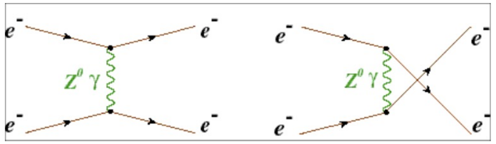
MOLLER Status Report

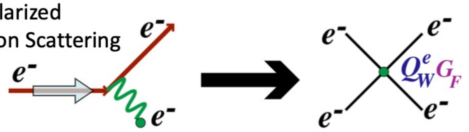
Hall A Collaboration Meeting

June 2022

MOLLER – a precision measurement of A_{PV} in e^-e^- scattering

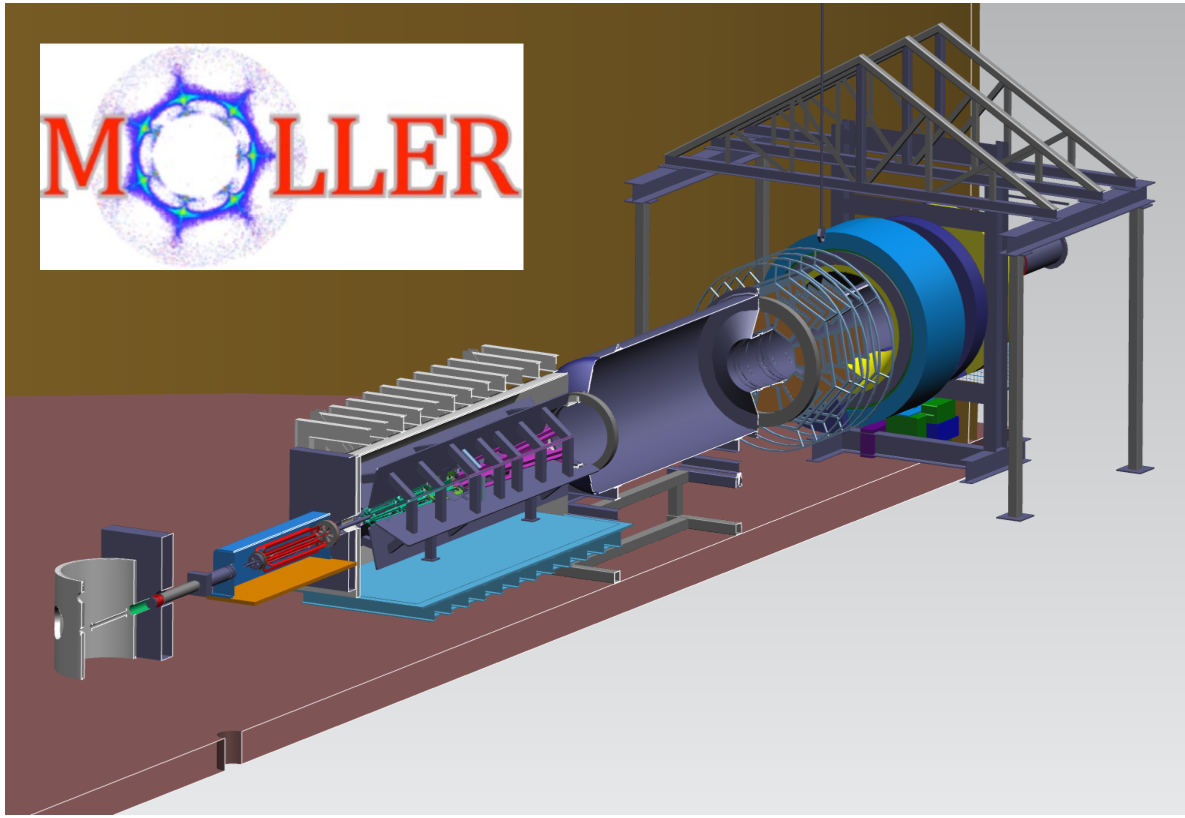


Fixed Target Polarized Electron-Electron Scattering



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{16\sin^2\Theta}{(3+\cos^2\Theta)^2} Q^e_W$$

$$Q^e_W = 1 - 4\sin^2\theta_W \sim 0.075$$



Jim Fast – MOLLER Project Manager

MOLLER – World leading measurement of A_{PV}

See presentation "MOLLER Physics" by Zuhal Demiroglu tomorrow at 15:30

- MOLLER aims to measure the parity violation asymmetry in $\vec{e}$-e or MØller scattering at 11 GeV

$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \rightarrow A_{exp} = \frac{Y_+ - Y_-}{Y_+ + Y_-}$$

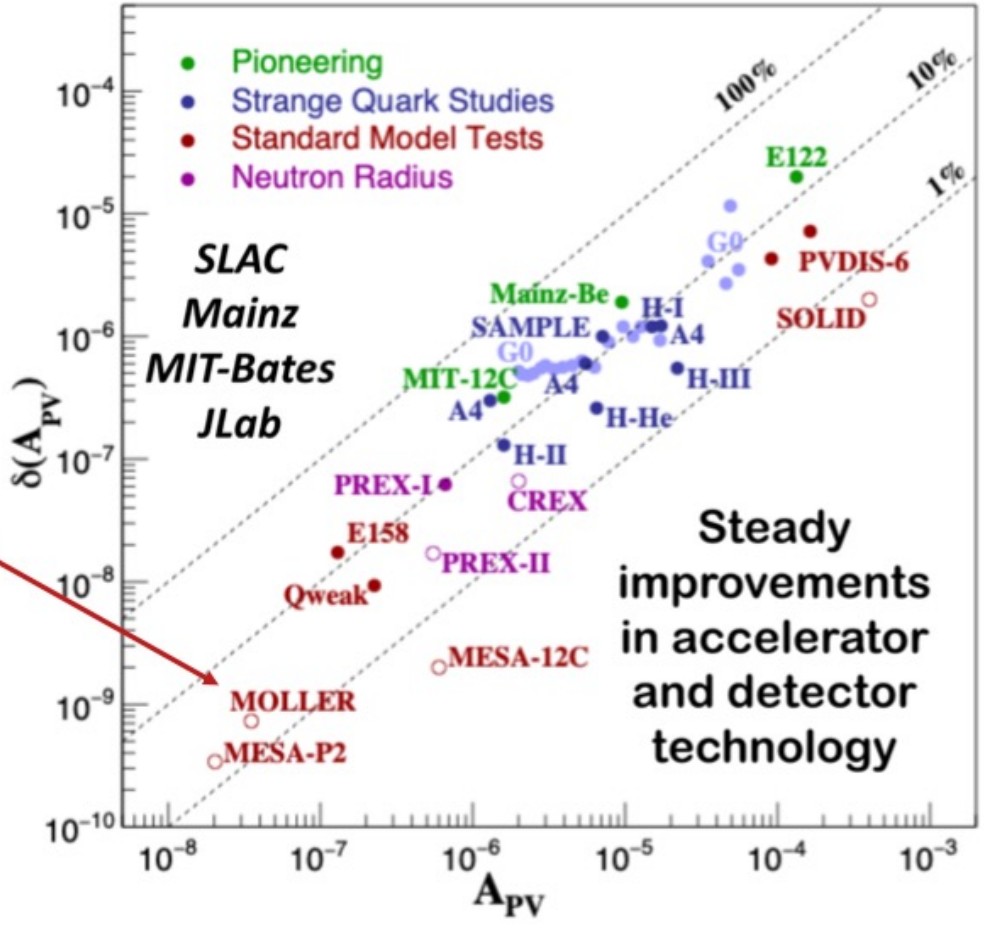
- $A_{PV} = A_{exp} \sim 32\ ppb, \quad \Delta A_{exp} \sim 0.8\ ppb$
- $A_{exp}(Qweak) \sim 226\ ppb, \ \Delta A_{exp} \sim 9.3\ ppb$

- The MOLLER experiment aims to achieve an order of magnitude better absolute precision than the Qweak completed measurement

11 GeV, 65 μA 90% beam polarization

$A_{PV} \sim 32$ ppb $\quad \delta(A_{PV}) \sim 0.8$ ppb

$\delta(Q^e_W) = \pm 2.1\ \%\ (stat.) \pm 1.1\ \%\ (syst.)$

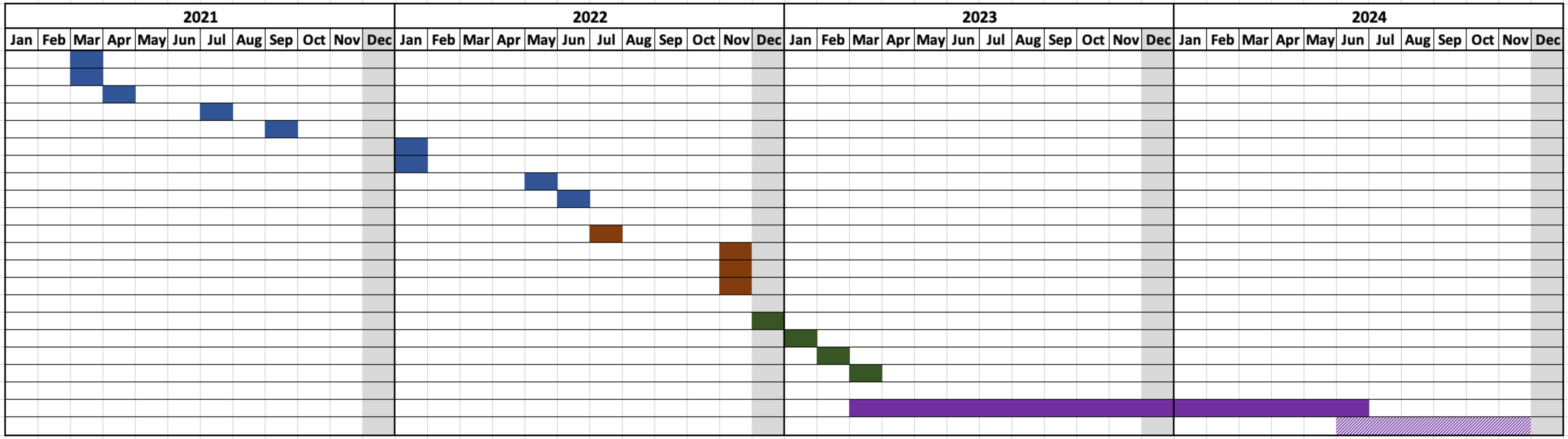


Jefferson Lab

MOLLER schedule from 10,000 meters

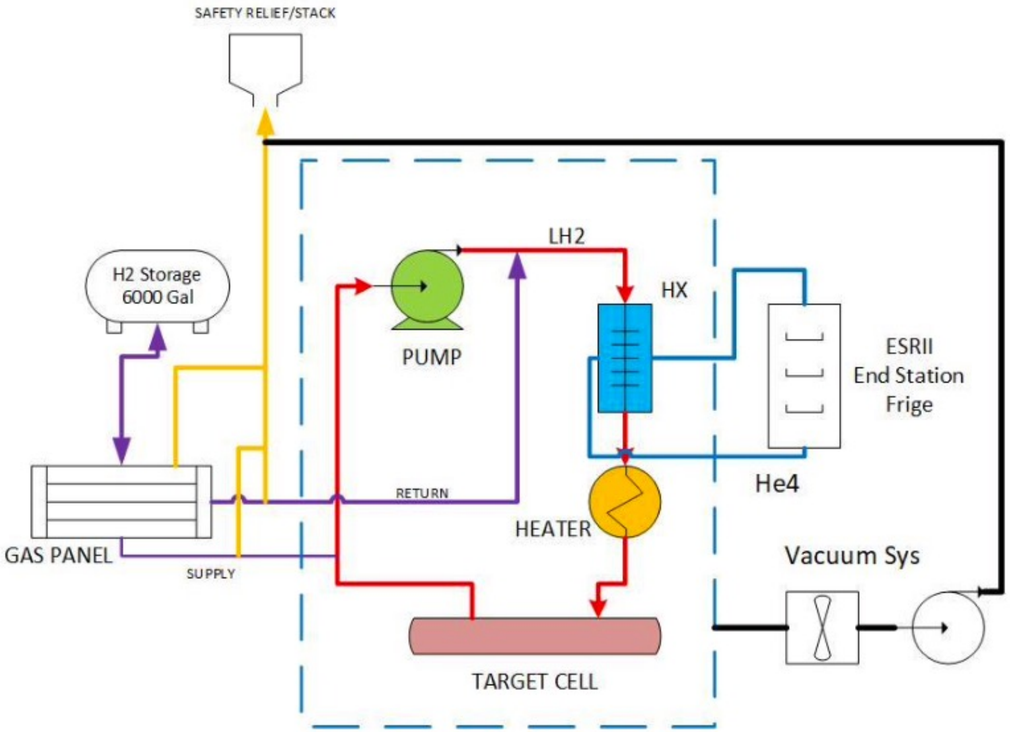
- Wrapped up all Preliminary Design Reviews last week
  - PDRs generally went well
  - Detectors and Upstream Toroid fell a little short of “60% design complete”
  - However, designs mature enough to continue to Final Design without further review
- Working on completing final designs
  - Need to complete Technical Design Report over this summer
- Targeting Final Design Review(s) in late CY2022 to support spring 2023 CD-2/3 approval
  - This is the DOE authorization to start construction; should be ready for installation about 18 months later

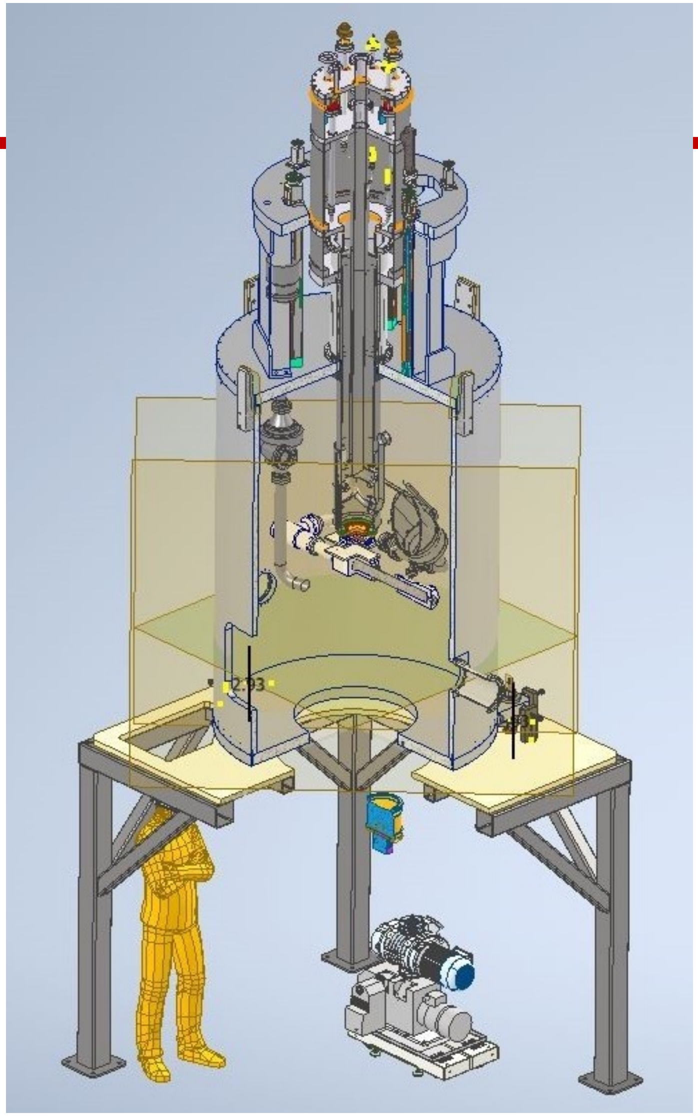
MOLLER Schedule		
Review	Start	End
PDR - Downstream Toroid	3/29/21	3/29/21
PDR - Trigger and DAQ	3/18/21	3/18/21
PDR - Magnet Power Supplies, Leads, Jumpers	4/30/21	4/30/21
PDR - Beam Pipes, Bellows and Windows	7/12/21	7/12/21
PDR - GEM Modules	9/14/21	9/14/21
PDR - Detector Systems (except GEMs)	1/12/22	1/14/22
PDR - Hydrogen Target	1/20/22	1/20/22
PDR - Spectrometers	5/23/22	5/24/22
PDR - Shielding and Utilties	6/1/22	6/1/22
FDR - Trigger and DAQ; Cables, LV, HV Supplies	7/11/22	7/15/22
FDR - Hydrogen Target and Shielding	11/17/22	11/21/22
FDR - Spectrometers and Infrastructure	11/17/22	11/21/22
FDR - Detectors and Beam Pipes	11/17/22	11/21/22
Independent Final Design Review	12/12/22	12/16/22
CD-2/3 Directors Review	1/16/23	1/20/23
CD-2/3 Independent Project Review	2/13/23	2/17/23
CD-2/3 ESAAB	3/16/23	3/16/23
Construction	3/17/23	6/17/24
Installation	6/18/24	12/15/25

