Update on Kaon-LT Experiment

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Hall C Users Meeting

E12-09-011 Collaboration

- Spokespersons

  Tanja Horn, Garth Huber, Pete Markowitz

- Graduate Students

  Vijay Kumar, Richard Trotta, Ali Usman

- Key Members

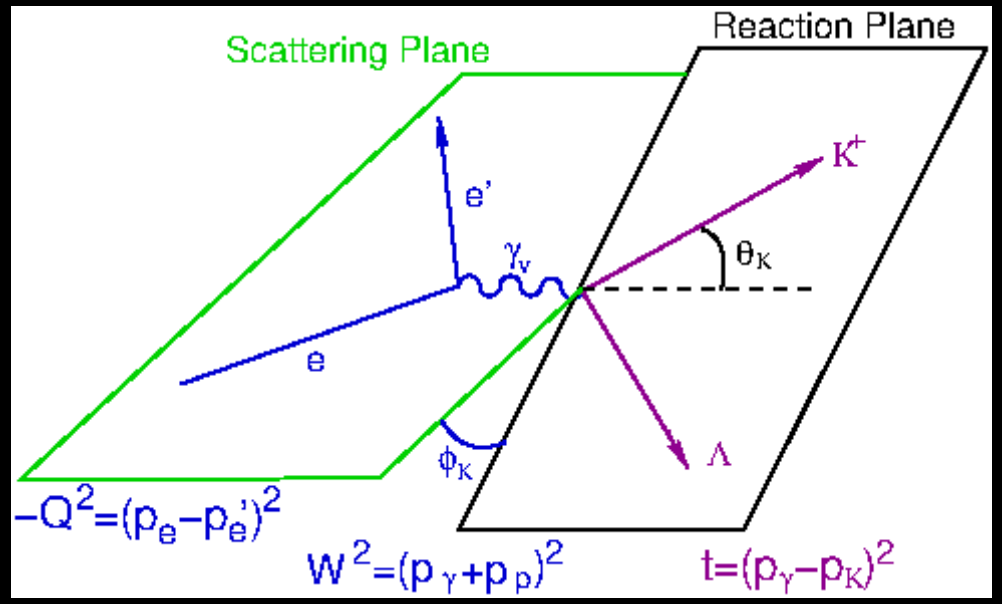
  Vladimir Berdnikov, Nathan Heinrich, Muhammad Junaid, Stephen Kay, Petr Stepanov, Carlos Yero

Kaon Electroproduction Reaction

- Kaon is an excellent candidate to study the structure of strange hadrons.
- ***Exclusive Kaon Electroproduction***

$$e^- + p \rightarrow e^{-\prime} + K^+ + \Sigma/\Lambda$$

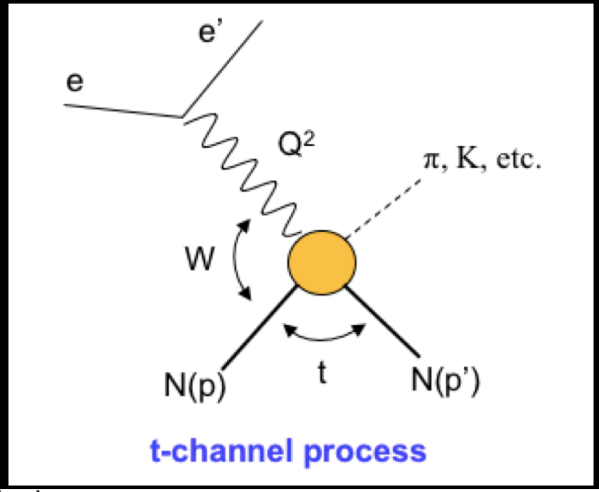
- Critical to understand reaction mechanism for GPDs and Form factor measurement.
- Study of GPDs require validation of soft-hard factorization.
- Kaon σ_L, σ_T and L/T ratio is unknown above the resonance region.

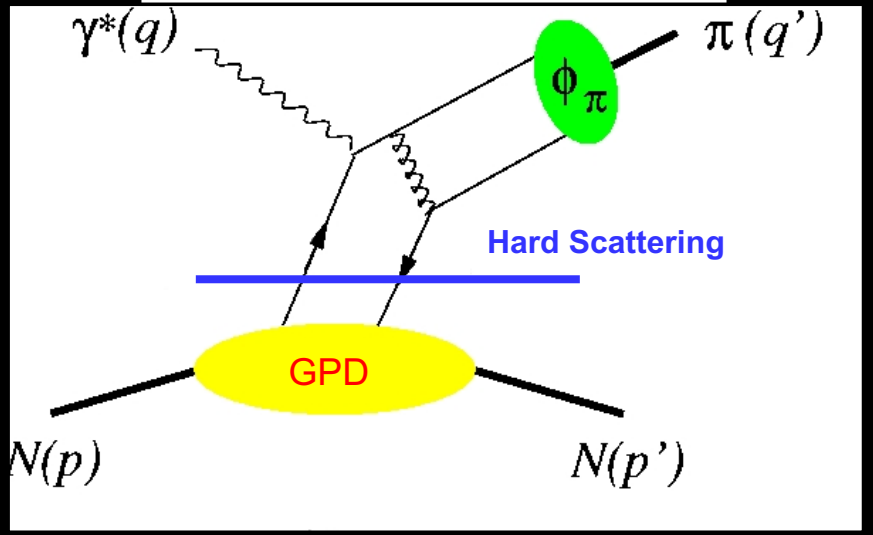


First experiment to study reaction mechanism, factorization and attempt precision measurement of K^+ Form Factor at high Q^2

Physics Motivation

- Meson production can be described by the t-channel exchange meson pole term in limit of small $-t$ and large W.
- At sufficiently high Q^2, the process should be understandable in terms of the "handbag" diagram.
- Non-perturbative (soft) physics is represented by GPDs.
  - Factorized from QCD perturbative (hard) processes for longitudinal photons.
- Measurement of GPDs require
  - Confirmation of the applicability of hard-soft QCD factorization mechanism at intermediate Q^2.

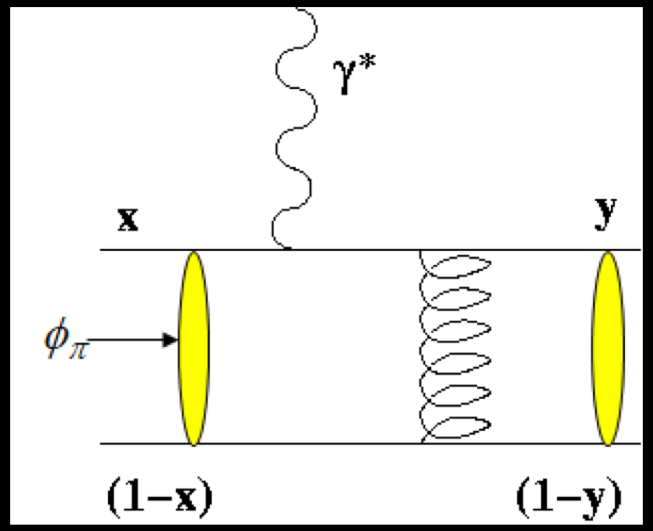




Form Factor

- Mesons give an ideal testing ground for our understanding of bound quark-antiquark system.
- Form Factor describes transverse spatial position of partons within hadrons.
- In pQCD, F_K can be written as

$$Q^2 F_K(Q^2) \rightarrow 16\pi\alpha_s(Q^2) f_K^2 \qquad (Q^2 \rightarrow \infty)$$



Questions

- ❑ What is the F_K at all Q^2?
- ❑ At what Q^2, non-pQCD transitions into pQCD?

