KaonLT (E12-09-011)

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Overview E12-09-011 (KaonLT)

Goals

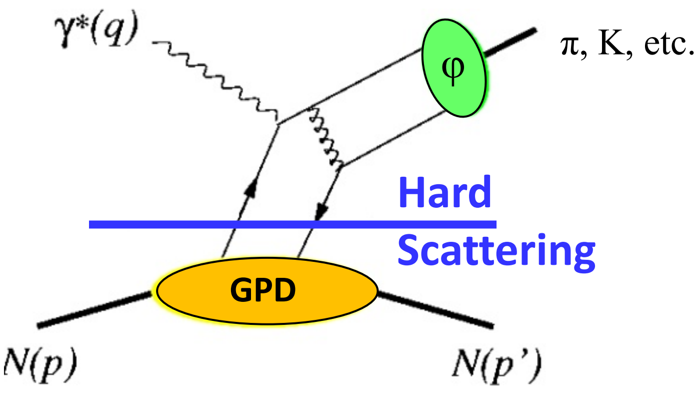
- L/T separated cross sections as a function of Q^2 at fixed x=0.25, 0.4 to investigate the reaction mechanism with strangeness towards 3D imaging studies
- L/T separated cross sections as a function of t up to the largest Q^2 to investigate the reaction mechanism towards kaon form factor extractions

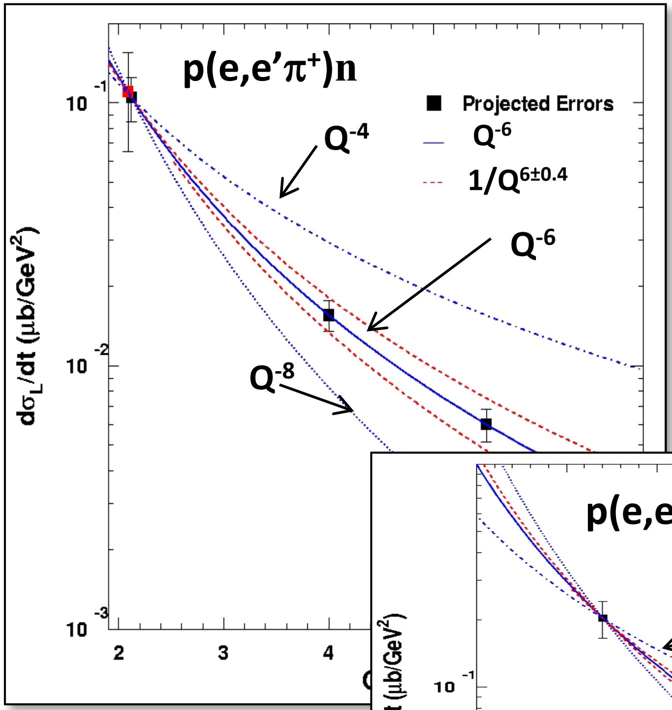
➢ The only source of L-T separated and precision $K^+\Lambda$, $K^+\Sigma^0$ cross sections for tests of the reaction mechanism towards hadron structure at the EIC

Motivation

- Kaon structure has an important place in studies of the transition from the nonperturbative to perturbative region
- Need to validate the hard-exclusive reaction mechanism – key are precision longitudinal-transverse (L/T) separated data over a range of Q^2 at fixed x/t
- EIC YR: comparison of F_π and F_K over a wide range in Q^2 will provide “unique information relevant to understanding the generation of hadronic mass”
- Need L/T separated data – not possible at EIC - JLab is the only source and can also provide information on a possible alternative validation method

