Update on the Kaon LT Experiment

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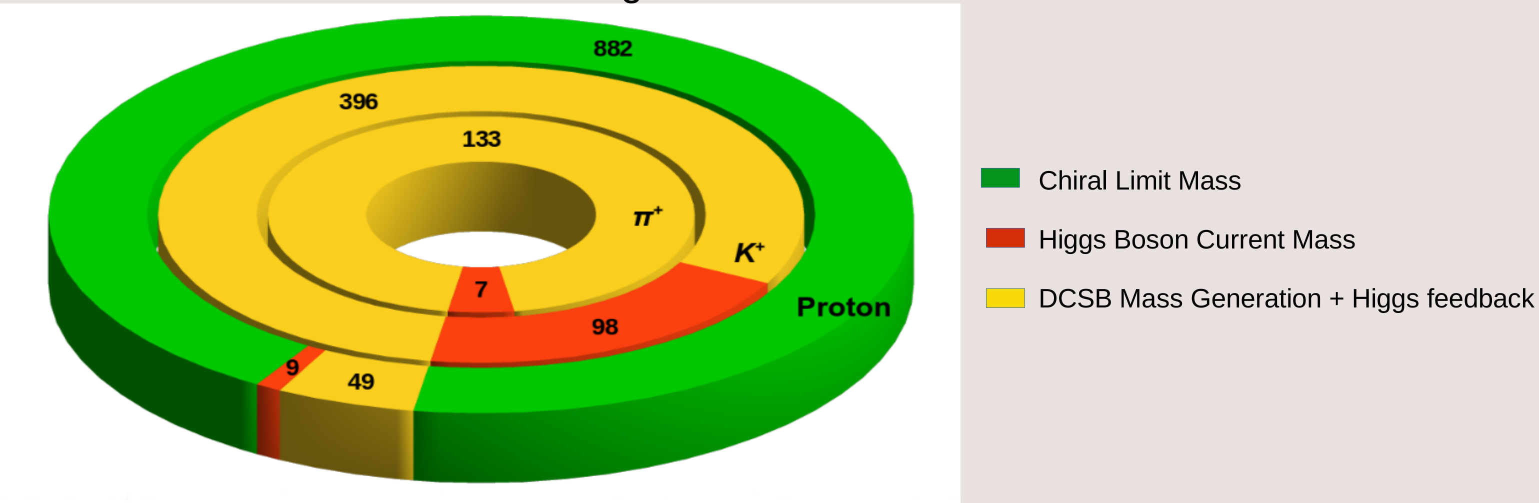
Outline

- Scientific overview
- Kaon LT experiment and its studies
- Rosenbluth separation overview
- Analysis updates
- Update on the Kaon LT PAC49
- Future perspectives

Dynamics of gluons in QCD

- **How does the mass of the nucleon arise?**
- **How does the spin of the nucleon arise?**

Hadron mass budget



- **Higgs mechanism is not sufficient !!!**
- Dynamical Chiral Symmetry Breaking (DCSB) is expected to provide most of the hadron mass.
- The pion and kaon are very important candidates to utilize in the DCSB study.
  - π the lightest quark system. Responsible for the long range character of the strong interaction.
  - K structure is involved with the strangeness.
  - Both are connected to the Goldstone modes of DCSB.

Kaon LT experiment (E12-09-011)

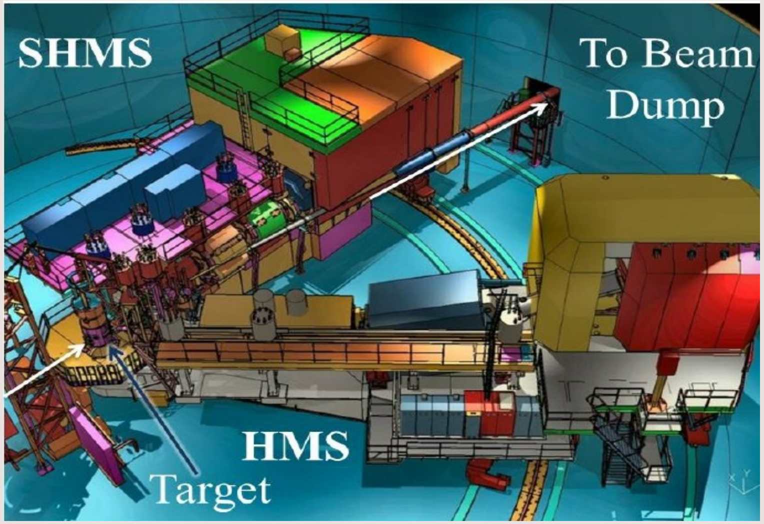
- Kaon LT experiment is carried out in Hall C at Jefferson Lab over fall 2018 and spring 2019.
  - Exclusive reaction of the experiment.
  - Studies for the separation of cross-sections (σ_L, σ_T, σ_{LT} & σ_{TT}).
  - Further studies for the "soft" and "hard" QCD factorization.
  - Attempt to extract the kaon form factor above the resonance region for the first time.
- The reaction system of the experiment is,

