Performance of the Tritium Target

Dave Meekins

1/31/2019

Jefferson Lab Tritium Target Performance

- Brief History
- Target Performance
  - Performance as a system
    - Containment/Confinement
    - Operations
  - Target/beam performance
- Summary

Long Long Ago…

How did the T2 Program get it's start?

- Talks began in late 1990s
  - NO WAY Tritium always makes a mess
- First formal proposal made in 2006 (MARATHON)
  - Experiment was approved with conditions on the target

"Its All About the Target"

Roy Holt -> Can we use a bit of T2 gas in a safe sealed small volume and perform the experiment?

- YES!
- Concept Review in 2010 → "This could work"
  - Grew to 5 Experiments
- Final Design Review in 2015
- First Beam: December 2017

Experimental Program

- E12-10-103   MARATHON: Deep Inelastic Scattering F2n/F2p
  - Petratos, Arriington, Gomez, Kratramatou, Meekins, Ronsome, Holt (Ret)
- E12-11-112: Isospin structure of 2N-SRCs (JLab)
  - P. Solvignon*, J. Arrington, D. Day, D. Higinbotham
- E12-14-011: p/n Momentum Distributions in A = 3
  - *Boeglin, Gilad, Hen, Weinstein*
- E12-14-009: Elastic scattering; charge radii
  - L. Meyers, J. Arrington, D. Higinbotham
- E12-17-003: Hyper-nuclear
  - Nakamora, Markowitz, Garibaldi, Urciuoli, Tang

* In Memorium

Tritium Target Safety

- Safety of public, personnel and environment is paramount
  - Minimize impact from any release scenario
- Responsible Engineer: Legally responsible for safe design, fabrication, inspection and testing. Ensure all applicable Codes and Standards have been met.
- Three layers of containment/confinement at all times
  - Shipping and handling
  - Loading
  - Installation/removal
  - Storage
- Controls
  - Engineering, Admin, PPE, Avoidance
- During operations the experimental Hall walls became the 3rd layer of confinement.
  - Special exhaust systems were constructed
- Custom Storage was developed

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Selected Applicable Codes and Standards

10 CFR 851 (DOE worker safety and health)
10 CFR 71
10 CFR 20
49 CFR 172 and 173 (DOT HAZMAT)
NEPA National Environmental Policy Act
DOE Orders: 460.1, 441.1, 458.1
DOE Office of Science Policies
DOE NNSA Packaging, Shipping, Filling, Handling, Security
DHS/DOE NMCA
SRS safety basis
JLAB pressure safety and RadCon
JLAB ERRs
Codes:

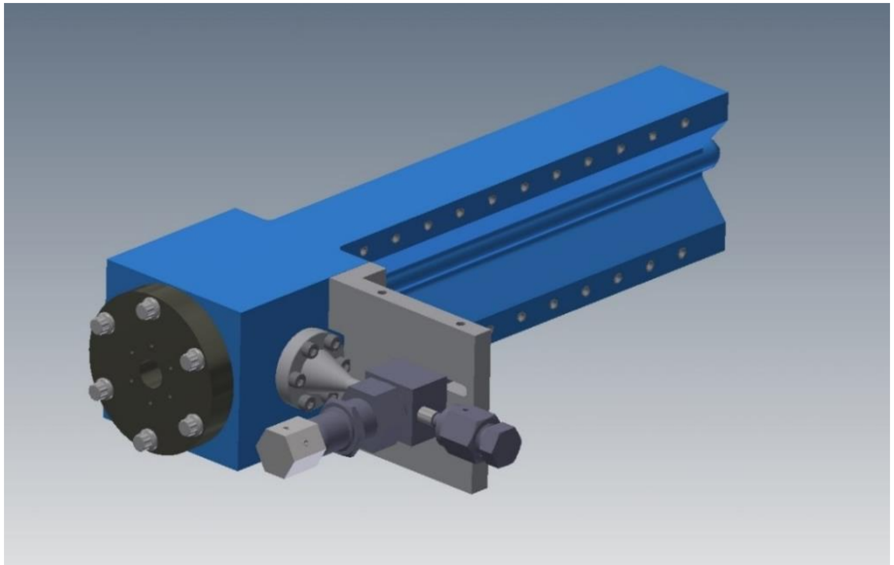
- ASME BPVC VIII D1 and D2 and IX, B31.3, STC-1
- AWS D1.1 and 1.6

Sealed Static Gas Cell

Target Fluids:

Why would you want anything but tritium?

- Load ~ 1100 Ci of T_2 (0.11 g)
- Fill pressure ~ 200 psi at 295K
- Volume = 33.4 cc
- Walls ~0.5 mm thick
- Ends ~0.25 mm thick



Successful Modular Design:

-Can ship in BTSP – ovoid JLAB "handling" T2

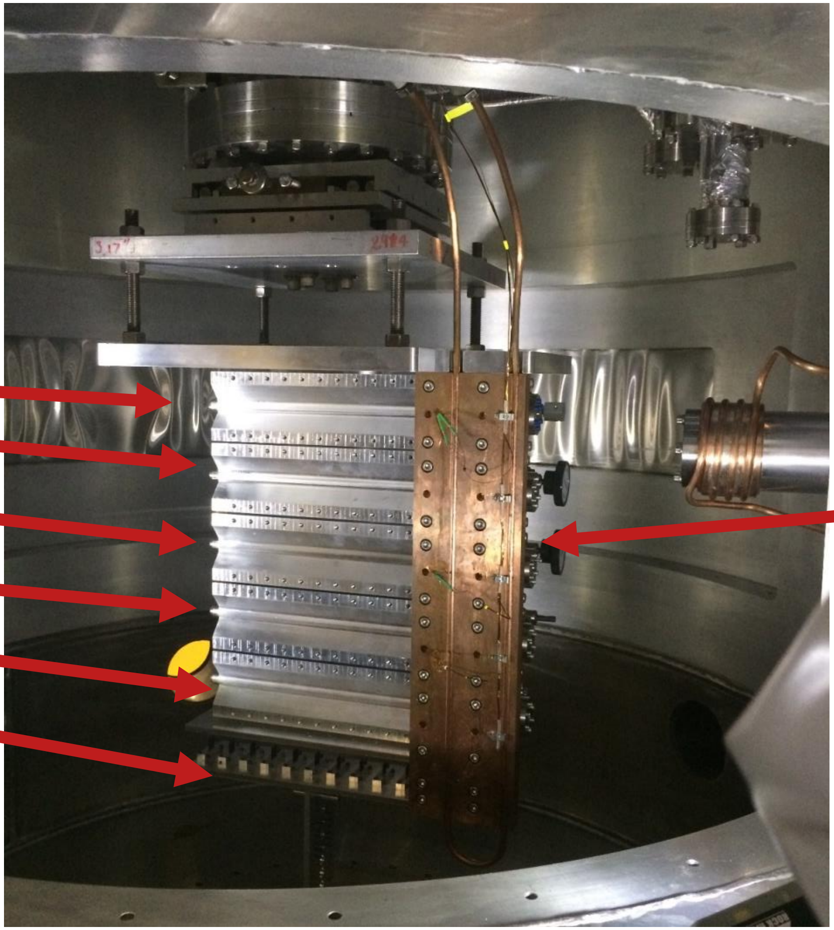
-Store in triple containment

-Install when needed

-Stayed removable covers allowed thin walled cell to meet SRS/safety basis and experimental requirements

Sealed Gas Cell

Internal Target Assembly



Tritium (T2)
He-3
D2
H2
Empty
Solid Targets

Heat Exchanger

Tritium Loss from Cell

Tritium(Hydrogen) Permeates Through Cell

- $T_2 \rightarrow T + T$ hops through lattice interstitial sites
- Conservative scaled estimates for unknowns based on H2 data

➡ Gives a loss of T2 as 0.5 Ci/year

$$Q = \frac{\chi C D A}{t}$$

Molar T2 loss

$$C = \frac{C_0 \sqrt{P_{op}}}{\sqrt{P_{atm}}} e^{-\frac{\Delta H}{RT}}$$

Solubility of T2 in 7075

$\chi = molar\ density$
$C_0 = solubility\ of\ T2\ in\ 7075\ at\ STP$
$D = Diffusion\ coef\ for\ T2\ in\ 7075$
$\Delta H = heat\ of\ solution$
$A = surface\ area$
$t = thickness$

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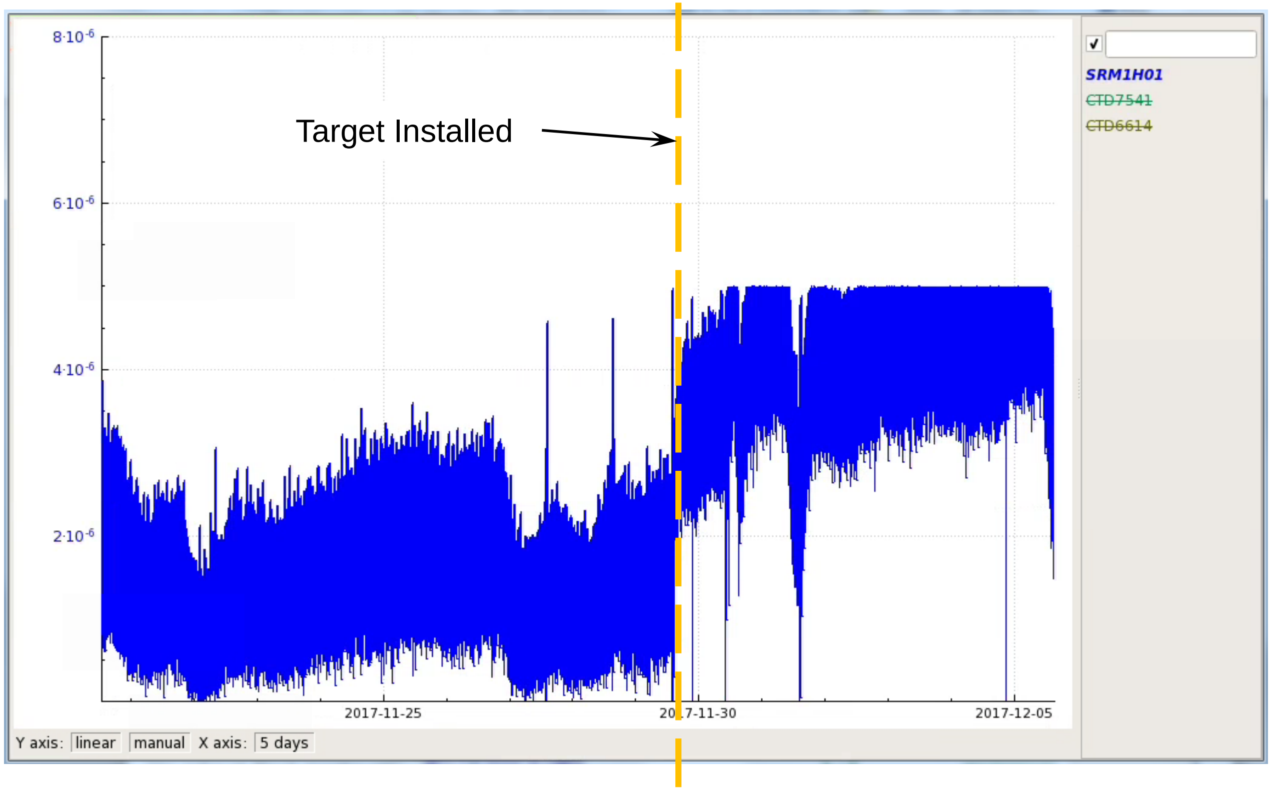
Tritium Loss From Cell

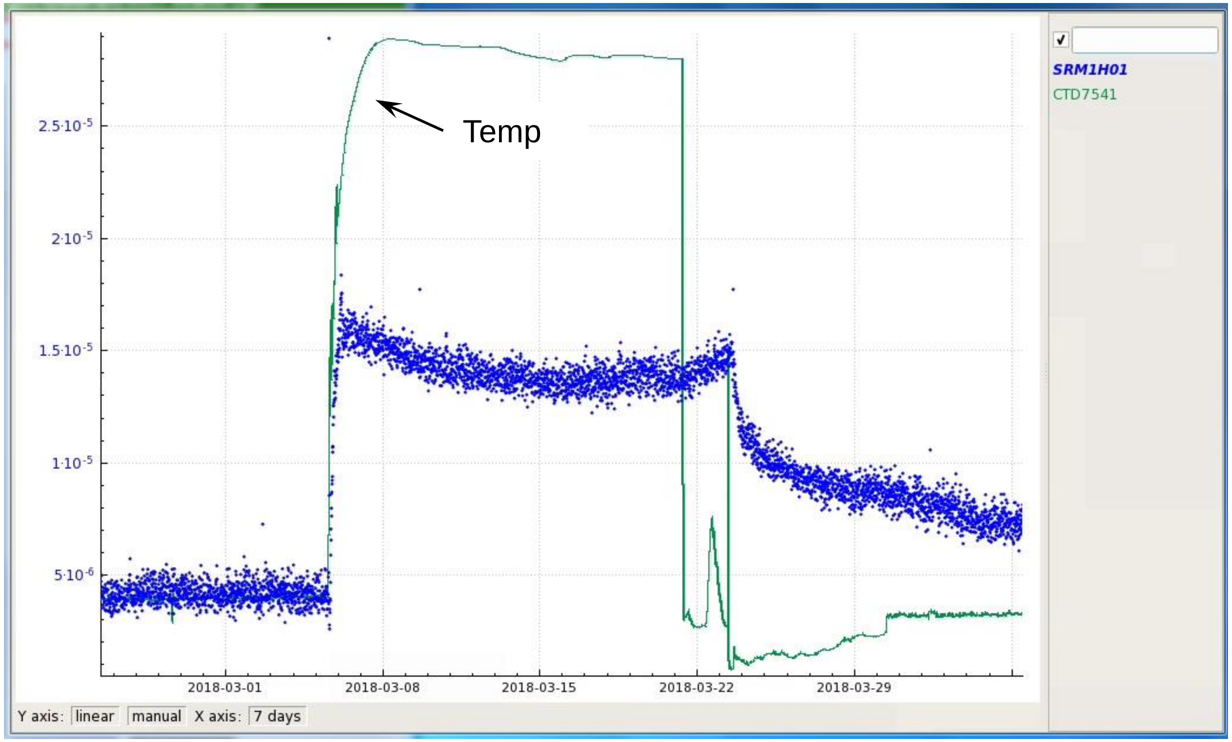
- Stack monitor measured T2 loss
  - Loss above background ~2µµCi/cc
  - ~11 mCi/month or <150 mCi which exceeds design

Stack monitor
(µµCi/cc-s)



Tritium Loss From Cell

- Loss measurements scale with target temperature as expected
  - Confident in measurements/model



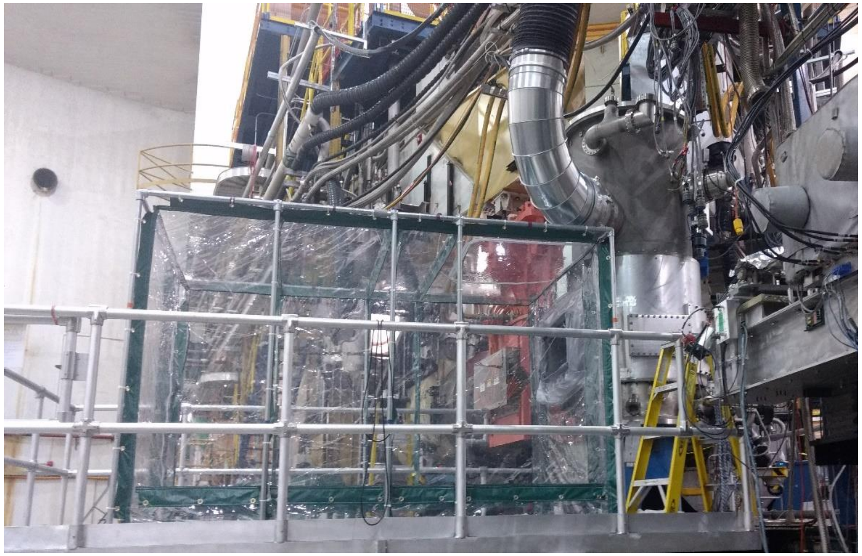
Exhaust System/Confinement

- Provided crucial 3rd layer of confinement/containment
  - Design requirements:
    - maintain slight negative pressure in Hall A (1–2 inH20) and in handling hut (2-3 inH2O)
    - 140 ft/s at chamber with hut installed ***LAMINAR***
    - Loads balanced with dampers and were concurrent
- Provide Smoke Removal
  - Required to operate in combination with other exhausts in Hall to remove smoke from fire
- System must not damage the roll up door in the Hall.
  - High suction can pull this door off tracks
- Exhaust fan speed variable
  - Pressure drops and flow rates must be balanced

Exhaust System/Confinement

Target Exhaust System and Stack

Transfer Hut



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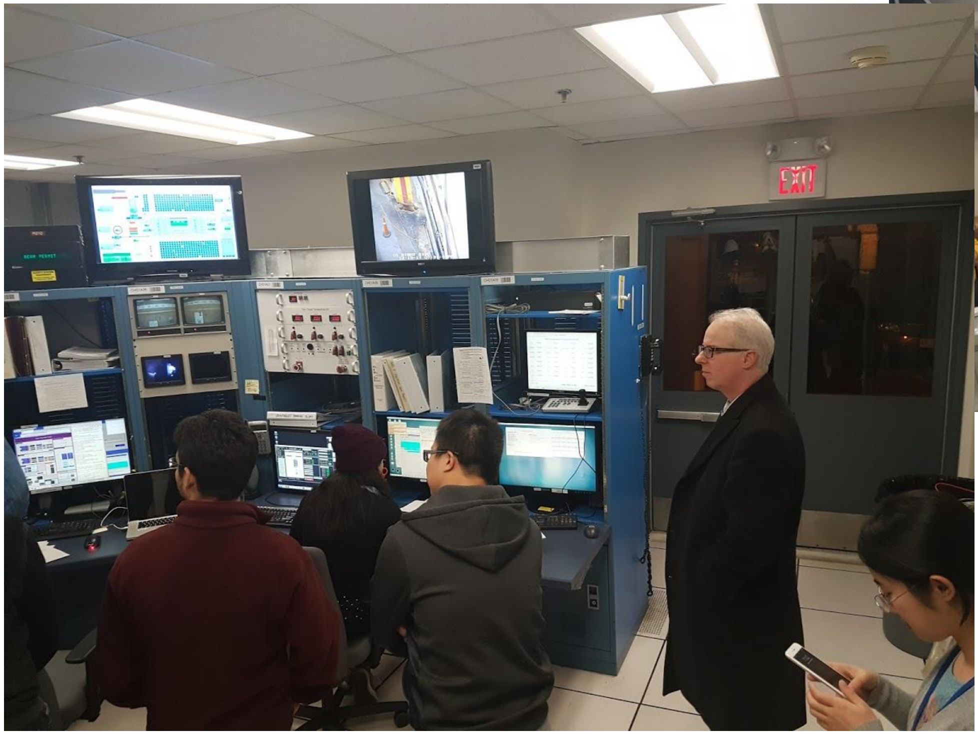
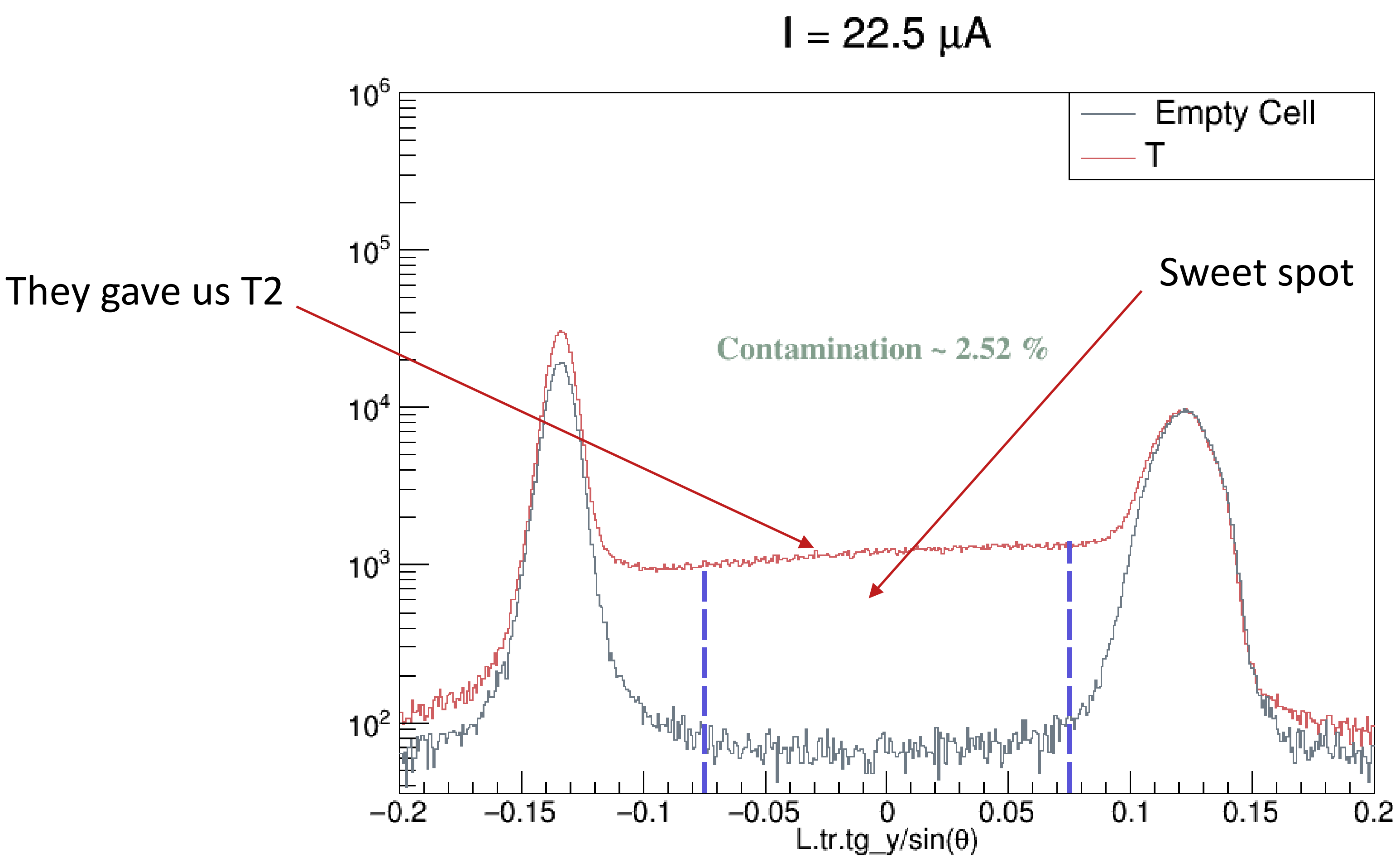
Exhaust System/Confinement

