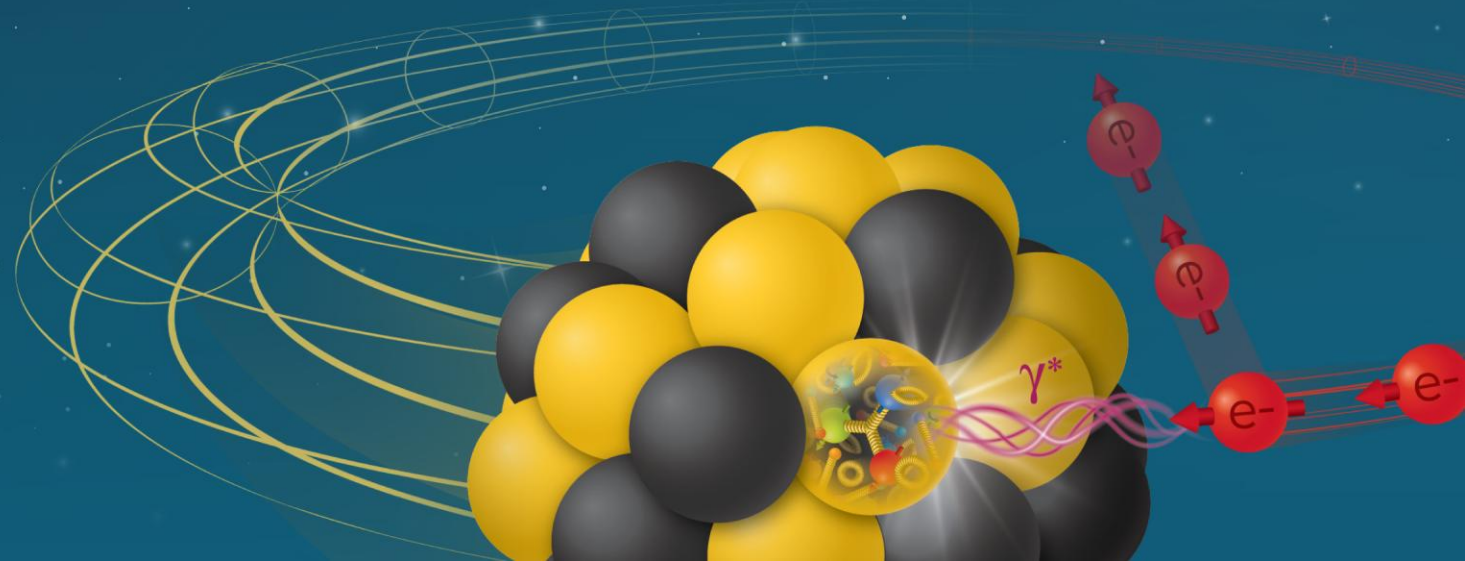


ePIC Barrel ToF Design – Initial Thoughts

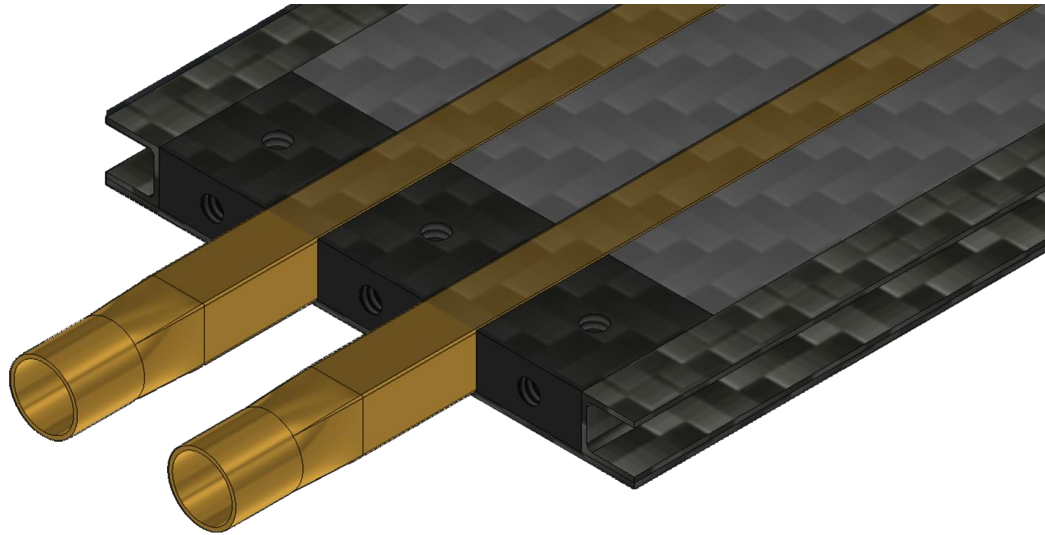
Dan Cacace, Rachid Nouicer

October 1st, 2026

Electron-Ion Collider



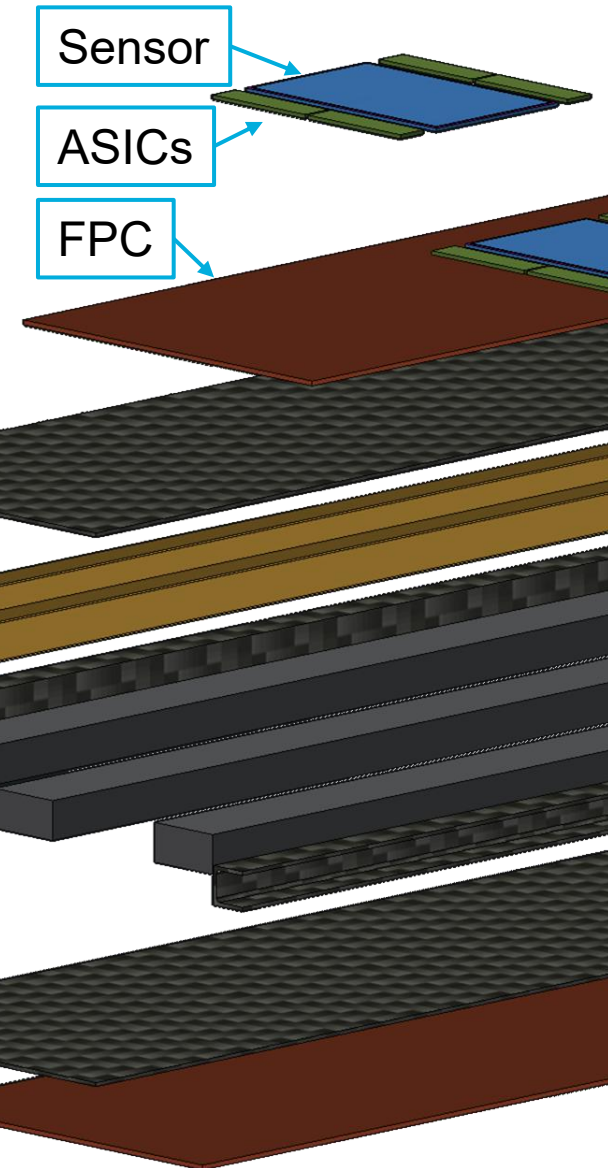
Stave Design – Components



- The staves are approximately 6mm thick, 50mm wide, 1300mm long
- The sensors and ASICs are centered on the stave to minimize unique parts and eliminate asymmetry mitigations.

