First look at KaonLT experiment data

Richard Trotta, Tanja Horn, Garth Huber, Pete Markowitz, Stephen Kay, Vijay Kumar, Vladimir Berdnikov, Mireille Muhoza, Nathan Heinrich,
and the KaonLT collaboration

CUA

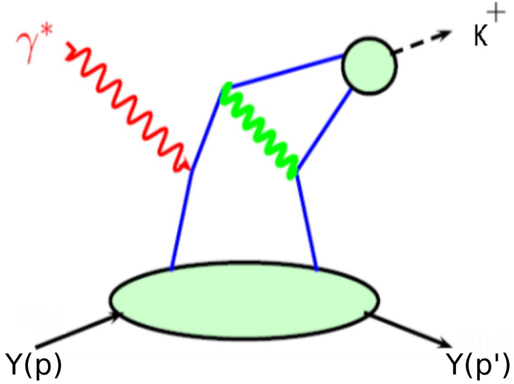
DEUS LUX MEA EST

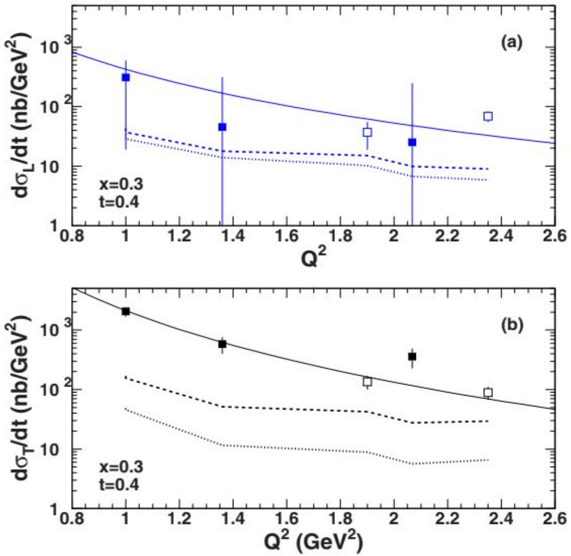
Jefferson Lab

L/T separated data for verifying reaction mechanism

- Jlab 6 GeV data demonstrated the technique of measuring the Q^2 dependence of L/T separated cross sections at fixed x/t to test QCD Factorization
  - Consistent with expected scaling of σ_L to leading order Q^{-6} but with relatively large uncertainties

- Separated cross sections over a large range in Q^2 are essential for:
  - Testing factorization and understanding dynamical effects in both Q^2 and –t kinematics
  - Interpreting non-perturbative contributions in experimentally accessible kinematics





M. Carmignotto et al., PhysRevC ***97****(2018)025204*

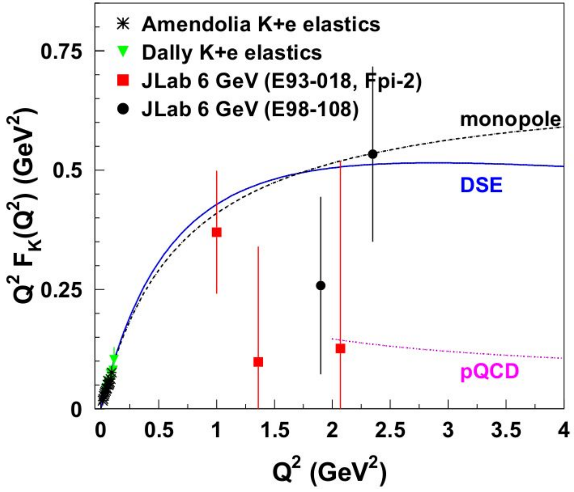
Meson Form Factors

- Pion and kaon form factors are of special interest in hadron structure studies
  - Pion - lightest QCD quark system and crucial in understanding dynamic generation of mass
  - Kaon - next simplest system containing strangeness

- Clearest case for studying transition from non-perturbative to perturbative regions

- Jlab 6 GeV data showed FF differs from hard QCD calculation
  - Evaluated with asymptotic valence-quark Distribution Amplitude (DA), but large uncertainties

- 12 GeV FF extraction data require:
  - measurements over a range of t, which allow for interpretation of kaon pole contribution

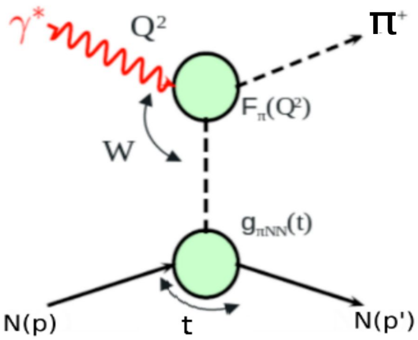


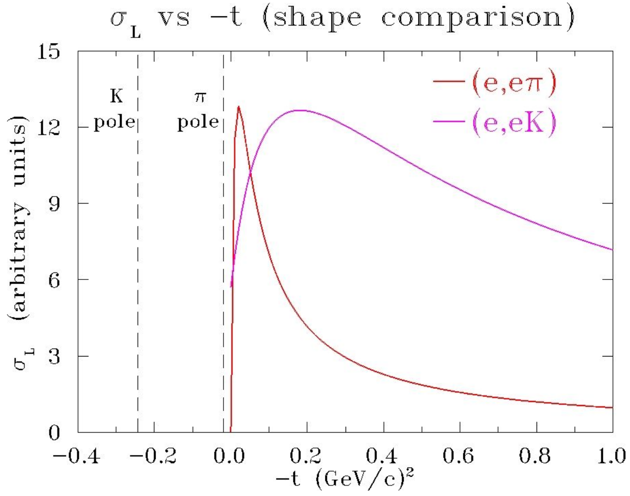
*M. Carmignotto et al., PhysRevC **97**(2018)025204*
F. Gao et al., Phys. Rev. D 96 (2017) no. 3, 034024

Experimental Determination of the π/K+ Form Factor

- At larger Q^2, $F_{\pi+}^{\;2}$ must be measured indirectly using the "pion cloud" of the proton via the p(e,e'π^+)n process
  - At small –t, the pion pole process dominates σ_L
  - In the Born term model, $F_{\pi+}^{\;2}$ appears as

$$\frac{d\sigma_L}{dt} \propto \frac{-t}{(t-m_\pi^2)} g_{\pi NN}^2(t) Q^2 F_\pi^2(Q^2,t)$$



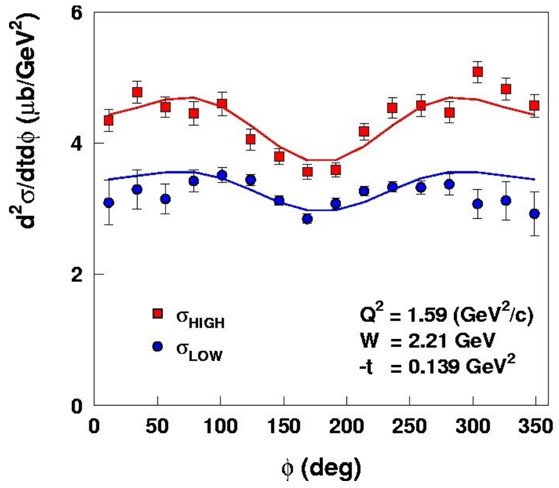


- Requirements:
  - Full L/T separation of the cross section – isolation of σ_L
  - Selection of the pion pole process
  - Extraction of the form factor using a model
  - Validation of the technique - model dependent checks

L/T Separation Example

$$2\pi \frac{d^2\sigma}{dt\,d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt}\cos 2\phi$$

σ_L will give us F^2_{K+}



T. Horn et al., PhysRevC ***97****(2006)192001*

- σ_L is isolated using the Rosenbluth separation technique
- Measure the cross section at two beam energies and fixed W, Q^2, -t
- Simultaneous fit using measured azimuthal angle (ϕ) allows for extracting L, T, LT, and TT
  - Careful evaluation of the systematic uncertainties is important due to the $1/\varepsilon$ amplification in the σ_L extraction
- Must have magnetic spectrometers for such precision cross section measurements
  - This is only possible in Hall C at JLab