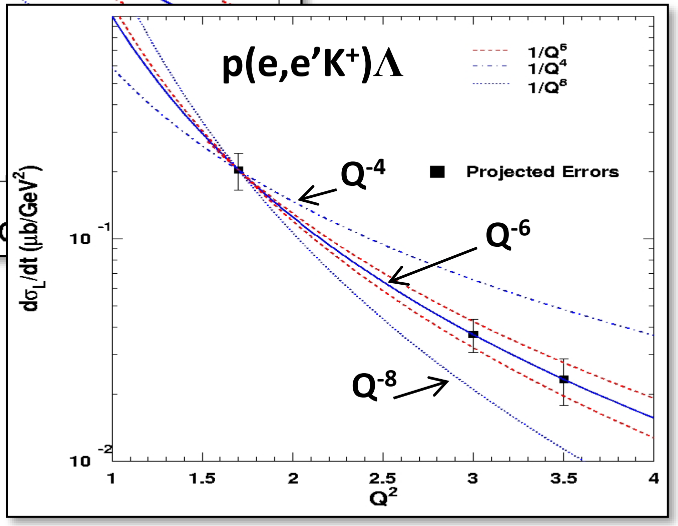
Review Scientific Motivation: Reaction Mechanism





π^+: to Q^2~9 GeV^2
K^+: to Q^2~6 GeV^2

Fit: $1/Q^n$



- One of the most stringent tests of the reaction mechanism is the Q^2 dependence of the π and K electroproduction cross section
  - σ_L scales to leading order as Q^{-6}
  - σ_T does not
- Experimental validation of reaction mechanism is essential for reliable interpretation of results from the JLab GPD program at 12 GeV for meson electroproduction

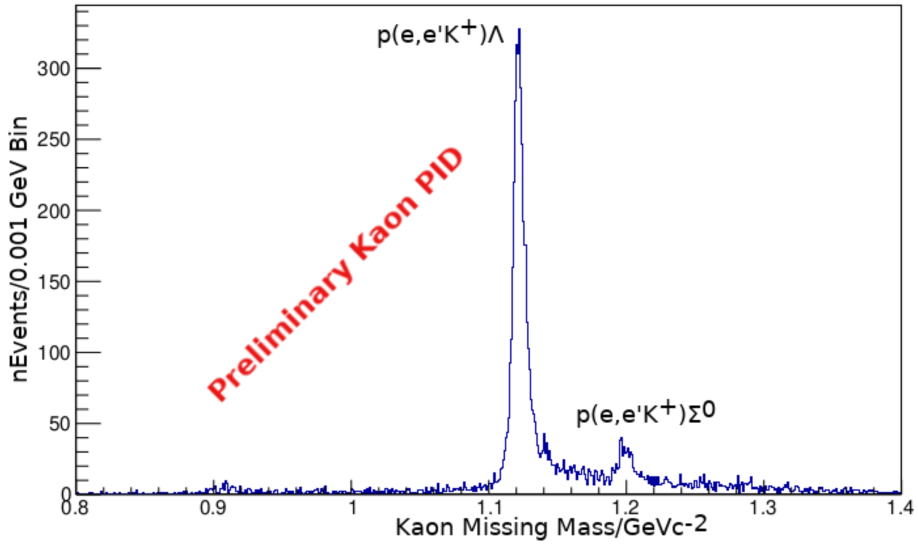
➢ **If σ_T is confirmed to be large, it could allow for detailed investigations of transversity GPDs. If, on the other hand, σ_L is measured to be large, this would allow for probing the usual GPDs**

Review Scientific Motivation: Form Factors

- ***Pion and kaon form factors*** are of special interest in hadron structure studies
  - pions and kaons are not pointlike; their internal structure is more complex than is usually imagined
  - precise $F_K(Q^2)$ data for a material domain above Q^2 ~5 GeV^2, could deliver insights into the size and range of nonperturbative EHM–HB interference effects in hard exclusive processes

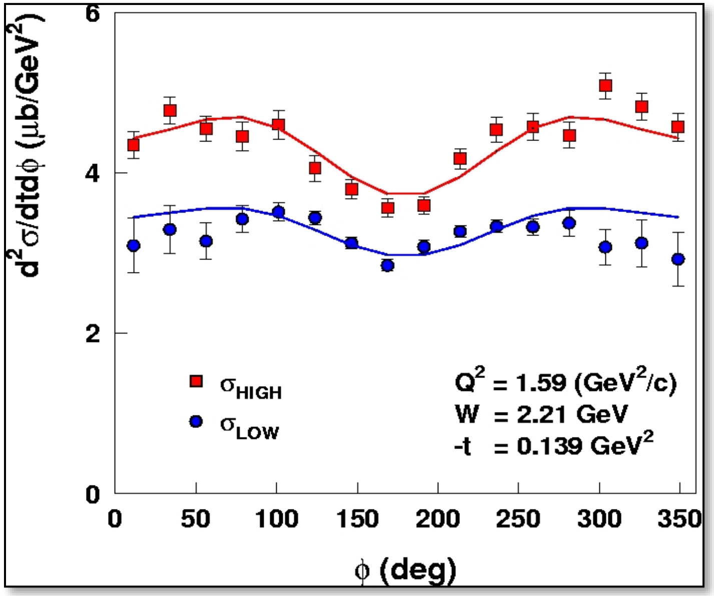
- Completed Hall C experiments have established JLab's capability for reliable F_π measurements using the π^-/π^+ validation methods

