Low Q^2 Results from the PionLT and KaonLT experiments at Jefferson Lab

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On behalf of the PionLT and KaonLT Collaborations

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PionLT/KaonLT Motivation

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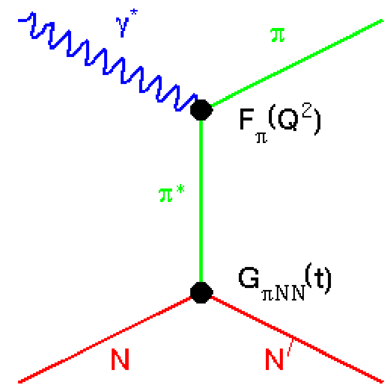
1) Determine the Pion Form Factor at Q^2>0.3 GeV^2:

- Indirectly measure F_π using the "pion cloud" of the proton via p(e,e'π^+)n

$$\left|p\right\rangle = \left|p\right\rangle_0 + \left|n\pi^+\right\rangle + \ldots$$

  - Pion pole process dominates σ_L in forward kinematics
  - Determining σ_L requires a Rosenbluth L/T-separation, which is experimentally challenging



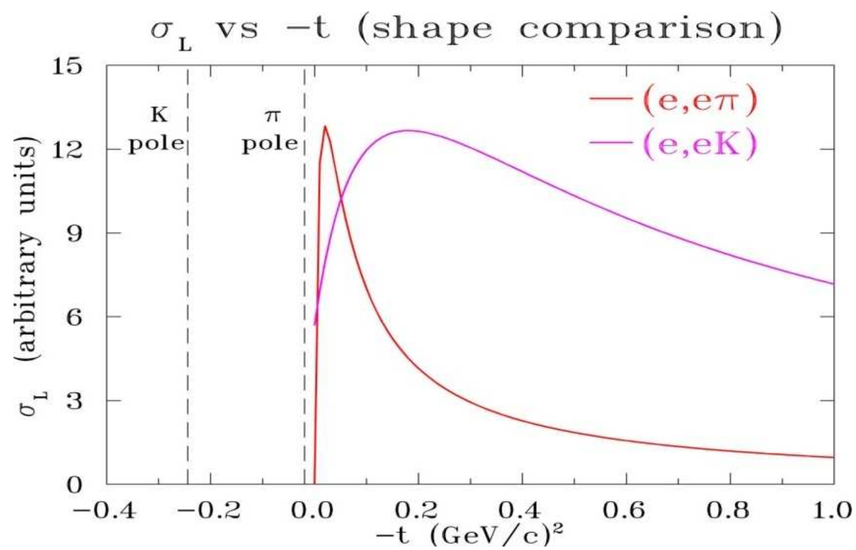
2) Can a similar method be used for K^+ Form Factor?

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

- Kaon pole further from kinematically allowed region

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_K^2)}\, g^2_{K\Lambda N}(t)\, F_K^2(Q^2,t)$$

Born Term Model pole equation to illustrate link between σ_L and elastic form factor



Meson Form Factors require a Model

- **Meson elastic form factors determined via the electroproduction technique are in principle model–dependent, although this dependence is reduced if σ_L data are taken at sufficiently low *-t***
- Our JLab 6 GeV studies indicate the method is reliable for low $-t < 0.4$ GeV^2 $p(e,e'\pi^+)n$ data [GMH et al., PRC 78 (2008) 045203]
  - A goal of KaonLT is to determine if the same holds for $p(e,e'K^+)\Lambda$
- **It is sometimes asked if the electroproduction technique is measuring the "physical" pion or kaon form factor**
- **The PionLT/KaonLT experiments have adopted a data-driven approach to address this concern to the greatest extent possible:**
  - Check consistency of model with data
  - Extract form factor at several values of $-t_{min}$ for fixed Q^2
  - Test that the pole diagram is really the dominant contribution to the reaction mechanism
  - **Verify that electroproduction technique yields results consistent with p-e elastic scattering at same Q^2**

