Polarization Transfer in Charged Pion Photoproduction

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> 60 collaborators!

(A proposal to Jefferson Lab PAC48)

Polarization Transfer in Wide-Angle Charged Pion Photoproduction

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Contents

- Field of Meson Photoproduction
- Observed yet unexplained cross sections
- Theoretical efforts
- Possible solution: Polarization tests of handbag mechanism?
- What are we proposing?
- 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*

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High-Energy Physics Laboratory and Department of Physics, Stanford University, Stanford, California

(Received February 27, 1956)

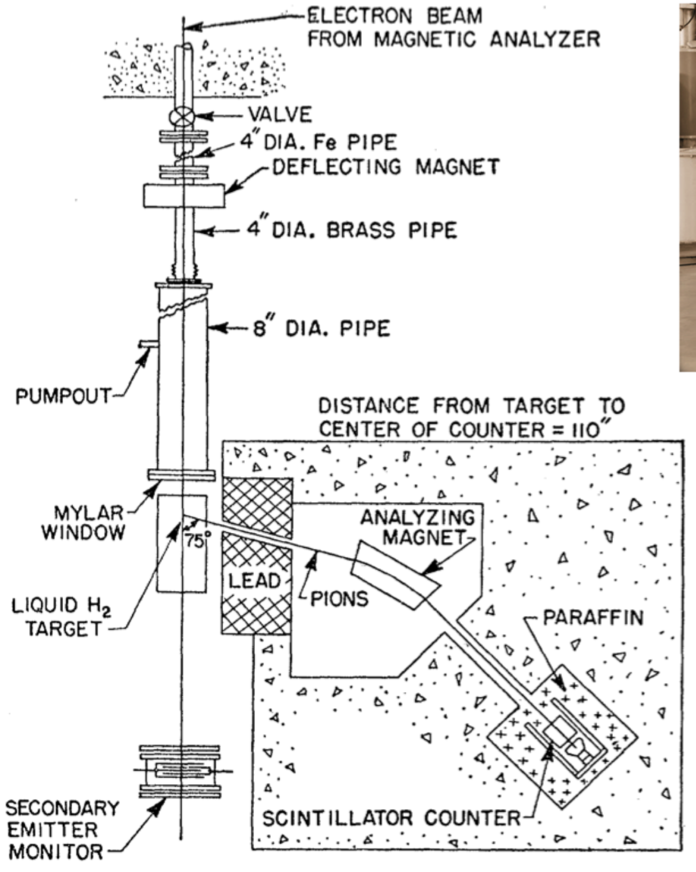
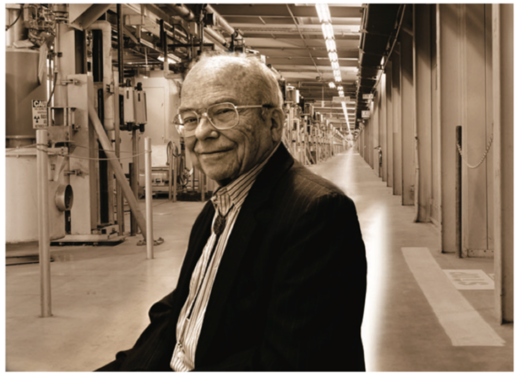


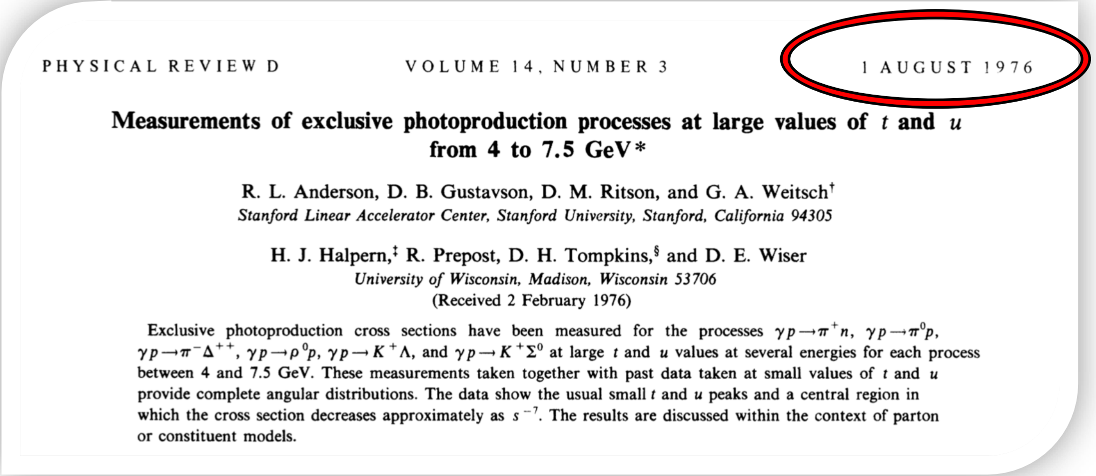
FIG. 3. Meson detection geometry.



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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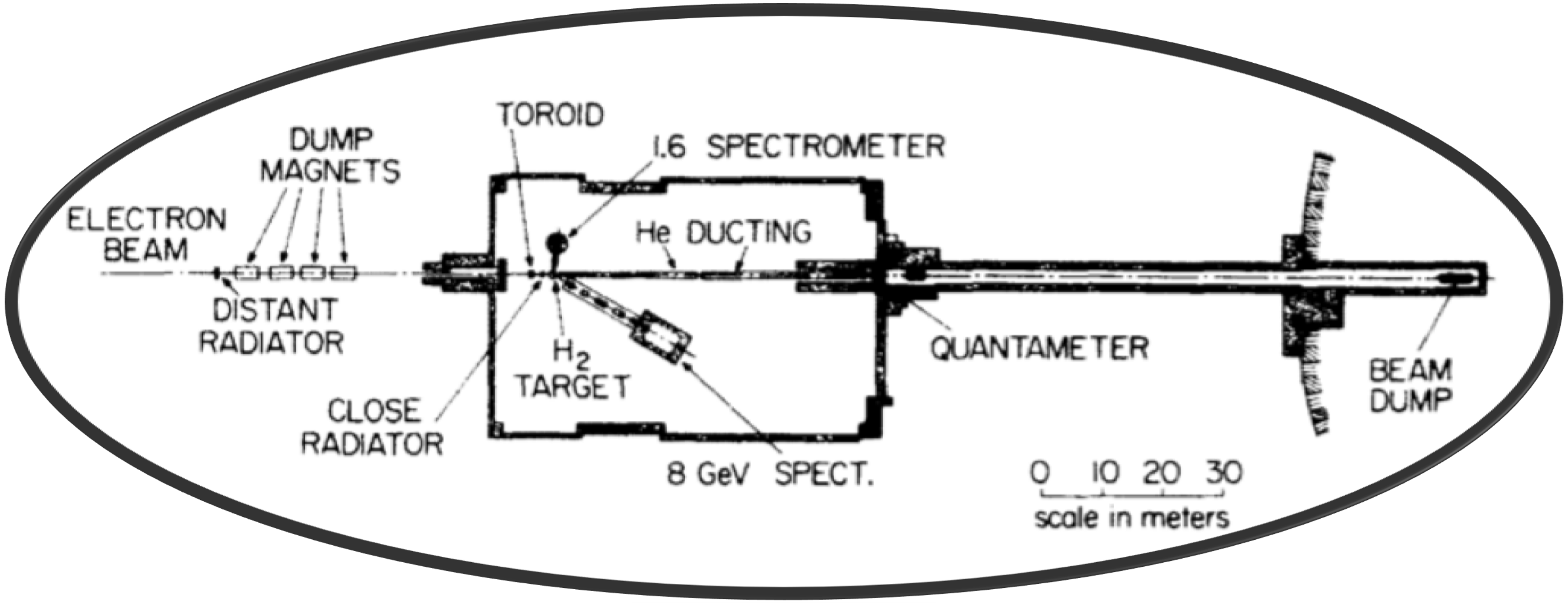
(Received 2 February 1976)

