Run group 2 – WACS + Pion
Run group 3 – polarized WACS

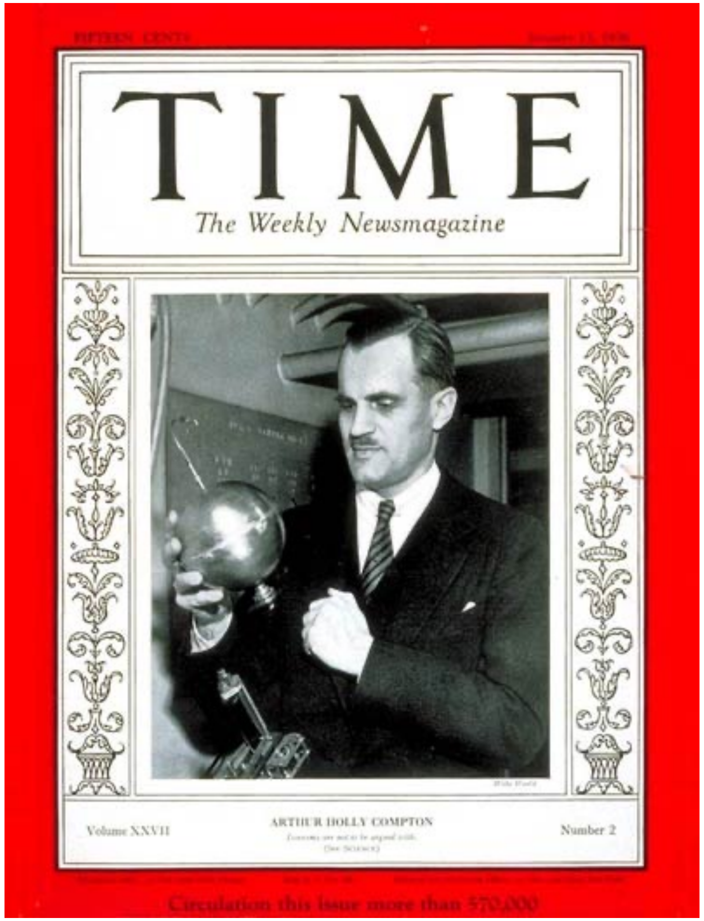
Bogdan Wojtsekhowski, for the Collaborations

RG2 (E12-14-003, E12-14-005) – 18 PAC days
Wide Angle Compton Scattering at 8 and 10 GeV Photon Energies
Wide Angle Exclusive Photoproduction of pi-zero Mesons

NPS at large angles and HMS - SHMS used as carriage for NPS

RG3 (E12-17-008) – 46 PAC days
Polarization Observables in Wide Angle Compton Scattering
at large s, -t, and -u

NPS+CPS - SHMS used as carriage for NPS, BB as a proton arm



In 1923, Compton published a paper in the *Physical Review* that explained the X-ray shift by attributing particle-like momentum to photons.

Run Group 2 (E12-14-003, E12-14-005)

Wide Angle Compton Scattering at 8 and 10 GeV Photon Energies

E12-14-003: D. Hamilton, S. Sirca, B. Wojtsekhowski

Wide Angle Exclusive Photoproduction of pi-zero Mesons

E12-14-005: D. Dutta, H. Gao, S. Sirca, M. Amaryan,
M. Kunkel, I. Strakovsky

NPS at large angles and HMS - SHMS used as carriage for NPS

Scientific Rating: A–

Recommendation: Approve

Title: **Wide-angle Compton scattering at 8 and 10 GeV photon energies**

Spokespersons: D.J. Hamilton, S. Sirca, B. Wojtsekhowski

Motivation: This proposal aims to measure the cross section for real Compton scattering from the proton at an incident photon energy of 8 GeV and 10 GeV (corresponding to values of s = 15.9 and 19.6 $(GeV/c)^2$, respectively) at wide c.m. scattering angles (in the range between 50º and 105º). Previous 6 GeV JLab polarization-transfer data have shown a clear indication for a partonic mechanism in the wide-angle Compton Scattering (WACS) process. These data have shown the WACS process to take place on a single quark, in stark contrast with the perturbative QCD picture, which involves three active quarks exchanging two hard gluons. How such a quark is embedded in the nucleon and if a factorization between the partonic subprocess and its embedding in the nucleon can be formulated in a more systematic way are still open questions, motivating cross section measurements at large s and t. The present experiment aims to extend the kinematic range of previous JLab WACS experiments by a factor of 2.

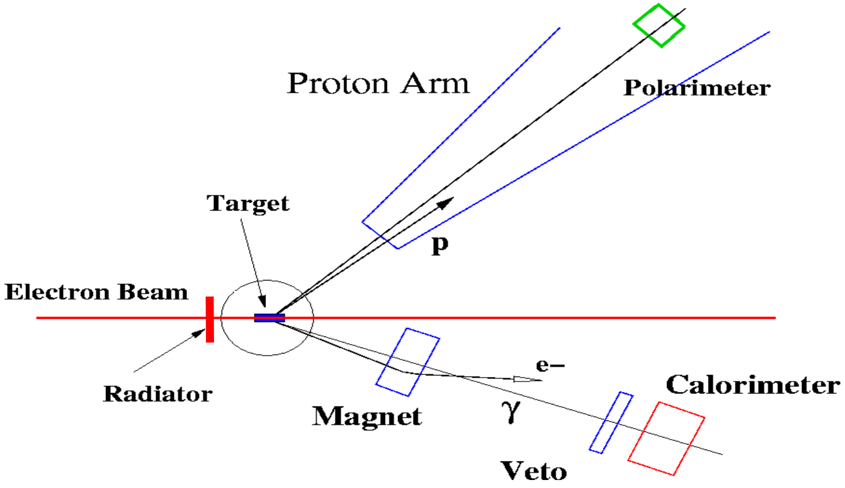
Measurement and Feasibility: This experiment will be performed in Hall C, using an untagged bremsstrahlung photon beam incident on a liquid hydrogen target. The scattered photon will be detected in a newly proposed neutral particle detector (NPS) for Hall C. The scattered electrons from the electron beam will pass through a liquid hydrogen target, with the scattered electron deflected by a sweeping magnet to allow discrimination between Compton and elastic electron-scattering processes. To ensure the exclusivity of the reaction, the recoil proton will be detected in the Hall C magnetic spectrometer HMS. The experimenters request 425 hours (18 days) of beam time.

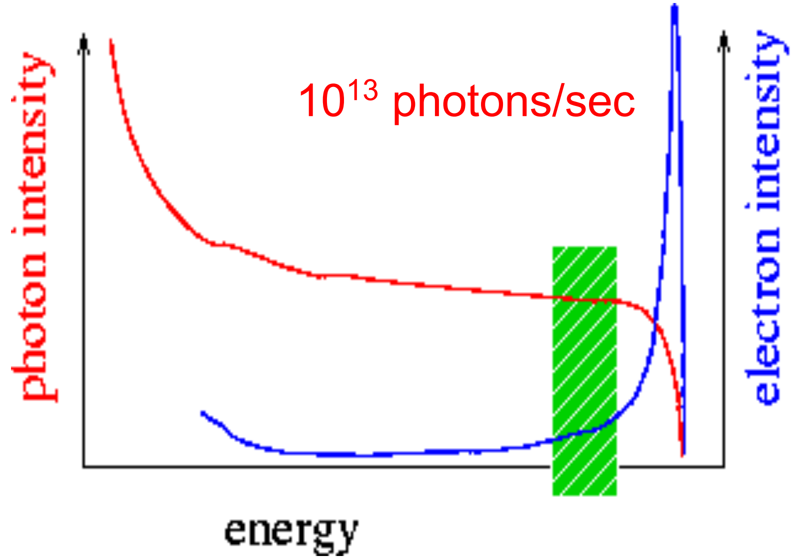
Issues: The proposal is a resubmission of PR12-13-009, which was deferred by PAC40. The PAC had two main issues: 1) it wanted to see a realistic π^0 background subtraction for each kinematic setting; 2) it was not convinced on the choice of kinematic points to make the strongest physics case. The proponents have done a good job addressing both questions. They refocused the experiment and chose 4 fixed intermediate values of –t for which a scan in s will permit a test of the factorization of the WACS process into a perturbatively calculable s-dependent part and a non-perturbative Compton Form Factor that only depends on t. Furthermore, they proposed two more measurements at –t = 9 and 11 $(GeV/c)^2$ to extend the range over which the Compton Form Factor is extracted. They dropped several data points at larger momentum transfers, reducing the beam time by about a factor of 2. In the new proposal, the proponents also made a detailed π^0 background subtraction. For the intermediate values of t considered in the present experiment, the π^0 background subtraction is under good control.

