The ALICE low-mass silicon tracker

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On behalf of the ALICE ITS

Outlook

- Introduction
- ITS pointing resolution performance
- Focus on the SPD components and material budget
- Towards the ITS upgrade

The ALICE experiment

Dedicated heavy ion experiment at LHC

- Study of the behavior of strongly interacting matter under extreme conditions of high energy density and temperature

Proton-Proton collisions

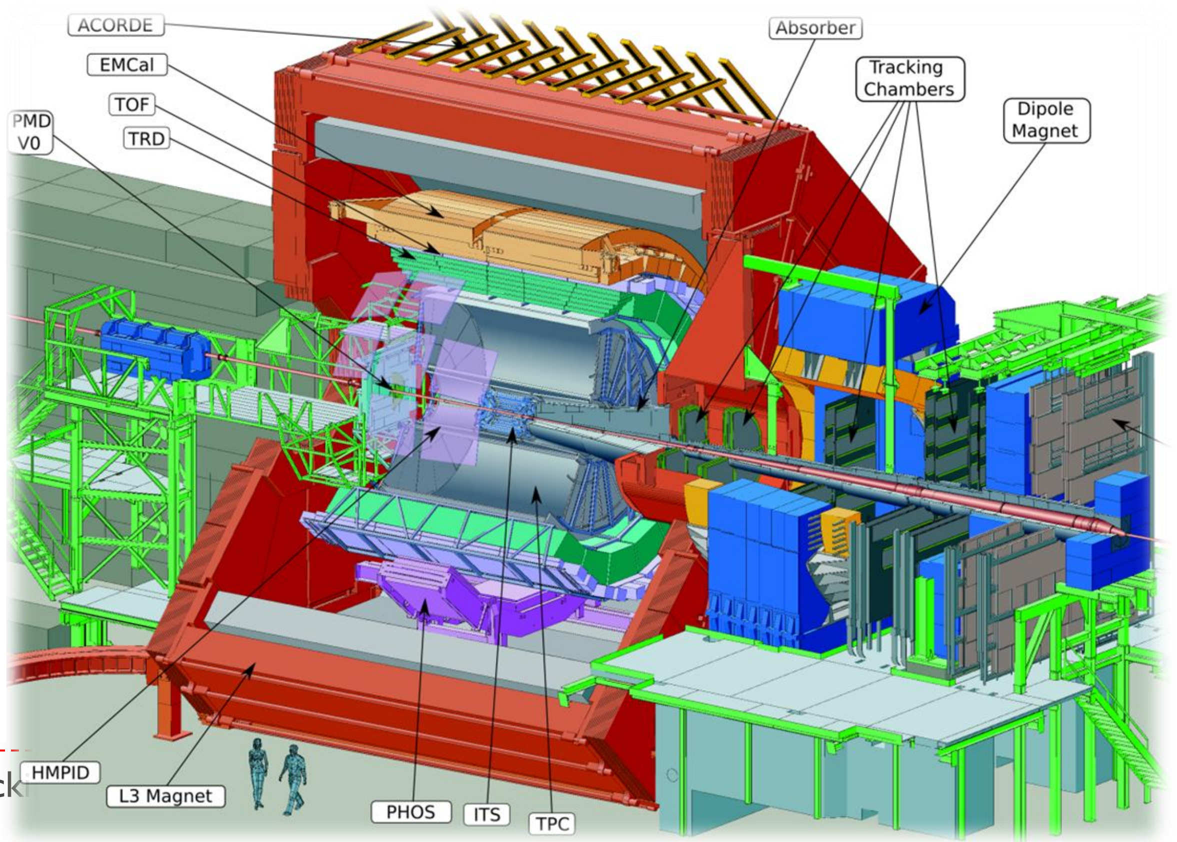
- Reference data for heavy-ion program
- Genuine physics (momentum cutoff <100MeV/c, excellent PID, efficient minimum bias trigger)

Barrel Tracking requirements ($|\eta| < 0.9$)

- Robust tracking for heavy ion environment
  - Mainly 3D hits and up to 150 points along the tracks
- Wide transverse momentum range (100 MeV/c – 100 GeV/c)
  - Low material budget (13% X0 up to the end of TPC)
  - Large lever arm to guarantee good tracking resolution at high pt

PID requirements over the large momentum range

- Combined PID based on several techniques: dE/dx, TOF, transition and Cherenkov radiation