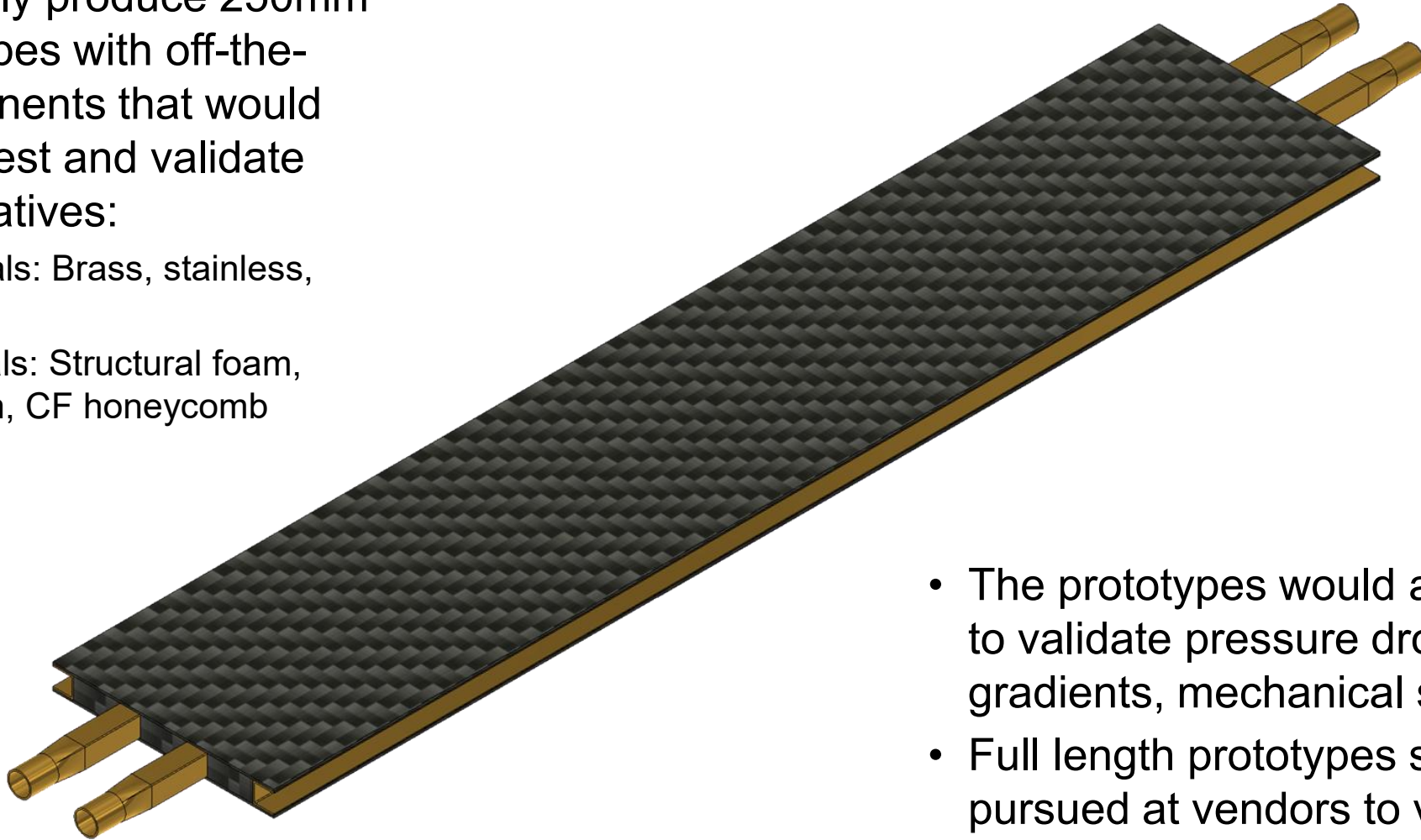


- Cooling tubes are brass and square for optimal thermal performance
- The side channels are to support the stave during wire bonding (like ATLAS)



Stave Design – Prototype

- We can easily produce 250mm long prototypes with off-the-shelf components that would allow us to test and validate some alternatives:
 - Tube materials: Brass, stainless, carbon fiber
 - Filler materials: Structural foam, thermal foam, CF honeycomb



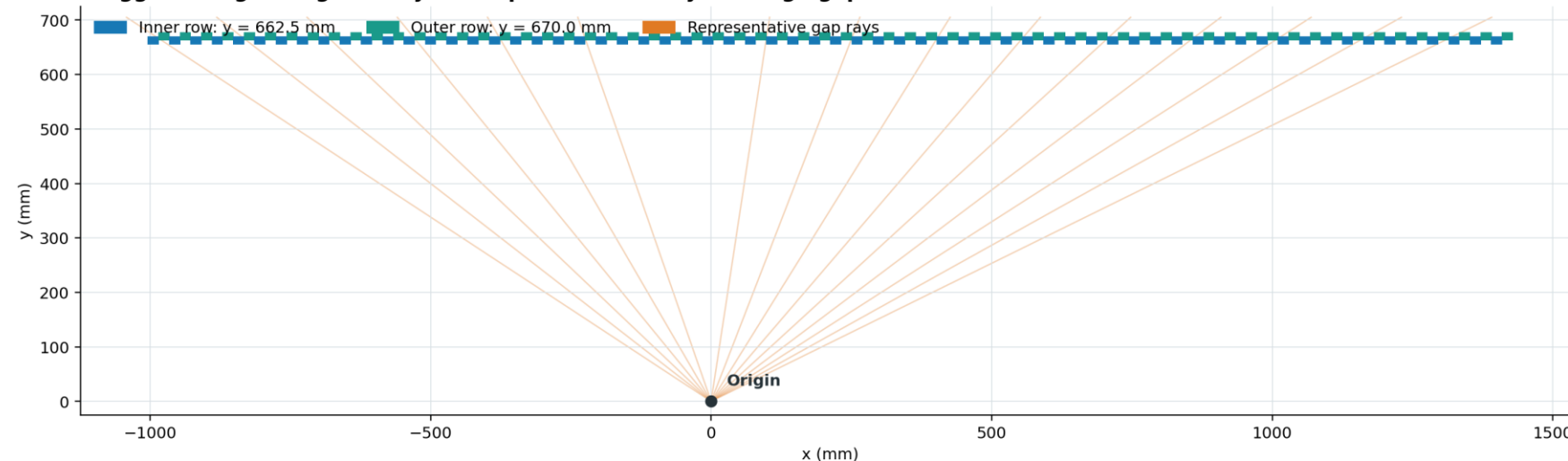
- The prototypes would also allow us to validate pressure drops, thermal gradients, mechanical stiffness, etc.
- Full length prototypes should be pursued at vendors to validate their capabilities and for additional testing

