# New Results on Hard Photodisintegration of Light Nuclei

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for the CLAS Collaboration

- Introduction
- Two-body photodisintegration of $^3He$
- Conclusion

The Gordon Research Conference on Photonuclear Reactions
Holderness School, NH
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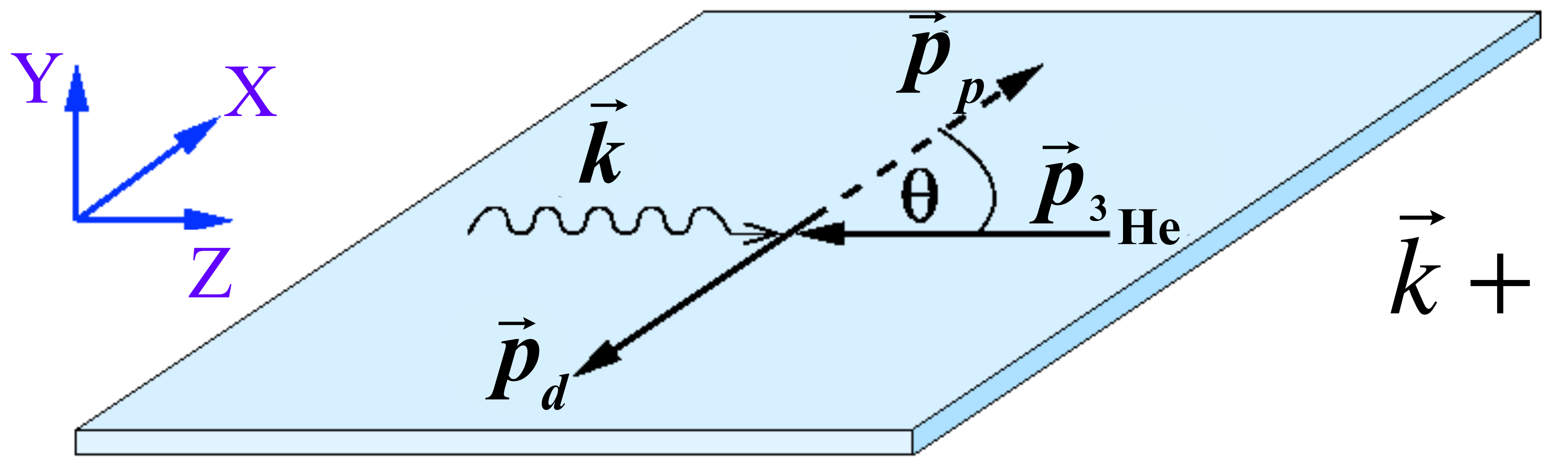
# Kinematics of $\gamma\,^3\text{He} \rightarrow pd$

Center-of-Mass Reference Frame (CM):




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

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

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

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

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

# Why Hard Scattering?

- Useful tool to explore strong dynamics at intermediate energies (> 1 GeV).

- Allows separation of scales: elementary mechanism is calculable while soft hadron structure is factored out (factorization).

Requires phenomenological input.

# Why photodisintegration of $^3$He?

- Real photon: $Q^2=0$. Factorization not proved.
- Hard scale is given by the overall momentum transfer in the reaction (size of interaction volume).
- Promising test of dimensional scaling in $A=3$ nucleon system: onset of partonic dynamics in nuclei.

# Dimensional Scaling Laws in Nuclear Physics

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

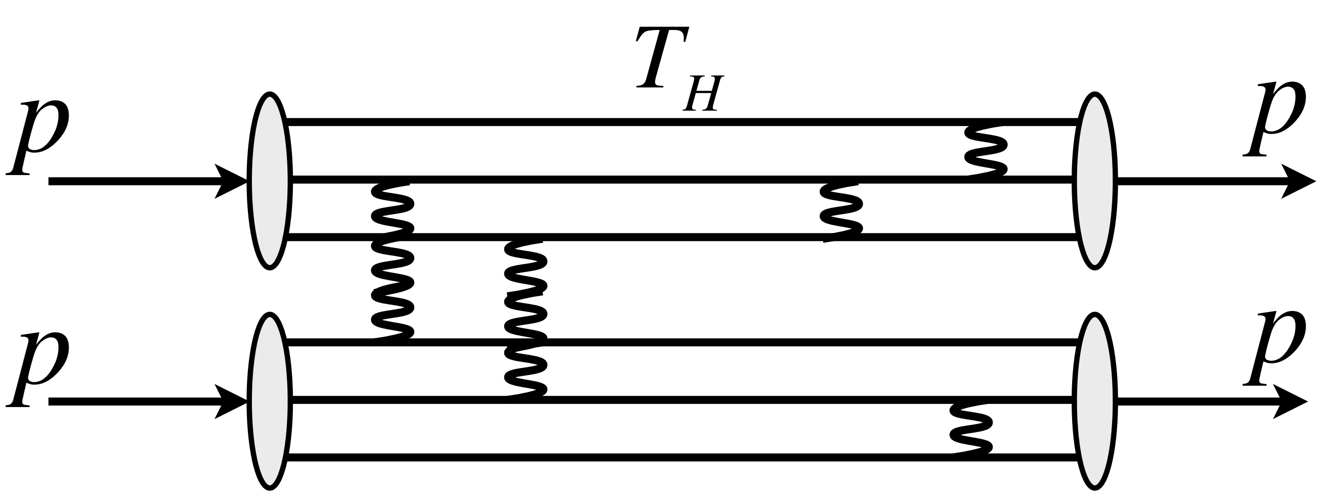
- At high t and high s, power-law behavior of the invariant cross section of an exclusive process A + B $\rightarrow$ C + D at fixed CM angle:

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

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

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




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

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

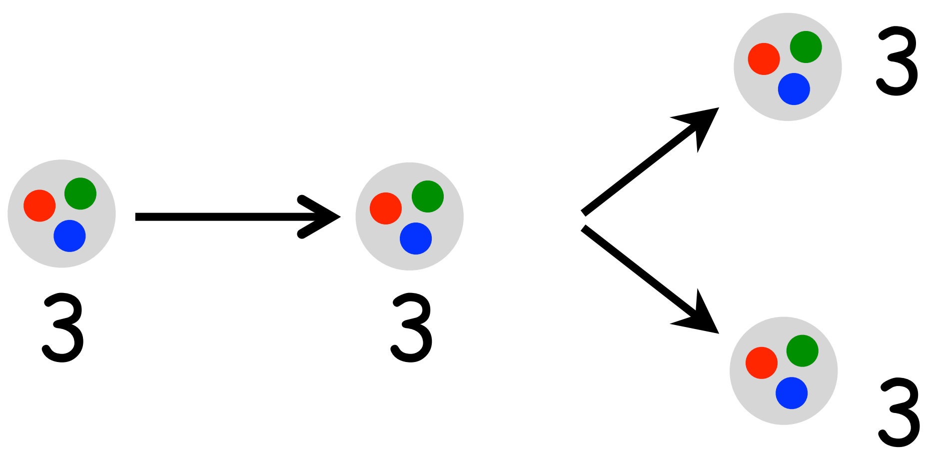
$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}}$$



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

$$pp \to pp$$




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

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

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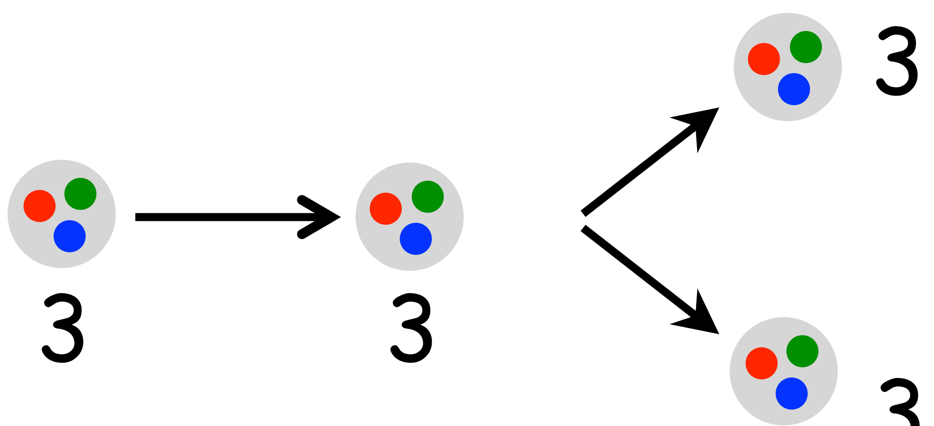


