Study of Dimensional Scaling in Two-Body Photodisintegration of ^3He

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Dimensional Scaling Laws in Nuclear Physics

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

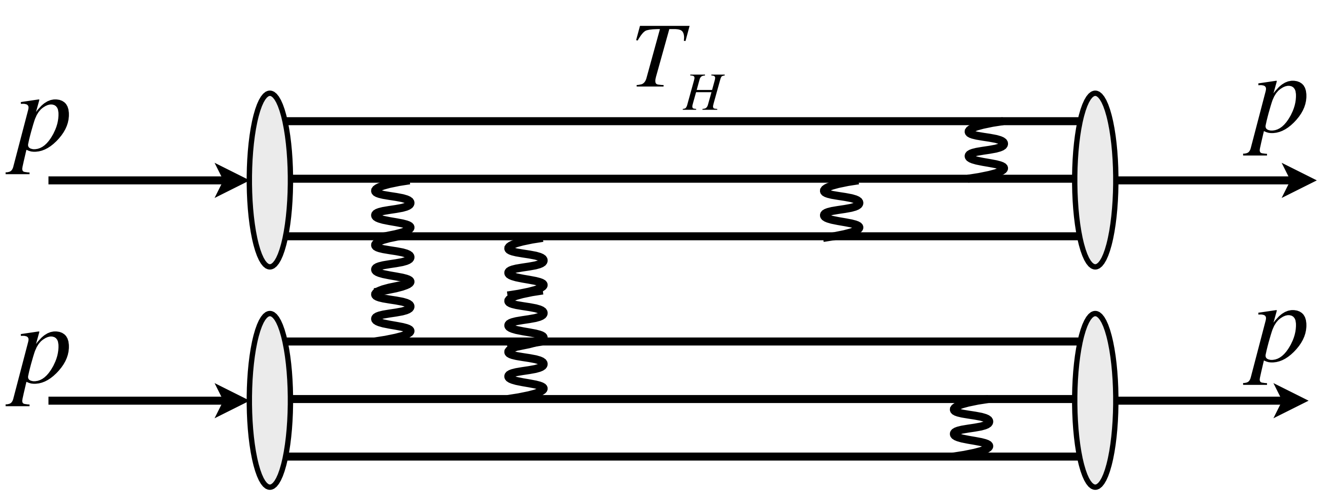
- At high t and high s, power-law behavior of the invariant cross section of an exclusive process A + B → C + D at fixed CM angle:

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

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

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



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

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

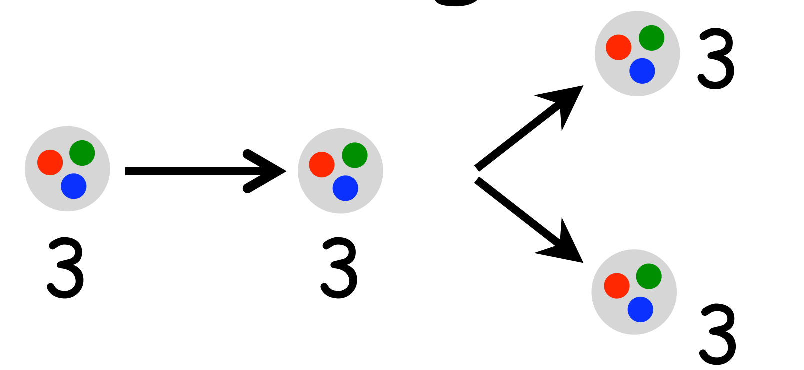
$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}}$$

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)