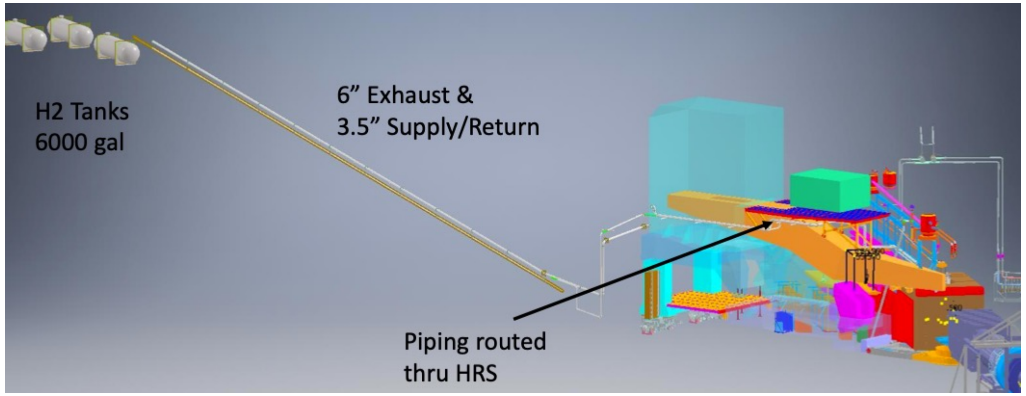


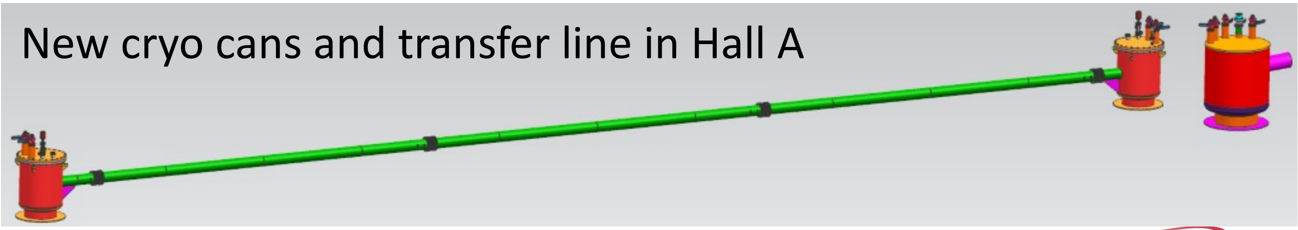
Target system schematic

- Integrated piping schematic
  - Vacuum system (warm)
  - H2 piping (warm)
  - He Piping (cryo)
  - Target loop (cryo)
- DA = D. Meekins
- Design pressures
  - H2 piping 150 psi
  - He piping 300 psi
  - Vacuum -15 psi
  - Target loop 100 psi
- Vacuum is insulation for Loop and He piping.
- All pumps, reliefs, blowdowns are vented to atm
- Exhaust piping is purged with inert gas to stack.
- Stack has 1.5 psi EOLR



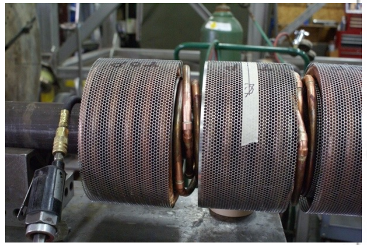


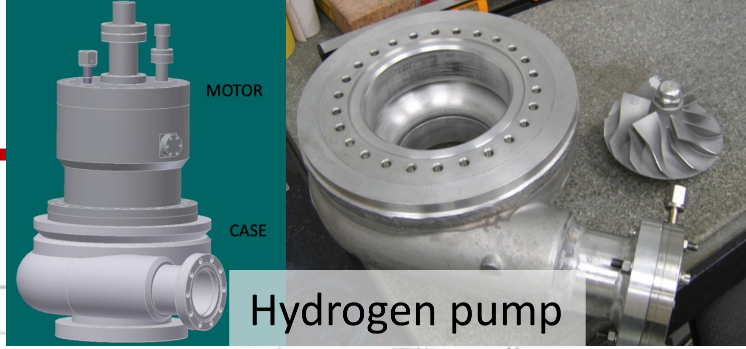


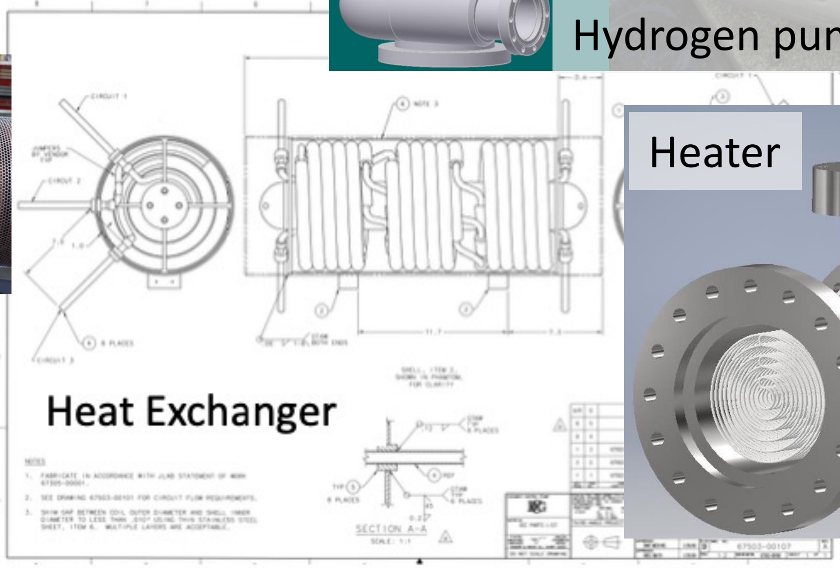


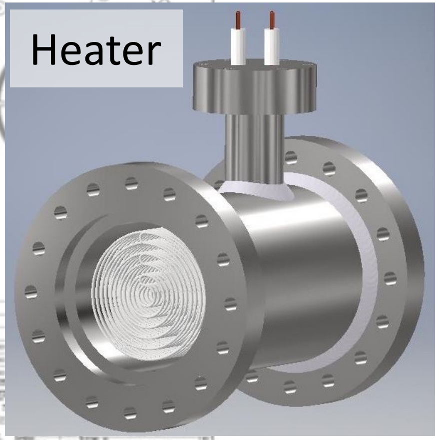
Target system elements

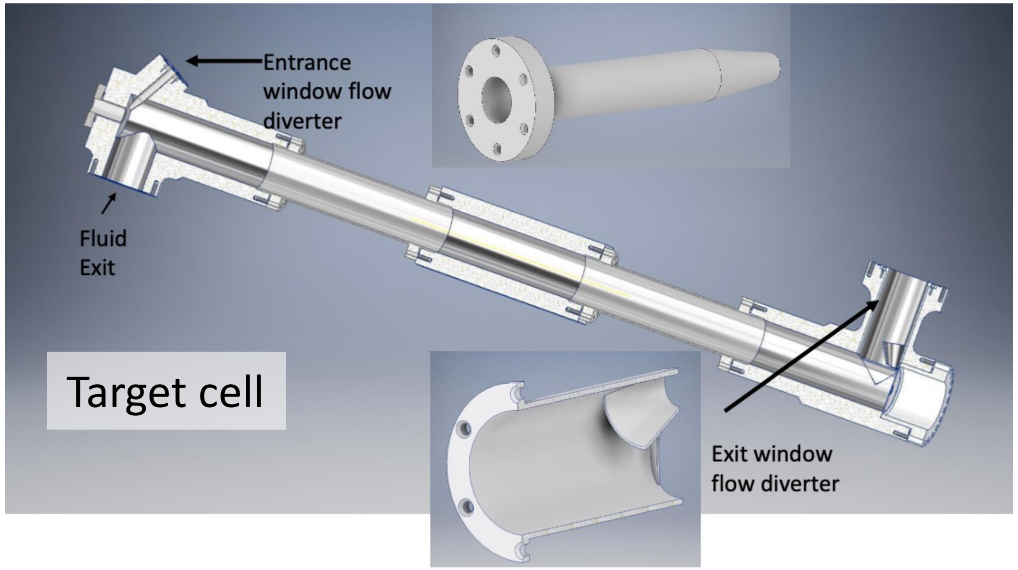
- Heat exchanger (5 kW cooling power, assessed with CFD)
  - ASME stamped vessel
- LH2 Pump (25 liters/s@4psid)
  - Case, impeller, shaft and motor
  - Very similar to Qweak pump with room temperature motor, not cold
- High power heater (4 kW, assessed with CFD)
- Solid targets (as requested by Collaboration, will be assessed with CFD)
- Piping: connecting loop components
- Cylindrical target Cell: 125 cm long, 7.6 cm ø
  - Extensive CFD to model the cell fluid space





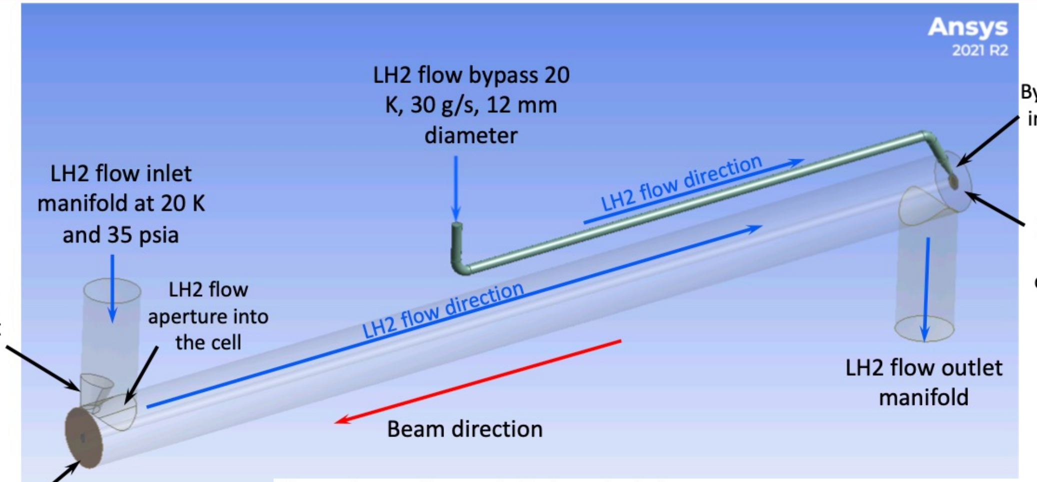






Target cell CFD calculations support design goals

MOLLER Cell Model 21 Flow Space



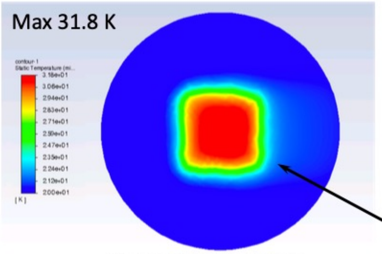
Internal flow diverter to jet at beam out nipple

Bypass jet at beam in window, 6 mm diameter

Beam-in cell Al window, 2 cm diameter, 0.125 mm thick

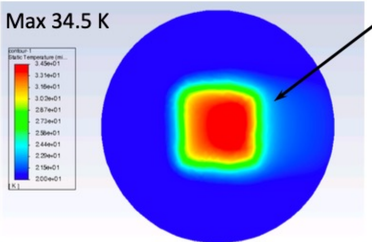
Beam-out cell Al window, 7.6 cm diameter, 0.25 mm thickness with a 12 mm diameter beam nipple 0.125 mm thick

Temperature profile snapshot in beam-in nipple



12 mm diameter nipple

Temperature profile snapshot in beam-out nipple

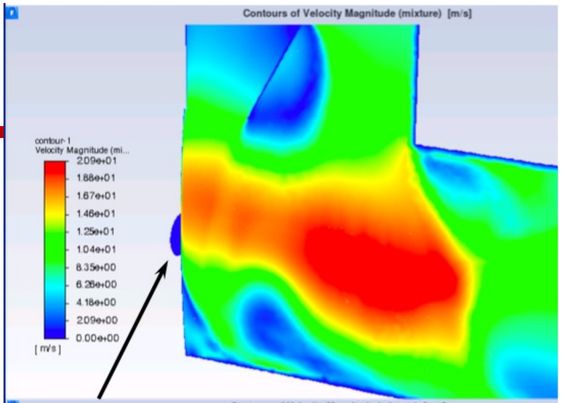


12 mm diameter nipple

4x4 mm^2 raster area

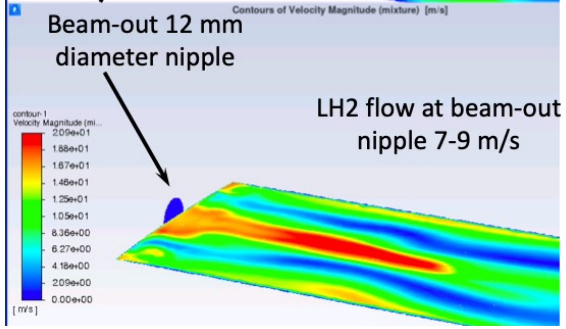
$$\Delta T_{max} \sim T_{wall} - T_{sat}$$

- For beam-in window $\Delta T_{max} \sim 9\ K$
- For beam-out window $\Delta T_{max} \sim 22\ K$
- The conditions for reaching CHF for LH2 are not met



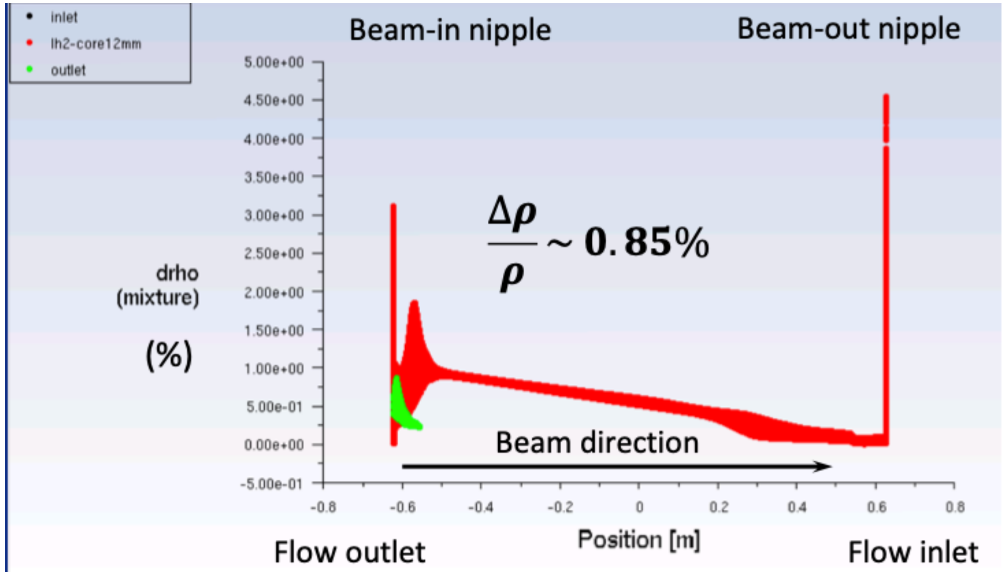
LH2 flow profile in horizontal cross-section, zooming in at cell windows

