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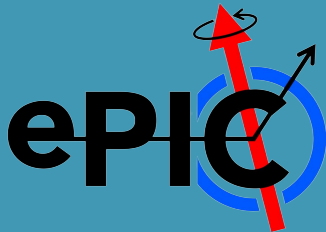
SVT integration updates

SVT Working Meeting at Berkeley

2026-10-08

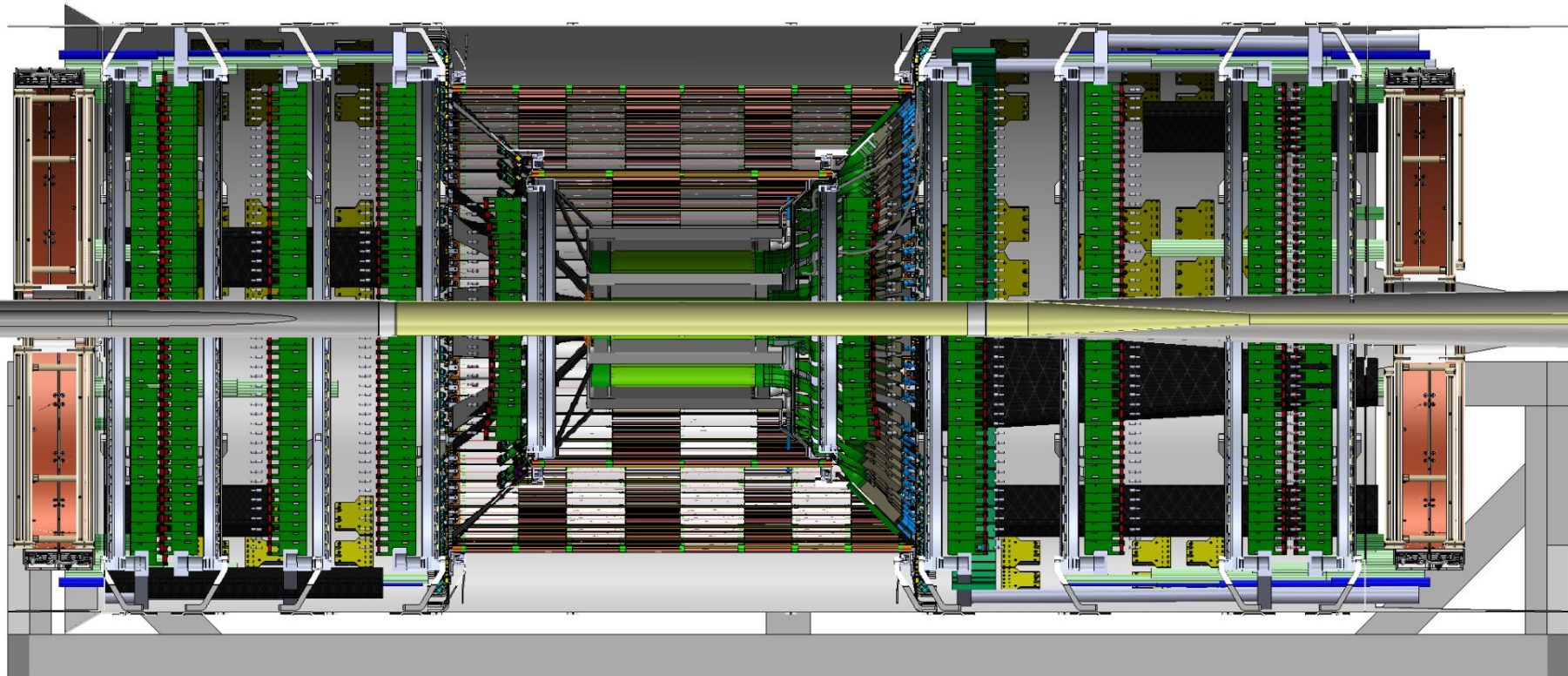
Joe Silber (LBNL) - mechanical engineer, presenting

Elaine Buron (LBNL) - CAD design



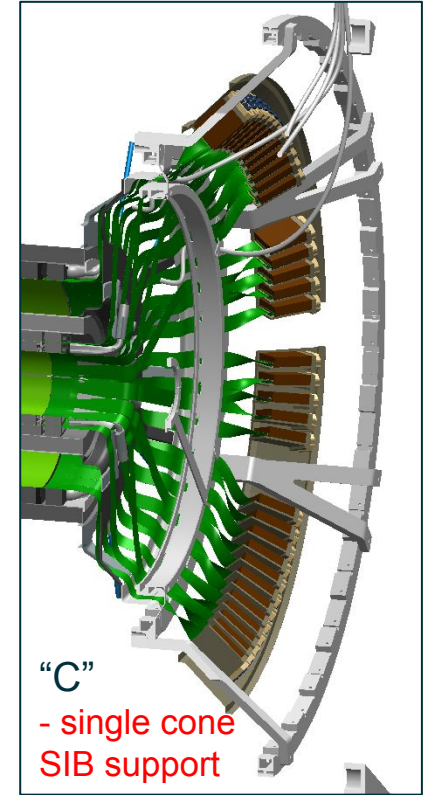
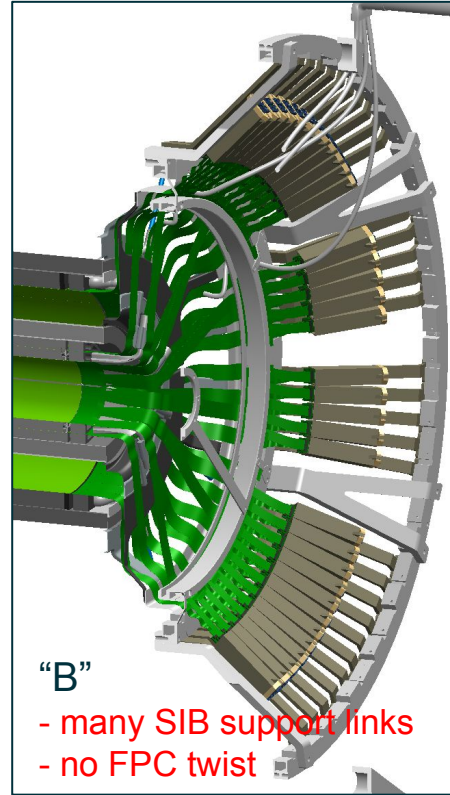
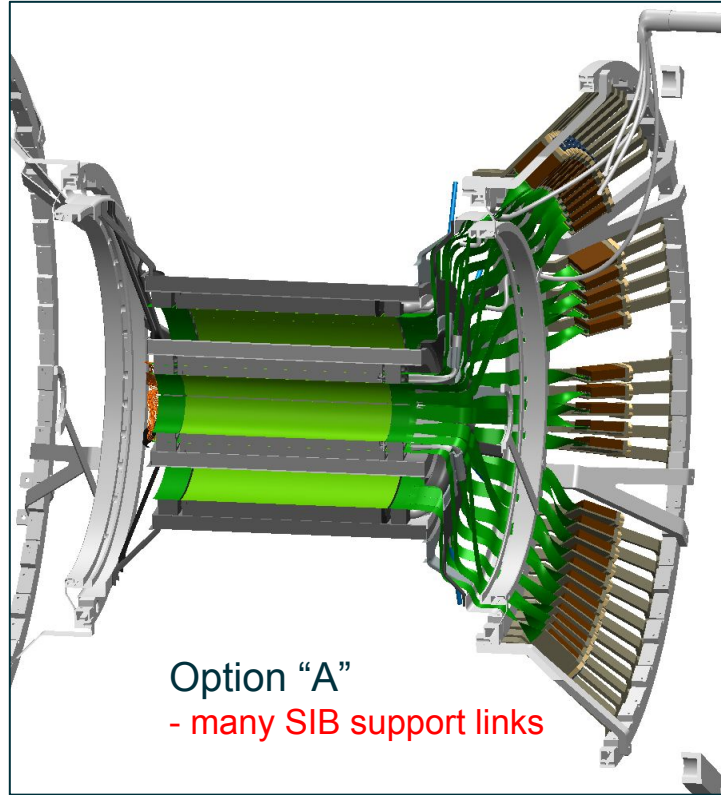
Current CAD model

(except IB, which is from March 2026 in this view)

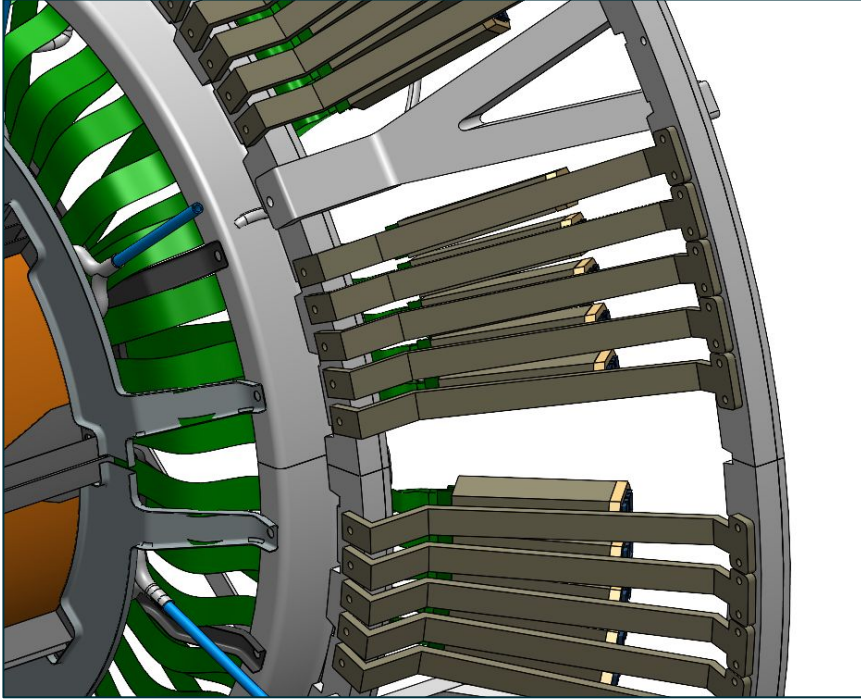


Inner Barrel

(three options from INFN-Padua, Sept 2026)

