Polarization Observables in Few Nucleon Systems with CLAS

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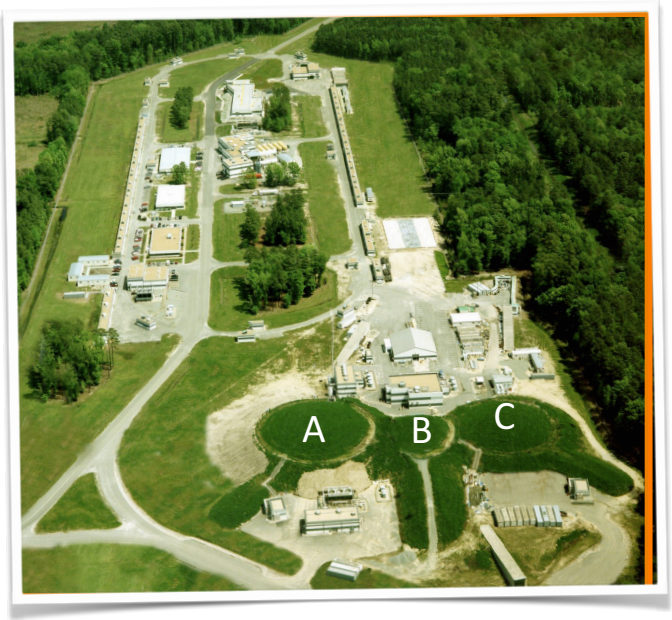
for the CLAS collaboration

DSPIN-2017 Dubna

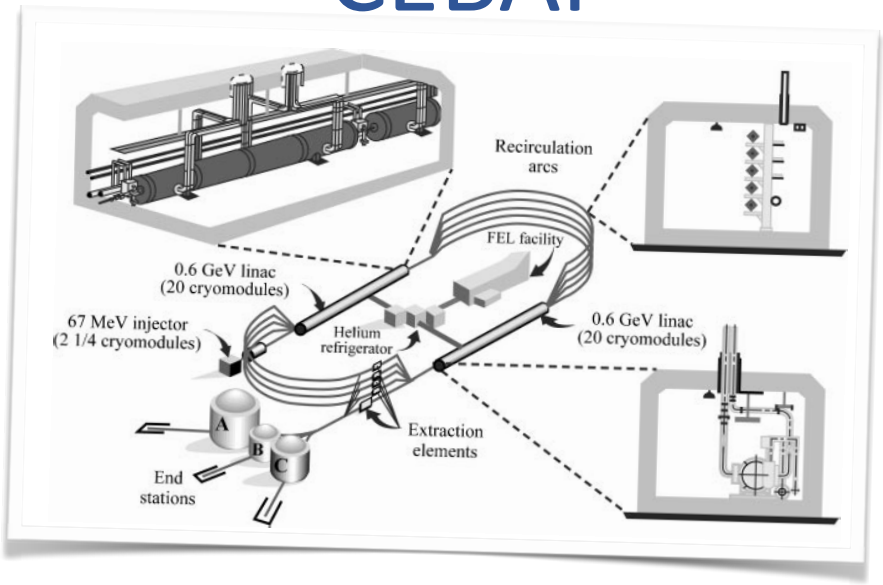
Outline

- Jefferson Lab and CLAS
- Photodisintegration of the deuteron → Studies of the transition region
- Study of FSI in exclusive reactions on deuteron → Stydy of the YN interaction

Jefferson Lab



CEBAF



Superconducting Electron Accelerator (338 cavities)

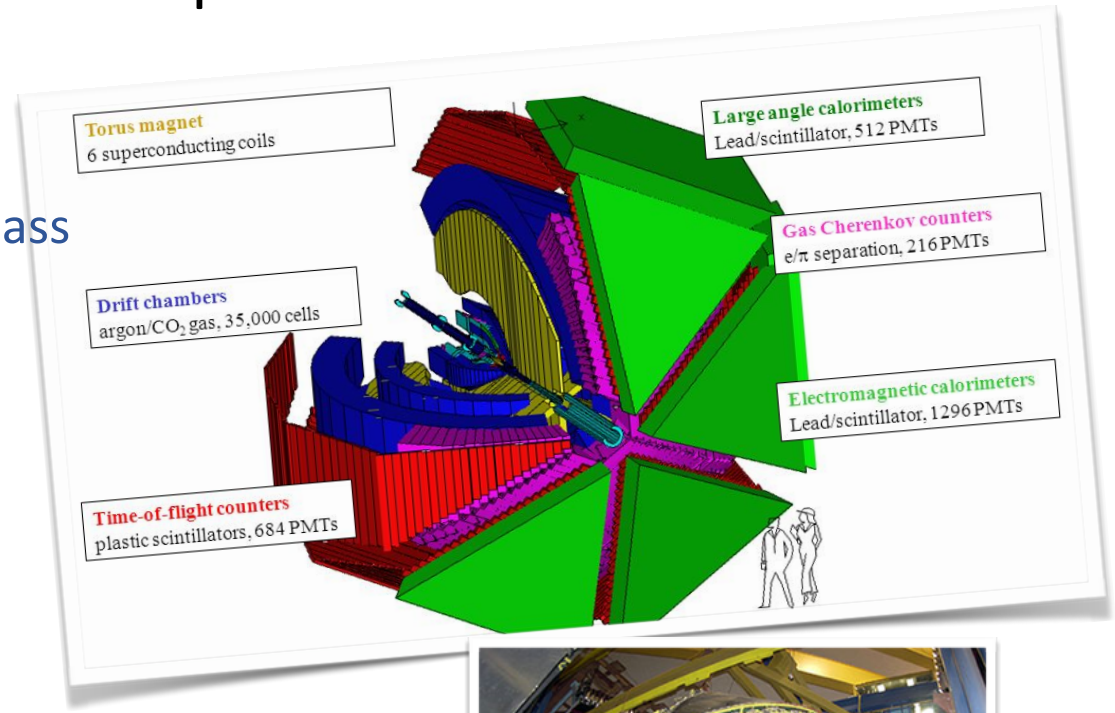
E_{max}=6 GeV $\Delta E/E = 10^{-4}$ P_e>80%

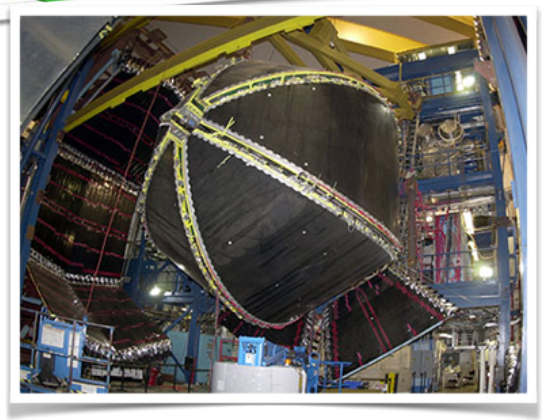
1500 Physicists over 30 countries

Operational since end of 1997

CEBAF Large Acceptance Spectrometer

- Six superconducting coils - six identical mass spectrometers
- Charge particle tracking 8° - 144°
- Neutral particle 8° – 70°
- Momentum resolution ~0.5%
- Angular resolution ~2 mr
- Particle ID
  - p/π identification <3.5 GeV/c
  - π/K identification <2 GeV/c

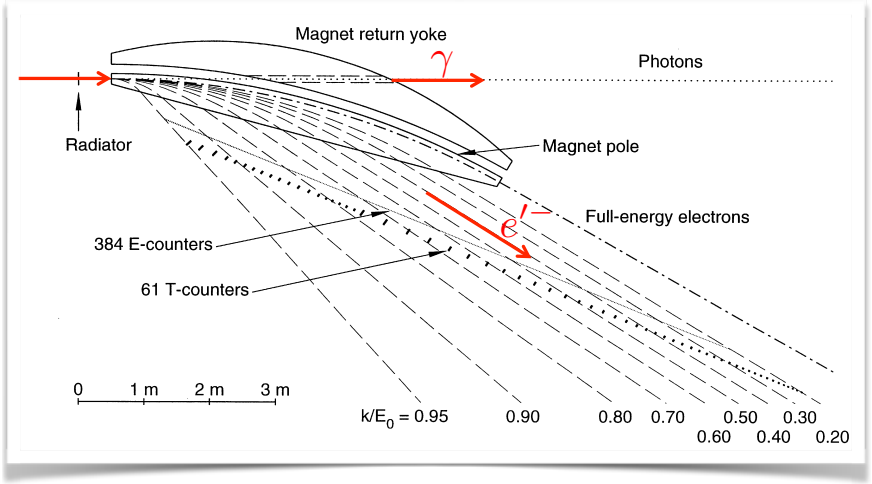




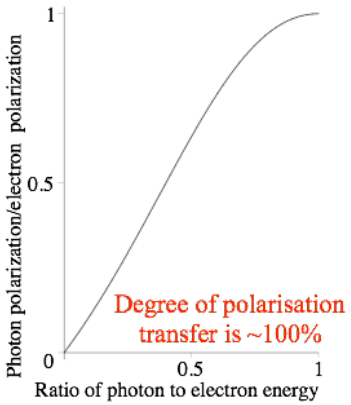
Tagger Spectrometer

$lum \sim 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

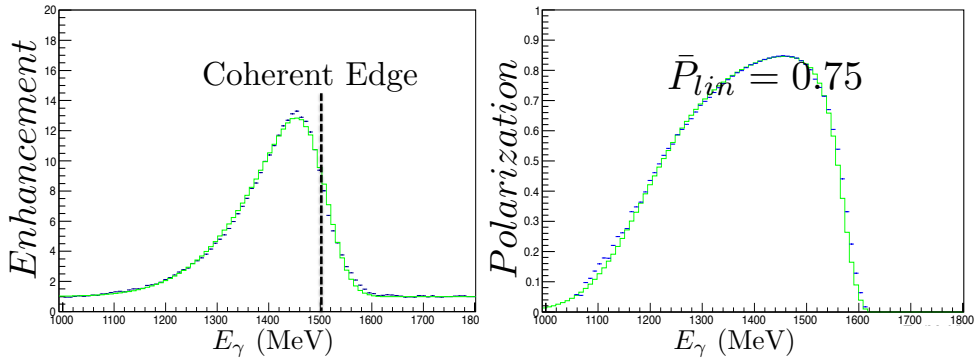
- Tagged photon beam
- $\Delta E/E = 10^{-3}$
- $E_\gamma = 0.2 - 0.9\ E_e$



