Exclusive π^0 Production Cross Section: L/T Separation

Joshua P. Crafts

The Catholic University of America

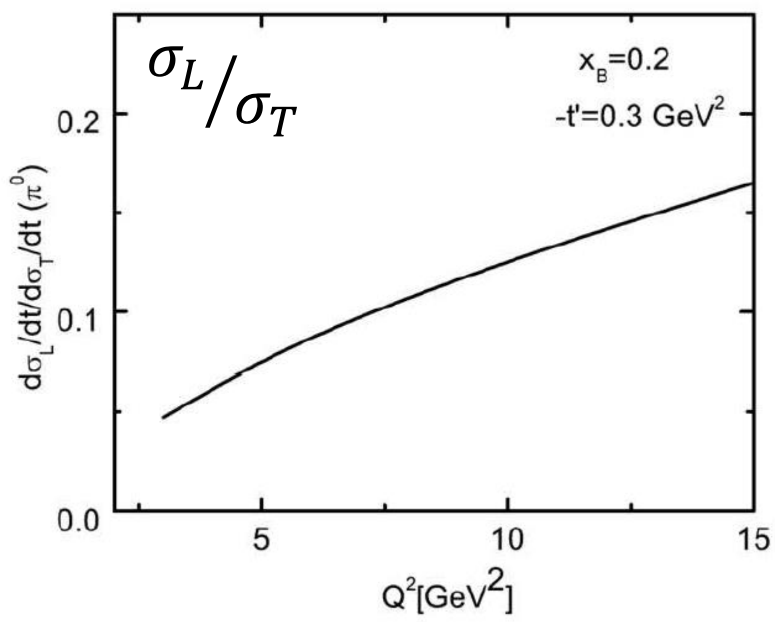
Presented to the Winter Hall C Collaboration Meeting

On behalf of the NPS Collaboration

Jan 19th, 2024

Outline

- Physics Motivations: Exclusive π^0
  - Original Exclusive π^0 measurement in Hall A and CLAS Collaboration.
  - Handbag factorization indicate that for asymptotically large photon virtualities, the longitudinally polarized photons should dominate.
  - It is of great interest to determine the relative longitudinal and transverse π^0 contributions to the cross section.
- 2-Photon Trigger
  - Implementation
- Current status of the exclusive π^0 production with the NPS.
  - Initial Missing Mass Calculation
- π^0 Asymmetry
- Looking Forward

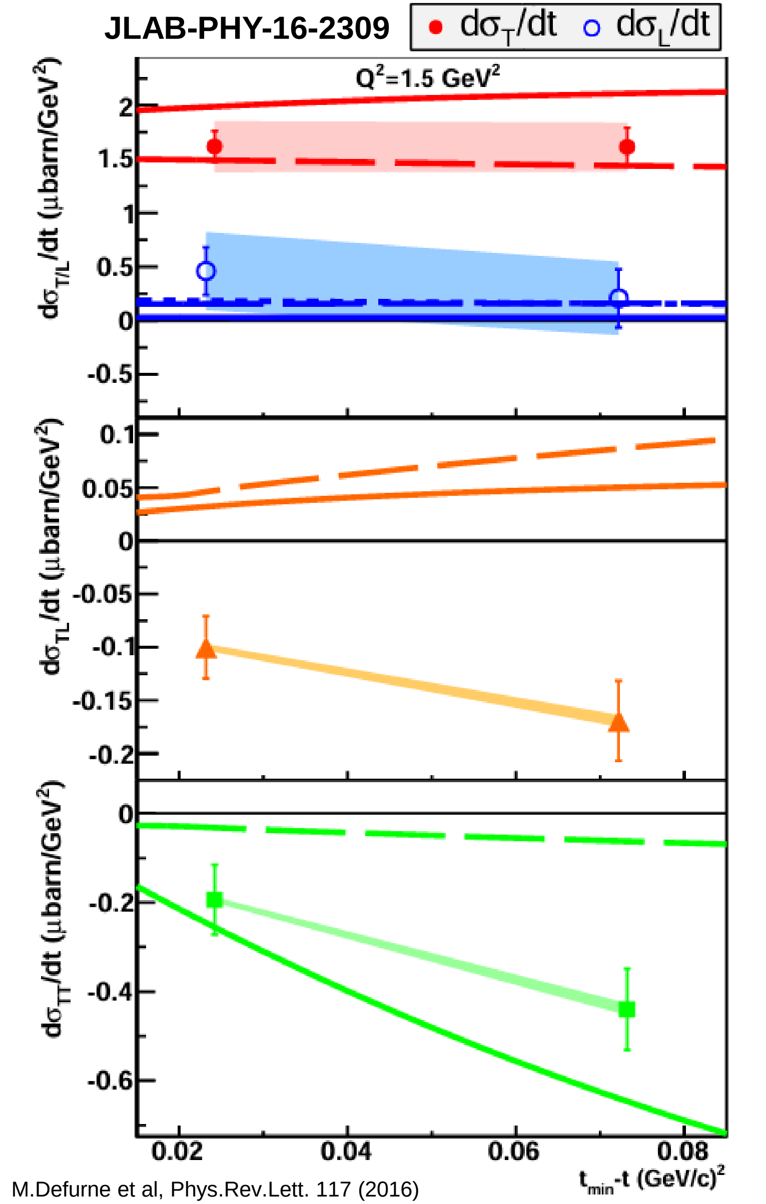


- The ratio of the longitudinal and transverse cross section for π^0 electroproduction.