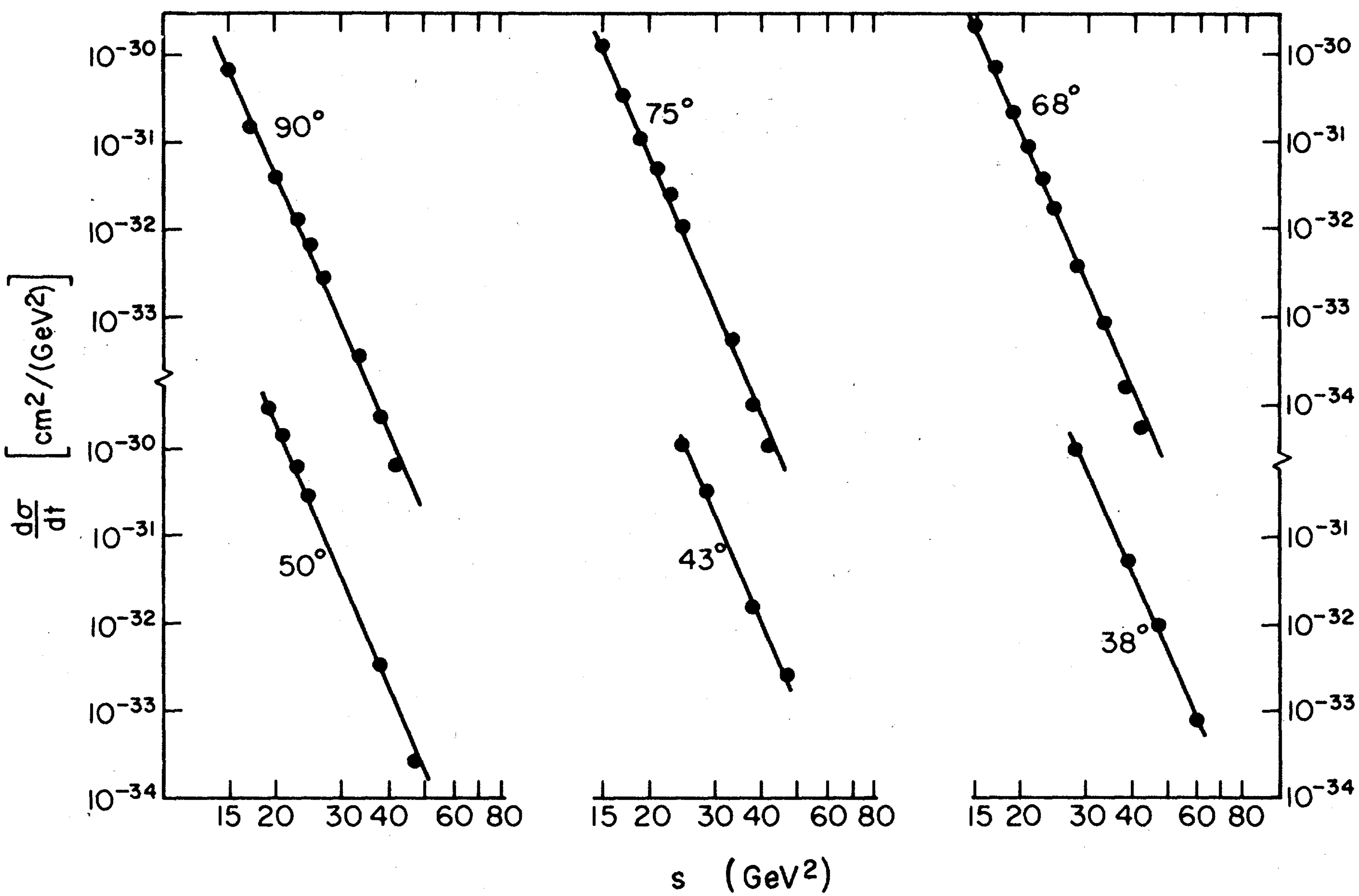
Dimensional Scaling Laws: The Findings

pp → pp

$$s^{10}\frac{d\sigma}{dt} \sim \text{const.}$$



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

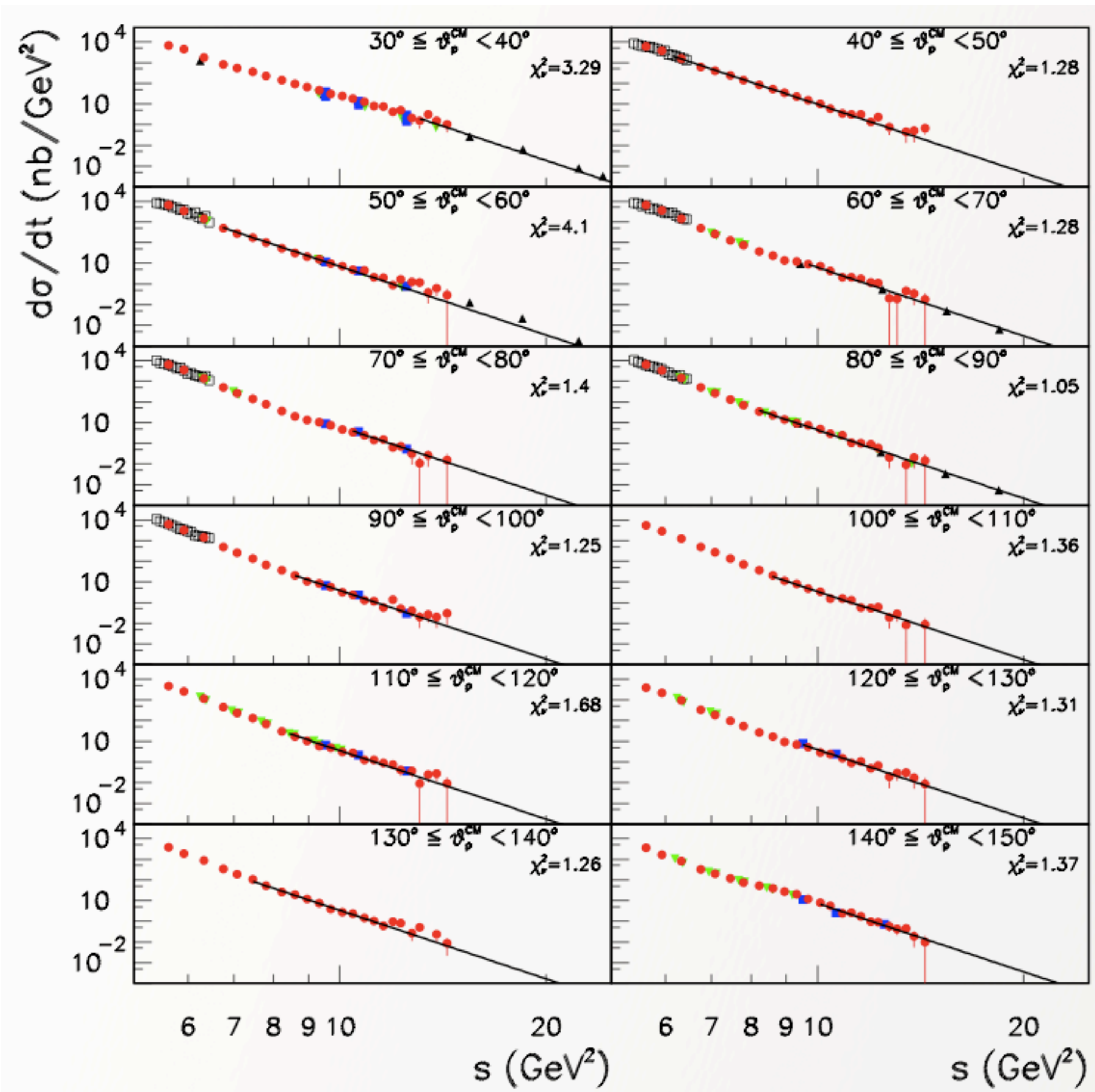


- Cross sections consistent with predicted scaling s^{-10} for a range of CM angles

P.V. Landshoff and J.C. Polkinghorne, Phys. Lett. B 44, 293 (1973)

Dimensional Scaling Laws: The Findings

$\gamma d \rightarrow pn$



$$\frac{d\sigma}{dt} = \frac{1}{s^{11}} f(t/s)$$

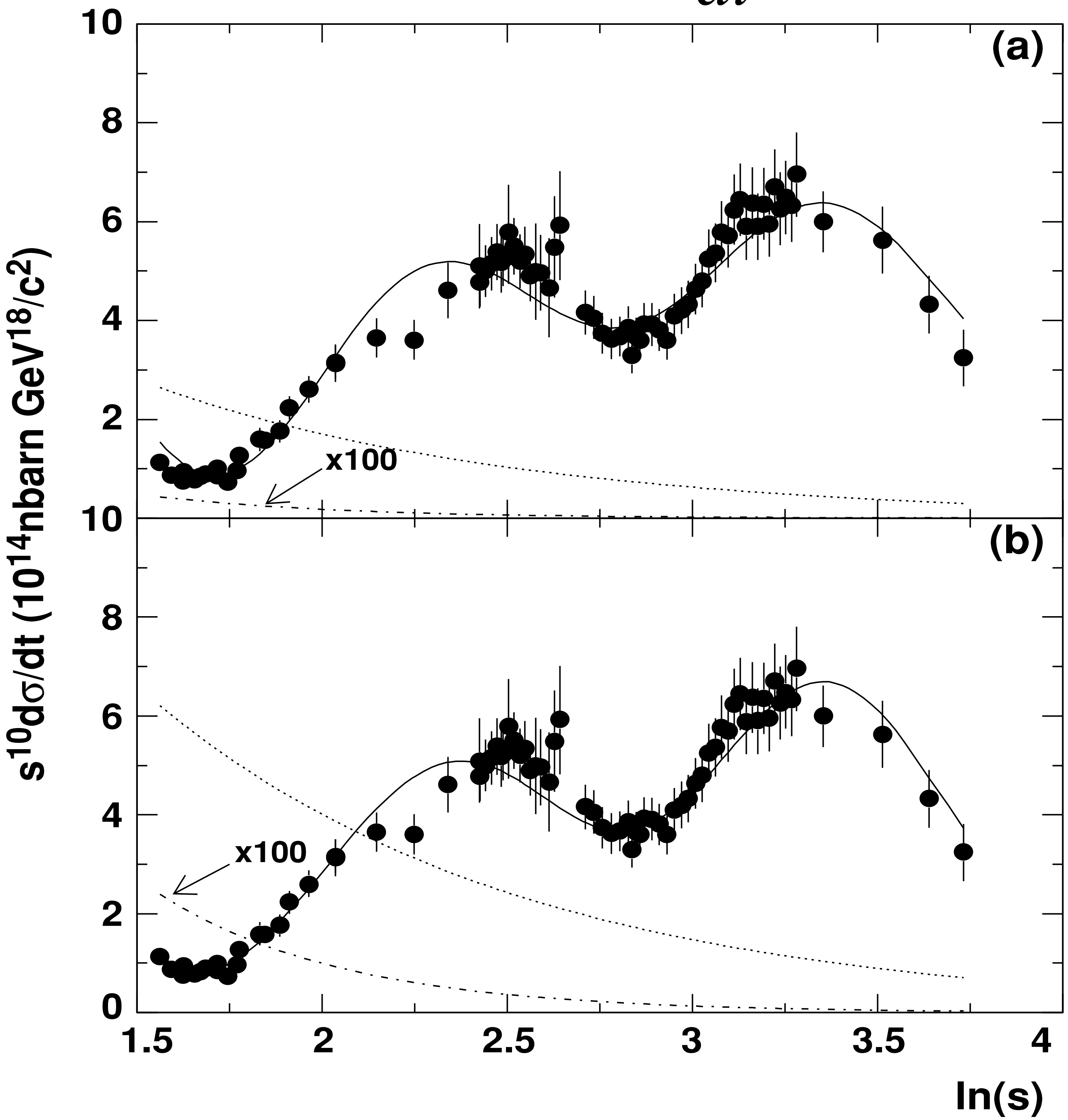
- Fits of $d\sigma/dt$ data at $p_T > 1.1$ GeV/c with As^{-11}
- All but two fits have $\chi^2 \leq 1.34$

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

Dimensional Scaling Laws: The Anomalies

pp → pp

$$s^{10} \frac{d\sigma}{dt} \sim \text{const.}$$

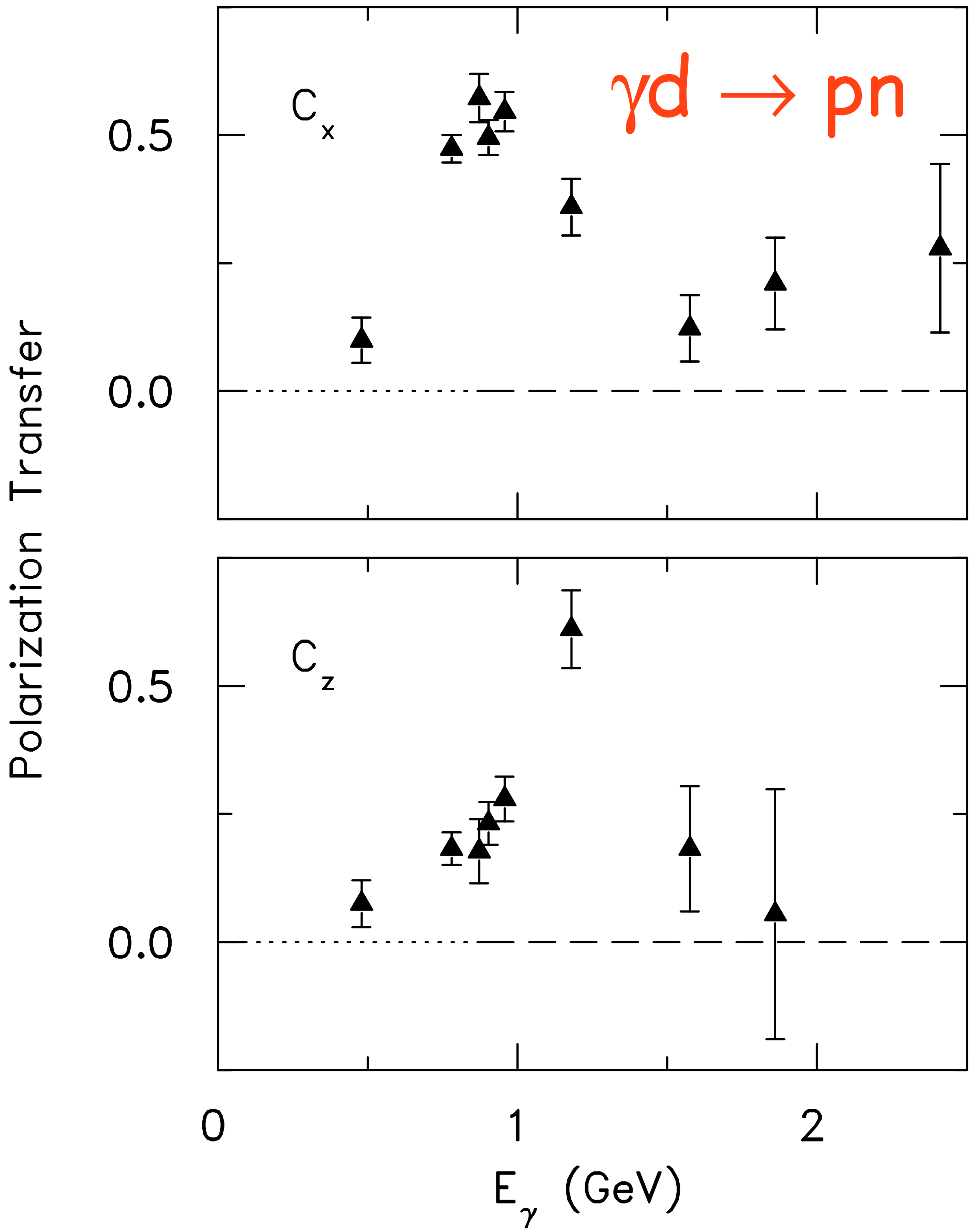


- Oscillations of the scaled cross sections around the scaling value
- Various hypotheses for its origin
  - contributions from non-zero parton orbital angular momentum
  - long distance subprocesses
  - resonance excitations related to the opening of the charm threshold

H. Gao and D. Dutta, Phys. Rev. C 71, 032201(R) (2005)

Dimensional Scaling Laws and pQCD: The Anomalies

pQCD prediction: Hadron Helicity Conservation



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

$$\lambda_d = \lambda_p + \lambda_n$$

- 12 helicity amplitudes
- 4 amplitudes conserve hadron helicity

$$F_{1+} = \langle 1\,1 \,|\, T \,|\, +\tfrac{1}{2} + \tfrac{1}{2} \rangle$$

$$F_{3-} = \langle 1\,-1 \,|\, T \,|\, -\tfrac{1}{2} - \tfrac{1}{2} \rangle$$

$$F_{5+} = \langle 1\,0 \,|\, T \,|\, +\tfrac{1}{2} - \tfrac{1}{2} \rangle$$

$$F_{5-} = \langle 1\,0 \,|\, T \,|\, -\tfrac{1}{2} + \tfrac{1}{2} \rangle$$

Dimensional Scaling Laws: What have we learned?

