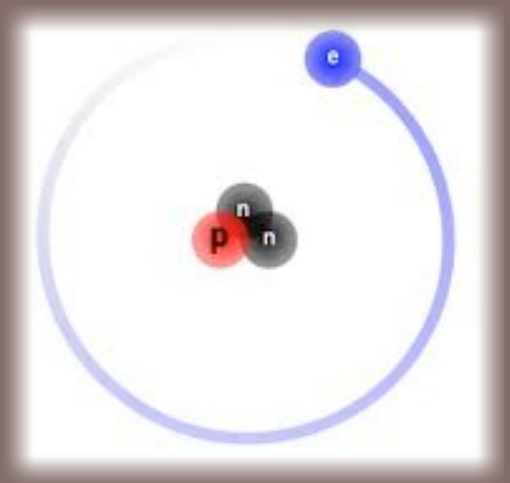
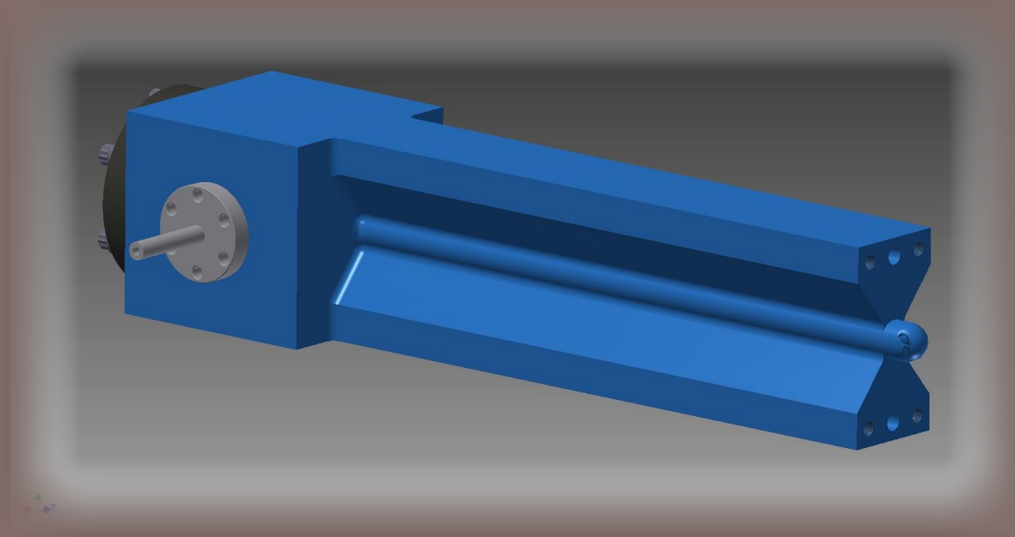
# Measurements with Tritium in Hall A

*Patricia Solvignon*

Jefferson Lab



Users Group Meeting
JLab
May 29-31, 2013

# Outline

**Tritium target: description and status**

**The MARATHON experiment**

**The x>1 experiment**

**New proposals: $^3$A(e,e'p) & Triton Elastic**

**Summary**

# Tritium target: people involved

**Tritium Target Task Force:**

R. J. Holt (ANL), A. Katramatou (Kent State),
W. Korsch (Univ. of Kentucky), D. Meekins (JLab),
T. O'Connor (ANL), G. Petratos (Kent State Univ.),
R. Ransome (Rutgers Univ.), J. Singh (ANL),
P. Solvignon (JLab) and B. Wojtsekhowski (JLab)

**Design Authority and Project Manager:** David Meekins (JLab)

**Target Design and ESH Informational Meeting** (JLab) Mar 8, 2010
**Target Conceptual Design and Safety Review** (JLab) June 3, 2010
**Target Design and RadCon meeting** (JLab) May 30, 2012
**Tritium Collaboration meeting** (JLab) May 21, 2013

Slide from Thia Keppel

# Hall A Projected Experiment Schedule as of 8/2012

| | February - May | August – December | February - June | August - December | February - June | September - December |
|---|---|---|---|---|---|---|
| 2014 | GMp / DVCS – I (APEX) | GMp / DVCS - I | | | | |
| 2015 | | | $^3H/^3He$ ($A_1^n$) | PREX (APEX) | | |
| 2016 | | | | | $A_1^n$ (SBS) (DVCS-II) (APEX) | SBS ($A_1^n$) (DVCS-II) (APEX) |

Experiments in parentheses represent potential schedule changes.

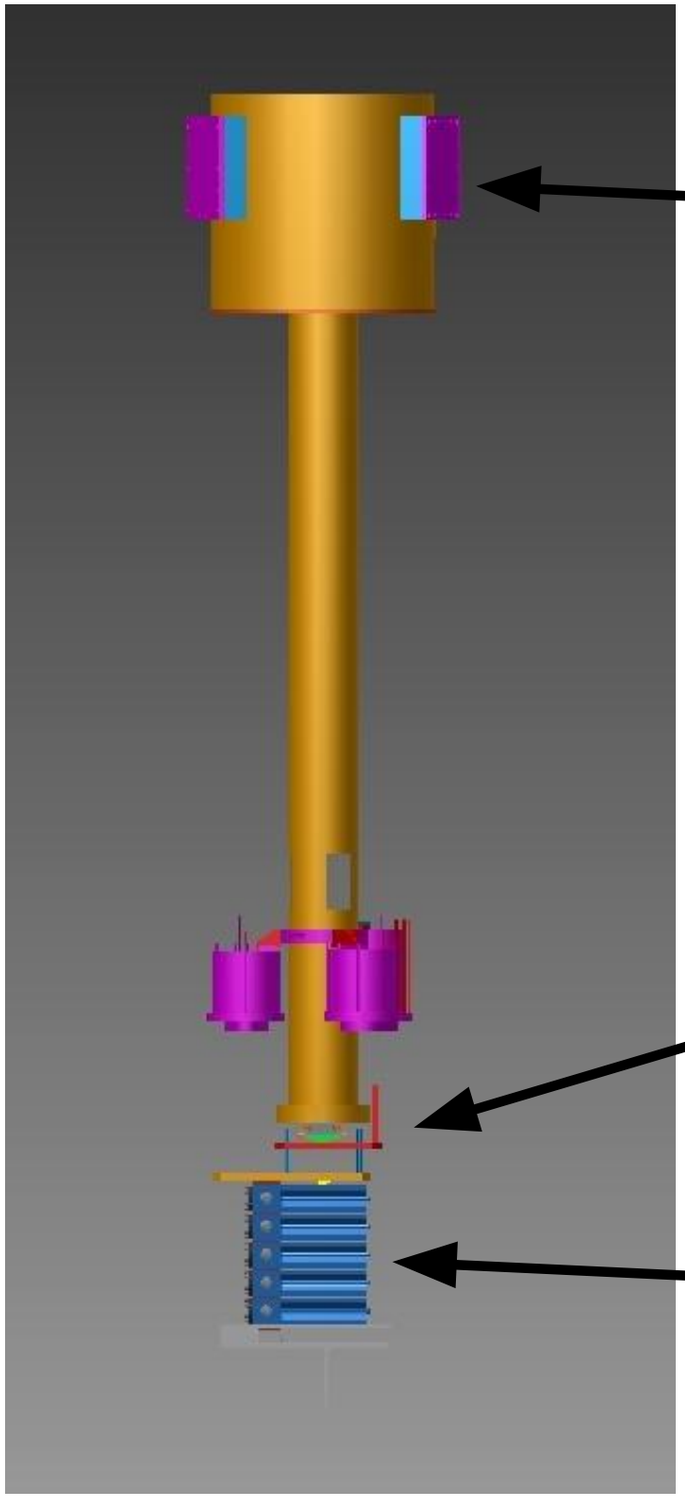
SBS →

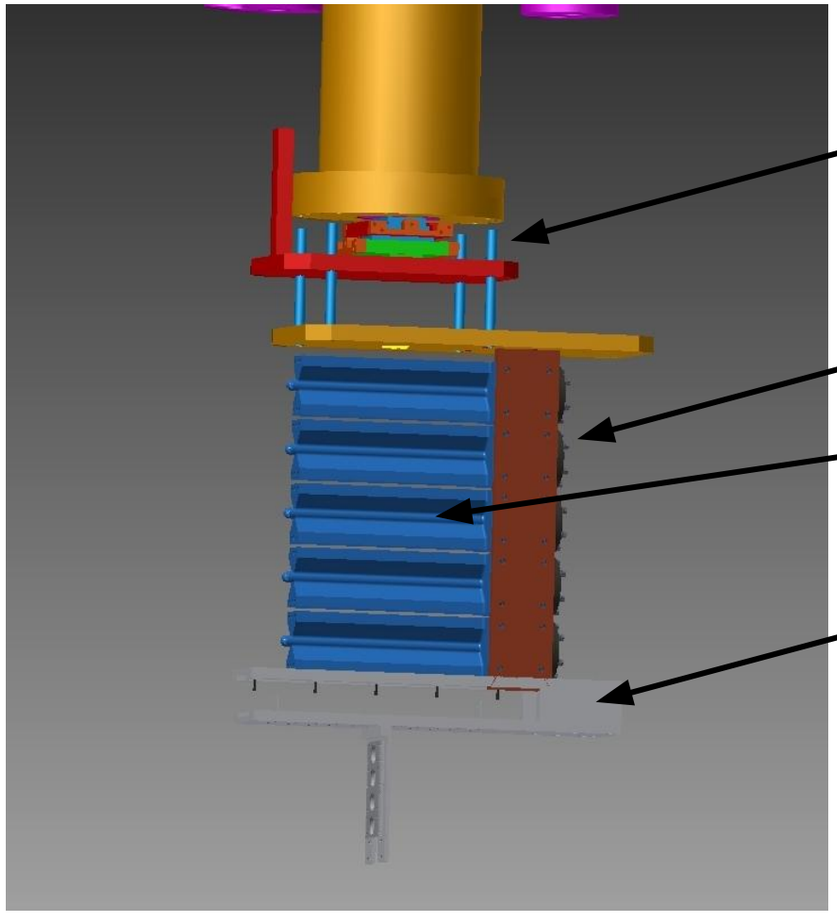
MOLLER, SOLID…?…

# Tritium targets at Electron Accelerators

| Lab | Year | Quantity (kCi) | Thickness ($g/cm^2$) | Current (μA) | Current *x* thickness (μA-$g/cm^2$) |
|---|---|---|---|---|---|
| Stanford HEPL | 1963 | 25 | 0.8 | 0.5 | 0.4 |
| MIT-Bates | 1982 | 180 | 0.3 | 20 | 6.0 |
| SAL | 1985 | 3 | 0.02 | 30 | 0.6 |
| Saclay | 1985 | 10 | 1.1 | 10 | 11.0 |
| JLab | (2015) | 1 | 0.084 | 25 | 2.1 |

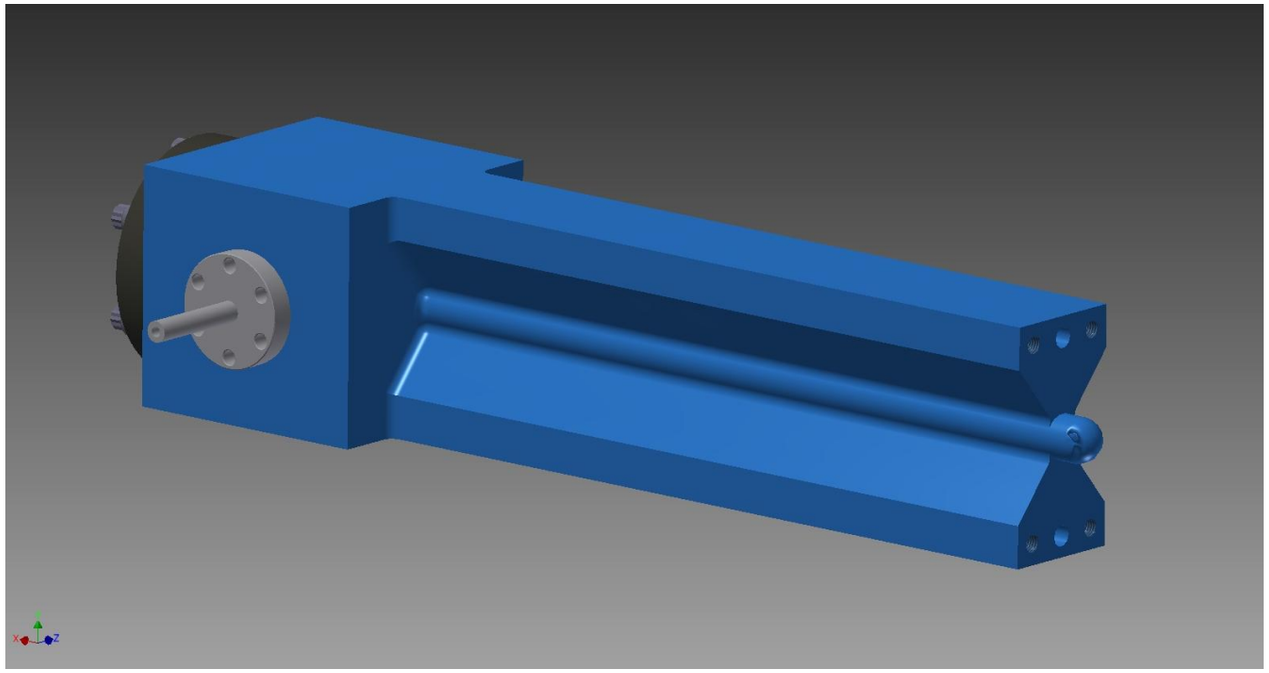
# Complete target stack

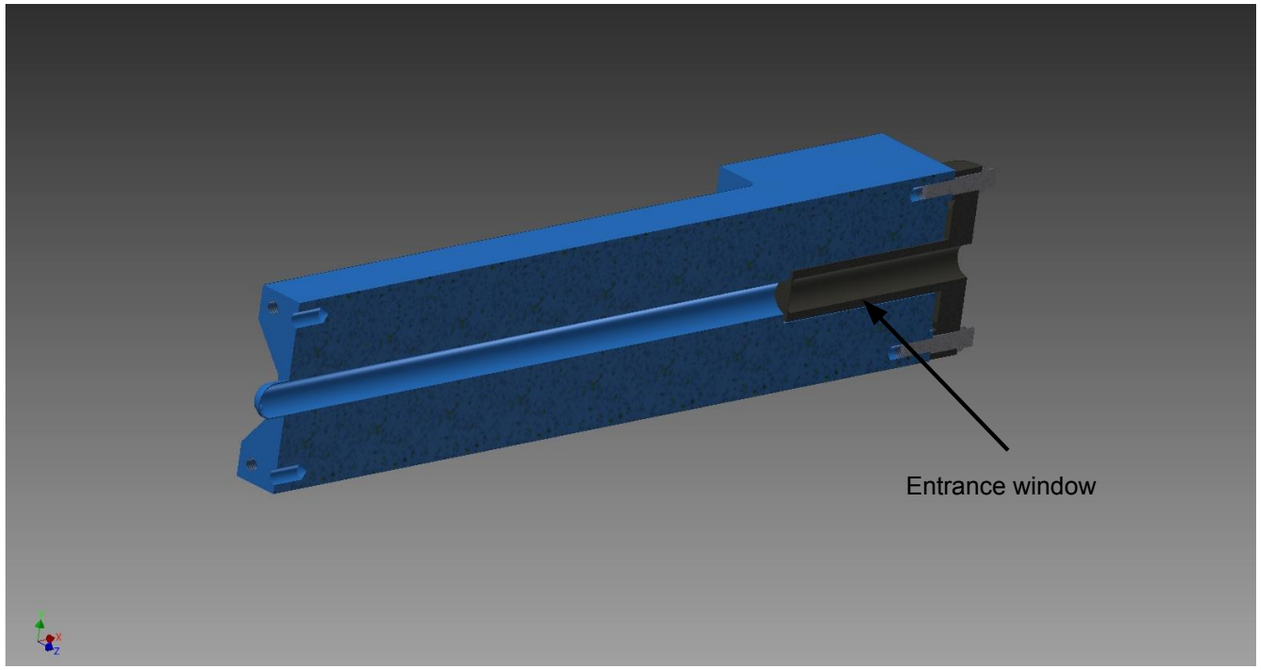



- 5 cells mounted to heat sink (T2, D2, H2, He3, empty cell)
- Use 15K He from ESR to stabilize and cool the cells (use the standard cryotarget cryostat for this)
- Alignment and optics target
- Total stack height is ~ 24 inches

