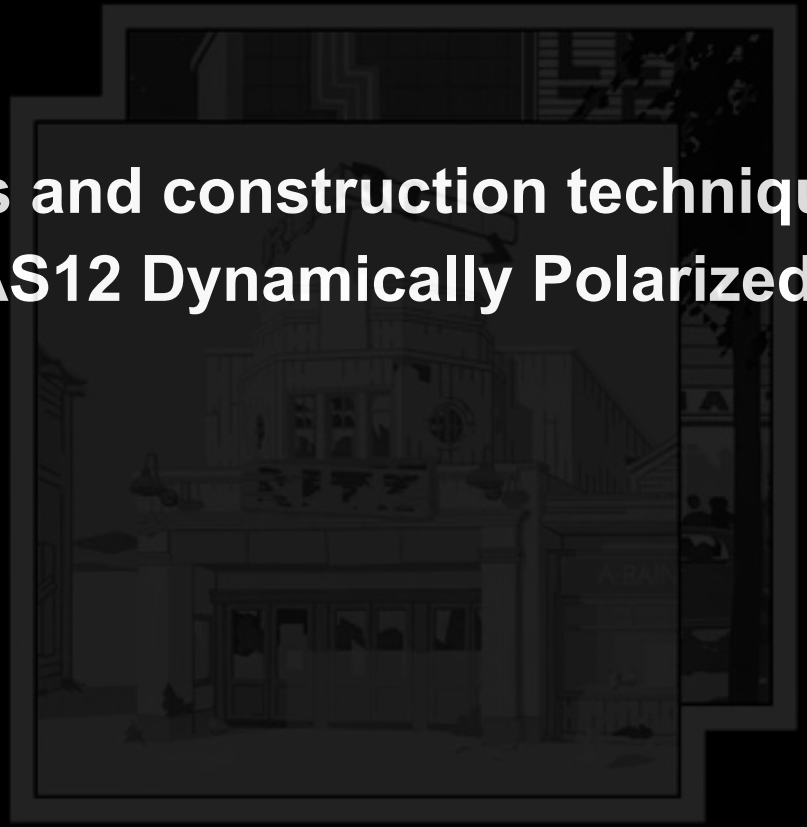
Designs and construction techniques for the CLAS12 Dynamically Polarized Target



Jefferson Lab

TARGET GROUP

Solid Polarized Targets at JLab

Solid Targets in the 6 GeV era:
UVa, Hall B, FROST, HDIce

Hall A

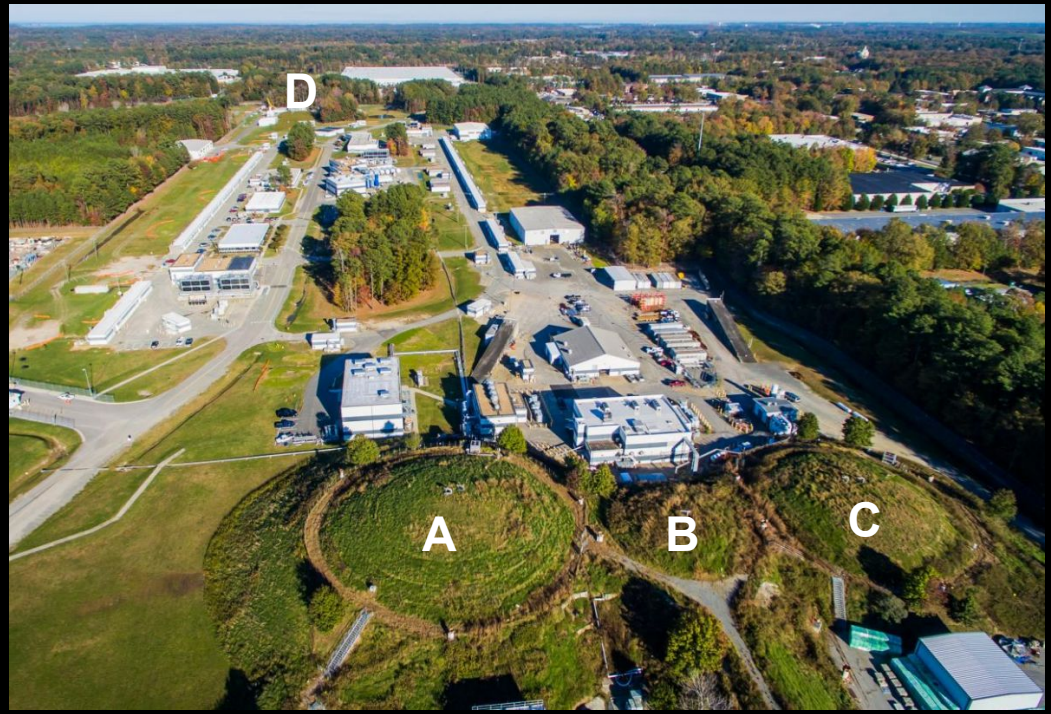
- g2p (2012),GEp (2012)

Hall B

- Eg1 (1999)
- Eg1b (2000)
- Eg4 (2004)
- Eg1-DVCS (2008)

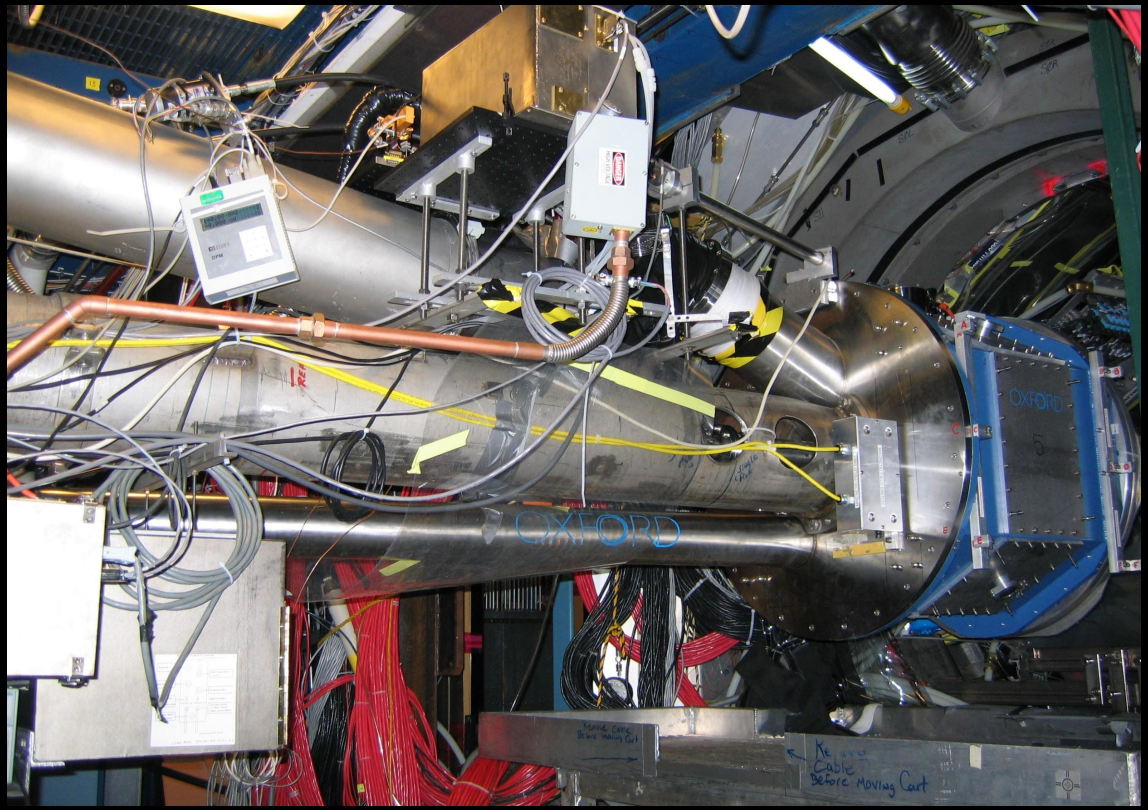
Hall C

- GEn (1998)
- GEn 2 and RSS(2000)
- SANE (2008)



The 6 GeV Polarized Target

Oxford Built, JLab Modified

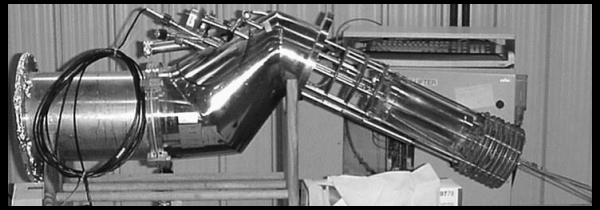


The 6 GeV Polarized Target

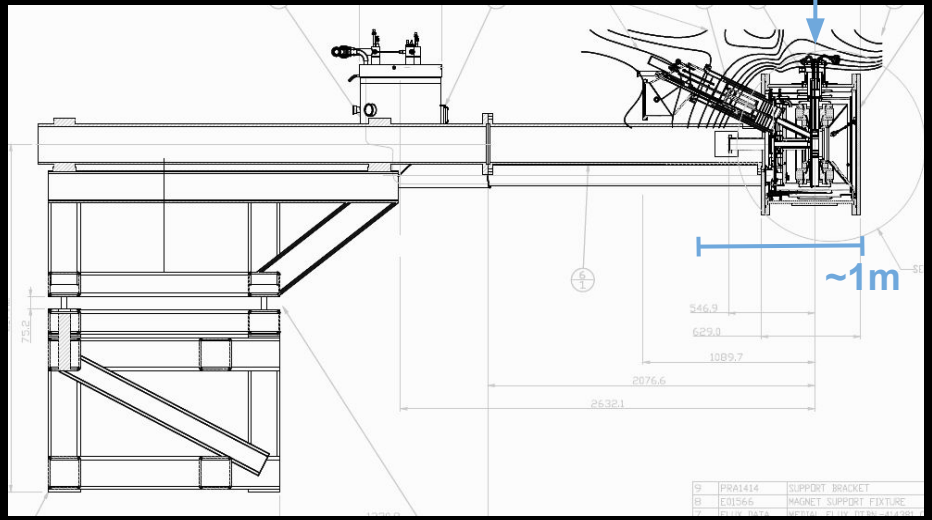
Oxford Built, JLab Modified

- Cantilevered Design
- Pump Tube at 30°⦜off beam line and attaches to 1 K Reservoir house between 5 T Split Coil Magnet
- Refrigerator installs in pump tube and shares a common 1 K Reservoir with a vertical Target Ladder (4 target)
- Fixed Microwaves
- Cleverly modified vertical refrigerator
- Magnet and target system share common Dewar supplied by the End Station Refrigerator (ESR) He liquidation plant

