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Low Energy Deuteron Photodisintegration

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and the Jefferson Lab E05-103 Collaboration

Physics / Motivation
Deuteron (pn) Photodisintegration

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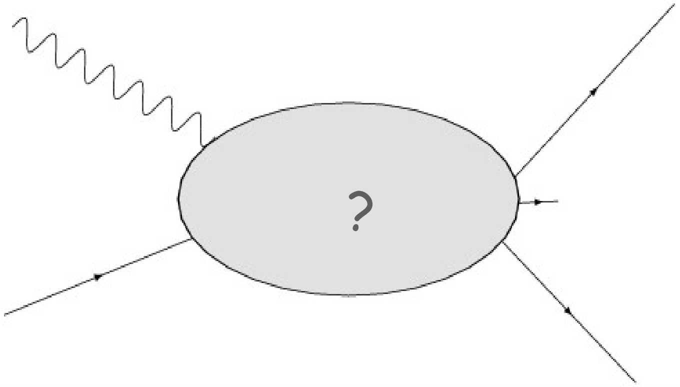
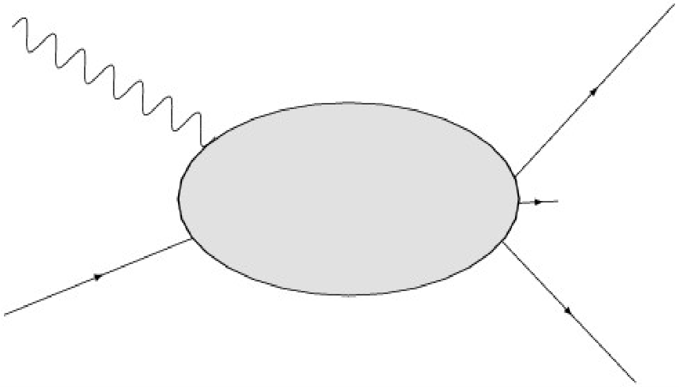
Background

- Understanding nuclear structure is hard
- No generally accepted solution to relativistic bound state problem
- Nucleons are themselves bound systems of quarks
- Effects from quark substructure of nucleons remain generally elusive (exception: EMC effect – nucleon quark distributions in nuclei) with arguments on both sides
- Investigate by probing the deuteron through photodisintegration

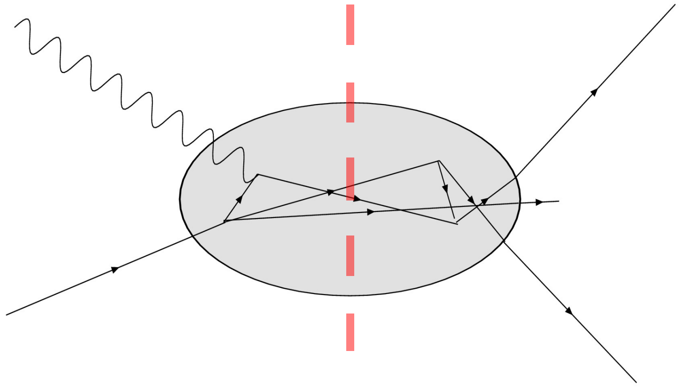


Conventional Hadronic Picture

- "Hadrons" in, hadrons out…so use a hadronic theory
- Precise comparison of calculations vs data
- General belief: the underlying quark degrees of freedom are hidden – quarks and hadrons are equivalent

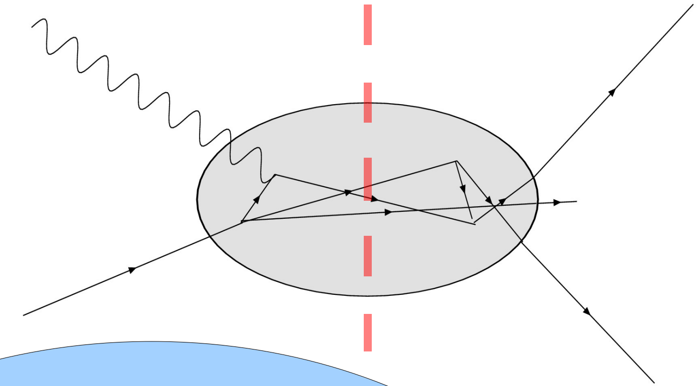


But Are Hadrons and Quarks Equivalent?