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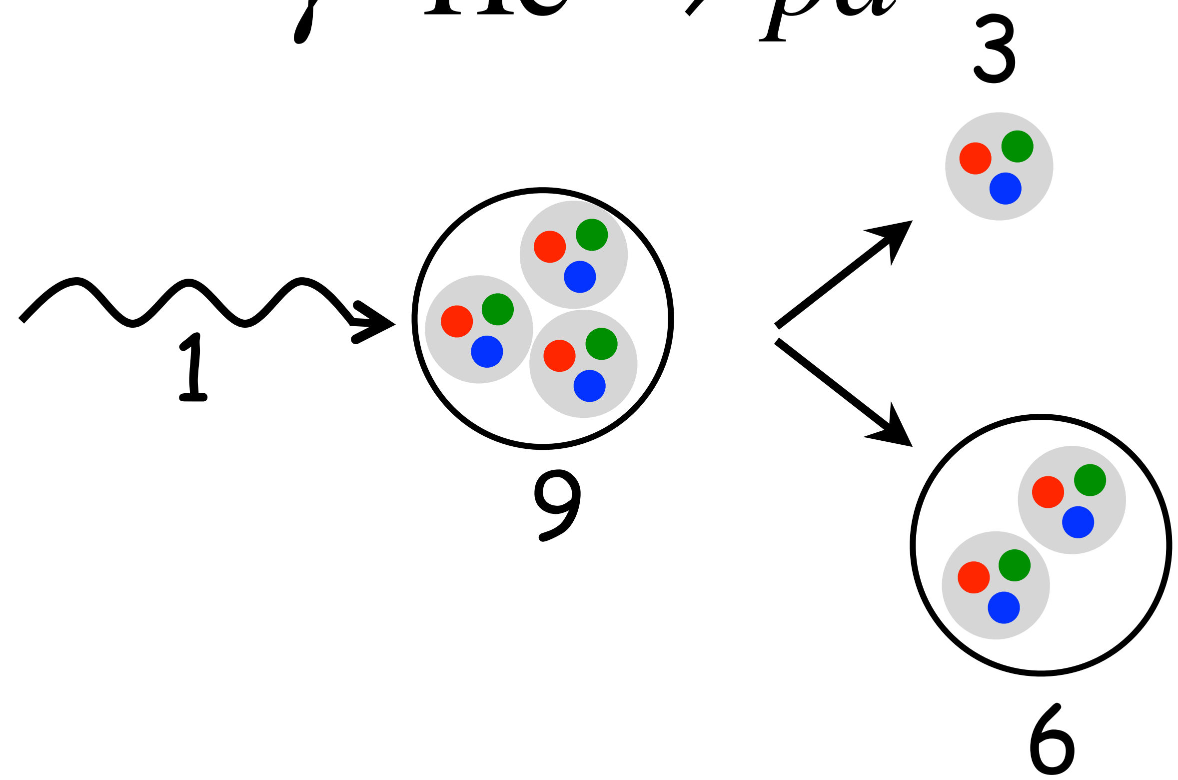
$$\gamma\,{}^3\mathrm{He}\rightarrow pd$$



