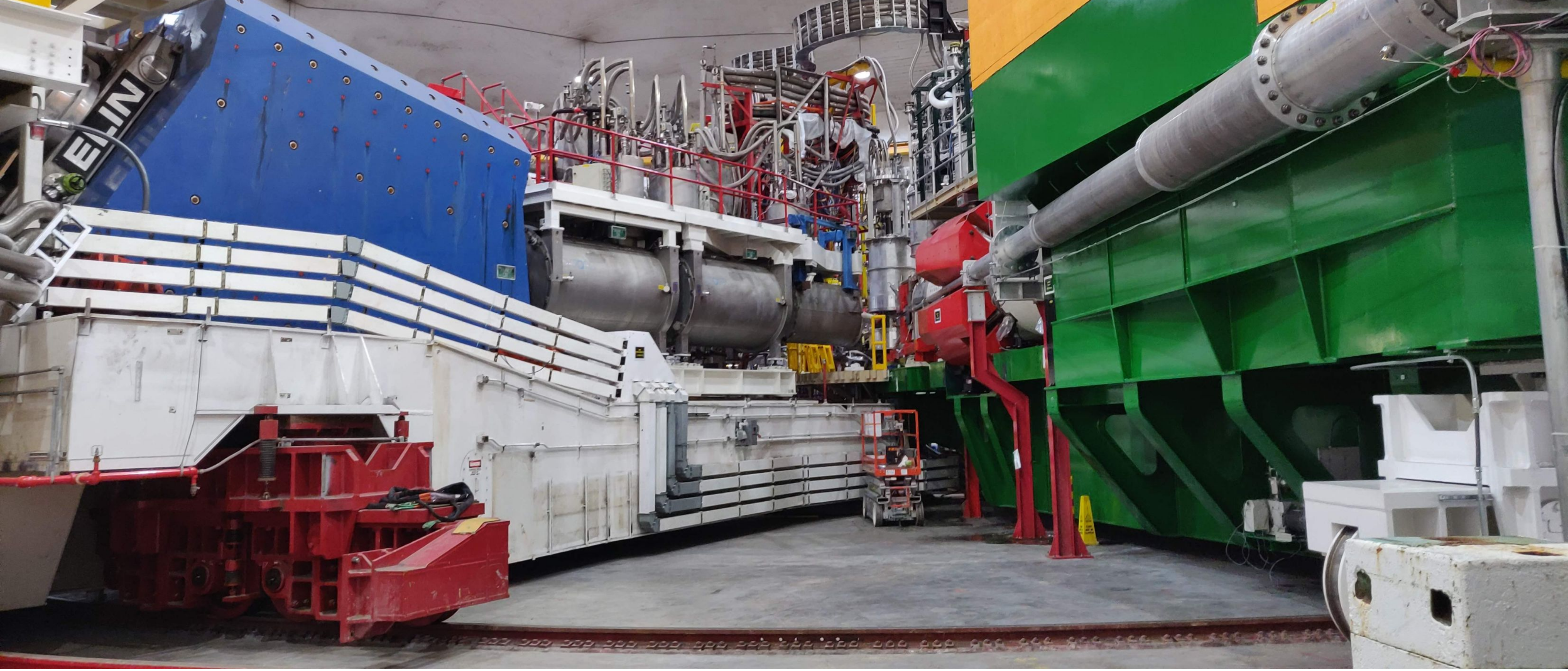


Calibrations Complete: PionLT (E12-19-006)

Nathan Heinrich

Jefferson Lab
Thomas Jefferson National Accelerator Facility

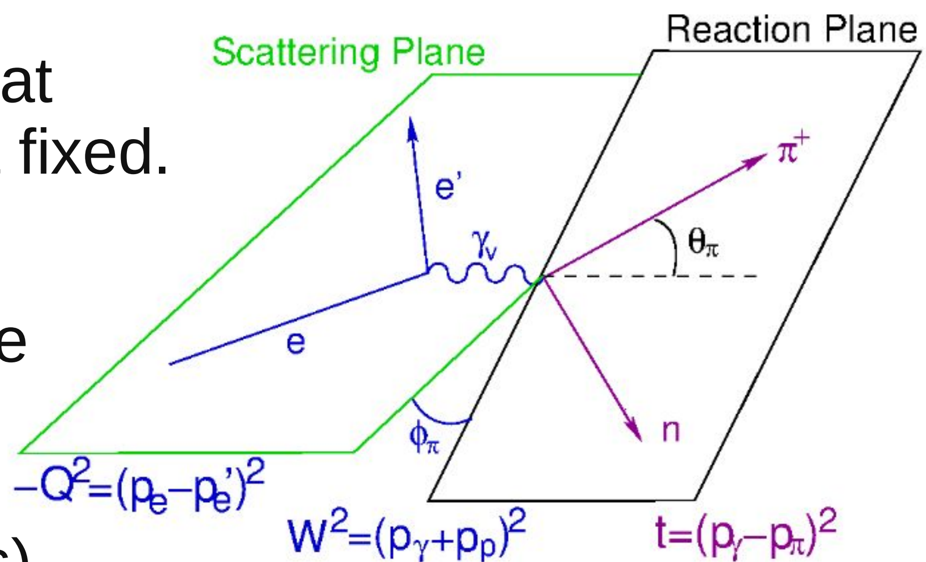
University of Regina

(Motivation)

LT Separations

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

- Extract components of cross section based on virtual photon polarization, using the above equation.
- To do this need to have full φ coverage at 2 values of ε while keeping Q^2, W, and t fixed.
- Extracting the components of the cross-section allows access into multiple structure functions
- These include Form Factors and Generalized Parton Distributions (GPDs)

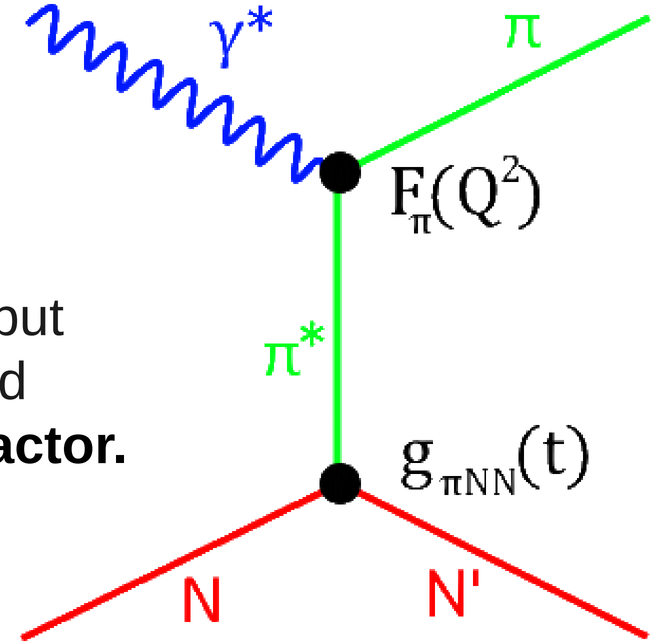


Virtual-photon polarization:

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

(Motivation)

π Form Factors



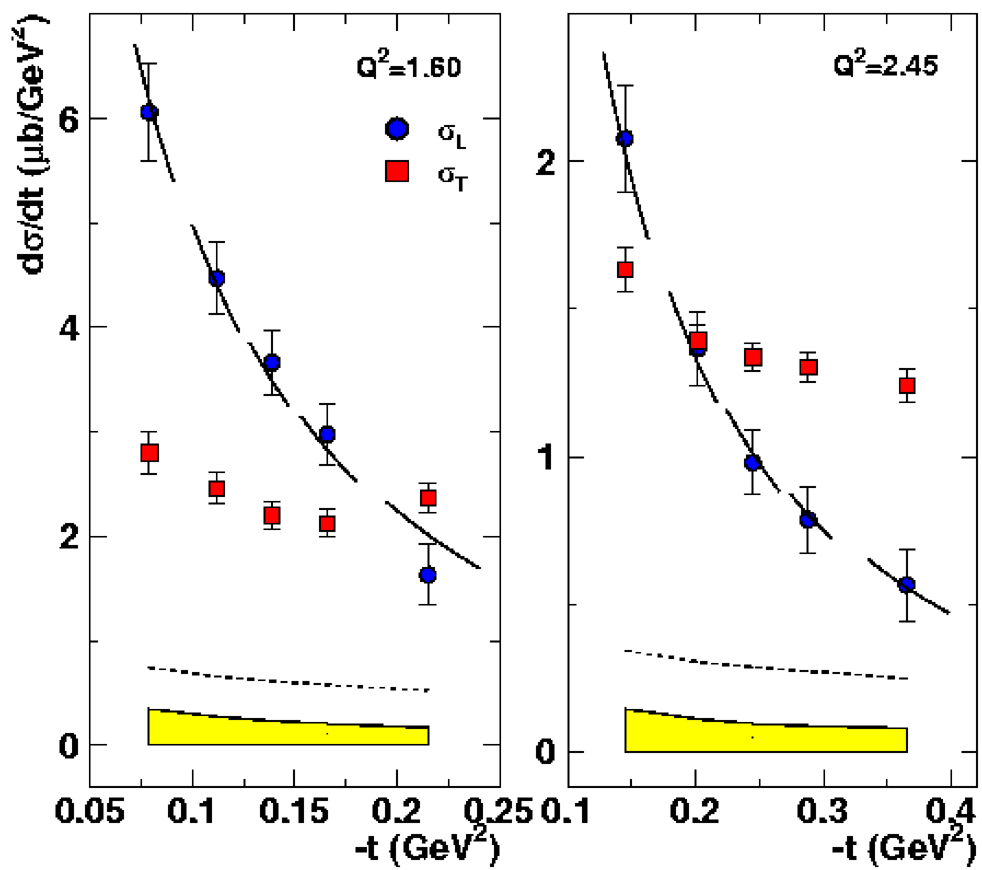
Form Factors are normally obtained via elastic scattering, but standard π^+ and K^+ targets are impossible to obtain, instead take H(e,e'π^+)n data, and use **a model to extract Form Factor.** For illustration the Born term model gives:

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

Instead, **VGL Regge Model** is used, because it has 1 free parameter (Λ_π) Then:

$$F_\pi = \left(1 + \frac{Q^2}{\Lambda_\pi^2}\right)^{-1}$$

Because of the use of model for fitting, several extra checks done to ensure dominance of pion pole.



Fπ-2 data: T. Horn et al., PRL 97(2006)192001.