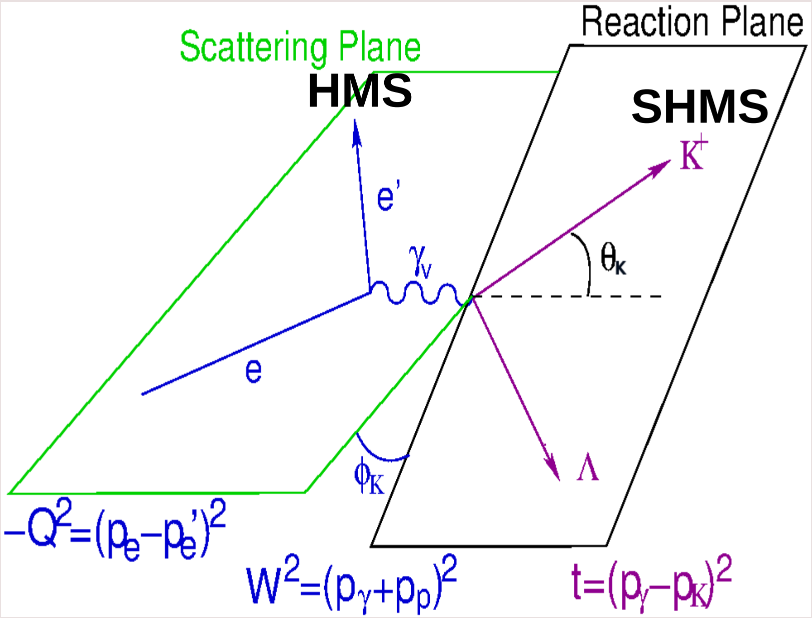
$$e + p \to e' + K^+ + \Lambda$$

$$M_\Lambda = 1115.68\ MeV^2/c^2$$

$$e + p \to e' + K^+ + \Sigma^0$$

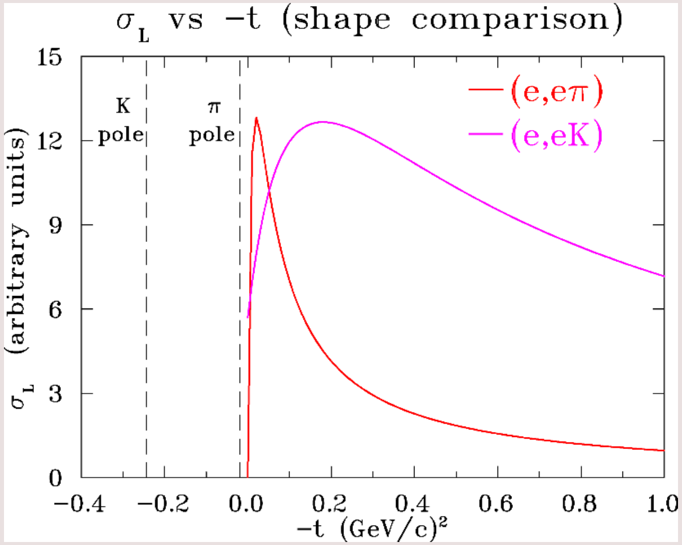
$$M_{\Sigma^0} = 1192.64\ MeV^2/c^2.$$





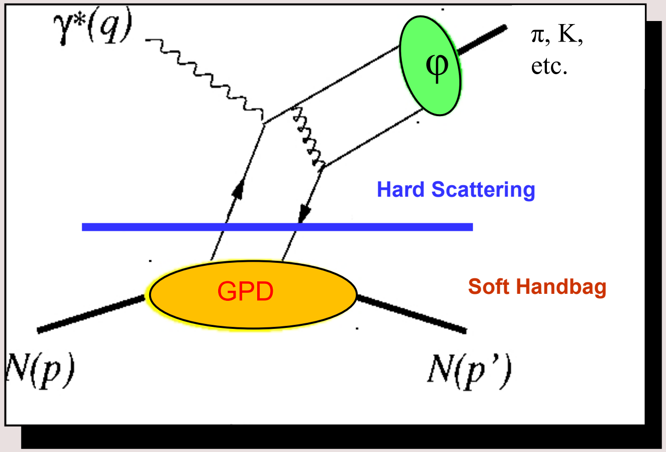
$e(p, e'K^+)\Lambda$ or Σ^0 L/T separation studies (search for the K^+ pole)

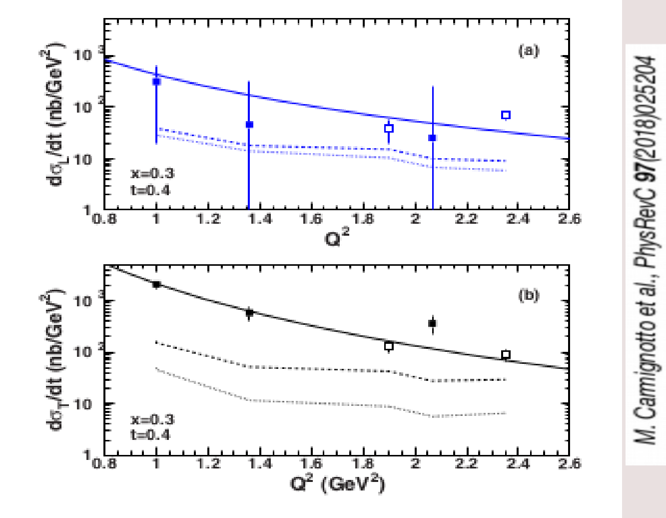
- The -t dependence studies at constant Q^2 are important to search the kaon pole.
  - The kaon pole is further away from the kinematically allowed region.
  - It dominates σ_L at smallest -t. This test is very crucial to the kaon form factor and has never been tested before.
- Challenges:
  - The L/T separation studies require a deep understanding of each detector used in the experiment.
  - The kaon PID is very challenging because the pion background is much higher in our data.
  - Systematic and statistical uncertainties are also challenges to our analysis.



$e(p, e'K^+)\Lambda$ or Σ^0 L/T separation studies (QCD factorization)

- The Q^2 dependence studies at constant x_B are important to the QCD factorization test.
  - Testing the factorization theorem and understand the dynamic effects in Q^2 and $-t$ kinematics.
  - Understand the non-perturbative contributions in the experimentally accessible kinematics.
  - One of the predictions, $\sigma_L \sim 1/Q^6$ and $\sigma_T \sim 1/Q^8$ at fixed x_B.
  - 6 GeV data analysis had made an effort to the QCD factorization test earlier.
  - We have collected data for the scaling studies at $x_B = 0.40$ and 0.25.





Kaon LT data collected

- The completed data that have been collected in Hall C at Jefferson Lab over fall 2018 and spring 2019 run plans are shown in the table below.

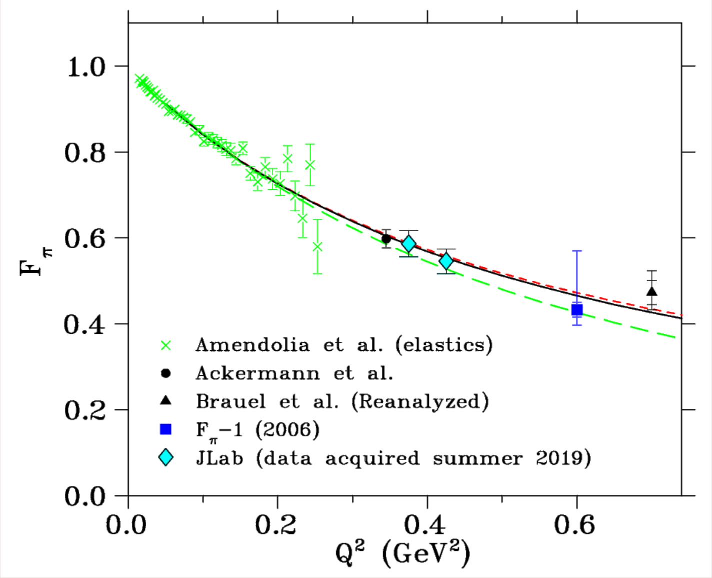
E_b (GeV)	Q^2 (GeV^2/c^2)	W (GeV)	x_B	$\varepsilon_{High}/\varepsilon_{Low}$	Study Type
10.6/8.2	5.5	3.02	0.40	0.53/0.18	scaling
10.6/8.2	4.4	2.74	0.40	0.72/0.48	scaling
10.6/8.2	3.0	3.14	0.25	0.67/0.39	both
10.6/6.2	3.0	2.32	0.40	0.88/0.57	scaling
10.6/6.2	2.115	2.95	0.21	0.79/0.25	both
4.9/3.8	0.5	2.40	0.09	0.70/0.45	FF

Pion LT (E12-19-006) data collected

- The Pion LT experimental data for low Q^2 have also been collected in Hall C at Jefferson Lab in summer 2019.

E_b (GeV)	Q^2 (GeV^2/c^2)	W (GeV)	x_B	ε
4.6/3.7/2.8	0.38	2.20	0.087	0.781/0.629/0.286
4.6/3.7/2.8	0.42	2.20	0.097	0.774/0.617/0.264

- We will use this data to compare the direct and indirect methods of extracting the pion form factor.
- The remaining experiment has been scheduled to be run from August to December and fall 2022.



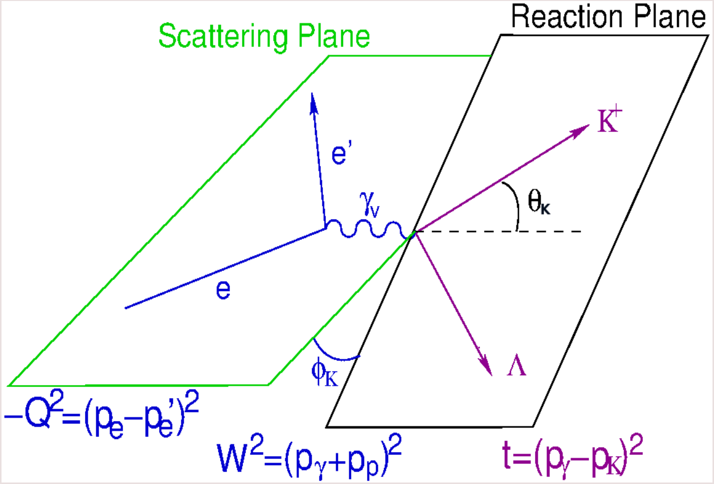
Rosenbluth separation overview (simple version)

