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ePIC SVT Outer Barrel

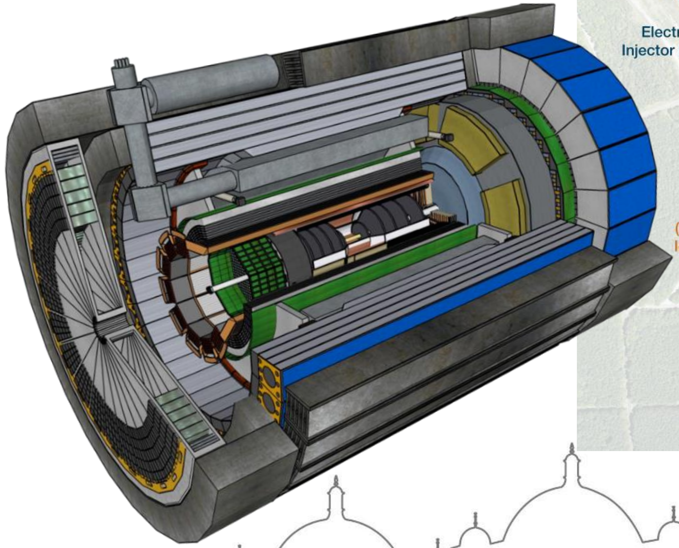
James Glover
on behalf of EIC-UK WP1 (MAPS)

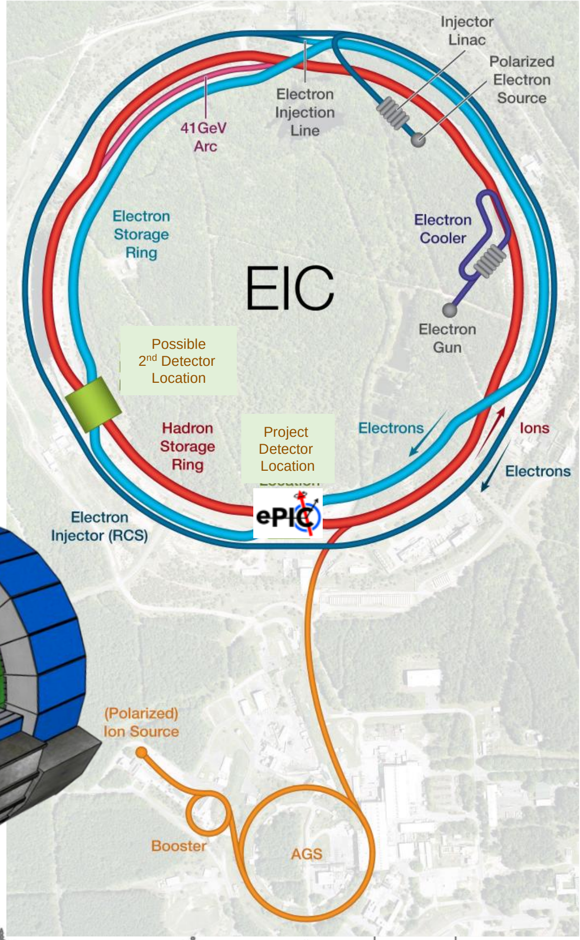
EIC UK meeting @ York

Fri, 1st March 2024

The ePIC detector

- ePIC is the first detector to utilise the new electron storage ring of EIC.
    - Added to the existing proton/ion beams of RHIC.
- ePIC will be replacing the STAR detector (at IP6).
    - Benefiting from the preexisting infrastructure, assembly hall, and control & DAQ room.
- Inner (tracking) detector consists of:
    - Silicon Vertex Tracker (SVT).
    - Multi Pattern Gas Detectors (MPGD).
    - AC-LGAD based Time of Flight (ToF).





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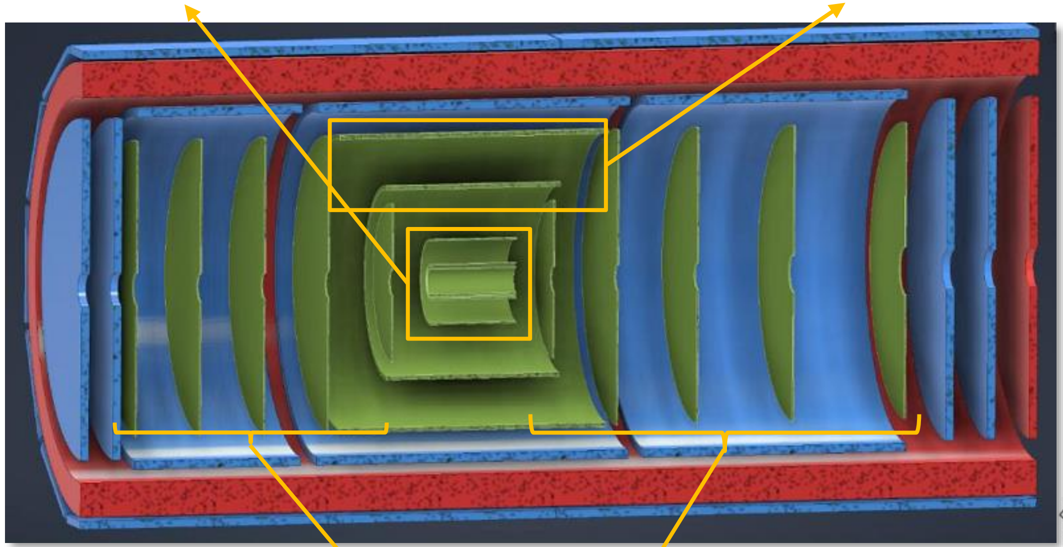
ePIC Silicon Vertex Tracker (SVT)

- The ePIC SVT will be the combination of 5 barrel layers and 10 endcap discs.
  - 3 Inner Barrel (IB) layers – same curved, wafer-scale stitched MAPS used within ITS3.
  - 2 Outer Barrel (OB) layers – longer than IB, optimised sensor for EIC.
    - Focus of EIC-UK WP1 (MAPS).
  - 5 discs for Electron and Hadron (going) Endcaps (EE/HE).
    - Same optimised sensor as OB.

(MAPS – Monolithic Active Pixel Sensor)

Inner Barrel (IB)
3 curved layers

Outer Barrel (OB)
2 stave-based layers



SVT MPGDs ToF (fiducial volume)

Electron/Hadron Endcaps (EE, HE)
5 discs on either side of the IP

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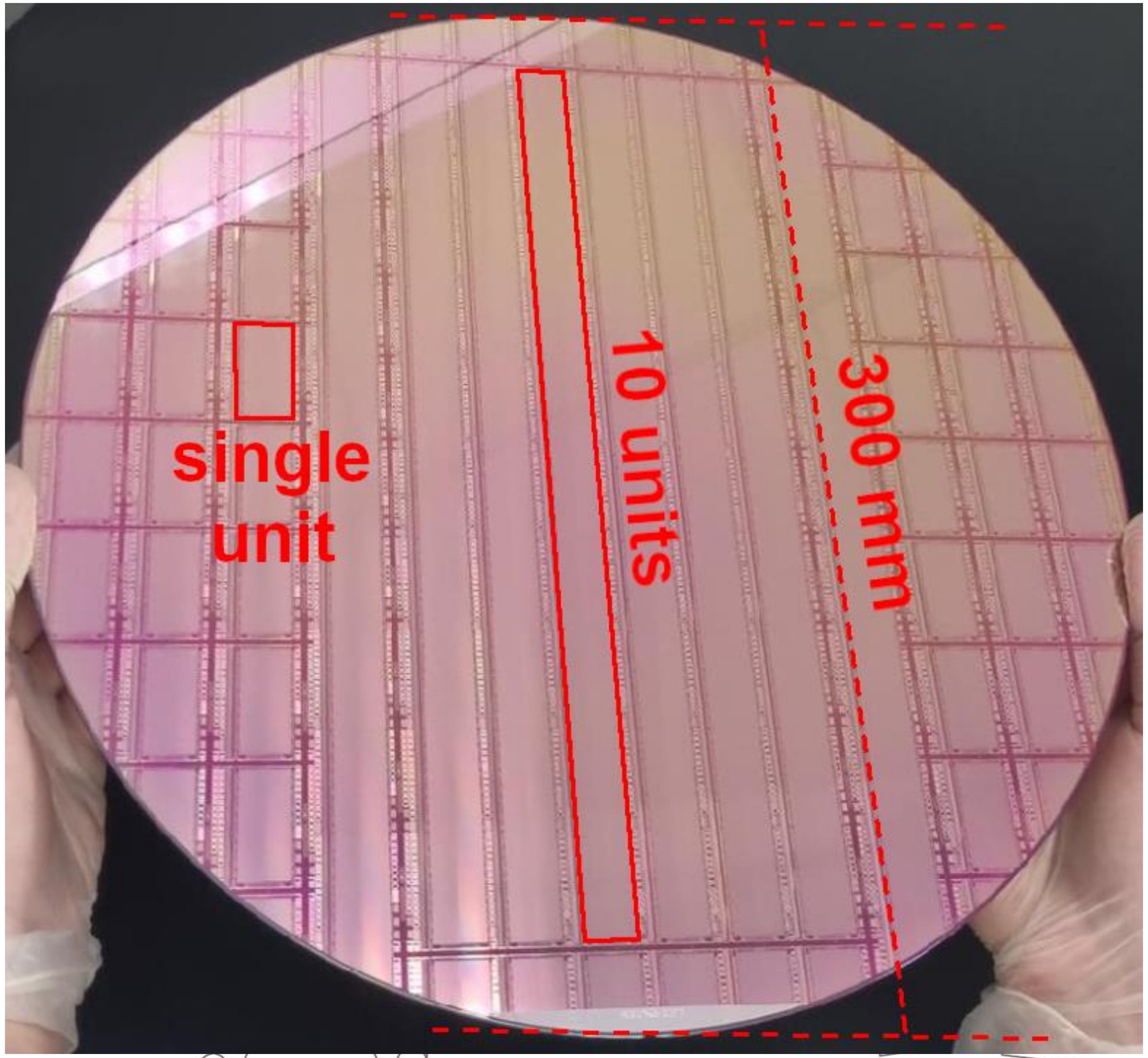
Stitched MAPS

- Stitching means that MAPS can be fabricated up to full wafer scales.
  - Unstitched fabrication was limited to structures that could fit in 1 “reticule”.
  - The equivalent of a single unit.
- This larger pixel array can be configured, with everything interconnected “on-wafer”.
  - Only need connections at the extreme ends for data/power/slow controls.
  - Wafer-scale stitched MAPS to be thinned and curved in ALICE ITS3 and ePIC SVT IB layers.



