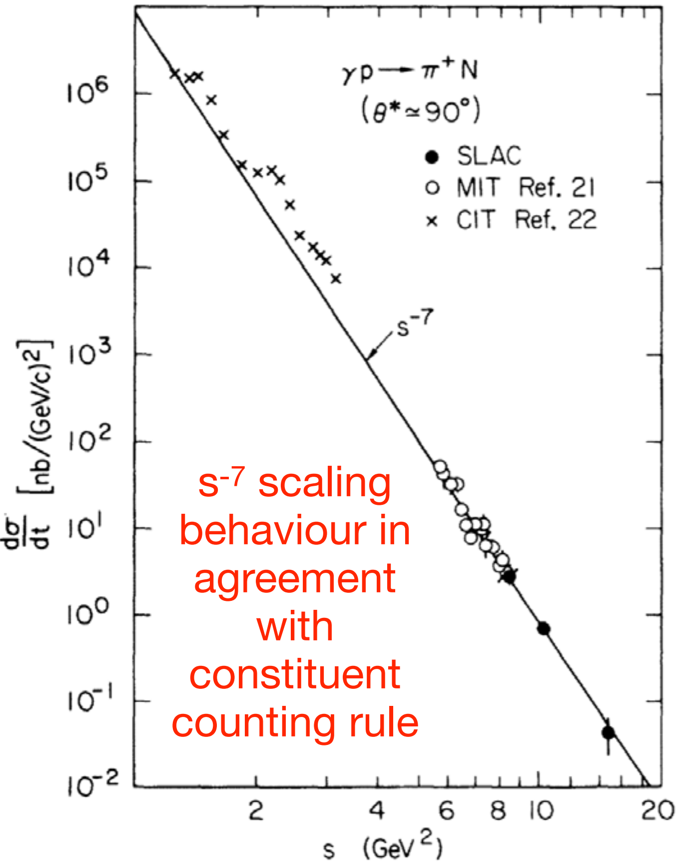
Double Spin Asymmetry in Wide Angle Charged Pion Photoproduction

Experiment E12-21-005

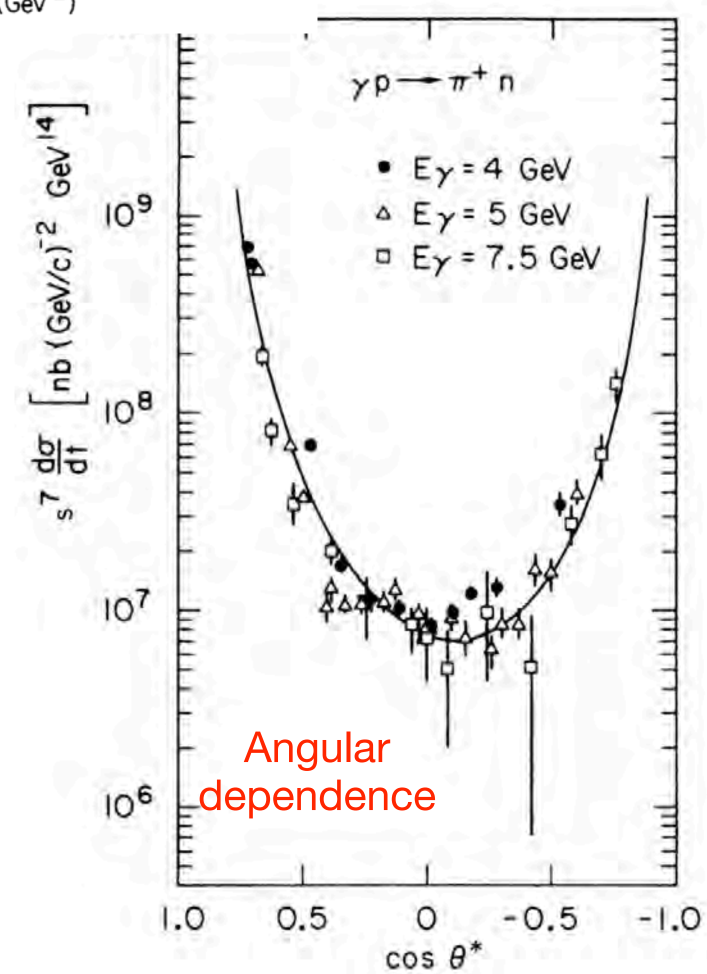
Spokespeople:
G. Cates (UVa);
R. Montgomery (UoG);
A. Tadepalli (JLab);
B. Wojtsekhowski (JLab)

And WAPP Collaboration
who supported proposal

SBS Weekly Meeting
6th December 2021



Phys. Rev. D 14, 679 (1976)



- Pion is crucial component in nuclear physics
  - long range nucleon-nucleon interaction; simplest QCD state; dynamical chiral symmetry breaking; nucleon/nuclear PDFs, up/down sea-antiquark asymmetry…

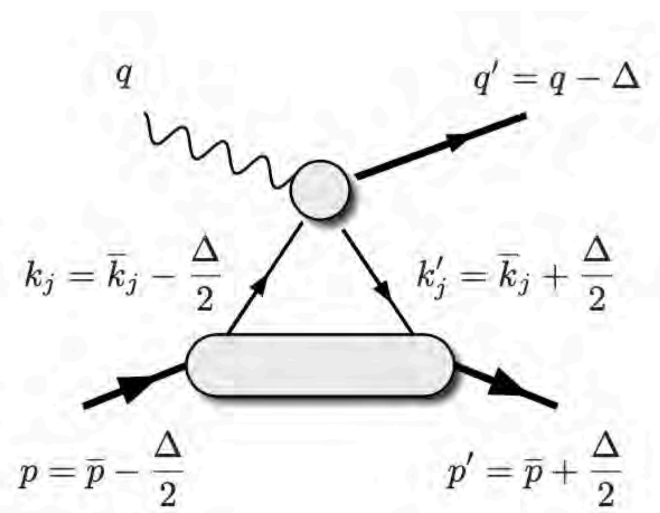
- Meson photoproduction γN→πN been around for long time
  - Simplest inelastic hadronic process → important testing ground for understanding of hadronic physics
  - Key probe in transition from meson-nucleon to quark-gluon degrees of freedom in exclusive processes

  - Initial studies @ SLAC in 1950's
  - Rich history on pion photoproduction since
    - SLAC, JLab, Bonn, Mainz, Spring-8
  - Lots of data in near threshold (EFT) and resonance (PWA) regions…different physics
  - Limited data in above resonance region (pQCDs, GPDs)

  - Many intriguing features observed and partly understood
  - e.g. scaling behaviour of meson photoproduction

  - Absolute cross-sections expected to be calculable in wide angle regime at sufficiently large s, -t, -u >> Λ^2_{QCD}
  - Large discrepancy between calculations and experiments exists

- Large interest in finding dominant mechanism of γN→πN and having QCD based calculation



H.W. Huang, P. Kroll, T. Morii,
Eur. Phys. J. C 23, 301 (2002)

Handbag mechanism: one q from ingoing and one q from outgoing nucleon participate in hard process only. Others are spectators

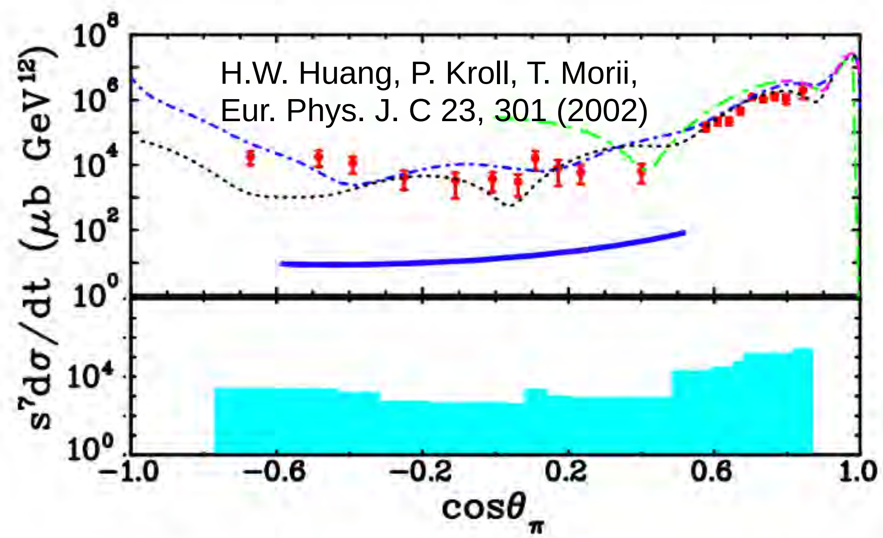
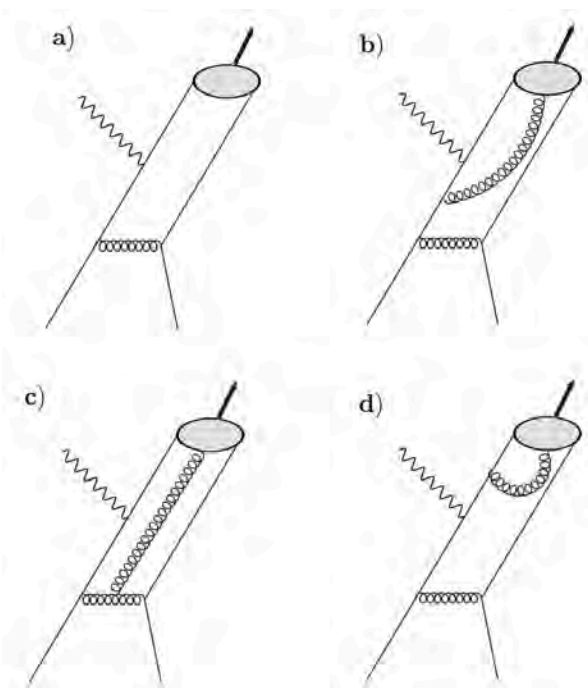


