High Energy Photoreactions

My physics overlaps with Roy, and more

Ron Gilman, Rutgers University*

Many experiments (I will focus on Roy's.):

- SLAC NE8 (+NE17)
- T_{20} @ Novosibirsk
- JLab E89-003 + 89-033 + ...
  - $\gamma d \rightarrow pn$
  - $\gamma N \rightarrow \pi N$

*Thanks to NSF PHY 13-06126.
Thanks to the organizers.
And especially, thank you, Roy.

My Background

PhD: I worked in Los Alamos A(π^+,π^-) with Terry Fortune.

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Pion double-charge exchange on ^{16}O and ^{18}O

Phys. Rev. C **17**, 1774 – Published 1 May 1978

R. L. Burman, M. P. Baker, M. D. Cooper, R. H. Heffner, D. M. Lee, R. P. Redwine, J. E. Spencer, T. Marks, D. J. Malbrough, B. M. Preedom, R. J. Holt, and B. Zeidman

ABSTRACT

The zero-degree differential cross section for pion double-charge exchange on $^{18}O(\pi^+,\pi^{+-})^{18}Ne$ was measured at three incident pion energies and found to be 2.00±0.34, 2.19±0.44, and 1.67±0.38 μb/sr at 139, 126, and 95 MeV, respectively. A similar measurement for ^{16}O at an energy of 145 MeV resulted in a value of 0.87 ± 0.21 μb/sr. The ratio of the ground-state transitions near 140 MeV is $\frac{\sigma(^{18}O)}{\sigma(^{16}O)} = 2.3 \pm 0.7$. The mass excess determined for ^{16}Ne is 24.4 ± 0.5

My Background

PhD: I worked in Los Alamos A(π^+,π^-) with Terry Fortune.

Double-analog transition $^{48}(\pi^+,\pi^-)^{48}$Ti at 35 and 50 MeV

Phys. Rev. C **35**, 1425 – Published 1 April 1987

H. W. Baer, M. J. Leitch, R. L. Burman, M. D. Cooper, A. Z. Cui, B. J. Dropesky, G. C. Giesler, F. Irom, C. L. Morris, J. N. Knudson, J. R. Comfort, D. H. Wright, and R. Gilman

ABSTRACT

Differential cross sections for the double-isobaric-analog-state transition in the reaction ^{48}Ca(π^+,π^-)^{48}Ti at an incident energy of 35 MeV were measured over the angular range 20°–80°. The cross section extrapolated to 0° is *3.1±0.8* μb/sr,

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Double-analog transition $^{48}(\pi^+,\pi^-)^{48}$Ti at 35 and 50 MeV

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ABSTRACT

Differential cross sections for the double-isobaric-analog-state transition in the reaction ^{48}Ca(π^+,π^-)^{48}Ti at an incident energy of 35 MeV were measured over the angular range 20°–80°. The cross section extrapolated to 0° is *3.1±0.8* μb/sr,

Lesson: publish

My Background

PhD: I worked in Los Alamos A(π^+,π^-) with Terry Fortune.

I joined ANL in 1986 - I was interested in Argonne for its EM physics, and heading towards a research program at CEBAF.

The interest in QCD & NP was overwhelming the interest in π's and Δ's in nuclei.

Terry: The problem with letting your students graduate...

At Argonne

Don: Bates A(e,e'p) and FNAL E665 μ DIS "EMC" experiment

Hal: Saclay p,d(e,e'π) and nuclear π excess

Roy: Novosibirsk T_{20} and SLAC NPAS NE8

Stuart, JimNap, ...

NE8 & T_{20}

A similar motivation - what was the role of quarks in nuclei?

In particular - could "high" energy nuclear reactions follow predictions from perturbative QCD?

For NE8: constituent counting rules: $d\sigma/dt(\theta_{cm}) \sim s^{2-n}$

Or the reduced nuclear amplitudes approach:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega_{\mathrm{cm}}} \propto \frac{1}{s - m_{\mathrm{d}}^2} F_{\mathrm{p}}^2(\hat{t_{\mathrm{p}}}) F_{\mathrm{n}}^2(\hat{t_{\mathrm{n}}}) \frac{1}{p_T^2} f^2(\theta_{\mathrm{cm}})$$

For T_{20}: does it approach $-\sqrt{2}$

NE8

Several trips to SLAC to setup.

Roy worked very hard, including weekends before PAC meetings. And when he was at Argonne.

VOLUME 61, NUMBER 22 PHYSICAL REVIEW LETTERS 28 NOVEMBER 1988

Measurement of the Differential Cross Section for the Reaction $^2H(\gamma,p)n$ at High Photon Energies and $\theta_{c.m.}=90°$

J. Napolitano,[a] S. J. Freedman, D. F. Geesaman, R. Gilman, M. C. Green,[b] R. J. Holt, H. E. Jackson, R. Kowalczyk, C. Marchand,[c] J. Nelson, and B. Zeidman
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439-4843

D. Beck, G. Boyd, D. Collins, B. W. Filippone, J. Jourdan, R. D. McKeown, R. Milner, D. Potterveld,[d] R. Walker, and C. Woodward
California Institute of Technology, Pasadena, California 91125

R. E. Segel and T.-Y. Tung
Northwestern University, Evanston, Illinois 60201

P. E. Bosted
American University, Washington, D.C. 20016

E. R. Kinney[e]
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

Z.-E. Meziani
Stanford University, Stanford, California 94305

R. Minehart
University of Virginia, Charlottesville, Virginia 22901
(Received 8 June 1988)

We have measured the differential cross section for two-body deuteron photodisintegration at $\theta_{c.m.}=90°$ and for photon energies between 0.8 and 1.6 GeV. At energies above $\simeq$1.2 GeV, the data appear to obey a simple scaling law predicted by constituent-counting rules assuming parton degrees of freedom for the deuteron and nucleons. Agreement with model calculations based on meson exchange or "reduced nuclear amplitudes" is discussed.

NE8

Several trips to SLAC to setu

Roy worked very hard, includ
meetings. And when he was a

High p_T data scale!

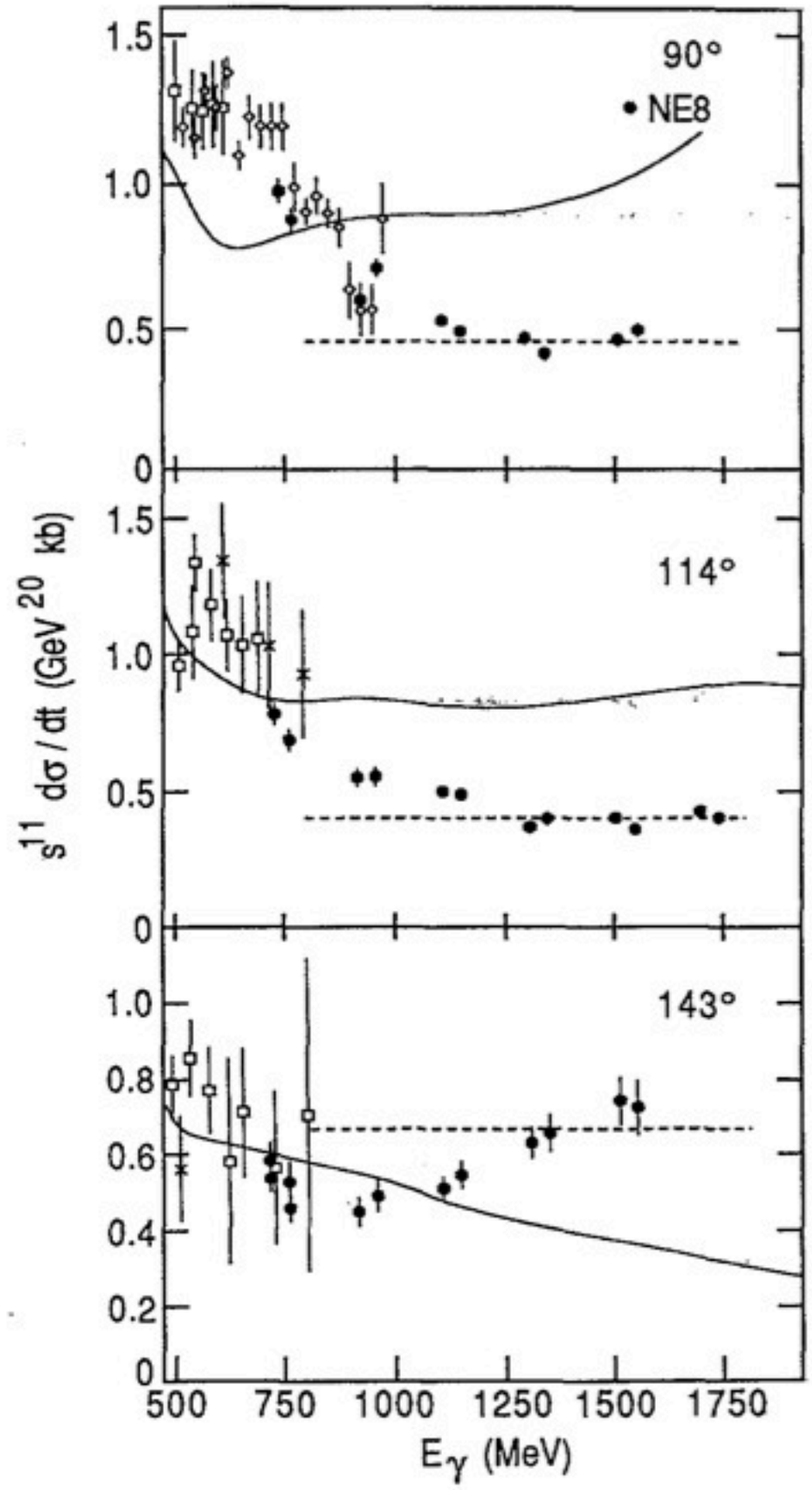

FIG. 14. Photon energy dependence of the disintegration cross section $d\sigma/dt$ scaled by the expected s^{11} dependence. (See text for discussion.) The data and solid curve are as in Fig. 13. The dashed line is arbitrarily normalized.

NE8

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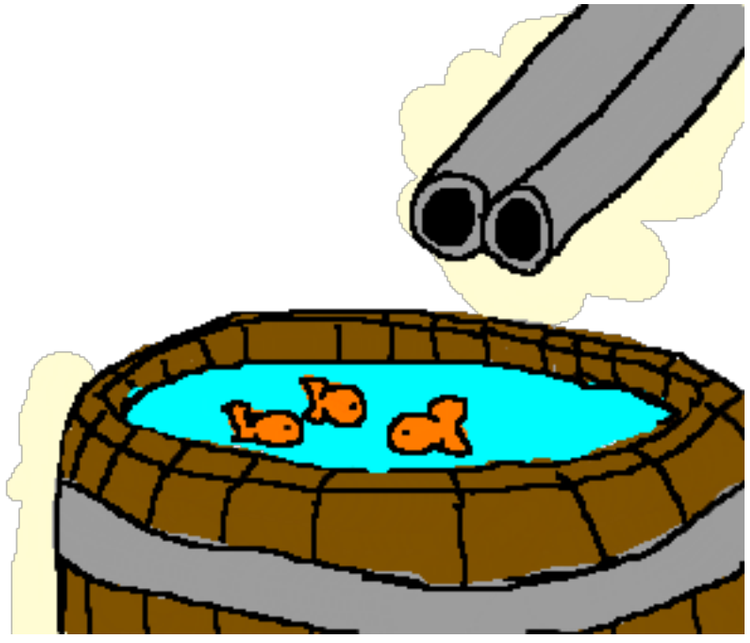

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T_{20}

I did not have the pleasure of going to Siberia until winter 1990, after I left Argonne for Rutgers - I only worked on simulations of the increased density in the target cell. Including while on NE8 shifts. Despite that...

