UNIVERSITY OF SOUTH CAROLINA

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Photodisintegration of Light Nuclei

Yordanka Ilieva

for the CLAS Collaboration

- Motivation
- Two-body photodisintegration of deuteron
- Two-body photodisintegration of ^3He

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Photodisintegration of Few-Nucleon Systems at Medium Energies

Large Momentum Transfer Exclusive Processes

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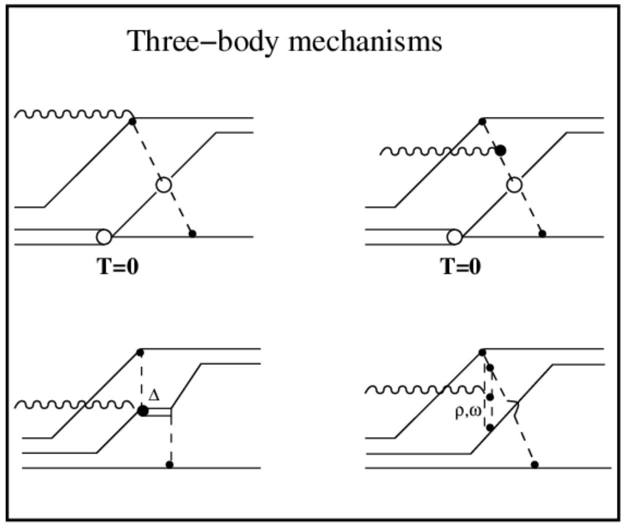
Large Momentum Transfer Exclusive Processes

Short-range dynamics



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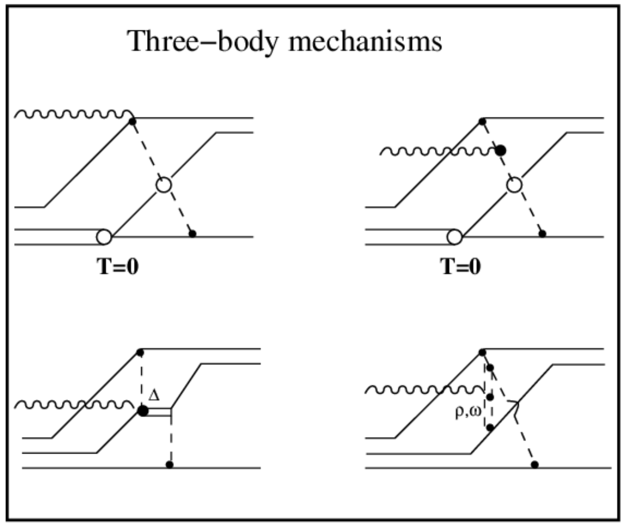
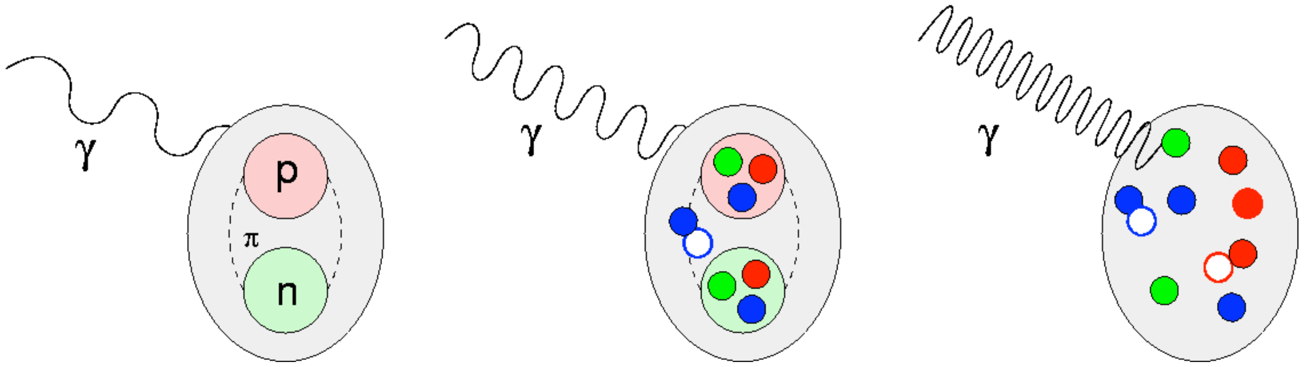
Large Momentum Transfer Exclusive Processes

Short-range dynamics

Transition from hadronic to partonic degrees of freedom





Dimensional Scaling Laws in Nuclear Physics

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

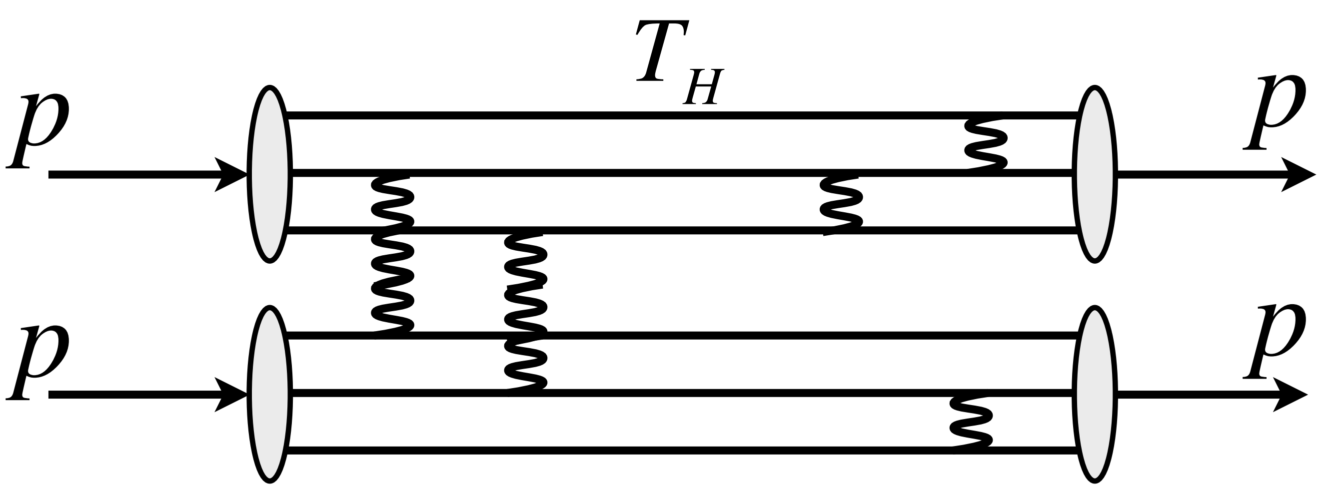
- At high t and high s, power-law behavior of the invariant cross section of an exclusive process A + B $\rightarrow$ C + D at fixed CM angle:

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

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

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



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

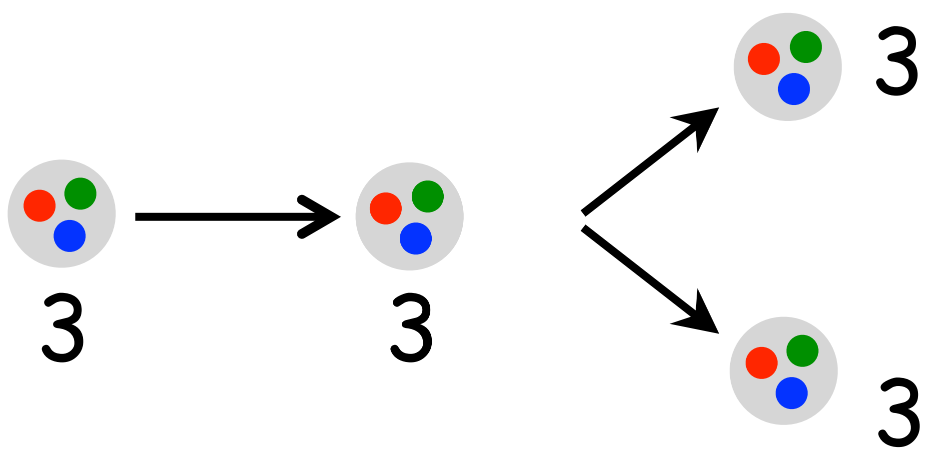
$$\text{where } [M] = [T_H] = \left(\sqrt{s}\right)^{4-n}$$

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

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)