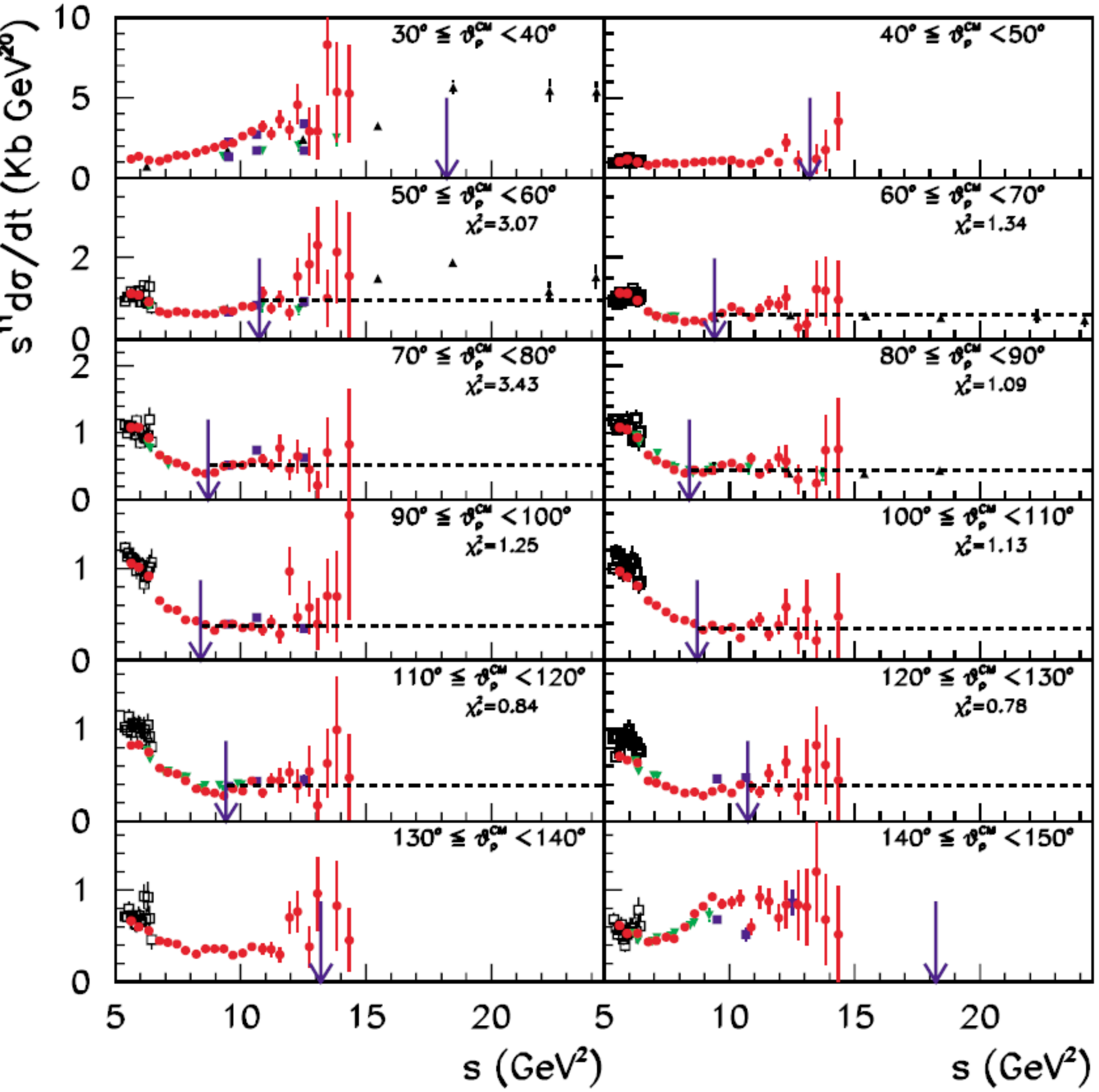

$$n-2=(1+9+3+6)-2=17$$

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

# Extensive Studies of Two-Nucleon Systems

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

$\gamma d \rightarrow pn$




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

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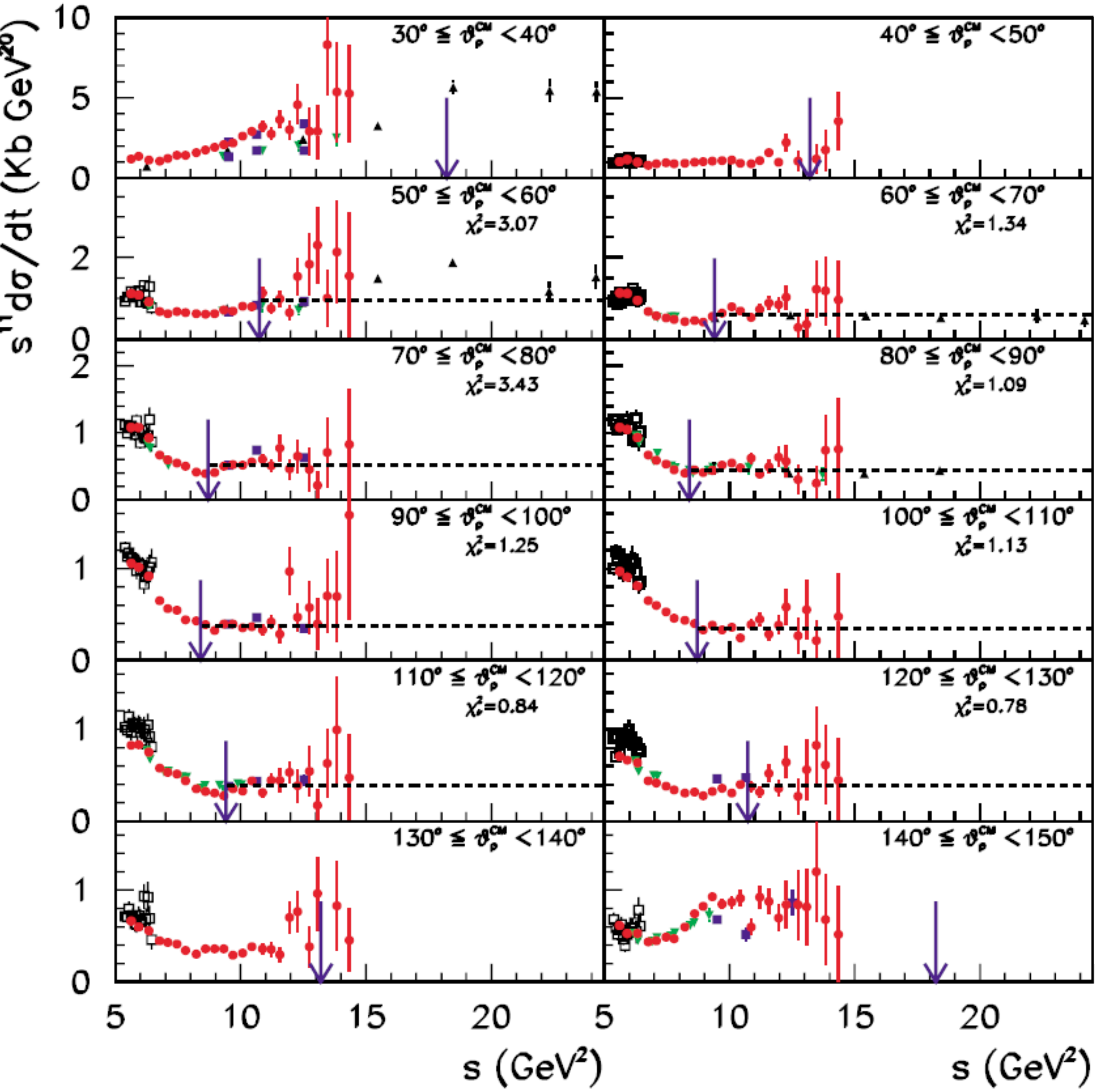
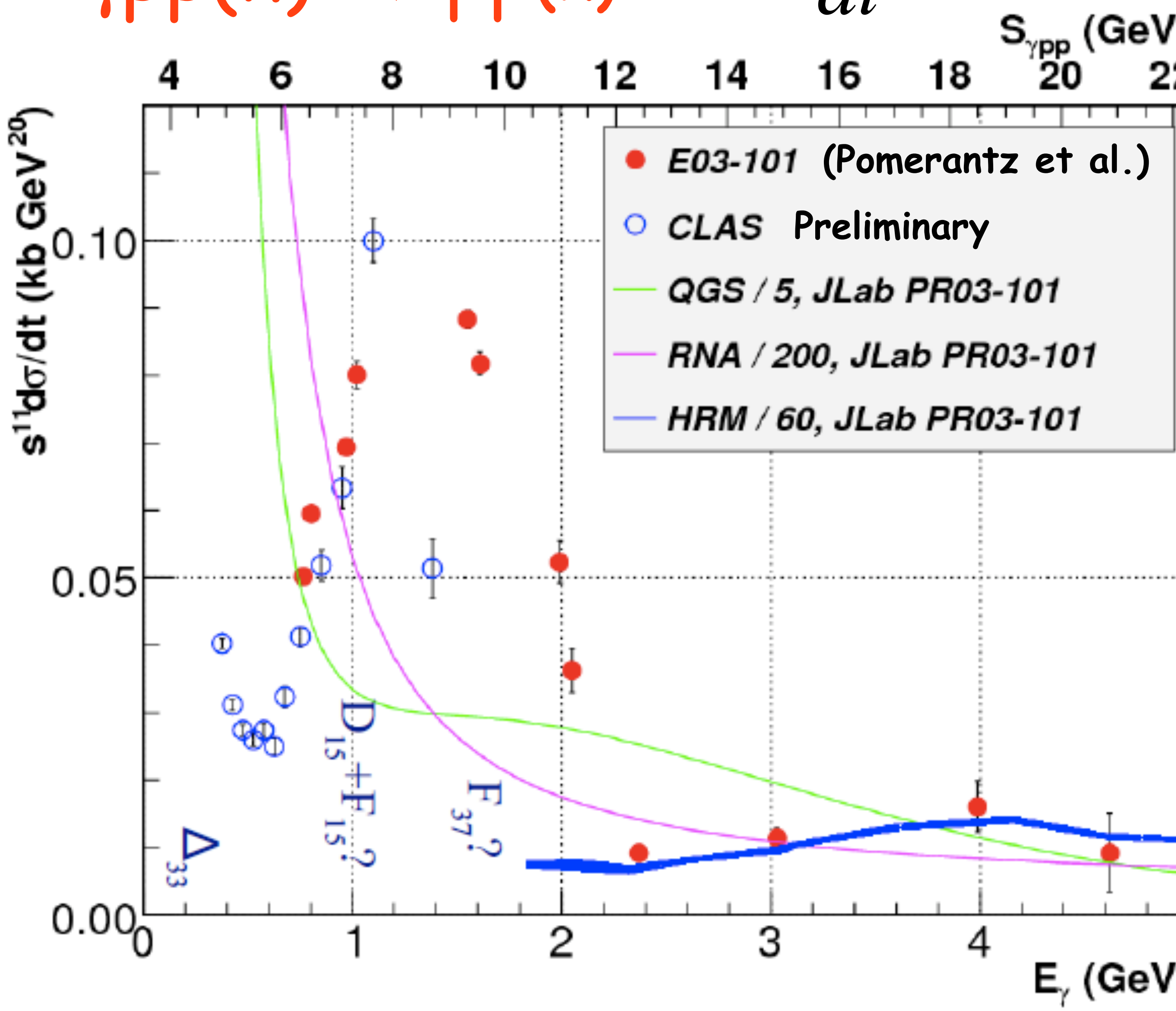



P. Rossi et al., Phys. Rev. Lett. **94**, 012301 (2005)

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




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

# 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?**

# What is the dynamical origin of dimensional scaling?

## 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

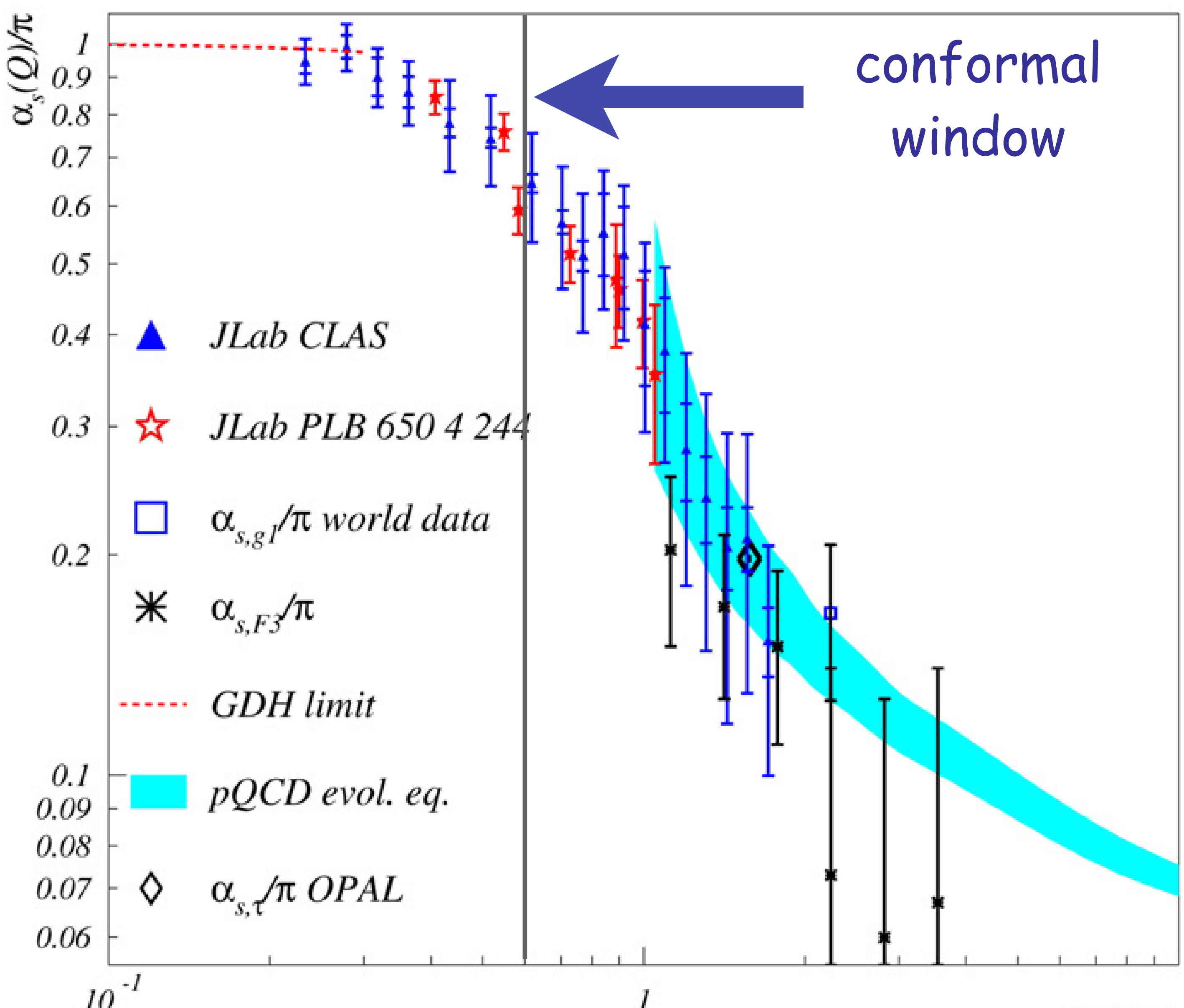
- Allows to treat confinement at large distances and conformal symmetry at short distances

