Tritium at 12 GeV

^{3}H

Ronald Ransome

Rutgers

The State University of New Jersey

Outline

- Some history and why 12 GeV
- Four tritium experiments
  - The u/d ratio/EMC effect
  - Elastic form factors
  - Coulomb sum rule
  - Polarization transfer
- Targets
- Safety
- Plans
- Conclusion

Some History

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Tritium targets successfully used at Bates and Saclay recently (late 1980's early 1990's)

Bates used 100 kCi high pressure gas target

Saclay used 10 kCi liquid target

But … no ^{3}H experiments at JLab

^3H at JLab

1998 PAC workshop and 1999 tritium workshop identified a number of tritium experiments.

Lab management then decided to include tritium only as part of the upgrade

Director Leeman has asked for clear identification of physics goals and review of safety issues before deciding how to proceed

Goals of this talk

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I want to review the result of previous workshops and encourage interest in a workshop soon (early 2005) to make the case for tritium to lab management.

Parton Distribution Functions

The goal of subnucleonic physics – determine the internal structure of the nucleon.

The distribution of the partons – valence and sea quarks, and gluons, need to be determined.

A major current issue – the ratio of the d/u ratio at high x

Predictions for d/u

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Several distinct predictions for d/u

1) SU(6) symmetry

$$\frac{d}{u} = \frac{1}{2} \qquad \frac{F_2^n}{F_2^p} = \frac{2}{3}$$

2) Dominance of $S = 0$ diquark configurations (Close, Carlitz)

Ignoring terms with $S = 1$ diquarks, then

$$\frac{d}{u} = 0 \qquad \frac{F_2^n}{F_2^p} = \frac{1}{4}$$

3) Dominance of $S_z = 0$ diquark configurations (Farrar, Jackson)

Ignoring terms with $S_z = 1$ diquarks, then

$$\frac{d}{u} = \frac{1}{5} \qquad \frac{F_2^n}{F_2^p} = \frac{3}{7}$$

Measurement of d/u

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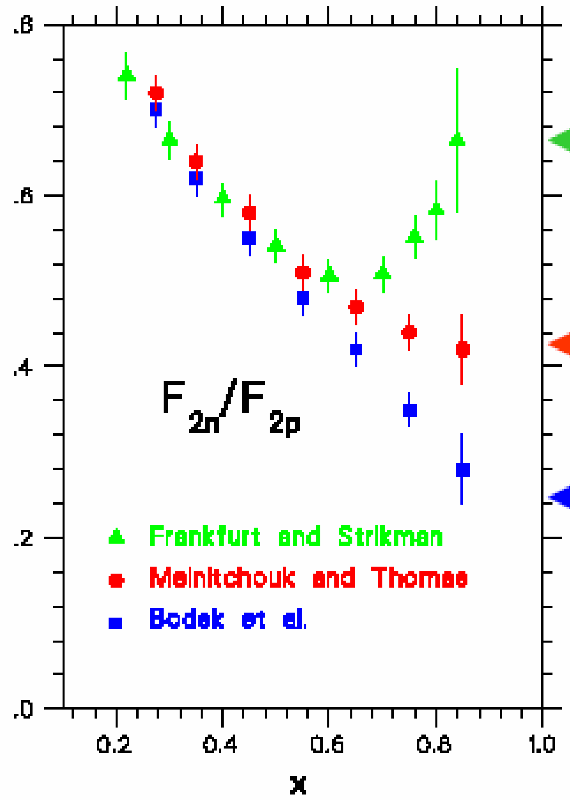
Comparison of electron-deuteron vs. proton scattering (problems with nuclear effects)

Neutrino-proton vs. antineutrino-proton scattering (the cleanest method in principle, but difficult to achieve)

Drell-Yan – $pp \rightarrow \mu^+\mu^-X$ (E906 at Fermilab)

d/u model corrections

Model dependence of extracting F_2^n from F_2^d



SU(6) symmetry

$S_Z = 0$ dominance

S = 0 dominance

$^3H/^3He$ ratio

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Nuclear corrections in deuterium not well known at high *x*

Nuclear corrections for $^3H/^3He$ should be similar – should be order 1% effect.

Apart from high precision neutrino scattering, probably the cleanest way to measure u/d

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u/d ratio at JLab

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Yellow band indicates uncertainty due to binding effects of deuteron.