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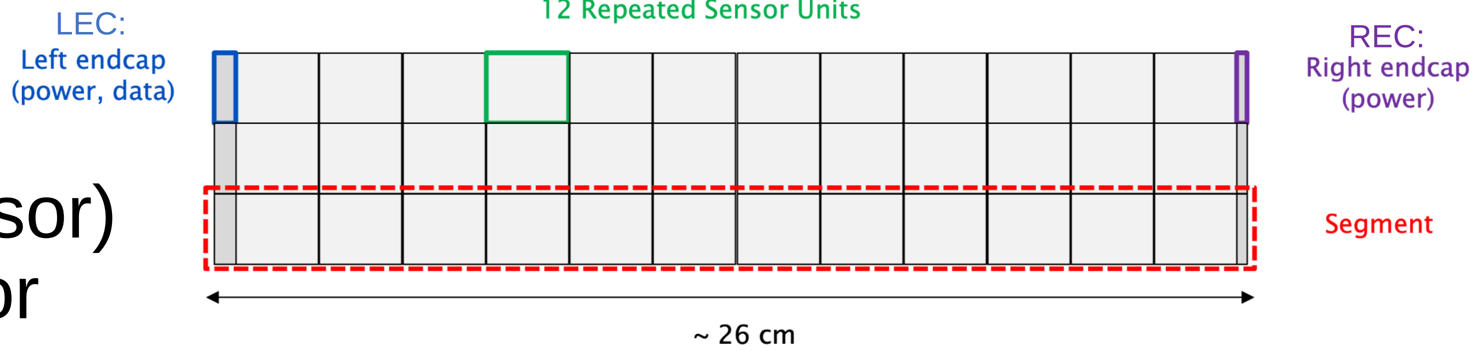
MAPS for EIC

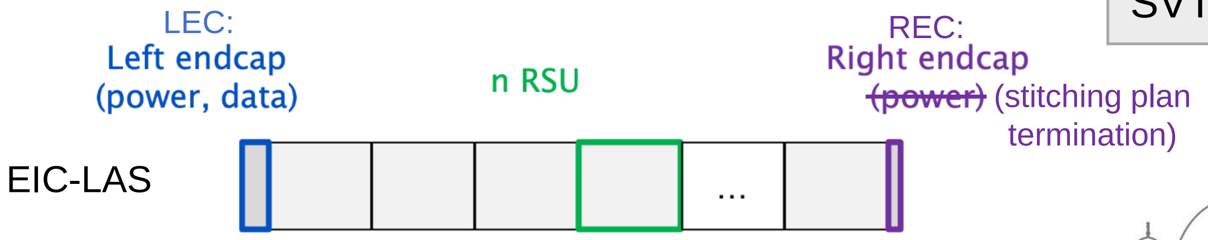
- Wafer-scale sensor used in IB.
- EIC-LAS (Large Area Sensor) is the EIC optimised sensor variant to help minimise the material required due to service (data/power/control) connections and improve yield for large area coverage.
  - For OB, EE, and HE of SVT.

IB example: L0 sensor



From: https://wiki.bnl.gov/EPIC/index.php?title=Si_Vertex_Tracker

IB	–	Inner Barrel
OB	–	Outer Barrel
EE	–	Electron (going) Endcap
HE	–	Hadron (going) Endcap
SVT	–	Silicon Vertex Tracker



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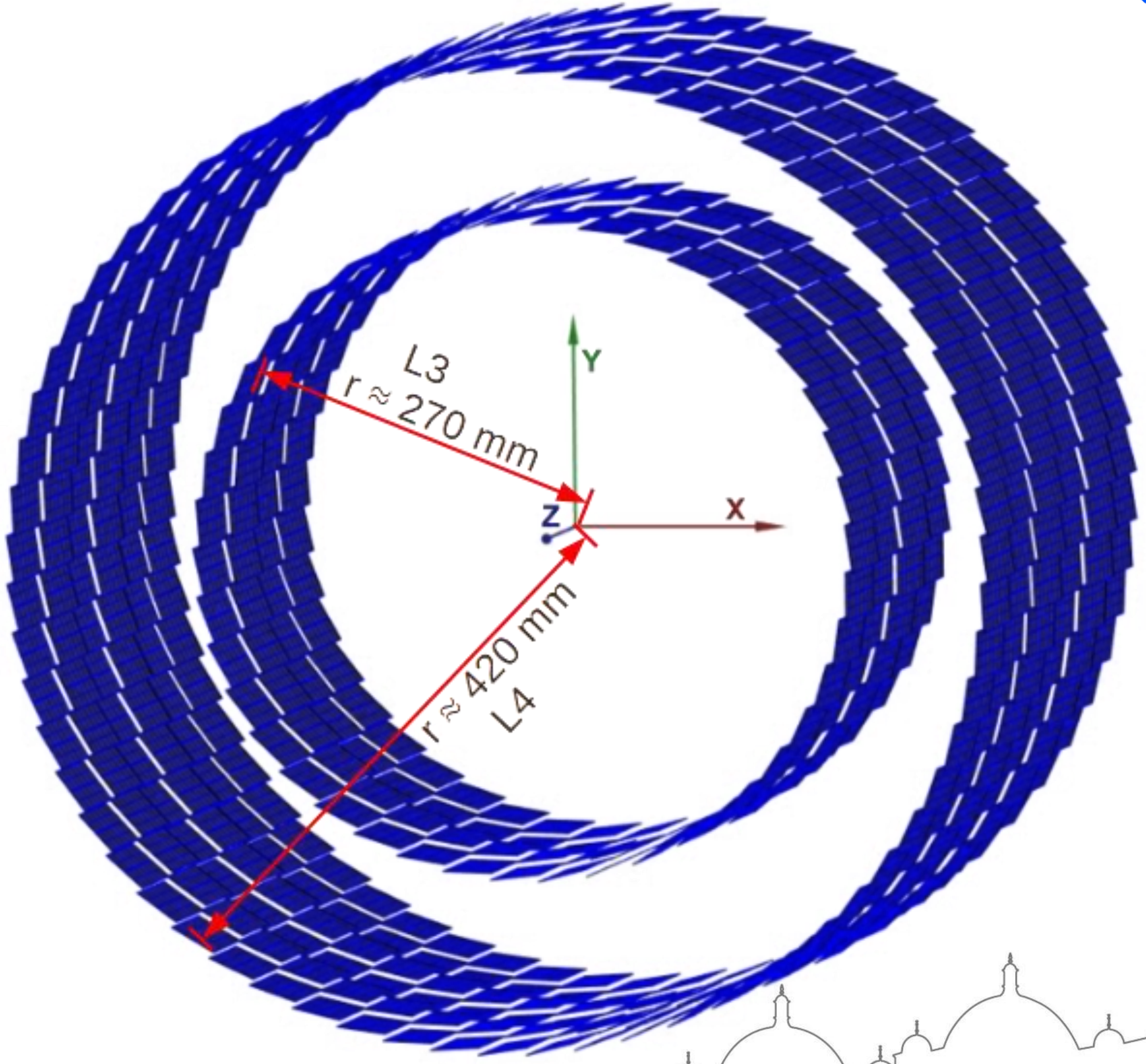
Outer barrel

- 2 stave-based layers (L3 and L4) of stitched MAPS.
- Stave repeated around the Z-axis until number of staves fully cover the circumference (at required radii).



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Initial stave considerations

Initial stave length/EIC-LAS considerations made by Peter Jones.

ePIC – SVT Barrel Layers

▪Sensor length considerations

Current conceptual design based on ITS3 LoI

	Layer	r (mm)	l (mm)	X/X_0 (%)	Area (m^2)	theta (deg)	eta
IB	L0	36.0	270	0.05	0.06	14.93	2.03
	L1	48.0	270	0.05	0.08	19.57	1.76
	L2	120.0	270	0.05	0.20	41.63	0.97
OB	L3	270	540	0.25	0.92	45.00	0.88
	L4	420	840	0.55	2.22	45.00	0.88

Comments
- Beam pipe radius = 31.76 mm
- New L0 radius is +5.64 mm
- New (and old) IB radii assume no overlap
- IB length is fixed by maximum 12 RSUs
- Note that lengths are active lengths – do not include the endcaps (4.5 mm and 1.5 mm)
- OB Opt 1: smaller radii to keep same eta coverage
- OB Opt 2: original radii with reduced eta coverage
- OB Opt 3: original radii and eta coverage by adding an additional sensor per layer
- T6 = 1x6 RSUs, T5 = 1x5 RSUs

Proposed new layout based on ITS3 ER2 sensor

	Layer	r (mm)	l (mm)	X/X_0 (%)	Area (m^2)	theta (deg)	eta	n_rsu	T6	T5
IB	L0	37.4	260	0.05	0.06	16.04	1.96			
	L1	49.8	260	0.05	0.08	20.97	1.69			
	L2	124.5	260	0.05	0.20	43.77	0.91			
OB Opt 1	L3	260	520	0.25	0.85	45.00	0.88	24	4	
	L4	390	780	0.55	1.91	45.00	0.88	36	6	
OB Opt 2	L3	270	520	0.25	0.88	46.08	0.85	24	4	
	L4	420	780	0.55	2.06	47.12	0.83	36	6	
OB Opt 3	L3	271	542	0.25	0.92	45.00	0.88	25		5
	L4	422	845	0.55	2.24	45.00	0.88	39	4	3

ePIC SVT DSC Meeting | 8 August 2023 5

https://indico.bnl.gov/event/20219/contributions/79348/attachments/49030/83511/EIC-SVT-08Aug23.pdf