The ALICE Inner Tracking System

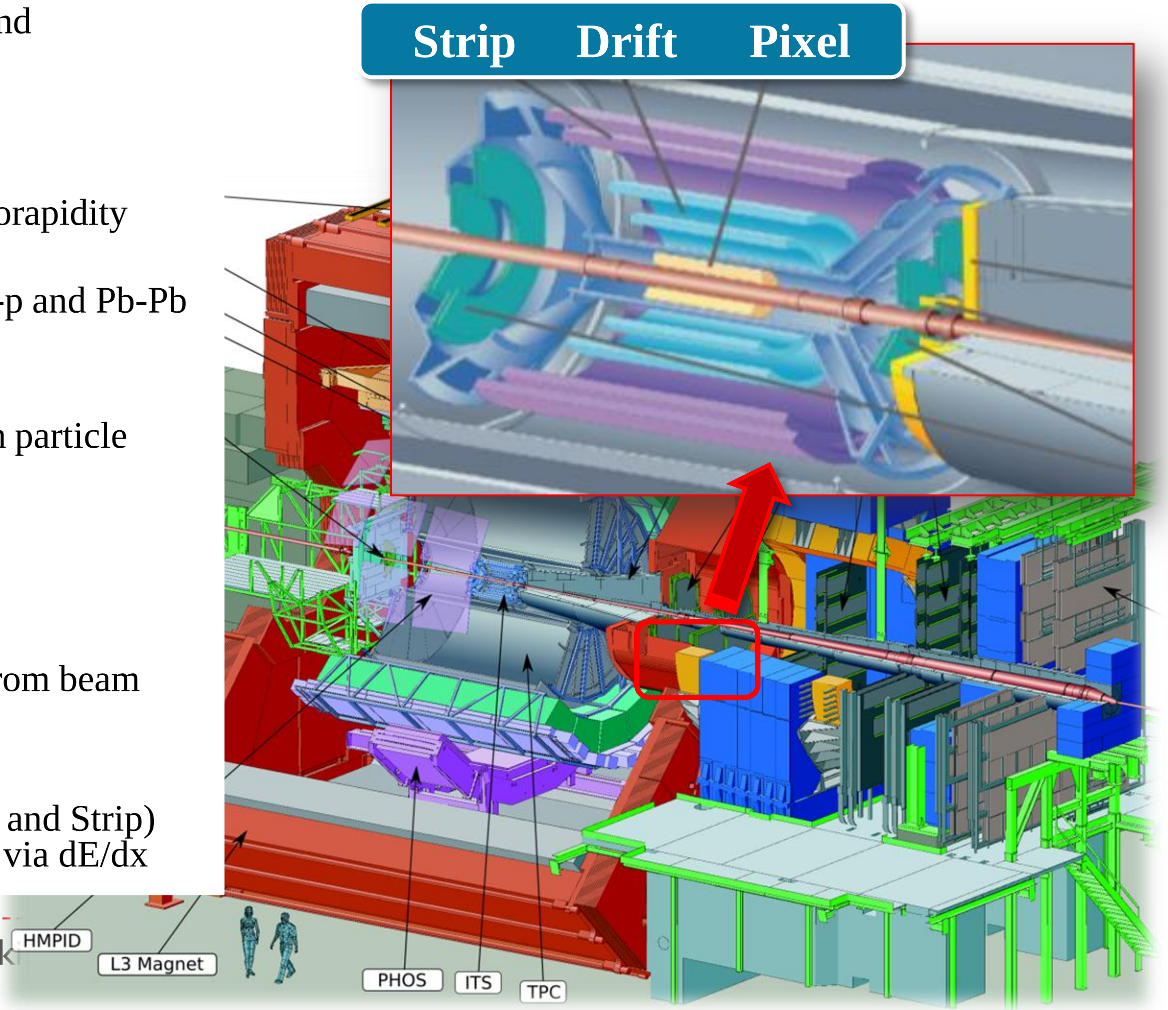
The ITS role in ALICE

- Secondary vertex reconstruction (c, b decays)
  - Good track impact parameter resolution (< 60 μm (rφ) for p_t > 1 GeV/c in Pb-Pb)
- Improve primary vertex reconstruction and momentum resolution
- Tracking and PID of low p_t particles
- Prompt L0 trigger capability (<800 ns)
- Measurements of charged particle pseudorapidity distribution
  - First Physics measurement both in p-p and Pb-Pb

Detector requirements

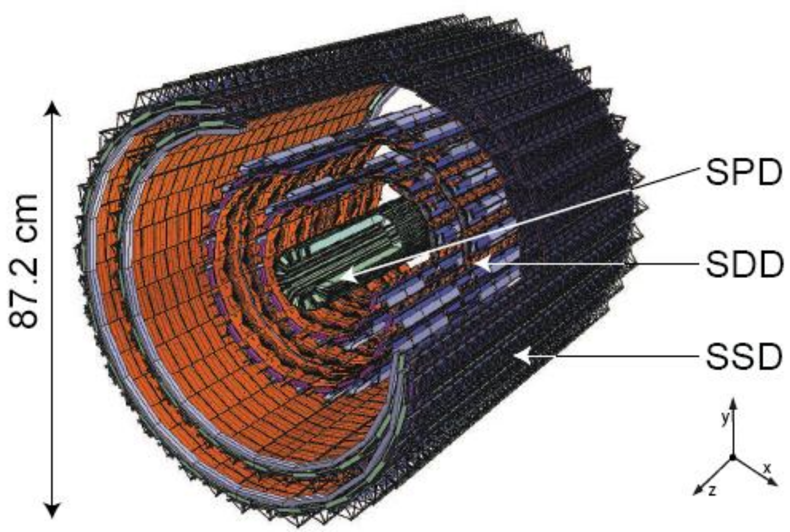
- Two dimension detectors to handle high particle density
- Good spatial precision
- High efficiency
- High granularity (≈ few % occupancy)
- Minimize distance of innermost layer from beam axis (mean radius ≈ 3.9 cm)
- Limited material budget
- Analogue information in 4 layers (Drift and Strip) for particle identification in $1/\beta^2$ region via dE/dx

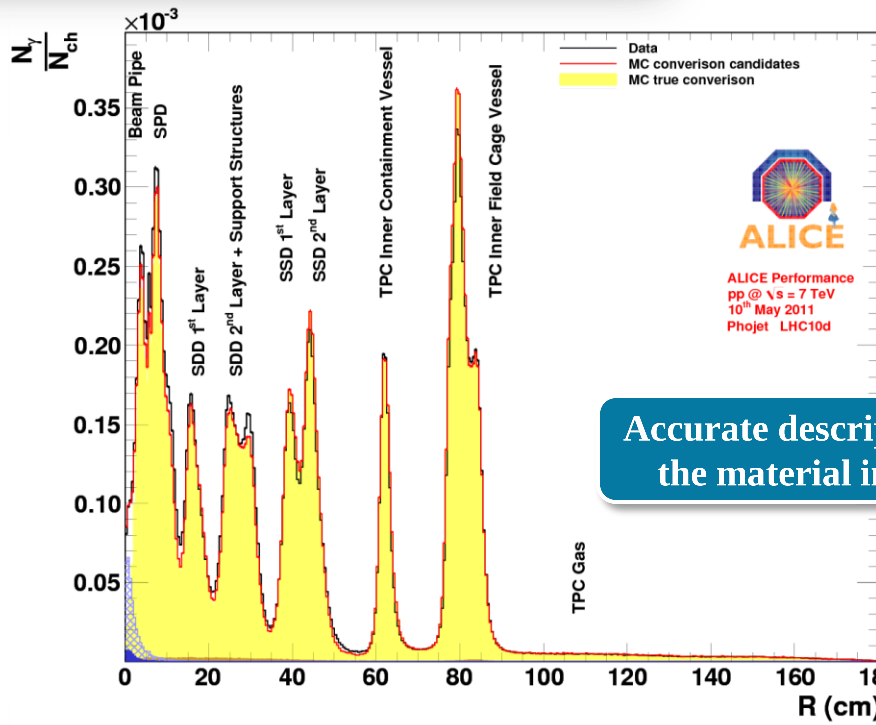
ITS: 3 different silicon detector technologies