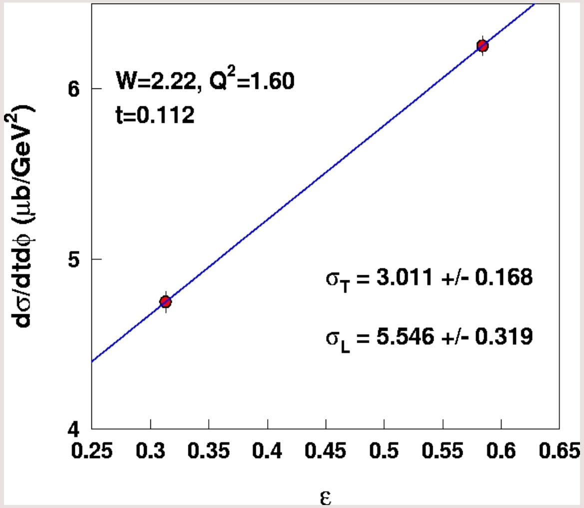
- Rosenbluth separation technique is one of the techniques that can be utilized to separate the cross-sections.
  - Measure cross-section for at least two values of **ε** at fixed Q^2, W and -t.
  - Cross-section at two values of **ε** is then fitted to separate the cross-sections.
- In parallel kinematics, $\theta_K = 0$. (θ_K w.r.t $\vec{q}$)
  - Only the σ_L and σ_T terms contribute.
  - The mathematical form is simple but requires uniform detector acceptance.

$$2\pi \frac{d^2\sigma}{dt\,d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt}$$

Virtual-photon polarization:

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





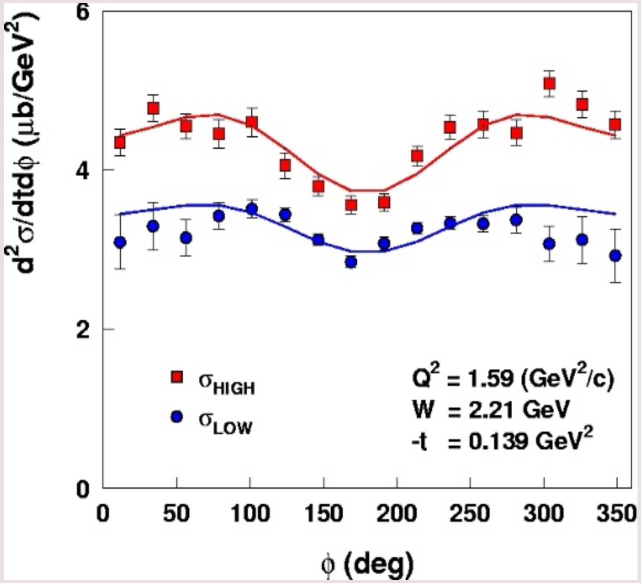
T. Horn, et al, PRL **97** (2006)192001

Rosenbluth separation overview (full version)

- In non-parallel kinematics, $\theta_K \neq 0$.
  - Cross-section at two values of ε is simultaneously fitted with a four variable function to determine all of the cross-section terms.

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

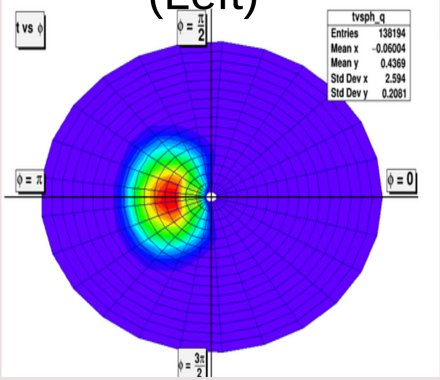
- We have collected the Kaon LT data for parallel and non-parallel kinematics settings.



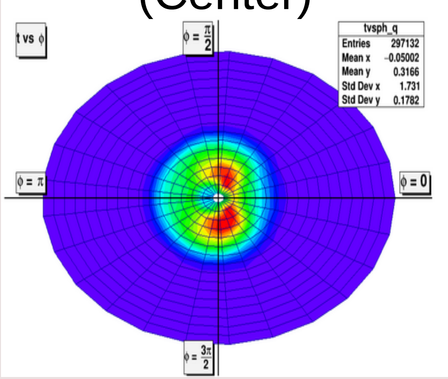
T. Horn, et al, PRL **97** (2006)192001

E_b = 10.6 GeV Q^2 = 3.0 GeV^2/c^2 W = 3.14 GeV

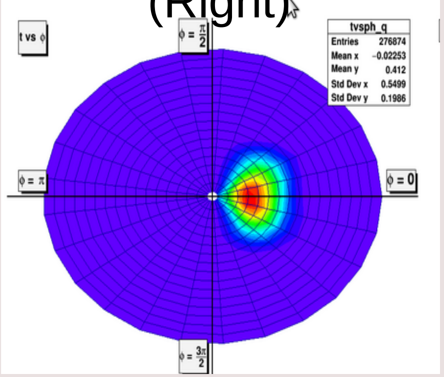
θ_{SHMS} = 12.42° (Left)



θ_{SHMS} = 9.42° (Center)



θ_{SHMS} = 6.65° (Right)

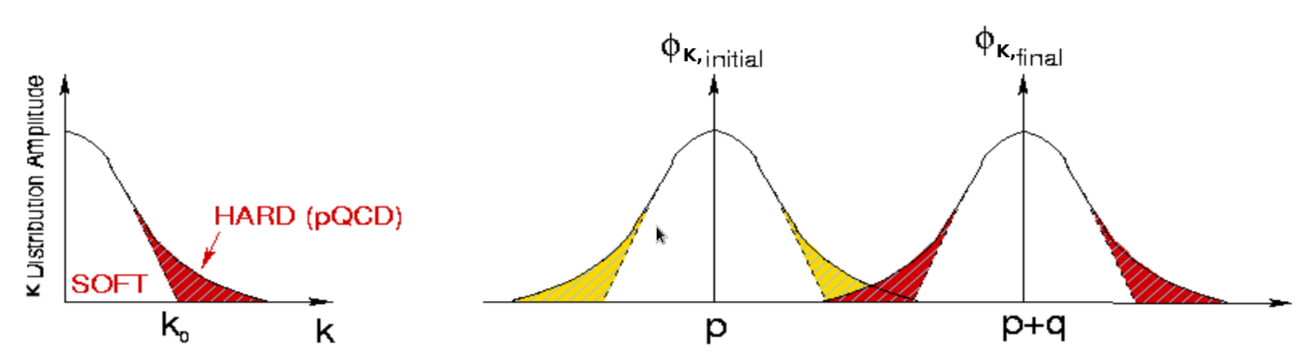


-t is the radius

The meson wave function (form factor)

- The electromagnetic form factor is an important physical observable connected directly to the internal structure of mesons.
- In quantum field theory, the form factor is the overlap integral,