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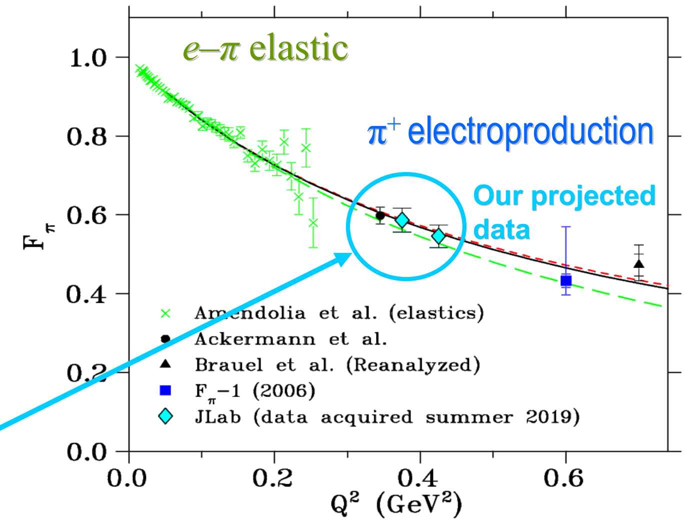
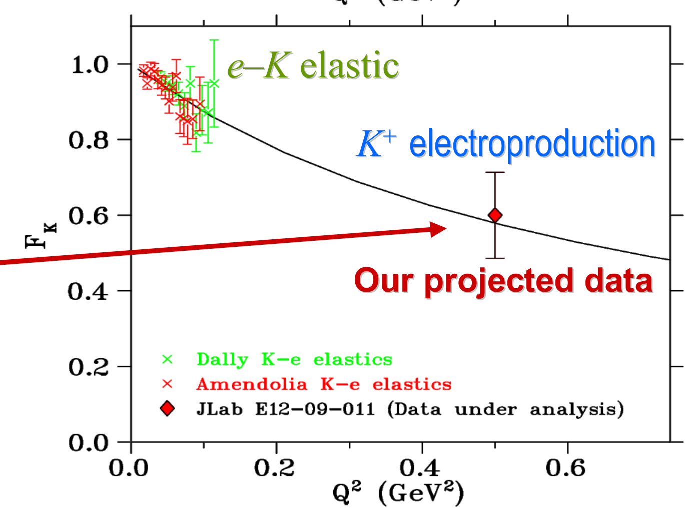
Low Q^2 Check of Electroproduction Technique

Directly compare $F_\pi(Q^2)$ values extracted from very low $-t$ electroproduction with values measured in elastic e-π scattering

- Q^2=0.35 GeV^2 data from DESY consistent with limit of elastic scattering data within uncertainties.
  [H. Ackermann, et al., NP **B137**(1978)294]
- **PionLT acquired $p(e,e'\pi^+)n$ data for a test at Q^2=0.375, 0.425 GeV^2 with much lower statistical and systematic uncertainties**
- **KaonLT data at Q^2=0.50 permits a test using $p(e,e'K^+)\Lambda$**





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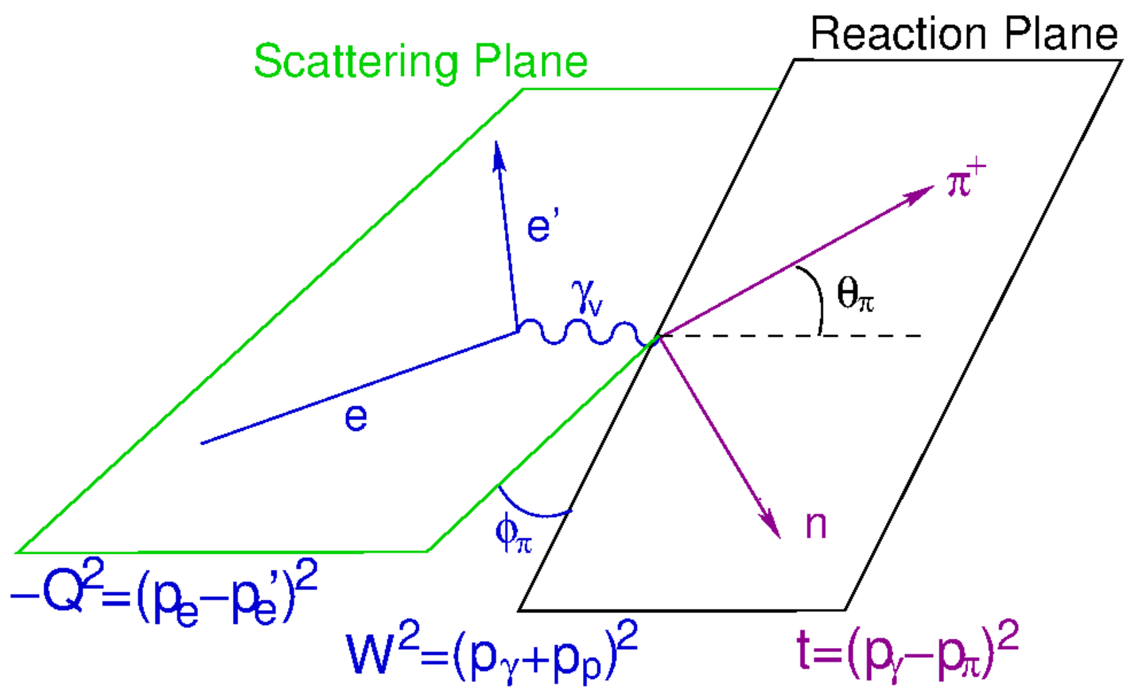
$$2\pi \frac{d^2\sigma}{dt\,d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt}\cos 2\phi$$