- Overwhelming experimental evidence for success at momentum transfer as low as 1 GeV
- Anomalies (can be related to resonance excitations)
- Some evidence that soft processes can mimic the predicted dimensional scaling behavior of cross sections
- Observed in a regime where pQCD is not applicable
  - not a feature of only pQCD?
  - manifestation of a more general symmetry?

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 we do not know how to interpret it.

Dimensional Scaling Laws: Where do we stand?

- A comprehensive theoretical description of exclusive processes in the non-perturbative regime has proved difficult (pQCD, models).
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What is the origin of the scale-invariance of the underlying non-perturbative dynamics in the regime of confinement?

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

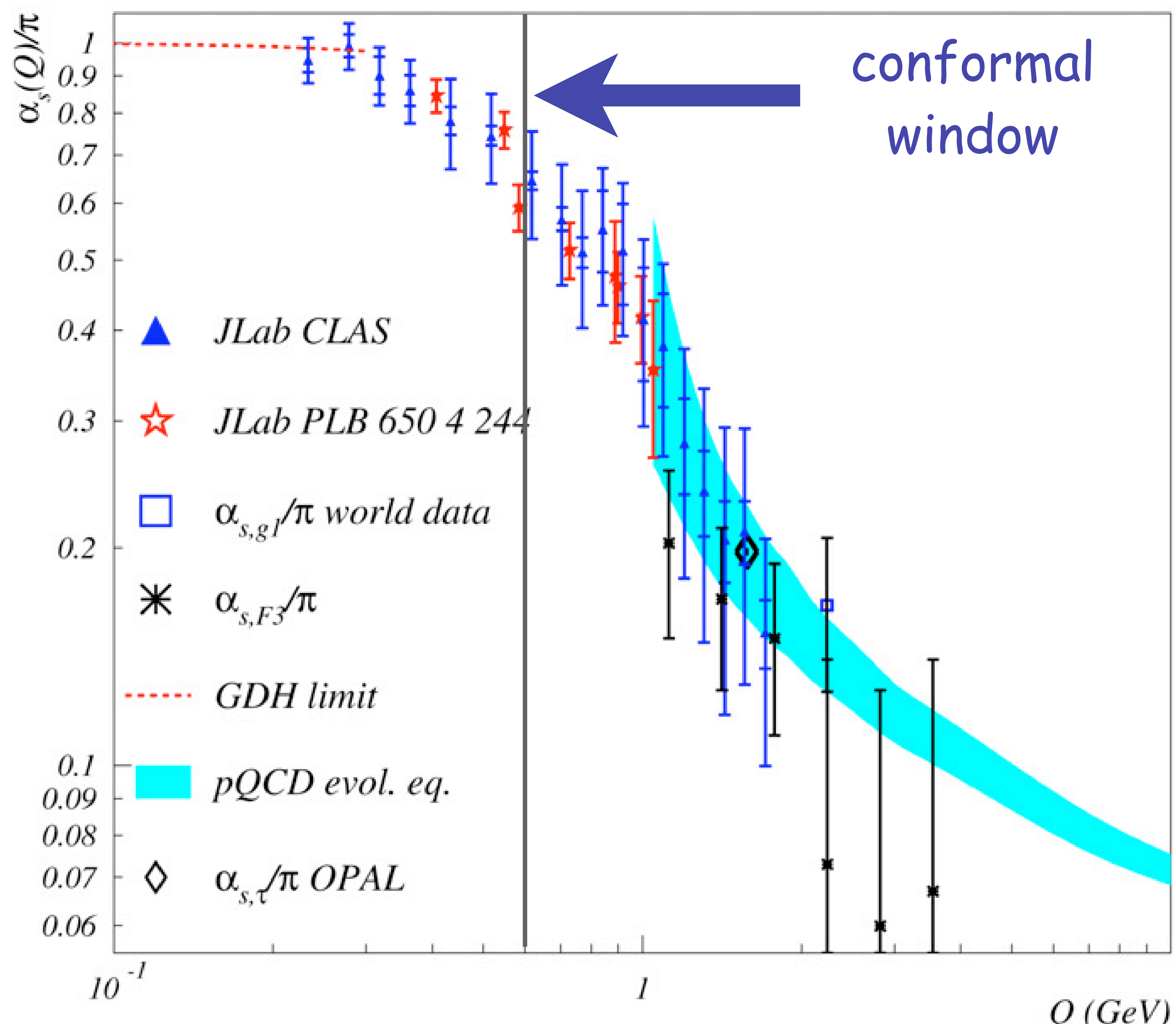
- Allows to treat confinement at large distances and conformal symmetry at short distances

- 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

- Dimensional Scaling Laws probe two very different dynamical regimes: interpretation depends on the average momentum transfer to each hadron constituent.
- In order to test the predictions of the novel AdS/CFT approach, we need to rigorously probe dimensional scaling in exclusive processes at small momentum transfer.
- 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.

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Dimensional Scaling Laws: Our Approach

- We study the reaction $\gamma^3He \rightarrow pd$ in the energy range 0.4 - 1.4 GeV

- Advantages
  - prior evidence that re-scattering mechanisms play significant role (ideal tool for sharing the momentum among many constituents so that the average momentum transfer per constituent is small).
  - low-energy studies show that the cross sections are not dominated by resonance excitation.

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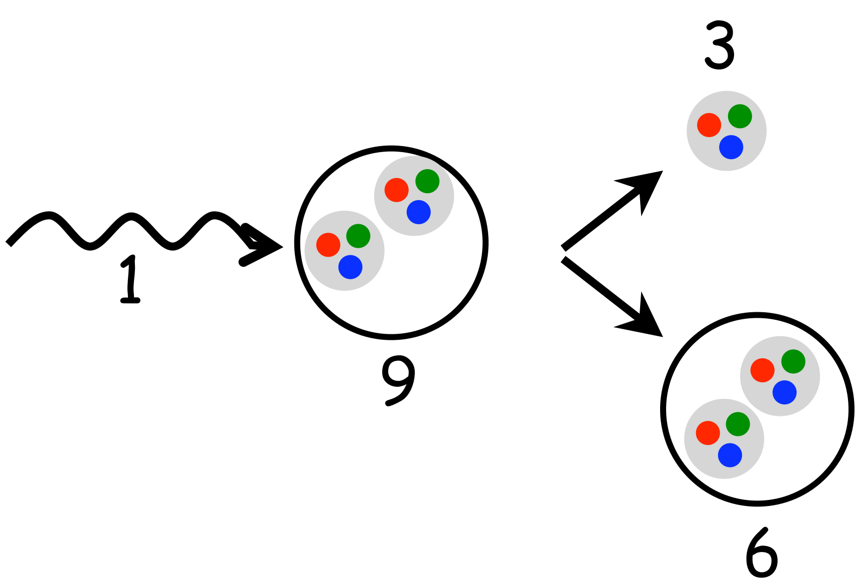

