L/T Separated Kaon Production Cross Sections from 5-11 GeV

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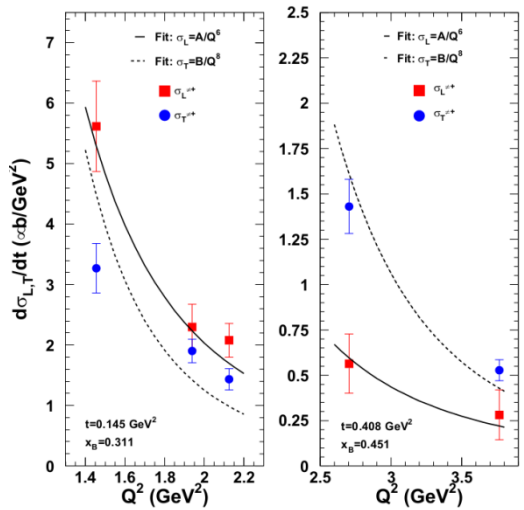
Marco Carmignotto, Salina Ali, Samip Basnet, Jonathan Castellanos, Arthur Mkrtchyan

For the Kaon-12GeV collaboration

Highlights:

- PAC “strongly endorses this proposal”
- First L/T separated data with SHMS
- Kaon scaling behavior and form factor extraction
- 40 days of beam time approved

Physics Motivation



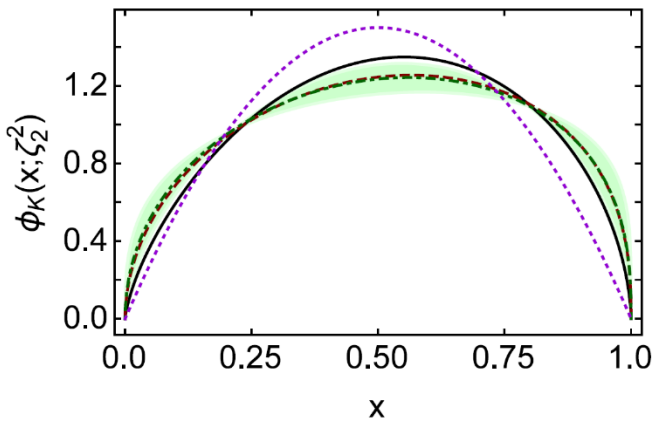
- Probe conditions for factorization for deep exclusive measurements of charged kaons

  The QCD scaling prediction ($\sigma_L \sim Q^{-6}$) is reasonably consistent with recent 6 GeV JLab π^+ σ_L data, *but* σ_T does not follow the scaling expectation ($\sigma_T \sim Q^{-8}$) and magnitude is large

  *[L. Favart, M. Guidal, T. Horn, P. Kroll, Eur. Phys. J. A **(2016)** 52: 158]*

  *[T. Horn et al., Phys. Rev. C **78**, 058201 **(2008)**]*

  - Data could open a new domain for GPD study since virtually nothing is known concerning these quantities when strangeness is in play



- New insight into transition between the non-perturbative and perturbative domains

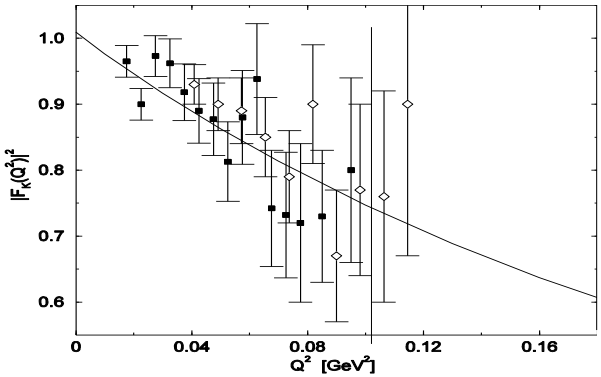
  Reliable prediction for trend of kaon form factor depends on the distortion and/or dilution of the kaon distribution amplitude

  - Data could contribute a great deal to our understanding of kaon internal structure

*[T. Horn, C.D.Roberts, J.of Phys. G, Vol. 43, Issue 7, 073001 **(2016)**]*

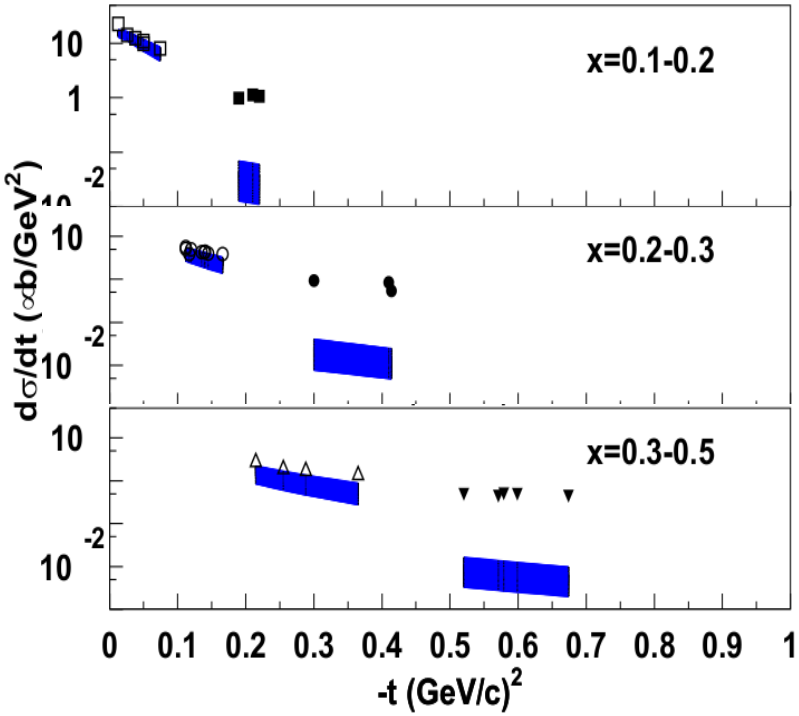
*[I. Cloet et al., PRL 111, 092001 **(2013)**]*

Determining the K^+ Form Factor



- Similar to π^+ form factor, elastic Kaon scattering from electrons used to measure charged kaon for factor at low Q^2 *[Amendolia et al, PLB 178, 435 (1986)]*
  - Kaon charge mean radius extracted from this data

- Can "kaon cloud" of the proton be used in the same way as the pion to extract kaon form factor via ***p(e,e'K⁺)Λ*** ? – *need to quantify the role of the kaon pole*



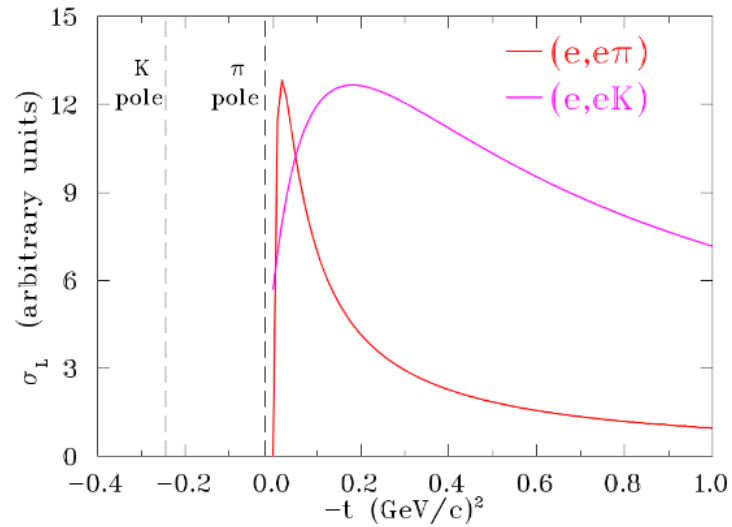
- ***At large t:***
  - *Unseparated* data: pion t-dependence is steeper than for kaons *[T. Horn, Phys. Rev. C **85 (2012)** 018202]*