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

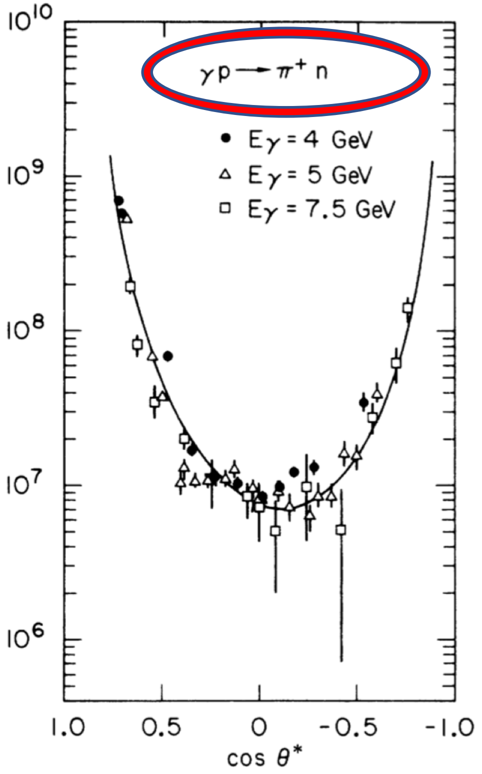


FIG. 6. $s^7 d\sigma/dt$ versus $\cos\theta^*$ for the reaction $\gamma p \to \pi^+ n$. The solid line shows the empirical function $(1-z)^{-5}(1+z)^{-4}$ where $(z=\cos\theta^*)$, which is an empirical fit to the angular distribution.

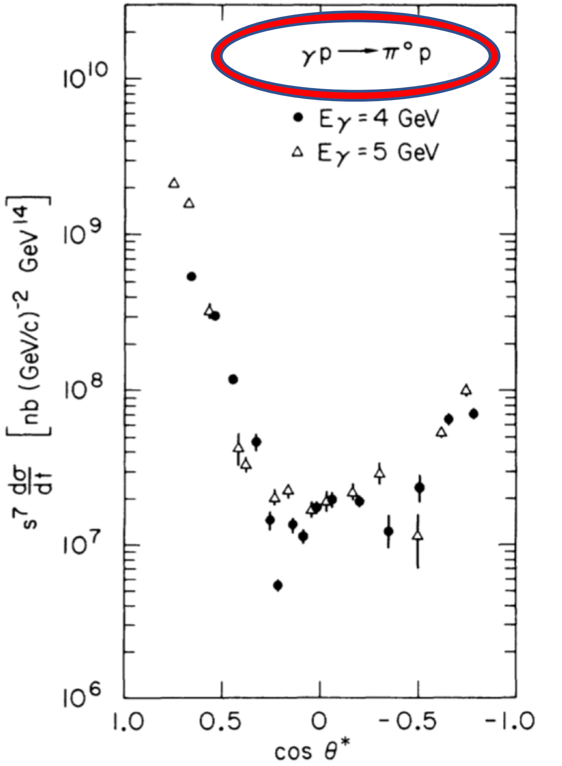


FIG. 9. $s^7 d\sigma/dt$ versus $\cos\theta^*$ for the reaction $\gamma p \to \pi^0 p$.

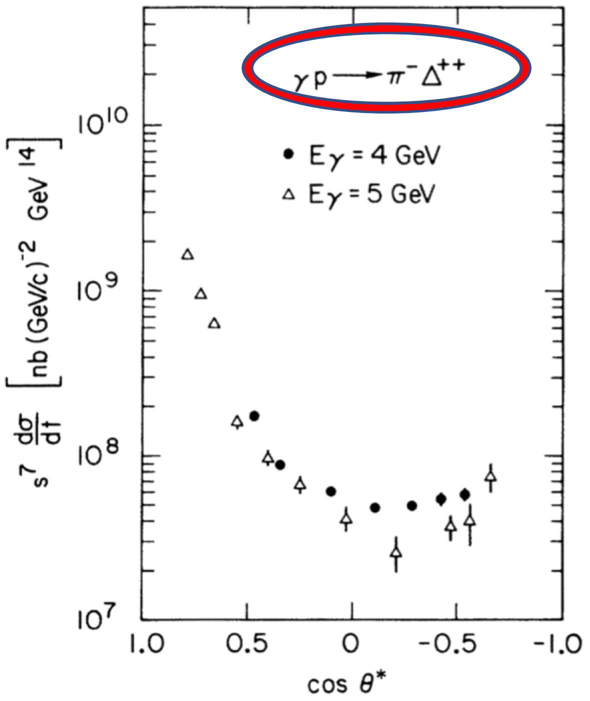


FIG. 12. $s^7 d\sigma/dt$ versus $\cos\theta^*$ for the reaction $\gamma p \to \pi^- \Delta^{++}$.