$$n - 2 = (1 + 9 + 3 + 6) - 2 = 17$$

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

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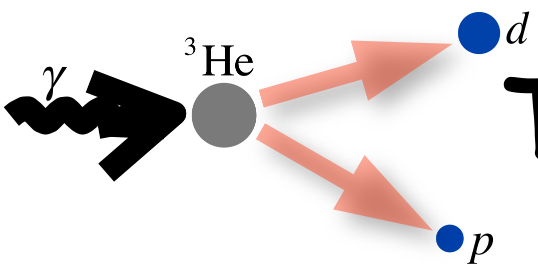
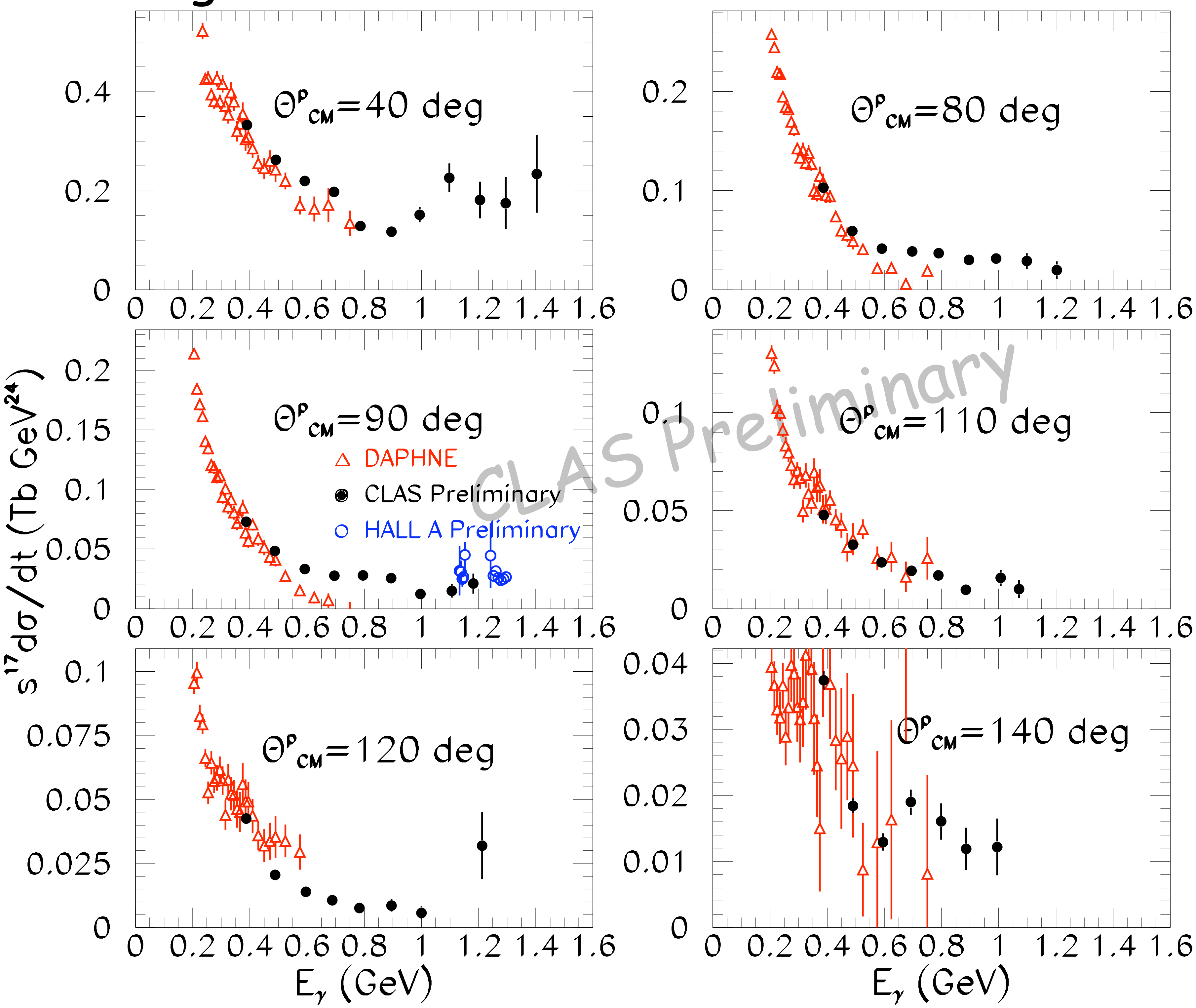


Two-Body Photodisintegration of ^{3}He

Scaling of invariant cross sections



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

- Dimensional Scaling Predicts n-2=17
- Indication that above ~0.7 GeV data consistent with scale invariance for all CM angles
- Consistent with the AdS/CFT hypothesis

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

I. Pomerantz et al., private communication (2010)

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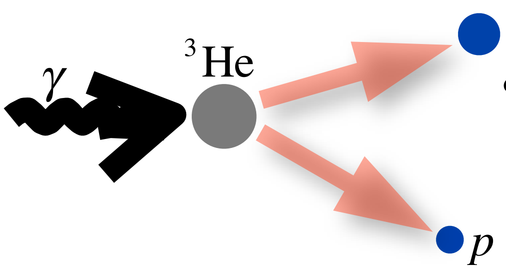
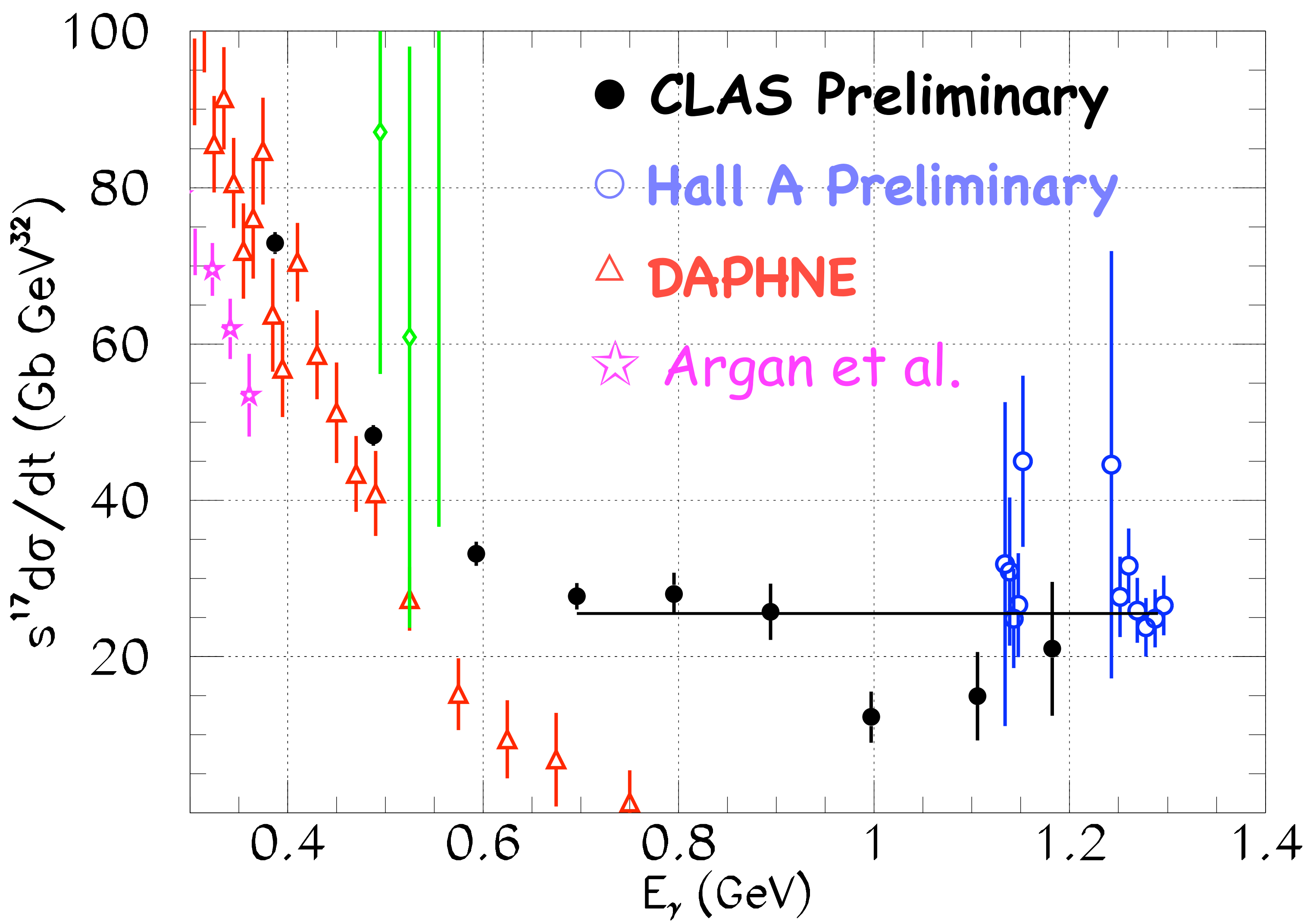


Two-Body Photodisintegration of ^{3}He

Scaling of invariant cross sections at 90°



- Extracted value from fits to 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

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

I. Pomerantz, Y. Ilieva et al., in preparation (2011)

P.E. Argan et al., Nucl. Phys. A **237**, 447 (1975)

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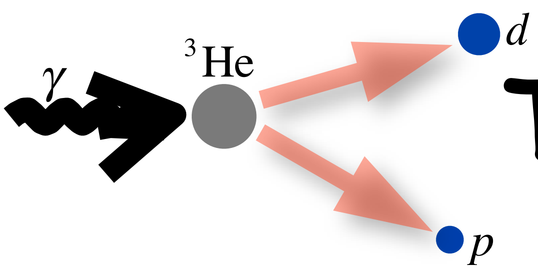
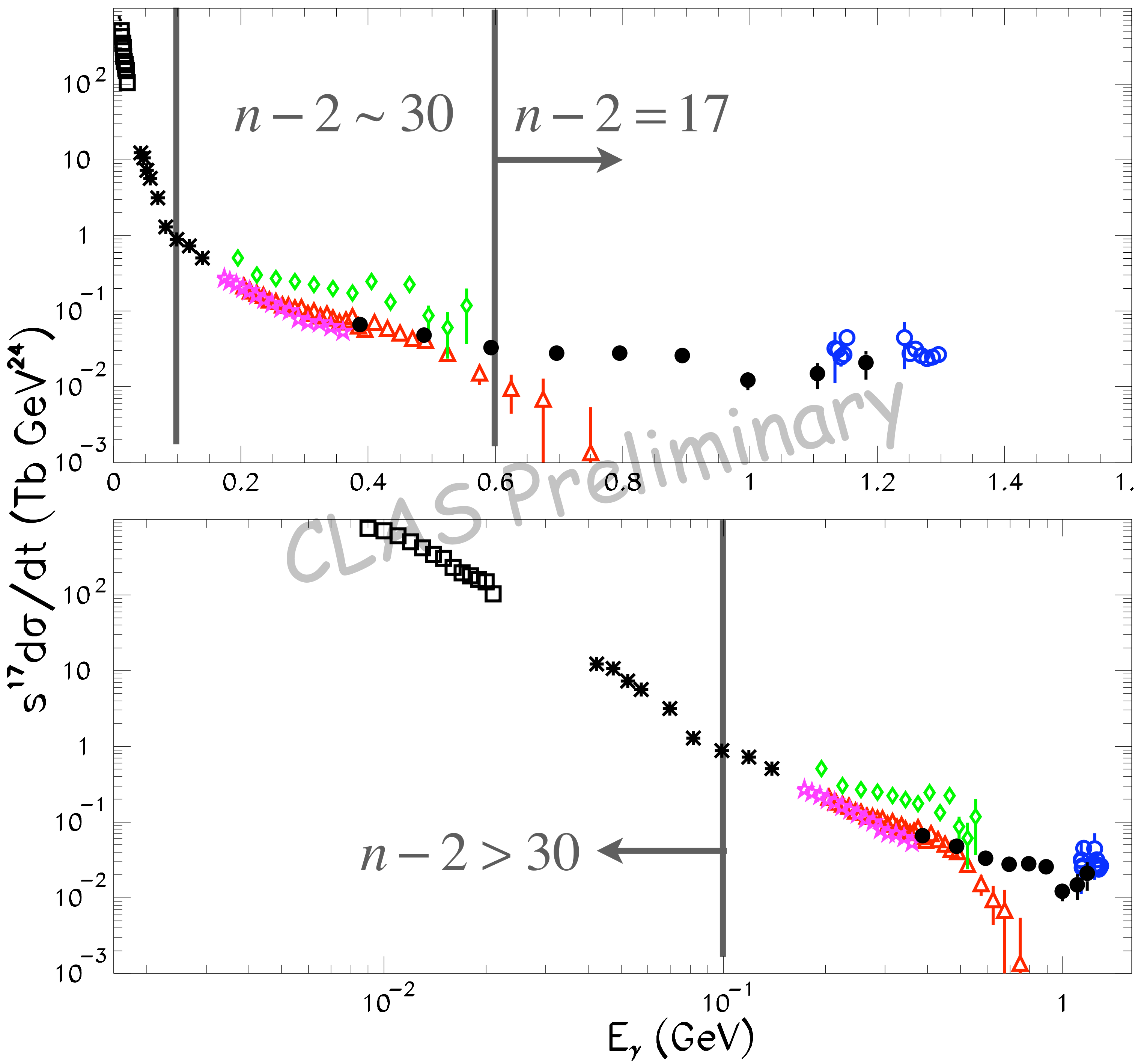


