Cooling Examples

SiTracker Meeting
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Harald Fox

Power & Cooling

ALICE:

- small fill factor CMOS design
- 40mW/cm^2
- Polyimid cooling pipe
- Water coolant
  - max 500mW/cm^2
  - 150mW/cm^2 cooling power
  - (50mW/cm^2 for end-of-stave cooling)

ATLAS:

- >350 mW/cm^2
- bi-phase CO2 as coolant
- Ti cooling pipe

ATLASPix3:

- large fill factor CMOS design
- high efficiency and 25ns demonstrated!

- 140mW/cm^2 w/o serial powering
  - amplifier + comparator / digital 1.25V*100mA + 1.8V*250mA
  - comparator in NMOS consumes power
  - MuPix uses CMOS in periphery, better in power
  - original estimate was ~340 mW/cm^2
  - Caveat: Power estimated at what occupancy?
- Power depends on readout speed and occupancy!
- CMOS can run at high ΔT
- ATLASPix is optimised for radiation hardness. This design choice can be traded against power consumption

CEPC tracker designs: TPC/Si

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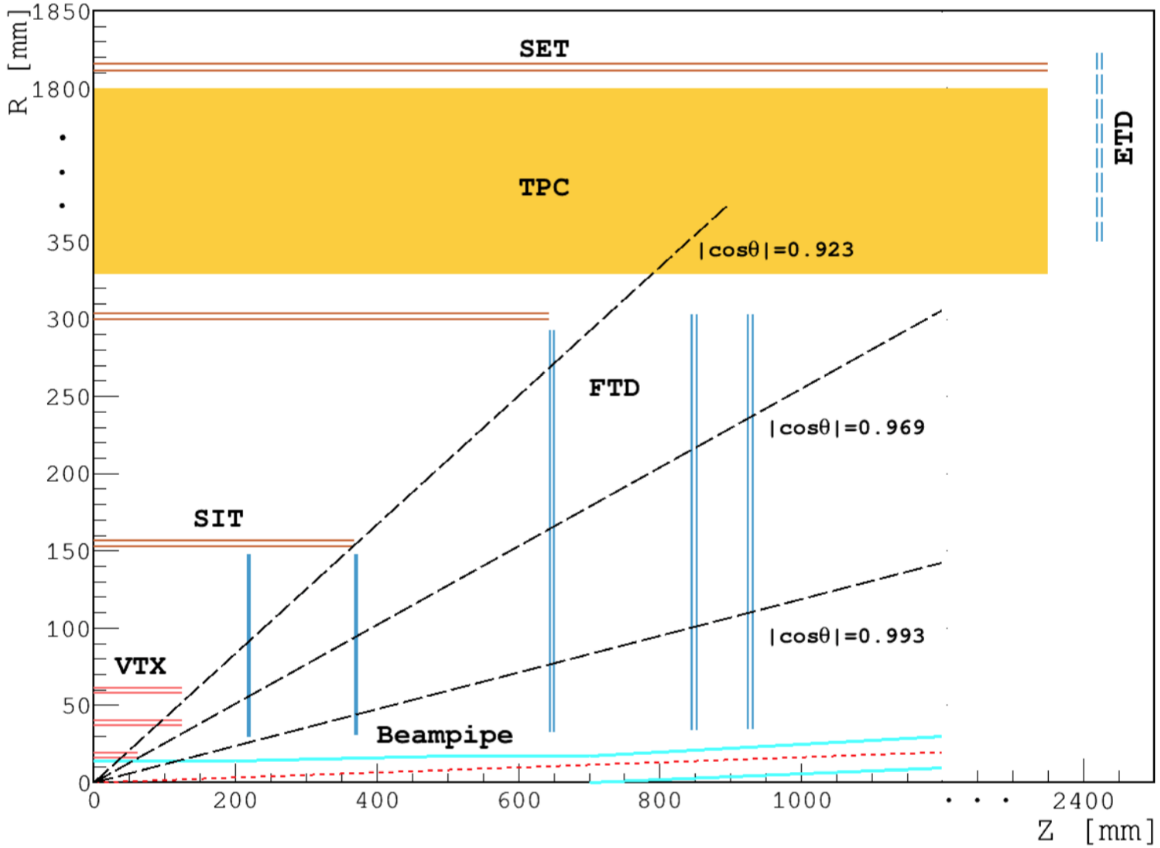
Baseline tracker design: TPC

and 3 layers / 5 disks of silicon sensors,

5.12 + 19.8 (ETD) + 53.5 (SET) = 78.4 m^2 in CMOS pixels



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%
		R_{in}	R_{out}		
FTD	Disk 1	39	151.9	220	0.50%
	Disk 2	49.6	151.9	371.3	0.50%
	Disk 3	70.1	298.9	644.9	0.65%
	Disk 4	79.3	309	846	0.65%
	Disk 5	92.7	309	1057.5	0.65%
ETD	Disk	419.3	1822.7	2420	0.65%

