Update on KaonLT Experiment

Richard Trotta on behalf of the KaonLT and PionLT collaboration

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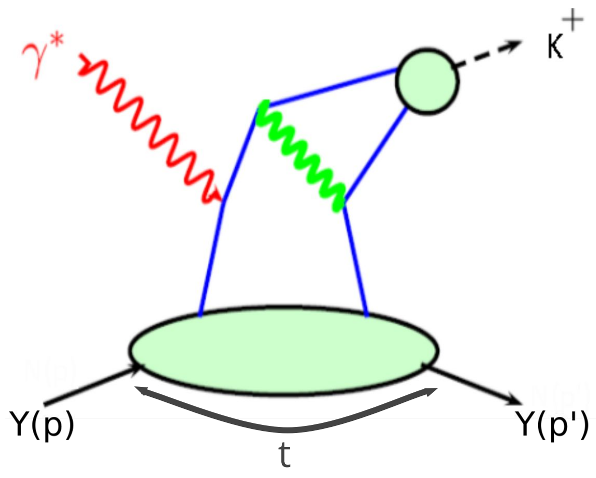
Jefferson Lab

L-T separated K^+ data for verifying reaction mechanism

- Jlab 6 GeV K^+ 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

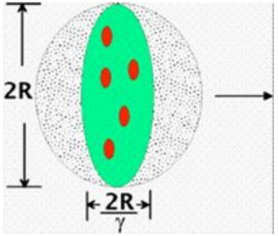
M. Carmignotto et al., PhysRevC ***97****(2018)025204*

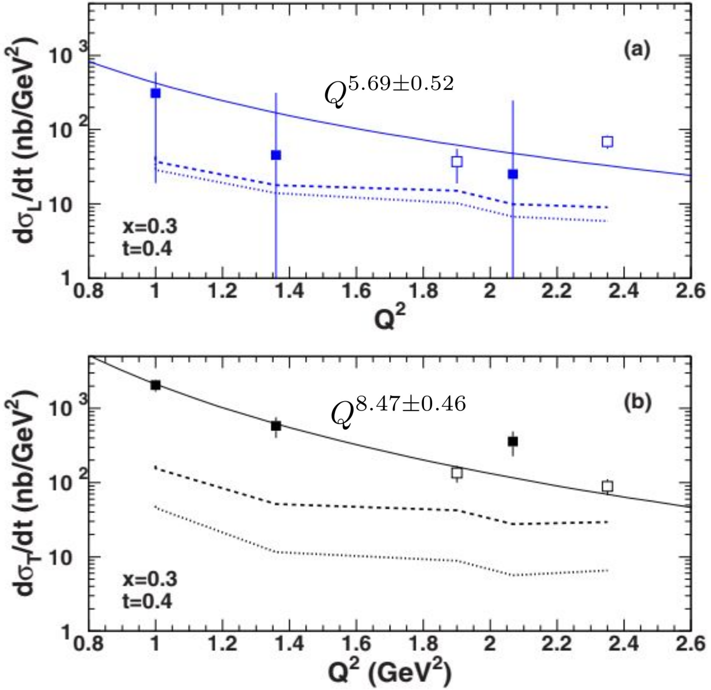
- Separated cross sections over a large range in Q^2 are essential for:
  - Testing hard-soft factorization and understanding dynamical effects in both Q^2 and –t kinematics
  - Interpreting non-perturbative QCD contributions in experimentally accessible kinematics



Hard-Soft Factorization

- The K^+ electroproduction cross section has a Q^2 dependence at fixed x and -t
  - Provides important insight into hard-soft factorization for systems including strangeness
  - Factorization of σ_L scales to leading order Q^{-6}
  - In that regime expect σ_T to go as Q^{-8} and consequently $\sigma_L >> \sigma_T$
  - Important because partons are "frozen" transversely in the reference frame of pQCD (i.e. infinite momentum frame)

