E12-09-01: LT Separated Kaon Production Cross Sections from 5-11 GeV

Tanja Horn, Garth Huber,

Pete Markowitz, et al.,

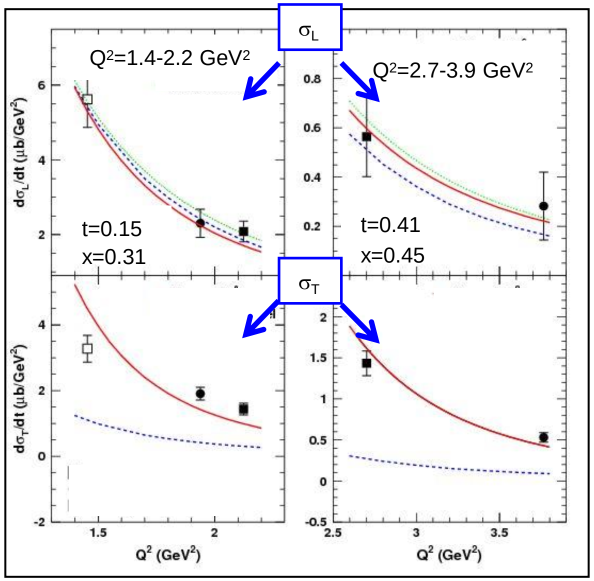
Proposal: E12-09-011

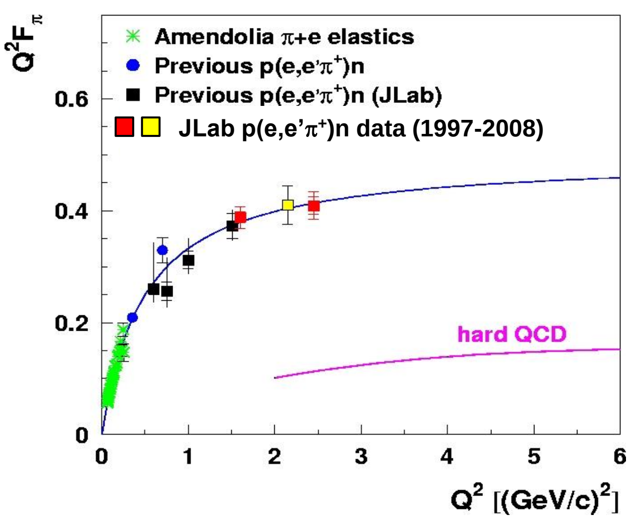
Scientific Rating: B+
Recommendation: 40 days

Title: "Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV"

The PAC strongly endorses this proposal, which is part of the JLAB investigations into exclusive meson production, in this case emphasizing on Kaons. The specific emphasis of this experiment is on L-T separated data, checking scaling behavior and t-channel mechanismsl. The actual grade being somewhat lower than some of the other experiments in related categories reflects the charge given to the PAC to emphasize priorities for the first five years. The PAC approves the 40 days of beamtime asked for.

QCD factorization and Strangeness





- Q^2 dependence of the meson cross section is an essential test of hard-soft factorization required for studies of the nucleon's transverse spatial structure
  - 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 *[T. Horn et al., Phys. Rev. C* ***78****, 058201* ***(2008)****]*

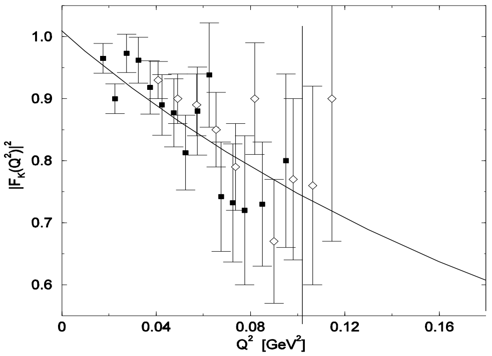
Kaon cross section data over a large range in Q^2 at 12 GeV can provide essential information about the reaction mech.
- Could open a new domain for GPD study since virtually nothing is known concerning these quantities when strangeness is in play

- Q^2 dependence of F_π follows prediction from pQCD, suggests factorization holds, as perhaps in the TFF

- Different magnitudes imply that factorization does not hold or something is missing in the calculation

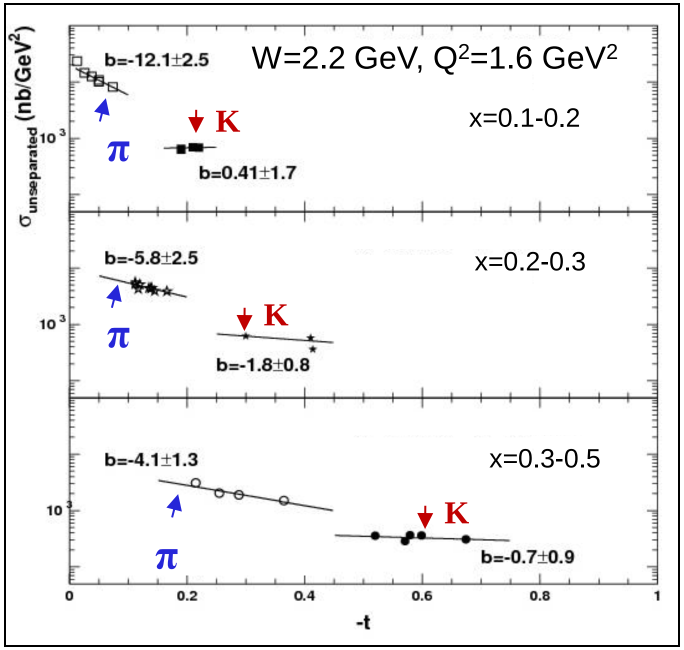
Kaon data may help to shed light on this puzzle

Reaction mechanism in systems containing strangeness: the K^{+} Form Factor



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

- 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*



- Unseparated data: pion t-dependence is steeper *at* low *t* than for kaons

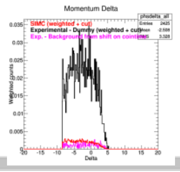
*[T. Horn, Phys. Rev. C **85 (2012)** 018202]*

- <u>However</u>, the kaon pole is expected to be strong enough to produce a maximum in σ_L

[Kroll/Goloskokov EPJ A47 (2011), 112]

JLab12 GeV essential for measurements at low *t*, which would allow for interpretation of the kaon pole contribution