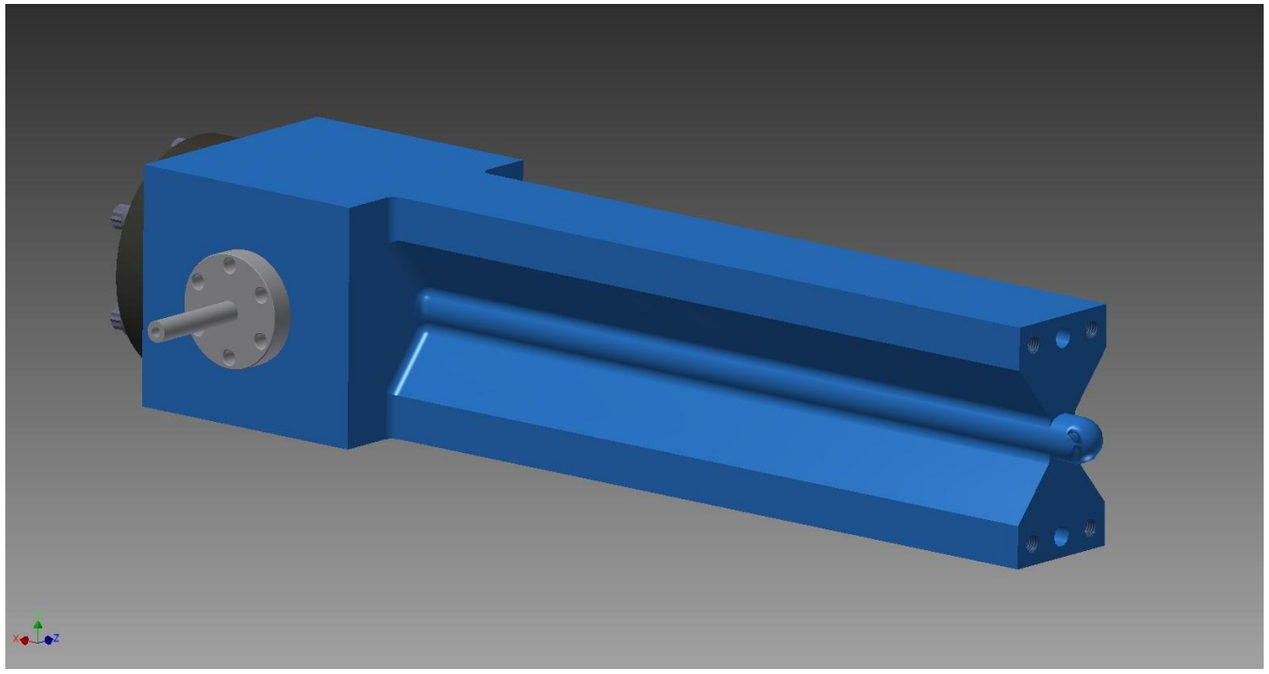
# Cell design and pressure testing

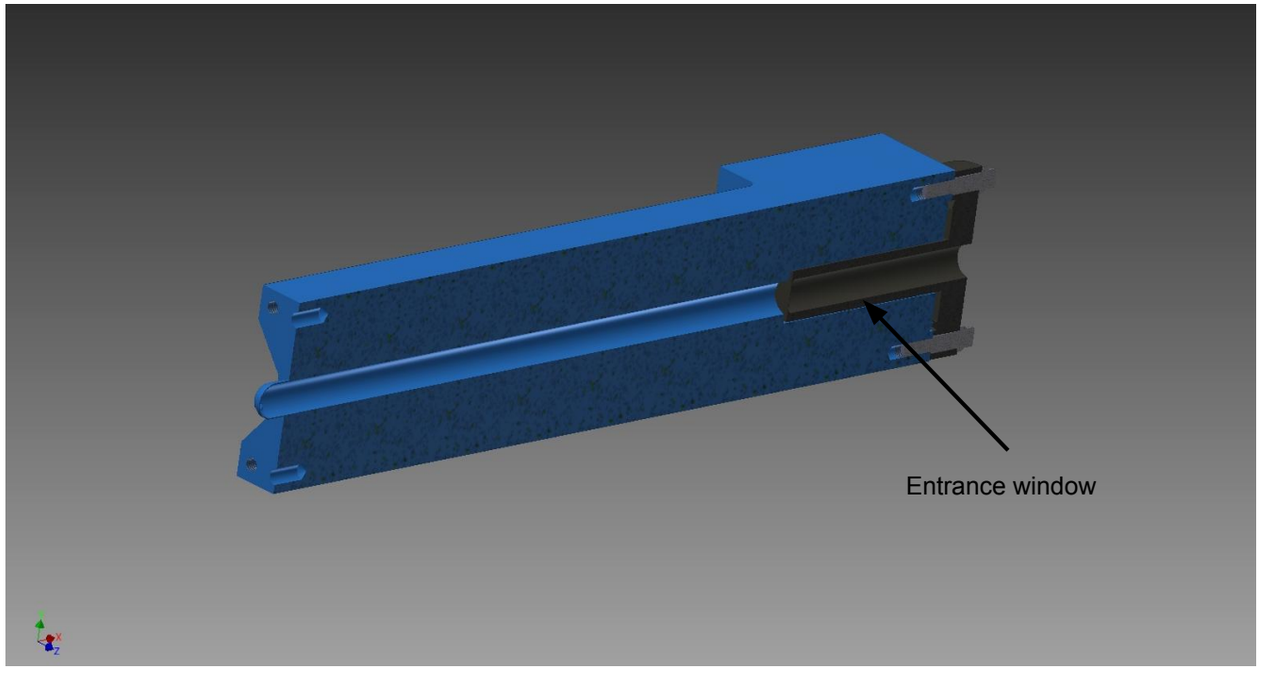




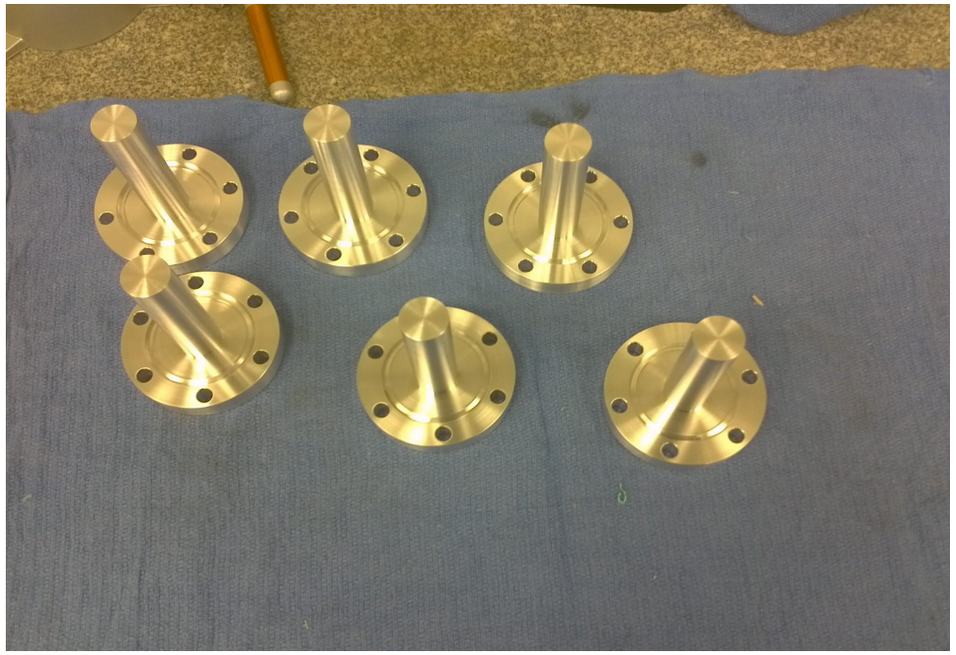

- Prototype cell made at Rutgers U. machine shop
- Made from Al 7075-T651
- Entrance windows attached with CF flange
- Design pressure: T2 = 200 psi, 3He = 375 psi
- Contains 1 kCi of T2
- Window thicknesses: entrance: 0.010 inch, exit: 0.010-0.018 inch, wall: 0.018 inch

# Cell design and pressure testing

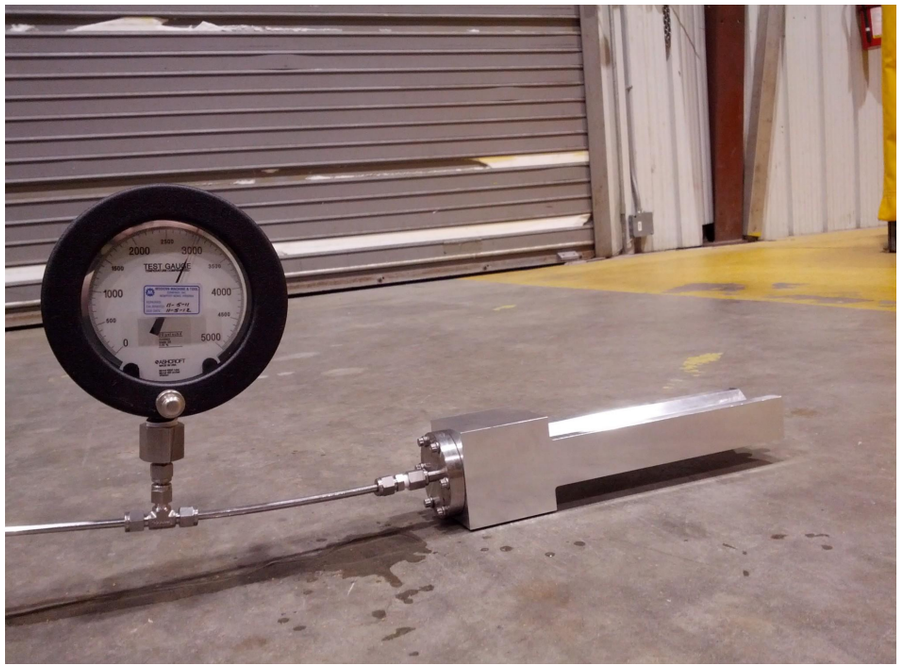





**Entrance window:**
**burst pressure 2900 psi**



**Main body:**
**burst pressure 3500 psi**
**factor of ~10 for safety**



Cell wall thickness at thinnest point was 0.014 inch

# More about the Tritium target system

- Filling cells:
  - Tritium cell will be filled at Savannah River Site (SRS) located in South Carolina
  - Other cells can be filled at JLab
- Scattering Chamber:
  - Pumps vented to outside stack
  - T2 detection (RGA with remote head for low P)
  - Reuse the Hall A target chamber
  - Require a hood system connected to vent
- Vent stack:
  - External stack of ~20m
  - Vent piping system connected to stack: 24/7 extraction fan, detection in piping for T2, air flow connected to FSD
  - Forced air/purged
- Beamline:
  - Require FSD on Raster
  - Beamline isolation: design by accelerator
  - Collimator: prevent steer and cell damage, design by accelerator
  - Best place for extra components: last girder

# Experiments planning to use it

**Approved experiment: MARATHON --> DIS**

**Approved experiment: Inclusive scattering at x>1**

**New proposal to PAC40: $^3$A(e,e'p)**

**LOI to PAC 40: Triton Elastic**

# E12-10-103

**M**e**A**surement of the $F_2^n/F_2^p$, $d/u$ **RA**tios and A=3 EMC Effect in Deep Inelastic Electron Scattering Off the **T**ritium and **H**elium Mirr**O**r **N**uclei.

Jefferson Lab PAC37 Proposal, December 2010

The JLab **MARATHON** Collaboration

Spokespeople: G. Petratos (Kent U.), J. Gomez (JLab), R. Holt (ANL), R. Ransome (Rutgers U.)

**Main physics goals**

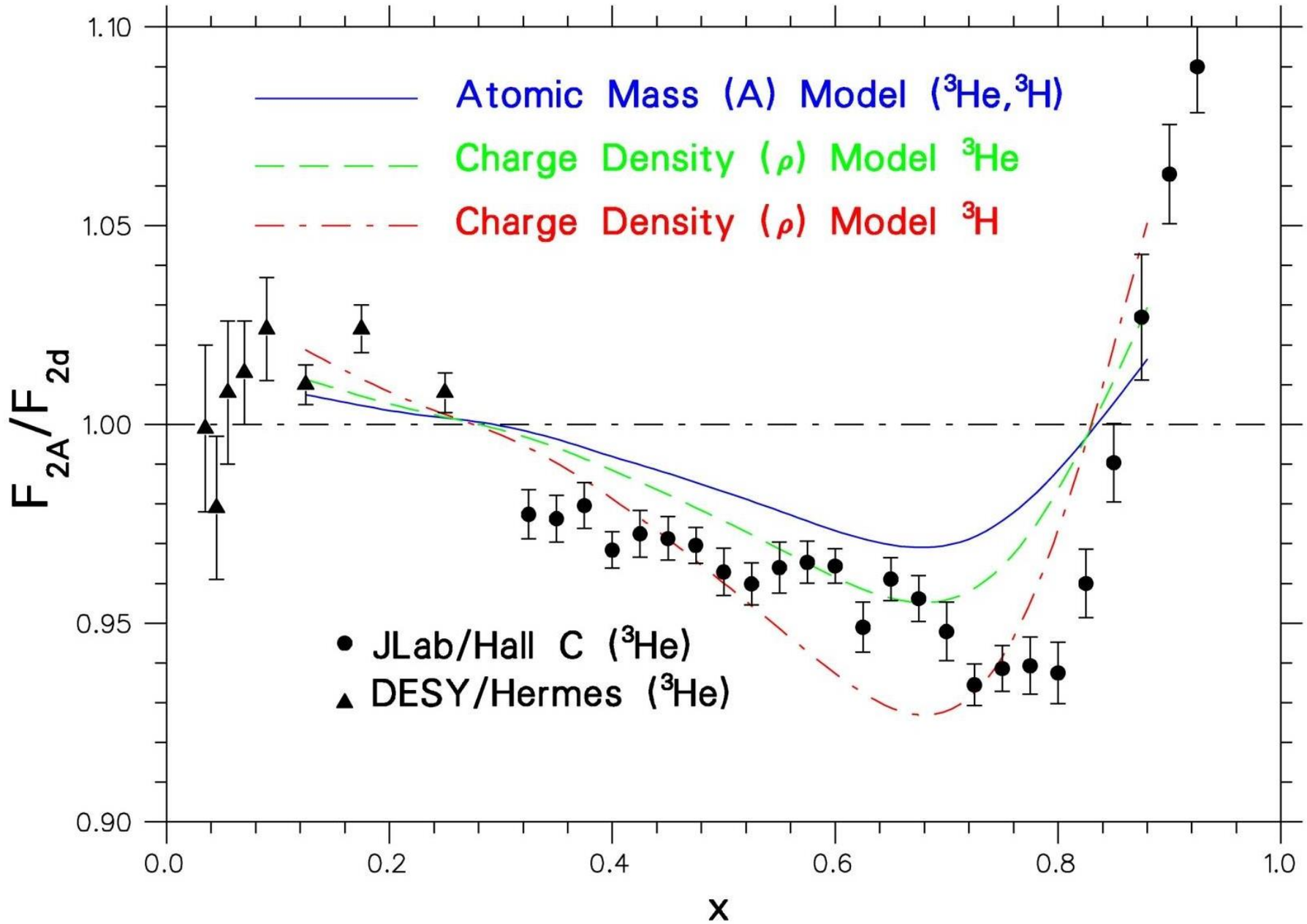
**EMC effect in $^3$H and $^3$He**

✓ A=3 data will be pivotal for the understanding of the EMC effect

✓ Ratio of the EMC effect in 3H and 3He is the best quantity for quantitative test of theory, free of most uncertainties

**Extraction of the ratios: n/p and d/u**

# EMC effect for A=3 mirror nuclei




**Hall A data on $^3$H, $^3$He will be of similar precision to Hall C data**

# MARATHON: nuclear corrections

**A way to get access to $F_2^n/F_2^p$**

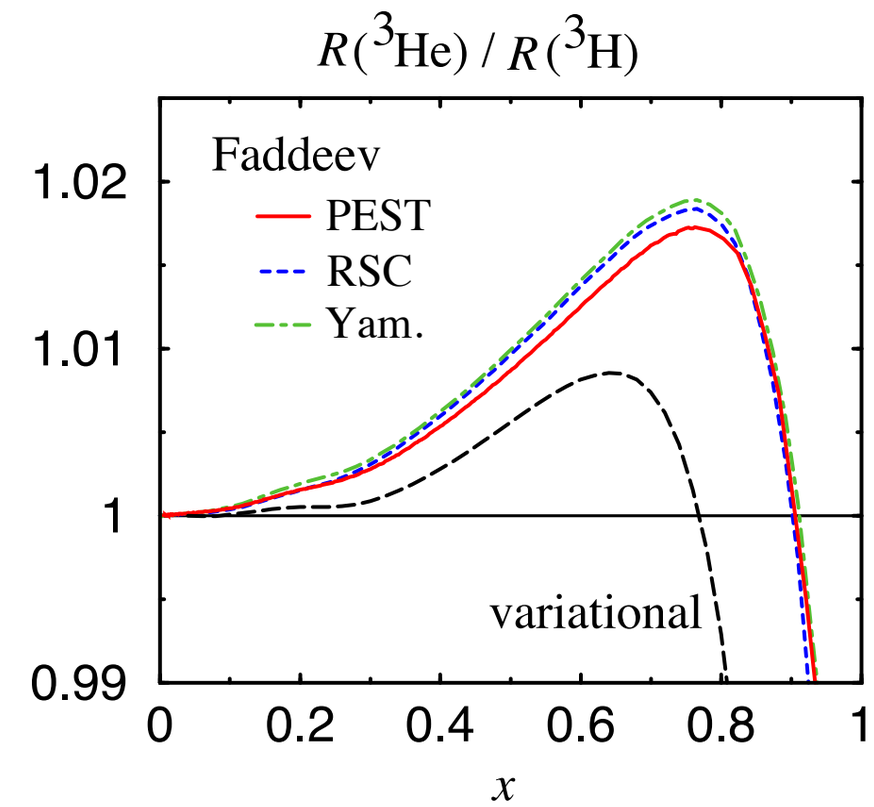
Measure $F_2$'s and form ratios:

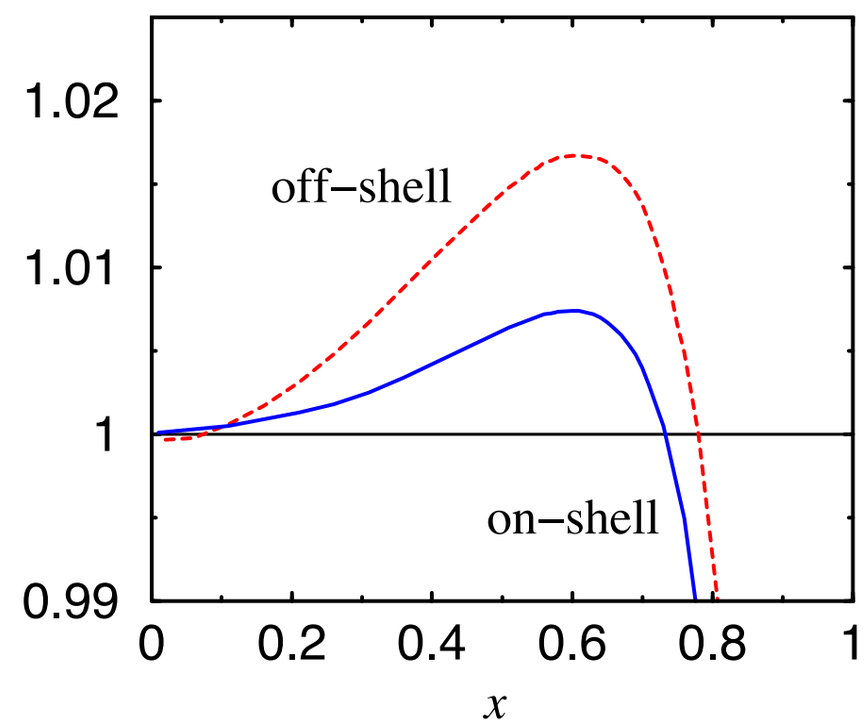
$$R(^3He) = \frac{F_2^{^3He}}{2F_2^p+F_2^n},\ R(^3H) = \frac{F_2^{^3H}}{F_2^p+2F_2^n}$$

Form "super-ratio": $r \equiv \frac{R(^3He)}{R(^3H)}$

then

$$\frac{F_2^n}{F_2^p} = \frac{2r - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - r}$$



# MARATHON: Physics motivations

SU(6)-symmetric wave function of the proton in the quark model (spin up):

$$|p\uparrow\rangle = \frac{1}{\sqrt{18}}\left(3u\uparrow[ud]_{S=0} + u\uparrow[ud]_{S=1} - \sqrt{2}u\downarrow[ud]_{S=1} - \sqrt{2}d\uparrow[uu]_{S=1} - 2d\downarrow[uu]_{S=1}\right)$$

u and d quarks identical, N and Δ would be degenerate in mass.

In this model: d/u = 1/2, $F_2^n/F_2^p$ = 2/3.

