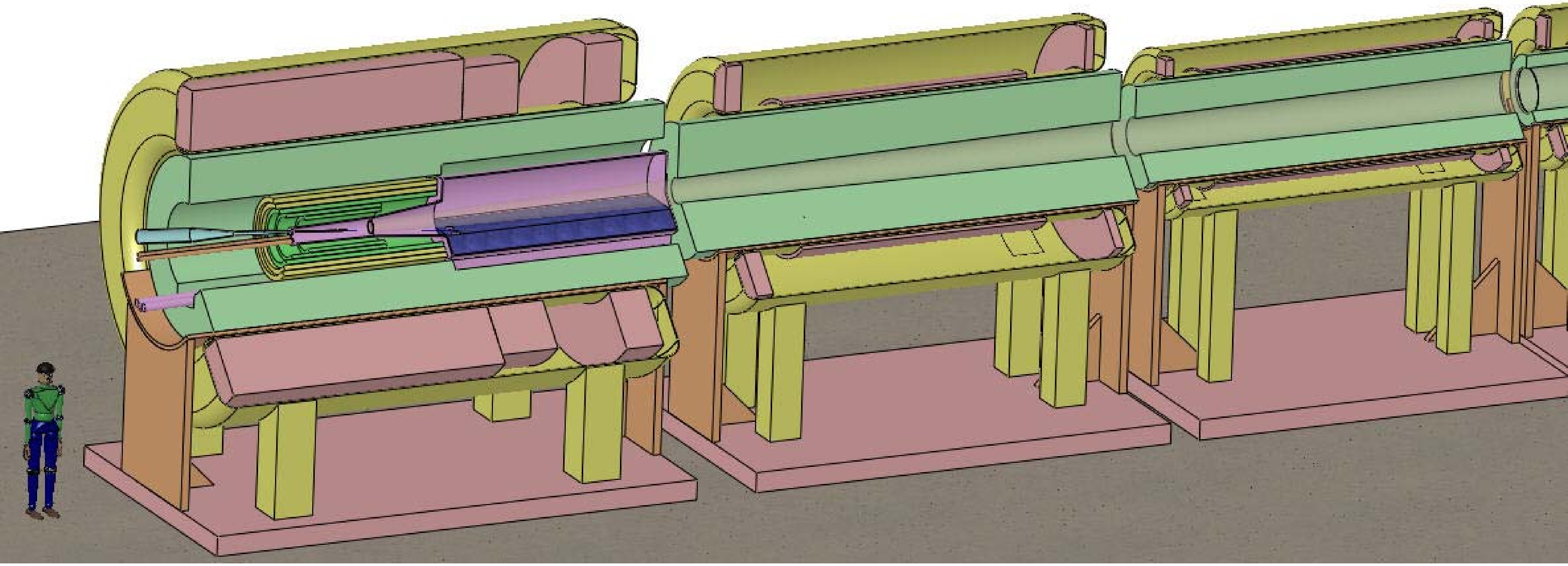
Engineering Issues for the High-Power-Target System of a Neutrino Factory



K. McDonald

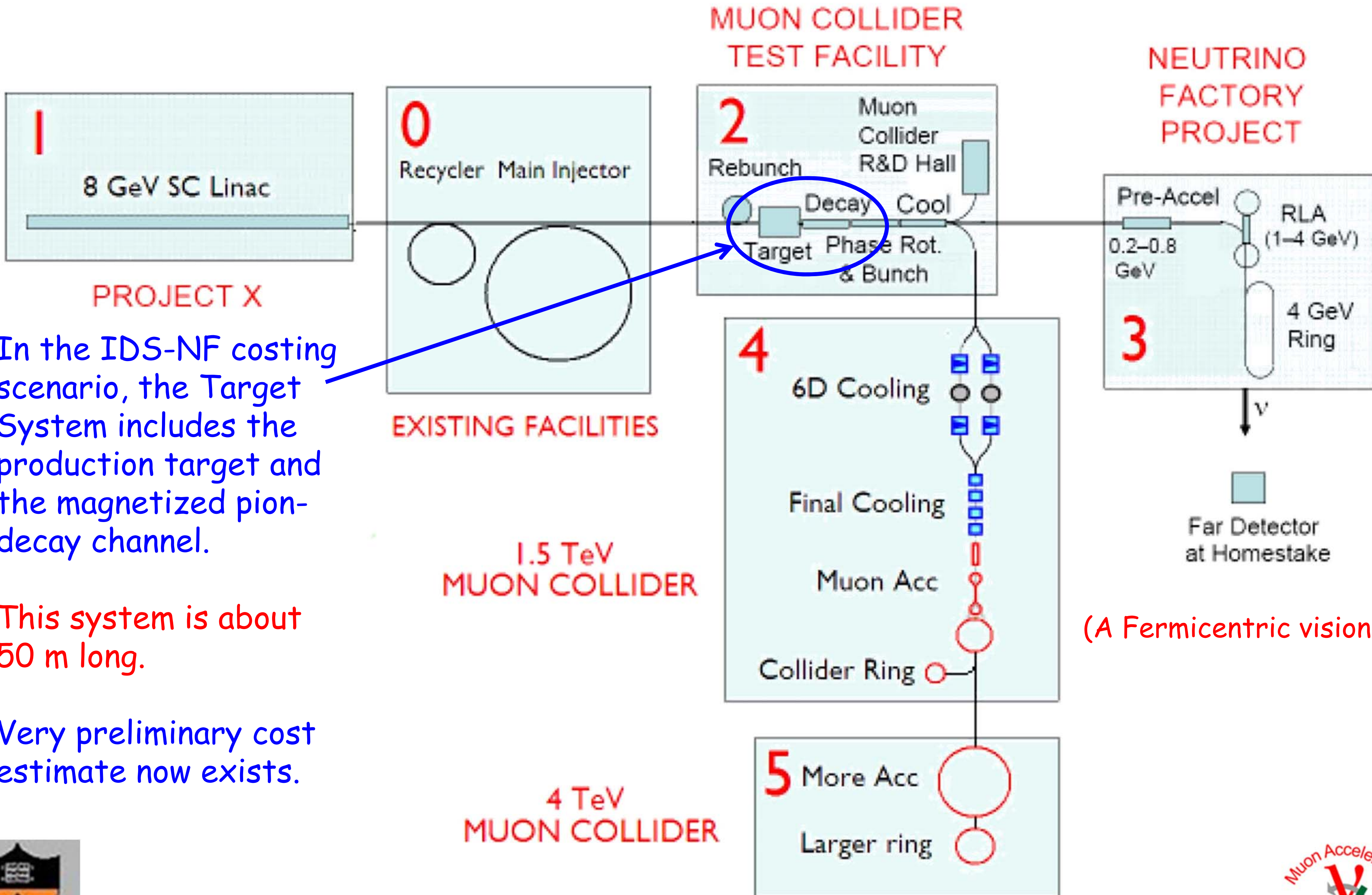
Princeton U.

(April 6, 2013)

10th IDS-NF Plenary Meeting

Rutherford Appleton Laboratory

The Target System of a Muon-Collider or Neutrino Factory



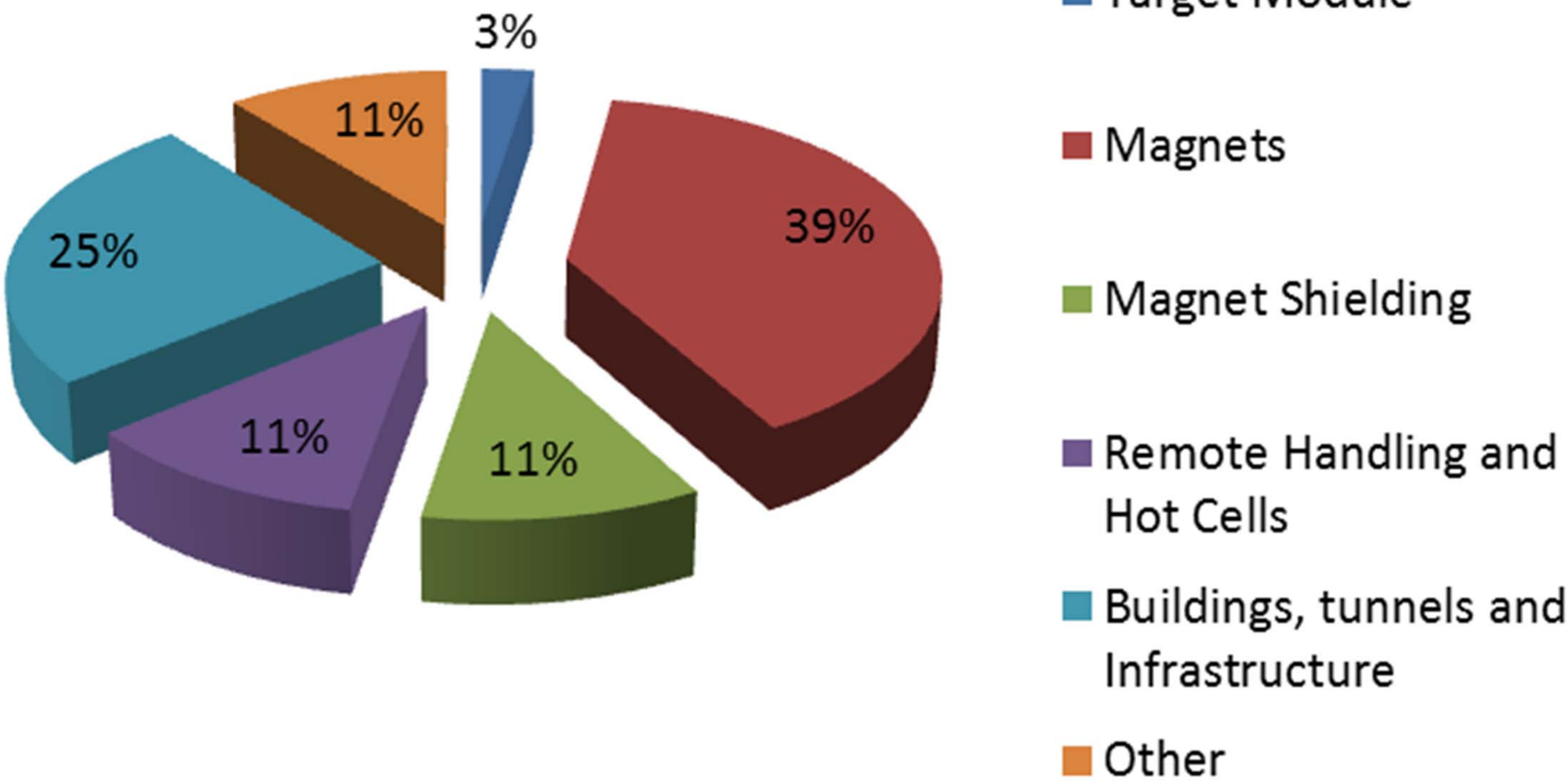
In the IDS-NF costing scenario, the Target System includes the production target and the magnetized pion-decay channel.