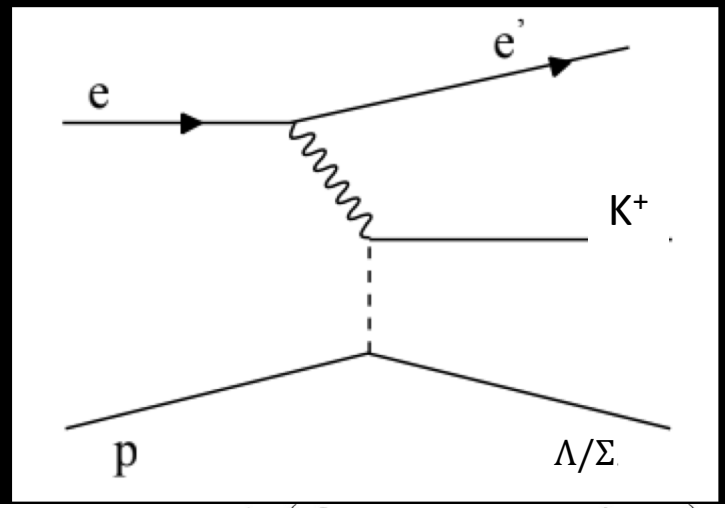
Hall C at Jefferson Lab is only facility in the world with the capacity to perform F_K measurement

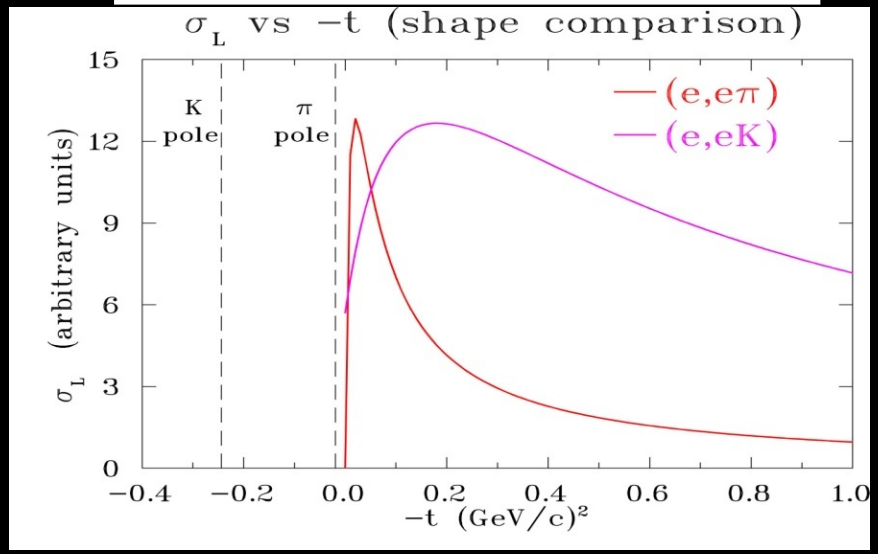
Measuring F_K from $p(e, e'K^+)\Sigma/\Lambda$

- At $Q^2 > 0.15\ GeV^2$, F_K is masured in directly using the "proton's kaon cloud" through kaon electroproduction.
- At sufficiently low $-t$, kaon pole process dominates the longitudinal cross-section, σ_L.
- Kaon pole is further away from the pion pole.
- In Born term model F_K appear as

$$\frac{d\sigma_L}{dt} \propto \frac{-t}{(t-m_K^2)}\, g_{KYN}(t)\, Q^2 F_K^2(Q^2, t)$$

- To access the pole diagram, need to measure σ_L through L/T separation.





Rosenbluth Separation

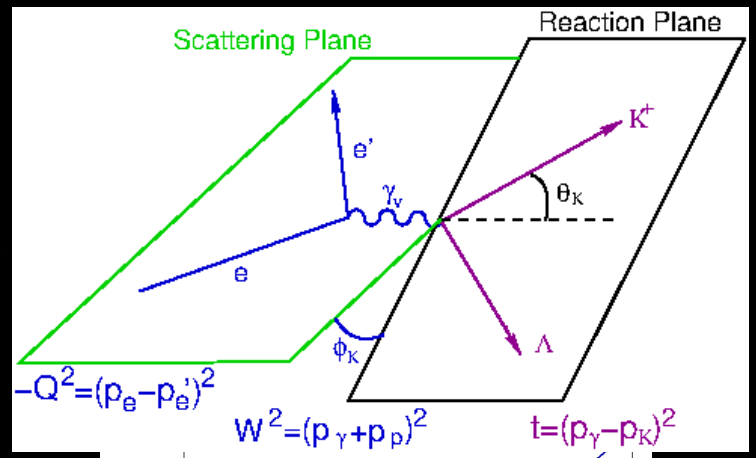
- "Rosenbluth Separation technique" is used to separate σ_L and σ_T terms.
- **In parallel kinematics (i. e. $\theta_K = 0$)**

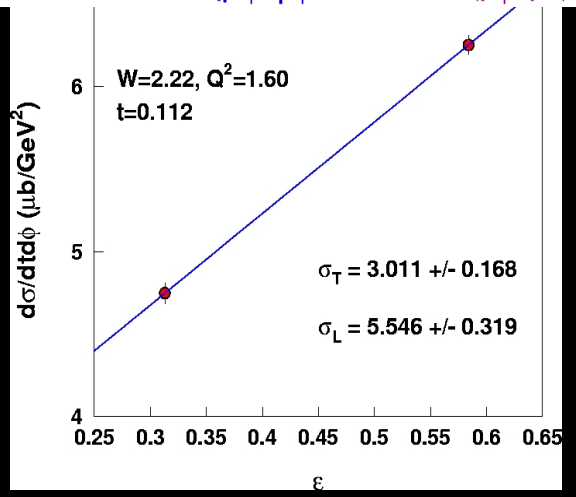
$$2\pi \frac{d^2\sigma}{dtd\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt}$$

- Here "ϵ" is polarization of virtual photon

$$\epsilon = \left[1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2} . tan^2\frac{\theta_{e'}}{2}\right]^{-1}$$

- Perform two scattering measurement with different beam energies "E_e" to vary "ϵ" and separate different cross-section terms.





Error Estimation

$$\frac{\Delta\sigma_L}{\sigma_L} = \frac{1}{\epsilon_1 - \epsilon_2}\frac{1}{\sigma_L}\sqrt{\Delta\sigma_1^2 + \Delta\sigma_2^2}$$

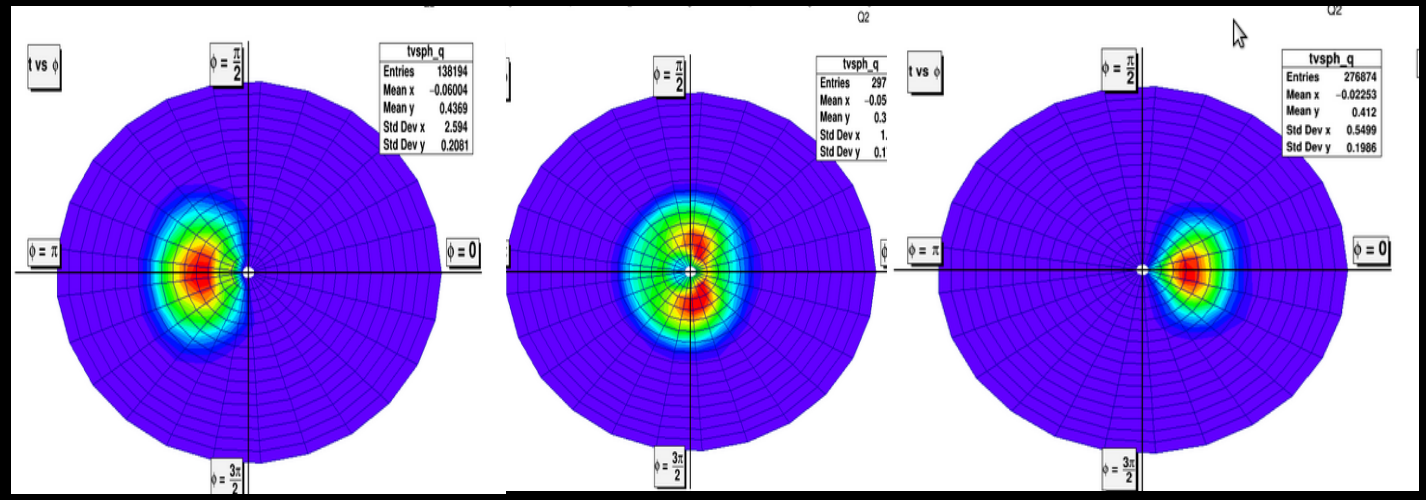
L/T/LT/TT Separated Cross-Section

- The physical cross-section can be decomposed into four structure functions.