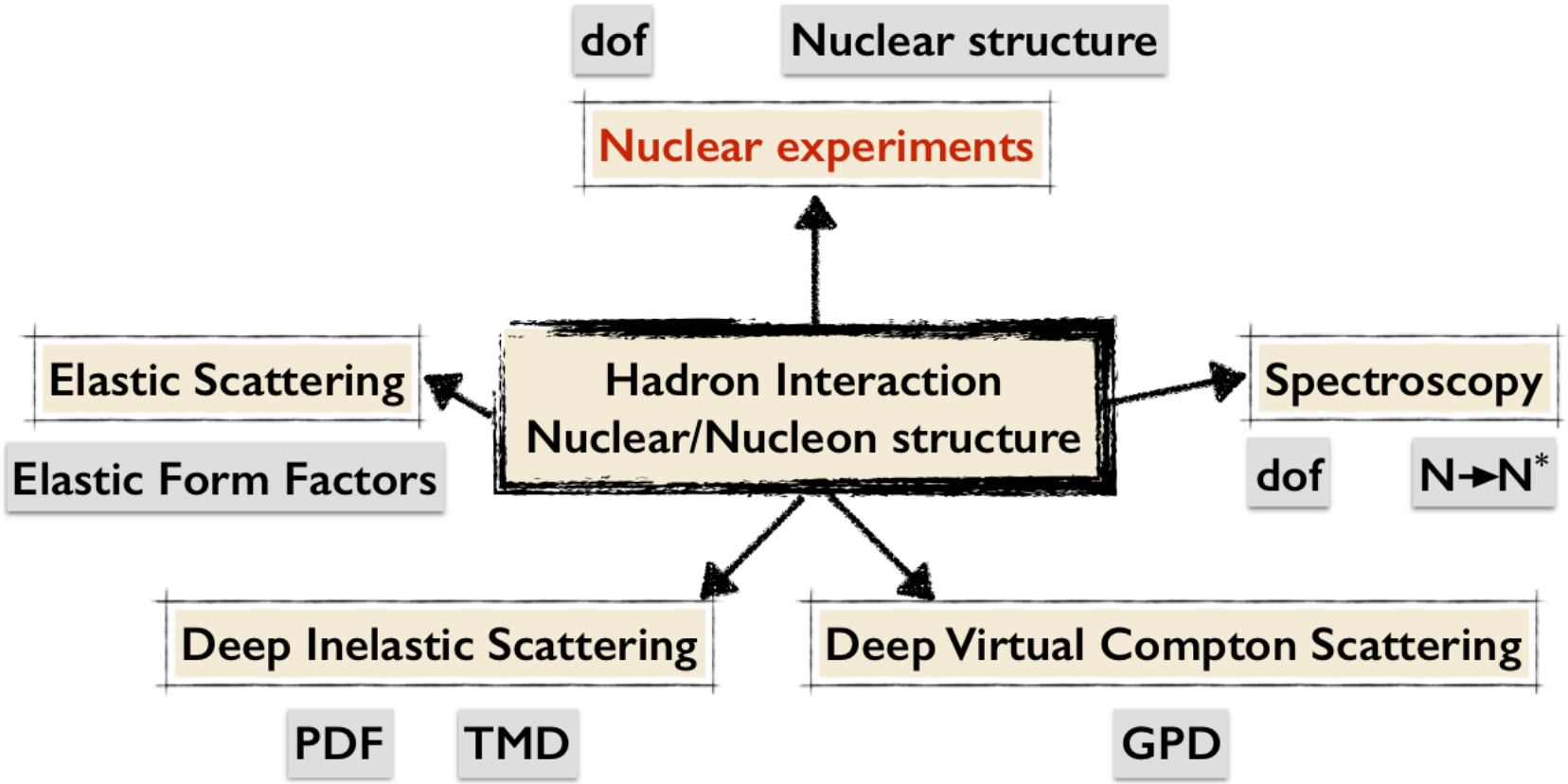
Circularly polarized



Linearly polarized



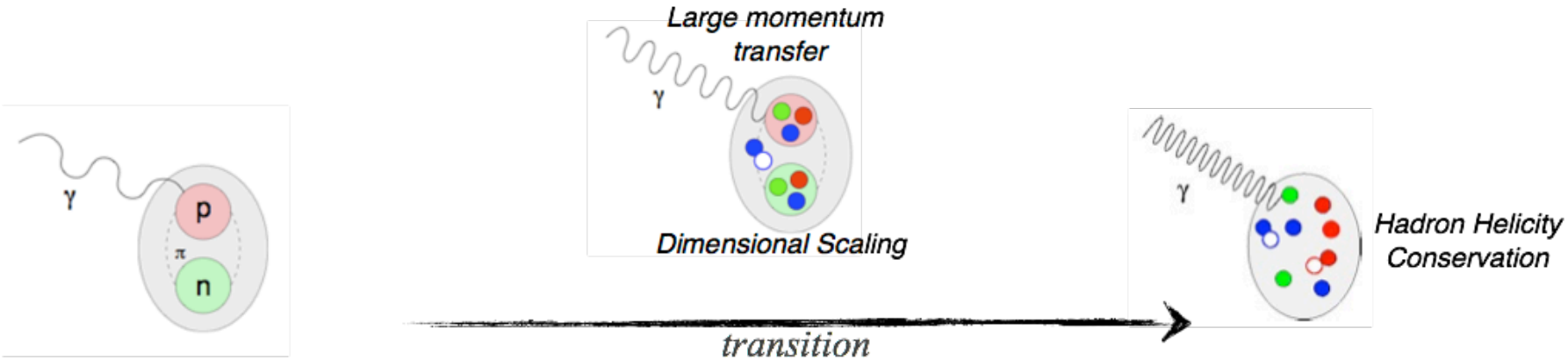
Deuteron Photodisintegration



Deuteron Photodisintegration

Large momentum transfer

Exclusive processes



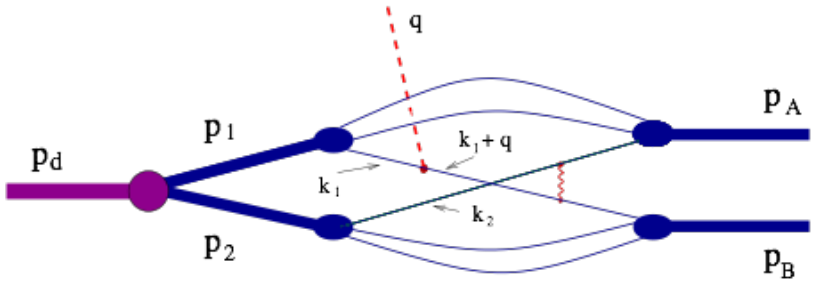
Access to quark-gluon dynamics

Dimensional scaling: Evidence for onset of quark-gluon dynamics in nuclear processes

Deuteron Photodisintegration

Hard Rescattering Mechanism (HRM)

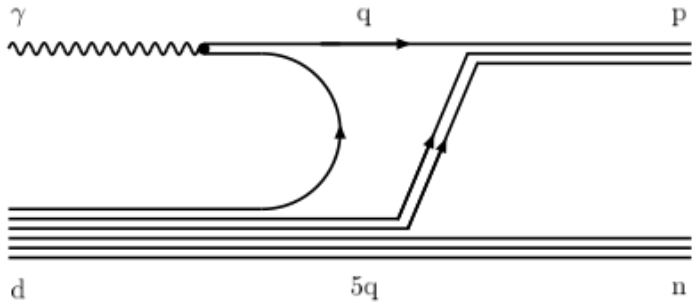
Photon is absorbed by a quark of one nucleon, followed by a high-momentum (hard) rescattering with a quark from the second nucleon



L. Frankfurt *et al.*, Phys. Rev. Lett. 84 3045 (2000)

Quark-Gluon String Model (QGSM)

