Deuteron Photodisintegration with CLAS

Yordanka Ilieva

- Motivation
- Two-body photodisintegration of deuteron
- Two-body photodisintegration of ^{3}He
- Opportunities for GlueX

Nuclear Photoproduction with GlueX

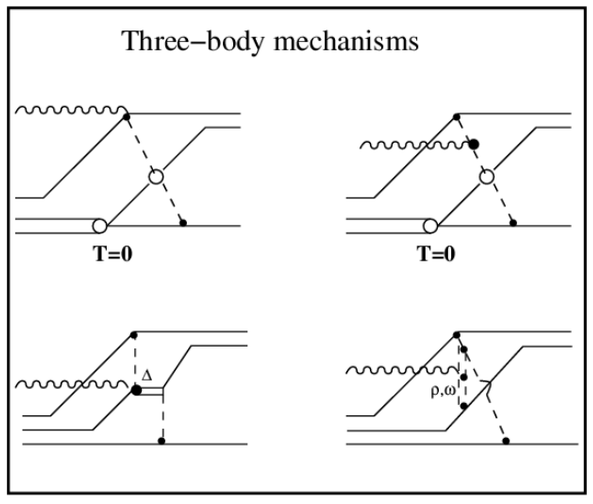
Newport News, VA

April 28, 2016

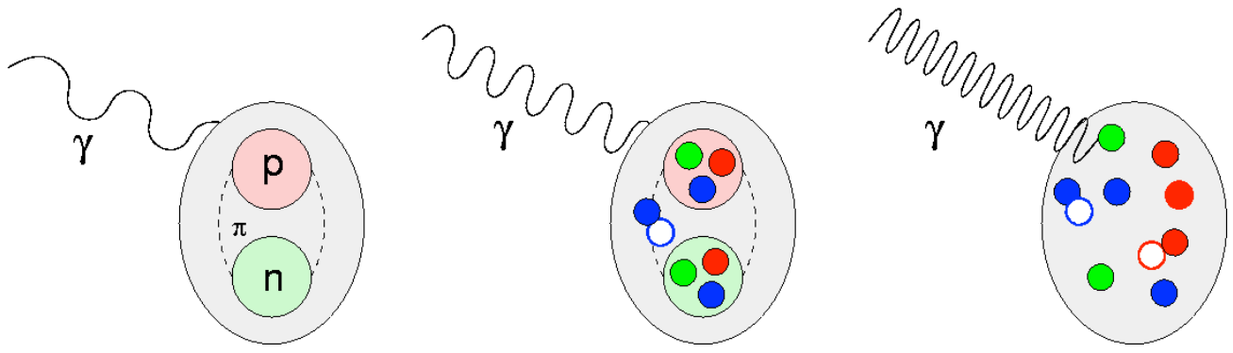
Photodisintegration of Few-Nucleon Systems at Medium Energies

Large Momentum Transfer Exclusive Processes (Hard Scattering)

Short-range dynamics (quark content of nuclei)



Transition from hadronic to partonic degrees of freedom



Dimensional Scaling Laws in Nuclear Physics

Brodsky, Farrar (1973): from dimensional analysis and perturbative QCD

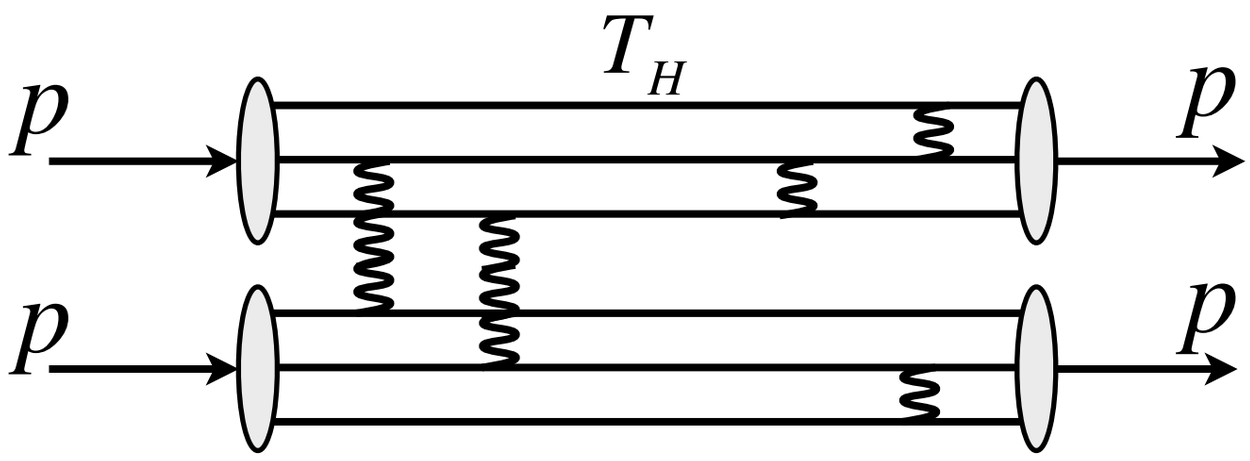
- At high t and high s, power-law behavior of the invariant cross section of an exclusive process A + B $\rightarrow$ C + D at fixed CM angle:

$$\frac{d\sigma}{dt} = \frac{1}{s^{n-2}} f(t/s)$$

where n is the total number of the initial and final elementary fields.

- The energy dependence of the scattering amplitude given by the 'hard-scattering amplitude' T_H for scattering collinear constituents from the initial to the final state