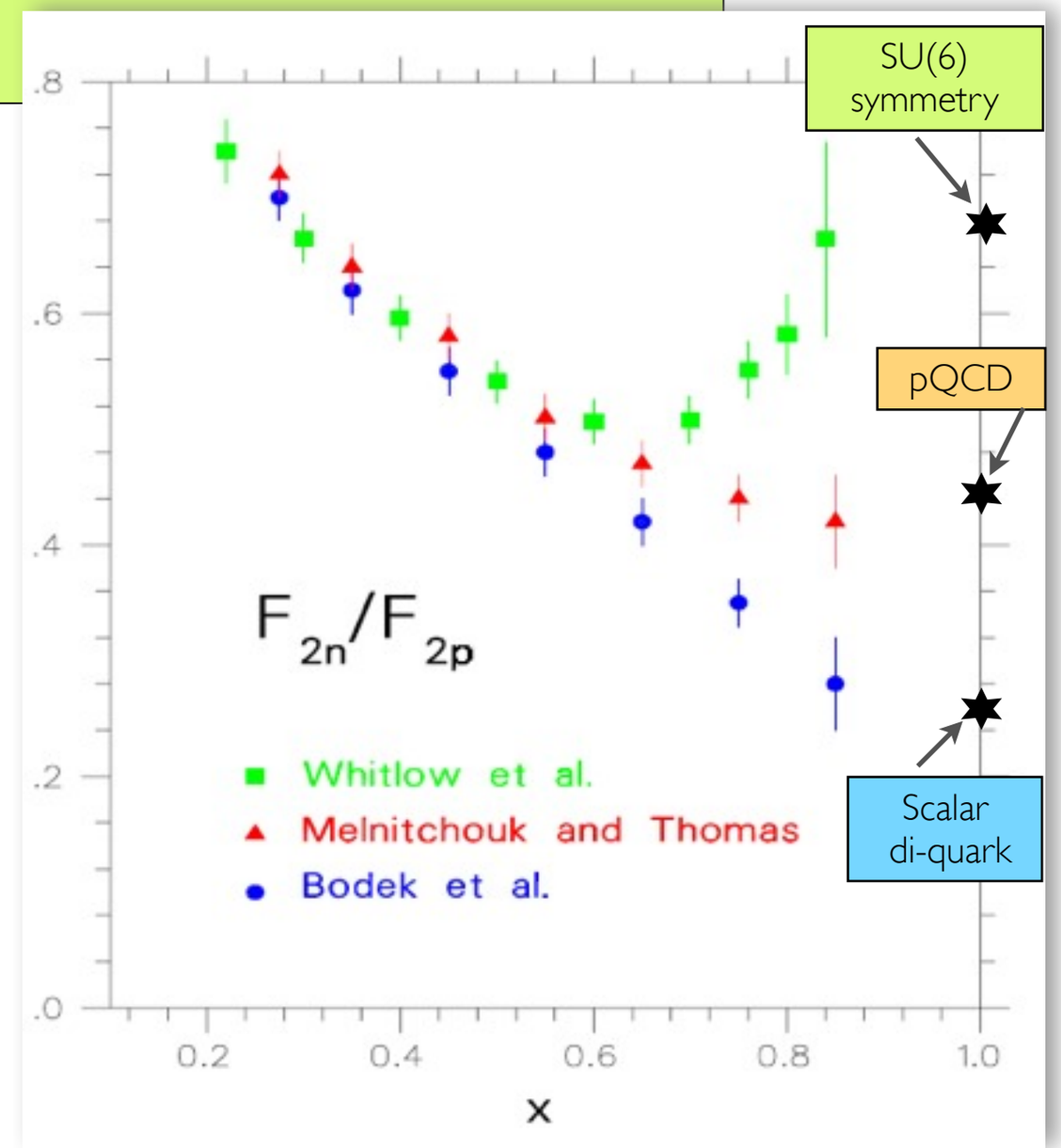
pQCD: helicity conservation (q↑↑p)

=> d/u =2/(9+1) = 1/5, $F_2^n/F_2^p$ = 3/7 for x ->1

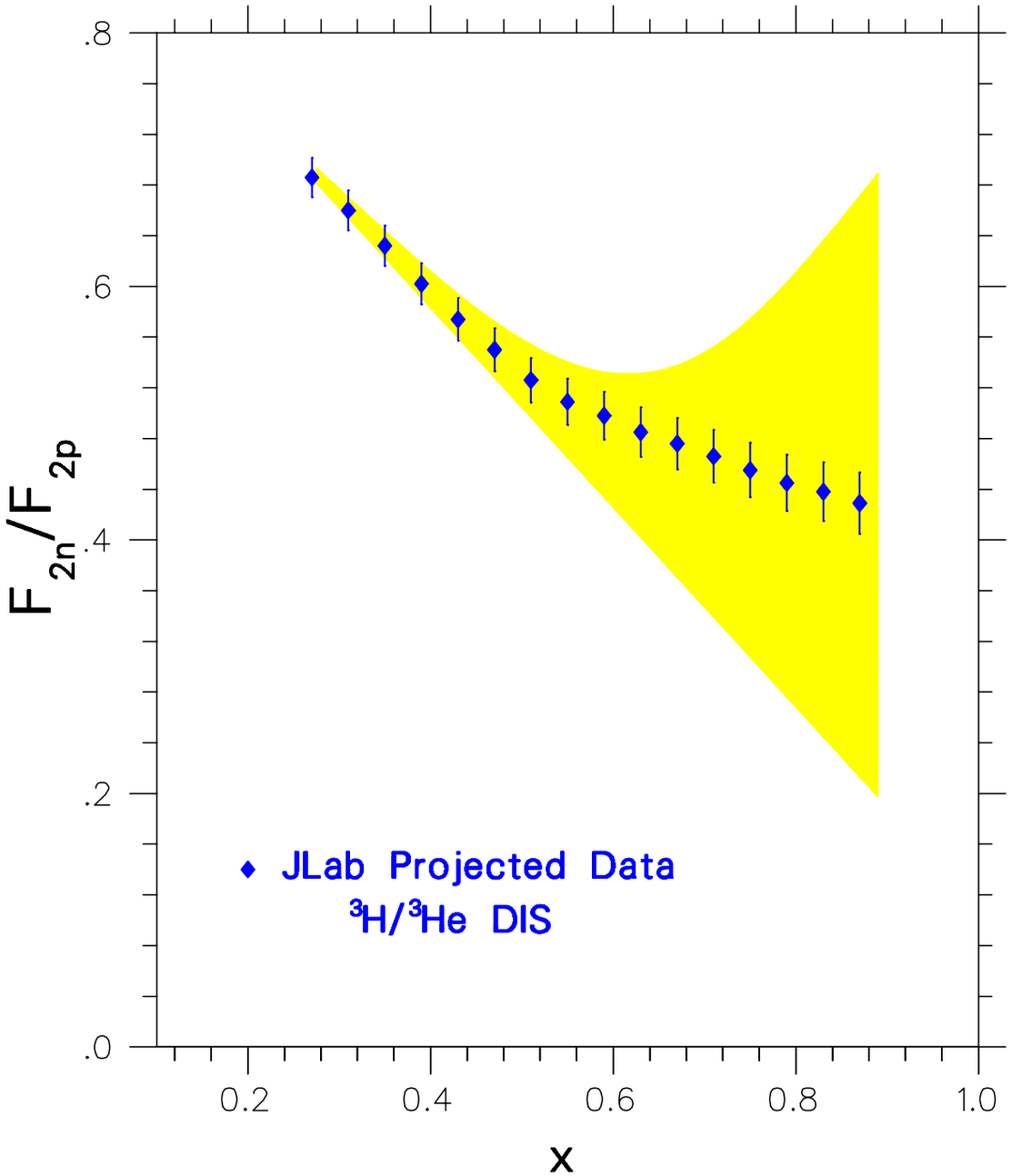
SU(6) symmetry is broken: N-Δ Mass Splitting

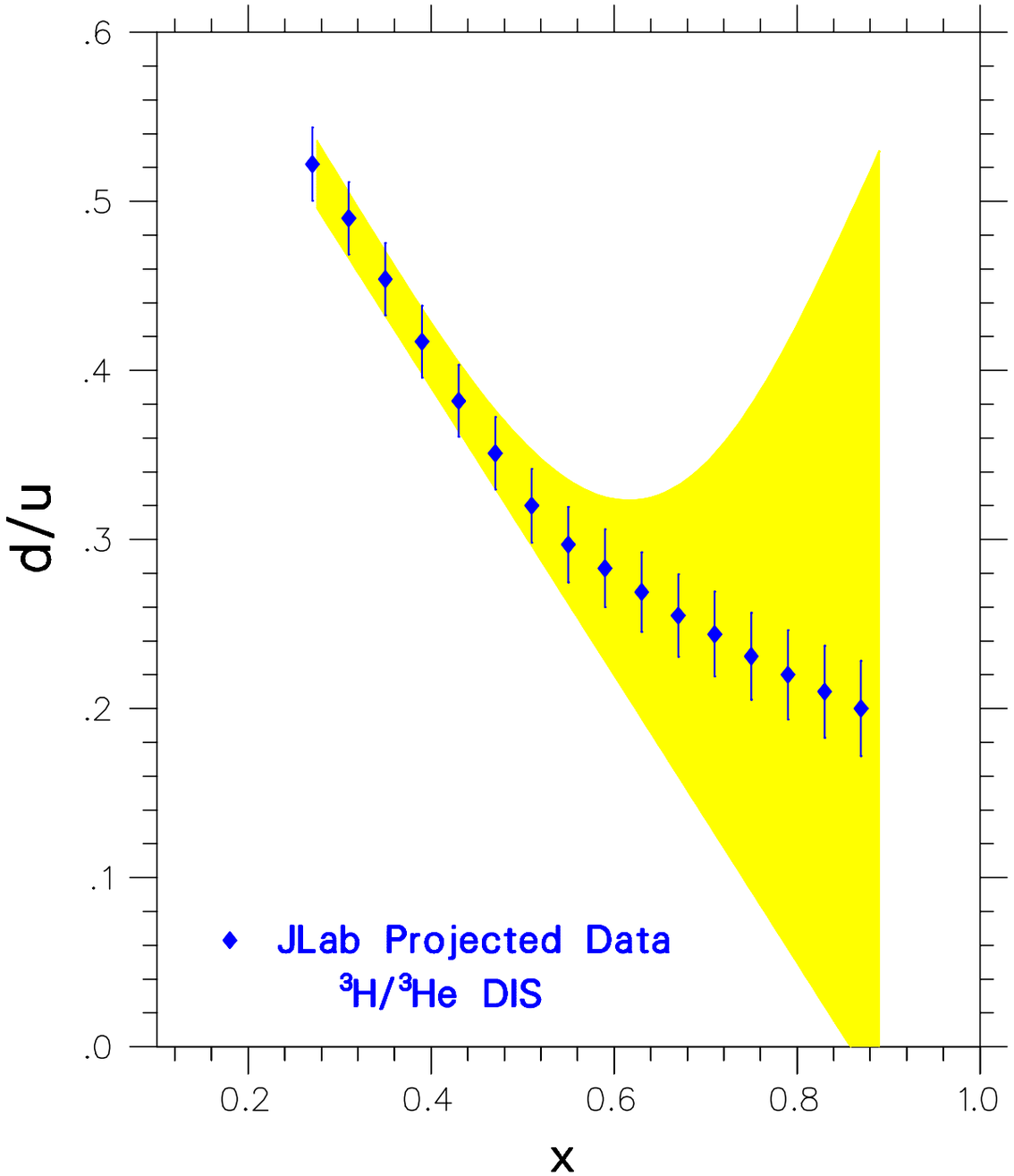
- Mass splitting between S=1 and S=0 diquark spectator.
- symmetric states are raised, antisymmetric states are lowered (~300 MeV).
- S=1 suppressed

=> d/u = 0, $F_2^n/F_2^p$ = 1/4, for *x* -> 1



# MARATHON: n/p and d/u projections



# MARATHON: Experimental Plan

- $^3$He/$^3$H DIS measurements approved to run in Hall A:
  - Beam Energy: 11.0 GeV – Beam Current: 25 μA
  - Small angles (15$^o$ - 23$^o$): Left HRS system
  - Large angles (4 settings: 42$^o$ , 47$^o$ , 52$^o$, 57$^o$): BigBite system
  - ~700 hours for *d/u* measurement (@ 100% efficiency)
- Desirable to check that the ratio $R=\sigma_L/\sigma_T$ is the same for $^3$He and $^3$H: Rosenbluth separation of DIS cross section. Need dedicated 3.3, 4.4, 5.5, 6.6, 7.7, 8.8 GeV energies.
  - Wide angular range (13$^o$ - 68$^o$): Left HRS system
  - ~300 hours for $R=\sigma_L/\sigma_T$ measurement (@ 100% efficiency)

# E12-11-112

## Precision measurement of the isospin dependence in the 2N and 3N short range correlation region

Spokespeople: P. Solvignon (JLab/UNH), J. Arrington (ANL), D. Day (UVa), D. Higinbotham (JLab)

### Main physics goals

**Isospin-dependence**

- ✓ Improved precision: extract R(T=1/T=0) to 3.8%
- ✓ FSI much smaller (inclusive) and expected to cancel in ratio

**3N SRCs structure (momentum-sharing and isospin)**

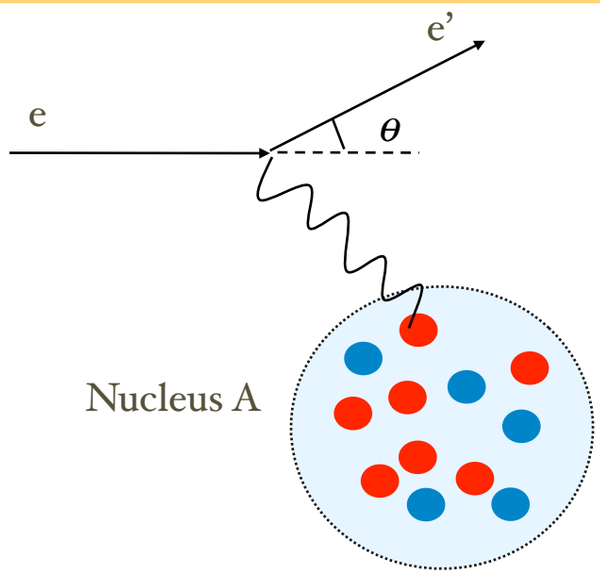
**Improved A-dependence in light and heavy nuclei**

- ✓ Average of $^3$H, $^3$He --> A=3 "isoscalar" nucleus
- ✓ Determine isospin dependence --> improved correction for N>Z nuclei, extrapolation to nuclear matter

**Absolute cross sections (and ratios) for $^2$H, $^3$H, $^3$He**: test calculations of FSI for simple, well-understood nuclei

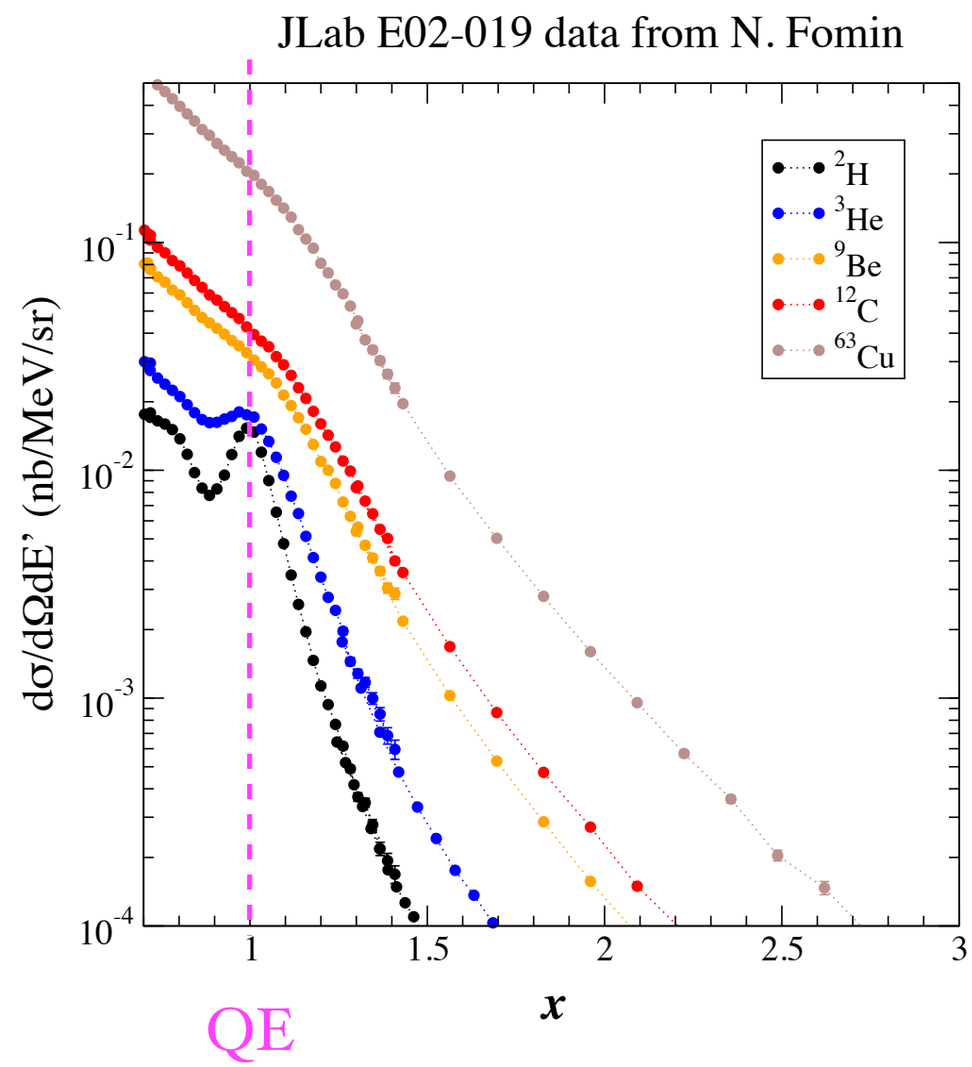
# Short-Range Correlations

## At $x \approx 1$: Quasi-Elastic Scattering



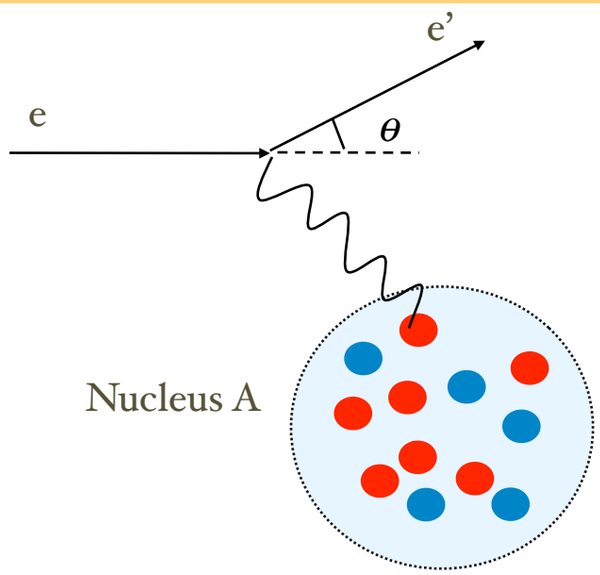

➡ Motion of nucleon in the nucleus broadens the peak.