- Exhaust system was certified by team from SRS/SRTE
- Smoke removal capacity exceeded 12000 cfm
- Tritium operations:
  - Laminar flow velocity ~160 ft/s at chamber for loading
  - Pressures in Hall and chamber ~-1.5 and -3 inH2O
- Fan speed was tweeked by 5% to optimize the performance
- System operated with 100% reliability in all modes

First Beam 15 December 2017



Background from Cell Endcaps



Sheren Alsalmi: Kent State

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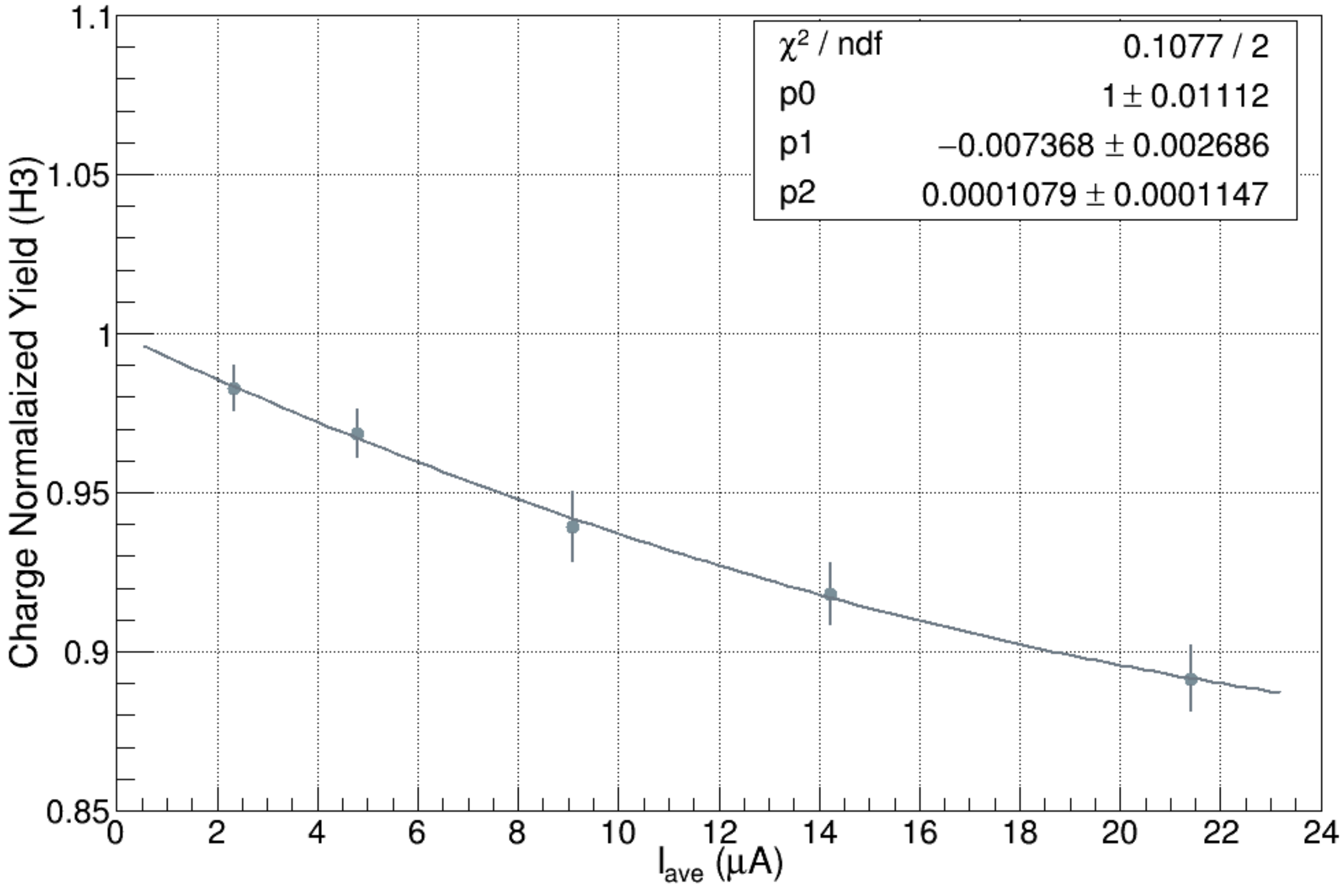
Target Performance Density Reduction



CFD: ~15% reduction

Sheren Alsalmi: Kent State

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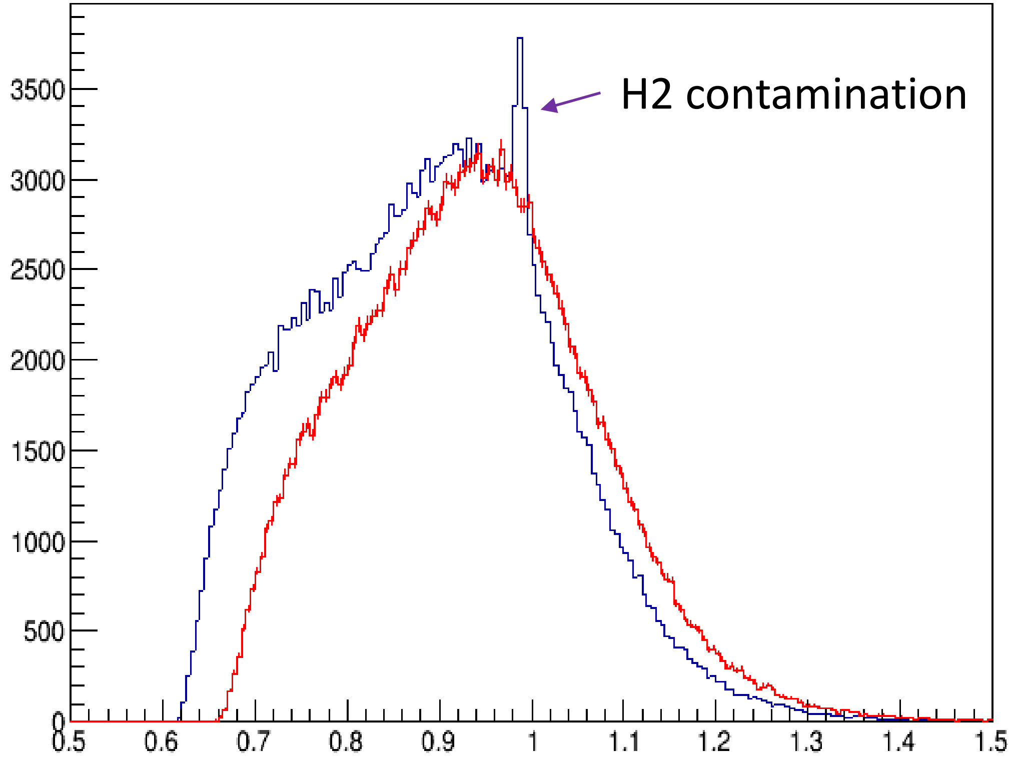
Tritium Gas Targets at Electron Accelerators

Lab	Year	Quantity (kCi)	Thickness (g/cm^2)	Current (μmA)	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	2017-2018	1.1	0.072	22.5	1.62

JLAB Target Stands up Well With Other Targets

Hydrogen Contamination in Second Cell

- Few % H2 contamination in the second cell
- Working with SRS to quantify this contamination



Shujie Li - UNH

Graduate Students and Post-Docs

- *S. Alsalmi
- J. Bane
- J. Castellanos
- R. Cruz-Torres
- H. Dai
- T. Hague
- T.Kutz
- S. Li
- H. Liu
- M. Nycz
- *D. Nguyen
- B. Pandey
- S. N. Santiesteban
- T. Su
- Kosuke

- F. Hauenstein
- R. E. McClellan
- A. Schmidt
- Z. Ye

13 PhD Students
2 Grad Student Model Citizens
4 Post-Docs

Summary

- Jefferson Lab has completed the Tritium Program
  - 13+ PhD Students
  - 4+ experiments completed (2 high impact)
- Staff and T2 Community collaborated effectively to address special hazards with T2
- Preliminary results are promising
  - Publications are expected soon.
- Target performed as expected
  - No significant loss of T2
  - **Roy's idea worked**
- Best measure of success: I still have a job at JLAB

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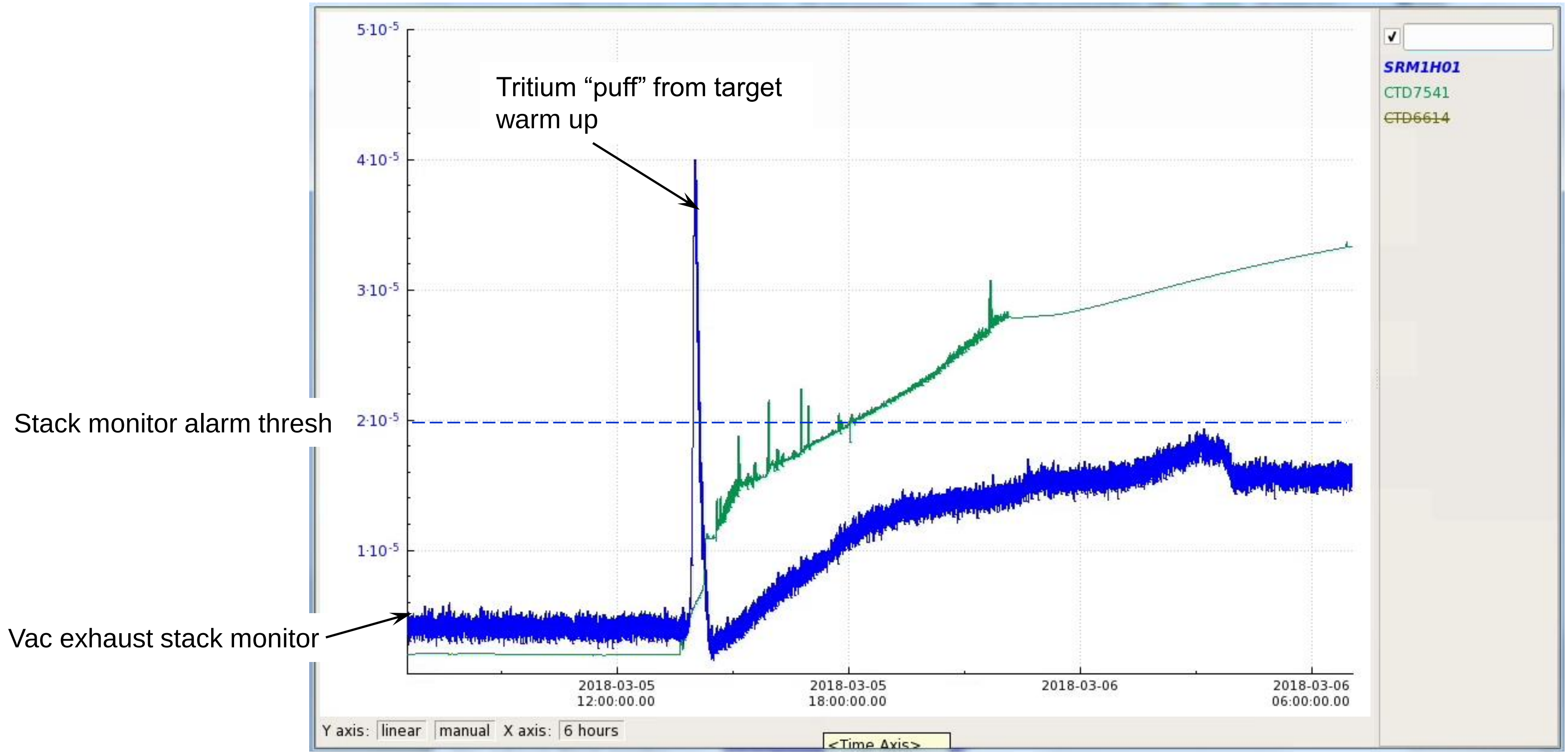
Acknowledgements

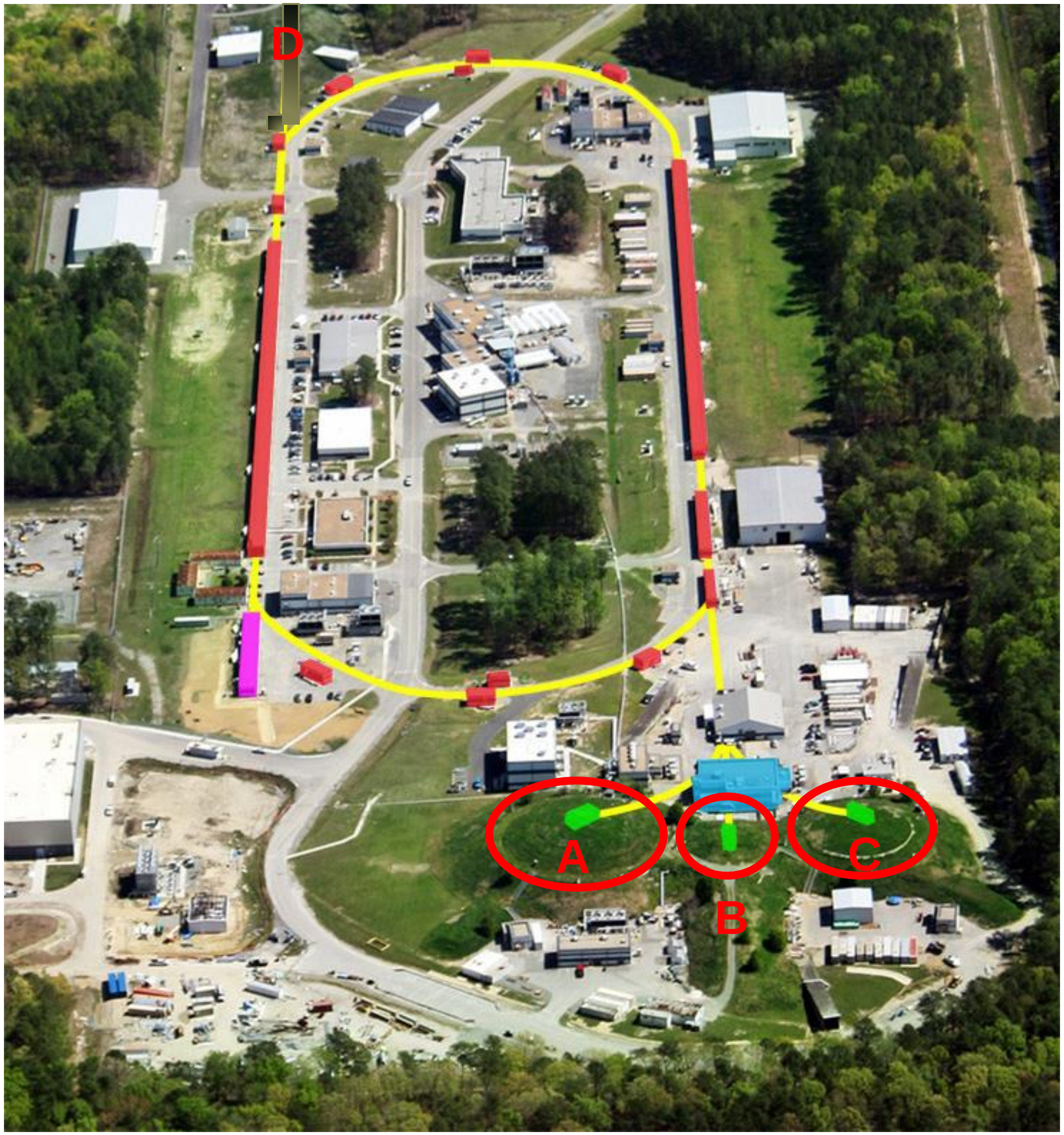
- Savannah River Site (SRTE and SRNL)
  - J. Novajosky et al.
- JLAB RadCon Group
  - K. Welch et al.
- JLAB Target Group
  - C. Keith et al.
- Spokespersons, users, and staff for strong cooperation with T2 overhead
- Excellent Grad Students and Post Docs --- Especially:
  - Sheren Alsalmi
  - Shujie Li
- DOE Office of Science
- DOE NNSA
- Too Many Others…

Experience with T_2 Target

- After long period at operating temperature, warm-up causes initial spike in exhaust stack tritium concentration –
- Hypothesis; ^3H "condenses" on target cell surface, causes puff on warm-up



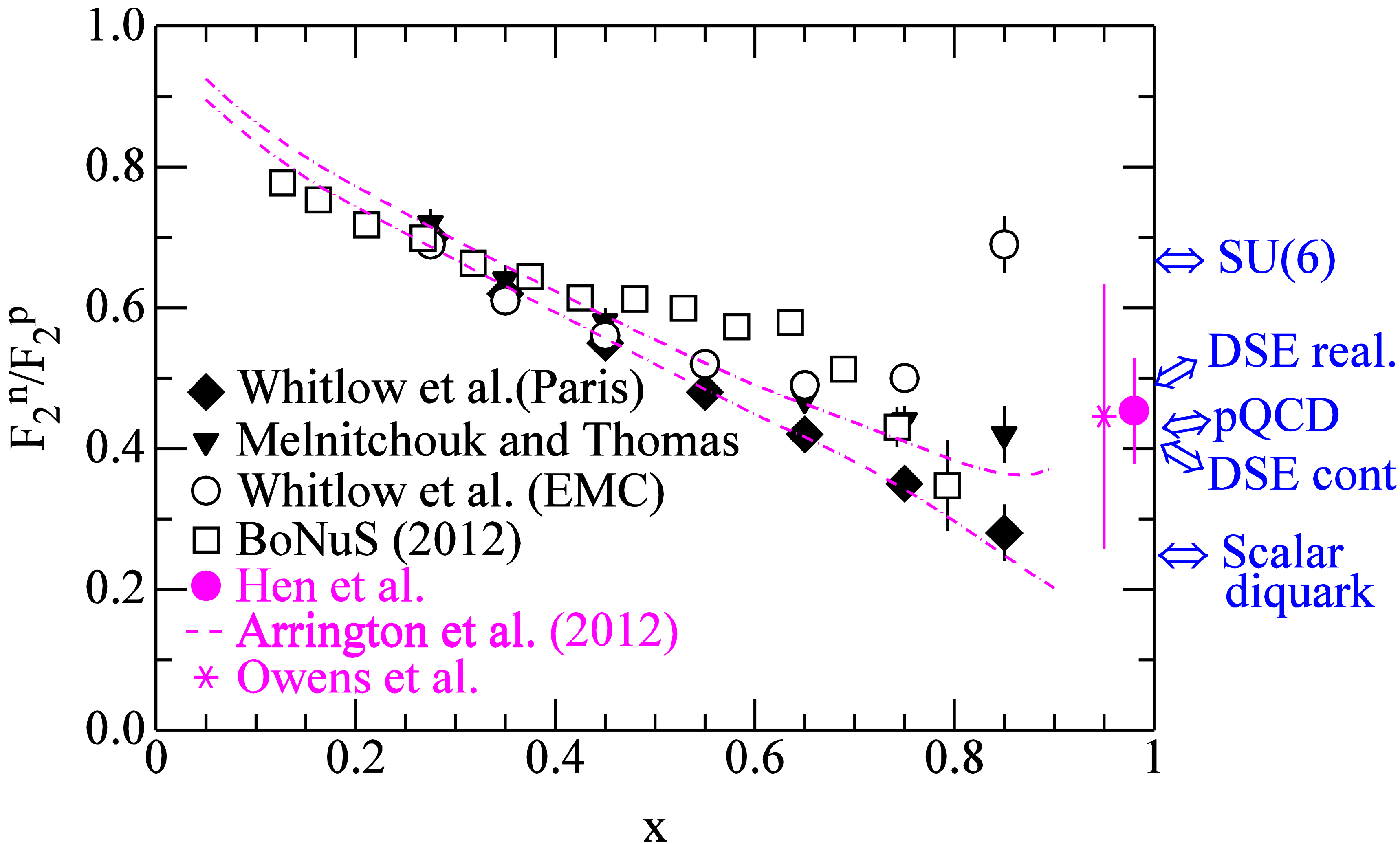
JLab accelerator CEBAF



Continuous Electron Beam
- Energy 0.4 – 6.0 GeV
- 200 μA, polarization 85%
- 3 x 499 MHz operation
- Simultaneous delivery 3 halls