P. Kroll

Physics Motivations

- Exclusive π^0
  - The first cross section measurements for exclusive π^0 electroproduction in the valence region were performed in Hall A and later by CLAS.
- The 6GeV data was L/T separated but while the σ_T was measured, it was only able to provide an upper bounds on σ_L. The subsequent 12GeV data was not L/T separated.
- The data provided evidence for strong contributions from transversely polarized virtual photons.
- This observation contrasts with the handbag factorization prediction.
  - Handbag approach indicates amplitudes for transverse photons are suppressed (~1/Q) compared to longitudinal.
  - Offers areas for refinement of our understanding.



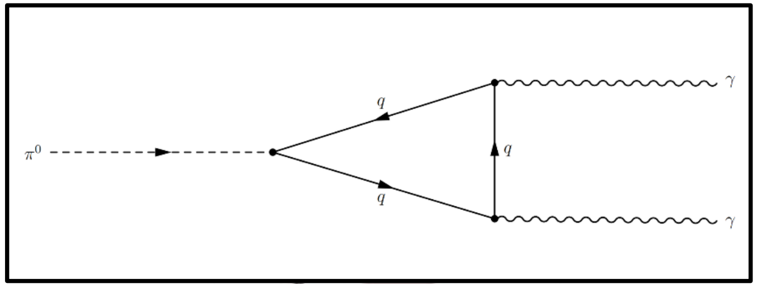
M.Defurne et al, Phys.Rev.Lett. 117 (2016)
S.Goloskokov and P.Kroll, Eur.Phys.J. A47, 112 (2011)
G. R. Goldstein, J. O. Hernandez, and S. Liuti, Phys.Rev.D84, 034007 (2011)

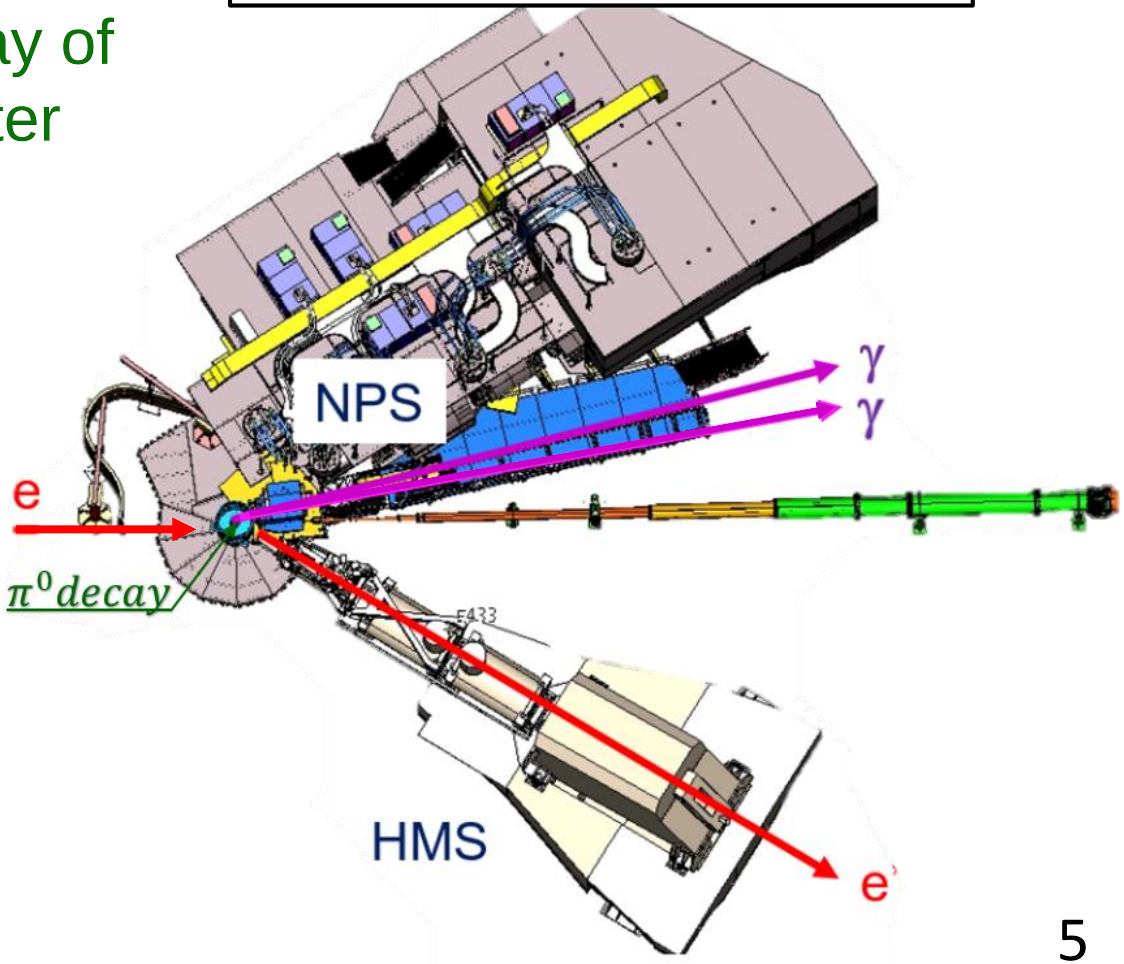
Physics Motivations Continued

- First π^0 L/T separated data came from Hall A with experiments E07-007 off the proton and E08-025 off the neutron.
  - Now Published, JLAB-PHY-15-2038 and JLAB-PHY-16-2309
  - x_B was at 0.36, DVCS will be over a larger kinematic range
- E12-13-010 DVCS Experiment provides a clean probe of transversity effects and allows for measurements of the L/T separated exclusive π^0 cross section in a larger kinematic range
  - Providing a constraint on σ_L and σ_T
  - Supported in part by NSF awards PHY2012430 and PHY2309976
- If σ_T is confirmed to be large this could subsequently allow for a detailed investigation of transversity GPDs
  - Also the separated longitudinal cross section could allow for probing the usual GPDs through neutral pion production.

