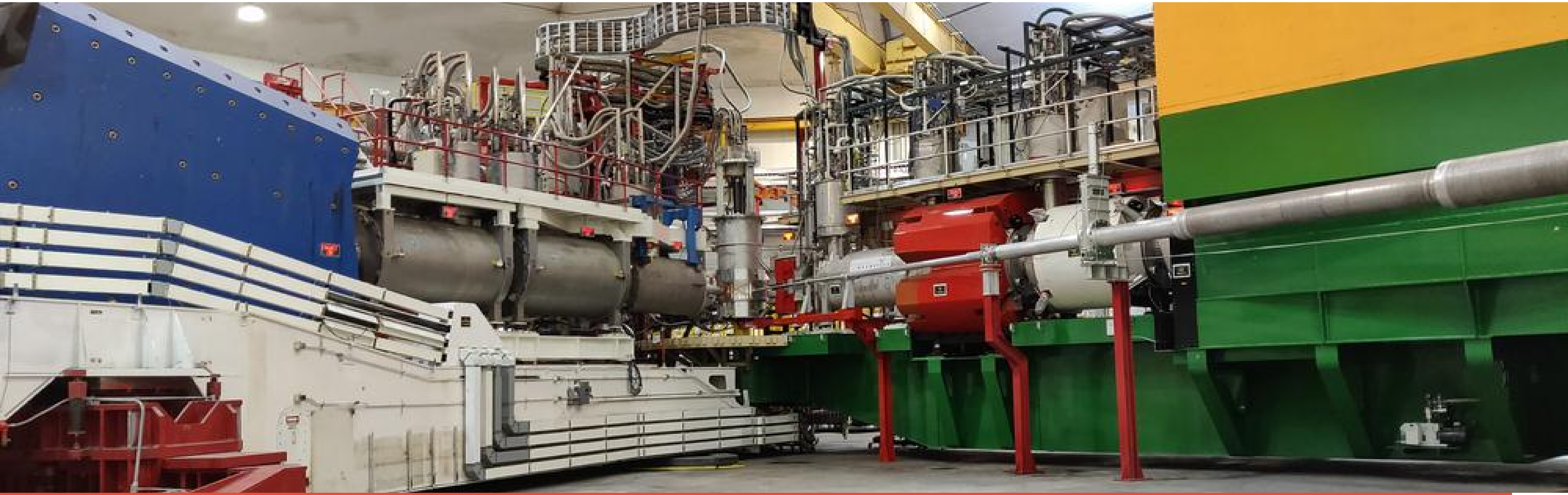

Charged Meson Form Factors At Jefferson Lab Hall C

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February 2021

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Thomas Jefferson National Accelerator Facility

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Background

- Mesons are particles made up of 2 quarks, of note the Pion(π) is the lightest meson, while the Kaon(K) is the lightest strange meson.

The Form Factor of a particle is defined in Quantum Field Theory as: $F_\pi(Q^2) = \int \phi_\pi^*(p)\phi_\pi(p+q)dp$ where ϕ is the wave function.

Is an important variable to study as it allows for comparison with theory:

Experiment

Comparison

Theory

$$\frac{d\sigma}{d\Omega} \rightarrow |F(q^2)| \leftrightarrow F(q^2) \leftarrow \rho(\vec{r}) \leftarrow \psi(\vec{r}) \leftarrow$$

Dirac\Schrödinger equation

Charge Density

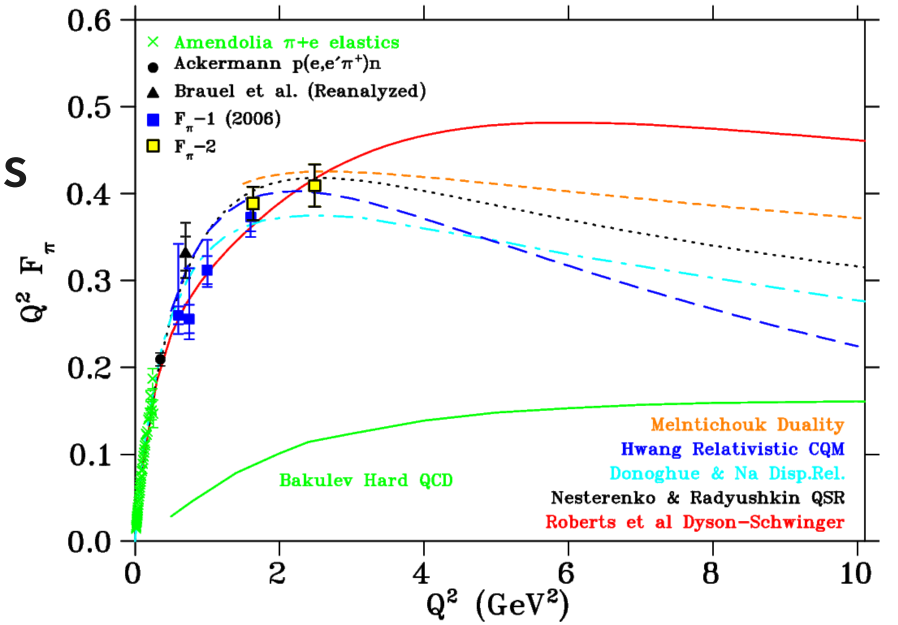
Motivation

This talk covers the Pion-LT and Kaon-LT experiments being done at Jefferson Lab Hall C.

These experiments seek to measure the form factors of the Pion and Kaon which to date have only been measured in the experimentally accessible low Q^2 region, and the high Q^2 region theoretically accessible with pertubative QCD.

These experiments will measure these form factors in the space between these two regions

Understanding the form factors of these light mesons will be crucial guidance to theory in this 'transition' region.

