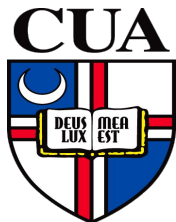
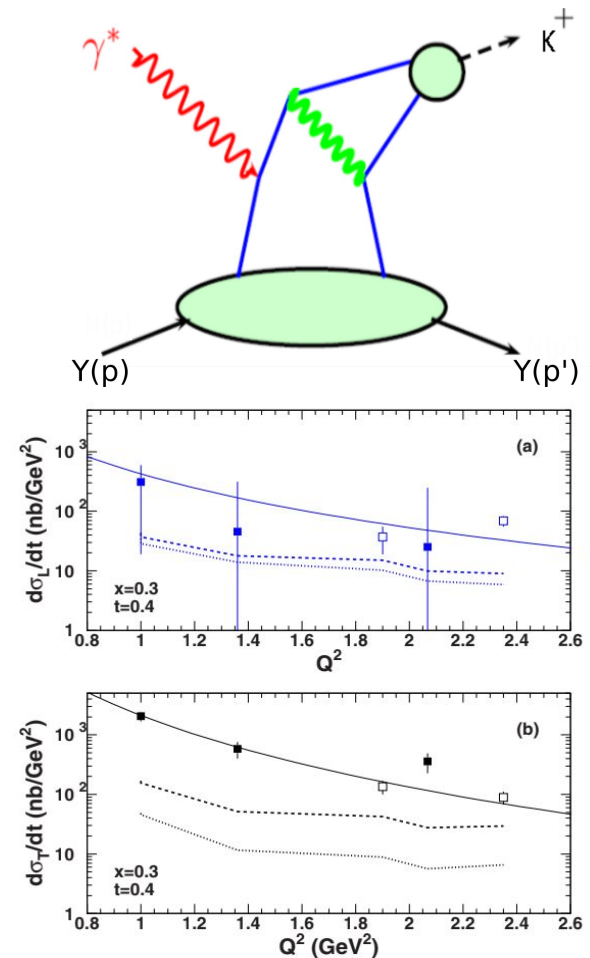

Update on KaonLT Experiment

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



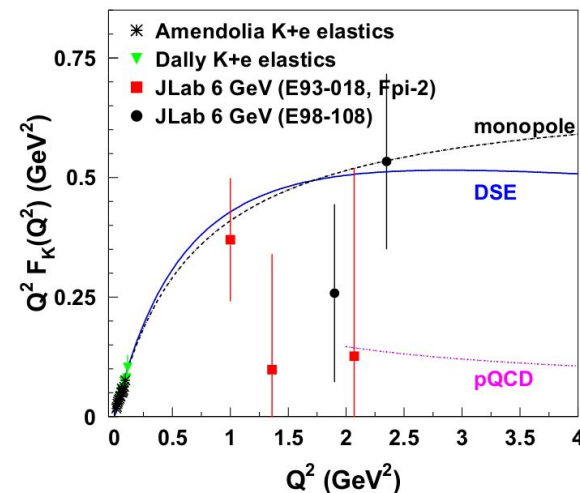
L/T separated data for verifying reaction mechanism

- 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



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

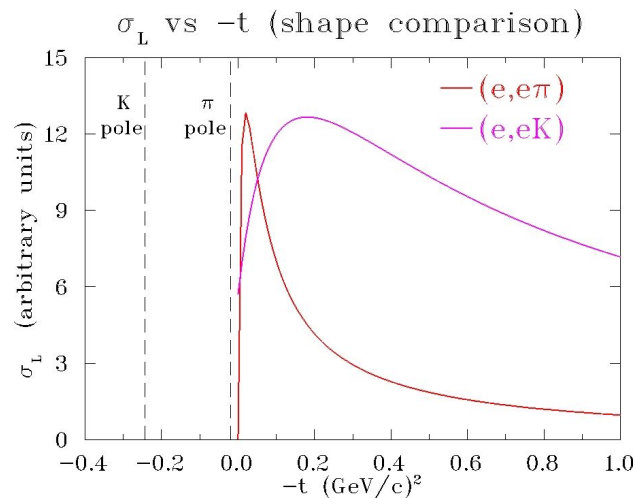
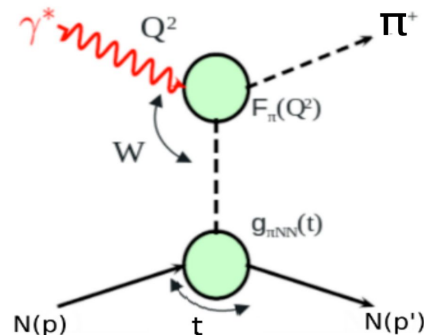
- At larger Q^2 , $F_{\pi^+}^2$ must be measured indirectly using the “pion cloud” of the proton via the $p(e,e'\pi^+)n$ process

- 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:

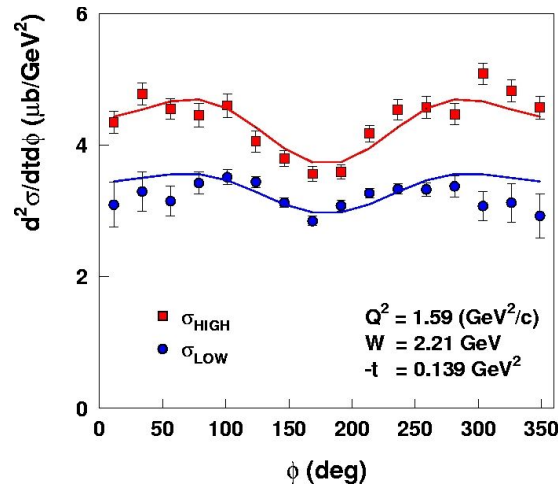
- Full L/T separation of the cross section – isolation of σ_L
- Selection of the pion pole process
- Extraction of the form factor using a model
- Validation of the technique - model dependent checks



L/T Separation Example

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

σ_L will give us $F_{K^+}^2$

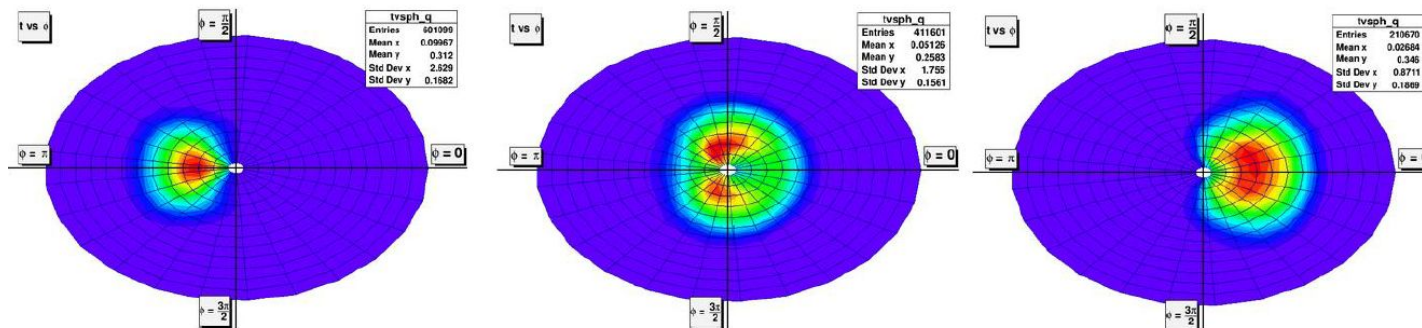


T. Horn et al., PhysRevC **97**(2006)192001

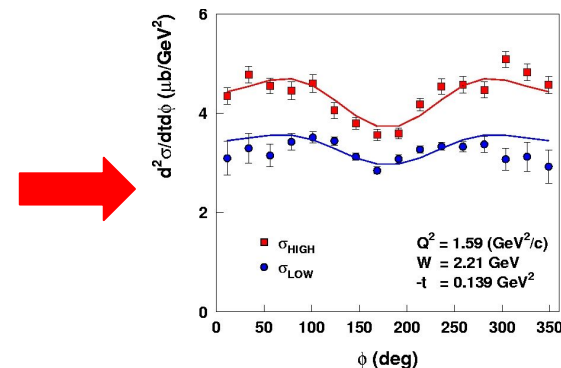
- σ_L is isolated using the **Rosenbluth separation technique**
- Measure the cross section at two beam energies and fixed W , Q^2 , $-t$
- Simultaneous fit using measured azimuthal angle (ϕ) allows for extracting L , T , LT , and TT
 - Careful evaluation of the systematic uncertainties is important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