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)

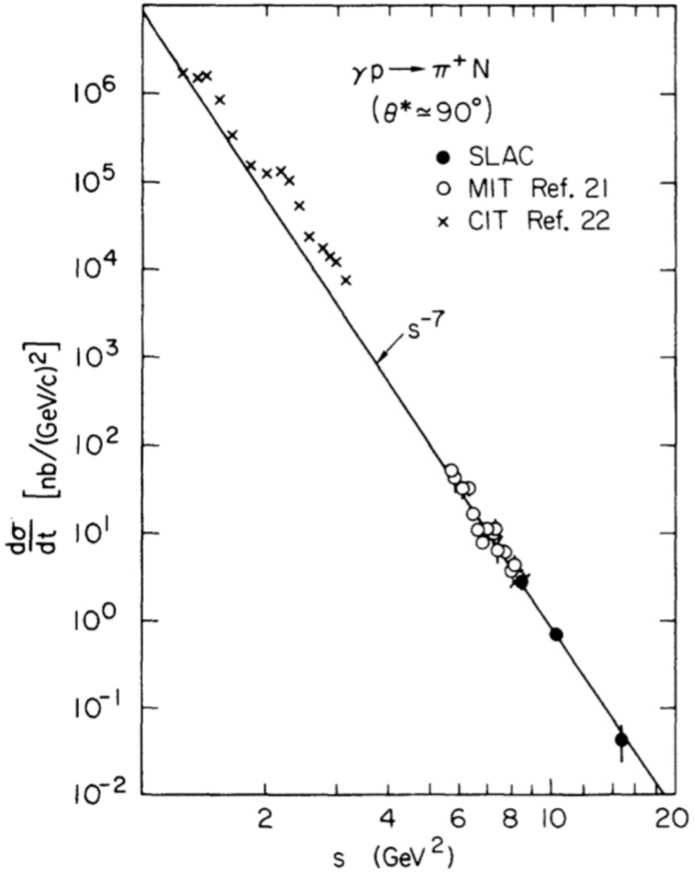


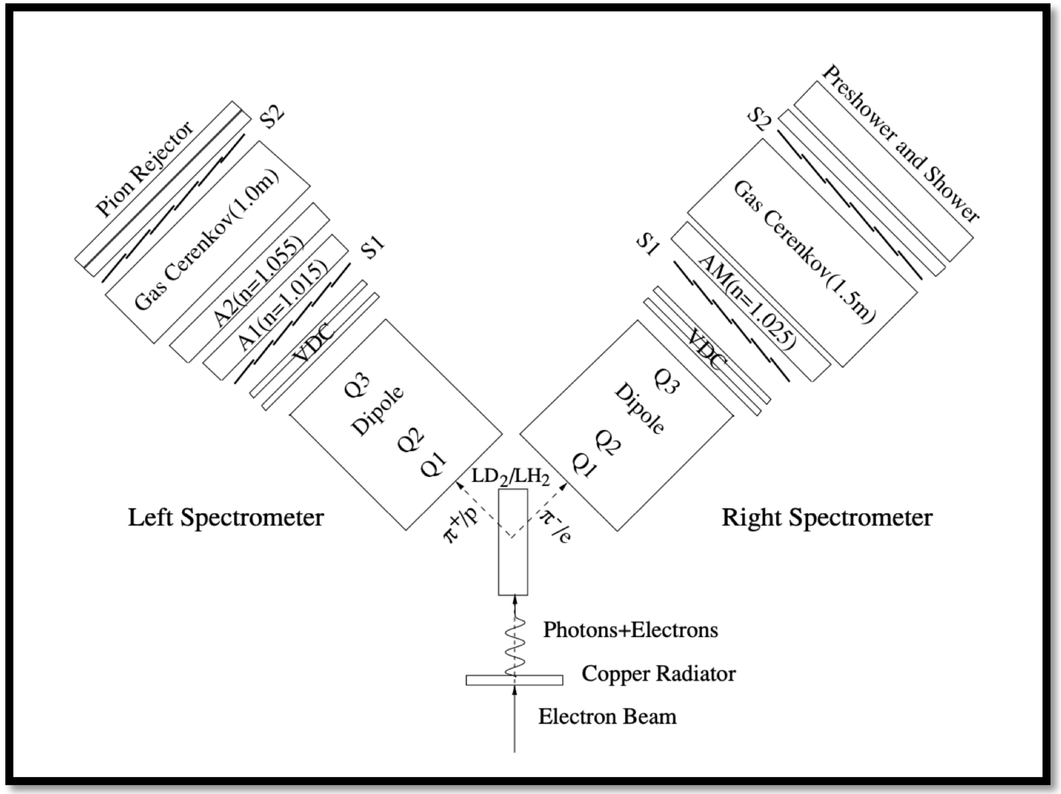
FIG. 20. 90° c.m. values of $d\sigma/dt$ versus s for the process $\gamma p \to \pi^+ n$ from several experiments from $E_\gamma = 700$ MeV to $E_\gamma = 7.5$ GeV. The solid line shows the function s^{-7} for reference.

Photoproduction experiments in Hall A

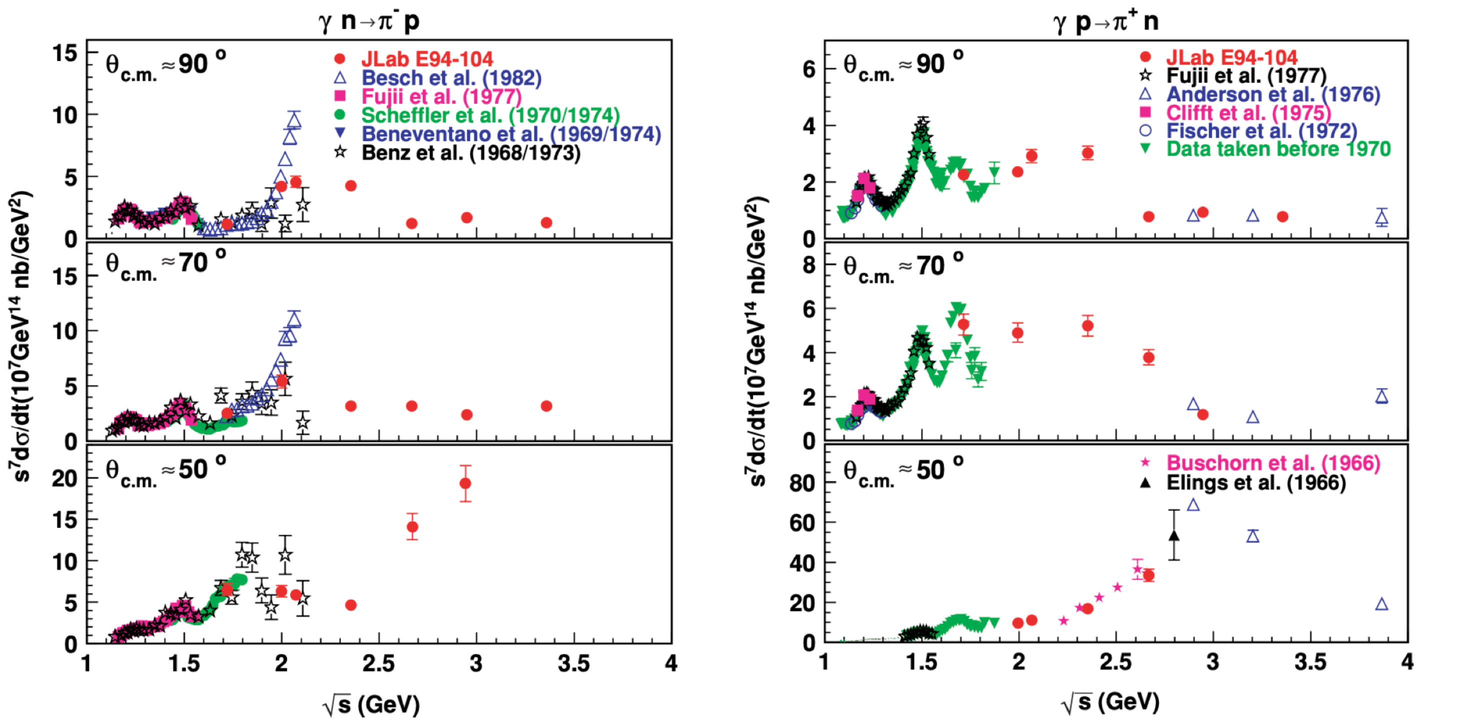
- Photoproduction experiments conducted in Hall A using LHRS and RHRS
- π^+ and π^- cross sections and their ratios studied for a range of s and t
- Many intriguing features that still have continued interest at Jefferson Lab