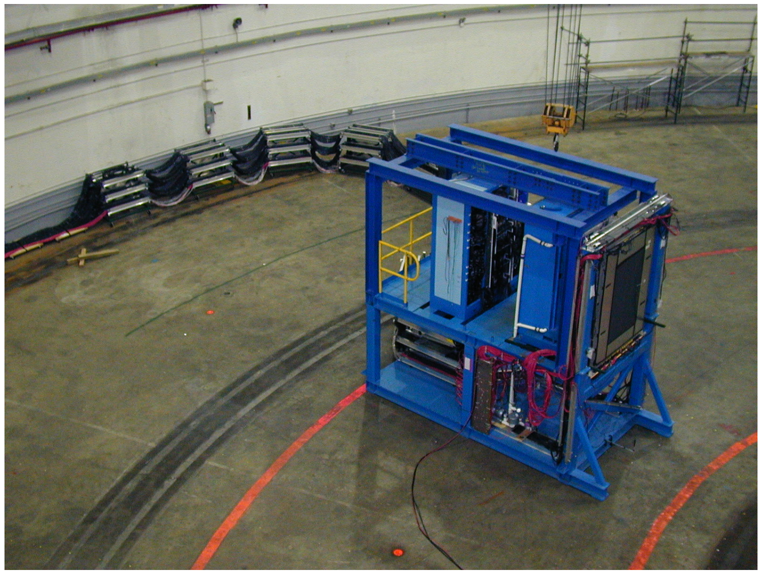
Recommendation: Approve
The PAC considers WACS to be the process of choice to explore factorization in a whole class of wide-angle processes.
The PAC recommends approval with the full allocation of the requested 18 days.

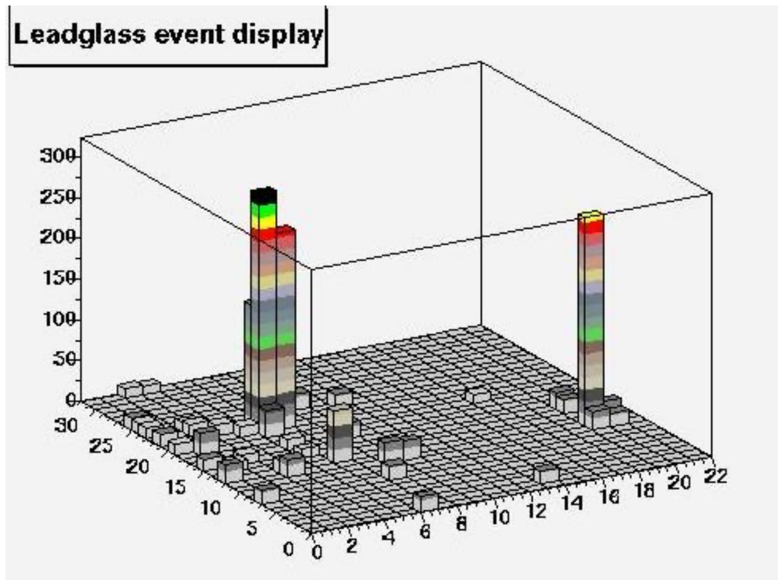
Mixed e/γ beam –> rates ~ 1300 higher than "clean" γ

