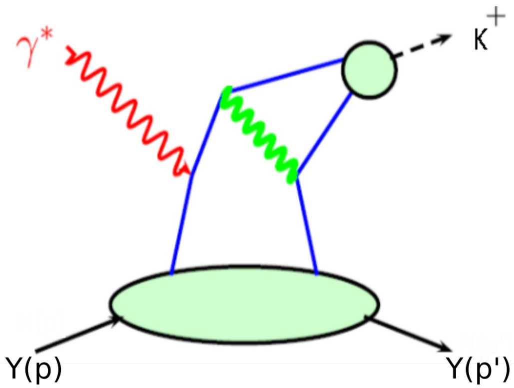
Update on KaonLT Experiment

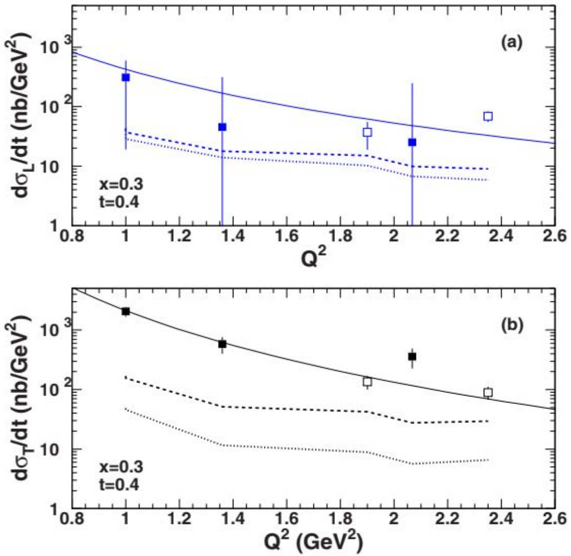
Richard Trotta, Tanja Horn, Garth Huber, Pete Markowitz,
Stephen Kay, Vijay Kumar, Vladimir Berdnikov, Ali Usman,
and the KaonLT collaboration

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*

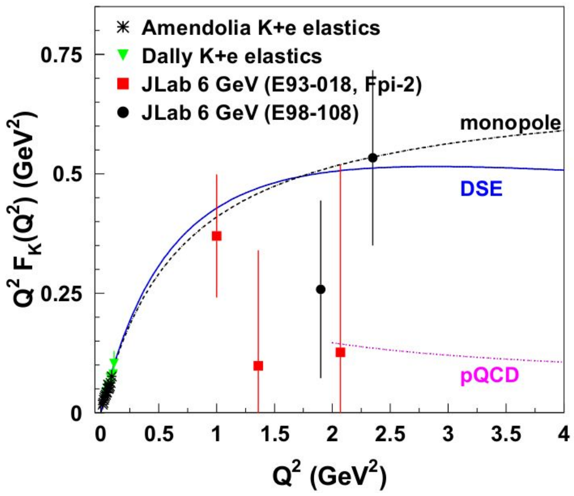
Meson Form Factors

- 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

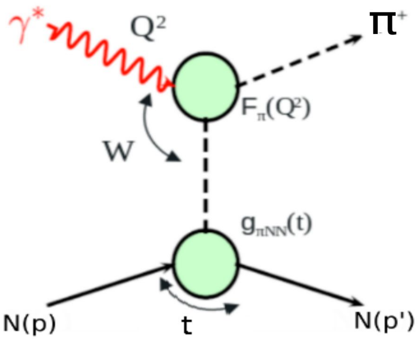


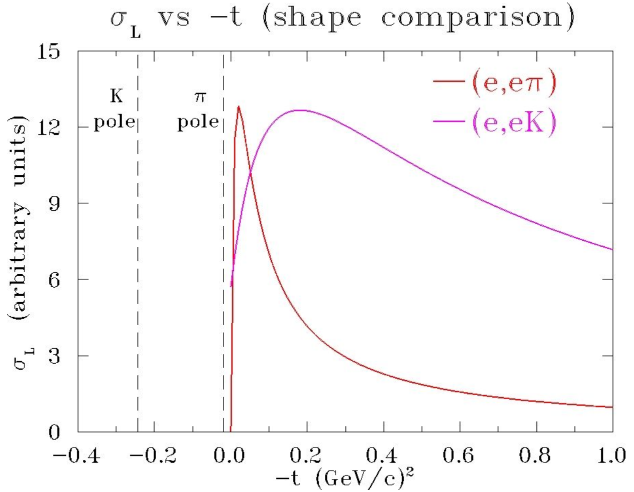
M. Carmignotto et al., PhysRevC ***97****(2018)025204*
F. Gao et al., Phys. Rev. D 96 (2017) no. 3, 034024

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

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

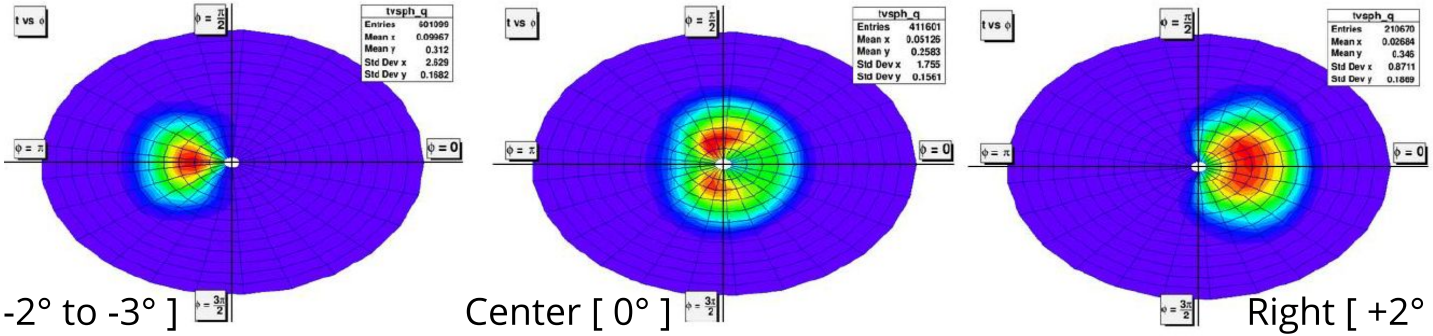




- Requirements:
  - Full L/T separation of the cross section – isolation of σ_L
  - Selection of the pion pole process
  - Extraction of the form factor using a model
  - Validation of the technique - model dependent checks

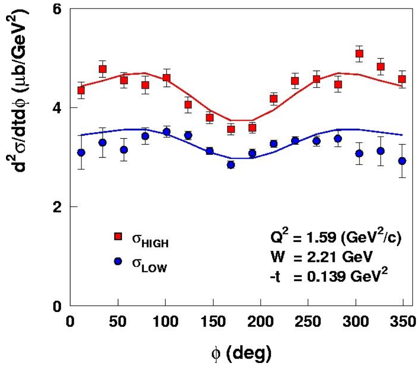
L/T Separation Example

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



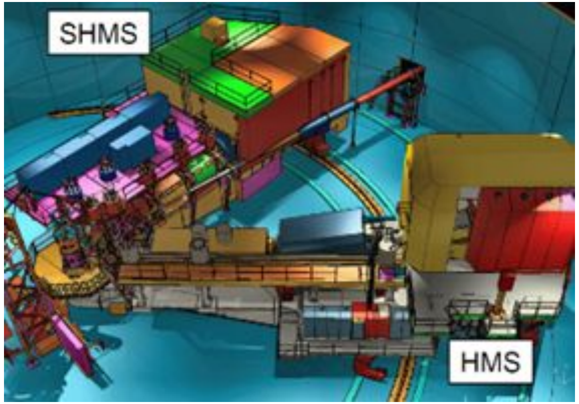
Left [-2° to -3°] Center [0°] Right [+2° to +3°]

