Polarization Transfer in Wide Angle Charged Pion Photoproduction (WAPP)

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Bogdan Wojtsekhowski – Jefferson Lab
(on behalf of the WAPP collaboration)

The spokespersons

John Arrington

Andrew Puckett

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Bogdan Wojtsekhowski

WAPP Collaboration: ~60 Collaborators from ~20 institutions

Contents

- Field of Meson Photoproduction
- Observed yet unexplained cross sections
- Theoretical efforts
- Possible solution: Polarization tests of handbag mechanism
- Approved experiment – NEW!
- Summary

Meson Photo- and Electroproduction

- Has been around for quite some time!

- Early measurements at Stanford conducted to study the ratio of the pions produced due to electro and photo production

PHYSICAL REVIEW VOLUME 102, NUMBER 5 JUNE 1, 1956

Pion Production by Inelastic Scattering of Electrons in Hydrogen*

W. K. H. Panofsky, W. M. Woodward,† and G. B. Yodh
High-Energy Physics Laboratory and Department of Physics, Stanford University, Stanford, California

(Received February 27, 1956)

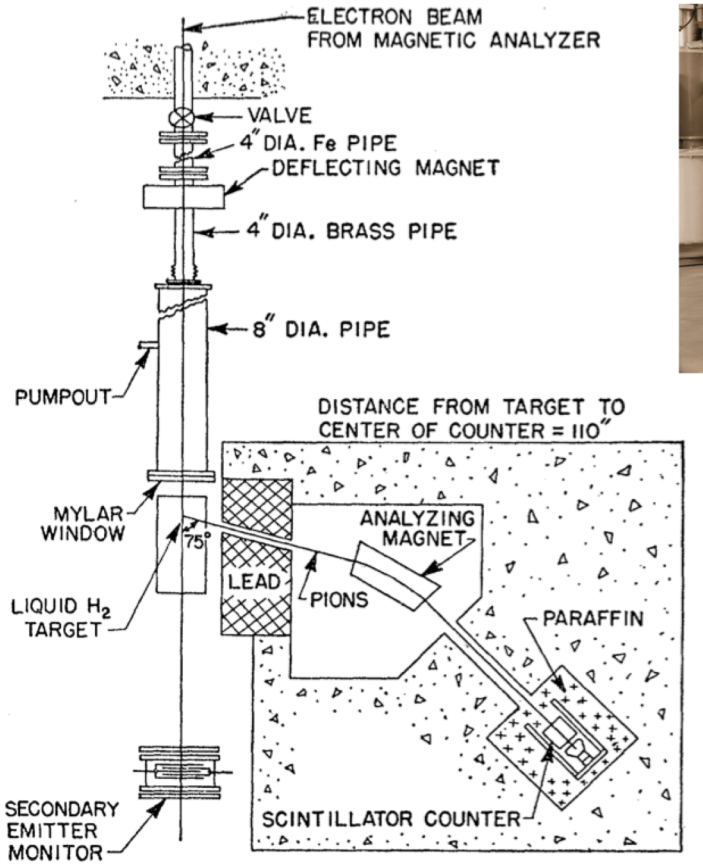
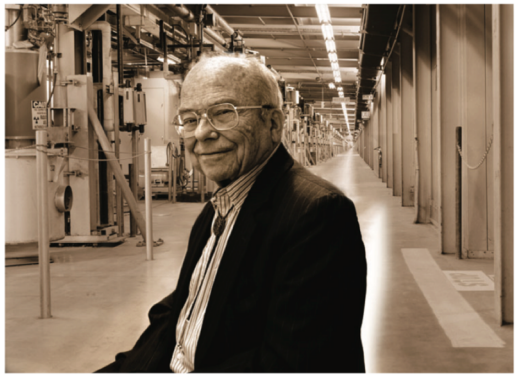


FIG. 3. Meson detection geometry.



Wolfgang K.H. Panofsky

Measurements of exclusive photoproduction

- Other measurements of exclusive photoproduction were conducted which revealed intriguing features

PHYSICAL REVIEW D VOLUME 14, NUMBER 3 1 AUGUST 1976

Measurements of exclusive photoproduction processes at large values of t and u from 4 to 7.5 GeV*

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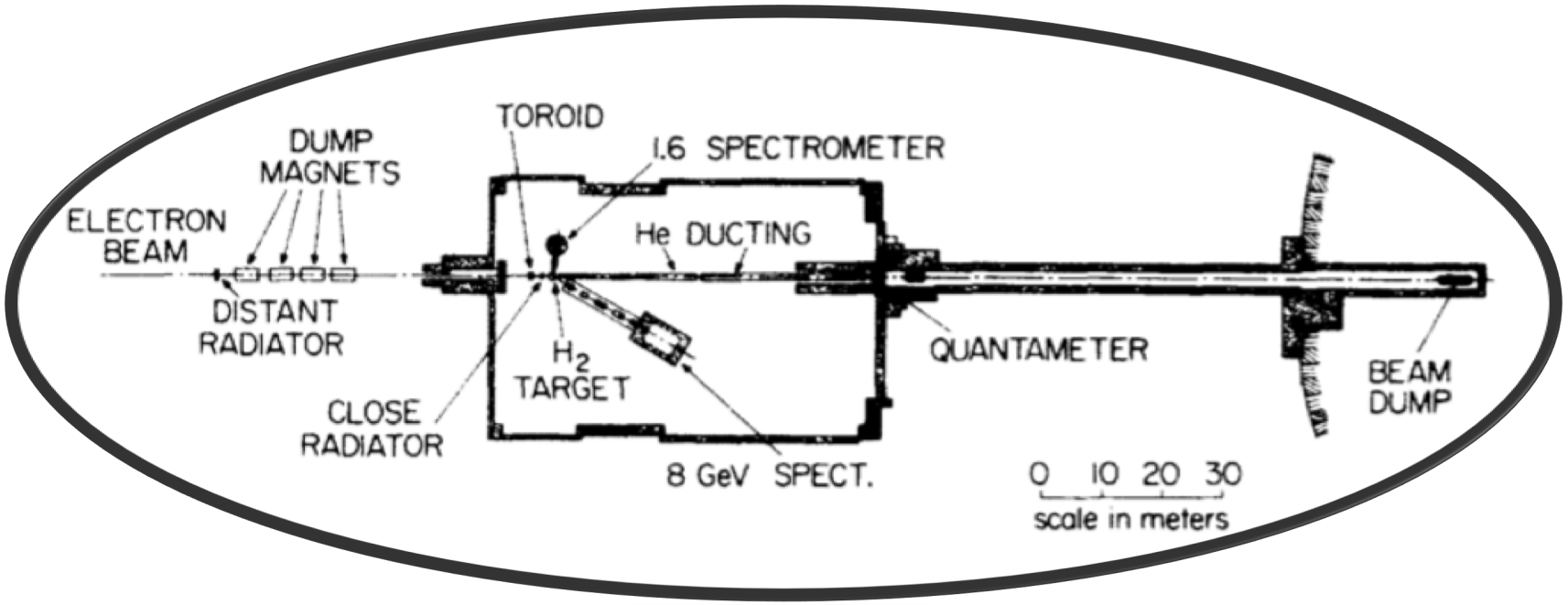
(Received 2 February 1976)

Exclusive photoproduction cross sections have been measured for the processes $\gamma p \to \pi^+ n$, $\gamma p \to \pi^0 p$, $\gamma p \to \pi^- \Delta^{++}$, $\gamma p \to \rho^0 p$, $\gamma p \to K^+ \Lambda$, and $\gamma p \to K^+ \Sigma^0$ at large t and u values at several energies for each process between 4 and 7.5 GeV. These measurements taken together with past data taken at small values of t and u provide complete angular distributions. The data show the usual small t and u peaks and a central region in which the cross section decreases approximately as s^{-7}. The results are discussed within the context of parton or constituent models.



Measurements conducted for a variety of physics processes and particles

TABLE I. List of reactions and photon energies covered in this experiment.