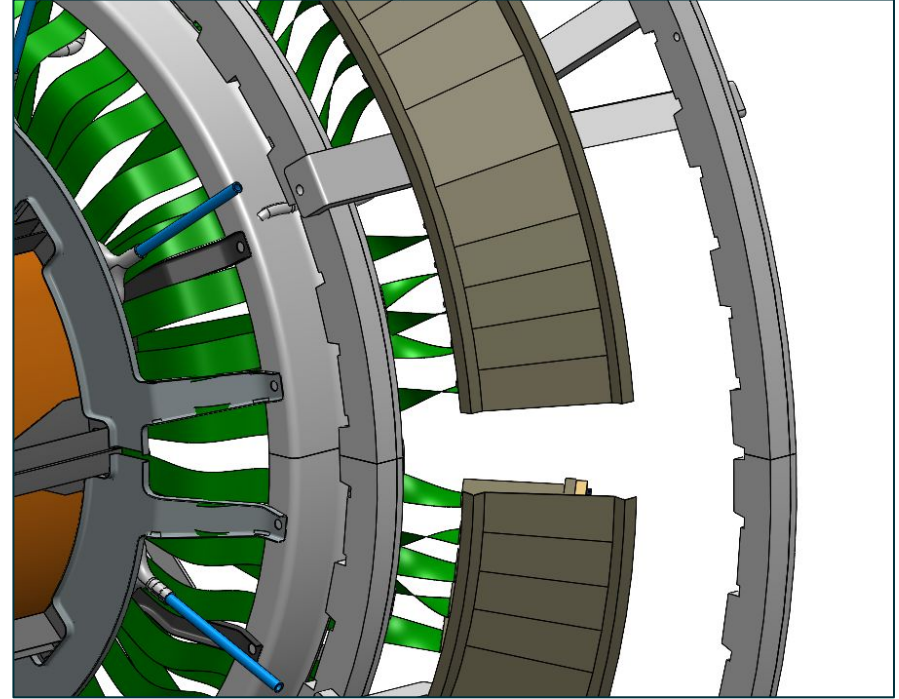


IB option B: many SIB support links



(note how the links couple structurally)

IB option C: unified cone SIB supports

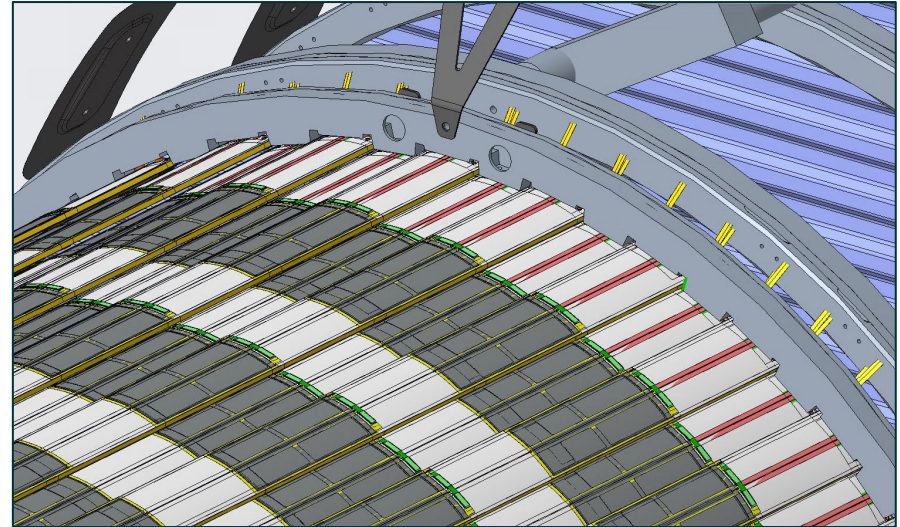
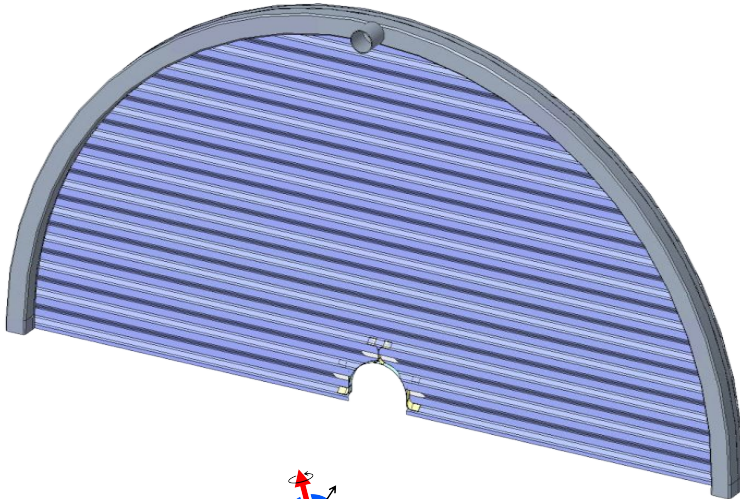


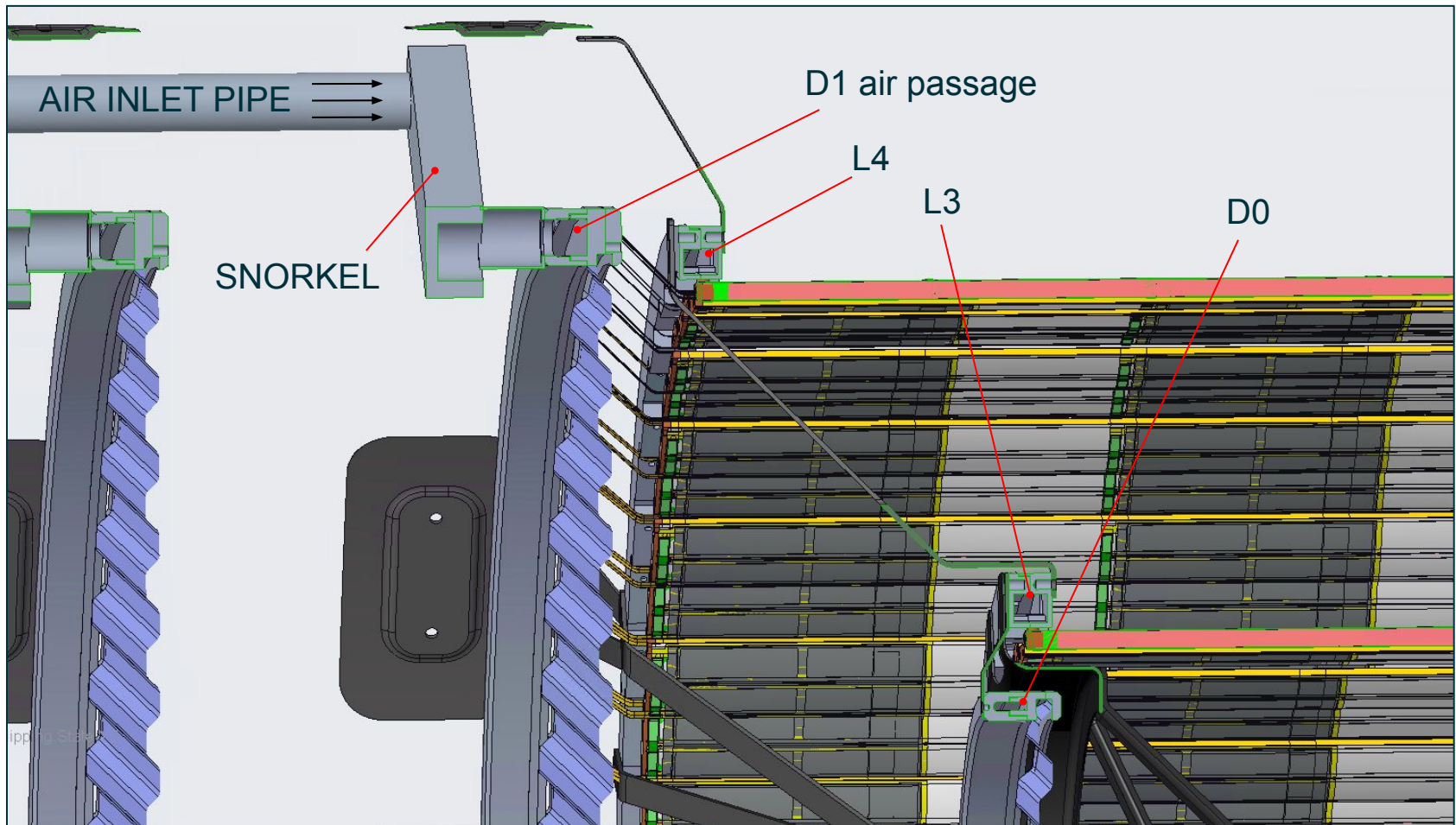
(note how the cones do not couple)

