

π^0 PHOTOPRODUCTION & LIGHT MESON DECAYS FROM PHOTON-INDUCED REACTIONS WITH CLAS

18 June 2015 | Reaction Theory Summer Workshop | Michael C. Kunkel | IKP-1 |
on behalf of the CLAS Collaboration and LMD group

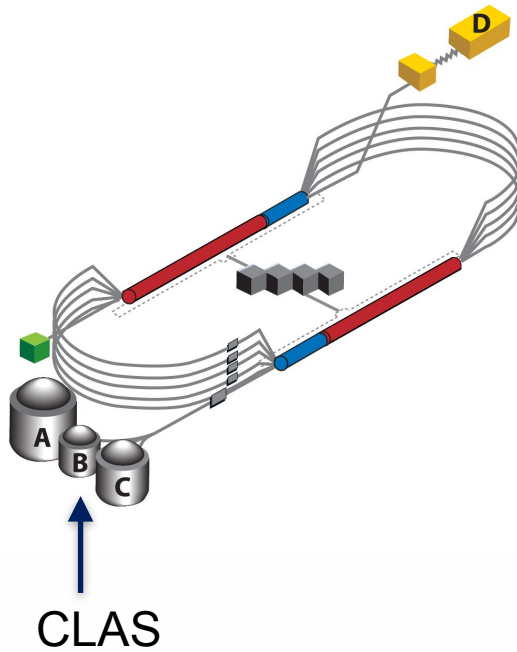
Motivation

- Provide insight into the mechanisms, baryon resonances and productions channels involved in π^0 production
 - For incident beam energies already explored previously as well as for incident beam energies in which there exists only a sparse and in some cases no amount of data

Goal

- Provide precise measurements of the π^0 cross-section
 - Compare to existing data
 - Compare to existing model

Thomas Jefferson National Laboratory

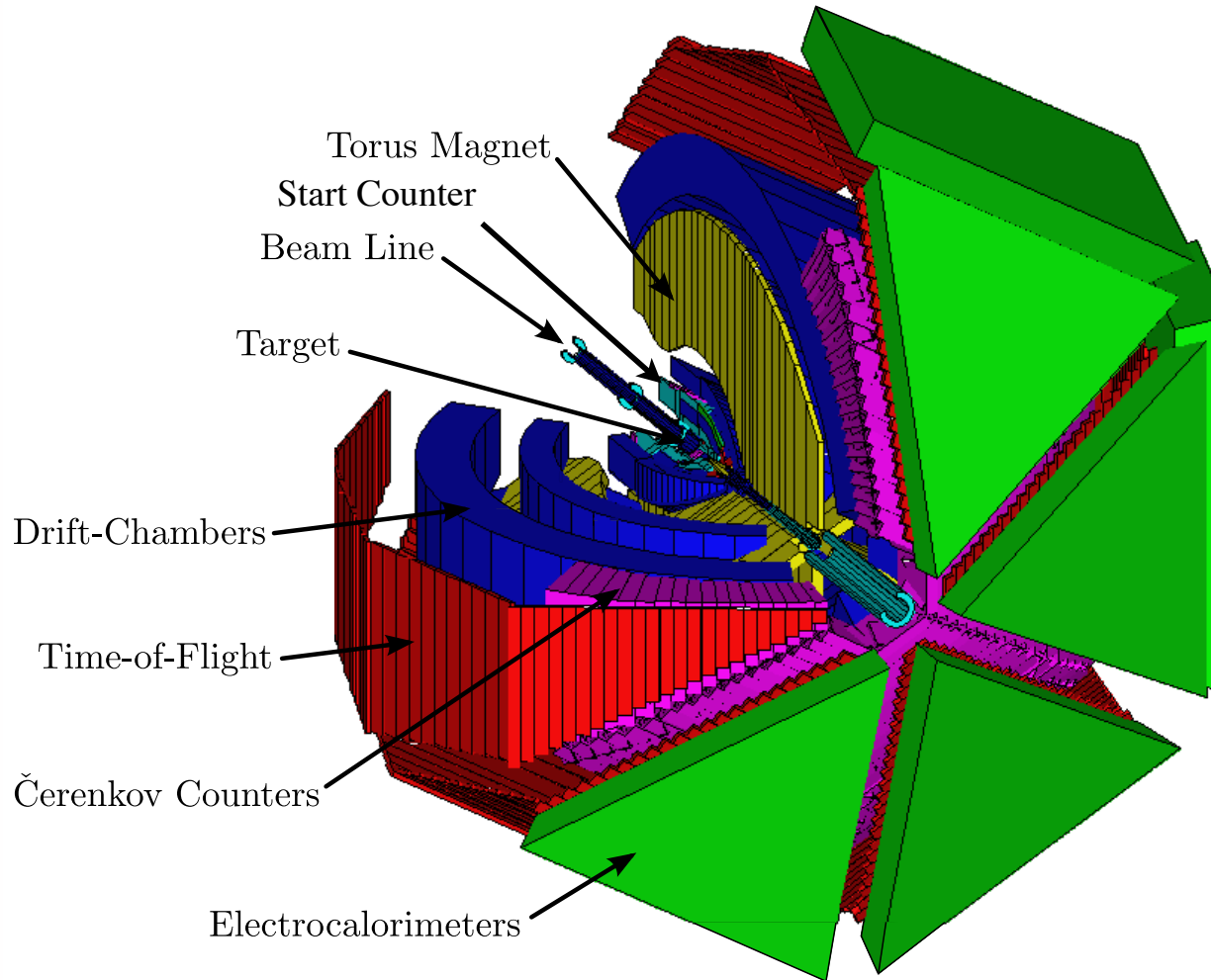


Continuous Electron Beam Accelerator Facility (CEBAF) at 12 GeV



Aerial View

CEBAF Large Acceptance Spectrometer (CLAS)



Primary modes of π^0 Decay

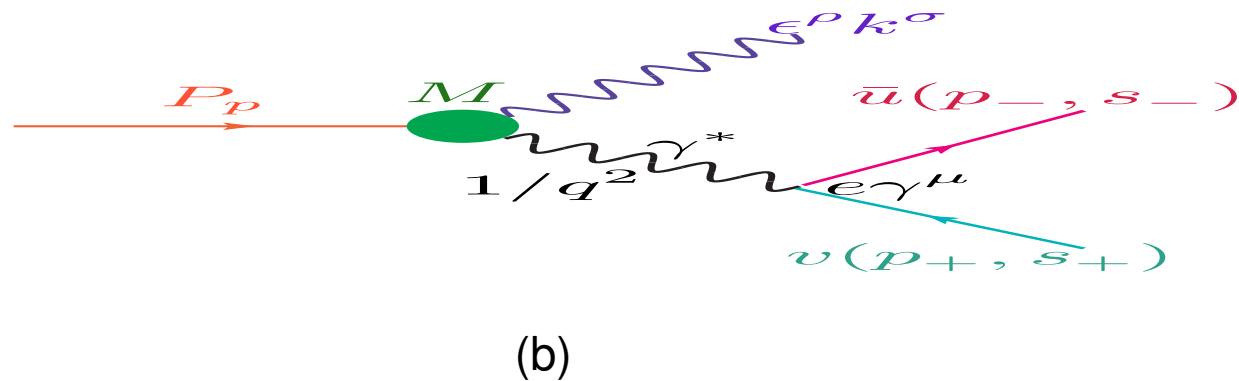
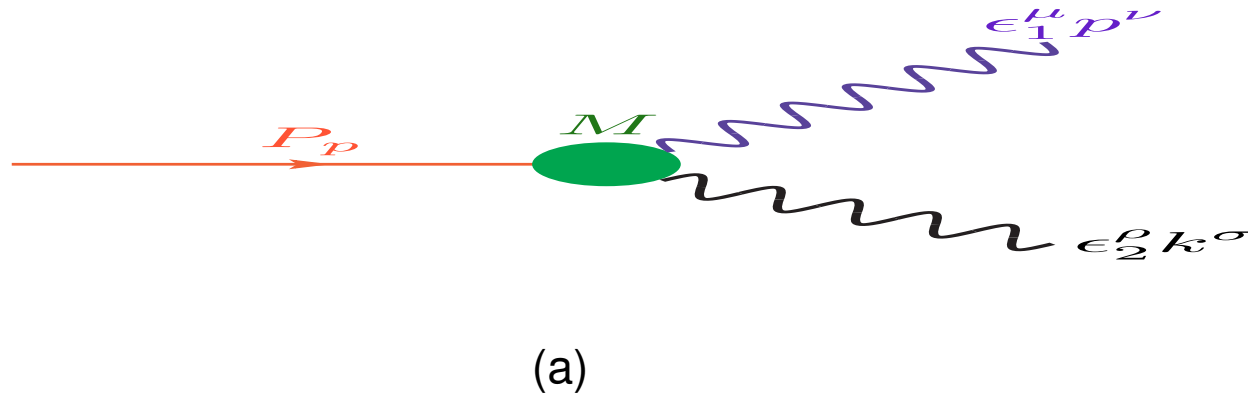


Figure : Feynman diagram of π^0 two photon decay (a). Feynman diagram of π^0 Dalitz decay (b).