- 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



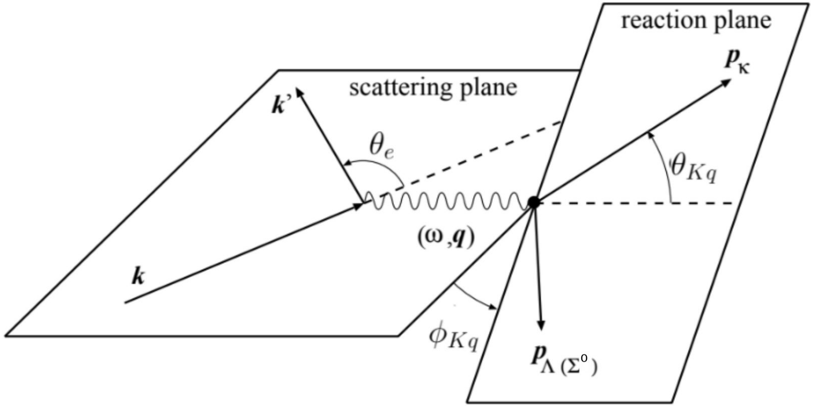
Fit using measured ε and ϕ dependence

Review E12-09-011 (KaonLT) Goals



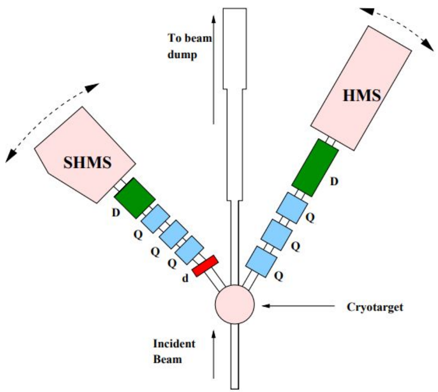
- Q^2 dependence will allow studying the scaling behavior of the separated cross sections
    - First cross section data for Q^2 scaling tests with kaons
    - Highest Q^2 for L/T separated kaon electroproduction cross section
    - First separated kaon cross section measurement above W=2.2 GeV

- 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

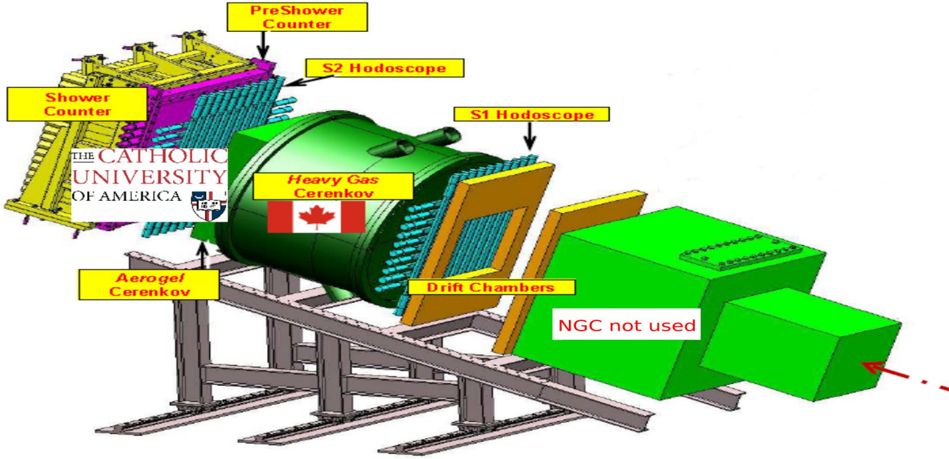
- The $p(e, e'K^+)\Lambda,\Sigma^0$ experiment ran in Hall C at Jefferson Lab over the fall 2018 and spring 2019.



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

Analysis Phases

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 ← Current Phase
    - Luminosity, elastics, Heeps, etc.
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

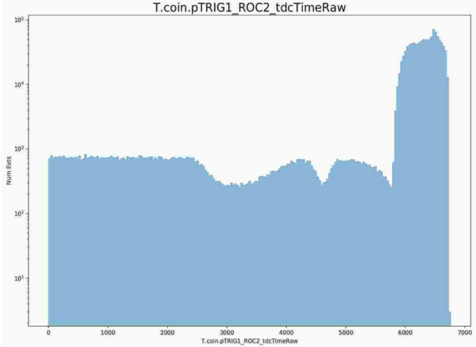
Phase 1: Timing Windows

- Applying cuts should be done only once reference time cuts are properly chosen.
    - See Carlos Yero paper for more info: https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1028

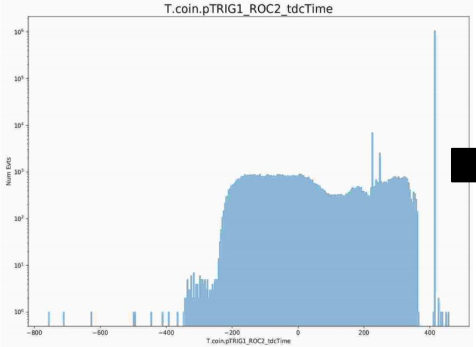
- TDC coincidence spectra are the outputs from the L1ACC pre-triggers. The cuts are applied to the raw TDC spectra first.

- Remove all cuts to the raw spectra to see the entire raw spectrum including background

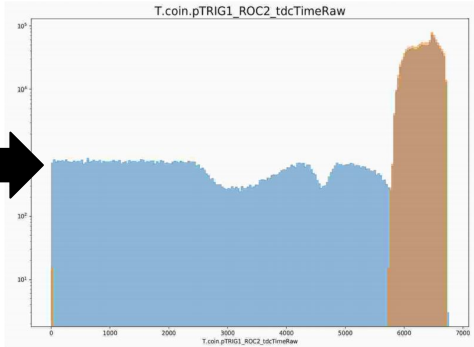
- Then subtract the background surrounding the peaks in order to clean the spectrum up a bit.



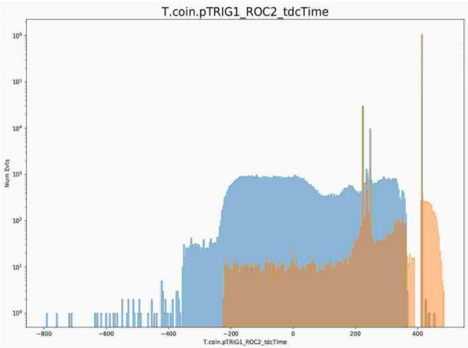
SHMS ¾ Raw (channels)



SHMS ¾ ref time corrected (ns)



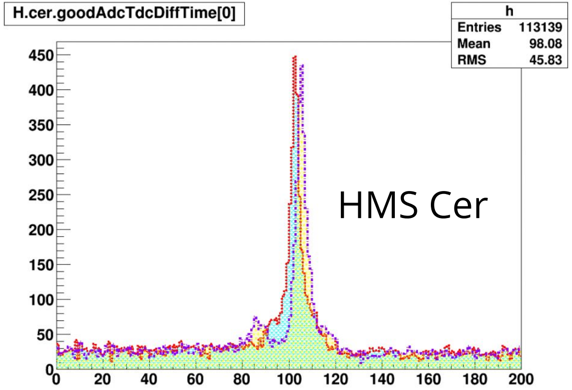
SHMS ¾ Raw (channels)

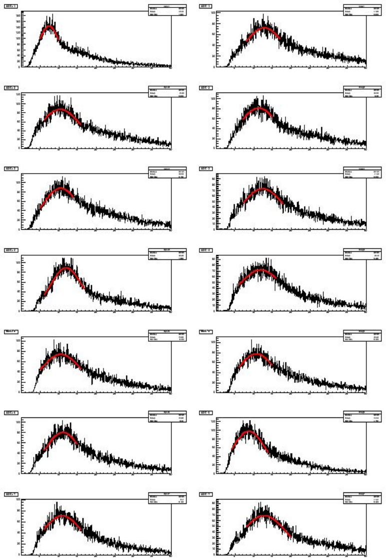


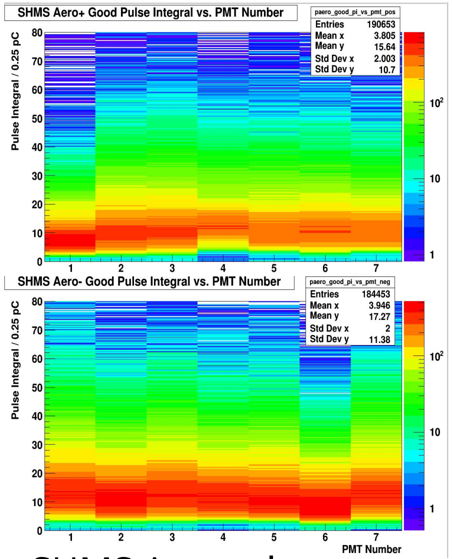
SHMS ¾ ref time corrected (ns)

