Determination of the Azimuthal Asymmetry in Deuteron Disintegration by Linearly Polarized Photons for E_γ=1.1-2.3 GeV

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Abstract

We plan to determine the azimuthal asymmetry in deuteron disintegration by linearly polarized photons in the energy range E_γ=1.1-2.3 GeV using the CLAS data obtained in the g13 experiment.

The aim is to search for quark and gluon degrees of freedom in the deuteron.

The measurement will provide:

- Novel spin-dependent information on the underlying mechanism of the reaction $\gamma+d\rightarrow p+n$
- Improvement of our understanding of the role of pQCD at low and intermediate energies
- Stringent constraints on the nonperturbative QCD-based models of photonuclear reactions

Outline

- Physics Motivation
  - Scaling laws in QCD and experimental data
  - Theoretical and experimental status of deuteron photodisintegration
- Our Planned Work
  - The plan
  - Experimental setup
  - Statistical uncertainties
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- Anticipated Results
  - QGSM predictions
  - HRM predictions
- Our Preliminary Analysis
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  - Asymmetry for $\theta_{cm}=90°$
- Summary

Physics Motivation

1. Scaling Laws in QCD and Experimental Data

The process of deuteron photodisintegration is especially interesting for investigation of the role of quarks and gluons in nuclear interactions. During the last 15 years, about 10 experiments have been performed for measuring its differential cross section.

$$\gamma + d \rightarrow n + p$$

The most remarkable property of the data is the energy behavior of the process. At E_γ>1 GeV

$$d\sigma/dt\ (\theta_{cm} \approx 90^\circ) \sim s^{-11}$$

Just such behavior is predicted by the constituent counting rules (CCR):

$$d\sigma/dt \sim h(\theta_{cm})/s^{n-2}$$

Physics Motivation

1. Scaling Laws in QCD

The history:

- Discovery in a massless field theory:
  - –Matveev, Muradyan, Tavkhelidze (1973)
  - –Brodsky, Ferrar (1973)
- Confirmation in pQCD:
  - Lepage, Brodsky (1980)
- Understanding of close relation to spin phenomena:
  - –Brodsky, Carlson, Lipkin (1979)
  - –Farrar, Gottlieb, Sivers, Thomas (1979)
- All-orders demonstration within AdS/CFT correspondence:
  - –Polchinsky, Strassler (2002)
  - –Brower, Tan (2003)
  - –Andreev (2003)

The mystery:

The dimensional scaling can be justified only in the high-energy limit when one can neglect all the masses, $t \sim s >> m^2$.

What mechanism is really responsible for the scaling at more modest energies?

Another consequence of chiral symmetry, namely, hadron helicity conservation (HHC), does not agree with data in the same kinematics.

What is the reason for the dramatic contrast between the CCR and HHC when both have the same origin—chiral symmetry?

Physics Motivation

1. Scaling Laws in QCD: Conclusion

- Experimental investigations of scaling phenomena and related spin-dependent effects have stimulated significant theoretical advances in understanding of the role of pQCD at low and intermediate energies.

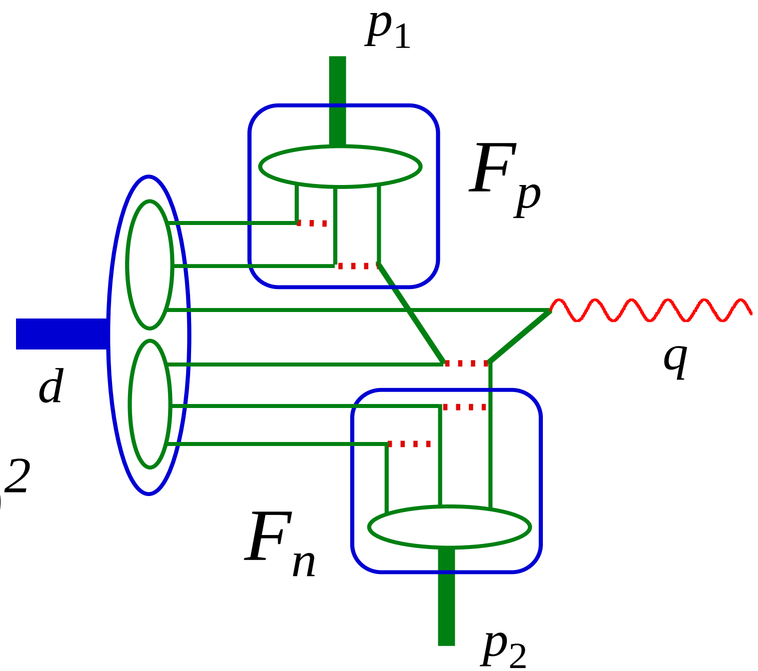
- These studies make it possible to develop in detail a number of nonperturbative QCD-based approaches to hadron dynamics at long distances.

- The results achieved to date provide a strong motivation for further investigation of scaling laws and spin effects in photonuclear reactions.

Physics Motivation

2. Deuteron Photodisintegration: Theoretical Models

1. Reduced Nuclear Amplitudes (RNA)
   - –Brodsky and Hiller (1983)
   - –Brodsky and Hiller (1984)



$$p_T^2 = (s/4 - m^2)\,\sin^2\theta_{cm}$$

$$\hat{t}_p = (p_1 - d/2)^2 \qquad \hat{t}_n = (p_2 - d/2)^2$$

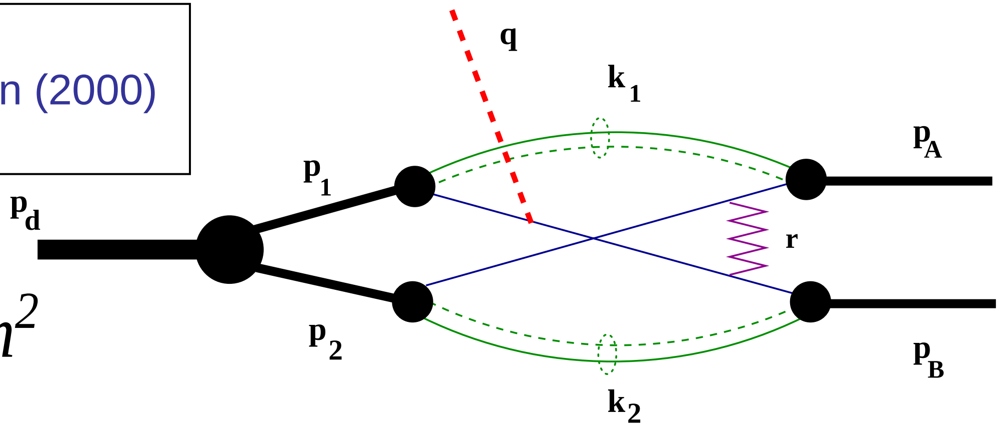
$$\frac{d\sigma}{dt} = \frac{m^2}{24\,\pi^2\,(s - m_d^2)^2} \sum |J|^2 \rightarrow \frac{1}{(s - m_d^2)^2} F_p^2\,(\hat{t}_p)\, F_n^2\,(\hat{t}_n) \frac{1}{p_T^2}\, f^2(\theta_{cm})$$

They start with a perturbative expression and include all the missing soft physics in phenomenological form factors F_p and F_n.

Physics Motivation

2. Deuteron Photodisintegration: Theoretical Models

2. Hard Rescattering Model (HRM)
   - –Frankfurt, Miller, Sargsian, and Strikman (2000)
   - –Sargsian (2004)



$$t_N = (p_B - p_d/2)^2 \qquad s' = s - m^2$$

$$C\,(t_N/s) = \frac{-2\,t_N\,/\,s'}{1+2\,t_N\,/\,s'} \approx \frac{-t\,/\,s'}{1+t\,/\,s'}$$

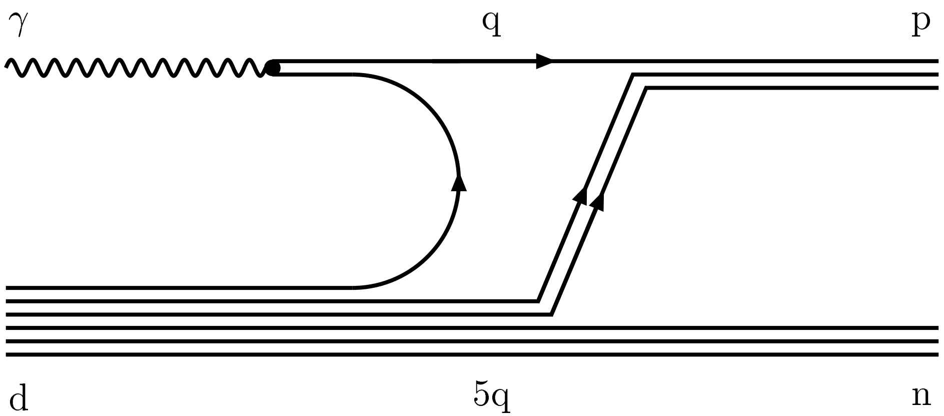
$$\frac{d\sigma^{\gamma d\to pn}}{dt} = \frac{4\,\alpha}{9}\pi^4\frac{1}{s'}C\,(t_N/s)\,\frac{d\sigma^{pn\to pn}\,(s,\,t_N)}{dt}\left|\int \Psi_d^{NR}\,(p_z{=}0,\,p_\perp)\,\sqrt{m_N}\,\frac{d^2\,p_\perp}{(2\,\pi)^2}\right|^2$$

This factorization is justified by the fact that the momenta involved in the integral are much smaller than the transferred momenta in the *pn* amplitude.