➡ little strength from QE above x ≈ 1.3



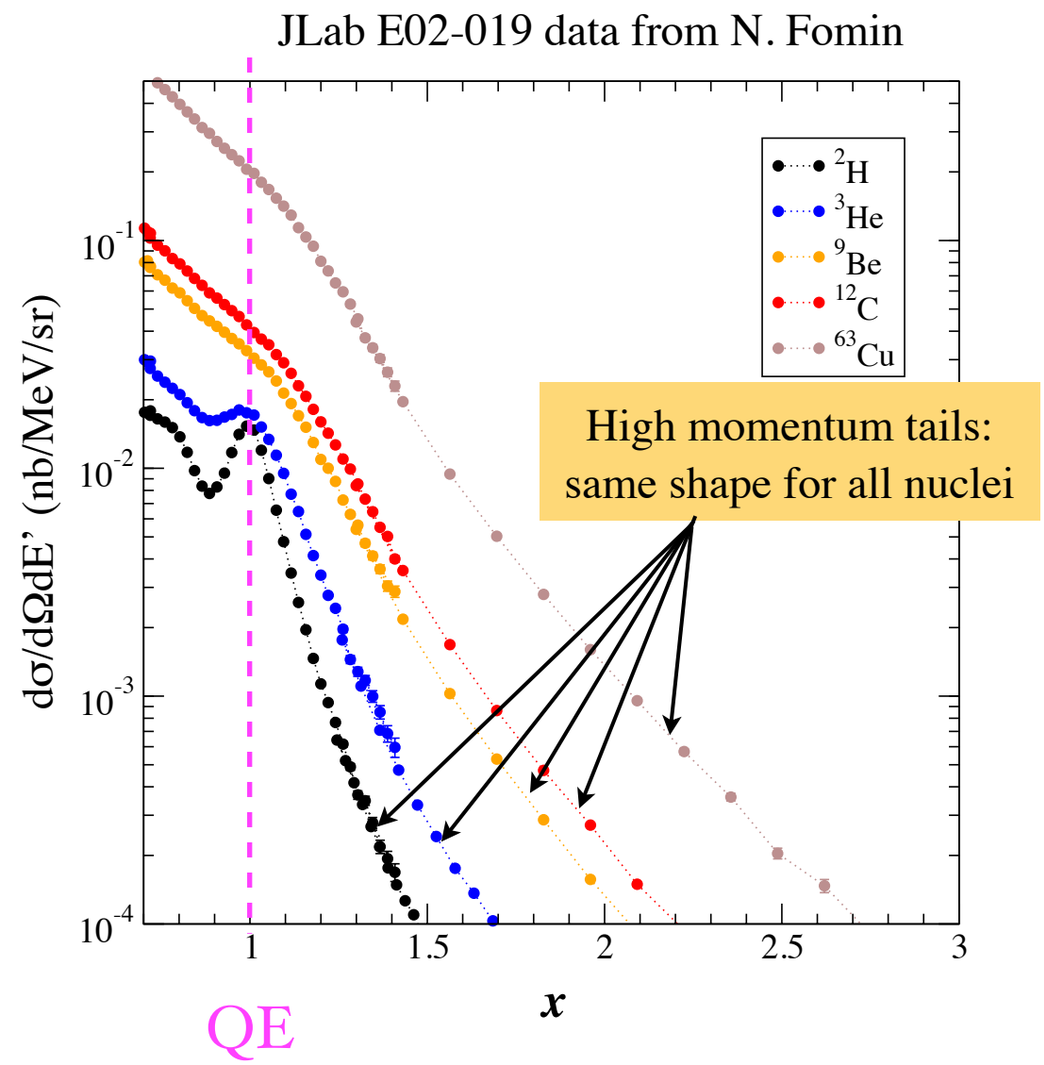
# Short-Range Correlations

## At $x \approx 1$: Quasi-Elastic Scattering

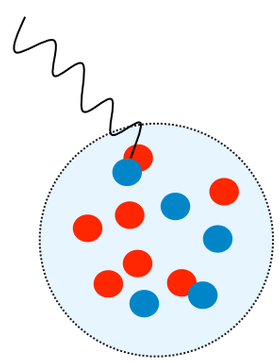



➡ Motion of nucleon in the nucleus broadens the peak.

➡ little strength from QE above x ≈ 1.3

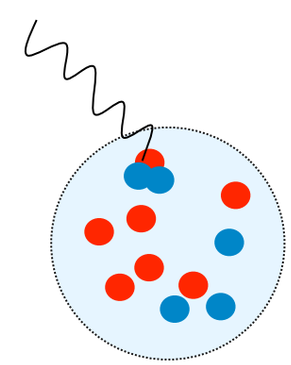



*1<x<2:*



2N-SRC

*2<x<3:*



3N-SRC

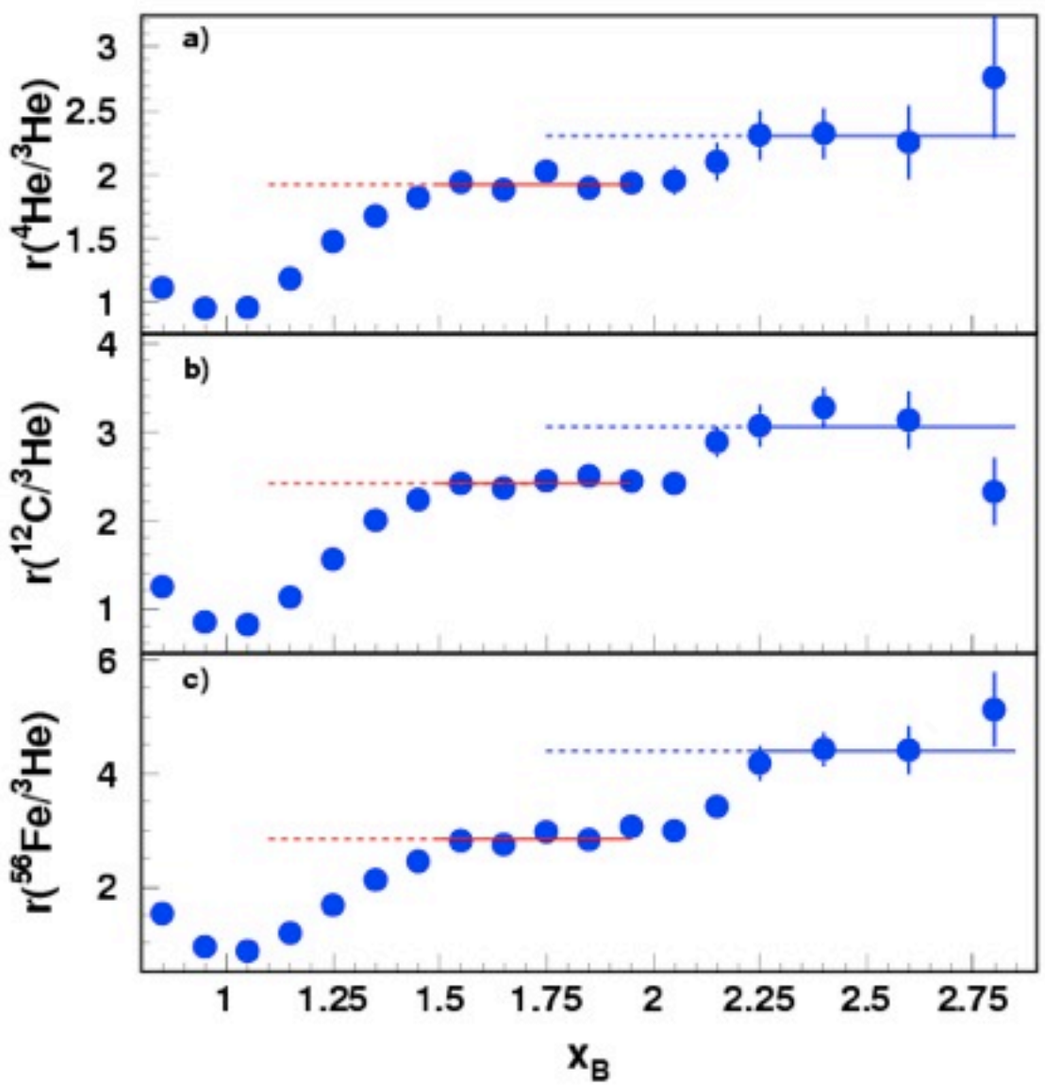
…

# Short-Range Correlations

First evidence of 2N-SRC at x>1.5 seen at SLAC (Frankfurt, Strikman, Day, Sargsian, PRC48, 2451 (1993)) and confirmed at JLab:

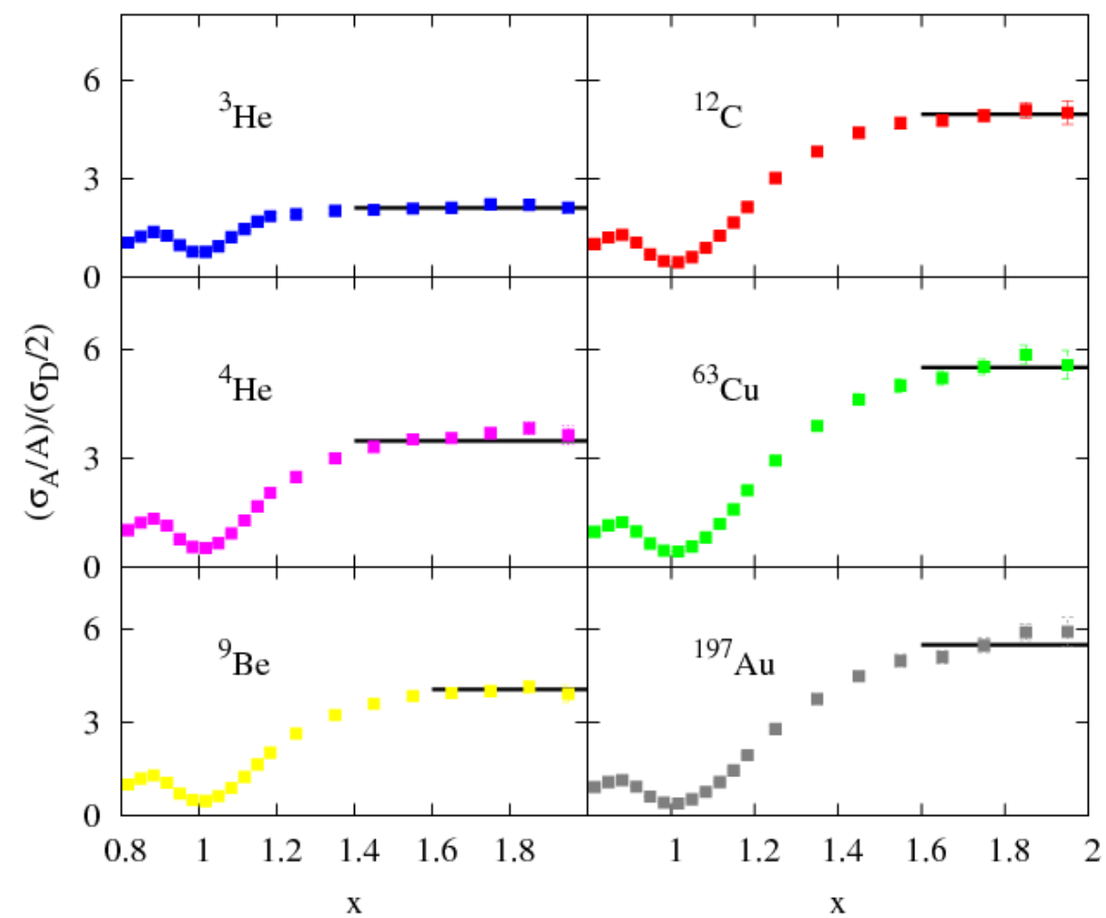
## Hall B

K. S. Egiyan et al., Phys. Rev. Lett. 96, 082501 (2006)




## Hall C

N. Fomin et al., Phys. Rev. Lett. 108, 092502 (2012)



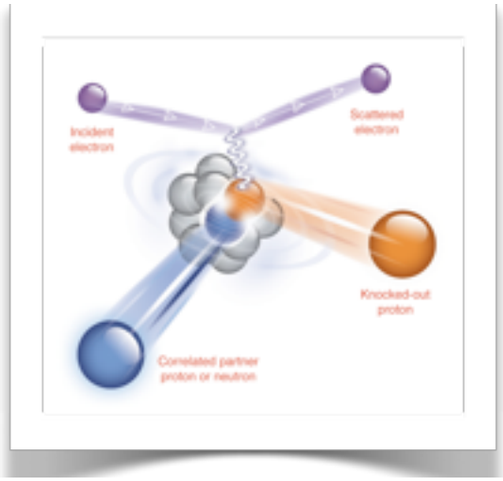

More details in Donal Day's talk on Friday morning

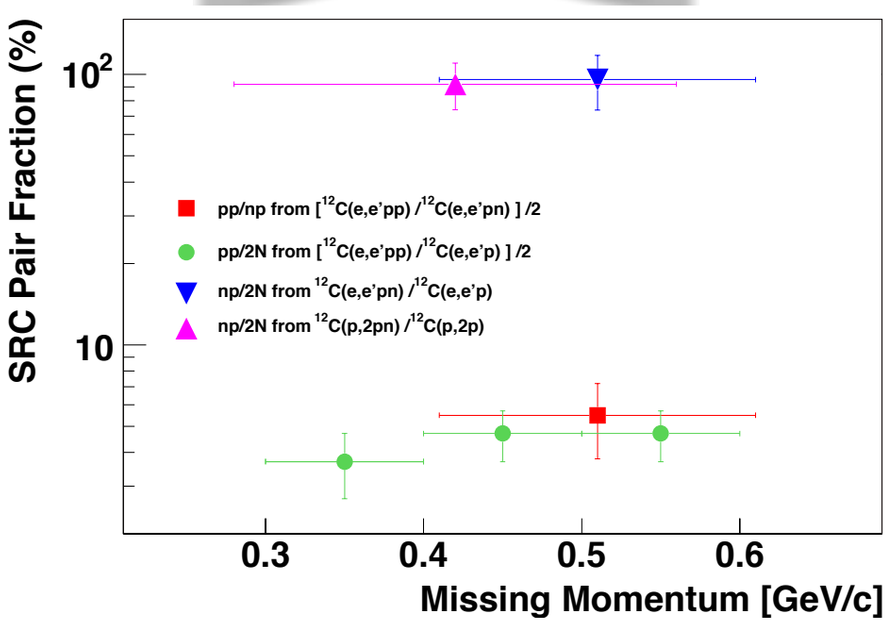
# SRC: isospin dependence

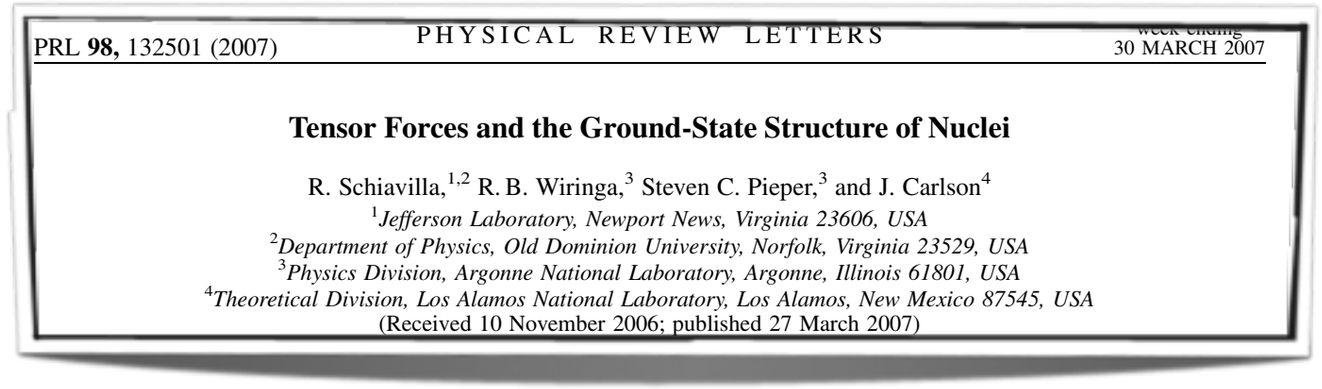
## Simple SRC model assumes isospin independence

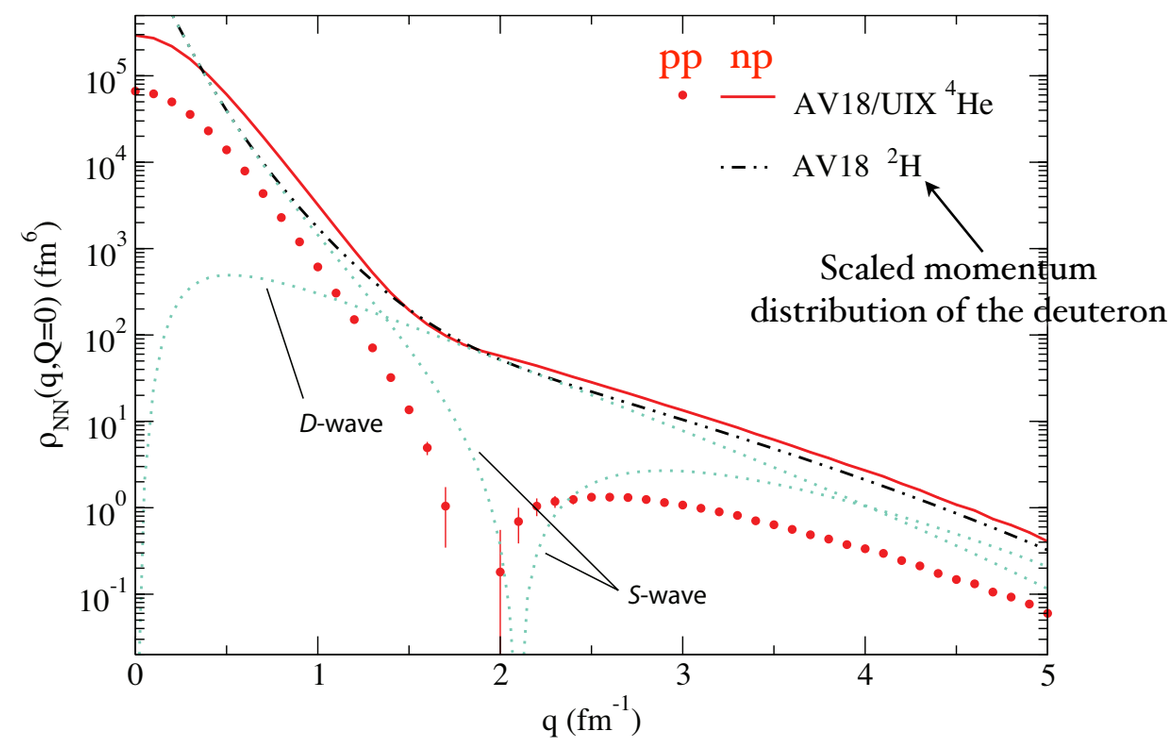
Two-nucleon knock-out experiment

R. Subedi et al, Science 320, 1476(2008)




**Data show large asymmetry between np, pp pairs:**

Qualitative agreement with calculations; effect of tensor force. Huge violation of often assumed isospin symmetry

# Isospin study from $^3$He/$^3$H ratio

## Simple mean field estimates for 2N-SRC

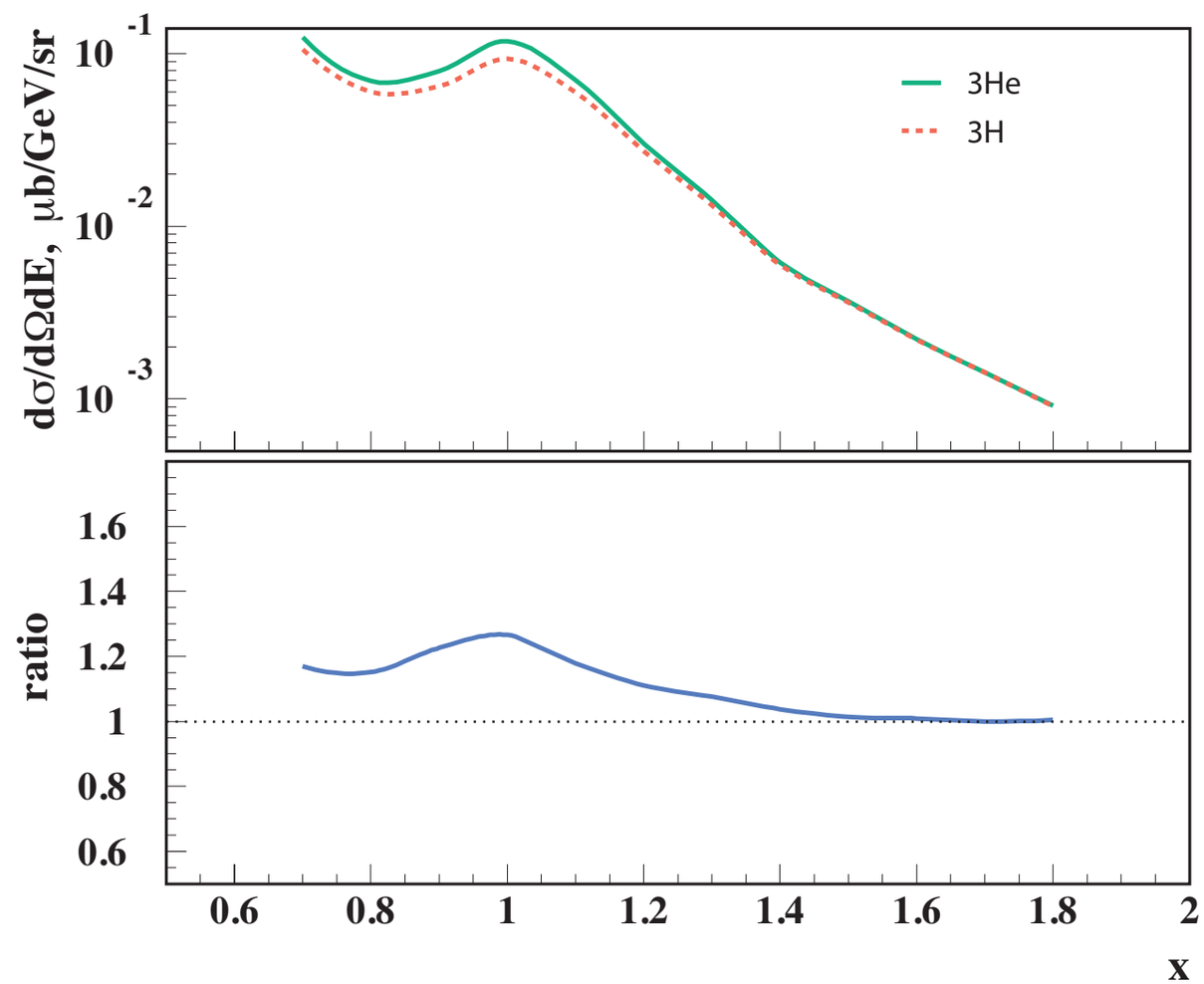
Isospin independent:

$$\frac{\sigma_{^3He}/3}{\sigma_{^3H}/3} = \frac{(2\sigma_p + 1\sigma_n)/3}{(1\sigma_p + 2\sigma_n)/3} \xrightarrow{\sigma_p \approx 3\sigma_n} 1.40$$

