L-T Separated Kaon production Cross Sections from 5-11 GeV

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- Motivation
- Experimental Details
- Summary

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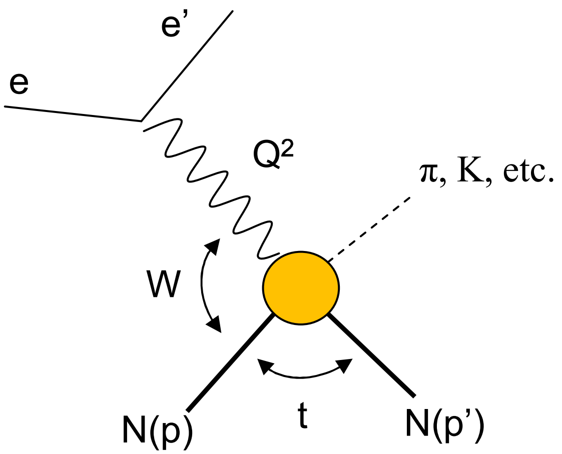
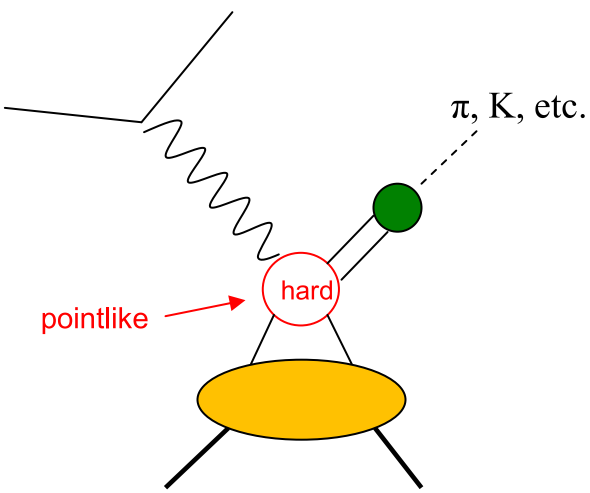
Meson Reaction Dynamics



t-channel process

- Meson production can be described by the t-channel exchange meson pole term in the limit of small –t and large W
  - Pole term is dominated by longitudinally polarized photons
  - Meson form factor describes the spatial distribution of the nucleon



handbag

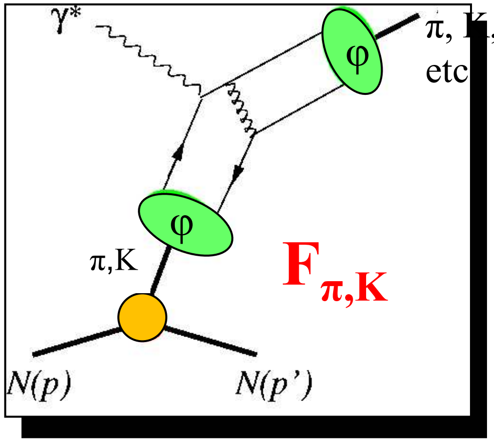
- At sufficiently high Q^2, the process should be understandable in terms of the "handbag" diagram
  - The non-perturbative (soft) physics is represented by the GPDs
    - Shown to factorize from QCD perturbative processes for longitudinal photons *[Collins, Frankfurt, Strikman, 1997]*

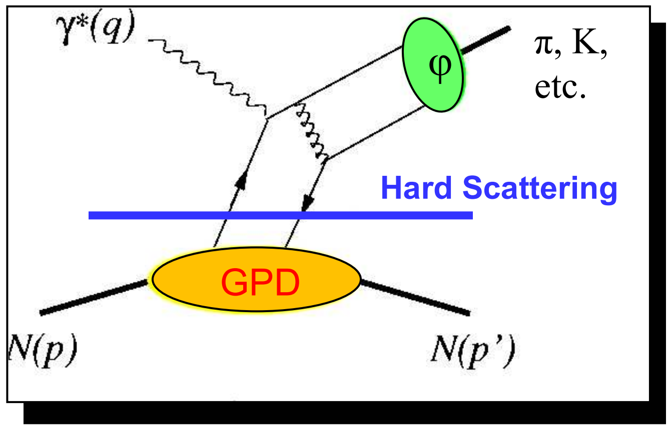
Form Factors and GPDs

- Form factors and GPDs are essential to understand the structure of nucleons, which make up nucleons and mesons (q-q̄ systems)

- But measurements of form factors and GPDs have certain prerequisites:
    - *Before we can start looking at form factors*, we must make sure that σ_L is dominated by the meson pole term at low -t
    - *Before we can learn about GPDs*, we must demonstrate that factorization applies

- A *comparison of pion and kaon* production data may shed further light on the reaction mechanism, and intriguing 6 GeV pion results





Context

- Understanding the kaon reaction mechanism is essential for form factor and GPD programs at 12 GeV
  - GPD studies require evidence of soft-hard factorization
  - Provides information about basic coupling constants through $\sigma(K^+\Sigma^\circ/K^+\Lambda)$ ratio
  - In order to reliably extract the kaon form factor, the influence of non-pole t-channel contributions must be shown to be modest in comparison to pole contributions

- Verifying dominance of pole contributions from unseparated kaon data is complicated by transverse contributions
  - Relative σ_L and σ_T contributions are also needed for GPD extractions since they rely on the dominance of σ_L

