Low Energy Deuteron Photodisintegration

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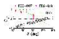
Motivation

Experimental details

Time request

Summary

Context

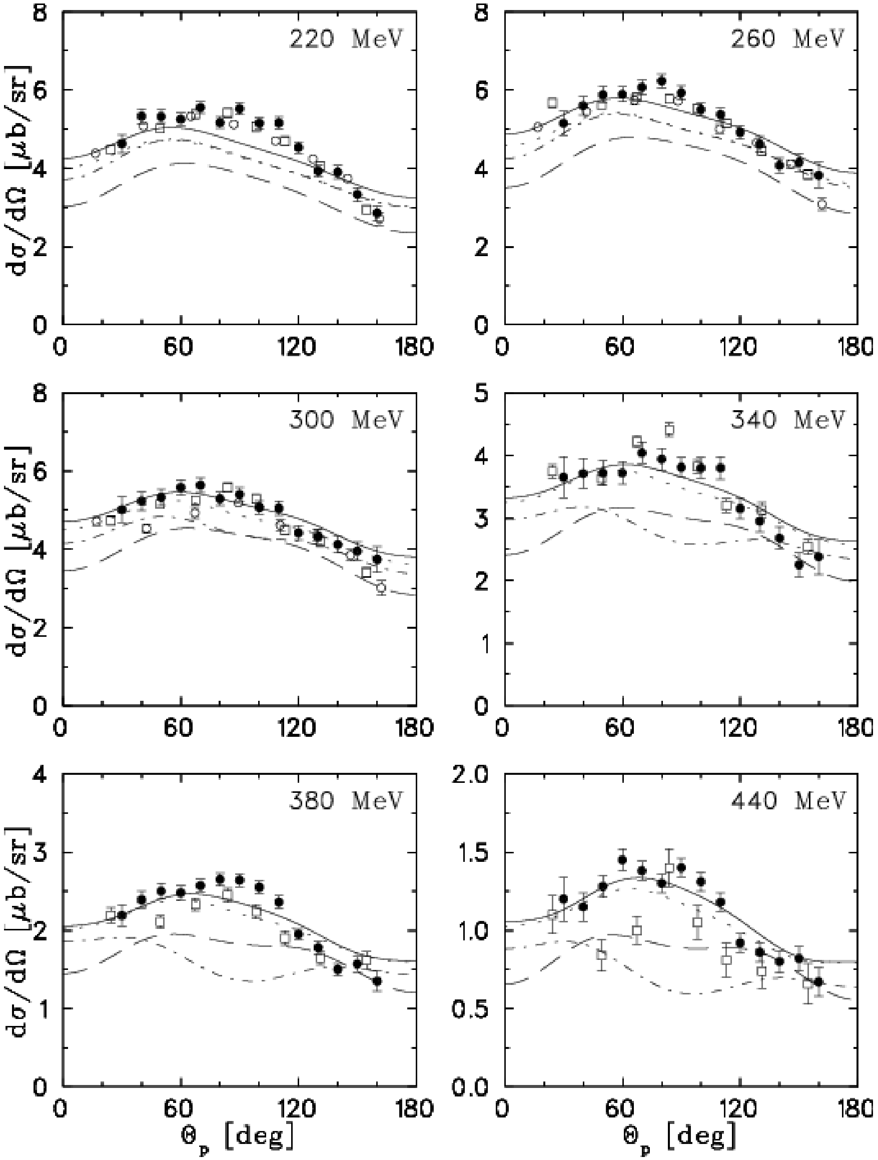
- Investigating and understanding the quark/hadron transition in nuclei has been a focus of JLab research
- Deuteron studies, particularly photo-disintegration, have been primary sources of information on the transition in nuclei; data above 1 GeV are not explained by conventional hadronic theory, but there are 5 competing quark model explanations
  - E89-012 (PRL 1998), E96-003 (PRL 2001), E99-008 (PRC 2002) + 93-017: cross sections 
  - 89-019 (PRL 2001), 00-007 (prelim), 00-107 (jeopardy)
  - 03-101 (^{3}He, in queue)

Motivation – "Breakdown" in Hadronic Theory at Low Energy

- Low and intermediate energy deuteron photo-disintegration has been extensively studied
  - Many (now mostly) consistent cross sections
  - ~1200 polarization data points
    - Mostly Σ, p_y, and T
- Generally well understood with modern calculations, particularly the work of Schwamb and Arenhövel, that incorporate:
  - Modern NN potentials
  - Relativity
- (But...)