Virtual-photon polarization:

$$\varepsilon = \left(1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$



- L-T separation required to separate σ_L from σ_T
- Data for at least 2 ε are required, preferably more
  - Uncertainty in $\sigma_L \sim 1/\Delta\varepsilon$, where $\Delta\varepsilon = \varepsilon_{HI} - \varepsilon_{LO}$
  - Need $\Delta\varepsilon > 0.2$ to avoid >500% statistical error magnification
- Need to take data at smallest available $-t$, so σ_L has maximum contribution from the π^+ pole
- Need to measure t–dependence of σ_L at fixed Q^2,W

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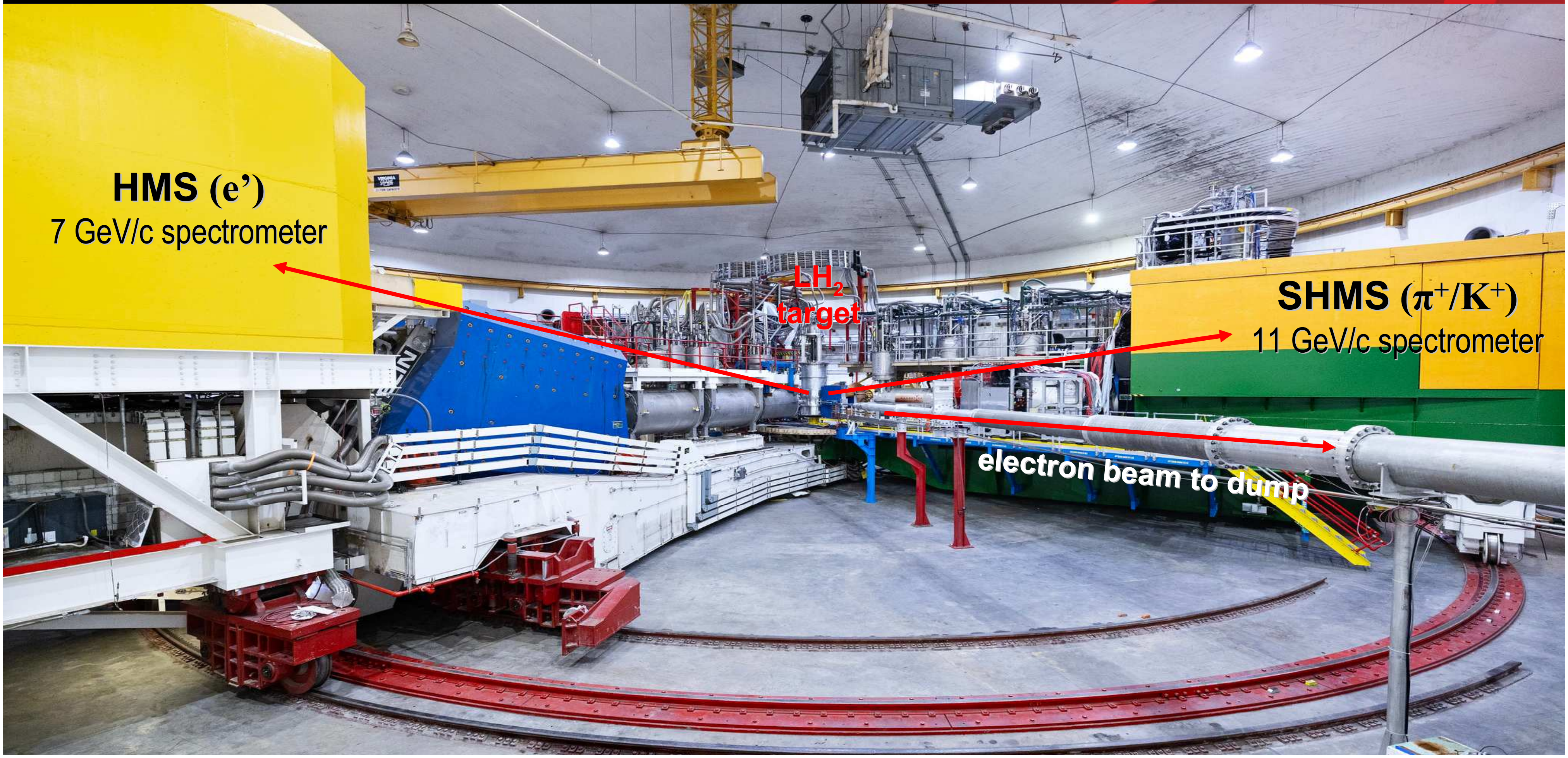
Jefferson Lab Hall C