Dimensional Scaling Laws: Examples

$$pp \to pp$$

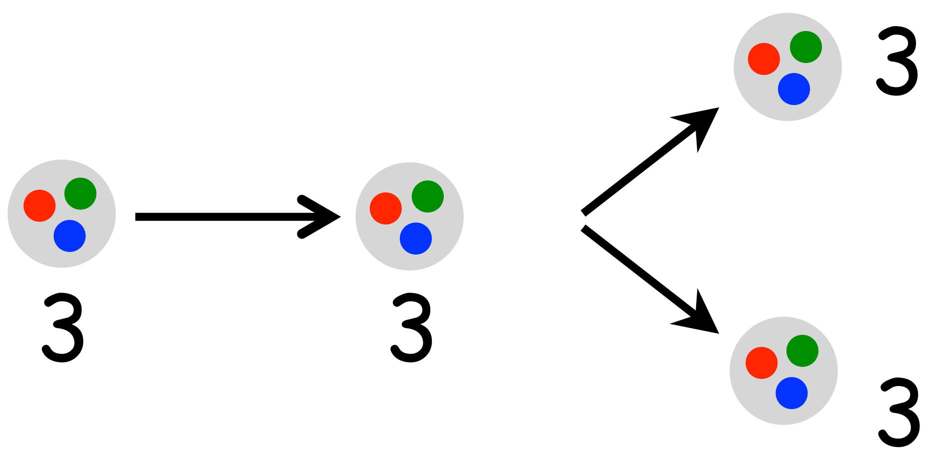


$$n - 2 = (4 \times 3) - 2 = 10$$

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{10}} f(t/s)$$

Dimensional Scaling Laws: Examples

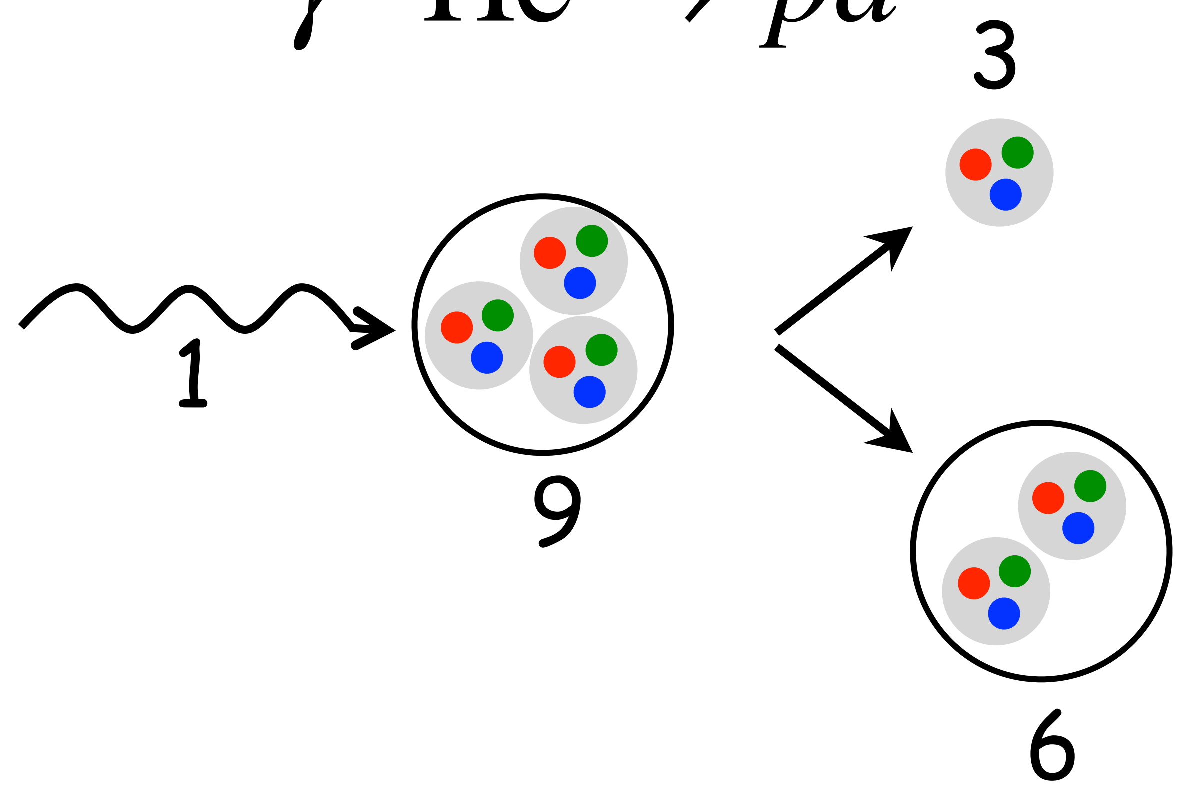
$$pp \rightarrow pp$$



$$n-2=(4\times 3)-2=10$$

$$\frac{d\sigma}{dt}\sim\frac{1}{s^{10}}f(t/s)$$

$$\gamma\,{}^3\mathrm{He}\rightarrow pd$$



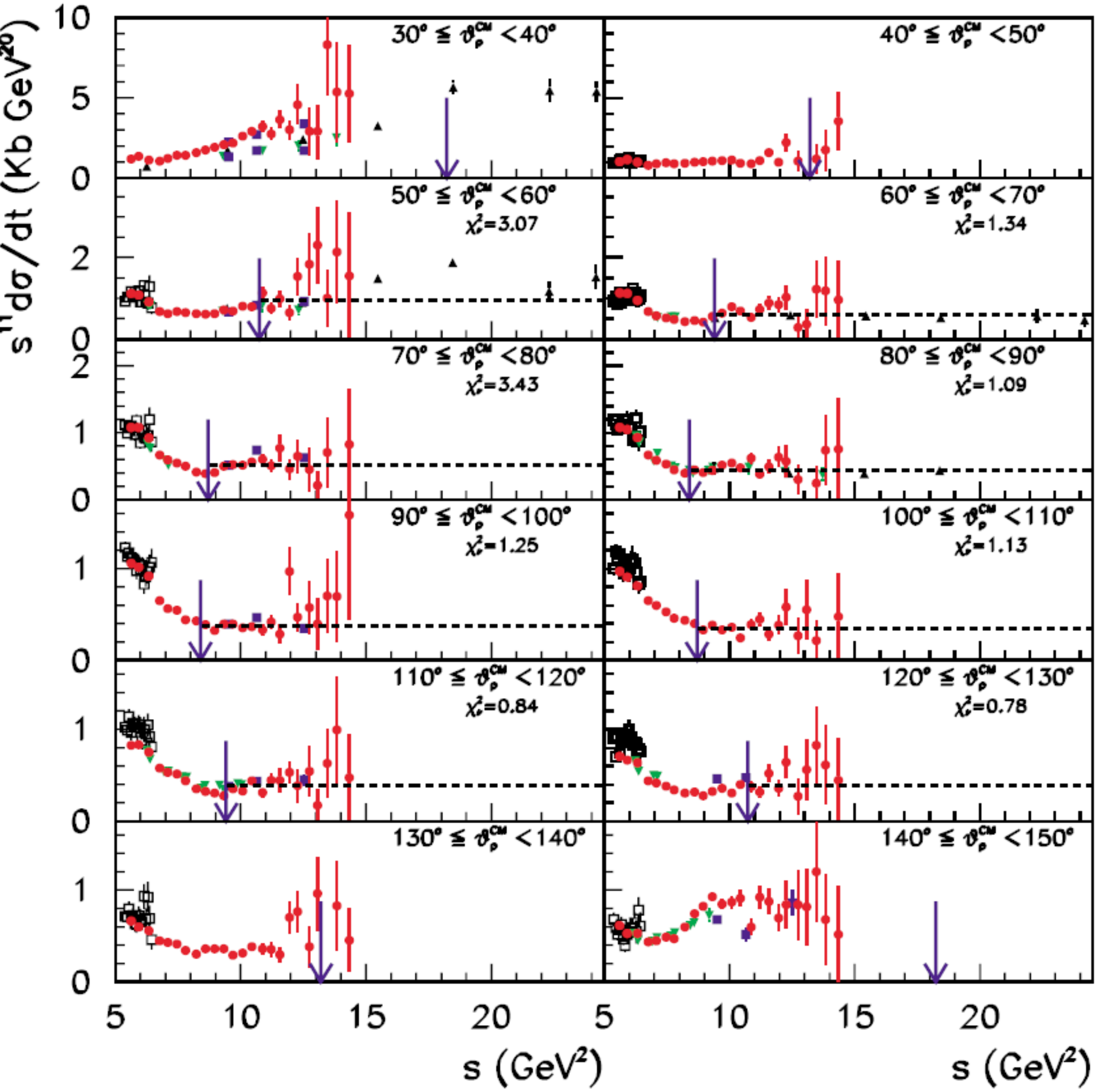
$$n-2=(1+9+3+6)-2=17$$

$$\frac{d\sigma}{dt}\sim\frac{1}{s^{17}}f(t/s)$$

Extensive Studies of 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)