E99-114 experiment



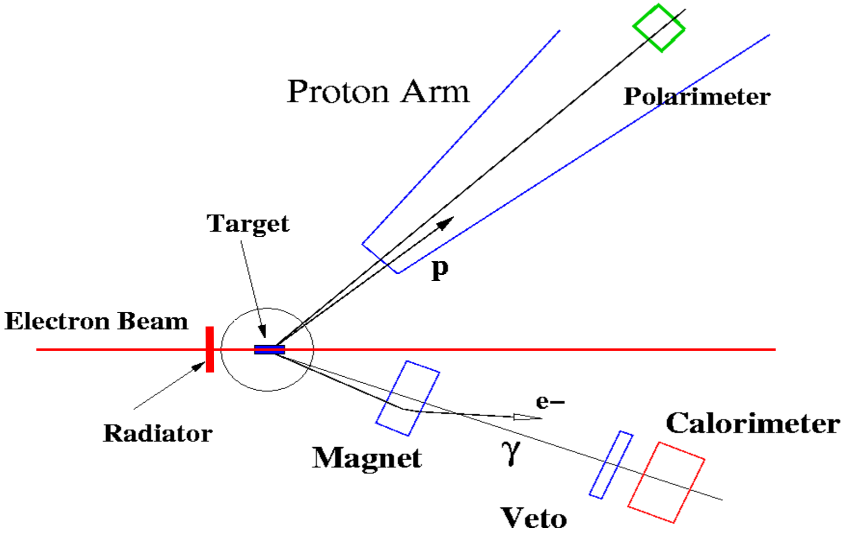


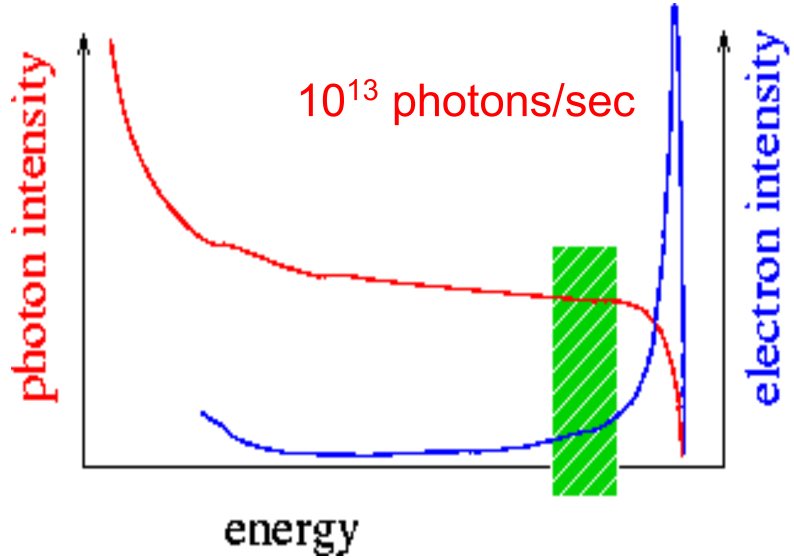




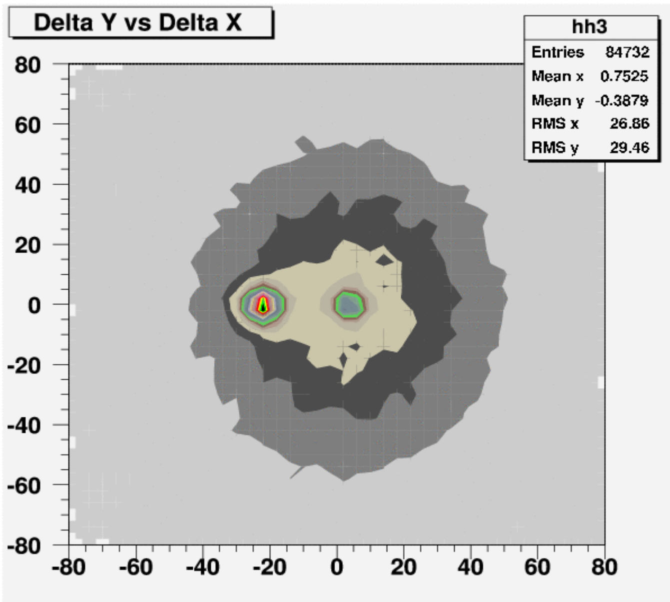
π^0 event

Mixed e/γ beam –> rates ~ 1300 higher than "clean" γ

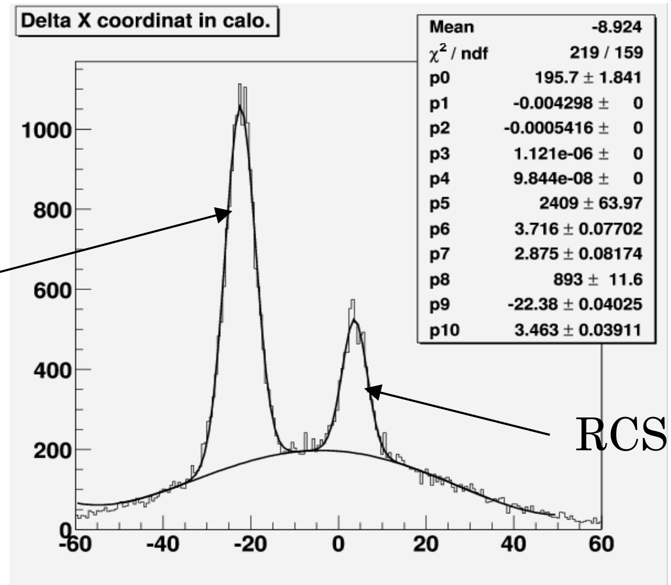




Two-body kinematics



ep elastic events



RCS events

Wide Angle Compton Scattering

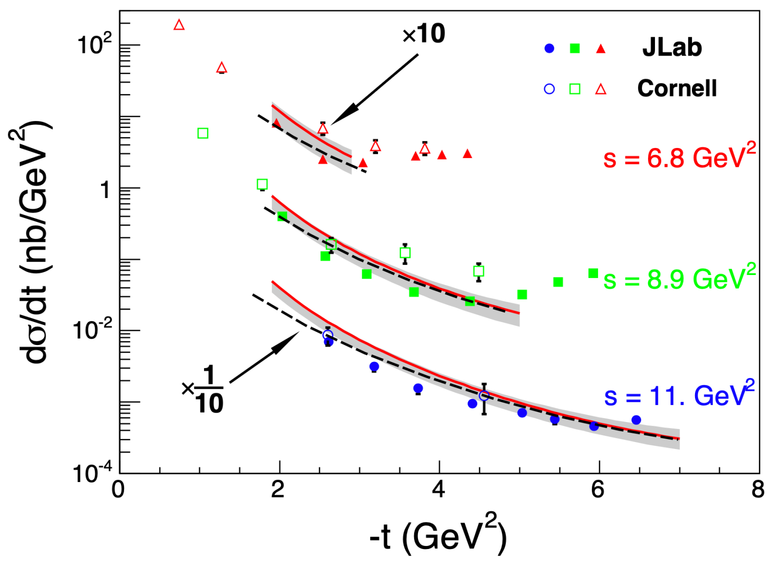
Cross section and asymmetries

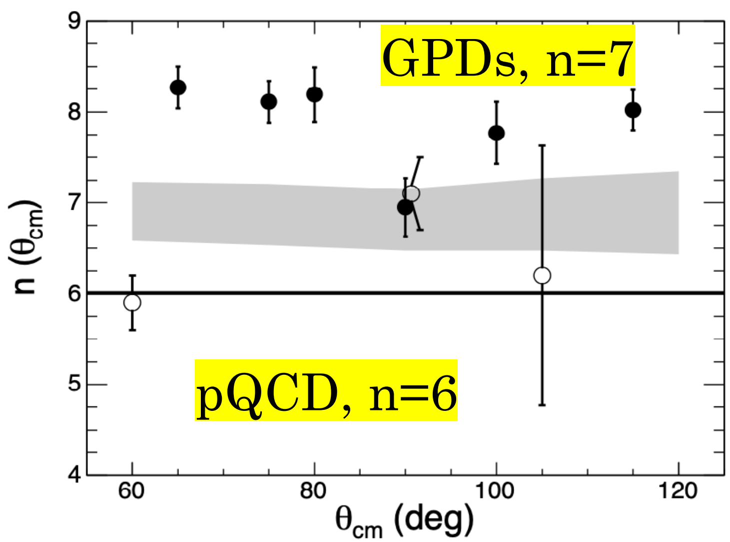
$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{\rm KN} \left\{ \frac{1}{2}\frac{(s-u)^2}{s^2+u^2}\left[R_V^2(t) + \frac{-t}{4m^2}R_T^2(t)\right] + \frac{1}{2}\frac{t^2}{s^2+u^2}R_A^2(t)\right\}$$

$$A_{LL} = K_{LL} = \frac{R_A(t)}{R_V(t)} A_{LL}^{\rm KN}$$

$$A_{LS} = -K_{LS} = A_{LL}\left[\frac{\sqrt{-t}}{2m}\frac{R_T(t)}{R_V(t)} - \beta\right]$$

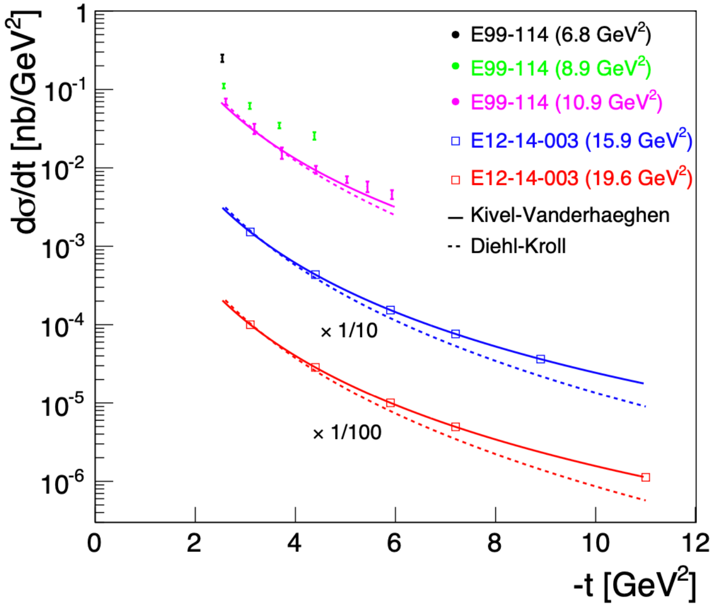
Diehl & Kroll, EPJ C73 (2013)

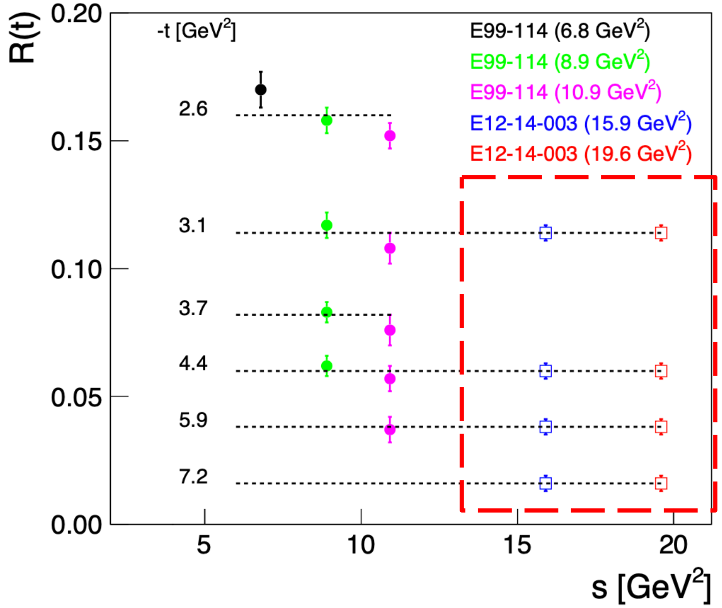




Wide Angle Compton Scattering at 8&10 GeV Photon Energies

E12-14-003: D. Hamilton, S. Sirca, B. Wojtsekhowski





- New measurements (all firmly in the wide-angle regime) will allow for a rigorous test of factorization in hard exclusive reactions and extraction of vector/SCET form factor.
- Extension to highest possible values of $-t$ will:
  - Offer new insights into the interplay between hard and soft physics and non-perturbative proton structure.
  - Allow for a direct comparison between $R_V(t)$ and the Dirac form factor (different quark charge and x weightings) and test the universality of leading quark mechanism.

Wide Angle Compton Scattering at 8&10 GeV Photon Energies

E12-14-003: D. Hamilton, S. Sirca, B. Wojtsekhowski

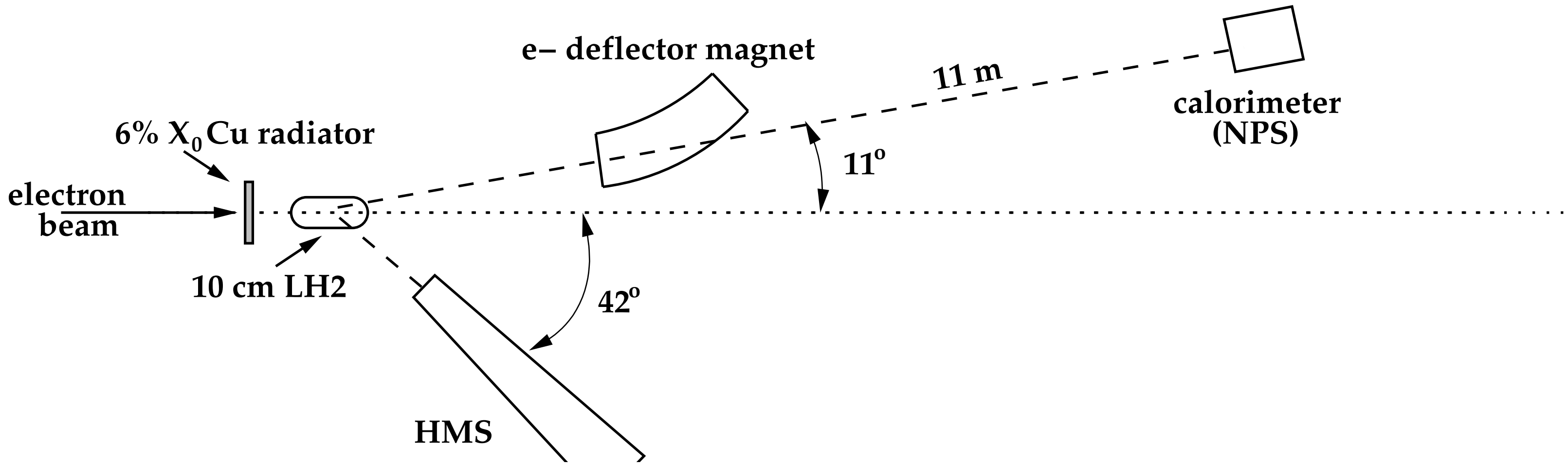
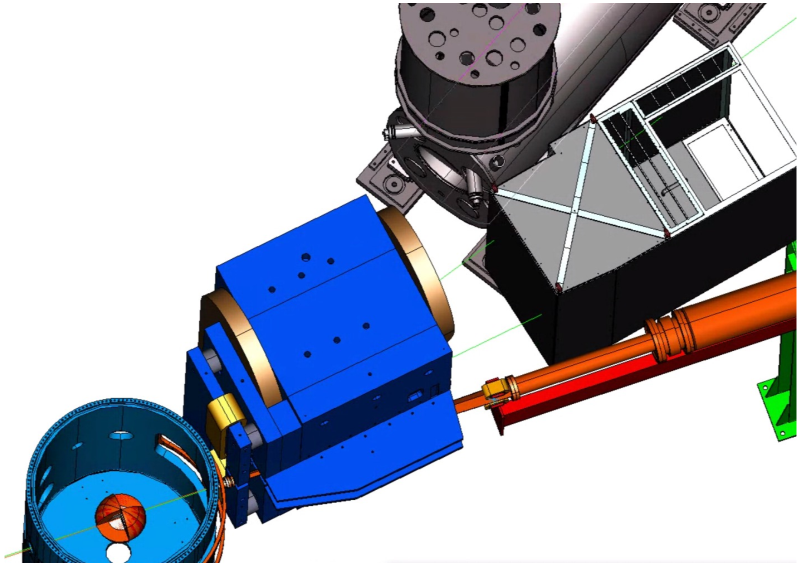


Table 2: Kinematics variables for WACS in five settings with a 4-pass, 8.8 GeV electron beam (4A–4E) and five settings with a 5-pass, 11 GeV electron beam (5A–5E).