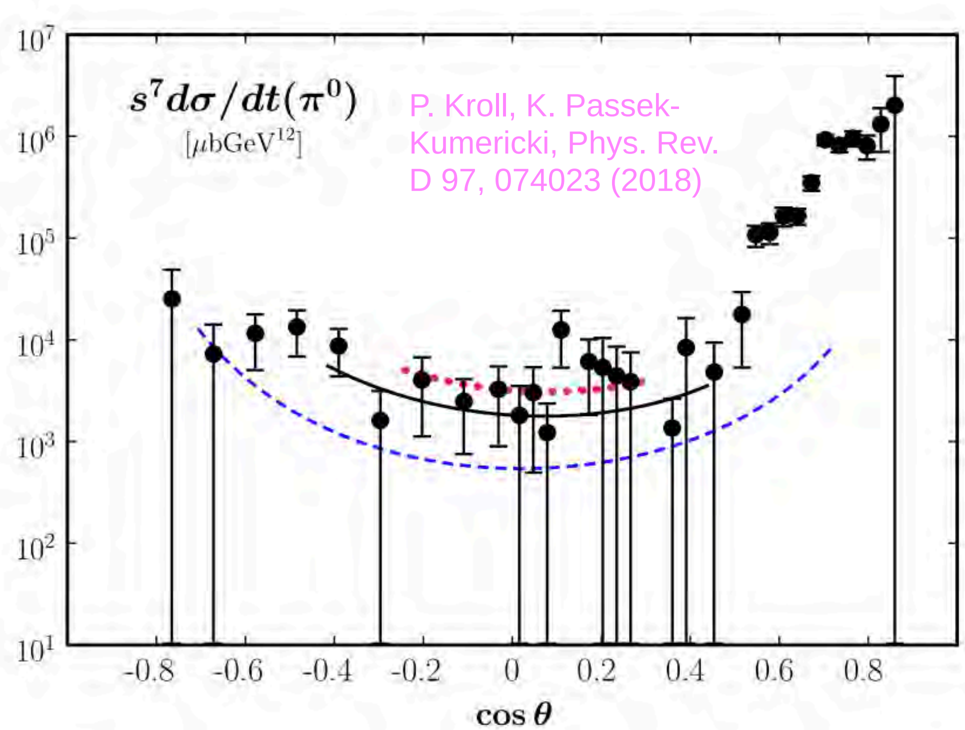
FIG. 5. Differential cross section of π^0 photoproduction. The CLAS experimental data at $s = 11$ GeV^2 are from the current experiment (red solid circles). The plotted uncertainties are statistical. The systematic uncertainties are presented as a shaded area in the subpanel. The theoretical curves for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

- Above resonance region and at sufficiently large s, -t, -u >> Λ^2_{QCD} GPD treatment should work
- Leading order treatment describes real Compton scattering quite well for chosen kinematics
- However calculations including twist-2 amplitudes underestimate CLAS π^0 cross-sections by >2 orders of magnitude

- Twist-2 treatment within GPD framework not sufficient
- Not describing fully nature of interaction mechanism!



B, c, d are twist-3 Fock components for DA



- Recent calculations by Kroll et al. found that inclusion of twist-3 contributions are dominant factor in agreement with cross-section

Twist-3 Dominance and the Smoking Gun for Experimentalists

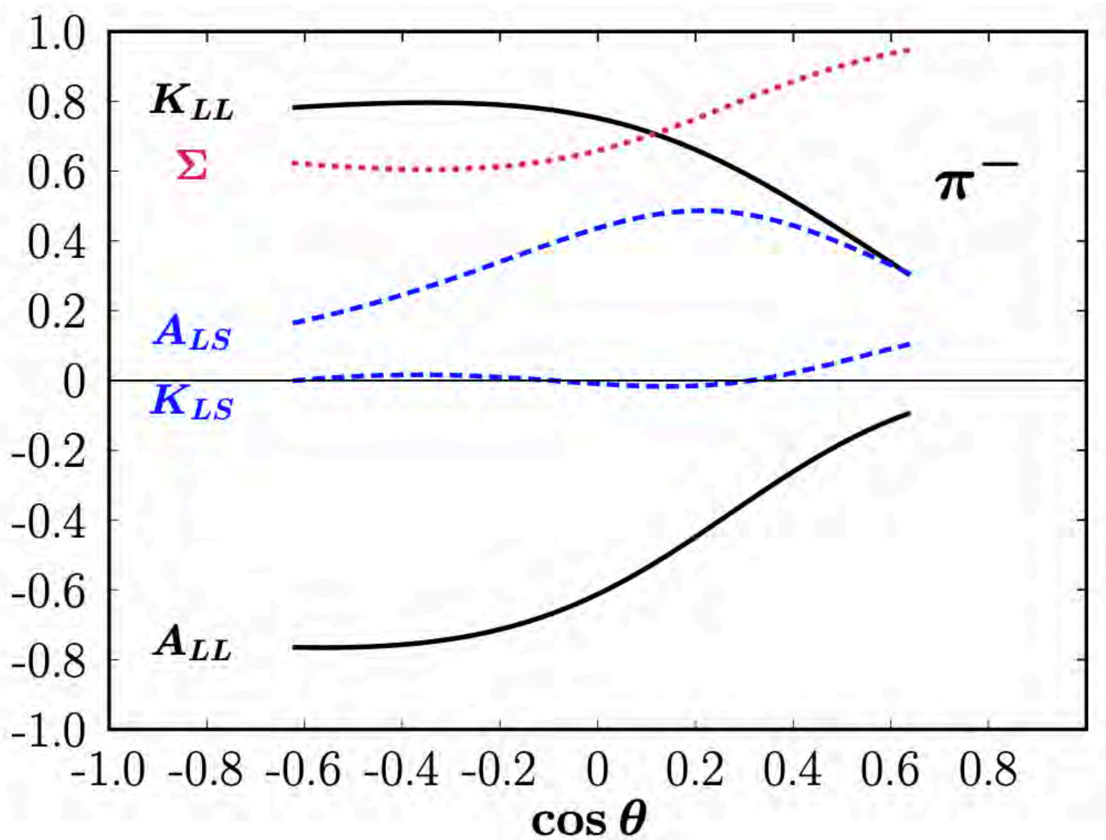
- Recent theoretical calculations by P. Troll and K. Passek-Kumericki appear to solve issue
- Phys Rev D 97, 074023 (2018)
- GPD-based theory including twist-2 and twist-3 amplitudes
- Range of applicability is s, -t, -u >> Λ^2_{QCD}

- Predictions suggest dominance of twist-3 contributions
- Signatures of twist-3 amplitudes: cross-sections and double polarisation observables A_{LL} and K_{LL}
- Measurements of A_{LL} and K_{LL} in this kinematic regime extremely valuable for testing validity of handbag mechanism in GPD framework

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

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

- Spin dependent polarisation observables KLL and ALL
- Correlations between helicities of incoming photon (+ or -) and longitudinal polarisation component for initial nucleon (A_{LL}) or final nucleon (K_{LL})



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

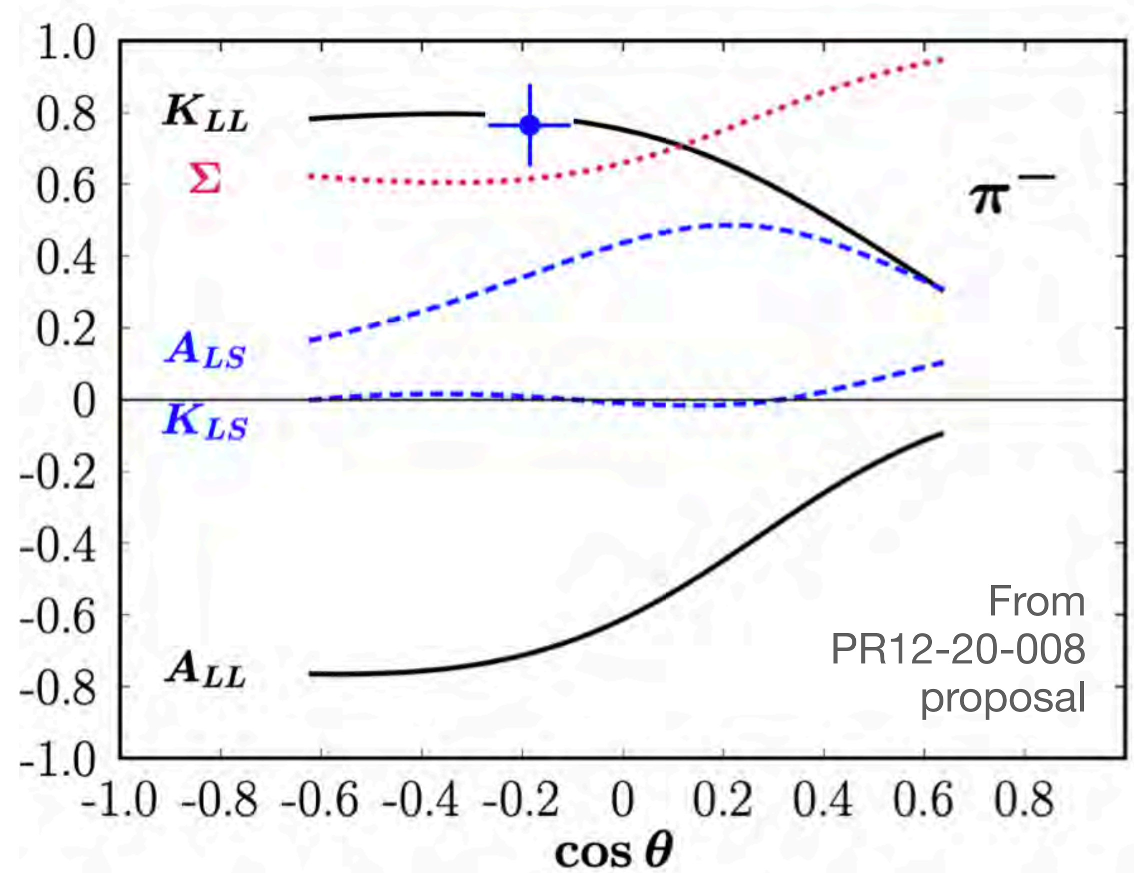
$$A_{LL}^{twist-3} = -K_{LL}^{twist-3}$$