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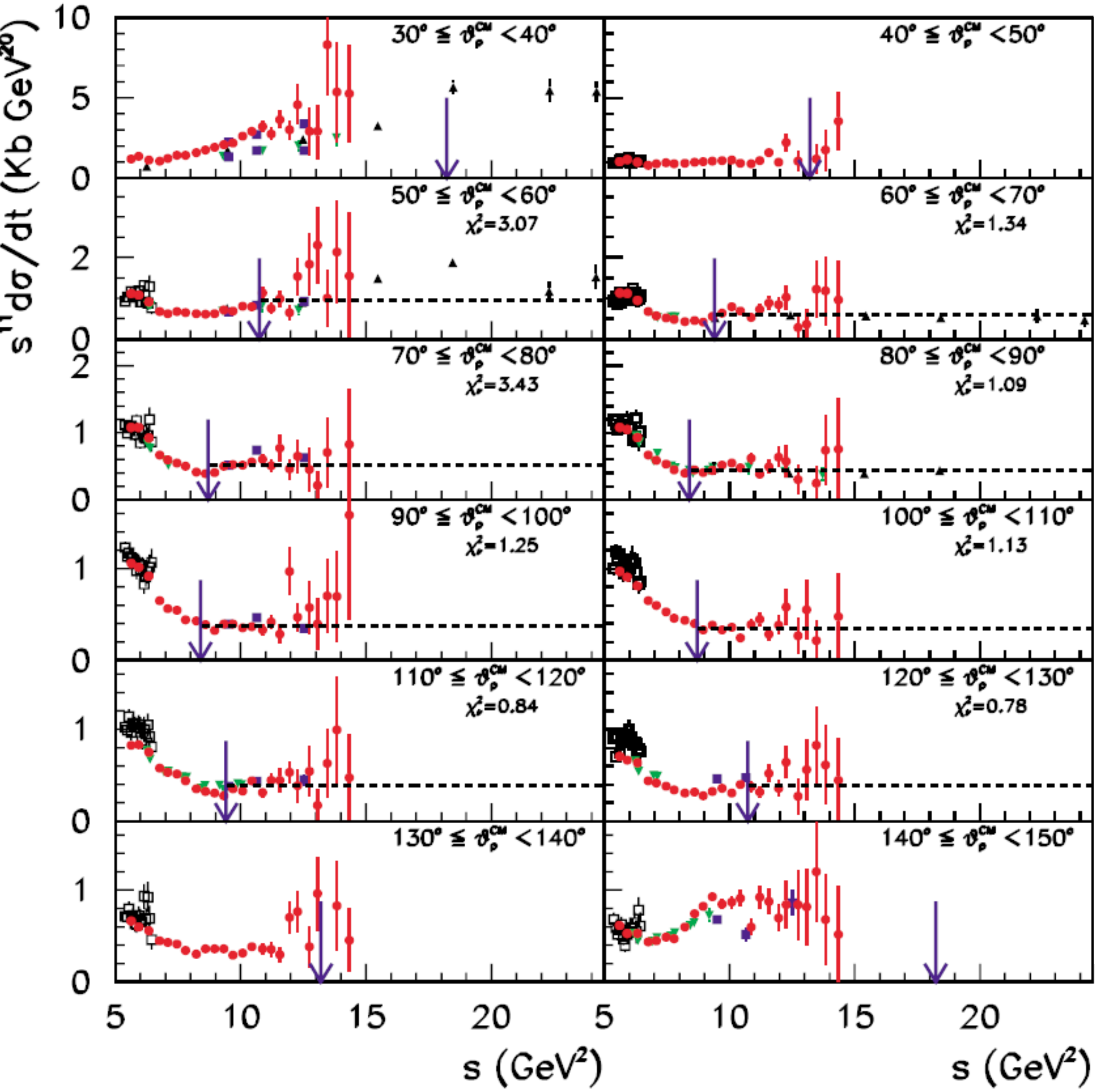

P. Rossi et al., Phys. Rev. Lett. **94**, 012301 (2005)

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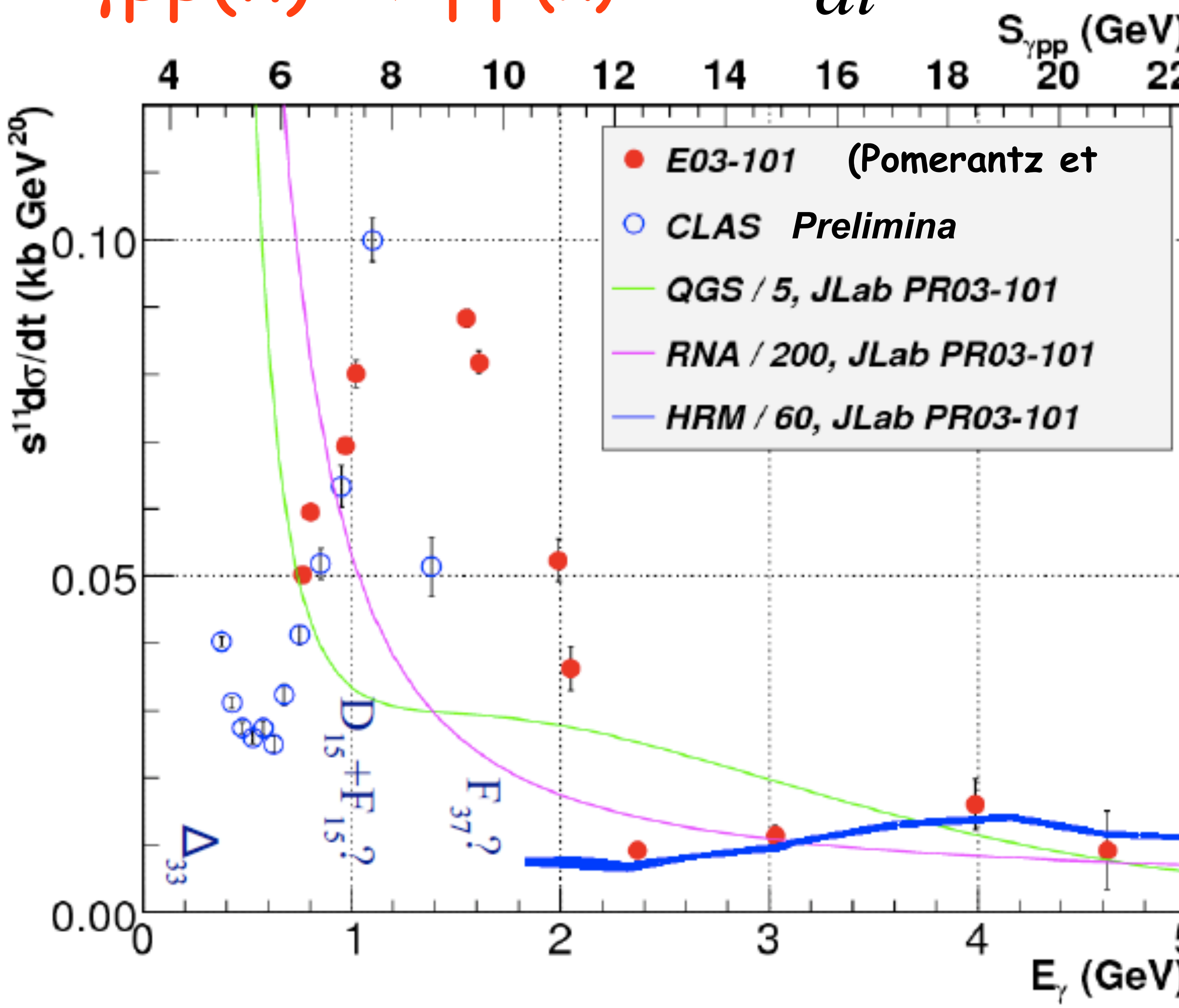


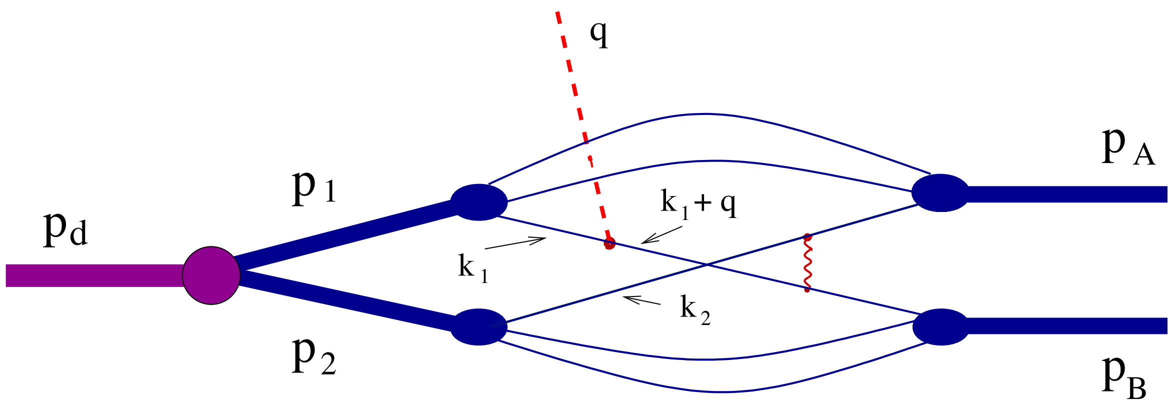
I. Pomerantz et al., Phys. Lett. B **684**, 106 (2010)
Figure from R. Gilman, talk given at High-Energy Nuclear Physics and QCD, FIU, Miami, FL, 2010

What is the dynamical origin of scaling at medium energies?

