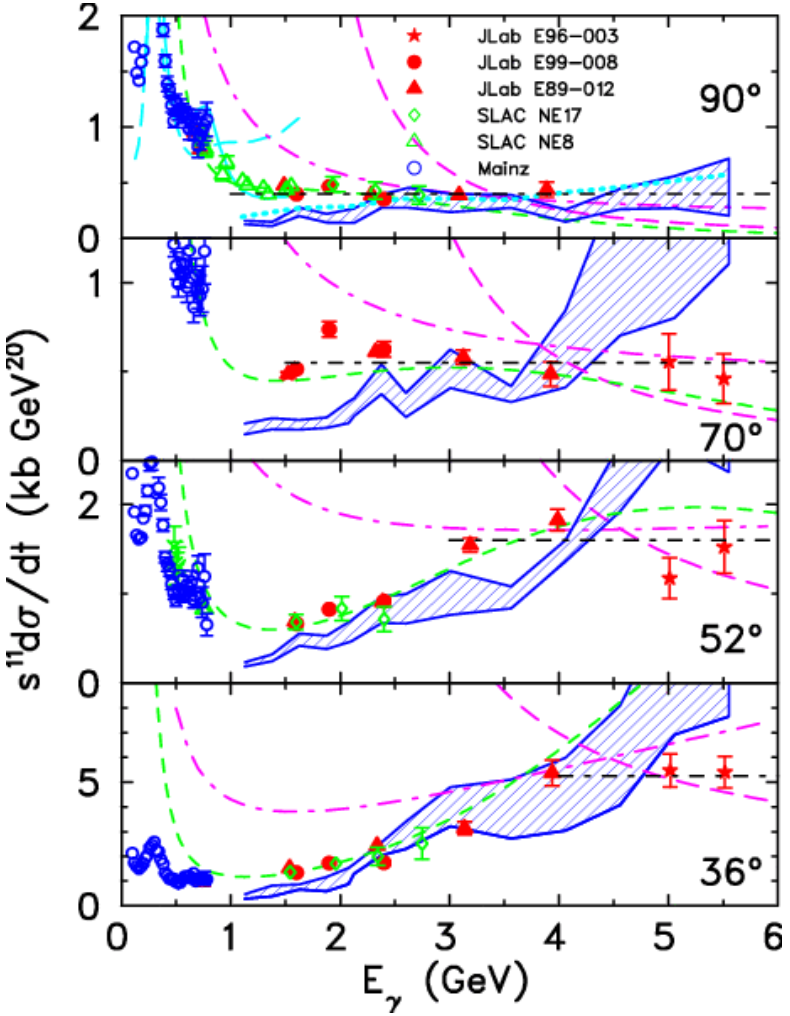


- RNA, HRM, TQC, CQM: Photon absorbed and quarks exchanged; might be related to NN elastic scattering



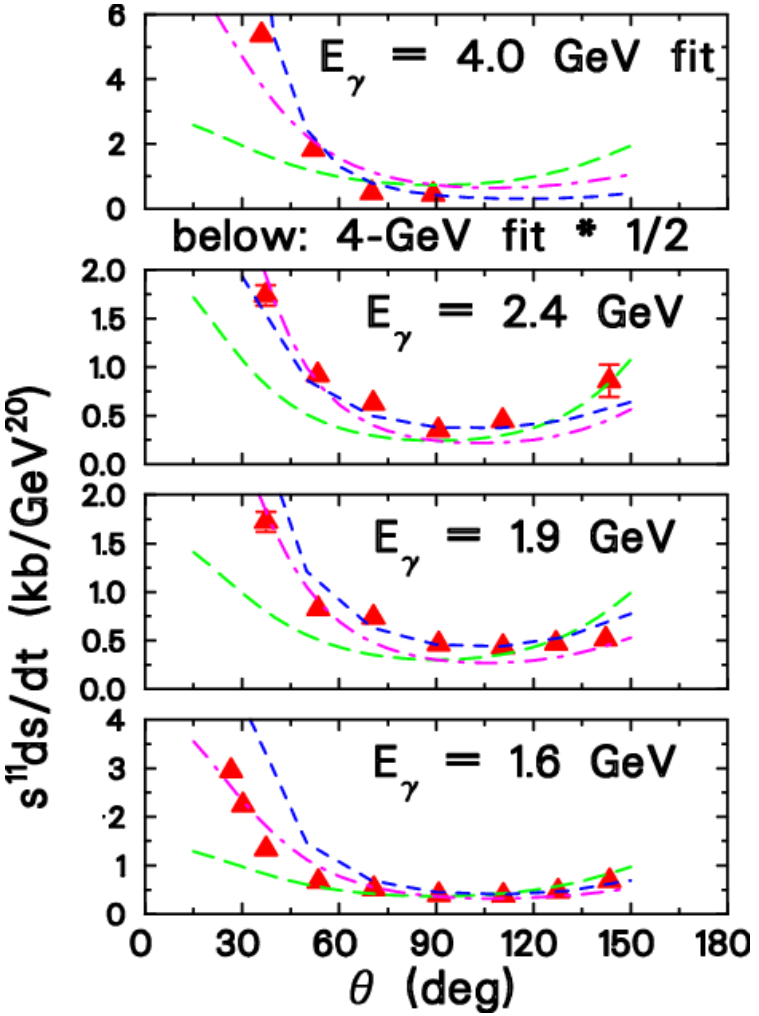
Hard Past: Excitation Functions

- Cross sections fall by factor of 1.2×10^6 from 1 – 6 GeV
- The onset of ~quark scaling, $d\sigma/dt \sim s^{-11}$, at each angle corresponds to $p_T \sim 1.3$ GeV



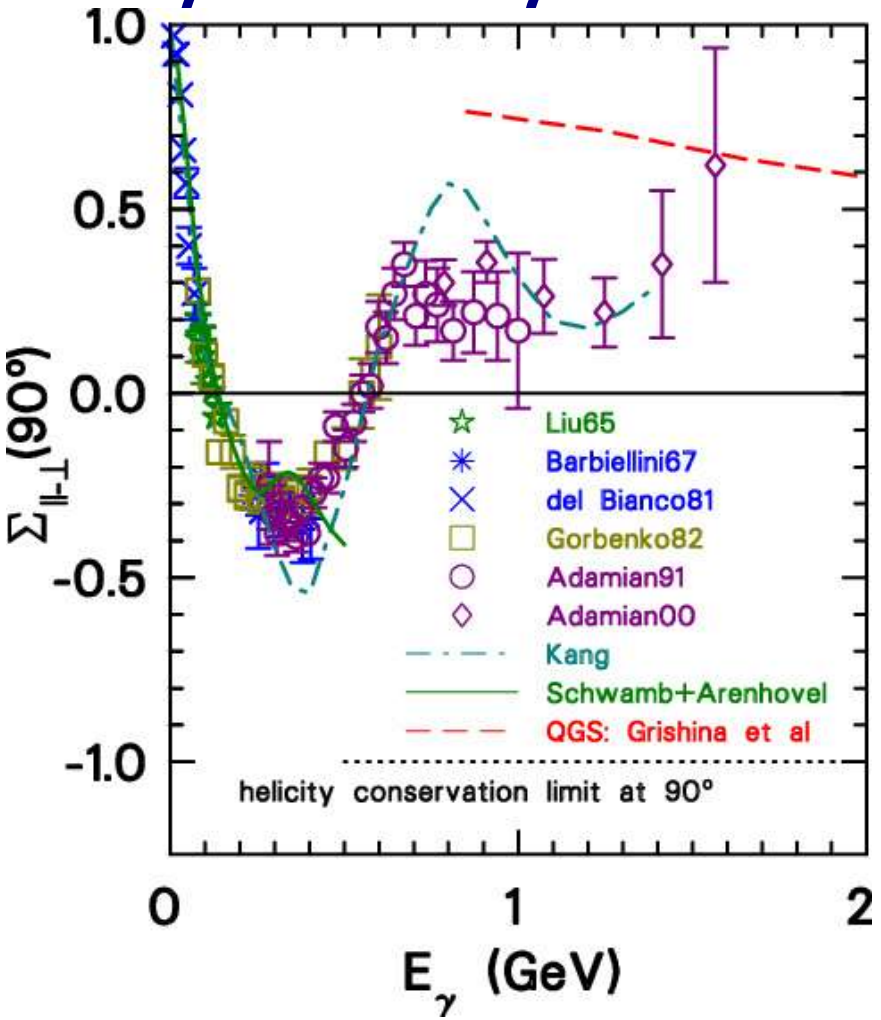
Hard Past: Angular Distributions

- Blue dash: HRM
- TQC (Radyushkin):
- $d\sigma/d\Omega_{sym} = NF_p^2F_n^2/$
  $\{[s-\Lambda^2]\sqrt{[s(s-m_d^2)]}\}$
- $d\sigma/d\Omega_{asym} = d\sigma/d\Omega_{sym}$ /
  $\{1-A\cos\theta/\sqrt{[1+m_p/E]}\}^2$
- Similar AD shapes -- insensitive to dynamics?