Time ~ 10 days

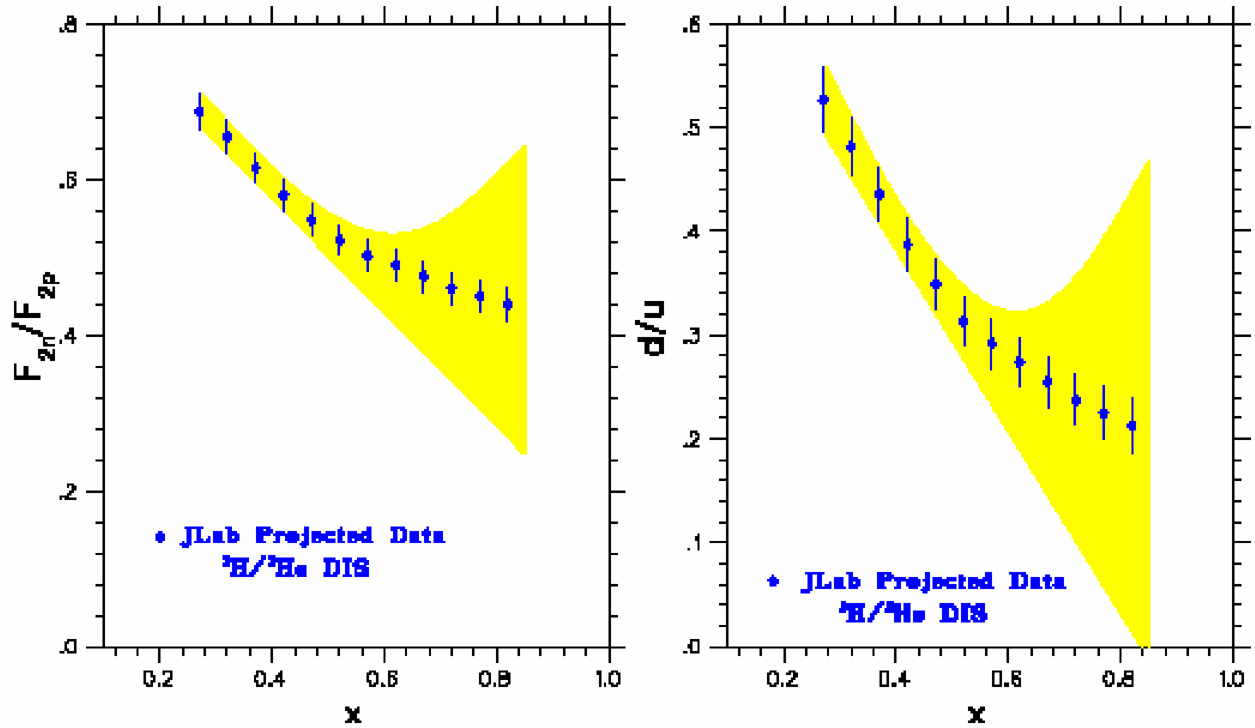

Figure 3: Projected data for the F_2^n/F_2^p structure function (left) and d/u quark (right) ratios from the proposed ^{3}H/^{3}He JLab DIS experiment. The error bars include experimental and theoretical systematic uncertainties added in quadrature. The shaded band indicates the present uncertainty due to possible binding effects in deuteron.

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EMC effect

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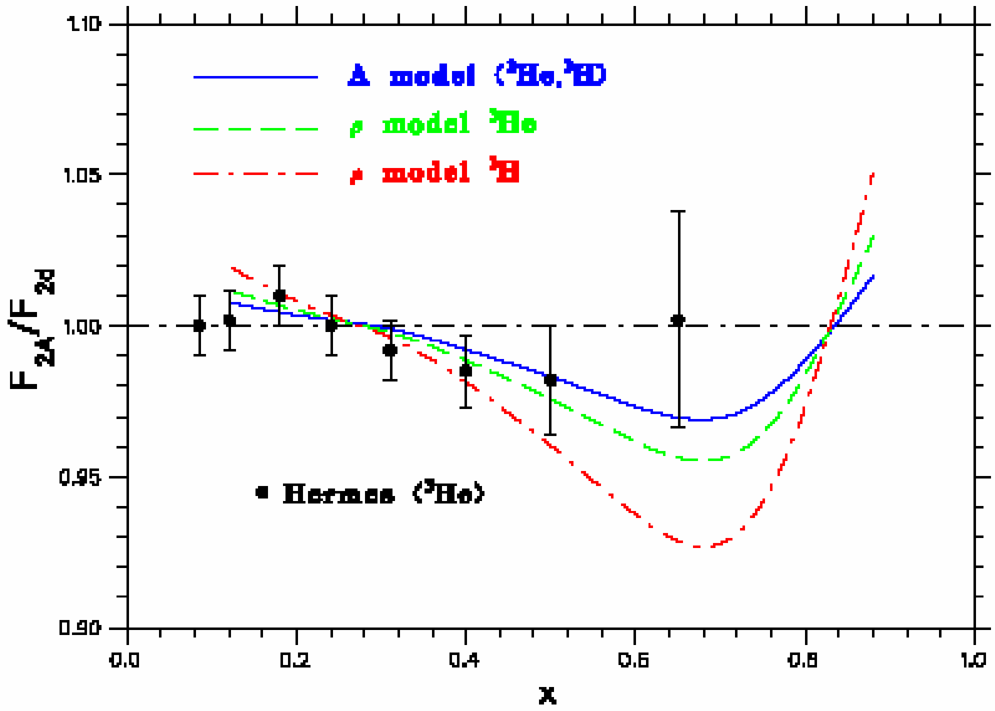

Figure 4: The ^{3}H and ^{3}He isoscalar EMC effect ratios $F_2(^3H)/F_2(d)$ and $F_2(^3He)/F_2(d)$ as predicted [25] by the atomic mass A model and the nuclear density ρ model. Also shown are recent data from the Hermes/DESY experiment [43].