- Hadrons are colorless – so if there are colored objects at some intermediate point in time, reactions / structure cannot be described in hadronic terms!
  - Farrar: high Q^2 deuteron form factor arises dominantly from hidden color configurations
- Hadronic and quark theories cannot be equivalent

Are Hadrons and Quarks Equivalent?



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Objection: the NN force is an effective force fit to NN data –so any hidden color effects are largely already there in NN scattering.

Parameters are not from a colorless world.

Are Hadrons and Quarks Equivalent?

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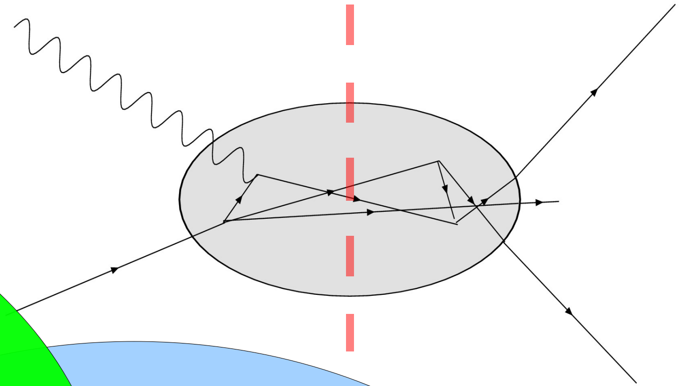

Could this be why the more effective NN forces of the 1990s succeeded, when the more strictly meson-baryon forces of the 1980s did not?

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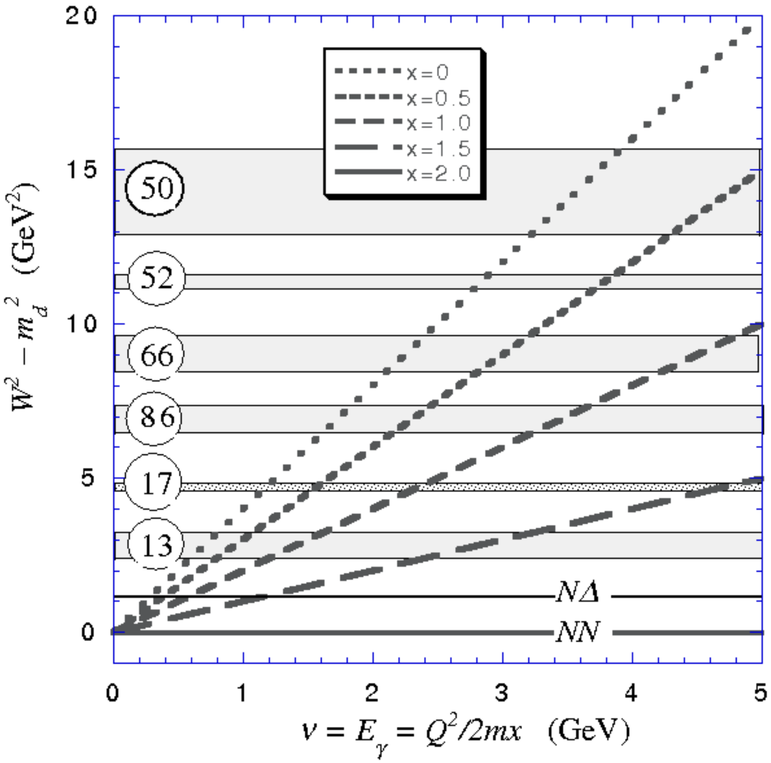
Why Large-Angle/Energy Photodisintegration?