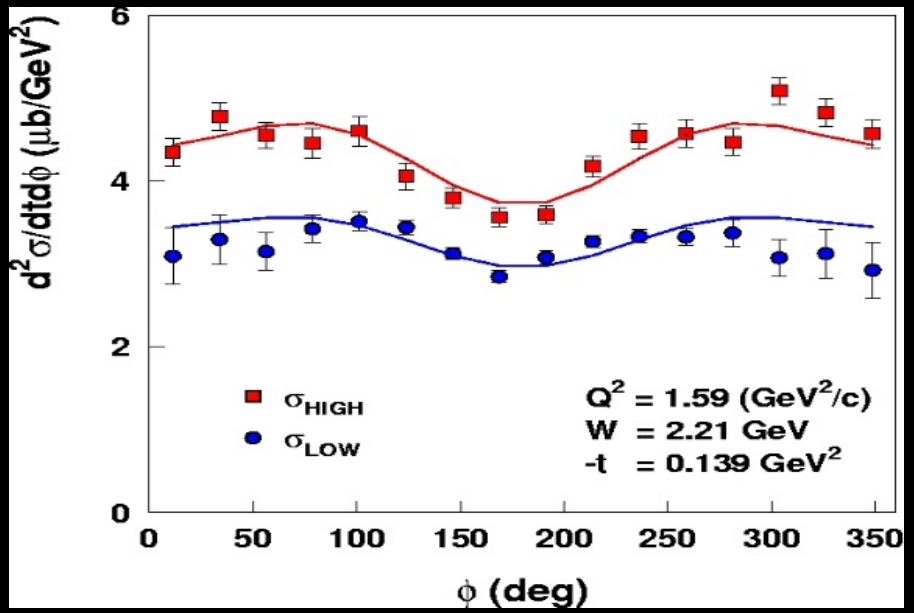
$$2\pi \frac{d^2\sigma}{dtd\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_{LT}}{dt} cos\phi + \epsilon \frac{d\sigma_{TT}}{dt} cos2\phi$$

- To study *t*-dependence of cross-section at fized Q^2 and *W*, we need to take data at non-parallel kinematics.

$E_{beam} = 10.6\ GeV$ $Q^2 = 3.0\ GeV$ $W^2 = 3.14\ GeV$



$\theta_{SHMS} = 12.42$ $\theta_{SHMS} = 9.42$ $\theta_{SHMS} = 6.65$



Kinematic Settings

- Data taken from Autumn 2018 – Spring 2019.
- Unique kinematic settings including SHMS at smallest possible angle.
- Critical to understand all systematic uncertainties for LT separation

E (GeV)	Q^2 (GeV^2)	W (GeV)	x_b	ε_{High} / ε_{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

$\theta_{SHMS} = 5.69$

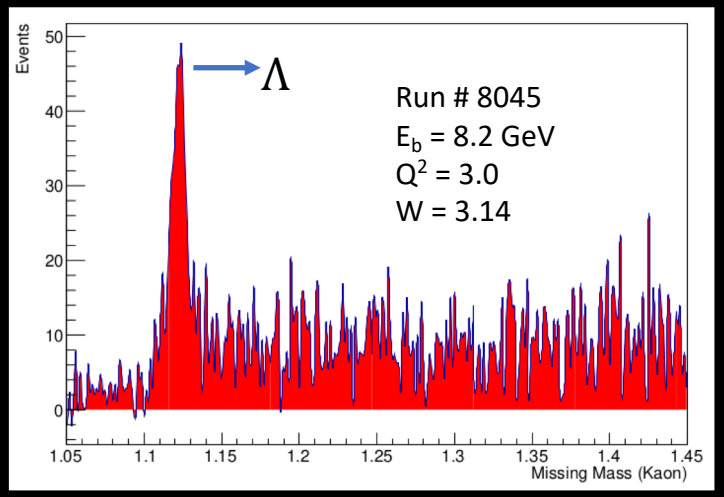
Analysis Flow

Planning and collection of experimental data

Calibrations of different detectors

Iteration of differential cross-section

Study reaction mechanism, factorization and attempt to extract Form Factor



Iterate

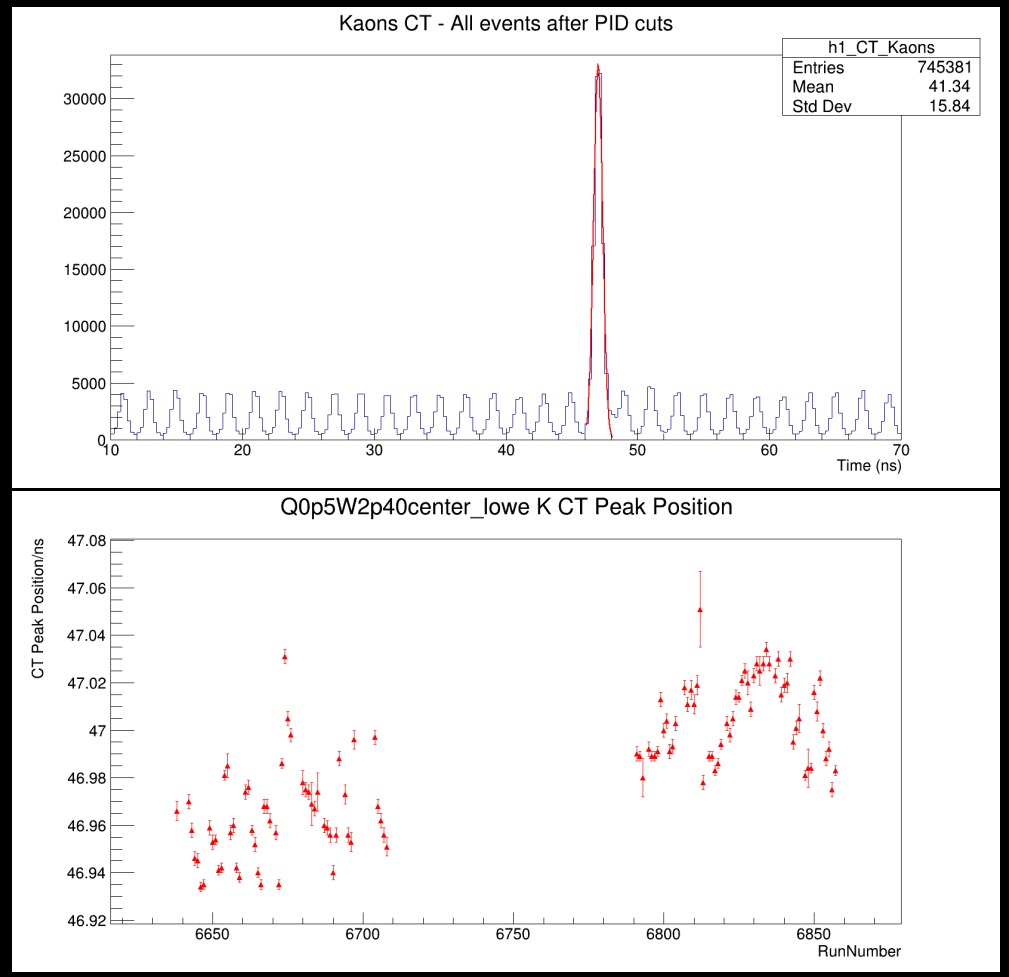
PID, Efficiencies and Kinematic offsets

Calculation of elastic cross-section

COIN Time Stability

- Need to study the stability of COIN time across all run periods.
- Acceptance cut
  - δ on HMS and SHMS
  - X_{FP} and Y_{FP} on HMS and SHMS
- PID cuts
  - HGC, Cal and SHMS Aero cuts
  - β cuts on SHMS
- Fit simple but constrained Gaussian to determine the parameters of cointime peak.
- Easy to track and calculate the cointime peak position.
- Will do run by run calculation for physics analysis.
- More details can be found at