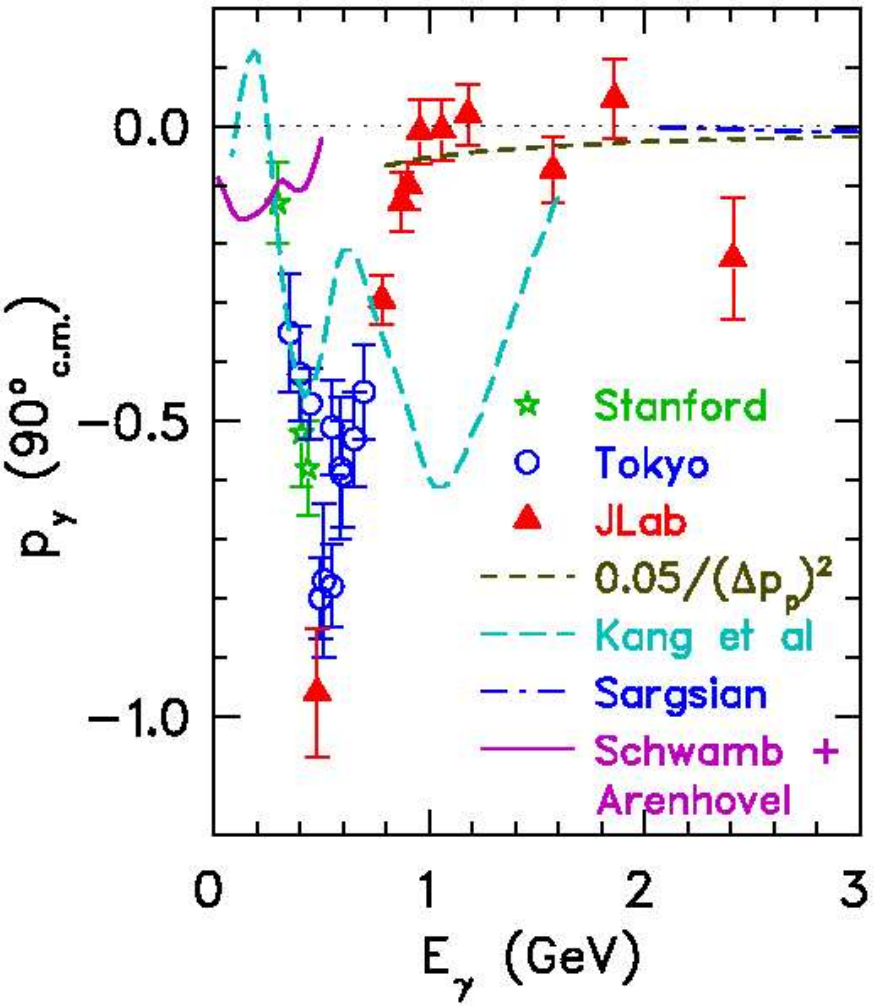
Hard Past: Σ Asymmetry

- HHC - Hadron Helicty Conservation – leads to Σ = -1
- Adamian et al. showed Σ heads away from HHC, with increasing energy
- Grishina et al. pointed out iso-vector (scalar) limit is Σ = 1 (-1)



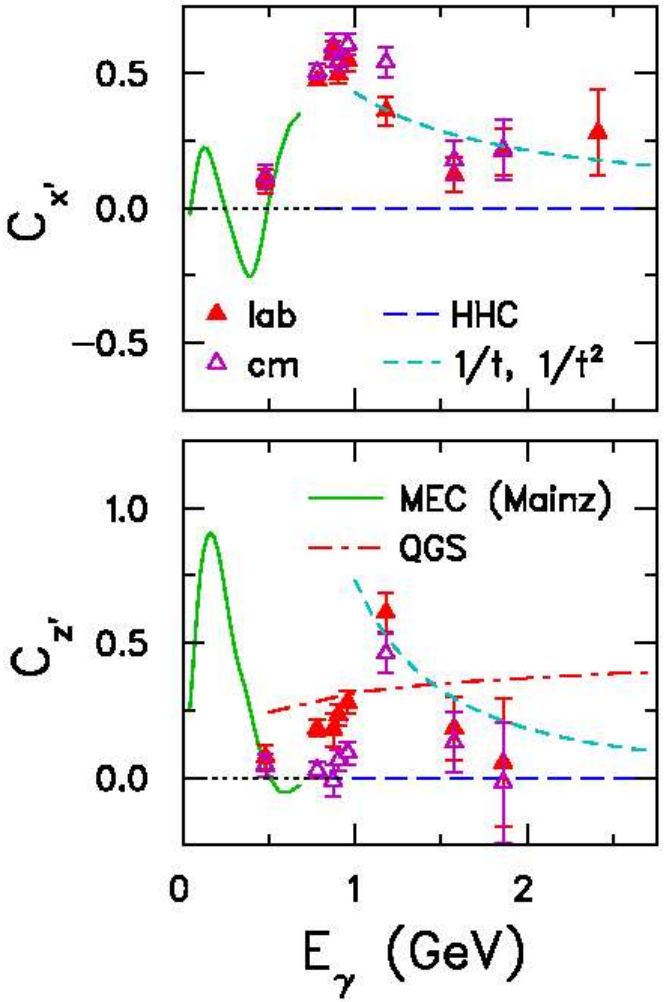
Hard Past: Induced Polarization p_y

- HHC leads to $p_y = 0$, and p_y vanishes above 1 GeV
- HRM predicts p_y small, <0
- Hadronic prediction, that $D_{13} + D_{15}$ leads to large resonance peak, falsified



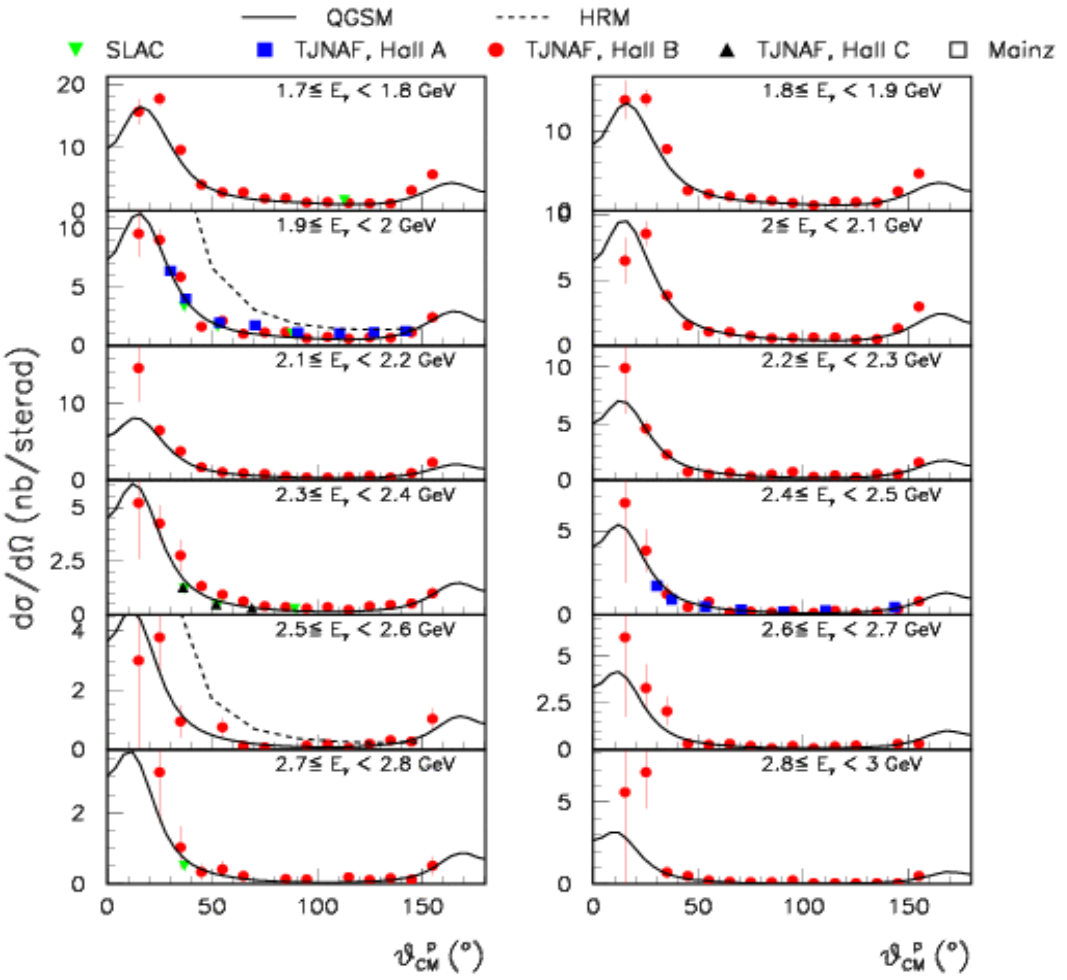
Hard Past: Polarization Transfer

- Schwamb & Arenhövel prediction good at low energies
- $C_{x'}$ small, but not vanishing, so no HHC
- Cannot rule out or strongly support HRM / QGS / approach to HHC