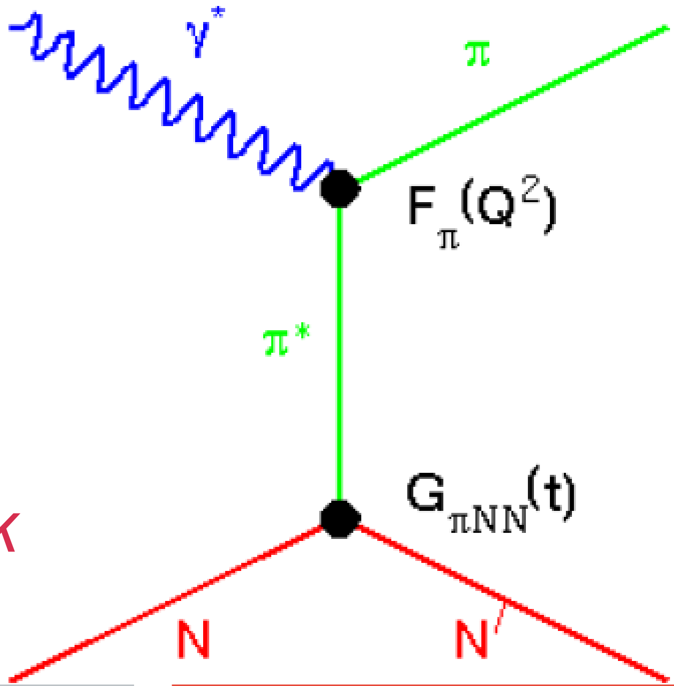


Measurement of Meson Form Factors

Since standard π and K targets are impossible to obtain due to short half lives, we must scatter off of the virtual π (or K) cloud inside a nucleon.

Scattering off of the virtual particle now requires a model dependent form factor extraction so from the Born Term Model Obtain:

$$\boxed{\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_\pi^2)} g_{\pi NN}^2(t) F_\pi^2(Q^2,t)}$$



But determining σ_L is difficult. (see next slide)

A similar reaction applies to *K*.

- first designated experiment with this technique on *K*

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LT separation

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

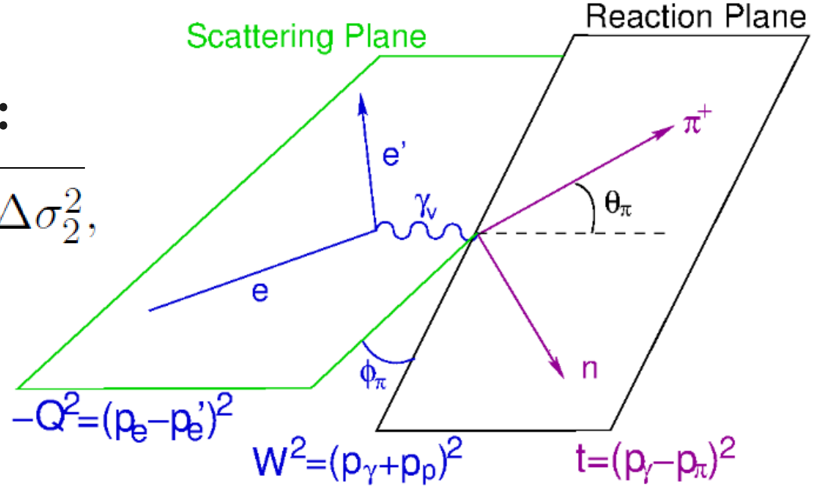
- Only 3 of Q^2, W, t, and θ_π independent
  - Vary θ_π to get multiple values of t
- Since θ_π non-zero, must obtain σ_{LT} and σ_{TT} by varying $\boldsymbol{\varphi}$ at two values of $\boldsymbol{\varepsilon}$
- Control of systematic uncertainties critical as:

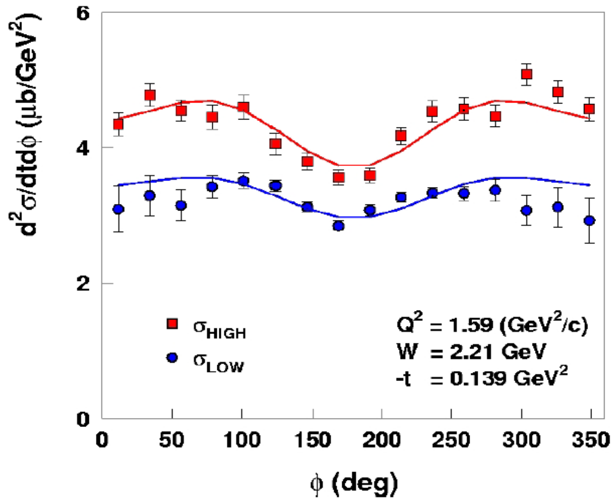
Virtual-photon polarization:

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

$$\frac{\Delta\sigma_L}{\sigma_L} = \frac{1}{(\epsilon_1 - \epsilon_2)}\frac{1}{\sigma_L}\sqrt{\Delta\sigma_1^2 + \Delta\sigma_2^2},$$