Process	Energy (GeV)
$\gamma p \to \pi^+ n$	4, 5, 7.5
$\gamma p \to \pi^0 p$	4, 5
$\gamma p \to \pi^- \Delta^{++}$	4, 5
$\gamma p \to \rho^0 p$	4, 6
$\gamma p \to K^+ \Lambda$	4, 6
$\gamma p \to K^+ \Sigma^0$	4, 6

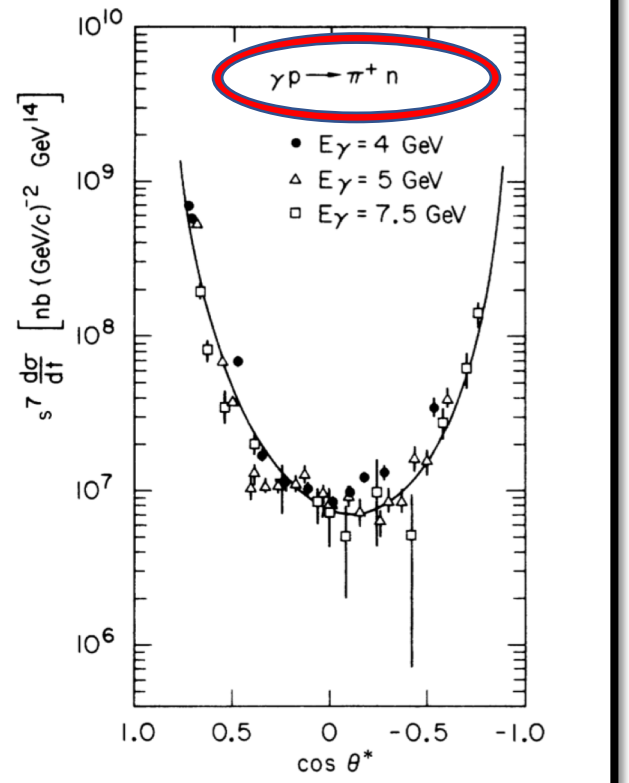


FIG. 6. $s^7 d\sigma/dt$ versus $\cos\theta^*$ for the reaction $\gamma p \to \pi^+ n$. The solid line shows the empirical function $(1-z)^{-5}(1+z)^{-4}$ where $(z = \cos\theta^*)$, which is an empirical fit to the angular distribution.

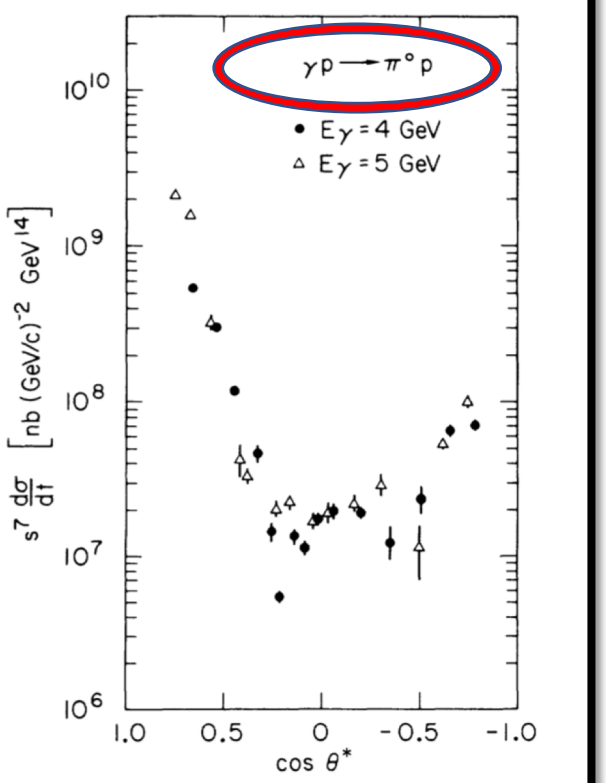


FIG. 9. $s^7 d\sigma/dt$ versus $\cos\theta^*$ for the reaction $\gamma p \to \pi^0 p$.

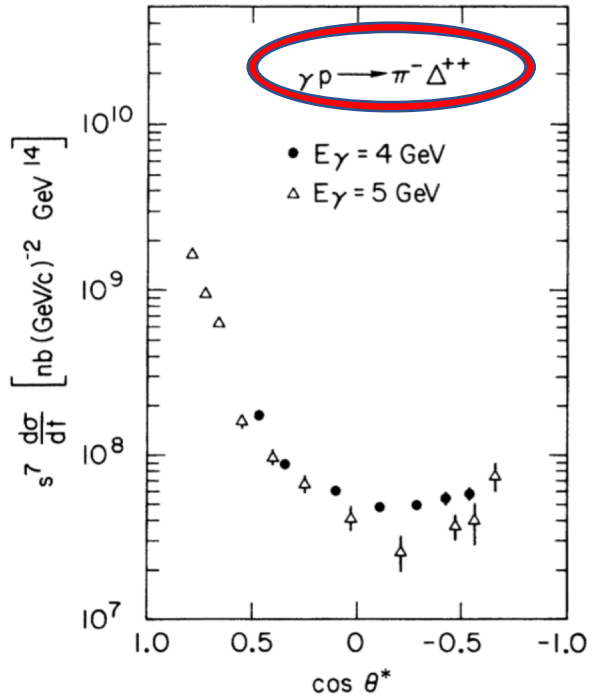


FIG. 12. $s^7 d\sigma/dt$ versus $\cos\theta^*$ for the reaction $\gamma p \to \pi^- \Delta^{++}$.

Mechanism of scaling

- Continuing interest in the features but the cross sections are still unexplained

- Models tried to explain the observed cross sections by considering the number of "active fields" involved in the photoproduction
  - CCR (Constituent Counting Rules)
  - HHC (Hadron Helicity Conservation)
  - pQCD (perturbative QCD)
  - Handbag approach in the GPD framework (Generalized Parton Distributions)

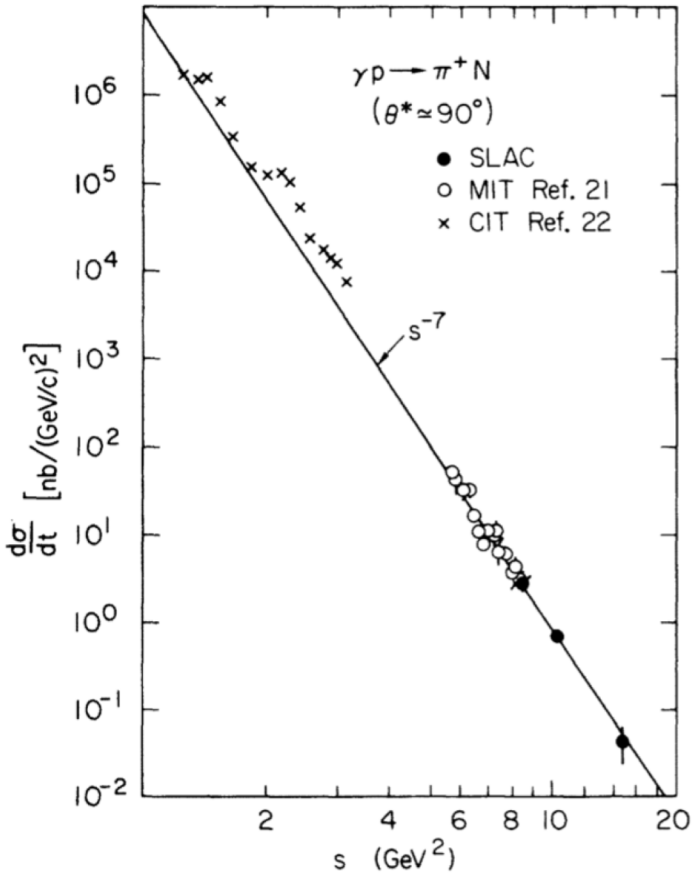
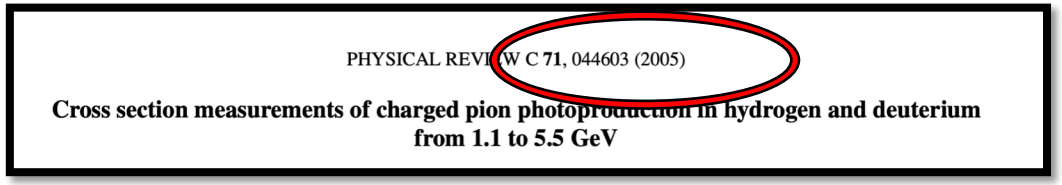