- Photodisintegration gives large t and $s=W^2$
  - Large s gives many resonances to sum over.
  - Large angle gives large t, which selects small size.
  - Need both to see quark behavior.
- For elastic or quasi-free electron scattering, W < or = m_p
  - Low W suppresses quark degrees of freedom

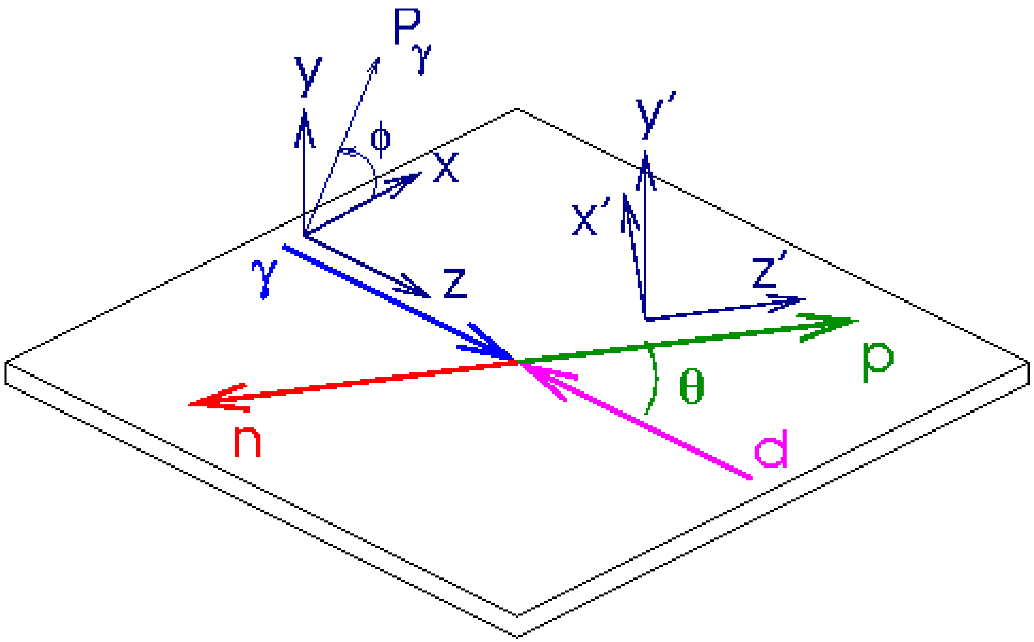


Large W, -t Photodisintegration a big success

- Differential cross section follow expected limit, constituent counting rules, for p_T > 1.3 GeV/c
  - Derived from dimensional analysis by Bradsky, Farrar, Metveev,...
  - Rederived from QCD
  - Corrected for orbital angular momentum
  - Rerederived from ADS/CFT
- Polarization observables for E_γ > 1 GeV moderately well predicted by quark model calculations
  - Hard rescattering model: Sargsian et al.
  - Quark-gluon string model: Kondratyuk, Grishina, et al.
- But there is no time to show / discuss this

Observables / Coordinate System in d(γ,p)n

- $d\sigma/d\Omega$, Σ, T, $C_{x'}$ (aka P_x^c), p_y, $C_{z'}$ (aka P_z^c)



