THE SNS 17ELS224
EXTRACTION LAMBERTSON SEPTUM MAGNET

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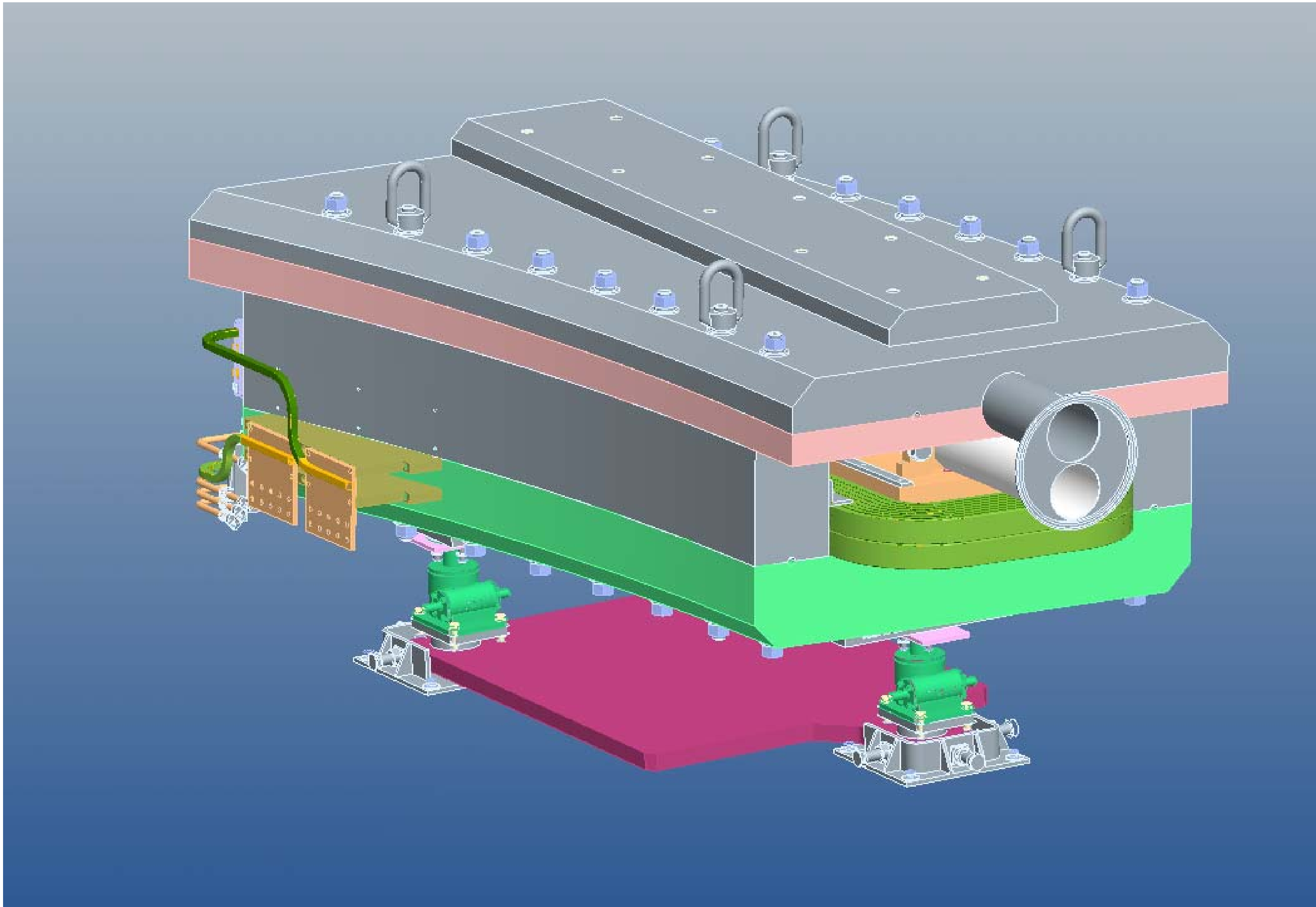
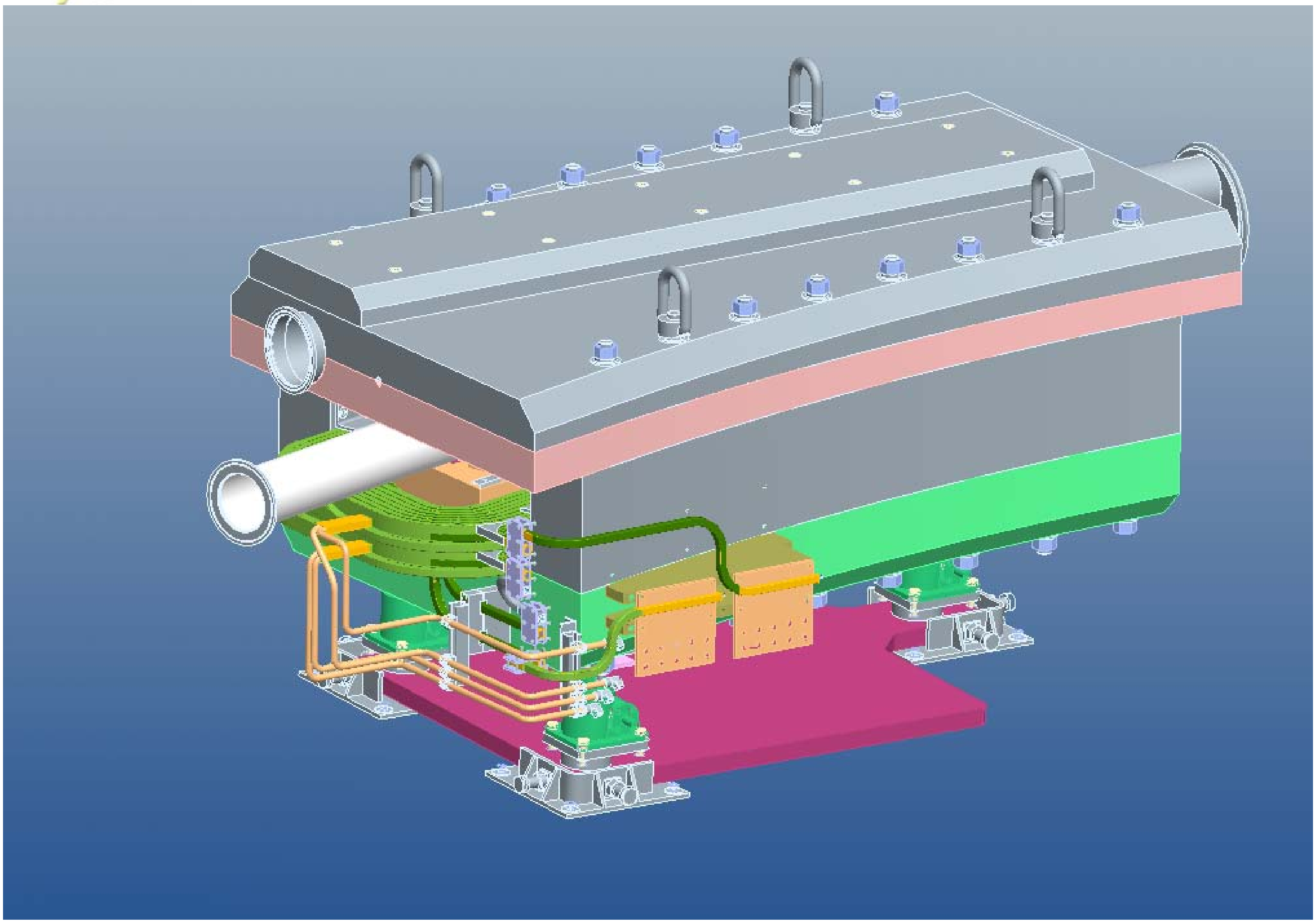
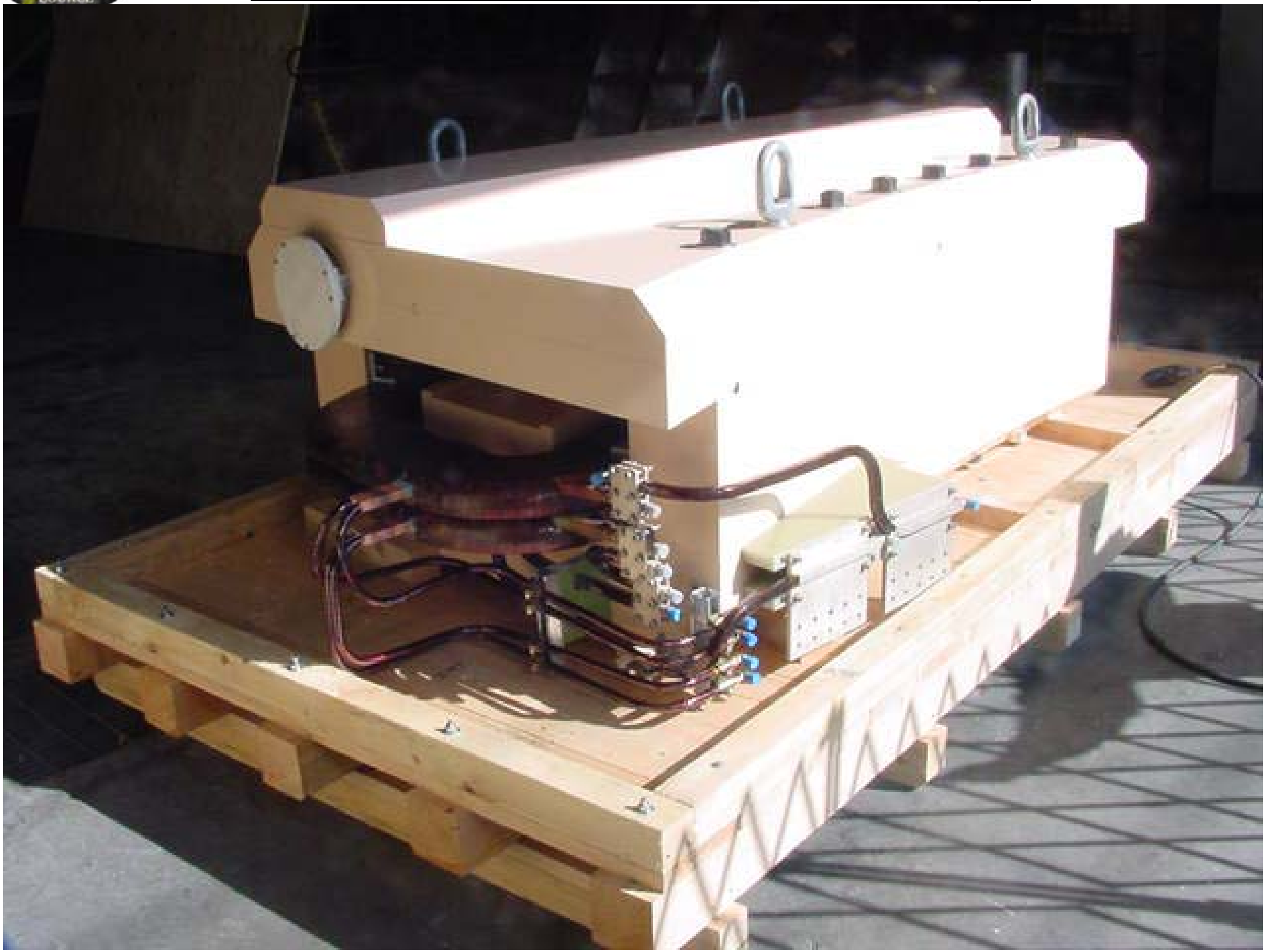
SNS Extraction Lambertson Septum (ELS) Magnet – UPSTREAM END



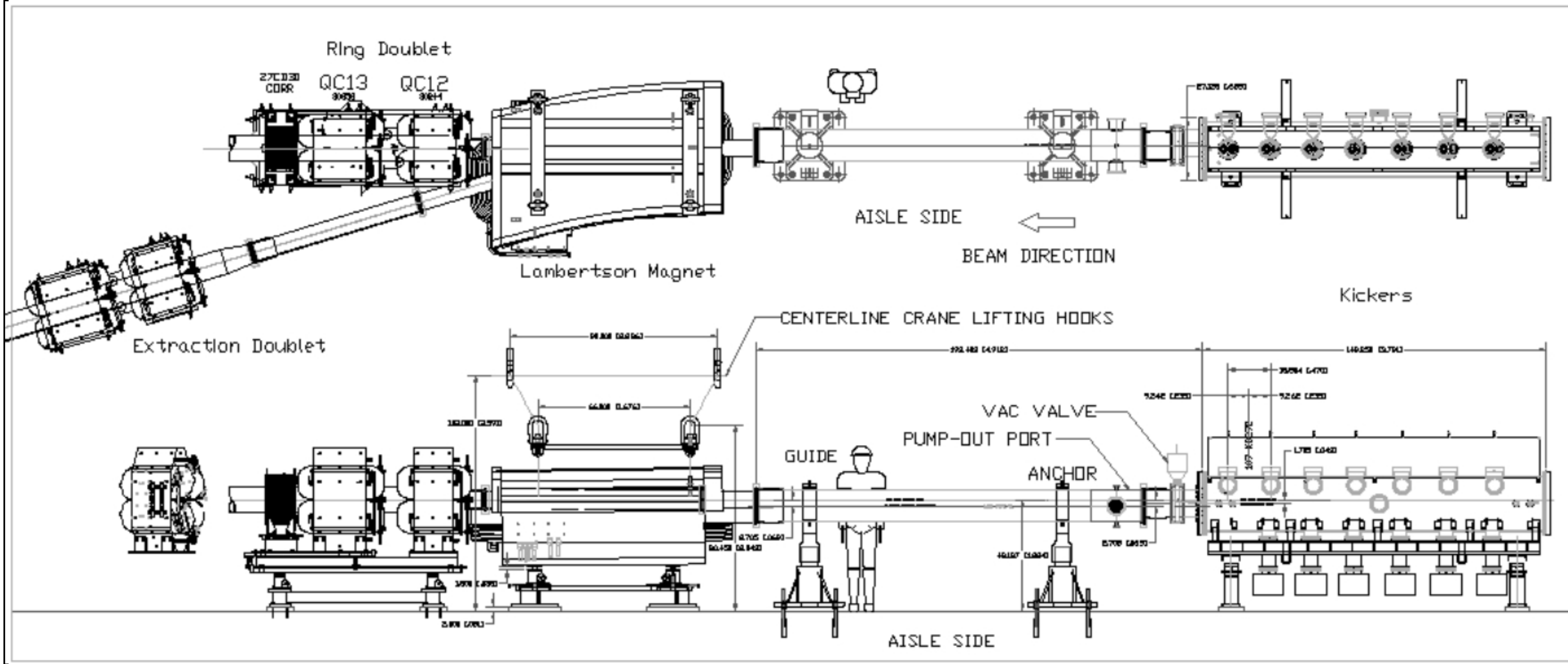
<u>SNS Extraction Lambertson Septum (ELS) Magnet – DOWNSTREAM END</u>