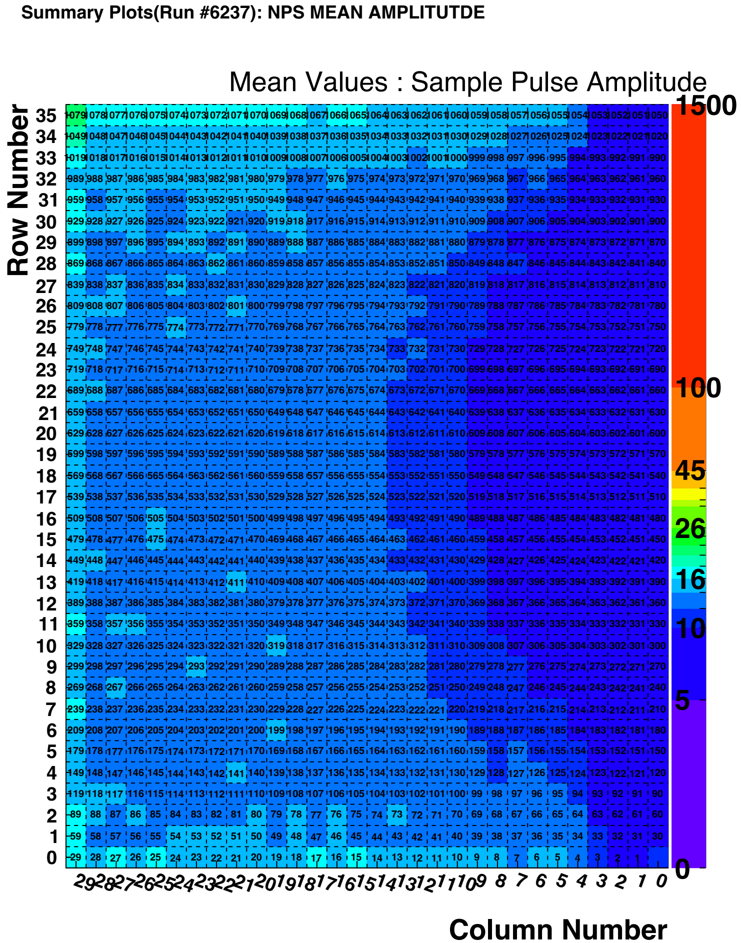
Kin	$E_{\rm in}$ [GeV]	θ_γ [°]	E_γ [GeV]	$\theta_{\rm p}$ [°]	$p_{\rm p}$ [GeV/c]	$\theta^{\rm cm}$ [°]	s [GeV^2]	$-t$ [GeV^2]	$-u$ [GeV^2]
4A	8	14.2	6.347	40.1	2.416	55.8	15.89	3.10	11.03
4B	8	17.9	5.663	33.7	3.138	67.6	15.89	4.39	9.75
4C	8	22.5	4.851	27.8	3.978	80.4	15.89	5.91	8.22
4D	8	26.9	4.161	23.7	4.684	90.9	15.89	7.20	6.93
4E	8	34.0	3.255	18.9	5.605	104.8	15.89	8.90	5.23
5A	10	11.0	8.362	41.7	2.399	48.9	19.65	3.07	14.81
5B	10	13.8	7.647	35.3	3.154	59.5	19.65	4.41	13.47
5C	10	16.9	6.848	30.0	3.981	70.1	19.65	5.91	11.97
5D	10	19.7	6.158	26.3	4.687	78.7	19.65	7.21	10.68
5E	10	29.9	4.135	17.8	6.739	103.2	19.65	11.01	6.88

