Charged Pion Electroproduction
on
H, 2H, 3He

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nucpi collaboration at Jefferson Lab (E91003)

- Motivation
- Outline of experiment E91003
- Iteration procedure comparison
- Monte Carlo to data comparison
- Conclusion and analysis issues

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Nuclear Pions in the Traditional Nuclear Physics View

1930s: Yukawa describes the nuclear force in terms of exchange particles.

1947: Discovery of pions, confirming Yukawa's prediction.

The Yukawa picture has been developed into a highly successful tool for modeling the nuclear force.

In this picture of nucleon interactions:

-The pion is the lightest exchange particle, and is the dominant component of the long range nuclear force.

-Pion exchange currents provide the bulk of the nuclear binding.

This implies the following consequences:

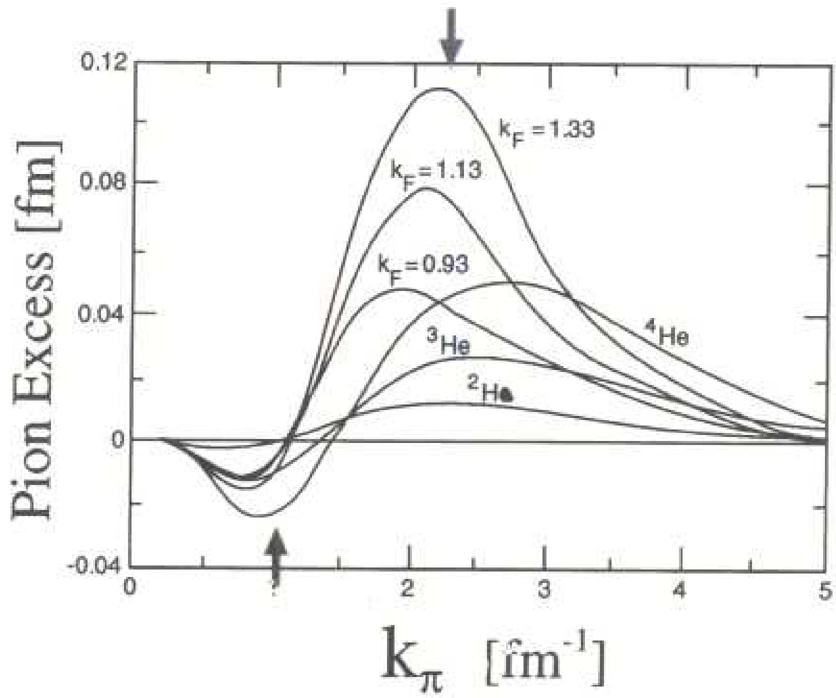
-An modification to the pion field in the nucleus.

-Modification of the sea quark distributions within a nucleus.

Pion Excess in Nuclei

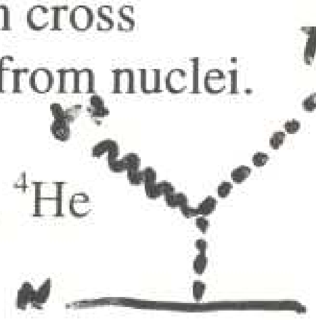
Pion excess, as a function of virtual pion momentum(k_π)

$$\frac{k_\pi^2}{2\pi^2 A}\langle\delta n^\pi(k_\pi)\rangle$$



Friman, Pandharipande, Wiringa; PRL 51, 763(1983)

The goal of JLab experiment e91003 was to measure the longitudinal portion of the pion electroproduction cross section, to look for an excess in pion production from nuclei.



Measure pion electroproduction from H, ^{2}H, ^{3}He, ^{4}He

$Q^2 = 0.4\ (\text{GeV/c})^2$

W = 1.15 (1.6) GeV, corresponding to $k_\pi \sim 0.47\ (0.2)$ GeV/c

At each W point, measure at two different beam energies, with Q^2 fixed to perform an L/T separation.

Also have data at W=1.95, Q^2=0.6,1.0,1.6: H and ^{2}H only.

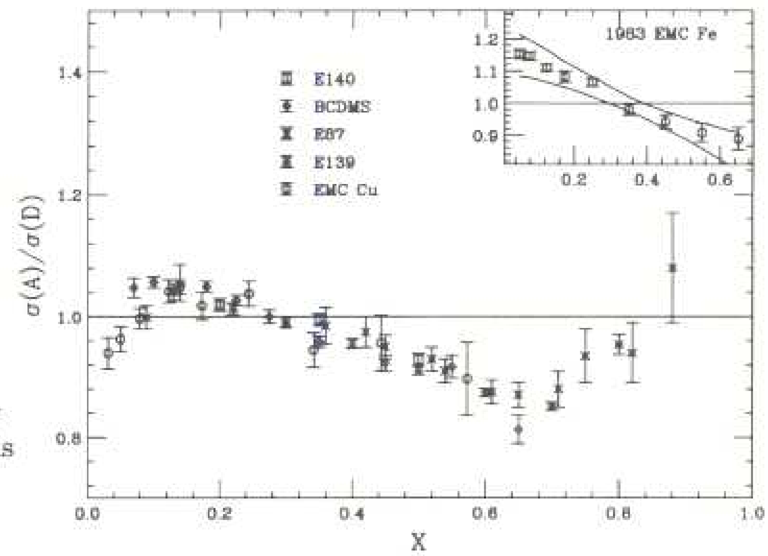
Measurements of the Pion Field in the Nucleus

The EMC collaboration measures the A-dependence of the quark distributions in nuclei in DIS scattering.

-Large modifications seen.

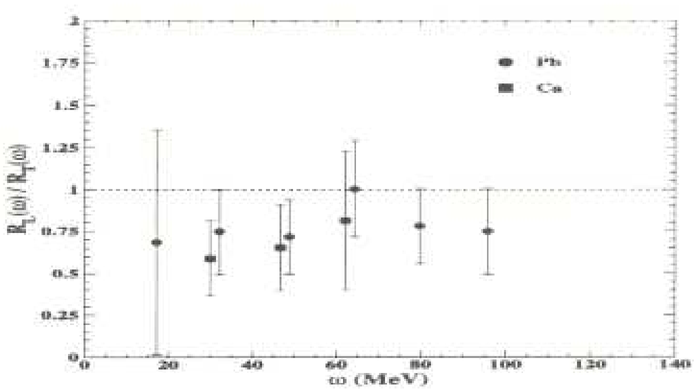
-Initial data consistent with the exceptation of nuclear pions.