Rims support each disk or outer barrel layer

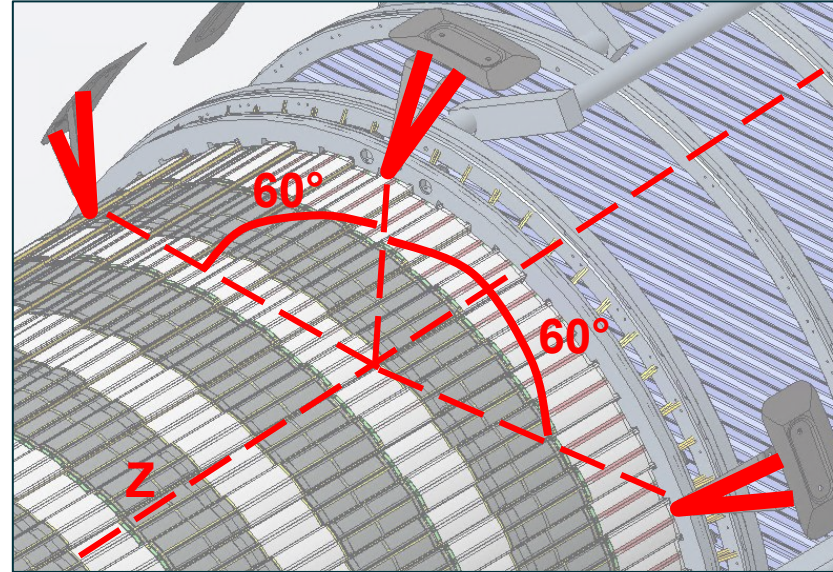
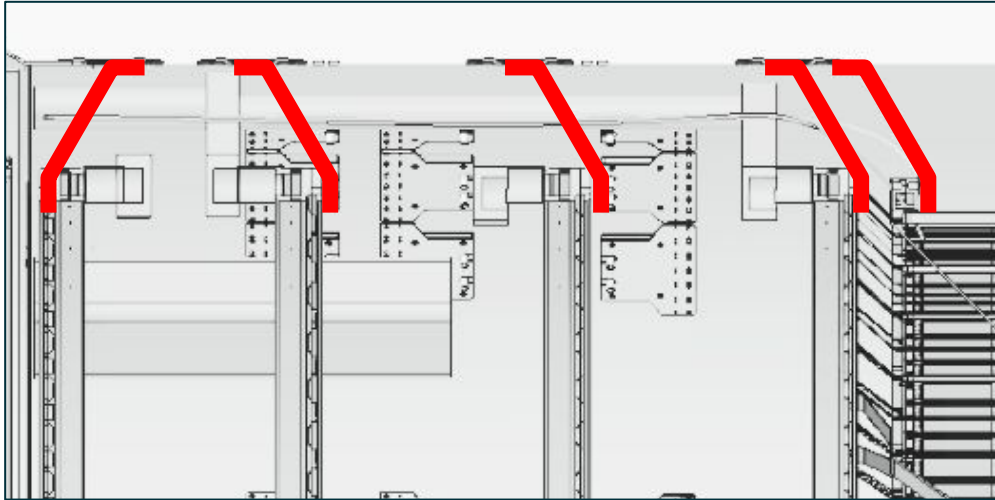
Rims are:

- Stiff
- Held at 3 points
- Air manifold for many corrugations or staves
- Always a half circle

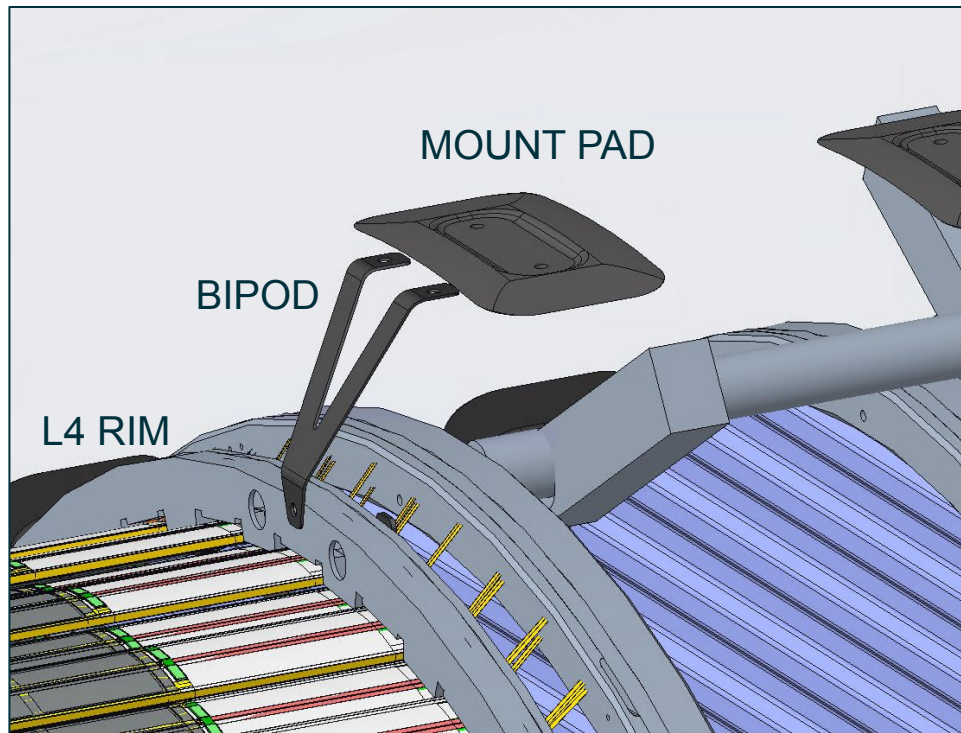




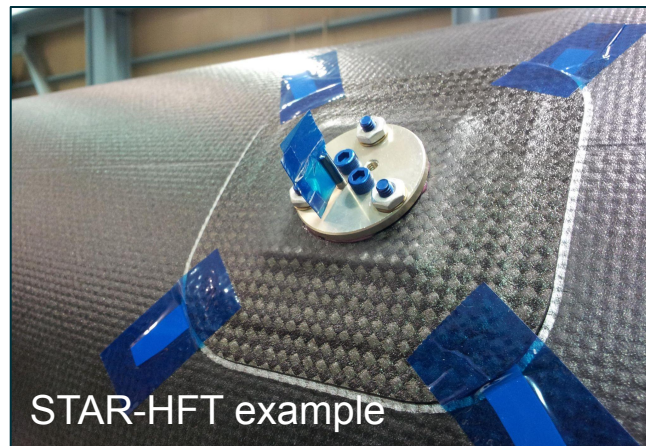
Bipods support large disks and L4



Mount pads are glued to outer surface of PST



- Mount pads based on heritage designs from STAR-HFT, ATLAS
- 3 bipods per half-rim approximates kinematic support, while allowing some Z flexure
- No structural analysis done yet, just laying out the concept in CAD



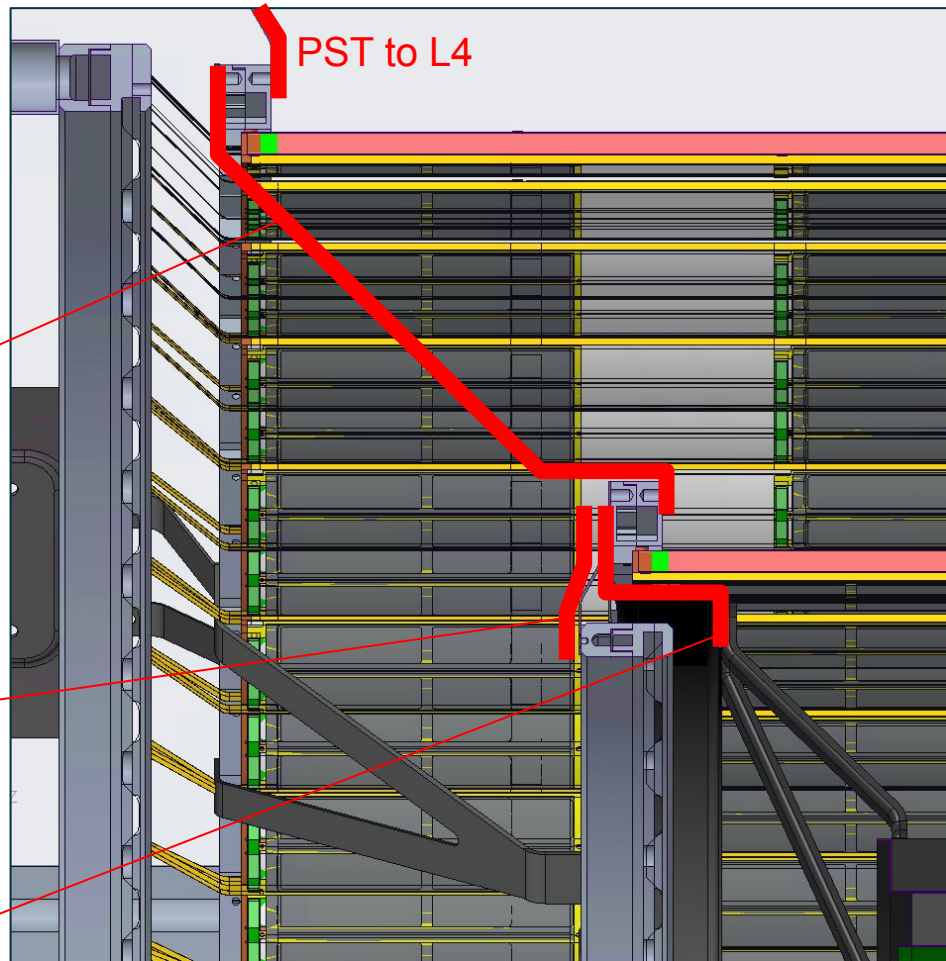
L0-L3 and D0 all supported via L4

This allows the baseline assembly sequence: L4, L3, IB, D0, D1, ...