External/Internal Conversion

- The π^0 decays to 2 photons $98.823 \pm 0.034\%$
 - Each photon has equal probability of pair producing e^+e^- pairs
- The π^0 decays to $e^+e^- \gamma$ $1.174 \pm 0.035\%$

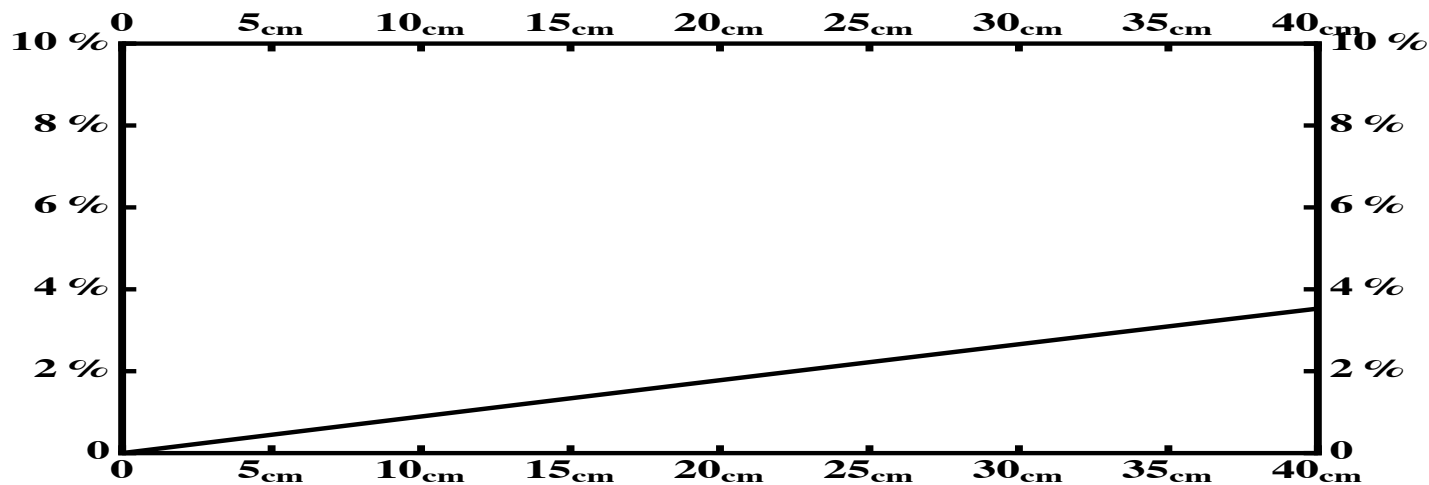


Figure : Probability of *pair production*, $\gamma \rightarrow e^+e^-$, in 40 cm of liquid hydrogen.

Photon Beam

- Bremsstrahlung photon beam
 - e^- beam of 5.7 GeV
 - gold radiator 10^{-4} radiation lengths
 - Tagged γ energies 1.1 \rightarrow 5.5 GeV
 - 6.2 mm diameter collimator 537 cm before ℓH_2 target

Target

- Liquid Hydrogen ℓH_2 Target
 - Unpolarized
 - 40 cm in length
 - 2 cm radius
 - γ beam had 1.5 cm radius exiting ℓH_2 target
 - Placed 90 cm upstream from CLAS center
 - Geometric acceptance of 6° instead of 8° in lab frame
 - Geometric acceptance of 100° instead of 140° in lab frame

e^+e^- Identification

- CC's were filled with perflourbutane C_4F_{10}
 - Index of refraction 1.0015
 - π^\pm threshold of 2.7 GeV
 - e^\pm threshold of 9 MeV
 - e^\pm detection efficiency > 97% for charged particles below 2.5 GeV.

e^+e^- Trigger

- e^\pm trigger
 - Single track
(ST*TOF)*(EC*CC)
 - L2 multiplicity of 2.
 - 2 tracks were detected in the Drift Chambers
 - Trigger bit was set to be 6 of 12

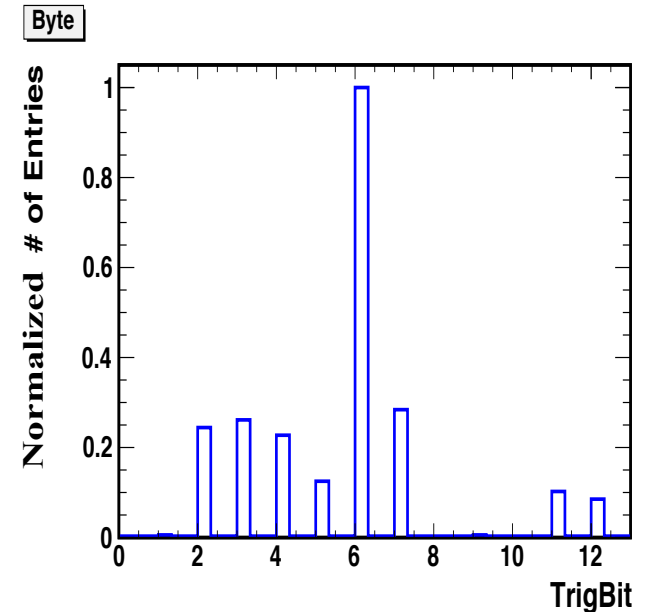


Figure : Triggers fired for leptons

Overview

- Data was taken in Hall B experiment G12
- Running Time: 04/2008 → 06/2008
- 44 Days of Beam Time
- 60 - 65 nA of current
- E_γ up to 5.5 GeV
- 126 TB Raw Data

- Raw sensitivity of 53 pb^{-1}
- 26.2×10^9 production triggers (3×10^6 di-lepton triggers)
- EC and CC combine to provide an e/π rejection factor of 10^{-6} for di-lepton pairs.
- $\frac{\Gamma_{e^+e^-\gamma}}{\Gamma_{\pi^+\pi^-\gamma}} = 0.237 \pm 0.026$

$\pi^- \pi^+$ Background

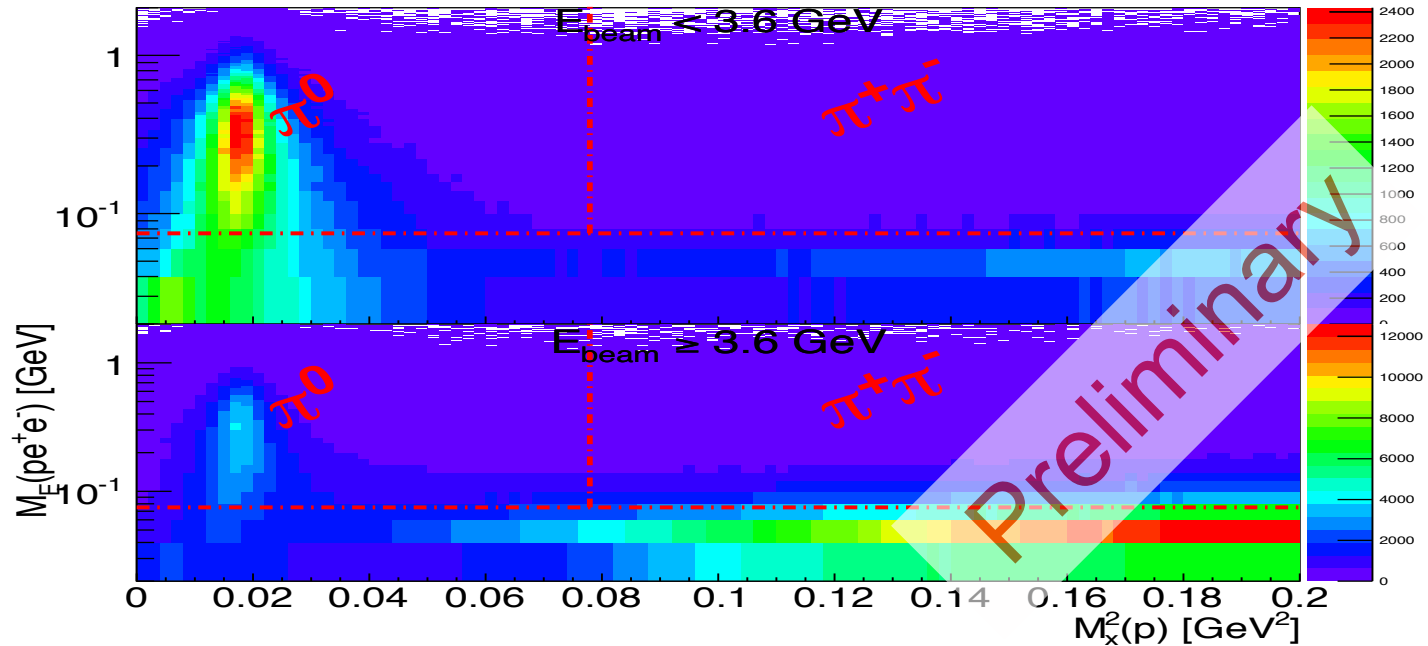


Figure : $M_x^2(p)$ vs. $M_E^2(pe^+e^-)$. The horizontal red dashed-dotted line depicts the 75 MeV cut used in this analysis. The vertical red dashed-dotted line depicts boundary of single π^0 to $\pi^+\pi^-$ production.

