HDice Technical Note 22 – *IBC dEdx* ,

Energy-loss Materials around HD targets in the In-Beam-Cryostat (IBC) used for g14

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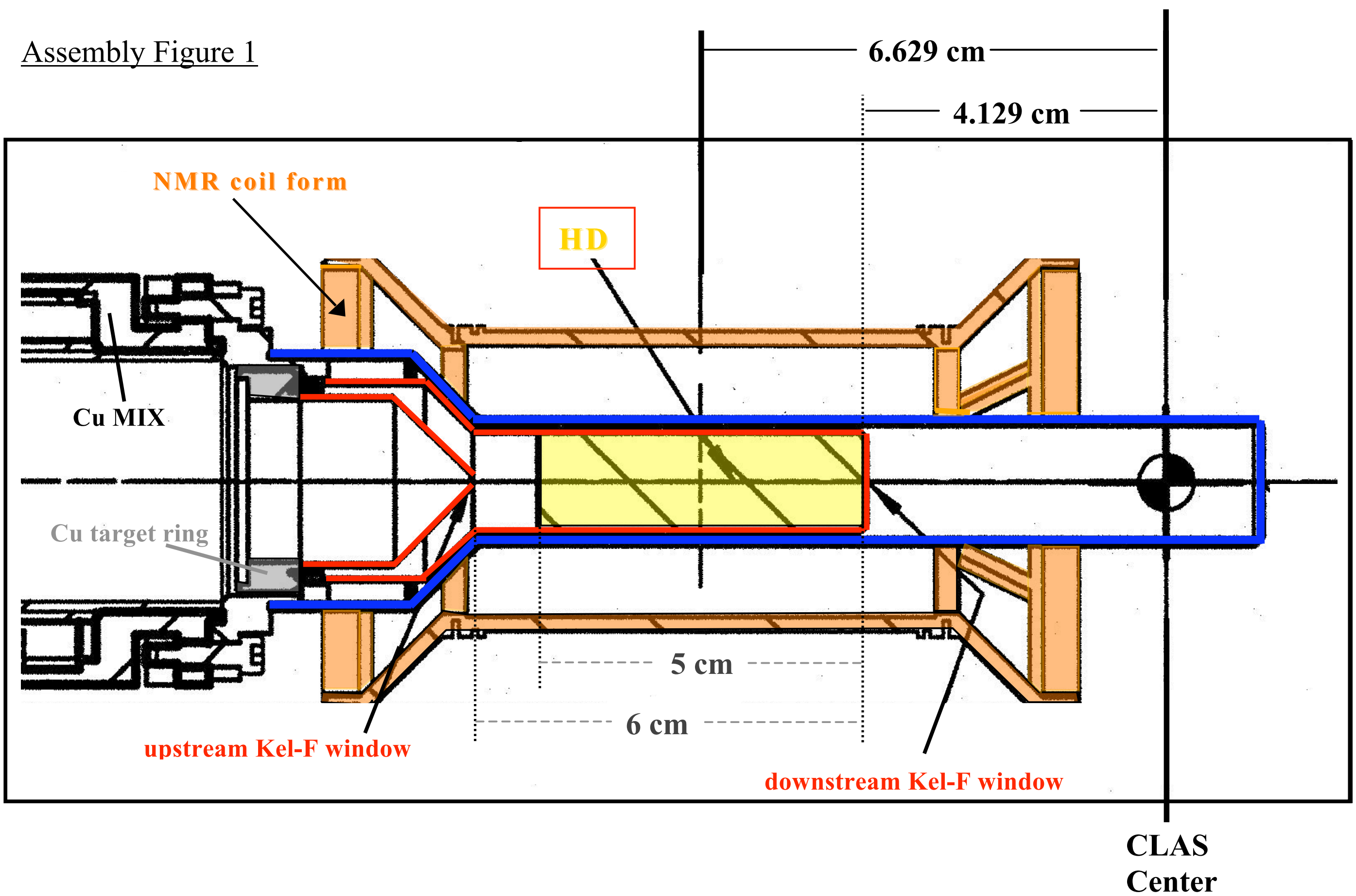
Abstract

Material within the IBC is specified for energy-loss simulations, starting from the center of the HD target cell and working outward. Positions are specified relative to (a) the nominal CLAS center (from a pre-run survey) and (b) the downstream end cap of the target cell, which is the easiest to recognize in a z-vertex reconstruction. Each section has a descriptive narrative, usually with a drawing, followed by a summary of material properties, thicknesses and densities. Colors in the figures designate different regions. The Appendix gives a sample energy-loss calculation for 25 MeV and 1000 MeV $\pi^{\pm}$ and for 65 MeV and 1000 MeV protons, both emerging from the target at 90^0 Lab. The largest contributors to the energy loss are the vacuum-can-backup-solenoid and the liquid helium can containing the super-conducting magnets.

A) Immediate target region

The solid HD, with it's Aluminum cooling wires, is held within a Kel-F plastic (C_2ClF_3) cylindrical **shell** (**red** in Figure 1 below). Outside of this is another Kel-F cylindrical **shell** that separates vacuum spaces. Around both of these is a Kel-F **form** that supports the NMR coils.

Assembly Figure 1



A.1 HD + Aluminum wire

Description

- density of solid HD below 1K is **0.147 gm/cc**. Ideally, the HD should be a right cylinder, although the shape of it's upstream end depends on lots of details during crystal growth. For energy loss analysis, assume that the HD forms a cylinder with an **OD of 1.505 cm**. The downstream end of the **HD (beam exit end) is 4.129 cm upstream of CLAS center**. The goal was to grow HD crystals that are 5 cm long. In the case of (*silver*) target # 21a, the length was approximately 4.0 cm.

- the density of the mesh of Aluminum cooling wires within the target varies slightly among different target cells, but is always about a factor of 100 smaller than that of Al; eg. for (*silver*) target # 21a, used in g14 from Dec 1/11 to Feb/12, the effective average density of Aluminum within the cell is **0.0280 gm/cc**.

A.1.1 Summary of Material Properties

- HD density, ρ(HD), is taken from I. Silvera, Rev. Mod. Phys. **52** (2980), Table XI, p 439.
- average HD length and mean Aluminum density for the 3 cells used in g14 is as follows:

Cell #	< ρ(HD) > (gm/cc)	< HD length > (cm)	< ρ(Al) > (gm/cc)
21a	0.1470	4	0.0280
19b	0.1470	5	0.0196
22b	0.1470	5	0.0268

- OD of solid HD + aluminum: **1.505 cm** (radius = 0.7525 cm)
- Distance of downstream end of HD –to- nominal CLAS center: **4.129 cm**

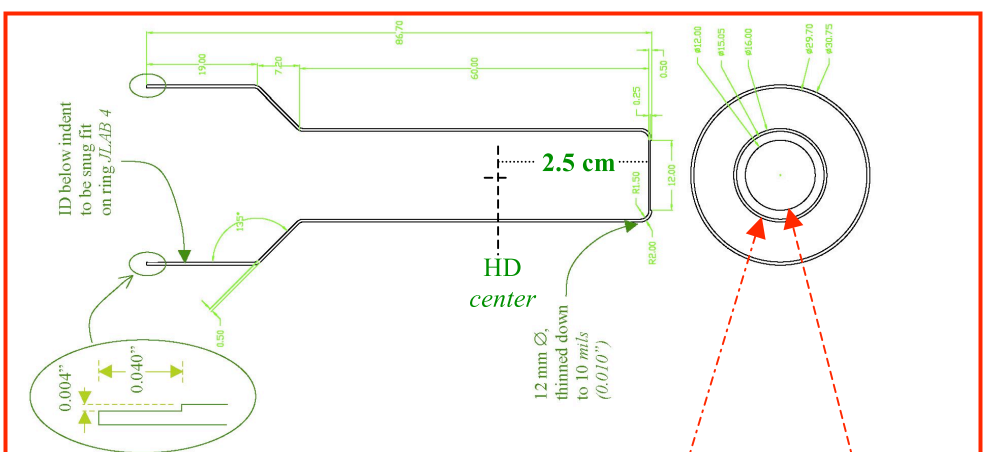
A.2 Target cell wall

Description

- the cell containing the HD is made of *Kel-F*, C_2ClF_3 plastic, density **2.12 g/cc.** This is depicted in **red** in Figure 1.