Agreement in ds/dΩ

- Low-energy deuteron photodisintegration well understood in modern calculations, particularly the work of Schwamb and Arenhövel: figure from NPA 690, 682 (2001)
- Some poor data, but overall agreement with a few problem regions



Agreement in Σ

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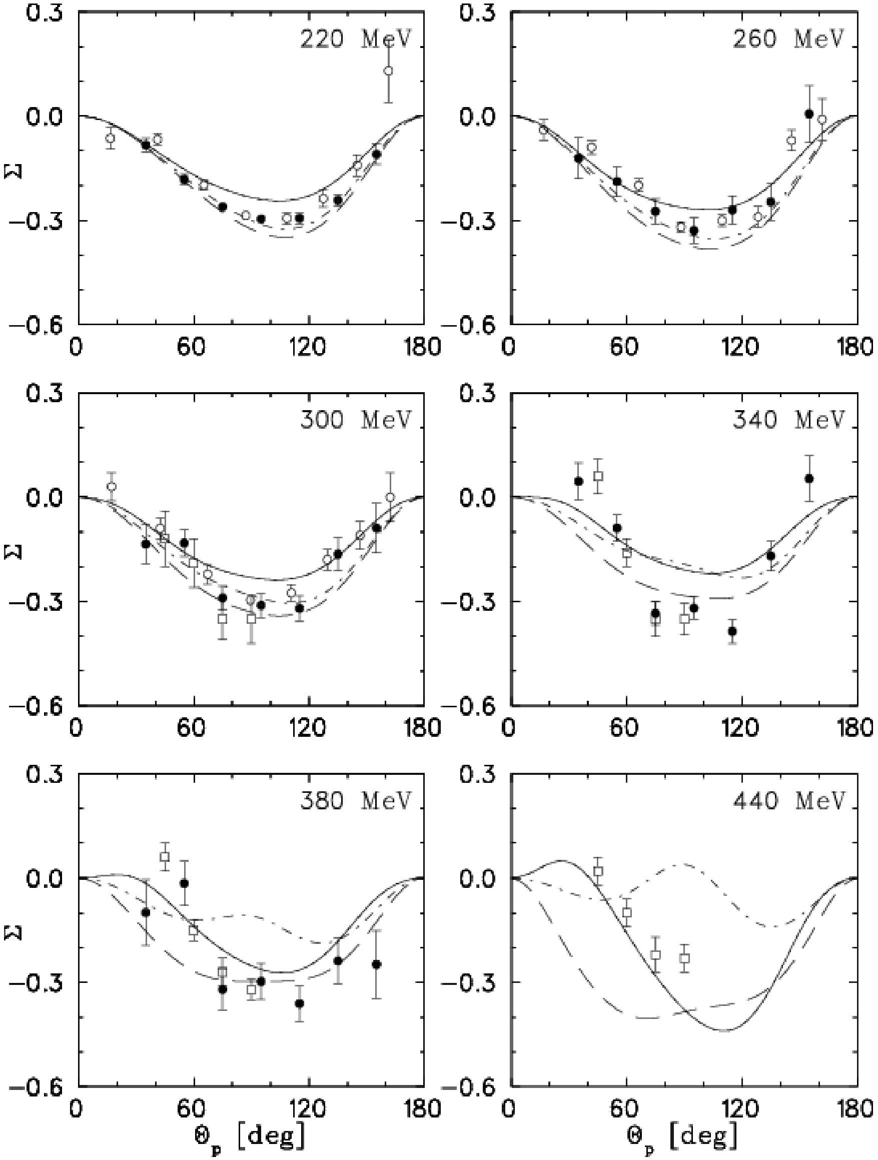
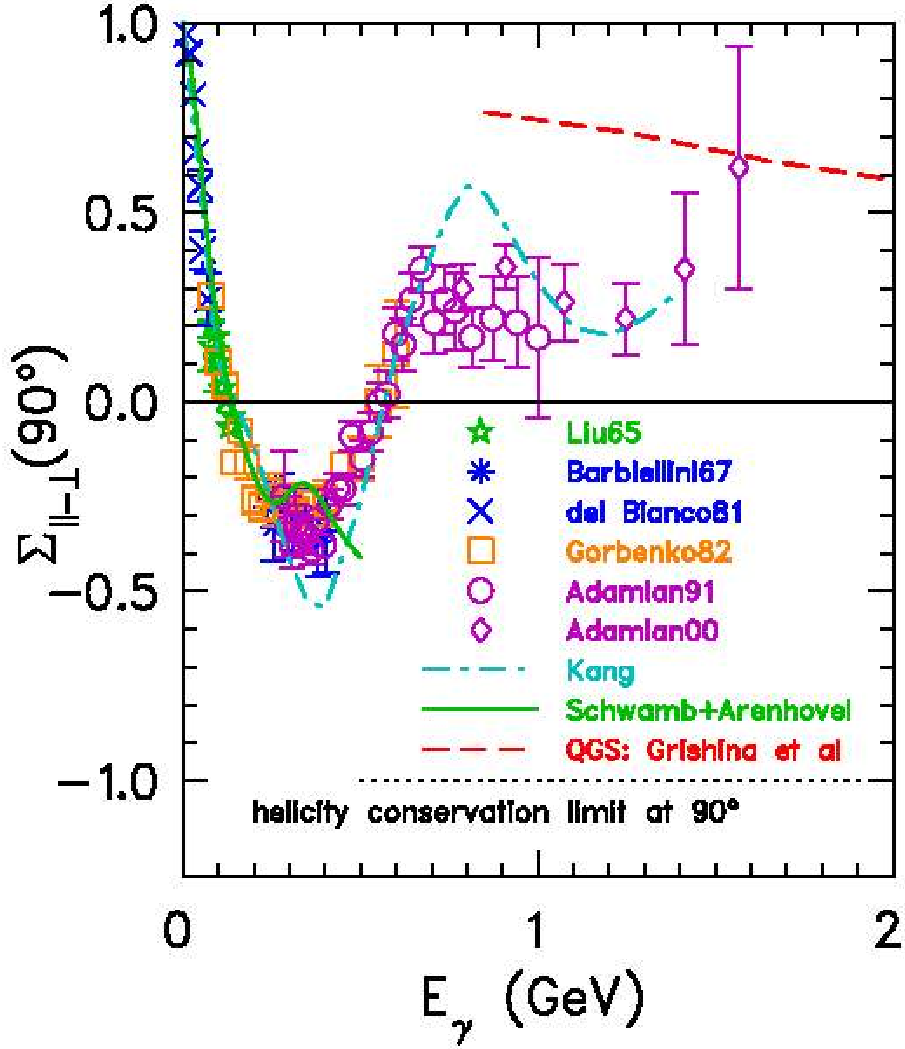