(Motivation)

Generalized Parton Distributions

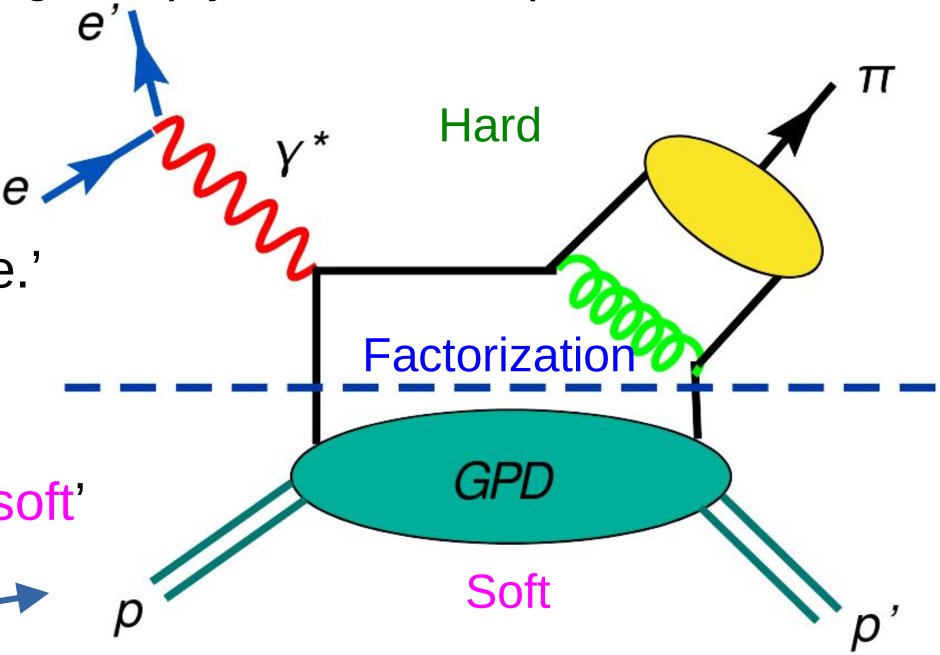
GPDs allow access to the position and longitudinal momentum of quarks in a hadron

Typically they are experimentally accessed using Deeply Virtual Compton Scattering (DVCS).

GPD’s can also be accessed via meson production if in ‘Hard Soft Factorization Regime.’

- Collins, Frankfurt Strikman [PRD 56(1997)2982].

When in this regime can separate process amplitude into ‘hard’ probe (perturbative) and ‘soft’ non-perturbative part parameterized by GPDs.



Shown in “Handbag Diagram”

Which is valid for longitudinaly polarized photon at ‘sufficiently high’ Q^2.

(Motivation)

Factorization Validity

Two methods of checking onset Factorization regime, the first is Q^{-n} scaling:

Factorization regime will have characteristic $1/Q^6$ scaling of σ_L with fixed x_B

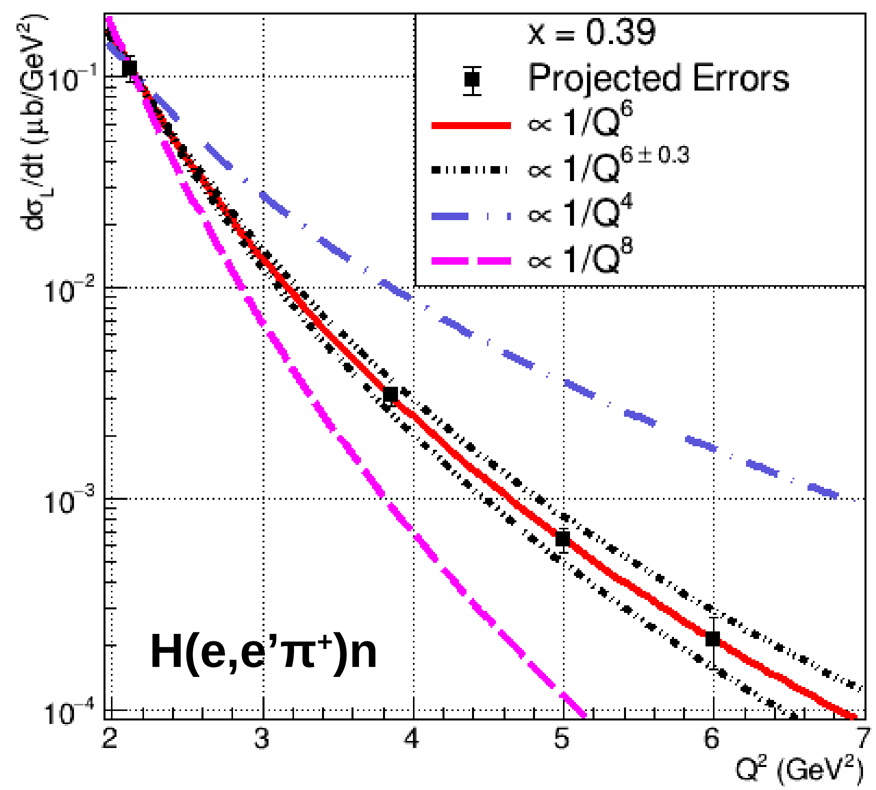
- It should also have $\sigma_L >> \sigma_T$

- Can test for this by extracting σ_L to see where this dependence begins
- This experiment does this for pion final state at 3 values of x_B:

  $x_B = 0.31, 0.39, 0.55$

- If it is shown that this regime is not reached it will have major validity implications for all meson production GPD experiments in this Q^2 regime.

Projected Scaling Study



X_B - Bjorken scaling variable, and represents longitudinal momentum fraction

(Motivation)

LT separated π^+/π^- Ratios

The second method of checking Factorization regime, is to compare LT separated π^+/π^- ratios.

We took Liquid Deuterium data [D(e,e'π^+)n & D(e,e'π^-)p]. Theory predicts that in the Factorization regime the ratio of Transverse cross section should approach the ratio of the square of up and down quark charges:

$$R_T = \frac{\gamma_T^* n \to \pi^- p}{\gamma_T^* p \to \pi^+ n} \xrightarrow{high\ -t} \frac{2Q_d^2}{2Q_u^2} = \frac{(-1/3)^2}{(+2/3)^2} = \frac{1}{4}$$

O. Nachtmann, Nucl. Phys. B 115 (1976) 61

The other use of the study is as a check of Pion pole dominance.

When the Pole term is dominant (ie. Form factor extraction possible), the ratio of the longitudinal cross section goes to unity. Deviations indicate inclusion of large isoscalar backgrounds:

$$R_L = \frac{\sigma_L(n(e,e'\pi^-)p)}{\sigma_L(p(e,e'\pi^+)n))} = \frac{|A_v - A_s|^2}{|A_v + A_s|^2} \longrightarrow 1$$

(Motivation)

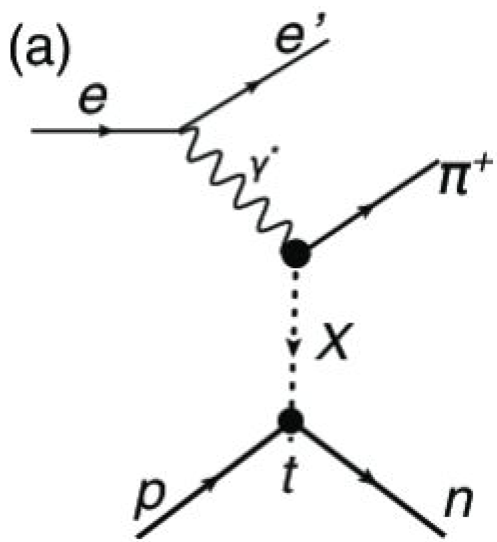
Beam Spin Asymmetries

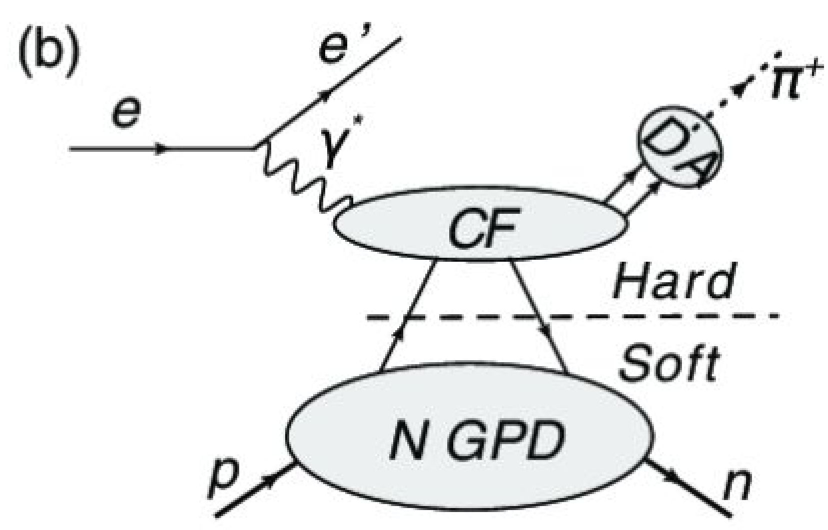
Due to the polarized beam delivered by default we have obtained a large amount of free BSA data. Alicia Postuma is doing this analysis for KaonLT data

These data can be used to access $\sigma_{LT'}$

$$BSA = \frac{1}{P}\frac{Y^{+} - Y^{-}}{Y^{+} + Y^{-}} = \frac{1}{P}\frac{\sigma^{-} - \sigma^{+}}{\sigma^{-} - \sigma^{+}} = \frac{\sqrt{2\epsilon(1-\epsilon)}\frac{\sigma_{LT'}}{\sigma_0}}{1 + \sqrt{2\epsilon(1+\epsilon)}\frac{\sigma_{LT}}{\sigma_0}\cos\phi + \epsilon\frac{\sigma_{TT}}{\sigma_0}\cos 2\phi}$$

Can compare Regge (a) and GPD (b) as approaches both predict $\sigma_{LT'}$





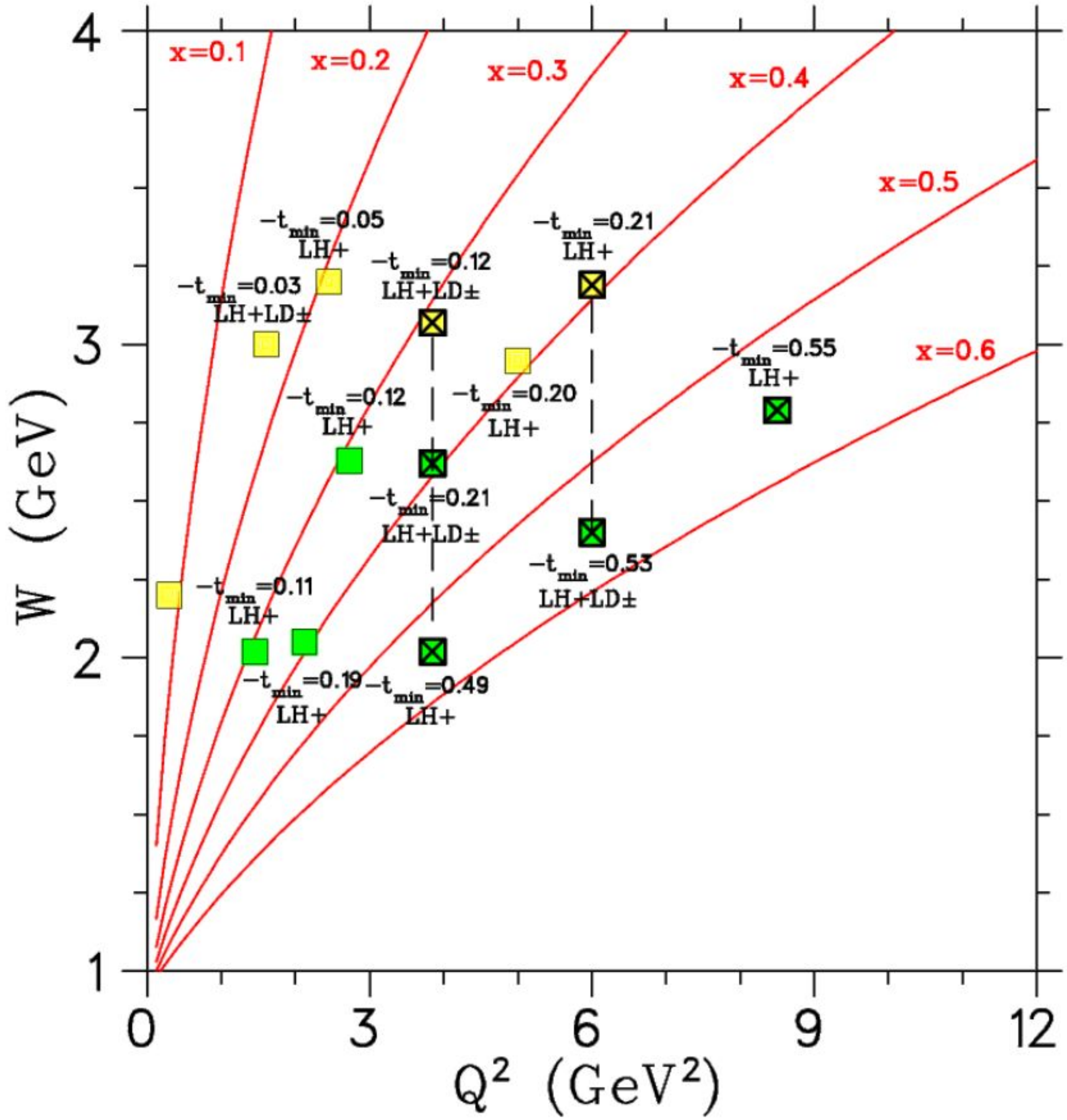
Experiment Status

Finished Taking data in the Fall of 2022

Got all of the data we requested. (~90% desired Stats)

Data in hand, Calibration studies dominated last year.