If twist-3 dominant: sign of K_{LL} opposite to A_{LL}

Never before measured for charged pions in wide angle regime… SBS can deliver this…

WAPP I

- PAC48 2020
- Proposal PR12-20-008
- "Polarisation Transfer in Wide-Angle Charged Pion Photoproduction"
  - Accepted → Experiment **E12-20-008**
  - 2 PAC days awarded
  - Will coincide with GEn-RP



PR12-20-008

Scientific Rating: B+

Recommendation: Approved

Title: Polarization Transfer in Wide-Angle Charged Pion Photoproduction

Spokespersons: J. Arrington, A.J.R. Puckett (contact), A.S. Tadepalli, B. Wojtsekhowski

Motivation: This experiment plans to measure the helicity correlation parameters K_{LL} and K_{LS} for π^- photoproduction in the wide-angle regime. The nature of the interaction mechanism for this relatively simple process is not yet well understood. Theoretical studies based on GPDs suggest the dominance of twist-3 contributions and predict a sizeable and positive K_{LL} and a small K_{LS}.

Measurement and Feasibility: The measurement will take place at Hall A, using the apparatus of the GEn-RP experiment (E12-17-004), scheduled to run in 2021, with minor modifications. The proposal requests 2 PAC days. The result is expected to be measurements of the polarization observables K_{LL} and K_{LS} at well-motivated kinematic points.

Issues: Twist-3 dominance predicts K_{LL} to be roughly equal and opposite to the initial nucleon helicity correlation parameter A_{LL}, but the uncertainty on the size of K_{LL} is presently unknown. Therefore, the significance of the proposed measurement by itself is limited, but could be enhanced by a future measurement of A_{LL}.

Summary: The PAC believes that it is important to understand the basic mechanism of wide-angle pion photoproduction. This measurement by itself can give a partial contribution to this effort. It could become more relevant if combined with other measurements and if the uncertainties affecting theoretical predictions are better understood.

Jefferson Lab Experiment E1220008

Polarization Transfer in Wide-Angle Charged Pion Photoproduction

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Experimental Abstract ( ), Author List ( )

As of 02 Dec, 2021, 06:35:00
For Corrections please contact users@jlab.org
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- PAC convinced by important physics
- Recommend a complimentary experiment to help complete the picture…

WAPP II

$$\vec{\gamma}\,\vec{n} \rightarrow \pi^- p$$

- PAC49 2021
- Proposal PR12-21-005
- "Double Spin Asymmetry in Wide-Angle Charged Pion Photoproduction"
  - Accepted → Experiment E12-21-005
  - 10 PAC days awarded

PR12-21-005

Scientific Rating: A−

Recommendation: Approved

Title: Double Spin Asymmetry in Wide-Angle Charged Pion Photoproduction

Spokespersons: B. Wojtsekhowski (contact), R. Montgomery, G. Cates, A. S. Tadepalli

Motivation: This experiment plans to measure the polarization transfer observable A_{LL} for π^- photoproduction in the wide-angle regime. The nature of the interaction mechanism for this relatively simple process is not yet well understood. Theoretical studies based on Generalized Parton Distributions (GPDs) suggest the dominance of twist-3 contributions and predict a sizeable and negative A_{LL}. The experiment plans to study also the θ and s dependence of this asymmetry, which is important for understanding the reaction mechanism.

Measurement and Feasibility: The measurement will take place at Hall A, using the apparatus of the polarized ^{3}He experiment E12-09-016, scheduled to run in 2022, with minor modifications. The proposal requests 10 PAC days. The result will be a measurement of the polarization observable A_{LL} and a check of the expected opposite sign of A_{LL} in comparison to the observable K_{LL}. The latter will be measured by E12-20-008, scheduled to run in 2021.

Issues: It would be interesting to have comparisons of the future data with more than one theoretical calculation, including the associated errors.

Summary: The PAC believes that the combination of data from this experiment and E12-20-008 will make it possible to check the theoretical prediction of opposite signs between the A_{LL} and K_{LL} observables, and contribute to the understanding of the basic mechanism of wide-angle pion photoproduction. The PAC recommends approval of the requested 10 PAC days.

Jefferson Lab Experiment E1221005

Double Spin Asymmetry in Wide-Angle Charged Pion Photoproduction

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Experimental Abstract ( ), Author List ( )

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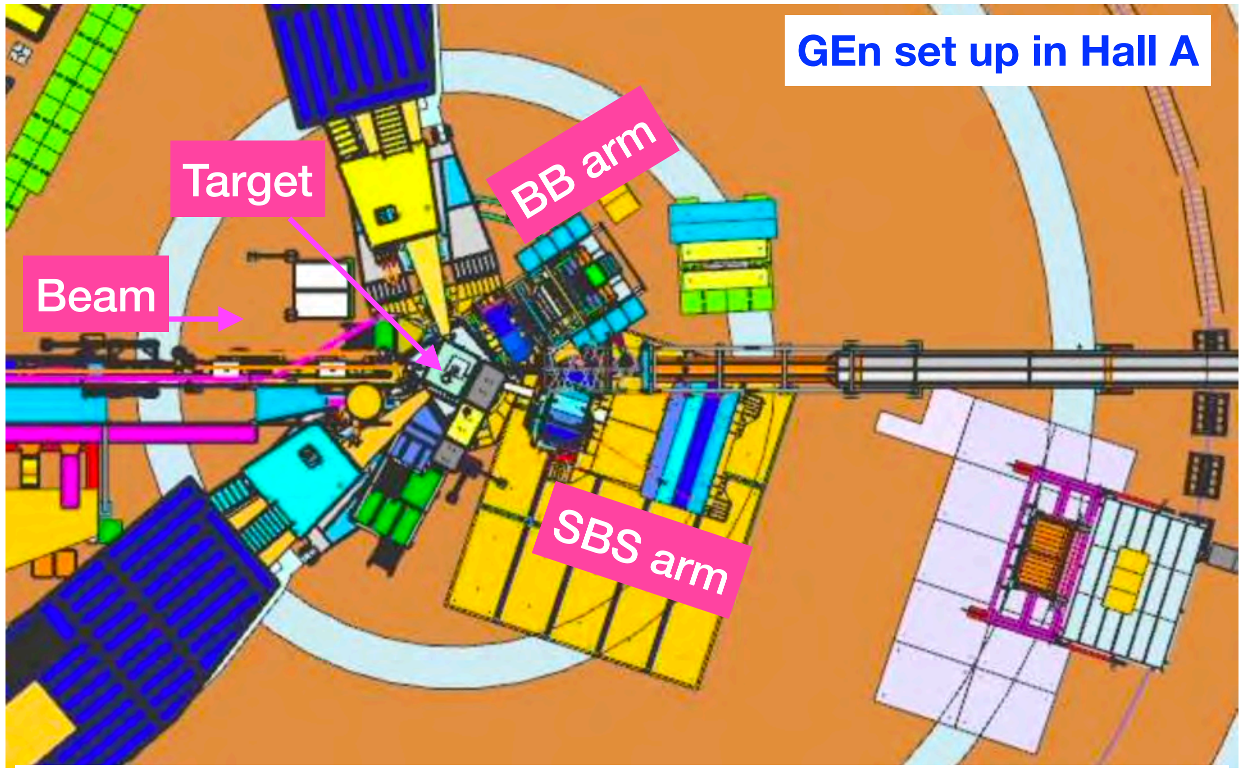
- Measure polarisation transfer observable A_{LL} for $\gamma n \rightarrow \pi^- p$ in wide angle regime
- Use SBS as proton arm; BB as pion arm; polarised ^{3}He target

- Shed light on following questions:
  - What is nature of interaction mechanism of meson photoproduction from nucleon at s, -t, -u >> Λ^2_{QCD} QCD scale parameter?
  - Does twist-3 contribution dominate twist-2 contribution in wide angle regime, as suggested by recent handbag mechanism cross-section calculations?

- Test following three aspects specifically:
  - Does A_{LL} equal $-K_{LL}$?
  - Does A_{LL} depend on θ_{CM} at s = 9 GeV^2 and large -u, -t?
  - Does A_{LL} have any s dependence at s > 9 GeV^2 ?