ITS parameters

Layer	Det.	Radius (cm)	Length (cm)	Surface (m2)	Chan.	Spatial precision (mm)		Cell (μm2)	Max occupancy central PbPb (%)	Material Budget (% X/X_0)	Power dissipation (W)	
						rφ	z				barrel	end-cap
1	SPD	3.9	28.2	0.21	9.8M	12	100	50x425	2.1	1.14	1.35k	30
2		7.6	28.2						0.6	1.14		
3	SDD	15.0	44.4	1.31	133 K	35	25	202x294	2.5	1.13	1.06k	1.75k
4		23.9	59.4						1.0	1.26		
5	SSD	38.0	86.2	5.0	2.6M	20	830	95x40000	4.0	0.83	850	1.15k
6		43.0	97.8						3.3	0.86		

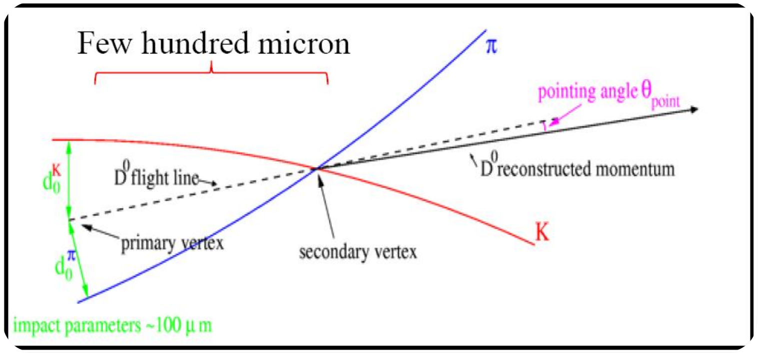


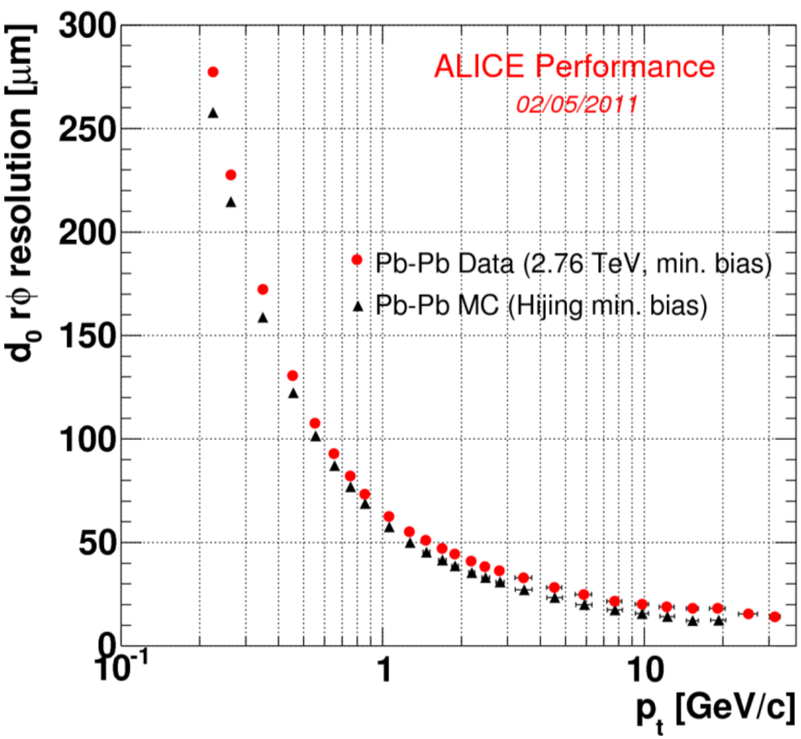


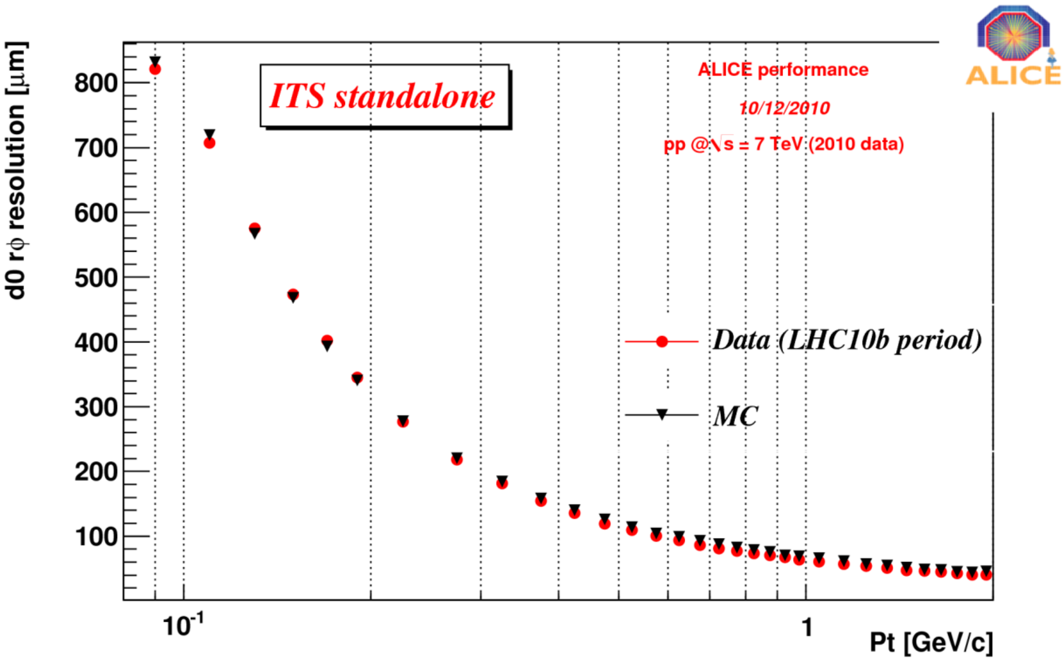
Accurate description of the material in MC