- 416 PhDs completed
- On average 22 US PhDs per year, close to 30% of US PhDs in nuclear physics
- On average 50 undergrads per year involved in research at Jefferson Lab
- 1385 users in FY12, anticipated to grow to ~1500+ users with 12-GeV operations
- **International: non-US nuclear physics users = 1/3 of total, from 33 countries**

Current neutron to proton structure function ratio



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

Spokespersons: G. Petatos, R. Holt, R. Ransome, J. Gomez

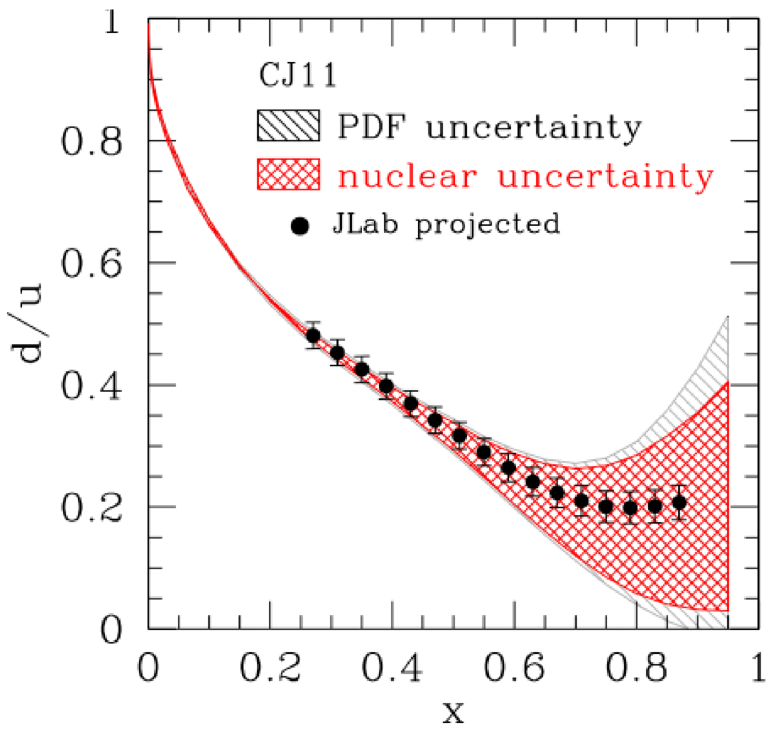
$$R(^3\mathrm{He}) = \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n} \qquad R(^3\mathrm{H}) = \frac{F_2^{^3\mathrm{H}}}{F_2^p + 2F_2^n}$$

- 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%



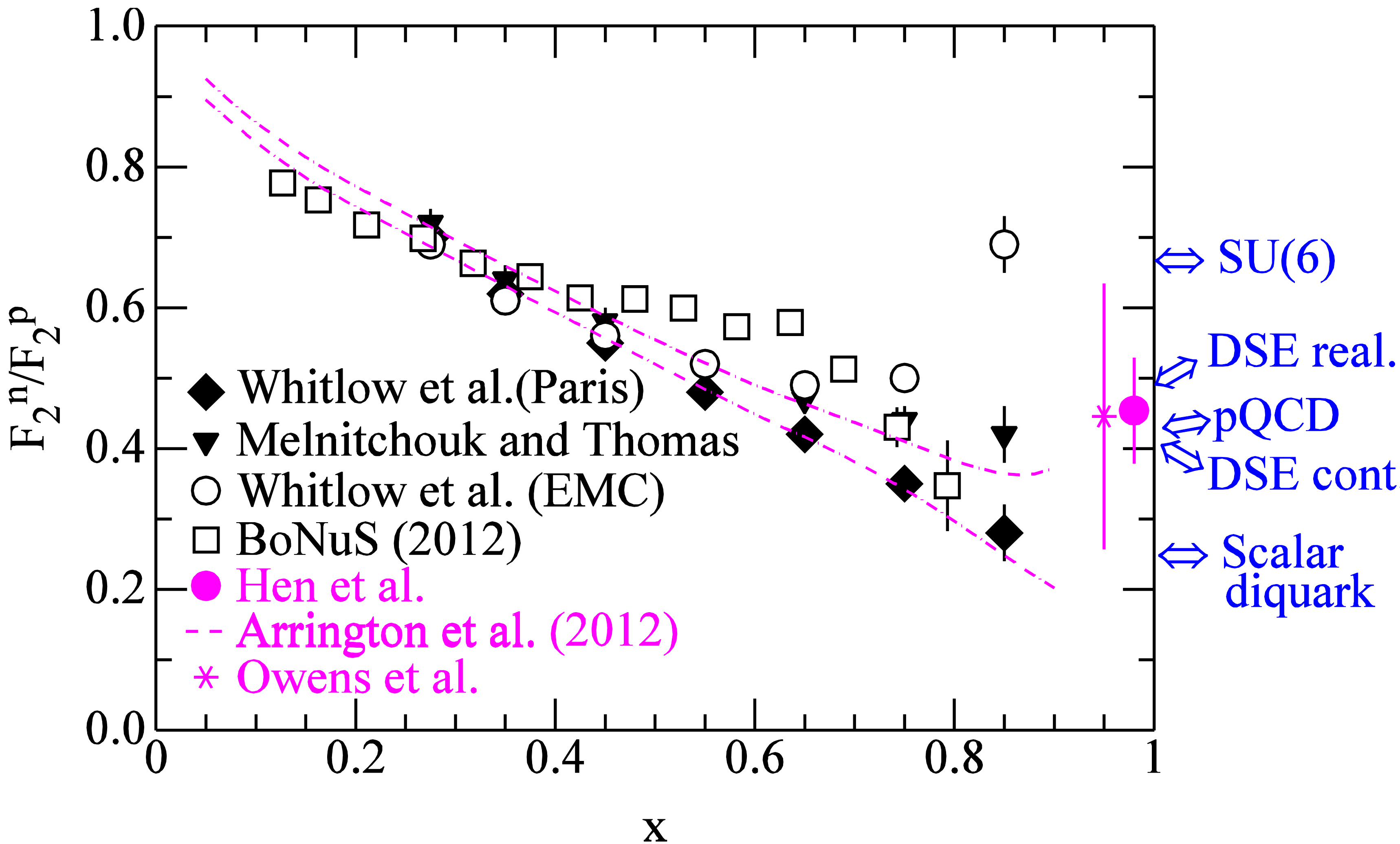
- Four Experiments Have Been Proposed To Use 3H & 3He
- Elastic Scattering 3He/3H Ratios (one experiment)
  - Make use of our 3He knowledge to better constrain the radius of 3H
  - Test of modern two- and three-nucleon potentials
- Quasi-Elastic Knock-Out (E12-11-112)
  - Distribution of the momentum of the proton(s) in 3H vs. 3He via (e,e'p)
  - Extreme Kinematics with (e,e') to probe short-range correlations
- Deep Inelastic Scattering (one experiment)
  - Ratios of Deep Inelasltic Structure Functions
  - Learning about the Quark Properties of Proton & Neutron
- Taken together, the elastic and quasi-elastic results will help constrain the nuclear corrections for the deep inelastic experiment and thus ensure the best possible extraction of the quark u/d ratios.

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

	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



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RJH, C. D. Roberts, RMP **82** (2010) 2991

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

- **$^3He/^3H$ is simplest asymmetric case:** P. Solvignon, J. Arrington, D. Day, D. Higinbotham

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)

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

- **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 $^3He/^3H$ 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

Engineered Controls

Exhaust stacks

- Large volume vent stack has two operational modes
  - Target handling with containment tent in place – directly ventilates the tent and target chamber (~1000 cfm)
  - Emergency ventilation of Hall in event of alarm or manual actuation (~7200 cfm)
- Target chamber exhaust purge stack
  - Constant forced purge of vacuum exhaust (~5 cfm)

$^3He(e,e'p)/^3H(e,e'p)$

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

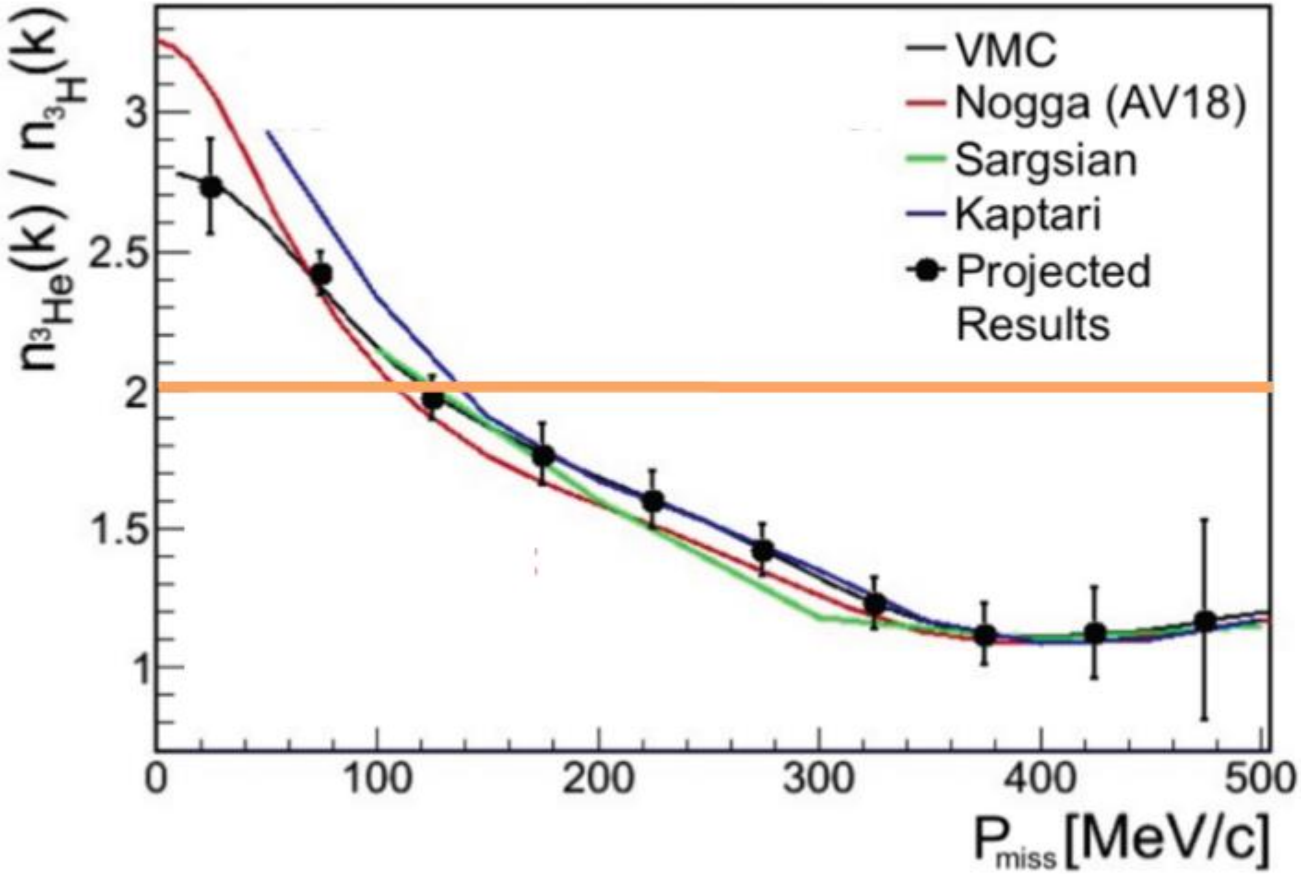
L. Weinstein, O.Hen,
W. Boeglin, S. Gilad

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

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

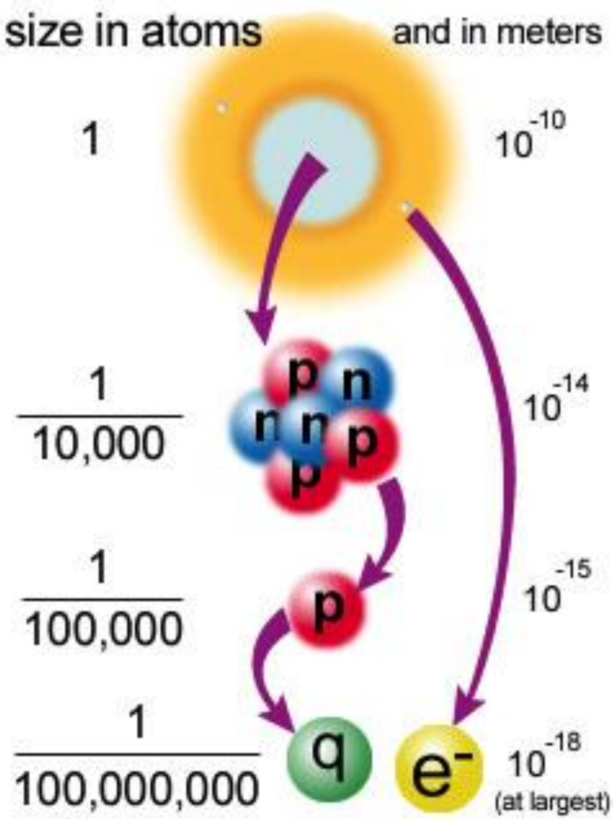
Precise theoretical calculations of $<r^2_{rms}>_{3H}$, $<r^2_{rms}>_{3He}$

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

How to probe the nucleons / quarks?



- Scattering experiments with high momentum electrons use electromagnetic interactions, which are well understood, to probe hadronic structure (which isn't).

E12-14-011

High energy electrons are a great tool for the job!

$$\boxed{d_{probed} \propto \lambda\!\!\!^{-} = \frac{\hbar}{p} \approx 10^{-18}\ \mathrm{m}}$$

Materials 3

- Tritium and Hydrogen Compatibility
  - Extensive experience with H2
  - Beam induced corrosion not expected below 180K (Flower et. al.)
  - Beam assisted embrittlement
    - $T_2 \rightarrow T + T$ Increases fugacity
      - Atomic tritium recombines rapidly
    - Modeled room fugacity ~3100 psi
    - Below threshold for H2 embrittlement
    - Many orders of magnitude below He-3 swelling threshold (Louthan)
- Test SRNL/SRTE using precracked coupons exposed to 2500 psi T2 underway
  - Test followed ASTM 1820 G168 (Precracked Stress Corrosion Testing)
  - Samples exposed for 4, 8, 12 months
  - M. Morgan, A. Duncan (SRNL)
- Tritium is expected to permeate through the cell and seals
  - ~0.5 Ci /year very conservative
- Calculations given in TGT-CALC-103-010

Tritium To JLAB

Shipping Is not Easy

Tritium is

HAZMAT
Radio Active Material
Nuclear Material (NNSA)
Pressurized Gas

Regulators:

- USDOE OS
- USDOE NNSA
- NRC
- DOT

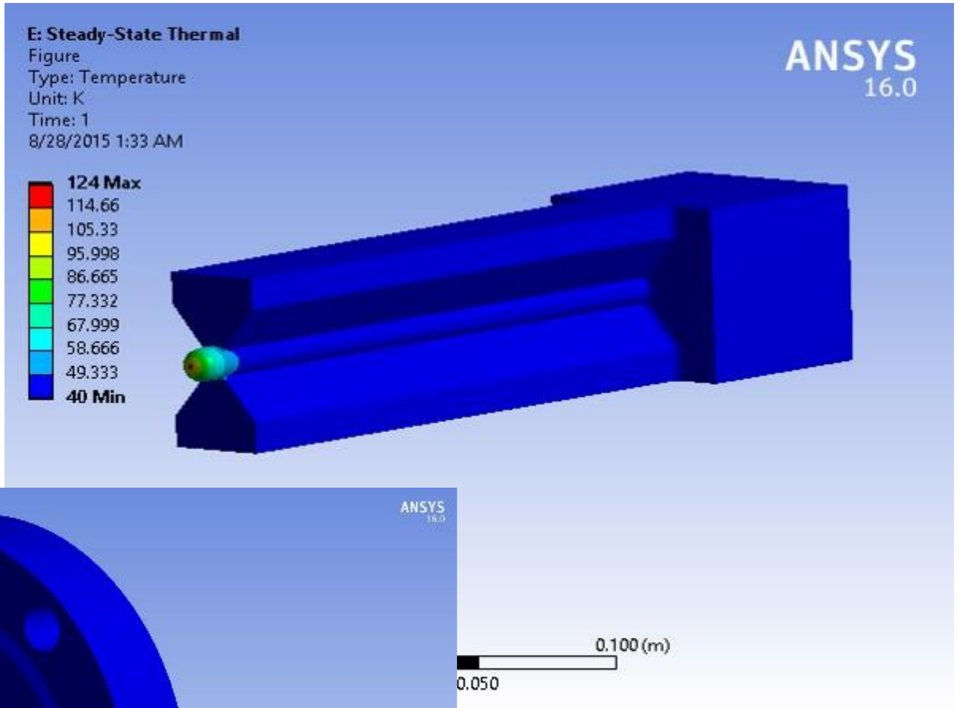
BTSP
Was almost ready for our config

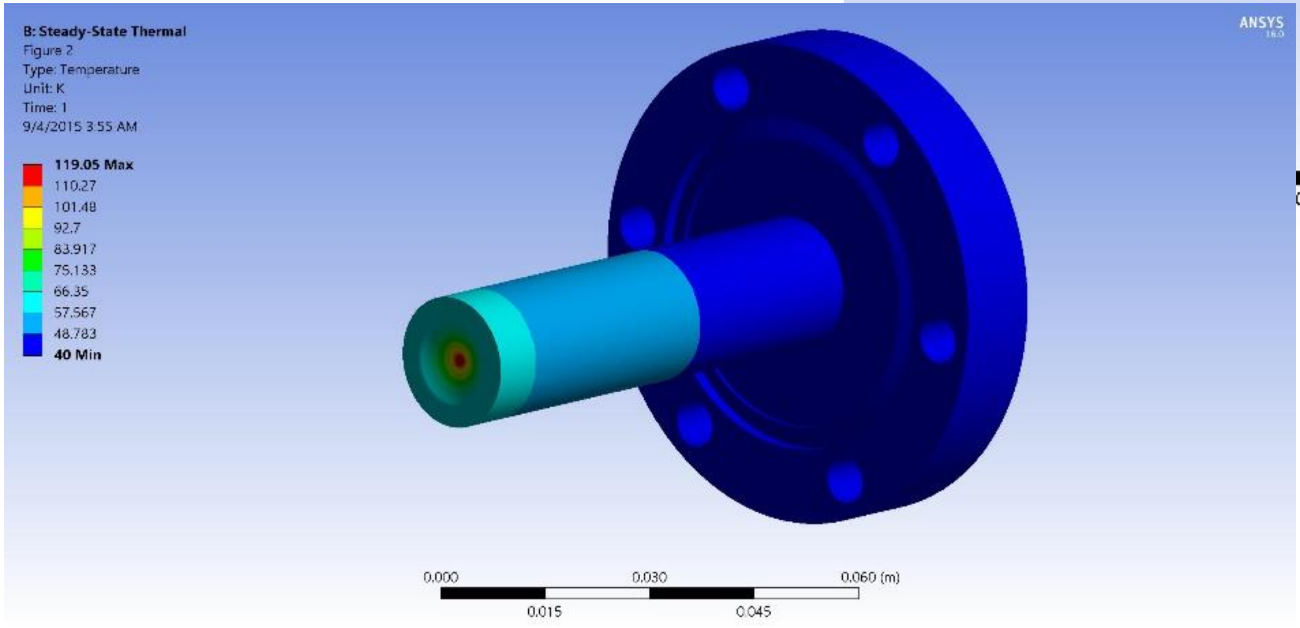
Installation and Removal

Beam Heating in the Cell

$I_{beam} = 20\mu A$ Max beam current
$A_{raster} = 2x2mm^2$ min raster

3W in Entrance
3.3 W in Exit
$T_{max} = 125K$ on exit
$T_{max} = 120K$ on entrance



