# E12-06-101: **Measurement of the Charged Pion Form Factor ($F_\pi$) to High $Q^2$**

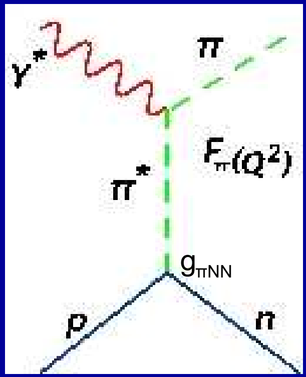
- The pion form factor is a topic of fundamental importance to our understanding of hadronic structure.
- The pion is the lightest QCD system and one of the simplest.
  - Calculated as a first test-case by all models of hadronic structure. → "The positronium atom of QCD".
- Clearest test case for study of transition between non-perturbative and perturbative regions of QCD.

## $F_\pi$ is experimentally challenging to determine.

- Above $Q^2$>0.3 GeV$^2$, one must employ the $p(e,e'\pi^+)n$ reaction.
- At small $-t$<0.2 GeV$^2$, the $t$-channel diagram dominates $\sigma_L$.
- In the $t$-pole approximation

$$\frac{d\sigma_L}{dt} \propto F_\pi^{\,2}$$

- In the actual extraction, a model incorporating the $\pi^+$ production mechanism is used to extract $F_\pi$ from $\sigma_L$.



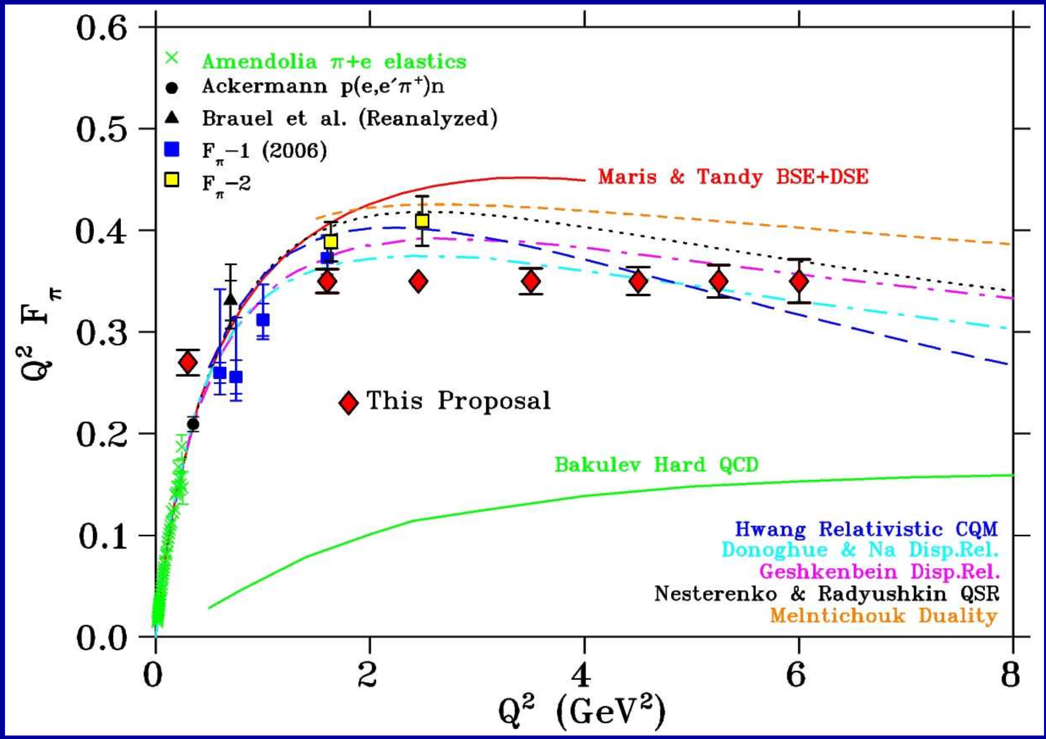
## Jefferson Lab is only lab with capability for reliable $F_\pi$ measurements.