- 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 $\alpha_s$ (asymptotic freedom)
- At large distances, dimensional scaling laws reflect the existence of infrared fixed point of QCD: $\alpha_s$ 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)

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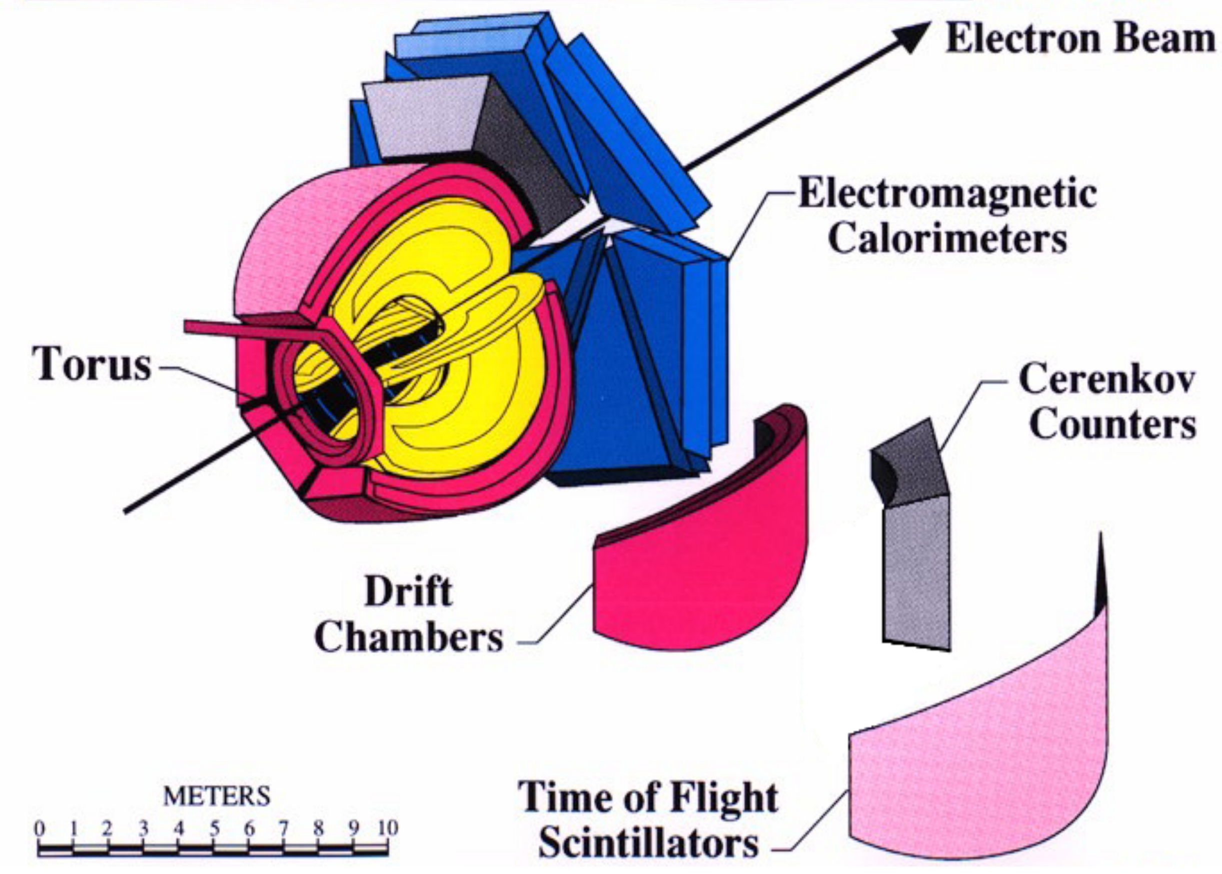
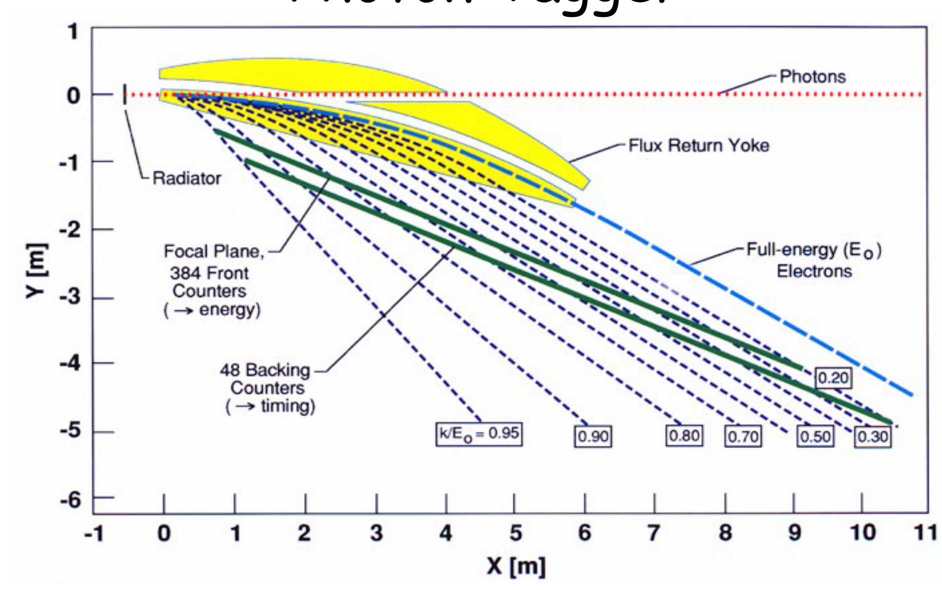
- We need to look at reactions in which the momentum transfer is shared among many constituents.
- We need to look for reactions that are not dominated by resonance excitation at low energies.
- The nucleus is an ideal laboratory.

# Photodisintegration of $^3He$ with the CEBAF Large Acceptance Spectrometer CLAS

- Data collected in JLab E93-004
- Both final state particles detected.
- Clean sample using the constraints. of two-body kinematics.
- Differential cross sections determined at $E_\gamma$=0.4 - 1.4 GeV, $\theta_{p,c.m.}$=30° - 140°.