Stave Sensor Eta Coverage Issue

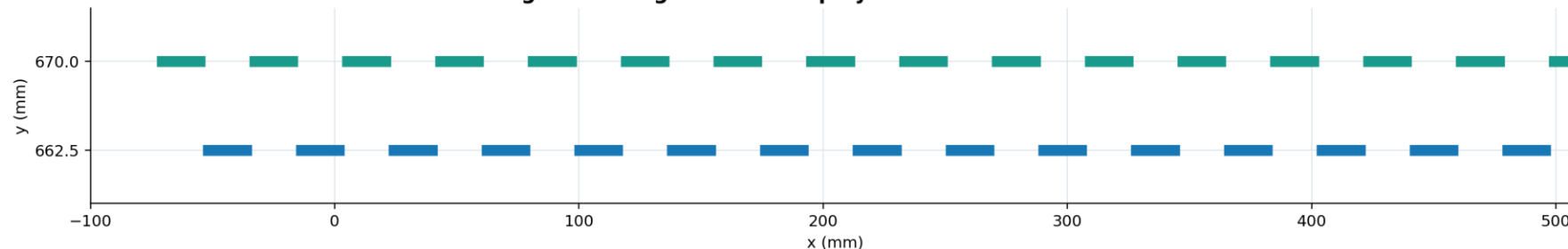
- Image to right is generated by AI and has not been validated but is useful for illustrating the concern.
- Sensor overlap is currently with respect to a perpendicular track however, tracks are not close to perpendicular at high eta.
- That combined with the stave thickness creates gaps between sensors
- **This is a problem for all current designs**

Angular coverage of 128 staggered 20 mm line segments

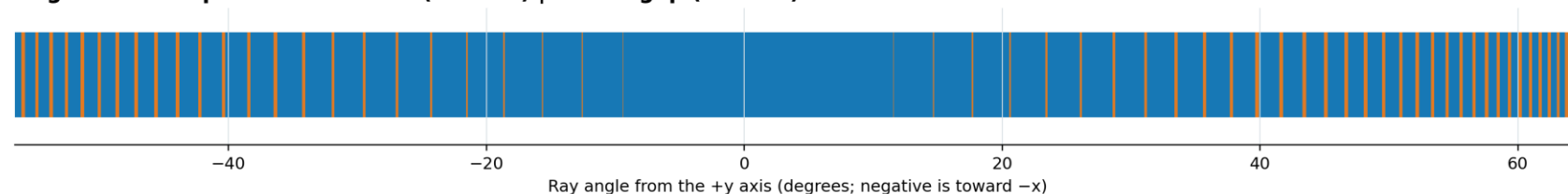
Staggered segment geometry and representative rays through gaps



Center detail at true scale: alternating 20 mm segments overlap by 1 mm



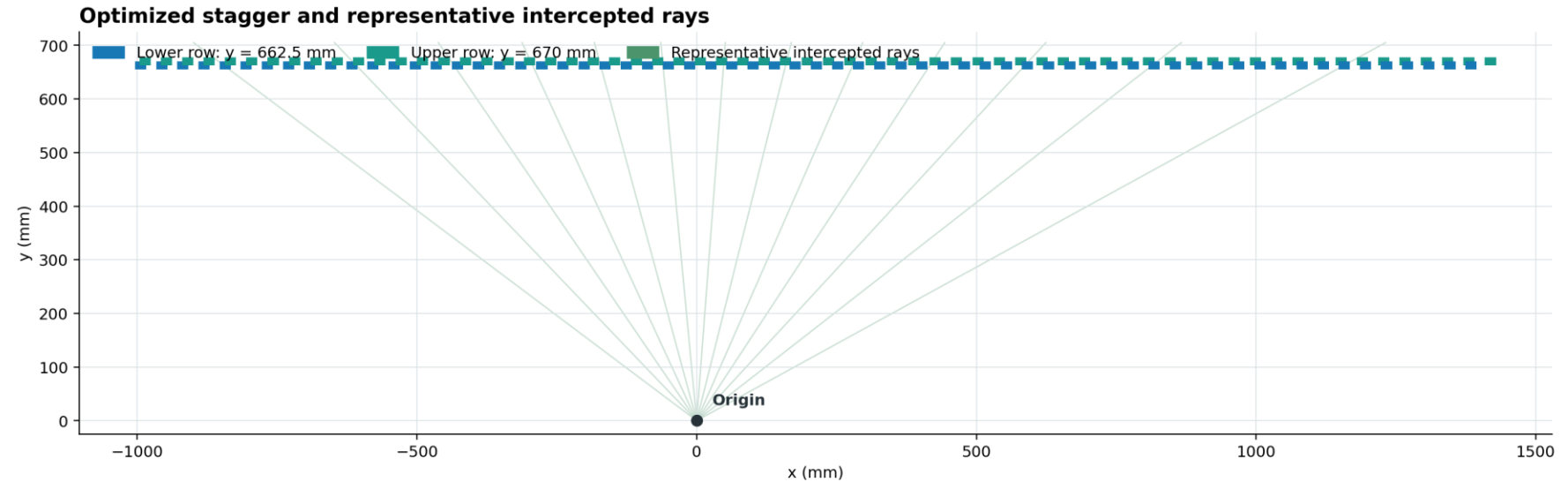
Angular interception: 108.13° hit (89.03%) | 13.33° gap (10.97%)



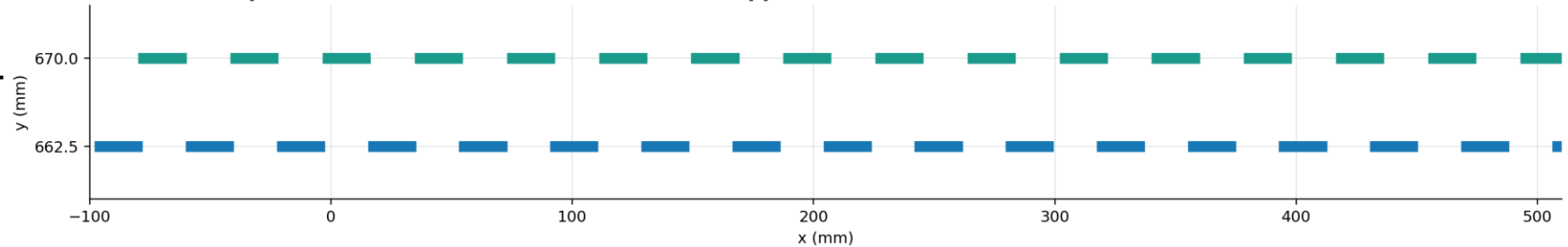
Stave Sensor Eta Coverage Possible Solution

- Image to right is generated by AI and has not been validated but is useful for illustrating the solution.
- The current pitch of the sensors is 38mm. Making the pitch of the inner and outer stave sensors different forces them out of sync.
- Sensor overlap is maintained at low eta with nearly perpendicular tracks and recovered at high eta with tracks at the respective angle.
- This recovers the gaps, but requires a “tuned” design, meaning the forward and backward staves would need to be assembled differently (but with the same parts). Also, if the stave radius changes, so does the sensor pitch.