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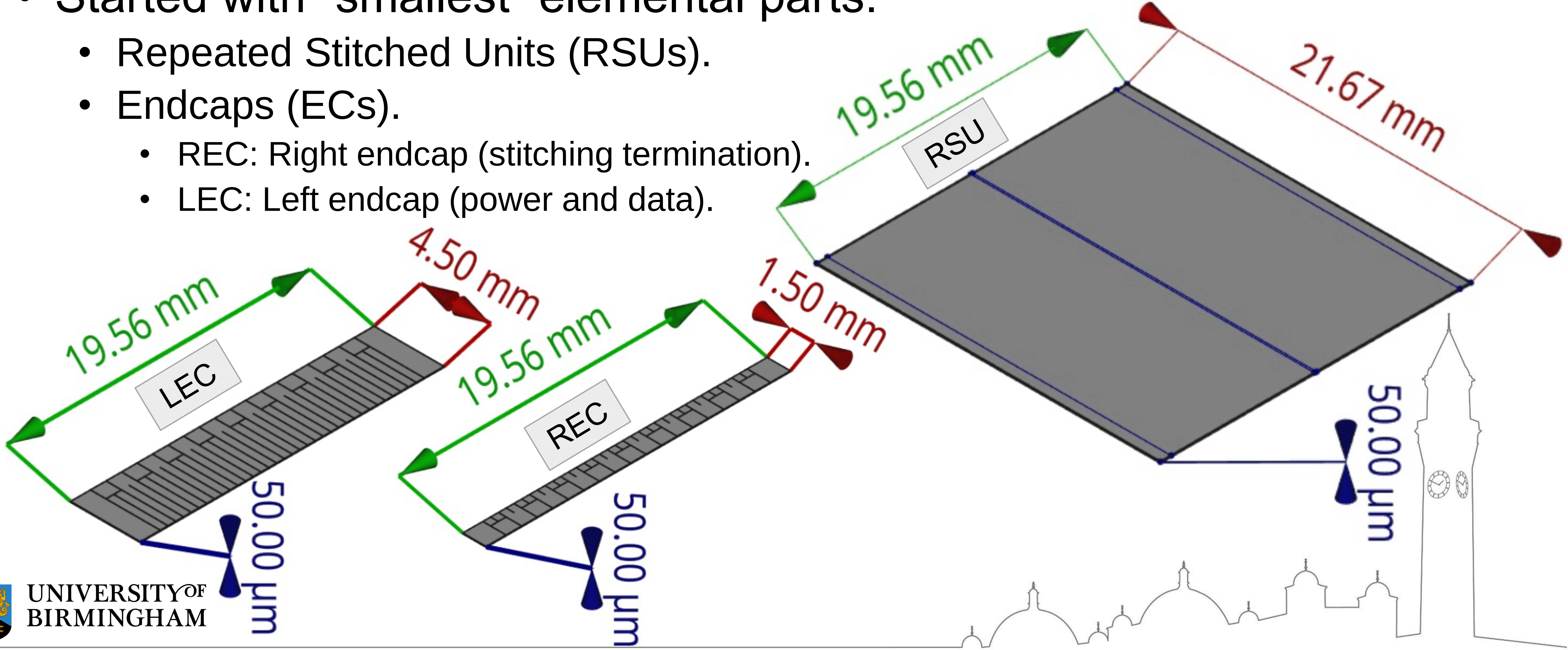
Start from smallest standard parts

- Started with "smallest" elemental parts.
  - Repeated Stitched Units (RSUs).
  - Endcaps (ECs).
    - REC: Right endcap (stitching termination).
    - LEC: Left endcap (power and data).



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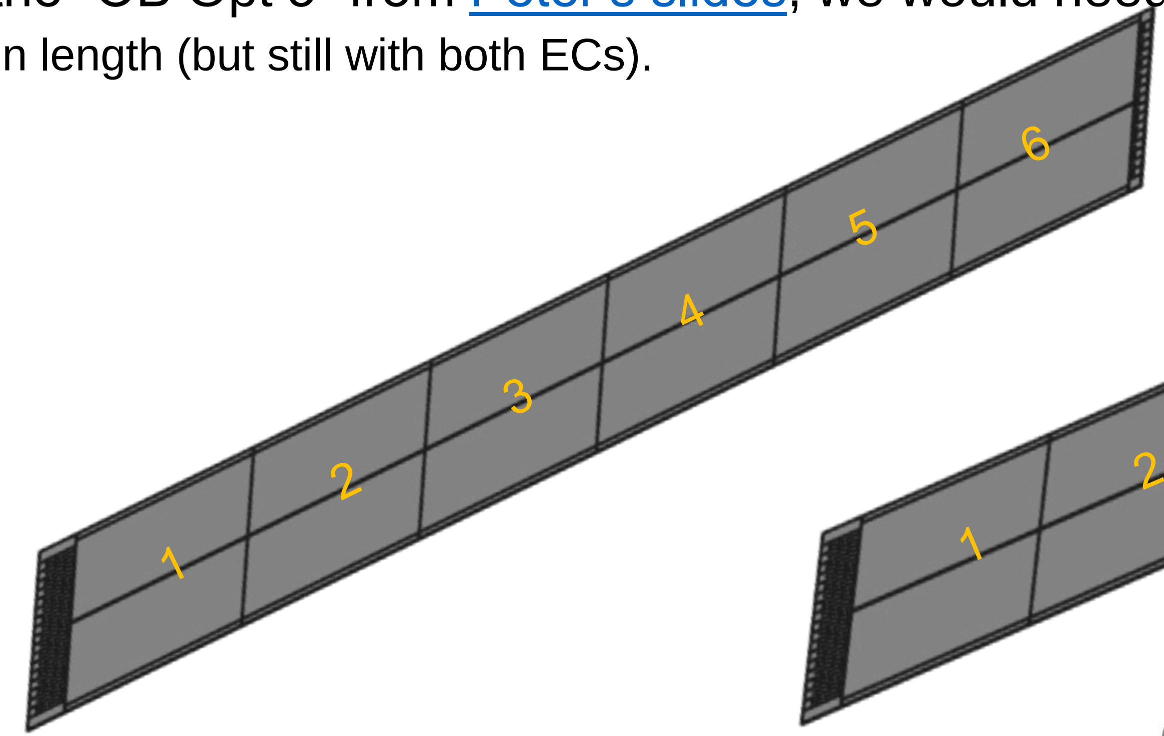
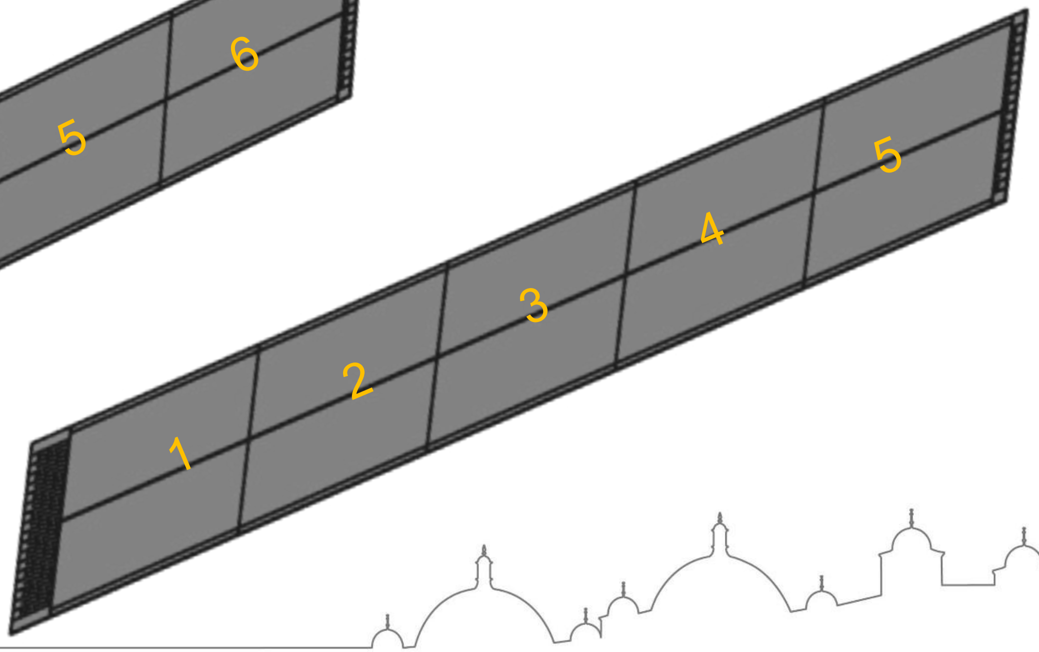
2 EIC-LAS lengths required

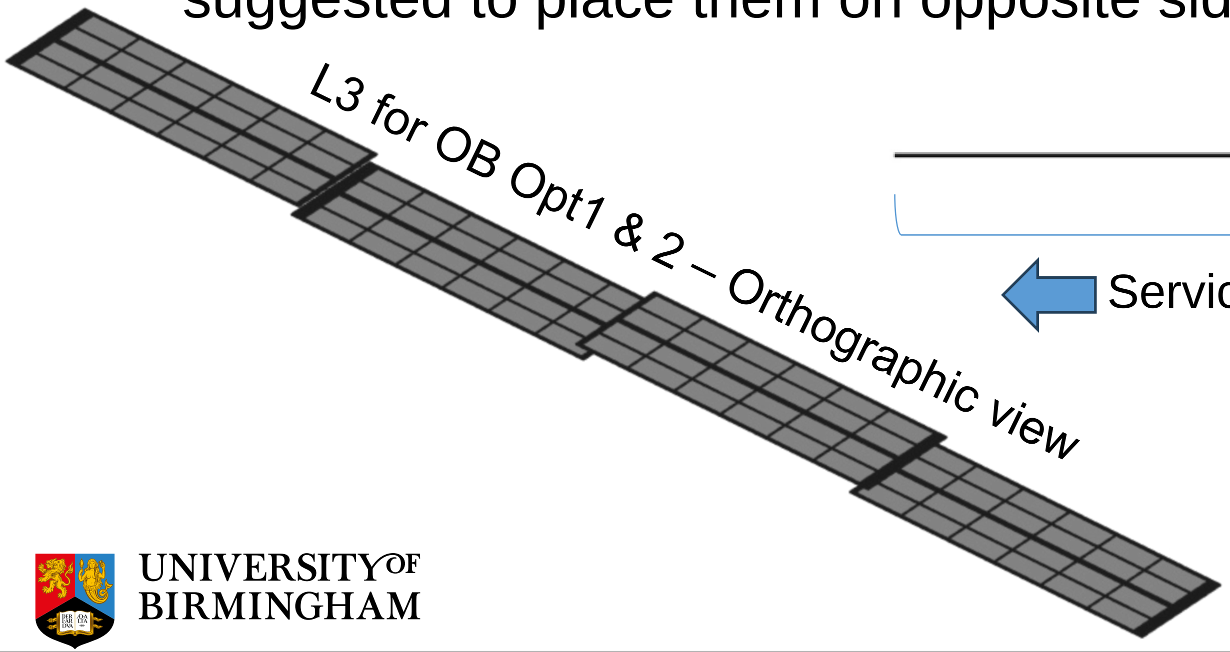
- A segment is the name for the collection for stitched RSUs both a “Power and Data” and “Power Only” endcap (to terminate the stitching plan).
- The aim is to have EIC-LAS (segments) with 6RSU (believed to be the longest we can power from just the LEC).
- To realise the “OB Opt 3” from Peter’s slides, we would need an extra flavour of EIC-LAS:
  - 5RSUs in length (but still with both ECs).