The amplitude is calculated by the exchange of three valence quarks with any number of gluon exchanges between them

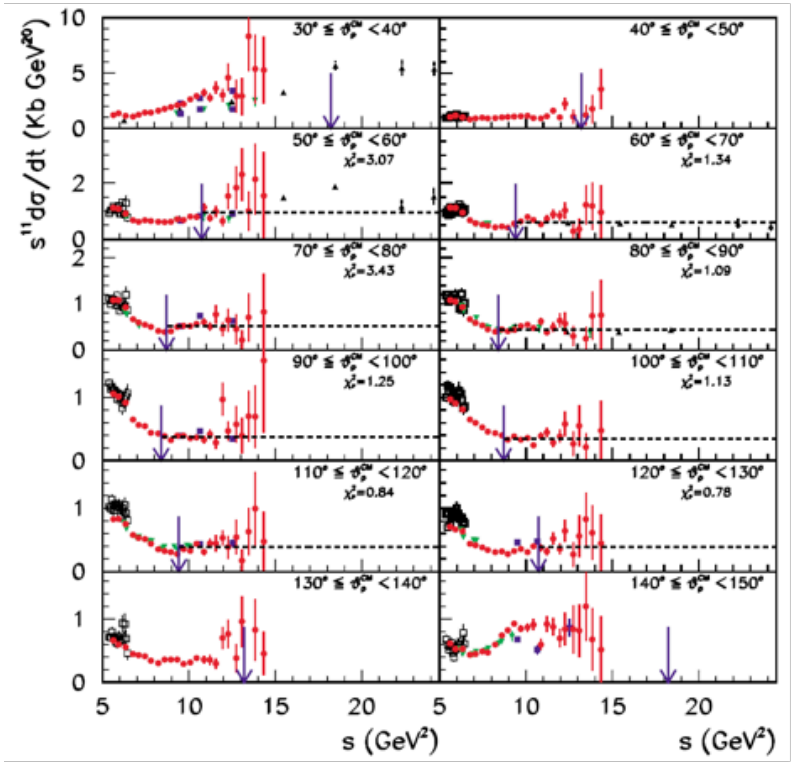


A.B. Kaidalov, Z. Phys C 12, 63 (2001)

Deuteron Photodisintegration

$\gamma d \rightarrow pn$

$$s^{11}\frac{d\sigma}{dt} \sim \text{const.}$$



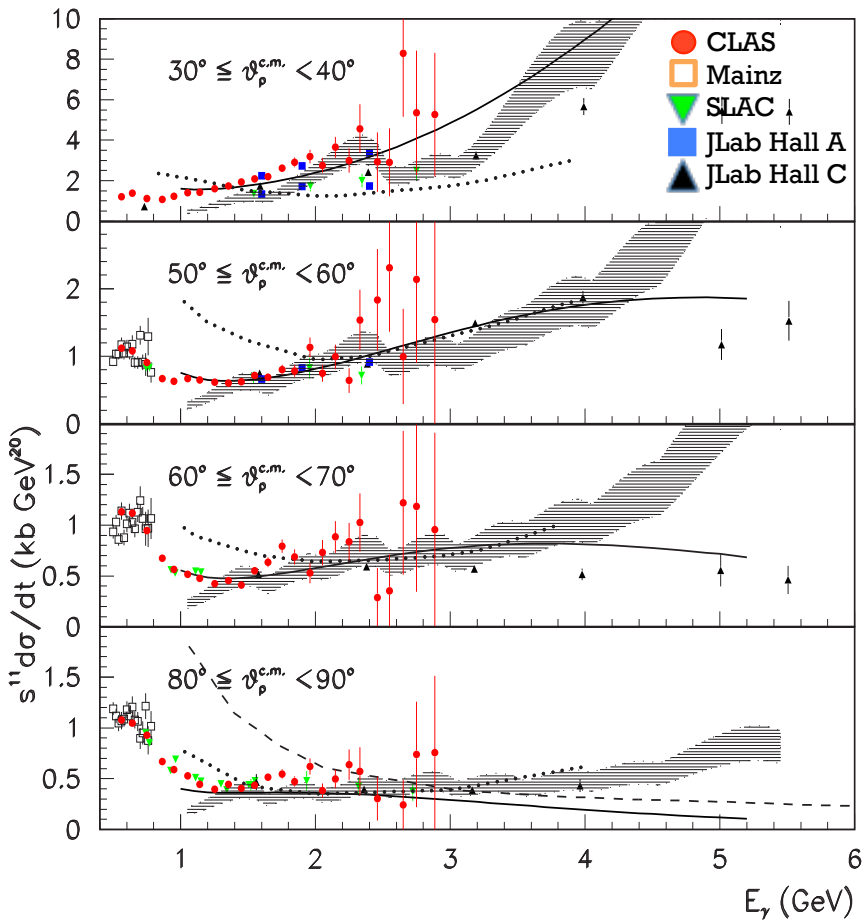
P. Rossi et al., Phys. Rev. Lett. 94, 012301 (2005)

$$p_T = \sqrt{\frac{1}{2}E_\gamma M_d \sin^2\theta_{c.m.}} = 1.1\ \text{GeV}/c$$

Theoretical Predictions
QGSM (solid line)
HRM (hatched area)

Both, QGSM and HRM describe the differential cross section with the same degree of success

Cross section alone does not provide enough information to understand the underlying dynamics



M. Mirazita et al., Phys. Rev. C 70, 014005 (2004); P. Rossi et al., Phys. Rev. Lett. 94, 012301 (2005)

Deuteron Photodisintegration

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_o [1 + p_y^N P_y + p_{lin}\Sigma\cos 2\phi + p_\circ(C_{x'}p_{x'} + C_{z'}p_{z'})]$$

Only two sets of data for the recoil proton polarisation obtained at JLab Hall A

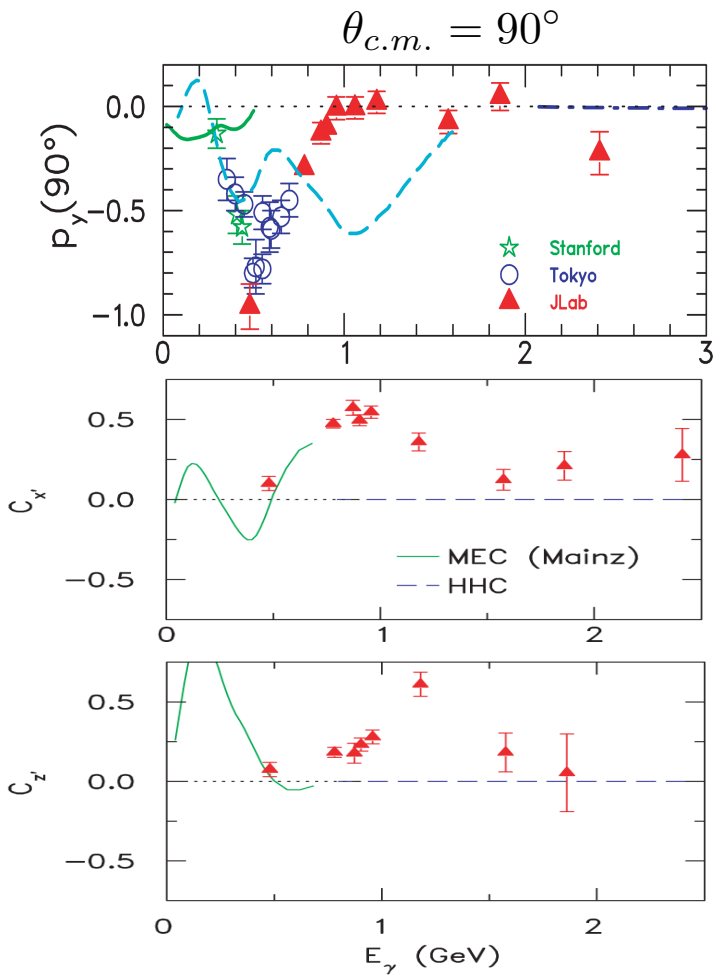
K. Wijesooriya et. al., Phys Rev Lett 86, 2975 (2001)

pQCD Limits (HHC)