L/T Separation Example

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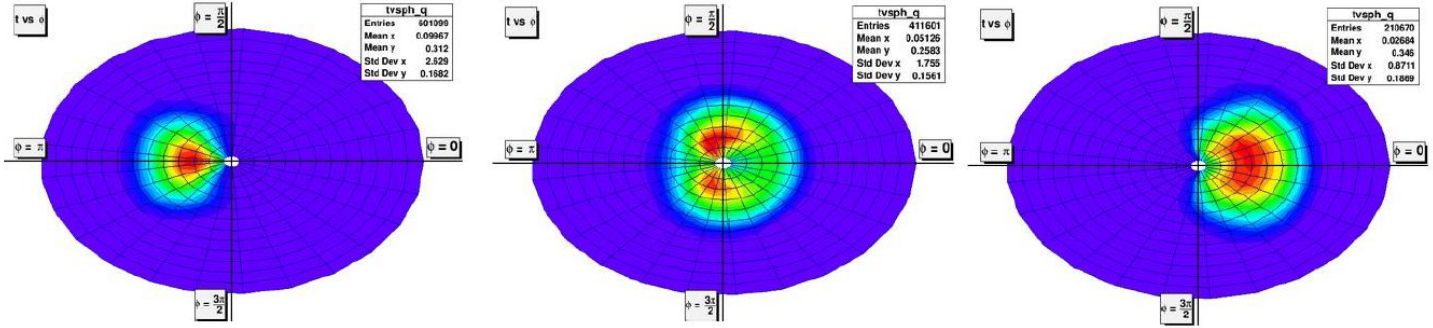
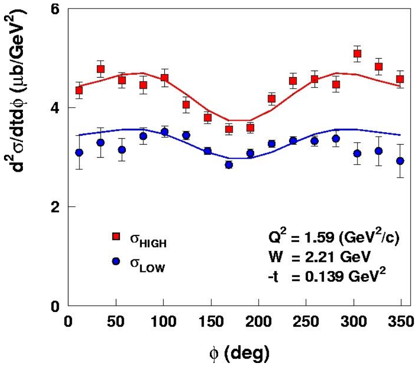


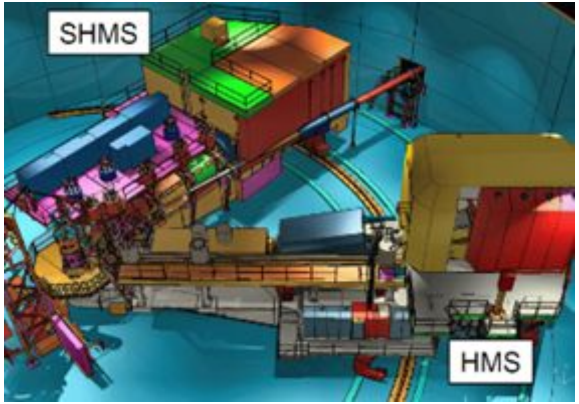
- Three SHMS angles for azimuthal (ϕ) coverage to determine the interference terms (LT, TT)

- Using the two beam energies (ε) to separate longitudinal (L) from transverse (T) cross section



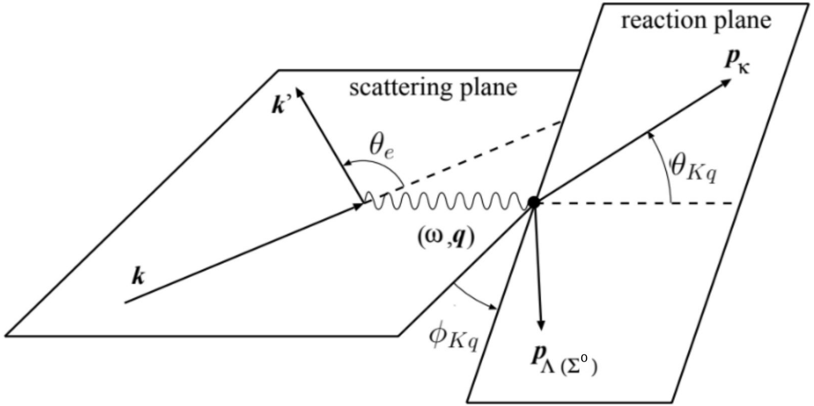
Fit using measured ε and ϕ dependence

Review E12-09-011 (KaonLT) Goals



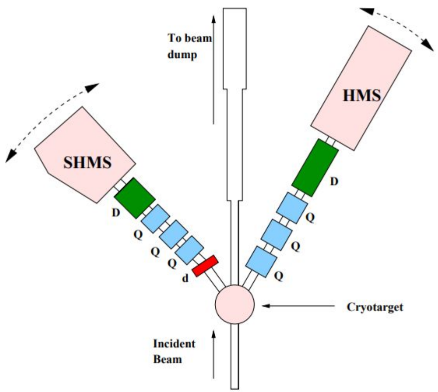
- Q^2 dependence will allow studying the scaling behavior of the separated cross sections
  - First cross section data for Q^2 scaling tests with kaons
  - Highest Q^2 for L/T separated kaon electroproduction cross section
  - First separated kaon cross section measurement above W=2.2 GeV

- t-dependence allows for detailed studies of the reaction mechanism
  - Contributes to understanding of the non-pole contributions, which should reduce the model dependence
  - Bonus: if warranted by data, extract the kaon form factor



Kaon LT - Data Collected

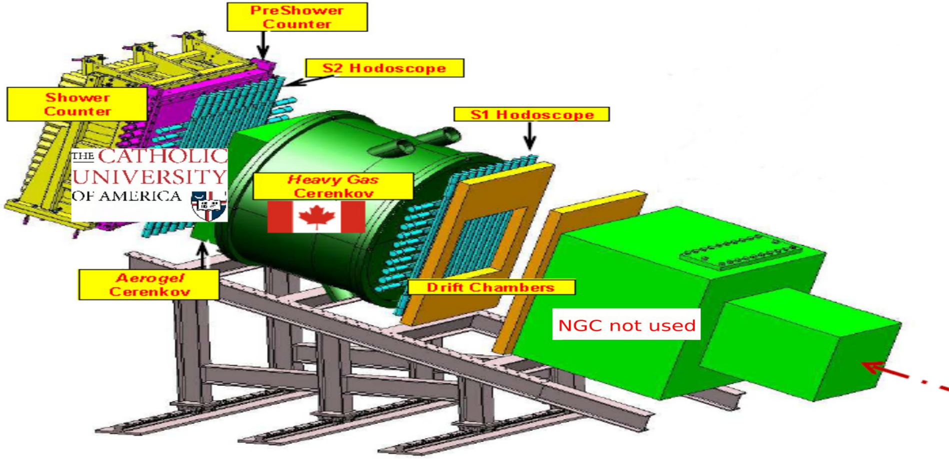
- The $p(e, e'K^+)\Lambda,\Sigma^0$ experiment ran in Hall C at Jefferson Lab over the fall and spring.



