



# **KaonLT: preliminary results for LT-separations at $Q^2=0.5$**

**Abdennacer Hamdi**

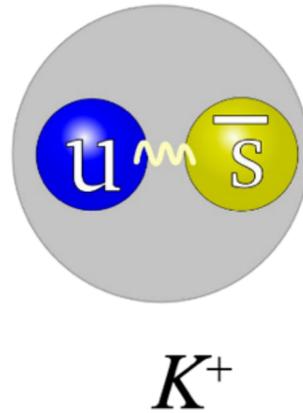
**On behalf of the KaonLT Collaborations**

Hall C Winter Collaboration Meeting

01/26/2026

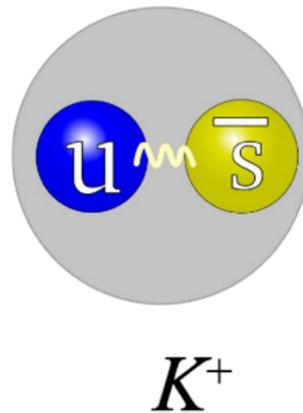
# Kaon Form Factor

- Simple valence structure of kaon is ideal test to our understanding of bound quarks
  - \* Higgs mechanism is not sufficient to explain the kaon mass → QCD dynamics !



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  - \* Higgs mechanism is not sufficient to explain the kaon mass → QCD dynamics !



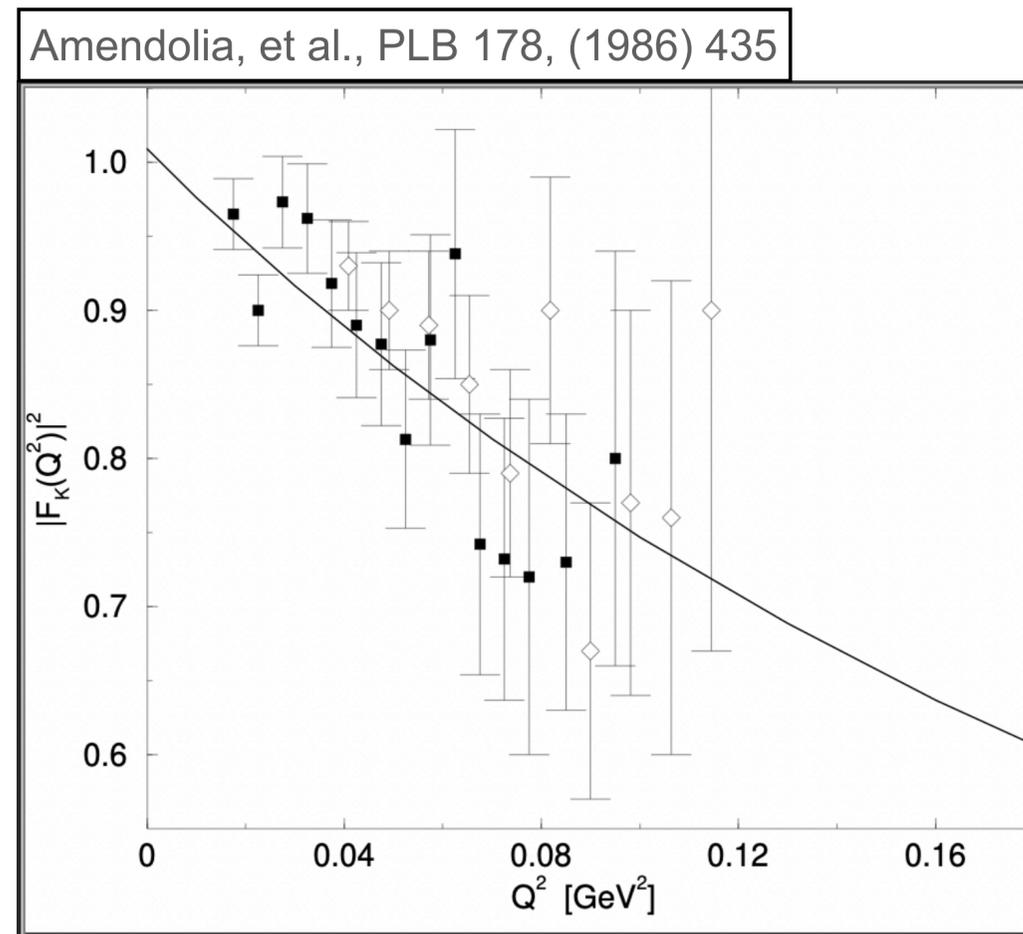
- QCD dynamics is studied in exclusive nuclear reactions
  - ▶ Hadron constituents, charge distributions, currents, color and flavour within the hadrons are encoded in the **form factors**

In single virtual photon exchange :  $\sigma_L \propto \frac{-tQ^2}{(t - m_K^2)^2} g_{KNN}^2(t) F_K^2(Q^2, t)$

# Direct Measurement

Used kaon beams (Fermilab, CERN) in the elastic scattering on electrons from nucleon targets,  $Q^2 < 0.13 \text{ GeV}^2$

- ▶ The cross section departs from point-like reaction by the form factor  $\frac{d\sigma}{dQ^2} = \left(\frac{d\sigma}{dQ^2}\right)_{\text{pt}} |F_K(Q^2)|^2$
- ▶ Allows the extraction of charged kaon radius  $\langle r_K^2 \rangle = -6 \left. \frac{dF_K(Q^2)}{dQ^2} \right|_{Q^2=0}$



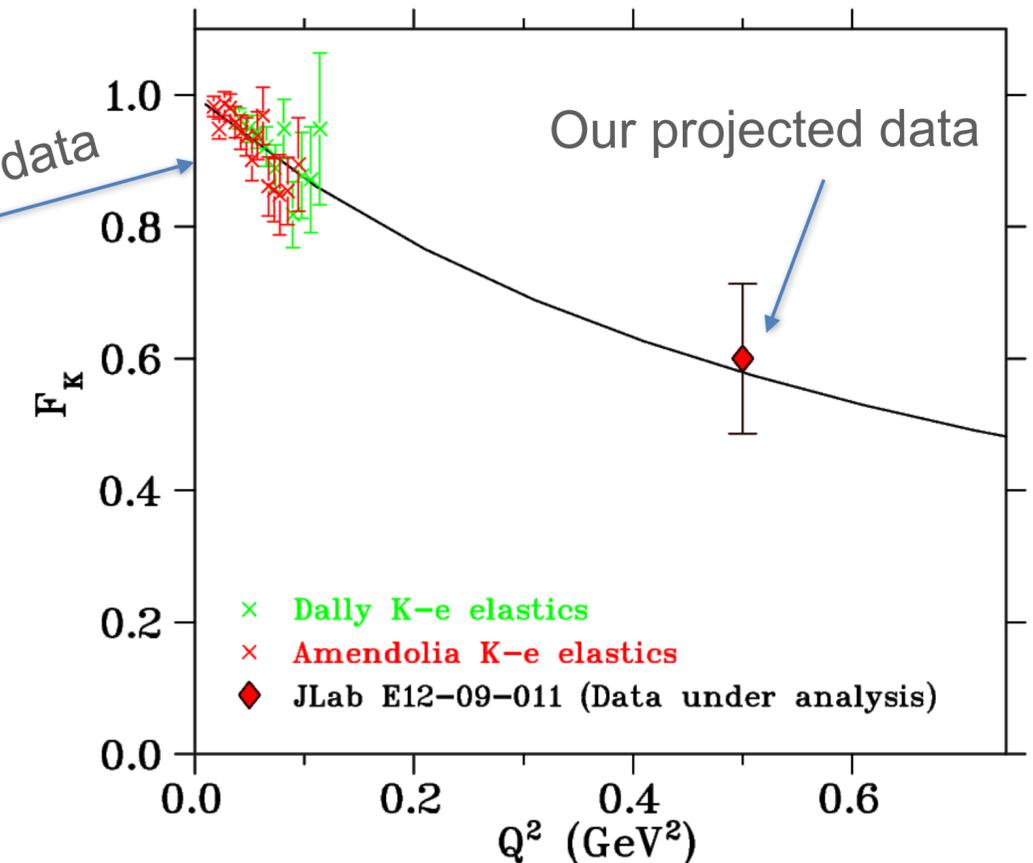
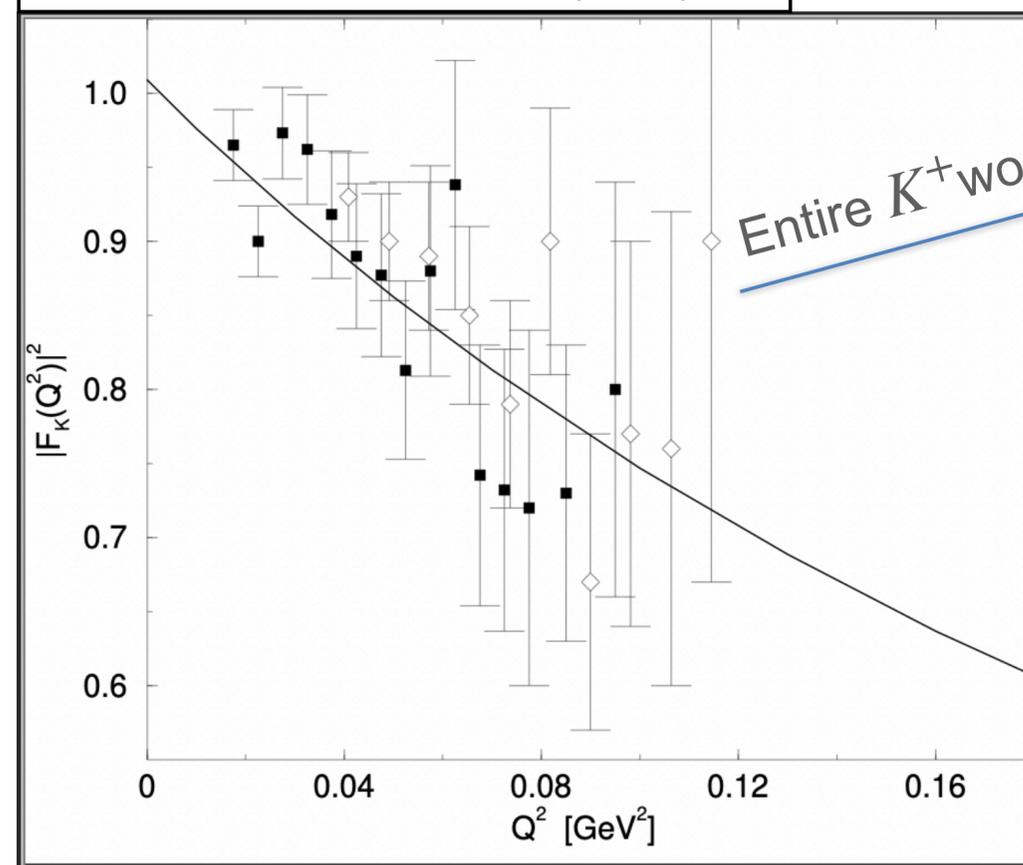
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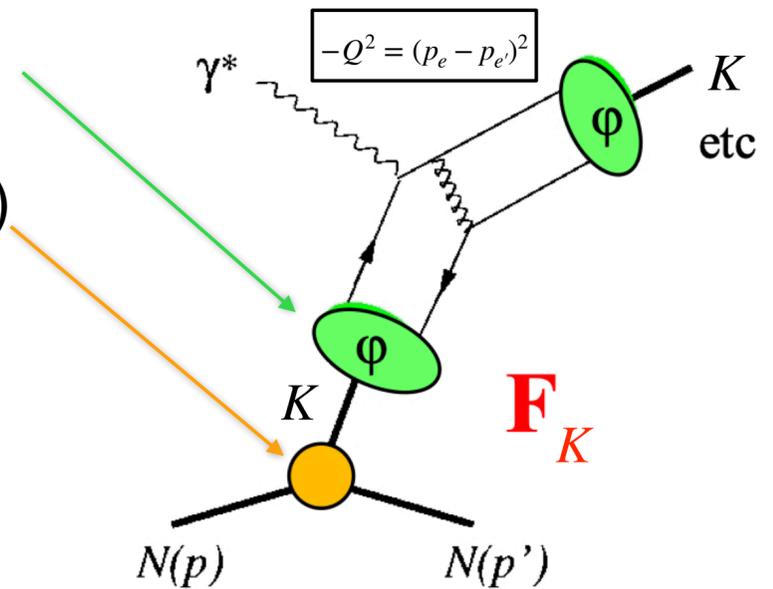
Amendolia, et al., PLB 178, (1986) 435



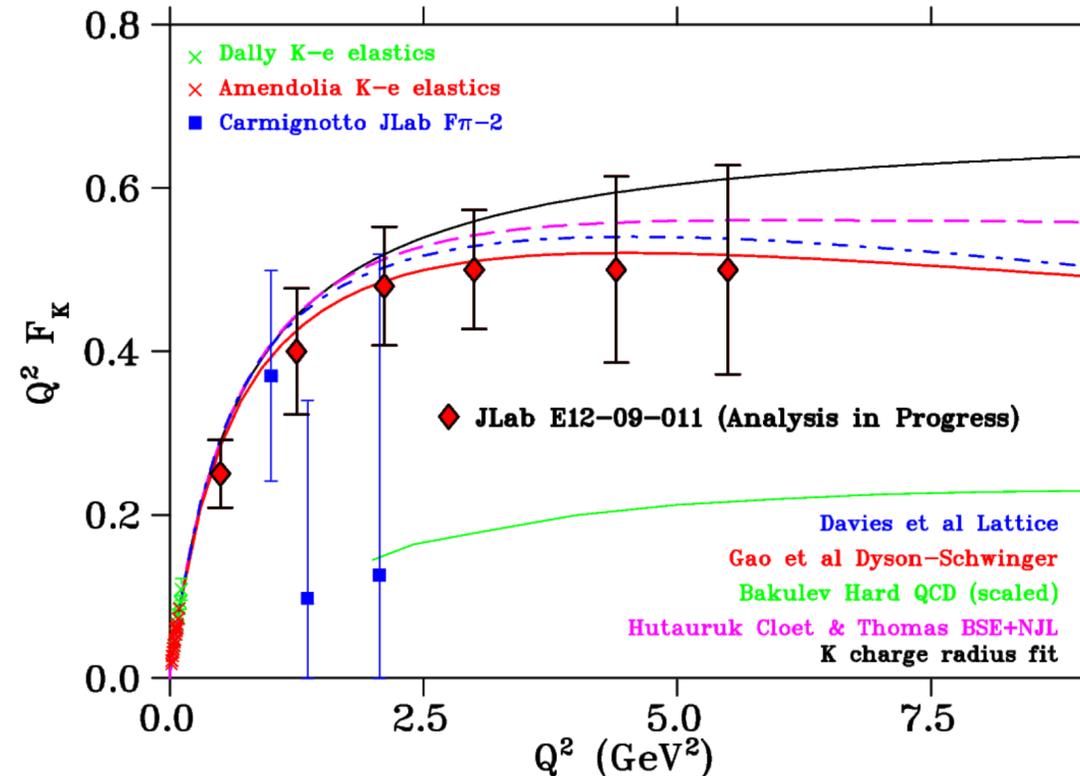
# Indirect Measurement

In the limit of small- $t$  and large  $W$ , the kaon is produced in the  $t$ -channel exchange of the meson pole term

