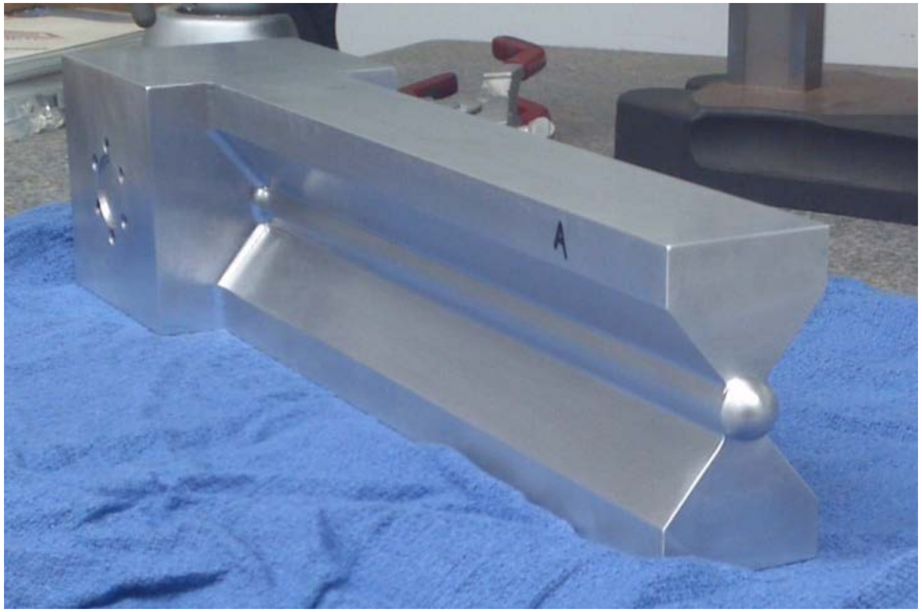
Introduction to the tritium target design

Roy J. Holt

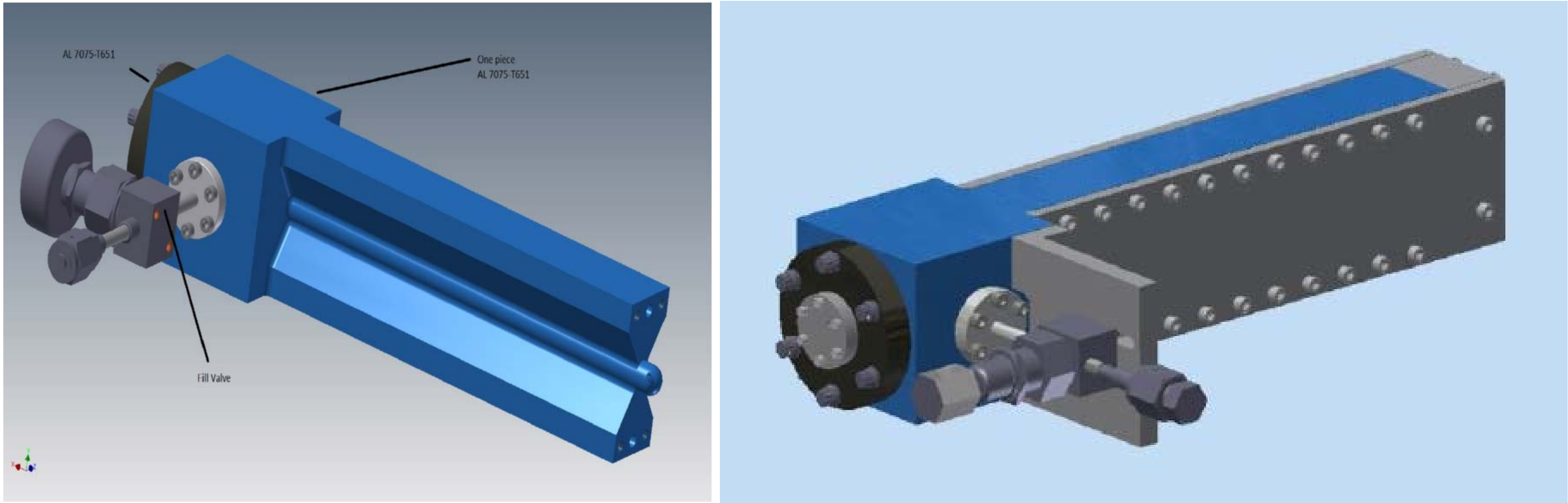
Tritium Target Review

Jefferson Lab, Newport News
15 September 2015



JLab ^{3}He & ^{3}H Measurements

E12-06-118: Marathon d/u ratios from ^{3}H(e,e')/^{3}He(e,e') DIS measurements
E12-11-112: x>1 measurements of correlations
E12-14-009: elastic: ^{3}H – ^{3}He charge radius difference [^{3}H "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. Brajuskovic et al., NIM A 729 (2013) 469

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 ~ 2.0 x 10^{36} tritons/cm^2/s
- Large acceptance spectrometers at JLab

Design Criteria

- Gas targets for accurate comparison of ^{3}He and ^{3}H
- 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
- ^{3}He, $^2H_2$ and H_2 targets at more than twice the pressure of the $^3H_2$ 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:
  $^3H_2$, ^{3}He, $^2H_2$, H_2 and Ar

