Services

Ernst Sichtermann

SVT WP4 + WP6 WG meeting

June 20, 2025

- The EIC project has captured service inventories from the Detector Subsystem Collaborations via spreadsheets on BNL sharepoint,
  - Electrical services
  - Cooling

- These inventories then inform service envelopes and design decisions,
  - So far, mostly geometrical
  - The recent cooling inventory will probably lead to thermal envelopes,

- Ben, Nick, Roland, and I (ES) met on Wednesday in the regular WP4+WP6 WG meeting to make sure we have a common understanding of where to find the current versions of these spreadsheets, how they are used and updated, etc.

SVT has filled the project spreadsheets based on three (date-versioned) writeups:

Services for the EPIC MAPS-based tracking and vertexing subsystem

Nicole Apadula (LBNL), Laura Gonella (Birmingham), Ernst Sichtermann (LBNL)

November 16, 2022

Note added: Elke Aschenauer, Brian Eng, Rahul Sharma, Roland Wimmer, and the authors met on Thursday November 16, 2022 to discuss the assumptions and estimates in this note. The consensus was to insert the service estimates based on projected sensor layout in the services spreadsheet for all subsystems (that is, the lower estimates) and to link this note for future reference. We furthermore discussed that an additional ground line may be needed or desirable. This line is not currently reflected in the services spreadsheet. Likewise, lines for external temperature probes (and possible other environmental sensors) are not included in the services spreadsheet.

Introduction

The EPIC inner tracking and vertexing subsystem is currently considered to be based on 65nm ALICE-ITS3 sensors, suitably adapted for EIC purposes. The layout is thought to consist of barrel layers and disks with a maximum outer radius approximately 0.45 m within an envelope between -1.30 m in the electron going direction to 1.80 m in the hadron going direction. As of the writing of this document, five barrel layers are foreseen complemented with five disks in both the electron and hadron arms (ten disks total). The reticle size is thought to be 18.85 mm wide and 30.00 mm long. Multiple reticles will be stitched along the length axis and will be powered and read out by a single periphery. The maximum number of reticles that can be stitched this way to form a sensor is nine with these dimensions and current technology. Several sensor lengths will be required for the EIC; the number of variants and the number of sensors per variant remain to be optimized. The currently unknown stitching yield is an important consideration in this optimization. Power is thought to be dominated by the periphery and to be at the level of 1W for a sensor with an active area that is one reticle wide and nine (stitched) reticles long; the variation with sensor length remains to be quantified. The sensors will be connected to flexible printed circuits (FPCs) which, in turn, will be connected to cables (possibly via patch panels). The actual FPCs remain to be designed and are outside of the scope of this document. The purpose of this document is to estimate electrical services and cooling needs within the above parameters and assumptions. The goal is to arrive at reasonably conservative estimates at this time, since we understand them to primarily serve routing paths and estimates of required service gaps.

Electrical services

Barrel

The three innermost barrel layers are anticipated to be constructed from wafer-scale curved sensors with 3, 4, and 5 reticles in the azimuthal coordinate. A total of 4, 4, and 8 of such sensors will be required for these layers of 270 mm active length and radii of 36, 48, and 120 mm, respectively. The two outermost barrel layers have active lengths of 540 mm and 840 mm and are located at radii of 270 mm and 420 mm, respectively. Yield permitting, these layers will be constructed using stitched sensors of nine and seven reticles, respectively, using a more traditional stave design. Allowing for 10% overlap, 2 × 100 and 4 × 156 of such sensors will be required. In this notation, 2 and 4 sensors are needed to span the barrel lengths of 540 mm and 840 mm, respectively, while 100 and 156 sensors will cover the full azimuth at the target radii of 270 mm and 420 mm, respectively. Services are estimated under the

Services for the EPIC MAPS-based tracking and vertexing subsystem

Update - March 20, 2023

Nicole Apadula (LBNL), Laura Gonella (Birmingham), Ernst Sichtermann (LBNL)

Introduction

This document provides an update to the initial services estimate of the ePIC Silicon Vertex Tracker (SVT) detector. The initial estimate can be found at this link and should be read in conjunction with this document.