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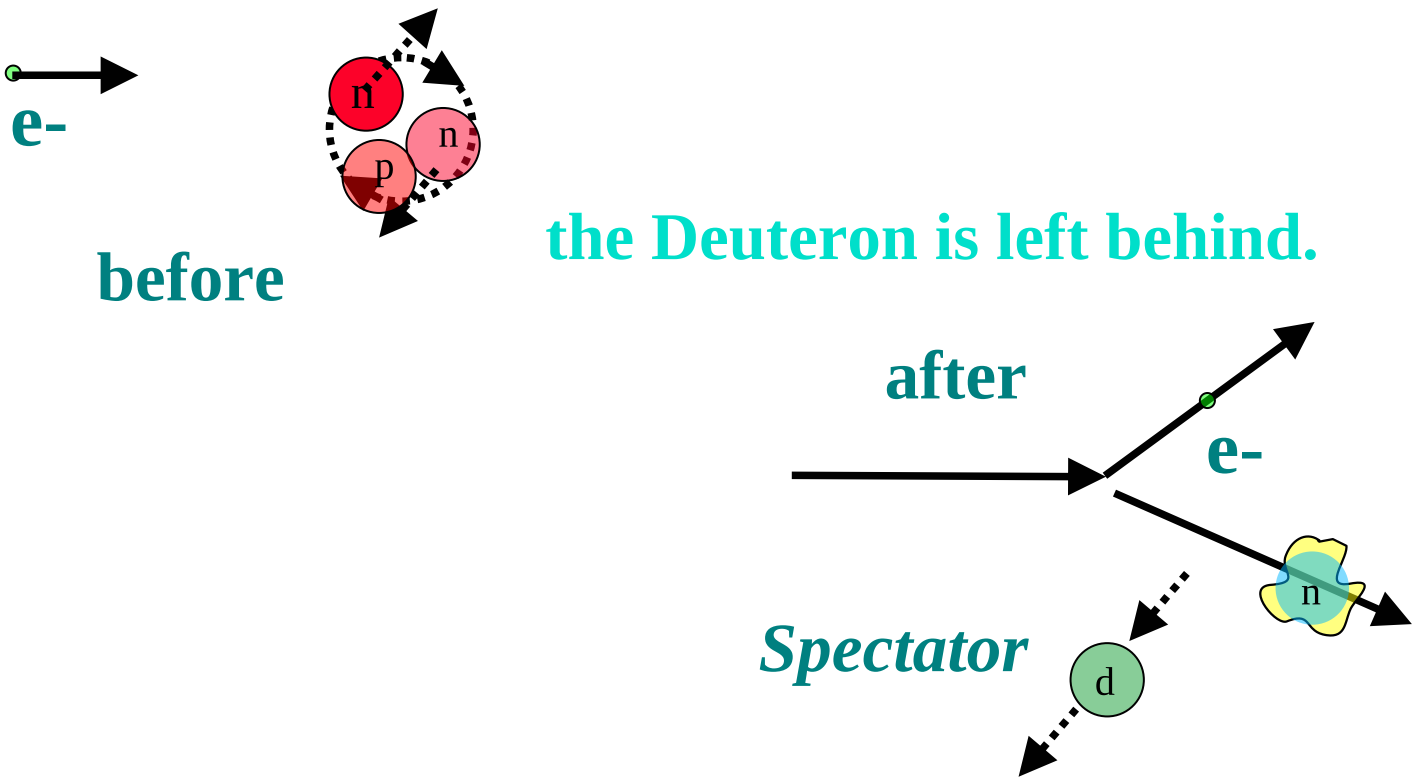
The BONUS Approach: An Effective Free Neutron Target (approved for Deuterium)….

Interaction on Neutron in ^{3}H (or Proton in ^{3}He):



Physics of Few Body Nuclei

KEY QUESTIONS (PAC 14 Few Body Workshop – July 15, 1998)

1. Can few-body systems be understood in terms of a "*standard model*" for nuclear physics with only nucleon degrees-of-freedom? Key issues include:

— Is a consistent and "exact" description of ^{2}H, ^{3}H, ^{3}He, ^{4}He possible within a standard model? (i.e. can a single interaction and current operator account for all nuclei?)

— Precise and complete tests of the "*standard model*" need to be identified and carried out experimentally.

— The basic Coulomb sum rule should be exploited as a test of the nucleon picture.

— A reliable "*standard model*" can provide a setting for extracting fundamental quantities from few-body systems, e.g. neutron form factors from measurements with the deuteron and ^{3}He.