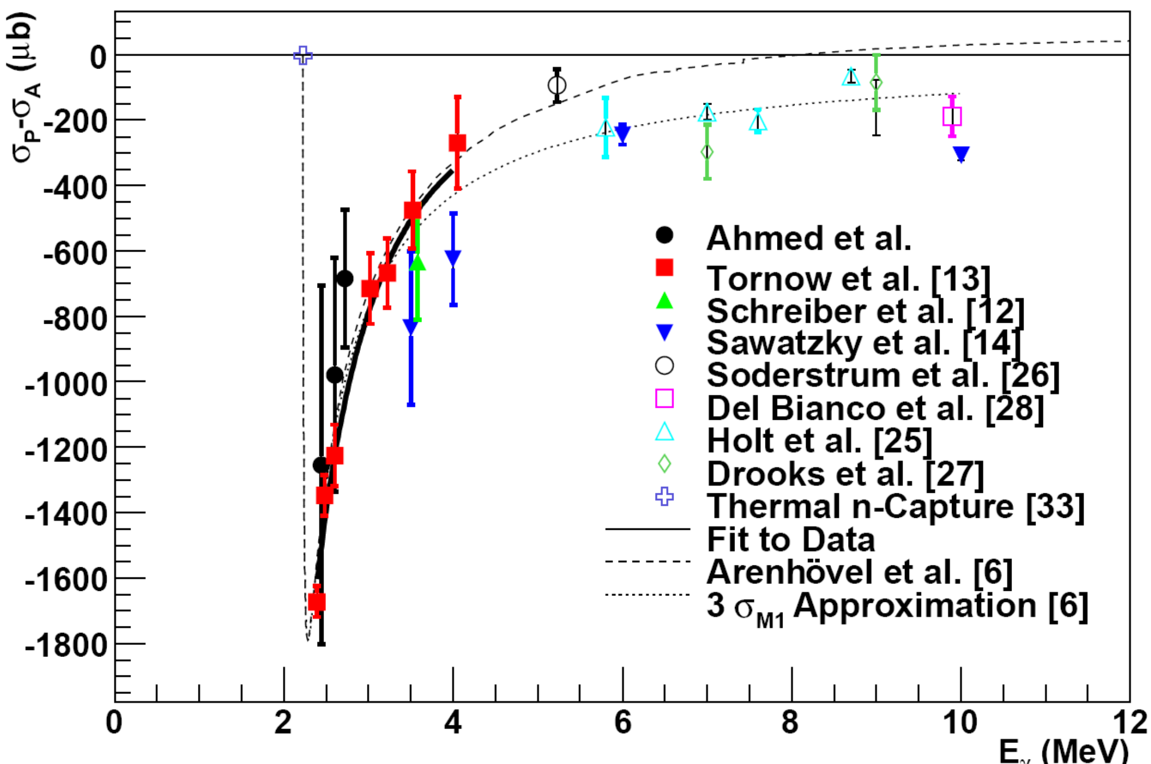
What is new at low energies?

- (Will not cover parity violating np -> dγ)
- HIGS
- Novosibirsk
- JLab
- R. Schiavilla re-analysis of P_y^n problem – no change from early 1990s H. Arenhovel analysis