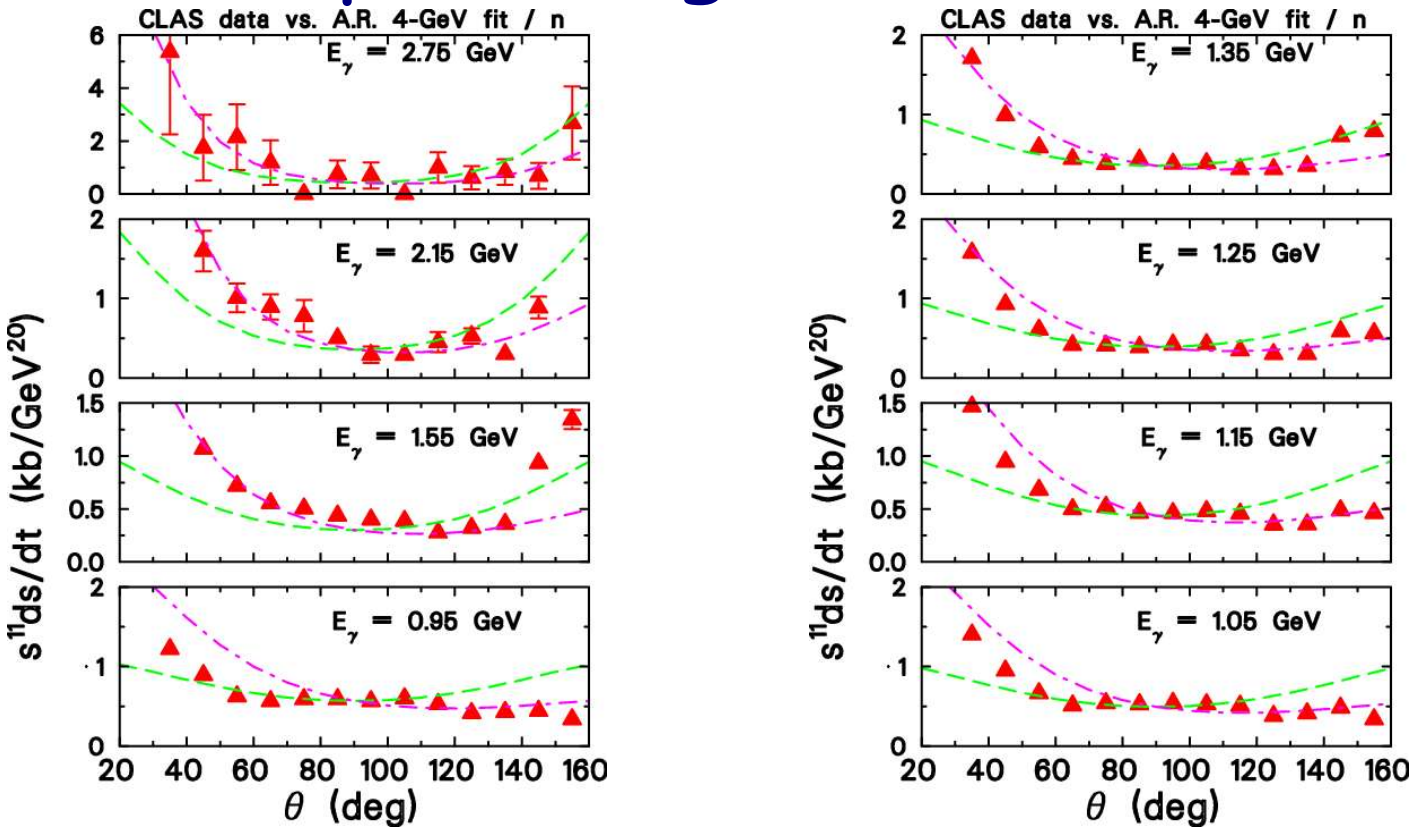


Hard Present: Hall B Distributions

- Beautiful set of angular distributions vs. energy
- Just discussed by P.Rossi – you either saw it or should not have missed it
- What could I possibly add?



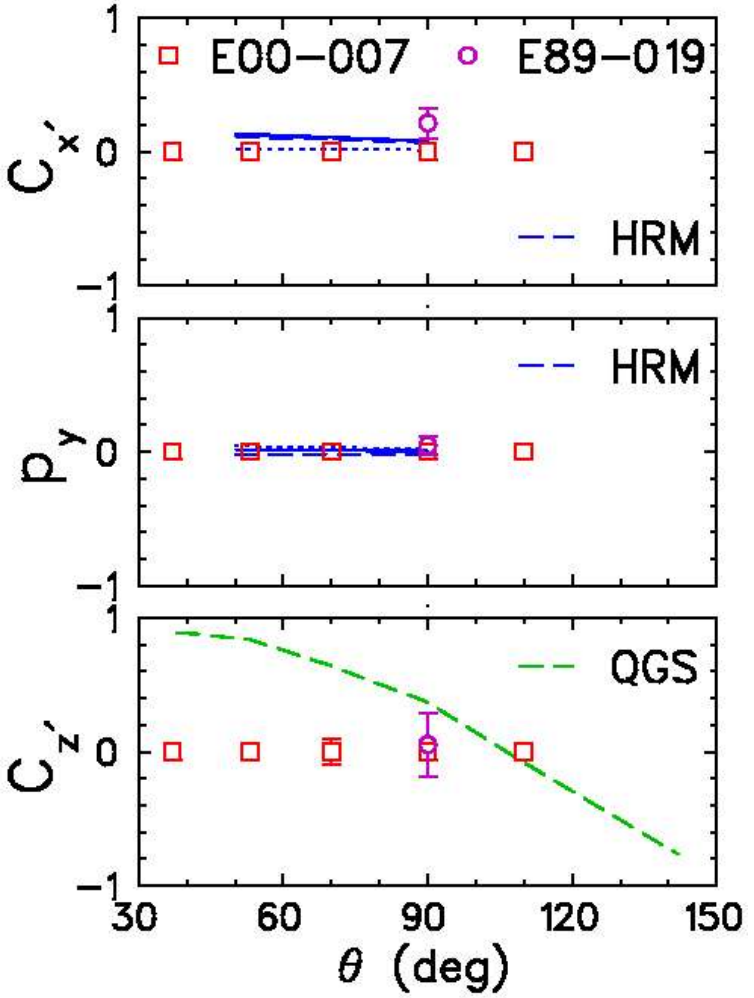
Shape Changes near 1 GeV



- Perhaps the hard physics is already there by ~1 GeV, over much of the angle range

New Hard Present: E00-007

- X. Jiang et al.
- Angular distributions at $E_\gamma \sim 2$ GeV
- VERY VERY preliminary:
  systematics not done,
  110° data not analyzed,
  absolute phases unclear,
  not corrected for P_e
- And the results are...