Final π^0 Mass Spectrum

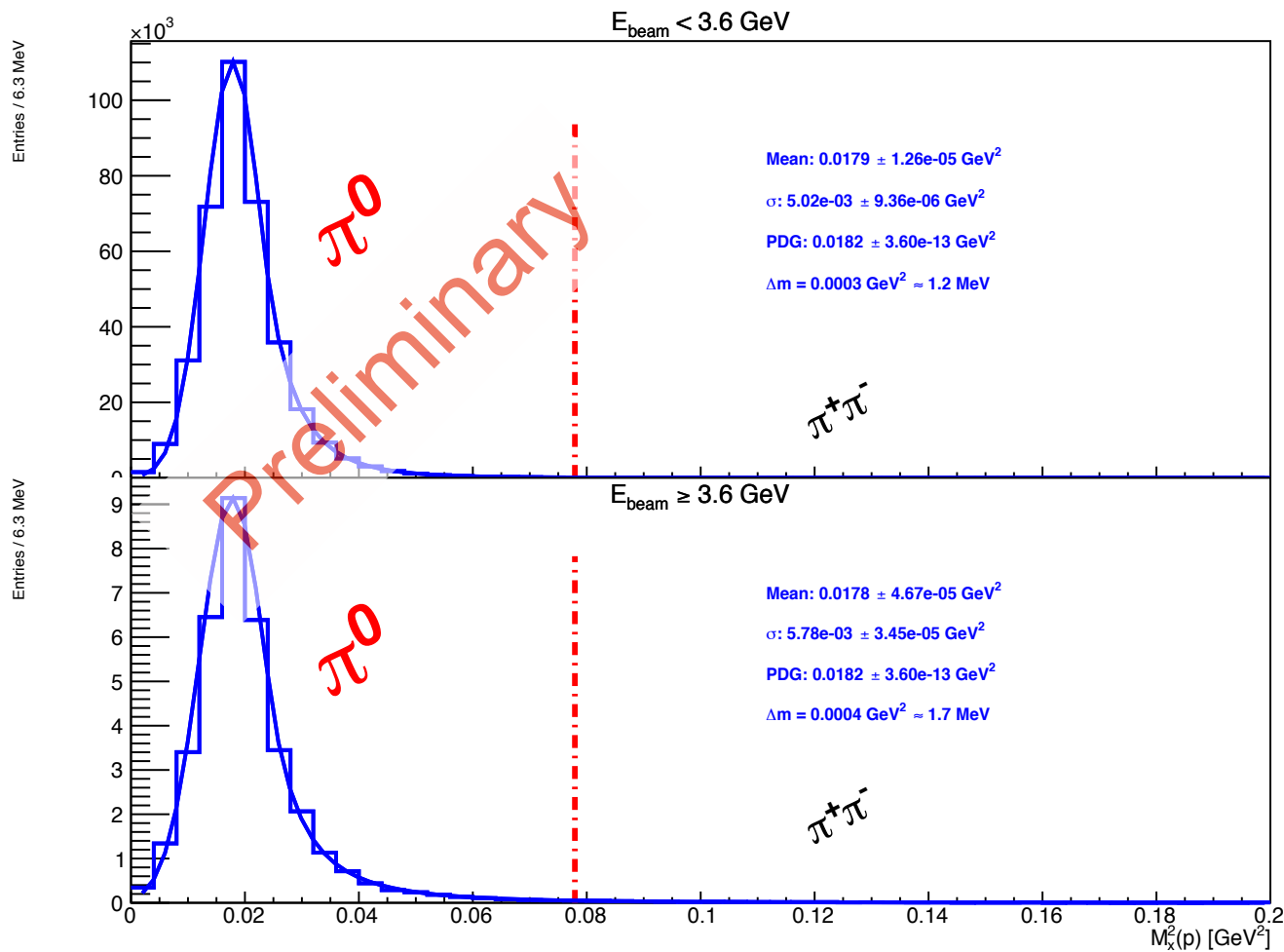


Figure : Final $M_x^2(p)$ data used in analysis.

Differential Cross-Section

- $$\frac{d\sigma}{d\Omega} = \frac{N_{\pi^0 \rightarrow e^+e^- \gamma}}{N_A} \frac{1}{\rho_t} \frac{1}{\Gamma_{\pi^0 \rightarrow e^+e^- \gamma}} \frac{1}{\Gamma_{total}} \frac{1}{\Delta\Omega}$$
- Where $N_{\pi^0 \rightarrow e^+e^- \gamma}$ is the acceptance for the c.m. angle
- $\frac{\Gamma_{\pi^0 \rightarrow e^+e^- \gamma}}{\Gamma_{total}}$ is the branching ratio of the dalitz decay
- L is flux
- ρ_t is target density = $(2. / 2.01588) \cdot 0.0717 \cdot 40. \cdot 6.022e23$
- $\Delta\Omega = 2\pi \Delta\cos\theta$

$\cos\theta$ vs. $d\theta/d\Omega / E_\gamma = 1.275\text{-}2.225$ GeV

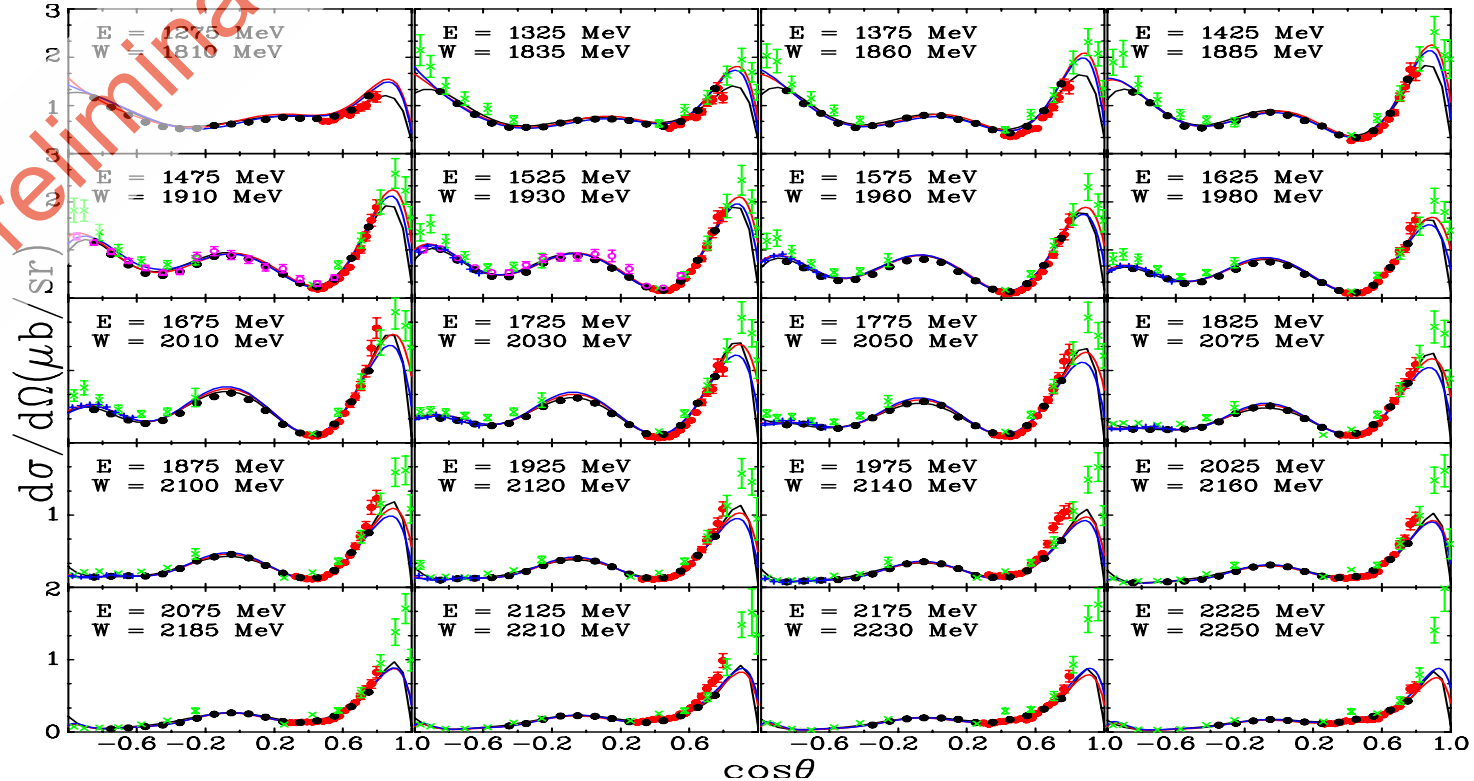


Figure : Red solid (blue solid) lines SAID KU14 (DU13) solution. Black solid lines BG2011-02 BnGa predictions. This work (red filled circles), previous CLAS (black filled circles), GRAAL (magenta open circles), LEPS (blue plus), CB-ELSA (green crosses). Previous bremsstrahlung measurements (black open circles).

