# ON THE SILICON TRACKER

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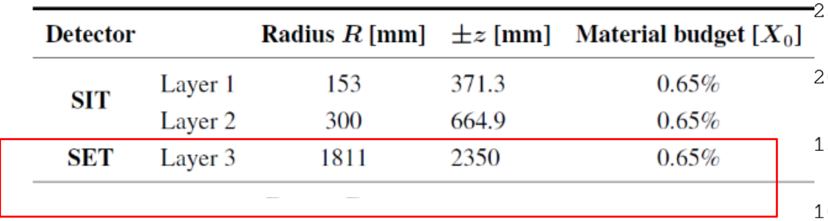
28 August 2020

# REQUIREMENTS

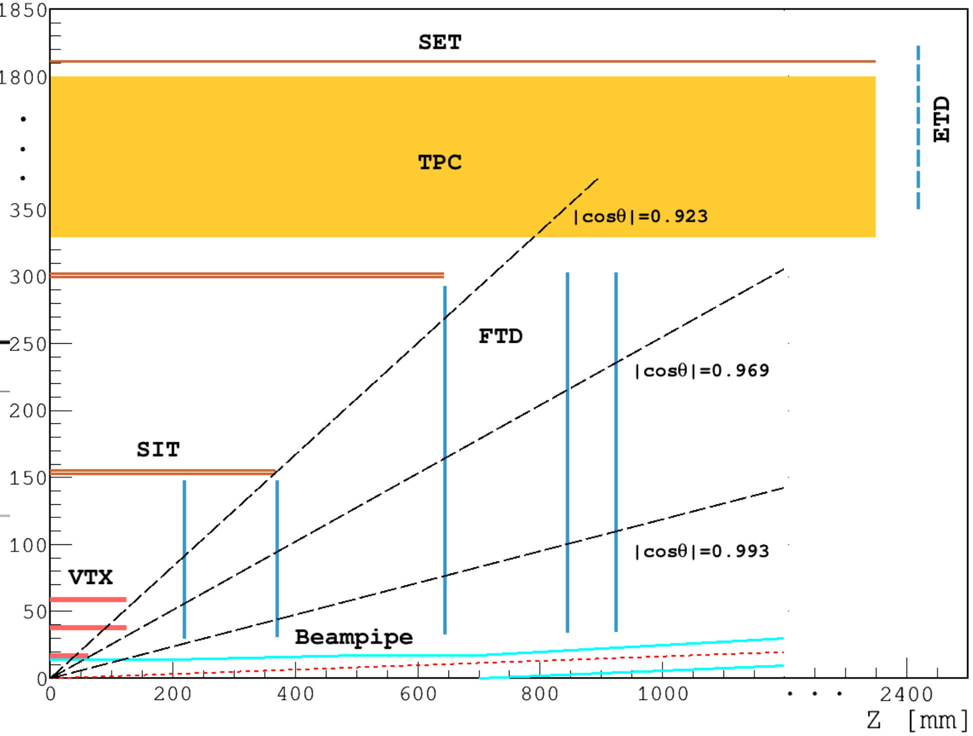
- **Large area tracking system** to deliver high track momentum resolution
- **Silicon tracker**: multiple high precision measurements along the track particle trajectory;
  - Spatial resolution $\sigma_{r\varphi} \sim 7\ \mu m$; time resolution $\sigma_t \sim 10\ ns$; low material budget, low cost

Silicon envelope



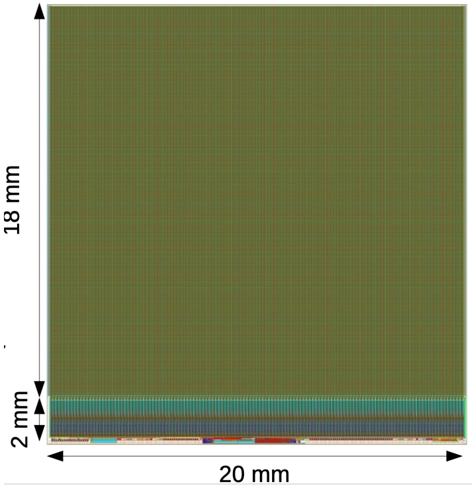
| Detector | | Radius $R$ [mm] | $\pm z$ [mm] | Material budget [$X_0$] |
|---|---|---|---|---|
| SIT | Layer 1 | 153 | 371.3 | 0.65% |
| | Layer 2 | 300 | 664.9 | 0.65% |
| SET | Layer 3 | 1811 | 2350 | 0.65% |