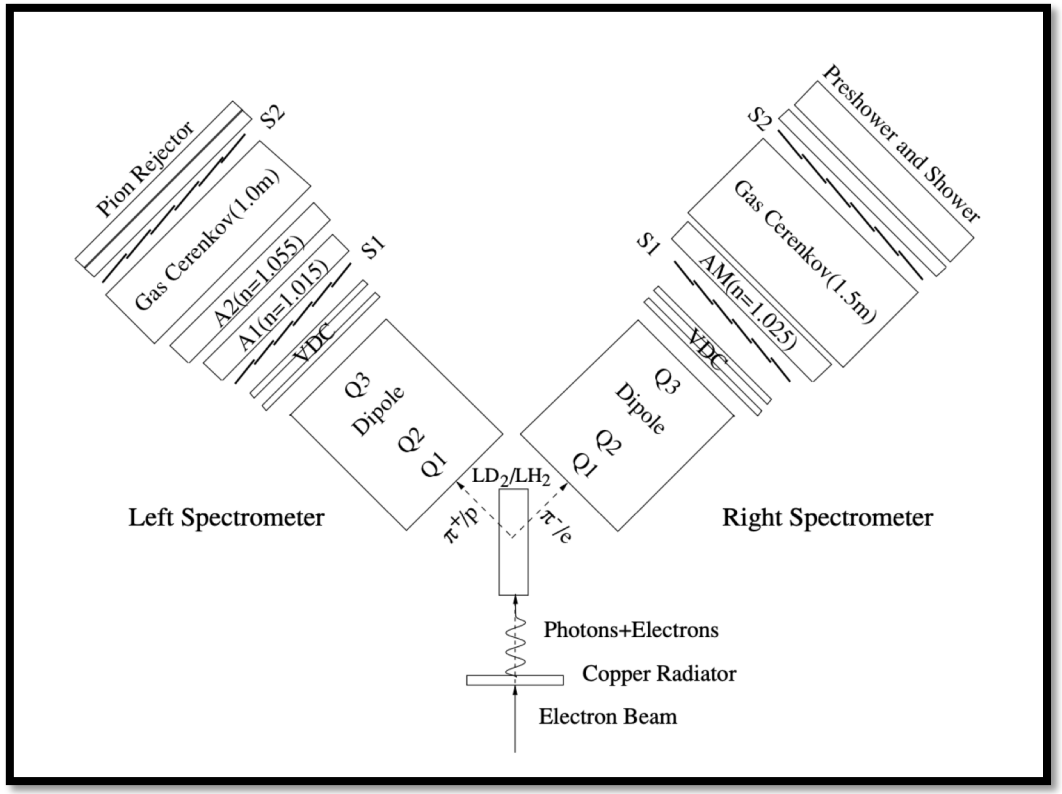
FIG. 20. 90° c.m. values of $d\sigma/dt$ versus s for the process $\gamma p \to \pi^+ n$ from several experiments from $E_\gamma = 700$ MeV to $E_\gamma = 7.5$ GeV. The solid line shows the function s^{-7} for reference.

Photoproduction experiments in Hall A

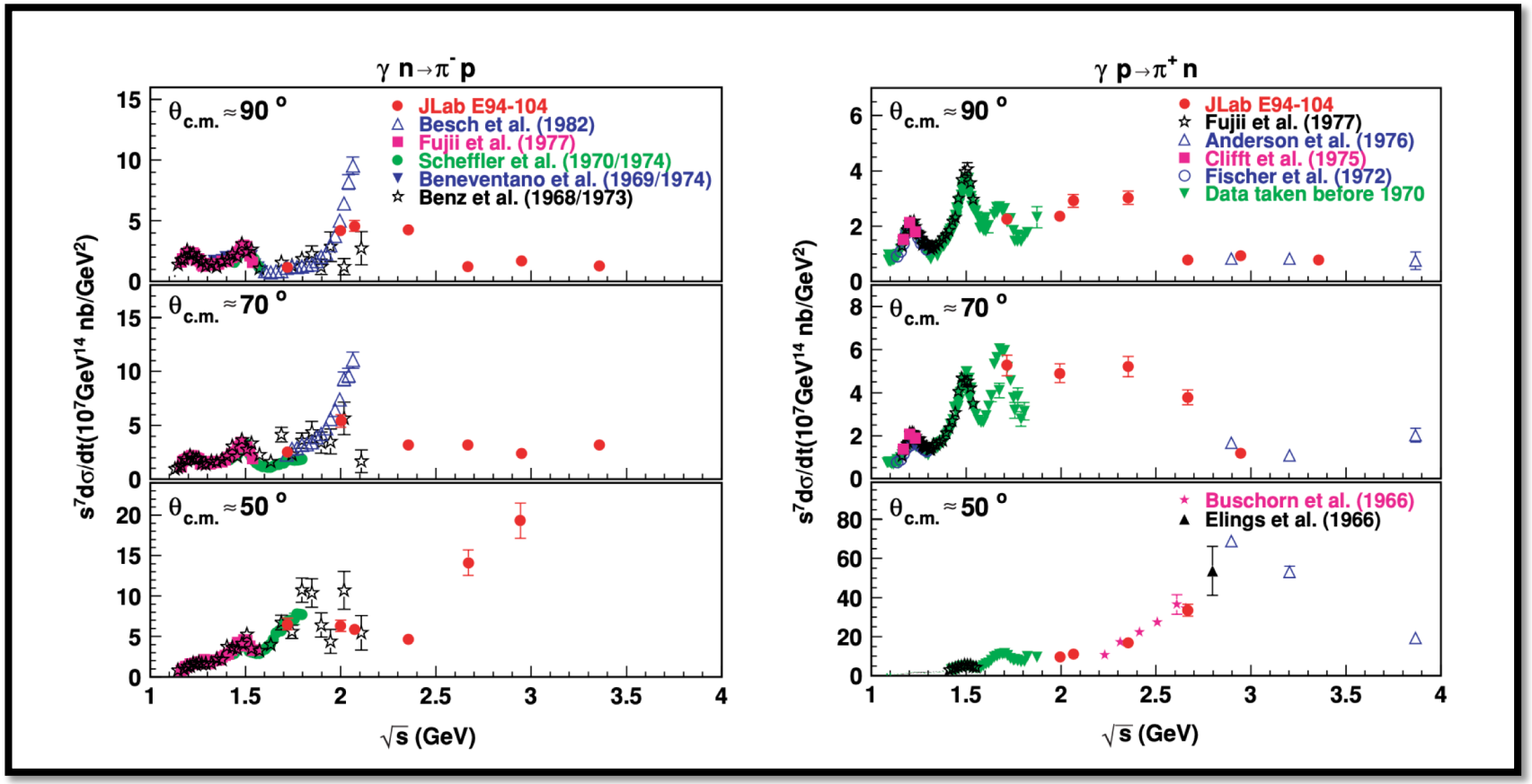
- Photoproduction experiments conducted in Hall A using LHRS and RHRS
- π^+ and π^- cross sections and their ratios studied for a range of s and t
- Many intriguing features that still have continued interest at Jefferson Lab


PHYSICAL REVIEW C **71**, 044603 (2005)

Cross section measurements of charged pion photoproduction in hydrogen and deuterium from 1.1 to 5.5 GeV



Experiment in Hall A E94-104



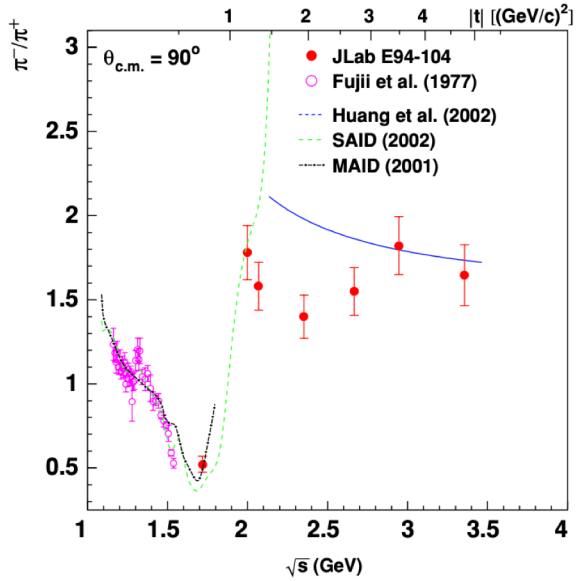


FIG. 18. (Color online). Exclusive charged pion ratio $d\sigma/dt(\gamma n \to \pi^- p)/d\sigma/dt(\gamma p \to \pi^+ n)$ versus center-of-mass energy $\sqrt{s}$ and momentum transfer squre $|t|$ at pion center-of-mass angle $\theta_{\text{c.m.}} = 90°$ from JLab E94-104 and previous world data [48], together with the SAID [66], MAID [67], and one-hard-gluon-exchange calculation [44,45].