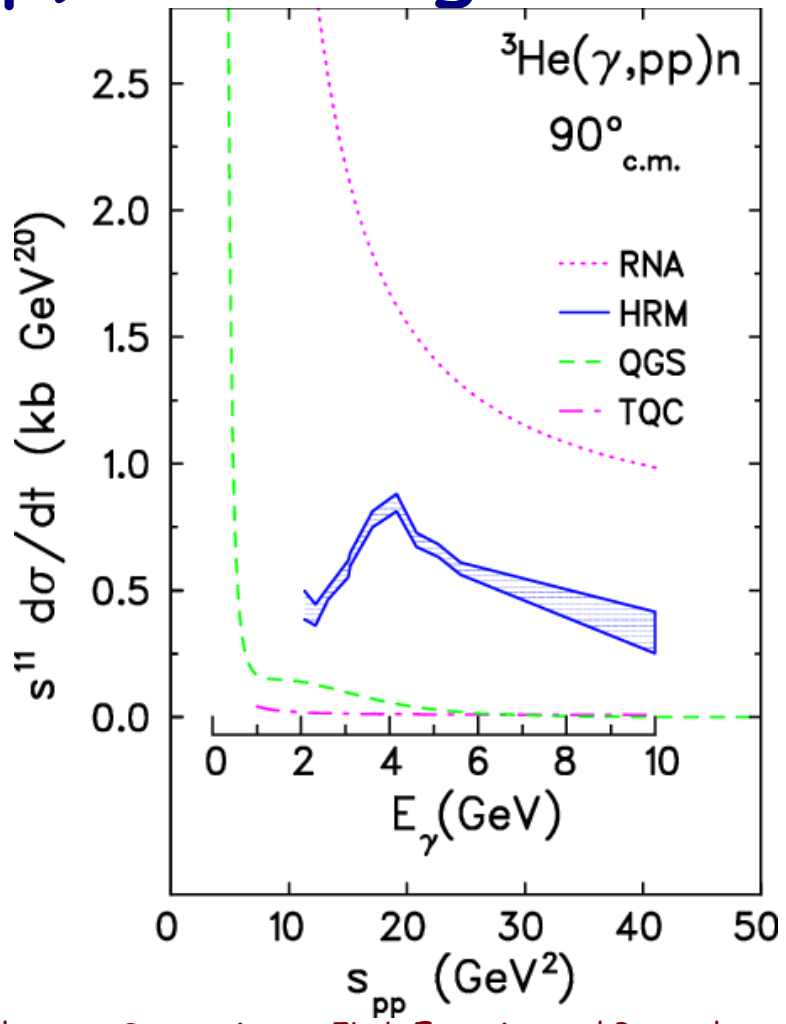
New Hard Present: E00-007

- And the VERY preliminary results are... 4 of 5 points
- Two analyzers agree
- $C_{x'}$ small
- $C_{z'}$, p_y large at forward angles
- Phases might change!

- Data figure too preliminary to post

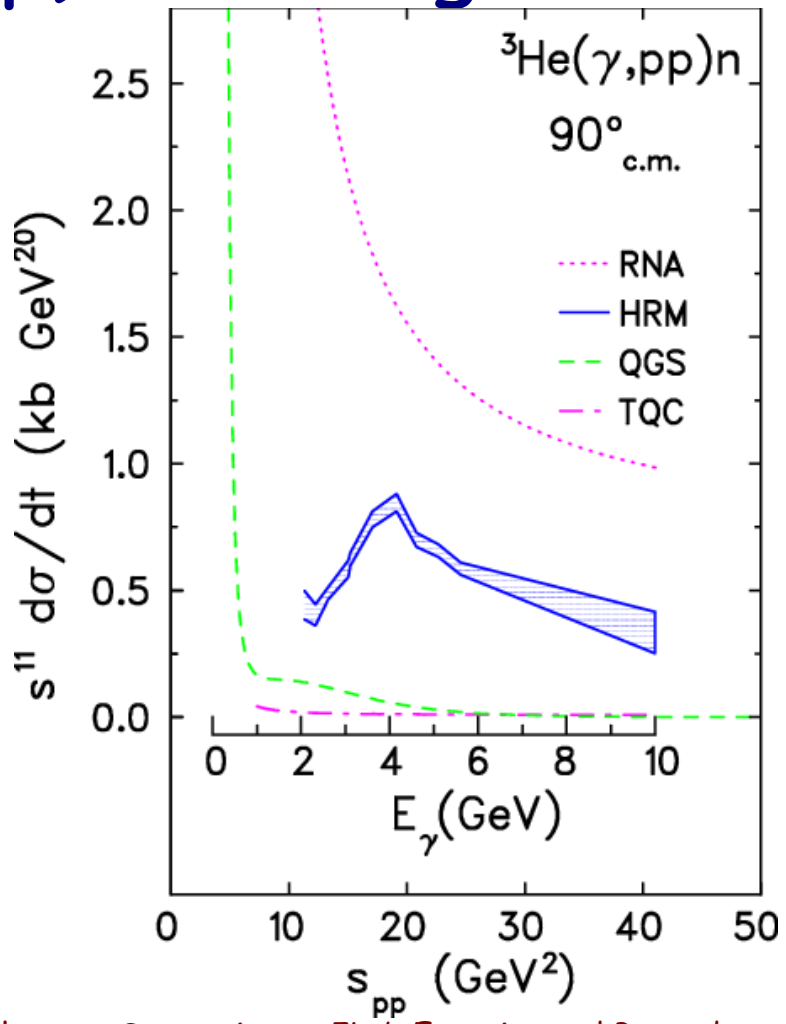
Hard Present: ^{3}He (pp) Disintegration

- Brodsky et al, PLB 578, 69 (2003)
- Ratio of pp to pn disintegration well determined in theory
- Large difference in relative predictions gives hope that we can identify dynamics



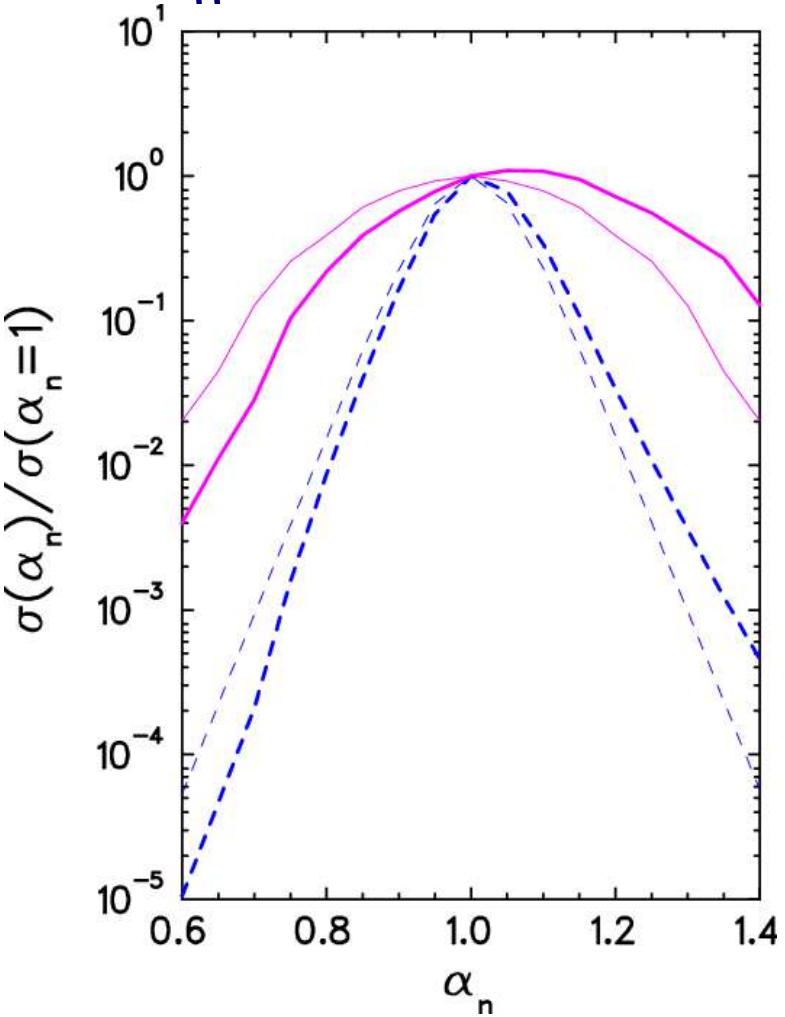
Hard Present: ^{3}He (pp) Disintegration

- At low energy, σ(γpp)/σ(γpn)~0.1 – pp dipole moment vanishes: JM Laget
- Quark models predict larger ratio
- Phase transition? Slow 2nd order or fast 1st order?



