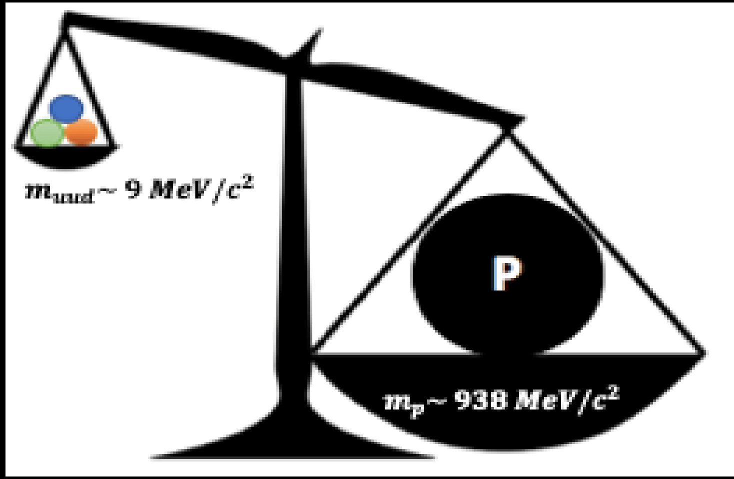

# Measurement of Charged Pion Form Factor at Jefferson Lab

**Ali Usman**

***$C^2$AM 2022 Conference***

# Physics Motivation




- Two well known hadronic states:
  - Baryons ($qqq$ $or$ $\bar{q}\bar{q}\bar{q}$)
  - Mesons ($q\bar{q}$)
- Interactions of quarks and gluons are described by Quantum Chromodynamics (QCD).
- Perturbative QCD explains the interaction of quarks inside a hadron in an asymptotically free state (i.e. very high energies).
- Non-perturbative QCD is used to explain the behavior of bound quarks at low energies.

**Open Questions**

- ❑ **How fundamental properties of hadrons arise from their constituent quarks and gluons?**
- ❑ **Which theoretical model precisely predicts the parton (quark-gluon) interactions in color confinement regime?**

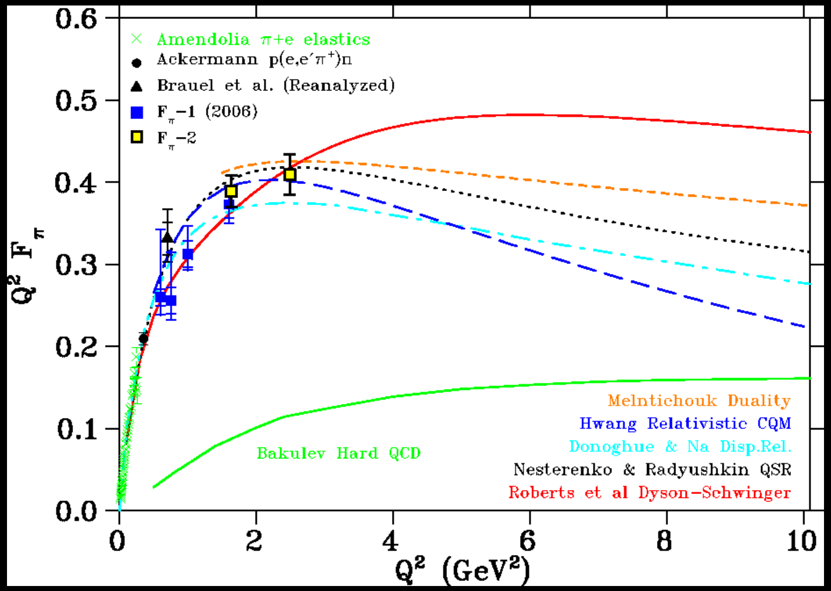
# Pion Form Factor

- Mesons give an ideal testing ground for our understanding of bound $q\bar{q}$ system.
- Pion is lightest meson with only two valence quarks (up and down).
- Pion is also known as positronium atom of QCD.


- Form Factor describes transverse spatial position of partons within hadrons.
- In pQCD, $F_\pi$ can be written as

$$Q^2 F_\pi(Q^2) \rightarrow 16\pi\alpha_s(Q^2) f_\pi^2 \qquad (Q^2 \rightarrow \infty)$$

- At low $Q^2$, an experimentally accessible non-pQCD process dominates quark-gluon interactions.