Kaons in JLab 6 GeV “pion” experiments

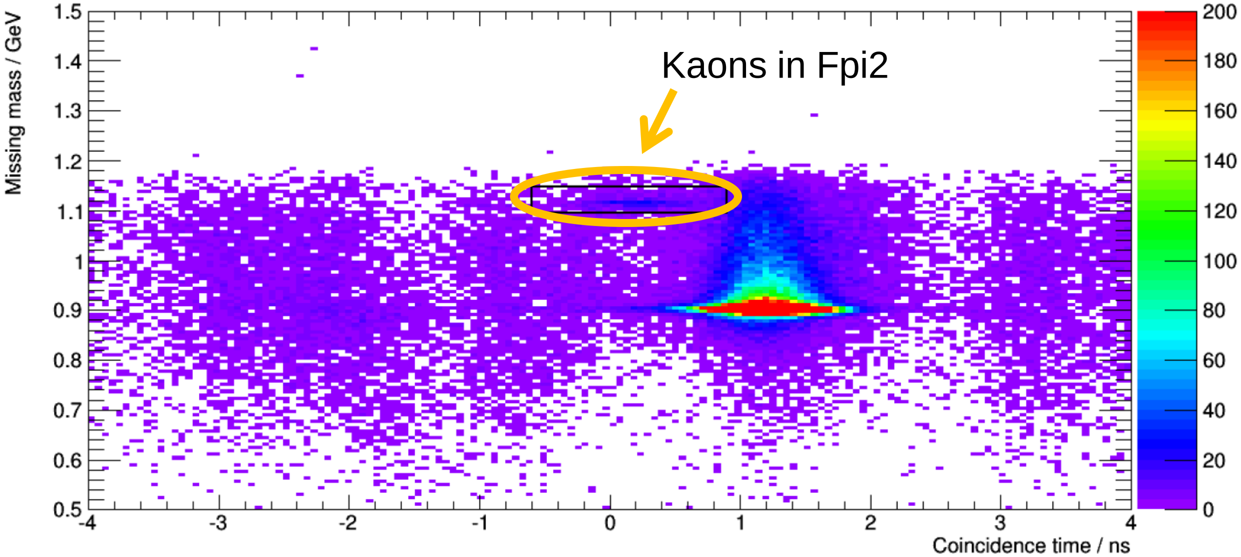


- 6 GeV pion experiments have kaons in their acceptance, e.g. FPI2, SIDIS

<u>Runs 47358-47371</u>:
- Ebeam = 5.2464 GeV

- e_Theta = 29.43 deg
- e_p = 1.7184 GeV/c

- h_Theta = 13.61 deg
- h_p = 3.3317 GeV/c

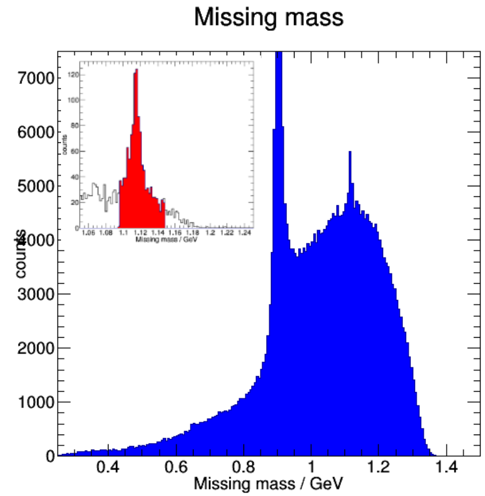


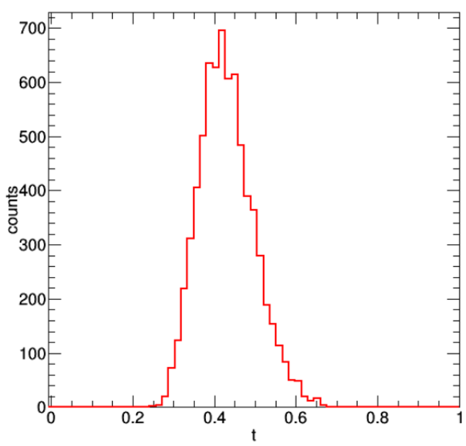
Q^2=2.45 GeV^2

High ε=0.54 8000-9000 events

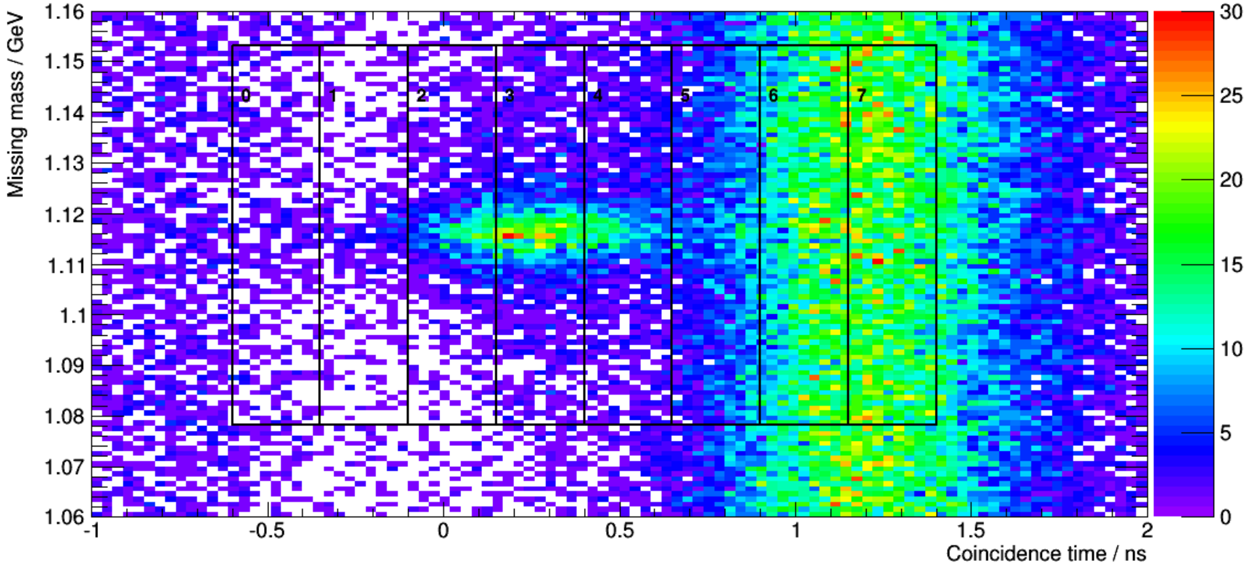
High ε=0.27 ~1200 events

Parallel kinematics

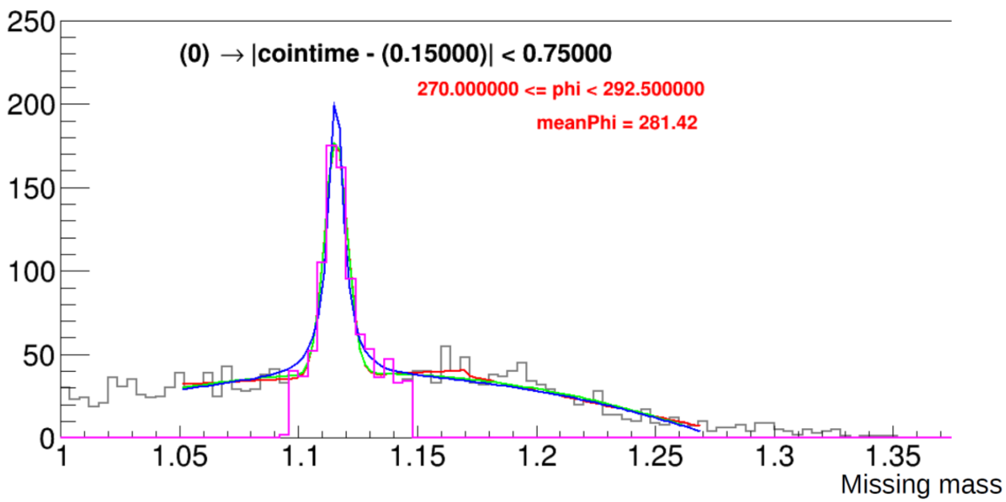




Background subtraction