HIGS near threshold $\gamma d \rightarrow pn$

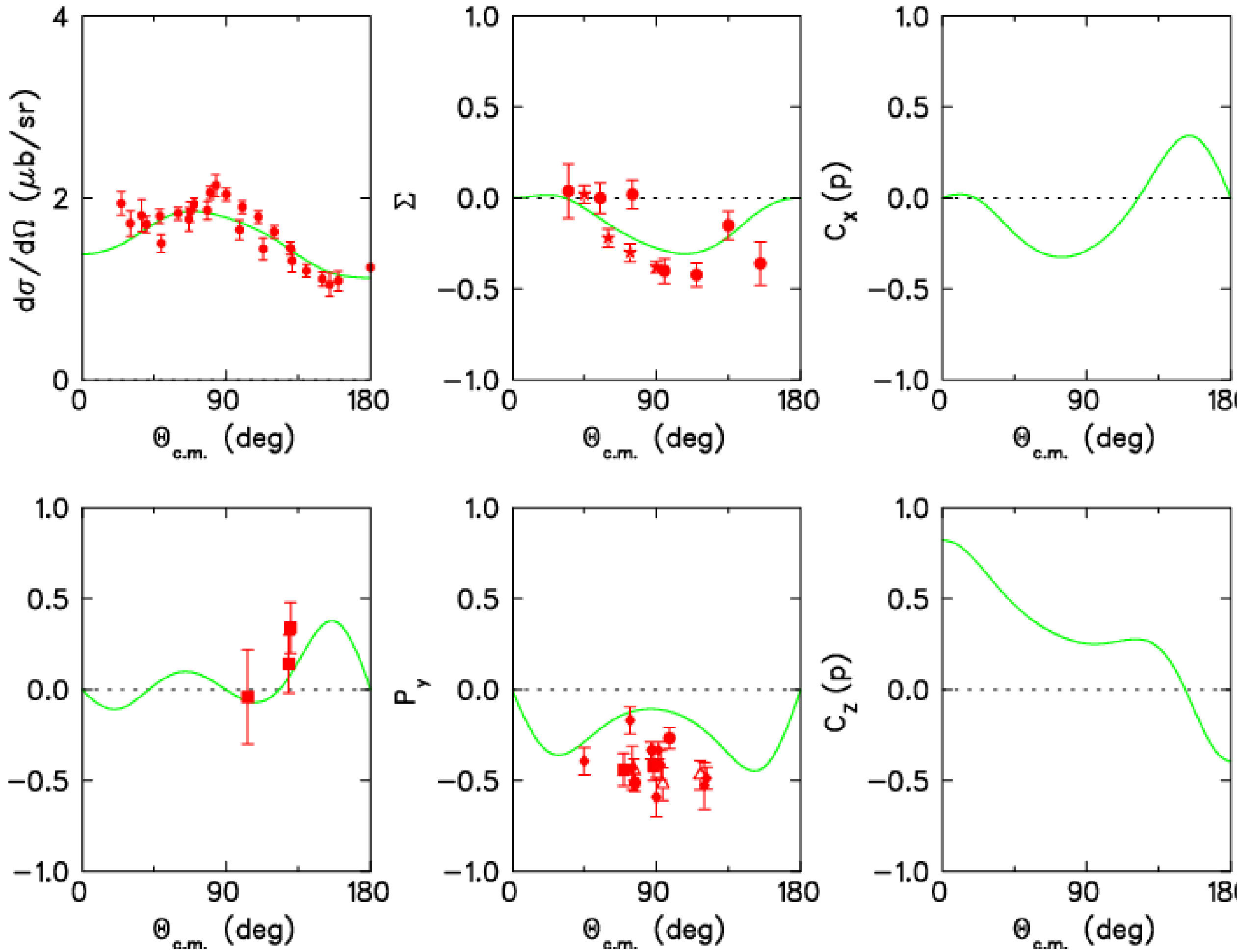
- Motivations: GDH sum rule, nucleosynthesis
- Ahmed et al., PRC, 2008
- Linear polarized γ's determine Σ asymmetry
- Angular distributions of $d\sigma/d\Omega$ and Σ or other polarization observables, determine s and p waves, E2/M1 amplitudes and $\sigma_P - \sigma_A$, the GDH integrand
- Data generally in good agreement with modern potential model and EFT (not shown) calculations

- Unitarity, analyticity, causality, … or dispersion relations, LET, optical theorem --> $\int^{\infty}_{threshold} (\sigma_P - \sigma_A)/\nu \, d\nu = -4\pi^2 \alpha S(\kappa/m)^2$