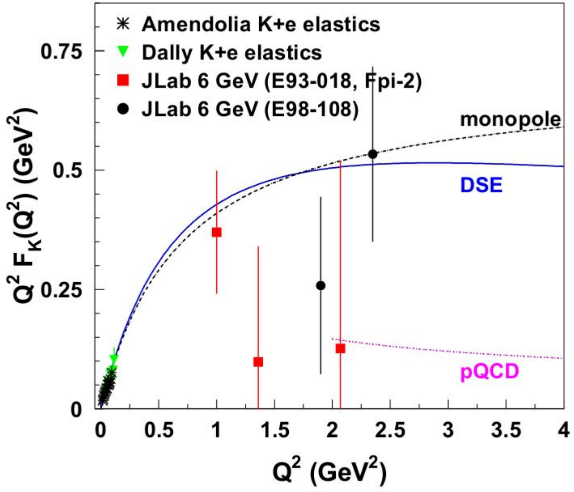




M. Carmignotto et al., PhysRevC ***97****(2018)025204*

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 strangenes and also crucial in understanding dynamic generation of mass
- 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

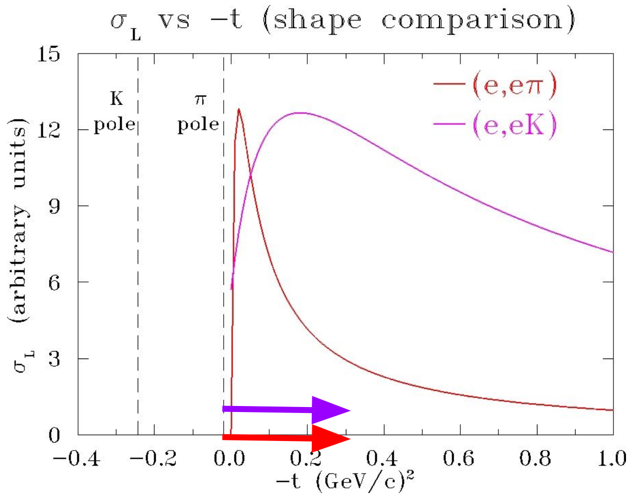
Comparing π^+ and K^+ Form Factor

- Large -t pion data lies a similar distance from the pole as kaon data
  - The Born term model should be approximately valid for kaon form factor
- The hard scattering limit in pQCD predicts a similar result

$$\frac{F_K(Q^2)}{F_\pi(Q^2)} \xrightarrow[Q^2\to\infty]{} \frac{f_K^2}{f_\pi^2}$$

- Requirements:
  - Full L/T separation of the cross section – isolation of σ_L (which requires $\sigma_L >> \sigma_T$)
  - Selection of the pion pole process
  - Extraction of the form factor using a model
  - Validation of the technique - model dependent checks