Measurement of Tensor Analyzing Power in Electron-Deuteron Elastic Scattering

R. Gilman,[1],[a] R. J. Holt,[1] E. R. Kinney,[1] R. S. Kowalczyk,[1] S. I. Mishnev,[2] J. Napolitano,[1],[b] D. M. Nikolenko,[2] S. G. Popov,[2] D. H. Potterveld,[1] I. A. Rachek,[2] A. B. Temnykh,[2] D. K. Toporkov,[2] E. P. Tsentalovich,[2] B. B. Wojtsekhowski,[2] and L. Young[1]

[1]*Argonne National Laboratory, Argonne, Illinois 60439-4843*

[2]*Institute of Nuclear Physics, Novosibirsk 630090, U.S.S.R.*

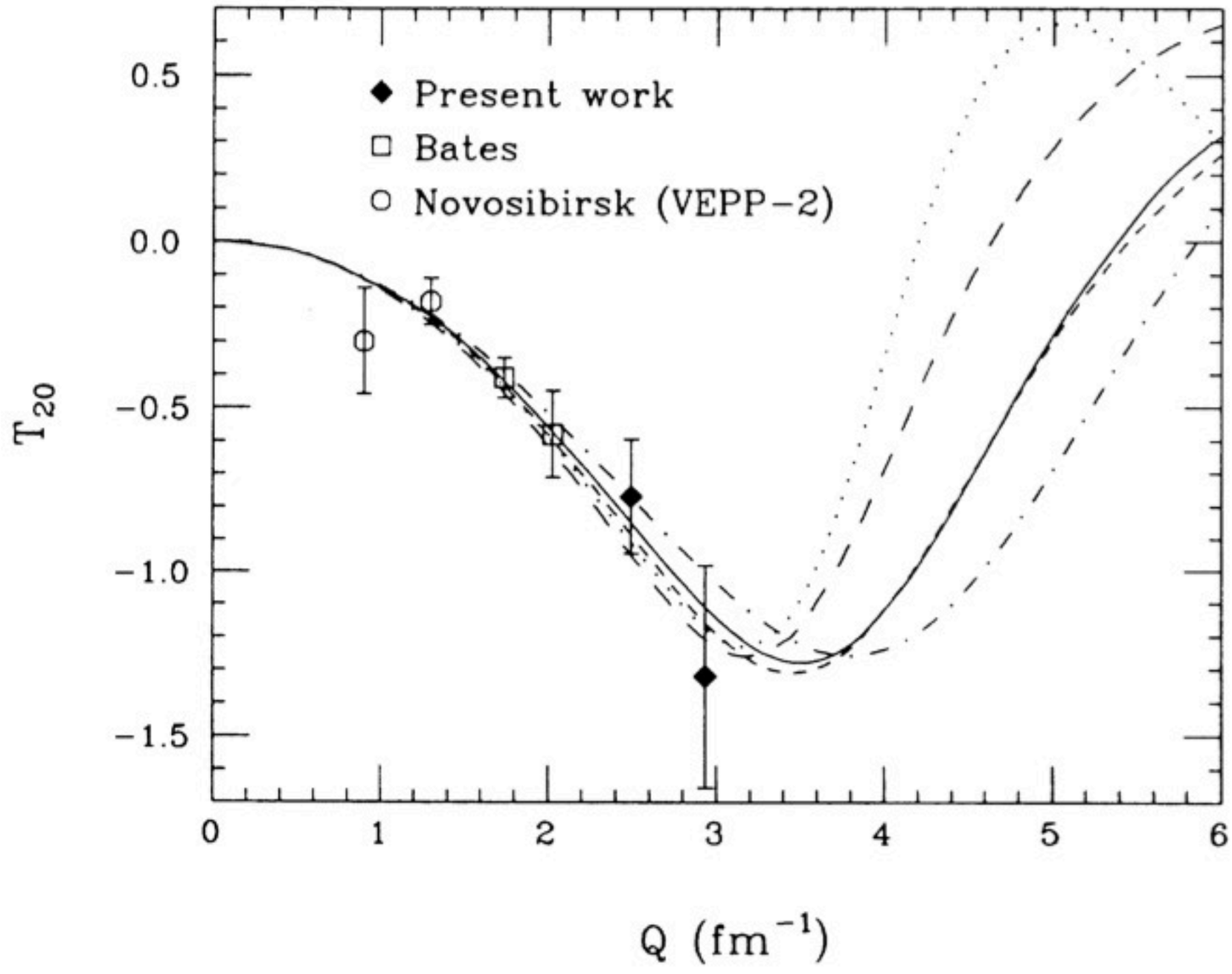
(Received 14 June 1990)

An internal-target technique was used to make the first measurements of the tensor analyzing power T_{20} of electron-deuteron elastic scattering in the four-momentum-transfer range of 2–3 fm^{-1}. Polarized deuterium atoms were confined within a storage cell in the VEPP-3 electron storage ring in Novosibirsk to achieve a total target thickness of 3×10^{12} cm^{-2}, 15 times greater than was previously possible with an atomic-beam target alone. The results for T_{20} are in agreement with reasonable models of the deuteron wave function.

1990 PRL: first storage cell in a ring!
First of several ANL/BINP measurements.

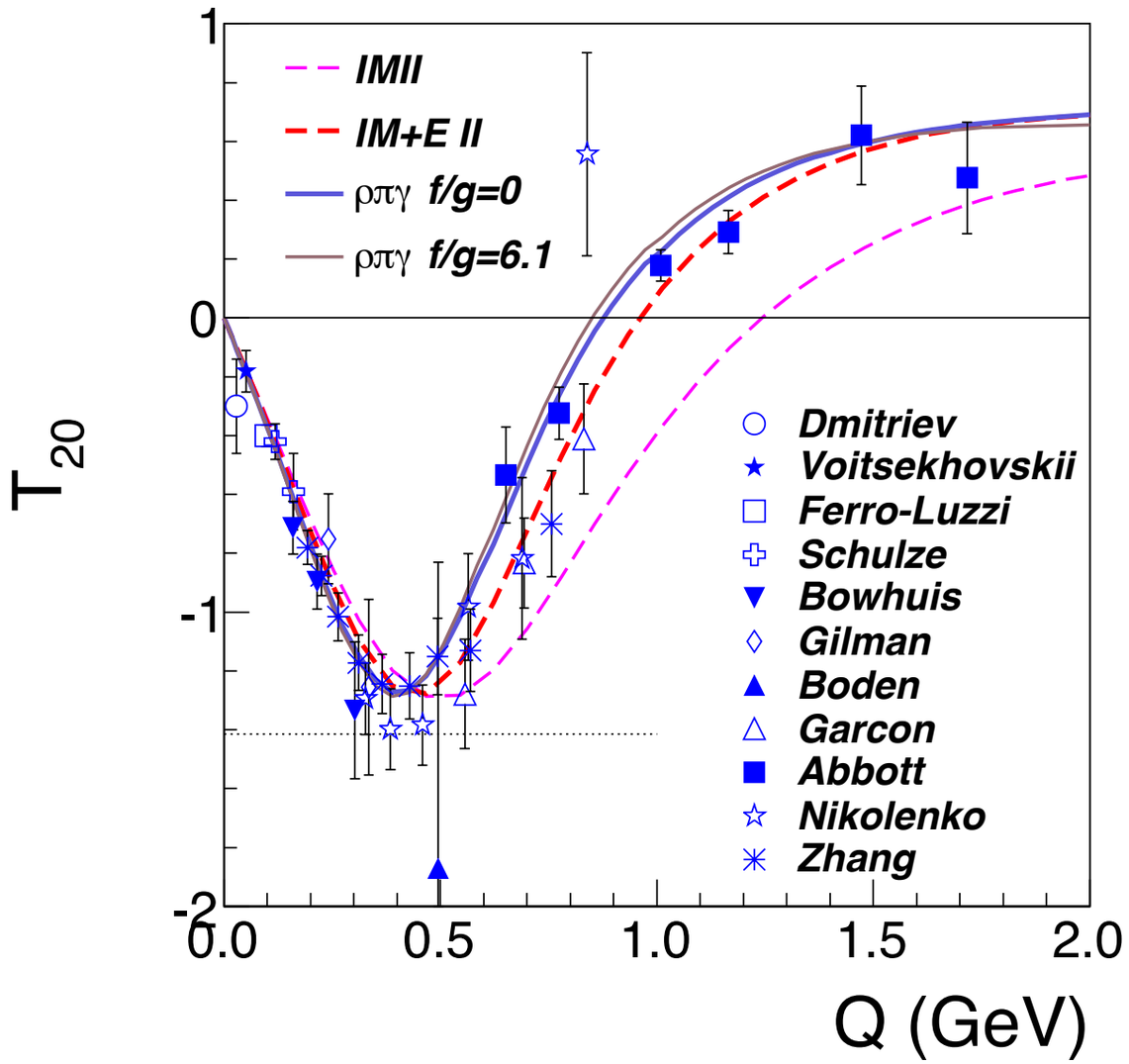
T_{20}

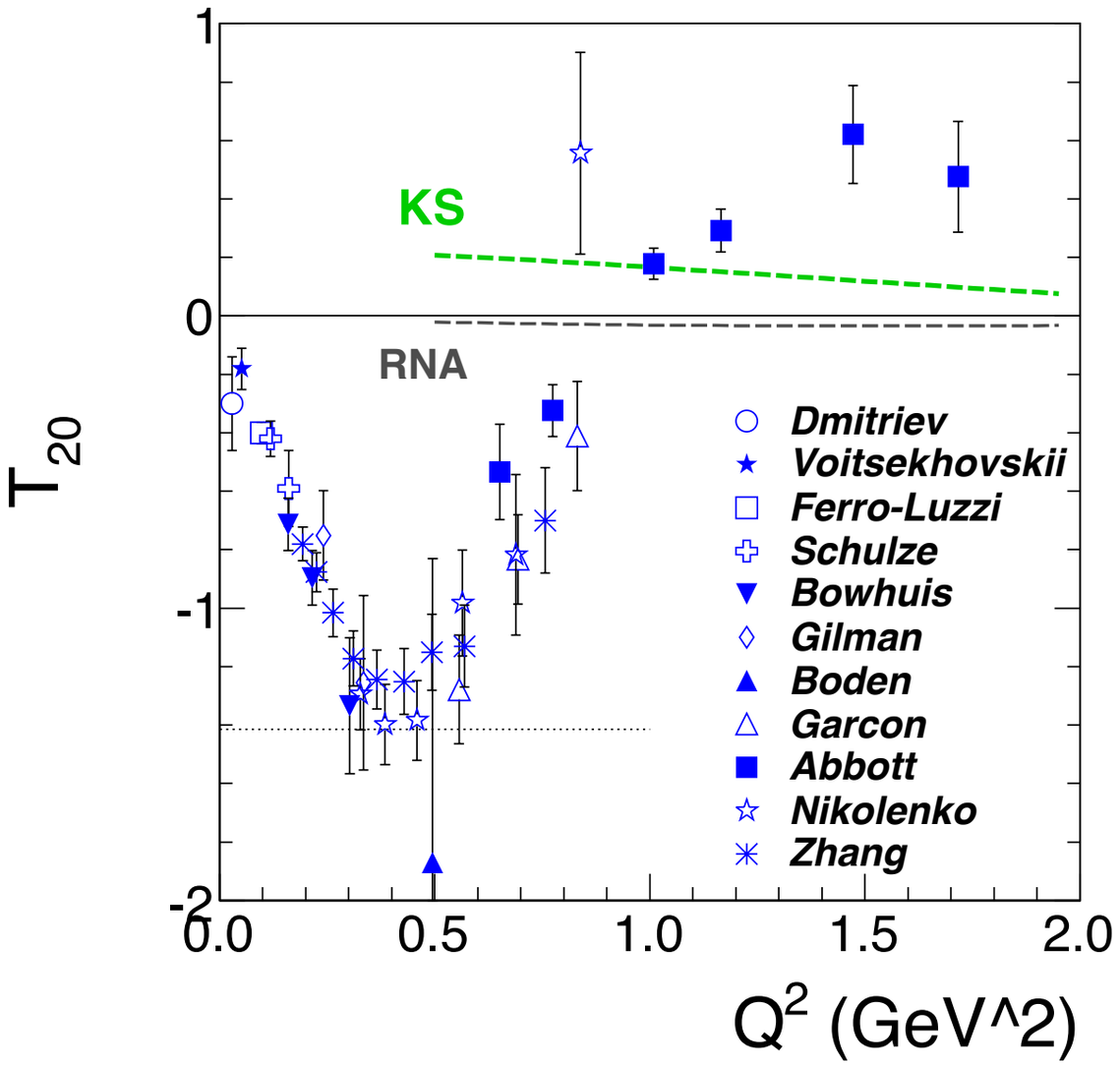
I did not have the pleasure of going to Siberia until winter 1990, after I left Argonne for Rutgers - I only worked on simulations of the increased density in the target cell. Including while on NE8 shifts. Despite that...



T_{20}

Figures from Holt + Gilman, ROP 75 (2012)





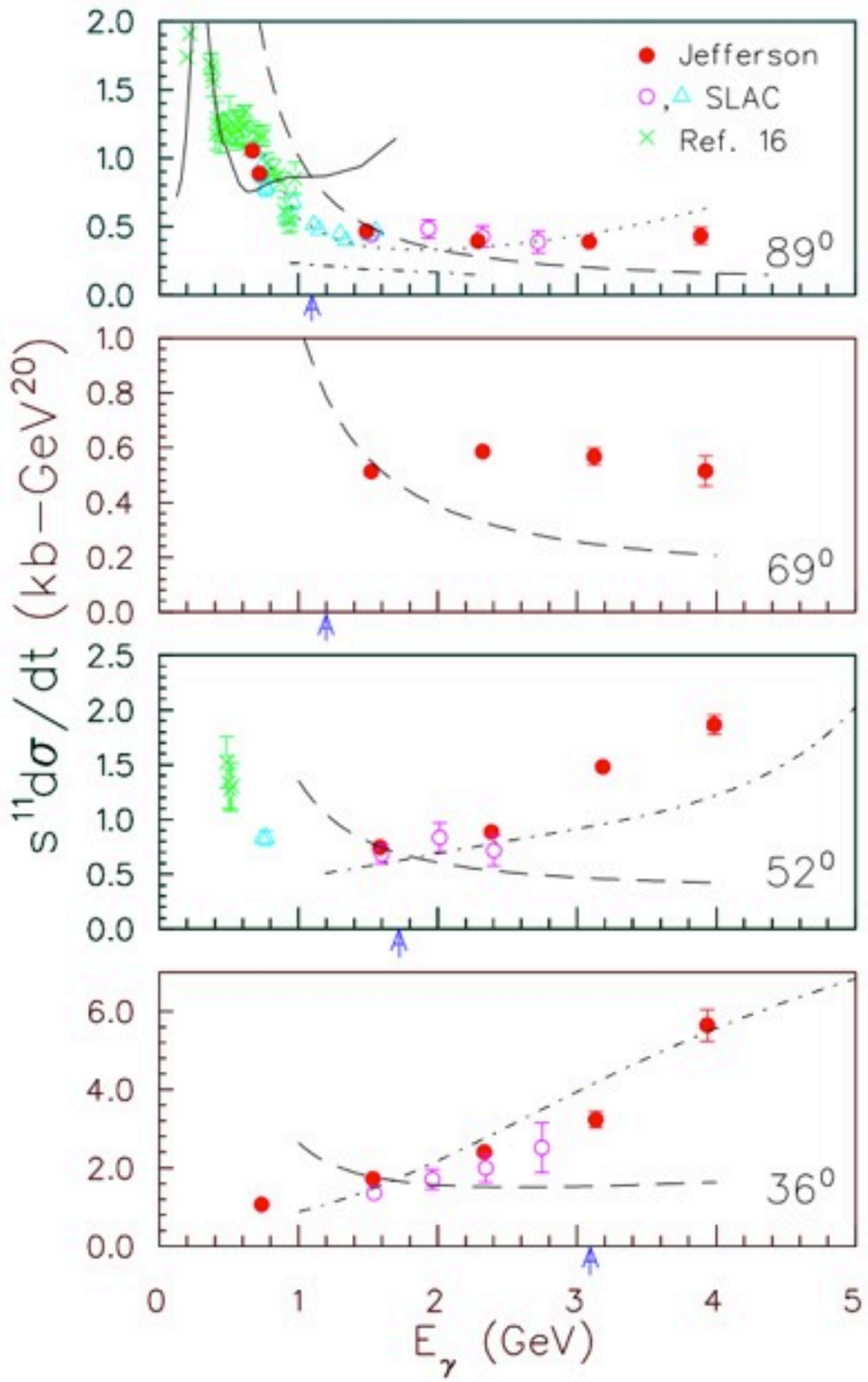
Argonne to JLab

Starting with the 1989 PAC, "we" submitted a series of high energy photoreaction proposals to the JLab PAC, and ran many experiments.