# Pion Electroproduction

- Elastic scattering of electrons from pions gives

$$e + \pi^+ \rightarrow e' + \pi^{+\prime}$$

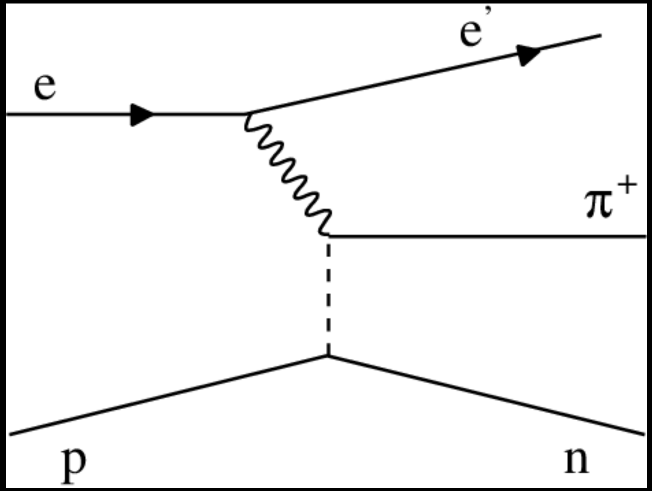
- Due to short pion mean lifetime (~ 26 ns), stable pion target is experimentally impossible.
- Pion beams are contaminated and only available at lower energies.
- ***Exclusive Pion Electroproduction***

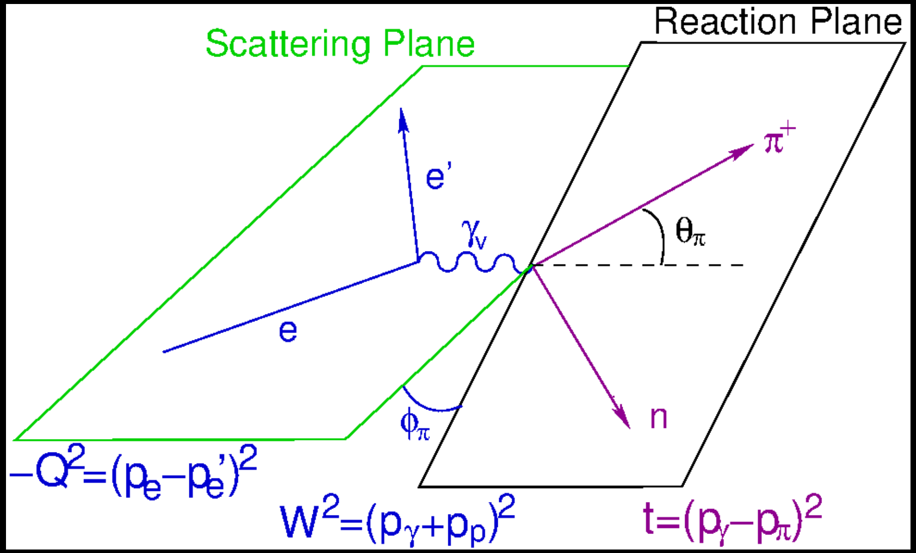
$$\boldsymbol{e^- + p \rightarrow e^{-\prime} + \pi^+ + n}$$

- In Born term model $F_\pi$ appears as

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

- Scattering from virtual pion cloud dominates at low $-t$, need to measure $\sigma_L$ through L/T separation.