Calibrations completed, moving to PID, Luminosity, and tracking studies!



- Pion Scaling Study
- π Form Factor (Fπ) Study
- ⊠ High Q^2 Fπ extraction
- Fixed x
- ¦ Fπ extraction on t

Experimental Configuration

Required 10.6, 9.9, 9.2, 8.5, 8.0, 6.4, and 6.0 GeV beam energies

Used HMS for electrons and SHMS for hadrons

HMS Momentum: 6.8 – 0.9 GeV
SHMS Momentum: 8.0 – 1.8 GeV

HMS Angles: 11.0^o – 58.5^o
SHMS Angles: 5.5^o – 38.9^o (Magnet touches beam line)

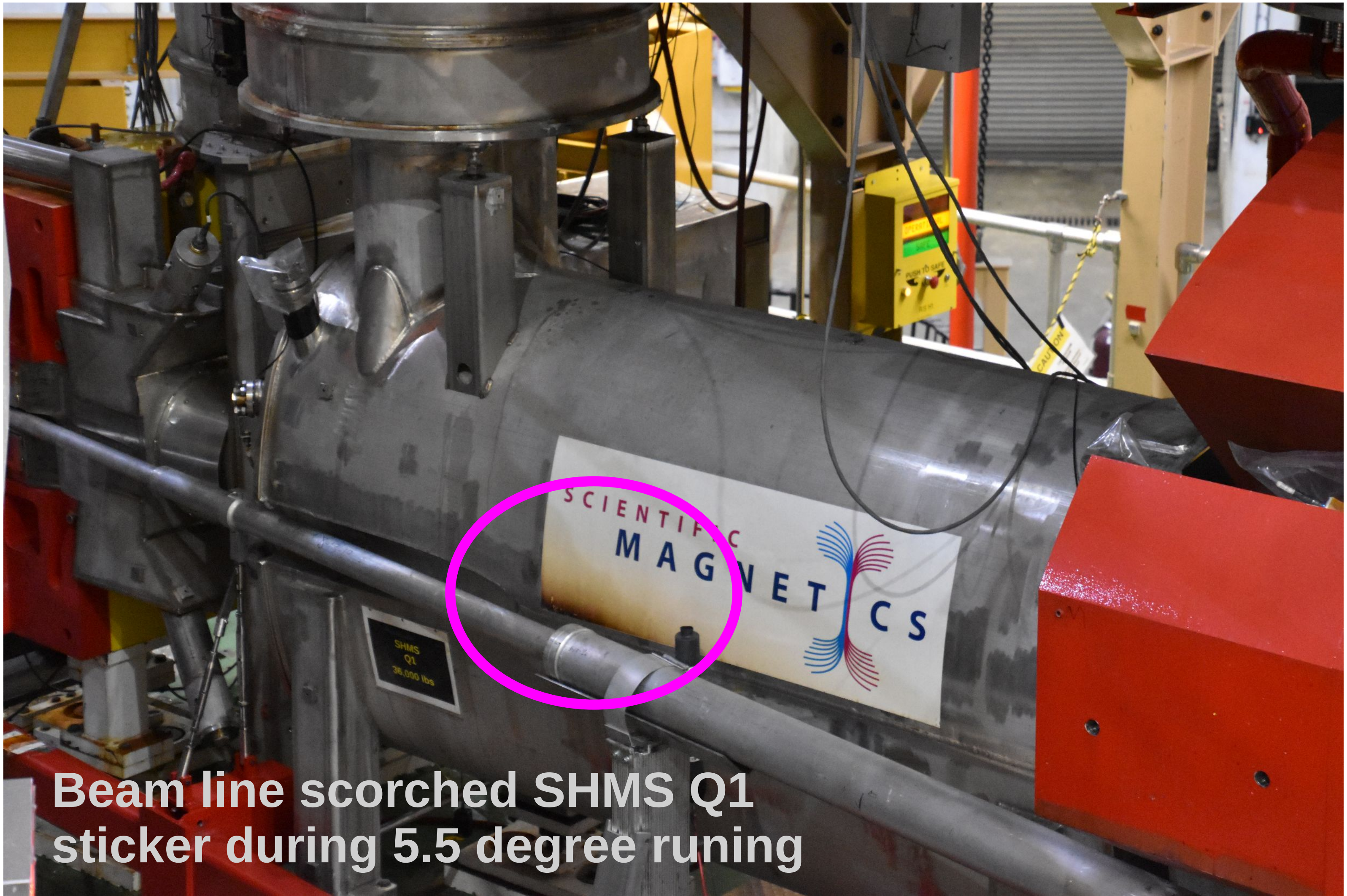
Min Opening Angle: 18^o (Spectrometers are touching)

Several Challenges presented to the hall with this experiment:

- Small angles required special beam pipe
- Small opening angles required special care to get HMS and SHMS to fit together

Thanks!

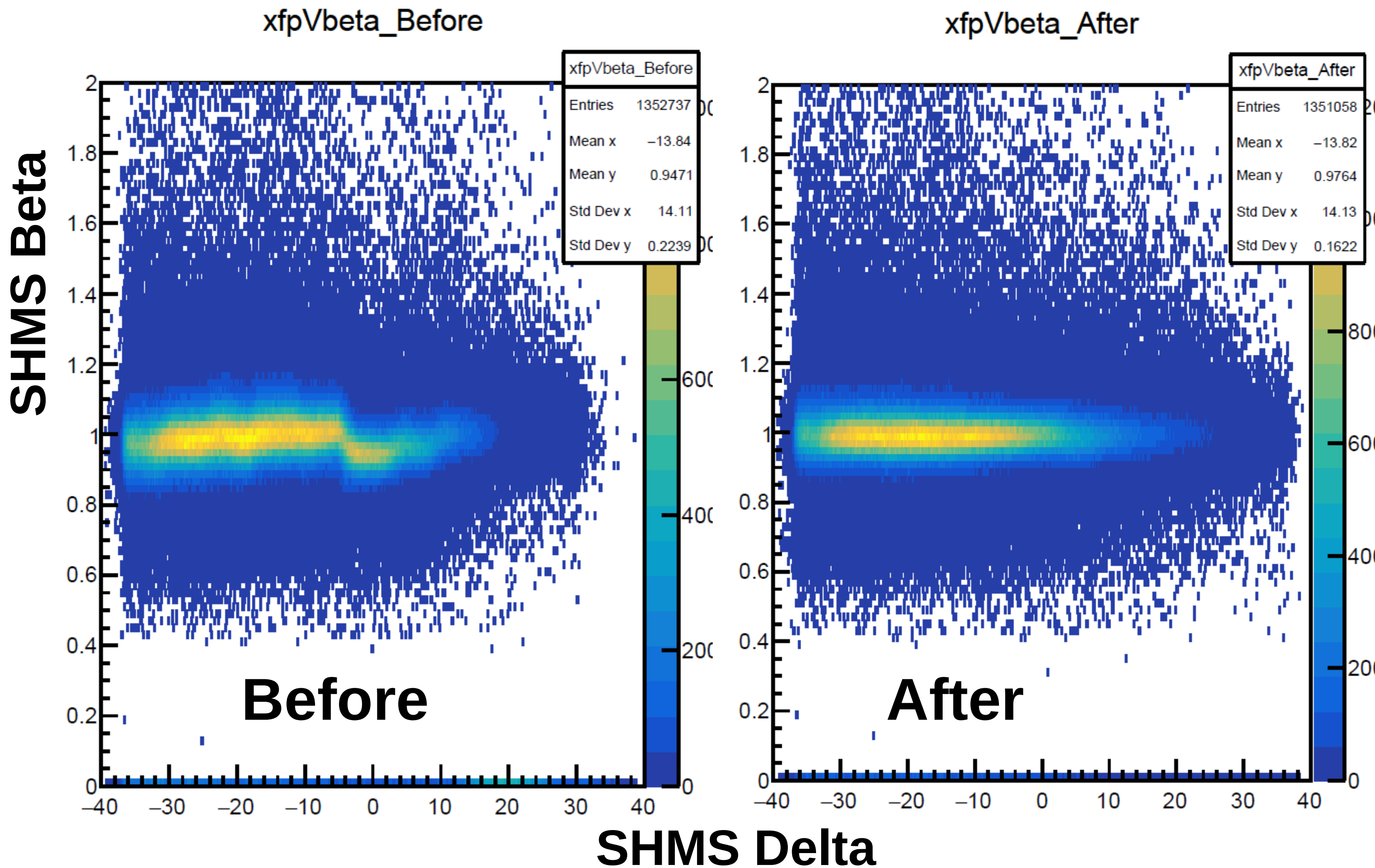
Thanks again to Hall and lab staff for making this possible!
Challenging experiment that pushed Hall C's limits



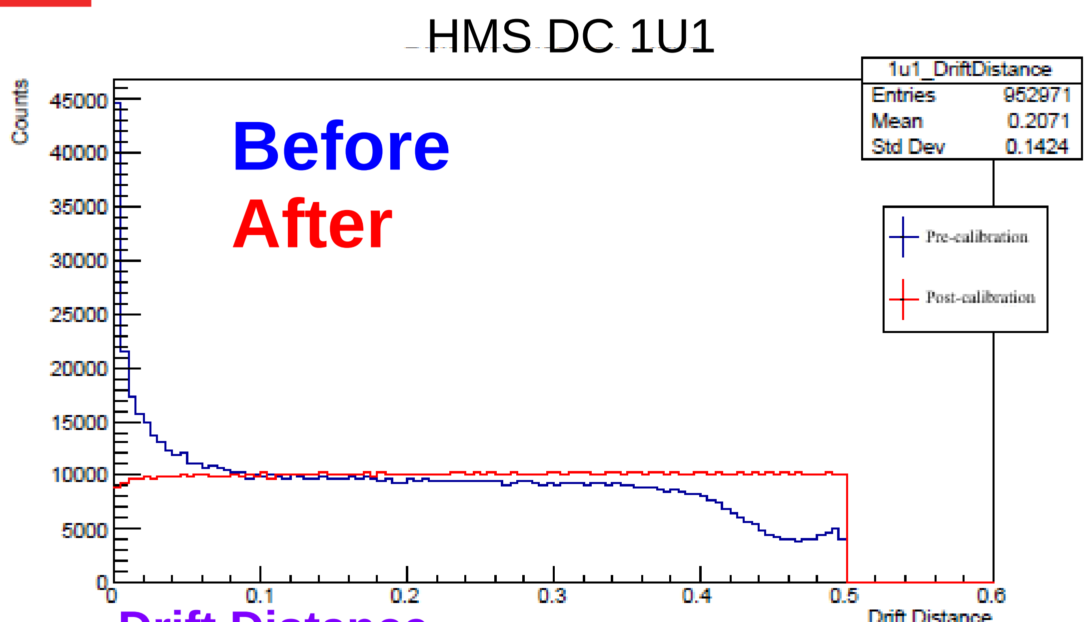
Beam line scorched SHMS Q1 sticker during 5.5 degree runing