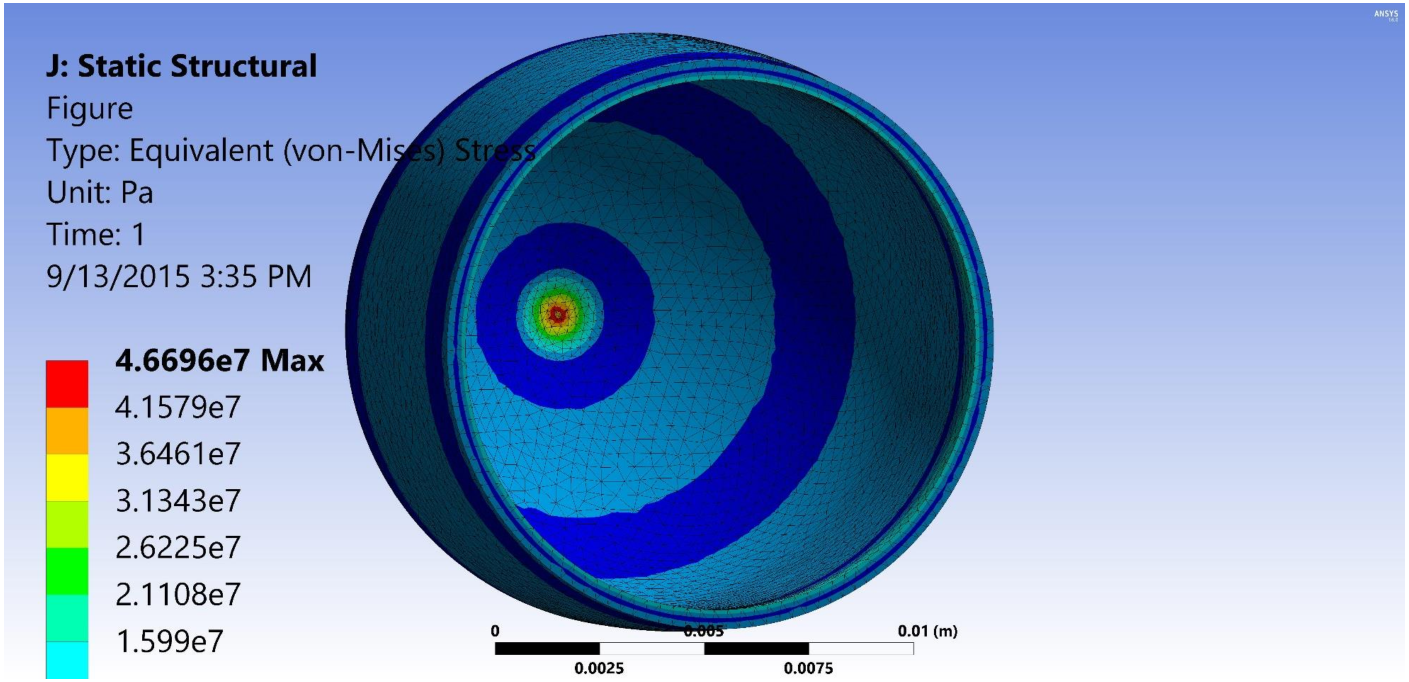


Other Beam Effects

Beam trips ~15 times / hour

- Significant cyclic load. ASME BPVC VIII D2 Part 5 analysis limits lifetime in beam

Raster Off does not "break" the cell



Hall A Tritium Target
Part 1

Dave Meekins

September 15, 2015

Overview

- Part 1: Target Design
  - Introduction
  - Target system design
    - Cell Design
    - Vacuum System
    - Exhaust system
    - Beamline Alterations
    - Control system
  - Expected Performance
- Part 2: Safety systems and failure modes
  - Tritium detection and monitoring
  - Tritium containment and release
  - Response to the prior review

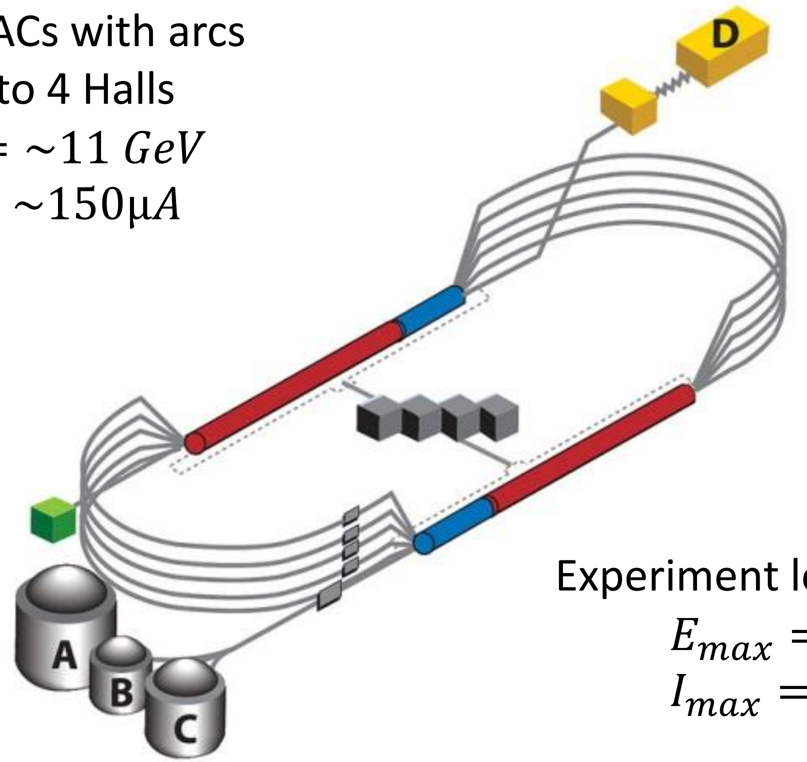
Design Philosophy

- Safety
  - Minimize impact from any release scenario
- Design shall be simple
- Minimize amount of tritium
- Do not “handle” tritium
- Three layers of containment
  - Operations
  - Installation/removal
  - Transport
- Perform well enough to run physics

CEBAF at JLAB

Continuous e Beam Accelerator
Pair of SRF LINACs with arcs
Delivers beam to 4 Halls

$$E_{max} = \sim 11\ GeV$$
$$I_{max} > \sim 150 \mu A$$



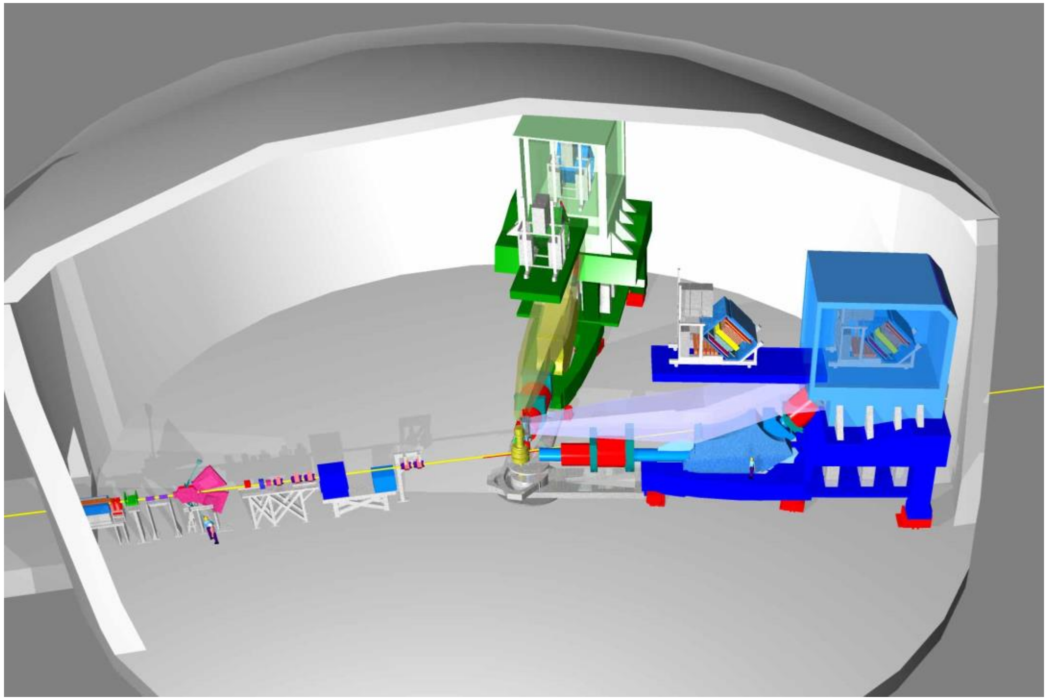
Experiment located in Hall A

$$E_{max} = \sim 11\ GeV$$
$$I_{max} = 20 - 25\ \mu A$$

Hall A

Dimensions:

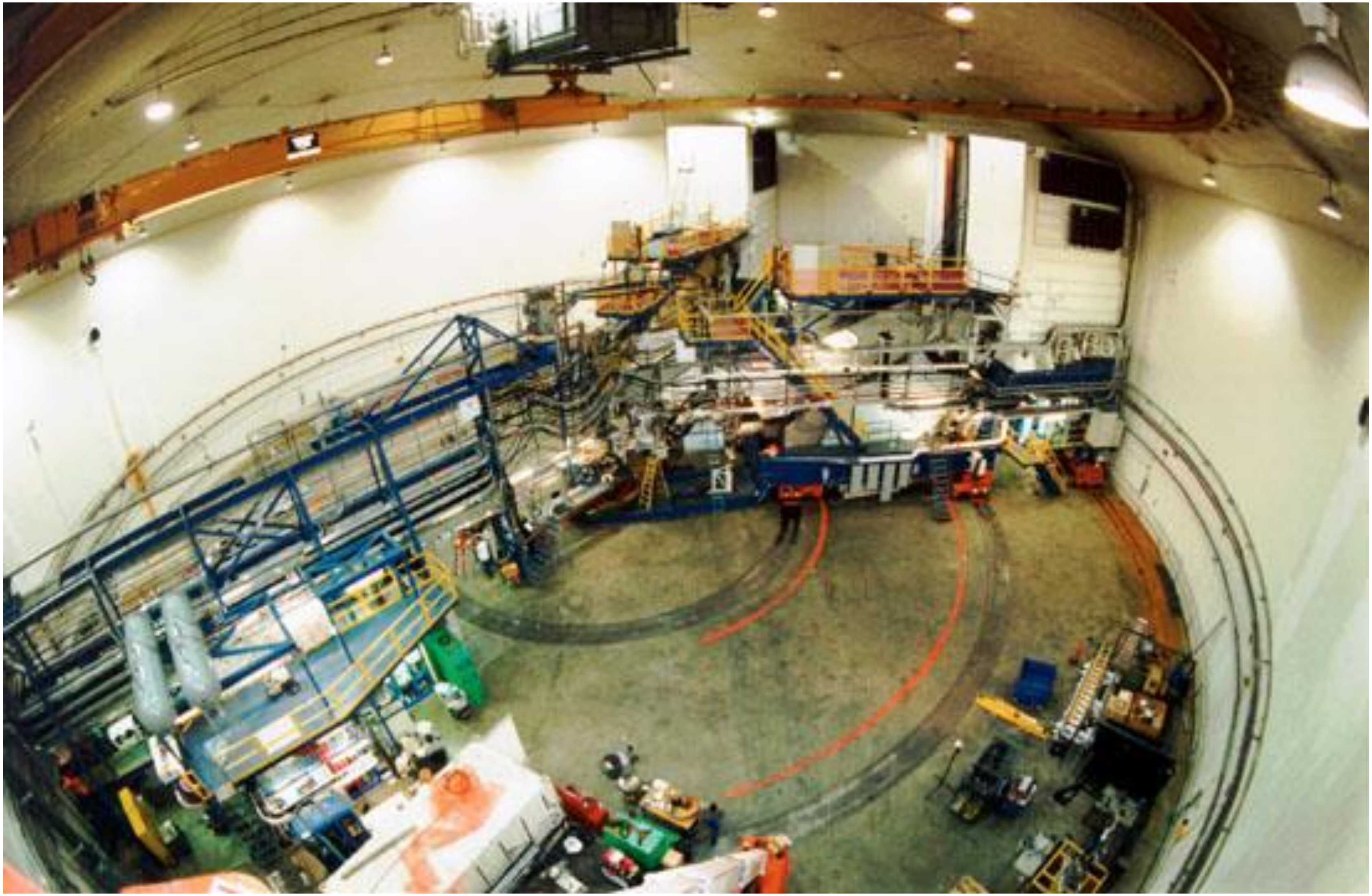
Diameter = 175 ft
Height = ~ 60 ft
Volume $40000\ m^2$
Multiple access ports
include Truck Ramp



Target

HRS: High Res Spectrometers

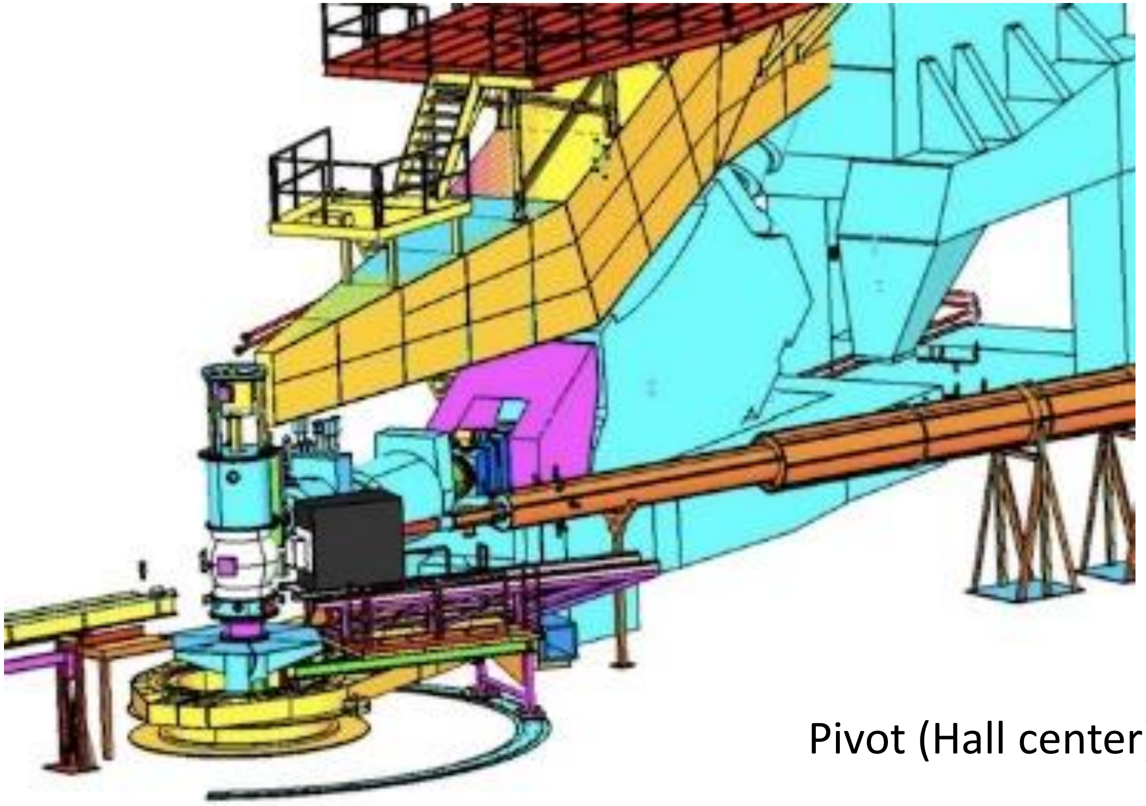
Arial View of Hall A



Target Chamber at Pivot

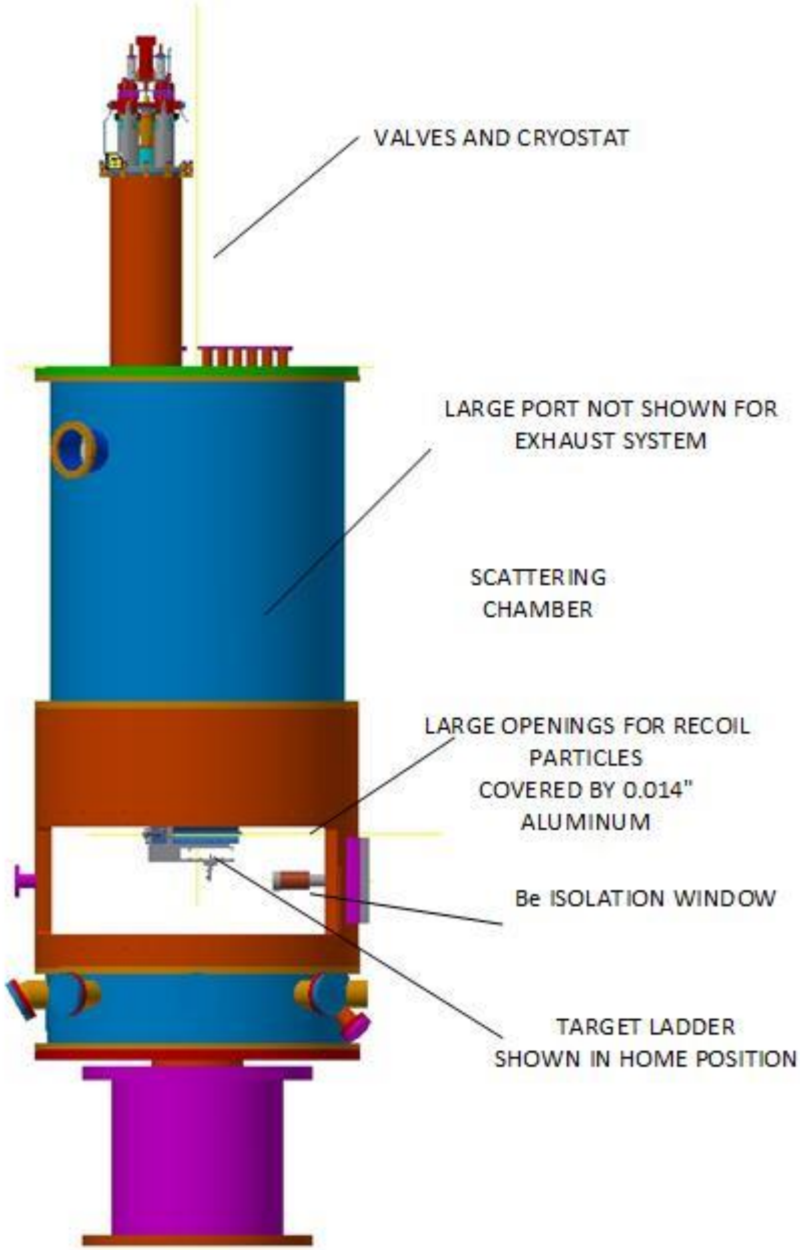
Target/Chamber

e Beam



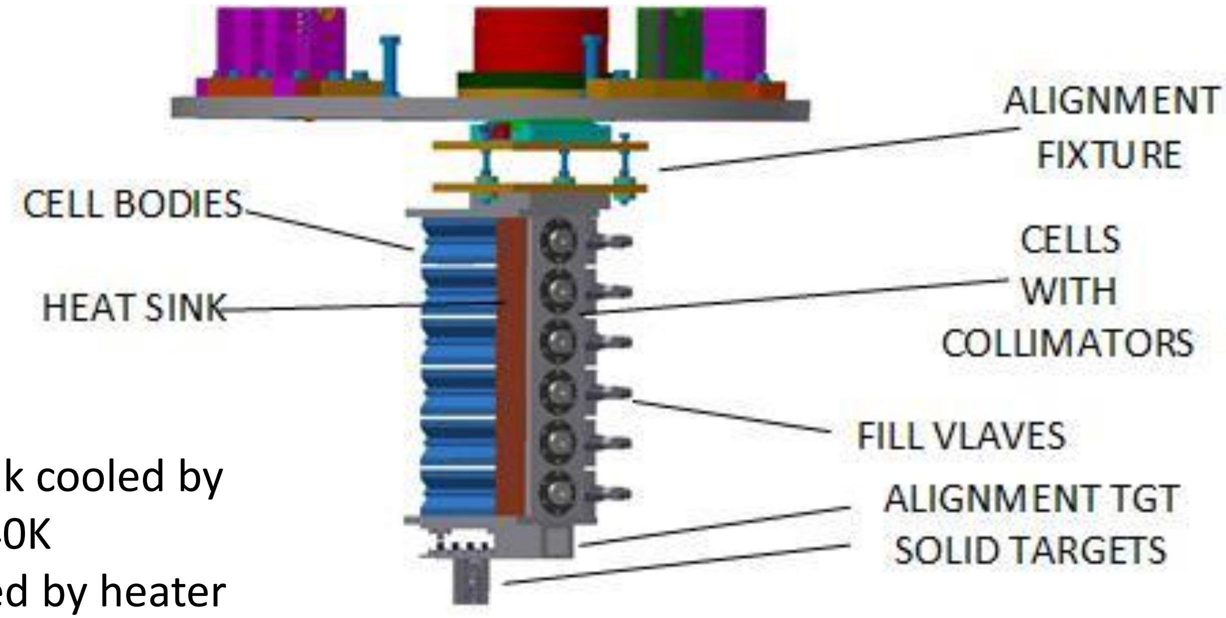
Pivot (Hall center)

