# TRITIUM TARGET UPDATE

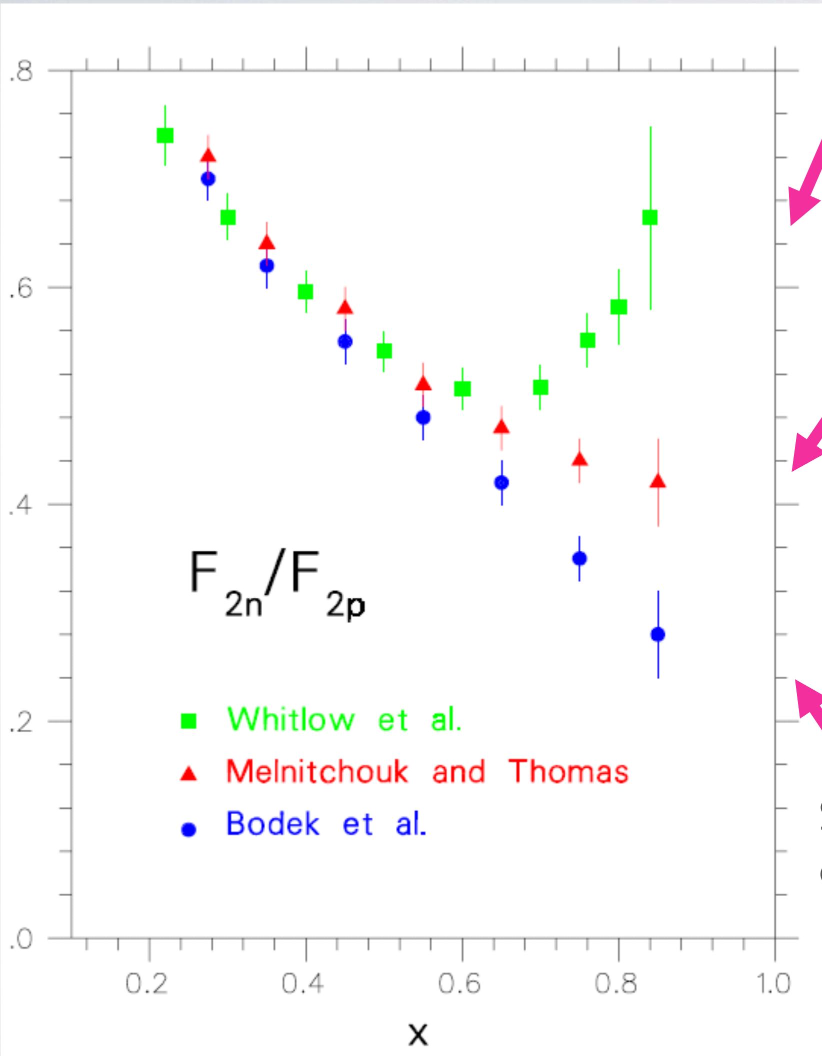
PATRICIA SOLVIGNON

***<u>Tritium Target Task Force:</u>***
***E. J. Beise (U. of Maryland), B. Brajuskovic (ANL),***
***R. J. Holt (ANL), W. Korsch (U. of Kentucky),***
***T. O'Connor (ANL), G. G. Petratos (Kent State U.),***
***R. Ransome (Rutgers U.), P. Solvignon (JLab),***
***B. Wojtsekhowski (JLab)***

Hall A Collaboration Meeting
December 14-16, 2009

# E12-06-118: EMC EFFECT AND d/u AT LARGE x

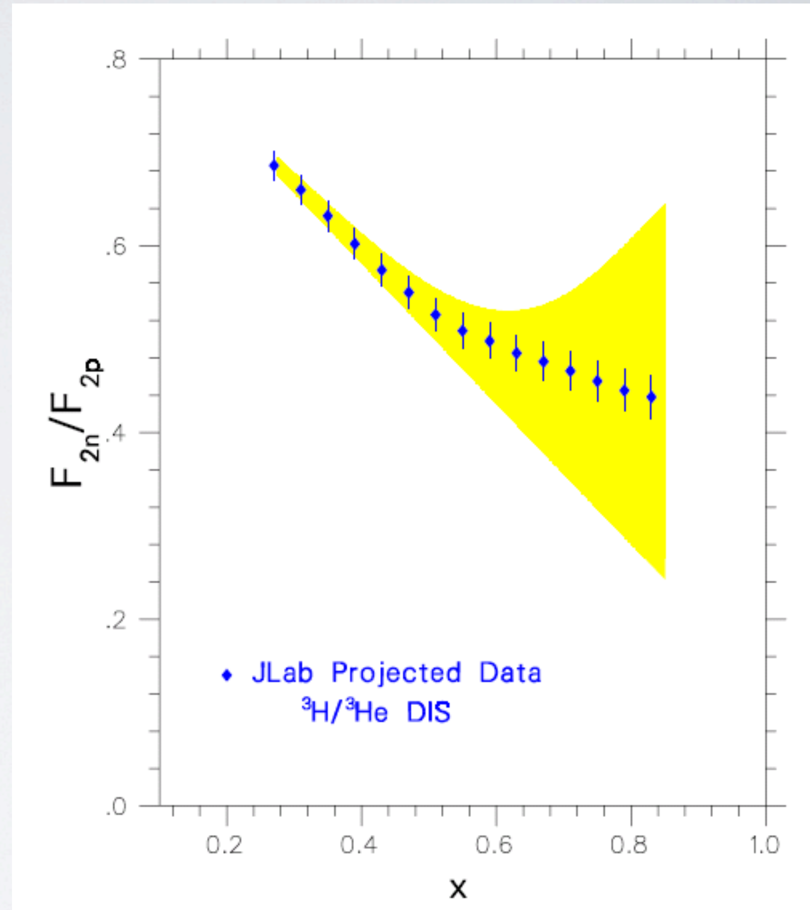
JLab E12-06-118:
G. Petratos, J. Gomez, R. J. Holt,
R. Ransome *et al*




SU(6) symmetry

pQCD

Scalar di-quark




**PAC30: Conditionally approved**

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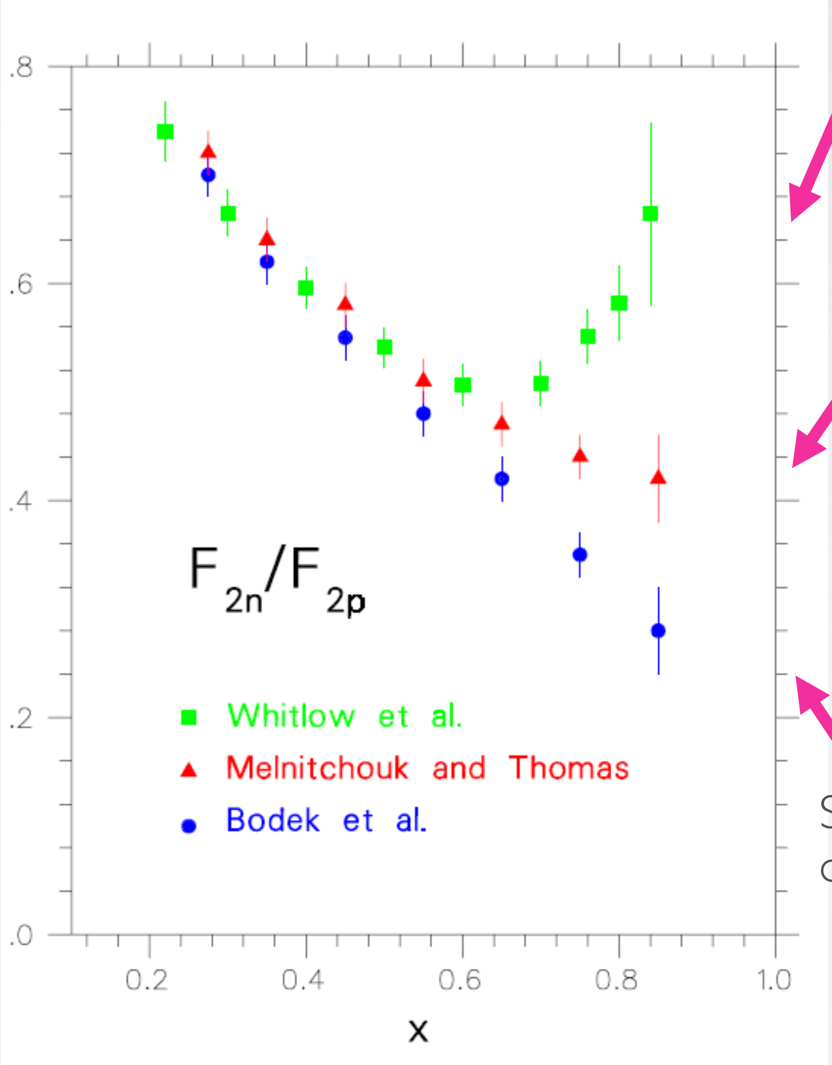