Transverse impact parameter

- A key plot to quote the tracker performance in terms of track and vertex reconstruction is the transverse impact parameter in the bending plane: $d_0(r\varphi)$
  - Distance between the track projection and the vertex position reconstruction in the bending plane
- The material budget mainly affect the performance at low p_t (multiple scattering)
- The point resolution of each layers drives the asymptotic performance







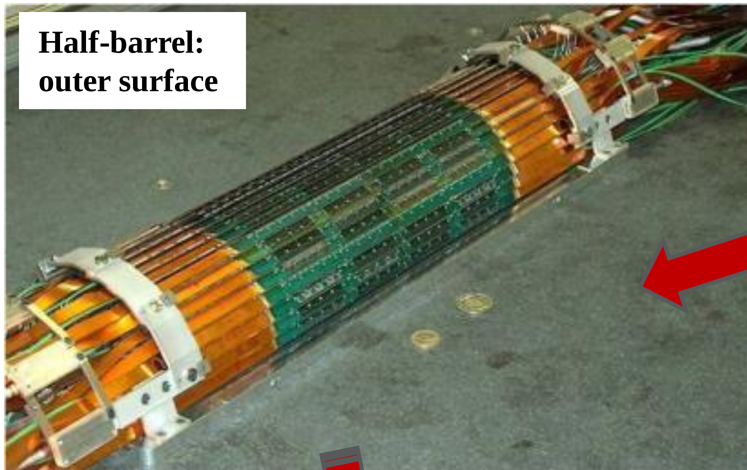
Some considerations

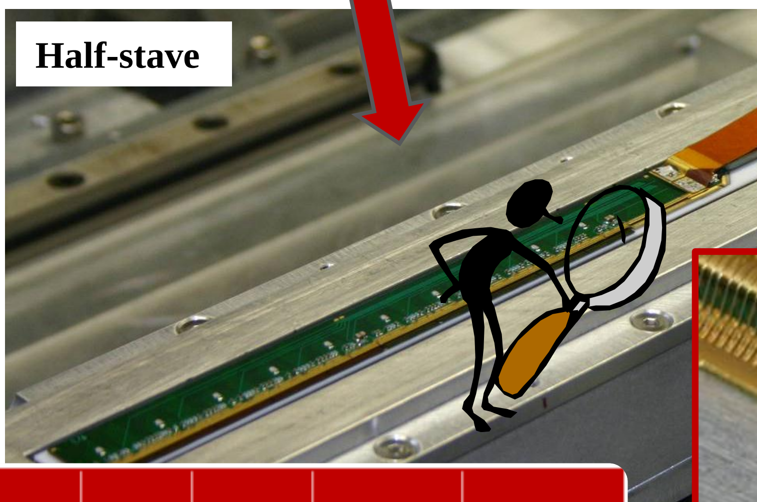
- The key requirements to obtain good tracking performance are:
  - Small channel dimension
  - Low material budget
  - First layer as close as possible to the interaction point

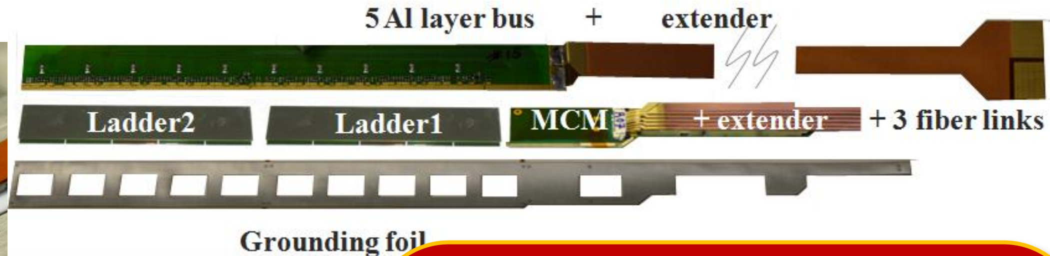
- From now on I will show how these requirements have driven the design of the silicon pixel detector in ALICE
  - Channel dimension: 50 μm (rφ) x 425 μm (z)
  - Material budget: 1.14 % of X0
  - Mean sensor radial position of the first layer = 39 mm
    - Beam pipe outer radius = 29.8 nm

Silicon Pixel Detector (SPD)

2 layers of pixels grouped in 2 half barrels mounted face to face around the beam pipe



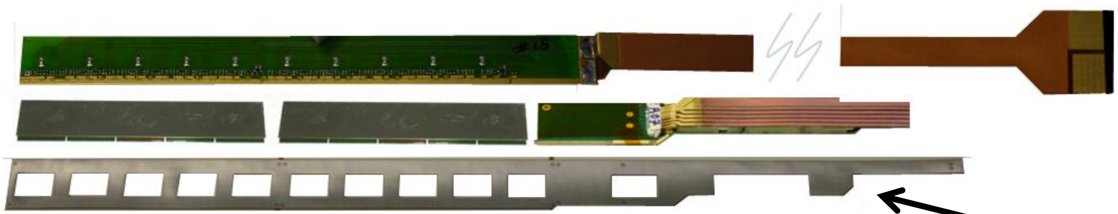




Layer	*Radius (cm)*	*# half-staves*	*Ladders/ half-stave*	*# ladders*
1	3.9	40	2	80
2	7.6	80	2	160

- ✓ Total surface: ~0.24m^2
- ✓ Power consumption ~1.4kW
- ✓ Evaporative cooling C_4F_{10}
- ✓ Operating at room temperature
- ✓ Fast two-dimensional readout (256μs)
- ✓ High efficiency (> 99%)
- ✓ L0 trigger capability
- ✓ Material budget per layer =1.14% X_0