Hodoscope Calibrations

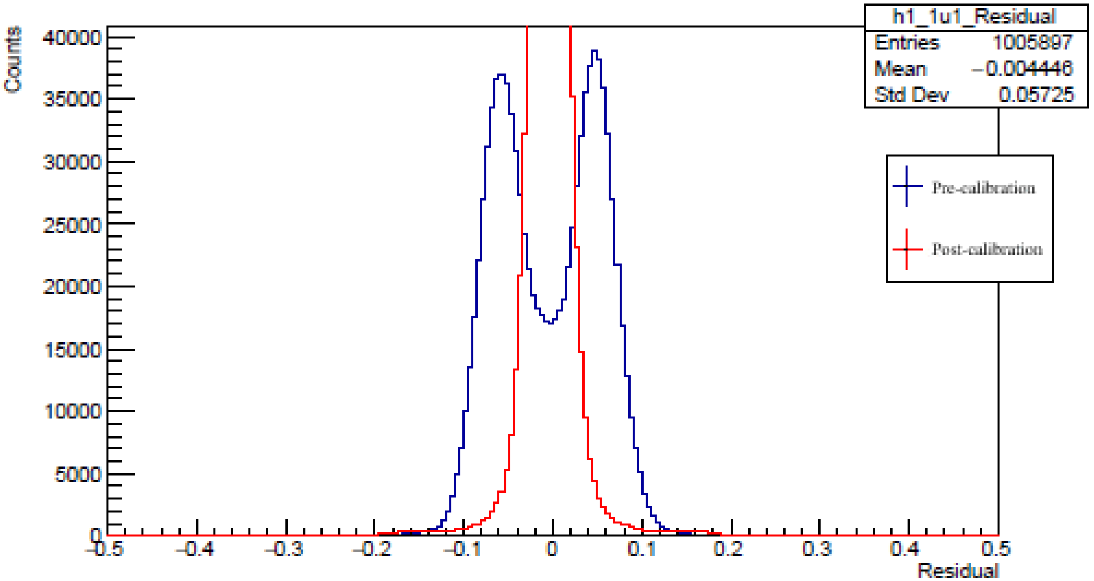
Hodoscope calibrations remove wiggles in Beta vrs. Delta distributions, by correcting Time Walk, and signal propagation in bars
Thanks to Dave Mack and Carlos Yero for helping on calibration scripts



Drift Chambers



Drift Distance



Residual

The Drift Distance distributions for each plane is flat, after calibration

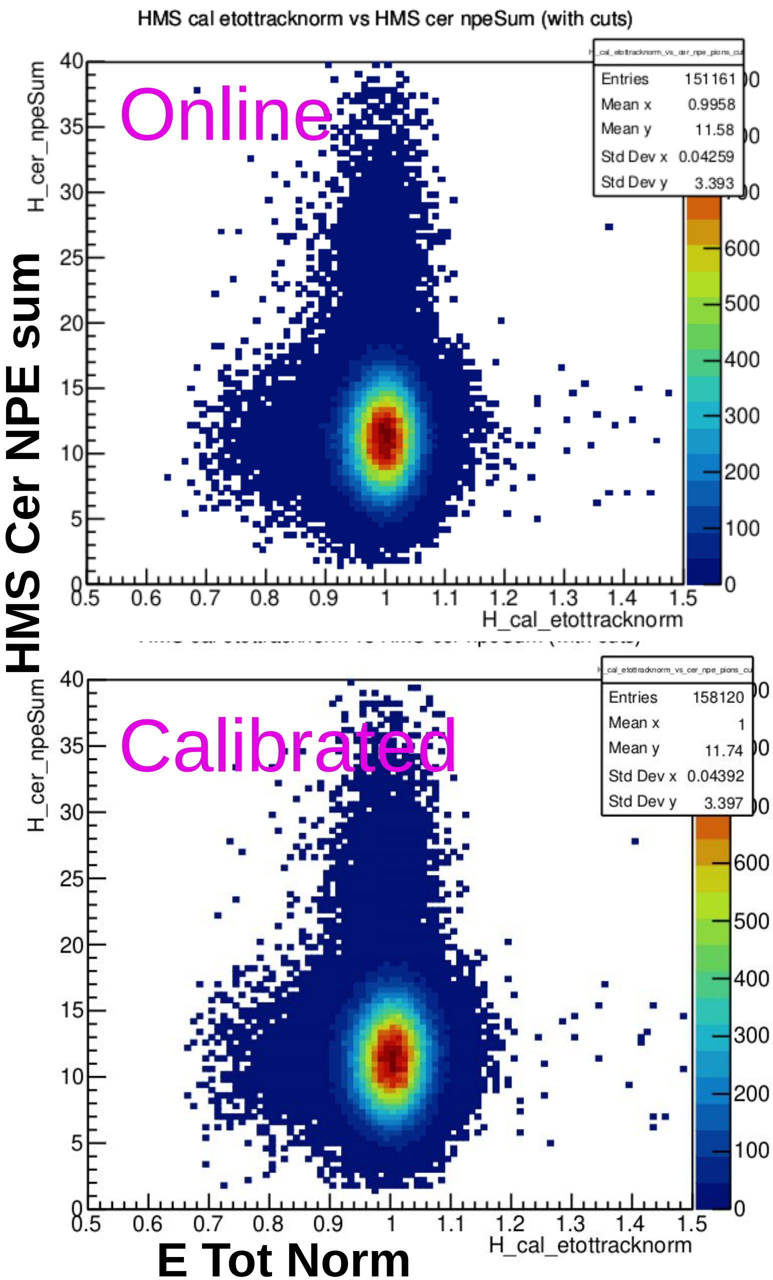
Residual is the measure of the difference between final position of track and the hit location obtained from each individual plane.

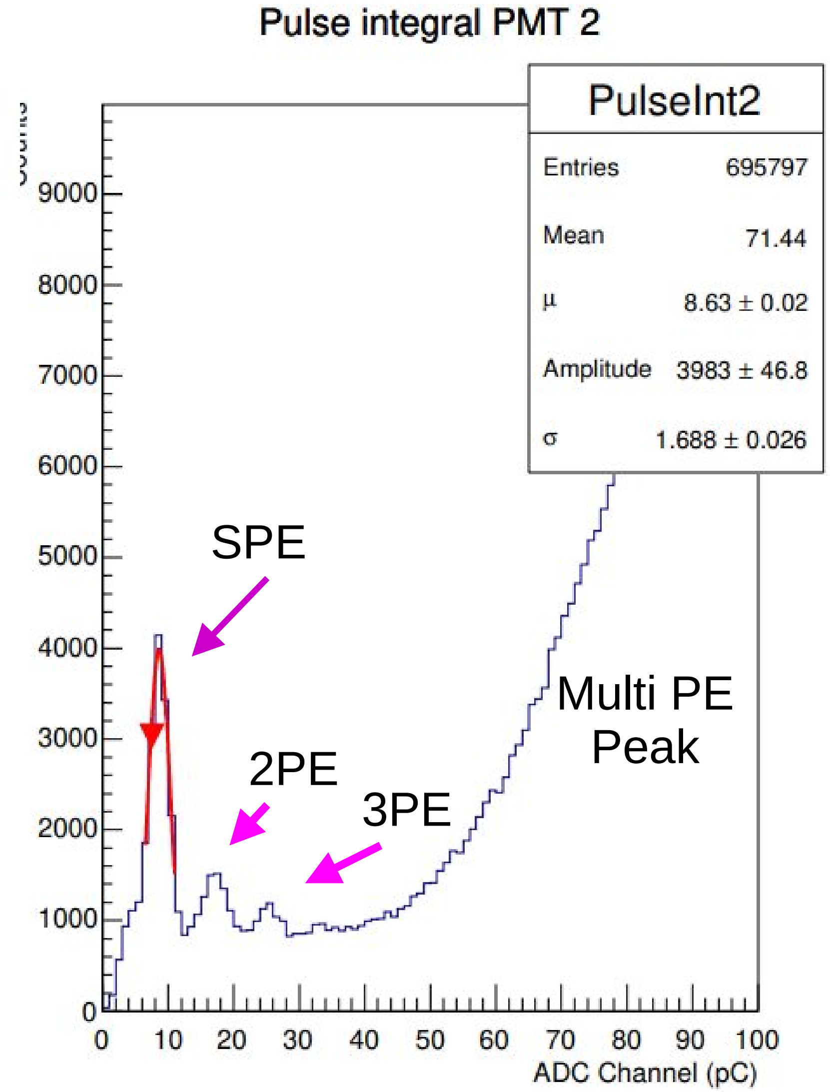
After the calibration (red), peak is much sharper which implies calibration has improved

Good Results obtained.