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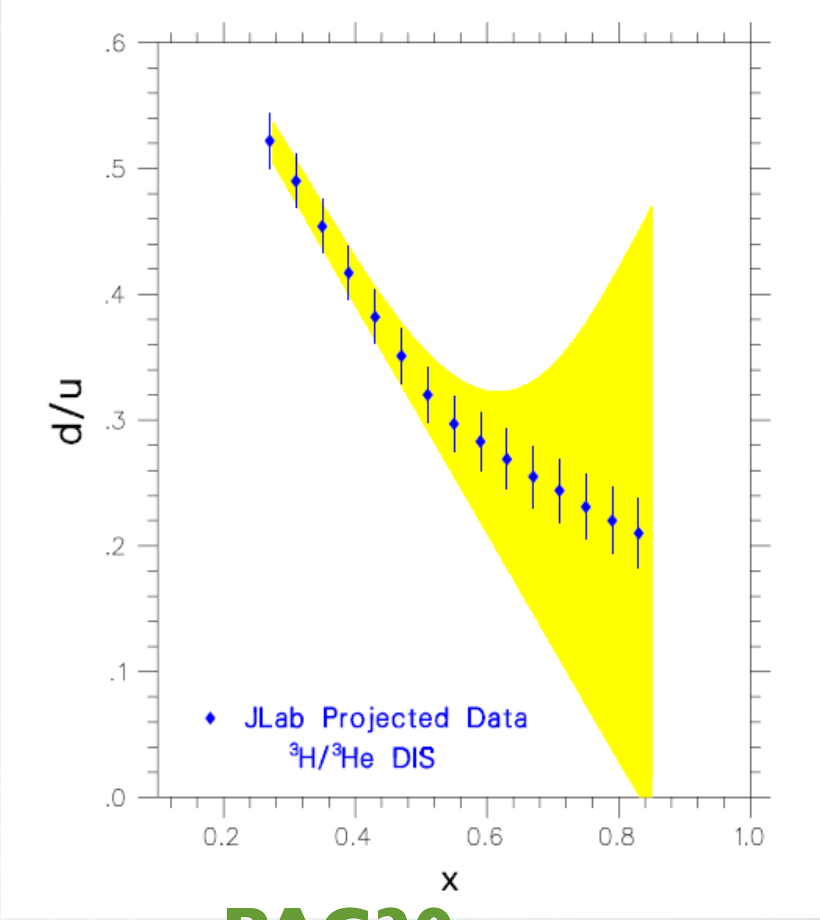
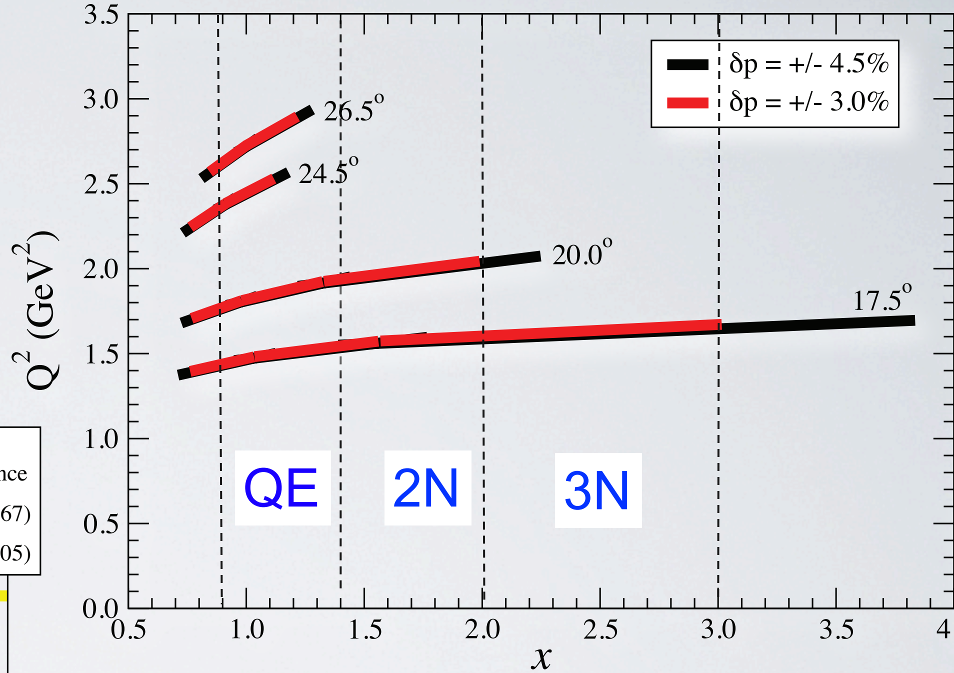
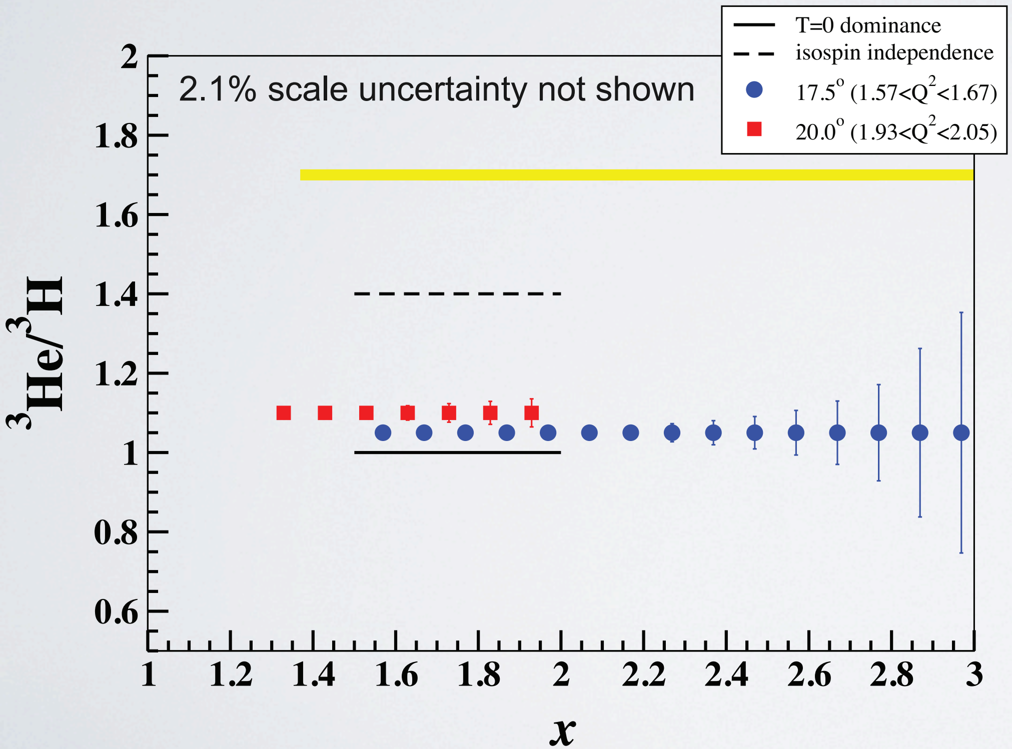



**PAC30: Conditionally approved**

# PR09-010: ISOSPIN STUDY OF SRC

- ✓ Beam energy: 4.4 GeV (unpolarized)
- ✓ Standard Hall A configuration
- ✓ $^3$H, $^3$He at room temperature, then H and $^2$H cryo-targets




JLab PR09-010:
P. Solvignon, J. Arrington and D. Day *et al*

**PAC34: Deferred with regret**

# SAFETY FIRST !

- **Minimize the amount and density of tritium necessary for the experiments:**
  - ➡ small cell diameter

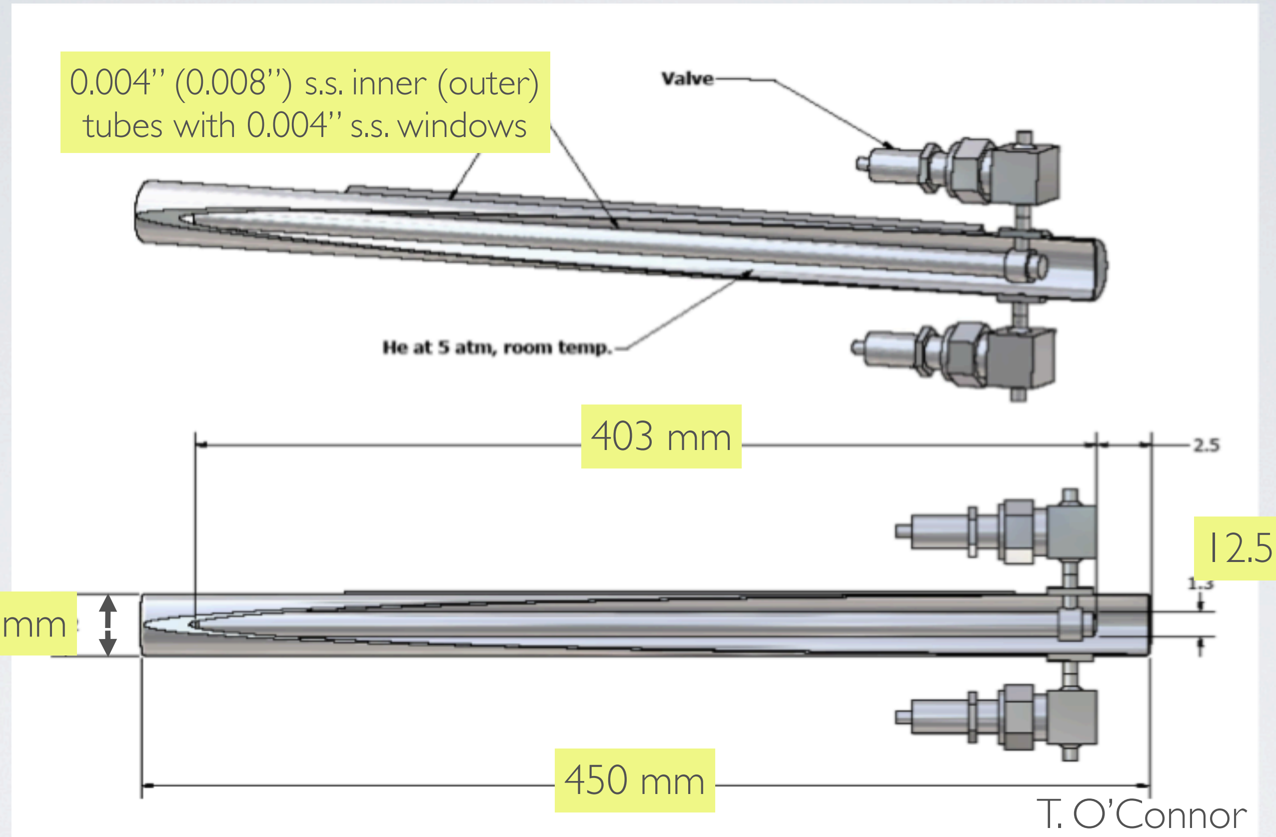
- **Keep the systems and procedure as simple and reliable as possible**
  - ➡ low power deposition density in the target ⇒ passive cooling possible
  - ➡ beam collimator ⇒ minimize beam scraping
  - ➡ target completely sealed, filled with 10 atm at the Safety and Tritium Applications Research facility (STAR) at Idaho National Lab (INL)
  - ➡ secondary containment: dedicated vacuum chamber, completely isolated from the accelerator and beam dump

# Tritium Targets at Electron Accelerators

| Lab | Year | Quantity (kCi) | Thickness (g/cm$^2$) | Current (μA) | Current x thickness (μA-g/cm$^2$) | Safe FOM (μA-g/cm$^2$/kCi) |
|---|---|---|---|---|---|---|
| Stanford HEPL | 1963 | 25 | 0.8 | 1 | 0.8 | 0.03 |
| MIT-Bates | 1982 | 180 | 0.3 | 20 | 6.0 | 0.03 |
| Saclay | 1985 | 10 | 1.1 | 15 | 16.0 | 1.6 |
| JLab | 201? | 1.6 | 0.13 | 30 | 3.9 | 2.4 |

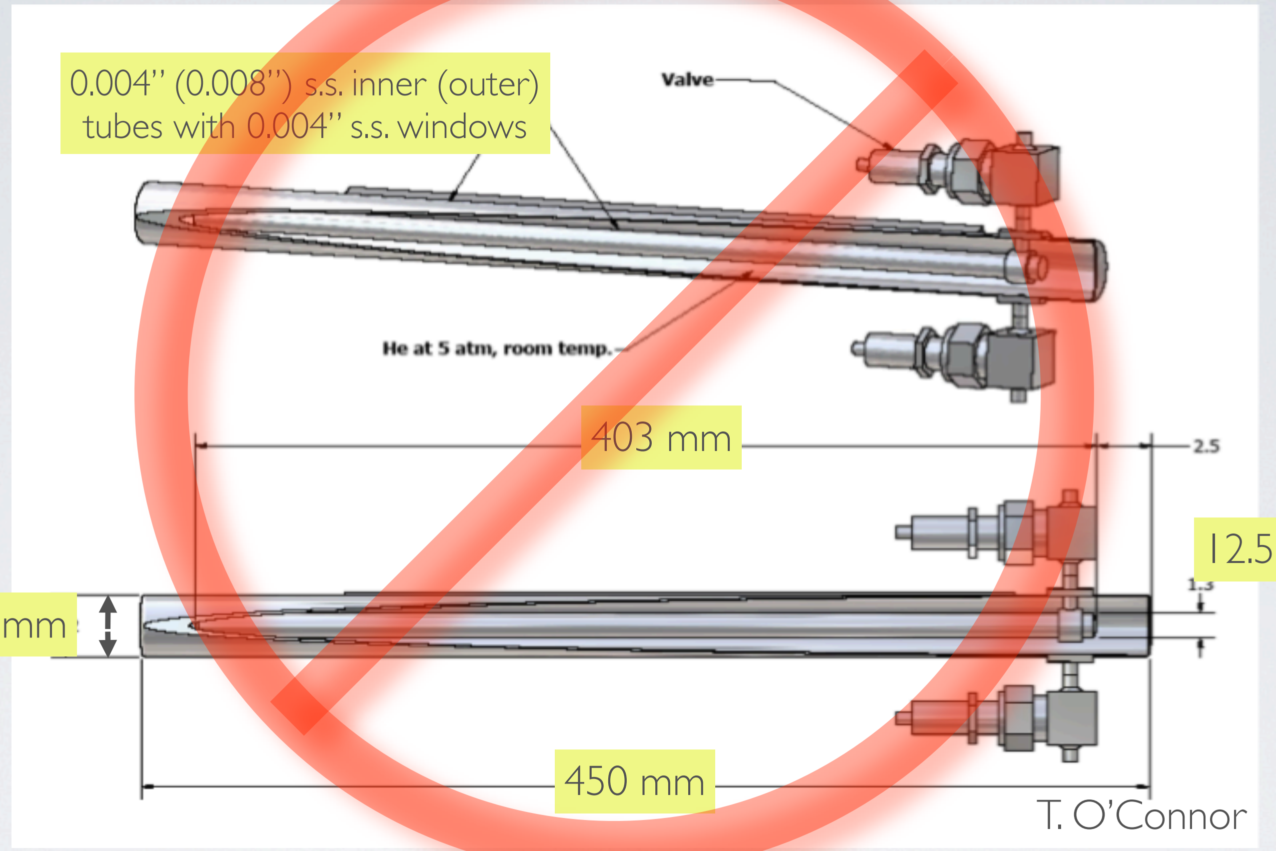
JLab also has a huge spectrometer acceptance advantage, ***eg.*** SBS