Modified Vertical Refrigerator



Target inserted here



Jefferson Lab

TARGET GROUP

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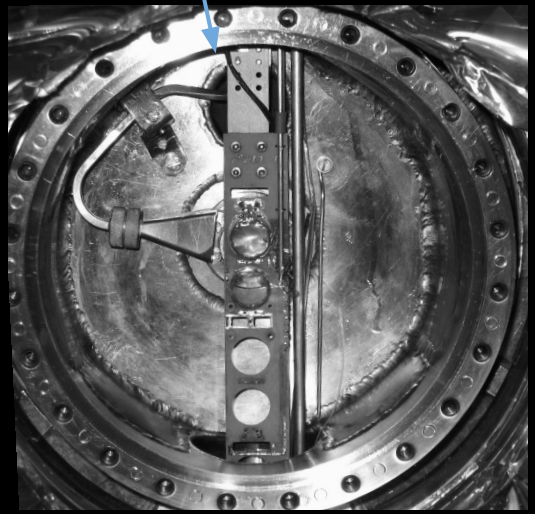
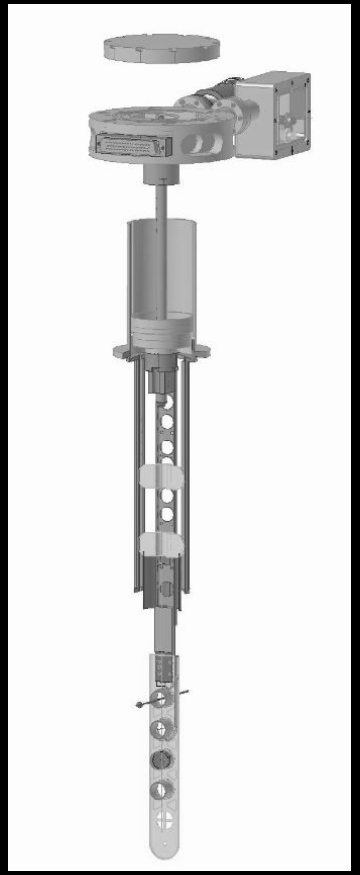
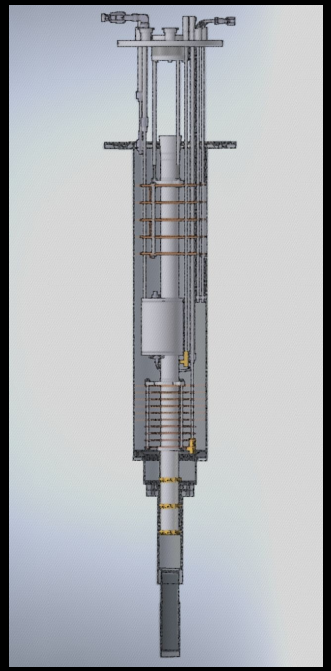


Target Insert



Vertical He^4 Evaporative Refrigerators

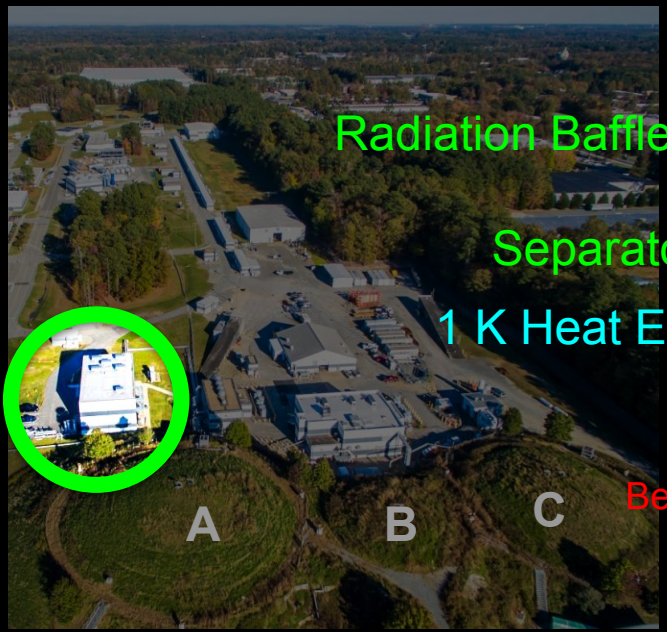


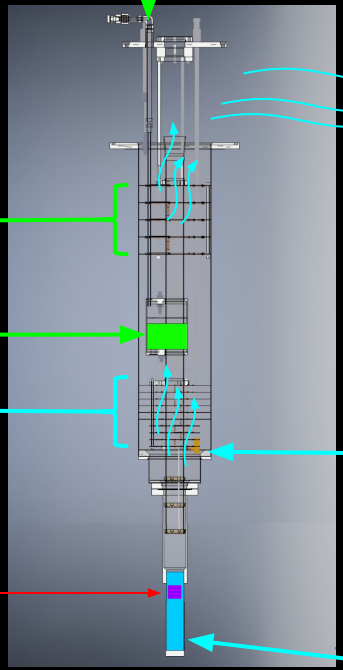
g2p/SANE Refrigerator

Vertical He^4 Evaporative Refrigerators

LHe From Buffer Dewar

JLab ESR Liquidation Plant fills Buffer Dewar (500 L typical)





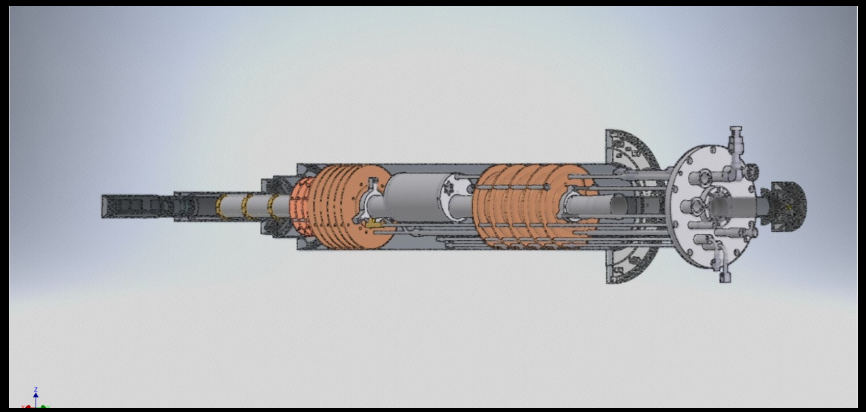
g2p/SANE Refrigerator

Target Material is Submerged in the 1 K Bath

Horizontal He^4 Evaporative Refrigerators

- Baffles Remains the same
- Separator Remains the same
- Heat Exchangers Remains the same
- 1 K Reservoir must have a Superfluid Tight seal or have Top Entery with Walls
- Can not load from the top as eg1, SANE, g2p refrigerator did.

  * We can load like FROST (Horizontal Dilution Refrigerator) although insertion tool would be too long.



Solid NH_3 DNP Target Material

NH_3 (melting point 195.5 K)

- Stored @ 77 K in Liquid Nitrogen
- $\rho NH3$ > LN ~ 0.807 g/ml
- Initial Irradiation Required to Create Polarization Center for DNP
- High Radiation Hardness
- Dilution Factor 17.6%
- Peak Polarization Drops with Additional Dose

Annealing NH_3

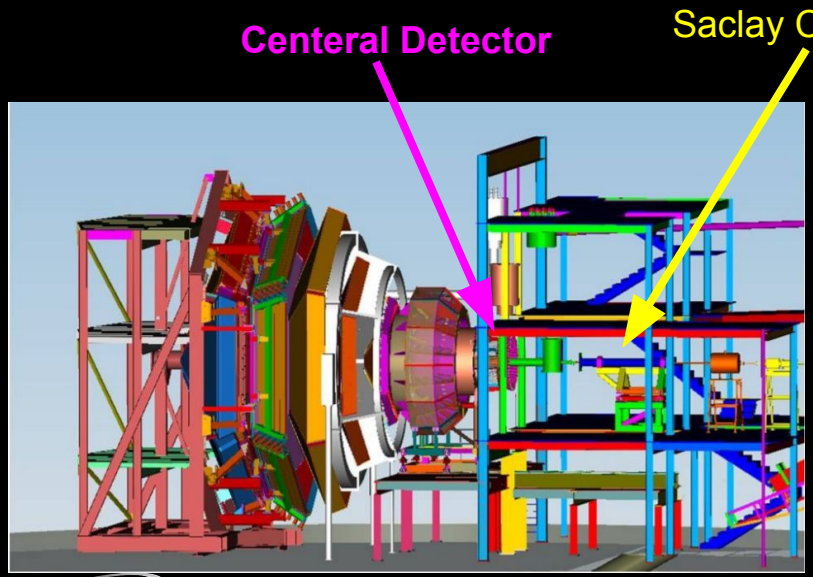
- Prescribed Time and Temperature
- Returns Material to previous

*Swapping Out Material and Annealing Off Line will be faster than Annealing in-sitsu with New Design

12 GeV POLTAR Polarizing Field and Target Constraints

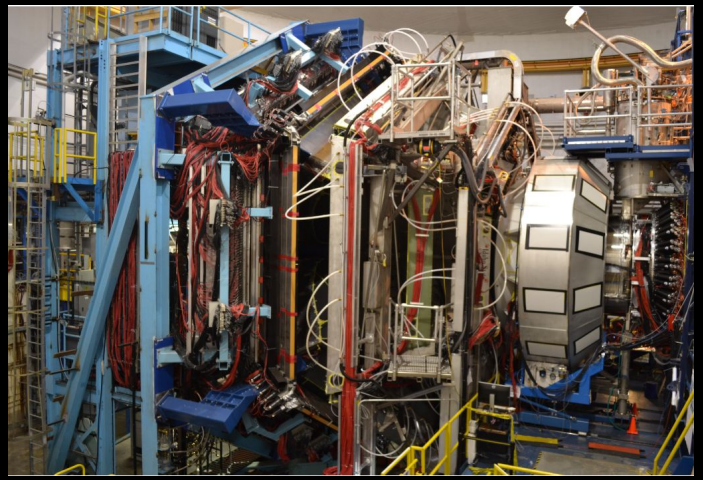
CLAS12 Space Restrictions

- Keep out Zone for SVT cart Ends 4.08 m Upstream
- SVT Internal ∅ 113.8 mm (4.48 in)
- Target Keep in ∅ 103.5 mm (4.088 in)
- 5 mm Radial Clearance



Fitting It All In

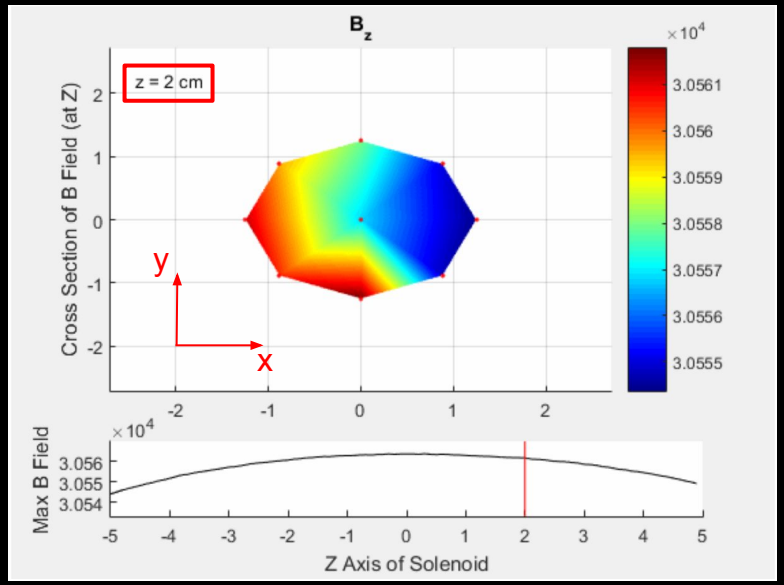
- Thin wall scattering chamber for IV
- Super insulation
- Radiant Heat Shield
- Pump Tube
- Microwave Waveguide
- NMR Coils
- 1 K He^4 Bath and Target



12 GeV POLTAR Polarizing Field and Target Constraints

Target Cell Length

- Target Length 20 to 60 mm



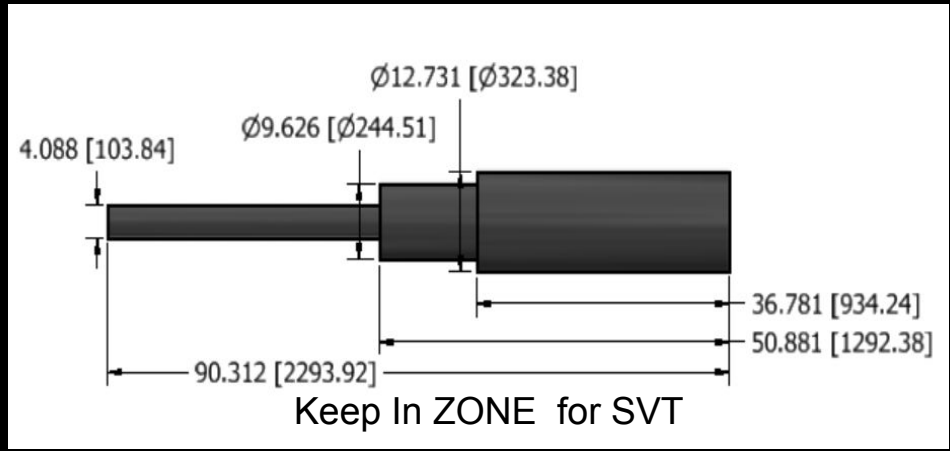
*Field maps provided by Victoria Lagerquist - ODU