Credit: Muhammad Junaid

HMS Cherenkov

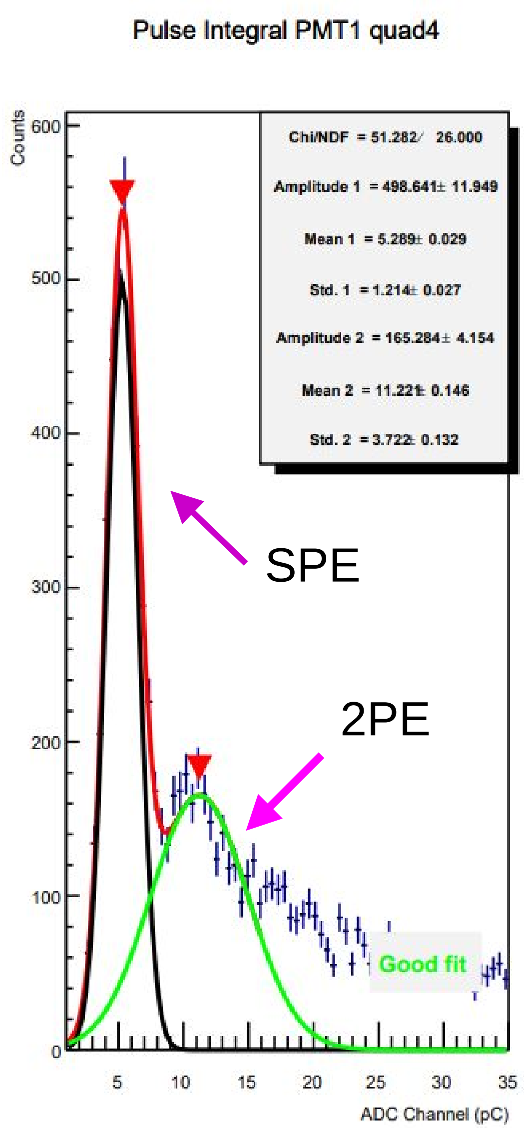




Simple Calibration done by fitting Single Photo-Electron (SPE) peak

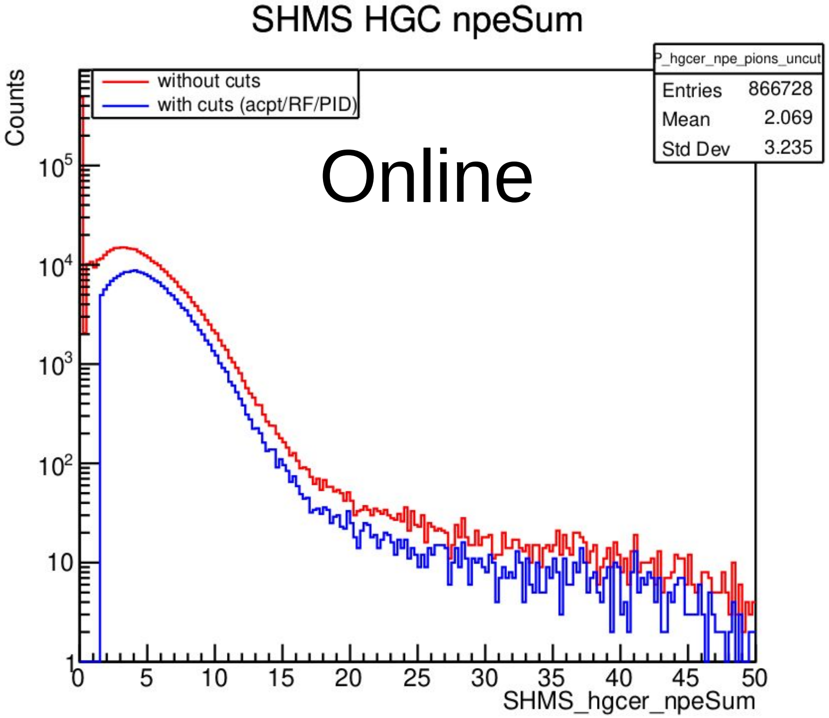
Got good stable results.

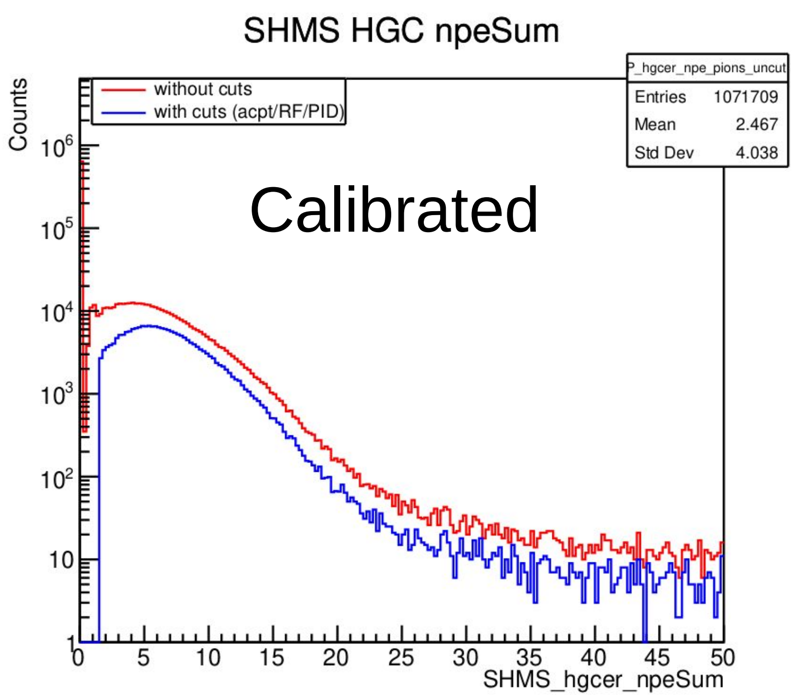
SHMS HGC



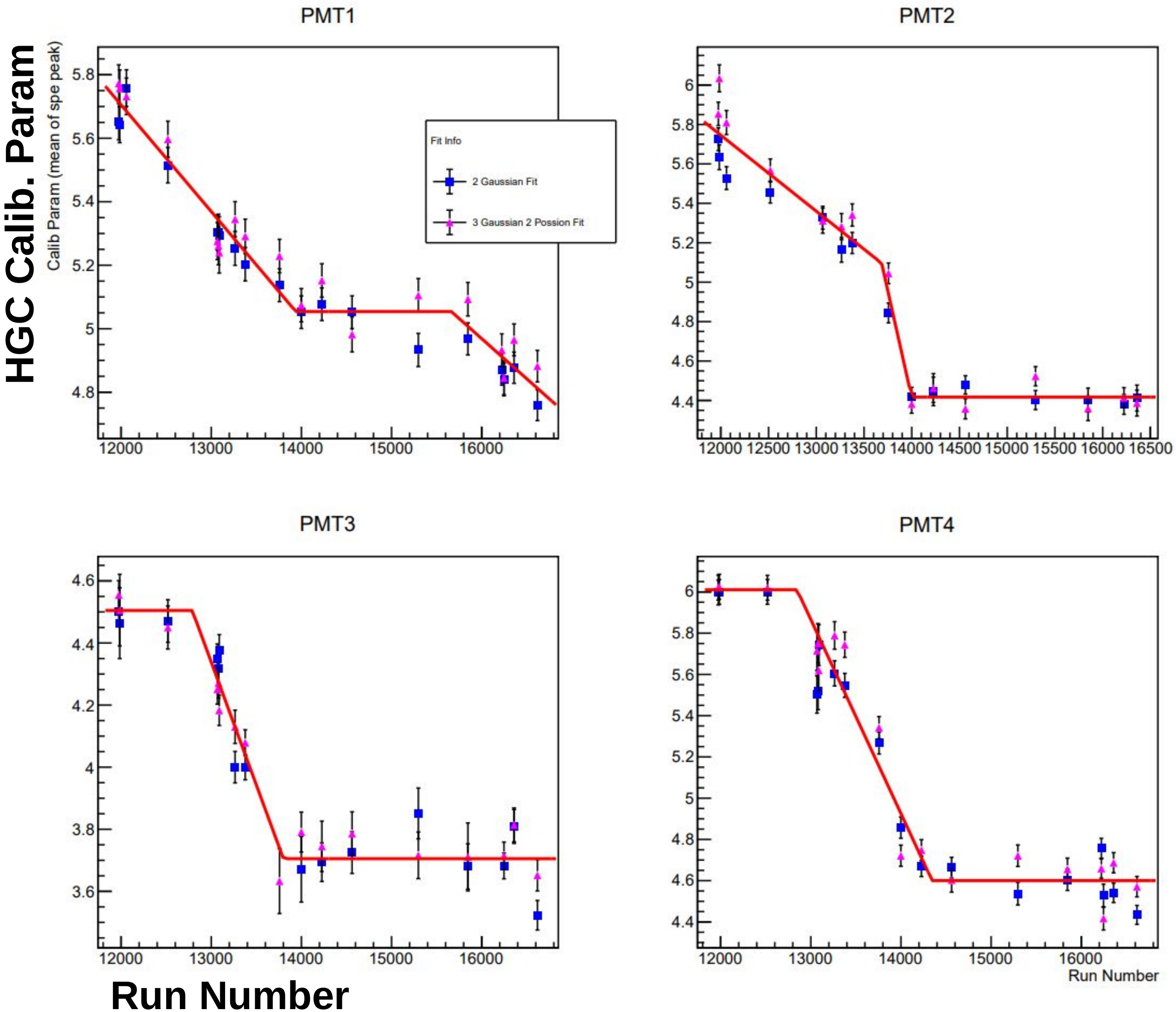
Calibration done using technique developed by Vijay Kumar: link

Got good results, but noticed concerning trend in calibration Parameters





Concerning Trend

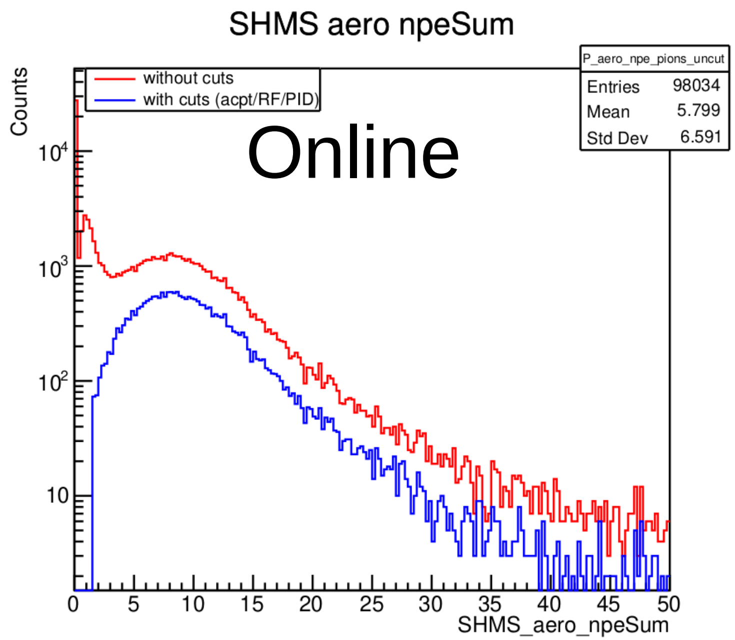


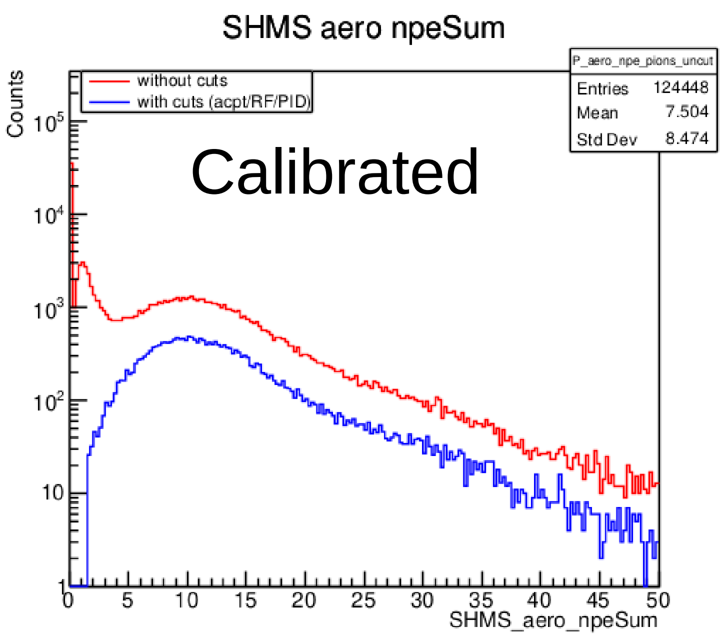
Noticed concerning linear trends in calibration parameters.