This system is about 50 m long.

Very preliminary cost estimate now exists.

(A Fermicentric vision)

From A. Kurup's Costing Talk



Extract from A. Kurup's Sheet TCDCostSummary.xlsx

Name	Total Cost	Comments
Target Module	########	Scaled from SNS
Magnets	########	Estimated by Bob Weggel
Magnet Shielding	########	Estimated by Bob Weggel
RF		
Quench Protection System		
Vacuum		
Cryogenics		
Diagnostics		
Controls and Interlocks		
Health and Safety		
Mechanical		
Decommissioning		
Remote Handling and Hot Cells	########	Scaled from LBNE
Buildings, tunnels and Infrastructure	########	Scaled from LBNE
Total	########	USD

Target and Capture Topology: Solenoid

Desire ≈ 10^{14} μ/s from ≈ 10^{15} p/s (≈ 4 MW proton beam)

R.B. Palmer (*BNL*, 1994) proposed a 20-T solenoidal capture system.

Low-energy π's collected from side of long, thin cylindrical target.

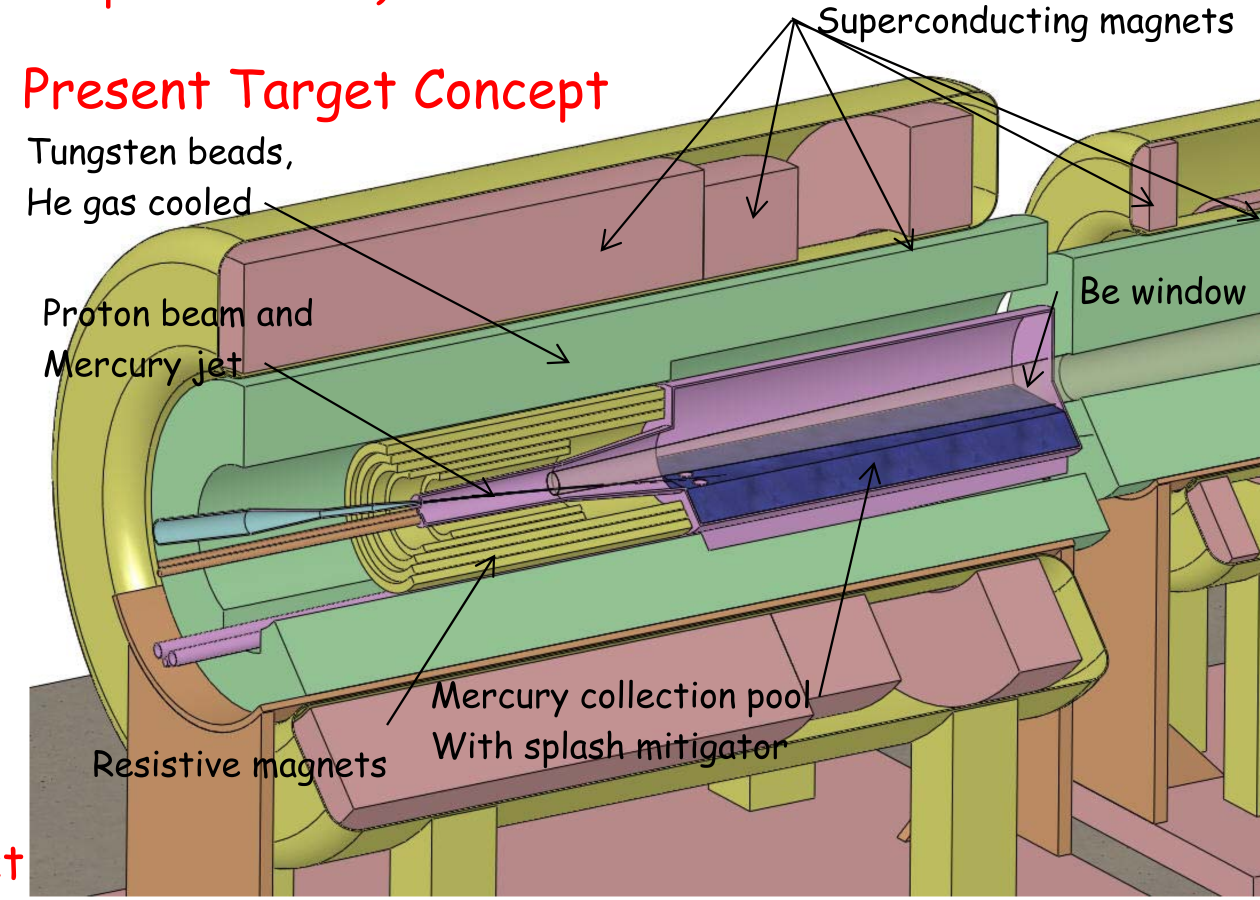
Solenoid coils can be some distance from proton beam.

⇒ ≥ 10-year life against radiation damage at 4 MW.

Liquid mercury jet target replaced every pulse.

Proton beam readily tilted with respect to magnetic axis.

⇒ Beam dump (mercury pool) out of the way of secondary π's and μ's.



Shielding of the superconducting magnets from radiation is a major issue.

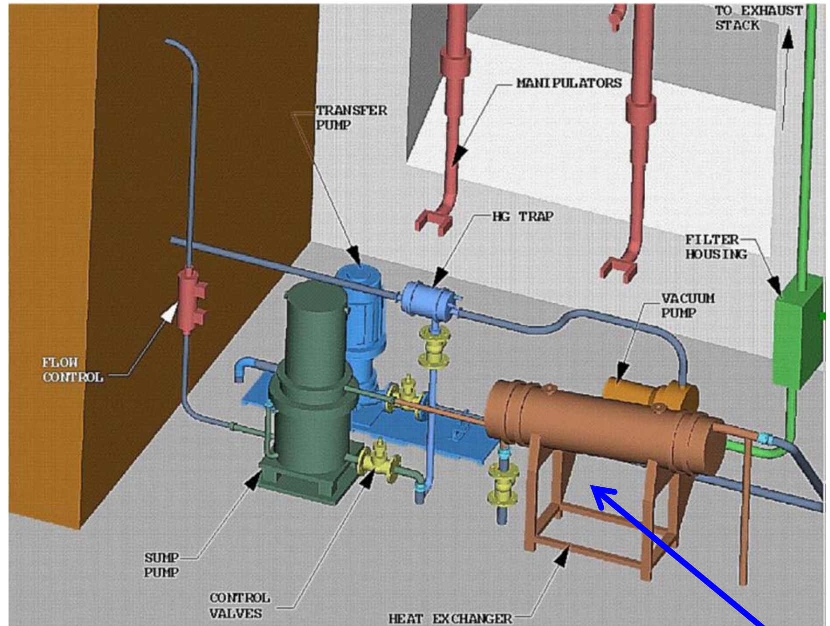
Magnet stored energy ~ 3 GJ!

5-T copper magnet insert; 15-T Nb_3Sn coil + 5-T NbTi outsert.

Desirable to replace the copper magnet by a 20-T HTC insert.

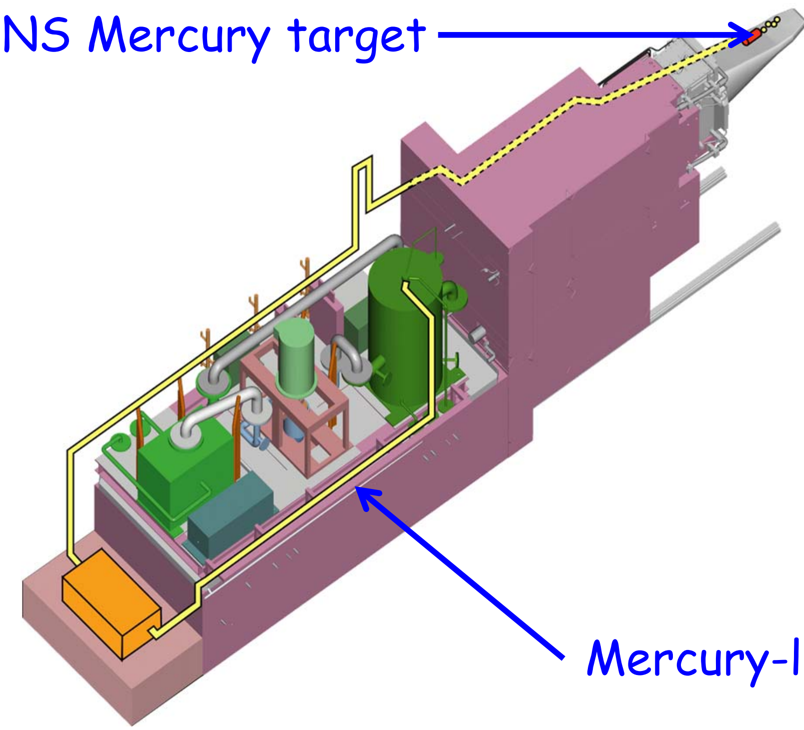
Target Module Costs Scaled from SNS (ORNL)