# Rosenbluth (L/T) Separation

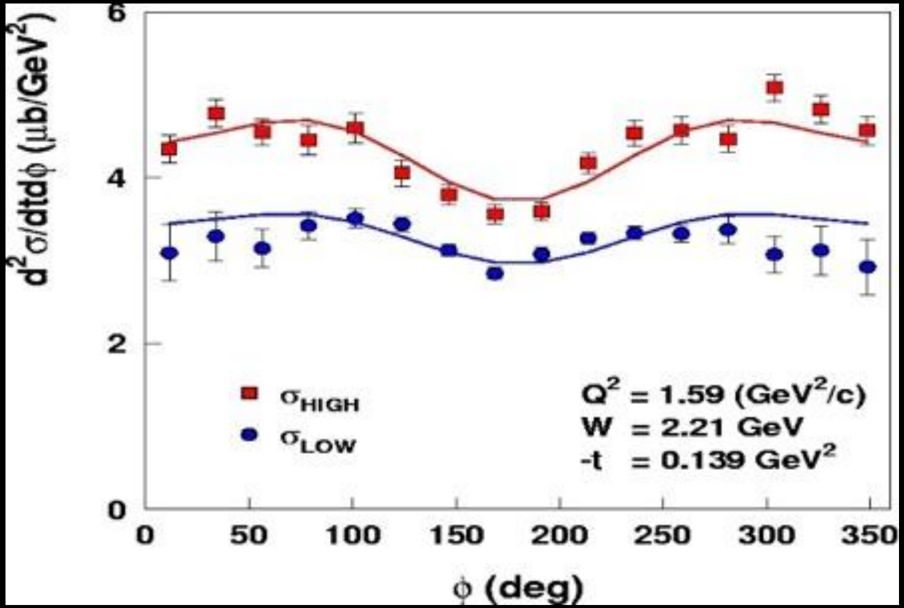
- Total physical cross-section can be decomposed into four structure functions.

$$2\pi \frac{d^2\sigma}{dt d\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{dt} cos\phi + \epsilon \frac{d\sigma_{TT}}{dt} cos2\phi$$

- "Rosenbluth Separation technique" is used to separate $\sigma_L$ and $\sigma_T$ terms.
- Here "$\epsilon$" is polarization of virtual photon

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

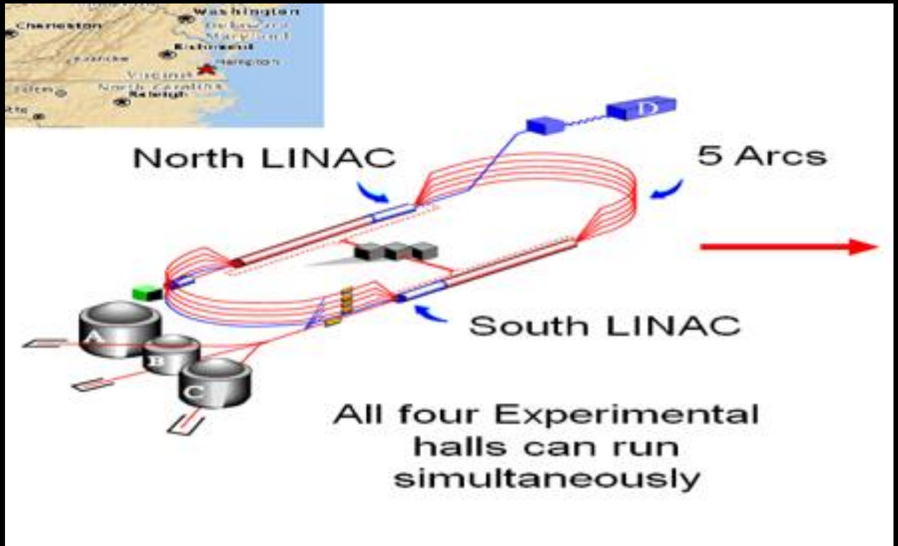
- Cross-section is separated by performing two scattering measurements with different "$\epsilon$" value.