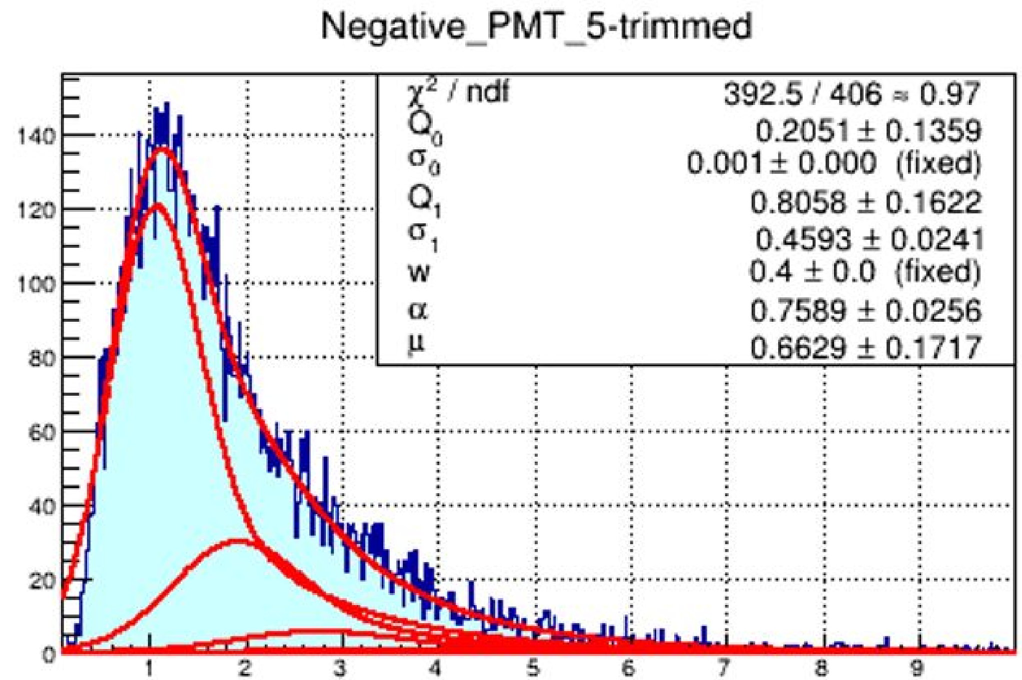
Dave Mack looked into potential causes.

Current theory is that permanent degradation of the dynode chain or photocathode occurred due to the high rates at small angles.

SHMS Aerogel





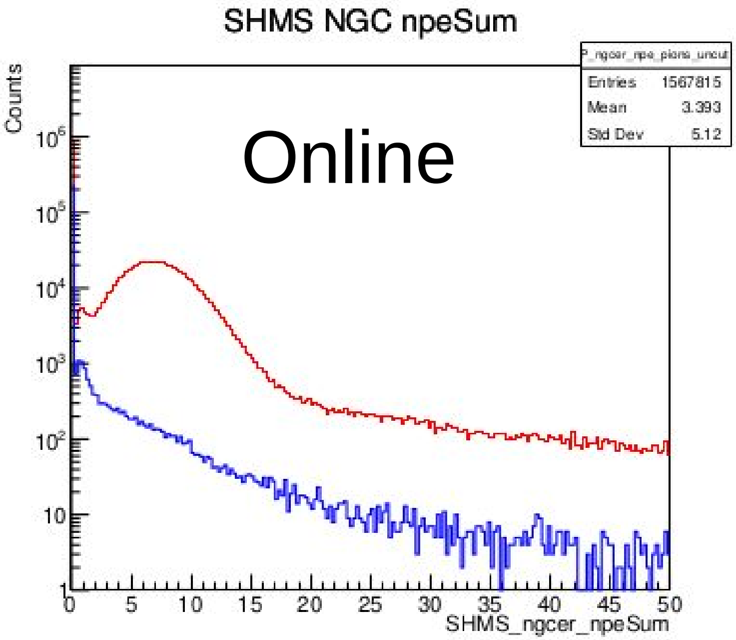


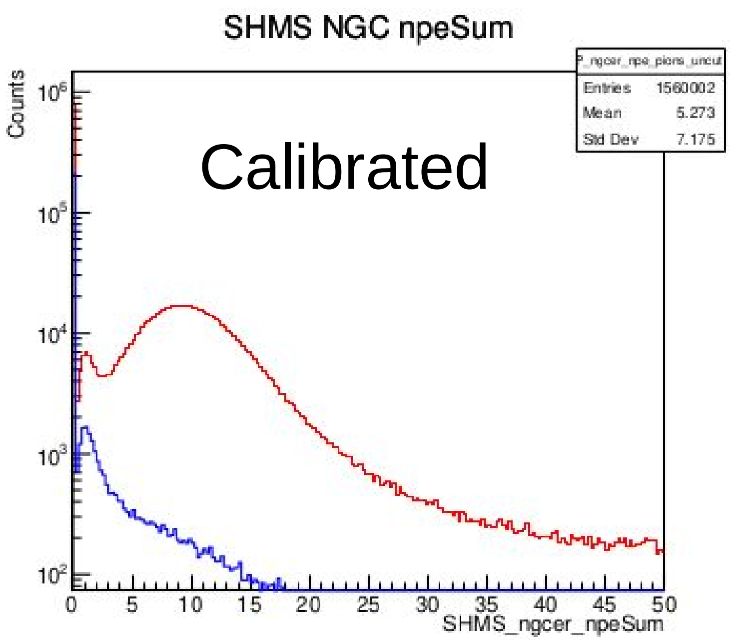
Aerogel calibrated using scripts developed by Peter Stepanov: link

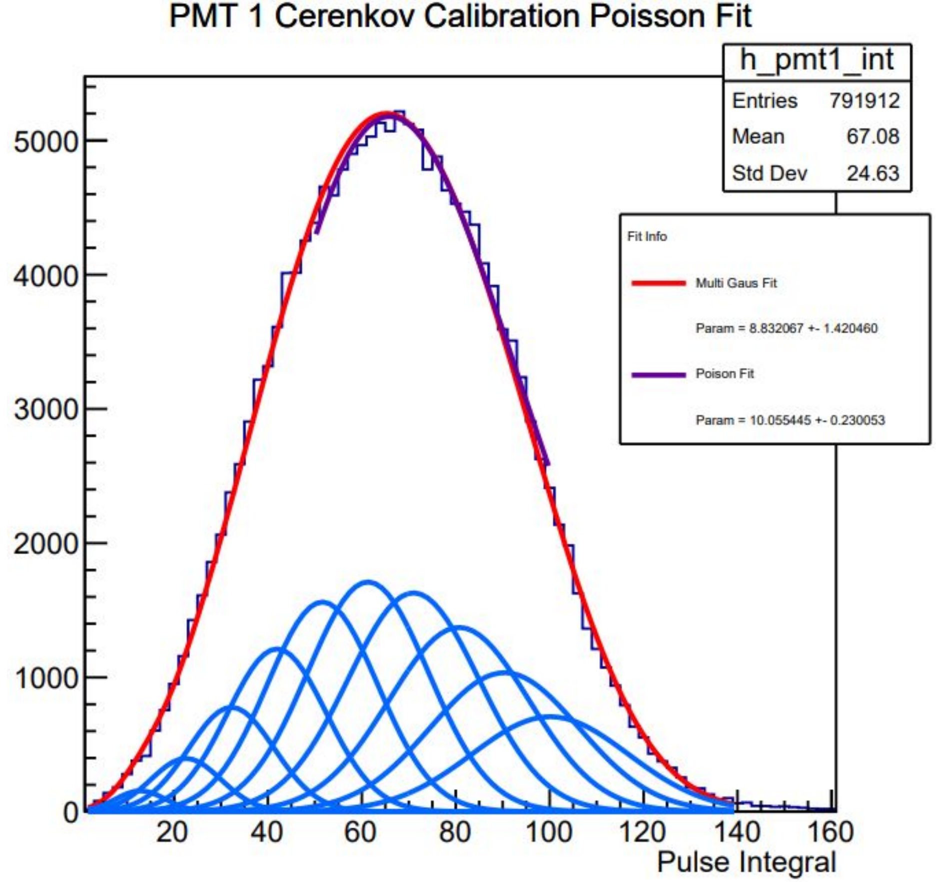
No clear SPE peak, so used a multi-Gaussian technique fully described here:

E.H. Bellamy, Absolute calibration and monitoring of a spectrometric channel using a photomultiplier,
Nuclear Instruments and Methods in Physics Research
https://doi.org/10.1016/0168-9002(94)90183-X

SHMS NGC







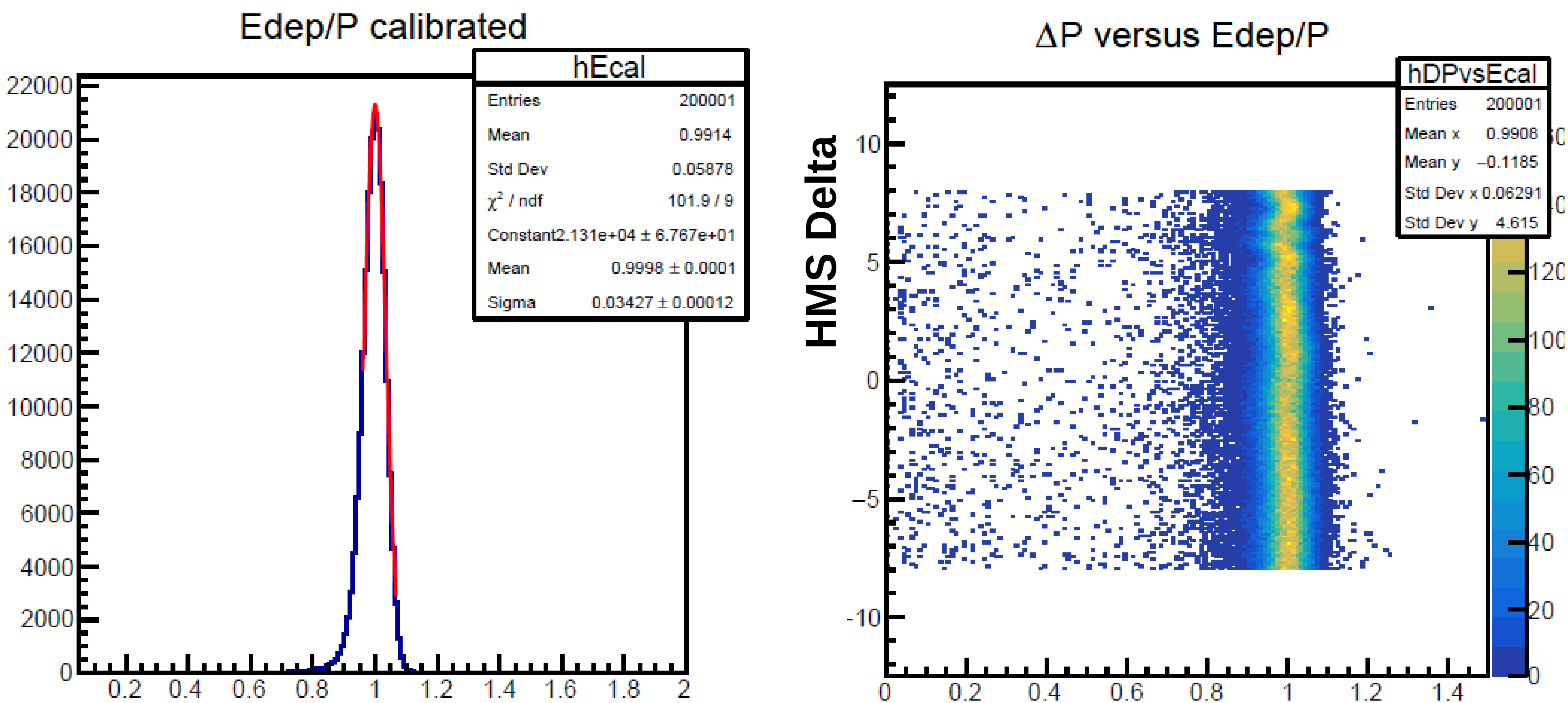
Also lacks clear SPE peak,

Use Poisson technique developed by Cameron Cotton: link

Also tested the multi-Gausian technique that was used for the Aerogel, which did not work as reliably

Calorimeters

Shown are HMS calorimeter plots, both calorimeters were calibrated to similar quality.
High delta still shows small wiggles, deemed acceptable



Normalized Energy

Credit: Muhammad Junaid

Up Next

With calibration done next tasks are:

- Rate dependence studies
  - Tracking Efficiency
  - Target Boiling
  - Live Times
- Particle ID Studies
- H(e,e'p) Studies
  - Elastics Coincidences
  - Spectrometer Offsets
  - Finalize Systematic Uncertainties

These studies should take the majority of the year

LT separations and physics come after that. First publications expected late 2025.