# THE DOUBLE-CELL DESIGN




- Primary and secondary containment
- Passive cooling – helium gas + heat sinks
- helium gas -> early warning of containment breach
- helium gas -> pressure relief on tritium cell

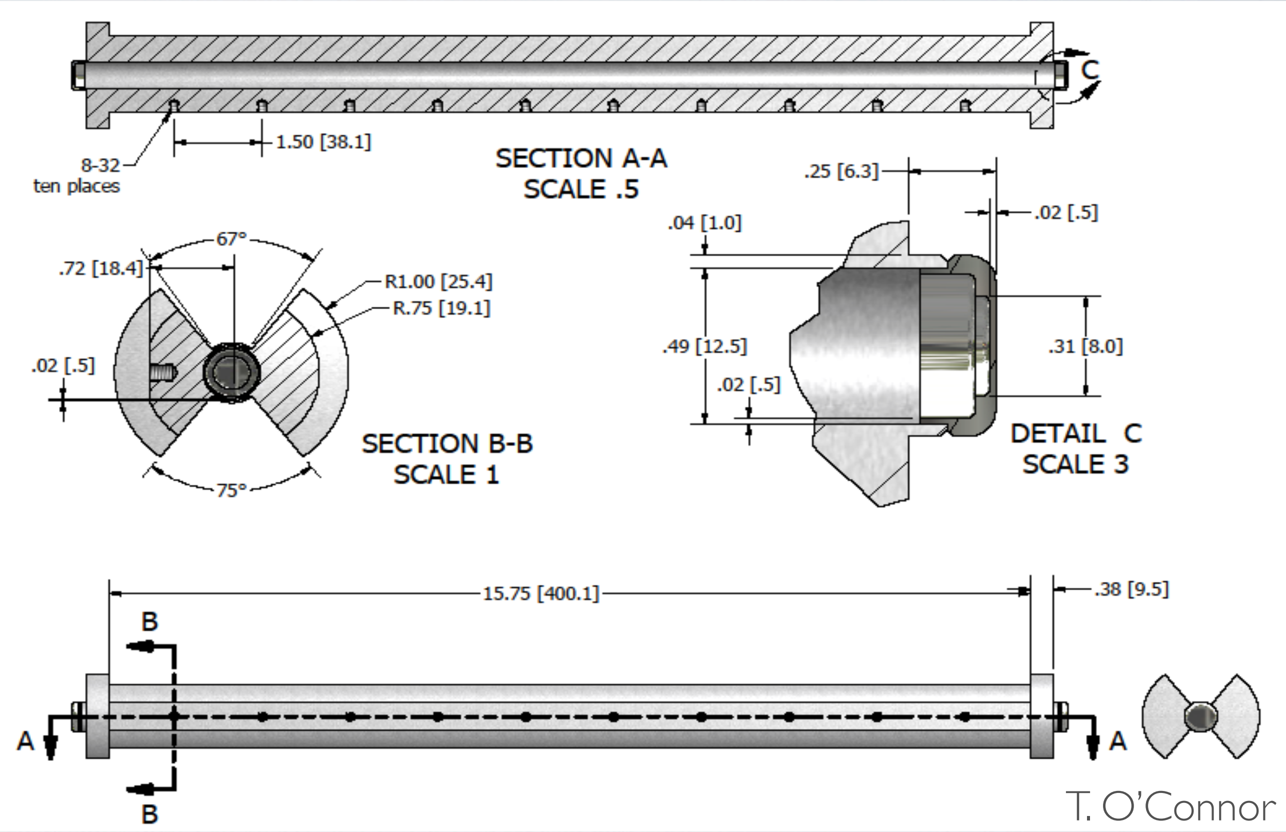
# THE DOUBLE-CELL DESIGN




**Forbidden by heat transfer calculations from Bran Brajuskovic (ANL)**

# NEW CELL DESIGN

- 1563 Ci of tritium gas
- 40cm long x 1.25cm diam.
- Aluminum (6061-T6): weldable and relatively high yield strength
- entrance, exit and side windows: 0.018” thick
- 10atm at room temperature initially, with slow increase as tritium decays to $^3$He




should qualify for the
***sealed source qualification***

# WELDING, FILLING AND SHIPPING

- The parts will be tested by fluorescent dye penetrant and radiography.
- Parts will be then electron beam welded ⇒ joint with same composition as the base material.
- Filling tubes will be welded on the vessels and helium leak tested (up to 300psi). Then radiographed again.
- Valves will be welded to the fill tubes, then removed after filling. Locks will be attached to the valves and a s.s. cap will be welded to the valves.
- The target assembly will be pressure and burst tested

  ⇒ requiring a FOS of 3 for Tritium and of 2 for $^3$He
- The target will be:
  1. filled at the STAR Facility at INL.
  2. shipped in a special shipping container to JLab
  3. placed in a target ladder contained in a dedicated scat. chamber♣

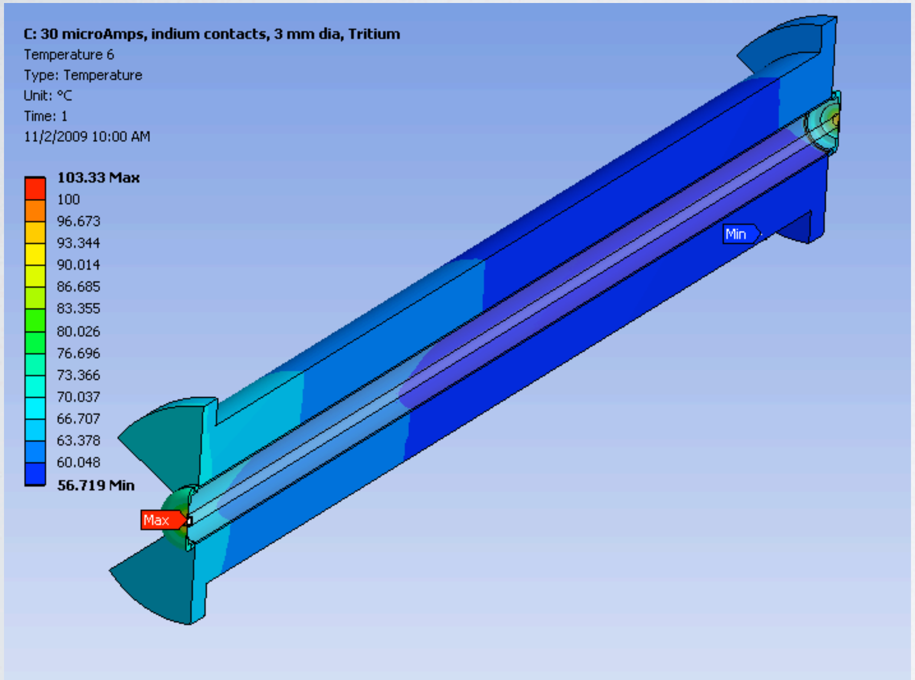
♣ *Alternative: target installed in the scat. chamber and then shipped to JLab. No handling of the target cell at JLab.*

# ELECTRON BEAM CONSIDERATIONS

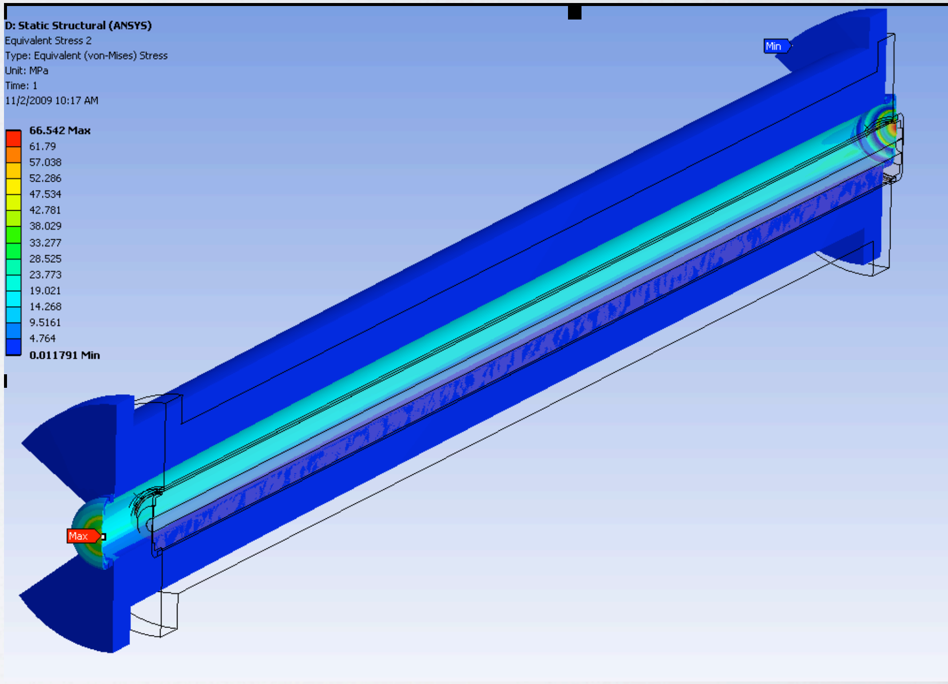
- Administrative limit: 30 μA
- Due to drop of the gas target density from beam heating (~10mW per mm of target length), we will run with beam current of 24 μA max.
- Raster size: 3mm diam.
- Aluminum: high thermal conductivity, low tritium diffusion rate, compatibility with tritium gas
- Finite element analysis heat transfer calculations

# FINITE ELEMENT HEAT TRANSFER CALCULATIONS

by B. Brajuskovic (ANL)




**Temperature map**



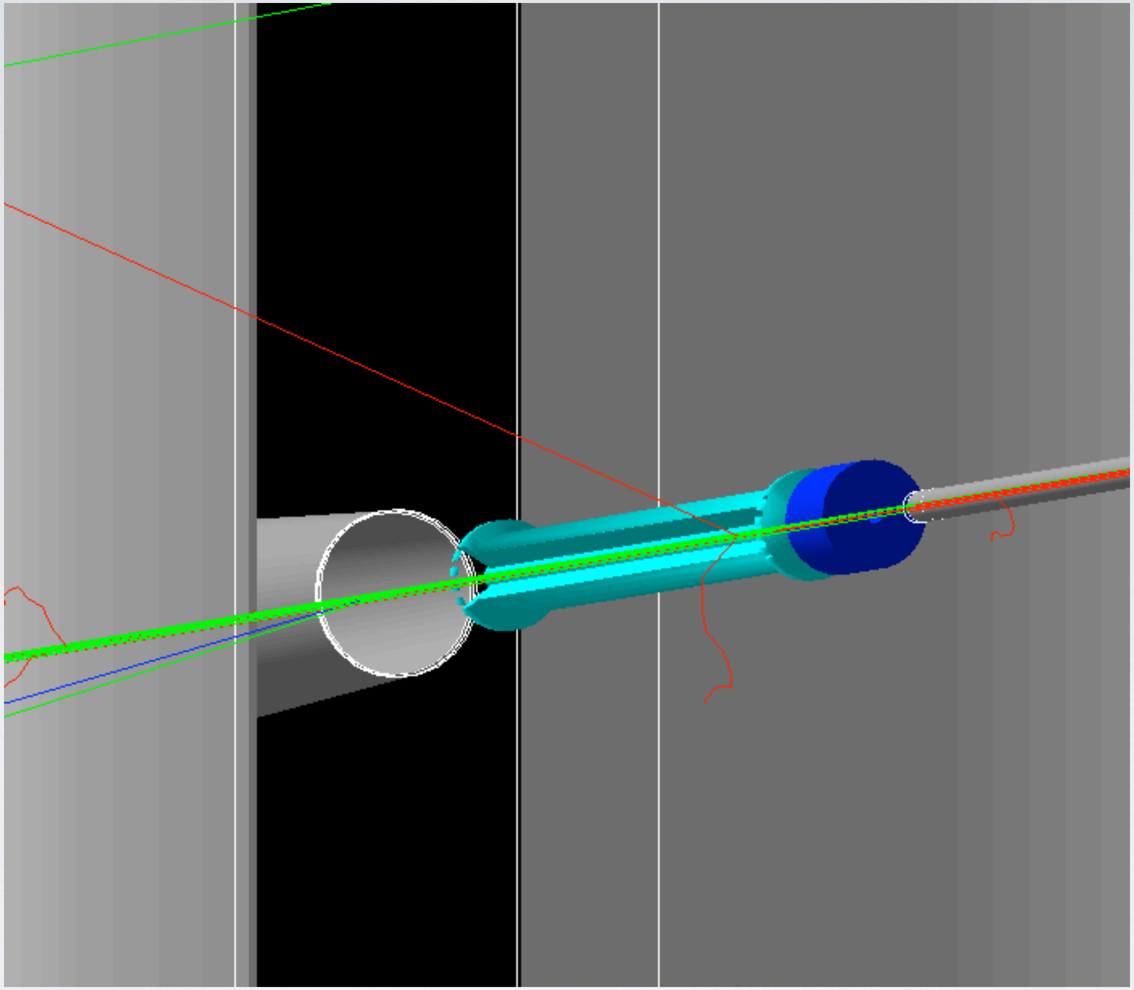

**Pressure map**

# FINITE ELEMENT HEAT TRANSFER CALCULATIONS

by B. Brajuskovic (ANL)