L4 to L3

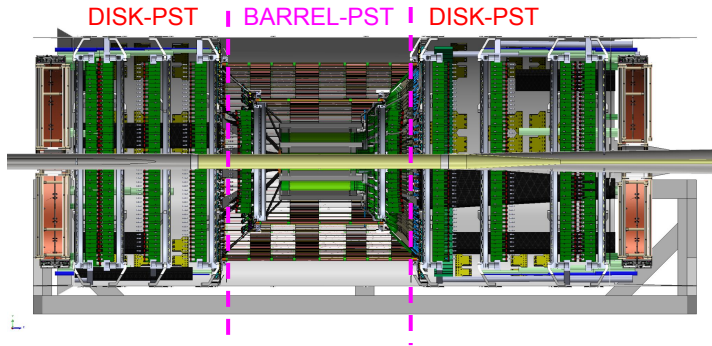
L3 to D0

L3 to IB

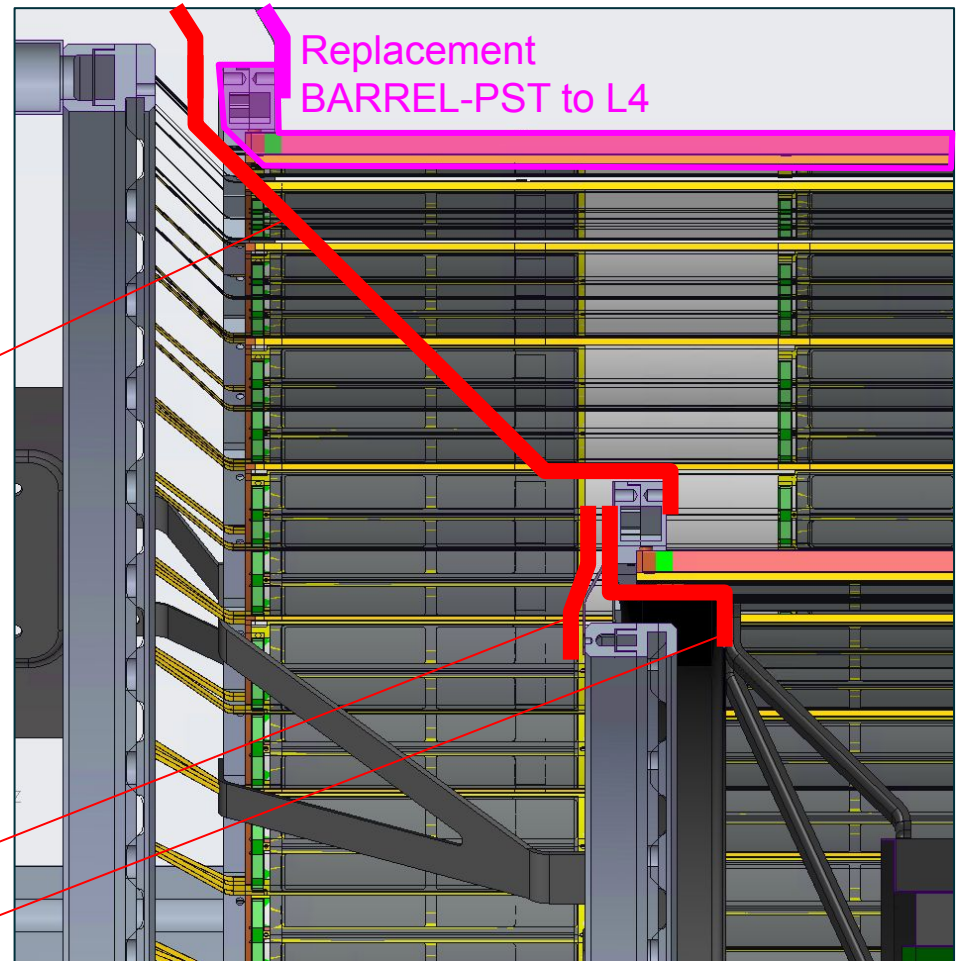


“L4 last” alternative concept

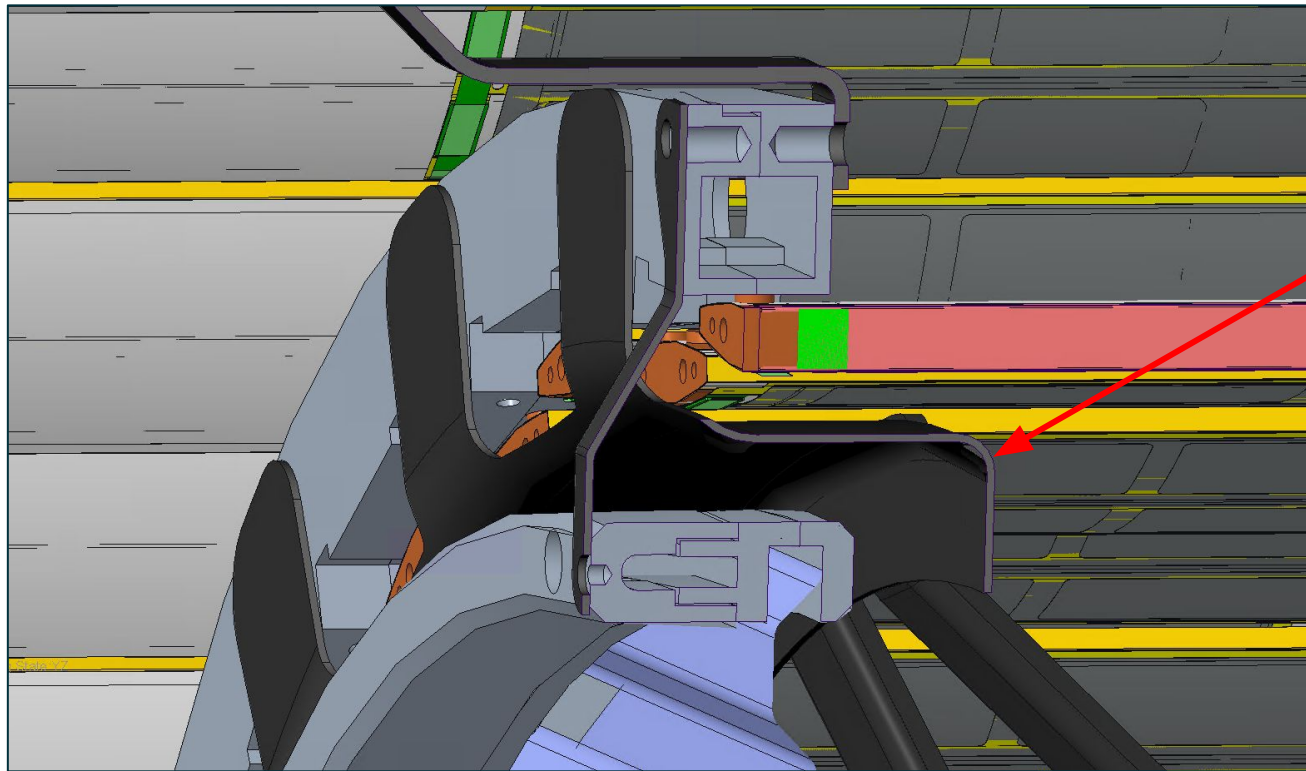
- Split the PST support shell into 3 pieces (2x disk regions + 1x barrel region)
- Assembly sequence: L3, IB, D0-D4, years go by..., L4



Original
DISK-PST to L3



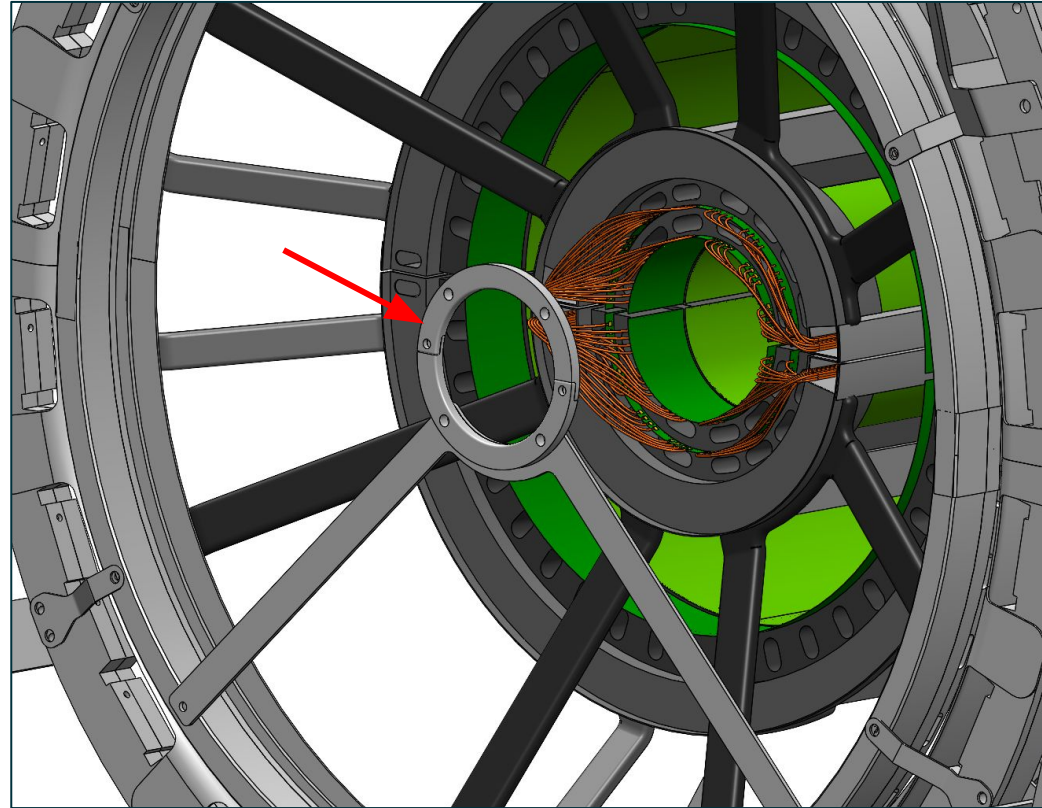
IB-L3 Support protects L3 staves when installing Inner Barrel services



IB-L3 Support

Interior beampipe support strategy

- Current design we have a fixed position (though not rotation) constraint ring on either side of the IB
- This is safest for assembly
- BNL expresses desire to be able to adjust BP position after installation without moving SVT
- This is an ongoing open discussion
- We will not solve it today just by talking
- Depends quantitatively on design details and req'ts at the ~ 0.5 mm scale, in particular details of the beampipe insulation, heat wrapping, deflection, clearance to IB sensors, PST halves alignment upon closure, flexibility of services at SVT exit, allowable flex of beampipe, beam dispersion, accuracy...