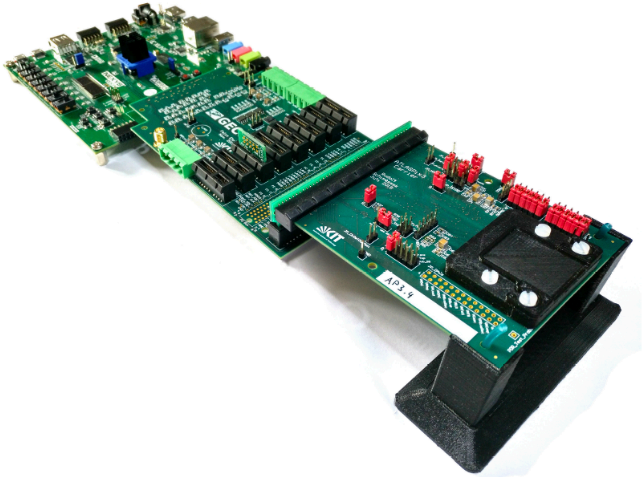
Long barrel



# SENSOR TECHNOLOGY: HV-CMOS

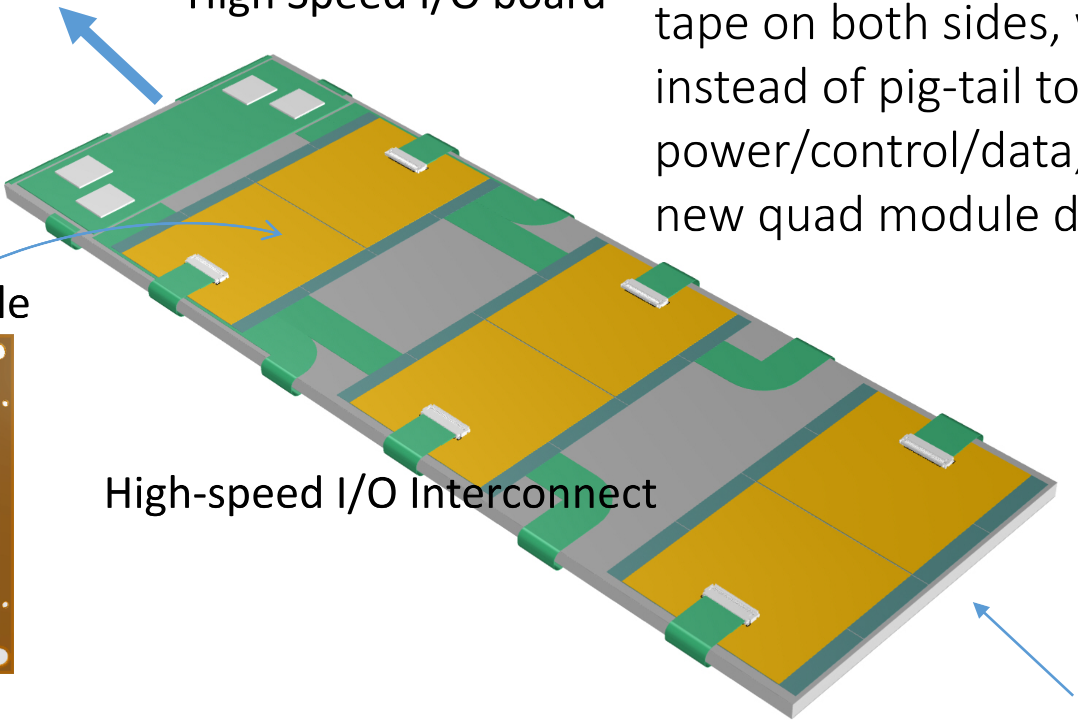
- HV-CMOS sensor can provide an alternative solution to conventional microstrip detectors for a large-area tracking system
    - lower cost, lower material budget, higher performance
- Adopted for Mu3e (MuPix), explored but dropped for the ATLAS ITk-Pixel/Strip (project time constraints), considered for the LHCb tracker upgrade, CLIC and CEPC silicon tracker + several other applications
- ATLASPix3 for performance evaluation and module/stave prototyping; next generation fabricated with a domestic process being considered





# BUILDING A DEMONSTRATOR

- To build a **short stave** to demonstrate the system feasibility → capability to readout multiple modules (reusing ATLAS designs/components)



Felix based DAQ

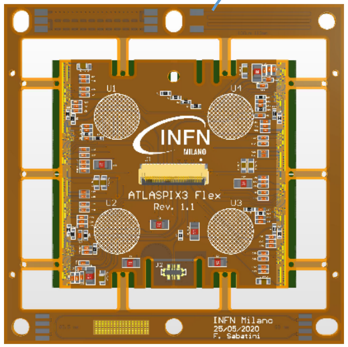
High Speed I/O board

**Alternative design (RAL)**: bus tape on both sides, wire bond instead of pig-tail to route power/control/data, with new quad module design

High-speed I/O Interconnect

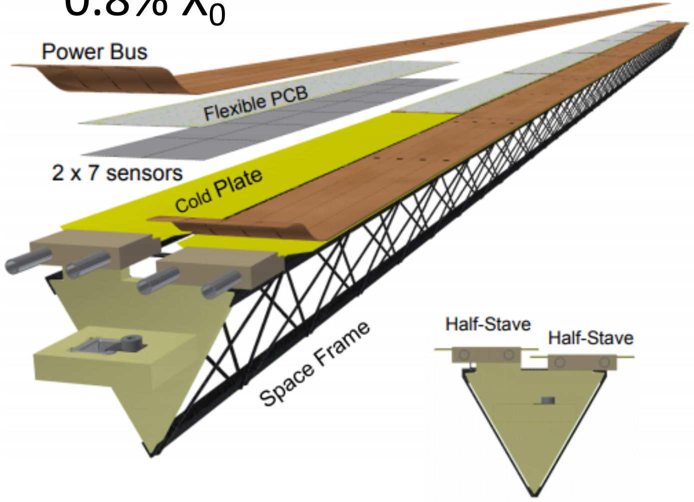
Thermo-mechanical support (ATLAS ITk-Pix/Strip)

