Photodisintegration of the deuteron, and 3He

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- Introduction / Motivation
- The Past
- The Recent / Future Present
- The Future Perfect

Exclusive Reactions at High Momentum Transfer
Jefferson Lab May 21-24, 2007

Motivation / Introduction

- 2007 Long Range Plan: "We recommend completion of the 12 GeV Upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement."

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- Yes, both.

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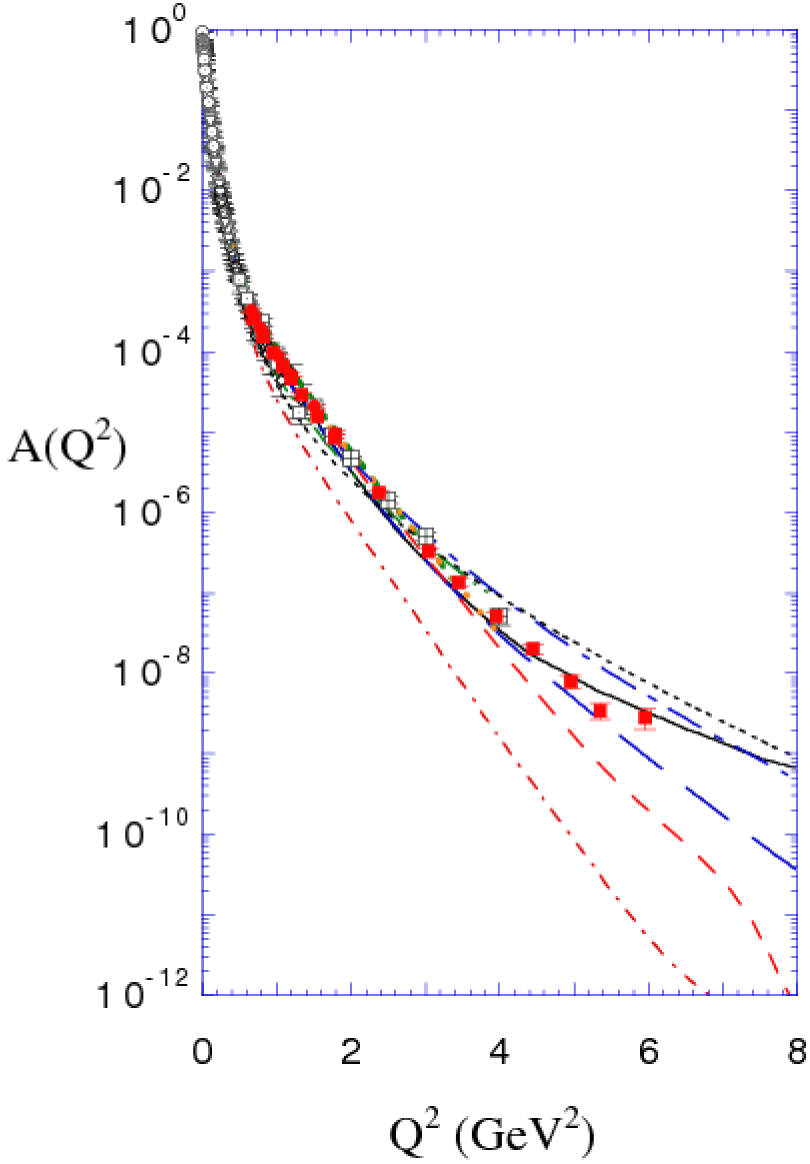
- Yes, both.
- The issue is under what conditions we are better off with a theory based hadrons vs. a theory based on quarks and gluons

Hadrons rule!

- Generally, exclusive reactions are well understood with hadronic theories based on the NN and photo-nucleon interactions, etc.:
  - A(e,e') elastic scattering
  - A(e,e'p) reactions, particularly quasifree kinematics
- Whatever the quark effects are, they appear to be effectively incorporated into the hadronic theory

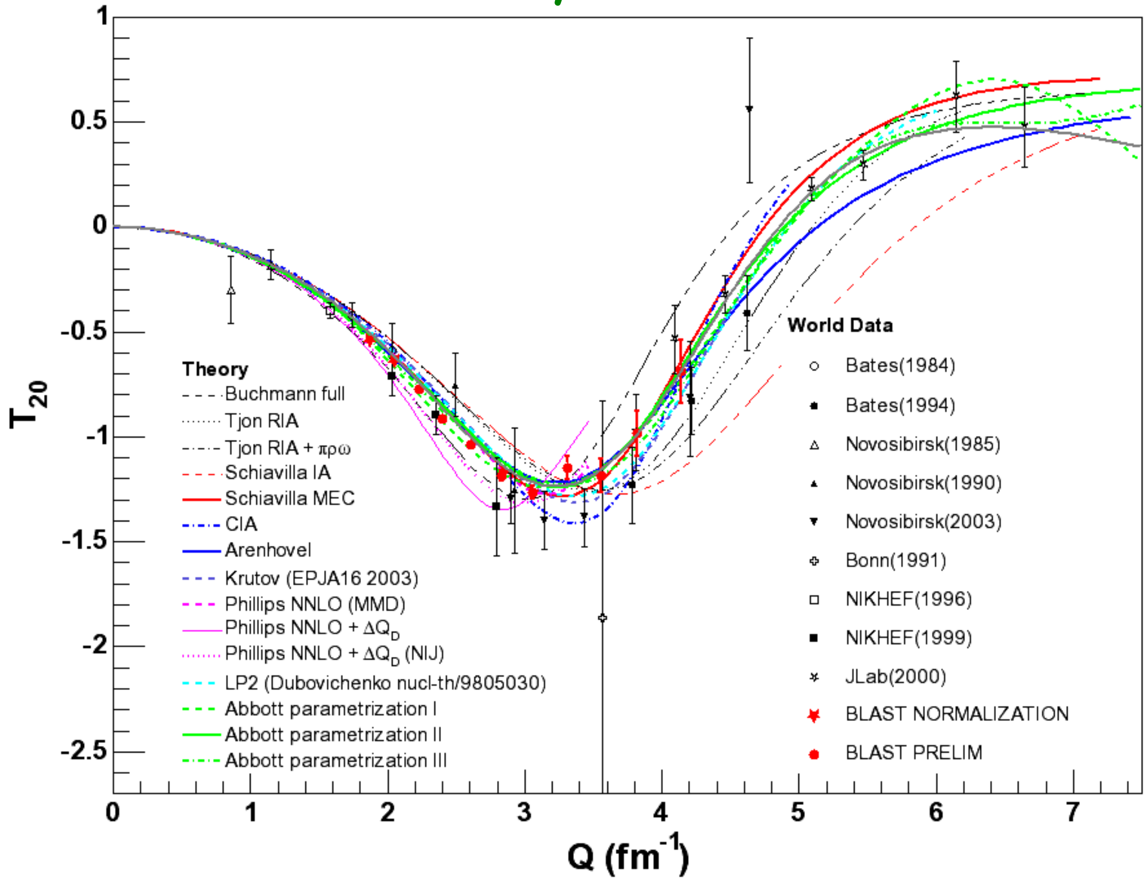
Hadrons rule!

- d(e,e')d elastic scattering described well as A(Q) falls > 8 orders of magnitude



Elastic ed T_{20} Data

- Improved low Q data were measured at Bates BLAST. (Figure from Tsentalovich, Nucleon05.) Data well described by several theories.



Quarks and gluons

- Some reactions are simply understood with quarks and gluons, or at least we have no good hadronic theory for them:
  - A(e,e') deep inelastic scattering
  - High Eγ photodisintegration reactions
- Both these reactions probe nuclei at high Q^2 (or -t) and high W