Models for $\gamma d \rightarrow pn$

- Quark Gluon String Model (QGSM)
  - Three quark exchange with arbitrary number of gluon exchanges
  - Nonlinear Regge trajectories

- Hard Rescattering Model (HRM)

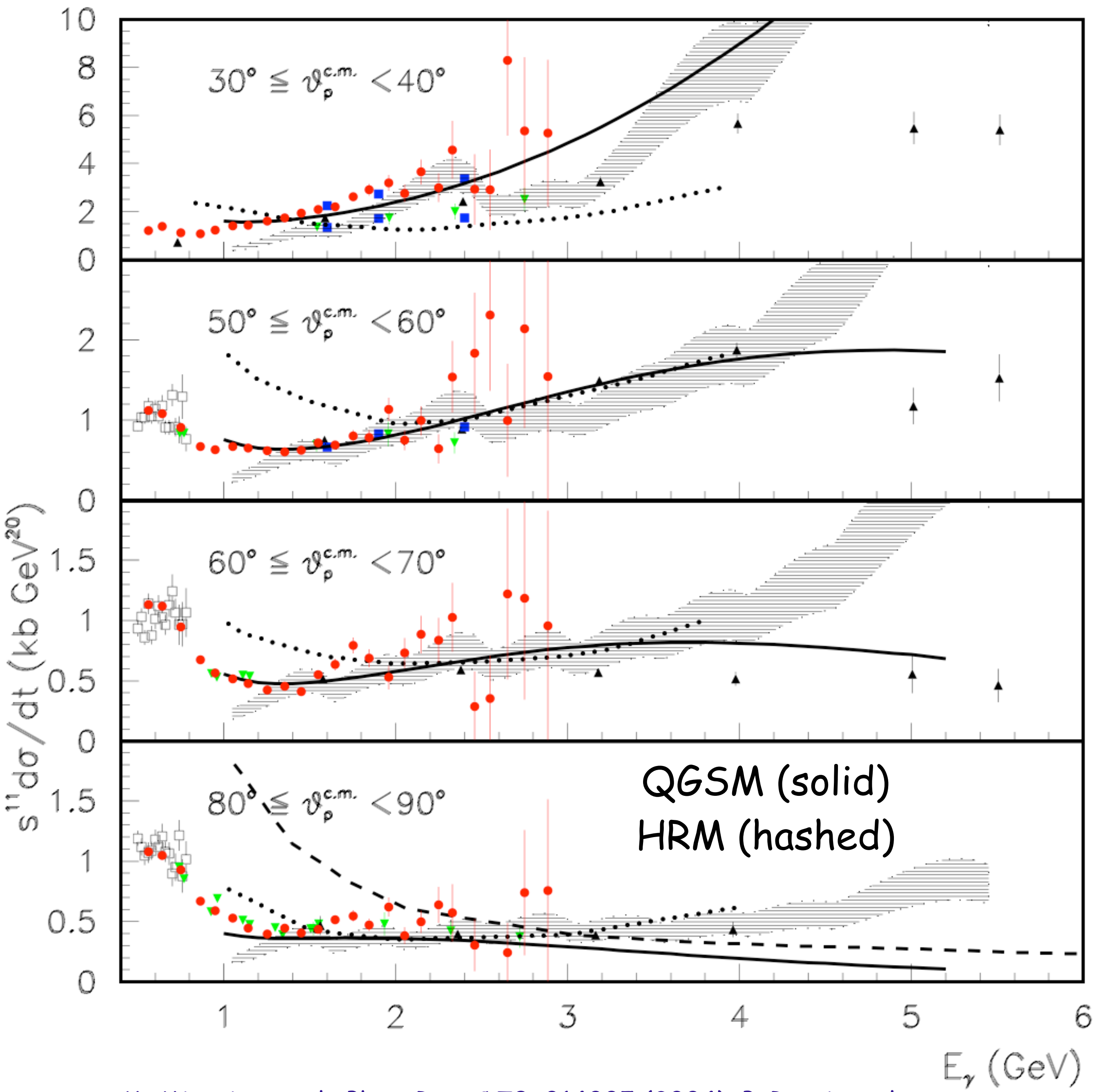


QGSM: V. Y. Grishina, L. Kondratyuk, W. Cassing, E. De Sanctis, M. Mirazita, F. Ronchetti, and P. Rossi, Eur. Phys. J. A 19, 117 (2004).
HRM: L.L. Frankfurt, G.A. Miller, M.M. Sargsian, and M.I. Strikman, Phys. Rev. Lett. 84, 3045 (2000)

What is the dynamical origin of scaling at medium energies?

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

E_γ=2.0 GeV



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

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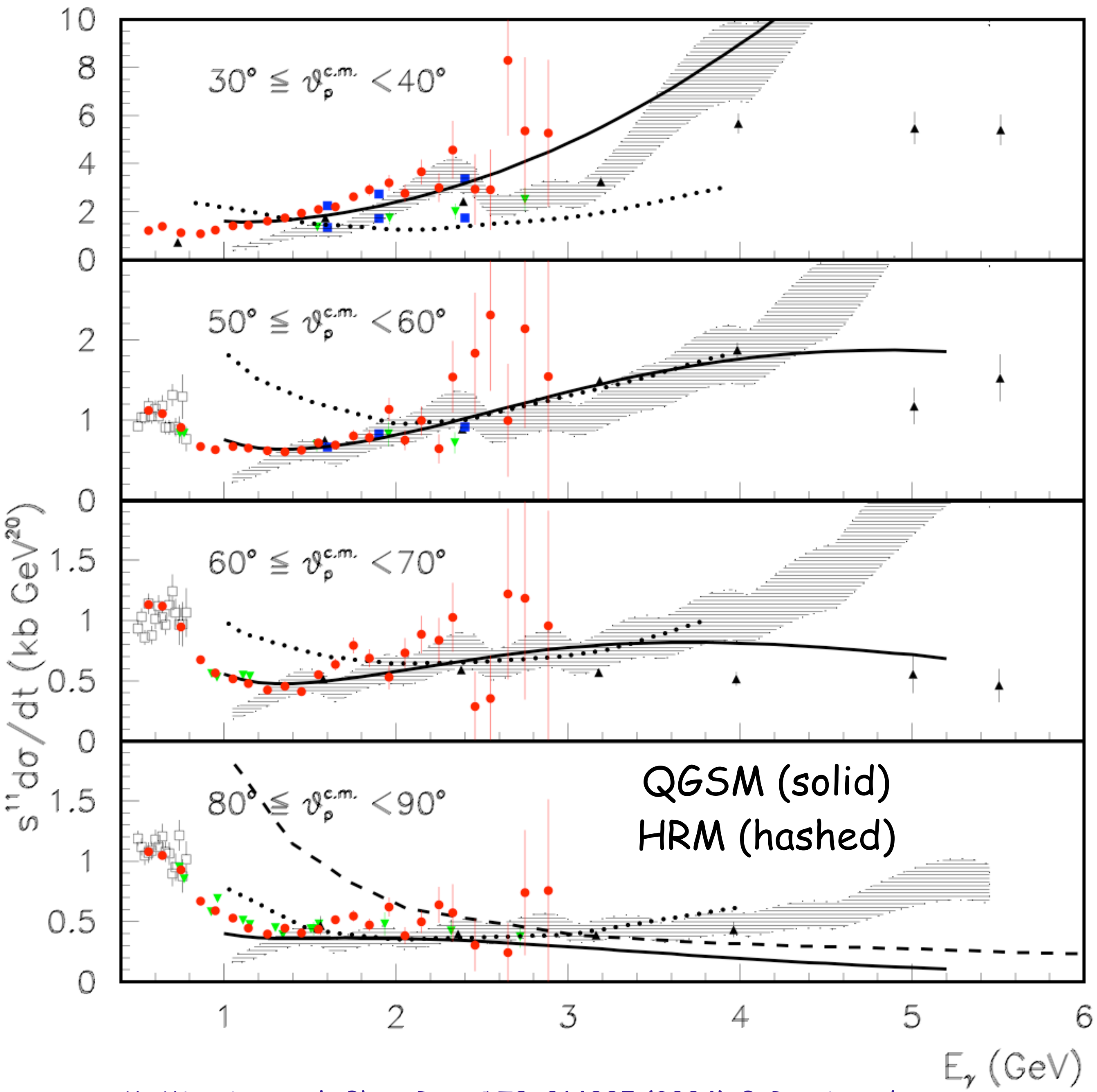