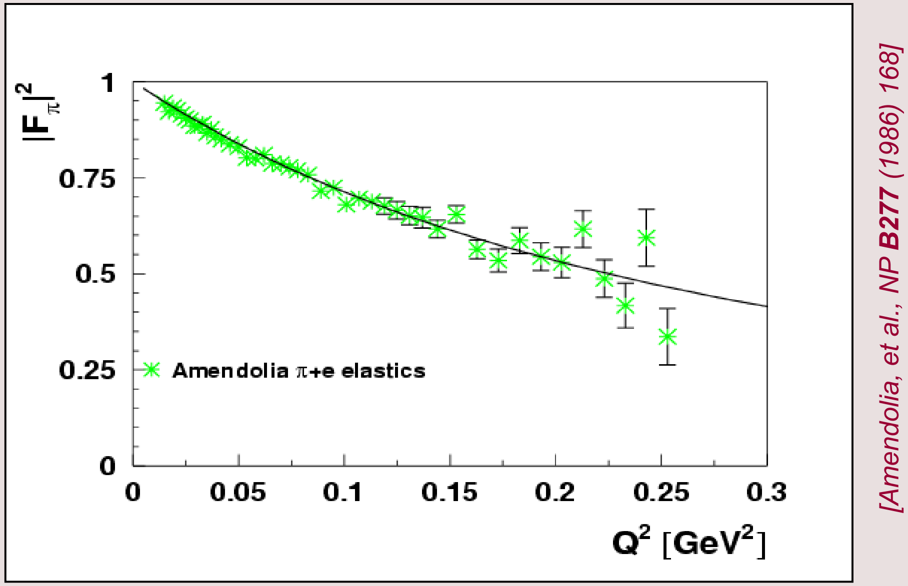
$$F_K(Q^2) = \int \phi_K^*(p)\phi_K(p+q)dp.$$

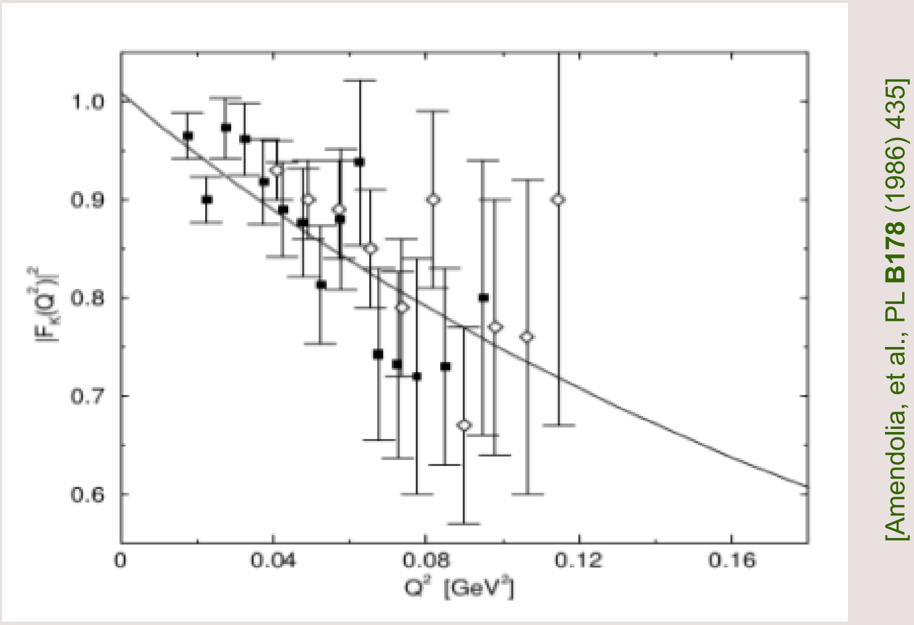


- The meson wave function can be separated into two parts.
  - Φ_K^{soft}, $(k < k_0)$ low momentum contributions only. Cannot be treated in pQCD.
  - Φ_K^{hard}, hard tail can be treated in pQCD.
- If our data analysis indicates that the K^+ pole dominates σ_L then we will attempt to extract the kaon form factor.

π and K form factors at low Q^2 (elastic scattering)

- $F_\pi(Q^2)$ and $F_K(Q^2)$ are known at low Q^2, extracted by using π^- and K^- beams on LH_2 target.
  - π^- of 300 GeV, data were collected up to $Q^2 = 0.28$ GeV^2.
  - K^- of 250 GeV, data were collected up to $Q^2 = 0.13$ GeV^2.
- These measurements were used to determined the charge radius of the π and K.
  - The slope of the fitting function at $Q^2 = 0$ provides the radius.
  - $\langle r^2 \rangle = -(6dF/dQ^2)_{Q2 = 0}$.
  - π charge radius $\langle r^2 \rangle^{1/2} = 0.657 \pm 0.012$ fm.
  - K charge radius $\langle r^2 \rangle = 0.340 \pm 0.050$ fm^2.



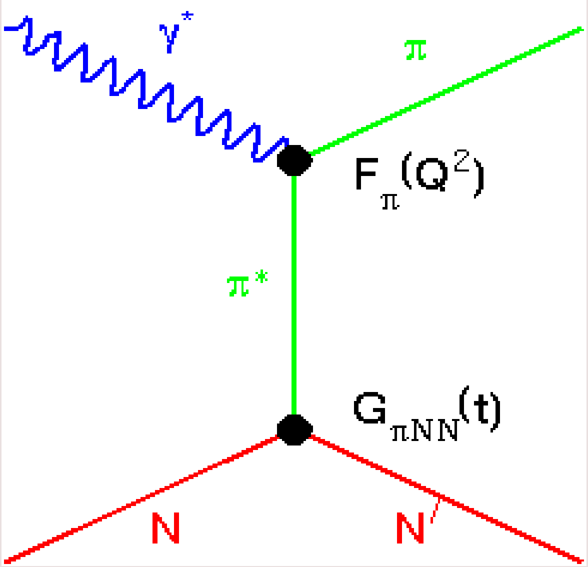


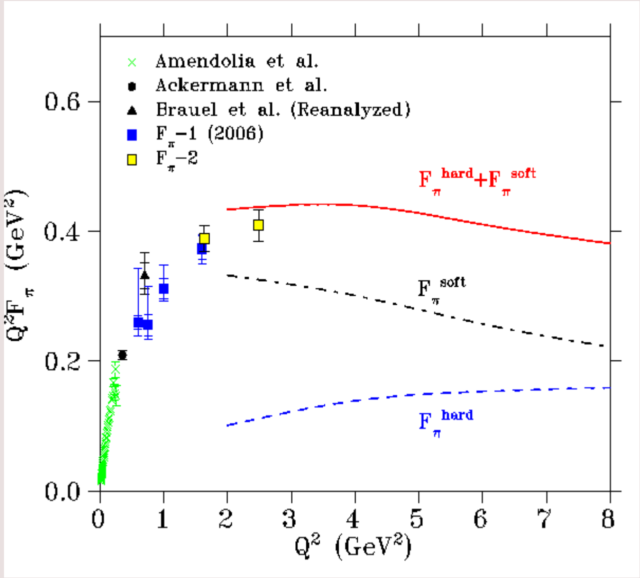
π and K form factors at higher Q^2

- At higher Q^2, the direct scattering is not achievable.
  - π and K beams of much higher energy which is not possible at the current experimental facilities.
- To access the form factors at higher Q^2, must employ an alternative method.
  - “Virtual cloud” of the π and K inside the proton makes the measurements possible.
  - This attempt has been made at 6 GeV era and a few other experimental facilities.
- In Born term model, the form factor appears as,

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

  - Indirect determination of the form factor is model dependent.

