Hall C Winter Collaboration Meeting 2026
KaonLT: preliminary high Q2 LT-separations

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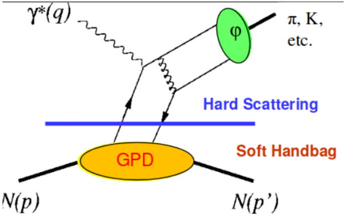
Physics Motivation: 3D Hadron Structure

Hard-Soft Factorization

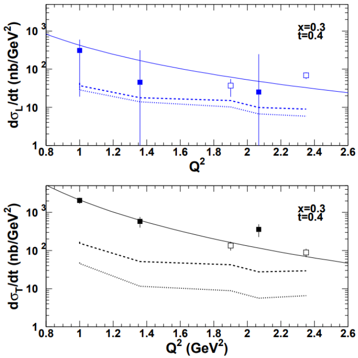
Assumption that the **hard** scattering process can be separated from the **soft** hadronic structure.



Power Scaling at fixed x_B

- Observed behavior at low Q^2:
  - $\sigma_L \sim Q^{-6}$
  - $\sigma_T \sim Q^{-8}$
- A first study of scaling behavior in a strange system at high Q^2.
- A direct testbed and bridge from *hadronic* to the *partonic* regime.

JLab 6GeV (E93-018 + FPI-2)



Jlab Q^{-n} scaling study from *Phys. Rev. C 97, 025204*, dashed and dotted lines represent VR and VGL models

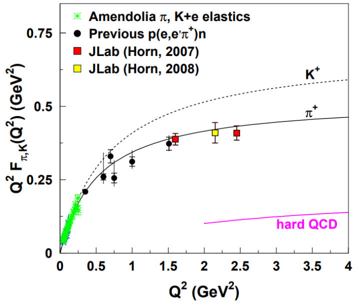
Kaon Form Factor Extraction

Kaon Form Factor F_K extraction from σ_L :

$$\sigma_L \approx \frac{-tQ^2}{(t-m_K^2)^2} g_{KNN}^2(t) \underbrace{F_K^2(Q^2)}_{\text{Kaon FF}} \rightarrow F_K(Q^2) = \frac{1}{1+Q^2/\underbrace{\Lambda_K^2}_{\text{cutoff}}}$$

- Form factor related to longitudinal cross section σ_L.
- Kaon Form factor data is scarce at high Q^2.
- Study the transition from **non-perturbative** to **perturbative** QCD.
- Extract by measuring struture functions $\sigma_{L,T,LT,TT}(t)$ at various kinematics and fit to Regge models.

Form factor, taken from pac proposal

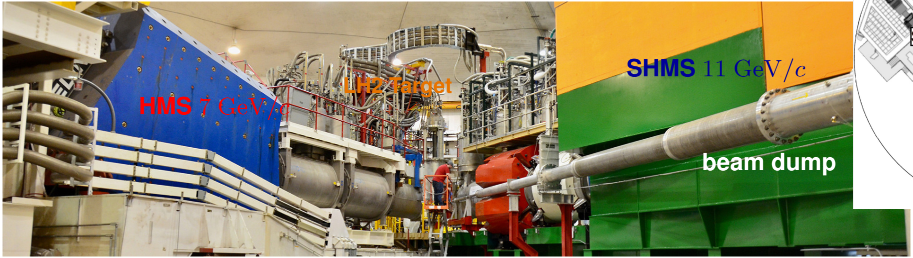


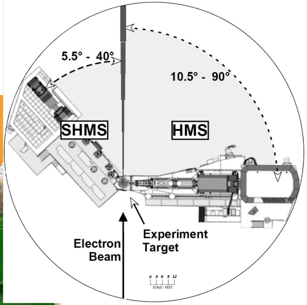
▶ **Experimental Requirement:** Need to run a dedicated experiment with **high statistics** for Kaon L/T separation to resolve the current uncertainties.