Operation mode	H (240)	W (160)	Z (91)
Track multiplicity (BX^{-1})	310	300	32
Bunching spacing (ns)	680	210	25
SIT-L1 occupancy (%)	0.19	0.58	0.52
FTD-D1 occupancy (%)	0.17	0.54	0.48

Table 4.6: Estimated occupancies of the first layers of the SIT (SIT-L1) and the FTD (FTD-D1). See context for more details.

40 - 300 mW/cm^2 power consumption

For 5 - 80m^2 we have to plan with 2 - 32kW of power

ClicDet: Air Cooling

Assumptions: 50mW/cm^2; vertex detector; barrel only; airflow between layers

2.2 - 12 m/s

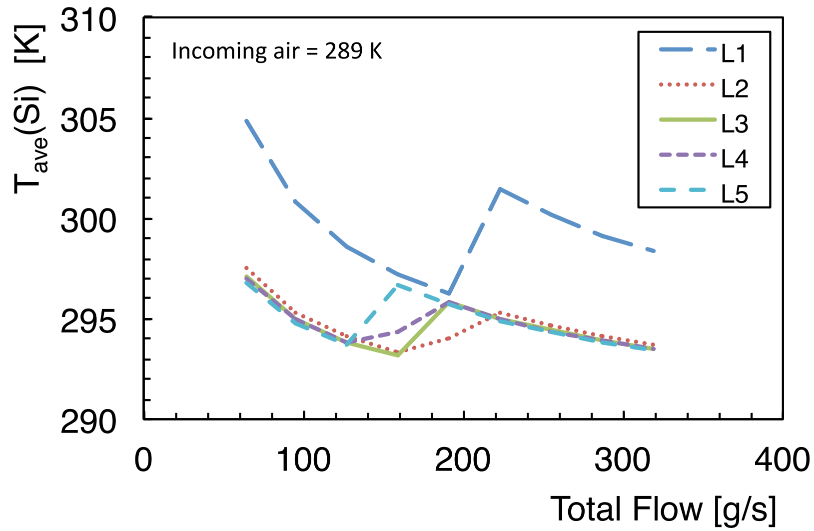
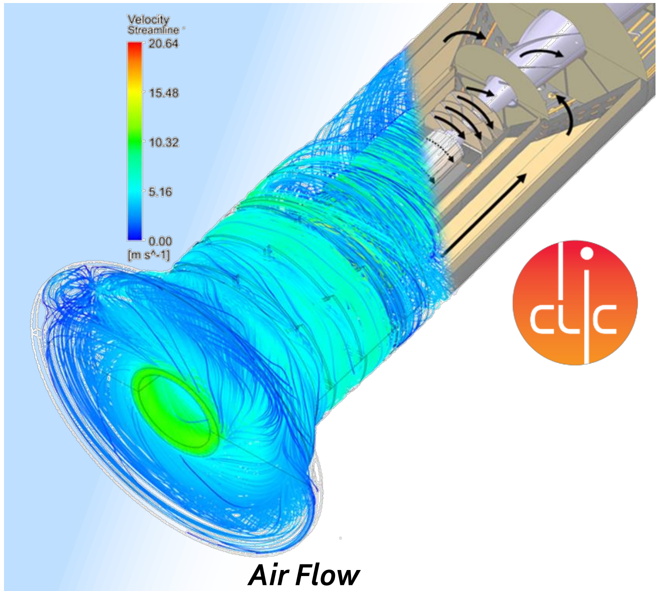


Fig. 4.12: Calculated average temperatures of the five barrel layers of the CLIC_SiD vertex detector as function of the total air-flow rate.