Exclusive π^0 in parallel with DVCS

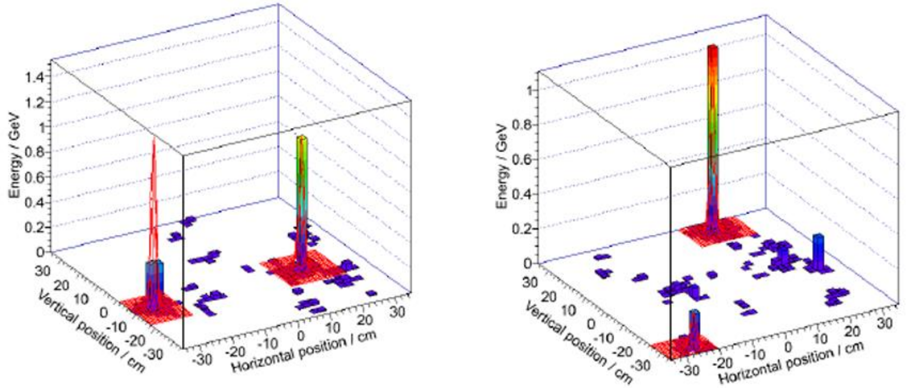
- The measurement is being done in parallel with the DVCS measurement by detecting in coincidence scattered electrons in the existing HMS and photons from the decay of π^0 using the Neutral Particle Spectrometer (NPS).
- The NPS will detect photons corresponding to π^0 electroproduction close to the direction of $\vec{q}$, the exchanged virtual photon three-momentum transfer.
  - Average lifetime of 8.5×10^{-17} seconds.
  - The HMS Spectrometer benefits from relatively small point-to-point uncertainties, which are crucial for meaningful L/T separations.



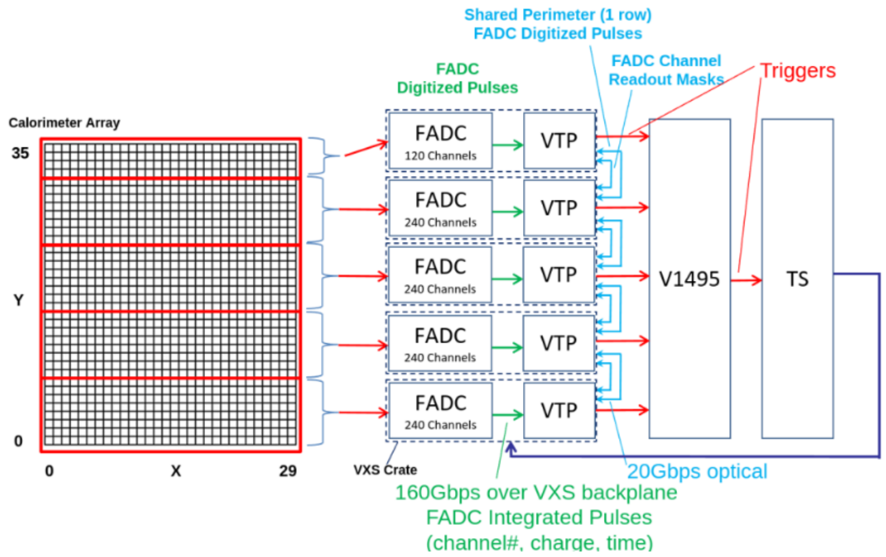


Two-Photon Trigger

- Timing windows & Trigger Thresholds
- The trigger initializes in the NPS if there is a 70MeV seed event.
- If the event then exceeds the readout threshold, usually 800MeV for each of 2-clusters, it is included in the trigger
  - A separate FPGA module monitors the five FADC crates for the NPS as there is a high likelihood that the two photons will be in different crates.
- If the two photons are detected within a 20ns window the FPGA passes the event up into the counting house where it is combined into coincidence with the HMS in NIM logic.