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



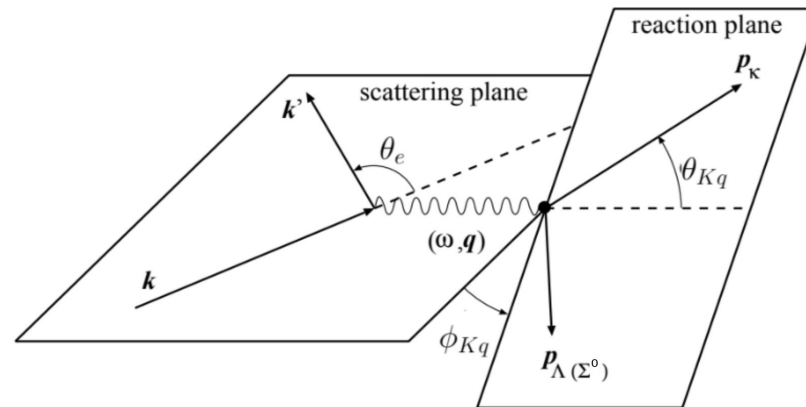
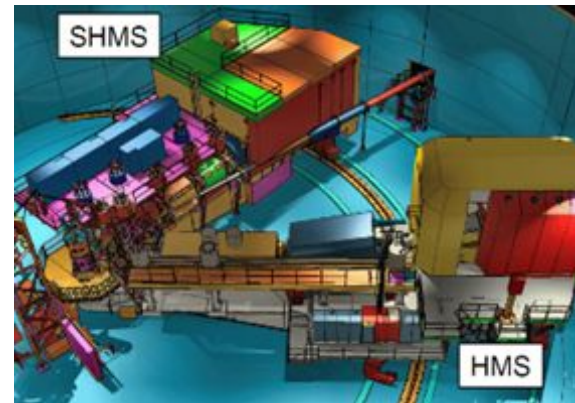
- Three SHMS angles for azimuthal (ϕ) coverage to determine the interference terms (LT, TT)
- Using the two beam energies (ε) to separate longitudinal (L) from transverse (T) cross section



Fit using measured ε and ϕ dependence

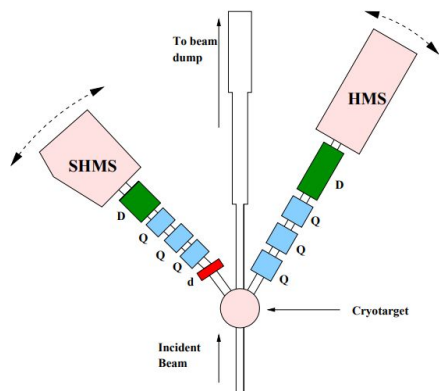
Review E12-09-011 (KaonLT) Goals

- 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

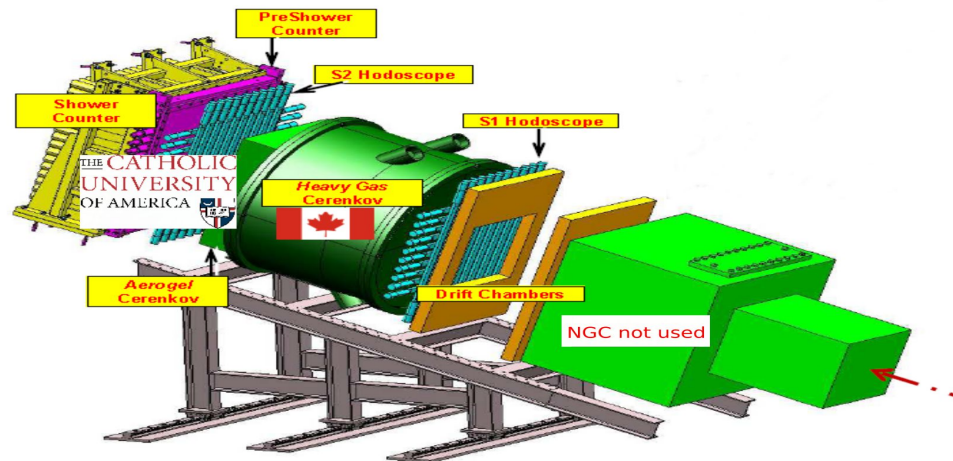
- The $p(e, e'K^+)\Lambda, \Sigma^0$ experiment ran in Hall C at Jefferson Lab over the fall and spring.



E (GeV)	Q^2 (GeV ²)	W (GeV)	x	$\epsilon_{\text{high}}/\epsilon_{\text{low}}$
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

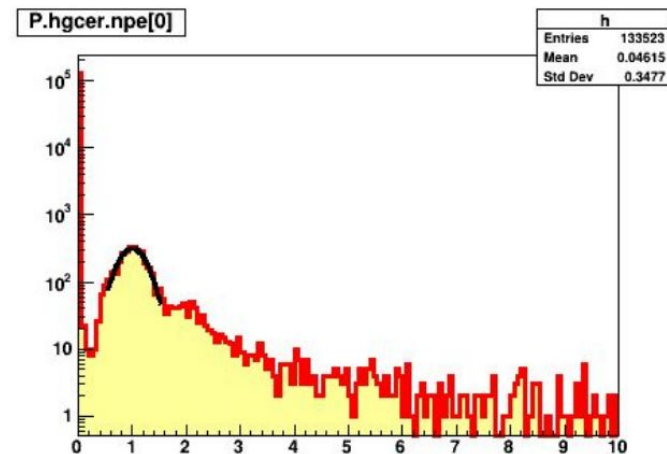
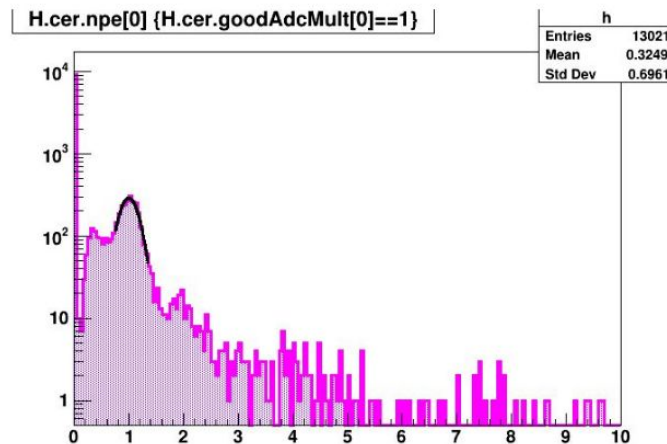
- Repeat until acceptable cross sections are reached

6. Possible attempt at form factor extraction

- Fit the data to a model and iterate

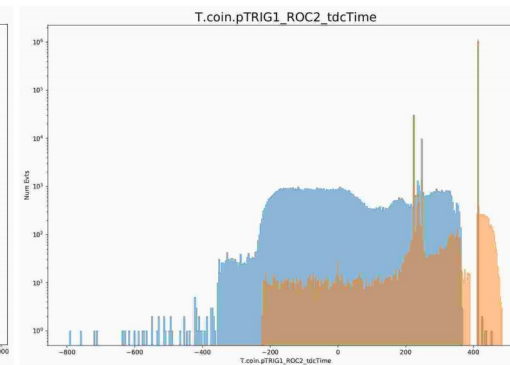
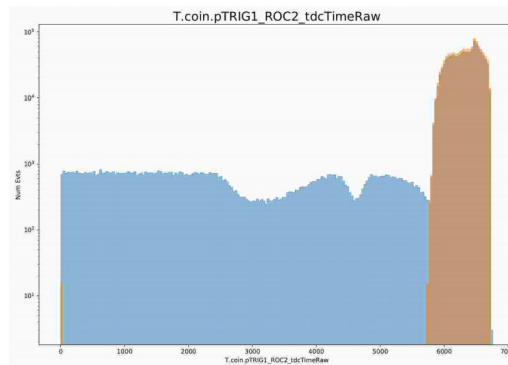
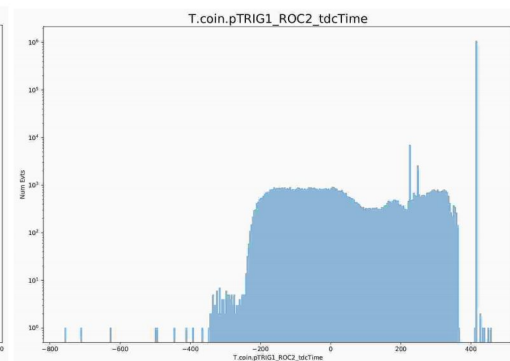
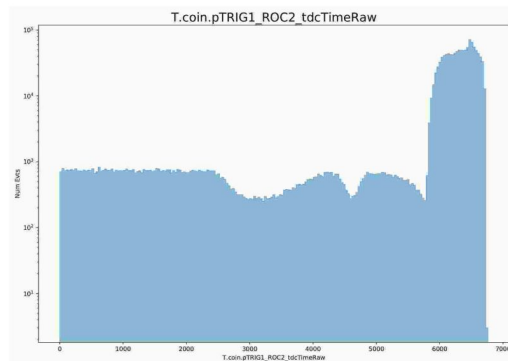
Phase 1: Cherenkov Calibrations