CLIC
Air Cooling

One of the main challenges of using gas cooling is to achieve a uniform gas delivery to all detector surfaces whilst minimizing the amount of material in the form of ducts/pipes.

Edge from laminar → turbulent flow

Alice: Air Cooling

Cooling System Requirements: Air Circulation and Thermal Shield

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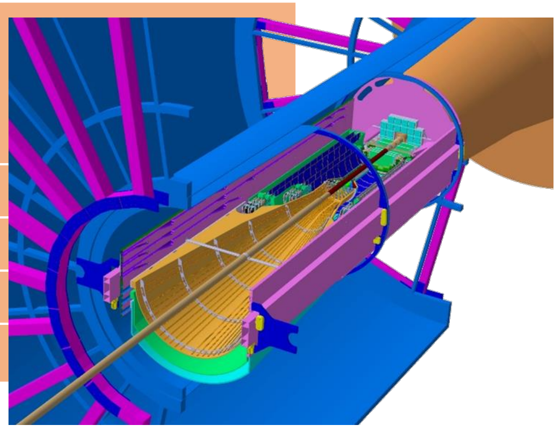
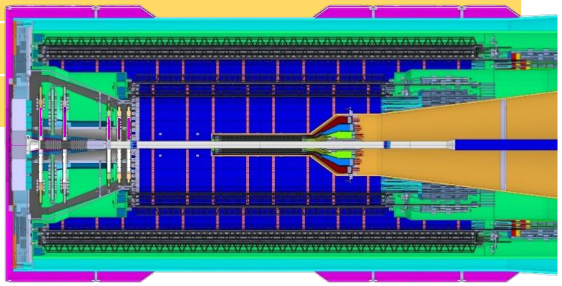
Requirement	Air Circulation
Flow	Φ ~ 150 m^3/h • IB airflow 12 m^3/h, • OB airflow 75 m^3/h; • Envelope airflow 25 m^3/h
Temperature	T_{out} =20°C
Humidity	RH_{out} =35% RH
Airflow direction	From A side
Air velocity	<2m/sec in the detector



Requirement	Thermal Shield
Thermal	Limit heat exchange between the ITS volume and TPC: provide high thermal resistance to radiation and convection heat transfer
Safety	Comply with Fire safety Instruction/Radiation tolerant
Accesibility	TPC inner bore



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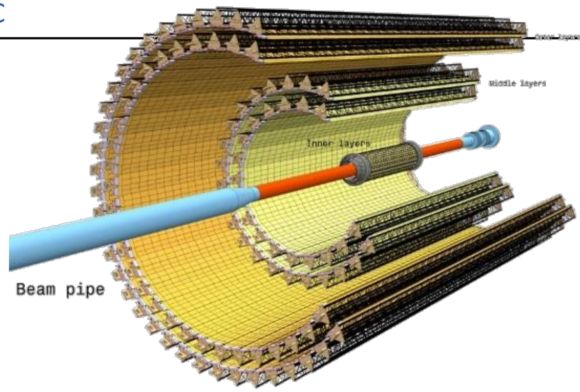
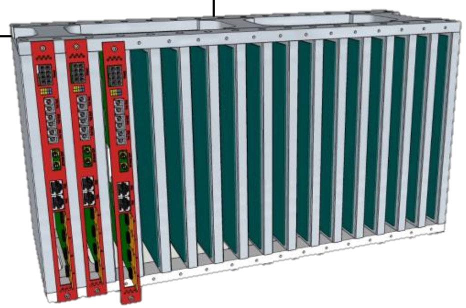
Detector and off-Detector Electronics: Specifications

ALICE

Specification	Detector	Off-Detector Electronics
Power dissipation	• IB : On-detector 119.55 W*, Bus 0W, Power cable 34W • OB-ML : On-detector 1168.99 W*, Bus 26W, Power cable 28W • OB-OL : On-detector 3468.96 W*, Bus 135W, Power cable 46W	• 10 kW**
Pressure drop stave/board	IB (3l/h)= 0.22 bar OB-ML (5 l/h)= 0.08 bar OB-OL (6.3 l/h)= 0.20 bar	(11l/h) = 0.3 bar
Chip/Board Operative T range	20°C-30°C	20°C-40°C





Remove 14.8kW
Water Temp range: 18 to 23°C
n.48 loops
n.4 controlled manifold:
- Detector IL,
- Detector ML,
- Detector OL
- Off -Detector Electronics