- $K^+\Lambda/K^+\Sigma^0$ cross sections can play a similar role. These data will be the foundation for determining the conditions under which a clean separation of these channels may be possible at the EIC



L/T Separation Example

- σ_L is isolated using the Rosenbluth separation technique
  - Measure the cross section at two beam energies and fixed W, Q^2, -t
  - Simultaneous fit using the measured azimuthal angle (ϕ_π) allows for extracting L, T, LT, and TT
- Careful evaluation of the systematic uncertainties is important due to the 1/ε amplification in the σ_L extraction
  - Spectrometer acceptance, kinematics, and efficiencies



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

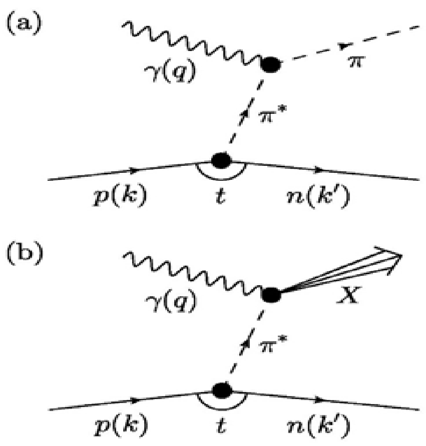
σ_L will give us $F_{\pi,K}$

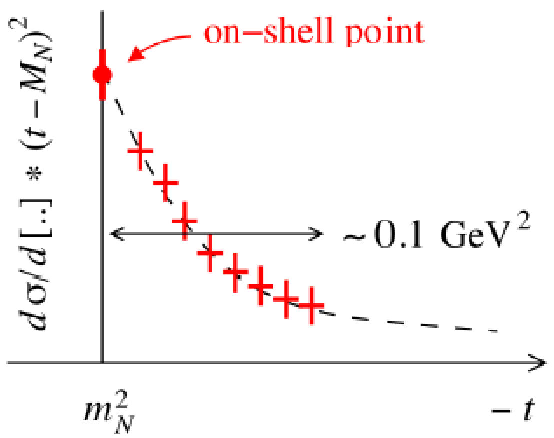
Magnetic spectrometers a must for such precision cross section measurements

- This is only possible in Hall C at JLab
- SHMS was built to meet these exp. req.

Accessing kaon structure through the Sullivan Process

- The **Sullivan process can provide reliable access to a meson target** as *t* becomes space-like if the pole associated with the ground-state meson remains the dominant feature of the process and the structure of the related correlation evolves slowly and smoothly with virtuality.





- To **check these conditions** are satisfied empirically, one can **take data covering a range in *t*** and compare with phenomenological and theoretical expectations.

- Recent **theoretical calculations found that for $-t \leq 0.9\ \mathrm{GeV}^2$, all changes in kaon structure are modest** so that a well-constrained experimental analysis should be reliable The Sullivan processes can provide a valid pion target for $-t \leq 0.9\ \mathrm{GeV}^2$

[S.-X. Qin, C. Chen, C. Mezrag and C. D. Roberts, Phys. Rev. C 97 (2018) 015203.]