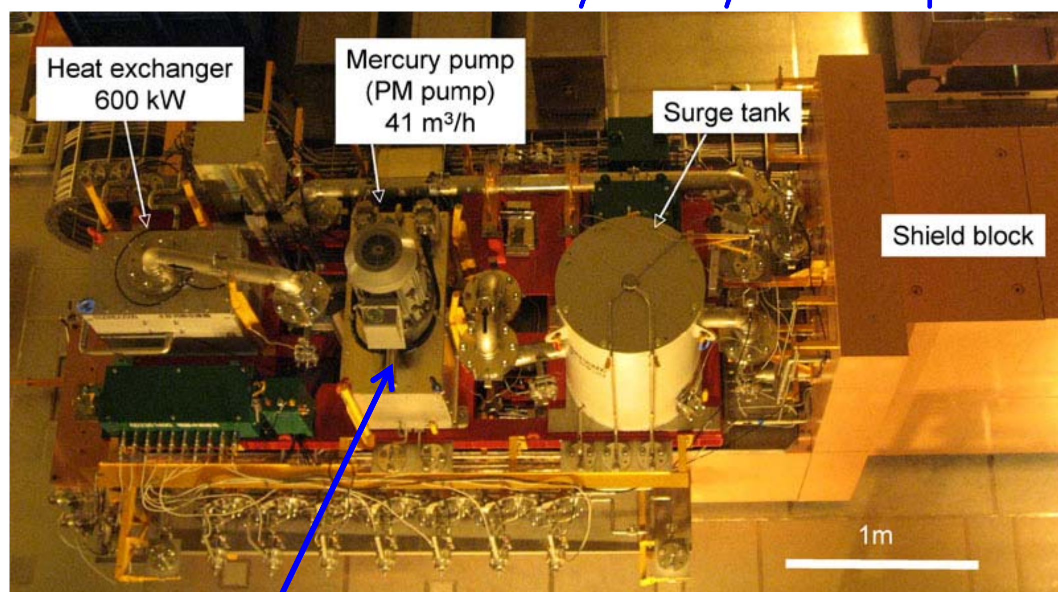
1.06 - Target Systems	116,396,901
1.06.01 - Target Assemblies	14,402,190
1.06.02 - Moderator Systems	8,661,901
1.06.03 - Reflector Assemblies	7,900,655
1.06.04 - Vessel Systems	11,848,901
1.06.05 - Target Station Shielding	13,405,475
1.06.06 - Target Utility Systems	10,730,099
1.06.07 - Remote Handling Systems	14,348,362
1.06.08 - Controls	3,076,899
1.06.09 - Beam Dumps	3,066,529
1.06.10 - Technical Support	12,896,977
1.06.11 - ORNL Field Coordination	16,058,914



Neutrino Factory Study 2 concept

SNS/JNS Mercury target



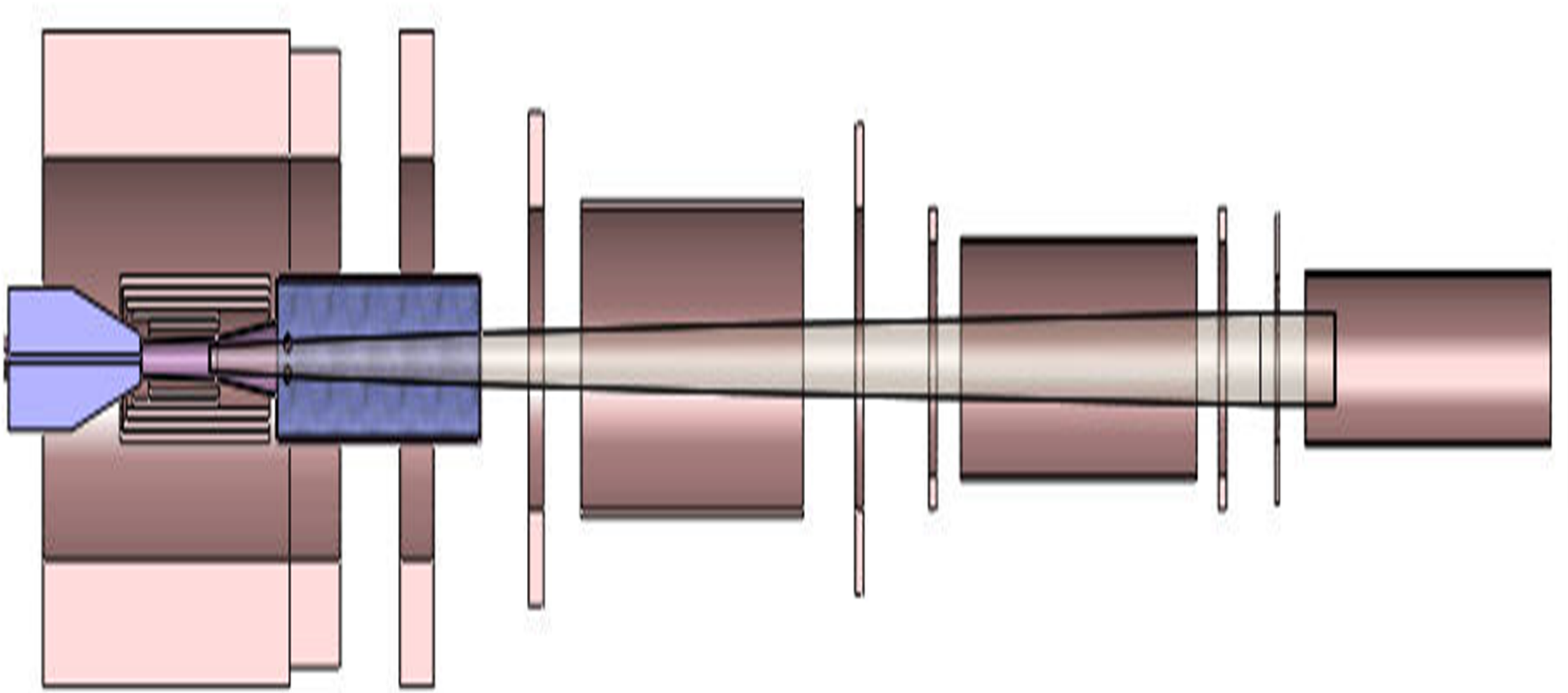


Mercury-loop utilities

Magnet and Shielding Costing by Bob Weggel

20-T, 120-cm-I.R. Target Magnets with Large Axial Gaps at 4, 10, 15 &20 m

Bob Weggel, Magnet Optimization Research Engineering, LLC
3/22/2012



Target Magnet IDS120j: three solenoids per cryostat; large axial gaps at z = 4, 10, 15 & 20 m [drawing courtesy Van Graves]. Target Magnet IDS120k is very similar, but the outboard solenoids in all cryostats except the first are of optimized (larger) inner radius, to improve field profile. U = 3.34 GJ.

Selected Parameters of Target Magnet IDS120k

	12.47	kA	0.1	meters ΔL_{elec}		1.724	$\mu\Omega$cm at 20 °C		7.0	nΩcm/deg		10.0	°C T_0	40.0	atmospheres ΔP		0.10m	ΔL_{hy}		
Coil designation		Units		Cu 1	Cu 2	Cu 3	Cu 4	Cu 5	SC 1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8	SC 9	SC 10	SC 11	SC 12
SSt shell thickness		cm		0.255	0.325	0.183	0.160	0.145												
Current density $j\lambda_{coil}$		kA/cm²	5.00	2.201	2.074	1.412	1.204	1.059	1.931	2.176	2.673	3.346	4.122	4.072	4.503	4.666	4.645	4.645	4.645	4.645
Coil length		cm		100.2	123.6	207.2	212.0	215.6	352.3	77.78	45.20	31.23	255.4	15.45	13.00	341.3	10.96	14.12	320.3	14.12
Gap between coils		cm							0.00	87.30	148.6	74.28	83.20	105.0	37.31	27.89	70.76	39.71	39.71	72.00
Upstream end		cm		-87.6	-111.0	-121.0	-125.8	-129.5	-240.9	111.4	276.5	470.2	575.7	914.3	1035	1085	1454	1536	1590	1950
Downstream end		cm		12.6	12.6	86.2	86.2	86.2	111.4	189.2	321.7	501.5	831.1	929.8	1048	1426	1465	1550	1910	1964
Inner radius		cm		18.34	23.85	29.58	36.21	43.30	120.0	120.0	120.0	120.0	89.65	118.3	72.36	69.92	69.94	71.88	50.08	71.88
Radial depth of conductor		cm		4.760	4.903	5.943	6.435	6.861	75.83	64.34	75.83	55.63	4.155	52.02	14.55	2.456	16.45	18.12	2.334	18.12
Outer radius		cm		23.10	28.76	35.52	42.64	50.16	195.8	184.3	195.8	175.6	93.81	170.3	86.91	72.38	86.39	90.00	52.42	90.00
Volume, inc. SSt shell		m³	39.93	0.066	0.108	0.260	0.347	0.444	26.51	4.79	3.40	1.61	0.61	0.73	0.09	0.37	0.09	0.13	0.24	0.13
Maximum on-axis field		T		20.22	19.01	17.89	16.88	15.97	15.13	13.54	8.29	4.77	3.58	2.17	1.90	1.77	1.53			
SC γ, MPa & fr.	6.00	none	0						0.093	0.070	0.029	0.018	0.017	0.011	0.011	0.011	0.010	0.010	0.010	0.010
Cu γ, MPa & fr.	8.95	100	0	0.550	0.550	0.550	0.550	0.550	0.154	0.174	0.214	0.268	0.330	0.326	0.360	0.373	0.372	0.372	0.372	0.372
SSt γ, MPa & fr.	7.80	700	700	0.051	0.062	0.030	0.024	0.021	0.521	0.495	0.436	0.313	0.159	0.174	0.088	0.056	0.061	0.061	0.061	0.061
SSt cm & SC M$	30M	$87.5	0.000	0.256	0.326	0.183	0.160	0.145	$74.2	$10.0	$2.96	$.176	$.062	$.049	$.006	$.025	$.005	$.008	$.014	$.008
Coil tons	$/m³	6.50	224.4	0.356	0.583	1.382	1.835	2.344	159.0	27.92	18.07	7.80	2.56	3.12	0.37	1.41	0.34	0.49	0.92	0.49
M$@$400/kg	0.40	$2.60	$89.8	4	4	4	4	4	paths/layer											
Magnet MW or MA-m		*11.26*	86.49	1.53	2.28	2.58	2.46	2.41	51.19	10.41	9.09	5.40	2.52	2.97	0.43	1.75	0.41	0.60	1.12	0.60

Coil dimensions are in rows 3 through 11. Anticipated for the complete magnet, but not tabulated above, are an additional seven sets of three solenoids each that repeat solenoids SC #10, SC #11 and SC #12 at multiples of 5 m, to a distance z = 50 m. The cost estimates in the columns with first-row entries "kA" and "0.1" include solenoids to z = 20 m.