Error Estimation

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

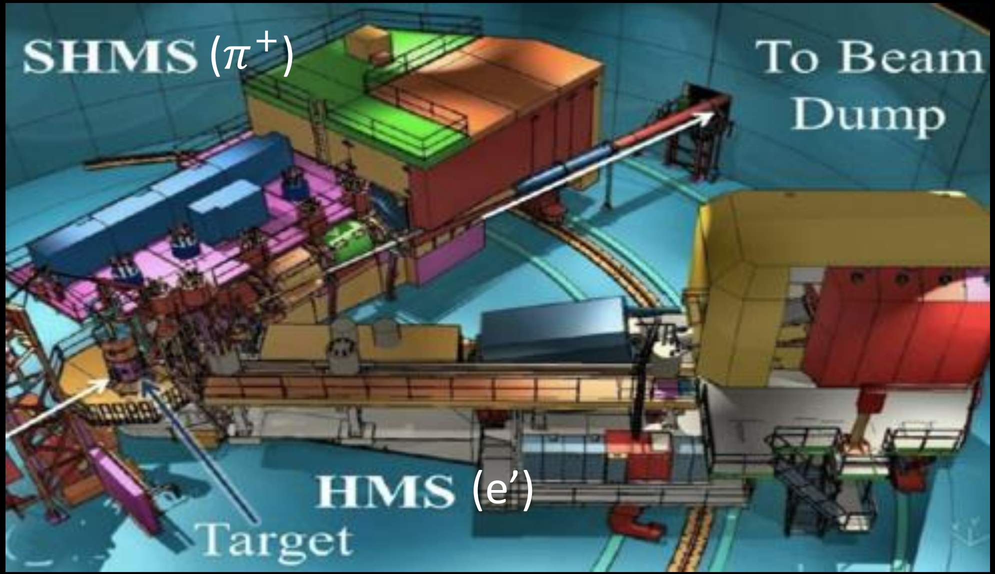
# Thomas Jefferson National Accelerator Facility