E (GeV)	Q^2 (GeV^2)	W (GeV)	x	$\varepsilon_{high}/\varepsilon_{low}$
10.6/8.2	5.5	3.02	0.40	0.53/0.18
10.6/8.2	4.4	2.74	0.40	0.72/0.48
10.6/8.2	3.0	3.14	0.25	0.67/0.39
10.6/6.2	3.0	2.32	0.40	0.88/0.57
10.6/6.2	2.115	2.95	0.21	0.79/0.25
4.9/3.8	0.5	2.40	0.09	0.70/0.45

Experimental Details

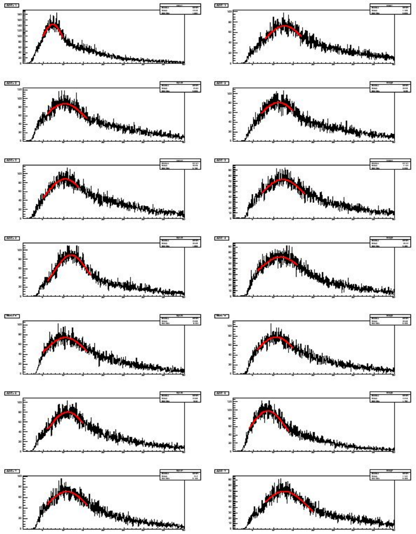
- Hall C: k_e=3.8, 4.9, 6.4, 8.5, 10.6 GeV
- SHMS for kaon detection :
  - angles, 6 – 30 deg
  - momenta, 2.7 – 6.8 GeV/c
- HMS for electron detection :
  - angles,10.7 – 31.7 deg
  - momenta, 0.86 – 5.1 GeV/c
- Particle identification:
  - Dedicated Aerogel Cherenkov detector for kaon/proton separation
    - Four refractive indices to cover the dynamic range required by experiments
  - Heavy gas Cherenkov detector for kaon/pion separation

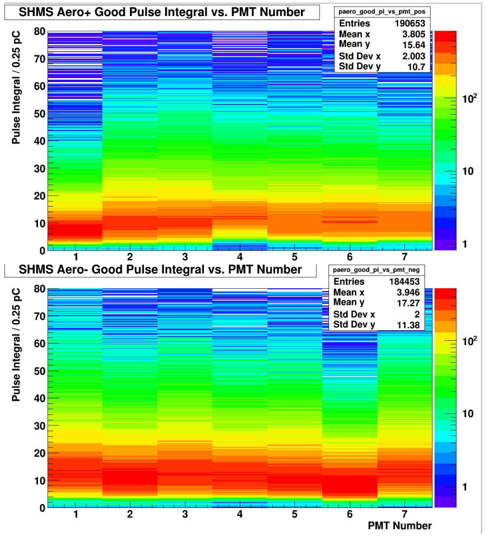


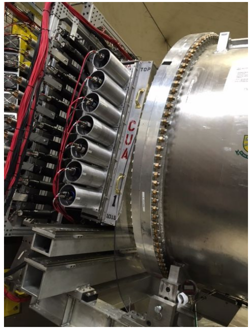
n	π_{thr} (GeV/c)	K_{thr} (GeV/c)	P_{thr} (GeV/c)
1.030	0.57	2.00	3.80
1.020	0.67	2.46	4.67
1.015	0.81	2.84	5.40
1.011	0.94	3.32	6.31

Aerogel Cherenkov detector in SHMS

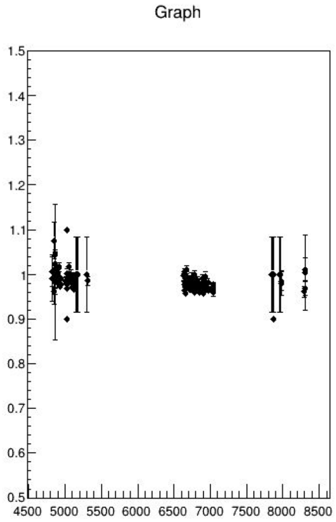
NSF MRI PHY-1039446

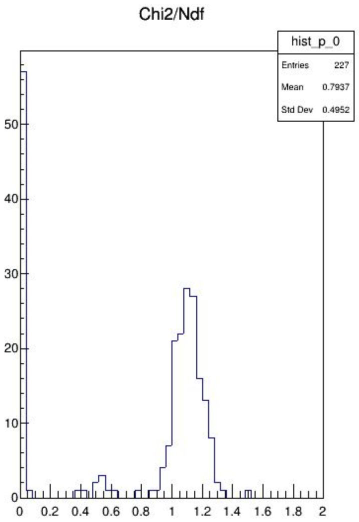






- ~15 successful tray exchanges since Fall 2018
- Aerogel performance as expected
- Trays require some optimization before next use - prevent damage from crane operation



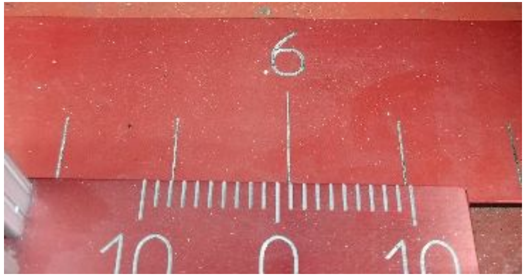


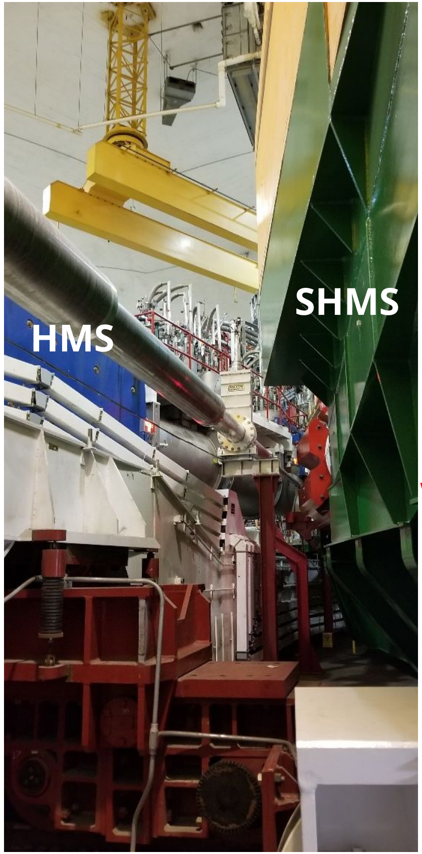
Analysis by V. Berdnikov

SHMS small angle operation

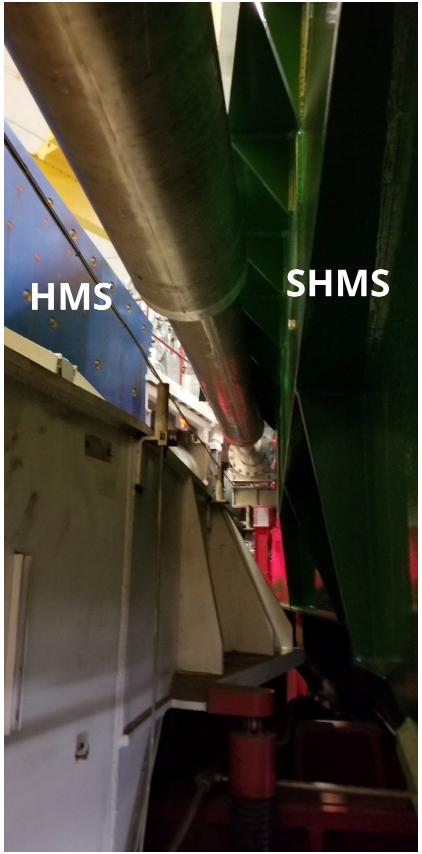
- Some issues with opening and small angle settings at beginning of run
  - SHMS at 6.01°
  - HMS at 12.7°

[12/17/18]





Work of many people ...



KaonLT Event Selection

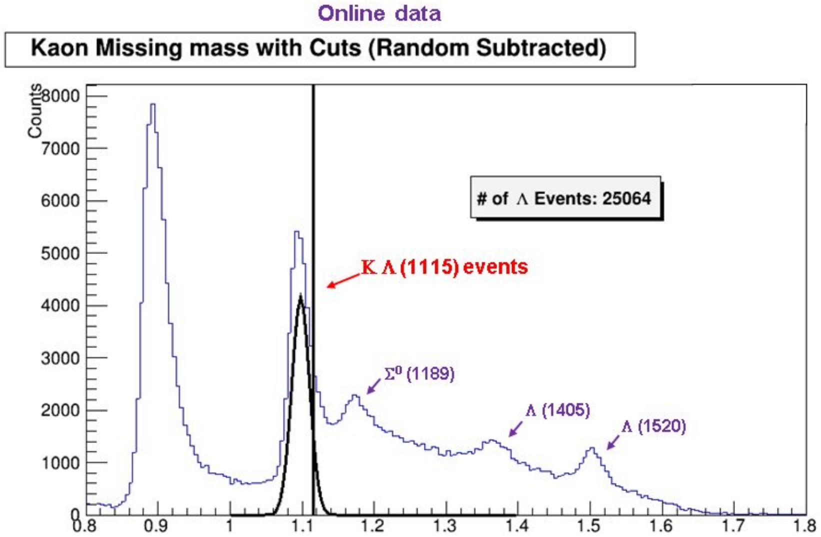
- Isolate Exclusive Final States through missing mass

$$M_x = \sqrt{(E_{det} - E_{init})^2 - (p_{det} - p_{init})^2}$$

- Coincidence measurement between kaons in SHMS and electrons in HMS
  - simultaneous studies of $K\Lambda$ and $K\Sigma^0$ channels…and a few others…
- Kaon pole dominance tests through

$$\frac{\sigma_L(\gamma^* p \to K^+ \Sigma^0)}{\sigma_L(\gamma^* p \to K^+ \Lambda)}$$