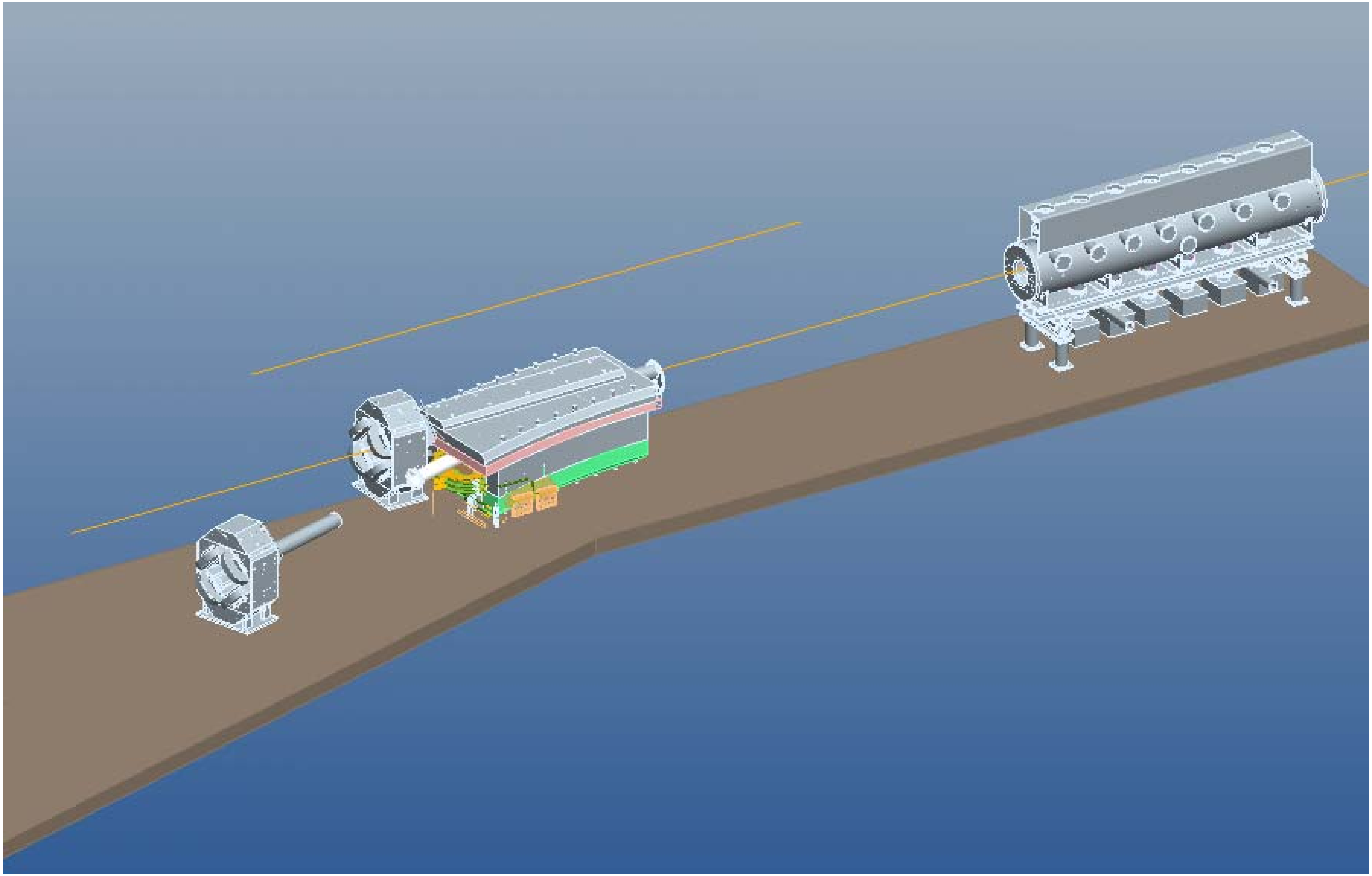
The SNS Extraction Lambertson Septum (ELS) Magnet



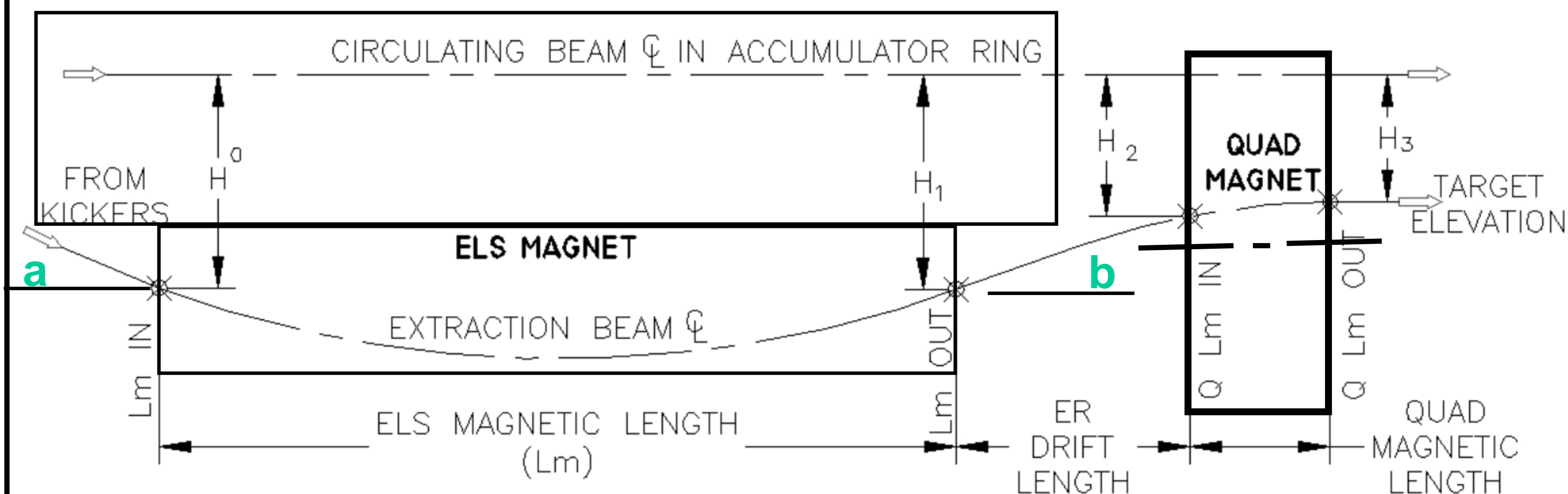
Extraction Region Plan and Elevation Views



Extraction Region Kicker-ELS-RTBT.Q1

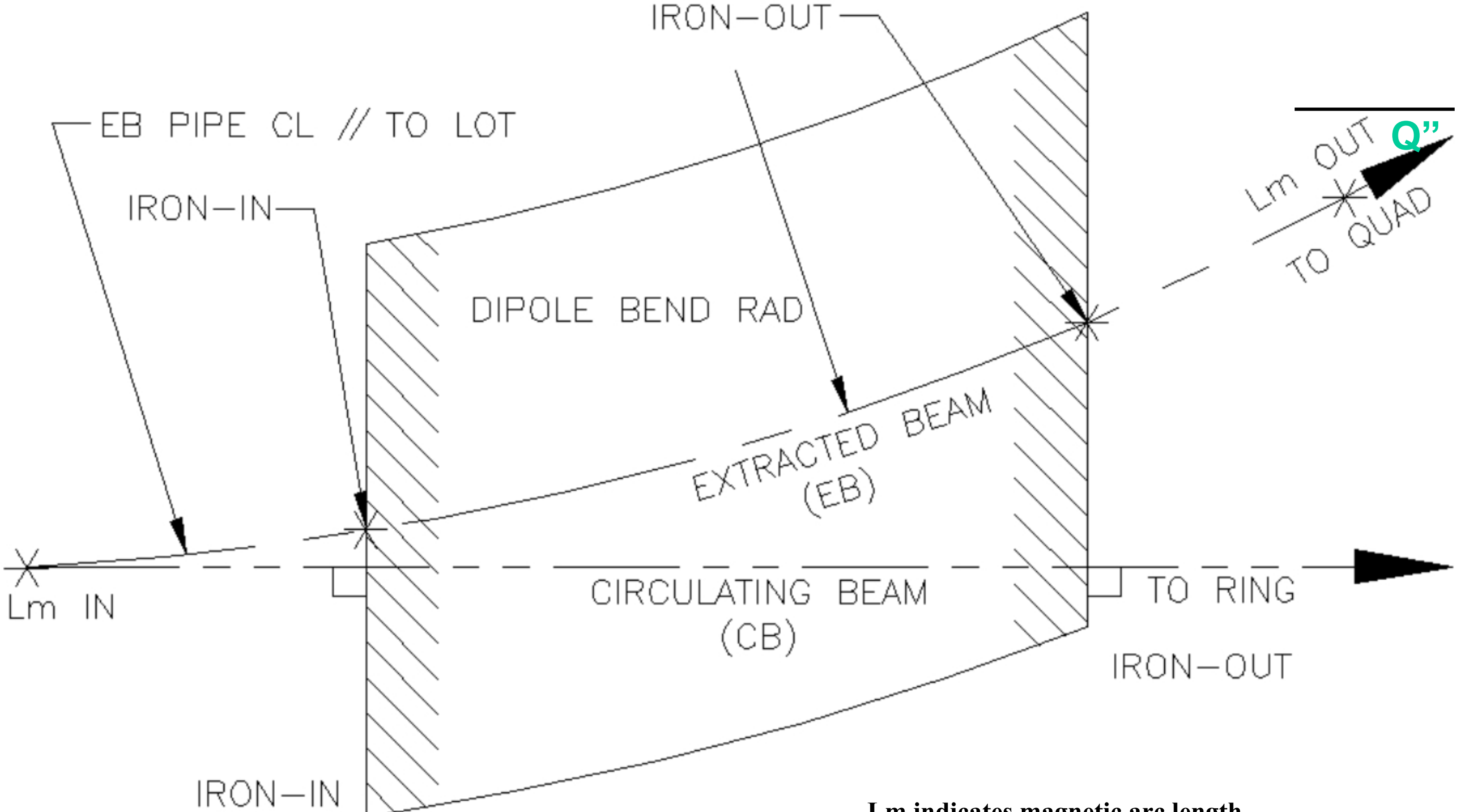


ELS elevation schematic (WCS perspective)



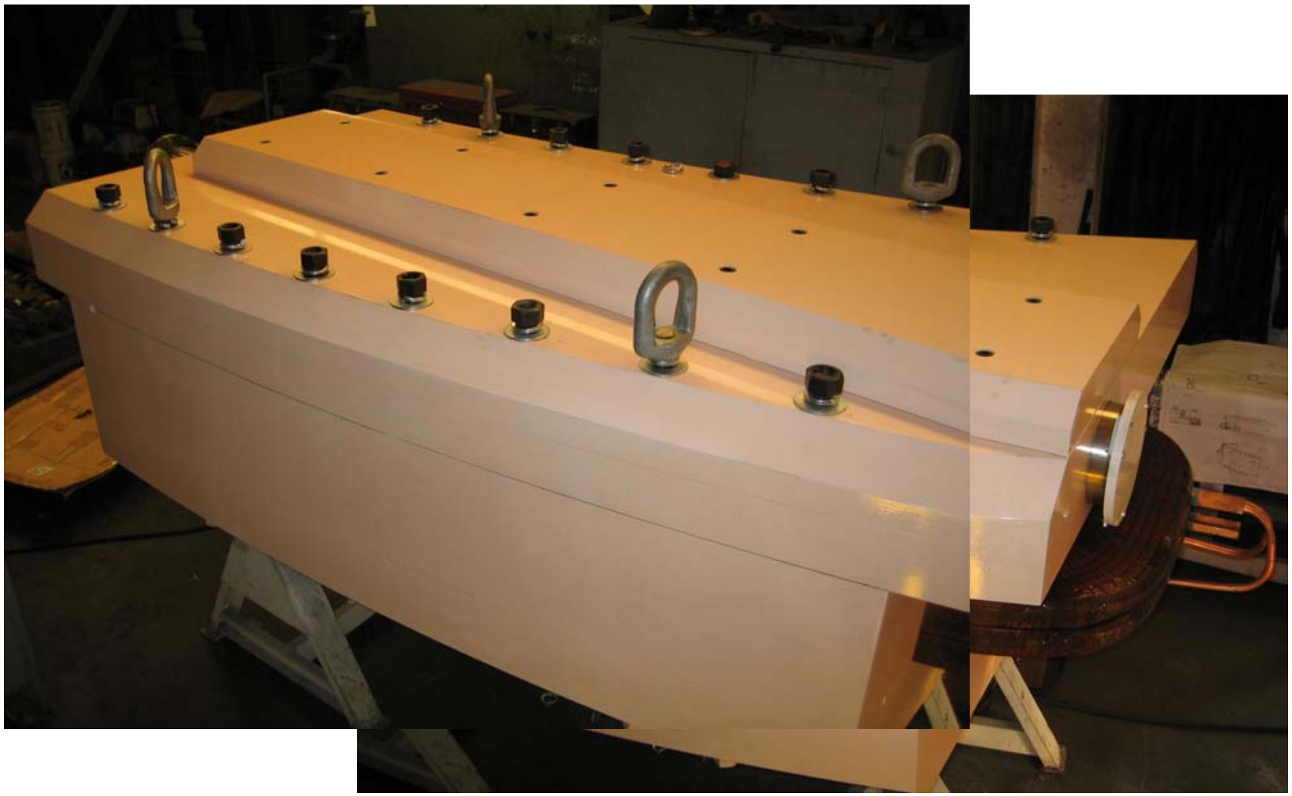
GIVEN ELEVATION OF EB CL RELATIVE TO RING CB			
at ELS iron in	h0i	169.00	mm
at Q1 Lm exit	h3	182.60	mm

ELS plan schematic (POP perspective)