(I've selected those questions related to tritium)

More from PAC 14 Workshop

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Experimental Opportunities for the future

— ^2H, ^3H, $^4He(e,e'p)$ to high-momentum transfer at large E_m and P_m. By probing the high-energy/momentum part of the spectral function these measurements are important for establishing the extent and role of short-range correlations in the "*standard model.*"

— Elastic form factors for ^3H: There is only one conditionally approved experiment using a tritium target. As this nucleus is one of only four few-body nuclear systems, careful tests of the "*standard model*" would require information on ^3H.

Elastic Form Factors

^{3}H

The most basic requirement for understanding light nuclei is the determination of the ground-state wave functions.

A complete description also requires separation of the isospin 0 and 1 components, which requires comparably good measurements on ^{3}H and ^{3}He.

Elastic Charge Form Factor

^{3}H

612 A. Amroun et al. / Nuclear Physics A579 (1994) 596–626

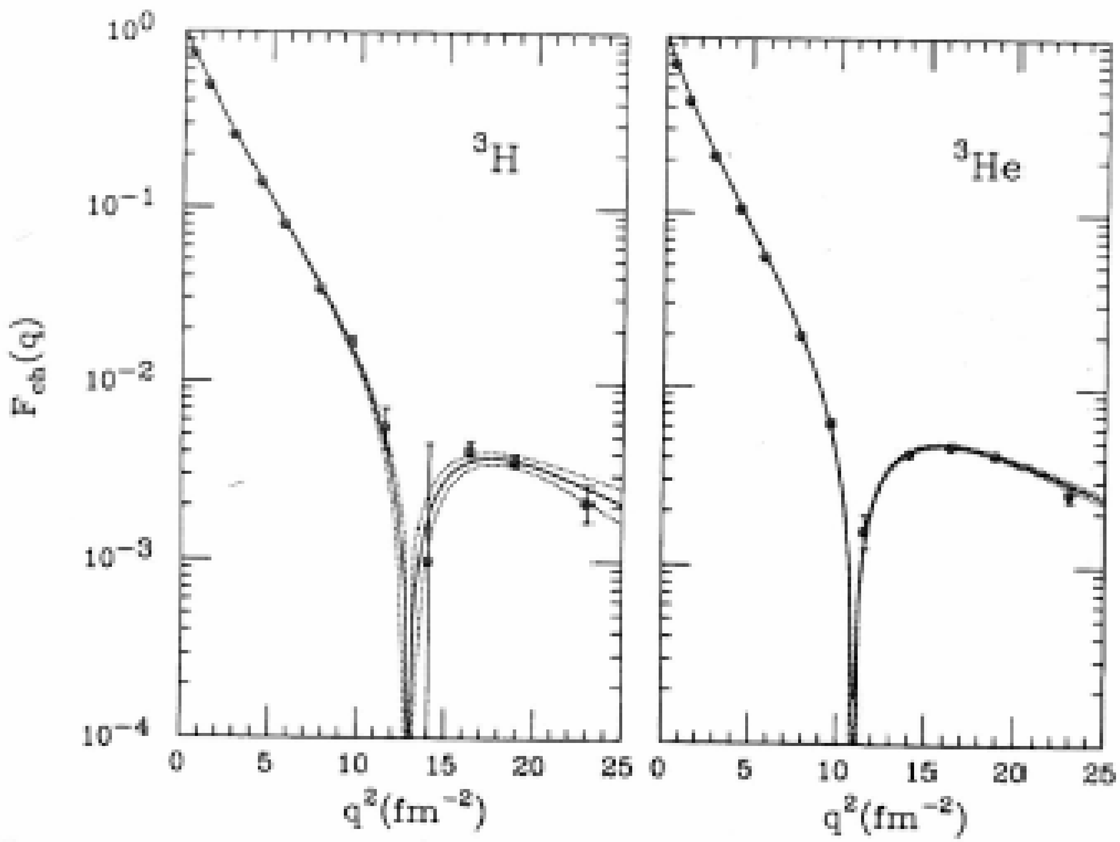

Fig. 6. Best-fit charge form factor for ^{3}H and ^{3}He (solid line) with limits of error band (dashed). The points correspond to values extracted via the usual Rosenbluth technique.