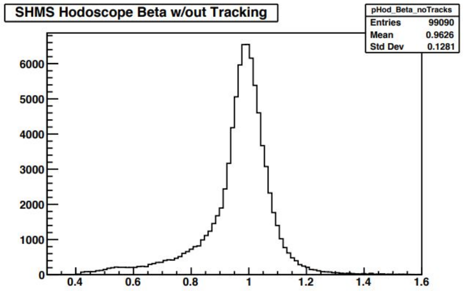
Phase 1: Detector Calibrations

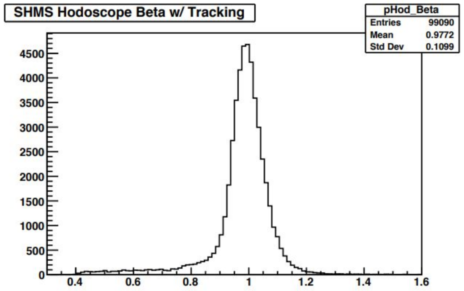
- The online calibrations of the HMS cherenkov, SHMS HGCer, aerogel, and HODO were determined to be satisfactory for our current analysis.
- Future calibrations will be completed on run by run basis











SHMS Hodo

SHMS Aerogel

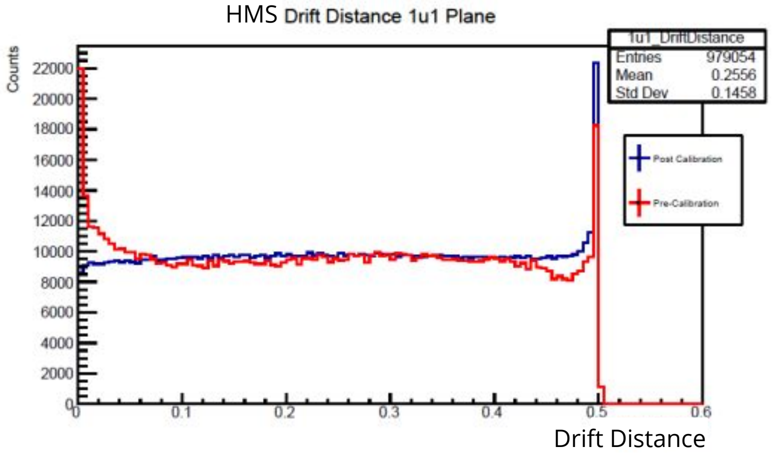
Phase 1: Drift Chamber Calibrations

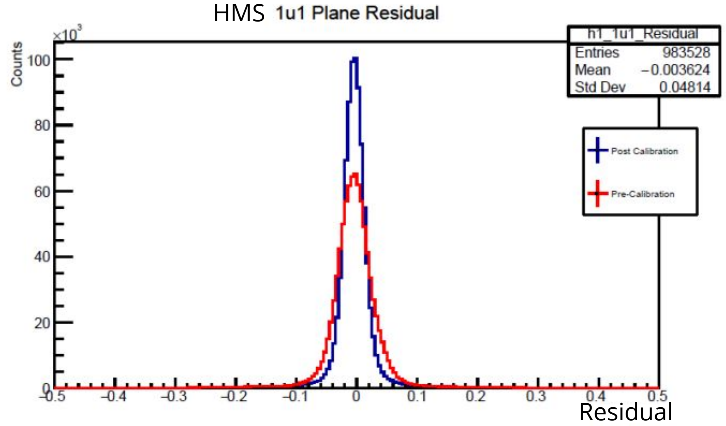
- Calibrating the chambers in each spectrometer is identical.

- Performance of the drift chambers is very sensitive to the gas mix within the chamber.
    - This gas mix is in turn dependent upon environmental conditions

- Purpose of the drift chamber calibration is to find the correct parameters to convert the recorded drift times to drift distances for each wire

- For the KaonLT and PionLT experiments, it was decided that a new calibration would be produced for every experimental shift
    - roughly every 8 hours





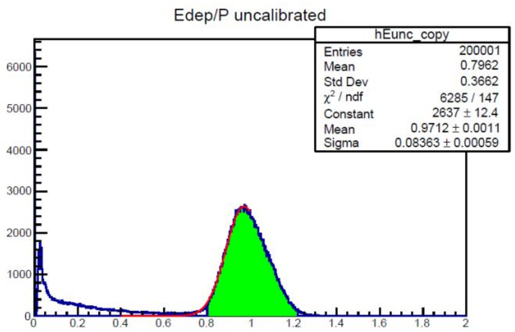
Phase 1: Calorimeter Calibrations

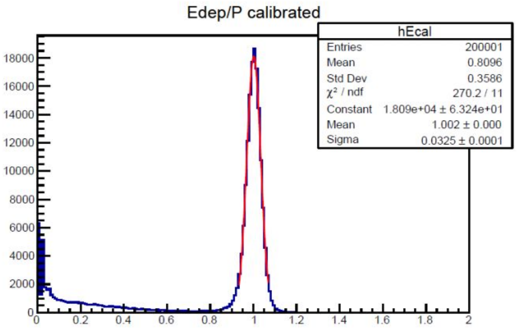
- Purpose of the calibration is to correctly convert the detected ADC signal from the calorimeter into an equivalent energy.

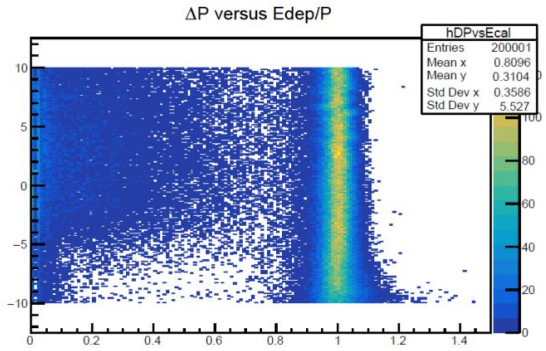
- Calibration script utilises electron events to perform the calibration.

- Many iterations were performed for all adequate runs

- There were tiny wiggles that can be seen in most runs
  - Vardan and others are aware. This is an ongoing issue.







Phase 2.1: Importance of Luminosity Runs

Singles E (GeV)	Q^2 (GeV^2)	W (GeV)	x	Target	Current (uA)	ε_{high}	ε_{low}
10.6	5.5	3.02	0.40	LH2,C	5,15,30,45,50,55	0.53	
10.6	3.0	3.14	0.25	LH2,C	50,70	0.67	
6.2	3.0	2.32	0.40	LH2,C	5,15,30,50,65,70		0.57

Careful evaluations of the systematic uncertainties is important due to the $1/\varepsilon$ amplification in the σ_L extraction

→

Spectrometer acceptance, kinematics , and efficiencies are the **primary contributors**

Phase 2.1: Importance of Luminosity Runs

COIN E (GeV)	Q^2 (GeV^2)	W (GeV)	x	Target	Current (uA)	ε_{high}	ε_{low}
10.6	5.5	3.02	0.40	LH2,C	5,15,30,45,50,55	0.53	
8.2	5.5	3.02	0.40	LH2,C	10,25,40,45,60		0.18
8.2	4.4	2.74	0.40	LH2,C	5,15,30,45,50,65		0.48
10.6	3.0	3.14	0.25	LH2,C	50,65,70	0.67	

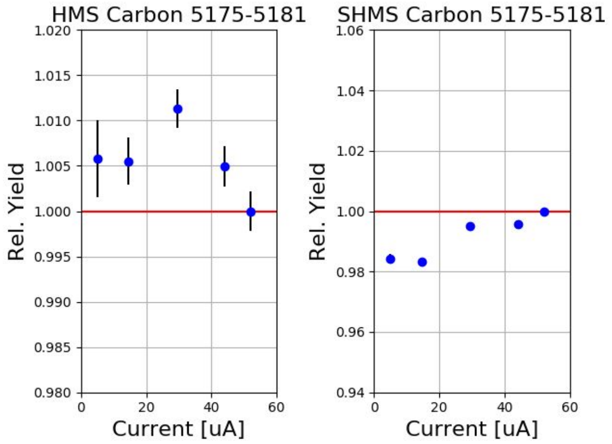
- Singles: 17 runs
- COIN: 50 runs (set singles+coin)
- Plus PionLT runs!