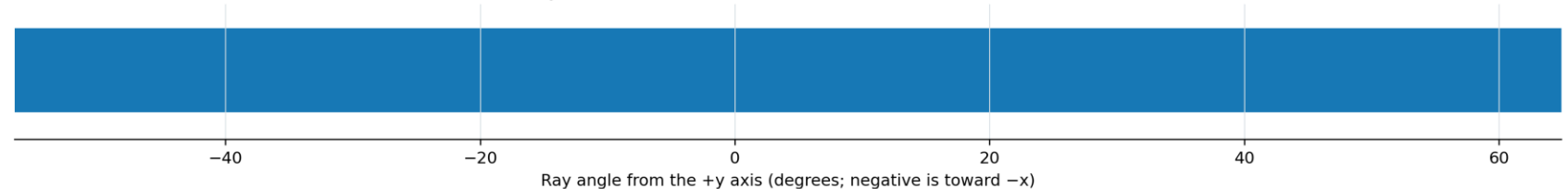
Optimized angular coverage of 128 staggered 20 mm segments



Constant row pitches: 37.750 mm lower and 38.177 mm upper



Angular interception: 121.46° hit (100.00%) | 0.0000° gap



Stave Width and Phi Coverage

Requirements

- The number of staves to be a multiple of 12
- The minimum side-to-side clearance between staves to be 5mm

This looks at the phi coverage as a function of stave width given the same requirements

Width (mm)	QTY (ul)	Pitch (deg)	Coverage (PHI) (%)	Overlap (mm)	Clearance (mm)
50	144	5.00	110.05	2.85	6.20
55	132	5.45	100.88	0.27	6.60
60	120	6.00	91.70	-2.45	7.75

Assumptions

- Purely geometric calculation (straight tracks)
- Stave centers at radius of 650mm or 675mm

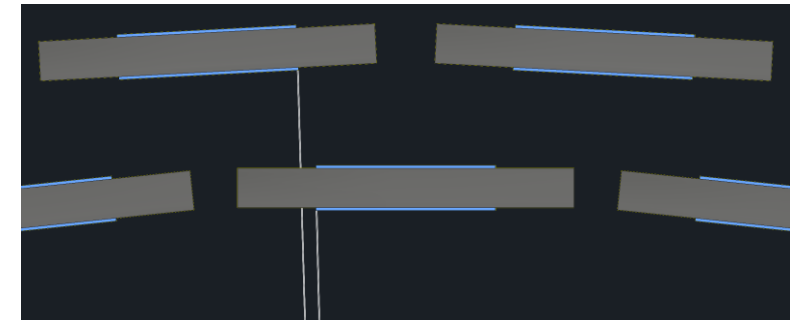
50mm Width



55mm Width



60mm Width



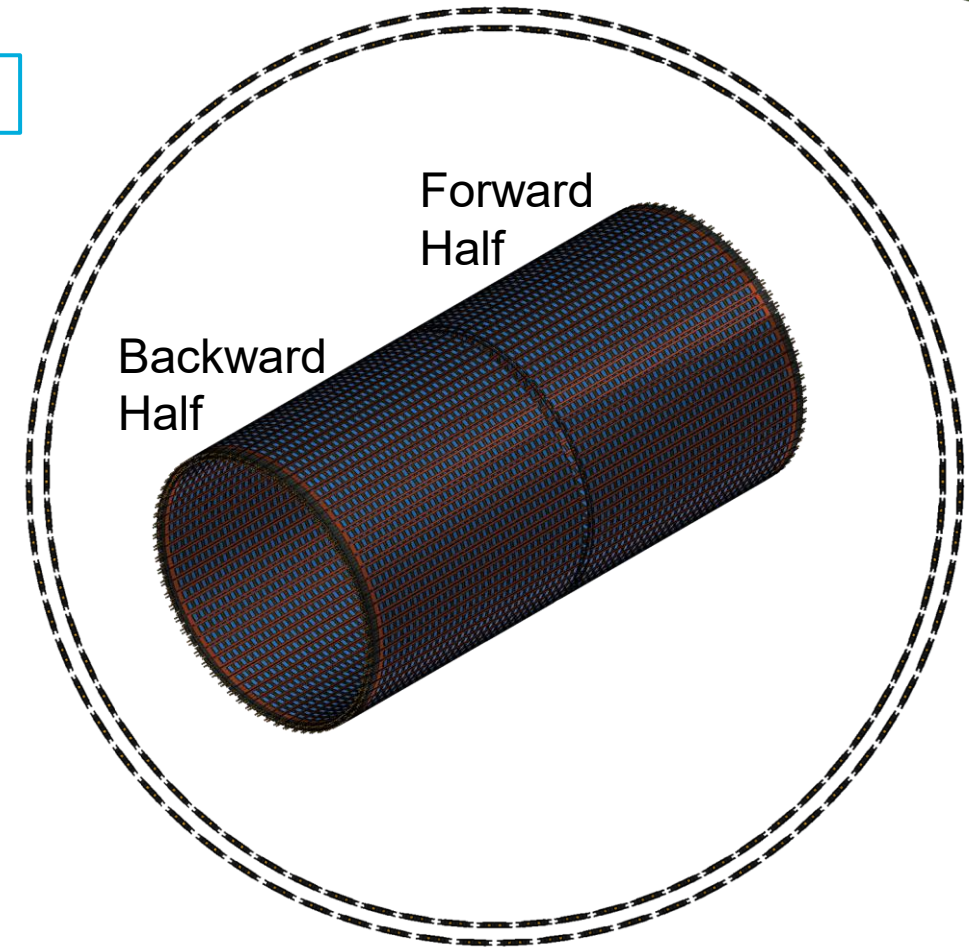
Barrel Design – Layout

- The integration efforts have led to the barrel to be divided into 12 sectors in phi and each of which is divided in half in eta.
- The ToF is supported by the GST (global support tube, a carbon fiber cylinder) by it's OD, installed on rails and must support the inner MPGD detector.
- There are often two approaches to achieve full hermetic coverage in phi by over lapping staves, one is to tilt the ladders and the other is to alternate the staves in radius.
- Either solution requires the active area be greater than 60% of the total width to allow for sufficient clearance and alternating ladders results in more clearance.
- All of this results in a 12-stave sector for both halves or $12 \times 12 \times 2 = 288$ staves in total.

