

1 K refrigerator for the CLAS12 Polarized Target

Design, Construction, and First Results

The 6 GeV 1 K Polarized Target

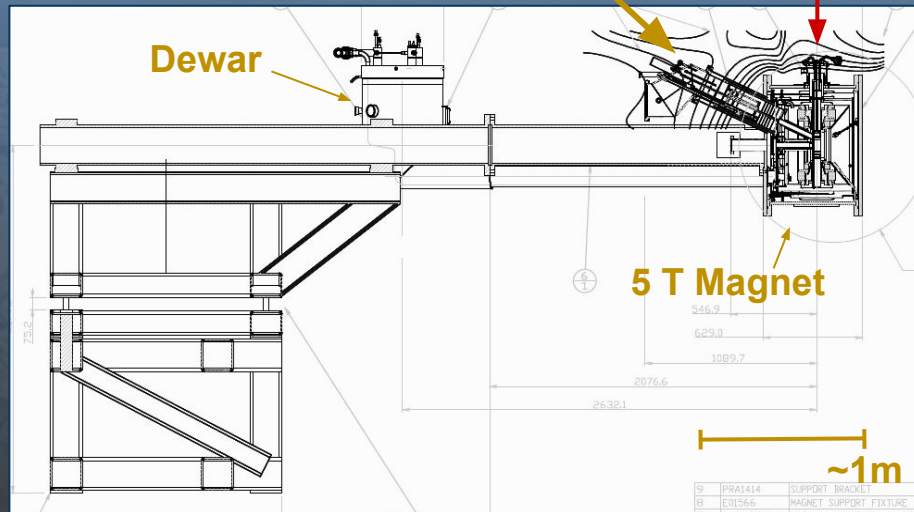
Oxford Built, JLab Modified

Modified Vertical Refrigerator

- 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 targets)
- Fixed Microwaves
- Cleverly modified vertical refrigerator
- Magnet and target system share common Dewar supplied by the End Station Refrigerator (ESR) He liquidation plant



Target
inserted
here



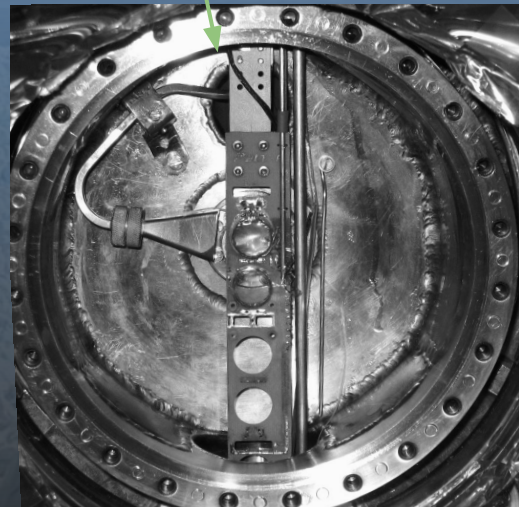
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No Superfluid Seal for Reservoir

Pump Tube



1K Bath Volume

Target Insert



The 6 GeV 1 K Polarized Target

Oxford Built, JLab Modified

NH_3 (melting point 195.5 K)

- Stored @ 77 K in Liquid Nitrogen
- $\rho_{\text{NH}_3} > \text{LN} \sim 0.807 \text{ g/ml}$
- 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

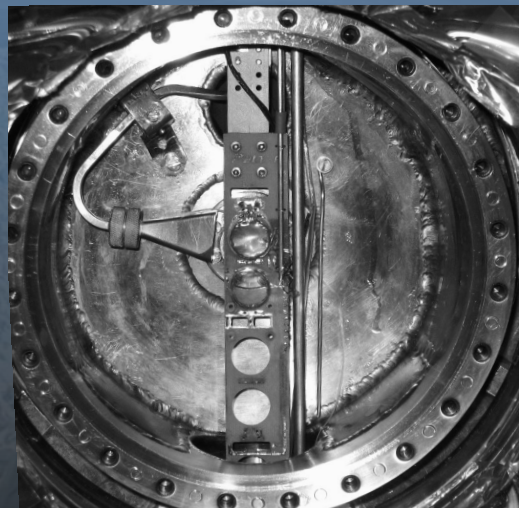
- Prescribed Time and Temperature
- Returns Material to previous

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

No Superfluid Seal for Reservoir



Irradiated NH_3



1K Bath Volume

CLAS12

Space Restrictions

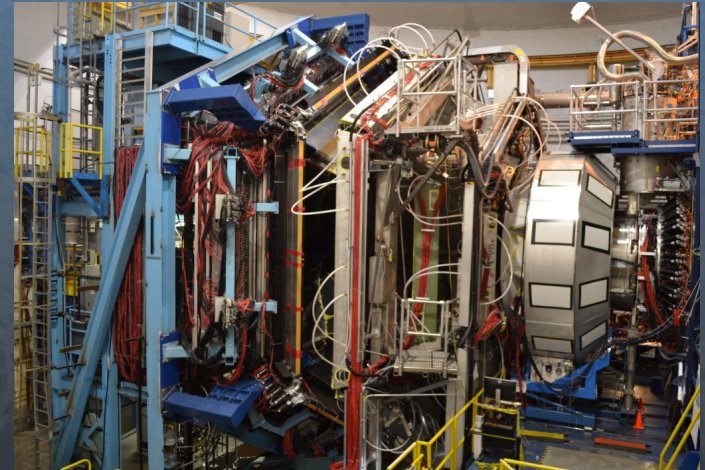
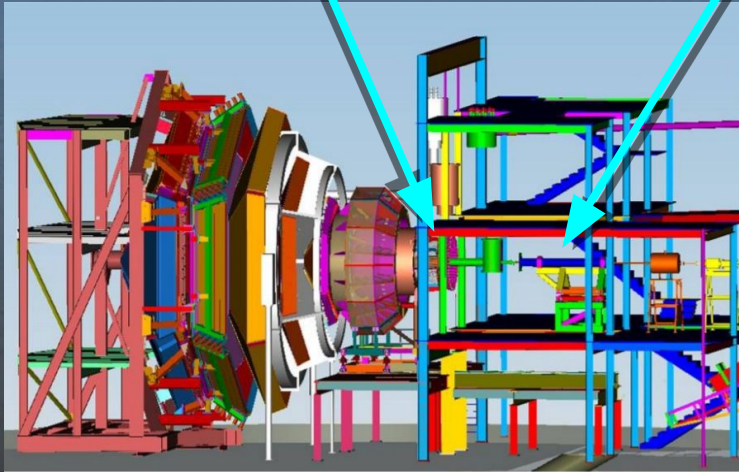
- Keep out Zone for SVT cart Ends 4.08 m Upstream
- SVT Internal \varnothing 113.8 mm (4.48 in)
- Target Keep in \varnothing 103.5 mm (4.088 in)
- 5 mm Radial Clearance

Fitting It All In

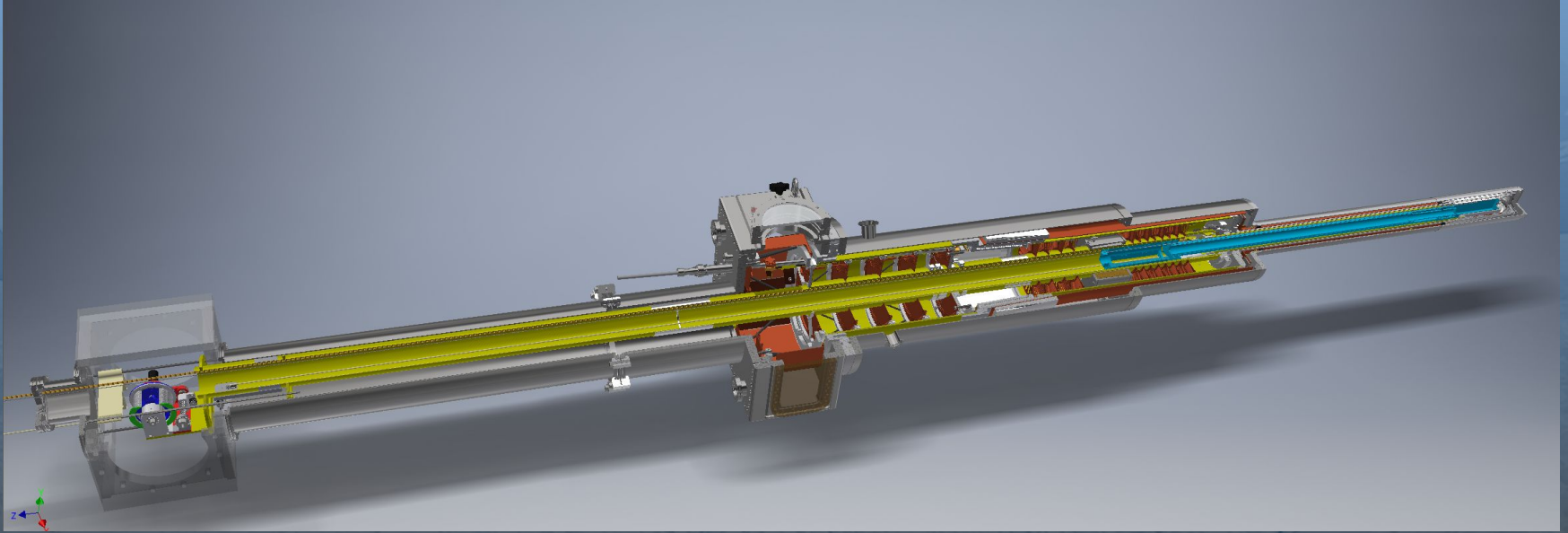
- Thin wall scattering chamber for IV
- Super insulation
- Radiant Heat Shield
- Pump Tube
- Microwave Waveguide
- NMR Coils
- 1 K ^4He Bath and Target