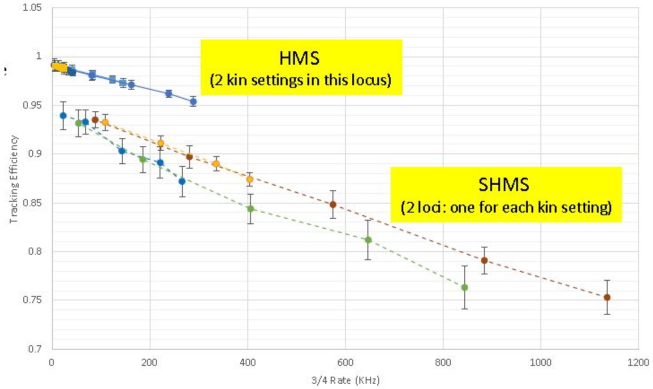
Previous luminosity/tracking analysis

- Singles luminosity scans has been previously looked out with online data

- 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%



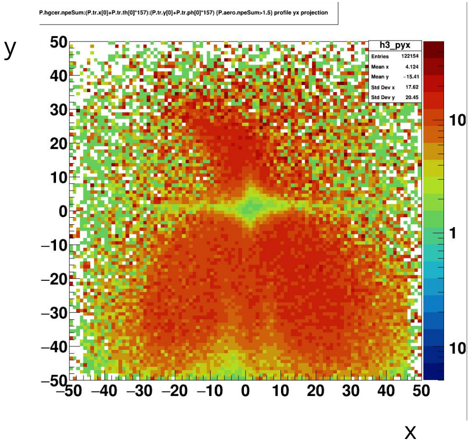


Analysis by D. Mack and R. Trotta

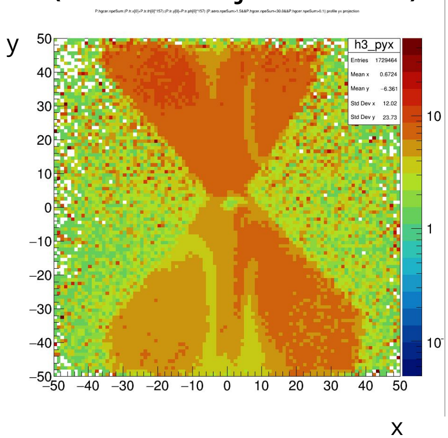
Phase 2.1: HGCer Challenges

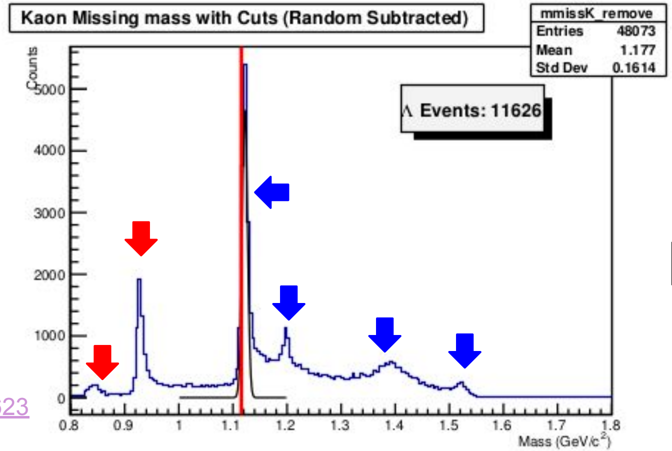
- A hole in the HGCer will allow unwanted pions and accidentals
- An in depth analysis will be required for proper efficiency determination
- This hole is already causing visible issues

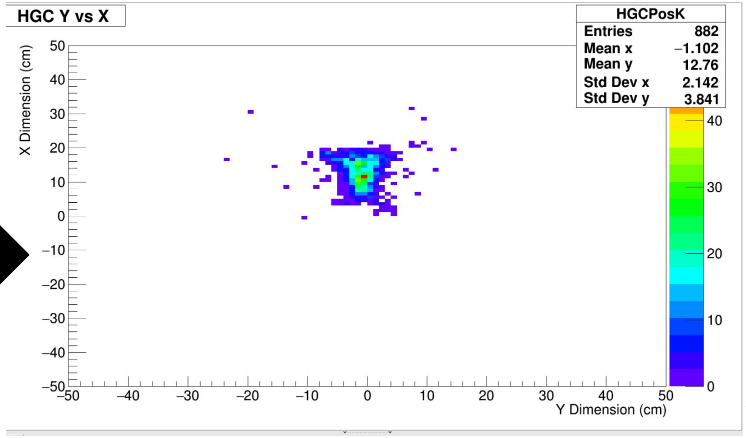
Fall



Spring
(After readjustments)







Stephen Kay analysis
https://logbooks.jlab.org/entry/3676623

Phase 2.2: Heep Runs

E (GeV)	$-P_{SHMS}$ (GeV)	$-P_{HMS}$ (GeV)	Type	Target	Current (uA)
10.6	6.30-8.04	5.32-6.59	Single+ COIN	LH2	10,15,30,35,40
8.2	4.35-5.75	4.35-5.75	Single+ COIN	LH2	65,70
6.2	3.28-3.94	2.94-3.71	Single+ COIN	LH2	25,50,65,70
4.9	2.58-4.64	2.58-4.37	Single+ COIN	LH2	10,35,70
3.9	2.48-3.01	2.03-3.01	Single+ COIN	LH2	50

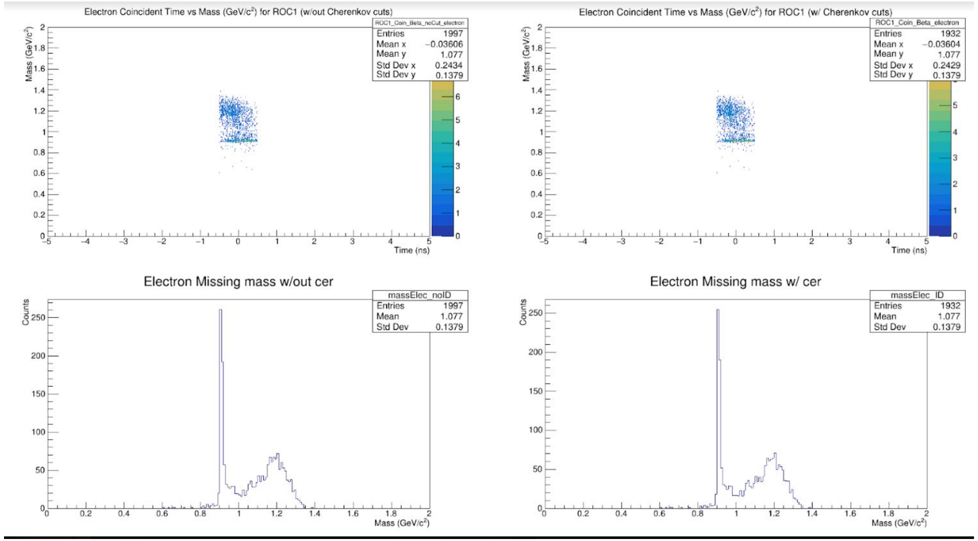
Conclusion

- E12-09-011 ran Fall 2018, Spring 2019
  - Also includes PionLT data from Summer 2019
- Currently in the second phase of analysis
- The calibrations are complete for all detectors
- Studies of efficiencies from luminosity are the immediate future
  - Nailing down our efficiencies is critical in diminishing our uncertainties for eventual cross section extraction
  - The hole in the HGCer will be a unique challenge for us to overcome which we look forward to figuring out.
- Acceptances and Heep studies will be the focus once this is complete