- ADC time window cut values
 - $\text{hcer_adcTimeWindowMin} = 90., 98.$
 - $\text{hcer_adcTimeWindowMax} = 115., 120.$
- HMS Calibration coefficients:
 - Fall 2018: $\text{hcer_adc_to_npe} = 1./10.69, 1./9.81$
 - Spring 2018: $\text{hcer_adc_to_npe} = 1./9.069, 1./9.035$
- SHMS Calibration coefficients:
 - Fall 2018: $\text{hcer_adc_to_npe} = 1./6.26, 1./7.3, 1./5.85, 1./6.98$
 - Spring 2018: $\text{hcer_adc_to_npe} = 1./5.92, 1./6.67, 1./5.28, 1./6.83$



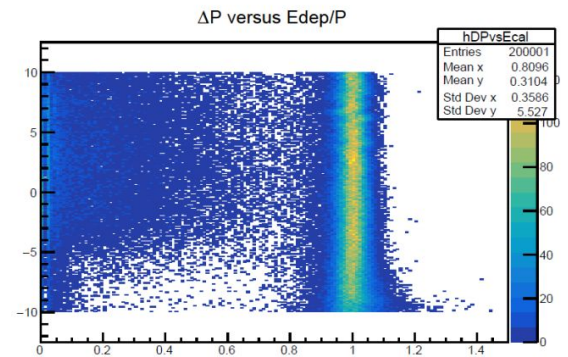
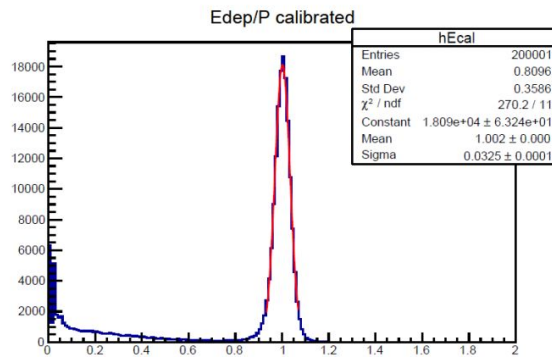
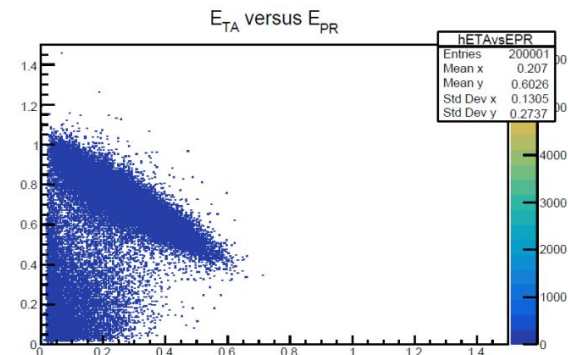
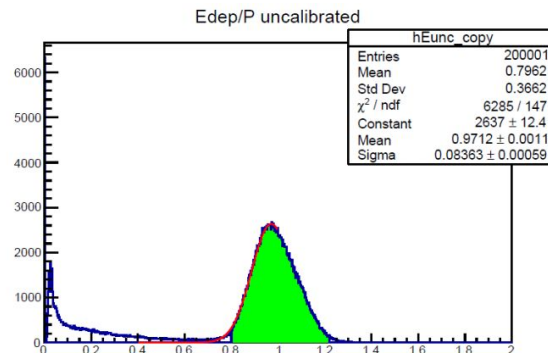
Phase 1: Timing Windows and Reference Time

-

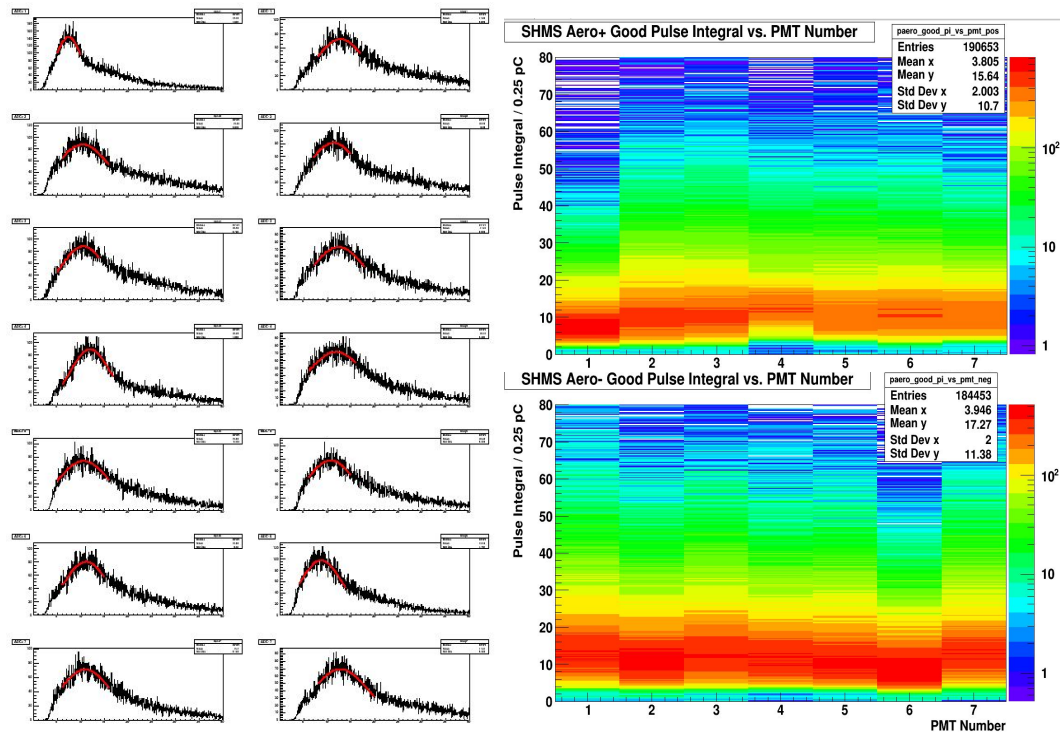


Phase 1: Calorimeter Calibrations

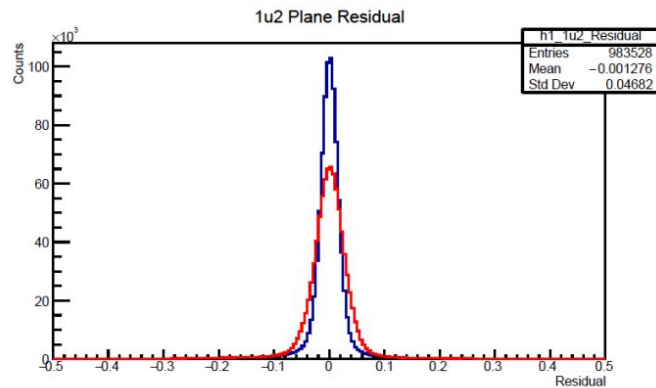
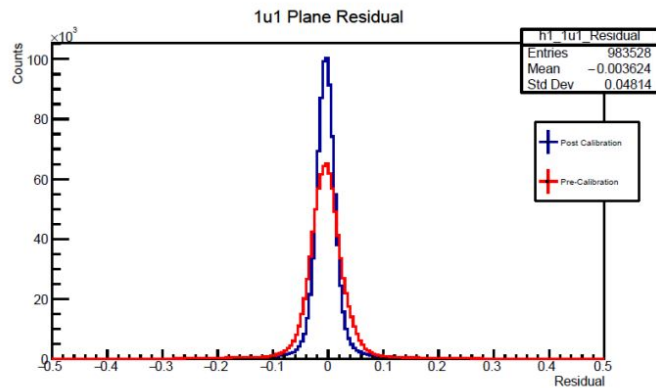
●