Expected Papers

We expect 9 papers from these data. Topics including:

- Q^{-n} scaling study
- Form Factors
- π^+/π^- ratios
- π Beam spin asymmetries

Currently there are only 2 Graduate students working on these data, Many opportunities to collaborate!

There are 7 papers yet to be assigned first authors,
if you are interested in filling these spots please contact:
Dr. Garth Huber (huberg@uregina.ca),
Dr. Dave Gaskell (gaskelld@jlab.org), or
Dr. Tanja Horn (hornt@jlab.org)

Conclusion

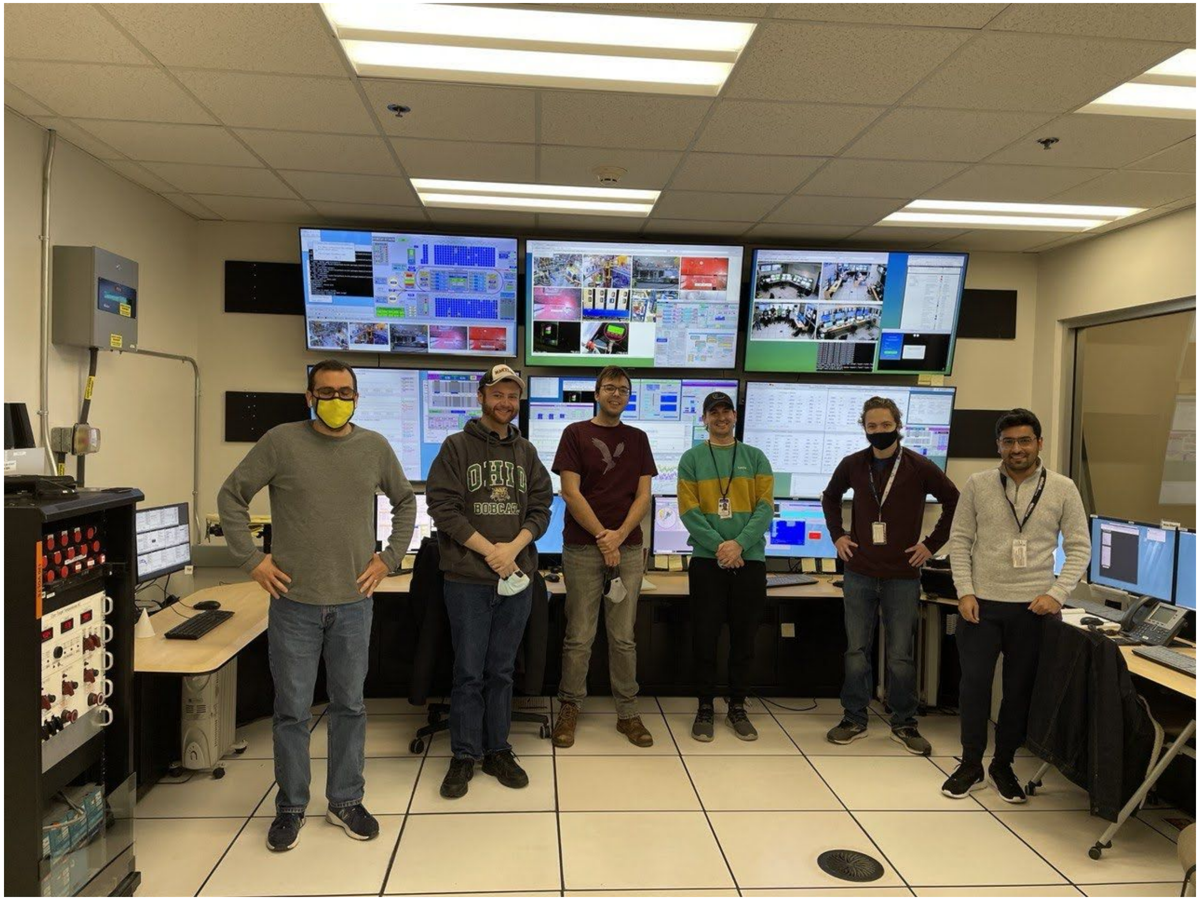
PionLT can probe many interesting physics questions

Data Analysis is underway.

Detector calibrations have been completed.

First papers are expected in 2025.