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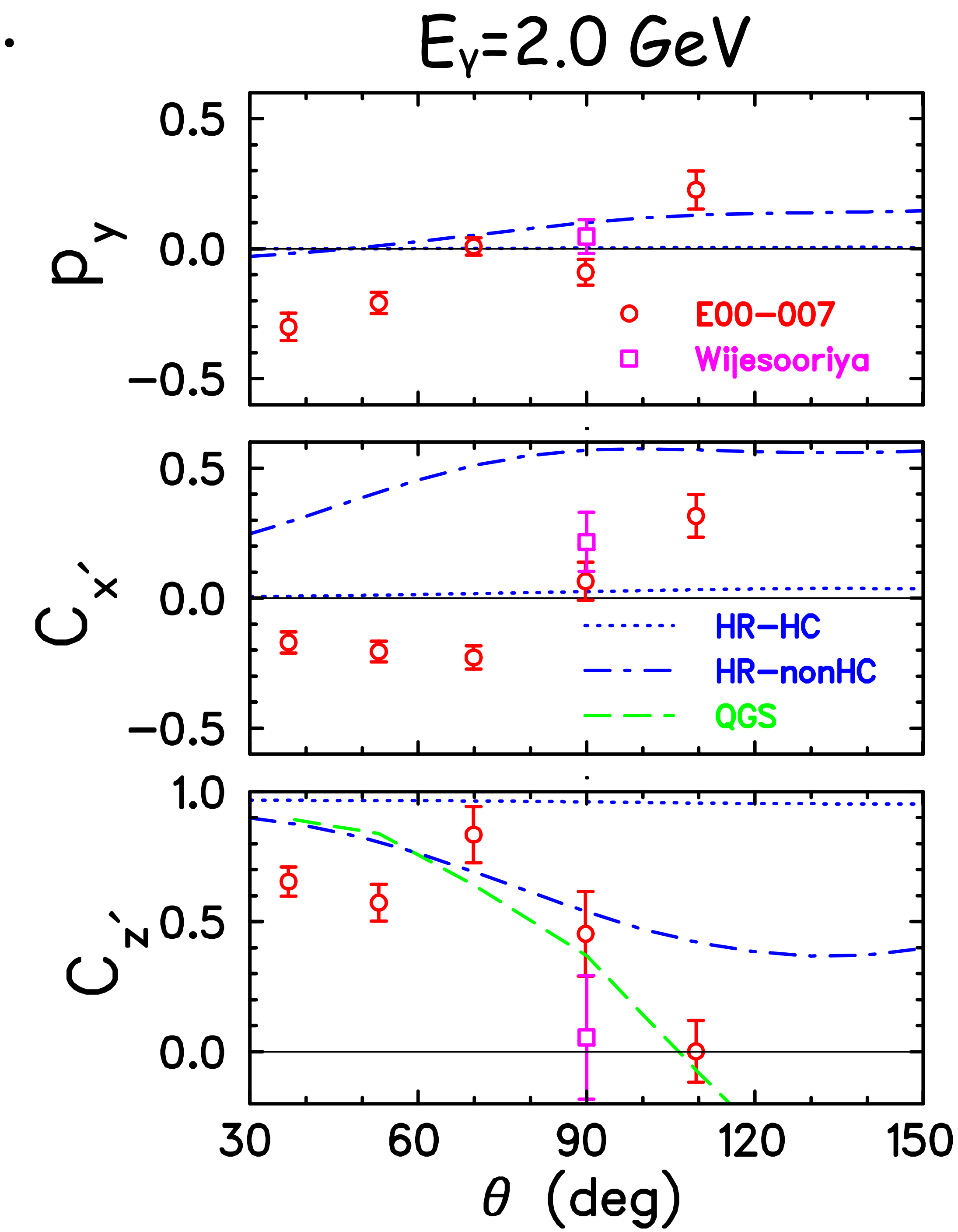

X. Jiang et al., Phys. Rev. Lett. **98**, 182302 (2007)

Onset of quark-gluon dynamics through dimensional scaling: What have we learned?

- Overwhelming experimental evidence for success at momentum transfer as low as 1 GeV. Kinematics depends on the exclusive process.
- pQCD interpretation ruled out.
- Determination of the onset of quark-gluon dynamics generally limited to kinematics above the resonance region.
- Onset of quark-gluon dynamics in $A > 2$ nuclei expected at much higher energies than 1 GeV.

Dimensional Scaling Laws:
Where do we stand?

- A comprehensive theoretical description of exclusive processes in the non-perturbative regime has proved difficult (pQCD, models).

- Overwhelming evidence for dimensional scaling, yes, but no general framework for interpretation across all processes.

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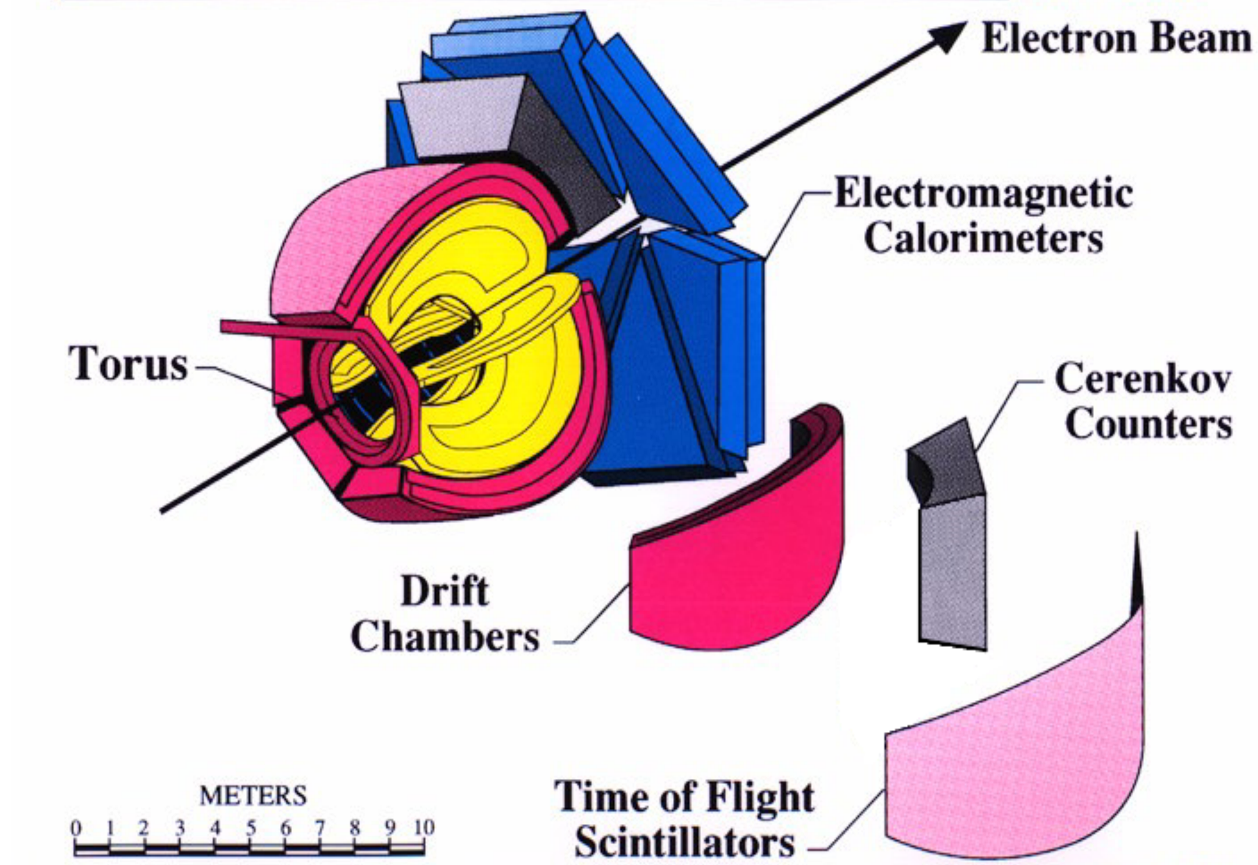
What is the origin of the scale-invariance of the underlying non-perturbative dynamics in the regime of confinement?

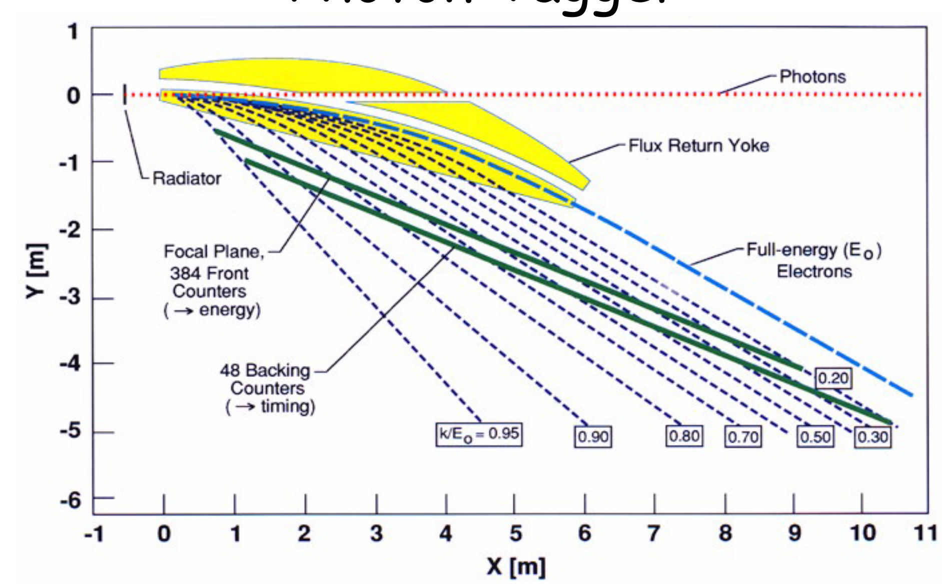
Photodisintegration of Light Nuclei with the CEBAF Large Acceptance Spectrometer CLAS