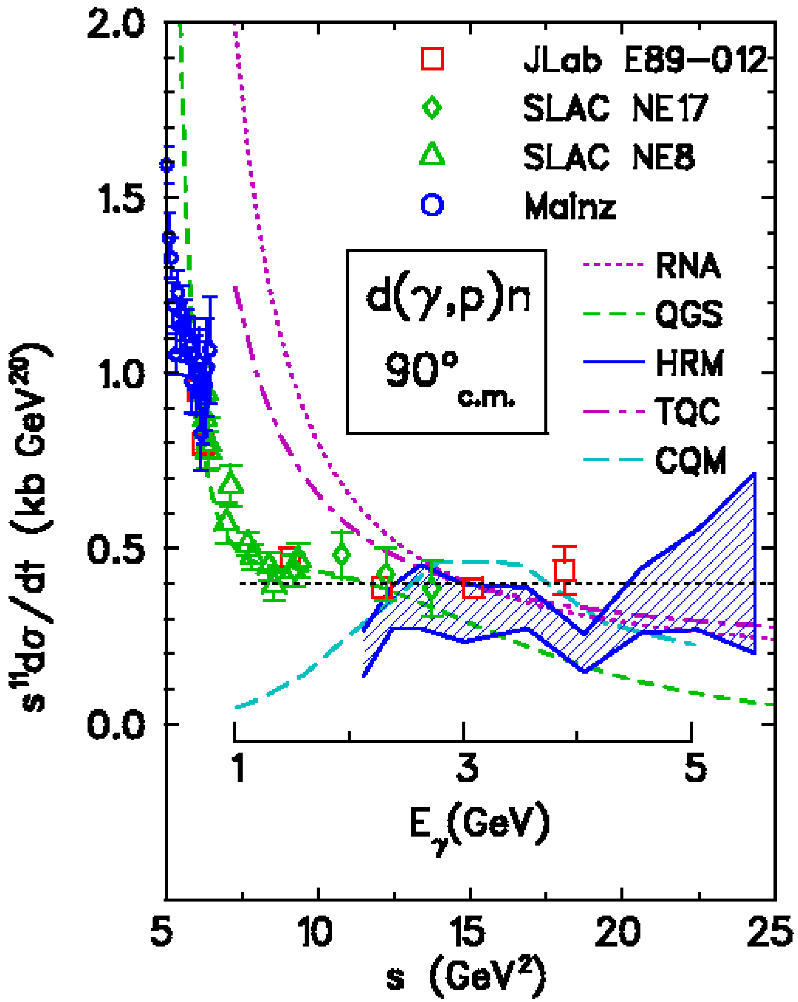
The Past

Hard Scattering Regime Experiments

- SLAC NE8, NE17
- JLab Hall C E89-012, E96-003
- Yerevan (Σ)
- JLab Hall A E89-019, E00-007 ($C_{x'}$, p_y, $C_{z'}$), E99-008
- JLab Hall B E93-017
- JLab Hall B: ^3He [S. Strauch]

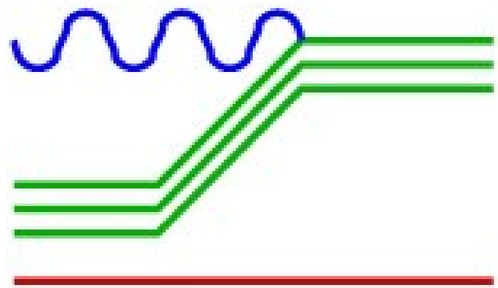
90° Excitation Functions

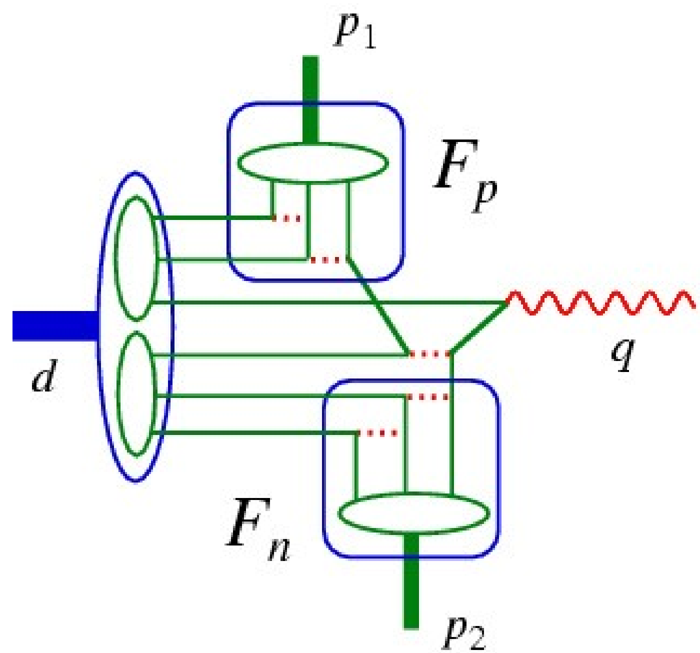
- Cross sections fall by a factor of 30,000 from 1 – 4 GeV, ~following ``expected'' quark scaling, $d\sigma/dt \sim s^{-11}$
- Hadronic theories not satisfactory and not shown
- Most quark models normalized



The Quark Models

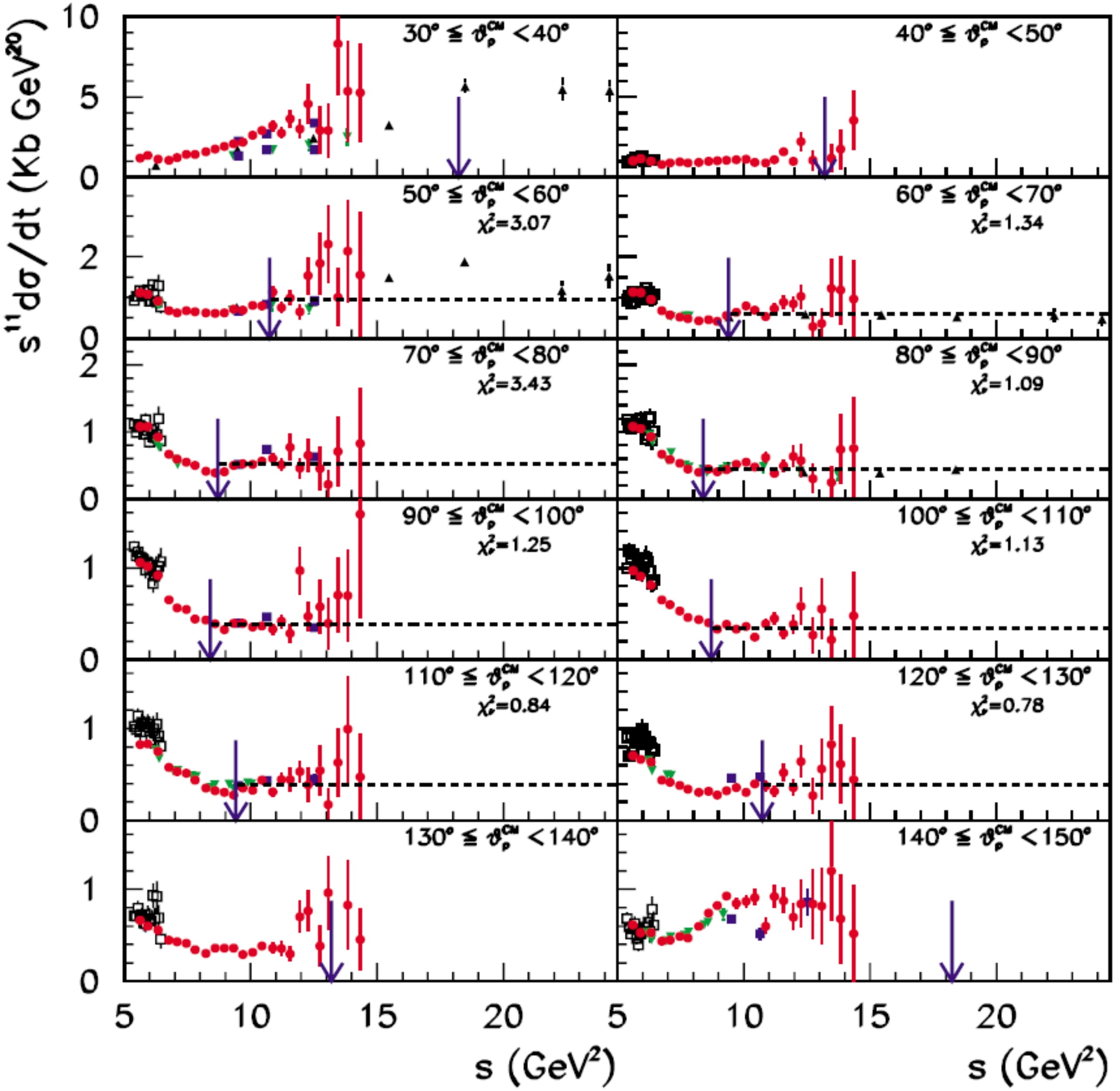
- QGS: Regge phenomenology to evaluate 3-quark exchange, justified by dominance of planar diagrams
- RNA, HRM, TQC, CQM: Photon absorbed and quarks exchanged; might be related to *NN* elastic scattering – all use hard scattering approximations