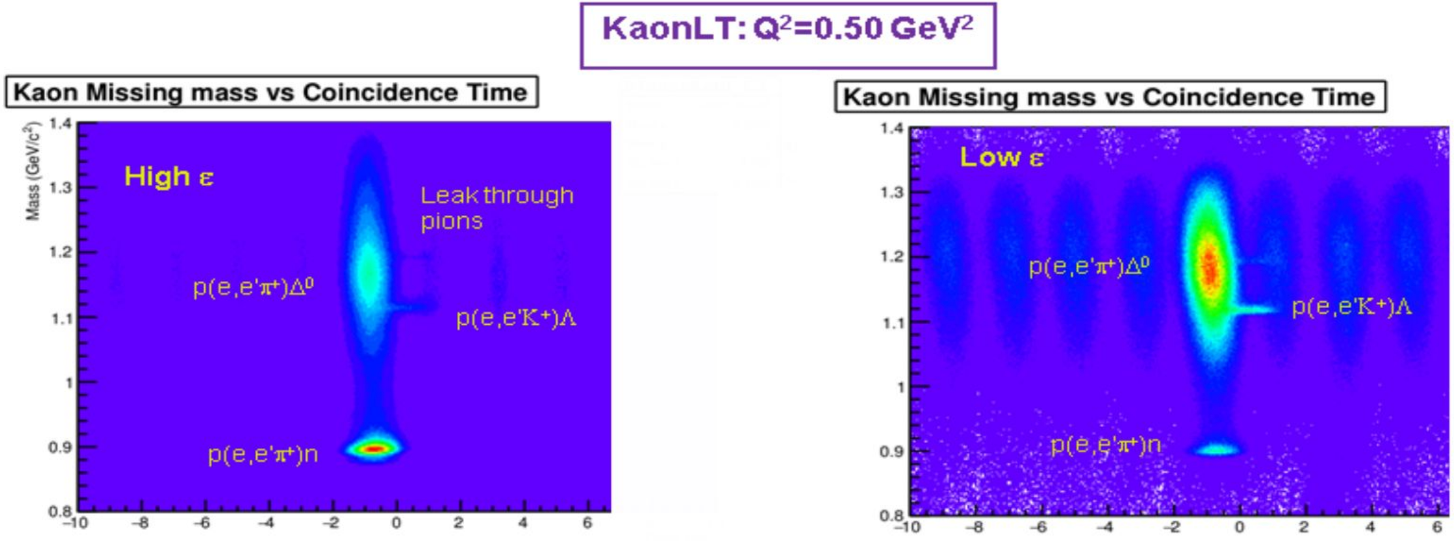
  - Should be similar to ratio of coupling constants $g^2_{pK\Sigma}/g^2_{pK\Lambda}$ in t-channel



Plot by R. Ambrose, S. Kay, R. Trotta

Interesting Physics in the other channels

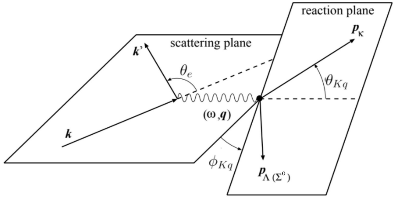
- Large difference in L/T ratio between $p(e.e'\pi^+)n$ and $p(e,e'\pi^+)\Delta^0$ final states – G. Huber hclog #3640187



Plots by R. Ambrose, S. Kay, R. Trotta

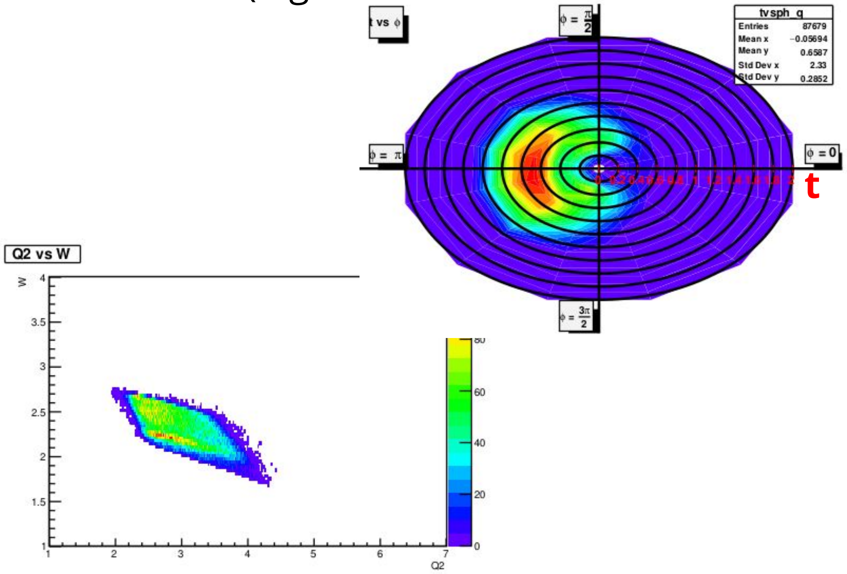
- Large increase in neutron missing mass peak at high epsilon is evidence of the pion-pole process at low Q^2 and small –t, which suggests $\sigma_L >> \sigma_T$
- Δ^0 exclusive longitudinal cross section expected to be at best $\sigma_L \sim \sigma_T$

Comparison of high and low ε [Q^2=3.0, W=2.32, x=0.40]

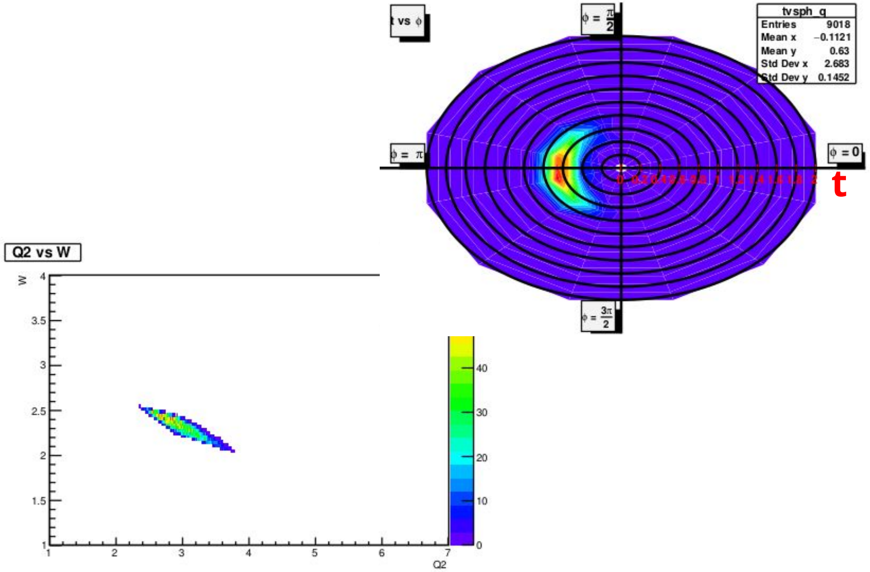


- [10.6 Gev (high ε), 6.2 Gev (low ε)]
- Left (θ_{high}=21.18,θ_{low}=16.28)