Central Detector

Saclay CryoTarget

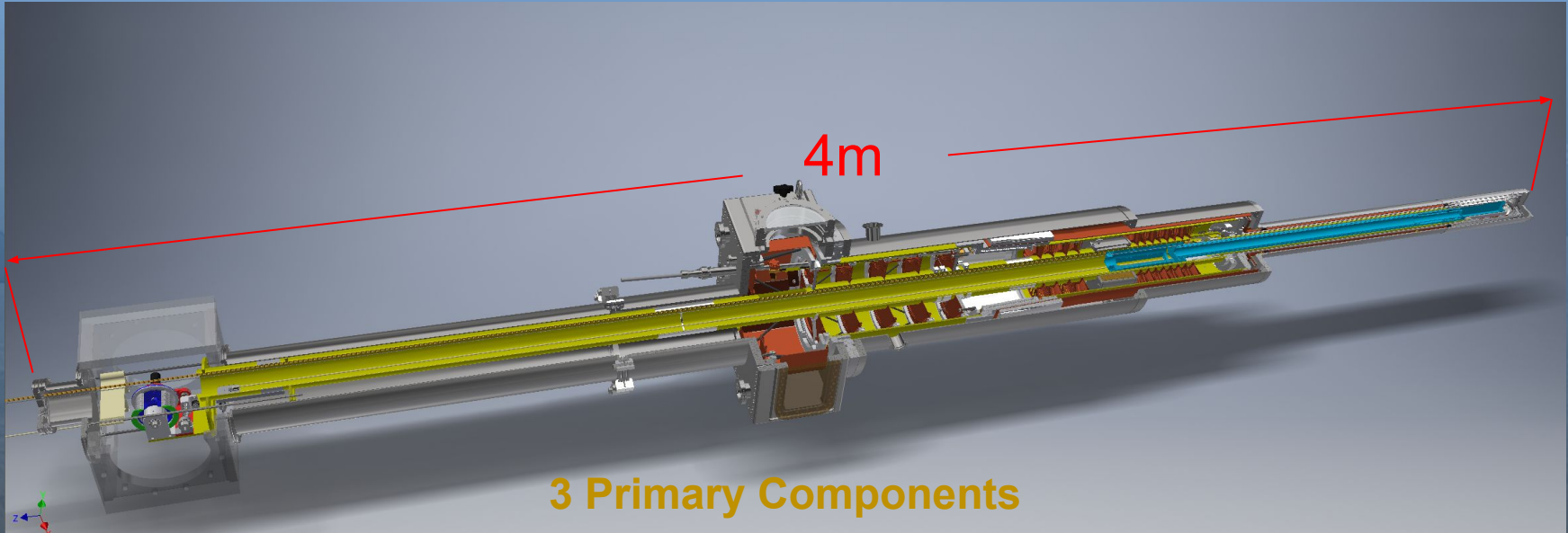


The CLAS12 Polarized Target



Modular 1 K Refrigerator

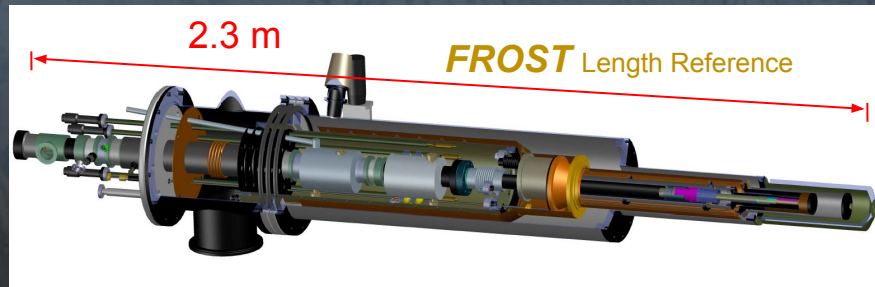
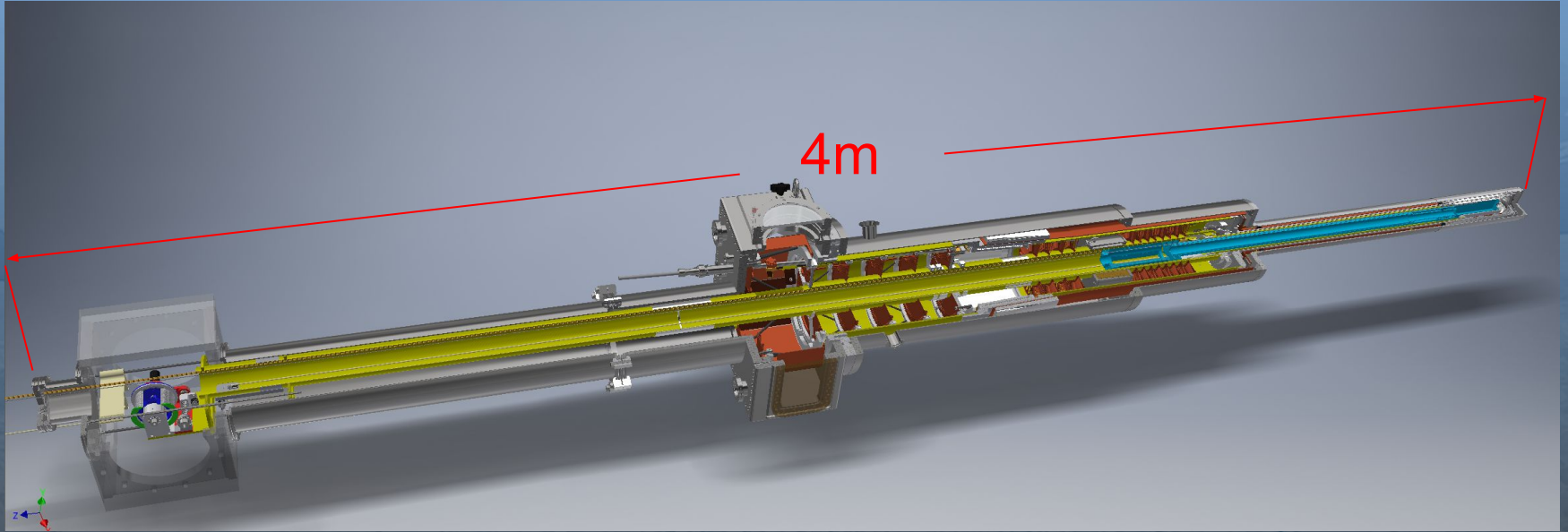
The CLAS12 Polarized Target



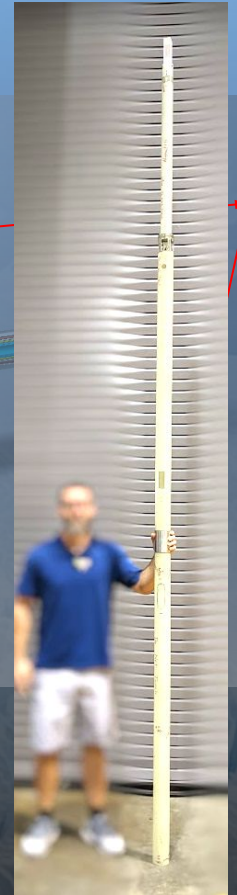
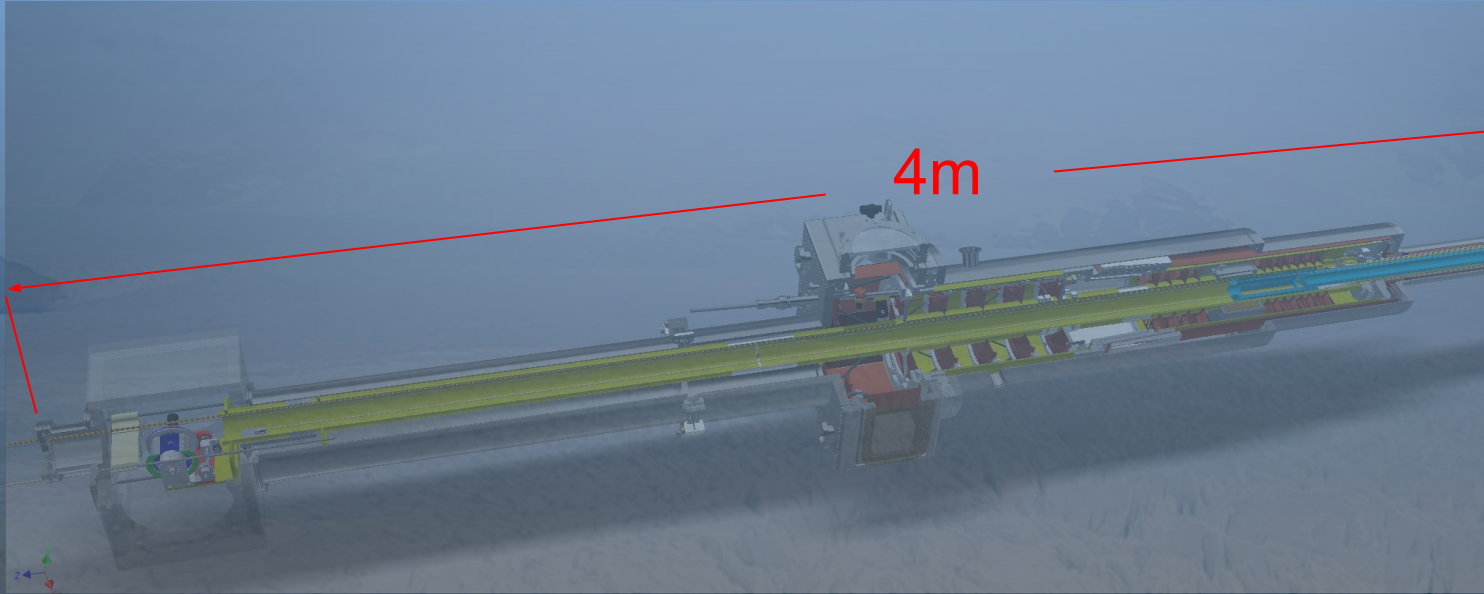
3 Primary Components

- 1 K Refrigerator
 - Open 79 mm bore for purpose built inserts
 - Load Lock for quick target changes
- “Rails” - Insert independent of the refrigerator structure
 - Trolley Motion Actuator
 - NMR System
 - Microwave waveguide and reflector
- “Trolley” - Top loading retractable 1 K bath
 - Removable target cells cartridges

The CLAS12 Polarized Target



The CLAS12 Polarized Target

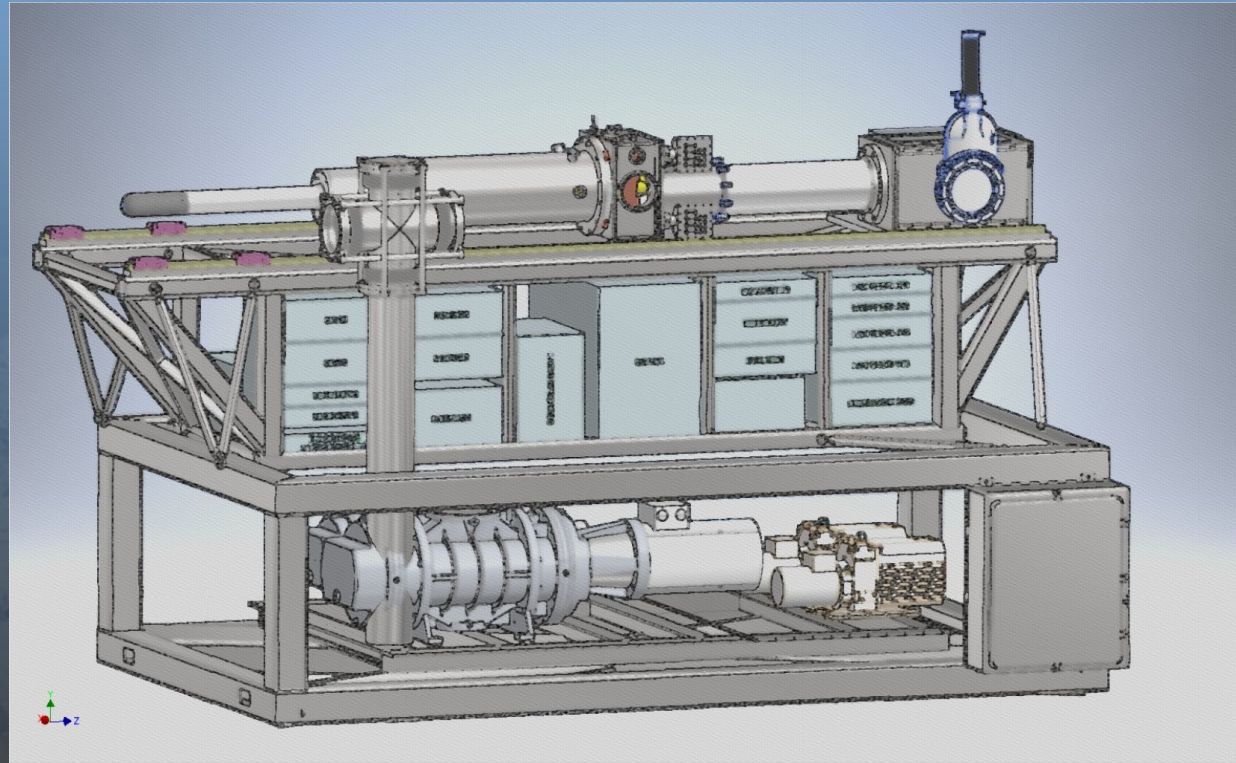


The CLAS12 Polarized Target

Beam Line Installation and Transport

Transportation Configuration

- Self contained for easy installation
- Refrigerator Retracted Over Cart
- Target assembly can be transported on flatbed