- cell wall is **0.050 cm** thick, made of *Kel-F*, C_2ClF_3 plastic, density **2.12 g/cc.** The outer cell diameter is **1.6 cm**

- the downstream exit window is thinned down to **0.025 cm** **over 1.2 cm diameter**



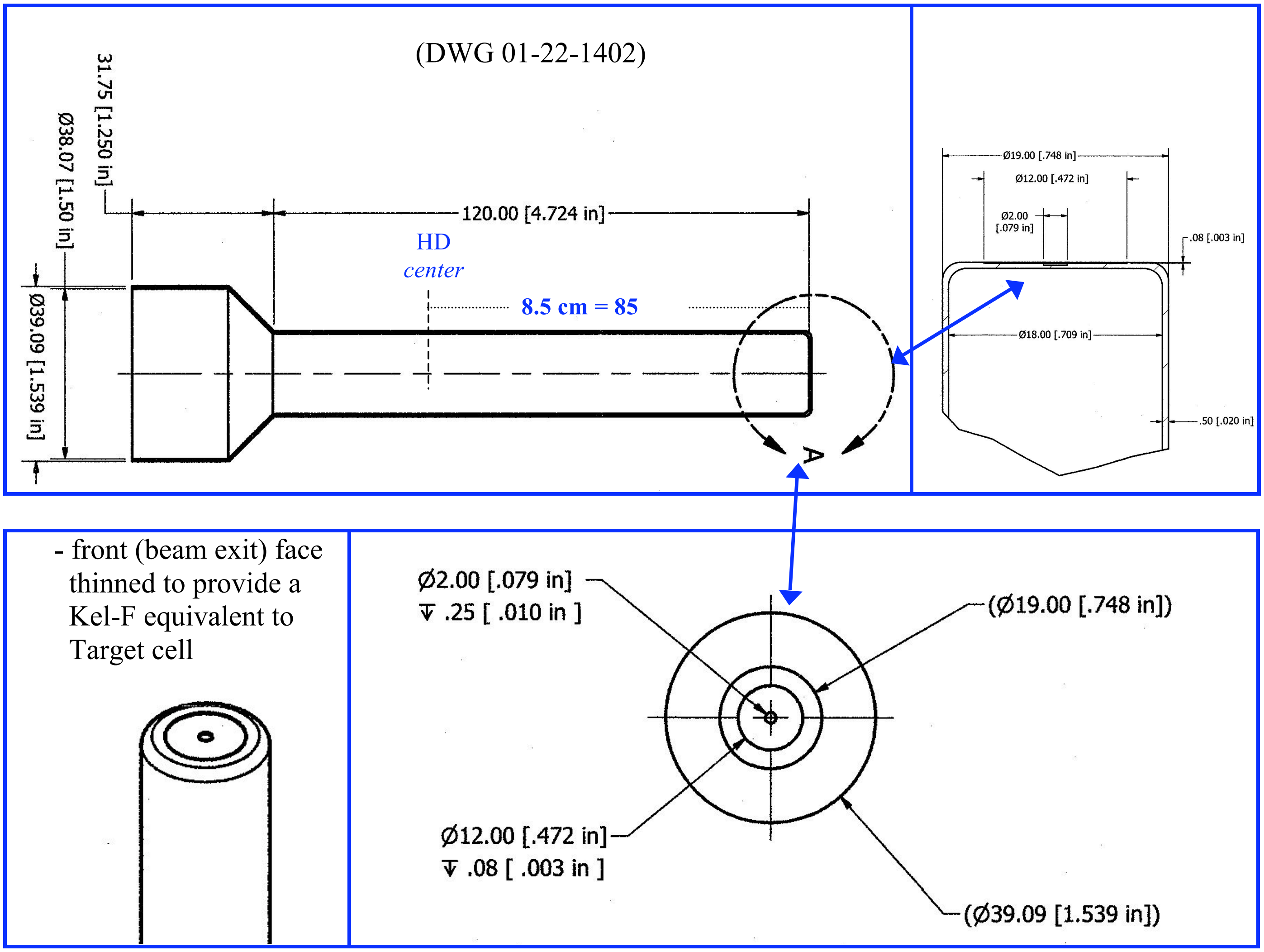
A.2.1 Summary of Material Properties

- The Kel-F (C_2ClF_3) cell wall is **0.050 cm** thick; the outer cell diameter is **1.60 cm;**
- the downstream exit window is thinned down to 0.010" = **0.025 cm over 1.2 cm central diameter**
- the density of Kel-F (C_2ClF_3) material is **2.12 g/cc.**

A.3 Inner-Vacuum-Can (IVC) nose

Description

- Surrounding the target cell is another cap that is also made of *Kel-F*, C_2ClF_3 plastic, density **2.12 g/cc.** This is depicted in **blue** in Figure 1. This cap separates vacuum regions within the IBC. The face of the downstream exit window is thinned down. The goal here was to create a Kel-F foil, for data subtraction, whose thickness represented the sum of all of the Kel-F in the target cell crossed by the beam. (Subtraction of the data from this end-cap assumed the beam was well aligned on the center of this cell, which was not always the case.)



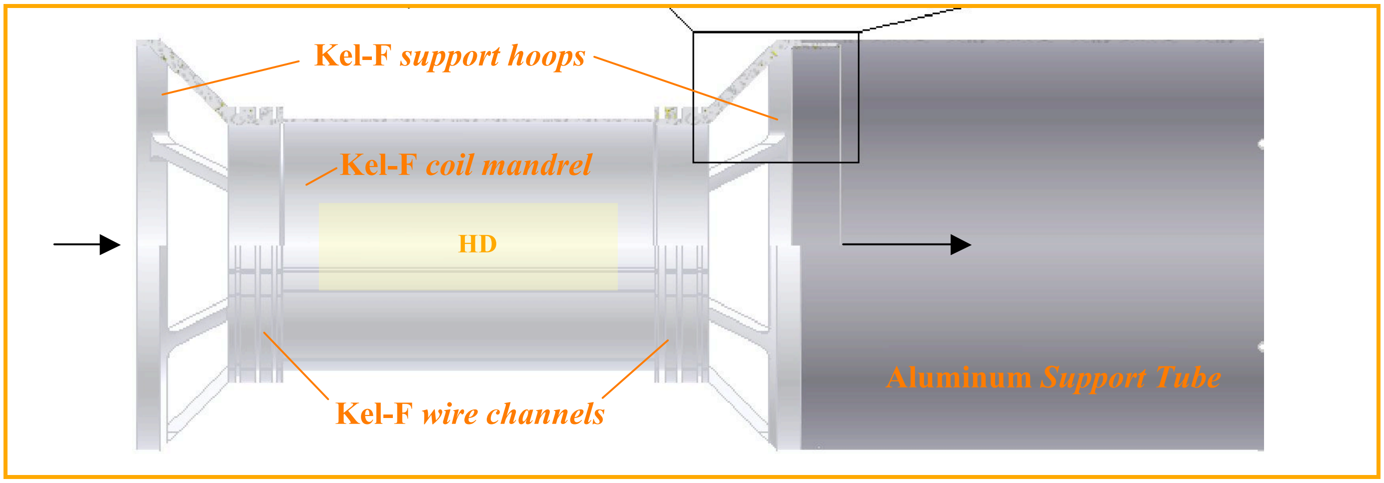
A.3.1 Summary of Material Properties

- The Kel-F (C_2ClF_3) side walls are **0.050 cm** thick; the outer cell diameter is **1.90 cm;**
- the face of the downstream exit window is thinned down.
  - the **central 0.1 cm radius is 0.025 cm thick** (0.010”);
  - the section of the front fact within **0.6cm < radius < 0.1cm is 0.042 cm thick**
  - the outer rim of the front face from **1.8cm < radius < 0.6cm is 0.050 cm thick**
- the density of Kel-F (C_2ClF_3) material is **2.12 g/cc.**