System



- Repurposed Qweak H2 Target
- Alter existing Cryostat
  - Alter internal piping
  - Add two valves
- H2 Loop piping and cell removed
- Alter cryo piping and instruments
- 15 K He from ESR
- Motion in “X” and “Y” directions
- Control system is similar to Hall A cryotarget
- “New Construction” pressure system

Target Ladder



Heat sink cooled by
ESR to 40K
Stabilized by heater

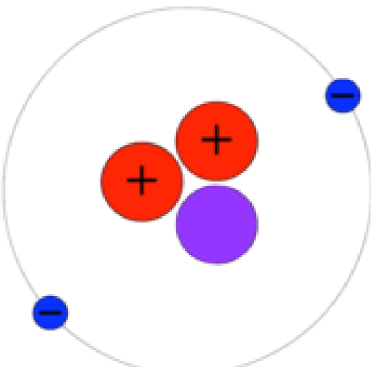
TARGET LADDER ASSEMBLY

Why Tritium?   A=3 Mirror Nuclei

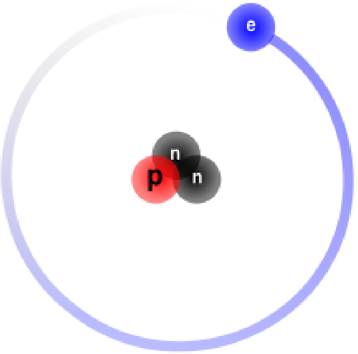
A=3 Is Lightest Pair of Mirror (Asymmetric) Nuclei

- Proton and Neutron are same particle but in different states
  - These states are Iso-spin states
- Isospin is an important construct for modeling
- Light enough for ab initio calculations now exist

Isospin Flip of p/n



He-3



H-3

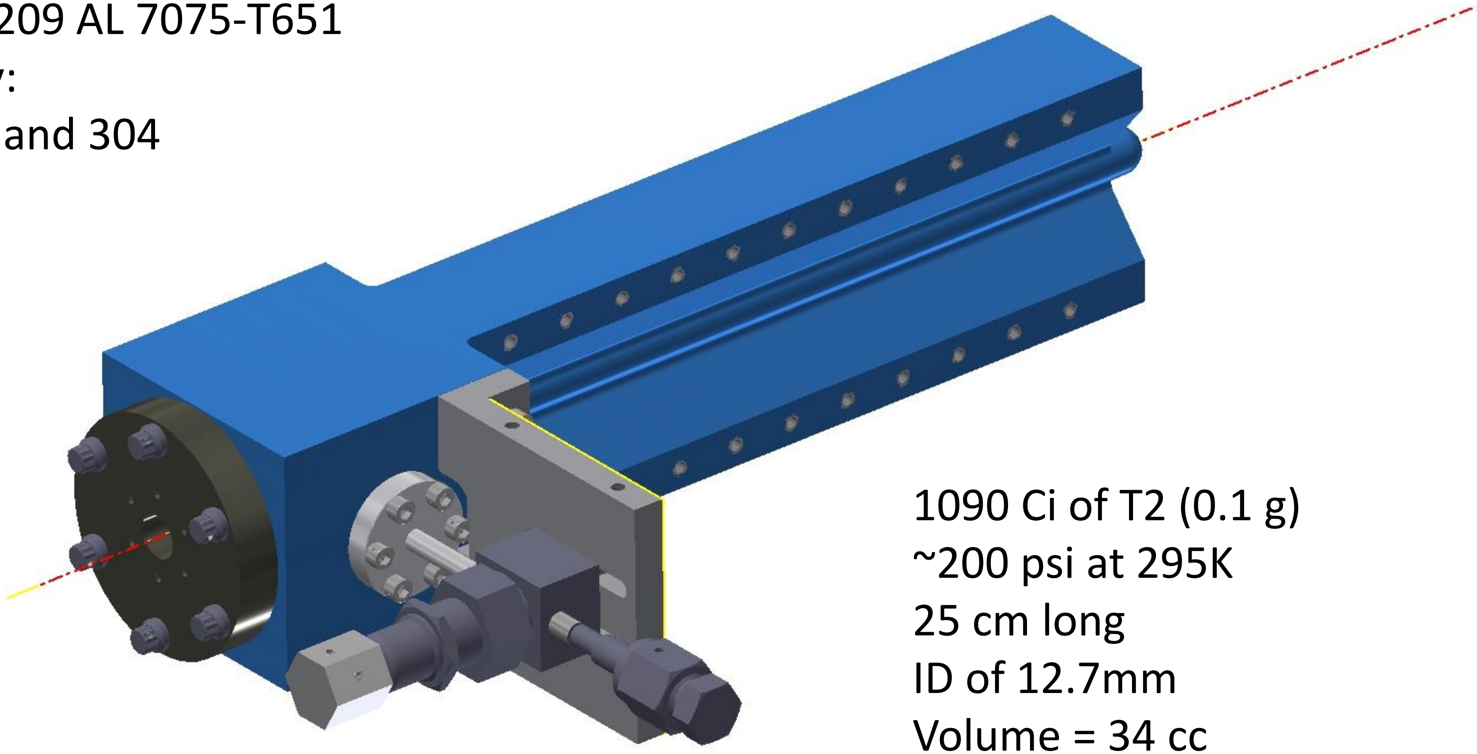
Target Cell

Main Body and Entrance Window

ASTM B209 AL 7075-T651

Valve assy:

SST 316 and 304



1090 Ci of T2 (0.1 g)

~200 psi at 295K

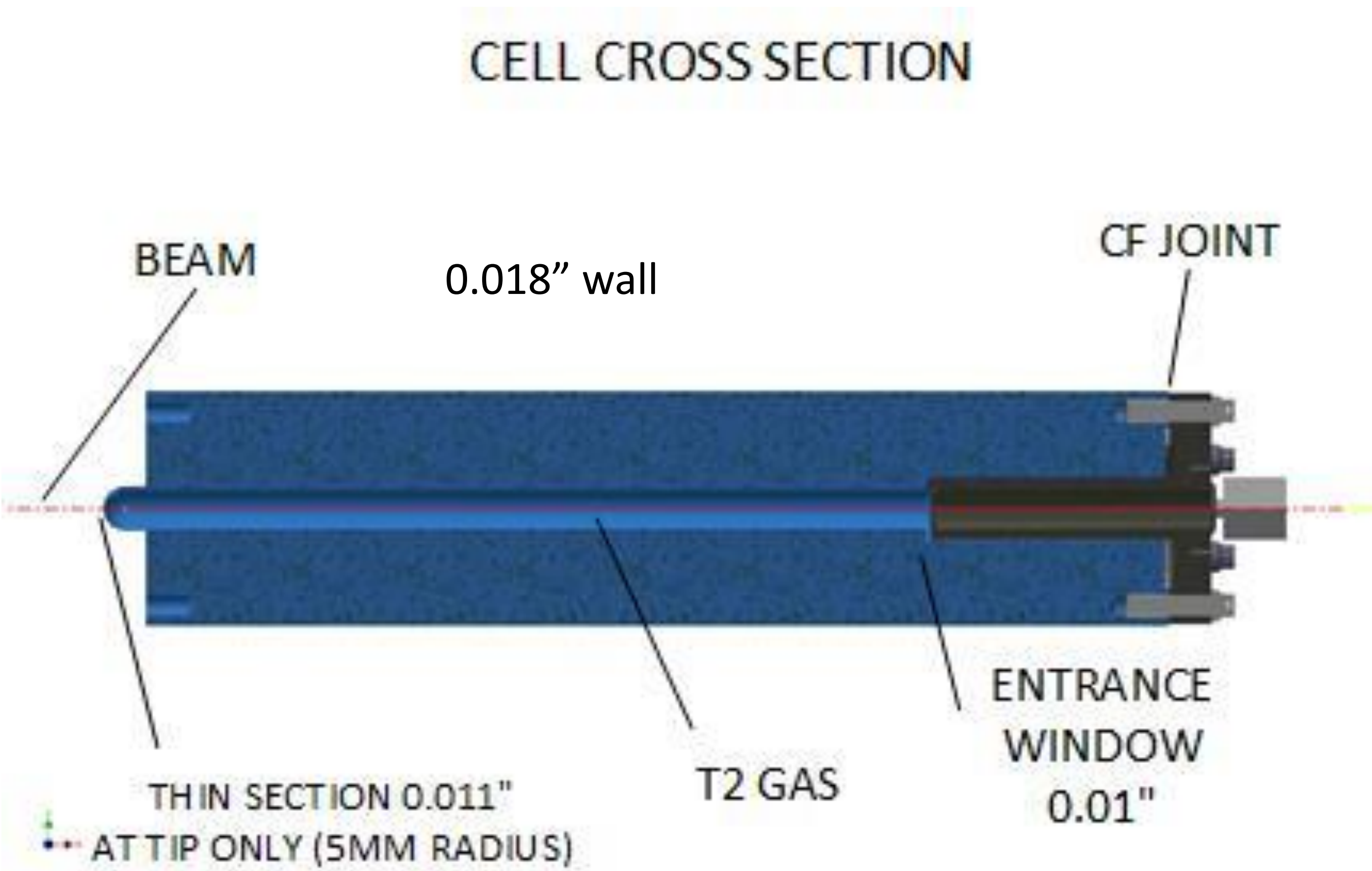
25 cm long

ID of 12.7mm

Volume = 34 cc

Aluminum CF seals

Cell Cross Section



Features

- Cell is “sealed”
  - No recirculation
  - JLAB does not “handle” the T2 gas
- Make Al-SST transition with CF flanges
  - Many years of successful experience at JLAB
  - Work well with H2, He, etc. at low temp < 1K
- Modular design
  - Can be installed as the final component of the system

Materials

- Main Body and Entrance
  - Aluminum 7075-T651 ASTM B209
  - Extensive use of this allow for 15 years
  - Strong, ductile, hard, non weldable
- Seals are Al 1100
- Valve assembly
  - SST 304/304L Fitting
  - Swagelok valve all metal bellows sealed (316L)
  - Butt welded ER316L (100% VT in process and RT)

Materials-2

- Al 7075 is unlisted
  - Design basis
    - $S_{\mathrm{ut}} = 72\ ksi$
    - $S_y = 61\ ksi$
    - $S_a = \min\left(\frac{1}{3}S_{ut}, \frac{2}{3}S_y\right) = 24\ ksi$ for tension
    - = 80% of 24 ksi for shear
    - = 150% OF 24 ksi bending
- Other wetted materials are SST
  - 304/304L
  - 316/316L
  - ER316L Filler for welds

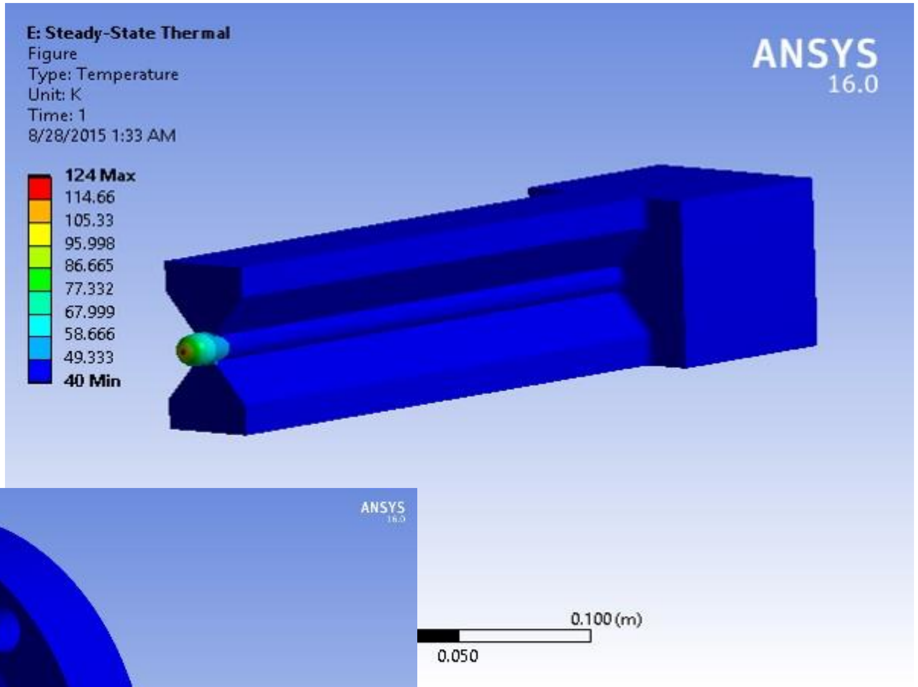
Materials 3

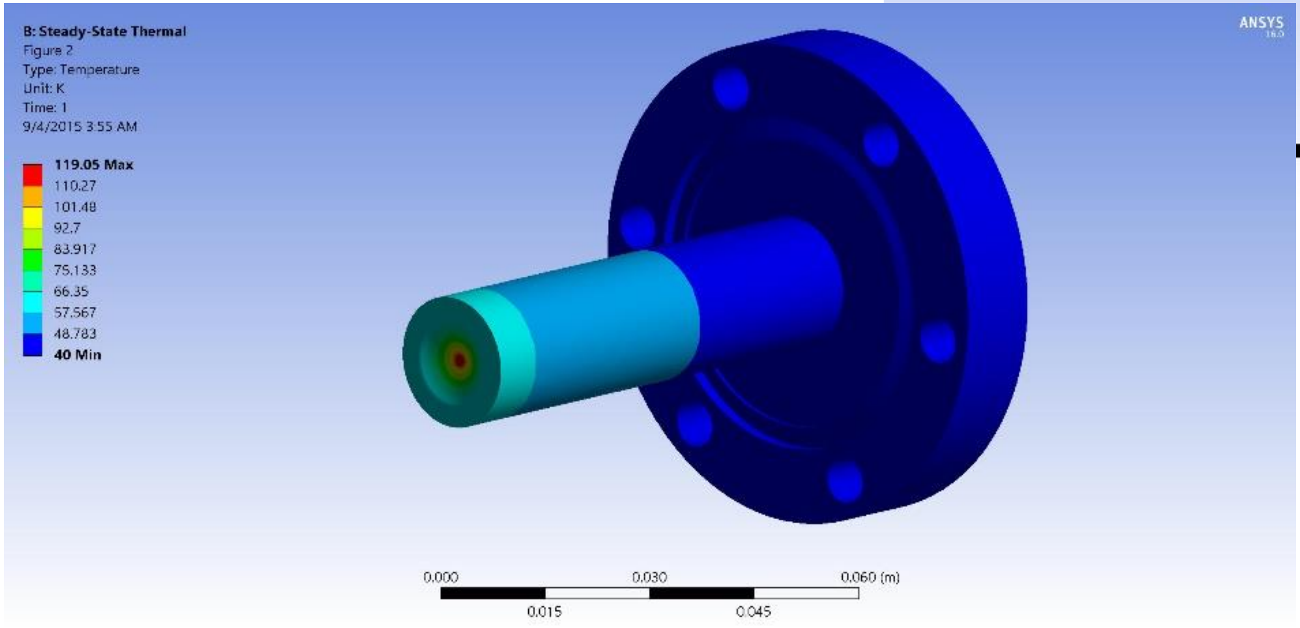
- Tritium and Hydrogen Compatibility
  - Extensive experience with H2
  - Beam induced corrosion not expected below 180K (Flower et. al.)
  - Beam assisted embrittlement
    - $T_2 \rightarrow T + T$ Increases fugacity
      - Atomic tritium recombines rapidly
    - Modeled room fugacity ~3100 psi
    - Below threshold for H2 embrittlement
    - Many orders of magnitude below He-3 swelling threshold (Louthan)
- Test SRNL/SRTE using precracked coupons exposed to 2500 psi T2 underway
  - Test followed ASTM 1820 G168 (Precracked Stress Corrosion Testing)
  - Samples exposed for 4, 8, 12 months
  - M. Morgan, A. Duncan (SRNL)
- Tritium is expected to permeate through the cell and seals
  - ~0.5 Ci /year very conservative
- Calculations given in TGT-CALC-103-010

Beam Heating

$I_{beam} = 20\mu A$ Max beam current
$A_{raster} = 2x2mm^2$ min raster

3W in Entrance
3.3 W in Exit
$T_{max} = 125K$ on exit
$T_{max} = 120K$ on entrance





Load Conditions

- At room temp
  - P = 200 psi
- At 40K Beam Off
  - Pressure = ~30 psi
  - Max Temperature = 40K
- Beam On
  - Pressure = 36 psi (avg temp of T2 = 53K)
  - Max Temperature = ~125K
- Cyclic loads
  - Cool down/warm up operating cycles = 20
  - 17800 beam trips (cycles between Beam On and Off)
    - 150 days, 33% duty factor, 15 trips/hr

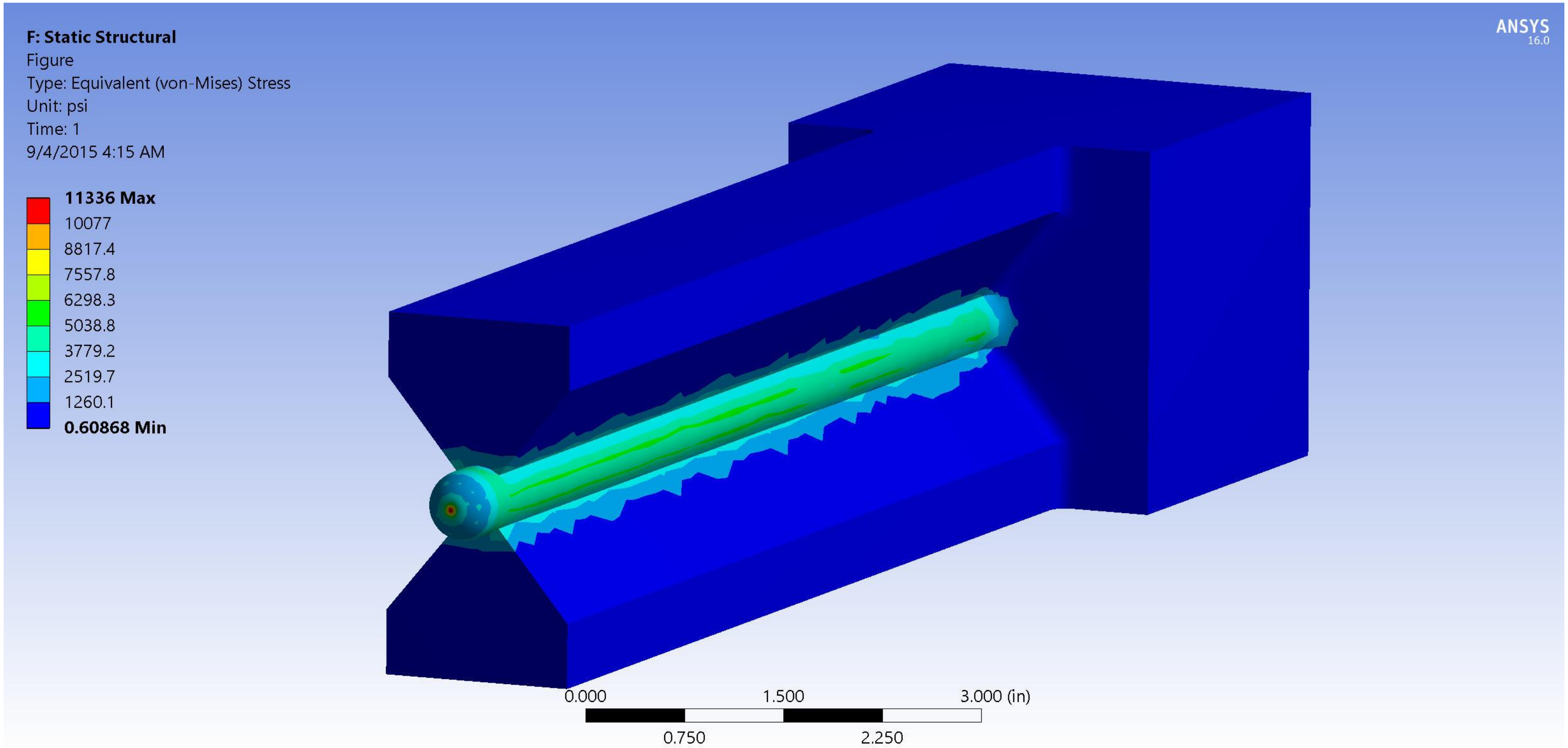
Analysis

- Applicable Code ASME B31.3 (2014)
  - Section 304.7.2 because of odd geometry
  - Used both Hand Calculations and FEA
  - Analysis conforming to ASME BPVC VIII D2 with load factors from B31.3 (i.e. 3 instead of 2.4 on P)
- Used cyclic screening analysis from D2
  - Depth of loads do not require a fatigue analysis
    - 175 psi pressure cycle (it is closer to 10 psi)
    - Considers temperature cycle from 40K to 125K
- Design pressure 675 psi
- No source of overpressure
- Calculations: TGT-CALC-103-002, 7, 8, 12, 13, 14, 15, 17.