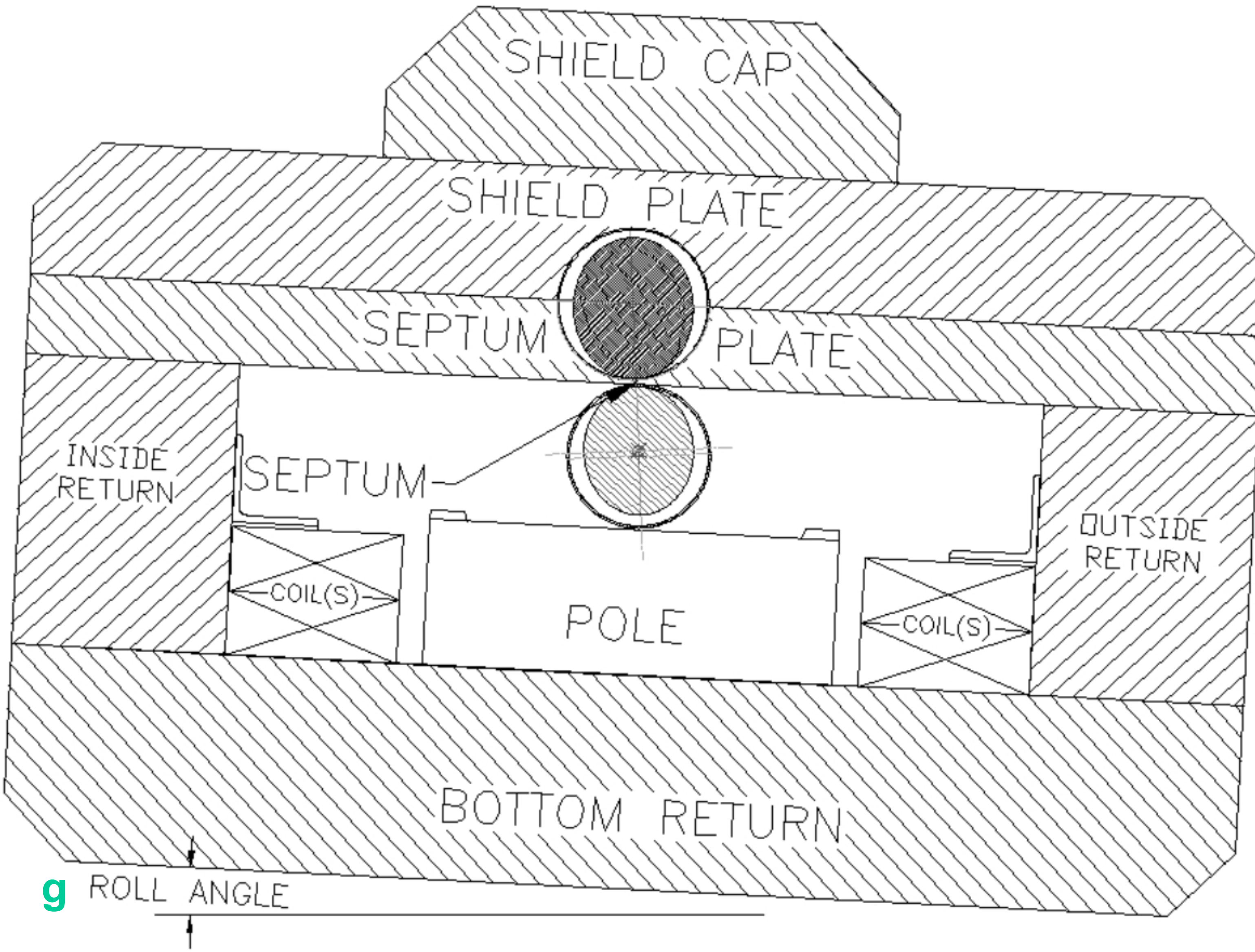


Lm indicates magnetic arc length

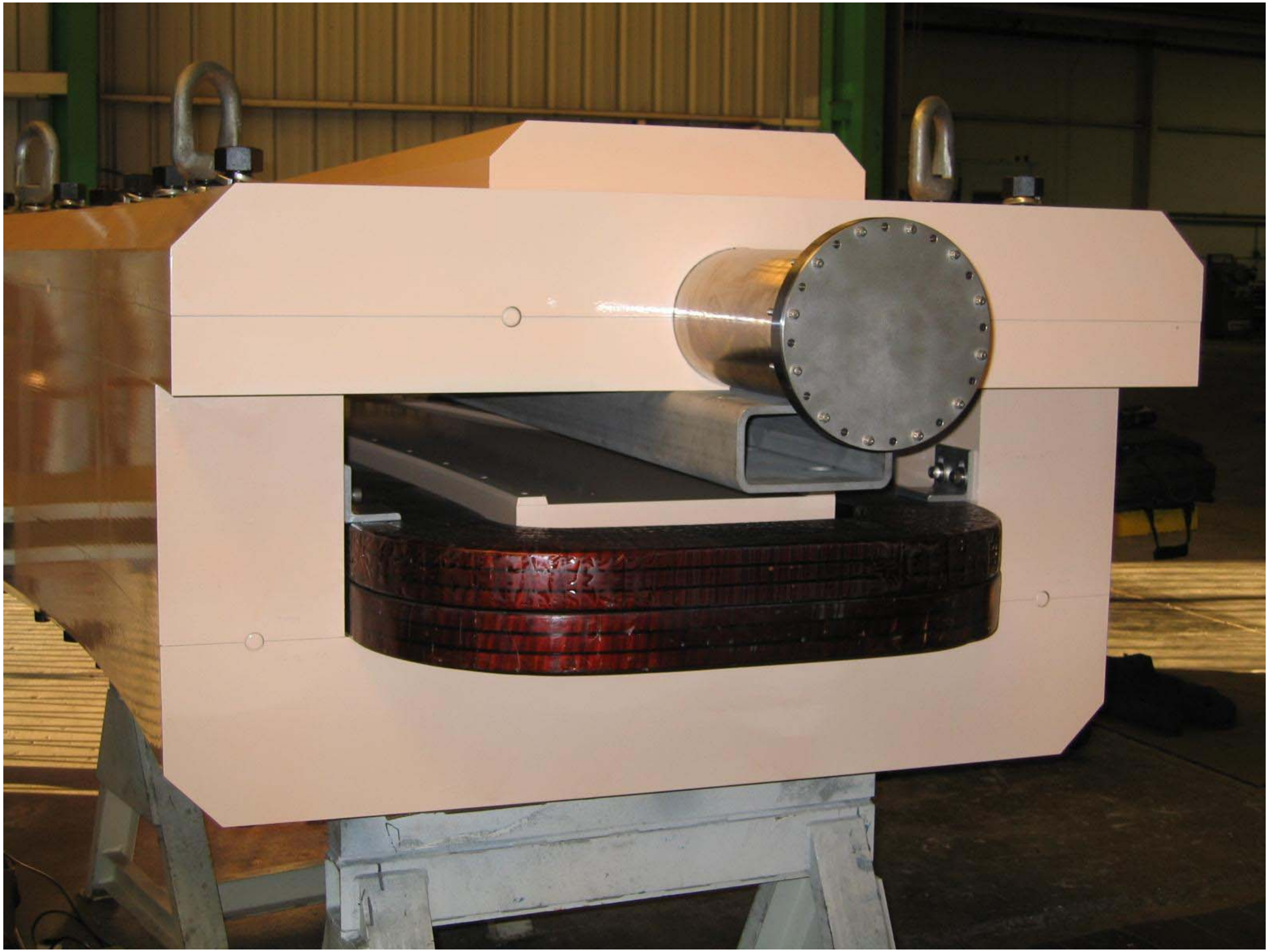
ELS plan schematic (POP perspective)



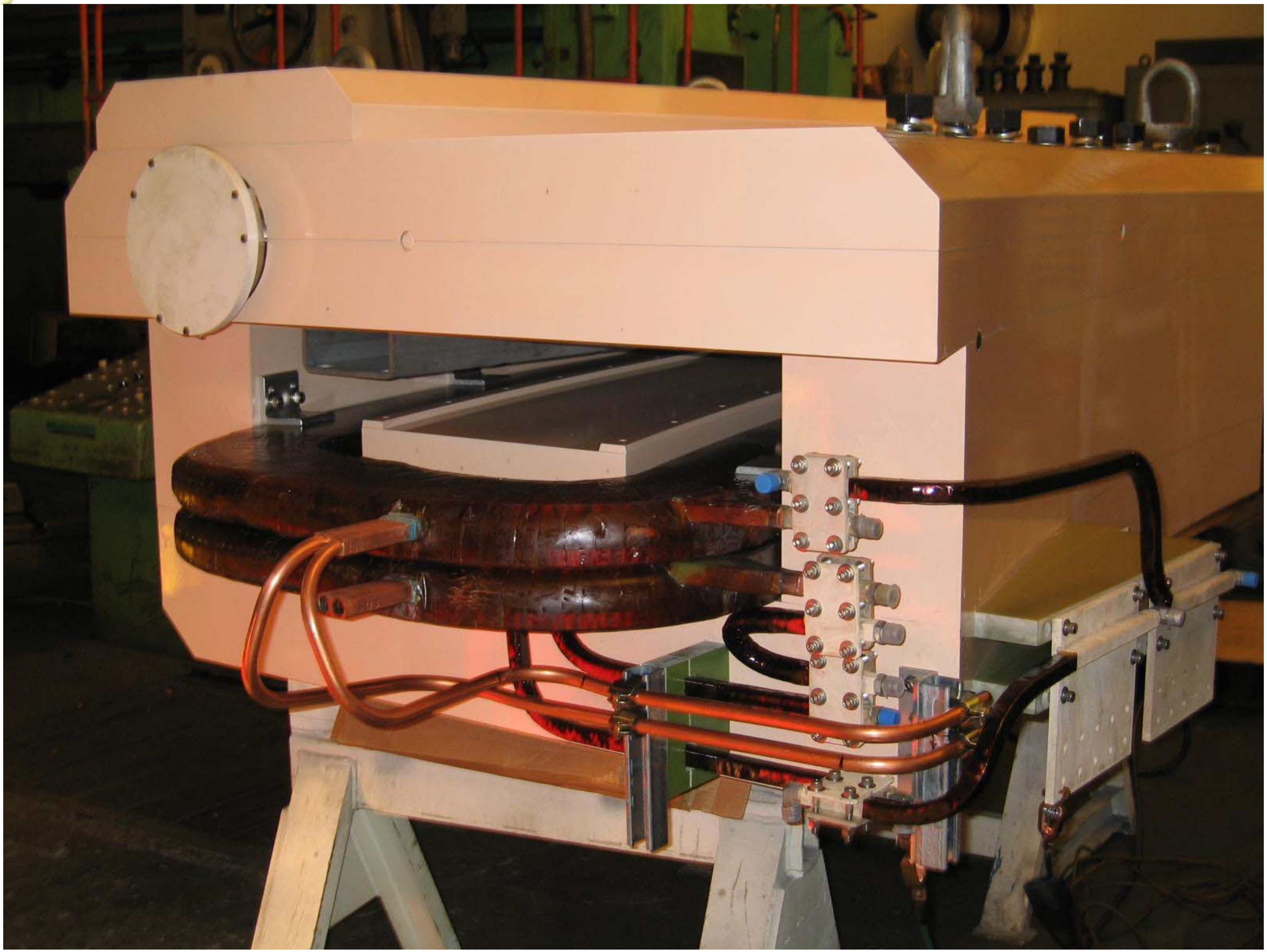
ELS X-Y cross-section at iron-inlet (WCS perspective)



ELS X-Y view at upstream end (iron-inlet)



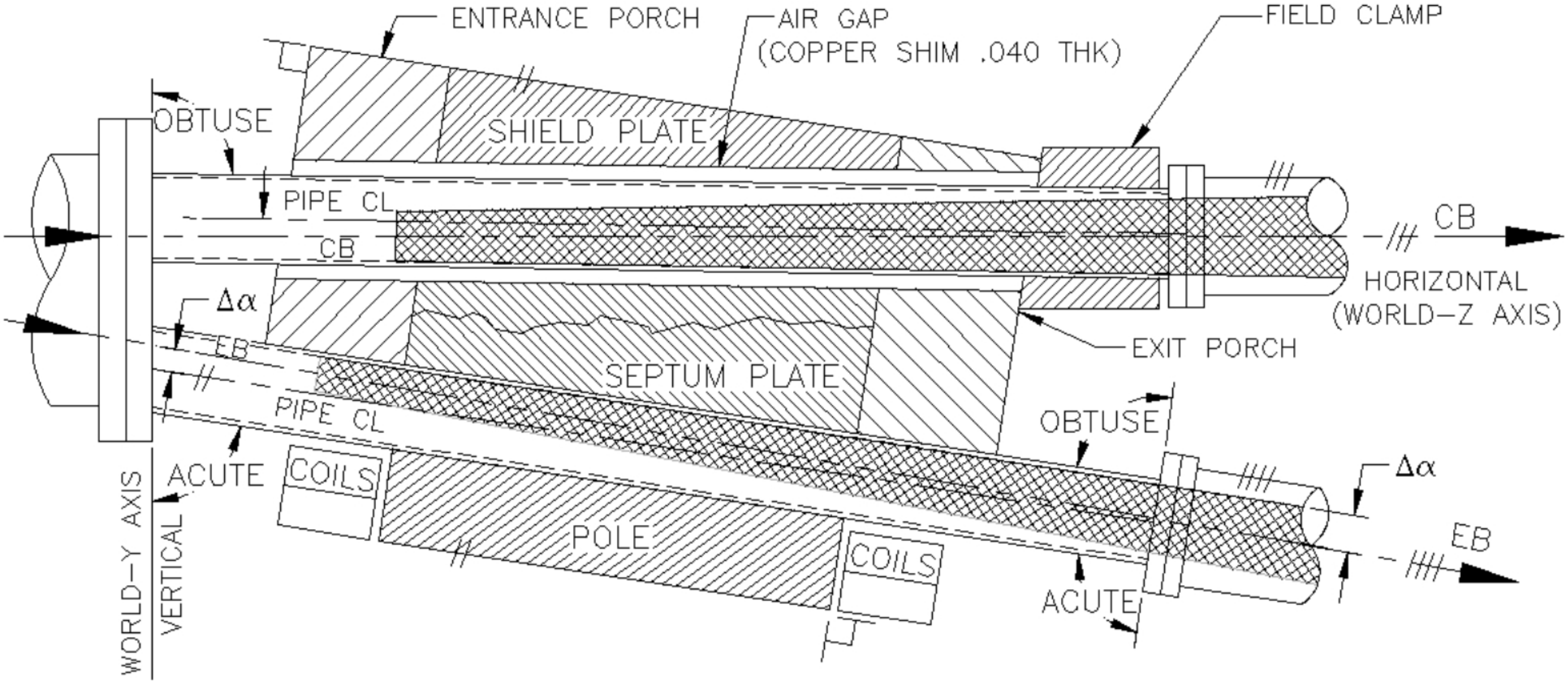
ELS X-Y view at downstream end (iron-outlet)