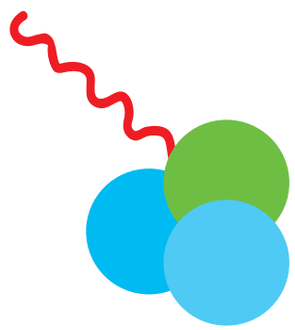
n-p (T=0) dominance:

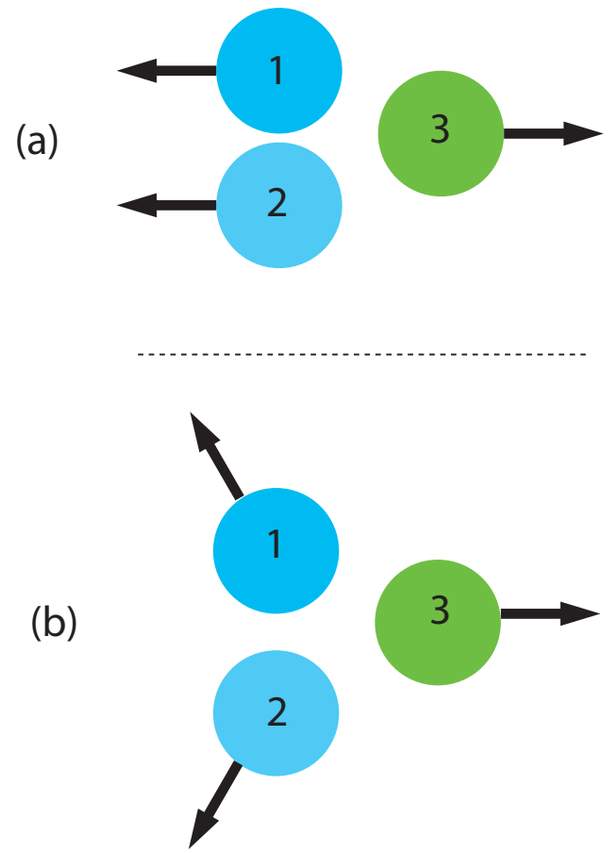
$$\frac{\sigma_{^3H}/3}{\sigma_{^3He}/3} = \frac{(2pn + 1\cancel{nn})/3}{(2pn + 1\cancel{pp})/3} = 1.0$$

**Inclusive cross section calculation from M. Sargsian using AV18/UIX**



# 3N-configuration






extremely large momentum

$$p_3 = p_1 + p_2$$

"Star-configuration"

$$p_1 = p_2 = p_3$$

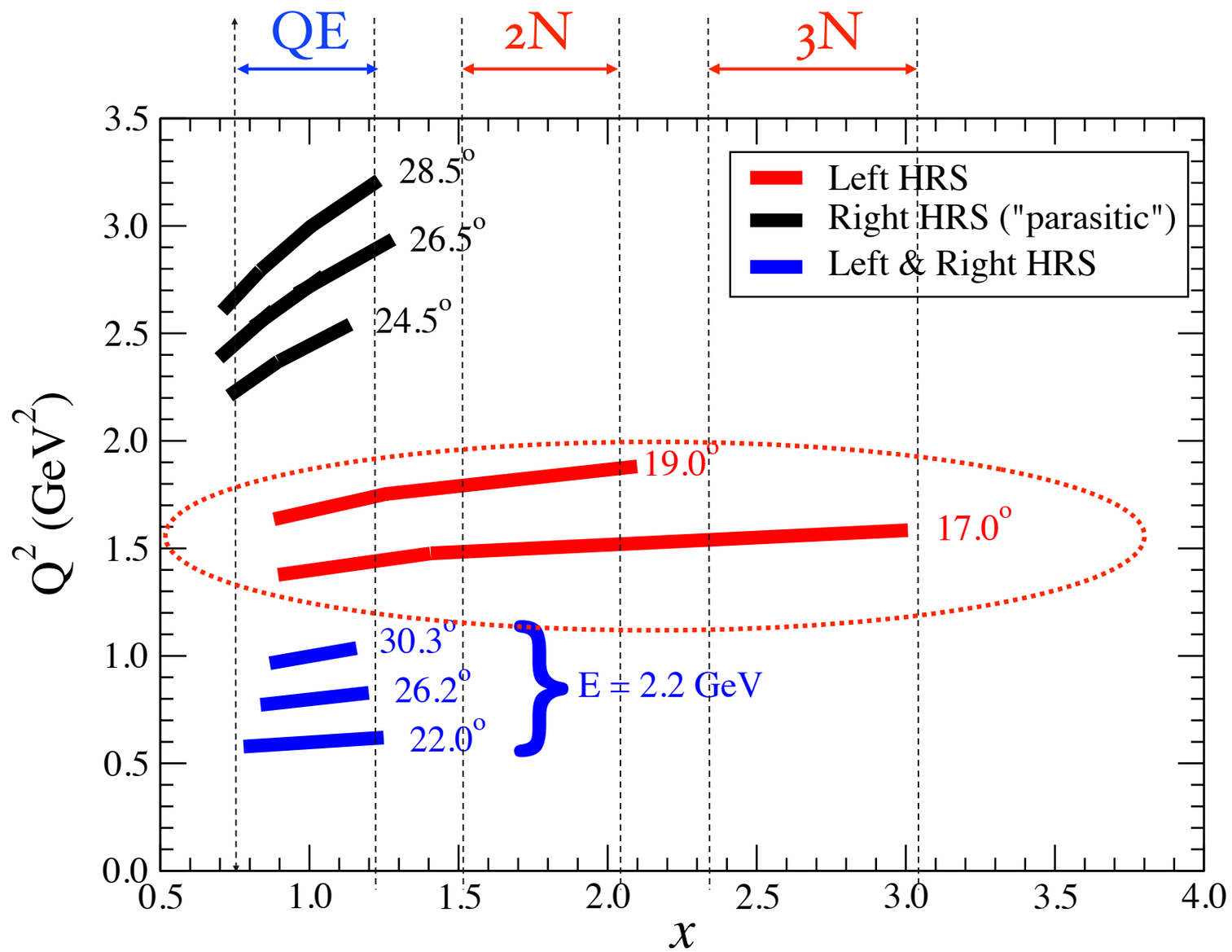
(a) yields $R(^3He/^3H) \approx 3.0$ if nucleon #3 is always the doubly-occurring nucleon
(a) yields $R(^3He/^3H) \approx 0.3$ if nucleon #3 is always the singly-occurring nucleon
(a) yields $R(^3He/^3H) \approx 1.4$ if configuration is isospin-independent, as does (b)

**$R \neq 1.4$ implies isospin dependence AND non-symmetric momentum sharing**

# E12-11-112: kinematics

Beam current: 25 μA, unpolarized, Raster interlock
Beam energy:
17.5 Days 4.4 GeV [main production]

**Left HRS running (380 hours)**

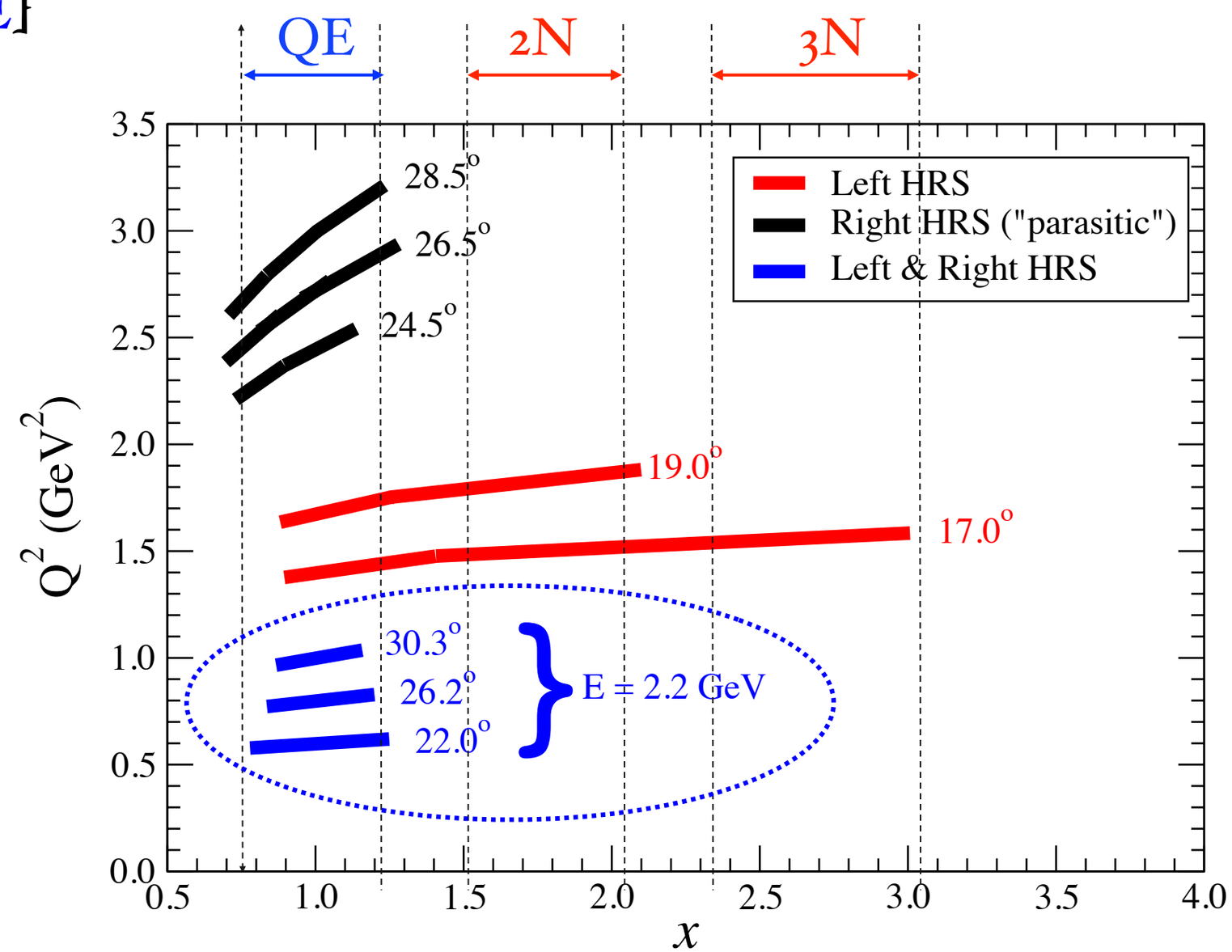


# E12-11-112: kinematics

Beam current: 25 μA, unpolarized, Raster interlock
Beam energy:
17.5 Days 4.4 GeV [main production]
1.5 days 2.2 GeV [checkout+QE]

**Left HRS running (380 hours)**

**Left+Right HRS running (about 1 day)**



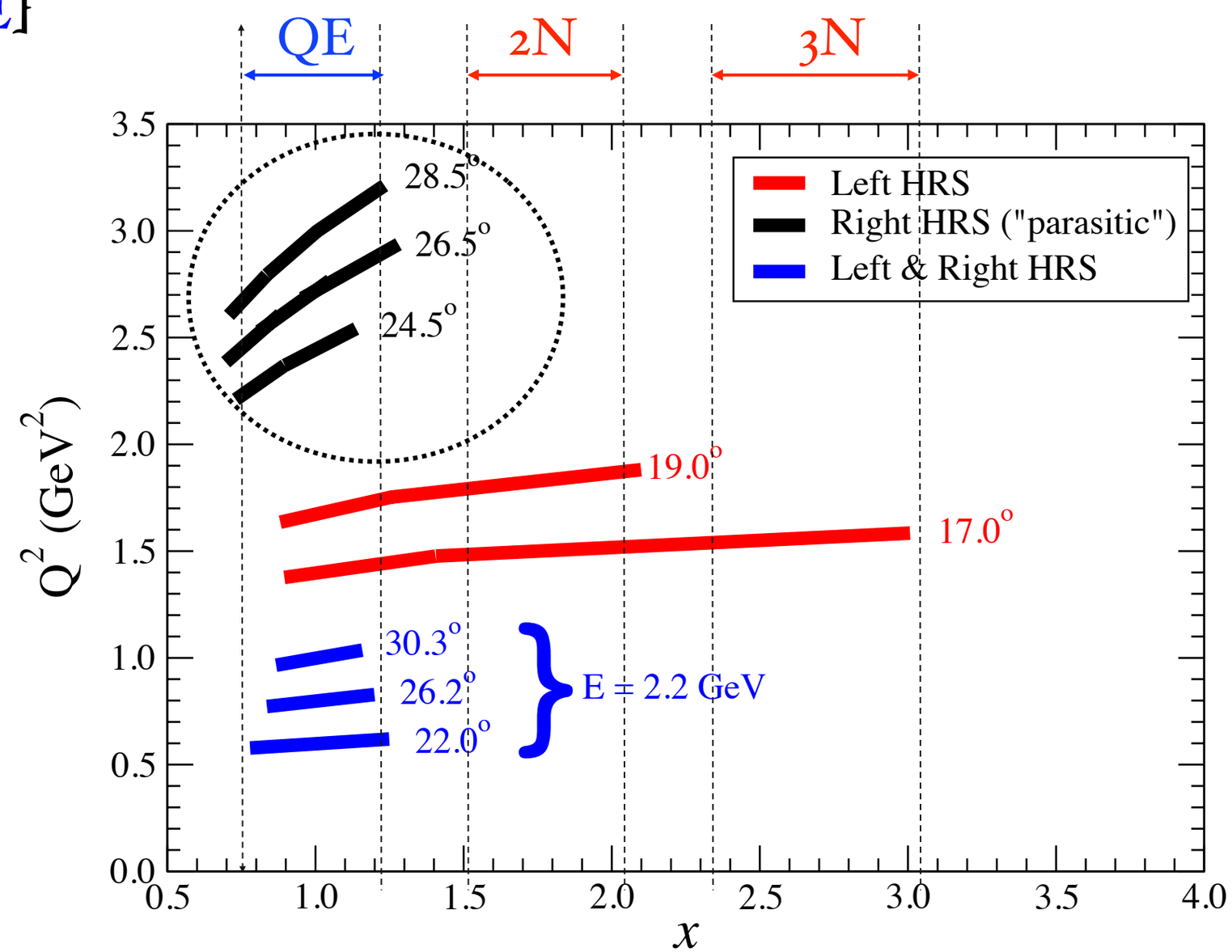
# E12-11-112: kinematics

Beam current: 25 μA, unpolarized, Raster interlock
Beam energy:
17.5 Days 4.4 GeV [main production]
1.5 days 2.2 GeV [checkout+QE]

