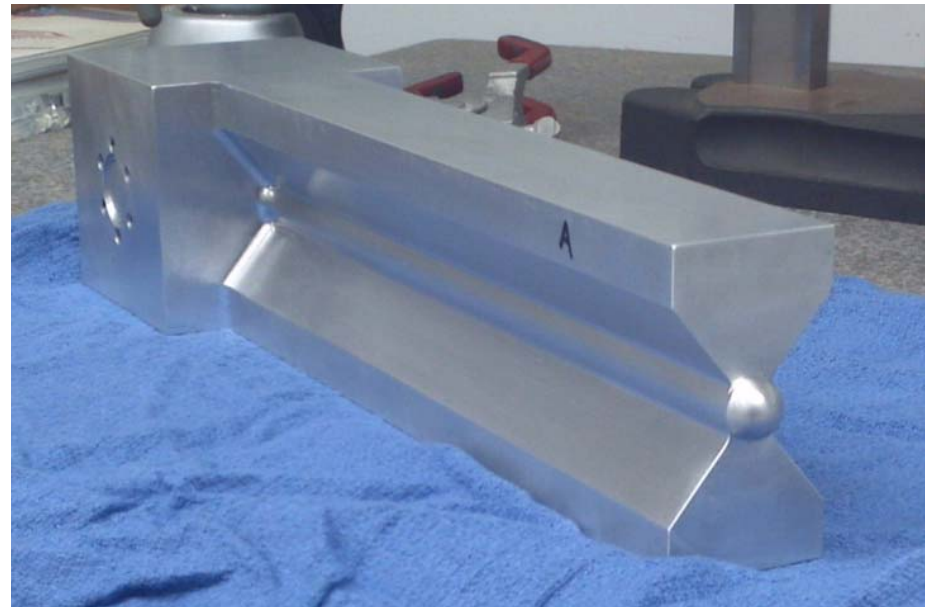


Introduction to the tritium target design

Roy J. Holt

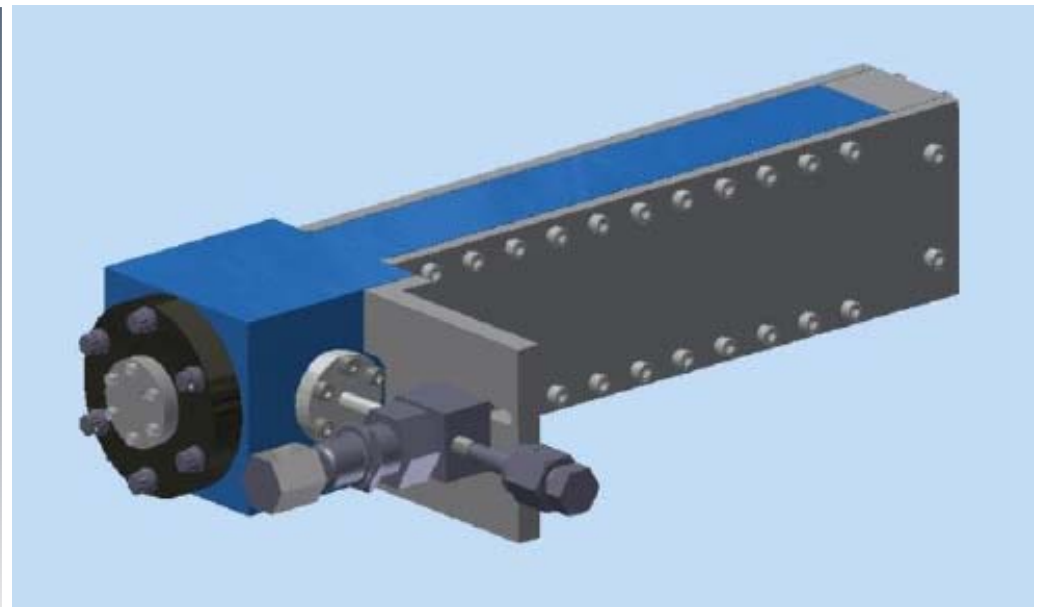
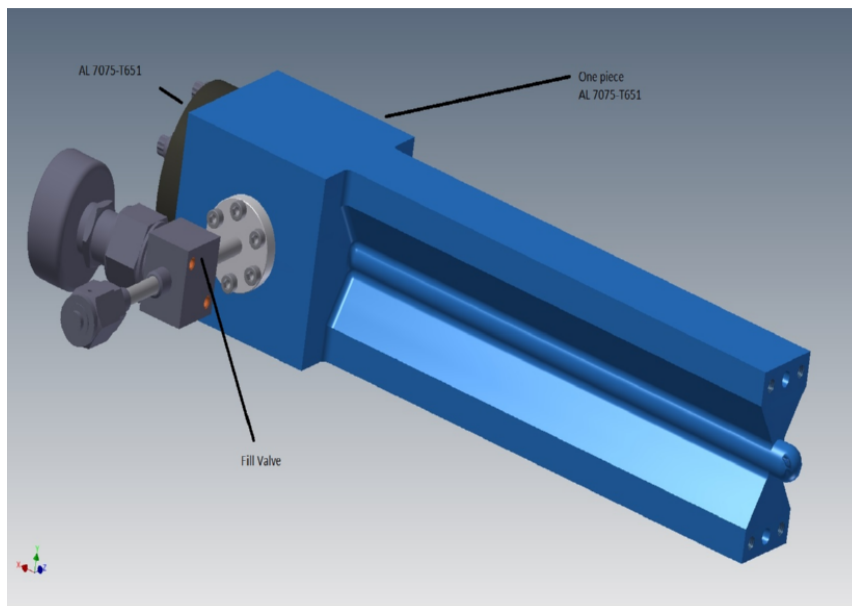
Tritium Target Review

Jefferson Lab, Newport News
15 September 2015



JLab ^3He & ^3H Measurements

- E12-06-118: Marathon d/u ratios from $^3\text{H}(e,e')/^3\text{He}(e,e')$ DIS measurements
- E12-11-112: $x > 1$ measurements of correlations
- E12-14-009: elastic: $^3\text{H} - ^3\text{He}$ charge radius difference [^3H “neutron skin”]
- E12-14-011: Nucleon Momentum Distributions in $A = 3$ Asymmetric Nuclei



Thermo-mechanical design of a static gas target for electron accelerators
B. Brajusovic et al., NIM A 729 (2013) 469

Design Criteria

- Gas targets for accurate comparison of ^3He and ^3H
- Minimize risk in terms of pressure, Curies, beam current, days of operation, on/off cycles (0.9-2.0 kCi and 15-24 μA)
- Detailed thermo-mechanical design of the target cell including FEA
- ^3He , $^2\text{H}_2$ and H_2 targets at more than twice the pressure of the $^3\text{H}_2$ target (500 psi/200 psi)
- Minimize tritium handling at JLab – fill/decommission offsite
- Completely sealed cell design
- Secondary containment – isolated scattering chamber
- Handling hut and ventilation system
- Tritium, vacuum, temperature, raster, coolant monitors/interlocks
- The target cell can be safely used with all required target gases:
 $^3\text{H}_2$, ^3He , $^2\text{H}_2$, H_2 and Ar



Tritium Gas Targets at Electron Accelerators

Lab	Year	Quantity (kCi)	Thickness (g/cm ²)	Current (μA)	Current x thickness (μA-g/cm ²)
Stanford	1963	25	0.8	0.5	0.4
MIT-Bates	1982	180	0.3	20	6.0
Saskatoon	1985	3	0.02	30	0.6
JLab	(2016)	1	0.08	20	1.6

- JLab Luminosity $\sim 2.0 \times 10^{36}$ tritons/cm²/s
- Large acceptance spectrometers at JLab

