

L/T Separated Kaon Cross Sections from exclusive electroproduction at High Q^2 from Hall C at Jefferson Lab

The 17th edition of the "International Conference on Meson-Nucleon Physics and the Structure of the Nucleon" (MENU 2026)



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On behalf of the KaonLT collaboration

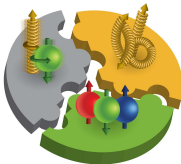
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Origin of Hadron Mass



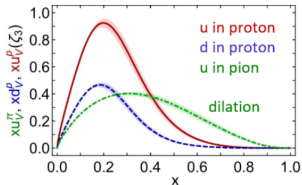
Most proton mass emerges from nonperturbative QCD dynamics.

Proton Spin Puzzle



How do quark/gluon spin and orbital angular momentum combine?

Partonic Structure



PDFs reveal the momentum distribution of partons.

Why study pion (π) and kaon (K) structure?

- **Proton Mass discrepancy** : Higgs mechanism only accounts for a small fraction of the visible mass (which mostly comes from quark-gluon interactions in the proton.)
- **Pion and Kaon** : Mass of light mesons is special $\rightarrow$ Goldstone bosons and carry the long-range force.
- **Spin crisis**: Proton spin is not fully accounted for by valence quarks, but also involves contributions from gluon spin and orbital angular momentum $\rightarrow$ requires information of GPD.
- **Meson PDF** : The mass of proton, pion, and kaon are vastly different, and so are the PDFs $\rightarrow$ need to understand the momentum contributions.

Deep Exclusive Meson Electroproduction

- **Sullivan process** : use the virtual meson cloud of the nucleon as the target.
- **Kaon electroproduction** : $e + p \rightarrow e' + K^+ + \Lambda/\Sigma^0$ offers strangeness for studying reaction mechanisms.
- virtual photon invariance $Q^2 = -(p_e - p_{e'})^2$
- γ^* -target energy $W = \sqrt{(p_{\text{tar}} + q)^2}$
- Mandelstam variable $t = (p_K - q)^2$

Rosenbluth Separation

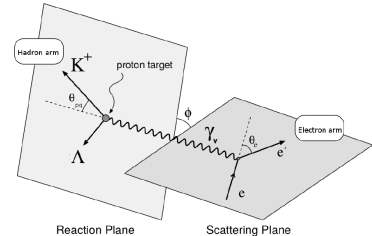
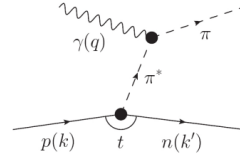
- measurement at multiple virtual photon polarization ϵ settings
- Extract longitudinal, transverse cross sections and interference terms simultaneously

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

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

- σ_L gives access to the form factor and tests of QCD factorization

Sullivan Exclusive



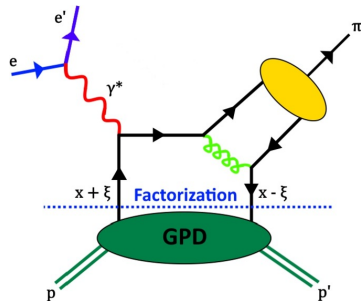
- Prerequisite of GPD extractions.
- **QCD factorization** separates the hard scattering part from the soft non-perturbative process.
- Test the onset of QCD factorization by measuring the Q^2 -dependence of L/T separated cross sections at fixed Bjorken x_B and Mandelstam variable $-t$.

Longitudinal: $\sigma_L \propto Q^{-6}$ (proven at leading twist)

Transverse: $\sigma_T \propto Q^{-8}$ (expected)

As $Q^2 \rightarrow \infty$: $\sigma_L \gg \sigma_T$

Phys. Rev. D 56, 2982



- 💡 If σ_L dominates and follows QCD scaling, one can access different combinations of GPDs through the flavor and quantum numbers of the produced meson (K^+).
- 💡 If instead $\sigma_T \gg \sigma_L$ over a large range of Q^2 , it presents sensitivity to transversity GPDs.

Pion, Jlab 6GeV PRC 78, 058201

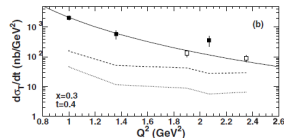
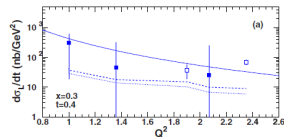
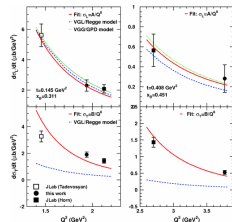
- Previous π data at $Q^2 > 1 \text{ GeV}^2$ show σ_L -scaling but predicted higher $F_\pi(Q^2)$ than hard QCD.
- $\sigma_L \sim Q^{-6}$ in pion but the extra suppression in σ_T was not observed $\rightarrow$ does similar scaling emerges in kaon where there is strange quark ?

Kaon, Jlab 6GeV PRC 97, 025204

- Jlab 6 GeV data remains moderate W below resonance region.
- Difficult for kaon due to scarcity of data at high Q^2 and low $-t$. Previous results had to combine data from different experiments.
- Require measurements at higher Q^2 to study this transition region from hadronic to partonic degrees of freedom in exclusive processes.