$$pp \rightarrow pp \equiv 3q3q \rightarrow 3q3q$$



$$\frac{d\sigma}{dt} \sim \frac{|M|^2}{s^2},$$

$$\text{where } [M] = [T_H] = \left(\sqrt{s}\right)^{4-n}$$

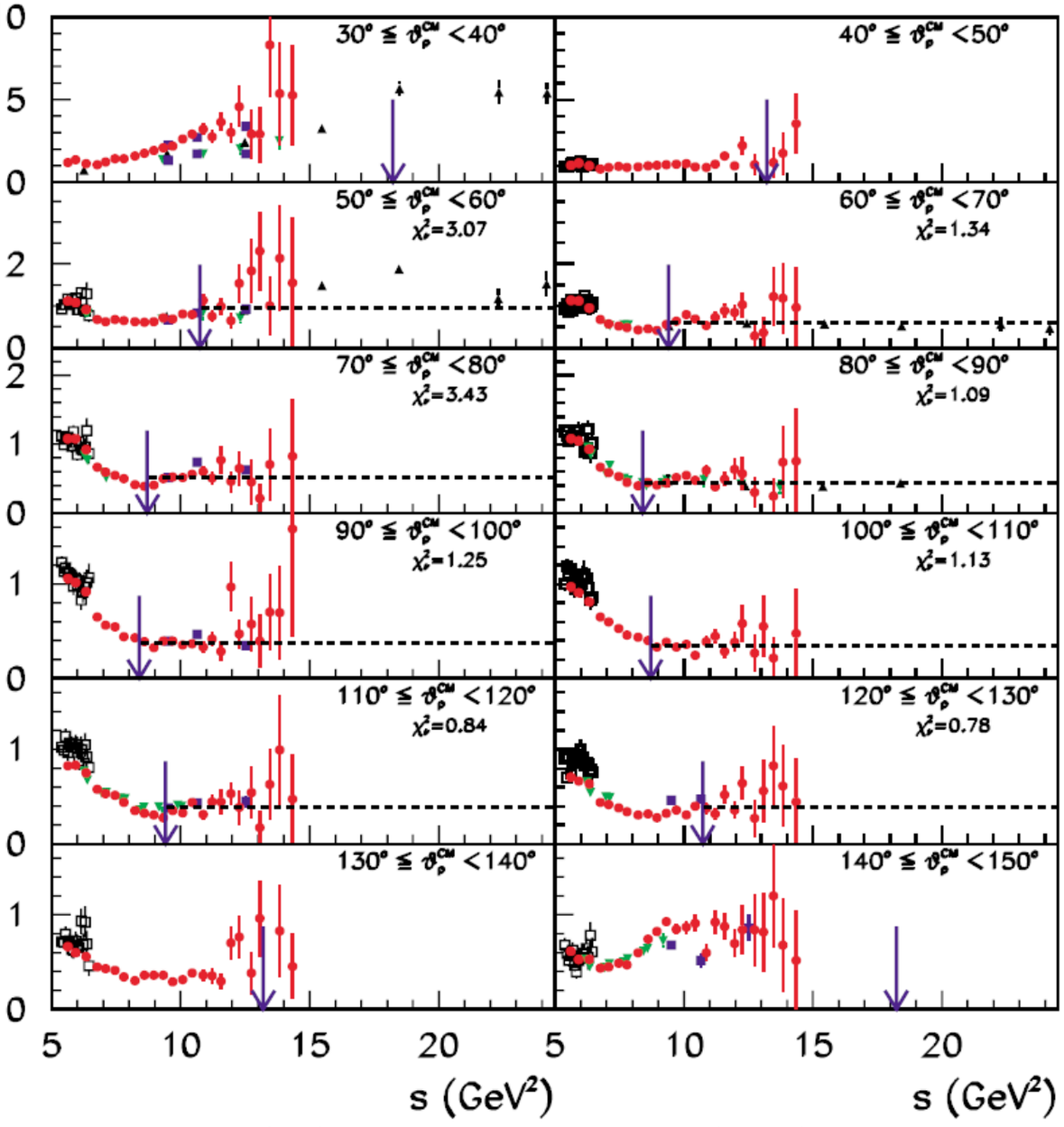
$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}}$$

S.J. Brodsky and G.R. Farrar, Phys. Rev. Lett **31**, 1153 (1973); S.J. Brodsky and J.R. Miller, Phys. Rev. C **28**, 475 (1983)