89-003: Holt et al.

Hall C high energy cross sections

The most significant finding was not the HMS gate valve.



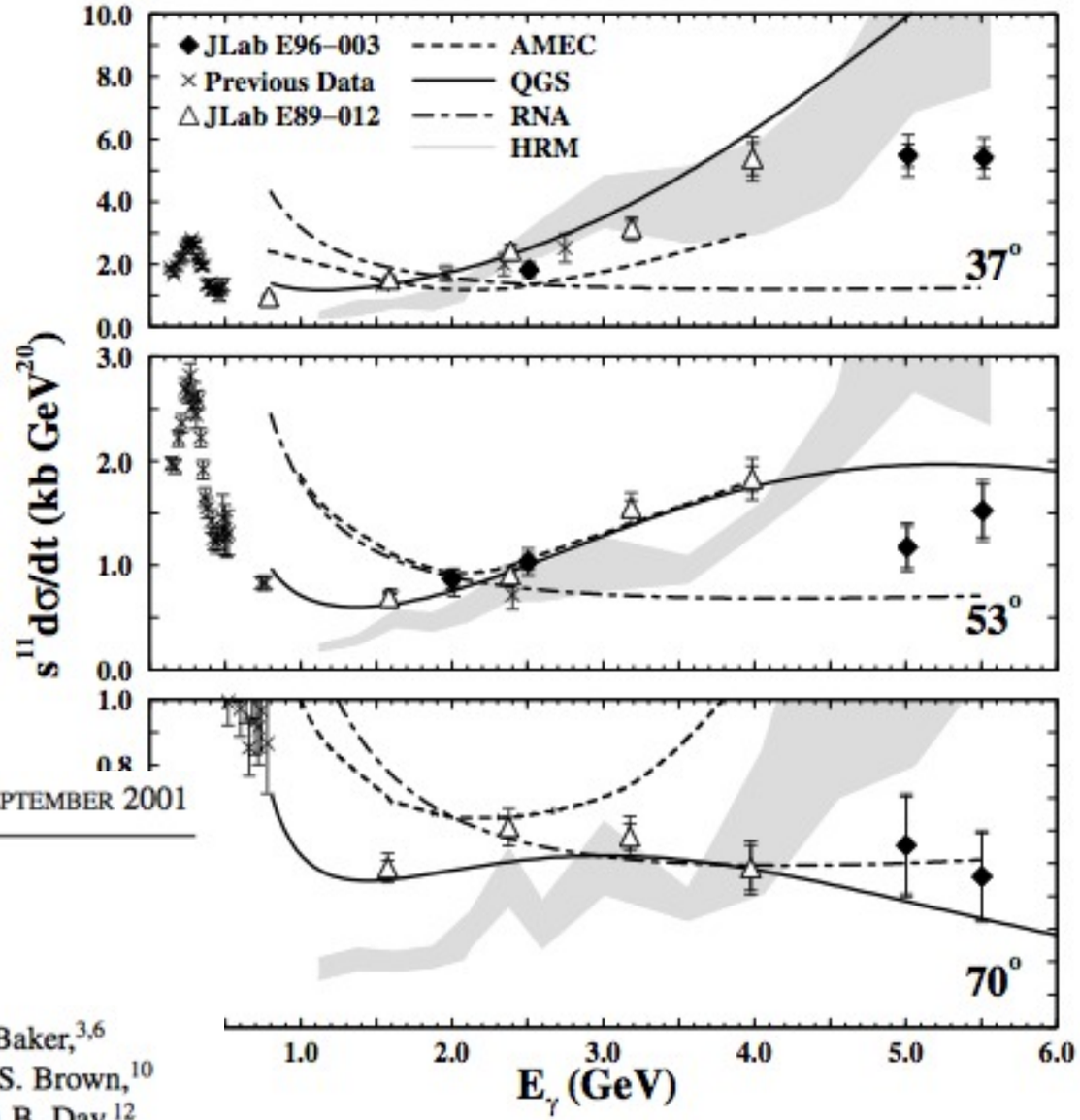
VOLUME 81, NUMBER 21 PHYSICAL REVIEW LETTERS 23 NOVEMBER 1998

Measurements of Deuteron Photodisintegration up to 4.0 GeV

C. Bochna,[1] B.P. Terburg,[1] D.J. Abbott,[2] A. Ahmidouch,[3] C.S. Armstrong,[4] J. Arrington,[5] K.A. Assamagan,[6] O.K. Baker,[2,6] S.P. Barrow,[7] D.P. Beatty,[7] D.H. Beck,[1] S.Y. Beedoe,[8] E.J. Beise,[9] J.E. Belz,[10] P.E. Bosted,[11] E.J. Brash,[12,18] H. Breuer,[9] R.V. Cadman,[1] L. Cardman,[2] R.D. Carlini,[2] J. Cha,[6] N.S. Chant,[9] G. Collins,[9] C. Cothran,[13] W.J. Cummings,[14] S. Danagoulian,[8] F.A. Duncan,[9] J.A. Dunne,[2] D. Dutta,[15] T. Eden,[6] R. Ent,[2] B.W. Filippone,[5] T.A. Forest,[1] H.T. Fortune,[7] V.V. Frolov,[16] H. Gao,[1,17] D.F. Geesaman,[14] R. Gilman,[18] P.L.J. Gueye,[6] K.K. Gustafsson,[9] J.-O. Hansen,[14] M. Harvey,[6] W. Hinton,[6] R.J. Holt,[1] H.E. Jackson,[14] C.E. Keppel,[6] M.A. Khandaker,[19] E.R. Kinney,[20] A. Klein,[21] D.M. Koltenuk,[7] G. Kumbartzki,[17] A.F. Lung,[9] D.J. Mack,[2] R. Madey,[3,6] P. Markowitz,[22] K.W. McFarlane,[19] R.D. McKeown,[5] D.G. Meekins,[4] Z.-E. Meziani,[23] M.A. Miller,[1] J.H. Mitchell,[2] H.G. Mkrtchyan,[24] R.M. Mohring,[9] J. Napolitano,[16] A.M. Nathan,[1] G. Niculescu,[6] I. Niculescu,[6] T.G. O'Neill,[14] B.R. Owen,[1] S.F. Pate,[25] D.H. Potterveld,[14] J.W. Price,[16] G.L. Rakness,[20] R. Ransome,[18] J. Reinhold,[14] P.M. Rutt,[18] C.W. Salgado,[19] G. Savage,[6] R.E. Segel,[15] N. Simicevic,[1] P. Stoler,[16] R. Suleiman,[3] L. Tang,[6] D. van Westrum,[20] W.F. Vulcan,[2] S. Williamson,[1] M.T. Witkowski,[16] S.A. Wood,[2] C. Yan,[2] and B. Zeidman[14]

96-003: Holt et al.
Hall C high energy cross sections

The last in the Hall C series, to the highest energies achieved. A number of models were developed.



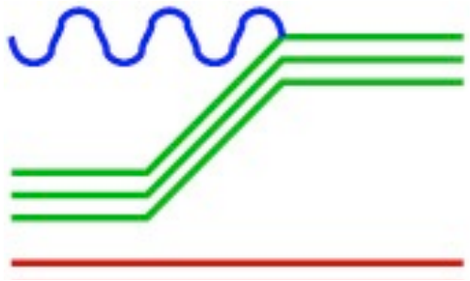
VOLUME 87, NUMBER 10 PHYSICAL REVIEW LETTERS 3 SEPTEMBER 2001

Measurement of the High Energy Two-Body Deuteron Photodisintegration Differential Cross Section

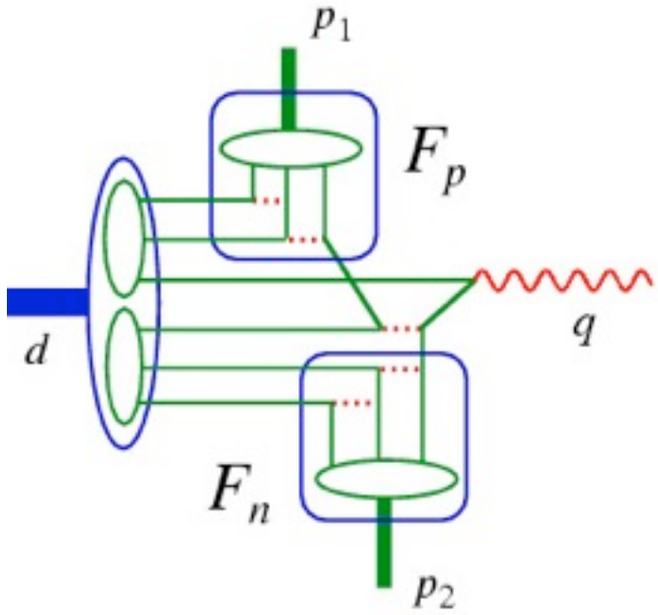
E. C. Schulte,[1] A. Ahmidouch,[2] C. S. Armstrong,[3] J. Arrington,[4] R. Asaturyan,[5] S. Avery,[6] O. K. Baker,[3,6] D. H. Beck,[1] H. P. Blok,[7] C. W. Bochna,[1] W. Boeglin,[8] P. Y. Bosted,[9] M. Bouwhuis,[1] H. Breuer,[10] D. S. Brown,[10] A. Bruell,[11] R. V. Cadman,[1] R. Carlini,[3] N. S. Chant,[10] A. Cochran,[6] L. Cole,[6] S. Danagoulian,[2,3] D. B. Day,[12] J. A. Dunne,[13] D. Dutta,[11] R. Ent,[3] H. C. Fenker,[3] B. Fox,[14] L. Gan,[6] H. Gao,[11] K. Garrow,[3] D. Gaskell,[4] A. Gasparian,[6] D. F. Geesaman,[4] R. Gilman,[3,15] C. Glashausser,[15] P. Gueye,[6] M. Harvey,[6] R. J. Holt,[1,*] H. E. Jackson,[4] X. Jiang,[15] C. E. Keppel,[3,6] E. R. Kinney,[14] Y. Liang,[9] W. Lorenzon,[17] A. F. Lung,[3] D. J. Mack,[3] P. E. Markowitz,[8] J. Martin,[11] K. McIlhany,[11] D. McKee,[18] D. G. Meekins,[19] M. A. Miller,[1] R. G. Milner,[11] J. H. Mitchell,[3] H. Mkrtchyan,[5] B. A. Mueller,[4] A. M. Nathan,[1] G. Niculescu,[20] I. Niculescu,[21] T. G. O'Neill,[4] V. Papavassiliou,[18] S. F. Pate,[18] R. B. Piercey,[13] D. H. Potterveld,[4] R. D. Ransome,[15] J. Reinhold,[8] E. Rollinde,[3] P. Roos,[10] A. Saha,[3] A. J. Sarty,[19,†] R. Sawafta,[2] E. Segbefia,[6] T. Shin,[11] S. Stepanyan,[5] S. Strauch,[15] M. F. Sutter,[11] V. Tadevosyan,[5] L. Tang,[6] R. Tieulent,[3] A. Uzzle,[6] W. F. Vulcan,[3] S. A. Wood,[3] F. Xiong,[9] L. Yuan,[6] M. Zeier,[12] B. Zihlmann,[12] and V. Ziskin[11]