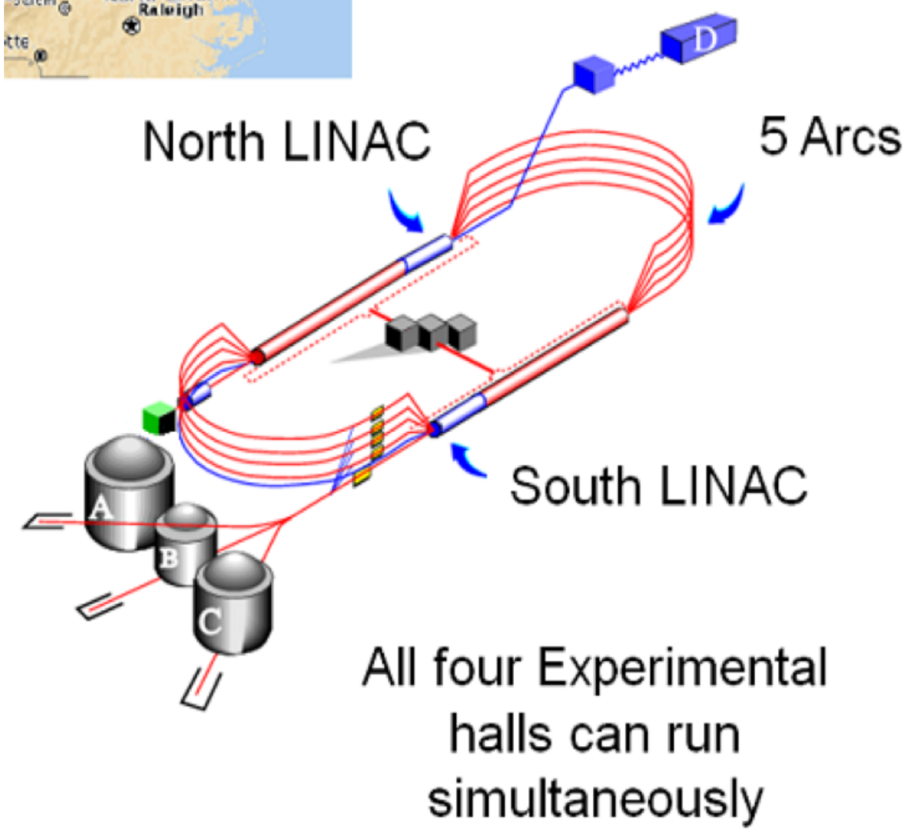
$$\sigma_1 = \sigma_T + \epsilon_1\sigma_L$$
$$\sigma_2 = \sigma_T + \epsilon_2\sigma_L$$





Jlab And Accelerator

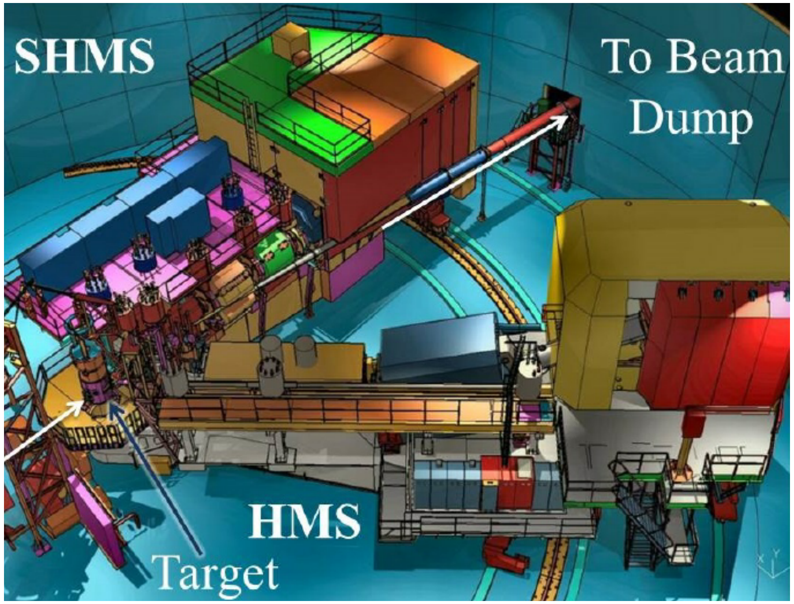
- Located in Newport News, Virginia
- 2 Superconducting LINACs configured in “Racetrack”
- Produces continuous e^- beam at 1497MHz
- Capable of 12GeV polarized e^- at up to 200μA
- 4 halls all running unique experiments
  - Capable of running simultaneously



Hall C

The Hall Contains a target and two detector arms.

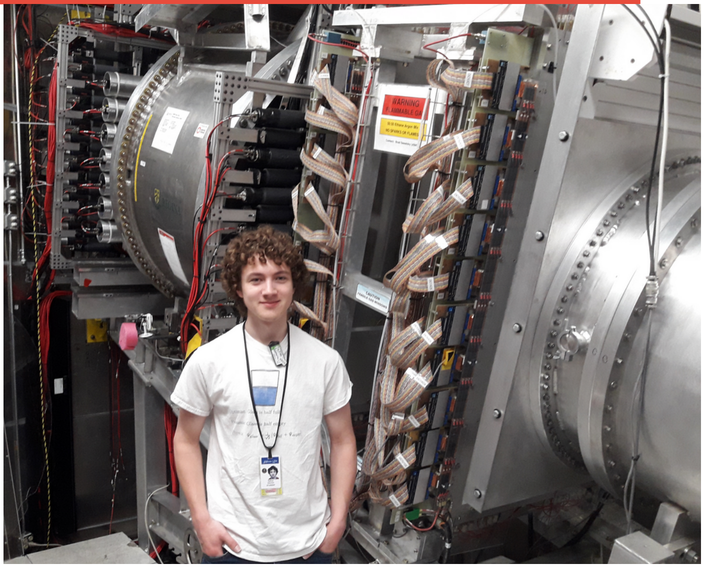
- **Target can have Liquid H_2, Liquid D_2, or solid targets**
  - High Luminosity of 10^{38} $cm^{-2}s^{-1}$
- **High Momentum Spectrometer (HMS) and Super High Momentum Spectrometer (SHMS):**
  - Both arms have 3 Quadrupole and 1 Dipole super conducting magnet
  - Dipole allows studies at specific momenta
  - Both contain similar detector packages that support high rate (<1MHz)