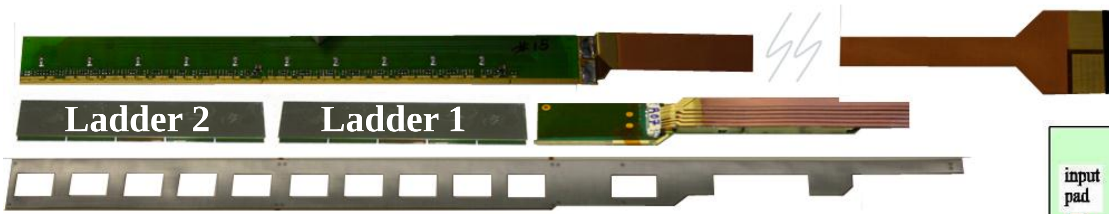
Half – stave components

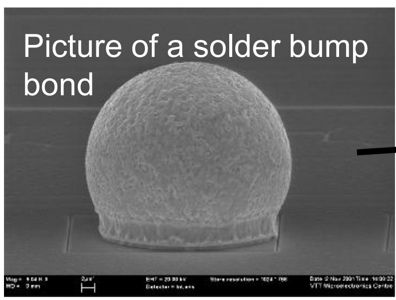


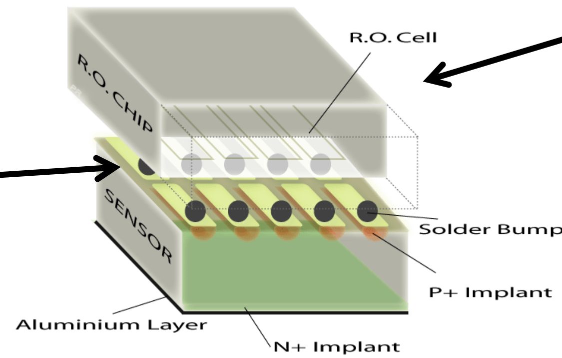
Grounding Foil

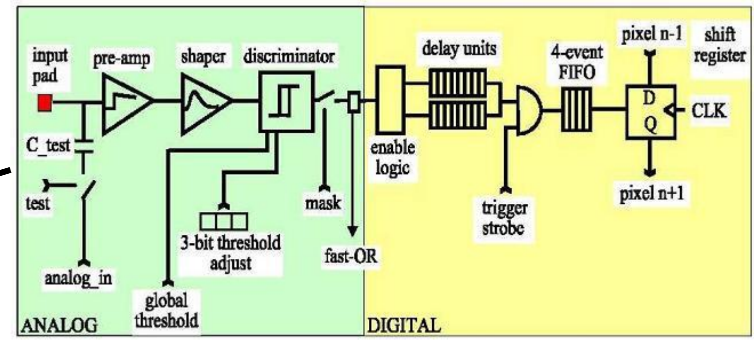
- Grounding foil: Aluminum-polyimide foil (25 + 50 µm thick)
  - Reference ground for the half-stave
  - The 11 openings are needed to improve the thermal coupling between the electronics and cooling duct via thermal grease
- X/X0 = 0.03 %

Half – stave components







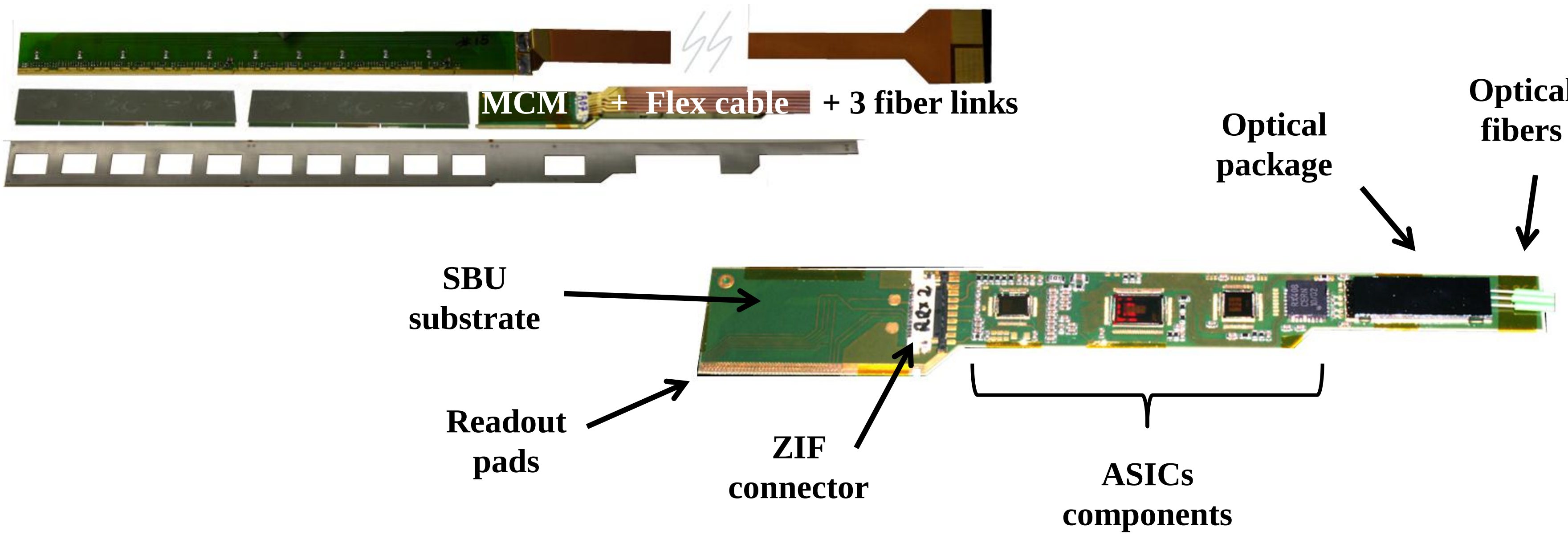


FEE chip

- Mixed signal (analogue, digital) Produced in 0.25µm CMOS process (6 metal layers)
- Radiation tolerant design (enclosed gates, guard rings)
- ~100 µW/channel
- ~1000 e- mean threshold (~200 e- RMS)
- ~120 e- mean noise

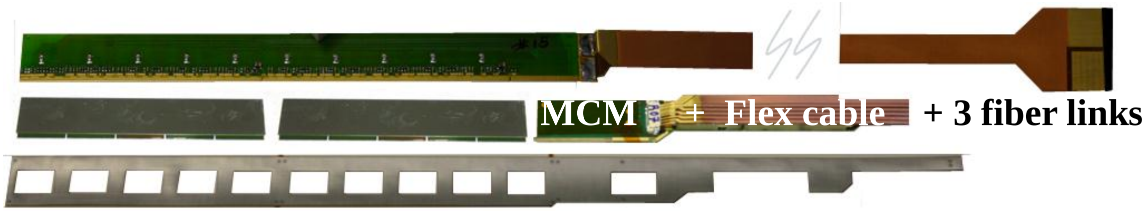
- Ladder: Sensor + FEE chip (200 + 150 µm thick)
  - A p+n silicon sensor matrix with 40960 pixels arranged in 256 rows and 160 columns
  - Pixel cell: 50 µm (rφ) x 425 µm (z)
  - 5 FEE chips Flip-chip bonded to the sensor through Sn-Pb bumps
- X/X0 = 0.38 %