Beam-out 12 mm diameter nipple

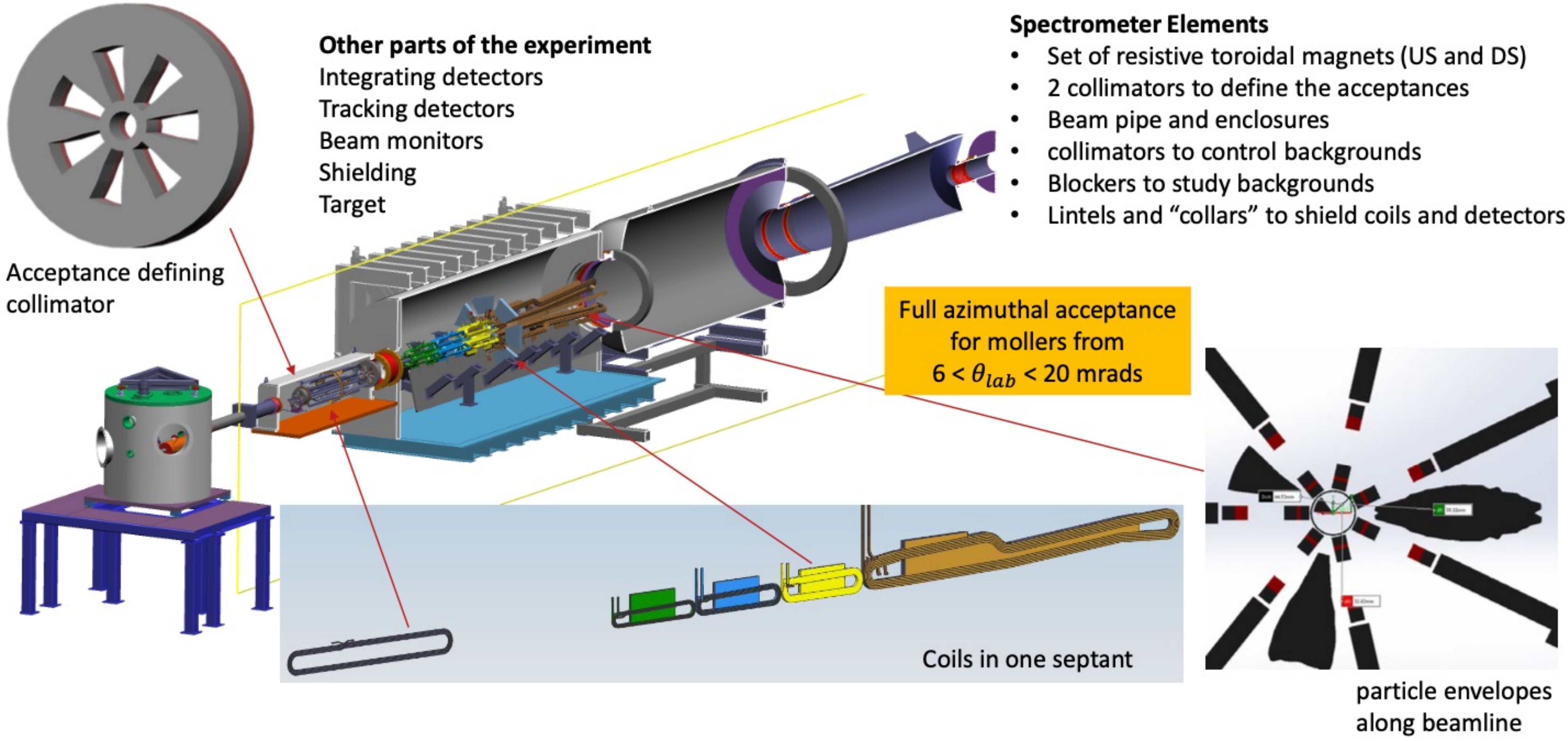


LH2 flow at beam-out nipple 7-9 m/s

LH2 flow profile in vertical cross-section, zooming in at cell windows

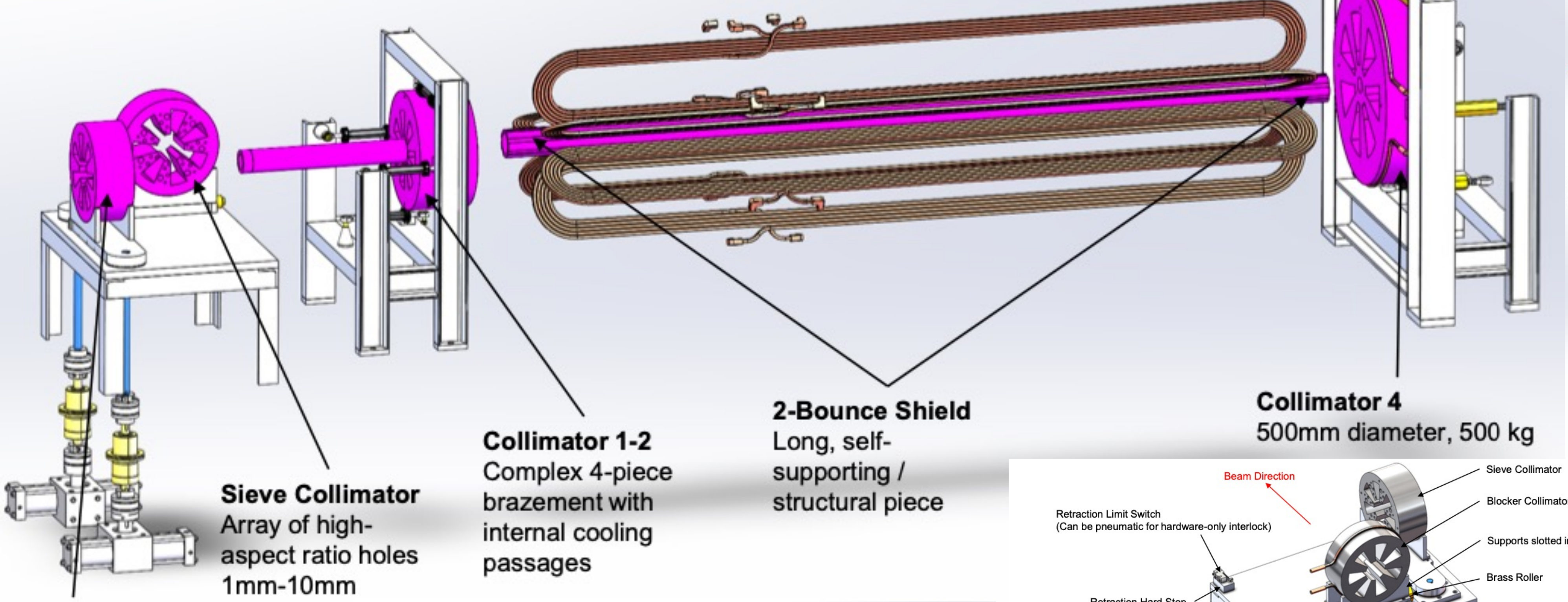


Spectrometer separates signal from background with ~100% acceptance



Upstream toroid and collimator region

The purpose of the collimators is to absorb scattered electrons and gamma radiation, combined with the bending of the spectrometer fields, to selectively exclude unwanted signals from the detectors



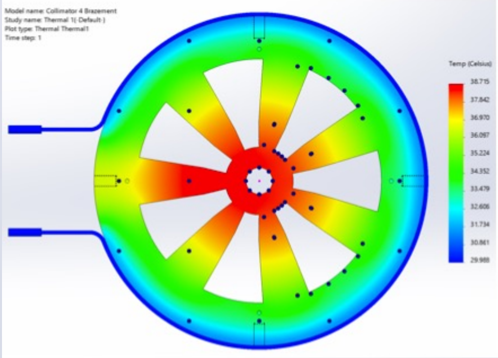
Blocker Collimator
Cooled during operation

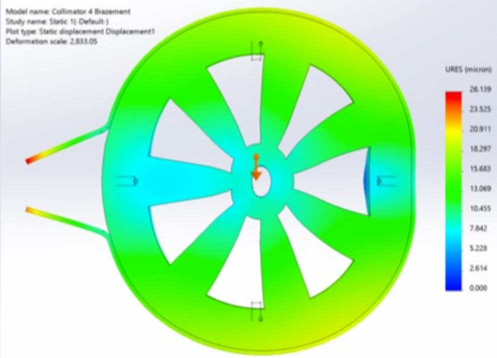
Sieve Collimator
Array of high-aspect ratio holes 1mm-10mm

Collimator 1-2
Complex 4-piece brazement with internal cooling passages

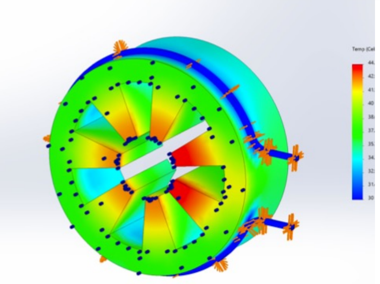
2-Bounce Shield
Long, self-supporting / structural piece

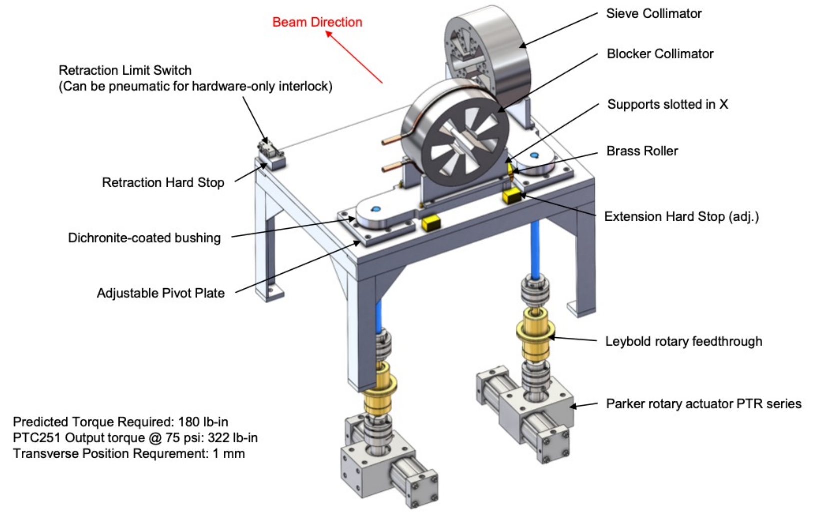
Collimator 4
500mm diameter, 500 kg





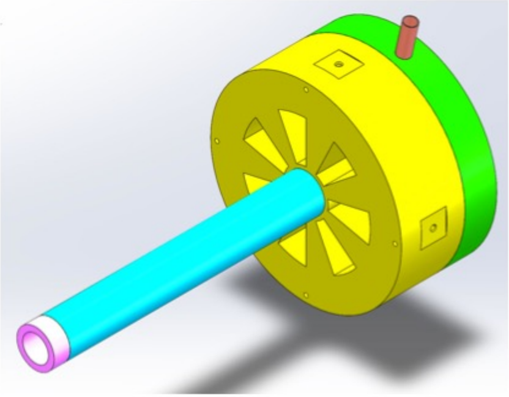
In this analysis, the coolant channel is kept at a constant 30 °C. This is reasonable since at the expected 4 GPM flow rate, the delta T across the blocker is only 0.95 °C, and the Reynold's number is very high indicating a high convective coefficient, thus, temperature gradients in the fluid and cooling channel can be neglected. The results of the FEA show very low temperature rise in the collimator, about 14.3 °C.

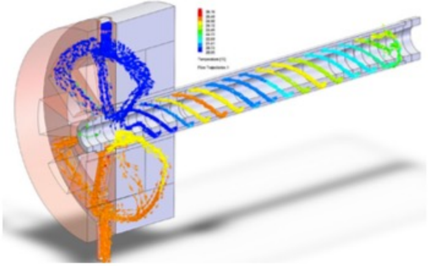


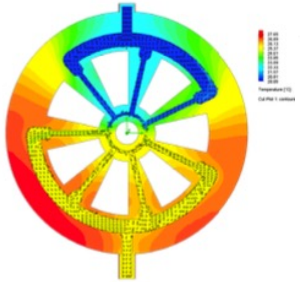


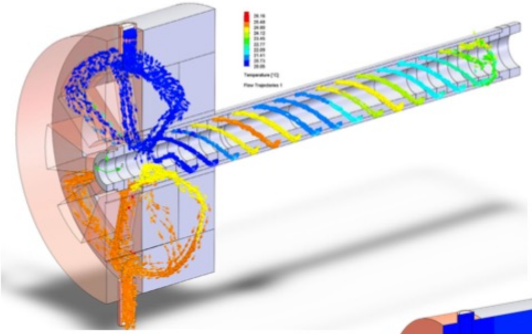
Primary collimator design and engineering

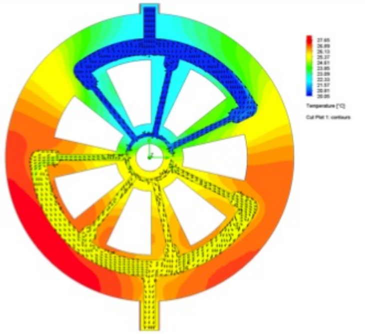
- Primary tungsten and copper collimator receives ~5 kW of deposited power
  - ~4 kW on long central tungsten tube, ~1 kW on acceptance defining section (W+Cu)



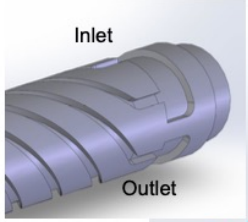


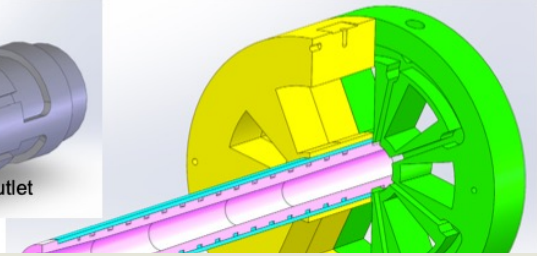


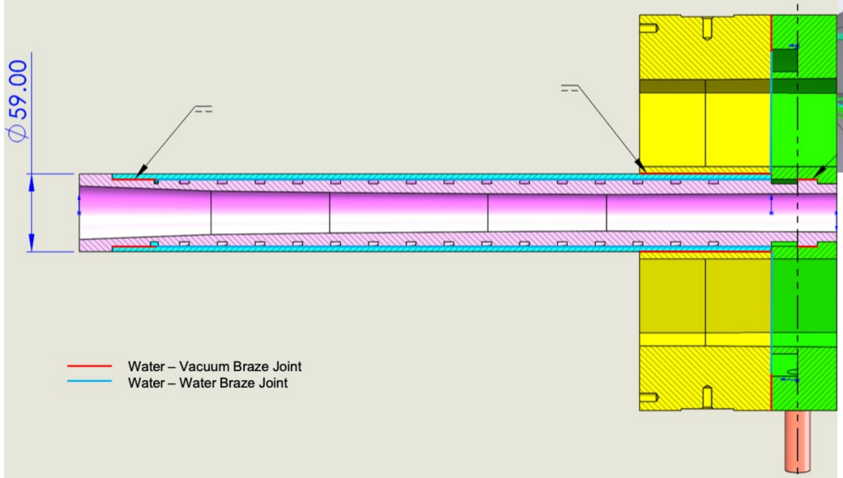


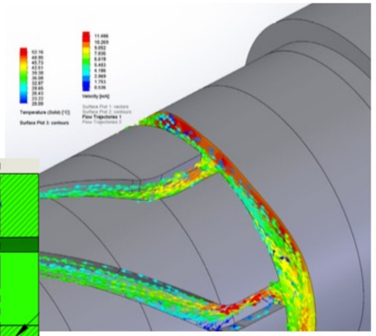


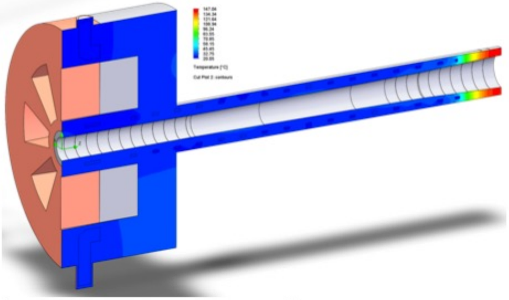
- Disc: 300mm dia x 150mm thick
- Core: 59mm dia x 575 mm long
- 90W 10Cu
- Min Density 17 g/cc
- Absorbs 4500 W in core, 900 W in disc
- +/- 100 um on petal surfaces
- +/-50 um on core inner profile, which has several different tapers along length
- Copper cooling fittings brazed to drilled holes
- Multiple water-vacuum braze interfaces
- Leakage between inlet and outlet channels is permissible, but ideally avoided where possible
- Temperature during operation: 30 - 150 C
- Radiation dose 6.6e11 Rads