A number of quark models were developed…

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

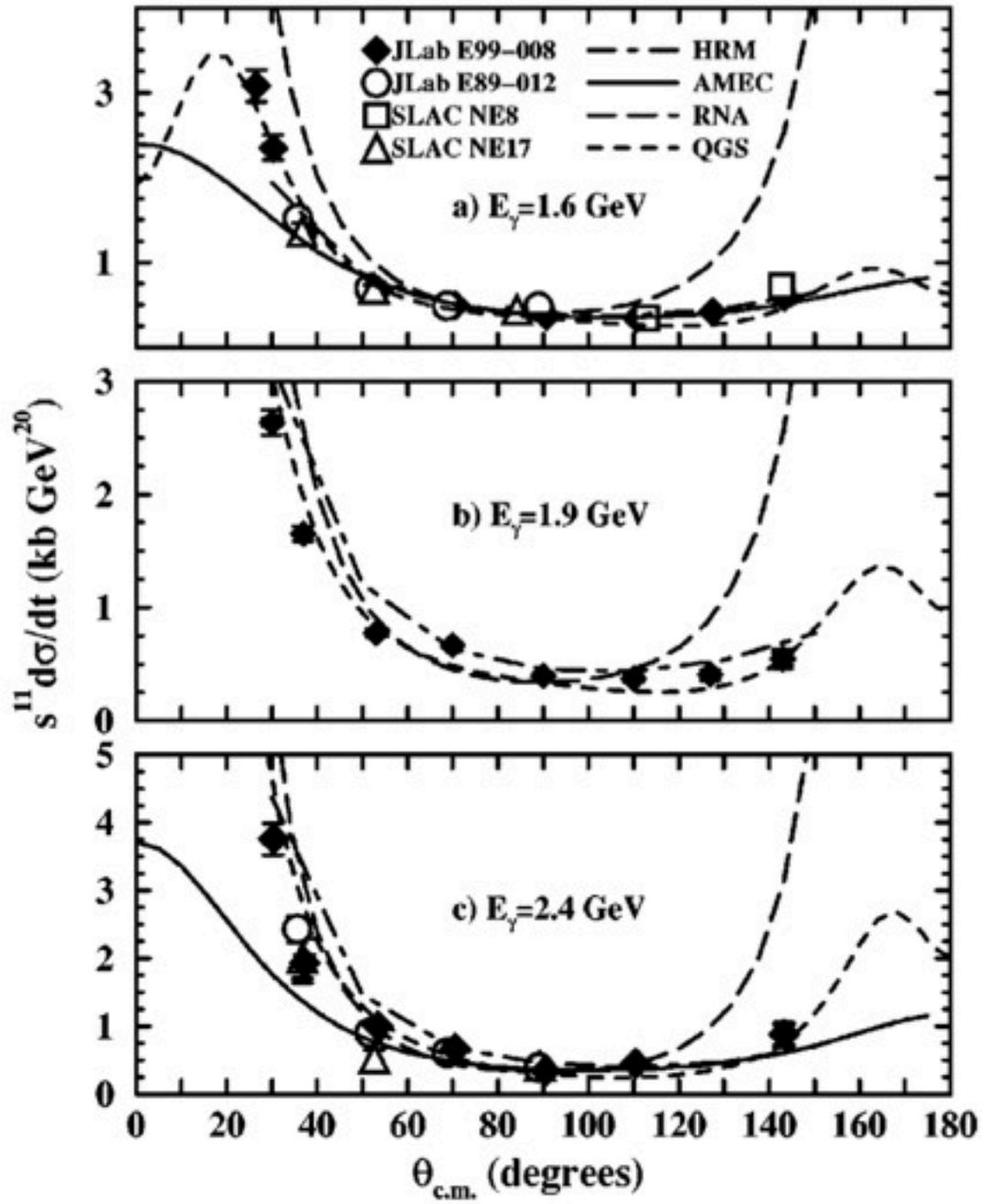


- RNA, HRM, TQC, CQM: Photon absorbed and quarks exchanged; might be related to NN elastic scattering – all use hard scattering approximations



99-008: Gilman, Holt, Meziani et al. Hall A high energy cross sections

In the end, Hall B had a large data set up to about 3 GeV from E93-017. Scaling once pT ≳ 1.1 GeV/c. P Rossi et al, PRL94.



PHYSICAL REVIEW C **66**, 042201(R) (2002)

High energy angular distribution measurements of the exclusive deuteron photodisintegration reaction

E. C. Schulte,[1,2] A. Afanasev,[3,4] M. Amarian,[5] K. Aniol,[6] S. Becher,[7] K. Benslama,[8] L. Bimbot,[9] P. Bosted,[10] E. Brash,[8] J. Calarco,[11] Z. Chai,[12] C. Chang,[13] T. Chang,[1] J. P. Chen,[3] S. Choi,[14] E. Chudakov,[12] S. Churchwell,[15] D. Crovelli,[16] S. Dieterich,[16] S. Dumalski,[8] D. Dutta,[12] M. Epstein,[6] K. Fissum,[17] B. Fox,[18] S. Frullani,[5] H. Gao,[12] J. Gao,[19] F. Garibaldi,[5] O. Gayou,[20,21] R. Gilman,[3,16] A. Glamazdin,[22] C. Glashausser,[16] J. Gomez,[3] V. Gorbenko,[22] J.-O. Hansen,[3] R. J. Holt,[2] J. Hovdebo,[8] G. M. Huber,[8] C. W. de Jager,[3] X. Jiang,[16] C. Jones,[19] M. K. Jones,[23] J. Kelly,[13] E. Kinney,[18] E. Kooijman,[24] G. Kumbartzki,[16] M. Kuss,[3] J. LeRose,[3] M. Liang,[3] R. Lindgren,[25] N. Liyanage,[3] S. Malov,[16] D. Margaziotis,[6] P. Markowitz,[26] K. McCormick,[27] D. Meekins,[28] Z.-E. Meziani,[14] R. Michaels,[3] J. Mitchell,[3] L. Morand,[16] C. Perdrisat,[20] R. Pomatsalyuk,[22] V. Punjabi,[29] A. Radyushkin,[3,23] R. Ransome,[16] R. Roche,[28] M. Rvachev,[30] A. Saha,[3] A. Sarty,[28] D. Simon,[7] S. Strauch,[16] R. Suleiman,[12] L. Todor,[23] P. Ulmer,[23] G. M. Urciuoli,[5] K. Wijesooriya,[1,2] B. Wojtsekhowski,[3] F. Xiong,[12] and W. Xu[12]

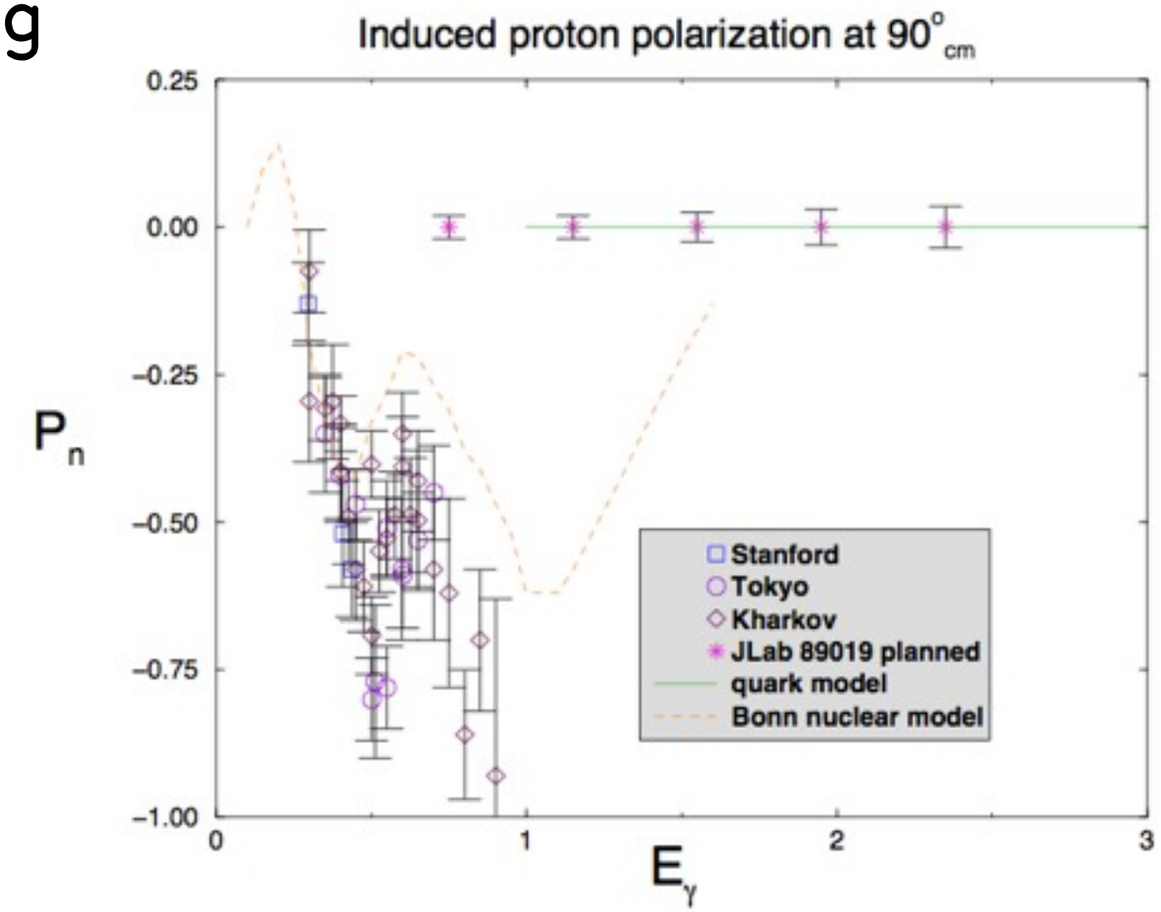
89-019: Gilman, Holt, Meziani et al. Hall A polarizations

Zein-Eddine remembered interesting old polarization data.

Roy agreed.

They sent me off to do the work.

The data were largely taken in the dibaryon craze of the late 1970s / early 1980s.



89-019: Gilman, Holt, Meziani et al.

Hall A polarizations

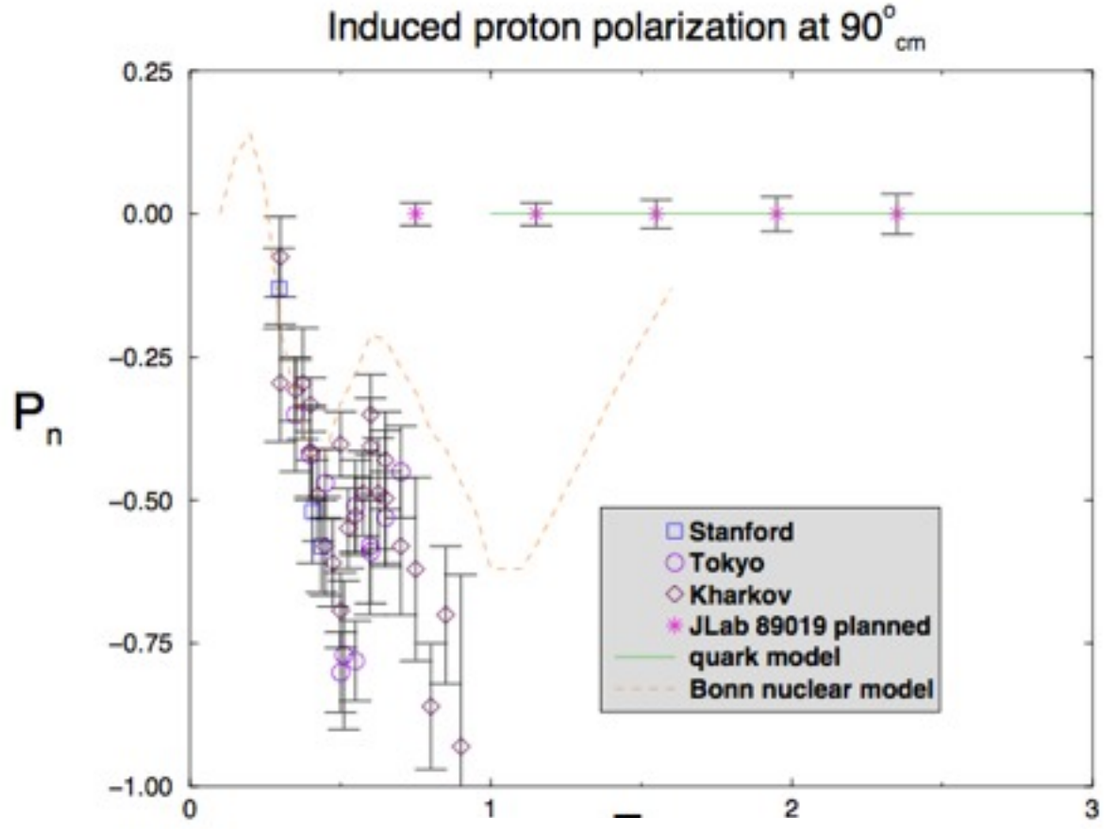
Simple initial idea:

pQCD leads to hadron helicity conservation (HHC).

HHC requires certain amplitudes vanish.

Spin observables approach constant values, often 0.