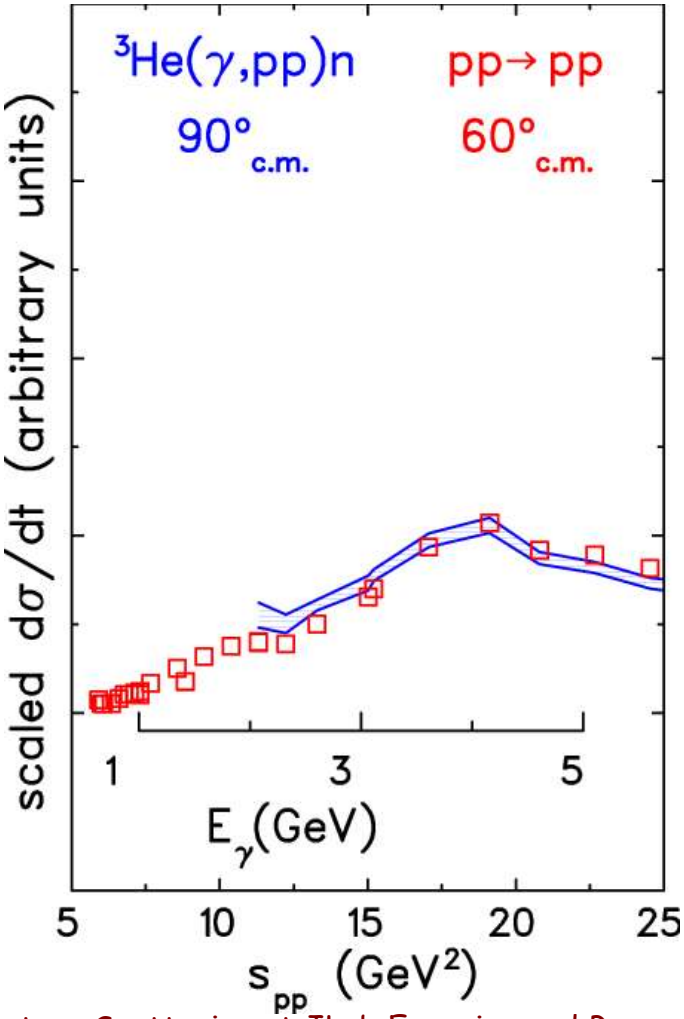
Hard Present: ^{3}He (pp) α_n Distribution

- Light cone momentum fraction is conserved: $\alpha_\gamma+\alpha_{He}=0+3=\alpha_{p1}+\alpha_{p2}+\alpha_n$
- FSI "do not" affect $\alpha = (E-p_z)/m$, so α_n reflects neutron spectator wave function
- RNA short range/broad, HRM long range/narrow



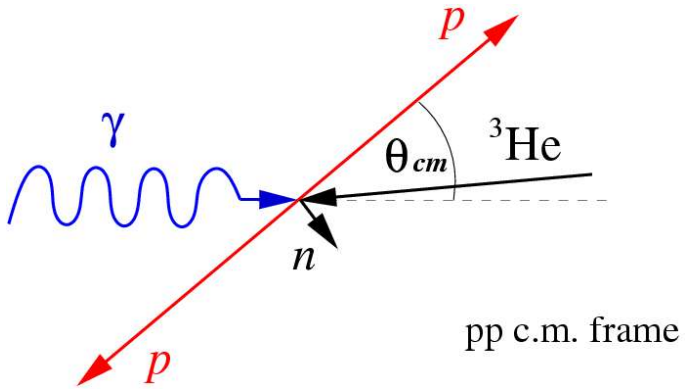
Hard Present: ^{3}He (pp) Oscillations

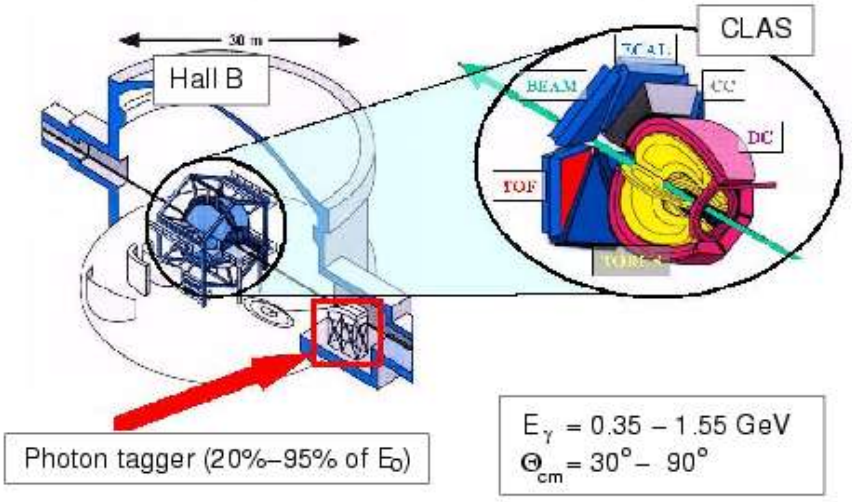
- Prominent oscillations in pp cross section, as opposed to flatter pn cross section, reflected in oscillations in γpp, as opposed to flatter energy dependence in γd?



New: ^{3}He(γ,pp)n Measured!

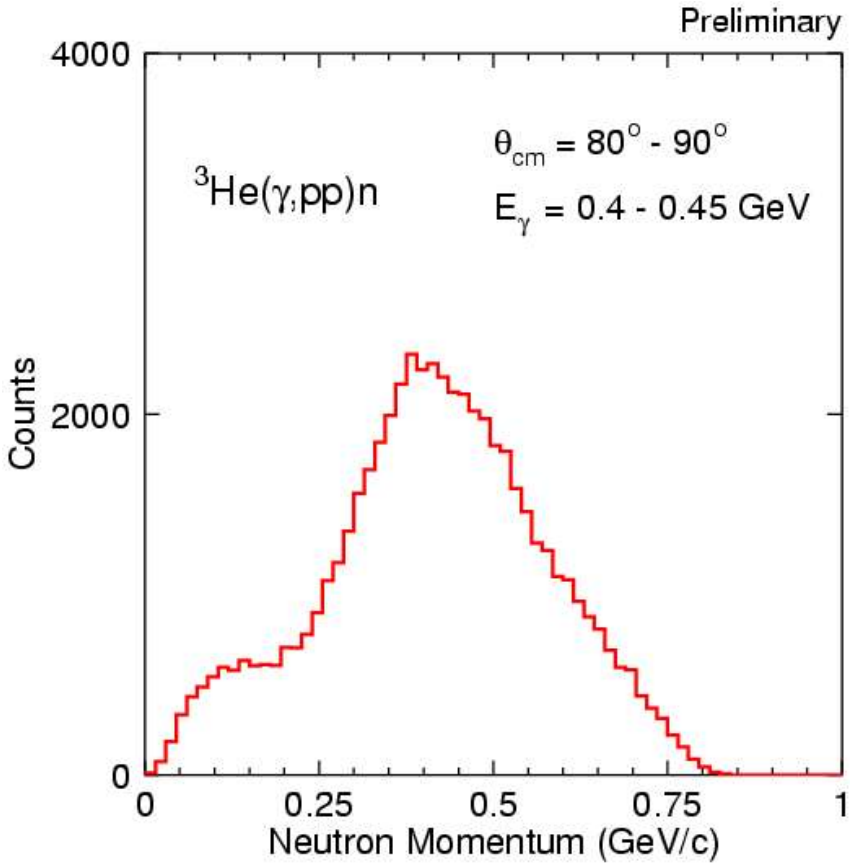
- Hall B experiment, analyzed by S. Strauch, GWU (now SC)
- VERY PRELIMINARY

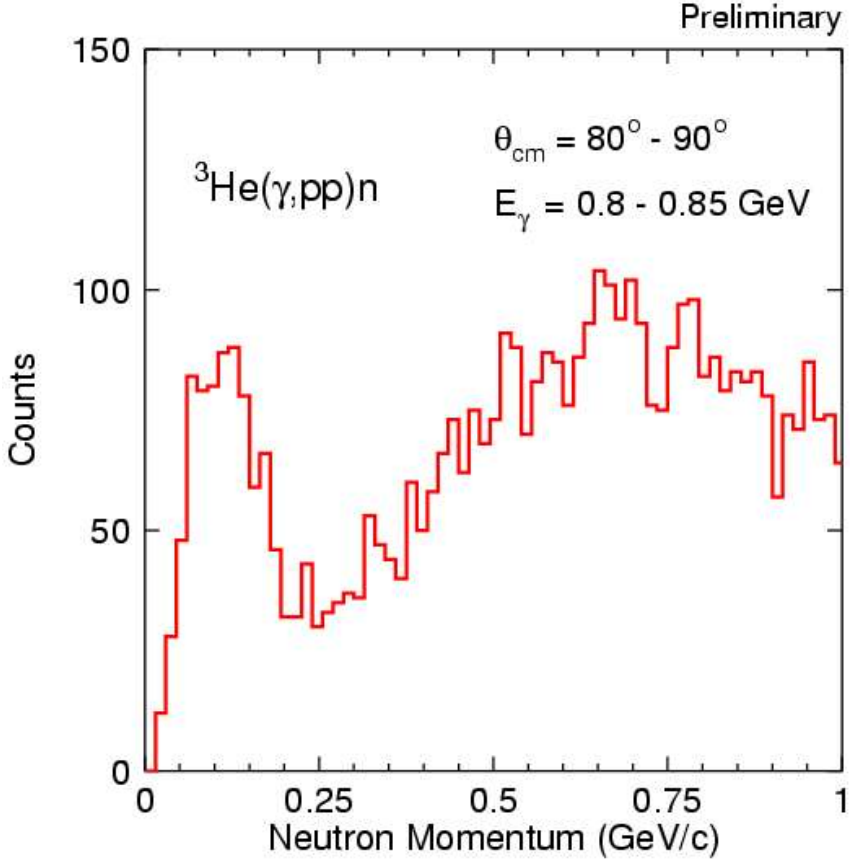




New: ^{3}He(γ,pp)n Neutron Spectator?