- Measured beam-spin asymmetry of two-body photodisintegration of d at E_γ=1.1 - 2.3 GeV, $\theta_{p,c.m.}$=35° - 145° with linearly polarized photon beam (JLab E06-103)



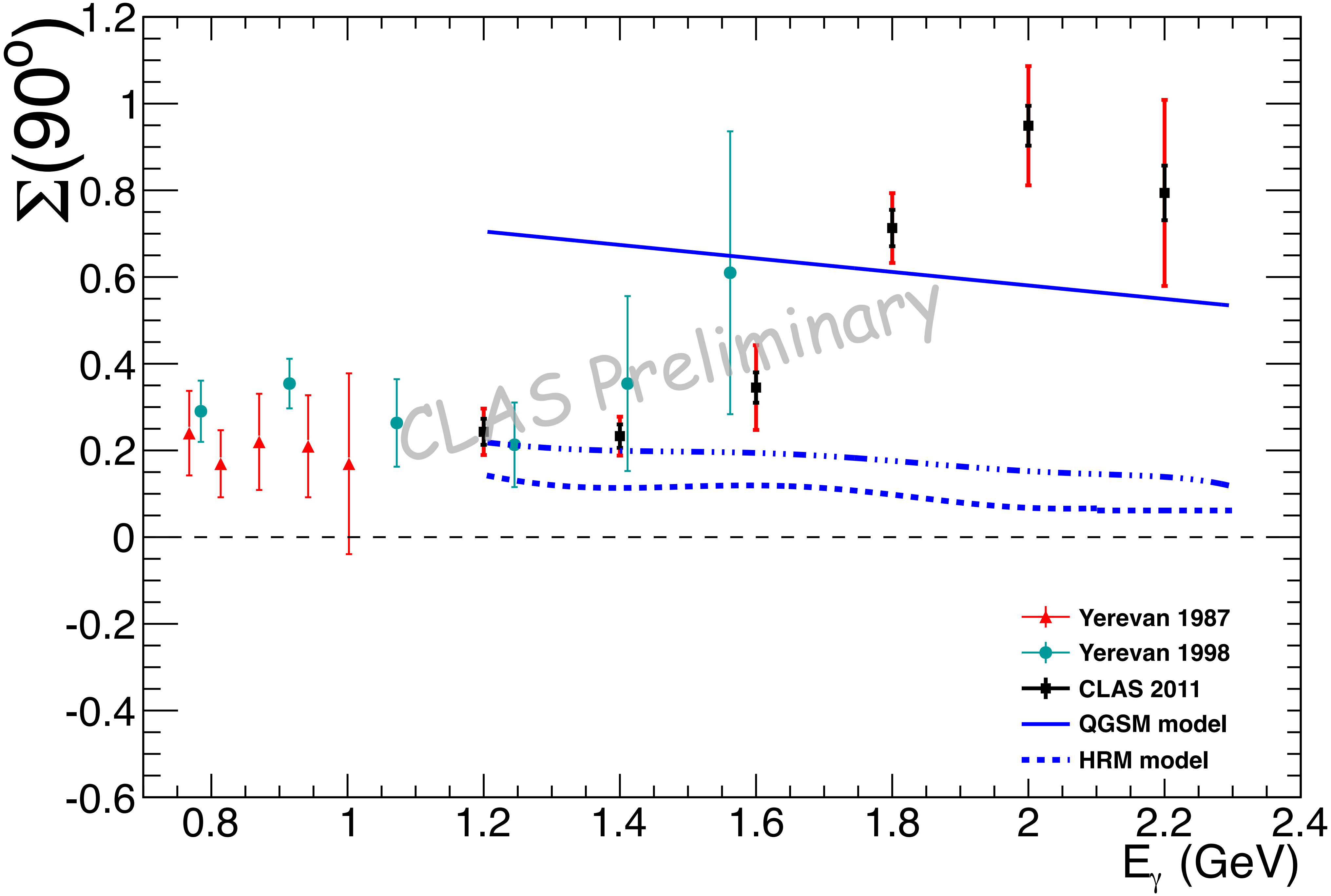
- Measured differential cross sections of two-body photodisintegration of ^3He at E_γ=0.4 - 1.4 GeV, $\theta_{p,c.m.}$=30° - 140° (JLab E93-044)

Photon Tagger



Two-Body Photodisintegration of d

Beam-spin asymmetry (N. Zachariou, PhD Thesis, GWU, 2012)



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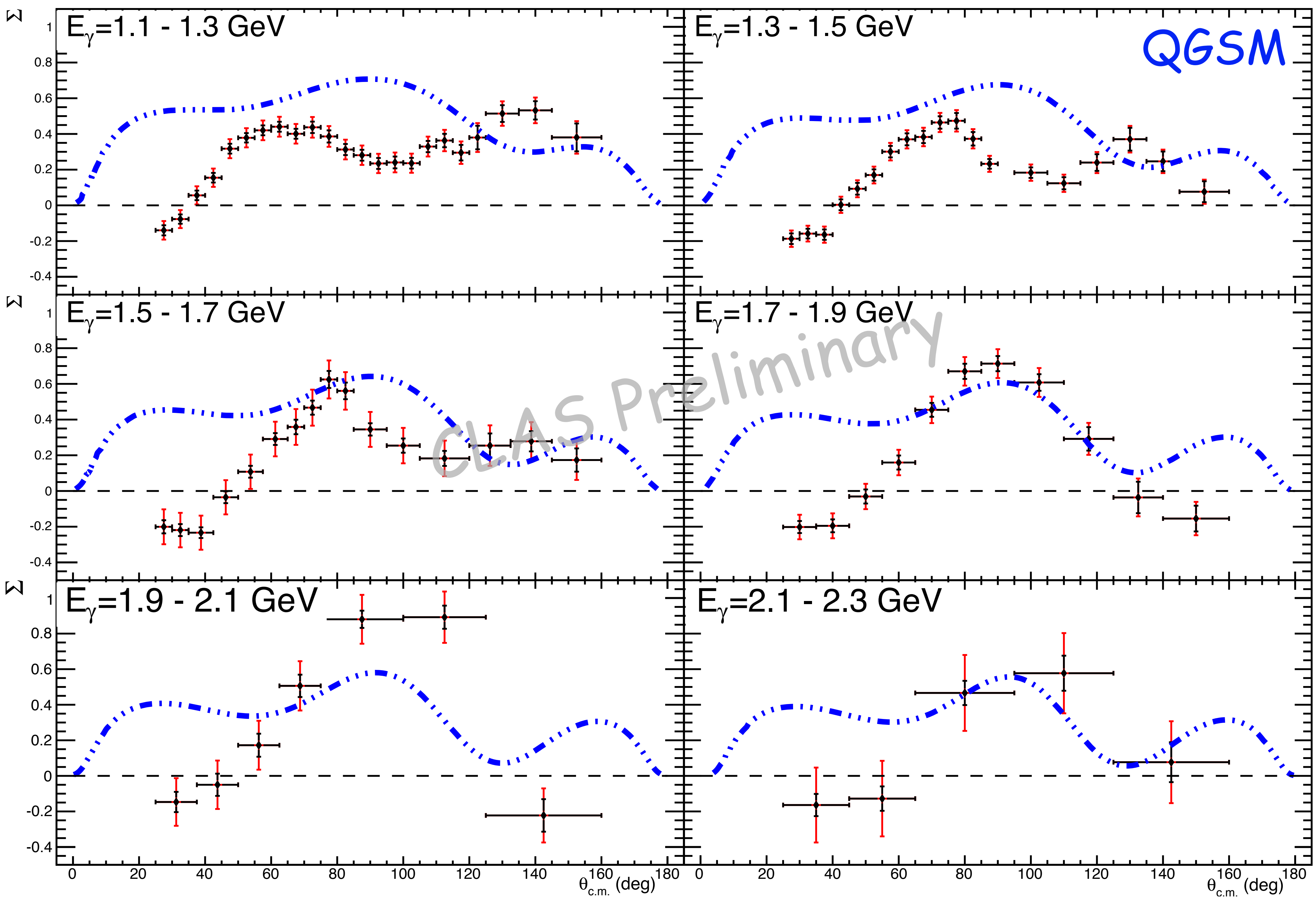


What can we learn about the onset of quarks and gluons in nuclear dynamics from two-body photodisintegration of ^3He at $E_\gamma = (0.4 - 1.4)$ GeV ?