| | Max. gas temp. | Average gas temp. | Maximum Al temp.- endcaps | Maximum Al temp. - body | Gas pressure | Maximum stress - endcaps | Yield stress - endcaps | FOS endcaps | Maximum stress - body | Yield stress - body | FOS body |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | °C | °C | °C | °C | bar | MPa | MPa | / | MPa | MPa | / |
| Hydrogen – indium foil | 102.9 | 65.6 | 103.3 | 71.2 | 12.71 | 66.1 | 228.6 | 3.45 | 27.1 | 237.6 | 8.76 |
| Hydrogen – silver foil | 103.8 | 67 | 104.1 | 72.1 | 12.77 | 66.3 | 228.4 | 3.44 | 29.9 | 237.4 | 7.94 |
| Deuterium-indium foil | 103 | 67.1 | 103.3 | 71.2 | 12.77 | 66.3 | 228.6 | 3.45 | 27.2 | 237.6 | 8.74 |
| Deuterium-silver foil | 103.8 | 68.5 | 104.2 | 72.1 | 12.82 | 66.6 | 228.3 | 3.43 | 30.0 | 237.4 | 7.91 |
| Tritium – indium foil | 103.1 | 69 | 103.3 | 71.2 | 12.84 | 66.5 | 228.6 | 3.44 | 27.3 | 237.6 | 8.70 |
| Tritium – silver foil | 103.9 | 70.4 | 104.2 | 72.1 | 12.89 | 66.8 | 228.3 | 3.41 | 30.2 | 237.4 | 7.86 |
| Helium – indium foil | 123.7 | 78.2 | 107.7 | 75.5 | 25.17 | 106.3 | 227.87 | 2.12 | 47.9 | 236.5 | 4.93 |
| Helium – silver foil | 125.3 | 80.1 | 109.0 | 76.9 | 25.3 | 106.8 | 227.45 | 2.09 | 58.5 | 236.1 | 4.03 |

# GEANT4 SIMULATION IN PROGRESS



**<u>Goal</u>: determine the need of windows collimation and optimize the position of the beam collimator**

# SUMMARY

- Scientific stage being set at JLab for d/u ratio measurement
- Totally sealed, passively-cooled sample, double containment, exhaust fan, interlocks
- All tritium gas handling performed at STAR Facility at INL
- Additional independent interlock on beam raster
- Target is ready for prototyping

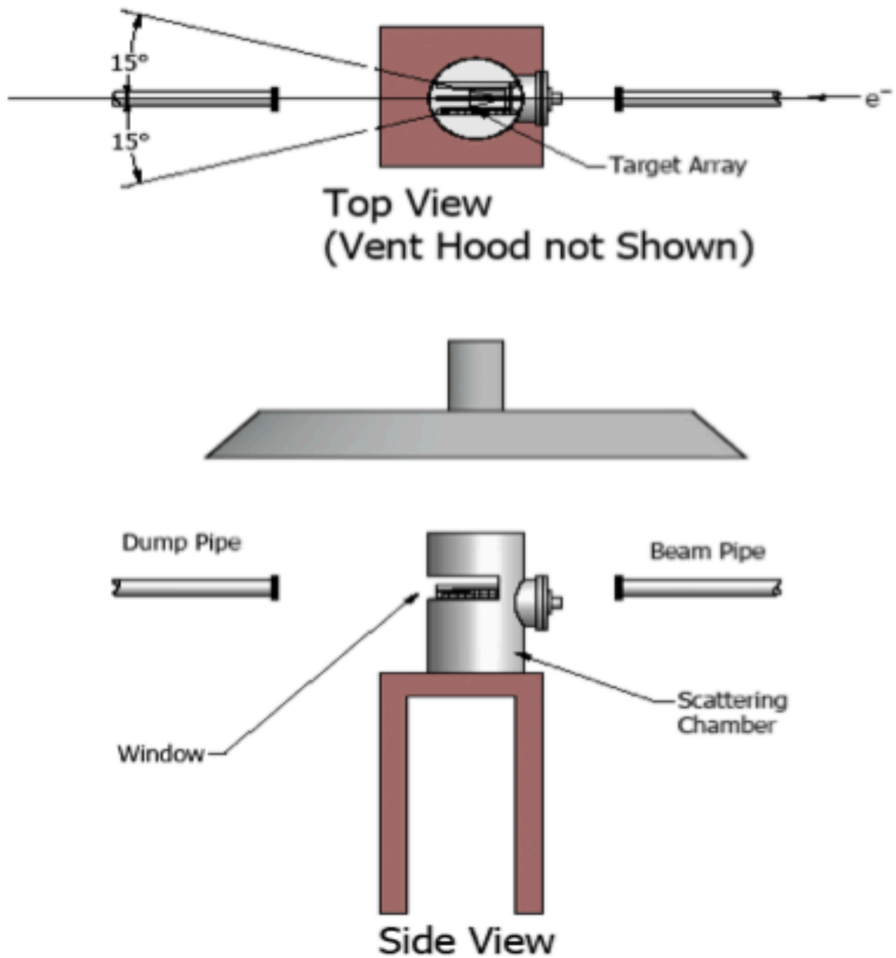
***Conclusion: A safe tritium target is possible at JLab.***

# EXTRA SLIDES

# SCATTERING CHAMBER AND VENT HOOD

**Vacuum chamber:**

- tertiary container
- NEG and ion pumps, no exhaust
- continuous helium leak detection
- isolated from accelerator

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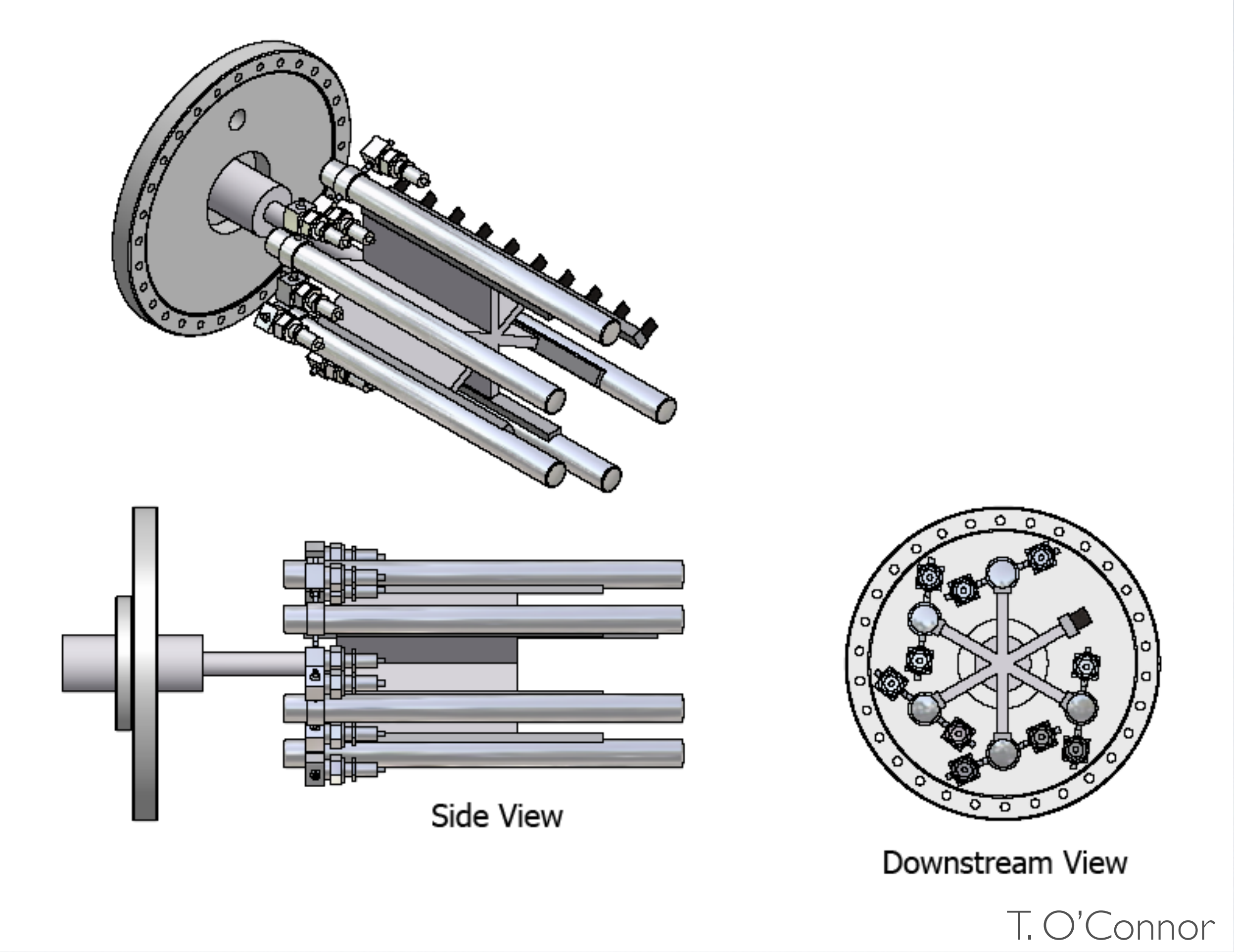
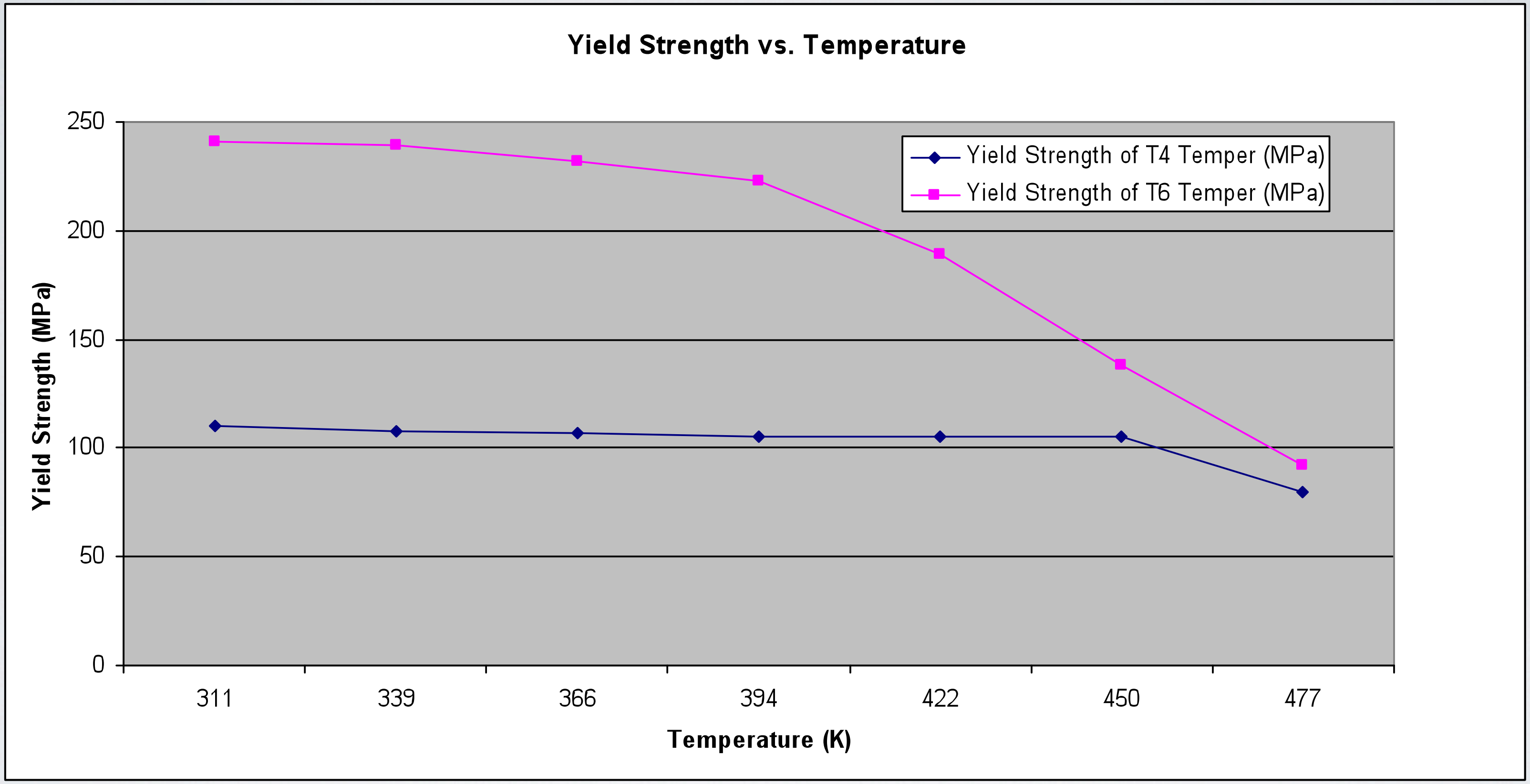
# TARGET HOLDER