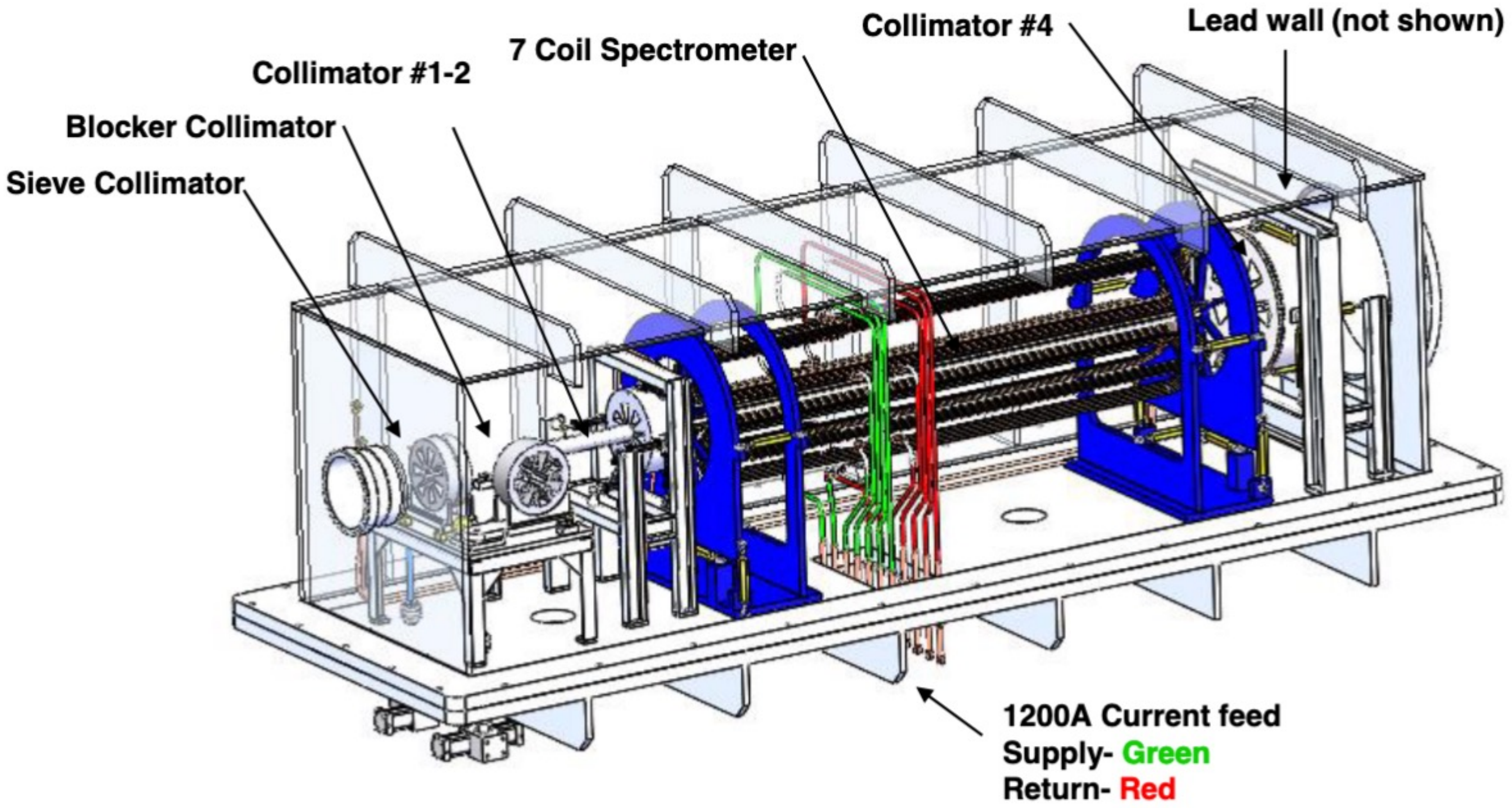




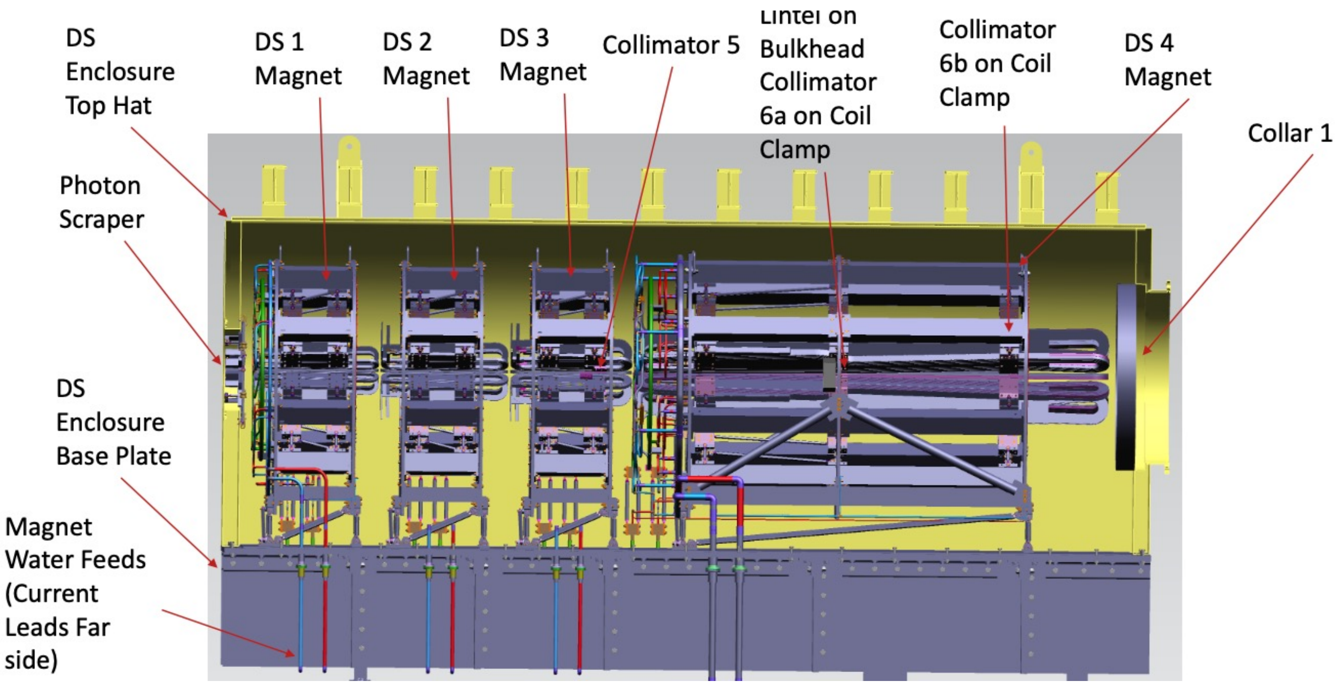


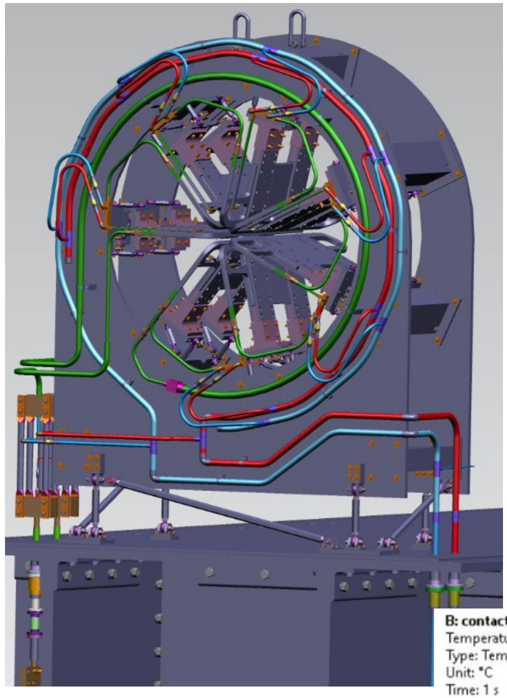
Maximum Tungsten Temperature	**147 C**
Maximum Water Temperature (20 C inlet)	53.2 C
Pressure drop	170 kPa (24.6 psi)
Water Temperature Rise	4.6 C

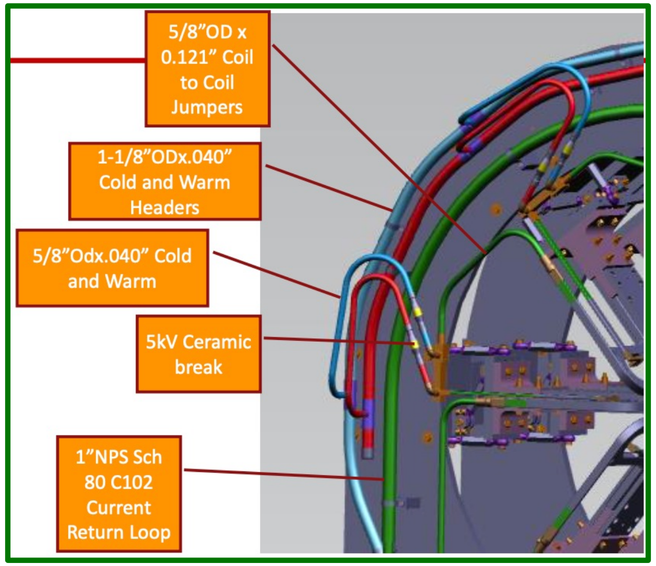
Upstream toroid design is underway, but behind other designs in maturity

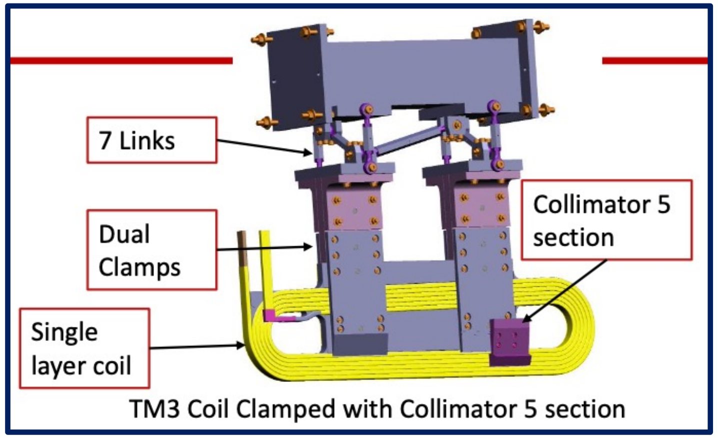


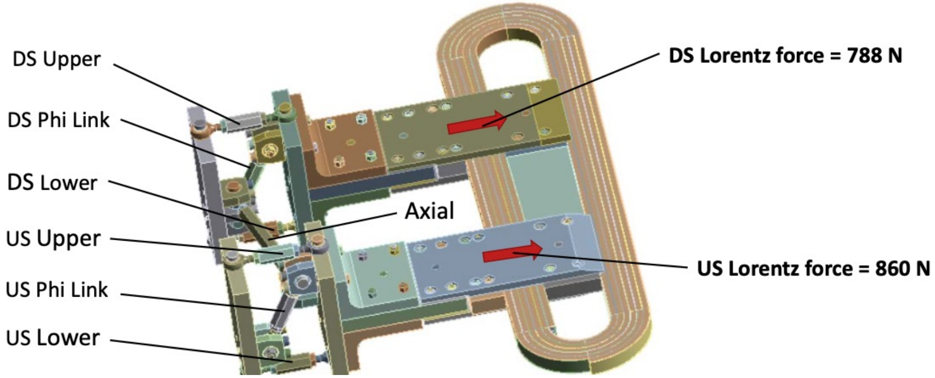
Downstream toroid design is maturing well