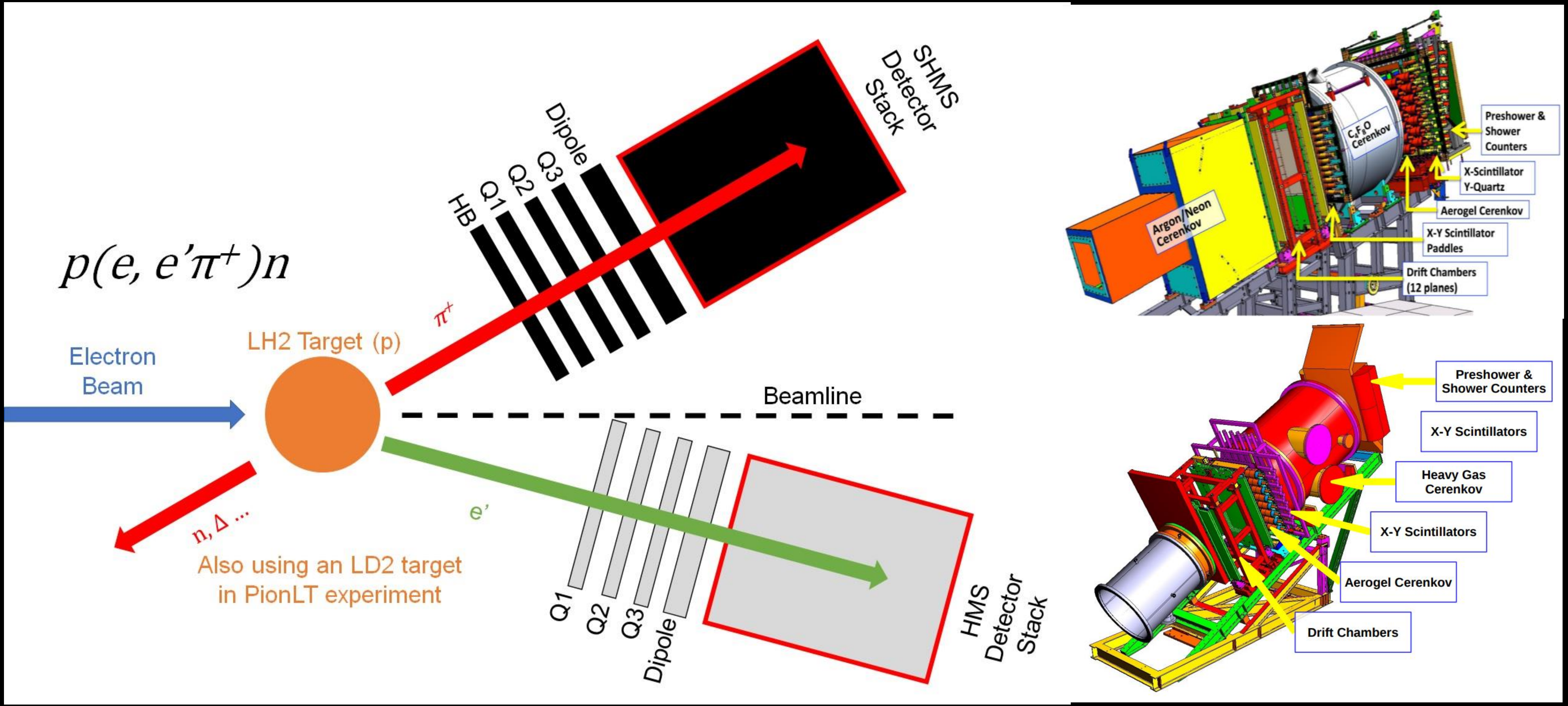

- Located in Newport News, VA
- Consists of two superconducting electron LINACs.
- Capable of delivering a 12 GeV electron beam of up to 200 $\mu A$.

***Hall C***

- Specifically designed to measure precise cross-sections.
- Two advanced rotatable magnetic spectrometers (HMS and SHMS).
- Particles of specific momentum are studied by using a magnet system.