- Fit the missing mass with a polynomial plus peak centered at Lambda missing mass
  - Uncertainty estimated from three different fit forms

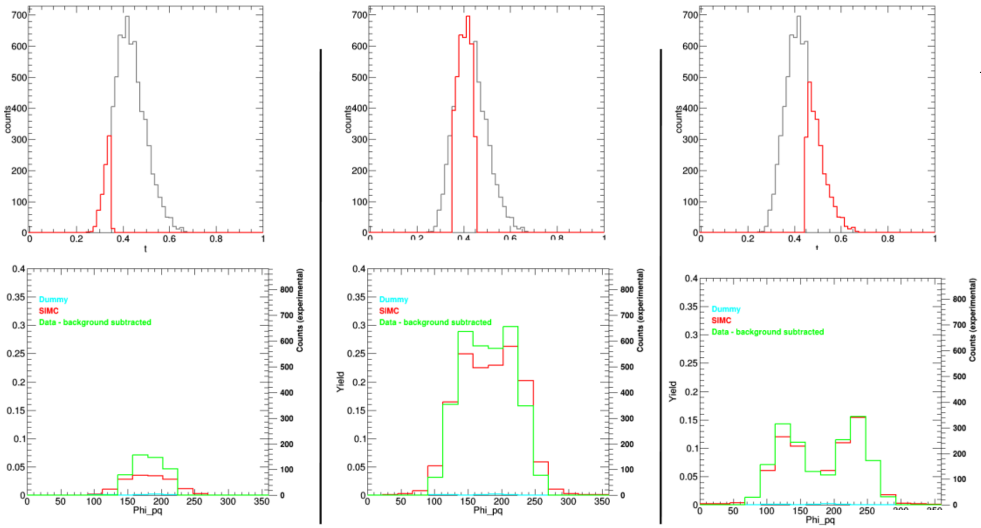


Binning, model, and yields

- ❑ Using factorized cross section model currently implemented in SIMC (D. Koltenuk) with a global scale factor

sig_factorized = **SCALE** * fact_q*fact_t*fact_w

Parallel kinematics

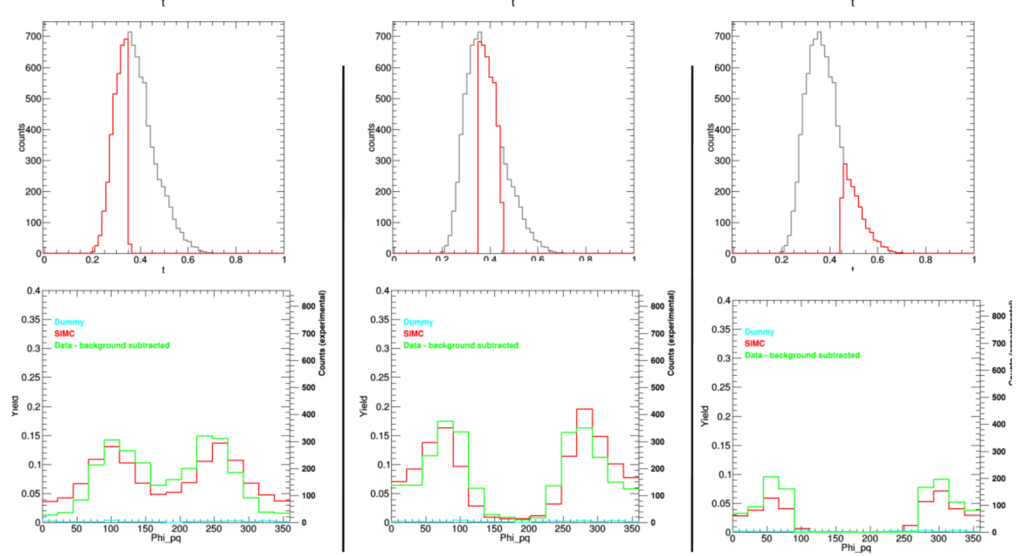


Red=SIMC

Green=background subtracted data

off-Parallel kinematics

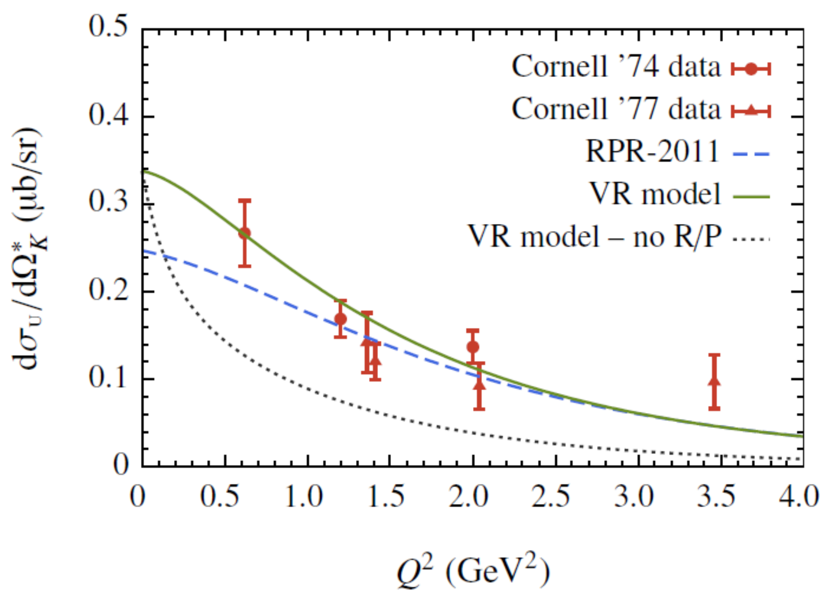
-t <= 0.35 | 0.35 < -t <= 0.45 | -t > 0.45