Physics Motivation

2. Deuteron Photodisintegration: Theoretical Models

3. Quark-Gluon String Model (QGSM)
   - –Kaidalov (1982, 1999)
   - –Kondratyuk *et.al.* (1993)
   - –Grishina *et.al.* (2001)
   - –Grishina *et.al.* (2004)



$$\frac{d\sigma^{\gamma d\to pn}}{dt} = \frac{1}{64\,\pi s}\frac{1}{(p_\gamma^{cm})^2}\Big[S_t|B^{(+)}(s,t)|^2$$

$$+ S_t|B^{(+)}(s,t)|^2 + S_u|B^{(-)}(s,u)|^2 + 2S_{tu}\mathrm{Re}(B^{(+)*}(s,t)B^{(-)}(s,u))\Big]$$

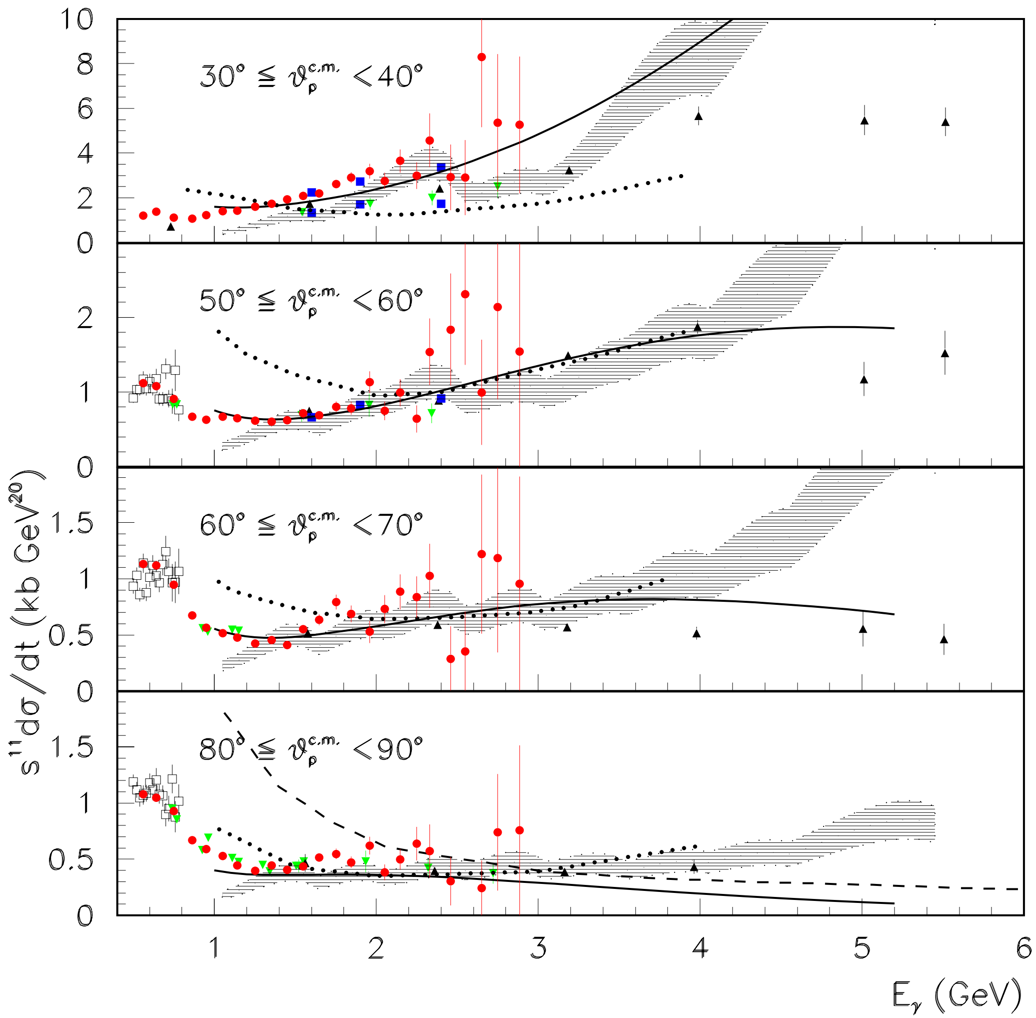
$$B^{(\pm)}(s,t) \sim \mathcal{M}_{Regge}(s,t) = F(t)(s/s_0)^{\alpha_N(t)}\exp\Big[-i\frac{\pi}{2}(\alpha_N(t)-1/2)\Big]$$

$$\alpha_N(t) = \alpha_N(0) - \alpha'_N(0)\,T_B\ln(1-t/T_B)$$

The model is based on i) a topological expansion in QCD and ii) a space-time picture of strong interactions ⇒ Regge phenomenology.

Physics Motivation

2. Deuteron Photodisintegration: Experimental Status



Results from:

- CLAS (full/red circles)
- Mainz (open squares)
- SLAC (full/green down-triangles)
- JLab Hall A (full/blue squares)
- JLab Hall C (full/black up-triangles)

Theoretical predictions:

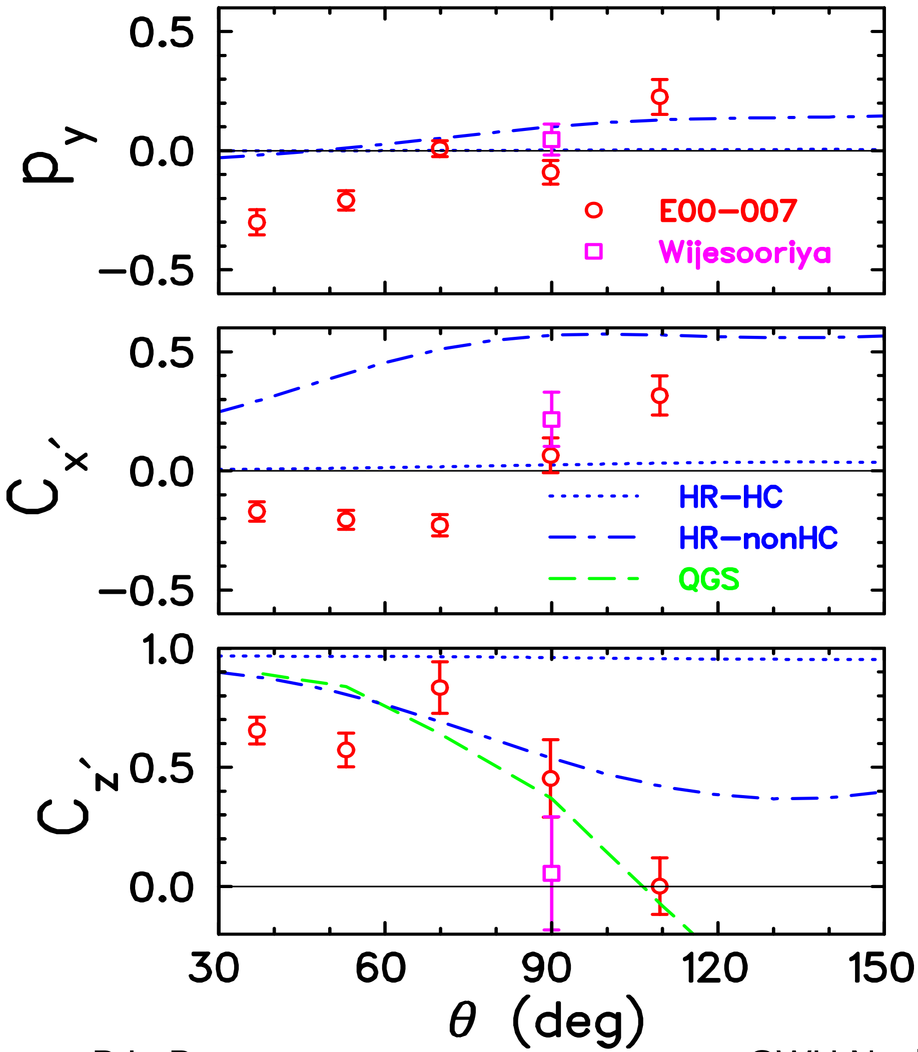
- QGSM (solid line)
- AMEC (dotted line)
- RNA (dashed line)
- HRM (hatched area)

Conclusion:

The approaches based on various physical principles describe the available unpolarized data with about the same degree of success.