Beam Sizes at Extraction for Various SNS Operating Modes

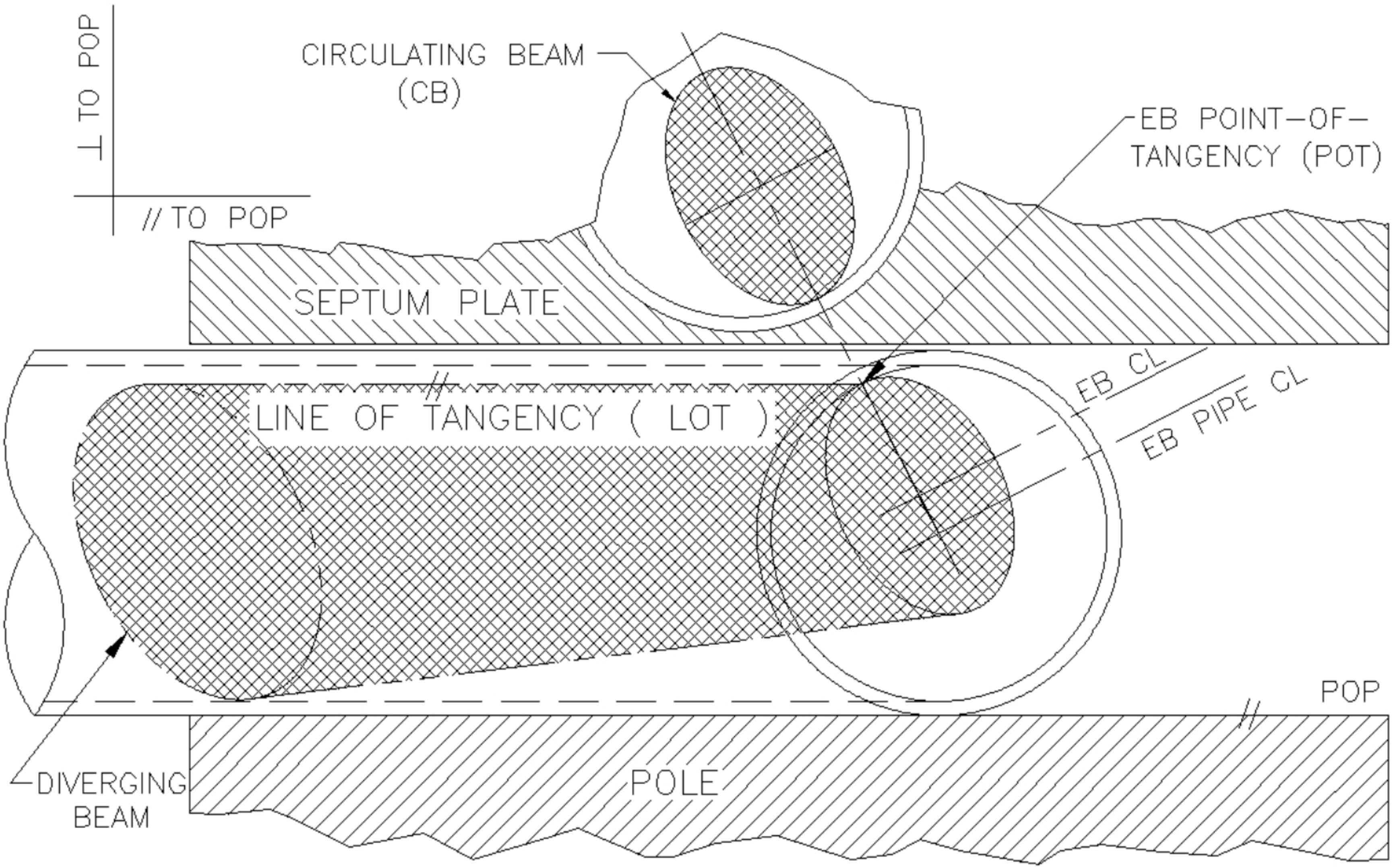
SNS Operating Mode Optics for Extraction Lambertson Septum Magnet per Nick Tsoupas					
Working Case Optics-NT-8-02				-J. Rank	4-03
Working Case		**I**	**II**	**III**	**IV**
			lattice baseline	:LS design basis	
Tune	*x*	5.24	6.20	5.80	6.30
	y	6.23	6.23	6.30	6.40
Beta-y	*septum iron-in*	10.990	13.049	14.099	12.261
	septum iron-out	13.281	14.099	15.799	14.000
EB y-radius @ 400 pi	*septum iron-in (mm)*	66.4	*72.3*	75.1	70.1
	septum iron-out (mm)	72.9	75.1	79.5	74.9
EB y-radius @ 400 pi	*septum iron-in (in)*	2.61	2.85	2.96	2.76
	septum iron-out (in)	2.87	2.96	3.13	2.95
EB y-dia. @ 400 pi	*septum iron-in (in)*	5.22	5.69	5.91	5.52
	septum iron-out (in)	5.74	5.91	6.26	5.90
CB y-radius @ 480 pi	*septum iron-in (mm)*	72.7	79.2	82.3	76.8
	septum iron-out (mm)	79.9	82.3	87.1	82.0
CB y-radius @ 480 pi	*septum iron-in (in)*	2.86	3.12	3.24	3.02
	septum iron-out (in)	3.15	3.24	3.43	3.23
CB y-dia. @ 480 pi	*septum iron-in (in)*	5.72	6.24	6.48	6.05
	septum iron-out (in)	6.29	6.48	6.86	6.46

ELS Y-Z section schematic (WCS perspective)

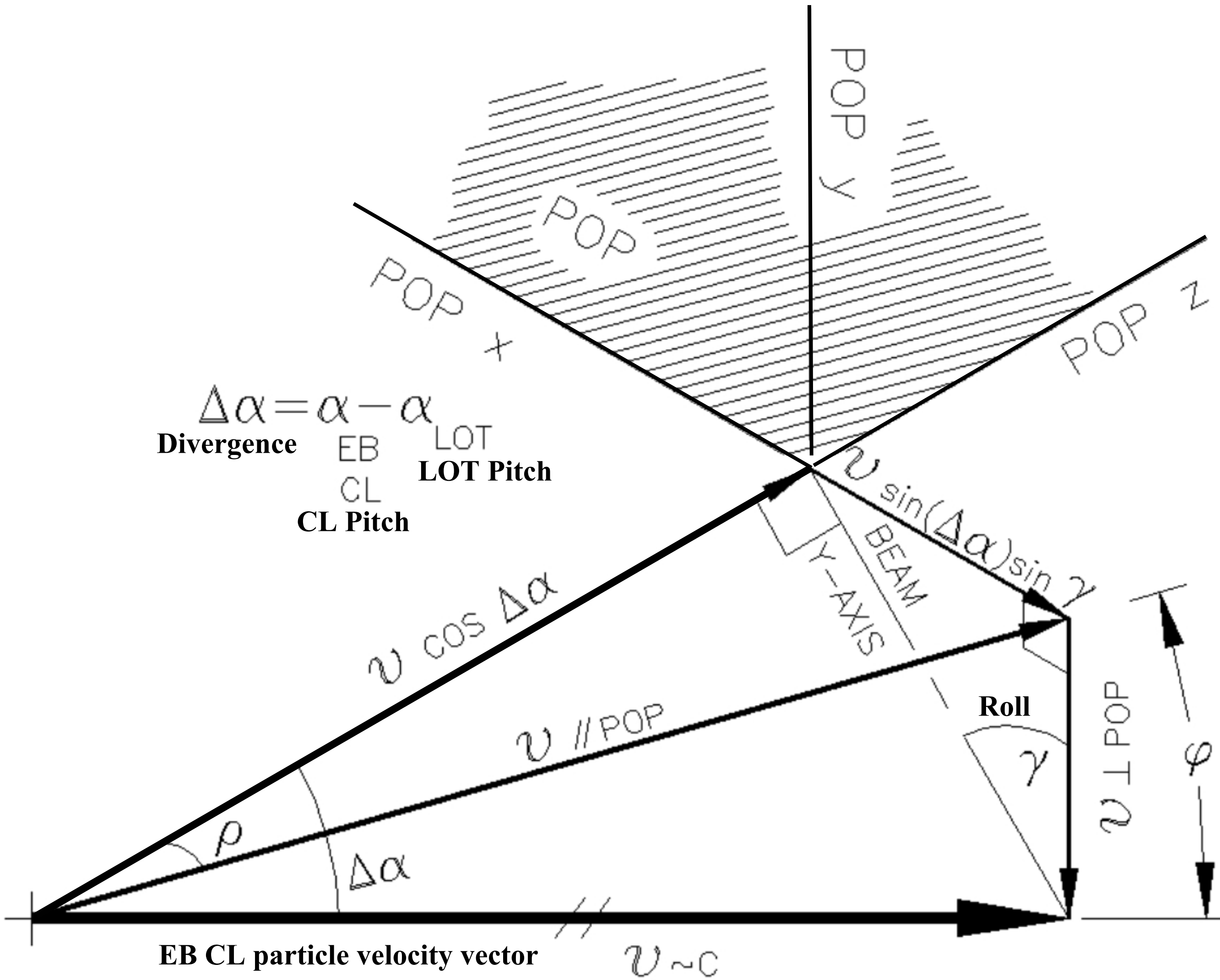


score lines indicate parallel surfaces and curves

ELS X-Y cross-section: WCS-to-POP transform (thru pitch & roll rotations)



Particle Beam Vector Diagram: EB CL particle resolved into POP components



POP-WCS coordinate system transformations

$$\overline{V_{pop}} := \left(\overline{V_{wcs}} \cdot [T_{pitch}]\right) \cdot [T_{roll}] \text{ where } \overline{V_{pop}} := \left(V''_x \;\; V''_y \;\; V''_z \right) \text{ thus}$$

$$\frac{V''_x}{V_{wcs}} := \left[\sin(\gamma) \cdot \left[\frac{\tan(\theta)}{\tan(\gamma)} + \sin(\alpha) \cdot \left(1 - \frac{\tan(\beta)}{\tan(\alpha) \cdot \cos(\theta)} \right) \right] \right]$$

$$\frac{V''_y}{V_{wcs}} := \left[\cos(\gamma) \cdot \left[\tan(\gamma) \cdot \tan(\theta) - \sin(\alpha) \cdot \left(1 - \frac{\tan(\beta)}{\tan(\alpha) \cdot \cos(\theta)} \right) \right] \right]$$

$$\frac{V''_z}{V_{wcs}} := \left[\cos(\alpha) \cdot \left(1 + \frac{\tan(\alpha) \cdot \tan(\beta)}{\cos(\theta)} \right) \right] \quad \text{where} \quad \begin{array}{l} \alpha \text{ is pitch angle} \\ \gamma \text{ is roll angle} \end{array}$$

Given $\left(V''_x\right)^2 + \left(V''_z\right)^2 := V_{wcs}$ and $V''_y := 0$ solve for α, γ

Figure 7: POP to WCS coordinate transformation.

POP-to-WCS Coordinate Tranformations: pitch and roll rotations

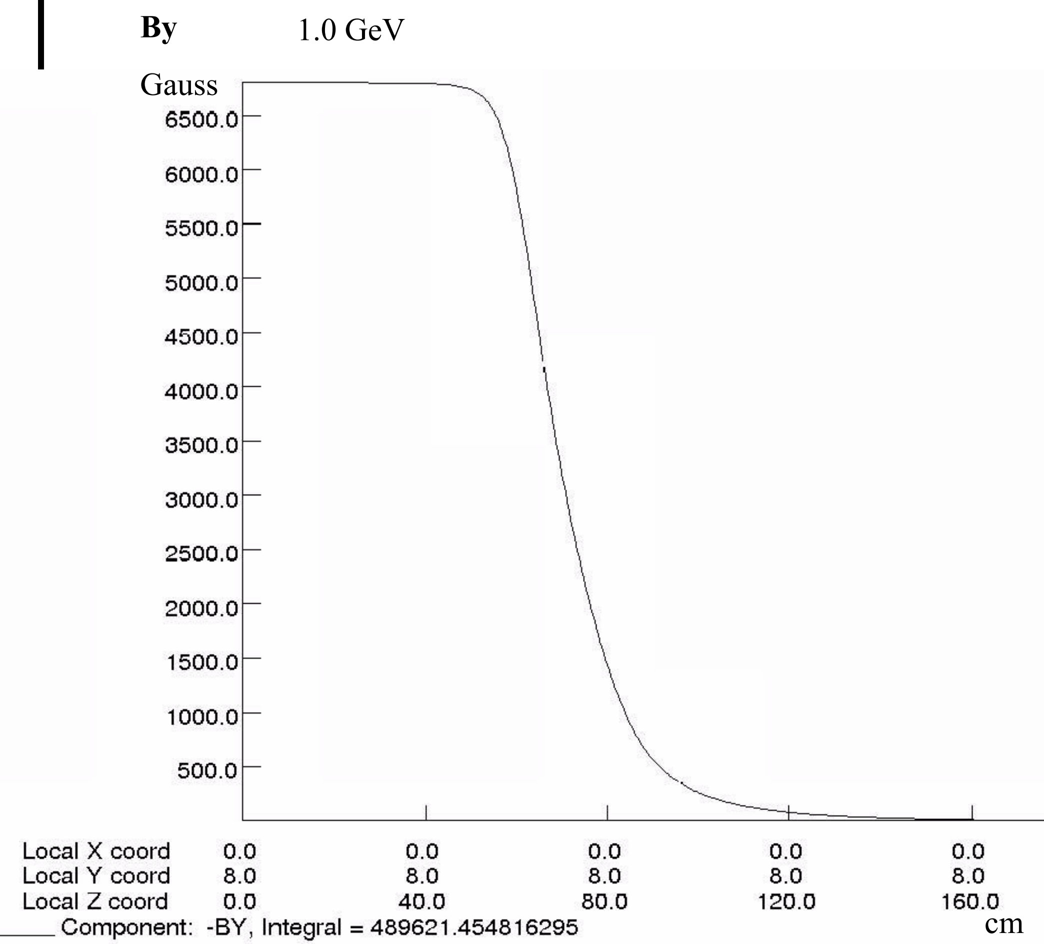
ELS GEOMETRY CALCULATION BY PITCH AND ROLL COORDIANTE TRANSFORMATIONS			
		Jim Rank 1/03	
Input angle in world coordinate system (WCS)			
angle for particle path lying in plane-of-pole (POP)			
; i.e, particle following the line-of-tangency (LOT)			
extraction angle projected on WCS X-Z plane	theta	0.293215	rad
angle of EB-out to Q1 MC w.r.t. WCS X-Z plane	beta-LOT	0.002043	rad
pole pitch angle about world X-axis	alpha-LOT	-0.011498	rad
solved pole roll angle about EB-in Z-axis	gamma	-0.045120	rad
Normalized EB-out velocity vector components			
in transformed coordinate system			
in pitched CS, after pitch transformation	Vx'/Vz	0.301918	
	Vy'/Vz	0.013632	
	Vz'/Vz	0.999909	
		1.091159	
	V'/Vz	1.044586	
in pitch and rolled CS, after roll transformatio	Vx"/Vz	0.302225	
; i.e., in POP coordinate system.	Vy"/Vz	0.000000	
	Vz"/Vz	0.999909	
		1.091159	
	V"/Vz	1.044586	
ELS bend angle in POP coordinate system	theta prime	0.293522	rad
		16.817588	deg
EB beam bend radius in POP		8449.10	cm
From magnetic field vector hand calculation			
(for comparison to transformation solution)			
solved pole roll angle about EB-in Z-axis	gamma	0.046148	rad
ELS bend angle in POP coordinate system	theta prime	0.293528	rad
		16.817905	deg
EB beam bend radius in POP		8448.94	cm