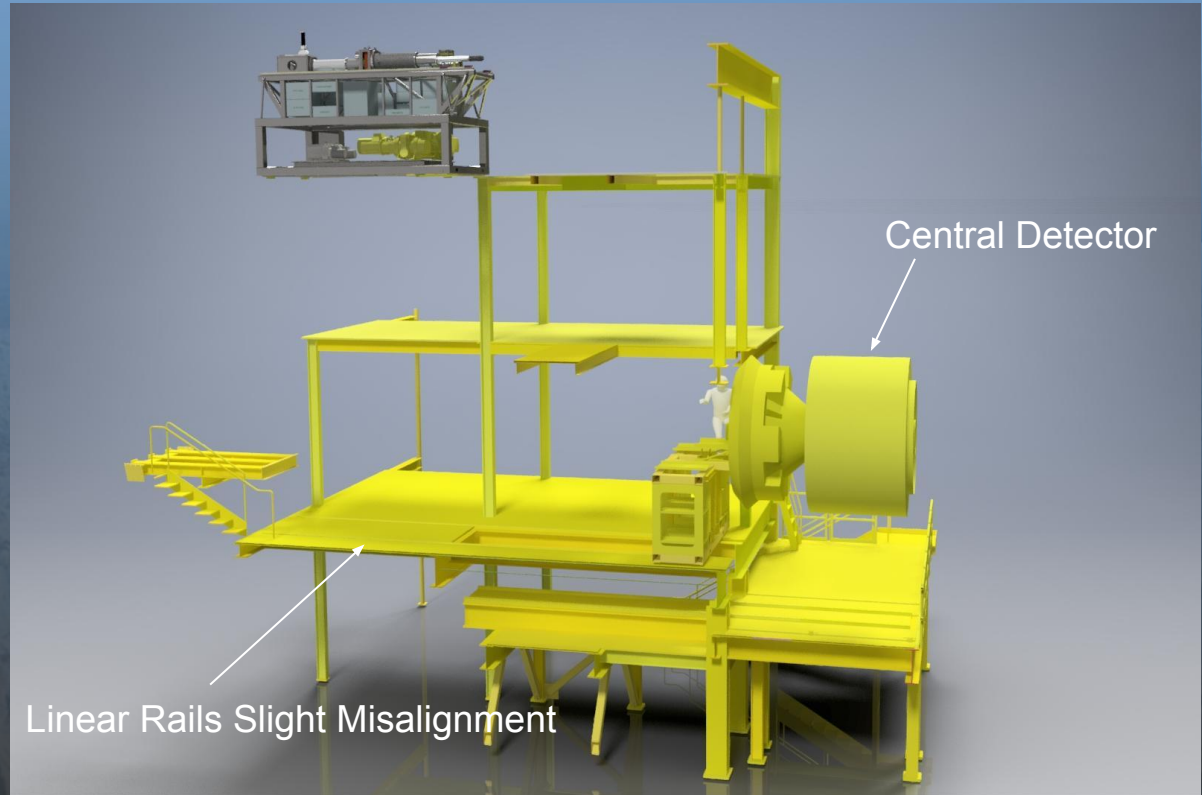


The CLAS12 Polarized Target

Beam Line Installation and Transport

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

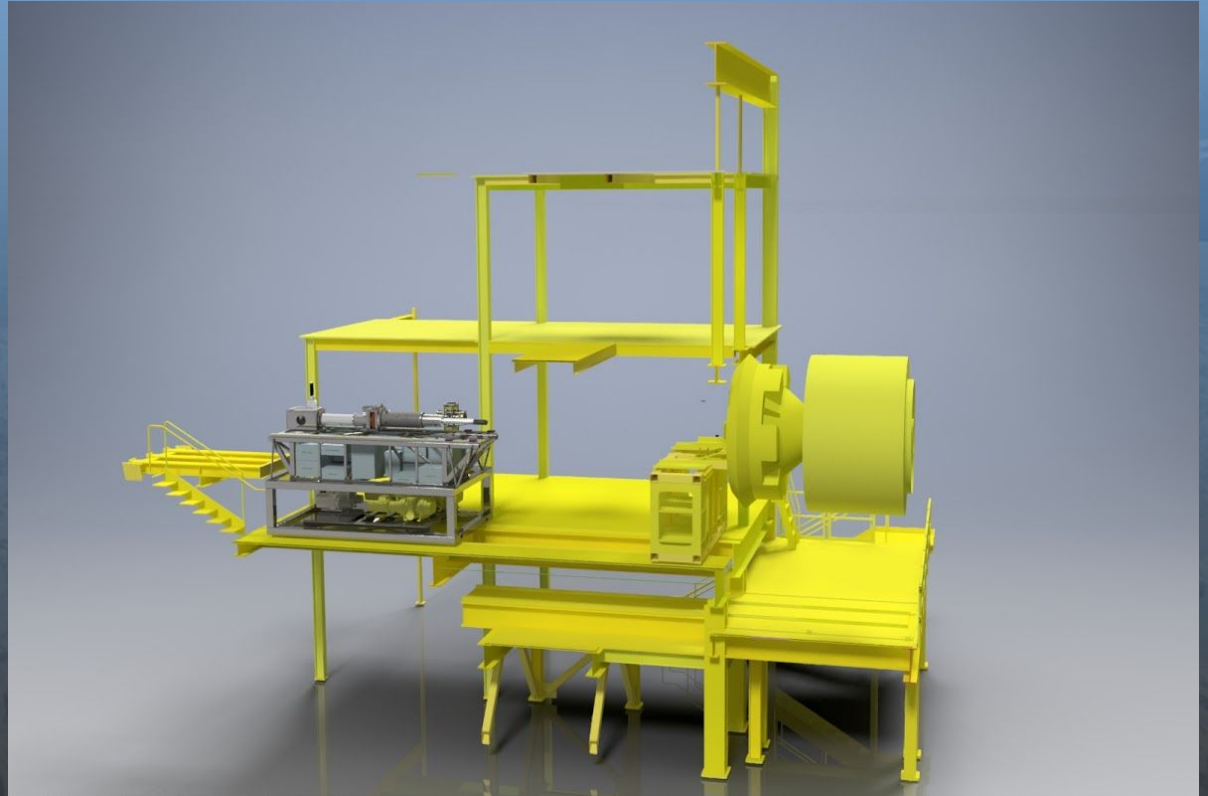


The CLAS12 Polarized Target

Beam Line Installation and Transport

Installation

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

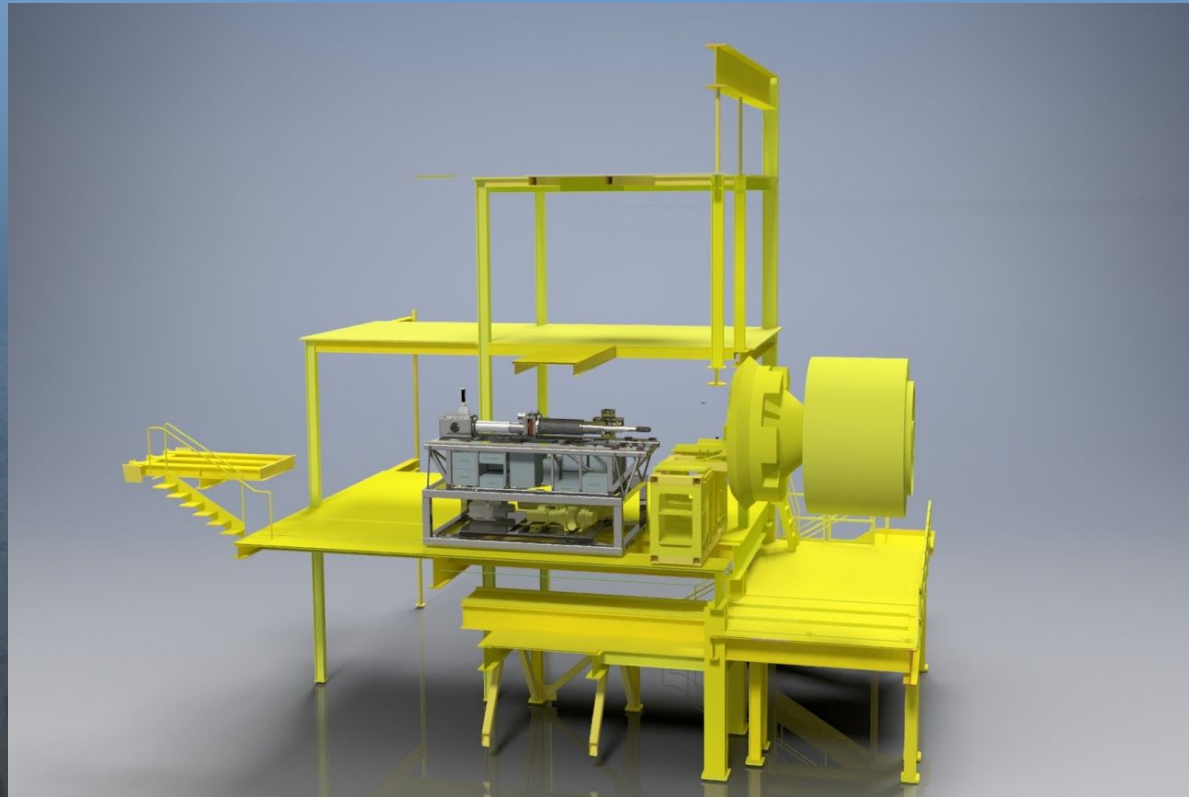


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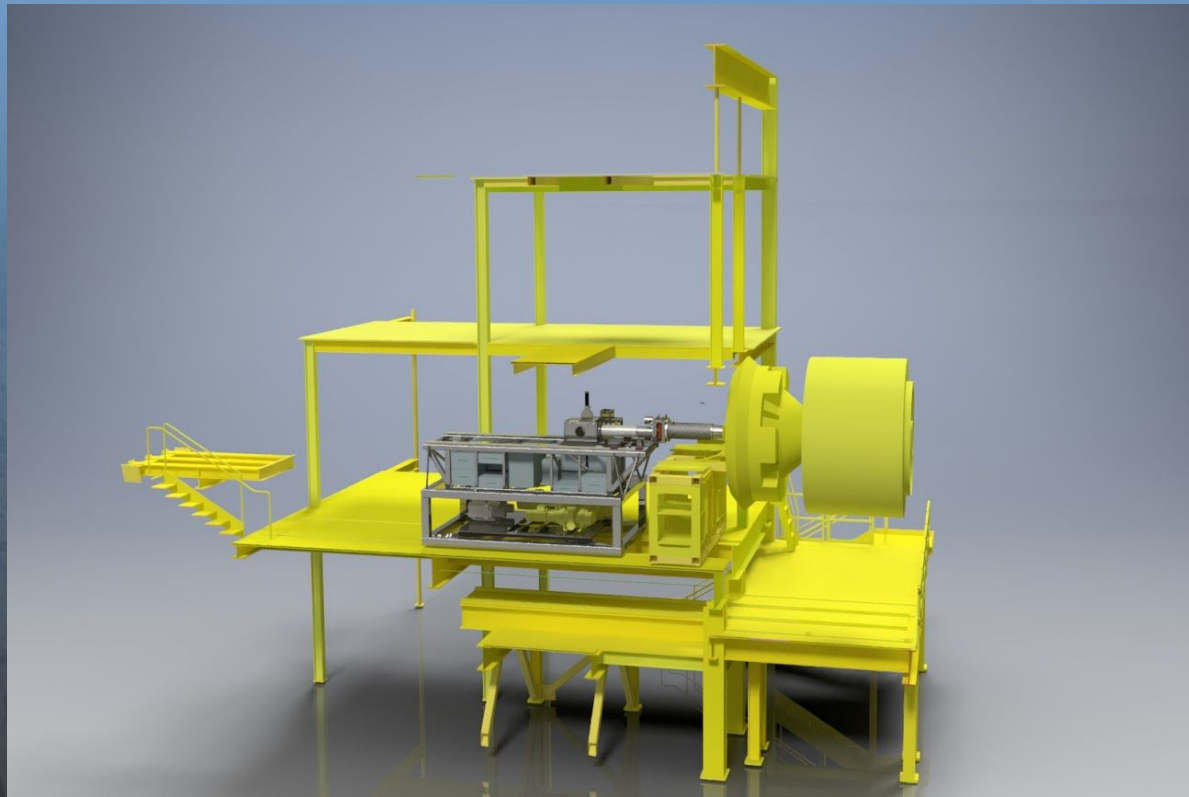


The CLAS12 Polarized Target

Beam Line Installation and Transport

Installation

- Alignment of target independent of Hall B Space Frame Superstructure Rails.