A. Amroun et al., NP A579, 596 (1994)

Elastic Magnetic Form Factor

A. Amroun et al. / Nuclear Physics A579 (1994) 596–626 613

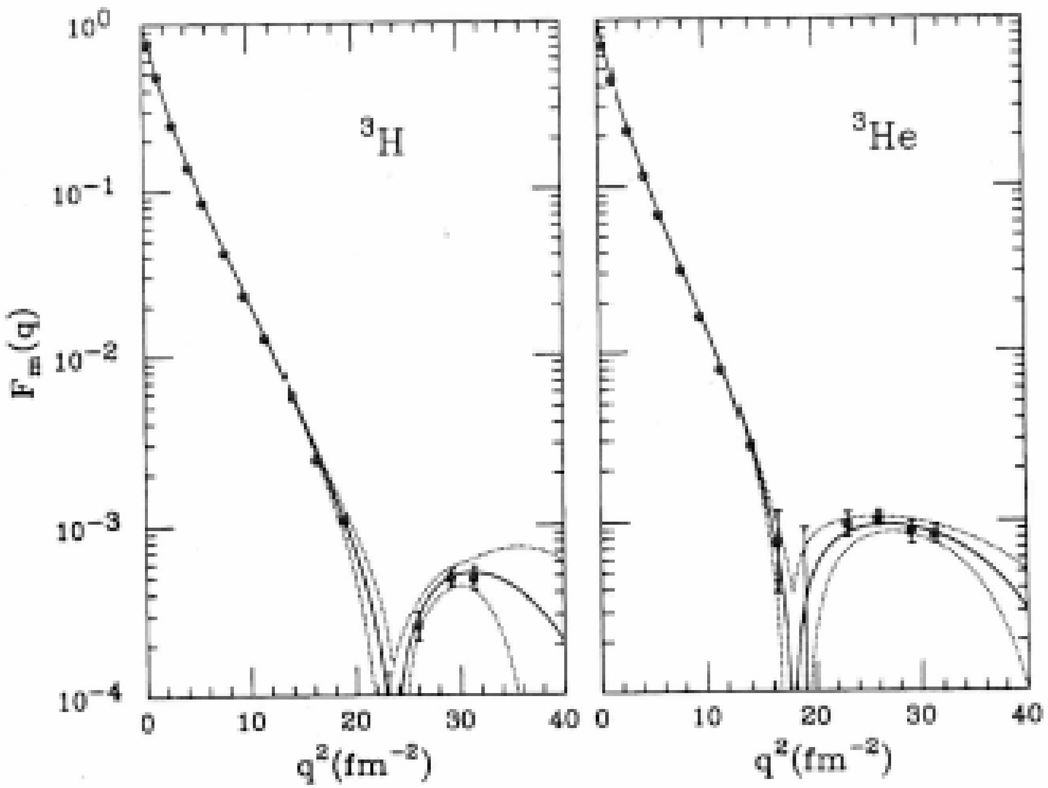

Fig. 7. Best-fit magnetic form factor for ^3H and ^3He (solid line) with limits of error band (dashed). The points correspond to values extracted via the usual Rosenbluth technique.

T=0,1 Separation Magnetic FF

^{3}H

A. Amroun et al. / Nuclear Physics A579 (1994) 596–626 619

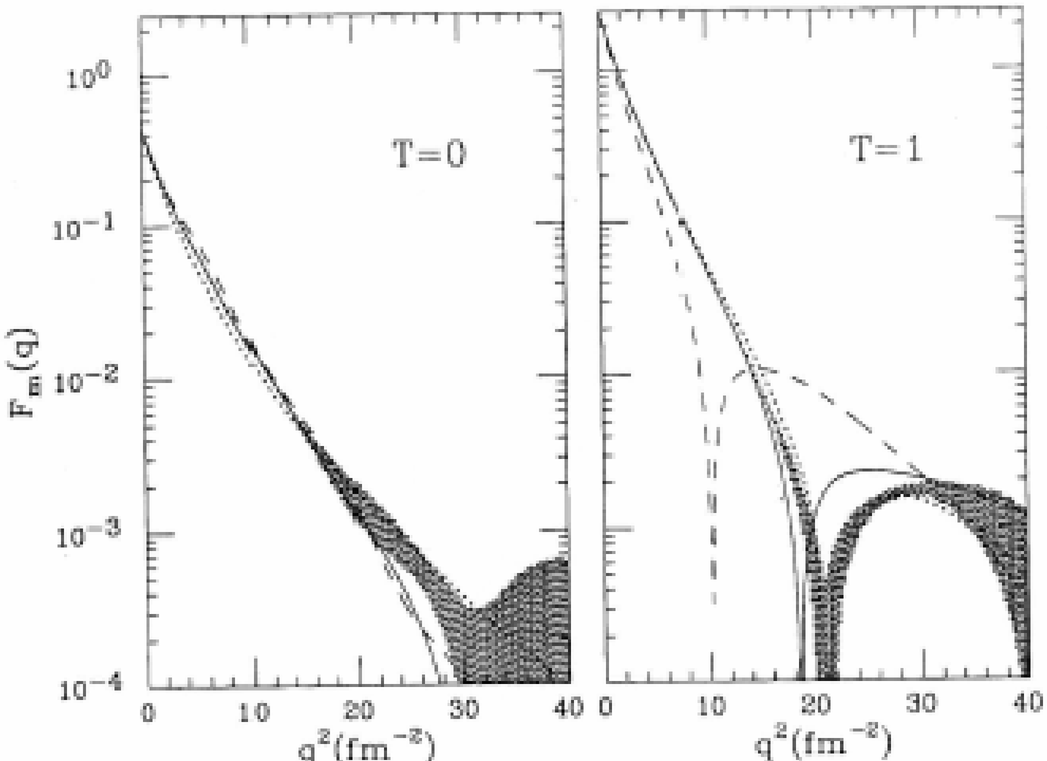

Fig. 13. Data for the $T = 0, 1$ magnetic form factor with calculations of Sauer et al. (solid) and Schiavilla et al. (dotted). The IA of Sauer et al. is shown as a dashed line.