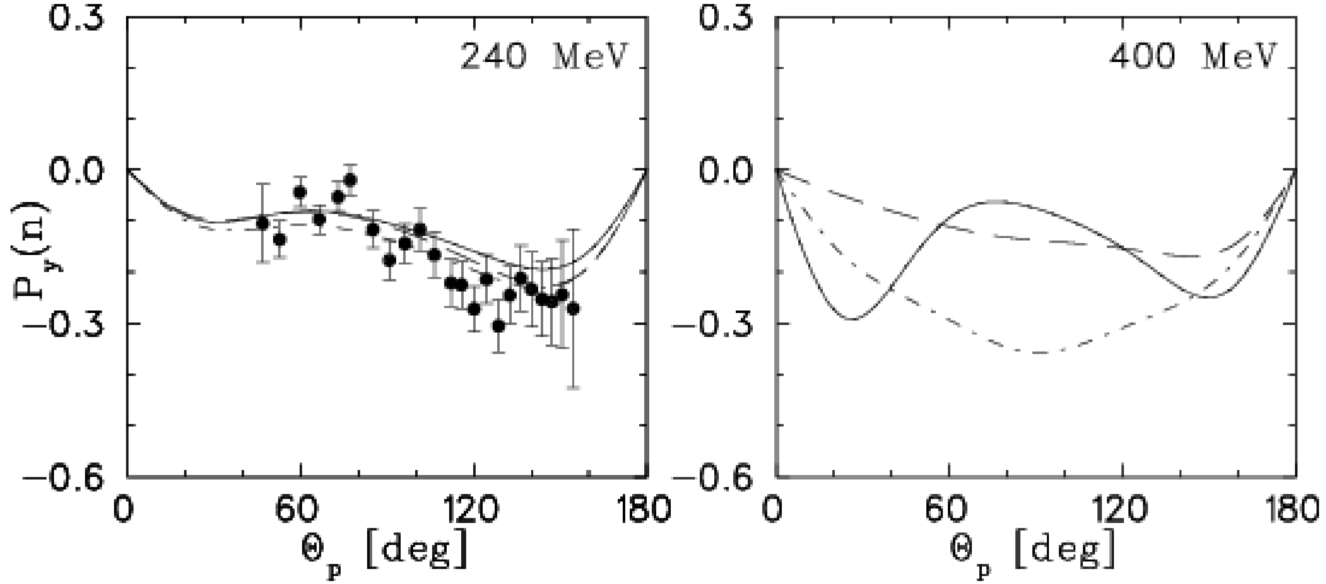
Agreement in Σ

- Schwamb and Arenhövel model works up to ~ 500 MeV
- Simpler Kang et al. in qualitative agreement up to 1.4 GeV