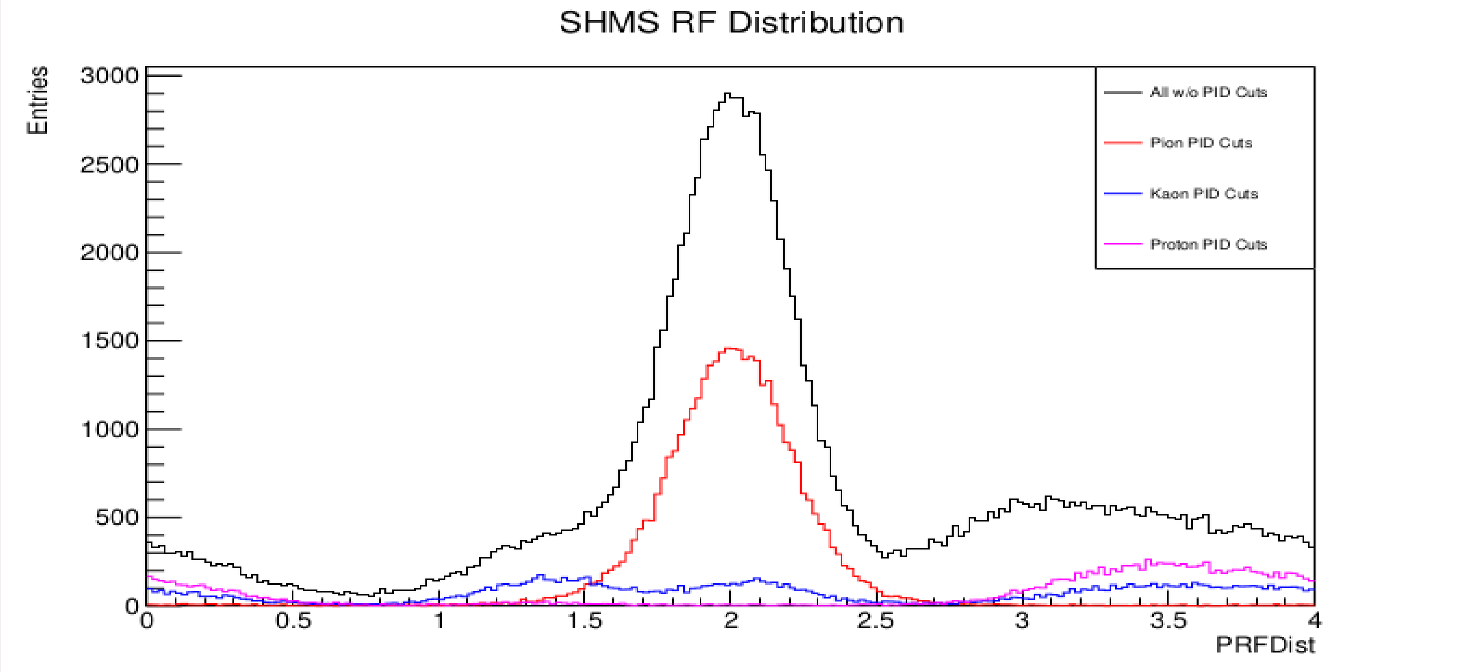




G.M. Huber et al., PRC **78** (2008) 045203.

Analysis update (RFTime & missing mass branches)

- A new branch of the RFTime variable has been added to hcana.
  - In some settings the RFTime variable is useful for PID.
  - New variable of the RFTime is calculated as,
  - RFTime = mod((BunchSpacing)(P_RF_tdcTime-P_hod_fpHitsTime+RF_Offset)).
  - RF_Offset is just to recentre the resulting distribution.

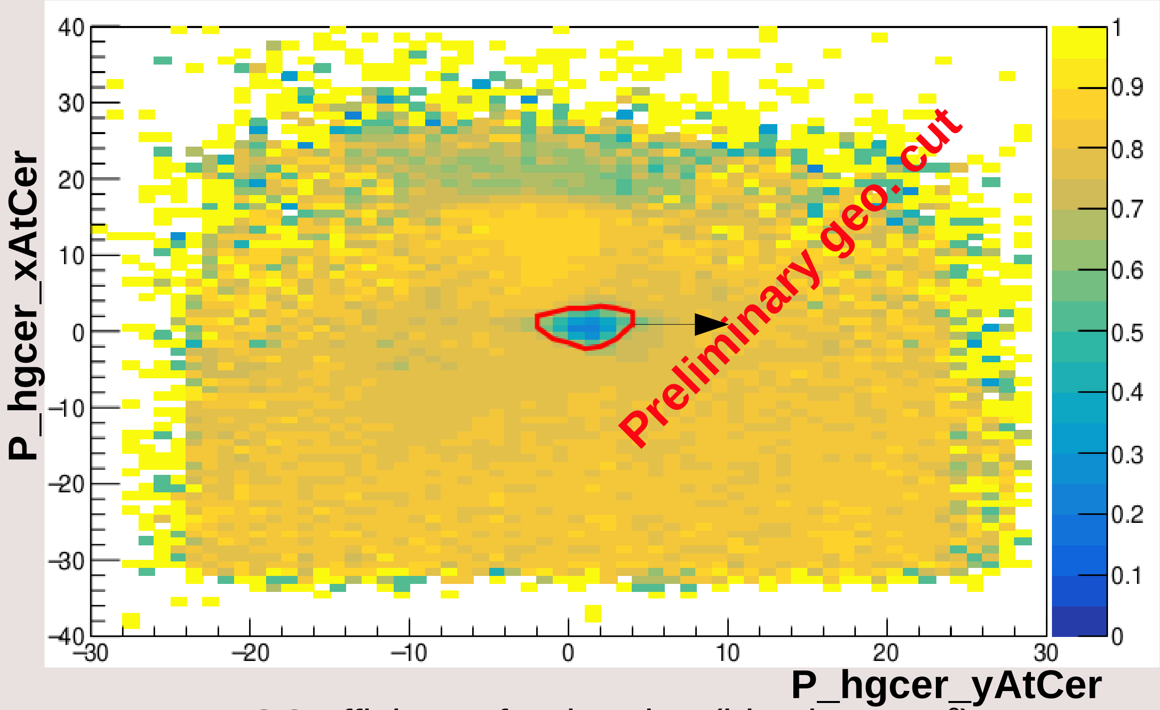


- New missing mass variables have also been added to hcana.

Stephen Kay (UofR), details of this work can be found at, DocDB 1129-v2

Analysis update (SHMS HGC efficiency & geometrical cut)

- Finalizing the HGC efficiency is challenging.
  - The collection of Cherenkov lights in the HGC is not uniform.
  - There is an inefficient region in the middle of the detector.
  - Decided to cut off the very inefficient region.
  - We are working to have position-dependent bin-by-bin HGC efficiency for regions outside the hole cut.



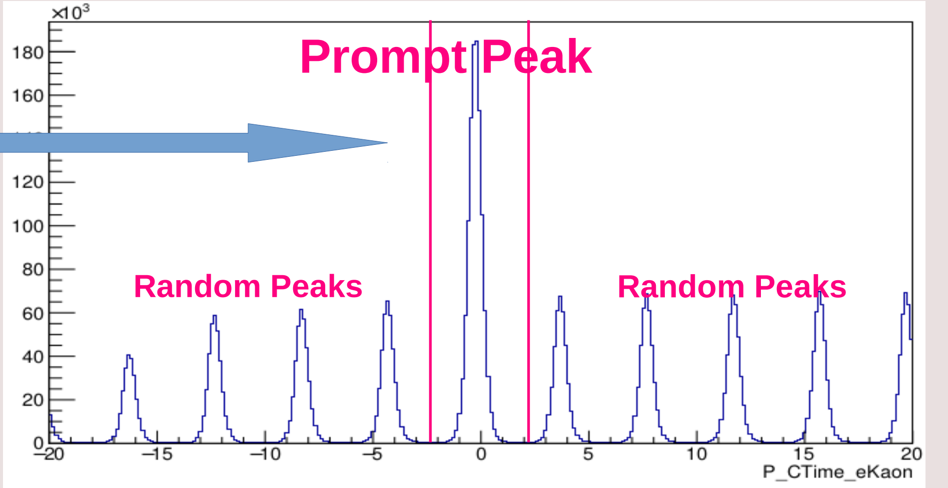
HGC efficiency for the pion (bin size 1cm^2)

Analysis update (PID in SHMS)