Horn et al., PRC 78, 058201

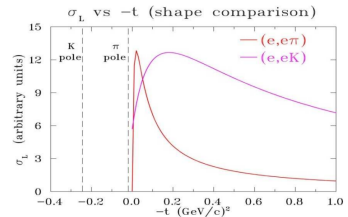
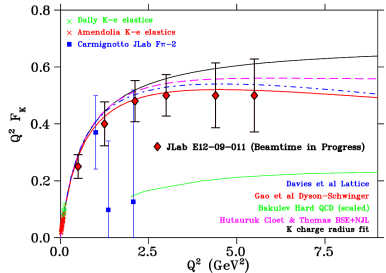
M. Carmignotto et al., PRC 97, 025204

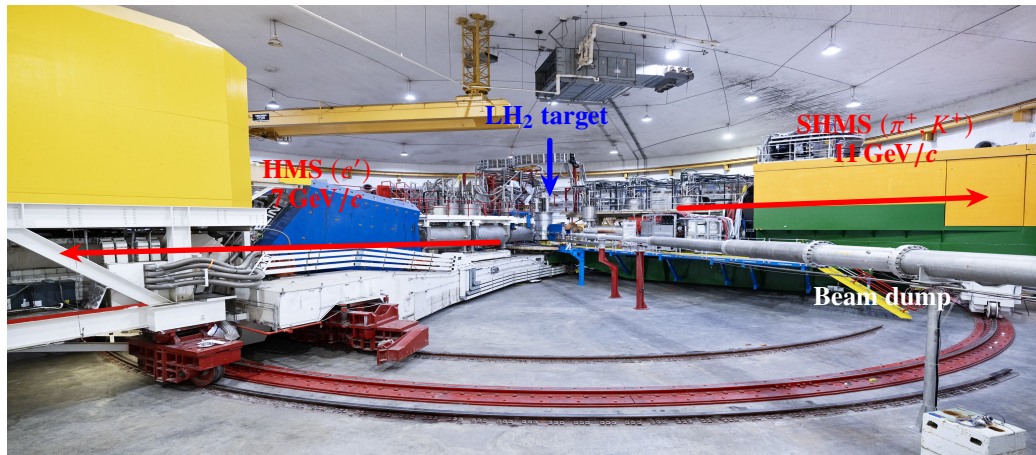


Kaon Form Factor $F_K(Q^2)$

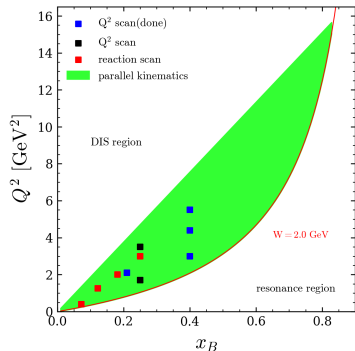
- Majority of kaon form factor $F_K(Q^2)$ data are only available at low $Q^2 < 0.13 \text{ GeV}^2$ from elastic scattering experiments (Amendolia, et al., PLB 178, (1986) 435).
- Accessing $F_K(Q^2)$ at higher Q^2 is possible through Sullivan exclusive process where the kaon cloud within the nucleon is used $\Rightarrow$ Directly testing the validity for $F_K(Q^2)$ extraction.
- Is the kaon pole contribution dominant at low $-t$? Extract $F_K(Q^2)$ through the longitudinal cross section σ_L .
- K^+ pole test : is the coupling constant ratio $g_{KN\Lambda}/g_{KN\Sigma} \approx 1$ as a function of $-t$?
- As the K^+ pole is further away from the physical region than the π^+ pole, a test for the dominance of the kaon pole is required.

$$\frac{d\sigma_L}{dt} \sim \underbrace{\frac{-t}{(t - M_K^2)^2}}_{\text{kaon pole}} g_{K\Lambda N}^2 Q^2 F_K^2(Q^2)$$



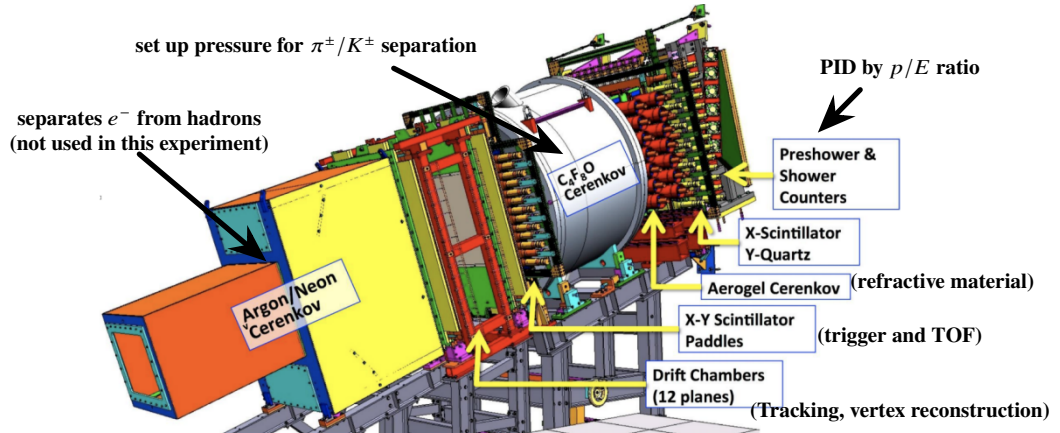


- E12-09-011 : First HMS-SHMS coincidence experiment in Hall C at 12 GeV era.
- precision reconstruction from optical calibration at high luminosity
- (Super) High Momentum Spectrometer (HMS/SHMS) for detecting scattered electrons and hadrons.
- SHMS allows small angle ($5.5^\circ - 40^\circ$) in the arms to achieve desirable kinematics.