**Right HRS running ("parasitic") Existing $^3$H QE data limited $Q^2 \leq 0.9$ GeV$^2$**

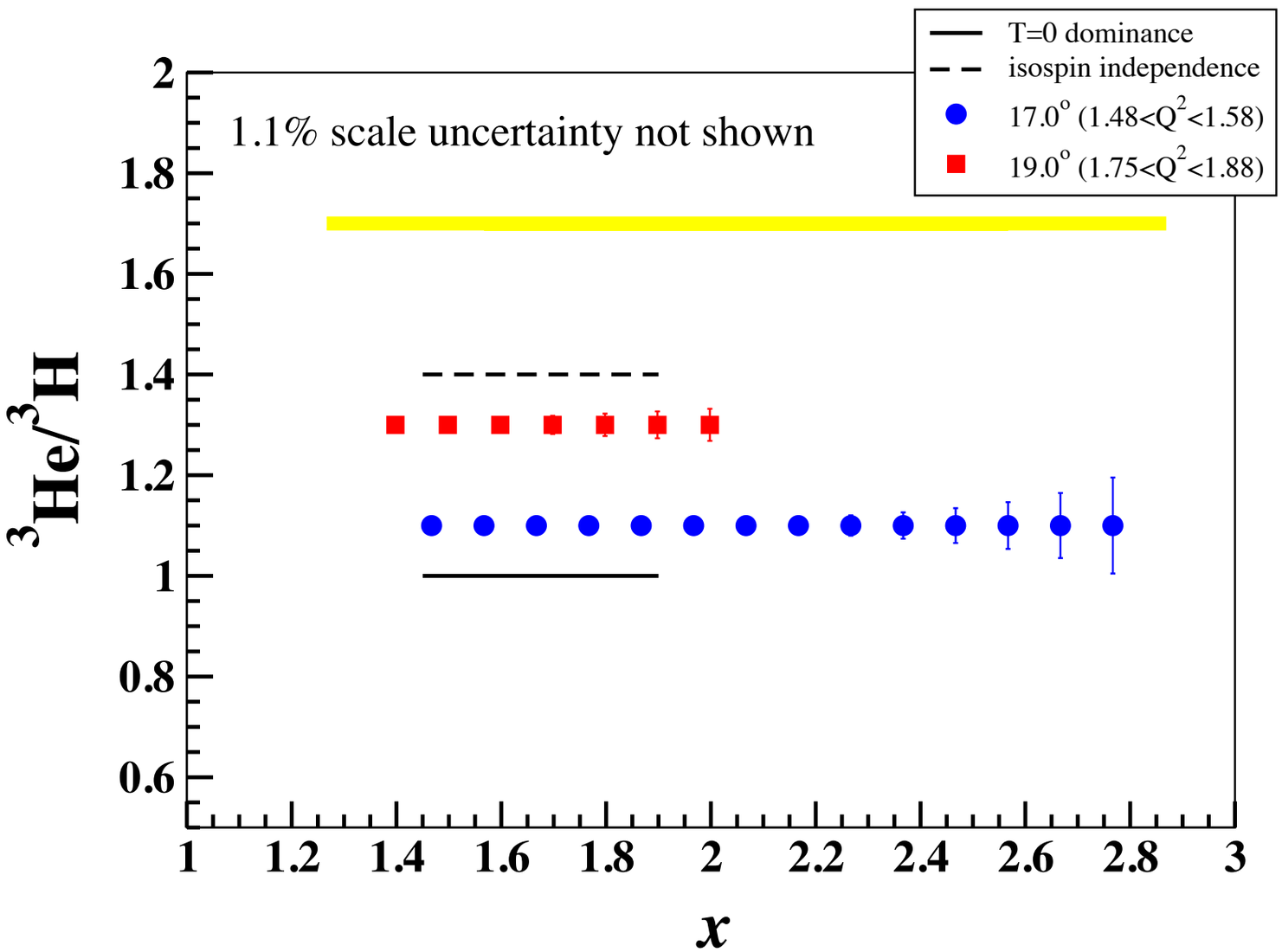
**Left HRS running (380 hours)**

**Left+Right HRS running (about 1 day)**



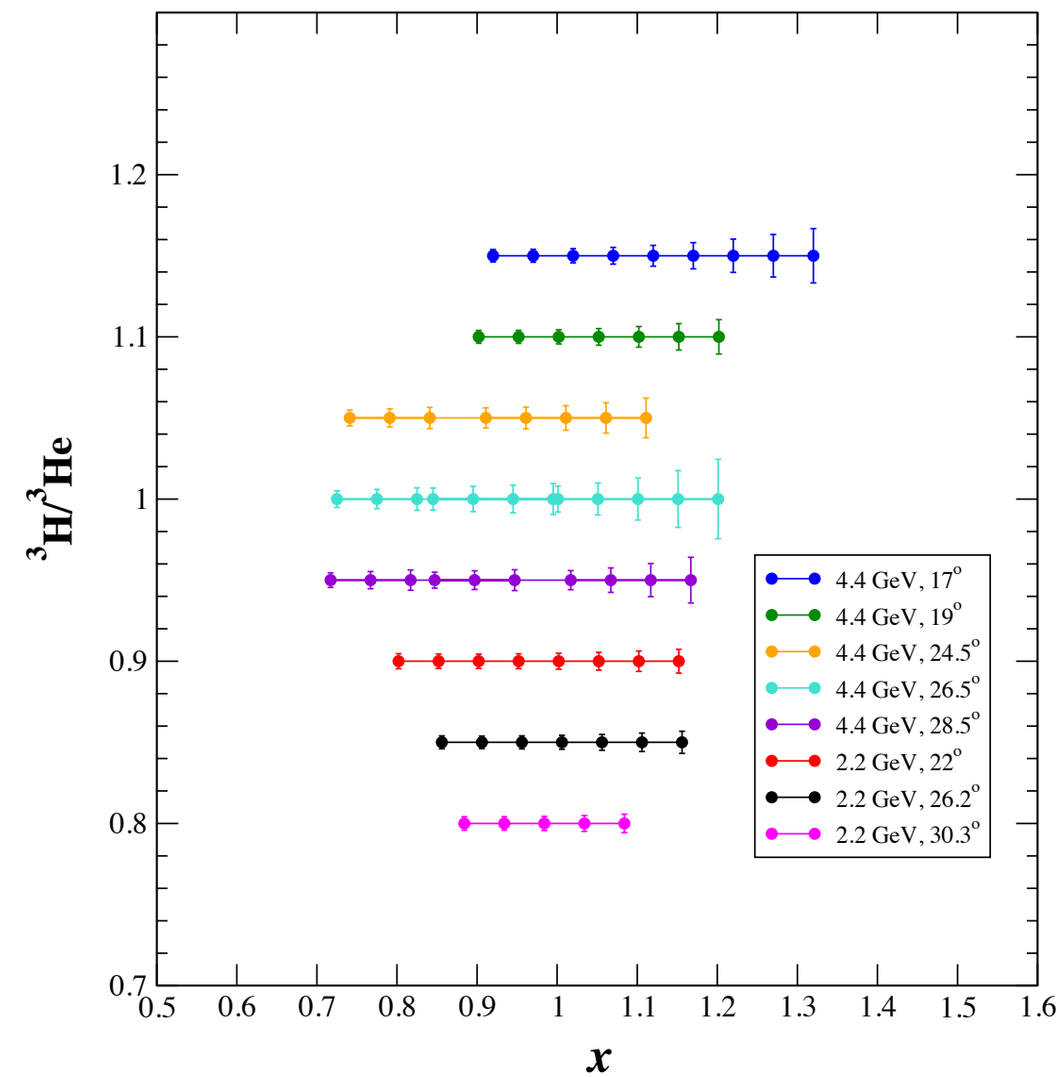
# E12-11-112: projected results

## Isospin study of SRC



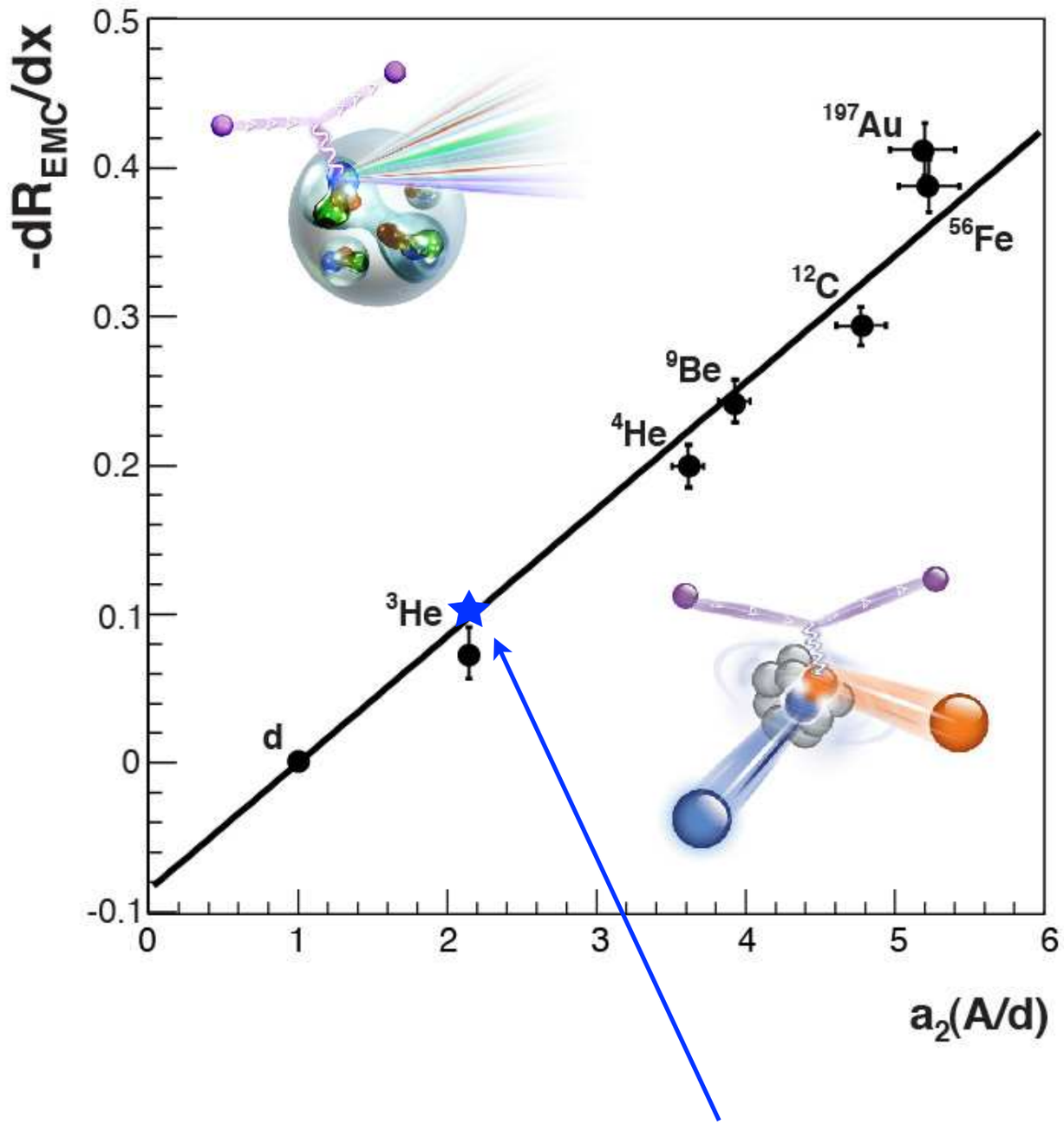

*At x>2, $^3He/^3H \neq 1.4$ implies isospin dependence AND non-symmetric momentum sharing*

## Extraction of $G_M^n$




*In PWIA, $^3He/^3H$ with 1.5% uncertainty corresponds to 3% on $G_M^n$*

# EMC vs. SRC




O. Hen, et al, PRC 85, 047301 (2012)
L. Weinstein, et al., PRL 106, 052301 (2011)

**from MARATHON and the x>1experiment results combined (no error bar projected at this time)**

# PR12-13-012

## Nucleon Momentum Distributions in Asymmetric Nuclei

## A Comparison of $^3$He$(e, e'p)$ and $^3$H$(e, e'p)$

Spokespeople: L. Weinstein (ODU), O. Hen (Tel-Aviv U.), W. Boeglin (FIU), S. Gilad (MIT)

### Main physics goals

**Comparison of ground state momentum distribution of protons in $^3$H and $^3$He**

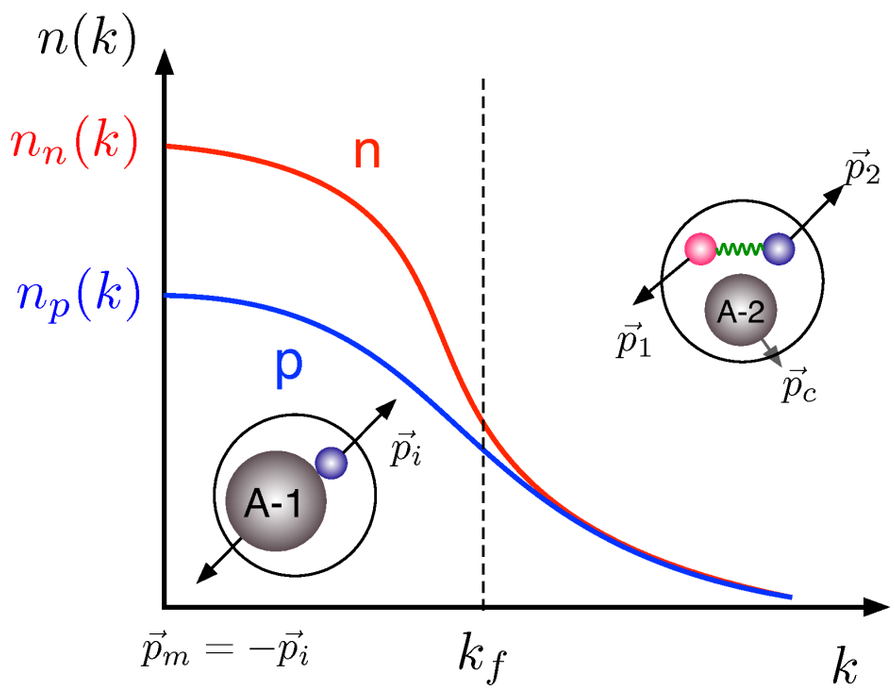
✓ kinematics chosen where FSI are expected to be small

**Nucleon momentum distribution in light asymmetric nuclei**

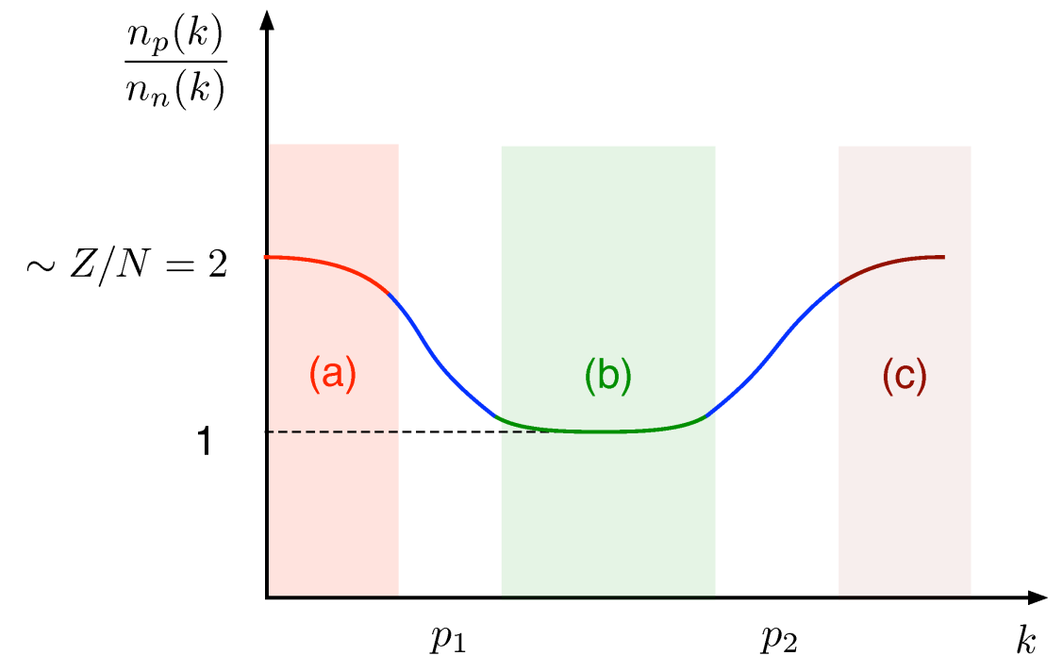
✓ y(A=3) = (N-Z)/(N+Z)=+/-0.3 --> asymmetries larger than in any heavy asymmetric nucleus

**Absolute cross sections and ratios for $^2$H(e,e'p), $^3$H(e,e'p), $^3$He(e,e'p)**

# PR12-13-012: projected results



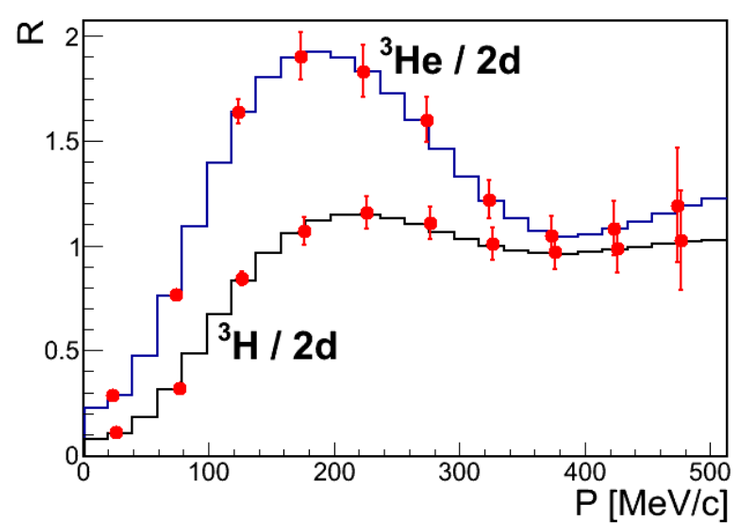

The naively expected ratio of proton to neutron momentum densities as a function of initial momentum for $^3$He. By isospin symmetry, it is also the expected ratio of $^3$He to $^3$H proton momentum densities.

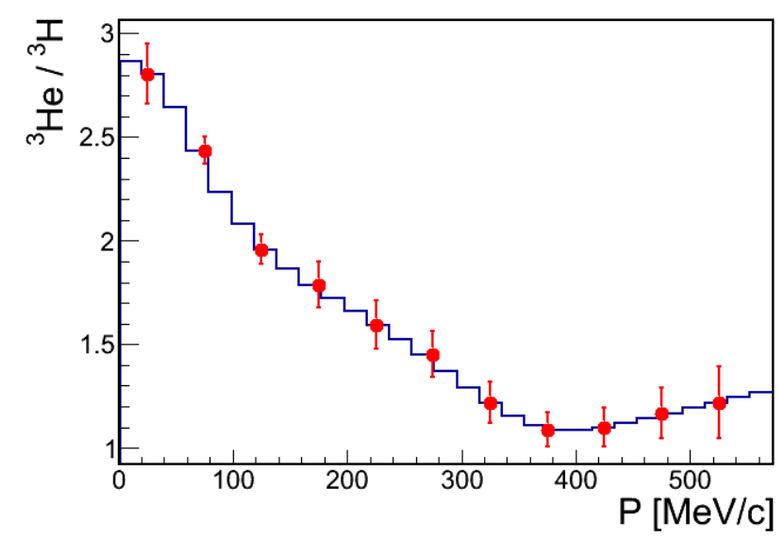



To minimize MEC, IC and FSI:

- high $Q^2$ ($Q^2 \approx 2$ (GeV/c)$^2$)
- $x = Q^2/2m\omega > 1$
- small $\theta_{rq}$ ($\theta_{rq} < 40°$)

Projected statistical uncertainties (32 PAC days)



# LOI: Triton FF

**MEASUREMENTS OF THE CHARGE AND MAGNETIC FORM FACTORS OF THE TRITON AT LARGE MOMENTUM TRANSFERS**

Letter of Intent

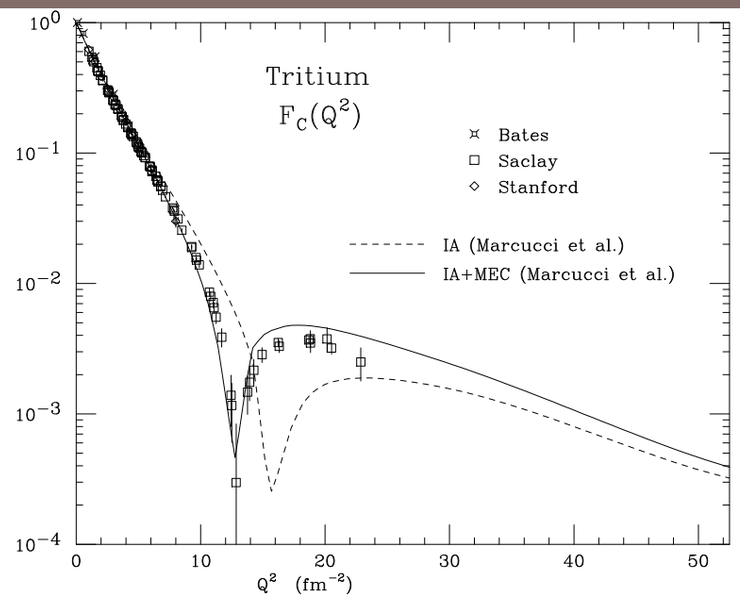
Spokespeople: G. Petratos (Kent U.), A. Katramatou (Kent U), A. Camsonne (JLab), N. Sparveris (Temple U.)

**Main physics goals**

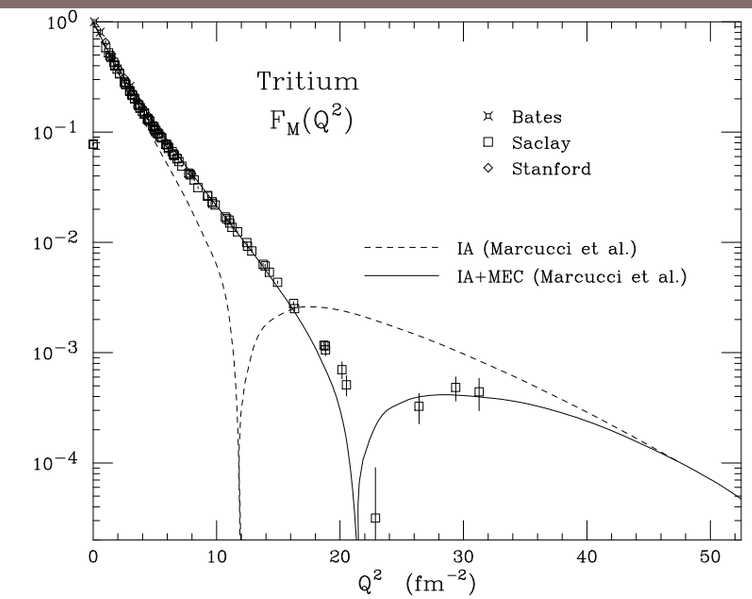
**Extract the charge and magnetic form factors of triton up to $Q^2 = 50\ fm^{-2}$**

- ✓ Rosenbluth separation technique: several angles using variable beam energies for a fixed $Q^2$
- ✓ Few-body electromagnetic FF provide fundamental information on their internal structure and dynamics: very sensitive to the choice of the nucleon-nucleon interaction potential, the treatment of MEC and relativistic corrections and to the possible admixture of multi-quark states.