$$\sigma_L \approx \frac{-tQ^2}{(t-m_K^2)^2} g_{KNN}^2(t) F_K^2(Q^2,t)$$



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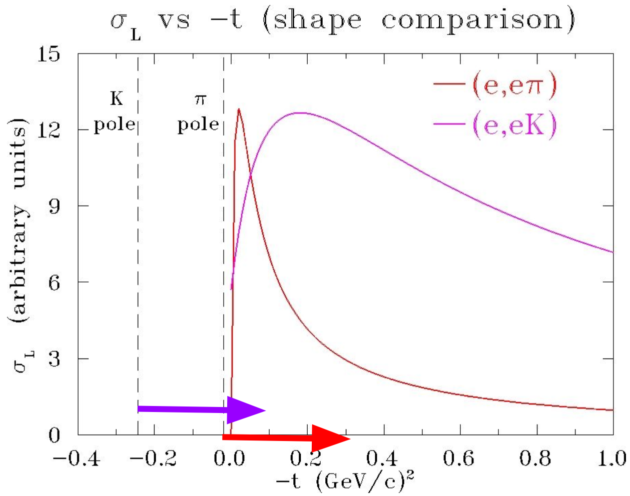
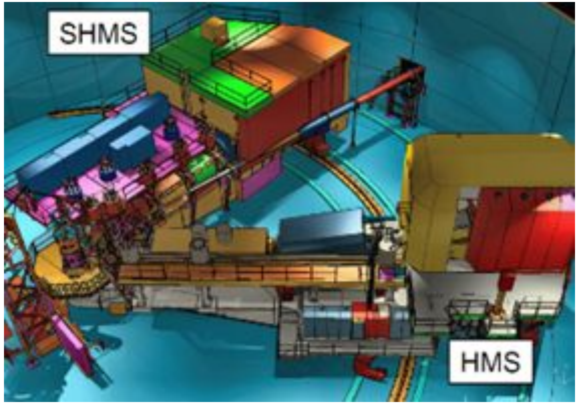
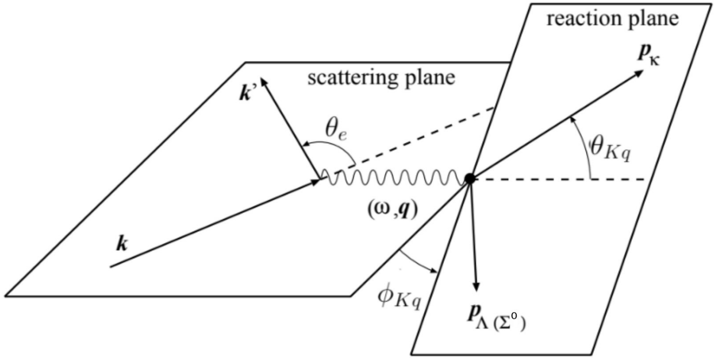


Review E12-09-011 (KaonLT) Goals

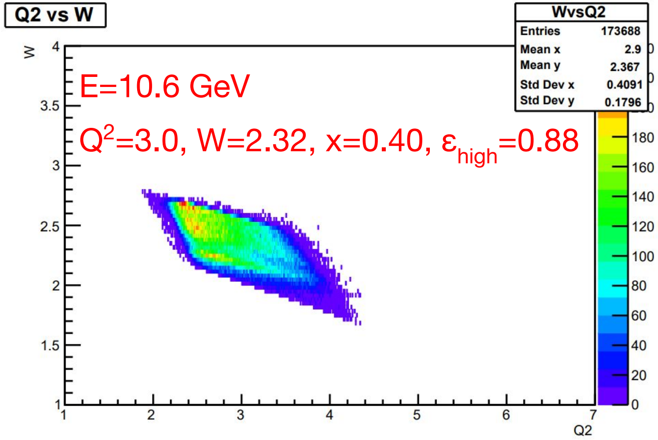
- Q^2 dependence will allow studying the scaling behavior of the separated cross sections
  - First cross section data for Q^2 scaling tests (x=0.25, 0.4) with kaons
  - Highest Q^2 (Q^2=5.5 GeV^2) for L/T separated kaon electroproduction cross section
  - First separated kaon cross section measurement above W=2.2 GeV
- $p(e,e'K^+)\Lambda,\Sigma^0$ 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 from Λ data





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	$\varepsilon_{high}/\varepsilon_{low}$	$\Delta\varepsilon$
10.6/8.2	5.5	3.02	0.40	0.53/0.18	0.35
10.6/8.2	4.4	2.74	0.40	0.72/0.48	0.24
10.6/6.2	3.0	2.32	0.40	0.88/0.57	0.31
10.6/8.2	3.0	3.14	0.25	0.67/0.39	0.28
10.6/6.2	2.115	2.95	0.21	0.79/0.25	0.54
4.9/3.8	0.5	2.40	0.09	0.70/0.45	0.25

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

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University of Regina

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

*PionLT experiment running (6 months)