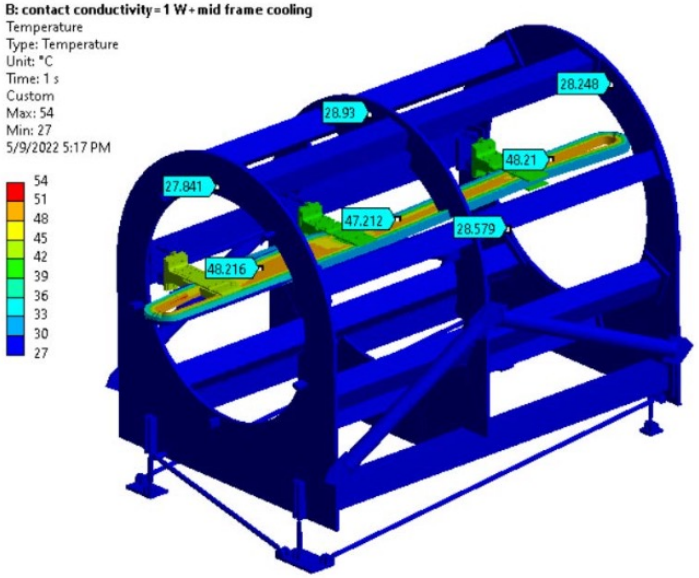






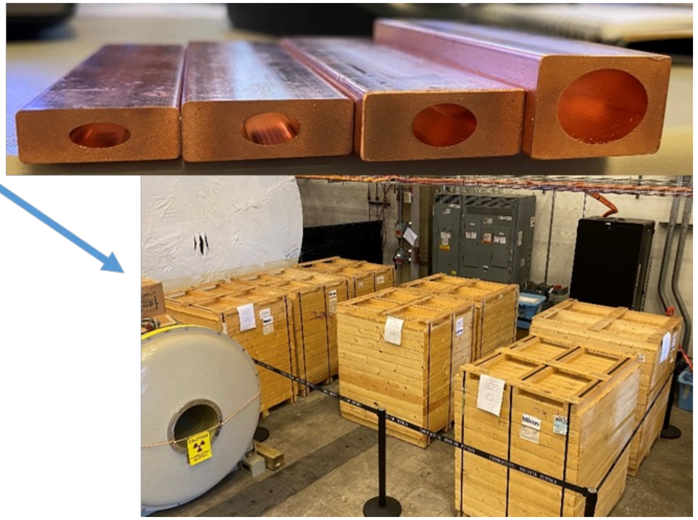




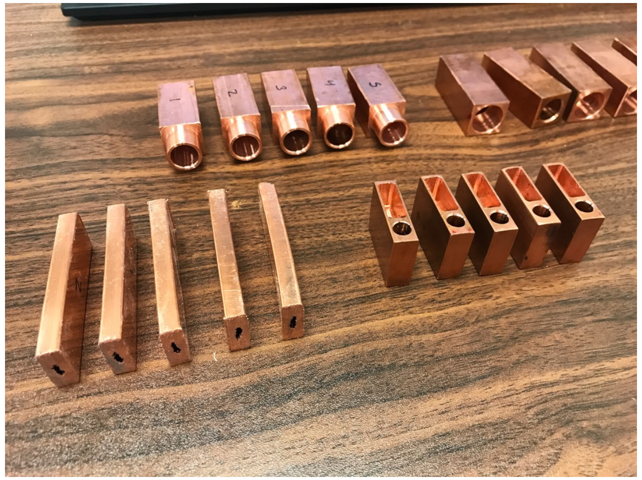


Downstream torus coil prototyping is nearing completion

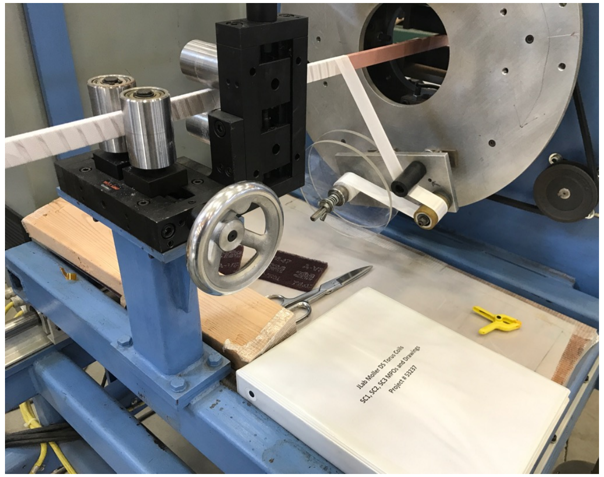
Conductors



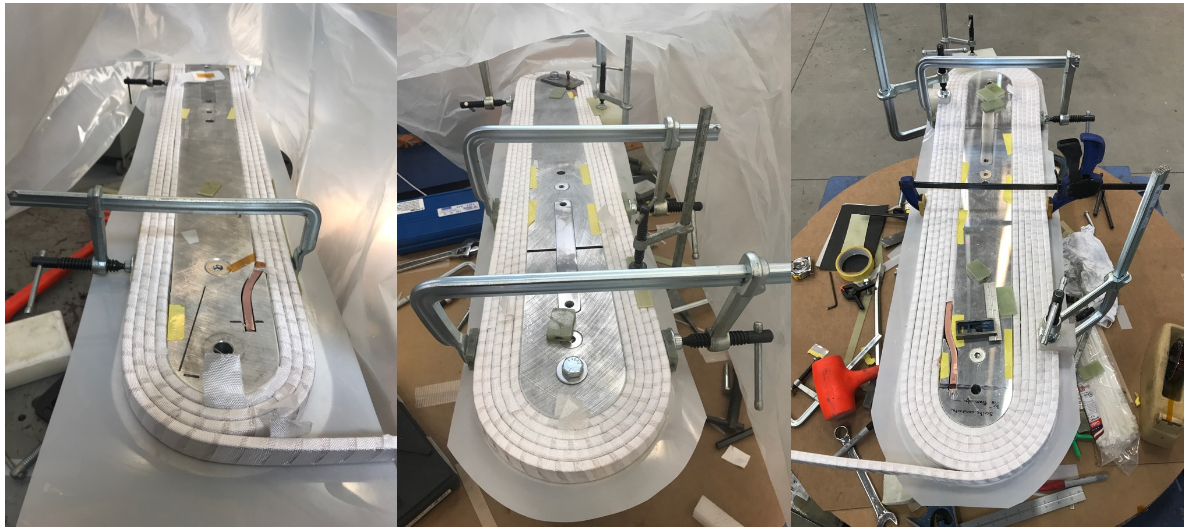
Coil winding mandrels



Brazing Qualification Parts



Conductor Insulation Wrapping

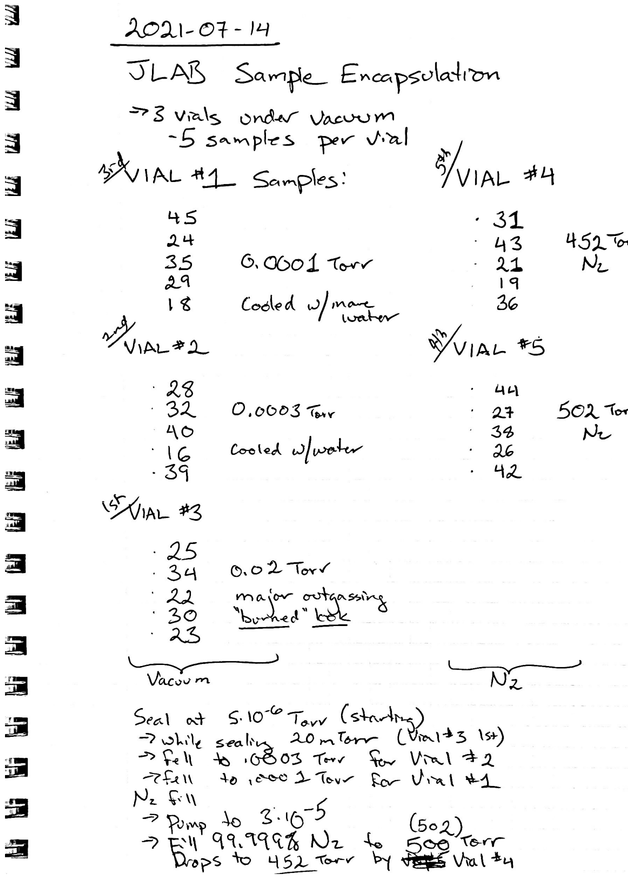


Sub-coil 1, 2 and 3 after winding

Potting compound irradiation tests

- Coils are potted with CTD-403 cyanate ester resin
  - Selected for extreme tolerance to radiation – developed for ITER
  - Prior post-irradiation strength tests all done in LN (77K)
  - Atmosphere during irradiations not well documented
    - Found a publication suggesting less damage during irradiation under vacuum vs inert gas or air
- MOLLER conducted set of tests closer to our conditions
  - Samples under vacuum (MOLLER condition) and inert gas (likely prior test conditions)
  - Wanted to tie to existing data at ~50 MGy and fill in data gap between 50 and 240 MGy
  - Testing done at slightly elevated temperature expected in MOLLER operations (~38 C)
- Multi-institution effort
  - Sample fabrication and testing done by the resin manufacturer (Composites Technology)
  - Encapsulation in quartz ampoules (vacuum and N2 gas) by Twinleaf (glass blower)
  - Irradiations done at UC Davis Triga reactor (can hold 3 sets of samples in core)
  - (5) sets of samples irradiated
    - Air and vacuum to ~50 MGy (actual 41 MGy) and 100 MGy (actual 84 MGy)
    - Vacuum to 124 MGy (left in reactor for both irradiations in center location with highest flux)

Sample prep and irradiation



2021-07-14

JLAB Sample Encapsulation

→ 3 vials under vacuum
- 5 samples per vial

3rd VIAL #1 Samples:
45
24
35 0.0001 Torr
29
18 Cooled w/ more water

2nd VIAL #2
· 28
· 32 0.0003 Torr
40
· 16 Cooled w/ water
· 39

1st VIAL #3
· 25
· 34 0.02 Torr
· 22 major outgassing
· 30 "burned" look
· 23

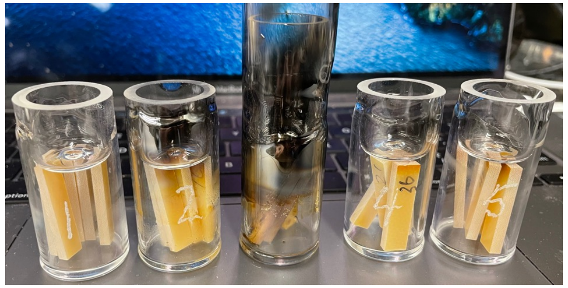
Vacuum

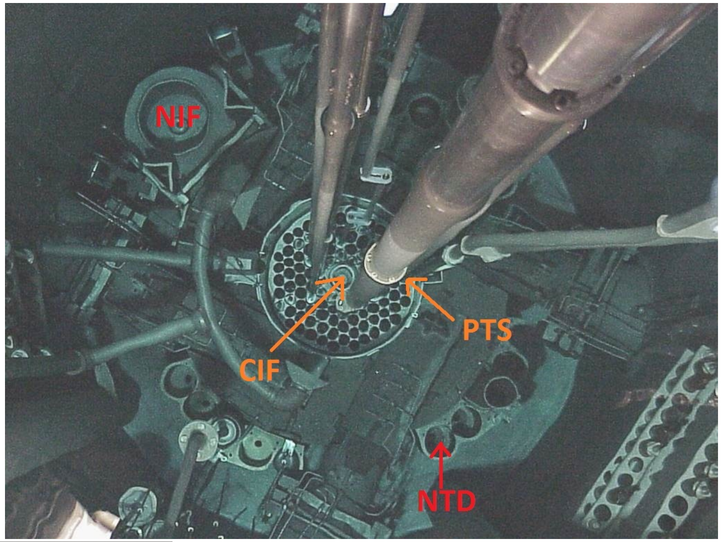
5th VIAL #4
· 31
· 43 452 Torr N_2
· 21
19
36

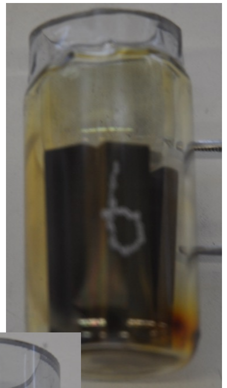
4th VIAL #5
· 44
· 27 502 Torr N_2
· 38
· 26
· 42

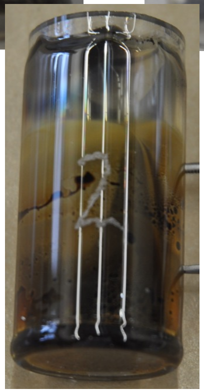
N_2

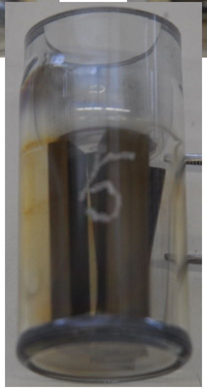
Seal at $5 \cdot 10^{-6}$ Torr (starting)
→ while sealing 20 mTorr (Vial #3 1st)
→ fell to .0003 Torr for Vial #2
→ fell to .0001 Torr for Vial #1
N_2 fill
→ Pump to $3 \cdot 10^{-5}$
→ Fill 99.999% N_2 to 500 (502) Torr
Drops to 452 Torr by Vial #4