-Later experiments found a much smaller enhancement at low x, but data is still fairly well described by pionic enhancement models (~10% enhancement for heavy nuclei).



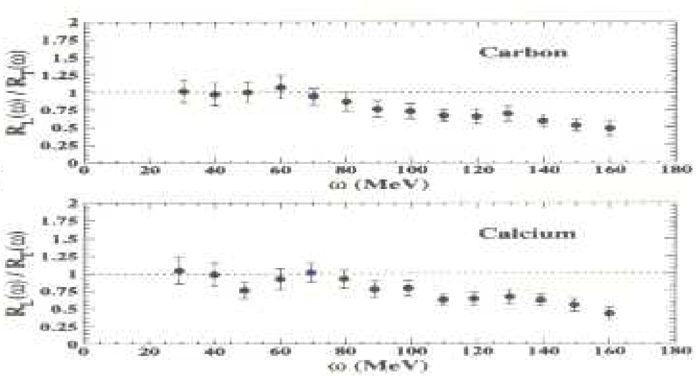
Polarization transfer in A($\vec{p}$, $\vec{p}$) and A($\vec{p}$, $\vec{n}$) scattering.

-Sensitive to pion field (charge exchange via emission or absorption of a charged pion.



-Found no enhancement with respect to p-p scattering (kπ > 400 MeV/c)

-These experiments may not be sensitive enough to rule out the pion excess predicted from conventional nuclear theory.
(D.S. Koltun)

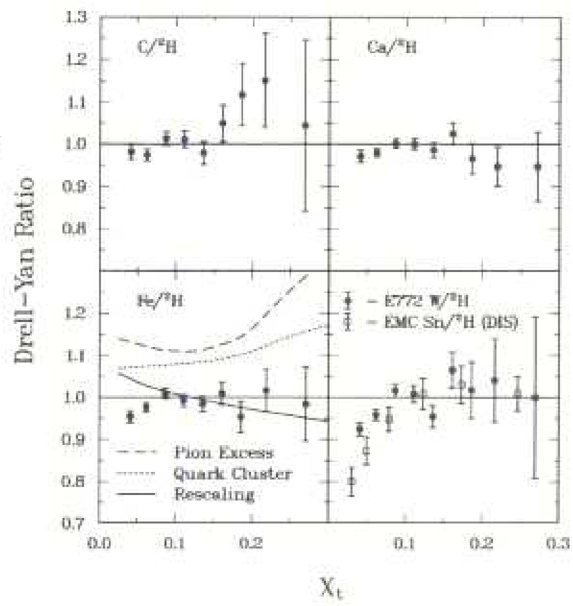


Measurements of the Pion Field in the Nucleus

E772 at Fermilab measures nuclear dependence of the Drell-Yan process.

-A clean probe, sensitive to sea quark distributions.

-Found no enhancement due to modification of the pion field. ($k_\pi > 400$ Mev/c)



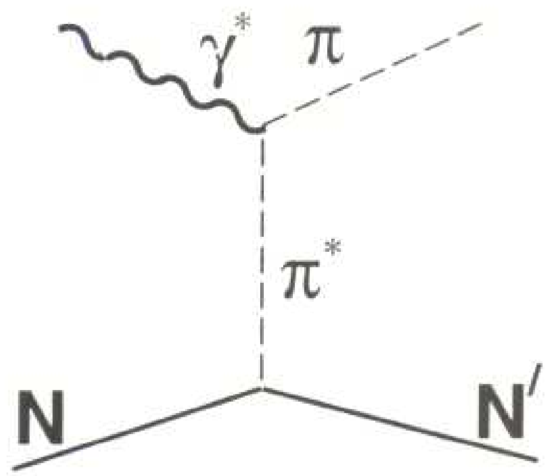
Pion Electroproduction from nuclei.

-Look for enhancement of virtual pion knockout from nuclei

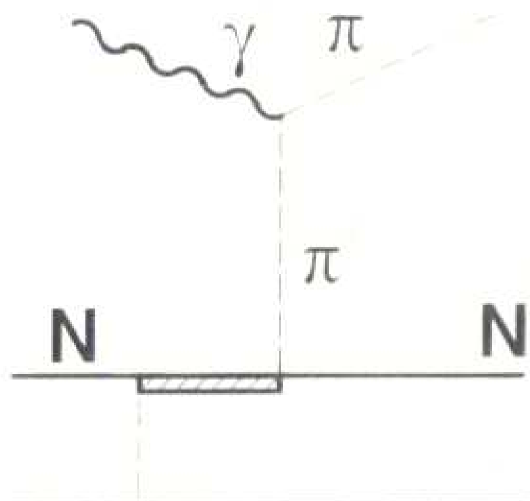
-Probe the nuclear pion field at lower momentum (200 MeV/c and 400 MeV/c).

Pion Electroproduction

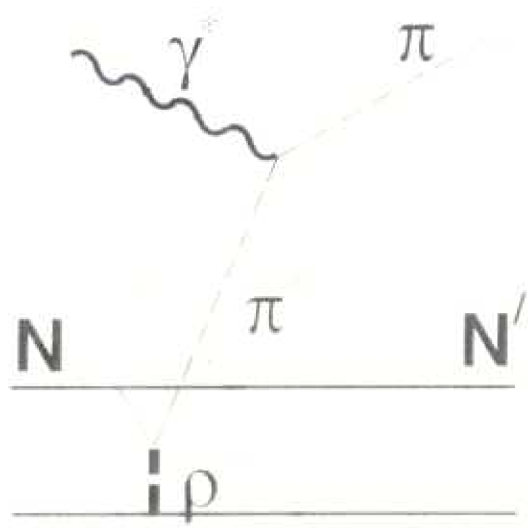
For $W < M_{\Delta}$, charge scattering from a single nucleon is dominated by the pole term.