- **HMS and SHMS MAGNETIC OPTICS:**
  - Point-to Point QQQD for easy calibration of magnetic optics acceptance and event reconstruction
  - SHMS Horizontal bend magnet allows spectrometer rotation to forward angles (5.5°); the HMS can rotate to a minimum of 10.5°
- **Rigid Support Structure and Connection to Pivot:** Provide Rapid & Remote Rotation, Pointing Accuracy & Reproducibility
- **Spectrometer Detector Packages:** Drift Chambers, Hodoscopes, Cherenkovs, PbG Calorimeter
- **Well-Shielded Detector Enclosures permit measurements at Very High Luminosity:** ~4×10^{38} cm^{-2} s^{-1}

PionLT/KaonLT Low Q^2 Kinematics

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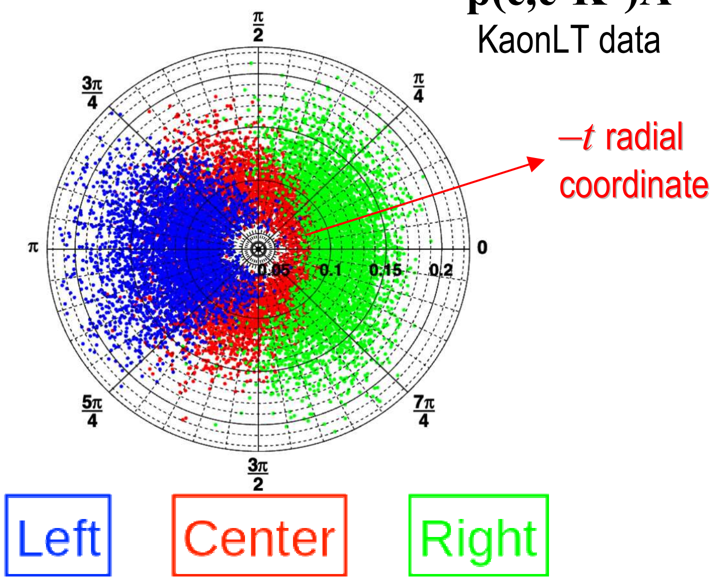
- 3 ε acquired for PionLT high quality L/T-separation, 2 ε for KaonLT
- Multiple SHMS angles needed for full φ (azimuthal) coverage

PionLT: $p(e,e'\pi^+)n$			
SHMS Azimuthal angle	**Low ε** =0.29 (2.7 GeV)	**Mid ε** =0.63 (3.6 GeV)	**High ε** =0.78 (4.5 GeV)
Q^2=0.375 GeV^2 W=2.2 GeV x_B=0.09			
Center ($\theta_{\pi q}$=0)	▲	▲	▲
Left1 ($\theta_{\pi q}$=+2^0)	▲	▲	▲
Left2 ($\theta_{\pi q}$=+4^0)	▲	▲	▲
Right1 ($\theta_{\pi q}$=–2^0)	X	▲	▲
Right2 ($\theta_{\pi q}$=–4^0)	X	▲	X
Q^2=0.425 GeV^2 W=2.2 GeV x_B=0.09			
Center ($\theta_{\pi q}$=0)	▲	▲	▲
Left1 ($\theta_{\pi q}$=+2^0)	▲	▲	▲
Left2 ($\theta_{\pi q}$=+4^0)	▲	▲	▲
Right1 ($\theta_{\pi q}$=–2^0)	X	X	▲
Right2 ($\theta_{\theta q}$=–4^0)	X	X	▲

$p(e,e'K^+)\Lambda$
KaonLT data



KaonLT: $p(e,e'K^+)\Lambda/\Sigma^0$		
SHMS Azimuthal angle	**Low ε** =0.45 (3.8 GeV)	**High ε** =0.69 (4.9 GeV)
Q^2=0.5 GeV^2 W=2.4 GeV x_B=0.09		
Center (θ_{Kq}=0)	▲	▲
Left (θ_{Kq}=+3^0)	▲	▲
Right (θ_{Kq}=–3^0)	X	▲