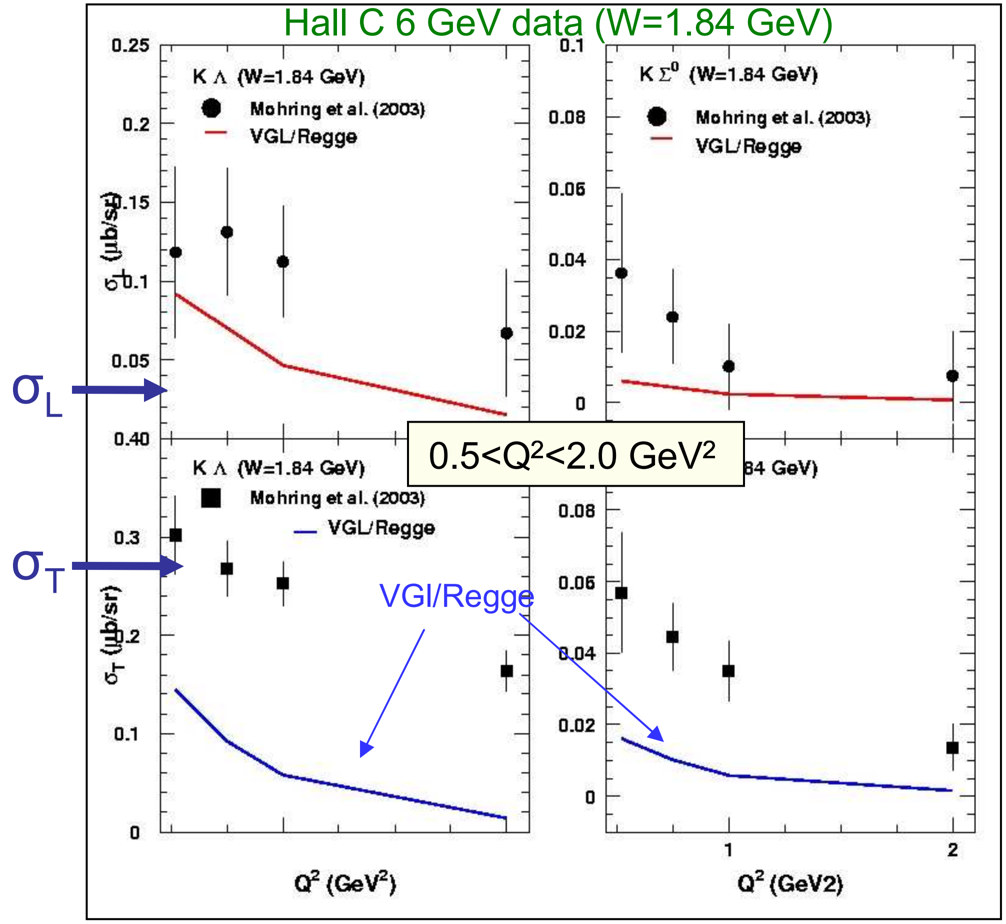
- Limited knowledge of L/T ratio at higher energies limits the interpretability of *unseparated* cross sections in kaon production

– Separated kaon production data from JLab suggest that transverse contributions are larger than predicted by Regge model calculations

Kaon σ_L, σ_T, and L/T ratio *unknown* above the resonance region

Transverse Contributions

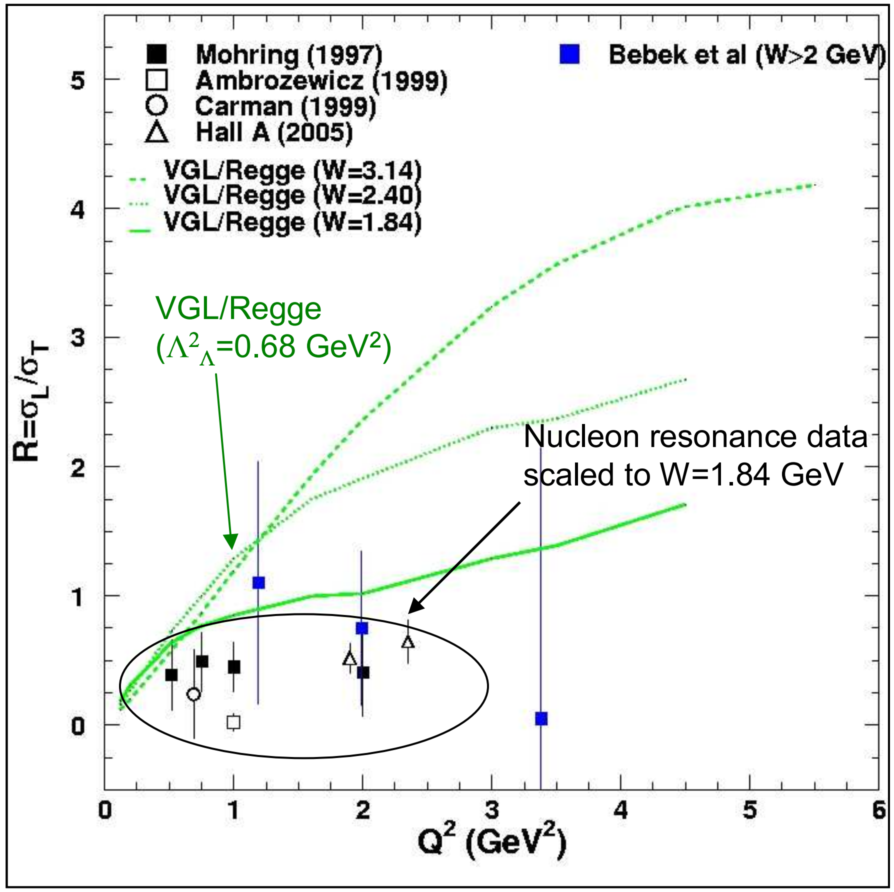
- In the resonance region at Q^2=2.0 GeV^2 σ_T is not small
- In pion production, σ_T is also much larger than predicted by the VGL/Regge model *[PRL**97**:192001 (2006)]*
- Why is σ_T so large? Difficult to draw a conclusion from current data
  - Limited W and Q^2 range
  - Significant uncertainty due to scaling in x_B and –t



High quality σ_L and σ_T data for both kaon and pion would provide important information for understanding the meson reaction mechanism

$R=\sigma_L/\sigma_T$: Kaon form factor prerequisite

- Meson form factor extraction requires a good reaction model
  - Need high quality data to develop these models
- Current knowledge of σ_L and σ_T *above* the resonance region is insufficient
  - Role of the t-channel kaon exchange in amplitude unclear
- Not clear how to understand reaction mechanism through current models



L/T separations above the resonance region are essential for building reliable models, which are also needed for form factor extractions

Kaon Production Mechanism: Summary

- Understanding $K^+\Lambda$ and $K^+\Sigma^\circ$ are important in our study of hadron structure
  - Flavor degrees of freedom provide important information for QCD model building and understanding of basic coupling constants
- $K^+\Lambda$ and $K^+\Sigma^\circ$ have been relatively unexplored because of lack of the necessary experimental facilities
  - There are practically no precision L-T separated data for exclusive K^+ production from the proton above the resonance region

- JLab measurements at beam energies up to 6 GeV:
  - Hall B: W=1.6-2.8 GeV (separated σ_L and σ_T *only* for W<2GeV)
    - focus on the resonance region
  - Hall C: W=1.84 GeV
    - full separation in the resonance region
  - Hall A: W=1.8-2.1 GeV (separated σ_L and σ_T *limited to the resonance* region)