Breakdown of hadronic theories in γd -> pn

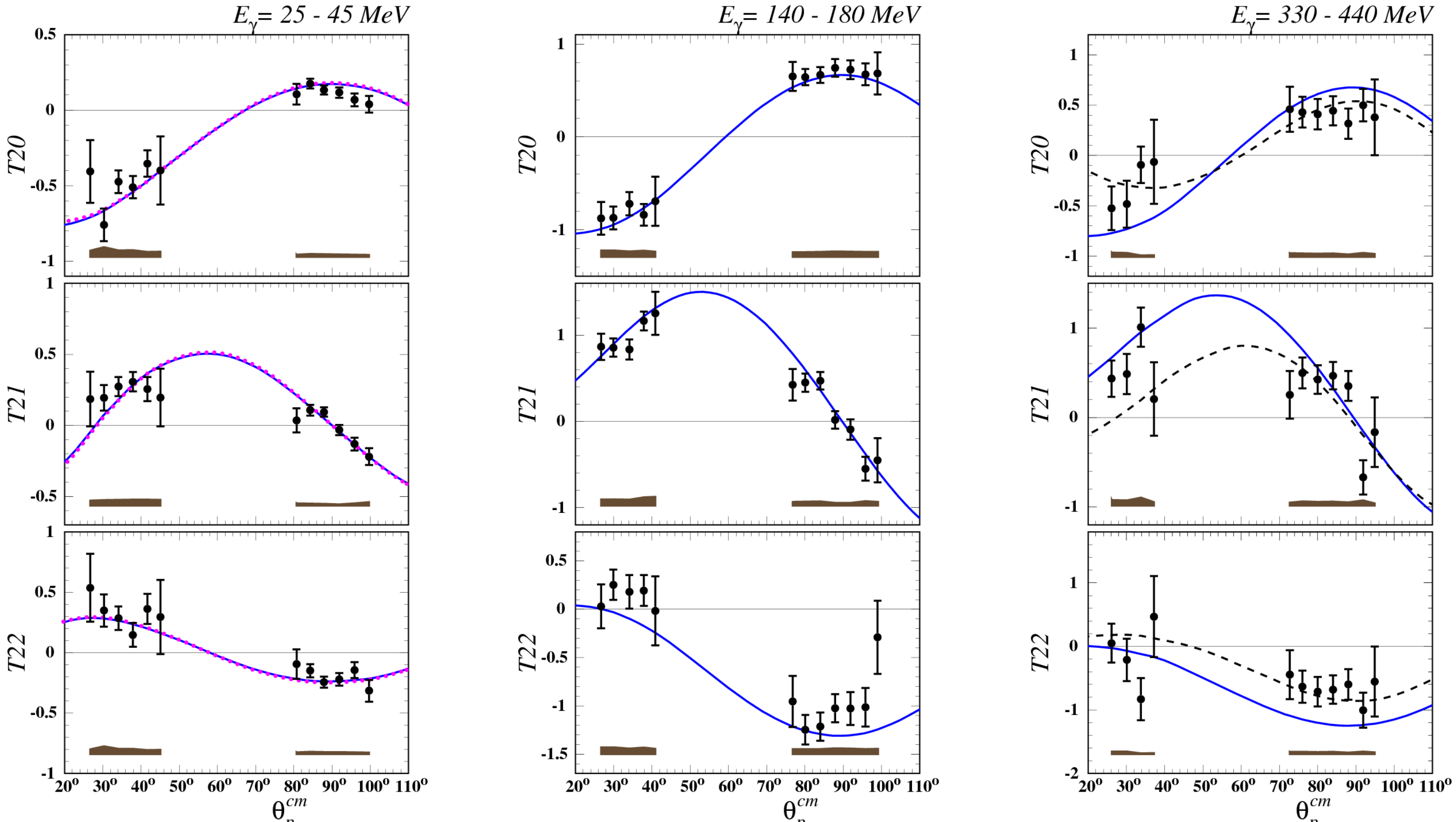
- E_γ = 400 MeV
- Schwamb & Arenhovel (green)
- P_y shows cleanest indication of problems
- See Gilman & Gross, JPG17, for more detail