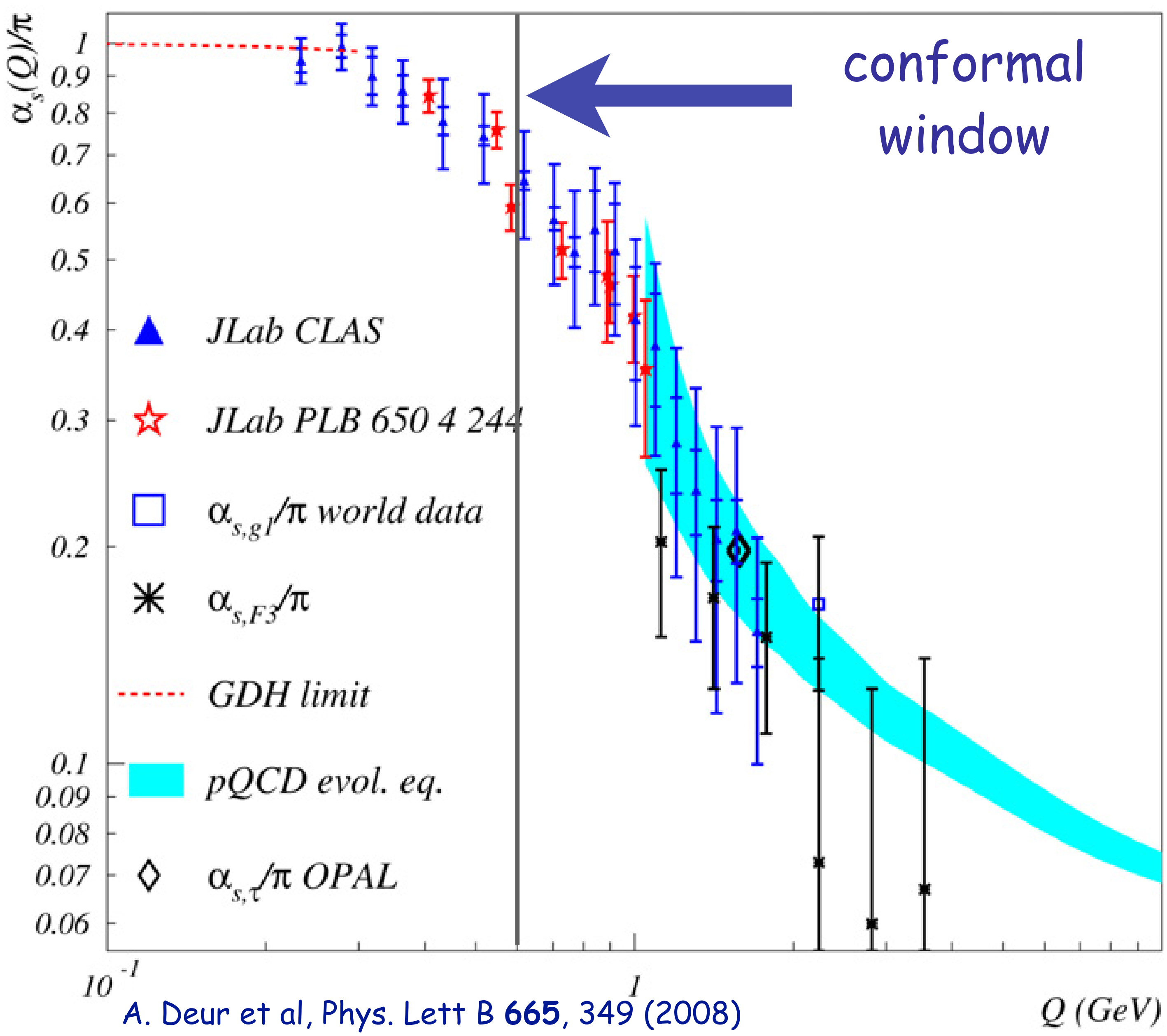
Dimensional Scaling Laws: A New Insight

- QCD is not conformal, however it has manifestations of a scale-invariant theory (dimensional scaling, Bjorken scaling)
- AdS/CFT Correspondence between string theories in Anti de Sitter space-time and conformal field theories in physical space-time
- Allows to treat confinement at large distances and conformal symmetry at short distances
- Non-perturbative derivation of Dimensional Scaling Laws!

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).

Dimensional Scaling Laws: A New Insight

- 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)

Dimensional Scaling Laws: Our Approach

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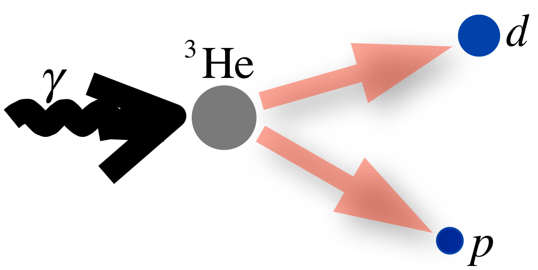
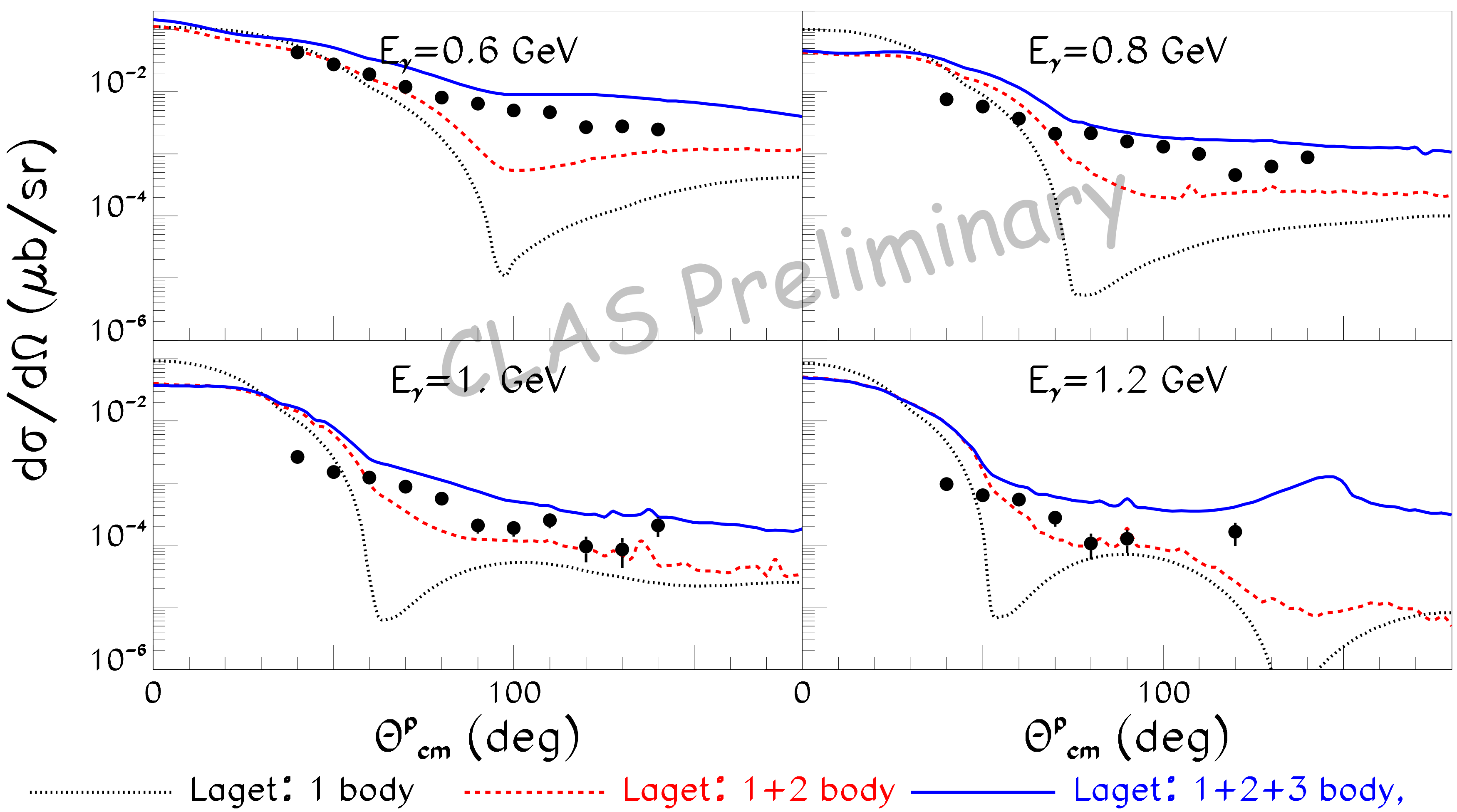
- We need to look at reactions in which the momentum transfer is shared among many constituents.
- We need to look for reactions that are not dominated by resonance excitation at low energies.
- The nucleus is an ideal laboratory.