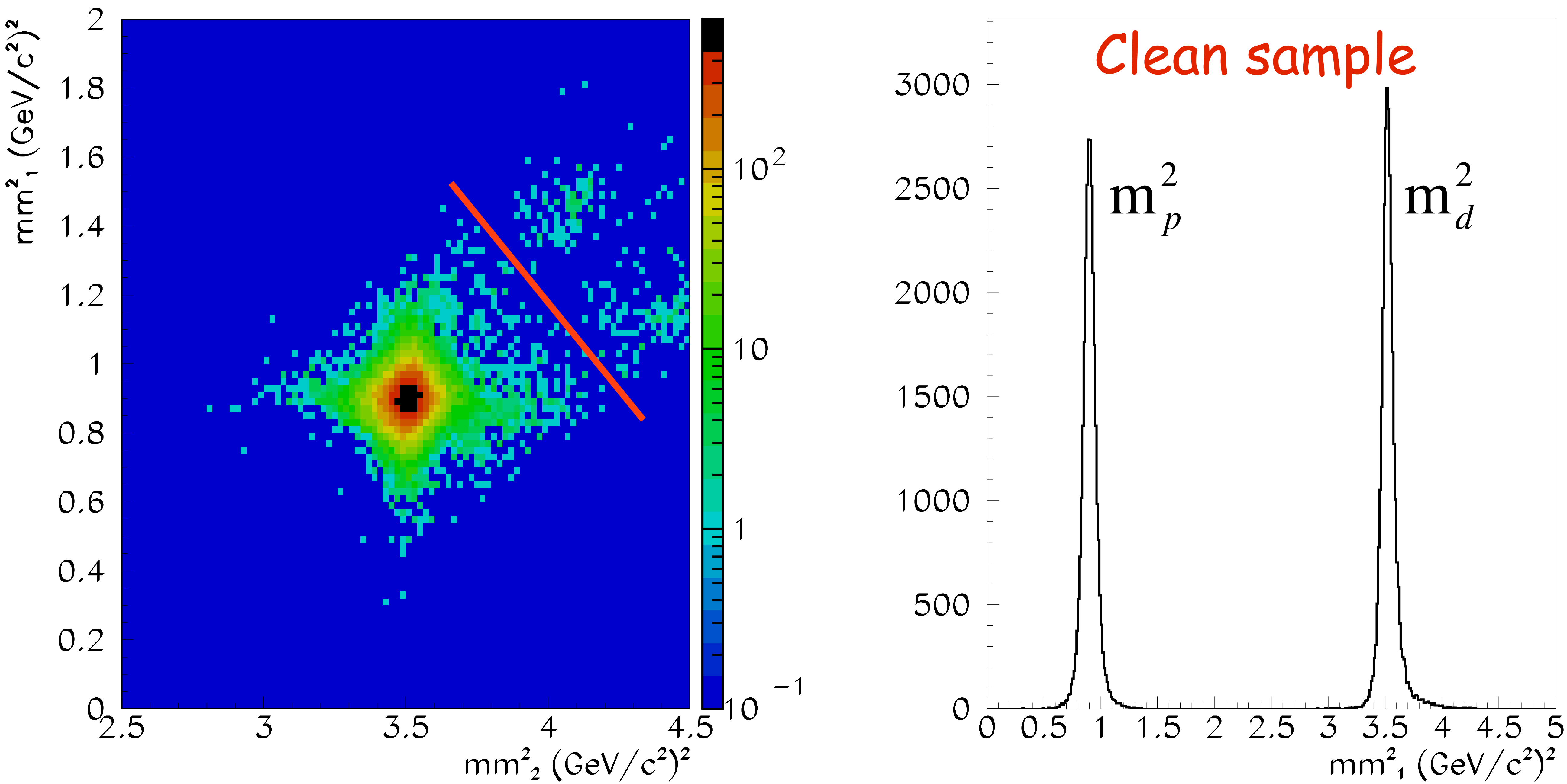



Photon Tagger

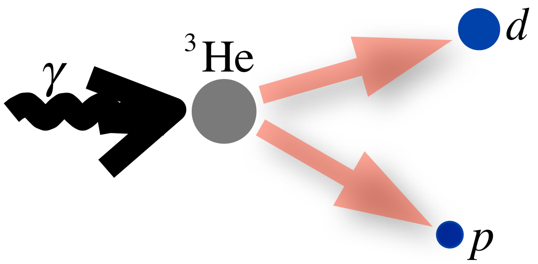


# Two-Body Photodisintegration of $^3$He at CLAS

Kinematic cuts applied for reaction identification

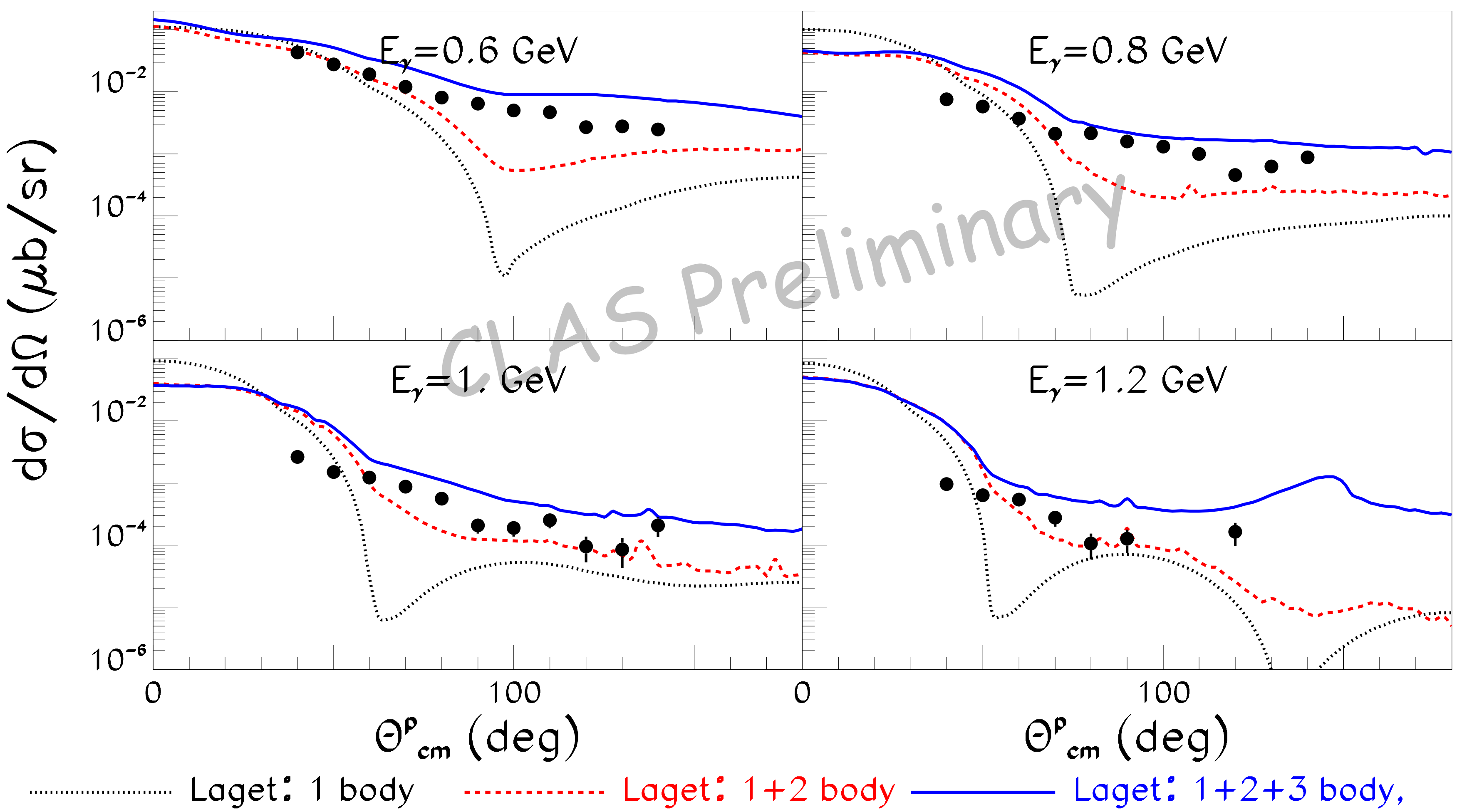



$$\mathrm{mm}_i^2 = (\tilde{P}_\gamma + \tilde{P}_{3\mathrm{He}} - \tilde{P}_i)^2$$