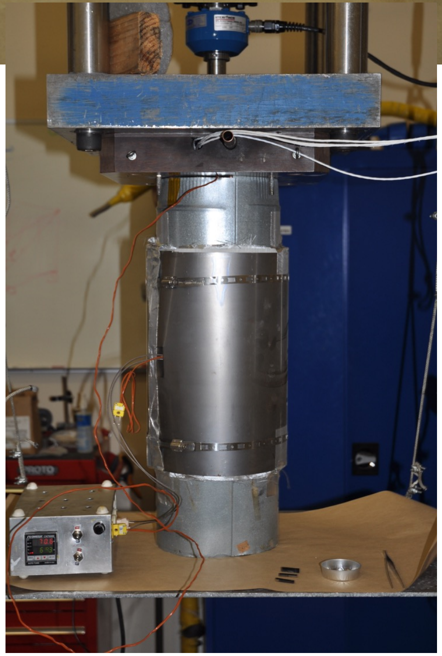


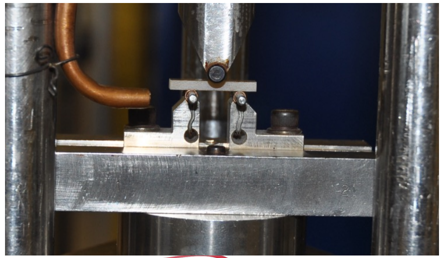






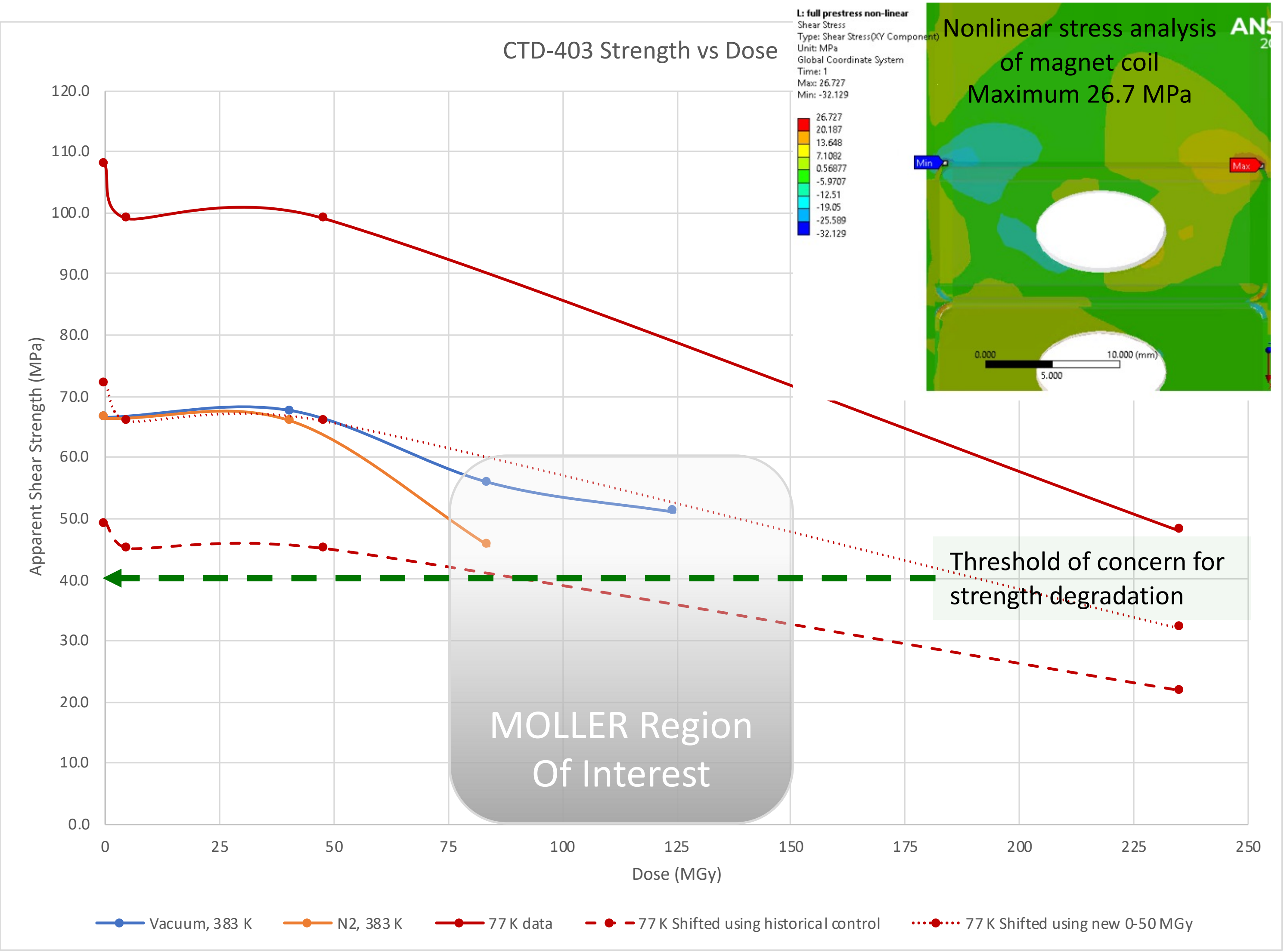




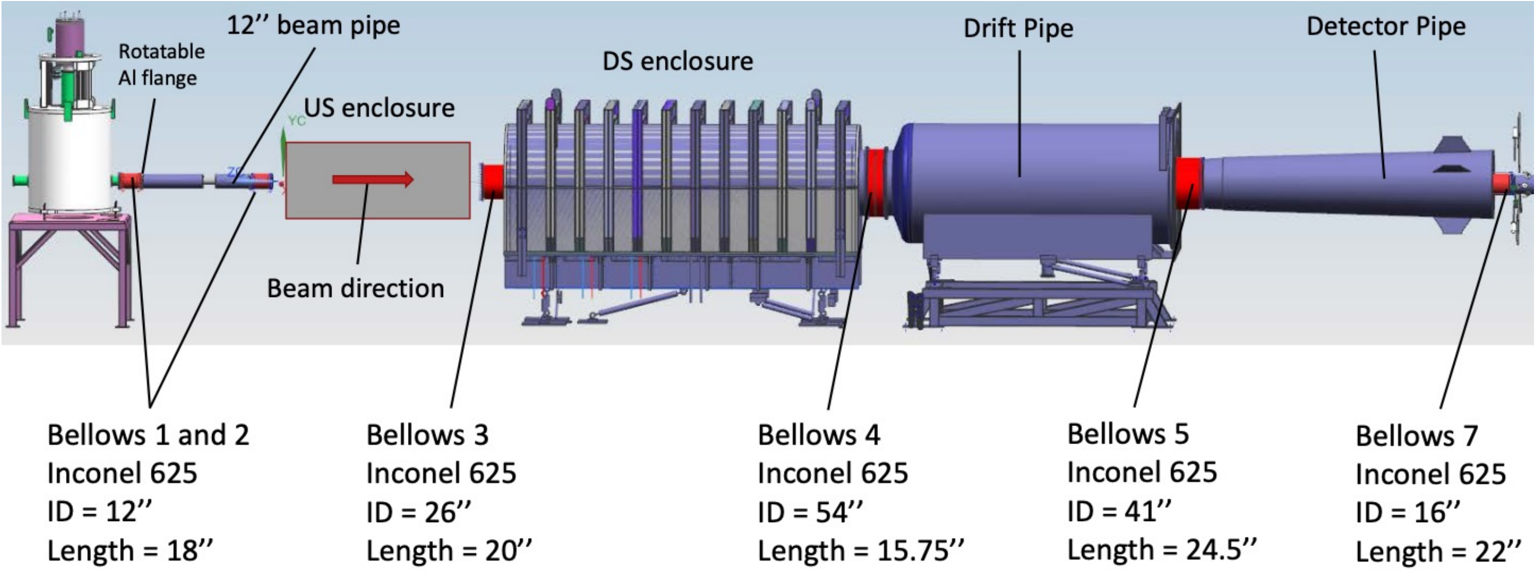


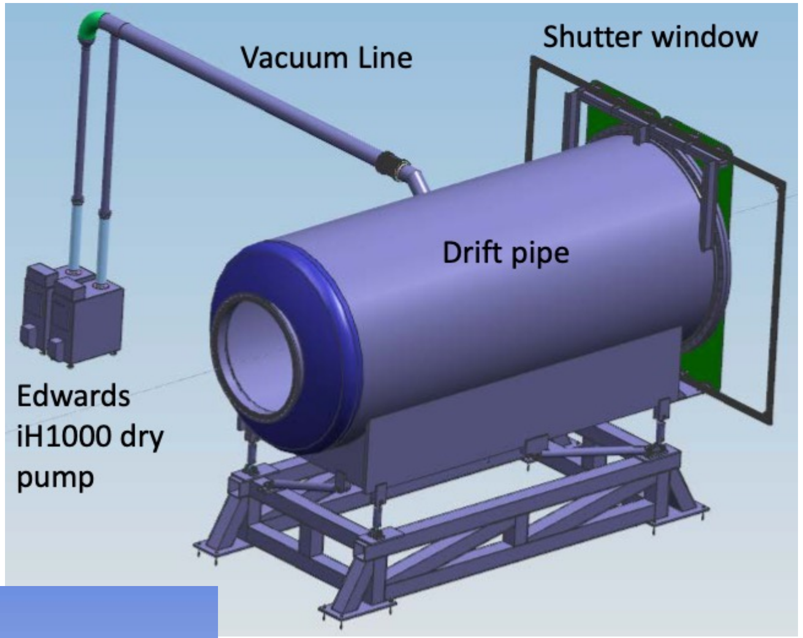
Test results better than anticipated
Confirmed publication hypothesizing less degradation for irradiations in vacuum

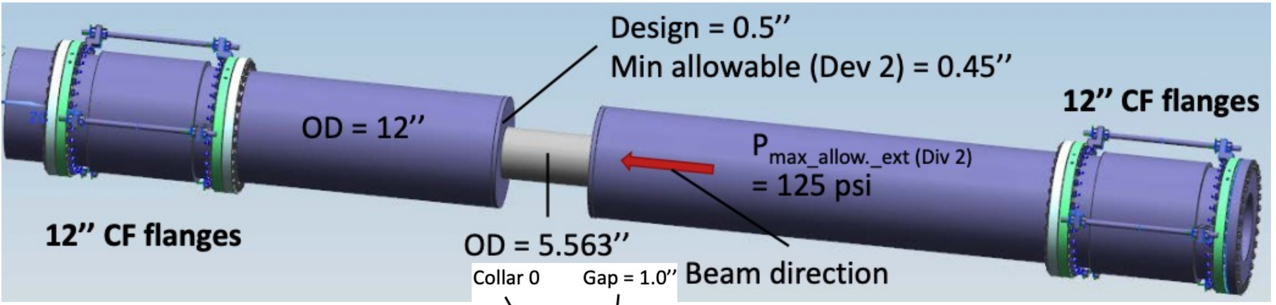
- Solid red curve is ITER data measured at 77 K
- Red dashed curve is the ITER data scaled for temperature dependence to 38 K using historical measurements of unirradiated samples - what we were expecting going in to tests
- Red dotted line uses our unirradiated strength value to scale the ITER low dose values
- Blue is our measurements of samples irradiated under vacuum
- Orange is our measurements of samples irradiated in N2
- Critical data for design of coil shielding

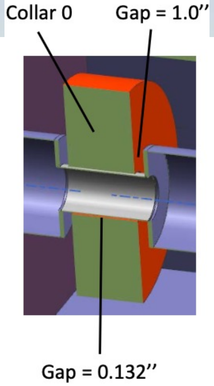


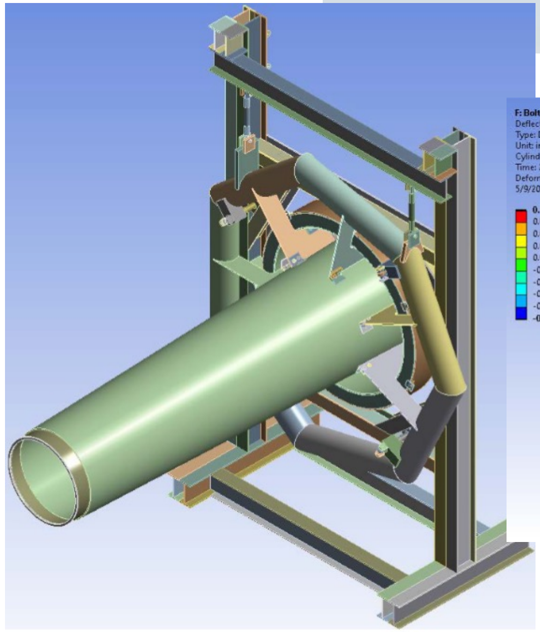
Beampipe, bellows and pion donut support are all coming together well

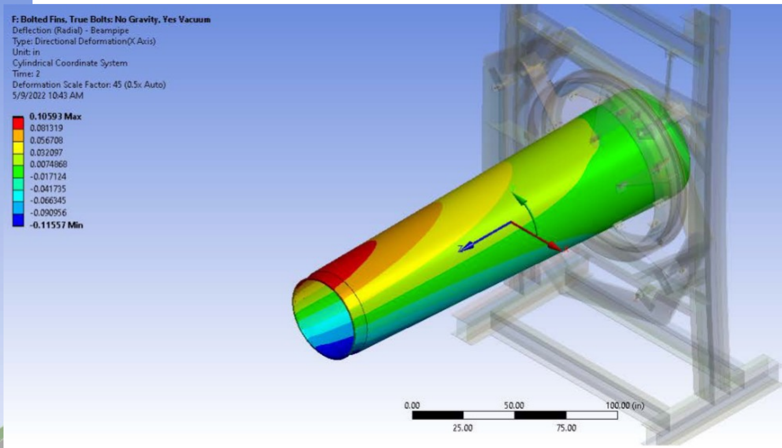




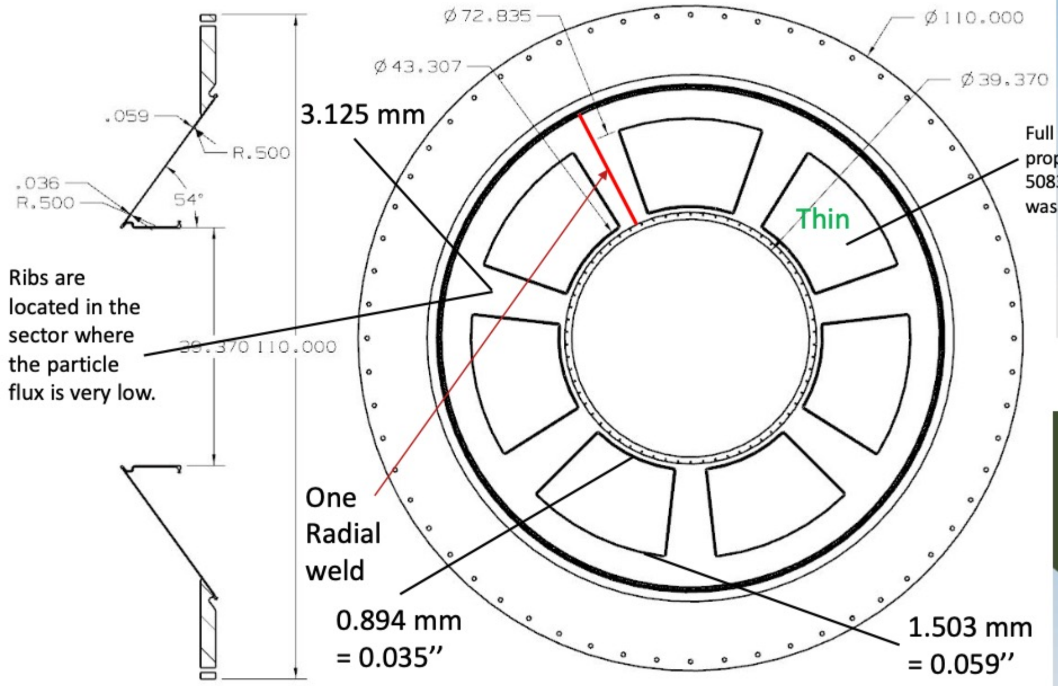


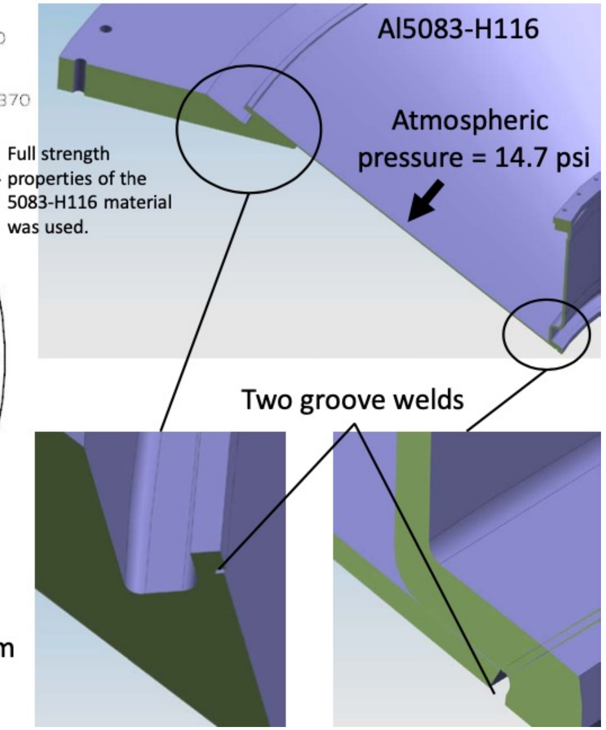


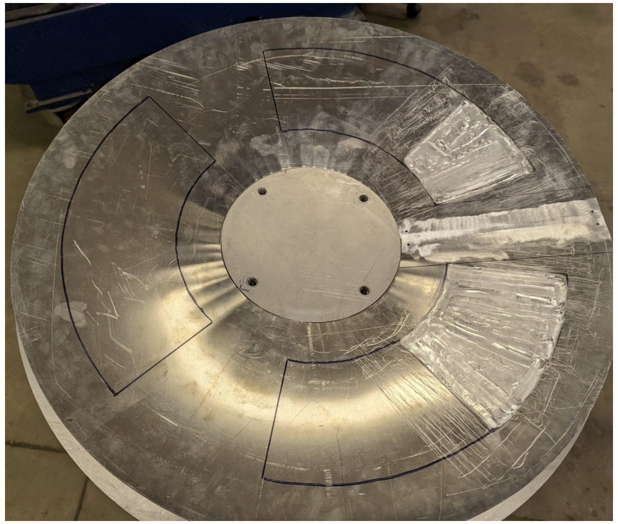




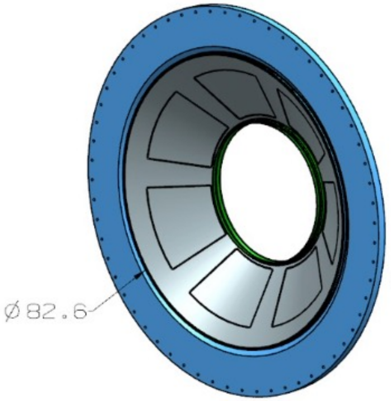
Drift pipe exit window - will be building a scaled test article





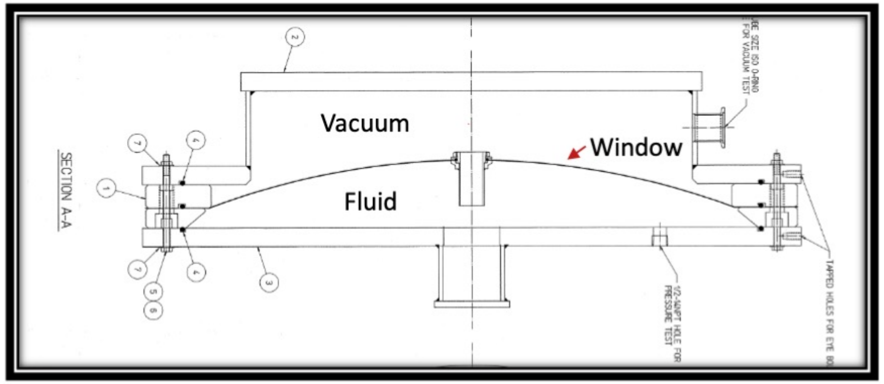


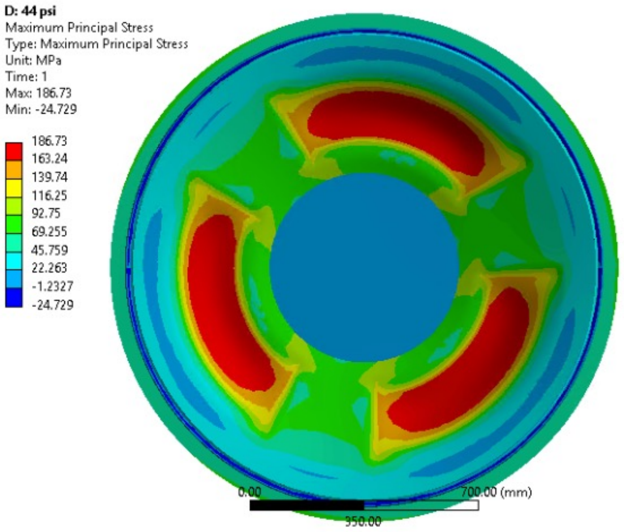
Rolled & Welded Pre-prototype Thin Window