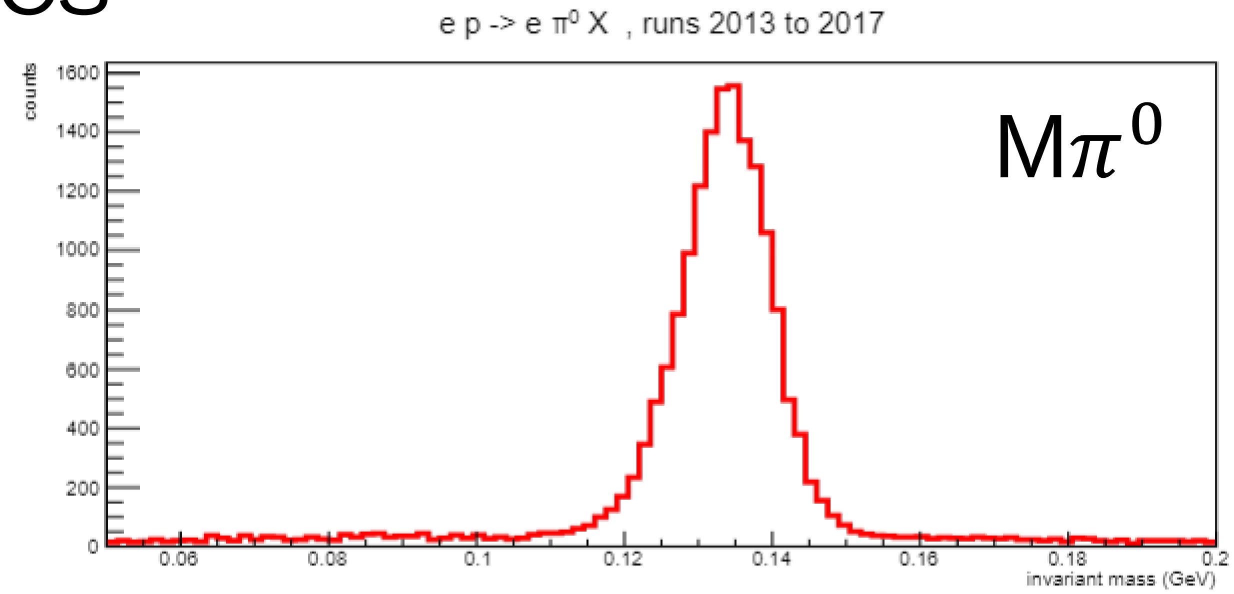


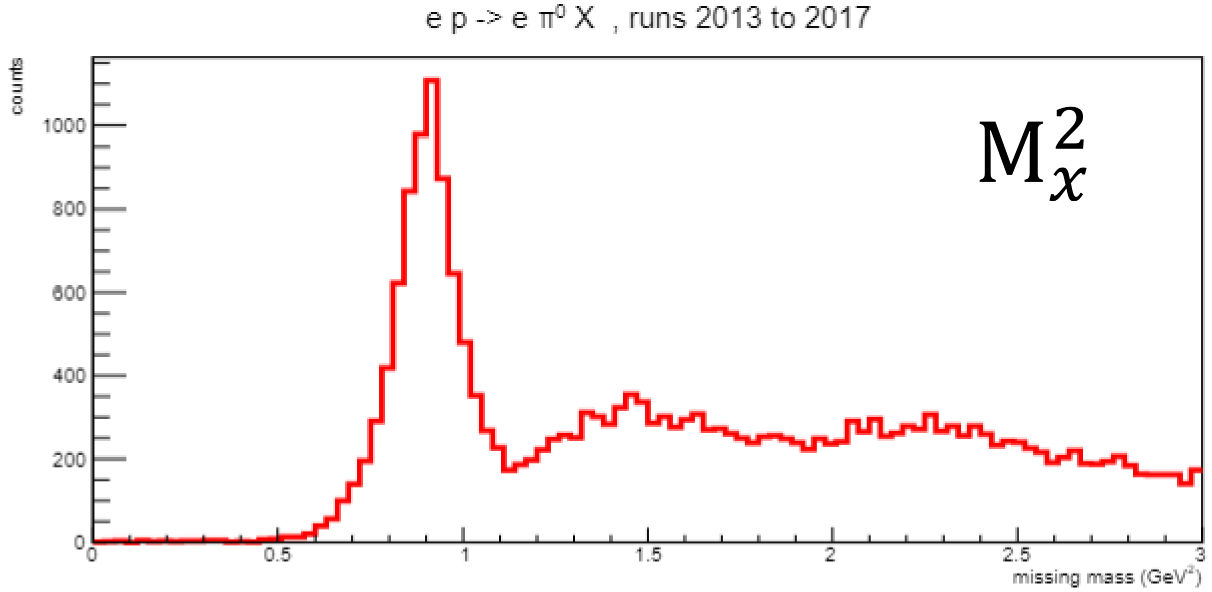
Geant4/GEM simulation of hits from π° 2γ decay along with background.
From M.Carmignotto.



π^0 Data in the context of DVCS

- In addition to the Exclusive π^0 physics.
- π^0 Data is being collected alongside the DVCS data, both being required for the DVCS physics.
- The π^0 is also providing useful information for calibration of the NPS detector itself.
  - Supplemental to the elastic calibration. $\pi^0 \rightarrow \gamma\gamma$ Calibration.
  - Mentioned in previous talks today by Hao.