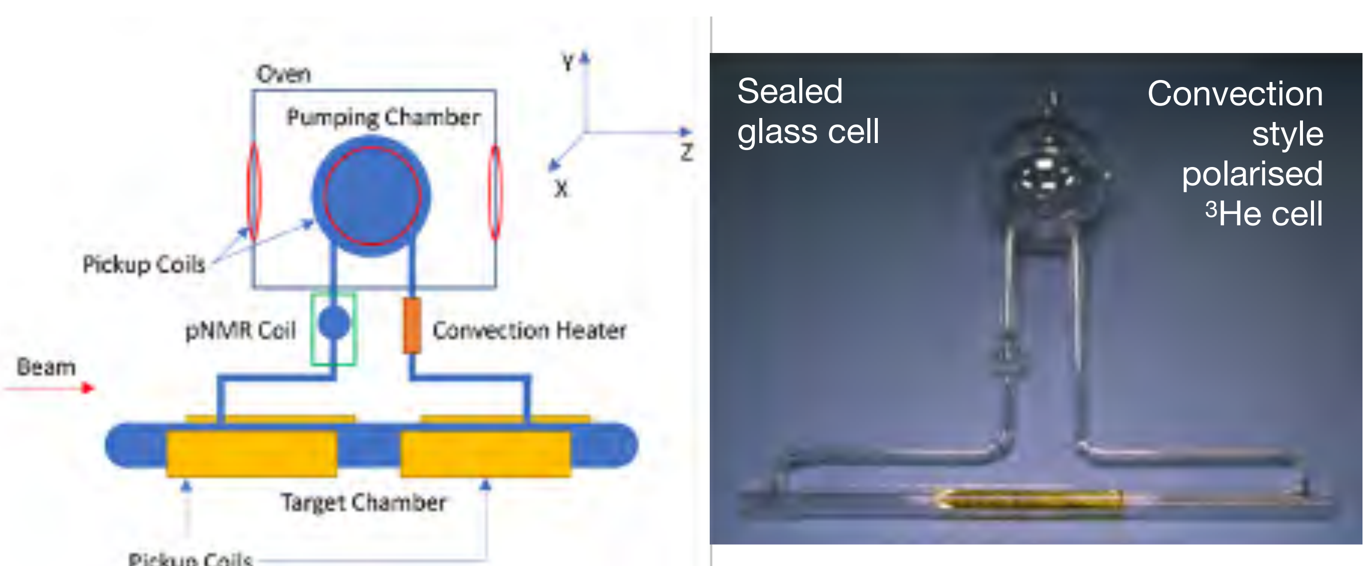
WAPP-II adds: Cu radiator before target; GEMs in SBS arm

- E12-21-005 (WAPP-II) will measure:

$$\vec{\gamma}\,\vec{n} \rightarrow \pi^- p$$

- BigBite for π^- arm
- SBS for proton arm

- Setup similar to E12-09-016 ^{3}He GEn experiment
- Add photon radiator 10cm upstream of target
    - 6% Cu radiator, 0.9mm thick
- Add GEM planes behind SBS dipole
    - Veto for charged particles (help proton ID)
- Beam energies (6.6, 8.8, 11GeV)
- Beam current 20μA



Spin exchange optical pumping technique

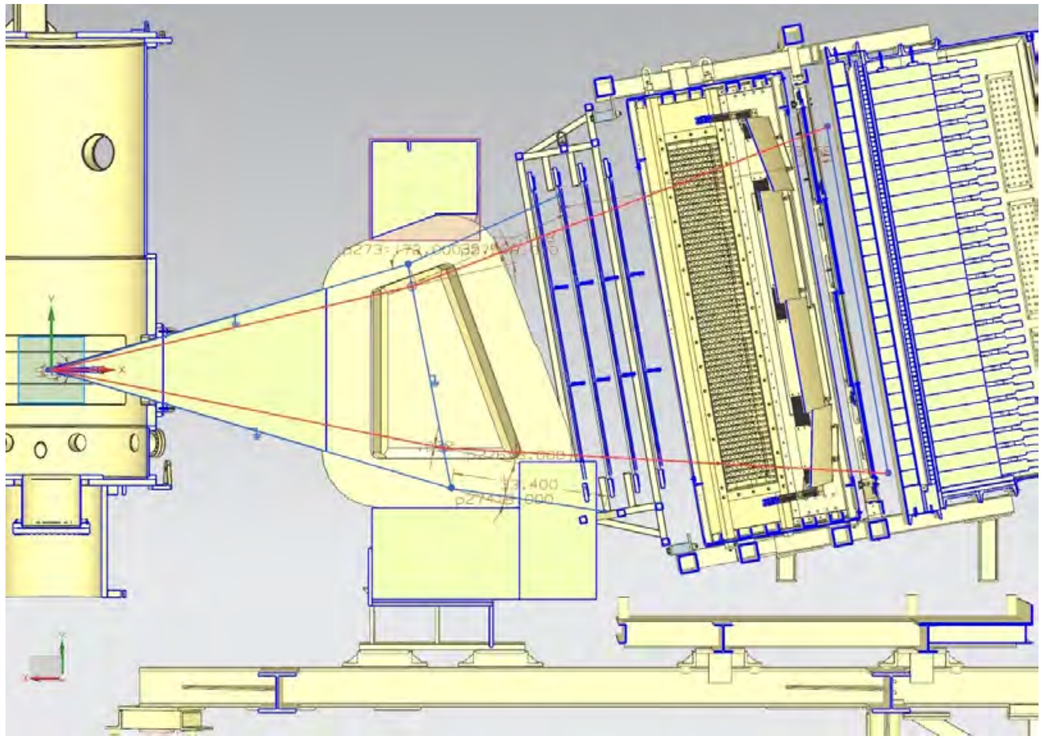
- Opportunistic…
- Make use of 2022 polarised ^{3}He target installation
- E12-09-016 GEn will measure:

$$^3\overrightarrow{He}(\vec{e}, e'n)pp$$

- Polarised He target:
    - 60cm, 10atm ^{3}He (nuclei polarisation ~60%)

E12-21-005 WAPP II Experimental Setup

BB (as is)

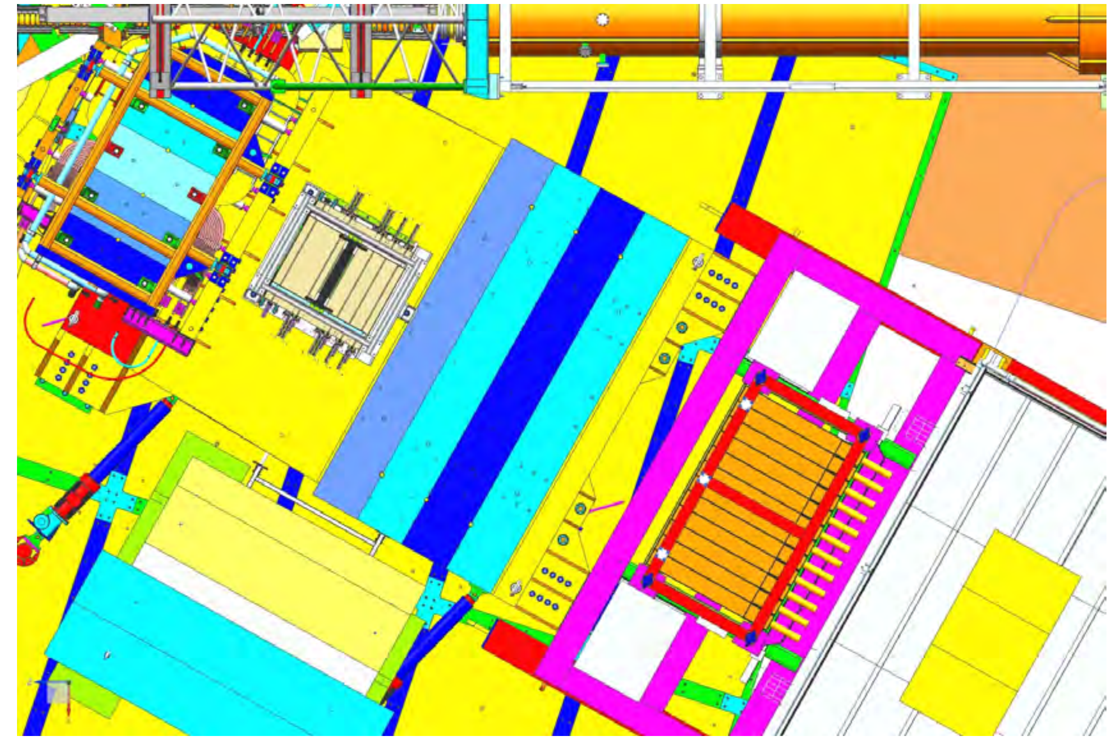


- Pion arm

- BigBite dipole
- GEM trackers
- GRINCH and timing hodoscope
- Preshower and shower calorimeters

- Solid angle ~50 msr
- Mom resolution 1%
- Angular resolution 1mrad
- Time resolution ~0.5ns