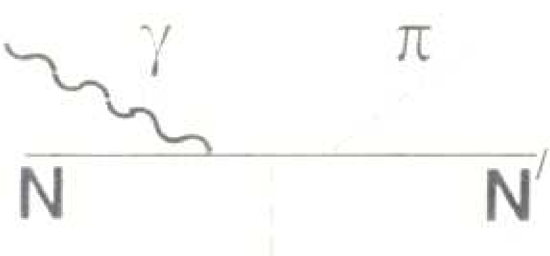


In nuclei, the electroproduction cross section is modified by nuclear pion currents.



The longitudinal component of the electroproduction cross section is sensitive to these contributions.





Experiment E91003

Run in Hall C at Jefferson Lab, Spring 1998

Experimental Setup:

Incident electron energies between 0.85 and 3.25 GeV.

Cryogenic Hydrogen, Deuterium, Helium-3 targets.

Electrons measured in HMS, pions in SOS.

Pions identified by time-of-flight in SOS and HMS-SOS coincidence timing.

Cross Section Extraction:

Compare measured yield with realistic simulation.

- Spectrometer acceptance.
- Detector and cut efficiencies.
- Radiation.
- Energy loss and multiple scattering.
- Pion decay ($\pi \to \mu\upsilon$).

Experimental and Analysis Issues:

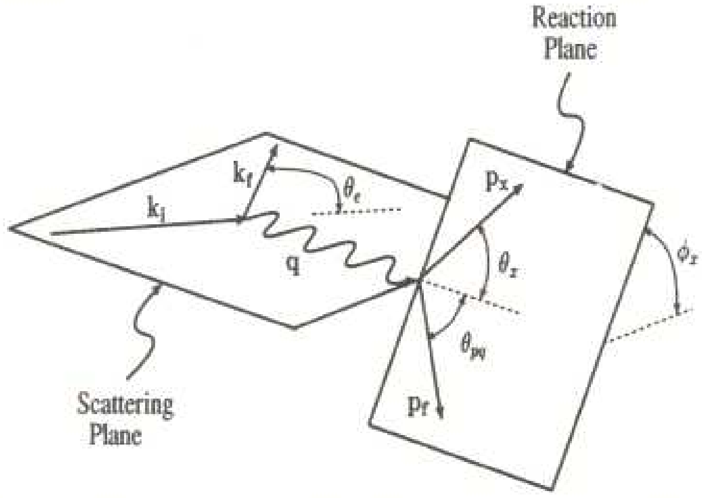
Separation of longitudinal component.

Multiple final states available in $^3He(e,e'\pi^+)$.

Limited p_π coverage for nuclear targets.

Final state interactions (π-N, N-N).

Longitudinal-Transverse Separation

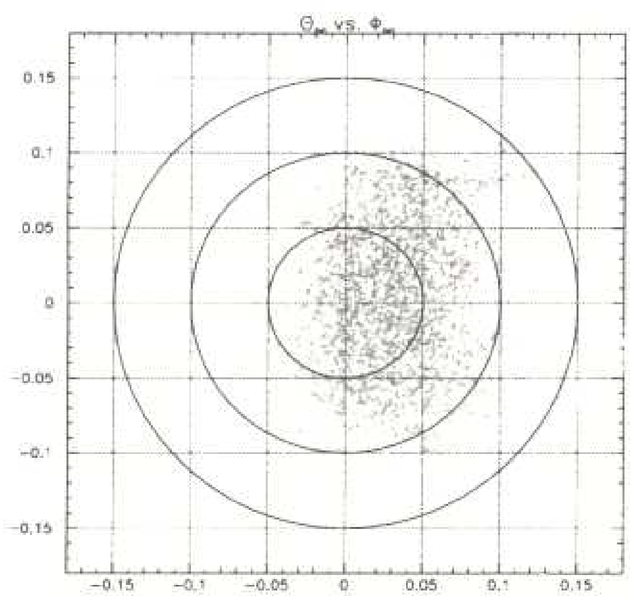


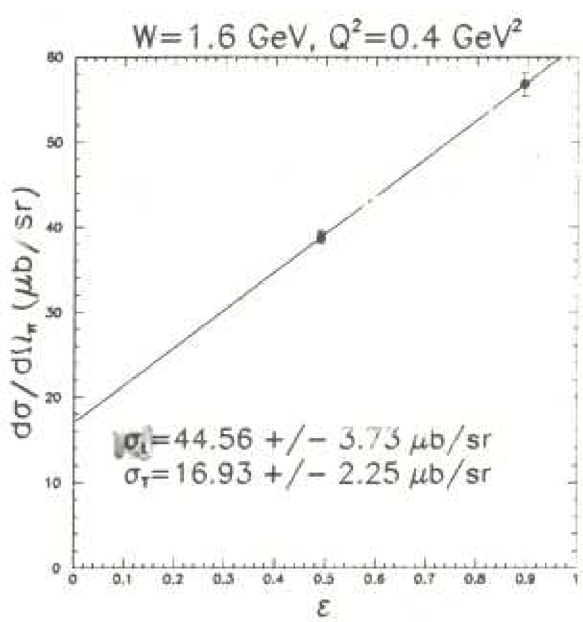
Five-fold pion electroproduction cross section,

$$\frac{d\sigma}{d\Omega_e dE d\Omega_\pi} = \Gamma_v \left[\frac{d\sigma_T}{d\Omega_\pi} + \varepsilon \frac{d\sigma_L}{d\Omega_\pi} + (2(\varepsilon+1)\varepsilon)^{1/2} \frac{d\sigma_{LT}}{d\Omega_\pi}\cos(\phi) + \varepsilon \frac{d\sigma_{TT}}{d\Omega_\pi}\cos(2\phi) \right]$$

virtual photon polarization $\varepsilon = [1 + 2(1+\omega^2/Q^2)\tan^2(\theta/2)]$

virtual photon flux $\Gamma_v = \dfrac{\alpha^2 E_f K_{eq}}{2\pi^2 E_i Q^2 (1-\varepsilon)}$