Extra Slides

Phase 2: PID Efficiencies

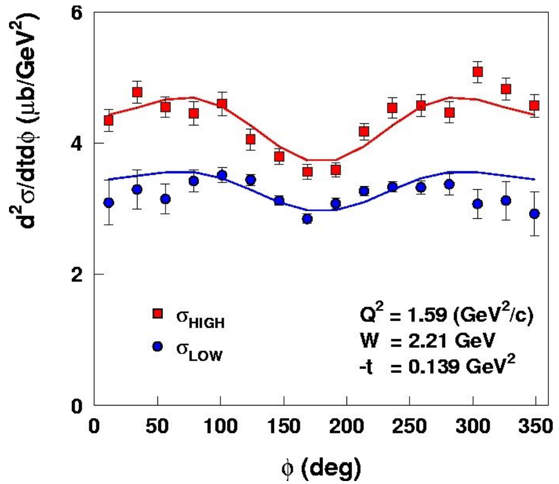
-



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+}



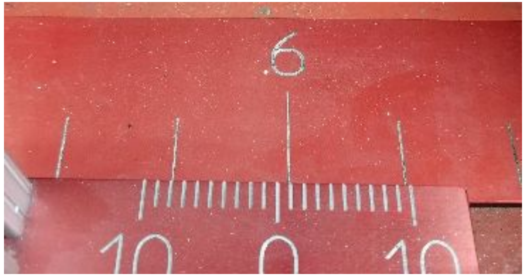
*T. Horn et al., PhysRevC **97**(2006)192001*

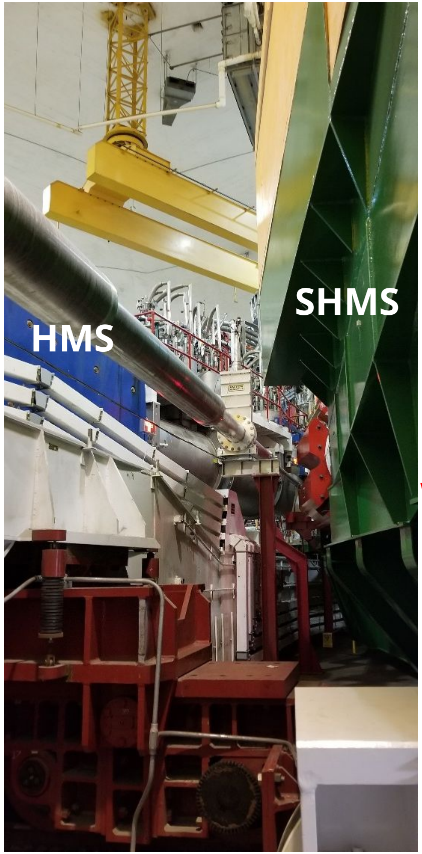
- σ_L is isolated using the Rosenbluth separation technique
- Measure the cross section at two beam energies and fixed W, Q^2, -t
- Simultaneous fit using measured azimuthal angle (ϕ) allows for extracting L, T, LT, and TT
    - Careful evaluation of the systematic uncertainties is important due to the $1/\varepsilon$ 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

SHMS small angle operation

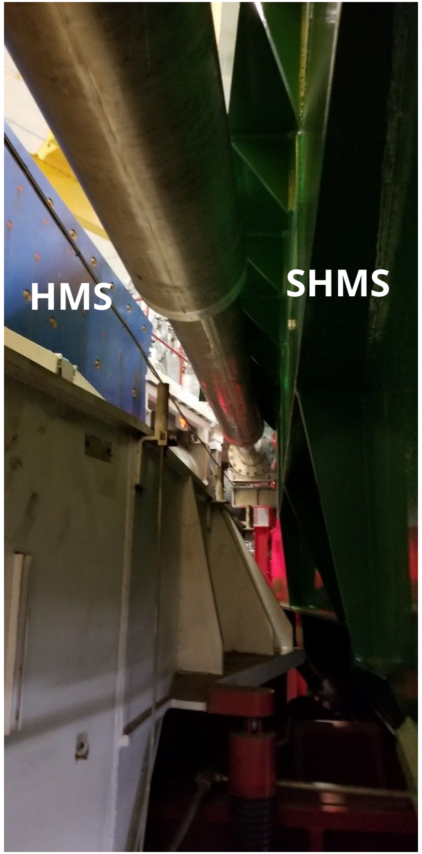
- Some issues with opening and small angle settings at beginning of run
  - SHMS at 6.01°
  - HMS at 12.7°

[12/17/18]



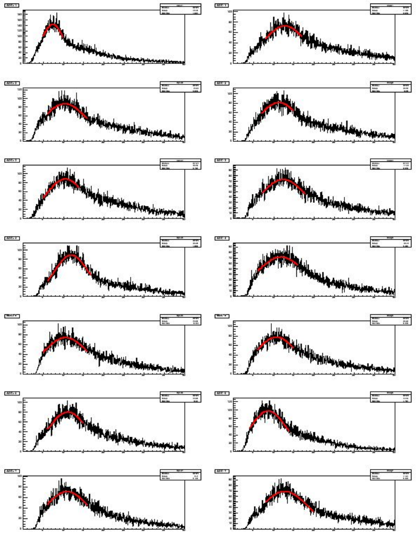


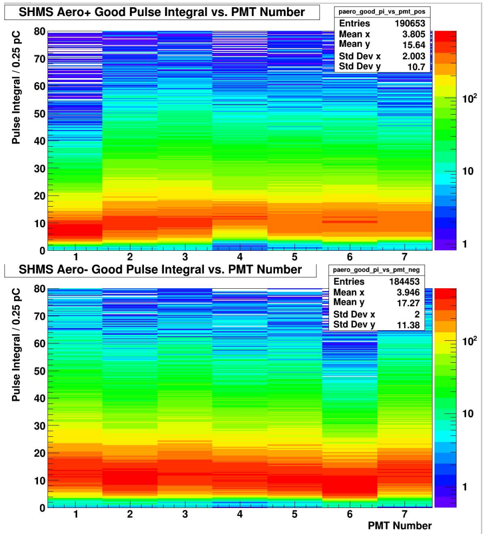
Work of many people ...

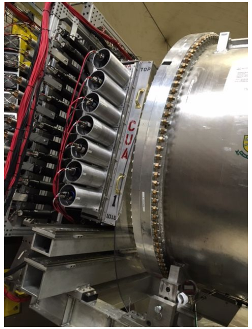


Aerogel Cherenkov detector in SHMS

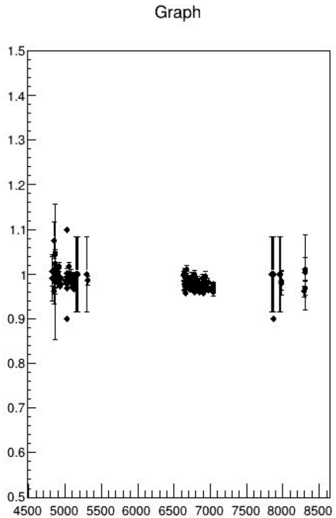
NSF MRI PHY-1039446

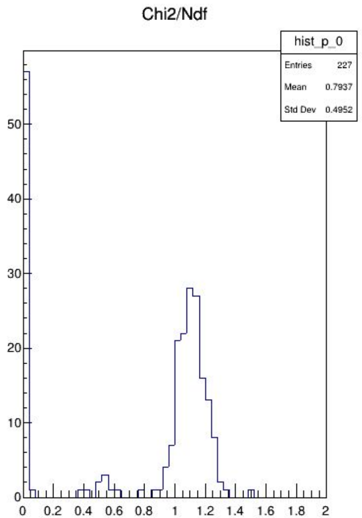






- ~15 successful tray exchanges since Fall 2018
- Aerogel performance as expected
- Trays require some optimization before next use - prevent damage from crane operation





Analysis by V. Berdnikov

KaonLT Event Selection

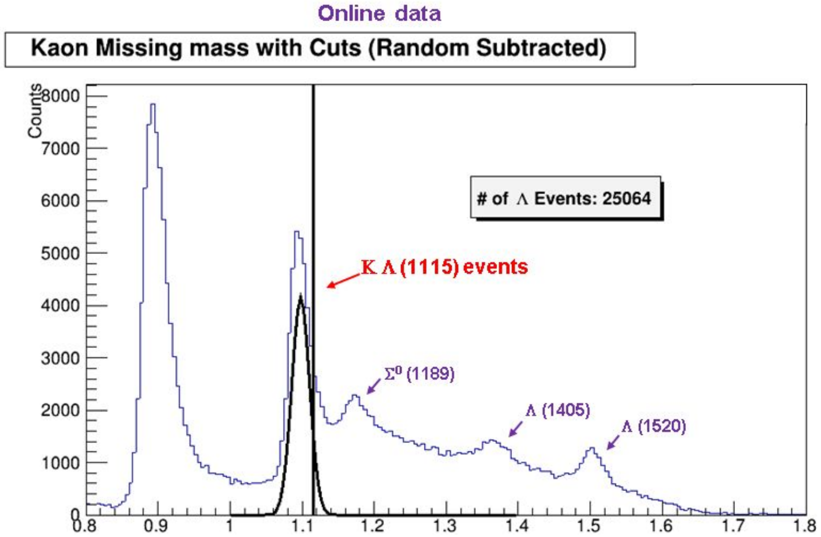
- Isolate Exclusive Final States through missing mass