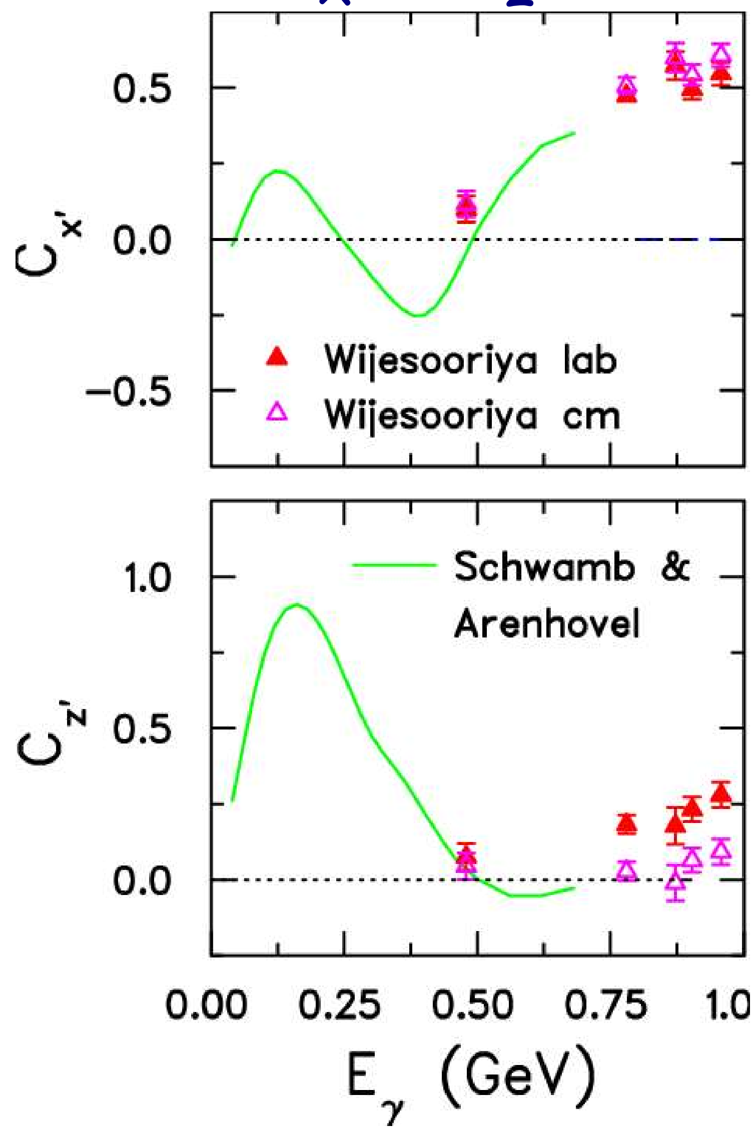
Agreement in p_y^n

- Low-energy deuteron photodisintegration is generally well understood with modern calculations, particularly the work of Schwamb and Arenhövel: figure from NPA 690, 682 (2001)