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



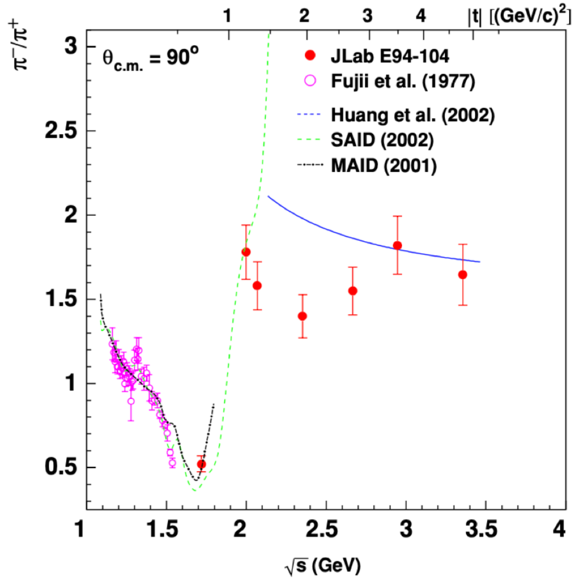


FIG. 18. (Color online). Exclusive charged pion ratio $d\sigma/dt(\gamma n \to \pi^- p)/d\sigma/dt(\gamma p \to \pi^+ n)$ versus center-of-mass energy $\sqrt{s}$ and momentum transfer squre $|t|$ at pion center-of-mass angle $\theta_{\mathrm{c.m.}} = 90^\circ$ from JLab E94-104 and previous world data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

But calculations fall short!

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

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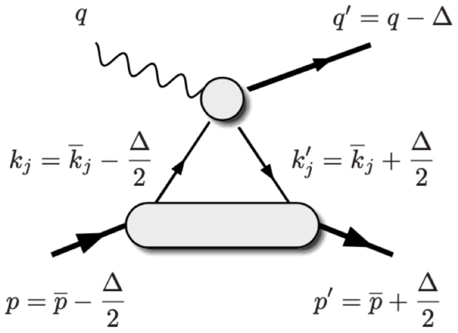

Fig. 1. The handbag diagram for photo- and electroproduction of mesons. The large blob represents a baryon GPD, while the small one stands for meson photo- and electroproduction off partons. The momenta of the various particles are indicated

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

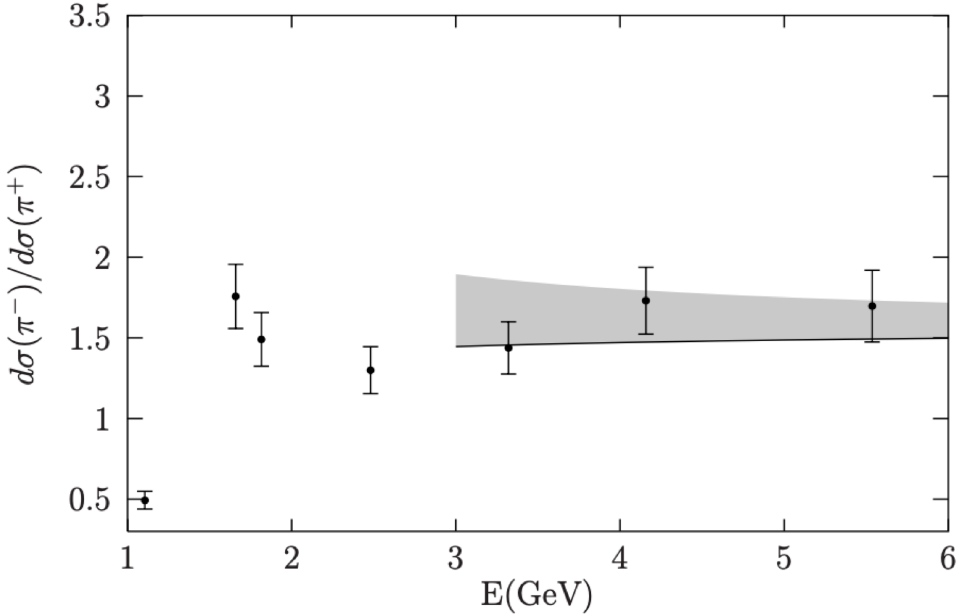

Fig. 4. The ratio of the $\gamma n \to \pi^- p$ and $\gamma p \to \pi^+ n$ cross sections versus photon beam energy E, at a CMS scattering angle of 90°. Data are taken from [31]. The solid line is the handbag prediction with the identification (48). The uncertainties due to target mass corrections [30]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

π^0 photoproduction experiments in Hall B

- Calculations using the Handbag model fall short by more than two orders of magnitude
- Missing some crucial information on the amplitude in the 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