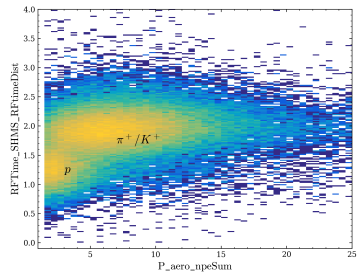
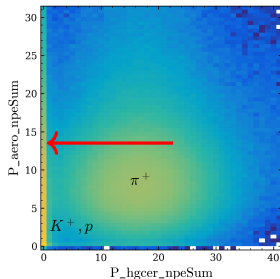
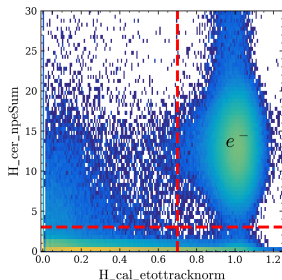


E [GeV]	Q^2 [GeV ²]	W [GeV]	$-t_{\min}$ [GeV ²]	x_B	ϵ
10.6					0.53
8.2	5.5	3.02	0.50	0.40	0.18
10.6					0.72
8.2	4.4	2.74	0.51	0.40	0.48
10.6					0.88
8.2	3.0	2.32	0.53	0.40	0.57
10.6					0.67
8.2	3.0	3.14	0.22	0.25	0.39
10.6					0.79
8.2	2.115	2.95	0.21	0.21	0.25
4.9					0.67
3.8	0.5	2.4	0.07	0.09	0.40

- Achieve high Q^2 and $W > 2$ GeV above resonance region for reliable K^+ measurements
- Measure cross sections at fixed $-t = 0.5$ GeV², $x_B = 0.4$ allows scaling studies for QCD factorization.
- Form factor extraction from separated cross sections σ_L if pole dominance is observed at low $-t$.
- ✓ Reaction mechanism studies at low Q^2 through $K^+\Sigma^0/K^+\Lambda$ cross section ratio.
- ⌚ Phase 2 expected to run as soon as 2027.



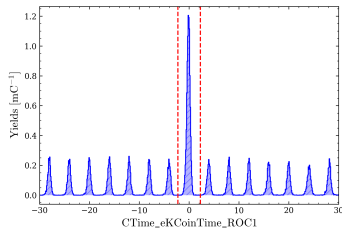
S. Ali, et al, 10.1016/j.nima.2025.171070



$$Q^2 = 3.0 \text{ GeV}^2, W = 3.14 \text{ GeV}$$

Center, Low $\epsilon \approx 0.3$

- HMS Aerogel Cherenkov n.p.e. > 1.5 + calorimeter $p/E > 0.7 \Rightarrow$ electron selection
- SHMS Aerogel Cherenkov n.p.e. > 2
- SHMS Heavy gas Cherenkov n.p.e. $= 0 \Rightarrow$ separates K^+ from π^+
- RF time-of-flight (normalized to 1 bunch spacing) allows further separation of K^+ from protons

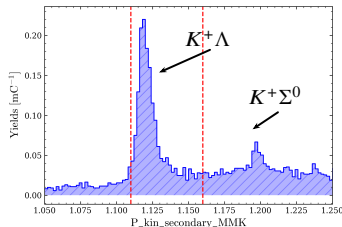


Coincidence time

- $t_{\text{coin}} = t_{\text{SHMS}} - t_{\text{HMS}} \in (-2.25, 2.25) \text{ ns} \Rightarrow$ 1 bunch spacing window selects true coincidence events
- Random coincidence events are selected from the sidebands with 3 bunch spacing windows each side.

Missing mass cut

$$M_X = \sqrt{(E_e + m_p - E_{e'} - E_{K^+})^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_{K^+})^2}$$



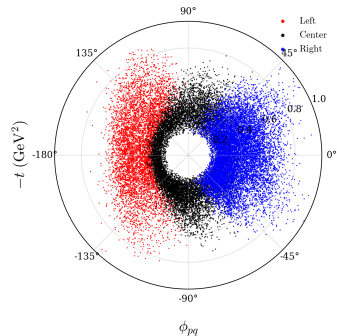
$Q^2 = 3.0 \text{ GeV}^2$, $W = 3.14 \text{ GeV}$
Center, Low $\epsilon \approx 0.3$

- $Q^2 = 3.0 \text{ GeV}^2$, $W = 3.14 \text{ GeV}$, Center, Low $\epsilon \approx 0.3$
- Nominal range of $K^+ \Lambda$ is selected by varying the missing mass cut on both side until a stable separated cross section is obtained.
- Simultaneous measurement of Λ and Σ^0 hyperons is possible only after fully understanding the background contribution from different processes.

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

- Hall C specializes in high-precision measurements of exclusive reactions with limited angular acceptance.
- Measure $\sigma(-t)$ fixed Q^2 and W , utilizing different ϵ settings.

	$E = 8.2 \text{ GeV}, \epsilon = 0.39$		$E = 10.6 \text{ GeV}, \epsilon = 0.67$	
Setting	HMS	SHMS	HMS	SHMS
Left	25.952°	9.973°	14.987°	12.523°
Center	25.952°	6.973°	14.487°	9.473°
Right	–	–	14.487°	6.558°



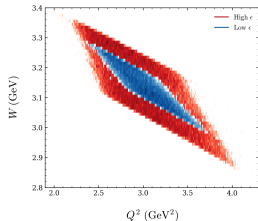
$Q^2 = 3.0 \text{ GeV}^2, W = 3.14 \text{ GeV}$
Center, High $\epsilon \approx 0.67$

- Complete ϕ_{pq} coverage is obtained by rotating the SHMS arms by $\theta_K \sim 3^\circ$ around the central angle.
- Differential cross section is then constructed by combining yields measurements from different SHMS angles.