Phase 1: Aerogel Calibrations



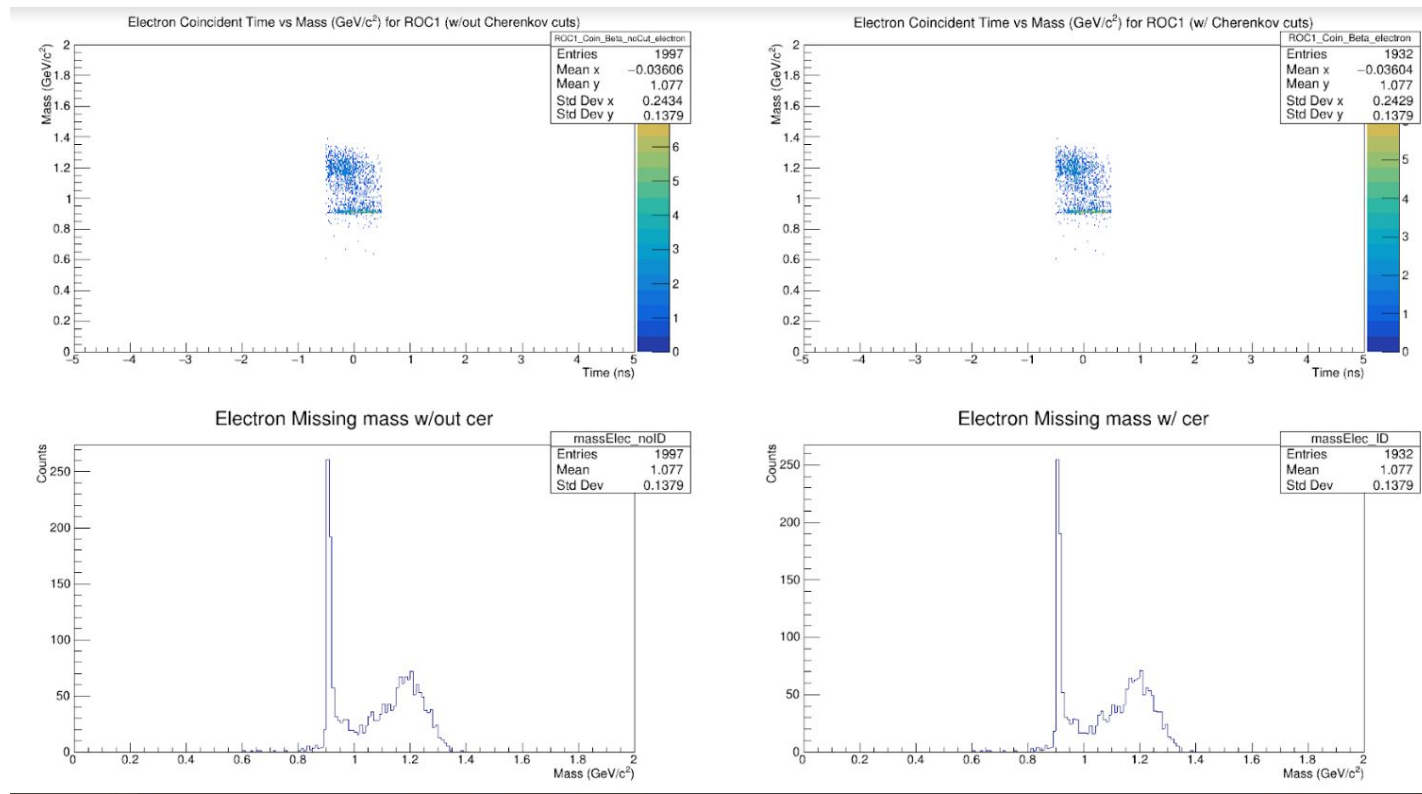
Phase 1: Drift Chamber Calibrations



Phase 1: Hodoscope Calibrations

-

Phase 2: PID Efficiencies



Phase 2: PID Efficiencies

```
// Delta cuts
if (TMath::Abs(H_gtr_dp[0]) > 10.0) return kTRUE;
if (P_gtr_dp[0] > 20.0 || P_gtr_dp[0] < -10.0) return kTRUE;
// SHMS cal cut
if (P_cal_etotnorm[0] > 0.6) return kTRUE;
// SHMS beta cut
if (abs(P_gtr_beta[0]-1.00) > 0.1) return kTRUE;
if ( ( CTime_eKCoinTime_ROC1[0] - 47.5) > -0.5 && (CTime_eKCoinTime_ROC1[0] - 47.5) < 0.5) { // Timing Cut
    if(H_cal_etotnorm[0] > 0.995 && H_cal_etotnorm[0] < 1.015){ // Calorimeter cut
        // No cer cut    h2ROC1_Coin_Beta_noID_electron->Fill((CTime_eKCoinTime_ROC1[0] - 47.5),sqrt(pow(emiss[0],2)-pow(pmiss[0],2)));
        h1massElec_noID->Fill(sqrt(pow(emiss[0],2)-pow(pmiss[0],2)));
        if(H_cer_npeSum[0] > 3.0){ // cer cut
            // cer cut
            h2ROC1_Coin_Beta_electron->Fill((CTime_eKCoinTime_ROC1[0] - 47.5),sqrt(pow(emiss[0],2)-pow(pmiss[0],2)));
            h1massElec_ID->Fill(sqrt(pow(emiss[0],2)-pow(pmiss[0],2)));
        }
    }
}
```

Conclusion

- E12-09-011 has completed its 2018-19 run
- Currently in the second phase of analysis
- The calibrations are complete for all detectors
- Studies on tracking, efficiencies for luminosity for the immediate future
- SIMC and offsets will be the focus once this is complete
- Early cross section data forecasted for the end of the year

Extra Slides

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]



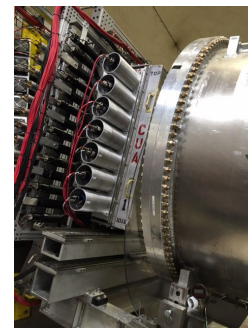
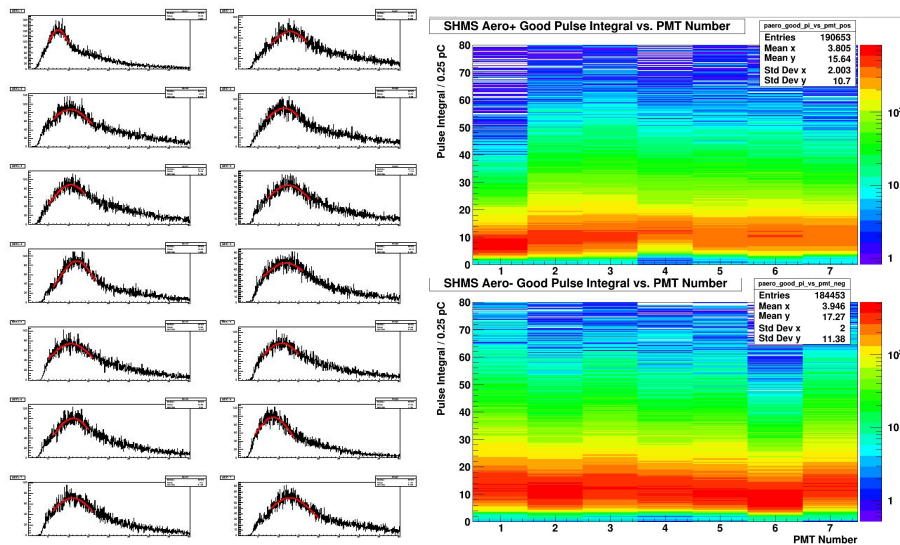
Work of many people ...