Physics Motivation

2. Deuteron Photodisintegration: Polarized Data

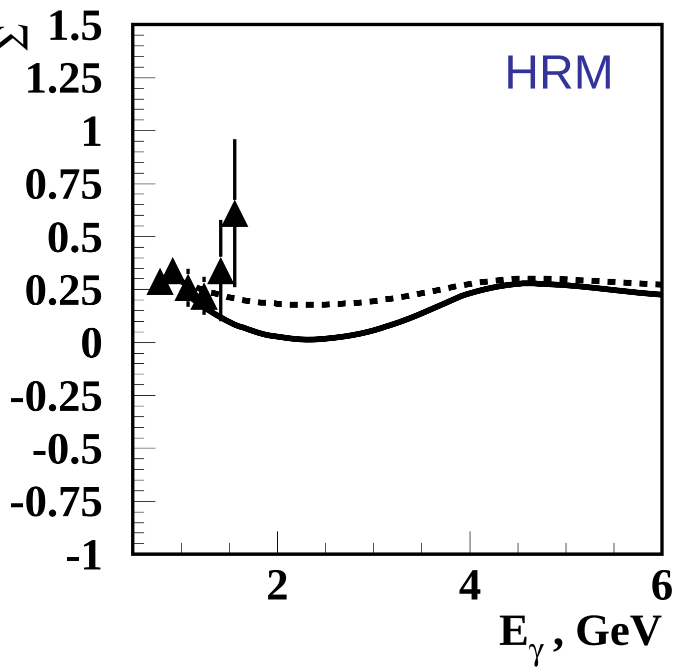


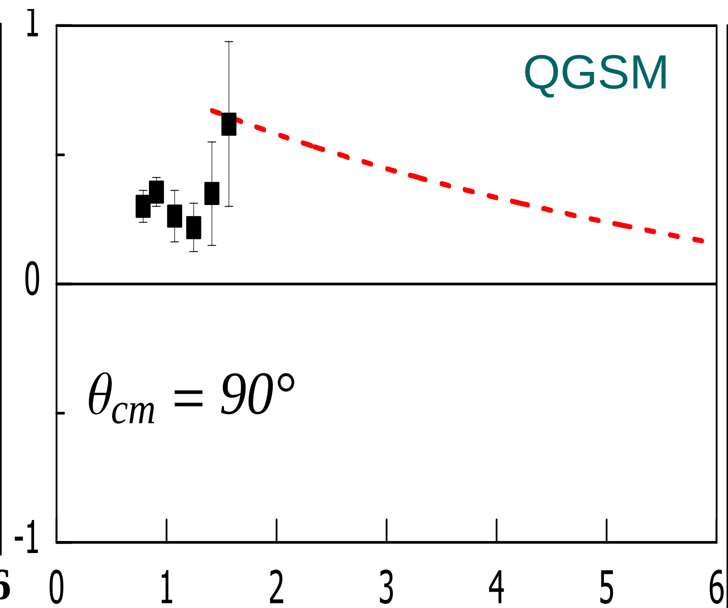
Conclusions:

- The are only two sets of data for the recoil proton polarization obtained at JLab (Hall A).
- Only two calculations of the spin observables are available, within the QGSM and HRM frameworks.
- Both models, QGSM and HRM, which predict the longitudinal polarization transfer are in qualitative agreement with available data.
- Neither model adequately explains the transverse polarization.

Physics Motivation

2. Deuteron Photodisintegration: Azimuthal Asymmetry





Summarizing,

- The only data in the energy range 0.8-1.6 GeV at θ_{cm}=90° are from Yerevan.
- The Yerevan data indicate that Σ(90°) might be large (~50%).
- The QGSM is able to describe a large asymmetry at E_γ≈1.6 GeV, while the HRM is not able to do so.

$$\Sigma = \frac{1}{\mathcal{P}_\gamma}\frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$

$$\frac{d^2\sigma}{dt\,d\varphi}(s,t,\varphi) = \frac{1}{2\pi}\frac{d\sigma_{unp}}{dt}(s,t)\left[1 + \mathcal{P}_\gamma\,\Sigma(s,t)\cos 2\varphi\right]$$

Our Planned Work

1. The plan

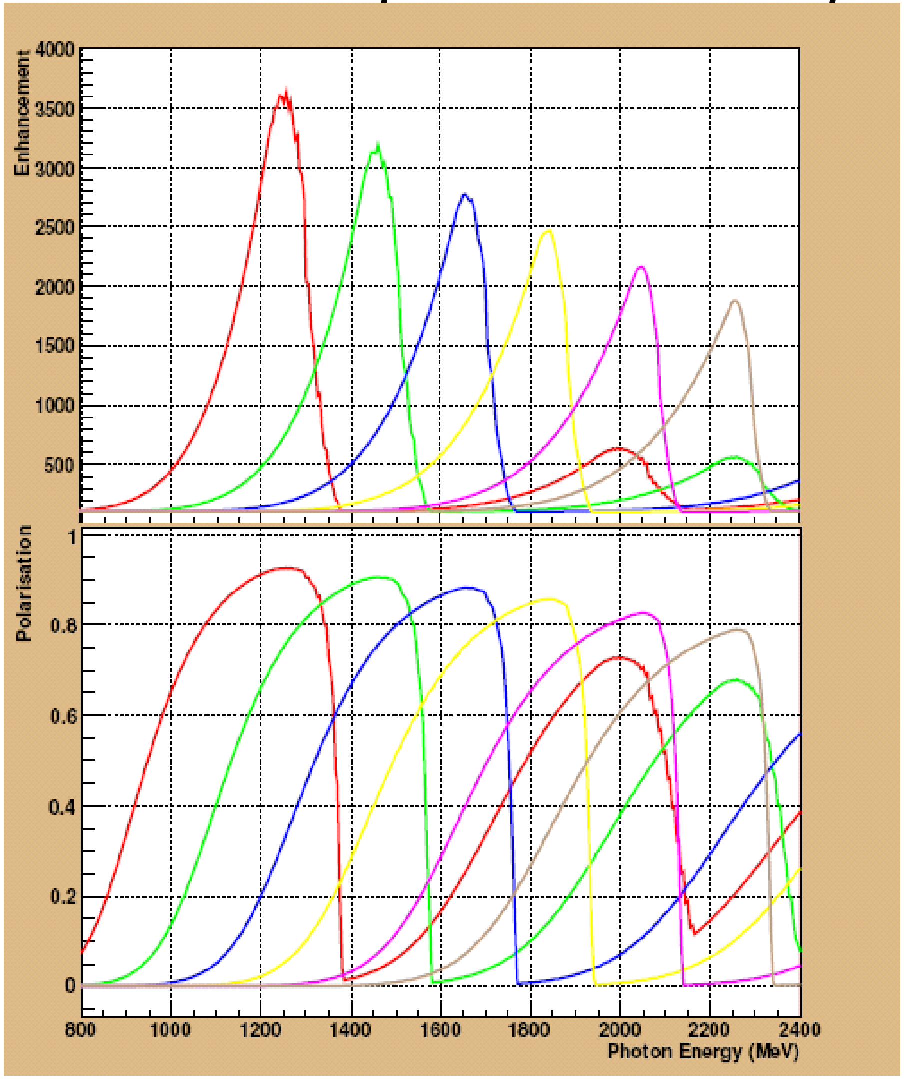
- We see that measurements of the azimuthal beam-spin asymmetry Σ for deuteron photodisintegration will give important complementary information on the underlying mechanism, and could thus provide a crucial test of nonperturbative calculations.

- We plan to determine the azimuthal asymmetry Σ for deuteron disintegration by linearly polarized photons for E_γ=1.1-2.3 GeV using the CLAS data obtained in the g13 experiment.

- By combining our anticipated data for Σ with the existing results for $d\sigma/dt$ and recoil proton polarizations, we will obtain a complete experimental description of deuteron photodisintegration in the 1-2 GeV region that will provide a stringent constraint on the theory.

Our Planned Work

2. Experimental Setup: The Beam Polarization



- In the CLAS g13 experiment, data were obtained for six photon-energy bins in the range 1.1-2.3 GeV, in steps of 200 MeV.
- The linear polarization of the photons is practically constant over each 200-MeV region.
- The mean value of the beam polarization varies slowly from $P_\gamma \approx 90\%$ at $E_\gamma = 1.2$ GeV to $P_\gamma \approx 70\%$ at $E_\gamma = 2.2$ GeV.

Our Planned Work

2. Experimental Setup: Uncertainties

Statistical uncertainties:

$$\delta\Sigma = \frac{1}{\mathcal{P}_\gamma}\frac{1}{\sqrt{N}}$$

E_γ (GeV)	1.2	1.4	1.6	1.8	2.0	2.2
$\delta\Sigma$ (%)	1.8	1.9	3.2	3.8	5.8	8.6

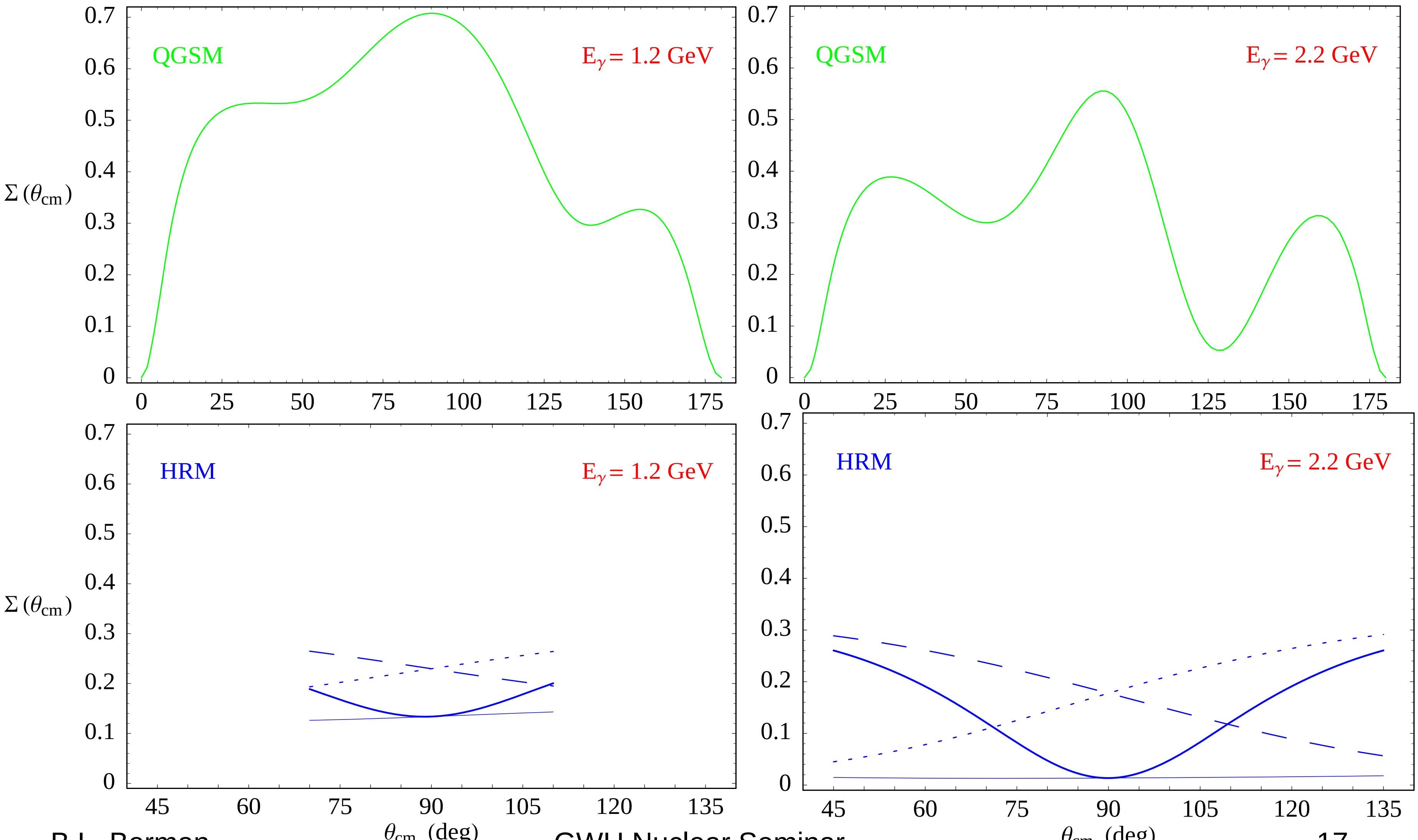
for θ_{cm}=90°

Systematic uncertainties: $\delta P_\gamma / P_\gamma \approx$(3-4)% PR-06-103 (g13)

- For the unpolarized case, systematic uncertainties come from the total number of incident photons, the target length and density, the proton detection efficiency, and the background contributions.
- The resulting total systematic uncertainty for the cross section is less than 10% for all the kinematic bins under consideration, Mirazita *et.al*. (2004).
- For the case of Σ, most of the above uncertainties cancel out.

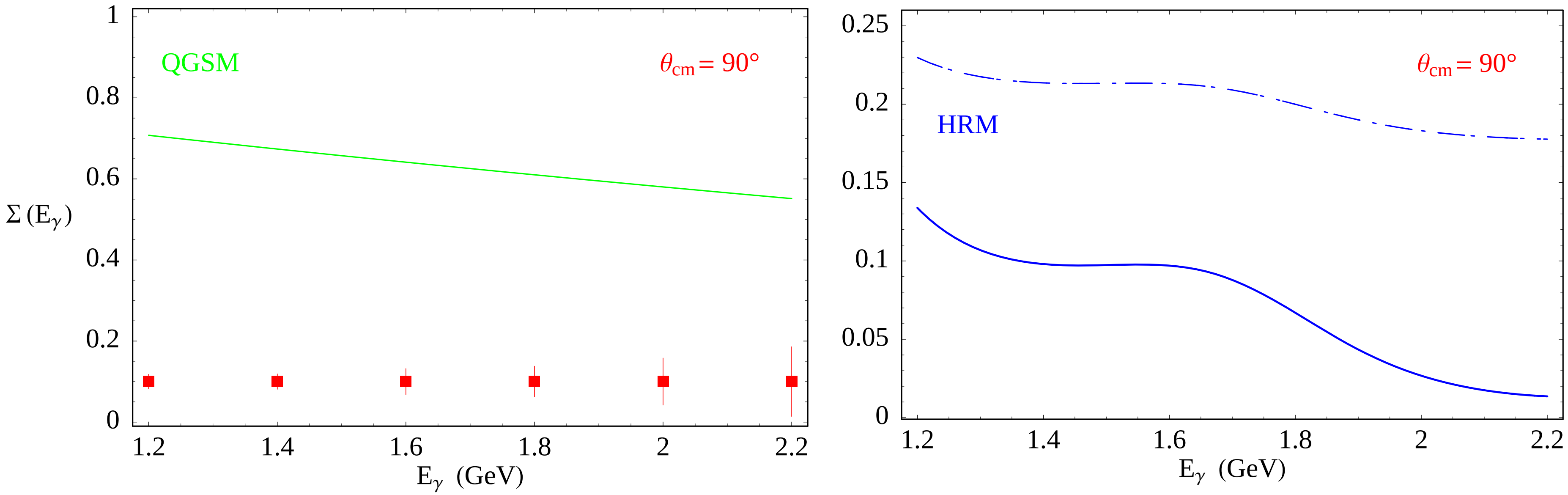
Anticipated Results

QGSM and HRM Predictions



Anticipated Results

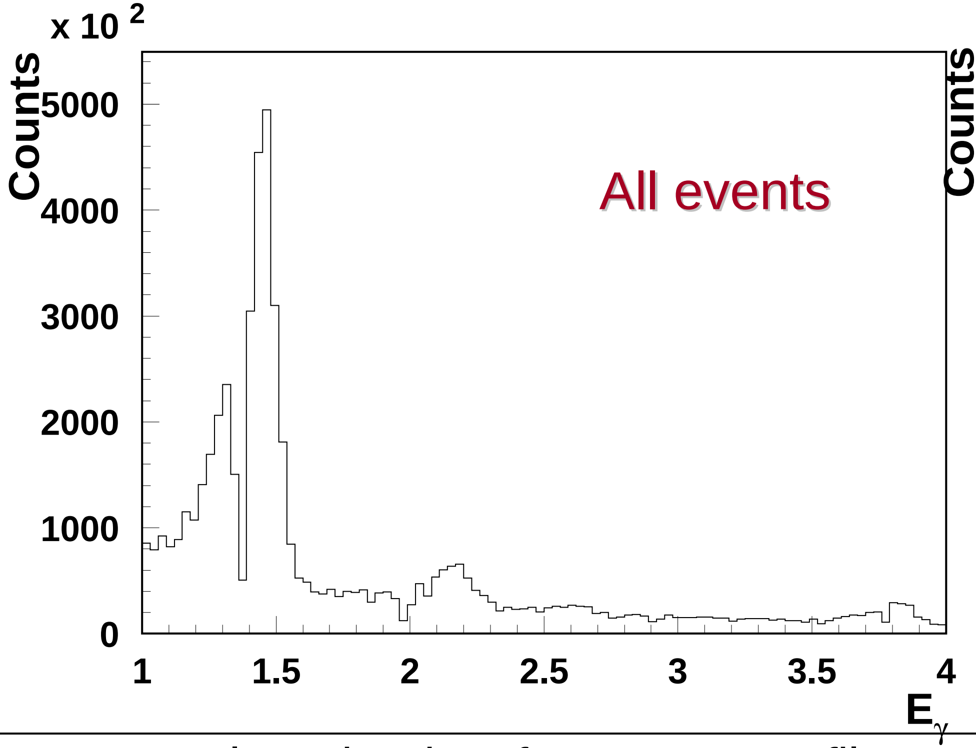
QGSM and HRM Predictions

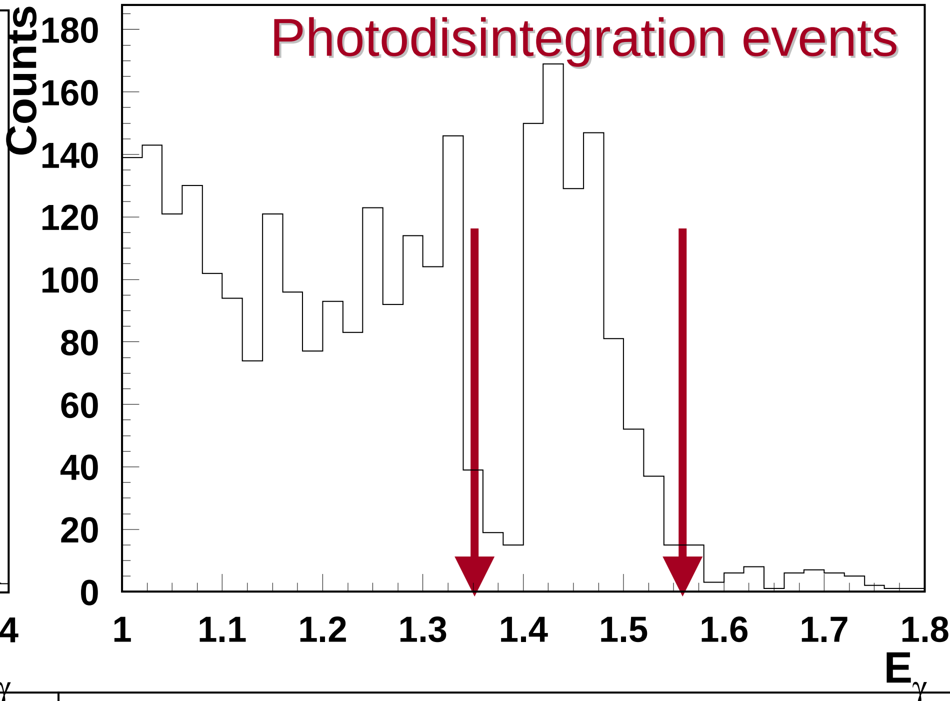


- One can see that the asymmetry $\Sigma(E_\gamma, \theta_{cm}=90°)$ is predicted to be less than 25% over the entire range in energy for all available versions of the HRM.
- We conclude that the large-angle predictions of the QGSM and HRM for Σ are strongly different over the entire energy range of the g13 experiment.