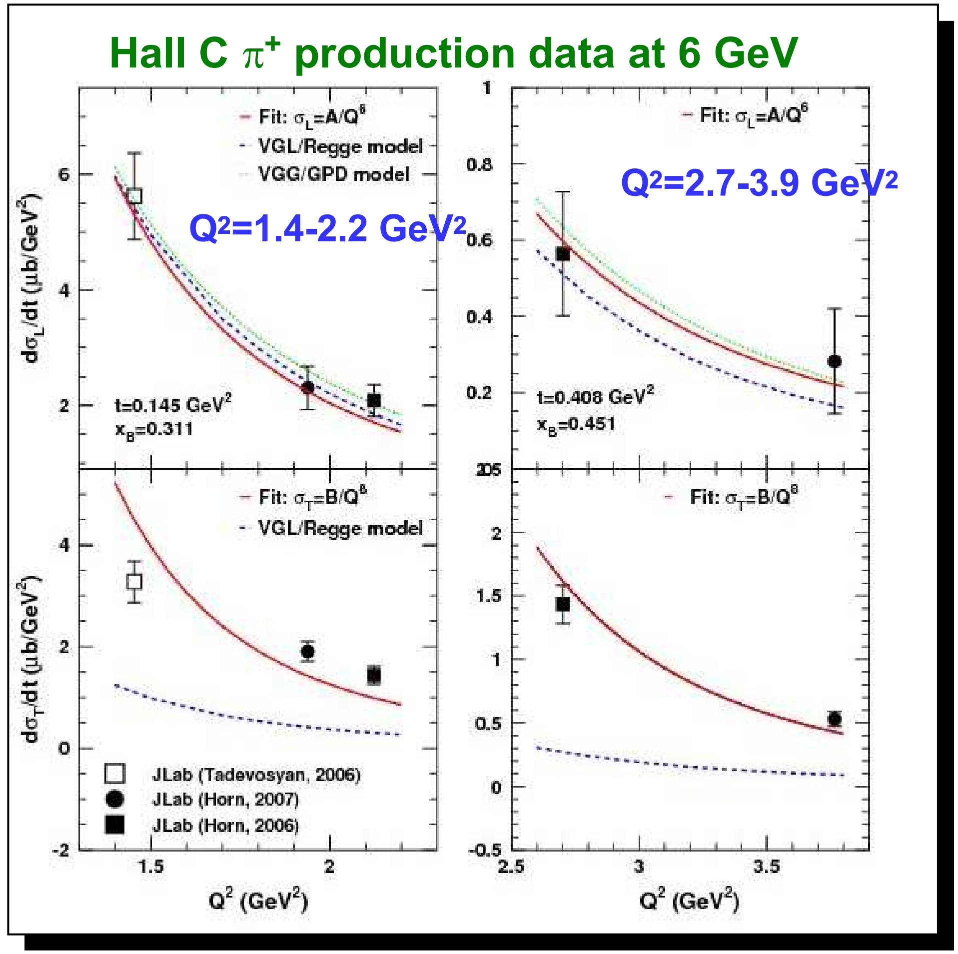
12 GeV: access to kaon production above resonance region!

High Q^2: Q^{-n} scaling of σ_L and σ_T

- To access physics contained in GPDs, one is limited to the kinematic regime where hard-soft factorization applies
- A test is the Q^2 dependence of the cross section:
  - $\sigma_L \sim Q^{-6}$ to leading order
  - $\sigma_T \sim Q^{-8}$
  - As Q^2 gets large: $\sigma_L >> \sigma_T$
- The QCD scaling prediction is reasonably consistent with recent JLab π^+ σ_L data, *BUT* σ_T does not follow the scaling expectation

σ_L →

σ_T →



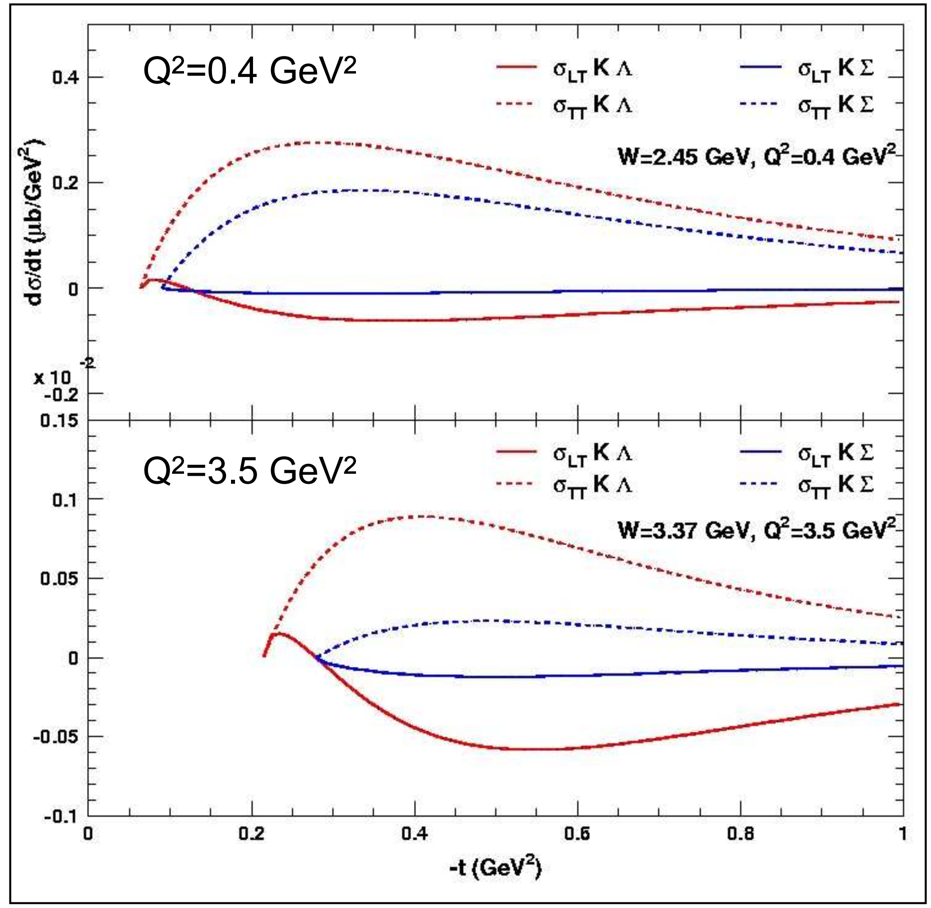
T. Horn et al., Phys. Rev. C78, 058201 (2008)

Kaon production data would allow for a quasi model-independent comparison that is more robust than calculations based on QCD factorization and present GPD models

Bonus: Interference Terms

- In the hard scattering limit, these terms are expected to scale:
  - $\sigma_{LT} \sim Q^{-7}$
  - $\sigma_{TT} \sim Q^{-8}$
- Additional information about the reaction mechanism may be obtained for free if one performs a full cross section separation