- ▶ Interaction with “kaon cloud” is sensitive to longitudinal cross section ( $\sigma_L$ )
- ▶ Interaction with “core” ( $p/\Lambda/\Sigma^0$ ) is sensitive to transverse cross section ( $\sigma_T$ )
- ▶ JLab kaon form factor measurements to higher  $Q^2 > 0.3 \text{ GeV}^2$
- ▶ Detector acceptance allows for simultaneous of  $K^+\Lambda$  and  $K^+\Sigma^0$  channels



$$|P\rangle = |P\rangle_0 + |\Lambda K^+\rangle + |\Sigma K^+\rangle + \dots$$



# Longitudinal-Transverse (L-T) Cross Section Separation

- L-T Separation can be utilized to separate  $\sigma_L$  from  $\sigma_T$

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

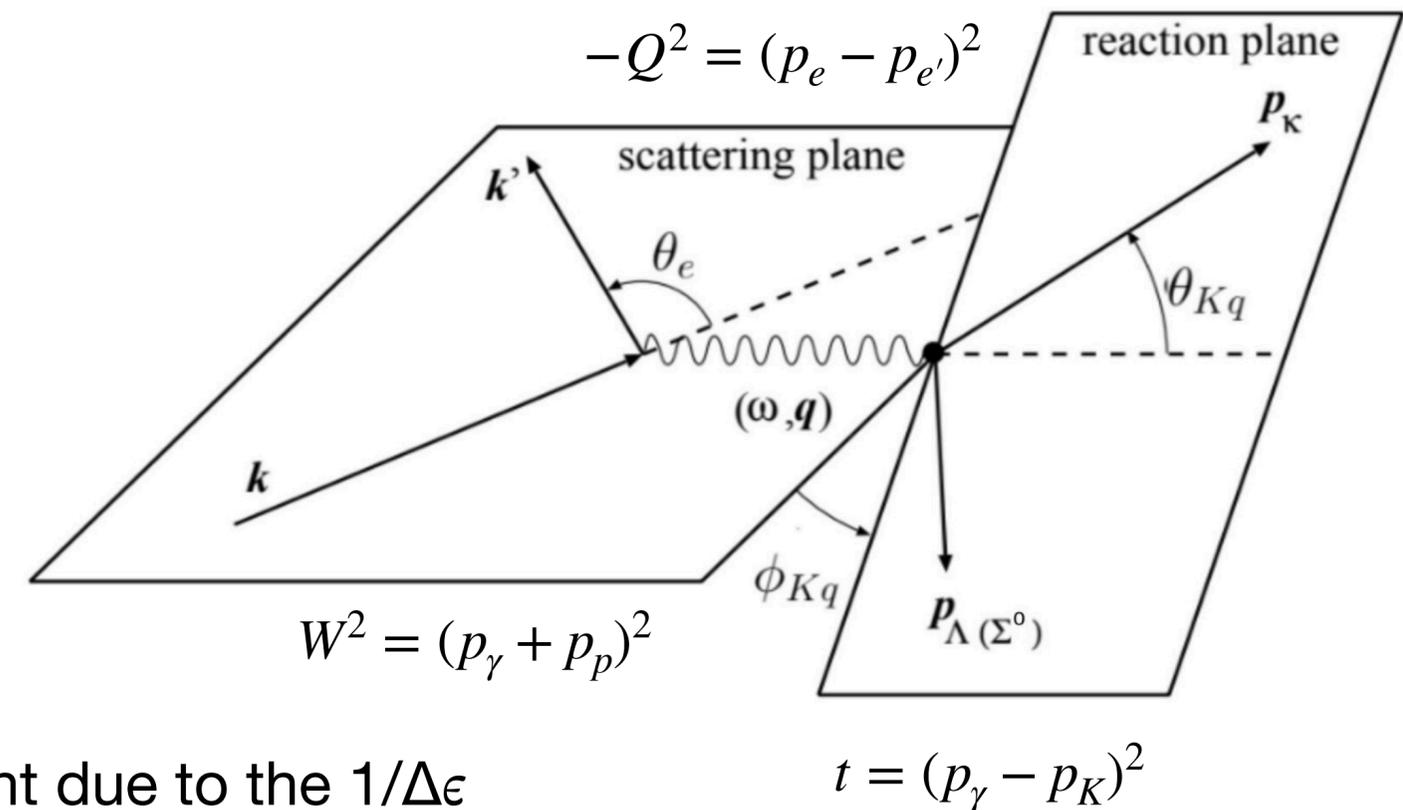
polarization of virtual photon

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

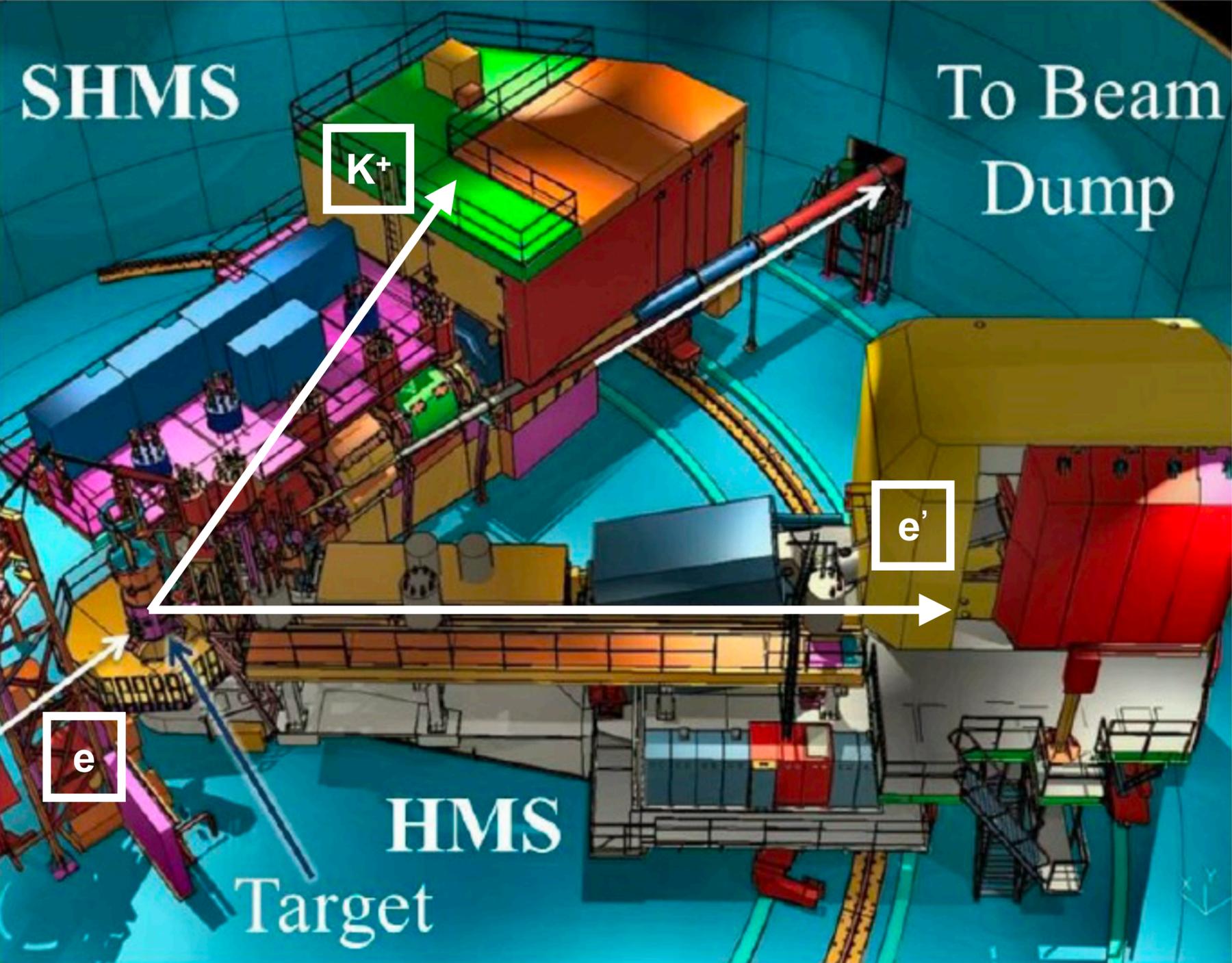
- Cross-section is separated by performing two scattering measurements at different  $\epsilon$  values with fixed  $Q^2$  and  $W$ , with full  $\phi_\pi$  coverage

- Meticulous evaluation of the systematic uncertainties is important due to the  $1/\Delta\epsilon$

amplification in the  $\sigma_L$  extraction: spectrometer acceptance, kinematics, and efficiencies.



# Kaon L-T Experiment in Hall C



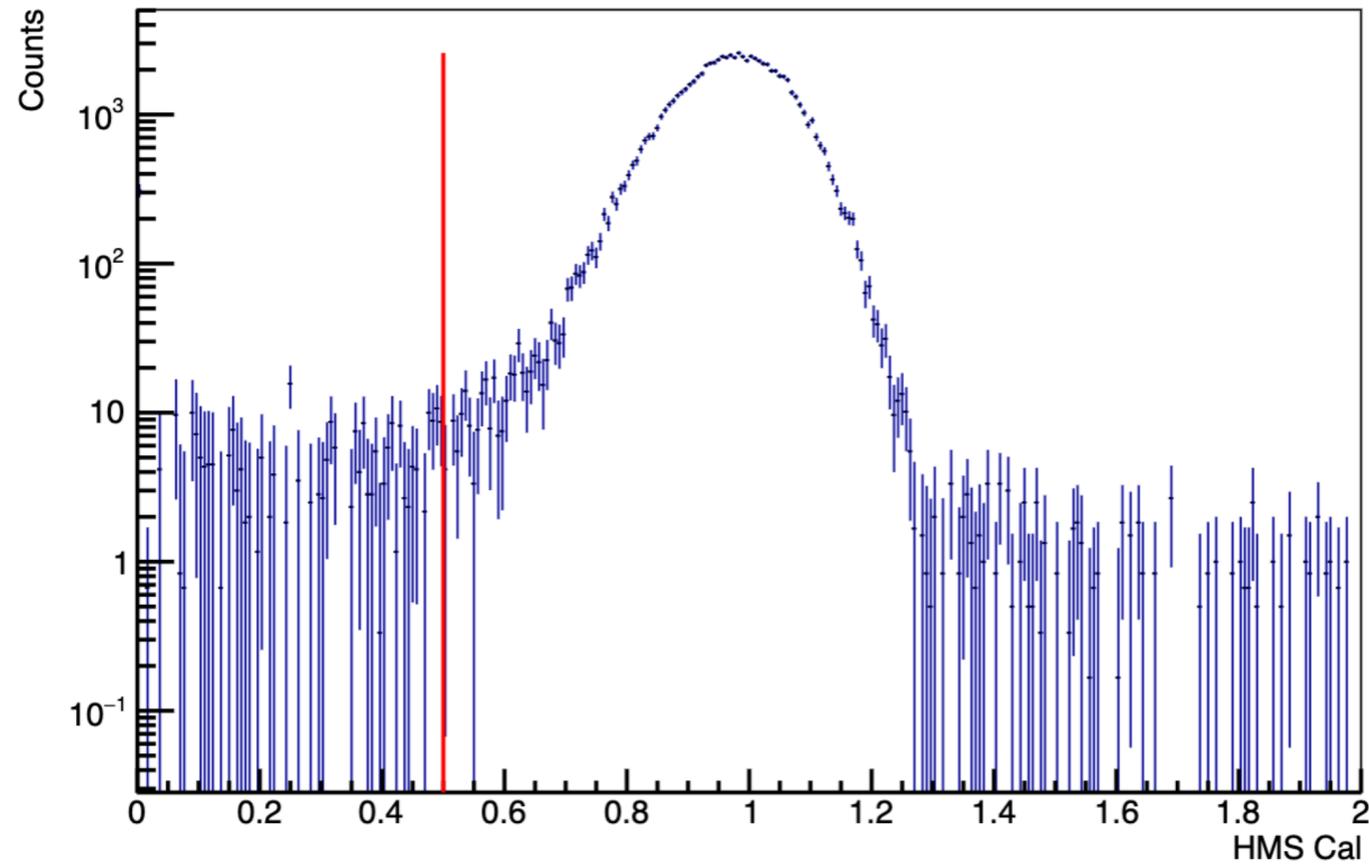
$Q^2$ (GeV <sup>2</sup> )	W (GeV)	$x_B$
0.5	2.4	0.09

HMS		SHMS	
P (GeV/c)	$\theta$ (deg)	P (GeV/c)	$\theta$ (deg)
0.968	21.14	2.583	6.79

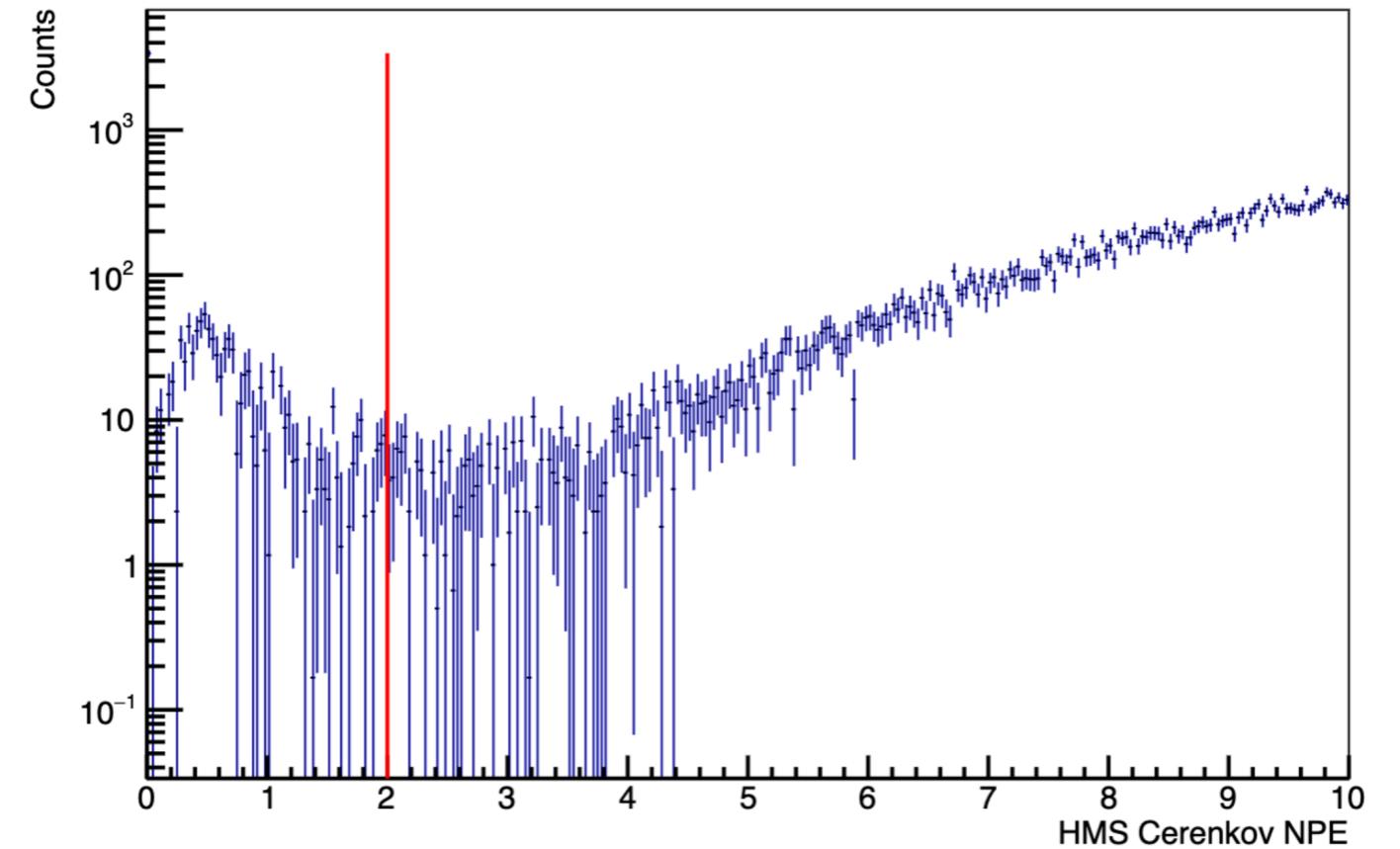
Azimuthal Angle $\phi$	Beam Energy (GeV)	
	3.8 (Low $\epsilon$ )	4.9 (High $\epsilon$ )
Center	✓	✓
Left	✓	✓
Right	✗	✓