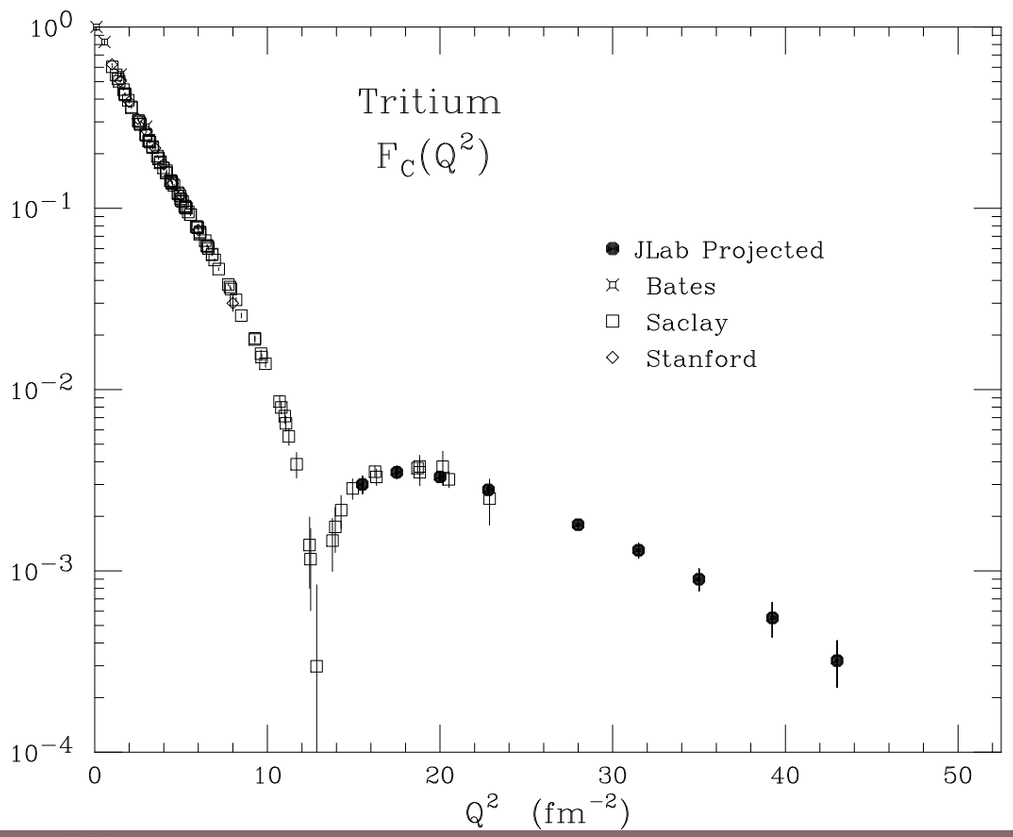
# Triton FF projected results

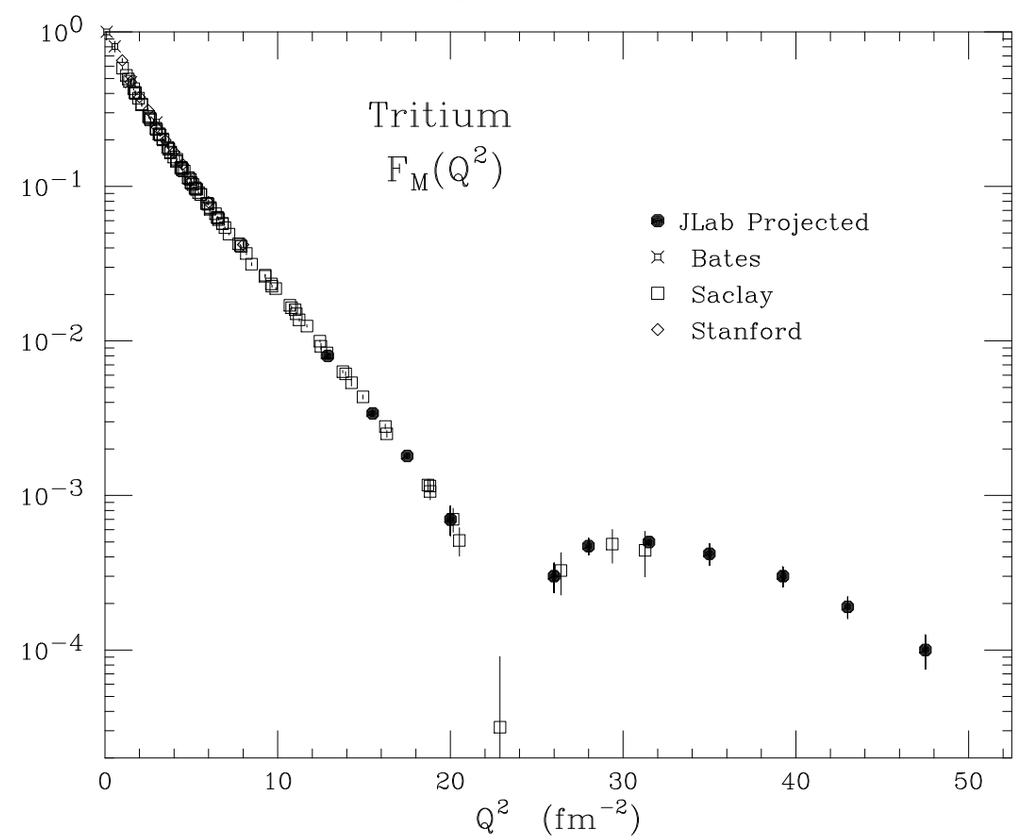



← Theoretical calculations →




Projected statistical uncertainties (7 PAC days)



# Summary

**The tritium target design is in its final stage:**

A preliminary review was done in June 2010: 35 action-items were given but no show-stoppers were found.

A second review is expected to take place before the end of the year.

**Two highly rated experiments are already scheduled:**

MARATHON: DIS $^3He/^3H$ --> EMC effect. Extraction of n/p and d/u.

The x>1 experiment --> isospin dependence of SRC from $^3He/^3H$. Added QE $^3He/^3H$ kinematics to extract $G_M^n$ at $0.6 \leq Q^2 \leq 1.0$ where disagreement between data sets is observed.

**A richer program is pending PAC40 approval.**

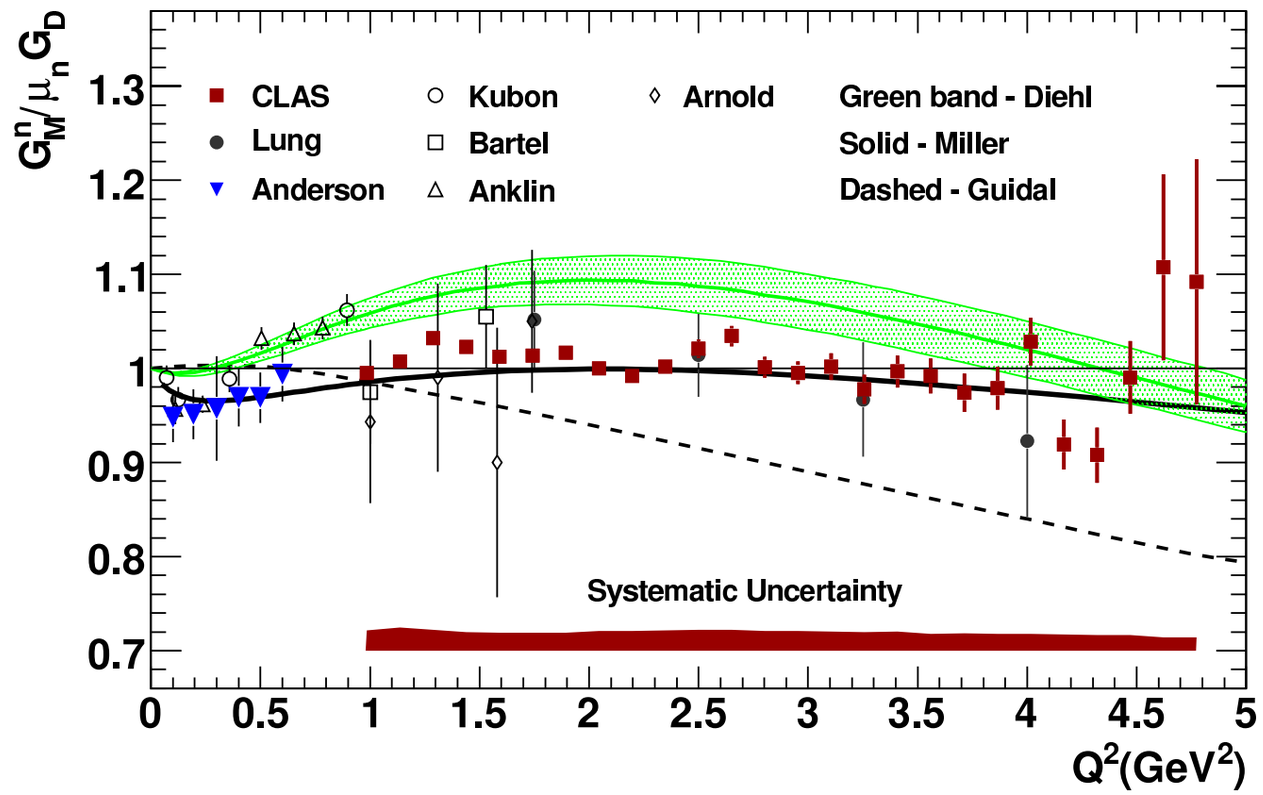
**2015 might be the only opportunity to take data on triton at JLab !**

# Extra slides

# E12-11-112: Neutron Magnetic FF

World $^3$H QE data:
$Q^2 \leq 0.9 GeV^2$

This experiment:
0.6, 0.8, 1.0, 1.4, 1.7, 2.4, 2.7 and 3.0 $GeV^2$




**In PWIA, $^3$He/$^3$H with 1.5% uncertainty corresponds to 3% on $G_M^n$**

- Limited to $Q^2 \leq 1$ $GeV^2$, where QE peak has minimal inelastic contribution
- This is the region with ~8% discrepancy between the Ankin, Kubon data and the CLAS ratio and the Hall A polarized $^3$He extraction.

**Nuclear effects expected to be small, largely cancel in ratio**

# Radiological Aspects of the Tritium Target for MARATHON/x>1

March 21, 2013

Keith Welch
Jefferson Lab
RadCon Deputy Manager

# Tritium Target RadCon Issues

Topics

- Regulatory Thresholds and Classification
  - Nuclear Materials Accountability
  - Facility Designation
  - Emergency Management
- Programmatic Aspects
  - Radiation Protection Program
  - Accelerator Safety Envelope/FSAD
- Other Issues
  - Environmental Impacts
  - Shipping
  - Residual Contamination

# Tritium Target RadCon Issues

## Regulatory Thresholds and Classification

- Radioactive Sealed Source Controls – 10 CFR 835 and O 231.1B
  - ✓*The target does not meet the definition of a sealed source*
- Nuclear Materials Controls – Order 474.2
  - – $^{3}H$ is "other accountable nuclear material"
  - ✓*Accountable quantity is 1g ~ 10,000 Ci*
- Nuclear Facility Status – 10 CFR 830
  - – Non-reactor nuclear facility -

    "…those facilities, activities or operations that involve, or will involve, radioactive and/or fissionable materials in such form and quantity that a nuclear or a nuclear explosive hazard potentially exists to workers, the public, or the environment, ***but does not include accelerators and their operations and does not include activities involving only incidental use and generation of radioactive materials*** or radiation such as check and calibration sources…"

  - ✓*The lab will not become a nuclear facility*

# Tritium Target RadCon Issues

Regulatory Thresholds and Classification(cont'd)

- Furthermore – *there is no such thing as a "tritium facility",* from the perspective of oversight or regulatory classification.
- However, DOE uses radioactivity quantities in DOE-STD-1027-92 to establish thresholds for both nuclear facility hazard analyses and emergency management classification.
  - There is some ambiguity as to whether exceeding the thresholds in this Standard creates a nuclear facility at an accelerator.
  - Emergency management order uses the Standard as a threshold for conducting Emergency Planning Hazard Assessments.

✓*The good news - For $^{3}H$, the threshold is 16,000 Ci*

*But wait, there's more…*

# Tritium Target RadCon Issues

## Regulatory Thresholds and Classification(cont'd)

- Emergency classes are driven largely by impacts to offsite populations, so regardless of material quantity, the safety analysis needs to confirm that a credible postulated accident does not significantly endanger the public.
- Dose goals –
  - 10 mrem at site boundary
  - 100 mrem to a non-rad-worker onsite

✓ *Preliminary analysis indicates that a 15-20 m stack will suffice*

# Tritium Target RadCon Issues

## Programmatic Aspects

- Radiation Protection Program (required by 10 CFR 835)
  - DOE approves the JLab RPP
  - It must address all aspects of compliance with the rule
  - It does this largely through our RadCon Manual and procedures
  - The RPP "Plan" itself is broad enough to cover the $^{3}H$ target
  - *RadCon Manual/procedures will need revision*
    - Possible bioassay screening (to prove negligible doses)
    - Contamination monitoring
    - Air monitoring (some hardware probably needed)
    - Emergency procedures

✓ *Relatively modest changes, DOE approval probably not necessary*

# Tritium Target RadCon Issues

## Programmatic Aspects

- Accelerator Safety Envelope/FSAD (required by O 420.2C)
  - DOE approves the JLab ASE and reviews FSAD
  - It must address all credible accident scenarios
  - Approval level driven by potential consequences on and off site
  - Offsite accident consequences appear "negligible"
  - *Local accident consequences need formal analysis/approval*
    - Formal documentation in form of an *Unreviewed Safety Issue* determination
      - Conducted by *Safety Configuration Management Board*
    - SCMB may recommend independent assessment
    - ASE/FSAD revision and approval
      - Assume ≥ 1 year for this process

# Tritium Target RadCon Issues

## Other Issues

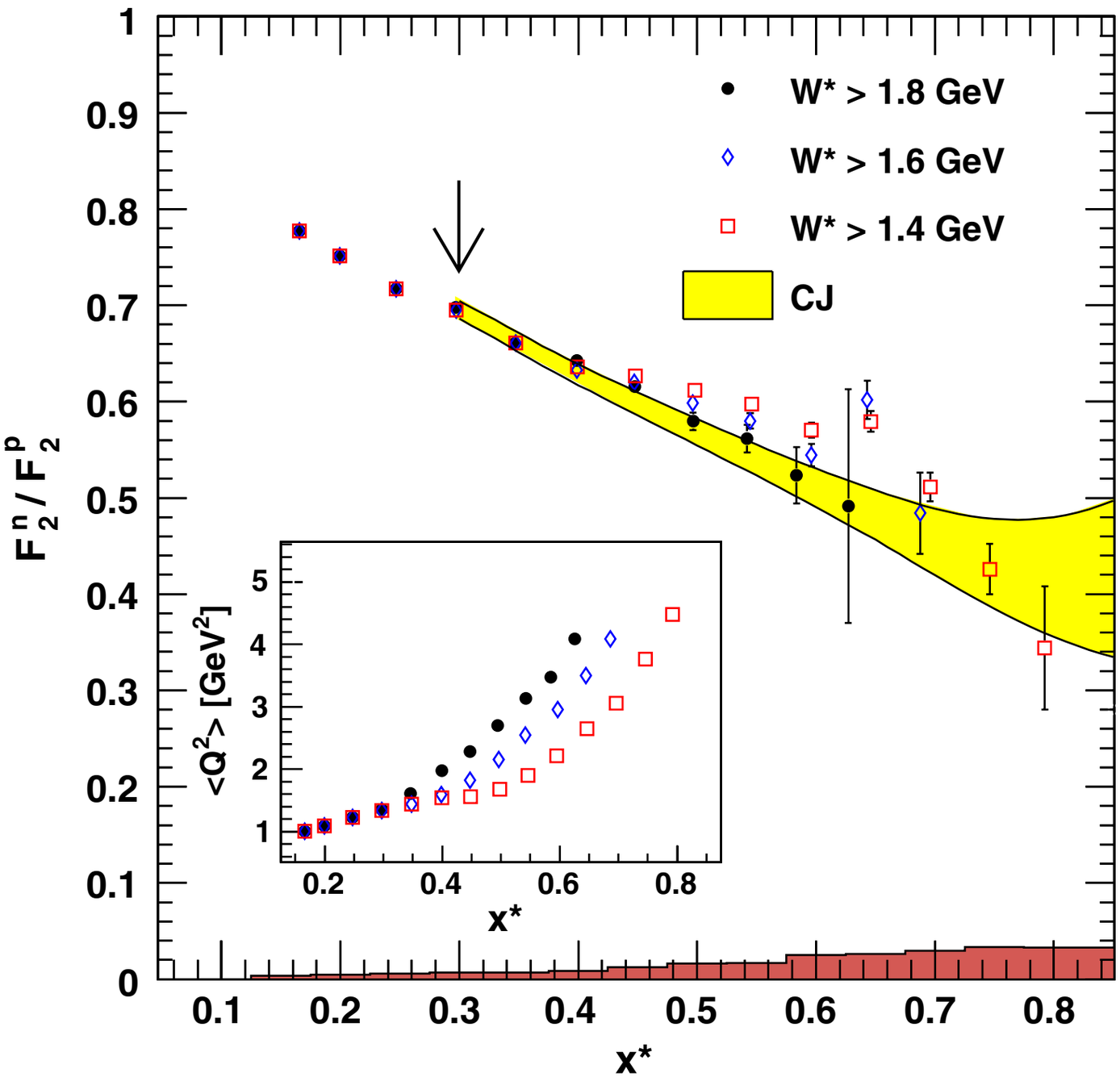
- Environmental Impact
  - $^{3}H$ lost by diffusion ("chronic" emissions)
    - Amount expected is within normal air emissions levels
    - Little/no impact expected on liquid discharges
  - *Mitigations for accidental release need to include Env. impact*
    - Release directly to hall would grossly contaminate sumps, possibly impact long term surface water discharges
    - Evaluate as part of ASE/FSAD revision
- Shipping
  - *JLab needs to review shipping plan*
    - Once we receive the target we take on liability of return shipment
    - Formal agreement that target will be accepted for return

# Tritium Target RadCon Issues

## Other Issues

- Residual Contamination
  - Target chamber internals, associated equipment will have low-level contamination
    - We have some experience with this from past $^{3}$He experiments
    - *Initial breach of target chamber needs careful planning*
    - *A general plan for decon/disposal of materials should be developed*
    - *Some local systems may be permanently designated internally contaminated*
  - In the event of accidental release to the hall, the nature of the radiation protection program for Hall A and environmental radiation protection program would change significantly.