** based on nominal 7.5KW+margin

* CHIP Power dissipation (based on Alpide 3:
- IB =41 mW/cm^2
- OB= 28 mW/cm^2

and 50% margin

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Alice: Water Cooling, Stavelet Study

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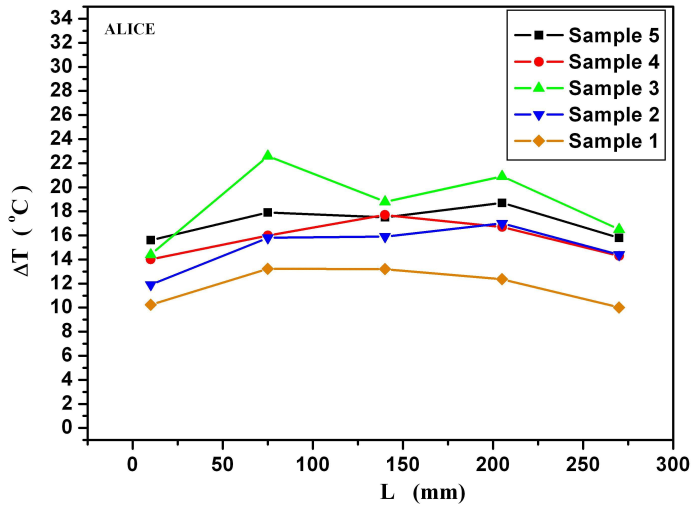


Figure 4. Normalized temperature profiles along the samples (at the central stave line). The vertical axis shows the difference between the temperature of the current point of the sample and the measured temperature of the inlet water. The heating power density was 0.5 W/cm^2.

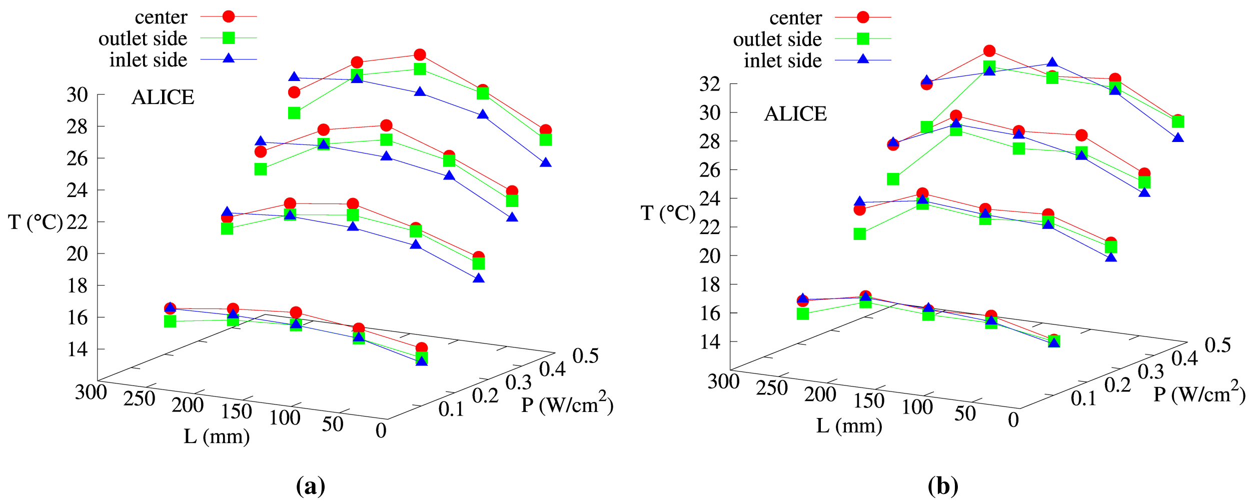
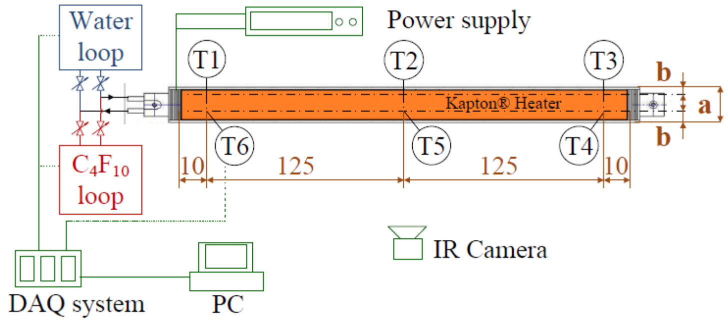


Figure 5. Temperature profile of the sample 4 (a) and sample 5 (b) at: 0.1, 0.3, 0.4 and 0.5 W/cm^2 power densities. Red dots — thermocouples located in the middle of the heater, green dots — thermocouples located on the edge of the heater close to the inlet channel (temperature 14°C) side, blue dots — thermocouples arranged along the edge of the heater close to outlet water channel.