Experimental Findings in Two-Nucleon Systems

$\gamma d \to pn$

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

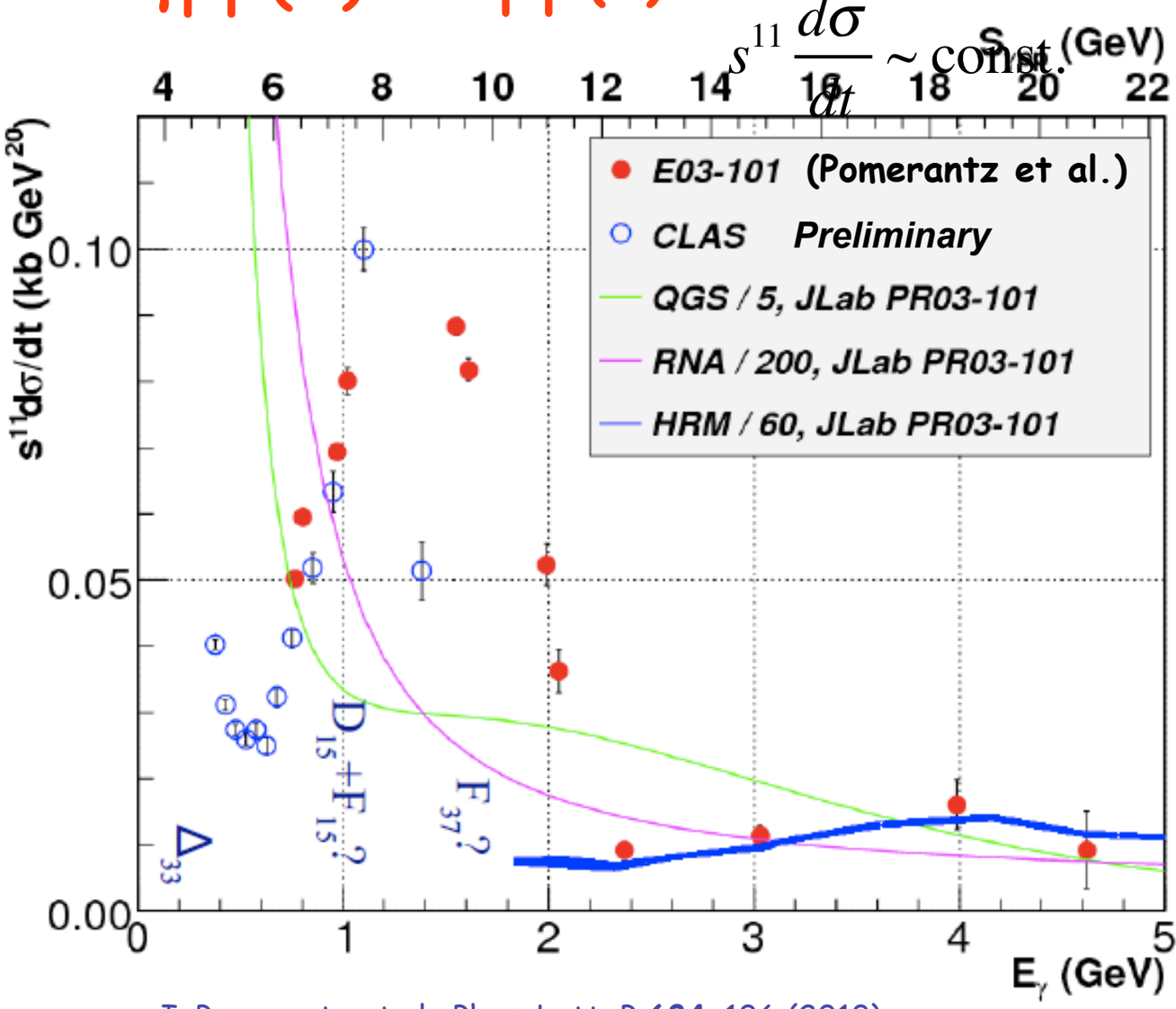


P. Rossi et al., Phys. Rev. Lett. **94**, 012301 (2005)

- Scaling at $p_T > 1.1$ GeV/c

$\gamma pp(n) \to pp(n)$

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



I. Pomerantz et al., Phys. Lett. B **684**, 106 (2010)
Figure from R. Gilman

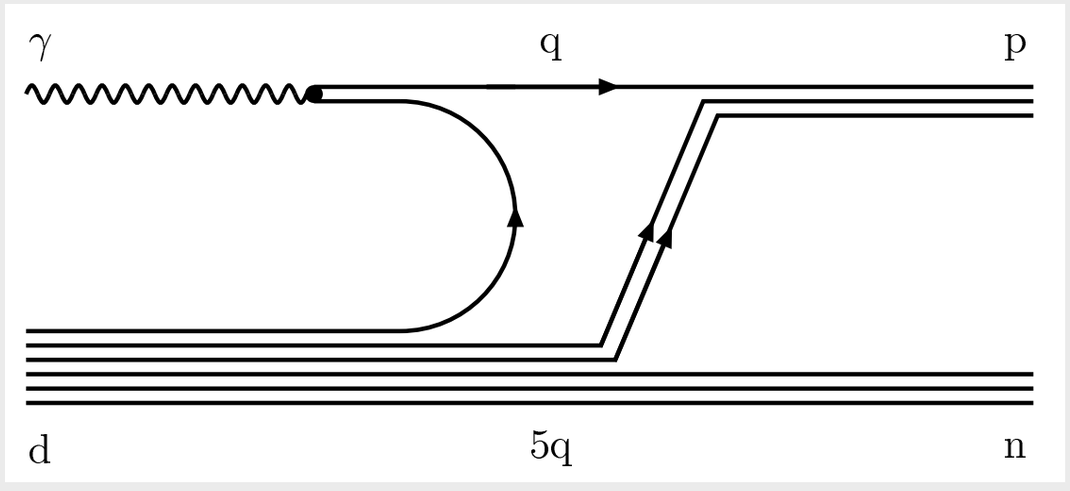
- Scaling at $p_T > 1.4$ GeV/c

Dynamics of Hard Photodisintegration in the Scaling Regime

Models for $\gamma d \to pn$

Quark Gluon String Model (QGSM)

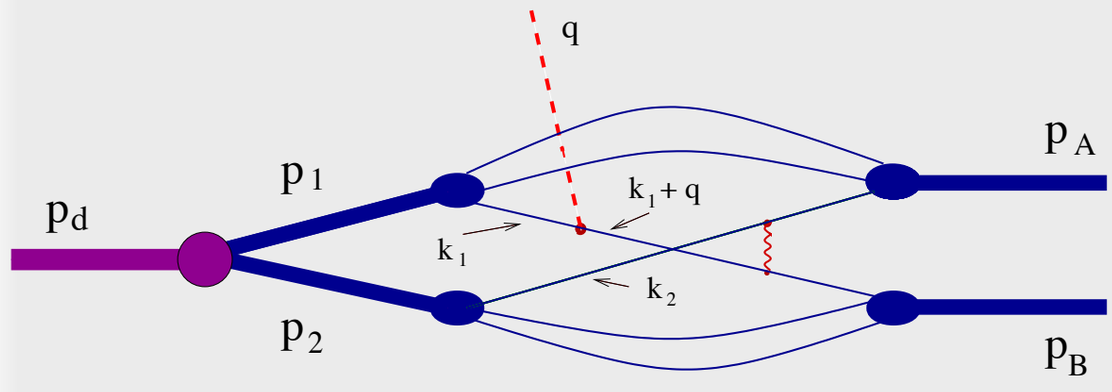
- Three quark exchange with arbitrary number of gluon exchanges
- Nonlinear Regge trajectories



V. Y. Grishina, L. Kondratyuk, W. Cassing, E. De Sanctis, M. Mirazita, F. Ronchetti, and P. Rossi, Eur. Phys. J. A 19, 117 (2004).

Hard Rescattering Model (HRM)

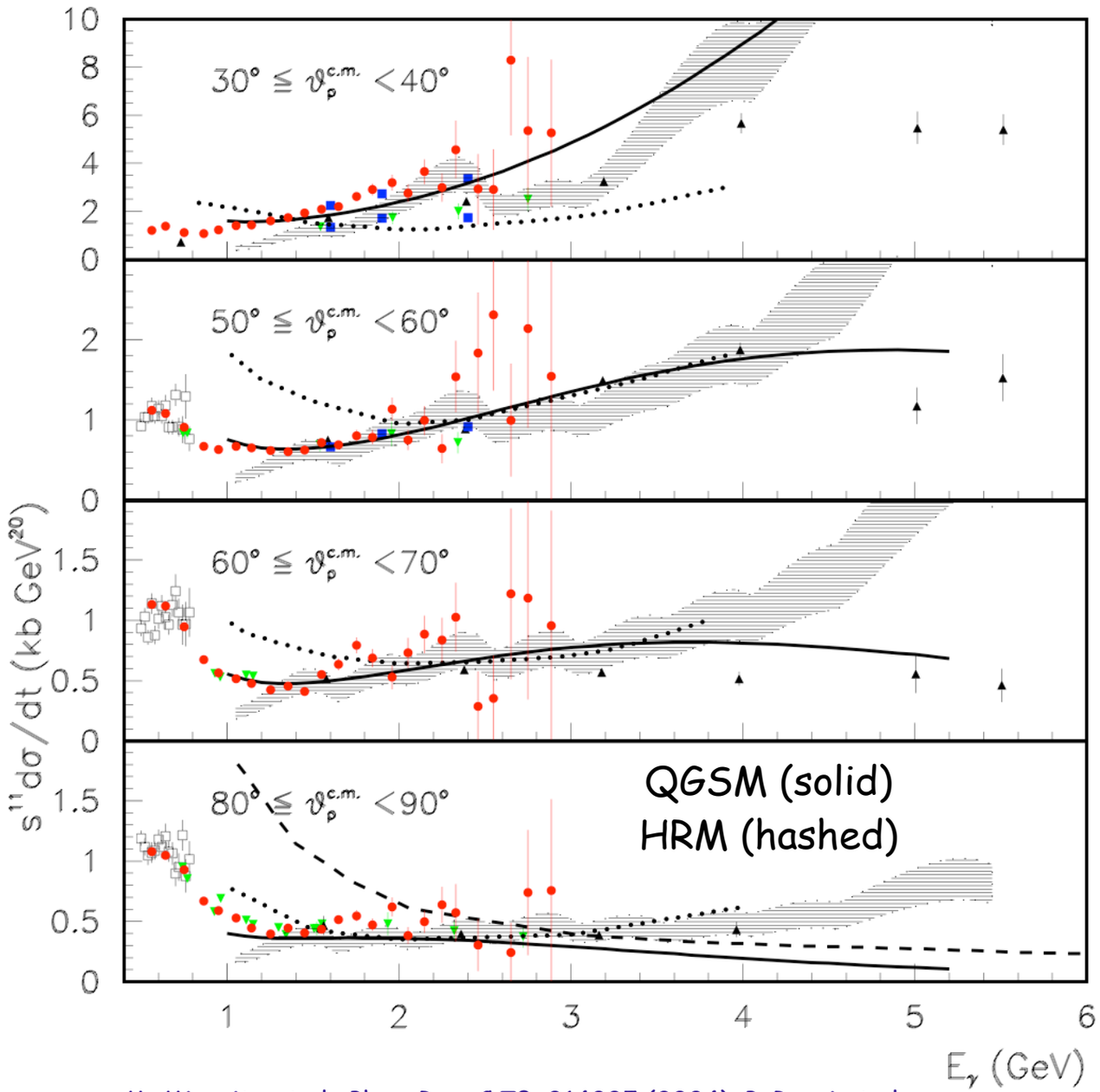
- Photon absorbed by a quark in one nucleon, followed by a hard scattering off a quark in the second nucleon
- Requires phenomenological input on pn elastic scattering