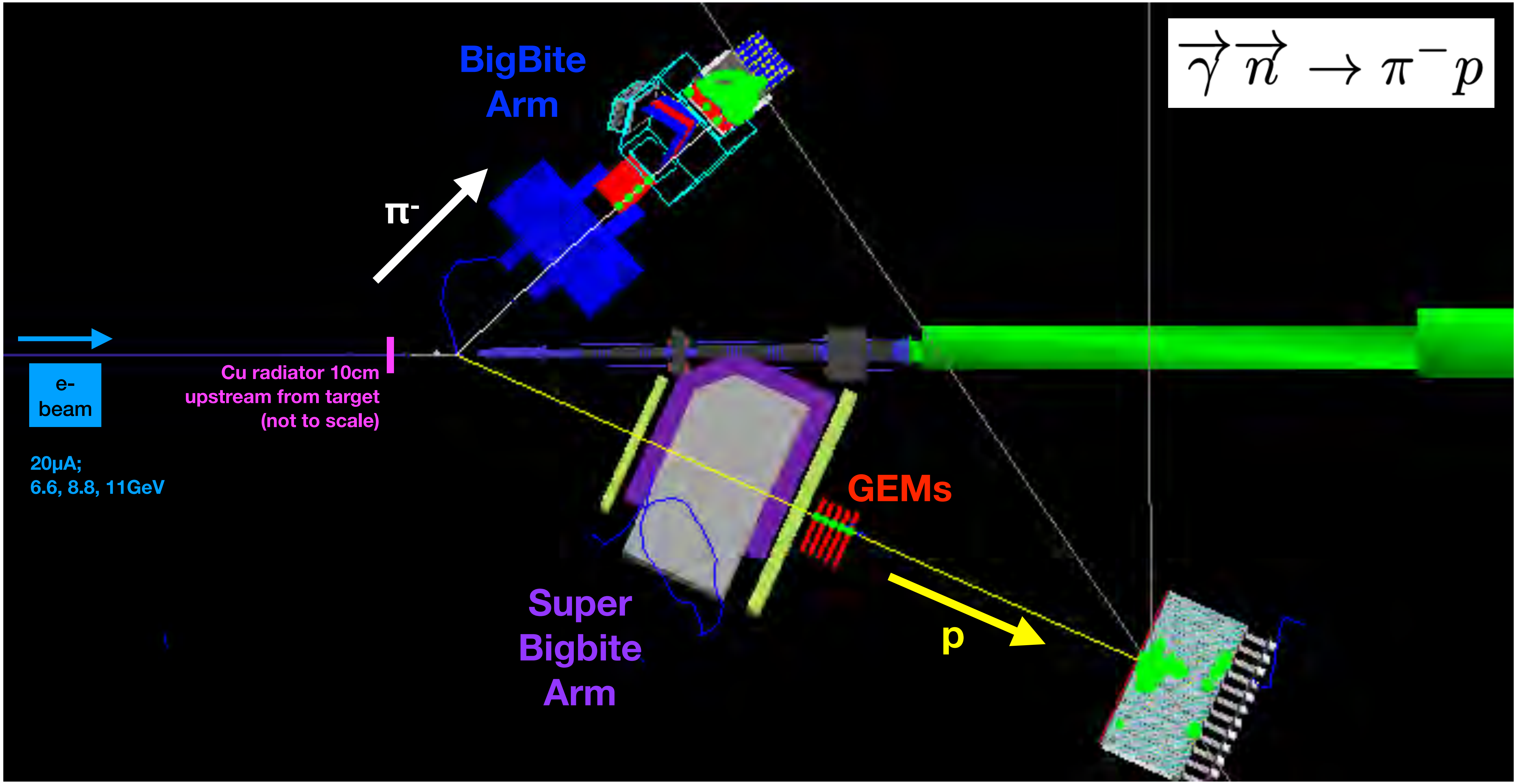
SBS (modified)



- Proton arm

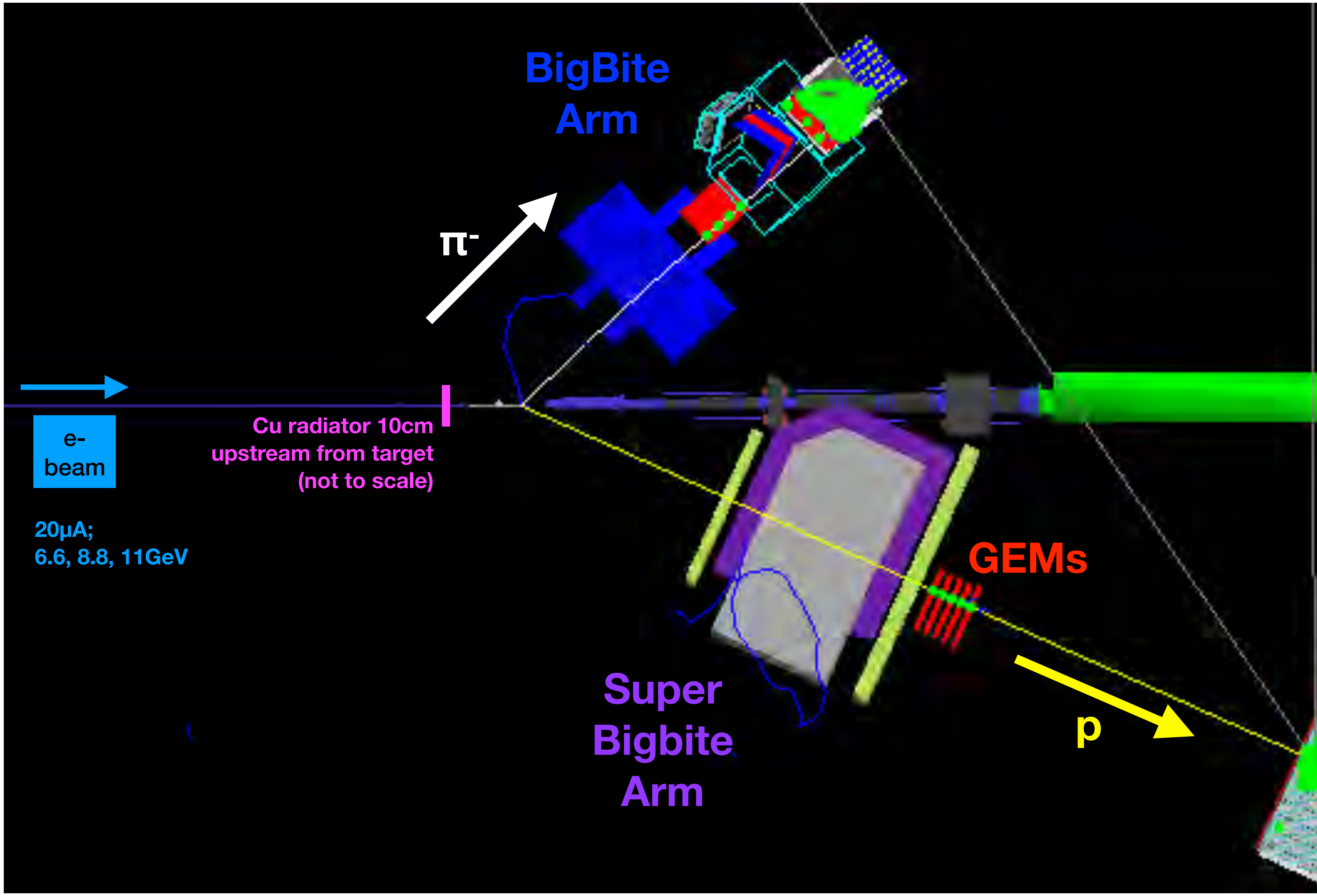
- 48D48 dipole
- GEM trackers (will add 5 layers from INFN and UVa mix)
- HCAL

- Solid angle ~35 msr
- Mom resolution 1%
- Angular resolution 1mrad
- Time resolution ~0.5ns



- g4sbs for simulations and projected results
- E12-09-016 GEn set-up simulated, with addition of Cu radiator and GEM planes behind SBS dipole

- Pion photoproduction generator developed by A. Puckett (UConn) for WAPP part 1 proposal (K_{LL})
    - many thanks to Andrew for help with this and g4sbs/analysis advice



$$\vec{\gamma}\,\vec{n} \to \pi^- p$$

- For analysis of g4sbs output used following detectors and cuts for analysis:

- BigBite: GEMs, PS and SH
- Good π^- track in GEMs
- PS veto(/anti-coincidence) to cut e^-/γ, energy deposition < 100 MeV
- Energy deposition in SH > 500 MeV

- Super Bigbite: GEMs and HCAL
- Good p track in SBS GEMs
- SBS HCAL energy deposition >80MeV

Simulated Kinematic Settings

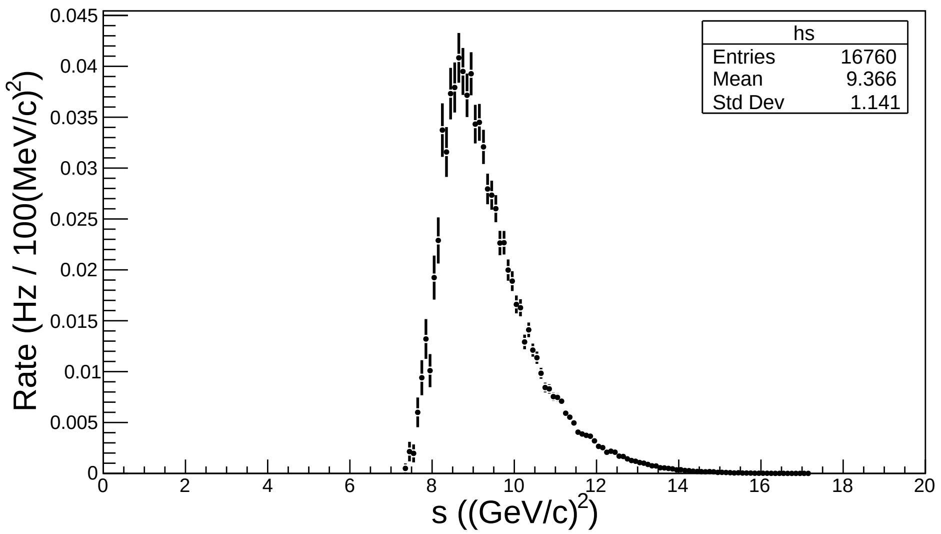
- 5 kinematic settings proposed to study physics aims
- 3 beam energies (3, 4, 5 pass)
- 5 BB/SBS angle settings (ie 5 configuration changes)
- → 3 centre of mass angles and 3 < s > settings