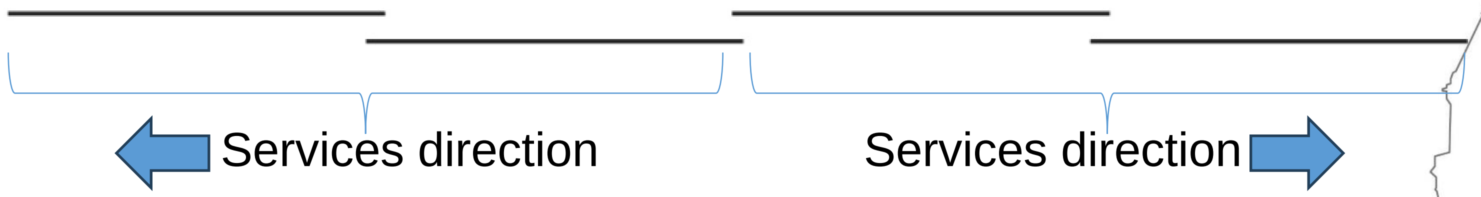


Construction of staves

- Numerous stave structures are required for the OB layers (L3 and L4).
- Peter also suggested different lengths and configurations for both L3 and L4 in his OB Opt 3.
  - Layer length and for module configuration are the same for OB Opt 1 and 2.
- To overlap the ECs of successive modules along the stave's length, it has been suggested to place them on opposite sides of the stave structure.



L3 for OB Opt1 & 2 – Side view



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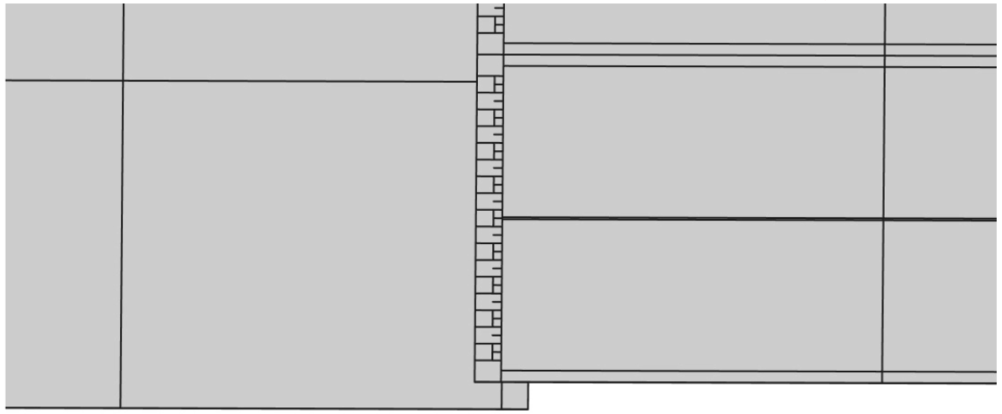
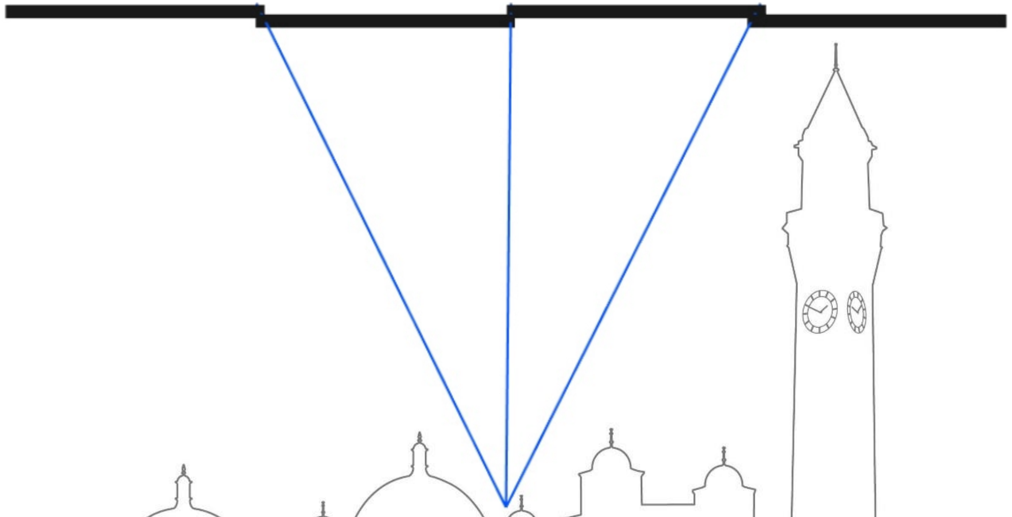
Overlapping modules along staves

- Initial designs had no active area overlaps along the stave length.



- 1st step was to consider the overlap needed for an ideal interaction point (X=0, Y=0, Z=0).
  - XY plane is perpendicular to the beam pipe (X=0, Y=0 is beam-pipe centre).
  - Z-axis is parallel to the beam pipe (Z=0 is centre of barrel length).



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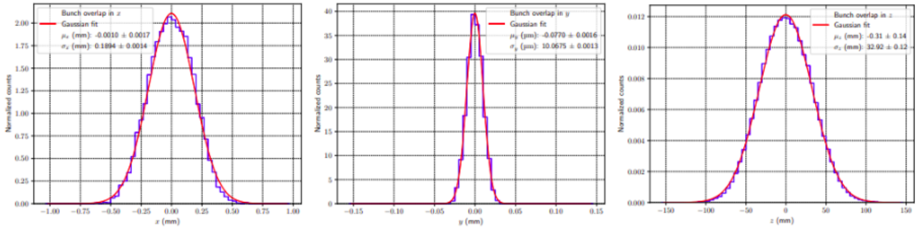
Interaction point variations

- Summary from Stephen Maple, original information from here.

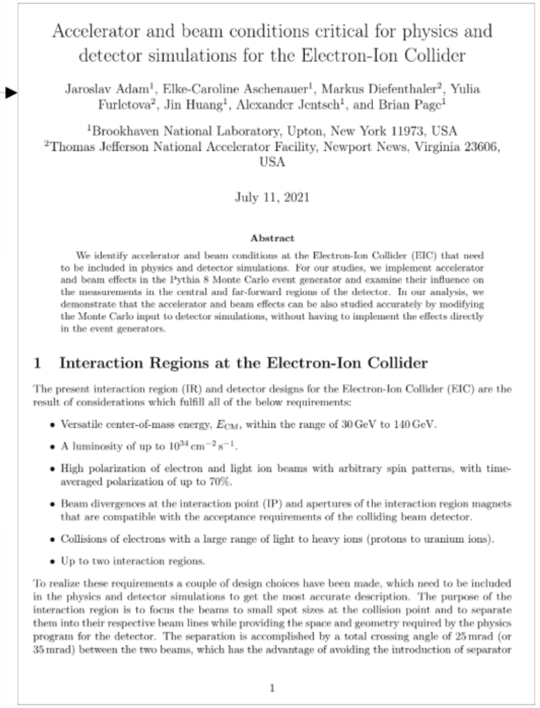
https://github.com/eic/documents/blob/master/reports/general/Note-Simulations-BeamEffects.pdf

Effect of beamspot on tracking performance

- A very helpful report on beam conditions at EIC was produced last year
  - This included a transport model which allows one to obtain the primary vertex distribution in terms of x, y, z



- → Generated single particle events in Fun4All with the origin vertex distributed according to these distributions



Accelerator and beam conditions critical for physics and detector simulations for the Electron-Ion Collider

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July 11, 2021

Abstract

We identify accelerator and beam conditions at the Electron-Ion Collider (EIC) that need to be included in physics and detector simulations. For our studies, we implement accelerator and beam effects in the Pythia 8 Monte Carlo event generator and examine their influence on the measurements in the central and far-forward regions of the detector. In our analysis, we demonstrate that the accelerator and beam effects can be also studied accurately by modifying the Monte Carlo input to detector simulations, without having to implement the effects directly in the event generators.

1 Interaction Regions at the Electron-Ion Collider

The present interaction region (IR) and detector designs for the Electron-Ion Collider (EIC) are the result of considerations which fulfill all of the below requirements:

- Versatile center-of-mass energy, E_{CM}, within the range of 30 GeV to 140 GeV.
- A luminosity of up to $10^{34}\,cm^{-2}\,s^{-1}$.
- High polarization of electron and light ion beams with arbitrary spin patterns, with time-averaged polarization of up to 70%.
- Beam divergences at the interaction point (IP) and apertures of the interaction region magnets that are compatible with the acceptance requirements of the colliding beam detector.
- Collisions of electrons with a large range of light to heavy ions (protons to uranium ions).
- Up to two interaction regions.

To realize these requirements a couple of design choices have been made, which need to be included in the physics and detector simulations to get the most accurate description. The purpose of the interaction region is to focus the beams to small spot sizes at the collision point and to separate them into their respective beam lines while providing the space and geometry required by the physics program for the detector. The separation is accomplished by a total crossing angle of 25 mrad (or 35 mrad) between the two beams, which has the advantage of avoiding the introduction of separator

1

16

Important points (interaction point variation in):
- X-axis = ± ~ 600 μm
- Y-axis = ± ~ 30 μm
- Z-axis = ± ~ 100 mm!