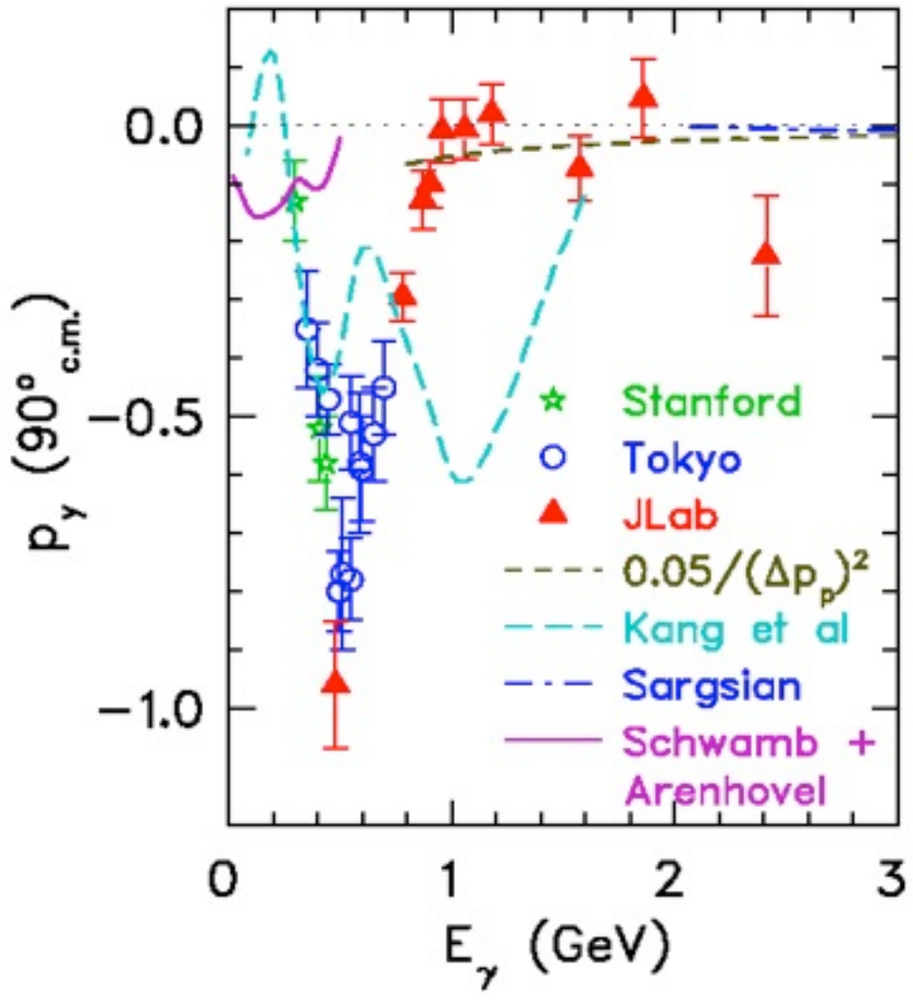
But we all now know there is lots of interesting spin physics.



- $P_n \to 0$
- $T \to 0$
- $\Sigma \to \approx -1$ near 90°
- $C_x \to 0$
- C_z probably small

89-019: Gilman, Holt, Meziani et al. Hall A polarizations

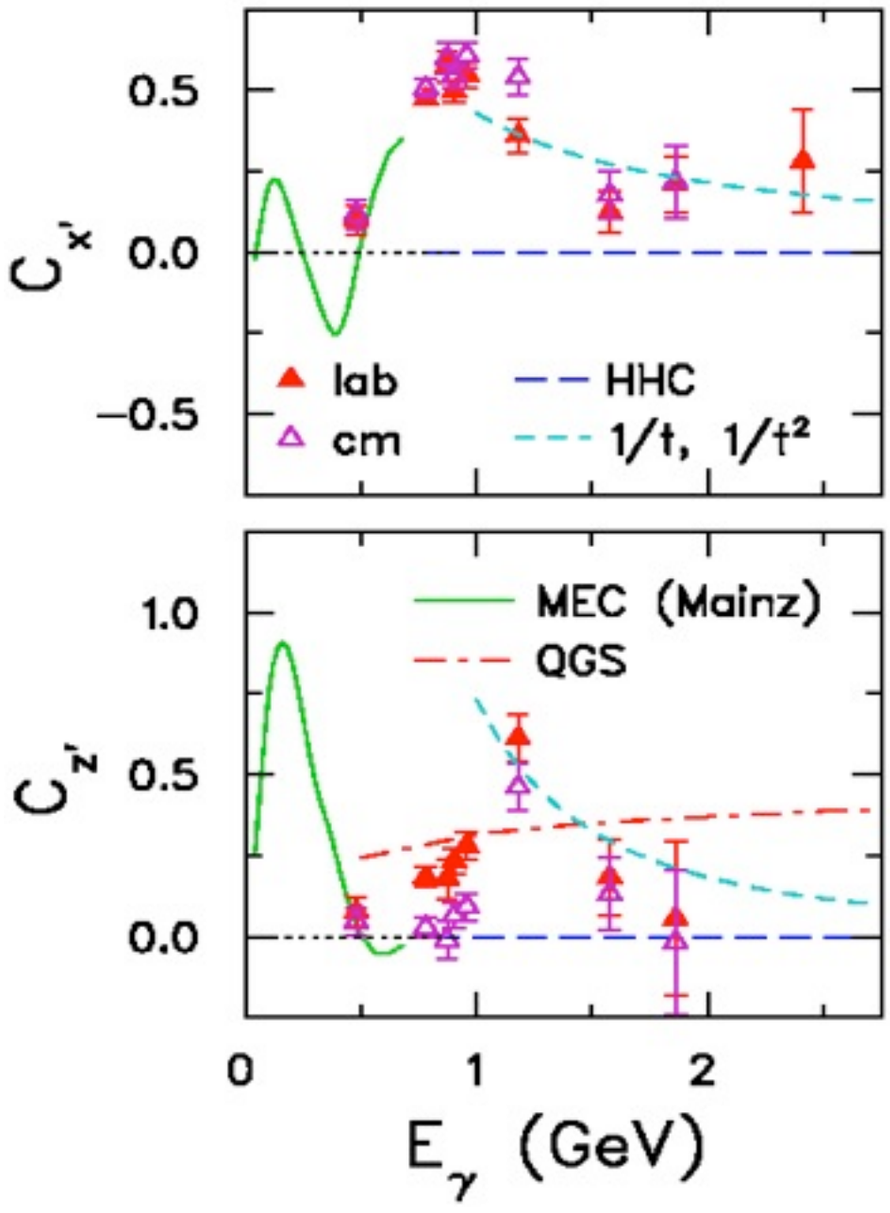
Wijesooriya et al., PRL 86 (2001)



Old Kharkov data had large $-p_y$ near 1 GeV due to experimental issues - not plotted

89-019: Gilman, Holt, Meziani et al. Hall A polarizations

By running the experiment with (circularly) polarized beam, we also managed to measure polarization transfer to the proton - never before done.

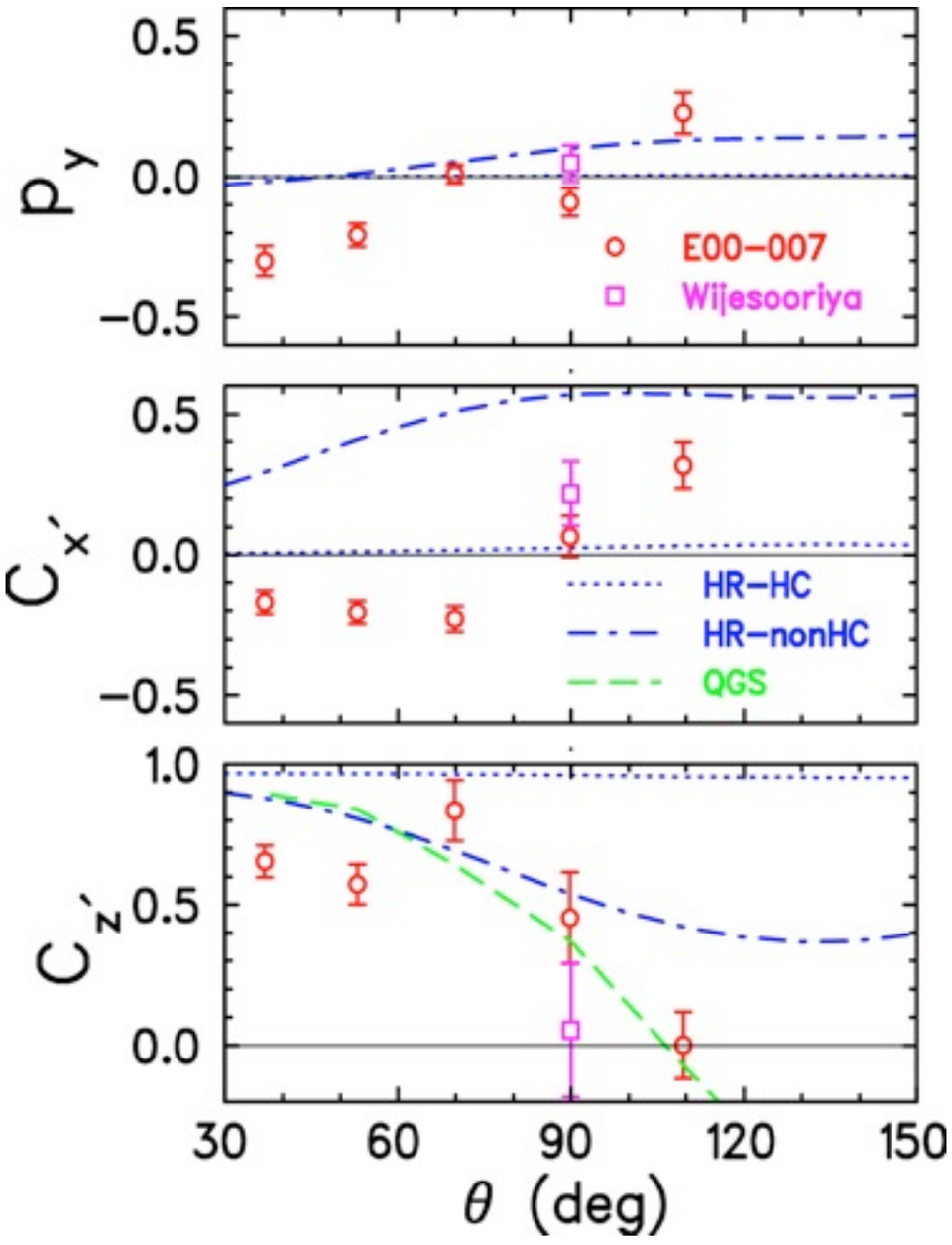


00-007: Gilman, Holt, Meziani et al.

Hall A polarizations

To better understand what was happening, we proposed to push the polarization measurements to higher energies at 90o, and to measure an angular distribution at about 2 GeV.

We only had enough beam time for the angular distribution.

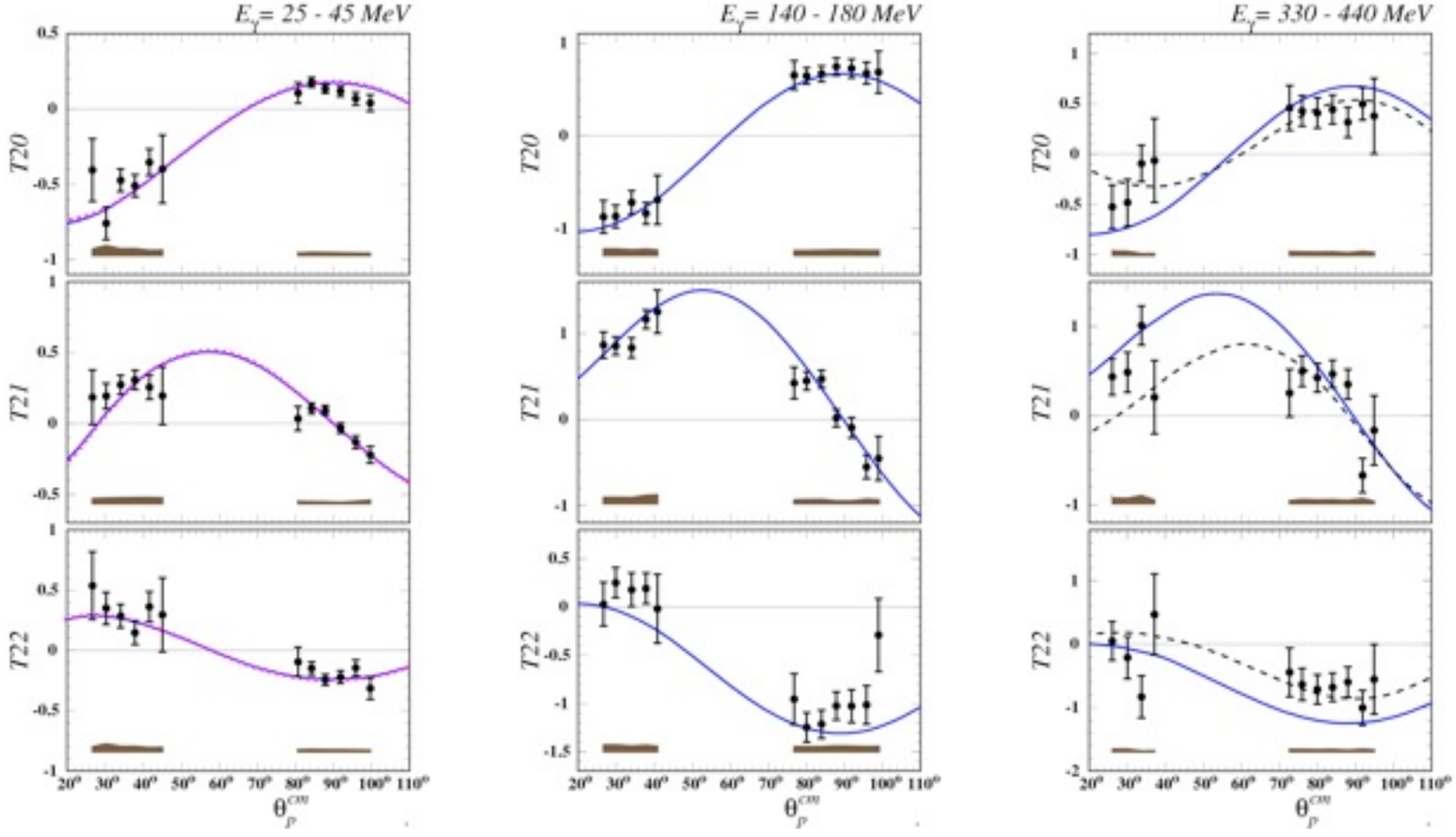


Low energy photo-disintegration

In E05-103, run in 2006, "I" went off to look for how ME calculations diverge from data, with low energy photodisintegration run in parallel with back-angle G0.