# NEW CELL DESIGN



# EXPERIMENT REQUIREMENT

**12 GeV experiment: E12-06-118, conditionally approved**

**"… the PAC considers the physics goals of this experiment as highlights of the 12 GeV physics program."**

**Condition: "A special JLab Management review of the safety aspects of the tritium target is the condition for approval."**

# SAFETY AND TRITIUM APPLICATIONS RESEARCH (STAR) FACILITY IDAHO NATIONAL LABORATORY

Director, Phil Sharpe

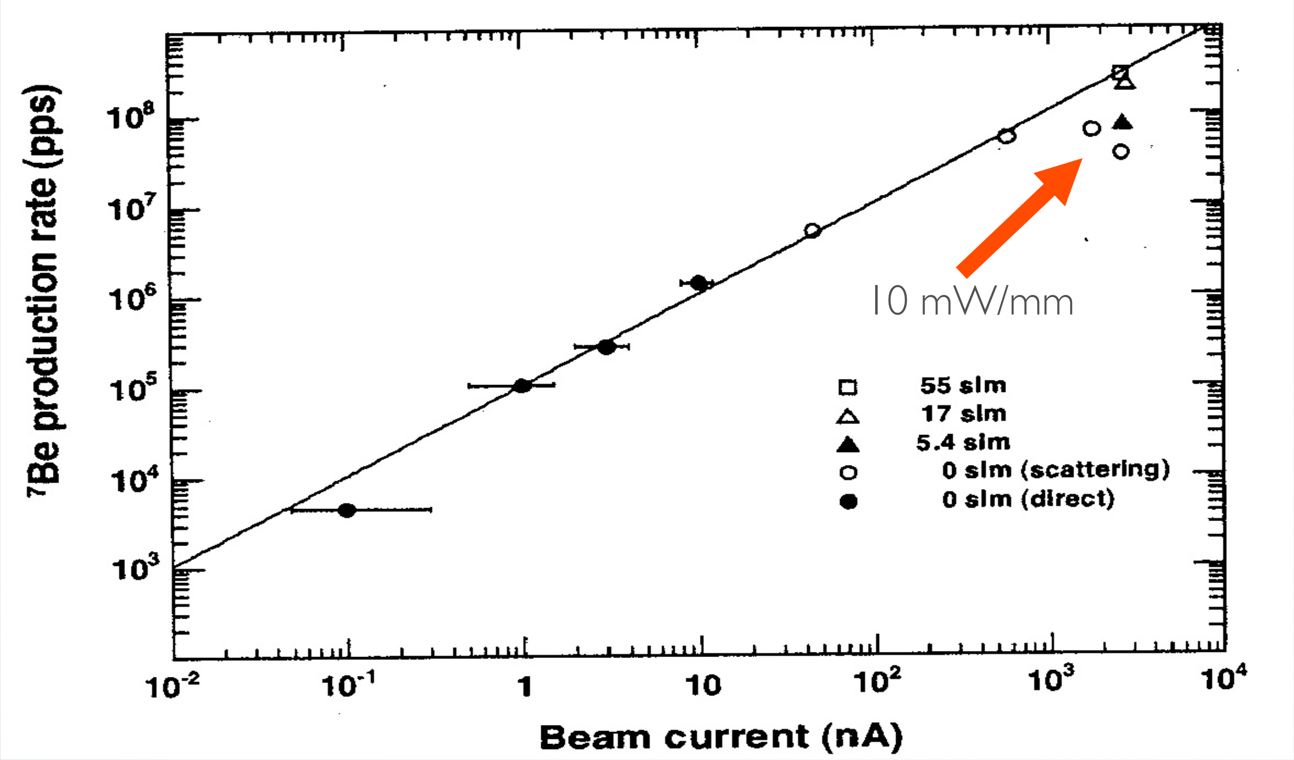
- Test s.s. materials through radiography,…
- Fabricate target cells
- Radiograph e-beam welds
- Pressure test target cells up to 80 atm
- Fill target cells with gases
- Seal target cells
- Ship target cells to JLab
- Receive target cells shipped from JLab and recover tritium gas

**STAR has shipped up to 2500 Ci of tritium gas.**

# BEAM CURRENT CONSIDERATIONS

Limit beam current to 30 μA

- >70 μA problem for Fe targets (C. Cochran, Ph.D. Dissertation, UVa 2000)
- <20 μA, correction = 0.1%/μA (K. Dow, Ph.D Dissertation, MIT 1982)
- Threshold in gas: 10 mW/mm -> 24 μA electron beam -> 1.7 μA for Bates target!?

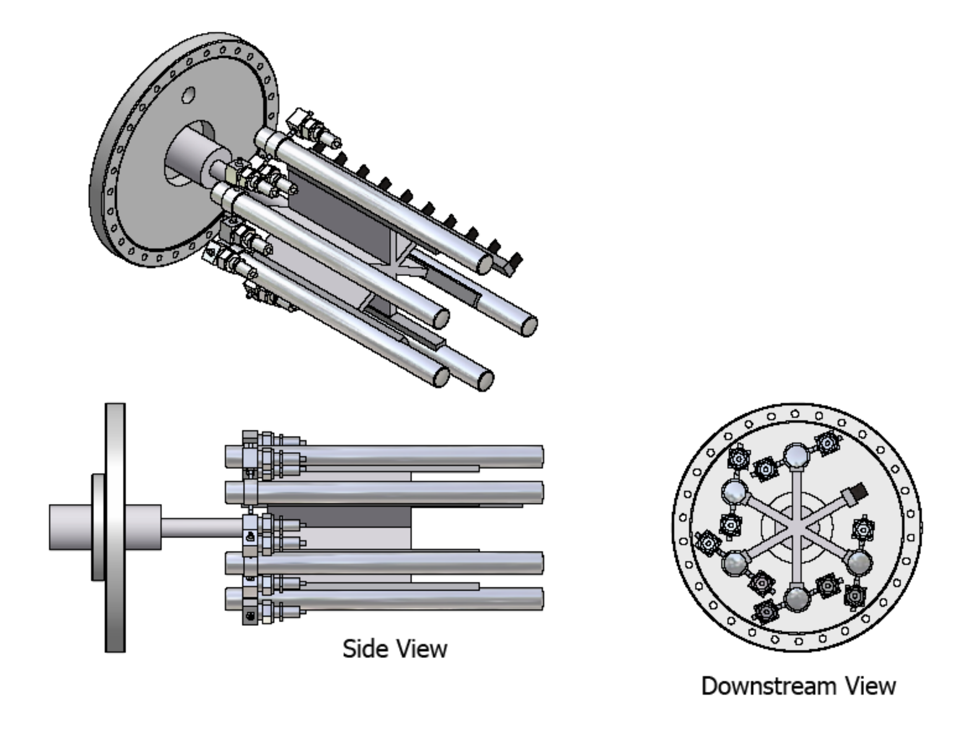



H. Yamaguchi *et al.* Nucl. Instrum. Meth. Phys. Res. **A 589**, 156 (2008).

# TARGET HEATING

- Tritium decay heat: 53 mW  (324 mW/g)
- Beam heating (30 μA):
  - 3.5 W per window -> 14 W
  - 5 W in gas
  - Total heating = 19 W

# TARGET COOLING



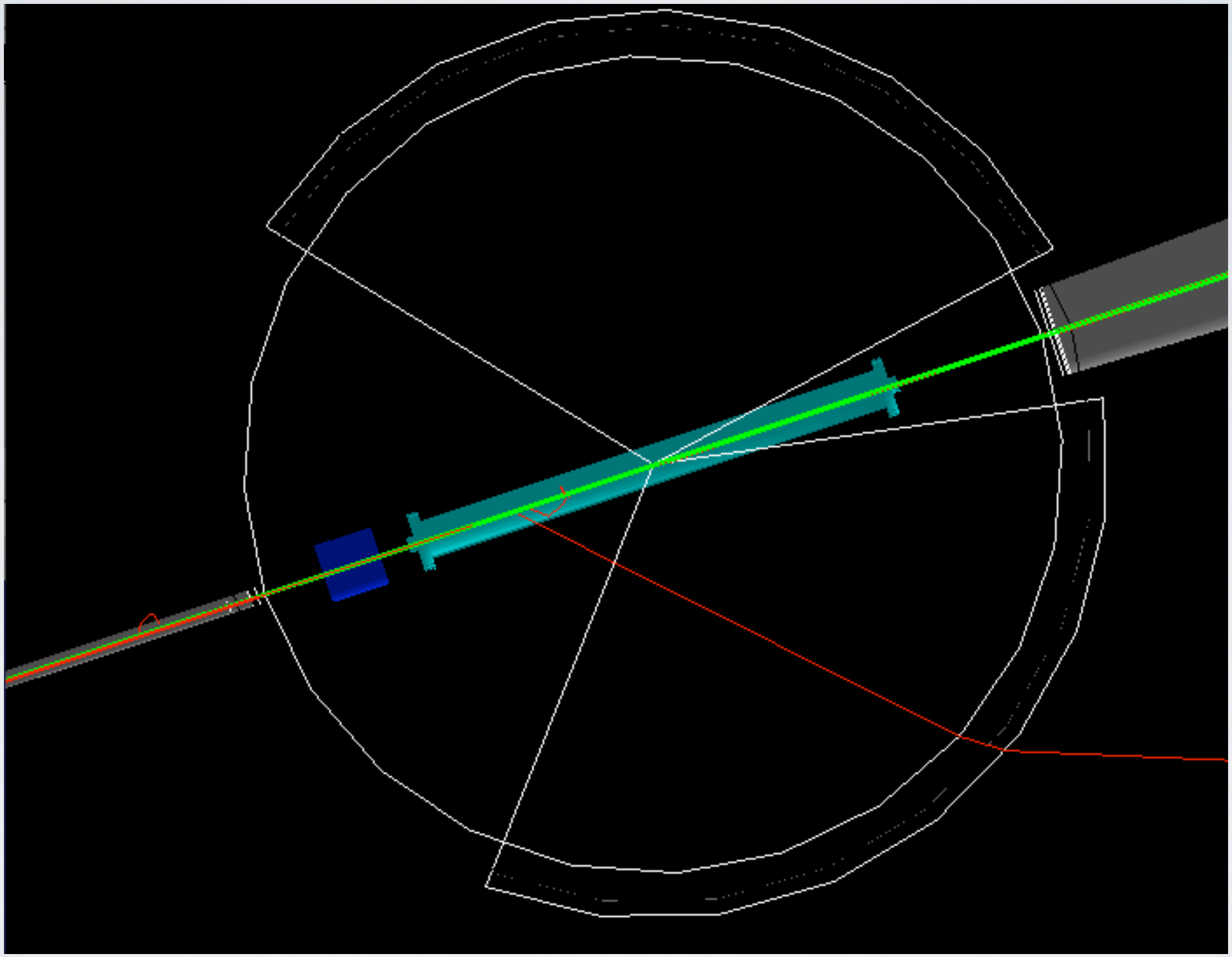

T. O'Connor

- Window cooling:
  - Conduction to edge: 0.005 W/K
  - Radiative cooling: 0.6 W
  - Helium conduction: 0.002 W/K
  - Helium convection: 0.001 W/K
- Target cell cooling in vacuum chamber
  - Radiative cooling alone: $\Delta T = 283$ C
  - Heat sinks: < 100 C