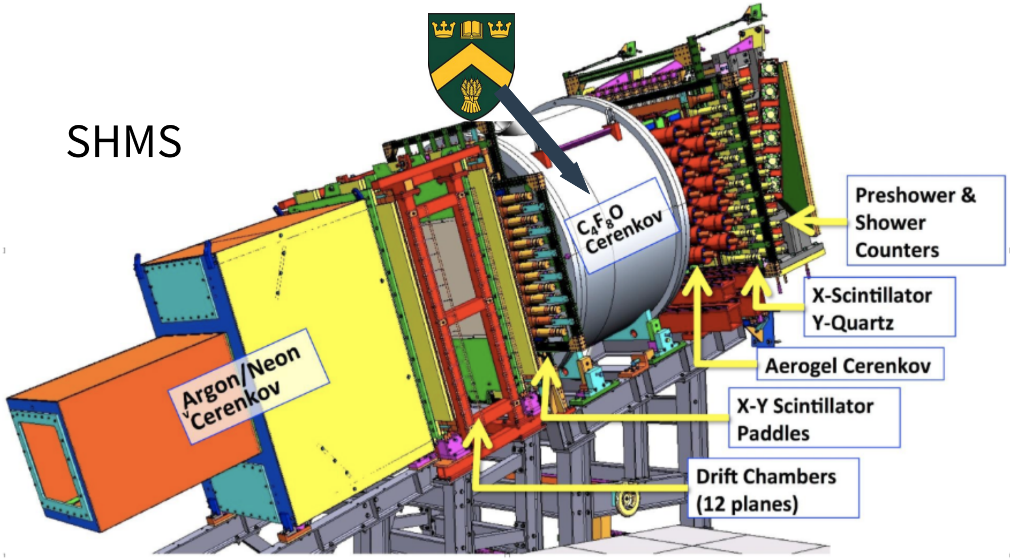
Spec	Angle Range	Momentum Range
HMS	10.5 - 90	0.5 – 7 GeV/c
SHMS	5.5 - 40	0.5 – 11 GeV/c

Detectors

Detector	Purpose	Notes
Aerogel Cerenkov	Particle ID, K^+/p discrimination	n = 1.011, 1.015, 1.03, 1.05
Heavy Gas Cerenkov (HGC)	Particle ID, Trigger, $\pi^\pm/K^\pm$ discrimination	C_4F_8O –Vary pressure to set n at $K^\pm$ threshold
Nobel Gas Cerenkov	Particle ID, Trigger. e^+/π^+ at high momentum	Not used in Kaon-LT, Only in SHMS
Hodoscopes	Trigger, Time reference, Measure β	
Drift Chambers	Momentum measurement, Tracking	5mm max. Drift, 300 micron resolution
Preshower and Shower Counters	Particle ID, Trigger, $e^\pm$ Tagging	