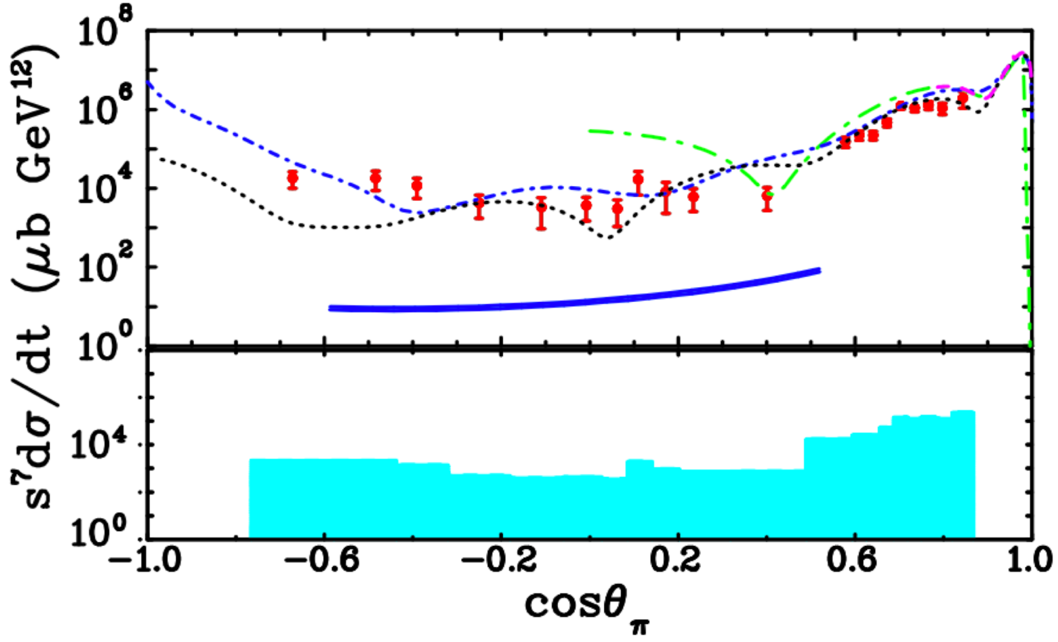

FIG. 5. Differential cross section of π^0 photoproduction. The CLAS experimental data at $s = 11$ GeV^2 are from the current experiment (red solid circles). The plotted uncertainties are statistical. The systematic uncertainties are presented as a shaded area in the subpanel. The theoretical curves for 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 twist 3

- Calculations with twist 2 and twist 3 contributions performed for π^0
- 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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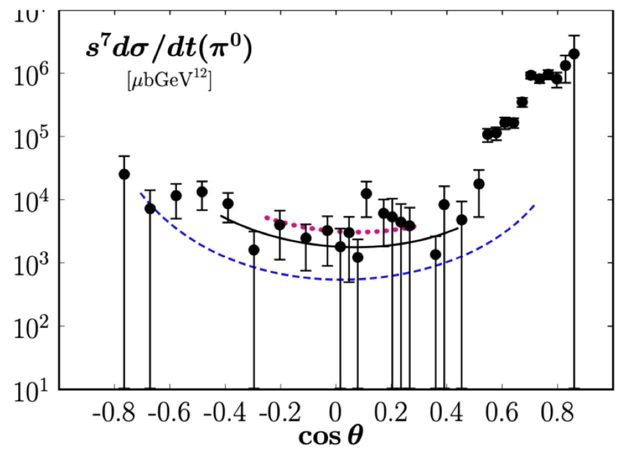


Figure 3: Results for the cross section of π^0 photoproduction versus the cosine of the c.m.s. scattering angle, θ. The solid (dashed, dotted) curves represent our results at $s = 11.06\,(20, 9)$ GeV^2. The data at $s = 11.06$ GeV^2 are taken from CLAS [34]. The cross sections are multiplied by s^7 and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