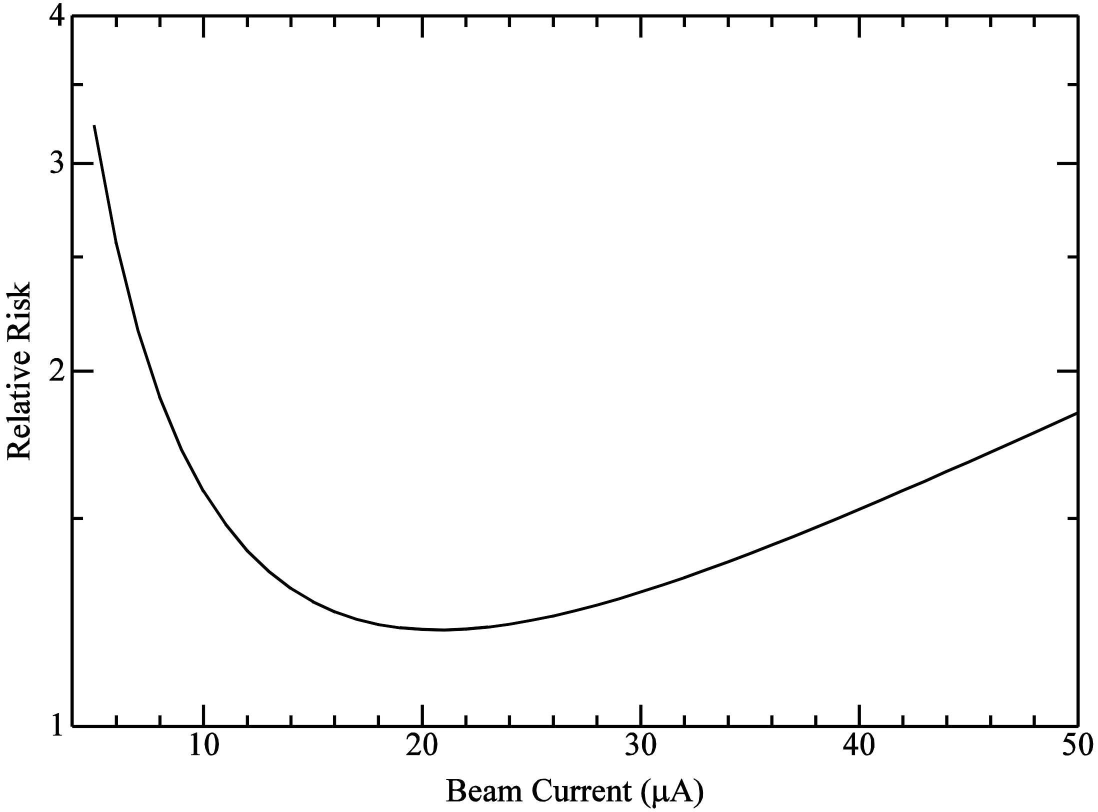
Tritium Gas Target Safety Algorithm for JLab

	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

$$\mathrm{Risk}_P = (1 - \exp(-P/C_P))\exp(P/C_P),$$

$$\mathrm{Risk} = \Sigma_p \, \mathrm{Risk}_P$$

Risk vs. Beam current



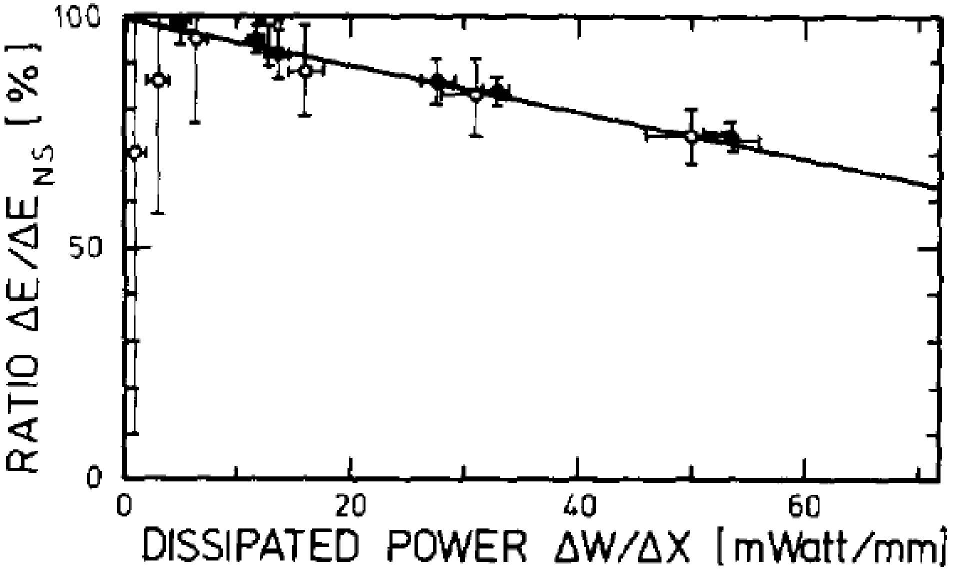
Relative risk vs. beam current when target is 1000 Ci. The optimum current is 21 μA. This assumes that the high risk value for time is 365 days.

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. Wojtsekhowki

Static gas target density and energy loss



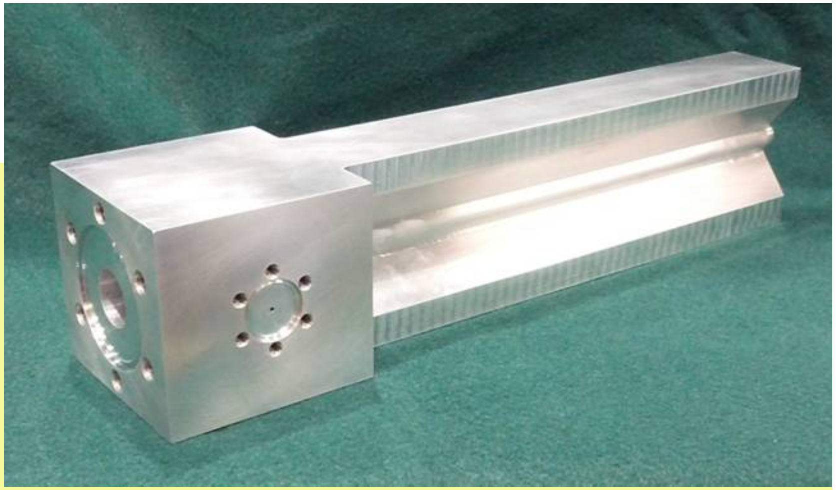
J. Gorres et al, NIM 177 (1980) 177
H. Yamaguchi et al, NIM A589(2008) 150

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 T_2 gas
- Tritium cell filled and sealed at Savannah River (SRTE)
  - Pressure: accuracy to <1%,
  - Purity: 99.8% T_2 gas, main contaminants are ^{3}He and D_2
  - 12.32 y half-life: after 1 year ~5% of ^{3}H decayed to ^{3}He
- Administrative current limit: 20 μA