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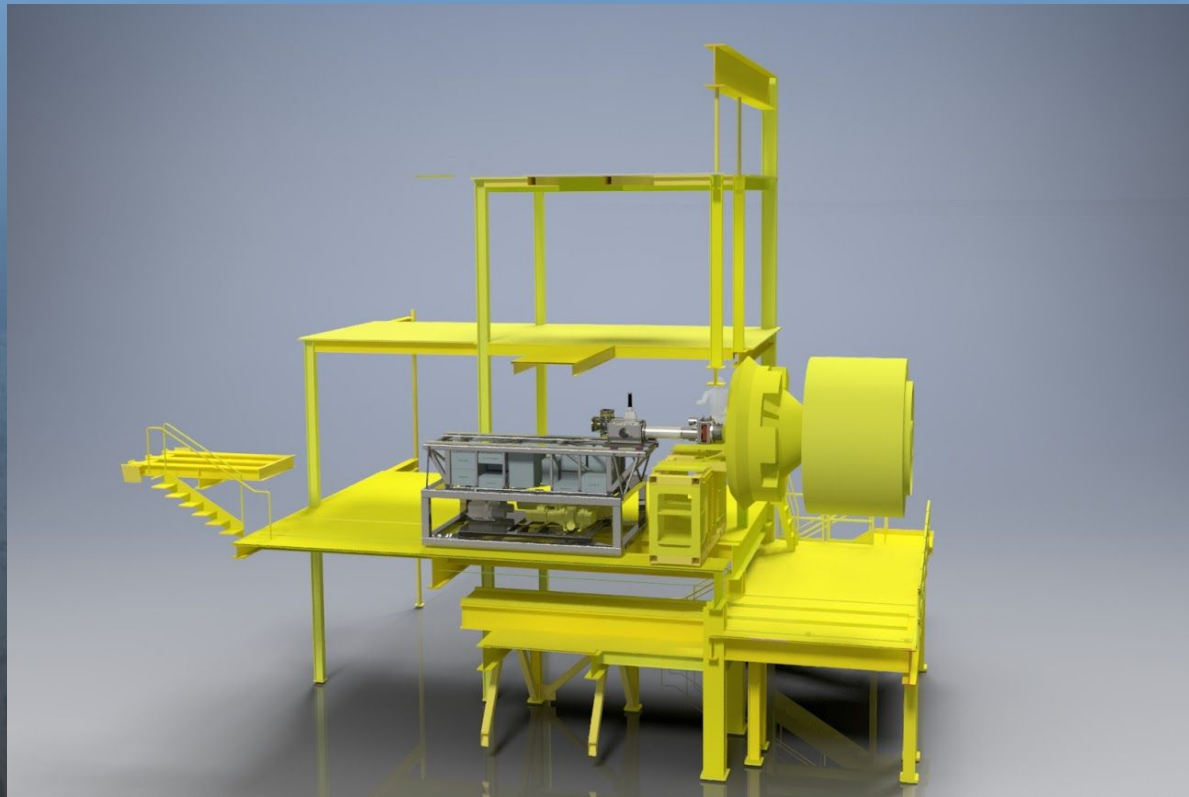


The CLAS12 Polarized Target

Beam Line Installation and Transport

Installation

- Alignment of target independent of Hall B Space Frame Superstructure Rails.
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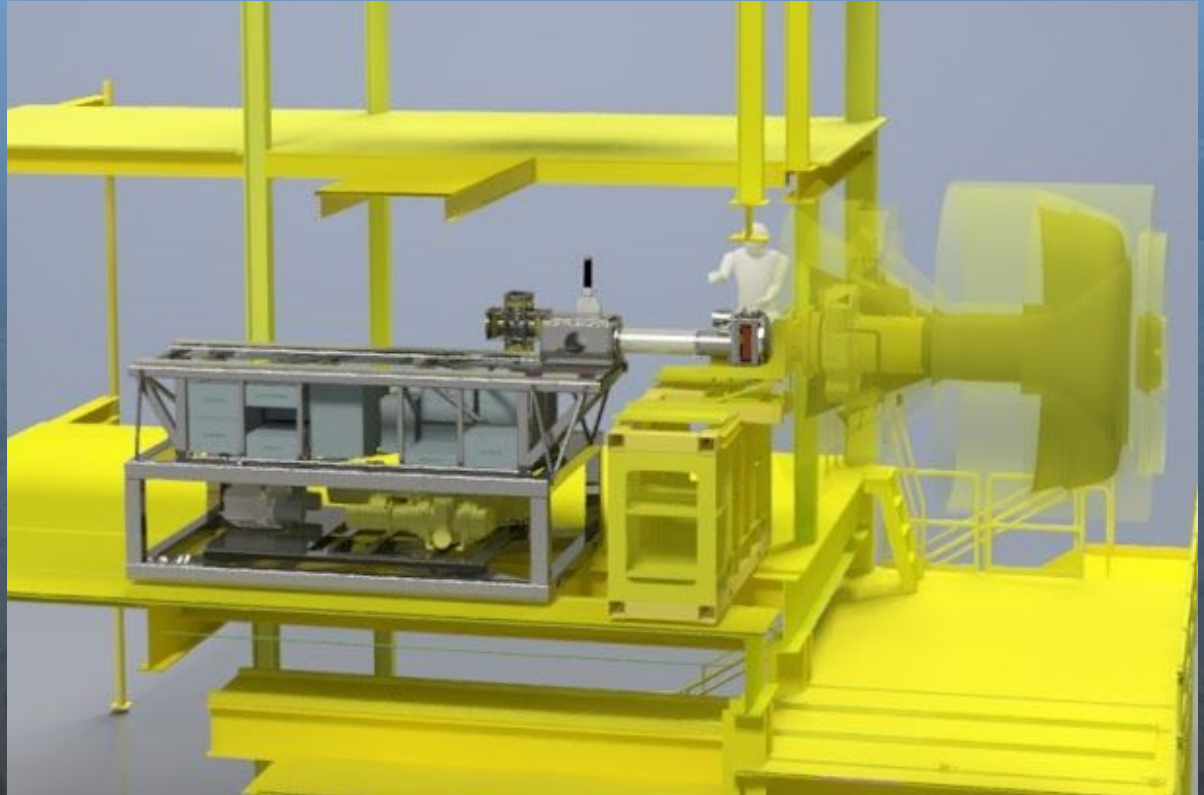


The CLAS12 Polarized Target

Beam Line Installation and Transport

Target Operation

- Cool down the refrigerator
- Throttle the Bypass valve and purge pump tube/fridge space with He
- Retract 1 K Bath
- Load target material through glove bag protected load lock
- Move target into position and cool down