Wide Angle Compton Scattering at 8&10 GeV Photon Energies

Sweeper magnet deflects scattered electrons vertically

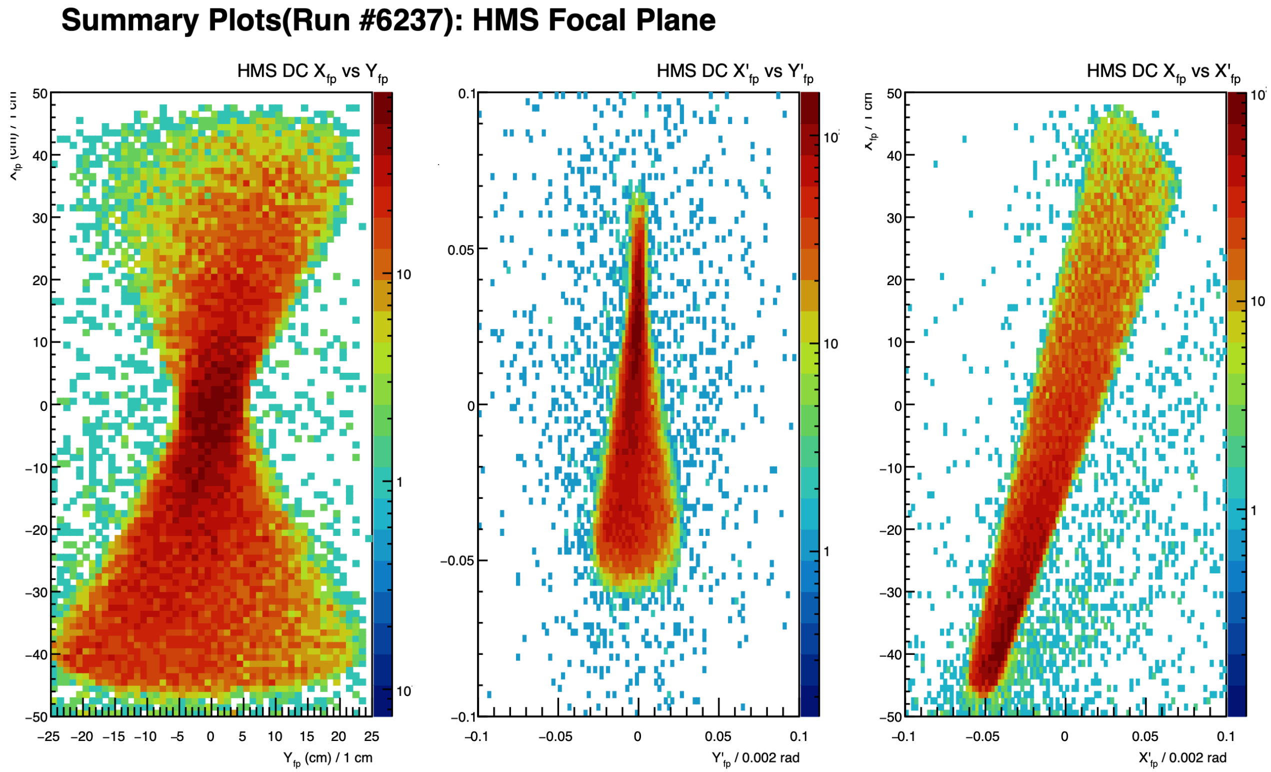


NPS signals

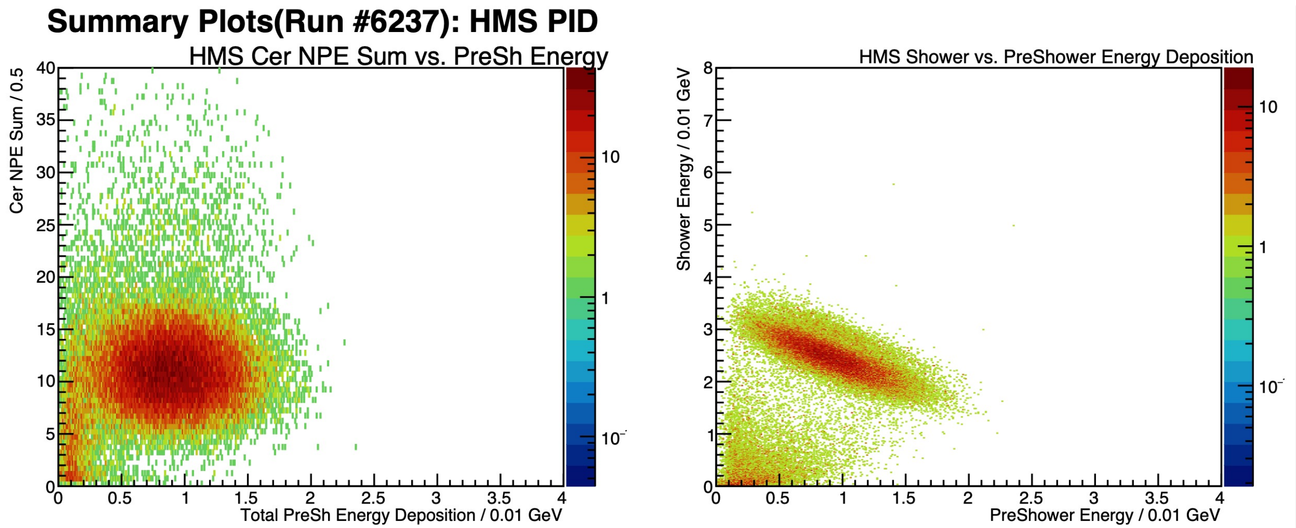


Wide Angle Compton Scattering at 8&10 GeV Photon Energies

HMS tracking

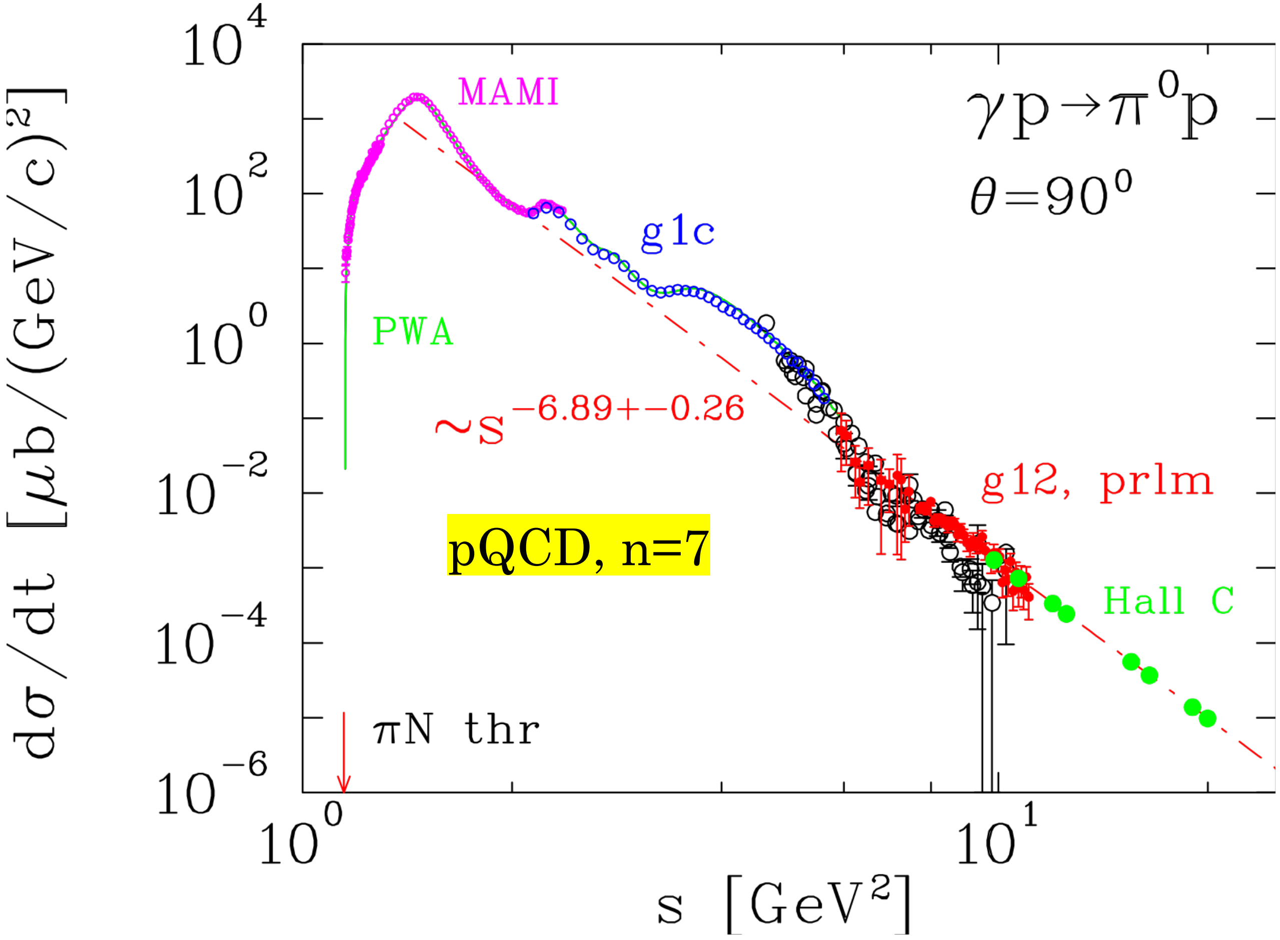


HMS PID



Wide Angle Exclusive Photoproduction of pi-zero Mesons

E12-14-005: D. Dutta, H. Gao, S. Sirca, M. Amaryan, M. Kunkel, I. Strakovsky



Scientific Rating: B

Recommendation: Approve

Title: **Wide angle exclusive photo production of π0 mesons**

Spokespersons: D. Dutta, H. Gao, S. Sirca, M. Amaryan, M. Kunkel, I. Strakovsky

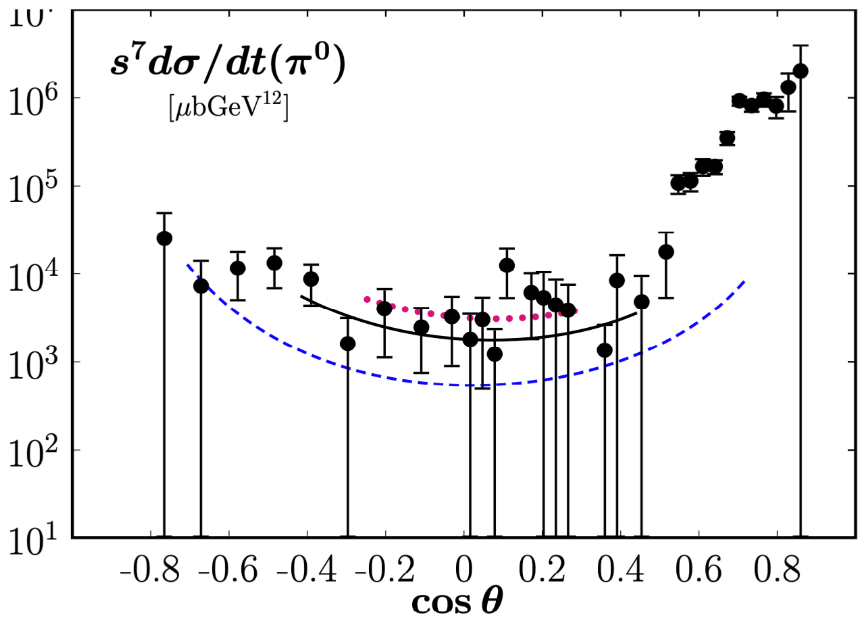
Motivation: This proposal aims to measure the differential cross-section of the $\gamma\, p \longrightarrow \pi^0\, p$ process in the energy range $10\ GeV^2 < s < 20\ GeV^2$ at large pion center of mass angles between 55° and 105°. The measurement will be carried out in Hall C using an electron beam impinging on a 6% copper radiator and a liquid hydrogen target. The recoil proton will be detected in the HMS spectrometer and photons from the $\pi^0 \longrightarrow \gamma\, \gamma$ decay will be detected in the Neutral Particle Spectrometer, which is under construction.

Measurement and Feasibility: The energy range and the scattering angles are large enough to allow the description of the process in terms of partonic interactions and the exploration of the elementary mechanism at work. The data will extend studies of the scaling behavior of the cross-section and allow for comparisons to handbag calculations — which severely under-predict existing cross sections — at higher energies than previously measured. The expected results could spur further theoretical development and test the limits of the Generalized Parton Distribution formalism for exclusive reactions. The case was also made that a reliable measurement could be made detecting either single photons from the π^0 decay or reconstructing the pion by detecting both photons.

Issues: There are no major technical issues. Theoretically, the interpretation of hard-exclusive meson production in terms of the handbag diagram and GPD formalism is inevitably more complicated than for hard-exclusive photon production. The PAC applauds the experimenters for designing their π^0 experiment to run in concert with the WACS proposal PR12-14-003, but must assign higher priority to the latter experiment.

Recommendation: **Approved for 18 days** to run in parallel with PR12-14-003
While the proposed measurements are of modest physics impact, most of the data can be taken in parallel with PR12-14-003. The PAC recommends that this experiment run entirely in parallel with PR12-14-003 and thus approves 18 days out of the requested 20.