Design Authority and Project Manager: Dave Meekins

Summary

- Experiments with ^{3}H 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

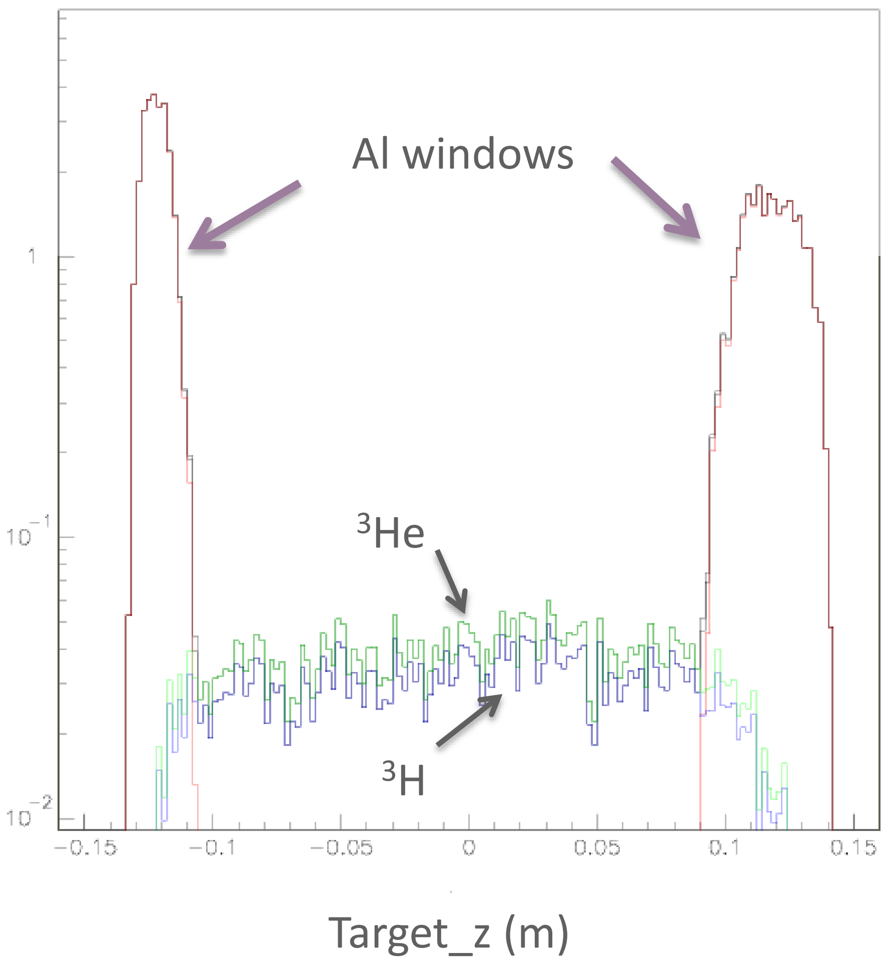
E12-10-103: DIS kinematics with an HRS (simulation)

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

Present design:

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

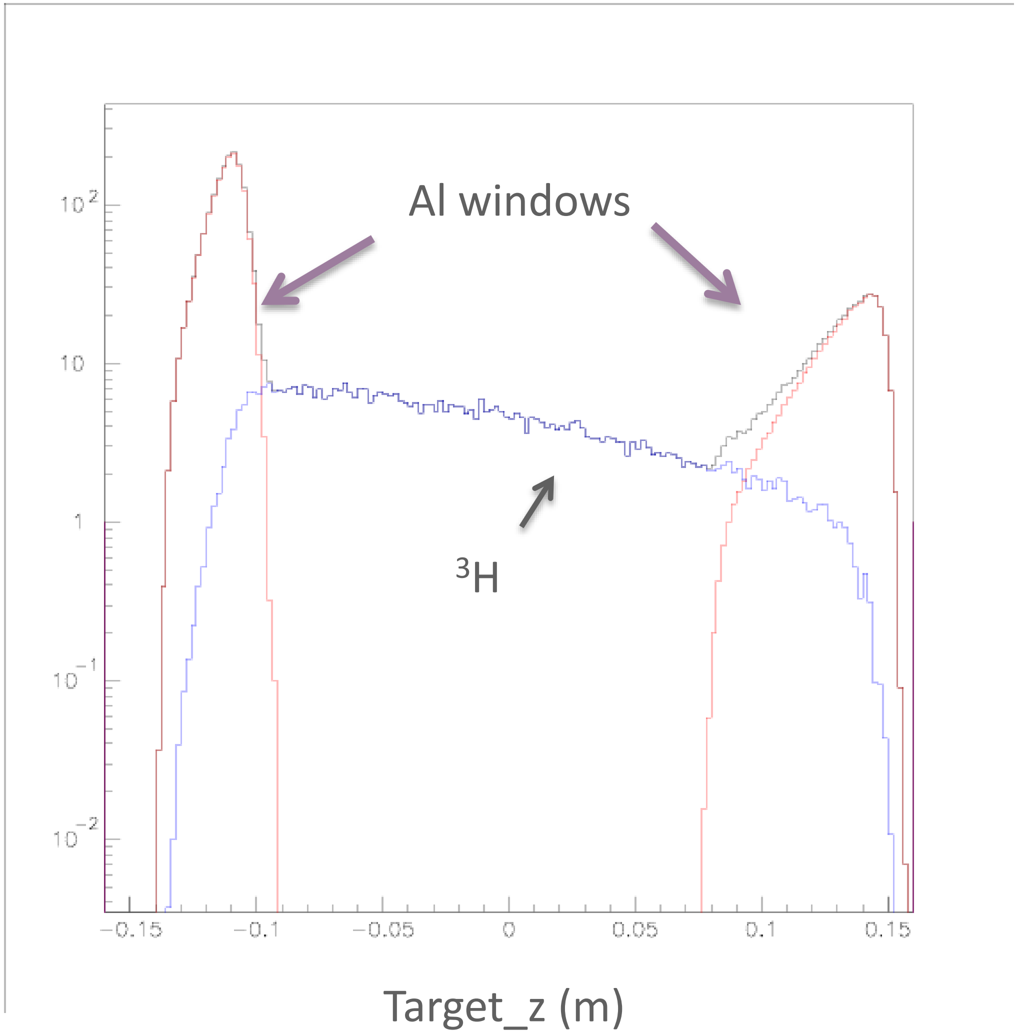
P. Solvignon



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 ^{3}H
- 0.010” Al upstream window
- 0.011” downstream window