But leading order calculations fall short!

Signatures of the handbag mechanism in wide-angle photoproduction of pseudoscalar mesons

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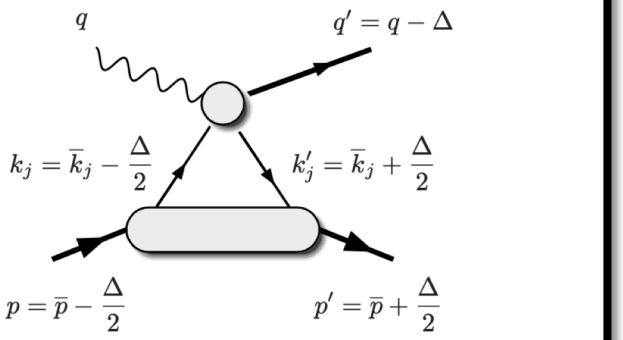
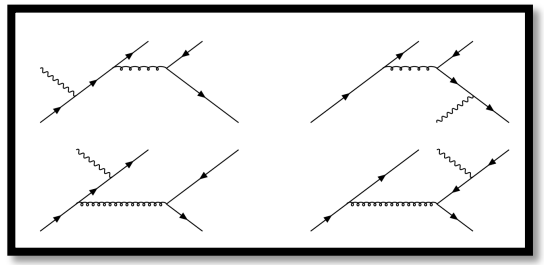
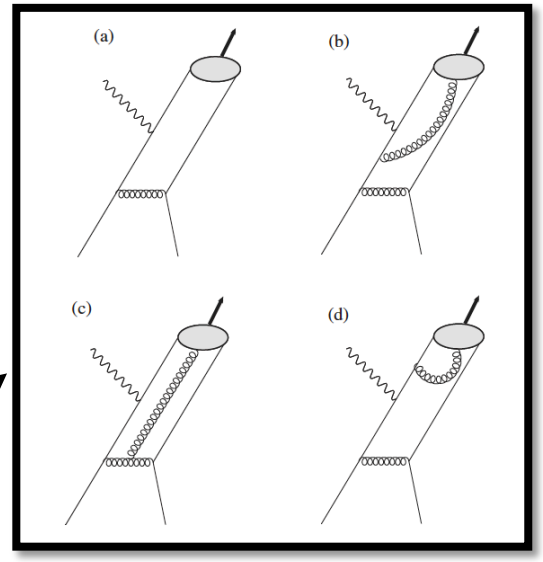


Fig. 1. The handbag diagram for photo- and electroproduction of mesons. The large blob represents a baryon GPD, while the small one stands for meson photo- and electroproduction off partons. The momenta of the various particles are indicated



Leading-twist one-hard-gluon exchange diagrams for the "hard" parton level subprocess $\gamma^{(*)}q \to Mq$



Feynman diagrams including two- and three-particle Fock components of the meson

$$\frac{d\sigma(\gamma n \to \pi^- p)}{d\sigma(\gamma p \to \pi^+ n)} \approx \left(\frac{e_u s + e_d u}{e_u u + e_d s}\right)^2$$

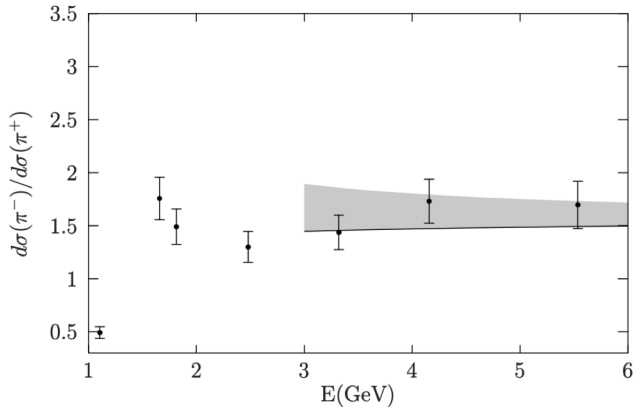


Fig. 4. The ratio of the $\gamma n \to \pi^- p$ and $\gamma p \to \pi^+ n$ cross sections versus photon beam energy E, at a CMS scattering angle of 90°. Data are taken from [31]. The solid line is the handbag prediction with the identification (48). The uncertainties due to target mass corrections [30] are indicated by the shaded band

π^0 photoproduction experiments in Hall B

- Calculations using the Handbag approach that includes only twist-2 fall short by more than two orders of magnitude
- Missing some crucial information in the amplitude used in calculations
- Figuring that out will shed light on the interaction mechanism responsible for these cross sections

Exclusive photoproduction of π^0 up to large values of Mandelstam variables s, t, and u with CLAS

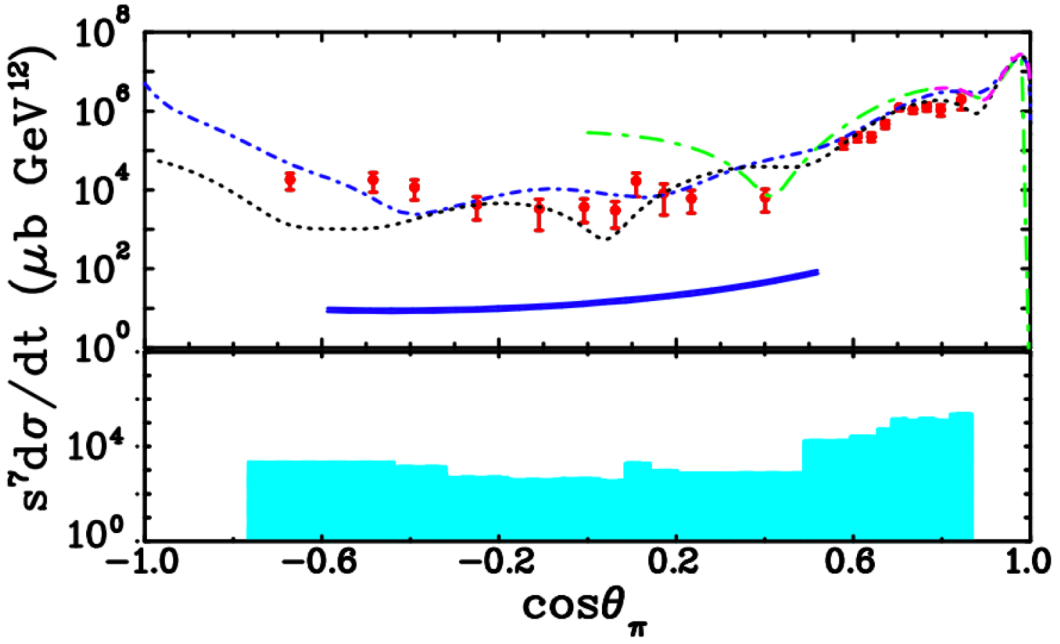


FIG. 5. Differential cross section of π^0 photoproduction. The CLAS experimental data at $s = 11$ GeV^2 are from the current experiment (red solid circles). The plotted uncertainties are statistical. The systematic uncertainties are presented as a shaded area in the subpanel. The theoretical curves for the Regge fits are the same as in Fig. 4 and the Handbag model by Kroll *et al.* [12] (blue double solid line).