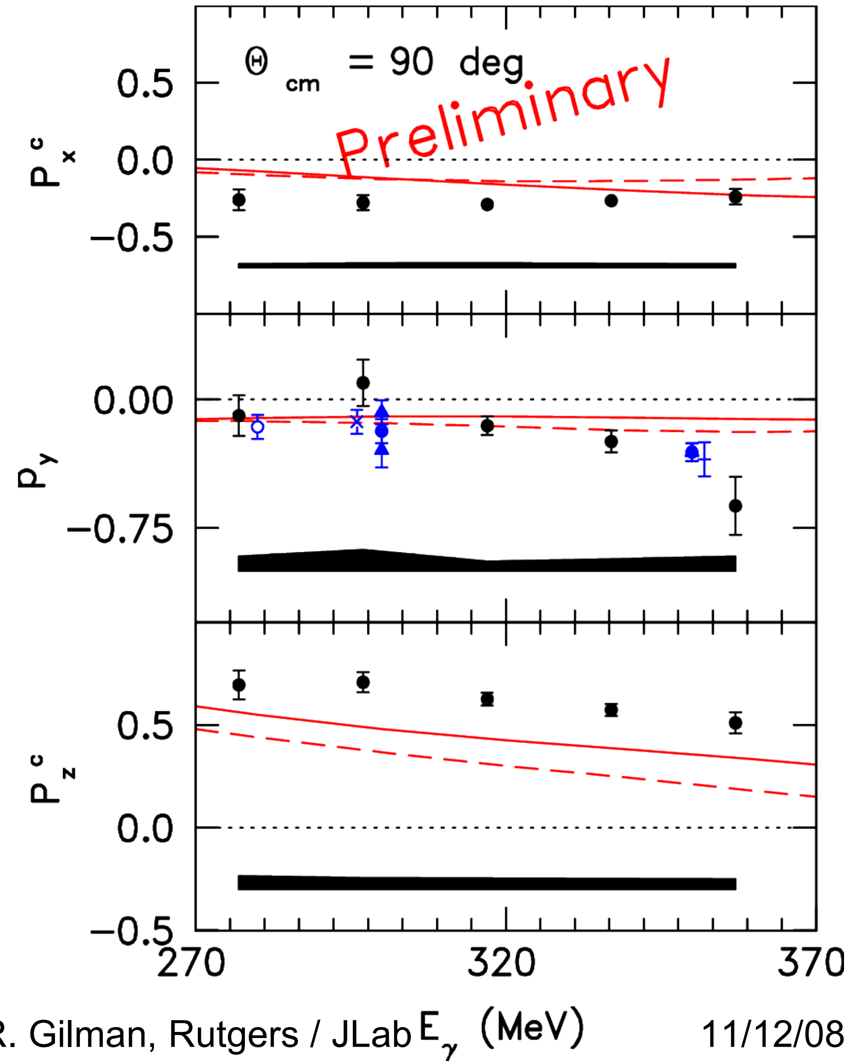
Novosibirsk t_{2i}

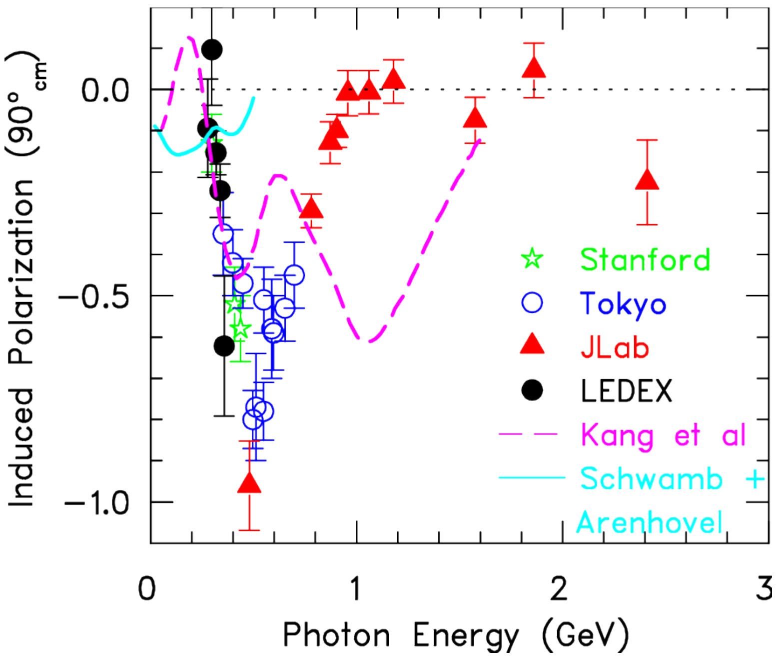
- I Rachek et al., PRL 98, 182303 (2007)
- 3 of 8 angular distributions shown
- Calculations from Levchuk, Arenhovel, Schwamb

- Calculations agree well with each other and data below π threshold
- Small differences arise above π threshold, and especially above Δ



Jefferson Lab LEDEX: Preliminary Results





- J. Glister et al., to be published
- Kharkov measurements not shown
- Latest p_y data consistent with earlier measurements
- Calculations from Schwamb