Completed Hall C experiments have established validity of experimental technique and are among the top-cited works from JLab to date.

SHMS with 5.5° forward angle capability and controlled systematics essential for extending precision $F_\pi$ measurements to higher $Q^2$.

- Statistical and uncorrelated systematic uncertainties amplified by $\Delta\varepsilon$.
- Rate estimates based on conservative extrapolation of p(e,e'$\pi^+$)n data.
- $Q^2$=6 GeV$^2$ set by 11 GeV beam & $-t_{min}$<0.2 GeV$^2$ requirement.

New higher $Q^2$ data would challenge QCD-based models in the most rigorous manner and provide a real advance in our understanding of light quark systems.



# Many model-dependence tests are also proposed to better establish the reliability of the extracted $F_\pi$ values

- Verify that electroproduction technique yields results consistent with π-e elastic scattering at same $Q^2$.
  - $Q^2$=0.30 GeV$^2$ comparison with exact values from π-*e* elastics.
  - $-t_{min}$=0.005 GeV$^2$ is 50% smaller than any previous electroproduction data.
- Extract form factor at several values of $-t_{min}$ for fixed $Q^2$.

| | $Q^2$ (GeV$^2$) | W (GeV) | $-t_{min}$ (GeV$^2$) | $F_\pi$ |
|---|---|---|---|---|
| Fπ-1 | 1.60 | 1.95 | 0.150 | 0.233 ±0.014 ±0.012 |
| Fπ-2 | 1.60 | 2.22 | 0.095 | 0.243 ±0.012 ±0.013 |
| **This Proposal** | **1.60** | **3.00** | **0.029** | |

  - Fπ-1,2 consistent within uncertainties despite ~50% different distances to pole.
  - New test much closer to pole, 2nd test planned also at $Q^2$=2.45 GeV$^2$.
- Verify that π-pole diagram is really the dominant contribution to the reaction mechanism.
  - $(e,e'\pi^-)/(e,e'\pi^+)$ ratios with $^2$H target at $Q^2$=1.60, 3.50 GeV$^2$ to verify *t*-channel dominance of $\sigma_L$ data.

A unique opportunity for JLab to dramatically improve the $F_\pi(Q^2)$ database.