Tritium Gas Target Safety Algorithm for JLab

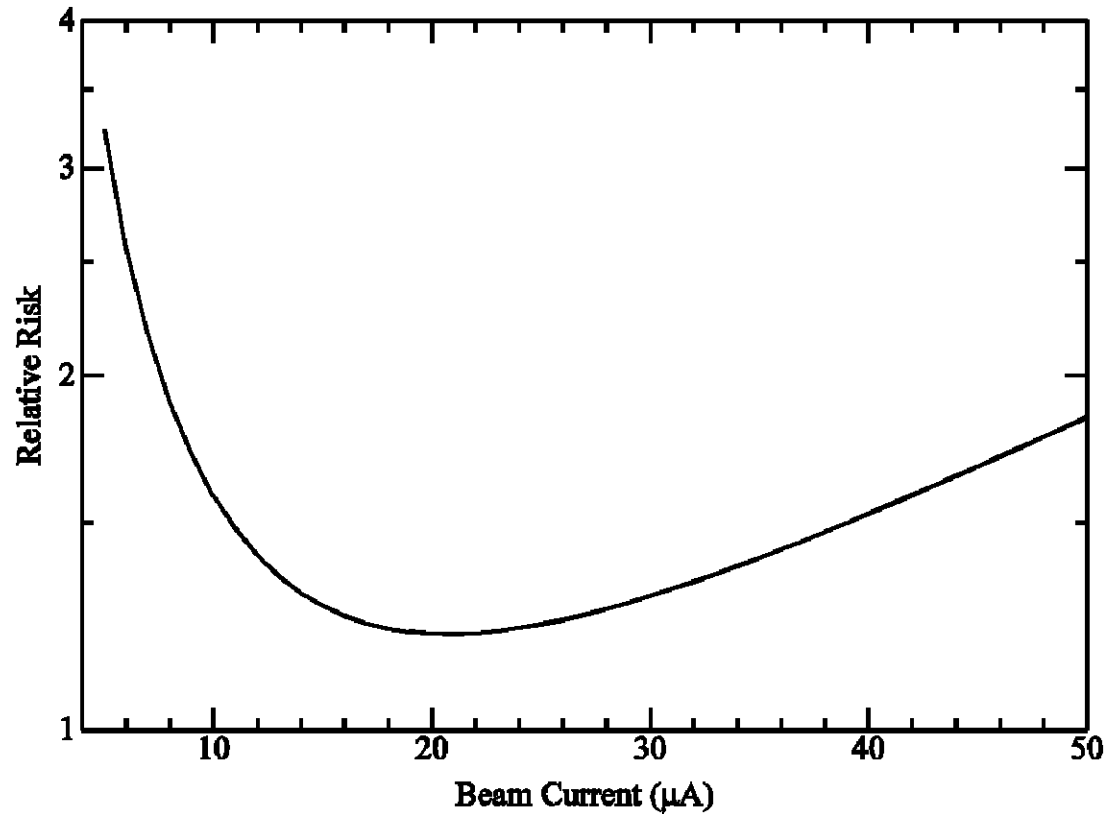
	Risk Level			
Parameter	Extremely Low	Low	Medium	High
Curies	<10	100	1000	5000
Beam current (μA)	<1	5	25	60
Pressure (psi)	<10	100	500	1500
Beam trips	<1000	1E4	1E5	2E5
Time (d)	<10	50	200	365-730

$$\text{Risk}_p = (1 - \exp(-P/C_p))\exp(P/C_p),$$

$$\text{Risk} = \sum_p \text{Risk}_p$$



Risk vs. Beam current



Relative risk vs. beam current when target is 1000 Ci. The optimum current is 21 μA . This assumes that the high risk value for time is 365 days.

Tritium target technical reports

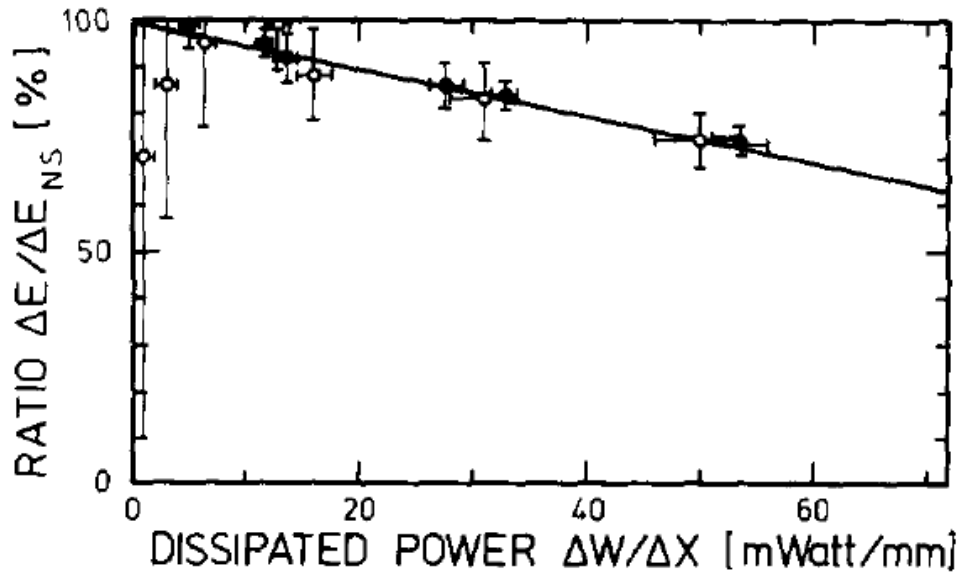


- Hall A Tritium Target System, D. Meekins *et al*, September, 2015
- A Tritium Gas Target for Jefferson Lab, R. J. Holt *et al*, July 13, 2015.
- Jefferson Lab Tritium Target Cell, D. Meekins, November 28, 2014
- Activation of a Tritium Target Cell, G. Kharashvili , June 25, 2014
- Thermomechanical Design of a Static Gas Target for Electron Accelerators, B. Brajuskovic et al., NIM A 729 (2013) 469.
- Absorption Risks for a Tritium Gas Target at Jefferson Lab, R. J. Holt, August 13, 2013.
- Beam-Induced and Tritium-Assisted Embrittlement of the Target Cell at JLab, **R. E. Ricker (NIST)**, R. J. Holt, D. Meekins, **B. Somerday (Sandia)**, March 4, 2013.
- Activation Analysis of a Tritium Target Cell for Jefferson Lab, R. J. Holt, D. Meekins, Oct. 23, 2012.
- Tritium Inhalation Risks for a Tritium Gas Target at Jefferson Lab, R. J. Holt, October 10, 2012.
- Tritium Permeability of the Al Target Cell, R. J. Holt, **R. E. Ricker (NIST)**, D. Meekins, July 10, 2012.
- Scattering Chamber Isolation for the JLab Tritium Target, T. O'Connor, March 29, 2012.
- Hydrogen Getter System for the JLab Tritium Target, T. O'Connor, W. Korsch, February 16, 2012.
- Tritium Gas Target Safety Operations Algorithm for Jefferson Lab, R. J. Holt, February 2, 2012.
- Tritium Gas Target Hazard Analysis for Jefferson Lab, E. Beise et al, January 18, 2012.
- Analysis of a Tritium Target Release at Jefferson Lab, **B. Napier (PNNL)**, R. J. Holt, January 10, 2012.
- Estimating the X-ray Dose Rate from the MARATHON Tritium Target, J. Singh, February 22, 2011.

Task force: R. J. Holt, A. Katramatou, W. Korsch, D. Meekins, T. O'Connor, G. Petratos, R. Ransome, J. Singh, P. Solvignon, B. Wojtsehowki



Static gas target density and energy loss



J. Gorres et al, NIM 177 (1980) 177
 H. Yamaguchi et al, NIM A589(2008) 150

Threshold for density fluctuations
10 mW/mm

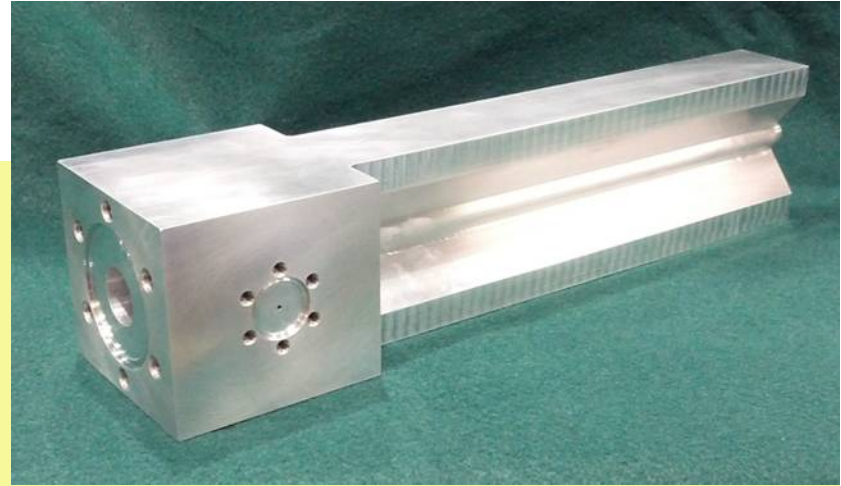
Lab	Year	Quantity (kCi)	Thickness (g/cm ²)	Current (μA)	Power loss (mW/mm)
Stanford HEPL	1963	25	0.8	0.5	3.2
MIT-Bates	1982	180	0.3	20	47.7
SAL	1985	3	0.02	30	4.8
JLab	(2016)	1	0.08	20	12.7

Density vs. current scan will be performed for the targets.