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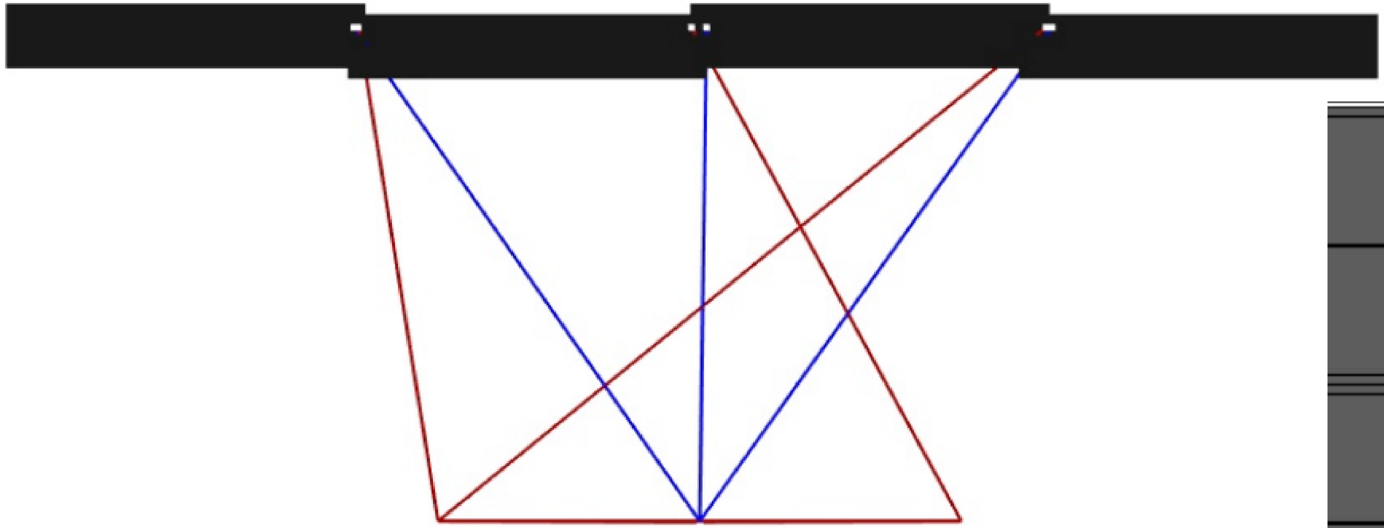
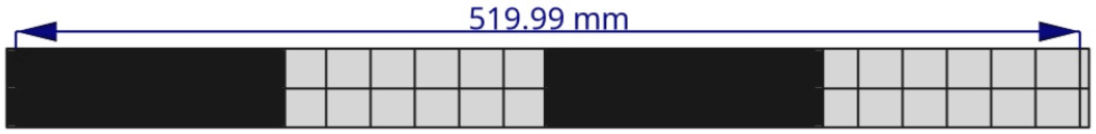
Accounting for IP variations

- Variations for all axis can be considered, but as ΔX > ΔY and ΔZ >> ΔX, the Z-axis has the biggest influence.



Stave length comparison

L3 for OB Opt 1 & 2 (no RSU overlap)

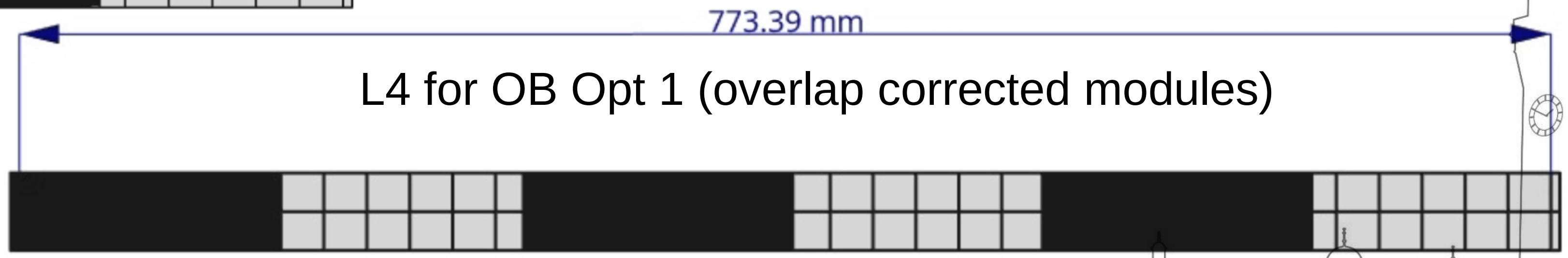


L4 for OB Opt 1 & 2 (no RSU overlap)

For Geometric Opt1, both L3 and L4 were reduced (in length) by ~1% (6 to 7 mm).

L3 for OB Opt 1 (overlap corrected modules)

L4 for OB Opt 1 (overlap corrected modules)



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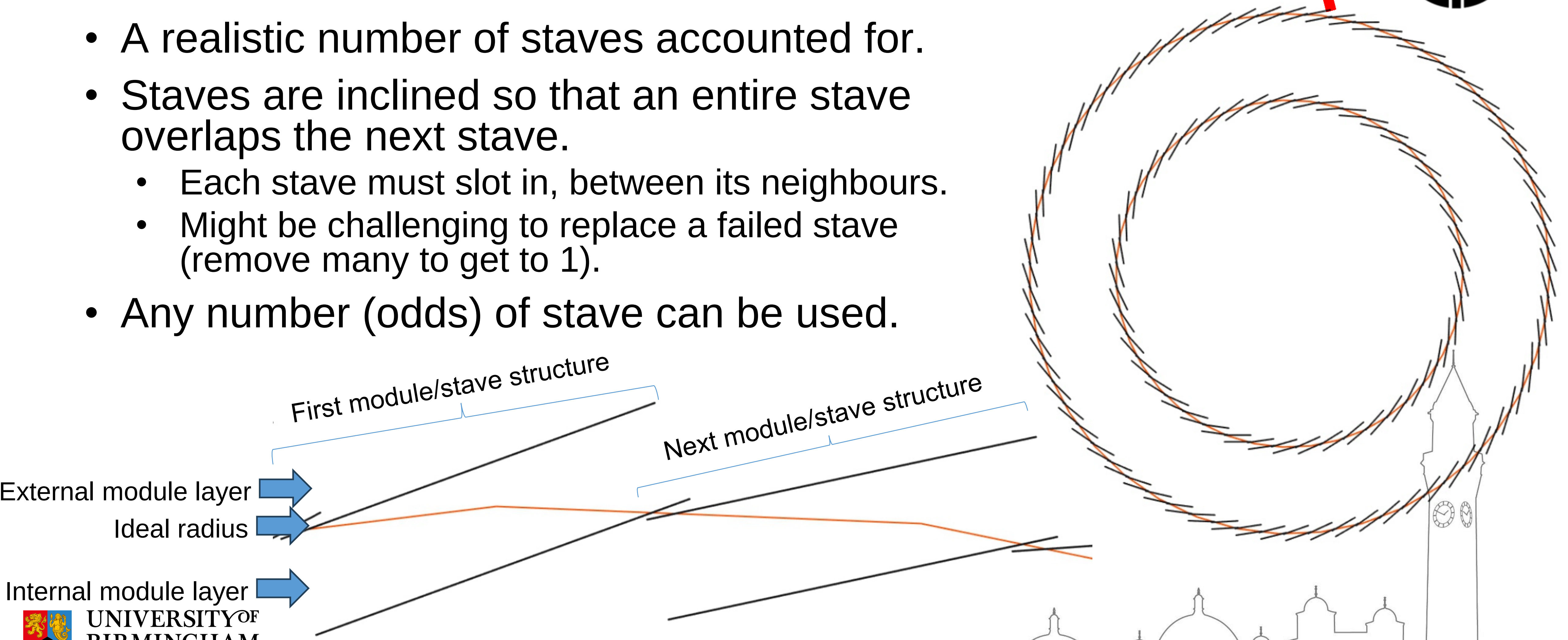
A tiled stave

- A realistic number of staves accounted for.
- Staves are inclined so that an entire stave overlaps the next stave.
  - Each stave must slot in, between its neighbours.
  - Might be challenging to replace a failed stave (remove many to get to 1).
- Any number (odds) of stave can be used.