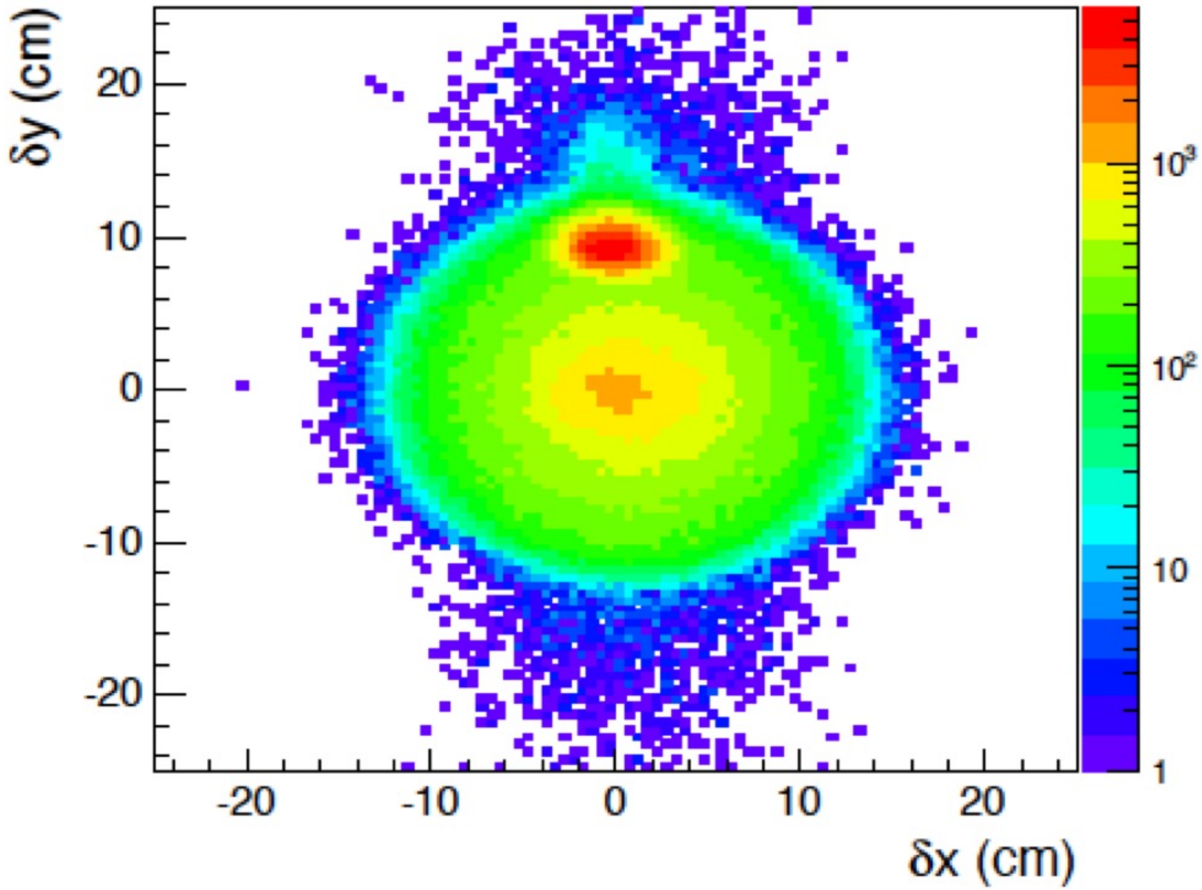
Wide Angle Exclusive Photoproduction of pi-zero Mesons



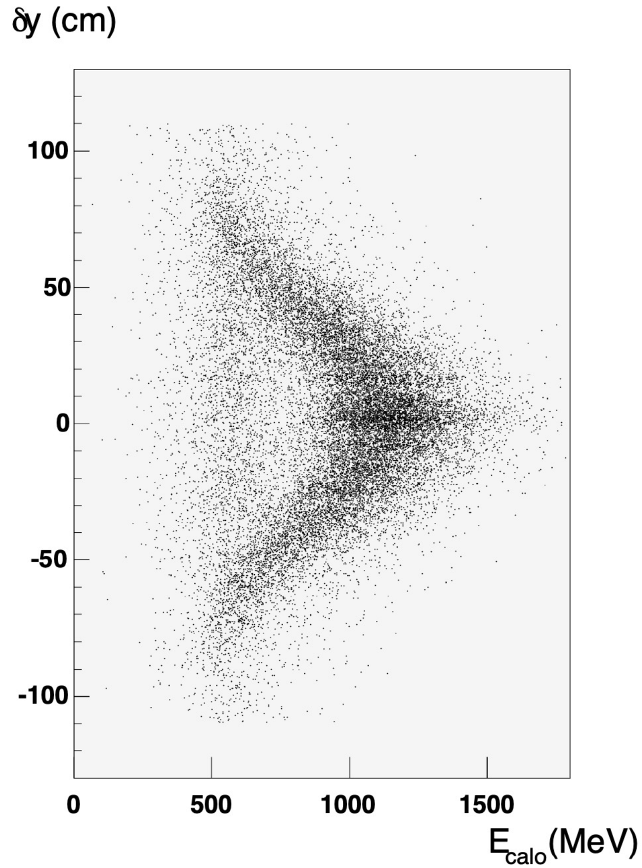
P. Kroll and
K. Passek-Kumericki,
PRD 97, 074023 (2018)

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 $2.5\ \mathrm{GeV}^2$.

Wide Angle Exclusive Photoproduction of pi-zero Mesons



single π^0 wings



E99-114 experiment

Run Group 2 (E12-14-003, E12-14-005) work to do:

- Experiment Readiness Review
- NPS preparation
- NPS calorimeter and Sweeper mounting at large angle side of SHMS
- Students/postdocs training

Run Group 3 (E12-17-008)

Polarization Observables in Wide Angle Compton Scattering
at large s, -t, and –u

D. Day, D. Hamilton, D. Keller, G. Niculescu, B. Wojtsekhowski and J. Zhang

NPS+CPS - SHMS used as carriage for NPS, BB as a proton arm
Polarized target with spinning cell

Scientific Rating: A-

Recommendation: C1 (Conditional Approval) for 46 days Required the lab approval

Title: Polarization Observables in Wide-Angle Compton Scattering at large s, t and u

Spokespersons: D. Day, D. Hamilton (Contact), D. Keller, G. Niculescu, B. Wojtsekhowski, J. Zhang

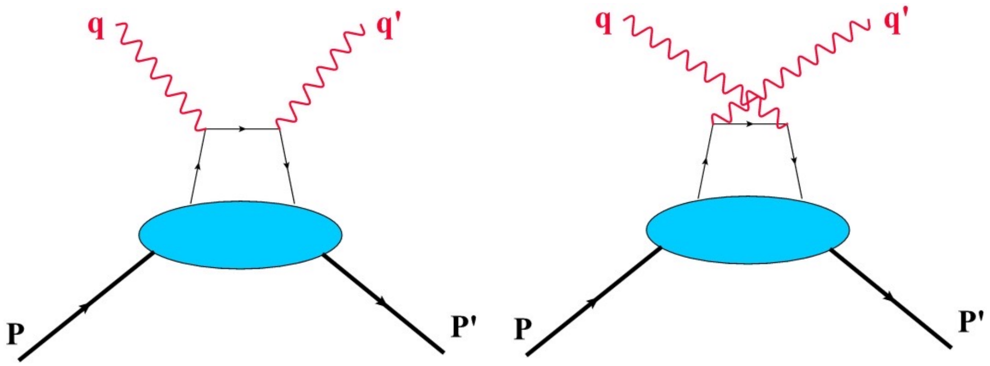
Motivation: Real Compton Scattering (RCS) off a proton is a fundamental and basic process which, at high energies, should be explained in terms of photon-quark interactions. The mechanism behind RCS in the regime of $\sqrt{s}$ = 5-10 GeV remains not well understood. Measurements have shown that these data cannot be described by pQCD calculations involving the scattering of three valence quarks, but the dominant mechanism could be the handbag model with the photon scattering of a single quark. The proposed measurements aim at disentangling the existing handbag mechanisms (CQM, SCET and GPD) that have been proposed to describe asymmetries previously measured in Wide Angle Compton Scattering (WACS). In particular the double longitudinal spin asymmetry K_{LL}, related to the helicity transfer from the photon to the scattered proton, is surprisingly large and stable with respect to the photon center-of-mass scattering angle. In the GPD and SCET formalisms, K_{LL} equals the spin asymmetry A_{LL} relative to the helicity of the photon and the initial photon, while in CQM the difference between these two quantities grows with the center-of-mass scattering angle.

Measurement and Feasibility: This proposal requests 46 days to measure the initial state correlation asymmetries A_{LL} and A_{LS} in WACS on a polarized proton target at photon energies of 8.8 GeV at Θ_{CM}=70, 90, 110 degrees and 11 GeV at Θ_{CM}=70 degrees. These kinematic points optimize statistical precision while also maintaining sufficiently high Mandelstam variables to facilitate interpretation within the handbag formalism.

Issues: The PR12-17-008 collaborators have done substantial work to show that the novel design of the Compact Photon Source (CPS) is feasible and that radiation levels in the hall are acceptable. The PAC recommends the collaboration continue to work closely with the lab while finalizing the design and price estimate for the CPS, and clearly establishing the expected maximum photon intensity.

Summary: Investigations into the mechanisms behind WACS will provide valuable insight into the nature of exclusive reactions and proton structure and are ideally suited for the facilities provided by the Jefferson Lab 12 GeV upgrade. The PAC commends the PR12-17-008 collaborators on successfully unifying the strongest aspects of the PR12-15-003 and PR12-16-009 proposals. Pending the successful review of the CPS, and subsequent approval of PR12-17-008, the PAC recommends the running time for the approved experiment E12-14-006 be subsumed into the running time for this proposal.

Compton scattering



In the GPD approach, interaction goes with a single quark, and the handbag diagram dominates.