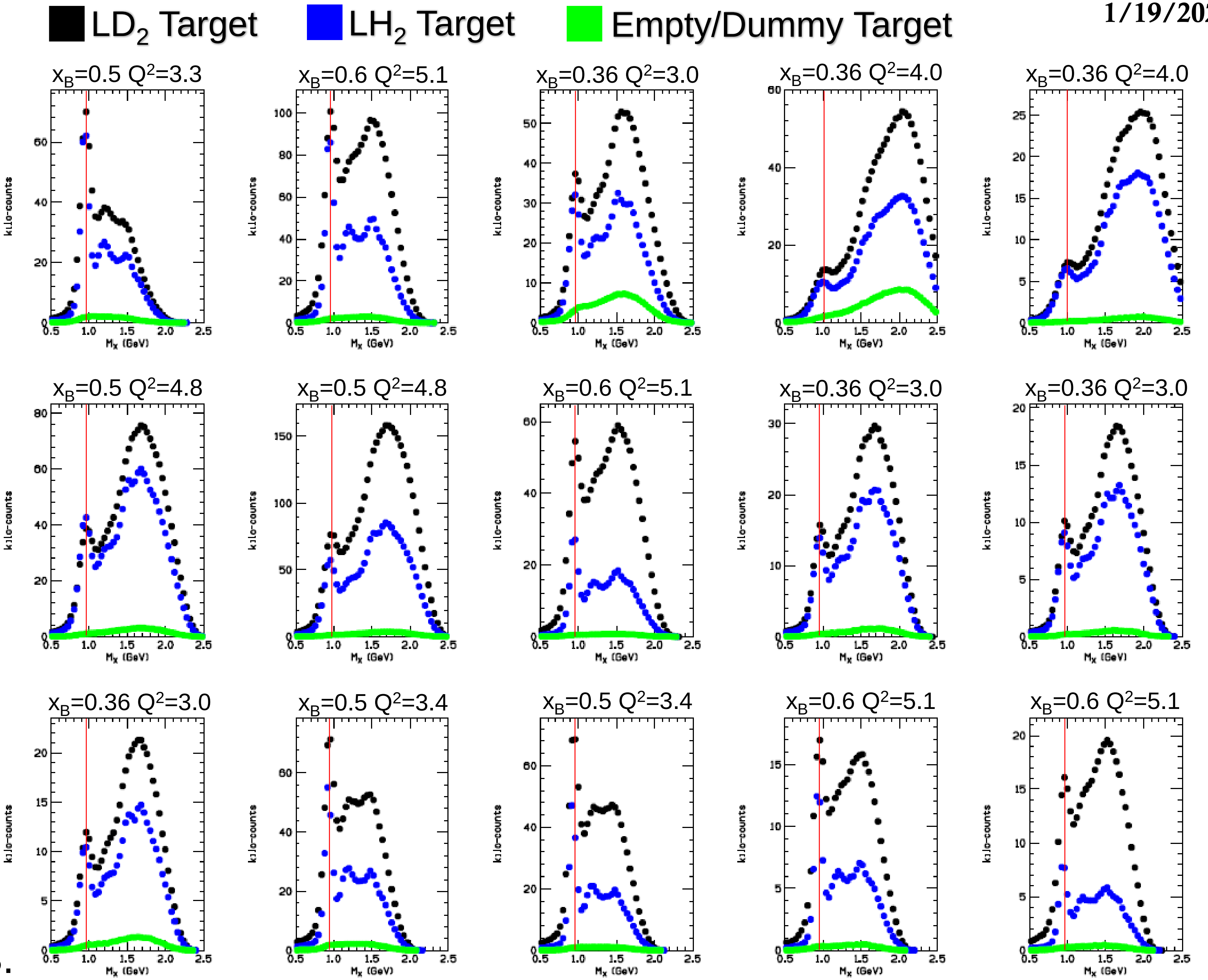




Credit to Wassim H.

Missing Mass

- Example of the Exclusive π^0 missing mass statistics for the different kinematics currently taken by the experiment currently.
- Three different targets were used.
  - Two cryogenic (LD_2 and LH_2) and the dummy/empty target.
- The π^0 peak can be isolated and in the kinematics shown here with of multiple kilo-counts collected.



Credit to Peter B.