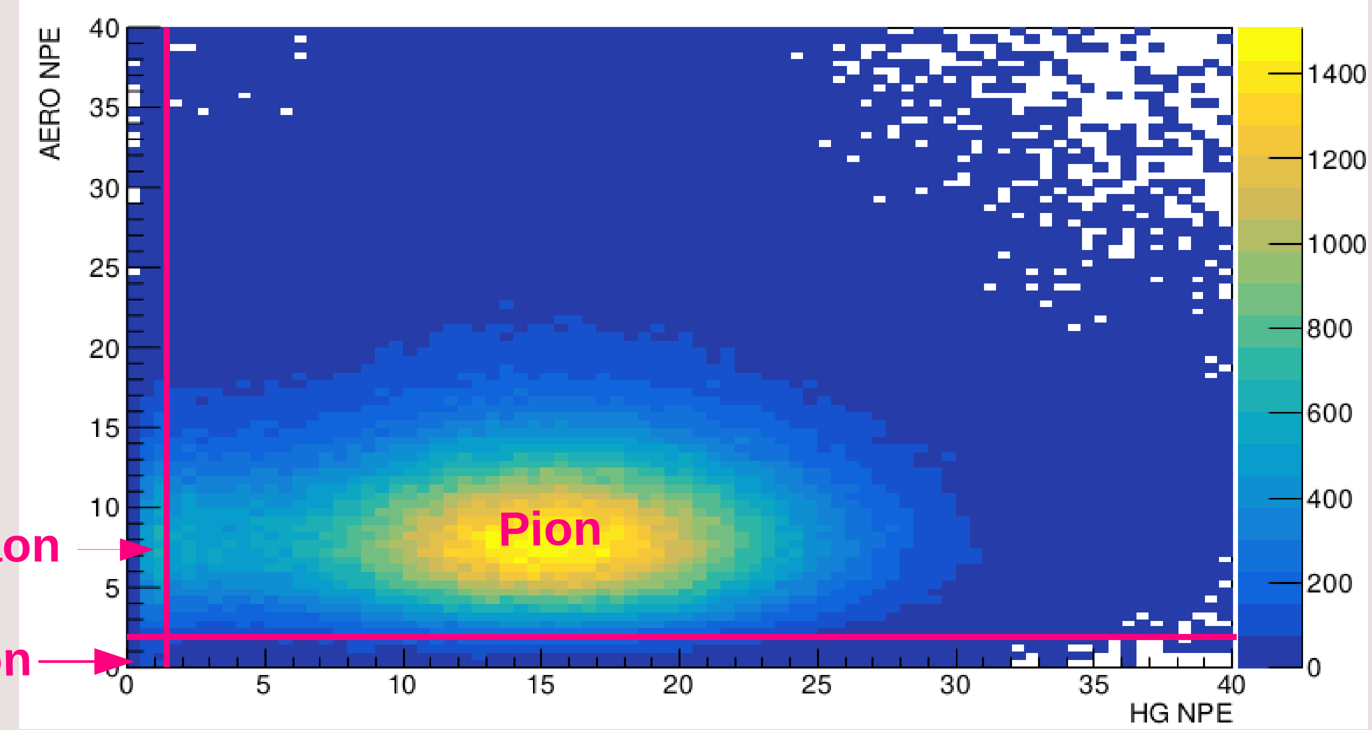
K⁺ → SHMS

e⁻ → HMS

Real coincidence



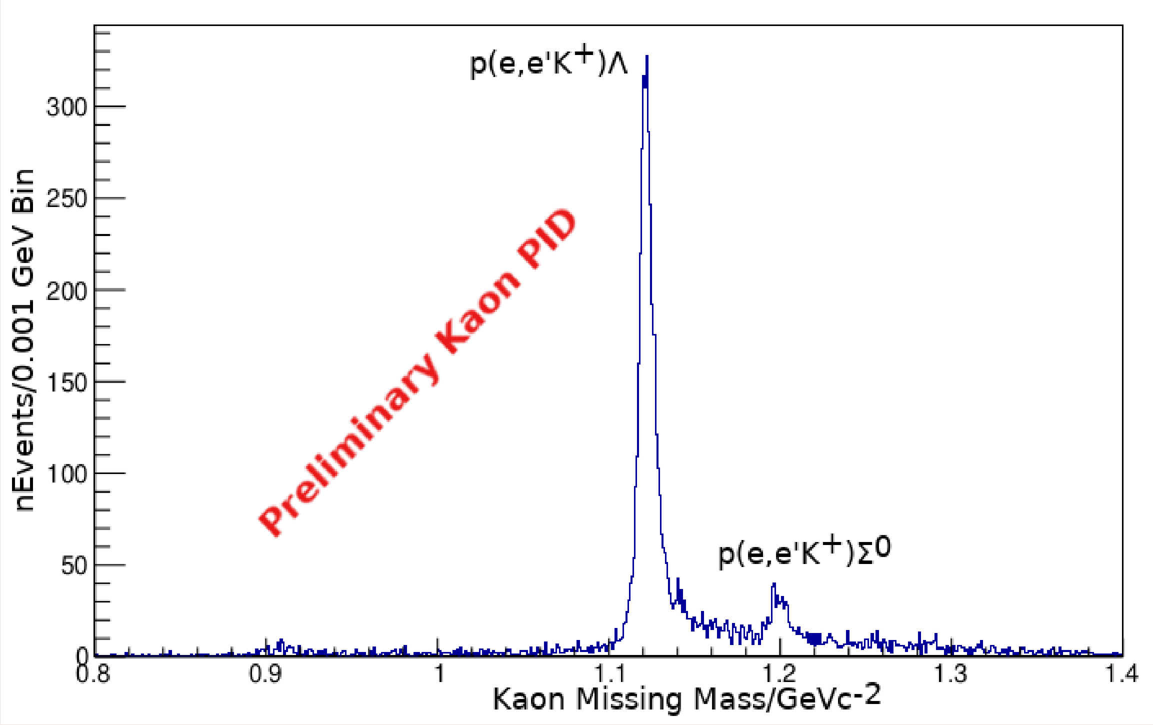
- Aerogel refractive index **1.011** of current analysis setting.
- Heavy Gas refractive index **1.00139** at 1 atm.
- Y axis Aerogel Cherenkov light (NPE).
- X axis Heavy Gas Cherenkov light (NPE).



Analysis update (kaon PID)

- The preliminary kaon PID is shown in the kaon missing mass plot.
  - The kaon sample looks clean but we need to optimize the kaon PID cuts.