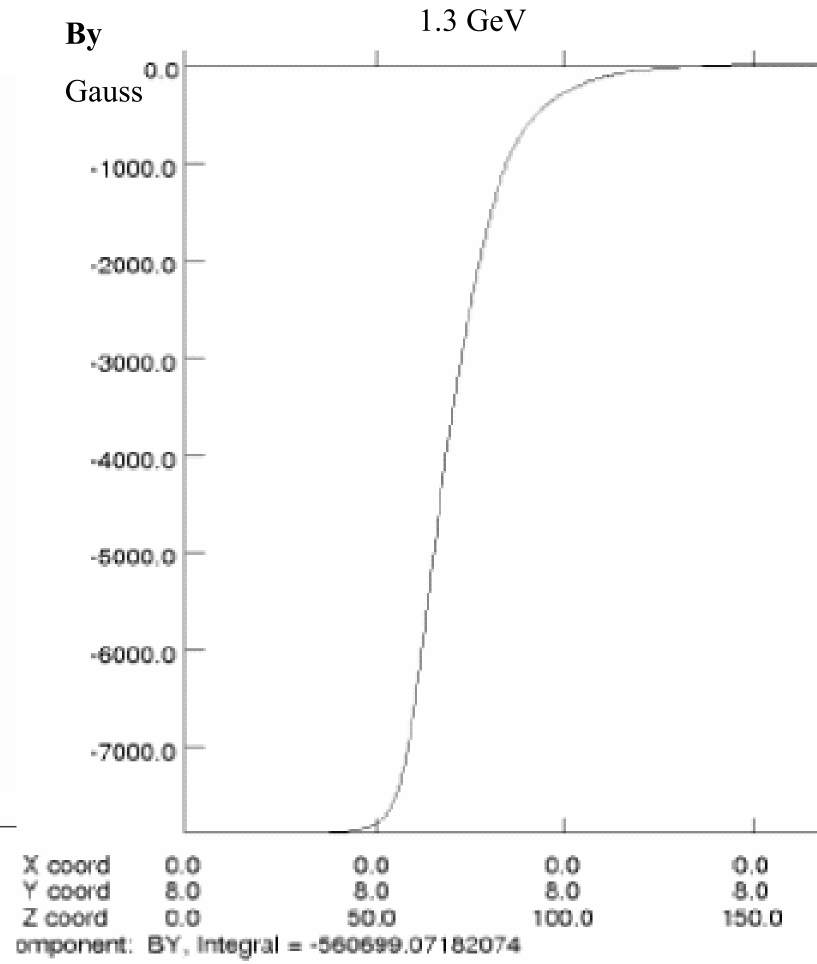
Physics Parameter Check

Dipole Beam Mechanics Check				rev 11/20/02	J Rank	
proton energy				1.0 GeV	1.3 GeV	
beam bend radius in POP		Ro	from geometry calc	8449.107	8449.107	mm
proton kinetic energy		T	from parameters	1.000	1.300	Gev
proton rest energy		mc^2	known	0.938	0.938	Gev
Lorentz factor		gamma rel	=(T/mc^2) + 1	2.066	2.386	
beam rigidity		B * ro	=3.13*((gamma rel)^2-1)^.5	5.657	6.778	T-m
required magnetic flux		Bo	= (B * ro) / ro	0.670	0.802	Tesla
		Bo		6695.703	8022.499	Gauss
magnetic length		Lm	from E/M analysis	248.000	248.000	cm
integrated field		Bo * Lm	calculated	1660.534	1989.580	kG-cm

Extracted Beam (EB) Field Profile: By plot at 1.0 GeV and 1.3 GeV

Opera E/M analyses by N. Tsoupas



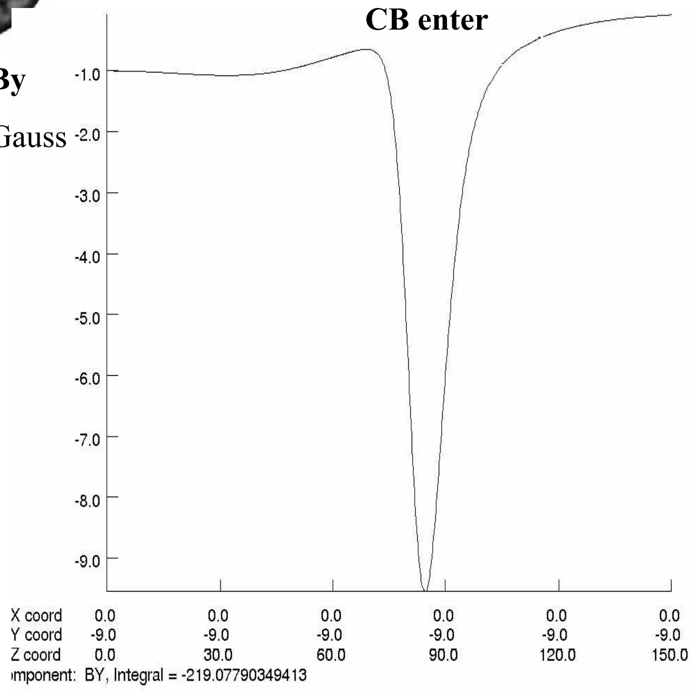


VECTOR FIELDS

CB field profile: By plot at entrance and exit, Bx plot at exit at 1.0 GeV

By

Gauss

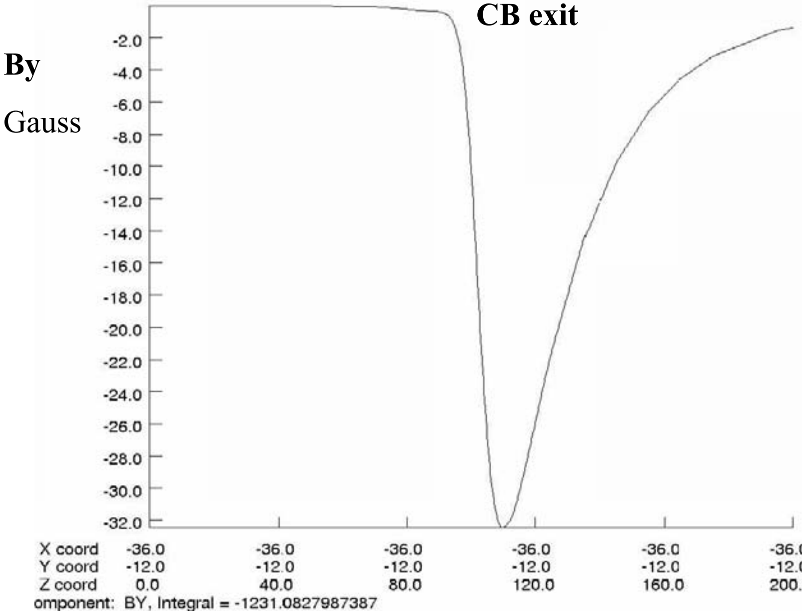


cm

CB enter

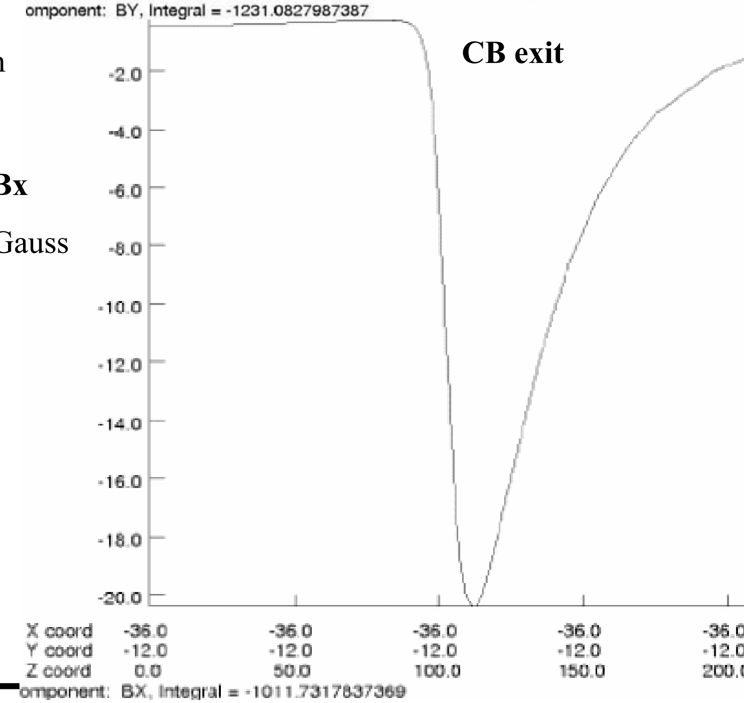
By

Gauss



Bx

Gauss



Due to near symmetry at the iron entrance the Bx field component seen by the Circulating Beam (CB) is negligible.

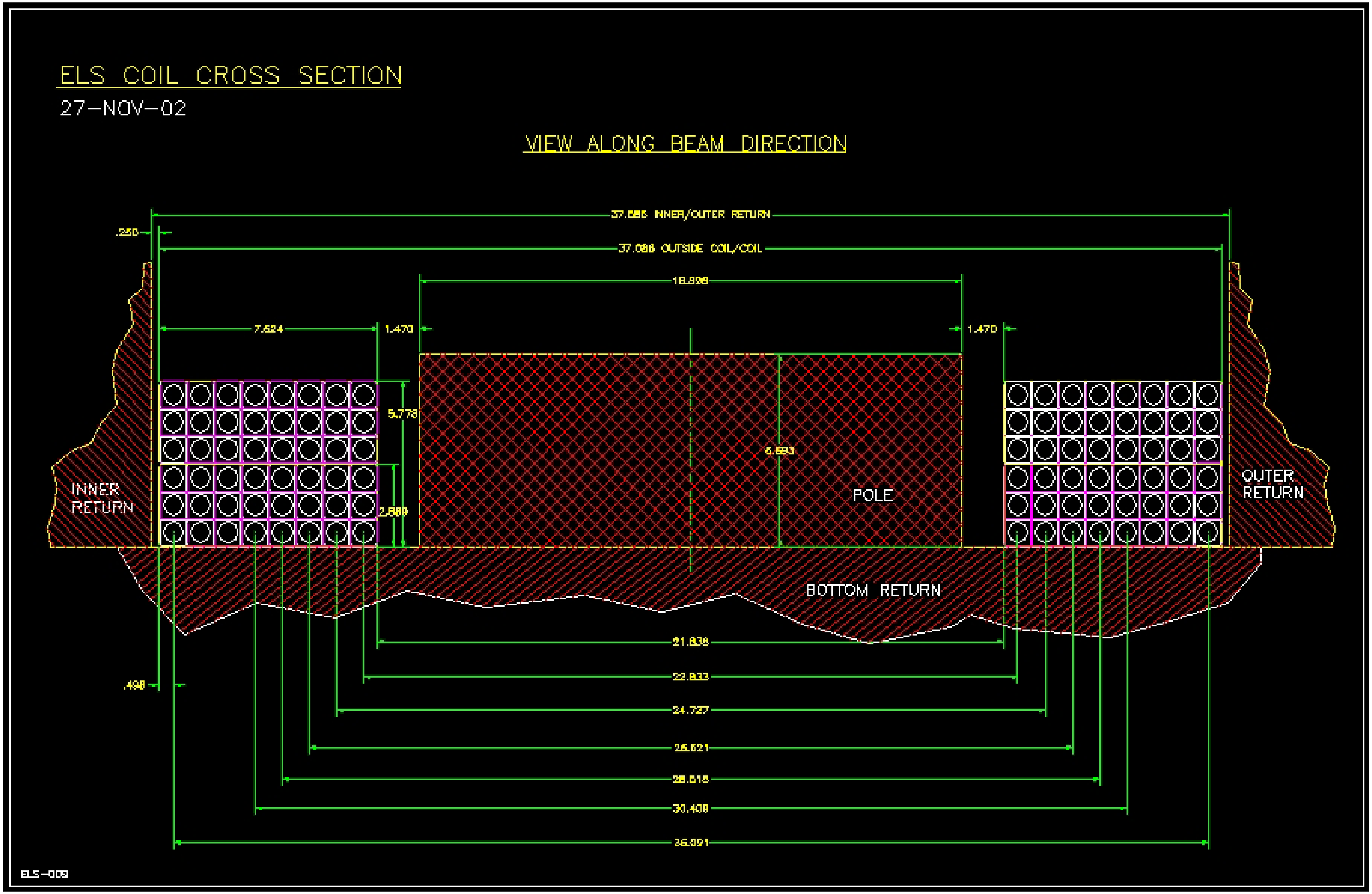
Opera E/M analyses by N. Tsoupas

CB end effects: multipoles for 1.0 GeV

Opera E/M analyses by N. Tsoupas

Multipoles wrt Circulating Beam at 1.0 GeV					N. Tsoupas
POSITION w.r.t. IRON	B_0 [Gauss.cm]	B_1 [Gauss.cm]	B_2 [Gauss.cm]	B_3 [Gauss.cm]	B_4 [Gauss.cm]
INSIDE	-100.00	-2.00	8.60	0.00	0.00
OUTSIDE	-500.00	-92.00	11.00	1.60	-1.80
TOTAL	-600.00	-94.00	19.60	1.60	-1.80
	A_0 [Gauss.cm]	A_1 [Gauss.cm]	A_2 [Gauss.cm]	A_3 [Gauss.cm]	A_4 [Gauss.cm]
INSIDE	-44.00	25.00	0.33	-3.20	0.00
OUTSIDE	-175.00	101.00	19.00	-3.20	1.10
TOTAL	-219.00	126.00	19.33	-6.40	1.10
	b_0 []	b_1 []	b_2 []	b_3 []	b_4 []
INSIDE	-0.898473	-0.0180	0.0773	0.0000	0.0000
OUTSIDE	-4.492363	-0.8266	0.0988	0.0144	-0.0162
TOTAL	-5.39	-0.84	0.18	0.01	-0.02
	a_0 []	a_1 []	a_2 []	a_2 []	a_4 []
INSIDE	-0.449236	0.2246	0.0030	-0.0288	0.0000
OUTSIDE	-1.572327	0.9075	0.1707	-0.0288	0.0099
TOTAL	-2.02	1.13	0.17	-0.06	0.01
All Units x E-4					
	B_n , A_n are the Integrated Multipoles at R=8.7 cm				
b_n , a_n same as Bn , An but Norm. to 10^4*B*L of main magnet					
R=8.7 cm $\varepsilon=480\pi$ B*L(of main magnet)=1.113 [T.m]					