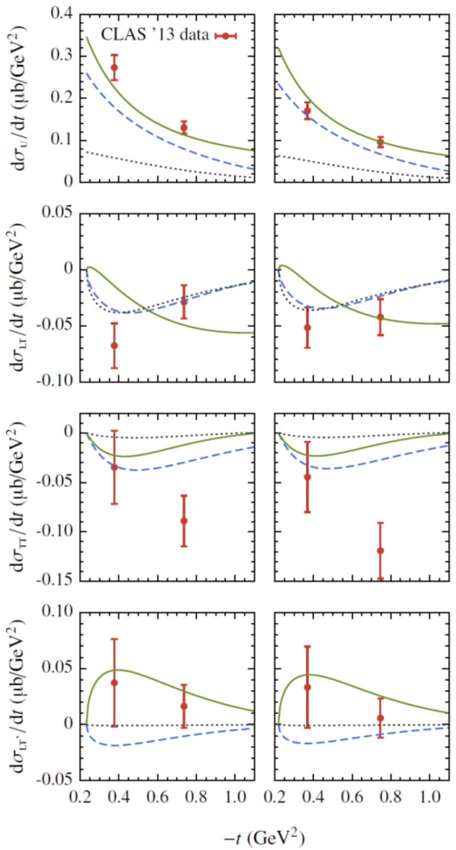


- ❑ Next: extract cross sections

Recent theory efforts: the "VR" model

- Extends the VGL Regge model by adding a hadronic model that includes DIS process, which dominates the transverse response at moderate and high Q^2
  - Residual effect of nucleon resonances in the proton EM TFF taken into account with a resonance-parton transition form factor *[T. Vrancx, J. Ryckebusch, J. Nys, Phys. Rev. C **89 (2014)** 065202]*





- Good agreement with unseparated kaon data

E12-09-011 Goals

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

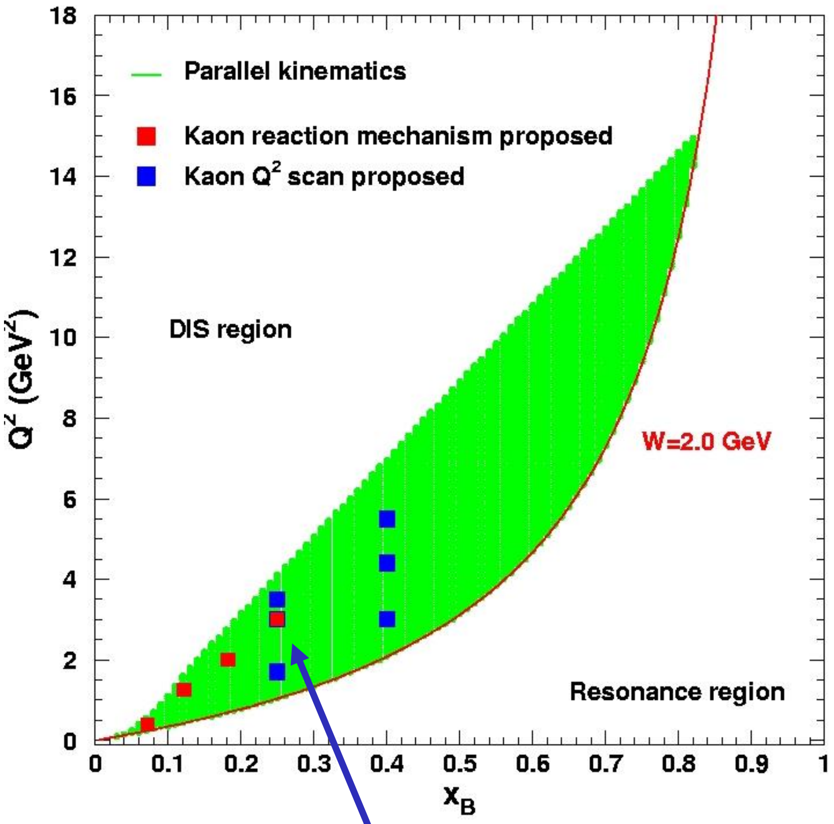
- Separated cross sections: L, T, LT, TT over a wide range of Q^2, t-dependence

- *The Q^2 dependence* will allow studying the scaling behavior of the separated cross sections
  - First cross section data for Q2 scaling tests with kaons
  - Highest Q2 for L/T separated kaon electroproduction cross section
  - First dedicated kaon cross section measurement above the resonance region

- *The t-dependence* allows for detailed studies of the reaction mechanism
  - Contributes to understanding of the non-pole contributions, which should reduce the model dependence in interpreting the data
  - Bonus: if warranted by data, extract the kaon form factor

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

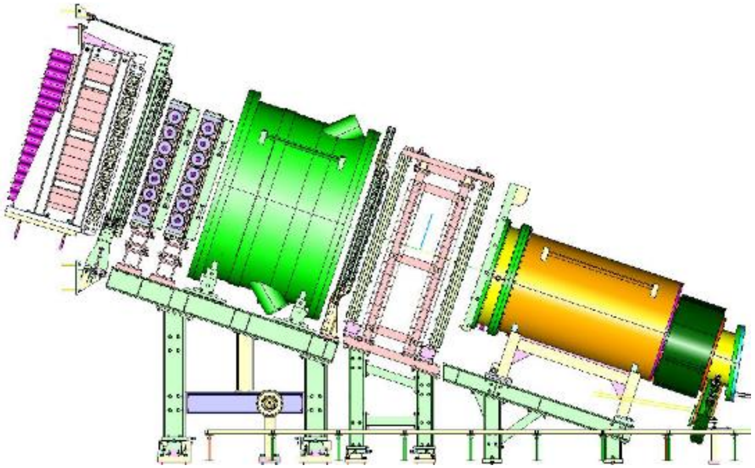


x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.1-0.2	0.4-3.0	2.5-3.1	0.06-0.2
0.25	1.7-3.5	2.5-3.4	0.2
0.40	3.0-5.5	2.3-3.0	0.5