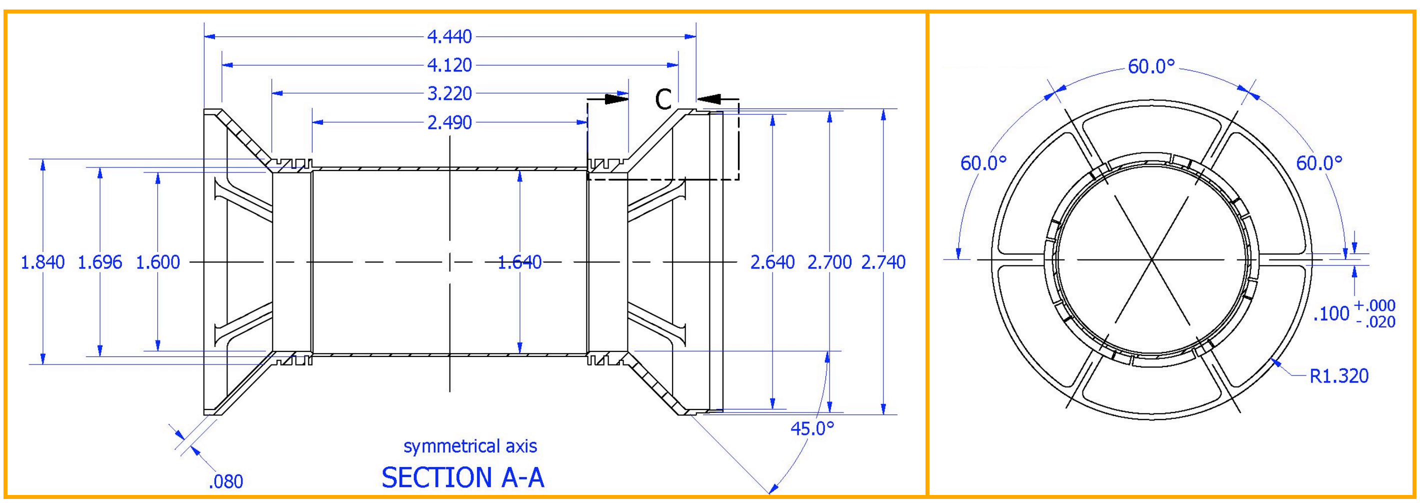
A.4 NMR coil form (DWG 2001-03-07)

Description

The NMR coils are wound on a Kel-F (C_2ClF_3) mandrel. The coil mandrel is supported at both ends by Kel-F hoops, 6.96 cm (2.74”) OD. The downstream hoop is attached to a thin aluminum support tube, 6.96 cm (2.74”) OD x 0.05 cm wall, and the assembly is a snug fit inside the LHe can. Within the two support hoops, the coil mandrel itself is a smaller diameter, 4.17 cm (1.64”) ID x 0.071 cm thick, and the coils

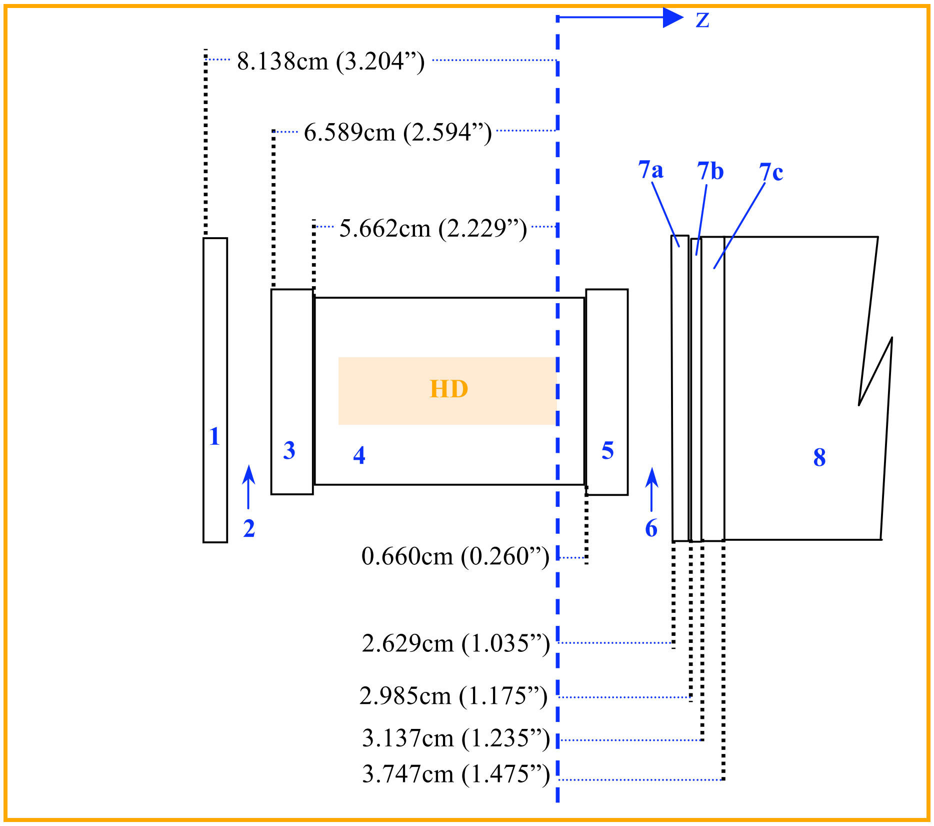


are centered on the nominal target position. The connection between the hoops and the coil mandrel is made at each end by 6 Kel-F ribs, 0.25 cm (0.100”) wide. The ribs are oriented to sit in the shadow of the CLAS torus coils, with two vertical ribs. Each rib subtends 7^0 from the target center. Nominally, this would not obscure the active area of the CLAS drift chambers, except that events originate in the HD throughout the beam spot diameter of ~ 0.95 cm. So orientation of the ribs minimizes their impact, but does not completely remove it. At either end of the coil mandrel are thicker rings of Kel-F that provide wire channels. These have a rather complicated machining pattern, but approximately these are Kel-F rings, 4.064cm (1.600”) ID x 0.927 cm (0.365”) long x 0.305 cm (0.120”) thick. (CAD dimensions below in inches.)



A.4.1 Summary of Material Properties

If CAD files cannot be used in simulations directly then, for purposes of energy loss calculations, an approximately *equivalent geometry* can be built up with sets of thin-walled rings. The z-position of each of these ring volumes is specified in the figure below by the z distance of the upstream end of the ring to the downstream end of the target (which is the easiest feature to identify with vertex reconstruction).



- the z-position of each *equivalent ring* is specified in the figure above, relative to the downstream tgt edge
- the dimensions of each equivalent ring is specified in the table below.
- the **density of Kel-F is 2.12 g/cc**; the **density of Aluminum is 2.70 g/cc**.

Volume region #	Length along z	OD	thickness, material
1	0.508cm (0.200")	6.960cm (2.740")	0.127cm (0.050") Kel-F (C_2ClF_3)
3	0.927cm (0.365")	4.674cm (1.840")	0.305cm (0.120") Kel-F (C_2ClF_3)
4	6.325cm (2.490")	4.308cm (1.696")	0.122cm (0.048") Kel-F (C_2ClF_3)
5	0.927cm (0.365")	4.674cm (1.840")	0.305cm (0.120") Kel-F (C_2ClF_3)
7a	0.356cm (0.140")	6.960cm (2.740")	0.127cm (0.050") Kel-F (C_2ClF_3)
7b	0.152cm (0.060")	6.960cm (2.740")	0.051cm (0.020") Aluminum + 0.127cm (0.050") Kel-F (C_2ClF_3)
7c	0.610cm (0.240")	6.960cm (2.740")	0.051cm (0.020") Aluminum + 0.066cm (0.026") Kel-F (C_2ClF_3) + 0.051cm (0.020") Aluminum
8	16.281cm (6.410")	6.960cm (2.740")	0.051cm (0.020") Aluminum

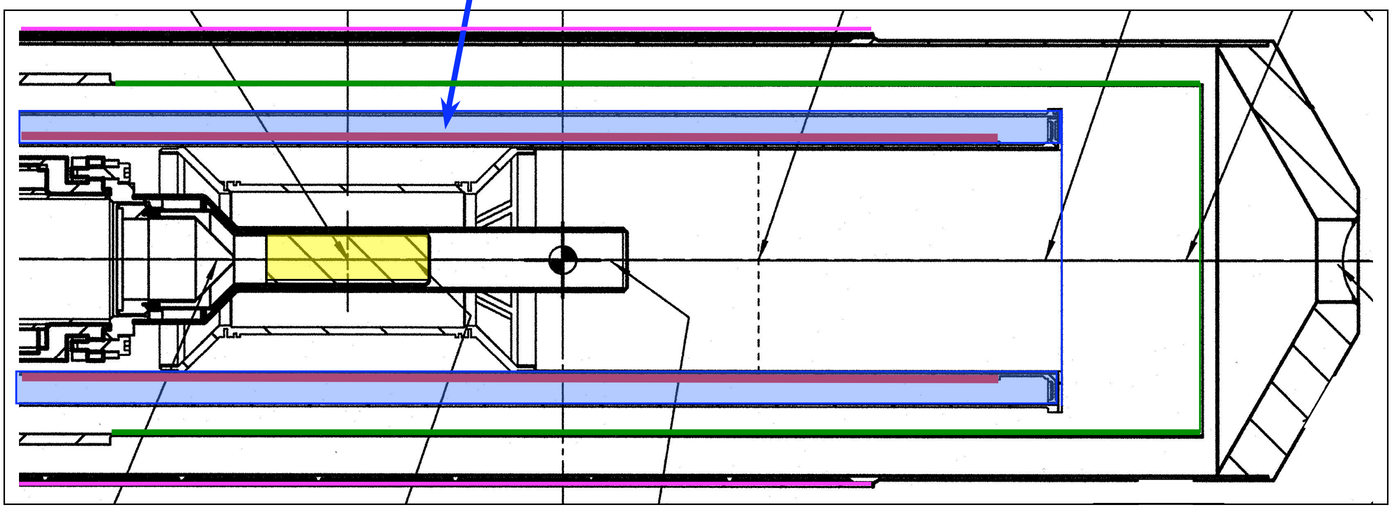
Here, volume 8 is the support ring that holds the coil form inside the magnet can and slips over the outside of the downstream Kel-F hoop. Another short Aluminum ring fits inside the Kel-F in volume 7c in order to capture the Kel-F when materials thermally contract, so ring 7c is a composite sandwich of Al +Kel-F +Al.