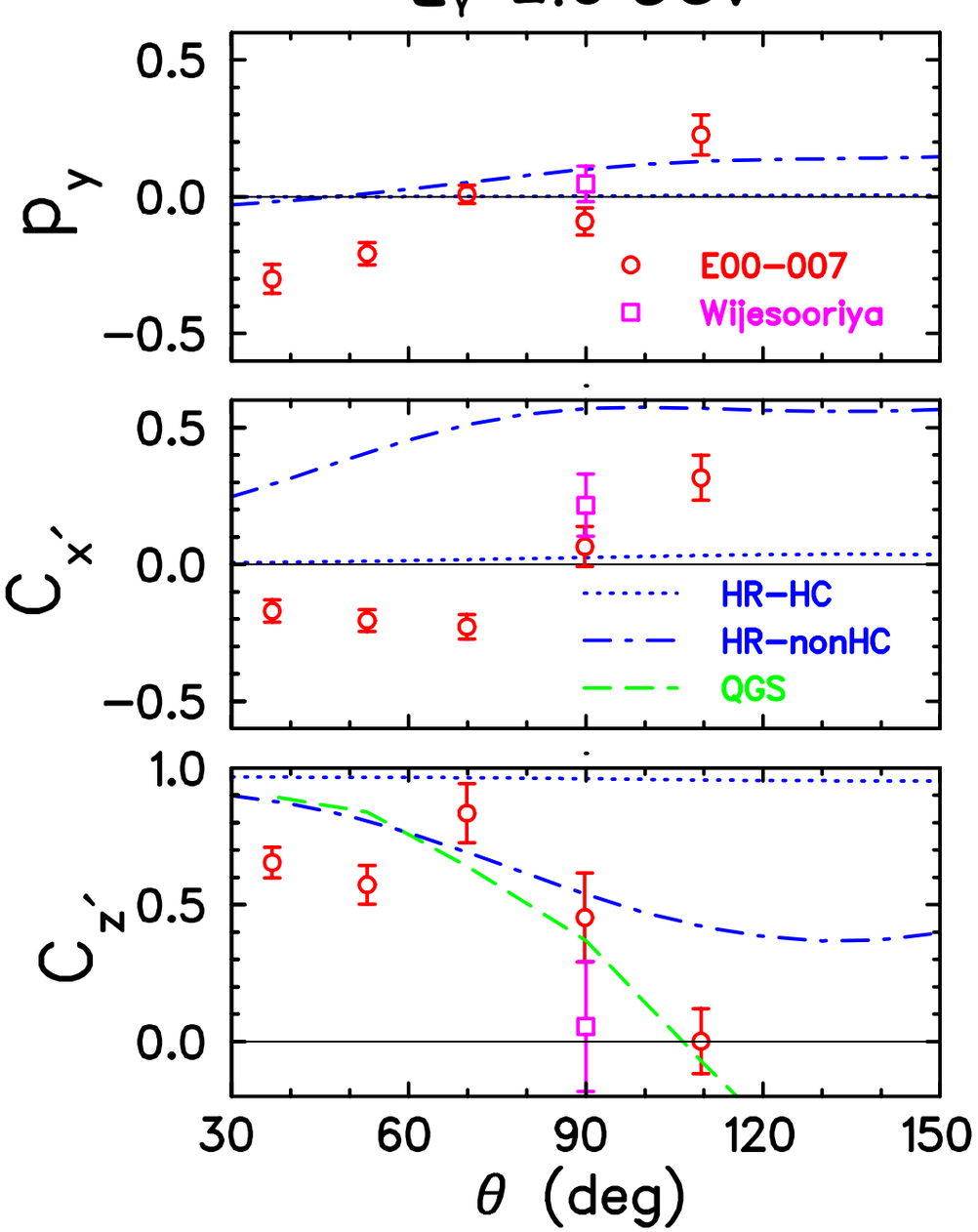
L.L. Frankfurt, G.A. Miller, M.M. Sargsian, and M.I. Strikman, Phys. Rev. Lett. 84, 3045 (2000)

Dynamics of Hard Photodisintegration in the Scaling Regime

Both, QGSM and HRM, models for $\gamma d \rightarrow pn$ describe well measured experimental observables.



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



X. Jiang et al., Phys. Rev. Lett. **98**, 182302 (2007)

Dynamics of Hard Photodisintegration in the Scaling Regime: Recent Data

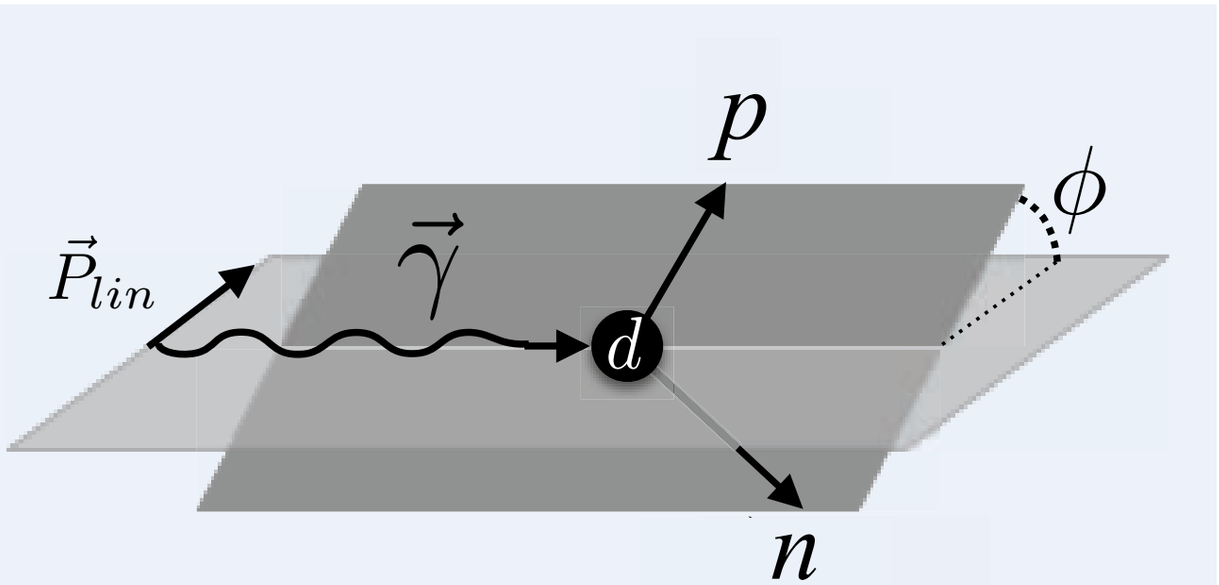


Figure from Nick Zachariou

Linearly Polarized Photons (E06-103)