Helicity correlation observables

- Helicity correlations A_{LL} and K_{LL} provide tests of the handbag mechanism

- Twist 3 contribution dominates twist 2

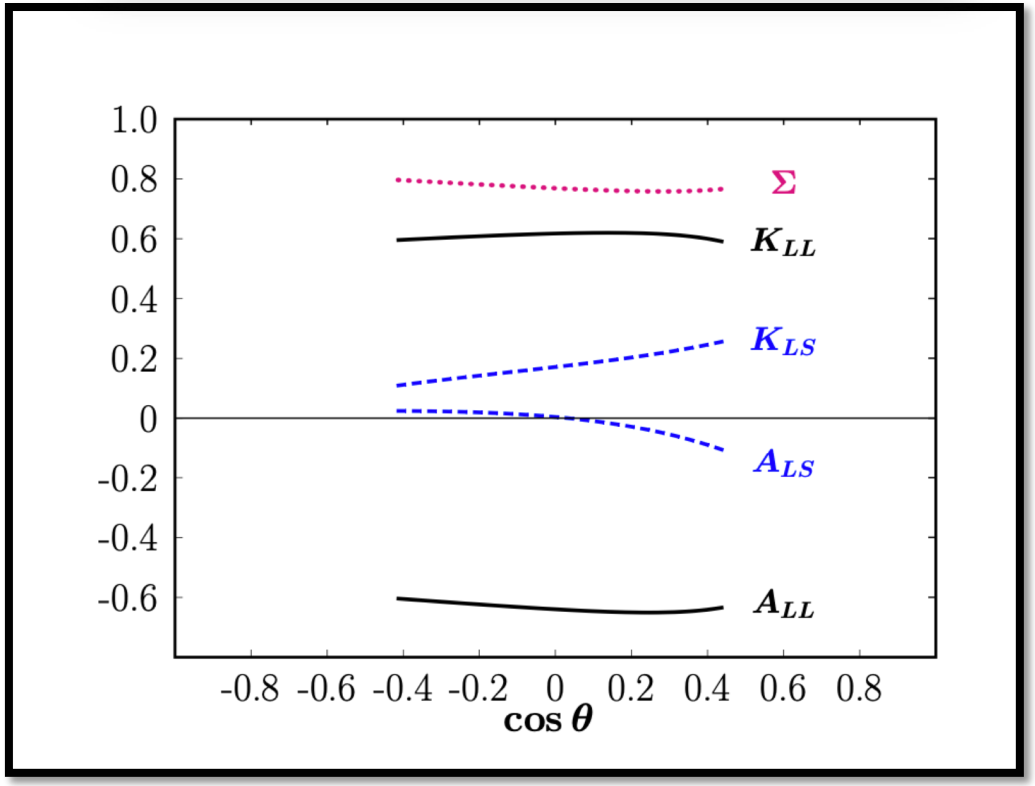
- Predictions made for pi0 and pi-

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

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

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

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



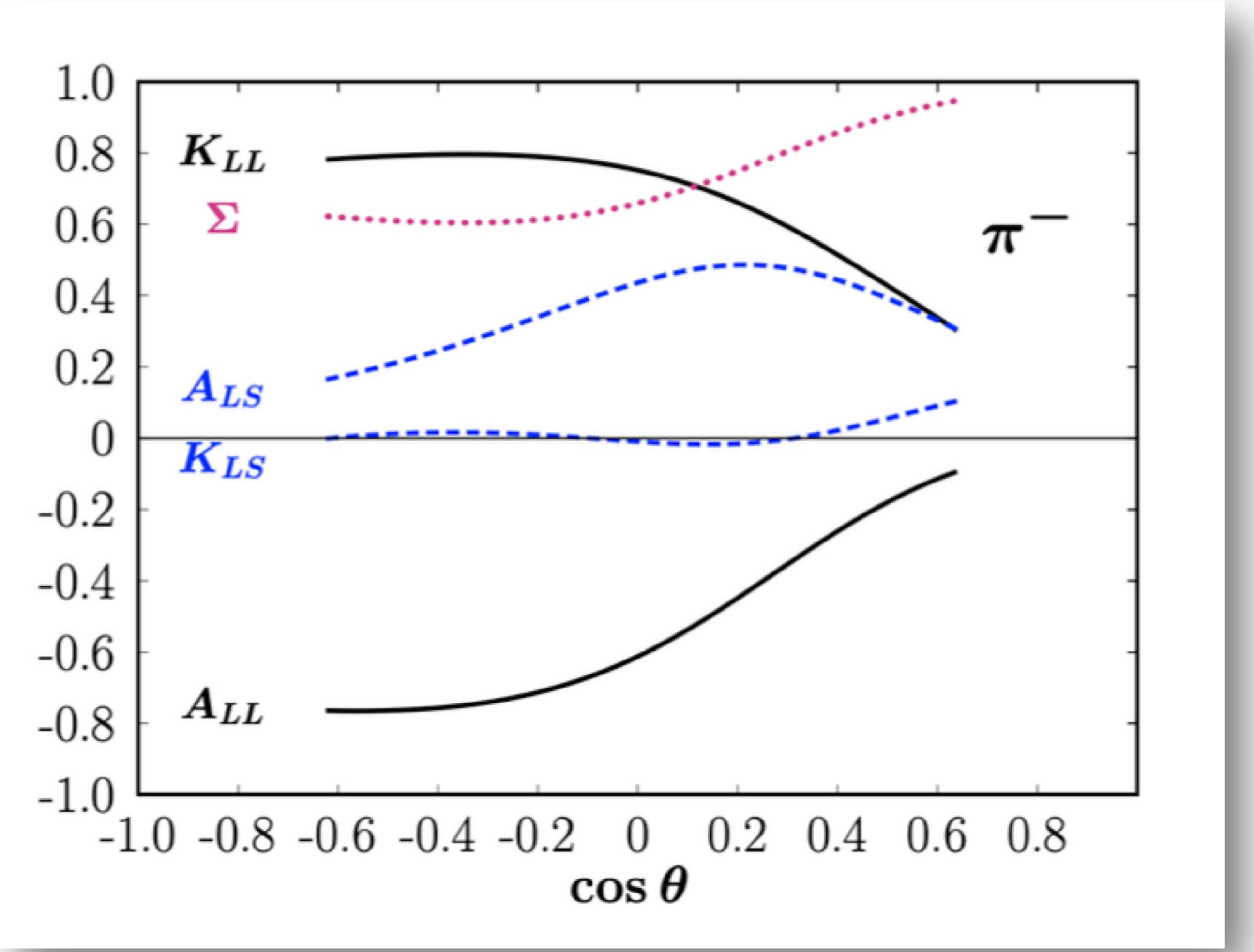
Predictions for π^-

- Measurements have been conducted for WACS for π^0 but not for WAPP

- Calculations made by Kroll et al for WAPP π^- case

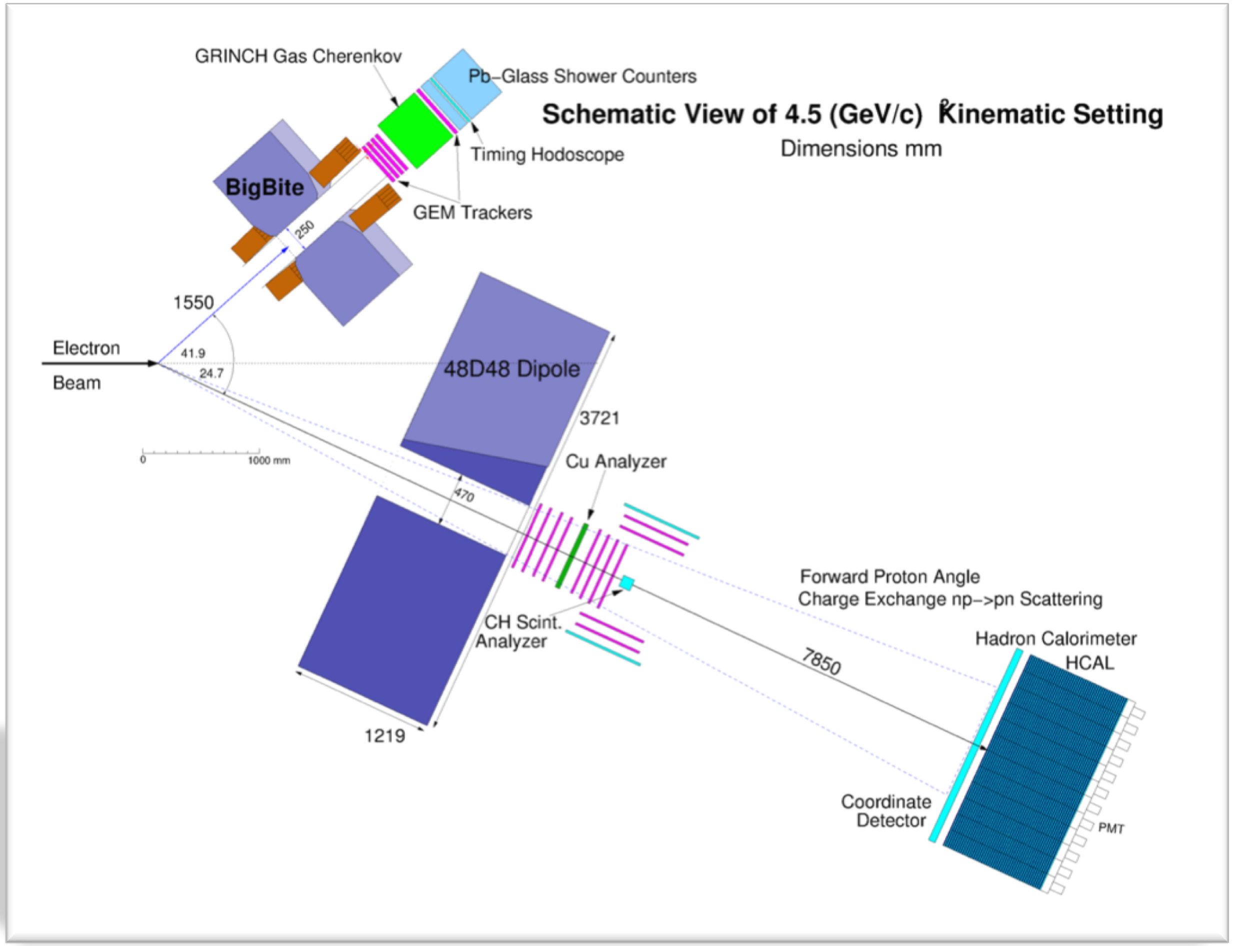
- Measurement will test as well as provide constraints for other models

- 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
- BigBite as the pion arm
- SBS as the nucleon arm