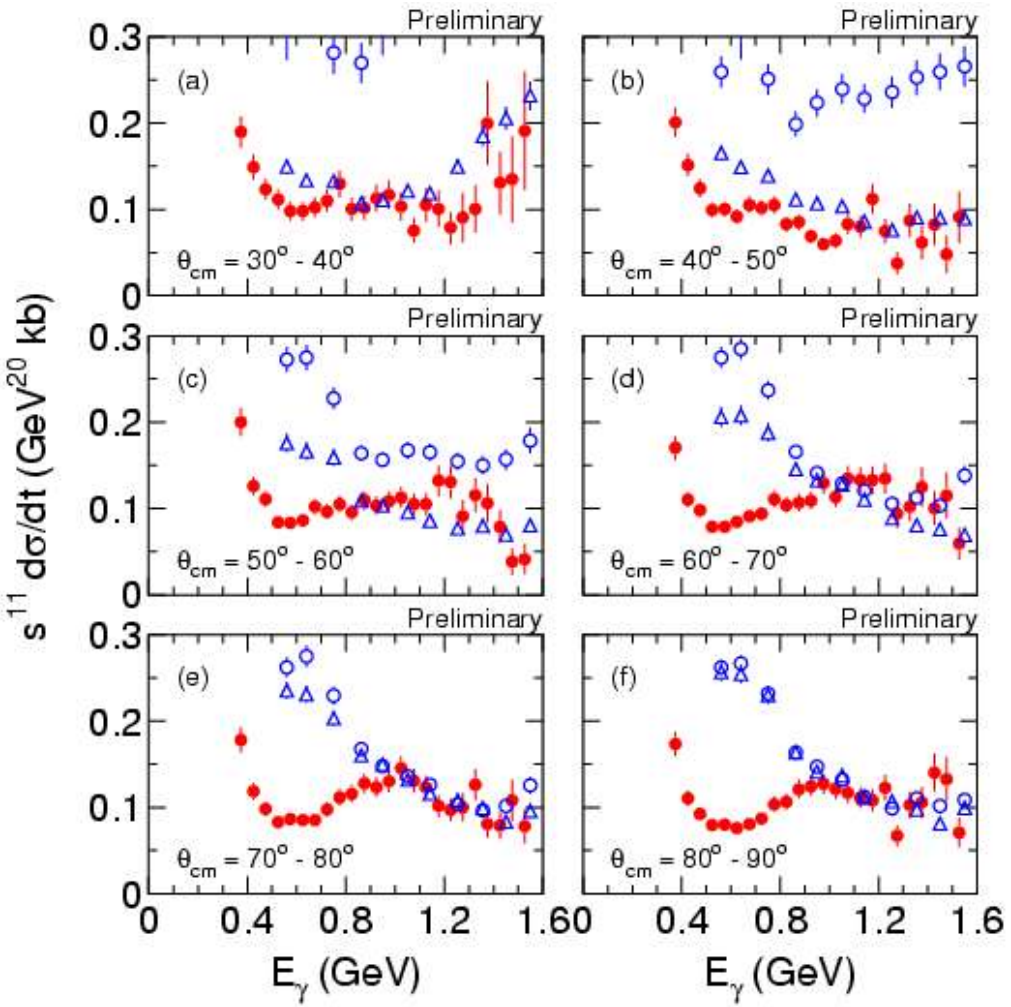
- Is the neutron a spectator? Cut at 0.1 – 0.25 GeV/c





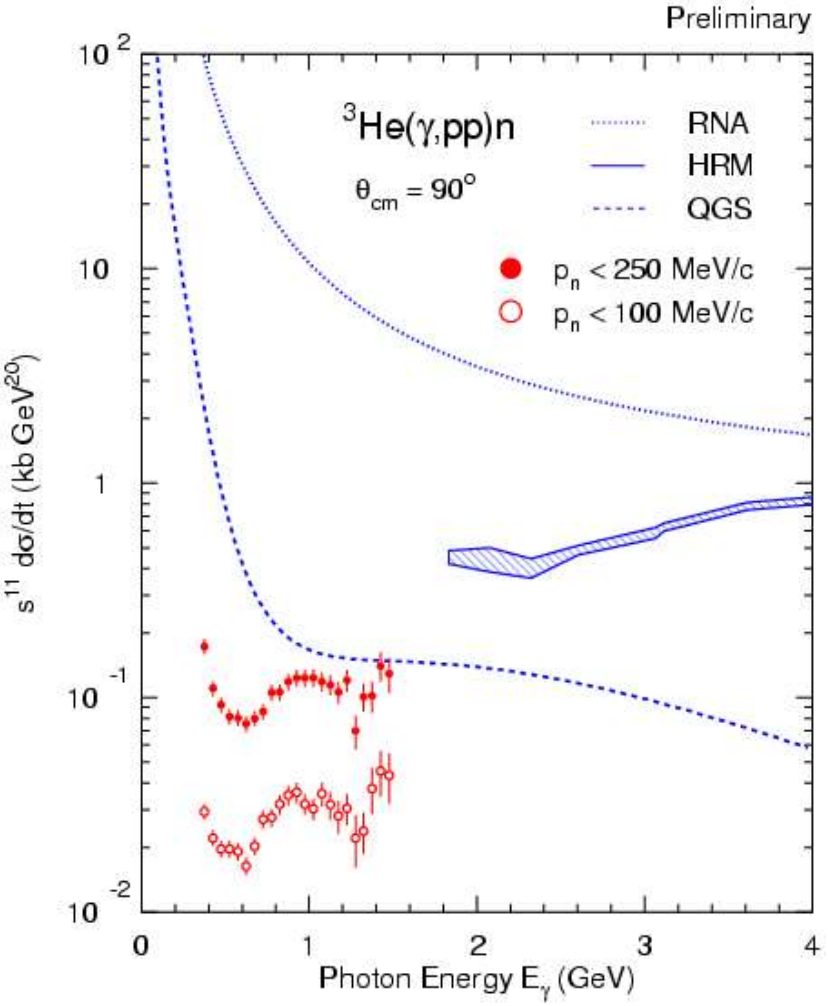
New: ^{3}He(γ,pp)n Cross Sections

- Red: "γpp->pp", symmetric about 90°
- Blue: γd->pn x $\frac{1}{4}$, asymmetric about 90°
- Cross sections for γpp like back-angle γd, near 1 GeV



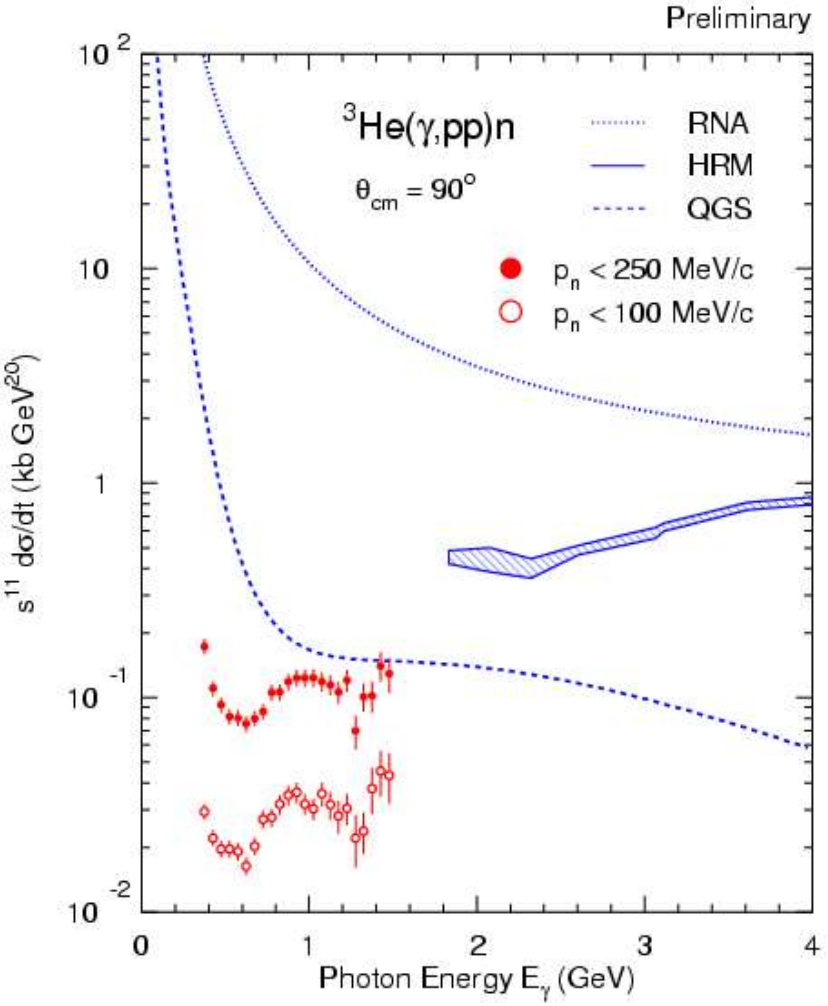
New: ^{3}He(γ,pp)n Cross Sections

- Theory done with 100 MeV/c cut
- Data small compared to γd, 10 – 25 % as large
- Hint of a phase transition starting at 1.4 GeV?