# Event Selection Using Calorimeter and Cerenkov Detector

- Select the recoiled electrons in the HMS by setting the total energy deposited in the calorimeter normalized by the particle's momentum  $> 0.5$

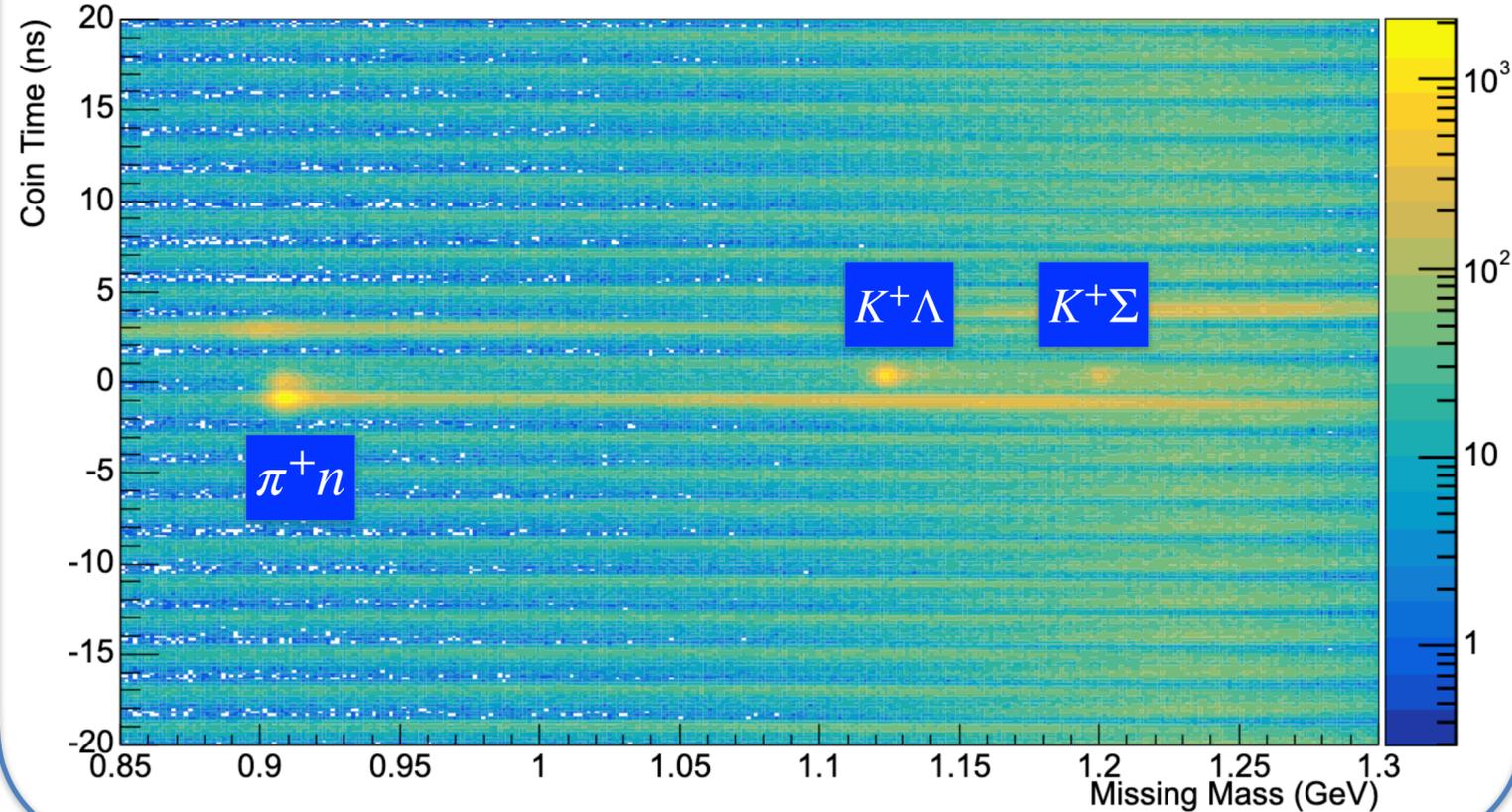


- Select electrons in the Cerenkov detector by setting the total number of photoelectrons  $> 2$

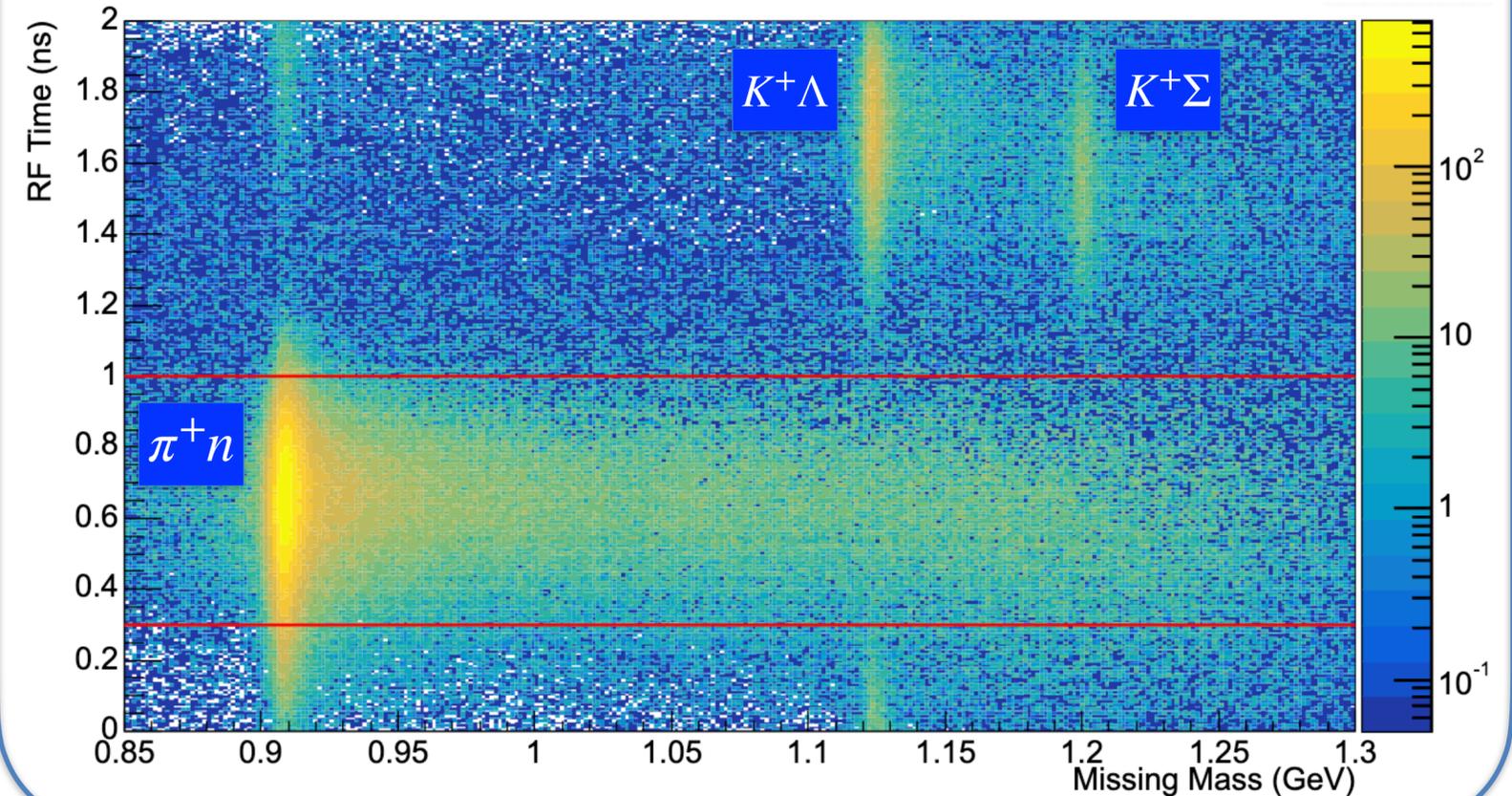


# Event Selection Using Timing Measurements

- Coincidence Time = HMS Time – SHMS Time, corrected for particle type using time of flight for electrons (HMS) and kaons (SHMS) can distinguish between real and random events



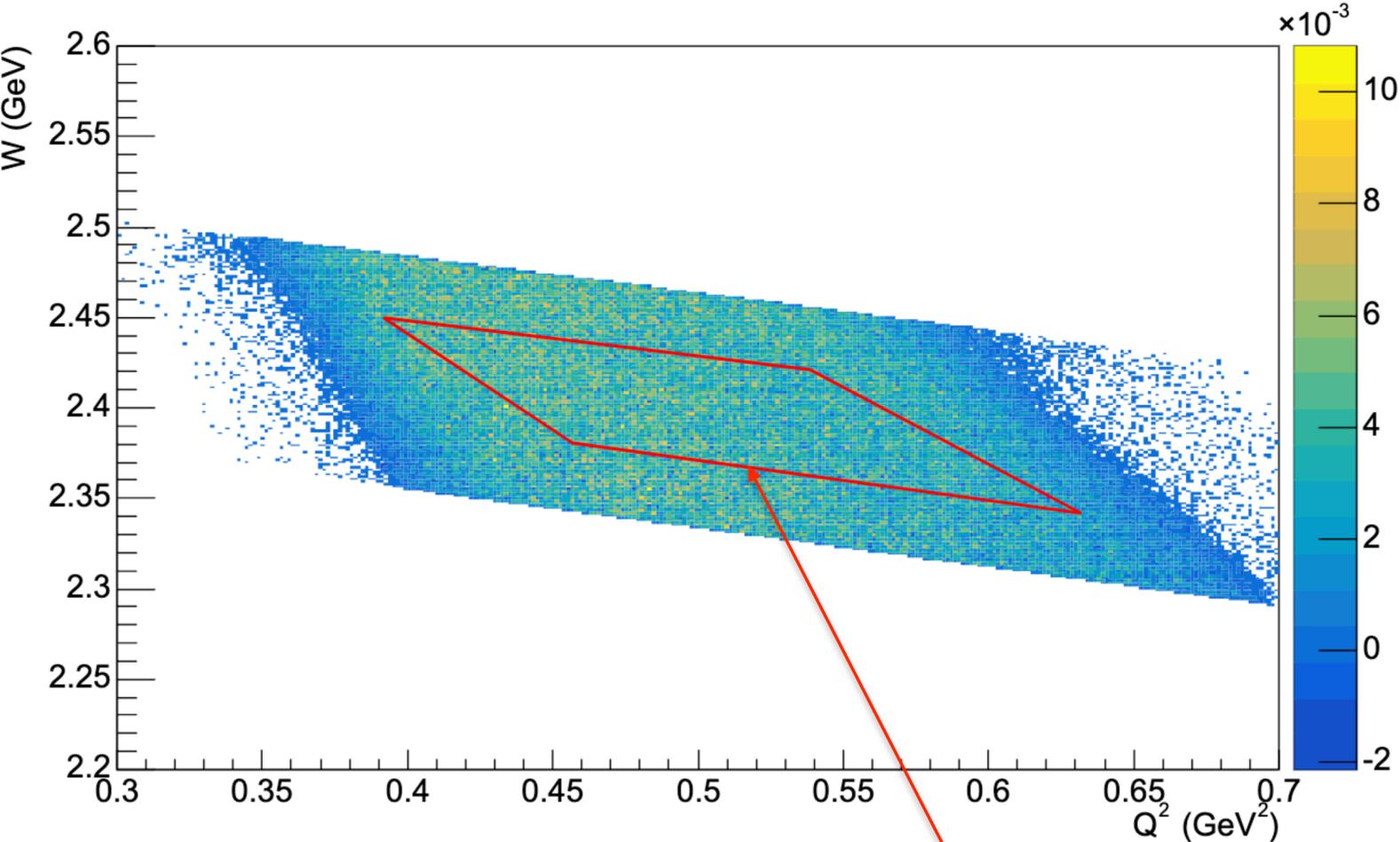
- RF Time is the time difference between the SHMS time, adjusted for particle type using time of flight, and radio frequency (RF) time signal from the accelerator



$$\text{Missing Mass} = \sqrt{(E_e + m_p - m_{e'} - E_{K^+})^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_{K^+})^2}$$

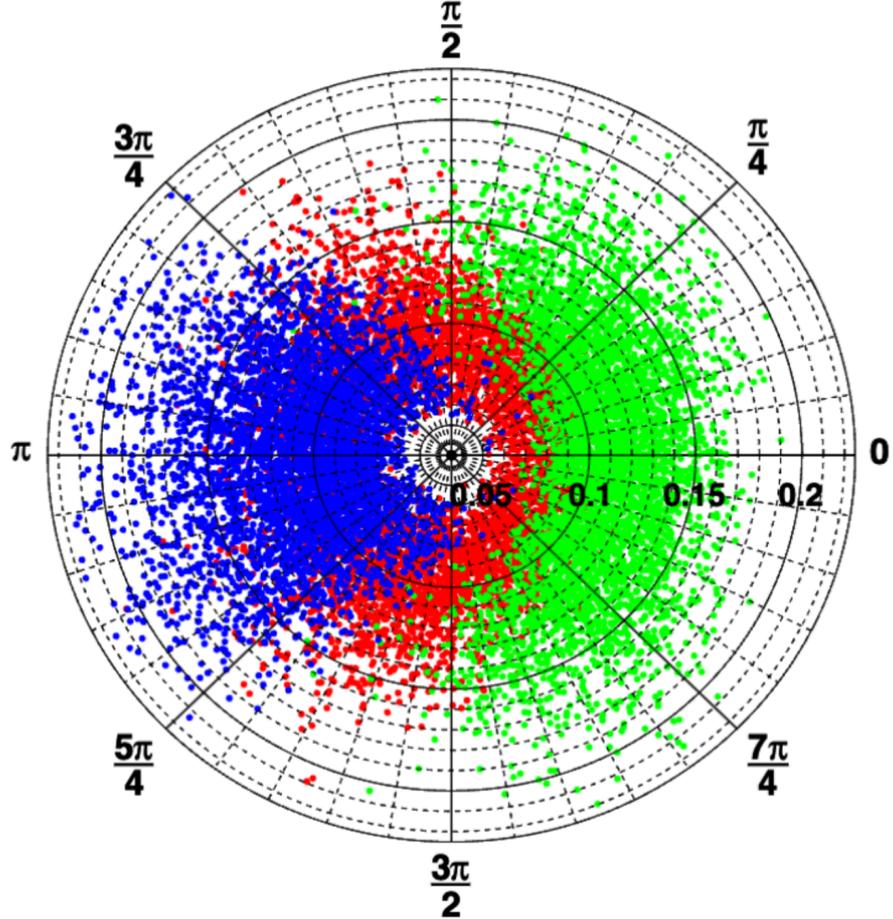
# Phase Space for L/T Separation

- For the L-T separation to be feasible, there must be an overlap in the  $(Q^2, W)$  phase space of both  $\varepsilon$  values



Low and High  $\varepsilon$  overlap region

- For the determination of the interference term in the cross section:  $\sigma_{LT}$ ,  $\sigma_{TT}$  we require a full azimuthal coverage at all  $-t$  regions