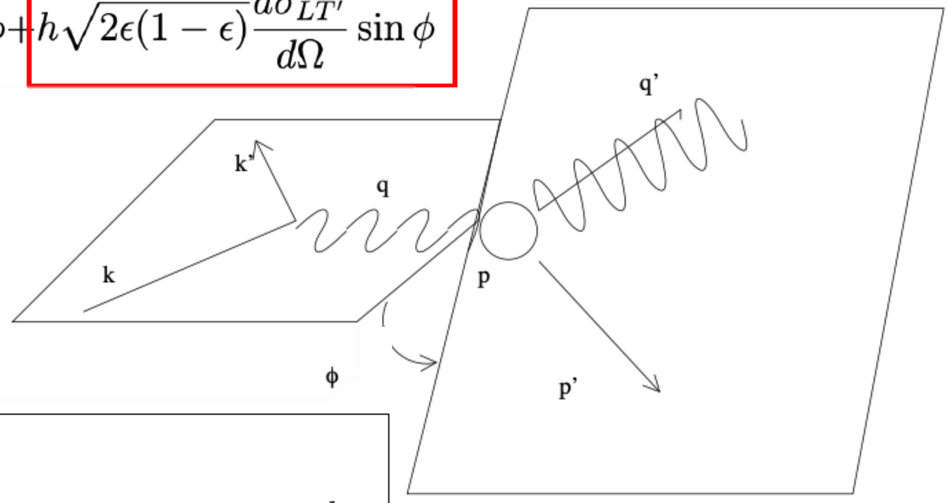
π^0 Asymmetry

Helicity dependent section

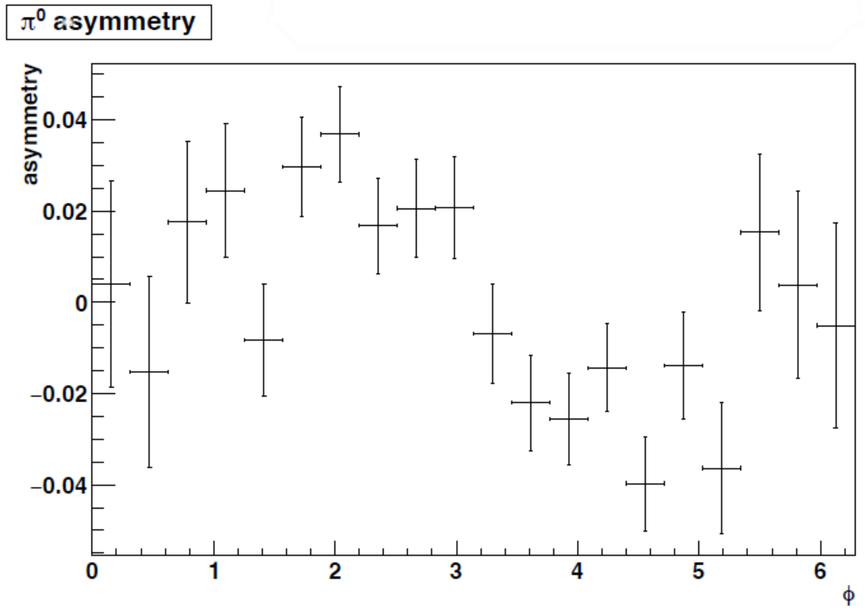
π^0 Cross Section: $$\frac{d\sigma_\nu}{d\Omega_f dE_f d\Omega} = \frac{d\sigma_T}{d\Omega} + \epsilon\frac{d\sigma_L}{d\Omega} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{LT}\cos\phi}{d\Omega} + \epsilon\frac{d\sigma_{TT}}{d\Omega}\cos 2\phi + h\sqrt{2\epsilon(1-\epsilon)}\frac{d\sigma_{LT'}}{d\Omega}\sin\phi$$

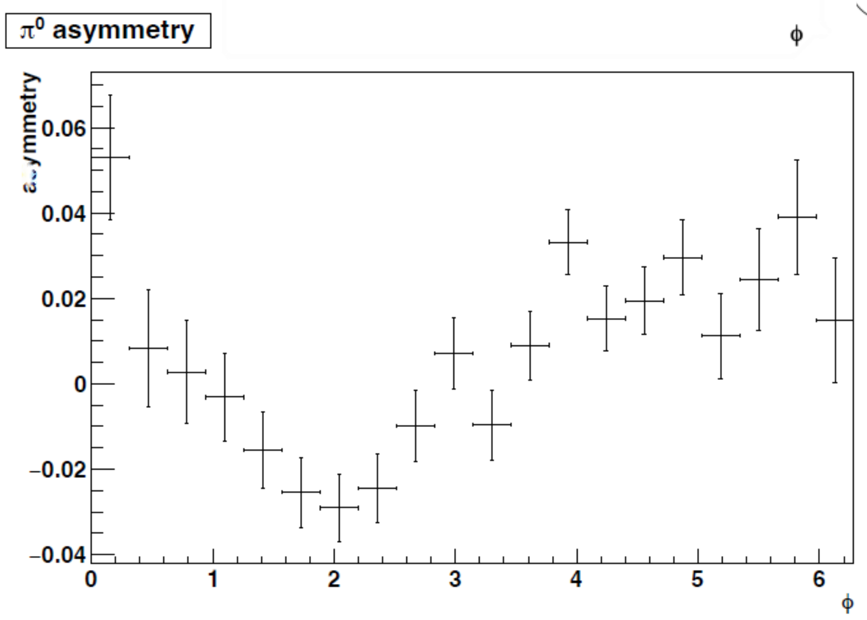
π^0 Asymmetry: $$\frac{N_+ - N_-}{N_+ + N_-}$$

Only helicity dependent part remains



Results for half wave plate out and in:





OUT 1723-1759 15 runs & 1945-1957 10 runs

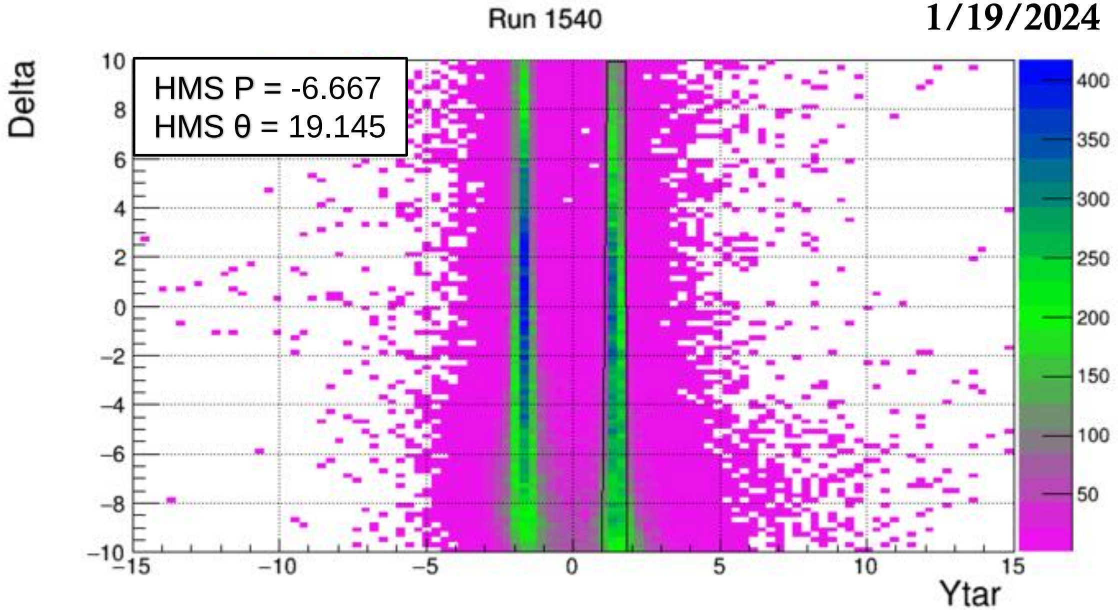
IN 1820-1937 66 runs

Credit to Yaopeng Z.