- ***At small t:***
  - *Kaon pole is expected to be strong enough to produce a maximum in σ_L*

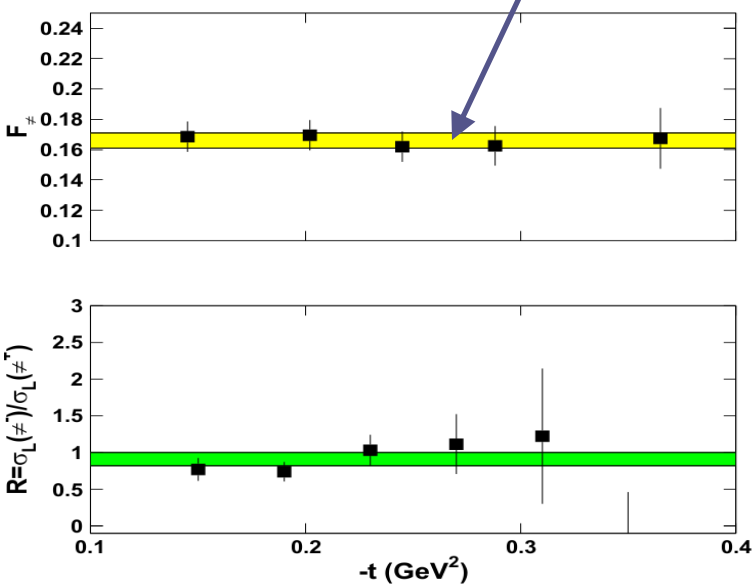
    [Kroll/Goloskokov EPJ A47 (2011), 112]
  - Verify this experimentally at 12 GeV JLab

Experimental Considerations

Experimental studies over the last decade have given *confidence* in the electroproduction method yielding the physical pion form factor



- Extraction of F_{π^+} from pion electroproduction data at small t by careful study of the model dependence
- Initial comparative extraction of F_{π^+} at low and large t suggests only small model dependence



- Large t pion data lie at similar distance from pole as most of the projected K^+ data

12 GeV π^+ experiment

Q^2	t	dt
2.45	0.145	0.165
2.45	0.202	0.222
2.45	0.288	0.265
2.45	0.219	0.308
2.45	0.365	0.385
4.0	0.40	0.470
4.0	0.70	0.720

12 GeV K^+ experiment

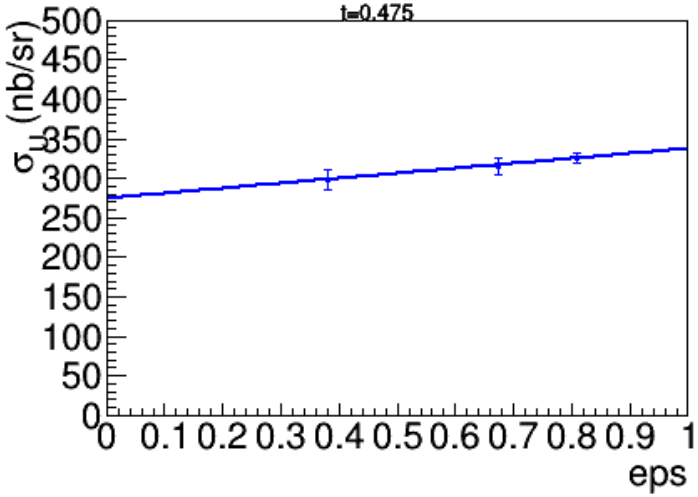
Q^2	t	dt
0.4	0.064	0.307
1.3	0.084	0.327
2.0	0.138	0.381
3.0	0.219	0.462
1.7	0.200	0.443
3.5	0.200	0.443
3.0	0.500	0.743
5.5	0.500	0.743

- Additional test: consistency of Λ/Σ^0 ratio with coupling constant ratios

JLab 6 GeV: F_K extractions from kaon electroproduction data

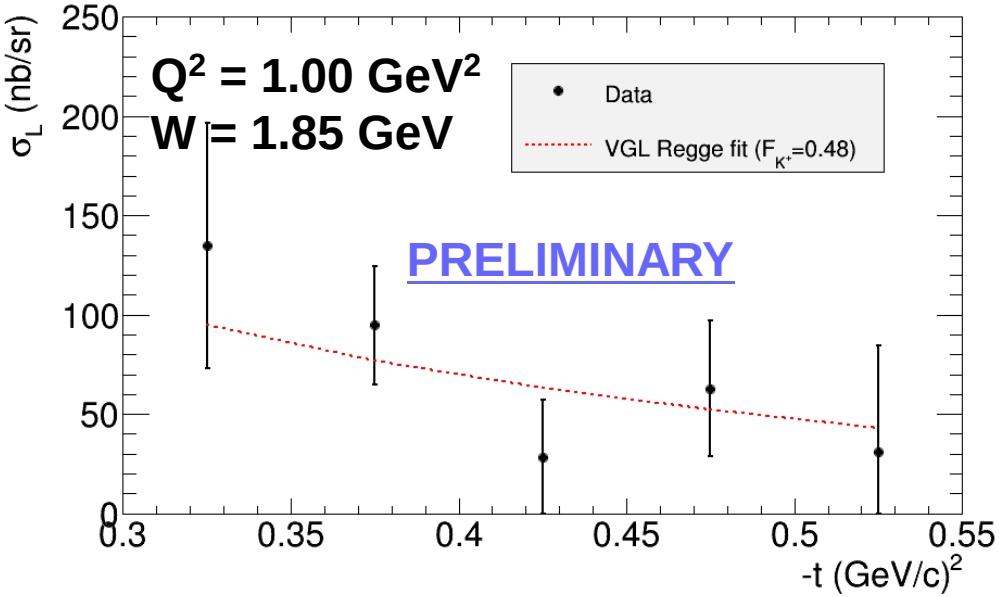
Kaon experiment (E93-018)

- Analyze data with same techniques as used for pion analysis and extract F_{K+}
- LT separation
- Extracted kaon Form Factor from longitudinal cross section data using VGL Regge model