Two-Body Photodisintegration of ^{3}He

Scaled invariant cross sections at 90°

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



- Dimensional Scaling Predicts n-2=17
- For energies ~(0.1 - 0.6) GeV data scale with n-2~30.
- Below ~0.1 GeV:

  parton picture break down (?)

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Summary and Perspectives

- First systematic study of dimensional scaling of an exclusive nuclear process, $\gamma^3He \rightarrow pd$ at low s and t.
- Results currently under CLAS analysis review.
- 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.
- Not understood what is the origin of scaling in other exclusive processes: dominance of hard re-scattering or conformal window scale invariance
  - Polarization measurement of $\gamma d \rightarrow pn$ (g13 data at JLab)
  - Exclusive kaon photoproduction at JLab 12 GeV (LOI-11-107)

The END

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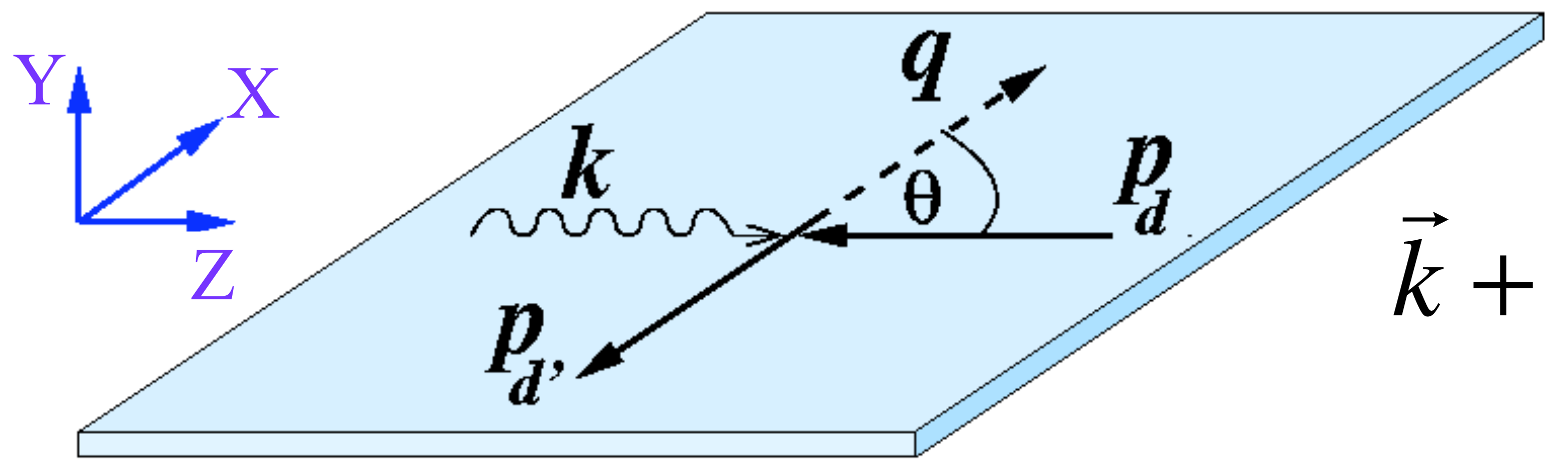
Kinematics of Exclusive Processes

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

Center-of-Mass Reference Frame (CM):



$$\vec{k} + \vec{p}_{^3\mathrm{He}} = \vec{p}_d + \vec{p}_p = 0$$

Center of mass energy, s, and momentum transfers, t and u

$$s = (\tilde{p}_\gamma + \tilde{p}_{^3\mathrm{He}})^2 = s(E_\gamma)$$

$$t = (\tilde{p}_d - \tilde{p}_{^3\mathrm{He}})^2 = t(E_\gamma, \theta)$$

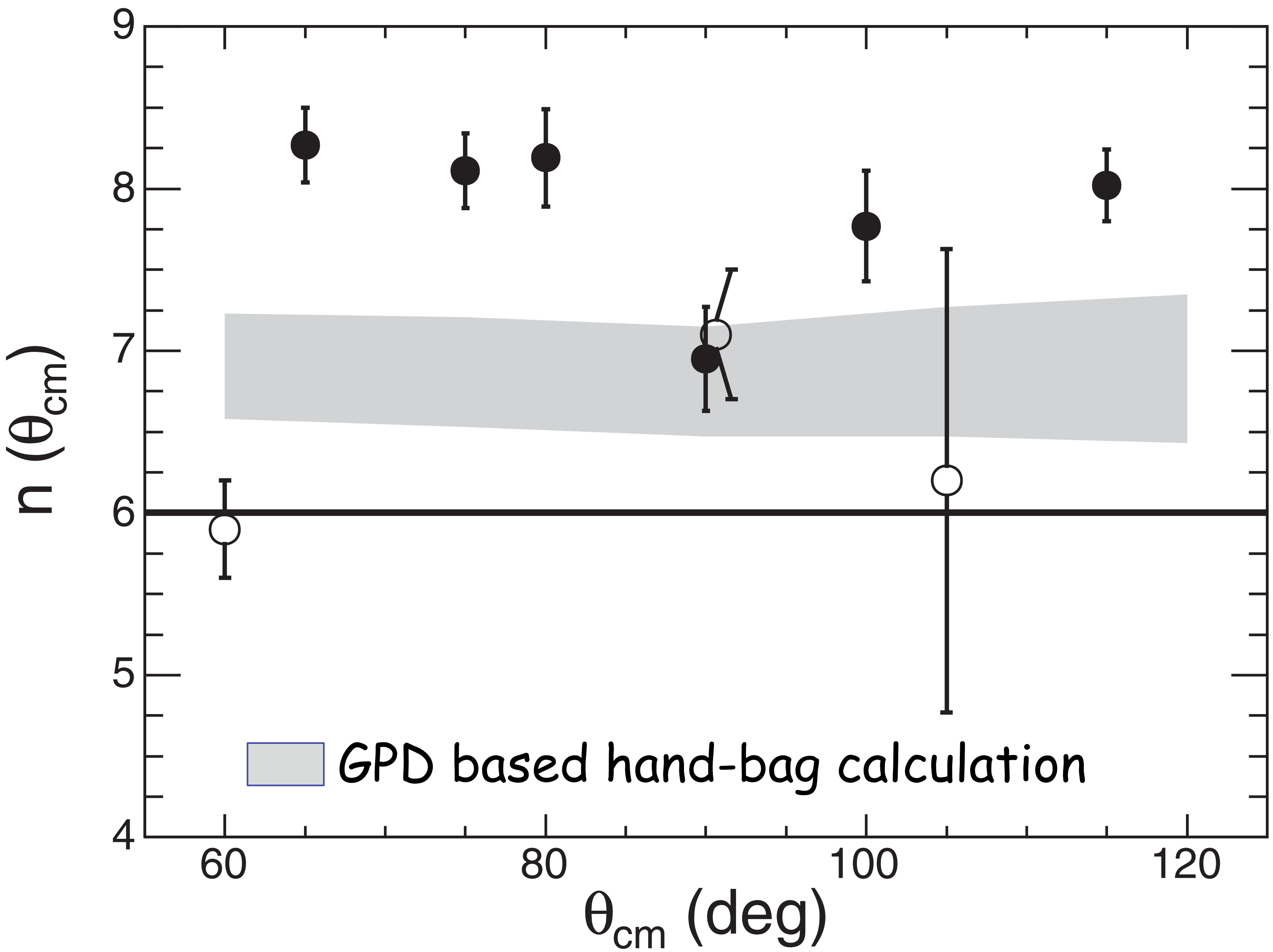
$$u = (\tilde{p}_p - \tilde{p}_{^3\mathrm{He}})^2 = u(E_\gamma, \theta)$$

At large energies, the cross section is a simple function of s.