Mandelstam variables >> λ_{QCD} to test out handbag mechanism

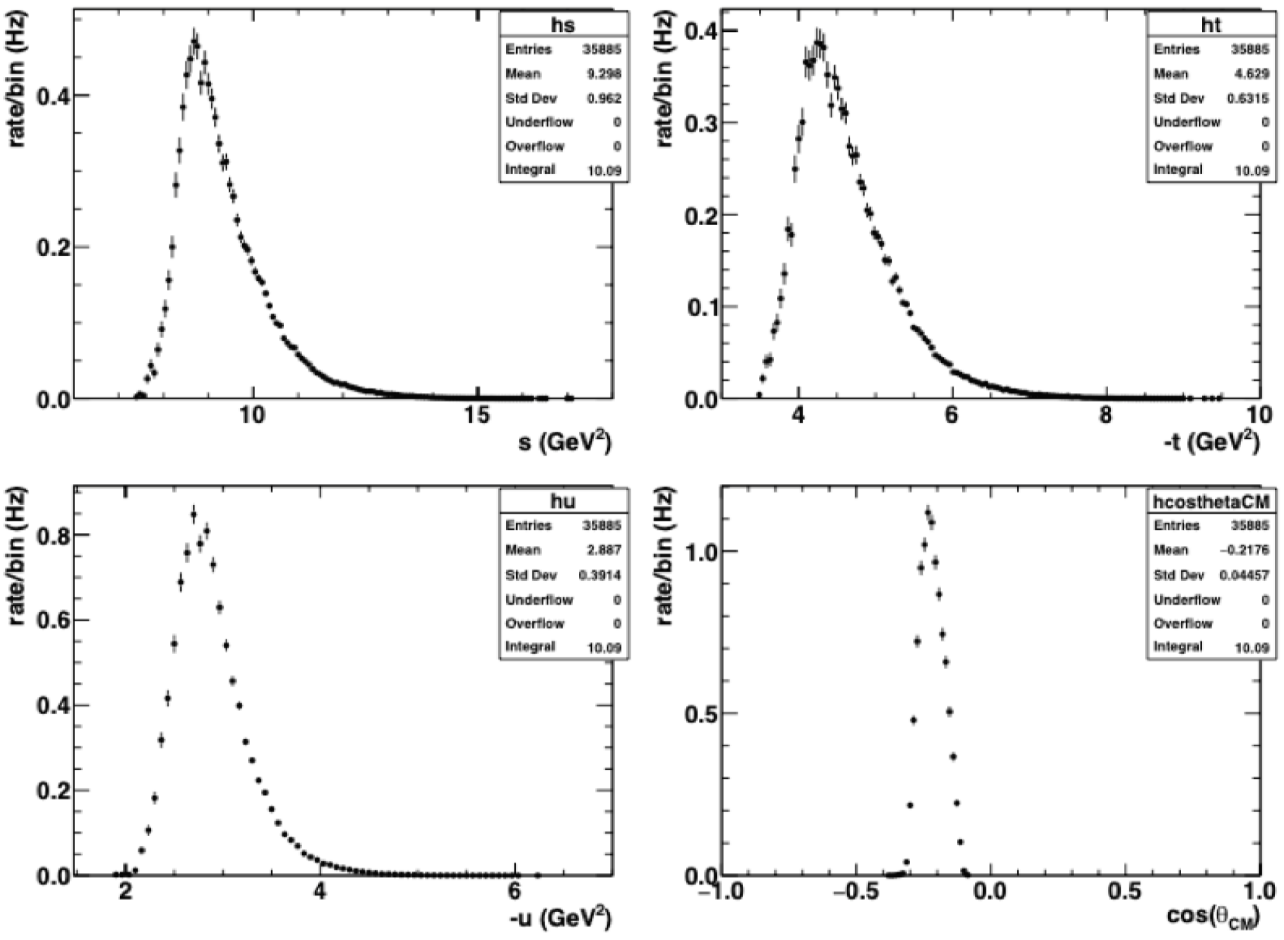


Figure 11: Distributions of s, $-t$, $-u$, and $\cos\theta_{CM}$ within the combined BigBite-SBS acceptance, from *g4sbs*, the SBS GEANT4-based Monte Carlo simulation package. See text for details.

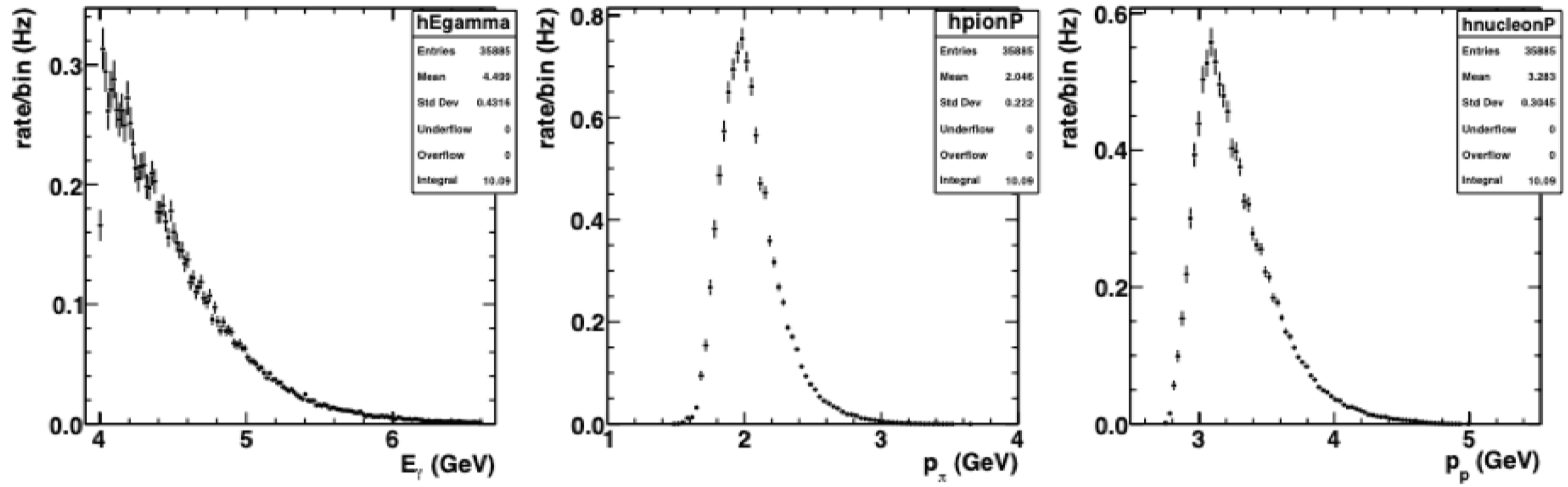


Figure 12: Distributions of E_γ, the incident photon energy, p_π, the π^- momentum in BigBite, and p_p, the proton momentum in SBS. Note that 4 GeV was the lower limit placed on E_γ for "signal" event generation.