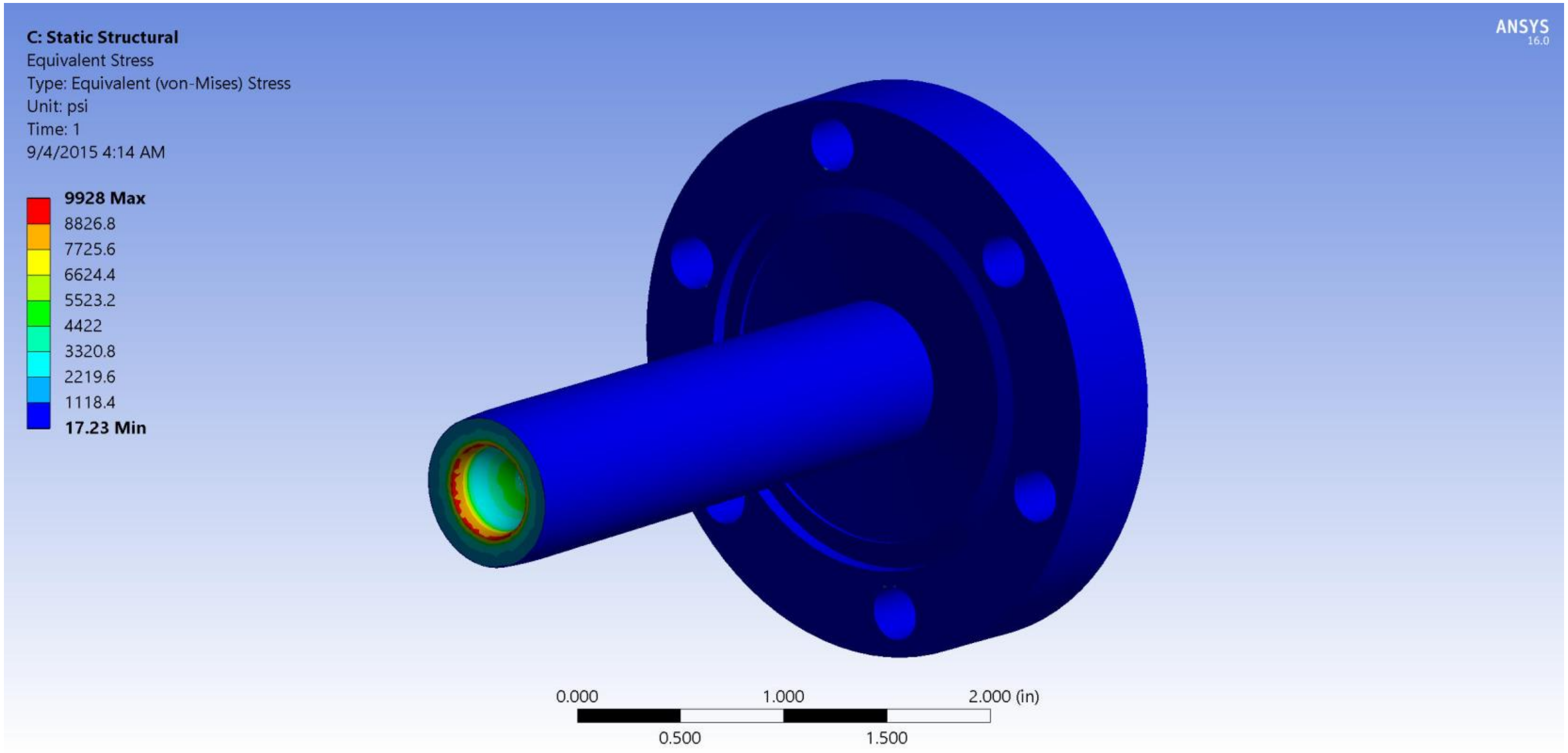
Thermo-Mechanical Model-1

- Full temperature load
  - Beam on at 20 µA 2x2 mm raster
  - Pressure load 400 psi internal (more than 10x)
  - Cooling using 40K heat sink
- Using an elastic-plastic model
  - Model solves and stresses are still below allowable even for over conservative case
  - Local plastic failure requirements met
  - Analysis not required because of screening analysis

Thermo-Mechanical Model-2

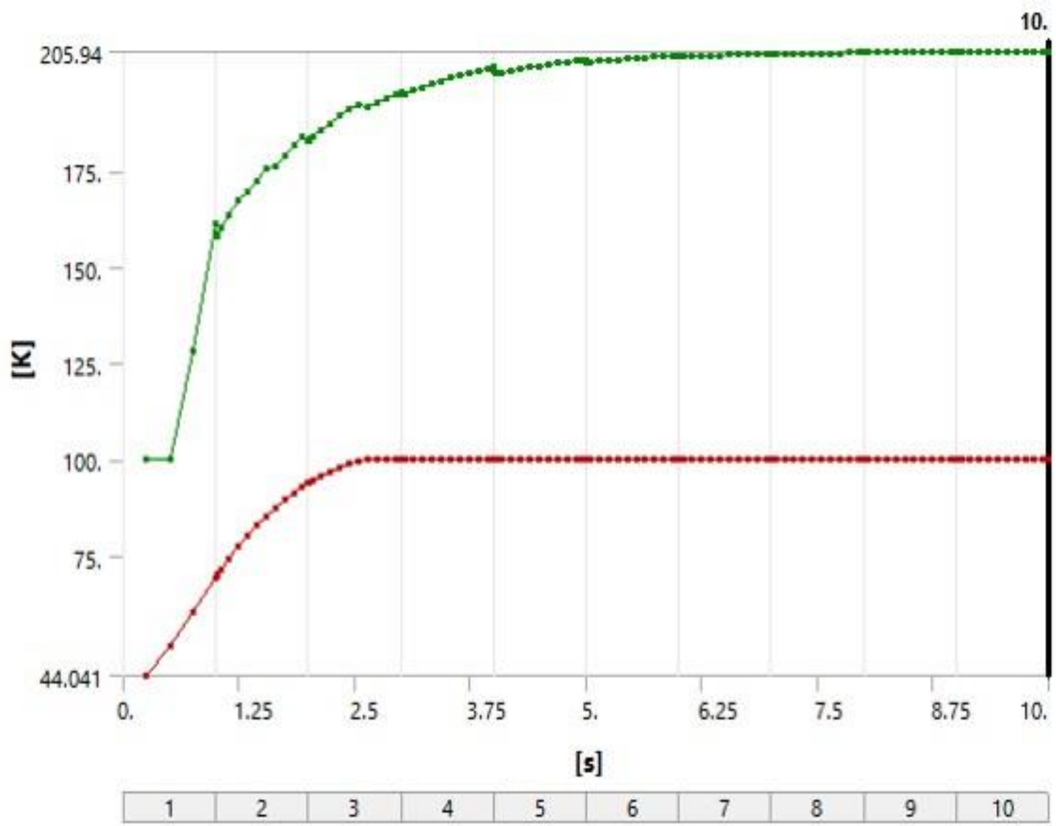


Thermo-Mechanical Model-3

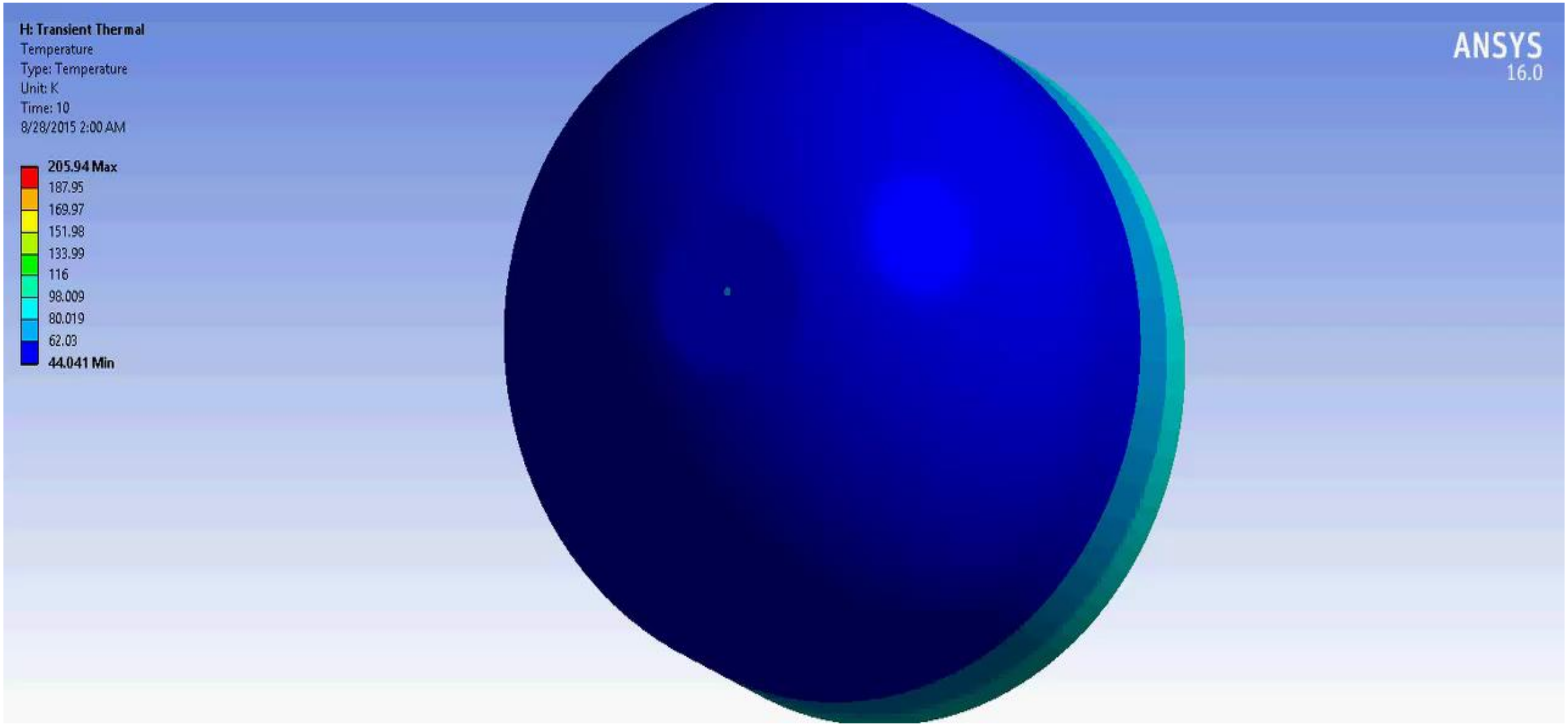


Raster Off

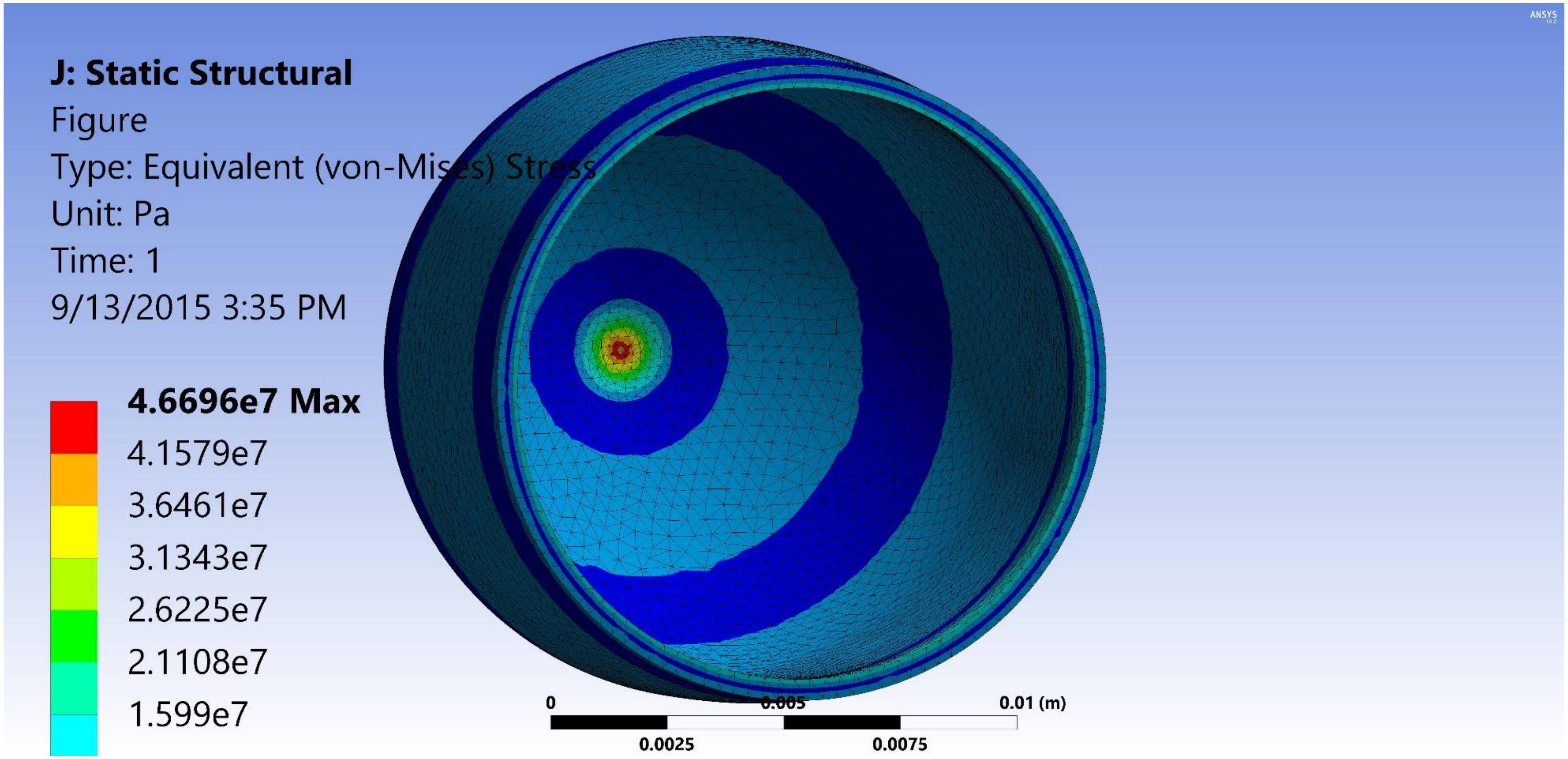
- Initial conditions:
  - Beam on full raster
  - 20 microA
- Exit window is worst case
- Beam spot no raster
  - 0.150 mm diameter
  - Square profile
- For high energy beam this spot size is very conservative
- Tune shall be checked at each energy
- Long term operations at these conditions are forbidden
- Typical FSD for raster failure
  - < 10 ms
- Red curve is upstream section temperature



Raster Off Time Dependence



Mech Therm Model of Raster Off



Commissioning Plan For Target Thickness

- Ensure beam profile is correct and BCM/Optics calibrated
- Step current 0-20 μA
- Collect data T2, H2, D2, He-3
- Collect data on Carbon
- Develop function for $L_{target} = L_{target}(I)$

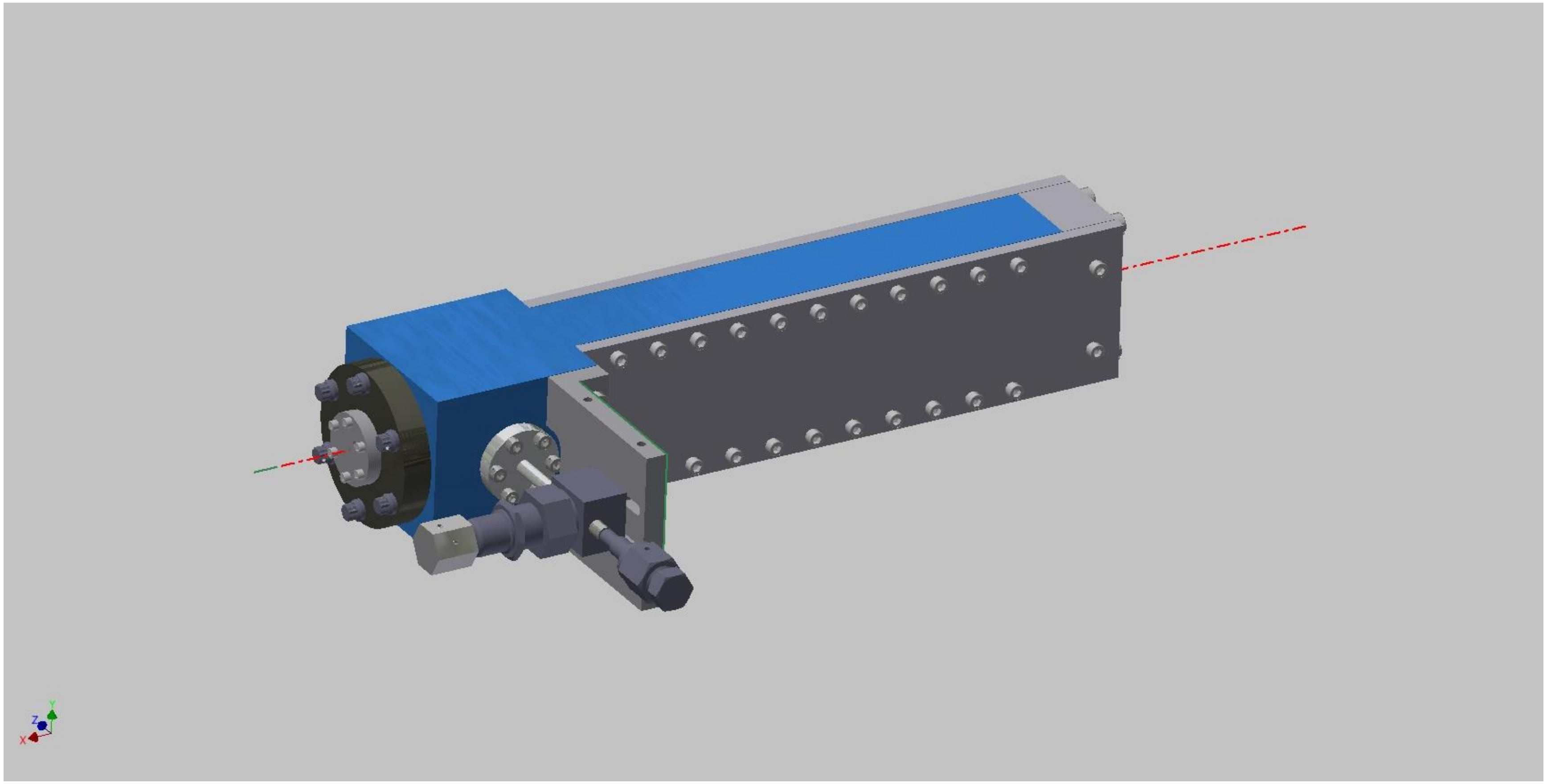
Filling/Shipping

- Fill at Savannah River Tritium Enterprises SRTE
- Different load conditions
  - Design pressure of 1000 psi required
  - Changing this (e.g. new relief device) not realistic
- Thin sections need to be protected during shipping

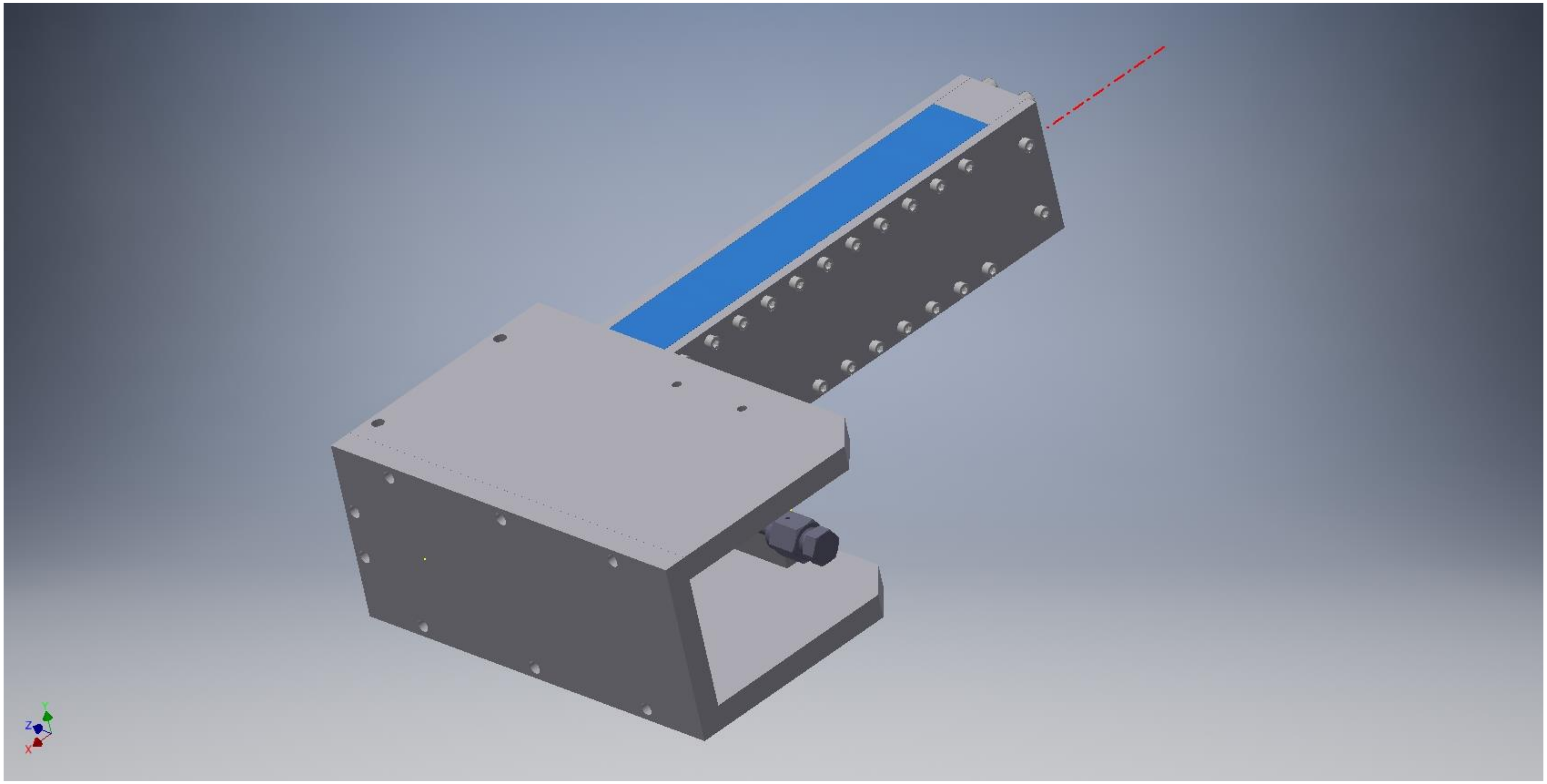
Solution:

- Shipping covers that act as stays

Filling Covers

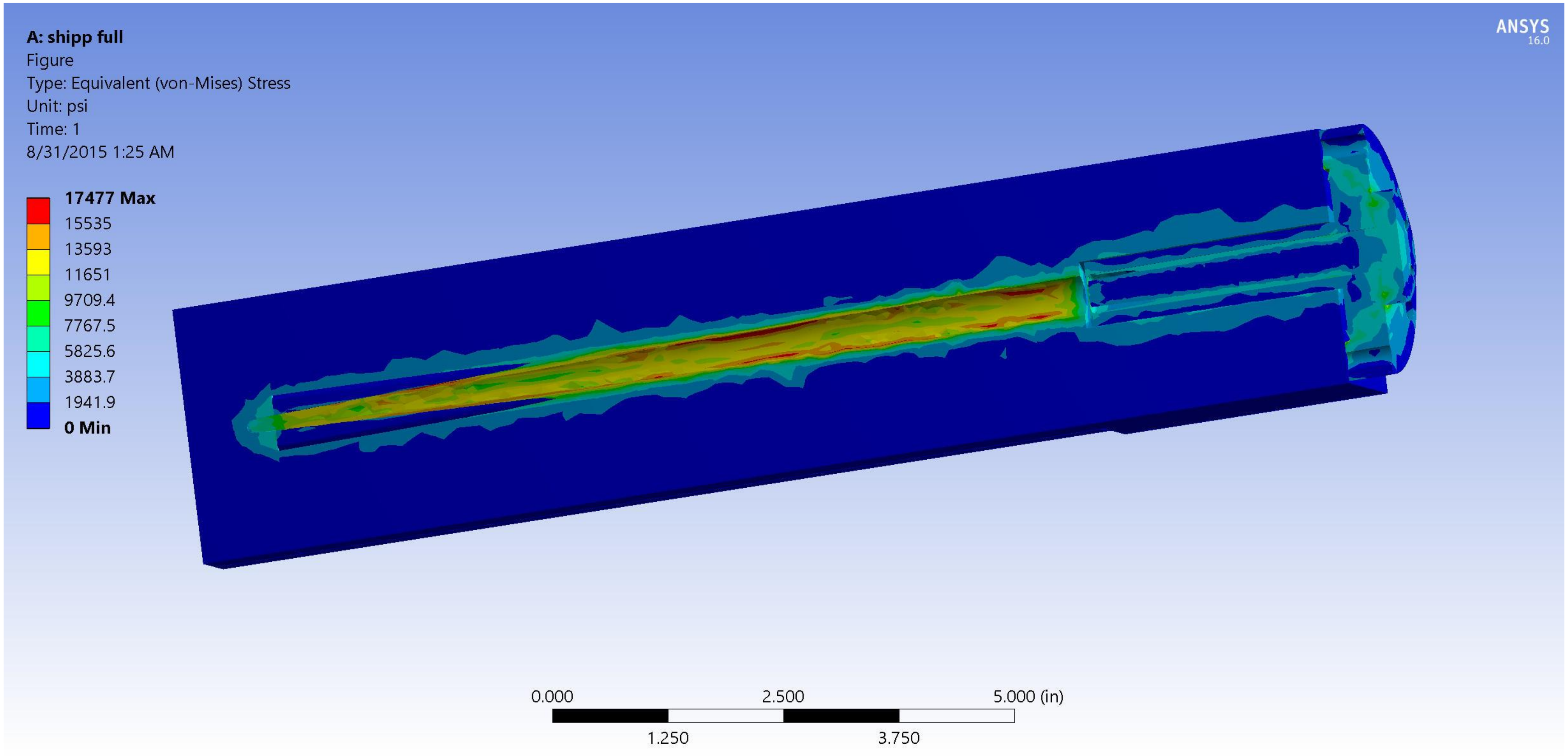


Valve Covers



Covers on Test Cell

FEA Covers On



Filling Cover Analysis

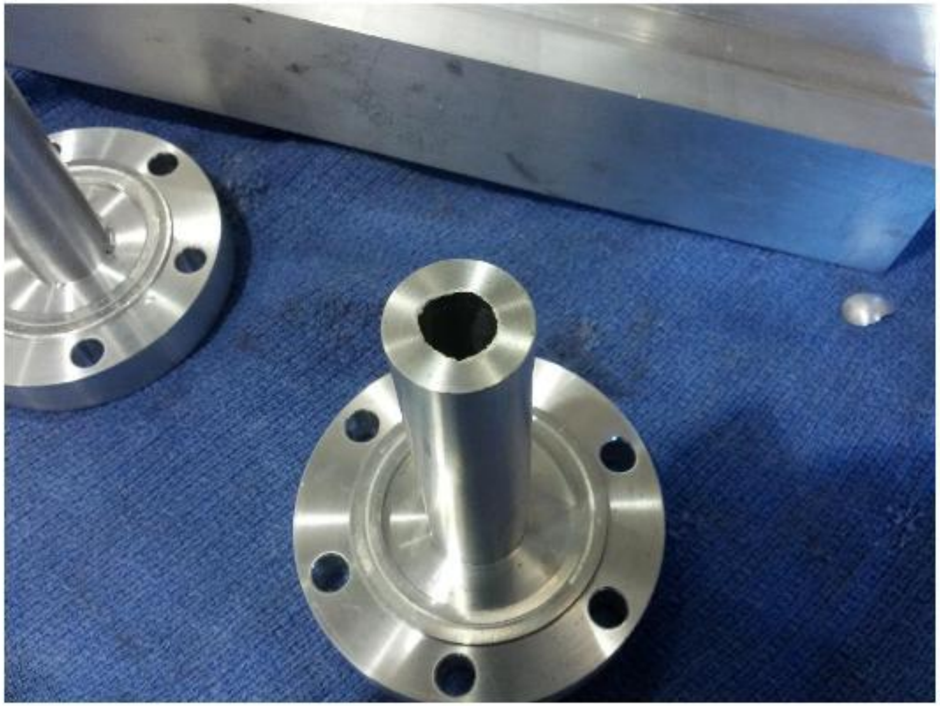
- Stayed sections
  - D2 Part 5 Elastic-Plastic
  - Pressure load = 3000 psi
  - Covers bonded on bolted surfaces
  - Reaction loads Used to determine bolt loads.
- Model solved (local failure checked)
- A design pressure of 1000 psi may be assigned in compliance with B31.3

Summary of Test Results

- Multiple hydrotests on components and assemblies
- Entrance: Minimum burst above 2900 psi
- Main body: Minimum burst above 3400 psi (0.014” section)
- Assembly with covers
  - Leaked above 4000 psi (seal was damaged)
  - Failed above 5500 psi

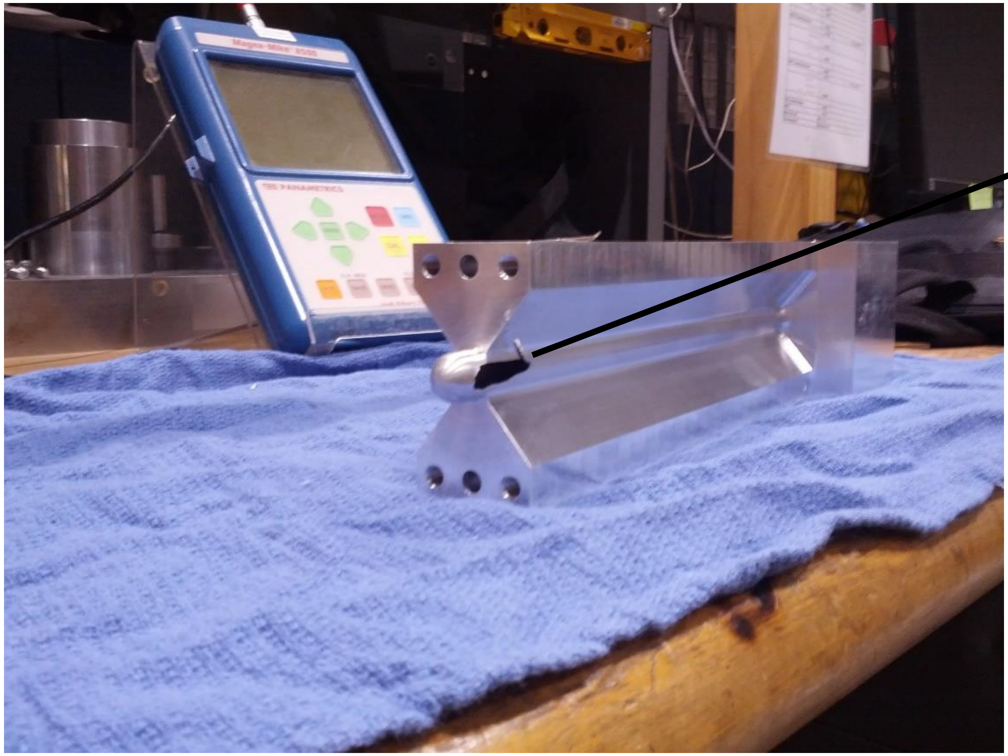
Entrance window hydro

Cell Entrance Window



Cell Entrance Window
Burst ~2900 psi

Exit window hydro

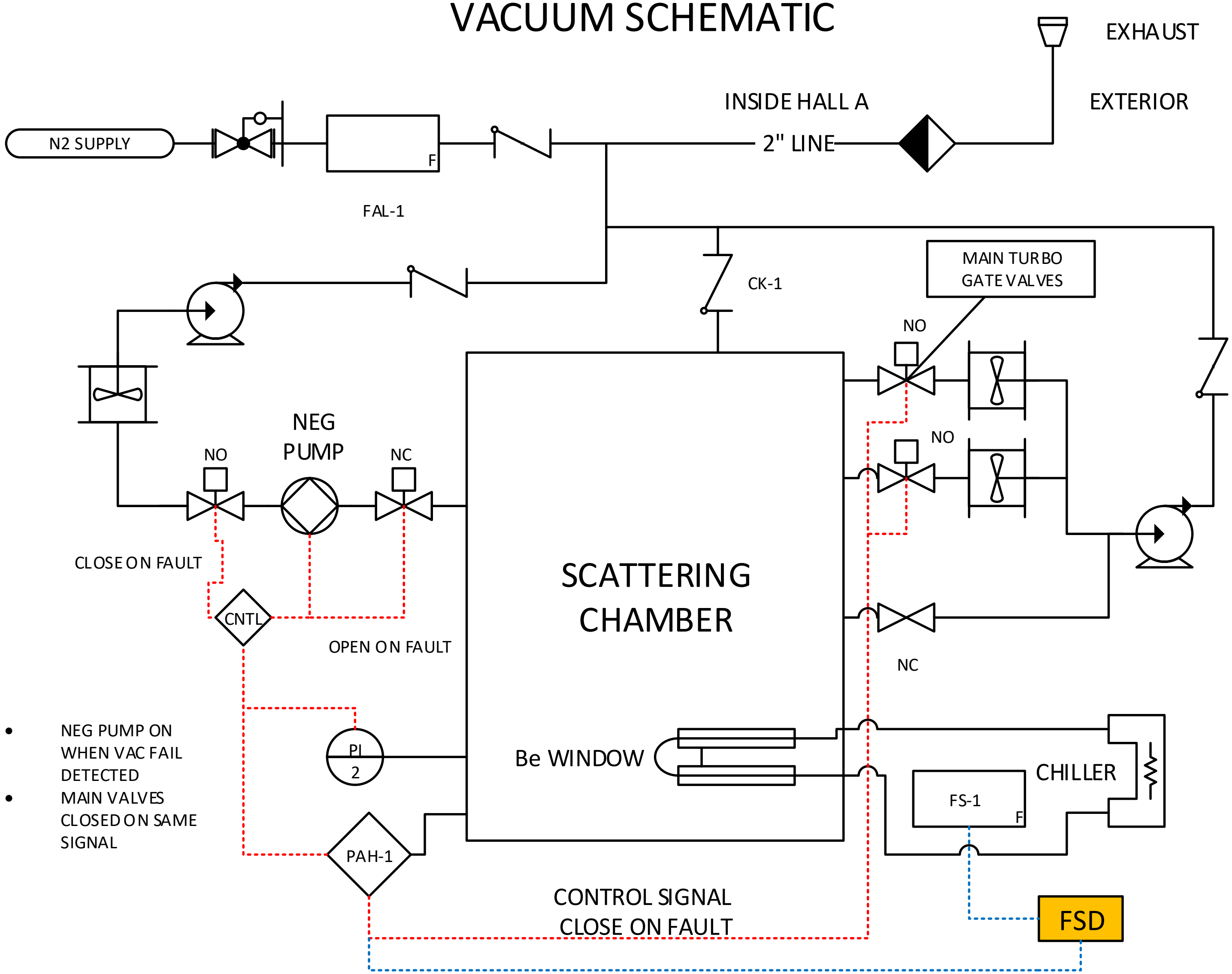


0.014” section
Failed above
3400 psi

Vacuum System

- Scattering chamber (standard Hall A)
  - 1900 liters
  - Thin sections for recoil particles (0.014” aluminum)
- Two 800 l/s turbos backed by Leybold D60 Mech pump
- NEG Pump with backing turbo and mech pumps
- Vacuum exhaust part of Tritium Exhaust System and is continuously purged with N2 (1 cfm)
- Isolated from upstream beamline vacuum (Be window)
- Remote RGA may help diagnose leaks. Serve as leak detector.

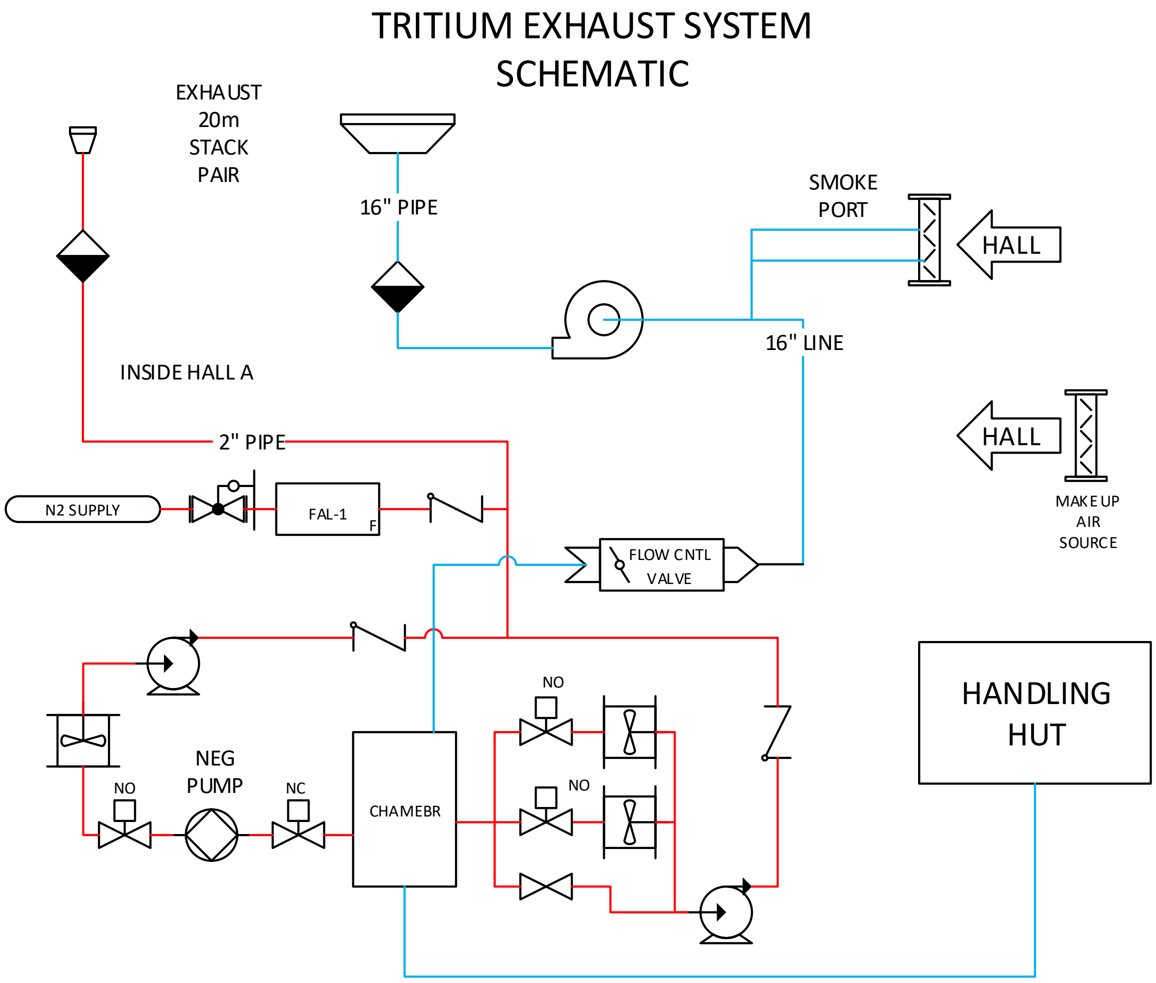
VACUUM SCHEMATIC



- NEG PUMP ON WHEN VAC FAIL DETECTED
- MAIN VALVES CLOSED ON SAME SIGNAL

Exhaust System

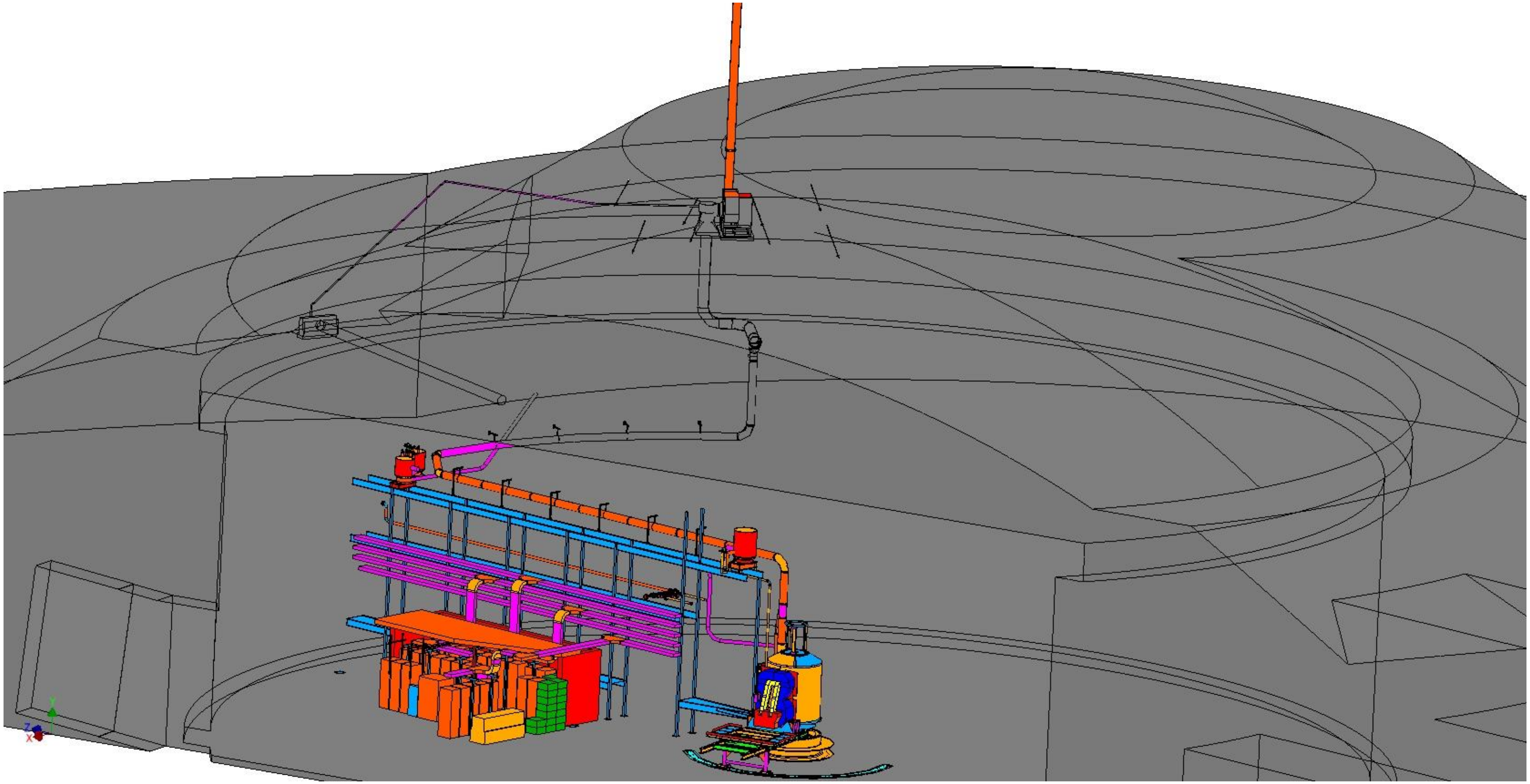
- 24” OD 20m tall Stack
- 12000 cfm blower multispeed
- 2” pump exhaust
  - Run parallel to stack
- Stack must also serve as smoke removal
- Provides controlled release of secondary and tertiary containment
- Pump exhaust is continuous
- Blower activated:
  - Manual
  - Interlocks