Design process from high level req'ts to detailed specs

High level requirements

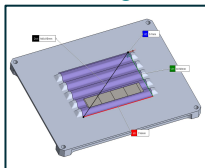
Table 9.2: SVT component temperature requirements (N/S is not specified).

Requirement	LEC	RSU	REC	AncASIC
Maximum T [°C]	65	40	N/S	80
Maximum T variation [°C]	10	1 over 3 mm 10 over full length	N/S	10

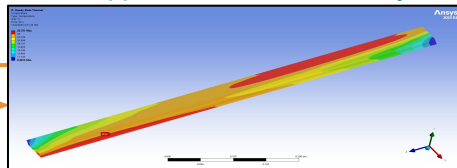
Req'ts on
silicon
 T_{max} , ∇T

Constraints on
 $\Delta T_{cooling} = T_{Si} - T_{air}$
 ΔP , air speed

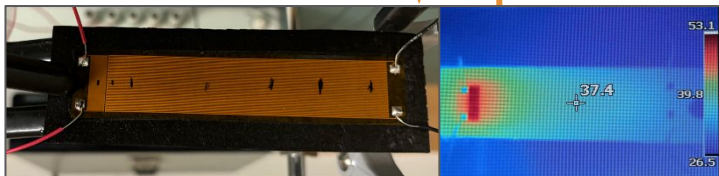
CAD design



Local supports heat transfer analysis



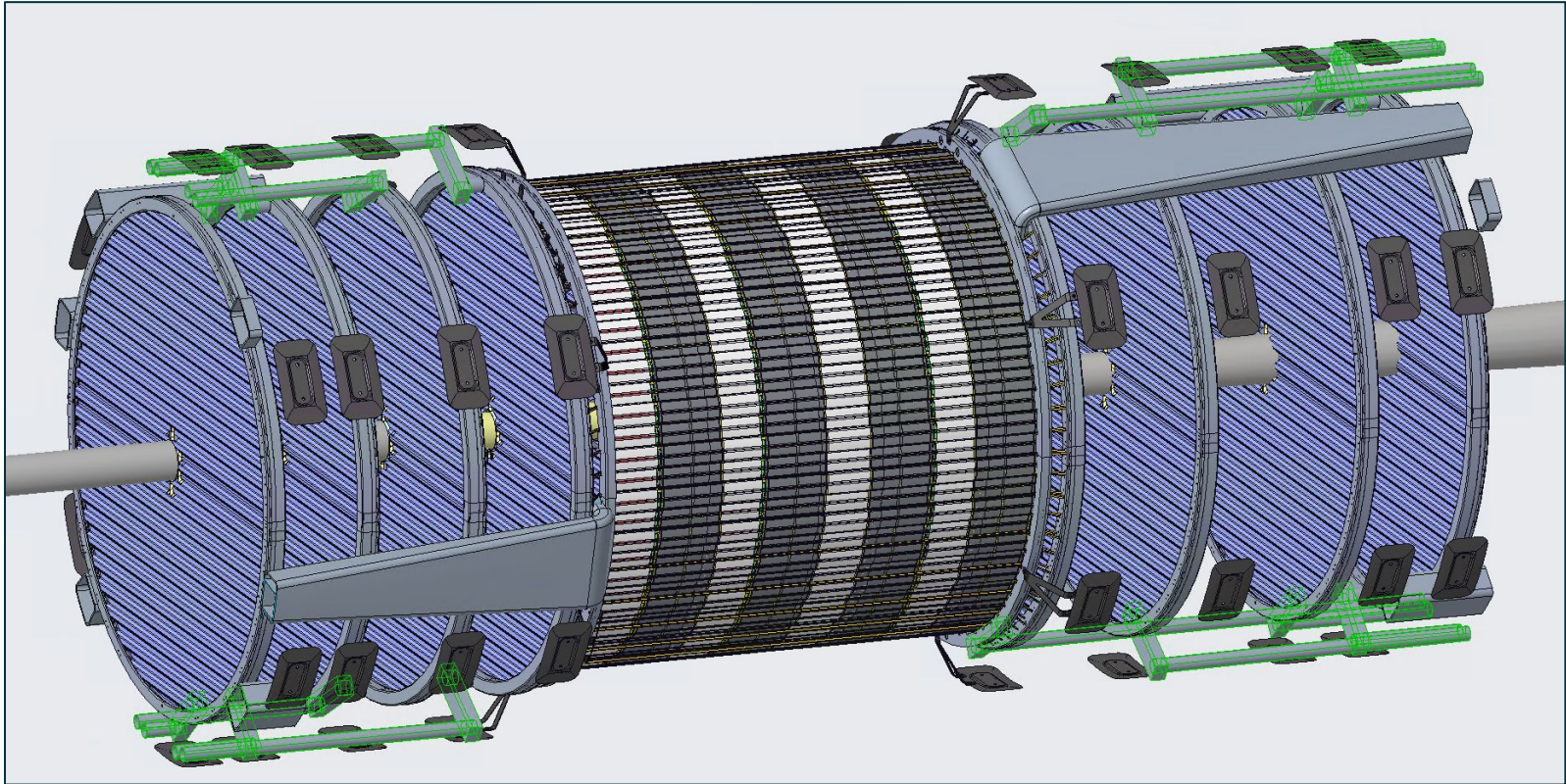
Local supports physical test



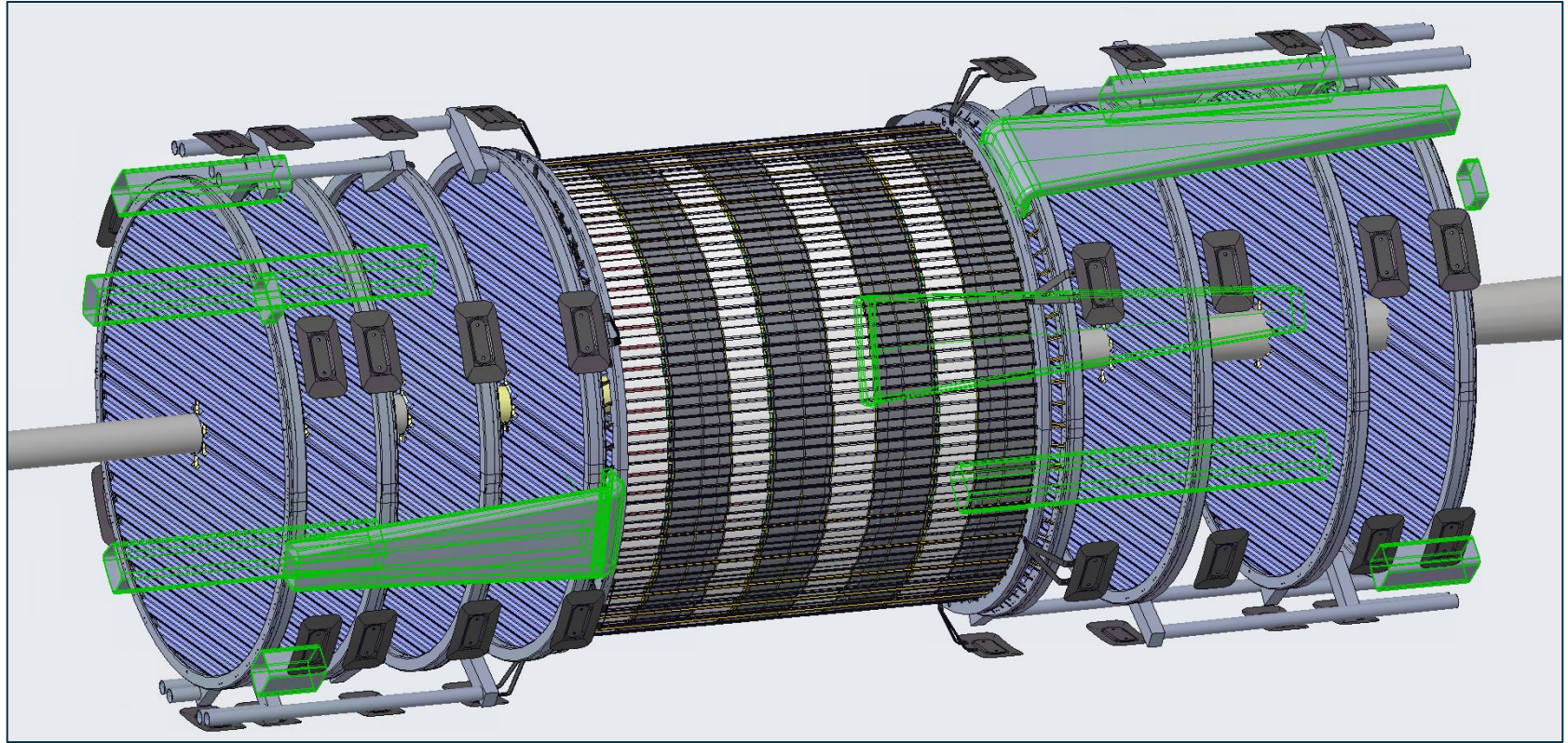
End-to-end system performance calculation