Measured at three virtual photon polarizations

[Analysis by Marco Carmignotto]



$$F_{K+}(Q^2) = \frac{1}{1 + Q^2 / \Lambda^2_{K+}}$$

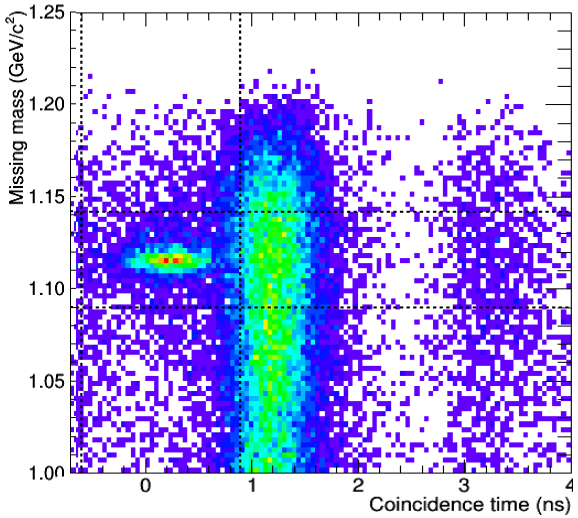
Fit of σ_L to model gives F_{K+} at each Q^2

- Preliminary data analysis shows maybe some pole-like behavior
- Data analysis ongoing – expect final results in a few months

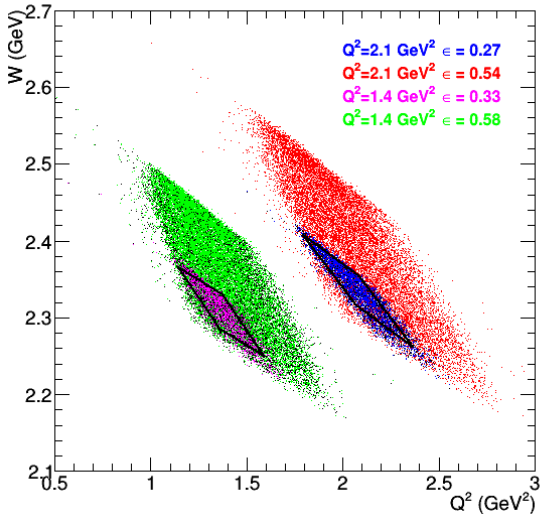
JLab 6 GeV potential FK extractions using kaons from "pion" experiments [Analysis by Marco Carmignotto]

Kaons in FPI-2 experiment

- Experiment not originally designed for K^+

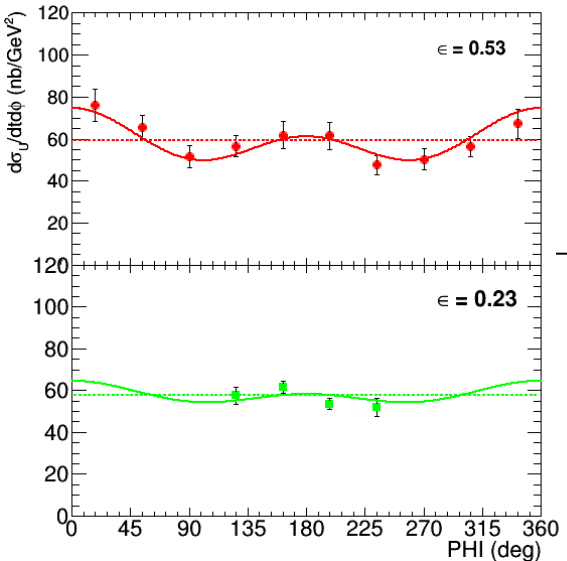


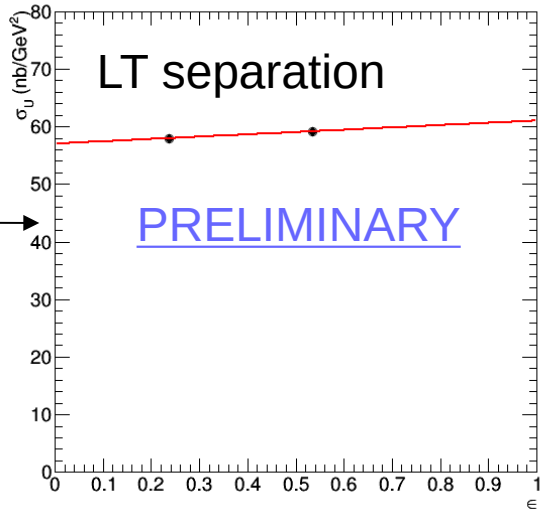
- LT separation above the resonance region
- Next steps: Systematic uncertainties and possibility of binning in t to determine F_K



Matching phase-space: kaons at edge of phase space

$Q^2 = 2.05\ GeV^2$
$W = 2.35\ GeV$
$\theta^*_{qK} = 2.6^o$





Insight from data: Kaon transverse charge density

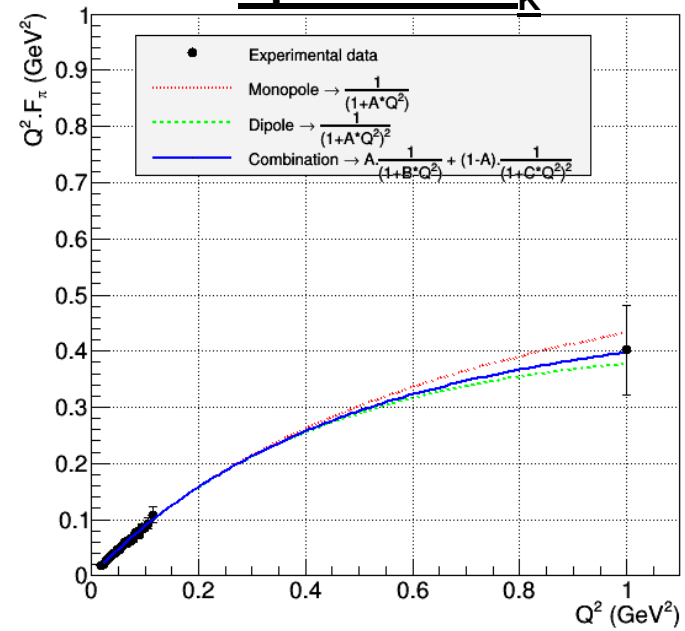
- In a *non-relativistic* model the pion charge distribution is the Fourier Transform of the form factor
- *However*, in particular for the *light-mass pion* this non-relativistic Fourier Transform interpretation is not correct
- Correct interpretation has been developed in terms of the *transverse charge distribution*

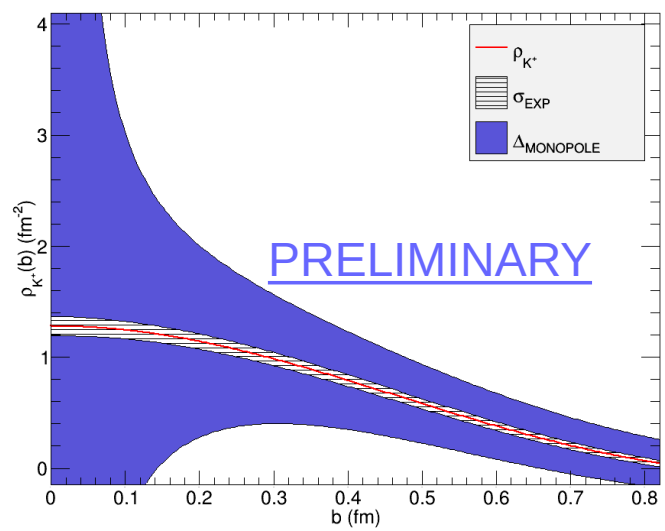
*[S. Venkat et al., PRC **83 (2011)** 015203]*

$$\rho_\pi(b) = \frac{1}{\pi R^2}\sum_{n=1}^{\infty} F_\pi(Q_n^2)\frac{J_0(X_n \frac{b}{R})}{[J_1(X_n)]^2} \qquad Q_n \equiv \frac{X_n}{R}$$