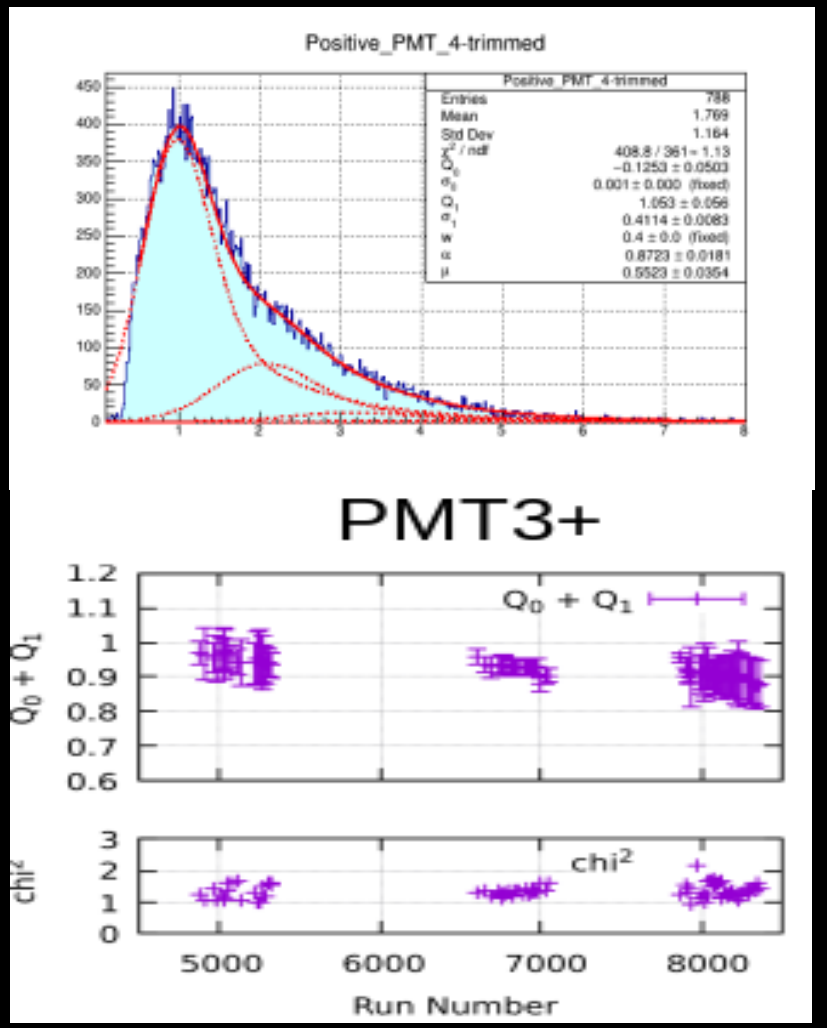
https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1103



Plots and study by S. Kay

Calibrations - Aerogel

- Kaon-LT Experiment used dedicated equipment for kaon/pion separation.
- Multiple trays of different refractive indices (1.011-1.030) were used throughout the experiment.
- PMT spectra were plotted and fitting algorithm was validated.
- Accounted for the experimental background.
- Analyzed stability of the parameters throughout different run periods.



Plots and study by V. Berdnikov & P. Stepanov

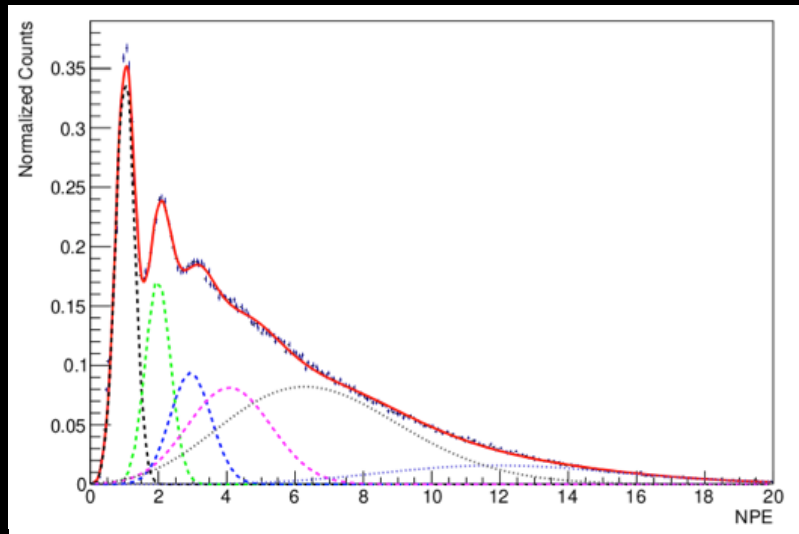
Calibrations - HGC

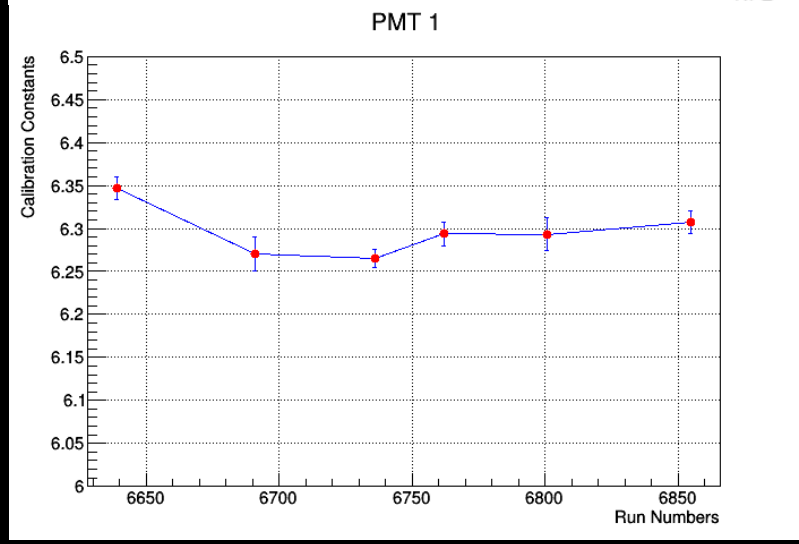
- Calibrations scripts improved by doing cross checks.
- New technique to study multiple NPEs as well as the poissonian background.
- Checked the stability of calibration parameters throughout multiple run periods.
- Kinematic Details

Run # 7045	E_{beam} = 4.9 *GeV*
P_{SHMS} = +2.583 *GeV/c*	$\theta_{SHMS} = 6.01$
Q^2 = 0.5	W = 2.4

- More details can be found at

https://hallcweb.jlab.org/doc-public/ShowDocument?docid=1100





Plots and Study by V. Kumar

Tracking Efficiency (Default)

- Kaon-LT Experiment is a L/T commissioning experiment which ran at very high rates.
- Therefore it is critical to study tracking efficiency for different particles.
- Tracking Efficiency is calculated as follows

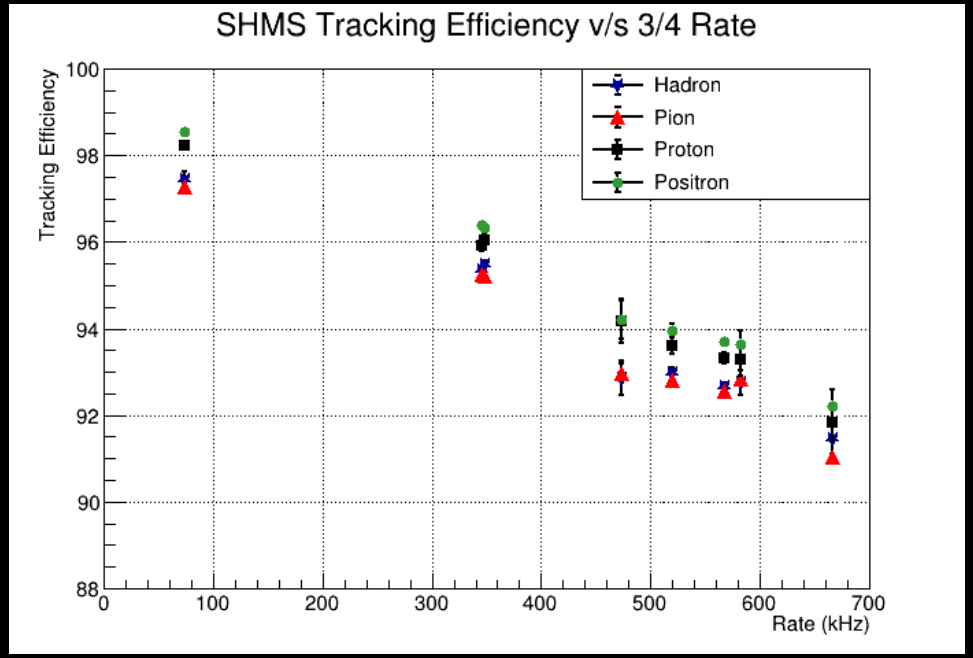
$$\epsilon_{tracking} = \frac{shmsscindid}{shmsscinshould}$$

shmsscinshould = hod + PID

hod = goodscinhit + goodstarttime + betanotrack

shmsscindid = shmsscinshould + dc.ntrack > 0

- Tracking efficiency drops rapidly with increase in rate therefore **Track Parameter Optimization** is needed.