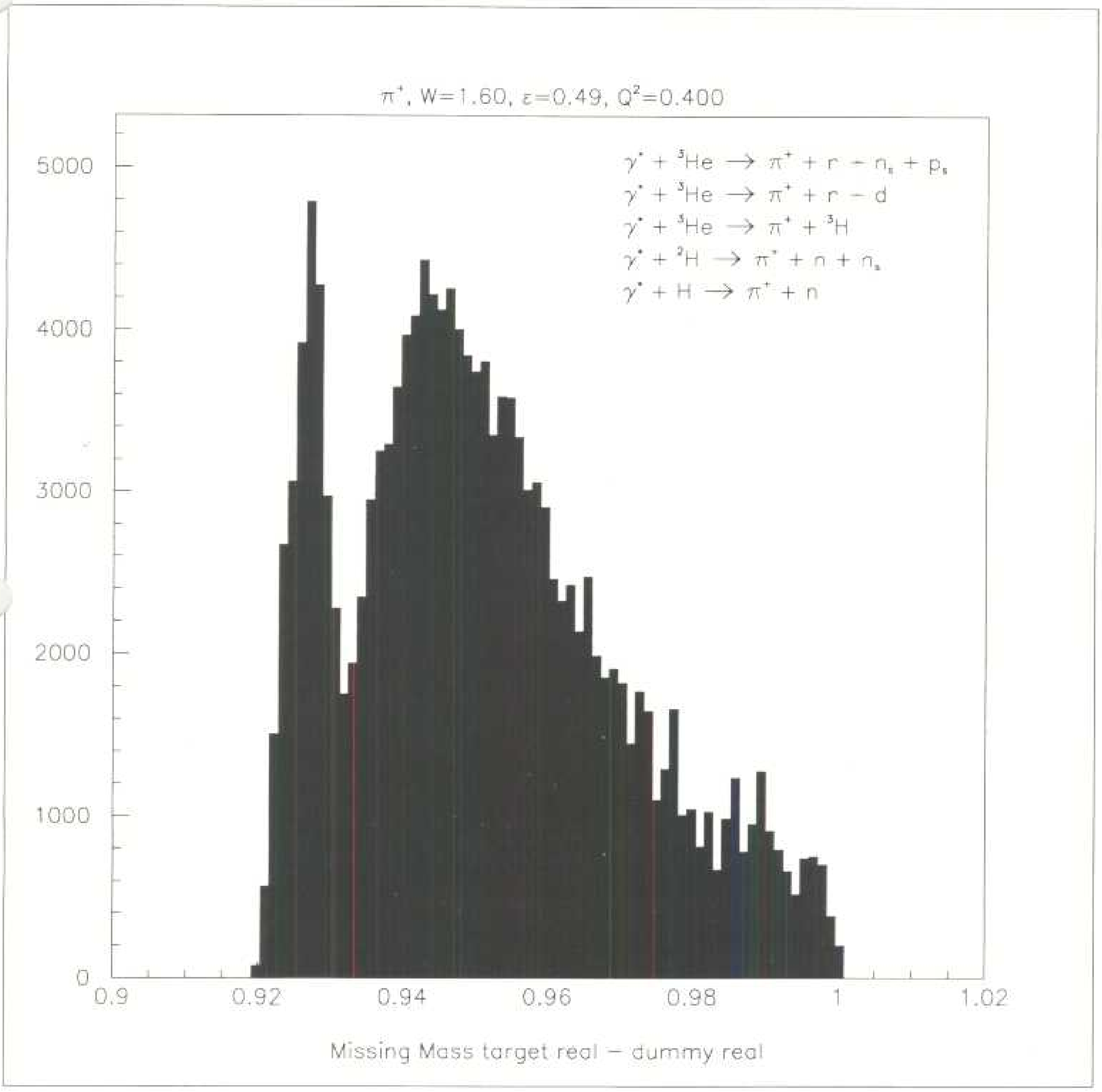


Data have reasonable ϕ coverage:
⇨ Small LT and TT terms

Check against analysis with very tight θ cut (full ϕ coverage).

Reduced Cross Section (σ^5/Γ_V) vs. ε

σ_L = slope $\qquad$ σ_T = intercept



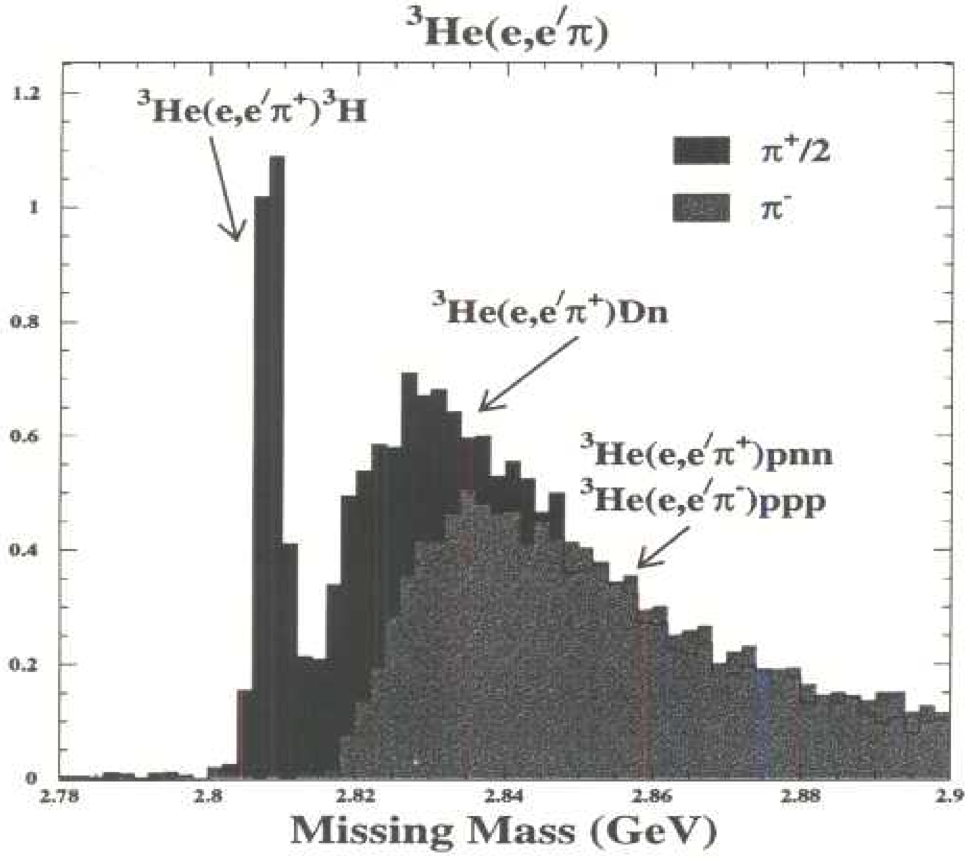
π⁺, W=1.60, ε=0.49, Q²=0.400
γ* + ³He → π⁺ + r − n_s + p_s
γ* + ³He → π⁺ + r − d
γ* + ³He → π⁺ + ³H
γ* + ²H → π⁺ + n + n_s
γ* + H → π⁺ + n
5000
4000
3000
2000
1000
0
0.9
0.92
0.94
0.96
0.98
1
1.02
Missing Mass target real − dummy real