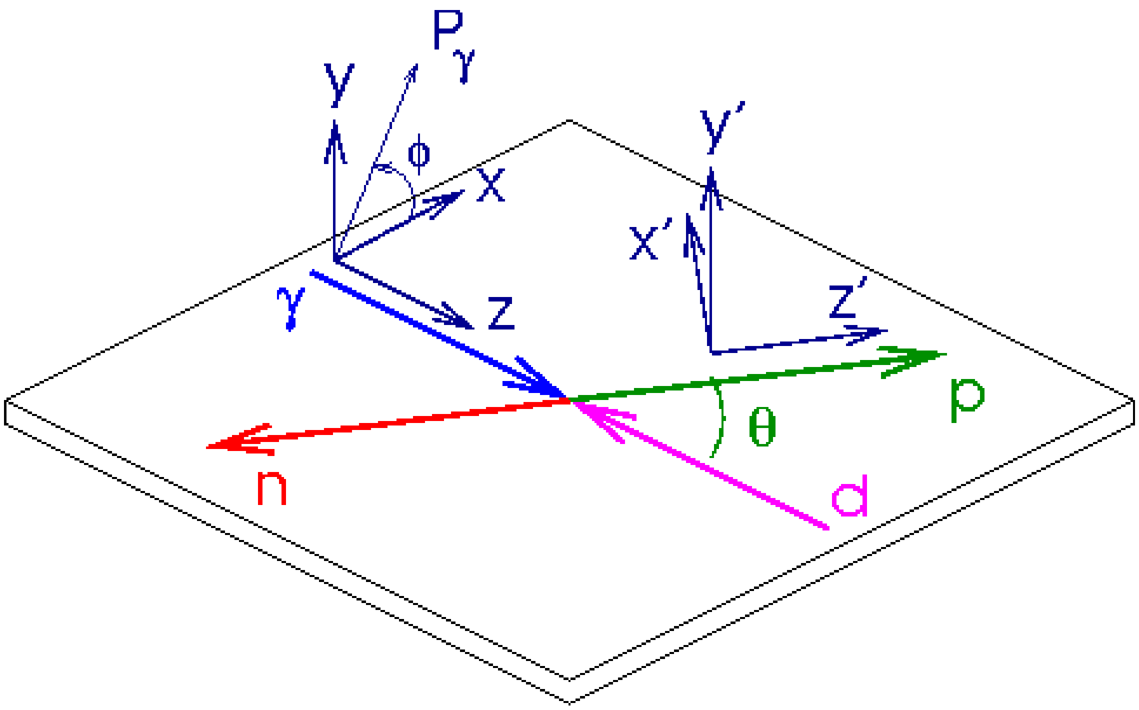
Onset of Scaling

- P. Rossi et al, PRL 94, 012301 (2005)
- Scaling needs $p_T > 1.1$ GeV/c



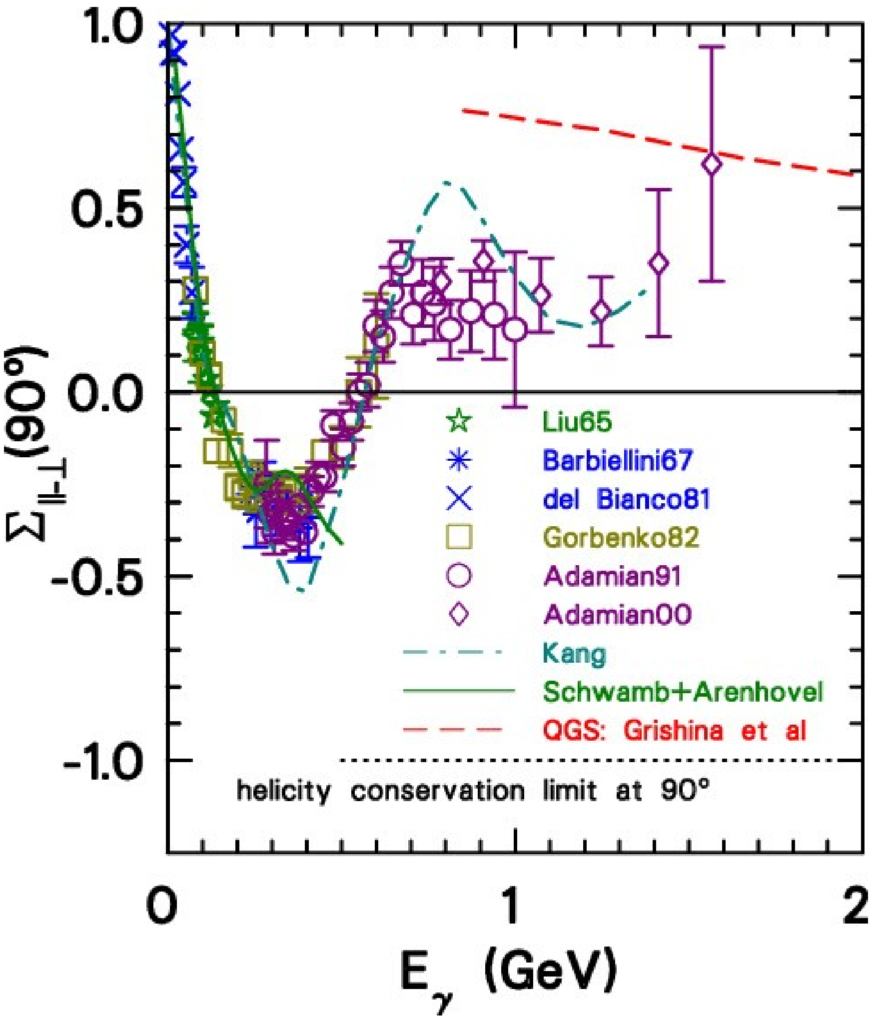
Some Observables in d(γ,p)n

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



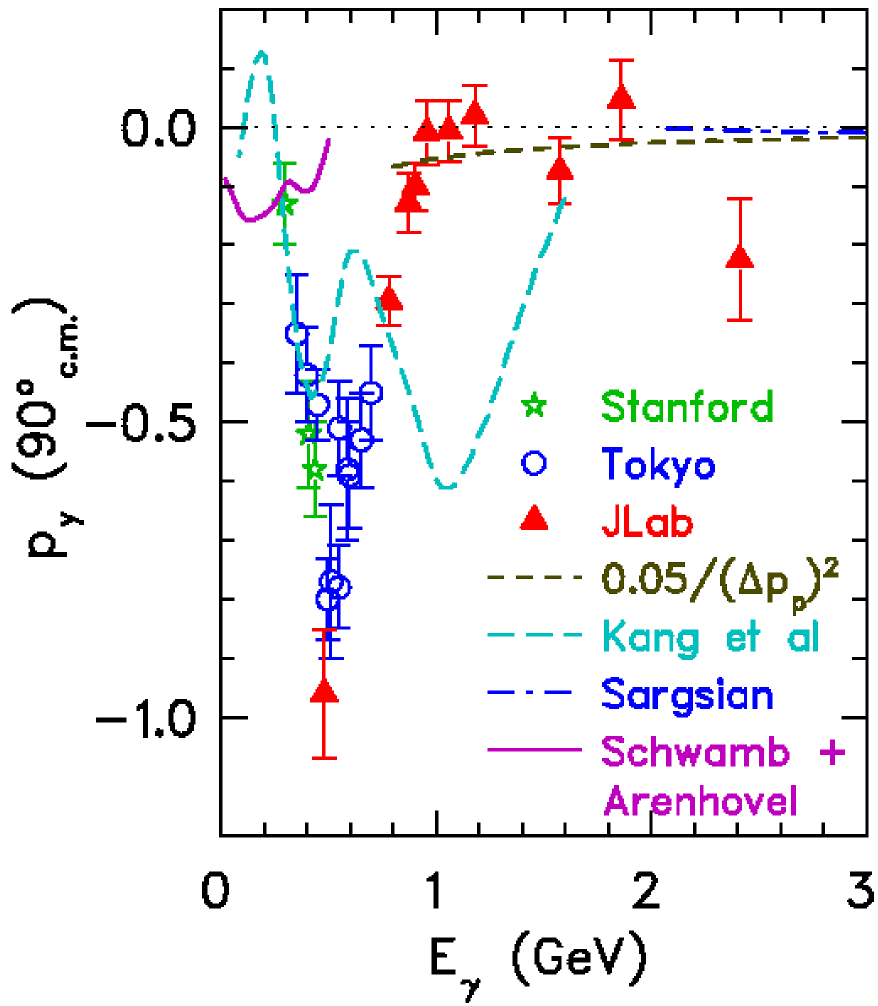
Σ Asymmetry

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



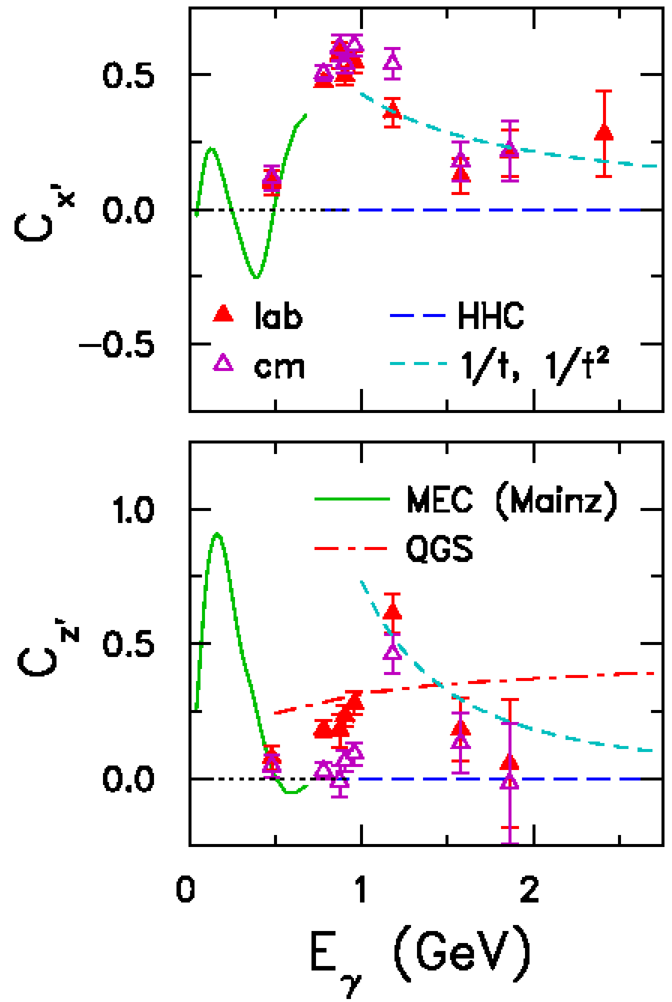
Induced Polarization p_y

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



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

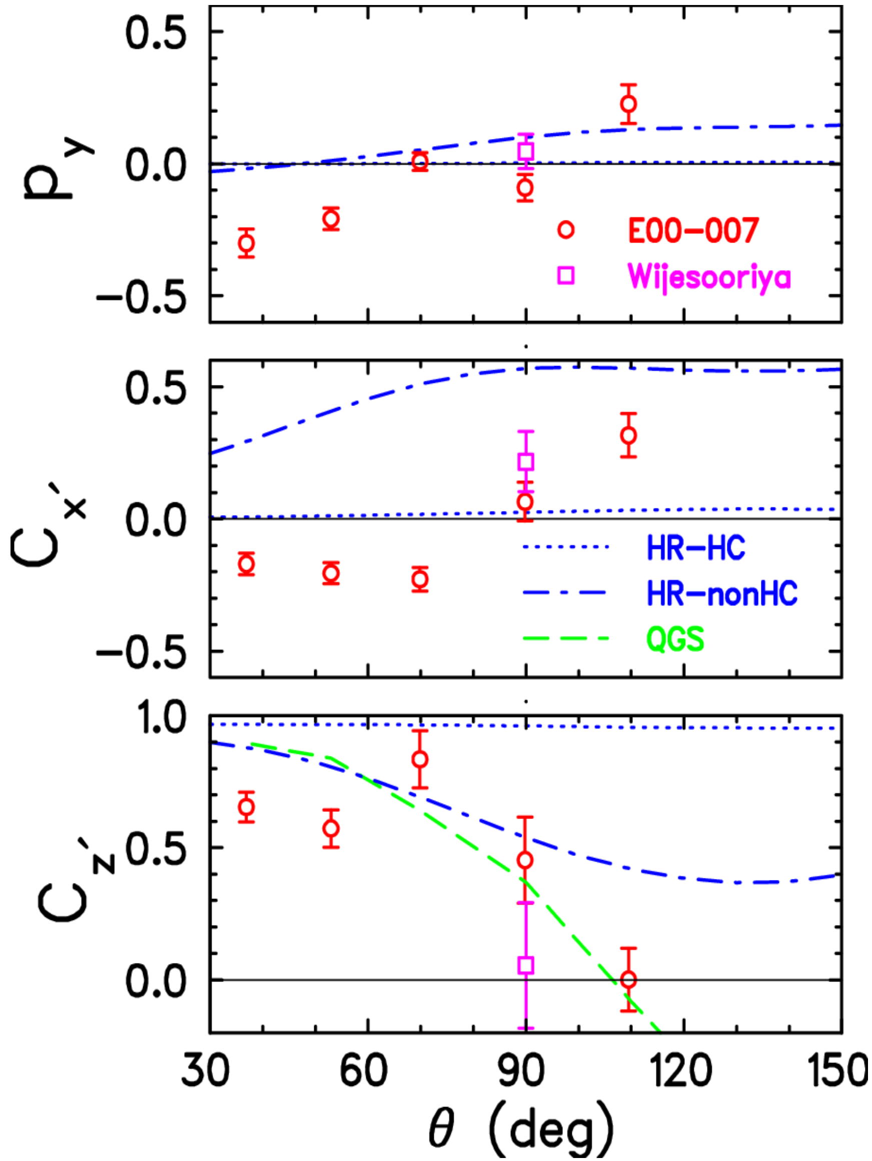


Recent / Future Present

- JLab E00-007: X Jiang et al., PRL 98, 182302 (2007)