Milano Quad-Module

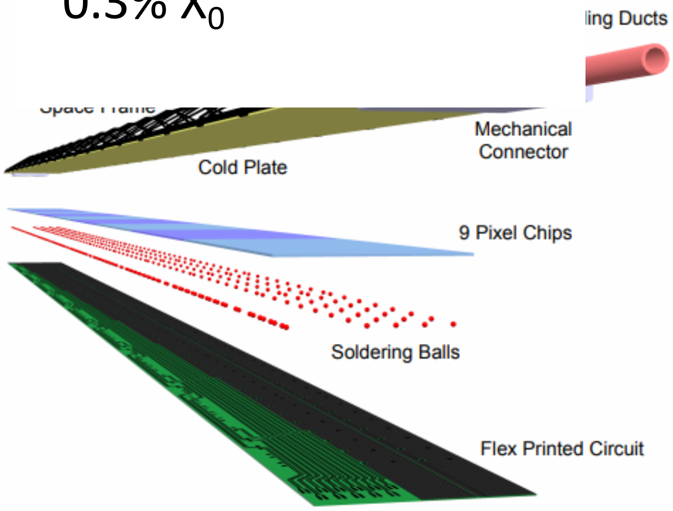


# SUPPORTING STRUCTURES

ALICE Outer Layer Stave
~0.8% $X_0$

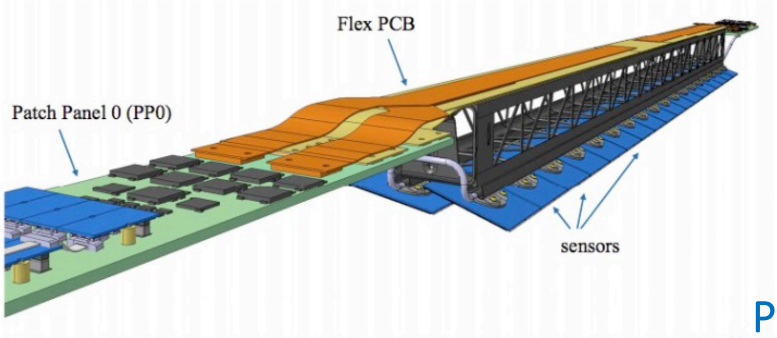


ALICE Inner Layer Stave
~0.3% $X_0$



ATLAS-ITK: 0.5% $X_0$ ITK alpine stave (+module)

ATLAS IBL: 0.7% $X_0$ IBL stave, (+module)



**CEPC design target:**

0.65% $X_0$ for stave + modules

Crucial elements:

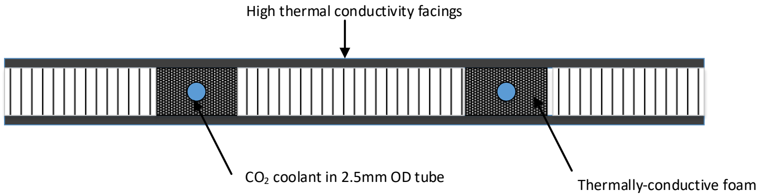
- Light-weighted carbon truss structure
- Al based flex (prototype with Cu)