SHMS

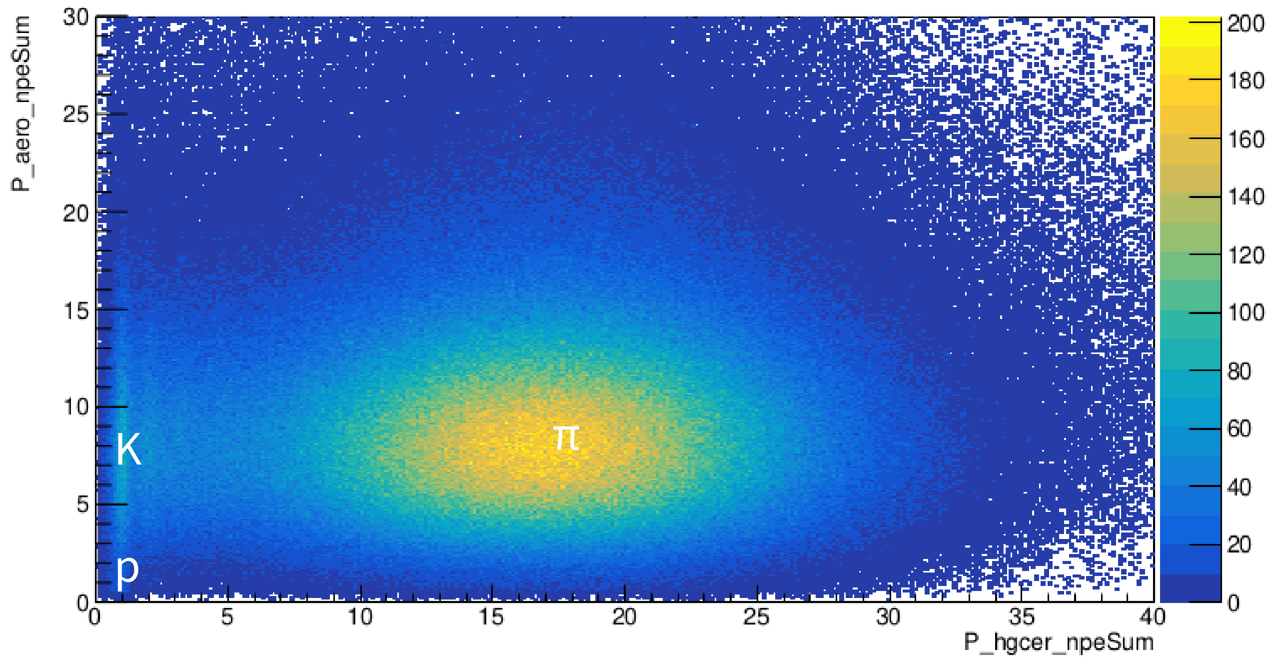


Unique Particle ID

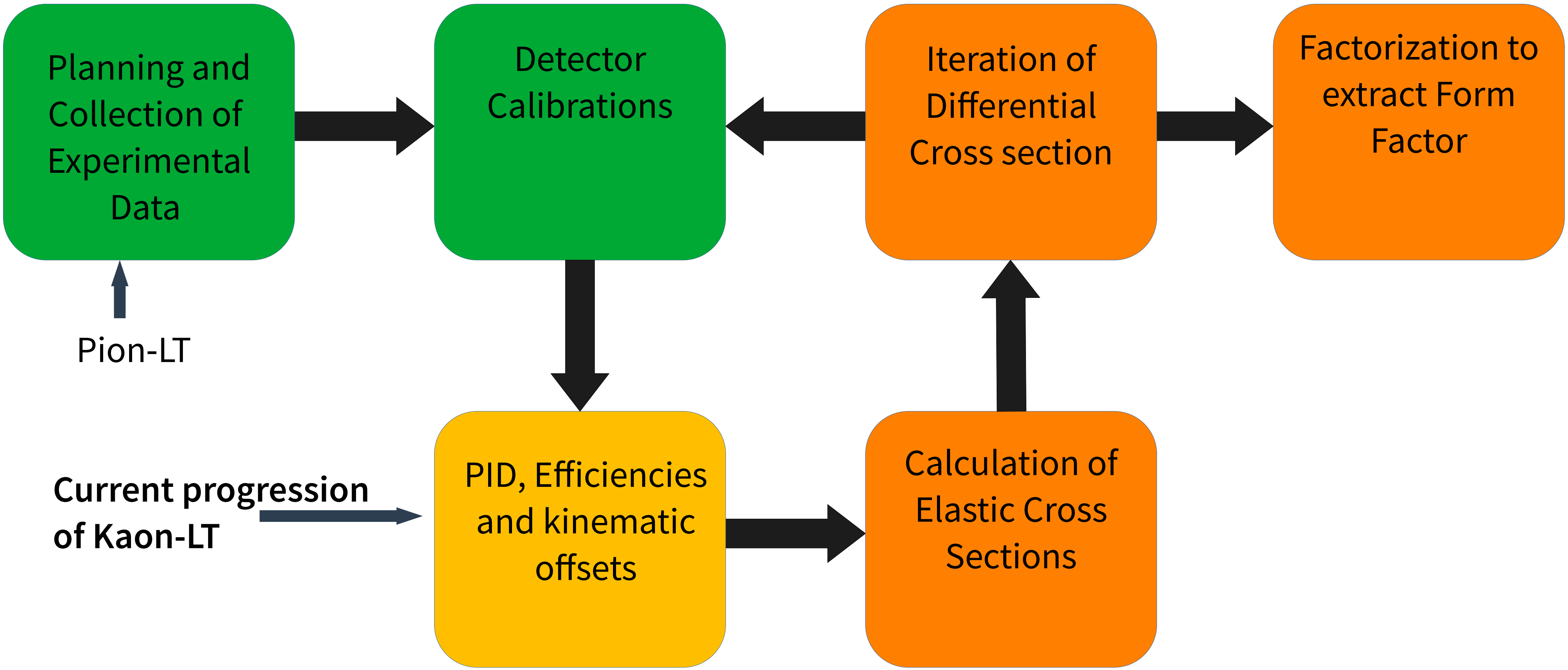
These detectors have a relatively unique method of particle ID.

- $\pi^{\pm}$ and $K^{\pm}$ separated by HGC (here n = 1.00143 at 1 atm)
- K and the p separated by the Aerogel Cerenkov (here n = 1.015)
- Preshower vs Shower counter separates $\pi^{\pm}$ from $e^{\pm}$

The combination of multiple threshold Cerenkov detectors in this way allows for efficient particle ID at our highest rates.



Analysis Flow



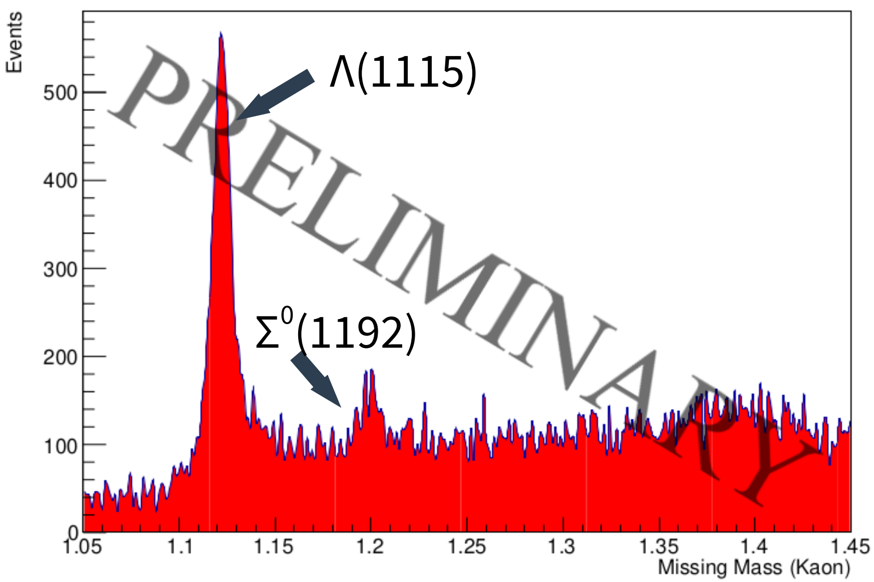
- In order to understand systematics the analysis will be iterated multiple times