$\cos\theta$ vs. $d\theta/d\Omega / E_\gamma = 2.275\text{-}3.375$ GeV

Preliminary

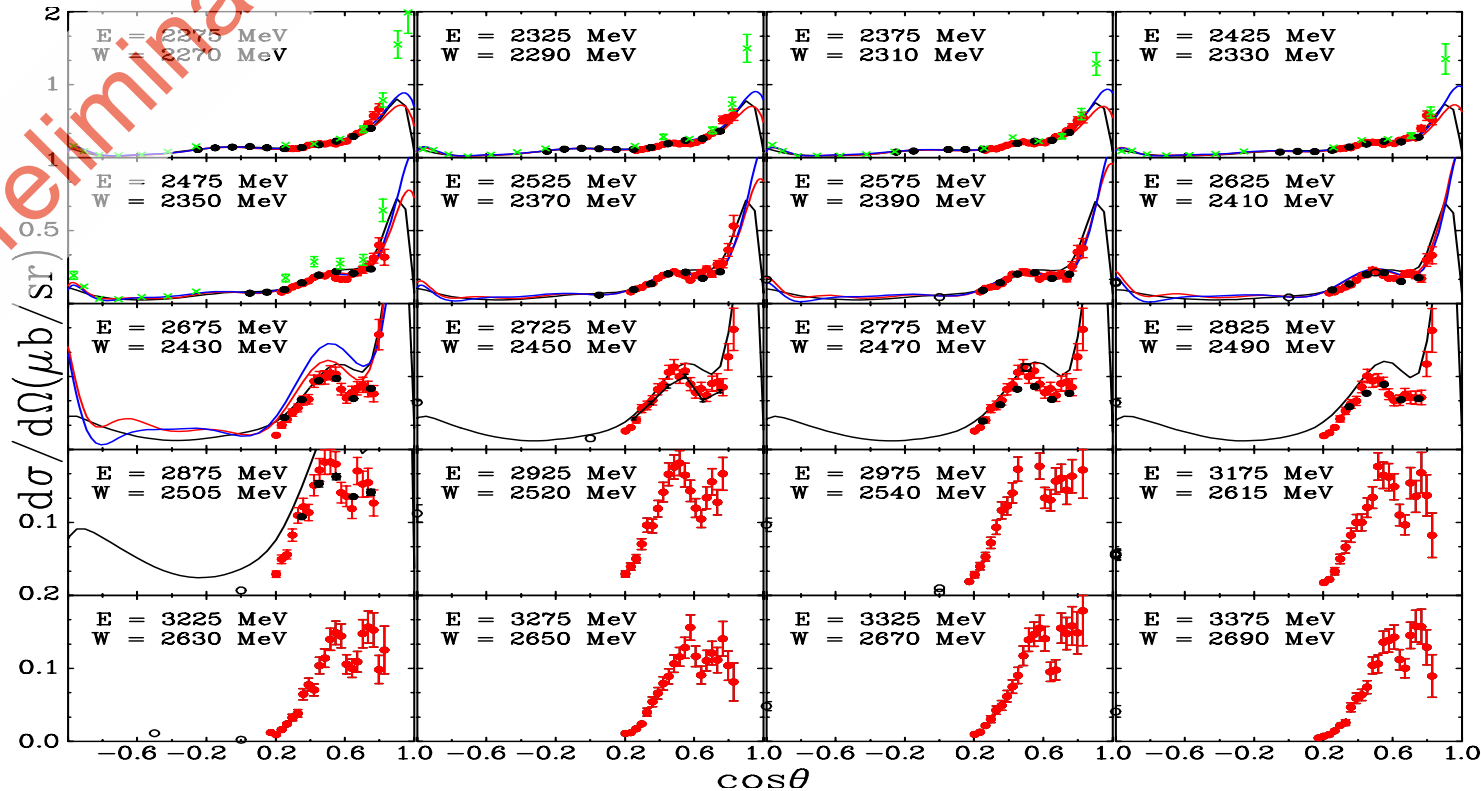


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$\cos\theta$ vs. $d\theta/d\Omega$ / $E_\gamma = 3.425\text{-}4.425$ GeV

Preliminary

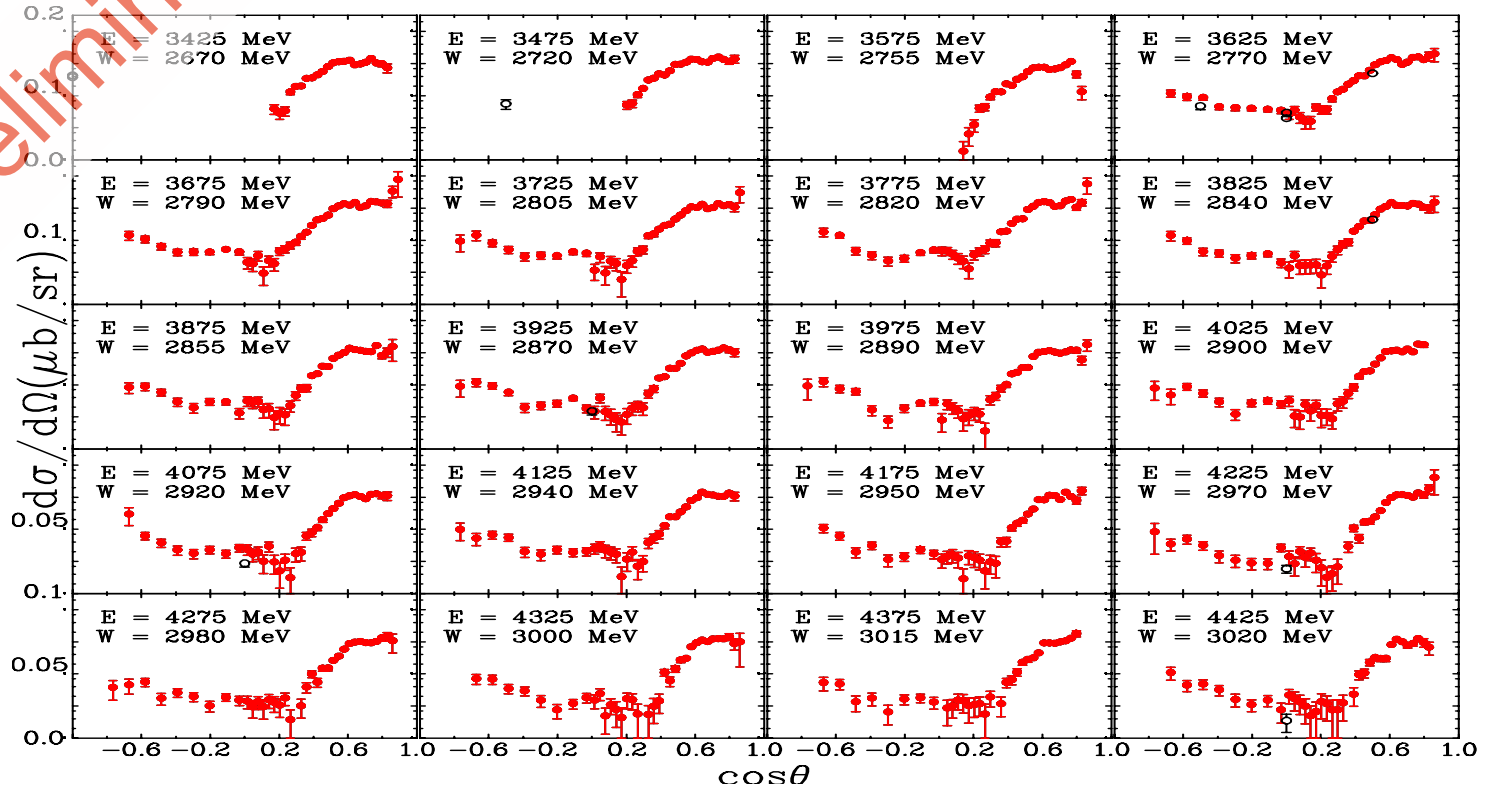


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$\cos\theta$ vs. $d\theta/d\Omega$ / $E_\gamma = 4.475\text{-}5.425$ GeV