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

Experimental Constraints

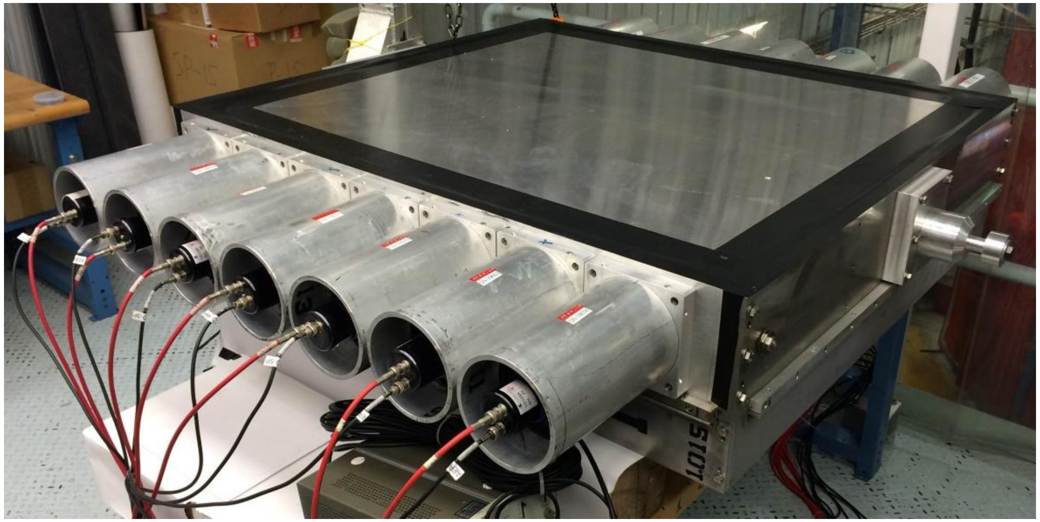
- Hall C: k_e=3.8, 5.0, 5.6, 6.6, 7.4, 8.2, 8.8, 9.3, 10.9 GeV
- SHMS for kaon detection :
  - Kaon angles between 5.5 – 30 deg
  - Kaon momenta between 2.7 – 6.8 GeV/c



- 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
  - Heavy gas Cherenkov detector for kaon/pion separation

Dedicated equipment: Aerogel cherenkov detector

NSF MRI PHY-1039446

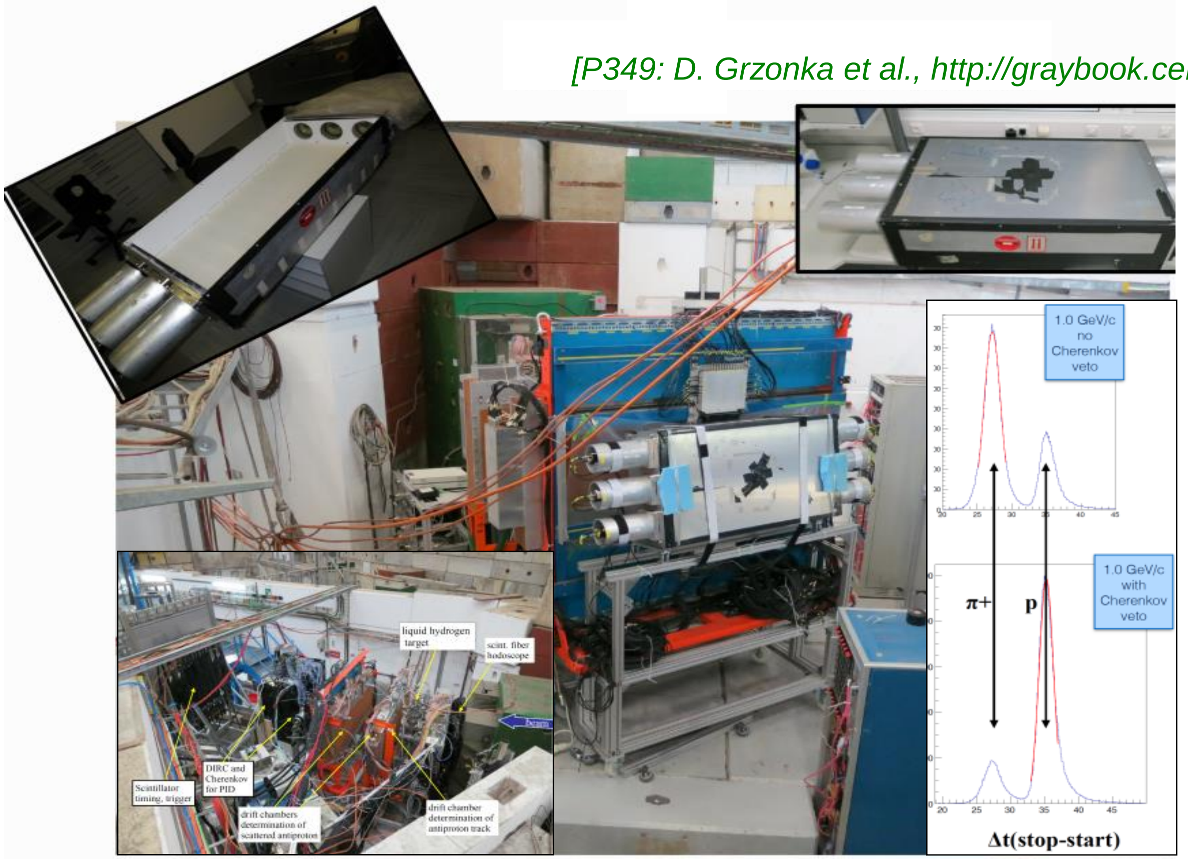


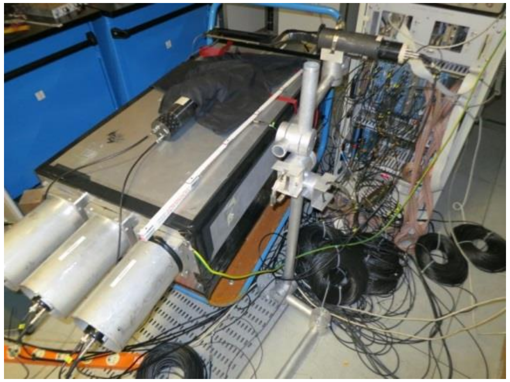
- Four aerogel refractive indices covering kaon momentum range 3-7 GeV/c
- 5-inch PMTs
  - 14+6 PMTs with one HV and one signal cable each