- Kinematic Settings

  Run # 8038, 8040, 8042, 8043, 8056, 8057, 8066, 8085

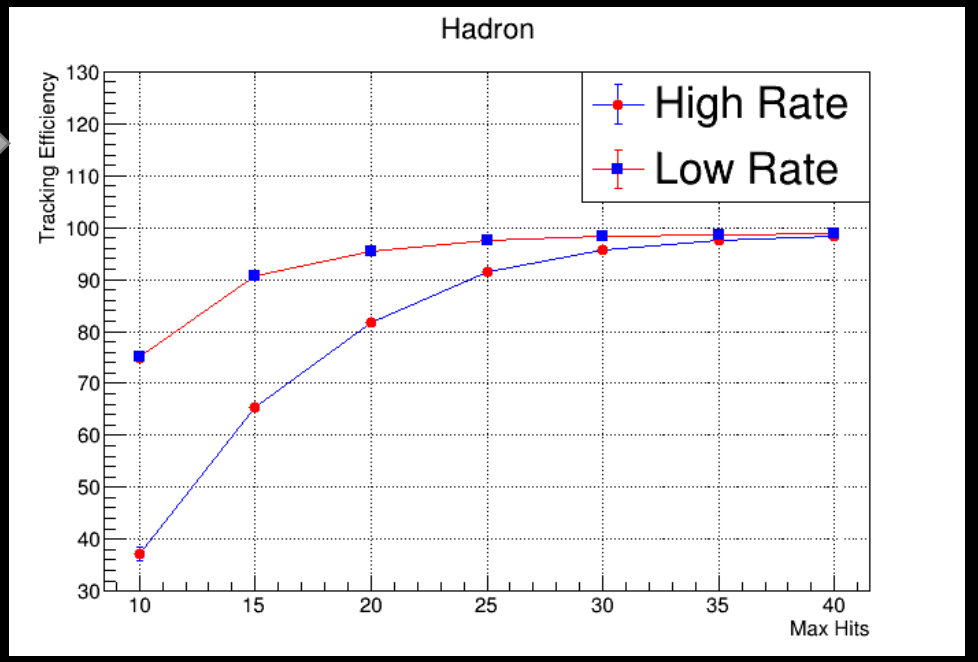
  E = 8.2 GeV

  $P_{shms} = +6.05\ GeV$

  $\theta_{shms} = 6.91$

Track Parameter Optimization

Parameters
Pmax_pr_hits
Pmin_hit
Pmin_combo
Pspace_point_criterion
Pntracks_max_fp
Pstub_max_spdiff
Pxt_track_criterion
Pxy_track_criterion
Pxpt_track_criterion
Pypt_track_criterion

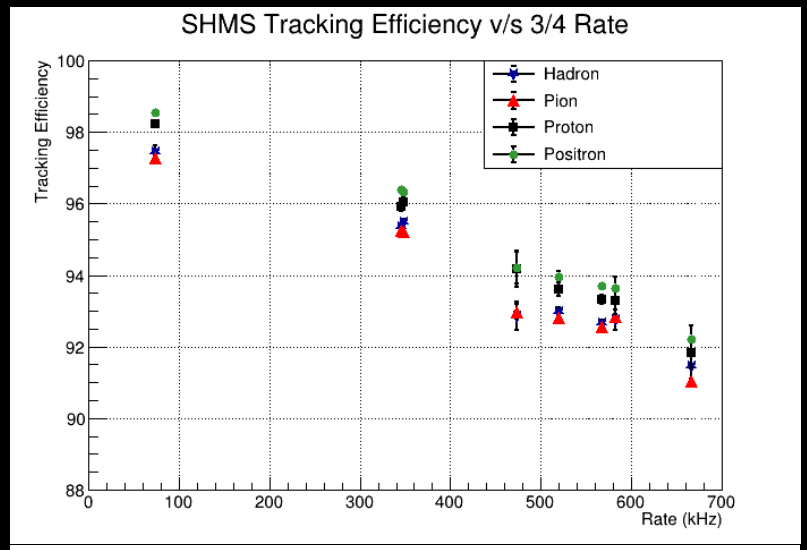


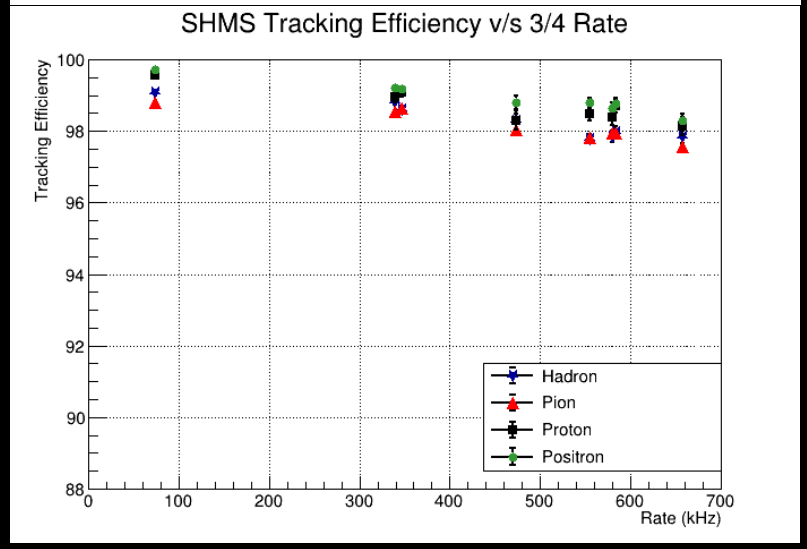
- Max hits → Maximum number of hits in two chambers.

High Rate	Low Rate
Run # 8038	Run # 8085
¾ rate -> 667 kHz	¾ rate -> 73 kHz
S1X rate -> 2541 kHz	S1X rate -> 509 kH

Tracking Efficiency (New)

- The SHMS tracking efficiency has improved after the optimization of tracking parameters.
- Efficiency slope for default and new parameters changed from -9.7%/MHz to -2.0%/MHz.
- Three tracking parameters have now been improved whereas others are unchanged.
- Still working to verify that the tracked normalized yield has little or no rate dependence with new tracking parameters.





Luminosity Analysis

- Measuring normalized yield v/s rate to make sure all the uncertainties are properly understood.
- Took luminosity data at different kinematics and targets.

Scalers → Carbon data

No-track → LH_2 without tracking

Track → LH_2 with tracking

Cuts

- abs(I-SetCurrent) < (|2.5|) uA
- **Delta**
  - HMS, (-8<delta<8)
  - SHMS, (-10<delta<20)
- **Start time**
  - H(P).hod.goodstarttime == 1
- **PID**