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

- 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

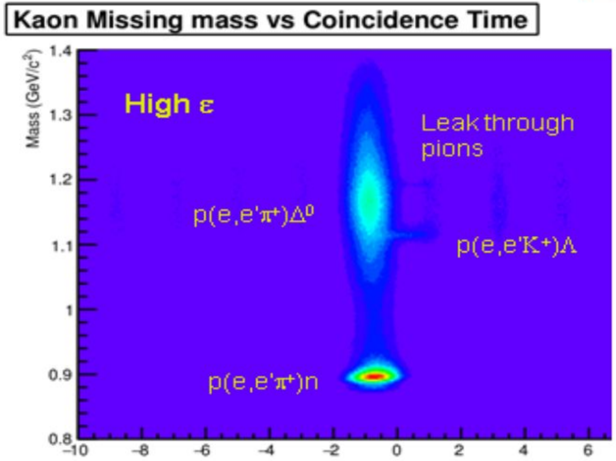


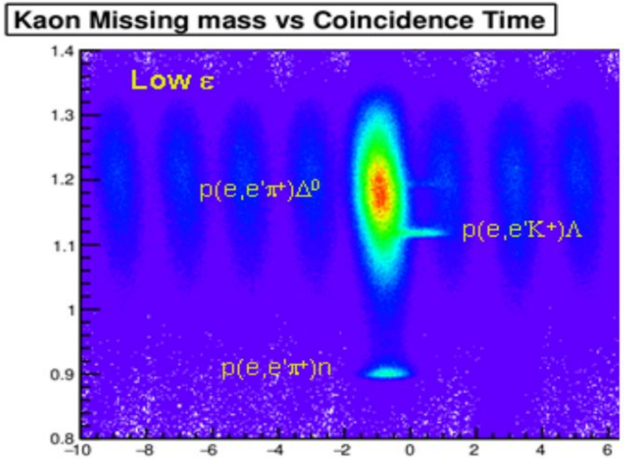
Plot by R. Ambrose, S. Kay, R. Trotta

Interesting Physics in the other channels

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

KaonLT: Q^2=0.50 GeV^2



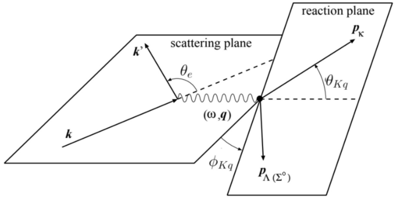


Plots by R. Ambrose, S. Kay, R. Trotta

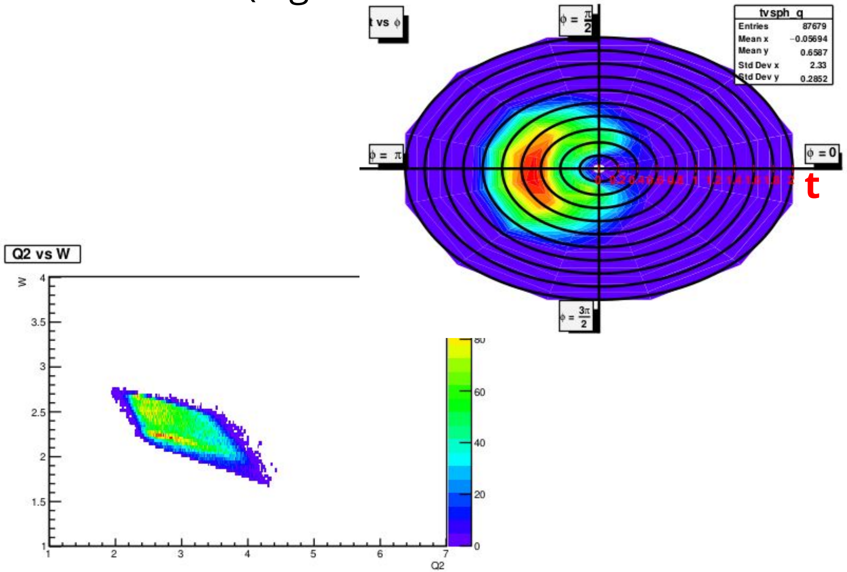
- Large increase in neutron missing mass peak at high epsilon is evidence of the pion-pole process at low Q^2 and small –t, which suggests $\sigma_L >> \sigma_T$
- Δ^0 exclusive longitudinal cross section expected to be at best $\sigma_L \sim \sigma_T$

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

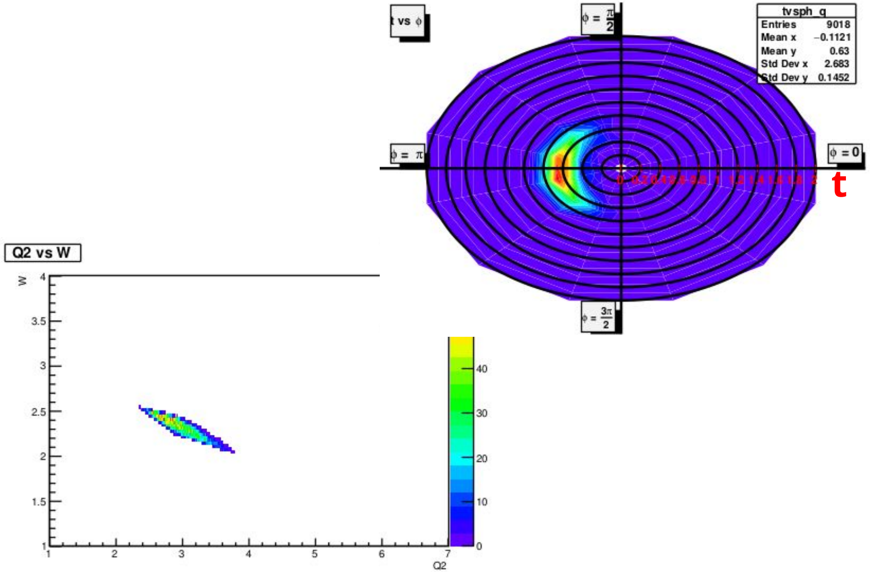
- [10.6 Gev (high ε), 6.2 Gev (low ε)]
- Left (θ_{high}=21.18,θ_{low}=16.28)



10.6 GeV (high ε)



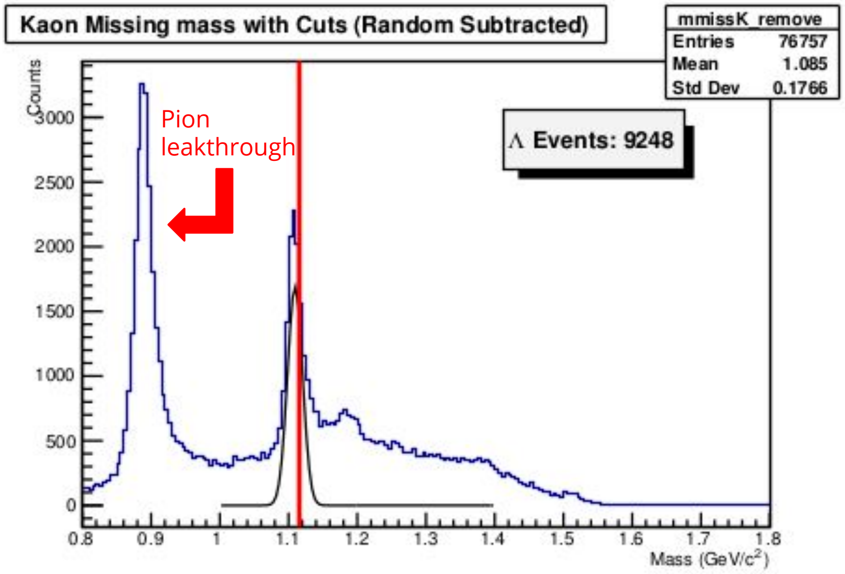
6.2 GeV (low ε)