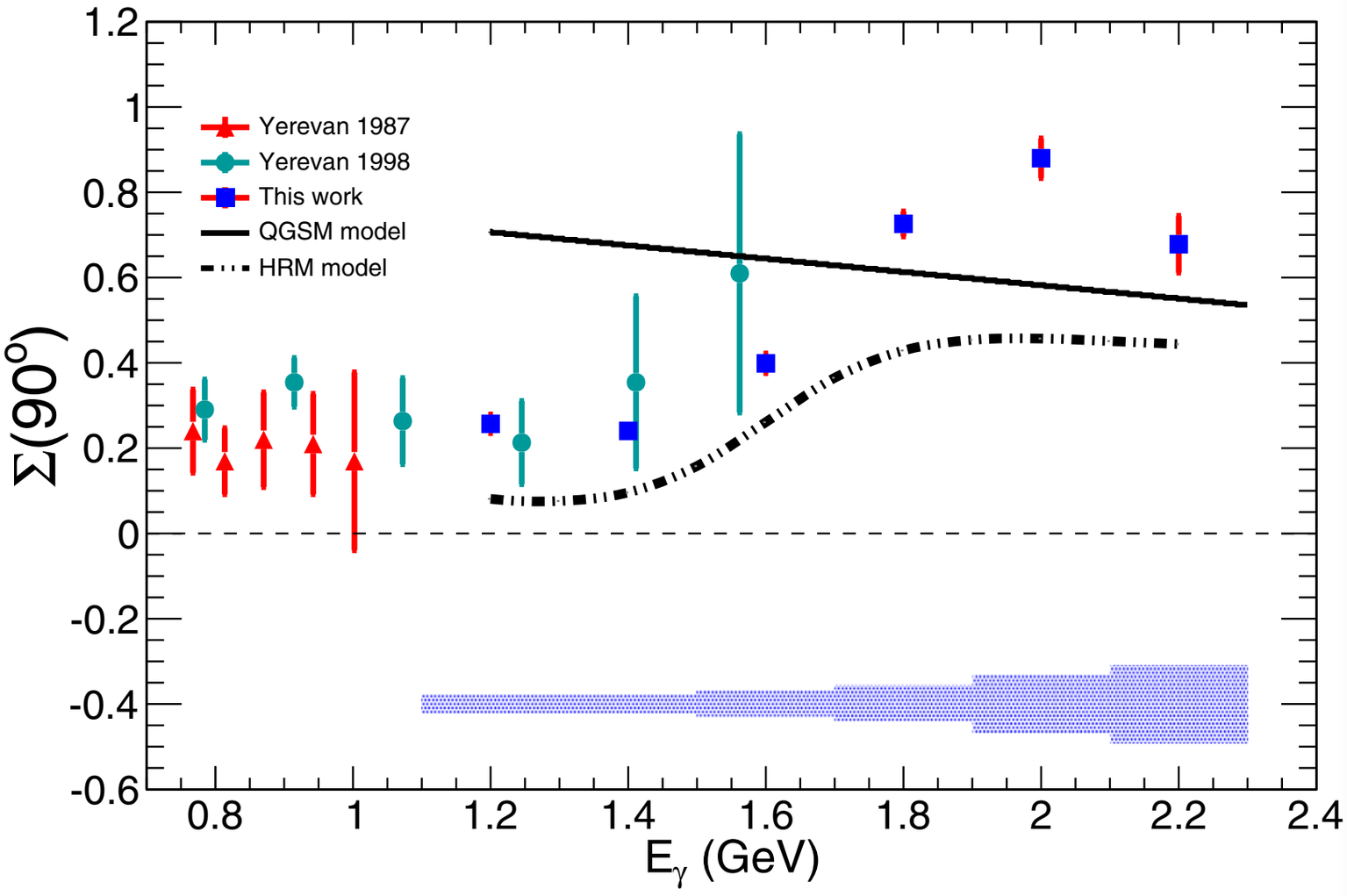
- CLAS Detector
- E_e = 3.3 - 5.2 GeV
- coherent edge at: 1.3, 1.5, 1.7, 1.9, 2.1, 2.3 GeV
- $P\gamma$ = 70% - 90%
- ~30×10^9 triggers

Linearly Polarized Photons:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0}\left[1 - P_{lin}\Sigma\cos 2\varphi\right]$$

Dynamics of Hard Photodisintegration in the Scaling Regime

Beam-spin asymmetry for $\gamma d \rightarrow pn$ (N. Zachariou, PhD Thesis). Based on CAA_NP07-01 (CLAS Approved Analysis).



- Σ at θ_{cm}= 90°
  - σ_{stat} = 6% — 15%
  - σ_{syst} < 6%
- The beam spin asymmetry is positive at E_γ = 0.75 - 2.3 GeV.
- Data suggest a continuous increase up to E_γ of 2 GeV.
- Current QGSM calculations do not reproduce the shape of the energy distribution.
- HRM reproduces the shape, underestimates the magnitude.

N. Zachariou, Y. Ilieva, B.L. Berman, N.Ya. Ivanov, M.M. Sargsian, R. Avakian, G. Feldman, P. Nadel-Turonski et al., Phys. Rev. C **91**, 055202 (2015)

Dynamics of Hard Photodisintegration in the Scaling Regime

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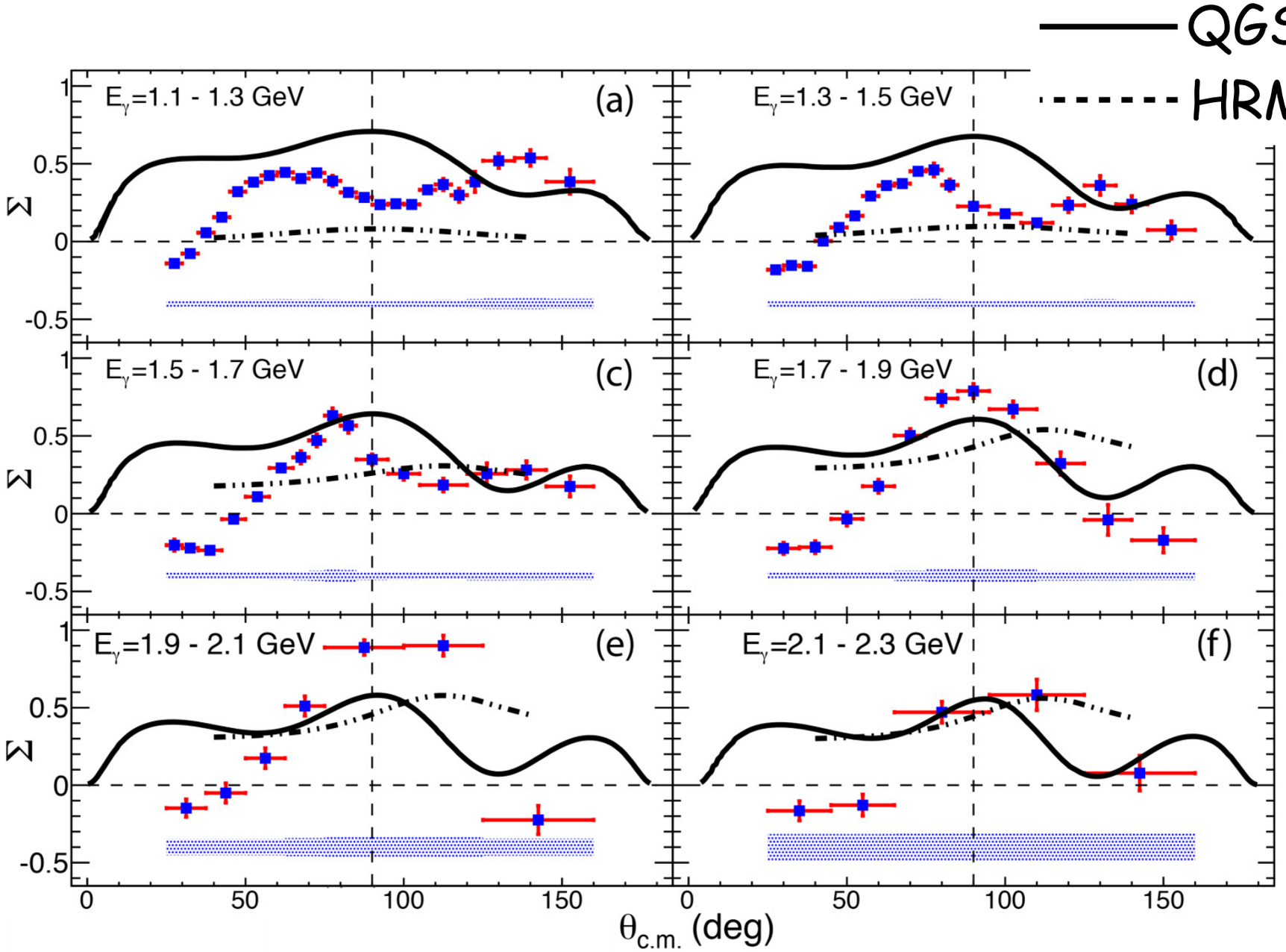
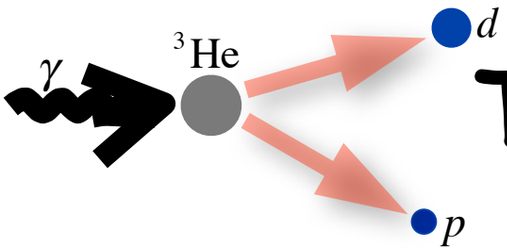