Half – stave components

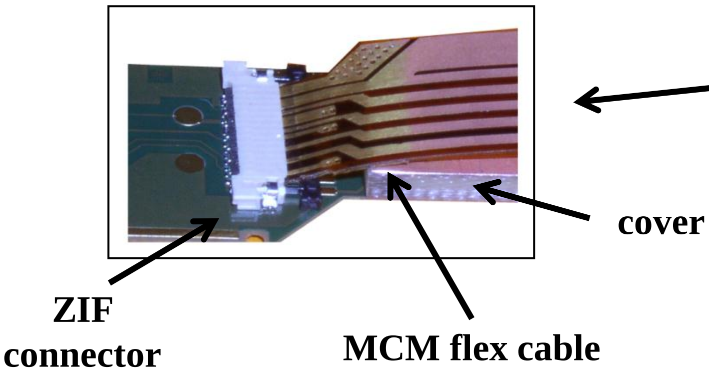


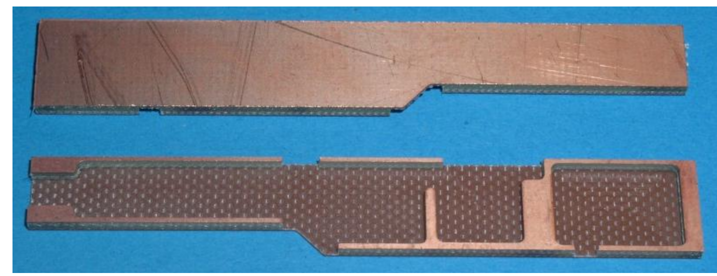
- Multi Chip Module (MCM)
  - 5-metal-layer SBU substrate (Polyimide – copper) ≈ 350 μm thick
  - Four ASICs produced in standard 0.25 μm CMOS technology with radiation hardness layout techniques
    - Analog Pilot, Digital Pilot, Giga-bit optical link (GOL) and RX40 to convert the optical link into electrical signals
  - A custom developed optical package 1.2 mm thick (STMicroelectronics) with three single-mode 1310nm optical fibers to communicate with the counting room

Half – stave components

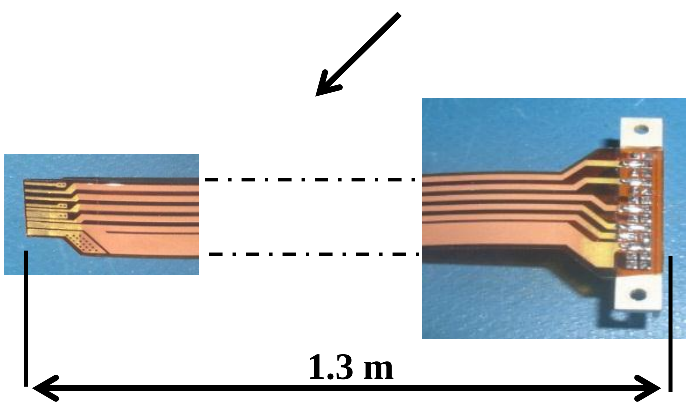


- These components are outside the barrel acceptance
- They were optimized anyway to reduce disturbance at high rapidity and to allow the detector integration





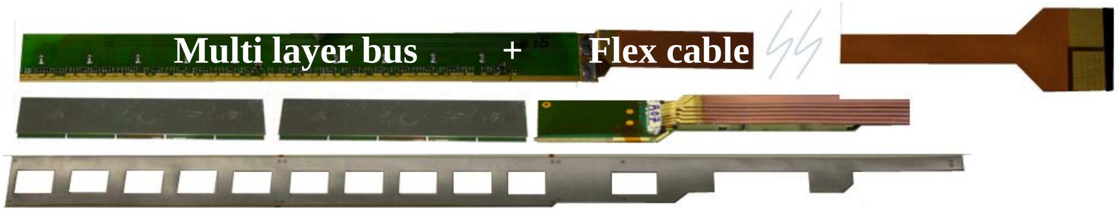
Cover to protect the electrical components (FR4, 300μm thick) glued after the qualification test