- Target temperature < 100 C.
- Finite element heat transfer analysis

Bran Brajuskovic (ANL) + summer student

# GEANT4 SIMULATION IN PROGRESS



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# SPECIAL ISSUES FOR TRITIUM

- Tritium diffusion through stainless steel
  - Entire cell at 400C -> 0.5 mCi/hr -> 1.2 Ci in 100 days
- X-rays from the target cell
  - 18.6 keV beta endpoint -> << 0.3 mrem/hr
- Radiation damage of target cell
  - $10^5$-$10^6$ orders of magnitude – no problem
- Hydrogen embrittlement of the target cell
  - Problem above 2000 psi, target at 150 psi ST
- Energy stored in pressurized gas cell (JLab ESH 6151 Appendix T4)
  - 75 and 250 J ~ to polarized $^3$He target
- Chemical energy in the gas cell
  - ~0.4 liters STP, 22 kJ, strongly diluted in scatt. chamber or Hall, 15 ppb
- Activation of the s.s. target cell
  - Target windows: 4.3 mrem/hr, after one month: 2.1 mrem/hr @ 1 m

# SUMMARY OF KEY ENGINEERED CONTROLS

- Small amount of tritium gas (1563 Ci) – MIT-Bates: 110 x larger sample
  - Small diameter cell with beam collimator
  - Super Big Bite Spectrometer
- All tritium handling performed offsite at Idaho National Lab
- Target cell completely sealed
  - Secondary containment with helium gas, completely sealed
  - Tertiary containment is sealed, evacuated scattering chamber with ion and NEG pumps, continuous helium and tritium leak detection
  - Scattering chamber isolated from accelerator
- Raster failure risk mitigation
  - Probability from Hall A experience ~ $3 \times 10^{-4}$
  - Independent raster monitor with battery backup
  - Independent FSS on raster
- Independent vent hood and task fan in target area
  - High velocity task fan interlocked to tritium or helium detection

# PROPOSED ADMINISTRATIVE CONTROLS

- Beam current should be limited to 30 μA
- Overhead crane locked out after target installation
- Trained tritium target operator(s) on shift at all times
- Beam condition, raster pattern and target parameters monitored
- Accelerator operators given special instructions
    - Independent operator check on beam current, raster, interlocks
- Full written and approved procedures for all operations with target
    - Target installation and removal
    - Target storage
    - Target motion
    - Beam on target

# WORST CASE ACCIDENTS

- Tritium containment breached – with task fan
  - 1563 Ci of tritium lost up 5-m stack in 1 hour
  - Person at site boundary: 0.3 mrem*
- Tritium containment breached – without task fan
  - 1563 Ci lost into Hall A (38,000 $m^3$)
  - Worker receives <0.33 mrem/hr
  - Hall A exhaust fans (36,000 cfm capacity)
  - After 2 hours @ 20,000 cfm, ~ 1 Ci level

*GENII v. 2 NESHAPS code for EPA, Bruce Napier, PNNL

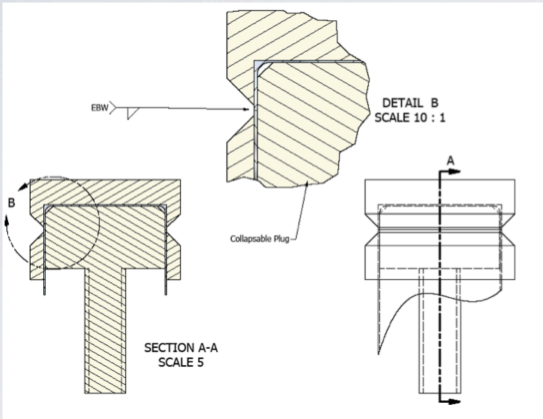
# Unrelated fire, natural disaster and other incidents

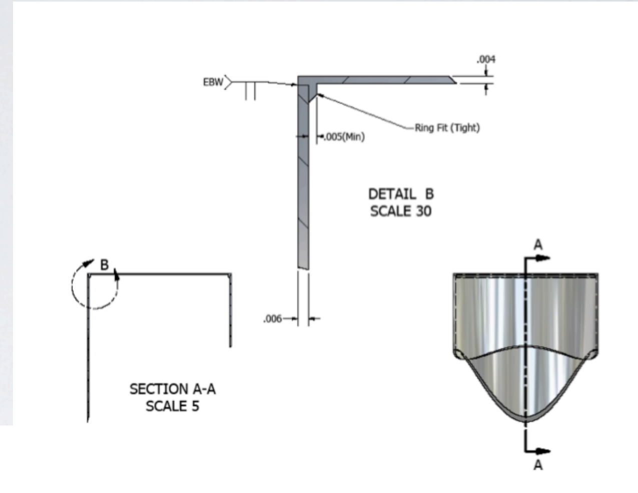
- Fire
  - Target containment is thermally well insulated
  - Normal evacuation of room
  - Access by fire department permissible after check for radiological hazards including tritium
- Massive scale earthquakes and tornadoes unprecedented
- Hurricanes cause power outages and flooding
  - Sealed, passive target with NEG pump not affected

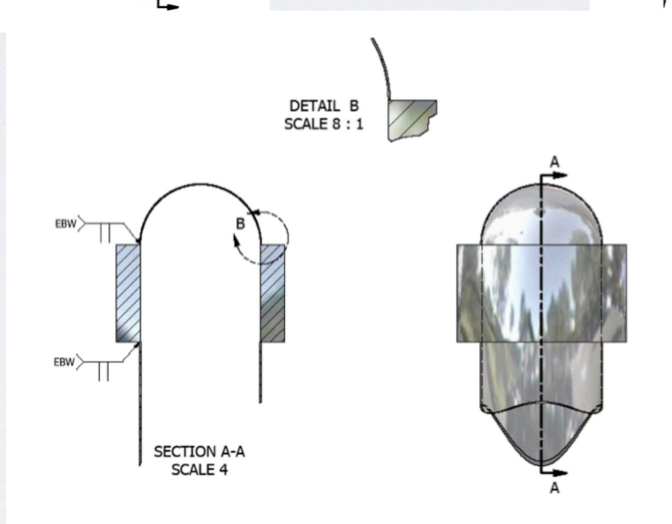
# Safety considerations

- Small diameter gas cell + SBS -> minimize amount of tritium
- Target filled, sealed, decommissioned at INL
- Reduced beam current (< 30 μA)
- Secondary and tertiary containment
- Target system isolated from accelerator
- Passive cooling of target cell
- Special ventilation system in target area
- Independent interlock on beam raster
- Target temperature monitor and interlock
- Helium and tritium detection with interlock
- Special procedures

# WINDOW WELD DESIGNS



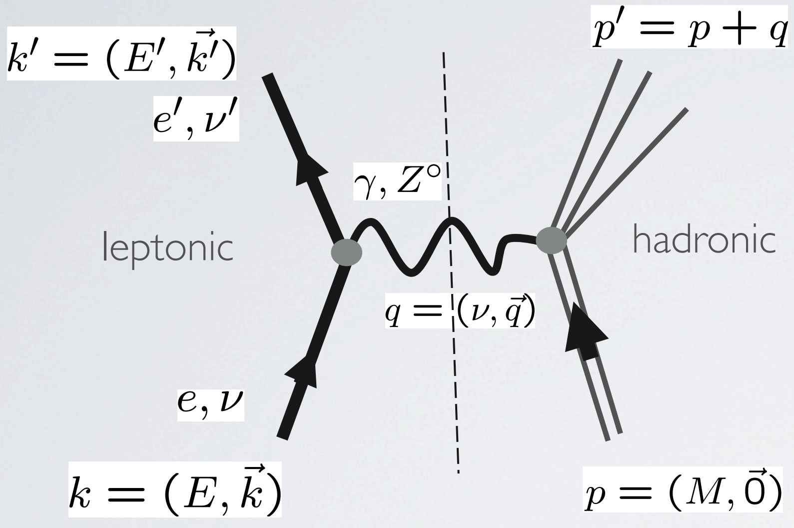




Stanford target

T. O'Connor

Finite element stress analysis in progress

# DEEP INELASTIC SCATTERING AND STRUCTURE FUNCTIONS




**Parton model:**

$$F_2(x) = 2xF_1(x) = x\Sigma e_i^2(q_i(x) + \bar{q}_i(x))$$

$$x = \frac{Q^2}{2M\nu}$$

$$F_2^p = x\left[\tfrac{4}{9}(u+\bar{u}) + \tfrac{1}{9}(d+\bar{d}) + \tfrac{1}{9}(s+\bar{s})\right]$$

$$u_p(x) = d_n(x) \equiv u(x)$$

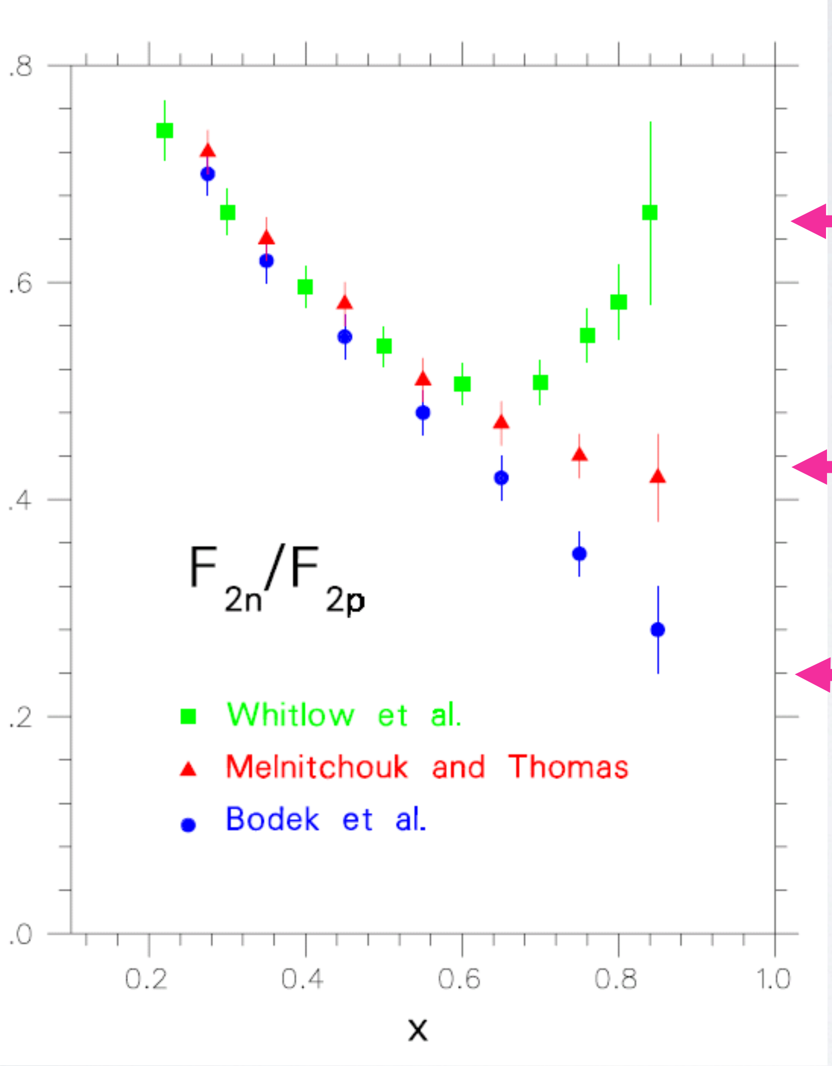
$$F_2^n = x\left[\tfrac{4}{9}(d+\bar{d}) + \tfrac{1}{9}(u+\bar{u}) + \tfrac{1}{9}(s+\bar{s})\right]$$