Common phase space in Q^2 , W

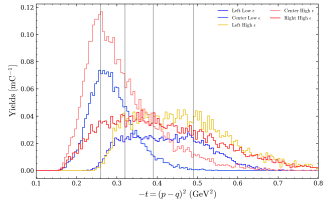
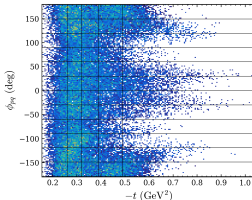
- LT separation requires common phase space in all ϵ settings.
- Boundaries in each setting are defined by kinematics and acceptance, and are estimated by a "diamond" fit.
- Common phase space is defined by the overlapping region of the diamonds in all settings.

$Q^2 = 3.0 \text{ GeV}^2$, $W = 3.14 \text{ GeV}$ Center



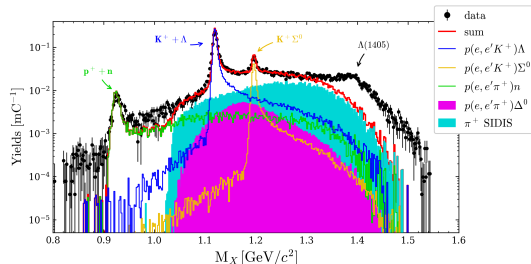
Optimal binning in $-t$

- $-t/\phi_{pq}$ bins are determined by requiring roughly equal statistics in each bin.
- Averaged kinematics are calculated for each bin, and used in cross section models.
- Uniform binning in ϕ_{pq} .



Physics background

- Monte Carlo (SIMC) is used to simulate the shape of different physics backgrounds.
- ⚡ Significant pion SIDIS and $p(e, e' \pi) \Delta^0$ overlapping.
- ⚡ Significant $p(e, e' \pi) n$ but far away.
- ⚡ Small $p(e, e' K) \Sigma^0$ tail.
- ⚡ Kaon SIDIS out of range.
- ⚡ Visible excited states $\Lambda(1405)$ but far away.



$Q^2 = 3.0 \text{ GeV}^2$, $W = 3.0 \text{ GeV}$
Center Low, $\epsilon = 0.39$, full $-t$, ϕ coverage

Random, dummy target

- Random coincidence ($\sim 5\%$).
- Al target frame ($\sim 2\%$).
- Proton corrected from likelihood model of detector response.

- Simultaneous fit to background processes and isolate $K^+ \Lambda$ yields.
- Repeat for all $-t$, ϕ bins.
- Estimate total background, NOT individually resolved.
- Yields are calculated using the formula:

$$Y = \frac{N_{\text{detected}}}{Q_{\text{eff}}}$$

where the $Q_{\text{eff.}} = Q_{\text{detected}} \cdot \epsilon_{\text{det}} \cdot \epsilon_{\text{track}} \cdot \tau_{\text{live}} \cdot$
other corrections.

Preparation

- Prepare background subtracted yields for each $(-t, \phi)$ bin.
- Propose functional form for $\sigma_{L,T,LT,TT}$ (next slide).

Perform Self-consistent iterative method

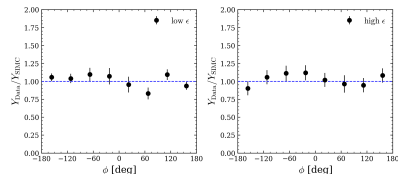
- 1 Compare data yields to SIMC
- 2 Compute unseparated cross section $\frac{d^2\sigma_{\text{EXP}}}{dt d\phi} = \frac{Y_{\text{data}}}{Y_{\text{simc}}} \cdot \frac{d^2\sigma_{\text{model}}}{dt d\phi}$
- 3 Extract separated cross sections through a simultaneous fit at each $-t$ bin

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

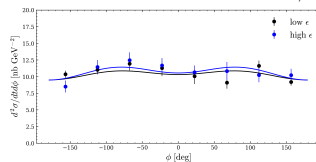
- 4 Update model parameters by fitting $\sigma_{L,T,LT,TT}(-t)$ using precise kinematics.

Repeat until convergence is reached (e.g. $\Delta\sigma_{L,T,LT,TT} < 1\%$).

Representative Yield Ratios ≈ 1



Unseparated Cross Section $\frac{d^2\sigma}{dt d\phi}$



$$Q^2 = 4.4 \text{ GeV}^2, W = 2.74 \text{ GeV} \\ -t_{\text{center}} = 0.55 \text{ GeV}^2$$

SIMC

- 💡 Simulate spectrometer acceptance, optics and reconstruct event vertex in the same way as data
- 💡 Radiation processes, multiple scattering, ionization energy loss and K^+ decay are taken into account
- 💡 Events are weighted by cross section model which depends on kinematic variables

Cross Section Model

$$\sigma_L = w \cdot p_0 \cdot \frac{t}{t^2 + M_K^2} \exp(-p_1 t)$$

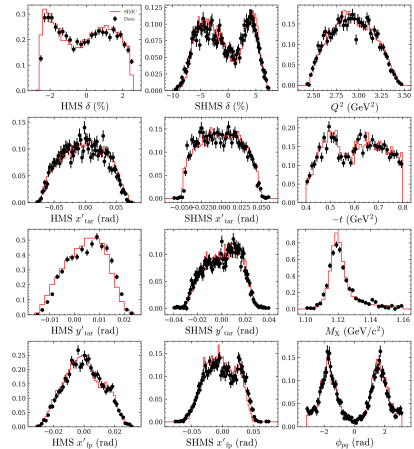
$$\sigma_T = w \cdot p_2 \cdot \exp(-p_3 t)$$

$$\sigma_{LT} = w \cdot p_4 \cdot \exp(-p_5 t) \sin \theta^*$$

$$\sigma_{TT} = w \cdot p_6 \cdot \exp(-p_7 t) \sin^2 \theta^*$$

$$w(W) = \frac{1}{(W^2 - M_p^2)^2}$$

- ☛ both model choice and parameters are part of regularization.
- ☛ Agreement between data and SIMC in both HMS, SHMS acceptance and kinematics are required for reliable cross section extraction.