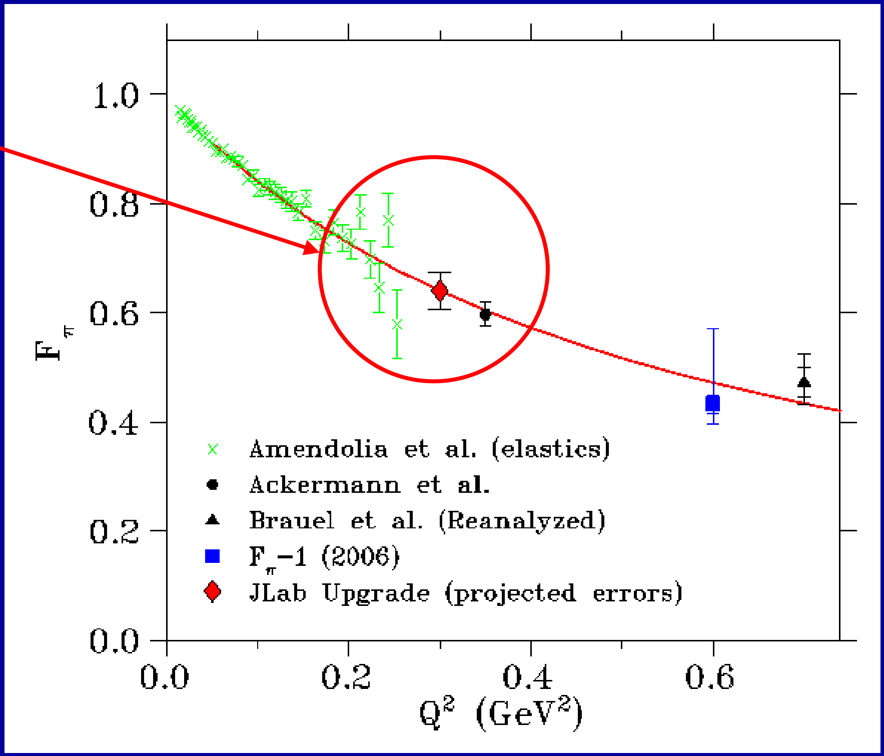
# Appendix

# Proposed Electroproduction Method Check (1)

**Directly compare $F_\pi(Q^2)$ values extracted from very low $-t$ electroproduction with the exact values measured in elastic $e$-$\pi$ scattering.**

## $Q^2$=0.30 GeV$^2$

- Precision low $-t$ data to test the electroproduction method of $F_\pi$.
- Perform a direct comparison with exact values from $\pi$-$e$ elastics.
- $-t_{min}$=0.005 is 50% smaller than any previous electroproduction data.
- Measurement requires 5.5° $\pi^+$ arm (SHMS), 2.8-4.2 GeV beam.
- Use 30 μA on 4cm $LH_2$ target to avoid potentially high accidental coincidence rates.



# Proposed Model-Dependence Test (2)

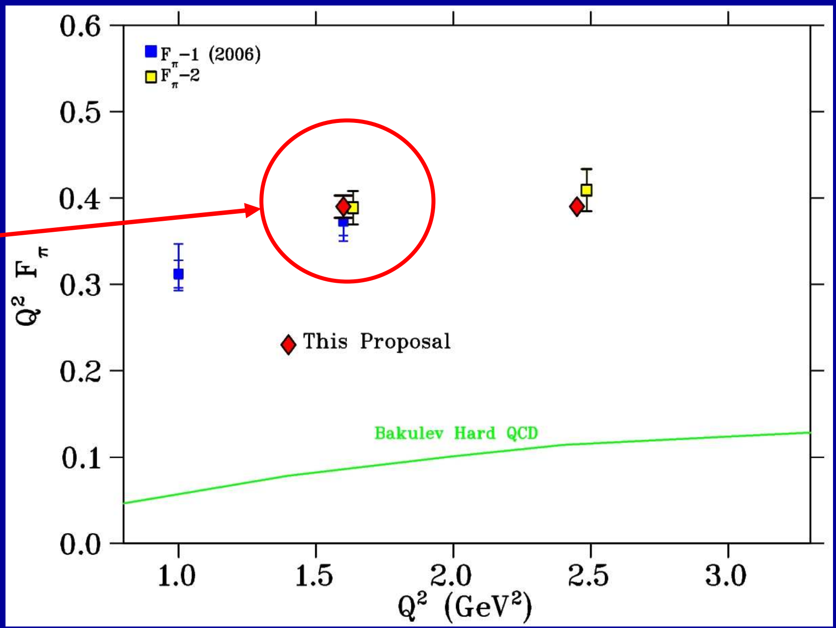
Does the VGL model handle the "off-shellness" of the pion appropriately?

**Test by extracting $F_\pi$ at different distances from pole.**

| $Q^2$ (GeV) | W (GeV) | \|t\| ($GeV^2$) |
|---|---|---|
| 1.60 | **3.00** | **0.029** |
| | 2.22 | 0.095 |
| | 1.95 | 0.150 |
| 2.45 | **3.20** | **0.048** |
| | 2.22 | 0.186 |

## $Q^2$=1.60, 2.45 $GeV^2$

- Repeat measurements taken in Fπ-1 and Fπ-2 but at widely different $W$ and $t_{min}$.
- Needed to better understand model-dependence of $F_\pi$ results.




Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.