The cost of each solenoid is based on its mass of superconductor (if any), copper, stainless steel and insulation. The assumed unit cost of fabricated Nb_3Sn (SC #1-#3) is 30 M\$/m^3; that of NbTi (SC #4 and up) is \$X M\$/m^3. The assumed cost of copper, stainless steel and insulation is $X/kg. Costs of cryostats, shielding vessels, shielding and other components have yet to be estimated.

The estimated cost of the resistive magnet is 6.50 metric tonnes x $X/kg = $Y M. The cost of SC#1 is the sum of two components: superconducting and non-superconducting. The non-superconducting cost is 159.0 tonnes x \$X/kg = Y M\$. The cost attributed to the superconductor is 26.51 m^3 x 0.093 x Y M\$/m^3 = Z M\$, for a total of \$X. M\$.

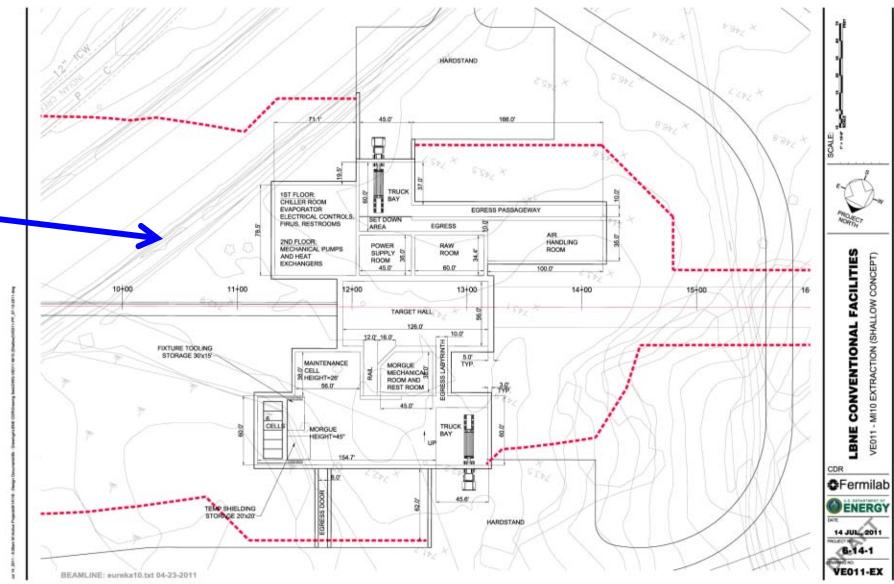
The non-superconducting unit cost of \$X/kg compares to the \$Y/kg reported for resistive magnets at the National High Magnetic Field Laboratory (NHMFL) at Tallahassee, Florida. The superconducting unit cost of Z M\$/m^3 approximately doubles the non-superconducting unit cost a superconducting magnet. The average unit cost for all the superconducting magnets is X M$ / 224.4 tonnes = $Y/kg. This compares with the$Z/kg reported for superconducting and hybrid magnets at the NHMFL.

Weggel's cost estimate agrees to within 2% with the Green-Strauss algorithm (A. Bross).

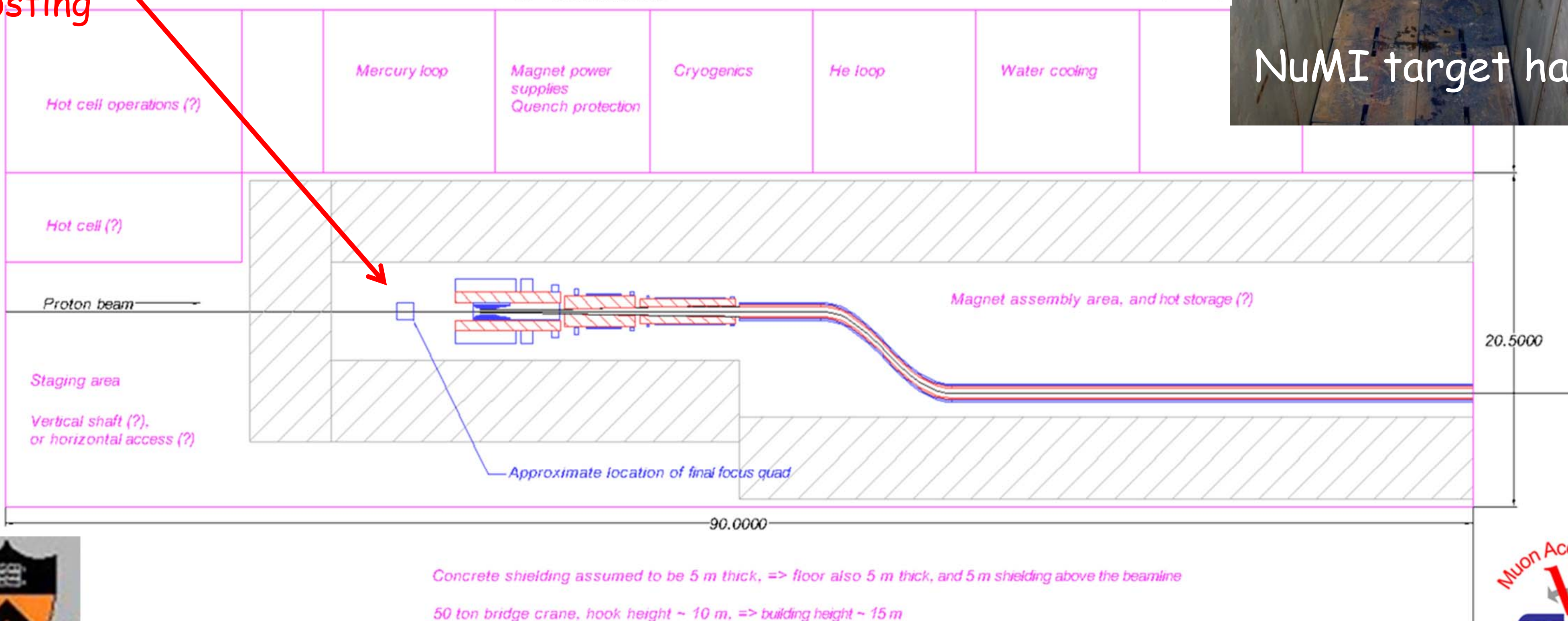
Target Hall

A major cost driver will be civil construction and shielding.