Sensor low voltage (LV) power

The sensor LV power is needed to power the integrated electronics. With respect to the initial estimate, this update assumes that the sagitta layers (L3, L4) and the disks (five disks, ED0-4, in the electron going direction; five disks, HD0-4, is the hadron going direction) will be powered in series by a constant current. The length of the serial powering chain, i.e. the number of sensors in the chain, is assumed to be, 2 for L3, 4 for L4, 3 for the disks. Each sensor is anticipated to operate at 1.2V with 0.85A current, giving a power consumption per sensor of 1W. We currently consider the current and total power figures independent of sensor size. To account for the uncertainty on sensor yield, for the sagitta layers and disks, a conservative sensor size of 1 x 4 reticles is assumed, with periphery on one side. This gives 450 sensors on L3, 1092 sensors in L4, 1100 sensors for the disks on each side.

The table 1 gives the number of serial powering chains, i.e. the number of cable pairs needed. Each cable should carry 0.85A. The split of analogue and digital current, and generation of analogue and digital voltages, is done by Shunt-LDO regulators placed close to or integrated in the sensor. Table 1 also shows the voltage across each SP chain is calculated as the product of the number of sensors in the chain and the voltage across one sensor. The cables for the sagitta layers split evenly between hadron and electron going direction.

Table 1

	Number of sensors	Length of SP chain, i.e. number of sensors in the chain	Number of SP chain, i.e. cable pairs (current + return)	Voltage across a SP chain
L3	450	2	225	2.4 V
L4	1092	4	273	4.8 V
ED0-4	1100	3	367	3.6 V
HD0-4	1100	3	367	3.6 V

In a serial powering scheme, the voltage drop on the cables is determined only by the allowed power density and the output voltage capability of the current source. The gauge should thus be chosen such that the heat load in the cables could be manageable. The current source will need to be chosen such that its output voltage capability can accommodate the voltage drop across the SP chain plus the voltage drop on the cables.

ePIC SVT
Notes in preparation of the
"Si Trackers/Gaseous Trackers/AG-LGAD TOF" meeting with the project
18 July 2023
N. Apadula, G. Deptuch, L. Gonella, Jo Schambach, E. Sichtermann, G. Viehhauser

Previous work on services estimates for the ePIC SVT is summarised in the documents at this link. These should be read in conjunction with this document.

The current ePIC SVT layout (i.e. October 2022 geometry, see figure 1) comprises:

- 3 Inner Barrel (IB) layers (curved silicon layers) – L0/L1/L2
- 2 Outer Barrel (OB) layers (stave-based layers) – L3/L4
- 5 Disks in the electron going direction – ED0/ED1/ED2/ED3/ED4
- 5 Disks in the hadron going direction – HD0/HD1/HD2/HD3/HD4

Total (active) area ~ 8.5 m^2.

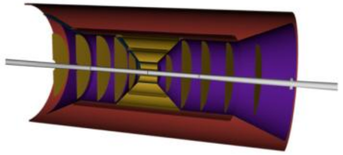


Figure 1: ePIC SVT geometry. The MPGD tracker is shown in red, and the support cone in purple.

The IB will consist of ITS3 wafer-scale sensors, thinned and bent around the beam pipe. The OB and ED0-4/HD0-4 will be made of carbon fibre support structures (staves and disks) tiled with the EIC Large Area Sensor (LAS). This will be a smaller size version of the ITS3 sensor, possibly with some modification in the endcaps to accommodate the ePIC readout needs (see section below on readout). The EIC LAS will come in 2-3 size variants to achieve the required coverage/acceptance and work within foundry manufacturing rules.

A description of the October 2022 configuration, sensor design, R&D progress and challenges can be found in the Technical overview of the ePIC SVT presented at the ePIC SVT kickoff meeting (9 June 2023).

It is worth noting that the design of the first ITS3 sensor prototype, i.e. the ER2 sensor, is advancing rapidly and thus even the recent information on the sensor design, presented at the ePIC SVT kickoff meeting, is in part outdated and more changes are expected over the next few months towards submission (planned for Q1-24). This has an impact on the overall ePIC SVT design (powering, readout, mechanics, cooling).

The most recent update was in July 2023 – we certainly know more today and it would not be too soon for an update (in an ideal world, updates would follow a schedule).