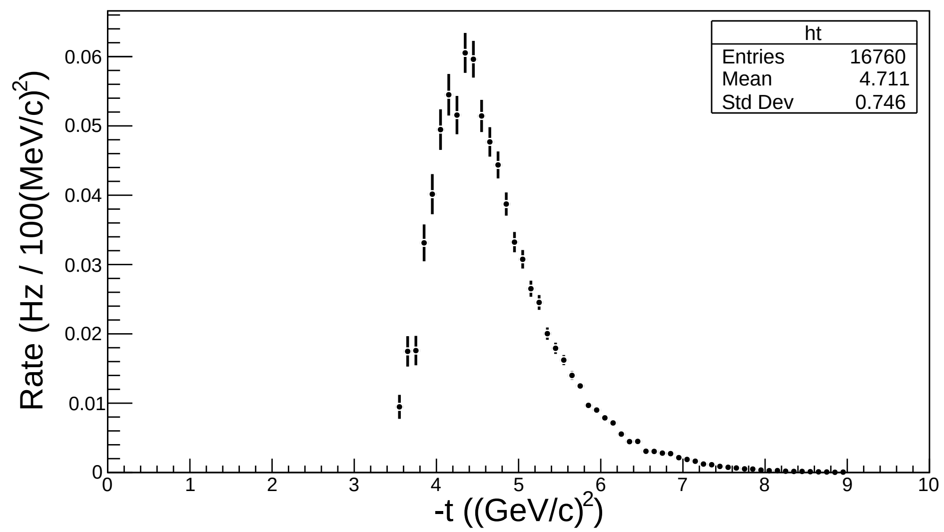
- Dependence study on θ_{CM} and s will provide confidence in results

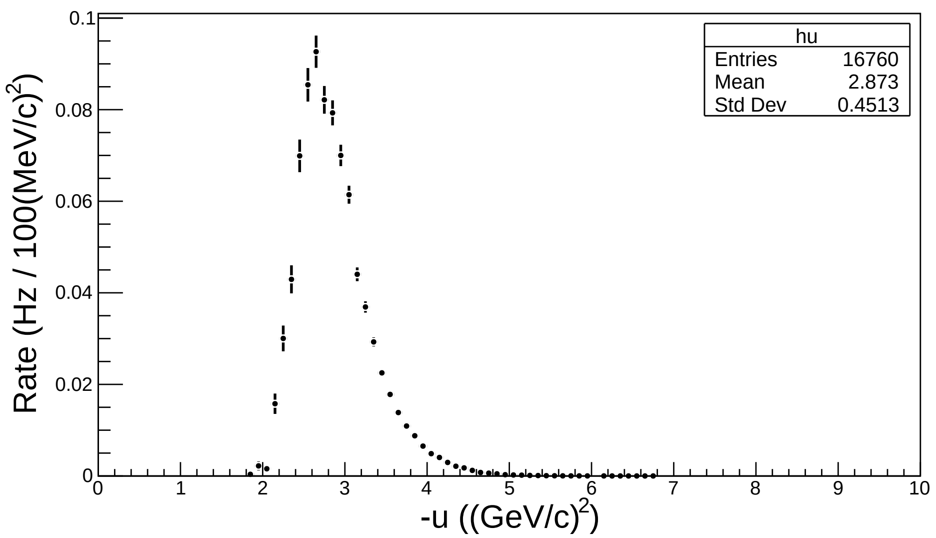
Kin	Beam E_e (GeV)	$\langle E_\gamma \rangle$ (GeV)	θ_{π^-} (°) (i.e. BB)	p_{π^-} (GeV/c)	θ_p (°) (i.e. SBS)	p_p (GeV/c)	θ_{CM}	< s > $(GeV/c)^2$	< -t > $(GeV/c)^2$	< u > $(GeV/c)^2$
A	6.6	4.5	41.9	2.02	24.3	3.29	103	9.3	4.7	2.9
B	6.6	4.5	30.0	2.74	32.8	2.53	82	9.3	3.3	4.3
C	6.6	4.5	52.0	1.58	19.5	3.74	116	9.3	5.5	2.1
D	8.8	6.0	37.2	2.61	21.9	4.23	103	12.1	6.4	4.0
E	11.0	7.5	33.7	3.20	20.2	5.15	103	15.0	8.1	5.2

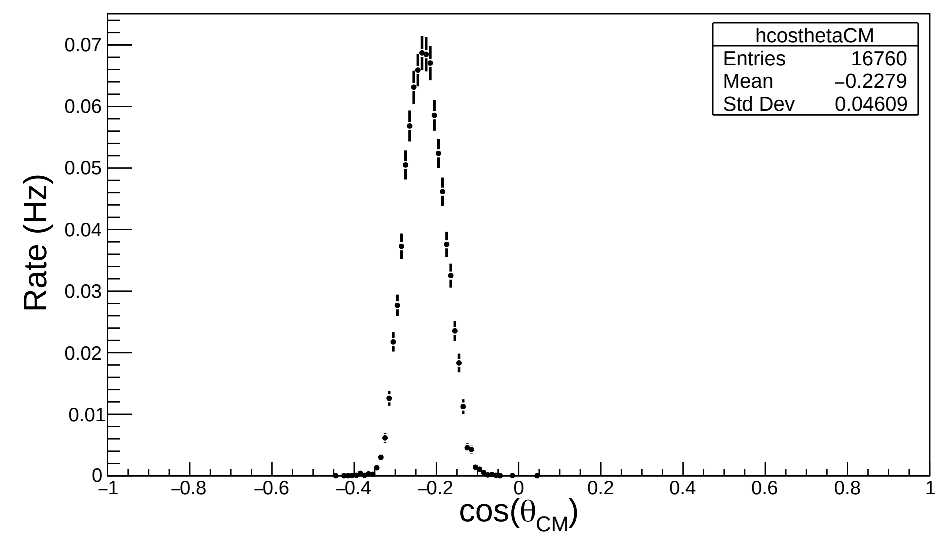
- All settings simulated in g4sbs to estimate kinematics, event rates, acceptances and efficiencies

Simulated Mandelstam Variables for Kin A Example









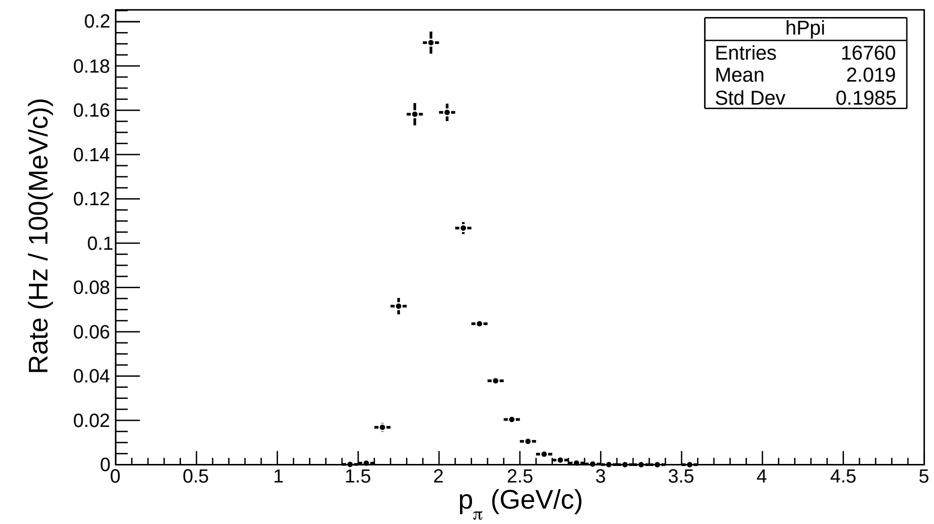
- Get distribution of E_γ from radiator
- Cut on E>4GeV in generator

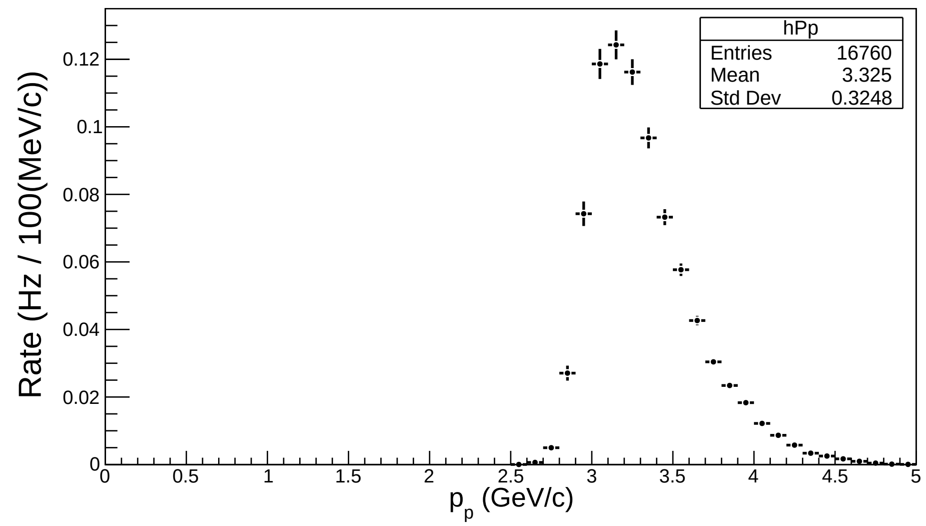
- Wide angle regime
- $s, -t, -u \gg \Lambda_{QCD}^2$