$$P_y \to 0$$
$$C_{x'} \to 0$$
$$C_{z'} \to 0$$

P_y consistent with 0 for $E_\gamma > 1$ GeV

$C_{x'}$ and $C_{z'}$ do not vanish above 1 GeV, inconsistent with HHC



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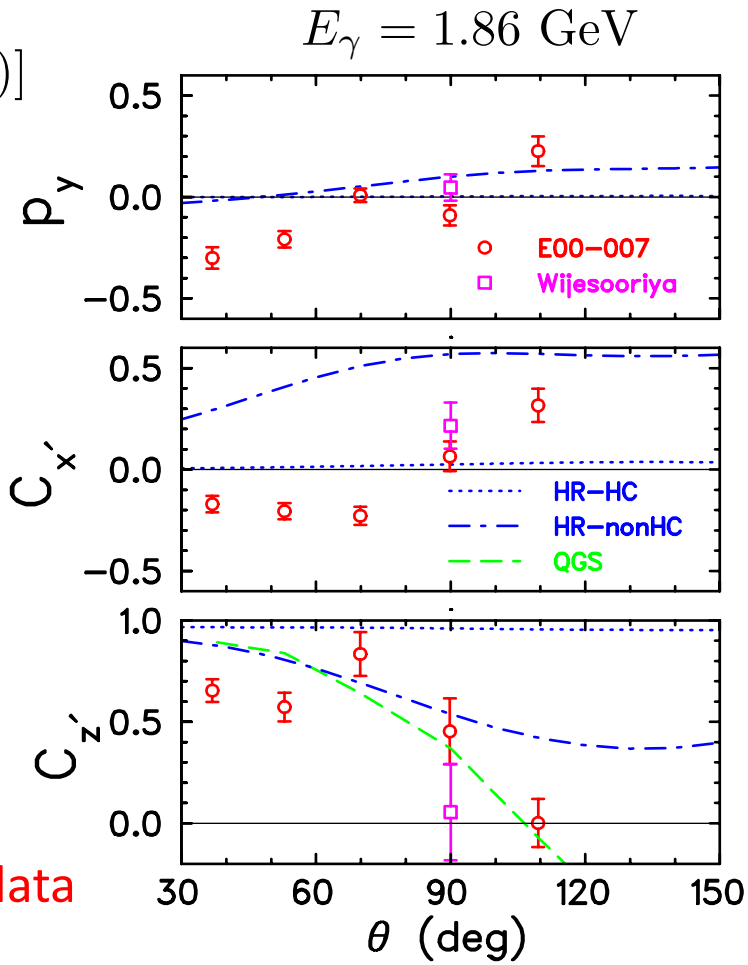
Comparison between theoretical predictions and available data is inconclusive



X. Jiang *et. al.*, Phys. Rev. Lett. **98** 182302

Deuteron Photodisintegration

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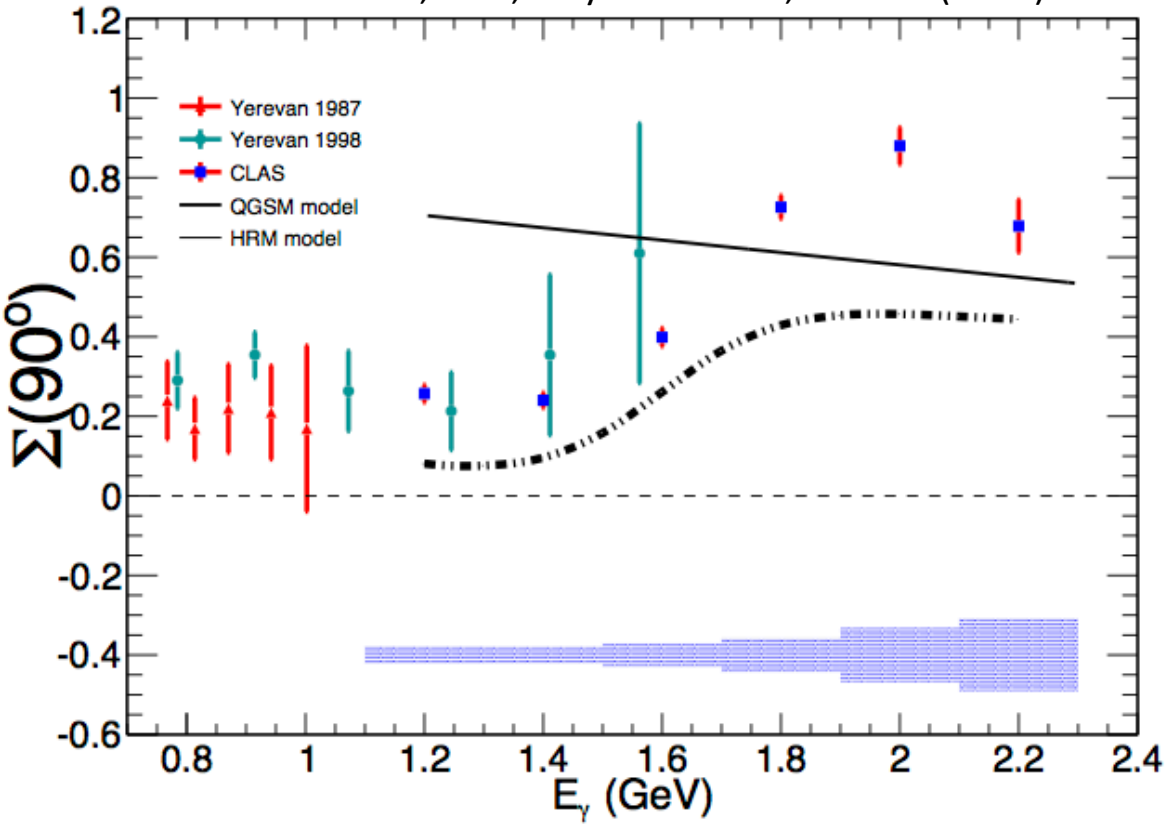
N. Zachariou, et al, Phys. Rev. C 91, 055202 (2015)

Experiment 06-103 (CLAS)

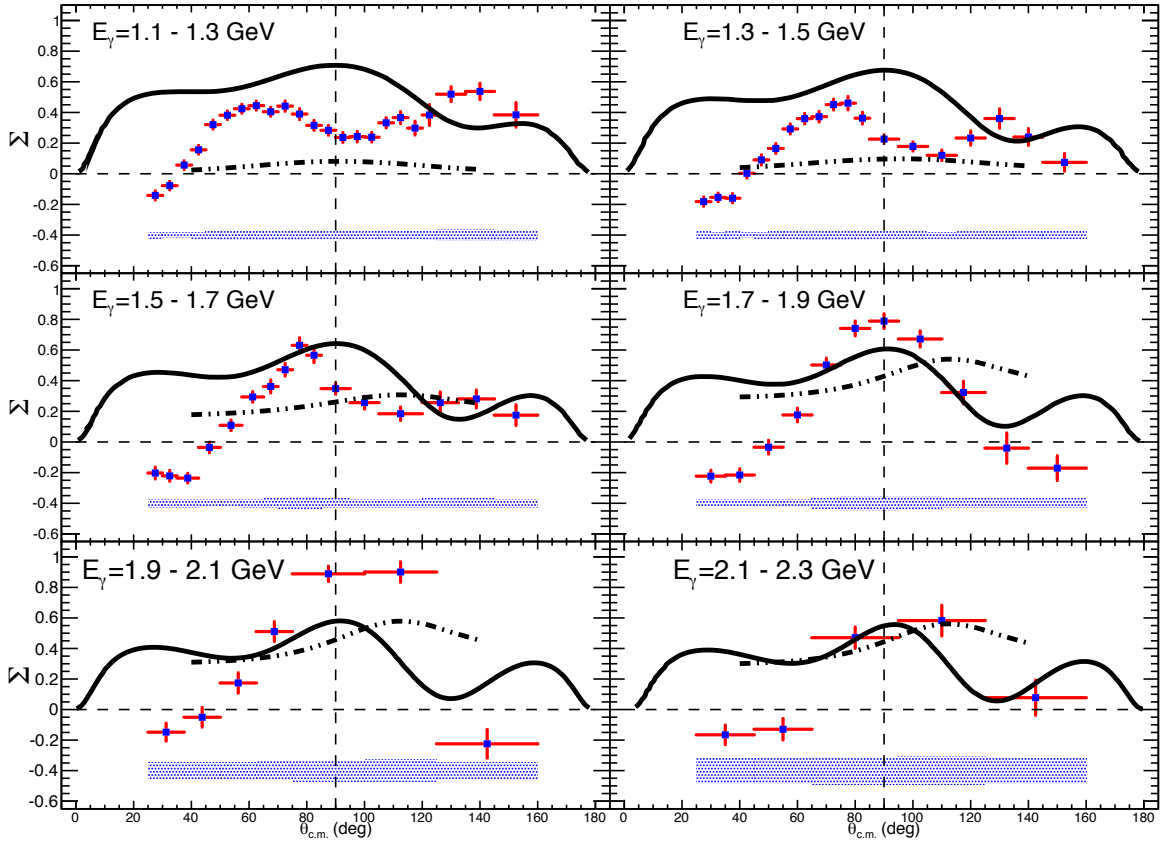
- Results agree with previous measurements
- Significantly improved measurements at lower energies
- Measurement extended up to 2.3 GeV



Deuteron Photodisintegration

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_o [1 + p_y^N P_y + p_{lin}\Sigma\cos 2\phi + p_\circ(C_{x'}p_{x'} + C_{z'}p_{z'})]$$

- Σ determined over 6 photon-energy bins (200 MeV wide)
- Σ shows a rich structure with minima at 90 deg at low photon energies and maxima at higher
- Both models seem to predict the maxima at higher photon energies at 90 deg



N. Zachariou, et al, Phys. Rev. C 91, 055202 (2015)

Study of the Hyperon-Nucleon Interaction

Motivation

The understanding of both nucleon-nucleon (NN) and hyperon-nucleon (YN) potentials is necessary in order to have a comprehensive picture of the strong interaction

- Understand the composition of neutron stars
- Understand hyper-nuclear structure and hyperon matter
- Extend NN to a more unified picture of the baryon-baryon interaction

Study of the Hyperon-Nucleon Interaction

How?