  - Recoil polarization angular distribution at 2 GeV
- Novosibirsk t_{2i} data: I Rachek et al., PRL 98, 182303 (2007)
  - tensor polarizations up to ~600 MeV
- JLab E05-103: J Glister et al.
  - Ran July-Sep 2006
  - Angular distribution for recoil polarizations from 280 – 360 MeV
- JLab Hall B $^3He(\gamma,pp)n$: S. Strauch et al. preliminary data, and Brodsky et al. theory article

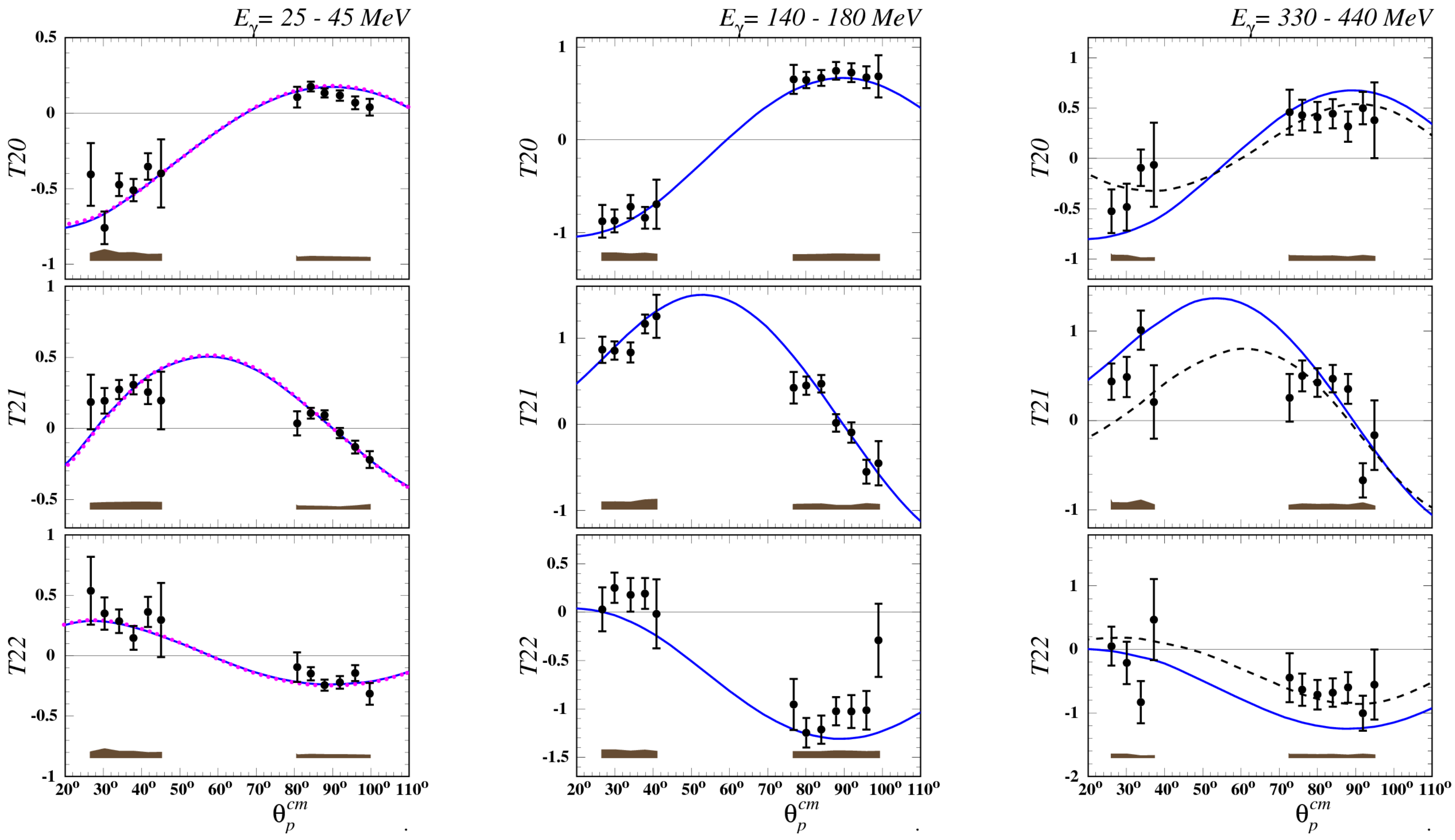
Hall A E00-007: X Jiang et al.

- $E_\gamma \sim 2$ GeV
- $C_{z'}$ large at forward angles, like QGS + HR
- $C_{x'}$ and p_y cross 0 near 90°: in HR, if isovector photon dominance, these ≈ φ_5, which vanishes at 90°
- Perhaps similar to Σ?