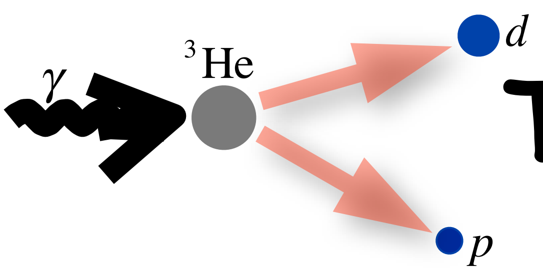

# Two-Body Photodisintegration of $^3$He $E_\gamma$ = (0.4 - 1.4) GeV

## Advantages for Study of Dimensional Scaling



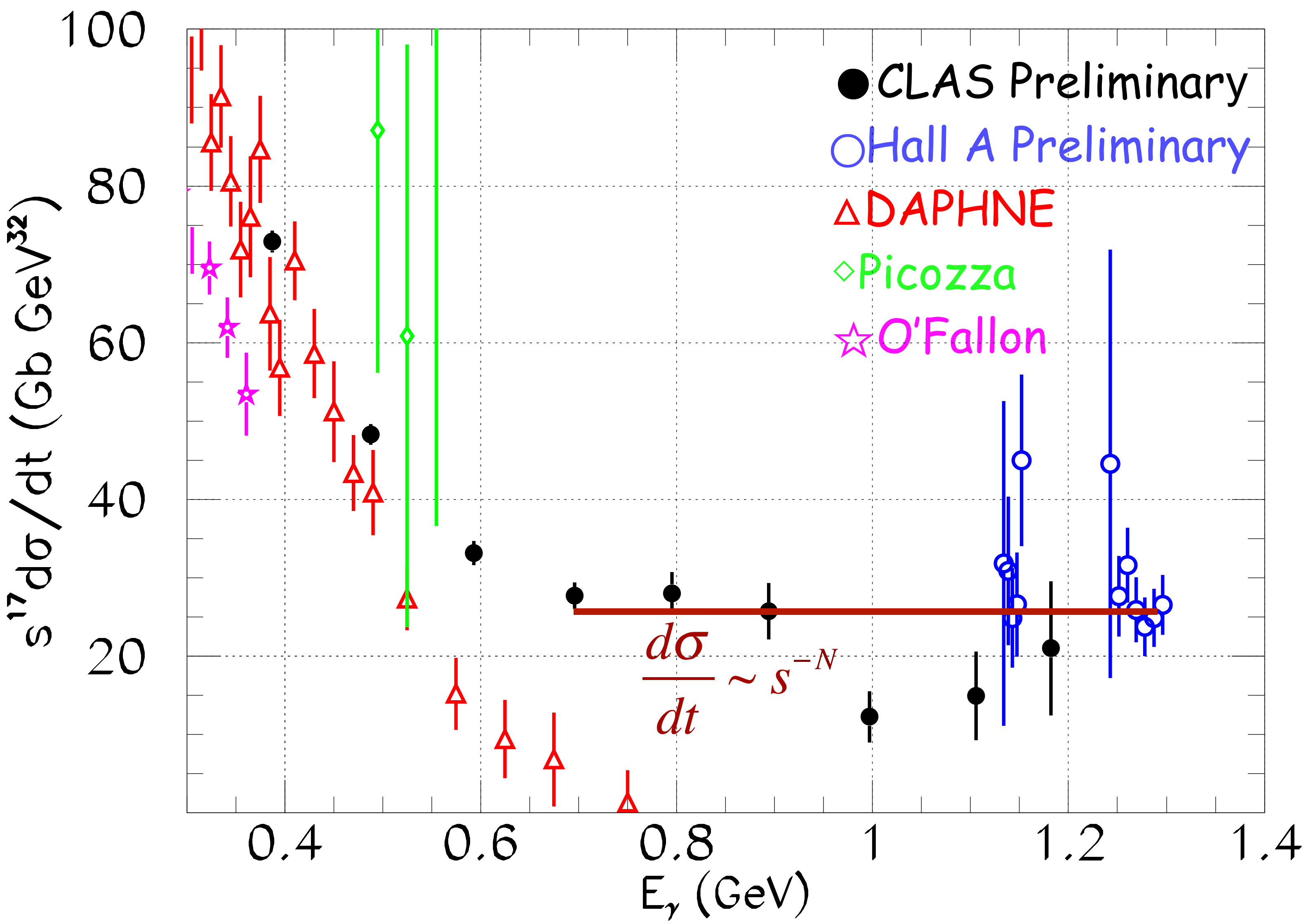

- Significant contribution of three-body mechanisms, especially at 0.6-0.8 GeV
- Resonance contribution to the cross section is suppressed.

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




# Two-Body Photodisintegration of $^3$He

Scaling of invariant cross sections at 90°




- Extracted value from fits to JLab data:

  N = 17 ± 1

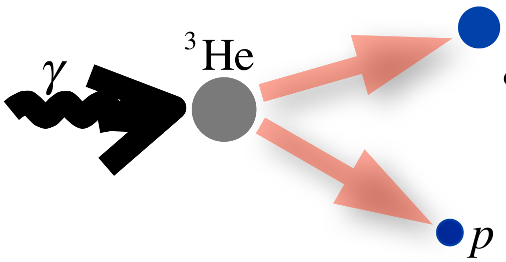
- $|t|_{thr}$ and $p_{\perp thr}$ are too low to support hard scattering hypothesis:

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

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

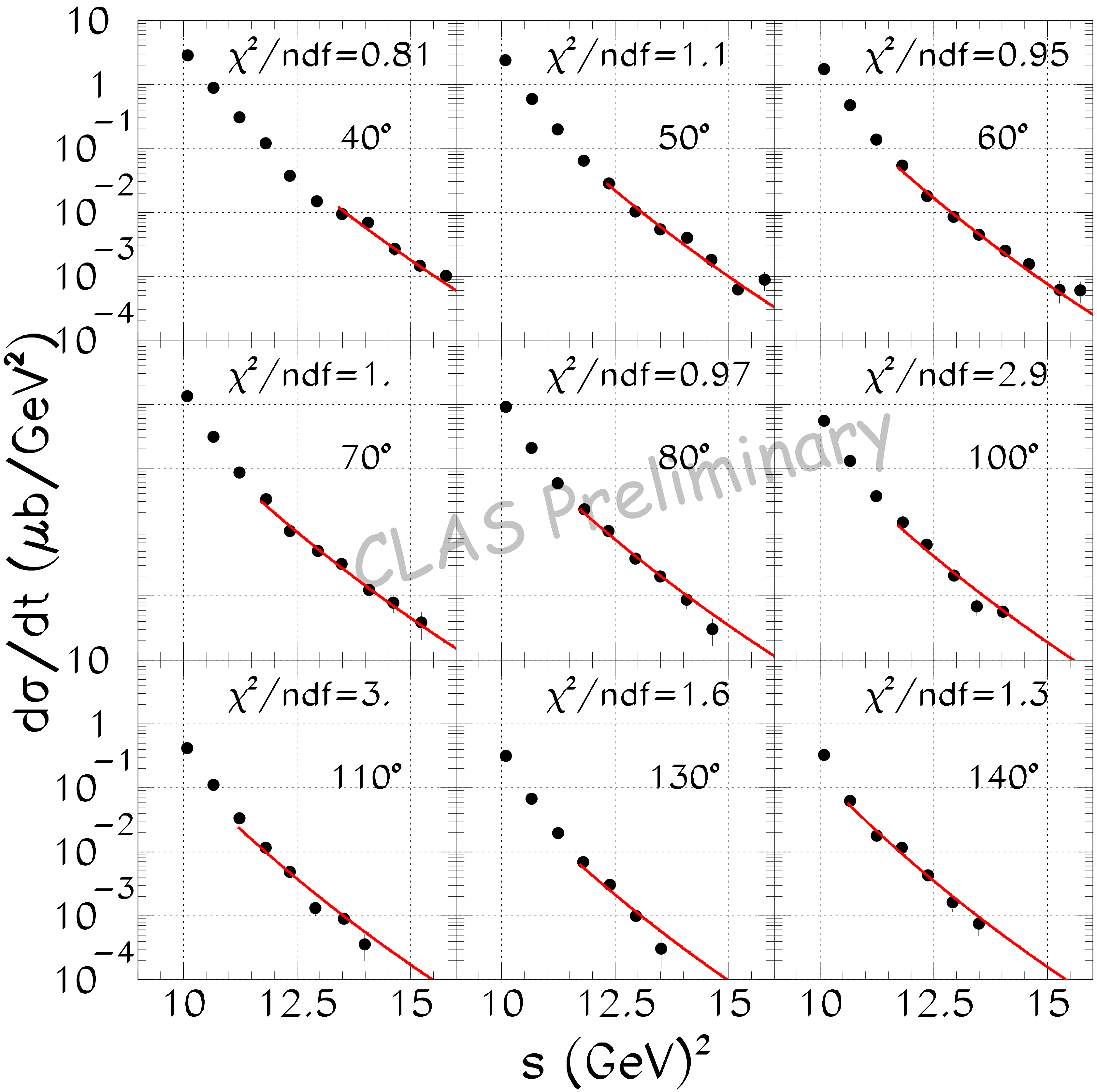
Data fitted by: $$\frac{d\sigma}{dt} = As^{-N}$$