Sector

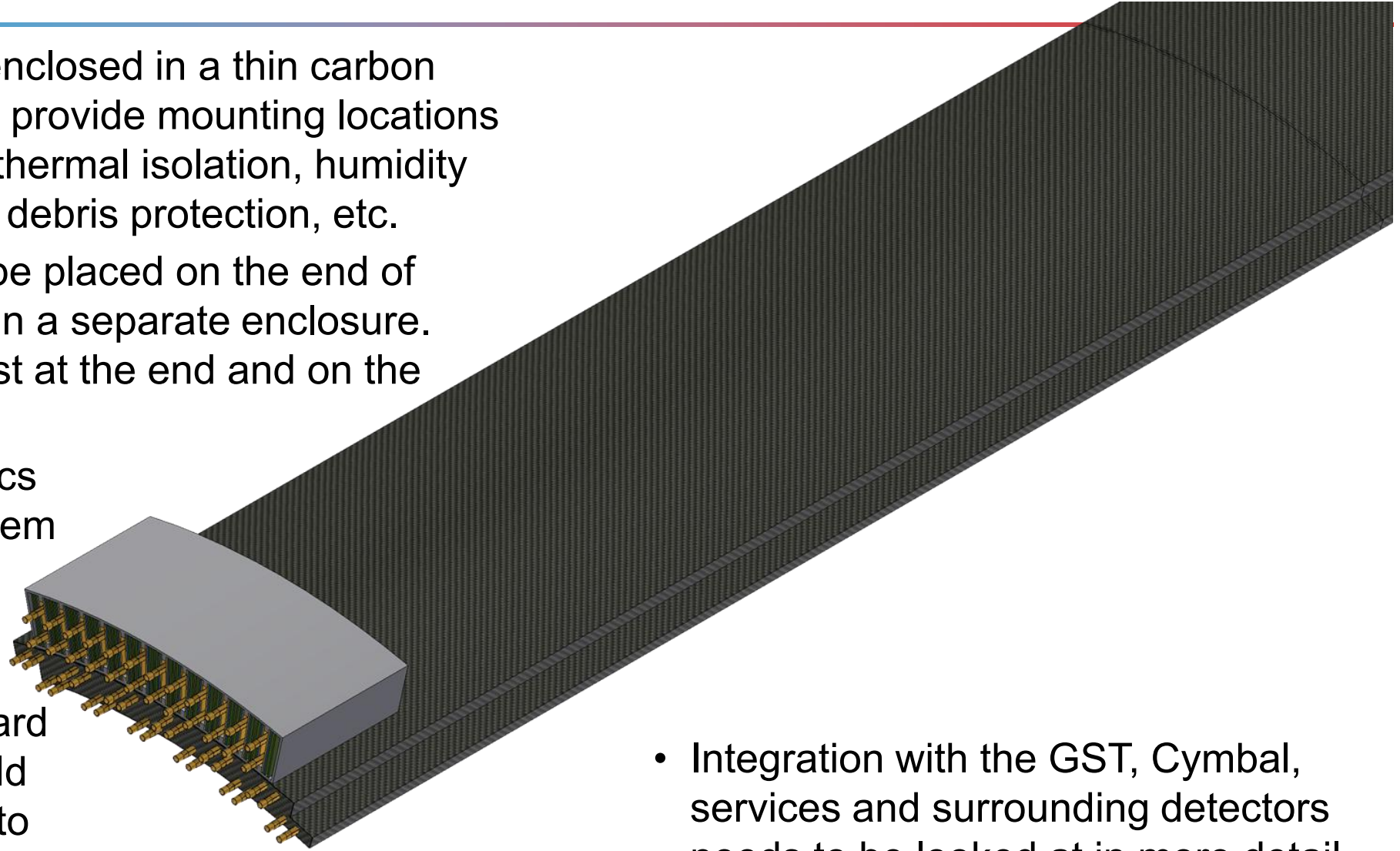


Barrel



Sector Design

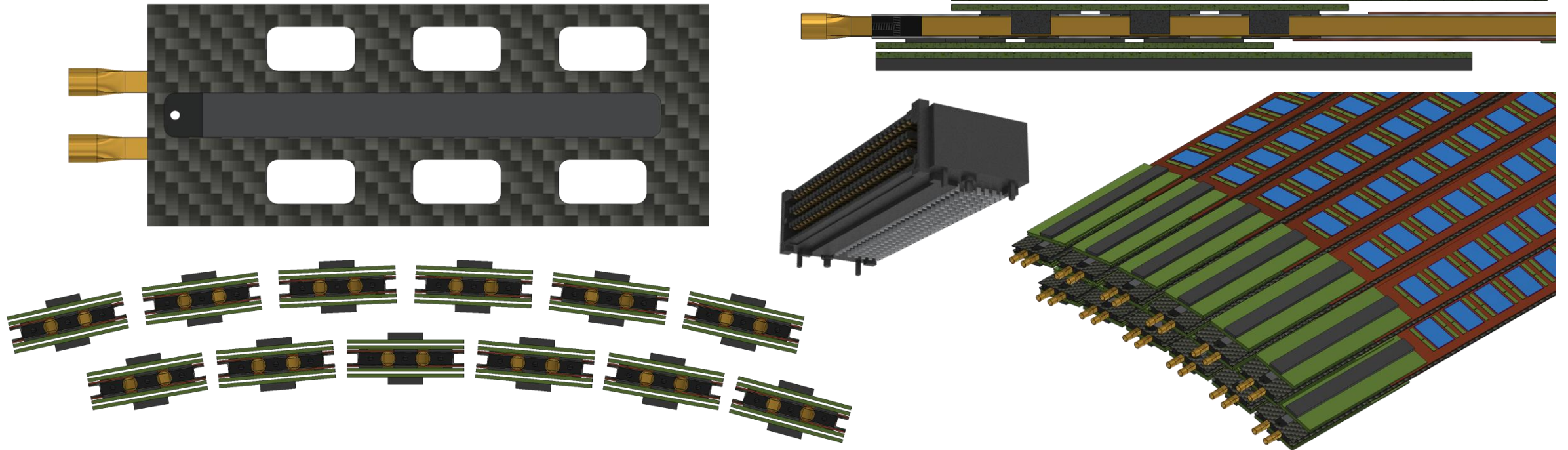
- Each sector should be enclosed in a thin carbon fiber enclosure. This will provide mounting locations for the installation rails, thermal isolation, humidity control, mechanical and debris protection, etc.
- The service hybrid can be placed on the end of each stave or collected in a separate enclosure. That enclosure could rest at the end and on the outside of the sector.
- Separating the electronics from the stave makes them easier to replace and allows the cooling to be controlled separately.
- The forward and backward halves attachment should be carefully considered to minimize the effect of the GST deflection on the ToF



- Integration with the GST, Cymbal, services and surrounding detectors needs to be looked at in more detail.