Exclusive Meson Experiments in Hall C @ 12 GeV JLab

E12-09-011 : KaonLT experiment in Hall C at JLab

- Exclusive electroproduction of kaons on protons $e + p \rightarrow e' + K^+ + \Lambda, \Sigma^0$
- HMS as electron arm, SHMS as hadron arm for kaon





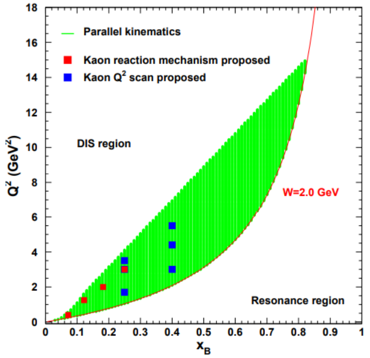
NIMA V1083(171070), 2026

- First coincidence experiment (HMS-SHMS) in the 12 GeV era !
- 12 GeV electron beam + small angle in SHMS allows precise measurements at high Q^2

Kinematic region

E [GeV]	Q^2 [GeV^2]	W [GeV]	x_B	ϵ
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	2.32	0.40	0.88 0.57
10.6 8.2	3.0	3.14	0.25	0.67 0.39
10.6 8.2	2.115	2.95	0.21	0.79 0.25

$p(e, e'K^+)\Lambda\Sigma^0$



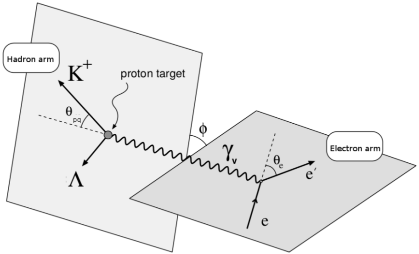
- **Virtual photon polarization:** $\frac{1}{\epsilon} = 1 + 2\mathbf{q}^2/Q^2 \tan^2(\theta_e/2)$
- Measure at two ϵ settings for Rosenbluth (LT) separation, large $\Delta\epsilon$ to minimize uncertainty

Technique for extracting σ_L and σ_T : Rosenbluth (LT) Separation

Rosenbluth formula

$$2\pi \underbrace{\frac{d^2\sigma}{dt d\phi}}_{\text{Measured Data}} = \underbrace{\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt}}_{\text{Extracted Terms}} + \underbrace{\sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi}_{\text{Interference Terms}}$$

- **Virtual photon polarization:** $\frac{1}{\epsilon} = 1 + 2\mathbf{q}^2/Q^2 \tan^2(\theta_e/2)$
- ϕ : azimuthal angle between scattering and reaction planes

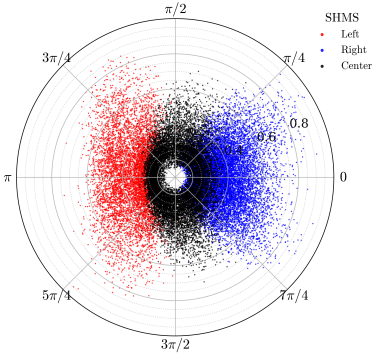


- Extract $\sigma_L, \sigma_T, \sigma_{LT}, \sigma_{TT}$ via simultaneous fit at two ϵ settings.

$$\chi^2_{\text{total}} = \chi^2(\epsilon_{\text{high}}) + \chi^2(\epsilon_{\text{low}})$$

Analysis Procedure : Adding ϕ coverage

	$E = 8.2$ GeV, $\epsilon = 0.39$		$E = 10.6$ GeV, $\epsilon = 0.53$	
Setting	HMS	SHMS	HMS	SHMS
Left	$25.952°$	$9.973°$	$14.987°$	$12.523°$
Center	$25.952°$	$6.973°$	$14.487°$	$9.473°$
Right	–	–	$14.487°$	$6.558°$