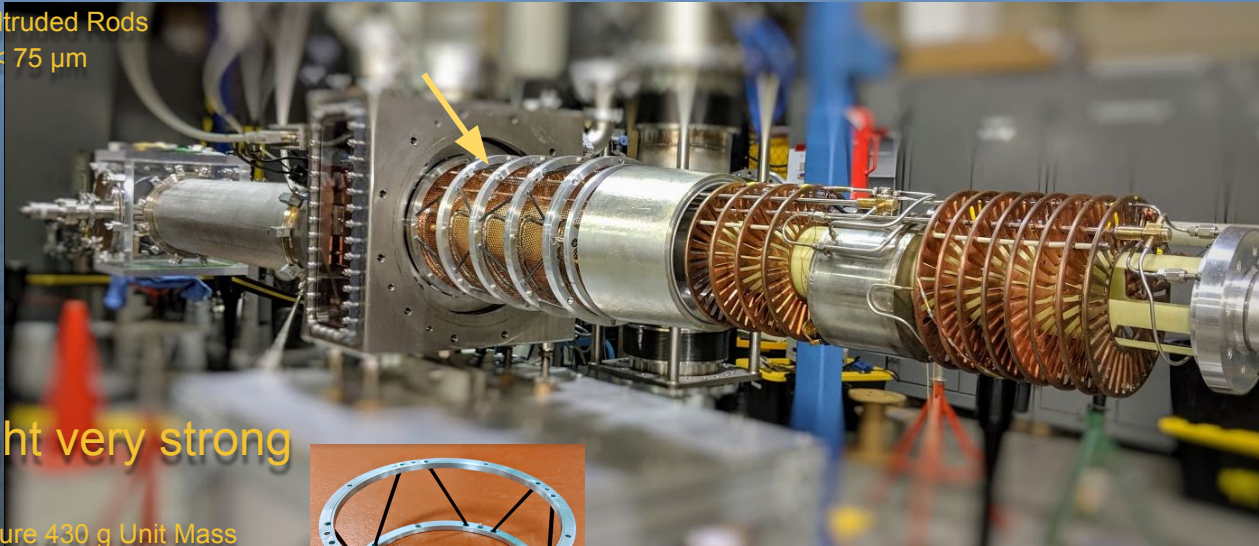


The CLAS12 Polarized Target

1 K Refrigerator Internal Components

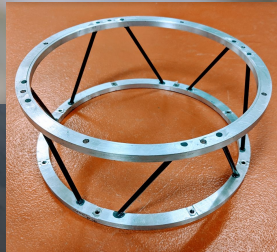
Modular Geometric Truss structure

- Carbon Fiber Pultruded Rods
- Tight Tolerance $< 75 \mu\text{m}$



Very lightweight very strong

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



The CLAS12 Polarized Target

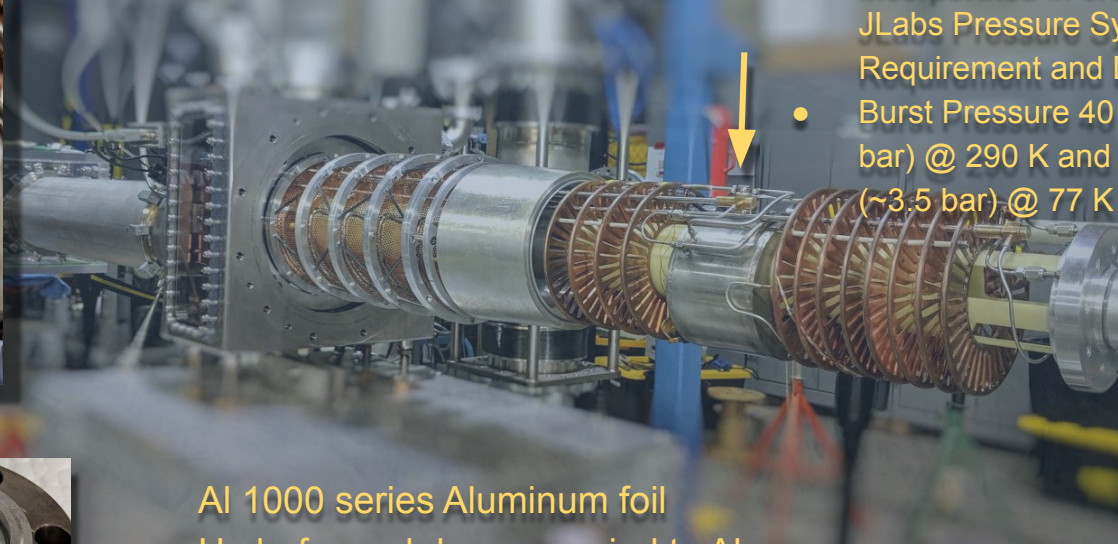
1 K Refrigerator Internal Components



Al 1000 series Aluminum foil
Hydroformed dome epoxied to Al
Conflat gasket and W blade

Cryogenic Rupture Disk

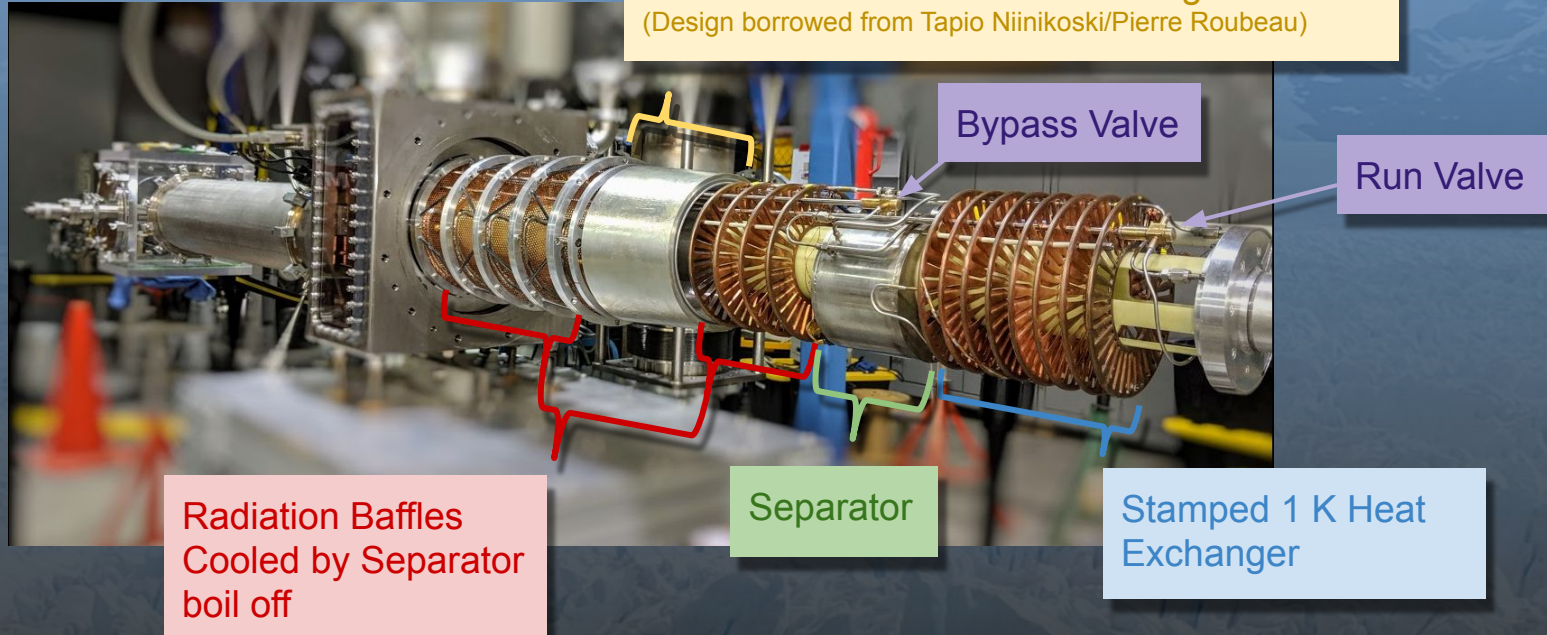
- Incorporated in order to satisfy JLab's Pressure Systems Requirement and DOE 10CFR851
- Burst Pressure 40 ± 5 psia (~ 1.4 bar) @ 290 K and 60 ± 10 psia (~ 3.5 bar) @ 77 K



The CLAS12 Polarized Target

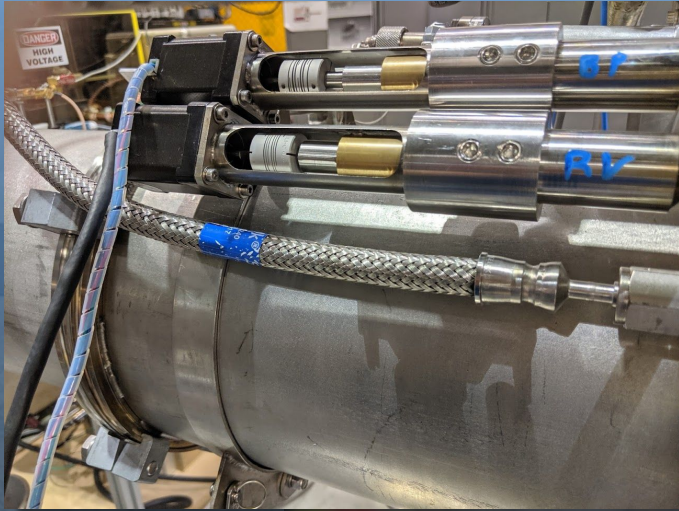
1 K Refrigerator Internal Components

Conical Heat Exchanger mates with Pump Tube Heat Sink providing cooling for Radiation Shields in the insulating vacuum
(Design borrowed from Tapio Niinikoski/Pierre Roubeau)



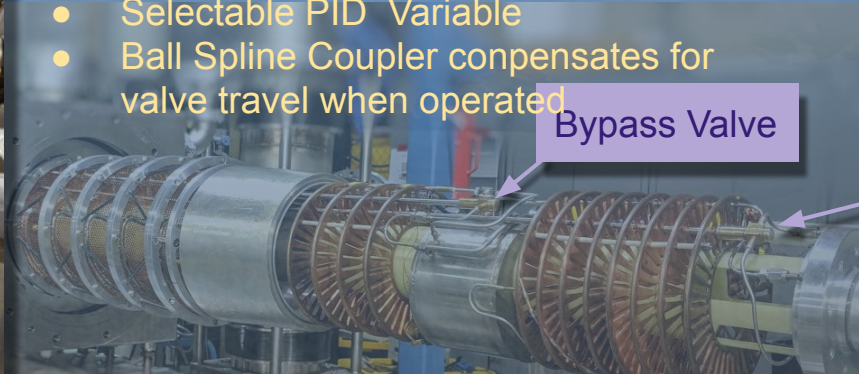
The CLAS12 Polarized Target

1 K Refrigerator Internal Components



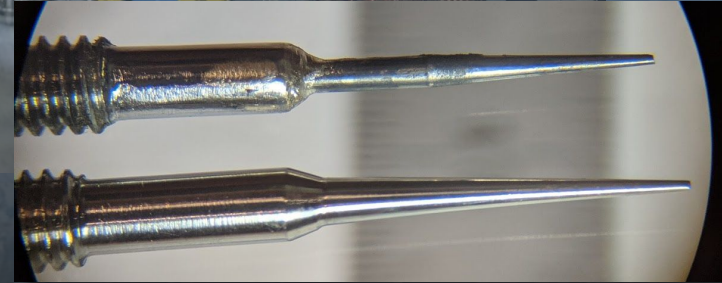
Automated Bypass and Run Valve

- Stepper Motor Controlled
- Selectable PID Variable
- Ball Spline Coupler compensates for valve travel when operated