Alice: Water Cooling, Stave

Thermal characterization

q [W cm^{-2}]	G [L h^{-1}]	$\Delta T_{CHIP-H20}$ [K]	ΔT_{H2O} [K]	Δp [bar]	v_{H2O} [m s^{-1}]
0.15	3.0	2.4	1.4	0.3	1.0



Water leakless (<1bar) baseline

Water in 15°C--->Tchip <30°C

Pixel max temperature non-uniformity < 5°C

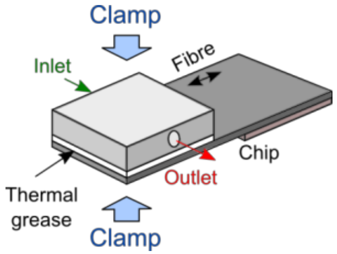
Pressure drop ΔP below 0.3 bar

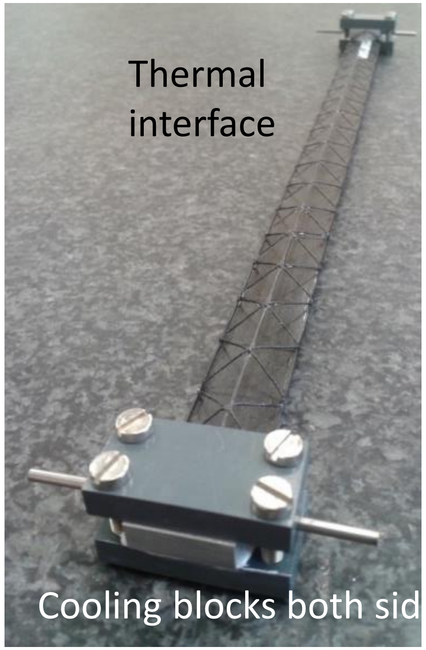
q [W cm^{-2}]	G [L h^{-1}]	$\Delta T_{CHIP-H20}$ [K]	ΔT_{H2O} [K]	Δp [bar]	$\Delta T_{HEATERS}$ [K]	v_{H2O} [m s^{-1}]
0.15	6.3	6.7	6.9	0.08	4	0.31

Alice: Water Cooling, end of stave

Alice: **studies: peripheral cooling, no pipes on the stave**

Carbon Fibre orientation **Cold plate section**





q [W cm^{-2}]	Power input [W]	Estim. power to flow [W]	T water [°C]	T map [°C]
0.02	0.82	0.56	12.6	
0.03	1.25	0.71	12.7	
0.04	1.64	0.80	12.9	
0.05	2.02	0.86	12.9	

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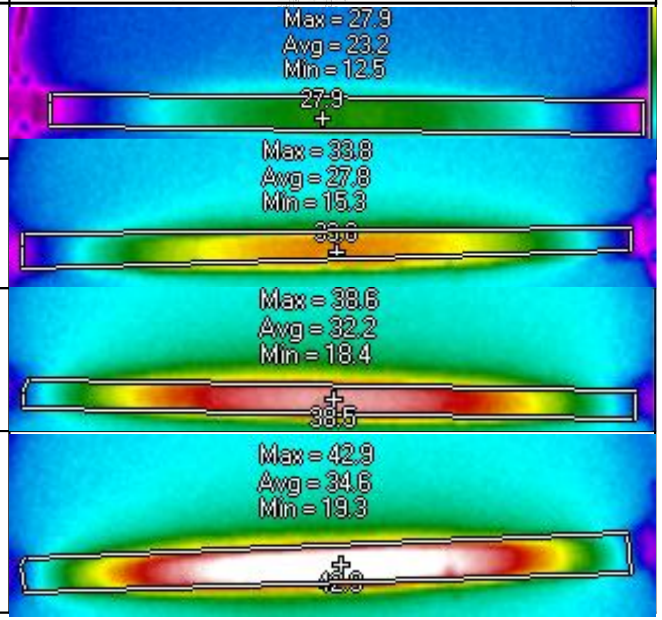