JLab Tritium Target

- Thin Al windows
 - Beam entrance: 0.010"
 - Beam exit: 0.011"
 - Side windows: 0.018"
 - 25 cm long cell at ~200 psi T₂ gas
- Tritium cell filled and sealed at Savannah River (SRTE)
 - Pressure: accuracy to <1%,
 - Purity: 99.8% T₂ gas, main contaminants are ³He and D₂
 - 12.32 y half-life: after 1 year ~5% of ³H decayed to ³He
- Administrative current limit: 20 μA



Design Authority and Project Manager: Dave Meekins

Summary

- Experiments with ^3H at JLab can *safely* provide:
 - *First* DIS measurements
 - *First* $x > 1$ measurements
 - *First* (e,e'p) measurements
 - *First* precision charge radius measurements
 - *First*
- Textbook physics experiments – benchmark data

Extra slides

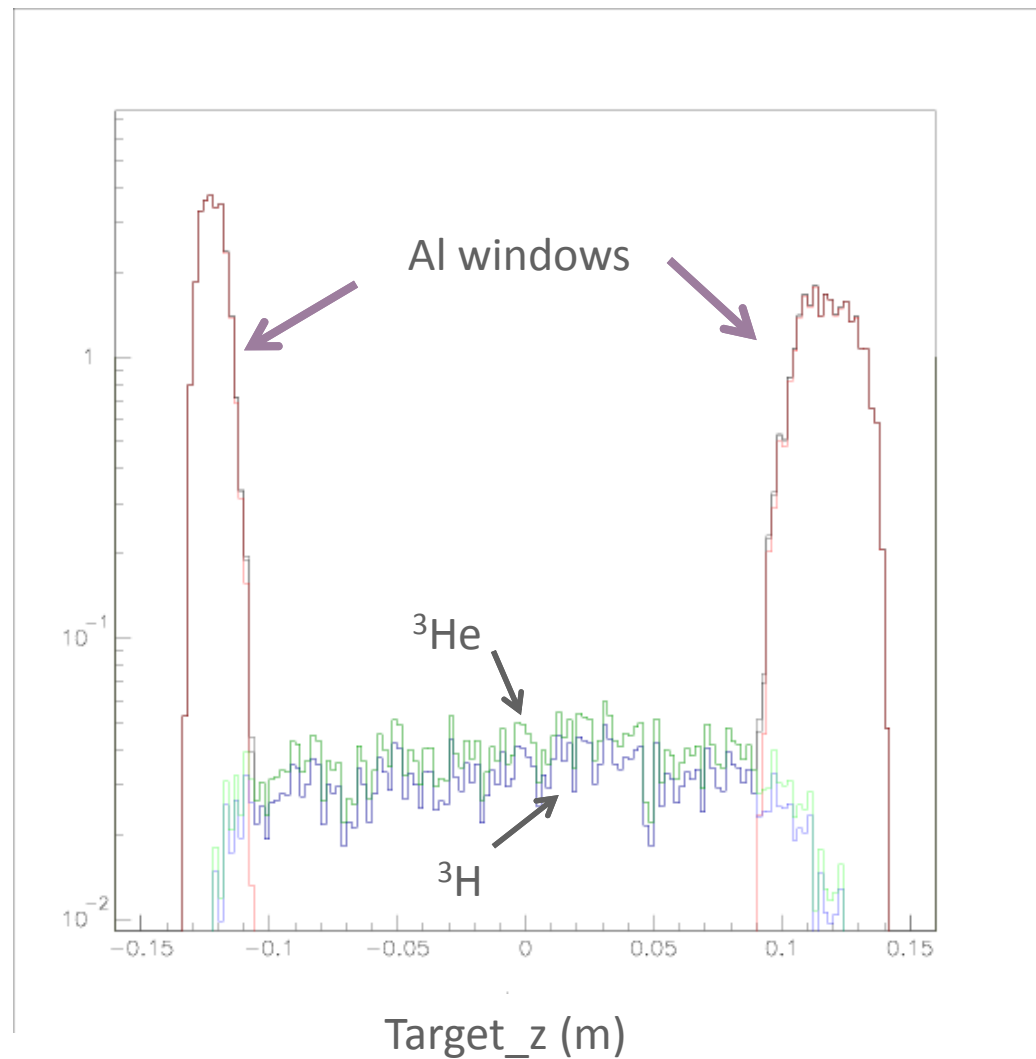
E12-10-103: DIS kinematics with an HRS (simulation)

- 11 GeV, 23.4 deg.
- 10 atm ^3H , 20 atm ^3He
- 0.018" Al windows

Present design:

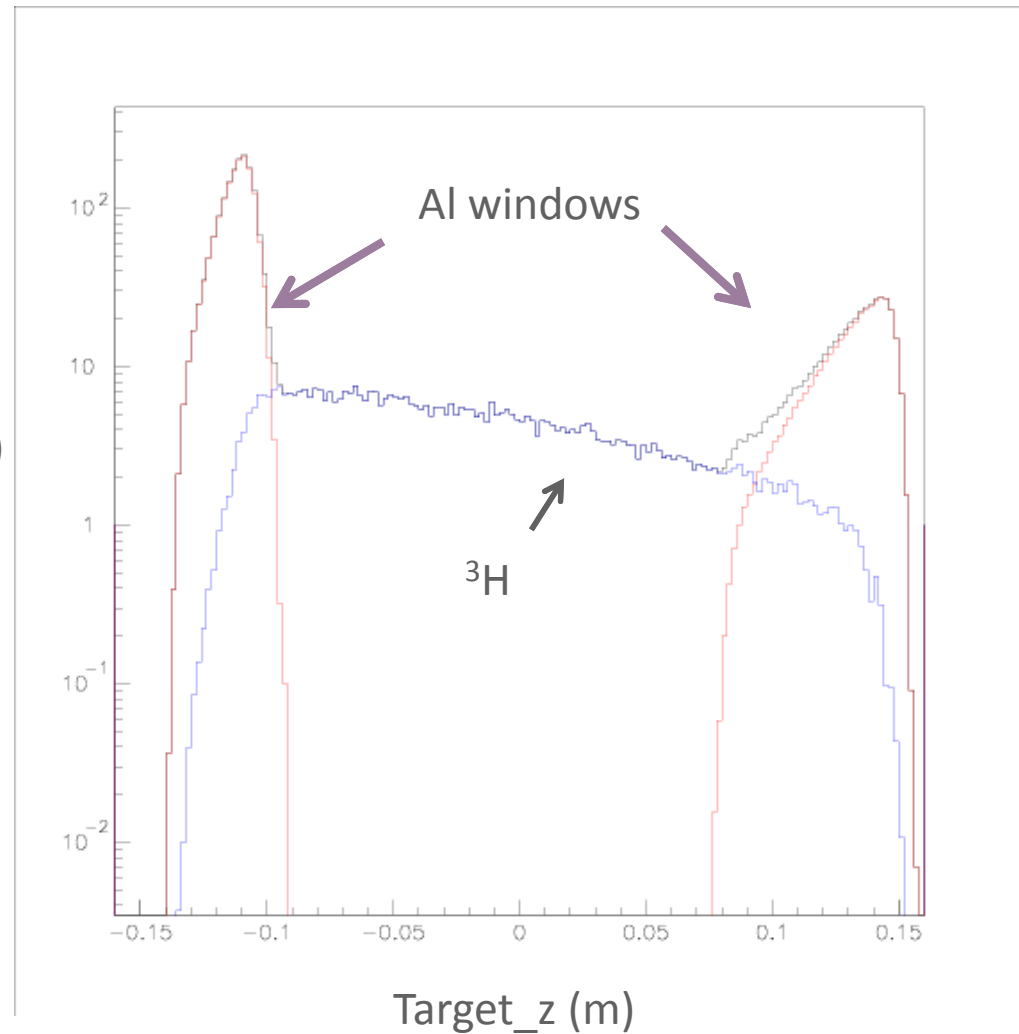
- 13.6 atm ^3H , 30 atm ^3He
- 0.010" upstream window
- 0.011" downstream window
- Target luminosity comparable to window luminosity
- BB at larger angles
- BB comparable z_{targ} resolution