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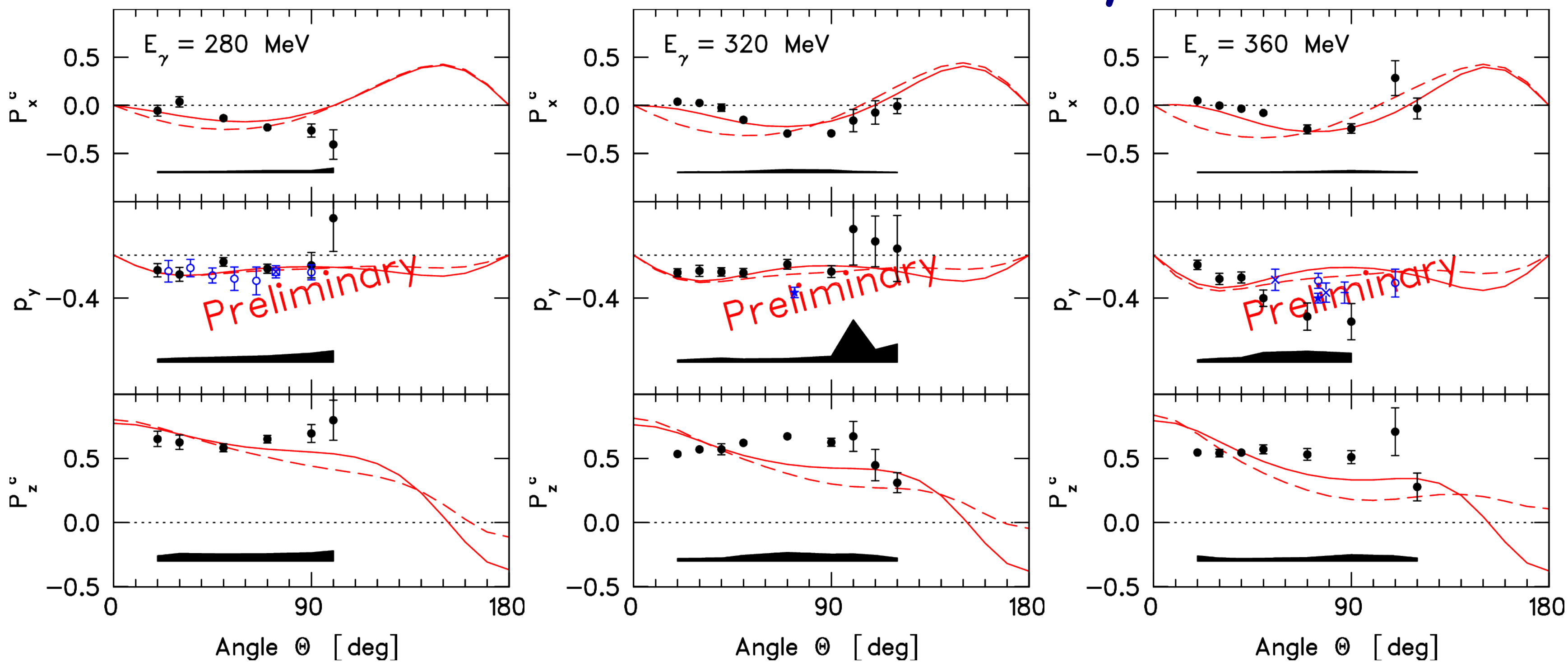

- J. Glister et al., to be published
- Schwamb's older, semi-empirical calculations (solid) better than newer ones (dashed) with no adjustable parameters similar to NN force story
- 3 of 5 angular distributions shown

Reaction from M. Schwamb

- The fact that the elder calculations work partially better than the newer ones is not very surprising. A similar situation occurs even in the unpolarized cross sections. *The elder calculations contain more free parameters and violate seriously unitarity, whereas the newer ones are much more stringent. Furthermore, the newer ones consider not only NN-scattering or deuteron breakup, but also pion production and annhilitation. Due to these facts -- more reactions are more consistently considered with less parameters -- one cannot expect a quantitative description.* As I told you, the weakest point is the implemented baryon-baryon interaction which needs to be improved. Unfortunately, till now no new calculations are available with respect to that point - this is indeed a very difficult topic.

Conclusions

- Conventional hadronic calculations work quite well... up to 300 MeV, corresponding to Δ excitation
- Many possible reasons for breakdown, some conventional, some ``exotic'':
  - Treatment of BB interaction
  - Implementation of relativity
  - Higher mass resonances
  - ...
  - Quark substructure
  - Hidden color
  - Dibaryons
- Remains to be seen how far theory can be extended by "conventional" improvements