Extending *NN* to *YN* potentials using SU(3) symmetry
free parameters remain

Elastic *YN* Scattering
poor database

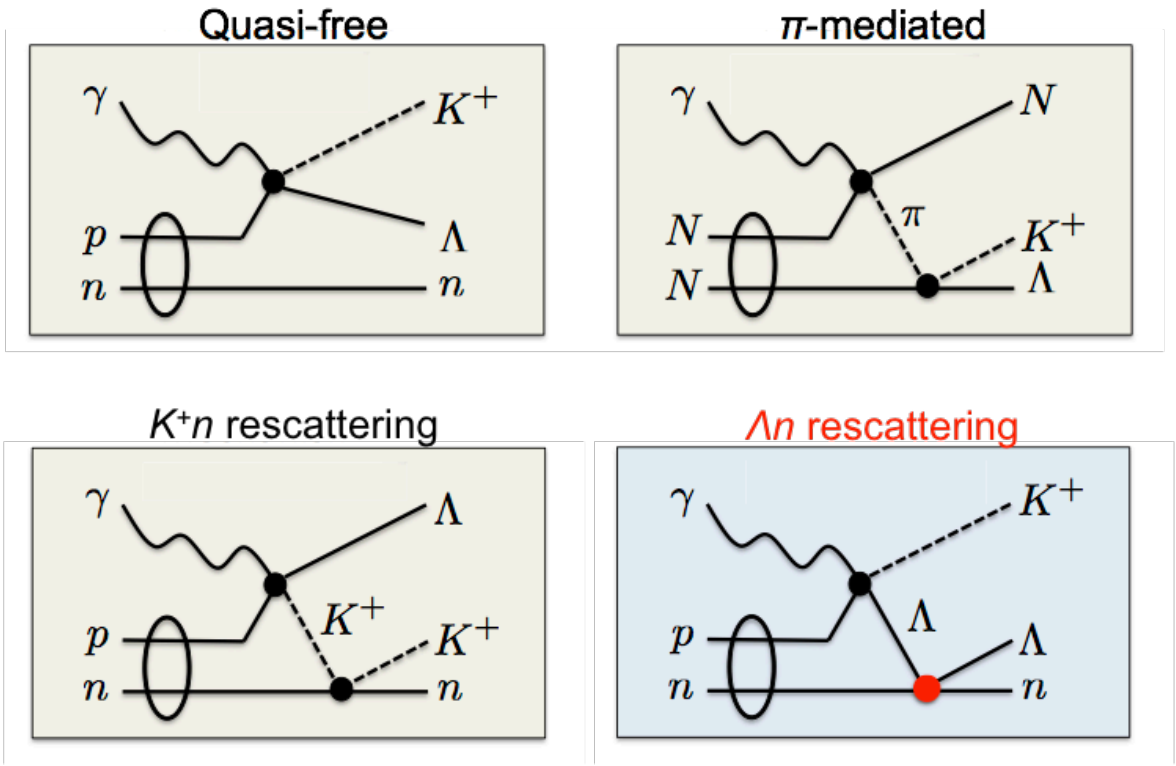
Study of Hypernuclei
no direct access on bare *YN* interaction

Final State Interactions (FSI) in Hyperon Production
simple target
sufficient counting rates in modern accelerators
model-dependent data interpretation

$$\vec{\gamma} d \to K^+ \vec{\Lambda} n$$

Study of the Hyperon-Nucleon Interaction

Exclusive Λ photoproduction off the deuteron

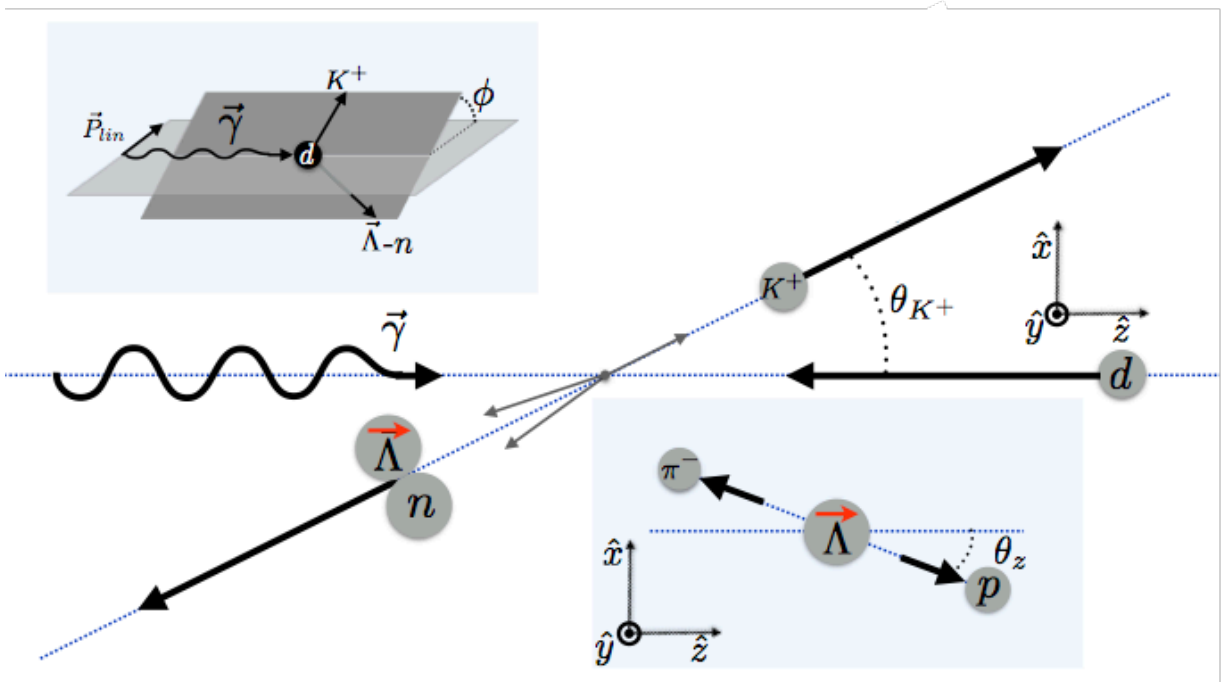


The QF events can be significantly reduced experimentally, enhancing rescattering contributions that will allow us to constraint YN theoretical models

Study of the Hyperon-Nucleon Interaction

Experimentally accessible phenomena

$$\frac{d\sigma}{d\Omega} = \sigma_0\{1 - P_{lin}\Sigma\cos 2\phi + \alpha\cos\theta_x(-P_{lin}O_x\sin 2\phi - P_{circ}C_x)$$
$$- \alpha\cos\theta_y(-P_y + P_{lin}T\cos 2\phi) - \alpha\cos\theta_z(P_{lin}O_z\sin 2\phi + P_{circ}C_z)\}$$



Beam Polarization

linearly polarized γ beam

circularly polarized γ beam

Λ Recoil Polarization

self-analyzing power

α=0.642

Study of the Hyperon-Nucleon Interaction

Theoretical Studies

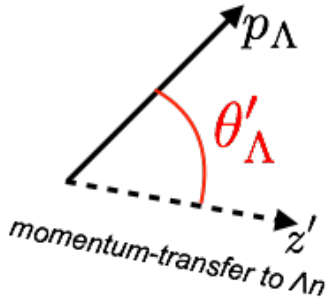
- Existing YN models allow the calculation of single and double polarization observables

- Two YN potentials (NSC97F and NSC89) give the correct hypetrition binding energy

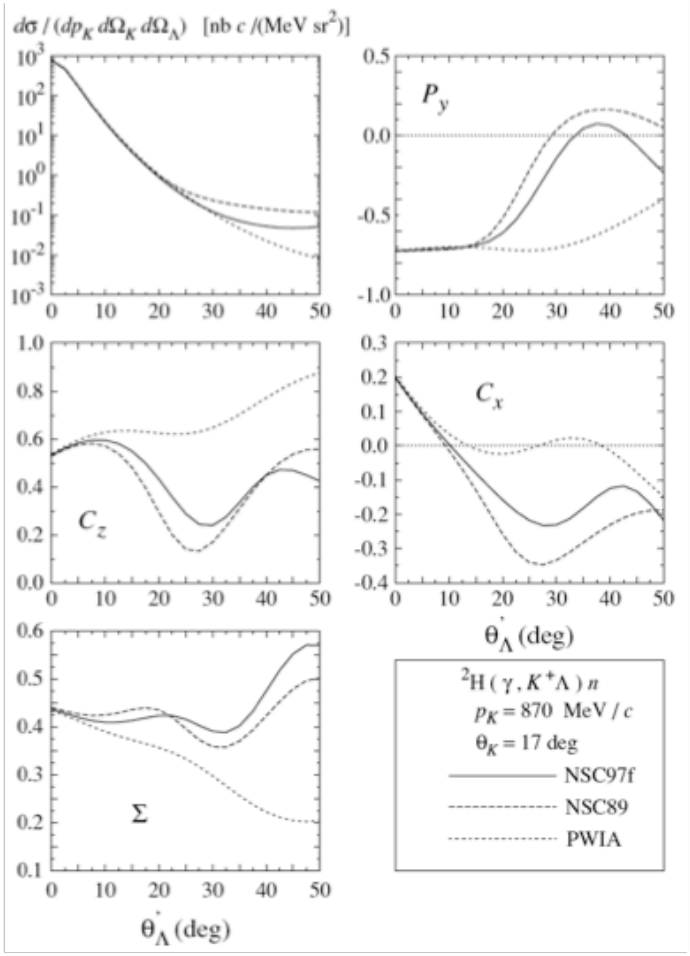
- NSC97F and NSC89 lead to very different predictions of polarization observables at some kinematics

$$\hat{z}' = \frac{\vec{p}_\gamma - \vec{p}_{K+}}{|\vec{p}_\gamma - \vec{p}_{K+}|}$$

$$\hat{y}' = \frac{\hat{z}' \times \vec{p}_{K+}}{|\hat{z}' \times \vec{p}_{K+}|}$$