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$p(e,e'\pi^+)n$ Event Selection

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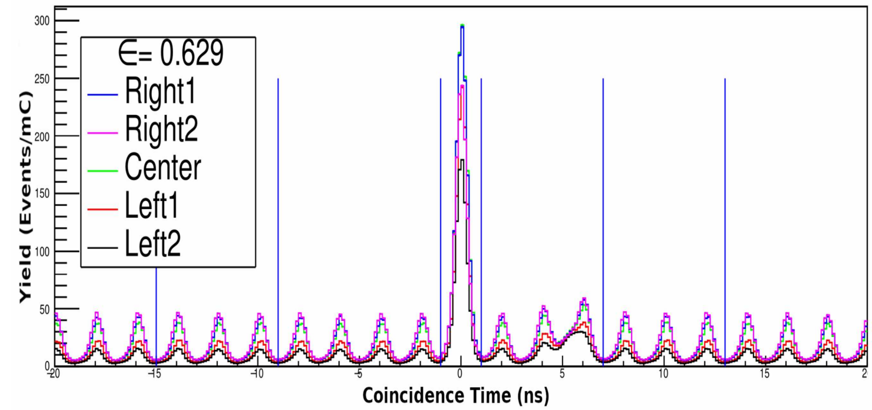
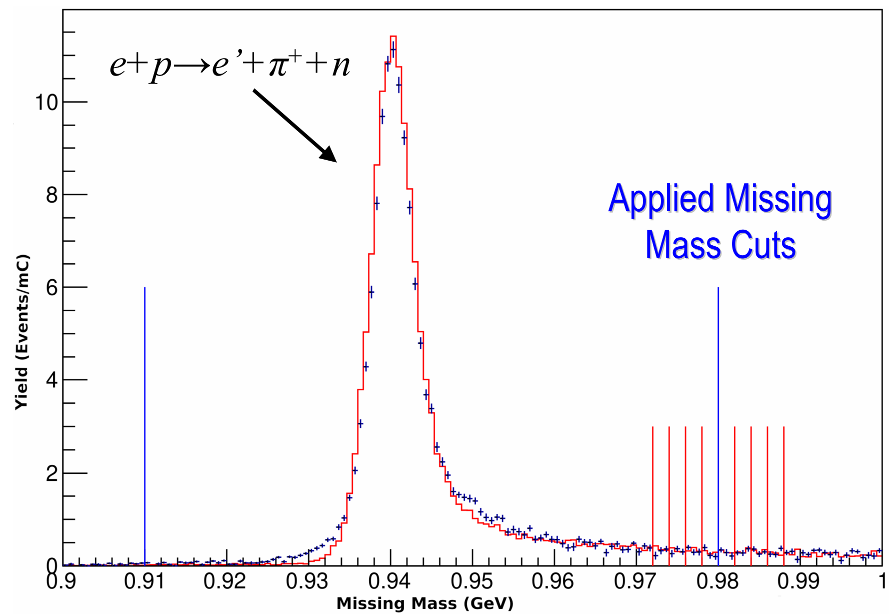
Coincidence measurement between π^+ in SHMS and electrons in HMS

Easy to isolate exclusive channel

- Excellent particle identification
- CW beam minimizes "accidental" coincidences
- Missing mass resolution easily excludes 2–pion contributions