$K^+\Lambda(\Sigma°)$ as calculated in VGL/Regge model

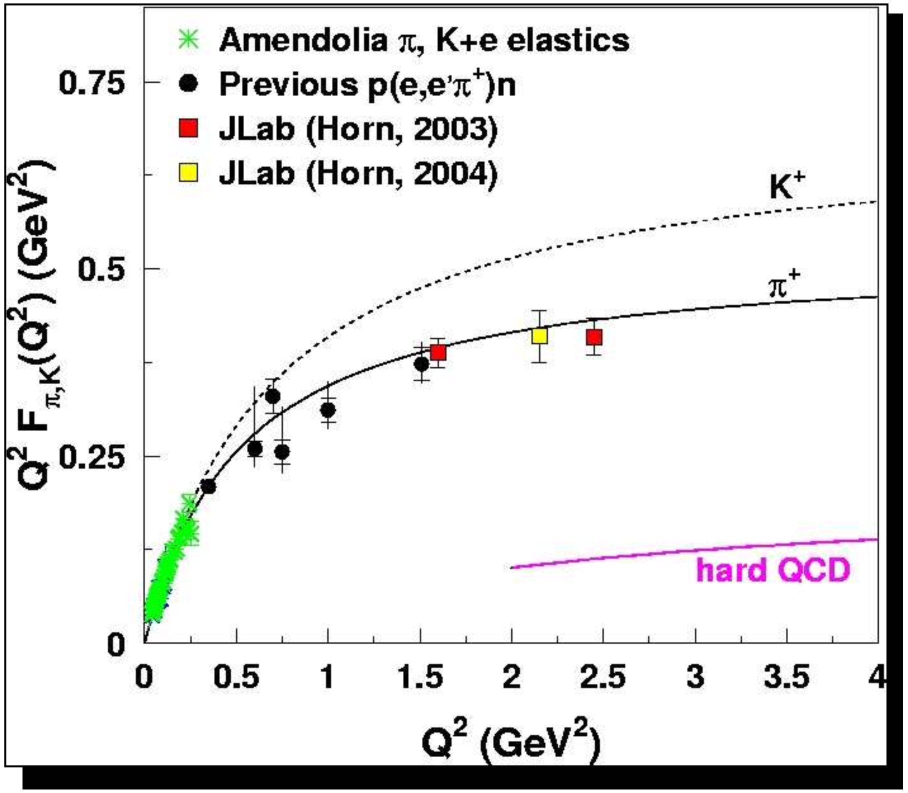


Bonus: $F_{\pi,K}$ - a factorization puzzle?

T. Horn et al., Phys. Rev. Lett. 97 (2006) 192001.

T. Horn et al., arXiv:0707.1794 (2007).

- The Q^2 dependence of F_π is also consistent with hard-soft factorization prediction (Q^{-2}) at values $Q^2>1$ GeV^2
- *BUT* the observed magnitude of F_π is larger than the hard QCD prediction
  - Could be due to QCD factorization not being applicable in this regime
  - Or insufficient knowledge about additional soft contributions from the meson wave function



Comparing the observed Q^2 dependence of $\sigma_{L,T}$ and FF magnitude with kaon production would allow for better understanding of the onset of factorization

Motivation Summary

- L/T separated kaon production cross sections play a large role in our understanding of form factors
  - If σ_L not dominated by the K^+ pole term at low -t, we cannot extract the form factor from the data and interpretation of unseparated data questionable
- The charged kaon L/T ratio is of significant interest to the study of GPDs at 12 GeV
  - Can only learn about GPDs if soft-hard factorization applies
  - If transverse contributions are large, the accessible phase space may be limited

Our theoretical understanding of hard exclusive reactions will benefit from L/T separated kaon data over a large kinematic range

- Constraints for QCD model building using both pion and kaon data
- Understanding of basic coupling constants (Σ°/Λ ratio)
- Quasi model-independent comparison of pion and kaon data would allow a better understanding of the onset of factorization

Experimental Goals

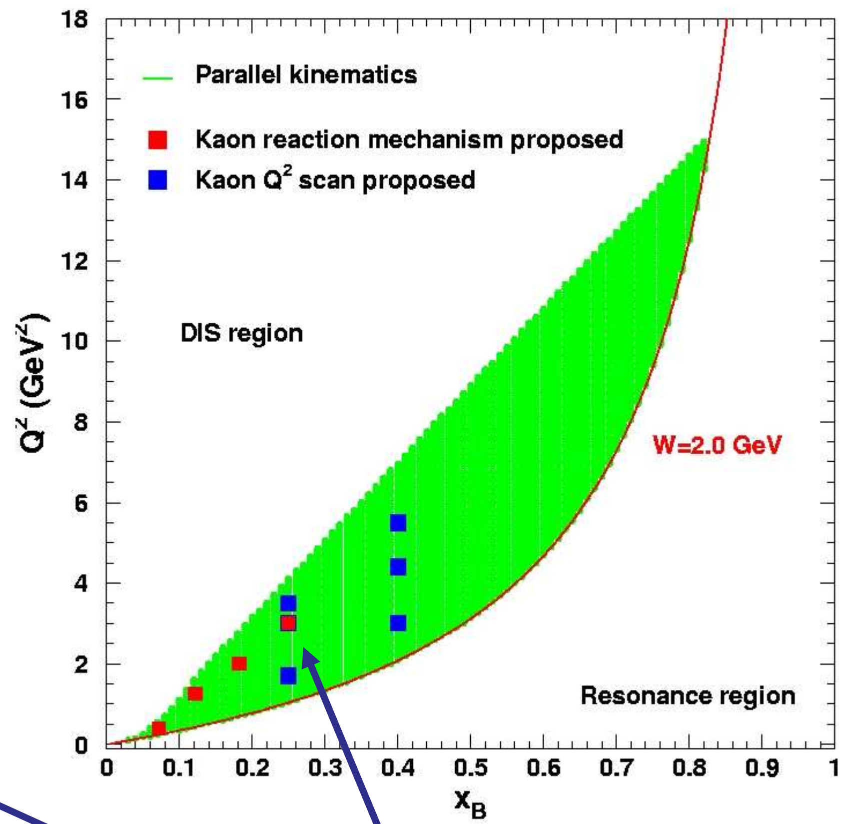
- Measure the –t dependence of the $p(e,e'K^+)\Lambda,\Sigma^\circ$ cross section at fixed Q^2 and W>2.5 GeV to search for evidence of K^+ pole dominance in σ_L
  - Separate the cross section components: L, T, LT, TT
  - First L/T measurement above the resonance region in K^+ production