1. Calibrations ✔
    - Calorimeter, aerogel, HG cer, HMS cer, DC, Quartz plan of hodo
    - Assure we are replaying to optimize our physics settings
2. [~2 months] Efficiencies and offsets* ← Current step
    - Luminosity, elastics, Heeps, etc.
3. [3-4 months] First iteration of cross section ← On-deck
    - Extract the kaon electroproduction cross section
4. [~1 months] Fine tune
    - Fine tune values to minimize systematics
5. [~3+ months] Repeat previous two steps
    - Repeat until acceptable cross sections are reached
    - This will highlight any potential complications
6. [~1 month] Possible attempt at form factor extraction
    - The Rosenbluth separation technique** is used to isolate the longitudinal term and thus the form factor can be extracted

**This is the first commissioning L-T separation for the HMS+SHMS setup

Efficiencies and offsets - considerations

- This is perhaps the most important step in the entire analysis.
- These studies are so critical because of a 1/Δε amplification and possibly small $R=\sigma_L/\sigma_T$ in the systematic uncertainty of the σ_L

$$\frac{\Delta\sigma_L}{\sigma_L} = \frac{1}{\epsilon_1 - \epsilon_2}\frac{\Delta\sigma}{\sigma}\sqrt{(1/R+\epsilon_1)^2 + (1/R+\epsilon_2)^2}$$

- Careful analysis will allow the required precision cross section measurements for extracting form factors.
- Two main tools: luminosity scans and elastic analysis

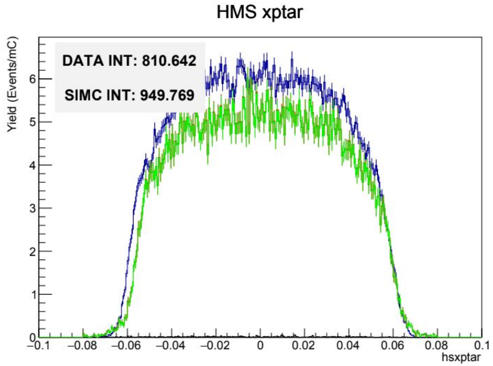
Source	pt-to-pt	t-correlated	scale (earlier)	scale (later)
Acceptance	0.4	0.4	2.0	1.0
PID		0.4	1.0	0.5
Coincidence Blocking		0.2		
Tracking efficiency	0.1	0.1	1.5	1.5
Charge		0.2	0.5	0.5
Target thickness		0.2	0.8	0.8
Kinematics	0.4	1.0		
Kaon Absorption		0.5	0.5	0.5
Kaon Decay		1.0	3.0	3.0
Radiative Corrections	0.1	0.4	2.0	2.0
Monte Carlo Model	0.2	1.0	0.5	0.5
Total	0.6	2.0	4.7	4.2

KaonLT Proposal, PAC 34

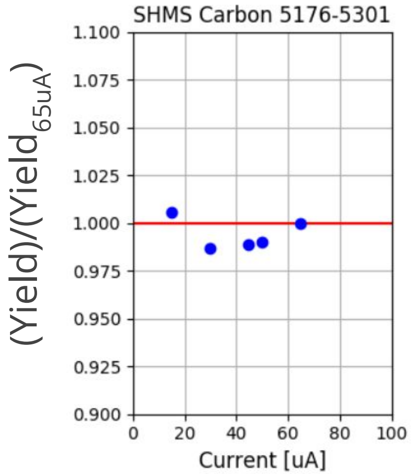
$$\text{Yield} = \frac{N}{Q_{tot}\epsilon_{tot}}$$

Efficiencies and offsets - experimental approach

- For KaonLT the luminosity scans provide a means to understand the accuracy of the efficiencies.
    - Data are taken as a function of current/rate on a carbon target and efficiency corrected yields are analyzed.
    - Since the carbon density should not change with current/rate, any deviation of the yield from unity is indicative of an issue with the efficiencies that needs to be addressed.



- The elastic scans provide information on spectrometer offsets in angle and momentum
    - Elastic data is taken at the same or similar kinematics to those for the production data and the normalized yields are compared to those calculated with SIMC
    - Any deviations from unity are indicative of discrepancies in the spectrometer angle, momentum, or the beam energy used in the analysis
    - For instance, elastic singles data is used to fit angle and momentum offsets then the elastic coincidence data examines the deviation of invariant reconstructed mass, missing energy, and missing momentum from their nominal values.