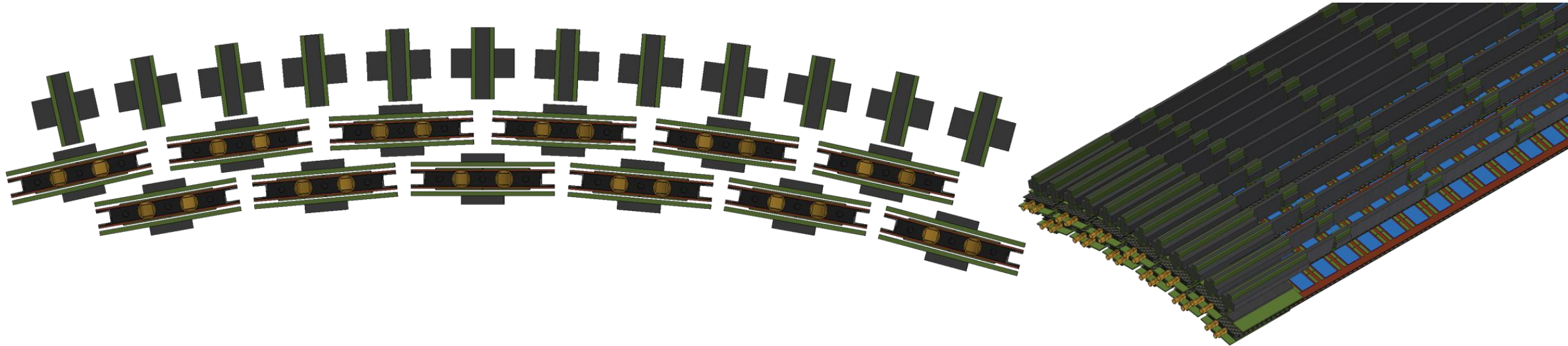
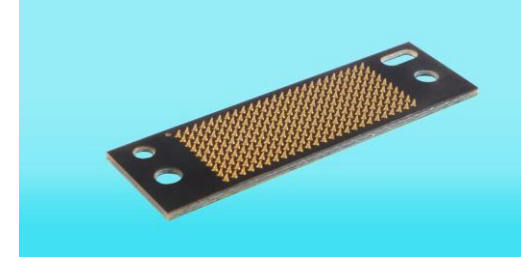
Service Hybrid Ideas – Option A

- Have the DC-DC converters and LDOs protrude into the stave and locally remove the stave core.
- Allows for the converters, LDOs and stave occupy the same radial space, reducing the overall stack up to ~22mm.
- Could consider cutting the stave short of the service hybrid and having a separate structure
- Using 90deg connectors would then allow the service hybrid to be removed separately without the need to remove the sector or stave

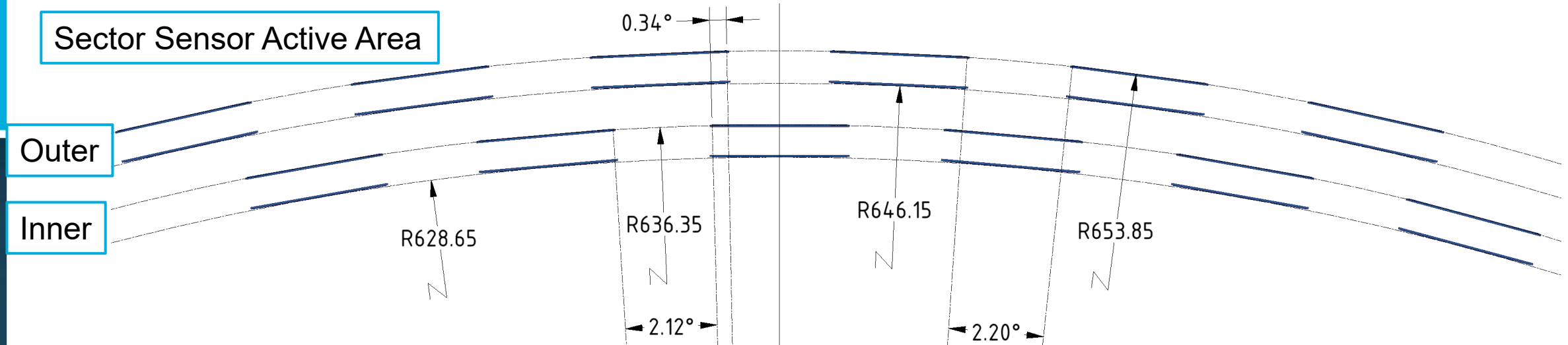


Service Hybrid Ideas – Option B

- Remove power pcb from stave entirely
- Have separate stave for power bd and jumpers between the power stave and sensor stave
- Separating the power pcb from the stave allows the cooling to be controlled separately.
- Could consider using a low-profile interposer style connector between signal pcb and FPC.



Design Summary Table



Layer	Radius (mm)	Pseudo rapidity	QTY of Ladders	Coverage (PHI) (%)	Clearance (mm)	Power (kW)	Radiation Length (%)
Inner	628.65 / 636.35	+1.49 / -1.16	72 / 144	58	5.0	6 / 12	3.55
Outer	646.15 / 653.85	+1.47 / -1.14	72 / 144	56	6.5	6 / 12	3.55
Total	-	+1.47 / -1.14	144 / 288	100	10.4	12 / 24	7.10

- There will be a ~25 mm gap between forward and backward halves (less if using half sensors)
- We may need a small gap in coverage at sector boundaries to allow for the GST deflection.
- Nearly half of the radiation length comes from the brass tube, this should be looked at to optimize
- Could consider reducing number of ladders as phi overlap of staves is maybe more than needed

Options, Needed Info and Next Steps

Options

- There are a few options for materials, carbon fiber layups, and configurations that should be explored.
- This design has the silicon directly mounted to the FPC, though a smaller intermediate FPC is being discussed.
 - The advantage is that the smaller FPCs can be QC'd separately, making for easier rework or higher yield.
 - The concerns are that the smaller FPC will not be flat and will result in worse thermal performance, more material and more difficult assembly.

Needed Info

- Is the 50mm or less width acceptable for the FPC?
- Can the silicon be centered on the width of the FPC?
- Dimensions and position of the ASICs.
- Are the wire bonds encapsulated? Assuming yes
- Design and thermal details of the service hybrid.

Next Steps

- Setup models for FEA.
- Add relevant details like needed info, epoxy joints, etc.
- Determine which material options and configurations to prioritize and implement.
- Run thermal, structural and model FEA.
- Interpret results and iterate.