Calculations with higher twists

- Calculations with twist 2 and twist 3 contributions performed for π^0 are not only important but dominant
- They are in reasonable agreement (black curve) with CLAS data
- Polarization test of the handbag mechanism is necessary and timely

Twist-3 contributions to wide-angle photoproduction of pions

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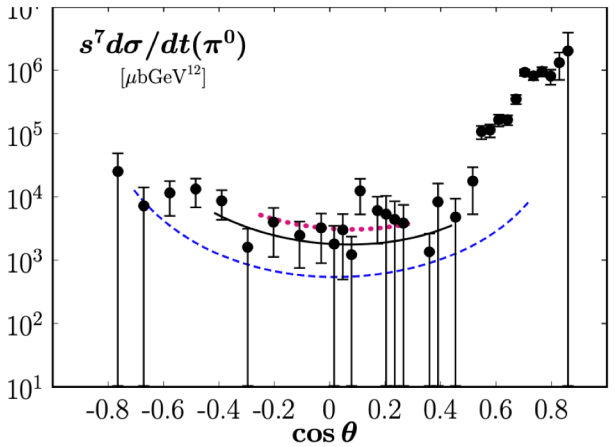


Figure 3: Results for the cross section of π^0 photoproduction versus the cosine of the c.m.s. scattering angle, θ. The solid (dashed, dotted) curves represent our results at $s = 11.06\,(20, 9)\,\mathrm{GeV}^2$. The data at $s = 11.06\ \mathrm{GeV}^2$ are taken from CLAS [34]. The cross sections are multiplied by s^7 and the theoretical results are only shown for $-t$ and $-u$ larger than $2.5\ \mathrm{GeV}^2$.

Helicity correlation observables

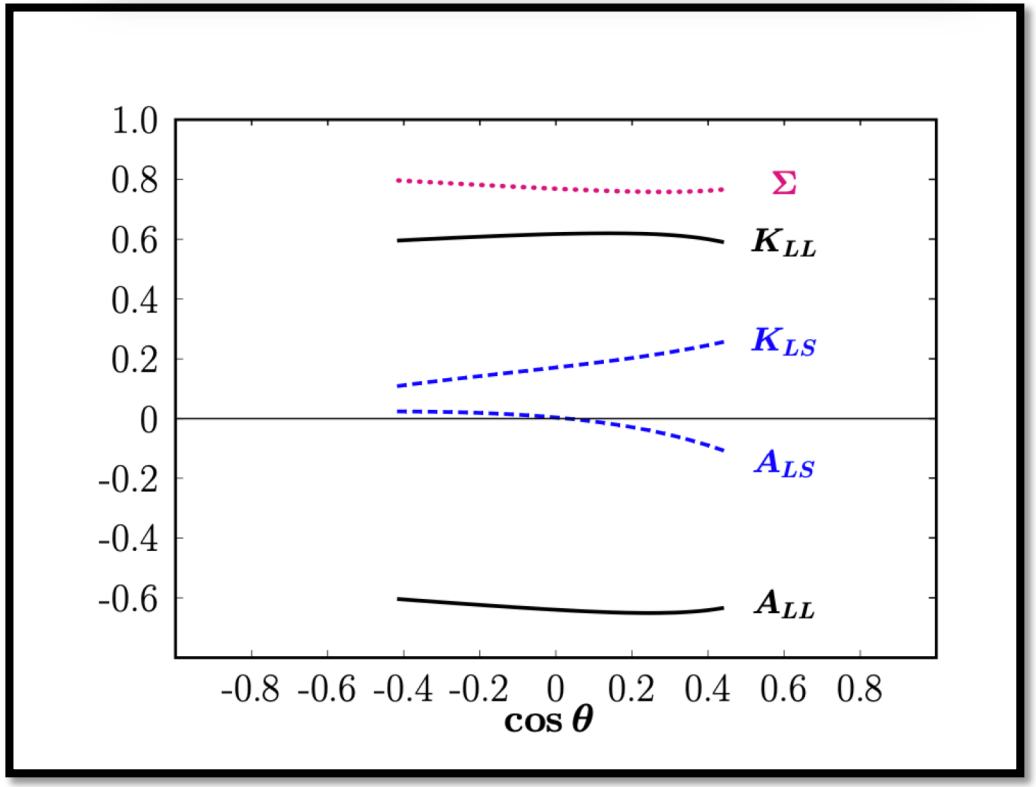
- Helicity correlations A_{LL} and K_{LL} provide tests of the handbag mechanism
- Twist 3 contribution dominates twist 2
- Predictions made for π^0 and π^- by Kroll et. al.

$$K_{LL} = \frac{d\sigma(+,\rightarrow) - d\sigma(-,\rightarrow)}{d\sigma(+,\rightarrow) + d\sigma(-,\rightarrow)}$$

$$A_{LL} = \frac{d\sigma(+\rightarrow) - d\sigma(-\rightarrow)}{d\sigma(+\rightarrow) + d\sigma(-\rightarrow)}$$