Refrigerator Diameter

- 103.5 mm
- Radial distance to contact with SVT 5 mm

Refrigerator Length

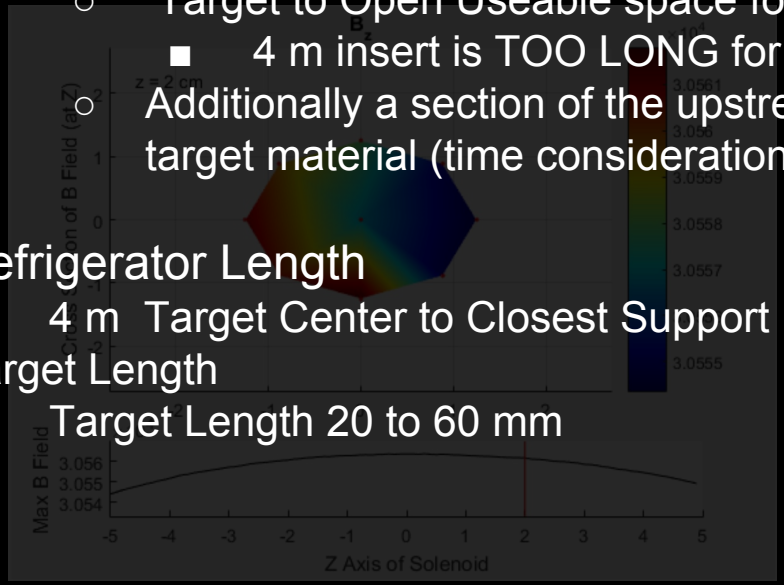
- 2.3 m to clear the SVT
- 4 m Target Center to open area for Beam Line Cart



12 GeV POLTAR Polarizing Field and Target Constraints

The new design will be limited to targets located along the beam line

- This requires frequent target changes
- Can not use FROST Style Removable Insert (FROST Insert wast ≳ 2 m Long)
  - Target to Open Useable space for CLAS12 must be ≳ 4 m)
    - 4 m insert is TOO LONG for most anyone
  - Additionally a section of the upstream beamline must be moved/remove to swap target material (time consideration)

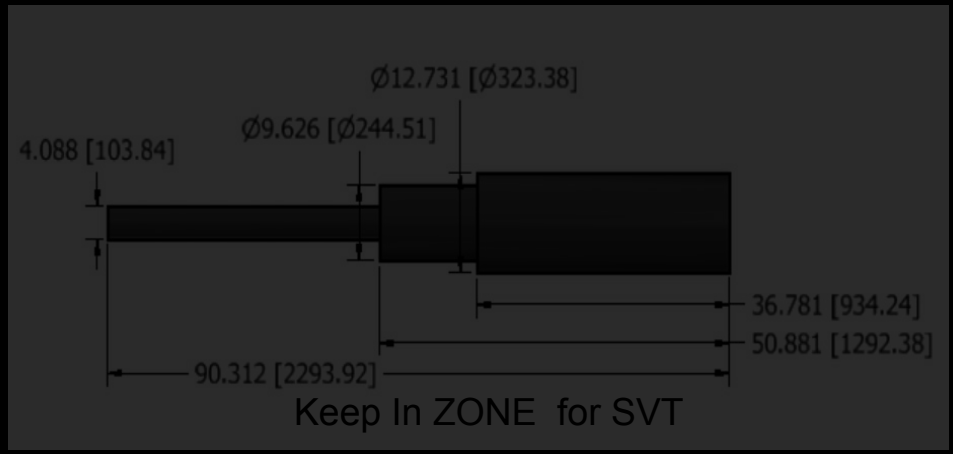


Refrigerator Length

- 4 m Target Center to Closest Support

Target Length

- Target Length 20 to 60 mm



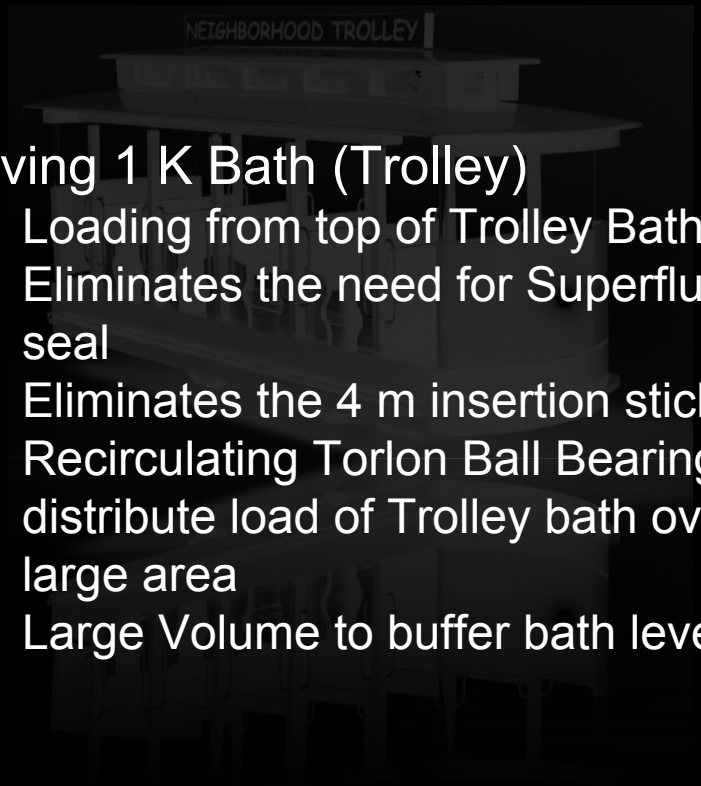
Solution 4 m Long insertion stick and a superfluid seal?

12 GeV POLTAR Target Design

Moving 1 K Bath (Trolley)

- Loading from top of Trolley Bath Eliminates the need for Superfluid seal or dismantling of the Fridge
- Eliminates the 4 m insertion stick
- Recirculating Torlon Ball Bearings distribute load of Trolley bath over large area
- Large Volume to buffer bath level

12 GeV POLTAR Target Design



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https://www.youtube.com/watch?v=22PTbdC2sjw

12 GeV POLTAR Target Size

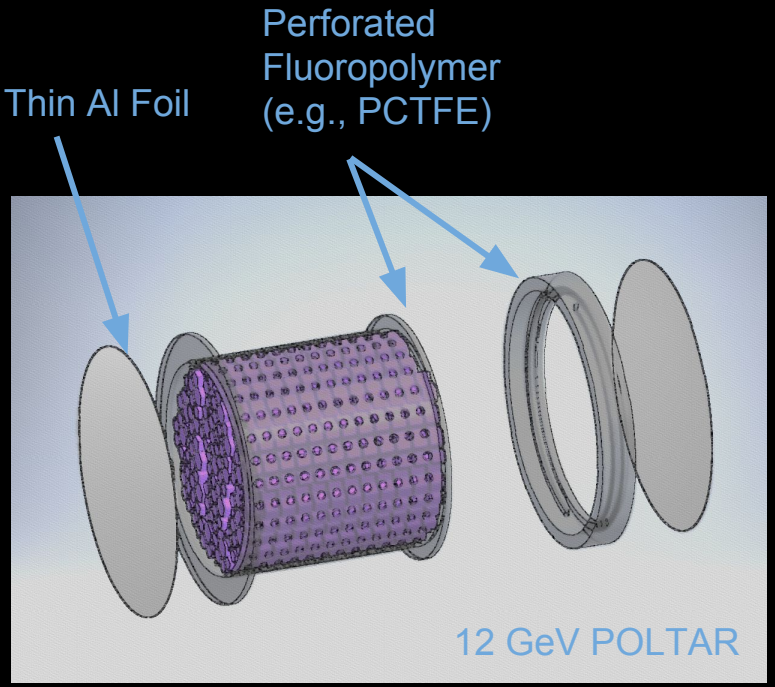
Target Diameter = 20 mm

Maximize Target Size
- Rastered Beam Size Reduces Local Dose
- Target Length luminosity

Target Length
- Target Length 20 to 60 mm
- Or Two…

Fill Factor Improved
- Consistency Between (Fill Target Cartridges Offline not Time Constrained)

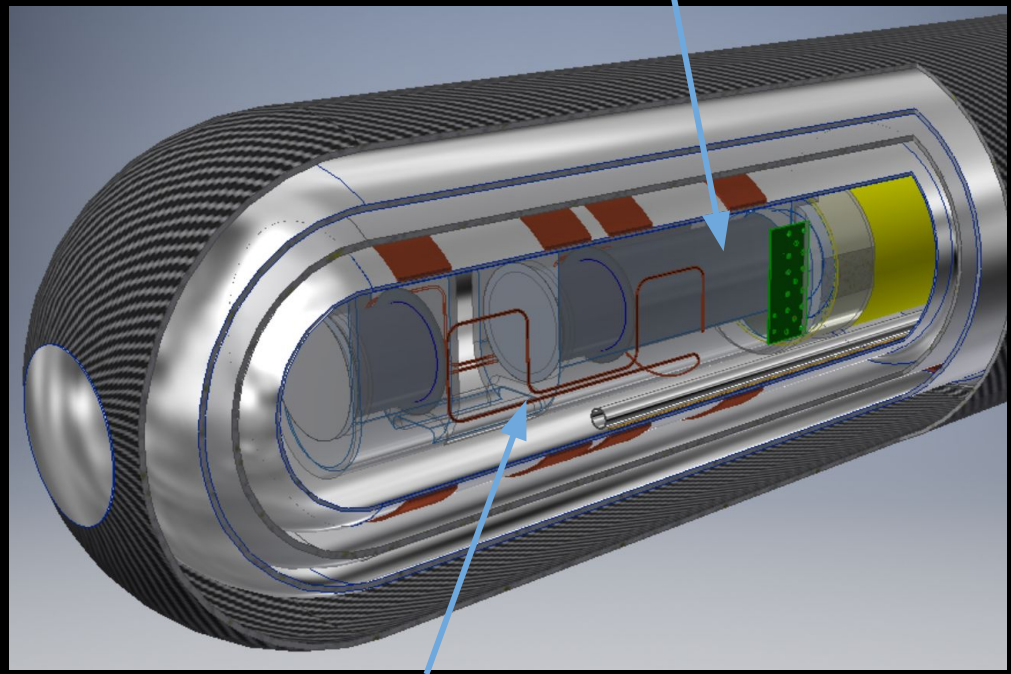
Annealing
- Possible Offline (Less Beam Down Time)



12 GeV POLTAR Target Design

Implication from Trolley and Cartridges

- NMR Coil(s) and System External to Target Material, Insert, and Bath
  - Bath Narrows @ Target Cell(s)
  - NMR Coil(s) Close Proximity to Material
- Microwave Waveguide(s) External to Target Insert