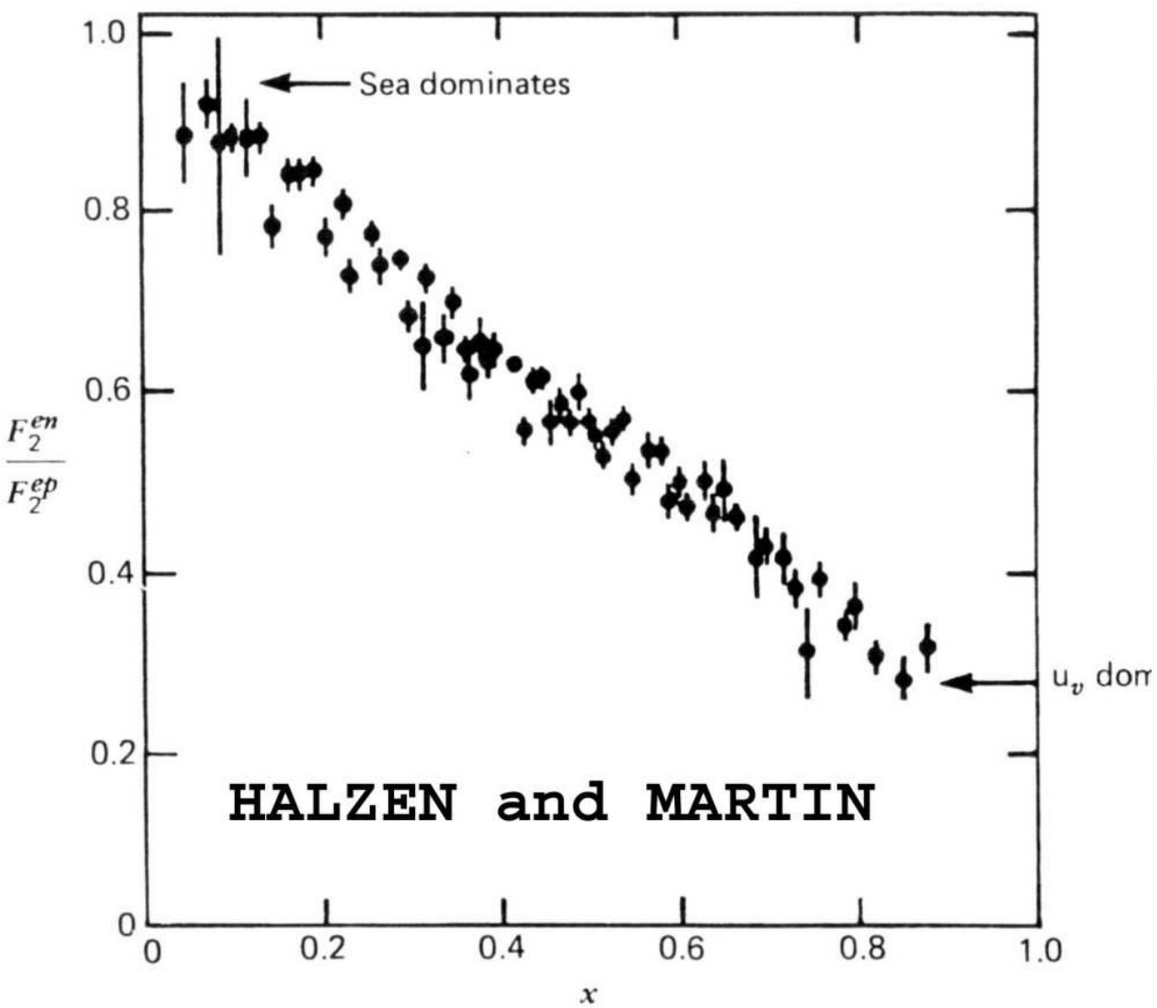
# BONUS

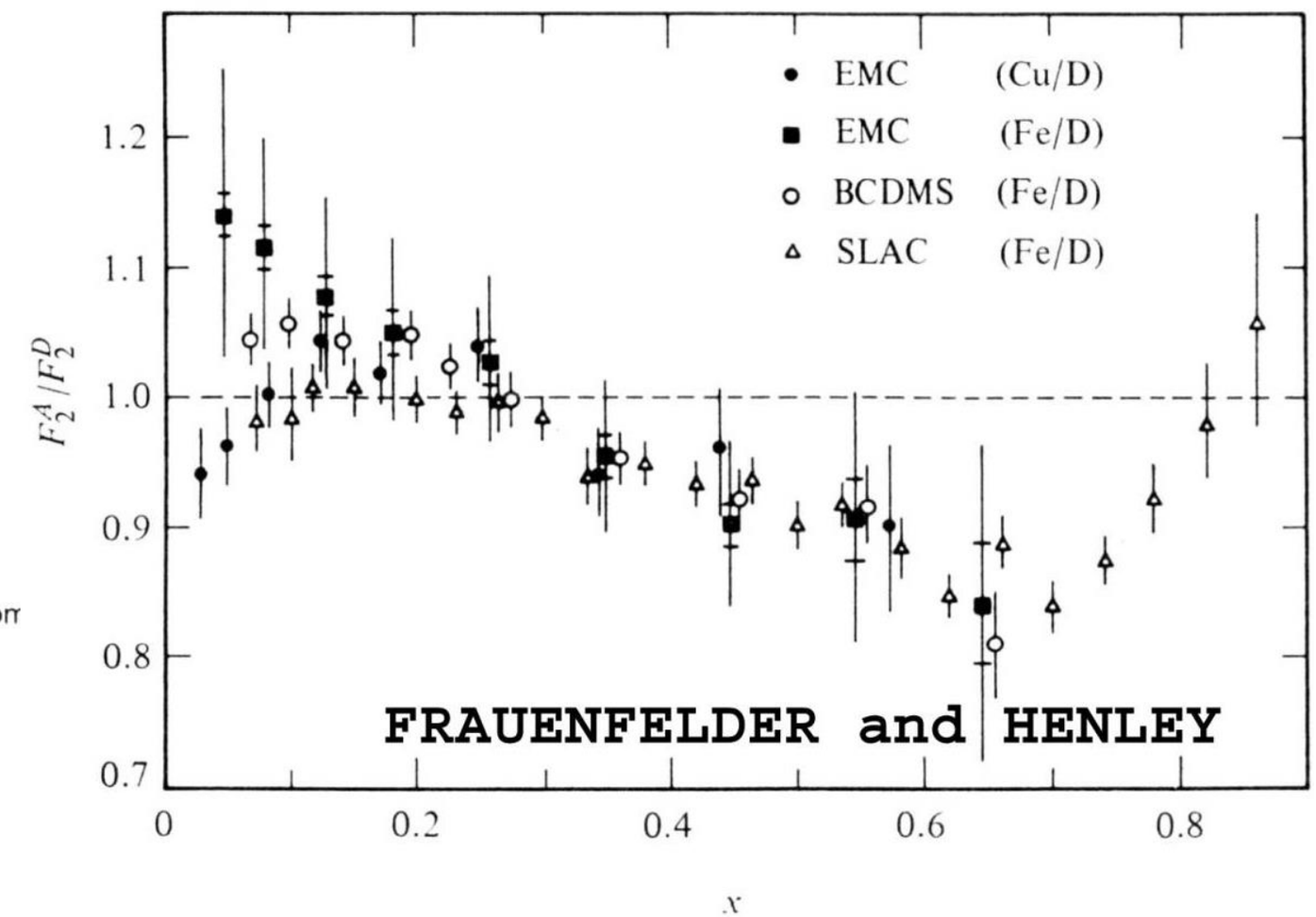


# The EMC effect

- Nuclear $F_2$ structure function per nucleon is different than that of deuterium: large Bjorken $x$ and nuclear mass $A$ dependence.
- Quark distribution functions modified in the nuclear medium.
- Possible explanations include:
  - Binding effects beyond nucleon Fermi motion
  - Enhancement of pion field with increasing $A$
  - Influence of possible multi-quark clusters
  - Change in the quark confinement scale in nuclei
- No universally accepted theory for the effect explanation.
- $A$=3 data will be pivotal for understanding the EMC effect.
- Theorists: Ratio of EMC effect for $^3$H and $^3$He is the best quantity for quantitative check of the theory, free of most uncertainties.

# $F_2^n/F_2^p$ Ratio and EMC Effect are Elementary Undergraduate Nuclear-Particle Textbook Physics!



# MARATHON: nuclear corrections

## A way to get access to $F_2^n$

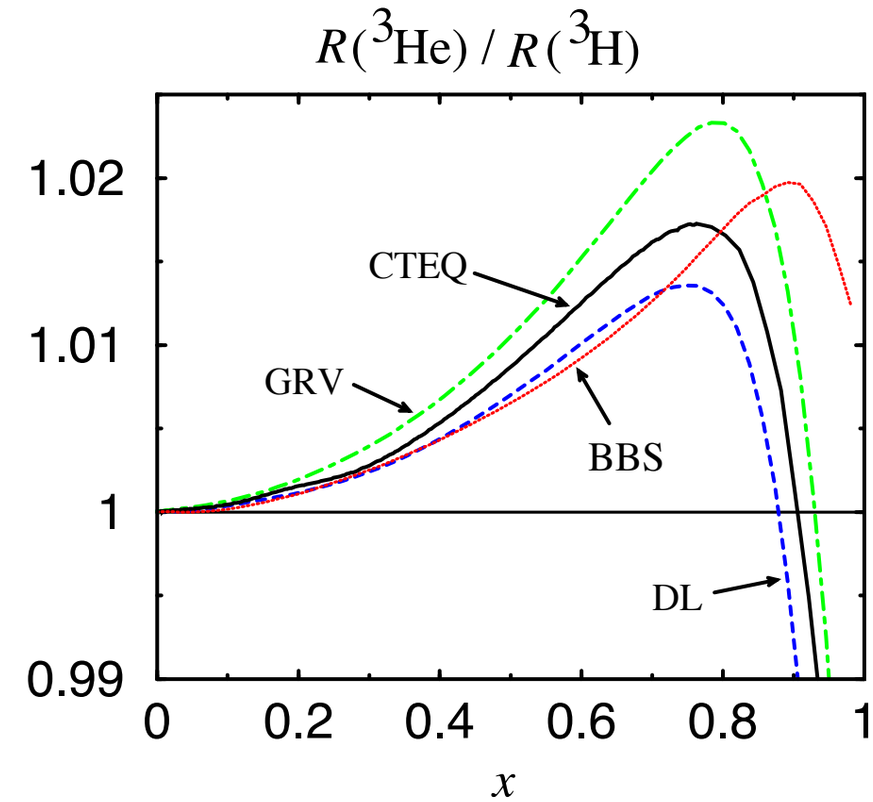
- Measure $F_2$'s and form ratios:

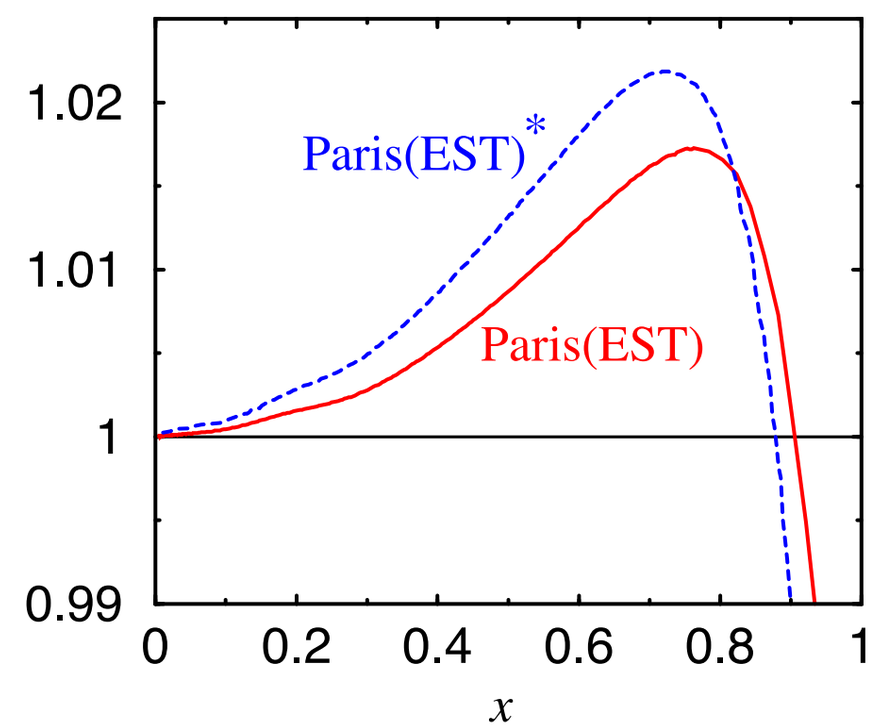
$$R(^3He) = \frac{F_2^{^3He}}{2F_2^p + F_2^n}, \quad R(^3H) = \frac{F_2^{^3H}}{F_2^p + 2F_2^n}$$

- Form "super-ratio", r, then

$$\frac{F_2^n}{F_2^p} = \frac{2r - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - r}$$

where $$r \equiv \frac{R(^3He)}{R(^3H)}$$



# MARATHON: nuclear corrections

## A way to get access to $F_2^n$

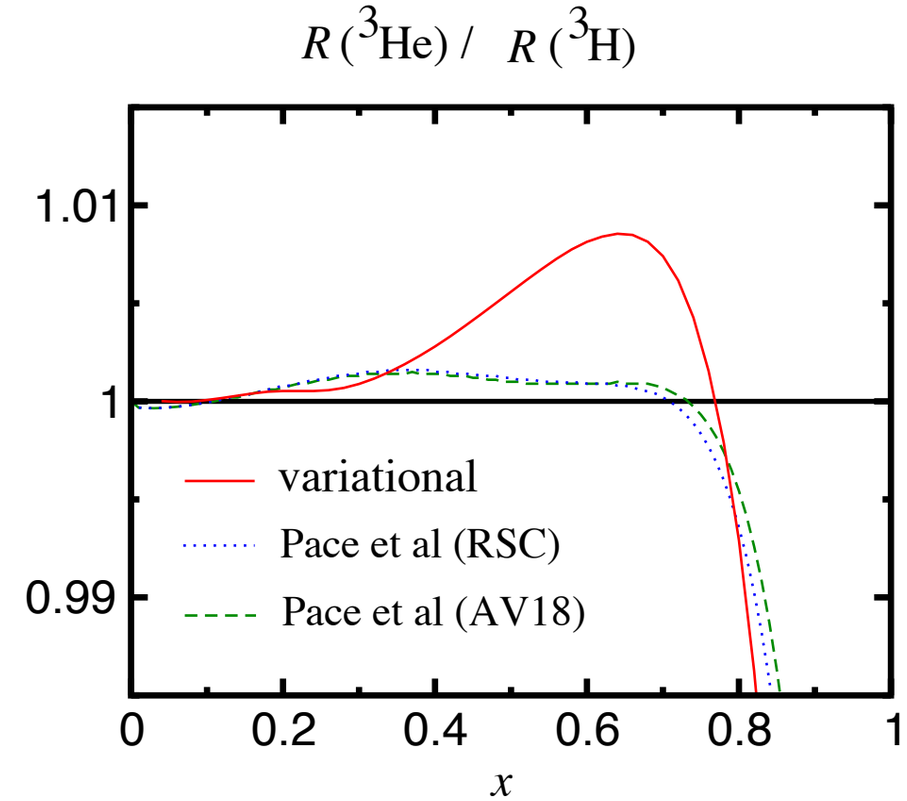
- Measure $F_2$'s and form ratios:

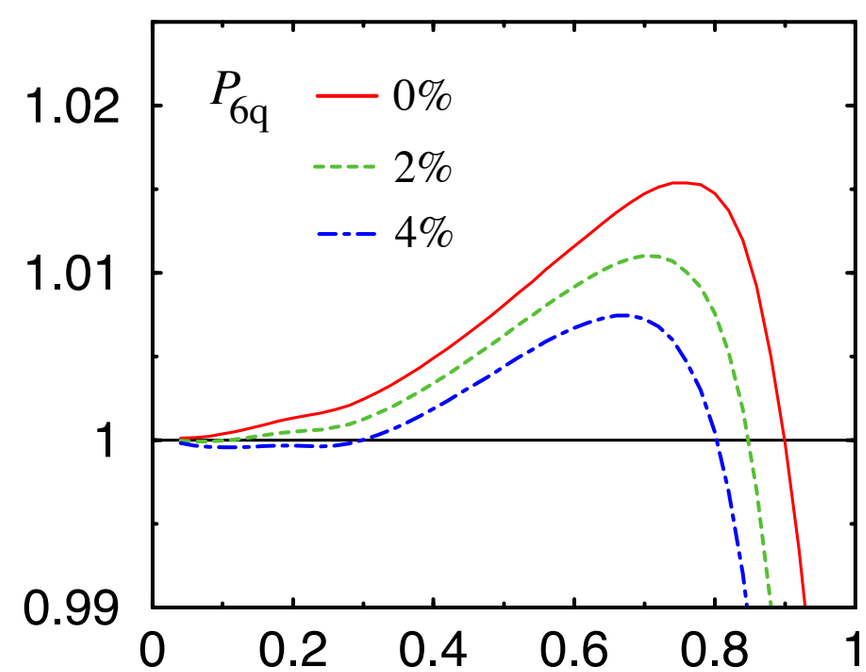
$$R(^3He) = \frac{F_2^{^3He}}{2F_2^p + F_2^n}, \quad R(^3H) = \frac{F_2^{^3H}}{F_2^p + 2F_2^n}$$

- Form "super-ratio", r, then

$$\frac{F_2^n}{F_2^p} = \frac{2r - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - r}$$

where $$r \equiv \frac{R(^3He)}{R(^3H)}$$




PRODUCT INFO | SPECIFICATIONS | REVIEWS

**Back in Stock Today! Limited Quantities Available!**

**The Nuclear Age of Wristwatches Has Arrived!**

We dare you not to be astonished by our latest watch, the **Nuclear Watch**! This remarkable watch provides a constant source of **nuclear illumination** for up to 25 years! You don't need batteries or maintenance of any kind for the glow; this watch will be lit for decades! No longer do you need to worry about using a backlight or having to deal with luminescent paint where the light fades quickly. The glow you'll see 24/7 is really from the **nuclear fission** happening inside the watch!

**Imagine Having a (Safe) Nuclear Reactor on your Wrist!!**

This incredible watch is powered by ~100 quadrillion radioactive hydrogen atoms! But don't worry, this watch is completely stable (the NRC even approves that it's 100% safe)! From the time you purchase the Nuclear Watch, we guarantee that over the next 12.3 years half those atoms will help light up your watch by destroying themselves at a rate of 250 million atoms every second! This still leaves the remaining 50 quadrillion atoms to continue working for you! The hour and minute hands have a constant **green illumination**, as do the dashes which mark each hour. The 12 o'clock dash mark shines bright orange. Now you can always tell exactly what time it is, whether it's day or night!

**Constant Glow so You Can Know the Exact Time, Anytime!**

This watch is great for anyone who has to work for long periods of time in dark environments, it's perfect for night driving or just for people who just like the idea of owning a watch that is constantly glowing with nuclear energy! For anyone who wants to have a real **glowing nuclear watch**, this is definitely the way to go! The Nuclear Watch is an impressive watch that is far superior to all those cheap imitators out there! When watches with luminescent paint or LED lights start to fade, the Nuclear Watch will still be glowing strong! An amazing watch which makes the perfect gift!

**More Powerful Than a Gamma Bomb!**

Specifications:

- Water Resistant 300 ft/100m
- Stainless Steel Black
- Polycarbonate Case
- 14 Nuclear Light Sources
- Reliable Safe Atomic Illuminations 24/7
- Complies with Nuclear Regulatory Commission (NRC) Regulations
- Constant Glow is Powered by Real Nuclear Energy
- Watch Itself Runs on Batteries


The Higgs Boson Watch



The Higgs Boson Watch