Dimensional Scaling Laws: The Anomalies

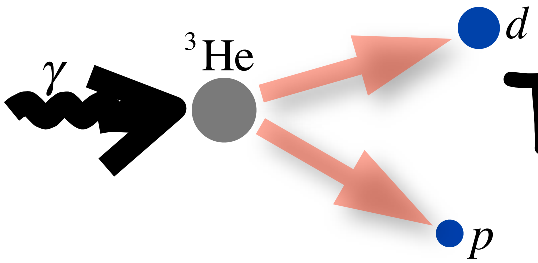
$\gamma p \rightarrow \gamma p$

$$s^6 \frac{d\sigma}{dt} \sim \text{const.}$$



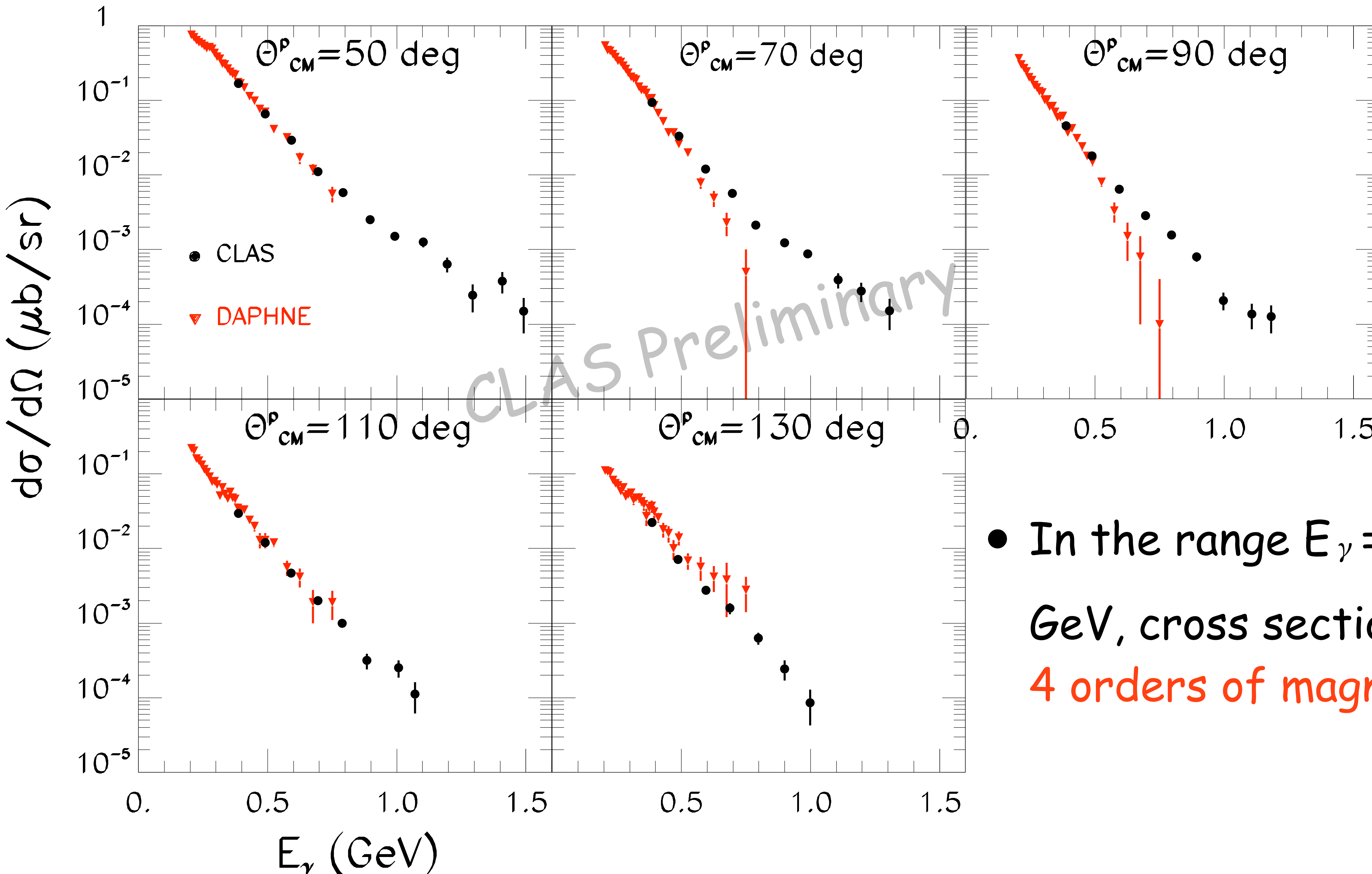
- Cross sections inconsistent with predicted scaling power
- Some theoretical studies suggest the process is dominated by soft subprocesses
- n ~ 8 due to the vector-meson component of the real photon?

A. Danagoulian et al., Phys. Rev. Lett. 98, 152001 (2007)



Two-Body Photodisintegration of ^{3}He

Comparison with previous measurements

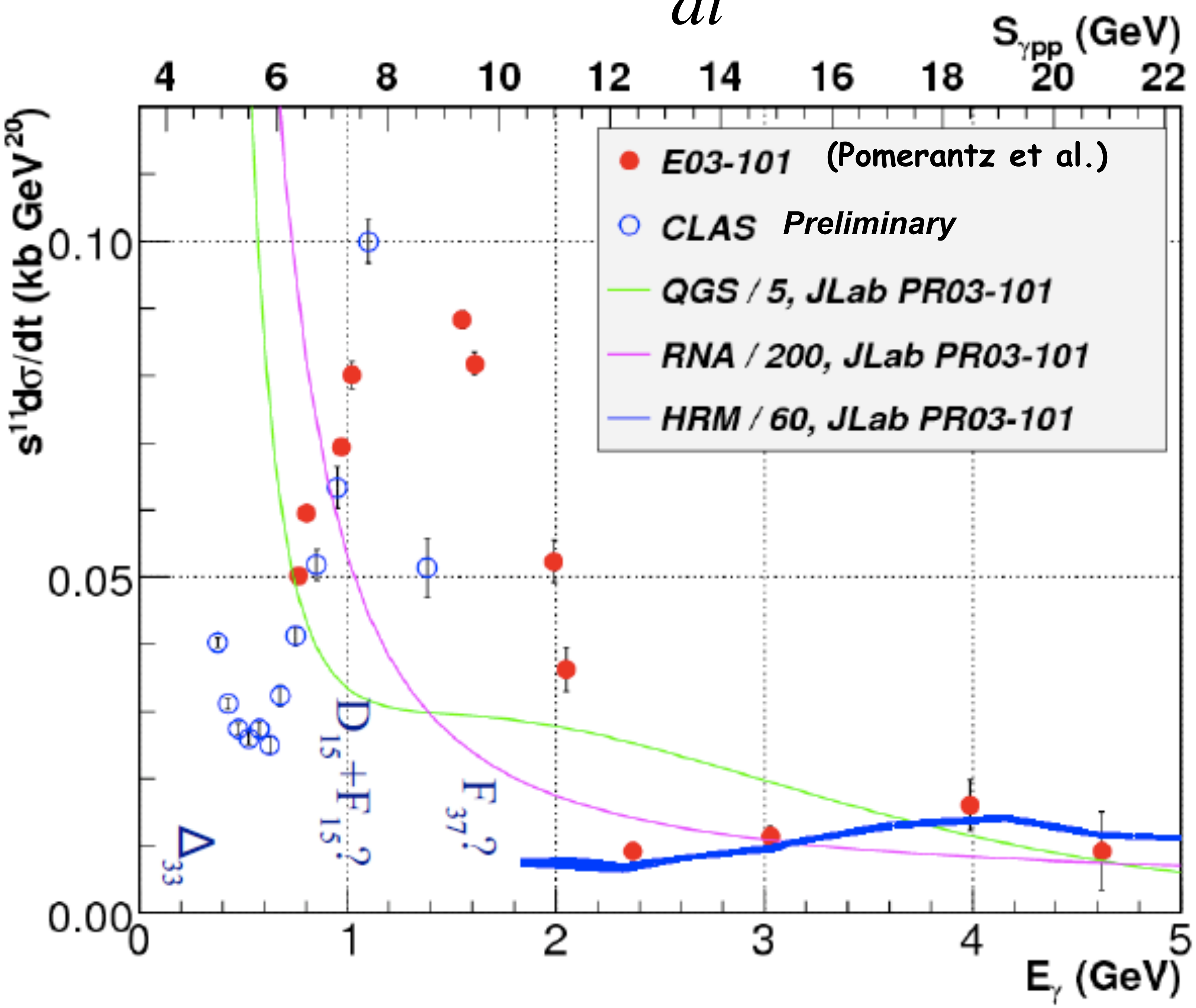


- In the range E_γ=0.2 - 1.5 GeV, cross sections drop 4 orders of magnitude.