Run Valve

- Old two pc tungsten Run Valve Needle
- New Monolithic Run Valve Needle

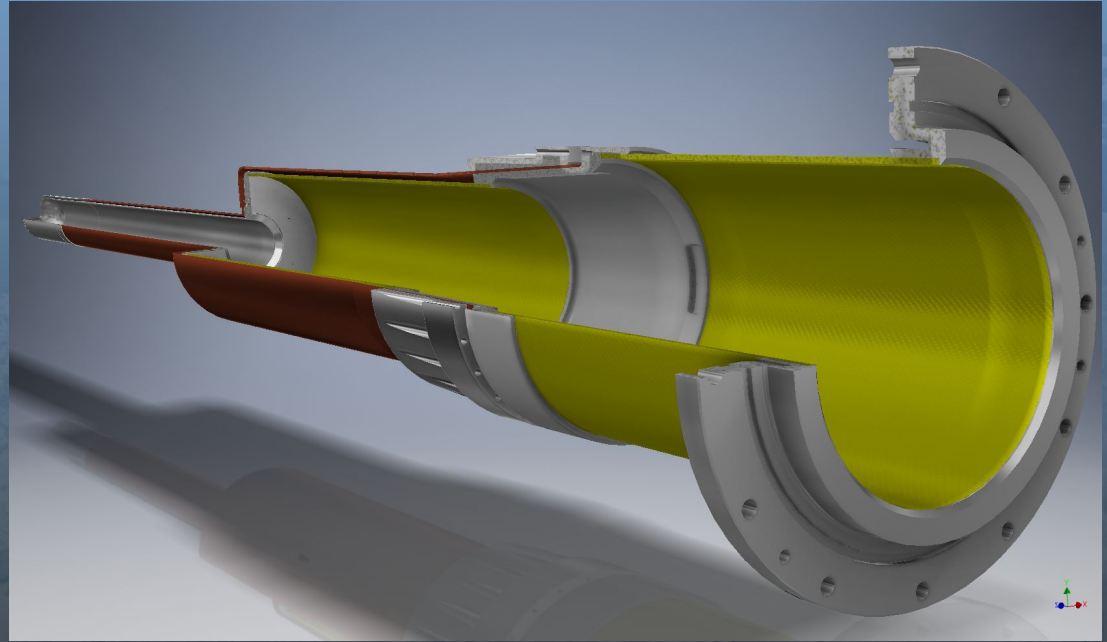


The CLAS12 Polarized Target

1 K Refrigerator Pump Tube and Heat Shields

Pump Tube

- G10/Al 6061/Al 7075
- Epoxied Joints maintain Tolerance better than welds
- 10 in ID Custom Laminated G10 tube with intra-laminated 316 Stainless Steel foil
- Reduced conductive heat load by a factor of 3.5 as compared to 316 SS

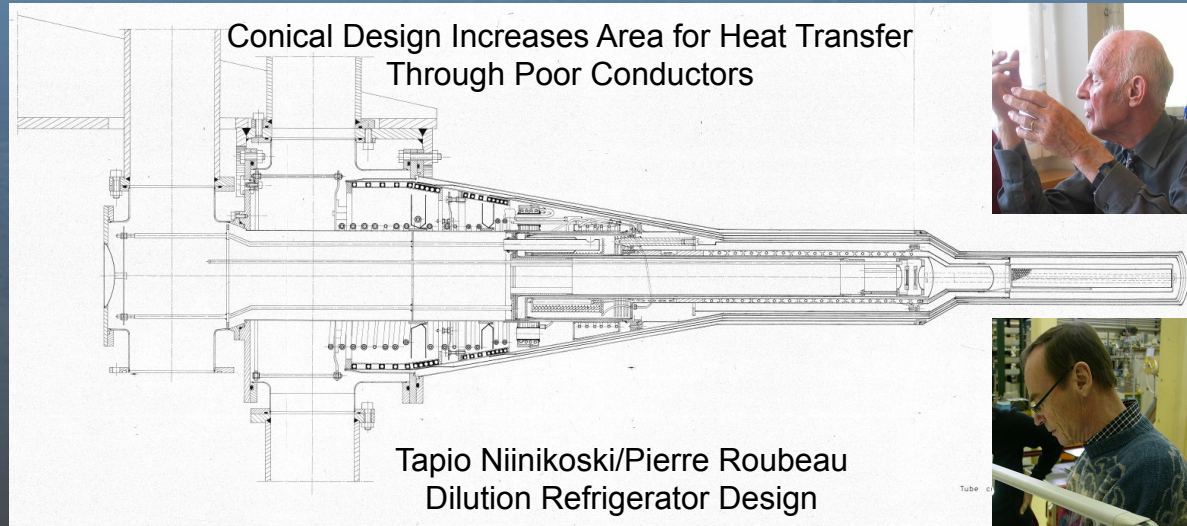


The CLAS12 Polarized Target

1 K Refrigerator Pump Tube and Heat Shields

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.



The CLAS12 Polarized Target

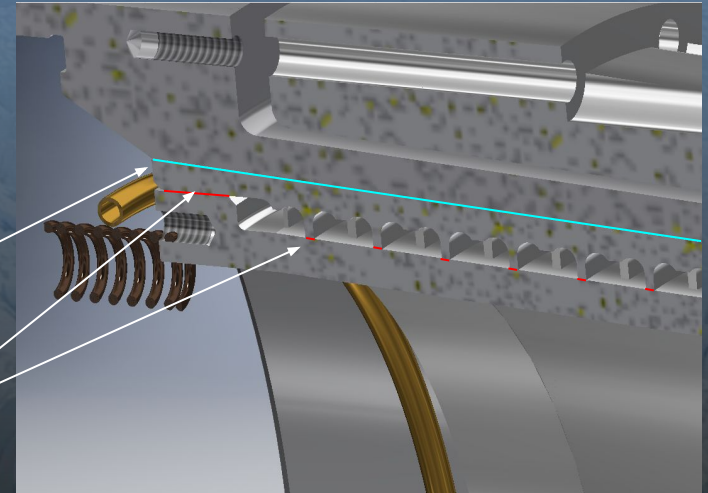
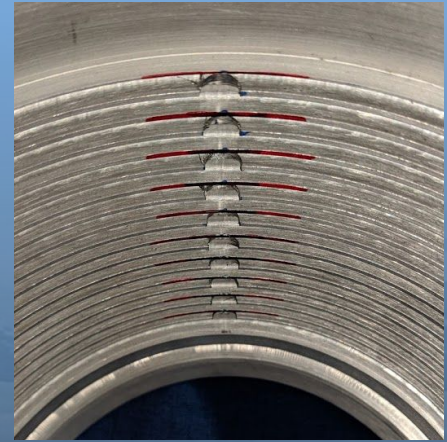
1 K Refrigerator Pump Tube and Heat Shields

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

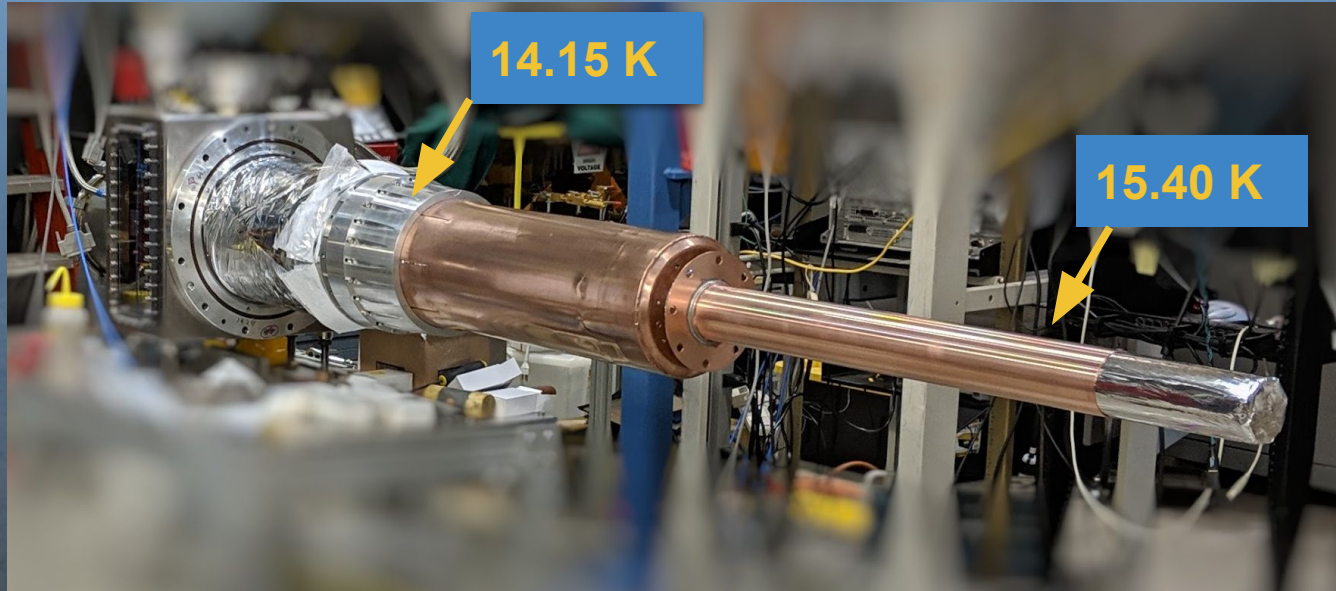


Apiezon Type N

3M DP190 Gray
Adhesive Epoxy
Highlighted in Red

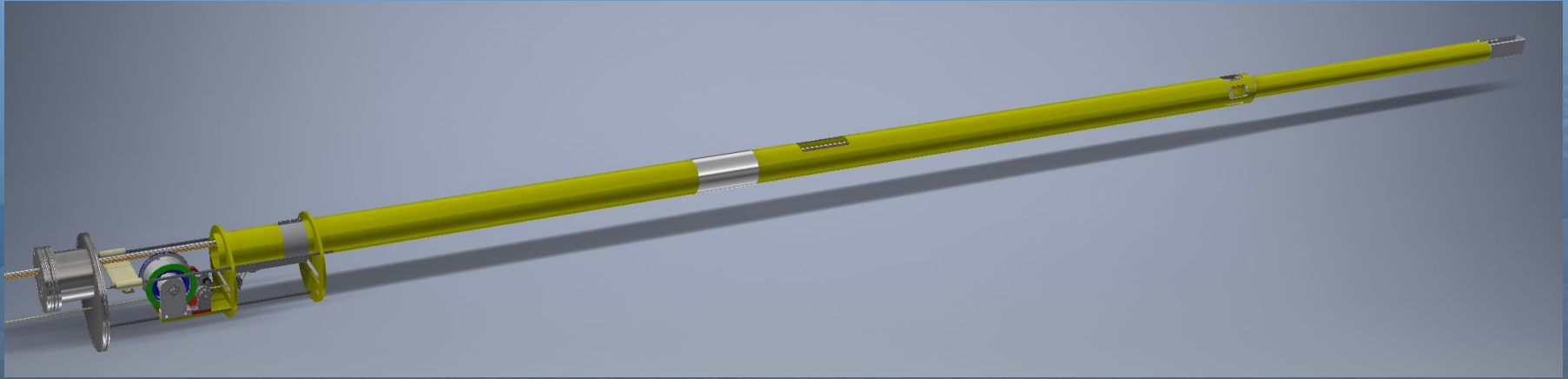
The CLAS12 Polarized Target

1 K Refrigerator Pump Tube and Heat Shields



The CLAS12 Polarized Target

“Rails” NMR/Microwave Carrier



Trolley Rails

- Spiral wound garolite tube, 1 mm wall
- Actuation via spooling winch in combination with block and tether
- Tether doubles as a wire harness