Only one thing is missing from this *nominally equivalent Geometry*, namely 6 Kel-F ribs, each with cross section 0.25 cm (0.100") x 0.406cm (0.160"), oriented every 60^0 in both regions 2 and 6 above. The ribs are oriented with a pair in the vertical plane. To 0^{th} order, the ribs could be ignored, since they sit in the shadow of the CLAS Torus coils. But that is strictly true only for particles originating along the target center line.

B) IBC magnet and thermal shields

A 4K **volume** surrounds the target region (A) and contains the super-conducting **magnets**, cooled by direct contact with liquid helium (LHe). Outside of this is an ***80K shield*** of Aluminum that is indirectly cooled by contact with evaporating LHe at the upstream end of the IBC. (Finally, outside of this is the mostly Aluminum **vacuum can** and the room-temperature AL **backup solenoid** of section C.)

Assembly Figure 2: **LHe magnet can: SS walls + SC coil + Liquid He**



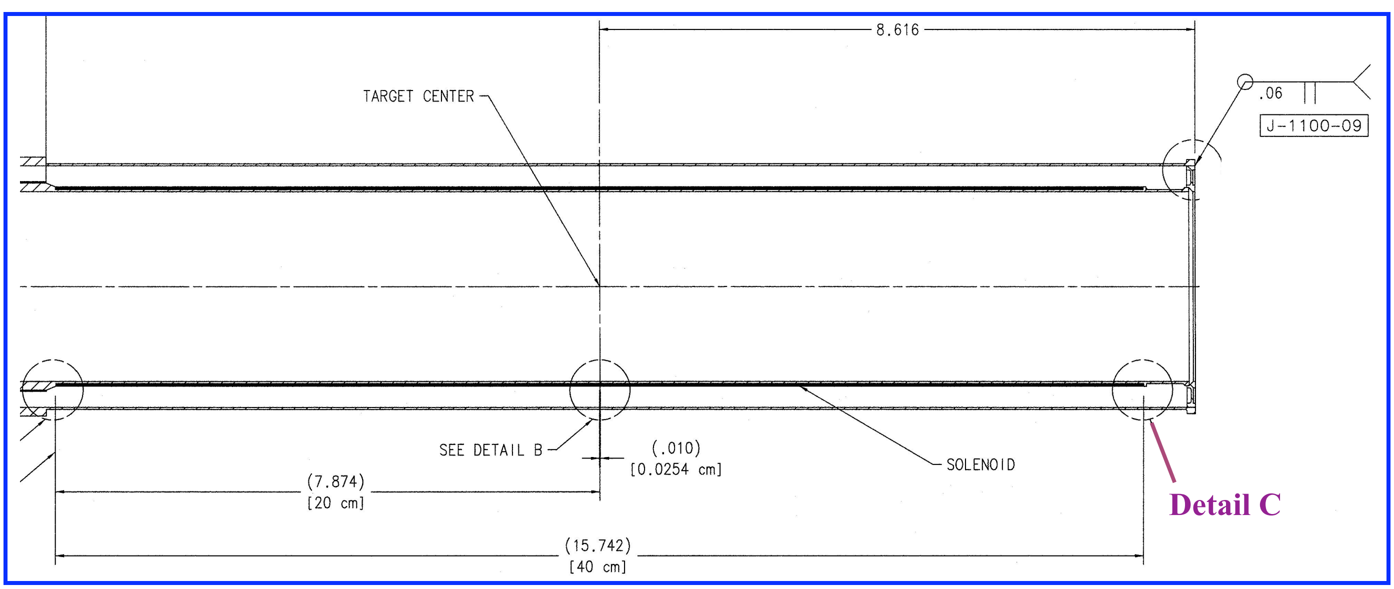
B.1 LHe magnet can: (DWG B00000-01-22-1100B-01)

The magnet can containing the liquid He and SC coils is made from two concentric tubes of aluminum.

B.1.1 Summary of Materials and Properties

Material is listed in the order seen by a transiting particle.

B.1.1.a inner wall: (DWG B00000-01-22-1116)
Al (**density 2.700 g/cc**) starting at a radial distance measured from the target axis of 3.490 cm (1.375"), with **wall thickness 0.076cm** (0.030"), and extending 31.41cm (8.616") down stream of the target center (including the 0.23cm thick end plate – as below).



- **Super-conducting (SC) magnet coils**:

There are two SC magnets surrounding the target, a solenoid and a transverse saddle coil. Both are made from windings of "Supercon 54S43" and are wound on the inner Al tube.

- **Superconducting wire**:

The superconducting wire, "Supercon 54S43", consists of NbTi multifilament (54 filament) wire embedded in a copper stabilizer. The diameter of the wire bundle is 0.229 mm (0.009") and the ratio of Cu –to- NbTi is 1.3 : 1.0. There is an additional thickness of 0.0125 mm of varnish insulator, so that the diameter of the net wire bundle is 0.254 mm (0.010") = 0.0254 cm. Spaces between wires are filled with Stycast 1265 epoxy, density 1.08 gm/cc.

- **Equivalent thickness**:

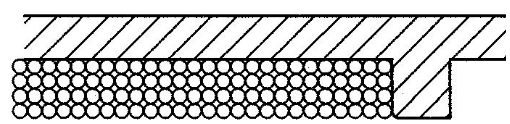
When the SC wire is modeled explicitly turn by turn, the gaps between the wires result in reduced energy loss. The amount of SC metal seen by the <u>average</u> trajectory is reduced from the wire diameter by the ratio of the cross sectional areas of the wire, π*(0.0229cm/2)^2, to the area of the square containing the wire and its insulating layer, (0.0254cm)^2 – ie. by a factor of 0.638.
Thus, one layer of SC coil winding may be approximated as a solid layer with the following composition:

- Cu: 0.0254 *(1.3/2.3) *(0.638) = 0.0092 cm thick, with density = 8.960 gm/cc
- Nb: 0.0254 *(0.5/2.3) *(0.638) = 0.0035 cm thick, with density = 8.570 gm/cc
- Ti: 0.0254 *(0.5/2.3) *(0.638) = 0.0035 cm thick, with density = 4.506 gm/cc
- Epoxy: 0.0254 *(0.362) = 0.0092 cm thick of $\mathbf{C_{21}H_{25}ClO_5}$ with density = 1.08 gm/cc