- Measure the Q^2 dependence of the $p(e,e'K^+)\Lambda(\Sigma^\circ)$ cross section at fixed x_B and –t to search for evidence of hard-soft factorization
  - Separate the cross section components: L, T, LT, TT
  - The highest Q^2 for any L/T separation in $K+$ electroproduction

- If warranted by the data, extract the Q^2 dependence of the kaon form factor to shed new light on the apparent pion form factor scaling puzzle

Experiment Overview

- Measure the separated cross sections at varying –t and x_B
  - If K^+ pole dominates σ_L allows for extraction of the kaon ff (W>2.5 GeV)
- Measure separated cross sections for the p(e,e'K^+)$\Lambda(\Sigma^\circ)$ reaction at two fixed values of –t and x_B
  - Q^2 coverage is a factor of 2-3 larger compared to 6 GeV at much smaller –t
  - Facilitates tests of Q^2 dependence even if L/T ratio less favorable than predicted



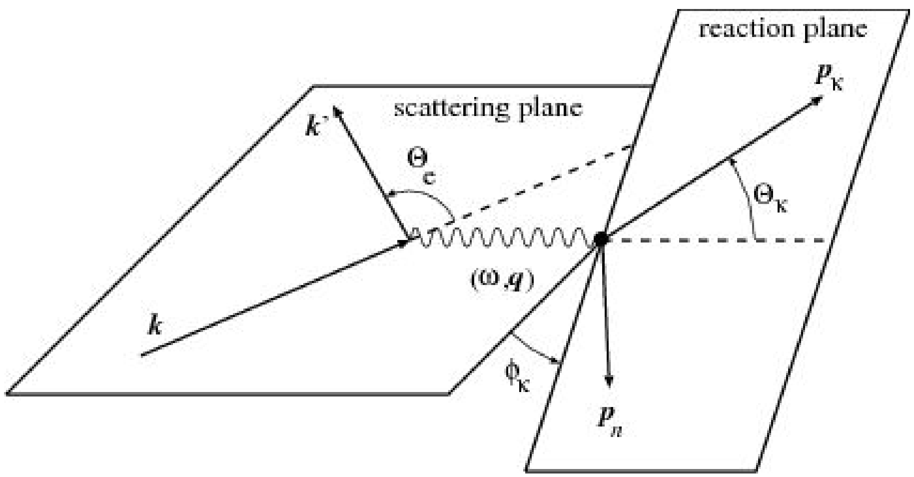
x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.1-0.2	0.4-3.0	2.5-3.1	0.06-0.2
0.25	1.7-3.5	2.5-3.4	0.2
0.40	3.0-5.5	2.3-3.0	0.5

Q^2=3.0 GeV^2 was optimized to be used for both t-channel and Q^{-n} scaling tests

Cross Section Separation

- The virtual photon cross section can be written in terms of contributions from transversely and longitudinally polarized photons.

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

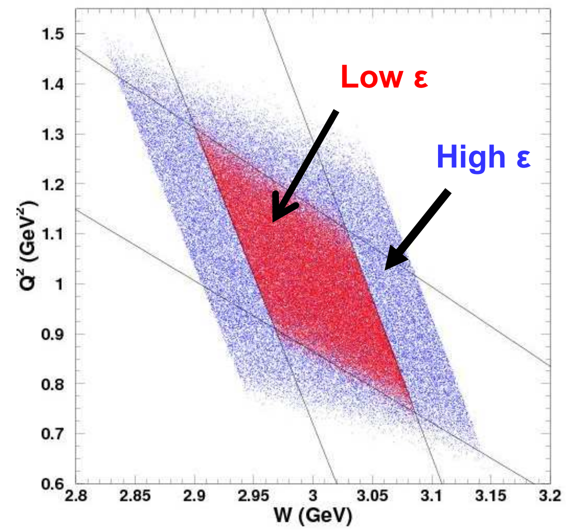


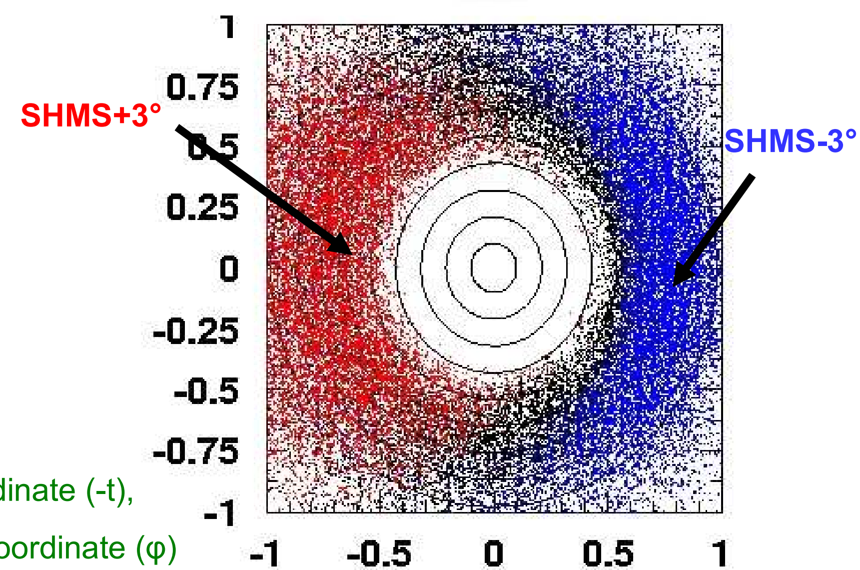
- Separate σ_L, σ_T, σ_{LT}, and σ_{TT} by simultaneous fit using measured azimuthal angle (φ_K) and knowledge of photon polarization (ε)

Separation in a Multi-Dimensional Phase Space

- Cuts are placed on the data to equalize the Q^2-W range measured at the different ε-settings

- Multiple SHMS settings (±3° left and right of the **q** vector) are used to obtain good φ coverage over a range of –t
  - Measuring $0<\varphi<2\pi$ allows to determine L, T, LT and TT