$$Q^2 = 3.0 \text{ GeV}^2, W = 2.32 \text{ GeV} \\ \text{Center, High } \epsilon \approx 0.5$$

Rosenbluth Separation

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

- Consider Rosenbluth separation with 2 ϵ settings with measurements $\sigma_{1,2}$ and define $R = \sigma_L / \sigma_T$,

$$\sigma_L \sim \frac{\sigma_1 - \sigma_2}{\epsilon_1 - \epsilon_2}$$

$$\frac{\Delta\sigma_L}{\sigma_L} \propto \frac{1}{|\epsilon_1 - \epsilon_2|} \sqrt{\left(\frac{1}{R} + \epsilon_1\right)^2 + \left(\frac{1}{R} + \epsilon_2\right)^2}$$

- The uncertainty in σ_L is amplified by $\Delta\epsilon$ and potentially large σ_T . It is therefore crucial to understand the systematics for accurate σ extraction.

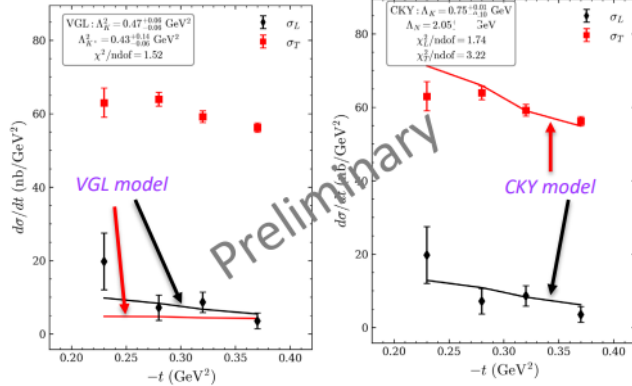
- Uncorrelated uncertainty is dominated by background contribution / Heavy Gas Cherenkov acceptance.
- Overall normalization is dominated by uncertainty in K^+ absorption and decay treatment.

Correction	Uncorrelated (pt-to-pt) (%)	ϵ -Uncorrelated t-corr. (%)	Correlated (scale) (%)
HMS Tracking	0.3	—	—
SHMS Tracking	0.4	—	—
EDTM	—	0.6	—
Coincidence Blocking	—	0.5	—
Beam Charge	—	—	0.7
Target Thickness	—	—	0.65
Kinematics	0.3	0.1	—
Kaon Absorption	—	—	—
Kaon Decay	1.0	—	3.0
PID	1.77	0.40	0.36
Acceptance	1.0	0.2	0.1
M_X Range	1.20	0.53	0.54
Background	2-3	0.6	0.08
Model Dependence	1.1	0.3	0.2
Total	3.5-4.1	2.3	3.2