Preliminary

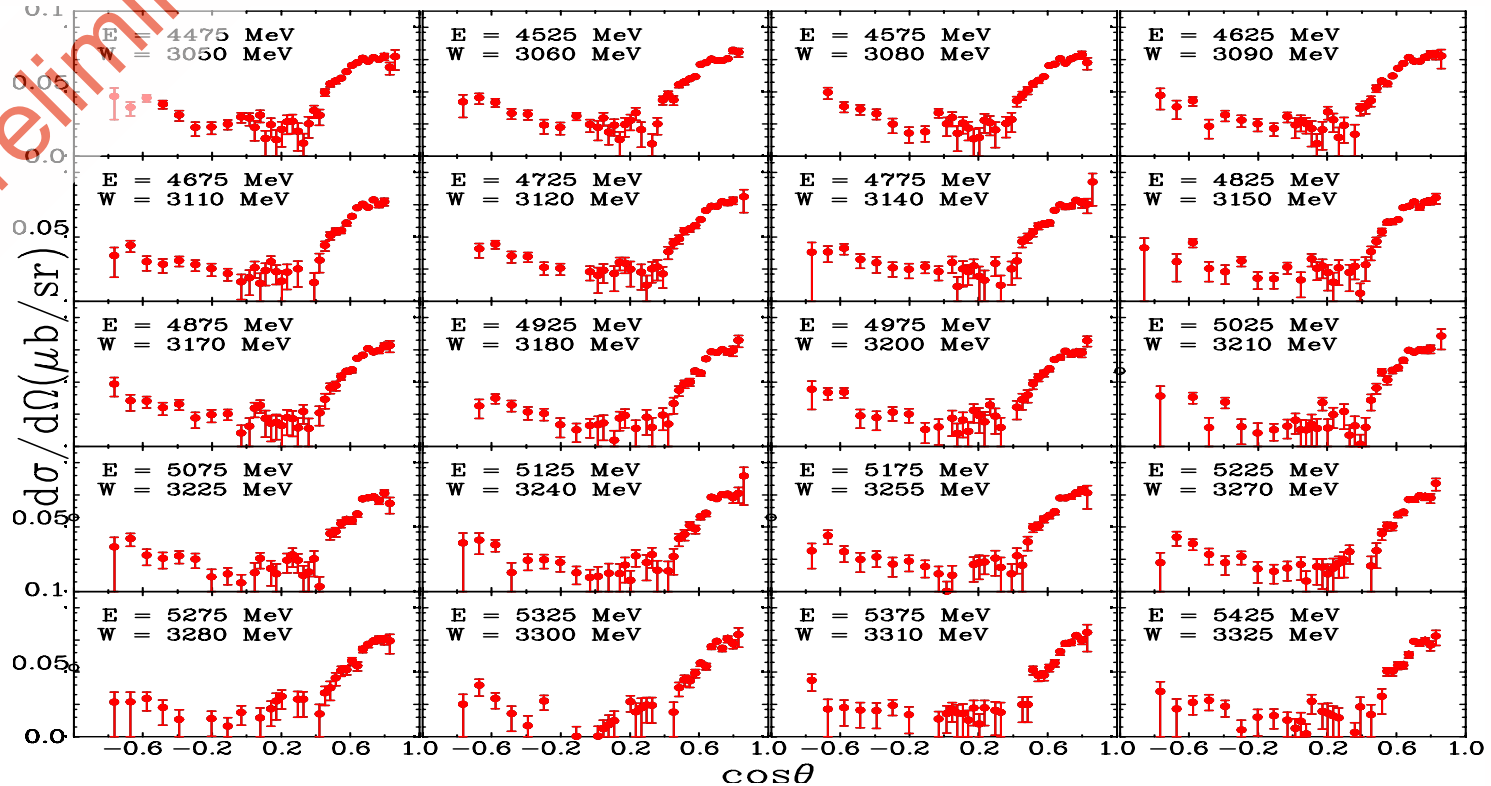


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Neutral Pion Photoproduction in a Regge Model

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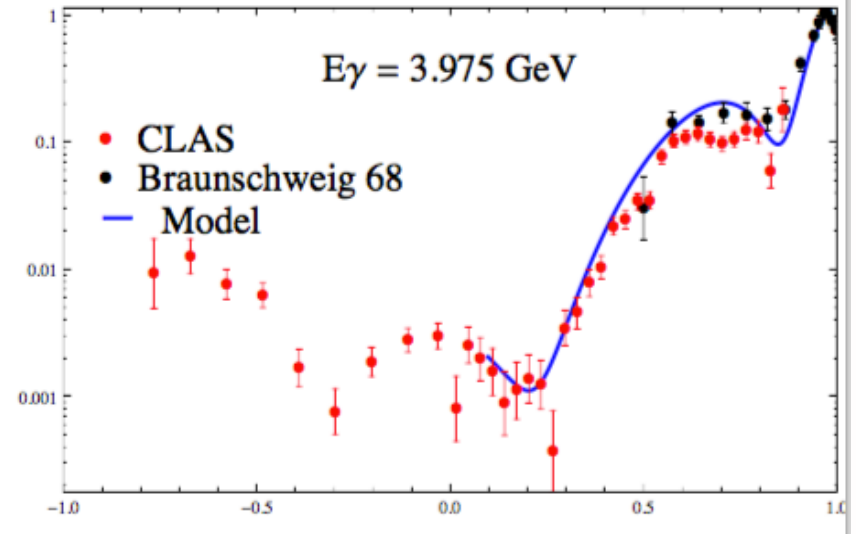
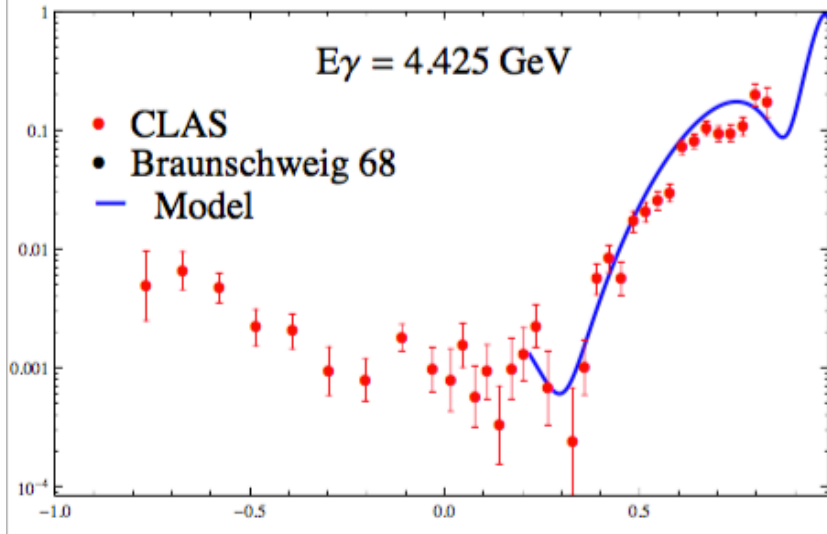
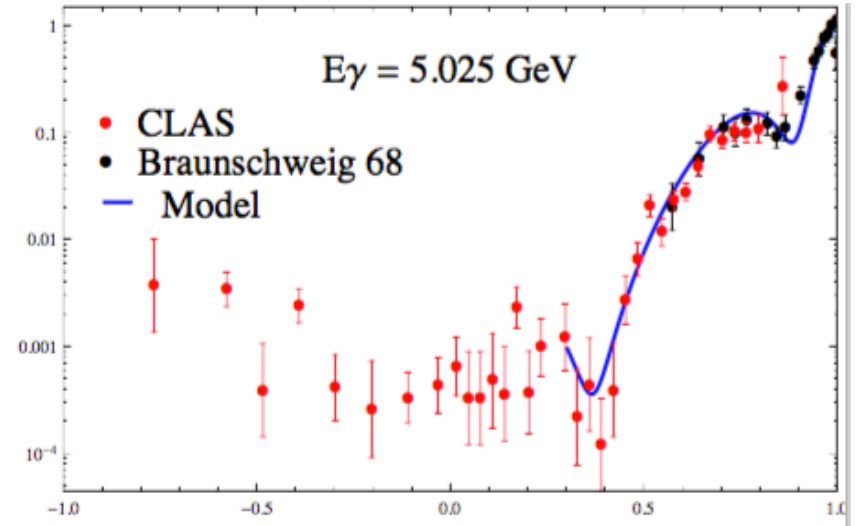
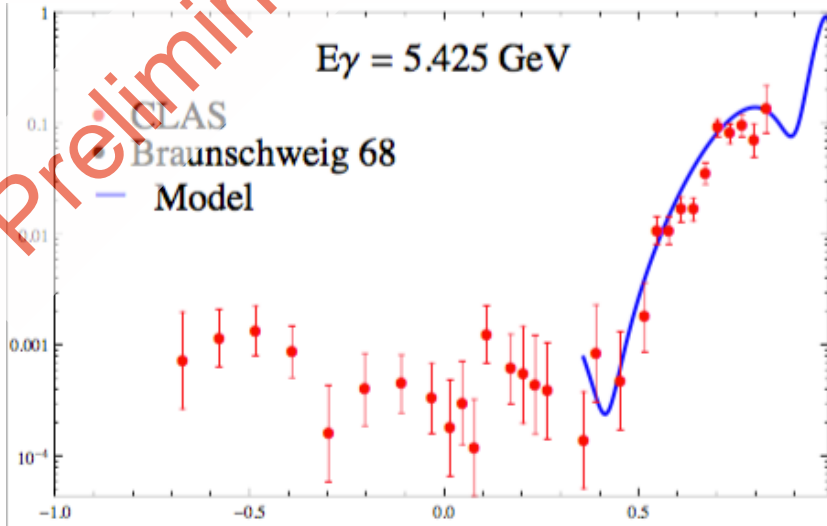
*Center for Exploration of Energy and Matter, Indiana University, Bloomington, IN 47403
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Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA*

(Dated: May 12, 2015)

The reaction $\gamma p \rightarrow \pi^0 p$ is investigated in the energy range above the resonance region. The amplitudes include the leading Regge singularities in the cross-channel and correctly describe the differential cross section for beam energies above 4 GeV and for momentum transferred above -3 GeV^2 . The energy dependence of the beam asymmetry and the reaction $\gamma n \rightarrow \pi^0 n$ seem to be quantitative consistent with the Regge-pole dominance.