Experimental Validation (Pion Form Factor example)

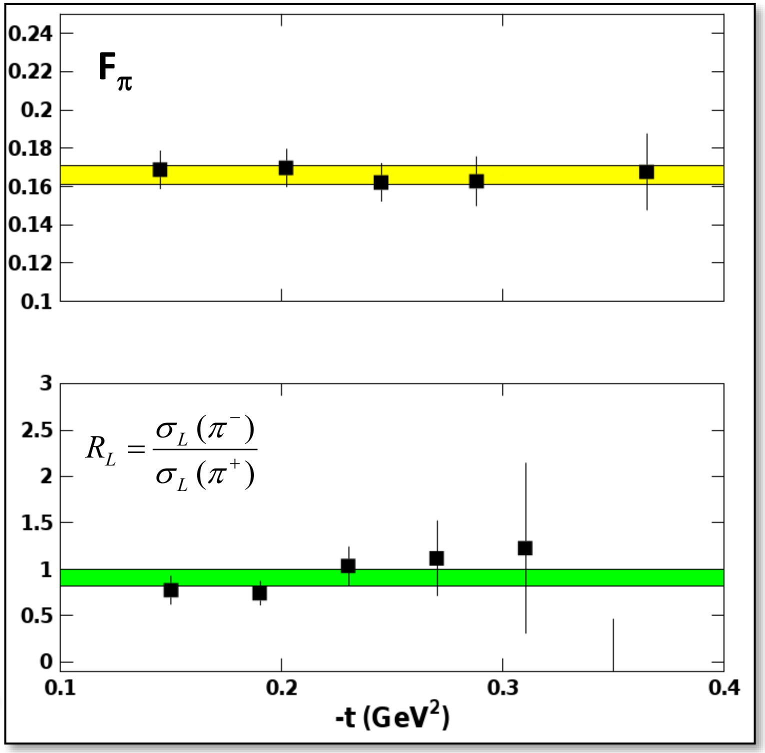
Experimental studies over the last decade have given more *confidence* in the electroproduction method yielding the physical pion form factor

Experimental studies include:

- Check consistency of model with data
  - F_π values seem robust at larger -t (>0.2) – increased confidence in applicability of model to the kinematic regime of the data
- Verify that the pion pole diagram is the dominant contribution in the reaction mechanism
  - R_L (= $\sigma_L(\pi^-)/\sigma_L(\pi^+)$) approaches the pion charge ratio, consistent with pion pole dominance

For the kaon need the ratio of L/T separated longitudinal $K^+\Lambda$ and $K^+\Sigma^0$ cross sections