Results : Longitudinal and Transverse Cross Sections σ_L and σ_T

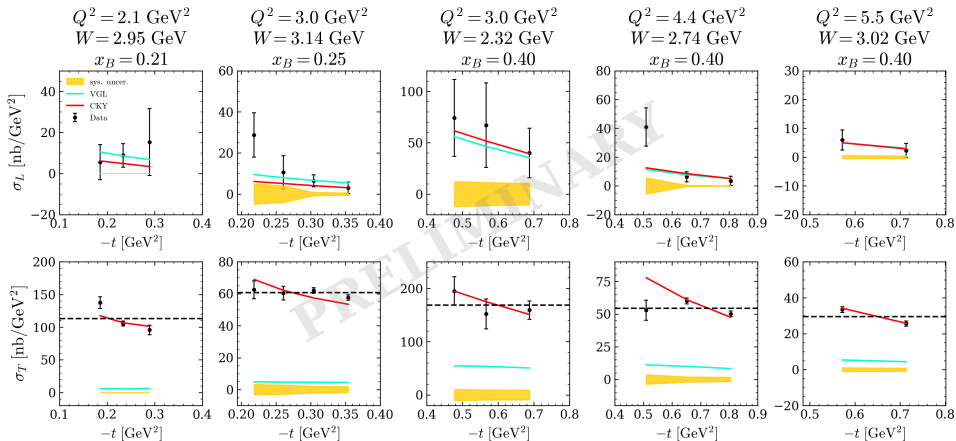
$$Q^2 = 3.0 \text{ GeV}^2$$

$$W = 3.14 \text{ GeV}$$



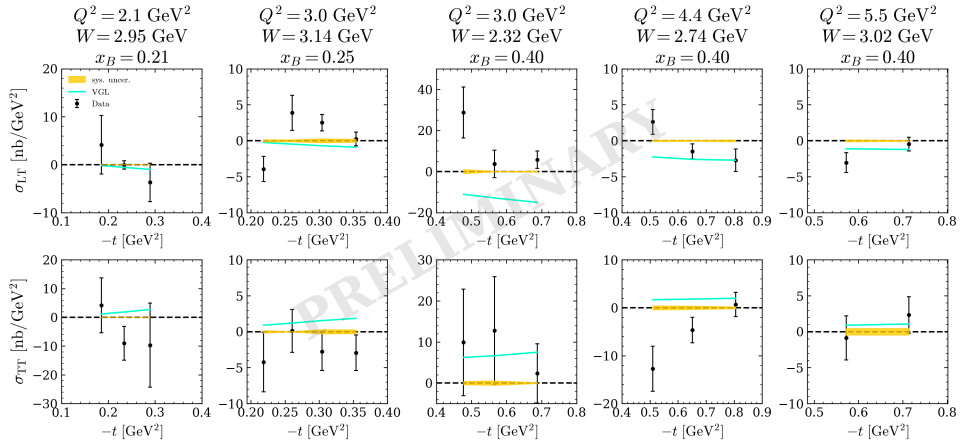
- VGL model (Vanderhaeghen, Guidal, Laget, PRC 57(1998)1454) : replace pole-like propagators with Regge propagators to describe the interaction with exchange of a family of particles with the same quantum numbers.
- CKY (B-G Yu, T.K. Choi, K.J. Kong (private communication 2023)) : including nucleon pole in the s-channel with charge form factor
- σ_T is better described by the CKY model compared to the VGL model with prescription $\Lambda_K \approx \Lambda_{K^*}$.
- σ_L decreases with $-t$ while σ_T remains relatively flat.

Results : Longitudinal and Transverse Cross Sections σ_L and σ_T



- In general, the longitudinal cross section σ_L does NOT dominate in any Q^2 .
- σ_T is better described by the CKY model compared to the VGL model with prescription $\Lambda_K \approx \Lambda_{K^*}$.
- σ_L exhibits an exponential trend in some settings $\rightarrow$ kaon-pole like behavior, important for extracting the kaon form factor

Results : Interference terms σ_{LT} and σ_{TT}

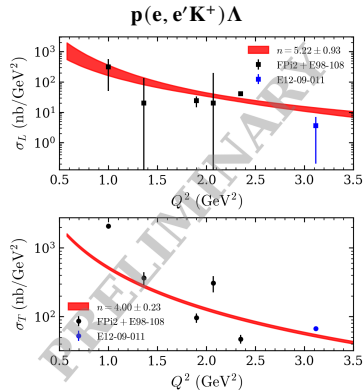


- Consistent with zero at small t .
- Interference terms remain small but are comparable σ_L .
- Models cannot simultaneously describe both $\sigma_{L,T}$ and interference terms.

- L/T separated cross sections as a function of Q^2 for testing the onset of factorization theorem

E [GeV]	Q^2 [GeV ²]	W [GeV]	$-t_{\min}$ [GeV ²]	x_B	ϵ
10.6	5.5	3.02	0.50	0.40	0.53
8.2					0.18
10.6	4.4	2.74	0.51	0.40	0.72
8.2					0.48
10.6	3.0	2.32	0.53	0.40	0.88
8.2					0.57
10.6	3.0	3.14	0.22	0.25	0.67
8.2					0.39
10.6	2.115	2.95	0.21	0.21	0.79
8.2					0.25

- Scaling relation fitted with existing Jlab 6GeV data (FPi2 and E93-018)
- data points are scaled to the same kinematics using CKY model.
- σ_L scales as Q^{-6} as expected from factorization.
- σ_T scales as Q^{-4} is generally larger than σ_L .
- More data points will be taken in Phase 2 Kaon LT experiment.

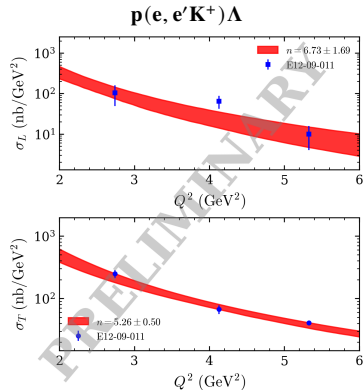


Q^2	W	t	x	λ_K	λ_N
1.00	1.81	0.41	0.295	—	—
1.36	2.37	0.4	0.30	—	—
2.07	2.37	0.4	0.30	—	—
1.90	2.3	0.4	0.30	—	—
2.35	2.5	0.4	0.30	—	—
3.12	3.11	0.354	0.261	0.6	2.0

- L/T separated cross sections as a function of Q^2 for testing the onset of factorization theorem

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- Scaling relation fitted with existing Jlab 6GeV data (FPi2 and E93-018)
- data points are scaled to the same kinematics using CKY model.
- σ_L scales as Q^{-6} as expected from factorization.
- σ_T scales as Q^{-5} is generally larger than σ_L .
- Results suggest the present kinematics for kaon are not yet in the factorization regime, which is consistent with the beam-spin asymmetry measurements using the same set of data (pion).



Q^2	W	t	x	λ_K	λ_N
2.74	2.41	0.477	0.357	1.0	2.2
4.13	2.81	0.510	0.371	0.9	2.6
5.33	3.03	0.572	0.390	0.9	2.7

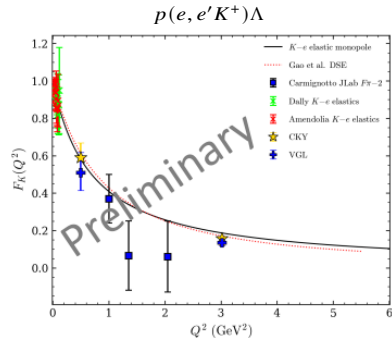
Extraction strategy

- The separated longitudinal cross section σ_L provides sensitivity to the **kaon electromagnetic form factor** at small $-t$.
- $F_K(Q^2)$ is extracted by comparing the measured σ_L with VGL, CKY model, assuming a significant kaon-pole contribution.
- The extraction remains **model dependent**, particularly due to non-pole contributions.

$$F_K(Q^2) = \frac{1}{1 + Q^2/\Lambda_K^2}$$

Preliminary results

- Successful first indirect extraction of form factor.
- Extracted F_K values appear **consistent with existing low- Q^2 elastic eK data**, suggesting Sullivan process provides a valid target.