$$\frac{F_2^n}{F_2^p} = \frac{u+\bar{u}+4(d+\bar{d})+s+\bar{s}}{4(u+\bar{u})+d+\bar{d}+s+\bar{s}}$$

$$\frac{1}{4} \le \frac{F_2^n}{F_2^p} \le 4$$

$$\frac{F_2^n}{F_2^p} = \frac{[1+4(d/u)]}{[4+(d/u)]}$$

# THE NEUTRON STRUCTURE FUNCTION AT HIGH X




SU(6) symmetry

pQCD

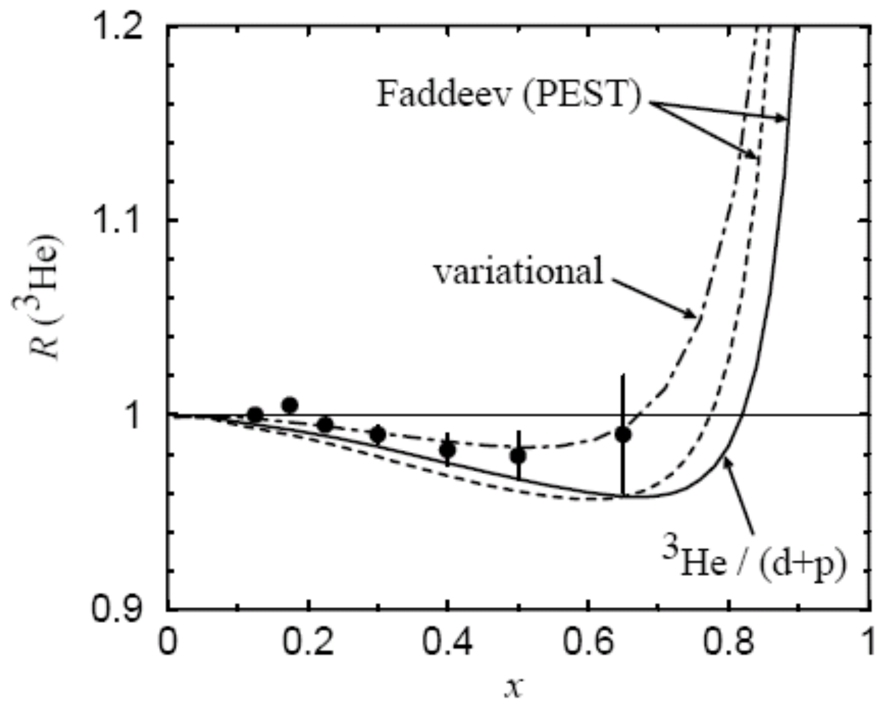
Scalar di-quark

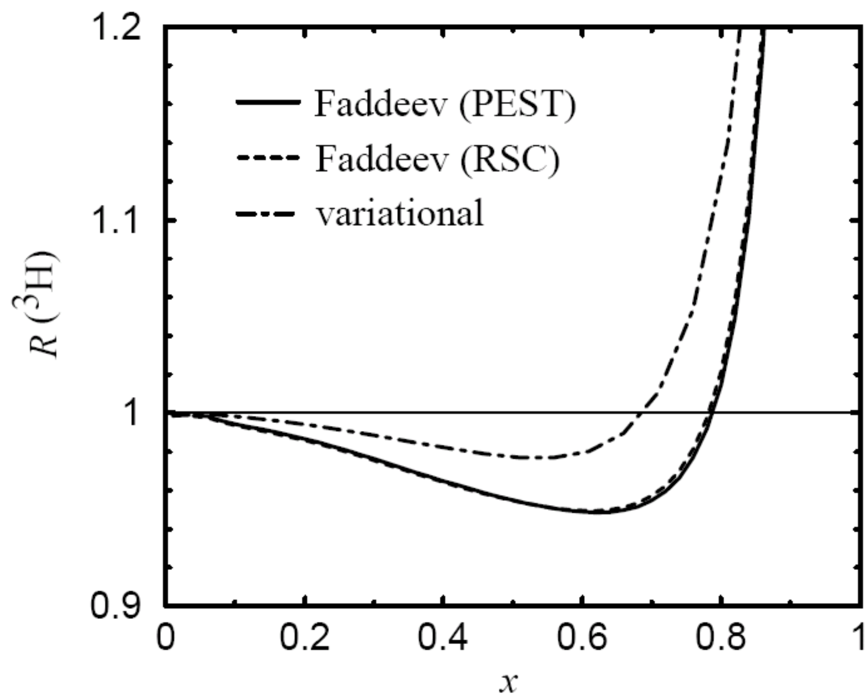
Reviews: N. Isgur, PRD 59 (1999),
S Brodsky et al NP B441 (1995),
W. Melnitchouk and A. Thomas PL B377 (1996) 11.

# THE EMC EFFECT IN $^3$HE AND $^3$H

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

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




I. R. Afnan *et al*, PRC 68 (2003)

# RATIO OF $^3$HE, $^3$H
# JLAB E12-06-118

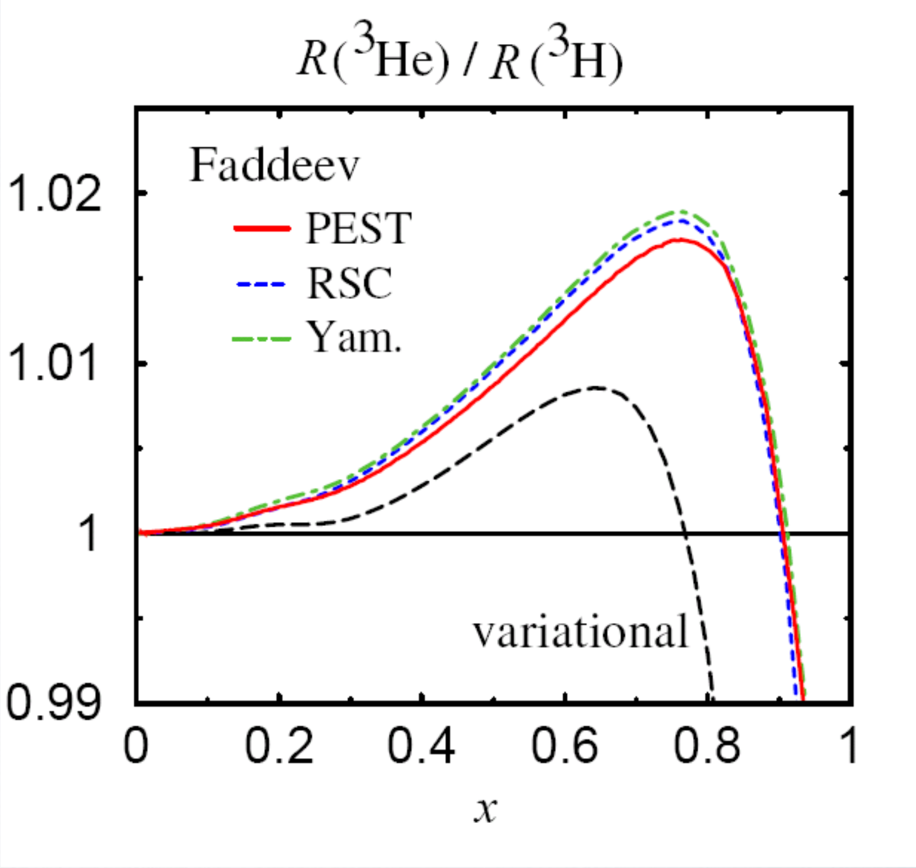
$$R(^3He) = \frac{F_2^{^3He}}{2F_2^p + F_2^n}, \; R(^3H) = \frac{F_2^{^3H}}{F_2^p + 2F_2^n}$$

- Measure $F_2$'s and form ratios:

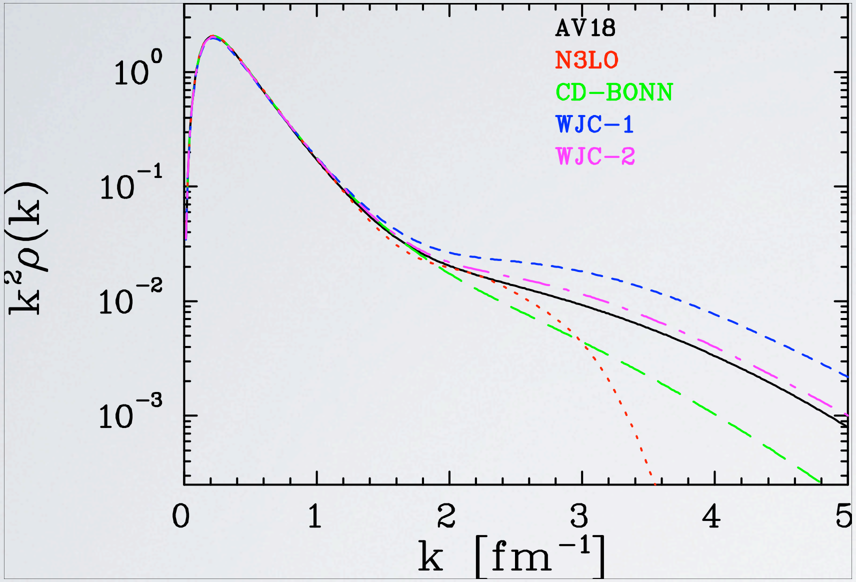
$$\frac{F_2^n}{F_2^p} = \frac{2r - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - r}$$

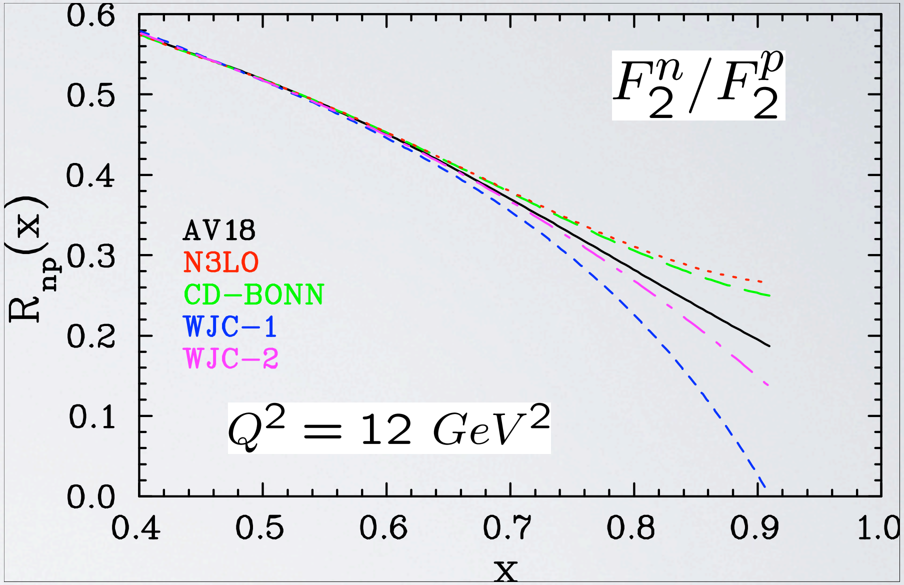
- Form "super-ratio": $r \equiv \dfrac{R(^3He)}{R(^3H)}$