Microwave Waveguide

(Nominal 140 GHz system)

- WR6 to Oversized Round Waveguide (ID 4.27 mm)
- OFHC Copper Waveguide transitions to CuZnNi at cold end
- Dispersive foil covered 3D printed reflector

Dual NMR System

- Currently install
 - Remote Tunable Cold Tank Circuit
 - Traditional $\lambda/2$ Circuit
- Other Configurations
 - Dual Targets with Opposing Polarization (w/ \vec{B} Shimming)
 - NH_3 and ND_3

The CLAS12 Polarized Target

Rails NMR/Microwave Carrier

Oversized Microwave
Waveguide ~2.5 m of
(OFHC)

Remote Tune
Cold Tank
NMR Circuit

$\lambda/2$ NMR Circuit

Tether/Wire Harness

Oversized Microwave
Waveguide ~1.6 m of
(CuZnNi)

PTFE NMR
Carrier w/ PFA
Laminated Coils

The CLAS12 Polarized Target

Rails NMR/Microwave Carrier

3D Printed Microwave
Foil Covered Reflector



Microwave Power Distribution

Microwave On

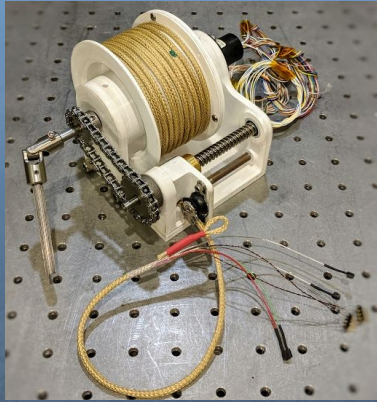
Microwave Off



Liquid Crystal Thermochromic Film

The CLAS12 Polarized Target

Rails NMR/Microwave Carrier

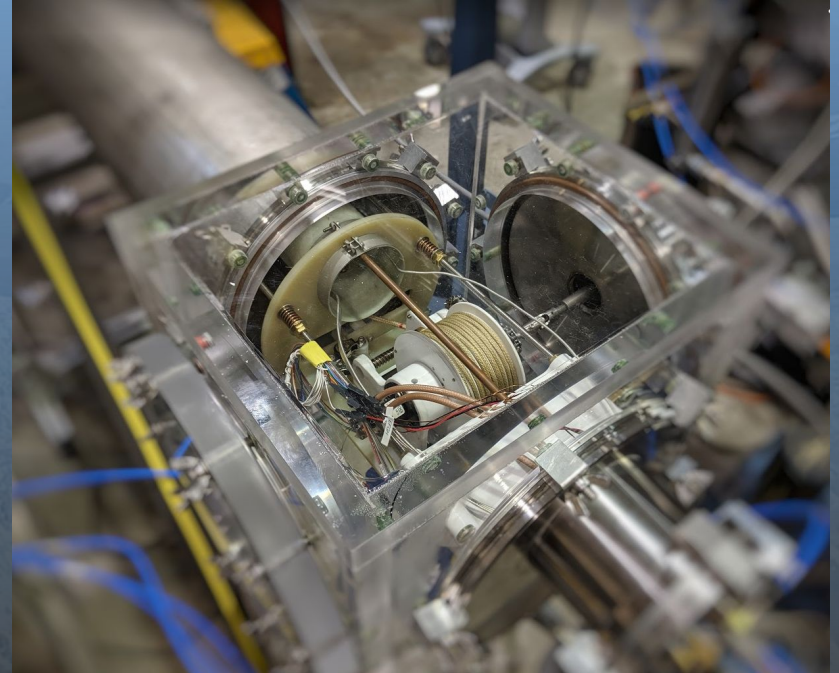


Spooling Winch

- 3D Printed PLA
- 18 Lead Low Noise Slip Ring Commutator

Tether sheaths Trolley wiring

- Two 36 AWG Quad twist
- Two Coax Level Probe
- Two Heater Leads

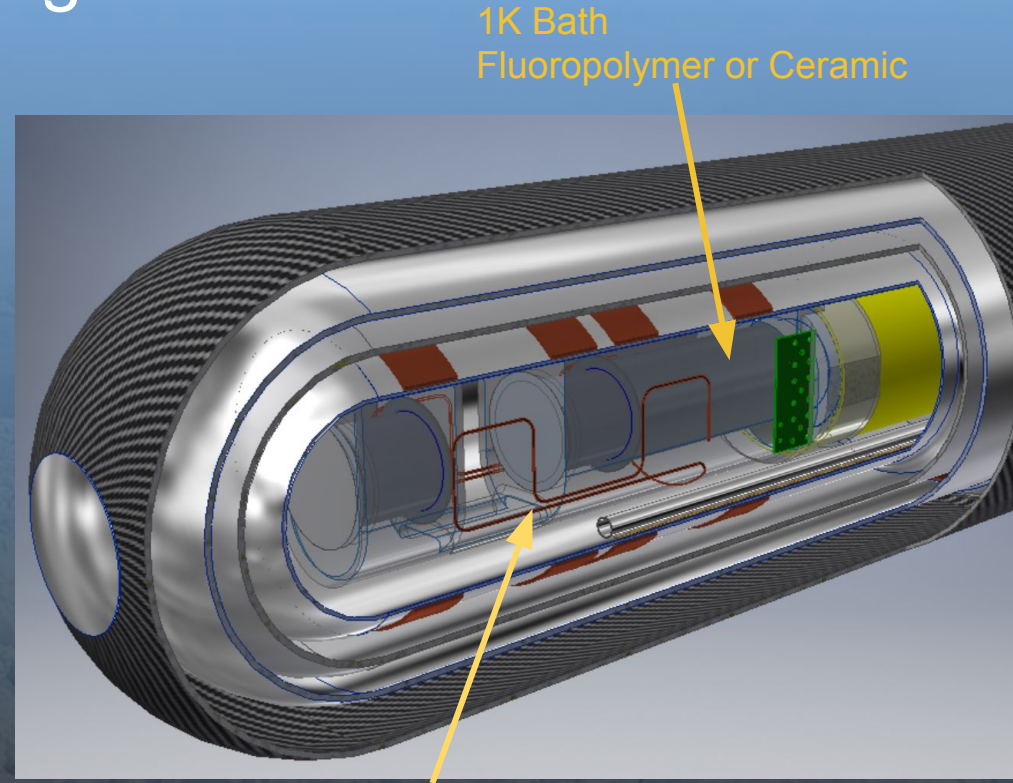


The CLAS12 Polarized Target

Rails NMR/Microwave Carrier

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



1K Bath Cut-ins for NMR Coils Increases Sensitivity

The CLAS12 Polarized Target

Retractable 1 K Bath “Trolley”

- Top loading bath eliminates the need for superfluid seal or dismantling fridge
- Re-entrant beam line
- Recirculating Torlon ball bearings distribute cantilevered load of bath over large area of the thin walled insert
- Large volume to buffer bath level (~ 500 ml)
- Capacitive level probe
- High/Low level Cernox temperature Sensors
- Open top target containment vessel completes bath
- PTFE Compression Seal



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The CLAS12 Polarized Target

Retractable 1 K Bath “Trolley”

Cartridge Design

Maximize Target Viability

- Rastered Electron Beam Reduces Local Dose

Target Length

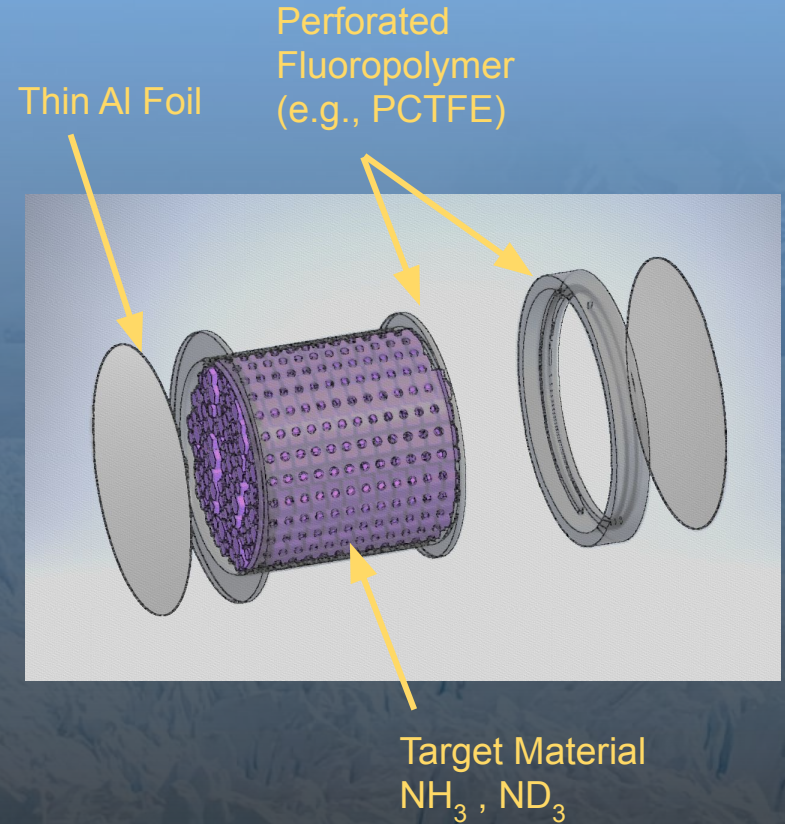
- Target Length 20 to 60 mm
- Or Two...