Aerogel Cherenkov detector project has been ***completed*** –
working on optimizations until installation in SHMS

SP-30 aerogel test during P349 Experiment at CERN

[P349: D. Grzonka et al., http://graybook.cern.ch/programmes/experiments/P349.html]





- ❑ Prepared with help from Hamlet’s group and shipped from CUA to Juelich in summer 2014
- ❑ Assembled and tested in Juelich with help from Marco Carmignotto (CUA)
- ❑ Shipped to CERN and installed in T1 beam line in Nov/Dec 2014
- ❑ First data run in December 2014 successful – SP-30 works as expected

Run Preparations: Combining Kaon and Pion Experiment Kinematics

- No significant improvement in statistics through overlap with the approved $p(e,e'\pi^+)n$ experiments *[E12-06-101, E12-07-105]*
  - Covers only a small region at very high –t, which is not interesting for studies of form factors or GPDs
  - Most events are off the focal plane
    - exclusive K^+ peak lies at $-5.5\% < \delta_{SHMS} < -2\%$
  - Missing Mass tail cut off by SHMS acceptance

Model: Kaon experiment runs 47 days and independently from pion experiments

➢ Pion experiments may acquire some data for checkout during some of the settings

E12-09-011: Kaon experiment

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

Approved 12 GeV pion experiments

x	Q^2 (GeV^2)	W (GeV)	-t (GeV/c)^2
0.16	1.6	3.0	0.03
0.21	2.45	3.2	0.05
0.31	2.73	2.6	0.12
0.31	4.0	3.1	0.12

Run Preparations: grouping by linac gradient

	W (GeV)	Q^2 (GeV^2)	E_e (GeV)	E'_e (GeV)	θ_e (deg)	ϵ	p_K (GeV)	θ_K (deg)	$-t_{min}$ (GeV/c)^2	x
	Intermediate Q^2 for reaction mechanism and form factor Q^2 dependence									
2b	2.45	0.40	3.80	0.857	20.17	0.411	2.669	5.64	0.064	0.072
3c	2.45	0.40	5.00	2.057	11.31	0.692	2.669	7.71	0.064	0.072
4b	3.14	1.25	7.40	1.949	16.93	0.477	5.189	5.85	0.084	0.122
5b	3.14	1.25	9.30	3.849	10.72	0.696	5.189	7.39	0.084	0.122
4b	3.14	2.00	7.50	1.649	23.19	0.396	5.561	6.20	0.138	0.182
4a	3.14	2.00	8.80	2.949	15.96	0.584	5.561	7.74	0.138	0.182
5a	3.14	2.00	10.90	5.049	10.94	0.751	5.561	9.16	0.138	0.182
5c	3.14	3.00	8.20	1.816	25.93	0.393	6.053	6.90	0.219	0.250
5a	3.14	3.00	10.90	4.516	14.18	0.689	6.053	9.63	0.219	0.250
	Scaling study at fixed x=0.25, $-t$=0.2									
3b	2.45	1.70	5.60	1.965	22.67	0.587	3.277	11.31	0.239	0.249
4a	2.45	1.70	8.80	5.165	11.10	0.858	3.277	14.92	0.239	0.249
5b	3.37	3.50	9.30	1.852	26.05	0.357	7.122	6.08	0.215	0.250
5a	3.37	3.50	10.90	3.452	17.54	0.555	7.122	7.79	0.215	0.250
	Scaling study at fixed x=0.40, $-t$=0.5									
3a	2.32	3.00	6.60	2.602	24.12	0.634	3.486	14.13	0.531	0.400
5a	2.32	3.00	10.90	6.902	11.46	0.887	3.486	18.35	0.531	0.400
5c	2.74	4.40	8.20	2.324	27.80	0.480	5.389	10.00	0.507	0.400
5a	2.74	4.40	10.90	5.024	16.30	0.734	5.389	13.06	0.507	0.400
5b	3.02	5.50	9.30	1.978	31.73	0.366	6.842	7.78	0.503	0.400
5a	3.02	5.50	10.90	3.578	21.64	0.560	6.842	9.88	0.503	0.400

- Standard Tune A=2.16 GeV/pass
- Special Tune B=1.85 GeV/pass
- Special Tune C=1.862 GeV/pass

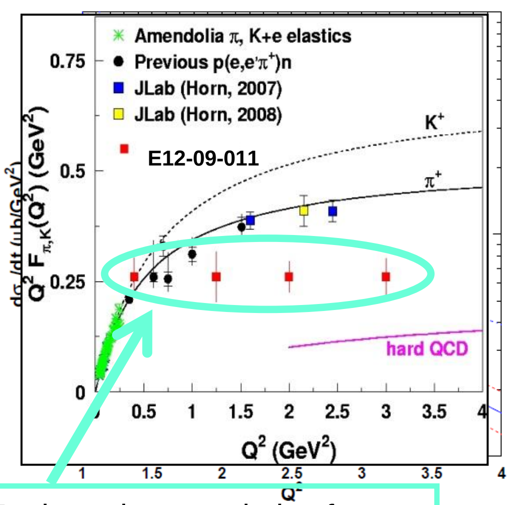
- Standard tune and special tune B provide most of the data