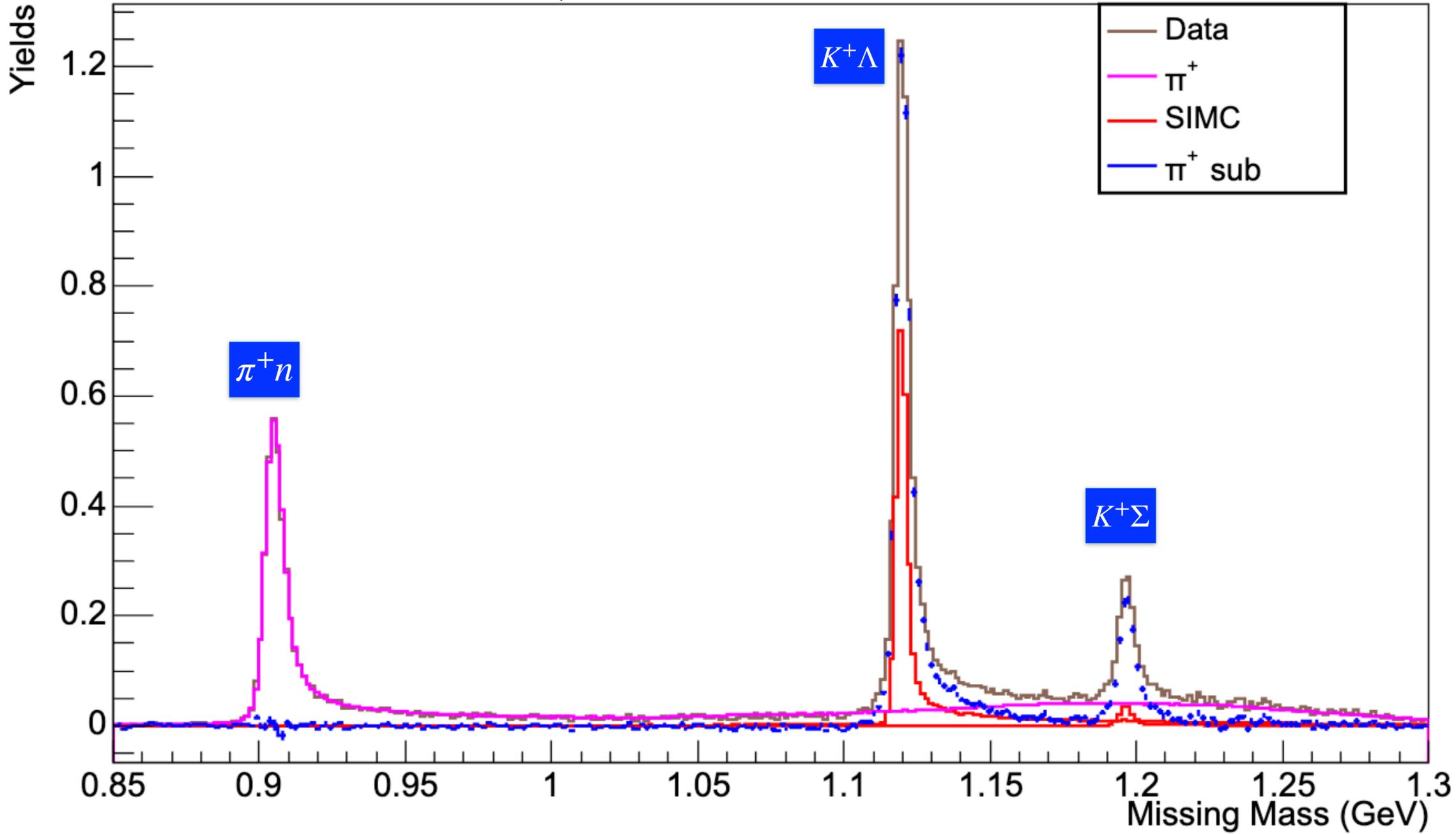


(Scattering, Reaction) plane Angle  $\phi$  : Left Center Right

# Missing Mass

- The  $\Lambda$  and  $\Sigma$  particles are reconstructed using the conservation of energy and momentum

$$\text{Missing Mass} = \sqrt{(E_e + m_p - m_{e'} - E_{K^+})^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_{K^+})^2}$$



# Yields Normalization

- To evaluate the cross section, we need to correct the measured  $\Lambda$  and  $\Sigma$  yields in data

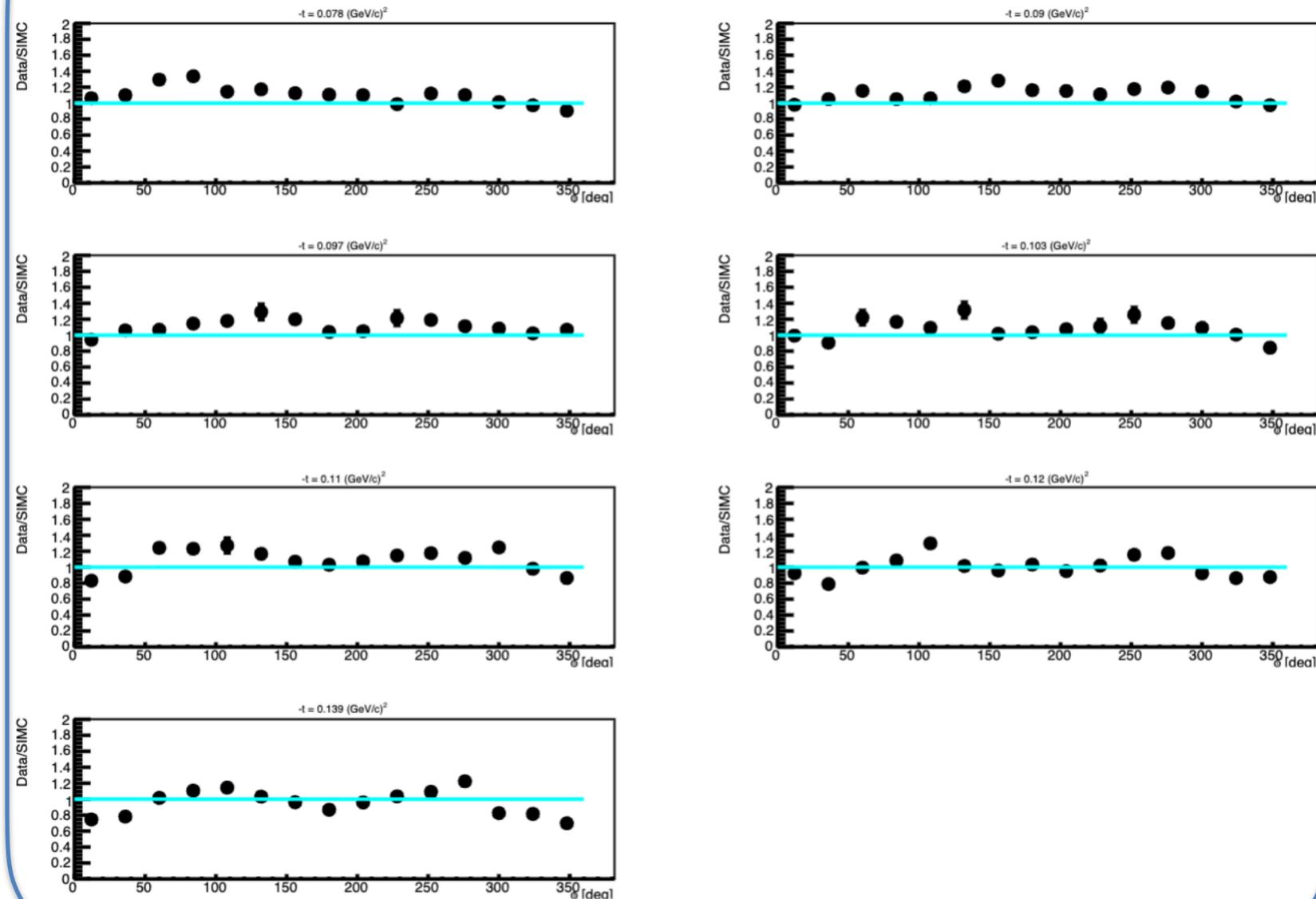
$$\text{Ratio} = \frac{\text{Data} \times \text{factors}}{SIMC}$$

Factors	
Charge	32.655
HMS Tracking efficiency	0.999
SHMS Tracking efficiency	0.992
HMS Cer detector efficiency	0.973
HMS Cal detector efficiency	0.996
RF time efficiency	0.982
HMS Hodo 3/4 efficiency	0.999
SHMS Hodo 3/4 efficiency	0.992
EDTM live time	0.979
Boiling factor	0.995
Kaon absorption	Ongoing
Coin Time Blocking	Ongoing

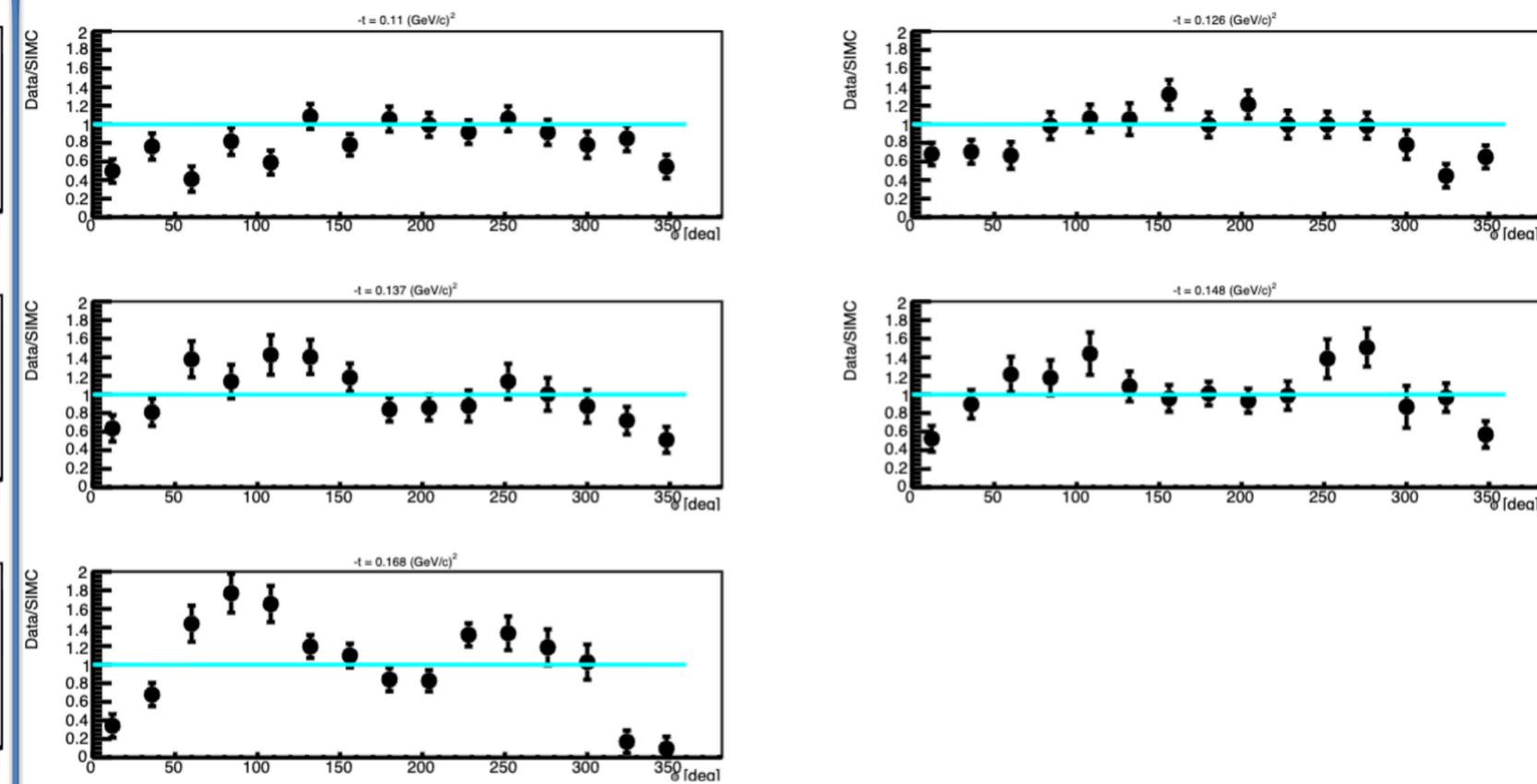
- Subtract statistically dummy runs from production data

# Normalized Yields Ratio

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



$p(e, e'K^+)\Sigma^0$

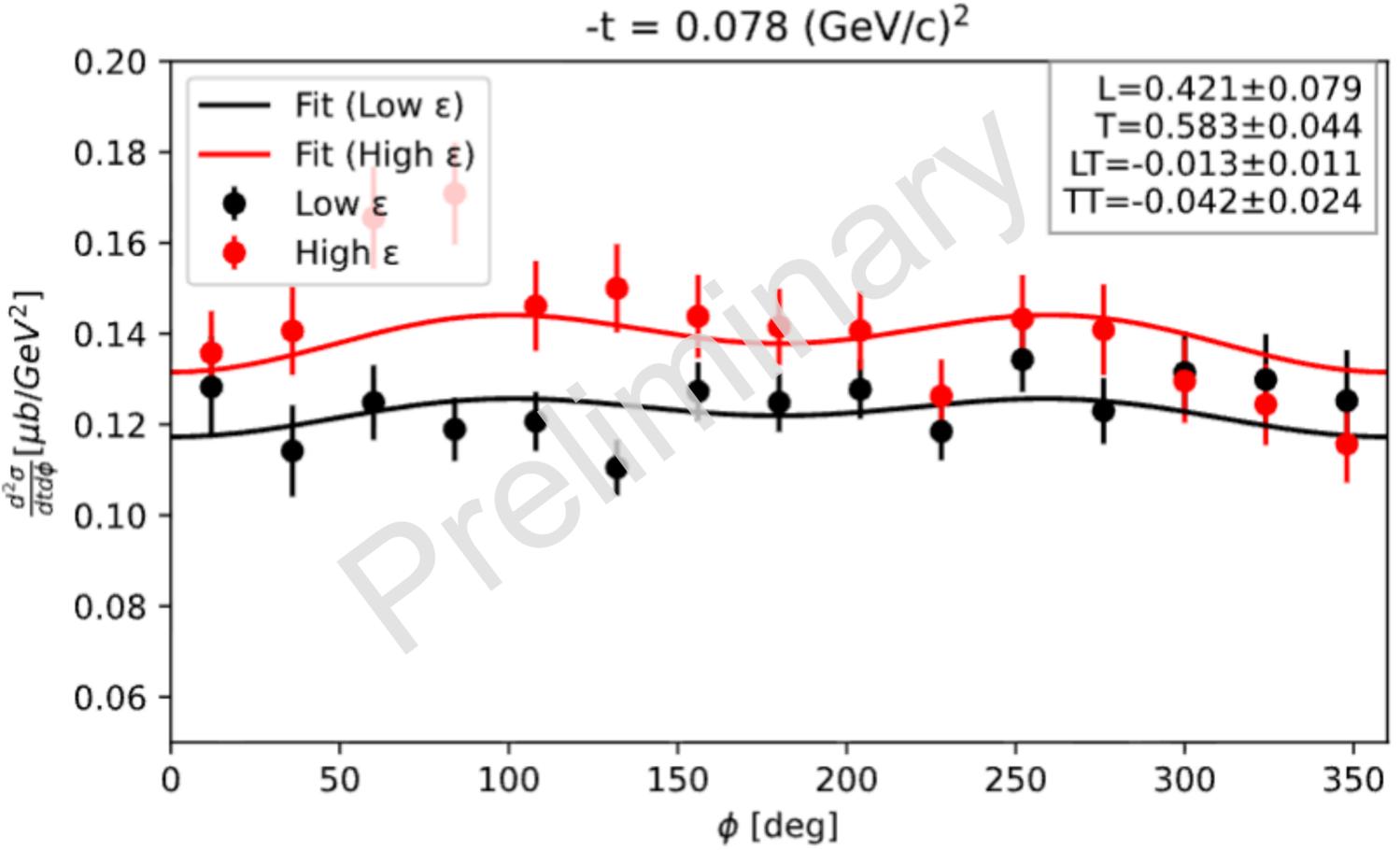


- The Data/SIMC ratios look good for the  $p(e, e'K^+)\Lambda$  channel
- Azimuthal modulations in the curves are due to the LT and TT interference terms → models not yet included