LBNE 2-MW target station ~ $175m



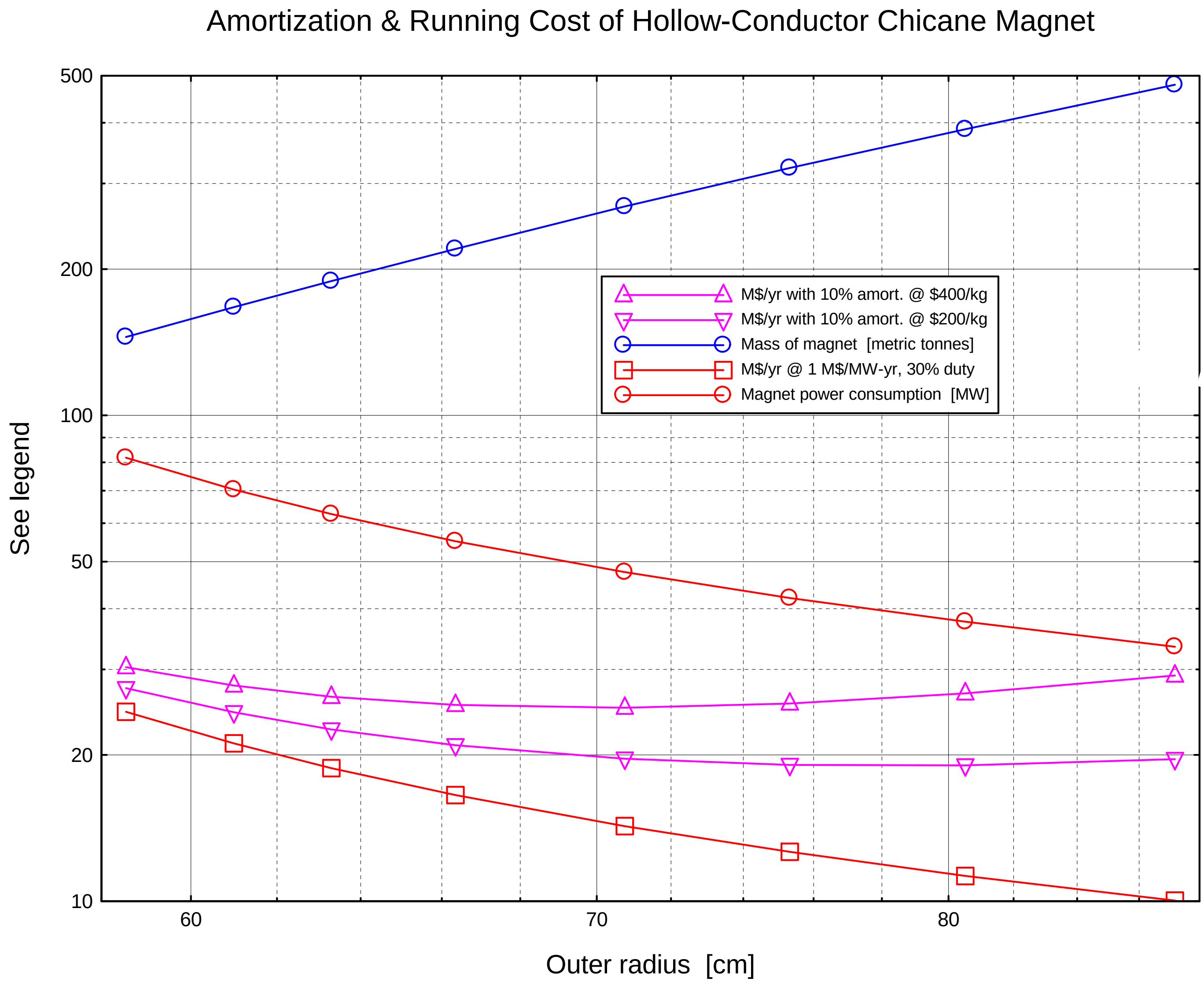
Crude sketch to start IDS-NF costing



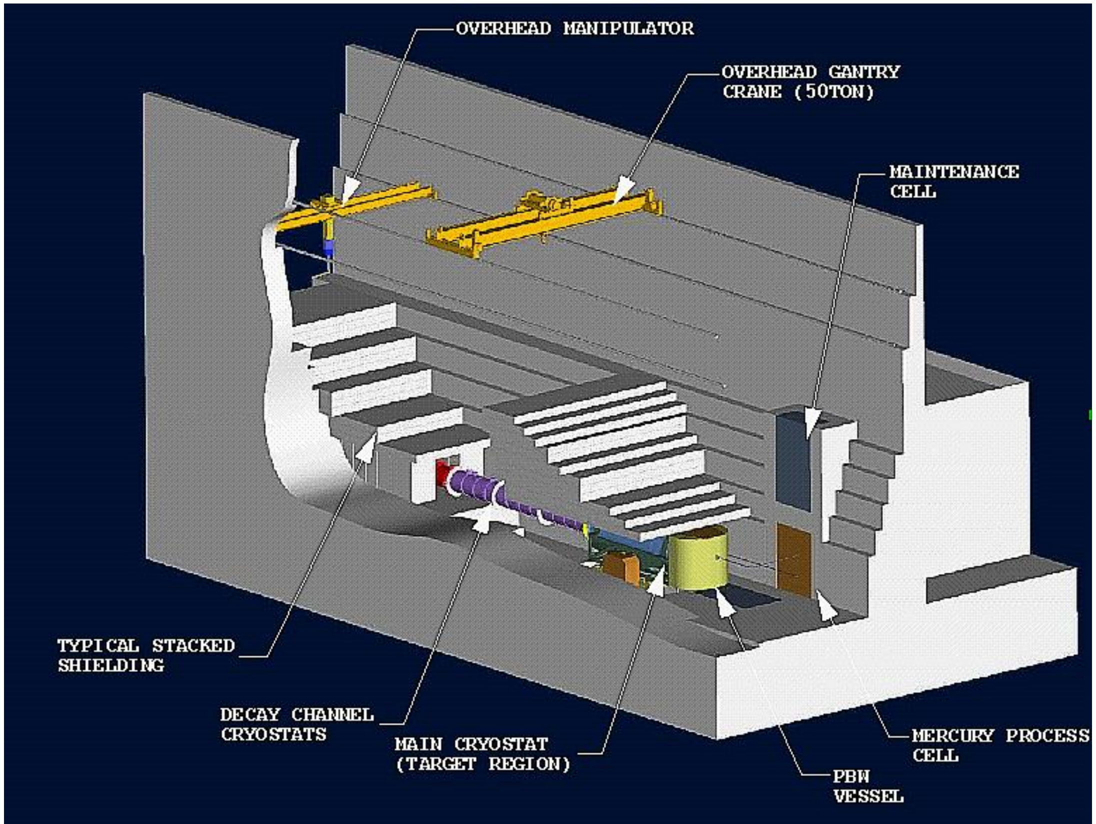
Decay Channel with Chicane

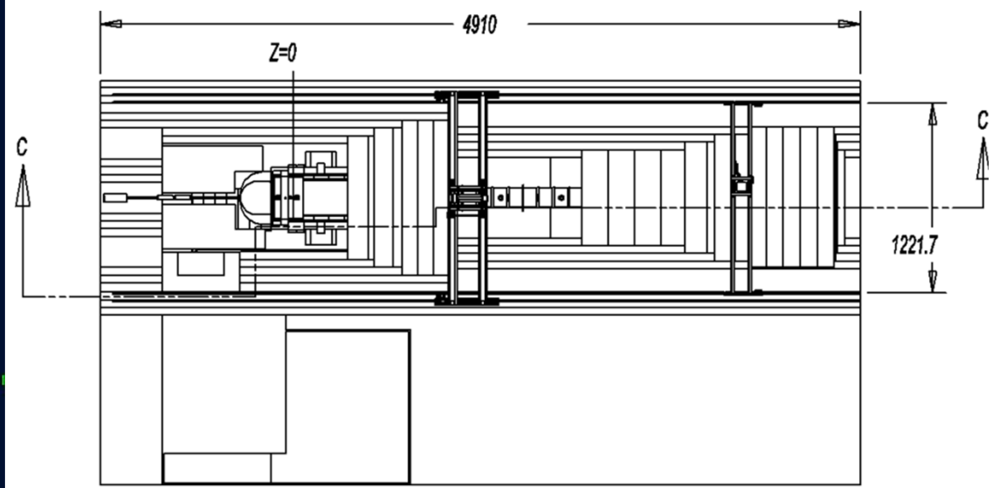
Concept fairly well developed, but little technical study yet of issues of shielding and magnet configurations.

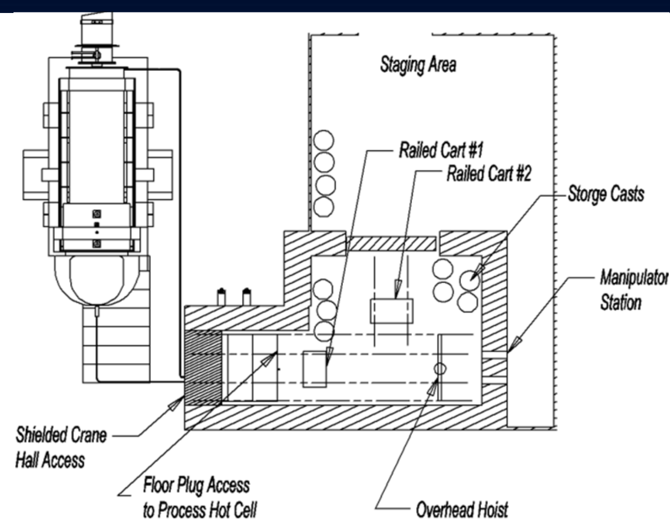
A recent, preliminary look by B. Weggel notes that use of HTS conductors is likely cost advantageous compared to copper or Nb conductors.