Detector window

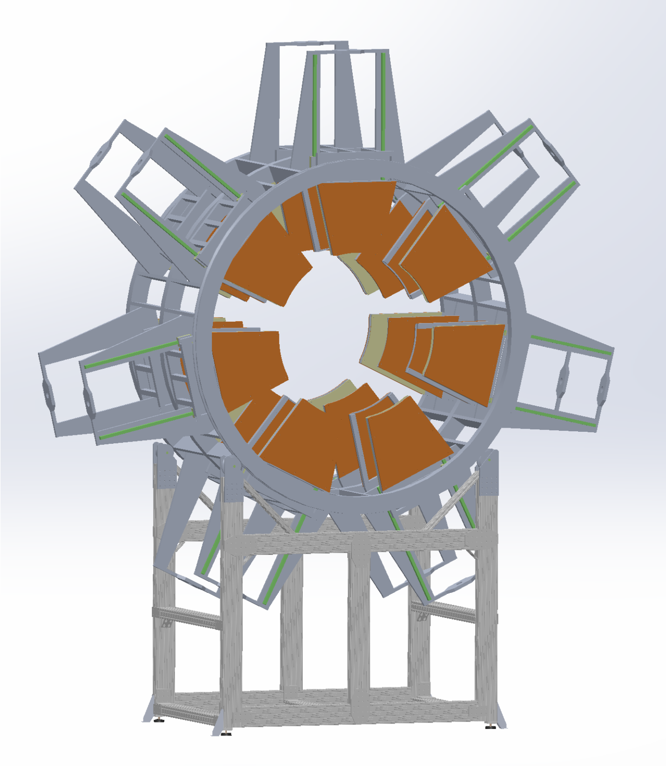
Prototype window

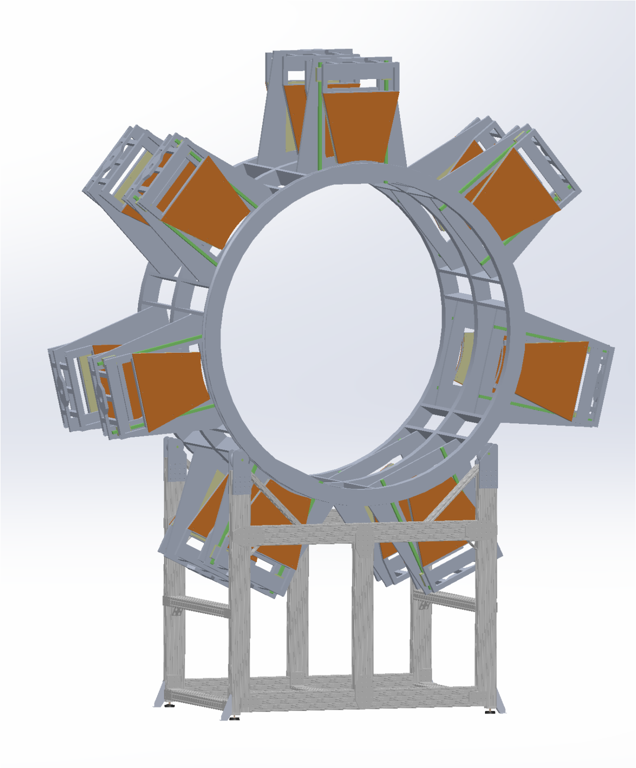




Tracking (GEM) detector design

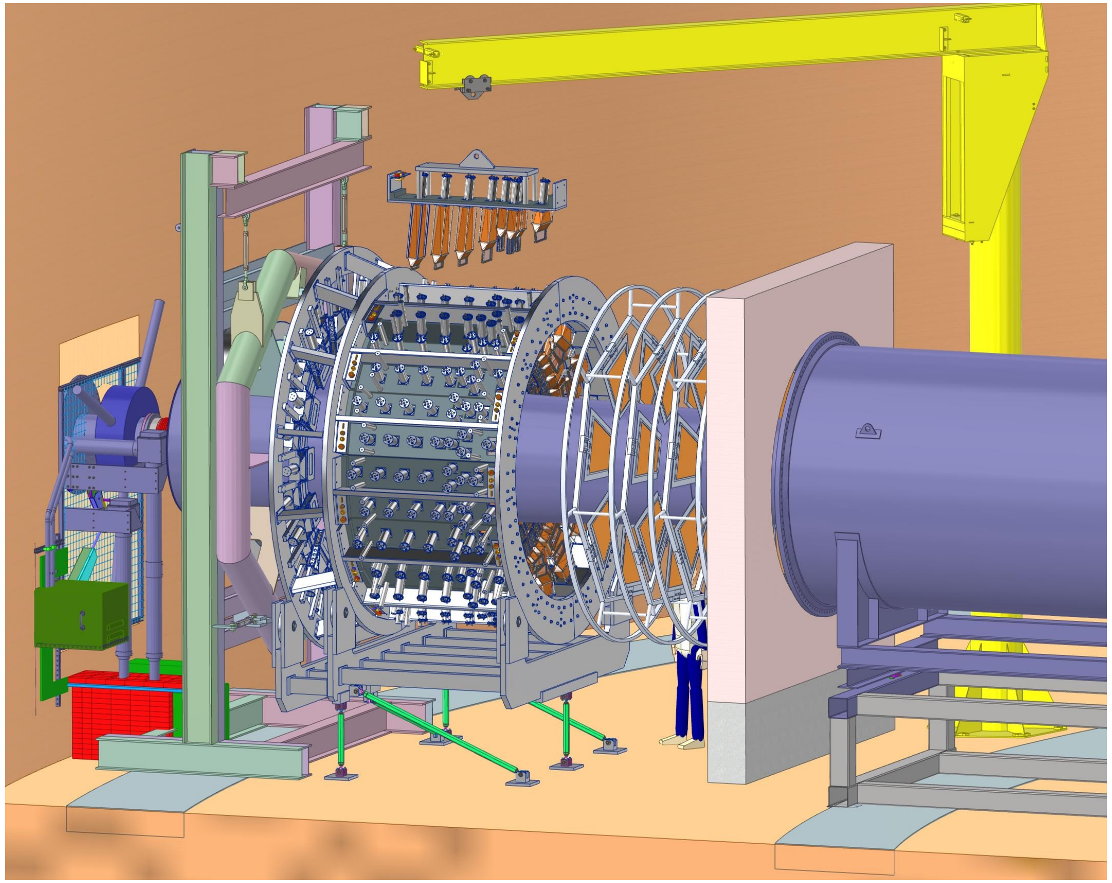
- GEM trackers will be used to image scattered electrons during low current calibration runs
- Trackers are retractable during normal high current running
- Trackers sit on rotating wheel support system so all azimuths can be covered
- Design of both linear (radial) motion system and support of sectors (two BGEMs plus a trigger scintillator) have matured significantly since the preliminary design review
- GEM prototyping will be underway shortly at both UVA and Stonybrook
  - NSF is funding UVA (4 sectors)
  - DOE is funding SBU (3 sectors)



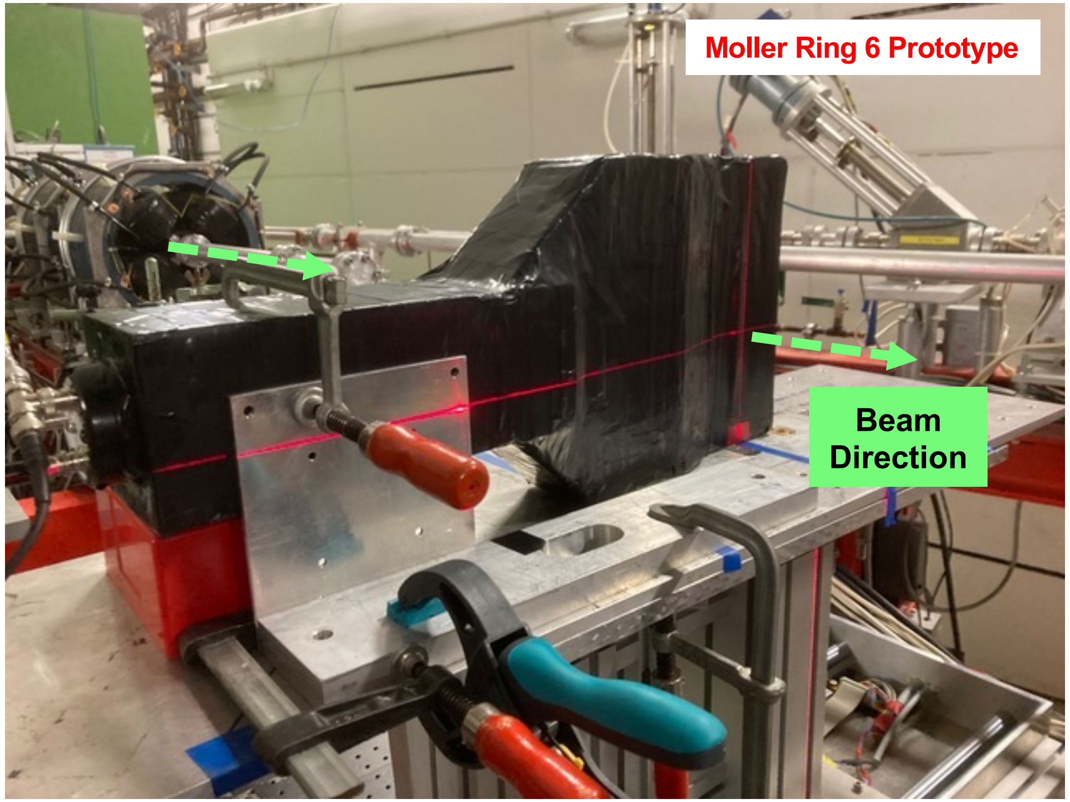


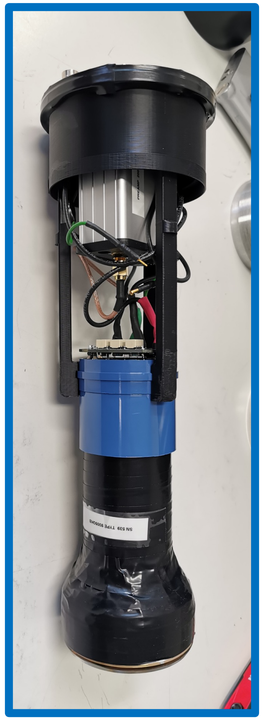
Detector region has evolved considerably

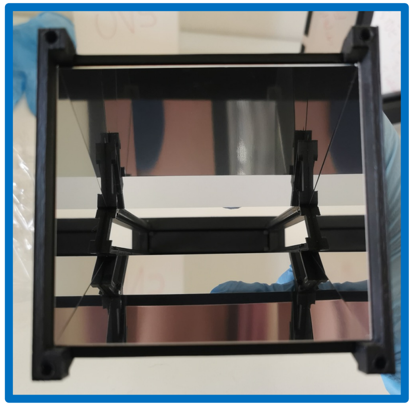
- Main detectors and Shower-Max integrated on “rotator” so all modules can be installed from above rather than needing complex materials handling to insert, e.g. from underneath the structure
- Requires robust, simple cable disconnects
  - Each 1/28th module has 8 detectors
  - One connector can provide all HV, one for LV, and one each for the two signal paths

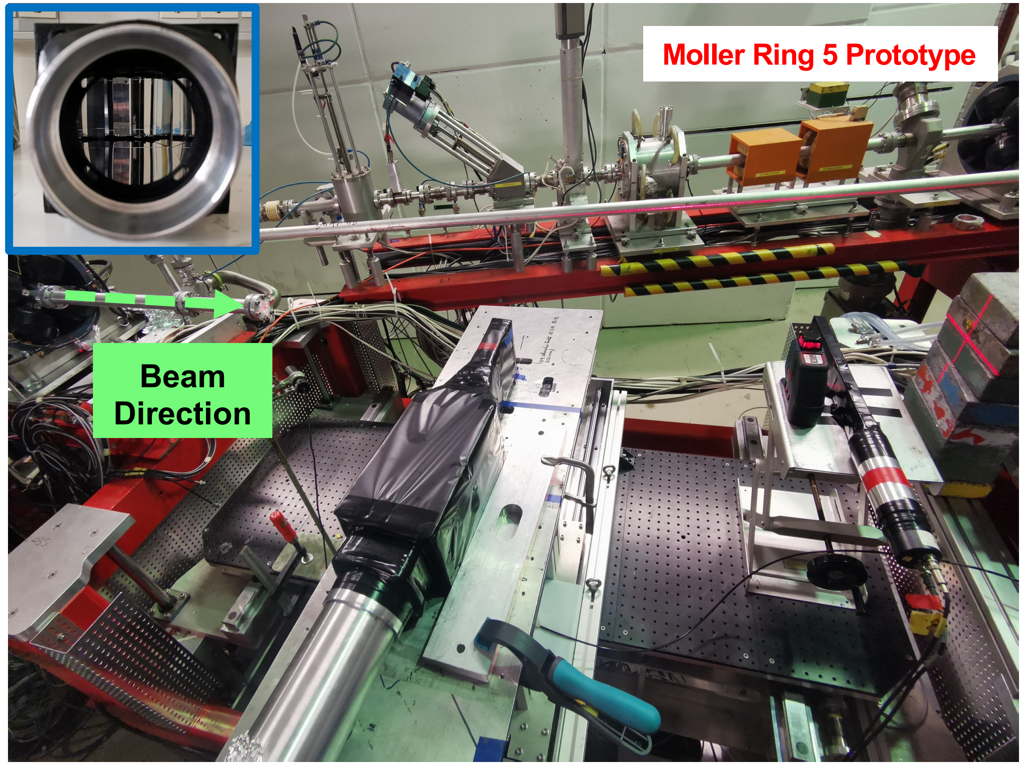


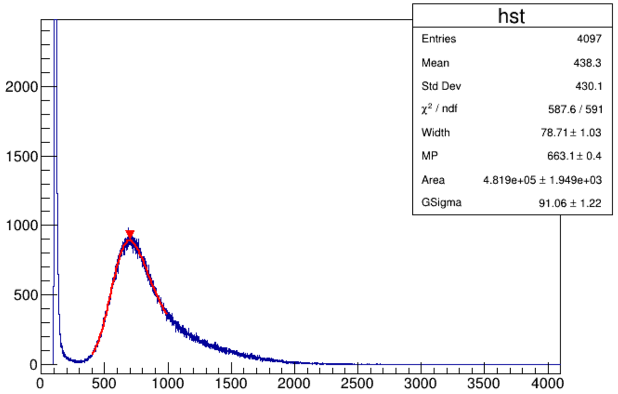
Latest beam test at Mainz – MOLLER ring 5 and 6 modules