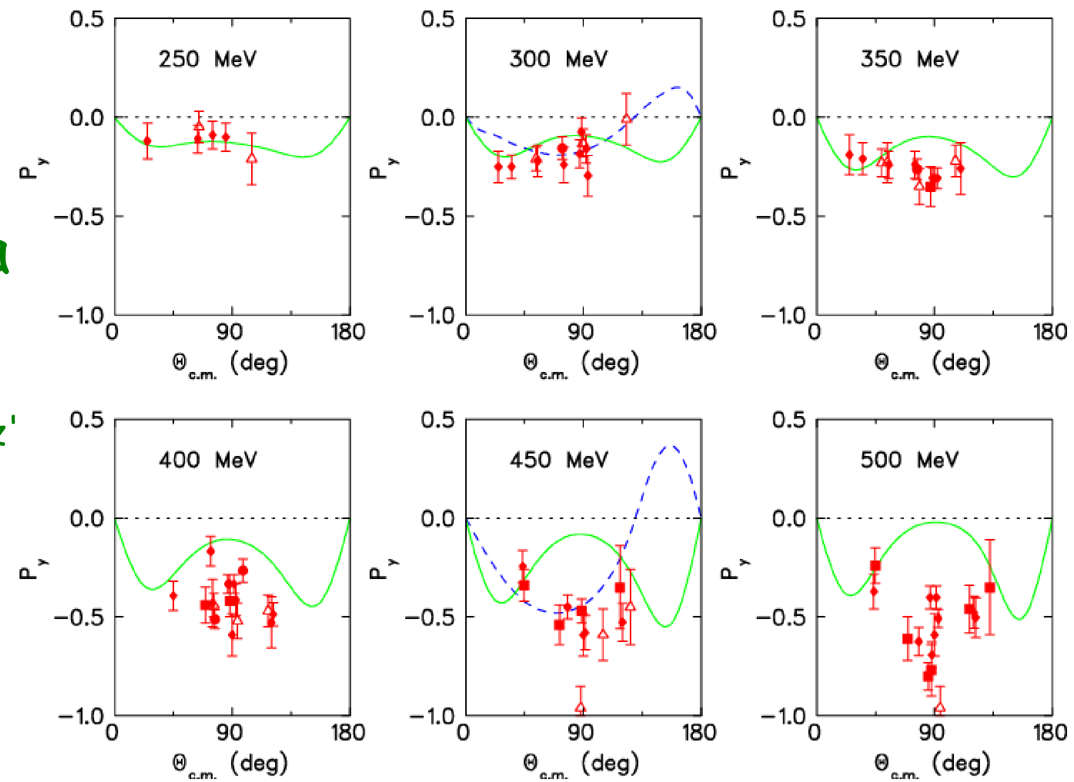
Novosibirsk t_{2i}

- I Rachek et al., PRL 98, 182303 (2007)
- Calculations from Levchuk, Arenhovel, Schwamb



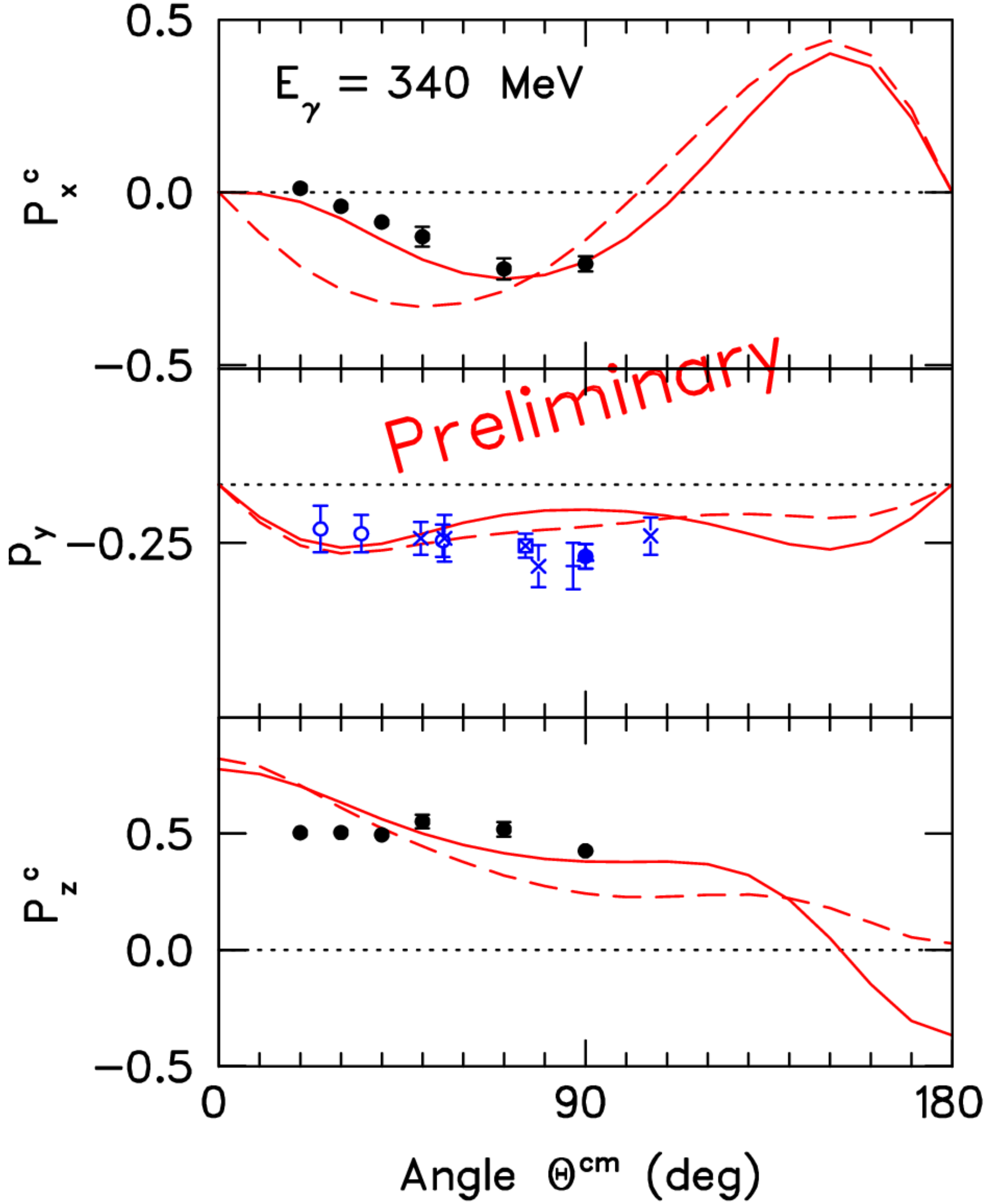
Hall A E05-103: J Glister et al.

- $E_\gamma \sim 280 - 360$ MeV
- Map out region in which calculations diverge from p_y data
- Determine $C_{x'}$ and $C_{z'}$ to further test breakdown
- Note that cross sections, Σ, ... are okay here



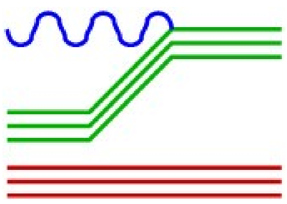
Hall A E05-103: J Glister et al.

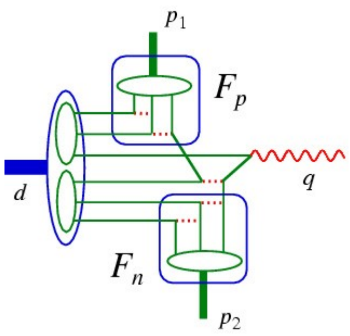
- Near on-line preliminary results
- Calculations from Schwamb: original (solid) and latest (dash)
- Data from 20-110°, 280-360 MeV

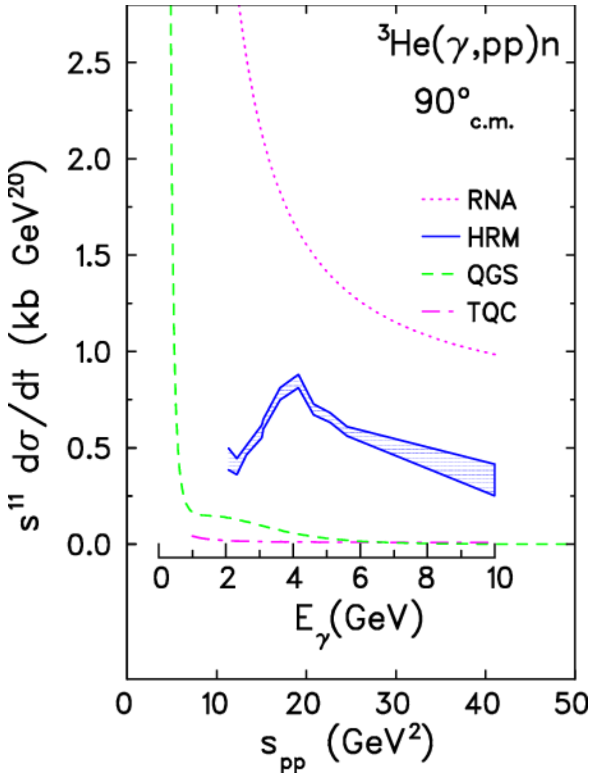


^{3}He (pp) Disintegration

- Brodsky et al, PLB 578, 69 (2003): ratio of pp to pn well determined in theory
- At low energy, σ(γpp) / σ(γpn) ~ 0.1: pp dipole moment vanishes: JM Laget
- Quark models predict larger ratio: slow 2nd order or fast 1st order phase transition?