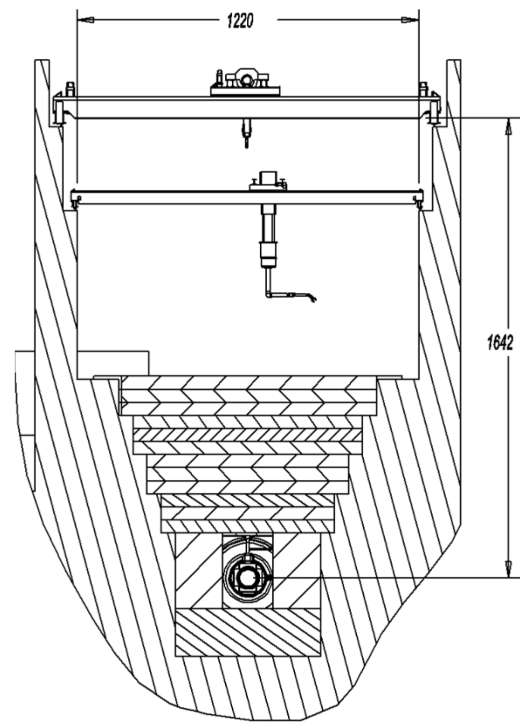
Neutrino Factory Study 2 Concepts



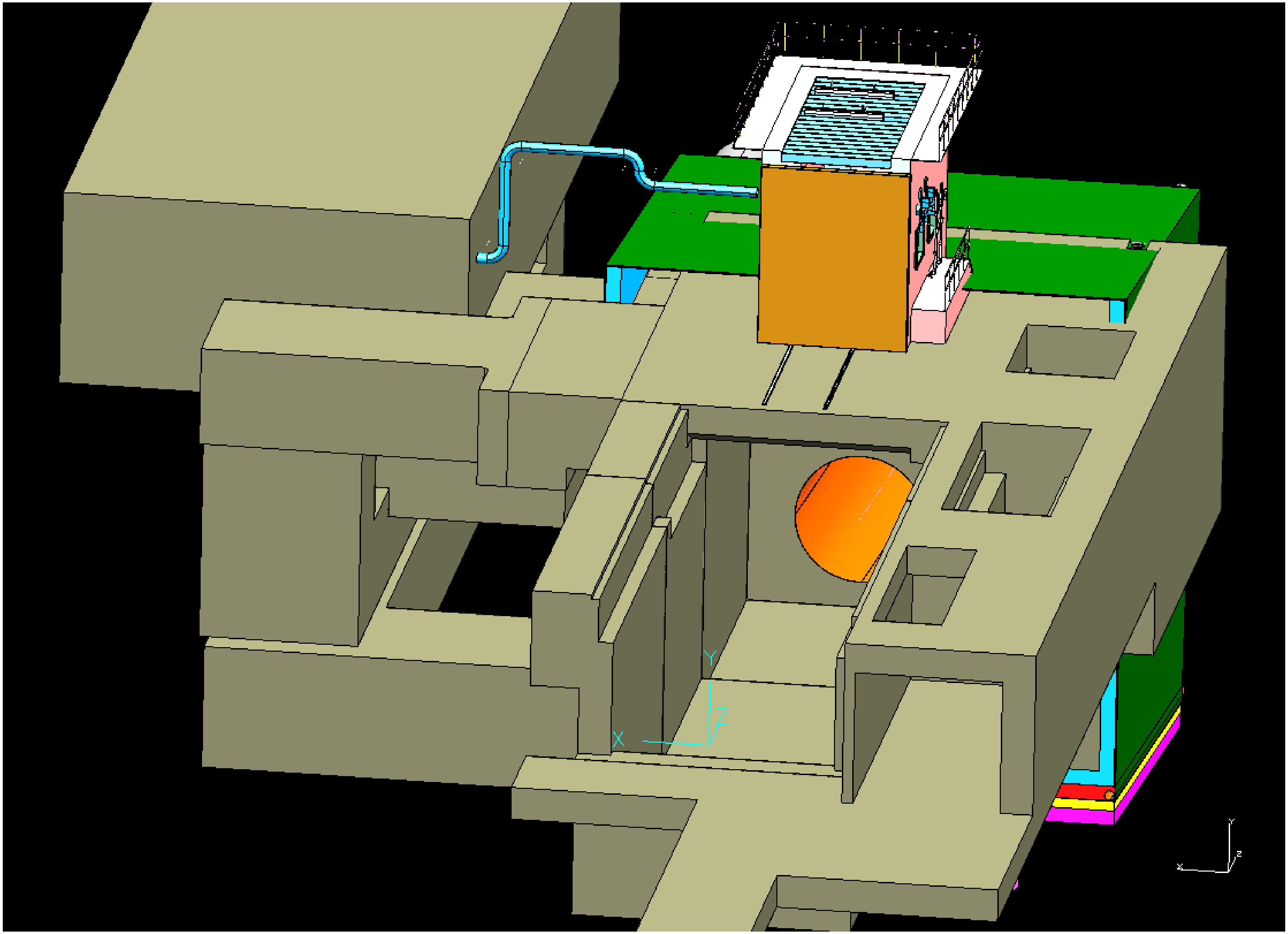




Maintenance Cell Section A-A

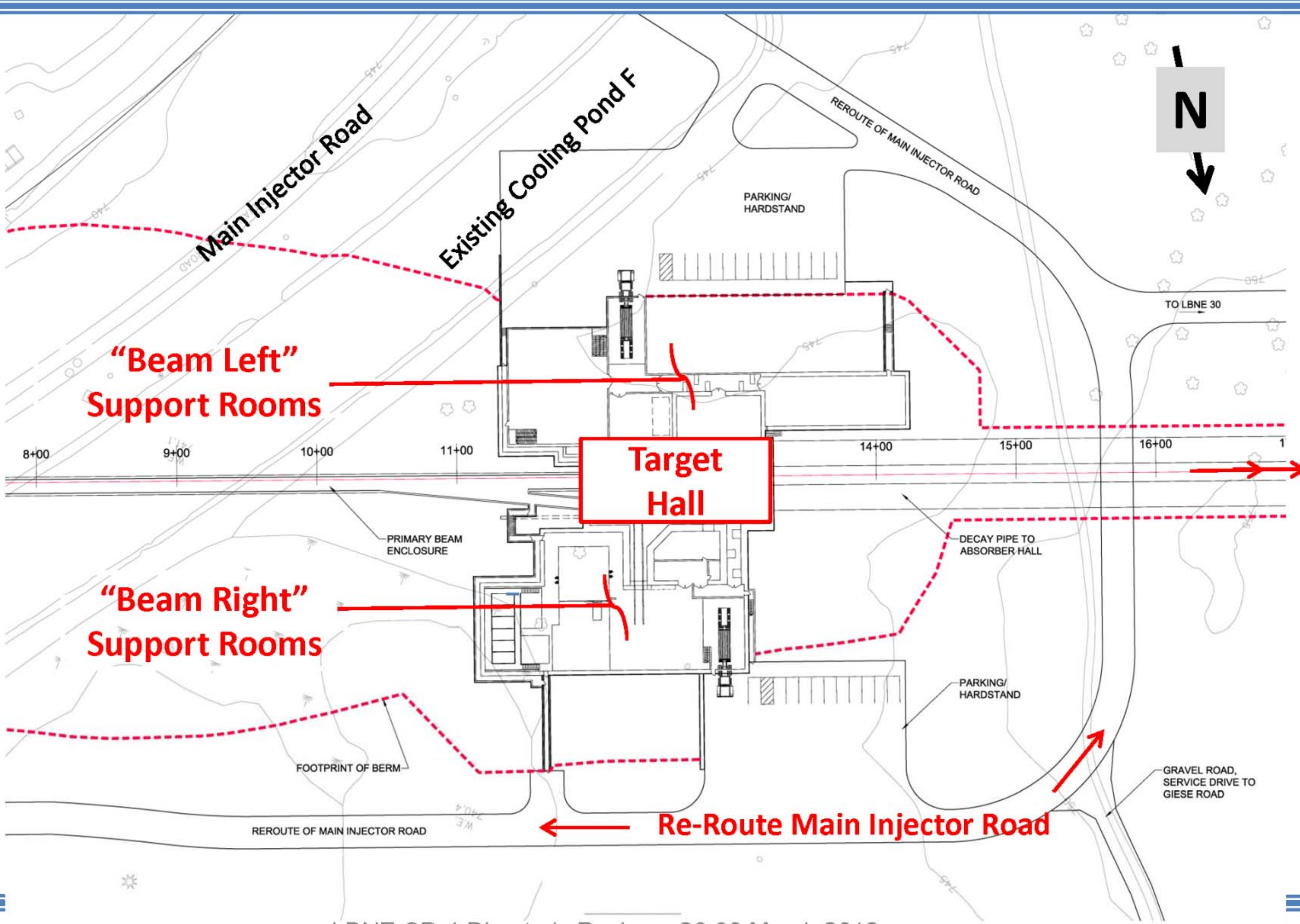


SECTION B-B
DECAY CHANNEL SHIELDING



LBNE Target Hall Concept

LBNE 20 – TARGET COMPLEX
Site Plan



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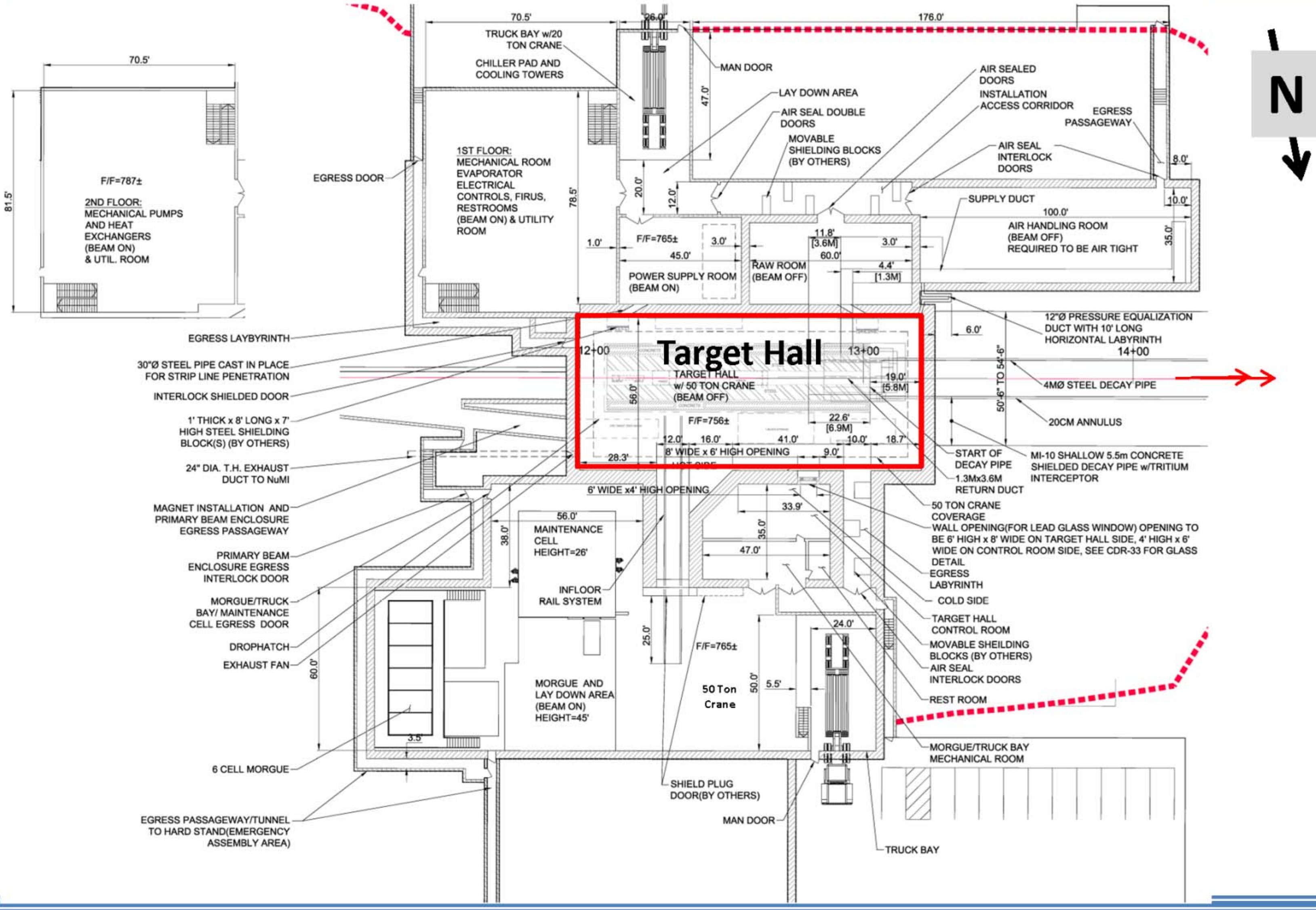
LBNE 20 – Target Complex