	source → ePIC	branches to hydron + electron sides	branches to top + bottom Barrels	pipes into ePIC to half drisks and half Barrels	pipes within SVT to half drisks and half Barrels	mainframe	disk channels	SVT internal volumes	exhaust ducts
	6	1	2	3	4	5	6	7	8
stage description	-	-	-	-	-	-	-	-	-
stage index	-	-	-	-	-	-	-	-	-
run channels (per parent channel)	n	n	n	n	n	n	n	n	n
total num channels in system	N = product(n)	m	1	2	3	4	5	6	7
mass flow per channel	M = (m ₀ or previous stage m) / n	kg/s	0.950	0.475	0.238	0.030	0.030	0.001	0.079
length	L	m	100	100	100	100	100	0.433	0.079
hydraulic diameter (mm)	D _h	mm	100	100	100	100	100	115	73.8
hydraulic diameter	D _h	mm	0.140	0.075	0.050	0.003	0.003	0.074	0.001
single channel cross-sectional area along length L	A _{ch} = π D _h ² / 4	m ²	7.856E-03	4.426E-03	1.96E-03	4.15E-04	4.15E-04	1.04E-04	2.96E-03
all channels total cross-sectional area	2A _{ch} = A _{tot} / N _s	m ²	7.856E-03	8.846E-03	7.856E-03	1.33E-02	1.33E-02	7.40E-02	3.58E-02
entrance temperature	T _i = T ₀ or previous stage T _i	°C	88	78	73	137.0	137.0	279.7	279.7
entrance pressure	P _i = P ₀ or previous stage P _i	bar	2.6	2.6	2.6	2.6	2.6	2.6	2.6
entrance density (ideal gas law)	ρ _i = P _i / (R · T _i)	kg/m ³	1.801	1.753	1.675	1.482	1.365	1.310	1.308
entrance dynamic viscosity	μ _i = μ _i (T _i) · 0.76	Pa·s	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05	1.73E-05
Reynold's number	Re = 4 · m / (π D _h μ _i)	-	6.99E+05	4.66E+05	3.50E+05	9.48E+04	9.48E+04	8.50E+03	7.91E+03
friction factor (Blasius)	f = 64/Re, Re < 2300 = 0.3164/Re ^{0.25} otherwise	-	0.011	0.012	0.013	0.018	0.018	0.033	0.034
friction pressure drop (Darcy-Weisbach)	ΔP _{fr} = f · (L/D _h) · (ρ _i / 2) · (A _{ch} / A _{tot})	Pa	4.438	5.317	10.025	9.440	4.394	153	0
downstream pressure	P ₀ = P _i - ΔP _{fr}	bar	1.382	1.332	1.154	1.084	1.040	1.039	1.043
ambient pressure in the downstream area of this stage	P ₀ _local_ambient	bar	1.013	1.013	1.013	1.043	1.043	1.043	1.013
downstream pressure relative to local ambient	description(P ₀ - P ₀ _local_ambient)	-	positive	positive	positive	positive	positive	positive	positive
module power input to stream	Q = Q _c · N _s if channel or stage else 0	W	0.6	0.6	0.6	0.6	0.6	8943.9	0.6

Air supply pipes



Air exhaust ducts



Air exhaust

- Exhaust via 12-14 ducts
- Duct hydraulic $\varnothing 52$ mm
 - I.e. much greater cross-section than input pipes (4 x $\varnothing 50$ mm)
- Ducts draw from interior volumes (see diagram)
- These volumes aren't "sealed" from each other, but significant impedance
- Suction could be done but probably not necessary
- Flapper valves at outlets to prevent ingress when flow off

ePIC SVT - interior air volumes diagram

Rev	Date	Author	Description
v1	2025-12-11	Joe Silber (LBNL)	initial release

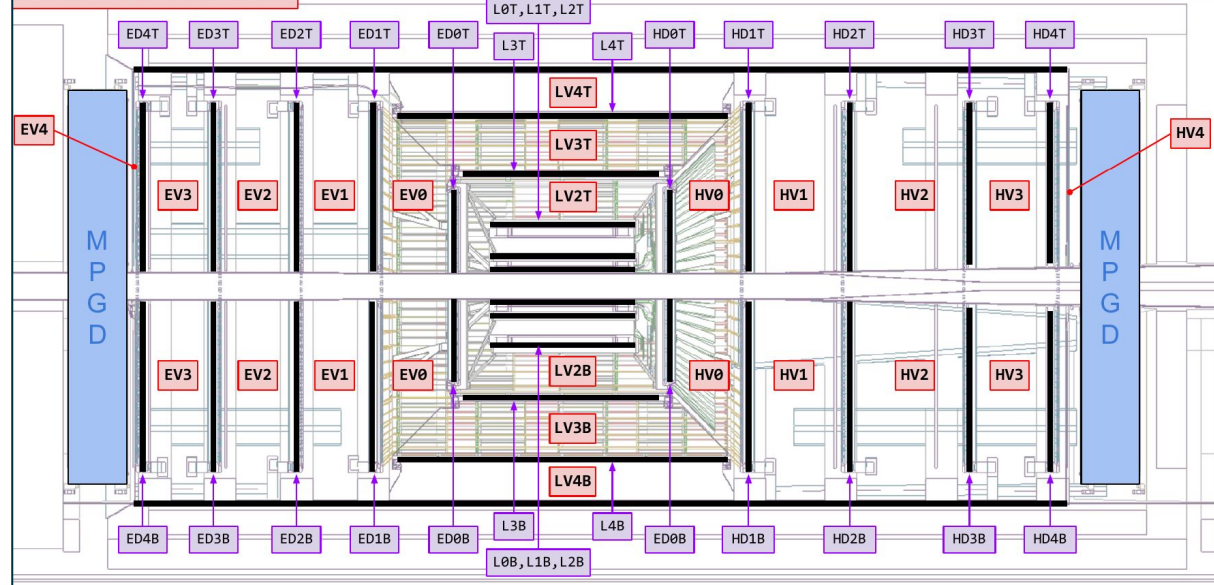
Notes

1.

References

1. [Live editable version of this document](#)
2. [ePIC SVT cooling system diagram](#)
3. [ePIC SVT cooling air flow stages](#)

EPIC SVT INTERIOR AIR VOLUMES



Link: [ePIC SVT interior air volumes diagram - v1.pdf](#)

ePIC SVT - cooling system diagram

Rev	Date	Author	Description
v1	2025-12-11	Joe Silber (LBNL)	initial release
v2	2025-12-12	Joe Silber (LBNL)	add liquid system
v3	2025-12-16	Joe Silber (LBNL)	space out e-/hadron & top/bottom

Nomenclature

SVT ... Silicon Vertex Tracker
TBD ... To Be Determined
L# ... Barrel layer IDs
D# ... Disk IDs
V# ... Disk interstitial volume IDs
LV# ... Barrel layer interstitial volume IDs
SCB ... Segment Control Board
CB ... Control Board

Notes

1. Graphical elements not intended to follow any standard.
2. Color-coding consistency not guaranteed.

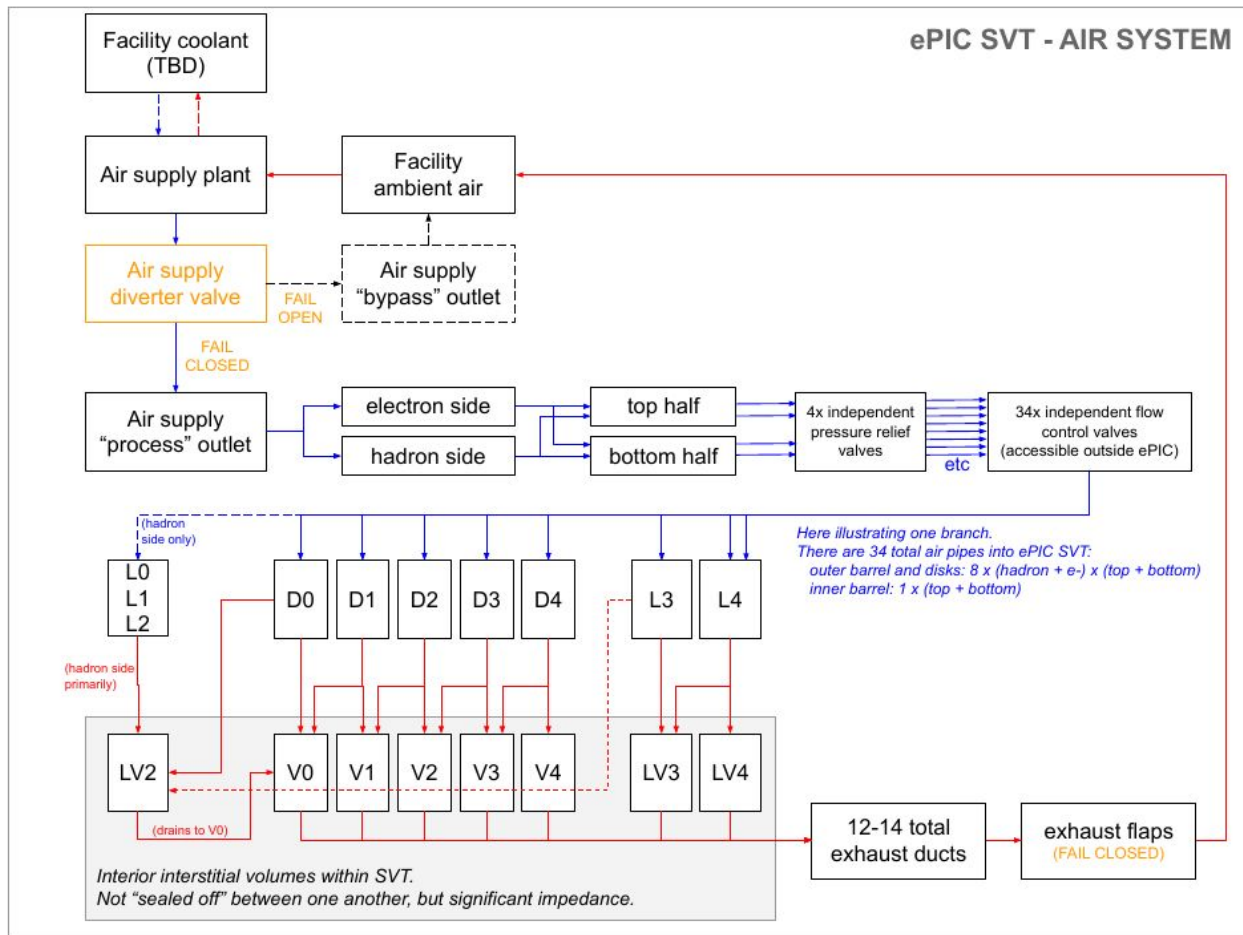
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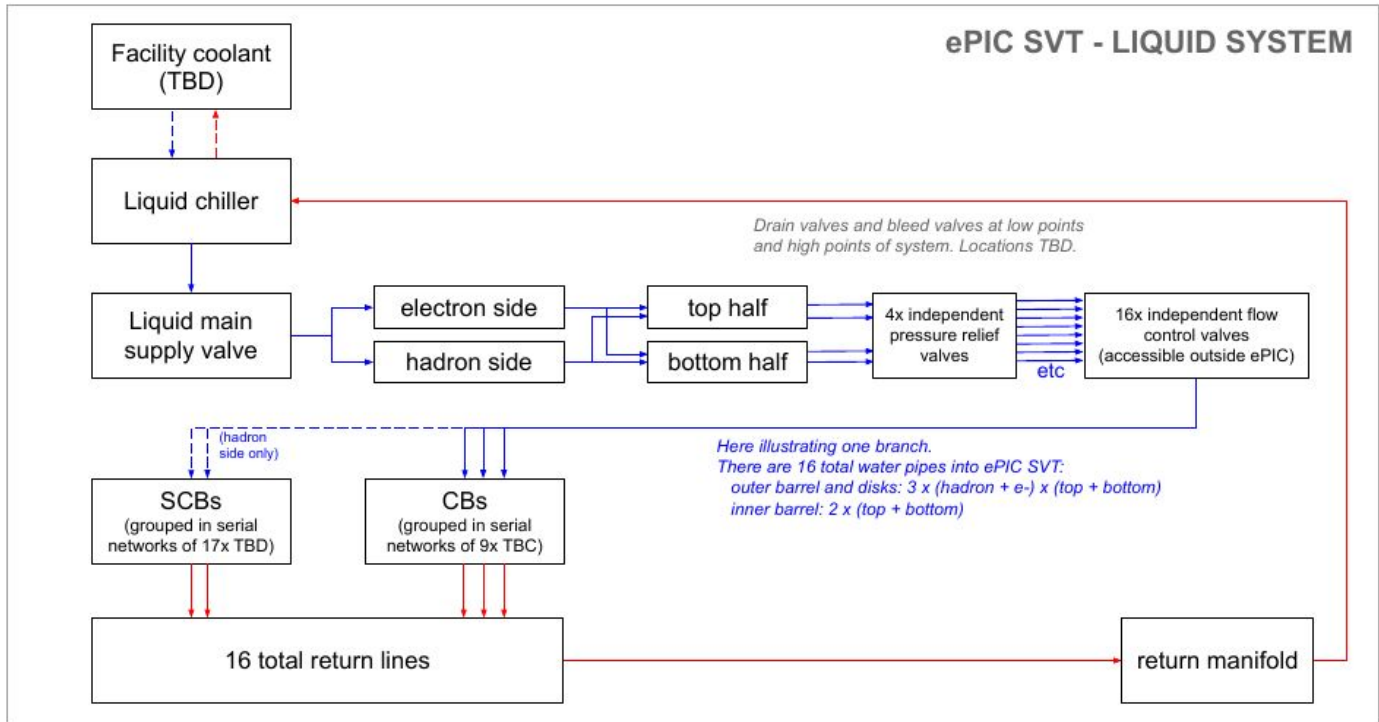
[ePIC SVT cooling system diagram - v3.pdf](#)