ATLAS Strips

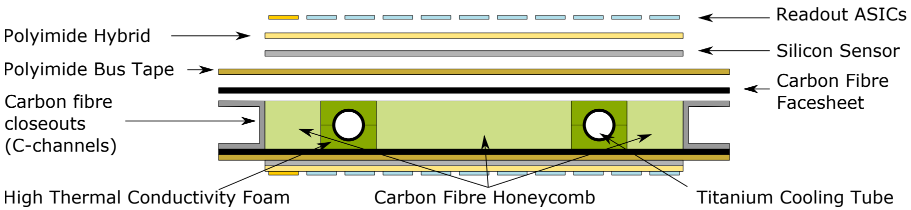


Figure 9.1: Schematic of the internal structure of the stave core, with the silicon sensors and ASICs added. Glue layers are not shown. Not to scale.

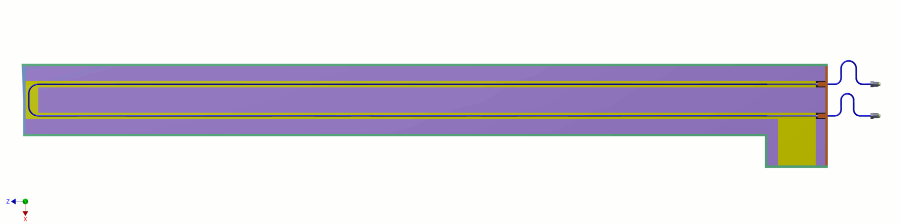


Figure 9.2: A stave core as seen from the top side. Violet colour indicates carbon-fibre honeycomb material and yellow indicates carbon-foam used in the assembly.

Table 9.5: Thermal properties used as input to the FEA.

Part or Interface	Material	$K_x/K_y/K_z$ [W/(m×K)]	Thickness [mm]	Comment
ASIC	Silicon	191 (250K) - 148 (300K)	0.30	
ABC130 to Hybrid	UV cure glue	0.5	0.08	50% coverage
HCC130 to Hybrid	UV cure glue or silver epoxy	0.5 or 3.0	0.08	75% coverage
Hybrid PCB	Cu/polyimide	72/ 0.23 (0.54)* / 72	0.2	*in via region
Power PCB	Cu/polyimide	see text	0.3	
PCB to sensor	FH5313 Epolite	0.23	0.12	75% coverage
Sensor	Silicon	191(250K) - 148(300K)	0.3	
Sensor to Bus	DC SE4445	2.0	0.1 - 0.2	100% coverage
Bus tape	Polyimide/ Cu/Al	0.17 / 0.24 / 0.17	0.17	
Bus to facing	-	(idealised)	-	co-cured
CFRP Facing	0-90-0 CFRP	90 / 1/ 180	0.15	K13C2U fibre, 45 g/m^2
Facing to Foam	Hysol 9396 + graphite powder	1.0	0.1	
Graphite Foam	Allcomp, 2g.cm-3	30	5 mm (core)	
Foam to Pipe	Hysol 9396 + graphite powder	1.0	0.1	
Cooling Pipe	Titanium (grade 2)	16.4	0.14-0.15 (wall)	2 mm inner dia.
Fluid film	Bi-phase CO_2	htc 4.5 - 17 [kW/m^2K]		