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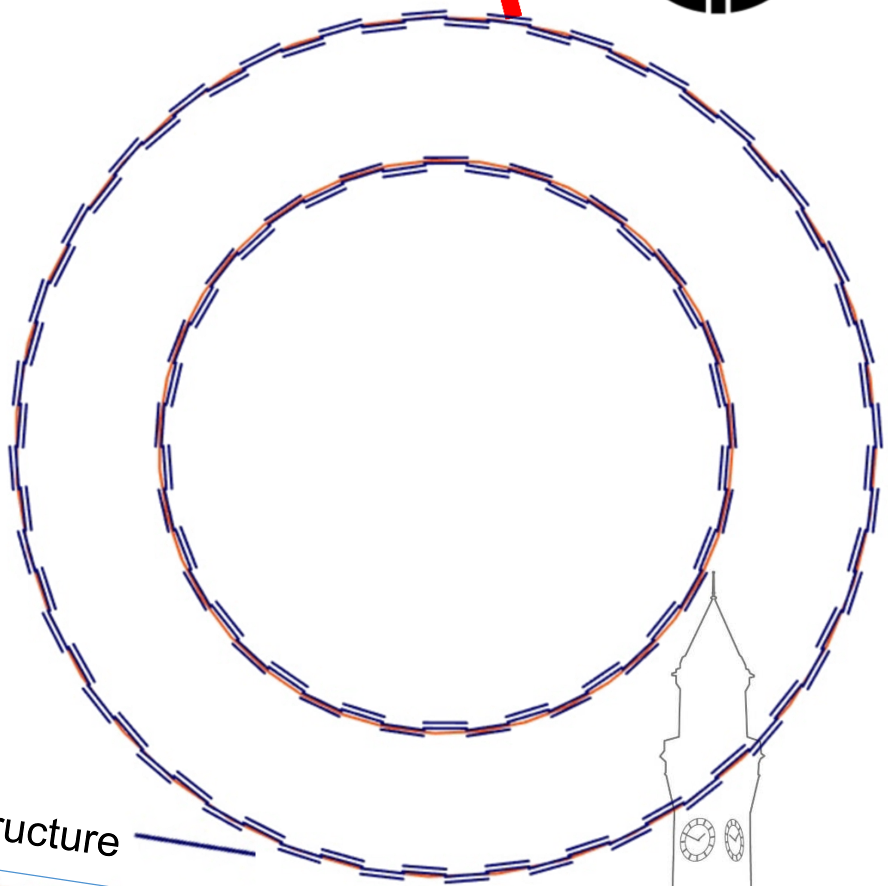
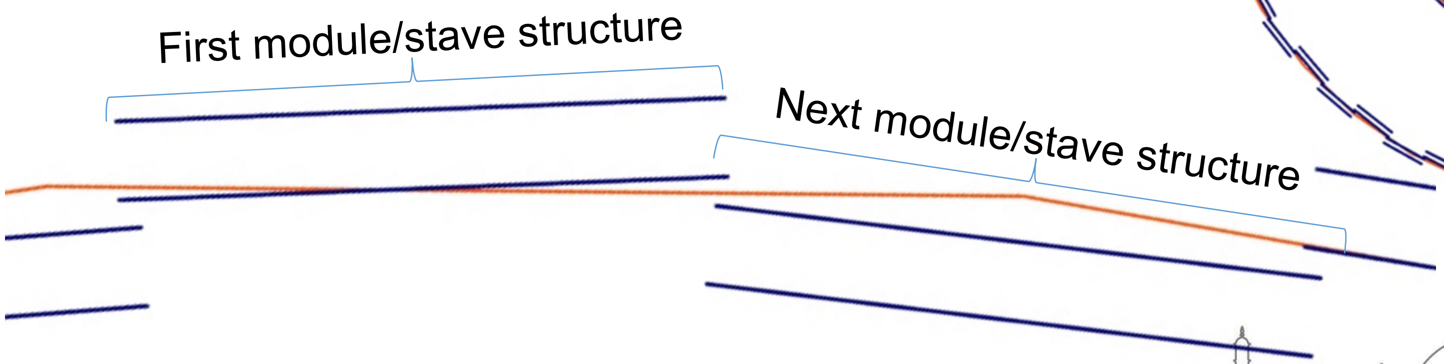
Castellated layout

- Alternating inner/outer structure.
  - Easier mounting/replacing (at most 3 staves removed to replace 1).
  - Preferred for its “easier” mounting/replacing of staves.
- Number of staves must be even.

- Some overlap of staves (in both designs).
  - To account to dead area at the sensor’s edge.





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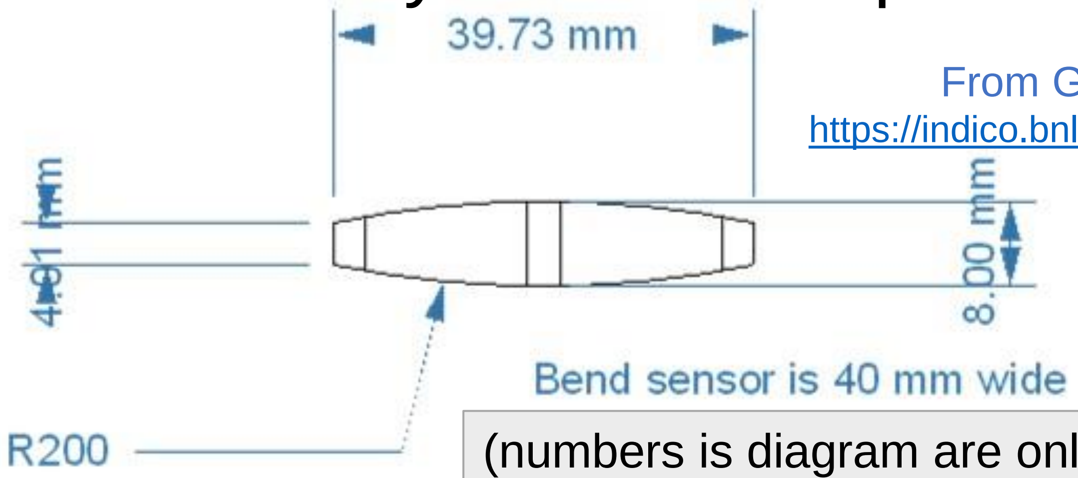
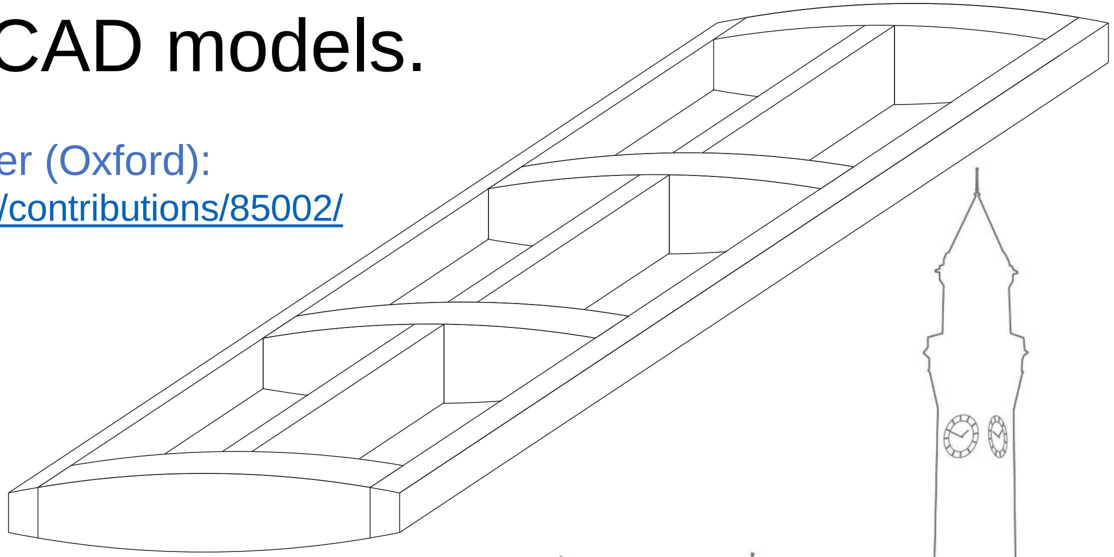
Conceptual stave structure

- Following these barrel layout studies, wider mechanical meetings have been held to look at the how the stave could be built and supported from only the extreme ends.
- Current plan is to thin and bend the sensor for increased rigidity.
- This is yet to be incorporated in the CAD models.



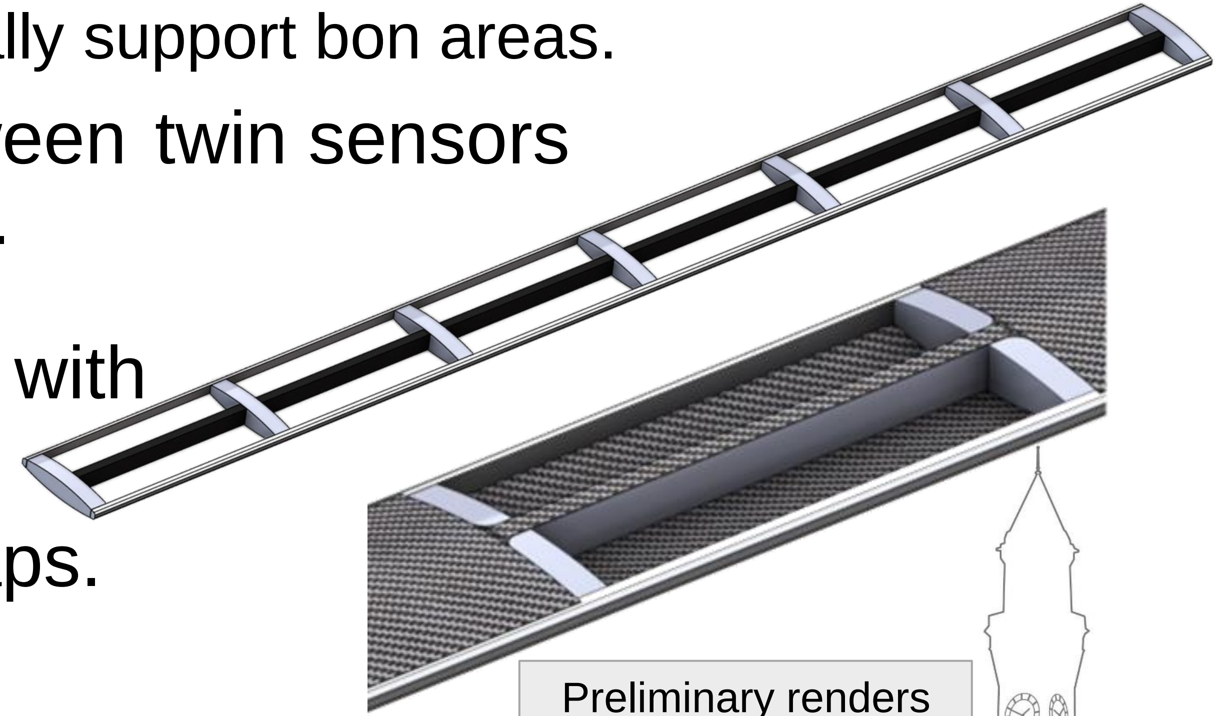
From Georg Viehhauser (Oxford):
https://indico.bnl.gov/event/20473/contributions/85002/

(numbers is diagram are only approximate, not set to current sensor size)



Curved staves

- LEC areas backed by carbon foam ribs.
  - Help heat dissipation and mechanically support bon areas.
- Central spar will support joint between twin sensors and maintain curvature of sensors.
- Surface between sensors covered with carbon fiber skin.
- Sensors are placed over empty gaps.
- Sensor edges to be sealed.
  - Creating an air-tight tube for air cooling.



Preliminary renders (subject to change)

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From Georg Viehhauser (Oxford): https://indico.bnl.gov/event/20473/contributions/85002/

Considering services

To reduce material:

- EIC-LAS is to have whole pixel array readout from a single data link in the LEC (hit rate is low enough to enable this).
  - Fibre-optics lines, for data readout, as close to the sensor as possible (e.g. end of stave) – radiation expected to be low enough to enable this.
  - To be done using a rad-hard electrical/optical transceiver – VTRx+.
  - Each VTRx+ has 4 available data lines for readout.
- Sensors to be powered in serial powering (SP) chains (reduces current per PSU channel and therefore wire gauge).
  - The greater the number of sensors per SP chain, the greater the material saving.