# Cross Section Extraction Method

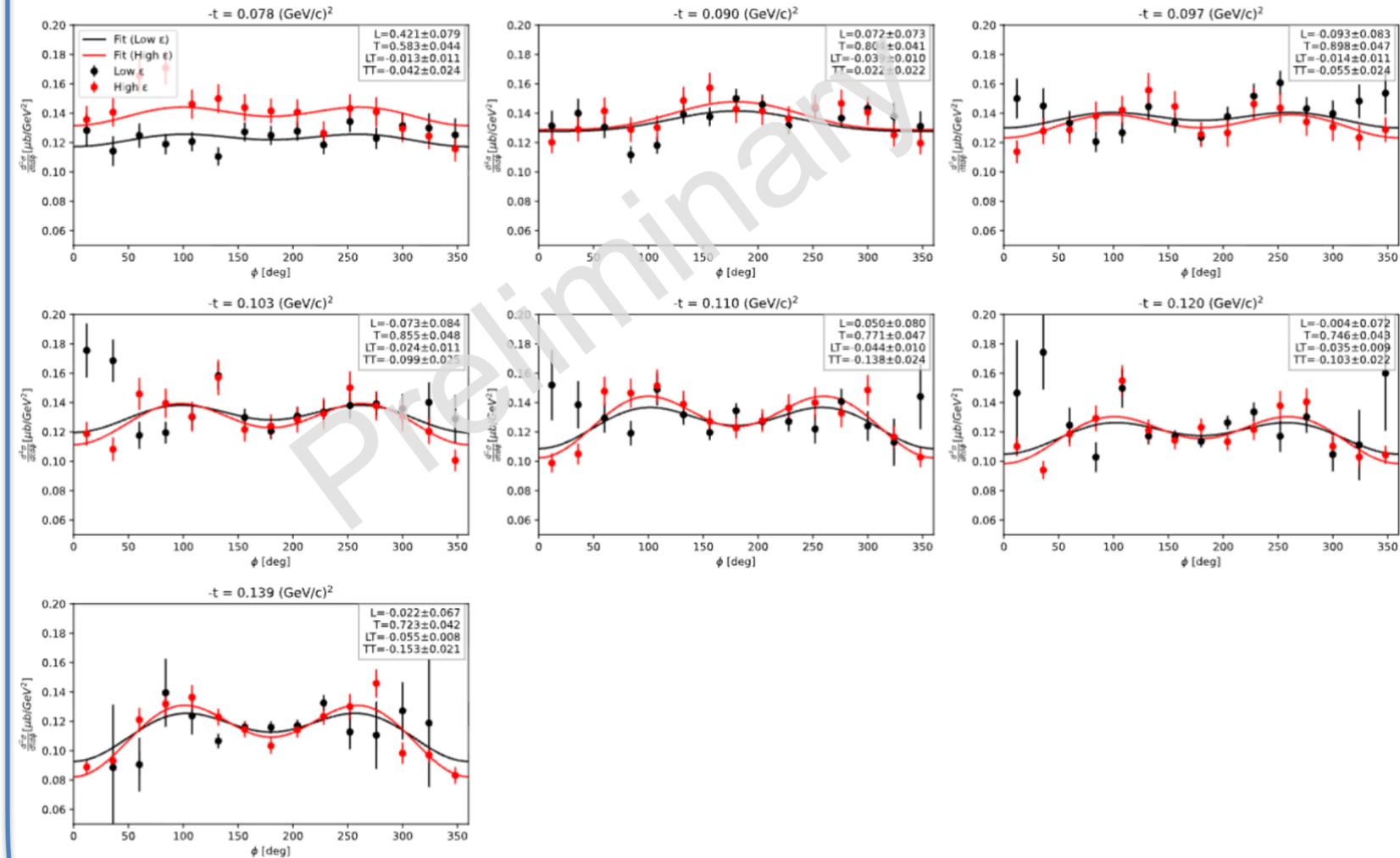
- Simultaneous Fit of the unseparated Cross section with : 
$$2\pi \frac{d^2\sigma}{dt d\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon + 1)} \frac{d\sigma_{LT}}{dt} \cos\phi + \epsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$

Extract cross section for each of the virtual photon polarizations L, T, LT, TT

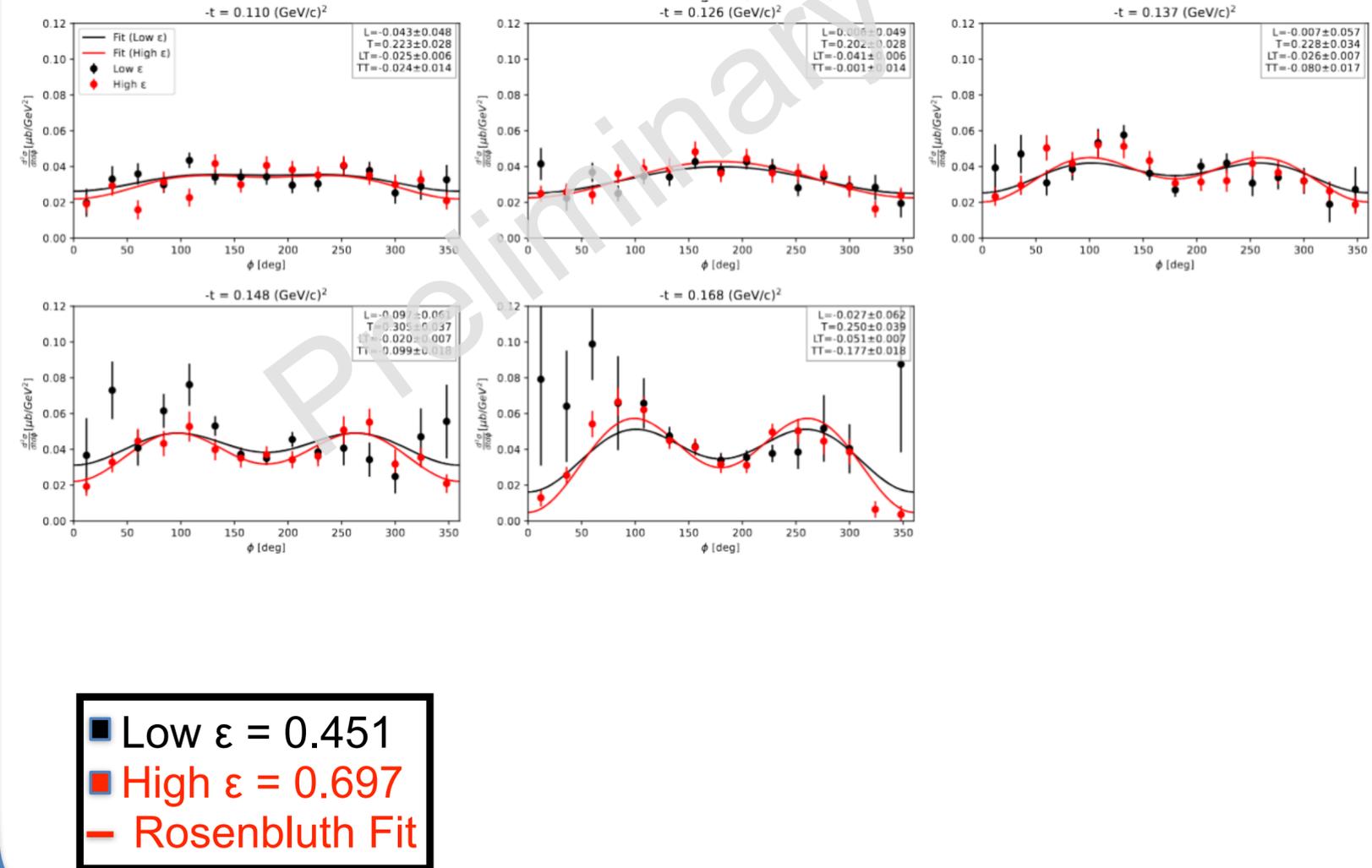


# Cross Section Extraction

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



## $p(e, e'K^+)\Sigma^0$

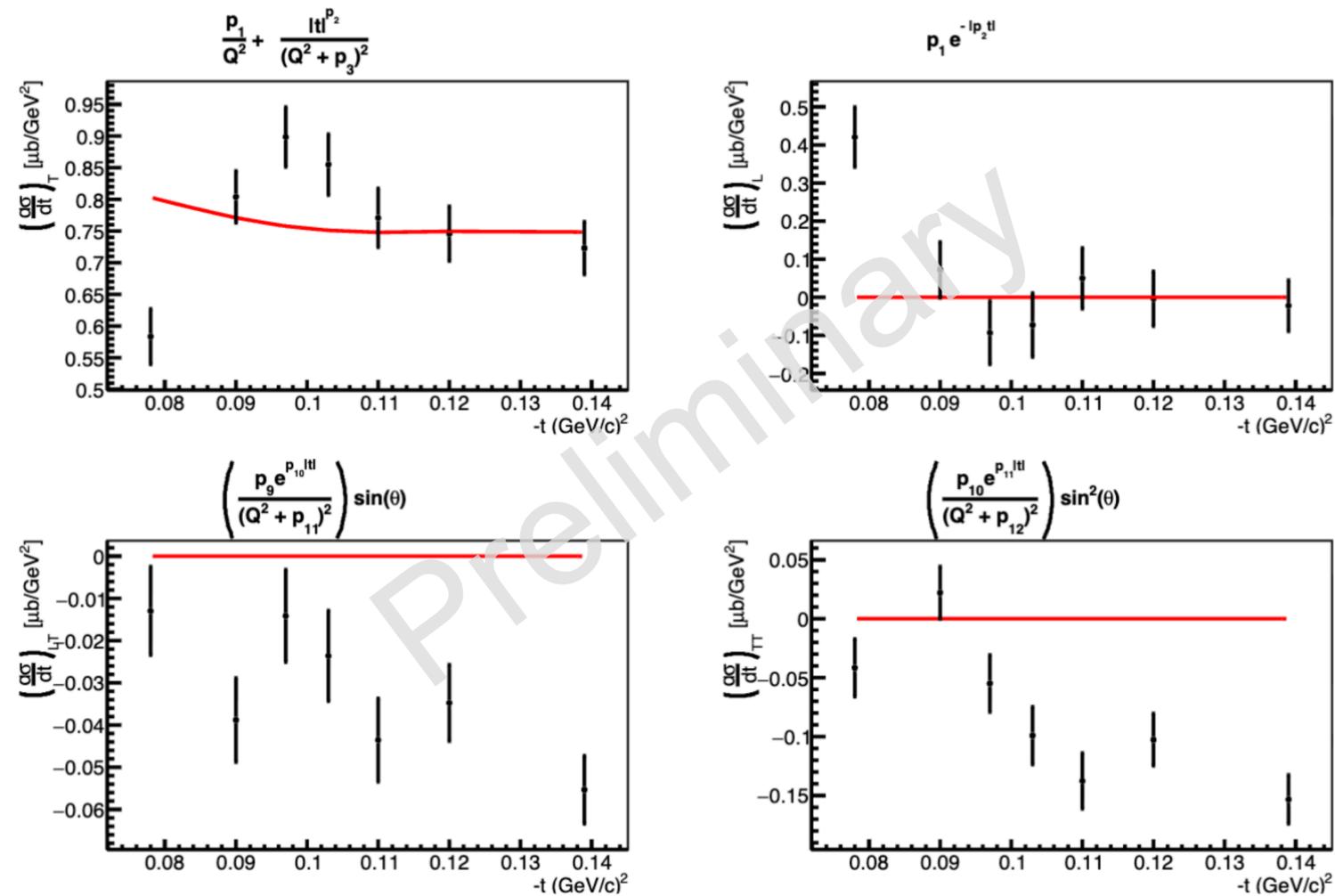


- $\sigma_L$  decreases with  $-t$  in the  $p(e, e'K^+)\Lambda$  channel
- Azimuthal modulations in the curves are due to the LT and TT interference terms