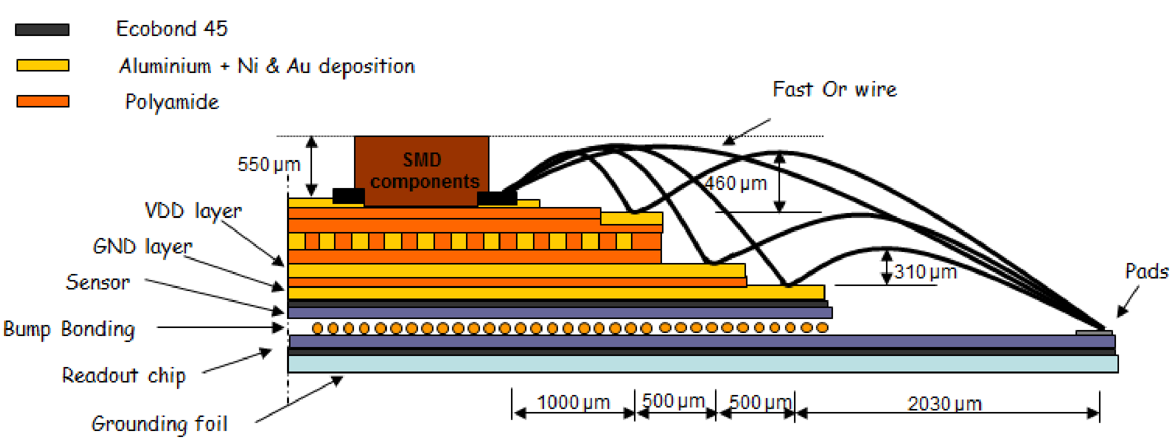
MCM flex cable

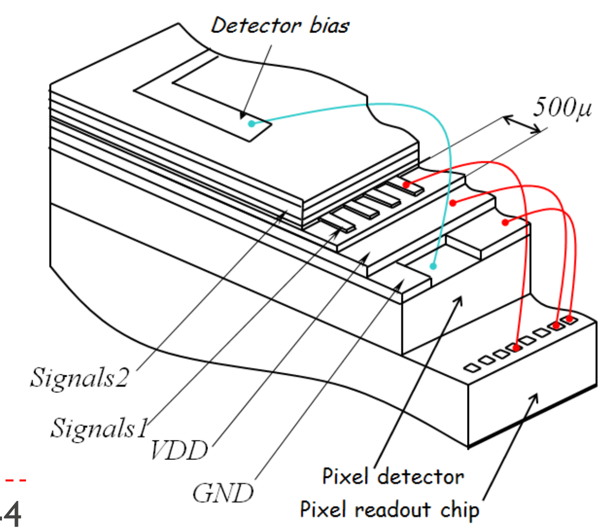
- Single layer polyimide/copper flex cable (200 μm thick)
- It provides power (2.5V / 0.5A), sense, bias and the detector temperature (used in the interlock)
- 1.3 m long to reach the first patch panel

Half – stave components



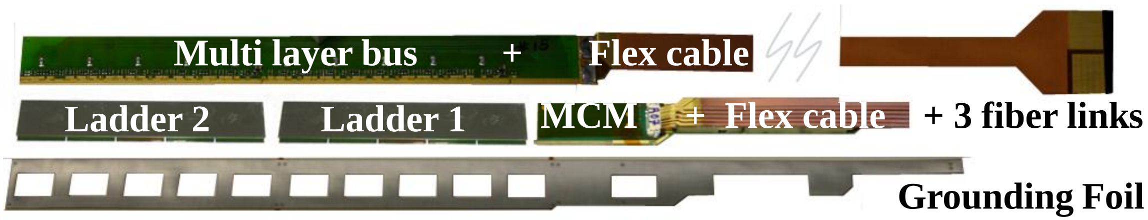
- 5-layer polyimide/aluminum (280 µm thick) bus to connect front-end chips and MCM
  - The aluminum was used to reduce the impact on the material budget
    - Almost 30% of reduction replacing Cu with Al
  - The bus distributes power/ground to the FEE chips (two 50 µm thick Al-layers)
  - The other three layers are used to carry data/control lines
  - The step side is needed to allow access to the different planes for the interconnection bonds
  - Decoupling capacitors and PT1000 are integrated on the top
- Overall X/X0 = 0.48 %





3-4

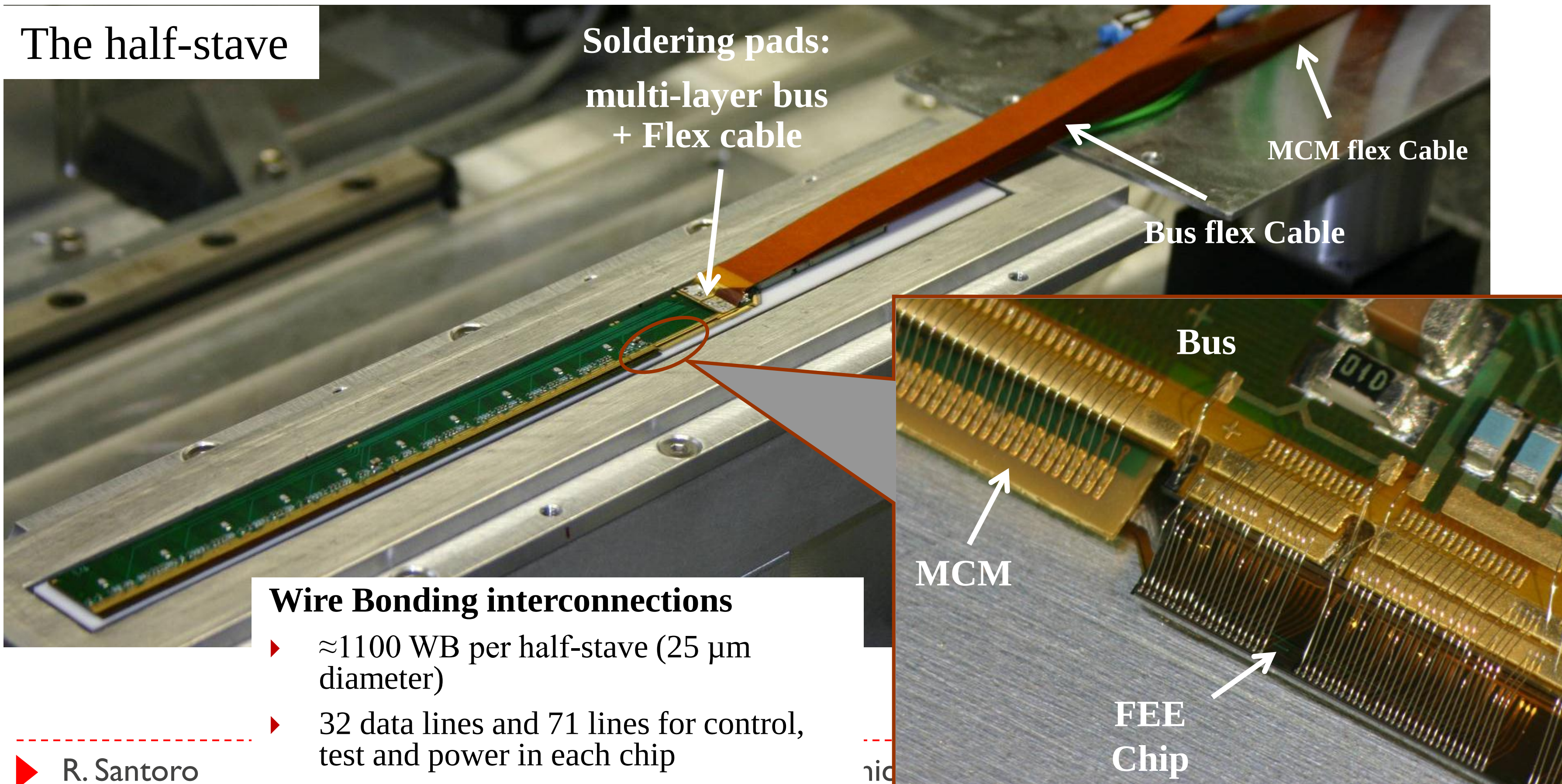
Half – stave components



Bus flex cable

- Double layer polyimide/copper flex cable (250 µm thick)
- It provides the power to the FEE chips (1.85V / 5A)