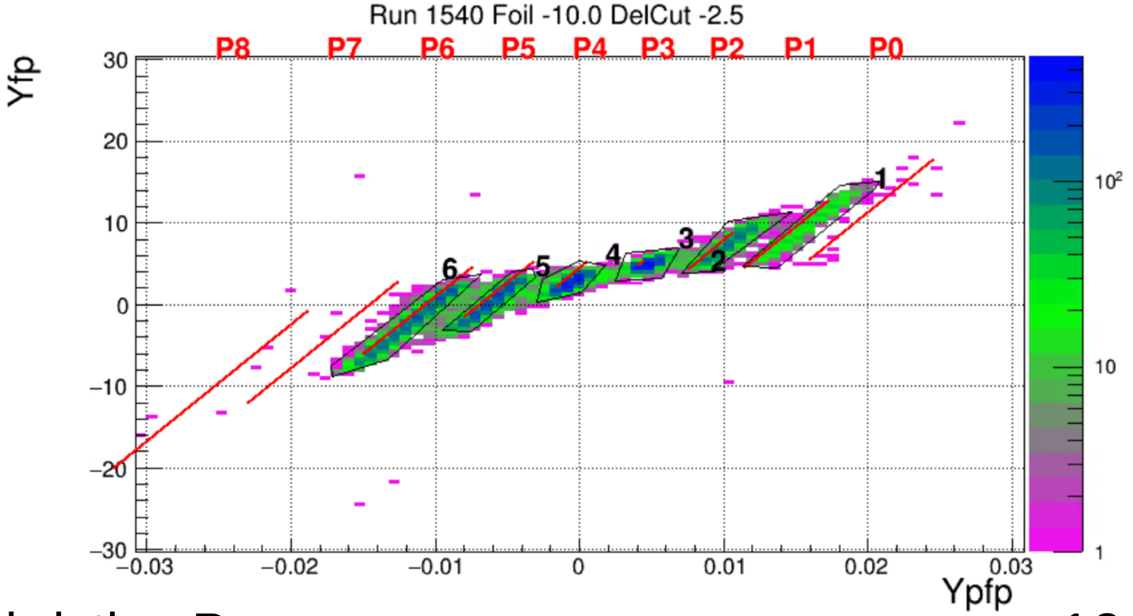
- We see a clear asymmetry of form A sin(ϕ) and of order magnitude ~0.04
- This suggests a non-zero LT ′ interference among the amplitudes describing the $\gamma^*p \rightarrow p\,\pi^0$ reaction"

Looking Forward

- "General disclaimer"
- The data we have shown here is preliminary and is very much a first pass and there is still more data to be taken.
- Significant effort is being invested now to verify and calibrate the various detector elements as well as monitoring beam stability and quality. Analysis refinements.
    - Target Boiling
    - NPS Calibration
    - BCM &BPM
    - Møller Calibration
    - HMS Optics Calibration for new kinematics
- Multiple in-progress items.



Graphical Target Position (Y-tar) -Delta cuts along 2 carbon foils cuts on the two foils at +/-8 cm



Graphical sieve hole cuts for the for one of the delta cuts

Credit to Christine P.

Summary

- The hall A experiments E07-007 and E08-025 set the stage for understanding the Exclusive π^0 L/T separation.
- Hall C E12-13-010 DVCS Experiment gives a probe of transversity effects and will allow for a L/T separation measurement across a larger kinematic range.
- The NPS detector in combination with the HMS spectrometer is using the two photon trigger to detect photons corresponding to π^0 electroproduction.
- The π^0 missing mass peak has been preliminarily identified.
- The π^0 asymmetry can be seen.
- Incredible effort is being invested to complete the experiment and refine the data being taken.