10.6 GeV (high ε)



6.2 GeV (low ε)



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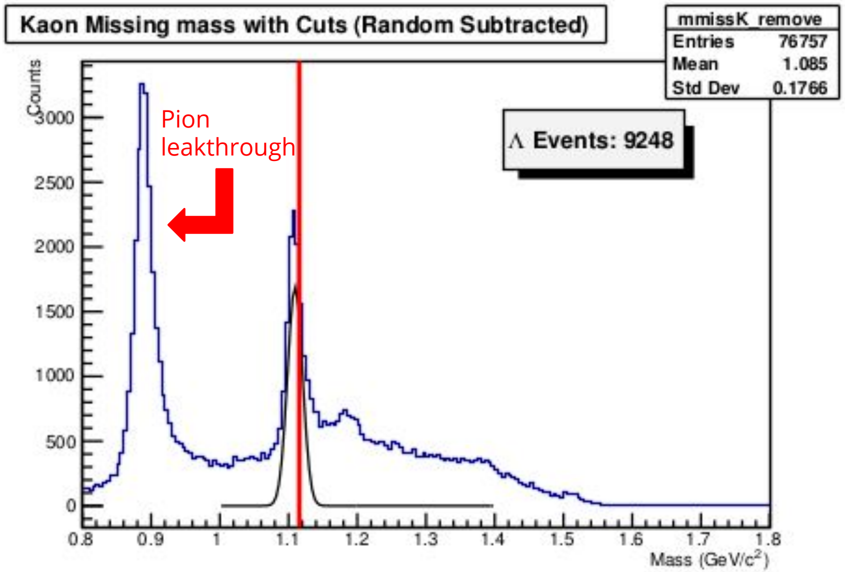

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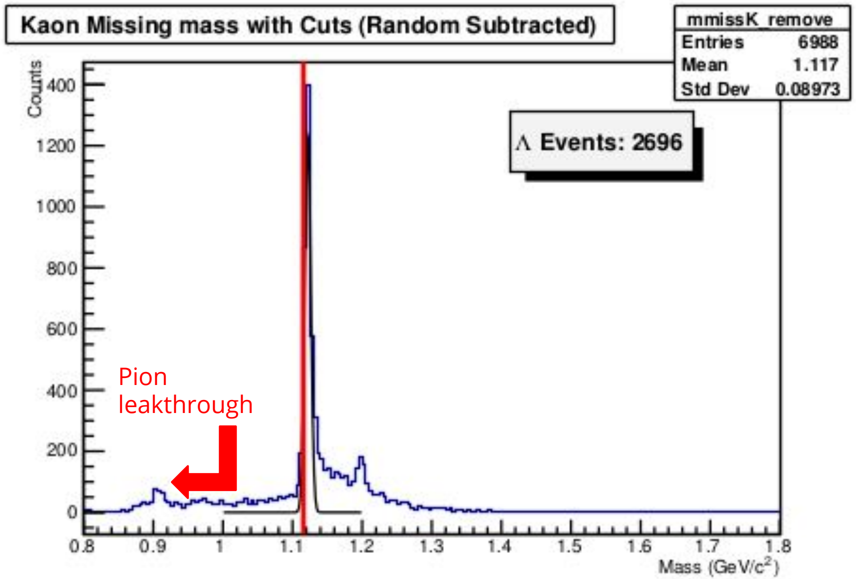
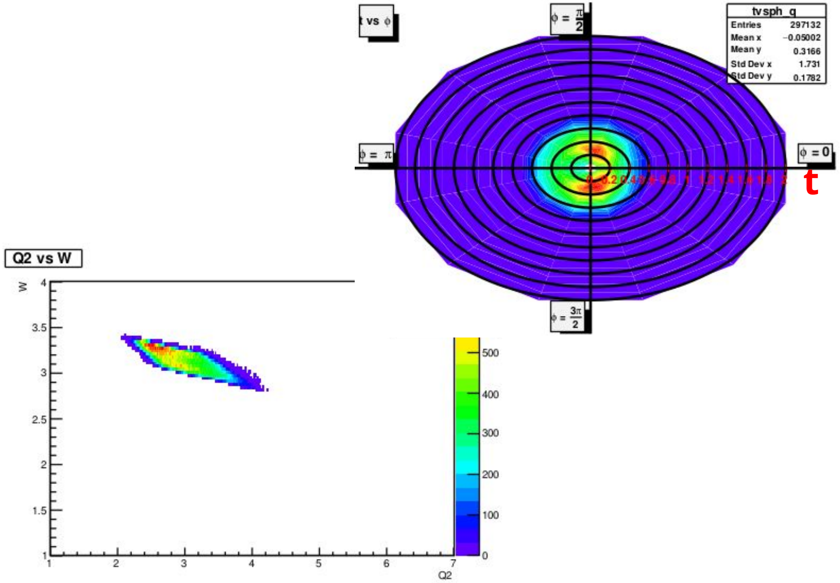


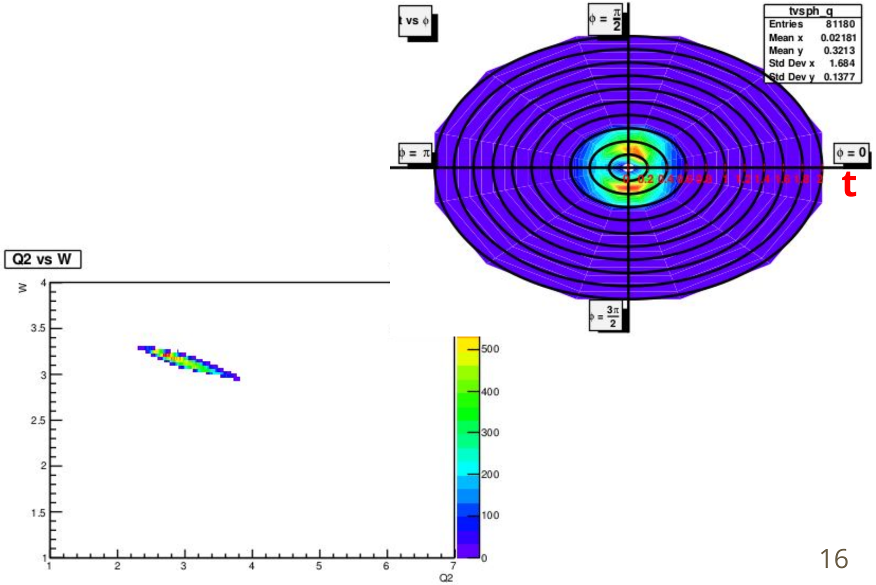
Comparison of high and low ε [Q^2=3.0, W=3.14, x=0.25]

- [10.6 Gev (high ε), 8.2 Gev (low ε)]
- Center (θ_{high}=9.42,θ_{low}=6.89)