Possibility to produce them in China to be explored

# SUPPORTING STRUCTURE FOR DEMONSTRATOR

## ATLAS ITk Strip

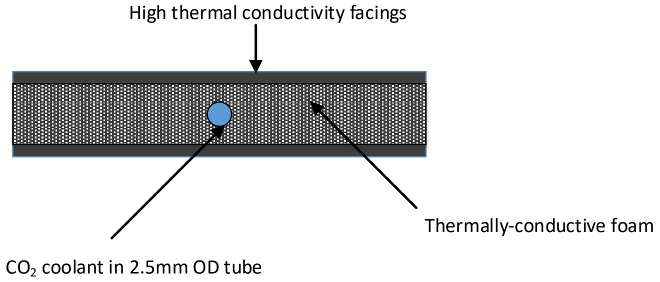
Power dissipation: 60 mW/cm$^2$



Support, electrical services & cooling,
Material budget: 0.7%$X_0$

## ATLAS ITk-Pixel

Power dissipation: 700 mW/cm$^2$



Support, electrical services & cooling,
Material budget: 1.5%$X_0$

## Demonstrator

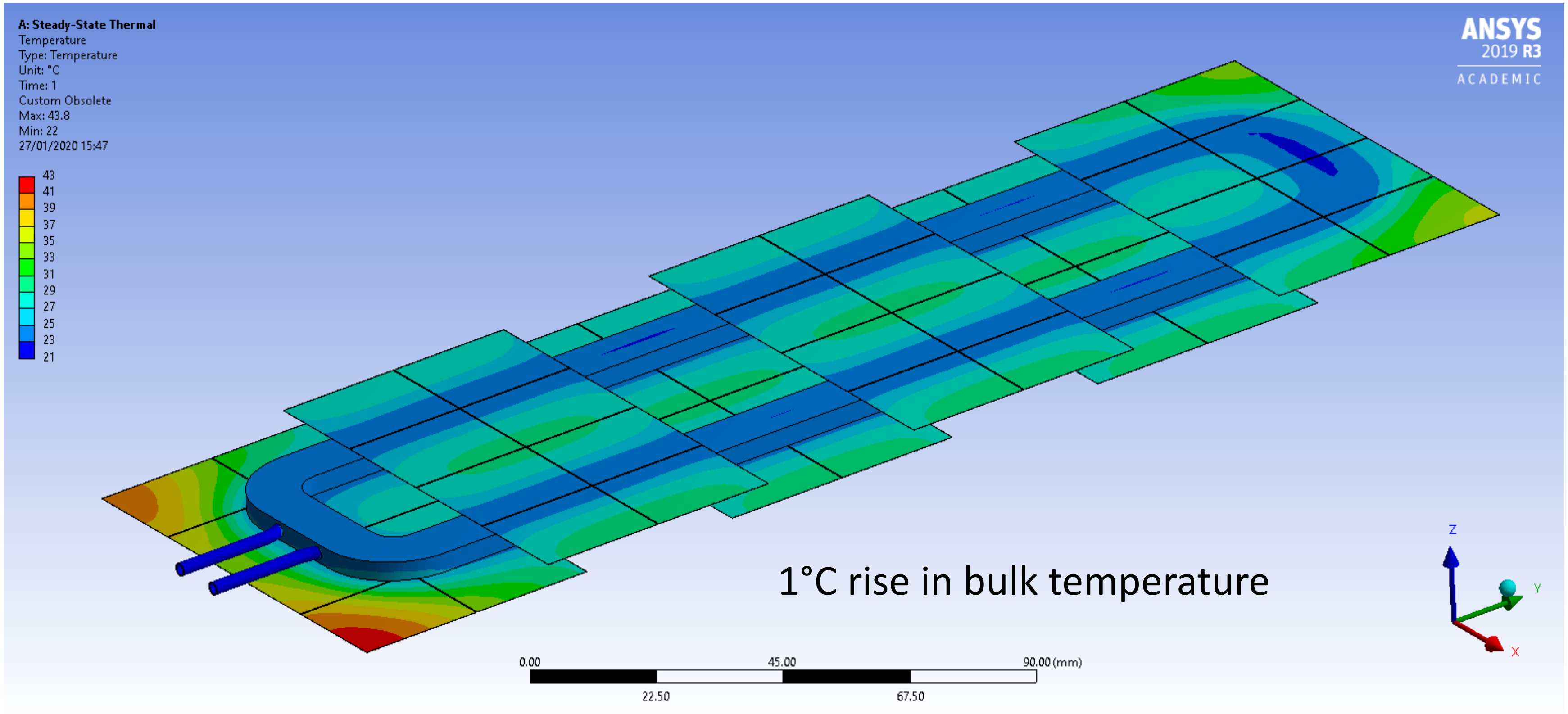
↓

Can be scaled up to a full barrel stave

| Parameter | Value | Units |
|---|---|---|
| Active Length | 248.2 | mm |
| Active Width | 80.6 | mm |
| Number of Quad Modules | 12 | |
| Number of HV-CMOS ASICs | 48 | |
| HV-CMOS ASIC Dimensions | 20 x 22 | mm |
| Total HV-CMOS area | 211.2 | cm$^2$ |
| Total Power (@0.14W/cm$^2$) | 27 | W |