ATLAS Pixel

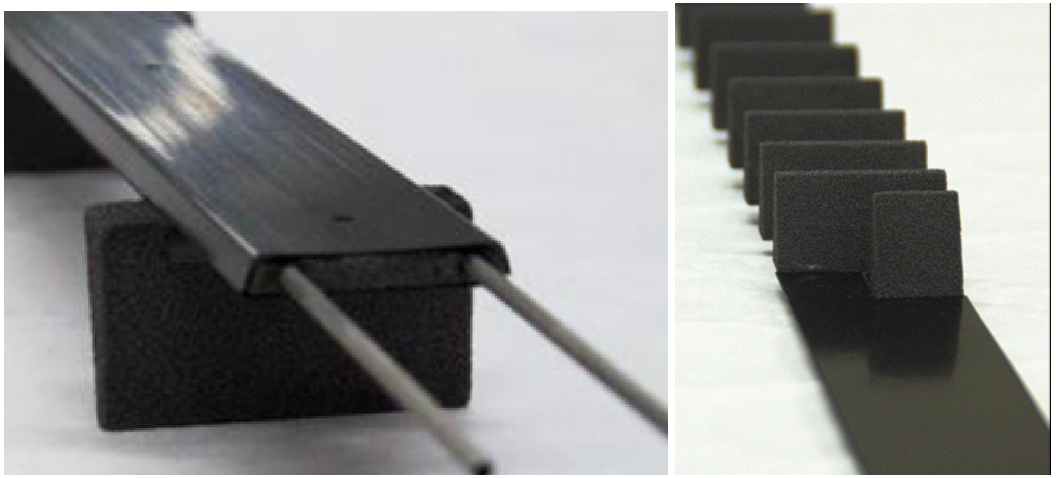
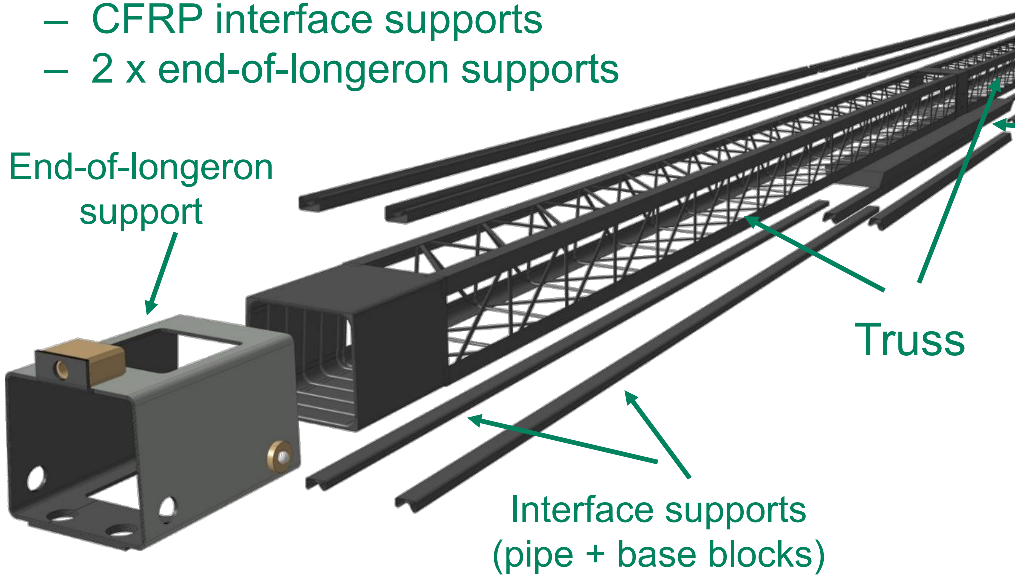
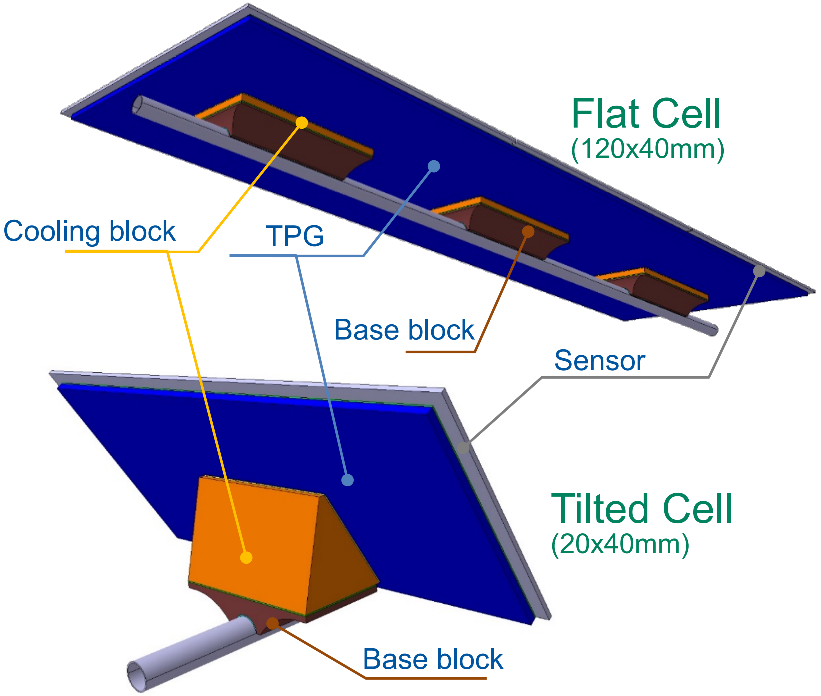


Figure 15.19: ALPINE design for the inclined layout.