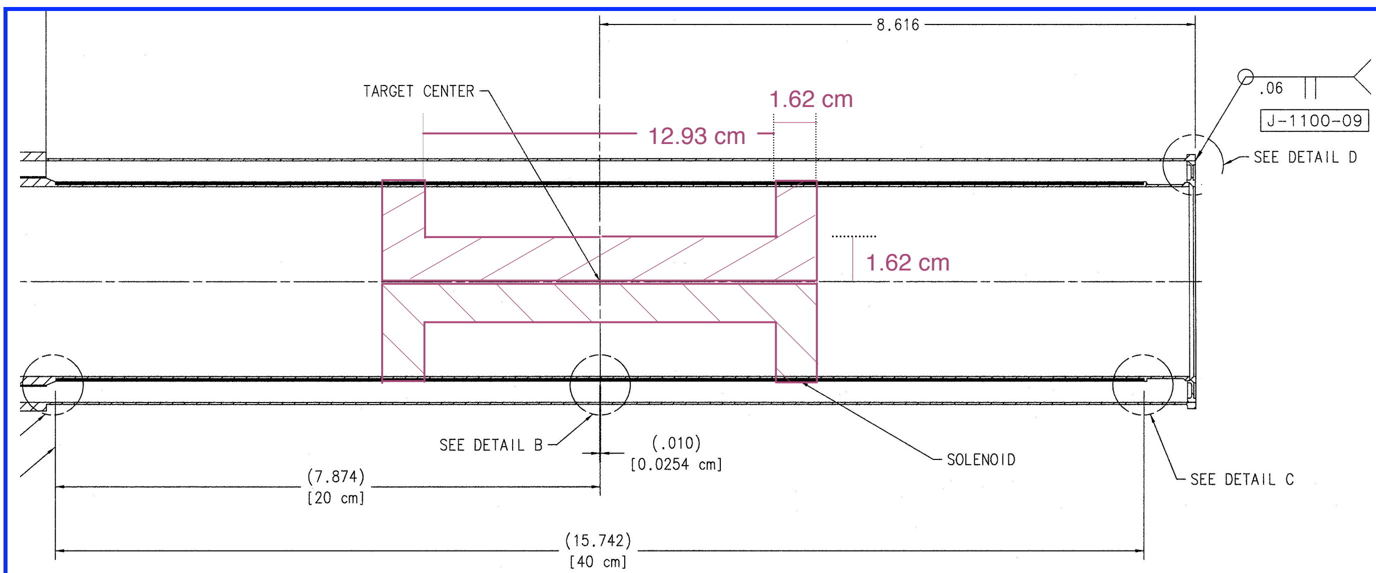
B.1.1.b SC solenoid:

• The solenoid surrounding the target has a total length of 40 cm and is centered on the center of the HD, 2.5 cm upstream of the downstream Kel-F cell window. The magnet is made from **4 layers** of "Supercon 54S43" wire, so that the total solenoid wire package can be approximated as 4 layers with composition as given above. The 1st layer has an **inner radius of 3.566 cm**.
• There is an additional 0.025cm (0.010") layer of Stycast 1265 epoxy, density 0.99 g/cc, that binds the coils into a rigid unit.

Detail C



B.1.1.c SC saddle coil:



- The saddle coil is wound as a single layer 54 turn pancake of Supercon 54S43 wire that is wrapped around the nose. The legs of the saddle coil are in the horizontal plane, so that the field is vertical.
- dimensions of the pancake are 12.93 cm inside length along the beam direction x 1.62 cm wide;
- thickness of the pancake single-layer wire package = 0.0254 cm NbTi and Cu, as above, plus an additional 0.025cm (0.010") layer of Stycast 1265.

B.1.1.d Liquid Helium:

LHe fills the magnet can:

- thickness: 0.75 cm, [1.750" – (1.405" +0.040" +0.010")] = 0.295" , as measured vertically perpendicular (ie. through the gap in the saddle coil) to target/beam axis
- LHe density at 4.2K = 0.1249 g/cc

B.1.1.e outer wall: (DWG B00000-01-22-1115)

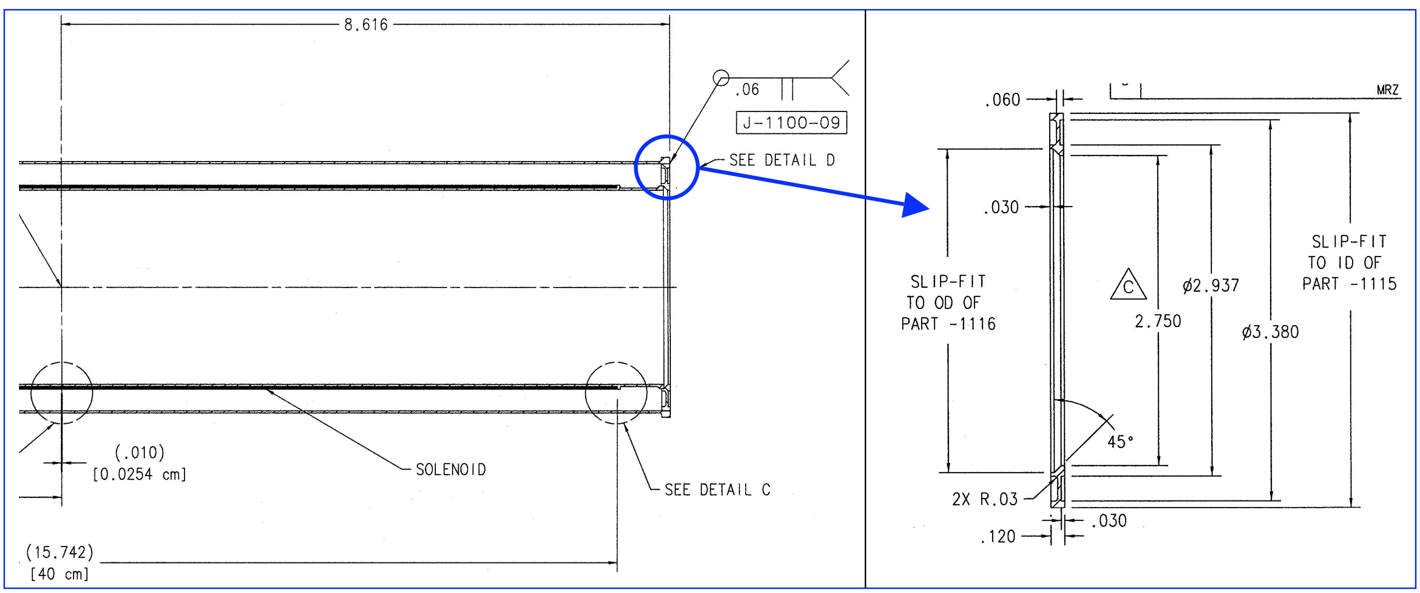
Al (density 2.70 g/cc) starting at a radial distance measured from the target axis of 4.445 cm (1.750"), with wall thickness 0.0813cm (0.032"), and extending 31.41cm (8.616") downstream of the target center.

B.1.1.f superinsulation: (Oxford NRC-2)

- 10 wraps of ¼ mil aluminized mylar, with mesh separators, spread radially over about 0.3175 cm (1/8");
• equivalent thickness: 0.0076cm (0.003") of $C_{10}H_8O_4$ at density = 1.40 gm/cc
(Al coating is typically 350 Angstroms and can be neglected.)

B.1.1.g downstream end plate: (DWG B00000-01-22-1117c)

Perpendicular to beam axis. Seals inner and outer Al tubes to make a single hermetic can.



- Al (density 2.7 g/cc) with thickness 0.076cm (0.030") over most of its area;
- + 0.05cm (0.020") Stycast Epoxy 2850FT-24LV, density 1.02 g/cc

B.2 80 K shield: (DWG B00000-01-22-0407)

- a thermal shield, conduction cooled by contact to an upstream cold plate, surrounds the LHe magnet can. This tube is surrounded by a layer of superinsulation.

B.2.1 Summary of Materials and Properties

Material is listed in the order seen by a transiting particle.

B.2.1.a 80K Aluminum shield

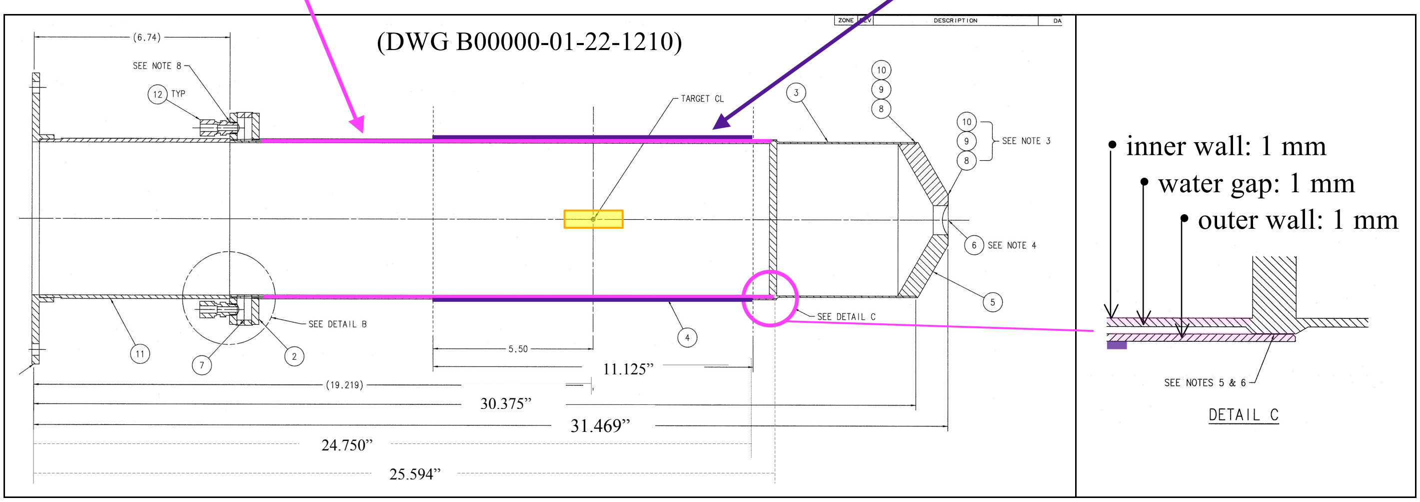
- a right cylinder, starting at a radial distance measured from the target axis of 5.398 cm (2.125"), and extending 26.14 cm (10.293") downstream from the target center. (These numbers have been corrected for thermal contraction.)
- thickness = 0.0508 cm (0.020") of Al 6061, with density = 2.70 gm/cc.