12 GeV POLTAR Target Design

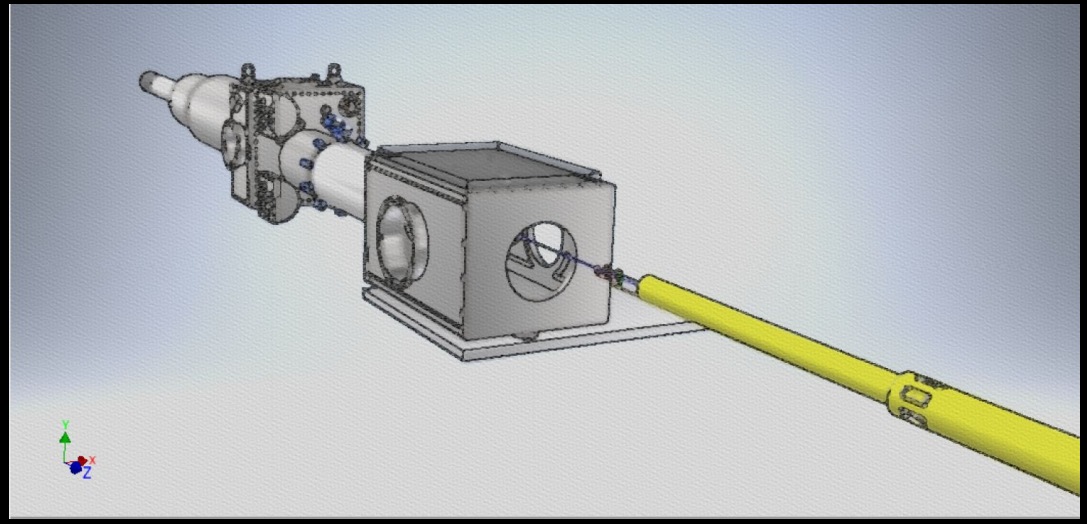
Trolley Tracks

NMR and Microwave Insert Doubles as Trolley Track

- Thin Wall Nested tubes
- Removable from rear flange of Pump Tube
- Easily Serviceable

Implications

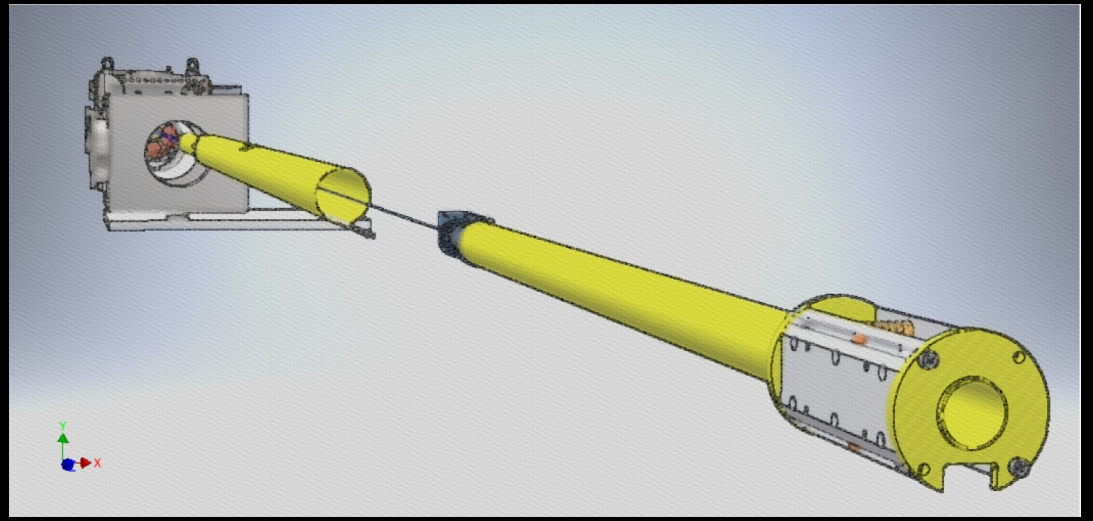
- No Central tube to build off of
- Need other Structure for HX, Baffles, and Separator Mounting



12 GeV POLTAR Target Design

1K Bath Trolley Also Removable

- Remove from rear of Trolley Track/NMR & Microwave Insert
- Serviceable
- Reconfigurable



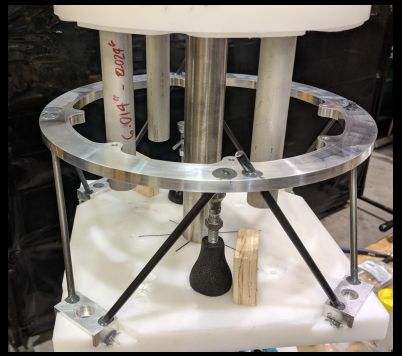
12 GeV POLTAR Target Design

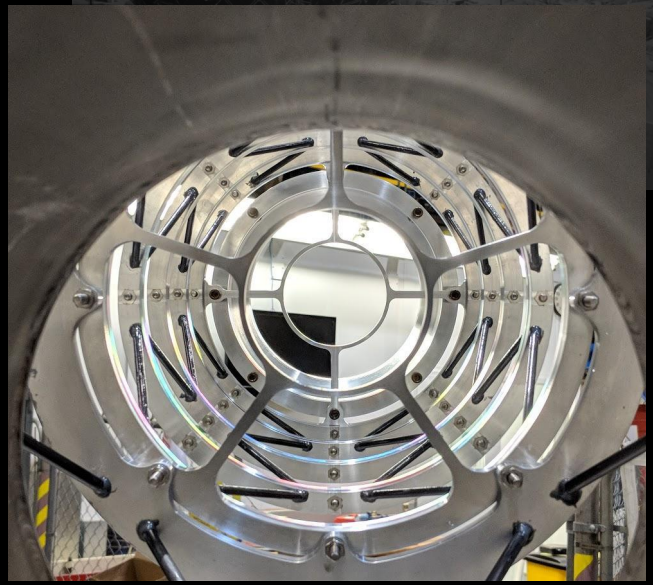
Modular Geometric Truss structure

- Carbon Fiber Pultruded Rods
- Assembly fixture HDPE
- Precision Ground Tool Steel Rod ∅1.5 in
- Tight Tolerance < 75 µm

Very lightweight very strong

- 430 g Unit Mass
- 500 lbf (230 kg) Axial Load
- 200 lbf (90 kg) Shear Load

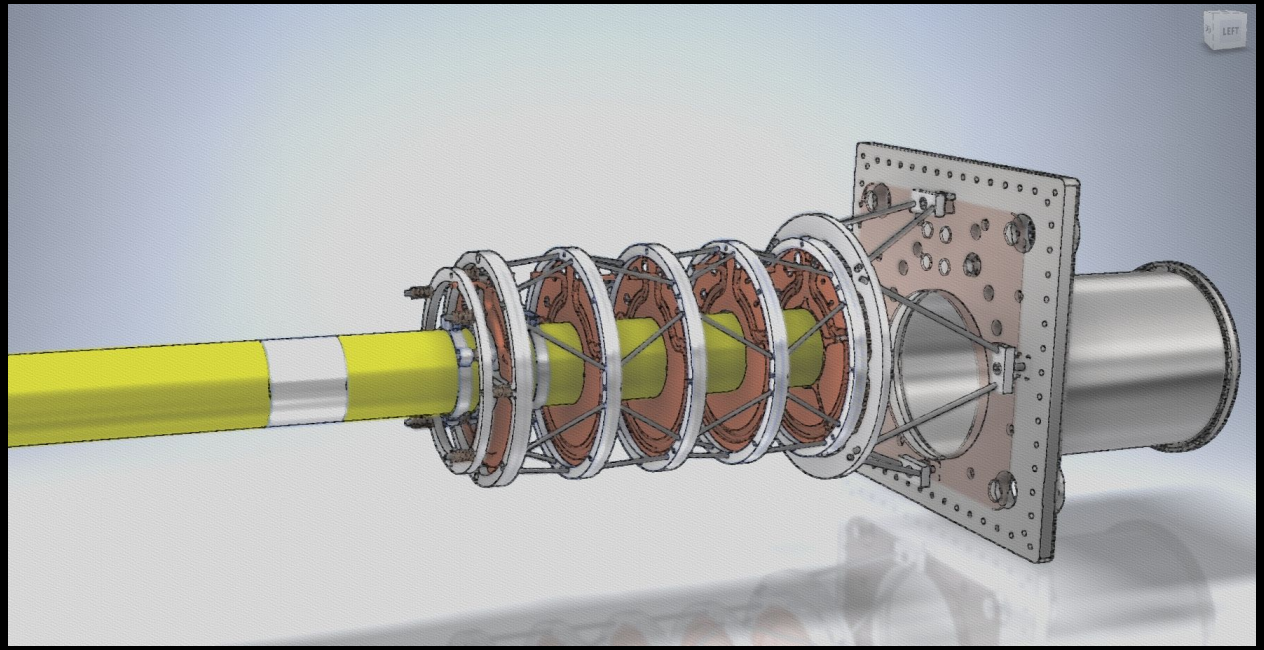




12 GeV POLTAR Target Design

Modular Geometric Truss structure

- Everything is supported by the Backplate of the Refrigerator
- Modular Unit Structure perfectly segmented to hold Baffles



12 GeV POLTAR Target Design

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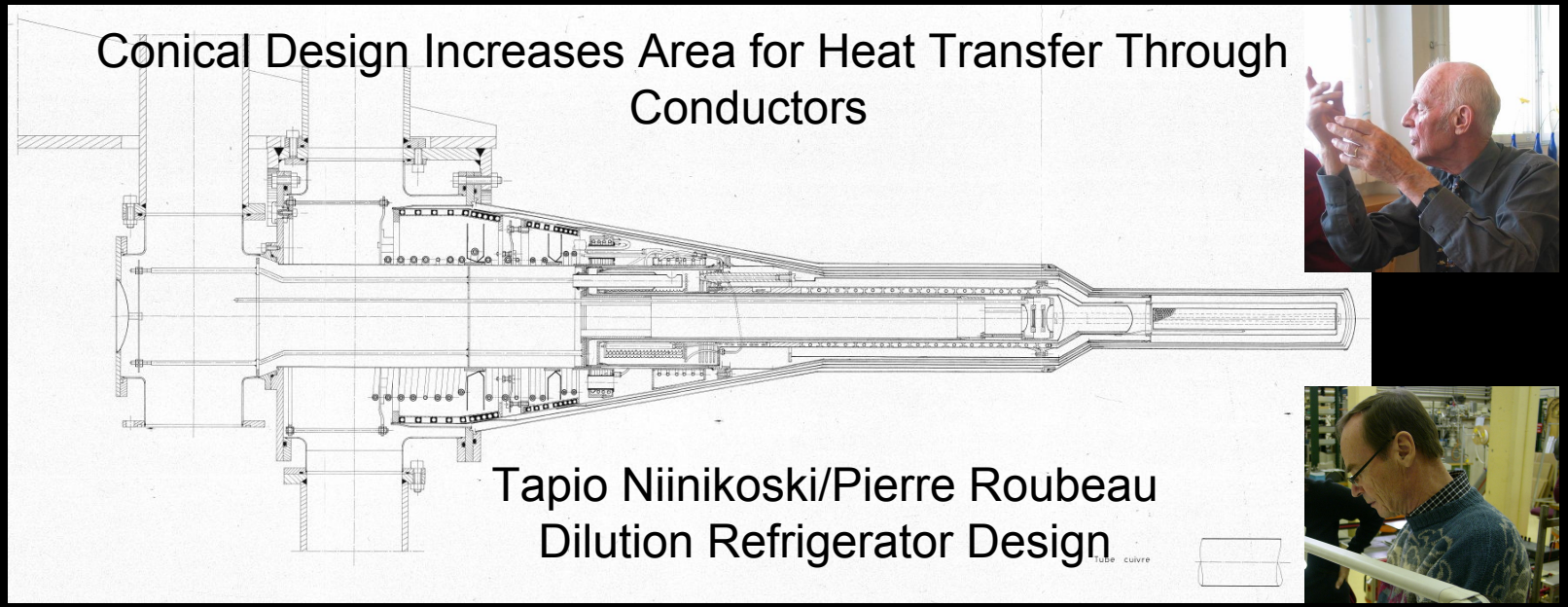
12 GeV POLTAR Target Design