Derived space needs for SVT services (electron side):

Subsytem	Type	Item	Material	Quantity	Diameter (cm)	Cable Shape	Cross Area (cm^2)	+50% Packing for Bundles	+50% for MISC spacing needs
Red Path IP to pfRICH Inner face									
Vertex Silicon	Power	LV digital	Aluminium	12	0.8		6.03	9.05	13.57
	Signal	Sensor Bias	Aluminium	34	0.2		1.07	1.60	2.40
	Signal	Data *	Fibers?	204	0.6		57.68	86.52	129.78
	Cooling	Cooling		12	0.3		0.85	1.27	1.91
Sagita Silicon	Power	LV serial power	Aluminium	29	0.9		18.45	27.67	41.51
	Signal	Signal Bias	Aluminium	771	0.3		54.50	81.75	122.62
	Signal	Data *	Fibers?	771	0.2		24.22	36.33	54.50
	Cooling	Cooling *		356	0.3		25.16	37.75	56.62
Silicon Disks	Signal	Sensor Bias	Aluminium	1100	0.3		77.75	116.63	174.95
	Cooling	cooling	tygon	550	0.63		171.45	257.17	385.76
	Power	LV current	Aluminium	92	0.9		58.53	87.79	131.69
	Signal	Data	Fibers?	1100	0.3		77.75	116.63	174.95

Uhm, yeah – perhaps.

Note that the SVT service allocations are electron-hadron side symmetric; we'll see a few factors of two in what follows. Note also that the available space is more/most constrained on the electron side. And, last, note that the actuals for the IB will not be symmetric.

- SVT overall configuration has been stable; 3 inner barrel layers, 2 outer barrel layers, 5 disks on either side of the interaction point; overall dimensions,

- Sensor (number) estimates continue to hold,

- Sensor power dissipation estimates have changed (increased) from the previously assumed 1W per left endcap (for a total of a 4kW subsystem).

- Ancillary ASIC power dissipation is now known to be non-negligible,

- Better knowledge exists for the serial powering chain in L3; the estimate for the disks on this point can also be refined,

- The ancillary ASIC will supply the bias voltages,

- Much more is known about the read-out chain,

- More recently, a somewhat separate inventory came about on power dissipation – let’s aim for a pass towards consistency (and further joint refinement),

Power and readout "chain" for Outer Barrel and Disks,

Three boards:

FPC Interface Board -- FIB

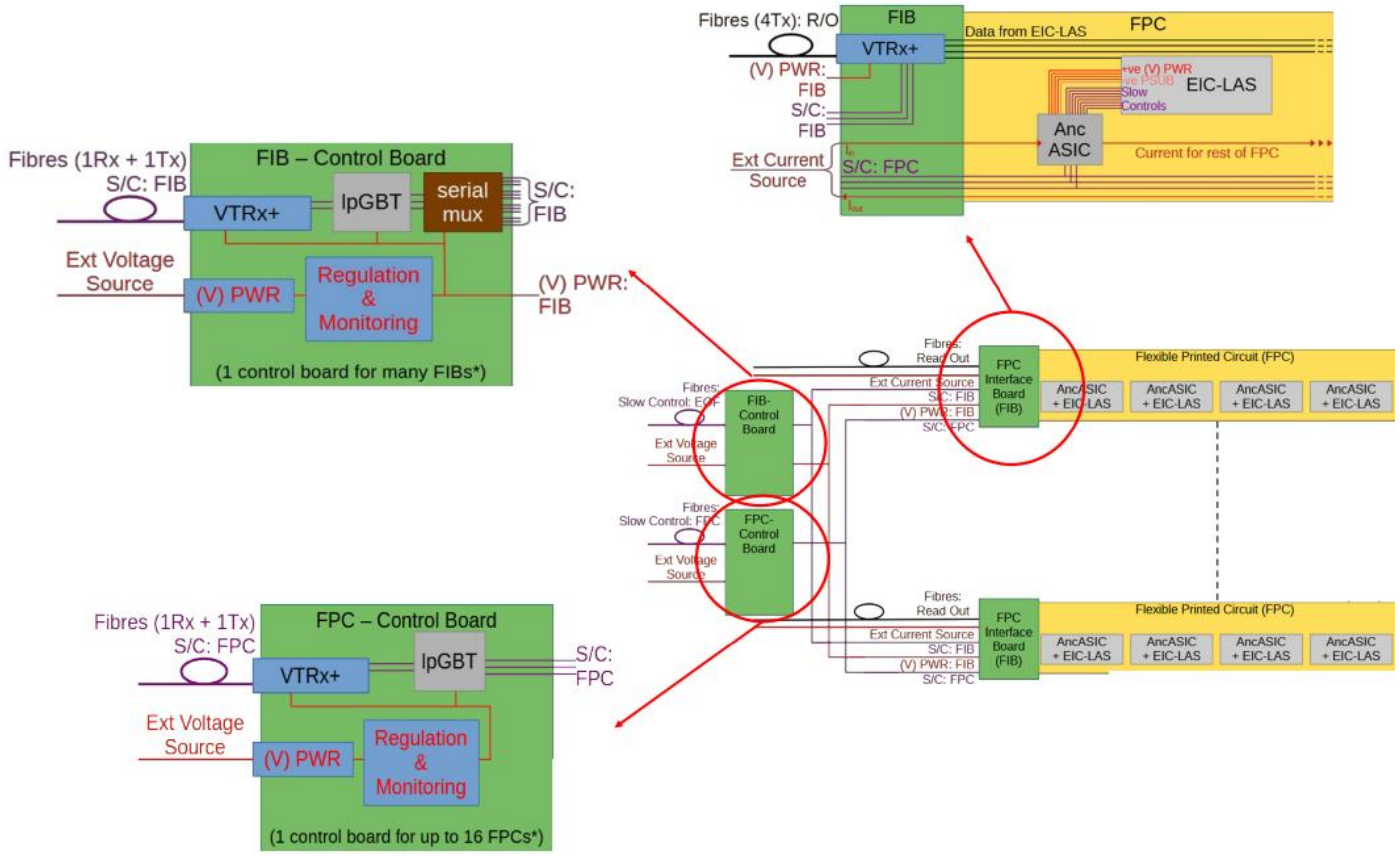
- AC-coupled data links to VTRx+ for up to four EIC-LAS, electro-optical conversion, connection to fibers,
- Routing of serial-powering current and slow control signals to FPC,

FIB Control Board – FIB CB

- Provides control signals and power for the VTRx+ on the FIB for up to 64 FIBs

FPC Control Board – FPC CB,

- Provides slow control signals for the ancillary ASIC/EIC-LAS modules on the FPC via the FIB for up to 16 FIBs / FPCs,



Power and readout "chain" for Outer Barrel and Disks,

Three boards:

FPC Interface Board -- FIB

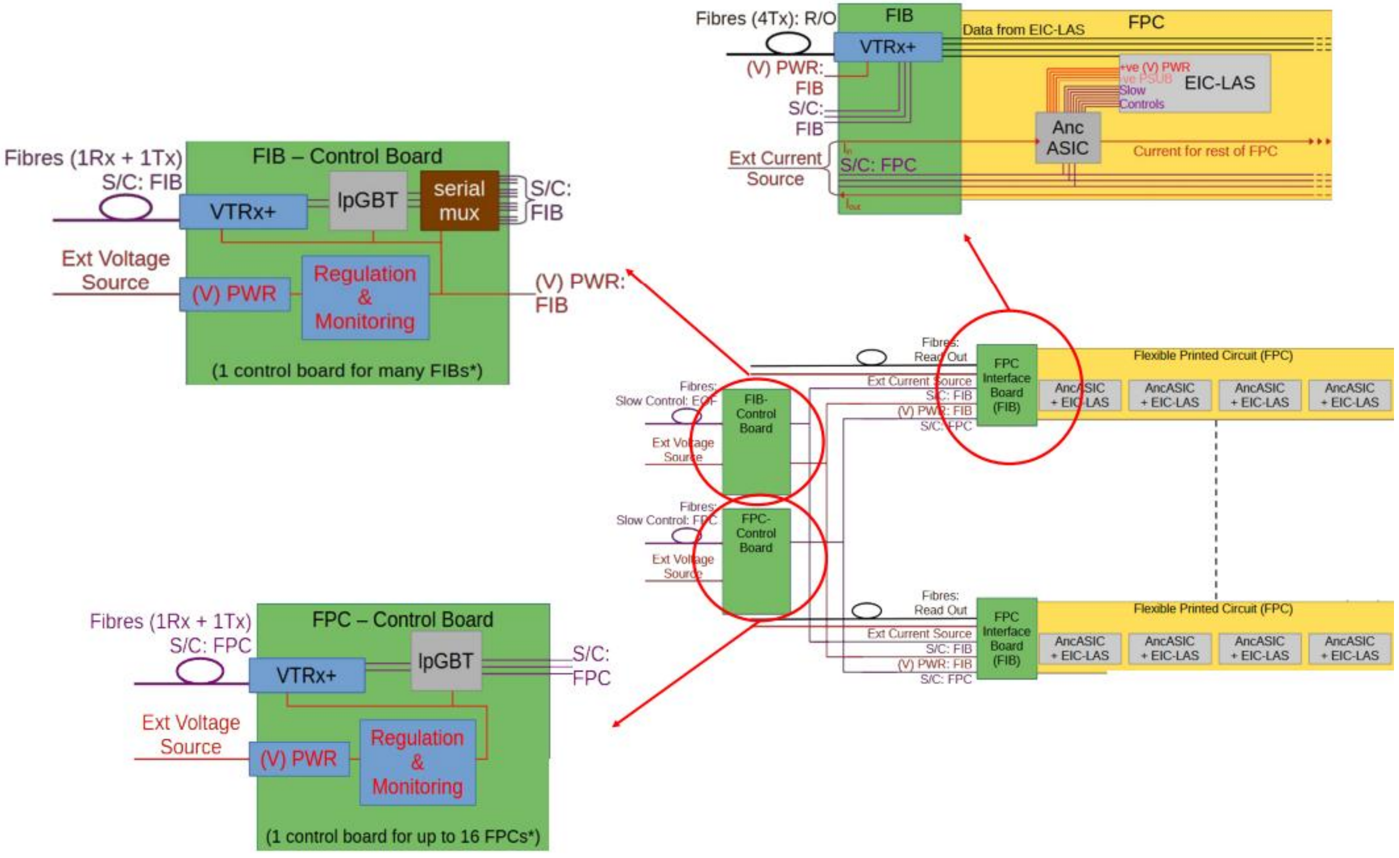
- Two conductors to/from outside the detector,
- Four fibers to be routed out the detector,
- VTRx+ power (1.2V, 2.5V, gnd) and control (three lines) to/from FIB CB i.e. internal to SVT envelope,
- Approx. 0.25 W dissipation,

FIB Control Board – FIB CB

- Two conductors to/from outside the detector,
- Two fibers to/from outside the detector,
- FIB voltages and slow control internal,
- Approx. 25 W dissipation; liquid cooled (TBD)

FPC Control Board – FPC CB,

- Two conductors to/from outside the detector,
- Two fibers to/from outside the detector,
- ASIC/EIC-LAS slow control internal,
- Approx. 2 W dissipation; liquid cooled (TBD)



Note:

All fibers originate/end at VTRx+,

SVT VTRx+ has been specified with short (5.5 cm) pig-tails,

The fiber counts here assume that harnesses route only fibers that are used

Counts, following the recent power dissipation inventory,

Outer Barrel:

- L3 will consist of 46 staves, each with 4 pairs of 6-RSU EIC-LAS
- L3 power dissipation approx. 22.5 W (max) per stave; 1.0 kW (max) total (not including FIBs, FIB-CBs, FPC-CBs)
- L3 will have 2 x 46 FIBs, 2 x 1 FIB-CBs, 2 x 4 FPC-CBs – half to be serviced from the electron and half from the hadron side,
  - L3 FIBs: 2 x 46 x 2 conductors to/from EIC-LAS, 2 x 46 x 4 TX fibers,
  - FIB-CBs: 2 x 1 x 2 conductors, 2 x 1 x 1 RX and 2 x 1 x 1 TX fibers, and liquid cooling (TBD)
  - FPC-CBs: 2 x 4 x 2 conductors, 2 x 4 x 1 RX and 2 x 4 x 1 TX fibers, and liquid cooling (TBD)