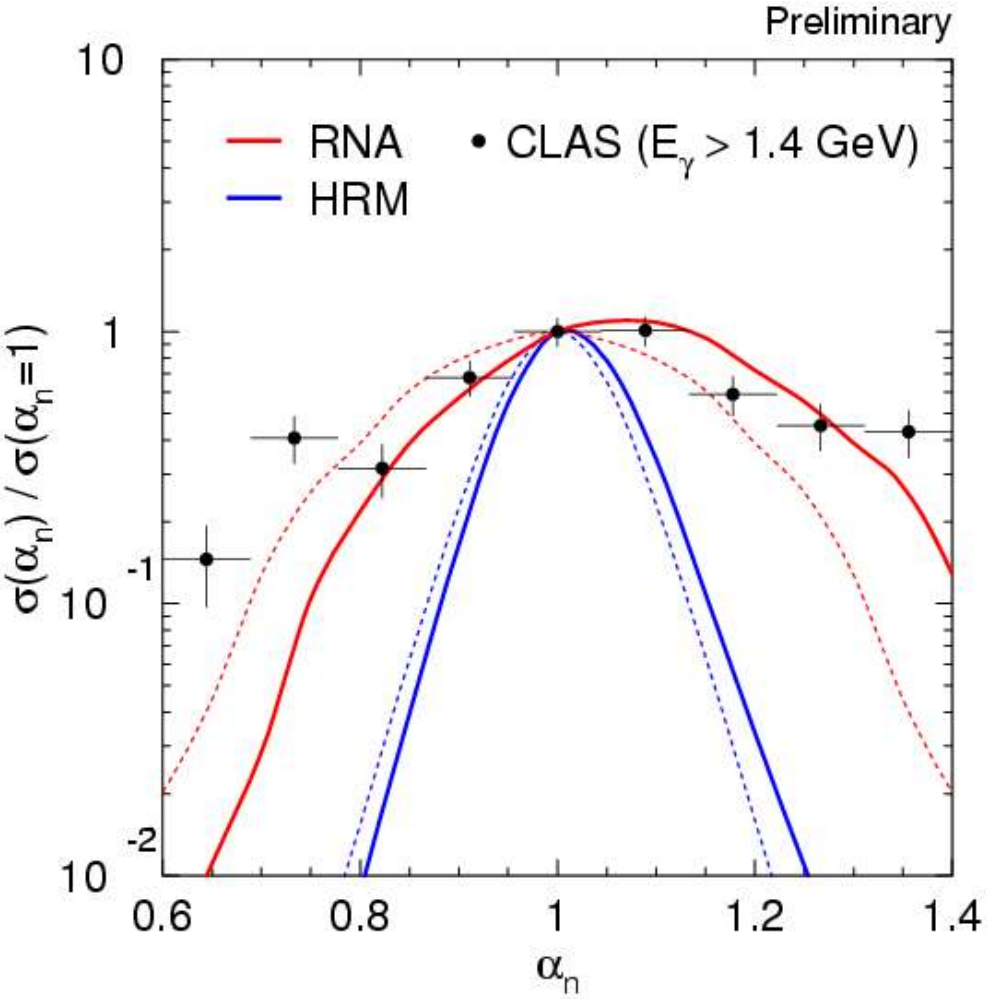
Cross Section Discussion

- Scaling of σ by E_γ ~ 1.3 GeV in γd, p_y vanished by ~ 1 GeV, $C_{x',z'}$ slowly vanishing?
- I told Steffen the transition would be complete by 1 or 1.3 GeV
- If I am right, is TQC right?



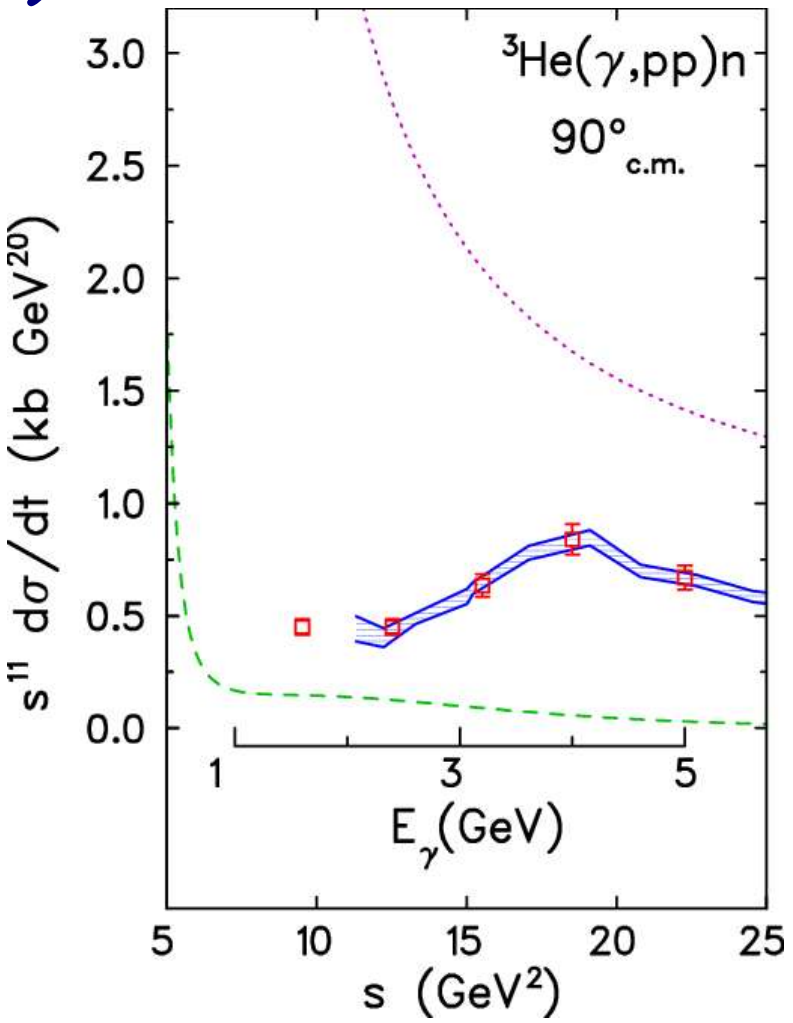
New: ^{3}He(γ,pp)n α_n Distribution

- Hard distribution from short-range physics? 1 GeV/c nucleons in c.m.
- Cross section too small for RNA, so if it continues to be small, TQC?
- More detailed α_n study underway



Future ^{3}He(γ,pp)n: Hall A E03-101

- Can cleanly distinguish 1/10, 1/4, ... x deuteron disintegration cross section vs "phase transition"
- Note: Hall B can ~match γd coverage, if needed in future



NN Disintegration Summary

- Future ~400 MeV data might help sort out the p_y problem
- Results coming out challenge theory
  - Hall B $d\sigma/d\Omega$
  - Hall A recoil polarization
  - Hall B γ^3He
- Future γ^3He data will help, a phase transition in the γ^3He would be very exciting
  - A follow up Hall B experiment with Σ asymmetry to map the transition?!
  - Or... rework existing theory?

Acknowledgements

- Thanks to A. Afanasev, B. Berman, F. Gross, K. Hicks, R. Holt, X. Jiang, L. Kondratyuk, K. McCormick, M. Mirazita, T. Nakano, E. Piasetzky, A. Radyushkin, F. Ronchetti, P. Rossi, A. Sandorfi, M. Sargsian, S. Strauch, W. Tornow, H. Weller, and K. Wijesooriya.
- Thanks to the organizers for the opportunity to give this talk.

- Additional recent theory references:
  Grishina *et al.*, nucl-th/0307032; Sargsian, to be published; Radyushkin, unpublished; Julia-Diaz and Lee, MPLA 18, 200 (2003), nucl-th/0210082; Brodsky and Hiller, PRC 28, 475 (1983).