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

Dimensional Scaling Laws: The Anomalies

$\gamma pp(n) \to pp(n)$ $\quad s^{11}\frac{d\sigma}{dt} \sim \text{const.}$



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

- Large resonance-like structure below 2 GeV, not observed in deuteron photodisintegration
- Various models describe equally well the shape of scaled cross section above 2 GeV
  - Quark-Gluon String M
  - Hard Rescattering M
  - Reduced Nuclear Amplitudes

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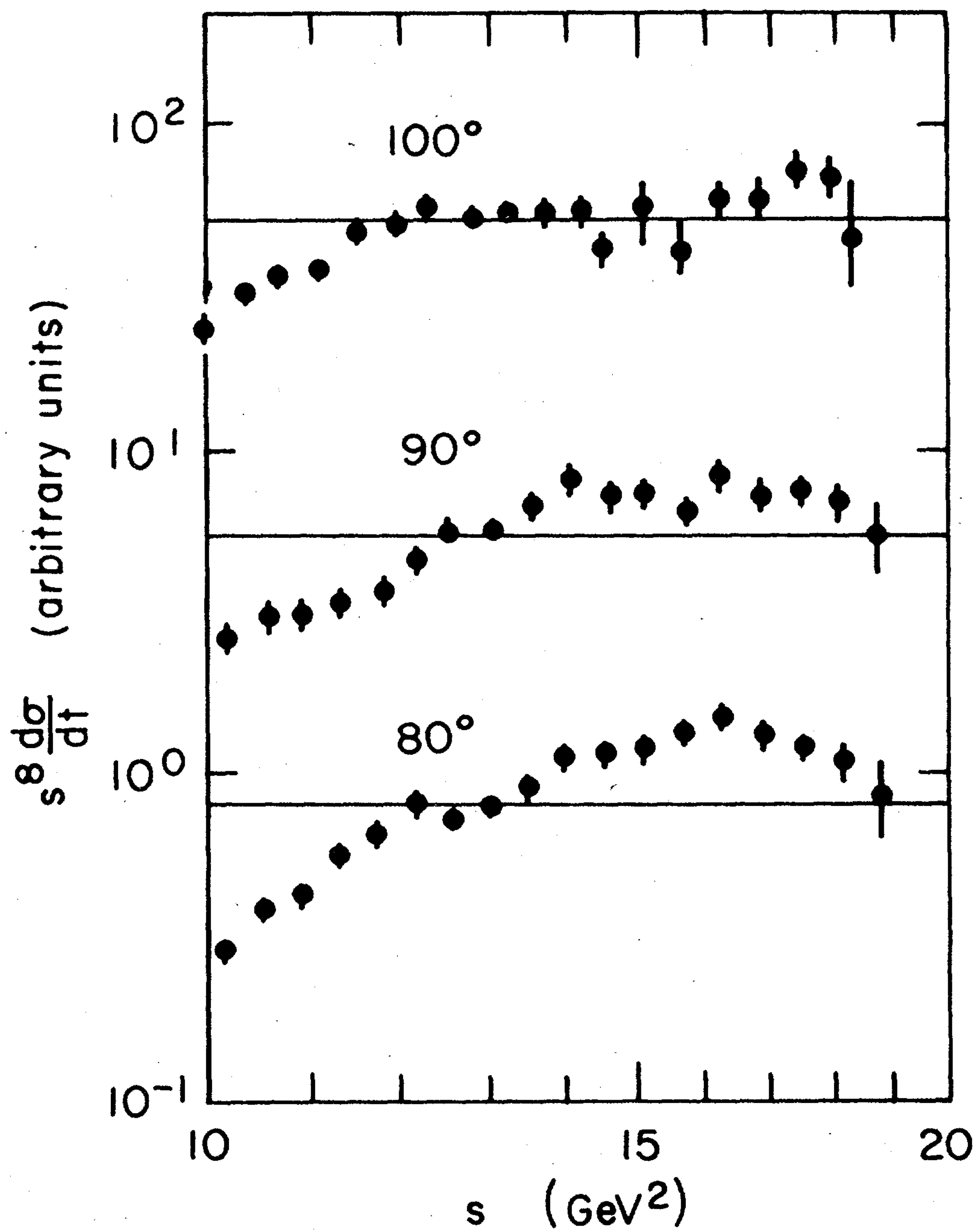
Dimensional Scaling Laws: The Findings

$\pi^- p \to \pi^- p$ $\quad s^8 \frac{d\sigma}{dt} \sim \text{const.}$

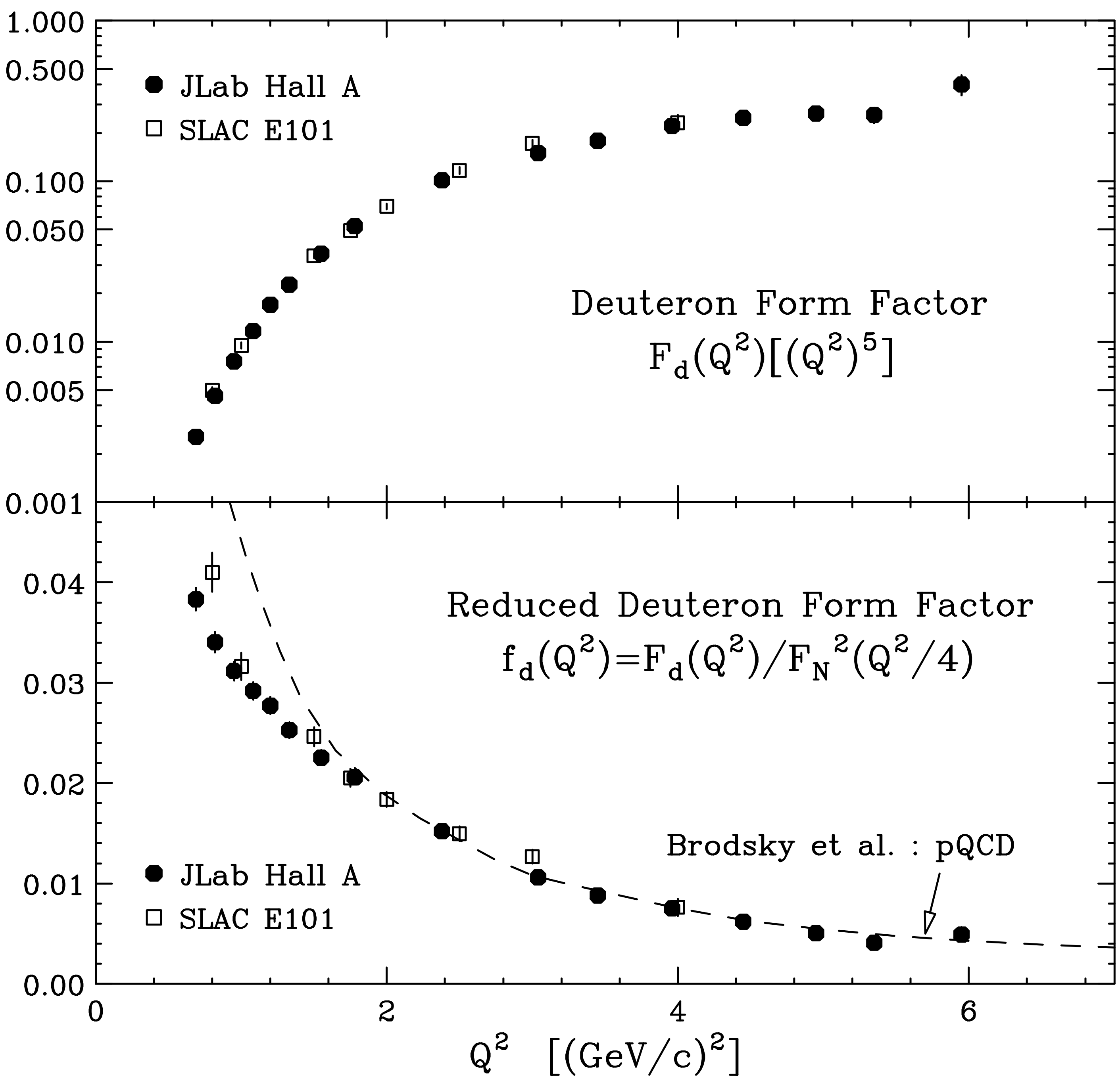


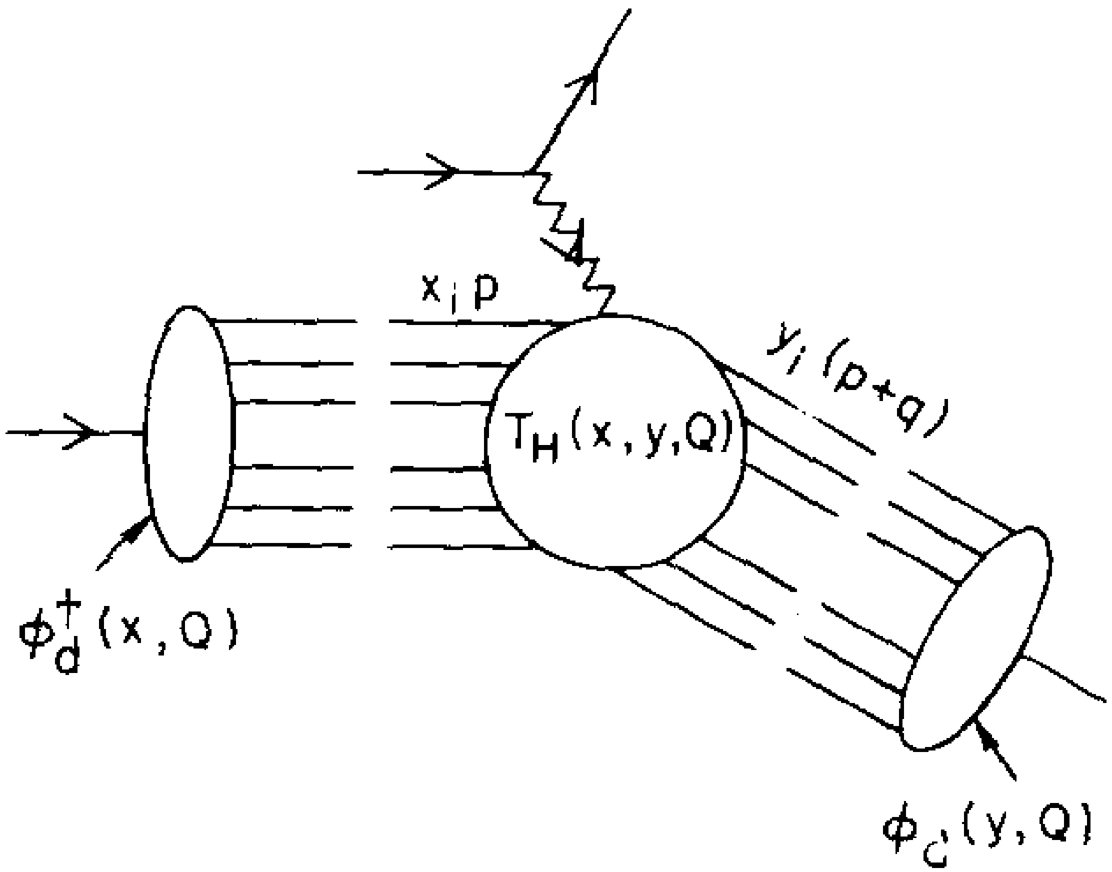
- Cross sections consistent with predicted scaling s^{-8} for large CM angles and $s > 12$ GeV^2