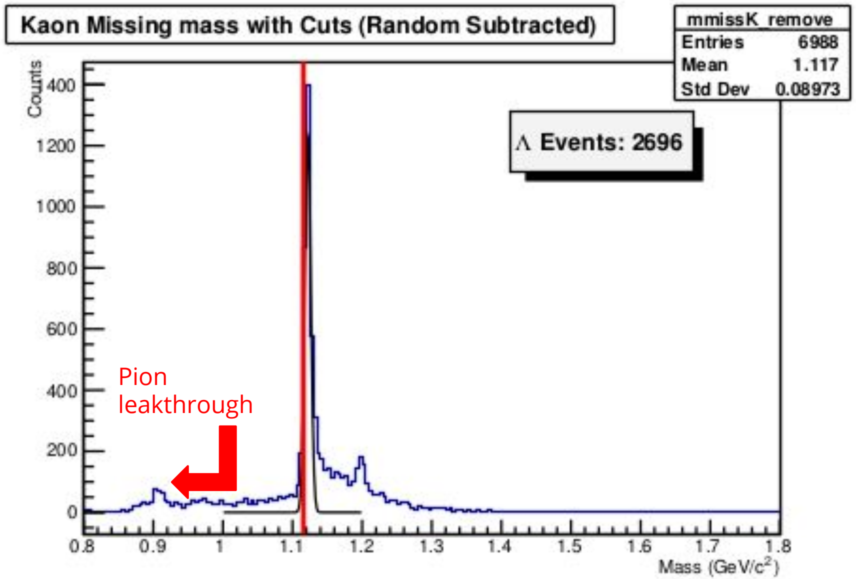
Comparison of high and low ε [Q^2=3.0, W=2.32, x=0.40]

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

10.6 GeV (high ε)



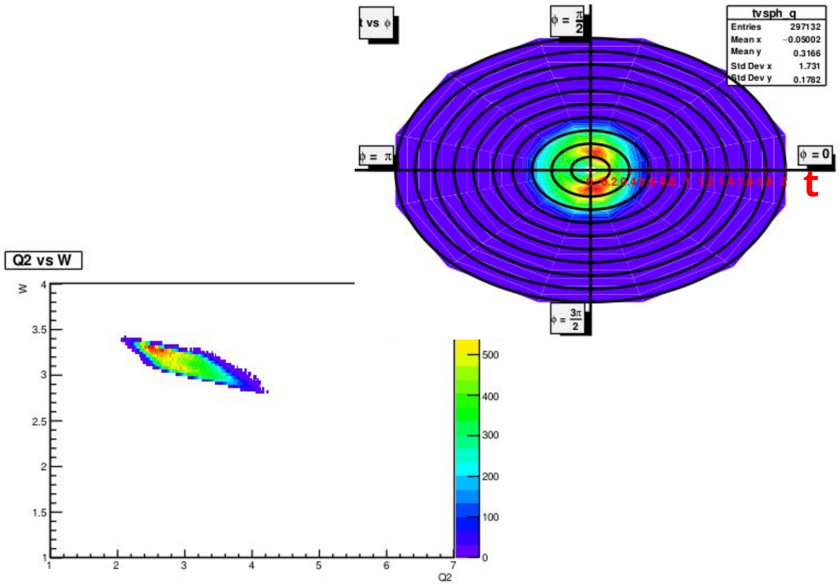
6.2 GeV (low ε)



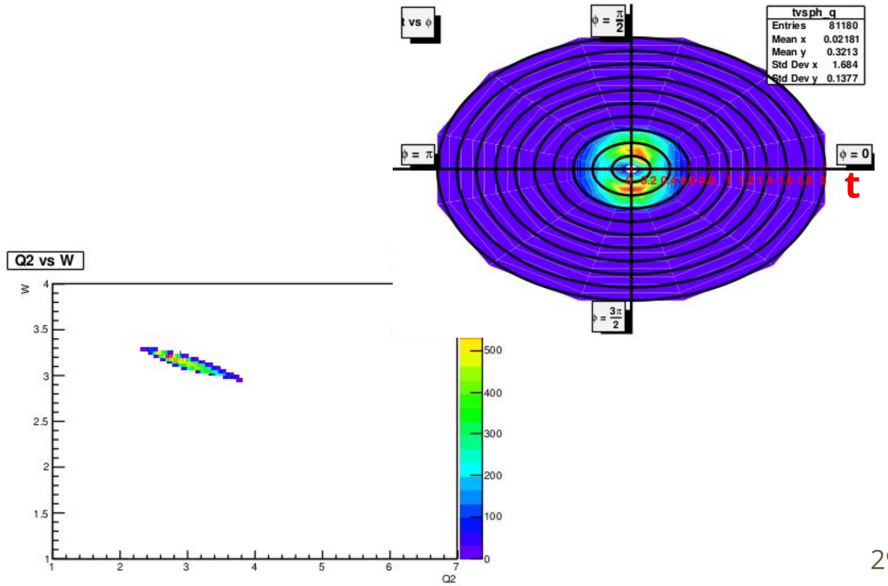
Comparison of high and low ε [Q^2=3.0, W=3.14, x=0.25]

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

10.6 GeV (high ε)



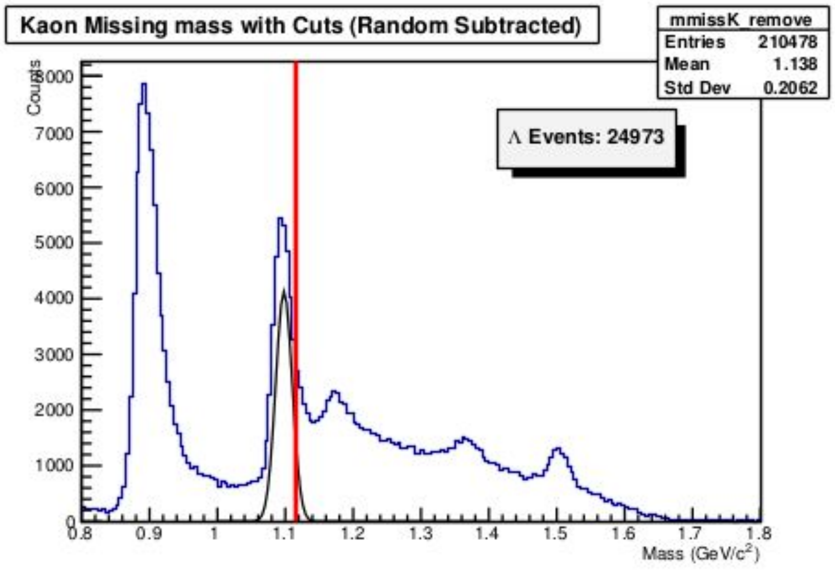
8.2 GeV (low ε)



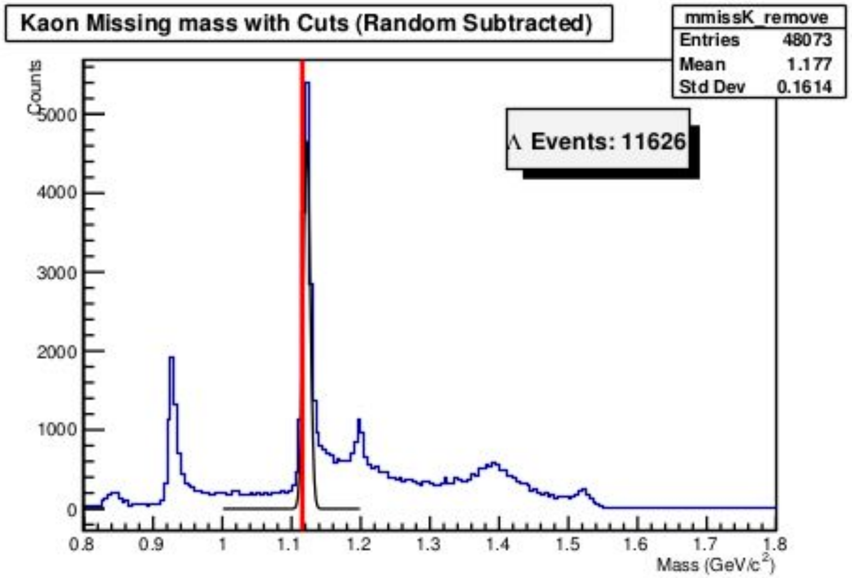
Comparison of high and low ε [Q^2=3.0, W=3.14, x=0.25]