- Uncertainty in space like data analysis dominated by incompleteness error (measurements of F_K very limited in Q^2)
- 12 GeV Jlab Measurements can improve this

Space-like F_K





[Mecholsky, Horn, Pegg, Carmignotto, Miller]

Insight from data: Kaon transverse charge density

- Evaluate kaon transverse density based on a dispersion representation of the kaon form factor
  - Dispersion relation uses ***time-like data***

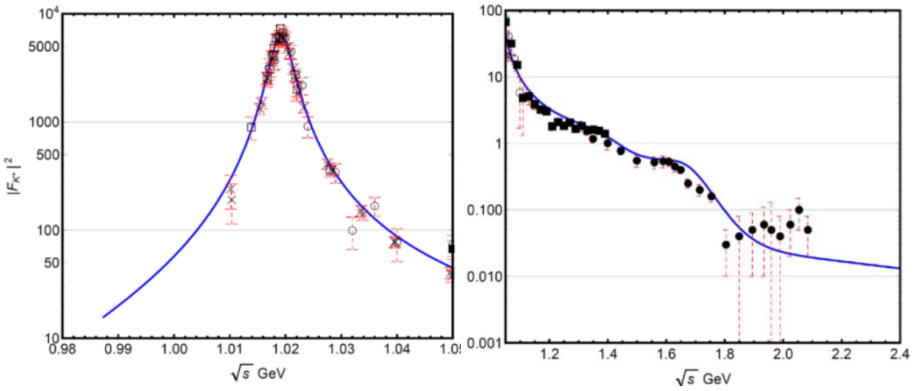
$$F_K(t) = \frac{1}{\pi} \int_{4m_K^2}^{\infty} dt' \frac{\mathrm{Im}\, F_K(t')}{t' - t + i\varepsilon}$$

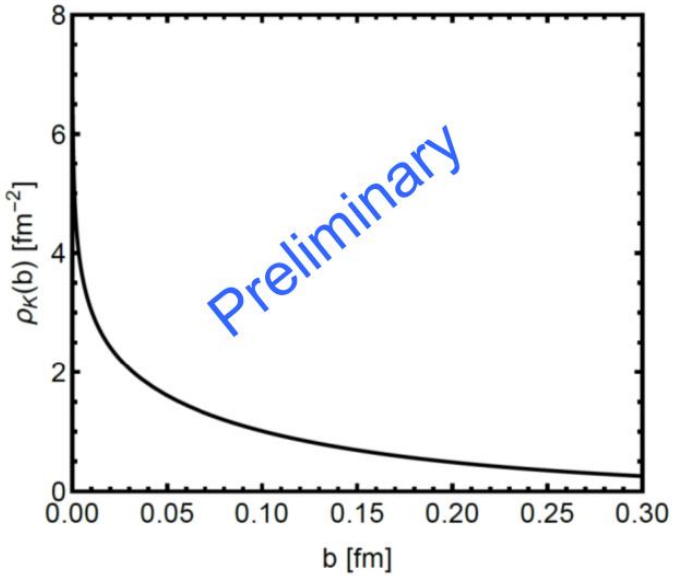
  - Low t dominates except for very small values of b – use model for high t

[C. Bruch et al., EPJC **39** (2005), 41]

$$\rho(b) = \frac{1}{2\pi} \int_{4m_K^2}^{\infty} dt\, K_0(\sqrt{t}\, b) \frac{\mathrm{Im}\, F_K(t)}{\pi}$$

Time-like F_K





- Studies of uncertainties ongoing

[Mecholsky, Horn, Pegg, Carmignotto, Miller]

E12-09-011 Goals

Measure the separated cross section of K^+ production above the resonance region

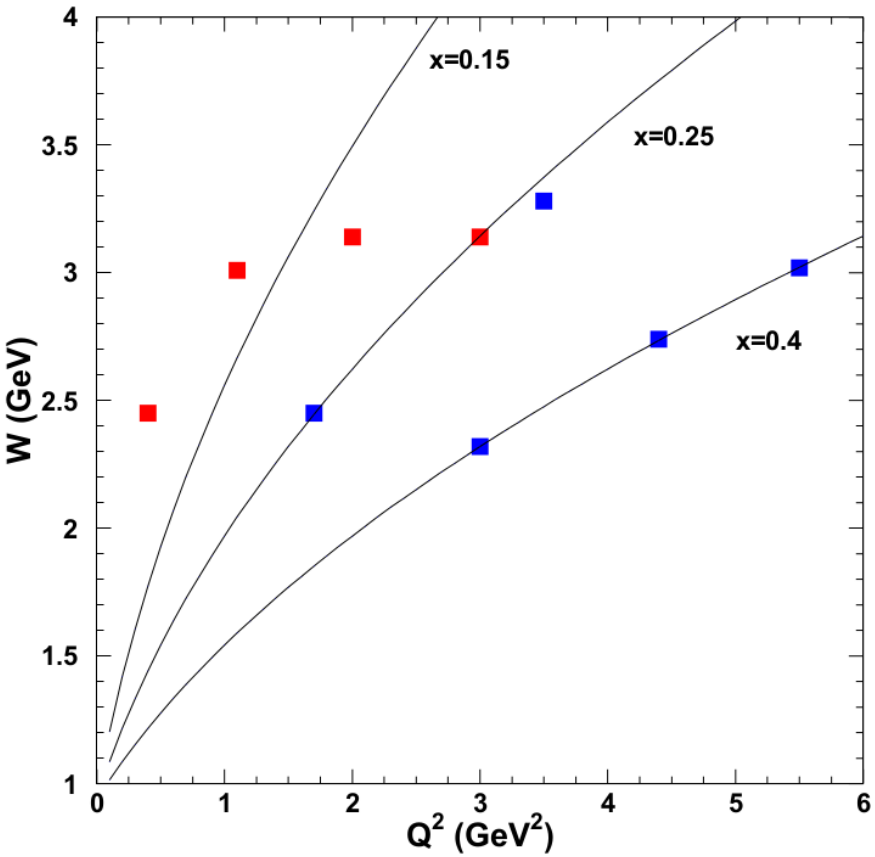
- Separated cross sections: L, T, LT, TT over a wide range of Q^2, t-dependence

- **Scaling behavior:** *Q^2* dependence of the separated cross sections
  - First cross section data for Q^2 scaling tests with kaons
  - Highest Q^2 for L/T separated kaon electroproduction cross section
  - Kaon cross section measurement above W=2.2 GeV

- **Reaction mechanism and form factor**: the t-dependence of the cross section
  - Contributes to understanding of the non-pole contributions, which should reduce the model dependence in interpreting the data
  - Determination of kaon form factor to highest possible Q^2