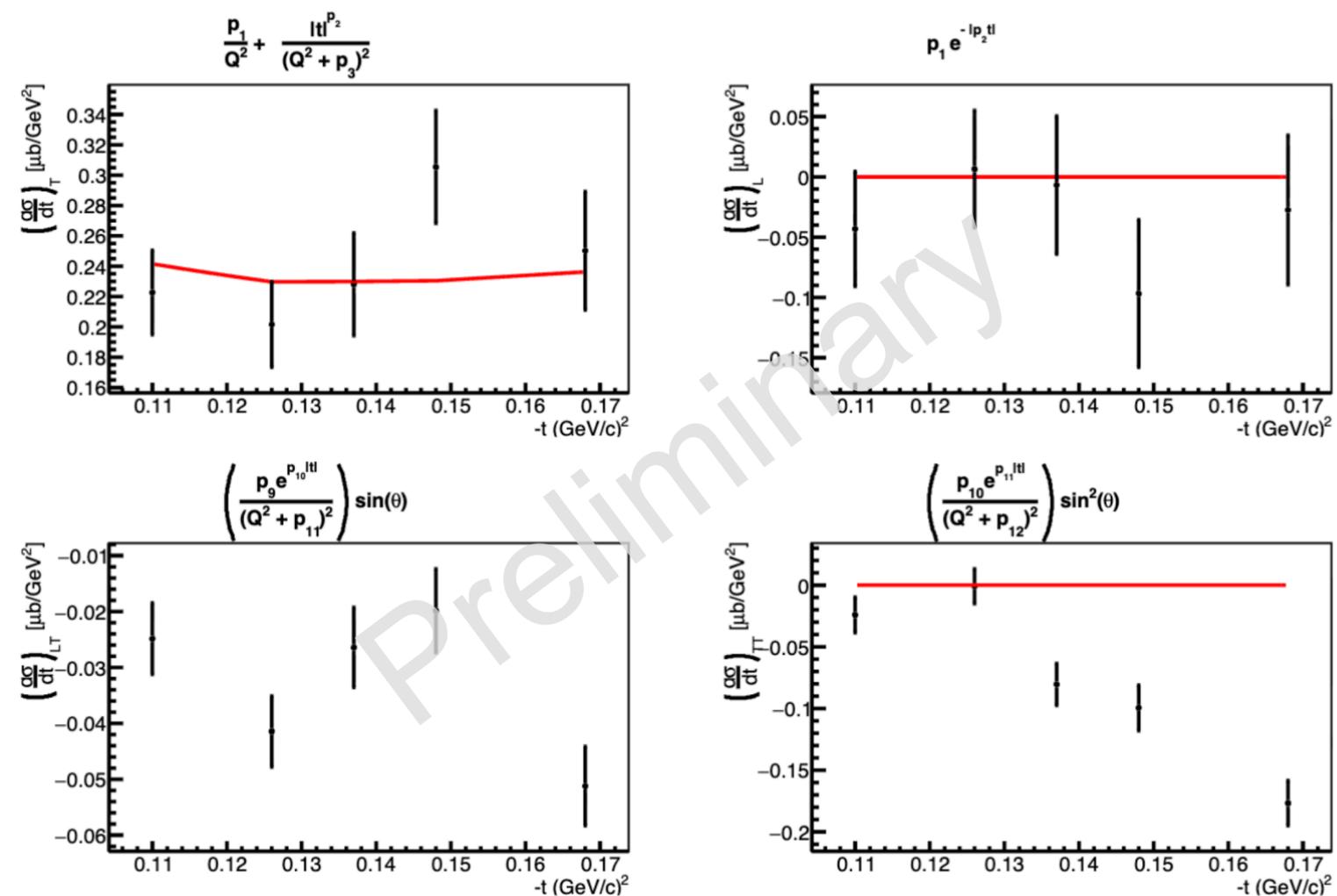
# L-T Separated Cross Section

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

$Q^2 = 0.5 \text{ GeV}^2$   
 $W = 2.4 \text{ GeV}$   
 — Model Fit

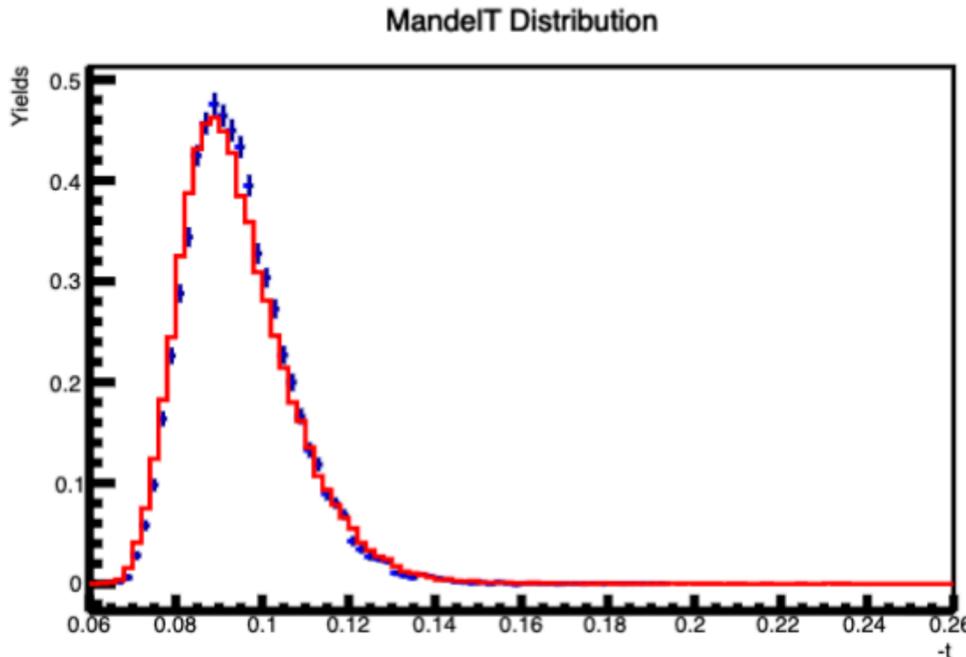
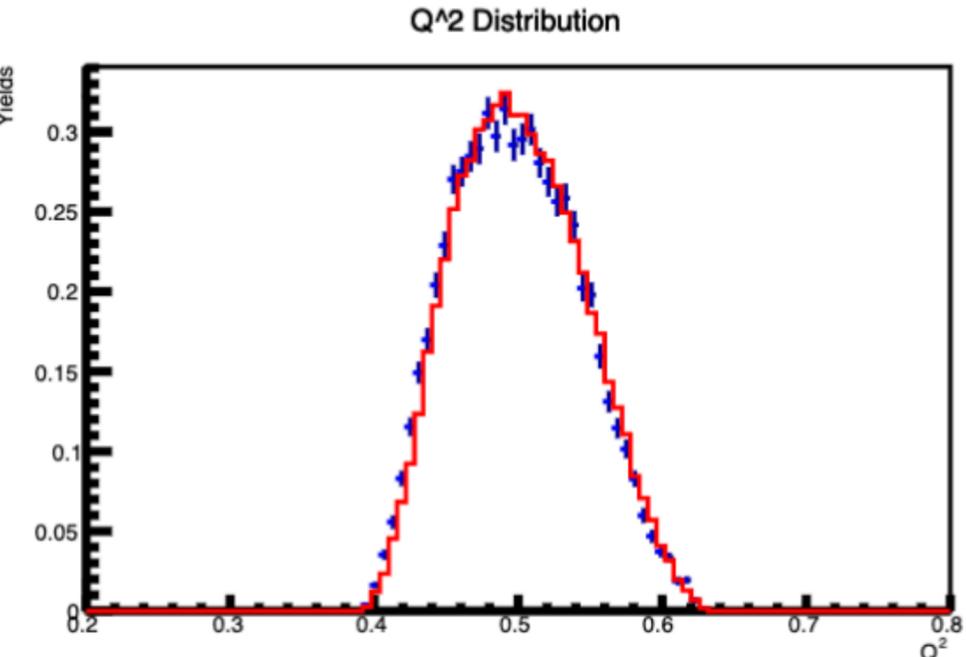
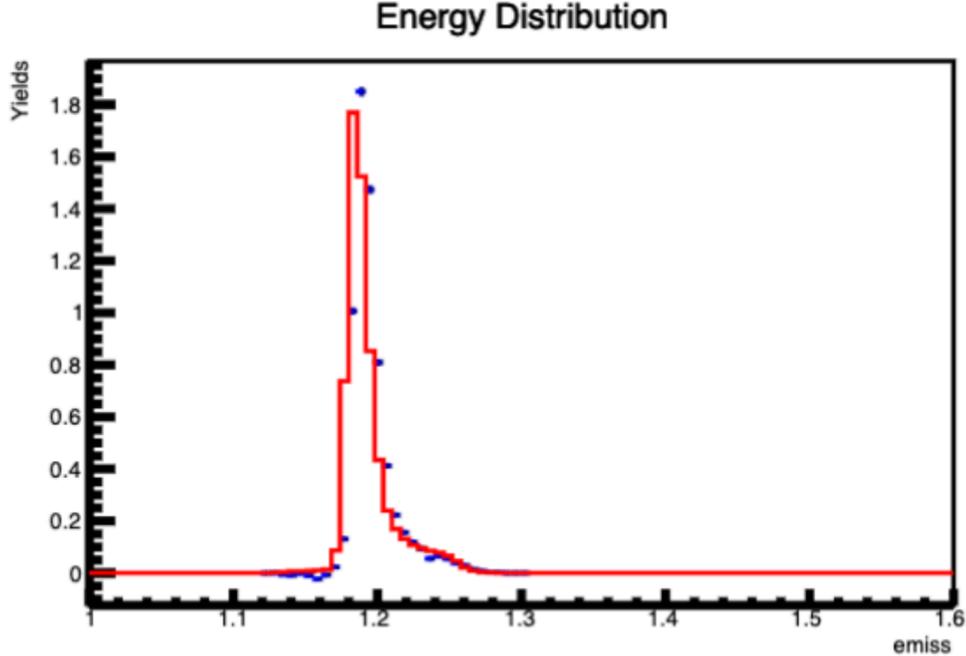
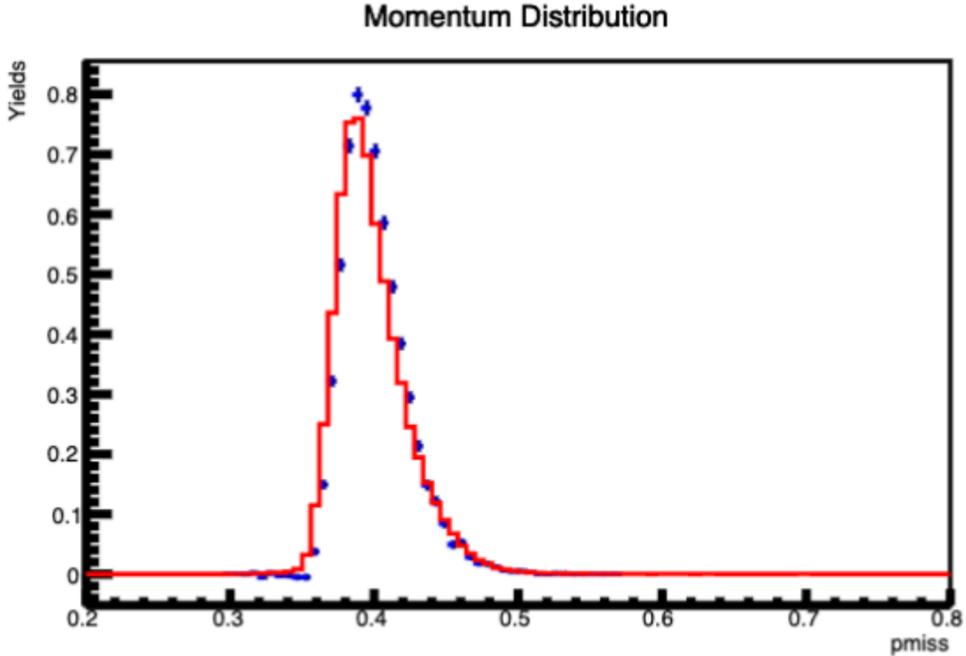


$p(e,e'K^+)\Sigma^0$



- Fit the separated cross sections, then extract the new model parameters
- Update SIMC models, then check if the Data/SIMC ratio and kinematics are improved

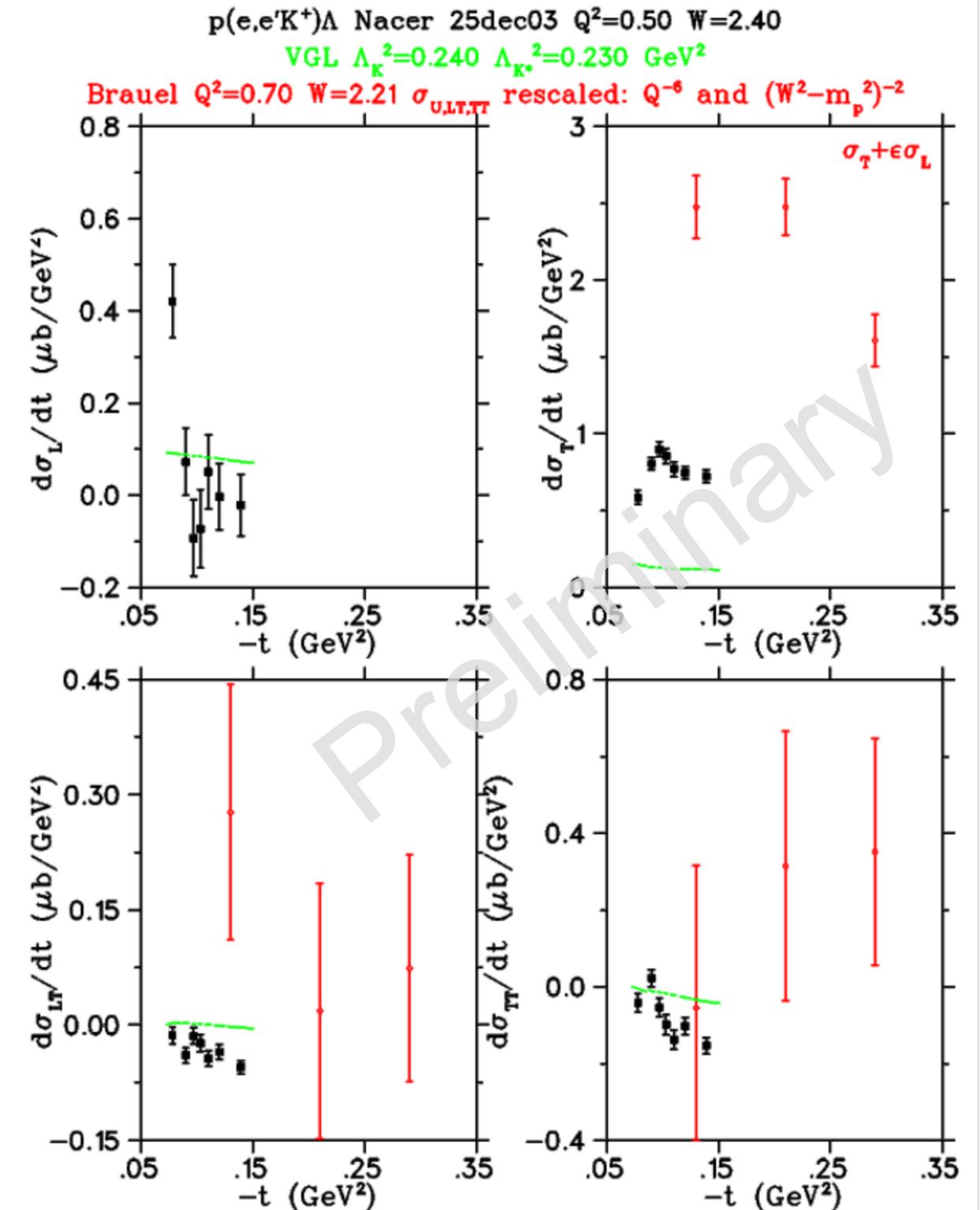
• Data  
— SIMC



Current SIMC models describe the data well

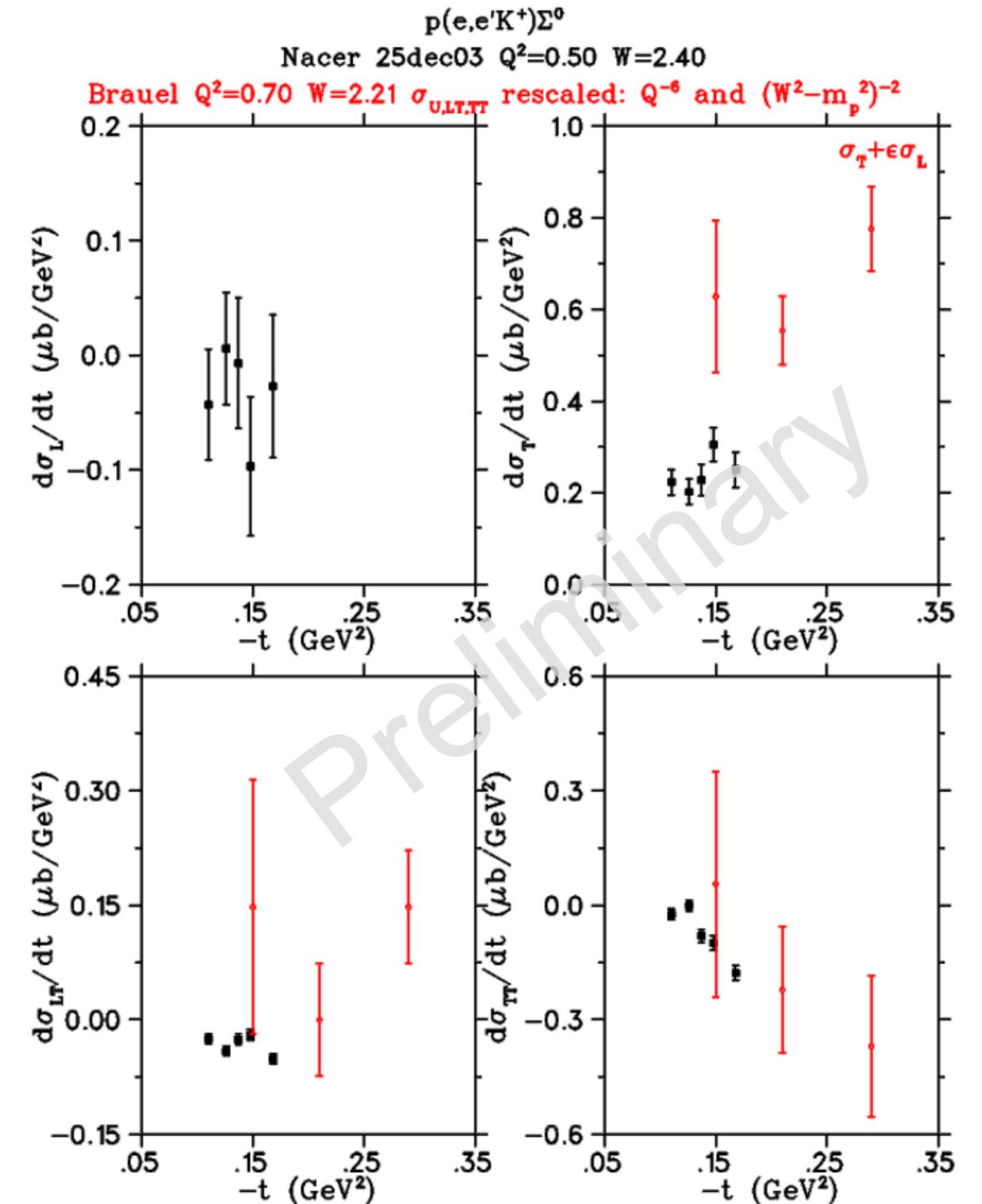
# Comparison of $p(e, e'K^+)\Lambda$ Cross Sections to theory prediction

- VGL Regge Model [Phys Rev C 61(2000)025204]  
kaon t-channel + Nucleon pole in s-channel.  
Model is evaluated at precise kinematics of data
- Brauel published unseparated cross sections, and are much higher (scaling only approximate)
- Only the 1st t-bin in  $\sigma_L$  allows for  $F_{K^+}$  extraction
- VGL does not describe  $\sigma_T$  well



# Comparison of $p(e, e'K^+)\Sigma^0$ Cross Sections to theory prediction

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kaon t-channel + Nucleon pole in s-channel.  
Model is evaluated at precise kinematics of data
- Brauel published unseparated cross sections, and are much higher (scaling only approximate)
- $\sigma_L$  is consistent with 0, no VGL fit
- $\sigma_{LT}$  and  $\sigma_{TT}$  are consistent with Brauel data within errors.