P. Solvignon



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

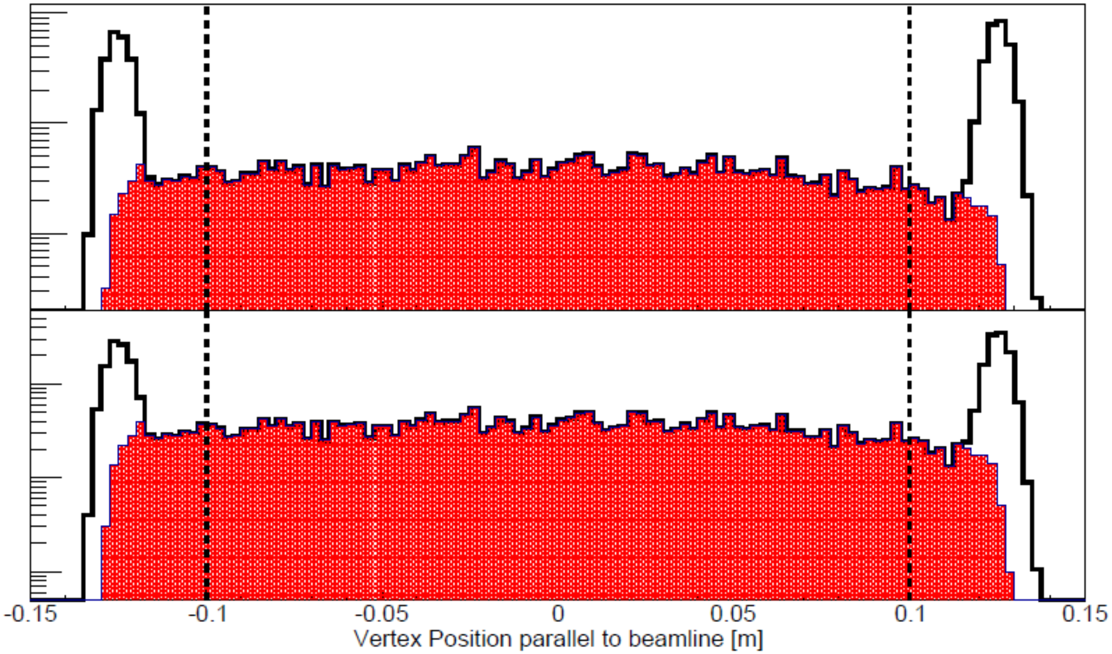


Fig. 3. The expected number of counts from the target and cell (black) and from the target alone (shaded) as a function of the scattering vertex along the beamline direction. ^{3}H is shown in the top panel and ^{3}He in the lower. The dashed vertical lines represent software cuts at ±10 cm to remove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

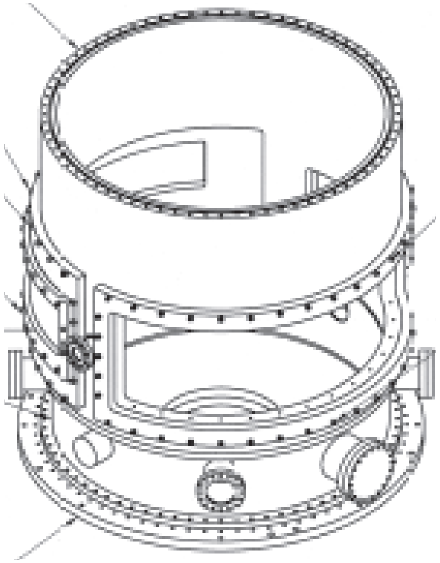
- Tritium-assisted embrittlement of Al
  - Swelling threshold = 0.0045 He/Al
  - Tritium diffusion into cell for one year -> ^{3}He/Al = 1.8E-10
  - M. R. Louthan, “Aluminum-Lithium Technology and Savannah River’s Contribution to Understanding Hydrogen Effects in Metals,” WSRC-2000-00061

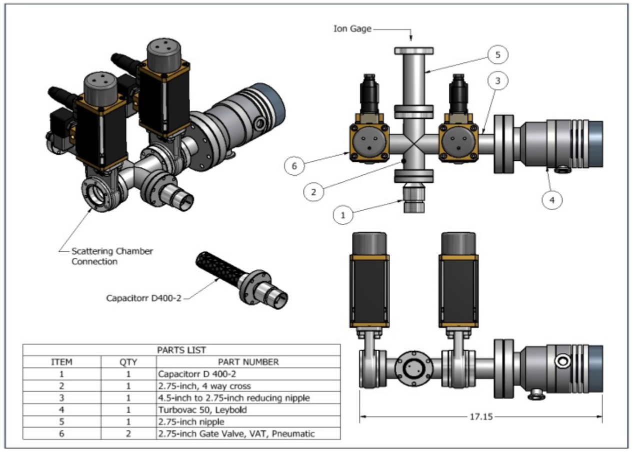
Special issues for tritium

- Tritium permeation through Al (J. Scully *et al*, Mat. Sci. For. **331-337** (2000) 1583)
  - n_{Al} = 6E22 cm^{-3}, C_H=1.6E-11, D=2.3E-7 cm^2/s, $J=n_{Al}C_HD/d$
  - 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 $mrem/hr/cm^2$ 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 ^{3}He 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

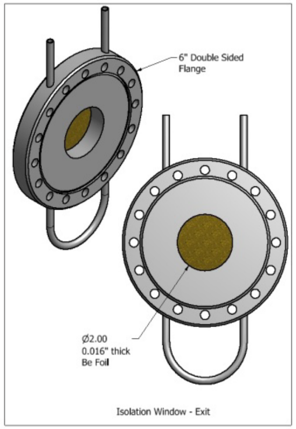
Secondary Containment - scattering chamber

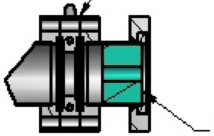
- May 30, 2012 meeting -> Use BB scattering chamber
- Completely isolated from beam line
  - Water cooled isolation windows
  - Rad-hard RGA’s to detect tritium
  - Activated getter pump
  - Ventilation system with stack (design?)





PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Capacitorr D 400-2
2	1	2.75-inch, 4 way cross
3	1	4.5-inch to 2.75-inch reducing nipple
4	1	Turbovac 50, Leybold
5	1	2.75-inch nipple
6	2	2.75-inch Gate Valve, VAT, Pneumatic





2.75" Double Sided Conflat
0.008" thick Be Window
1" diameter
diffusion bonded

Tungsten Collimator
ID = 8mm, L = 25.4mm

DETAIL C

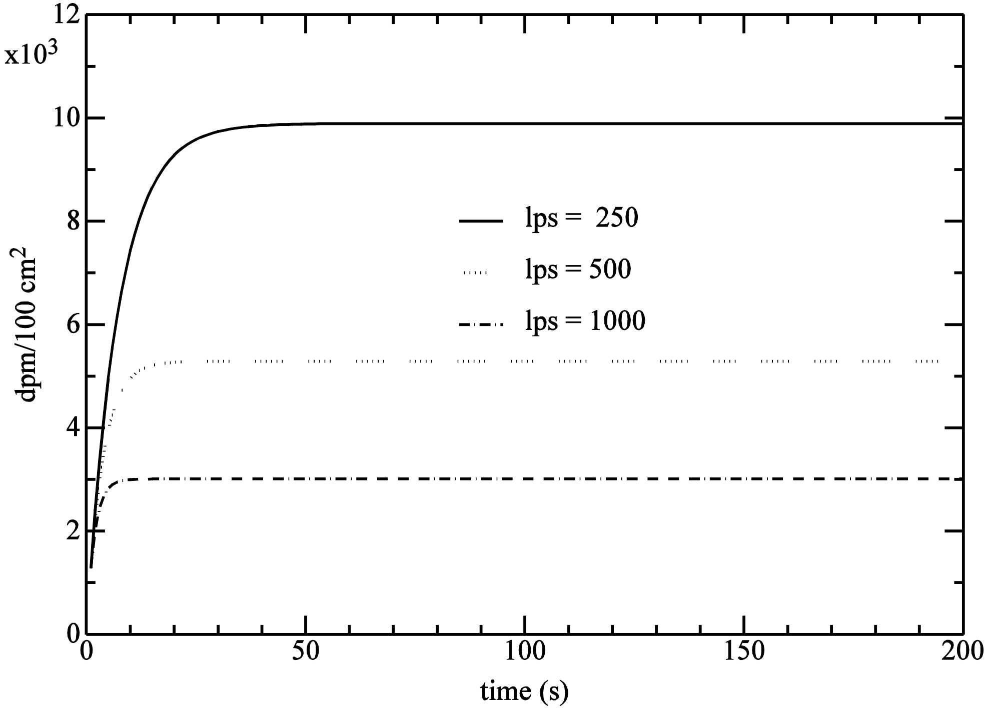
T. O’Connor

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



$$A_i = A_{poly} T_i$$

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:

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

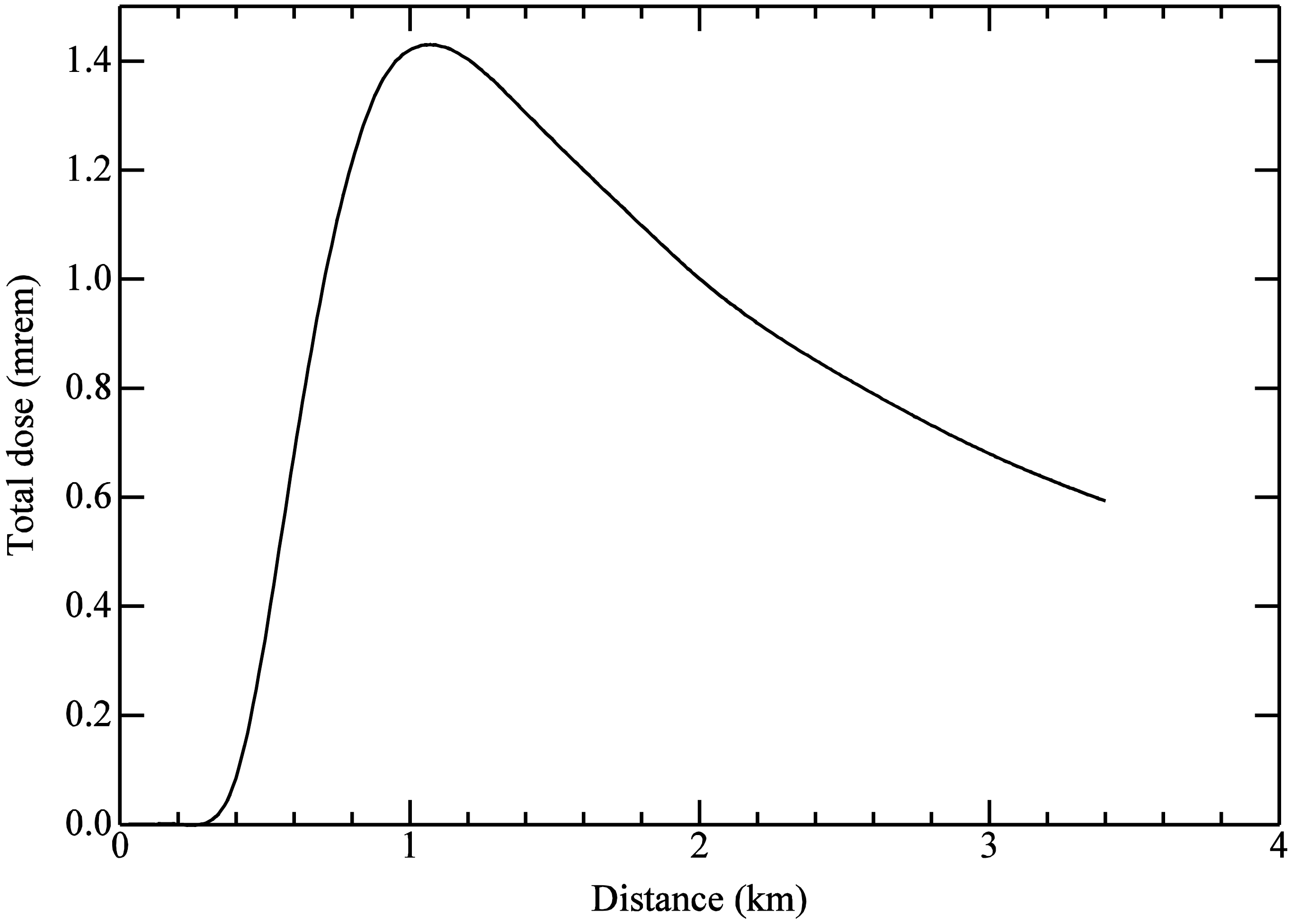
Stack height and maximum dose

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:

ndays = (61 days)(1000 Ci)(25 μA)/((nci)(ib))