Roy was too busy and did not take part. But...

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



Mini-summary for $\gamma d \rightarrow pn$

We started off with a simple pQCD / RNA picture of the high energy reaction.

pQCD worked too well.

RNA, which should work better than pQCD, did not.

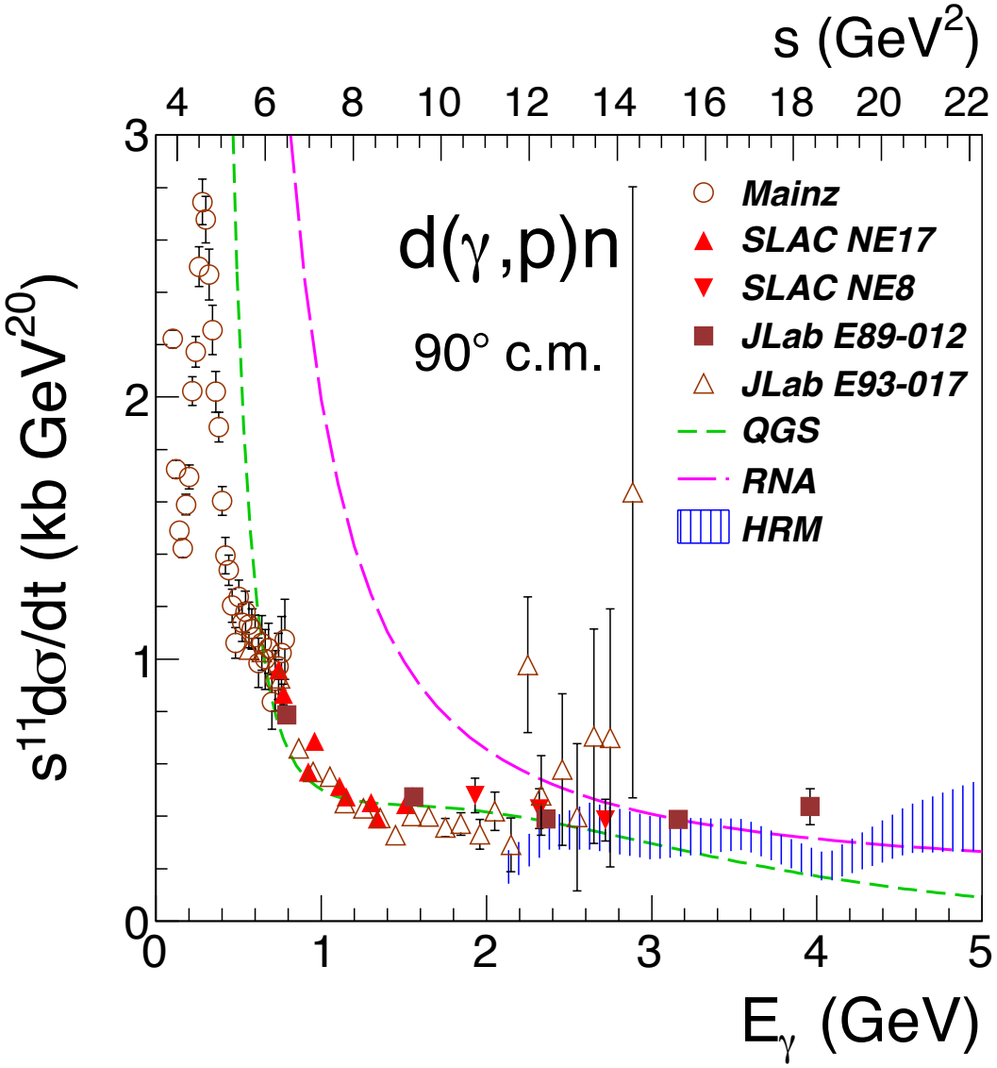
We ended up compare these and a few quark-inspired models to the data, but without a clear answer.

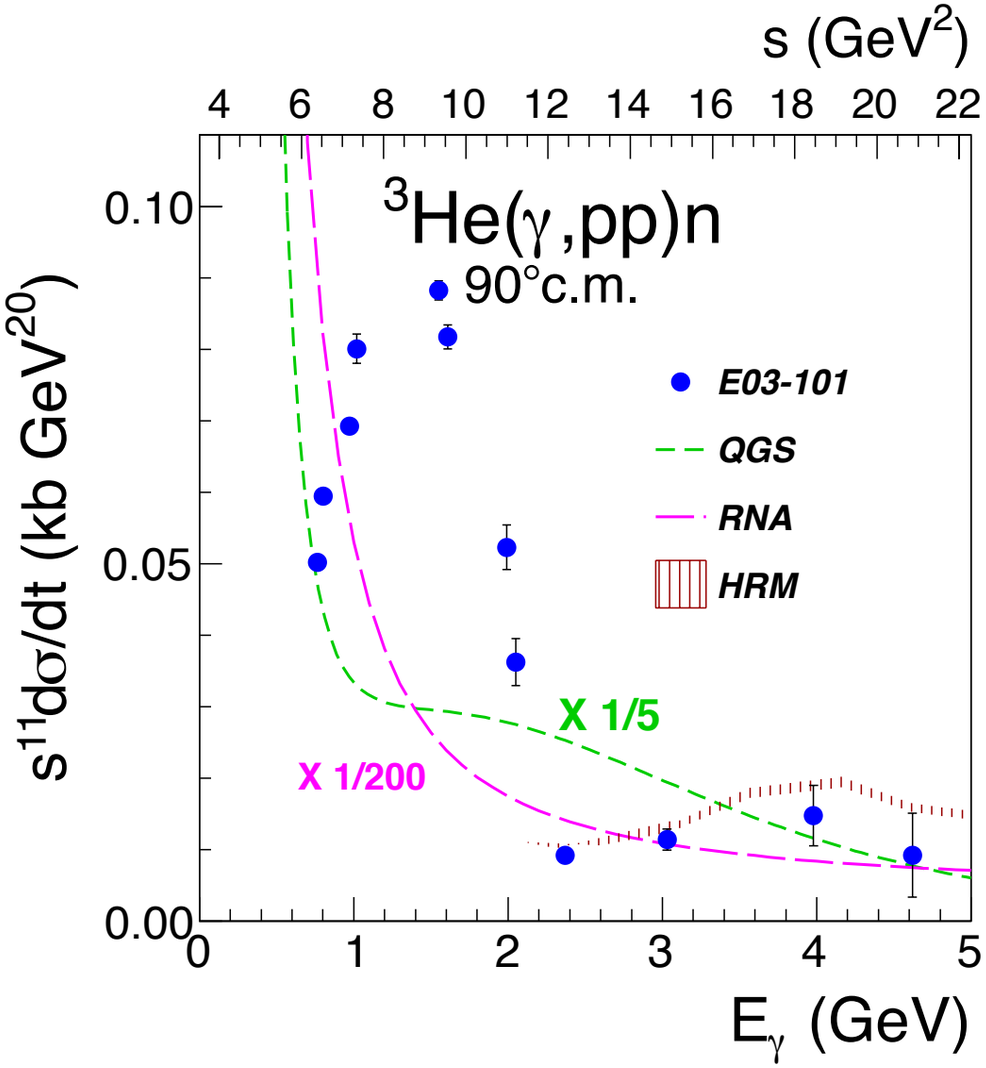
Subsequently - post Roy - we hoped to distinguish better by going from pn disintegration to pp disintegration in ^{3}He.

pp vs pn Photodisintegration

Figures from Holt + Gilman, ROP 75 (2012).

Note how much pp is reduced compared to pn.





Going back to 1994

Two important things happened in 1994.

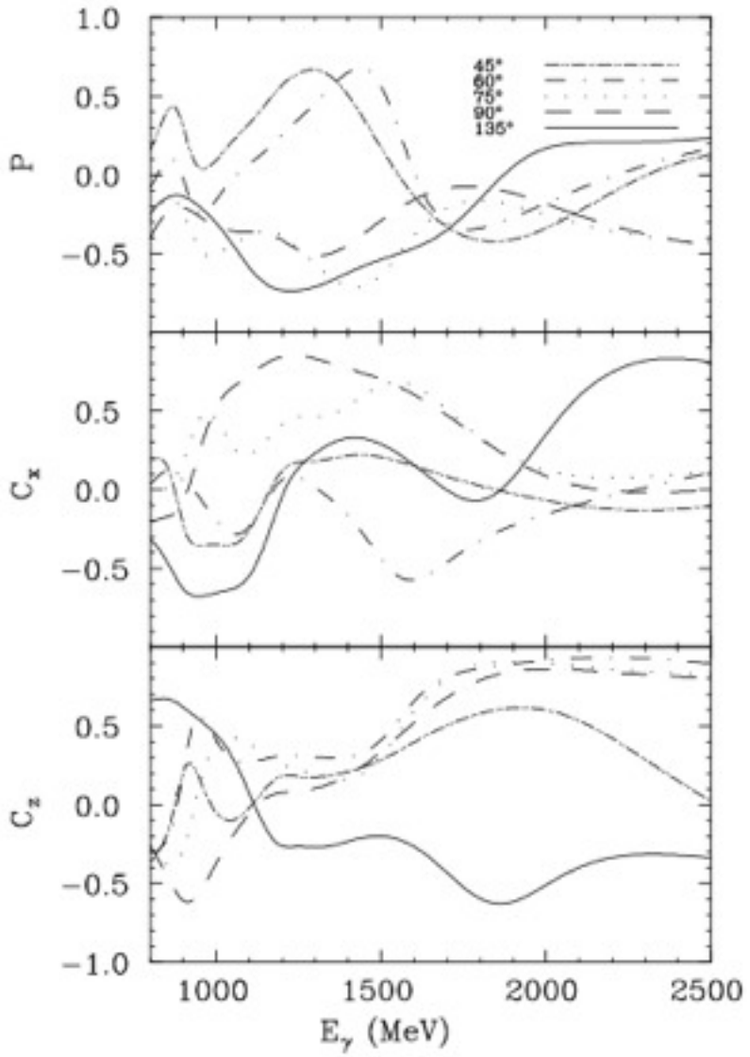
First, Roy suggested we look into pion photoproduction.

Second, at GRC, Roy introduced me to a new collaborator.

$\gamma p \rightarrow p\pi^0$

Many high energy photoreactions were known to scale.

But polarizations had not been measured.

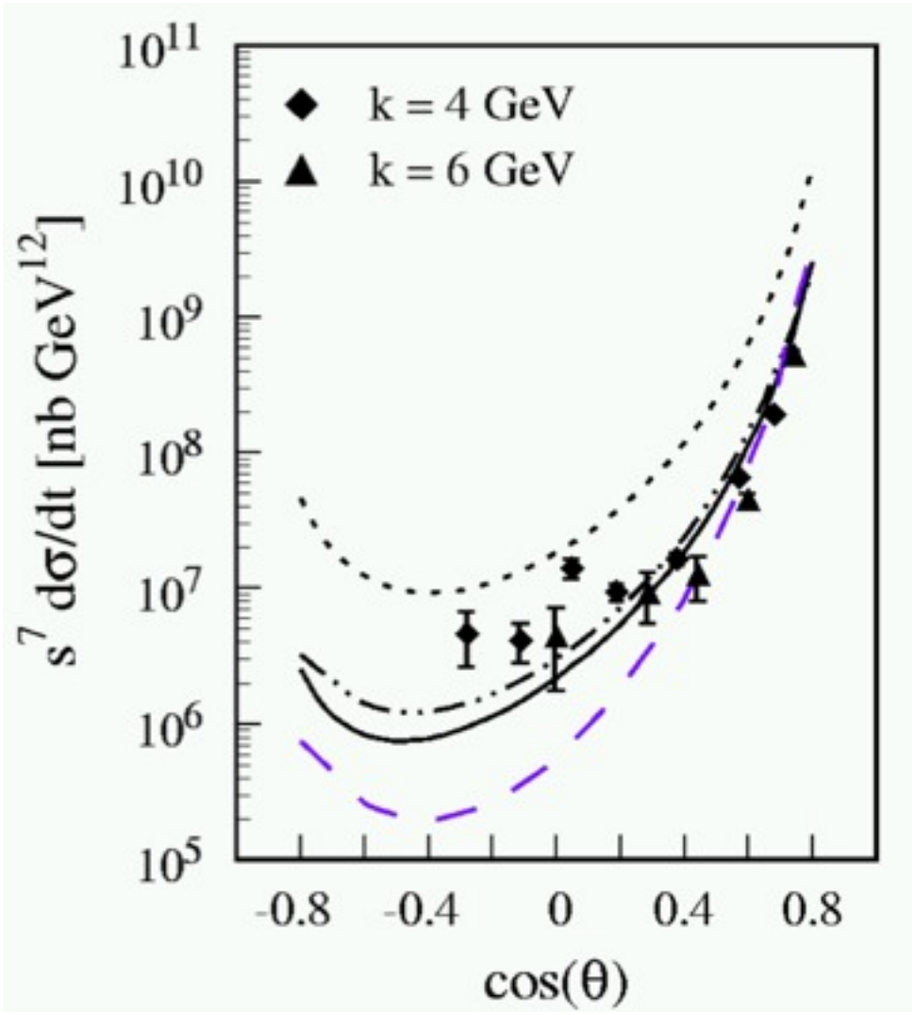


Inadequately constrained PWA indicates resonance induced structures.