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




# Two-Body Photodisintegration of $^3$He

## Invariant cross sections at other kinematics



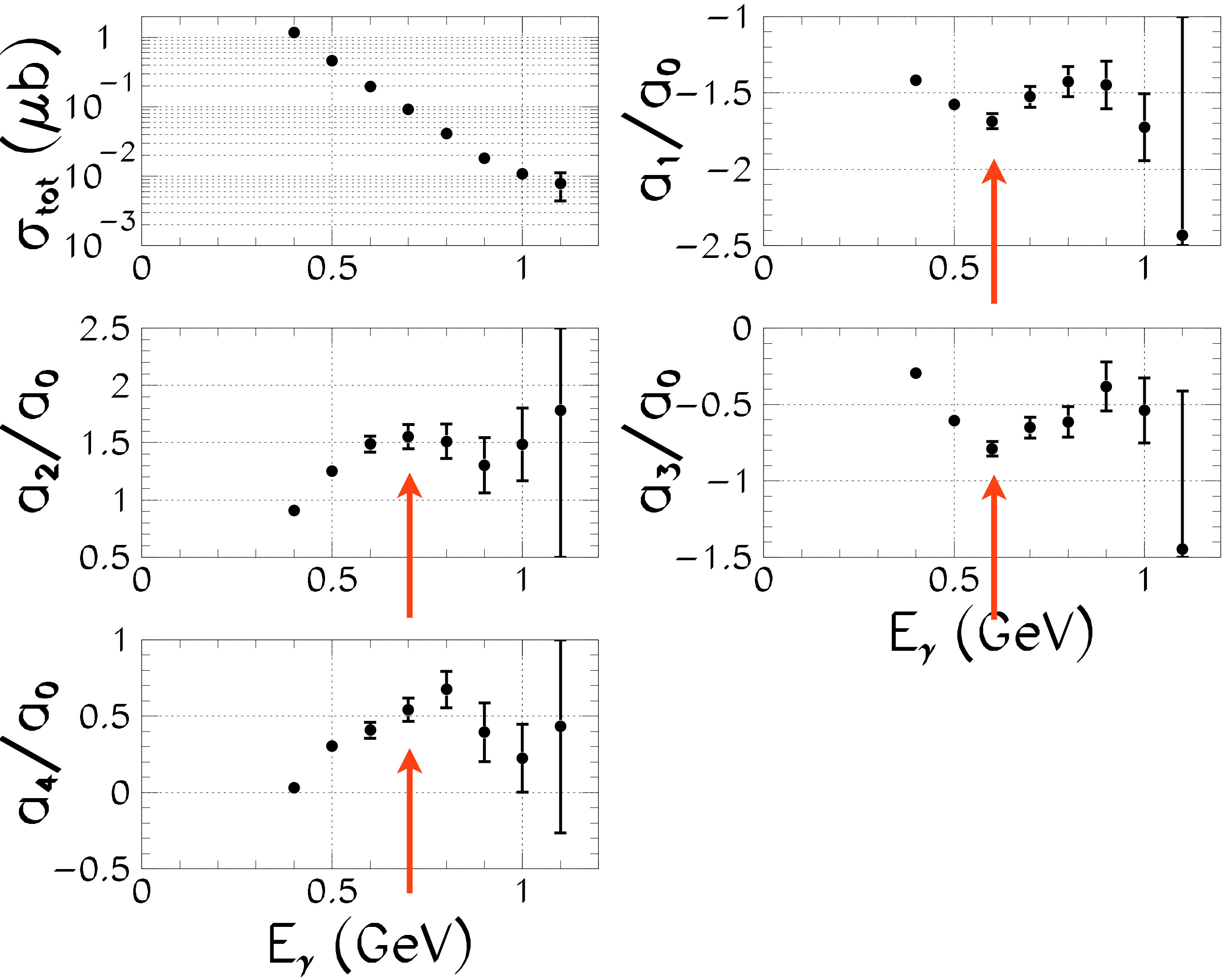

Fitted by: $\frac{d\sigma}{dt} = As^{-17}$

**General trend**

- Above $E_\gamma$~0.7 GeV data consistent with scale invariance for most CM angles
- Fit quality deteriorates when scaling power is changed by ±3σ

# Why does it happen?

Qualitatively: complexity of reaction dynamics via 4th order Legendre polynomial fits to differential cross sections

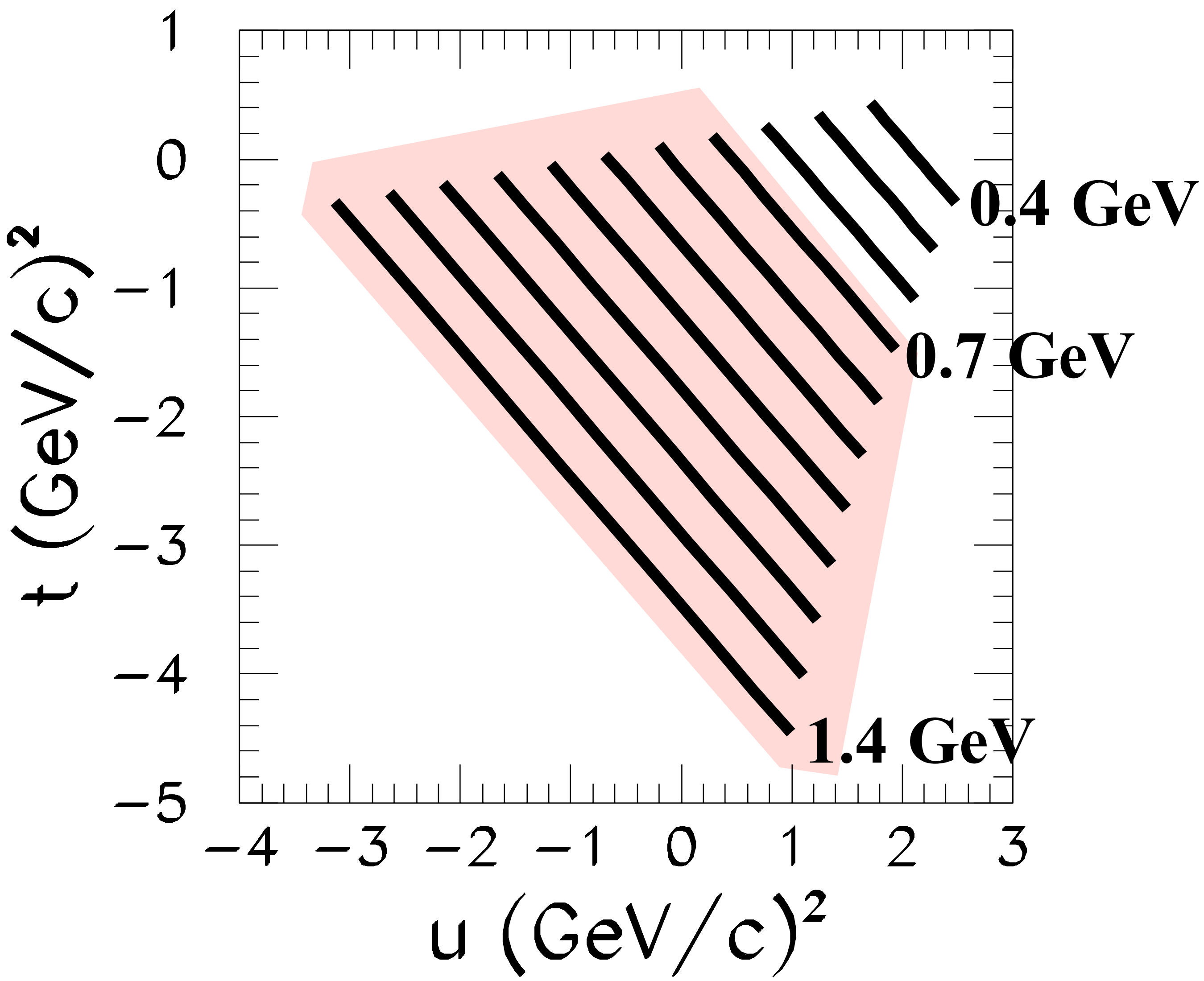



**General trend**

- Change in dynamics at $E_\gamma \sim 0.7$ GeV

# Why does it happen?

A closer look at kinematics



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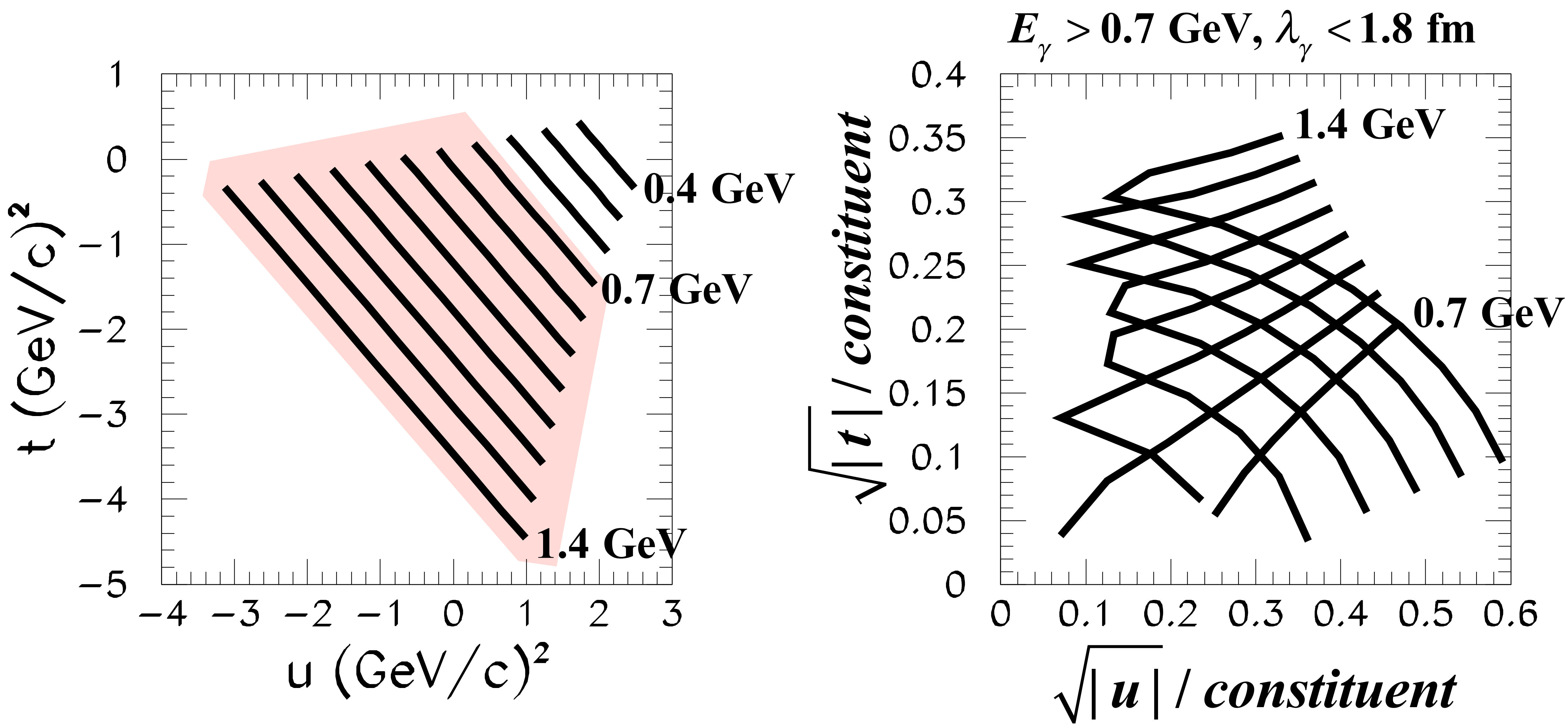