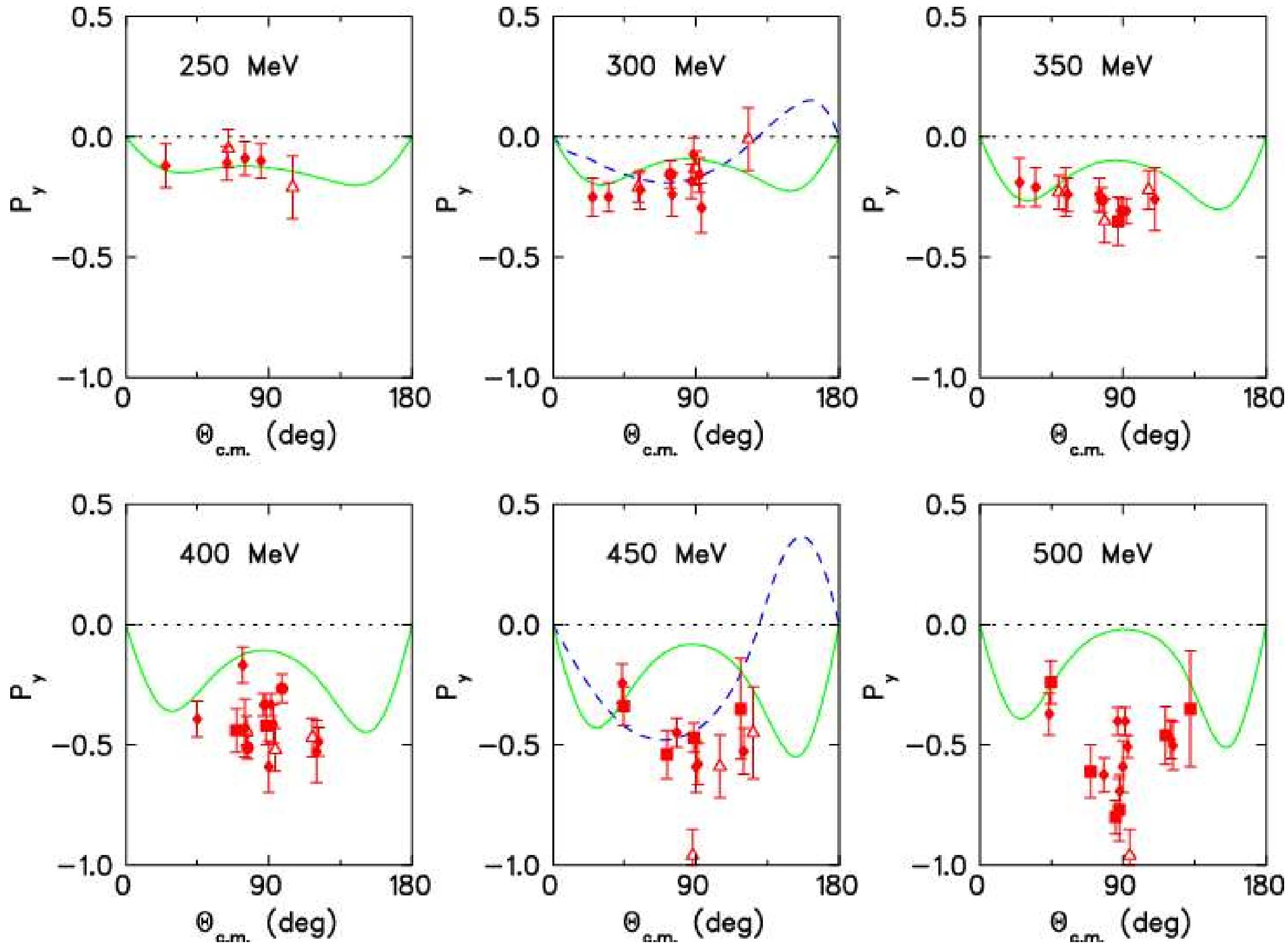
Agreement in $C_{x'}$, $C_{z'}$

- Schwamb and Arenhövel agree with the Hall A $\theta_{cm} = 90°$ E89-019 data at 480 MeV, and point towards higher energy data
- Theory in c.m.



But...

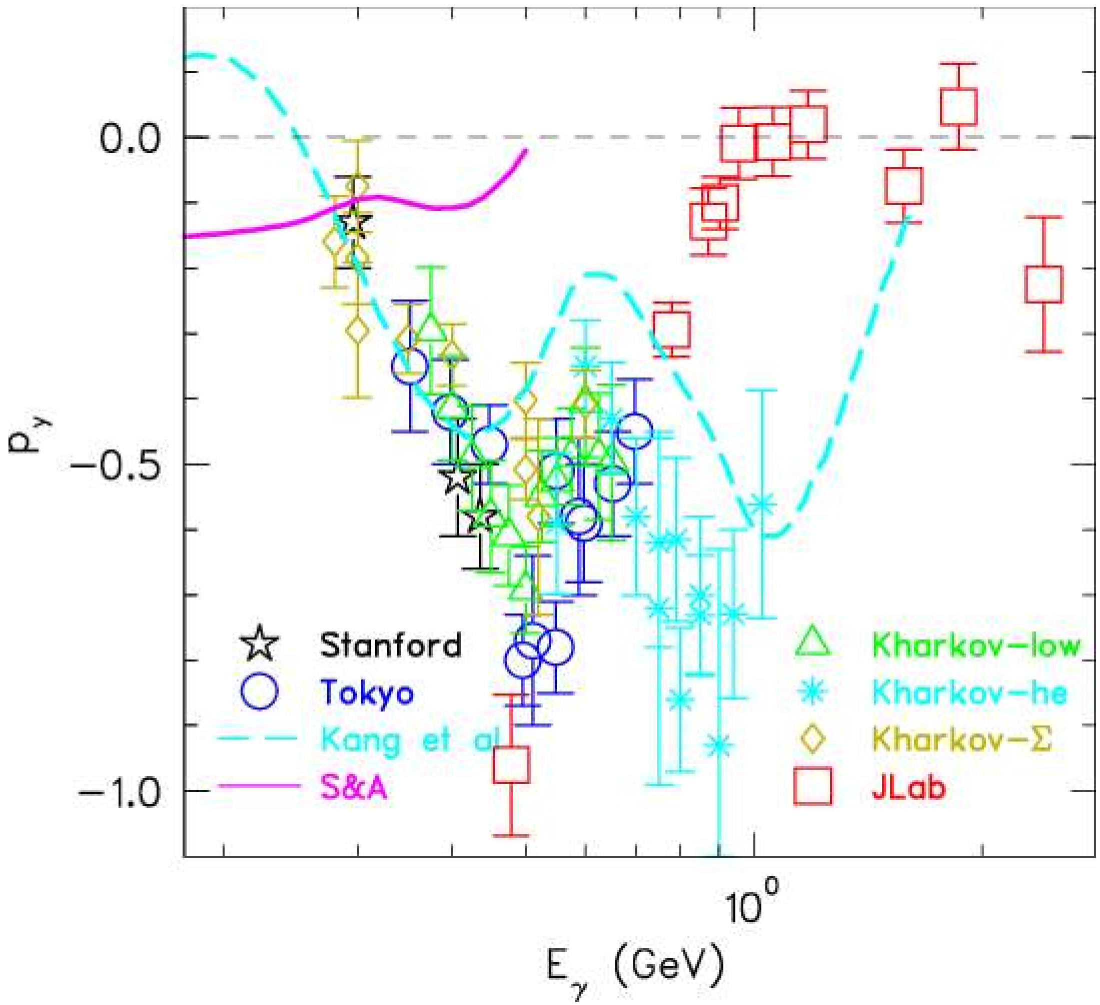
- ... the situation is not so good for the induced proton polarization