$$M_X = \sqrt{(E_{\text{det}} - E_{init})^2 - (p_{\text{det}} - p_{init})^2}$$

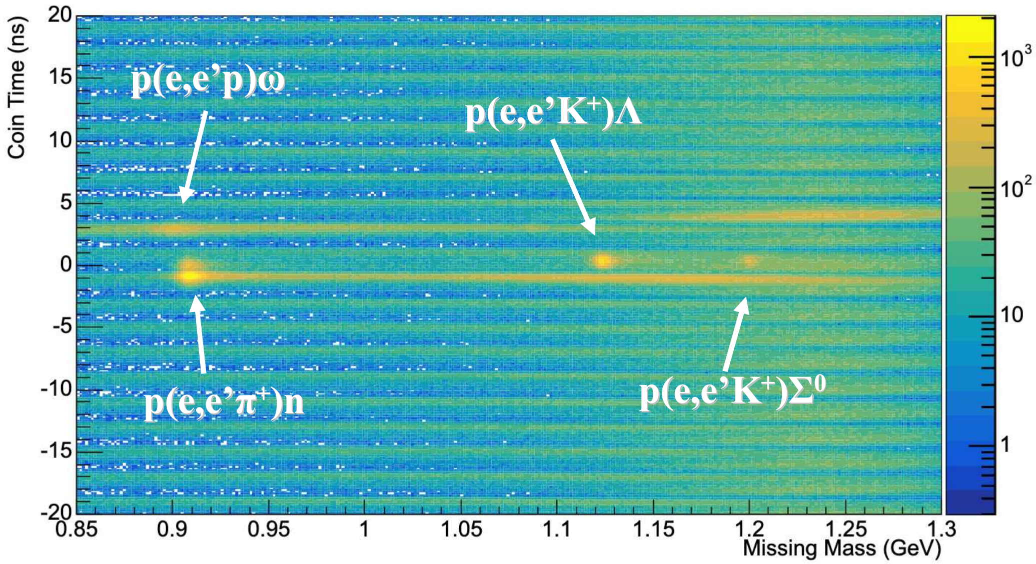




PionLT data: Q^2=0.375 Mid ε SHMS Center Setting

$p(e,e'K^+)\Lambda$ Event Selection

Clean K^+ identification is more work, due to high π^+/K^+ ratio

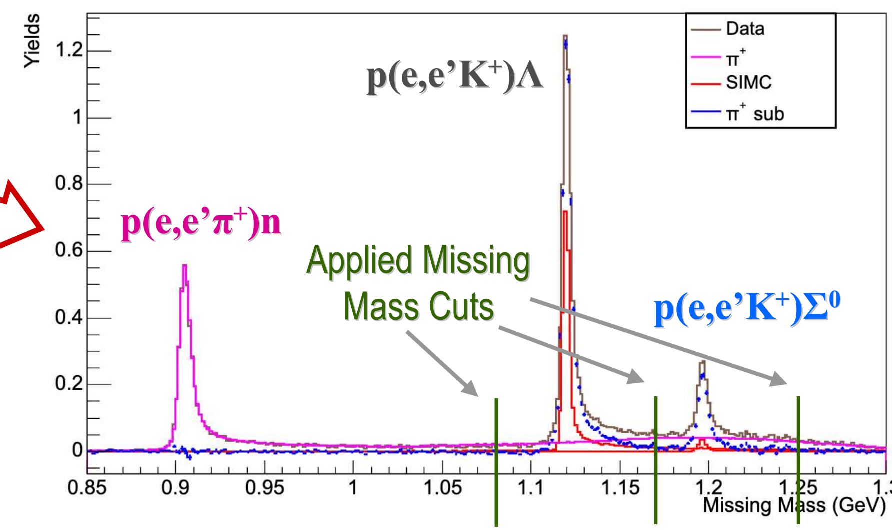


With the lower SHMS momenta used for Low Q^2 measurements

$$CoincidenceTime = t_{HMS} - t_{SHMS}$$

corrected for particle type using time of flight for electrons (HMS) and kaons (SHMS) is effective to distinguish different reaction types

- Some π^+ background remains after time cuts
- A separate sample of pure $p(e,e'\pi^+)X$ events is obtained with alternate cuts, normalized and subtracted from the $p(e,e'K^+)X$ data
- The subtracted Λ/Σ^0 peak shapes agree well with MC simulation



KaonLT data: Q^2=0.35 Low ε SHMS Center Setting

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The different meson arm (SHMS) settings are combined to yield φ-distributions for each *t*-bin