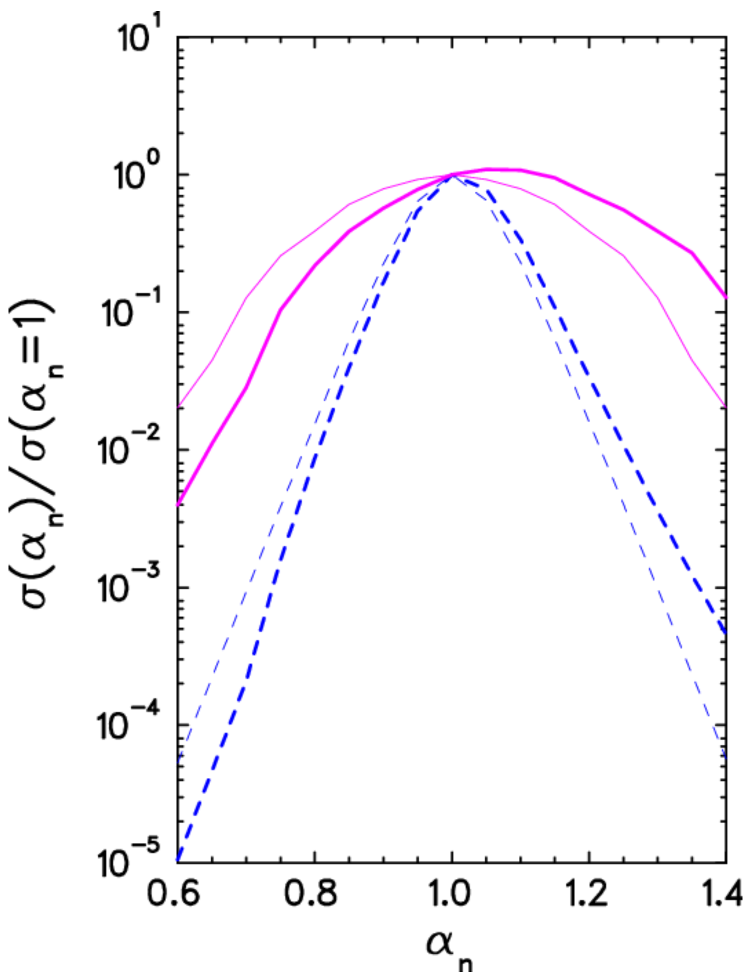






^{3}He (pp) α_n Distribution

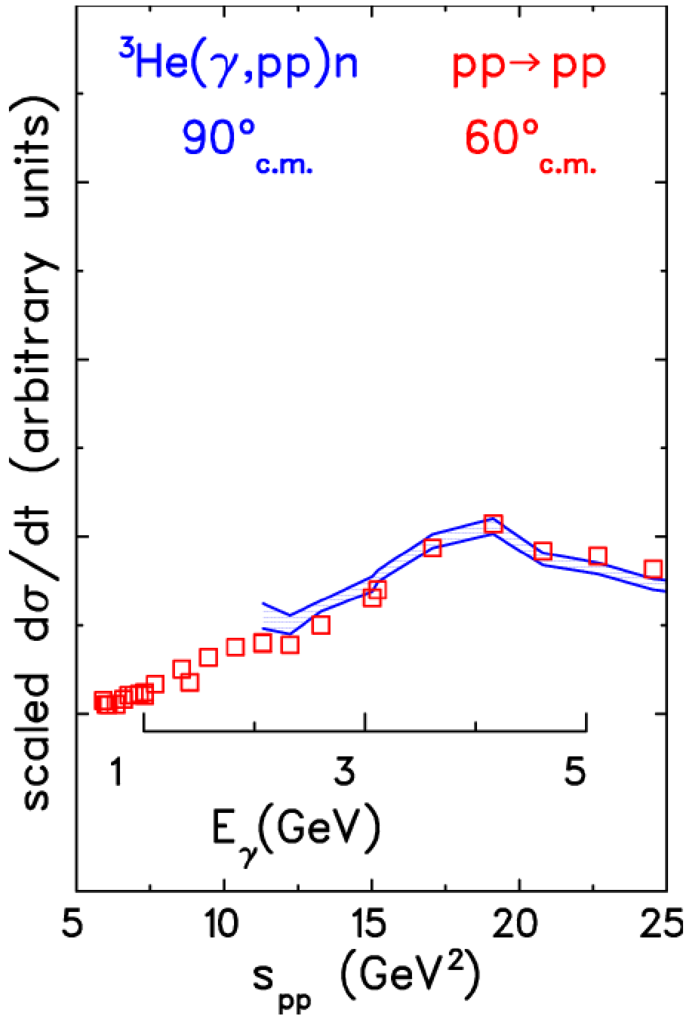
- Light cone momentum fraction, $\alpha = (E-p_z)/m$, is conserved: $\alpha_\gamma+\alpha_{He}=0+3=\alpha_{p1}+\alpha_{p2}+\alpha_n$
- Soft FSI "do not" affect α, so α_n reflects neutron spectator wave function



- RNA short range/broad, HRM long range/narrow
- Model-independent check of long vs short range dynamics

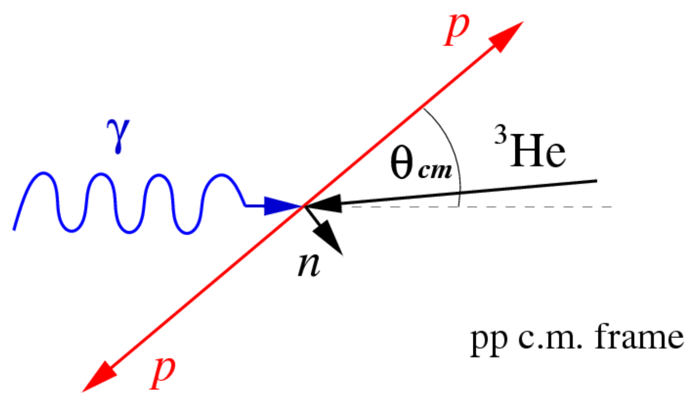
^3He (pp) Oscillations

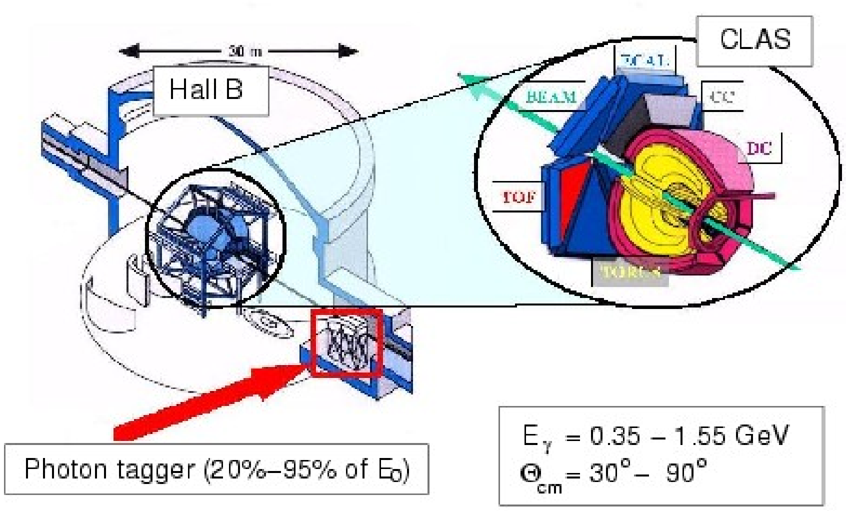
- Prominent oscillations in pp cross section, as opposed to flatter pn cross section, reflected in oscillations in γpp, as opposed to flatter energy dependence in γd?
- To match s and t, compare 60° pp to 90° γpp



$^3He(\gamma,pp)n$ Measured!