ELS Stacked Pancake (2) Coils

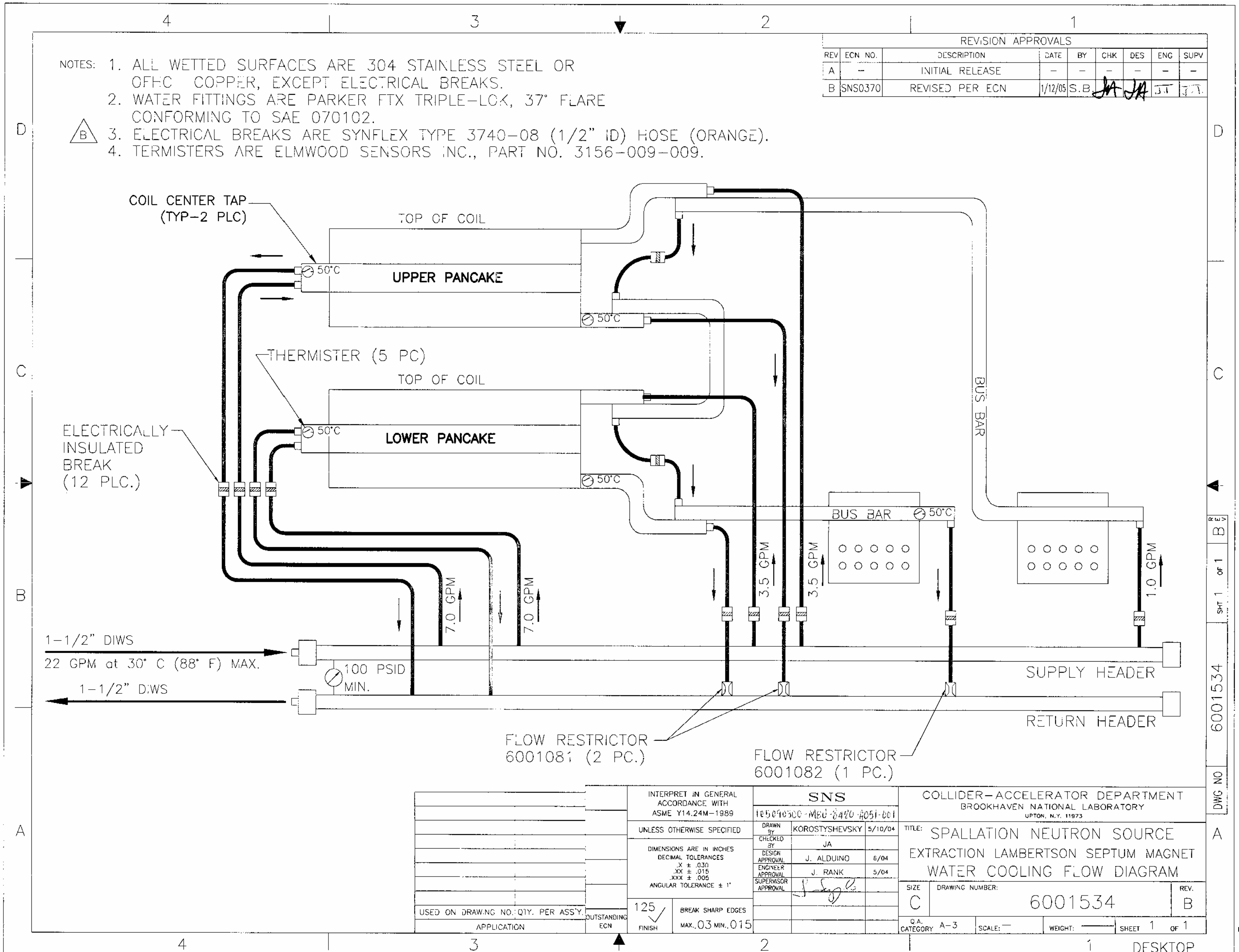


ESL and 17D224 universal coil

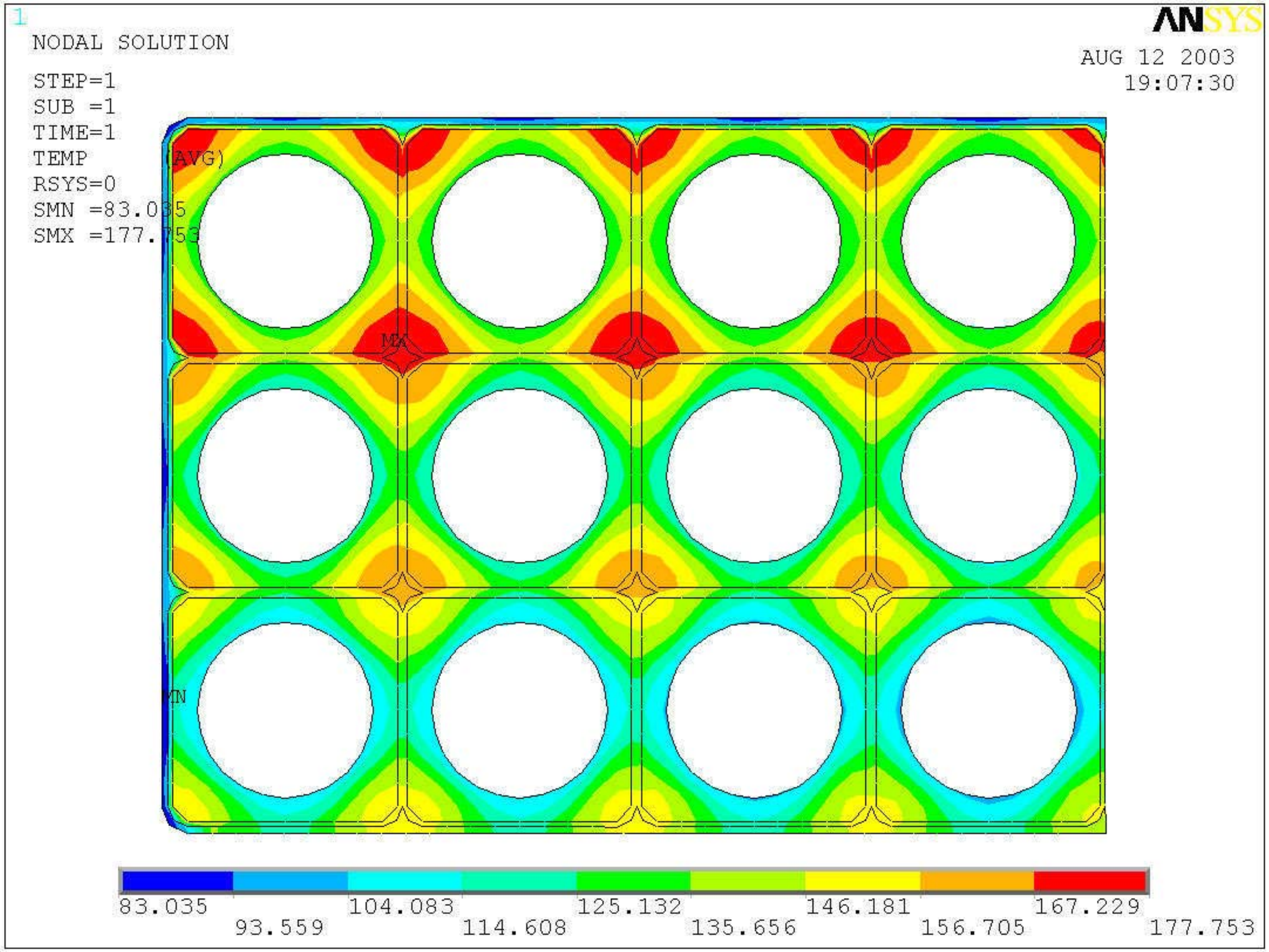
Coil Design Calculation: configuration, current, cooling, pressure drop

Coil Design Lambertson Dipole Magnet at 1.3 GeV				J Rank
COIL: SwissMetal 13293 (Sq.)	2.3 cm sq cross-section	########	rev 11/20/02	rev 8/7/2003
	SYMBOL/EQUATION	VALUE	UNITS	CRITERIA
magnetic flux density	B	0.802	Tesla	(=1E4 Gauss)
gap height	r	17.02	cm	
Dipole Excitation	NI=B*r/mu	108623.7	Amp-Turns	single pole tip
coils per magnet	c	1		peak allowable
power supply current per turn	I	2262.99	amps	2400A PS max
req'd number of turns per coil	N= NI/I	48	turns	
mass/unit length of conductor	M/L	24.40	g/cm	
conductor cross-section	Ax=(M/L)/dens	2.91	sq cm	
current density	J=I/Ax	777.9	amps/sq. cm	< 1000 A/sq cn
cond. length per turn	L	662.7	cm	Li=224,Pw=48
number of layers per coil	n	6	coil sect height	15
number of turns per layer	t	8	coil sect width	20
OFHC Cu resistivity at avg temp	ro	1.81515	microOhm-cm	at 40.6 deg. C
coil layer electrical resistance	R =(ro*t*L)/Ax	3307.73	micro-Ohms	at 40.6 deg. C
	R	3.31E-03	Ohms	
number of layers in series circuit	s	6		
power supply current per circuit	I	2262.99	amps	
voltage drop across circuit	V=I*(s*R)	44.91	volts	
power dissipated per circuit	P=VI	101635.9	Watts	
power dissipated per coil	Pc=P*(n/s)	101635.9		
heat generated per layer	q=(I^2)*R	16939.31	Watts	
number of parallel cool flow paths	p	2		
number of layers in cool flow path	m=n/p	3		
allow. temp. rise across cool path	dT	20	deg. C	<< 30 deg. C !!
water inlet temp	To	30.56	deg. C	SNS imposed
water outlet temp	Tf	50.56	deg. C	
kinematic water visocity at avg te	nu	7.00E-06	sq ft/sec	
volumetric flow rate per cool path	Qp=3.8*q*m/(dT)	9.66	GPM	
volumetric flow rate for magnet	Qm=Qc*c	19.31	GPM	
cooling passage hyd. diameter	d	1.80	cm	
coolant flow velocity	v	7.86	ft/sec	5 < v < 15 ft/se
Reynolds number	Re=v*d/nu	66268.3		>> 3000 !!!
friction factor	f	0.02		see iteration
pressure drop thru cooling passag	dp=fL/d*dens*(v^2)/2g	73.3	psi	at 40.6 deg. C

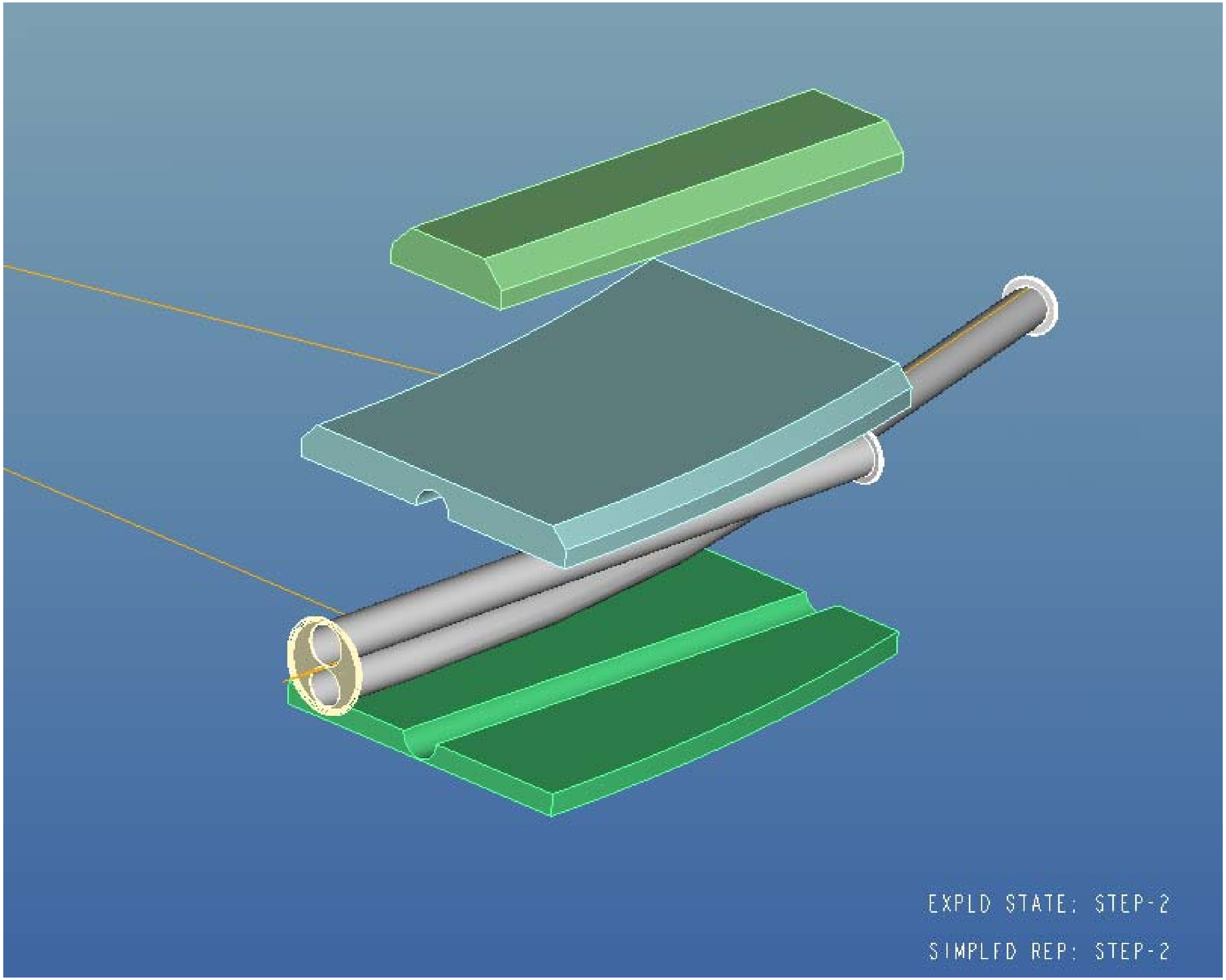
Cooling Water Schematic



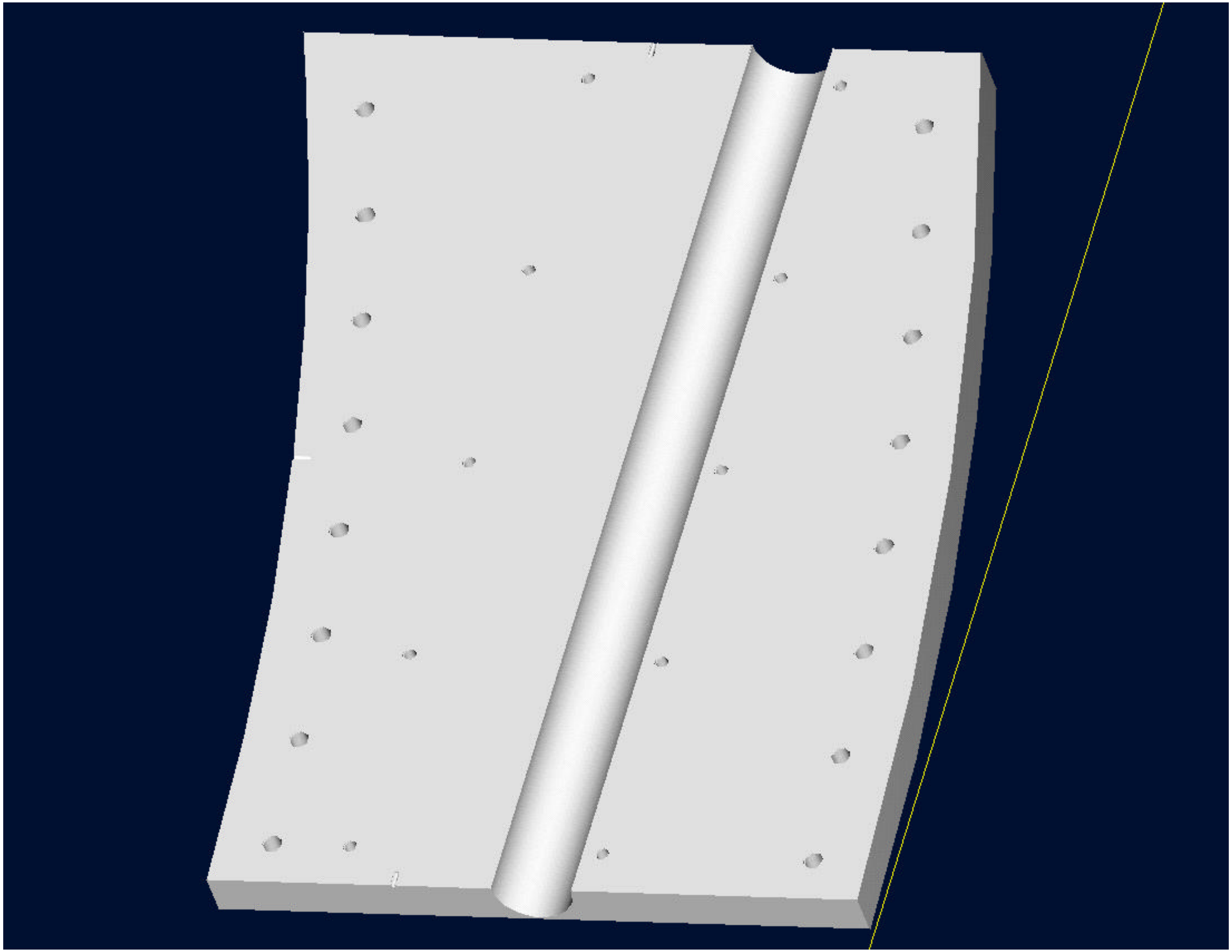
Temperature (deg F) Contour Plot of ¼ Coil Cross-section