B.2.1.b superinsulation: (Oxford NRC-2)

- 20 wraps of ¼ mil aluminized mylar, with mesh separators, spread radially over about 0.635 cm (¼") ;
• equivalent thickness: 0.0127cm (0.005") of $\mathbf{C_{10}H_8O_4}$ at density = 1.40 gm/cc
(Al coating is typically 350 Angstroms and can be neglected.)

C) IBC Outer Vacuum Can (OVC)

The vacuum can is the outermost layer in Assembly Figure 2 above. The material of the nose surrounding the target is Aluminum. The front face is Rohacell with a thin (50 µm) Al beam exit window. The nose incorporates a **water cooling channel**, on top of which is a room-temp **backup solenoid**, wound from a single layer of Al wire. (Dimensions on the assembly below have been updated with *as built* values.)



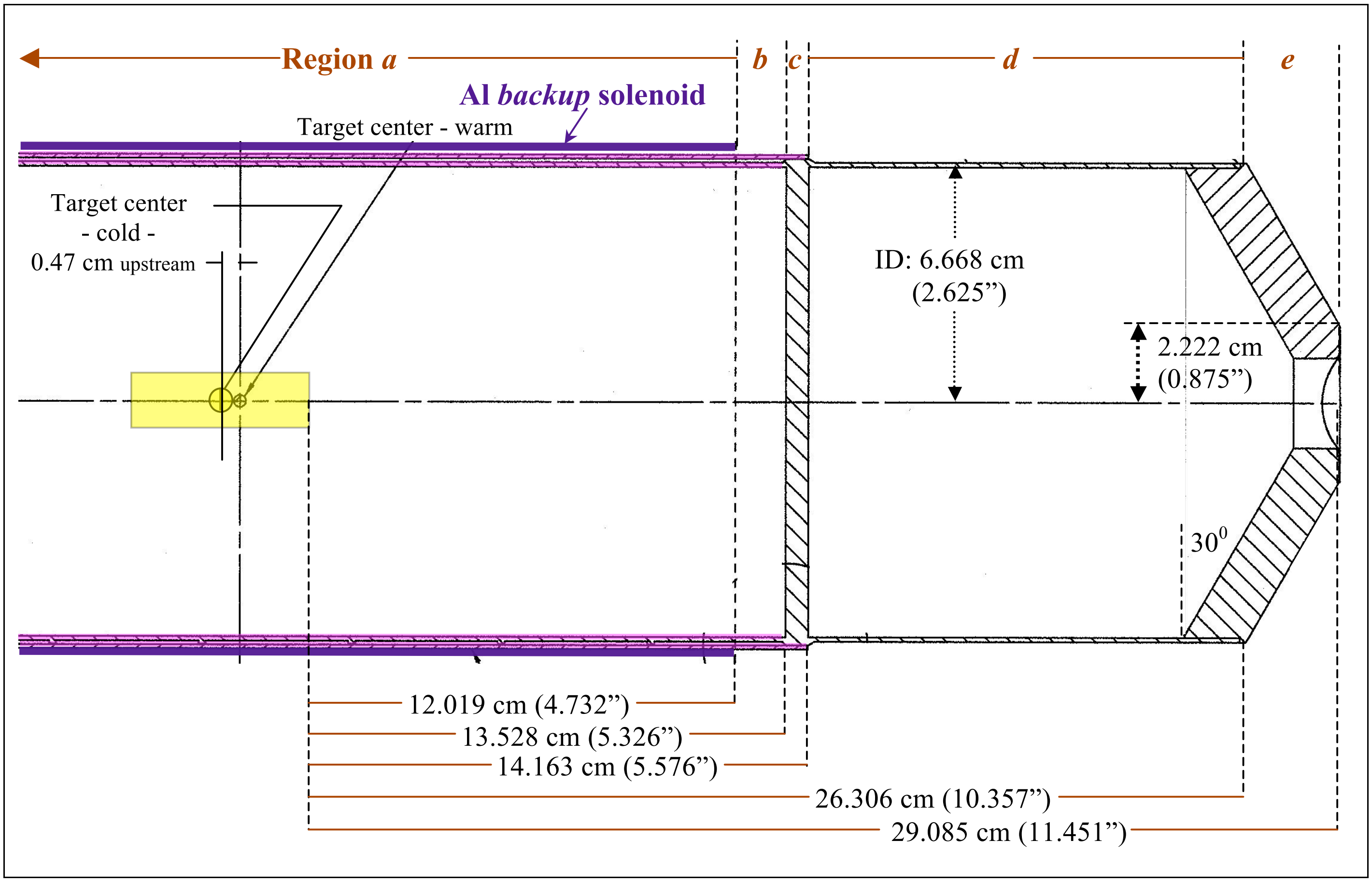
C.1 Central OVC cooling jacket and backup coil (DWG B00000-01-22-1211)

Description

A water cooling jacket is incorporated into the central region of the OVC nose (**Regions 1 and 2** below). The jacket is created by the inner OVC nose and a larger ID outer tube that is glued over the OVC, leaving a gap for water. To force the water to flow around the length of the nose, thin aluminum ribs extending outward to the outer tube ID have been machined on the inner OVC nose to provide water channels. These ribs occupy a very small fraction of the surface area and we suggest they be neglected in evaluating dE/dx.

C.1.1 Summary of Materials and Properties

When the IBC is cold, the target center is shifted upstream relative to the OVC by 0.5 cm due to thermal contraction of the interior cold components. The OVC nose can be modeled as 5 regions. Material are listed below in the order seen by a transiting particle.



C.1.1.*a* Region *a*: ($\theta_{Lab} > 29^0$ approx, from tgt center)

- region starts 12.019 cm (4.732") forward of the downstream end of the HD and extends upstream to smaller z values (beyond the back-angle acceptance of CLAS), and at a radius of 6.668 cm (2.625");
- first layer is 0.1 cm of Aluminum-6061 in thickness, density = 2.70 gm/cc;
  dE path thickness = [0.100 cm / sin(θ_L)];
- second layer is 0.1 cm of water in thickness, density = 1.00 gm/cc;
  dE path thickness = [0.100 cm / sin(θ_L)];
- third layer is 0.1 cm of Aluminum-6061 in thickness, density = 2.70 gm/cc;
  dE path thickness = [0.100 cm / sin(θ_L)];
- forth layer is Aluminum wire - 0.1024cm Al with a 5 micron anodized Al_2O_3 coating ;

As in Section B.1.1, the amount of metal seen by the average trajectory is reduced from the wire diameter by the ratio of the cross sectional areas of the Al wire, π*(0.1014cm/2)^2, to the area of the square containing the wire, its insulating layer and the Sytcast 1265 glue, (0.1024cm)^2 – ie. by a factor of 0.747 . Thus the 4th layer can be approximated as a solid layer with the following composition:

- Aluminum-6043: 0.1024 *(0.747) cm thick, with density = 2.72 gm/cc
  dE path thickness = [0.077 cm / sin(θ_L)];
- Epoxy: 0.1024 *(0.253) cm thick of $\mathbf{C_{21}H_{25}ClO_5}$ with density = 1.08 gm/cc
  dE path thickness = [0.026 cm / sin(θ_L)];