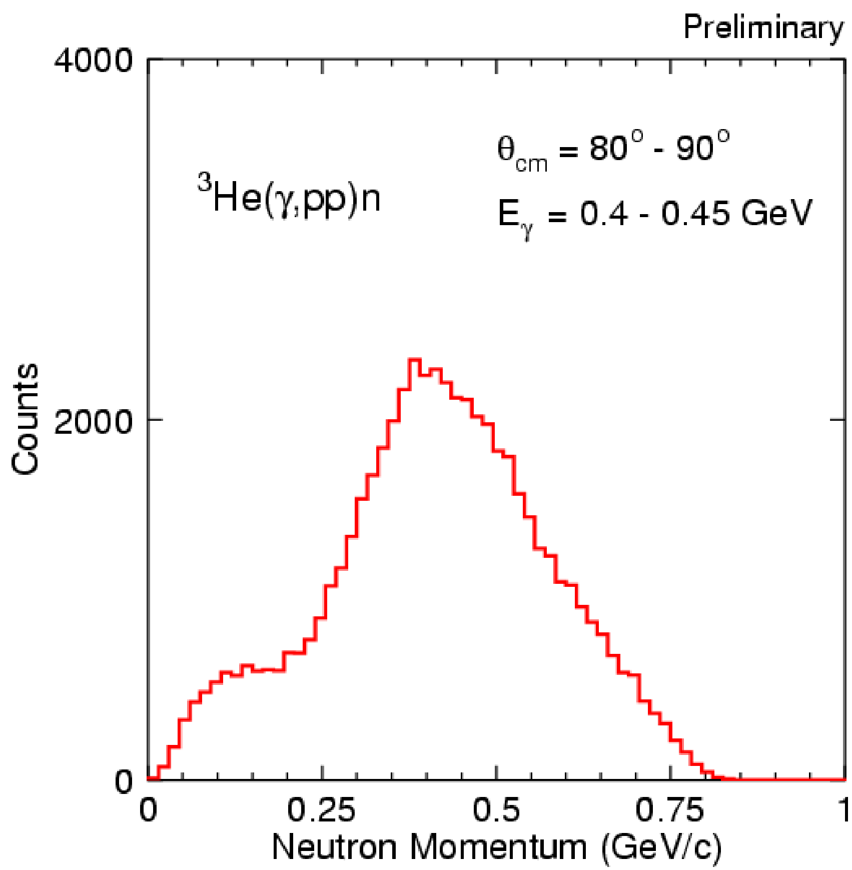
- Hall B experiment, analyzed by S. Strauch, GWU (now SC)
- PRELIMINARY

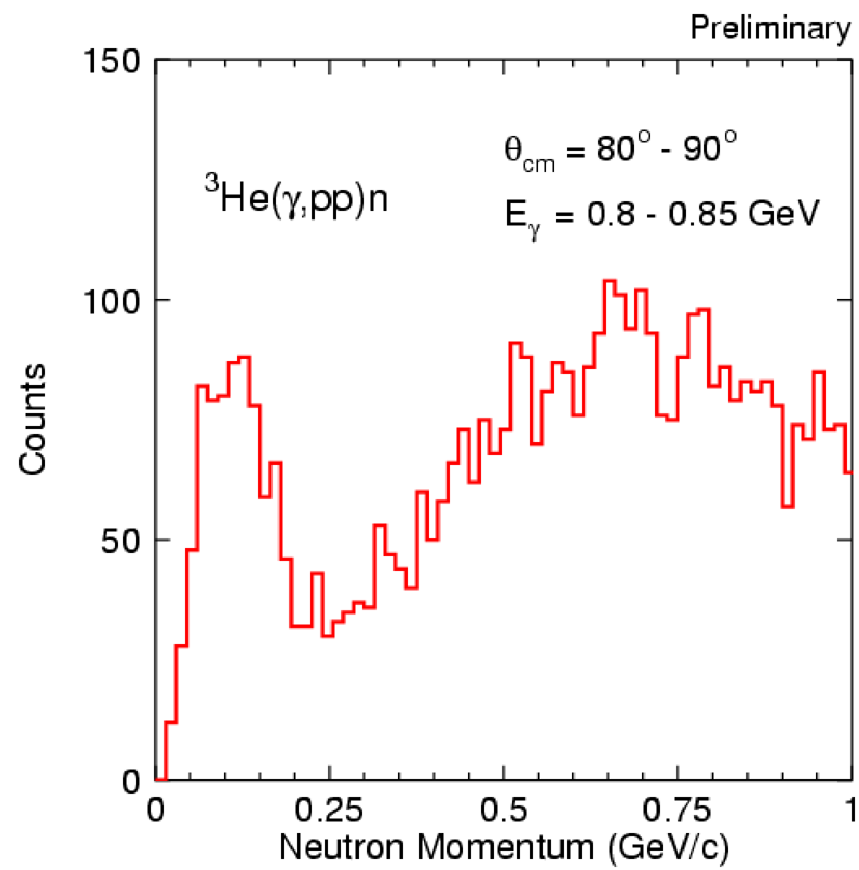




$^3He(\gamma,pp)n$ Neutron Spectator?

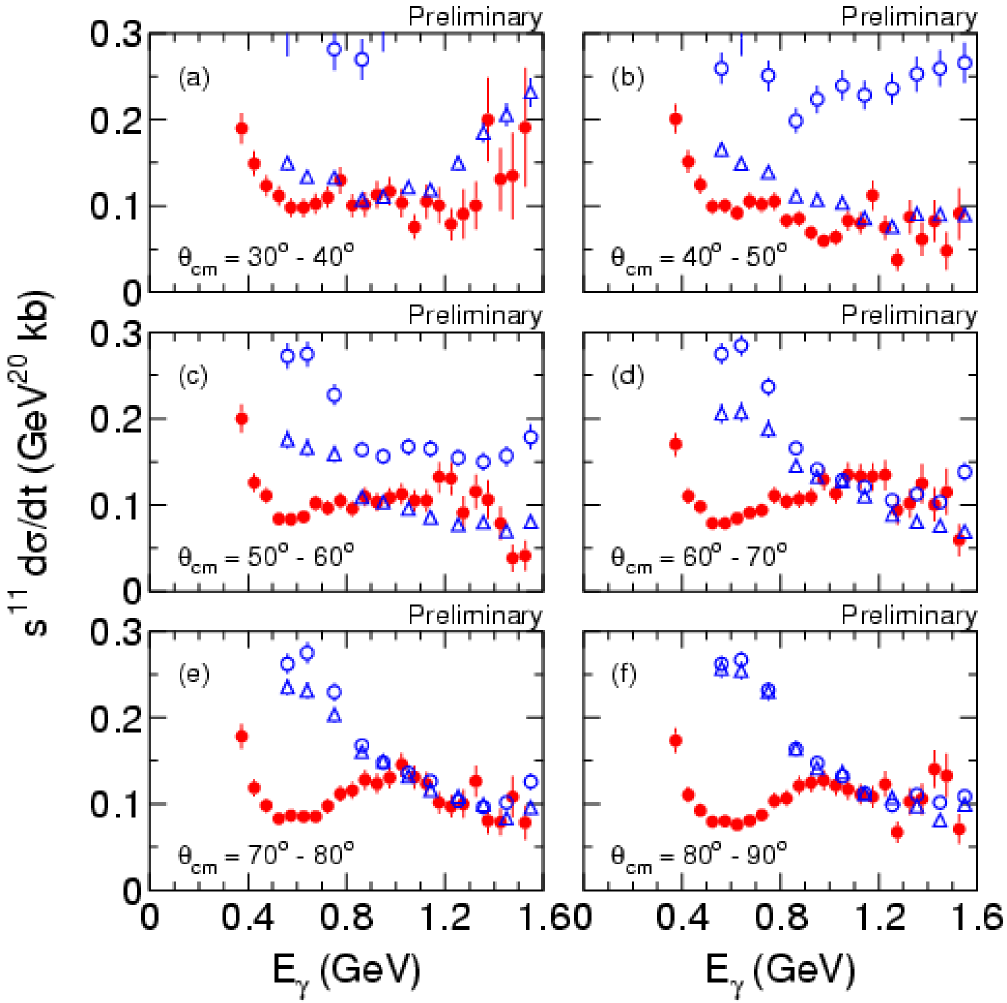
- Is the neutron a spectator? Cut at 0.1 – 0.25 GeV/c





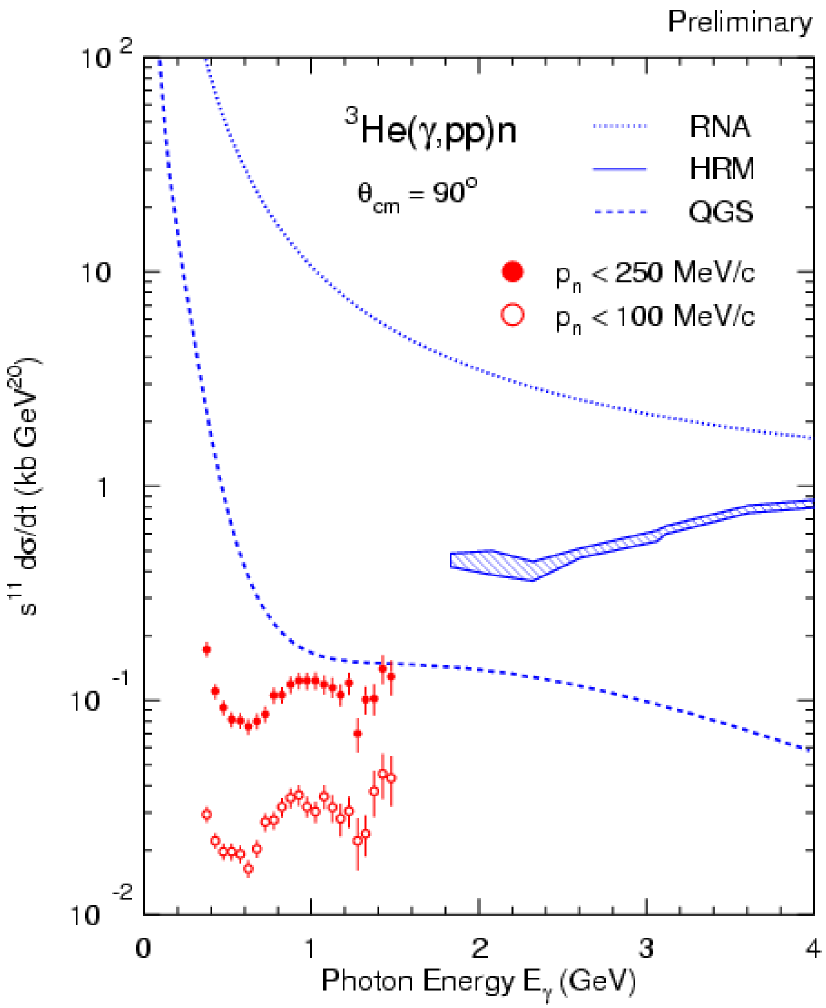
^{3}He(γ,pp)n Cross Sections

- Red: "γpp->pp", symmetric about 90°
- Blue: γd->pn x ¼, asymmetric about 90°
- Cross sections for γpp like back-angle γd, near 1 GeV