HHC eliminates 2 of 4 amplitudes, leading to

$P, C_x \rightarrow 0$

$C_z \rightarrow (s^2-u^2)/(s^2+u^2)$



$\gamma p \rightarrow K^+ \Lambda^0$ compared to calculations by Farrar et al. and by Kroll et al.

E94-012: $\gamma p \rightarrow p\pi^0$, Gilman, Holt et al.

Pion photoproduction ran in fall 1999, interleaved with E89-019.

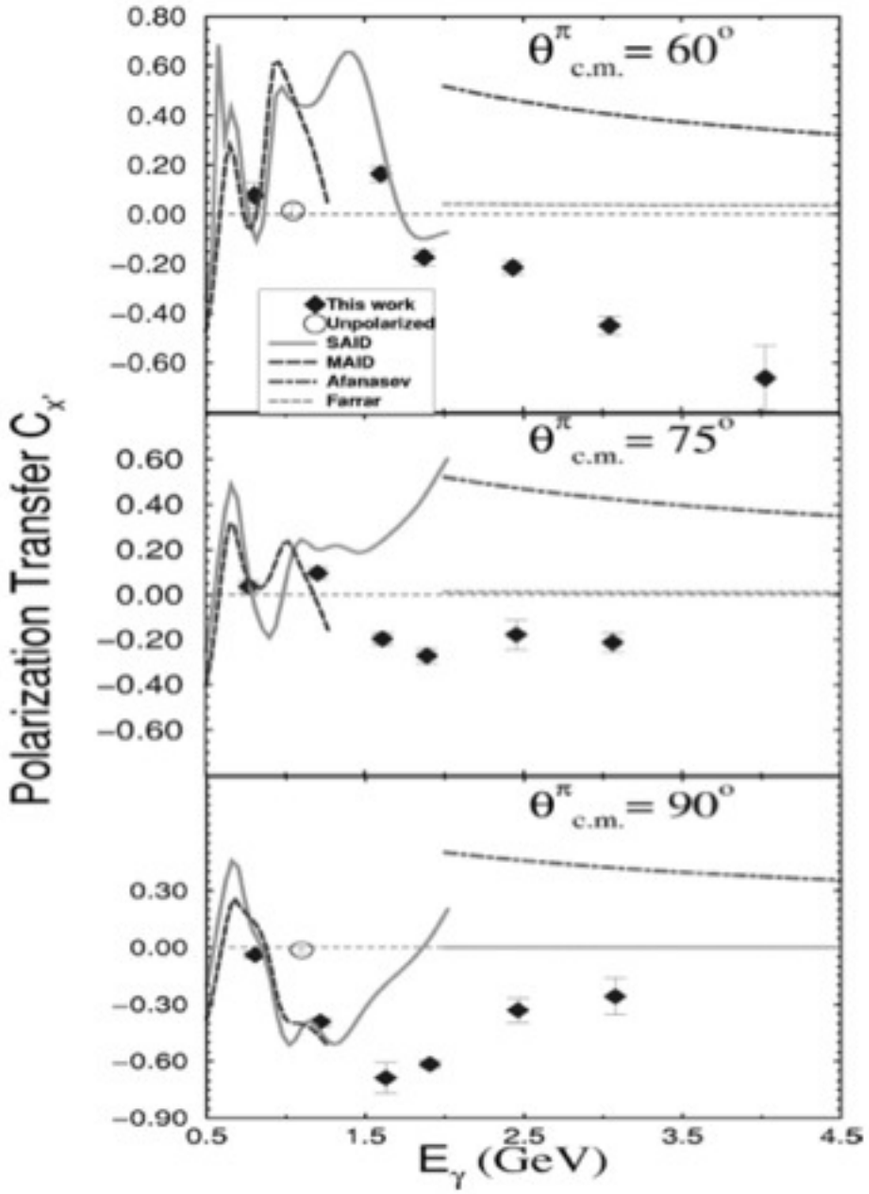
Krishni Wijesooriya, with a little help from Olivier Gayou, analyzed everything.

PHYSICAL REVIEW C **66**, 034614 (2002)

Polarization measurements in neutral pion photoproduction

K. Wijesooriya,[1,*] A. Afanasev,[21,27] M. Amarian,[12] K. Aniol,[4] S. Becher,[10] K. Benslama,[24] L. Bimbot,[23] P. Bosted,[17] E. J. Brash,[24] J. Calarco,[19] Z. Chai,[18] C. C. Chang,[16] T. Chang,[11] J. P. Chen,[27] S. Choi,[26] E. Chudakov,[27] S. Churchwell,[7] D. Crovelli,[25] S. Dieterich,[25] S. Dumalski,[24] D. Dutta,[18] M. Epstein,[4] K. Fissum,[15] B. Fox,[5] S. Frullani,[12] H. Gao,[18] J. Gao,[3] F. Garibaldi,[12] O. Gayou,[2,29] R. Gilman,[25,27] A. Glamazdin,[14] C. Glashausser,[25] J. Gomez,[27] V. Gorbenko,[14] O. Hansen,[27] R. J. Holt,[1,11] J. Hovdebo,[24] G. M. Huber,[24] C. W. de Jager,[27] X. Jiang,[25] C. Jones,[3] M. K. Jones,[22] J. Kelly,[16] E. Kinney,[5] E. Kooijman,[13] G. Kumbartzki,[25] M. Kuss,[27] J. LeRose,[27] M. Liang,[27] R. Lindgren,[28] N. Liyanage,[27] S. Malov,[25] D. J. Margaziotis,[4] P. Markowitz,[8] K. McCormick,[6] D. Meekins,[9] Z. -E. Meziani,[26] R. Michaels,[27] J. Mitchell,[27] L. Morand,[25] C. F. Perdrisat,[29] R. Pomatsalyuk,[14] V. Punjabi,[20] R. D. Ransome,[25] R. Roche,[9] M. Rvachev,[18] A. Saha,[27] A. Sarty,[9,†] E. C. Schulte,[1,11] D. Simon,[10] S. Strauch,[25,‡] R. Suleiman,[13] L. Todor,[22] P. E. Ulmer,[22] G. M. Urciuoli,[12] B. Wojtsekhowski,[27] F. Xiong,[18] and W. Xu[18]

E94-012 $\gamma p \rightarrow p\pi^0$: 3 observables, 6 angles, a range of energies



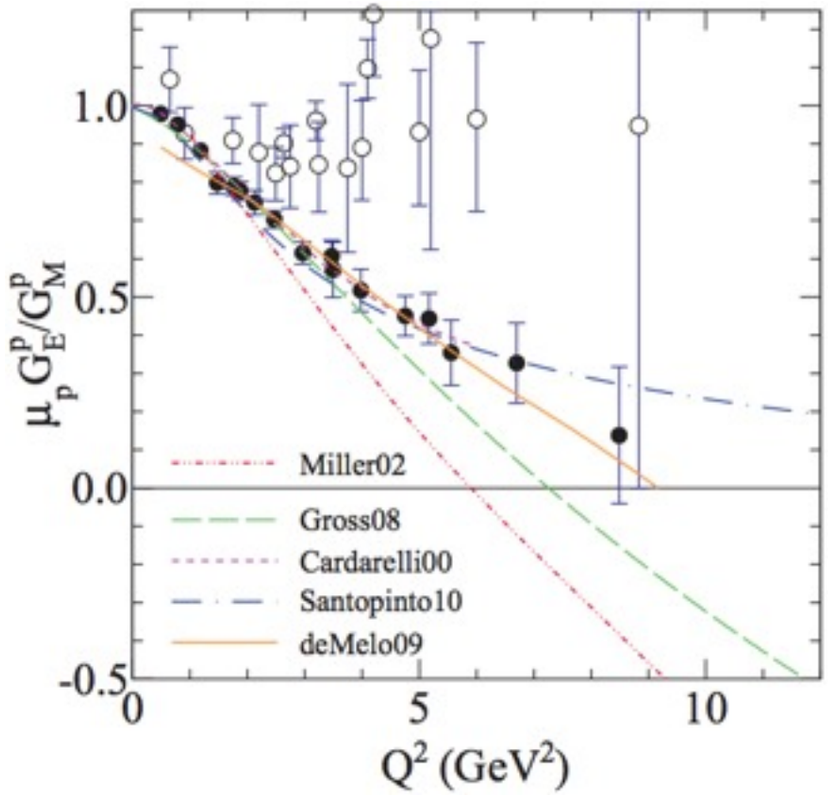
Interesting behavior of polarizations, not an approach to simplicity.

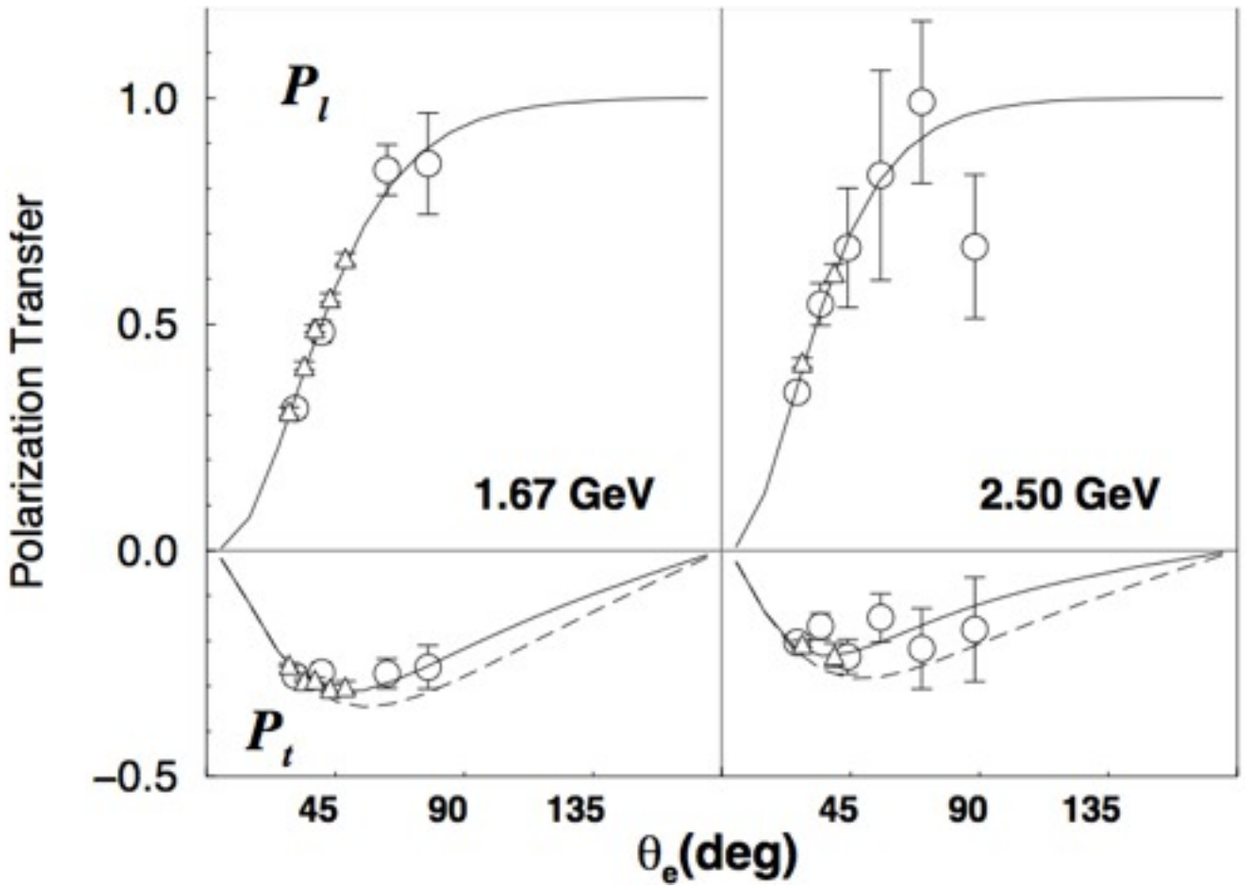
"Spin" is frame dependent, but "spin" is a 4-vector. A problem anticipated by Dmitrasinovic.

And coordinate systems are inconvenient. So we committed one of the few sins possible in physics.

E94-012 $\gamma p \rightarrow p\pi^0$: and the G_E^p/G_M^p puzzle

The Jones et al. result was not universally accepted, and Roy kept playing devil's advocate. But the polarimeter calibrations from E94-012 allowed us to publish the first confirmation. Gayou, Wijesooriya, et al., PRC 64 (2001).