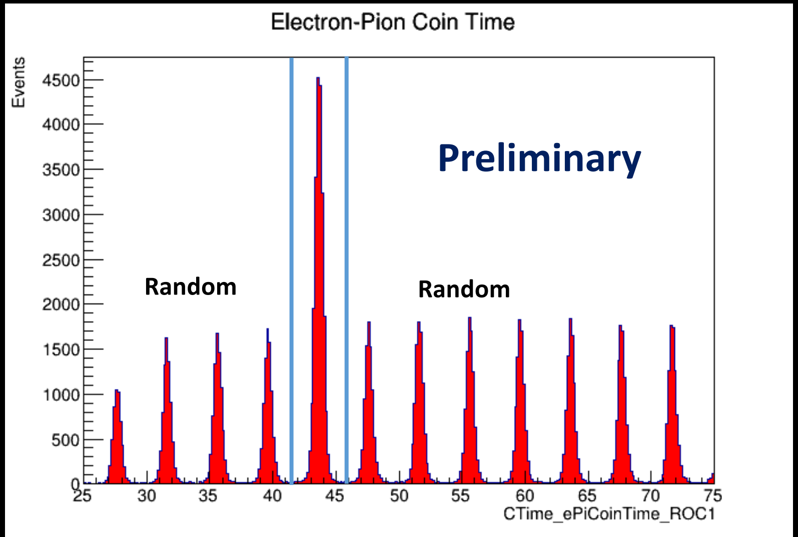


# Schematic View of Hall C

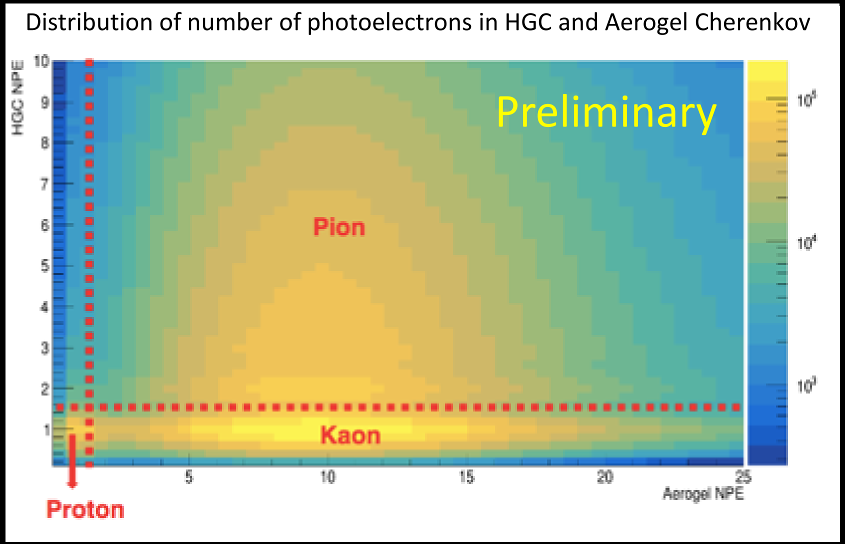


# Data Analysis

- $e' - \pi^+$ Coincidence

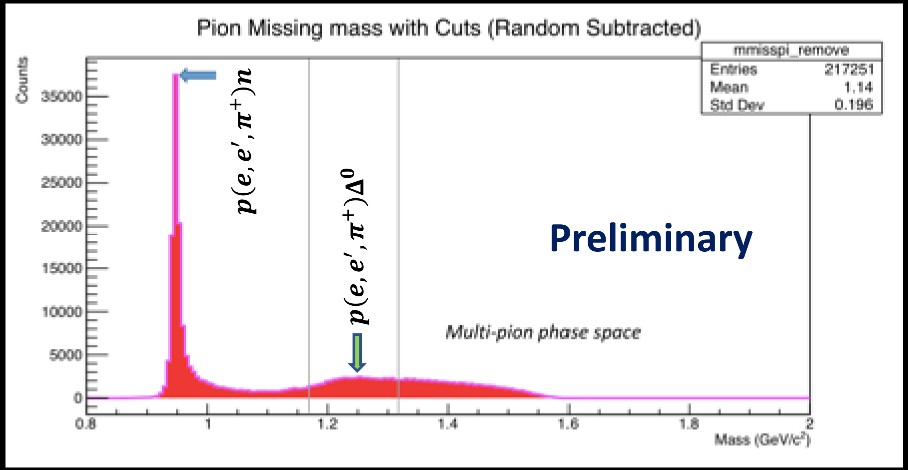



- Particle Identification




- Missing Mass

$E_e = 10.6\ GeV$
$Q^2 = 3.0\ GeV^2$
$W = 3.14\ GeV$



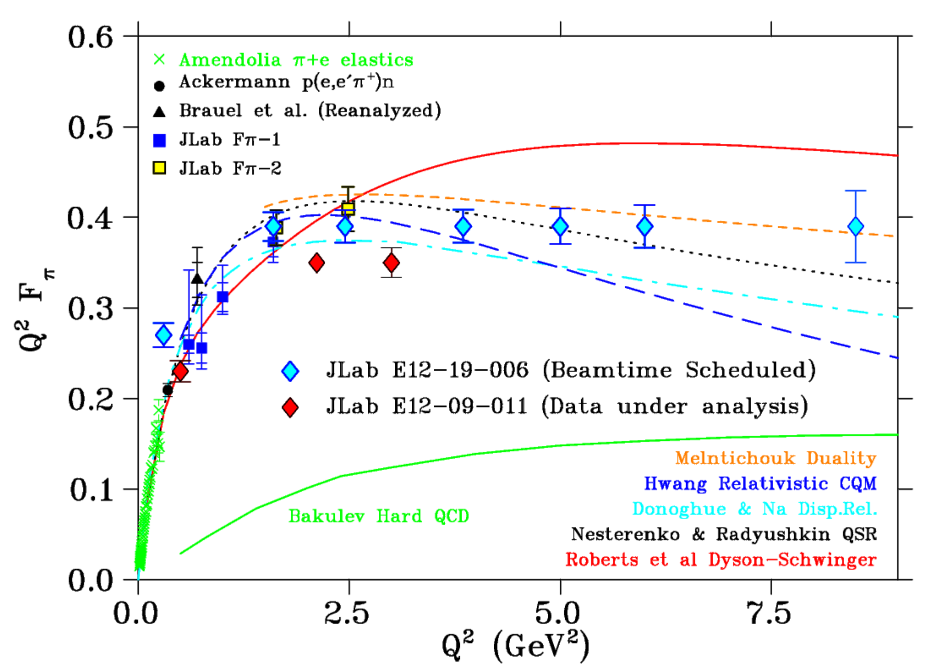

$$M_m = \sqrt{(E_e + m_p - E_{e'} - E_{\pi^+})^2 - (p_e - p_{e'} - p_{\pi^+})^2}$$

# $F_{\pi}$ Projected Results

- Two proposed experiments at Jefferson Lab Hall C will extend current $F_{\pi}$ results up to $Q^2$ of 8.5 $GeV^2$.
- The projected results for both experiments primarily show estimated statistical error and y-axis position is arbitrary.

**E12-09-011**

- Data Collected in 2018-19
- Analysis in progress
- Results expected in 2023-24




E12-19-006

- Data collection in progress (2021-22)
- Results will be published in ~2025-26.

**These experiments will help in understanding of hadron internal structure.**

# Collaborators

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