# FEA

T. Jones (Liverpool)

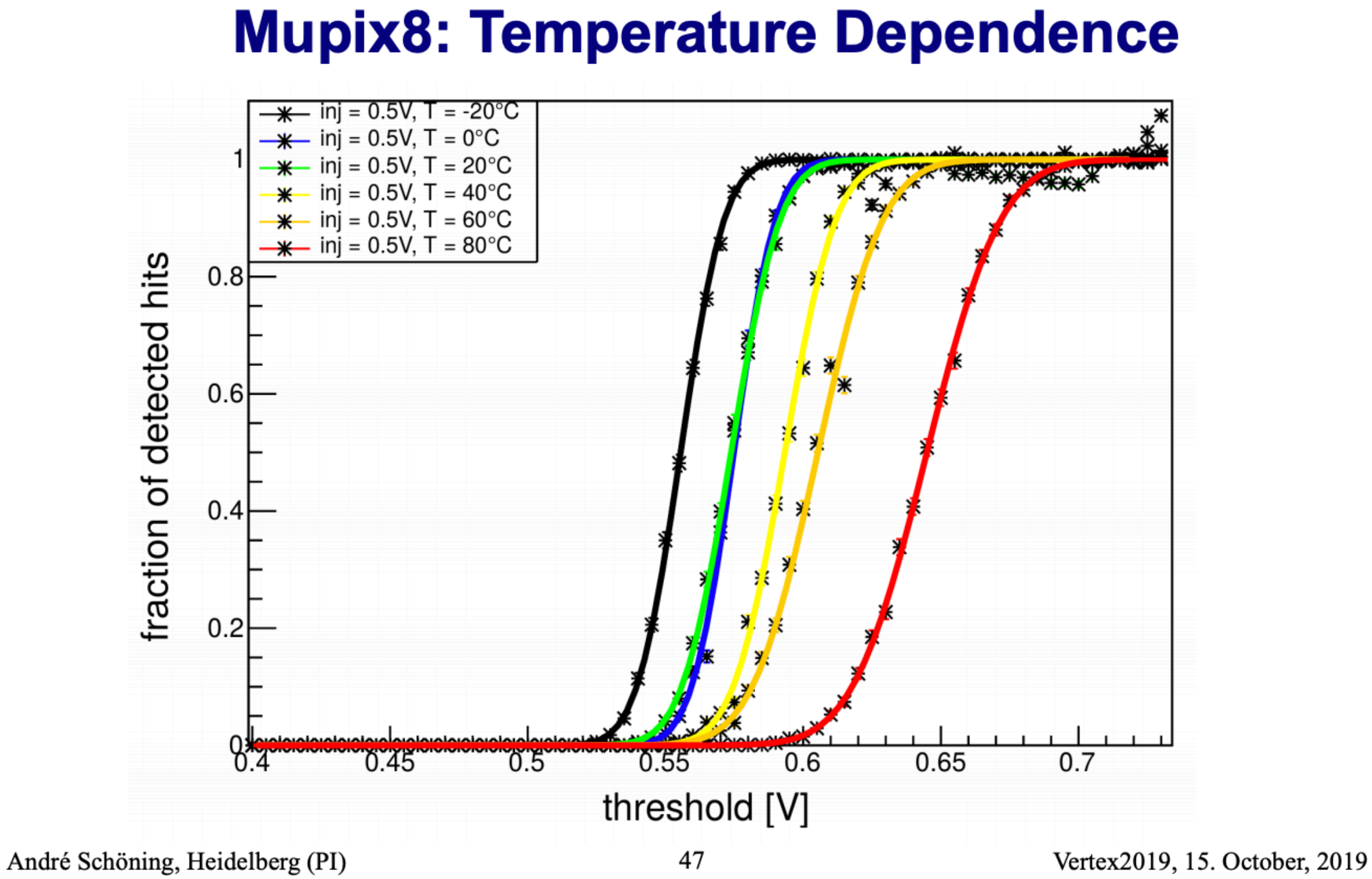


1°C rise in bulk temperature

- ATLAS ITk-Strip structure with water cooling (not $CO_2$) to cope with total power dissipation of 28 W (ATLASPix3) + ? (I/O board)
- Assume for $T_{ASIC}$ = 30 °C and on/off temperature rise $\Delta T_{Off/On}$ = 20 °C

# COOLING & TEMPERATURE CONTROL

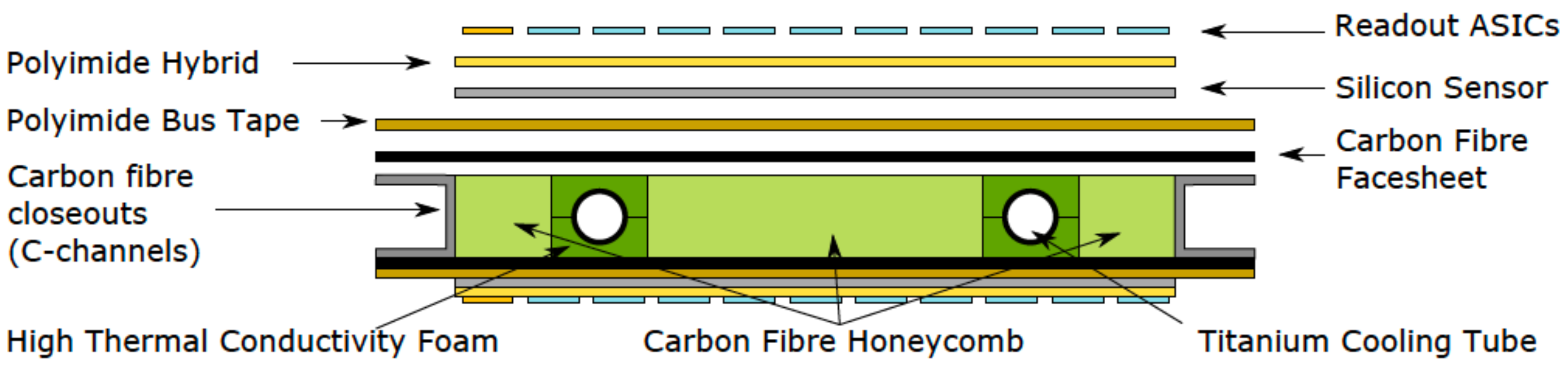
- Temperature dependent performance of HV-CMOS sensors; temperature variation tolerance?



**Mupix8: Temperature Dependence**

André Schöning, Heidelberg (PI) 47 Vertex2019, 15. October, 2019

# MATERIAL BUDGET



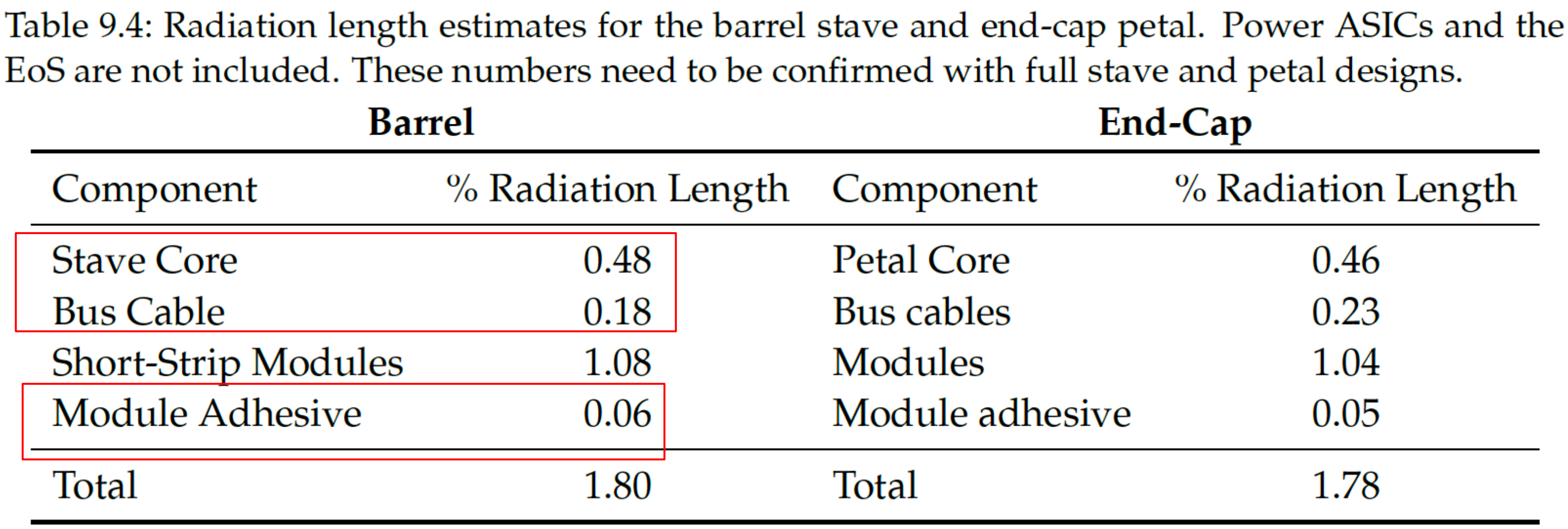


Table 9.4: Radiation length estimates for the barrel stave and end-cap petal. Power ASICs and the EoS are not included. These numbers need to be confirmed with full stave and petal designs.