Extract the Kaon Electroproduction Cross Section

- SIMC, including a model of the experimental setup, is used to simulate a variety of effects.
- A model for the kaon electroproduction model is developed, including a χ2 minimization to achieve the best agreement between data and SIMC.
- This is achieved by iterating the model input cross section.
- The experimental cross section can then be extracted as long as the model input cross section properly describes the dependence on all kinematic variables.

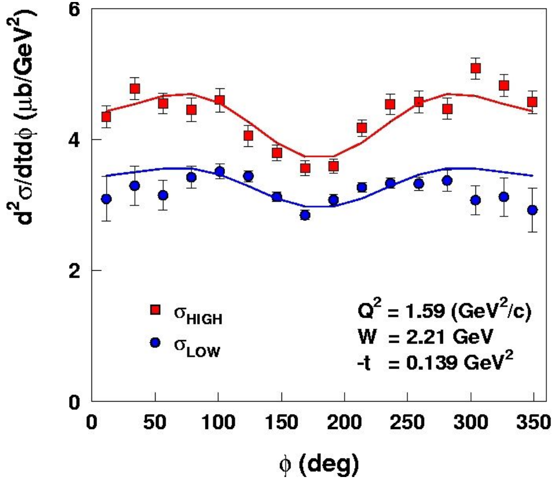
$$\boxed{2\pi \frac{d^2\sigma}{dt\,d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\,\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt}\cos 2\phi}$$

Example polynomial showing expected kinematic dependency

$$\frac{d\sigma_i}{dt} = A_i \cdot e^{B_i|t-t_c|} \cdot \frac{1.0}{(1.0 + C_i Q^2)/(1.0 + C_i Q_c^2)}$$

L/T Separation

- σ_L is isolated using the Rosenbluth separation technique
- Measure the cross section at two beam energies and fixed W, Q^2, -t



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

1. Phase space matching to constrain the kinematic region for the two differing beam energies
2. Extract cross section in -t and ϕ bins

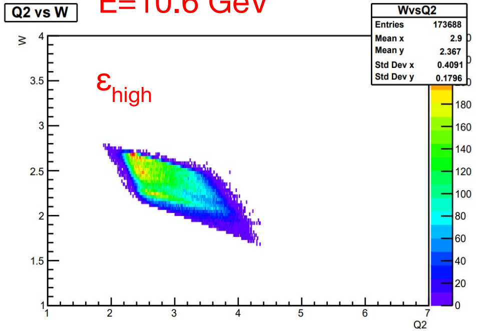
$$\left(\frac{d\sigma^2_{exp}}{dtd\phi}\right)\Bigg|_{Q^2=\bar{Q^2},t=\bar{t}} = \frac{Y_{exp}}{Y_{SIMC}}\left(\frac{d\sigma^2_{model}}{dtd\phi}\right)\Bigg|_{Q^2=\bar{Q^2},t=\bar{t}}$$

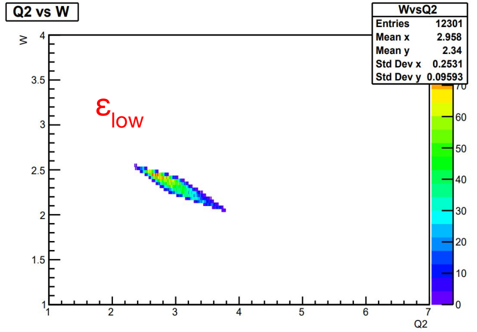
3. This allows for the simultaneous extraction of the interference terms

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

$$\frac{d\sigma}{dt} = \frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}$$