Polarization observables are sensitive to θ'_Λ and p_{K+}



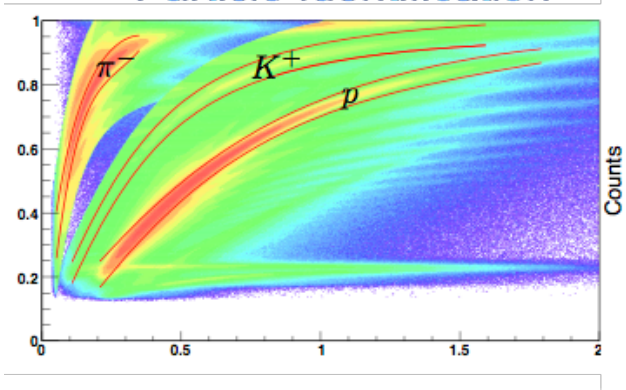
Study of the Hyperon-Nucleon Interaction

Analysis of $\vec{\gamma} d \rightarrow K^+ \vec{\Lambda}(n)$

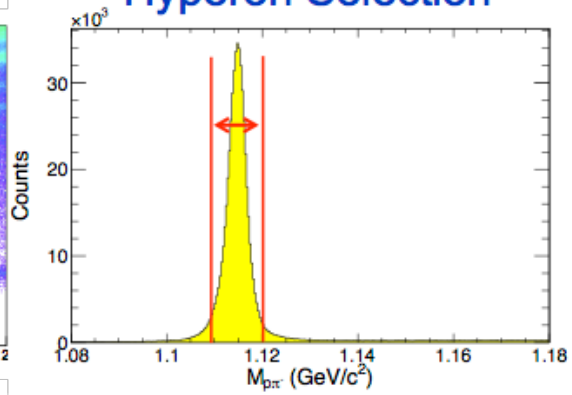
$\hookrightarrow p\pi^-$

(Branching ratio 63.9%)

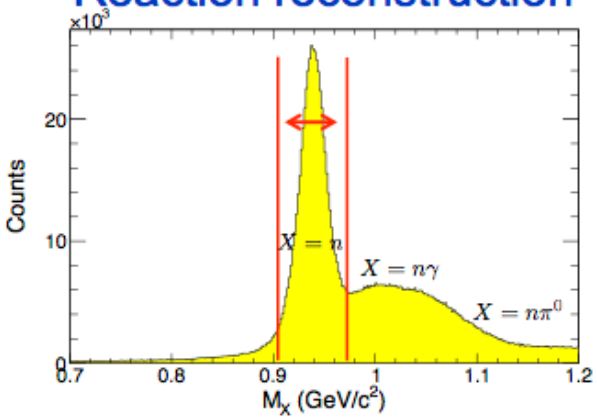
Particle Identification

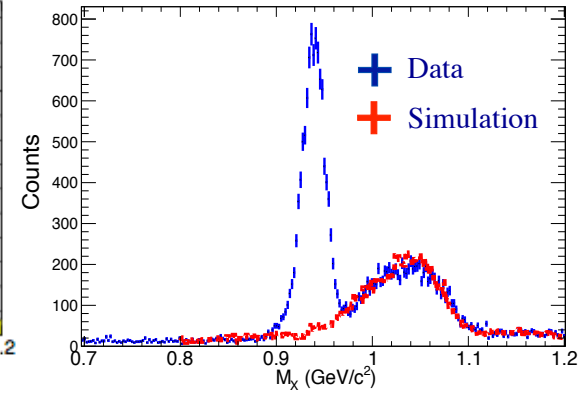


Hyperon Selection



Reaction reconstruction





Generated Background Reactions

$\gamma n \rightarrow \pi^0 n$	$\pi^0 p \rightarrow \Lambda K^+$
$\gamma p \rightarrow \Lambda K^+$	$K^+ n \rightarrow K^+ n$
$\gamma p \rightarrow \Lambda K^+$	$\Lambda n \rightarrow \Lambda n$
$\gamma p \rightarrow \Sigma K^+$	$\Sigma n \rightarrow \Sigma n$
$\gamma p \rightarrow \pi^+ n$	$\pi^+ n \rightarrow \Lambda K^+$
$\gamma p \rightarrow K^+ \Sigma^{*0}$	$\Sigma^{*0} \rightarrow \Lambda \pi^0$
$\gamma n \rightarrow K^+ \Sigma^{*-}$	$\Sigma^{*-} \rightarrow \Lambda \pi^-$

$\gamma p \rightarrow \Lambda K^+$

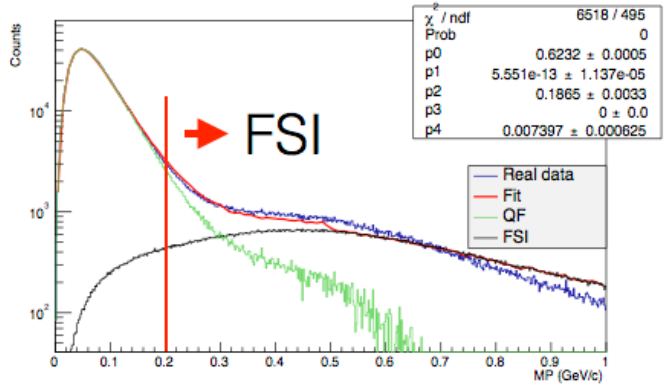
$\gamma p \rightarrow \Sigma K^+$

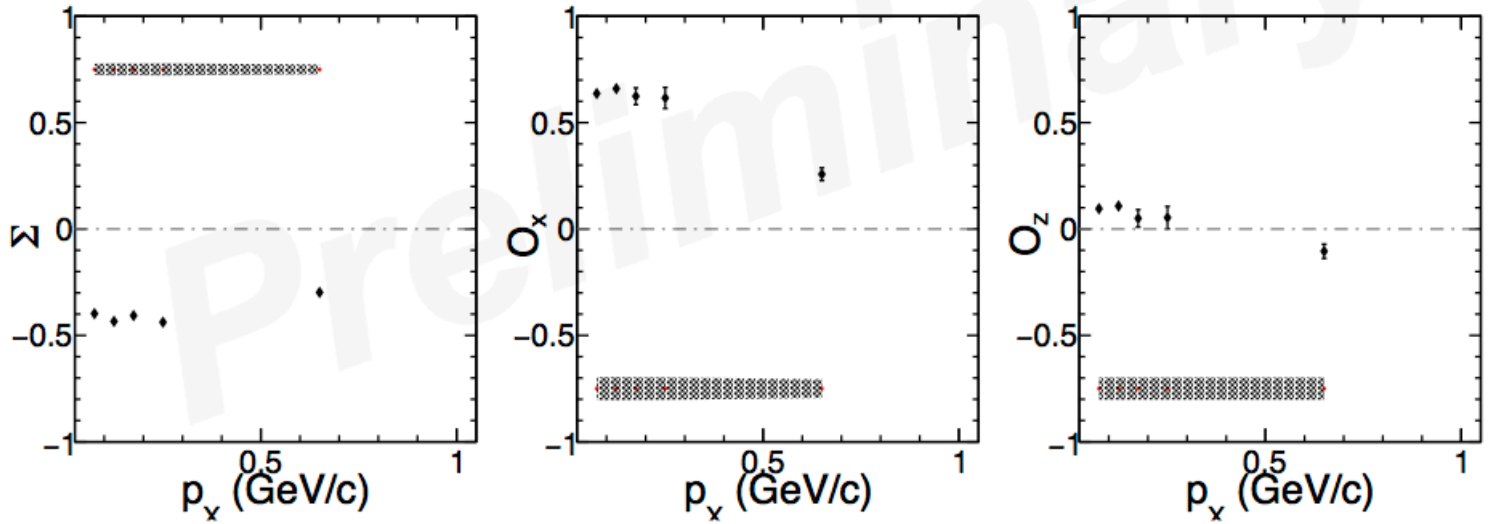
Study of the Hyperon-Nucleon Interaction

Analysis of $\vec{\gamma}d \rightarrow K^+\vec{\Lambda}(n)$

$\hookrightarrow p\pi^-$

(Branching ratio 63.9%)