Stack

STACK
LOCATION

Exhaust Routing



Exhaust Routing in Hall A

General Requirements

- Collect T2 from any release inside Hall A and exhaust in a controlled fashion
- Exhaust point shall be 20 m above grade at site boundary
- Must serve as part of the smoke removal system (at least 1/3 of the 36000 cfm required)
- Must have at least two modes to service hut and to exhaust from Hall A. (500 and 12000 cfm)
- Must stack vacuum pump exhaust
  - Scattering chamber, dump line, getter system
- Makeup air comes from new louvered door at bottom of ramp.
  - Prevents overpressure no ramp door.
  - Test required for louver system
  - Air from outside from smoke removal system on ramp with damper removed

Transfer Hut

- Installed on purpose built platform
  - Only in place for installation/removal
  - Clear plastic hung from frame
  - “Standard” design
- Directly attached to chamber adapter
- Air is drawn from Hall into hut then chamber and out exhaust system
- Air flow across opening 150 fpm ensure T2 containment
- Design and fabrication is underway at SRTE
- Test installation and air flow in June 2016
- Makeup air 500 cfm supplied existing penetrations

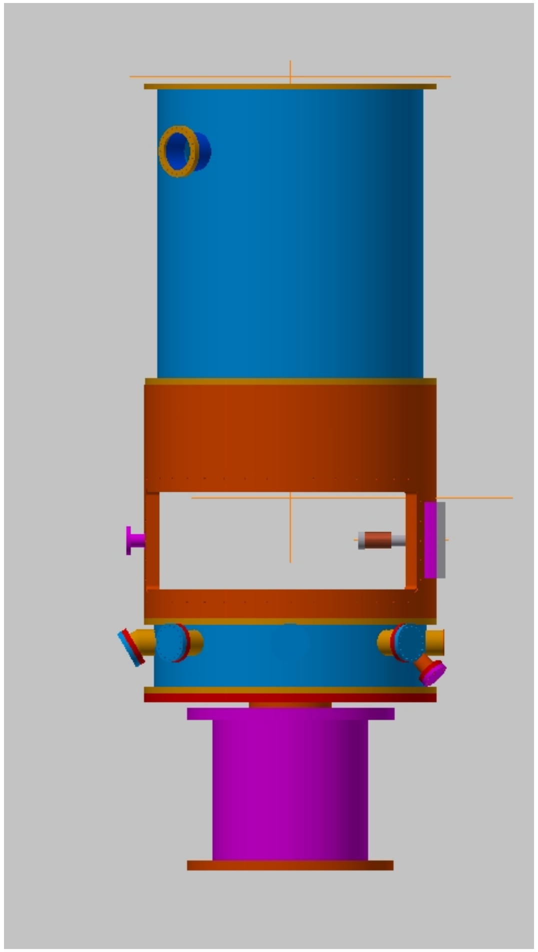
Exhaust Summary

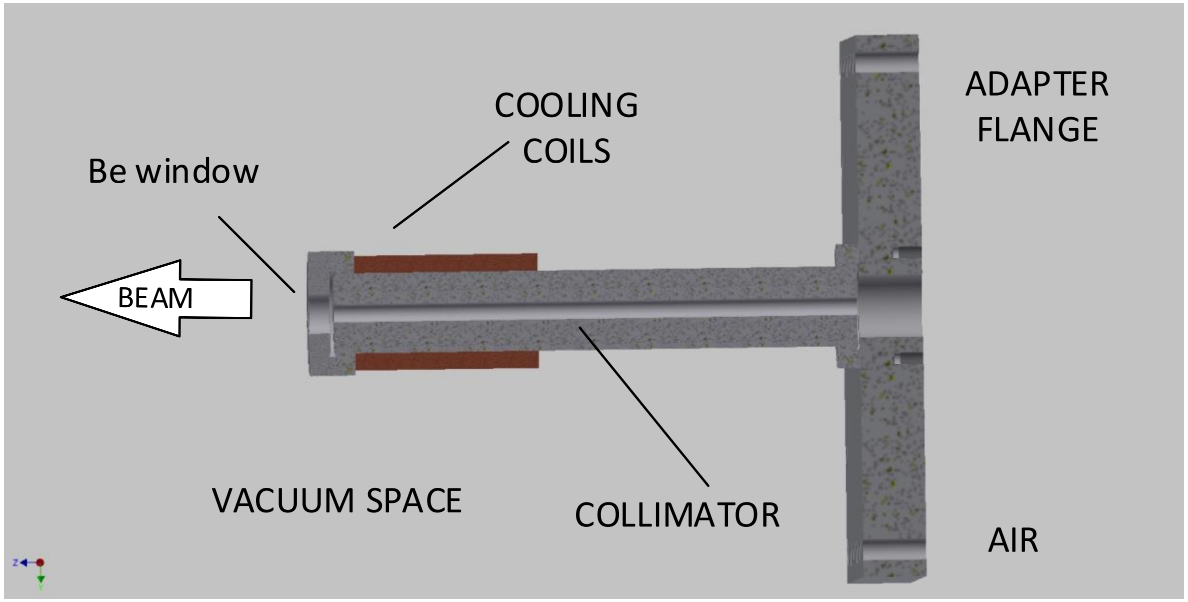
- Exhausts secondary (vacuum chamber) and tertiary (Hall A) containment to 20 m stack
- Two speed
  - ~500 cfm
  - 12000 cfm
- Exhaust system activated
  - Vacuum switch failure (interlock)
  - Truck ramp lower door (interlock)
  - Manual activation (Hall and Counting House) (manual)
  - Low speed activated manually for hut (manual)
  - T2 monitor (interlock)

Beamline Alterations

- No plans to substantially alter beamline
- Upstream beamline shall be isolated by a Be window
  - 0.008” thick 1” ID.
  - Water cooled (3W beam power 25 µA)
  - Reentrant (Resides in chamber)
- Window is 15 cm from entrance to cell
- Densimet collimator 10 cm long installed in tube upstream of window. (W 90% , Cu 8%, Ni 2%)
- Maintenance is possible if required.
- 12 mm thick collimator attached to cells
- Collimators should prevent steering error from affecting cell
  - Last steering element is 8 m upstream and 2” radius beam pipe.

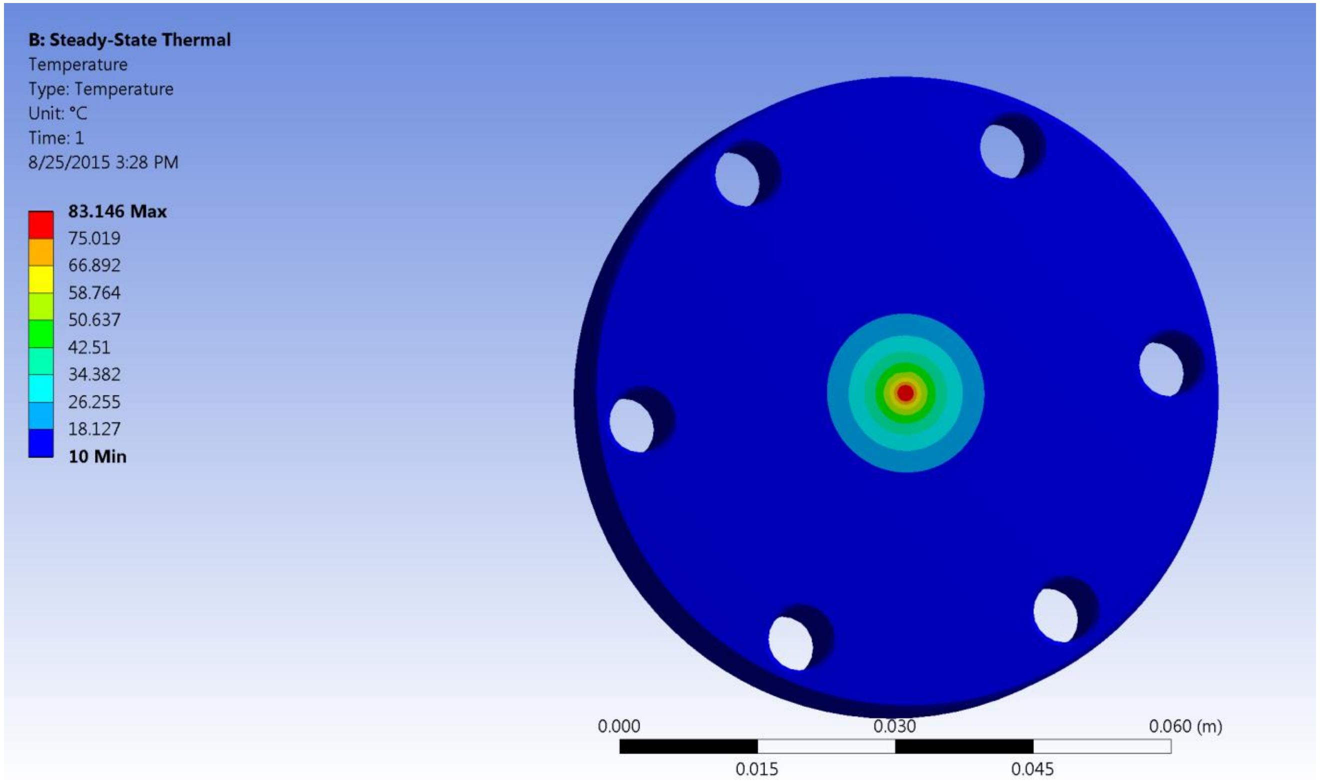
Be Isolation Window





- 0.008” Be window
- Cooled by self contained water chiller to 10C
- Integrated collimator Densimet

Be Window Heating



- 30 μA
- 2x2 mm raster
- Steady state
- Chiller set to 10C

Control System

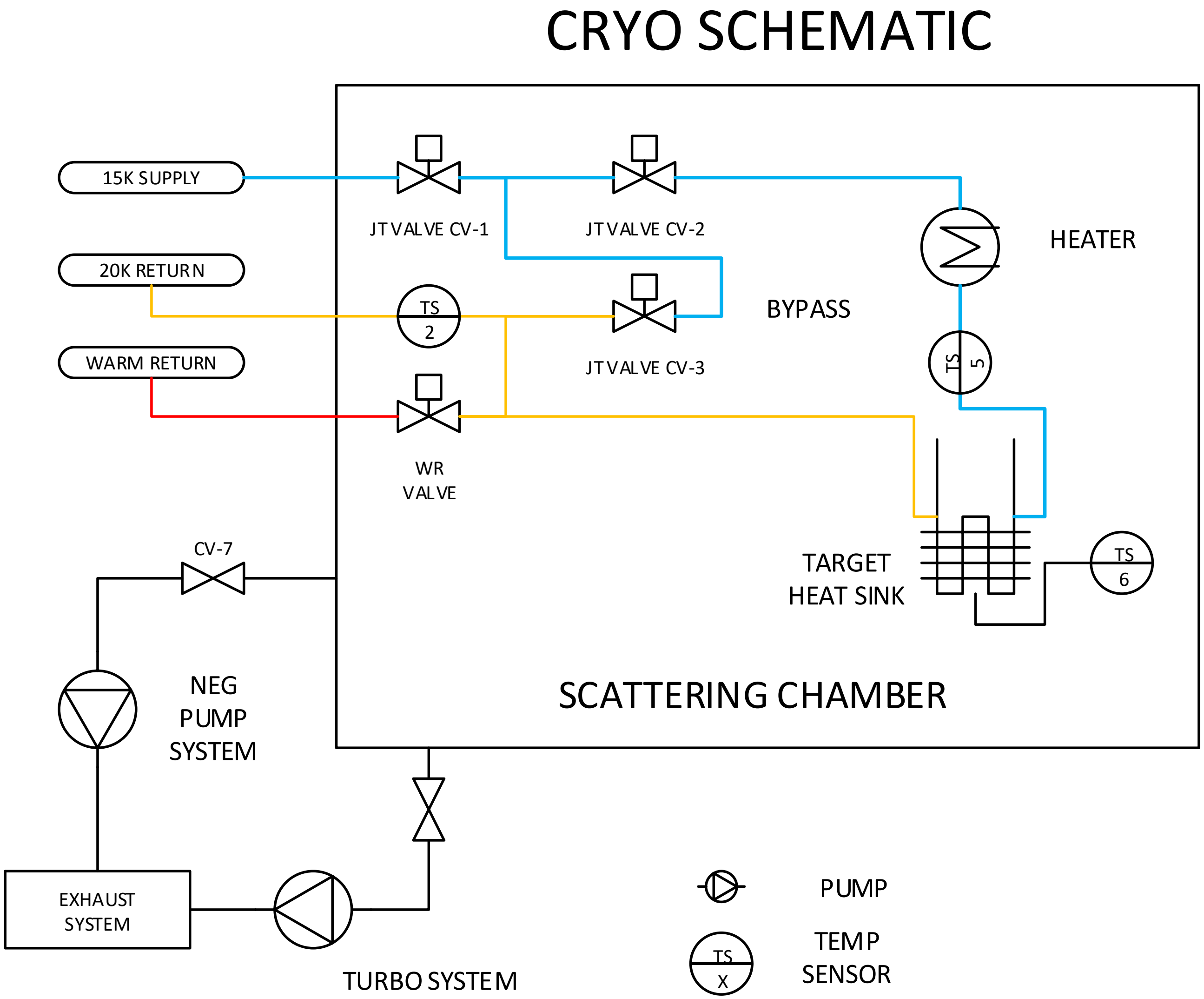
- Use EPICS (distributed I/O)
  - Temperature/motion/valve control
  - User Interface (UI) through EDM
- FSD on high temperature
  - Uses interlocks from redundant 718s
- UI has integrated alarm handler
- EPICS data logger runs continuously
- Communications failures Alarm as well

EPICS Controls

- Monitor various temperature and vacuum levels associated with the target system;
- Maintain a constant target temperature using an automatic, feedback-driven heater;
- Monitor and control the flow of cryogenic helium coolant to the target;
- Control both the vertical and horizontal motion of the target cells;
- Provide a set of alarms to alert users to off-normal target conditions;
- Provide a set of strip charts to track the target performance;
- Archive target performance data;
- EPICS is not used for safety or integrity

Cryo-System

- ESR 15K He for cooling
- Must return ~25K
- PID Control heater
  - 40K
- Return mixed with bypass.
- Bypass valve on PID
- Alarms/interlocks on TS-5 (a/b) and TS-6 (a/b)



Operations

- Dedicated target operator while target is cold
  - 100% Shift coverage
- Target to be moved to “home” position during any access
- Operator responds to alarms
  - Calls experts if needed
- Emergencies are handled by MCC or guards when machine is down.

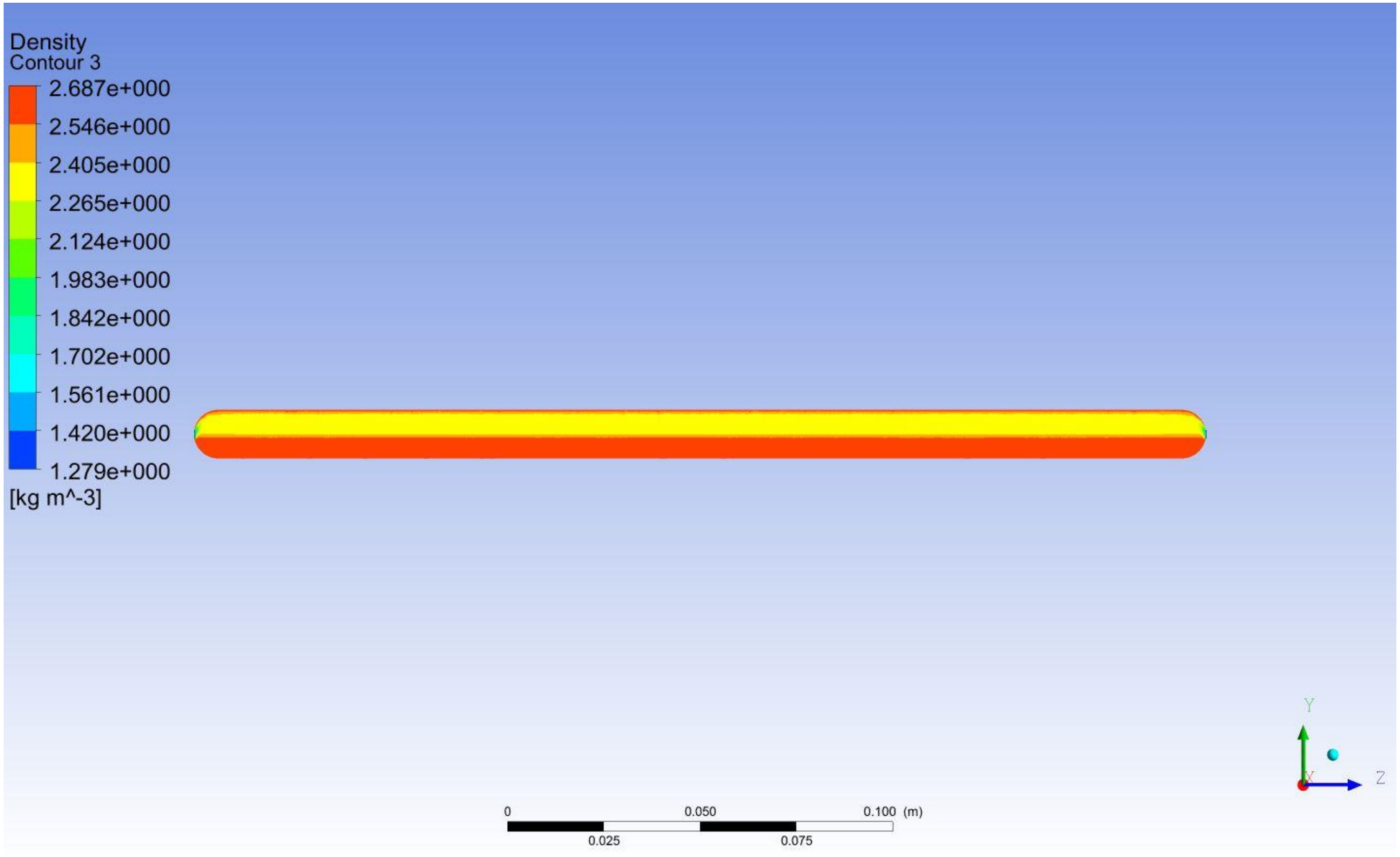
Performance Characteristics

- ½ life for tritium is ~12 .5 years
  - 5% conversion to He-3 over 1 year run
  - Conversion starts immediately
  - Fill as close to run date as possible
- Fill purity 99.8% T2 +/- 0.02%
- Quantity of T2 from $PV = nRTZ$
- Where $Z = 1.01$ is the compressibility of tritium at the fill pressure of 200 psia.
- The uncertainties on the quantities above are:

$$\delta P = 0.2\, psia$$
$$\delta V = \ 0.5\, cm^3$$
$$\delta T = 0.025K$$

- This gives an uncertainty of
- $\delta n = 1.5\%$

Density Change in Beam



Density Model

- T2 properties derived from H2
  - Viscosity, Thermal Conductivity, Heat Capacity, etc.
  - Assumed a Real Gas model
  - Buoyancy, convection on wall included
- Assumed fixed 2.8W from 20 µA and 2x2 mm raster (11 mW/mm linear power density)
  - Did not correct heat load for density
- Averaged 20% reduction in density along beam path