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

Energy deposition in the preshower and shower

- GEn-RP trigger designed to have increased e$^-$ efficiency
- Threshold cuts have to be applied on at the trigger level to suppress e$^-$ and increase pion detection efficiency
- Need to demonstrate the feasibility of such a configuration change

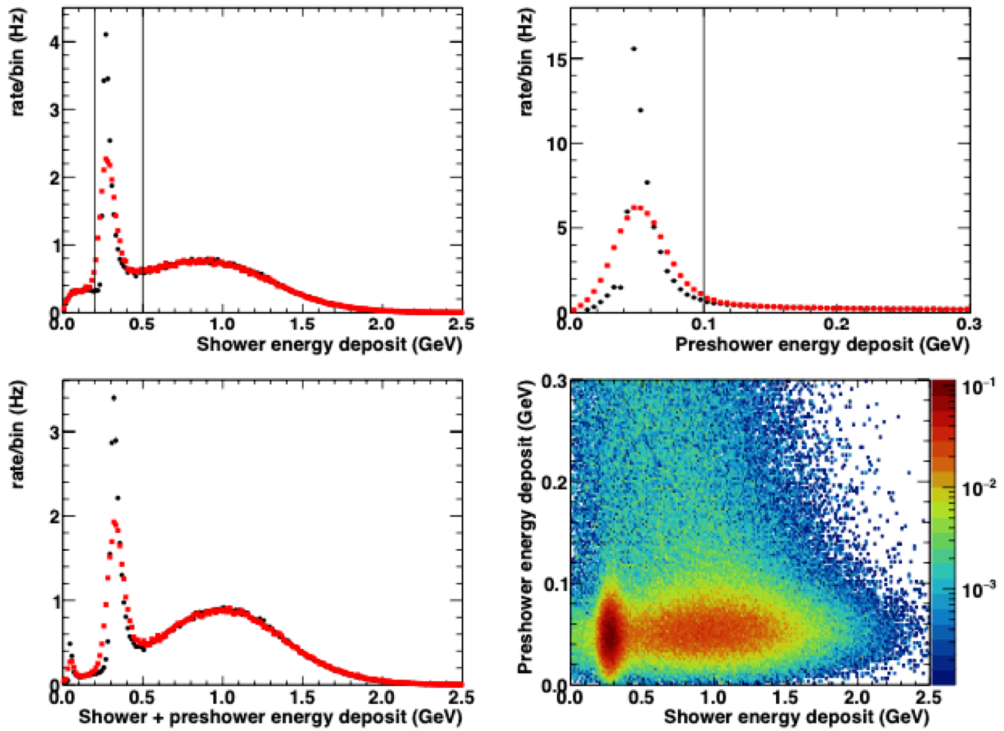
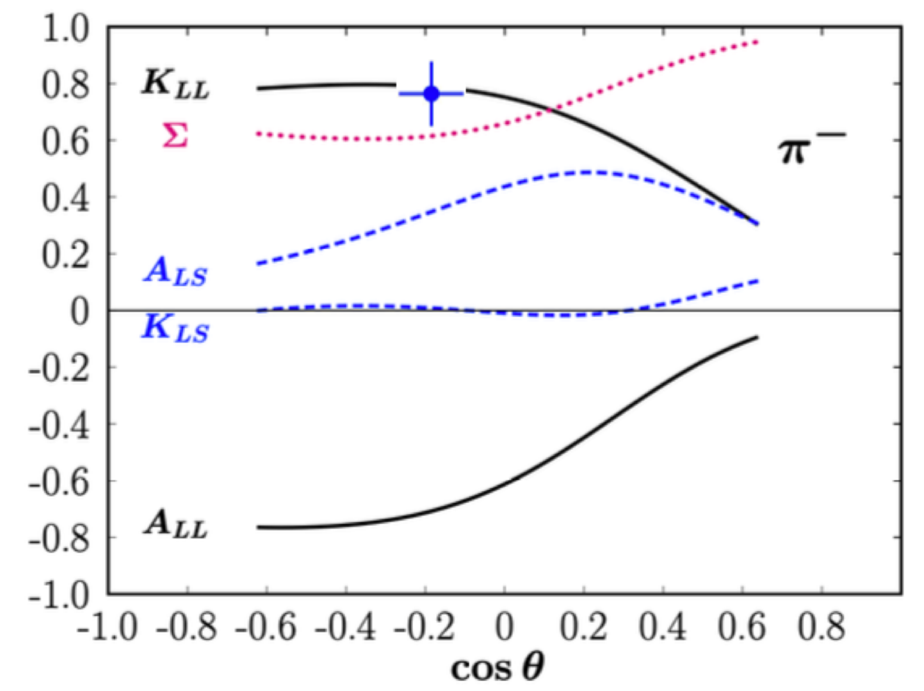


Figure 13: Simulated preshower and shower energy depositions by good signal π^-, illustrating the BigBite trigger logic for charged pions. Black circles represent the "true" energy depositions, while red squares represent the energies smeared by the calorimeter energy resolution. Top Left: shower energy deposition. The vertical lines at 0.2 GeV and 0.5 GeV represent possible thresholds. Top Right: preshower energy deposition, illustrating dominant minimum-ionizing peak. The vertical line illustrates the "veto" threshold above which triggers will be rejected, as they are predominantly electron and photon-induced. Bottom left: Sum of shower and preshower for good signal π^-. Bottom right: correlation between preshower and shower signals, smeared for detector resolution.

Projected results for K_{LL}

- 48 hours with 16 hours beam energy change procedure (4.4 to 6.6 GeV)
- 5 micro amps electron beam
- 15 cm LD_2 target with 6% Cu radiator upstream (already included in GMn run plan)
- Photons with 4.0 – 6.0 GeV impinge on the target
- π^- will be detected by the BigBite arm and proton by SBS arm with spectrometer angles same as the GEn-RP setup



E_γ	$< s >$	$< -t >$	$< -u >$	K_{LL}	K_{LS}
GeV	$(\mathrm{GeV}/c)^2$	$(\mathrm{GeV}/c)^2$	$(\mathrm{GeV}/c)^2$	accuracy	accuracy
4.5-5.5	9.3	4.6	2.9	± 0.05	± 0.05

Summary

- Wide angle pion photoproduction is an interesting and a powerful took to study the interaction mechanism in the wide angle regime

- A solution (handbag approach in the framework of GPDs) has been proposed and a test of the polarization observables is timely and necessary

- Proposal has been submitted to PAC48

- With minimal beam time request and experiment configuration change, we can test something fundamental that will contribute to the 3D picture of the nucleon

- There is an intention to measure A_{LL} using polHe3 (proposal to a future PAC)!

Thank you!

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