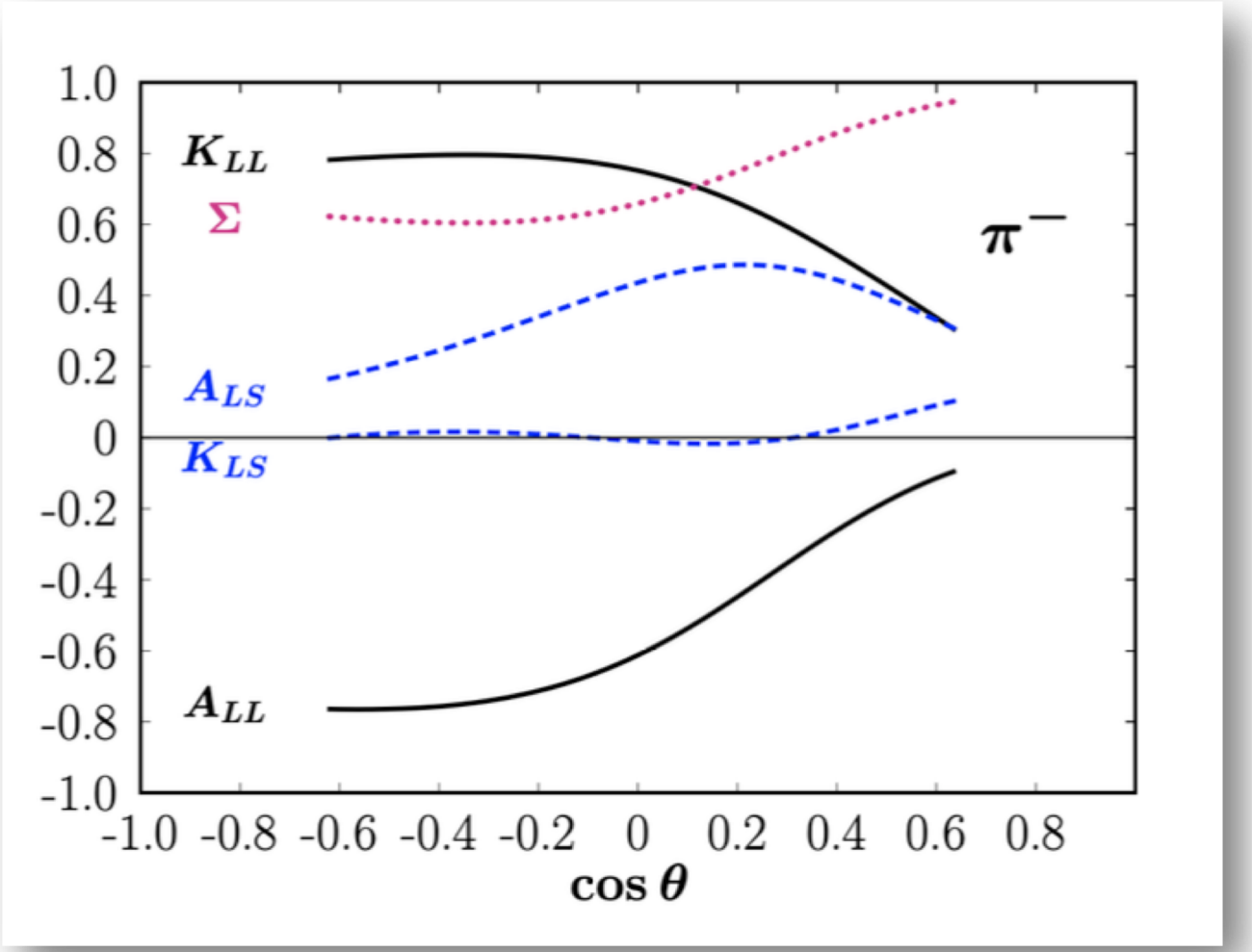
$$A_{LL}^{twist-2} = K_{LL}^{twist-2}$$

$$A_{LL}^{twist-3} = -K_{LL}^{twist-3}$$



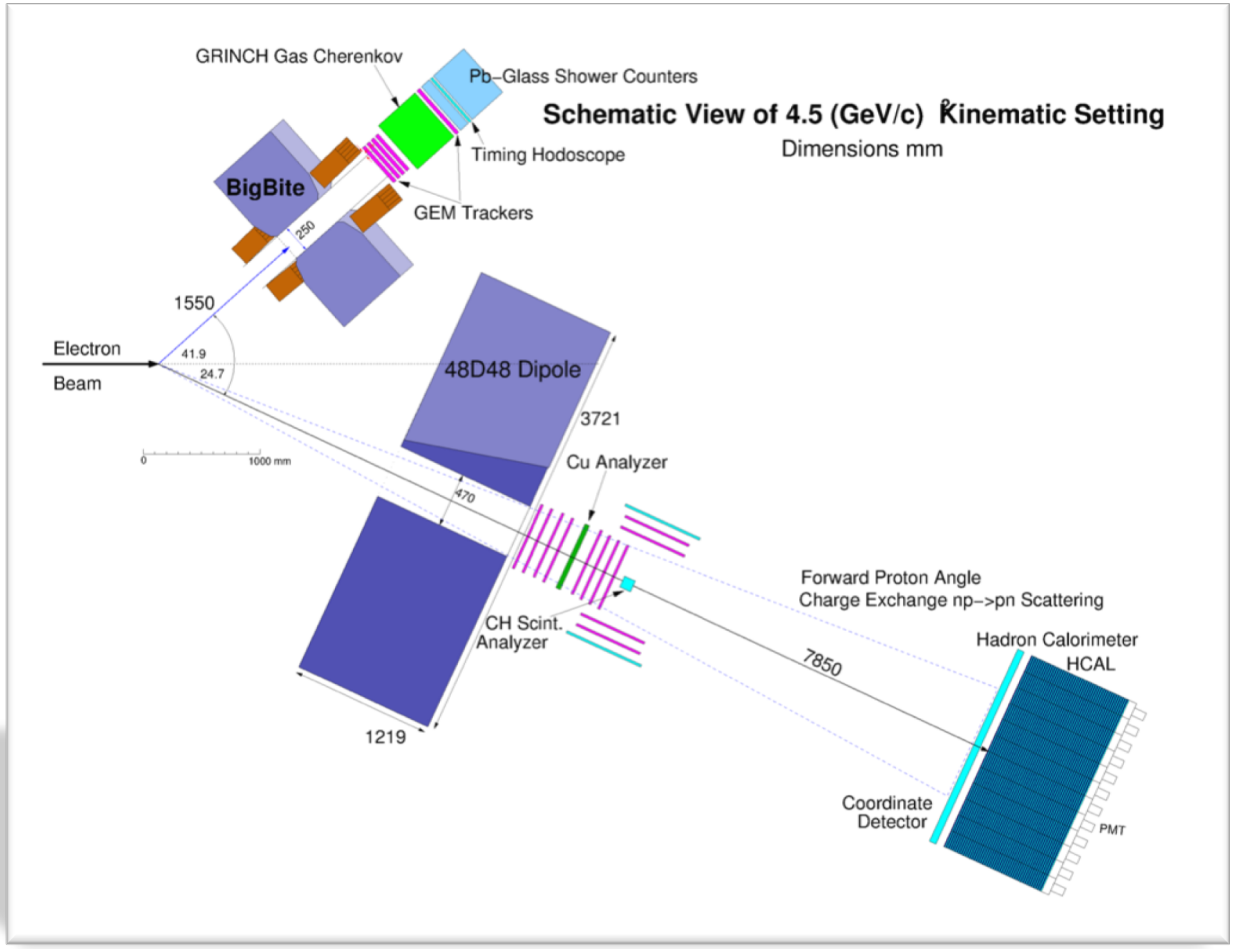
Predictions for π^-

- Measurements have been conducted for WACS for π^0 which show good agreement with handbag mechanism
- Calculations made by Kroll et al for WAPP π^- case
- Measurement will test the calculations as well as provide constraints for other models
- This measurement is fundamental, important and the first of its kind in the wide angle regime!

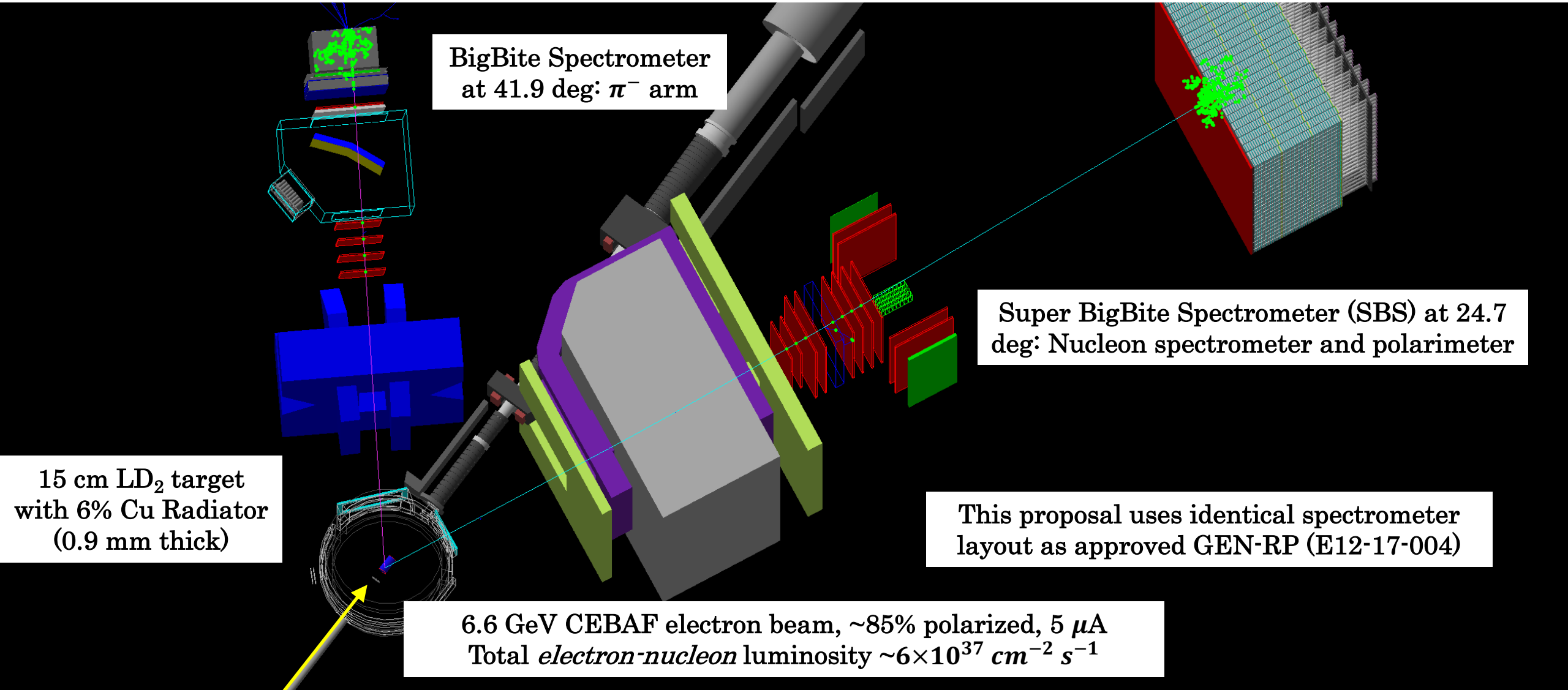


Experimental setup: same as GEn-RP setup

- 6.6 GeV electron beam (photons in the range 4.0 – 6.0 GeV)
- LD2 target with 6% Cu radiator upstream
- 5 micro amps beam for 2 PAC days to reach 5% absolute statistical uncertainty
- BigBite as the pion arm
- SBS as the nucleon arm
- Experiment approved!