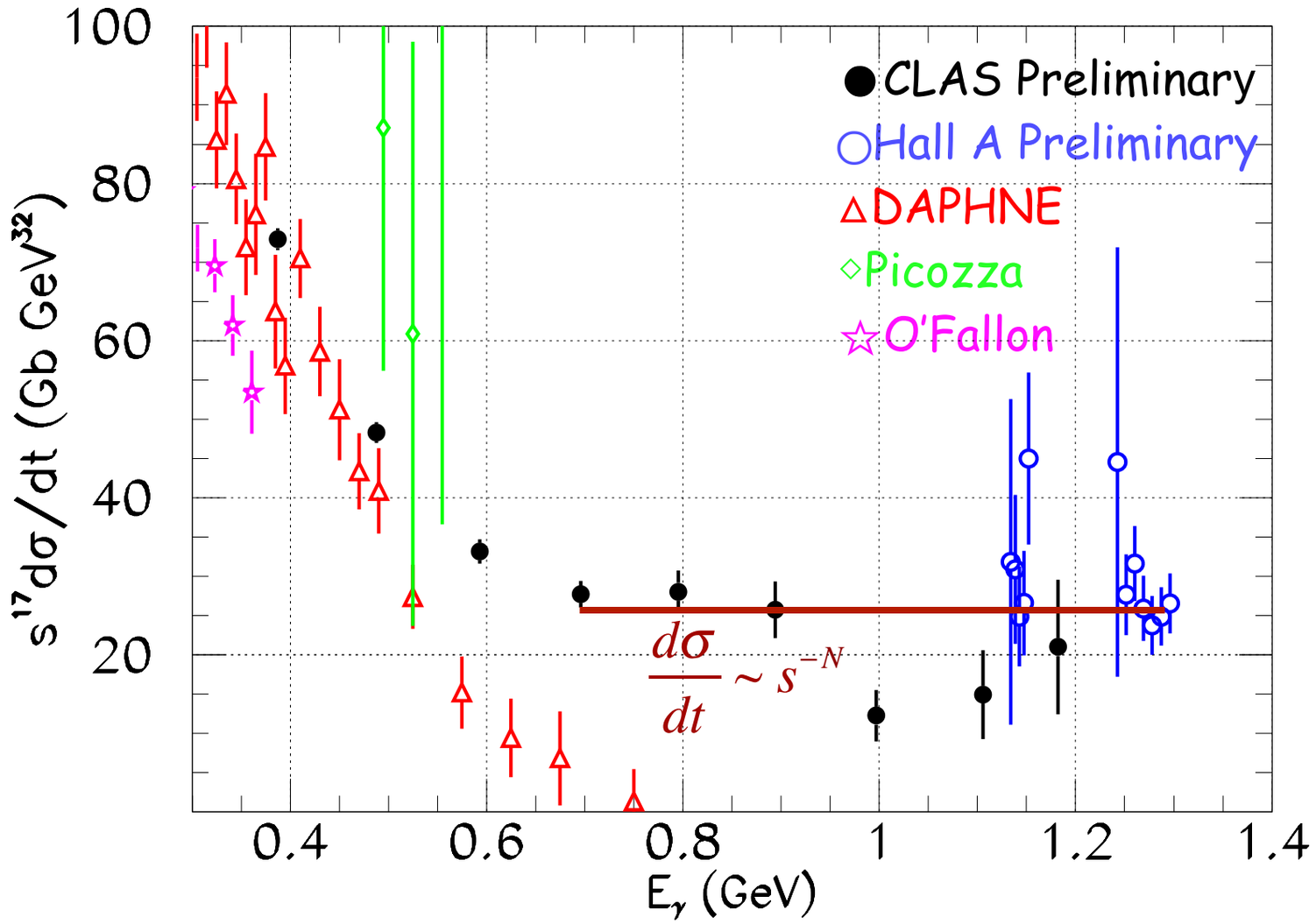
- Rich structures at low energies evolving to a single peak at 90° at higher E_γ.
- Kinematics at the limit of applicability of HRM.
- Complex dynamics - QGSM needs more work.

N. Zachariou, Y. Ilieva, B.L. Berman, N.Ya. Ivanov, M.M. Sargsian, R. Avakian, G. Feldman, P. Nadel-Turonski et al., Phys. Rev. C **91**, 055202 (2015)



Two-Body Photodisintegration of ^{3}He

Scaling of invariant cross sections at 90°



Data fitted by: $\frac{d\sigma}{dt} = As^{-N}$

- Extracted value from fits to JLab data:

  $N = 17 \pm 1$

- $|t|_{thr}$ and $p_{\perp thr}$ are too low to support hard scattering hypothesis:

  $|t|_{thr} = 0.64$ (GeV/c)^2

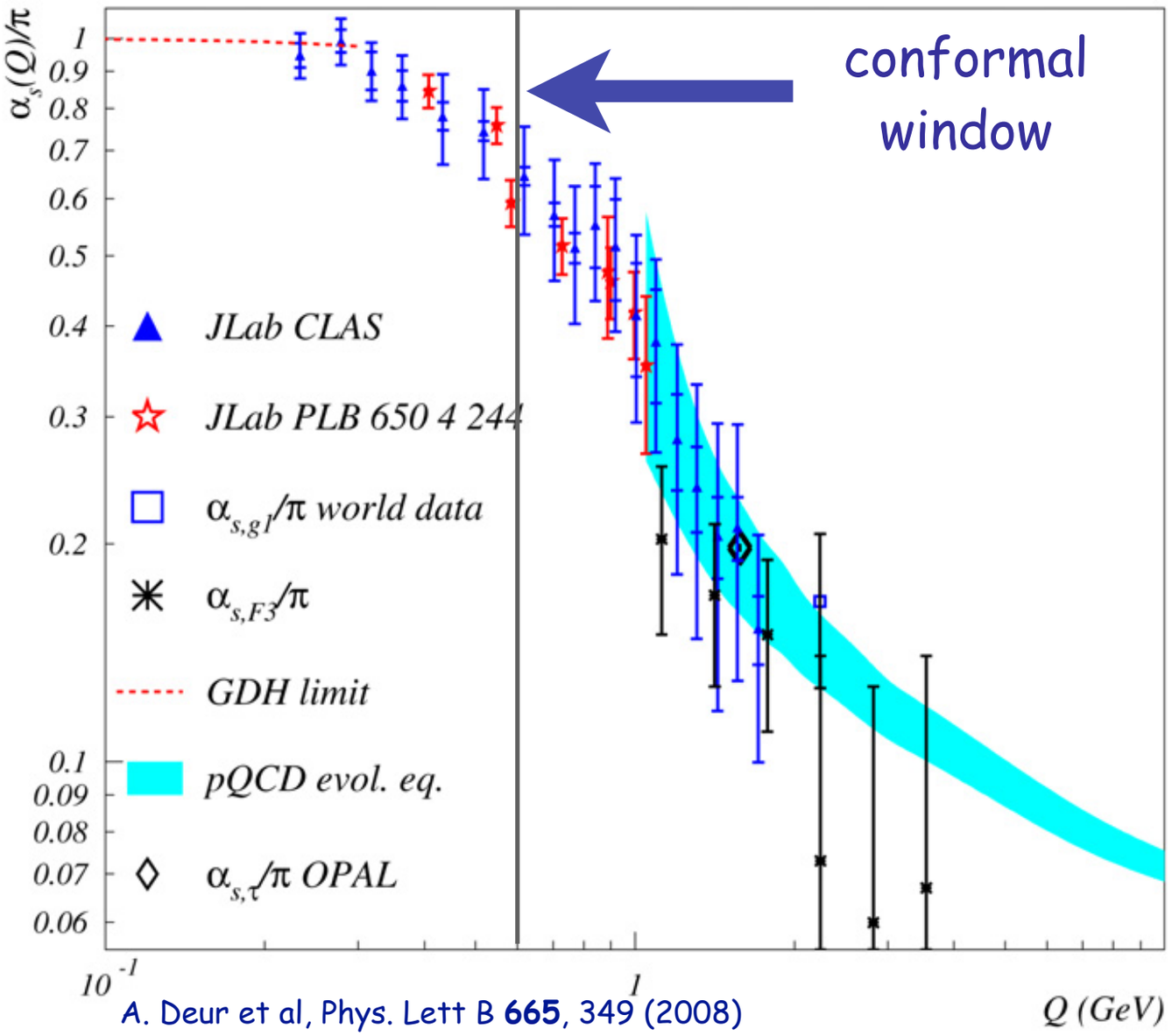
  $p_{\perp thr} = 0.95$ GeV/c

- Our data are consistent with the the hypothesis of conformal window from AdS/CFT

I. Pomerantz, Y. Ilieva, R. Gilman, D. Higginbotom, E. Piazetski, S.Strauch et al., Phys. Rev. Lett. 110, 242301 (2013).

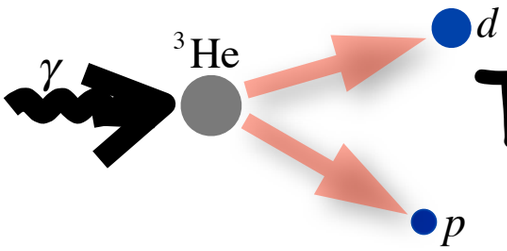
AdS/CFT: Conformal Window

- At short distances, dimensional scaling laws reflect the scale independence of α_s (asymptotic freedom)
- At large distances, dimensional scaling laws reflect the existence of infrared fixed point of QCD: α_s is large but scale-independent
- Scale-invariance is broken in the transition between these two dynamical regimes



A. Deur et al, Phys. Lett B **665**, 349 (2008)

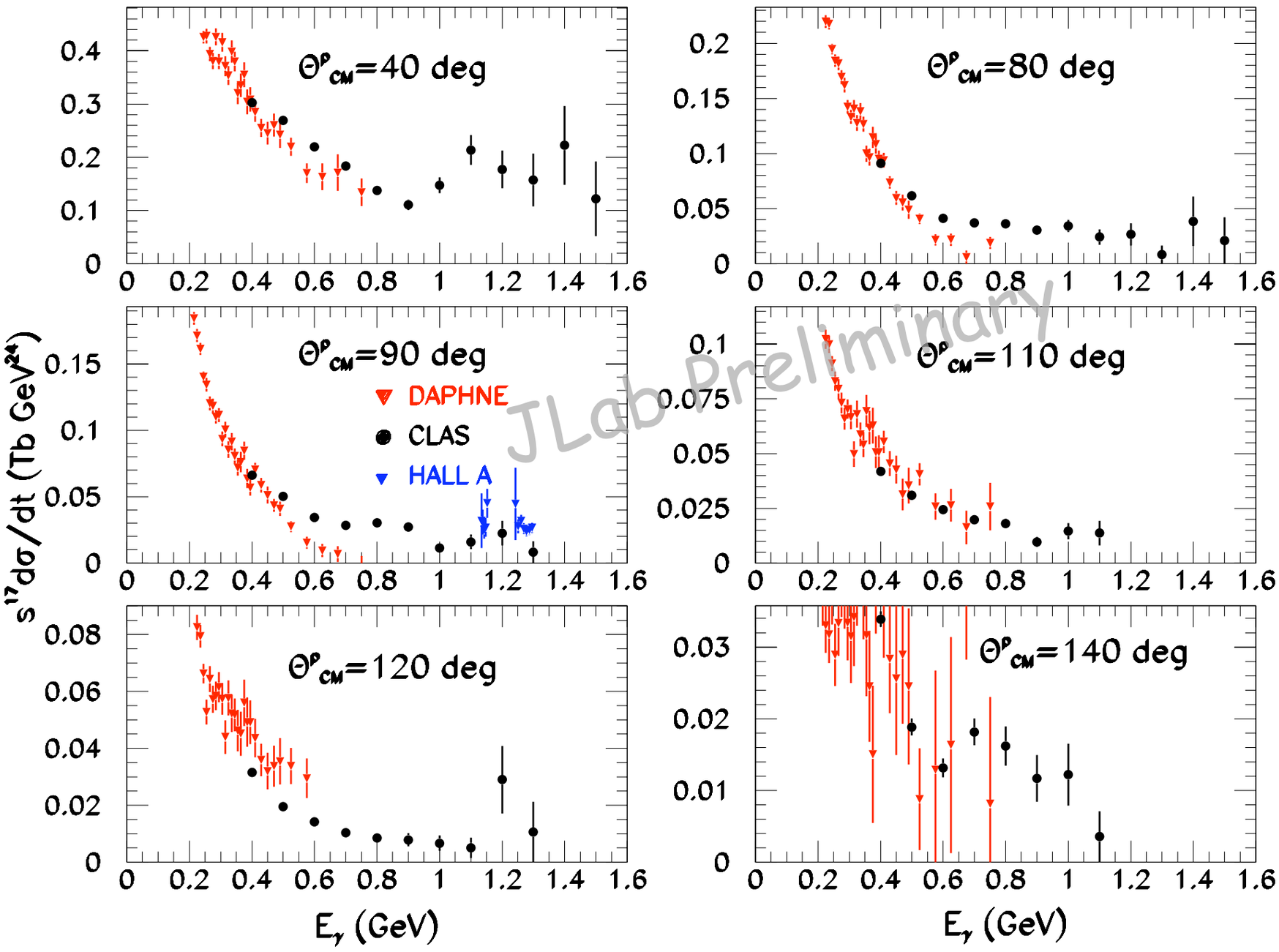
S.J. Brodsky and G.F. de Teramond, Phys. Rev. D **77**, 056007 (2008);
J. Polchinski and G.R. Strassler, Phys. Rev. Lett. **88**, 031601 (2002).