| **Barrel** | | **End-Cap** | |
|---|---|---|---|
| Component | % Radiation Length | Component | % Radiation Length |
| Stave Core | 0.48 | Petal Core | 0.46 |
| Bus Cable | 0.18 | Bus cables | 0.23 |
| Short-Strip Modules | 1.08 | Modules | 1.04 |
| Module Adhesive | 0.06 | Module adhesive | 0.05 |
| Total | 1.80 | Total | 1.78 |

# DEMONSTRATOR MATERIAL BUDGET

## Stavelet Demonstrator

| Stave el | Comp | Material | Thick [um] | X0 [cm] | X0[%] |
|---|---|---|---|---|---|
| Module | FPC metal | Al<br>(Cu) | 50 | 8.896<br>(1.435) | 0.056<br>(0.348) |
| | FPC insulat | Polyimide | 100 | 28.41 | 0.035 |
| | ASIC | Silicon | 100<br>(150) | 9.369 | 0.106<br>(0.160) |
| | Glue | Eccobond 45 | 100 | 44.37 | 0.023 |
| | Total (Al and Si 100um)<br>Total (Al and Si 150um)<br>Total (Cu and Si 150um) | | | | 0.22<br>0.274<br>0.566 |
| Everything else | Total | | | | 0.6 |
| Total (Module Al and Si 100um)<br>Total (Module Al and Si 150um)<br>Total (Module Cu and Si 150um) | | | | | 0.82<br>0.874<br>1.166 |

## ALICE Outer Layer Stave

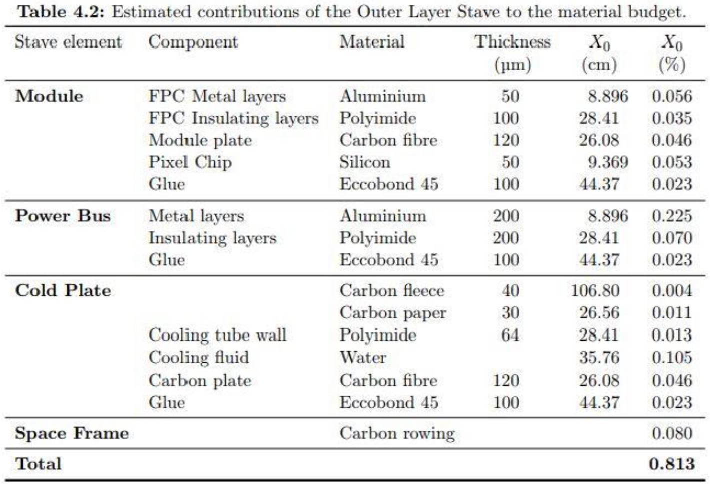


**Table 4.2:** Estimated contributions of the Outer Layer Stave to the material budget.

| Stave element | Component | Material | Thickness (μm) | $X_0$ (cm) | $X_0$ (%) |
|---|---|---|---|---|---|
| **Module** | FPC Metal layers | Aluminium | 50 | 8.896 | 0.056 |
| | FPC Insulating layers | Polyimide | 100 | 28.41 | 0.035 |
| | Module plate | Carbon fibre | 120 | 26.08 | 0.046 |
| | Pixel Chip | Silicon | 50 | 9.369 | 0.053 |
| | Glue | Eccobond 45 | 100 | 44.37 | 0.023 |
| **Power Bus** | Metal layers | Aluminium | 200 | 8.896 | 0.225 |
| | Insulating layers | Polyimide | 200 | 28.41 | 0.070 |
| | Glue | Eccobond 45 | 100 | 44.37 | 0.023 |
| **Cold Plate** | | Carbon fleece | 40 | 106.80 | 0.004 |
| | | Carbon paper | 30 | 26.56 | 0.011 |
| | Cooling tube wall | Polyimide | 64 | 28.41 | 0.013 |
| | Cooling fluid | Water | | 35.76 | 0.105 |
| | Carbon plate | Carbon fibre | 120 | 26.08 | 0.046 |
| | Glue | Eccobond 45 | 100 | 44.37 | 0.023 |
| **Space Frame** | | Carbon rowing | | | 0.080 |
| **Total** | | | | | **0.813** |