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

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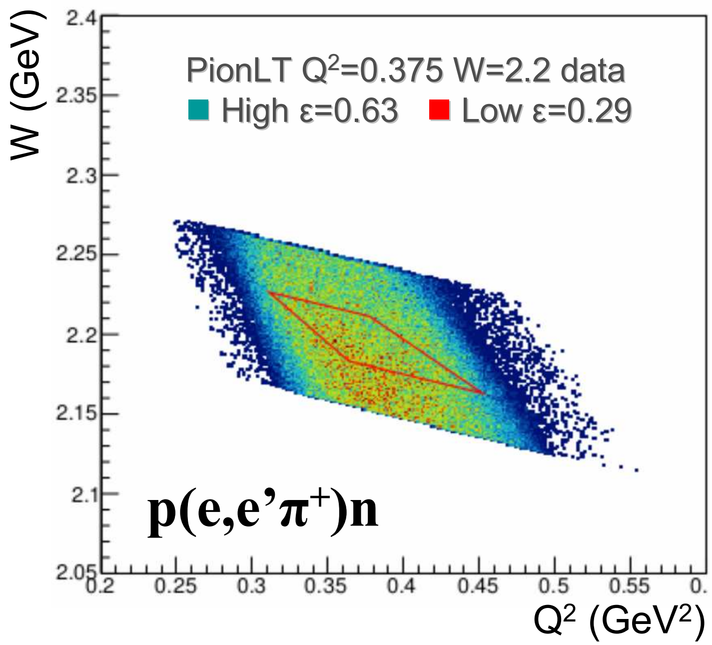
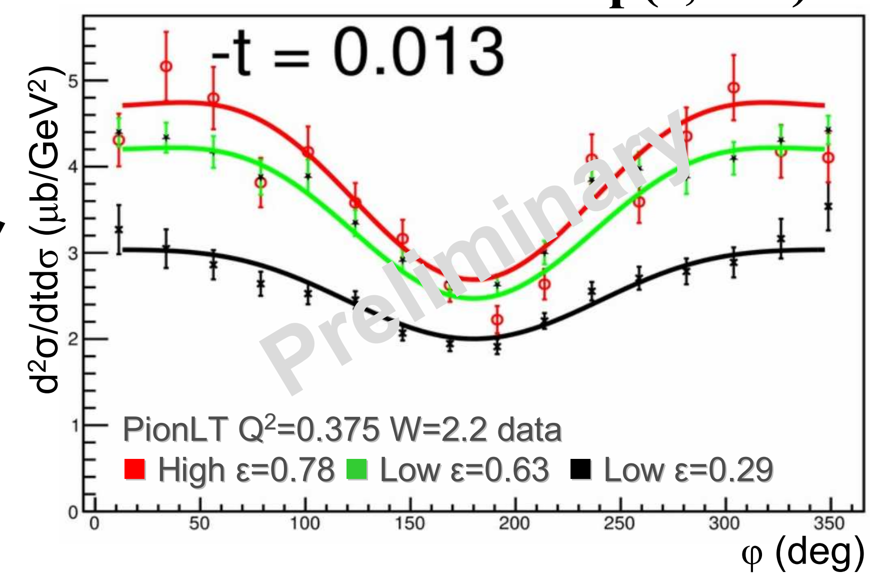


Diamond cuts define common (W,Q^2) acceptance at both ε

- Extract σ_L by simultaneous fit of Rosenbluth formula using measured azimuthal angle (φ_π) and knowledge of virtual photon polarization (ε)

p(e,e'π⁺)n



Preliminary L/T-separated results

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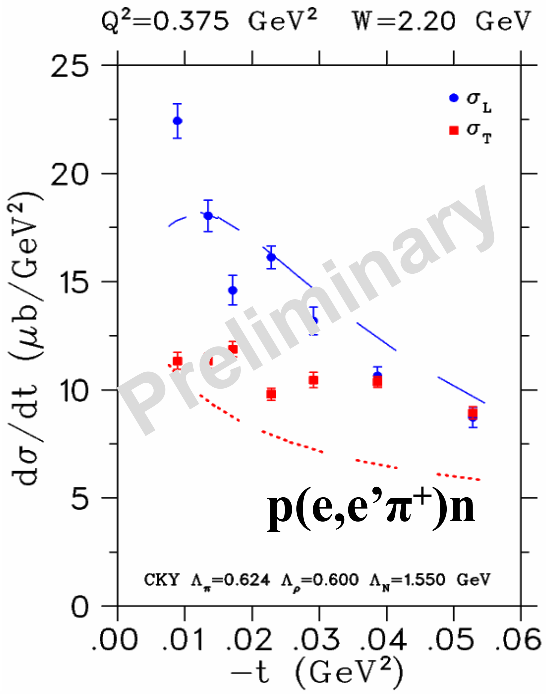
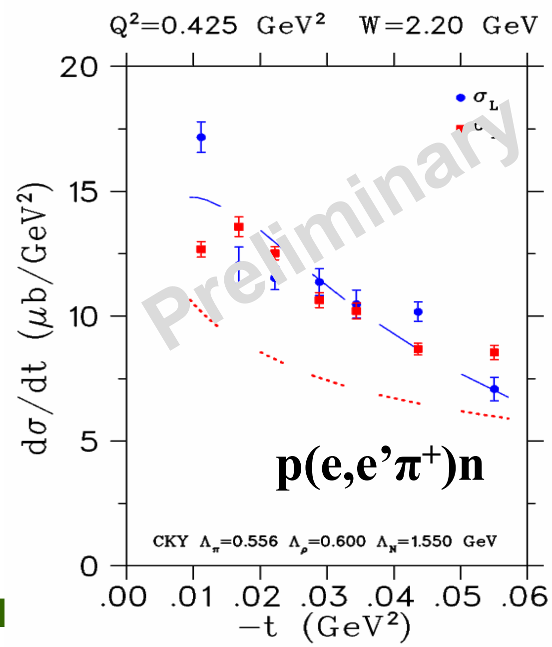