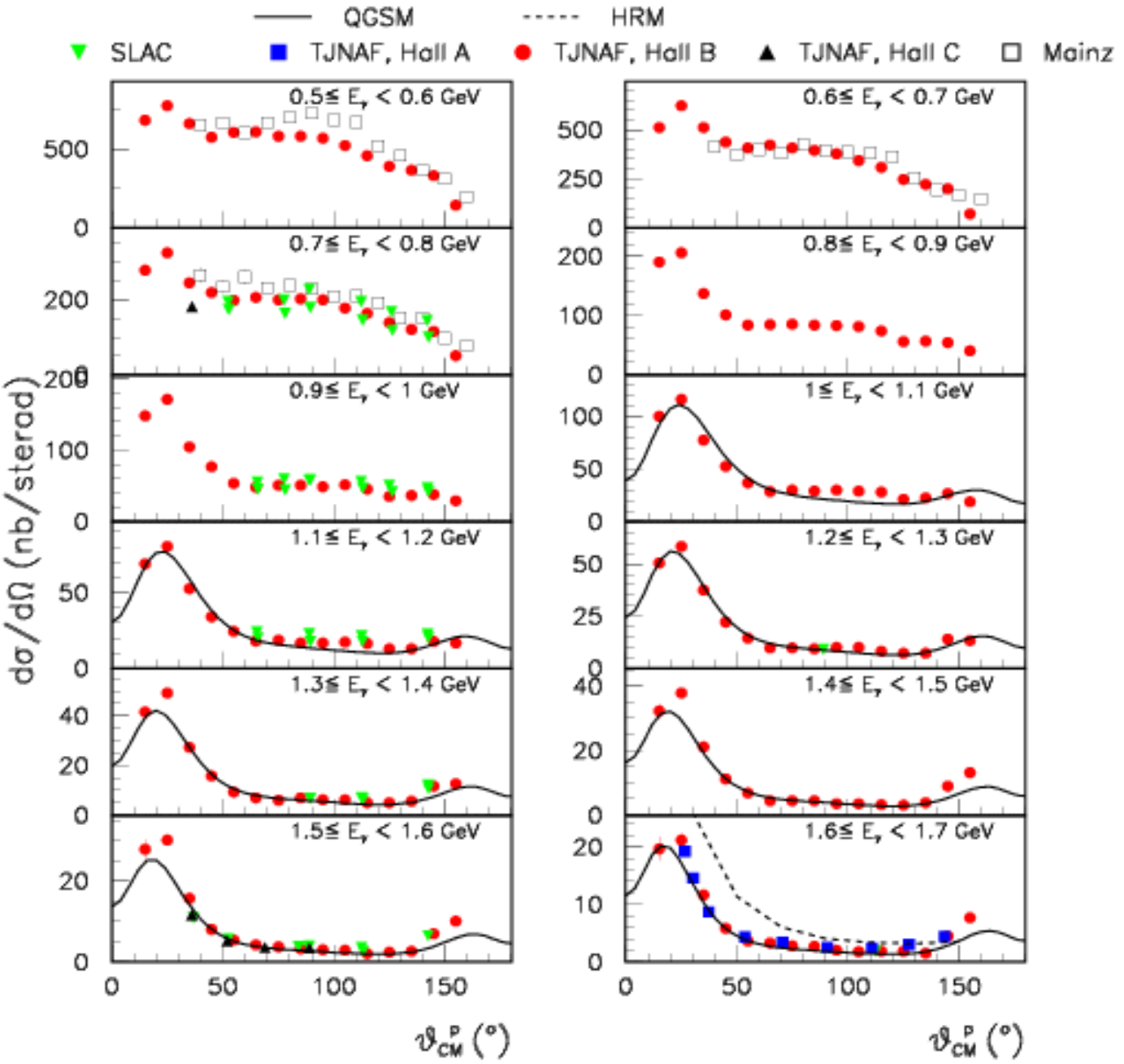
Recent Developments

- SLAC: σ, 800 – 2700 MeV
- Jefferson Lab Halls A, B, C: σ, $p_{y'}$, $C_{x'}$, and $C_{z'}$, 500 – 5500 MeV
- Yerevan: Σ, 800 – 1600 MeV
- Spring-8/LEPS: σ and Σ, 1500 – 2400 MeV
- 5 ``nonperturbative'' quark models developed

Hall B Angular Distributions

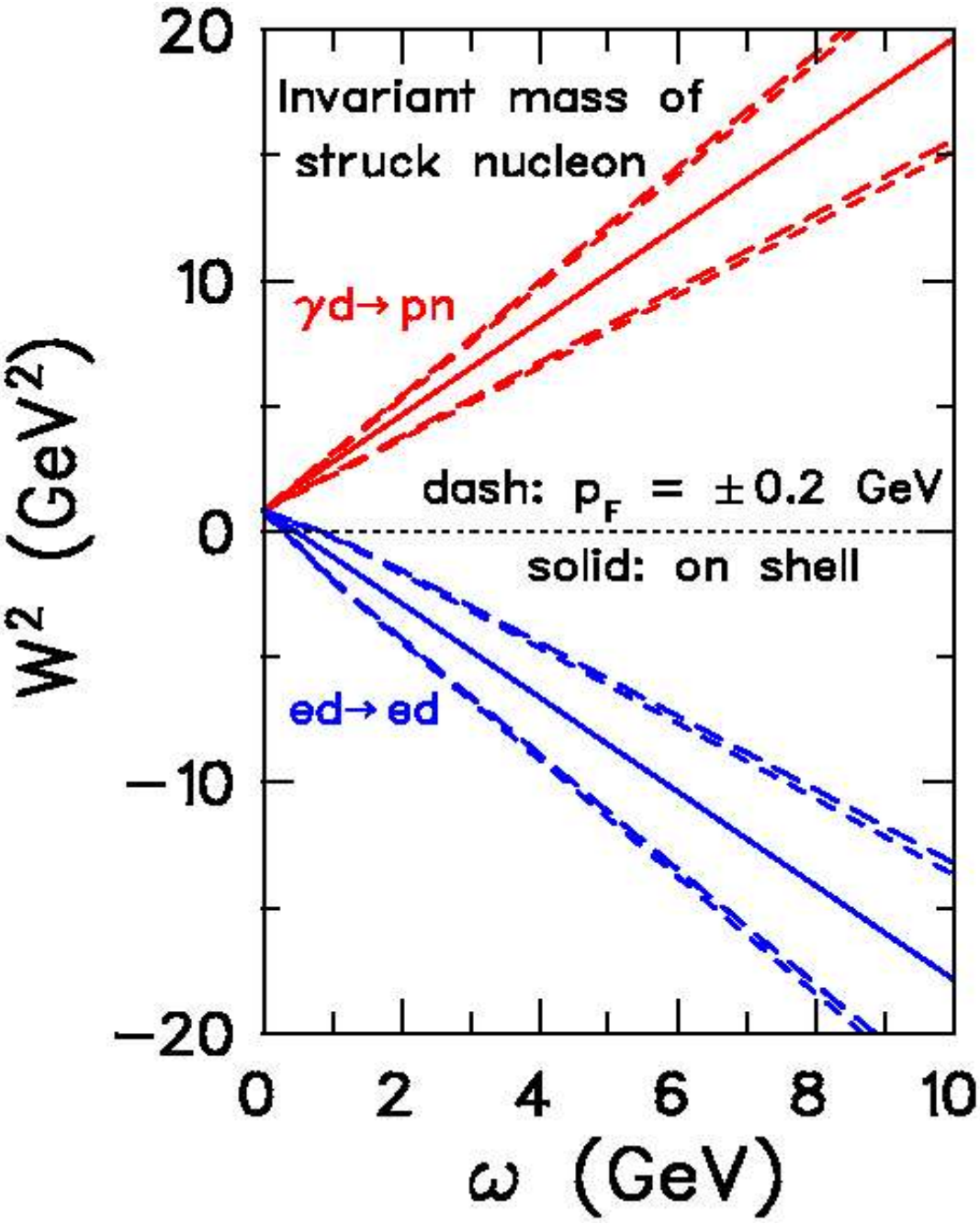
- There is a beautiful systematic set of complete angular distributions from Hall B CLAS, for E = 1-3 GeV –

  see (poster) Rossi *et al*., hep-ex/0302029, EPJA 17, 433 (2003), to be published.



ed vs. γd Kinematics

- The difference between *ed* and *γd* is emphasized by considering the γ to strike one nucleon.
- *γd*: $W^2 = 2\omega M_N + M_N^2$. Higher ω excites more resonances - average them with quarks.
- *ed*: $W^2 = 2\omega(M_N - M_d) + M_N^2$. Higher ω moves away from resonances



Spring-8/LEPS

- SPring-8/LEPS measured very forward-angle $d\sigma/d\omega$ and Σ, for 1.5 – 2.4 GeV, $\theta = 0 \rightarrow 45^{\circ}_{cm}$ - analysis is underway.
- It should be possible to determine whether there is a forward minimum or a forward maximum in the cross section.