Study of the Hyperon-Nucleon Interaction

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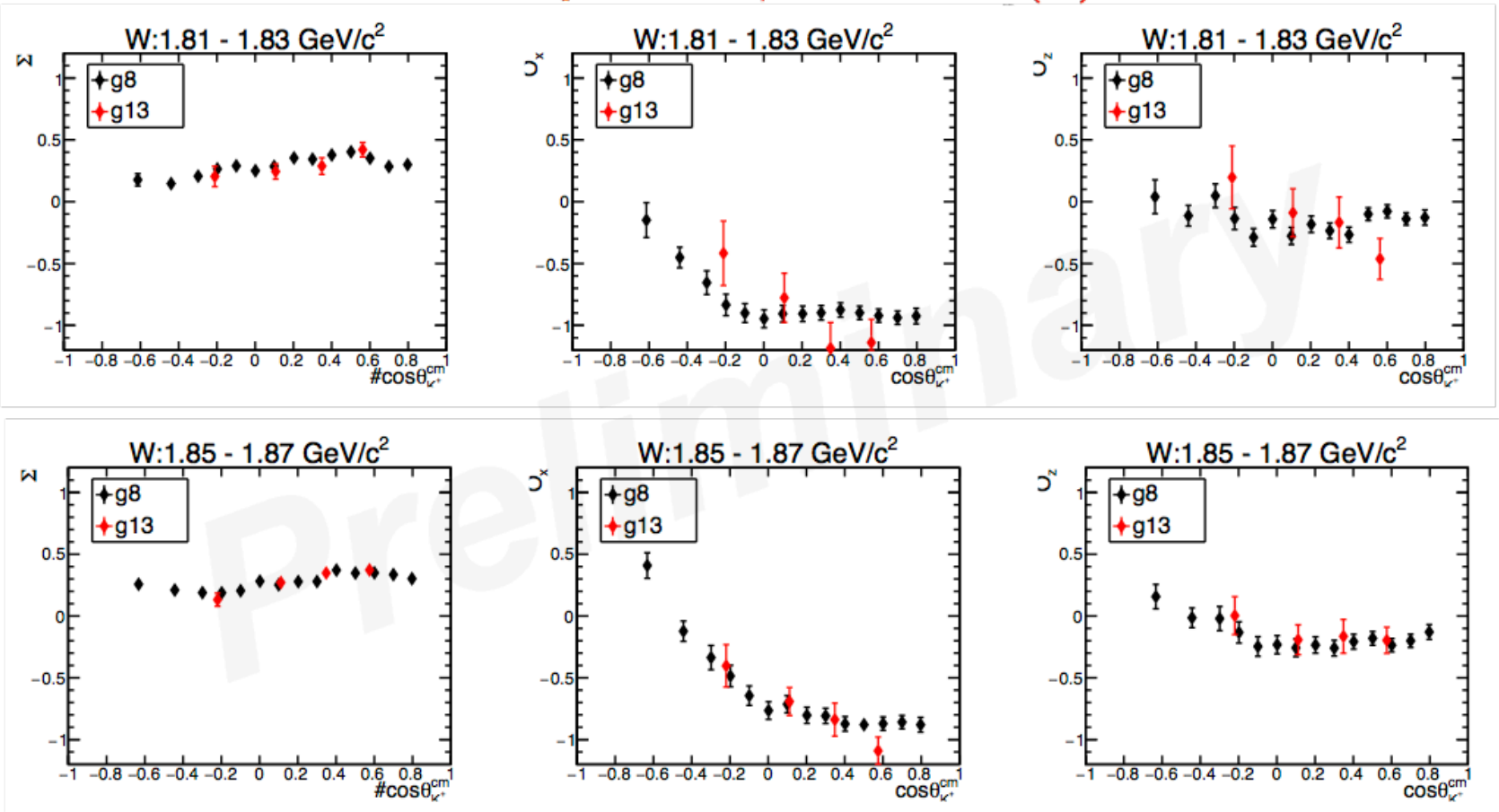

Study of the Hyperon-Nucleon Interaction

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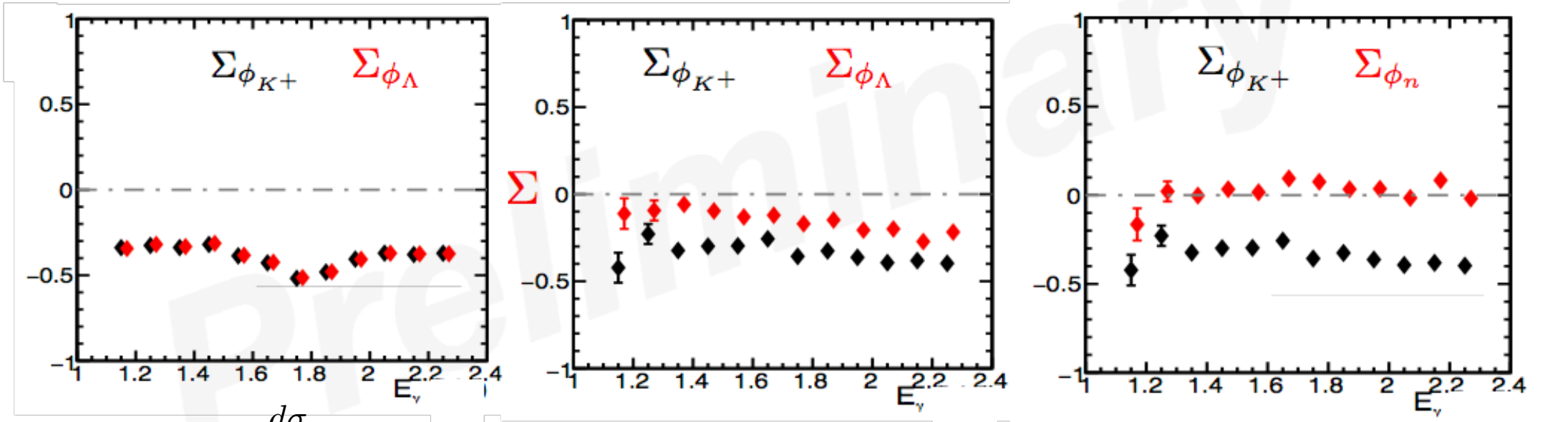
$\hookrightarrow p\pi^-$

(Branching ratio 63.9%)

QuasiFree data

FSI data



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$$- \alpha\cos\theta_y(-P_y + P_{lin}T\cos 2\phi) - \alpha\cos\theta_z(P_{lin}O_z\sin 2\phi + P_{circ}C_z)\}$$

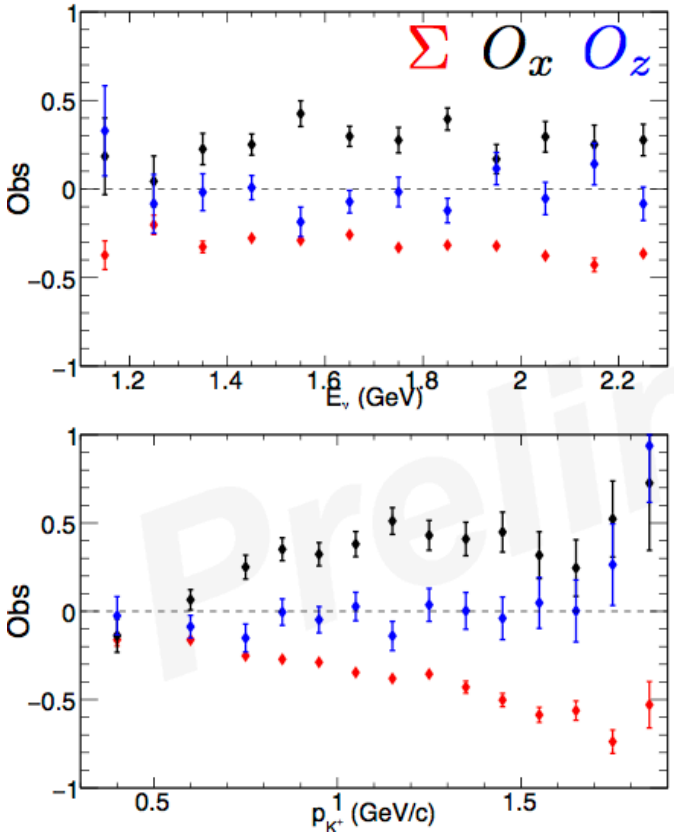
Study of the Hyperon-Nucleon Interaction

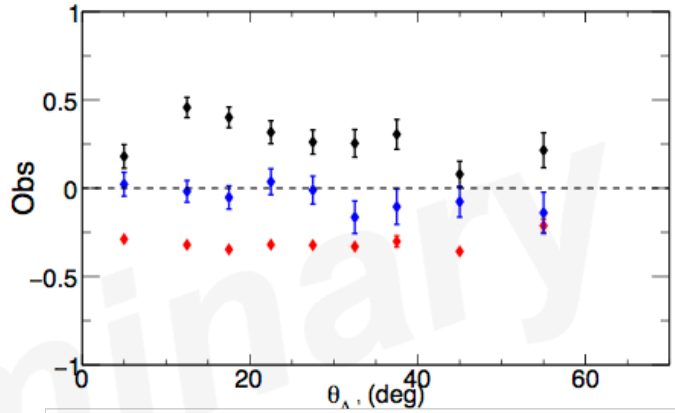
Analysis of $\vec{\gamma}d \rightarrow K^+\vec{\Lambda}(n)$