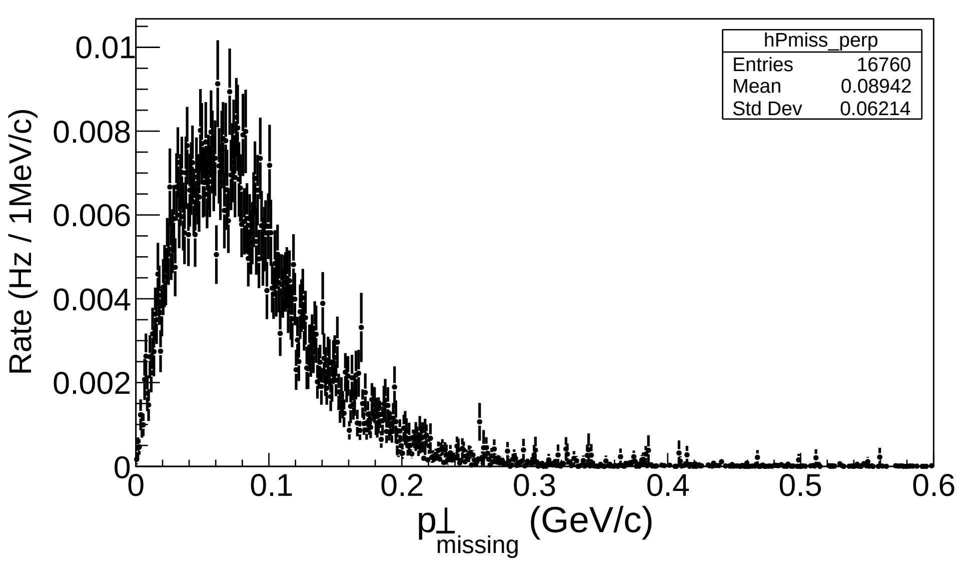
Kin	Beam E_e (GeV)	E_γ (GeV)	$\langle E_\gamma \rangle$ (GeV)	θ_{π^-} (°) (i.e. BB)	p_π (GeV/c)	θ_p (°) (i.e. SBS)	p_p (GeV/c)	θ_{CM} (°)	$\langle s \rangle$ $(GeV/c)^2$	$\langle -t \rangle$ $(GeV/c)^2$	$\langle u \rangle$ $(GeV/c)^2$
A	6.6	4 - 5.5	4.5	41.9	2.03	24.3	3.29	103	9.3	4.7	2.9

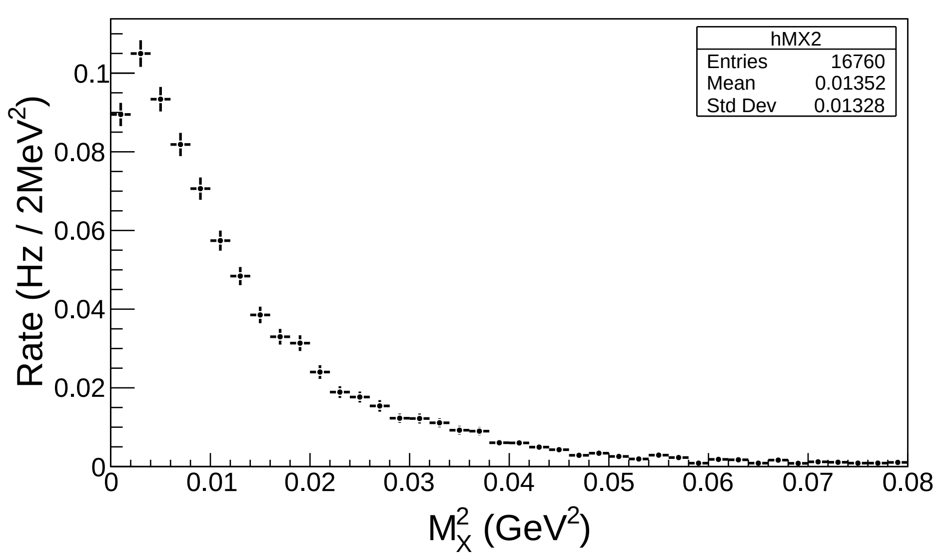
- Cross-section weighted Mandelstam variables for all proposed kinematics settings large enough for handbag mechanism to play dominant role in observed cross-sections and polarisation observables
- (P. Kroll Pays. Rev. D 97 074023 (2018))

Momentum Distributions and Exclusivity for Kin A Example



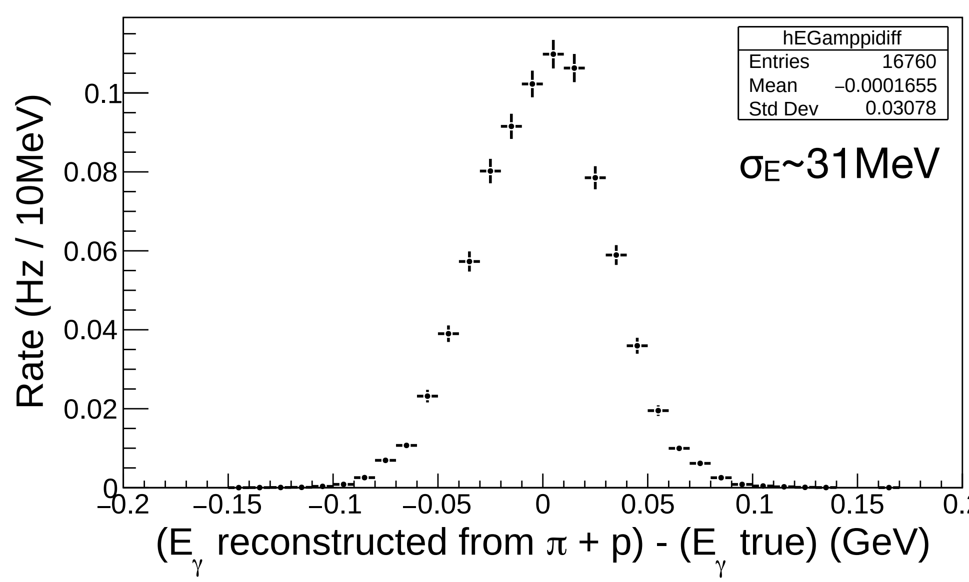






$$E_\gamma = \frac{s_{p\pi} - m_n^2}{1(E_\pi + E_p - p_\pi cos\theta_\pi - p_p cos\theta_p)}$$

$$s_{p\pi} = (E_p + E_\pi)^2 - (p_p + p_\pi)^2$$



- Distributions are cross-section weighted, acceptance averaged and smeared for estimated momentum and angular resolutions

- $p_{missing}^{\perp}$= total momentum of pion and proton projected to plane perpendicular to beam direction
- Measure of event “acoplanarity:” angle between pion and proton production planes
- Cut at <=0.1GeV/c to remove in-elastic and non-exclusive events

- Resolution of photon energy reconstruction allows removal of background e.g. events with multi-pion final states
- Cutting on missing mass parameter will also be used for this (M_x<=0.05GeV²)

Parameterised Cross-section and Projected Rate Calculations

- Cross-section parameterisation*:

$$\frac{d\sigma}{dt}_{\gamma n \to \pi^- p} = 1.7 \times 0.83 \times (10/s)^7 (1 - cos(\theta_{CM}))^{-5} (1 + cos(\theta_{CM}))^{-4}$$

- Event rate $N_{\pi^- p}$:

$$N_{\pi^- p} = \frac{d\sigma}{dt}_{\pi^- p} \frac{p^2_{\pi^-}}{\pi} \Delta\Omega_{\pi^-} f_{\pi^- p} \left[\frac{\Delta E_\gamma}{E_\gamma} \frac{t_{rad}}{X_0} \mathcal{L}_{e-n} \right]$$

process cross-section

Range of Δt, expressed in p_π and BB solid angle (50msr)

fraction of events detected in SBS obtained from g4sbs

Number of photons per incident electron and for photon energy range.
$t_{rad}/X_0 \sim 0.082$
$\mathcal{L} \sim 1.8 \times 10^{36}$ Hzcm^{-2}

Kin	A	B	C	D	E
$f_{\pi\text{-}p}$	0.31	0.18	0.51	0.35	0.37
Pion detection	0.41	0.38	0.37	0.42	0.37
Proton detection	0.86	0.81	0.88	0.92	0.93
$p_{miss\perp}$ cut	0.85	0.86	0.82	0.82	0.84
Estimated counts per hour	1420	980	1150	530	120

- To get final estimated rate, $N_{\pi\text{-}p}$ corrected for
  - expected DAQ dead time
  - from g4sbs studies: losses due to pion/proton detection/ trigger efficiencies and event selection cut on missing momentum for reaction

* π^+ cross-section from: R.L. Anderson et al., Phys. Rev. D 14, 679 (1976)
Correction for π^- from π^+/π^+ yields from deuteron from: L.Y. Zhu et al., Phys. Rev. Lett. 91 (2003) 022003; Phys.Rev. C71 (2005) 044603

Proposed Measurements

- Below table accepted by PAC (who awarded 10 PAC days)
- Accounts for:
  - Production at kinematics (photon/neutron polarisations; dilution from $\pi^-\Delta^{++}$ background)
  - Spectrometer angle changes
  - Target polarisation measurement (every 4 hours)
  - BB optics runs and trigger checkout for π^- (as opposed to e')
  - Beam pass changes and associated beam positioning

Kin	Beam E_e (GeV)	$\langle E_\gamma \rangle$ (GeV)	$\cos(\theta_{CM})$	$\langle s \rangle$ (GeV/c)^2	$\langle -t \rangle$ (GeV/c)^2	$\langle u \rangle$ (GeV/c)^2	Beam on target (hours)	Time (hours)	ΔA_{LL} accuracy
A	6.6	4.5	-0.23	9.3	4.7	2.9	6	37	±0.05
B	6.6	4.5	0.14	9.3	3.3	4.3	6	27	±0.05
C	6.6	4.5	-0.44	9.3	5.5	2.1	8	27	±0.05
D	8.8	6.0	-0.23	12.1	6.4	4.0	16	47	±0.05
E	11.0	7.5	-0.23	15.0	8.1	5.2	60	98	±0.05