Form Factors

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Form factors are well measured and in agreement with theory to q^2 of about 20-25 fm^{-2}. The theory also explains A=2,3,4 nuclei up to about this value.

Above this value, there are inconsistencies between the A=2,3,4 nuclei, and data becomes poor, esp. for ^3H.

Conclusion of Rocco – need determination of second minimum in ^3H magnetic FF (q^2~40 fm^{-2})

Coulomb Sum Rule

^{3}H

A fundamental property of any strongly interacting system is the two body distribution function.

In nuclei, the proton-proton distribution function (PPDF) is related to the integral of the longitudinal response function.

The PPDF is sensitive to short range correlations.

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Coulomb Sum Rule

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The Coulomb sum is defined as below. G_E is the effective proton electric form factor in the nucleus.

$$S_L(k) = \frac{1}{Z}\int_{\omega_{el}^+}^{\infty} d\omega \frac{R_L(k,\omega)}{\left[G_{E,p}(k,\omega)\right]^2}$$

$$\equiv 1 + \rho_{LL}(k) - Z\frac{\left|F_L(k)\right|^2}{\left[G_{E,p}(k,\omega_{el})\right]^2}$$

ρ_{LL} is the long.-long. dist. function and F_L is the elastic form factor.

Coulomb Sum Rule

^3H

For tritium, ρ_{LL} is zero if only proton is considered.
But… measured value is non-zero.

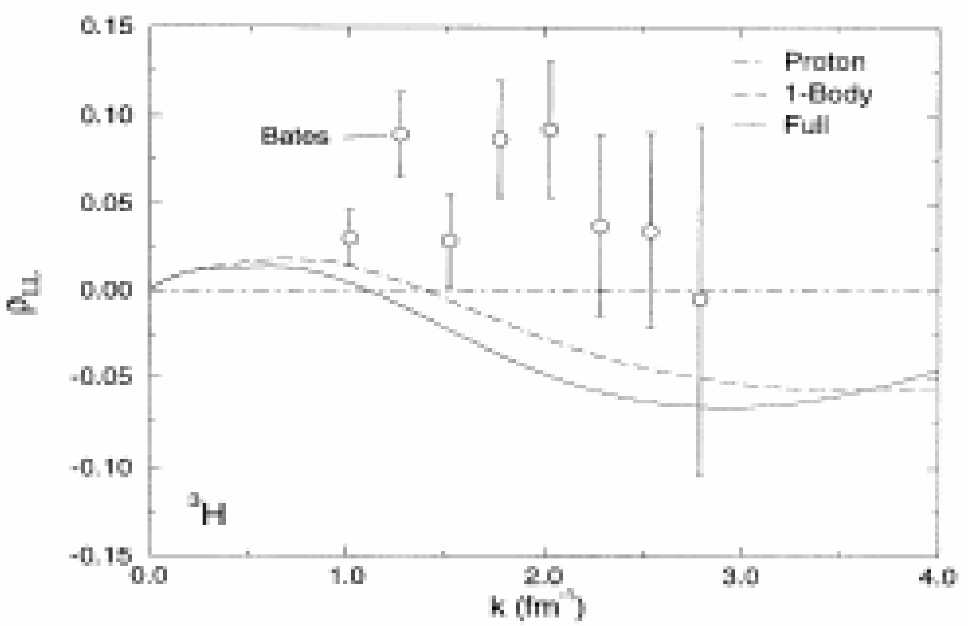

FIG. 3. Same as in Fig. 1 but for ^{3}H.

Data from Bates (Beck et al. PRL 64, 268 (1990)

Calculation from Schiavilla, Wiringa, Carlson, PRL 70, 3856 (1993).

Coulomb Sum Rule

^3H

Schiavilla et al. also find a 10% discrepancy between calculation and sum rule for ^3H.

We don't know if the problem is with the experiment, the theory (or both), but it is clear that we are not "done" with ^3H and another experiment is needed.

Measurement of FF and Coul. Sum

^{3}H

Cathleen Jones made count rate estimates to measure and separate FF for 1999 workshop.

Separation of charge and magnetic form factors require measurements at many angles and energies.

Jones estimated separation could be done to 50 fm^{-2} and F_M to 100 fm^{-2}.