Aerogel Cherenkov detector in SHMS

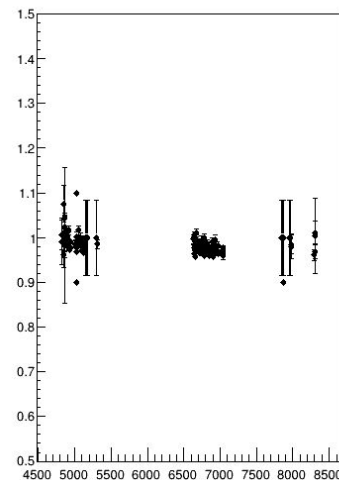


NSF MRI PHY-1039446

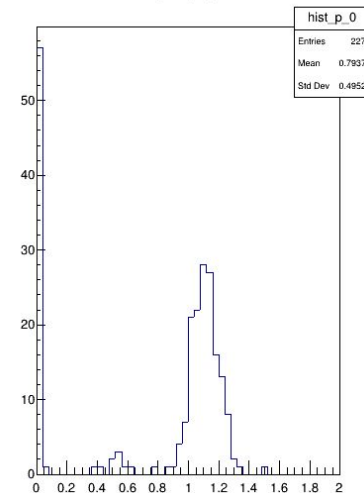


- ~15 successful tray exchanges since Fall 2018
- Aerogel performance as expected
- Trays require some optimization before next use - prevent damage from crane operation

Graph



Chi2/Ndf



Analysis by V. Berdnikov

KaonLT Event Selection

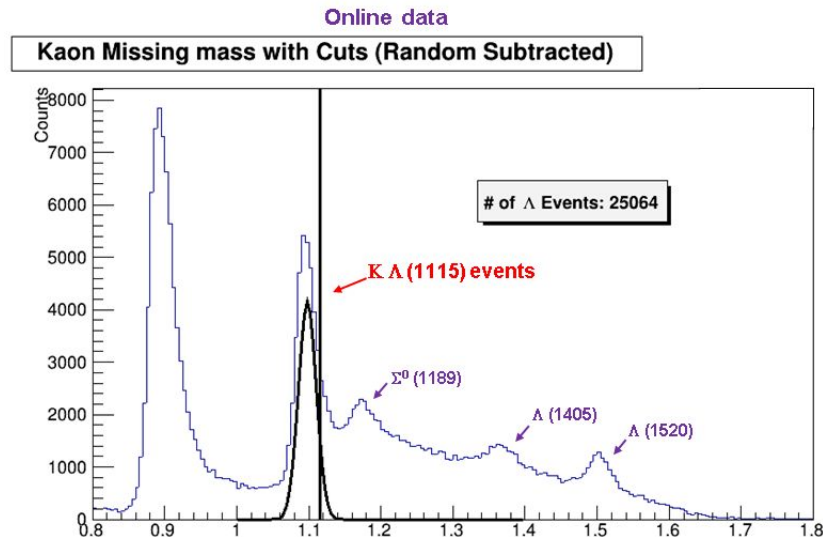
- Isolate Exclusive Final States through missing mass

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

- 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

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

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



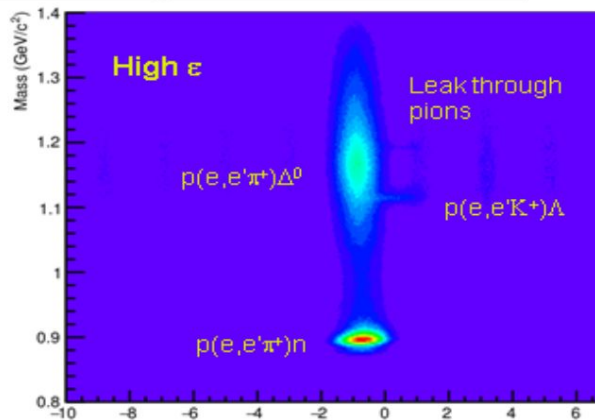
Plot by R. Ambrose, S. Kay, R. Trotta

Interesting Physics in the other channels

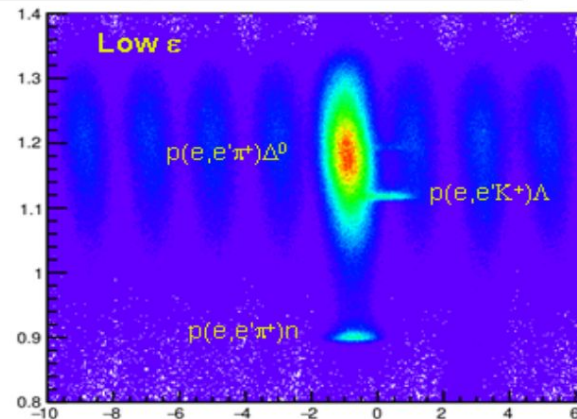
- Large difference in L/T ratio between $p(e,e'\pi^+)n$ and $p(e,e'\pi^+)\Delta^0$ final states – G. Huber hclong #3640187

KaonLT: $Q^2=0.50 \text{ GeV}^2$

Kaon Missing mass vs Coincidence Time



Kaon Missing mass vs Coincidence Time

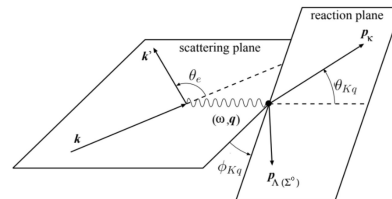


Plots by R. Ambrose, S. Kay, R. Trotta

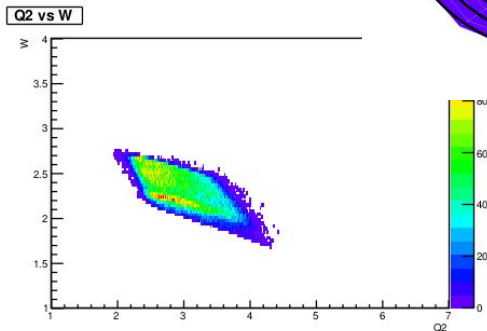
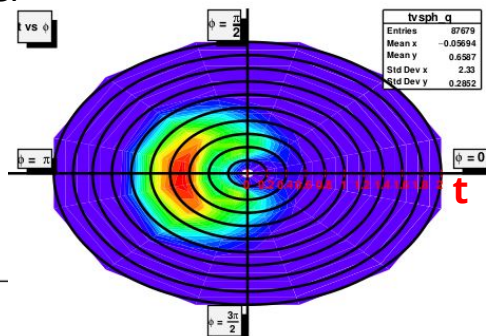
- Large increase in neutron missing mass peak at high epsilon is evidence of the pion-pole process at low Q^2 and small $-t$, which suggests $\sigma_L \gg \sigma_T$
- Δ^0 exclusive longitudinal cross section expected to be at best $\sigma_L \sim \sigma_T$

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

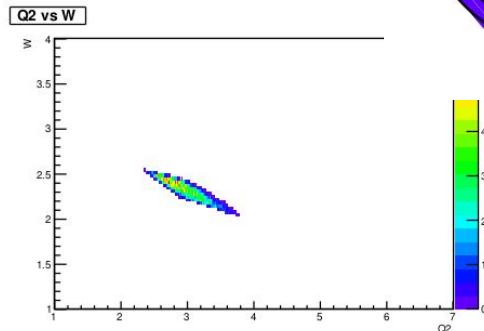
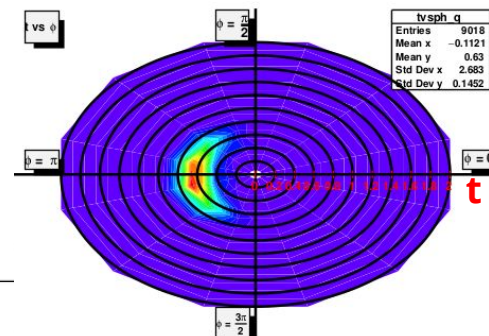
- [10.6 GeV (high ε), 6.2 GeV (low ε)]
- Left ($\theta_{\text{high}}=21.18^\circ, \theta_{\text{low}}=16.28^\circ$)



10.6 GeV (high ε)



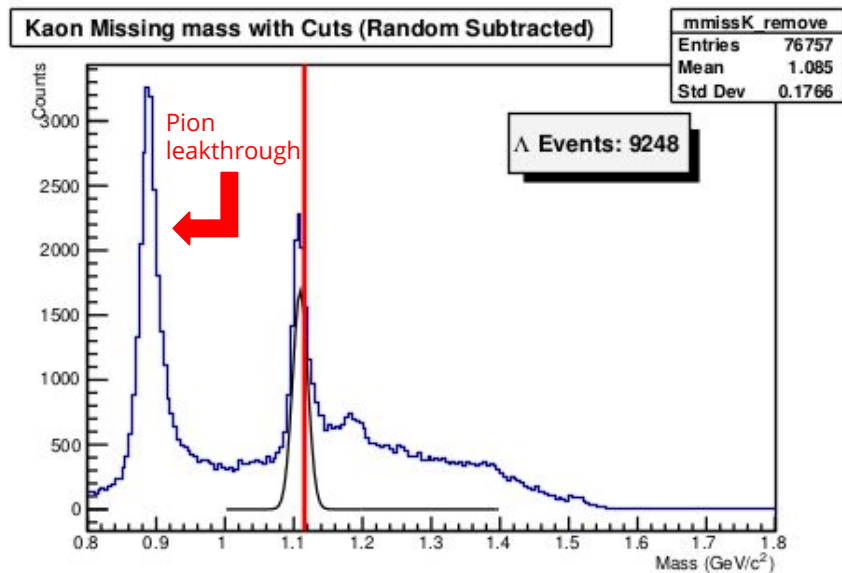
6.2 GeV (low ε)