To-Do:

- decide with INFN whether L0/L1/L2 must be 2x input lines, one top and one bottom, for assembly logic

ePIC SVT - AIR SYSTEM





To-Do:

- add DPBs liquid cooling
- update liquid network sizes

System calcs + humidity management + air quality + control considerations → detailed specs on air supply plant

	A	B	C	D	E	F	G	H	I
1	ePIC SVT Air Supply Plant - Requirements								
2									
3	Contact				Color key:				
4	Joe Silber -jsilber@lbl.gov-				NEW				
5	Lawrence Berkeley National Laboratory				CALCULATED				
6					LINKED				
7	Version history								
8	v1 - 2025-11-11 - JHS - initial version								
9	v2 - 2025-11-19 - JHS - wider T_stability, diverter, moisture in terms of DPs, possible enclosure, add'l comments								
10	v3 - 2026-03-19 - JHS - state volumetric flow in SCFM								
11									
12	Abstract								
13	The Silicon Vertex Tracker (SVT) is a key subsystem of the Electron-Proton/Ion Collider (ePIC) detector. It will probe the smallest internal building blocks of visible matter – quarks and gluons – and help us understand the underlying laws that govern the strongest force in nature.								
14	The SVT is composed of thousands of custom silicon sensors. They will be cooled by a steady supply of cleaned, conditioned, cooled air. This specification is for the plant which will generate that cooling air. This specification does not include the transmission of that air to the SVT.								
15									
16	ID	Category	Description	Name	Value (SI)	Units (SI)	Value (US)	Units (US)	Comments
17	00	process air	temperature - nominal	T_nom	37	°C	97.4	°F	Possible future relaxation of T_nom to +12°C (TBD)
18	01	output air	temperature - adjustment range - min	T_min	-5	°C	23.0	°F	Possible future relaxation of T_min to +7°C (TBD)
19	02	output air	temperature - adjustment range - max	T_max	30	°C	86.0	°F	
20	03	output air	temperature - stability about setpoint	T_stability	±2	°C	±3.6	°F	
21	04	output air	pressure dew point - max allowable	PDP_max_allow	-10	°C	14.0	°F	Pressure dew point shall never exceed this value when output stream is flowing through the process outlet. Possible future relaxation of PDP_max_allow to +3°C (TBD).
22	05	output air	pressure dew point - stability	PDP_stability	±2	°C	±3.6	°F	
23	06	output air	pressure dew point - setpoint adjustment	PDP_setpoint	Pressure dew point shall be settable within a range defined by the AQ_water class (at low end) to PDP_max_allow (at high end).				
24	07	output air	pressure - nominal	P_nom	0.44	bar (gauge)	6.4	psi (gauge)	
25	08	output air	pressure - adjustment range - min	P_min	0.03	bar (gauge)	0.4	psi (gauge)	
26	09	output air	pressure - adjustment range - max	P_max	0.75	bar (gauge)	10.9	psi (gauge)	
27	10	output air	pressure - stability about setpoint	P_stability	±0.02	bar (gauge)	±0.29	psi (gauge)	
28	11	output air	mass flow rate - nominal	m_nom	1.0	kg/s	132	lbm/min	
29	12	output air	mass flow rate - adjustment range - min	m_min	0.1	kg/s	13	lbm/min	
30	13	output air	mass flow rate - adjustment range - max	m_max	1.3	kg/s	198	lbm/min	
31	14	output air	volumetric flow rate - nominal	V_nom	2941	Sm ³ /hr	1731	SCFM	stated at standard air conditions, not at true air density of plant output
32	15	output air	volumetric flow rate - min	V_min	294	Sm ³ /hr	173	SCFM	stated at standard air conditions, not at true air density of plant output
33	16	output air	volumetric flow rate - max	V_max	4412	Sm ³ /hr	2597	SCFM	stated at standard air conditions, not at true air density of plant output
34	17	output air	air quality - solid particulate	AQ_solidparticulate	Class 3	per ISO 8573-1:2010	-	-	Oil-free compression or high-end filtration is critical to prevent oil contamination Class 2 PDP = -40°C, Class 3 = -20°C, might consider Class 4 (PDP=+3°C) if significant cost savings and if T_min could be increased to -10°C (TBD)
35	18	output air	air quality - total oil	AQ_oil	Class 1	per ISO 8573-1:2010	-	-	
36	19	output air	air quality - humidity / water	AQ_water	Class 3	per ISO 8573-1:2010	-	-	

	A	B	C	D	E	F	G	H	I
37	20	output air	output diverter	diverter_valve	Plant shall have an integrated 5 way diverter valve on the output stream. Outlets are to "process" (goes to SVT instrument and bypass) (exhaust). Fail safe state is g. upon loss of power) shall be to the bypass outlet.				
38	21	facility	hose inner diameter - process air	Dh_process	100	mm	4	in	Connects to the SVT
39	22	facility	hose inner diameter - bypass air	Dh_bypass	TBD	mm	TBD	in	Connects to facility exhaust
40	23	facility	hose fitting type - process air	fitting_process	TBD	-	-	-	
41	24	facility	hose fitting type - bypass air	fitting_bypass	TBD	-	-	-	
42	25	facility	electrical - plug form	e_plug	TBD	-	-	-	
43	26	facility	supply voltage	V_supply	TBD	-	-	-	
44	27	facility	supply frequency	f_supply	60	Hz	-	-	
45	28	facility	heat rejection - coolant	coolant	99	-	-	-	
46	29	facility	heat rejection - coolant temperature	Tc	TBD	°C	-	K	
47	30	facility	heat rejection - coolant flow rate limit	Vc	TBD	L/min	-	-	
48	31	facility	heat rejection - coolant pressure	Pc	TBD	-	-	-	
49	32	environment	ambient temperature during operation - avg	T_amb_avg	21	°C	73.4	°F	Based on 15 year STAR WAH data 99.73% (3σ) envelope
50	33	environment	ambient temperature during operation - min	T_amb_min	19	°C	64.4	°F	Based on 15 year STAR WAH data 99.73% (3σ) envelope
51	34	environment	ambient temperature during operation - max	T_amb_max	32	°C	89.6	°F	Based on 15 year STAR WAH data 99.73% (3σ) envelope
52	35	environment	ambient dewpoint during operation - avg	DP_amb_avg	5.2	°C	41.4	°F	Based on 15 year STAR WAH data 99.994% (4σ) envelope
53	36	environment	ambient dewpoint during operation - max	DP_amb_max	22	°C	71.8	°F	Based on 15 year STAR WAH data 99.994% (4σ) envelope
54	37	control	fault condition on process air	process_fault	System shall have a process fault condition based on measured state of the output air. The state is logically TRUE when any of the key parameters (temperature, pressure, or pressure dew point) falls outside either its user configured allowable range or the limit values listed here (whichever is more restrictive).				
55	38	control	output diverter control	diverter_ctrl	System shall automatically direct output air to the bypass outlet during startup, shutdown, or process fault state.				
56	39	control	control interface - local	ctrl_local	Plant shall have a local user interface panel by which it can be operated.				
57	40	control	control interface - remote	ctrl_remote	Plant shall have an API allowing customer to integrate it into our facility's control system, for configuring, monitoring, and real time control.				
58	41	control	emergency shut-off - local	shutoff_local	Emergency shut-off shall be readily achievable by pressing an easily identifiable hardware button, by any person physically stationed near the plant.				
59	42	control	emergency shut-off - remote	shutoff_remote	Emergency shut-off shall be readily achievable by a simple electrical interlock signal.				
60	43	maintenance	uptime during normal operations	uptime	99.9	%	-	-	
61	44	package	max width	W_max	TBD	m	TBD	in	
62	45	package	max length	L_max	TBD	m	TBD	in	
63	46	package	max height	H_max	TBD	m	TBD	in	
64	47	package	max weight	M_max	TBD	kg	TBD	lbm	
65	48	package	enclosure	enclosure	TBD; possibly enclose loud components (e.g. compressor) for moderate sound dampening.				