Septum and Shield Plate Assembly: exploded view



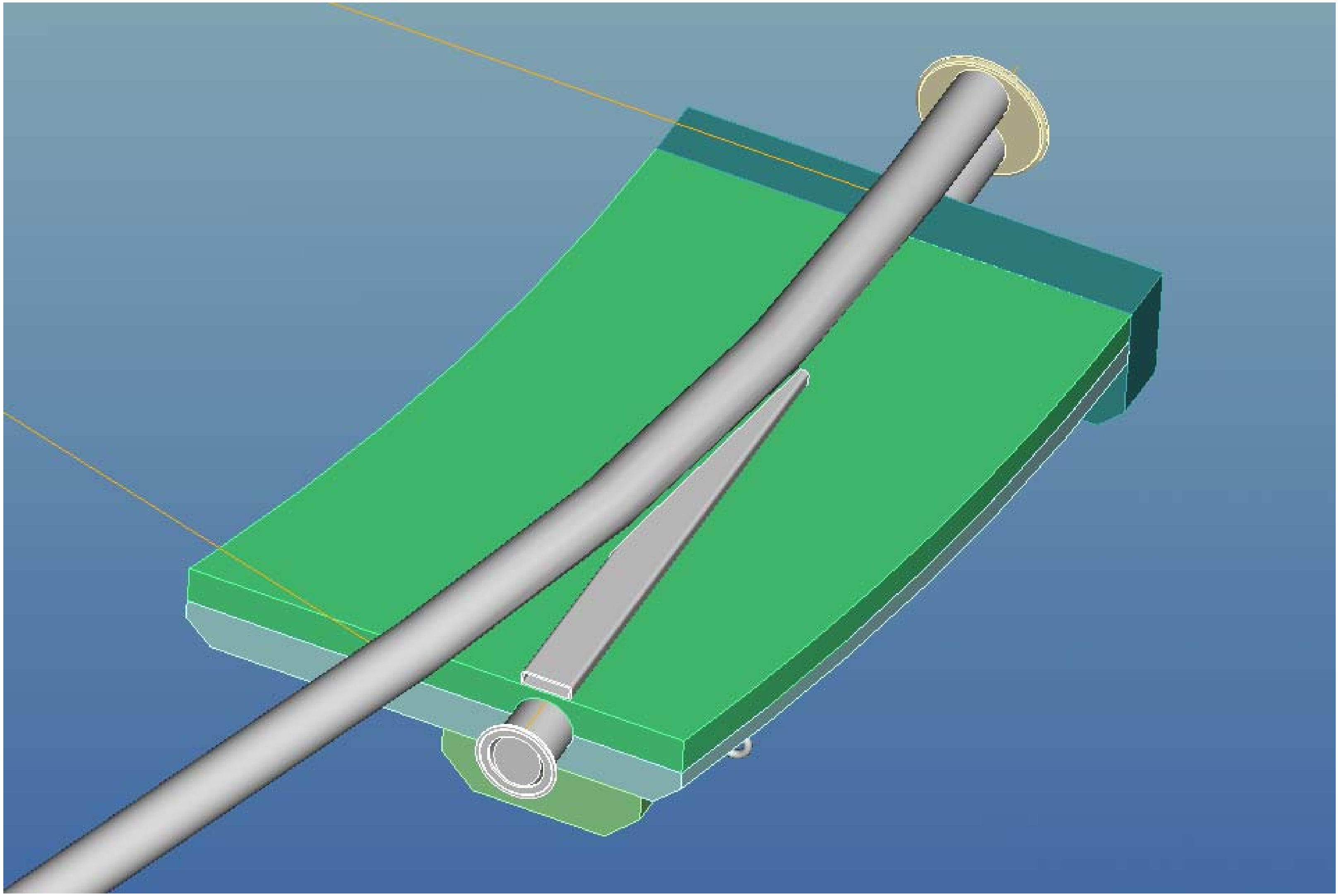
Upper Yoke Assembly: pinning and bolting



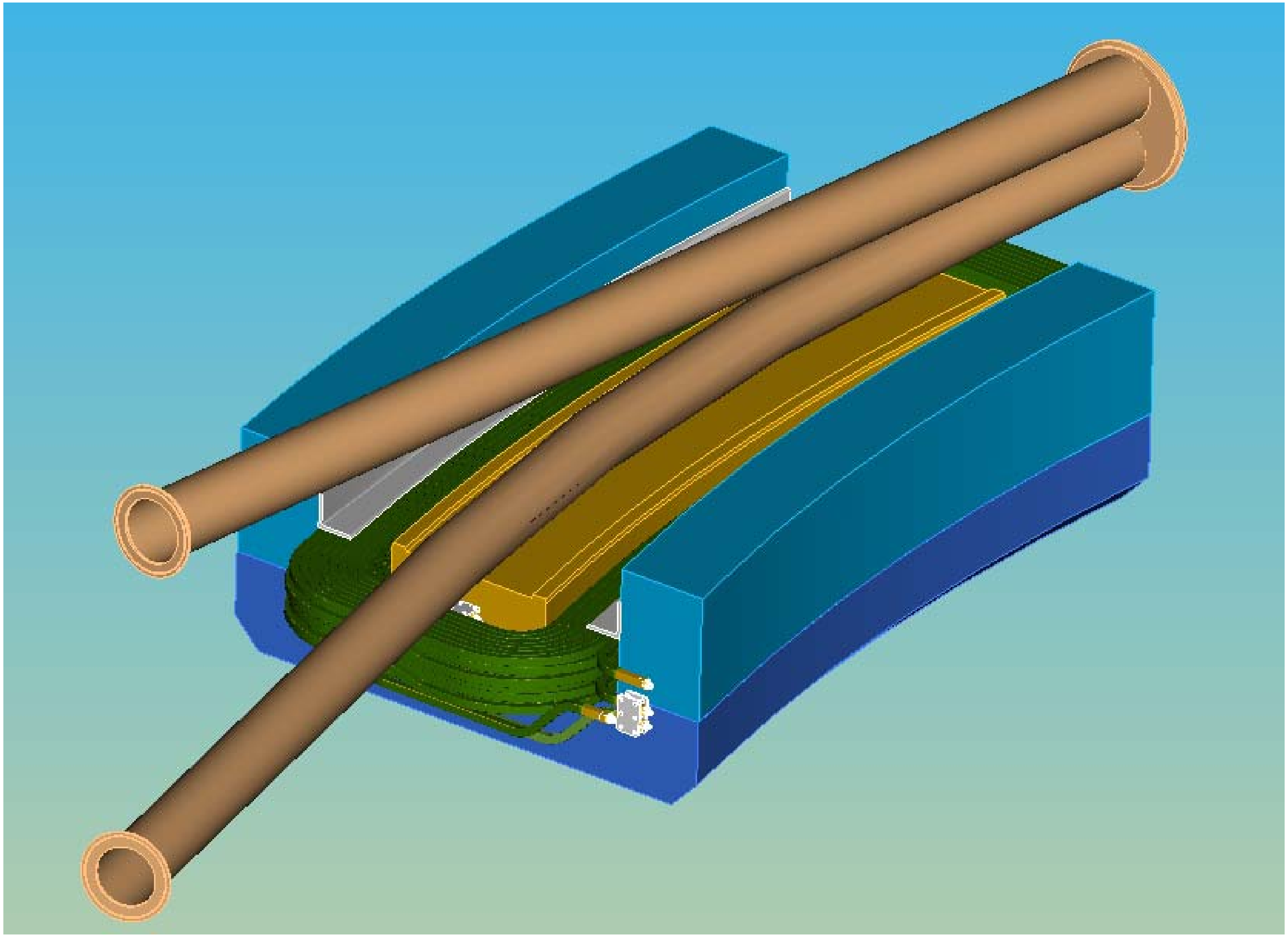
RTBT ASSEMBLY

Determination of Manufacturing and Assembly Tolerances for ELS Magnet Circulating Beam (*Ring CB*) Vacuum Chamber and Shielding								
		allowable tolerance stack-up based on permissible beam loss						
		nom value						
% change emittance	**De/ e**		**-1.0%**	**-2.0%**	**-4.0%**	**-8.0%**	% loss	
resulting emittance	**e**	**480**	**475.2**	**470.4**	**460.8**	**441.6**	**p**	mm-rad
fractional OD reduction	**Df / f**		-0.005	-0.01	-0.02	-0.04		
allowable tolerance stack-up	**basis: DS transition**	6.85	0.034	0.069	0.137	0.274		inches
allowable tolerance stack-up	**basis: US transition**	6.30	**0.032**	**0.063**	**0.126**	**0.252**		inches
	nominal CB tube ID	6.85" dia.						
		tolerance stack-up for CB chamber assemblies						
		clamshell assembly		slip fit				
		commercial	custom	commercial	custom			
sept plate flatness	over 90" length of plate	0.010	0.010	0.010	0.010			
sept plate planar tolerance	top (cut) to bottom (datum) face	0.005	0.005	0.005	0.005			
septum cut centerpoint	milling machine accuracy	0.002	0.002	0.002	0.002			
design clearance	design for assembly	0.005	0.005	0.125	0.090			
0.040" shim thickness	precision copper shim	0.001	0.001	0.001	0.001			
Ni plating thickness ID + OD	control over plating process	0.001	0.001	0.001	0.001			
CB tube diameter (OD)	ASTM A513 welded & DOM tub	0.026		0.026				
CB tube diameter (OD)	honed & centerless ground tube		0.010		0.010			
CB tube wall thickness	ASTM A513 welded & DOM tub	0.006		0.006				
CB tube wall thickness	honed & centerless ground tube		0.005		0.005			
TOTAL ASS'Y STACK-UP		**0.056**	**0.039**	**0.176**	**0.124**			

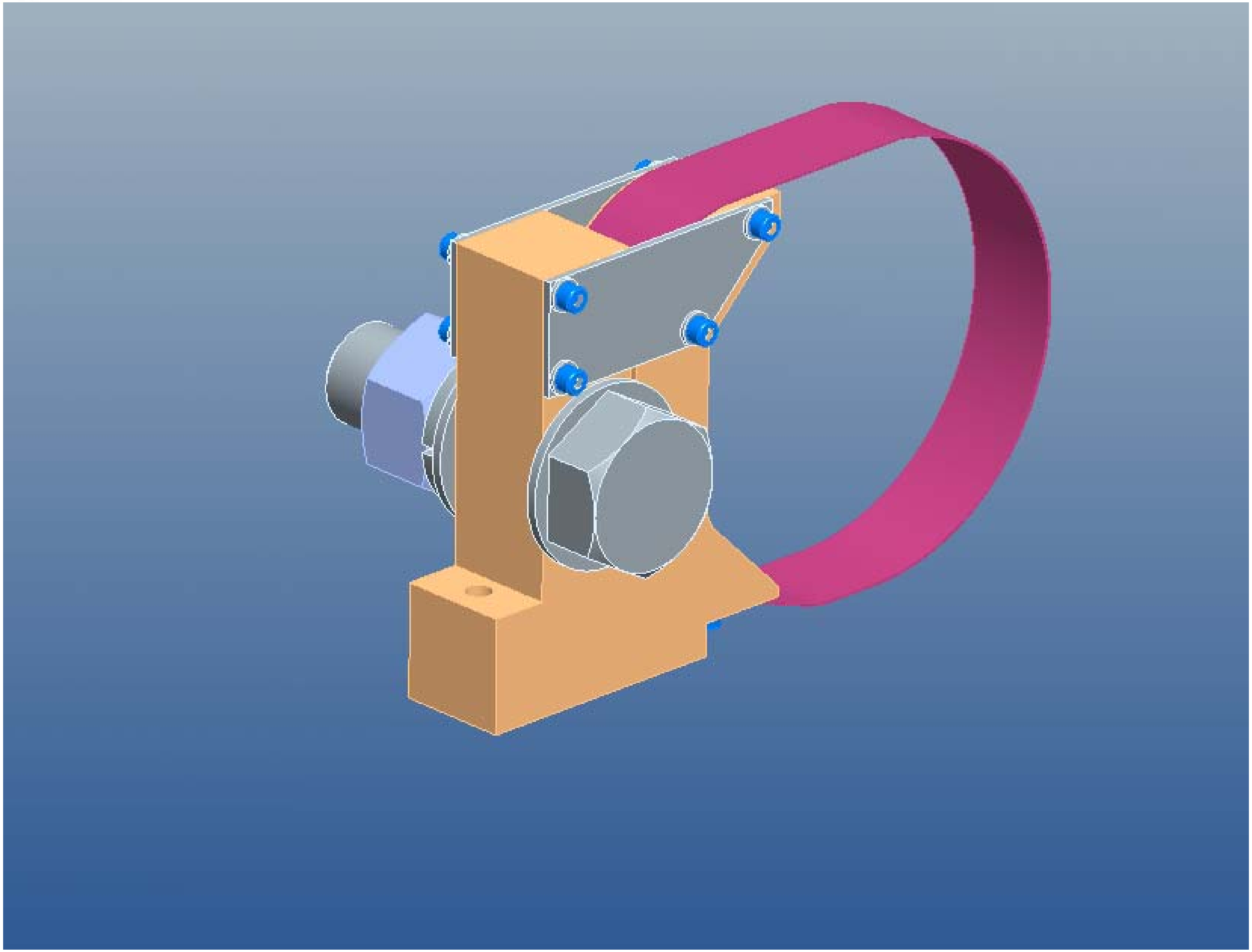
Septum and Shield Plate Assembly: underside with septum reinforcement