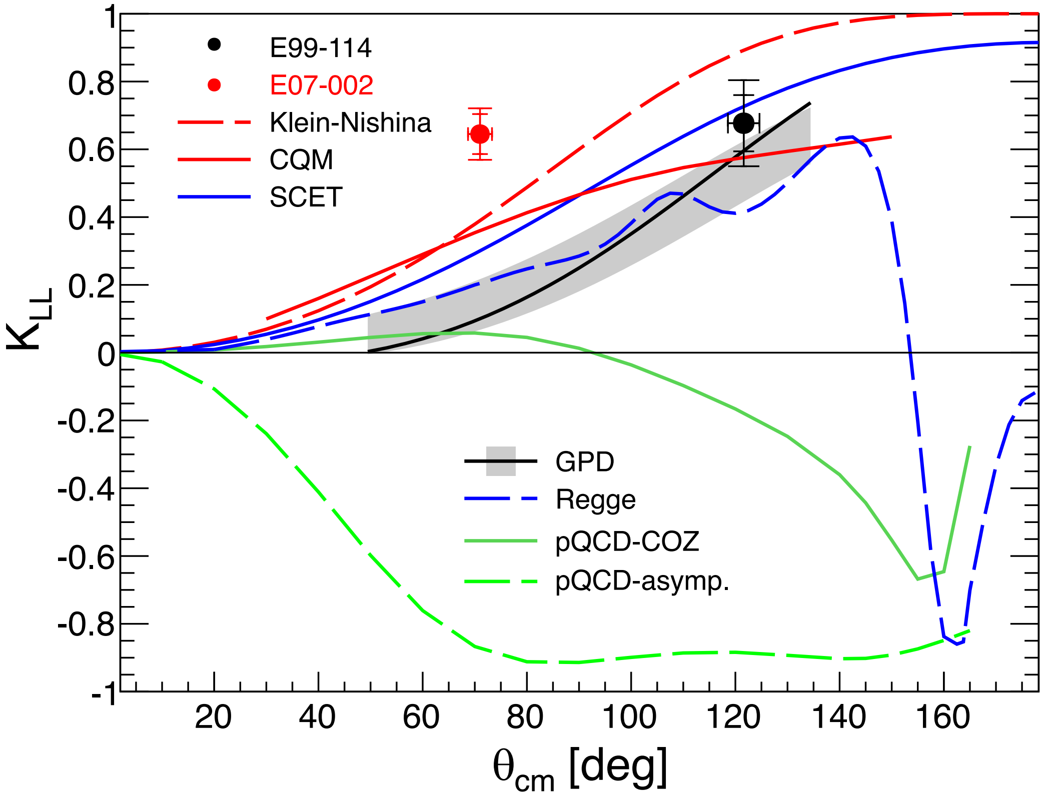
M.Diehl & P.Kroll

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}_{KN}\left(\frac{1}{2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 + R_A^2\right] - \frac{us}{s^2+u^2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 - R_A^2\right]\right)$$

$$K_{LL} = A_{LL} \qquad K_{LL}\frac{d\sigma}{dt} \equiv \frac{1}{2}\left[\frac{d\sigma(+,\uparrow)}{dt} - \frac{d\sigma(-,\uparrow)}{dt}\right]$$

- Test of the handbag predictions to the <10% level is an important task.
- The K_{LL} (A_{LL}) asymmetry is an observable of choice to test a reaction mechanism.
- The NLO corrections are supposed to vary as 1/s (N.Kivel & M.Vanderhaeghen).

Physics Motivation



E99-114
s=6.9, t=-4.0, u= -1.1 GeV^2

PRL 94, 242001 (2005)

E07-002
s=7.8, t=-2.1, u= -4.0 GeV^2

Strong evidence for additional physics

PRL 115, 152001 (2015)

New measurement at large s, -t, -u values is necessary to clarify the mechanism of WACS

Polarized WACS, E12-17-008

$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{\mathrm{KN}} \left\{ \frac{1}{2}\frac{(s-u)^2}{s^2+u^2}\left[R_V^2(t) + \frac{-t}{4m^2}R_T^2(t)\right] + \frac{1}{2}\frac{t^2}{s^2+u^2}R_A^2(t) \right\}$$

$$A_{LL} = K_{LL} = \frac{R_A(t)}{R_V(t)} A_{LL}^{\mathrm{KN}}$$

$$A_{LS} = -K_{LS} = A_{LL}\left[\frac{\sqrt{-t}}{2m}\frac{R_T(t)}{R_V(t)} - \beta\right]$$

Diehl & Kroll, EPJ C73 (2013)

Kin	E_{Beam} [GeV]	E_{in} [GeV]	θ_γ [°]	E_γ [GeV]	D_{NPS} [m]	θ_{p} [°]	p_{p} [GeV/c]	D_{BB} [m]	θ^{cm} [°]
L1	8.8	6.0	21.5	4.16	3.0	35.5	2.62	1.5	70.0
S1	8.8	6.0	21.5	4.16	3.0	35.5	2.62	1.5	70.0
L2	11.0	9.5	17.4	6.49	3.0	30.5	3.82	1.5	70.0
L3	8.8	6.0	30.2	3.22	3.0	26.5	3.63	2.5	90.0
L4	8.8	6.0	42.3	2.25	1.0	19.4	4.55	3.5	110.0
S4	8.8	6.0	42.3	2.25	1.0	19.4	4.55	3.5	110.0

Polarization Observables in Wide Angle Compton Scattering at large s, -t, and –u

1. A 2.5 μA polarized electron beam incident on a 10 % radiator inside a new Compact Photon Source (CPS) produces a high-intensity untagged photon beam.
2. The proton target is the UVA/JLab solid polarized ammonia target.
3. The recoil proton is detected with the BigBite spectrometer equipped with GEM trackers and trigger detectors.
4. The highly-segmented $PbWO_4$ NPS calorimeter is used to detect the scattered photon.