Conical HX/Heat Shield Heat Sink

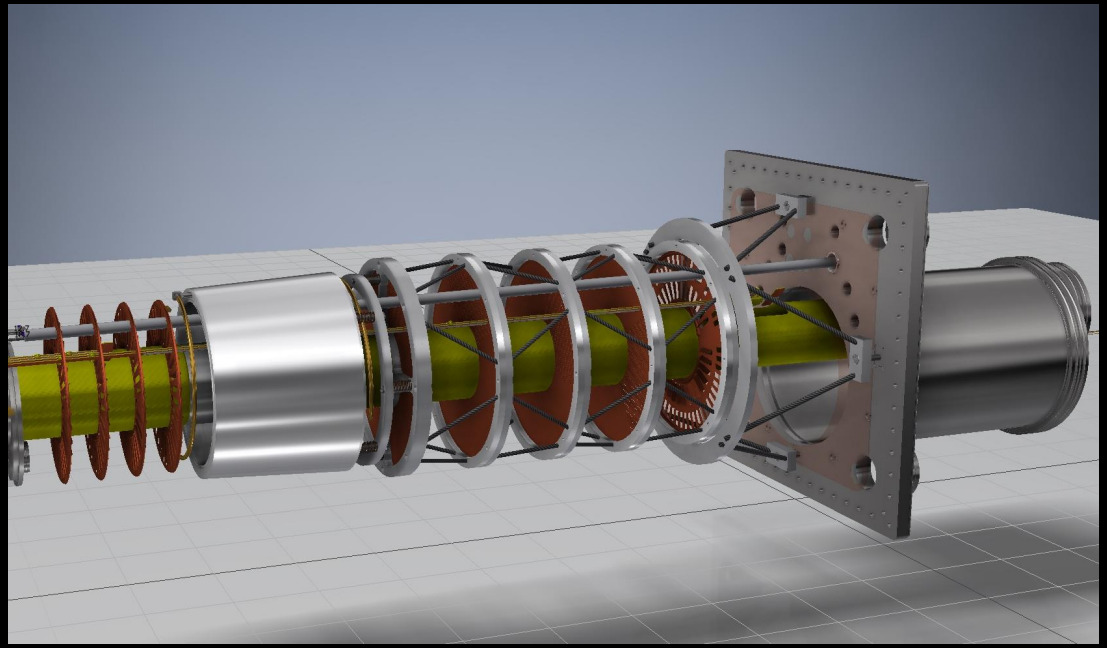
Exhaust He gas(boil off) from the separator cools a conical section of the Pump Tube for the 1K Pot. A radiation heat shield is soldered to the outside of this section thereby utilizing the enthalpy of the exhaust gas.



12 GeV POLTAR Target Design

Modular Geometric Truss structure

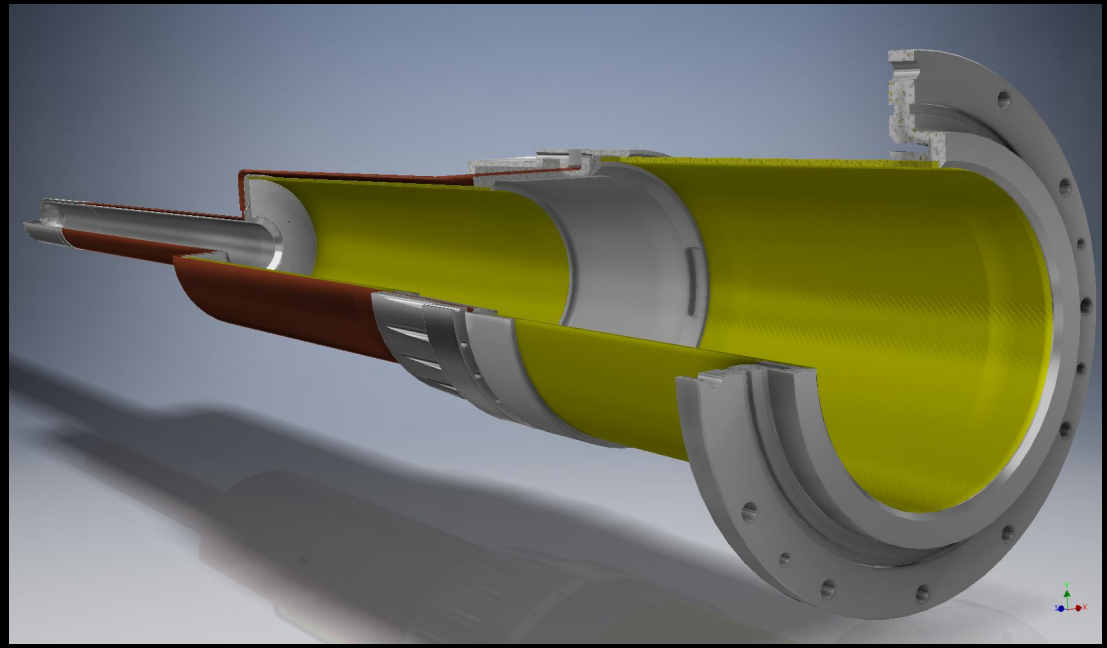
- Conical HX Spring loaded into Pump Tube to ensure good thermal contact with Pump Tube Heat Sink
- All Refrigerator Components are modular and can be uncoupled without cutting or grinding of parts



12 GeV POLTAR Target Design

Pump Tube

- G10/Al 6061 Tube
- Epoxied Joints
- Maintain Tolerance better than welds
- 10 in ID Custom Laminated G10 tube with intra-laminated 316 Stainless Steel foil



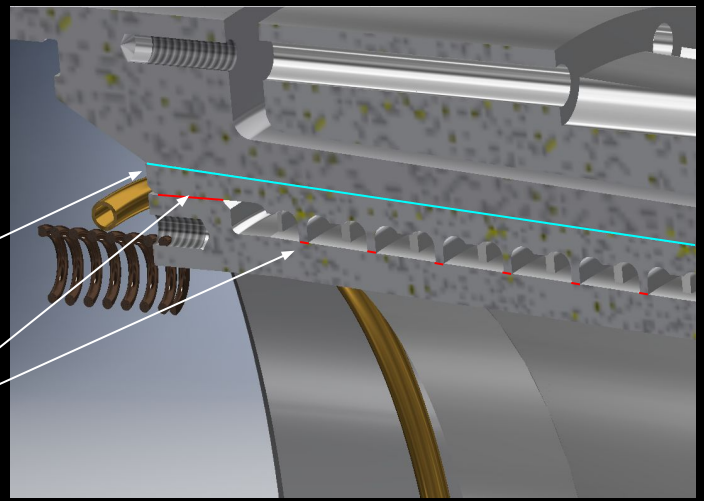
12 GeV POLTAR Target Design

Aluminum 6061

- Thermal Conductivity @ 80 K ~ 100 (Wm-1K-1)
- Ultimate tensile strength > 290 MPa (42,000 psi) and increases as T decreases
- Yield strength > 240 MPa (35,000 psi) also increases as T decreases

Epoxy 3M DP190 Gray

- Etched Aluminum Overlap Shear Strength 2500 psi (17.2 MPa)
- Epoxy Wetted and Abraded Aluminum