Final States in ^{3}He.

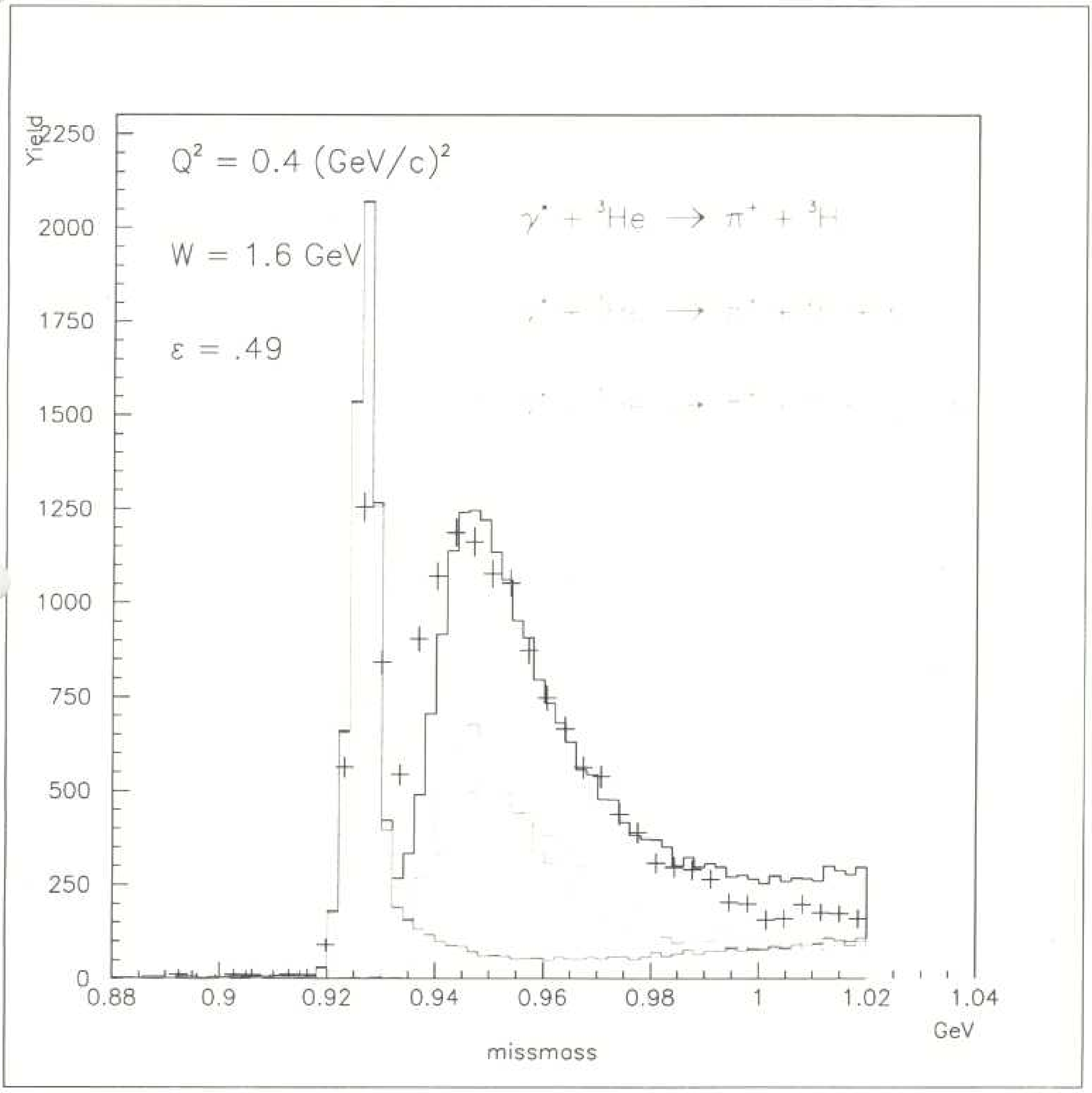
π^+ production from proton gives π-n final state
π^+ production from deuteron gives π-n-n final state
π^+ production from ^{3}He allows for multiple final states:

π-n-n-p $\quad$ π-n-^{2}H $\quad$ π-^{3}H

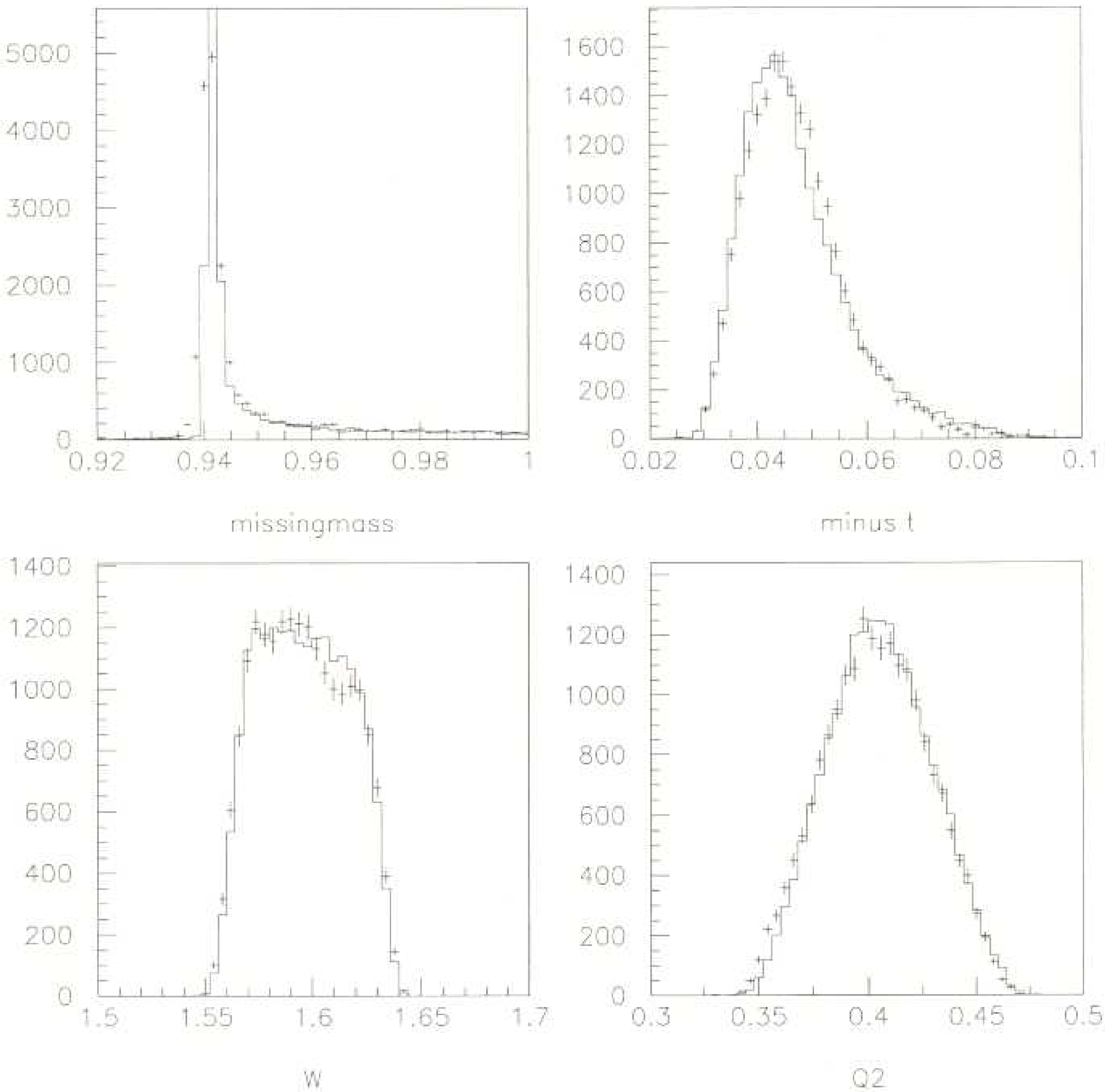
For ^{3}He we measured π^- production, which has only π-p-p-p final state, and compared the cross section to deuterium π^- production.