Kinematic Coverage

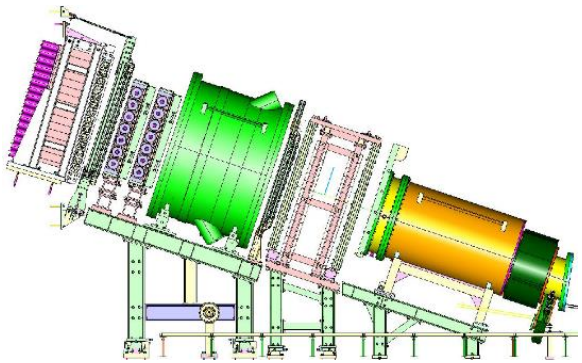
- Measure the separated cross sections at varying –t and x_B
- Measure separated cross sections for the $p(e,e'K^+)\Lambda(\Sigma^\circ)$ reaction at two fixed values of –t and x_B
  - Q^2 coverage is a factor of 2-3 larger compared to 6 GeV at much smaller –t



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

Experimental Constraints



- Hall C: k_e=3.8, 5.0, 5.6, 6.6, 7.4, 8.2, 8.8, 9.3, 10.6 GeV
- Beam current: 70 μA
- SHMS for kaon detection :
  - Kaon angles between 5.5 – 30 deg
  - Kaon momenta between 2.7 – 6.8 GeV/c
- HMS for electron detection :
  - angles between 10.7 – 31.7 deg
  - momenta between 0.86 – 5.1 GeV/c
- Particle identification:
  - Dedicated aerogel Cherenkov detector kaon/proton separation
    - Four refractive indices to cover the dynamic range required by experiments
  - Heavy gas Cherenkov detector for kaon/pion separation

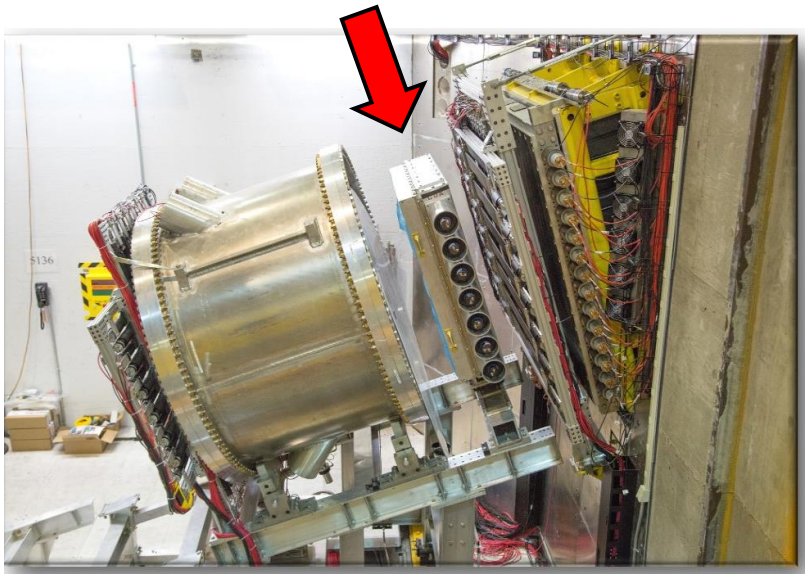
First needed in:

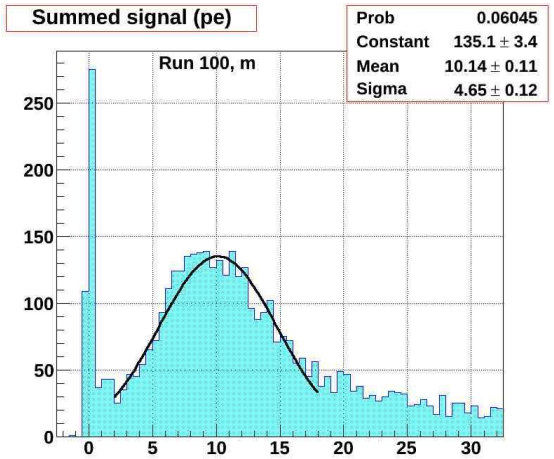
- June 2017
- December 2017

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

Dedicated equipment: Aerogel Cherenkov Detector in SHMS

NSF MRI PHY-1039446





[Arthur Mkrtchyan et al.]

- Installed in SHMS detector hut and tested with cosmic rays
- Four aerogel refractive indices covering kaon momentum range 3-7 GeV/c
- 14+6 PMTs (5-inch)

Aerogel Cherenkov detector project has been ***completed***

We are working on optimizations of lowest index tray (n=1.011)

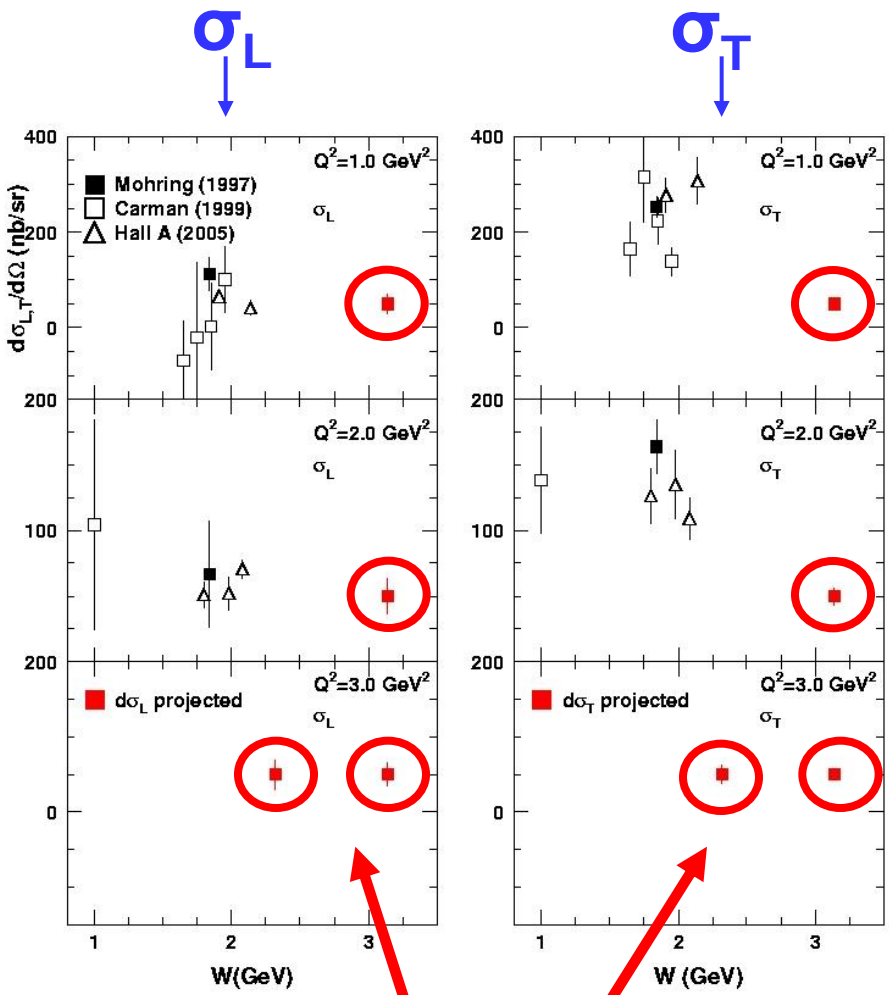
Run plan for Summer – June/2017

Q^2 (GeV^2)	W (GeV)	E (GeV)	E' (GeV)	th_e (deg)	eps	p_k (GeV)	th_k (deg)	|tmin| (GeV^2)	x
1.70	2.45	5.60	1.965	22.67	0.587	3.277	11.31	0.239	0.249
0.40	2.45	5.00	2.057	11.31	0.692	2.669	7.71	0.064	0.072
0.40	2.45	3.80	0.857	20.17	0.411	2.669	5.64	0.064	0.072