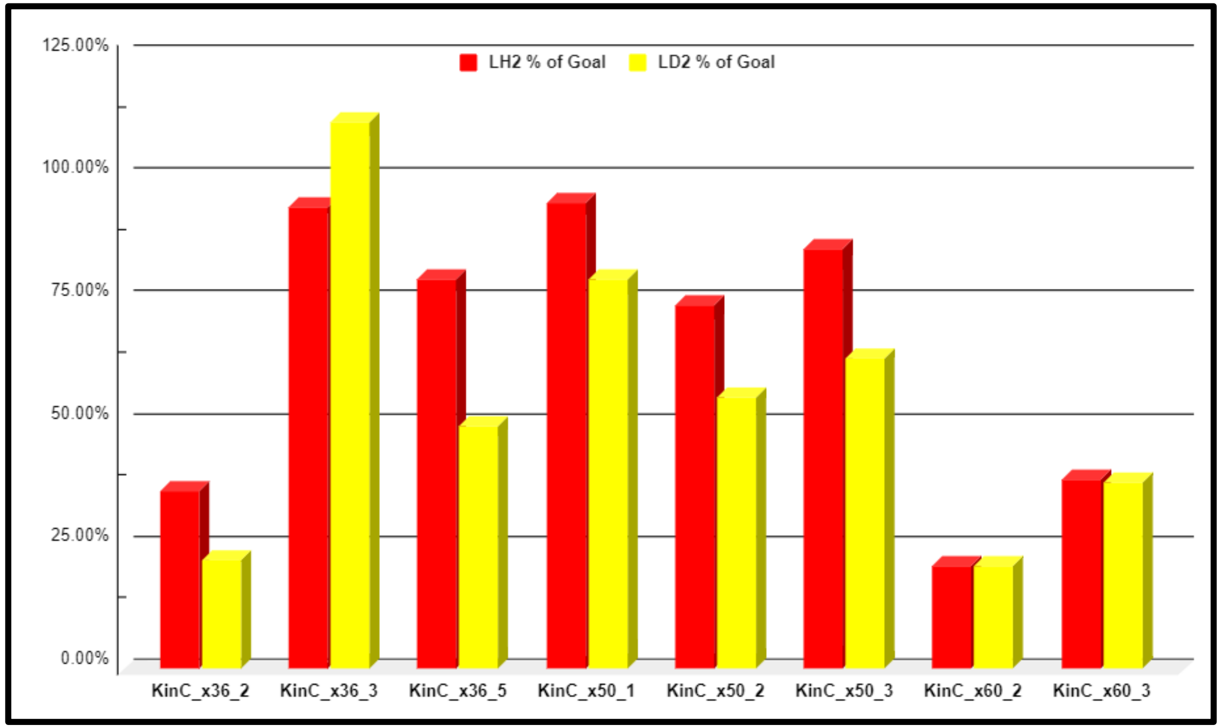
Run Summary

2023 Charge Accumulation

x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)	Coulomb Goal Per Target	LH2 % of Goal	LD2 % of Goal
0.36	KinC_x36_3	5	3.0	0.60	94%	111%
	KinC_x36_5	5	4.0	1.40	79%	49%
	KinC_x36_2	4	3.0	3.30	36%	22%
0.50	KinC_x50_2	5	3.4	3.00	74%	55%
	KinC_x50_3	5	4.8	6.40	86%	63%
	KinC_x50_1	4	3.4	1.90	95%	79%
0.6	KinC_x60_3	5	5.1	11.60	39%	38%
	KinC_x60_2	4	5.1	19.00	21%	21%

2024 Charge Goals → May

x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)	Coulomb Goal Per Target	LH2 % of Goal	LD2 % of Goal
0.25	KinC_x25_1	5	2.1	2.6		
	KinC_x25_2	5	2.4	2.6		
	KinC_x25_3	4	2.4	2.6		
	KinC_x25_4	3	3.0	2.6		
0.36	KinC_x36_6	5	5.5	4.30		
	KinC_x36_4	4	4.0	2.70		
	KinC_x36_1	3	3.0	2.30		
0.5	KinC_x50_0	3	3.4	7.90		
0.6	KinC_x60_4	5	6.0	19.20		
	KinC_x60_1	3	5.1	25.60		



- Our objectives are:
  - Obtain a spin-dependent cross section
  - Extract L/T separation for π^0

Plenty of opportunities to get involved

!!TAKE SHIFTS!!

Thank you to the NPS Collaboration;
Thanks to all my colleagues
at JLab and elsewhere
Thank you all for your time


I WANT YOU TO
SIGN UP FOR SHIFTS

Backup Slides

Winter Hall C Collaboration Meeting
1/19/2024

Kinematic Setting	Pass	SHMS Theta (deg)	NPS Theta (deg)	Coulomb Goal Per Target	LH2 % of Goal	LD2 % of Goal	% of Dummy to LH2	Re-summed Kinematics	LH2 % of Goal	LD2 % of Goal	Coulombs, H+D
KinC_x36_1	3			2.3							0.00
KinC_x36_2	4	30.66	14.36	1.1	29.16%	16.06%	6.60%	KinC_x36_2	36.24%	22.15%	0.50
KinC_x36_2'	4	28.76	12.46	1.1	44.78%	25.22%	7.86%				0.77
KinC_x36_2''	4	32.90	16.60	1.1	34.77%	25.17%	15.09%				0.66
KinC_x36_3	5	32.26	15.96	0.6	94.07%	111.43%	25.88%	KinC_x36_3	94.07%	111.43%	1.23
KinC_x36_4	4			2.7							0.00
KinC_x36_5	5	28.42	12.12	1.4	79.37%	49.47%	20.92%	KinC_x36_5	79.37%	49.47%	1.80
KinC_x36_6	5			4.3							0.00
KinC_x50_0	3			7.9							0.00
KinC_x50_1	4	35.29	18.99	1.9	95.06%	78.36%	9.99%	KinC_x50_1	94.95%	79.27%	3.30
KinC_x50_1'	4	33.38	17.08	1.9	94.84%	80.17%	13.38%				3.33
KinC_x50_2	5	36.88	20.58	3.00	74.23%	55.20%	16.74%	KinC_x50_2	74.23%	55.20%	3.88
KinC_x50_3	5	31.75	15.45	6.4	85.61%	63.27%	7.98%	KinC_x50_3	85.61%	63.27%	9.53
KinC_x60_1	3			25.6							0.00
KinC_x60_2	4	32.87	16.57	9.5	23.15%	21.78%	12.99%	KinC_x60_2	20.91%	20.92%	4.27
KinC_x60_2'	4	28.76	12.46	9.5	18.67%	20.05%	12.82%				3.68
KinC_x60_3	5	35.02	18.72	5.8	58.46%	50.98%	11.17%	KinC_x60_3	38.54%	37.89%	6.35
KinC_x60_3'	5	34.02	17.72	5.8	18.62%	24.80%	8.23%				2.52
KinC_x60_4	5	32.39	16.09	19.2	0.00%	0.00%	0.00%				0.00
KinC_x25_1	3			2.6							0.00
KinC_x25_2	4			2.6							0.00
KinC_x25_3	5	28.92	12.62	2.6	0.00%	0.00%	0.00%				0.00
KinC_x25_4	5			2.6							0.00
				116.6	7.29	5.97	Total Charge -->				41.81
							% of Total Goal				17.93%