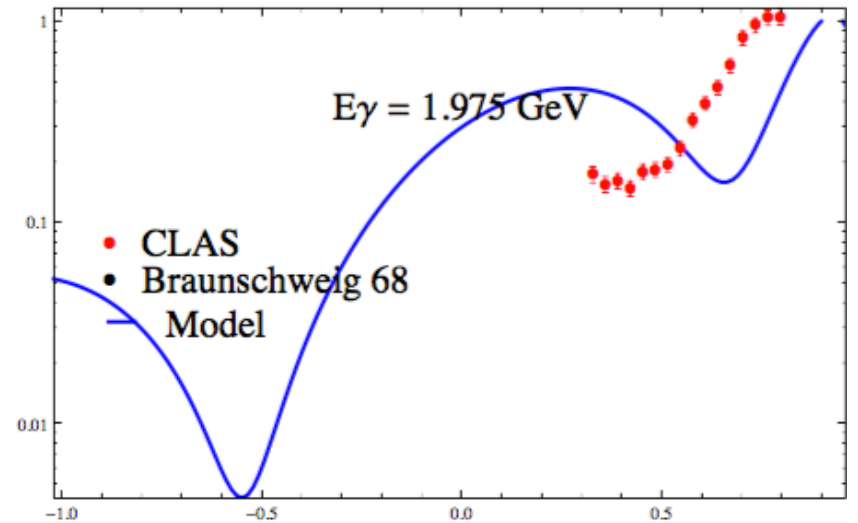
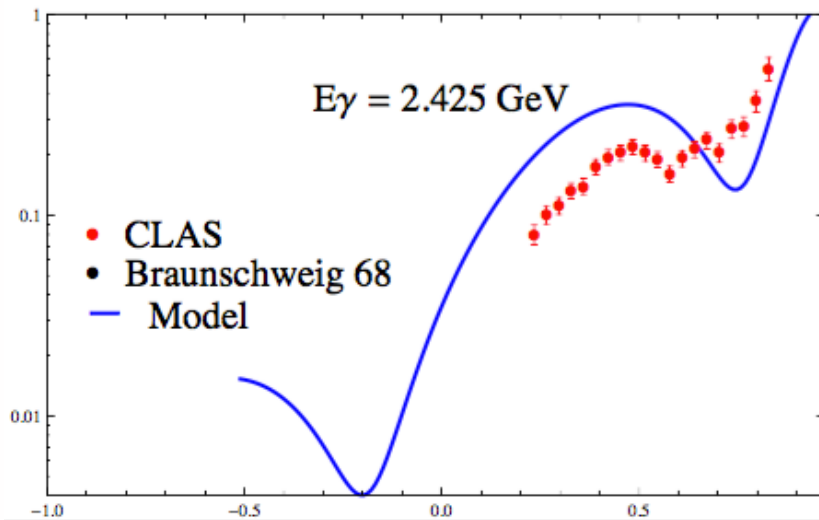
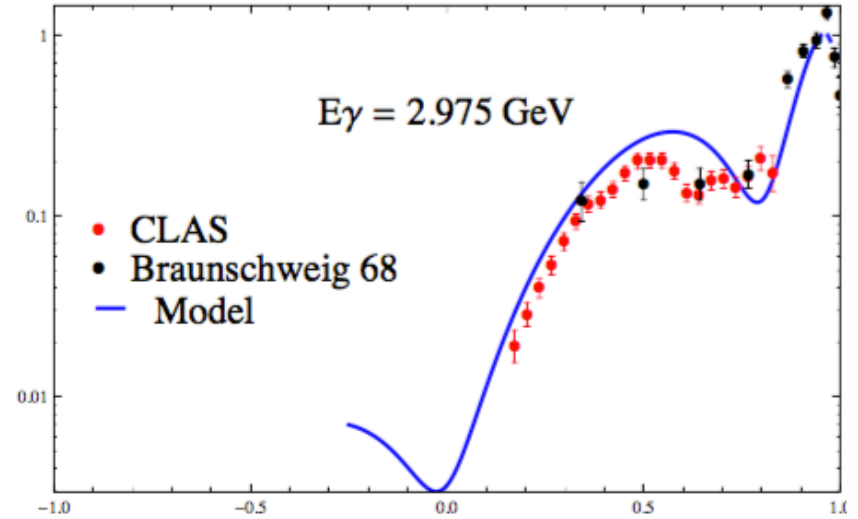
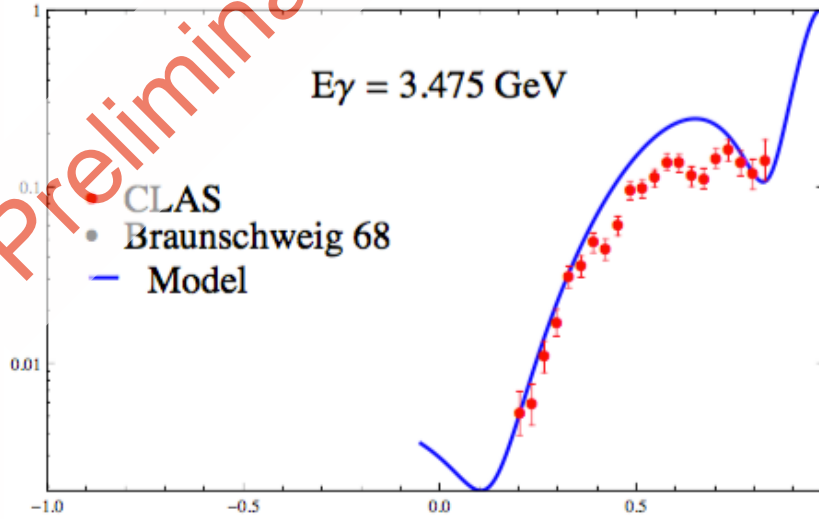
VM Model <http://arxiv.org/pdf/>

Preliminary



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Preliminary



Systematics

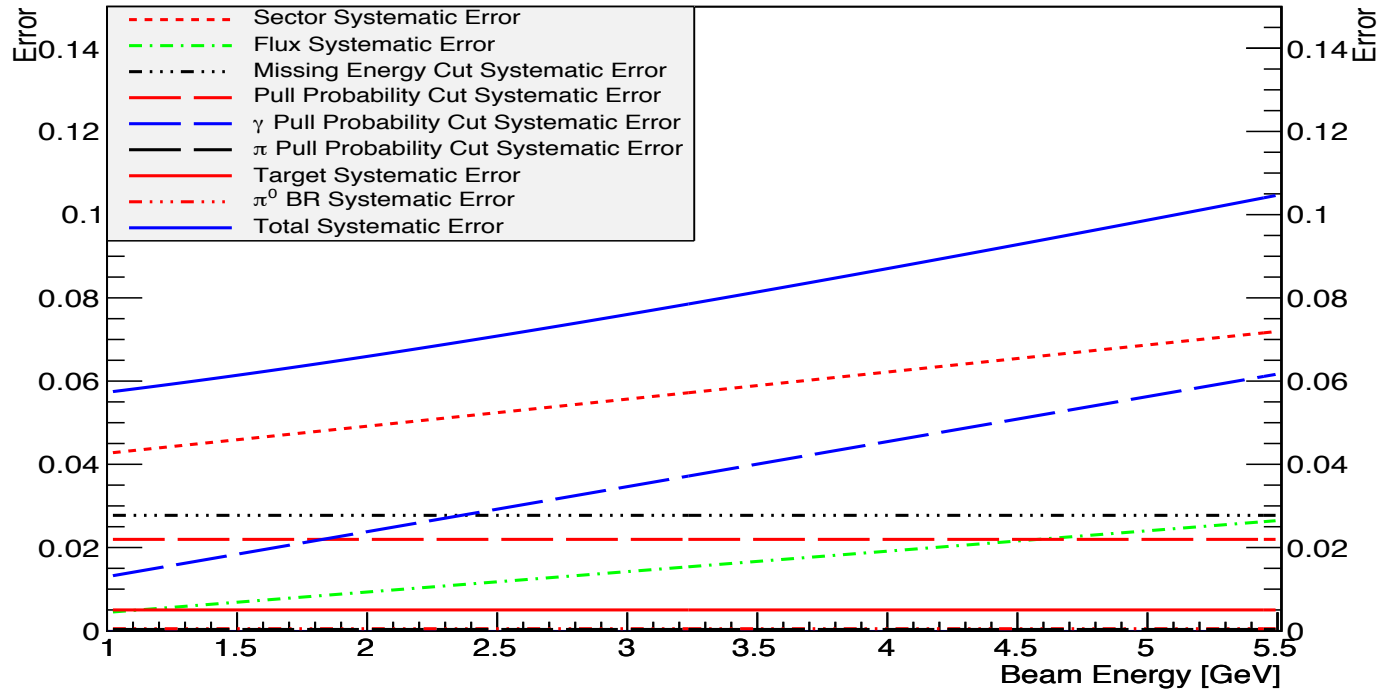
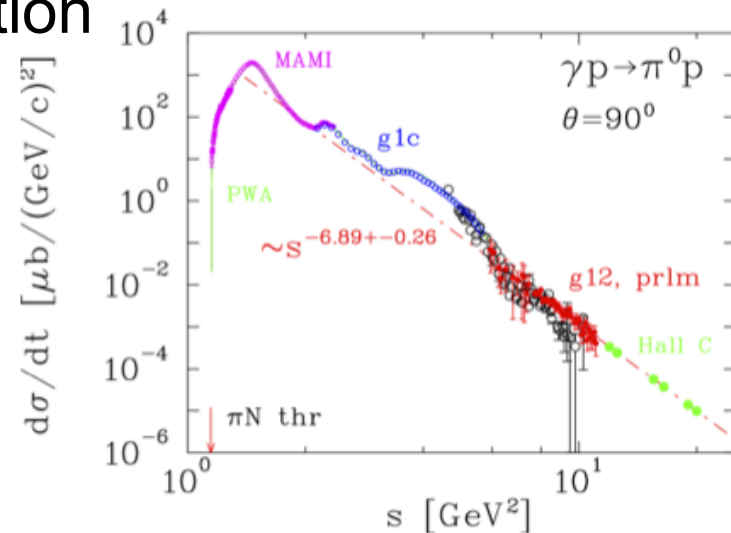


Figure : Plot showing the contribution of the all systematic errors as well as the combined which was calculated adding all systematic errors in quadrature.