E=10.6 GeV

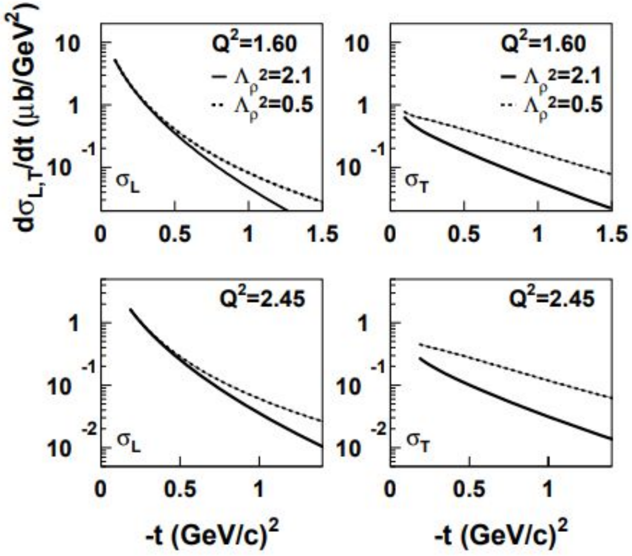




Form Factor Extraction

- The product of the kaon form factor is related to σ_L through the probability of the virtual photon interacting with a kaon
- If σ_L shows an exponential fall off with t this is a sign of the point-like behavior warranting the form factor extraction
- The extraction of the kaon form factor is done by fitting the longitudinal cross section calculated by the VGL Regge model to the experimental data.
- The model is evaluated for different values of Λ^2_{K+}

M. Vanderhaeghen, M. Guidal, and J.-M. Laget, Phys. Rev. C 57, 1454



T. Horn's Thesis

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

$$\boxed{\sigma_L \approx \frac{-tQ^2}{(t-m_K^2)^2}g^2_{KNN}(t)\boxed{F_K^2(Q^2,t)}} \rightarrow \boxed{F_K(Q^2,t) = (1+Q^2/\Lambda_K^2)^{-1}} \rightarrow \frac{\chi^2}{\text{dof}} = \frac{1}{\text{dof}}\sum_{\text{t bins}}\frac{(\sigma_L^{VGL}-\sigma_L^{exp})^2}{\Delta\sigma_L^2}$$

Summary and Outlook

- E12-09-011 ran Fall 2018, Spring 2019
  - Also have the PionLT data from Summer 2019, Fall 2021, and Winter 2022 available
  - See Jacob's PionLT talk following this one!
- Currently in the late stages of the second phase of analysis
  - Studies of efficiencies and offsets from luminosity and elastic analysis being worked on by Ali Usman, Vijay Kumar, and Richard Trotta
- Next stage is to extract the kaon electroproduction cross section for both Λ, Σ^0 channels
  - This is achieved by iterating the model input cross section.
  - The experimental cross section can then be extracted as long as the model input cross section properly describes the dependence on all kinematic variables.

Thanks to everyone in the KaonLT collaboration

Salina Ali, Ryan Ambrose, Darko Androic, Whitney Armstrong, Carlos Ayerbe Gayoso, Samip Basnet, Vladimir Berdnikov, Hem Bhatt, Deepak Bhetuwal, Debaditya Biswa, Peter Bosted, Ed Brash, Alexandre Camsonne, Jian-Ping Chen, Junhao Chen, Mingyu Chen, Michael Christy, Silviu Covrig, Wouter Deconinck, Markus Diefenthaler, Burcu Duran, Dipangkar Dutta, Mostafa Elaasar, Rolf Ent, Howard Fenker, Eric Fuchey, Dave Gaskell, David Hamilton, Ole Hansen, Florian Hauenstein, Nathan Heinrich, Tanja Horn, Garth Huber, Shuo Jia, Mark Jones, Sylvester Joosten, Muhammad Junaid, Md Latiful Kabir, Stephen Kay, Vijay Kumar, Nathaniel Lashley-Colthirst, Bill Li, Dave Mack, Simona Malace, Pete Markowitz, Mike McCaughan, Robert Michaels, Rachel Montgomery, Jacob Murphy, Gabriel Niculescu, Maria Niculescu, Zisis Papandreou, Sanghwa Park, Eric Pooser, Love Preet, Julie Roche, Greg Smith, Petr Stepanov, Holly Szumila-Vance, Vardan Tadevosyan, Aram Teymurazyan, Richard Trotta, Hakob Voskanyan, Carlos Yero, Ali Usman