Link: [ePIC SVT air supply plant reqts - v3.xlsx](#)

Compressors vs blowers

Key takeaways from numerous discussions with vendors during Dec 2025 - May 2026

Compressors

- Provide sufficient pressure to drive air through desiccant (adsorption) dryers that achieve -40°C dewpoint (Class 2)
- Require large storage tank (~ 1 gallon storage per SCFM of system flow)
- Large ones will provide ~ 1500 SCFM of flow, need more than one compressor in parallel to get more
- Power consumption ~ 20 kW / 100 SCFM
 - i.e. 320 kW @ SVT's nom 1600 SCFM
- ~ 100 psi gauge, which must be regulated down to SVT's nominal 6 psi

Blowers

- Refrigerated drying only, will achieve $+3^{\circ}\text{C}$ dewpoint (Class 4)
- More compact system
- Very high flow rates available
- Power consumption ~ 5 kW / 100 SCFM
 - i.e. 80 kW @ SVT's nom 1600 SCFM
- ~ 10 -20 psi gauge, depending on model

N.B. Either option requires an after cooler to bring the air to desired temperature.

The after cooler itself requires cooling, on the order of 30-40 kW, probably by facility water.

Four basic implementation options for air supply

<https://indico.bnl.gov/event/31239/>

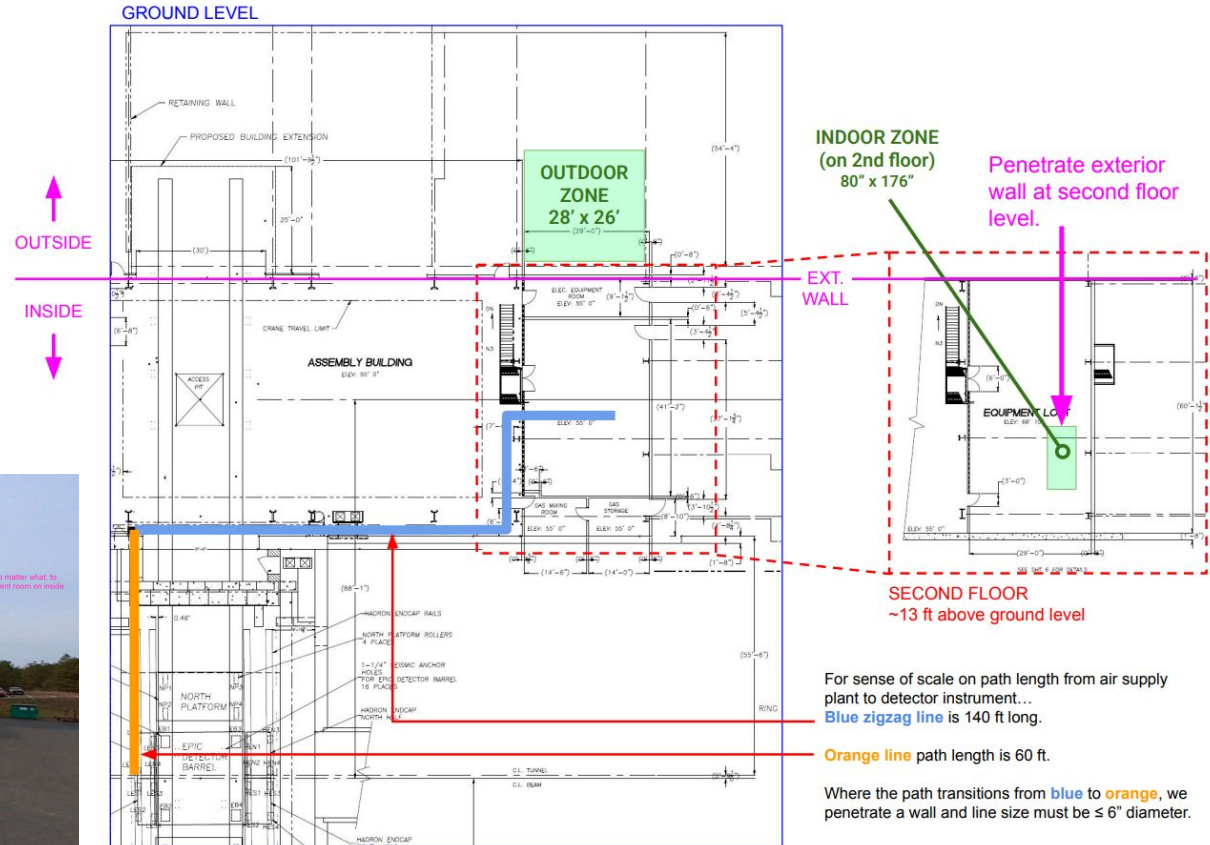
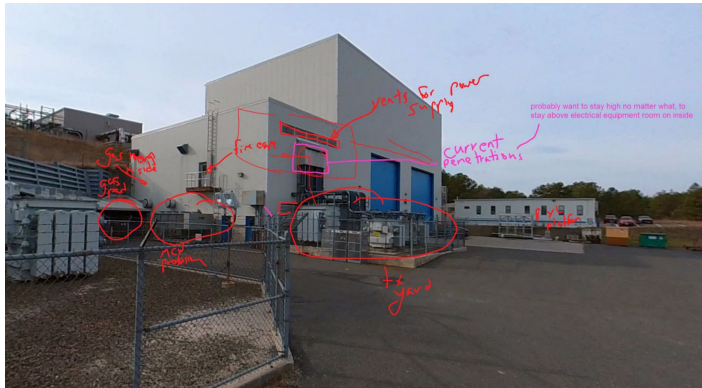
		Dec 2025 baseline	“80% of baseline”	“Slow & cold”	“Fast & warm”
Design targets	air speed thru detector channel	10 m/s	8 m/s	3 m/s	10 m/s
	air temp at channel inlet	+5°C	+5°C	-10°C	+9°C
Air supply nominals*	pressure	6 psig	4 psig	1 psig	6 psig
	flow rate	1600 SCFM	1300 SCFM	500 SCFM	1600 SCFM
	dewpoint	-40°C	-40°C	-40°C	+3°C
	air temp at supply	+3°C	+3°C	-12°C	+7°C
Source		double large compressor	single large compressor	single small compressor	blower
Approx system power draw		400 kW	300 kW	150 kW	150-200 kW
Rough size estimate	footprint	1056 ft ²	740 ft ²	420 ft ²	512 ft ²
	height	15 ft	14 ft	10 ft	7 ft
Comments		generous operating margins	tighter margins on ΔT & ∇T , low T available	higher ∇T , more insulation, less vibration	narrower T oper range (limited by dewpoint)

* Real air supply plant will require margin on these nominal values.

Modification option on any of these: water cool L3+L4 → reduces air needs by 37%.

Air supply plant location

- will not be small equipment
- have worked out feasible plan for where to locate it on site with BNL engineers



Liquid cooling of CBs and SCBs

- Will group CBs and SCBs into serial cooling networks
 - assemble and test a network outside detector, prior to assembly
- System thermodynamic and flow estimates completed
 - see [version 4 spreadsheet](#)
- Iterating parameters with BNL engineers now
 - reduce ΔT_{water} from 3° to $< 2^\circ$
 - increase flow rate

ePIC SVT liquid cooling - v4

Key assumptions:

1. 18C input water temperature
2. max available pressure loss 0.5 bar
3. power per CB or SCB = 7.1 W
4. thus total input power = 1250 W
5. water flow rate 0.1 kg/s = 6.0 L/min
6. on the SVT side we shall design a decent but not technically aggressive custom internal heat exchange geometry for the cold plates
7. quantities and INNER diameters of water supply lines...
 - 7a. from supply manifold to hadron + electron sides --> 2 lines total @ 19 mm ID each
 - 7b. exterior branches to top + bottom halves --> 4 lines total @ 19 mm ID each
 - 7c. interior branches to CB and SCB networks --> 16 lines total @ 5 mm ID each
8. identical quantities and sizes for return lines

Key outputs:

9. water temperature rises from 18C to 21C
10. pressure drop is 0.14 bar = 2.0 psi
11. max cold plate temperature = 21.1C

Some current open discussion points

- Inner barrel mechanical design options downselect, especially cone vs many-links?
- Split the PST half-shells into disk vs barrel regions, to enable later L4 install?
- Run air-cooled sensors “slow & cold”, i.e. 3 m/s @ -10C, to reduce air system size ~2-3x?
- %Xo and development costs if water cool L3 + L4, to reduce air system size ~0.4x?
- Supply top/bottom halves of IB with independent air lines, to simplify assembly logic?
- Minimizing insulation thickness at air routes into SVT
- Beam pipe support – post-assembly DOF of adjustability vs assembly interference derisk