10.6 GeV (high ε)



8.2 GeV (low ε)



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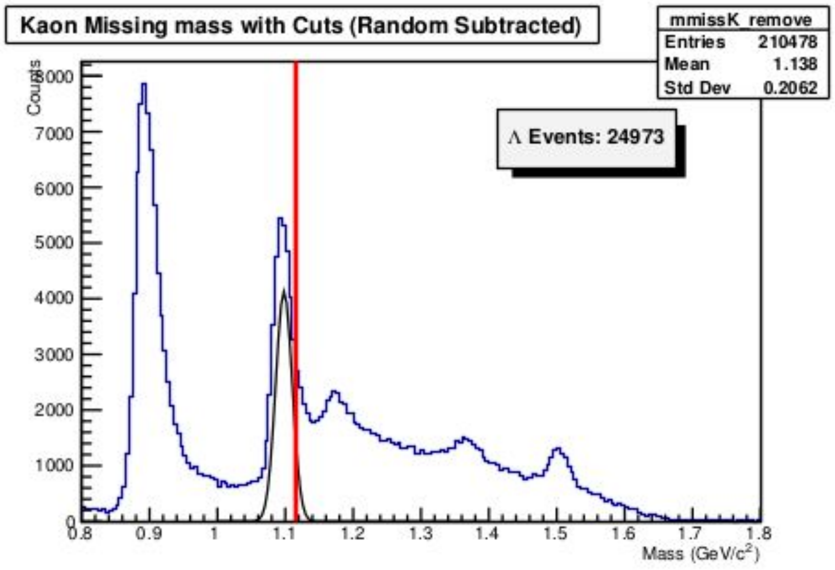
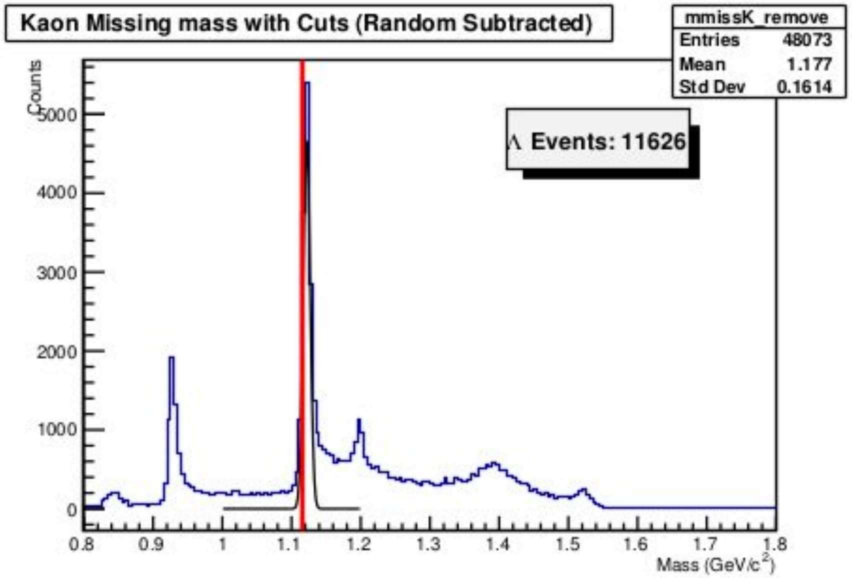


8.2 GeV (low ε)



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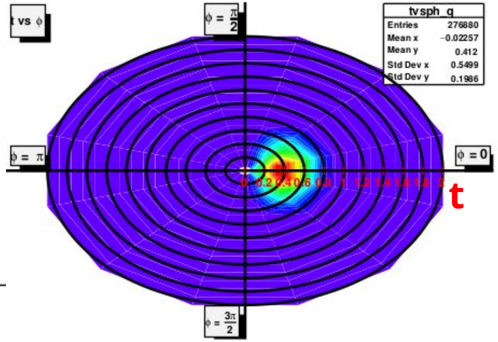
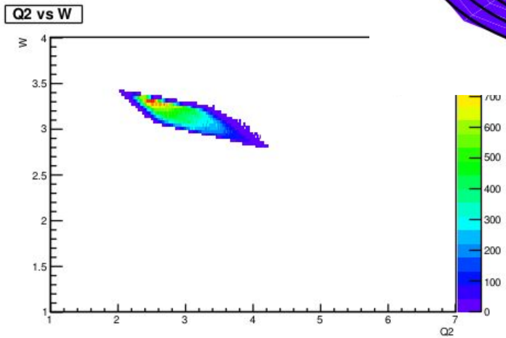
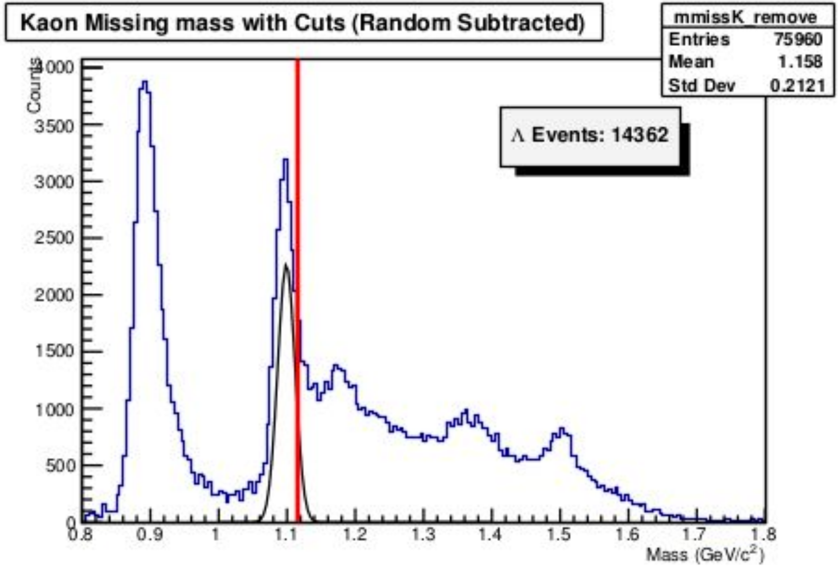


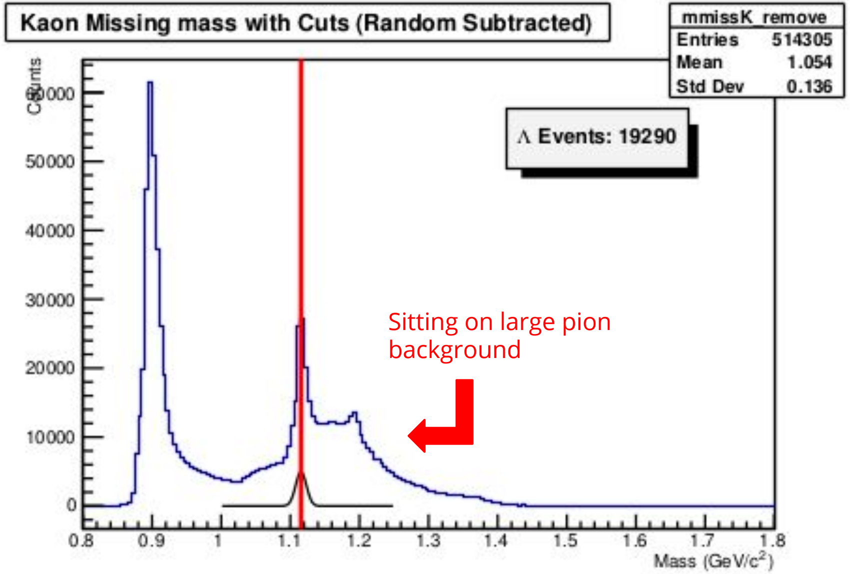




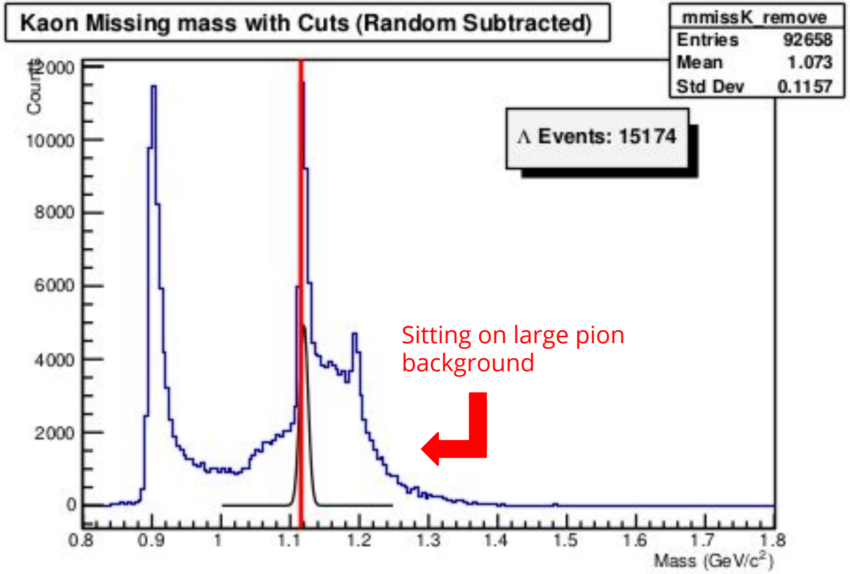
Comparison of high and low ε [Q^2=0.5, W=2.40, x=0.09]

- [4.9 Gev (high ε), 3.8 Gev (low ε)]
- Center (θ_{high}=8.86,θ_{low}=6.79)