C.1.1.*b* Region *b*: (29^0 > θ_{Lab} > 26^0 approx, from tgt center)

- region defined by distances between 12.019 cm (4.732") < **z** < 13.528 cm (5.326"), as measured from the downstream end of the HD , and at a radius of 6.668 cm (2.625");
- first layer is 0.1 cm of Aluminum-6061 in thickness, density = 2.70 gm/cc;
dE path thickness = [0.100 cm / sin(θ_L)];
- second layer is 0.1 cm of water in thickness, density = 1.00 gm/cc;
dE path thickness = [0.100 cm / sin(θ_L)];
- third layer is 0.1 cm of Aluminum-6061 in thickness, density = 2.70 gm/cc;
dE path thickness = [0.100 cm / sin(θ_L)];

C.1.1.*c* Region *c*: (26^0 > θ_{Lab} > 25^0 approx, from tgt center)

- region defined by distances between 13.528 cm (5.326") < **z** < 14.163 cm (5.576"), as measured from the downstream end of the HD , and at a radius of 6.668 cm (2.625");
- the layer is 0.38 cm (0.150") of Aluminum-6061 in thickness, density = 2.70 gm/cc;
dE path thickness = [0.380 cm / sin(θ_L)];

C.1.1.*d* Region *d*: (25^0 > θ_{Lab} > 14^0 approx, from tgt center)

- region defined by distances between 14.163 cm (5.576") < **z** < 26.306 cm (10.357"), as measured from the downstream end of the HD , and at a radius of 6.668 cm (2.625");
- the layer is 0.1 cm of Aluminum in thickness, density = 2.70 gm/cc;
dE path thickness = [0.100 cm / sin(θ_L)];

C.1.1.*e* Region *e*: (14^0 > θ_{Lab} > 4^0 approx, from tgt center)

- region defined by distances between 26.306 cm (10.357") at transverse distance = 6.668cm (2.625") < **z** < 29.085 cm (11.451") at transverse distance = 2.222cm (0.875"), as measured from the downstream end of the HD
- first layer material is West-407 filler epoxy, **(0.55)*($C_8H_{10}O_2$) + (0.45)*(SiO_2)**, density = 0.121 gm/cc, material thickness = 0.10 cm (0.039") at an angle of 30^0 to the vertical;
dE path thickness = [0.100 cm / cos(30 – θ_L)];
- second layer material is Rohacell-110, **$C_5H_8O_2$**, density = 0.110 gm/cc, and is 1.588 cm (0.625") thick at an angle of 30^0 to the vertical.
dE path thickness = [1.588 cm / cos(30 – θ_L)];
- (There is also a 25 micron skin of Aluminum on the inside surface of the West-407, but we suggest this be neglected.)

<u>Appendix</u>: sample energy loss calculations

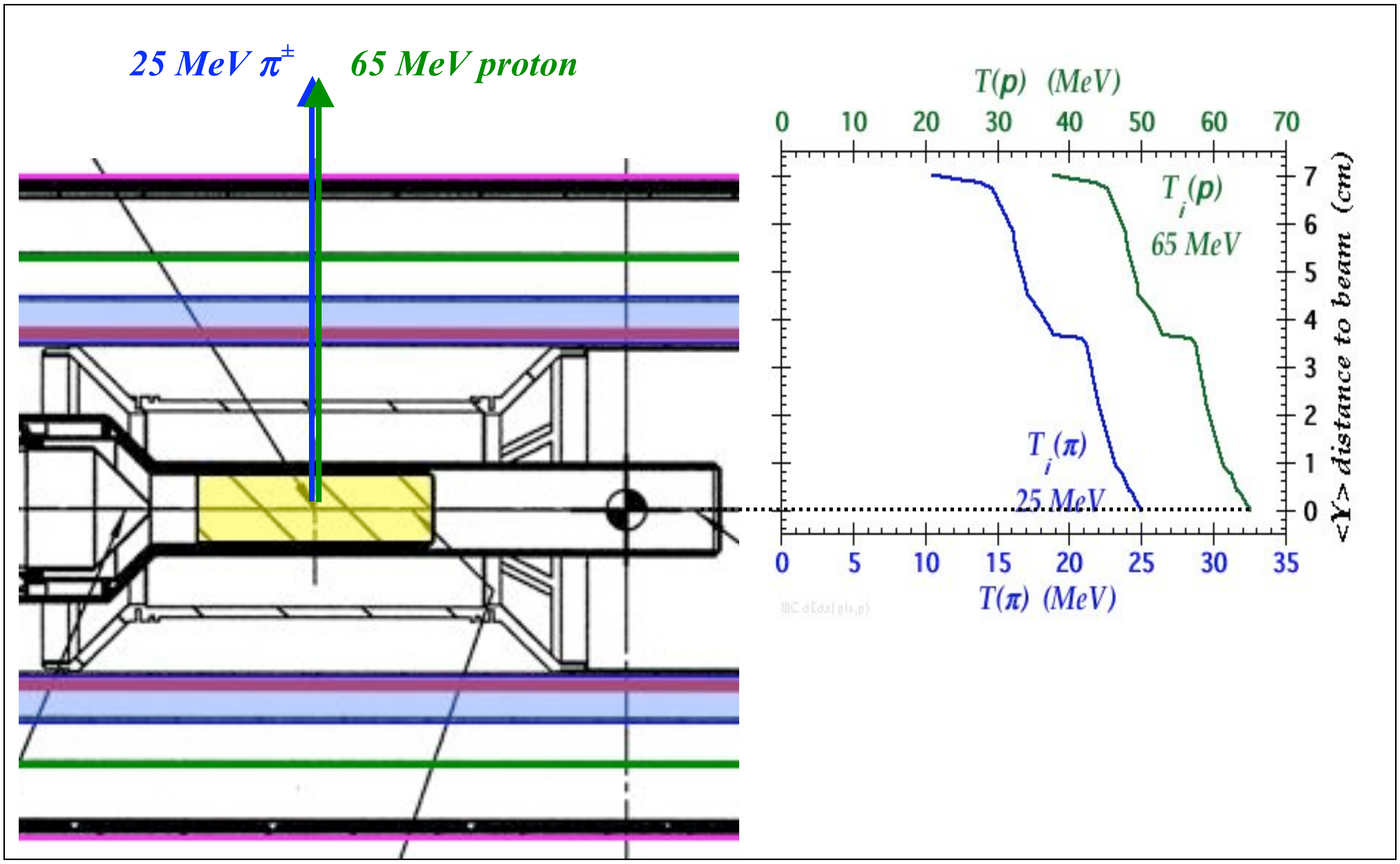
In the two tables below, the energy-loss is tracked first for $\pi^{\pm}$ with kinetic energies (**T**) of **25** MeV and **1000** MeV, and then for protons with **T** of **65** MeV and **1000** MeV, both emerging from the target at 90^0 Lab. Differential values are listed for each layer discussed above, along with the perpendicular distance from the central IBC axis to the center of the material layer, <**Y**>. In past CLAS runs, the low energy detection thresholds have typically been about 100 MeV/c for pions (**T**$_\pi$ =32 MeV) and 300 MeV/c for protons (**T**$_p$ =47 MeV), limited by energy loss in the target cryostats and closed orbit bends in the torus that prevent low energy particles from reaching the TOF counters. The g14 thresholds will be slightly higher due to somewhat larger losses in the HDice IBC material, but not appreciably.