- Proposal in work for CLAS in for investigating the electromagnetic structure of mesons J/Ψ , η' , ρ/ω , η , $\pi^0 \rightarrow e^+e^-[X]$ ($X \rightarrow 0, \gamma, \pi^0$)
 - Cross-section measurements will be preformed for all mesons
- Hall-C proposal already approved to measure s^7 dependence of cross-section



Summary

- π^0 cross-section has been extracted with precision in energy ranges previously measured and also not previously measured
 - Measured cross-section agrees well with previous data
 - VM Model agrees well with data for cross-section measurements produced at higher beam energies
- Measurement of π^0 cross-section in CLAS from 6.5 - 10.5 GeV (quasi-real photon beam) will be a bi-product of future transition form factor measurement (pending proposal approval)
 - Further validate VM model
- PAC approved proposal in Hall-C to investigate s^7 scaling for π^0 and measure π^0 cross-section at specific angles

Shameless Plug



The g11 and g12 experiments

g11 $\gamma p \rightarrow pX$	g12 $\gamma p \rightarrow pX$
60 - 65 nA 4.023 GeV e^- beam $0.803 < E_\gamma < 3.815$	60 - 65 nA 5.714 GeV e^- beam $1.142 < E_\gamma < 5.425$
40 cm (2 cm radius) liquid H_2 target placed at CLAS center	40 cm (2 cm radius) liquid H_2 target placed -90cm from CLAS center
Trigger required at least two charged tracks in different sectors	Trigger required at least two charged tracks in different sectors for $E_\gamma > 3.6$
20×10^9 productions triggers as 21 TB of raw data	26×10^9 productions triggers as 128 TB of raw data
	Cherenkov Counters and Electromagnetic Calorimeter in trigger for entire E_γ range

CLAS Light Meson Decay (LMD) Program Institutional Contributors

- Old Dominion University, Norfolk, Virginia 23529
- Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188300, Russia
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- Norfolk State University, Norfolk, VA 23504, USA
- Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

Light Meson Decays in CLAS

CLAS Light Meson Decay (LMD) Program was established to investigate

<i>Meson Decay</i>	<i>Physics</i>	<i>Meson Decay</i>	<i>Physics</i>
$\pi^0 \rightarrow e^+ e^- \gamma$	Heavy photon upper limit	$\eta(') \rightarrow \pi \pi^+ \gamma$	Box anomaly
$\eta(') \rightarrow e^+ e^- \gamma$	Transition Form Factor	$\omega \rightarrow \pi \pi^+ \eta$	Upper limit branching ratio $< 3.6 \times 10^{-3}$
$\omega \rightarrow \pi^0 e^+ e^-$	Transition Form Factor	$\eta, \omega, \Phi \rightarrow \pi \pi^+ \pi^0$	Dalitz plot analysis
$\eta(') \rightarrow \pi^0 e^+ e^-$	C violation	$\eta' \rightarrow \pi \pi^+ \eta$	Dalitz plot analysis/meson mixing
$\eta(') \rightarrow \pi \pi^+ e^+ e^-$	CP violation	$\Phi \rightarrow \pi \pi^+ \eta$	G-parity violation

Light Meson Decays in CLAS

CLAS Light Meson Decay (LMD) Program was established to investigate

<i>Meson Decay</i>	<i>Physics</i>	<i>Data Set</i>
$\eta(') \rightarrow \pi \pi^+ \gamma$	<i>Box anomaly</i>	<i>g11, g12</i>
$\omega \rightarrow \pi \pi^+ \gamma$	<i>Upper limit branching ratio</i>	<i>g11, g12</i>
$\eta, \omega, \Phi \rightarrow \pi \pi^+ \pi^0$	<i>Dalitz plot analysis</i>	<i>g11, g12</i>
$\eta' \rightarrow \pi \pi^+ \eta$	<i>Dalitz plot analysis/meson mixing</i>	<i>g11, g12</i>
$\Phi \rightarrow \pi \pi^+ \eta$	<i>G-parity violation</i>	<i>g11, g12</i>
$\Phi \rightarrow \omega \gamma$	<i>C violation, rare decay</i>	<i>g11, g12</i>
<i>NULL</i>	<i>Invisible decay</i>	<i>g11, g12</i>
f_1	<i>isospin symmetry breaking, f1</i>	<i>g11, g12</i>