A simulated WAPP ($\vec{\gamma}n \rightarrow \pi^- \vec{p}$) event in the GEN-RP setup



<Mandelstam variables>

$$4.0 \leq E_\gamma \text{ (GeV)} \leq 6.6$$

$$\begin{aligned} E_e &= 6.6 \text{ GeV} \\ \langle s \rangle &= 9.3 \text{ GeV}^2 \\ \langle -t \rangle &= 4.6 \text{ GeV}^2 \\ \langle -u \rangle &= 2.9 \text{ GeV}^2 \\ \langle \cos(\theta_{CM}) \rangle &= -0.22 \end{aligned}$$

- Acceptance-averaged Mandelstam variables are all sufficiently "large" for applicability of the handbag approach

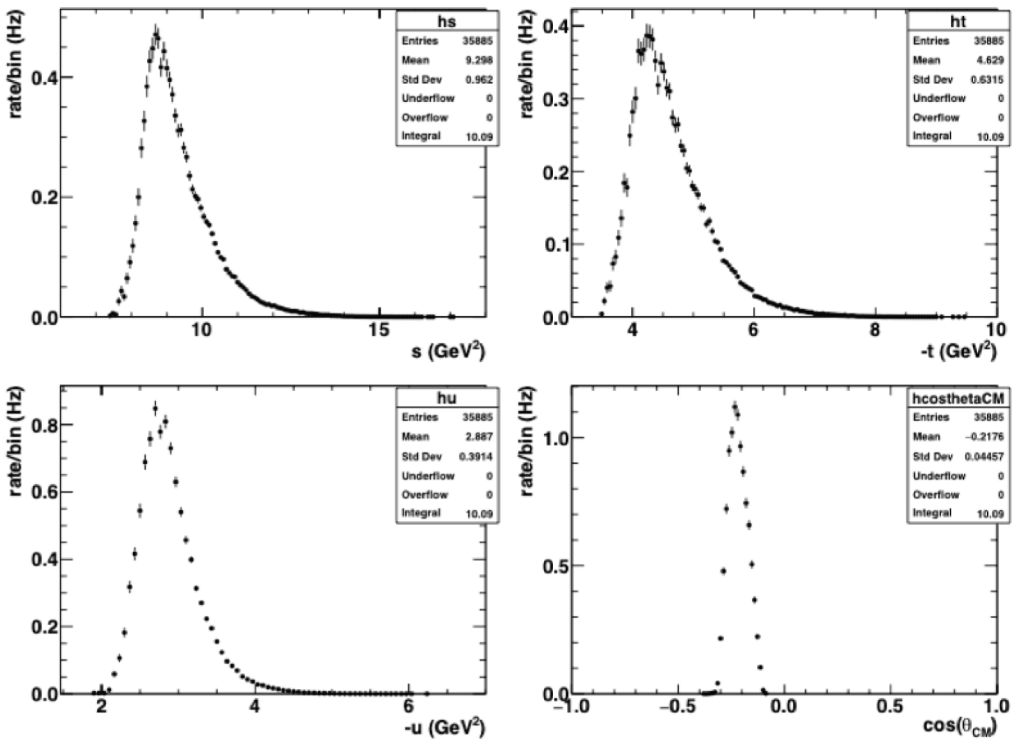
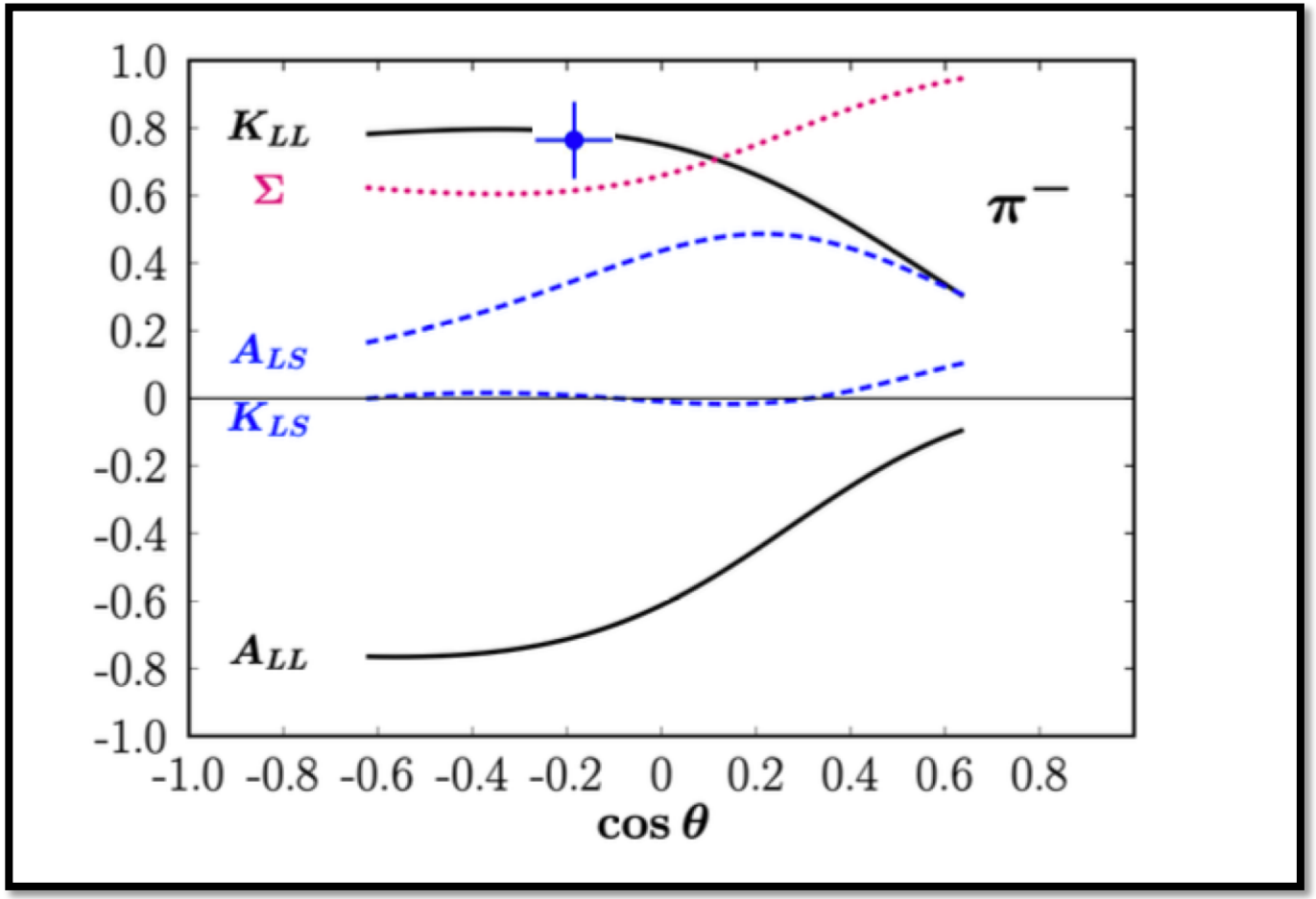


Figure 11: Distributions of s, $-t$, $-u$, and $\cos\theta_{CM}$ within the combined BigBite-SBS acceptance, from *g4sbs*, the SBS GEANT4-based Monte Carlo simulation package. See text for details.

Projected results for K_{LL}

$$\vec{\gamma}n \rightarrow \pi^- \vec{p}:$$
$$\Delta(K_{LL}) = \pm 0.05 \text{ (absolute)}$$
$$\Delta(K_{LS}) = \pm 0.05 \text{ (absolute)}$$



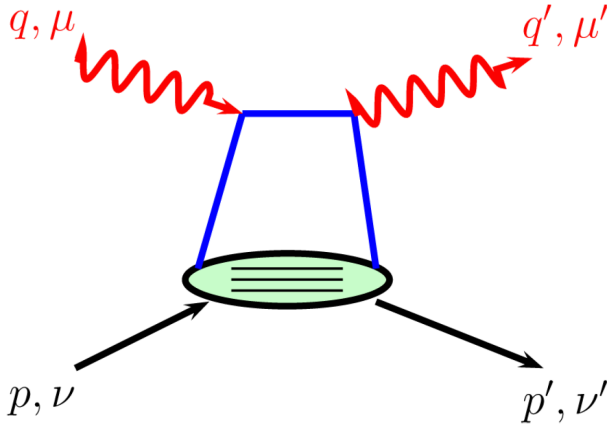
Summary

- Wide angle pion photoproduction is an interesting and a powerful took to study the interaction mechanism in the wide angle regime
- Calculations show that twist-3 not only important but dominate the Wide Angle regime
- A solution (handbag approach in the framework of GPDs) has been proposed and an independent test of the polarization observables is timely and necessary
- Experiment approved by PAC48 and will be incorporated into GMn run plan!
- We can test something fundamental that will contribute to the 3D picture of the nucleon