Lower Yoke Assembly: pole, pole shims, coils, coil clamp

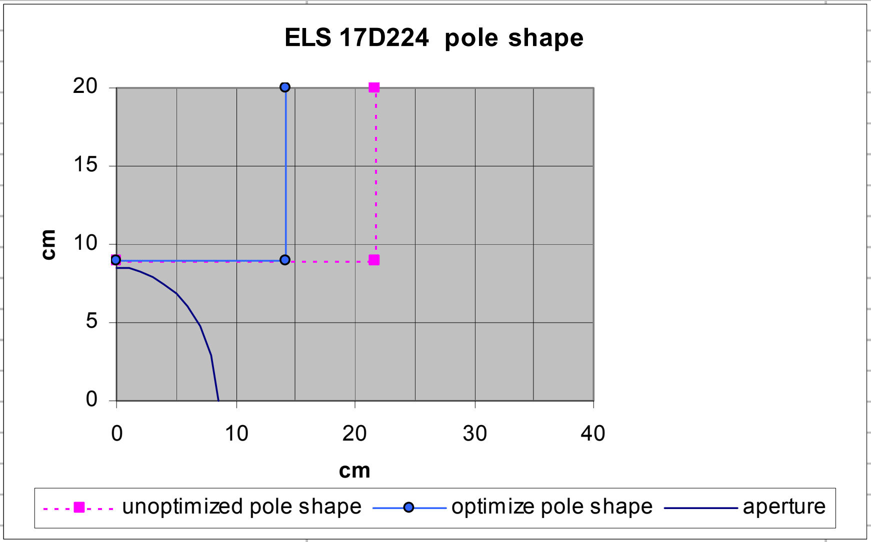


EBP band clamp

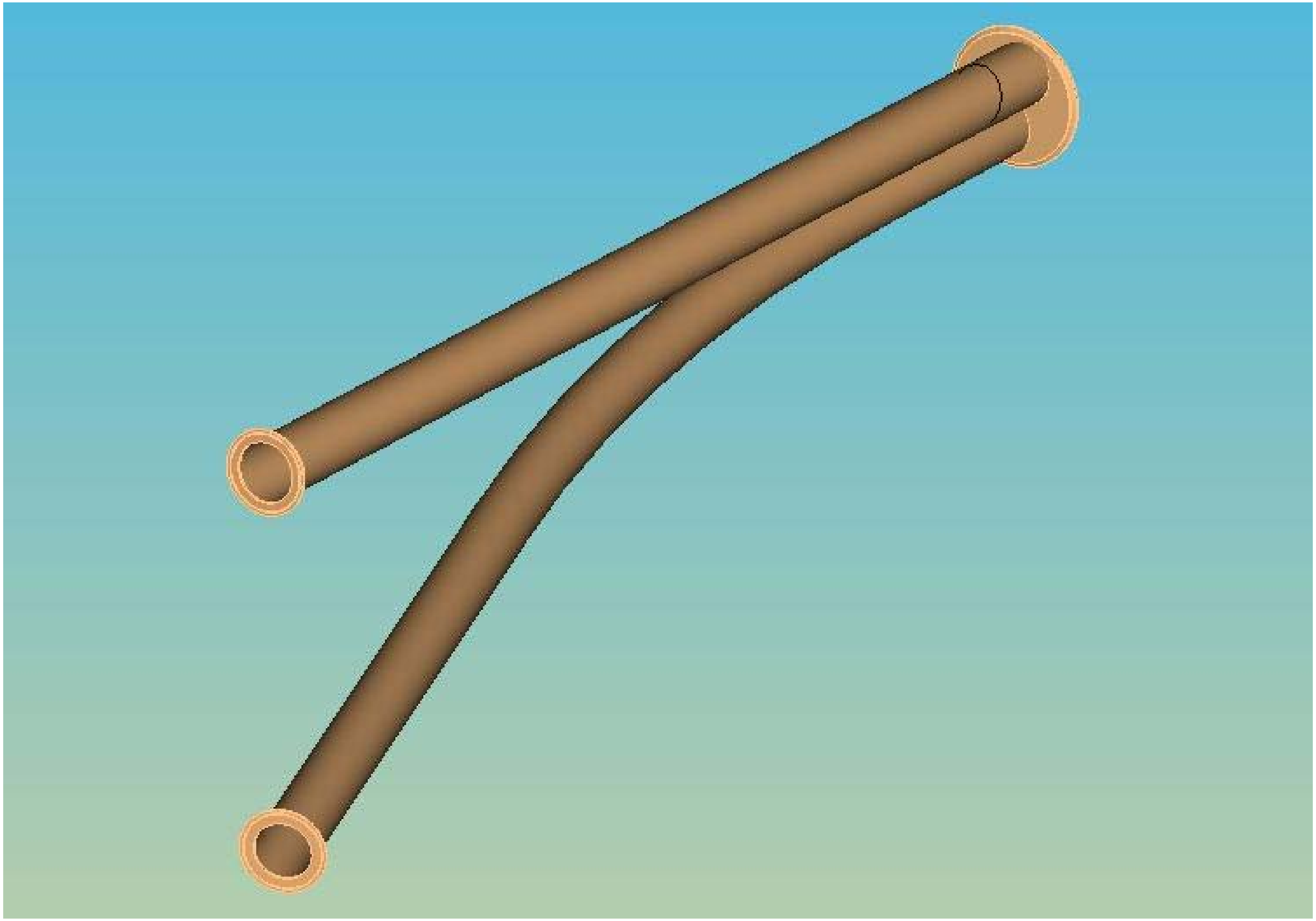


ELS 17D224 Pole Optimization

ELS 17D224 - Lambertson magnet pole optimization			
homogeneity	(delta B)/B [change in flux density/nom. flux den	0.001	
gap	2h	17.020	cm
aperture width	2w	16.274	cm
UNOPTIMIZED DIPOLE POLE EDGE			
unoptimized pole overhang / halfgap	Lu = - 0.36 x ln(dB/B) - 0.90	1.587	cm
OPTIMIZED DIPOLE POLE EDGE			
optimized pole overhang / halfgap	Lo = - 0.14 x ln(dB/B) - 0.25	0.717	cm
unoptimized pole overhang	Au = Lu * h	13.504	
optimized pole overhang	Ao = Lo * h	6.102	
LAMBERTSON POLE SHAPE			
unoptimized pole edge X-coordinate	Xu	21.640	cm
optimized pole edge X-coordinate	Xo	14.239	cm



Vacuum Chamber Y-Weldment: CStl CB tube, SStl EB pipe



Proposed ELS vacuum chamber fabrication procedure

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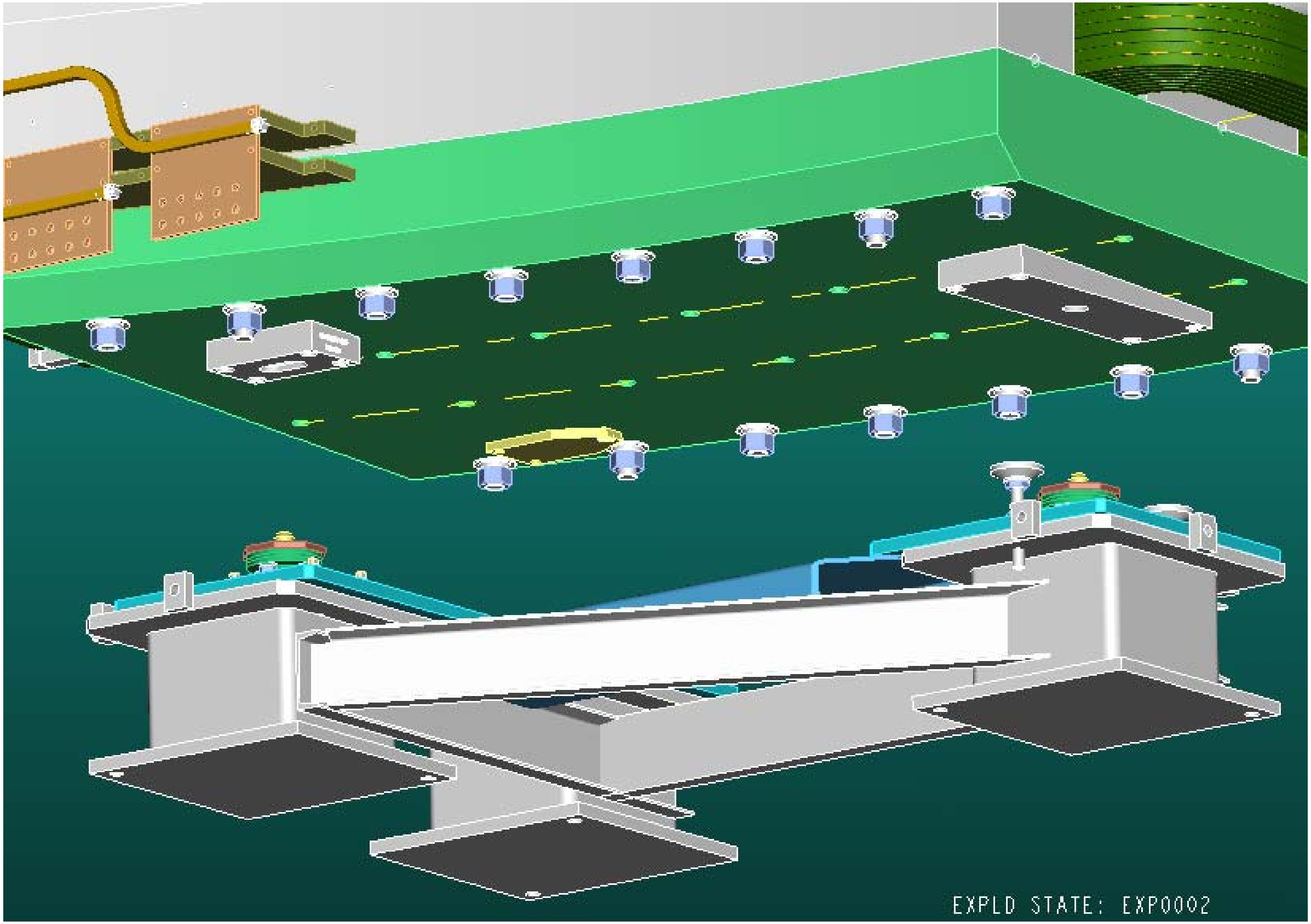
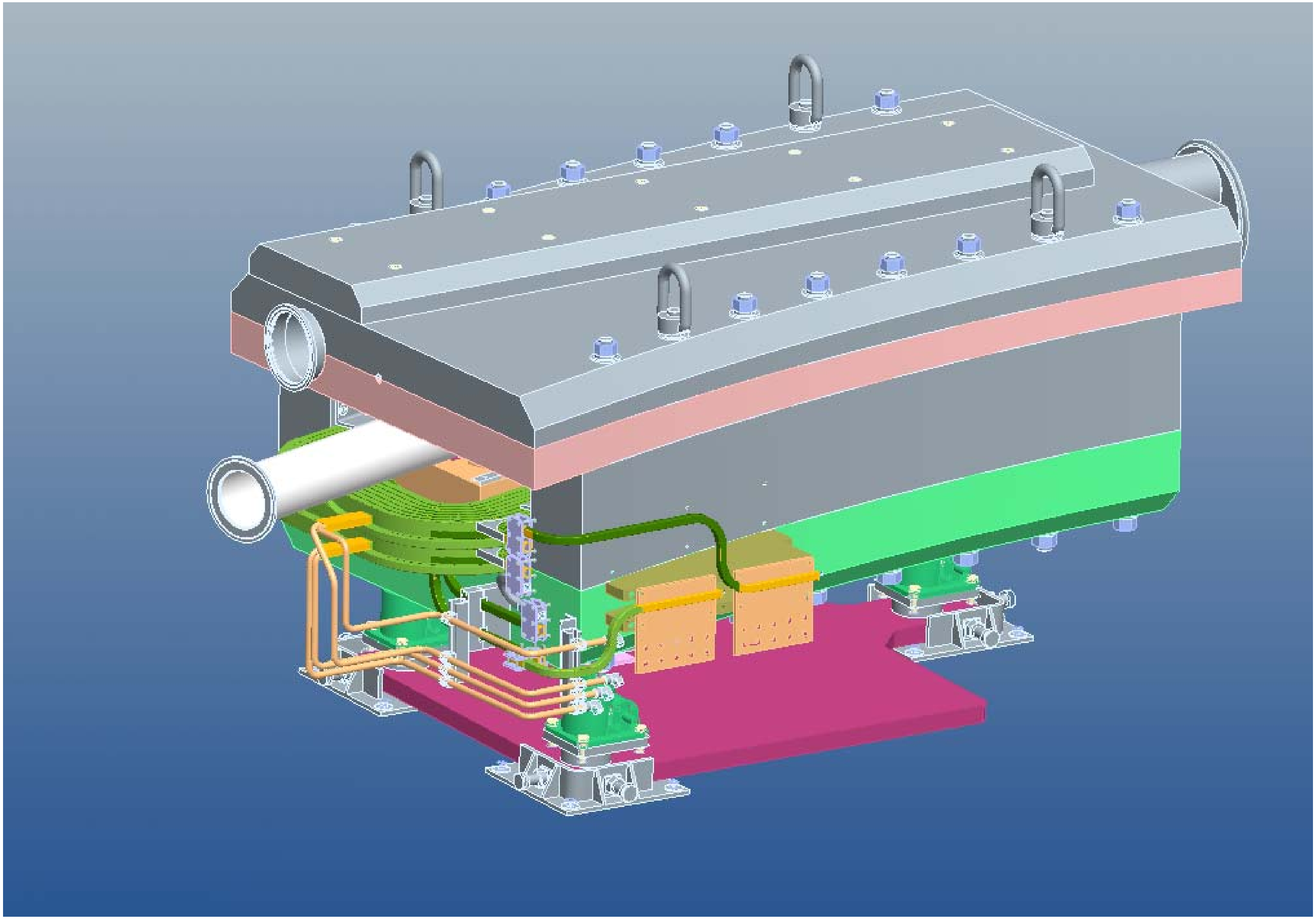
1. fabrication and processing of circulating beam pipe (CBP): by BNL
    a. procure CB tube: ASTM A513 welded & DOM tube, C1026
    b. centerless grind to final OD; broach/grind wall along LOT; concentric bore D/S end only to final wall
    c. nickel plate CBP: remove oxidation in acid bath, vacuum fire clean, mask weld ends and plate
    d. cut to final length; align and weld D/S flange and oversized SS stub pipe with temp flange; TiN coat
    e. leak test and ship CBP to vendor for installation in magnet assembly
2. fabrication of extracted beam pipe (EBP): by vendor
    a. contact cement CBP and wrap in copper shim; align and install in magnet
    b. precision bend 304L stainless EB pipe
    c. machine Y-flange; align, fixture and weld EB assembly; test alignment and fit in pole clamps
    d. leave EBP uninstalled and ship separately with magnet assembly to BNL
3. assembly and testing: at BNL, by BNL
    a. at BNL: perform magnet measurement on both EB and CB (see below), make necessary adjustments
    b. Wach's cut SS stub of CBP to length, clean and slip fit in Y-flange
    c. align and clamp EBP to pole in existing hole pattern; weld butt joint between CBP and EBP
    d. blank three flanges and leak test completed vacuum chamber assembly

Kinematics System: pinned, slotted, and floating wedges



The SNS Extraction Lambertson Septum (ELS) Magnet



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