Target Hall, Support Rooms, Service Rooms



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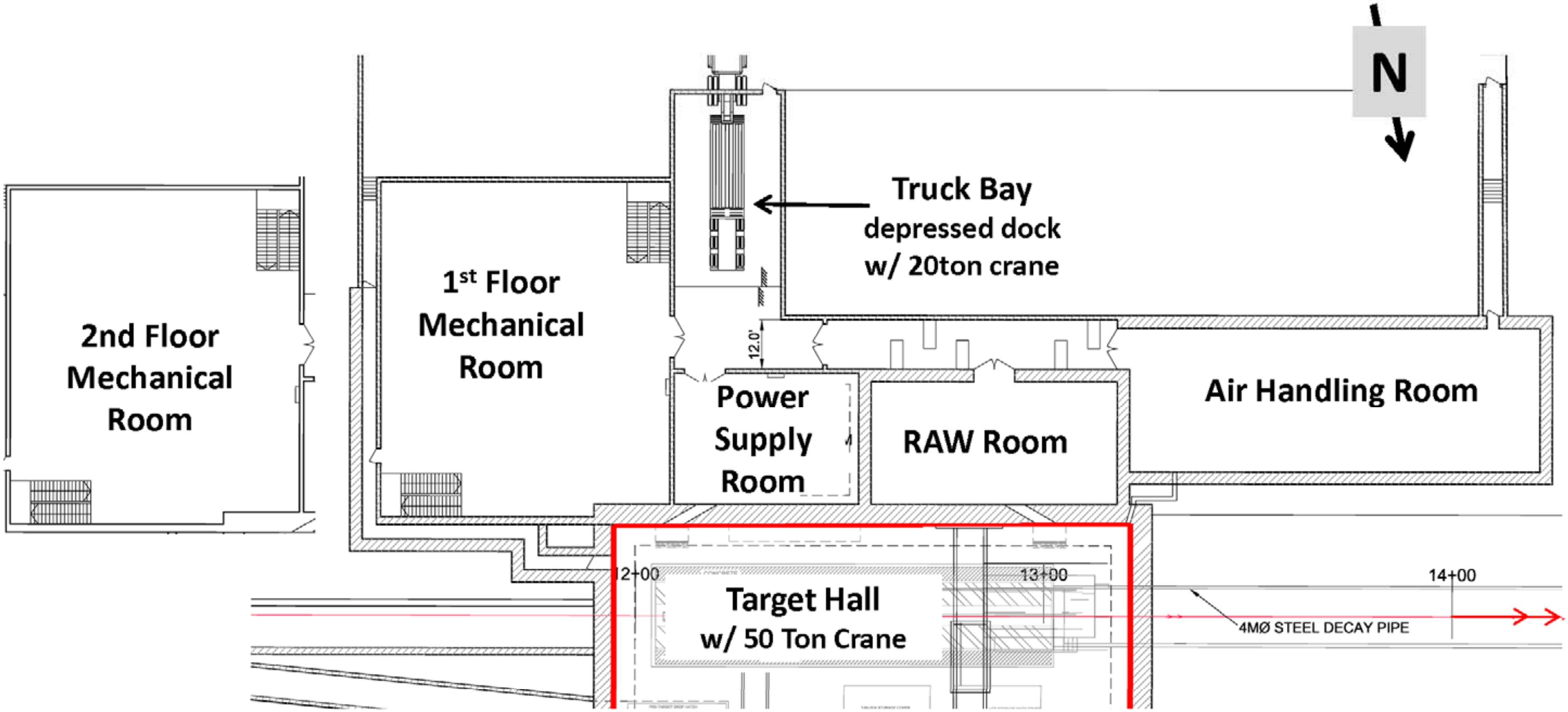
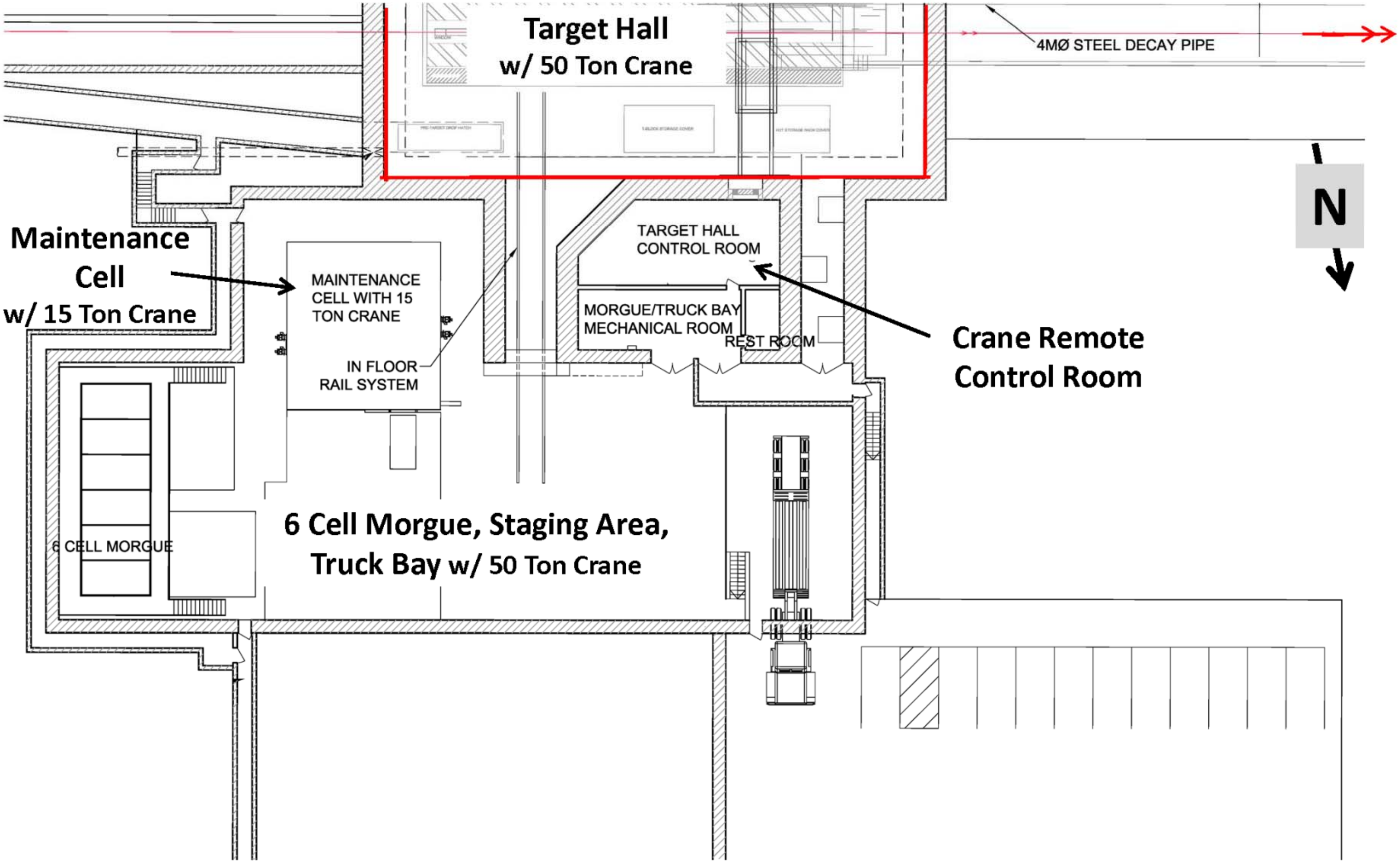
"Beam Left" Service and Support Rooms



Power Supply Room, RAW Room, Air Handling Room, Truck Bay, 2 Story Mechanical Wing