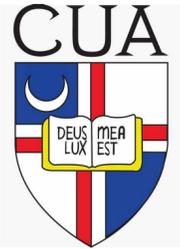


# Summary & Outlook

- First measurement of the  $p(e,e'K^+)\Lambda,\Sigma^0$  polarized cross sections at this kinematic  $Q^2 = 0.5 \text{ GeV}^2$ ,  $W = 2.4 \text{ GeV}$
- Finalize the optimization of cross section models, and if data allows extract the form factor
- Evaluate the coin time blocking factor per run and include it in the yield normalization
- Evaluate systematics uncertainties on the measured separated cross sections
- Measurement of  $\frac{\sigma_T(\gamma^*p \rightarrow K^+\Sigma^0)}{\sigma_T(\gamma^*p \rightarrow K^+\Lambda)}$  to probe the reaction mechanism
- This talk focuses on the measurement at  $Q^2 = 0.5 \text{ GeV}^2$ , also ongoing analysis up to  $Q^2 = 5.5 \text{ GeV}^2$
- This is first attempt to measure kaon form factor indirectly, this measurement can **only** be done at JLab Hall C

# Kaon-LT Collaboration

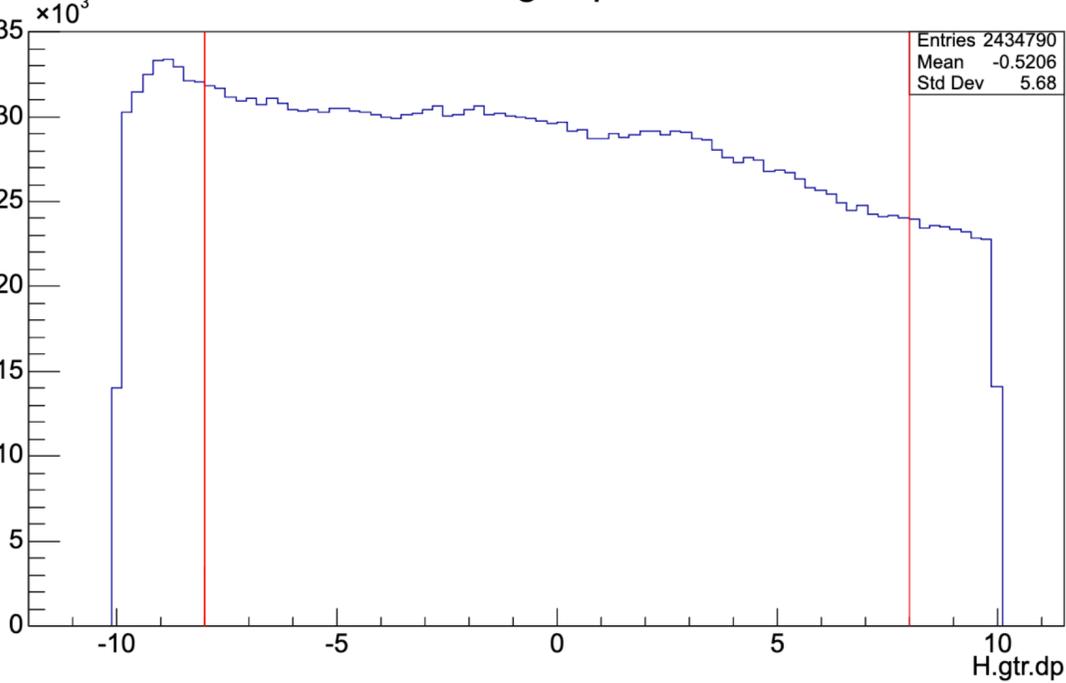
Garth Huber, Dave Gaskell, Tanja Horn, Pete Markowitz, Julie Roche, Stephen Kay, Abdennacer Hamdi, Richard Trotta, Muhammad Junaid, Ali Usman, Vijay Kumar, Nermin Sadoun, Alicia Postuma, Nathan Heinrich, Chi Kin Tam



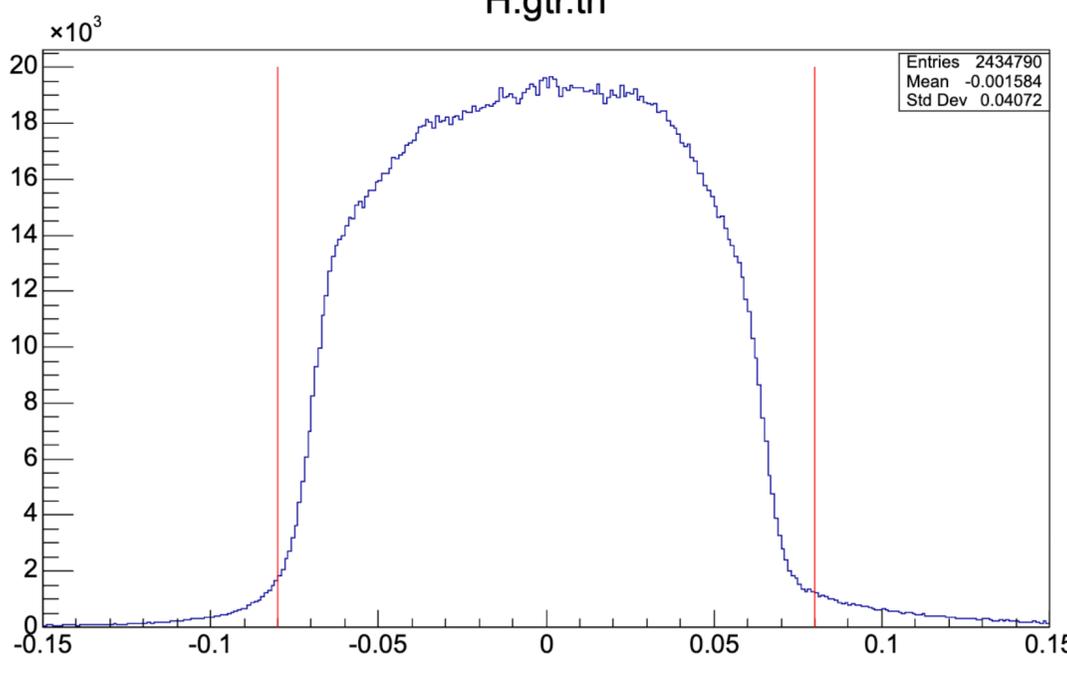
**Backup**

# Acceptance Cuts

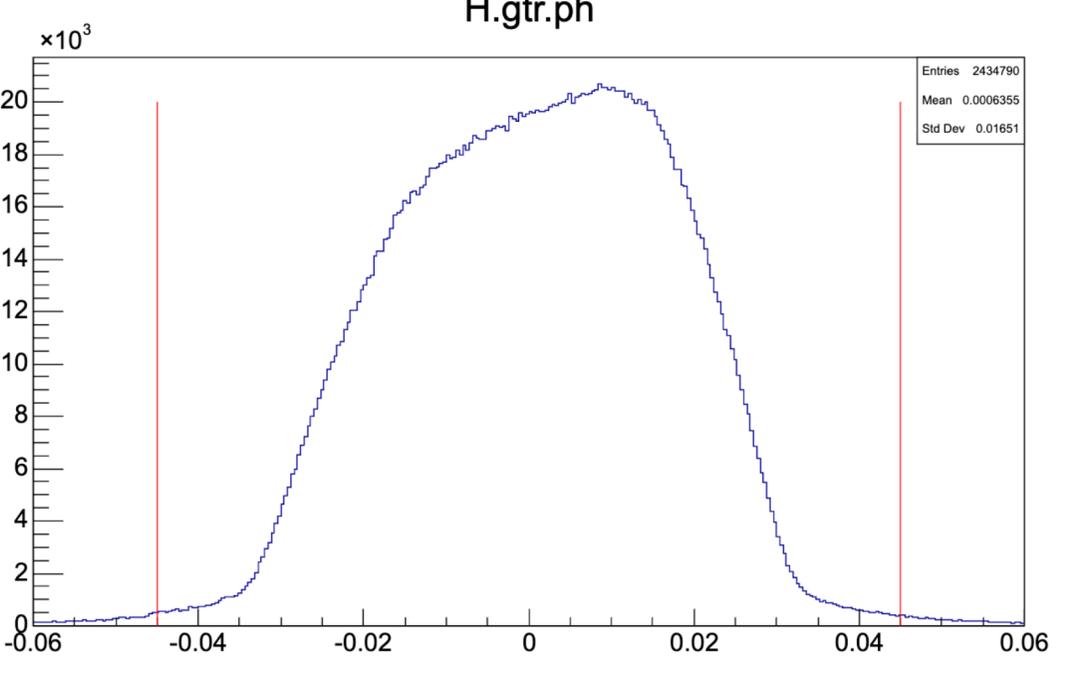
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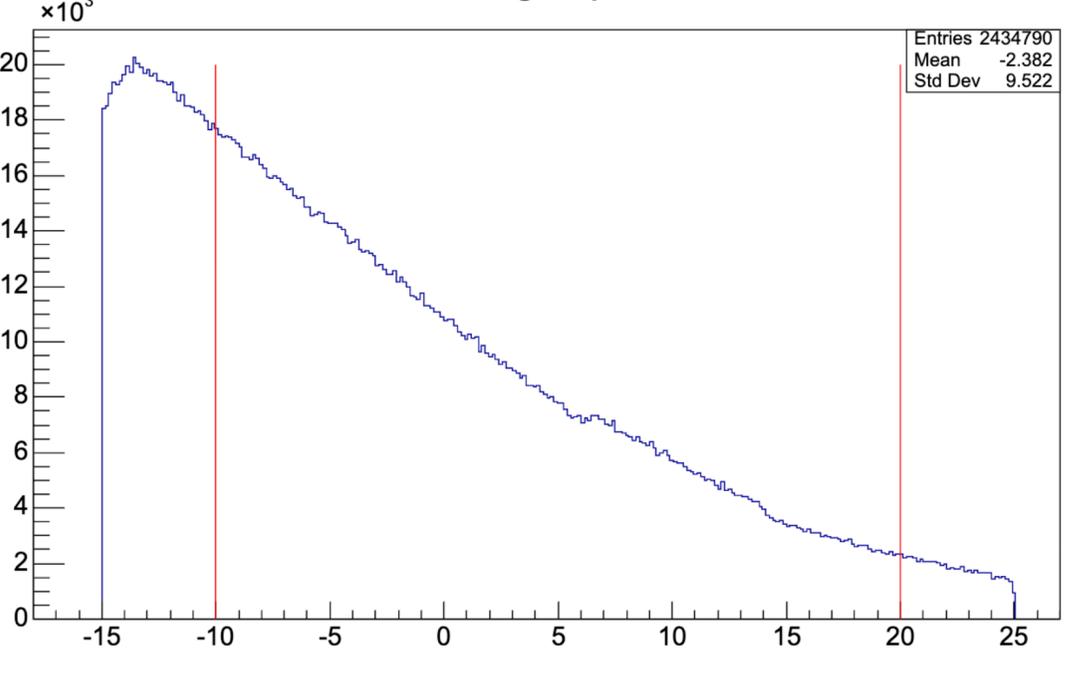
H.gtr.th