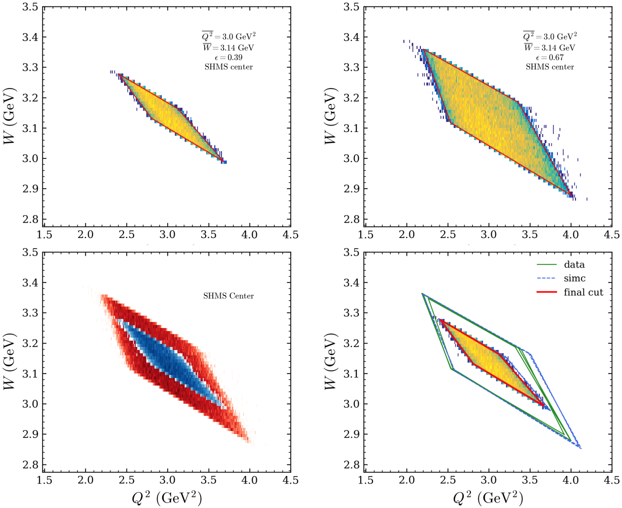


- Must Overlay data at Left/Center/Right SHMS settings to ensure a complete ϕ coverage in each $-t$ bin !

Analysis Procedures : Coverage Selection by Diamond cut

Phase space matching

- LT separation requires consistent phase space between two ϵ settings (e.g. Q^2, W, θ)
- HMS, SHMS acceptance depend on ϵ for fixed energy settings
- Apply diamond cut in both data and SIMC $\rightarrow$ take the overlapping region

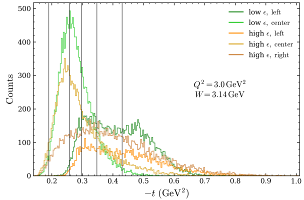


Analysis Procedures : Binning selection in $|-t|$ and ϕ

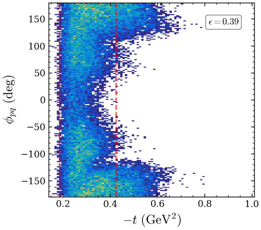
Mandelstam variable $t = (p_\gamma - p_{K+})^2$

- LT separation requires at least one ϵ setting has full ϕ coverage
- Optimal binning choice due to scarce statistics
- Keep as many bins in $|-t|$ for their dependence in σ_L

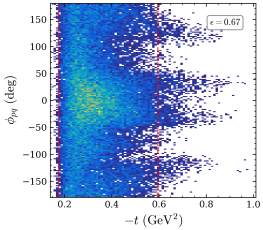
1D distribution



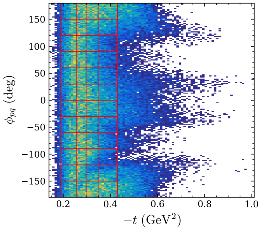
Low ϵ



High ϵ



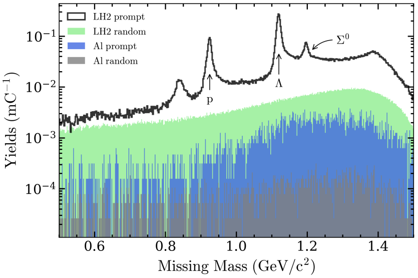
Combined

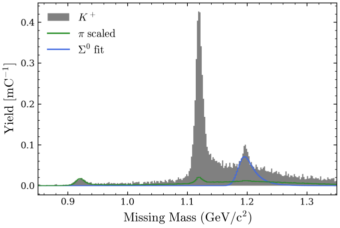


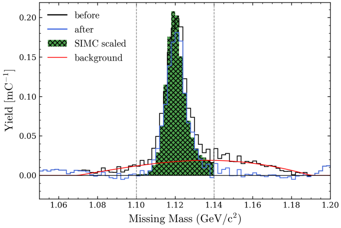
Analysis Procedures : Removing Background

Background contributions

- Random coincidence ($\sim 2\%$)
- dummy Al target ($\sim 5\%$)
- pion contamination $\rightarrow$ scale π data
- Σ^0 peak contamination
- empirical fit to match SIMC Λ shape







- **Repeat for each t/ϕ bin and extract yields** $M_X \in (1.10, 1.14)\ \mathrm{GeV}/c^2$

Analysis Procedures: Functional Form for Monte Carlo

Parameterization of cross section model in SIMC

- Used to weight each event in SIMC to match experimental kinematics and acceptance
- The choice of functional form must faithfully represent Hall C acceptance and kinematic distributions.