Apiezon Type N

3M DP190 Gray
Adhesive Epoxy
Highlighted in Red

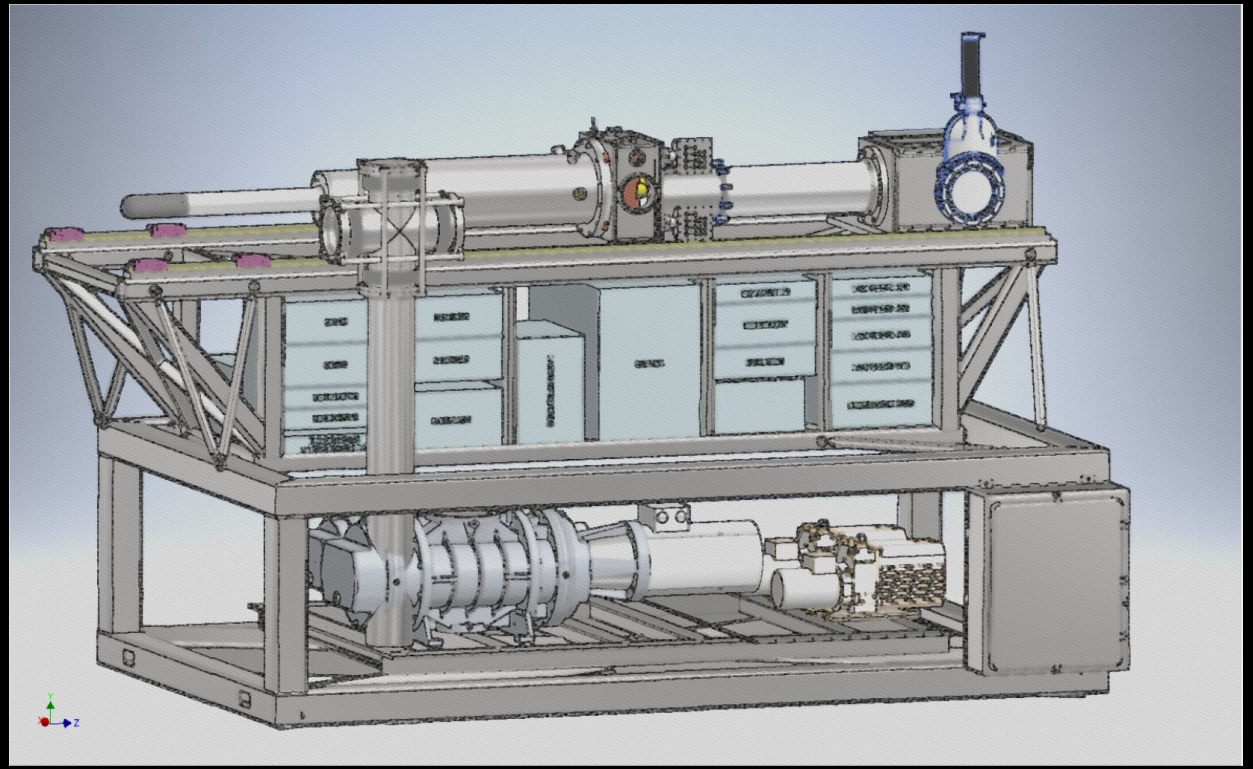
Jefferson Lab

TARGET GROUP

12 GeV POLTAR Plug and Play Target

Transportation Configuration

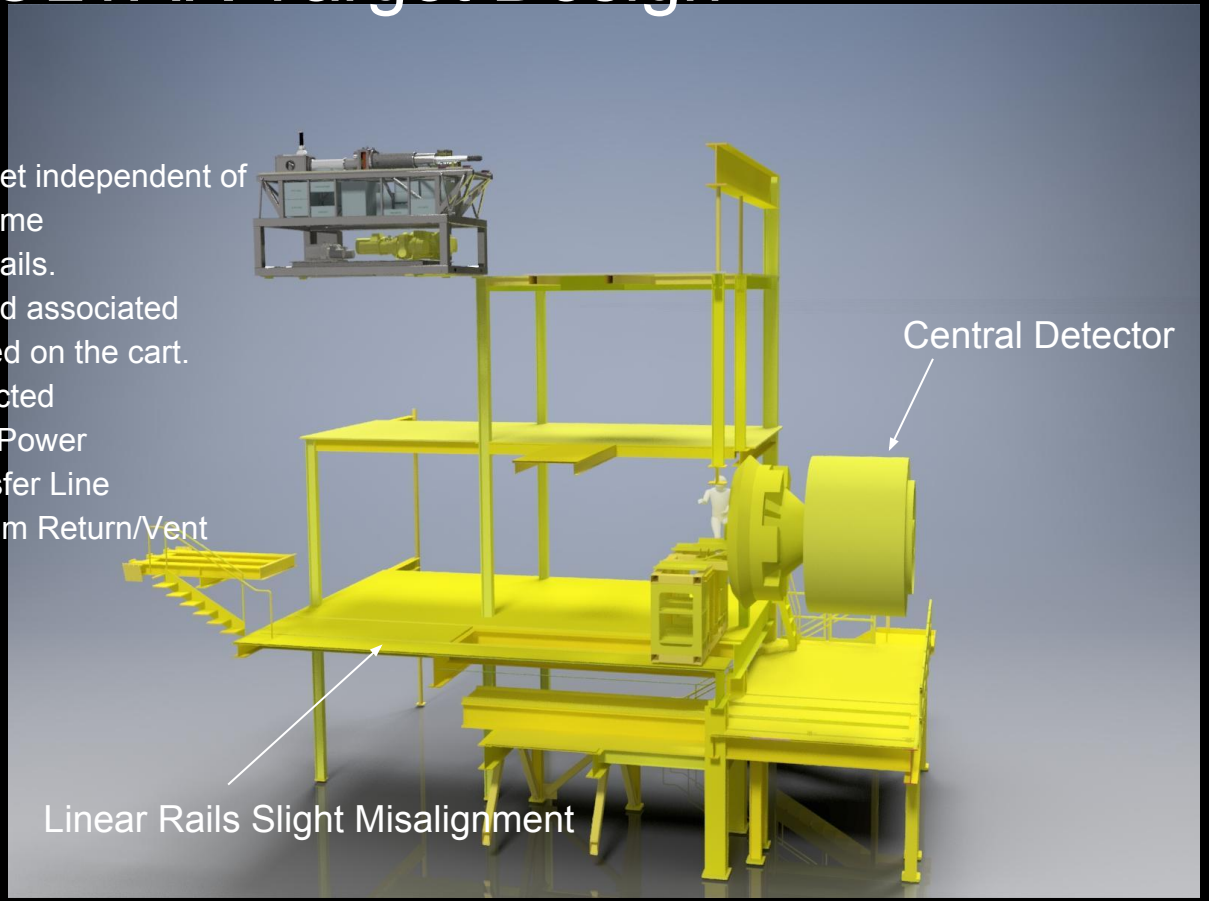
- Refrigerator Retracted Over Cart
- Isolation Valve for Refrigerator
- Modeling Complete Target System Allows Strategically Place Lifting Points Based on COG



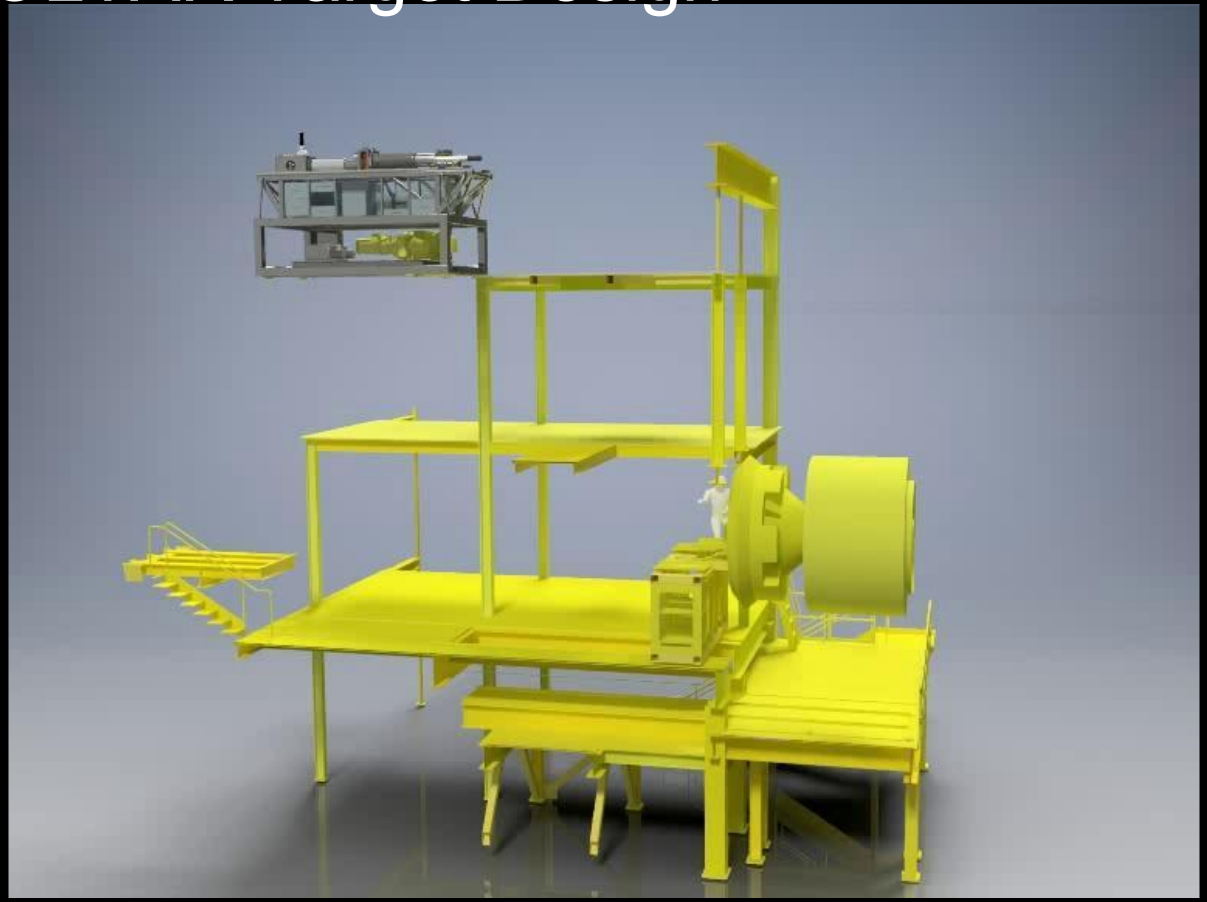
12 GeV POLTAR Target Design

Installation

- Alignment of target independent of Hall B Space Frame Superstructure Rails.
- All electronics and associated equipment housed on the cart.
- Line to be connected
  - 3 Phases Power
  - LHe Transfer Line
  - ESR Helium Return/Vent



12 GeV POLTAR Target Design



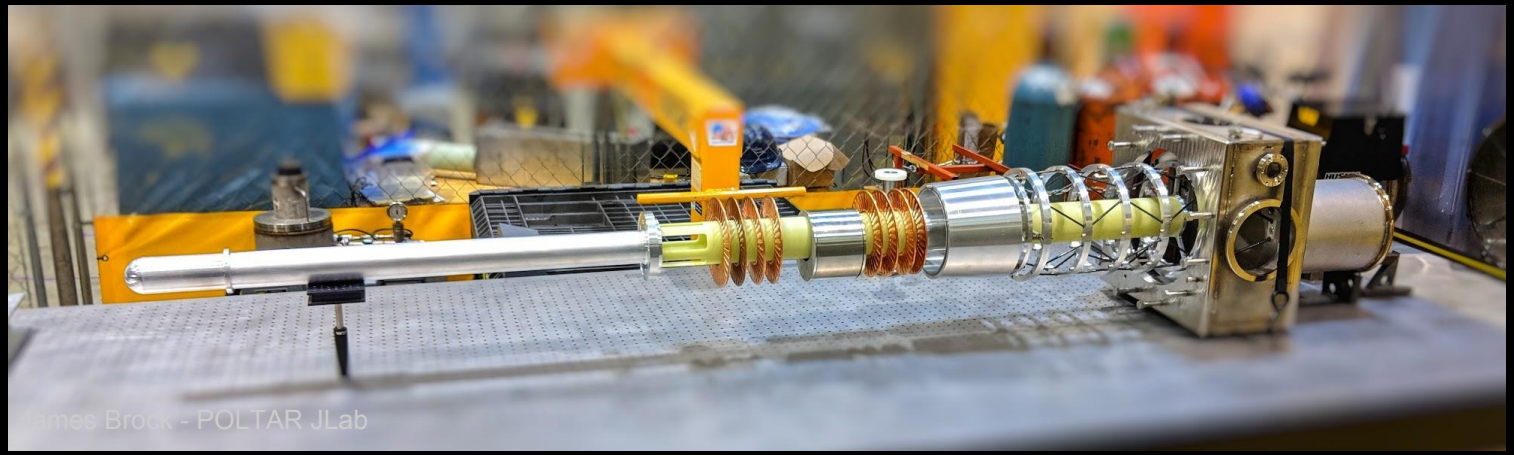
https://youtu.be/6DJA5Ik0NrA

12 GeV POLTAR Target Design

- Target Material Loading/Changing Faster Now with Trolley and Cartridges
  - Rad Damage Material Can be Annealed Offline
- Modular Refrigerator Design Can Be Easily Modified
  - Target Geometry can easily be changed by swapping out Trolleys
  - NMR/Microwave configurations swappable as well
  - Shim Coil Carrier (not mentioned) swappable as well
- Entire 12 GeV POLTAR Install Time ~8 hrs (One Shift)
  - Plug and Play

THE END

Construction Status



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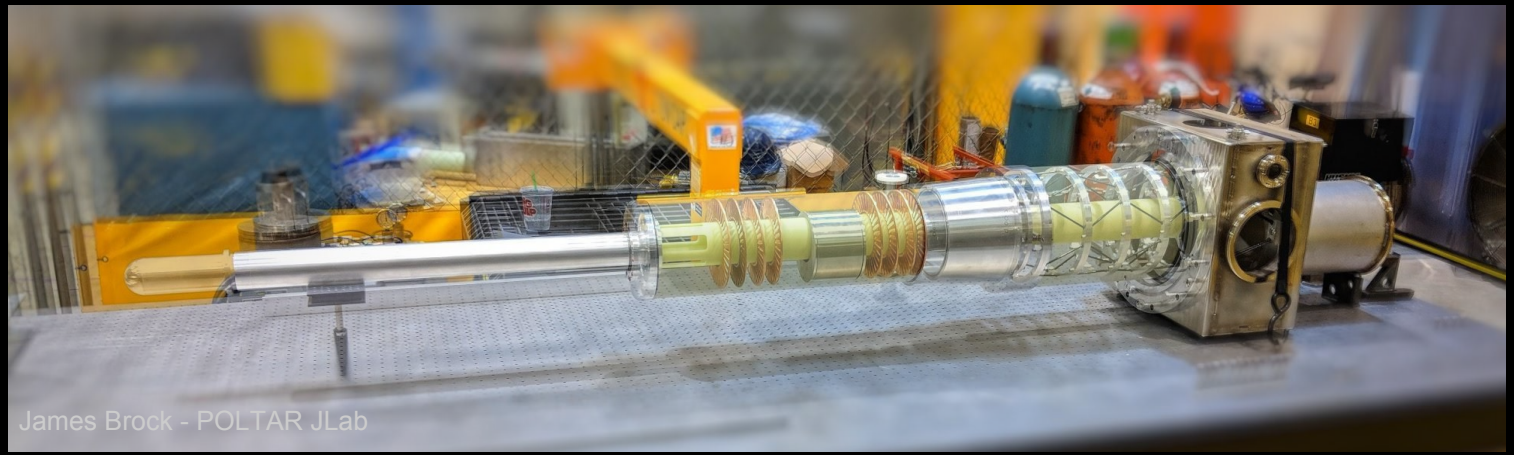