P. Solvignon



E12-11-112: $x > 1$ kinematics with an HRS (simulation)

- Worst case- other cases are:
 - larger angles (larger window separation)
 - higher energies (better resolution)
 - Lower x (larger cross section)
- 4.4 GeV, 17.0 deg, $p=3.98$ GeV
- 13.6 atm ^3H
- 0.010" Al upstream window
- 0.011" downstream window



P. Solvignon



E12-14-009: Elastic scattering from $A=3$ nuclei

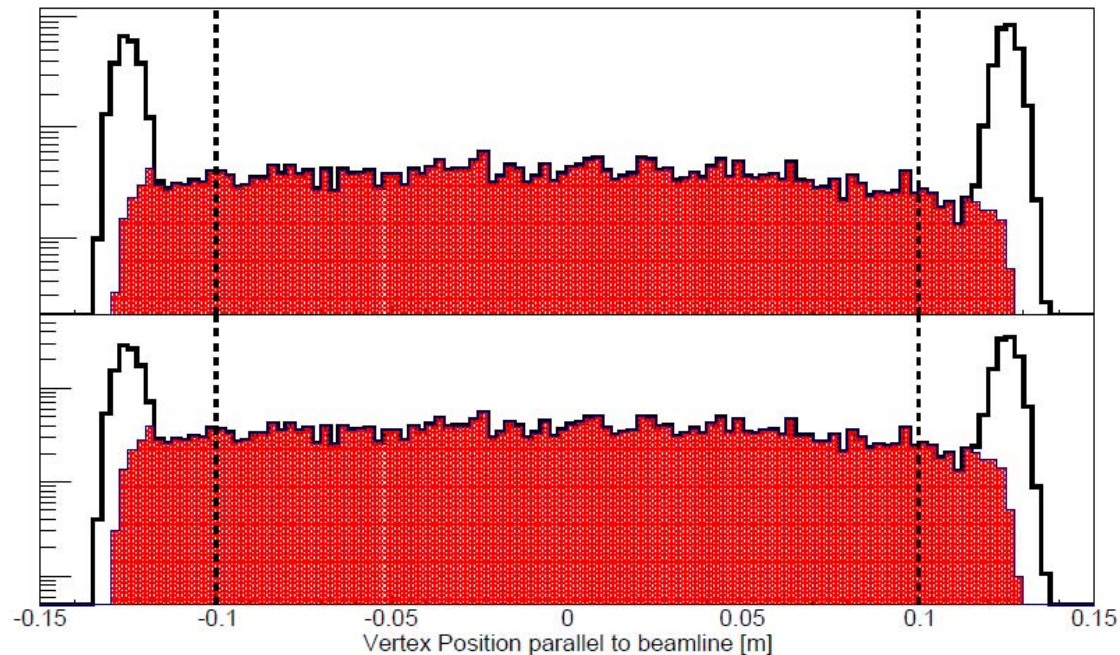


Fig. 3. The expected number of counts from the target and cell (black) and from the target alone (shaded) as a function of the scattering vertex along the beamline direction. ^3H is shown in the top panel and ^3He in the lower. The dashed vertical lines represent software cuts at ± 10 cm to remove the contribution from the windows.

Beam and Tritium-assisted Embrittlement

- Beam-induced corrosion of Al, threshold at 180 K
 - Beam dissociates hydrogen molecules into atoms – atomic fraction = 10 ppm
 - Cryo-cool target when beam is on – keep windows below 180 K.
 - H. M. Flower, “Electron Irradiation Induced Aqueous Corrosion of Aluminum and Magnesium,” *Radiation Effects* **33** (1977) 173; G. Bond et al., *Scripta Metallurgica* 20 (1986) 653.

- Tritium-assisted embrittlement of Al
 - Swelling threshold = 0.0045 He/Al
 - Tritium diffusion into cell for one year \rightarrow ${}^3\text{He}/\text{Al} = 1.8\text{E}-10$
 - M. R. Louthan, “Aluminum-Lithium Technology and Savannah River’s Contribution to Understanding Hydrogen Effects in Metals,” WSRC-2000-00061



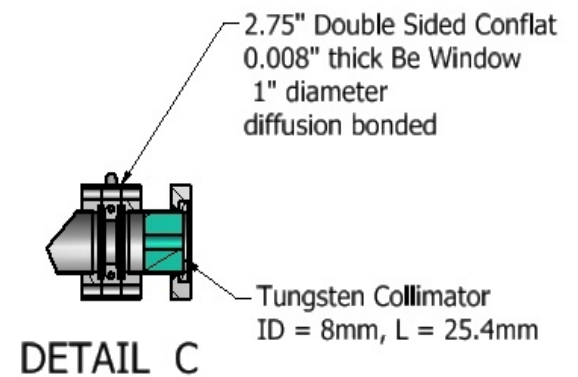
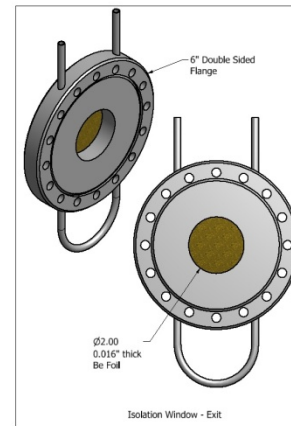
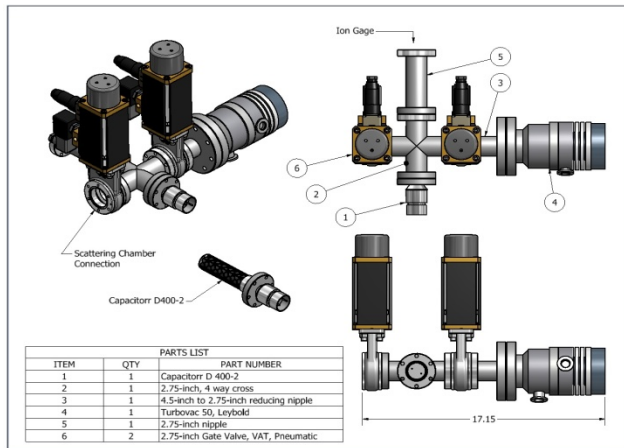
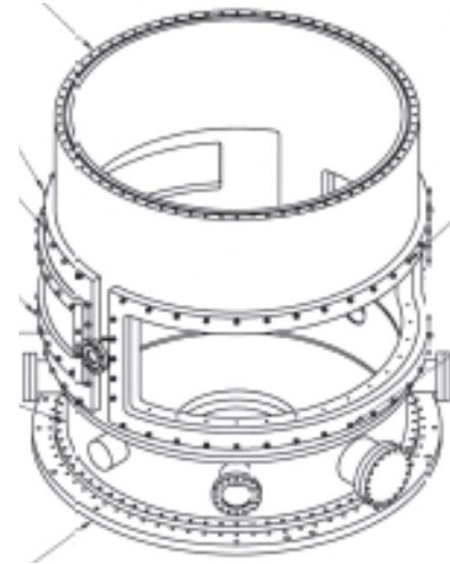
Special issues for tritium

- Tritium permeation through Al (J. Scully *et al*, Mat. Sci. For. **331-337** (2000) 1583)
 - $n_{Al} = 6E22 \text{ cm}^{-3}$, $C_H = 1.6E-11$, $D = 2.3E-7 \text{ cm}^2/\text{s}$, $J = n_{Al} C_H D / d$
 - Ambient temperature -> 142 mCi in one year, diffusion; 371mCi/y for seals and valve
- X-rays from the target cell (J. Singh)
 - 18.6 keV beta endpoint -> < 3.6 mrem/hr/cm² at window surfaces
- Radiation damage of target cell
 - 10^5 - 10^6 orders of magnitude – Al cells routinely used for target cells
- Hydrogen embrittlement of the target cell
 - 7000 series Al tested at Sandia up to 15000 psi, target at 200 psi (B. Somerday)
- Energy stored in pressurized gas cell (JLab ESH 6151 Appendix T4)
 - 125 and 250 J ~ to polarized ³He target
- Chemical energy in the gas cell
 - ~0.4 liters STP, 17 kJ, strongly diluted in scatt. chamber or Hall, 10 ppb
 - ~1E-4 of hydrogen gas in standard cryotargets
- Activation of the Al target cell (7075)
 - Target windows: 1.7 mR/hr; after 2 days: 0.07mR/hr @ 1 m
- Full tritium release in Hall A
 - 0.2 mrem/hour for a worker



Secondary Containment - scattering chamber

- May 30, 2012 meeting -> Use BB scattering chamber
- Completely isolated from beam line
 - Water cooled isolation windows
 - Rad-hard RGA's to detect tritium
 - Activated getter pump
 - Ventilation system with stack (design?)