4.9 GeV (high ε)



3.8 GeV (low ε)



Analysis Phases

Current Phase

1. Calibrations
    - Calorimeter, aerogel, HG cer, HMS cer, DC, Quartz plan of hodo
    - Assure we are replaying to optimize our physics settings
2. Efficiencies and offsets
    - Luminosity and elastics
3. First iteration of cross section
    - Bring everything together
4. Fine tune
    - Fine tune values to minimize systematics
5. Repeat previous step
    - Repeat until acceptable cross sections are reached
6. Possible attempt at form factor extraction
    - Fit the data to a model and iterate

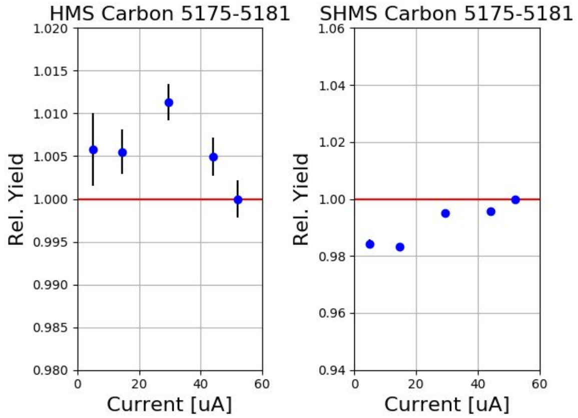
Phase 1: Early luminosity analysis (pre-calibrations)

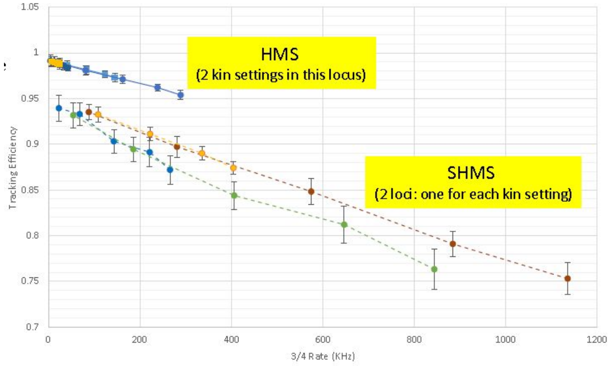
- Understanding efficiencies from luminosity scans has been ongoing with only one run period having been looked at

- Relative yield has been reduced to ~2% spread for carbon target

- Tracking efficiencies are a big contributor
  - At a given ¾ rate, HMS tracking efficiency is ~4% higher than that of the SHMS
  - HMS tracking efficiency is mostly independent of kinematic setting – not the case for the SHMS
  - SHMS tracking efficiency extrapolates to ~95% at 0 KHz – hadron tracking efficiency low by 4-6%

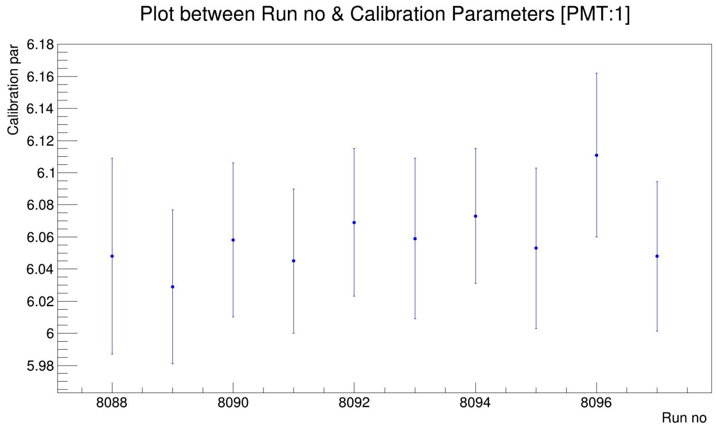
P_{HMS}=-4.204, Θ_{HMS}=14.51 P_{SHMS}=+6.053,Θ_{SHMS}=6.55





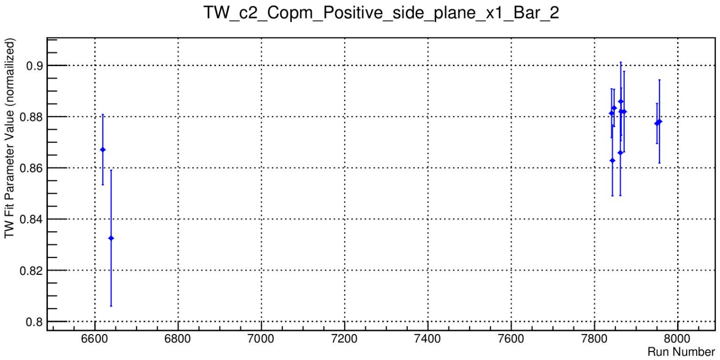
Analysis by D. Mack and R. Trotta

Phase 1: Calibration of SHMS HGC detector and hodoscope time walking



Heavy Gas Cherenkov

- Run dependence of calibration parameters for PMT1 to check the consistency of calibration.



Hodoscope timewalking

- Plot from PMT 2+ on S1X plane, similar for others

Analysis by V. Kumar, N. Heinrich and M. Muhoza

Conclusion

- Kaon can provide an interesting way to expand previous data of charged pion form factor with access to the mechanism involving strangeness

- E12-09-011 has completed its 2018-19 run

- Potential to extract the Kaon form factor from the L/T separated cross sections to the highest Q^2 achievable at Jlab
    - Full azimuthal coverage, good phase space matching and favorable rates to allow Kaon cross section separation

- Provide much needed data for Q^2 scaling at fixed x and -t in Kaon electroproduction to validate QCD factorization for hadron imaging studies

- Currently in the first phase of analysis

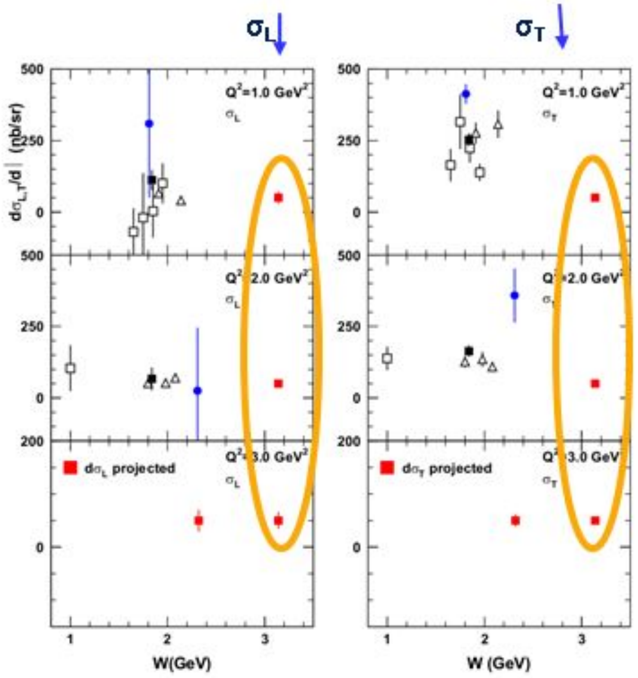
Extra Slides

KaonLT Sample Projections

- E12-09-011: Separated L/T/LT/TT cross section over a wide range of Q^2 and t

E12-09-011 spokespersons: T. Horn, G. Huber, P. Markowitz

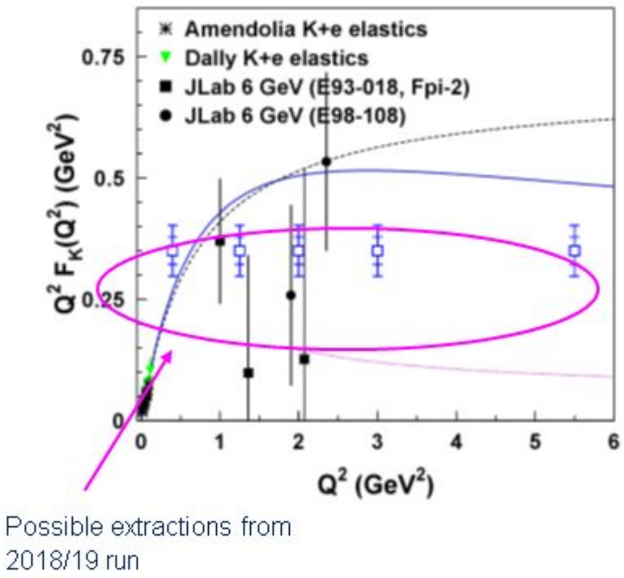
- JLab 12 GeV Kaon Program features:
  - First cross section data for Q^2 scaling tests with kaons
  - Highest Q^2 for L/T separated kaon electroproduction cross section
  - First separated kaon cross section measurement above W=2.2 GeV