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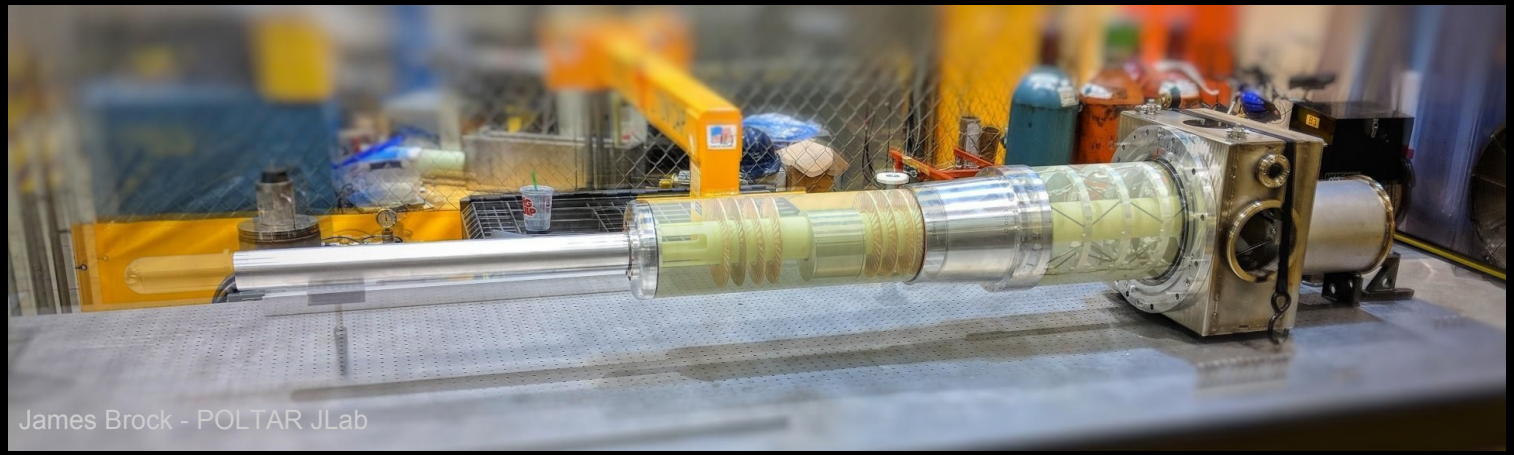

Construction Status

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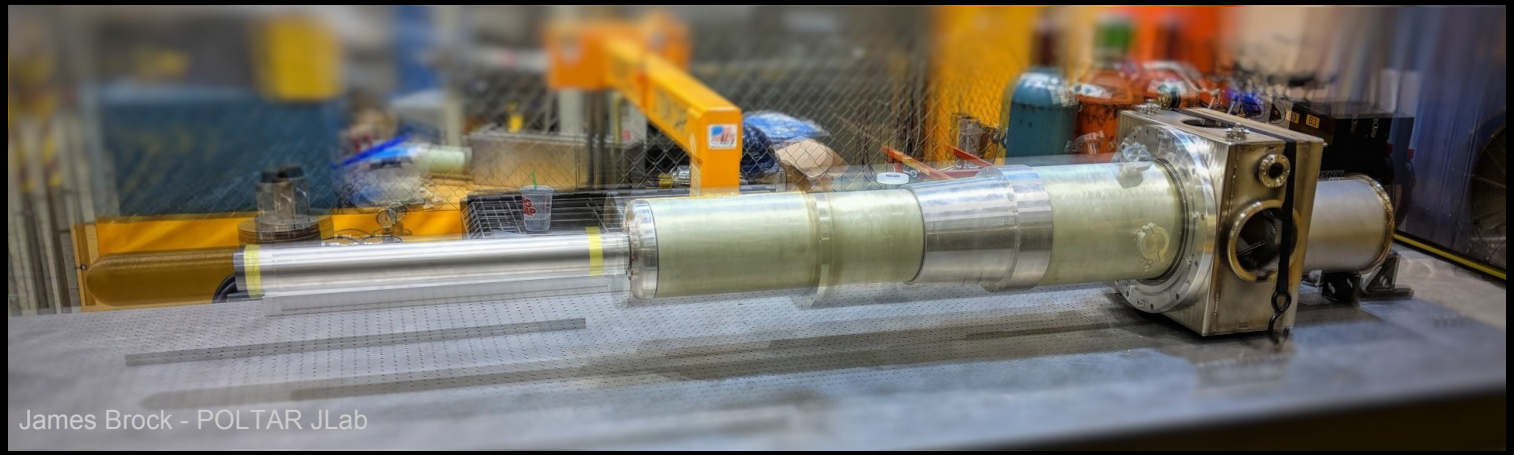


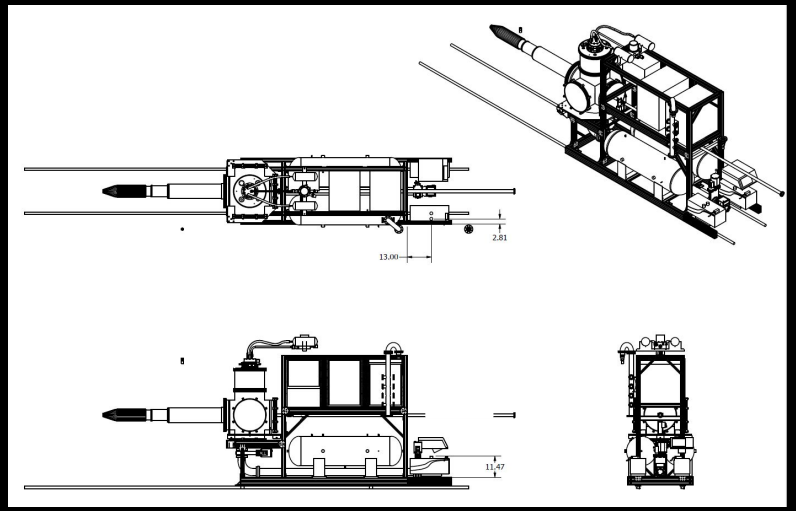
Construction Status

Construction Status

Plug and Play Target

Self Contained Target Cart

- Alignment System
- Electronics
- Gas Panel and Tanks
- Target
- Vacuum System



- Target system is mobile and modification in between experiments can be made and tested as configured on beam line.
- Installation time reduced from weeks to days. In a pinch 1 shift.

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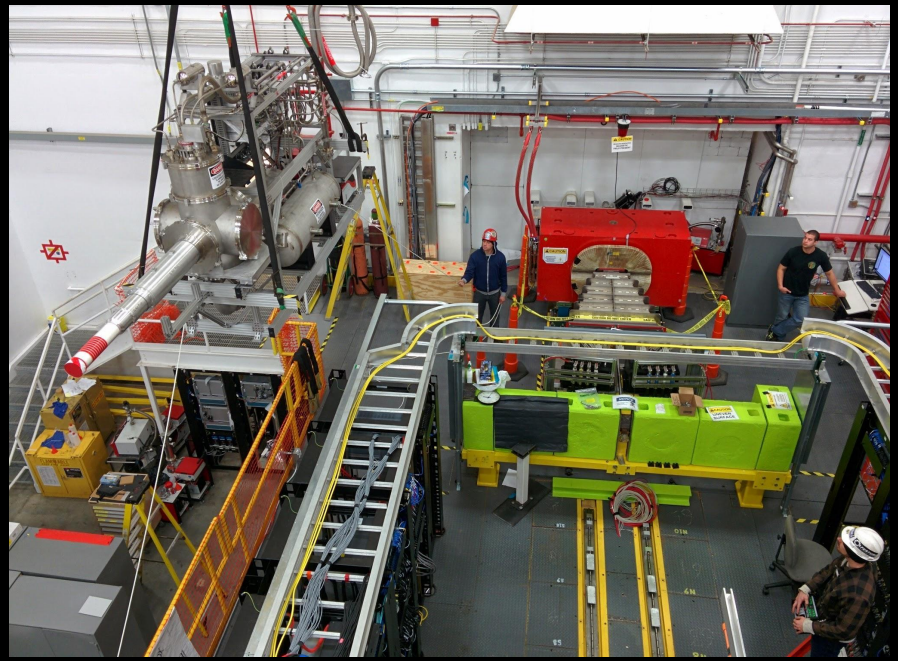
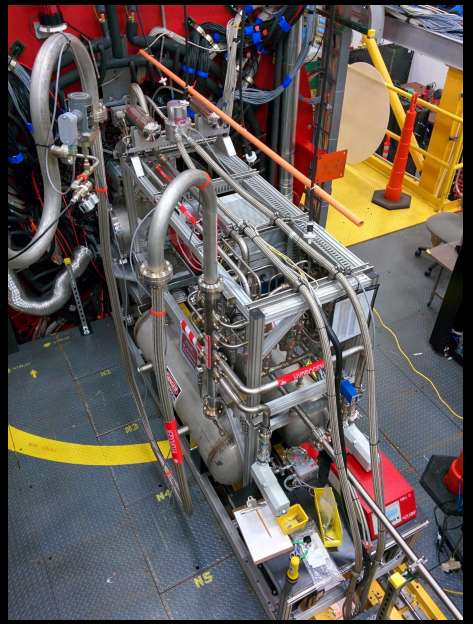
Plug and Play Target



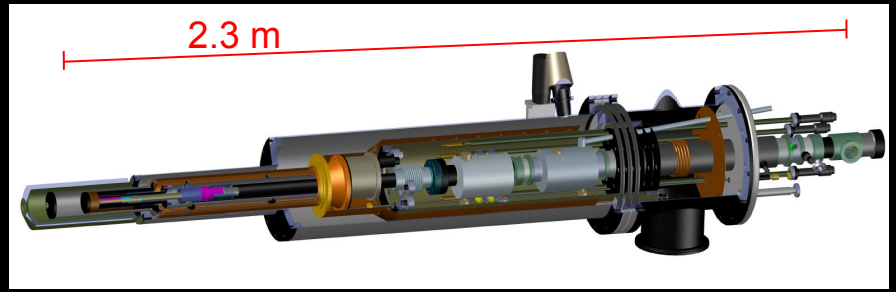


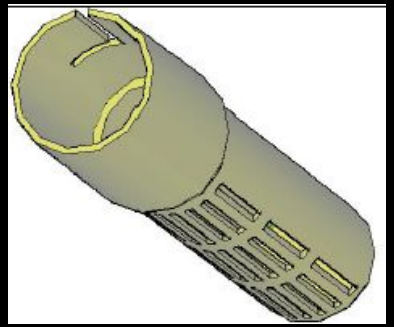
Hall D Installation Photos

Loading Frost Target

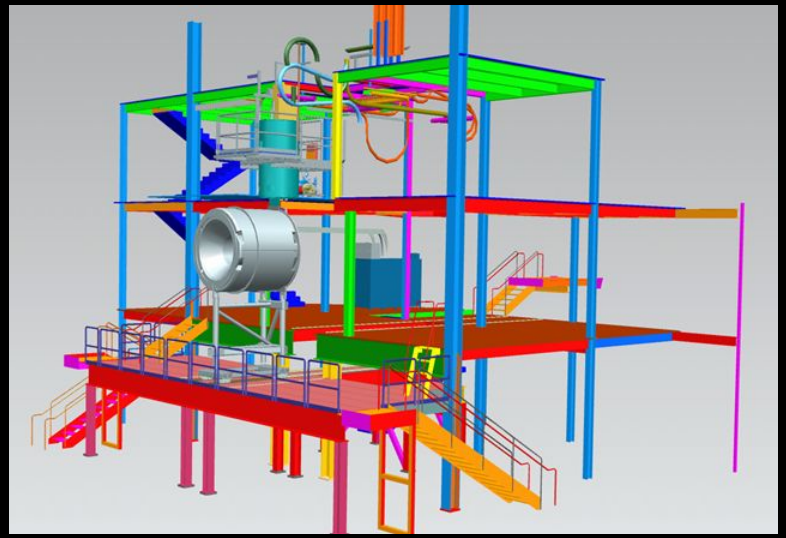
FROST

- Horizontal dilution refrigerator
- Tempo doped Butanol loaded in LN2 (different material not Rad Hard)
- Cam Locked Kel-F (PCTFE) Cell over Aluminum entrance window (worked very well)
- Superfluid Tight Seal Mechanism (worked wonderfully but complicated)
- Insertion Tool 2.3 m Long (unwieldy)