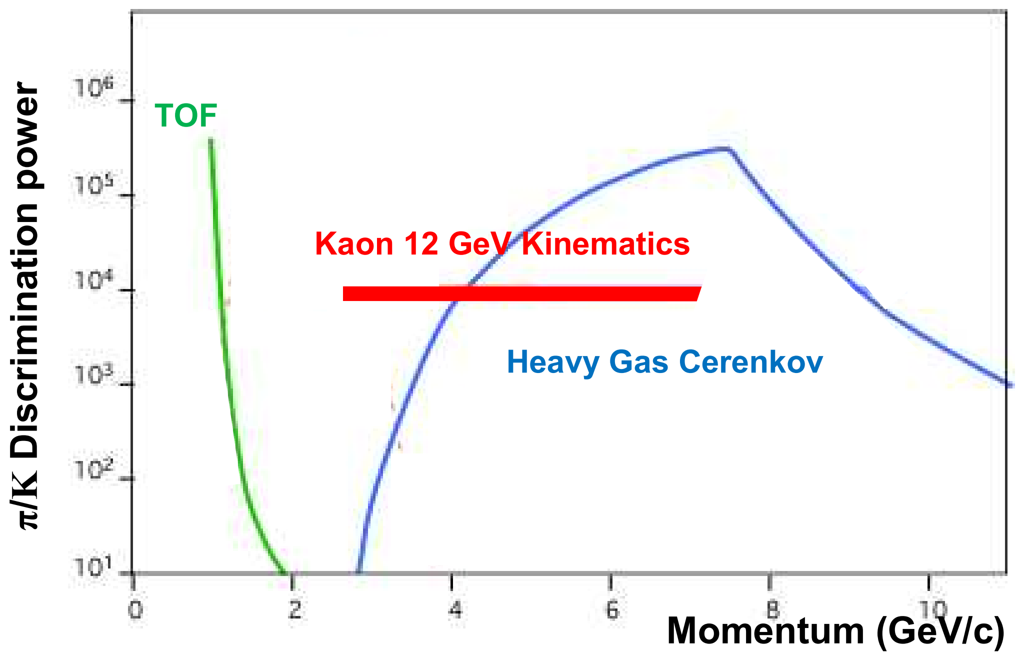


Radial coordinate (-t),

Azimuthal coordinate (φ)

Kaon PID

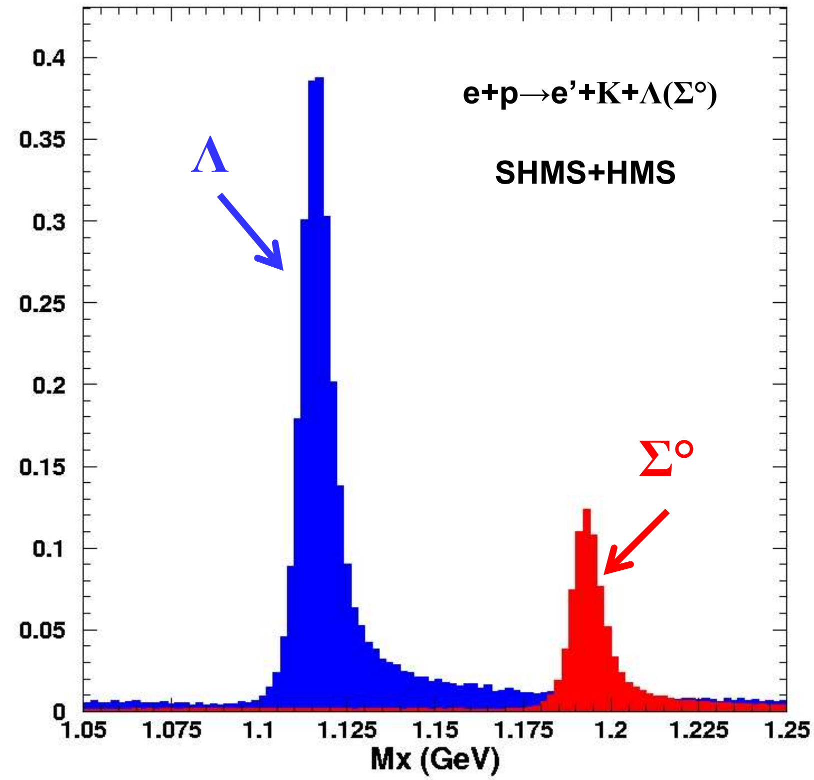
- π^+/K^+ separation provided by heavy gas Cerenkov for p_{SHMS}>3.4 GeV/c
  - Detector is being built by U.o.Regina
- For reliable K^+/p separation above 3 GeV/c an aerogel Cerenkov is essential
  - Provision has been made in the SHMS detector stack for two threshold aerogel detectors



- Four sets of aerogel would provide reliable K^+/p separation over the full momentum range (2.6-7.1 GeV/c)
- Alternate PID methods (such as RICH) are also possible

Expected Missing Mass Resolution

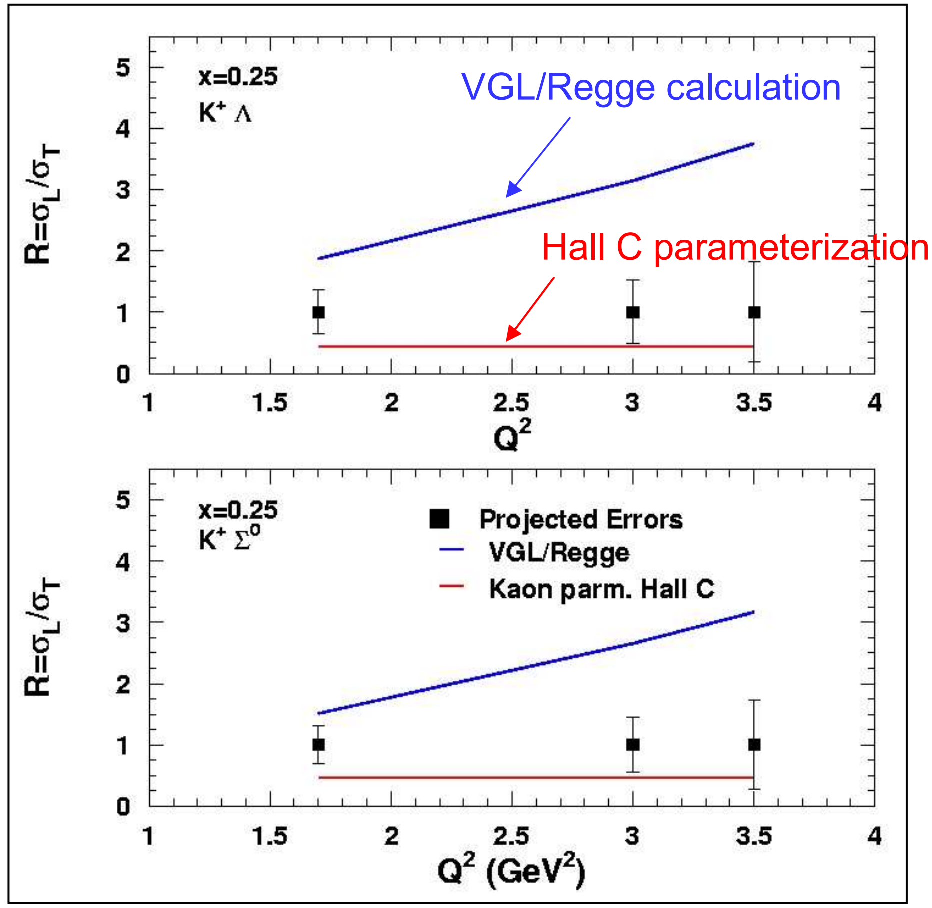
- Missing mass resolution (~30 MeV) is clearly sufficient to separate Λ and Σ° final states
- Good π^+/K^+ (p/K^+) separation using gas (aerogel) Cerenkov, and also accidental coincidence subtraction
- Acceptance allows for simultaneous studies of both Λ and Σ° channels
  - Total effect of the Λ tail and possible collimator punch-through to $K^+\Sigma^\circ$ projected to be <0.1% of the size of the tail