S.R. Amendolia et al., Phys. Lett. B 178 (1986) 435.

E.B. Dally et al., Phys. Rev. Lett. 45 (1980) 232.

1. Test of kaon-pole dominance

- Compare the longitudinal cross-section ratio for $K^+\Sigma^0$ and $K^+\Lambda$ production with the expectation from hadronic couplings.

$$\frac{\sigma_L(K^+\Sigma^0)}{\sigma_L(K^+\Lambda)} \sim \frac{g_{K\Sigma N}^2}{g_{K\Lambda N}^2}$$

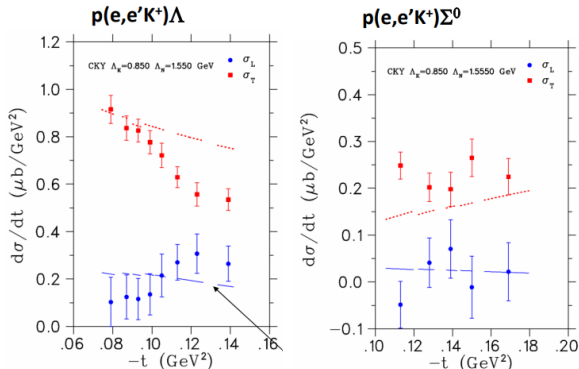
- Preliminary KaonLT results at $Q^2 = 0.5 \text{ GeV}^2$ provide an initial test of the **pole-dominance**

2. Test of the $-t$ dependence

- Measure σ_L over a range in $-t$ and compare with theoretical predictions.
- Calculations suggest a viable kaon target for $-t \lesssim 0.9 \text{ GeV}^2$.
- Constrain non-pole contributions and quantify uncertainties in the kaon-pole extrapolation.
- Pole dominance test at higher Q^2 is under way !

Preliminary low- Q^2 pole test

$$Q^2 = 0.5 \text{ GeV}^2, W = 2.40 \text{ GeV}$$



Credit: A. Hamdi, G. Huber (U. Regina)

Publication in preparation

Testing the onset of QCD factorization

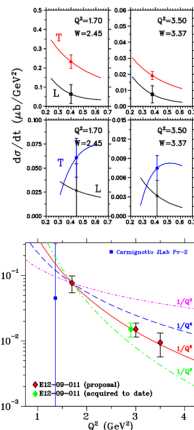
- At $x_B = 0.4$, $\sigma_L \sim Q^{-6}$ scaling is observed, whereas σ_T does not exhibit the expected scaling.
- Combining the JLab 6 GeV and KaonLT data at $x_B \approx 0.3$ suggests $\sigma_L \sim Q^{-6}$, albeit with large uncertainties.
- $\sigma_T \gg \sigma_L$ throughout the measured Q^2 range.

Regge-model fits and form-factor extraction

- Cross sections are fitted with the VGL and CKY Regge models.
- The preliminary kaon form factor agrees with the charged-kaon radius measurement by Amendolia *et al.*

Phase 2 TODO

- Begin data taking as early as 2027.
- Perform an L/T-separated Q^2 scan at $x_B = 0.25$ to test the hard-soft reaction mechanism.
- Establish high-precision $K^+\Lambda$ and $K^+\Sigma^0$ data and better constrain the couplings used in form-factor extraction.



Projected Phase 2 data

Spokespersons (PionLT/KaonLT): Tanja Horn (CUA), Garth Huber (U. Regina),
Dave Gaskell (JLab), Pete Markowitz (FIU)



PionLT and KaonLT PAC proposals

Postdocs: Chi Kin Tam (CUA), Abdennacer Hamdi (U. Regina)

Former Postdocs: Vladimir Berdnikov (now at Jlab), Stephen Kay (now at U. of York)

Graduate Students:

KaonLT (E12-09-011)	PionLT (E12-19-006)
Richard Trotta (CUA, PhD 2024, now at UVA)	Nathan Heinrich (U. Regina)
Ali Usman (U. Regina, PhD 2025)	Muhammad Junaid (U. Regina)
Vijay Kumar (U. Regina, PhD 2024)	Kathleen Ramage (U. of Glasgow)
Alicia Postuma (U. Regina)	Sameer Jain (CUA)
Fernando Chandra (U.Regina)	Nermin Sadoun (U. Regina)

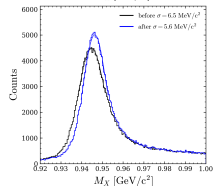
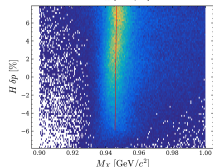
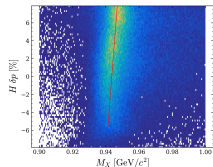
Example of non-student driven Analyses: Gabriel Niculescu (JMU), Ioana Niculescu (JMU)

Thank you for your attention !