Run plan for Winter – December/2017

- Scheduled for 288 hours at E=10.6 GeV
  - High ε points for scaling studies at x=0.250 (most for x=0.400) and possible form factor extractions between Q^2=2.0-5.5 GeV^2
- Scheduled for 120 hours at E=8.5 GeV
  - Complete low ε points for scaling studies at x=0.250 (remaining high ε for x=0.400) and possible form factor extractions between Q^2=2-5.5 GeV^2
- Scheduled for 48 hours at E=6.4 GeV
  - Complete low ε points for scaling studies at x=0.400 and possible form factor extractions between Q^2=2-5.5 GeV^2

E12-09-011 sample projections



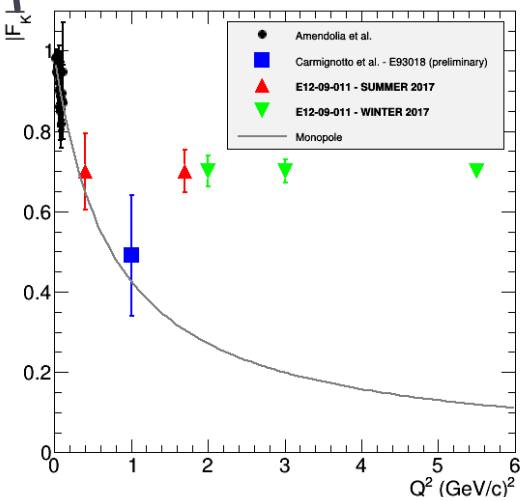
E12-09-011: Precision data for W > 2.5 GeV

JLab 12 GeV Kaon Program features:

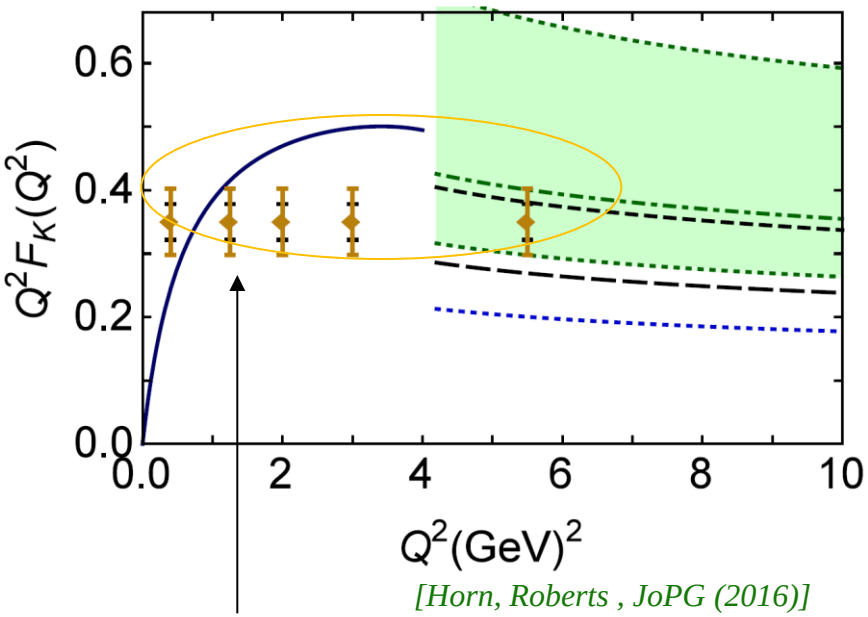
- First cross section data for Q^2 scaling tests with kaons
- Highest Q^2 for L/T separated kaon electroproduction cross section
- First separated kaon cross section measurement above W=2.2 GeV

Possible F_{K+} extraction from 2017/18 run

- **<u>Summer/Fall 2017</u>**: Low Q^2: directly compare $F_K(Q^2)$ values extracted from very low –*t* electroproduction with values measured in elastic e-K scattering
  - Validation check
  - Possibility to learn about F_K in medium?



- **<u>Winter17/Spring18</u>**: Possible kaon form factor extraction to highest possible Q^2 value achievable at JLab
  - Extraction like in the pion case by studying the model dependence at small -t
  - Comparative extractions of F_π at small and larger t show only modest model dependence, where larger t data lie at a similar distance from pole as kaon data



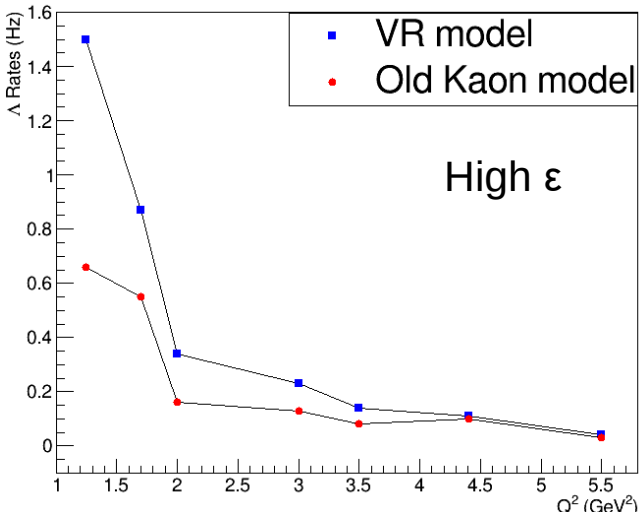
[Horn, Roberts , JoPG (2016)]

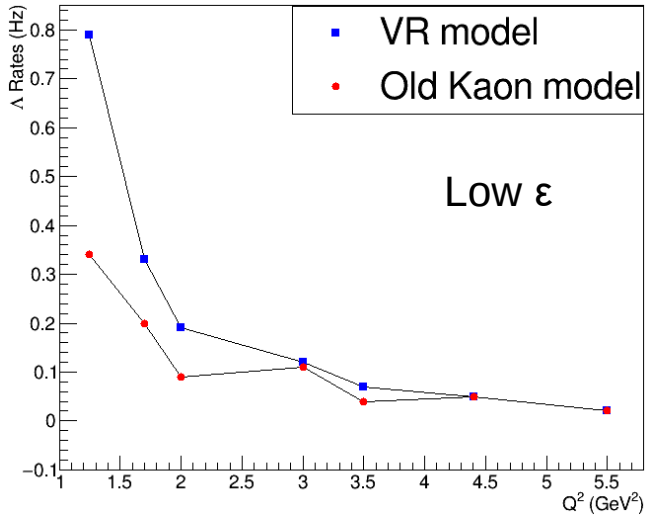
Possible extractions from 2017/18 run

Models comparison

[Basnet, Huber]