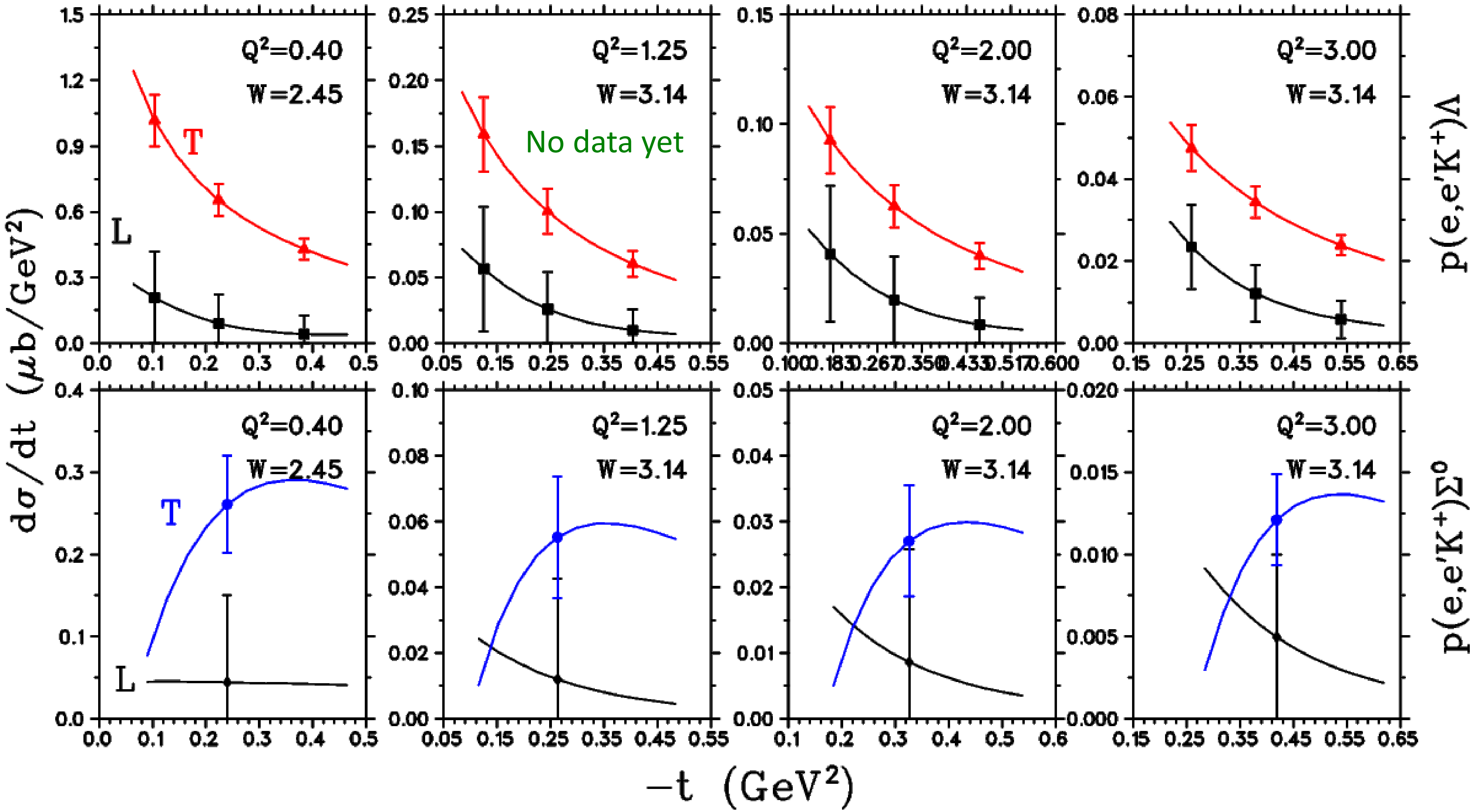
Q^2=2.45 GeV^2, W=2.22 GeV



$$R_L = \frac{\sigma(n(e,e'\pi^-)p)}{\sigma(p(e,e'\pi^+)n))} = \frac{|A_v - A_s|^2}{|A_v + A_s|^2}$$

KaonLT Projections: $K^+\Lambda$ and $K^+\Sigma^0$ cross sections

Projections based on PAC38 proposal



KaonLT data over a range of Q^2 will shed light on the $K^+\Lambda$, $K^+\Sigma^0$ reaction mechanism