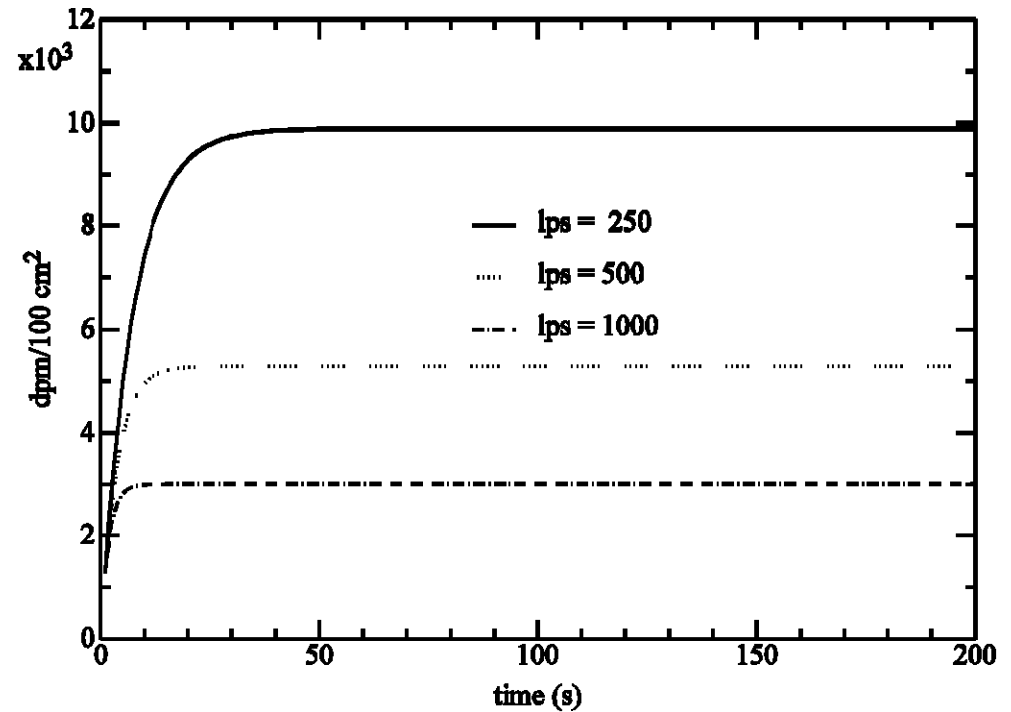


T. O'Connor



Contamination of scattering chamber?

- 10,000 dpm actionable limit not exceeded if 250 l/s speed is available within 1 second of losing the primary containment.
- Two 1000 l/s turbos on chamber, vented to stack
- >100 l/s NEG pump available



$$A_i = A_{\text{poly}} T_i$$

where A_{poly} is the absorption rate in CH_2 , and T_i is the time at step i . The pump with speed, S , is turned on after delay T_d , the absorption rate is given by:

$$A_i = A_{i-1} + A_{\text{poly}} \exp(-(T_i - T_d)/(V_c/S))$$



Stack height and maximum dose

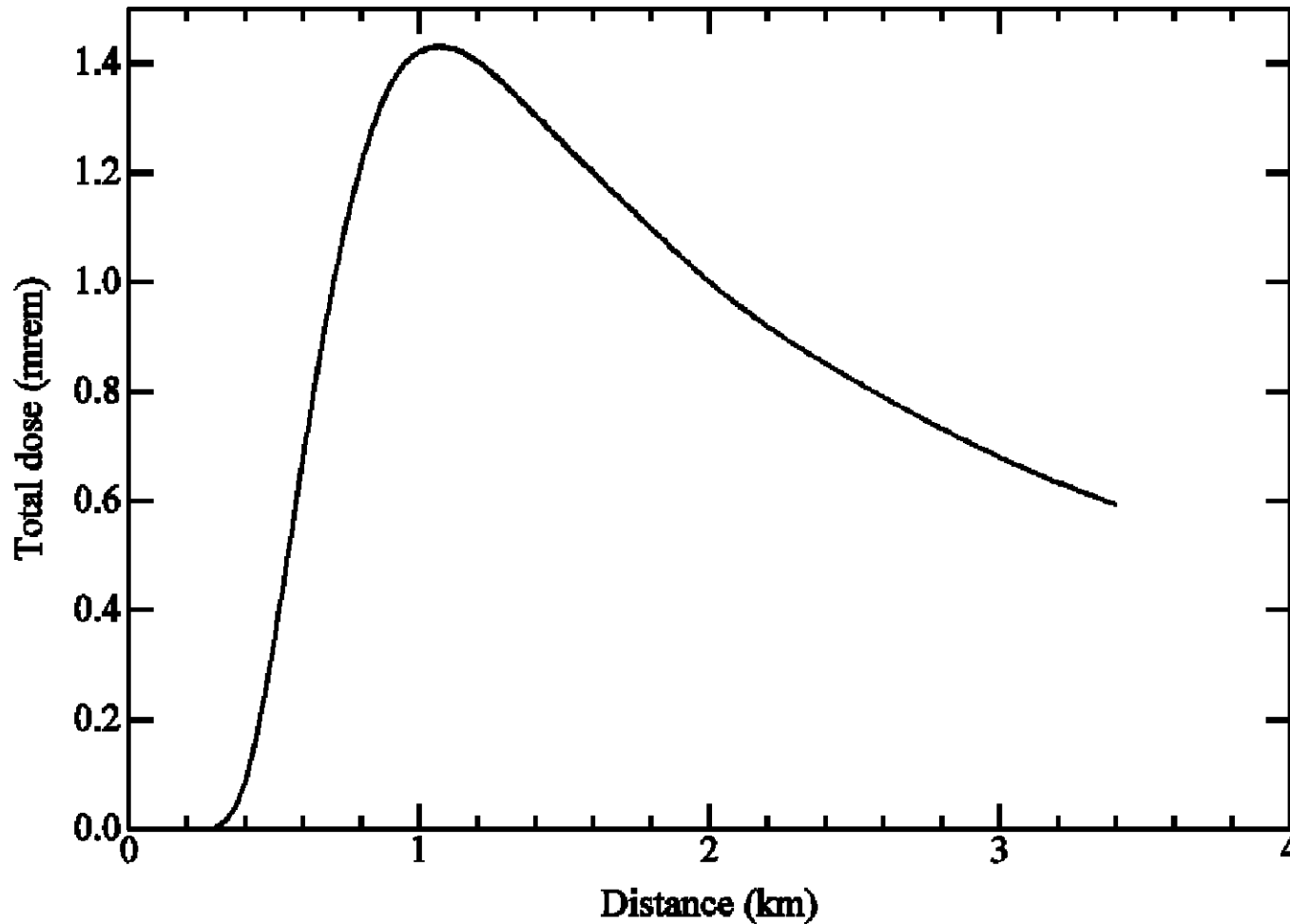
HotSpot calculations by
Bruce Napier, Pacific Northwest National Lab

Assumptions: 100% HTO, 60 minute sampling time, class F weather (minimal dispersion)

Stack height (m)	Dose at 300 m 600 Ci (mrem)	Distance at max dose (m)	Max dose 600 Ci (mrem)	Max dose 1000 Ci (mrem)
0	160	<100	890	1483
5	54	200	67	112
10	6.5	500	9.7	16
15	0.28	750	3.2	5.3
20	0.0036	1000	1.4	2.3



Dose vs. distance for a 20 m stack (600 Ci, 100% HTO, class F weather, 60 min sampling time)



Algorithm for number of days and beam trips

The total number of days for experiments is 61 at 1000 Ci and 25 μA :

$$\text{ndays} = (61 \text{ days})(1000 \text{ Ci})(25 \mu\text{A})/((\text{nci})(\text{ib}))$$

where nci = no. of Ci and ib = beam current.