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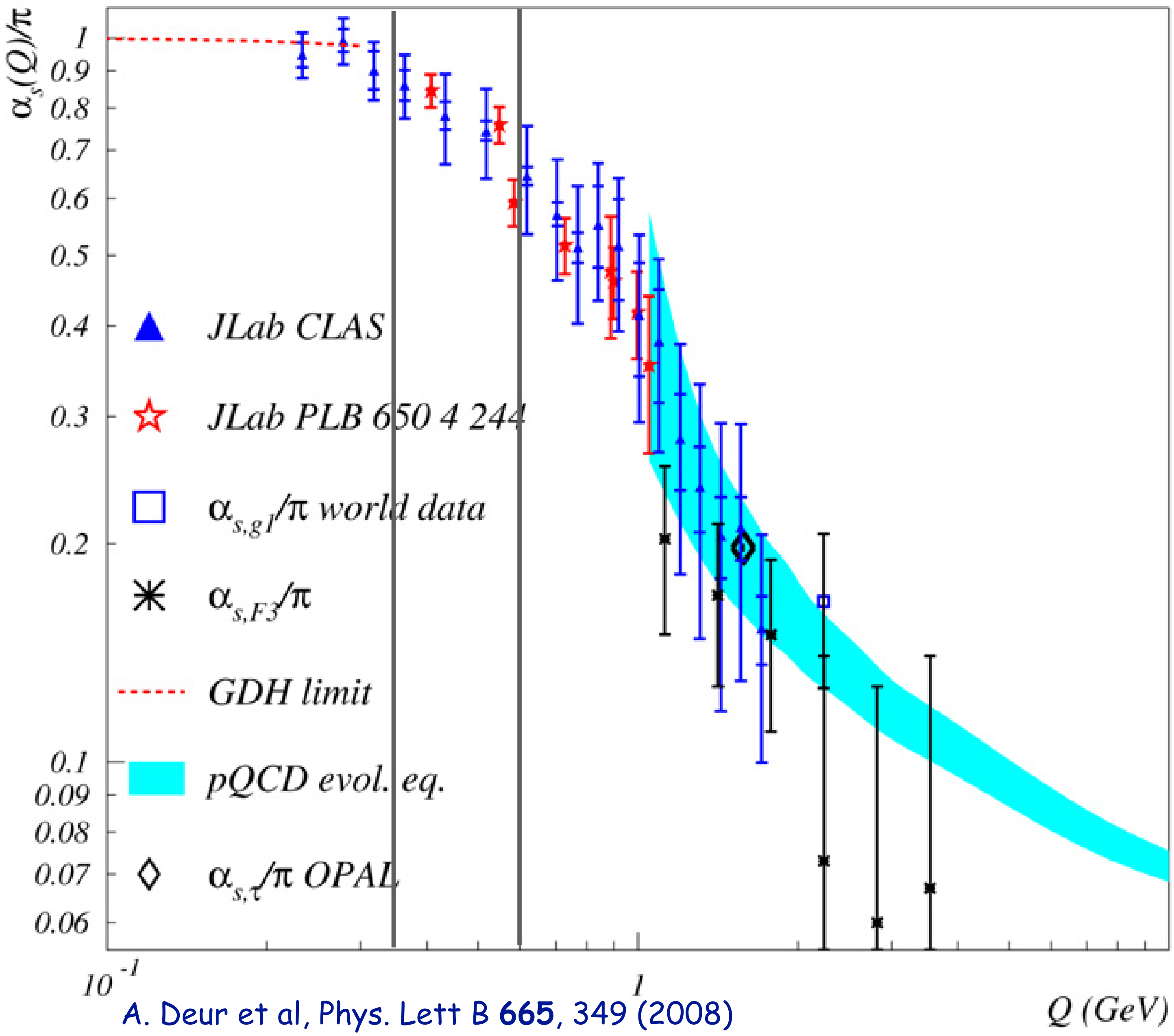


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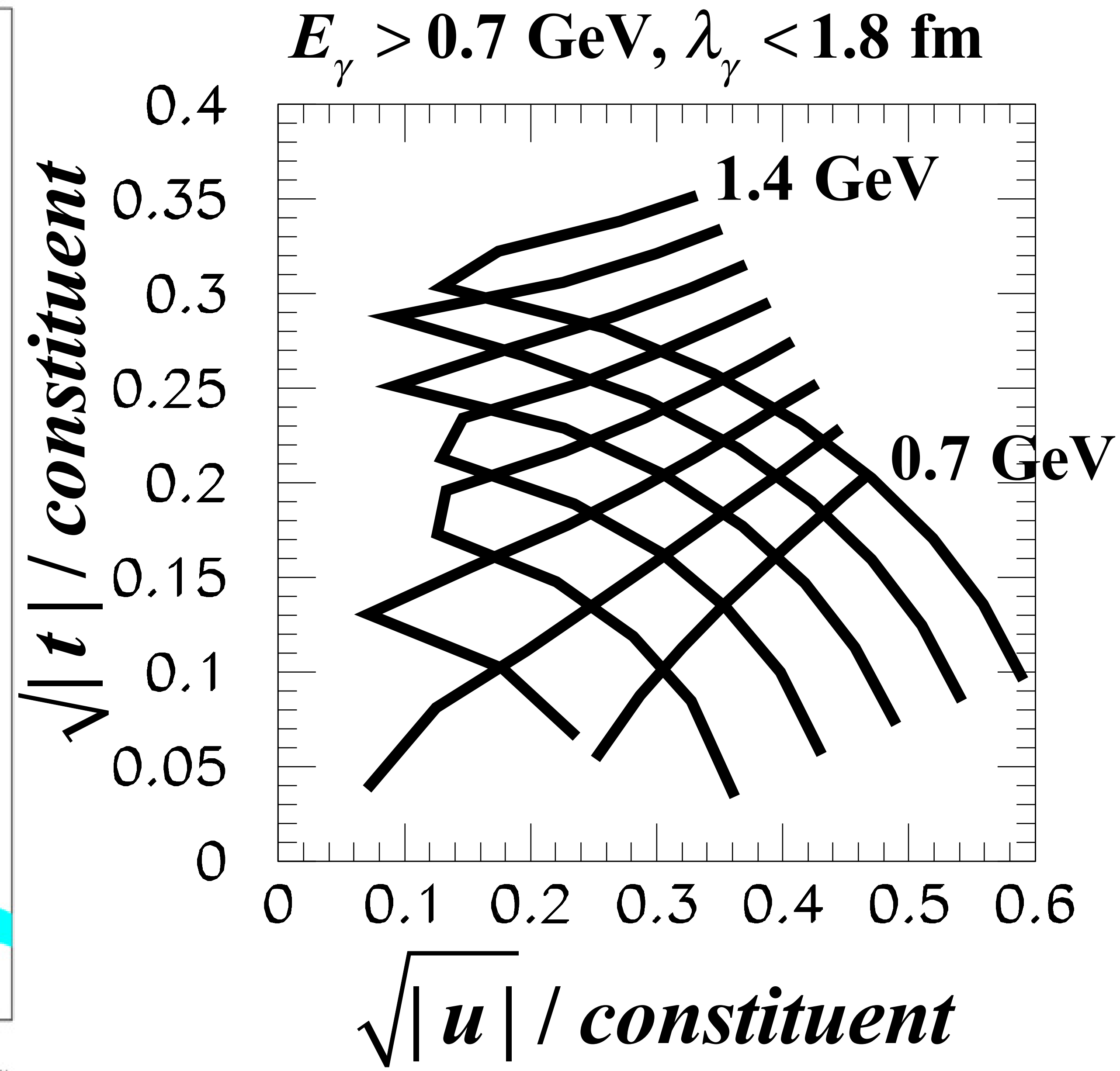

# Conclusion

- Our result suggests exclusive processes with A=3 nucleus may be more advantageous for experimental study of onset of dimensional scaling.
- Novelty: supports qualitatively the non-perturbative interpretation of scaling.
- Significance: indicates the quark-gluon picture is relevant for nuclei even at energies below 1 GeV.

**The END**