Study of expected rates with SIMC (Q^2 = 2.0 GeV^2, 70 μA)





Two models used for estimation:

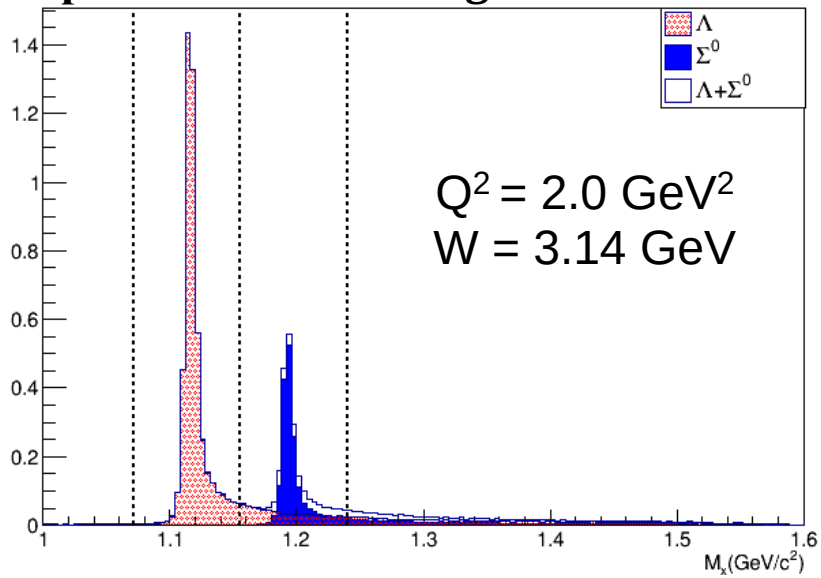
- ***"Old Kaon"***: empirical model from fits of prior kaon electroproduction data

  [D. Koltennuk (1999), T. Horn (2007)]

- ***VR:*** improved model featuring Reggeized background amplitudes

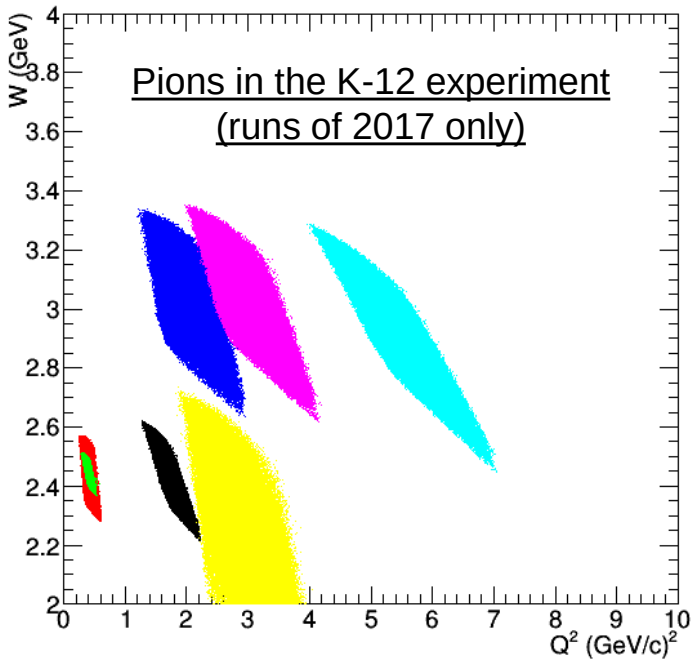
  [Vrancx and Ryckebusch (2014), Corthals (2007)]

Example Λ and Σ^0 missing mass distribution



Pions for free from K^+ experiment?

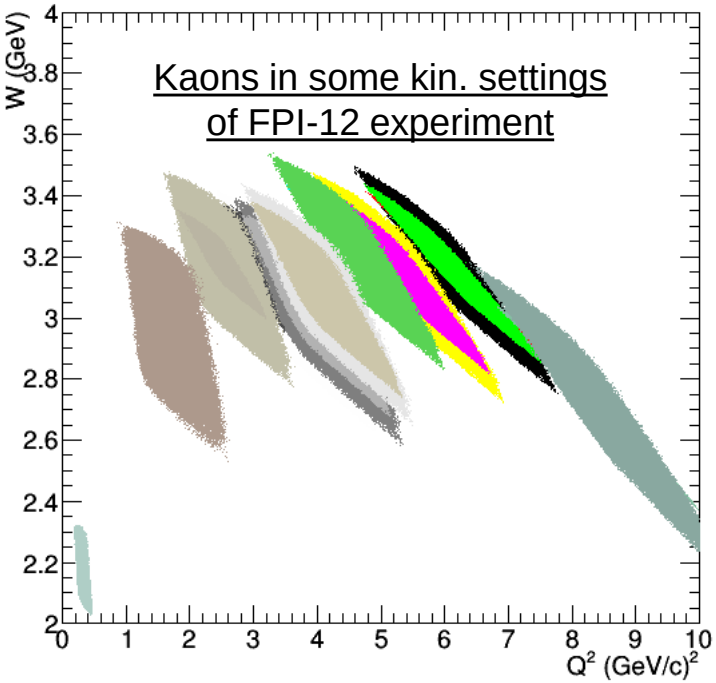
[Ali, Horn, Carmignotto]



- Pions will be in the acceptance of Kaon-12
  - Need to understand spectrometers' acceptances
  - Possibility of LT separation at Q^2=0.4 GeV^2
  - Coincidence pion can help calibrating detectors' efficiencies

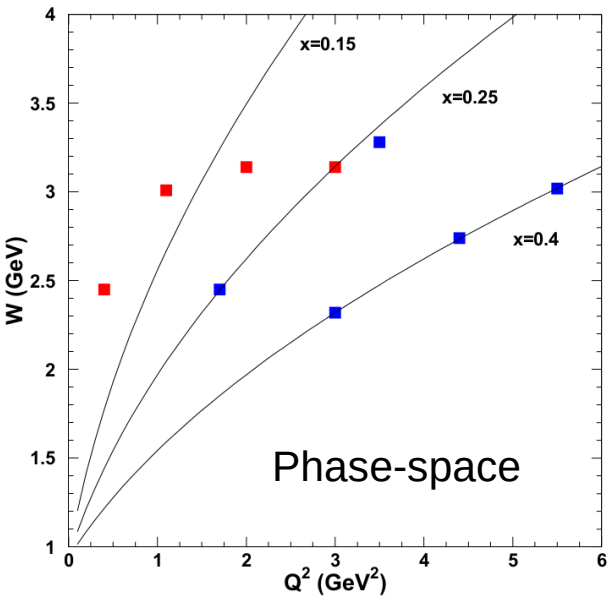
Kaon from π^+ 12GeV experiment?