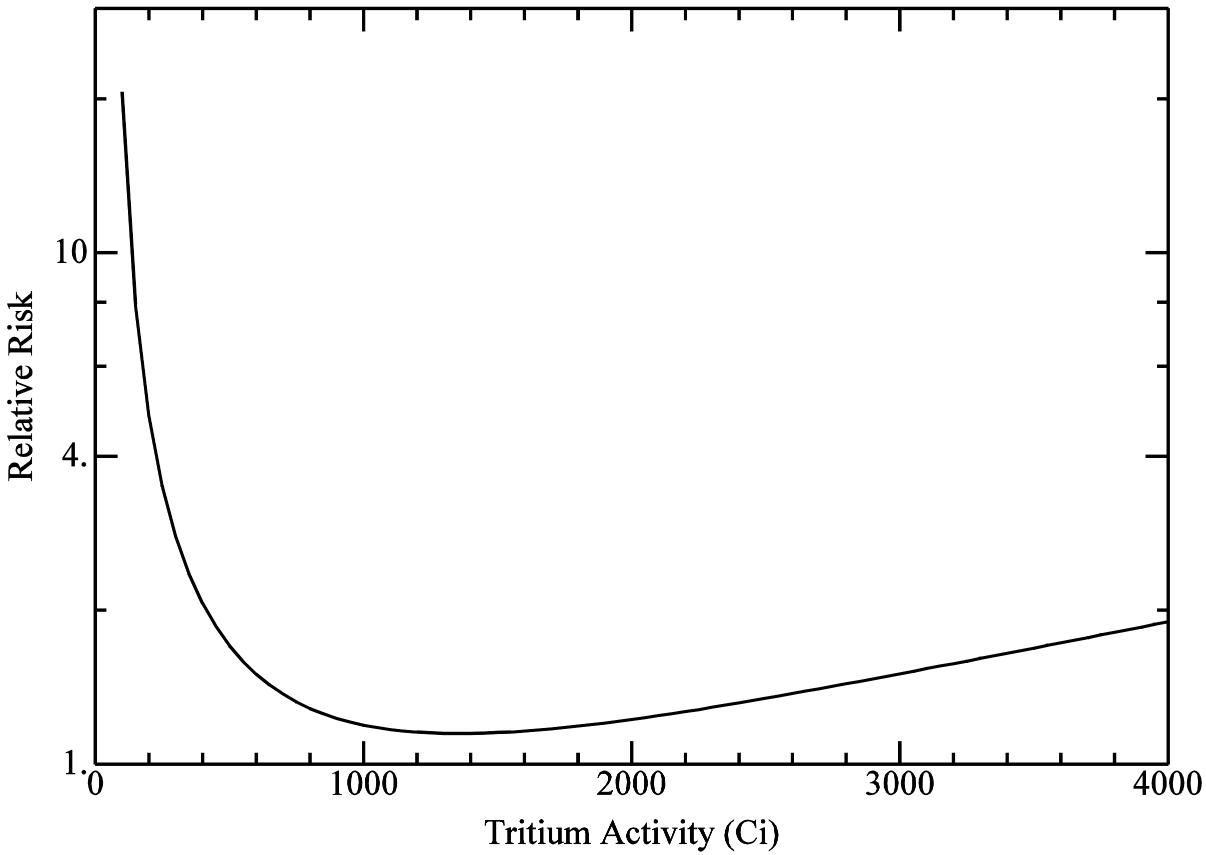
where nci = no. of Ci and ib = beam current.

Cycling risk (beam trips):

Risk_{cyc} = (1 – exp(-ncyc/cychi))exp(ncyc/cychi)exp(press/presshi)exp(ib/ibhi),

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

Risk vs. Target Activity



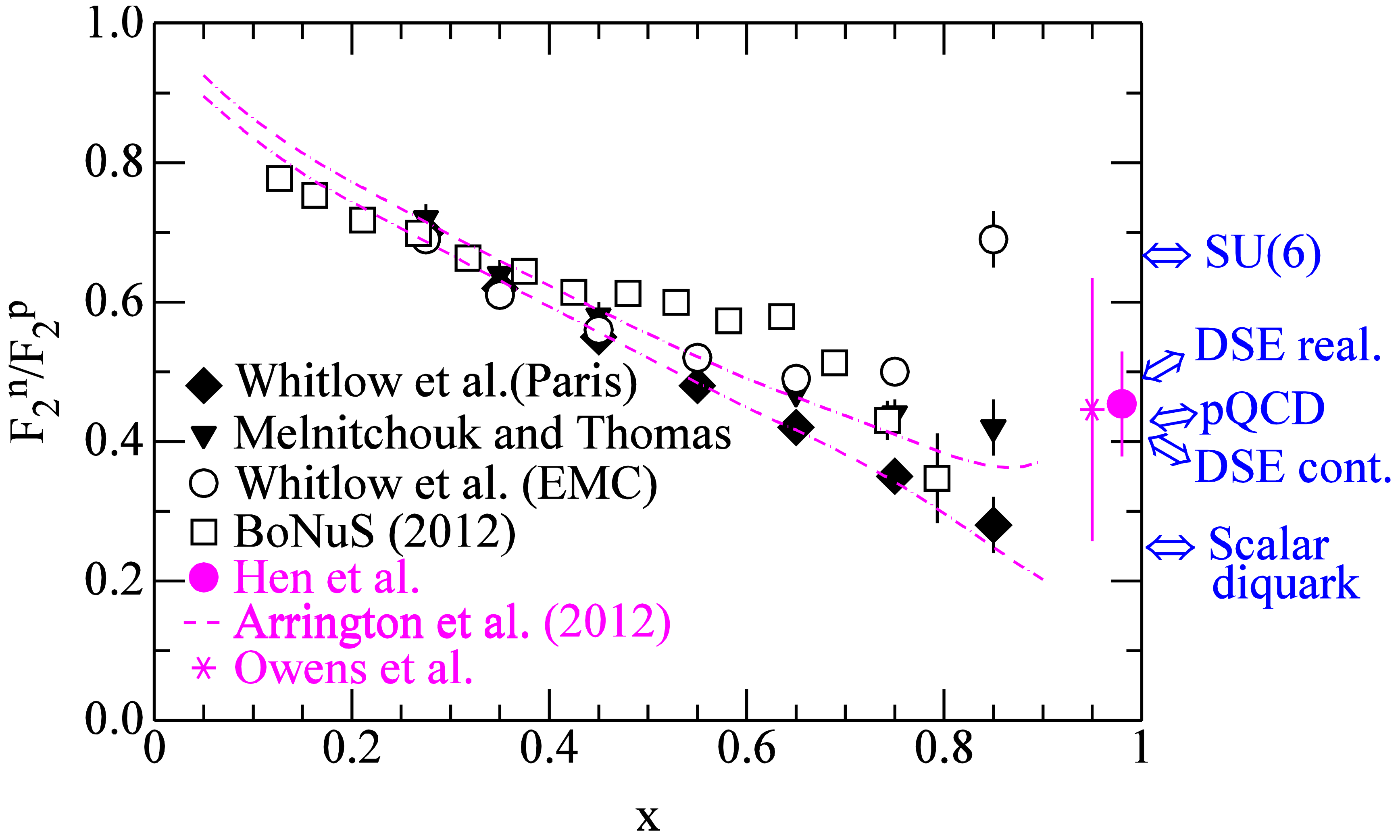
Relative risk vs. curies when the beam current is 21 μA. The optimum target activity is 1350 Ci. This assumes that the high risk time is 365 days.