Our Preliminary Analysis

1. Event Selection: Photon Energy Spectra

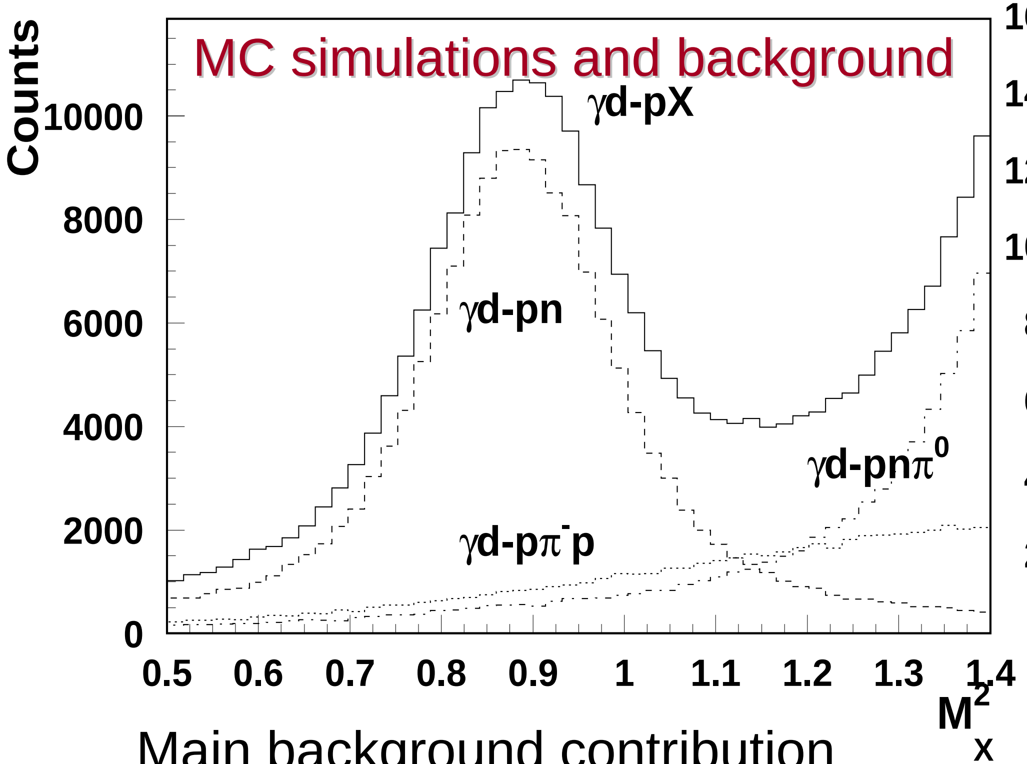


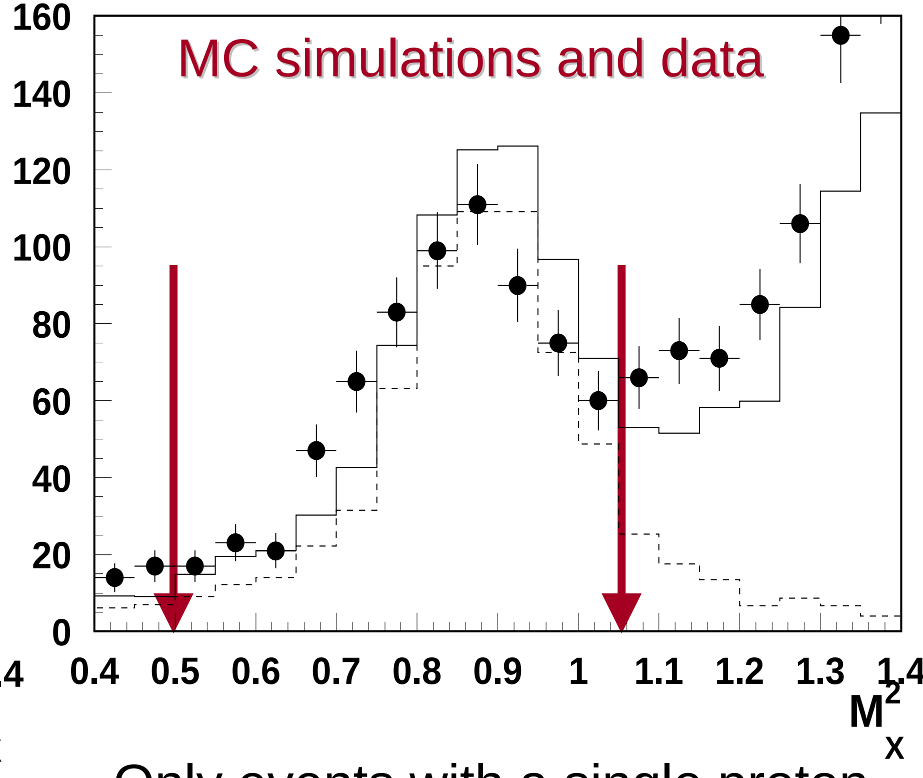


- We analyze the data from .A1-.A20 files for runs 54674 (PERP) and 54675 (PARA) - only 1% of the available data.
- The electron beam energy for these runs is $\boldsymbol{E_e = 4.475}$ ***GeV***.
- The photon energy spectrum for all events is given in the left plot.
- Cuts on the missing mass were performed: $\boldsymbol{0.5 < M_X^2 < 1.05}$ ***GeV²***.
- The photon energy spectrum for photodisintegration events is given in the right plot.
- The events in range $\boldsymbol{1.35 < E_\gamma < 1.55}$ ***GeV*** are selected for our analysis.

Our Preliminary Analysis

1. Event Selection: Missing Mass and Background





Main background contribution originates from the processes $\gamma d \rightarrow p\pi^- p$ and $\gamma d \rightarrow pn\pi^0$. Total background contribution is less that 10%.

Only events with a single proton in the final state were selected. Cuts on the missing mass were performed: $0.5<M_X^2<1.05$ **GeV²**, where $M_X^2=(p_\gamma + p_d - p_p)^2$.

Our Preliminary Analysis

2. Asymmetry for θ_{cm}=90°: Data Analysis

$$\frac{dN^{PARA}}{d\varphi} = \frac{N_0^{PARA}}{2\pi}\left[1 + \mathcal{P}_\gamma\, \Sigma \cos 2\varphi\right] A(\varphi)$$

$$\frac{dN^{PERP}}{d\varphi} = \frac{N_0^{PERP}}{2\pi}\left[1 - \mathcal{P}_\gamma\, \Sigma \cos 2\varphi\right] A(\varphi)$$

Azimuthal acceptance

We make use of the fact that in the 54674 (PERP) and 54675 (PARA) runs the photon polarization directions are perpendicular to each other.

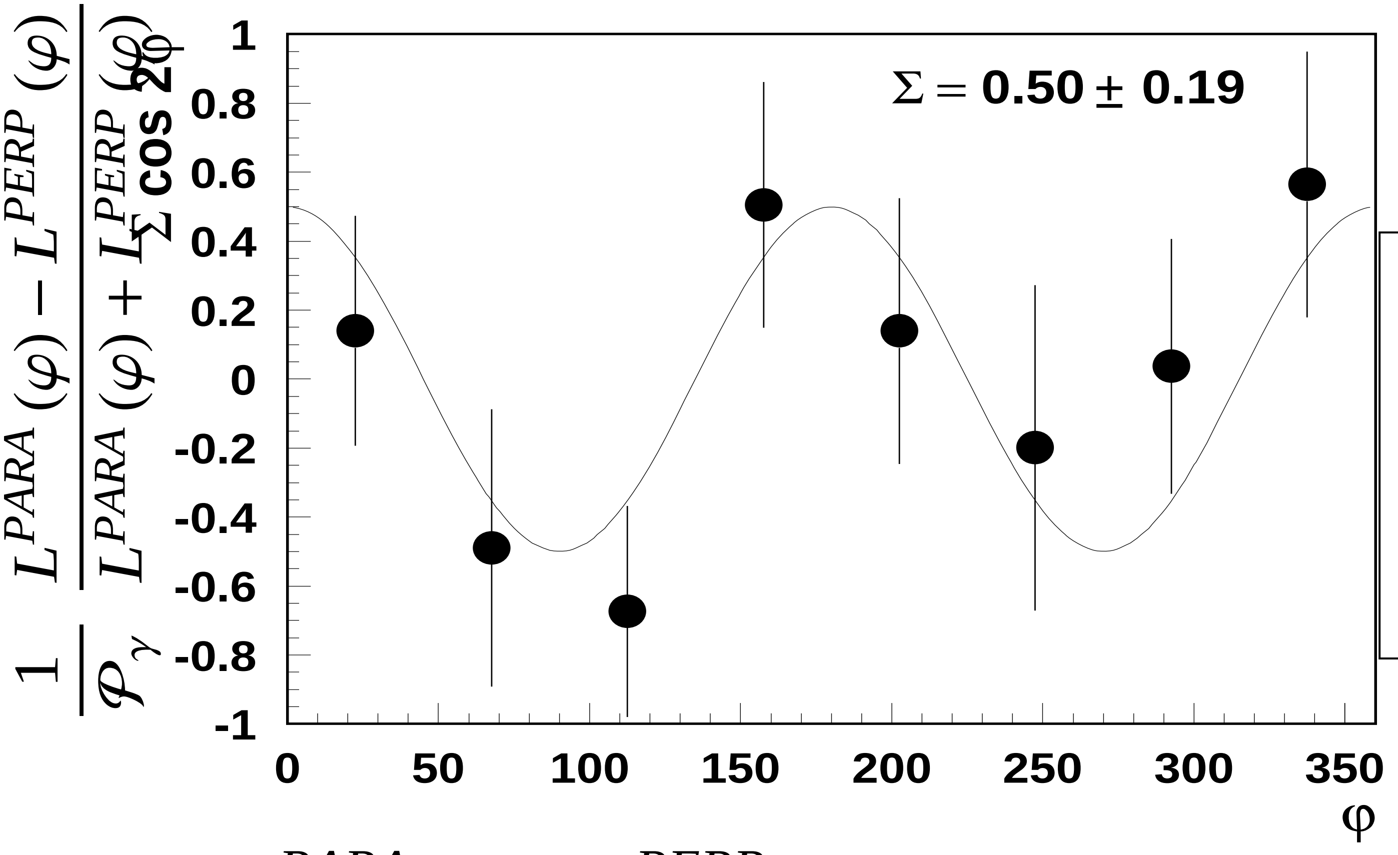
$$L^{PARA}(\varphi) = \frac{2\pi}{N_0^{PARA}}\frac{dN^{PARA}}{d\varphi}$$

$$L^{PERP}(\varphi) = \frac{2\pi}{N_0^{PERP}}\frac{dN^{PERP}}{d\varphi}$$

$$\frac{1}{\mathcal{P}_\gamma}\frac{L^{PARA}(\varphi) - L^{PERP}(\varphi)}{L^{PARA}(\varphi) + L^{PERP}(\varphi)} = \Sigma \cos 2\varphi$$