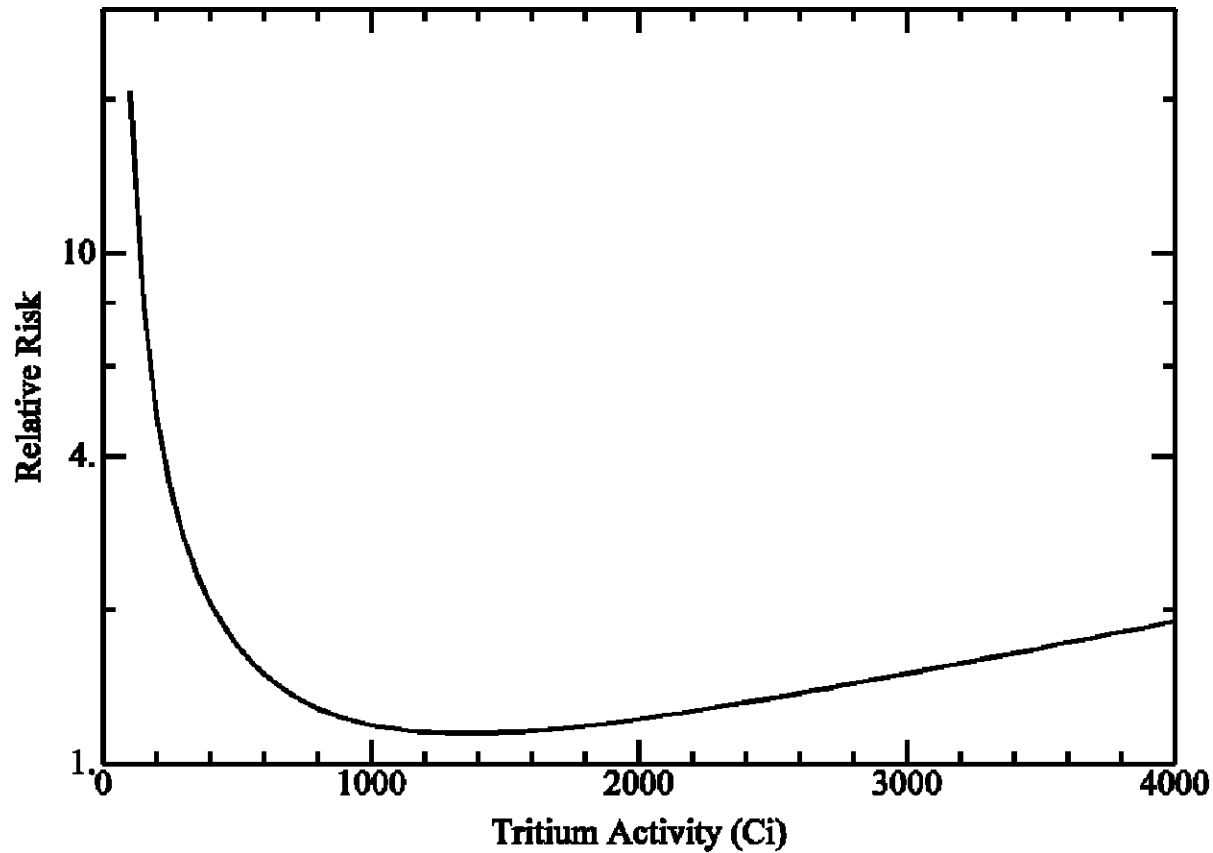
Cycling risk (beam trips):

$$\text{Risk}_{\text{cyc}} = (1 - \exp(-\text{ncyc}/\text{cychi}))\exp(\text{ncyc}/\text{cychi})\exp(\text{press}/\text{presshi})\exp(\text{ib}/\text{ibhi}),$$

Where ncyc = no. of cycles and press = gas pressure.



Risk vs. Target Activity



Relative risk vs. curies when the beam current is 21 μ A. The optimum target activity is 1350 Ci. This assumes that the high risk time is 365 days.



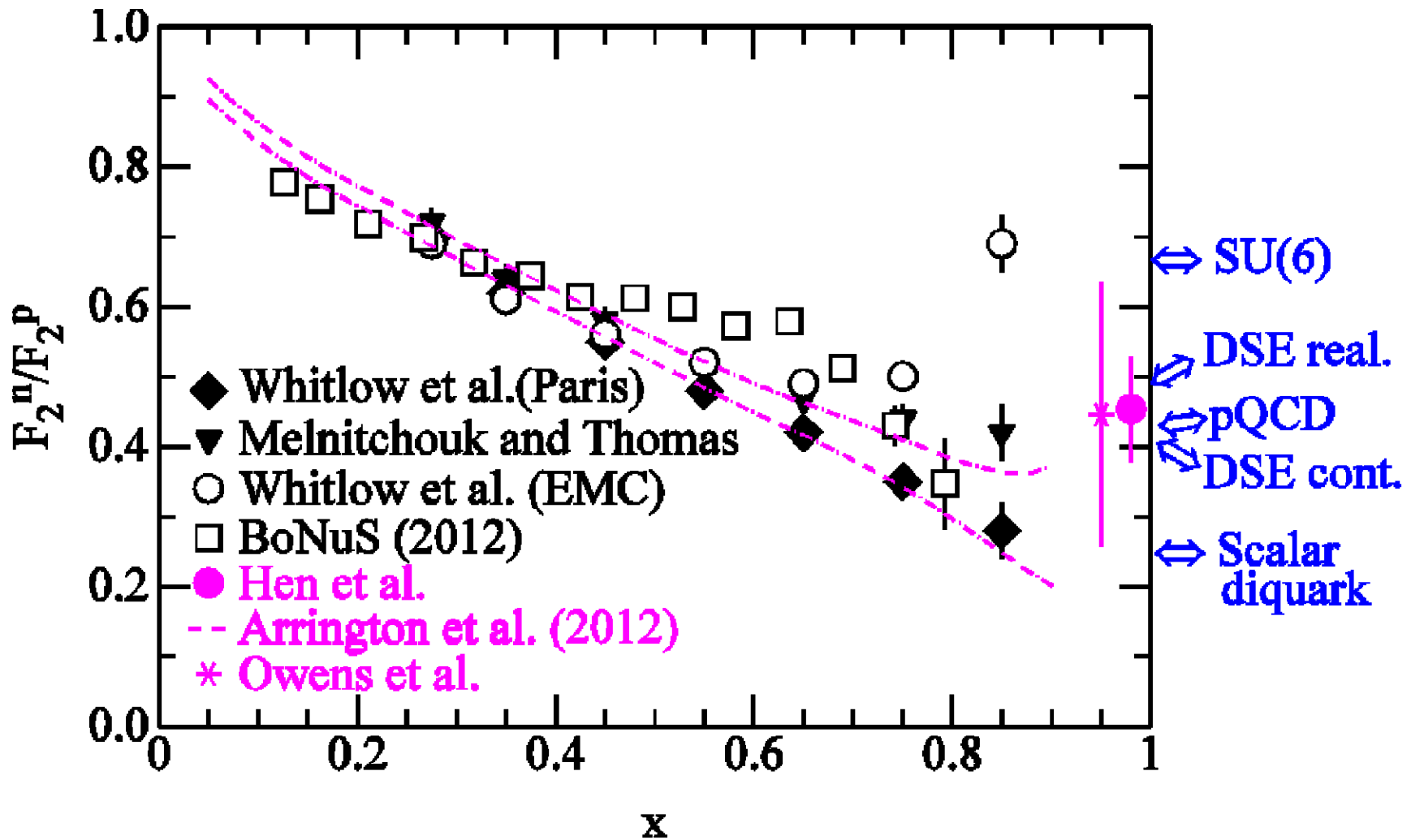
F_2^n/F_2^p , d/u ratios and A_1 for $x \rightarrow 1$

	F_2^n/F_2^p	d/u	A_1^n	A_1^p
<i>SU(6)</i>	2/3	1/2	0	5/9
Diquark/Feynman	1/4	0	1	1
Quark Model/Isgur	1/4	0	1	1
Perturbative QCD	3/7	1/5	1	1
Dyson-Schwinger	0.49	0.28	0.17	0.59