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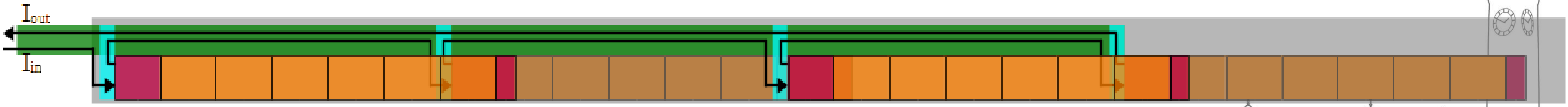
FPC design

The flexible printer circuit (FPC) will be the interconnect between clusters of EIC-LAS. This needs:

- To enable the readout of data from many EIC-LAS to 1 VTRx+.
- Host the current to voltage regulation (for each EIC-LAS) and interconnections within a SP chain.
- Clusters of 4 EIC-LAS per SP chain work well with VTRx+ readout.

FPC designs are preferring clusters 1 EIC-LAS wide (even if interfacing sensors on different sides of the same structure).



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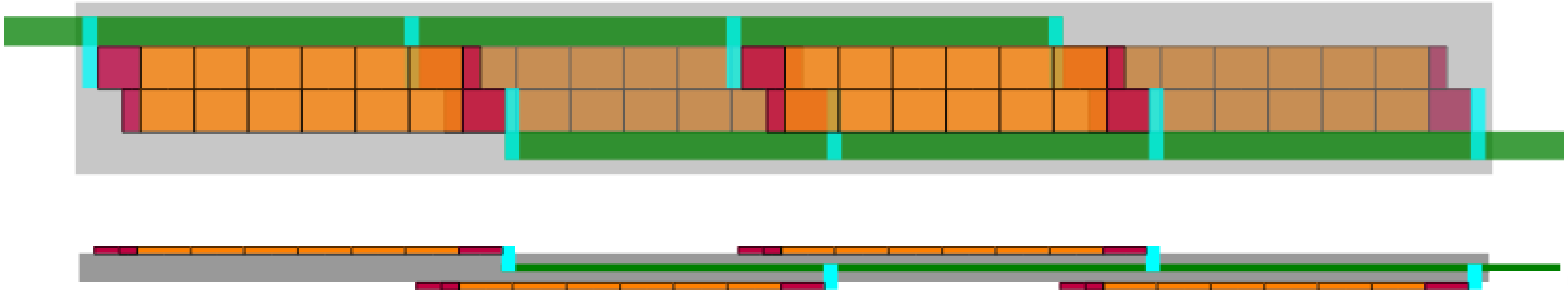
Effects of stave designs

- The FPC design prefers staves for EIC-LAS in multiples of 4 (in length).
- A convenient layout for L3 (with 6 RSUs) could look as follows:

Layer 3 (EIC-LAS w. 6*RSU)



- This ties in well with the Opt1 or 2 previously reported.

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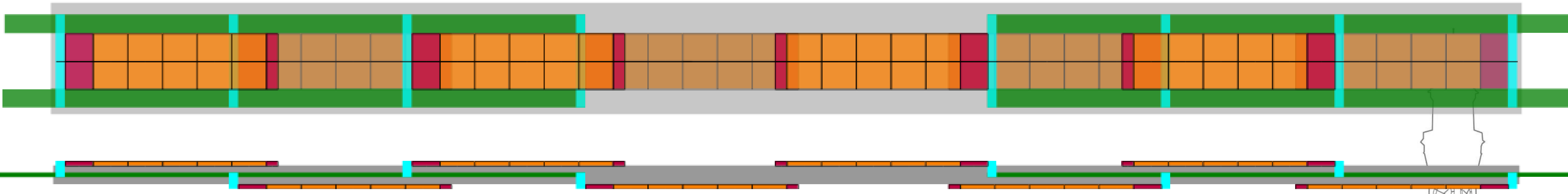
Layer 4 staves

- To enable multiples of 4 in a L4 stave, switching to 5 RSU long EIC-LAS would be closer to the suggested staves lengths (Opt3's length, but built from only 5 RSU long EIC-LAS).
- This will lead to needing some overlap of RSUs (active sensors area) to get to the stave lengths required.

Layer 4 (EIC-LAS w. 5*RSU)



Stave length (no RSU overlap) = 866.67 mm. Longest stave in Peter's studies = 845 mm. Therefore, ~1 RSU too long!

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Summary

- Building CAD model of entire ePIC SVT OB.
- Variations of stave structure and layer configuration are being considered.
    - Includes consideration for sensor overlap between neighbouring staves.
- Some consideration for overlap of modules along the length of OB staves.
    - This includes consideration for the variation in the interaction point.
- Consideration for curved sensors also on the OB staves.
- Seen the effect services and FPC design will play on how the EIC-LAS will need to be laid out on a stave.

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Thank you very much!

Any questions?

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Additional (support) slides

MOSAIX to EIC-LAS

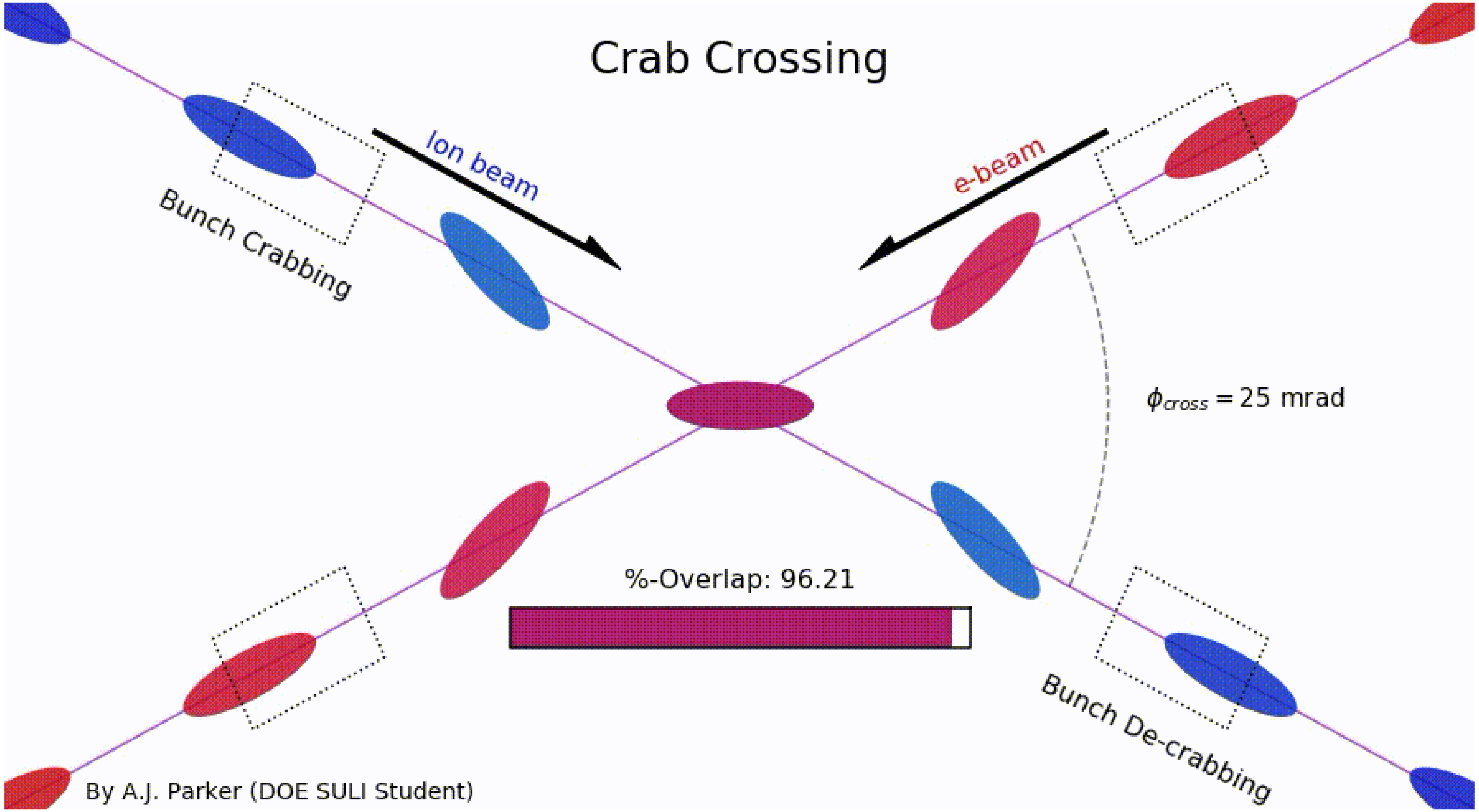
From Iain Sedgwick (STFC): https://indico.bnl.gov/event/20473/contributions/84984/

Inner Barrel		Outer Barrel
• 12 RSUs	Yield likely too low →	• Reduced number of RSUs
• 8 data links	Excess material for required data rate →	• Single data link
• 7 slow control links	Excess material when built into stave →	• Multiplex slow control
• Direct powering	Excess material when built into stave →	• Serial powering

Must be done on 65nm MOSAIX database (Reduced number of RSUs; Single data link)

Could be on support chip (Multiplex slow control; Serial powering)