- Currently agreeing inclusion into upcoming run plan and any necessary modifications
  - eg configuration changes not on weekend
  - outstanding tasks (check opening in target magnetic box for large SBS/BB angles, beam line braces)

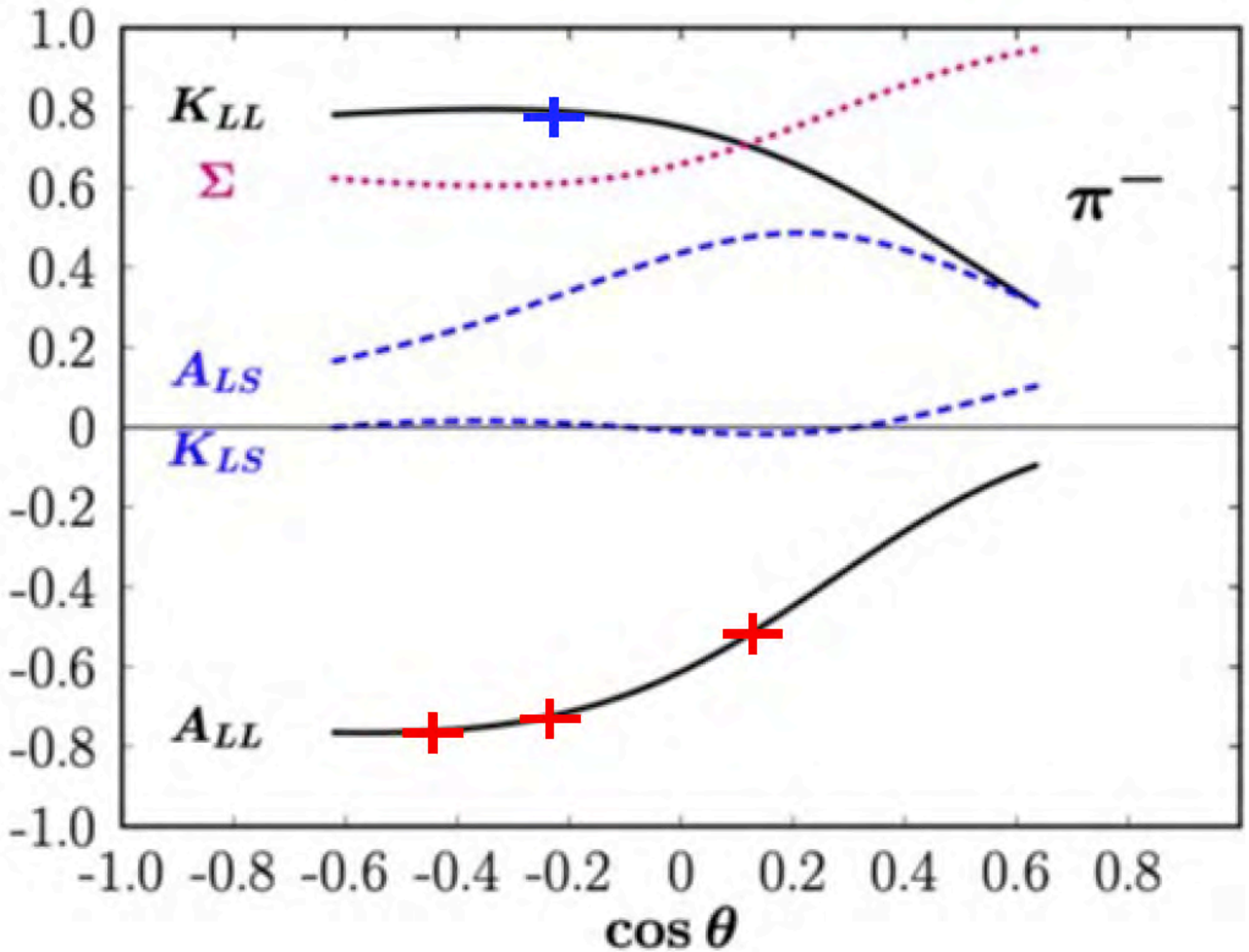
- Expect to run starting late October 2022

From latest experiment schedule (accessible via Hall A webpage)

Projected A_{LL} Data Points

- WAPP I K_{LL} point in blue
- WAPP II A_{LL} points in red

- 5% statistical uncertainties on points shown
- Not shown is 15% theoretical uncertainty band
- Uncertainties expected to provide clear test of WAPP I and WAPP II original aims



Summary

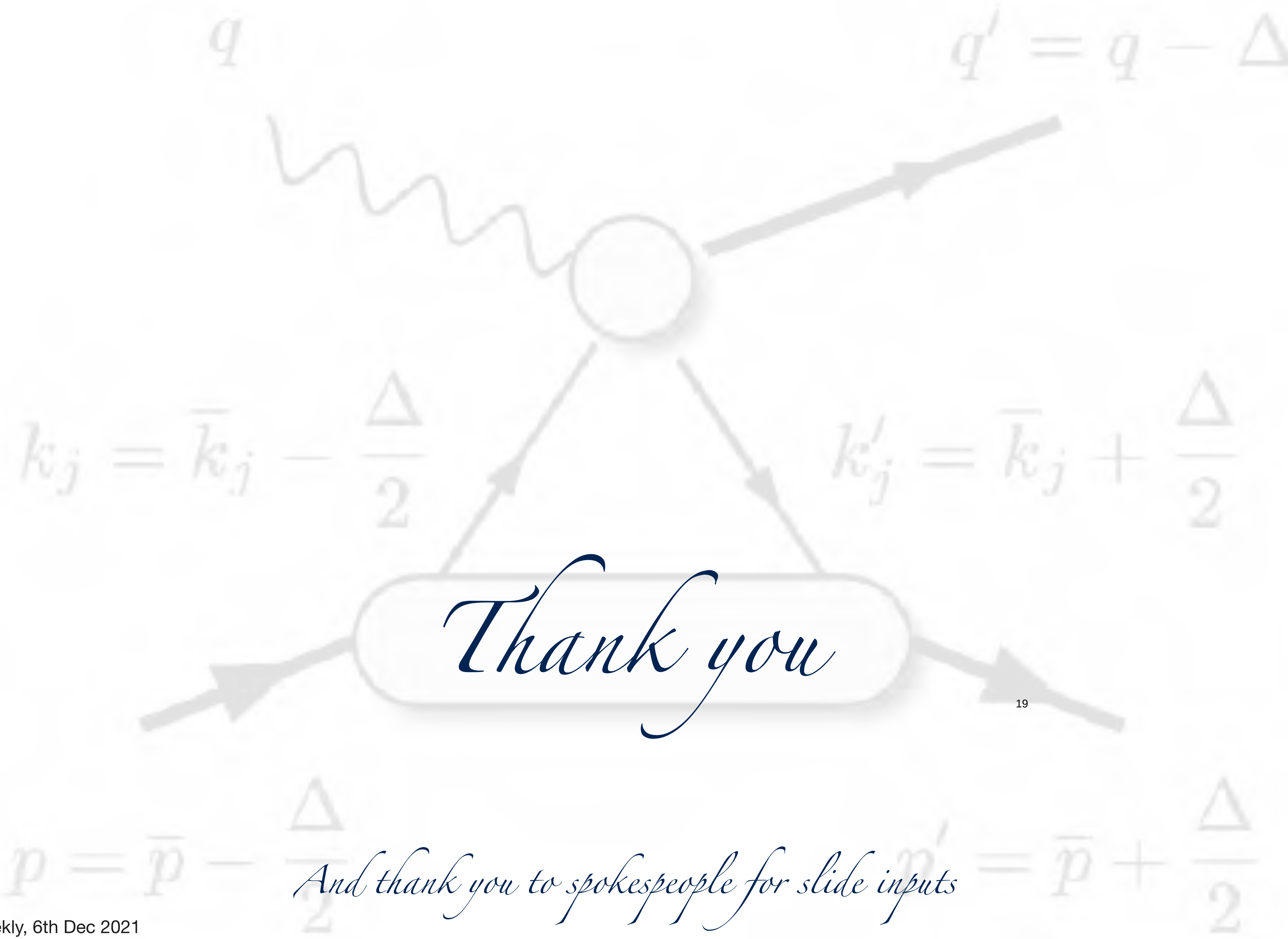
- Nature of interaction mechanism for pion photoproduction still not well understood after decades of study (~70 yrs!)
  - Very simple reaction (production of lightest meson from nucleon)
  - We should strive to understand mechanism within QCD and cross-section from first principles

- Recent theoretical studies based on GPDs in handbag mechanism framework suggest
  - Dominance of twist-3 contributions
  - Sizeable and negative A_{LL}

- E12-21-005 (WAPP II) can provide independent test of these predictions
- Will measure:
  - polarisation transfer observable A_{LL} for π^- photoproduction in wide angle regime
  - dependence of A_{LL} on θ_{CM} and s, providing confidence in results

- Measurement plans to start running October 2022
- Apparatus of polarised ^{3}He experiment E12-09-016 (plus SBS GEMs and Cu radiator)
- 10 PAC days and A- case awarded in PAC 49
- Specifics of final run plan/execution in current discussions
- We invite you to join us and please help out on our run period

- Results essential to combine with upcoming experiment E12-20-008 (WAPP I) (w/ GEn-RP run)
  - Compare sign of K_{LL}
  - Contribute to understanding of basic mechanism of wide angle pion photoproduction
  - Contribute to knowledge on 3D picture of nucleon



Thank you

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And thank you to spokespeople for slide inputs