***eg* 1. charged pion Energy loss in tgt 21a, starting with kinetic energy T at target center**

dEdx Layer	material	density (gm/cc)	thickness (cm)	Lab angles theta / ϕ	<Y> distance (cm)	**dE** in layer (MeV)	**T** leaving layer (MeV)	**dE** in layer (MeV)	**T** leaving layer (MeV)
tgt center				**90 /90**	0	$\pi^{\pm}$	**25.000**	$\pi^{\pm}$	**1000.000**
A.1.1	HD	0.147	0.7500	90 /90	0.375	0.773	24.227	0.337	999.663
A.1.1	Al	0.028	0.7500	90 / 90	0.375	0.099	24.128	0.040	999.624
A.2.1	$C_2 Cl F_3$	2.120	0.0500	90 / 90	0.775	0.450	23.678	0.203	999.421
A.3.1	$C_2 Cl F_3$	2.120	0.0500	90 / 90	0.925	0.455	23.223	0.203	999.218
A.4.1.4	$C_2 Cl F_3$	2.120	0.1220	90 / 90	2.093	1.133	22.090	0.495	998.723
B.1.1.a	Al	2.700	0.0760	90 / 90	3.452	0.898	21.192	0.386	998.337
B.1.1.b :									
coil layer 1	Cu	8.960	0.0092	90 / 90	3.579	0.315	20.877	0.138	998.199
	Nb	8.570	0.0035	90 / 90	3.579	0.109	20.768	0.047	998.152
	Ti	4.506	0.0035	90 / 90	3.579	0.065	20.703	0.028	998.124
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.579	0.054	20.649	0.022	998.102
coil layer 2	Cu	8.960	0.0092	90 / 90	3.604	0.321	20.328	0.138	997.964
	Nb	8.570	0.0035	90 / 90	3.604	0.110	20.218	0.047	997.917
	Ti	4.506	0.0035	90 / 90	3.604	0.066	20.152	0.028	997.889
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.604	0.055	20.097	0.022	997.867
coil layer 3	Cu	8.960	0.0092	90 / 90	3.630	0.327	19.770	0.138	997.729
	Nb	8.570	0.0035	90 / 90	3.630	0.113	19.657	0.047	997.682
	Ti	4.506	0.0035	90 / 90	3.630	0.067	19.590	0.028	997.654
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.630	0.056	19.534	0.022	997.632
coil layer 4	Cu	8.960	0.0092	90 / 90	3.655	0.333	19.201	0.138	997.494
	Nb	8.570	0.0035	90 / 90	3.655	0.115	19.086	0.047	997.447
	Ti	4.506	0.0035	90 / 90	3.655	0.069	19.017	0.028	997.419
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.655	0.058	18.959	0.022	997.397
potting	$C_{21}H_{25}CLO_5$	1.080	0.0250	90 / 90	3.680	0.156	18.803	0.059	997.338
B.1.1.c	N/A at ϕ=90								
B.1.1.d	He	0.125	0.7500	90 / 90	4.055	0.645	18.157	0.211	997.127
B.1.1.e	Al	2.700	0.0813	90 / 90	4.486	1.110	17.047	0.413	996.714
B.1.1.f	$C_{10}H_8O_4$	1.400	0.0076	90 / 90	4.685	0.062	16.985	0.022	996.693
B.1.1.g	N/A at ϕ=90								
B.2.1.a	Al	2.700	0.0508	90 / 90	5.423	0.722	16.263	0.258	996.435
B.2.1.b	$C_{10}H_8O_4$	1.400	0.0127	90 / 90	5.766	0.108	16.155	0.037	996.398
C.1.1.a :									
	Al	2.700	0.1000	90 / 90	6.718	1.503	14.652	0.508	995.890
	H_2O	1.000	0.1000	90 / 90	6.818	0.743	13.909	0.227	995.663
	Al	2.700	0.1000	90 / 90	6.918	1.696	12.213	0.508	995.155
	AL-6043	2.720	0.0770	90 / 90	6.969	1.448	10.765	0.394	994.761
	$C_{21}H_{25}CLO_5$	1.080	0.0260	90 / 90	6.969	0.251	10.514	0.061	994.700
					$\Delta E_{\pi+}$:	**14.5**		**5.3**	
					$E^f_{\pi+}$:		**10.5**		**994.7**

***eg* 2. proton Energy loss in tgt 21a, starting with kinetic energy T at target center**									
dEdx Layer	material	density (gm/cc)	thicknes (cm)	Lab angles theta / ϕ	**<Y>** distance (cm)	**dE** in layer (MeV)	**T** leaving layer (MeV)	**dE** in layer (MeV)	**T** leaving layer (MeV)
tgt center				**90 /90**	0	***proton***	**65.000**	***proton***	**1000.000**
A.1.1	HD	0.147	0.7500	90 /90	0.375	1.577	63.423	0.326	999.674
A.1.1	Al	0.028	0.7500	90 / 90	0.375	0.190	63.233	0.037	999.637
A.2.1	C_2ClF_3	2.120	0.0500	90 / 90	0.775	0.893	62.340	0.194	999.444
A.3.1	C_2ClF_3	2.120	0.0500	90 / 90	0.925	0.903	61.437	0.194	999.250
A.4.1.4	C_2ClF_3	2.120	0.1220	90 / 90	2.093	2.241	59.196	0.472	998.777
B.1.1.a	Al	2.700	0.0760	90 / 90	3.452	1.757	57.439	0.361	998.416
B.1.1.b :									
coil layer 1	Cu	8.960	0.0092	90 / 90	3.579	0.605	56.834	0.128	998.288
	Nb	8.570	0.0035	90 / 90	3.579	0.207	56.627	0.044	998.244
	Ti	4.506	0.0035	90 / 90	3.579	0.125	56.502	0.026	998.218
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.579	0.107	56.395	0.021	998.198
coil layer 2	Cu	8.960	0.0092	90 / 90	3.604	0.609	55.786	0.128	998.070
	Nb	8.570	0.0035	90 / 90	3.604	0.209	55.577	0.044	998.026
	Ti	4.506	0.0035	90 / 90	3.604	0.127	55.450	0.026	998.000
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.604	0.108	55.343	0.021	997.979
coil layer 3	Cu	8.960	0.0092	90 / 90	3.630	0.611	54.732	0.128	997.851
	Nb	8.570	0.0035	90 / 90	3.630	0.212	54.520	0.044	997.807
	Ti	4.506	0.0035	90 / 90	3.630	0.129	54.391	0.026	997.781
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.630	0.109	54.282	0.021	997.760
coil layer 4	Cu	8.960	0.0092	90 / 90	3.655	0.615	53.667	0.128	997.632
	Nb	8.570	0.0035	90 / 90	3.655	0.215	53.452	0.044	997.588
	Ti	4.506	0.0035	90 / 90	3.655	0.131	53.321	0.026	997.562
	$C_{21}H_{25}CLO_5$	1.080	0.0092	90 / 90	3.655	0.110	53.211	0.021	997.541
potting	$C_{21}H_{25}CLO_5$	1.080	0.0250	90 / 90	3.680	0.304	52.907	0.057	997.484
B.1.1.c	N/A at ϕ=90								
B.1.1.d	He	0.125	0.7500	90 / 90	4.055	1.208	51.699	0.198	997.286
B.1.1.e	Al	2.700	0.0813	90 / 90	4.486	2.096	49.603	0.387	996.899
B.1.1.f	$C_{10}H_8O_4$	1.400	0.0076	90 / 90	4.685	0.118	49.485	0.020	996.879
B.1.1.g	N/A at ϕ=90								
B.2.1.a	Al	2.700	0.0508	90 / 90	5.423	1.348	48.137	0.242	996.637
B.2.1.b	$C_{10}H_8O_4$	1.400	0.0127	90 / 90	5.766	0.203	47.934	0.035	996.602
C.1.1.a :									
	Al	2.700	0.1000	90 / 90	6.718	2.754	45.180	0.476	996.126
	H_2O	1.000	0.1000	90 / 90	6.818	1.403	43.777	0.220	995.906
	Al	2.700	0.1000	90 / 90	6.918	2.967	40.810	0.476	995.430
	AL-6043	2.720	0.0770	90 / 90	6.969	2.424	38.386	0.369	995.061
	$C_{21}H_{25}CLO_5$	1.080	0.0260	90 / 90	6.969	0.415	37.971	0.059	995.002
					ΔE_p :	**27.0**		**5.0**	
					E^f_p :		**38.0**		**995.0**

The energy of emerging **25** MeV $\pi^{\pm}$ and **65** MeV protons are tracked in the right panel of the figure below as a function of the distance from the center of the target. For comparison, the relevant section of Assembly figure 2 is shown to the left with the same vertical scale. As expected, the largest contributors to the energy loss are the vacuum-can-backup-solenoid package and the Liquid helium can containing the super-conducting magnets.



The cases detailed in the above tables can serve as a 1st order bench-mark to verify the coding of a full simulation.

Notes

1) The energy loss in a molecular material is calculated as,

$$dE_{molecule} = \frac{1}{M}\sum N_i A_i dE_i\left(\frac{\rho_{molecule}}{\rho_i}\right)$$

where M is the molecular Mass, N_i is the number of atoms of atomic number A_i , and dE_i is the energy loss in the elemental material with density ρ_i .

2) The chemical formula used here for StyCast 1265, namely $C_{21}\ H_{25}\ Cl\ O_5$, is that of a generic butyphenyl – propyl ether epoxy. I have requested the correct formulation from the manufacturer, but as of Aug 16/12 the discussions regarding non-disclosure agreements have yet to converge. When they do, this report will be updated.