C. D. Roberts, RJH, S. Schmidt, PLB 727 (2014) 249



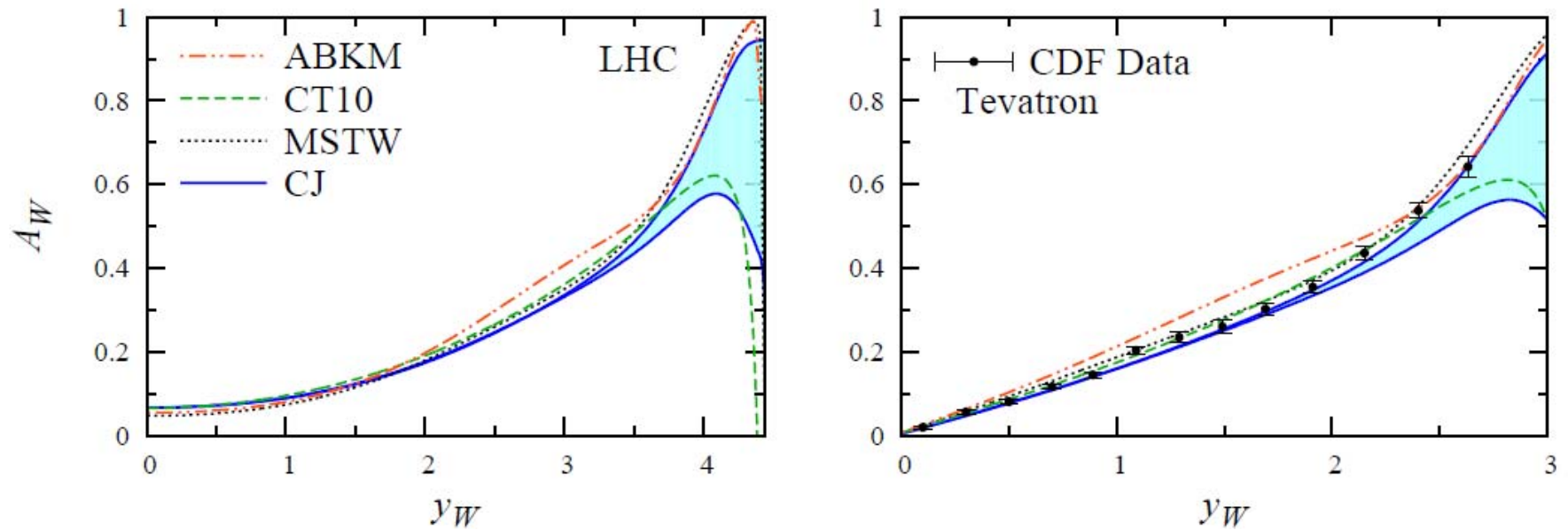
Present status: Neutron to proton structure function ratio



C. D. Roberts, RJH, S. Schmidt, PLB **727**(2013) 249;
 RJH, C. D. Roberts, RMP **82** (2010) 2991

High x impacts high energy physics

W charge asymmetry vs. W rapidity



High x and low Q^2 evolves to low x and high Q^2

A. Accardi, Mod. Phys. Lett. A28 (2013) 35; arXiv 1308.2906v2

From three-body nuclei to the quarks

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

- Mirror symmetry of A=3 nuclei
 - Extract F_2^n/F_2^p from **ratio** of measured $^3\text{He}/^3\text{H}$ structure functions

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

\mathcal{R} = Ratio of “EMC ratios” for ^3He and ^3H

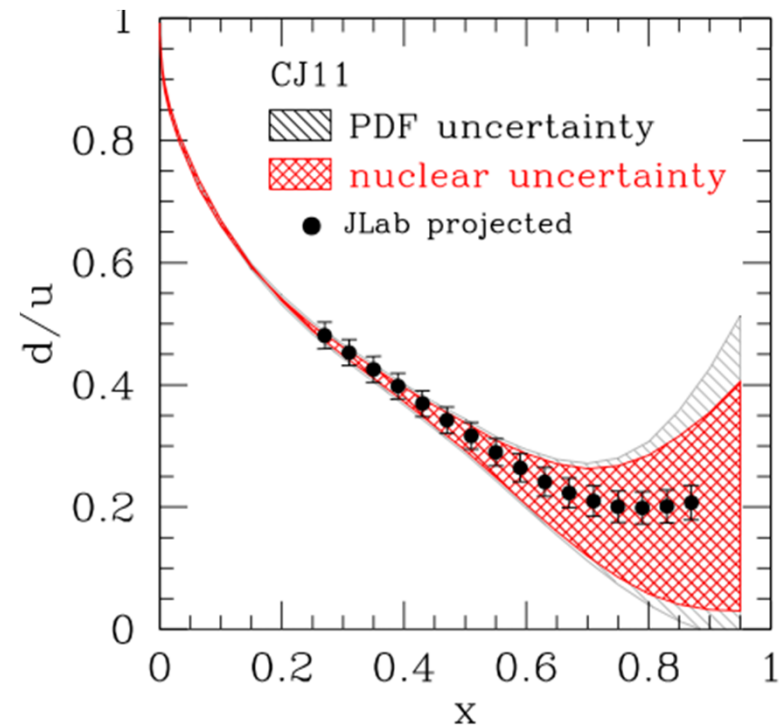
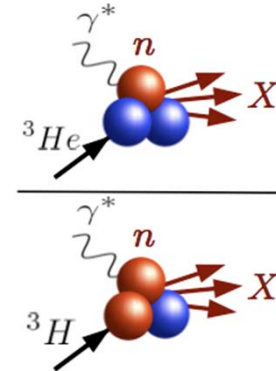
Relies only on difference in nuclear effects