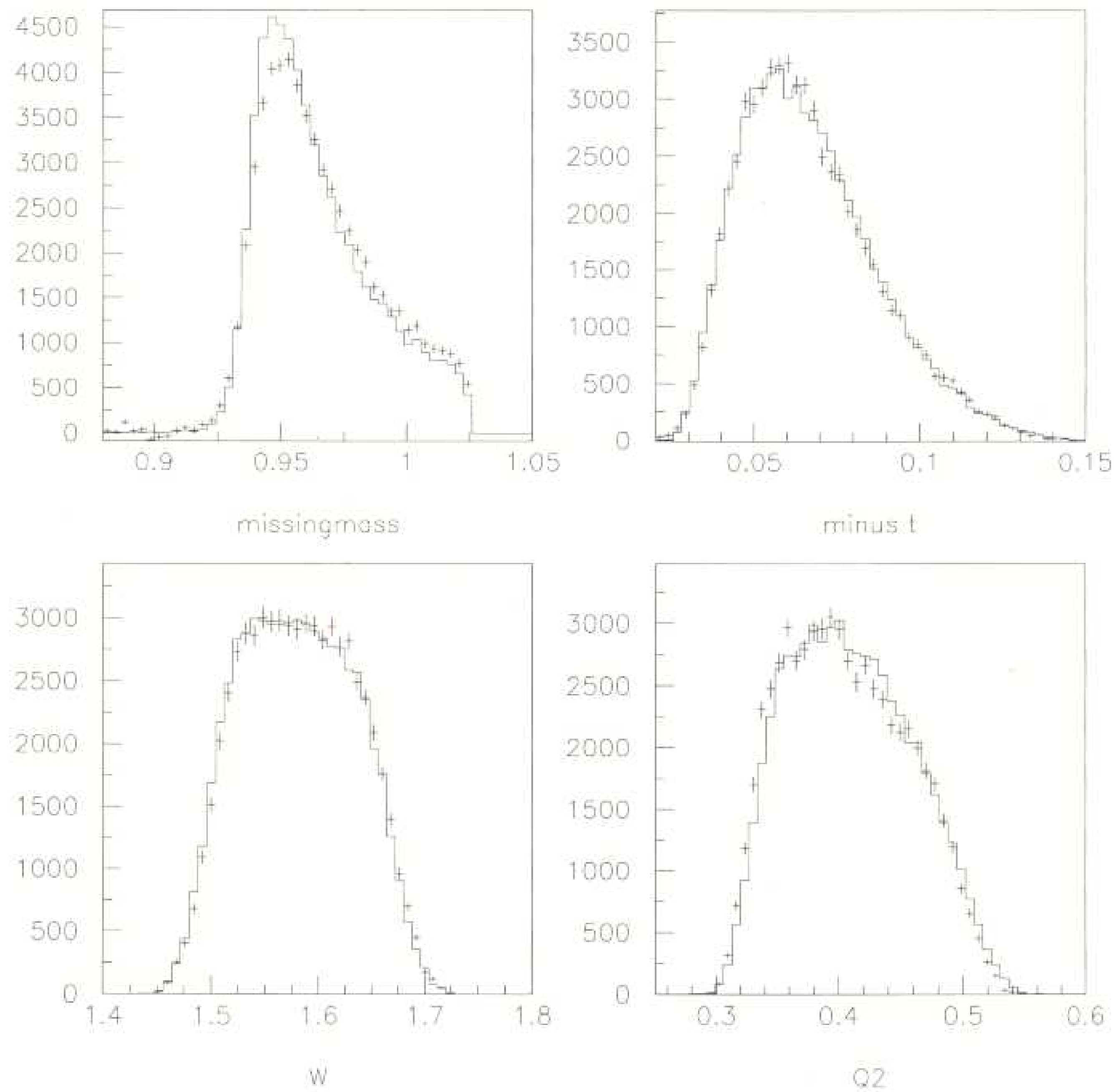


In addition, we can measure the coherent production (π-^{3}H final state):

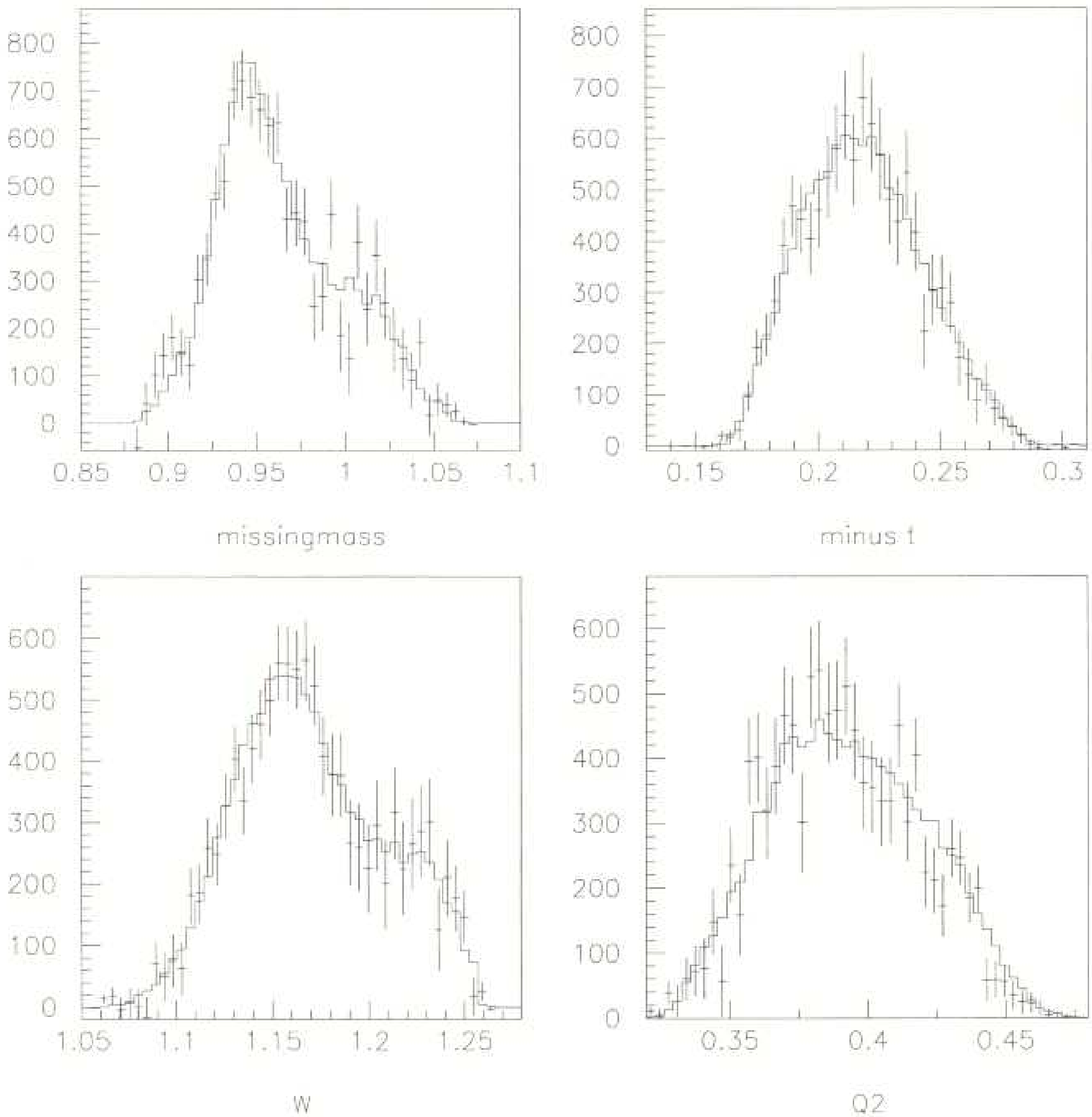


$Q^2 = 0.4\ (GeV/c)^2$
W = 1.6 GeV
ε = .49
$\gamma^* + {}^3He \rightarrow \pi^+ + {}^3H$
Yield
2250
2000
1750
1500
1250
1000
750
500
250
0
0.88
0.9
0.92
0.94
0.96
0.98
1
1.02
1.04
GeV
missmass