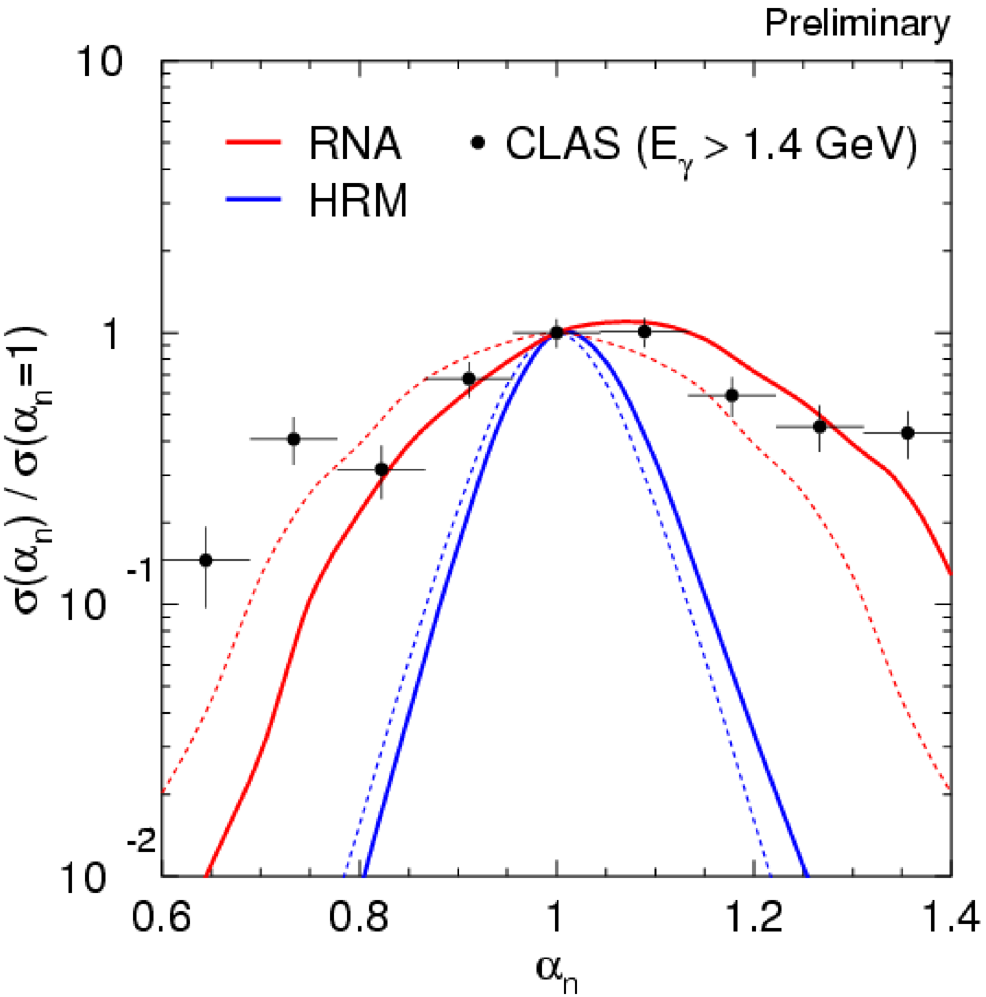
^{3}He(γ,pp)n Cross Sections

- Theory has 100 MeV/c cut
- Data small compared to γd, 10 – 25 % as large
- Scaling of σ by E_γ ~ 1.3 GeV in γd, p_y vanished by ~ 1 GeV, $C_{x',z'}$ slowly vanishing => I would expect a transition by 1 or 1.3 GeV
- Hint of a phase transition starting at 1.4 GeV -or- perhaps QGS or TQC is the right approach?



$^3He(\gamma,pp)n$ α_n Distribution

- Hard distribution from short-range physics, evidence for TQC?
- 1 GeV/c nucleons in c.m. are too low in energy: lots of rescattering broadens distribution

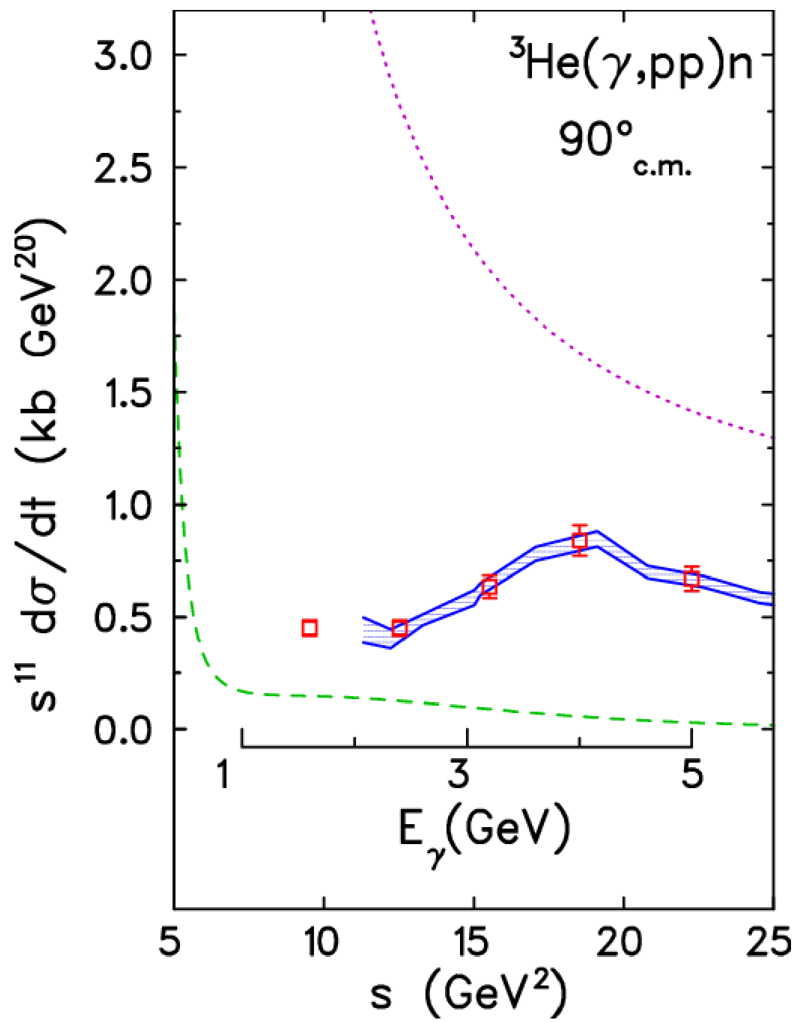


Future Perfect

- Hall A E03-101: $^{3}He(\gamma,pp)n$

$^{3}He(\gamma,pp)n$: Hall A E03-101

- Is pp disintegration much smaller than, about equal to, or much larger than deuteron disintegration
- Is there a sudden change in the ratio (phase transition)?
- Is the process long or short range (a_n)?
- Scheduled to start in ~2½ weeks



Future Perfect

- Hall A E03-101: ^{3}He(γ,pp)n
- The results of the ^{3}He experiment that is about to start will clearly influence any future work, but we can examine what is possible:
  - Study issue of iso-scalar vs iso-vector by measuring Σ asymmetry in Hall B up to ~3 GeV
  - If SRC are determined to be underlying physics, expand study to selected heavier targets as part of the SRC program
  - If there is a "phase transition" in ^{3}He/d, study it
  - Continue to higher energies with 12 GeV upgrade

Summary

- Hadronic d.o.f. describe few-body elastic and QF scattering well; going to high Q^2 is insufficient to guarantee large quark effects
- We know lots of details in γd -> pn – it is clear that detailed models like those used at low energy do not work – but the underlying quark dynamics is unclear
- ^{3}He photo-disintegration will help sort out if any of the existing quark models represents the underlying physics