Electron	*Proton*
Cer > 0.5	HGC < 1.5
2.0 > Cal > 0.6	0 < Cal <= 0.6
	Aero < 1.5

- Scalers

$$Y_{scaler} = \frac{N_{scaler}}{Q_{tot}}$$

$$N_{scaler} = \Sigma(\mathbf{trigscaler}) - \mathbf{EDTM_{scaler}}$$

$$Q_{tot} = (H.BCM.scaler.charge)$$

- No track

$$Y_{No\ Track} = \frac{N_{electrons}}{Q_{tot}\epsilon_{cpuLT}}$$

$$N_{electrons} = \int (\frac{H}{P}.hod.goodscinhits)$$

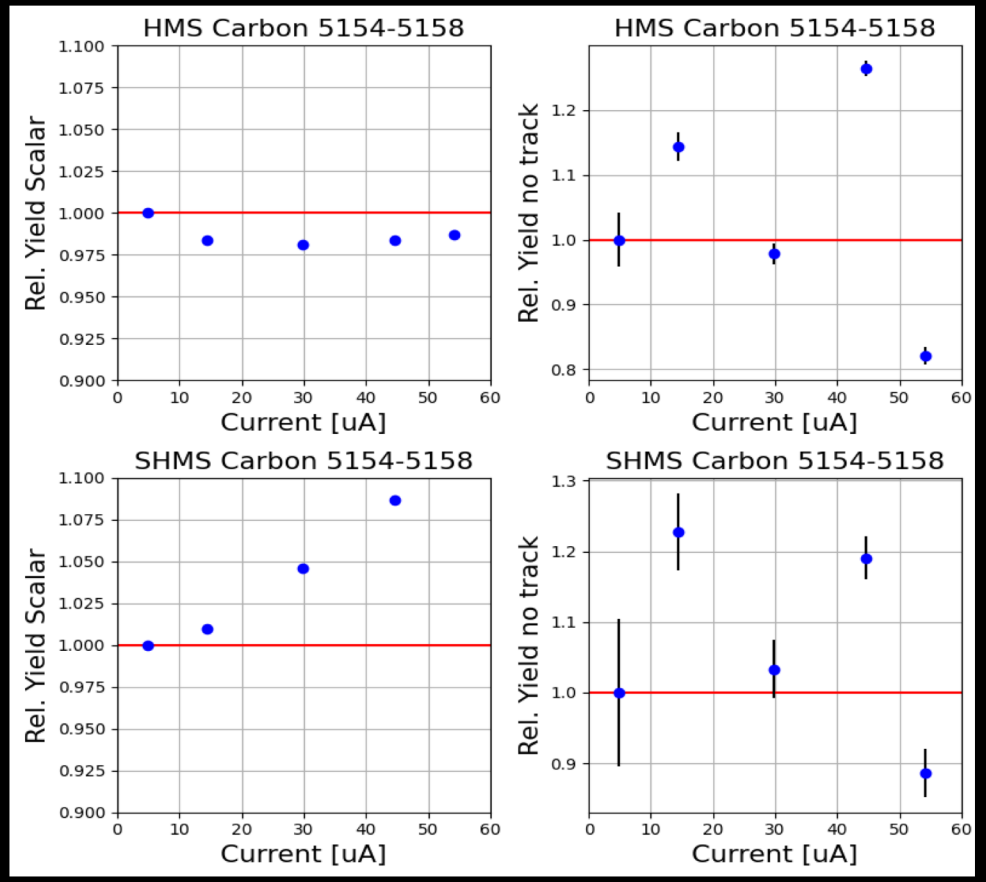
- Track

$$Y_{Track} = \frac{N_{track}}{Q_{tot}\epsilon_{track}\epsilon_{cpuLT}}$$

$$N_{tracks} = tracks$$

Luminosity Analysis

- Scalers analysis is looking good and consistent with unity.
- The no-track analysis shows no obvious boiling but shows unexplained rate dependence.
- Currently investigating both no-track and track analysis.



$P_{HMS} = -3.266$

$\theta_{HMS} = 12.53$

$P_{SHMS} = 6.842$

$\theta_{HMS} = 6.495$

Run # 5154, 5155, 4156, 5157, 5158

I (uA) – 55, 45, 30, 15, 5

Plots and Study by R. Trotta

PID Studies

- Hole in the center region of mirrors in Heavy Gas Cherenkov during 2018 is well known.
- Required precision by Kaon-LT Experiment needs a unique approach to deal with this issue.
- Dividing Cherenkov into various regions to understand efficiencies.
- Kinematic Details

Run # 5018 (Before 2019 realignment) E_{beam} = 10.6 *GeV*

P_{SHMS} = +6.053 *GeV/c* $\theta_{SHMS} = 12.46$

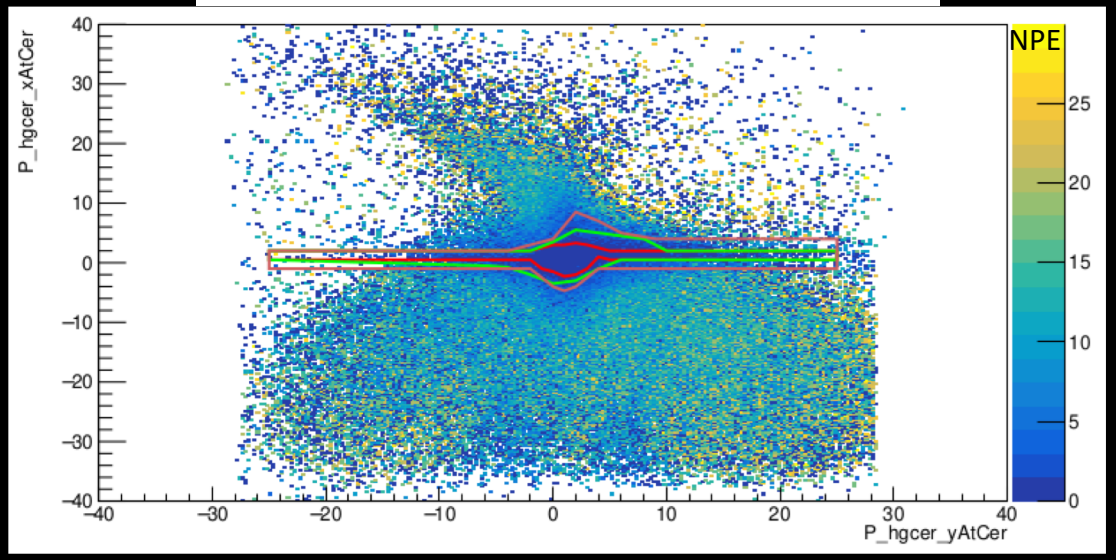
- HGC Regions

1st region → NPE <= 1.5 2nd Region → 1.5 < NPE < 5.0

3rd Region → 5.0 < NPE < 7.0 4th Region → NPE > 7.0

$$x_{\mathrm{HGC}} = x_{\mathrm{Focal\ Plane}} + x'_{\mathrm{Focal\ Plane}} * z_{\mathrm{HGC}},$$