Sample projections

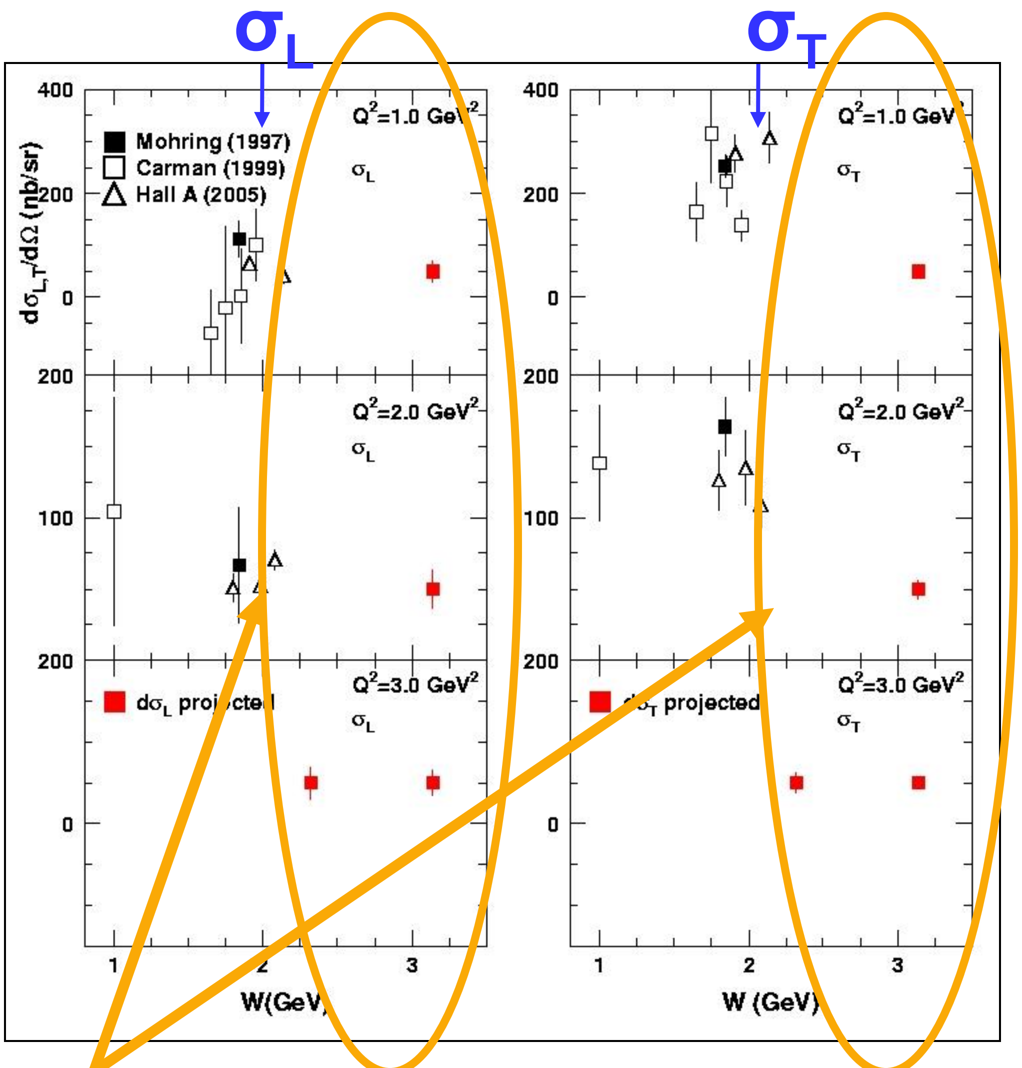
- L/T separated kaon cross sections to investigate hard-soft factorization and non-pole contributions

- 12 GeV data could allow for comparing the observed Q^2 dependence and magnitude of π^+ and K^+ form factors

  *[C. Shi, et al., arXiv:1406.3353 **(2014)**]*

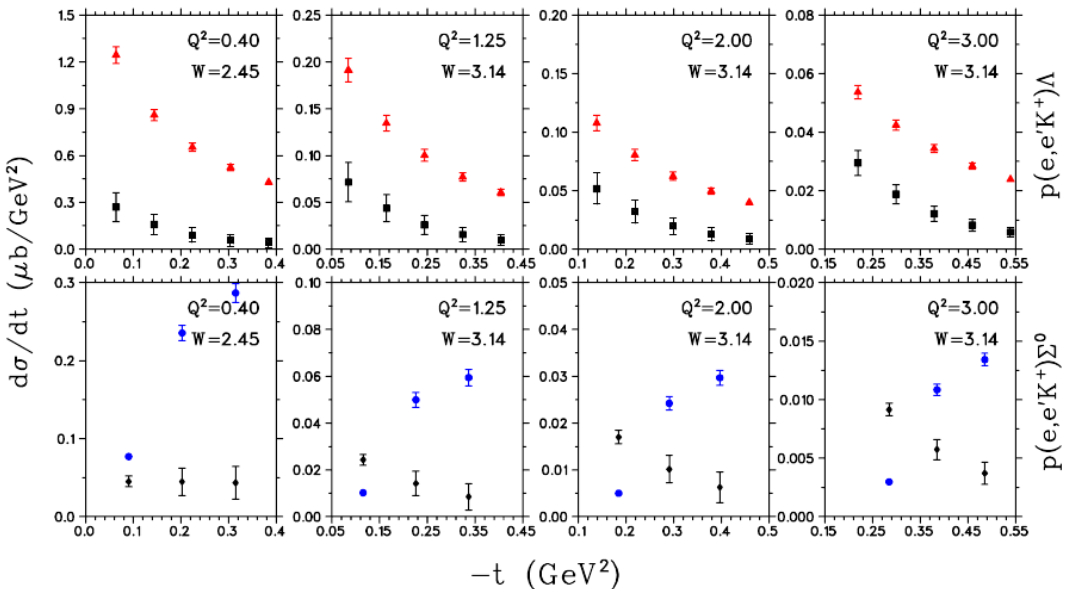


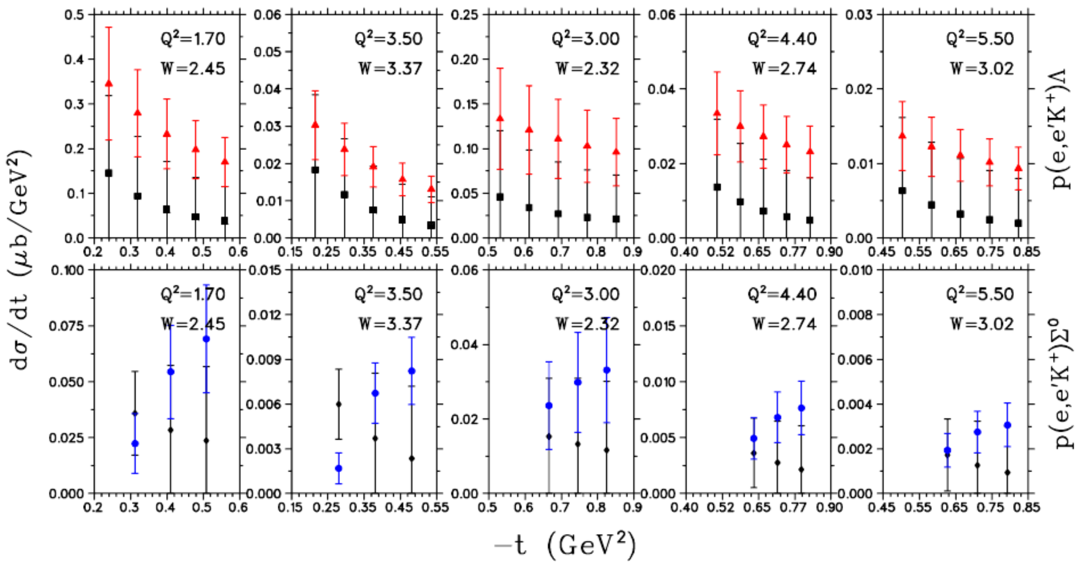
Projected uncertainties for kaon experiment at 12 GeV