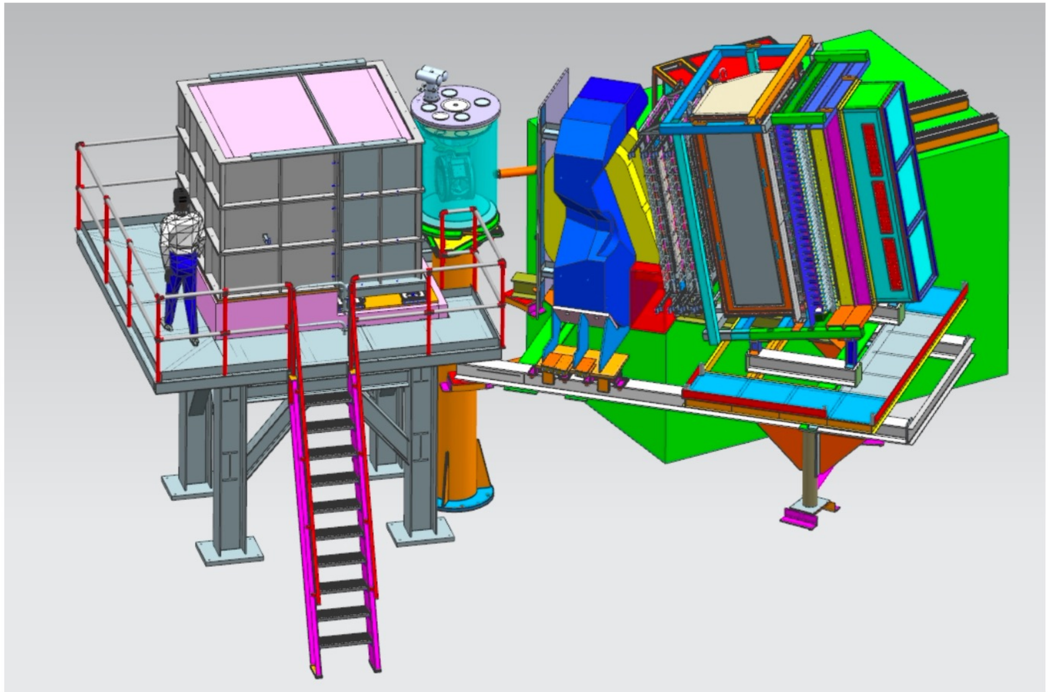


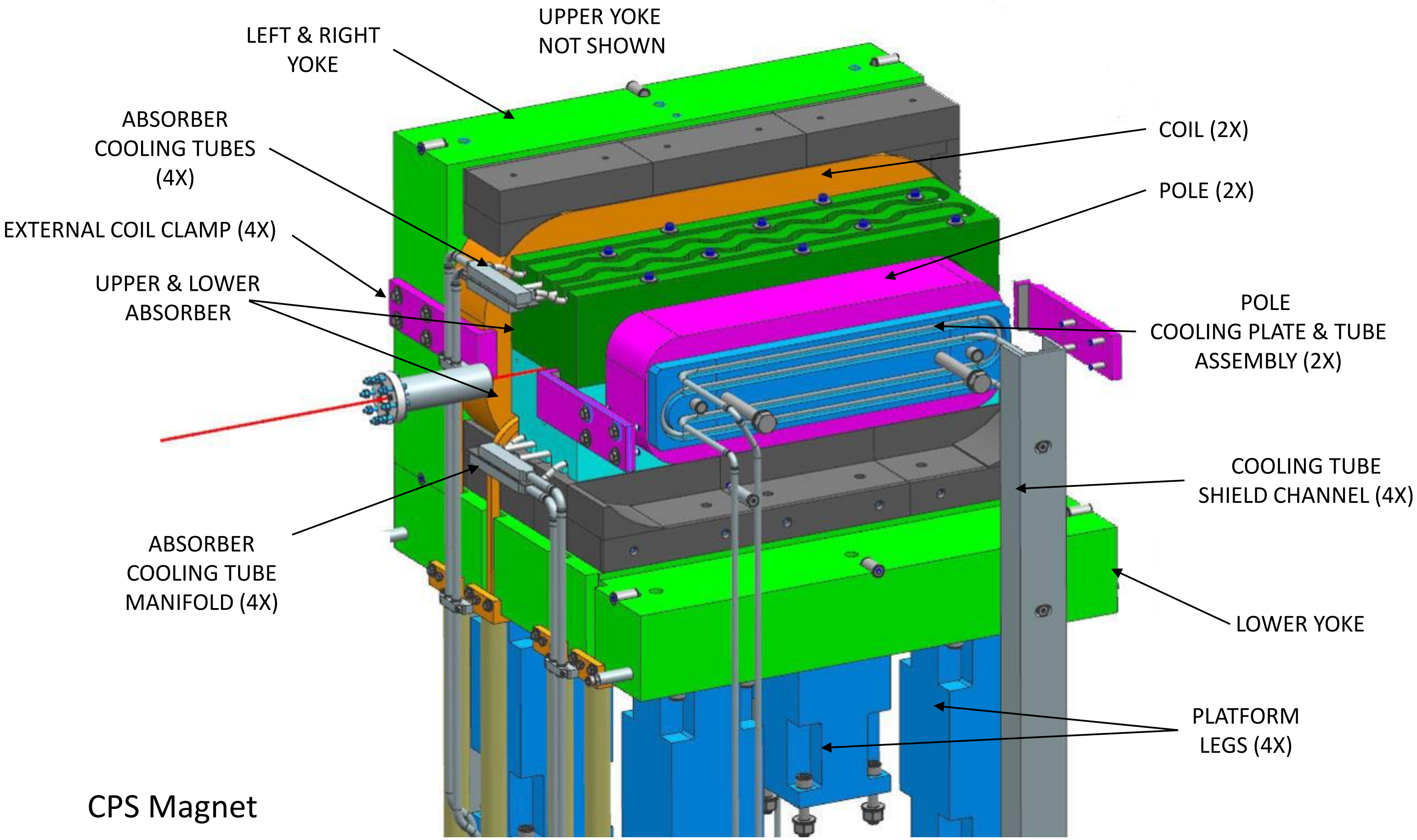
Figure from Steve Lassiter

The use of the CPS and BigBite results in a factor of 30 improvement in figure-of-merit over previous experiments and opens up a new range of polarized physics opportunities at JLab.

Compact Photon Source

S. Lassiter

CPS in Hall C

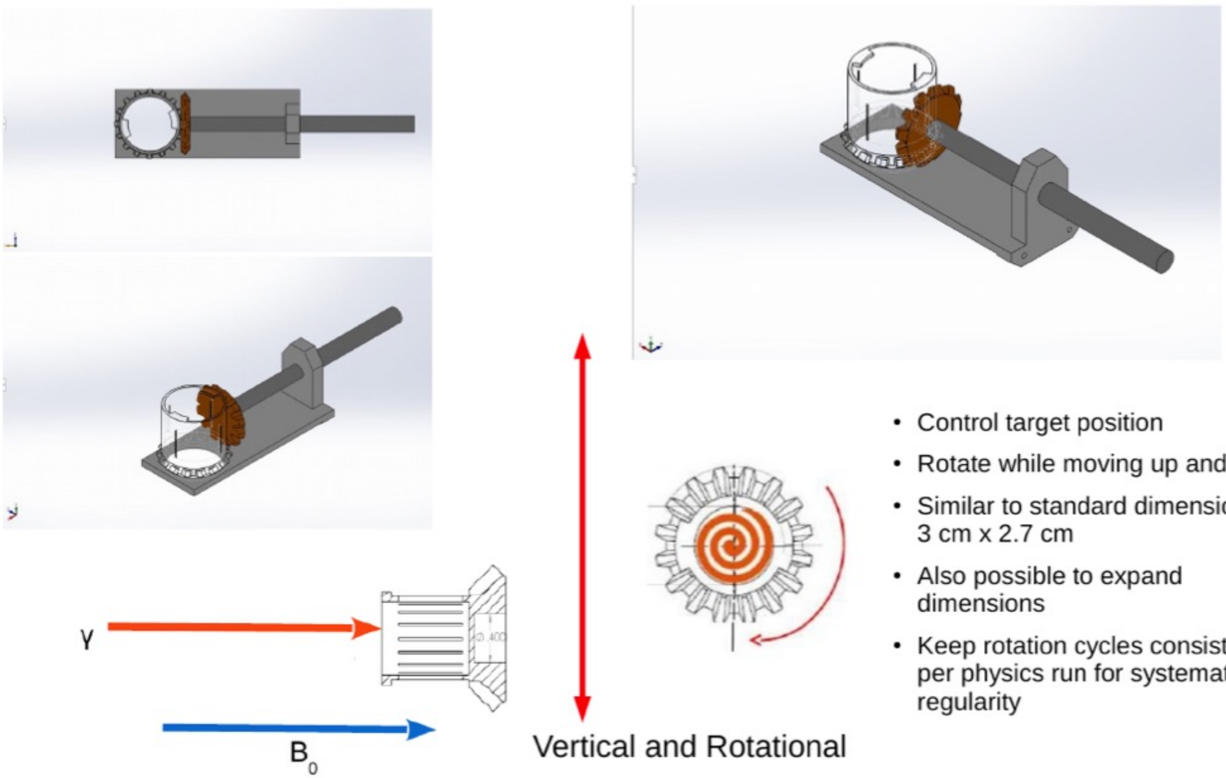


CPS Magnet

Spinning NH3 polarized target

3. Uniform Illumination of the target cups

Dustin Keller



- Control target position
- Rotate while moving up and down
- Similar to standard dimensions 3 cm x 2.7 cm
- Also possible to expand dimensions
- Keep rotation cycles consistent per physics run for systematic regularity

Figure 1: A simple geared cup example specialized so that the target cup does not interact with the beam. Vertical motion combined with rotation of cup will allow uniform coverage of target cell. The red dot represents the fixed position of the photon beam. The colored bead in the cup can be seen moving as the cup rotates counterclockwise and the target ladder is moved up.

Run Group 3 (E12-17-008) work to do:

- Experiment Readiness Review
- CPS detailed design and test
- Polarized target with spinning NH3 cell
- NPS calorimeter and BB spectrometer mounting
- BB detector package with hadron calorimeter
- Students/postdocs training

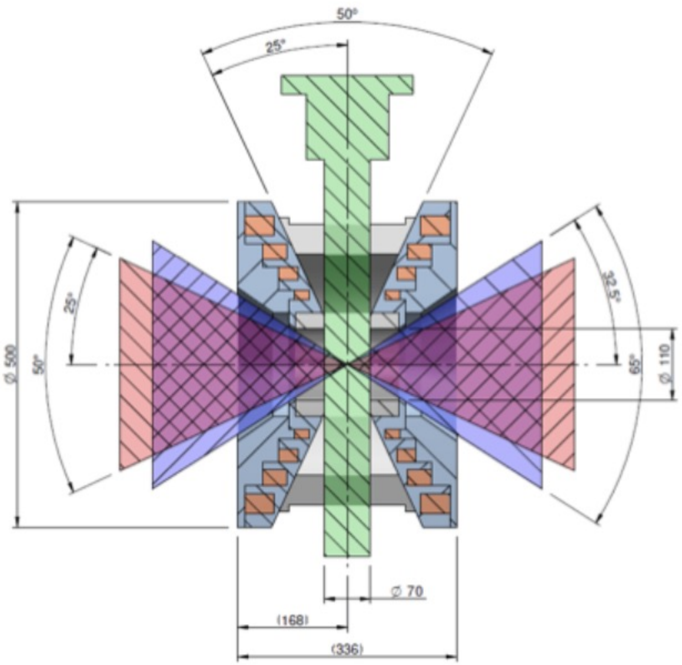
Summary

- Run group 2 (WACS + Pion) is very close to being ready to run. NPS needs some modest work, as recommended in lessons-learned analysis of GR1a.

- Run group 3 (Polarized WACS) is based on CPS which reached an advanced stage. However, it still needs more design and tests. The experiment also needs significant design/construction work on the polarized target, BB + detector, and NPS.

A new target magnet

A new magnet with improved acceptance for transverse polarization was procured for experiments in Hall C.
Compared to the original Hall B and C magnets:
±35° acceptance for longitudinal polarization (30% smaller)
±25° acceptance for transverse polarization (67% larger)



Cross-section through the magnet showing the beam and cold finger access diameters (in mm) and

The coils are shimmed using iron to achieve desired 100 ppm uniformity for dynamic polarization.

- Cost saving
- Higher coil margin (SSP)
- Uniformity guaranteed only at 5.0 T