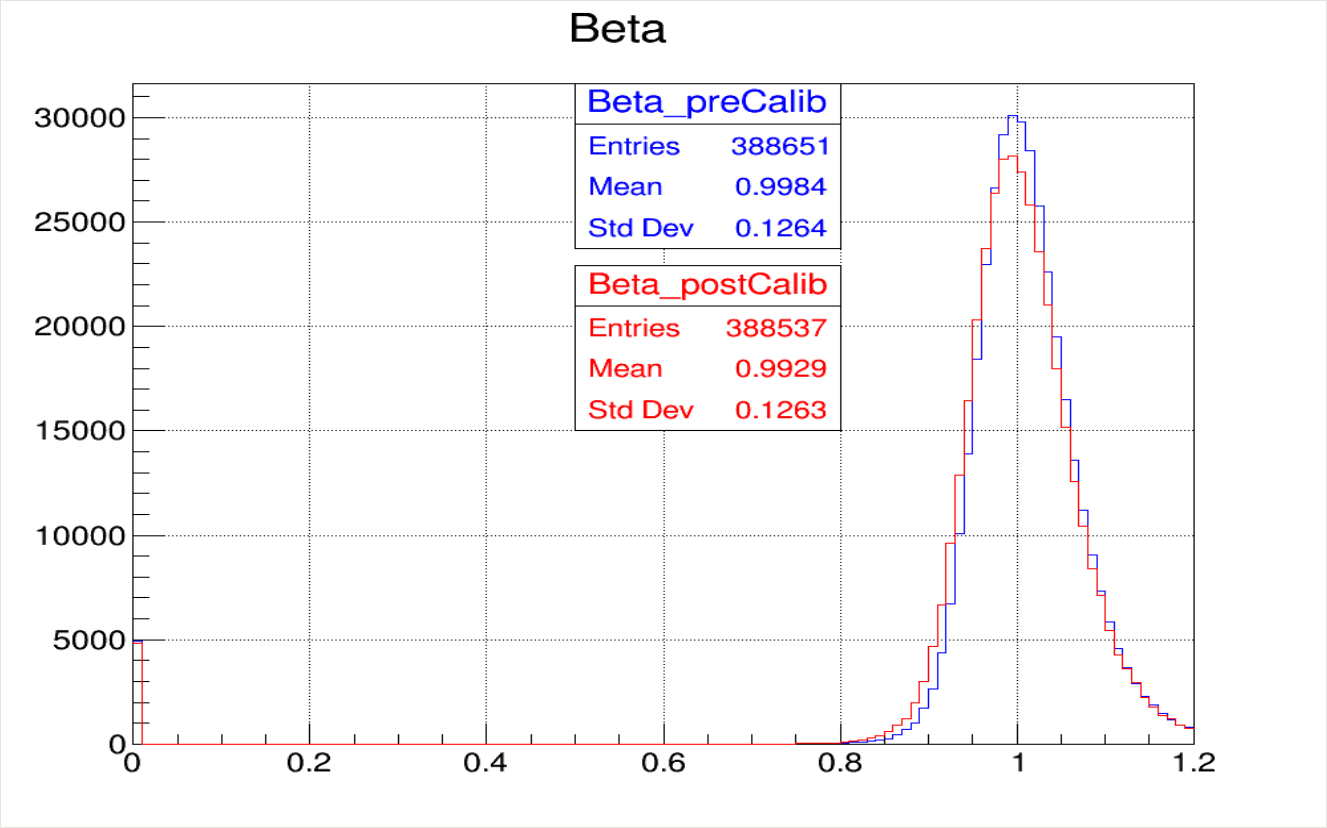
$$E_b = 6.19\ GeV, Q^2 = 3.0\ GeV^2/c^2 \quad W = 2.32\ GeV, P_{SHMS} = 3.48\ GeV/c$$



$$M_{miss} = [(E_b + m_p - E_{e'} - E_{K^+})^2 - (P_e - p_{e'} - p_{K^+})^2]^{1/2}$$

Analysis update (verifying the online SHMS Hodoscope calibration)

- The online Hodoscope calibration has been verified. Both the calibrations (online & offline) are almost equivalent.



Nathan Heinrich (UofR)

Analysis update (scaler luminosity yields)

- The preliminary scaler luminosity study has been completed.