- 2 x TRUSS + Central sandwich step
- CFRP interface supports
- 2 x end-of-longeron supports

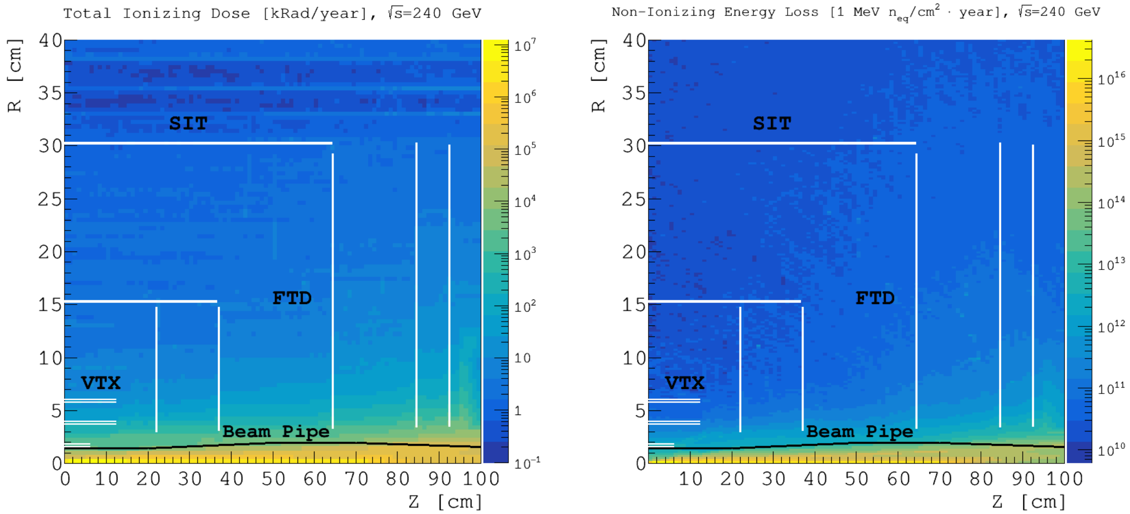




Layer	TFM (K·cm²·W⁻¹)		
	Conductive	Convective	Global
0	11	4.3	**15**
1	16	8.6	**25**
2	12	8.6	**21**
3	15	8.6	**24**
4	18	8.6	**27**

D. GIUGNI

Occupancy



(a) (b)

Figure 9.8: Total ionizing dose (TID) and non-ionizing energy loss (NIEL) distribution in $r - z$ for the machine operation at $\sqrt{s} = 240$ GeV. The white lines indicate the locations of the vertex detector (VTX), the forward tracking disks (FTD) and the silicon inner tracker (SIT).

	H (240)	**W** (160)	**Z** (91)
Hit Density [hits/cm^2·BX]	2.4	2.3	0.25
TID [MRad/year]	0.93	2.9	3.4
NIEL [10^{12} 1 MeV n_{eq}/cm^2·year]	2.1	5.5	6.2

Table 9.4: Summary of hit density, total ionizing dose (TID) and non-ionizing energy loss (NIEL) with combined contributions from pair production and off-energy beam particles, at the first vertex detector layer ($r = 1.6$ cm) at different machine operation energies of $\sqrt{s} = 240$, 160 and 91 GeV, respectively.

Cooling Summary

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Microchannel Cooling:

preferred option: spread out, low X_0, nice project

embedded in carbon fibre

possible over a long distance?

Ti-pipe cooling:

from X_0 point of view actually not as prohibitive as one might think

lots of UK investment

we know how to do it

can absorb any kind of heat

Water cooling:

highly focussed X_0

water is not a good substance

easy to use

commercial product/fitting

Conclusion:

carefully check X_0 (distribution) for Ti and ITS options

R&D programme for Microchannel cooling