*I. Afnan et al, PRC 68 (2003)*



# EXTRACTIONS WITH MODERN DEUTERON WAVE FUNCTIONS

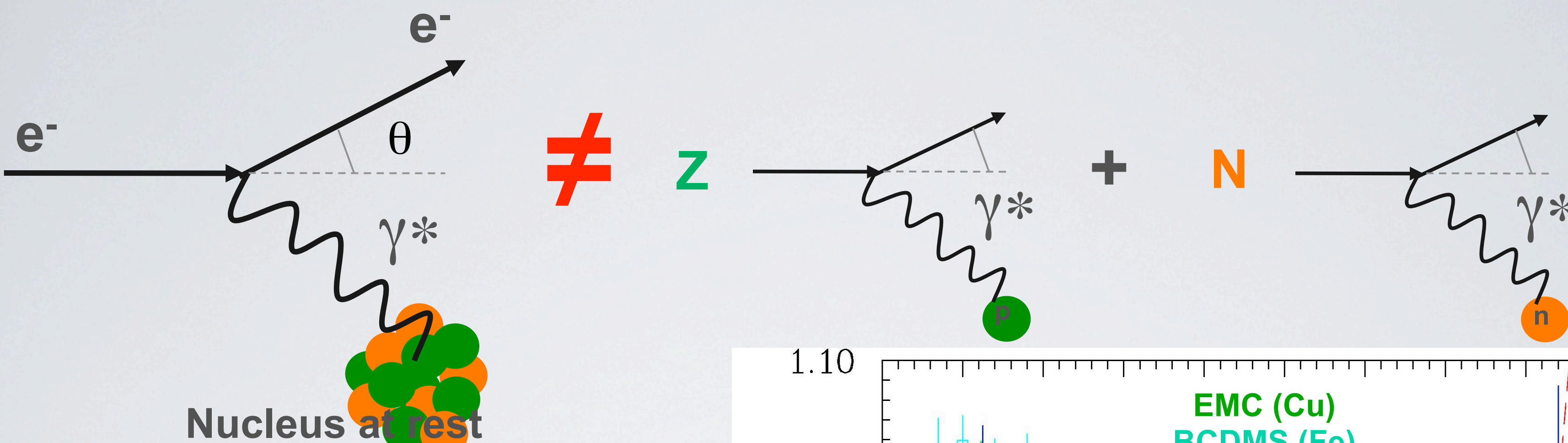



The ratio at high ***x*** has a strong dependence on deuteron structure.

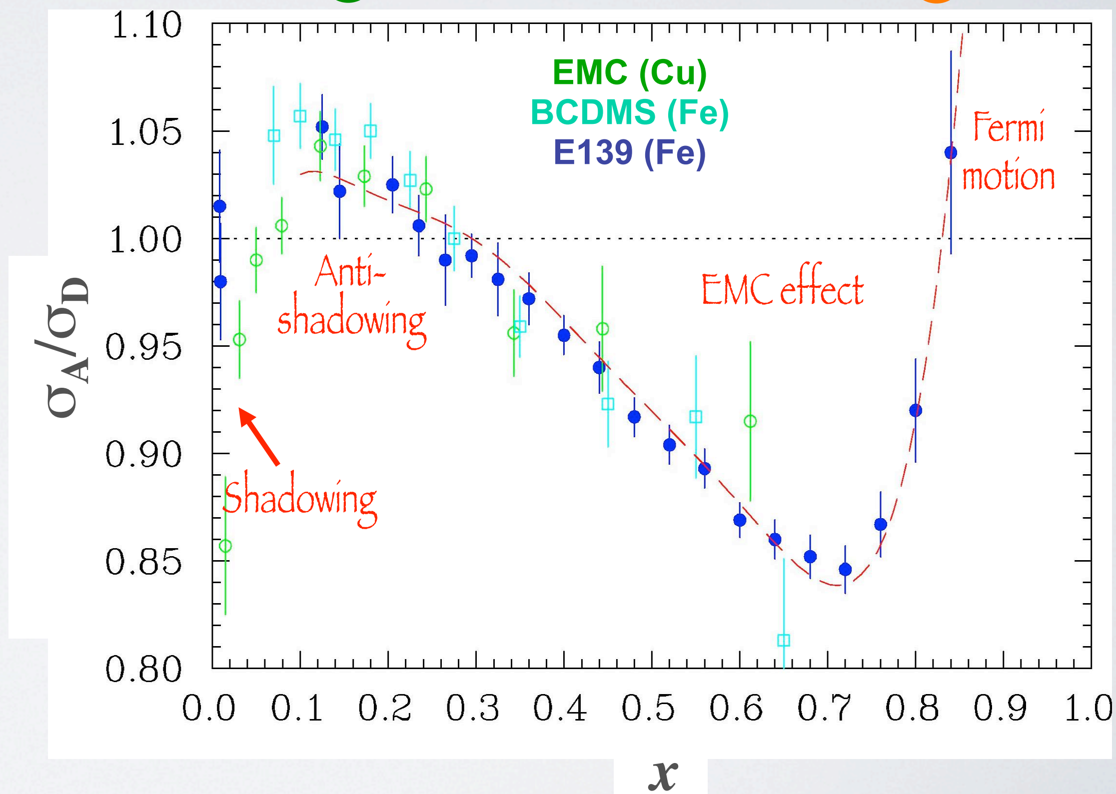
J. Arrington ***et al***, J. Phys. G **36** (2009)

# THE EMC EFFECT




**Nucleus at rest**

(**A** nucleons = **Z** protons + **N** neutrons)

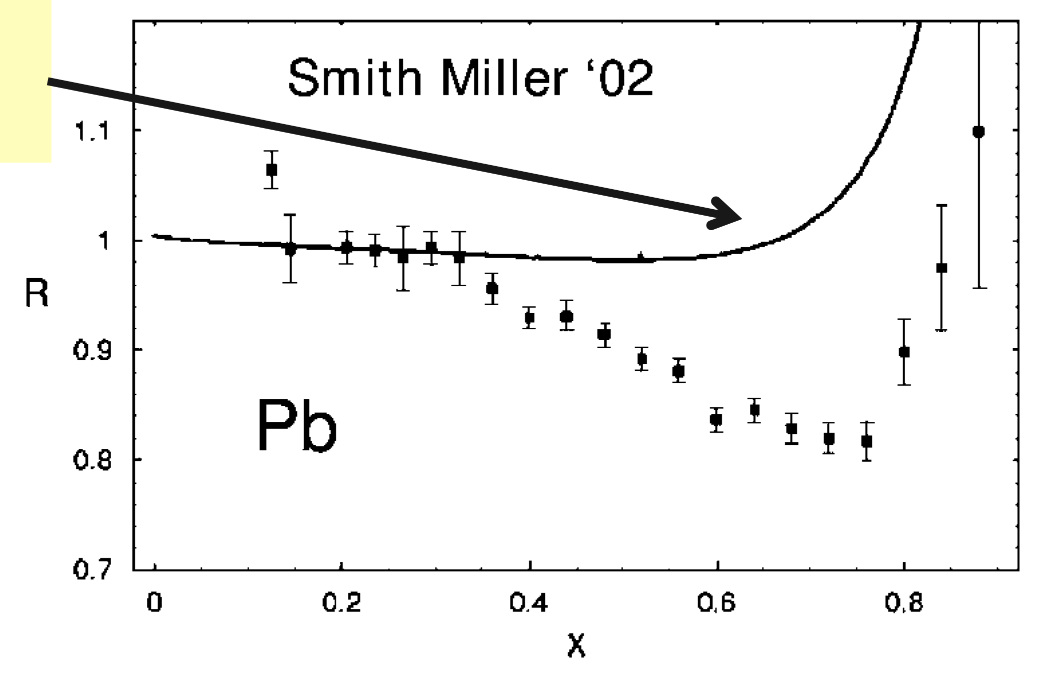



Effects found in several experiments at CERN, SLAC, DESY

# EMC EFFECT REMAINS A MYSTERY

**Smith & Miller**,
PRC 65, 015211 and 055206 (2002)

Conventional nuclear physics

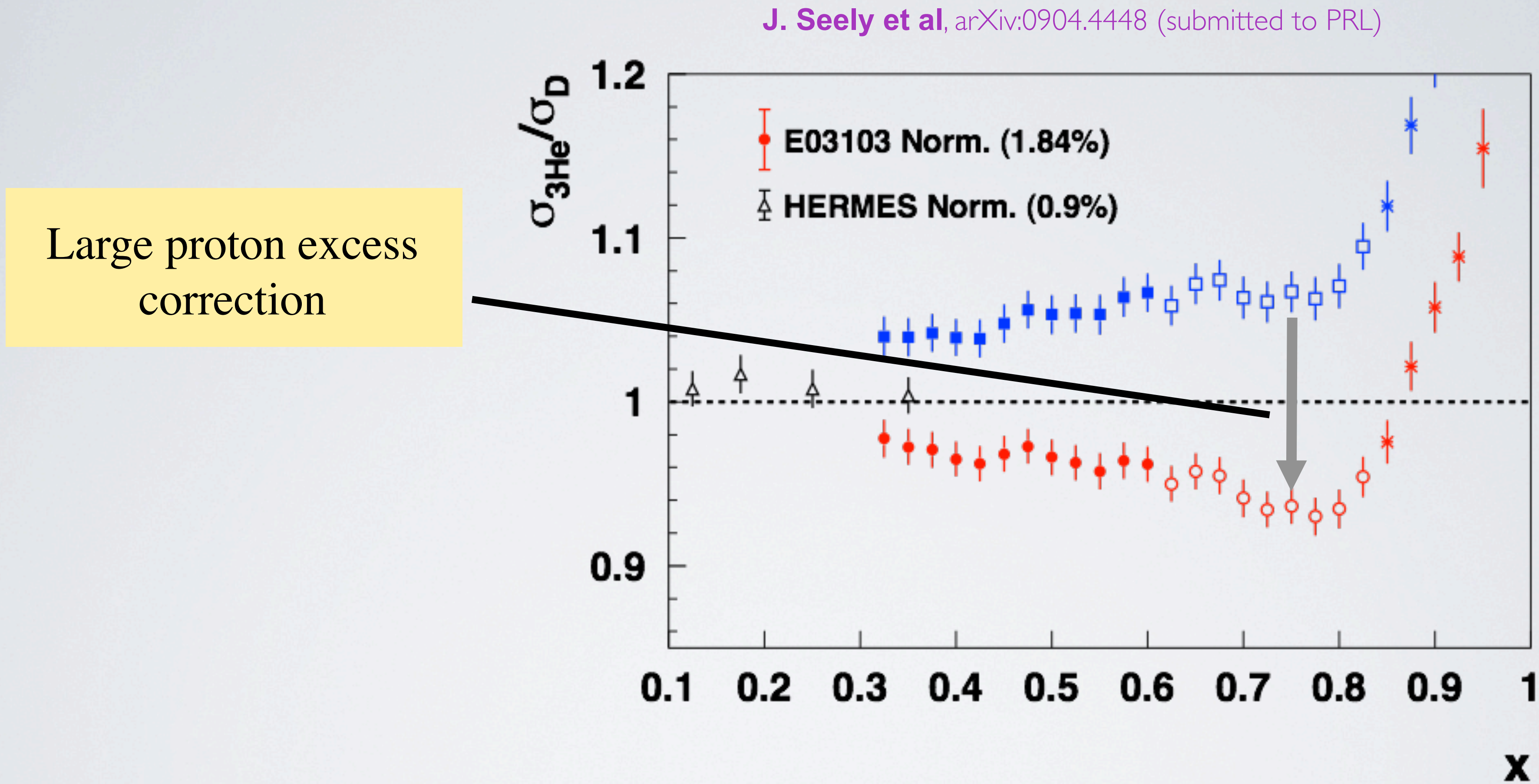



*"… some effect not contained within the conventional framework is responsible for the EMC effect."*

New strategy:
Measure the EMC effect in light nuclei:

- nuclear effects can be calculated reliably
- determine density and isospin effects

# ³HE EMC RATIO




Measure EMC effect in the triton:

Don't rely on corrections.