- L4 will consist of 70 staves, each with 8 pairs of 5-RSU EIC-LAS
- L4 power dissipation approx. 48.2 W (max) per stave; 3.4 kW (max) total (same)
- L4 will have 2 x 140 FIBs, 2 x 3 FIB-CBs, 2 x 12 FPC-CBs – half to be serviced from the electron and half from the hadron side
  - L4 FIBs: 2 x 140 x 2 conductors to/from EIC-LAS, 4 x 70 x 4 TX fibers,
  - FIB-CBs: 2 x 3 x 2 conductors, 2 x 3 x 1 RX and 2 x 3 x 1 TX fibers, and liquid cooling (TBD)
  - FPC-CBs: 2 x 12 x 2 conductors, 2 x 12 x 1 RX and 2 x 12 x 1 TX fibers, and liquid cooling (TBD)

It is to be checked (by routing) if the odd number of FIB-CBs per side is compatible with the SVT clamshell of top and bottom halves.

Counts, following the recent power dissipation inventory,

Similar counting for the disks results in:

- 740 FIBs: 2 x 370 x 2 conductors to/from EIC-LAS, 2 x 370 x 4 TX fibers,
- 18 FIB-CBs: 2 x 9 x 2 conductors, 2 x 9 x 1 RX and 2 x 9 x 1 TX fibers, and liquid cooling (TBD)
- 70 FPC-CBs: 2 x 35 x 2 conductors, 2 x 35 x 1 RX and 2 x 35 x 1 TX fibers, and liquid cooling (TBD)

Same to be checked for the odd FIB-CBs and FPC-CBs per side as for the outer barrel,
Finalized sensor layout and grouping will reduce the disk electrical service load.

Comparing the counts

Outer barrel:

existing estimate: 2 x 29 cables for LV power – current estimate: 2 x 186 x 2 conductors*

existing estimate: 2 x 771 bias cables – current estimate: none; handled by ancillary ASIC

existing estimate: 2 x 771 signal cables – current estimate: 1488 (= 368 + 1120) fibers

current estimate adds a modest external load related to slow control (FIB-CB and FPC-CB)

Disks:

existing estimate: 2 x 92 cables for LV power – current estimate: 2 x 370 x 2 conductors*

existing estimate: 2 x 1100 bias cables – current estimate: none; handled by ancillary ASIC

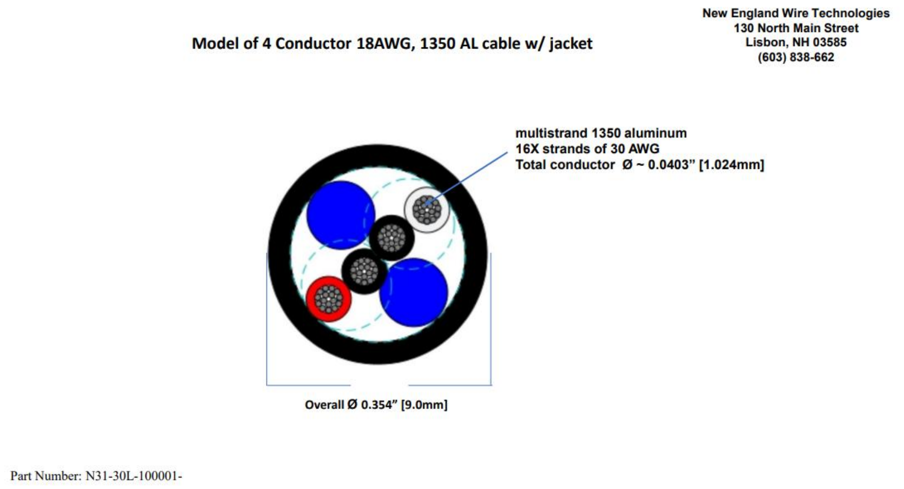
existing estimate: 2 x 1100 signal cables – current estimate: 2960 fibers

current estimate adds a modest external load related to slow control (FIB-CB and FPC-CB)

* Note that conductors and cables are different objects; the apparent “order of magnitude” difference is instead a factor.