Our Preliminary Analysis

2. Asymmetry for θ_{cm}=90°: Azimuthal Distributions



$1.35 < E_\gamma < 1.55$ GeV

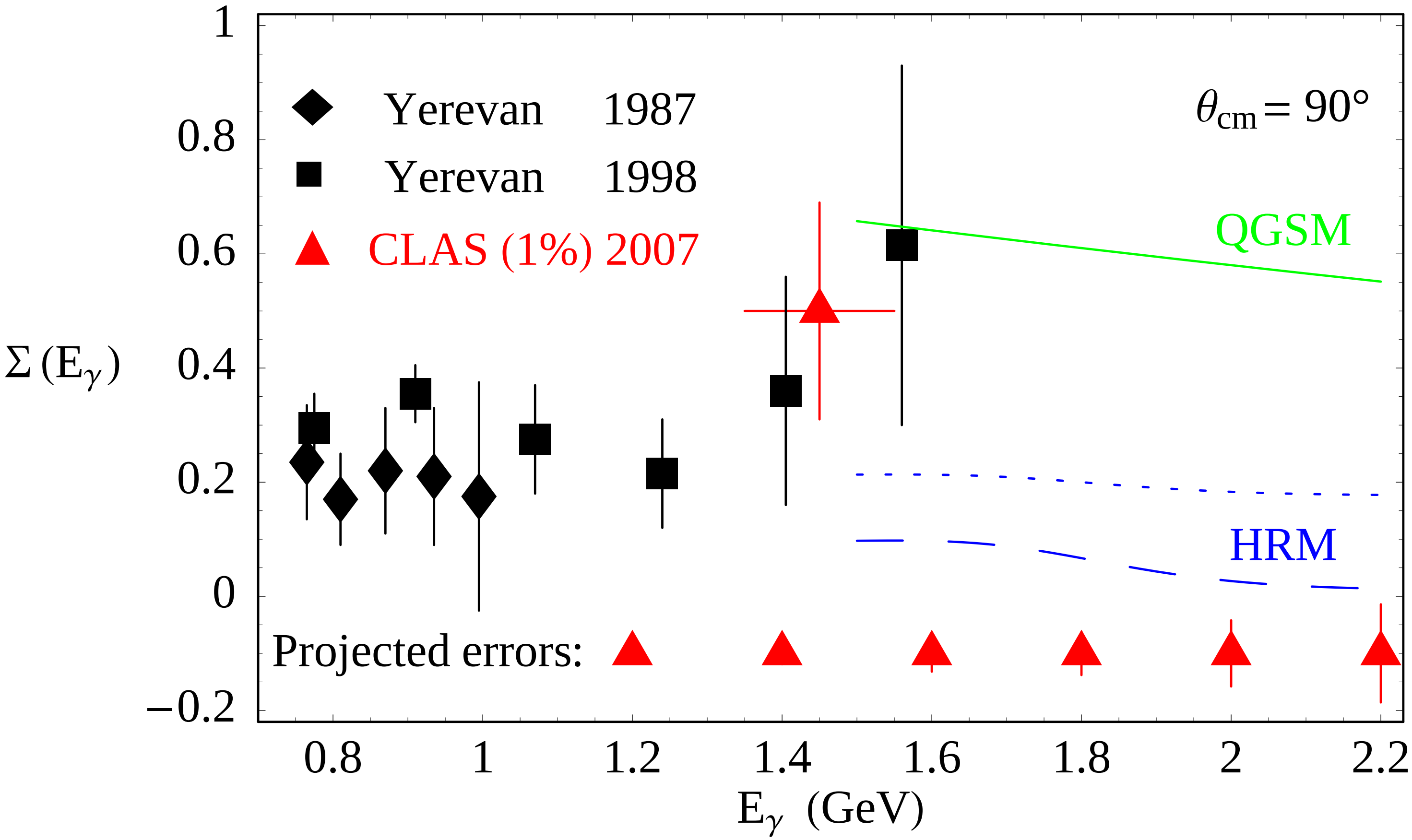
$0.5 < M_X^2 < 1.05$ GeV^2

$80° < \theta_{cm} < 100°$

$$\frac{1}{\mathcal{P}_\gamma} \frac{L^{PARA}(\varphi) - L^{PERP}(\varphi)}{L^{PARA}(\varphi) + L^{PERP}(\varphi)} \rightarrow C + \Sigma \cos(2\varphi + \varphi_0)$$

Our Preliminary Analysis

2. Asymmetry for θ_{cm}=90°: *Comparison with Data*



Summary

We plan to determine the azimuthal asymmetry Σ in deuteron disintegration by linearly polarized photons in the energy range E_γ=1.1-2.3 GeV using the CLAS data collected in the g13 experiment.

Our expected statistical and systematic uncertainties in the determination of the asymmetry Σ are easily less than 10%.