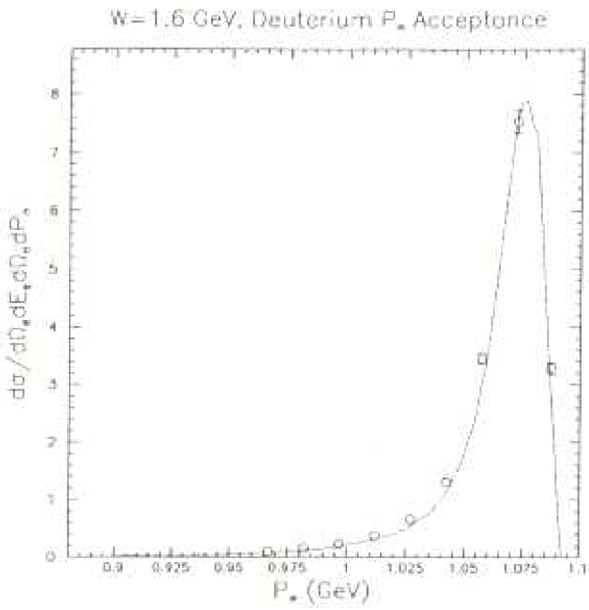

missingmass
minus t
W
Q2



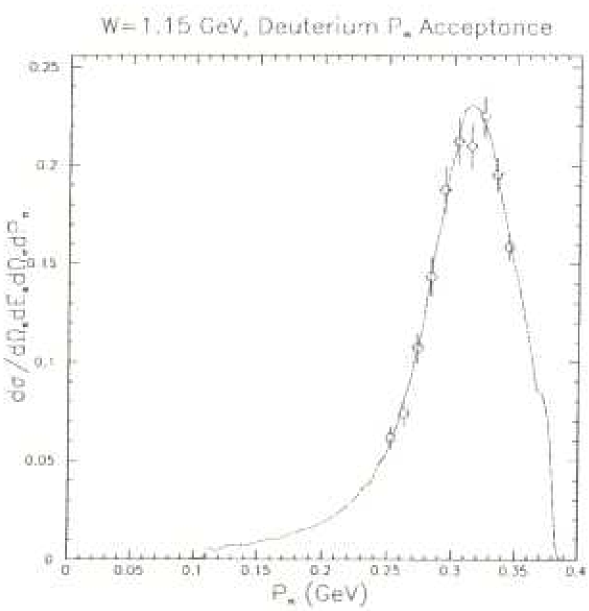
missingmass
minus t
W
Q2


800
700
600
500
400
300
200
100
0
0.85
0.9
0.95
1
1.05
1.1
missingmass
0.15
0.2
0.25
0.3
minus t
1.05
1.1
1.15
1.2
1.25
W
0.35
0.4
0.45
Q2

P_π coverage in Deuterium, ^{3}He



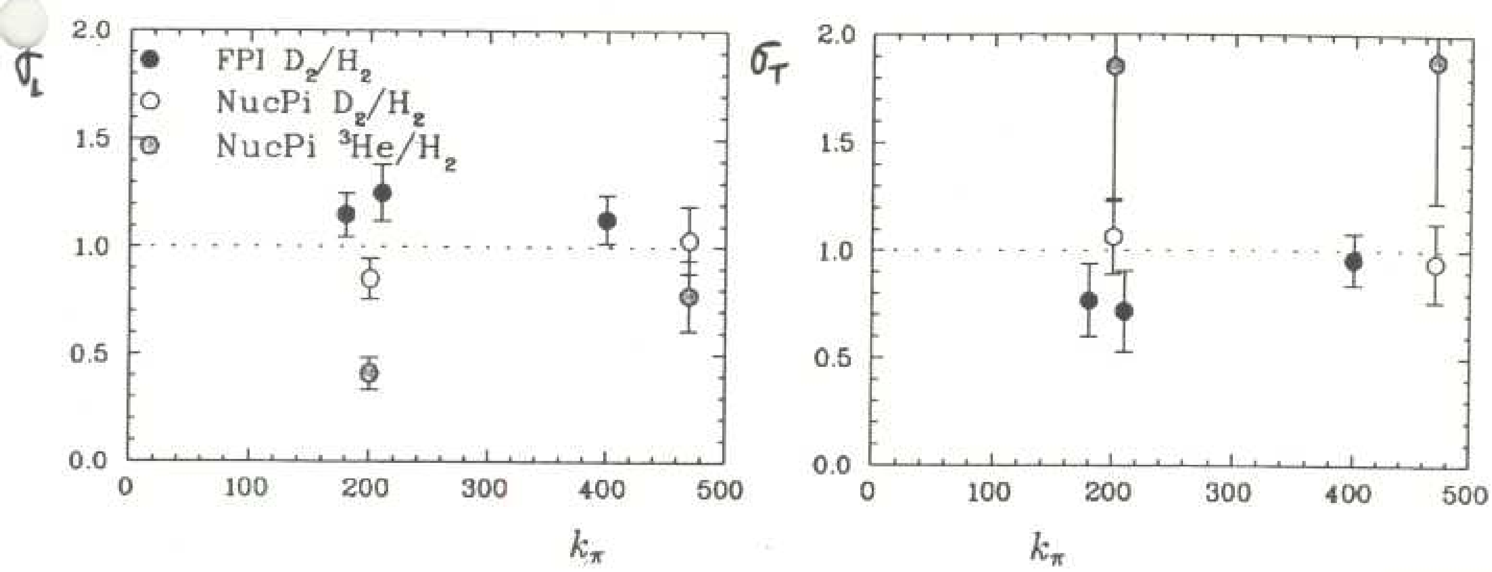
P_π acceptance at low k_π is ~99% for deuterium, similar for ^{3}He



P_π acceptance at high k_π is $\lesssim$80% for deuterium, $\lesssim$65% for ^{3}He

Because we measure only part of the p_π distribution, we must model the distribution to estimate the measured fraction or measure the ratio over a limited p_π range.

Dave Gaskell, Ph.d Thesis, 2001



- $\frac{d\sigma_L}{d\Omega}$ Ratios around one

- $\frac{d\sigma_T}{d\Omega}$ Ratios around one; ^3He ratio > 1

  errors are large because σ_T small relative to σ_L

- Quenching observed in early experiments on the deuteron at $k_\pi = 200$ MeV is present here and ^3He is greater

  → R. Gilman et al PhysRevLett 64, 622 (1990)

- No evidence in data for pion enhancement

- Need to extend data to ^4He where prediction for pion excess is stronger

Conclusions

- E91003 has data for a high precision L-T separation on H, 2H, 3He

- No evidence of pion excess from pion electro-production. Present analysis will confirm results.

^4He → ~x2

- Program needs to be extended to 4He

Higher W → ~1/2 uncertainties

- A reliable calculation for pion electroproduction could significantly improve our measurements.