Calculated to within 1.5%

Most systematic, theory uncertainties cancel

JLab E12-06-118: Marathon

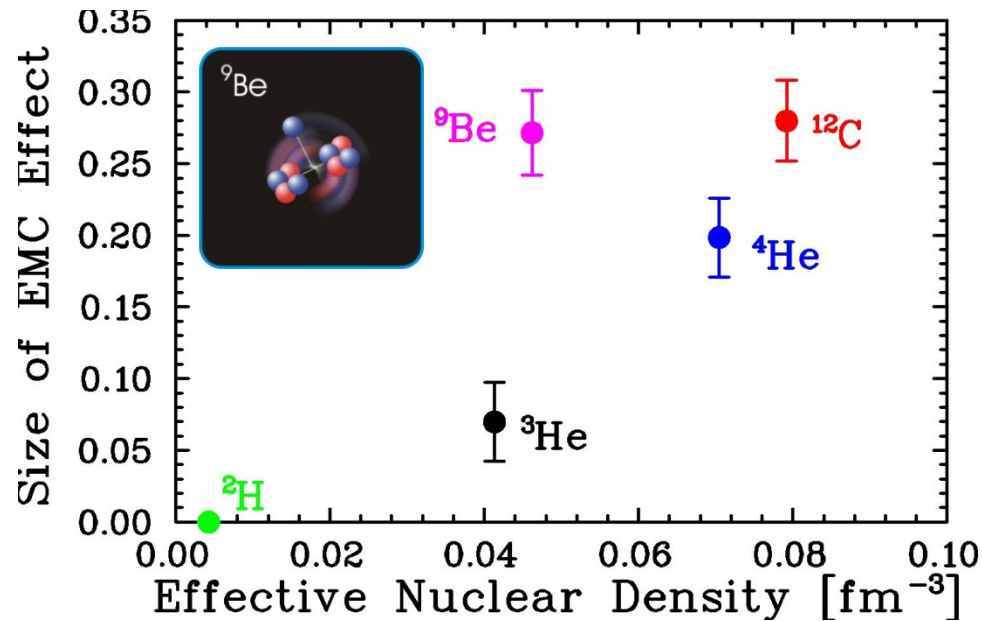
G. Petratos, RJH, R. Ransome, J. Gomez



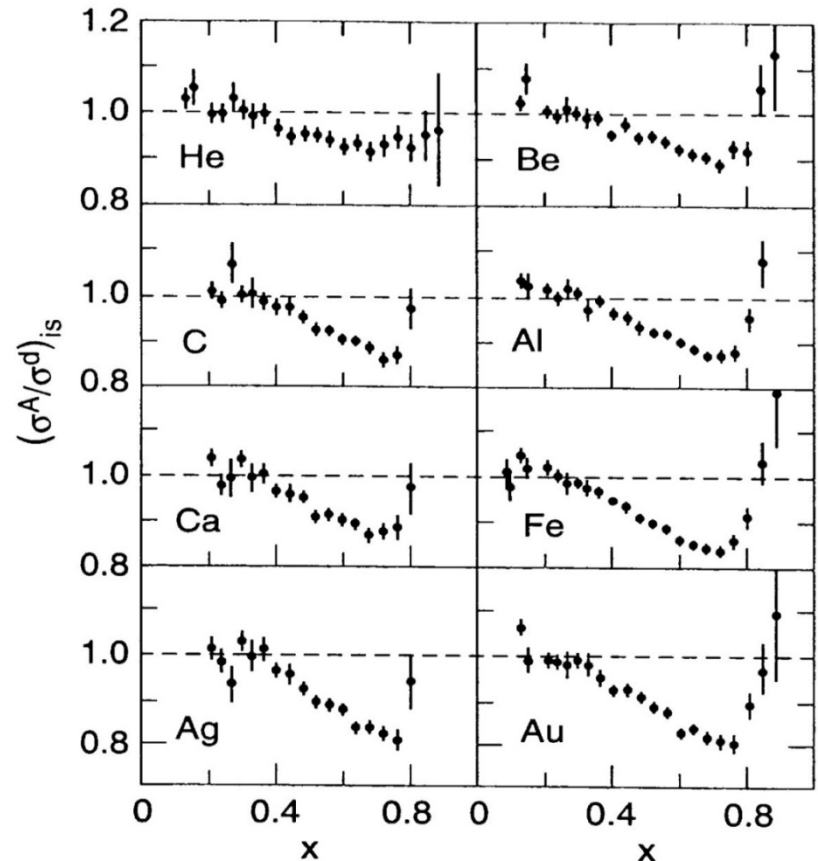
$$\frac{F_2^n}{F_2^p} = \frac{[1+4(d/u)]}{[4+(d/u)]}$$

A look at quarks in the nucleus: the EMC effect

- EMC effect discovered 1982 (H. Montgomery et al.), remains a mystery today
- Scattering from quarks in a nucleus is not just a superposition of scattering from quarks in nucleons
 - Dependence on nuclear density, short range correlations, flavor, spin, isospin?



J. Seeley et al, PRL 103 (2009)



SLAC E-139, 1984, J. Gomez et al.

Isospin structure of 2N-SRCs (JLab E12-11-112)

P. Solvignon, J. Arrington, D. Day, D. Higinbotham

- ${}^3\text{He}/{}^3\text{H}$ is simplest asymmetric case:

Simple estimates for 2N-SRC

Isospin independent

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

Full n-p dominance (no T=1)

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

- 40% difference between full isosinglet dominance and isospin independent
- Few body calculations [M. Sargisan, Wiringa/Peiper (GFMC)] predict n-p dominance, but with sizeable contribution from T=1 pairs
- Goal is to measure ${}^3\text{He}/{}^3\text{H}$ ratio in 2N-SRC region with 1.5% precision
→ Extract R(T=1/T=0) with uncertainty of 3.8%

Extract R(T=1/T=0) with factor of two improvement over previous triple-coincidence, smaller FSI

${}^3\text{He}(e,e'p)/{}^3\text{H}(e,e'p)$

JLab E12-14-011 Proton and Neutron Momentum Distributions in $A = 3$ Asymmetric Nuclei

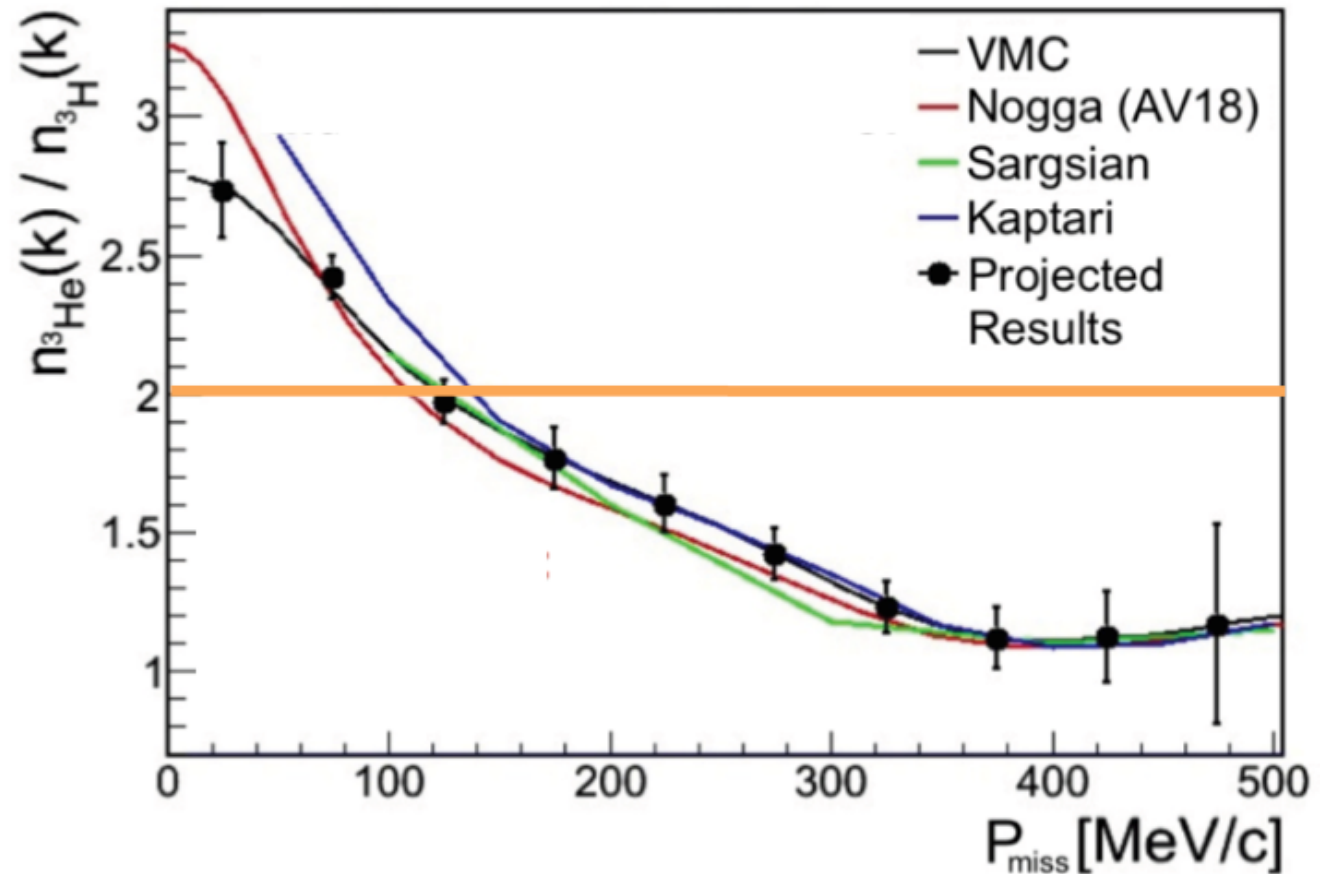
L. Weinstein, O. Hen,
W. Boeglin, S. Gilad

${}^3\text{He}/{}^3\text{H}$ ratio for proton
knockout yields n/p ratio
in ${}^3\text{H}$

np-dominance at high- P_m
implies n/p ratio $\rightarrow 1$

n/p at low P_m enhanced

No neutron detection
required



arXiv:1409.1717



Charge radii: ^3He and ^3H

First opportunity for ^3H at JLab (E12-14-009)

L. Meyers, J. Arrington, D. Higinbotham

Precise theoretical calculations of $\langle r_{rms}^2 \rangle_{^3\text{H}}$, $\langle r_{rms}^2 \rangle_{^3\text{He}}$

Experimental results: large uncertainties, discrepancies

	$\langle r_{rms}^2 \rangle_{^3\text{H}}$	$\langle r_{rms}^2 \rangle_{^3\text{He}}$	
GFMC	1.77(1)	1.97(1)	
χEFT	1.756(6)	1.962(4)	
SACLAY	1.76(9)	1.96(3)	$\longrightarrow \Delta R_{\text{RMS}} = 0.20(10)$
BATES	1.68(3)	1.87(3)	$\longrightarrow \Delta R_{\text{RMS}} = 0.19(04)$
Atomic	-----	1.959(4)	

With new tritium target \rightarrow improve precision on ΔR_{RMS} by factor 3-5 over SACLAY results