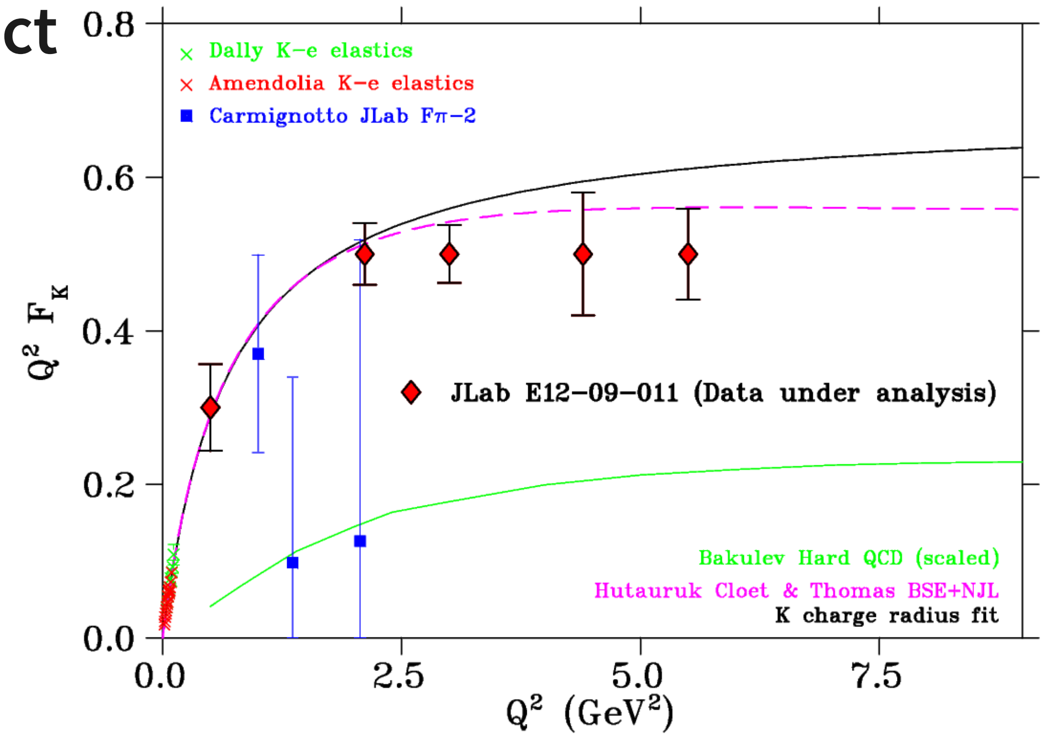
Kaon-LT Status

The Kaon-LT experiment has finished taking data in 2018-2019, and analysis is progressing steadily.

First results are expected sometime in the next 2-3 years.

This data will also be used to extract extra π data points!



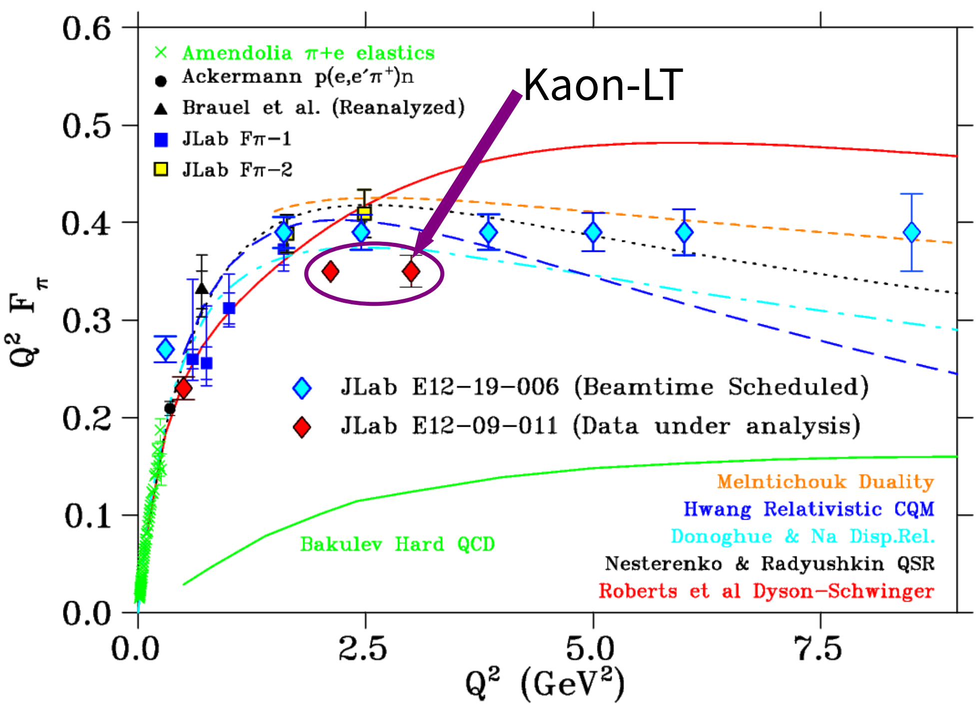


Pion-LT Status

The first round of data taking finished in Summer 2019.

Another round of data taking is Scheduled for this fall, and a further third round is set to take place sometime 2023.

E_b = 2.8 GeV	Done	Summer - 2019
E_b = 3.7 GeV	Done	Summer - 2019
E_b = 4.2 GeV	Done	Summer - 2019
E_b = 4.5 GeV	Done	Summer - 2019
E_b = 8.0 GeV	Scheduled	Fall - 2021
E_b = 9.2 GeV	Scheduled	Fall - 2021
E_b = 9.9 GeV	Scheduled	Fall - 2021
E_b = 6.0 Gev	Planned	2023
E_b = 6.7 Gev	Planned	2023
E_b = 8.8 Gev	Planned	2023
E_b = 11.0 Gev	Planned	2023



Recap/Overview

- The Pion and Kaon Form factors are important for understanding QCD in transition region.
- Jefferson Lab Hall C is uniquely poised to preform precision measurement of the form factor.

Kaon-LT

- Data collection finished
- Analysis in progress

Pion-LT

- Data collection in progress
- Set to continue into 2023

Stay Tuned

Thank You

Co Authors: G.M.Huber, T. Horn, S.J.D. Kay, A. Usman, R.L. Trotta, M. Junaid, D. Gaskell

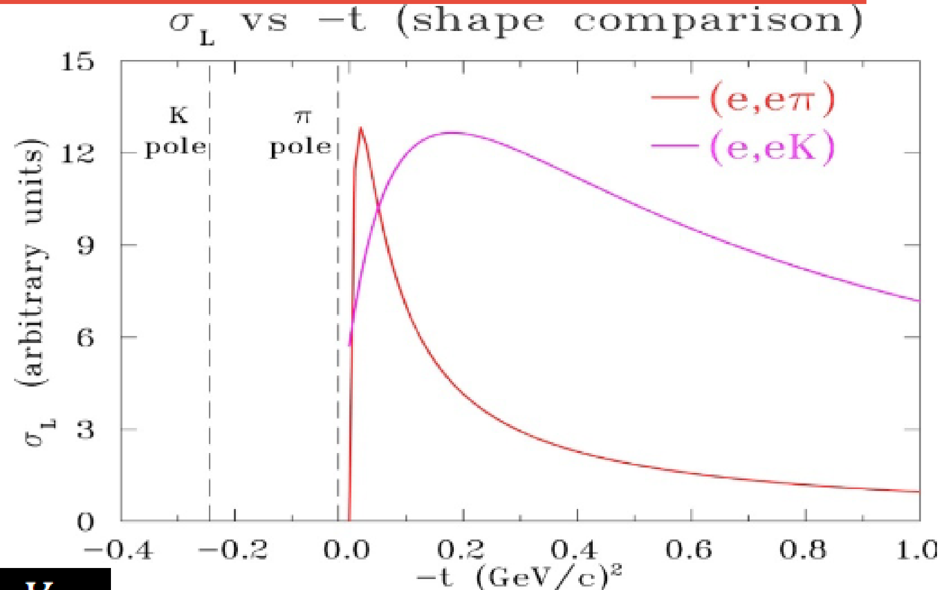
Collaborators: P. Markowitz, P. Stepanov, J. Murphy, C. Yero