First Pass FEA Results

Electron-Ion Collider



FEA Input

Structural and Modal

- Stave simply supported: One end held fixed, other end fixed except longitudinally.
- Boundary conditions applied to bolt holes in endcaps.
- Gravitational acceleration applied
- 450 gram distributed load applied to stave to represent FPC and silicon.

Materials

- Carbon Fiber: NT91500-520S, 0/90/0 layup
- Foam: Rohacell IG-F 110
- Endcaps: PEEK 450G
- Epoxy: EP75-1
- Cooling Tube: Brass
- Coolant: Water

Other materials are worth exploring. These are used as a baseline from previous experience and expert opinion.

Thermal

- Water temperature: 18C
- Water flow rate: 0.6l/m
- Water heat transfer coefficient: 500W/m²C
- No natural convection
- ASICs: 0.3125W each, 80W total
- Tube inner: 4.3mm square
- Service Hybrid not on stave

Structural FEA

Deflection
1.25mm

B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
9/1/2026 10:36:01 AM

1.258 Max
1.1182
0.97843
0.83865
0.69888
0.5591
0.41933
0.27955
0.13978
0 Min



Stress
21.5MPa

B: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
9/1/2026 10:36:43 AM

21.551 Max
19.156
16.762
14.367
11.973
9.5781
7.1836
4.7891
2.3946
3.3395e-5 Min



Strain
0.003mm/mm

B: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: mm/mm
Time: 1 s
9/1/2026 10:38:17 AM

0.0032293 Max
5e-5
4.3751e-5
3.7501e-5
3.1252e-5
2.5003e-5
1.8753e-5
1.2504e-5
6.2547e-6
5.3251e-9 Min



Modal FEA

Exaggerated for clarity

First Mode
20.5 Hz

C: Modal
Total Deformation
Type: Total Deformation
Frequency: 20.447 Hz
Unit: mm
9/1/2026 9:52:45 AM

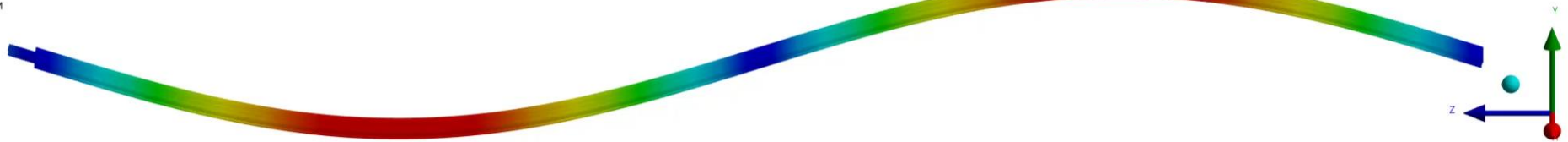
912.83 Max
811.41
709.98
608.56
507.13
405.7
304.28
202.85
101.43
0 Min



Second Mode
80 Hz

C: Modal
Total Deformation 2
Type: Total Deformation
Frequency: 79.994 Hz
Unit: mm
9/1/2026 9:58:16 AM

913.61 Max
812.1
710.58
609.07
507.56
406.05
304.54
203.02
101.51
0 Min



Third Mode
143 Hz

C: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 142.98 Hz
Unit: mm
9/1/2026 9:59:08 AM

916.76 Max
814.9
713.04
611.17
509.31
407.45
305.59
203.72
101.86
0 Min

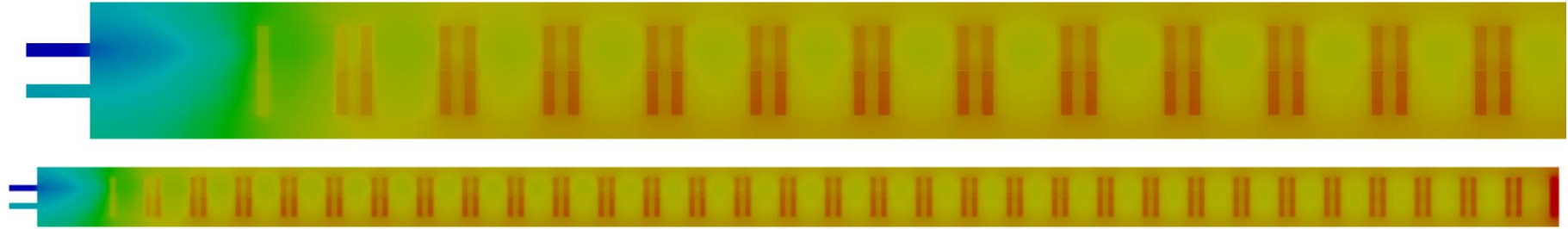


Thermal FEA

Temperature of Stave

D: Steady-State Thermal
Temperature
Type: Temperature
Unit: °C
Time: 1 s
9/1/2026 9:13:27 AM

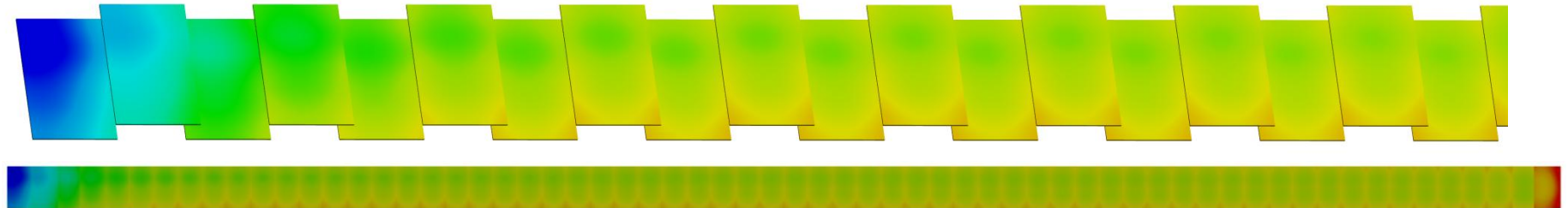
26.186 Max
25.277
24.367
23.457
22.548
21.638
20.729
19.819
18.91
18 Min



Temperature of Sensors

D: Steady-State Thermal
Temperature 2
Type: Temperature
Unit: °C
Time: 1 s
9/1/2026 9:18:30 AM