Fill Factor Improved

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

Annealing

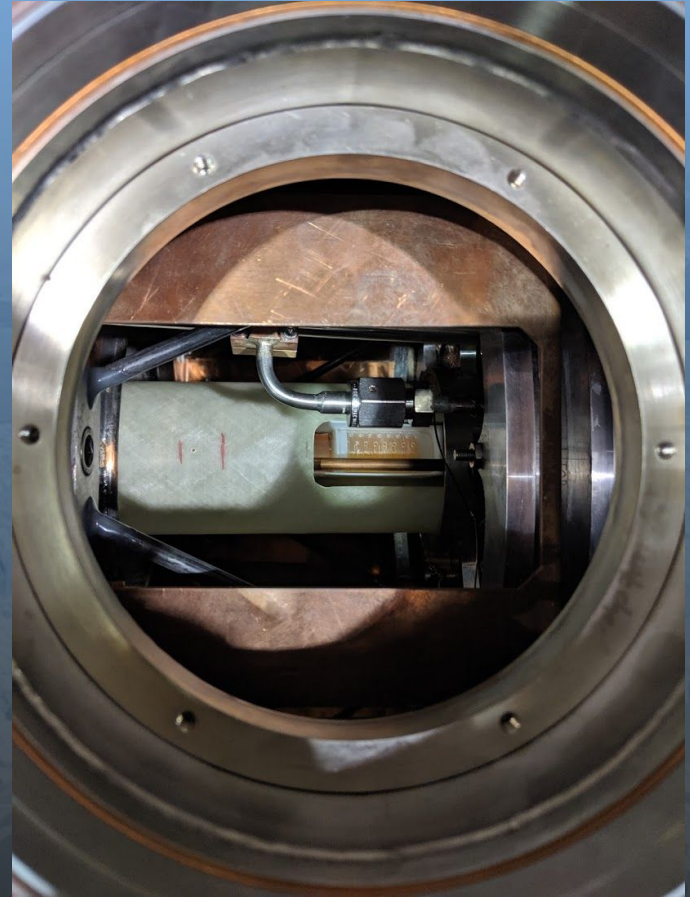
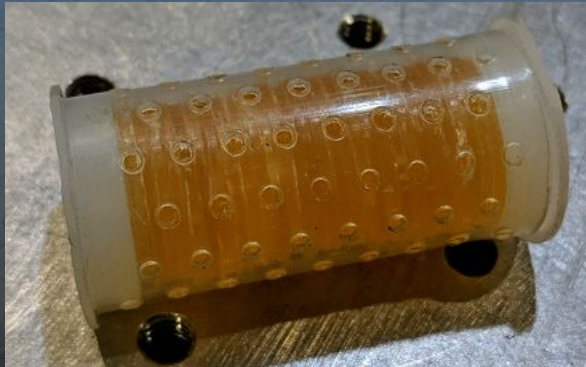
- Offline annealing possible with removable cartridges (Less Beam Down Time)



The CLAS12 Polarized Target

Retractable 1 K Bath “Trolley”

- Test material is Tempo doped epoxy
- Cartridge is a porous FEP cell with PTFE end caps
- Target Cartridge is loaded through fridge load lock



The CLAS12 Polarized Target

EEL Test 2019

Pre Cool Stress Test April 2019

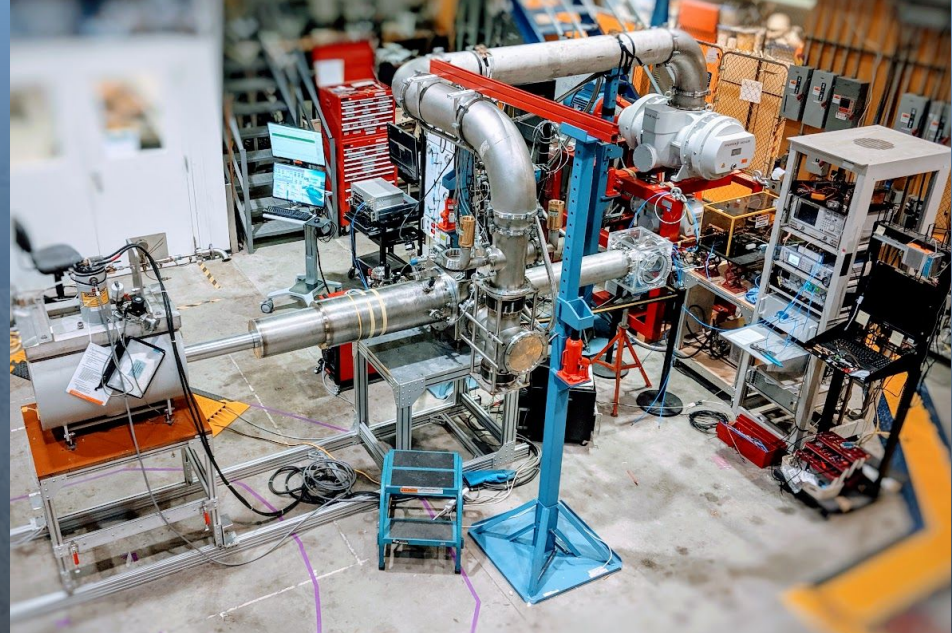
- 77K
- System Vacuum Integrity

First Cool Down May 2019

- NMR System Test
- Stationary 1K Open Bath

Second Cool down September 2019

- NMR System Test
- Stability and Power Measurements
- Trolley Motion 1 K Bath



The CLAS12 Polarized Target

EEL Test 2019

Load Conditions	T_Bath	Evaporative Cooling Power	Fridge Flow He	LHe Consumption***
No Load	0.969 K	120 mW	2.00 slpm	0.159 LLHe/hr
220 mW	0.983 K	392 mW	6.34 slpm	0.503 LLHe/hr
471 mW *	1.00 K	581 mW	9.4 slpm	0.745 LLHe/hr
1500 mW **	1.187 K	3693 mW	59.8 slpm	4.740 LLHe/hr

* Heater Film boiling prevented accurate power measurements above this value.

** Minimum μ -wave power transmitted through waveguide measure at 295 K

*** Separator Flow was kept high to mitigate oscillations from the He transfer line 60 slpm (4.76 LLHe/hr)

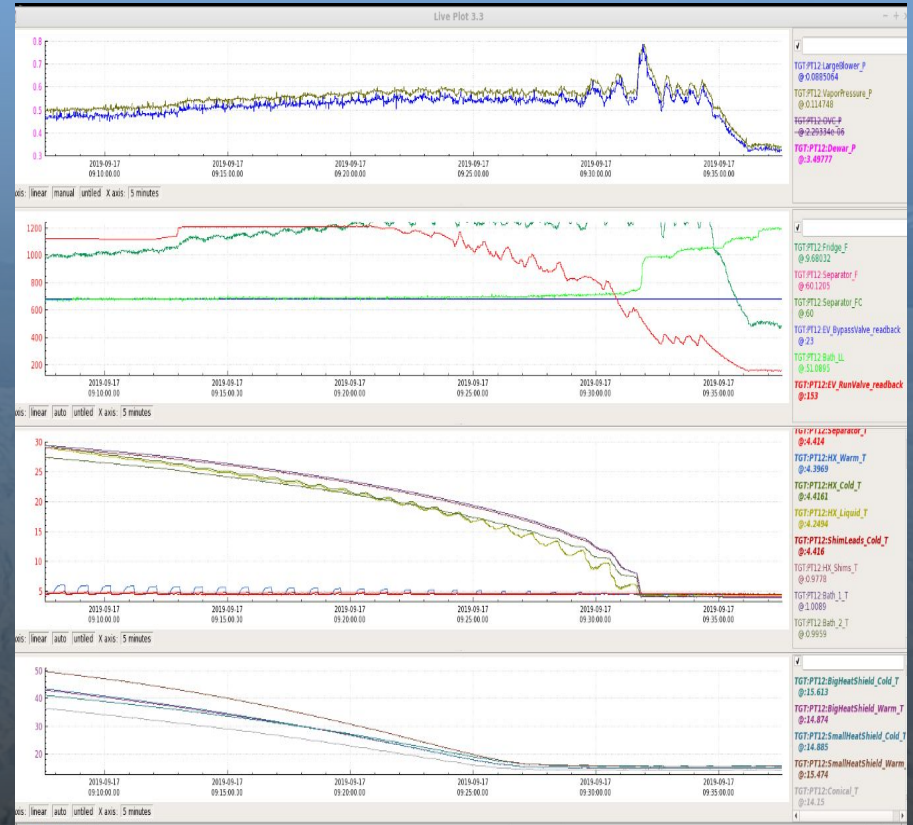
The CLAS12 Polarized Target

Thank you

The CLAS12 Polarized Target

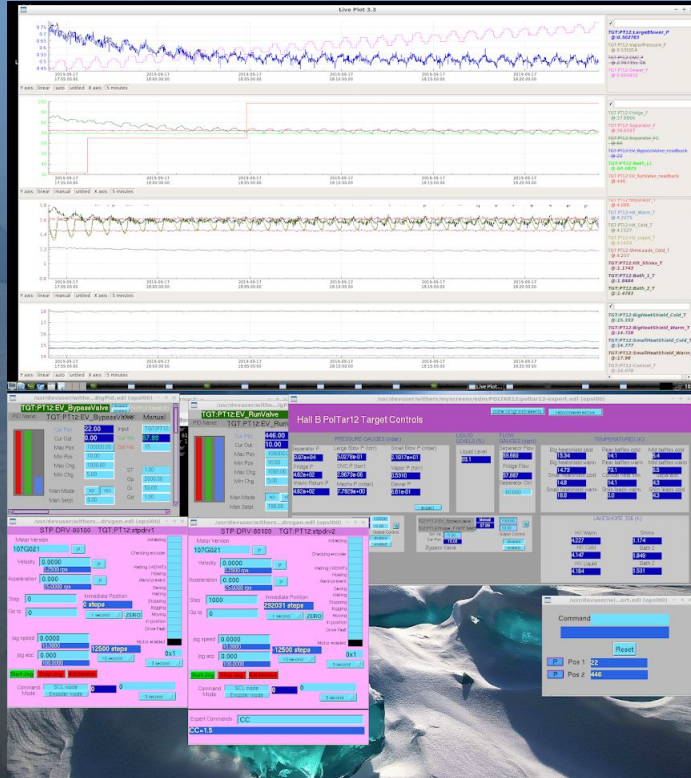
Text

Cooldown from Fridge Dormant State
to 1 K ~1 hr

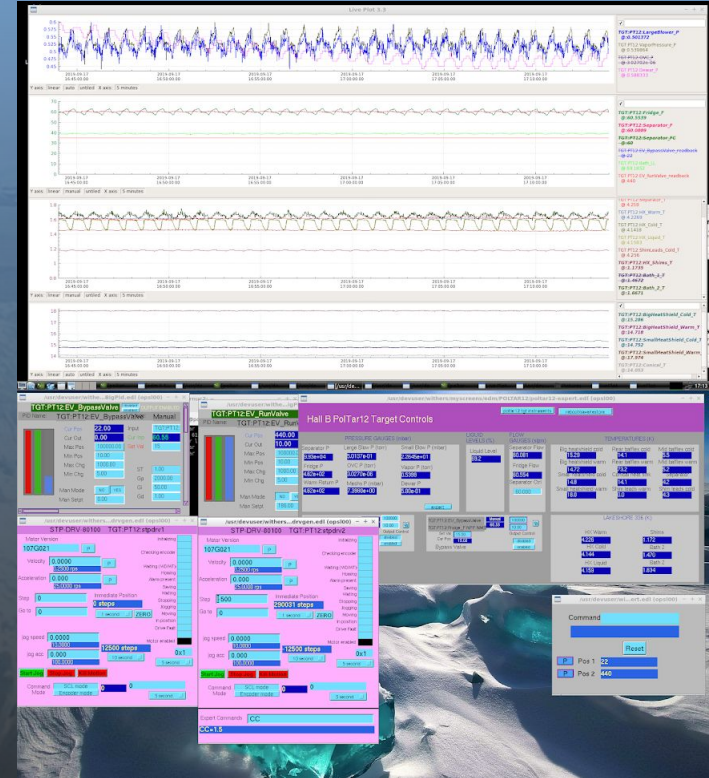


The CLAS12 Polarized Target

- Polarized and Stable



+ Polarized and Stable



The CLAS12 Polarized Target

Trolley retracted MAX bath temp 80 K