## ALICE Inner Layer Stave

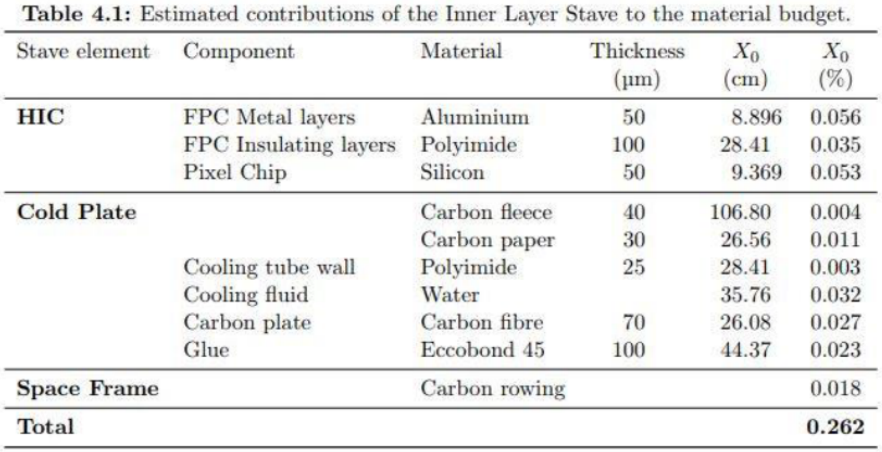


**Table 4.1:** Estimated contributions of the Inner Layer Stave to the material budget.

| Stave element | Component | Material | Thickness (μm) | $X_0$ (cm) | $X_0$ (%) |
|---|---|---|---|---|---|
| **HIC** | FPC Metal layers | Aluminium | 50 | 8.896 | 0.056 |
| | FPC Insulating layers | Polyimide | 100 | 28.41 | 0.035 |
| | Pixel Chip | Silicon | 50 | 9.369 | 0.053 |
| **Cold Plate** | | Carbon fleece | 40 | 106.80 | 0.004 |
| | | Carbon paper | 30 | 26.56 | 0.011 |
| | Cooling tube wall | Polyimide | 25 | 28.41 | 0.003 |
| | Cooling fluid | Water | | 35.76 | 0.032 |
| | Carbon plate | Carbon fibre | 70 | 26.08 | 0.027 |
| | Glue | Eccobond 45 | 100 | 44.37 | 0.023 |
| **Space Frame** | | Carbon rowing | | | 0.018 |
| **Total** | | | | | **0.262** |

# BEYOND THE DEMONSTRATOR

- Improved design over the ATLAS ITk-Strip stave structure (less material) or new design of a long truss structure with sufficient rigidity
  - Sufficient cooling capacity, alignment/monitoring with laser

ALICE

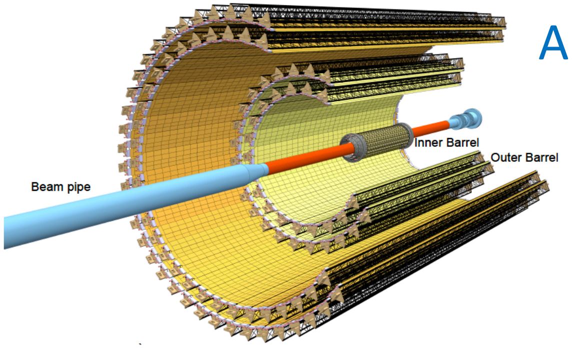
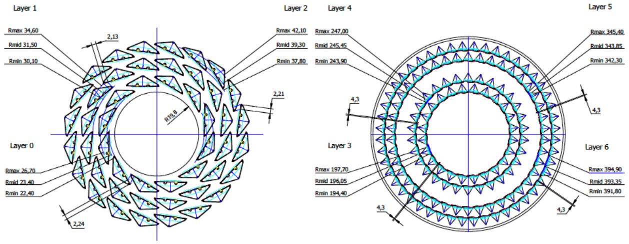
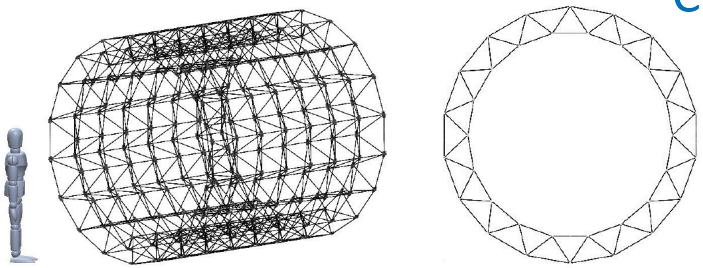


Figure 1.1: Layout of the new ITS detector.