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Elastic Form Factors

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Energy	Angles	Q^2	Time
1.6 GeV	30-66	16-58 fm^{-2}	31 hr
2.4	19-43	16-56	28
3.2	14-32	16-70	40
3.6	12-34	18-95	297
4.0	12-31	27-100	200
Total			596 hours
			About 25 days

Coulomb Sum Rule

^{3}H

No detailed calculations have been made but…

Should be similar to ^{4}He measurements proposed by Chen, Choi, and Meziani

Requires many beam energies – 0.4-1.2 GeV in 0.1 GeV steps, 1.2-4.0 GeV in 0.4 GeV steps.

Time estimate is of order 10 days.

Polarization Transfer

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All measurements of the neutron form factors rely on deuterium or ^3He targets.

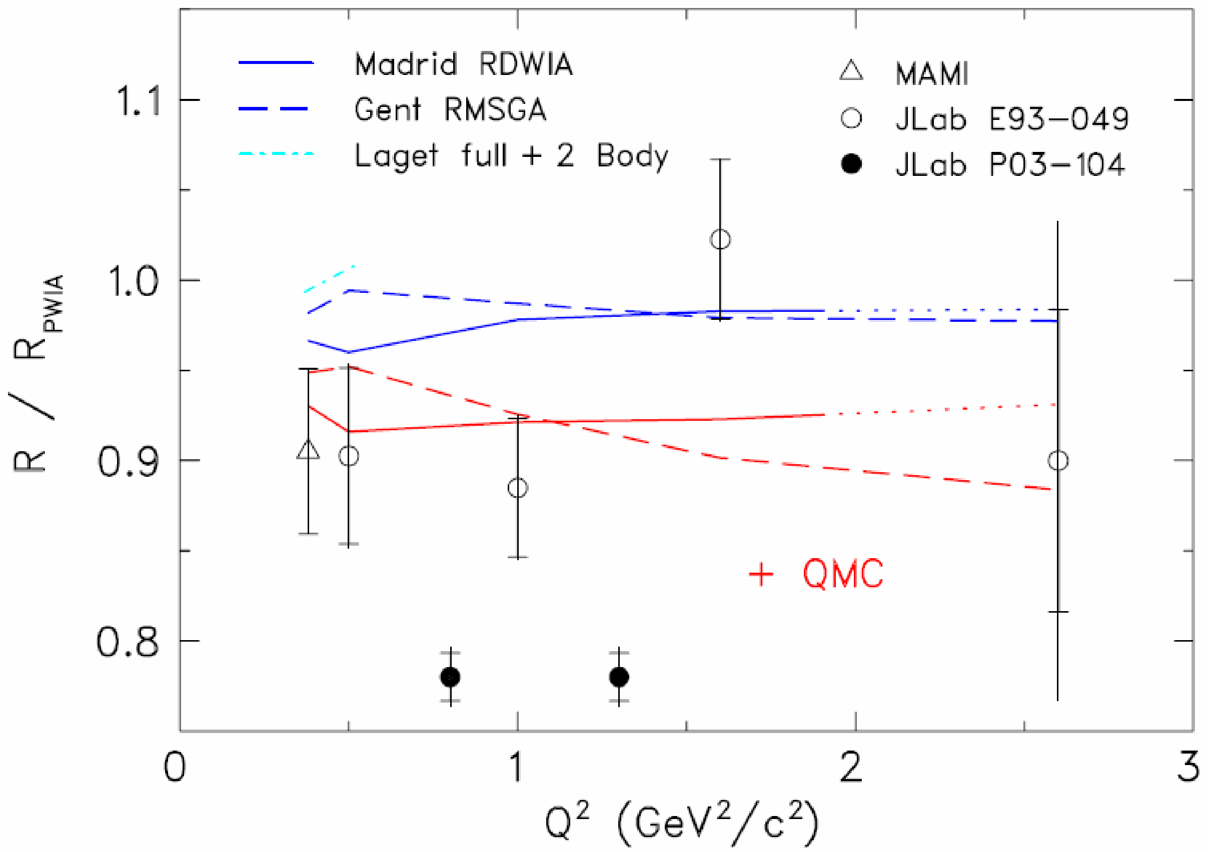
Measurements on ^4He have shown larger deviations than predicted – Medium modifications? Incomplete models? Whatever the case, our model of light nuclei is still incomplete.

How good are extractions of neutron FF from ^3He?

We don’t really know with any precision.