Comparing the counts

I (ES) found* the following drawing that “specifies” a 9mm diameter aluminium cable with four 18 AWG conductors,



The “blue blobs” could be one form or another of mechanical strengtheners; the dotted blue lines could have multiple meanings as well

The double insulation may or may not be part of – say – safety requirements;

The packing factor of the actual conductors is not optimal;

Whichever way, 1) we almost certainly do not want all this extraneous material in the SVT envelope and 2) let’s nevertheless take the four conductor 9mm diameter cable as the assumption to re-evaluate the cross-sectional areas. In practice, I suspect that we will end up specifying a somewhat lower AWG (thicker) aluminium conductor cable with a better packing factor.

* BNL sharepoint – Experimental Program – ePIC – Engineering – STP-files – 18_AWG_Al_cable_model.pdf

Comparing the areas for electrical services

Outer barrel:

Existing estimate: 2 x 29 cables for LV power or 2 x 18.45 cm^2

Current estimate: 2 x 186 x 2 conductors with 4 conductors per cable implies 186 cables or 118.33 cm^2 (at equal AWG)

Existing estimate: 2 x 771 cables for bias or 2 x 54.40 cm^2

Current estimate: no separate bias cables

Existing estimate: 2 x 771 signal cables or 2 x 24.22 cm^2

Current estimate: 1,488 fibers or 124 12-fiber ribbons or 15.50 cm^2 if these ribbons have 2.5 by 5.0 mm dimensions

Disks:

Existing estimate: 2 x 92 cables for LV power or 2 x 58.53 cm^2

Current estimate: 2 x 370 x 2 conductors with 4 conductors per cable implies 370 cables or 235.39 cm^2 (at equal AWG)

Existing estimate: 2 x 1,100 bias cables or 2 x 77.75 cm^2

Current estimate: no separate bias cables

Existing estimate: 2 x 1,100 signal cables or 2 x 75.75 cm^2 – aside, I (ES) do not know the origin of the different diameter w.r.t. OB

Current estimate: 2,960 fibers or 247 12-fiber ribbons or 30.88 cm^2 if these ribbons have 2.5 by 5.0 mm dimensions

Realistically, I (ES) tend to think that AWG will need to go down (i.e. we will need thicker conductors since the currents are larger than originally estimated) for LV and that modest differences can be compensated with a more space-economical choice of the LV power cables (with possibly some help from more compact fiber ribbons if or as needed).

Note that neither estimate includes services associated with the FIB-CBs and FCP-CBs. They will be subdominant, but do need to be accounted for.

Overall, the existing space allocations for SVT electrical and optical services appear to cover the currently estimated needs with a little to spare.

Cooling

Cooling:

project inventory underlines that air-cooling is ours to demonstrate – default is liquid, despite even the first SVT input,
10 m/s air flow through each disk corrugation channel would imply approx. 0.23 m^3/s or 450 cfm air flow per endcap (5 disks),
450 cfm requires a 40-50 mm diameter "shop-air" supply for reasonable network designs and lengths (e.g. CAGI handbook),
in practice, this will probably mean 6 — 8 of somewhat smaller-diameter tubes (two endcaps, IB, OB; top and bottom halves),
1,000 cfm in total for SVT is probably at the upper end of what will practically be achievable,
1,000 cfm or 0.47 m^3/s of air could cool 6 kW with a 10^{o}C temperature increase (if fully efficient),
Total power to cool is 8 to 12 kW,
internal distribution and regulation, as well as return path design is important and urgent.

Existing service estimates have 2 x 25.16 and 2 x 171.45 cm^2 for the OB and disks for cooling,
The cross section of a 40 (50) mm diameter pipe is 12.57 (19.63) cm^2
2 x 8 to 15 of such pipes, or their equivalent, should thus fit within the existing estimate for cooling,
Interestingly, if "shop-air" expands by a factor 7 (i.e. P.V = constant) even the return-path for 2 supplies might just fit,

In my (ES) opinion, air-cooling is an edge-case. The design-implications of a pivot to liquid cooling would be considerable. Distribution and regulation must have high priority.