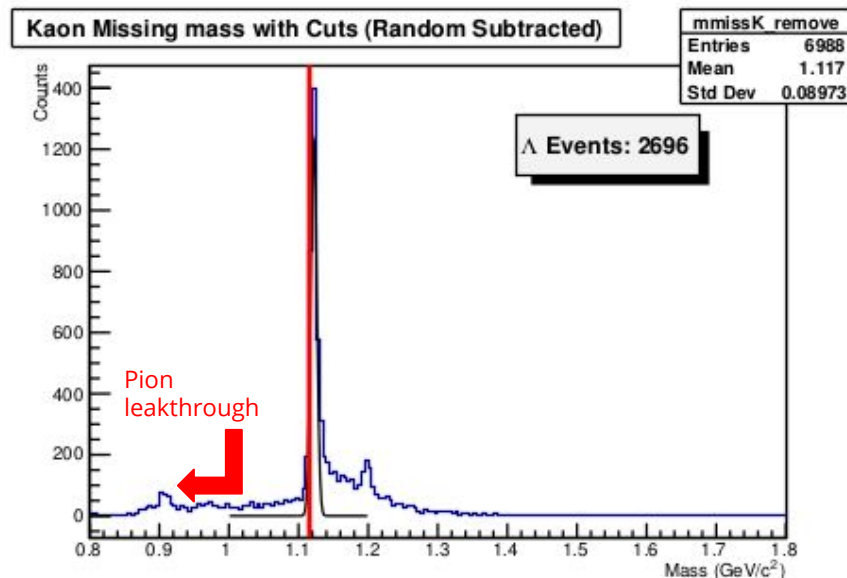
Comparison of high and low ϵ [$Q^2=3.0$, $W=2.32$, $x=0.40$]

- [10.6 GeV (high ϵ), 6.2 GeV (low ϵ)]
- Left ($\theta_{\text{high}}=21.18, \theta_{\text{low}}=16.28$)

10.6 GeV (high ϵ)



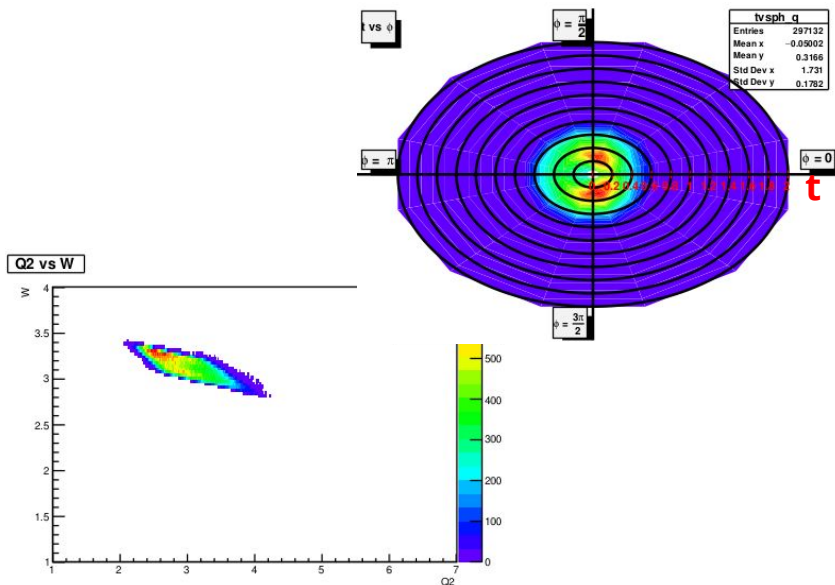
6.2 GeV (low ϵ)



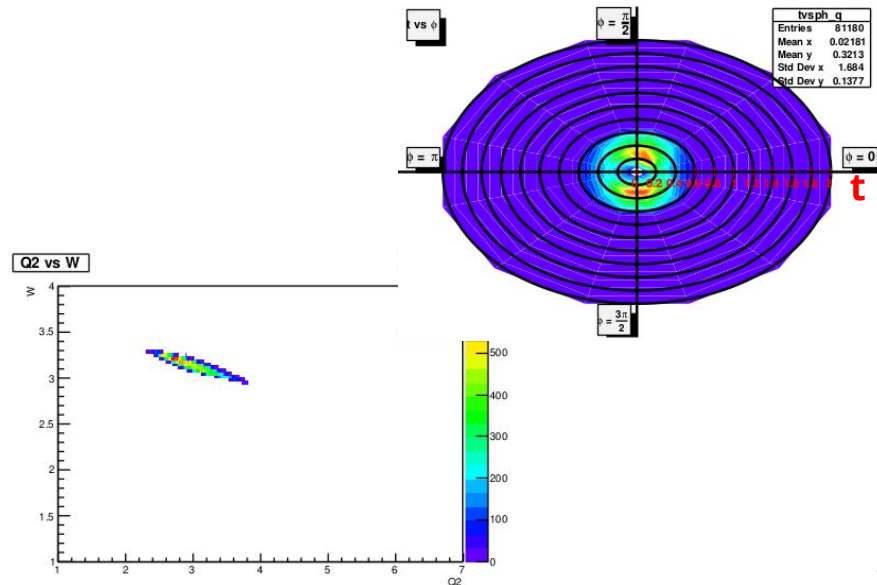
Comparison of high and low ϵ [$Q^2=3.0$, $W=3.14$, $x=0.25$]

- [10.6 GeV (high ϵ), 8.2 GeV (low ϵ)]
- Center ($\theta_{\text{high}}=9.42, \theta_{\text{low}}=6.89$)

10.6 GeV (high ϵ)



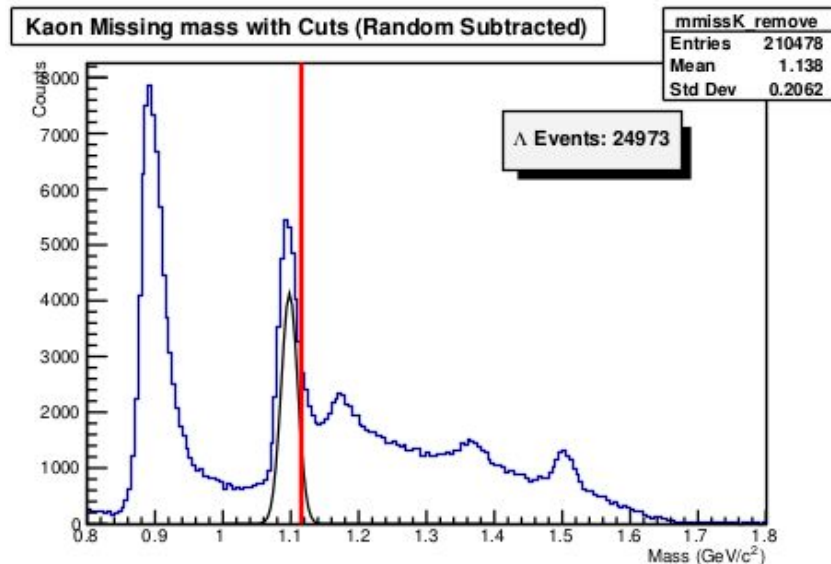
8.2 GeV (low ϵ)



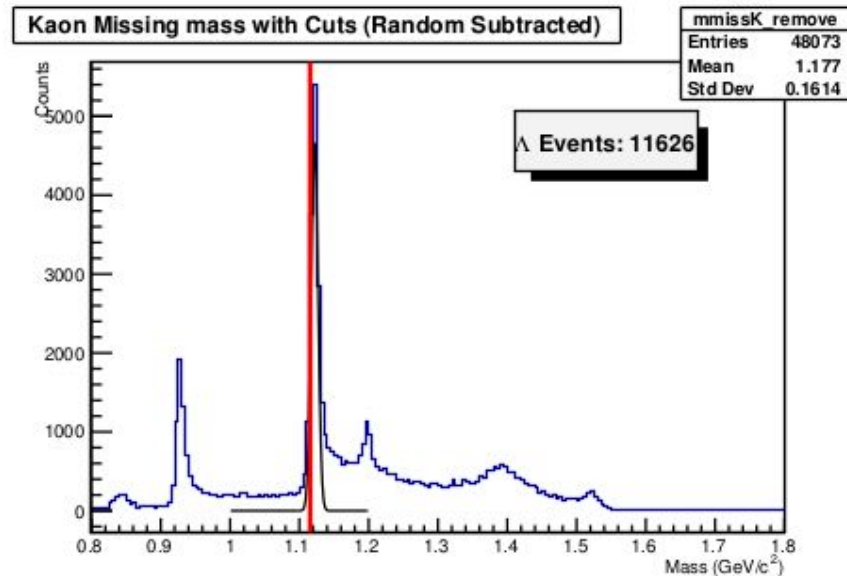
Comparison of high and low ϵ [$Q^2=3.0$, $W=3.14$, $x=0.25$]