"Beam Right" Service and Support Rooms



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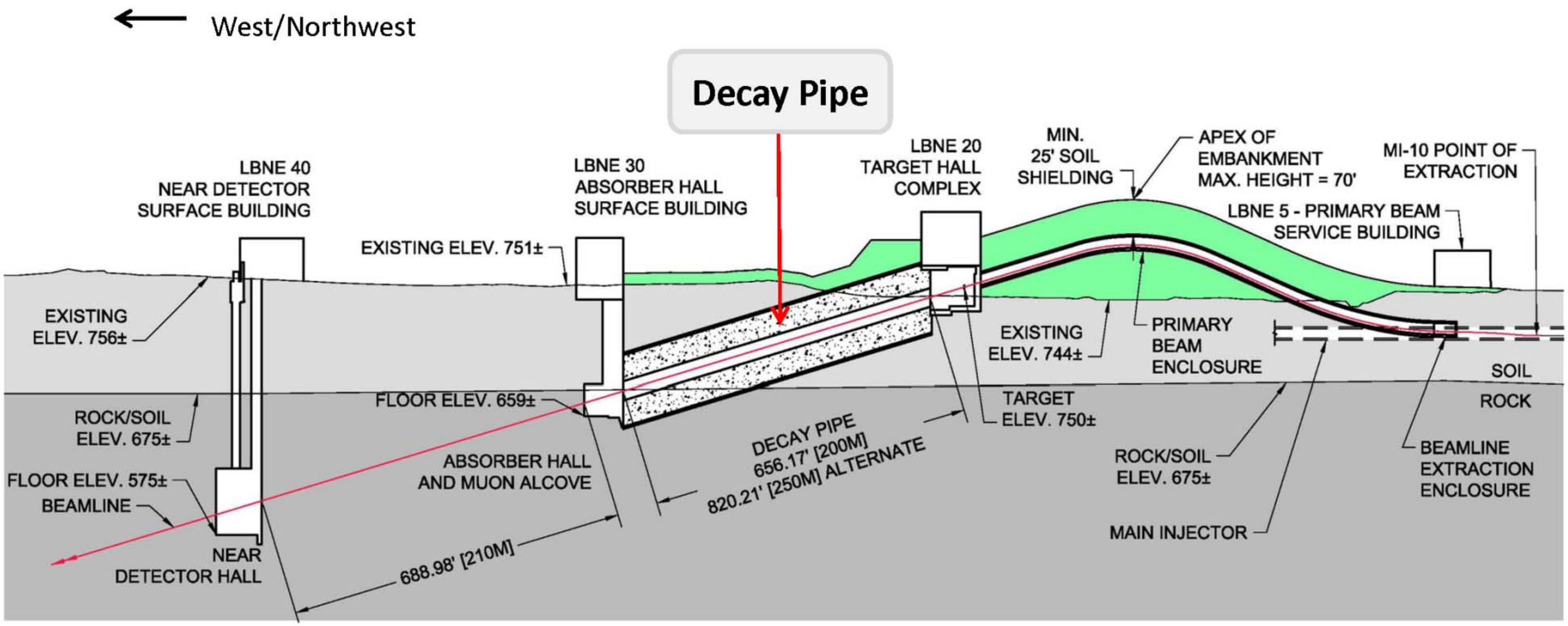
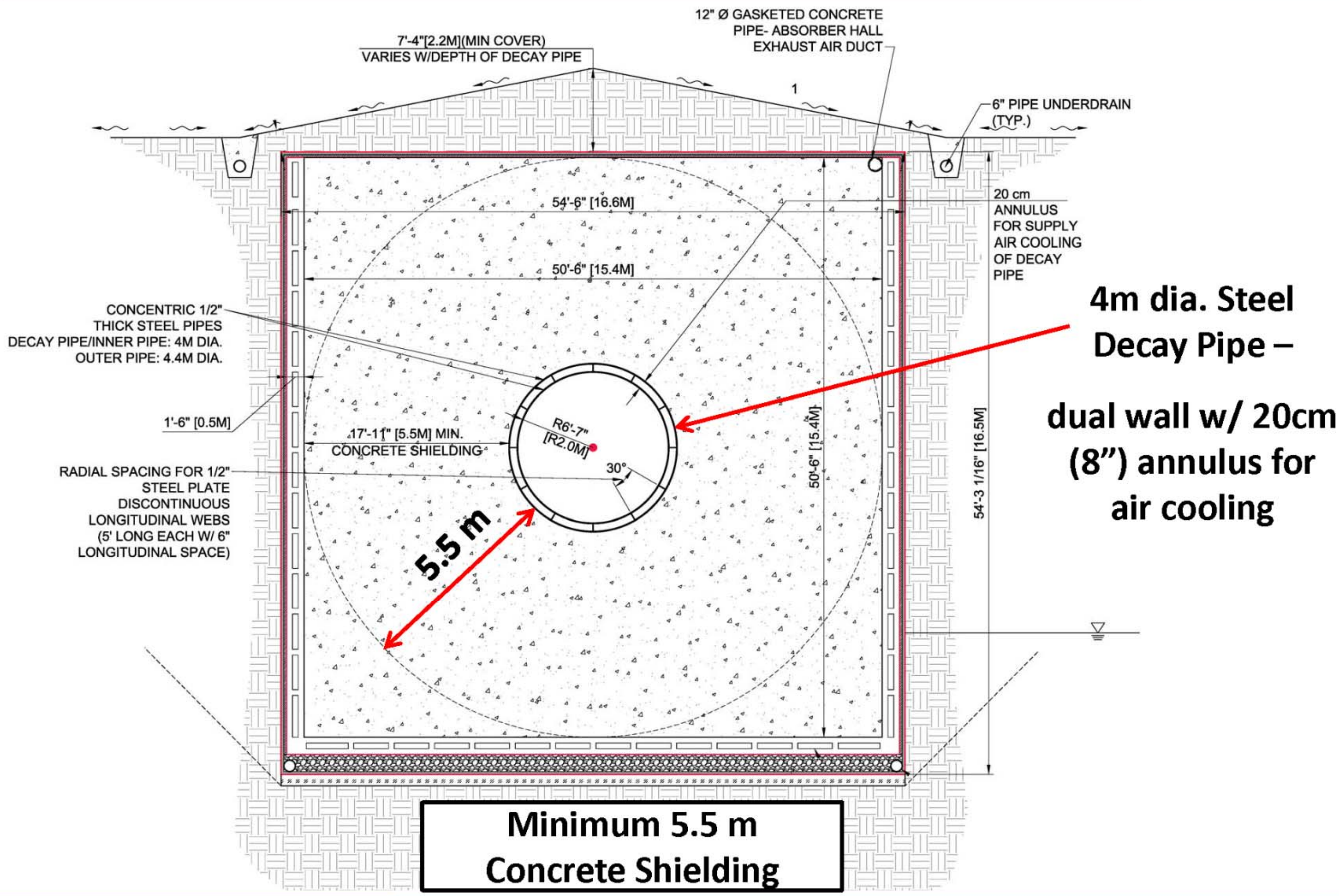
Decay Pipe



scale
H : V
1.0 : 0.33

The NF Target System Hall is equivalent in many ways to the LBNE Decay Pipe.

Decay Pipe Cross Section



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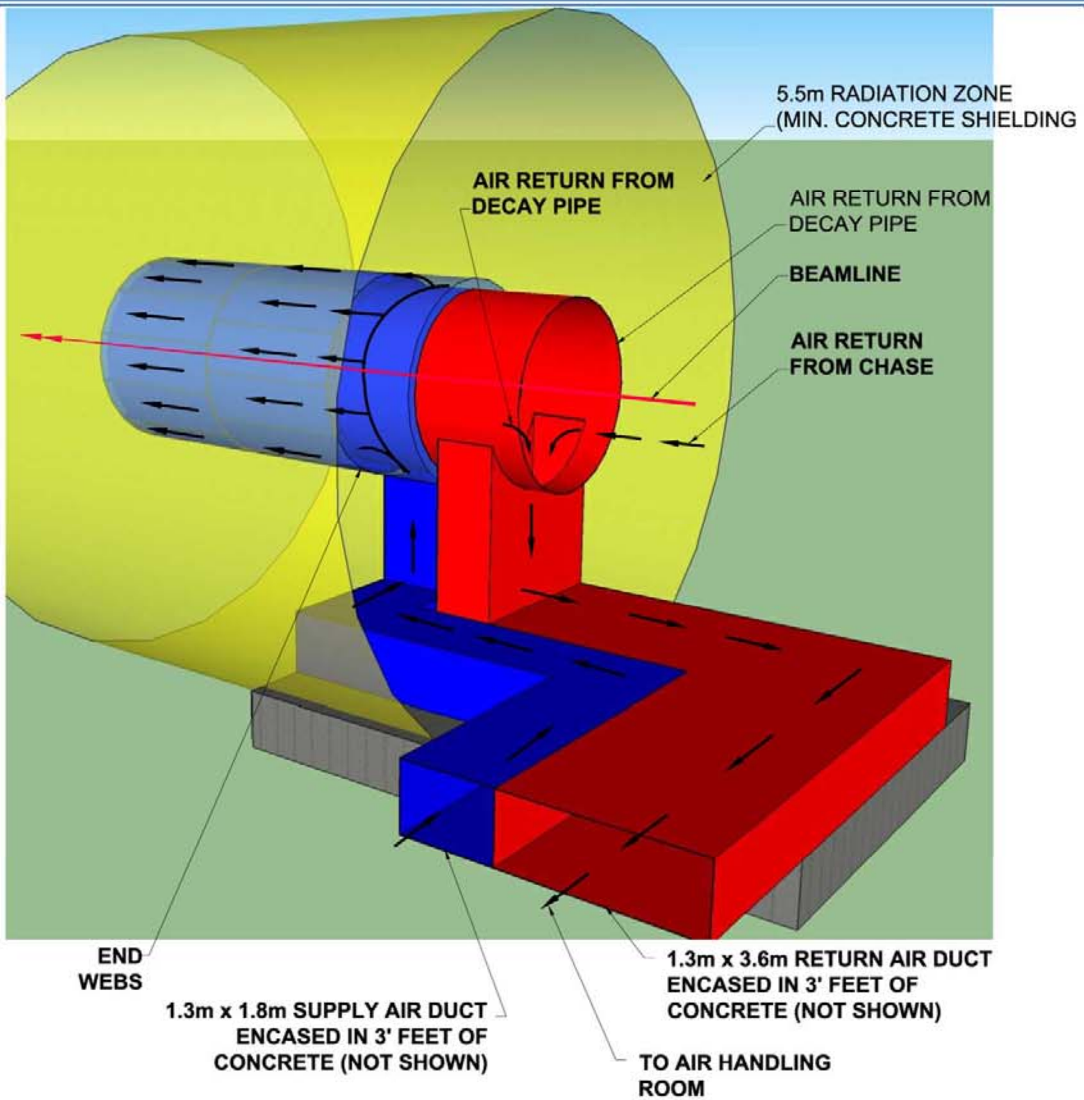
We may need concrete shielding ~ 5.5 m thick around the entire target system.

Decay Pipe Air Cooling Ducting at Target Hall



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We must have an activated-air handling system for the Target System Hall.