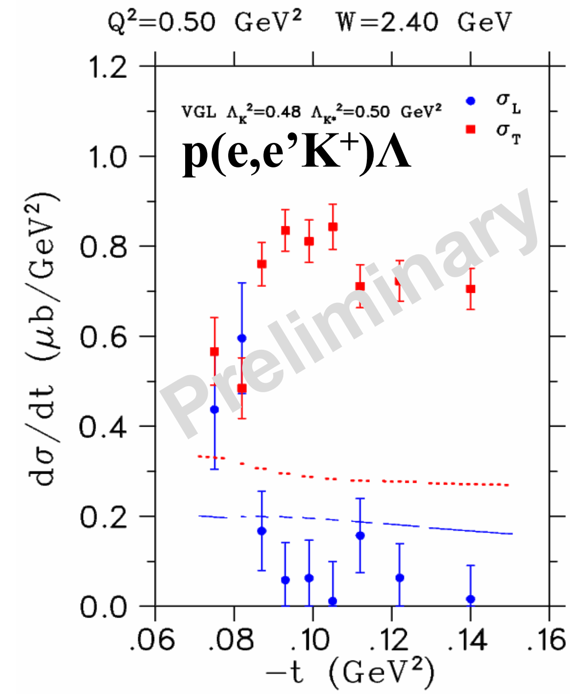


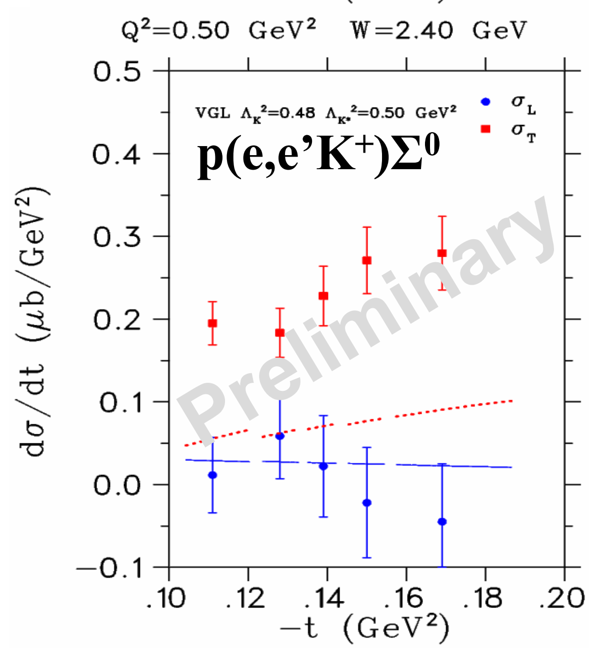
p(e,e'π⁺)n

- σ_L shows rise at low –*t* characteristic of π pole dominance
- T/L is significantly larger than expected from old Ackermann data
  [NP B137 (1978) 294]
  - Our large σ_T is readily apparent in large ε=0.29 cross section
- Curves are CKY Regge Model prediction
  [J Korea PhysSoc 67 (2015)L1089]

p(e,e'K⁺)Λ/Σ⁰

- As expected, T/L ratio is much larger than π⁺ and rise in σ_L at low –*t* is less
- Σ^0/Λ ratio is small
- Curves are VGL Regge model prediction
  [PRC 61 (2000) 025204]





Next steps

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- **The end result of PionLT/KaonLT will be an order of magnitude increase in the world data set for exclusive pion and kaon reactions and form factors over a wide kinematic range ($0.4<Q^2<8.5$ GeV^2, $2.0<W<3.3$ GeV)**
  - We hope this will encourage model development for $p(e,e'\pi^+)n$, $p(e,e'K^+)\Lambda/\Sigma^0$ reactions, so we can glean maximum new hadron structure information from these data
- **Expecting papers on Low Q^2 L/T/LT/TT separated results for $p(e,e'\pi^+)n$, $p(e,e'K^+)\Lambda$ and $p(e,e'K+)\Sigma^0$ by end of year**
  - Low Q^2 experimental systematic uncertainty studies not yet completed
- **Much work remains to understand $d\sigma_L/dt$ model fit systematic uncertainties before we can release meson form factor results**
  - Plan to compare VGL, CKY and PKT model fits to data to better understand model dependence in form factor results
  - It will be interesting to see whether Low Q^2 F_π F_K results are consistent (within uncertainties) to π^+ and K^+ charge radius results from meson-electron elastic scattering method

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PionLT/KaonLT Collaboration

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