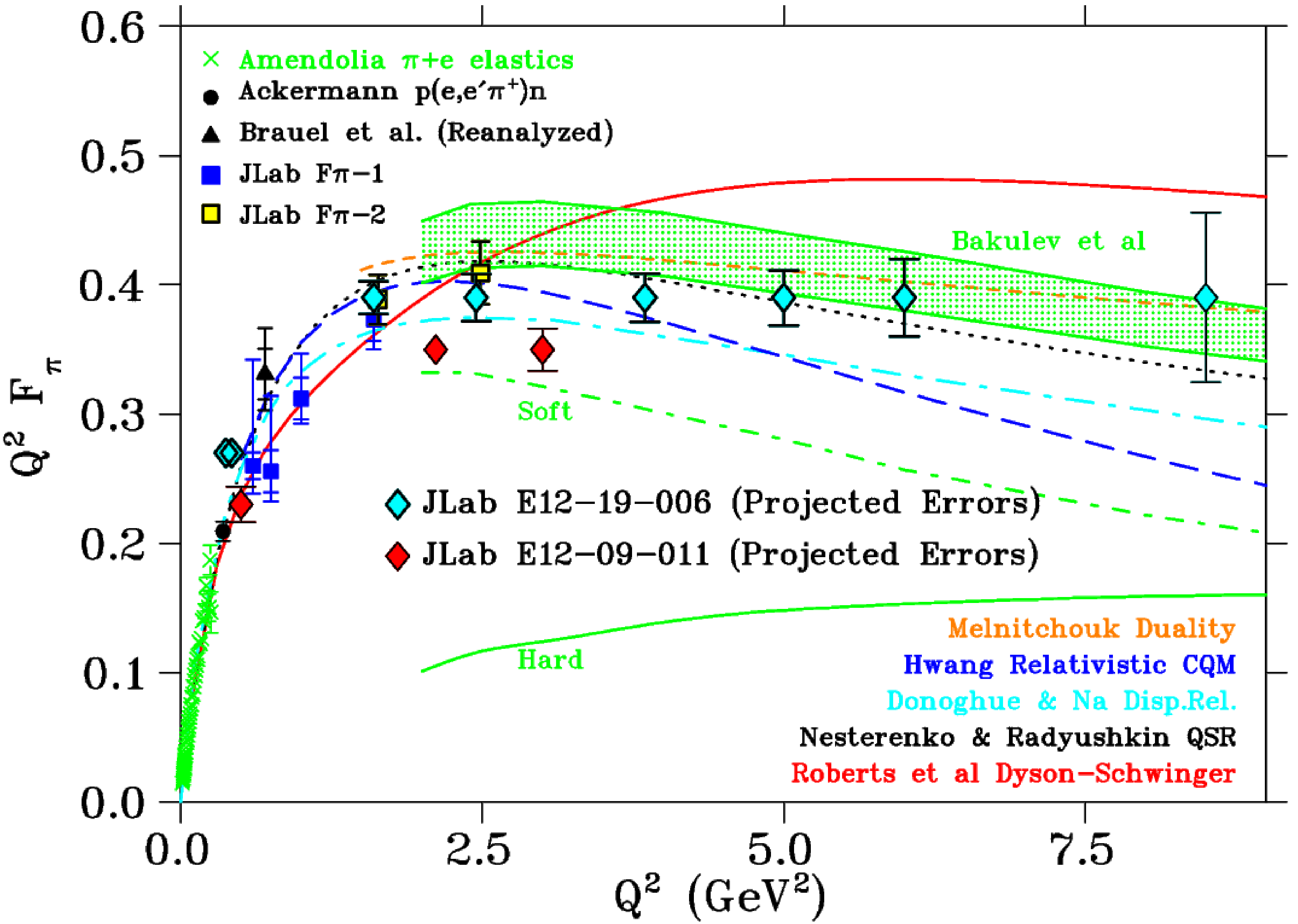
Thank You



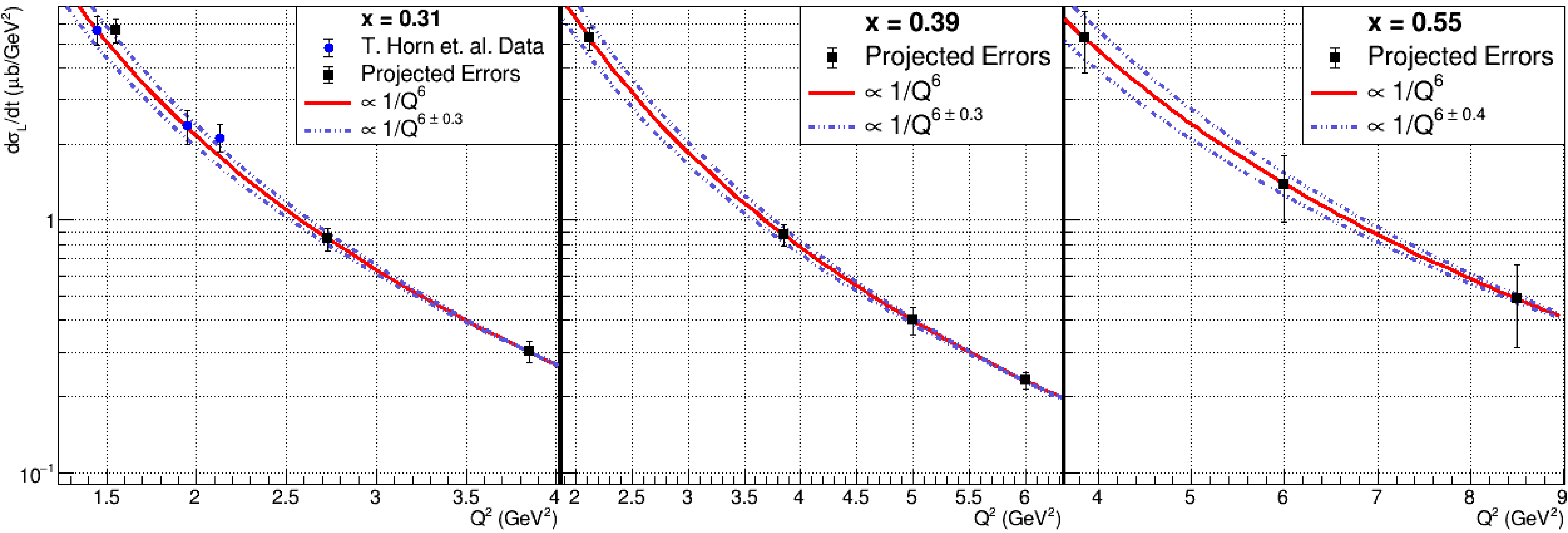
Thanks To All Our Collaborators

NSERC SAPIN-2021-00026   NSF PHY2012430 and PHY2309976

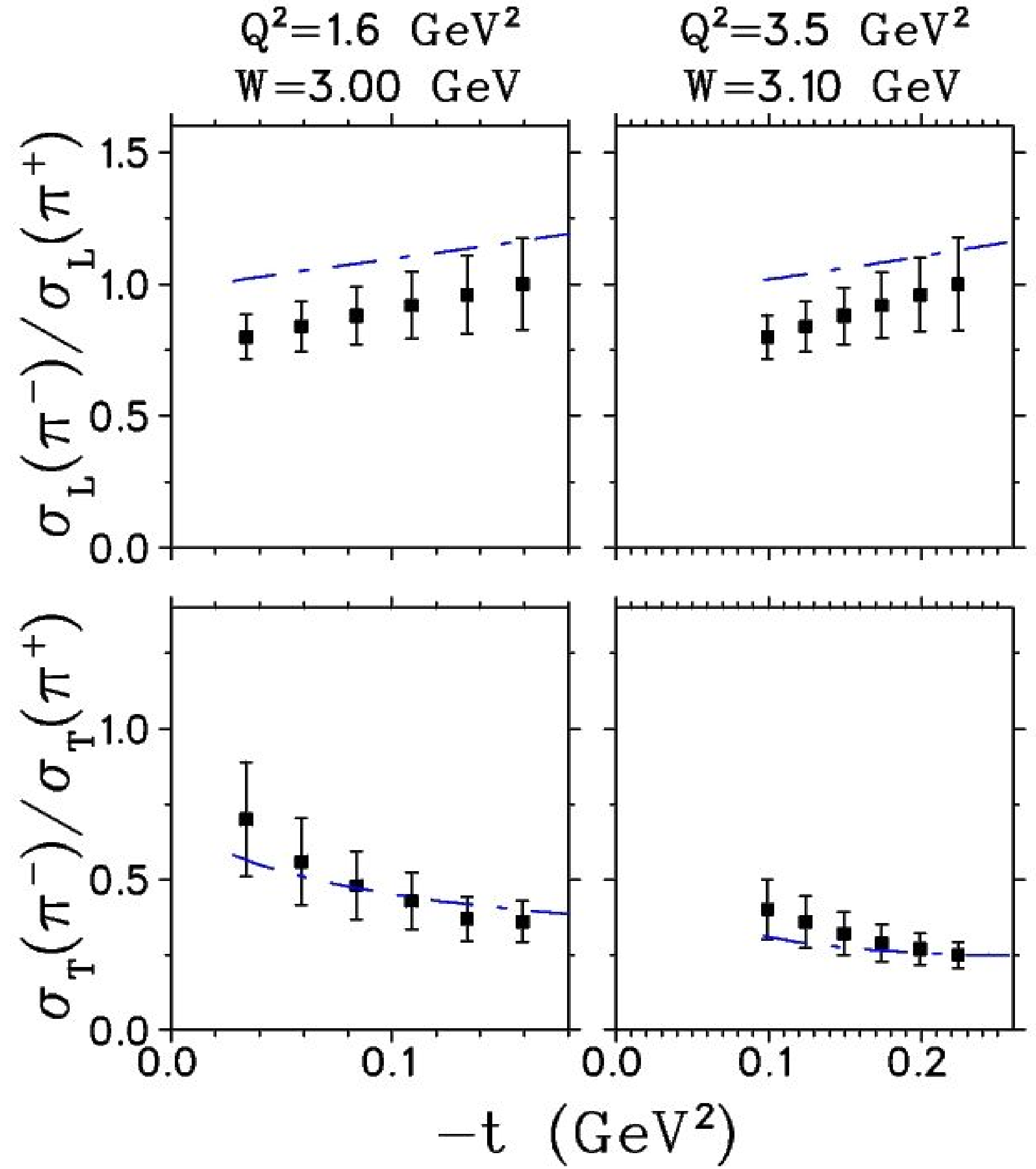
Projected Errors (Form Factors)



Projected Errors (Q^2 Scaling)



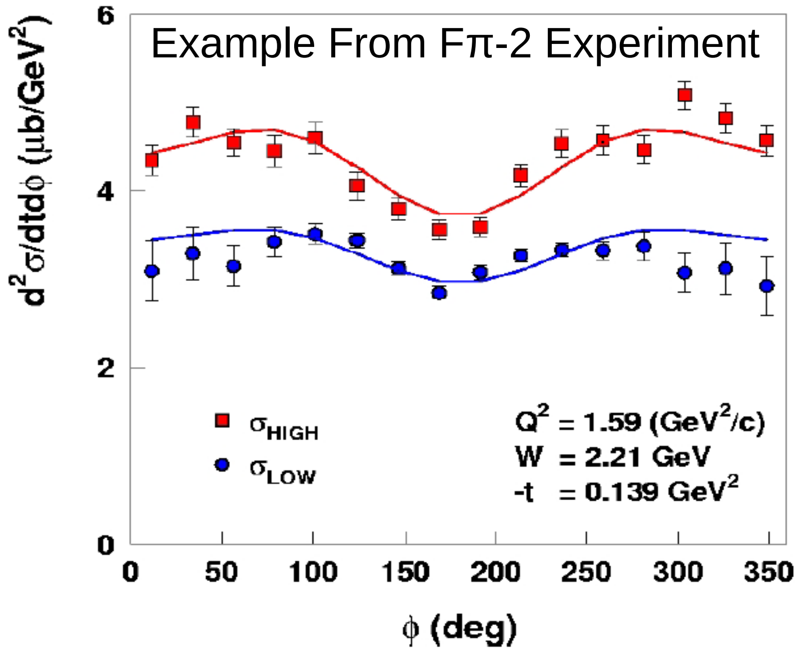
Projected Errors (π+/π- Ratios)



Error Amplification

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

Fitting gives something like this:



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

Control over the systematics is important as all uncorrelated errors are amplified:

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

Thus the errors are amplified by the Δε points (typically Δε ~ 0.3).

This means we must keep excellent control of our systematic errors.

Virtual-photon polarization:

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

What are GPDs?

We'd like to be able to fully describe hadronic structure.

Wigner Distributions are 6 dimensional objects that describe both the position and momentum of a quantum system. These can be applied to the quark gluon D.o.F in QCD to describe hadrons.

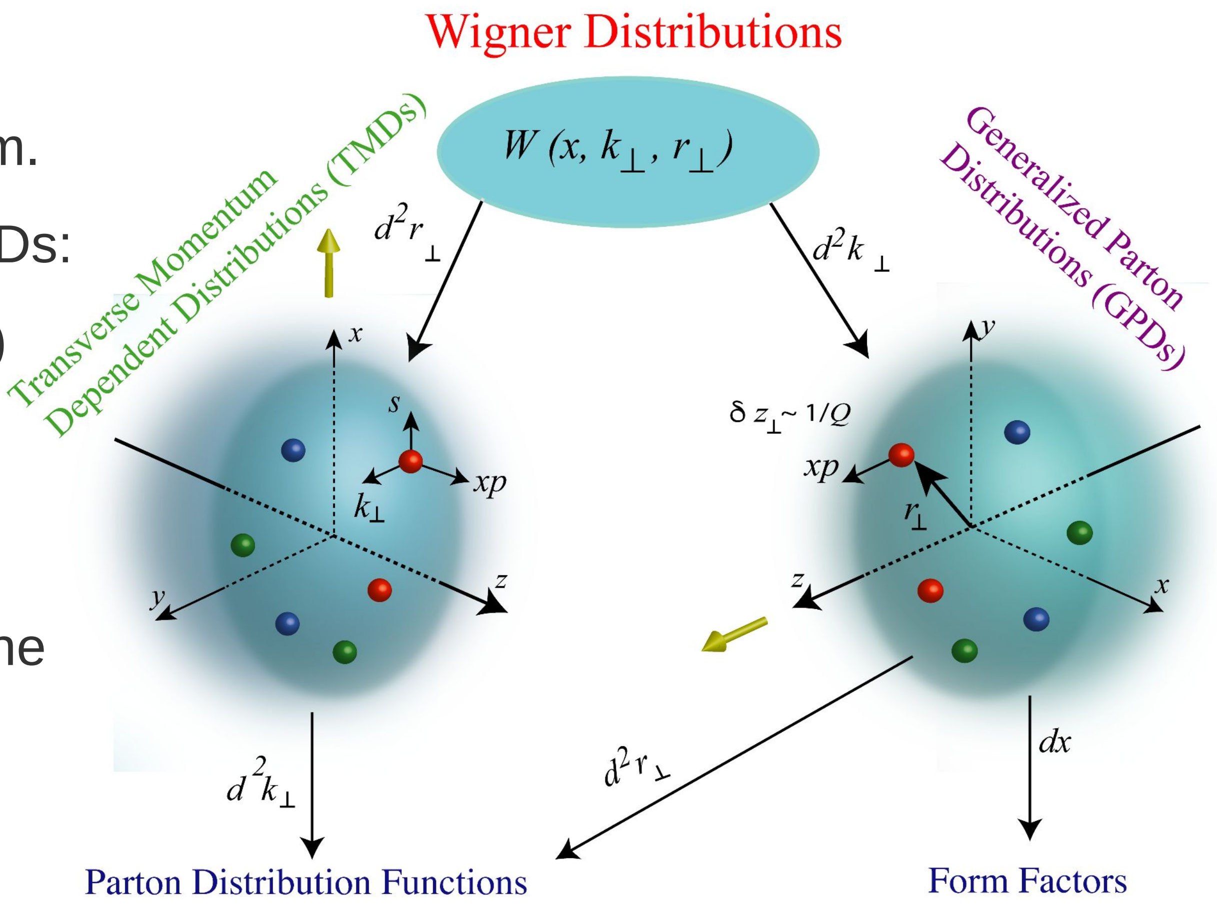
GPDs are these Wigner distributions integrated over transverse momentum.

For each quark flavor there are 8 GPDs:

- 4 conserve chirality (chiraly even) and 4 do not (chiraly odd).

Most experiments have focused on accessing the chiral even GPDs.

While there have been advances in the measuring the chiraly odd GPDs, this talk will focus on the even GPDs.



GPDs and Experiment

GPDs are universal quantities and reflect nucleon structure independent of probing reaction

- There are 2 main methods to extract the chirality conserving GPDs:
  - **D**eeply **V**irtual **C**ompton **S**cattering
    - Sensitive to all 4
  - **D**eep **E**xclusive **M**eson **P**roduction
    - Pseudoscalar mesons access $\tilde{H}$ $\tilde{E}$
    - Vector mesons access H E

The combination of the 2 methods is needed to disentangle the different GPDs

$H^{q,g}(x,\xi,t)$ Spin Average No Hel. Flip	$E^{q,g}(x,\xi,t)$ Spin Average Helicity Flip
$\tilde{H}^{q,g}(x,\xi,t)$ Spin Diff. No Hel. Flip	$\tilde{E}^{q,g}(x,\xi,t)$ Spin Diff. Helicity Flip