- [10.6 GeV (high ϵ), 8.2 GeV (low ϵ)]
- Center ($\theta_{\text{high}}=9.42, \theta_{\text{low}}=6.89$)

10.6 GeV (high ϵ)



8.2 GeV (low ϵ)

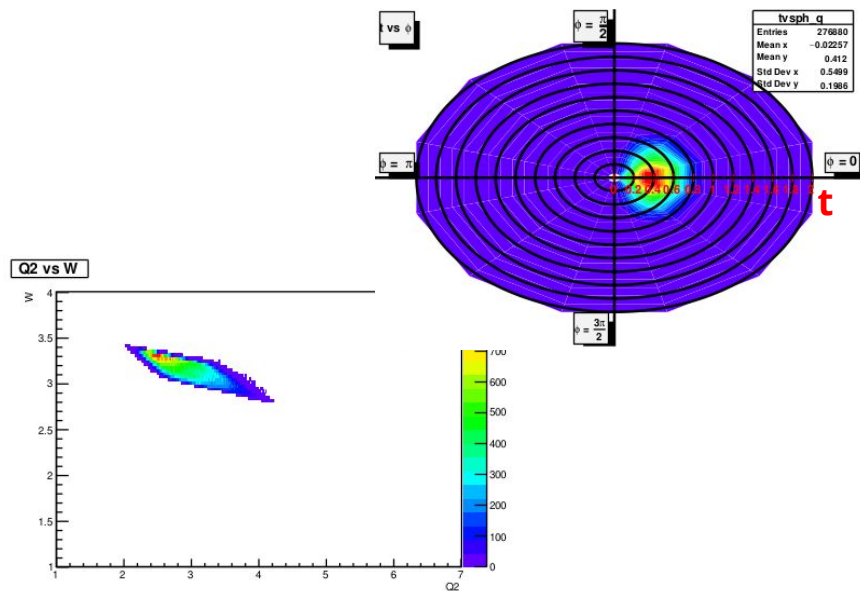


Comparison of high and low ϵ [$Q^2=3.0$, $W=3.14$, $x=0.25$]

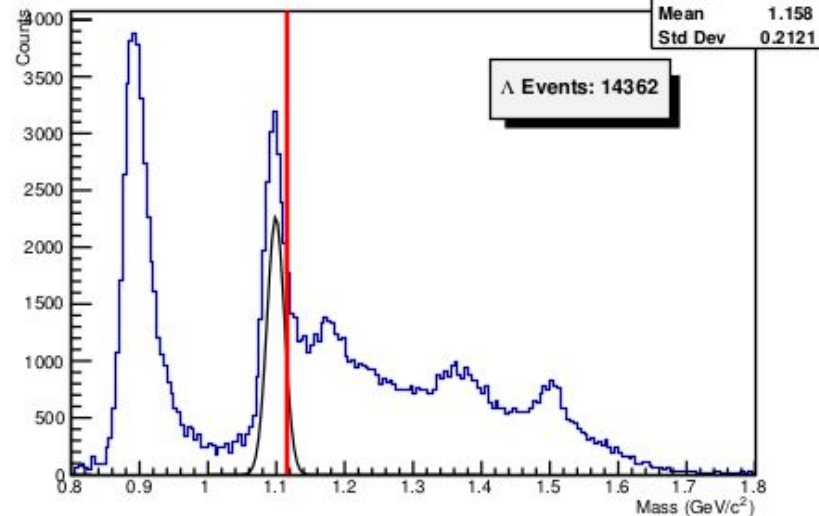
- [10.6 GeV (high ϵ)]
- Right ($\theta_{\text{high}}=6.65$)



10.6 GeV (high ϵ)



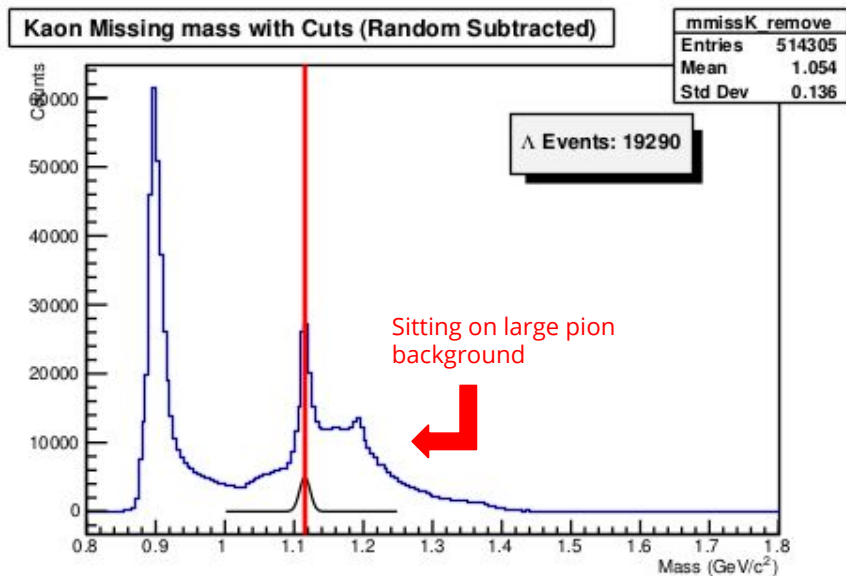
Kaon Missing mass with Cuts (Random Subtracted)



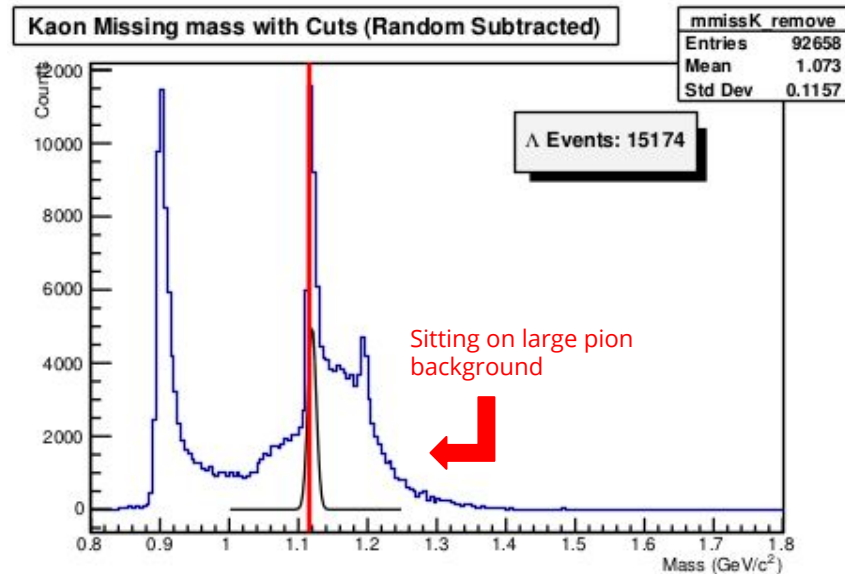
Comparison of high and low ϵ [$Q^2=0.5$, $W=2.40$, $x=0.09$]

- [4.9 GeV (high ϵ), 3.8 GeV (low ϵ)]
- Center ($\theta_{\text{high}}=8.86, \theta_{\text{low}}=6.79$)