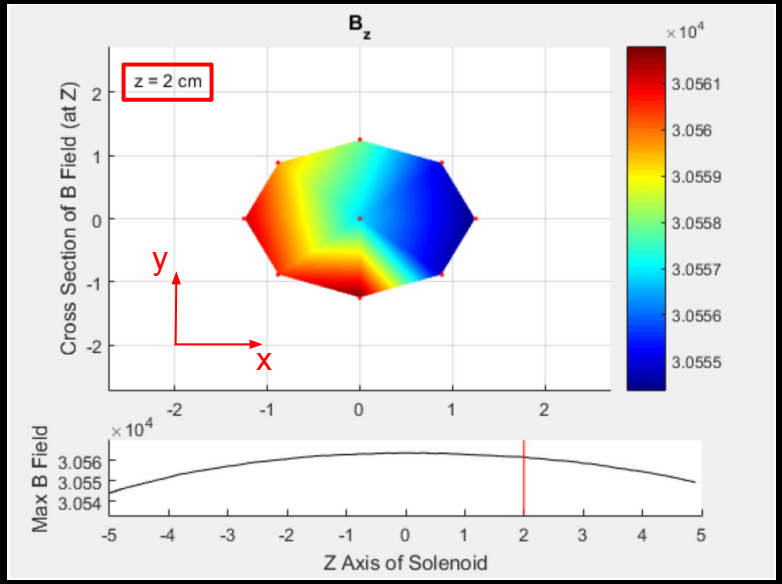




CLAS12 Solenoid



View of the CD Solenoid from down stream beam feft.



*Field maps provided by Victoria Lagerquist - ODU

A 5T Solenoid is incorporated into the Central Detector and will provide the polarizing field for the 12 GeV Polarized Target.

Inside the solenoid are two detectors. The CTOF and SVT severely restrict the volume for the Polarized Target, the “Keep In Zone”

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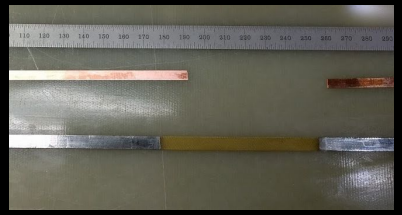
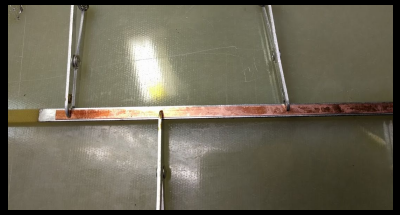
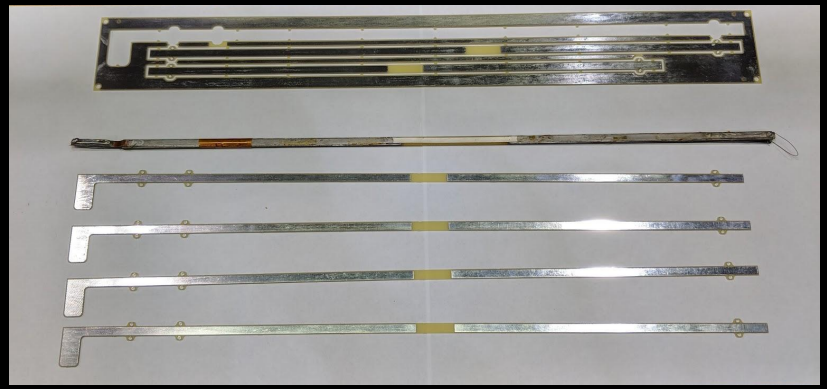
Shim Coil Magnet Leads

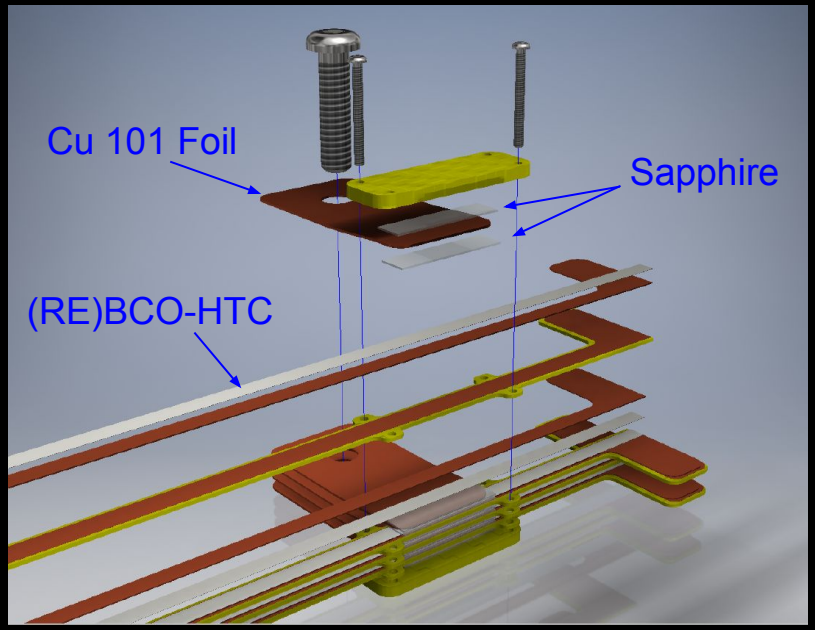
PCB layered Construction

- HTC Leads solder to Cu C101 with woods metals
- Slack points are left unsoldered along Lead run for thermal motion
- C101 bridges the G10 segments
- 3 m long









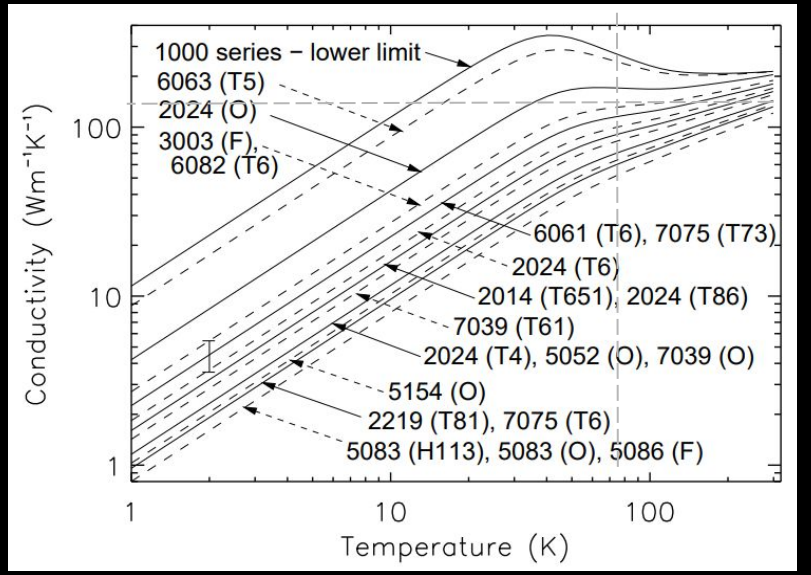
SuperPower Inc. (Furukawa Subsidiary) Wire SF4050-AP

- Critical Bend Diameter = 11 mm
- I_c minimum = 80 Amps
  - 480 A/cm at 4.2K, 10 T
  - 540 A/cm at 40K, 3 T
- 4 mm x 0.055 mm
- Soldered to substrate with Wood's Metal (Bi 50%, Pb 25%, Sn 12.5%, Cd12.5%) T_c= ~ 8 K, B_c= 12 T, Resistivity (1^{-8} Ω m) at 20ºC = 52, at 77K = 19.3

12 GeV POLTAR Target Design

Aluminum 6061
- Thermal Conductivity @ 80 K ~ 100 (Wm-1K-1)
- Ultimate tensile strength > 290 MPa (42,000 psi) and increases as T decreases
- Yield strength > 240 MPa (35,000 psi) also increases as T decreases

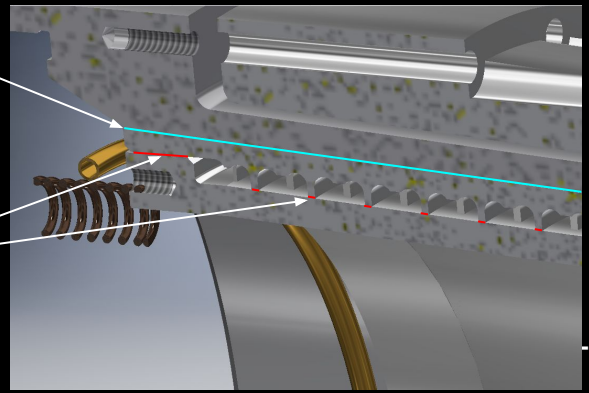
Epoxy 3M DP190 Gray
- Etched Aluminum Overlap Shear Strength 2500 psi (17.2 MPa)
- Epoxy Wetted and Abraded Aluminum



Woodcraft, A.L. 2005. Predicting the thermal conductivity of aluminium alloys in the cryogenic to room temperature range. Cryogenics 45 (6) 421-431

Apiezon Type N

3M DP190 Gray
Adhesive Epoxy
Highlighted in Red



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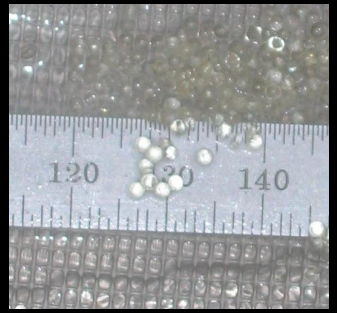
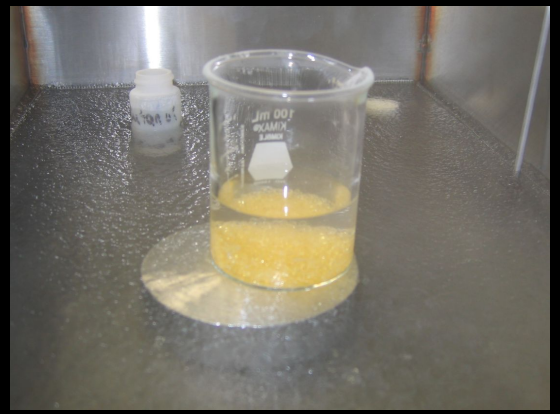
DNP Target Materials used at JLab

Physical properties target material pose some problems.

- NH_3 (melting point 195.5 K)
  - ρ_{NH3} > LN ~ 0.807 g/ml
  - Create polarization center via irradiation
  - High Radiation Hardness
  - Dilution Factor 17.6%
- Butanol (melting point 183.1 K)
  - Butanol + 5% H_2O + 5% Tempo
  - Add polarization center via chemical doping
  - Moderate Radiation Hardness
  - Dilution Factor 13.5%
- LH (melting point 962 K)
  - Reacts with H_2O in air
  - Create polarization center via irradiation
  - Very High Radiation Hardness
  - Dilution Factor 25%





*Including deuterated species of the molecules. Deuterated molecules almost double the dilution factor but polarization drops by about half.

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