- The discrepancy systematically increases with energy

Problems Emphasized at 90°

- Neither hadronic calculation reproduces data well
- Induced polarization very large near 500 MeV
- Despite some poor p_y data, it is clear there is a problem



Comment

- The agreement with $C_{x'}$, but disagreement with p_y, near 500 MeV, is odd – these two are the imaginary and real parts of the same combination of amplitudes
  - $\sigma(\theta)\, C_{x'} = 2\, \mathrm{Re}\, \Sigma_{i=1,3}\, (F^*_{i,+} F_{i+3,-} + F_{i,-} F^*_{i+3,+})$
  - $\sigma(\theta)\, p_y = 2\, \mathrm{Im}\, \Sigma_{i=1,3}\, (F^*_{i,+} F_{i+3,-} + F_{i,-} F^*_{i+3,+})$
- Schwamb and Arenhövel predict the magnitude of this combination of amplitudes is small
- The data tells us that the magnitude is about as large as the cross section
- Perhaps the good agreement of the $C_{x'}$ (and $C_{z'}$) data point is fortuitous

Historical Note

- Most outstanding problem: the breakdown in the ability to describe the induced proton polarization p_y that starts at $E_\gamma \sim 300$ MeV (W-md ~ 280 MeV), leading to a peak at $\theta_{cm} = 90°$, $E_\gamma \sim 500$ MeV (W-md ~ 570 MeV)
- This peak led to the "dibaryon" excitement of the 1970s-1980s; it remains an unexplained, leading indicator of the difficulty awaiting hadronic theory at higher energies

Motivation Summary

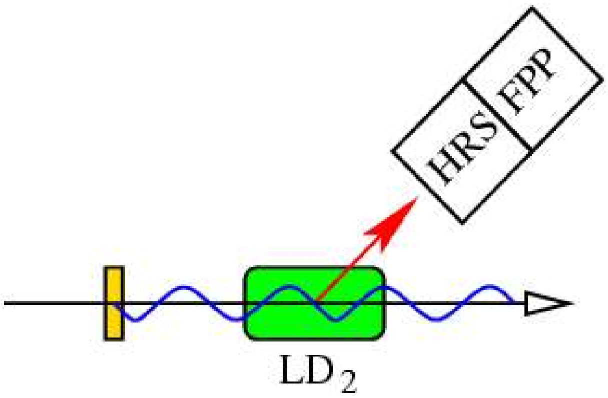
- While $\gamma d \rightarrow pn$ at low energies, up to a few hundred MeV, is understood with conventional hadronic theory, it starts to fail at ~300 MeV, most obviously in p_γ – a ~30 year old unsolved problem
- We propose a systematic set of high precision data, to more clearly see how the theory "breaks down", and give clues to the underlying physics

From H. Arenhövel

- ``I think your proposal is very interesting, because we certainly need more precise data on the outgoing nucleon polarization in that energy region for clarification of the various theoretical treatments. Therefore, I and also Michael Schwamb support wholeheartedly your proposal.''
- ``I only would not call it "low energy" but "intermediate energy". ''
- JLab theory review by F Gross and W van Orden also "enthusiastic" for similar reasons: ``This new data... would be of considerable help''

Experiment Overview

- 10 μA, ~400-500 MeV beam, polarized electrons
- 4% X_0 radiator (untagged γ's)
- 15 cm LD_2 target
- P into HRS with FPP
- Done before: Hall A E89-019, E00-007, ...



- Low energy beam generally impossible to schedule, but target of opportunity: 1 pass beam into Hall A during low energy 1 pass G0 run in Hall C

Feasibility - Already Done

- During E89-019, we had 3 hours of beam (2 1/3 hours of production data) at 528 MeV
- 1.2 kHz DAQ rate for 8 μA, 4% photon radiator, LD_2
- The data obtained at θ^{cm} = 90° were:
  - $P_y = -0.96 \pm 0.11$
  - $C_{x'}^{cm} = 0.08 \pm 0.04$
  - $C_{z'}^{cm} = 0.10 \pm 0.04$
- The total acceptance was about 80 MeV, the average photon energy was 480 MeV

Backgrounds

- There is 100 (140) MeV region of photon energy before start of $\gamma d \rightarrow pn\pi^0$ background at forward angles (90°)
- End caps rates low, removed by target cuts
- Pions rates are low, and pion momentum is too low at forward angles for pions to be seen
  - TOF in detector stack separates π/p
- In-target radiator is seen directly for angles < 20°, otherwise we have had no radiator background problems (no one-bounce problem) in Hall A

Spin-Transport "Problem"

- In HRS, with 45° bend, the spin transport p_y hole is for γ = 1.115, T = 108 MeV, p = 464 MeV/c
- Our momentum range is about 500 – 750 MeV/c, so the "natural" size of our p_y uncertainty is ~3 x the size of the polarization-transfer uncertainties

What is Needed?