Model Structure Functions

$$\sigma_L = w \cdot p_0\, f(t)\, \exp(-p_1\, t)$$
$$\sigma_T = w \cdot p_4\, \exp(-p_5\, t)$$
$$\sigma_{LT} = w \cdot p_8\, \exp(-p_9\, t) \sin(\theta^* + \delta)$$
$$\sigma_{TT} = w \cdot p_{12}\, \exp(-p_{13}\, t) \sin^2 \theta^*$$

Global W-Weight

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

Physics

t-dependence: Exponential terms included in every structure function to describe fall-off.

Pole factor: $f(t) = \frac{1}{(t-M_K^2)^2}$ accounts for t-channel dominance in σ_L.

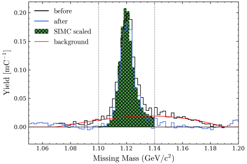
Interference terms: Angular $\sin\theta^*$ dependence ensures $\sigma_{LT}, \sigma_{TT} \to 0$ at parallel kinematics.

W-dependence: Global weight w accounts for variations across different t-bins.

Note: Any choice of form is valid as long as it correctly weights the cross-section within the Hall C acceptance.

0 Prepare Data Yields

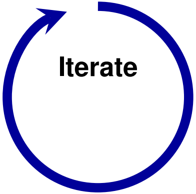
- diamond, acceptance, cointime
- subtract backgrounds
- M_X cut



1 Prepare σ_{MC} Model

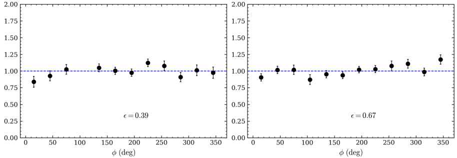
$$\sigma_L \equiv \sigma_L(t, \bar{Q^2}, \bar{W}, \bar{\theta^*}; p_0, p_1, \cdots)$$

5 Fit $\{p_i\}$ for next iteration



2 Compare Data Yields to SIMC Yields for each t/ϕ bin

$$\mathrm{R} = Y_{\mathrm{data}}/Y_{\mathrm{SIMC}}$$

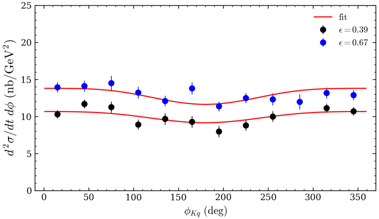


3 Normalize Cross Section with Yield Ratio

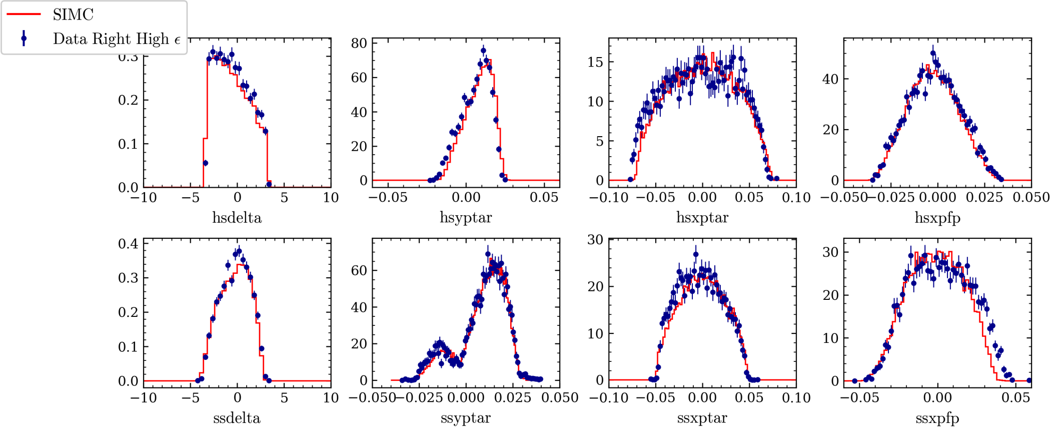
$$\sigma_{\mathrm{EXP}} = \frac{Y_{\mathrm{data}}}{Y_{\mathrm{SIMC}}} \cdot \sigma_{\mathrm{SIMC}}$$