Two-Body Photodisintegration of ^{3}He

Scaling of invariant cross sections

$$s^{17}\frac{d\sigma}{dt} \sim \text{const.}$$



- Indication that above ~0.7 GeV data consistent with scale invariance for all CM angles
- Onset of dimensional scaling depends on the momentum transfer to individual constituents: supports AdS/CFT hypothesis

V. Isbert et al., Nucl. Phys. A **578**, 525 (1994)

I. Pomerantz et al., private communication

Dynamics of Hard Photodisintegration in the Scaling Regime: Where do we stand?

- Two-nucleon photodisintegration cross sections measured up to 5.5 GeV. Suggest onset of quark-gluon dynamics at $p_T > 1.1$ GeV.

- Unpolarized cross sections do not allow to gain insight in the details of hard-scattering dynamics.

- pQCD interpretation ruled out (polarization-transfer observables).

- Beam-Spin Asymmetry allows to establish the lower limit of applicability of factorization (HRM).

- Two-body photodisintegration of ^{3}He indicates the importance of redistribution of the overall momentum transfer to elementary constituents (complex reaction mechanisms).

Dynamics of Hard Photodisintegration in the Scaling Regime: Experimental Prospects

$\gamma d \to pn$

- Polarization observables above 2 GeV are interesting to study reaction dynamics.
- Differential cross sections above 6 GeV would be interesting to track dimensional scaling.
- Simple process to measure, requires detection of a single proton.
- Large-acceptance detector is a plus to optimize beam time.

Dynamics of Hard Photodisintegration in the Scaling Regime: Experimental Challenges

$\gamma d \to pn$

- Counting Rate (cross section decreases as s^{-11}): At E_γ=2.9 GeV, $d\sigma/d\Omega$~0.2 nb/sr at 90°.

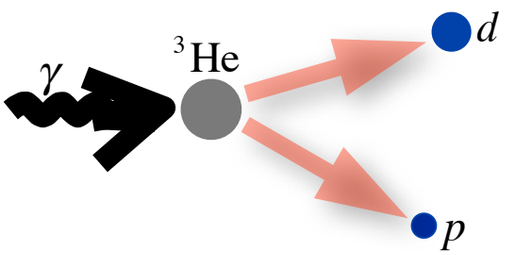
- Reaction identification based on the missing-mass technique ($\gamma d \to pX$) depends on the width of M_X, which increases as E_γ increases, and so the signal-background separation becomes more uncertain.

Dynamics of Hard Photodisintegration in the Scaling Regime: Overall Challenges

$\gamma d \to pn$

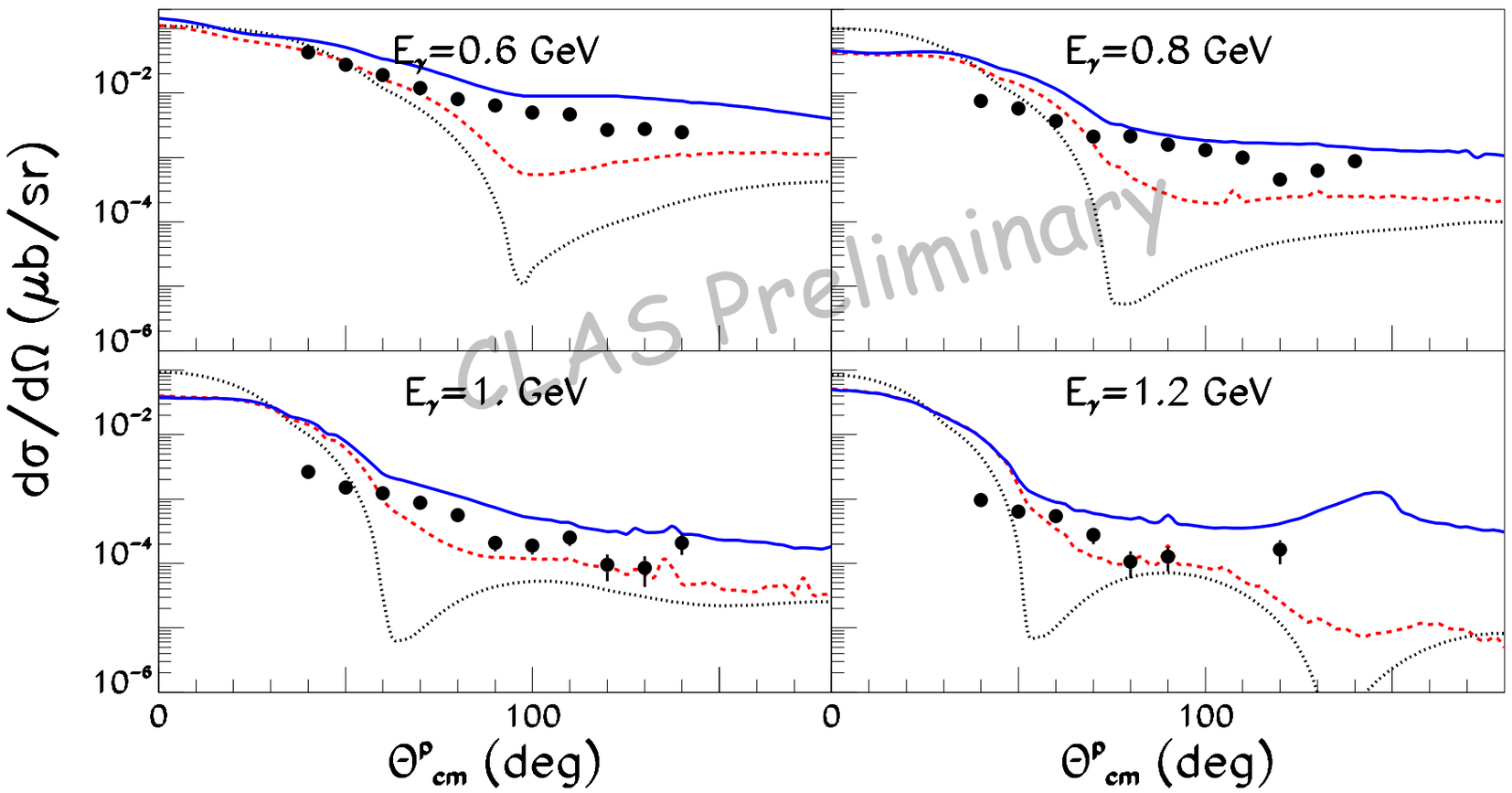
- Complex helicity structure (12 independent helicity amplitudes): complete measurement not realistic.
- Physics output depends crucially on theoretical modeling and updates of the models (manpower, interest, engagement).
- HRM modeling strongly depends on empirical input from NN elastic scattering.
- What are the most promising experimental observables to optimize physics output?
- PAC case? - perhaps as a part of a run group proposal. Single-charged trigger is required.

The END



Two-Body Photodisintegration of ^{3}He
E_γ = (0.4 - 1.4) GeV

Advantages for Study of Dimensional Scaling



- Significant contribution of three-body mechanisms, especially at 0.6-0.8 GeV
- Resonance contribution to the cross section is suppressed.

J. M. Laget, Phys. Rev. C **38**, 2999 (1988)