t vs. $d\sigma/dt / E_Y = 1.275-2.225$ GeV

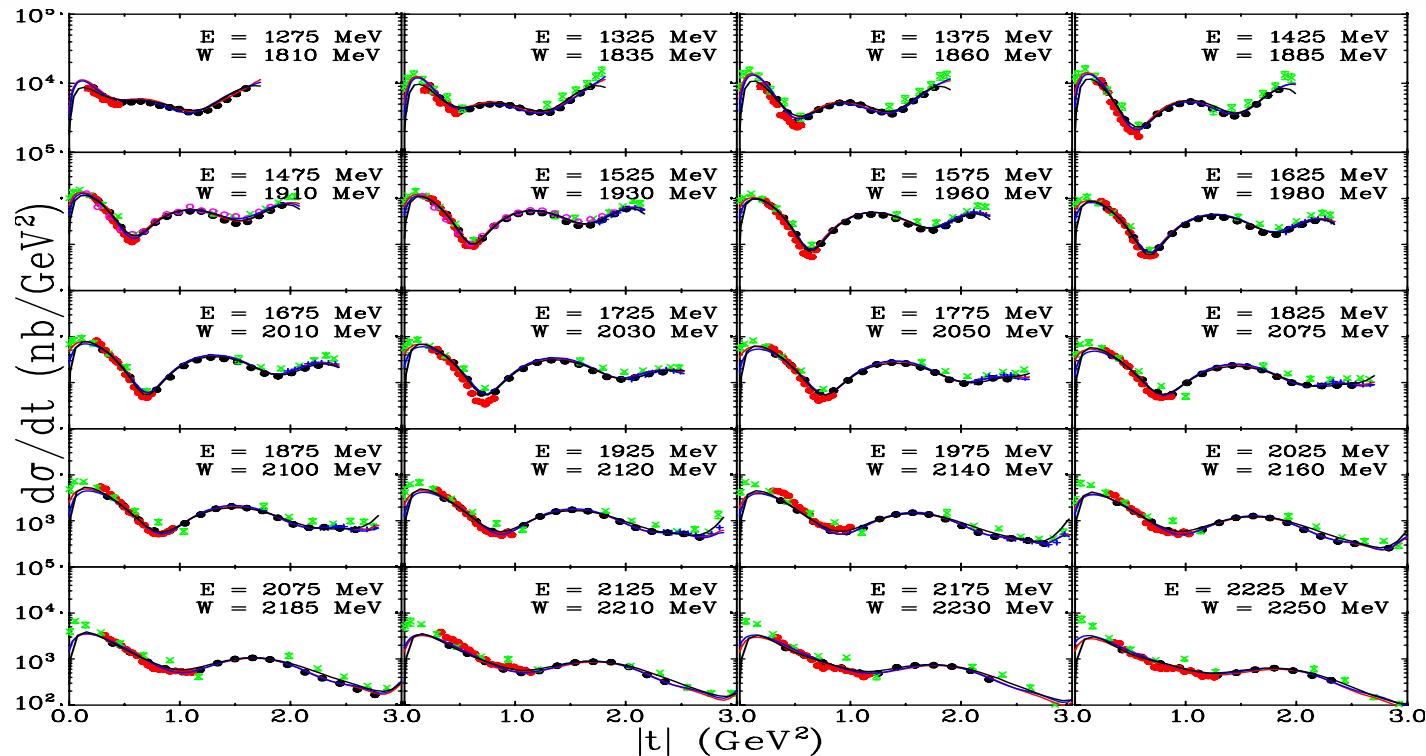


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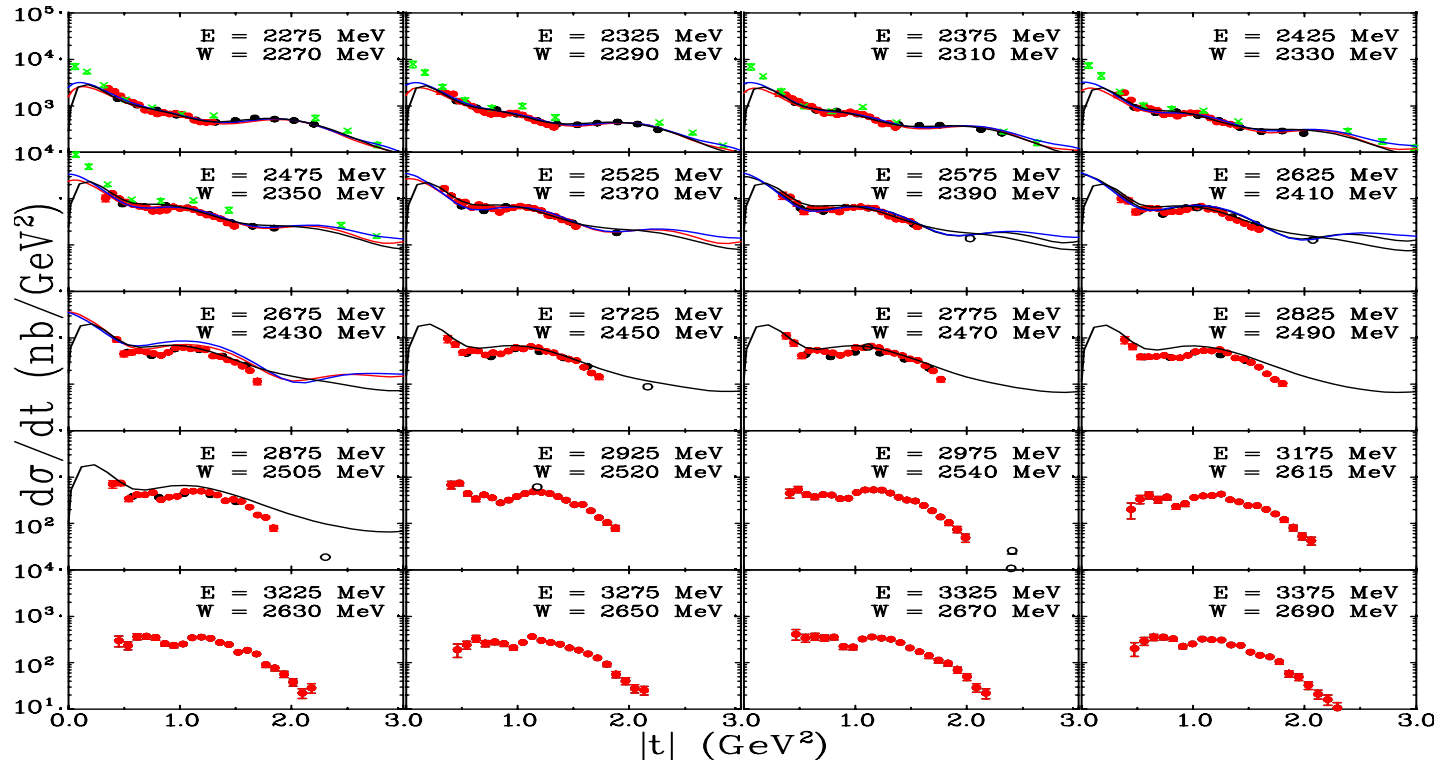


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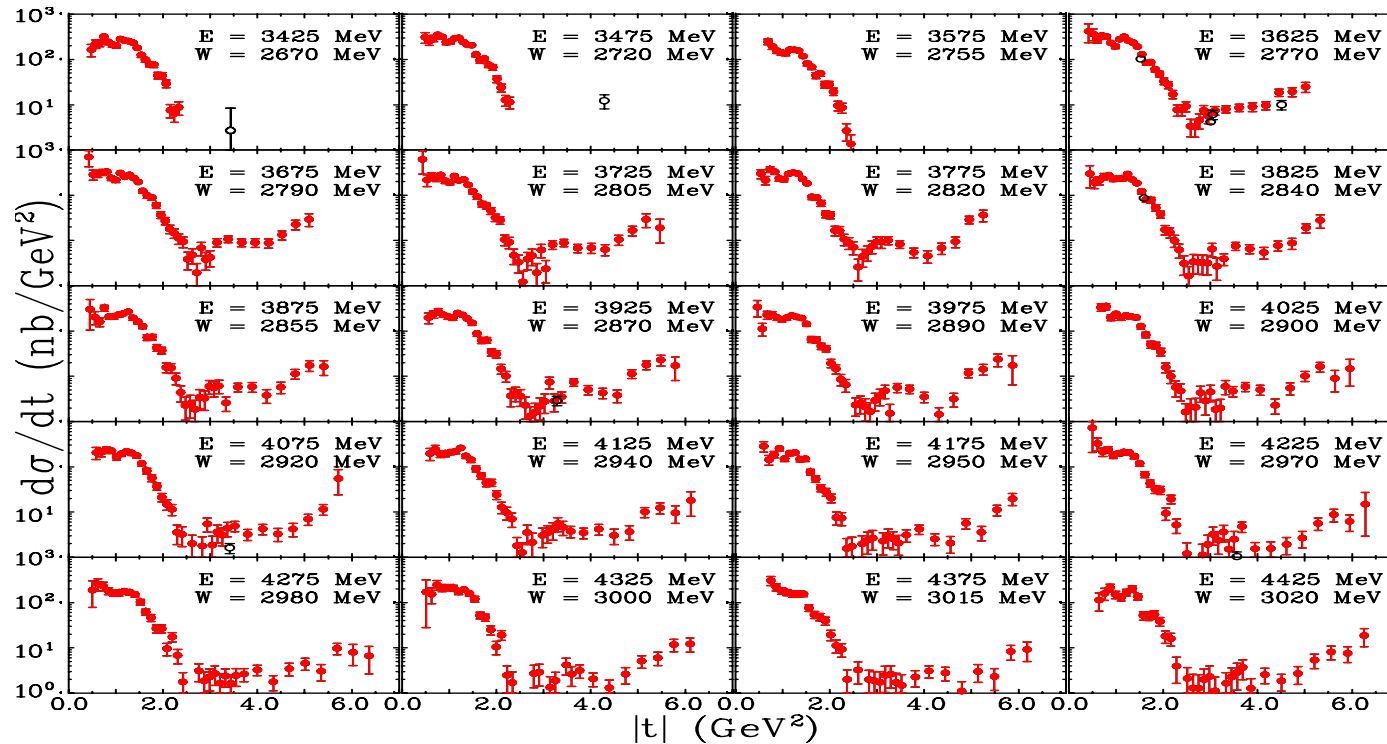


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t vs. $d\sigma/dt / E_\gamma = 4.475\text{-}5.475$ GeV

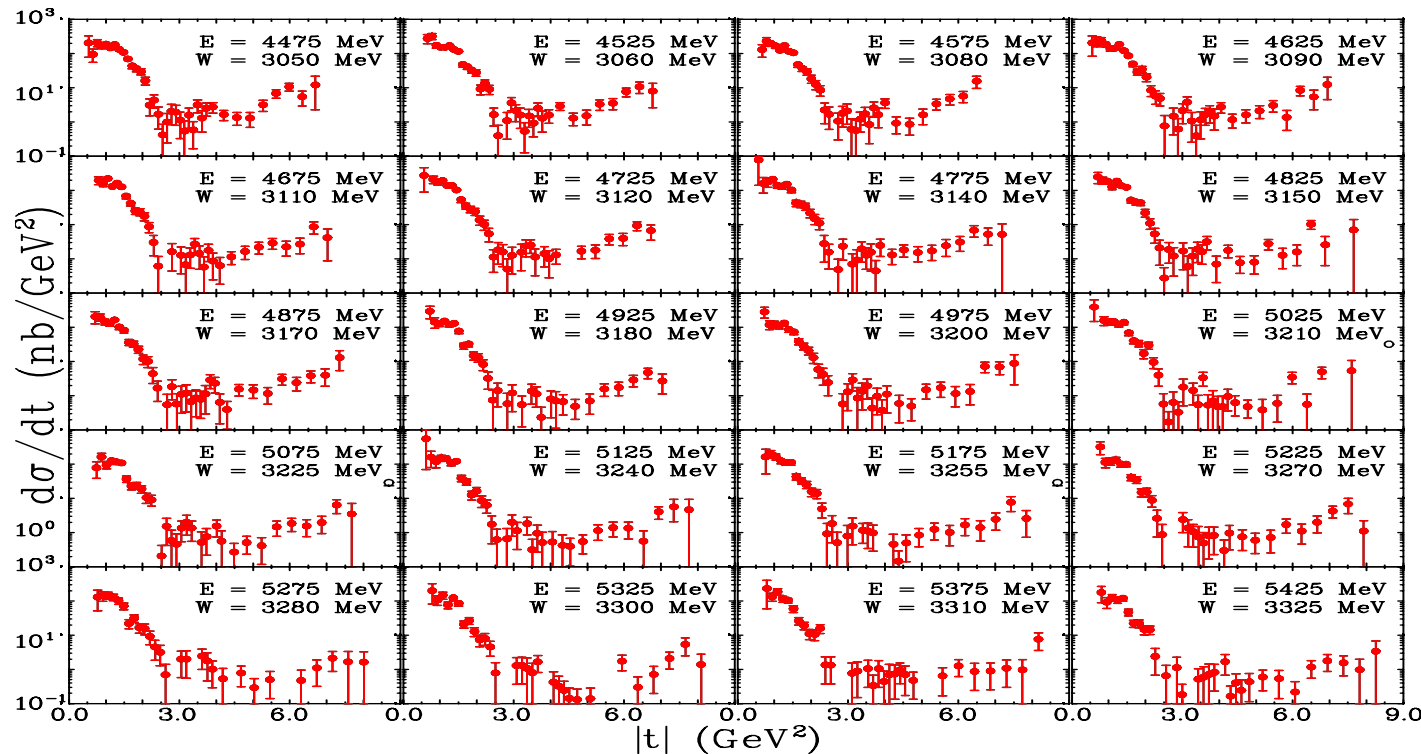


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