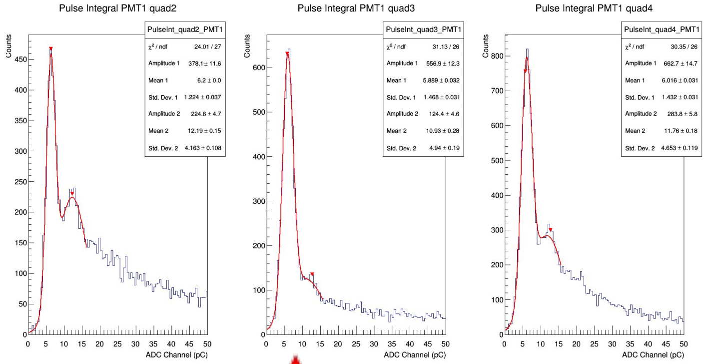
blue points from M. Carmignotto, PhD thesis (2017)

KaonLT: Projections for $F_{K+}(Q^2)$ Measurements

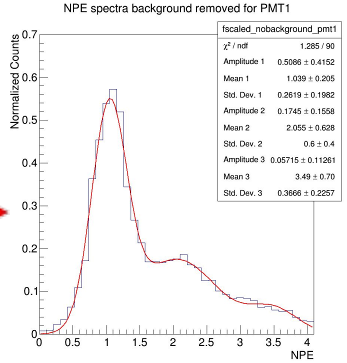
- E12-09-011: primary goal L/T separated kaon cross sections to investigate hard-soft factorization and non-pole contributions
- Possible K^+ form factor extraction to highest possible Q^2 achievable at JLab
  - Extraction like in the pion case by studying the model dependence at small t
  - Comparative extractions of F^2_π at small and larger t show only modest model dependence
    - larger t data lie at a similar distance from pole as kaon data

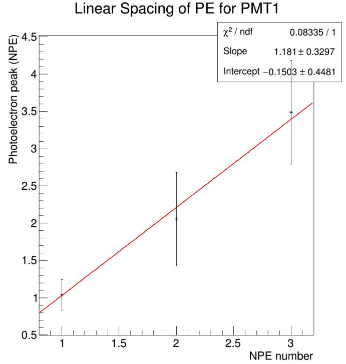


P1: Calibration of HGC Detector (SHMS)

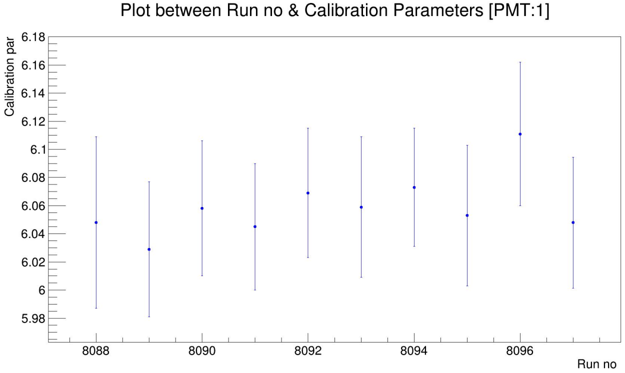


To see the second & third photo-electron, we fitted the scaled histogram with Poisson function and subtracted the higher photoelectron.





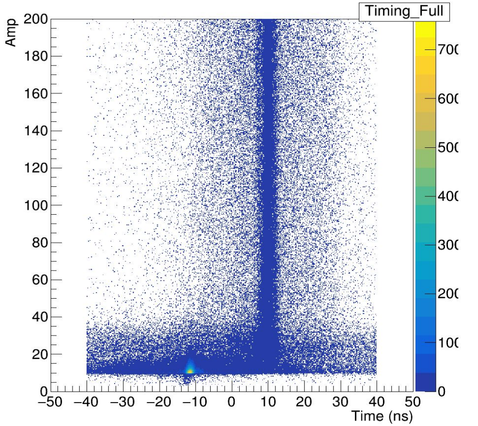
Showing the SPE in HGC for PMT1 FADC and fit it with a Gaussian function to get the mean of peaks.

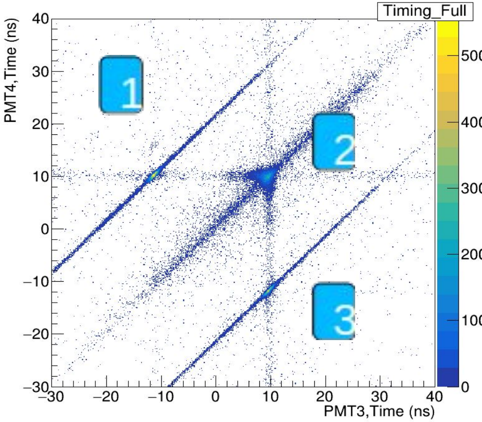


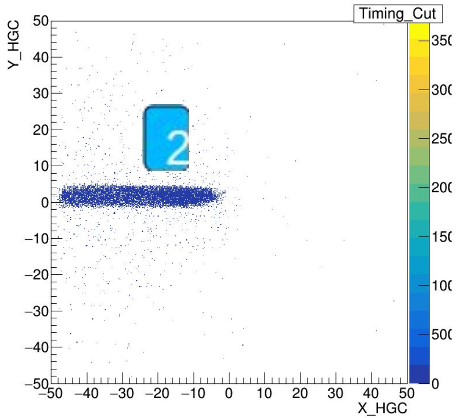
Run dependence of calibration parameters for the PMT1 to check the consistency of calibration.

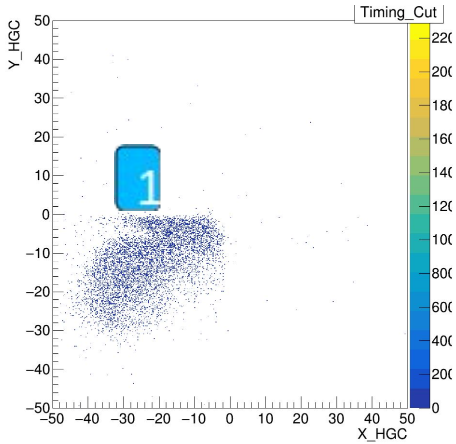
HGC Timing Study

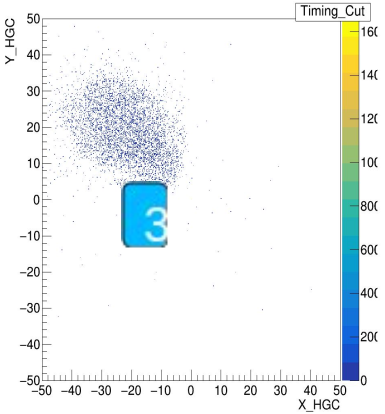
- In addition to main timing peak at +10ns, there is an unexpected second peak at -10ns.
- To better understand the origin of the unexpected peak, plot b/w Timing vs Amplitude.
    - 2nd peak corresponds to small pulses only.
- We also checked the tracking position in focal plane coordinates.
    - Interesting correlation between hit position and timing remains a mystery.











P1: SHMS Hodoscope Time Walk Calibration

In order to correct for time walk we:

- Plot ADC amplitude against TDC – ADC time
- Fit This Function: $f_{TW} = c_1 + \frac{1}{\left(\frac{a}{TDC_{Thrs.}}\right)^{c_2}}$
- Subtract second term
- Check parameter stability over run periods 6600 - 8000, stable within error
- Plots from PMT 2+ on 1x plane, similar for others