$\hookrightarrow p\pi^-$

(Branching ratio 63.9%)

FSI Results





Study of the Hyperon-Nucleon Interaction

Analysis of $\vec{\gamma}d \rightarrow K^+\vec{\Lambda}(n)$

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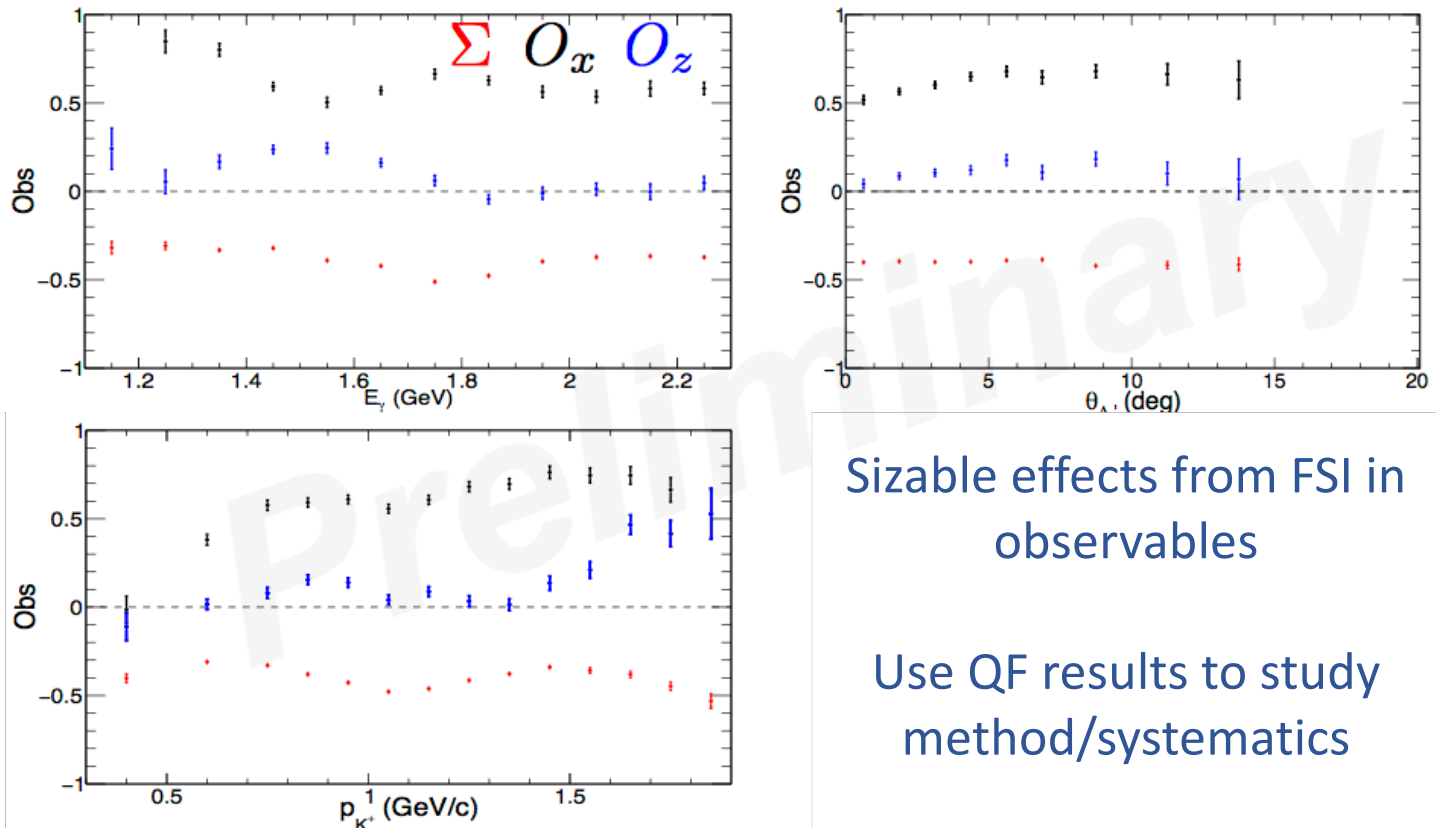
QF Results



Sizable effects from FSI in observables

Use QF results to study method/systematics

Study of the Hyperon-Nucleon Interaction

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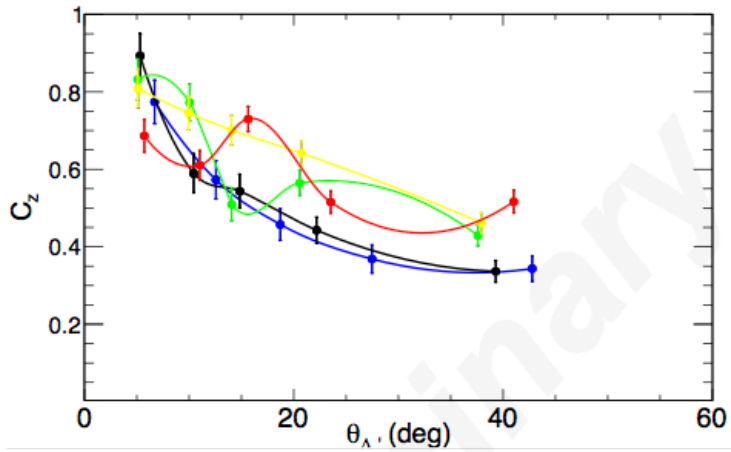
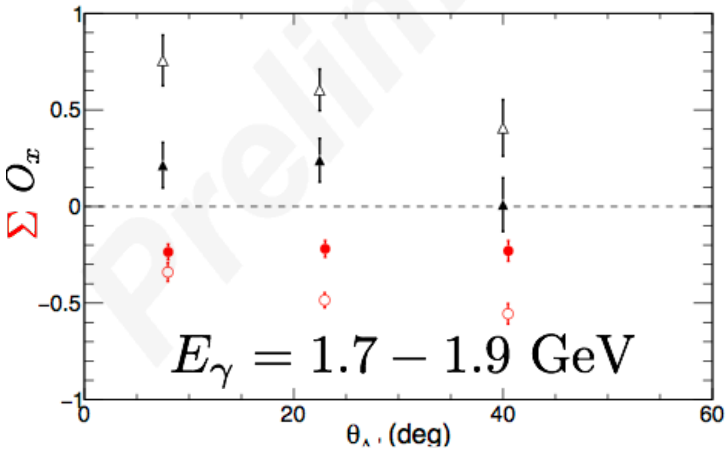




- Adequate statistics for extracting observables 2-fold and 3-fold differential
- Goal is to better tune the free parameters of YN potentials
- Work with theorists to interpret the data

Summary

Determination of polarization observables in few body systems can place stringent constraints on the underlying dynamics of the reaction, as well as study initial and final state effects.

The CLAS system at JLab provided the effective tools needed to reliably and precisly determine polarization observables over w wide range of kinematic variables.

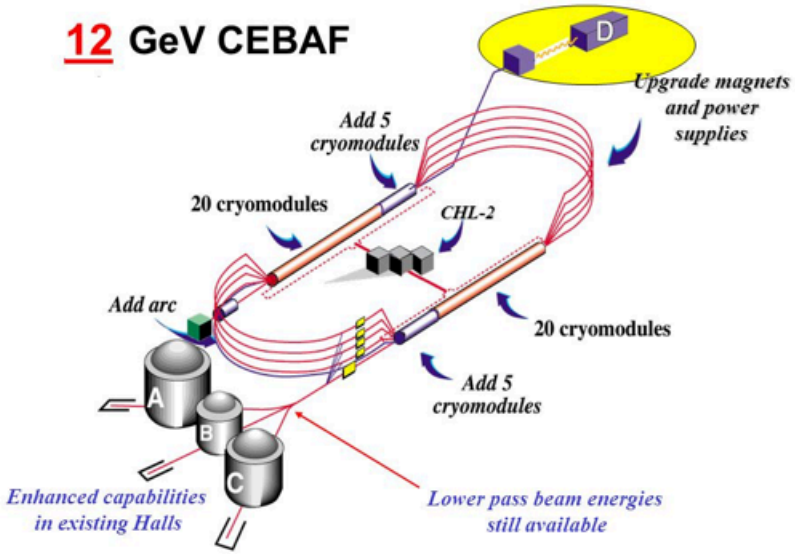
Beam-spin asymmetry of deuteron photodisintegration is very sensitive to the underlying reaction mechanism.

The available theoretical predictions, at their current state fail to adequately predict the energy and angular dependence of the beam-spin asymmetry.

Studies on the YN interaction are feasible through the study of FSI in exclusive reactions

Our results will place stringent constraints on the available YN potentials and contribute to the understanding hadron dynamics in which the strange quark is involved

Upgraded Jefferson Lab



Electron energy doubled to 12 GeV

Three experimental halls upgraded to accommodate new physics opportunities

A new experimental hall for real photon experiments has been constructed