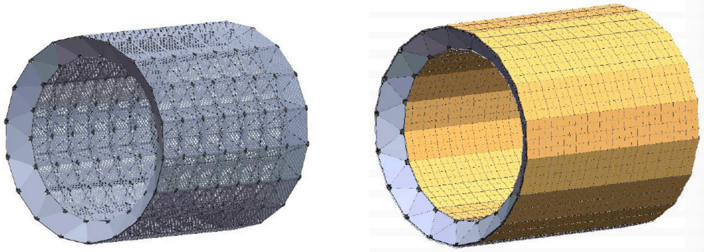


CLIC



a) Isometric view of the space frame

b) Side view of the space frame

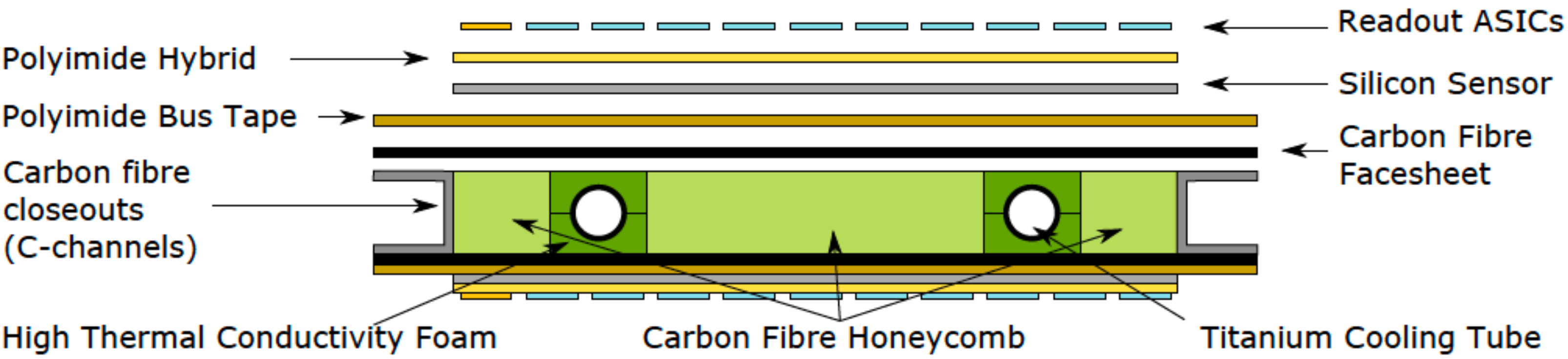


c) Space frame with composite panels installed

d) Space frame with modules installed

- Reliable power distribution, data/clock transmission over long distance

# MODULE MATERIAL CALCULATION



Readout ASICs

Polyimide Hybrid

Silicon Sensor

Polyimide Bus Tape

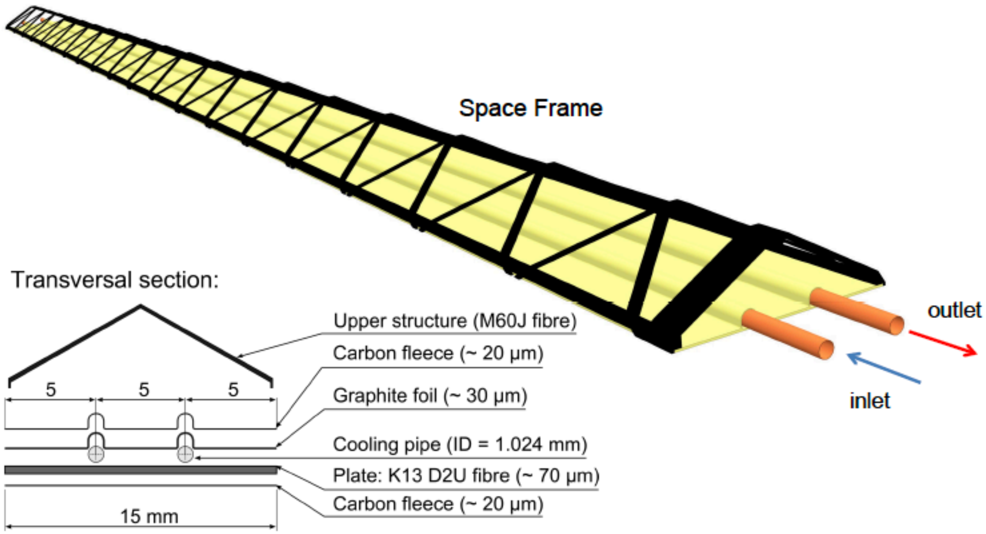
Carbon Fibre Facesheet

Carbon fibre closeouts (C-channels)

High Thermal Conductivity Foam

Carbon Fibre Honeycomb

Titanium Cooling Tube



# MODULE MATERIAL CALCULATION

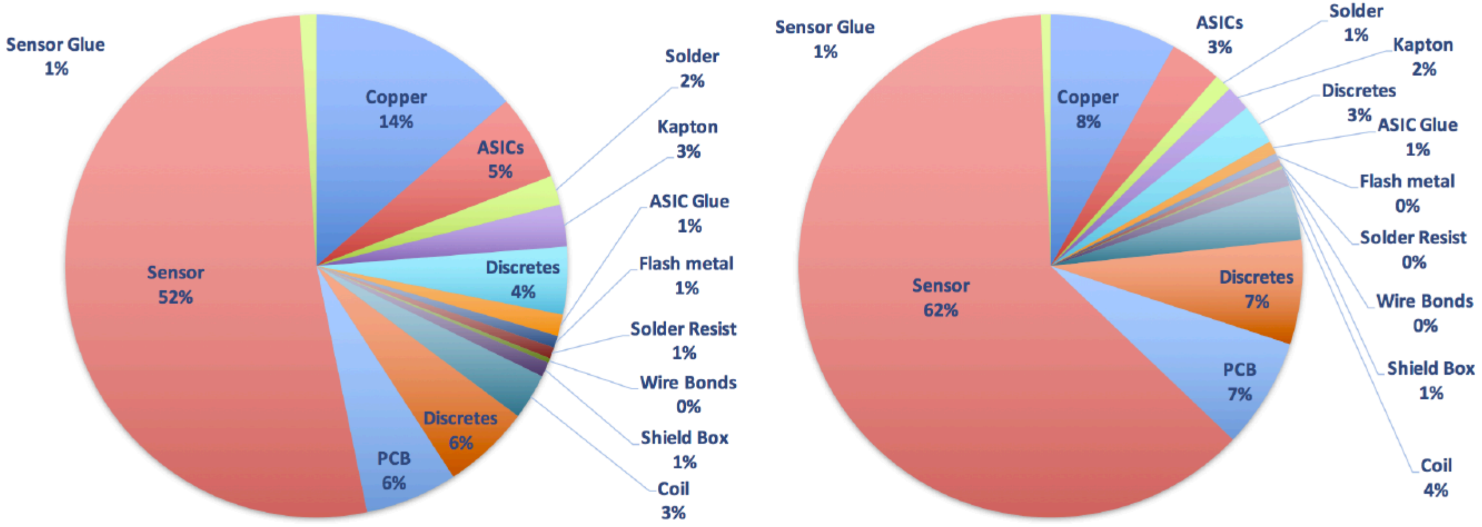


Figure 7.4: Fractional contributions for different materials to the radiation length of the barrel modules. Left: Short-strip barrel module. Right: Long-strip barrel module.

0.65% $X_0$

0.55% $X_0$