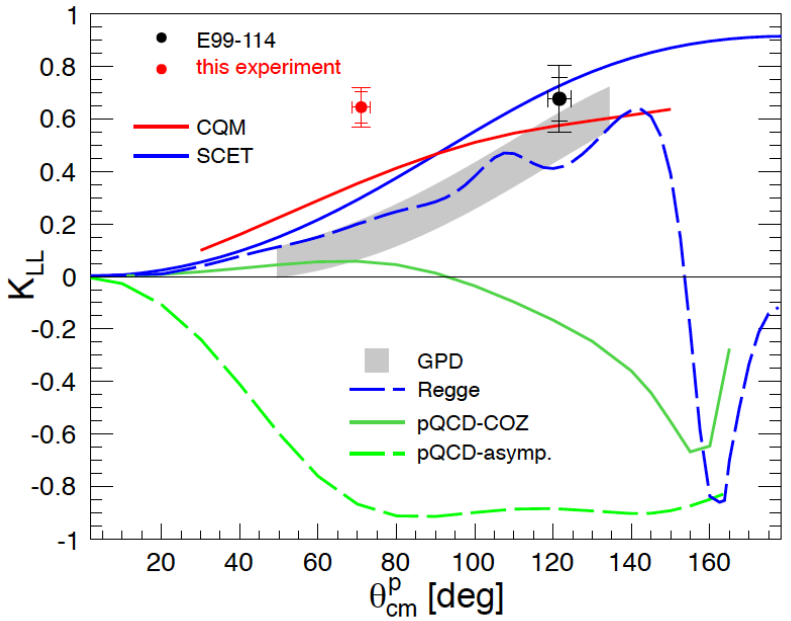
Thank you!

Slide courtesy: Andrew Puckett

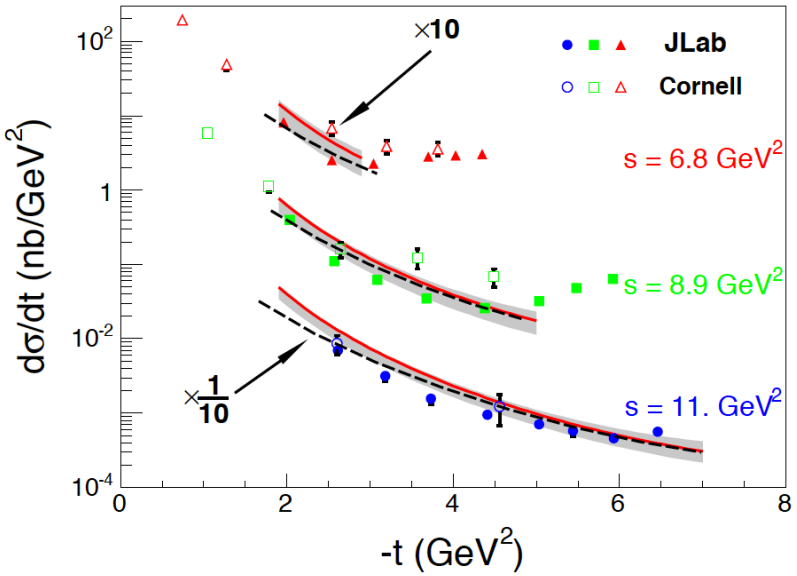
Real Compton Scattering (RCS)



Handbag diagram for RCS: Kroll, EPJ A, 53, 130 (2017)



RCS K_{LL}: Fanelli *et al.*, Phys. Rev. Lett. **115**, 152001 (2015) and Hamilton *et al.,* Phys. Rev. Lett. **94**, 242001 (2005)



RCS cross sections: A. Danagoulian *et al.*, PRL **98**, 152001 (2007), compared to GPD-based calculations

- RCS cross sections from Hall A in reasonable agreement with *leading-twist* GPD/handbag predictions
- Polarization transfer K_{LL} for RCS measured in Halls A and C.
  - Hall A result (2005) consistent with pre-existing GPD-based prediction
  - Hall C result (2015) not consistent with any calculation available at the time.
- Updated GPD calculations (Kroll, Eur. Phys. J. A **53** (2017) 6, 130) consistent with Hall C WACS K_{LL} result after improved modeling of poorly known axial GPD $\widetilde{H}$

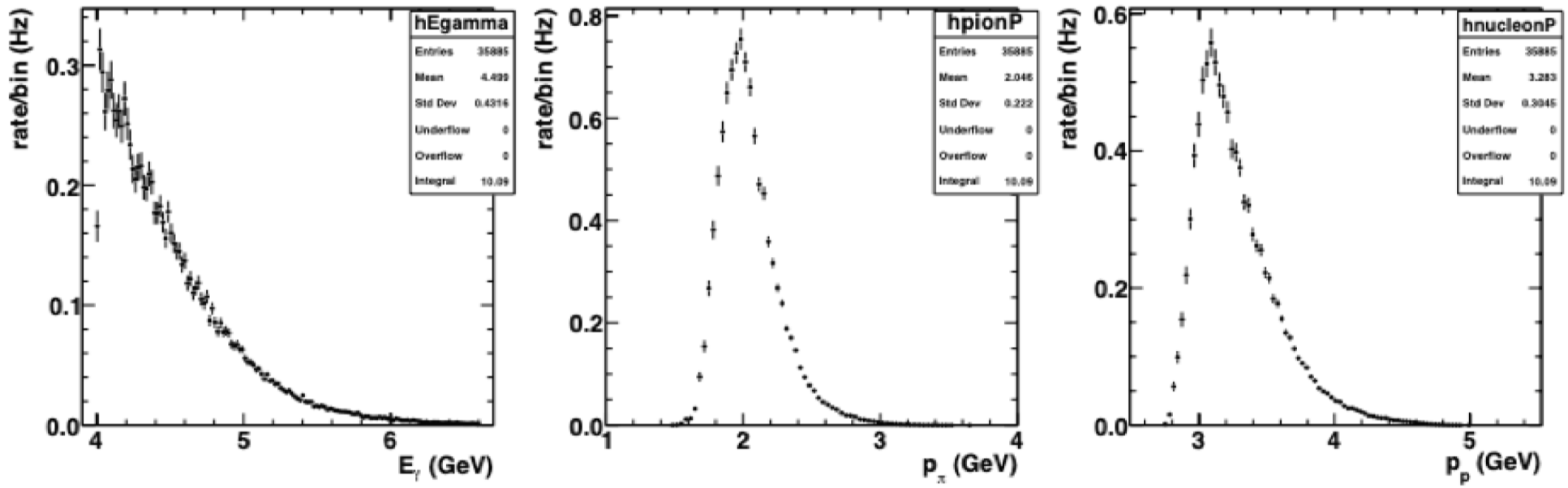


Figure 12: Distributions of E_γ, the incident photon energy, p_π, the π^- momentum in BigBite, and p_p, the proton momentum in SBS. Note that 4 GeV was the lower limit placed on E_γ for "signal" event generation.

$$s^7 \frac{d\sigma}{dt}(\gamma p \to \pi^+ n) \;=\; 0.828 \times 10^7 (1-z)^{-5}(1+z)^{-4} \;\left(\mathrm{nb/GeV^2 \cdot GeV^{14}}\right)$$

Single arm and coincidence rates

Table 1: Estimated single arm and coincidence trigger rates from PYTHIA, assuming 5 μA on 15-cm LD_2 target with 6% Cu radiator. The "Pion" logic consists of requiring the preshower signal to be *less than* 100 MeV and applying the indicated threshold on the *shower*. The "Electron" logic consists of applying the indicated threshold on the sum of preshower and shower signals. The coincidence timing window is assumed to be 30 ns wide for the accidental rate estimate.

Trigger Logic	"Pion"	"Pion"	"Electron"	"Electron"
Threshold (GeV)	0.2	0.5	0.2	0.5
"Signal" pion efficiency	75%	49%	97%	71%
BigBite singles rate (kHz)	422	91	976	289
HCAL singles rate (kHz)	416	416	416	416
Accidental coin. rate (kHz)	5.3	1.1	12.2	3.6
Real coin. rate (kHz)	6.2	2.5	14.3	6.5
Total coin. rate (kHz)	11.5	3.6	26.5	9.8
Physics signal rate ($\gamma n \to \pi^- p$, Hz)	16.3	10.4	23.5	17.2