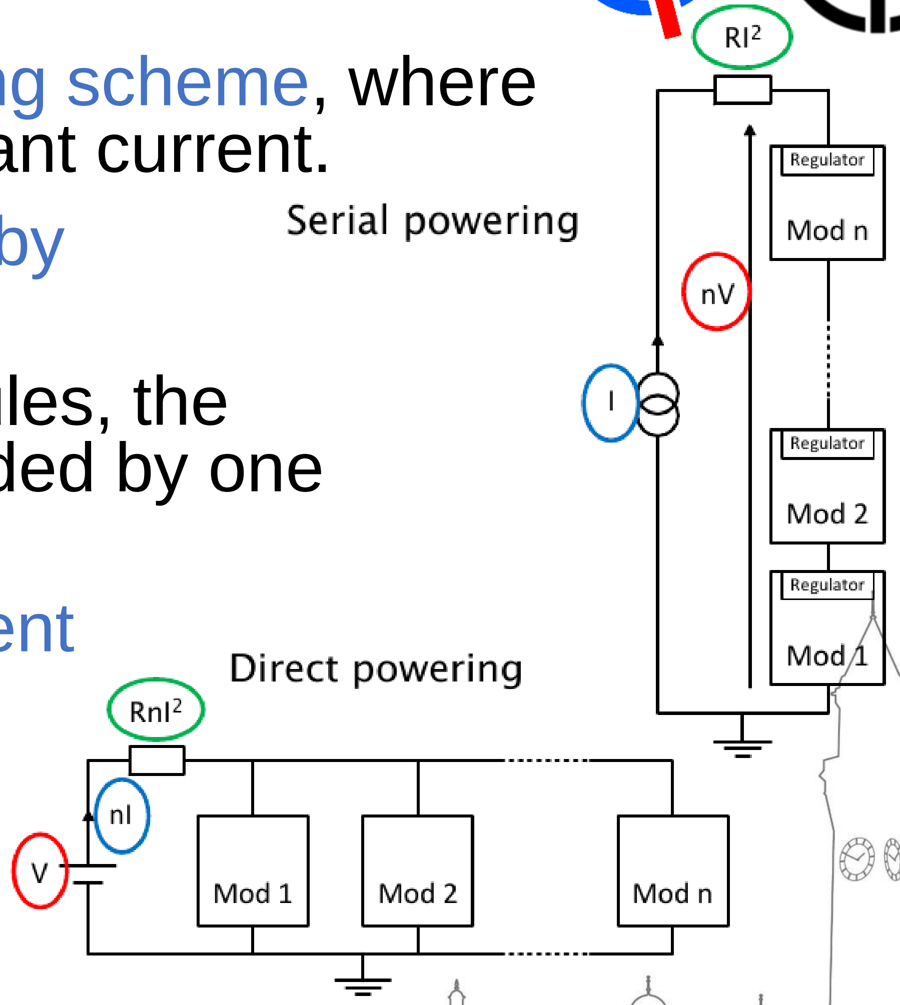
Beam crossing



From E. C. Aschenauer: https://indico.bnl.gov/event/20473/contributions/85389/

Serial powering basics

- Serial powering is a current based powering scheme, where modules are powered in series by a constant current.
- The current to voltage conversion is done by regulators close to/on module.
- In a serial powering chain made of n modules, the transmitted current is only the current needed by one module, I.
- For n modules powered in series, the current is reduced of a factor n with respect to a direct powering scheme → Higher power efficiency and reduced cable volume.
  - Cable cross-section and the power losses on the cables scale by the same factor.



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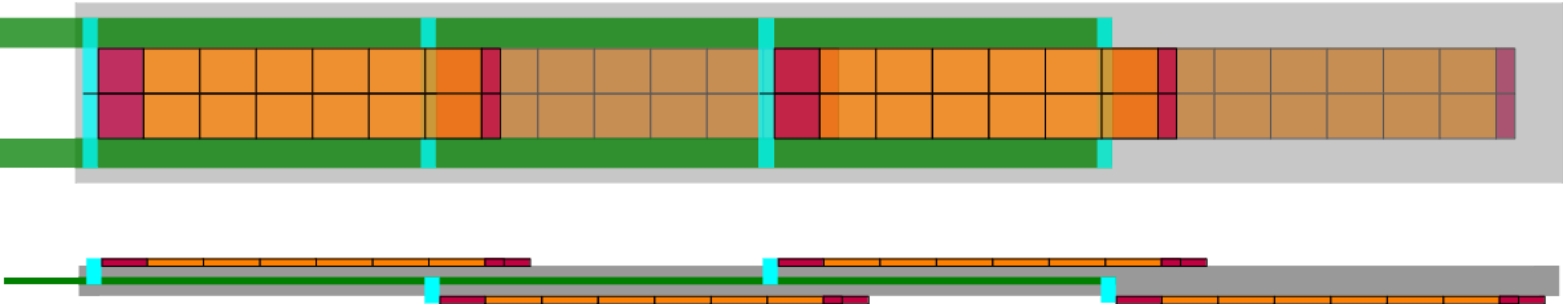
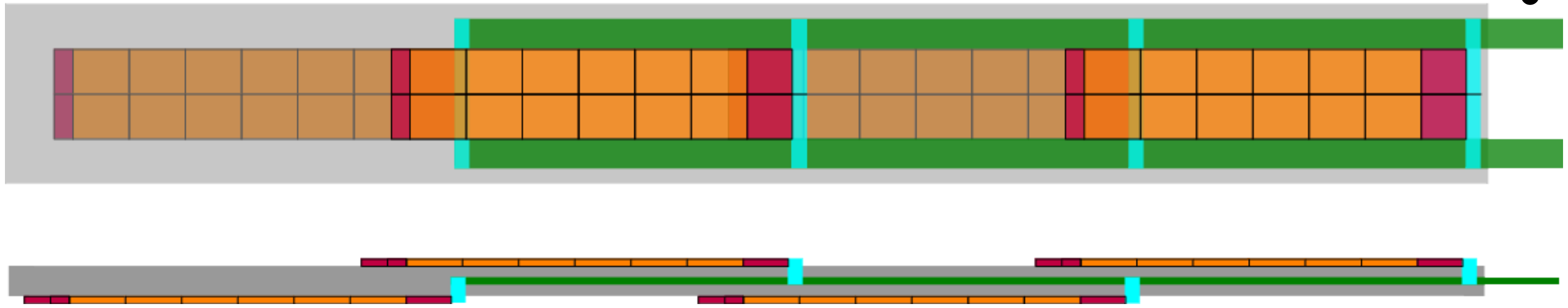
More likely L3 (6 RSU) layout

Layer 3 (EIC-LAS w. 6*RSU) Stave N



Layer 3 (EIC-LAS w. 6*RSU) Stave N+1



- Both FPCs (on 1 stave) are likely to come from the same stave edge.
  - Having neighbouring EIC-LAS in the same orientation for easier mounting.
- If so, alternating staves would need to be connected to from opposite sides (to balance material).

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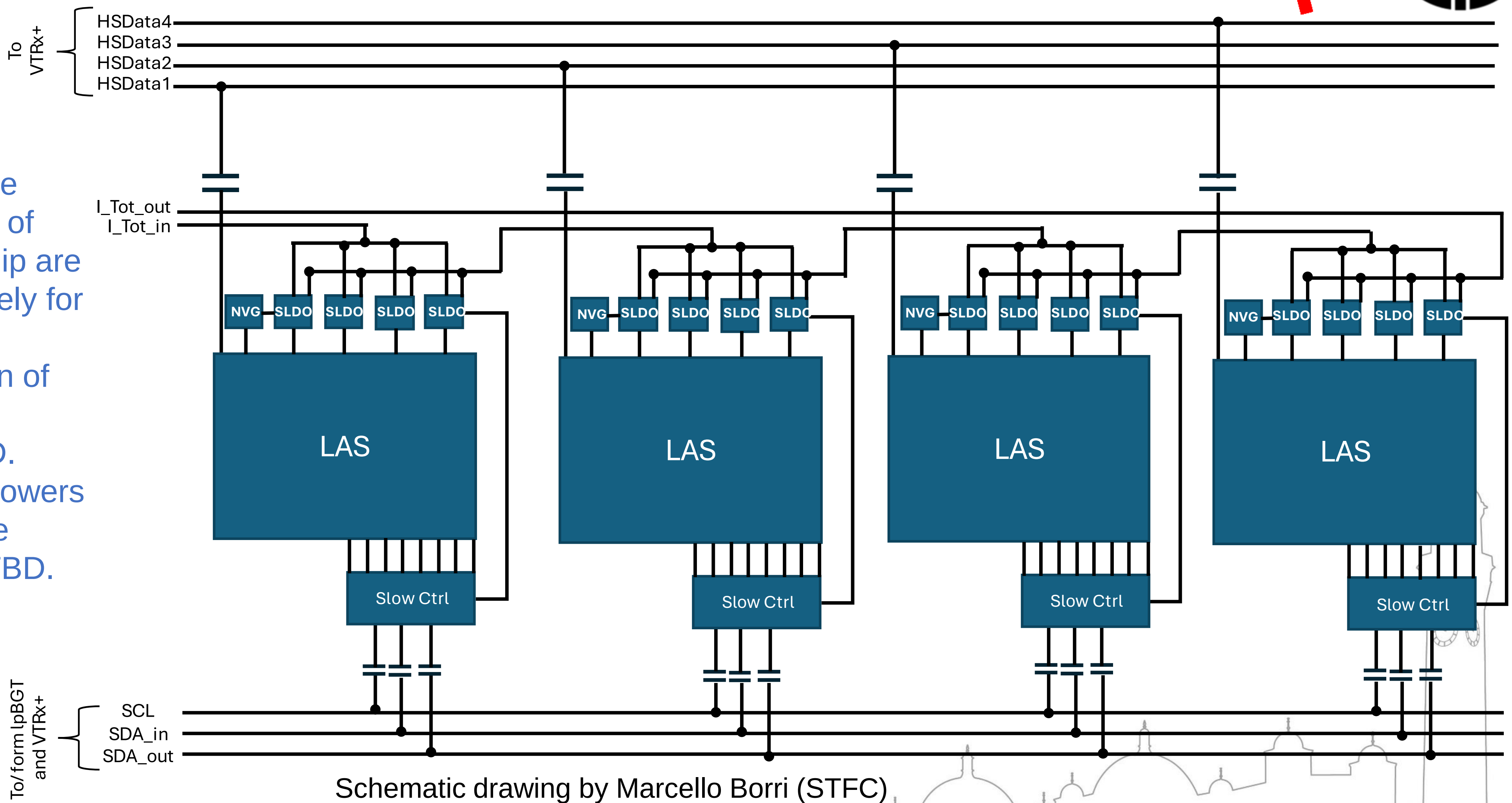
EIC-LAS connections on FPC

- On this slide the three functions of the ancillary chip are shown separately for clarity.
- Precise location of AC-coupling capacitors TBD.
- Which SLDO powers what part of the auxiliary chip TBD.



Schematic drawing by Marcello Borri (STFC)

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