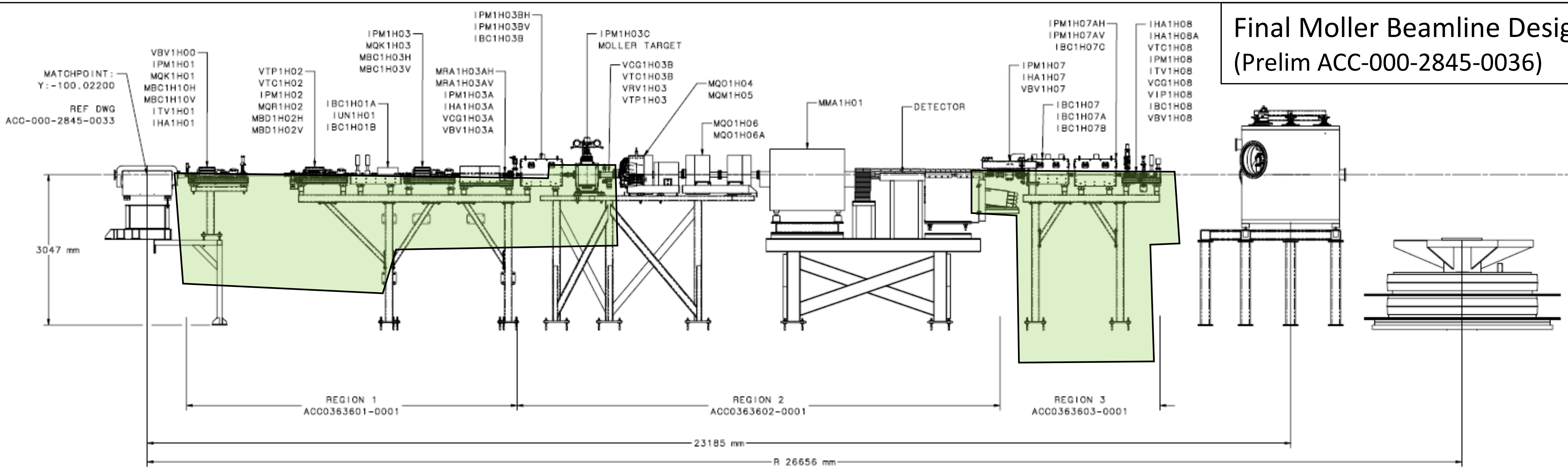






Jefferson Lab

Hall A Moller beamline – target moved 4.5 m upstream from pivot



Final Moller Beamline Design
(Prelim ACC-000-2845-0036)

- Majority of New Design Scope is located in Regions 1 and 3
  - Existing Hall A Moller polarimeter Quads, Dipole and Detector box are unaffected and will remain in place
  - New Unser box (Unser-BCM-BCM) will use commercial “Unser”; has ½ the current noise of the Hall A unit
- Region 1 section being assembled and installed ahead of main MOLLER down as “prototype”
  - Improves beamline performance for SBS-era experiments
  - Gain operational experience with new beamline and instrumentation prior to MOLLER engineering run
  - Reduces work coordination issues in Hall A during the MOLLER installation down (i.e. shortens long down period)

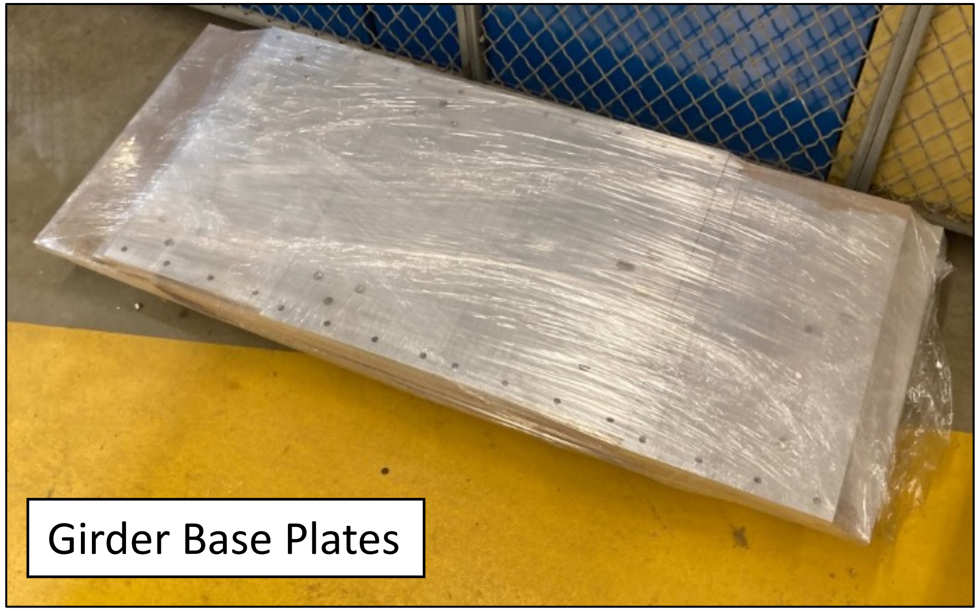
Hall A entrance beamline for MOLLER – prototype procurement progress

Pedestal, Stand Platform and Braces Stored in Test Lab High Bay

Girder/Vacuum Hardware

MCG Coils Currently being Fabricated at Technicoil, along with QR Coils to replace Spare QR that will be used for Moller Beamline.

MCG Magnet Steel Components



Girder Base Plates

MOLLER – a DOE Major Item of Equipment (MIE)

- Falls under DOE-O-413.3B Change 5

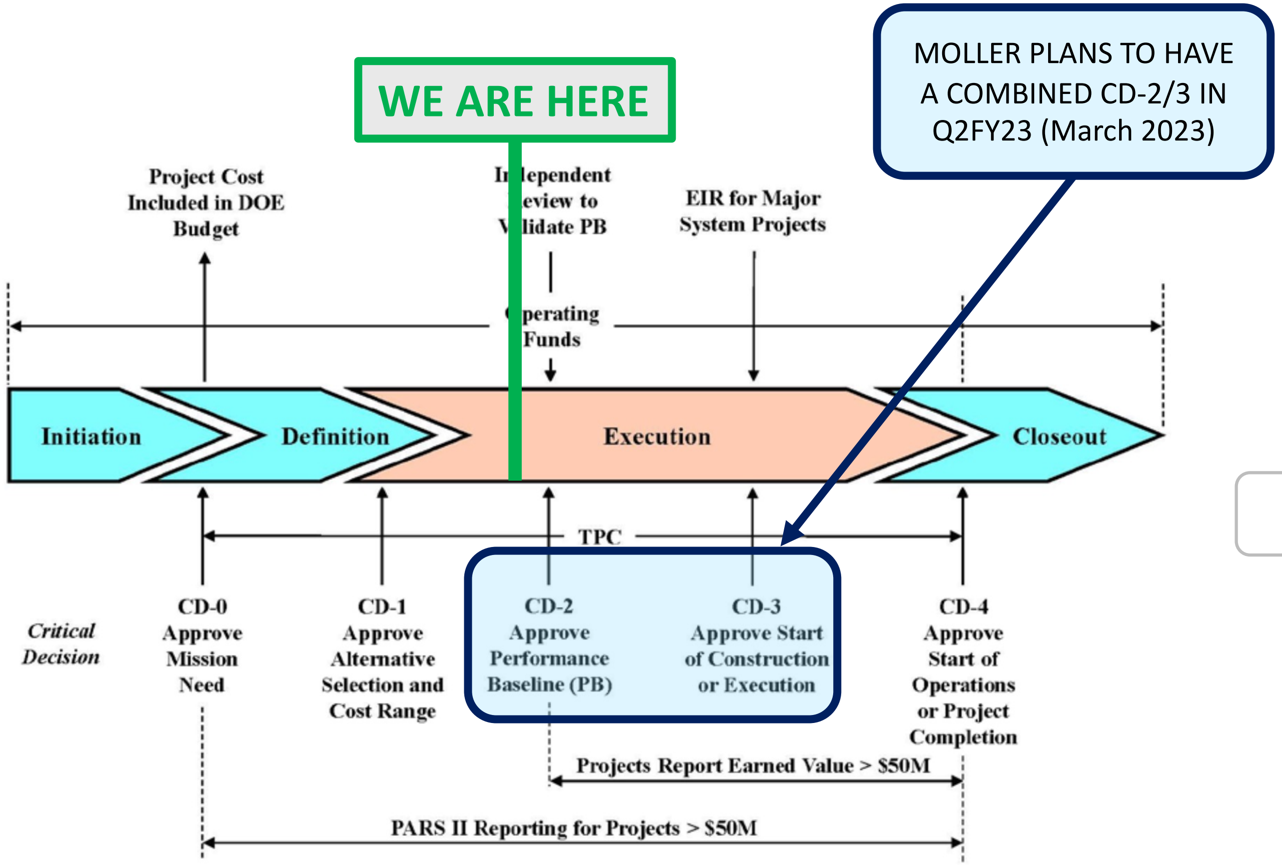
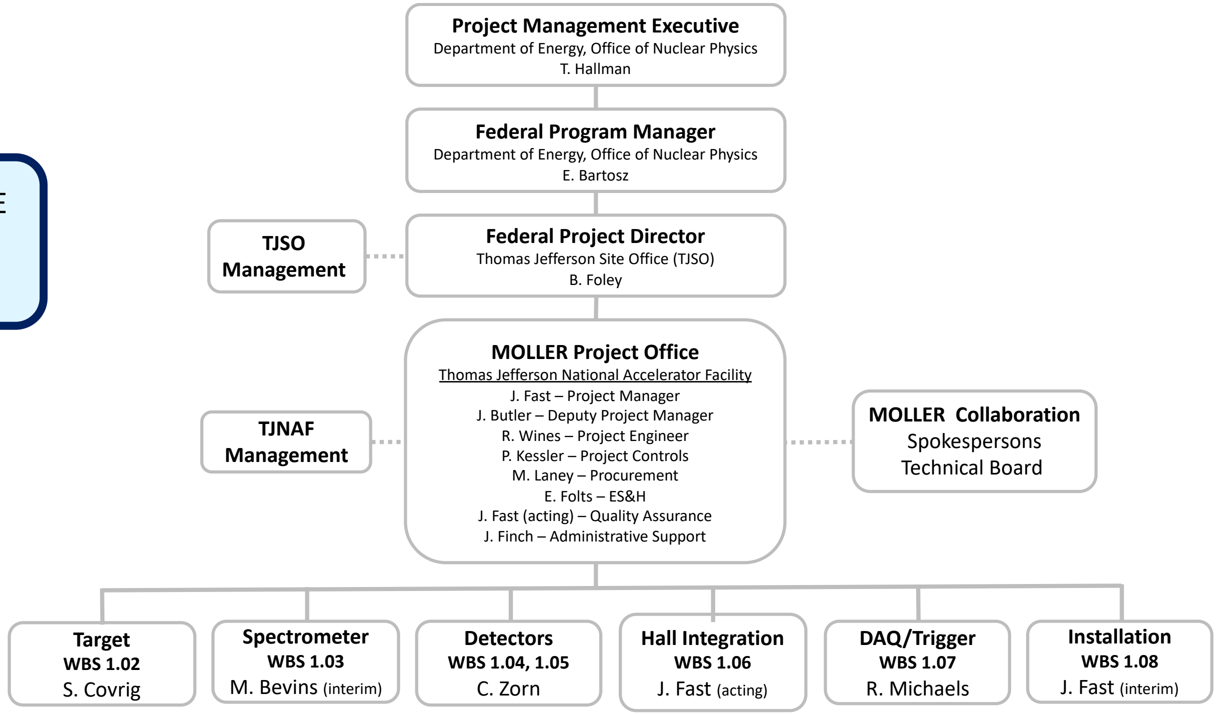


Figure 2. Typical DOE Acquisition Management System for Other Capital Asset Projects (i.e., Major Items of Equipment and Operating Expense Projects)



Working on hiring "Engineering Physicists" to fill two of these three positions

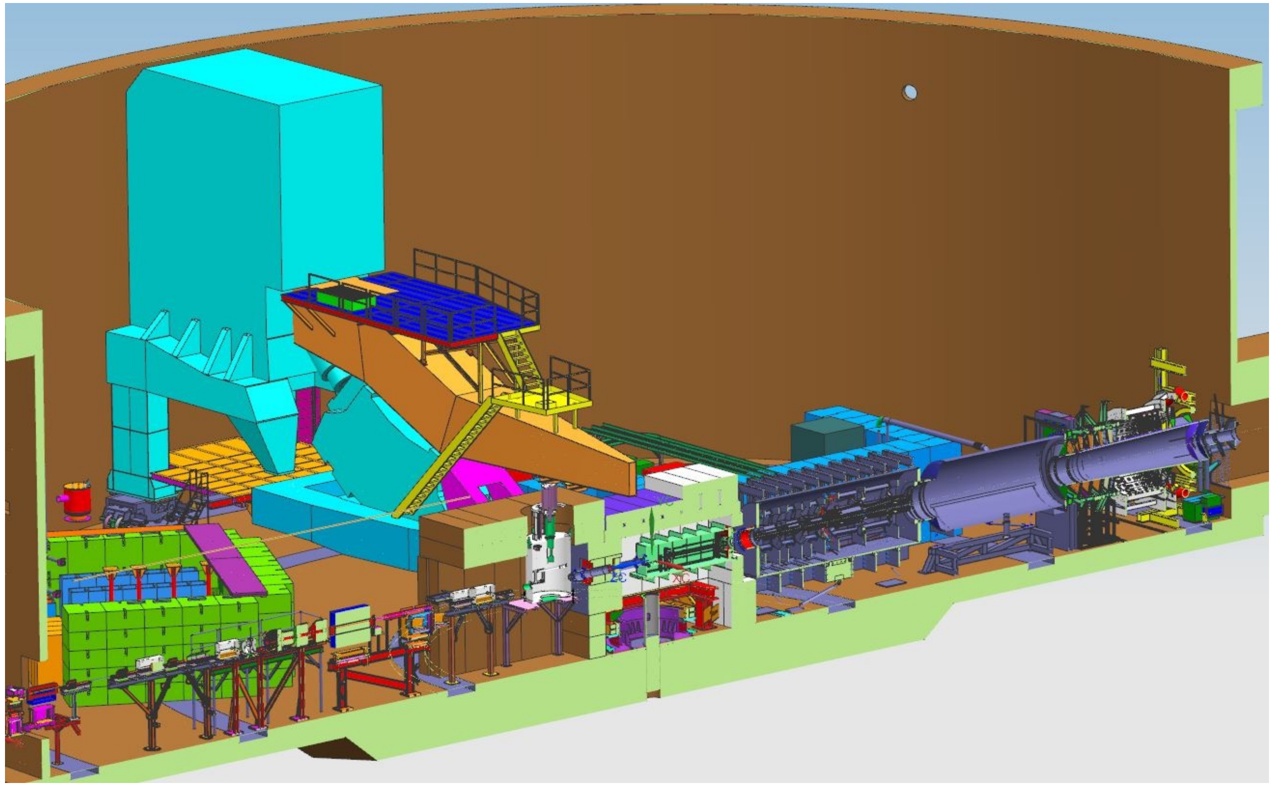
Jefferson Lab

Funding outlook

- FY20 funding was $2M (TEC)
  - All carried over to FY21 – awaiting CD-1 approval for spending this flavor of funding
- FY21 funding was $5M
  - $3.2M carried over to FY22
- FY22 funding President's Budget Request was $7M
  - Actual appropriation was only $5M
  - **Still ample to get the project through CD-2/3**
- Challenge is going to be FY23 where we requested ~$14M
  - We need ~$8M to stay on schedule
    - Any less and we will have to slip the schedule one year
  - President's Budget Request supports only $4M [worst case scenario]
    - Estimate is that we will have >$2.5M in carryover to help us through FY23
    - We can maintain the team and get through this lean year, but funding will be very tight
  - Congressional marks are not available yet
    - **Congress funds science very well**
    - We are awaiting news on House and Senate marks (typically come out during the summer)

Summary

- We have been making steady progress since CD-1; continue to be on track towards CD-2/3 Spring 2023
- We had a very successful set of Preliminary Design Reviews over the past several months
- FY22 allocated funding is sufficient for us remain on course to CD-2/3 with minimal impact on CD-4, but current President's Budget Request for FY23 would result in a 1 year delay
- The tight integration we have of the scientists and engineers on MOLLER is essential
  - Reviewers, DOE and NSF have all commented favorably about this!
- But much work remains to be done to complete final designs and navigate DOE reviews…



See presentation "MOLLER Physics" by Zuhal Demiroglu tomorrow at 15:30