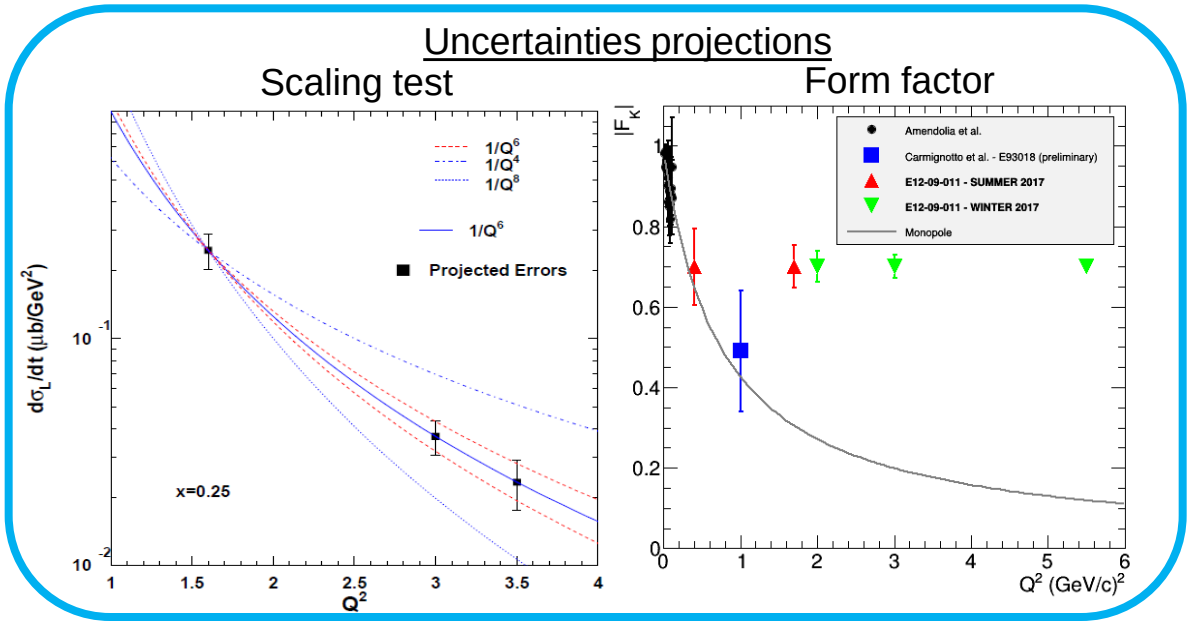
- Possibility of LT separation to even higher Q^2, from upcoming FPI-12 experiment
  - Statistics are limited (under evaluation)
  - There are overlapping kinematics (different epsilon)!
  - Try to have kaon PID during FPI-12 if possible



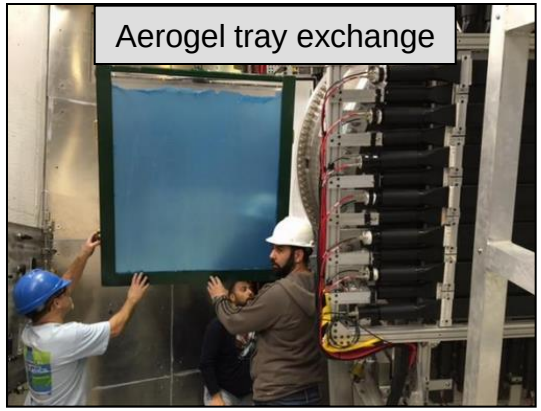
Summary

- **E12-09-011**: primary goal L/T separated kaon cross sections to investigate hard-soft factorization and non-pole contributions





Together with π^+ these data could make a substantial contribution towards understanding not only the K^+ production mechanism, but hard exclusive meson production in general



Aerogel Cherenkov detector: built and tested – ready to go!

Supported in part by:

NSF MRI PHY-1039446
NSF PHY-1306227

JSA Graduate Fellowship [Marco Carmignotto]

Backup

PAC34 Report

Proposal: PR12-09-011

Scientific Rating: N/A

Title: Studies of the L-T separated kaon electroproduction cross sections from 5-11 GeV

Spokespersons: T. Horn, G. Huber, P. Markowitz

Motivation: This experiment proposes to measure the electroproduction of kaons in the deep inelastic region in a wide range of Q^2 with separation of the longitudinal and transverse cross sections.

The first motivation is a detailed study of the reaction mechanism, in particular to check the dominance the kaon pole in the longitudinal cross section, which would allow to extract the kaon form factor. This later point is however doubtful because the pole is so far from the physical region that there is no reason to believe that it dominates the amplitude. Therefore the extraction of the form factor would go through a model, with all the ambiguities that this implies. So this first motivation reduces to a study of the reaction mechanism and by itself does not justify the experiment.

The second motivation, which is a study of the scaling behavior of the longitudinal cross section, is much better. According to the QCD factorisation theorem this part of the cross sections can be written as a convolution of generalized parton distributions (GPDs) with a known hard scattering kernel and a meson distribution amplitude. This would open a new domain for GPD study since virtually nothing is known concerning these quantities when strangeness is in play. As the factorisation theorem is only valid at asymptotically large Q^2 , it is compulsory to first test that the regime of validity has been reached and this can be done by comparing the Q^2 variation of the cross section against the prediction of QCD. This is a solid physics case which certainly justifies the experiment.

In summary the experiment is well motivated in so far as its major part is devoted to the scaling study, which of course must be performed at fixed x_B and t.

Measurement and Feasibility: The authors have extensive experience since this is the third generation of L-T separated meson production in Hall C. They will use the familiar HMS for the electrons and the SHMS for the Kaons.

Issues: The detection of the kaons requires several aerogels which have to be funded and built. Due to the beam intensity limitation in the early years of the 12 GeV operations a longer target may be necessary. The experience requires several non standard energies, which may pose scheduling problems. The reaction mechanism study must be only a minor part of the experiment and there is moreover no reason to perform it at very small Q^2. Therefore the measurements at $Q^2 = 0.4 GeV^2$ should be removed from the proposal.

Recommendation: Approval

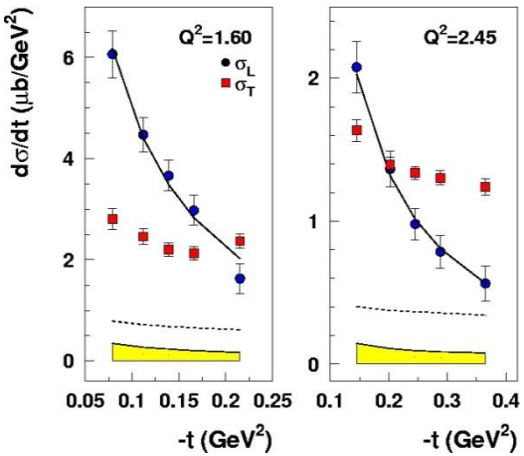
Extraction of F_π from σ_L Jlab data

[Horn et al., PRL **97**, (2006) 192001]

- JLab 6 GeV F_π experiments used the VGL/Regge model as it has proven to give a reliable description of σ_L across a wide kinematic domain

  [Vanderhaeghen, Guidal, Laget, PRC **57**, (1998) 1454]

  - Feynman propagator replaced by π and ρ trajectories
  - Model parameters fixed by pion photoproduction data
  - Free parameters: $\Lambda_\pi^2, \Lambda_\rho^2$



$$t = m_\pi^2$$

$$F_\pi(Q^2) = \frac{1}{1 + Q^2/\Lambda_\pi^2}$$

$$\Lambda_\pi^2 = 0.513,\ 0.491\ GeV^2$$

$$\Lambda_\rho^2 = 1.7\ GeV^2$$

Fit of σ_L to model gives F_π at each Q^2