- Special G0 run intended for summer 2006 shutdown offers opportunity for low energy beam
- G_E^n runs in Hall A spring 2006, hall reconfigured to standard setup summer 2006
- Photon radiator and cryo-target will need to be reinstalled: +few hours
- Front FPP chambers and electronics rack need to be reinstalled: ~3-4 days
  - We do the FPP check out and calibration
  - Expect FPP needed for other expts in 2006-2007
- FPP code currently is old ESPACE FORTRAN, need few months to convert to Hall A root C++ analyzer

20-MeV bins

- Observables strongly energy dependent, so we need small energy bins
- Observed p_y goes from -0.2 at 300 MeV to -1 at 500 MeV, or 0.08 / 20 MeV bin
- Predicted Cz' goes from 0.75 at 230 MeV to 0 at 500 MeV, or ~0.052 / 20 MeV bin
- Final binning will depend on observed energy dependences and measurement uncertainties
  - Estimated resolution for reconstructed Eγ ~ few MeV

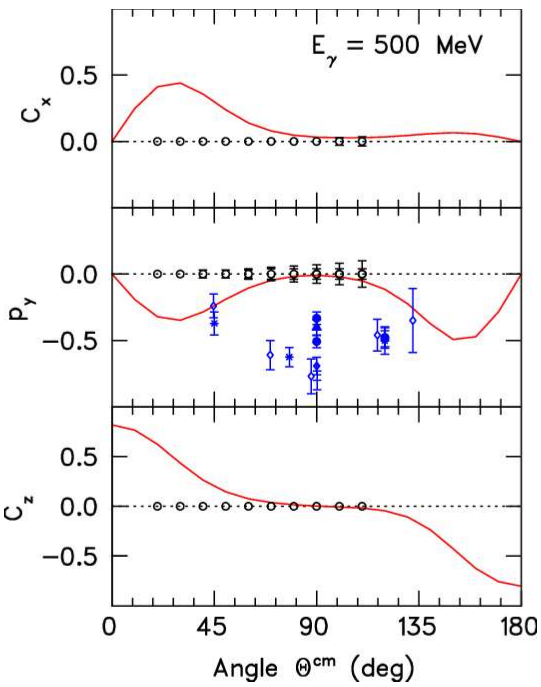
Estimated Uncertainties

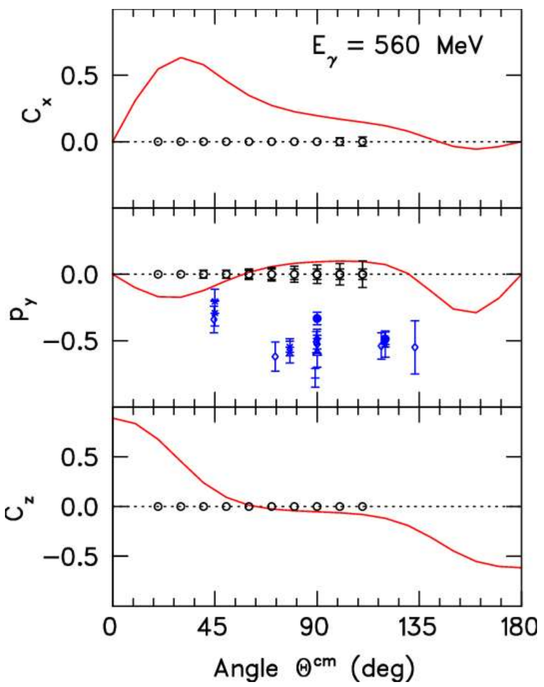
- For 585 MeV beam, with standard assumptions plus FPP performance and spin transport
- Uncertainties for each 20 MeV bin
- Program takes 11 days for production γd, plus 3 days for FPP/ep calibrations (also gives P_{beam})
- 5 of 10 angle settings given below, as examples

Θcm (deg)	20	50	80	90	110
# settings	2	2	2	2	3
Typical Δp_y	0.03	0.04	0.06	0.06	0.12
Typical $\Delta c_{x'}$	0.02	0.02	0.02	0.02	0.03
Typical $\Delta c_{z'}$	0.02	0.02	0.02	0.02	0.03

Expected Results

- 580 MeV beam, 20 MeV bins, 2 examples below
- $C_{x'}$ and $C_{z'}$ previously basically unmeasured
- More systematic, better precision data for p_y