$$z_{\mathrm{HGC}} = 156.27\ \mathrm{cm},$$

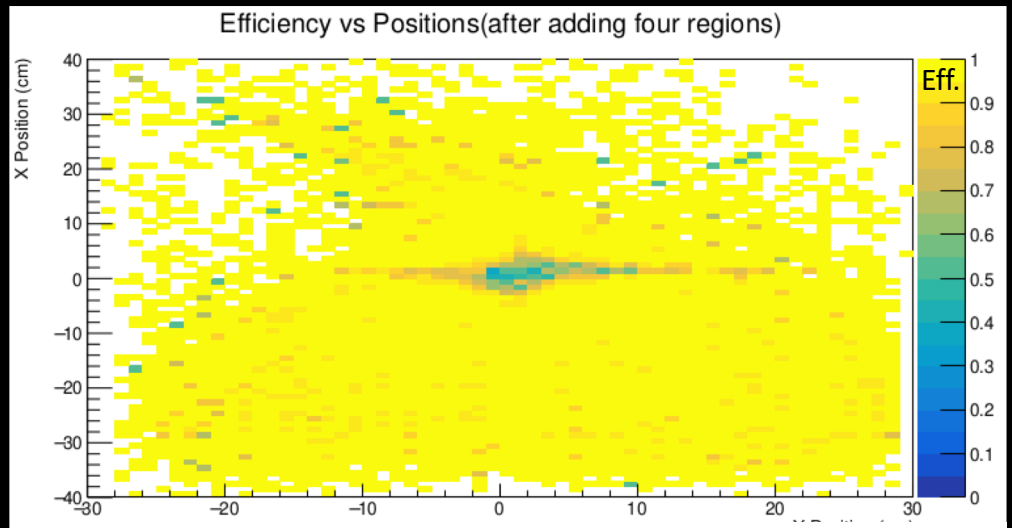


Plots and Study by V. Kumar

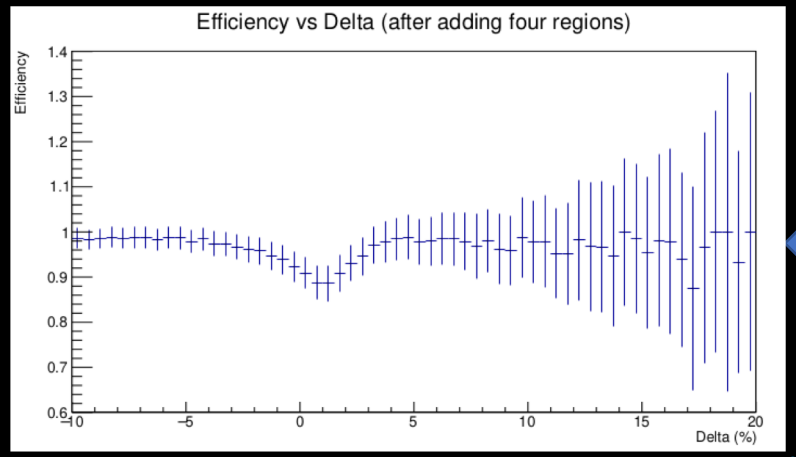
PID Studies

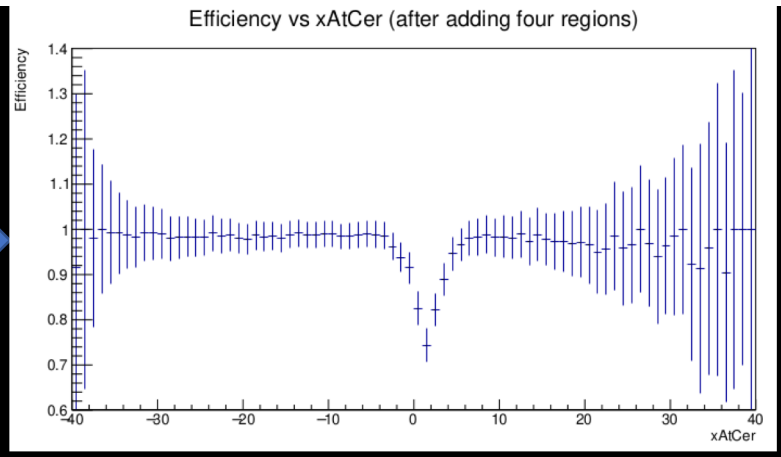
- Efficiency plotted vs XatCer makes the efficiency dip more sharp than vs. Delta
  - Corresponds more closely to the actual configuration of the mirror setup

- Will perform a (Xcer, Ycer) 2D efficiency study for HGC, for both the 2018 and 2019 mirror configurations.



$$\text{efficiency} = \frac{[\text{Particle ID}][\text{Tracks}][\text{Beta}][\text{Timing}][\text{HGC}]}{[\text{Particle ID}][\text{Tracks}][\text{Beta}][\text{Timing}]} \times 100\%$$





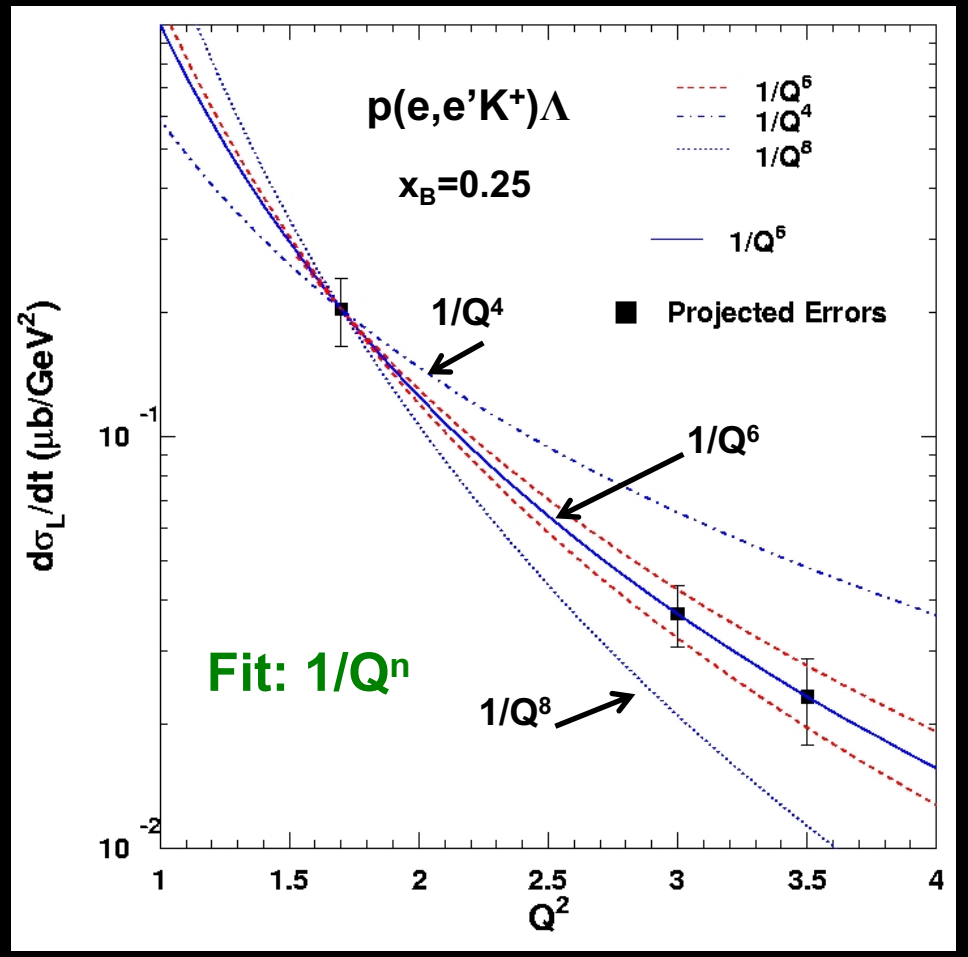
Plots and Study by V. Kumar

Outlook – Q^{-n} Scaling

- QCD scaling predicts $\sigma_L \sim Q^{-6}$ and $\sigma_T \sim Q^{-8}$.
- Will evaluate Q^2 dependence of σ_L and σ_T at fixed x and t.

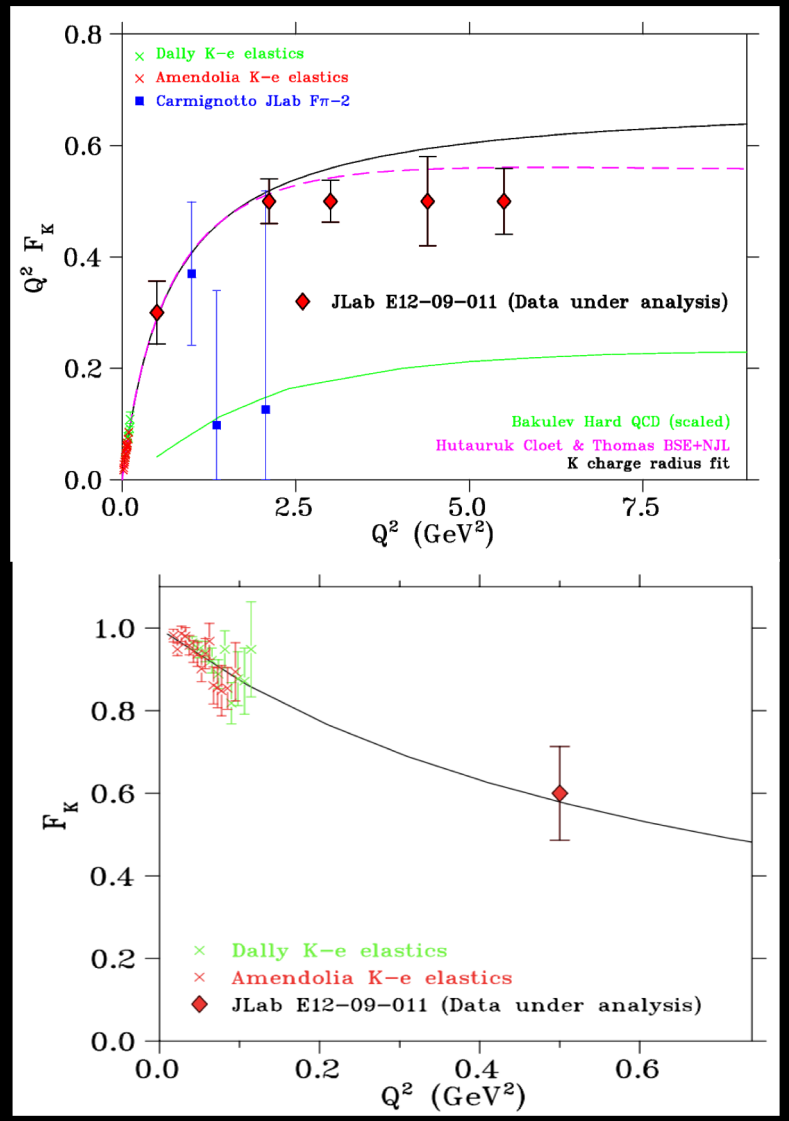
x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.25	1.7-3.5	2.5-3.4	0.2
0.40	3.0-5.5	2.3-3.0	0.5

- Will be first dedicated L/T separated measurement at high Q^2 (Q^2~5.5 GeV^2) to test this prediction.
- Will compare data from Pion-LT Experiment (E12-19-006) to see π^+ and K^+ channels behave consistently, or not.