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
SU(6)	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

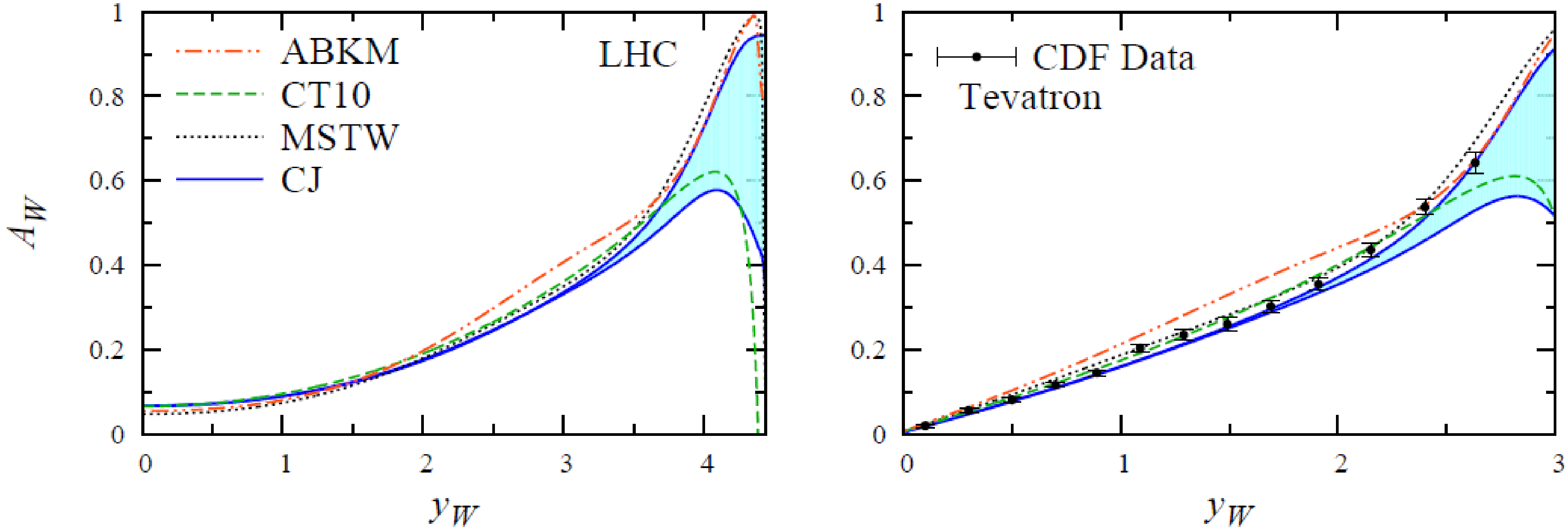
Present status: Neutron to proton structure function ratio



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

High x impacts high energy physics

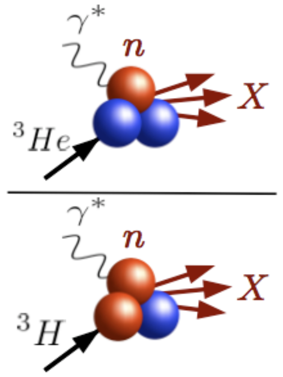
W charge asymmetry vs. W rapidity



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



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

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

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

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

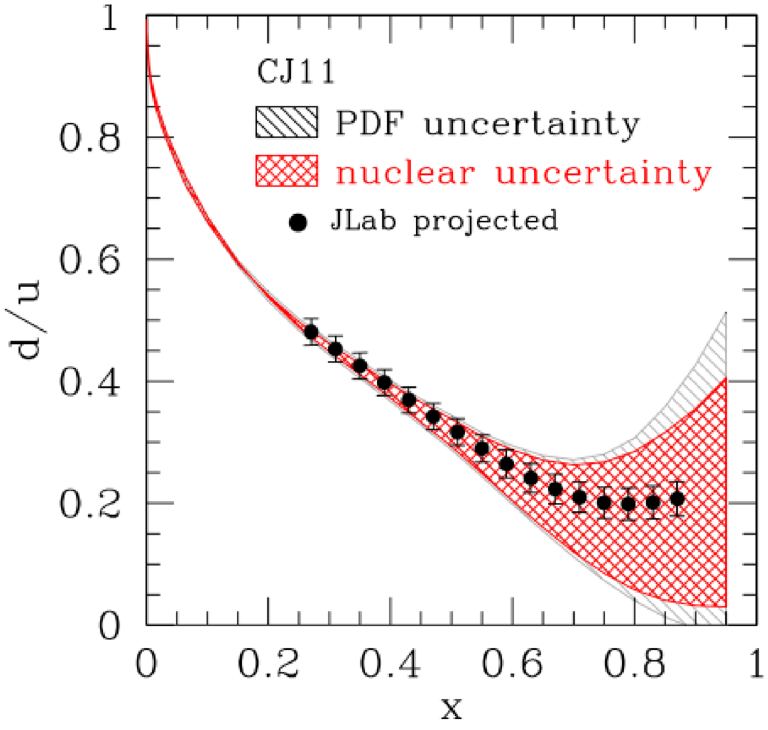
Relies only on <u>difference</u> in nuclear effects