- Possible form factor extractions at EIC – origin of hadron mass

KaonLT Projections: $K^+\Lambda$ and $K^+\Sigma^0$ cross sections

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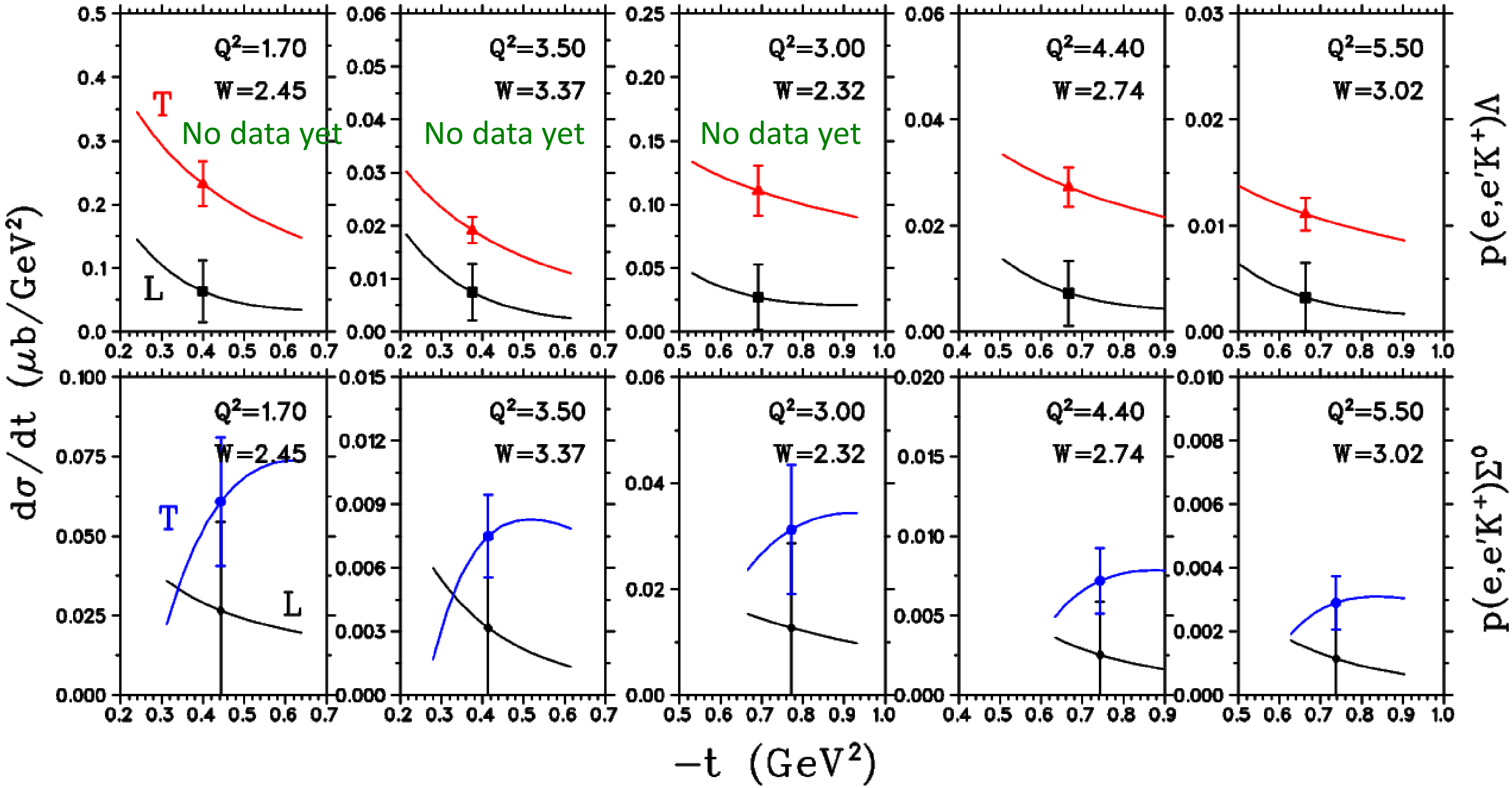


KaonLT data over a range of Q^2 will shed light on the $K^+\Lambda$, $K^+\Sigma^0$ reaction mechanism

- Possible form factor extractions at EIC – origin of hadron mass

KaonLT Status

- KaonLT took data in 2018/19
- The experiment complete fraction is 80% (32 days out of 40 approved days at PAC38)
- The completion fraction by setting taking into account beam delivery issues is listed in the table →

Table 1: Completion status by setting for the E12-09-011 (Kaon-LT) experiment. The scattered electron is detected in the HMS and the K^+ in the SHMS. The different beam energies for each Q^2, W, x combination are at different ϵ, needed for the L/T/LT/TT separation. At each ϵ, multiple hadron arm settings are needed to acquire data over a broad t-range. The listed t-ranges are determined by a Monte Carlo simulation of the HMS+SHMS acceptance; numbers are not listed for some settings as the MC event files could not be regenerated on short notice. q indicates the acquired and approved electron beam charge per setting. Hours per setting include both full and dummy target data taking.