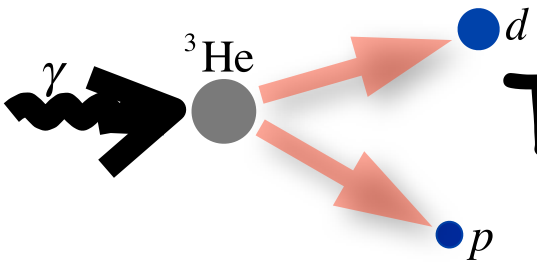
Two-Body Photodisintegration of ^{3}He
E_γ = (0.4 - 1.4) GeV

Advantages for Study of Dimensional Scaling



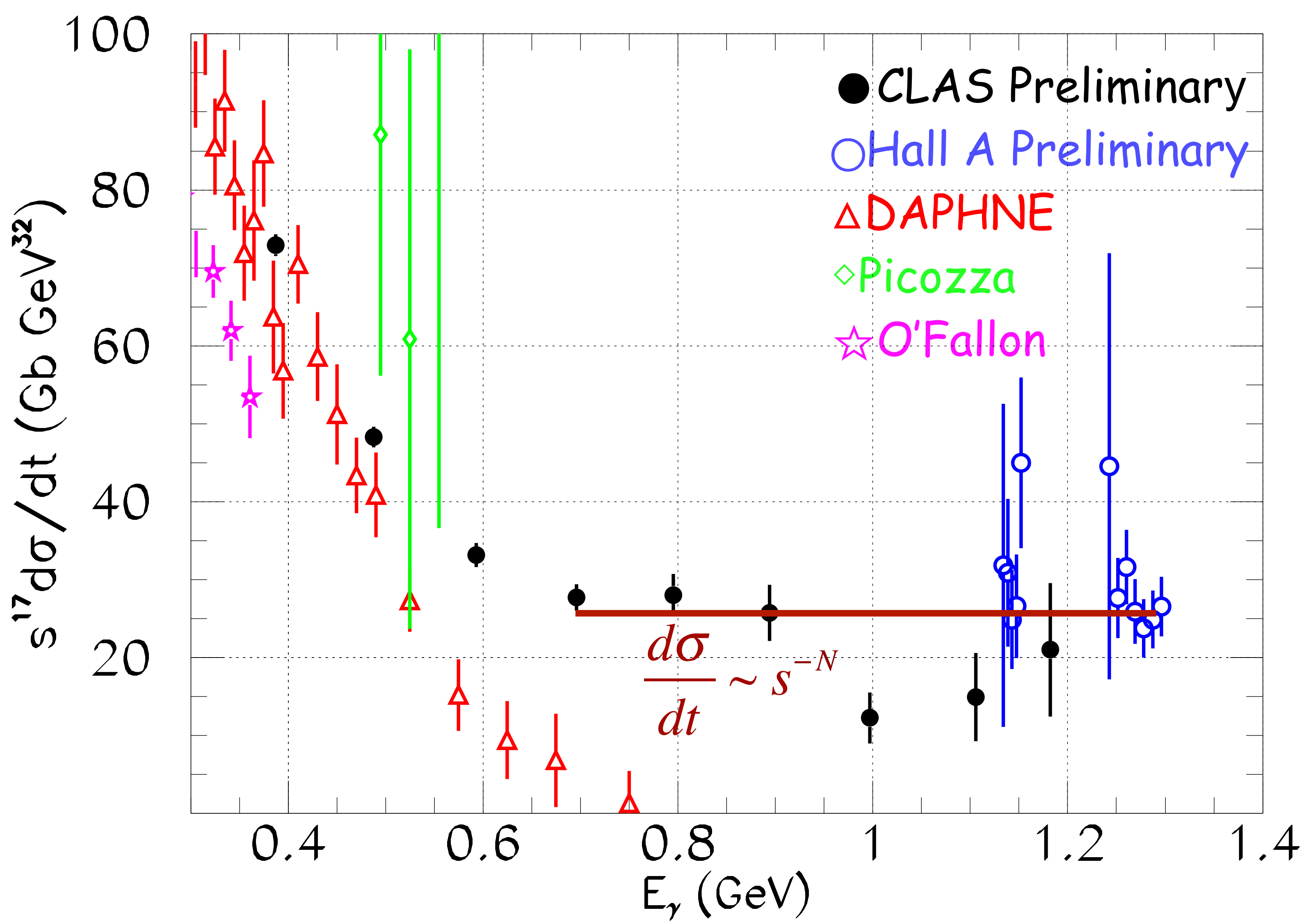
- Significant contribution of three-body mechanisms, especially at 0.6-0.8 GeV
- Resonance contribution to the cross section is suppressed.

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



Two-Body Photodisintegration of ^3He

Scaling of invariant cross sections at 90°



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

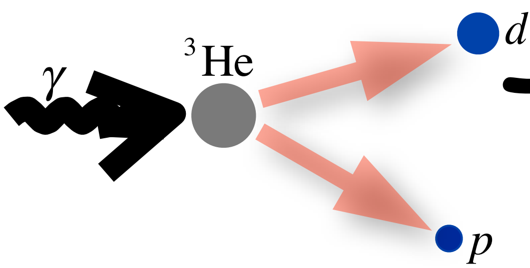
- Extracted value from fits to JLab data:

  N = 17 ± 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

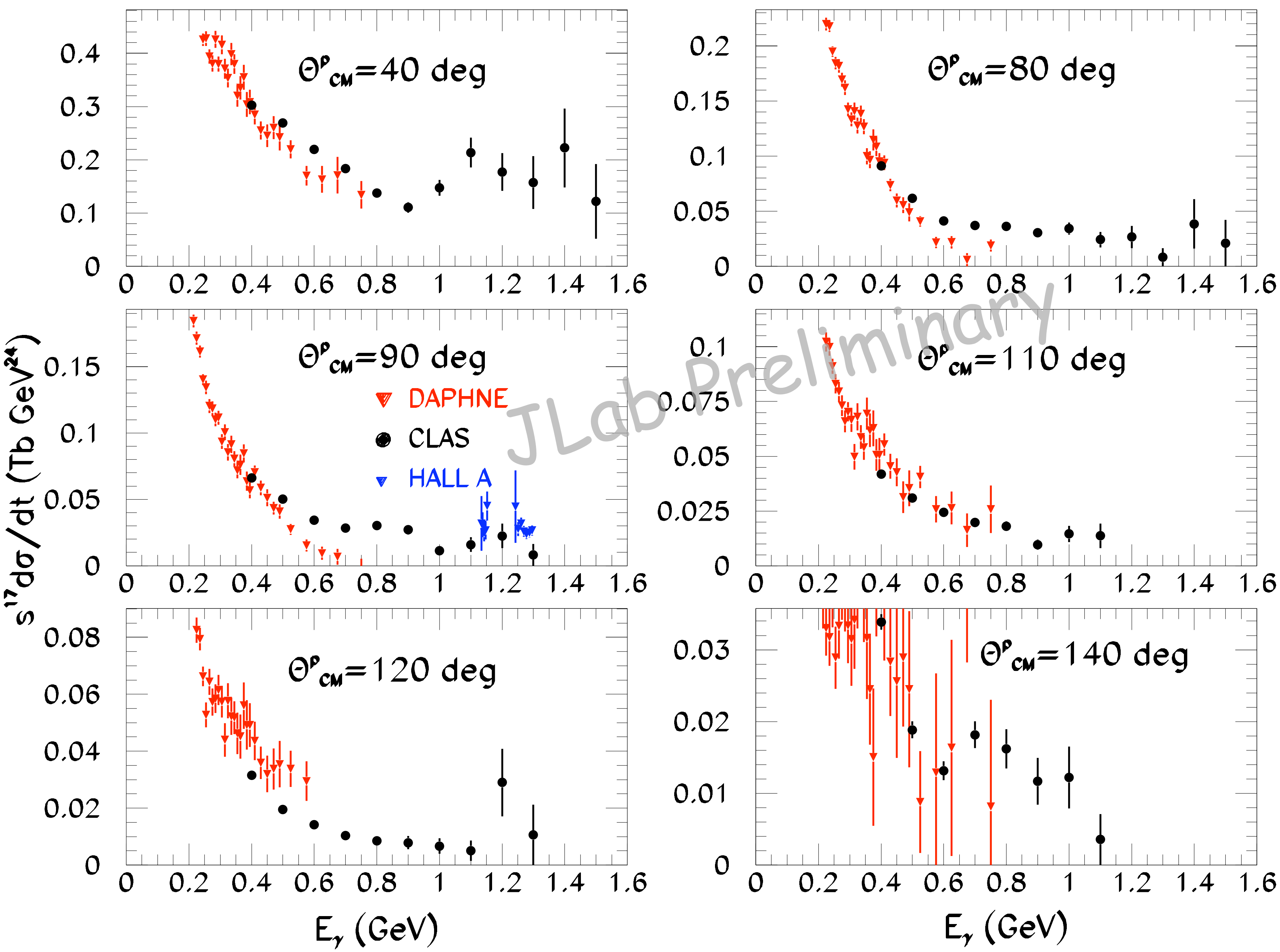
I. Pomerantz, Y. Ilieva, R. Gilman, D. Higginbotom, E. Piazetski, S.Strauch et al., in preparation (2012)



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

Summary

✓ Two-body photodisintegration of d, $\gamma d \rightarrow pn$

- Beam-spin asymmetry measured over a large kinematic range
- Sensitivity to reaction mechanisms
- Work in progress with theorists

✓ Two-body photodisintegration of ^3He, $\gamma^3He \rightarrow pd$

- First systematic study of dimensional scaling of an exclusive nuclear process involving A>2 nucleus at low s and t.
- Solid experimental evidence for onset of dimensional scaling at CM angles of 90°.
- Indication for onset of dimensional scaling at other CM angles.
- Observed scaling is qualitatively consistent with the hypothesis of conformal window at very low momentum transfer.

The END