4 **Simultaneously fit $\sigma_L, \sigma_T, \sigma_{LT}, \sigma_{TT}$ for each t bin**

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



HMS and SHMS distributions

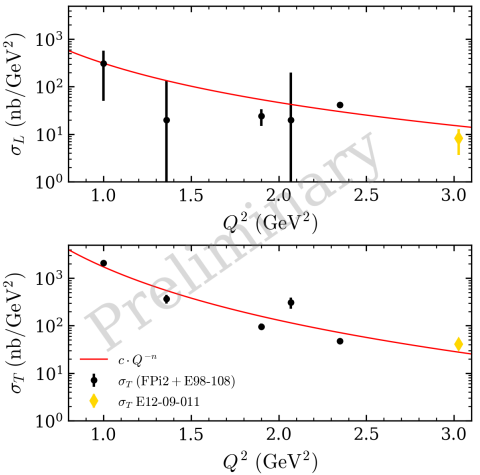


- Agreement between data and SIMC in both HMS and SHMS kinematic distributions after iteration.

Q^{-n} Scaling at $x_B \approx 0.3$

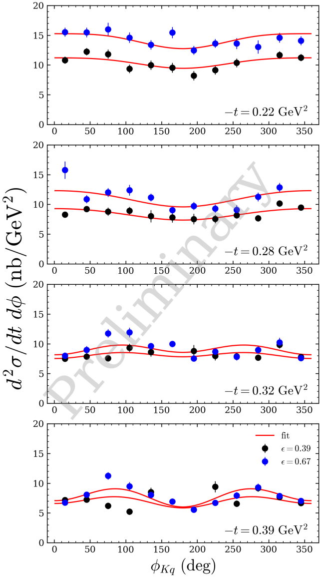
Test QCD Scaling Predictions

- Existing data : E93-018 and FPI2 at $x_B = 0.3, t = 0.4$.
- This work : $Q^2 = 3.0$ GeV^2, $x_B = 0.25, t \approx 0.4$ GeV^2.
- Fit results:
  - $\sigma_L \sim Q^{-5.50 \pm 0.25}$
  - $\sigma_T \sim Q^{-7.47 \pm 0.13}$

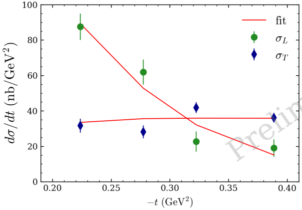


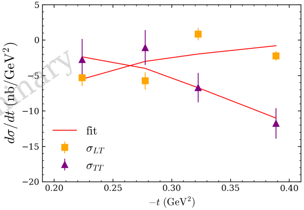
- Preliminary result shows consistency QCD scaling predictions.
- Further analysis required to scale new data to the same x_B and t using Regge model.

Preliminary Result $Q^2 = 3.0\ \text{GeV}^2, W = 3.14\ \text{GeV}, x_B = 0.25$



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





Result Summary

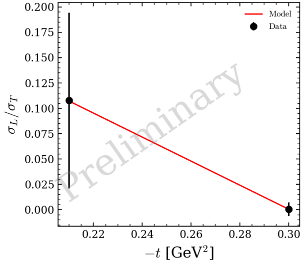
- Longitudinal term σ_L decreases exponentially with t indicating kaon pole dominance $\rightarrow$ Form factor extraction
- Transverse term $\sigma_T < \sigma_L$ and relatively flat across t $\rightarrow$ non-pole contribution
- Interference terms $\sigma_{TT} \rightarrow 0$ at low $|t|$ and $\sigma_{LT} \approx 0$ at all t (Only stat. uncertainty shown).