E94-012 $\gamma p \rightarrow p\pi^0$

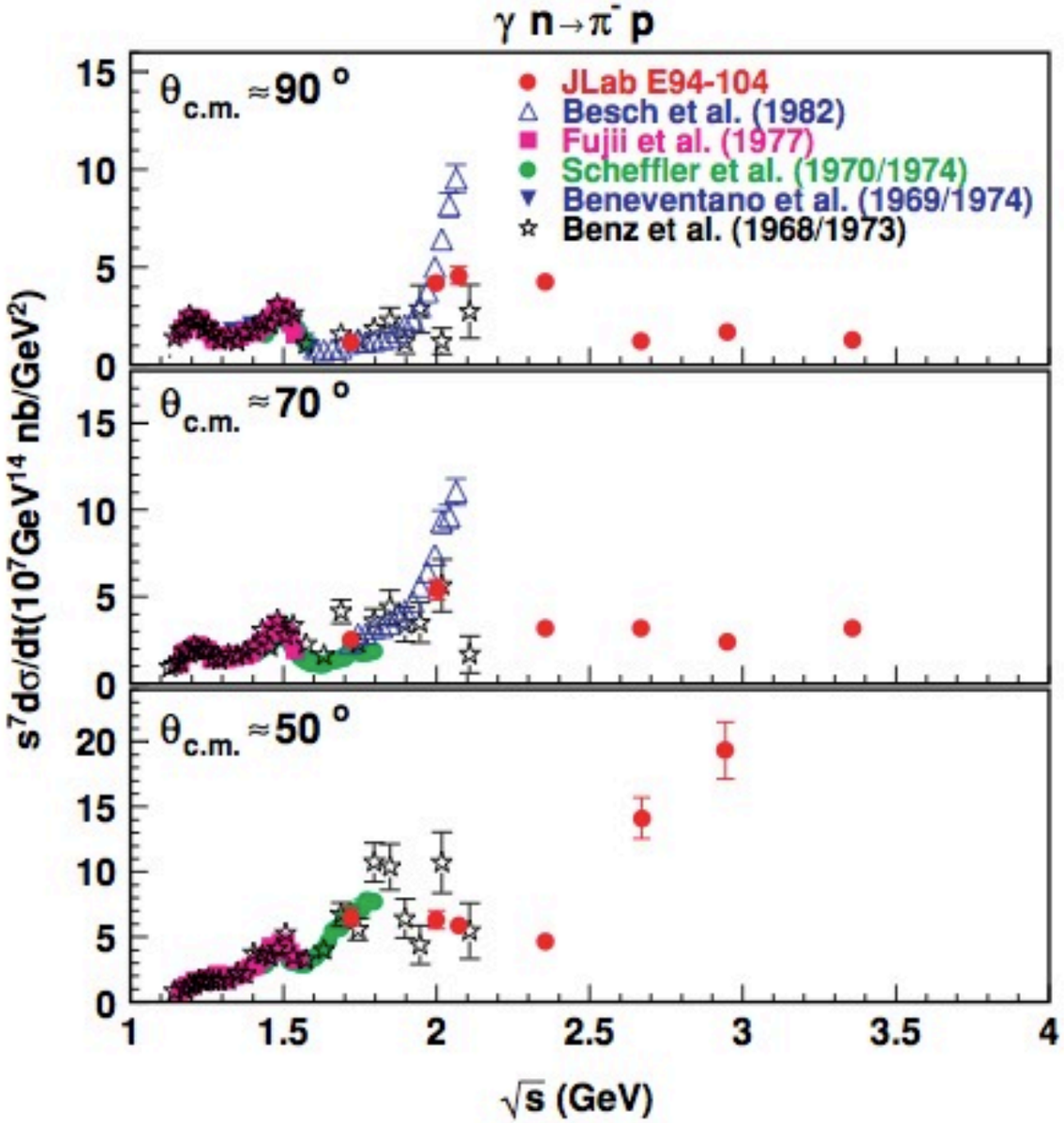
In the end, it seemed from the polarizations that small underlying resonance contributions interfere and generate interesting behavior.

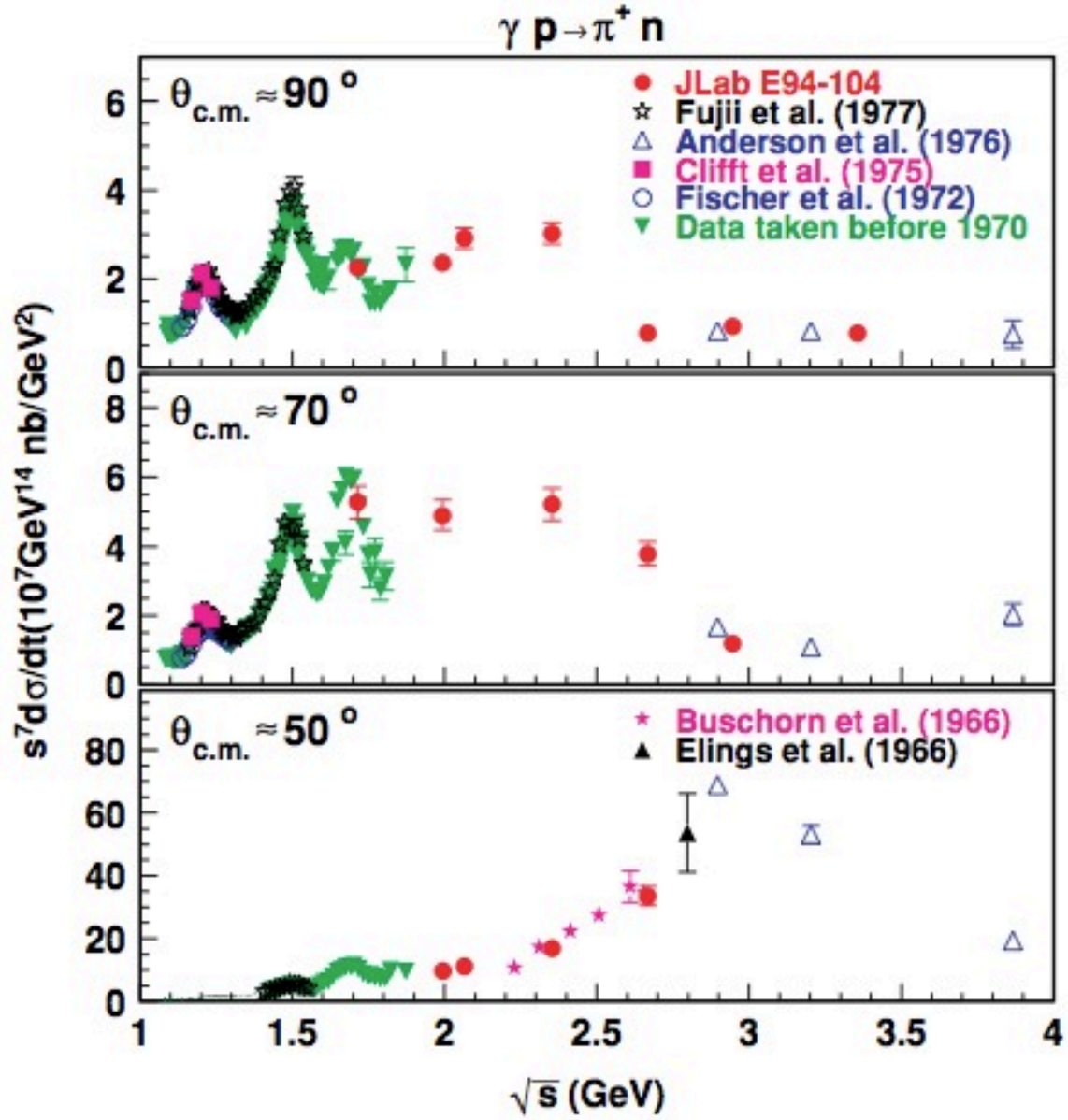
One does not get the simpler patterns seen in deuteron photodisintegration, which generates higher momentum transfer to the nucleon.

More Meson Photoproduction

At the same time these experiments, Roy also teamed up with Haiyan Gao to run a series of meson photoproduction cross section experiments:

LY Zhu et al, PRL 91 & PRC 71





More Meson Photoproduction

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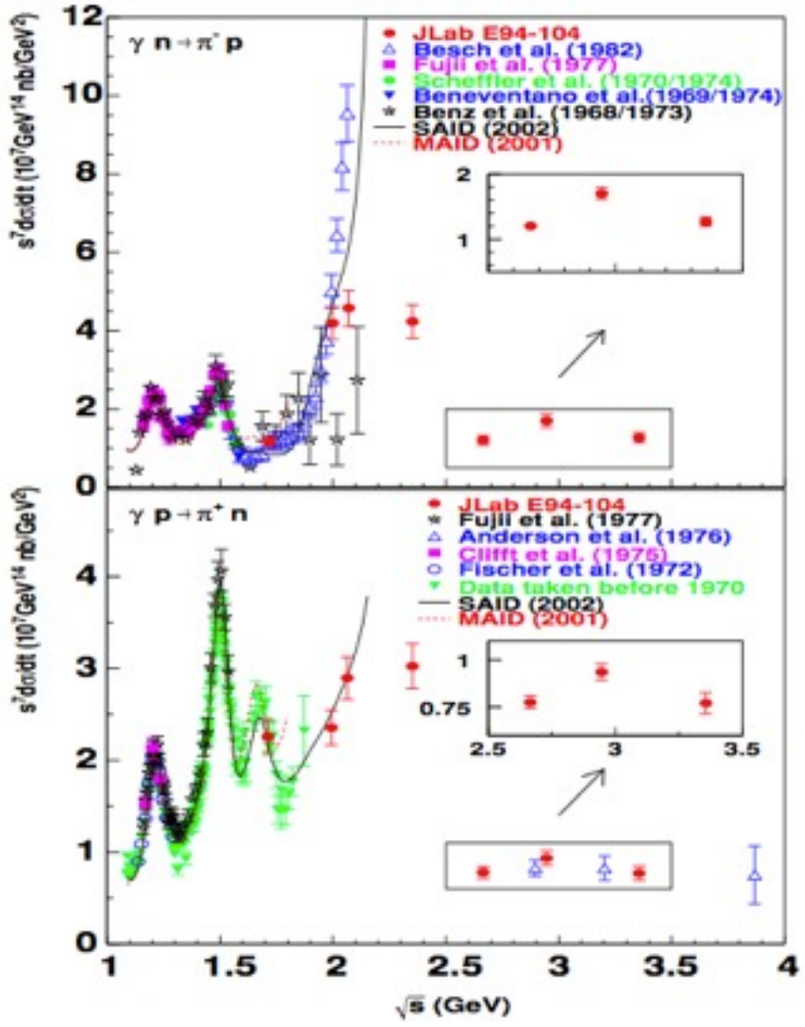
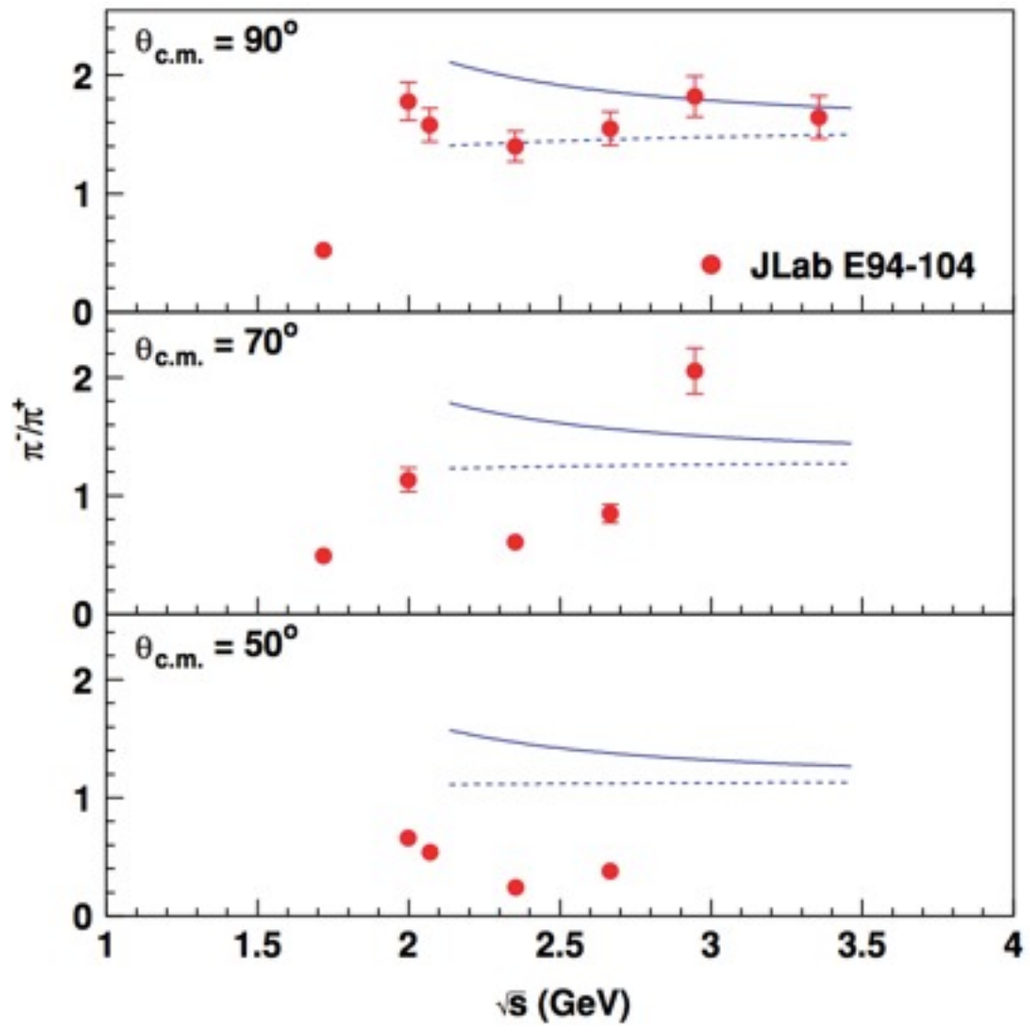
LY Zhu et al, PRL 91 & PRC 71

Oscillations about scaling at high energy?

$$\frac{d\sigma/dt(\gamma n \to \pi^- p)}{d\sigma/dt(\gamma p \to \pi^+ n)} \simeq \left(\frac{ue_d + se_u}{ue_u + se_d}\right)^2$$





Not the end of my collaboration with Roy

In 1988, we generated a t shirt. I still have 2 and wear them occasionally.

In 2014, when my student Arun and Roy are on shift at Seaquest, they sometimes skype me.

Thank you again, Roy.