Simulation at Q^2=2.0 GeV^2 , W=3.0 and high ε

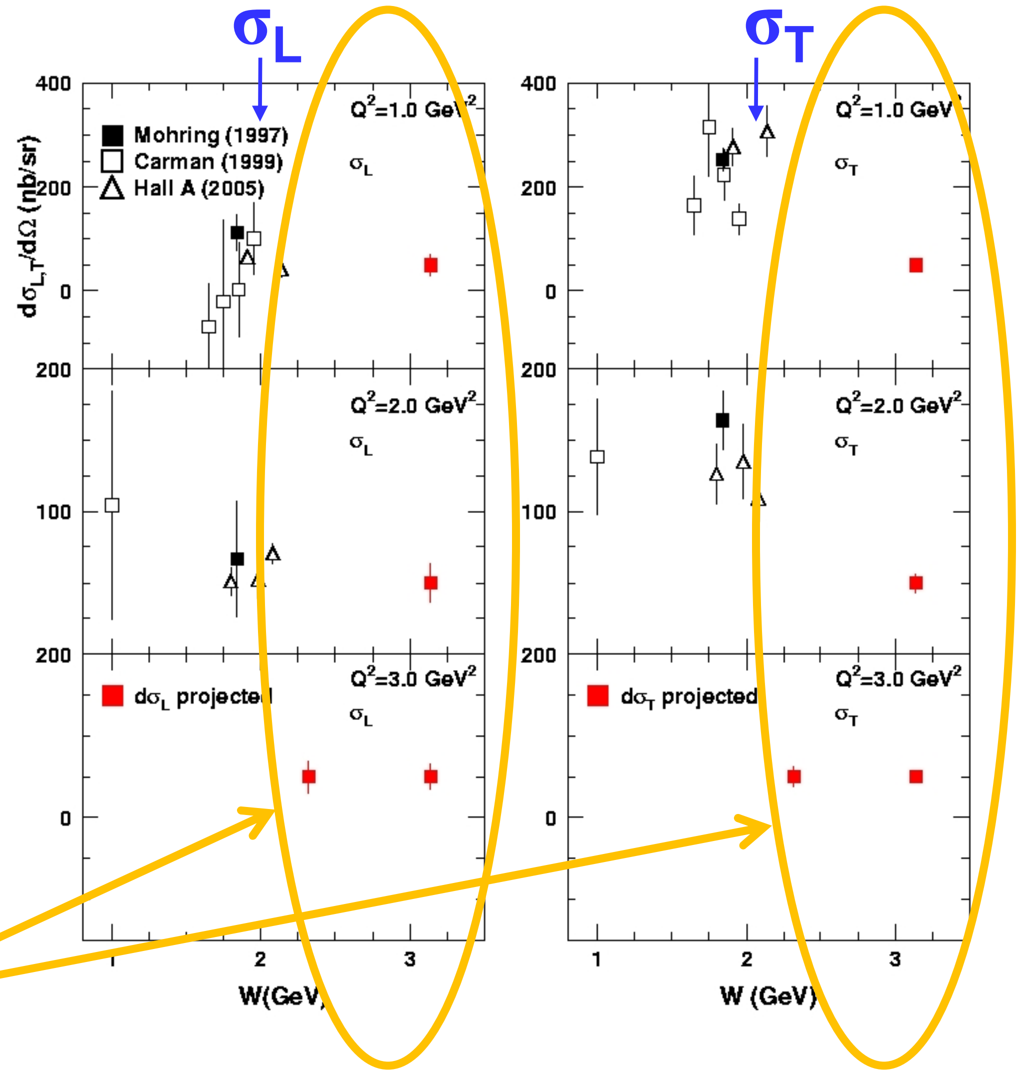
Projections of $R=\sigma_L/\sigma_T$

- Empirical kaon parameterization based on Hall C data was used in rate estimates
  - Conservative assumptions on the evolution of L/T ratio
  - Projected Δ(L/T)=28-60% (10-33% using VGL/Regge) for typical kinematics
- PR12-09-011 may indicate larger values of R, with associated smaller uncertainties
  - Reaching Q^2=8 GeV^2 may ultimately be possible



Projected Uncertainties for σ_L and σ_T

- High quality kaon L/T separation above the resonance region
- Projected uncertainties for σ_L and σ_T use the L/T ratio from Hall C parameterization