(Proposal to Jefferson Lab PAC 34)

Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV

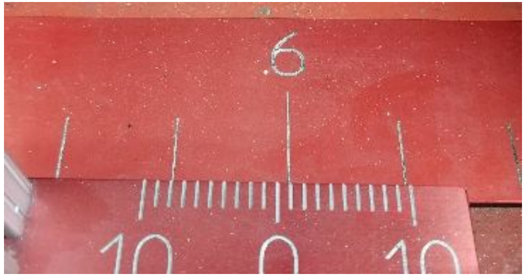
December 15, 2008

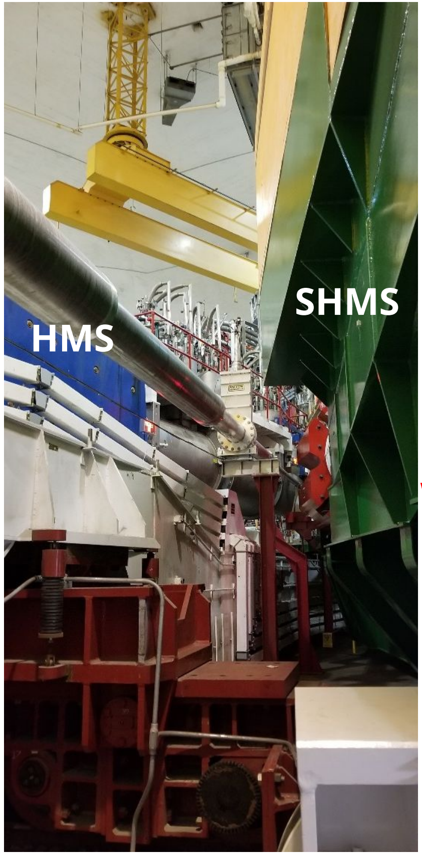
Extra Slides

SHMS small angle operation

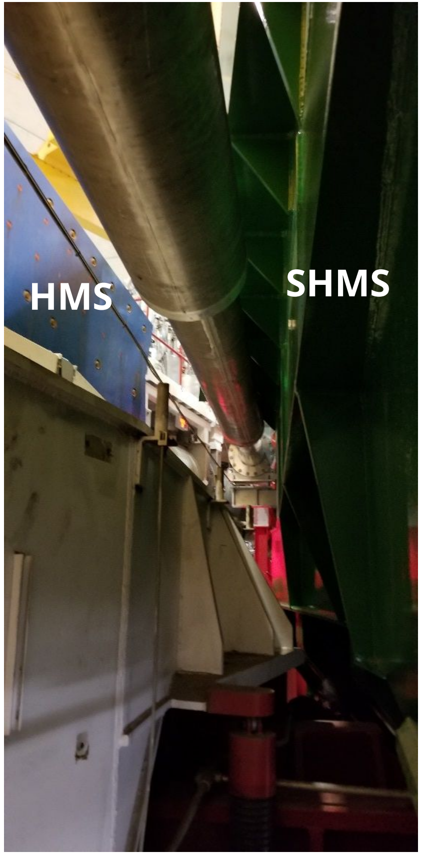
- Some issues with opening and small angle settings at beginning of run
  - SHMS at 6.01°
  - HMS at 12.7°

[12/17/18]





Work of many people ...



L/T Separation

- After validation of the Sullivan process, the longitudinal term allows one to access the physics.
- The ϕ dependence is fit for all terms simultaneously then the L-T terms can be extracted from the known ε dependence where the longitudinal term is the slope and the transverse is the intercept at $\varepsilon=0$.
- In order to minimize the systematic uncertainties, this will need to be done a few times as values are fine-tuned and the previous steps are further optimized.