6.2 GeV

P_{HMS}= -3.939
θ_{HMS}= 13.00

P_{SHMS}= -3.939
θ_{SHMS}= 11.00

65, 50, 30, 15, 5 uA
7841, 7846, 7847, 7864, 7865

HMS: Electron
Cer > 0.5
2.0 > Cal > 0.6

SHMS: Electron
Hgcer > 1.5
Aero > 1.5
0.6 < Cal <= 2.0

8.2 GeV

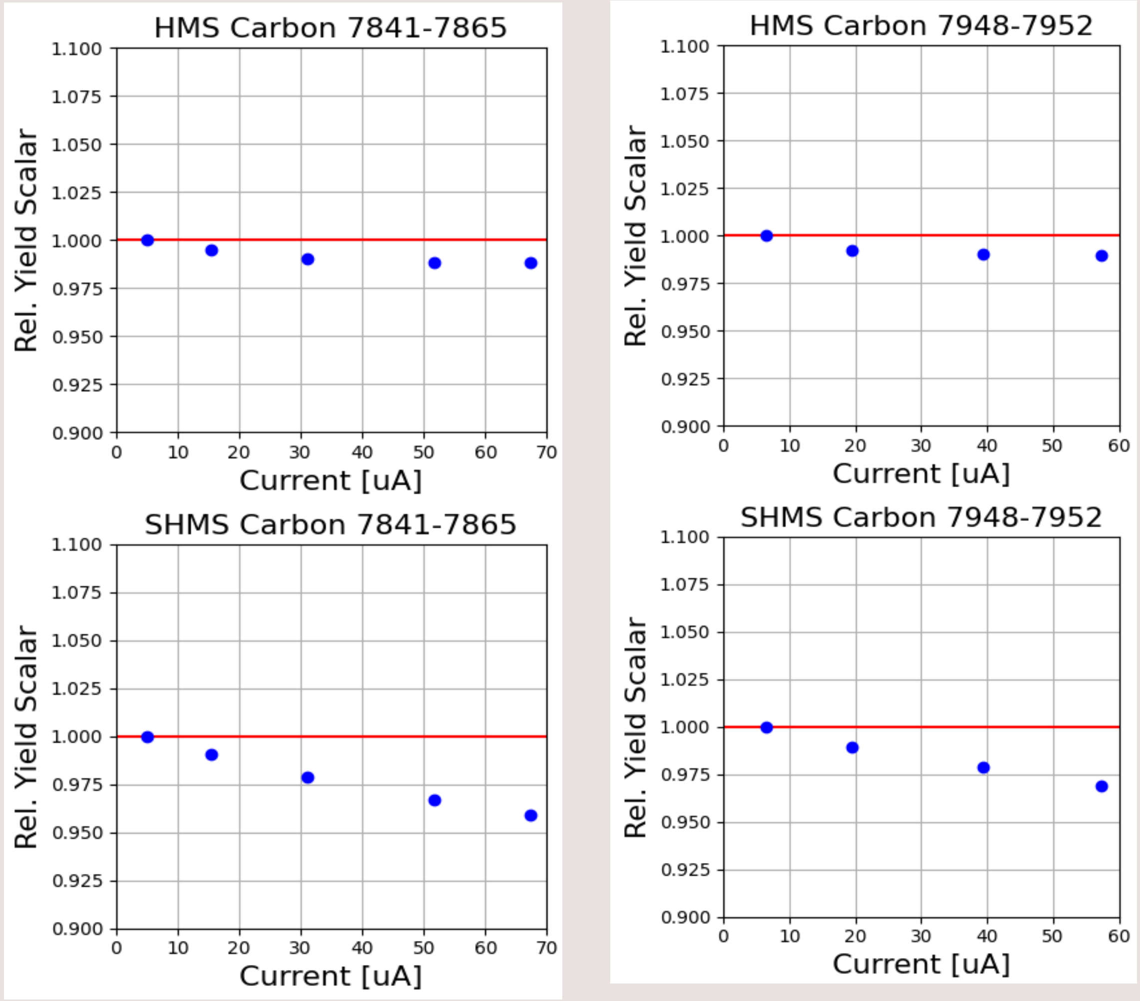
P_{HMS}= 5.745
θ_{HMS}= 12.97

P_{SHMS}= 5.745
θ_{SHMS}= 9.51

65, 50, 30, 15, 5 uA
7948, 7949, 7950, 7951, 7952

HMS: Hadron
Cer < 0.5
0.0 < Cal <= 0.6

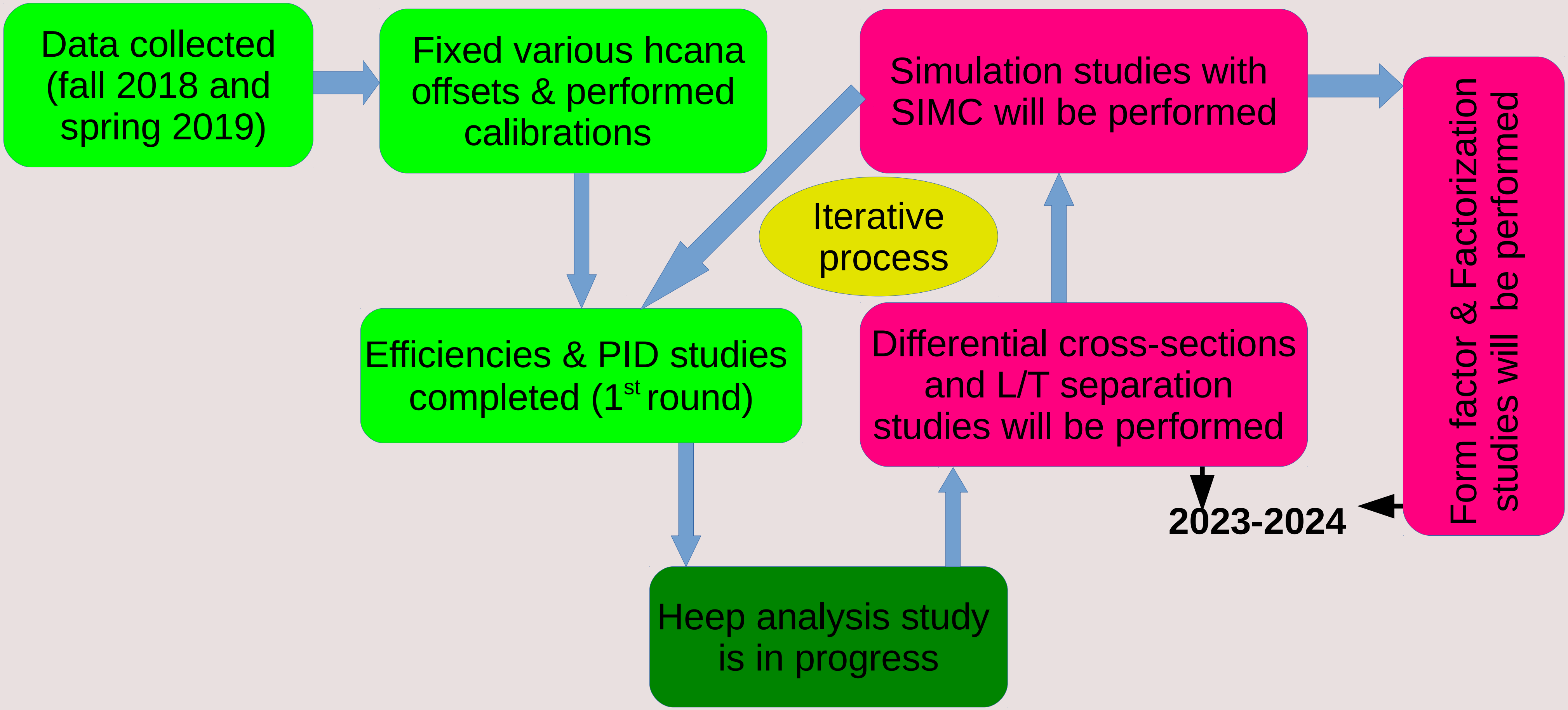
SHMS: Proton
Hgcer < 1.5
Aero < 1.5
0 < Cal <= 0.6



Richard Trotta (CUA)

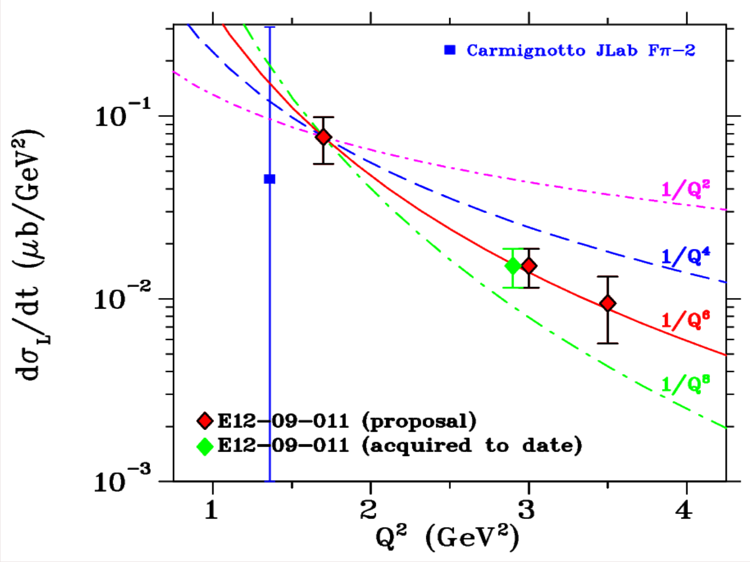
Analysis update (analysis flow chart)

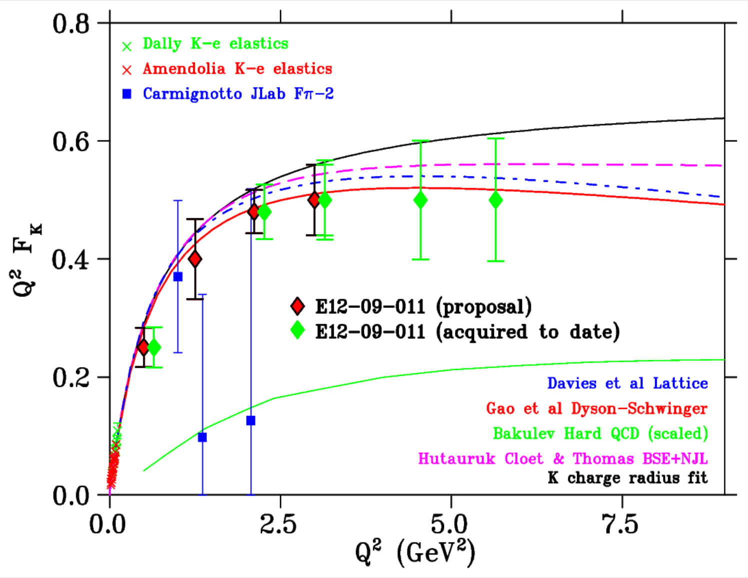
- The data analysis of the Kaon LT experiment is an iterative process.



Update on the KaonLT PAC49

- Overall **~60%** of our approved data were acquired in fall 2018 and spring 2019 run plans.
  - Q^2 scan at $x_B = 0.40$.
  - And $F_K(Q^2)$ points.
- The statistics at the higher beam energies are systematically lower except for one of the settings.
  - This increases the originally projected uncertainties and makes difficult to extract the science for the Q^2 scan at $x_B = 0.25$.
- A KaonLT PAC49 jeopardy document has been submitted, requesting a total of 18 days beam time.
  - Q^2 scan at $x_B = 0.25$.
  - And $F_K(Q^2)$ points.
- Spokespersons:
  - T. Horn, G. Huber and P. Markowitz





Summary and future perspectives

- The Kaon LT experiment is for the high precision L/T/LT/TT separation studies. The data analysis is intricate and the international journal publications are expected to be published in 2-3 years.
- I will start the $p(e, e'K^+)\Lambda$ L/T/LT/TT separation cross-sections studies at $Q^2 = 0.5$ GeV^2/c^2 after completing the ongoing studies.
- I will also start the $p(e, e'\pi^+)n$ L/T/LT/TT separation cross-sections studies at $Q^2 = 0.5$ GeV^2/c^2 from the Kaon LT experiment and at $Q^2 = 0.38$ and 0.42 GeV^2/c^2 from the Pion LT experiment.
- Other studies such as simulations (SIMC) will also be carried out with the physics analysis.
- Other students are also preparing to start the main physics analysis at higher Q^2.

SAPIN-2021-00026

Thank You!