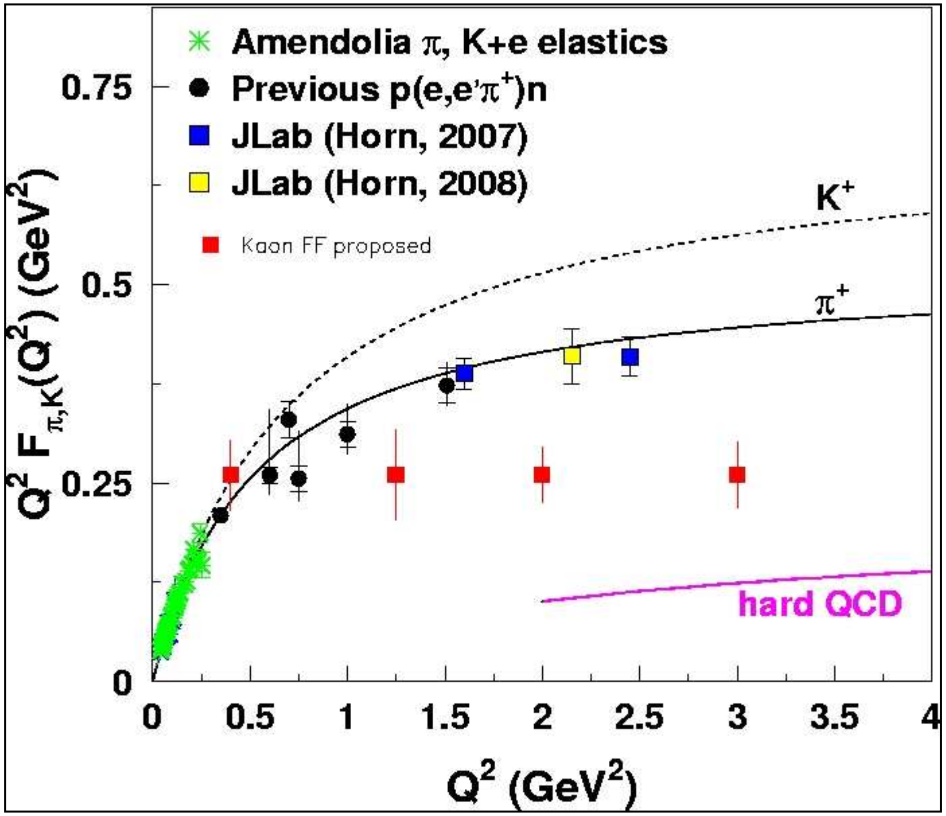


PR12-09-011: Precision data for W > 2.5 GeV

Projected Uncertainties for the Kaon FF

- If the K^+ pole dominates low -t σ_L, we would for the first time extract F_K above the resonance region (W>2.5 GeV)

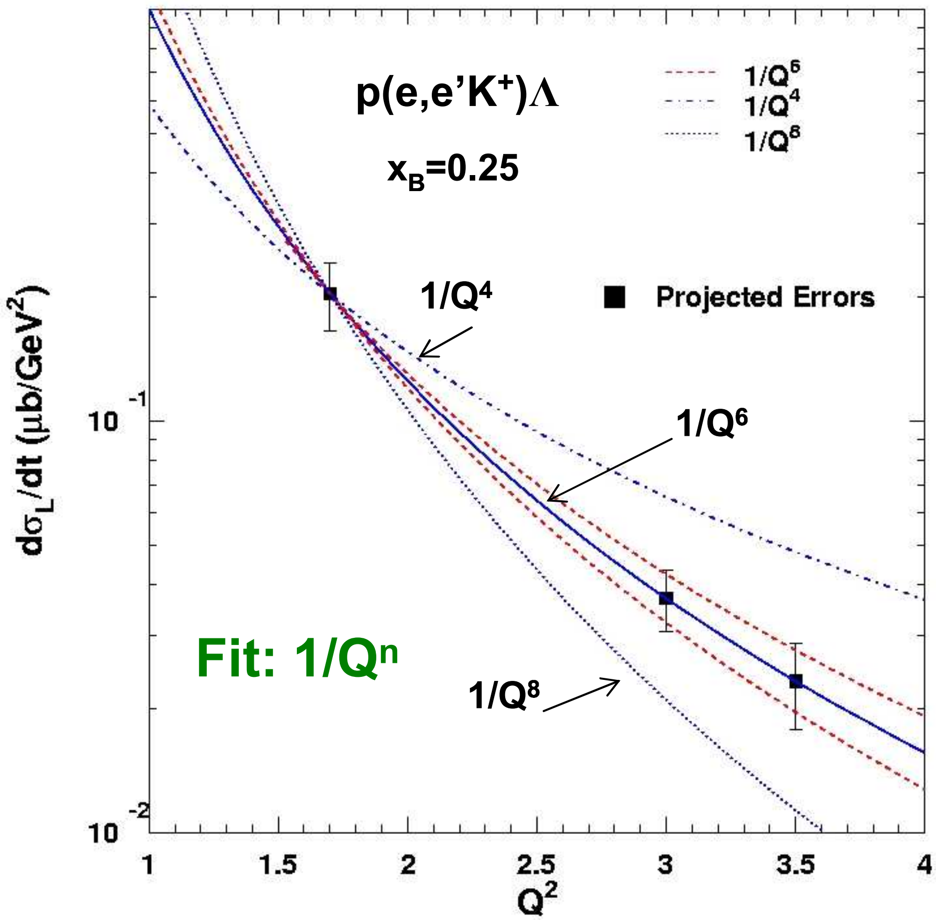
- Projected uncertainties for σ_L use the L/T ratio from Hall C parameterization



Projected Uncertainties for Q^{-n} scaling

- QCD scaling predicts $\sigma_L \sim Q^{-6}$ and $\sigma_T \sim Q^{-8}$
- Projected uncertainties use R from the Hall C parameterization

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



Is onset of scaling different for kaon than pion?
Kaons and pions together provide quasi model-independent study

Beam Time Estimate

Q^2 (GeV^2)	xB	LH2 (hrs)	Dummy	Overhead (hrs)	Total (hrs)
0.40	0.072	189.4	12.9	8	210.3
1.25	0.122	29.5	2.1	8	39.6
2.00	0.182	113.4	7.9	12	133.3
3.00	0.250	159.3	11.2	8	178.5
Subtotal react mech					**561.7 (23.4 days)**
1.70	0.25	39.4	2.8	8	50.2
3.50	0.25	103.5	0.7	8	112.2
Subtotal x=0.25					**162.4 (6.8 days)**
3.00	0.40	19.2	1.3	8	28.5
4.40	0.40	62.6	4.4	8	75.0
5.50	0.40	179.5	12.5	8	200.0
Subtotal x=0.40					**303.5 (12.6 days)**
Subtotal LH_2/K^+		895.8	55.8	76	1027.6
Calibrations					48.0
Beam energy					48.0
Total					**1123.6 (46.8 days)**

PR12-09-011 Summary

- L/T separated K^+ cross sections will be essential for our understanding of the reaction mechanism at 12 GeV
  - If transverse contributions are found to be large, the accessible phase space for GPD studies may be limited
  - Basic coupling constants in kaon production (Σ°/Λ ratio)
  - If t-channel exchange dominates σ_L, we can perform the first reliable extraction of the kaon form factor above the resonance region

- L/T separated K^+ data over a wide kinematic range will have a significant impact on our understanding of hard exclusive reactions
  - Constraints on QCD model building using both pion and kaon data
  - Quasi model-independent comparison of kaon and pion data would allow better understanding of the onset of factorization

Request 47 days to provide first precision L/T separated kaon production data above the resonance region. Excellent candidate for early running.