Q^2 (GeV^2)	W (GeV)	x	$-t_{min}$ (GeV^2)	$-t_{max}$ (GeV^2)	Type	E_e (GeV)	θ_{SHMS} (deg)	q_{actual}/q_{PAC}	Hrs Approved	Hrs To Do
0.5	2.40	0.09	0.062	0.135	FF	3.8	6.79	136%	52.3	
							9.79	127%	52.3	
						4.9	6.00	23%	23.5	18.1
			0.062	0.180			6.86	57%	23.5	10.1
							8.86	41%	23.5	13.9
1.25	3.14	0.12	0.06	0.25	FF	7.4	5.85		9.3	9.3
							8.85		9.3	9.3
						9.3	5.50		5.1	5.1
			0.06	0.35			7.39		5.1	5.1
			0.10	0.50			10.39		5.1	5.1
1.7	2.45	0.25	0.17	0.45	Scaling	5.6	11.31		12.9	12.9
			0.23	0.45			14.31		12.9	12.9
			0.12	0.78		8.8	11.92		5.6	5.6
			0.16	0.66			14.92		5.6	5.6
			0.21	0.67			17.92		5.6	5.6
2.115	2.95	0.21	0.14	0.31	Both	6.2	6.20	114%	25.6	
			0.19	0.45			8.48	103%	25.6	
						8.2	5.50		10.1	10.1
			0.13	0.43			7.74		10.1	10.1
							10.74		10.1	10.1
						10.6	7.74	49%	10.1	5.2
			0.12	0.66			10.74	43%	10.1	4.9
							13.74	42%	10.1	5.1
3.0	3.14	0.25	0.17	0.47	Both	8.2	6.69	122%	43.3	
			0.25	0.65			9.89	116%	43.3	
						10.6	6.65	78%	20.6	4.6
			0.13	0.70			9.42	73%	20.6	5.5
							12.42	77%	20.6	4.8
3.0	2.32	0.40	0.36	0.96	Scaling	6.2	13.28	127%	7.3	
			0.46	0.96			16.28	109%	7.3	
						10.6	15.18	73%	3.5	
			0.46	0.96			18.18	169%	3.5	
							21.18	107%	3.5	
3.5	3.37	0.25	0.16	0.50	Scaling	9.3	6.08		25.4	25.4
			0.26	0.77			9.08		25.4	25.4
			0.15	0.90		10.9	5.50		14.4	14.4
			0.15	0.64			7.79		14.4	14.4
			0.25	0.85			10.79		14.4	14.4
4.4	2.74	0.40	0.35	1.00	Scaling	8.2	10.00	105%	18.2	
			0.49	1.06			13.00	194%	18.2	
						10.6	9.81	66%	9.0	2.0
			0.32	1.35			12.81	63%	9.0	2.3
							15.81	69%	9.0	1.7
5.5	3.02	0.40	0.39	0.86	Scaling	8.2	5.90	148%	44.4	
			0.52	1.16			8.48	143%	44.4	
						10.6	6.65	72%	25.8	7.2
			0.33	1.20			9.56	74%	25.8	6.7
							12.56	73%	25.8	7.0
TOTAL Physics									860.2	300.1
Calibrations and Overhead									96.0	33.5
GRAND TOTAL									956.2	333.6
PAC Days									39.8	13.9