Outlook – Kaon Form Factor

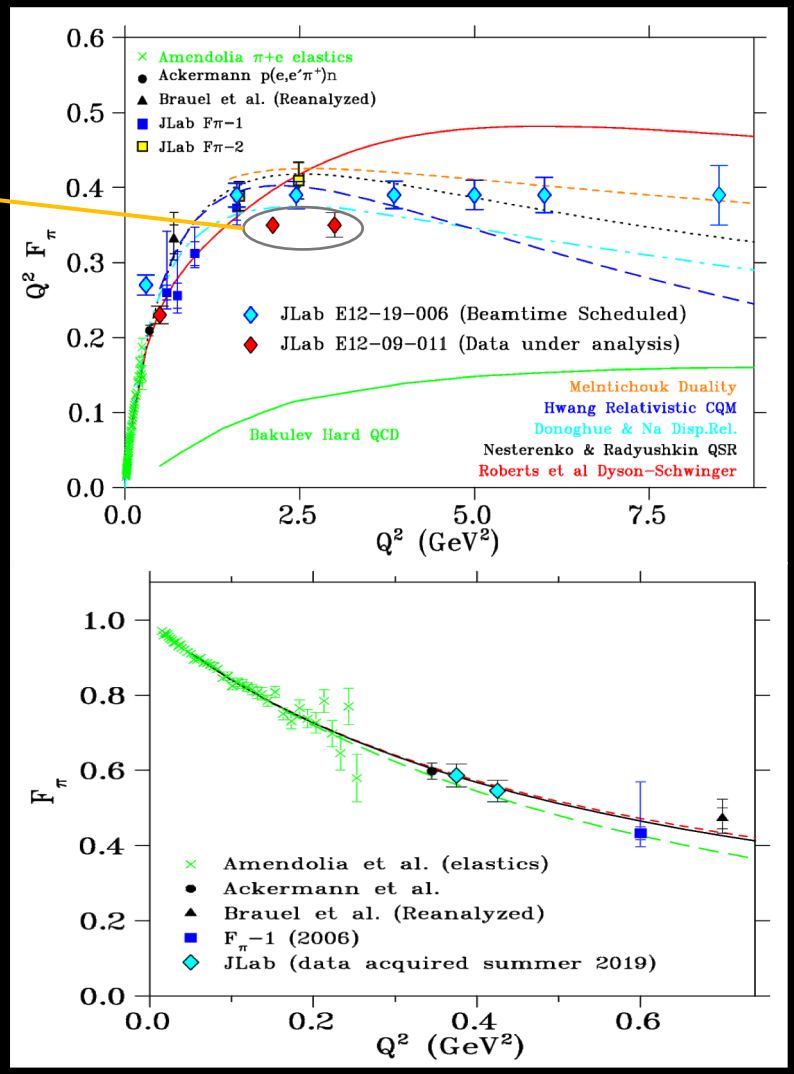
- Kaon-LT Experiment gives access to highest possible Q^2 data (i.e Q^2~5.5 GeV^2).
- Will perform pole dominance studies and attempt to extract F_K at Q^2 up to 5.5 GeV^2.
- Includes both $p(e, e'K^+)\Sigma^0$ as well as $p(e, e'K^+)\Lambda^0$ which allows us to perform ratio between two channels.
- Low Q^2 data will help compare with results from Fermilab and CERN which used K^+ beam



Outlook – Physics Channels

Pion Data

- In Kaon-LT , the $p(e, e'\pi^+)n$ real coincidence rate is much higher than the $p(e, e'K^+)\Lambda$ coincidence rate, giving high quality, high statistics pion data.
- Some of the Q^2 points have sufficiently low $-t$ which allows to perform pion form factor measurement.
- $p(e, e'\pi^+)\Delta^0$ is also available along with $p(e, e'\pi^+)n$ which will allow to measure the ratio for two reactions.

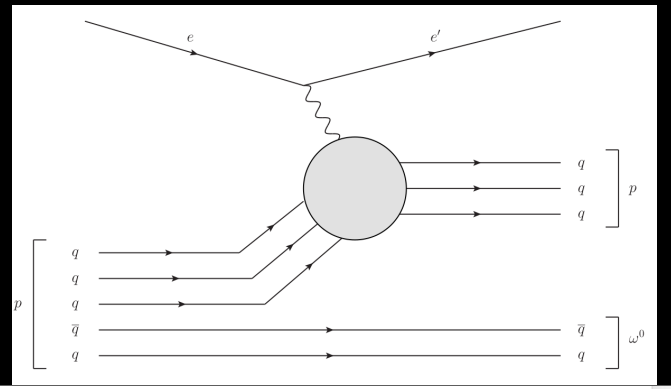


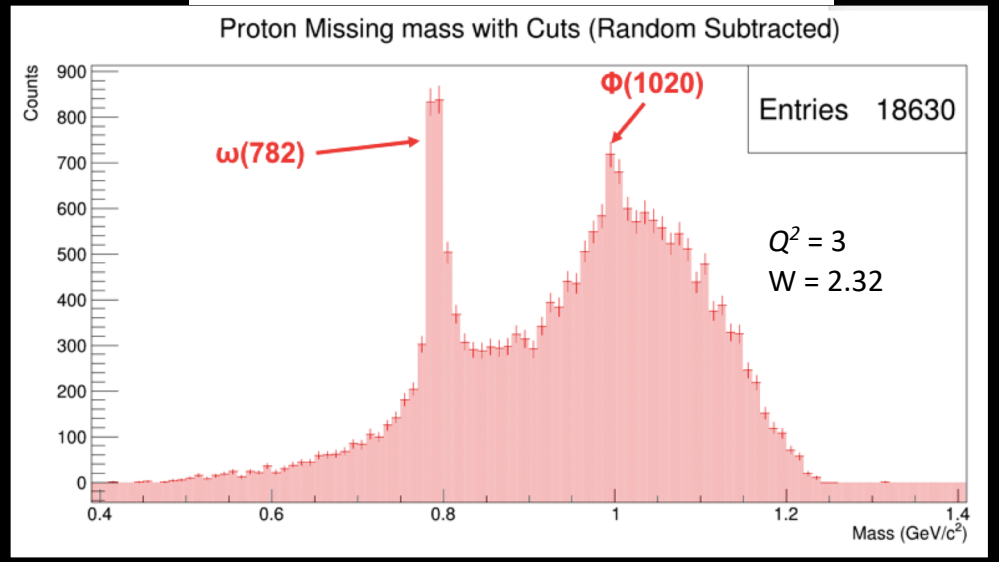
Watch out for Garth's talk on the upcoming Pion-LT Experiment (E12-19-006)

Outlook – Physics Channels

U-channel Proton Data

- Another free dataset available within the Kaon-LT dataset.
- Key to study relatively unexplored backward angle physics.
- Will be challenging to precisely distinguish different particles.





Plots and study by S. Kay

Watch out for Bill's talk on the new u-channel π^0 proposal.

Summary

- Data taking and detector calibrations are now complete.
- Currently working on tedious but most important step of efficiencies, PID and offsets.
- First iteration of cross-section will be out before the end of this year.
- Will need to re-check everything and make sure that all the uncertainties are well understood.
- Will perform pole dominance studies and attempt to extract form factor.

Stay Tuned !!!

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