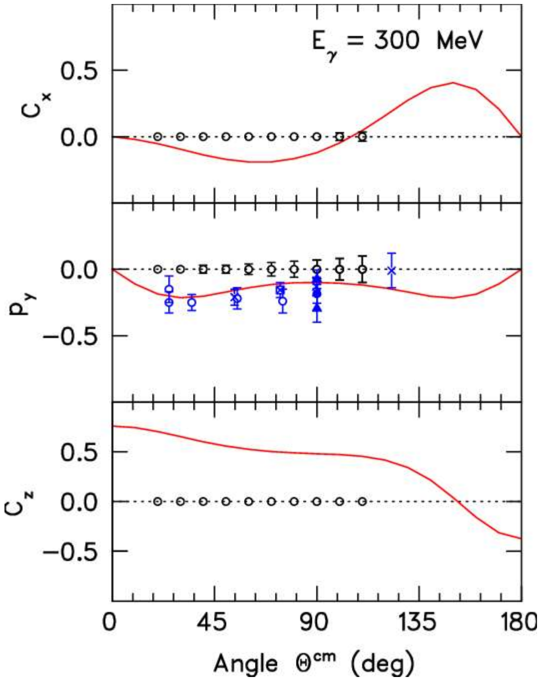
Estimated Uncertainties

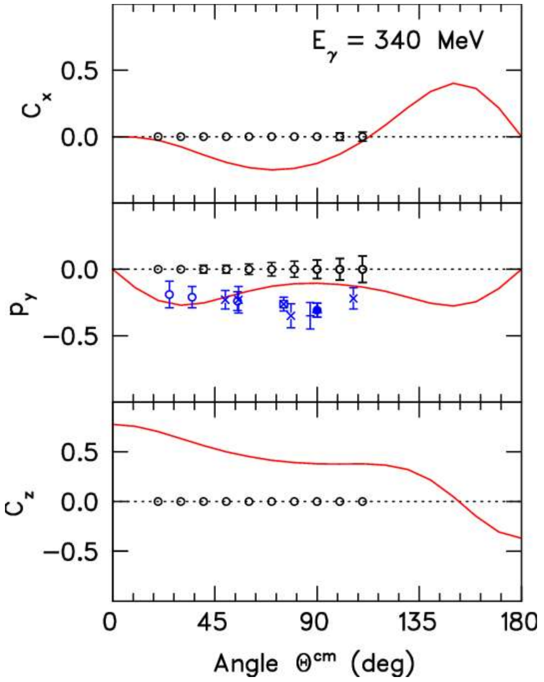
- For 360 MeV beam, with standard assumptions plus FPP performance and spin transport
- Uncertainties for each 20 MeV bin
- Program takes 14 days for production gd, plus 3 days for FPP/ep calibrations (also gives P_{beam})
- 5 of 10 angle settings given below, as examples

Θcm (deg)	20	50	80	90	110
# settings	2	3	3	3	4
Typical Δp_y	0.03	0.05	0.05	0.10	0.15
Typical $\Delta c_{x'}$	0.01	0.01	0.01	0.02	0.03
Typical $\Delta c_{z'}$	0.01	0.01	0.01	0.02	0.03

Expected Results

- 360 MeV beam, 20 MeV bins, 2 examples below
- $C_{x'}$ and $C_{z'}$ previously basically unmeasured
- More systematic, better precision data for p_y





Why Two Energies

- G0 proposes 2 energy settings, 585 and 360 MeV, plan to run higher energy run first
- It appears what happens afterward depends on the online results of the first part of the experiment
- There are questions about whether parity quality beam will be technically feasible as the beam energy is lowered
- We are not sure what energy will run, but would like to be able to take advantage of whatever energies G0 ultimately uses

TAC Report

- Verify FPP status: We agree - FPP not used since 2002, but also requested for two experiments likely to be scheduled late '06 / early '07
- Multiple low-energy beam feasibility: We agree – have been in contact with accelerator, tests will be needed, but people optimistic
- Radiator/target effect on beam dump: in 1999, beam hitting flow diverters limited radiator; 4 % radiator OK at 530 MeV, expect we will need 3 % at 360 MeV
- Beam polarization: $\Delta C_{x'}$, $\Delta C_{z'}$ << Δp_y, so it is not necessary to adjust request

Summary: Low Energy γd -> pn

- Induced polarization is a 30-year old unsolved problem; systematic, precise data is the best hope to lead to a solution: 10 c.m. angles x 5 20-MeV photon energy bins
- $C_{x'}$, and $C_{z'}$ are nearly unmeasured, and there is valuable information in their comparison with theory
- Py will be more systematically measured, with improved uncertainties, compared to the previous measurements
- Requires 14 (17) days at 580 (360) MeV
- An easy experiment in Hall A that is nearly impossible to do elsewhere; no conflict with other proposals / experiments - if there is low energy G0 run