Calculated to within 1.5%

Most systematic, theory uncertainties cancel

JLab E12-06-118: Marathon

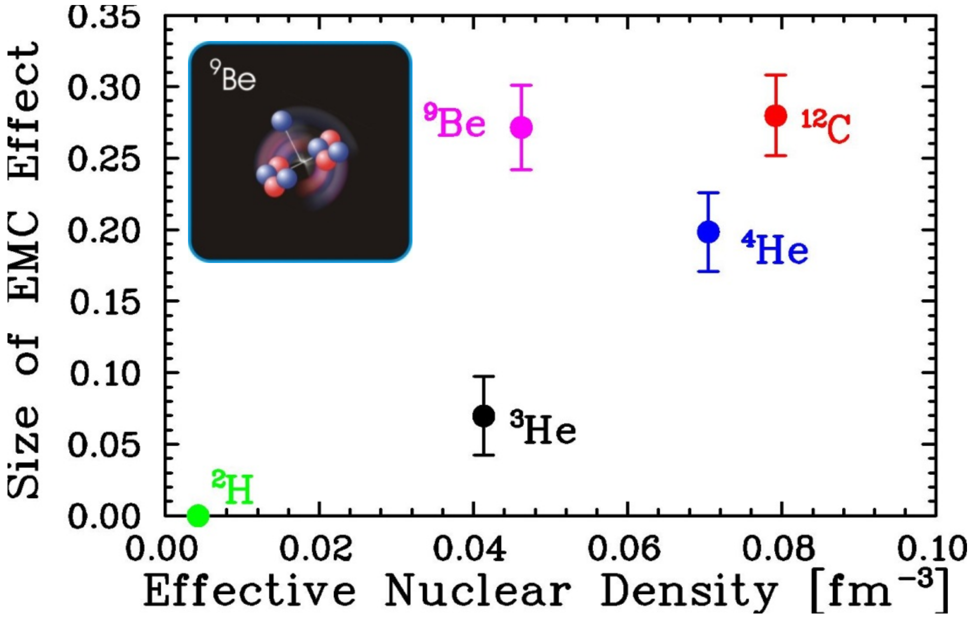
G. Petratos, RJH, R. Ransome, J. Gomez



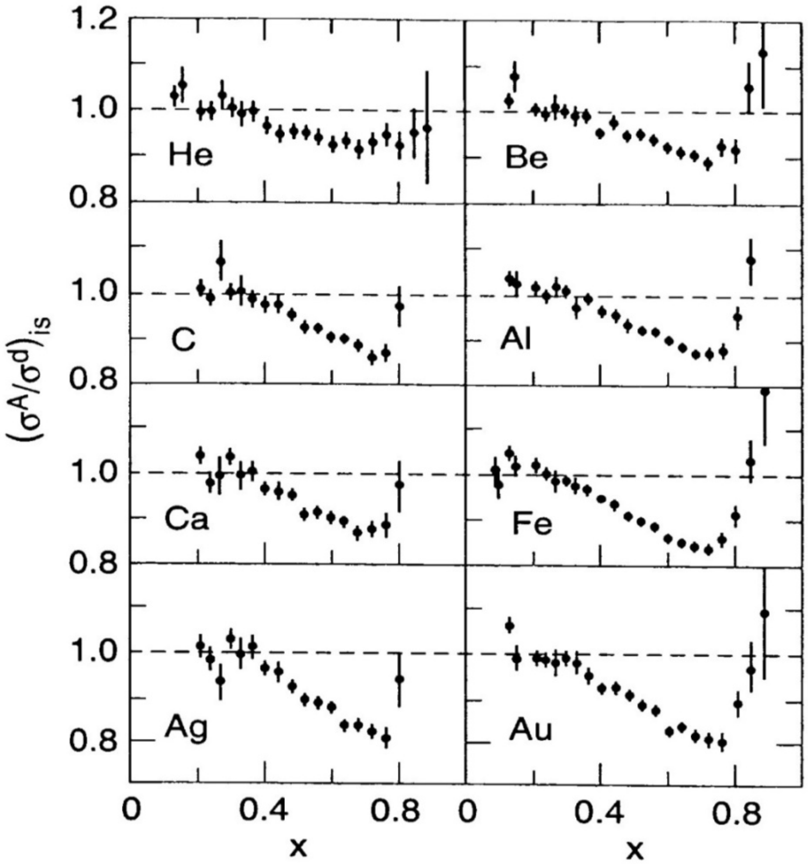
$$\frac{F_2^n}{F_2^p} = \frac{[1+4(d/u)]}{[4+(d/u)]}$$

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}He/^{3}H is simplest asymmetric case:**

Simple estimates for 2N-SRC

Isospin independent

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

Full n-p dominance (no T=1)

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

- **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}He/^{3}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}He(e,e'p)/^{3}H(e,e'p)

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

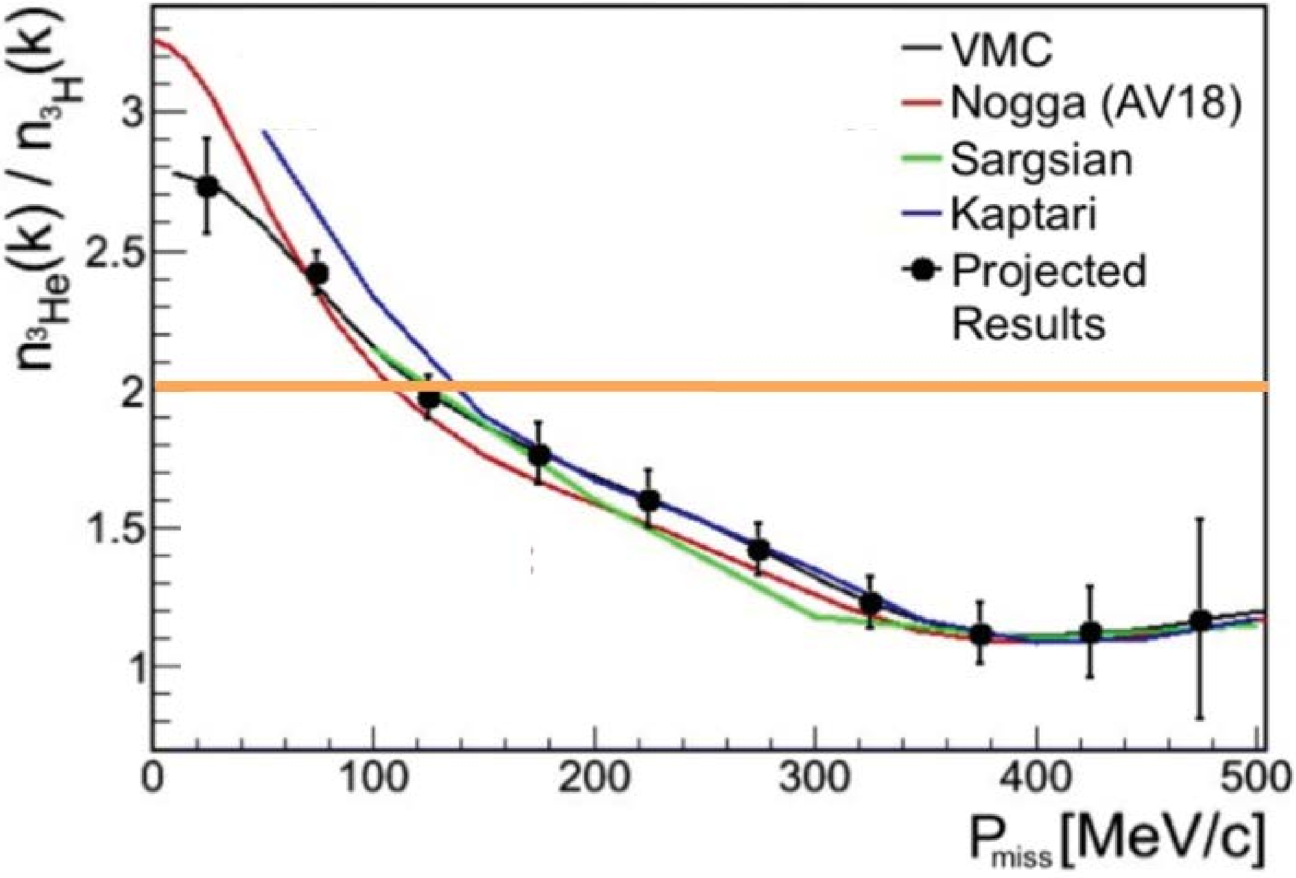
L. Weinstein, O.Hen,
W. Boeglin, S. Gilad

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

np-dominance at high-P_m implies n/p ratio → 1

n/p at low P_m enhanced

No neutron detection required



arXiv:1409.1717

Charge radii: ^{3}He and ^{3}H

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

L. Meyers, J. Arrington, D. Higinbotham

Precise theoretical calculations of $<r^2_{rms}>_{3H}$, $<r^2_{rms}>_{3He}$

Experimental results: large uncertainties, discrepancies

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

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