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

10.6 GeV (high ε)



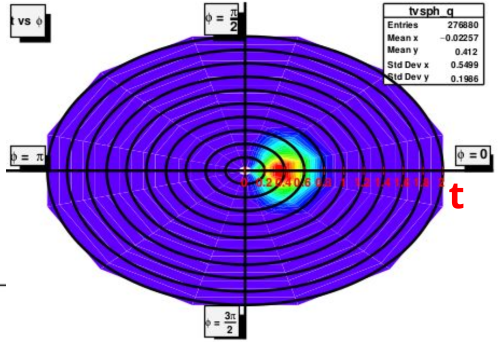
8.2 GeV (low ε)

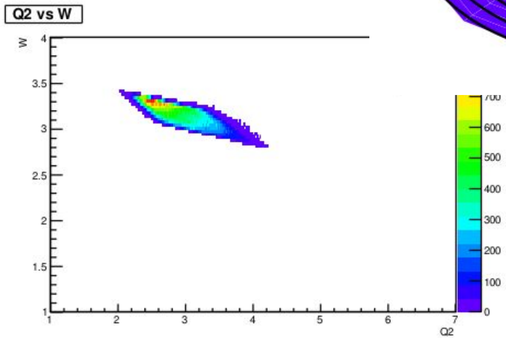


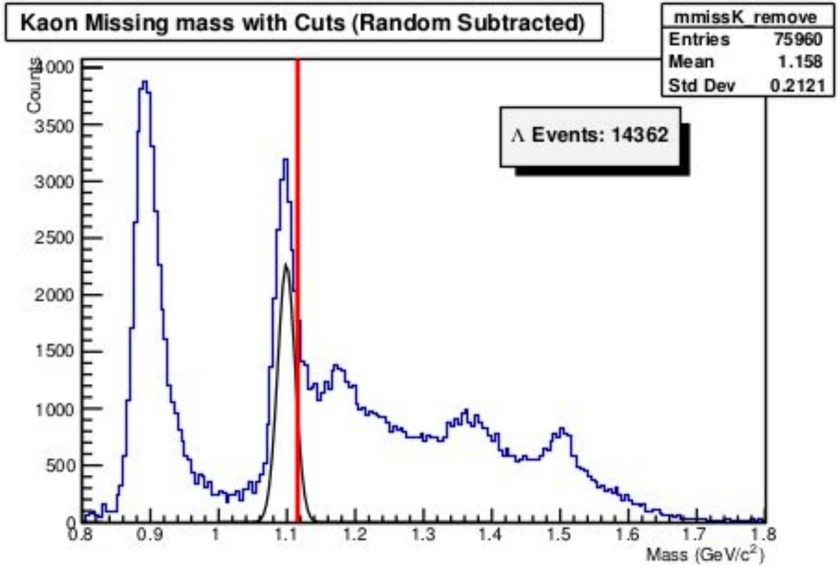
Comparison of high and low ε [Q^2=3.0, W=3.14, x=0.25]

- [10.6 Gev (high ε)]
- Right (θ_{high}=6.65)

10.6 GeV (high ε)



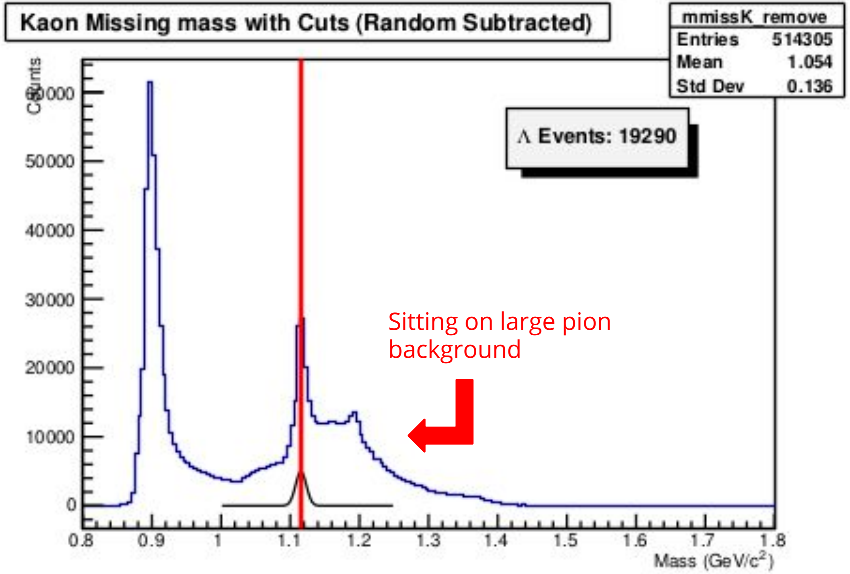




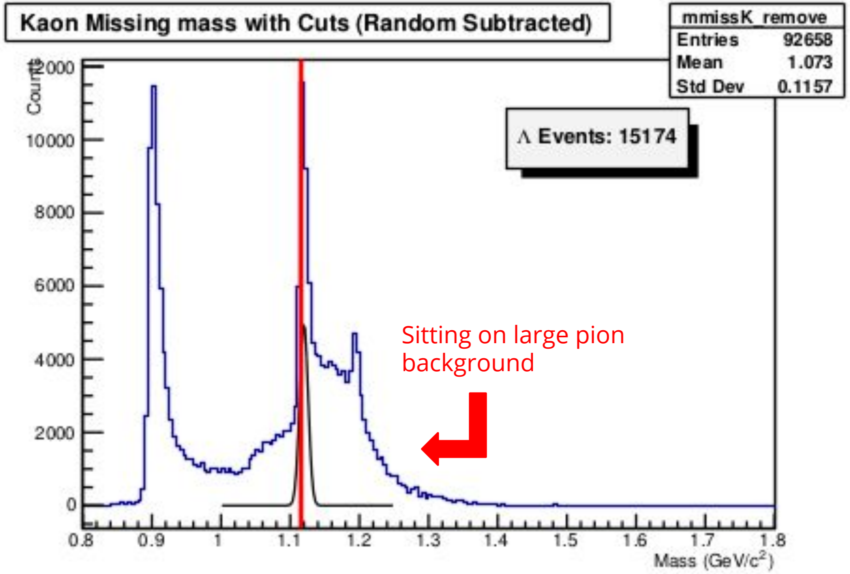
Comparison of high and low ε [Q^2=0.5, W=2.40, x=0.09]

- [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)

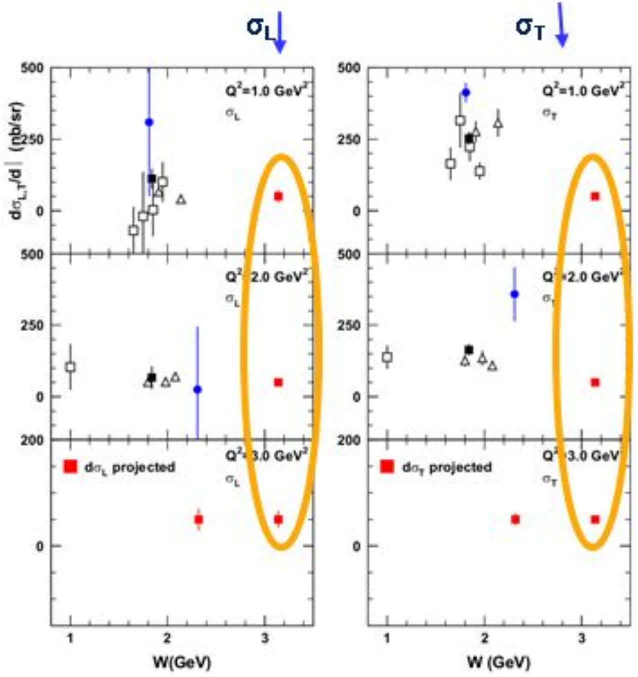


KaonLT Sample Projections

- 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