4.9 GeV (high ϵ)



3.8 GeV (low ϵ)

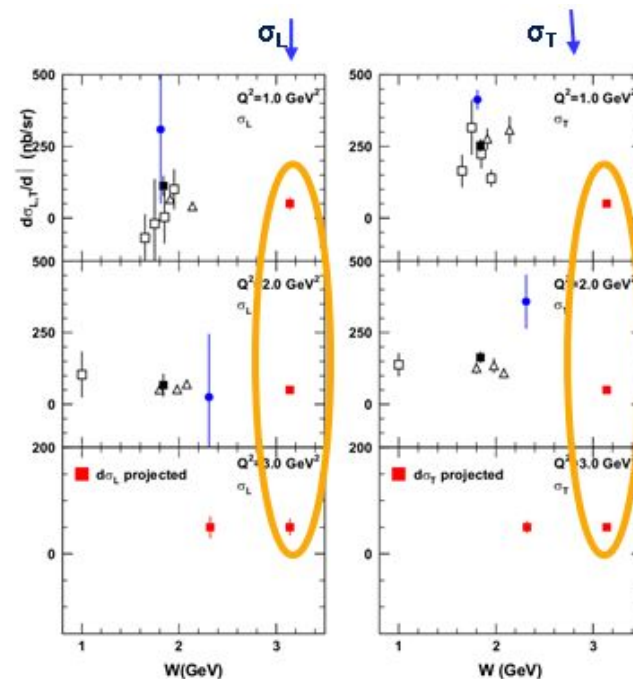


KaonLT Sample Projections

- 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

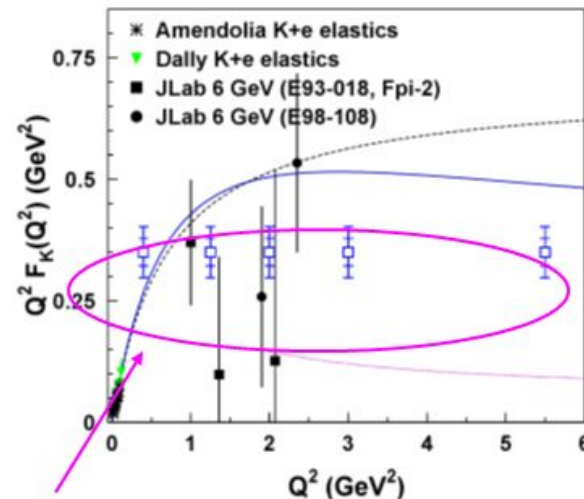
- JLab 12 GeV Kaon Program features:
 - First cross section data for Q^2 scaling tests with kaons
 - Highest Q^2 for L/T separated kaon electroproduction cross section
 - First separated kaon cross section measurement above $W=2.2$ GeV



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

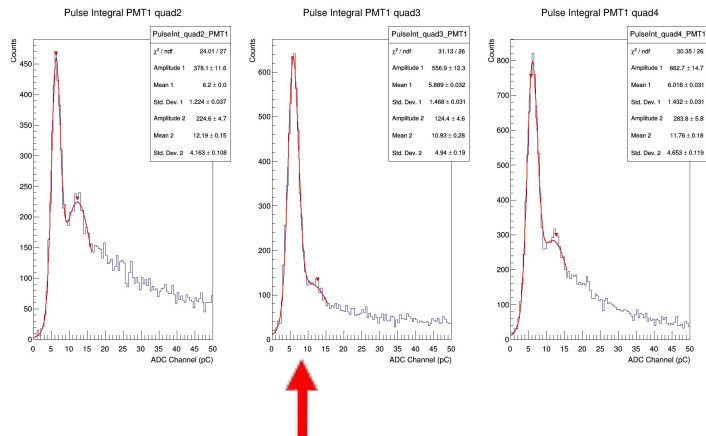
KaonLT: Projections for $F_{K^+}(Q^2)$ Measurements

- 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_{π}^2 at small and larger t show only modest model dependence
 - larger t data lie at a similar distance from pole as kaon data

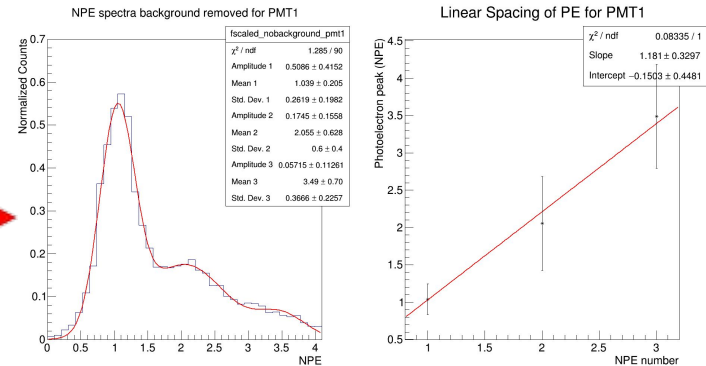


Possible extractions from
2018/19 run

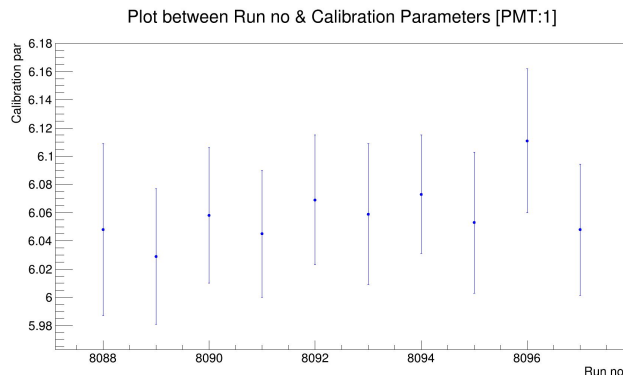
P1: Calibration of HGC Detector (SHMS)



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



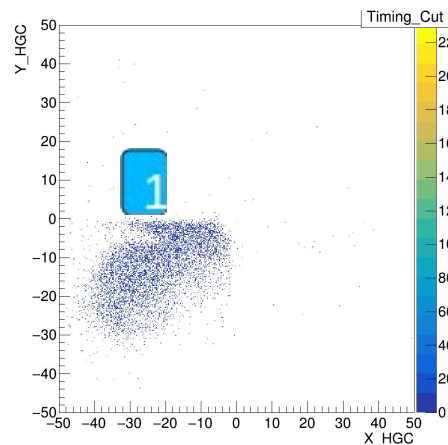
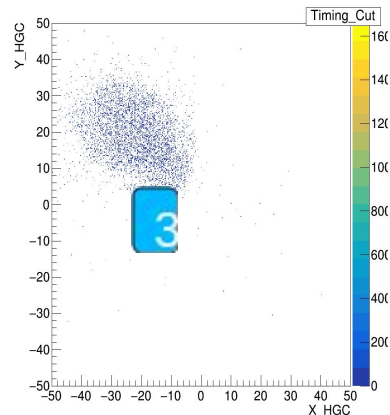
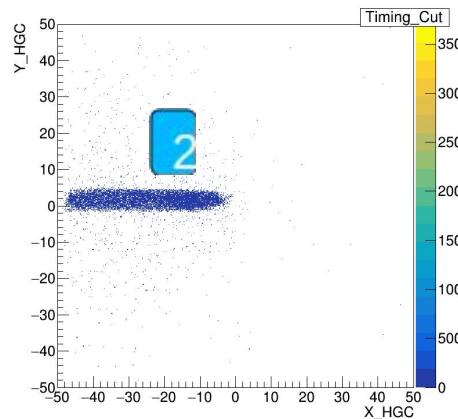
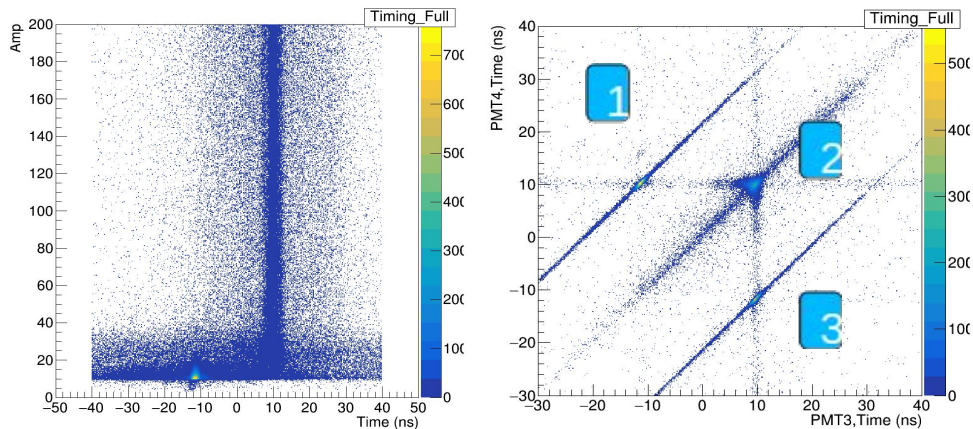
Showing the SPE in HGC for PMT1 FADC and fit it with a Gaussian function to get the mean of peaks.



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