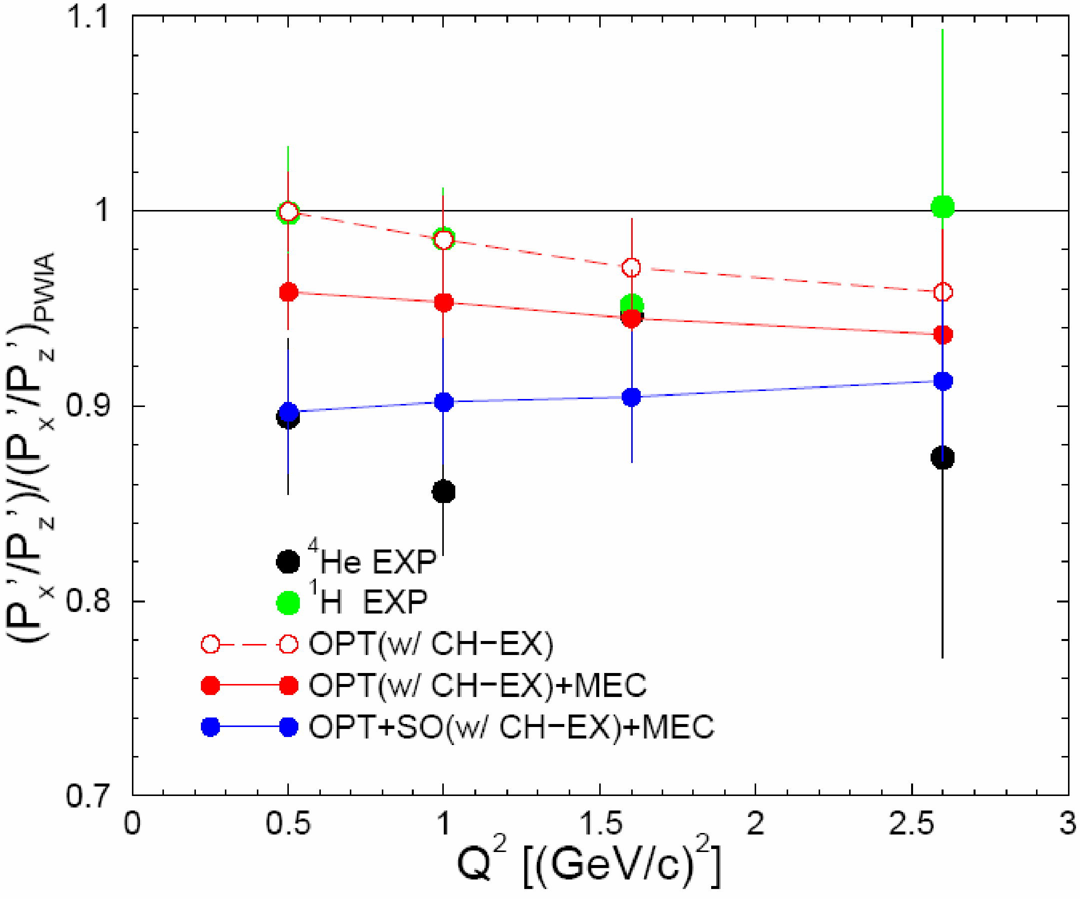
Polarization Transfer

^3H



Polarization Transfer

^3H



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Polarization Transfer

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High precision polarization transfer measurements can be made in a relatively short time (10-15 days).

Check on models used to extract neutron form factors.

Summary of Program

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At least 4 worthwhile experiments could be performed in 4-6 months.

Need many lower energies – a good time would be at start of upgrade, before Hall D fully online

Possible Target

^3H

High pressure (16 atm) at 45 K

40 cm long cylinder 1.5 cm diameter

Luminosity – 3 x 10^{37} for 10 cm @ 80 μA

Activity – 20 μCi

Allows coincidence or two arm experiments (not possible with liquid target).

Polarized Target

A polarized tritium target would be nice for lots of experiments.

But – difficult to build, not very thick (probably only 0.2-0.3 g of tritium), can't handle much beam.

A technical challenge, but if unpolarized target is built approved, may be worth pursuing.

Safety Issues

^{3}H

- Mass of tritium is small, < 3 g (1g/kCi)
  - NOT a significant explosion hazard
  - Volume at STP is about 25 liters – less than 1 cubic foot
- Burned tritium (i.e. tritiated water) is greatest hazard
  - Gas molecules will exchange with hydrogen in water vapor
- Catastrophic release must be vented high enough to limit exposure at site boundary to allowed value
  - DOE limit is 100 mrem, JLab design goal is 10 mrem
- Requires appropriate plumbing and exhaust stack to keep site boundary exposure below JLab goal
  - 40 ft high stack should be sufficient for 20-30 kCi

Plans

- Workshop early 2005 to firm up physics case, identify other possible experiments
- Define safety issues
- Cost estimate for target and modifications to hall
- Approval from Management & PAC

Conclusions

- A complete "standard model" of nuclear physics is still lacking
- Measurement of ^{3}H needed to complete the program JLab was built for!
- $^{3}H/^{3}He$ measurements can contribute significantly to the important problem of the u/d ratio as well as understanding the EMC effect in light nuclei.
- An unpolarized target is technically fairly simple and can be built to satisfy safety considerations
- A polarized target is more difficult – needs development
- The time to do ^{3}H experiments is at the start of the upgrade

Concluding Thanks

Much of the material for this talk was from work presented at the 1999 workshop. I want to particularly note the following:

Cathleen Jones, Bob May, Wally Melnitchouk, Makis Petratos, Rocco Schiavilla, and Steffen Strauch.

Also thanks to Jen-Chieh Peng and Jorge Morfin for slides in the u/d ratio.