K.A. Jenkins et al., Phys. Rev. D 21, 2445 (1980); Phys. Rev. Lett. 40, 425 (1979)

Dimensional Scaling Laws: The Findings

Deuteron Form Factor





$$T_H^{6q+\gamma^*\to 6q} = \left[\frac{\alpha_s(Q^2)}{Q^2}\right]^5 t(x,y)[1+O(\alpha_s(Q^2))]$$

$$F_d(Q^2) \sim \frac{1}{Q^{10}}$$

$$Q^{10}F_d(Q^2) \sim \text{const.}$$

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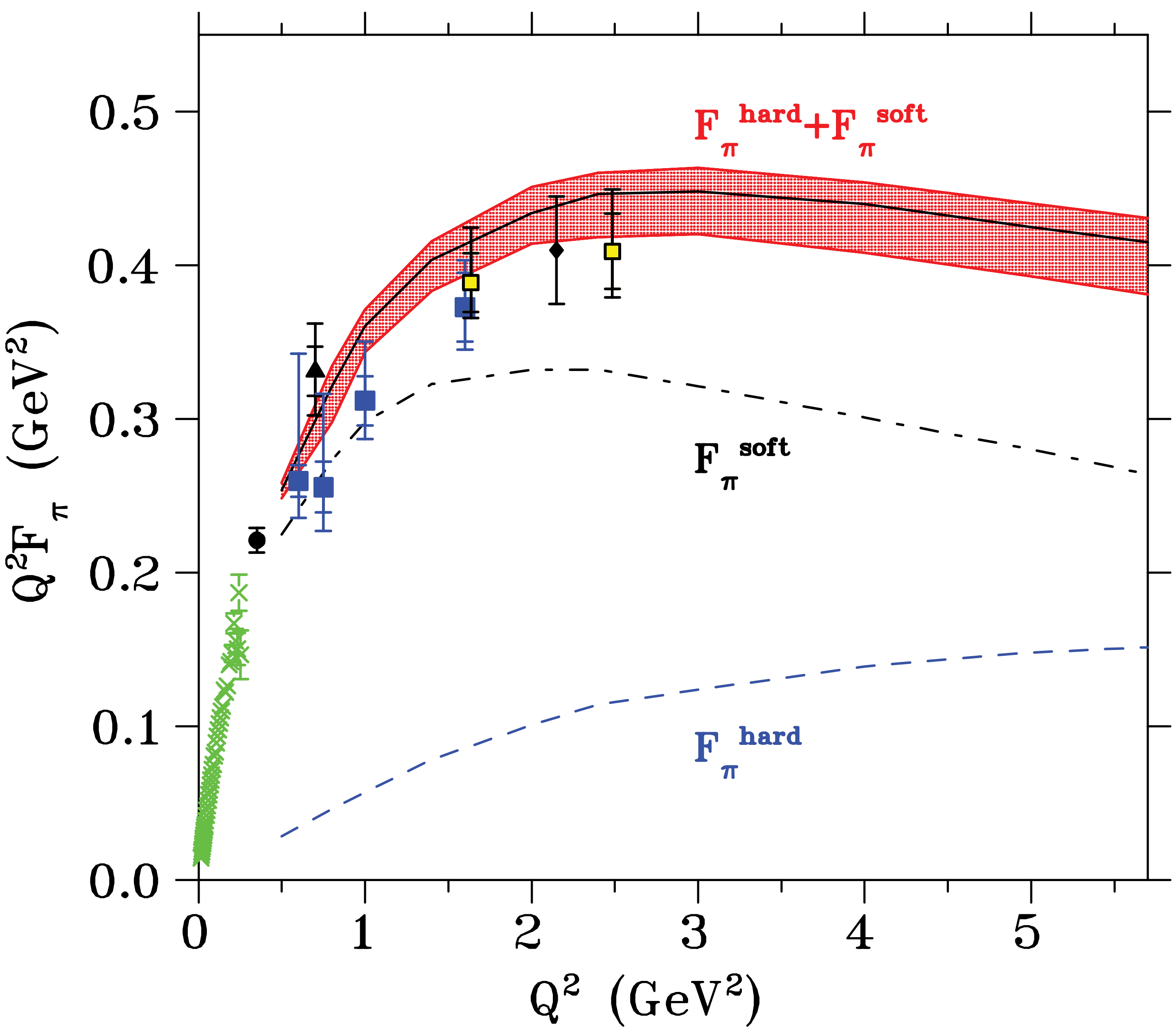
L.C. Alexa et al., Phys. Rev. Lett. 82, 1374 (1999)

S.J. Brodsky, Nucl. Phys. A 416, 3c (1984)

Dimensional Scaling Laws and pQCD: The Anomalies

Pion Form Factor $Q^2 F_\pi \sim \text{const.}$



- Data show indications of approaching scaling behavior
- Data are far above the pQCD prediction
- Non-perturbative contributions dominate in the kinematic range of measured data.

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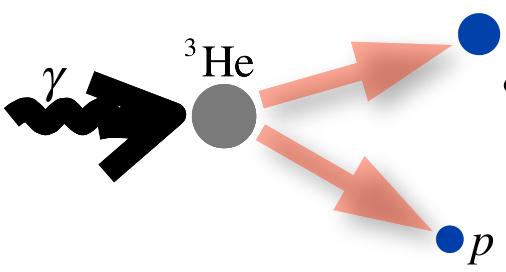
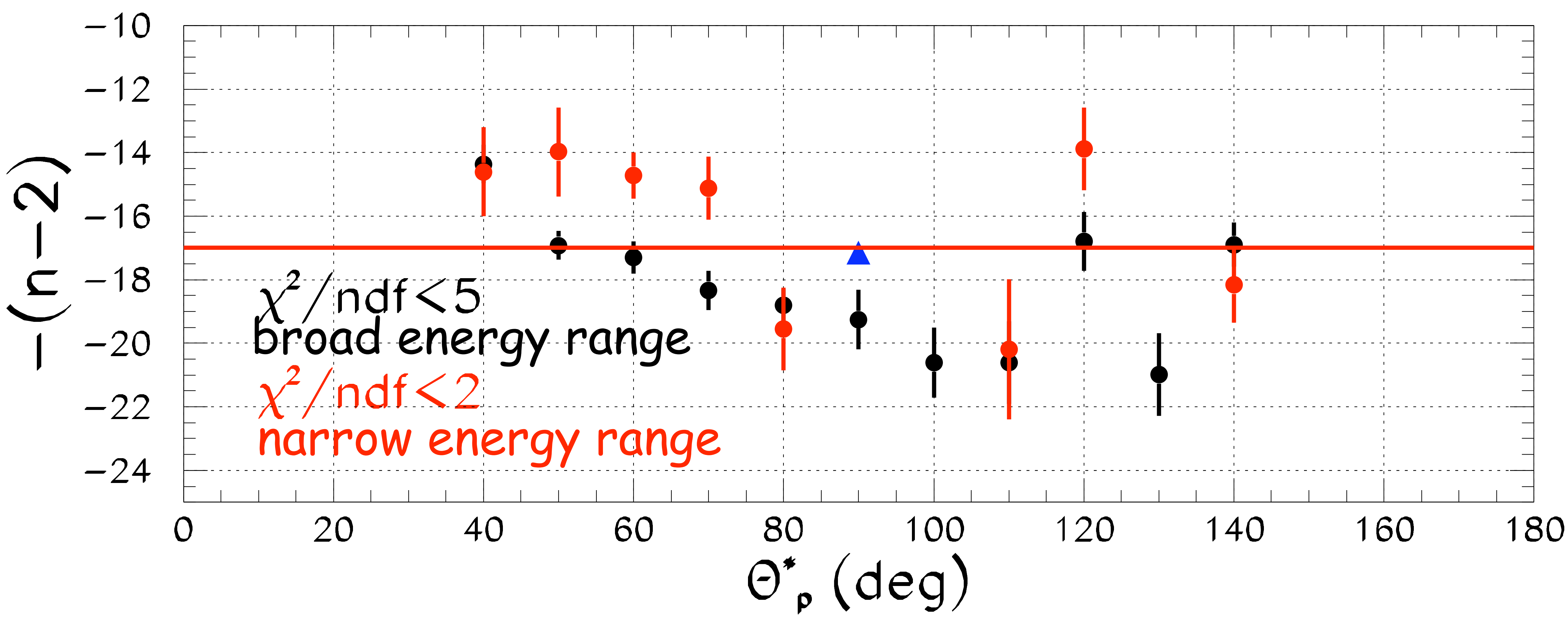
G.M. Huber et al., Phys. Rev. C **78**, 045203 (2008)



Two-Body Photodisintegration of ^{3}He

Can we make quantitative statements at other angles?



- Difficulty: lack of good statistics data in the higher-energy end
- χ^2/ ndf may not be a reliable criterion to conclude about scaling
- With limited energy coverage, a minimum length of fitted energy range may be needed.
- Using only CLAS data, it is difficult to make conclusive statements.

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