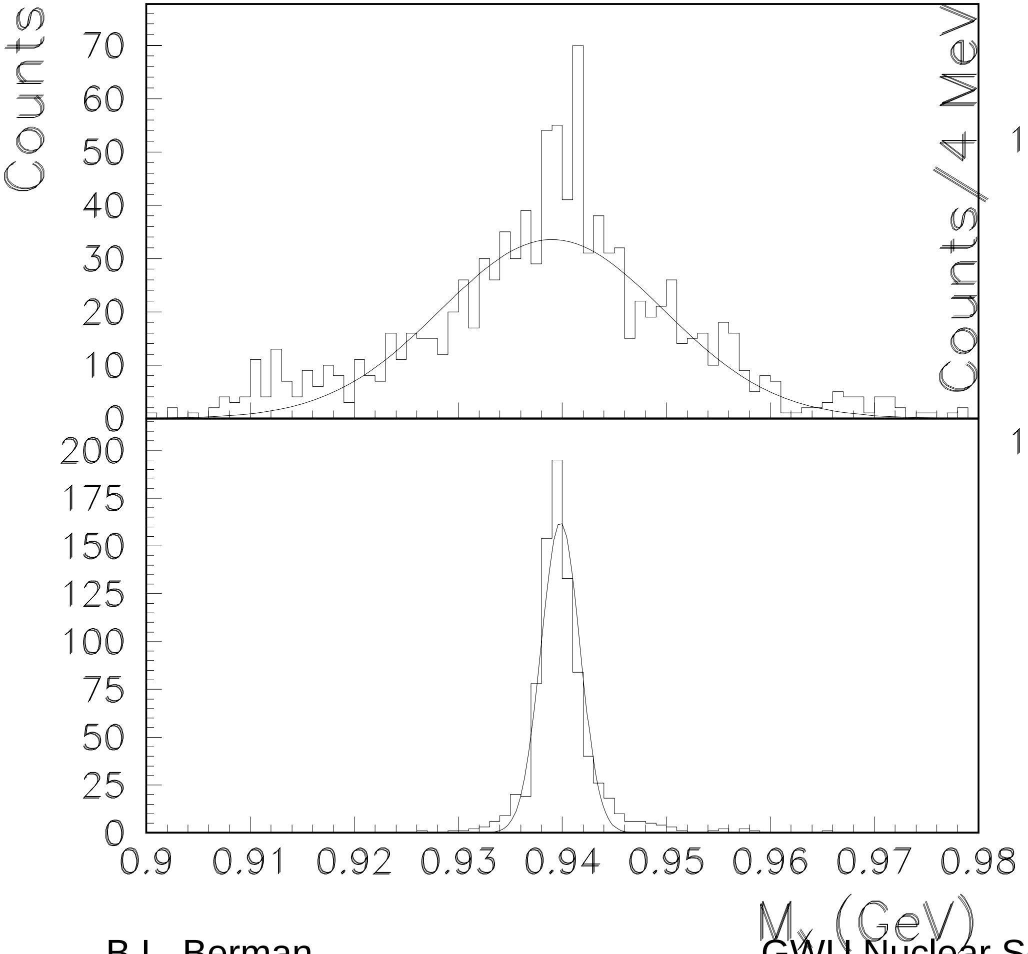
Our planned analysis would

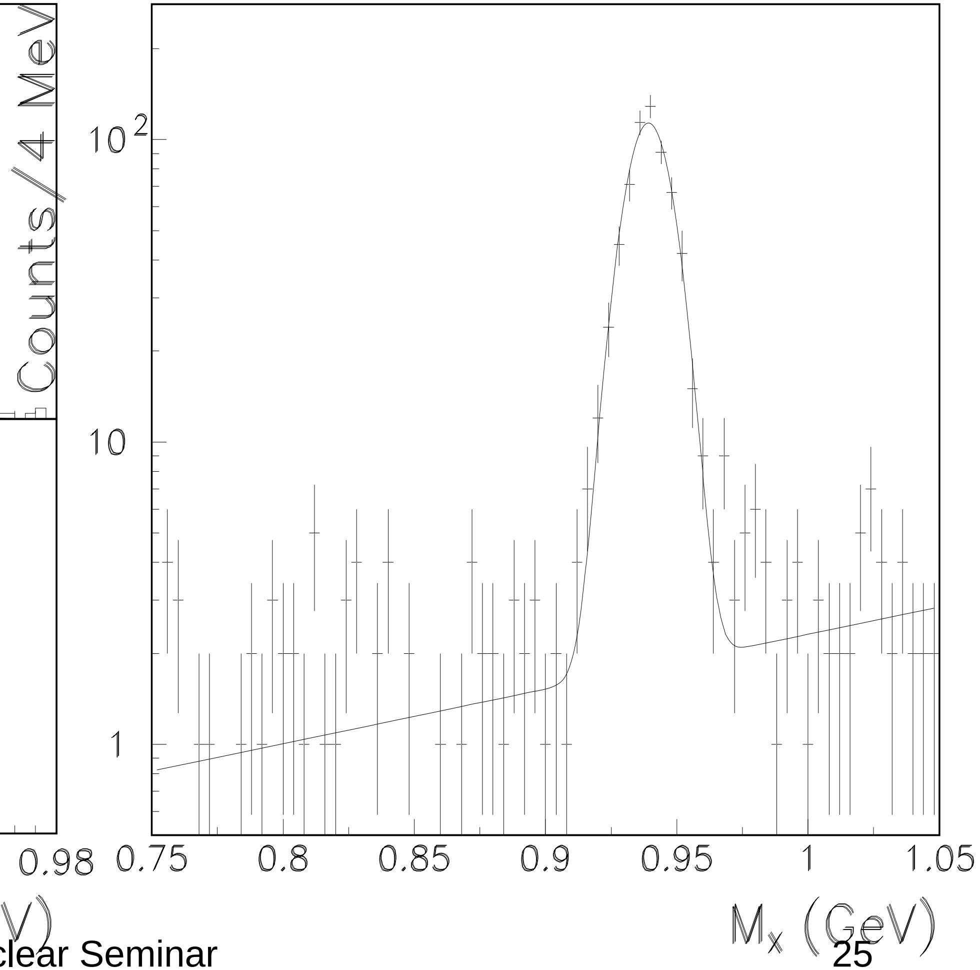
- provide new spin-dependent information on the underlying mechanism of the reaction $\gamma+d\rightarrow p+n$;
- improve our understanding of the role and domain of applicability of pQCD at low and intermediate energies;
- provide stringent constraints on the nonperturbative QCD-based models of photonuclear reactions.

Supporting Slides

2. Experimental Setup: Momentum Corrections and Background

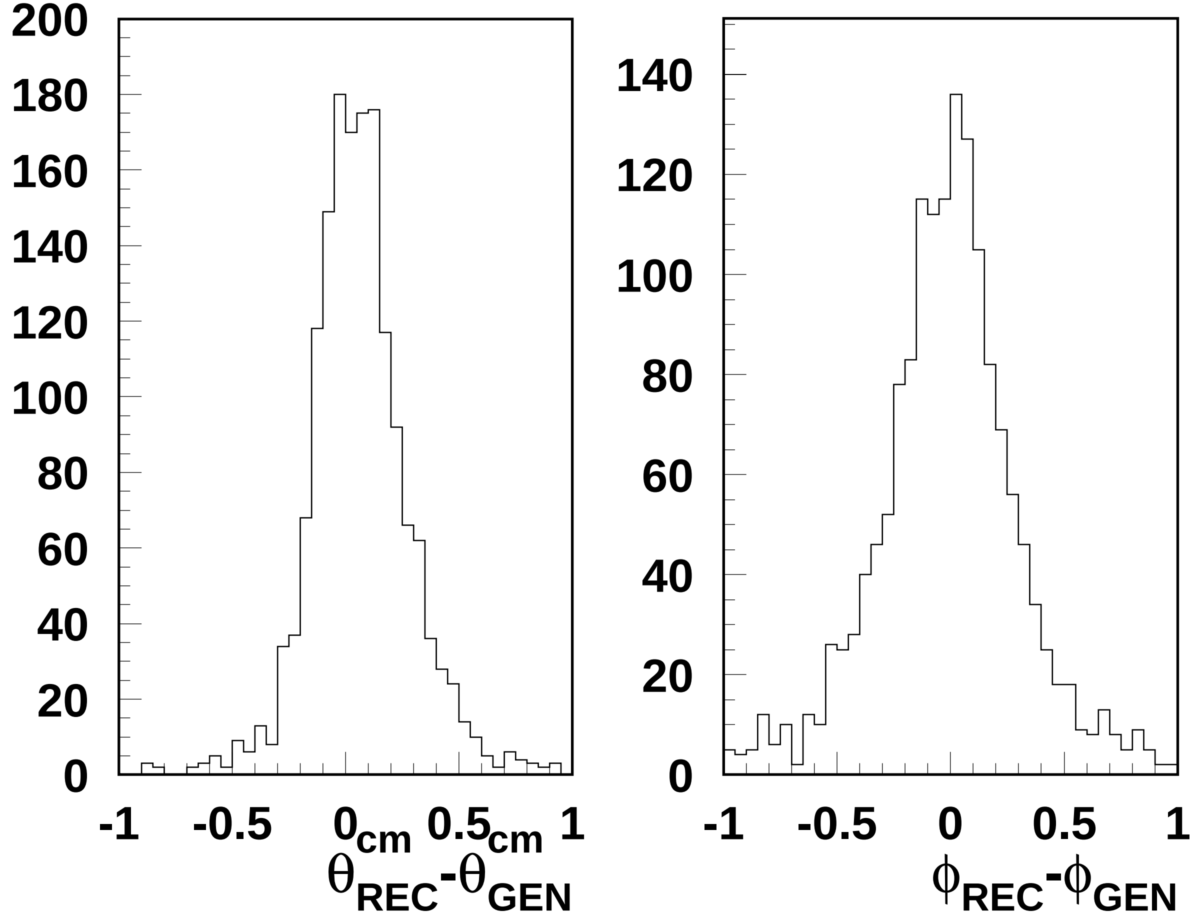
Two examples from Mirazita *et.al.*, (2004), E-93-017





Supporting Slides

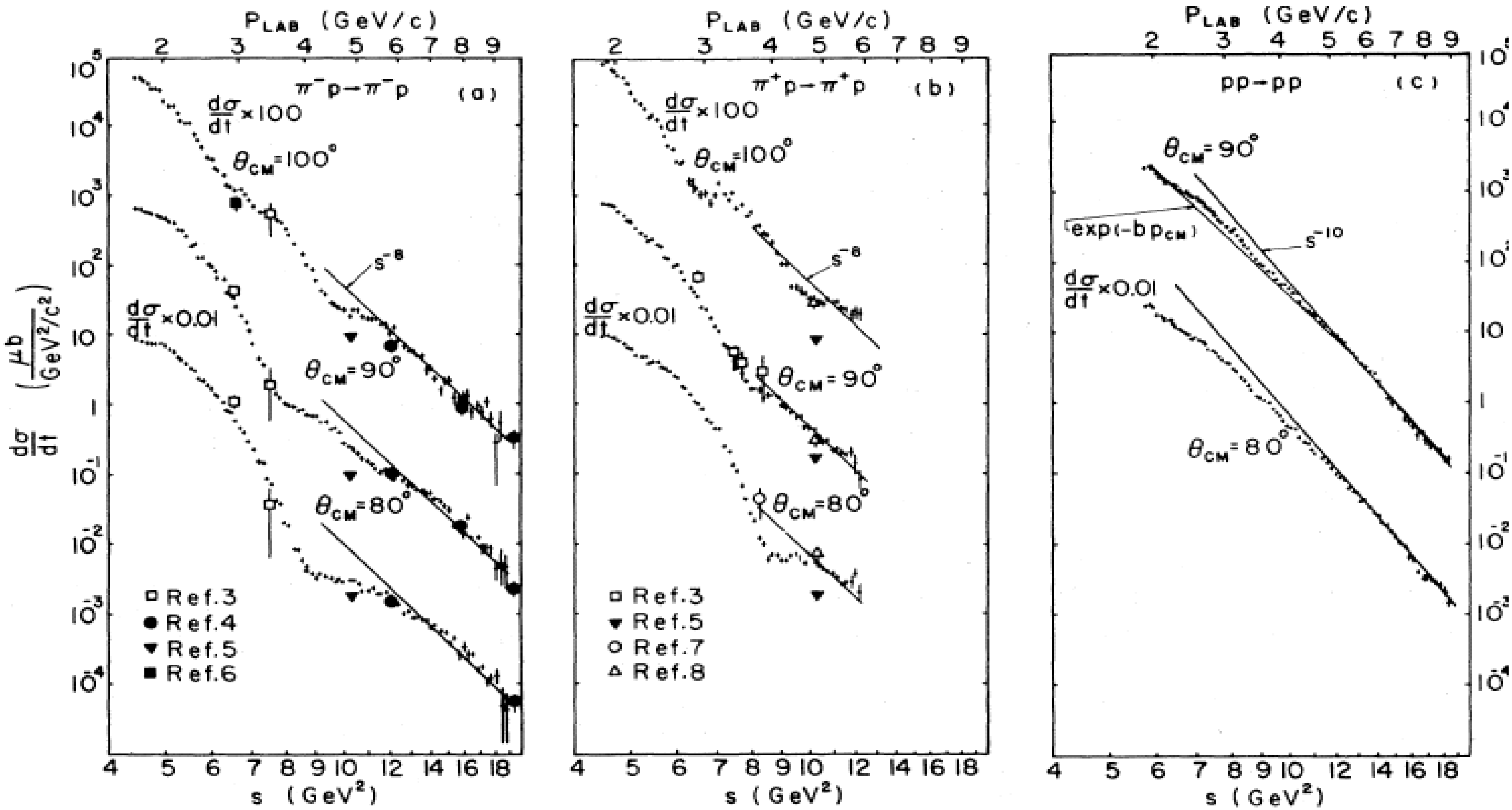
Energy loss corrections



Physics Motivation

1. Scaling Laws and Data: The Oscillations

Experimentally, dimensional scaling has an approximate character.
In reality, substantial oscillations about the power-law behavior take place:



Physics Motivation

1. Scaling Laws in QCD: Present Status

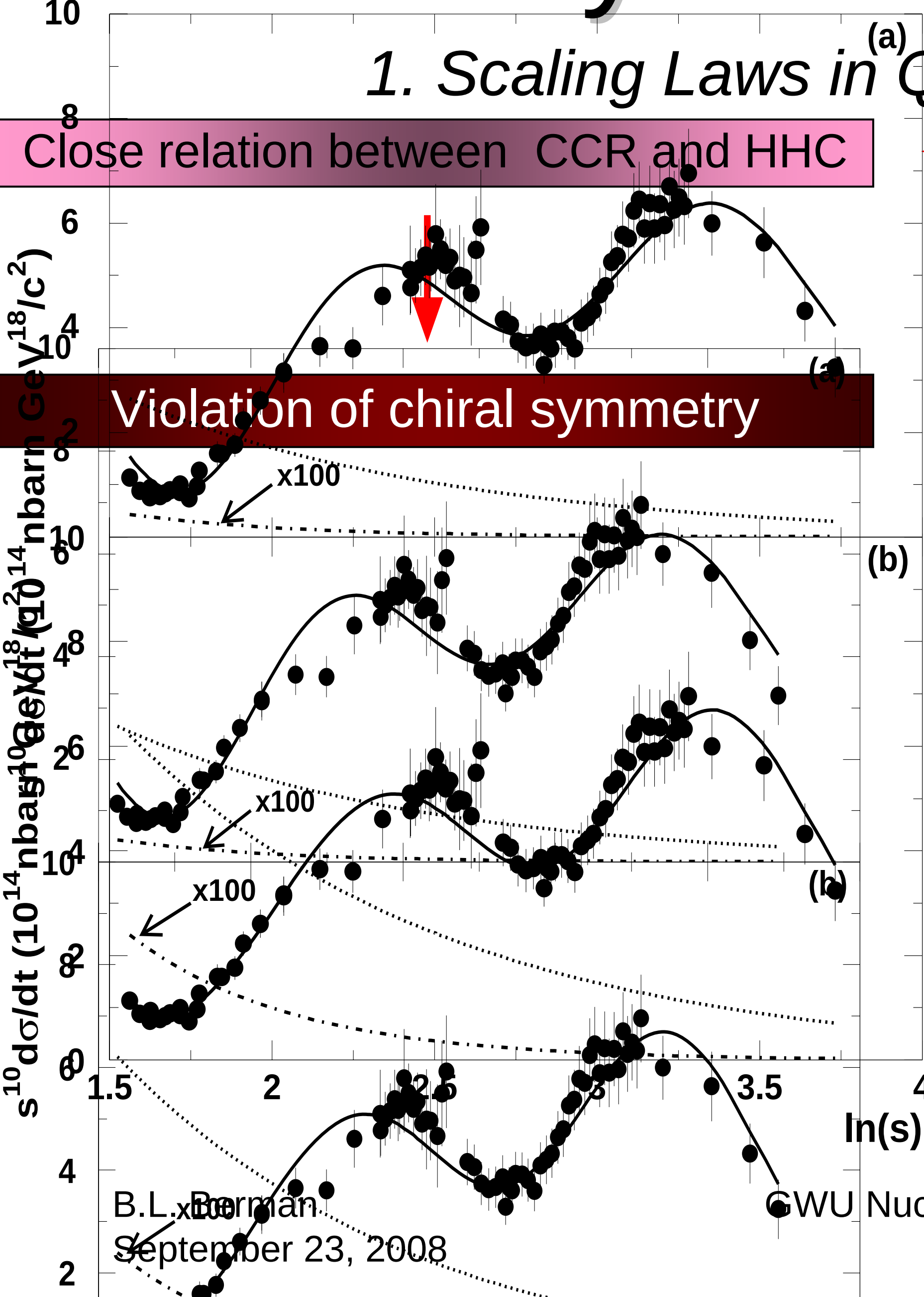
Close relation between CCR and HHC

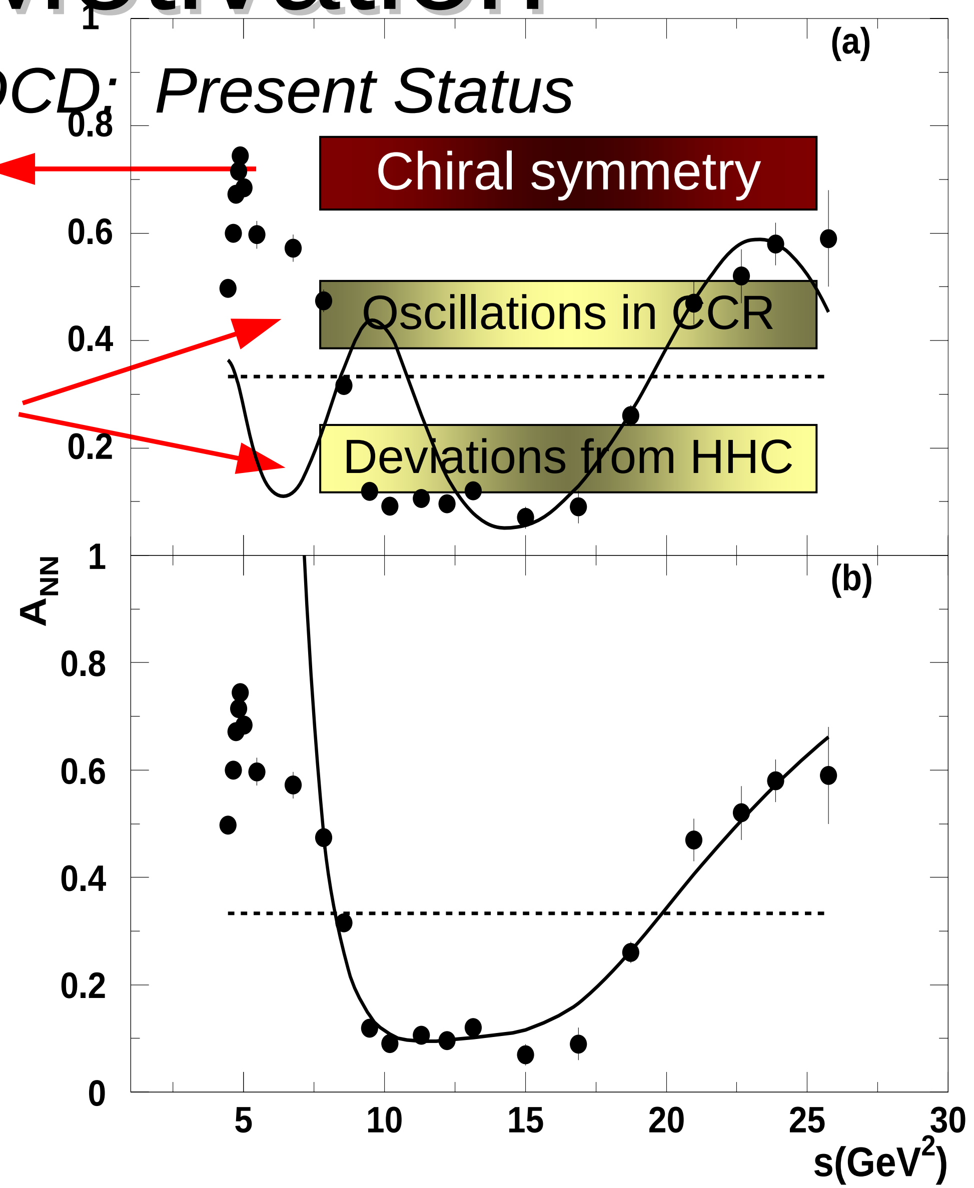
Chiral symmetry

Violation of chiral symmetry

Oscillations in CCR

Deviations from HHC





Physics Motivation

1. Scaling Laws in QCD: Present Status

Interpretation of oscillations

Parton orbital angular momentum:
- –Ji, Ma, Yuan (2003)

Intrinsic charm:
- –Brodsky and de Teramond (1988)

Short- and long-distance interference:
- –Brodsky, Carlson, Lipkin (1979)
- –Ralston and Pire (1990)

Breakdown of quark-hadron duality:
- –Zhao and Close (2005)

Radiative corrections:
- –Sen (1983)
- –Farrar, Sterman, Zhang (1989)
- –Carlson, Chachkhunashvili, Myhrer (1992)

AdS/CFT correspondence:
- –Brodsky and de Teramond (2007)

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