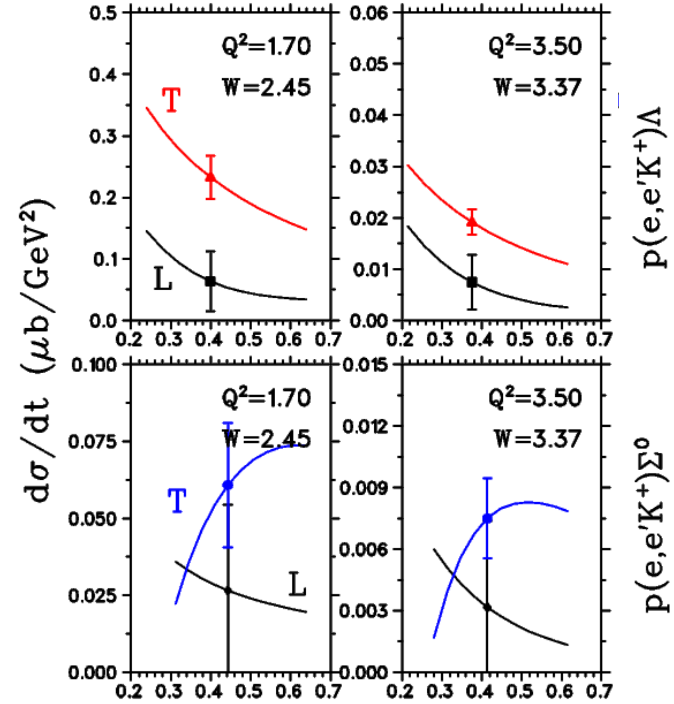
KaonLT Request to PAC49

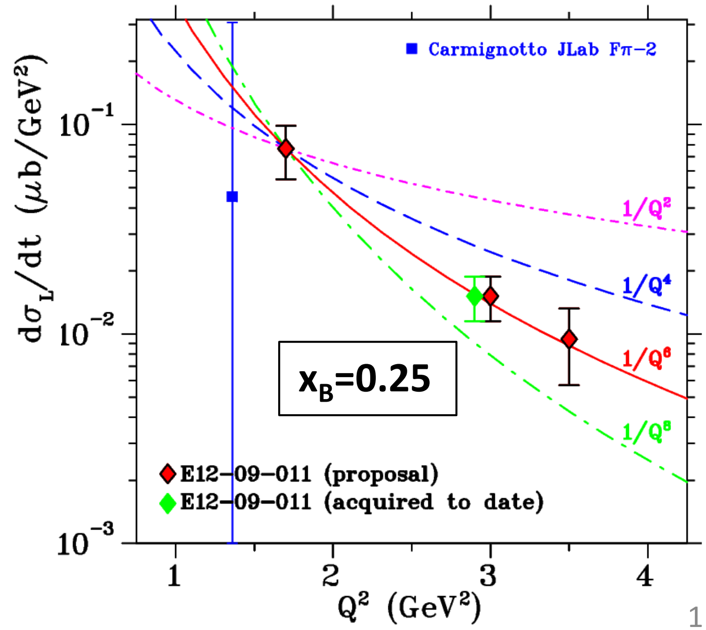
- **Approve the remaining 7-8 days of remaining beam time** to establish a high-precision data base of $K^+\Lambda$, $K^+\Sigma^0$ cross sections
  - Shed light on the reaction mechanism
  - Establish validation technique for possible kaon form factor measurements at the EIC

- **Additional beam time would allow for**:
  - performing L/T separations for the Q^2 scan at x_B=0.25 to validate the hard-soft reaction mechanism (possible GPD access)

PAC34: "…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…."

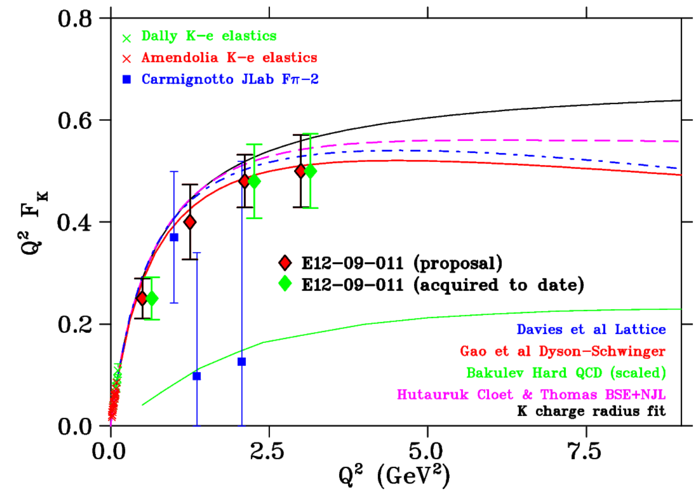
  - improving the uncertainties of possible 12 GeV kaon form factor extractions





Summary KaonLT Program at 12 GeV

- Enables measurements of the separated K^+ cross sections as function of Q^2 at x=0.25, 0.4
- Enables measurements of the separated $K^+\Lambda$, $K^+\Sigma^0$ cross sections as a function of t to Q^2=5.5 GeV^2
- May allow for kaon form factor extraction to the very largest Q^2 accessible at 12 GeV JLab, 5.5 GeV^2



- The only source of L-T separated towards hadron structure at colliders
  - The EIC cannot do L/T separations
  - JLab L/T separated data will be crucial for interpretation of EIC data for decades to come
- Use the remaining days for precision $K^+\Lambda$, $K^+\Sigma^0$ cross sections for tests of the reaction mechanism towards hadron structure at the EIC
- Additional beam time will allow for performing the Q^2 scan at x_B=0.25 for validation of hard-soft factorization and improving the uncertainties in possible form factor extractions