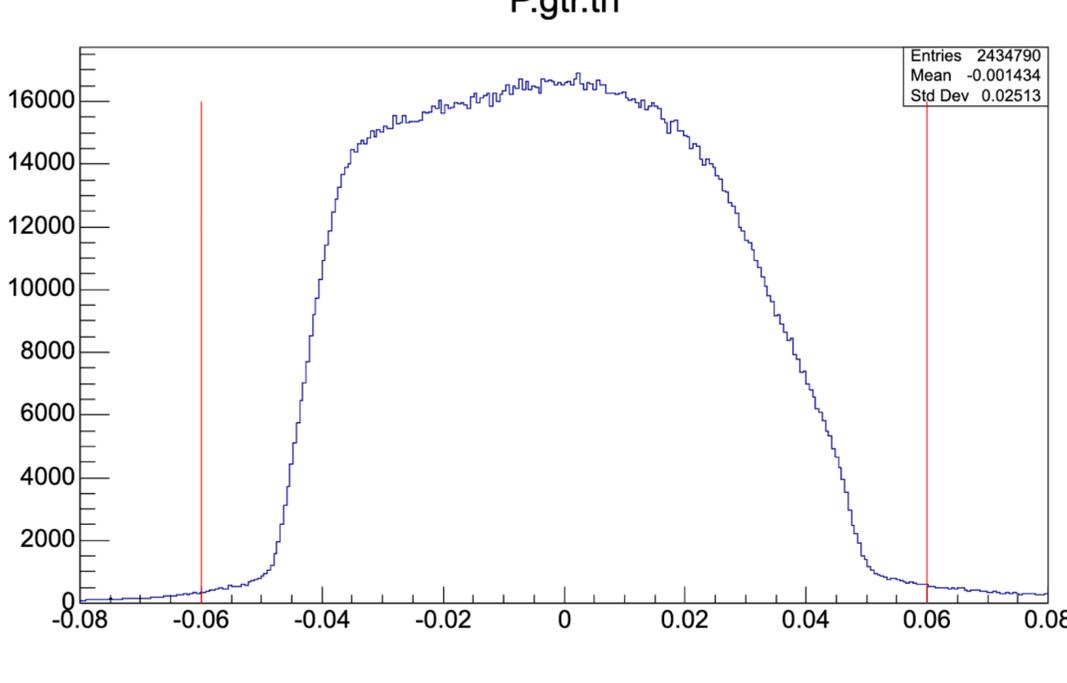
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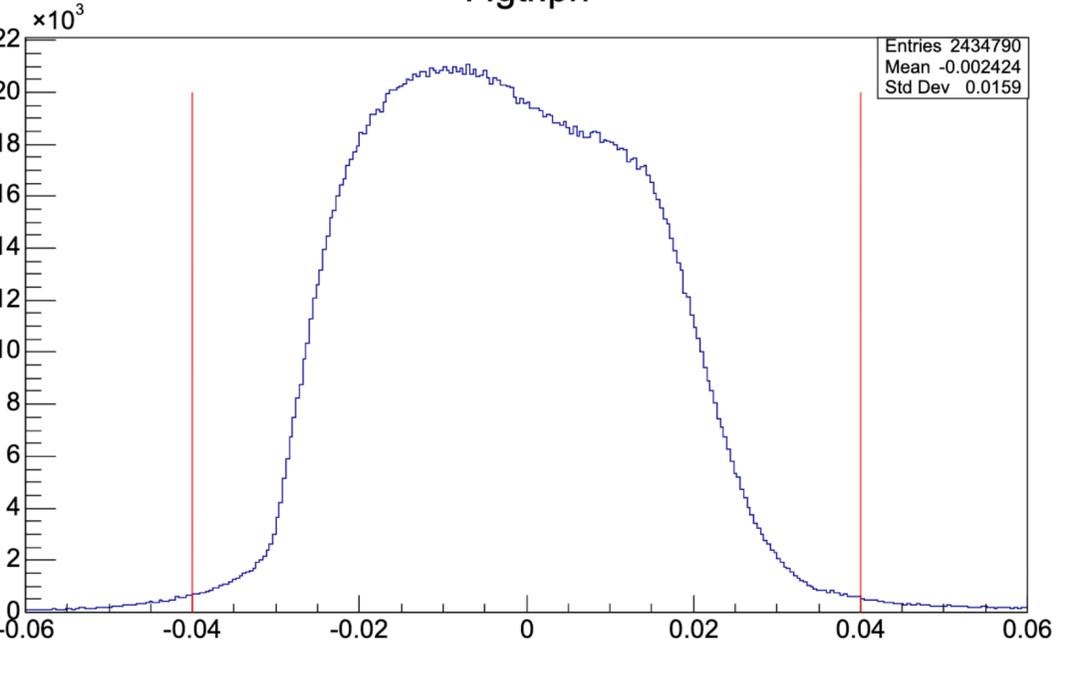
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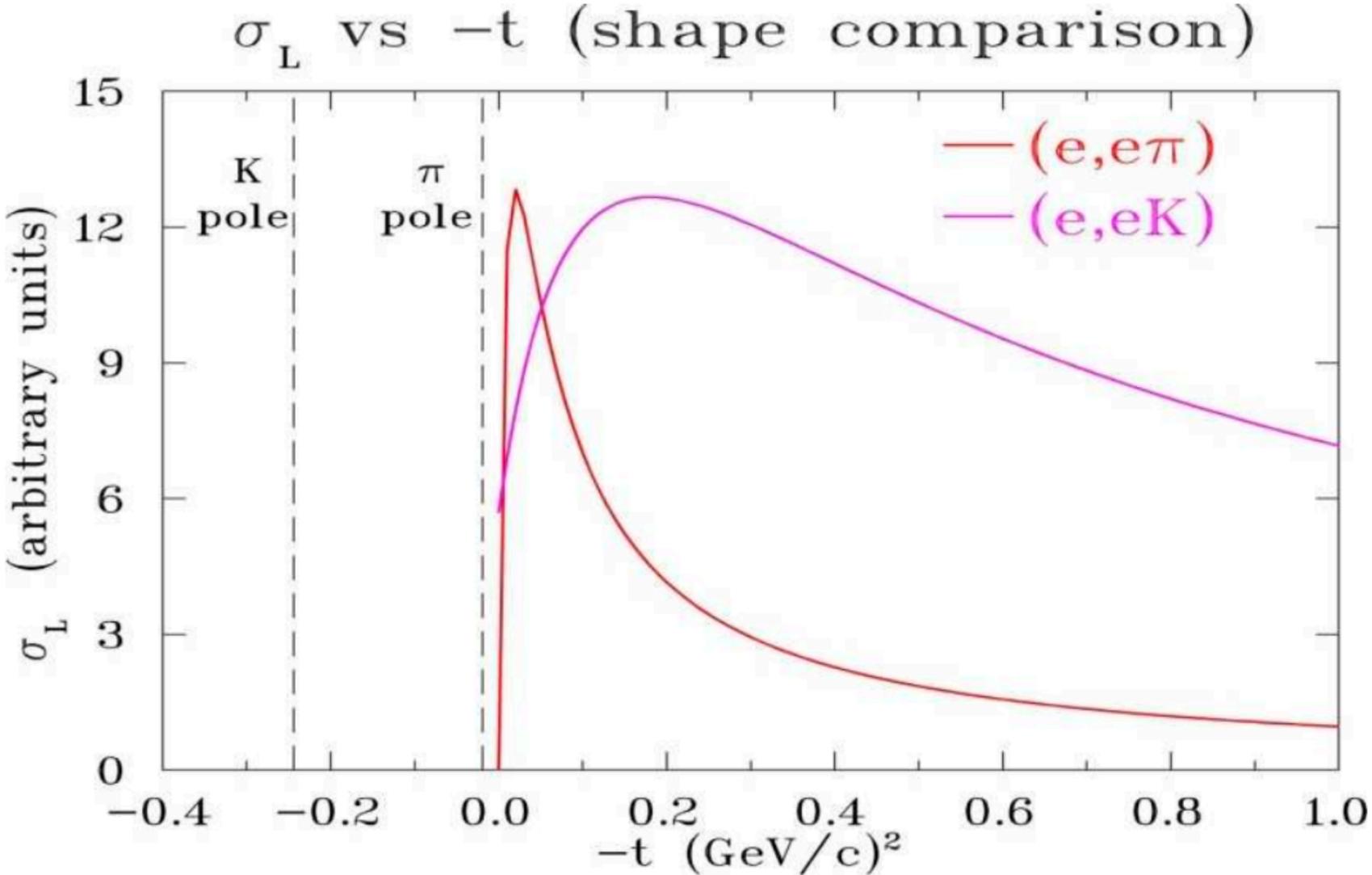
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# Cross Section Extraction Method



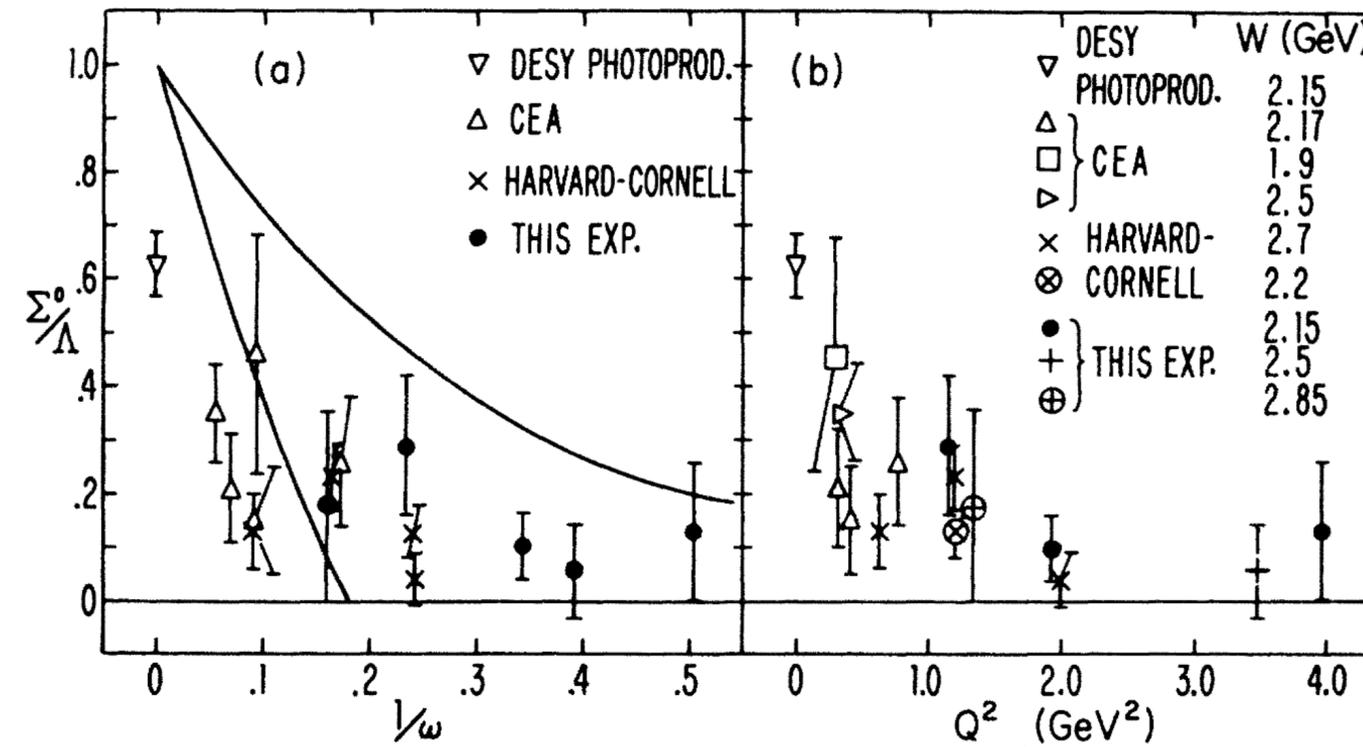


FIG. 8. (a) A plot of the ratio of the cross sections for the  $K^+ \Sigma^0$  and  $K^+ \Lambda$  channels as a function of  $1/\omega$  for data with  $\theta^* < 15^\circ$ . The solid curves are the upper and lower limits of a parton-model analysis due to Nachtmann (see Ref. 20). (b) A plot of the ratio of the cross sections for the  $K^+ \Sigma^0$  and  $K^+ \Lambda$  channels as a function of  $Q^2$  for data with  $\theta^* < 15^\circ$ .

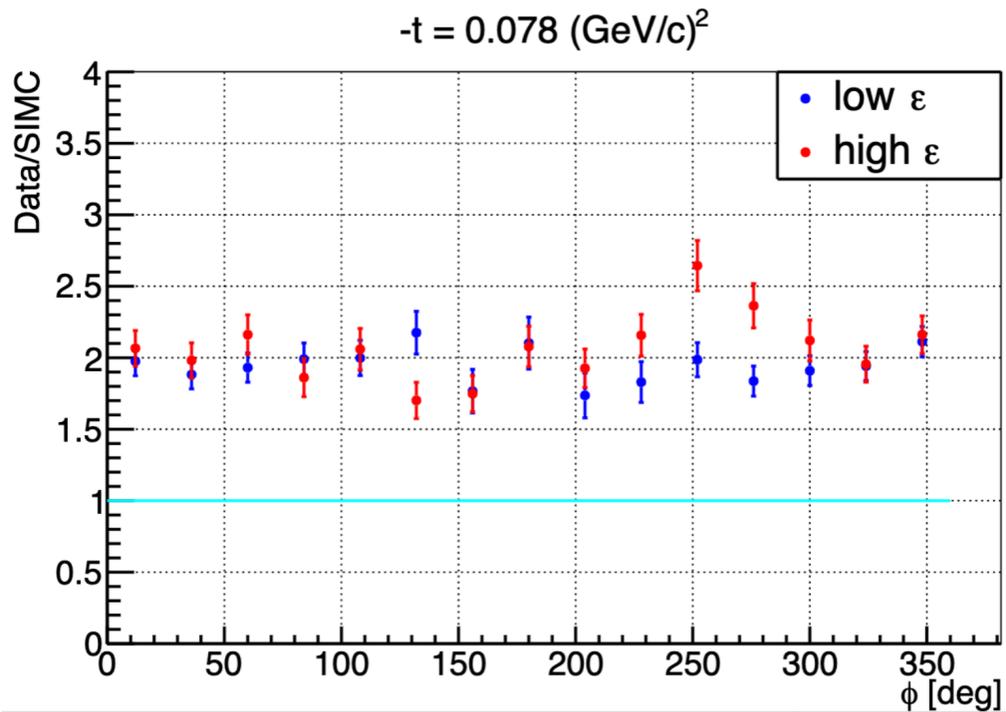
- A simple parton model [NP B74(1974)422] is built to explain the surprisingly large drop in the  $\Sigma^0/\Lambda$  Ratio with  $Q^2$
- Measurement of  $\sigma_T(\Sigma^0)/\sigma_T(\lambda)$  at  $Q^2 = 0.5 \text{ GeV}^2$  is an opportunity to test this prediction, which is related to the electron-nucleon DIS structure function ratio  $F_1^{\gamma^*n}/F_1^{\gamma^*p}$

# Cross Section Extraction Method

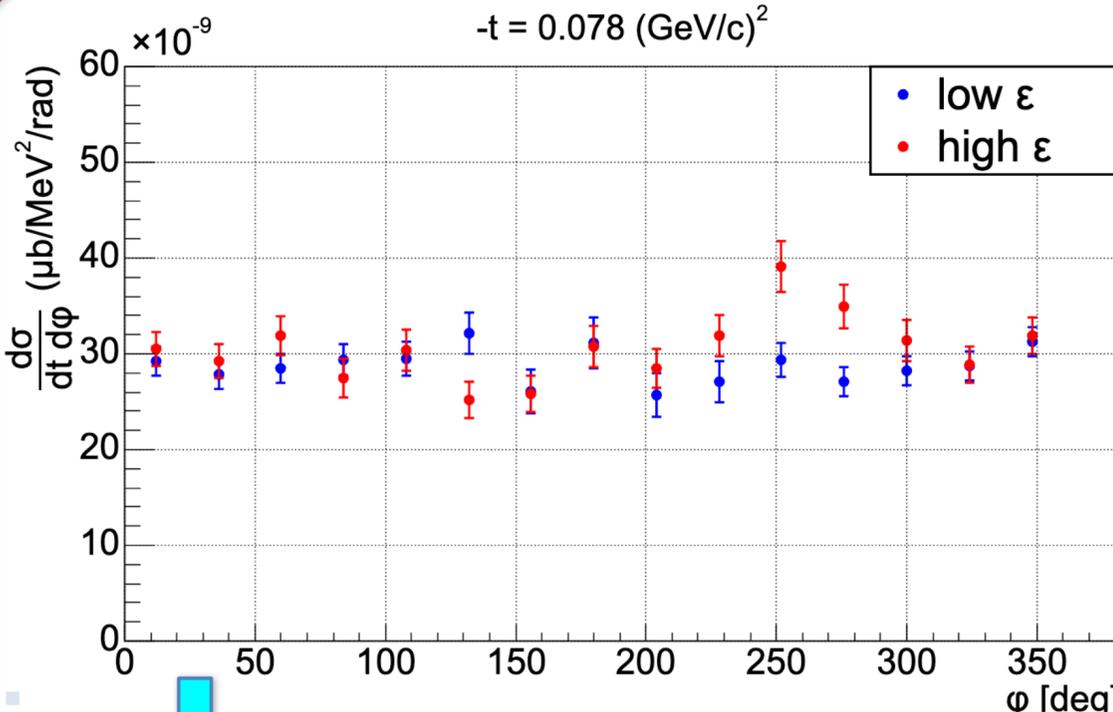
[D. Koltenuk (1999), T. Horn (2007)]

data/sim yield ratio integral over a region kinematics

Empirical Model estimates cross section at a point kinematics



$$\left(\frac{d\sigma_{exp}^2}{dtd\phi}\right) \Big|_{Q^2=\bar{Q}^2, t=\bar{t}} = \frac{Y_{exp}}{Y_{SIMC}} \left(\frac{d\sigma_{model}^2}{dtd\phi}\right) \Big|_{Q^2=\bar{Q}^2, t=\bar{t}}$$



Improving ratio ( $\approx 1$ ) & model parameters



Simulation Fit of the unseparated Cross section with :  $2\pi \frac{d^2\sigma}{dtd\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_{LT}}{dt} \cos\phi + \epsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$

Extract cross section for each of the virtual photon polarizations L, T, LT, TT