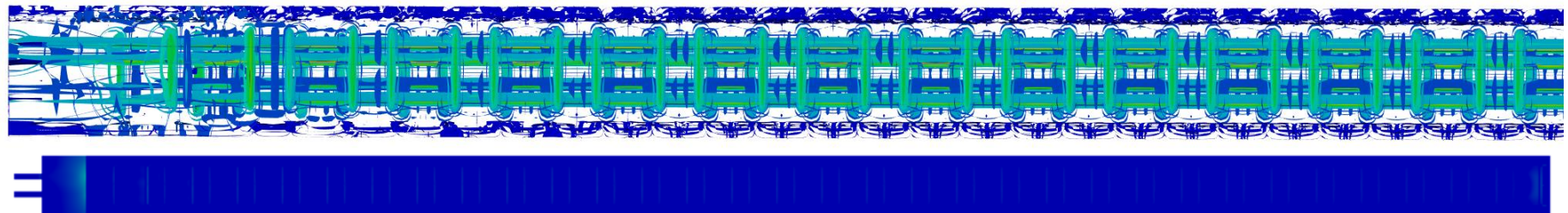
24.966 Max
24.623
24.279
23.935
23.591
23.248
22.904
22.56
22.216
21.873 Min



Heat Flux of Stave

D: Steady-State Thermal
Total Heat Flux
Type: Total Heat Flux
Unit: W/mm²
Time: 1 s
9/1/2026 9:24:58 AM

0.17132 Max
0.1
0.0875
0.075
0.0625
0.05
0.0375
0.025
0.0125
1.8194e-8 Min



FEA Summary and Conclusions

Structural and Modal

- Deflection is the driving factor, so stress and strain are very low.
- Deflection is fine, but higher than one might like
- First mode is fine, but lower than one might like
- Both can be improved with thicker or higher modulus CF, more CF “beams”, attaching adjacent staves at a few locations along Z, etc.

General

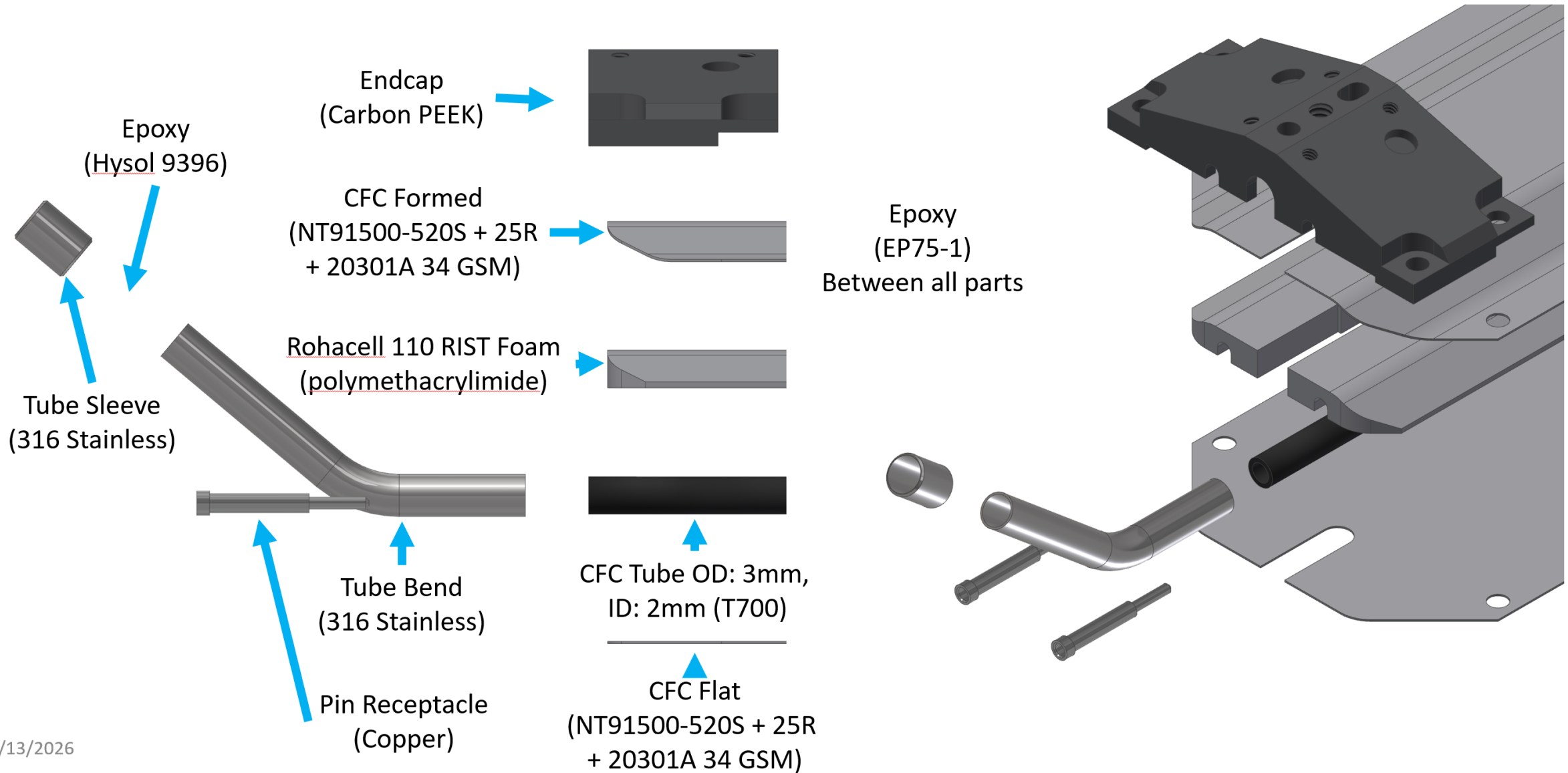
- This is the first results from a preliminary design.
- Structural results look reasonable but can use some optimization.
- Thermal results look good, can try to optimized more for radiation length if needed.
- There are several other options mentioned in the preceding slides that are also worth exploring in detail.

Thermal

- Temperatures across stave and sensors pretty uniform.
- Water temperature change 2C, as targeted.
- Pressure drop <7,000pa, should be fine for negative pressure system.
- Need to get a better understanding of surrounding thermal environment to determine thermal contribution.



Reference – sPHENIX Staves

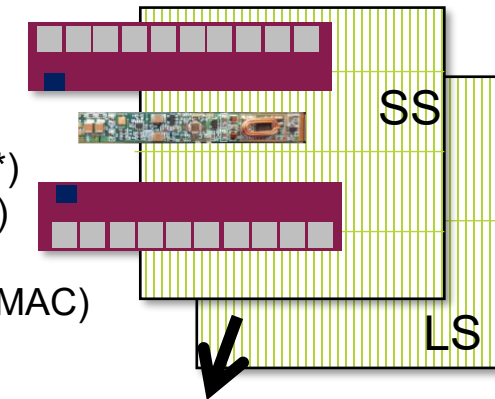


8/13/2026

Reference – ATLAS Staves

1 Sensor
+20(10) FE chips (ABC*)
+2(1) controllers (HCC*)
+2(1) hybrids
+1 Power board (incl. AMAC)
=1 SS(LS) Module

2 flavors:
SS short strip inner
LS long strip outer



x 28 +



+



=