# Proposed Higher $Q^2$ Points (3)

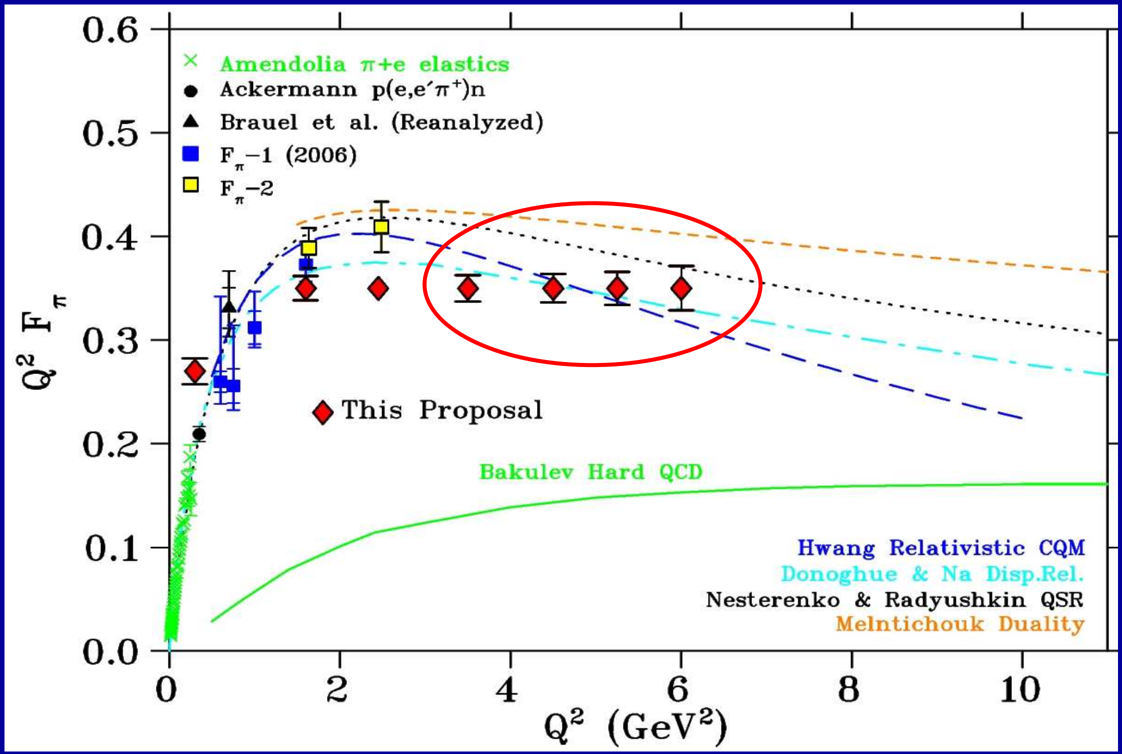
## $Q^2$=5.25, 6.00 GeV$^2$

- Constraints: $|t_{min}|\approx 0.2$, $\Delta\varepsilon\approx 0.3$, 10.9 GeV beam, 5.5° $\pi^+$ arm.

  $\Rightarrow$ max $Q^2\approx 6.0$ GeV$^2$.
- Take $Q^2$=5.25 GeV$^2$ "nearby" where expected precision is better.

| $Q^2$ (GeV) | W (GeV) | $\Delta\varepsilon$ | \|t\| (GeV$^2$) |
|---|---|---|---|
| 5.25 | 3.20 | 0.31 | 0.17 |
| 6.00 | 3.20 | 0.26 | 0.21 |

| $Q^2$ (GeV) | W (GeV) | $\Delta\varepsilon$ | \|t\| (GeV$^2$) |
|---|---|---|---|
| 3.50 | 3.10 | 0.37 | 0.10 |
| 4.46 | 3.28 | 0.30 | 0.12 |




## $Q^2$=3.50, 4.46 GeV$^2$

- Crucial if highest $Q^2$ points suggest a "turnover" in $Q^2F_\pi$ and pQCD limit being reached.