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

VR model predictions for E12-09-011





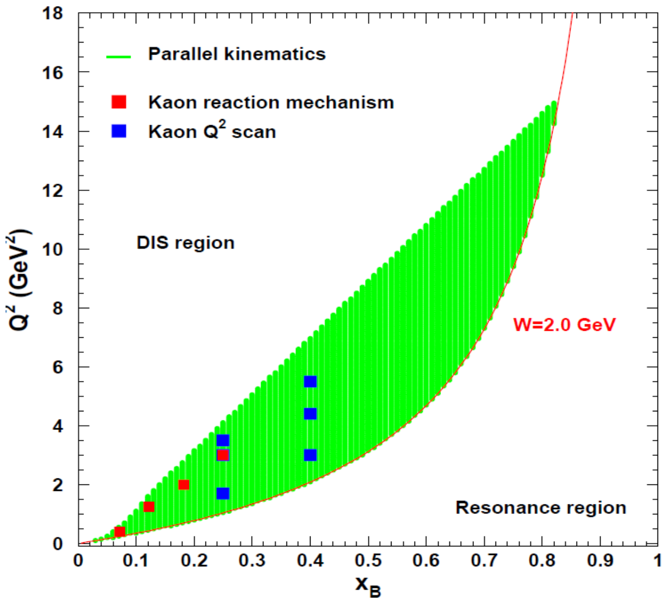
- L/T ratios predictions from the VR model are lower than VGL at low Q2, but higher at higher Q2

W (GeV)	Q^2 (GeV^2)	E_e (GeV)	E'_e (GeV)	θ_e (deg)	ϵ	p_K (GeV)	θ_K (deg)	$-t_{min}$ (GeV/c)^2	x	R
Intermediate Q^2 for reaction mechanism and form factor Q^2 dependence										
2.45	0.40	3.80	0.857	20.17	0.411	2.669	5.64	0.064	0.072	0.55
2.45	0.40	5.00	2.057	11.31	0.692	2.669	7.71	0.064	0.072	0.55
3.14	1.25	7.40	1.949	16.93	0.477	5.189	5.85	0.084	0.122	1.19
3.14	1.25	9.30	3.849	10.72	0.696	5.189	7.39	0.084	0.122	1.19
3.14	2.00	7.50	1.649	23.19	0.396	5.561	6.20	0.138	0.182	2.37
3.14	2.00	8.80	2.949	15.96	0.584	5.561	7.74	0.138	0.182	2.37
3.14	2.00	10.90	5.049	10.94	0.751	5.561	9.16	0.138	0.182	2.37
3.14	3.00	8.20	1.816	25.93	0.393	6.053	6.90	0.219	0.250	3.15
3.14	3.00	10.90	4.516	14.18	0.689	6.053	9.63	0.219	0.250	3.15
Scaling study at fixed x=0.25, $-t$=0.2										
2.45	1.70	5.60	1.965	22.67	0.587	3.277	11.31	0.239	0.249	1.87
2.45	1.70	8.80	5.165	11.10	0.858	3.277	14.92	0.239	0.249	1.87
3.37	3.50	9.30	1.852	26.05	0.357	7.122	6.08	0.215	0.250	3.75
3.37	3.50	10.90	3.452	17.54	0.555	7.122	7.79	0.215	0.250	3.75
Scaling study at fixed x=0.40, $-t$=0.5										
2.32	3.00	6.60	2.602	24.12	0.634	3.486	14.13	0.531	0.400	2.23
2.32	3.00	10.90	6.902	11.46	0.887	3.486	18.35	0.531	0.400	2.23
2.74	4.40	8.20	2.324	27.80	0.480	5.389	10.00	0.507	0.400	3.31
2.74	4.40	10.90	5.024	16.30	0.734	5.389	13.06	0.507	0.400	3.31
3.02	5.50	9.30	1.978	31.73	0.366	6.842	7.78	0.503	0.400	3.90
3.02	5.50	10.90	3.578	21.64	0.560	6.842	9.88	0.503	0.400	3.90

Summary

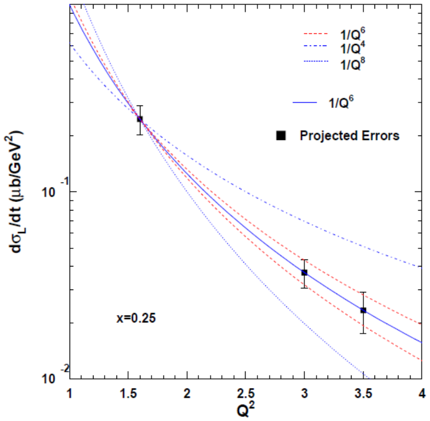
- **E12-09-011**: primary goal L/T separated kaon cross sections to investigate hard-soft factorization and non-pole contributions

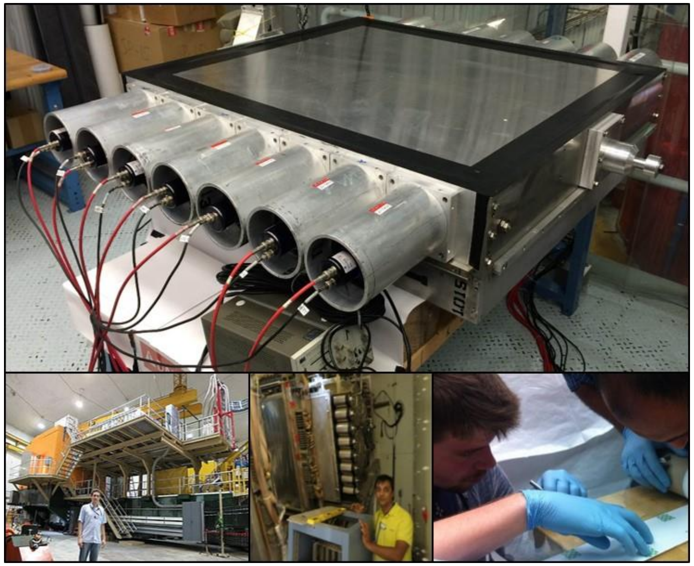
JLab with 2.16, 1.85, 1.862 GeV/pass (“12”, 10.1, 8.2 GeV)



47 days (~20 days Q2 tests, ~23 days reaction mechanism, +calibrations)

Projections for Scaling test:





Aerogel Cherenkov detector built and tested

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

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

Beam Time Estimate (PAC34)

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)**