[Link to full list of physics topics](#)

[Link to KaonLT experiment wiki](#)

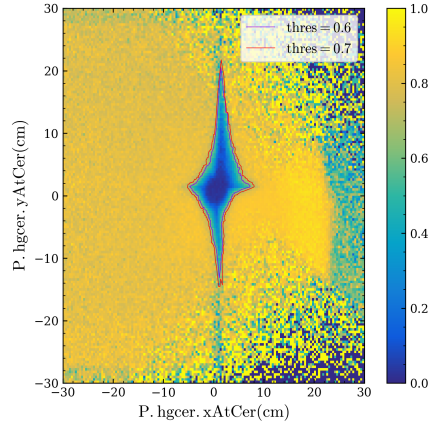
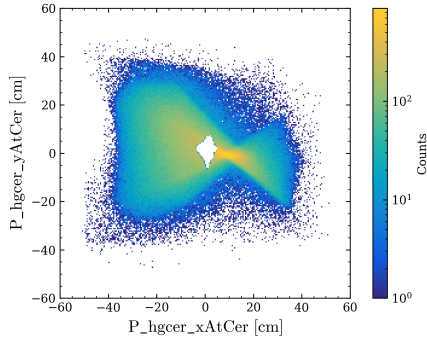
Backup



- HMS power supply saturation during experiment $\Rightarrow$ Corrected by decorrelating reconstructed momentum from Missing Mass

$$\delta p_{\text{HMS}}^{\text{corr}} = \delta p_{\text{HMS}}^{\text{recon}} + \alpha \cdot x'_{\text{fp}}$$

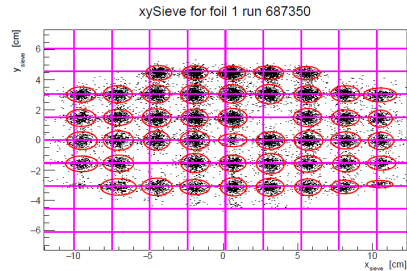
- resolution improvement from $\sigma_{\text{MM}} \sim 0.7 \text{ MeV}$ to $\sigma_{\text{MM}} \sim 0.6 \text{ MeV}$
- momentum-dependent correction applied to all runs, with α determined from the slope and resolution of $\pi^+ + n$ peak

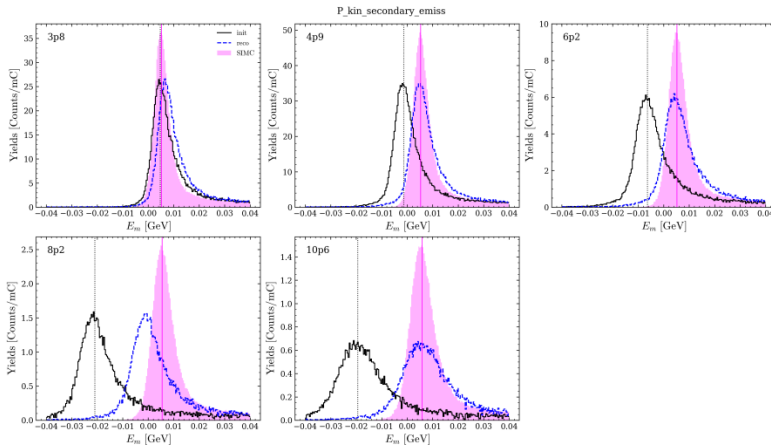


- Low efficiency region at the center of HgCer due to the mirror support structure
- relative efficiency N_{did}/N_{should} where denominator includes all detector cuts except the HgCer cut.
- Start at the center, radiates out and find the bin passing a certain threshold in efficiency.

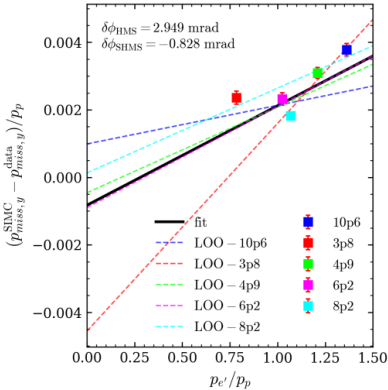


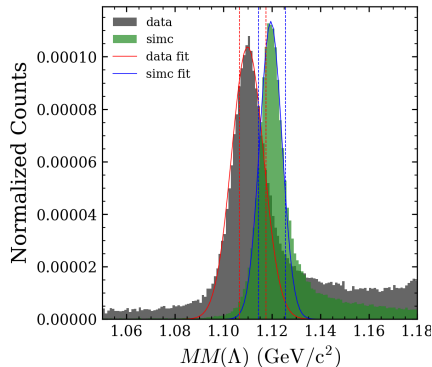
$$\begin{aligned}
 x'_{\text{tar}} &= \sum_{i,j,k,l,m} X'_{ijklm} x_{\text{fp}}^i x_{\text{fp}}'^j y_{\text{fp}}^k y_{\text{fp}}'^l x_{\text{tar}}^m, \\
 y_{\text{tar}} &= \sum_{i,j,k,l,m} Y_{ijklm} x_{\text{fp}}^i x_{\text{fp}}'^j y_{\text{fp}}^k y_{\text{fp}}'^l x_{\text{tar}}^m, \\
 y'_{\text{tar}} &= \sum_{i,j,k,l,m} Y'_{ijklm} x_{\text{fp}}^i x_{\text{fp}}'^j y_{\text{fp}}^k y_{\text{fp}}'^l x_{\text{tar}}^m, \\
 \delta &= \sum_{i,j,k,l,m} D_{ijklm} x_{\text{fp}}^i x_{\text{fp}}'^j y_{\text{fp}}^k y_{\text{fp}}'^l x_{\text{tar}}^m.
 \end{aligned}$$





■ W , $P_{miss,x}$, $P_{miss,z}$ and E_{miss} .





Problem

- Imperfect optic calibration leads to a shift in the missing mass peak < 10 MeV.
- Kinematics offsets found by HeepCheck is not perfect since it is an over-constrained problem.

Solution

- Apply a missing mass shift correction to each setting
- This correction is accompanied by a shift in $-t$ according to conservation laws while assuming the same Q^2 and W .