Cross section extraction other settings

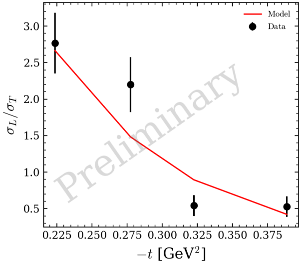
Preliminary Findings σ_L/σ_T

- $\sigma_L \sim \exp(t)$ in all settings suggest kaon pole dominance
- Feasibility of form factor extraction at high $Q^2 \approx 5\ \mathrm{GeV}^2$.
- $\sigma_T > \sigma_L$ at $Q^2 = 2.1, 4.4\ \mathrm{GeV}^2$
- relatively low statistics available these settings and further analysis required.

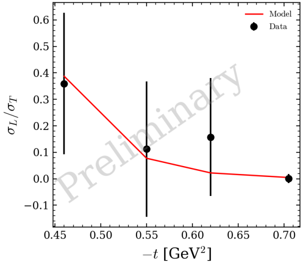
$Q^2 = 2.1\ \mathrm{GeV}^2$, $W = 2.95\ \mathrm{GeV}$



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



$Q^2 = 4.4\ \mathrm{GeV}^2$, $W = 2.74\ \mathrm{GeV}$



Preliminary Form Factor Extraction

Monopole Parameterization

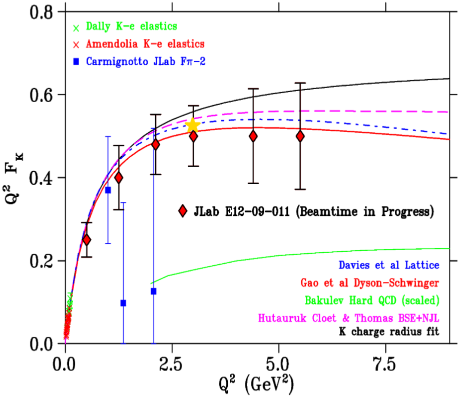
$$F_K(Q^2) = \frac{1}{1 + Q^2/\Lambda_K^2}$$

- Simultaneous fit of all structure functions using **VGL Regge model**.
- Model evaluated at precise kinematics (Q^2, W) for each t-bin.

χ^2 Minimization

$$\chi^2 = \sum_{i,j} \left(\frac{\sigma_{i,j}^{\text{data}} - \sigma_{i,j}^{\text{VGL}}(\Lambda_K)}{\delta\sigma_{i,j}^{\text{data}}} \right)^2$$

- **Best Fit:** $\Lambda_K^2 \approx 0.6849 \pm 0.0562$
- **Result:** $Q^2 F_K \approx 0.55$ at $Q^2 = 3.0$



Summary and Outlook

Summary

- ✓ **E12-09-011 Data:** Collection complete; analysis in progress for $Q^2 = 2.1 - 5.5$ GeV^2.
- ✓ **Methodology:** Successfully implemented iteration method for SIMC cross-section optimization.
- ✓ **Pole Dominance:** Preliminary results confirm Kaon pole dominance across multiple settings.
- ✓ **Extraction:** Preliminary F_K extraction at $Q^2 = 3.0$ GeV^2 via VGL Regge model.

Outlook

- → **Cross Analysis:** Verify results and perform rigorous systematic uncertainty studies.
- → **Scaling Study:** Complete $Q^2 = 2.1, 4.4, 5.5$ GeV^2 analysis to fit σ_L scaling.
- → **Modeling:** Incorporate Q^2-dependence into the global cross-section model.
- → **Finalization:** Apply Coincidence Blocking and corrected HMS matrix values in Replay.

Thank You for your attention!

Questions?

Backup : Q^{-n} Scaling across $x_B = 0.40$

Backup : Systematic Uncertainties Study (To-be-done)