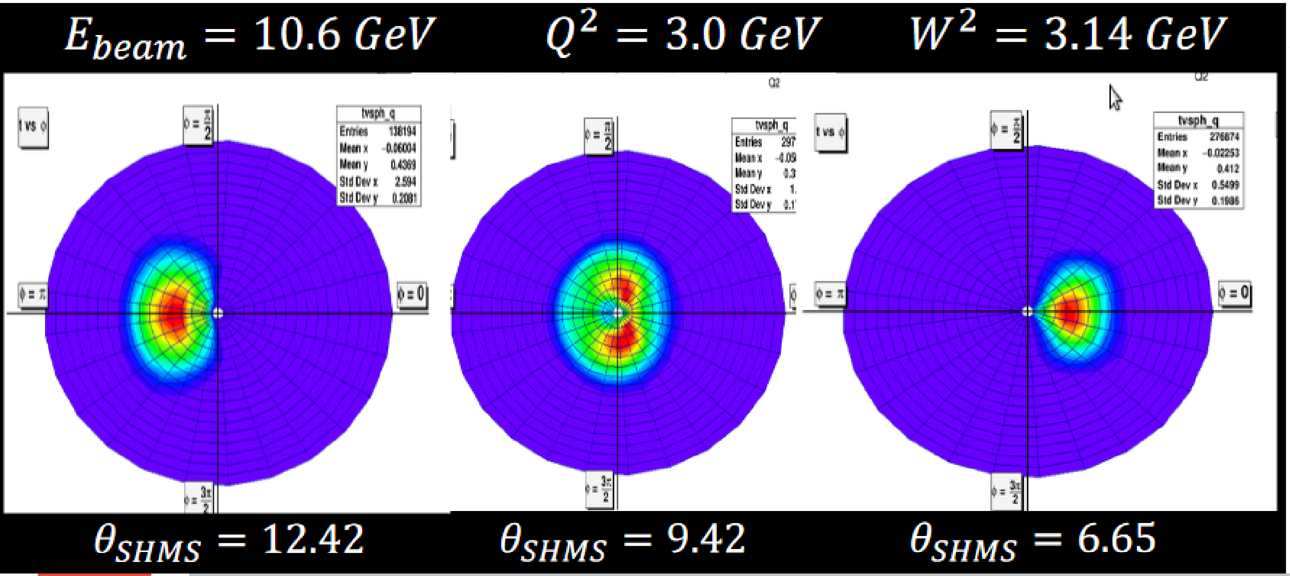
Backup

Hall C Pic

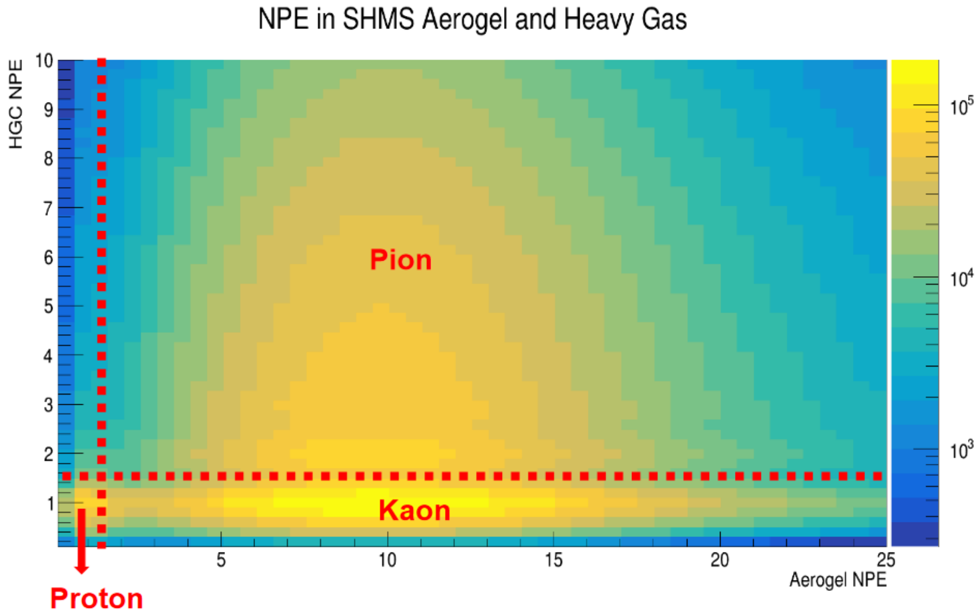
Hall C Pic

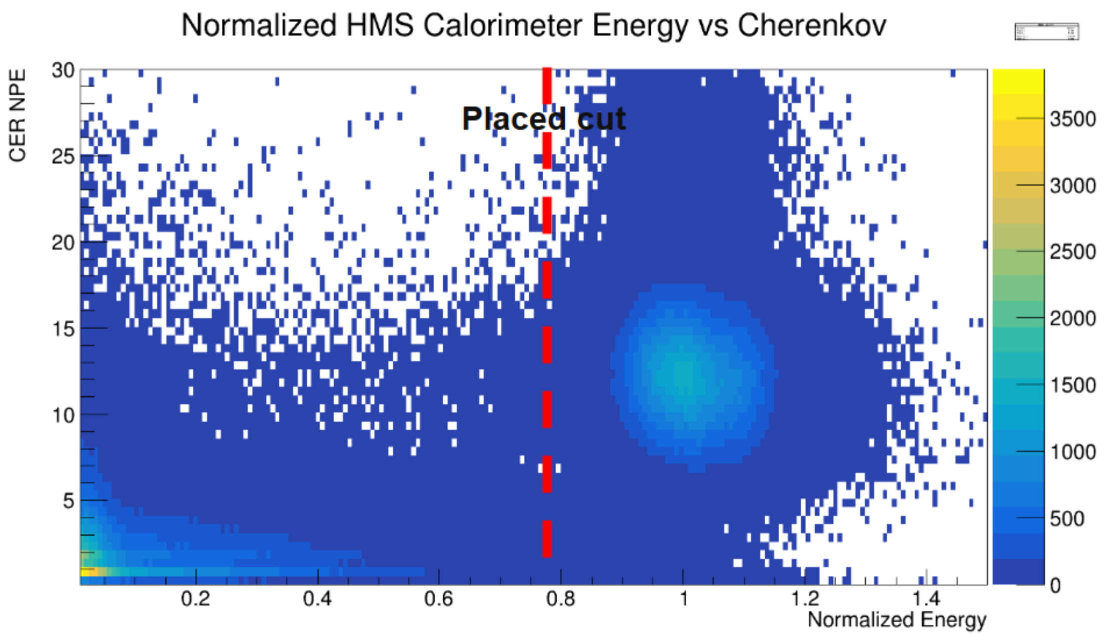
LT Separation extra



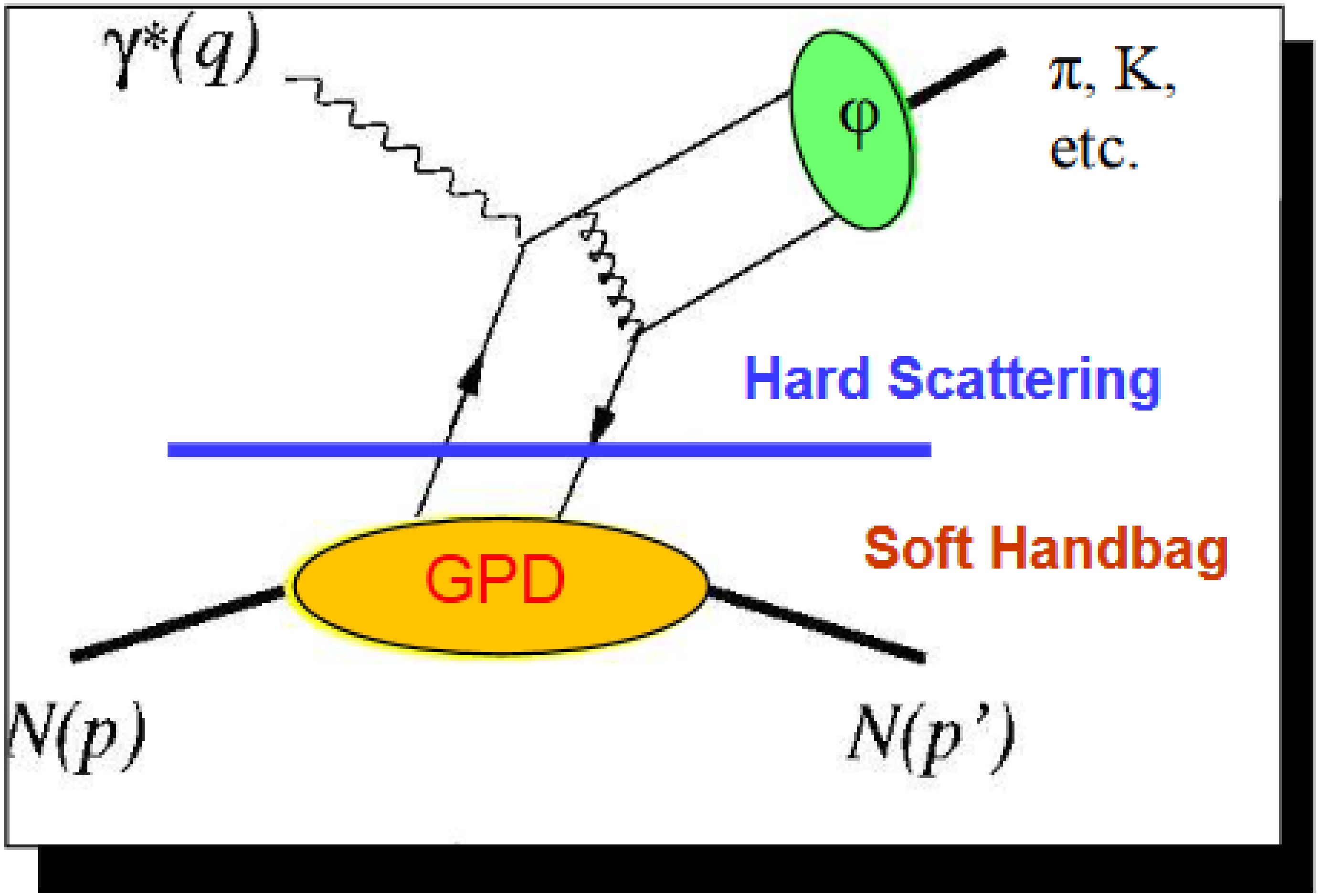


PID example


NPE in SHMS Aerogel and Heavy Gas
HGC NPE
Aerogel NPE
Pion
Kaon
Proton


Normalized HMS Calorimeter Energy vs Cherenkov
CER NPE
Normalized Energy
Placed cut

Reaction Clarified



Missing Mass