The half-stave



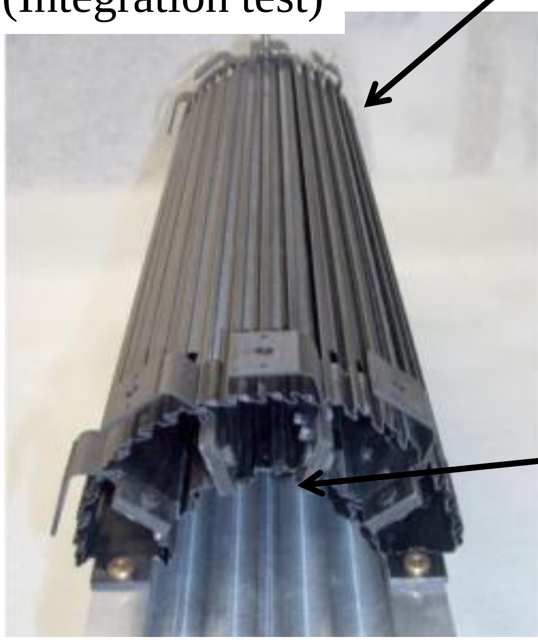
Wire Bonding interconnections

- ≈1100 WB per half-stave (25 µm diameter)
- 32 data lines and 71 lines for control, test and power in each chip

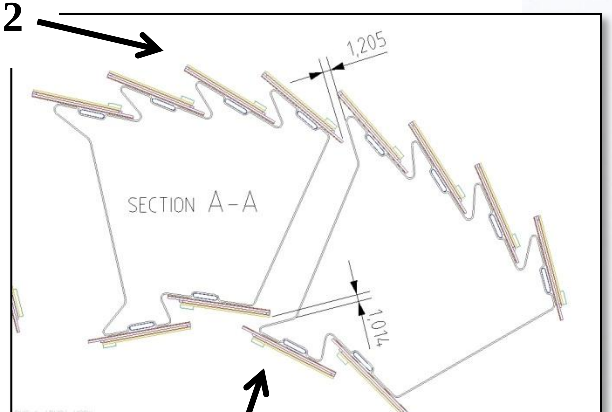
Sector components

- Carbon fiber support structure
  - 1/10 of the 2-layer barrel structure
  - Two layers of unidirectional high-modulus carbon fiber tapes 100μm thick
  - The central part is 200μm thick while ends are thicker (600μm) to allow the precise positioning and fixing
  - The special design allows to accommodate the cooling pipes and to overlap the half-staves in rφ.
  - The global and local deformations of the CFSS are of the order of 1 μm

Bare half-barrel
(Integration test)

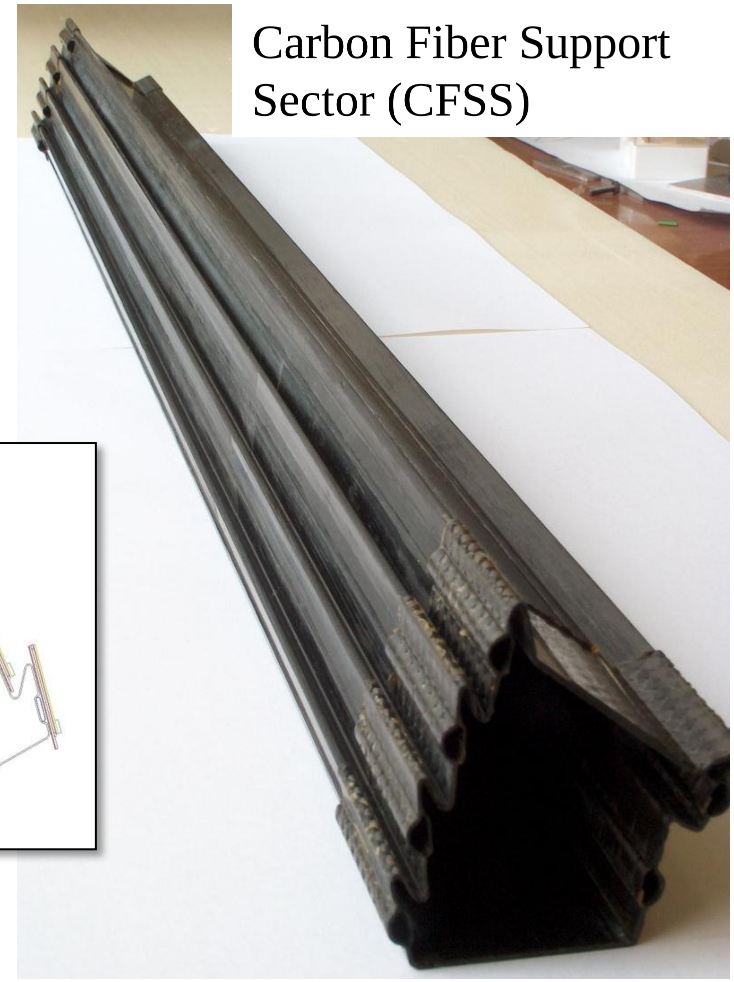


Layer 2



Layer 1
(close to the beam pipe)

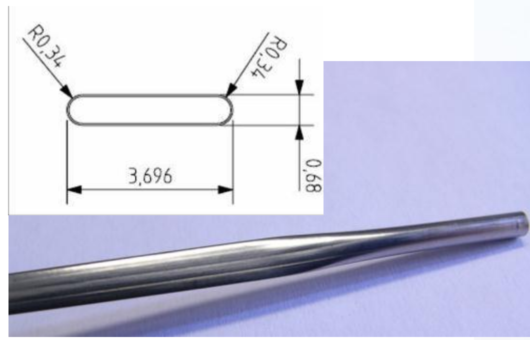
Carbon Fiber Support Sector (CFSS)



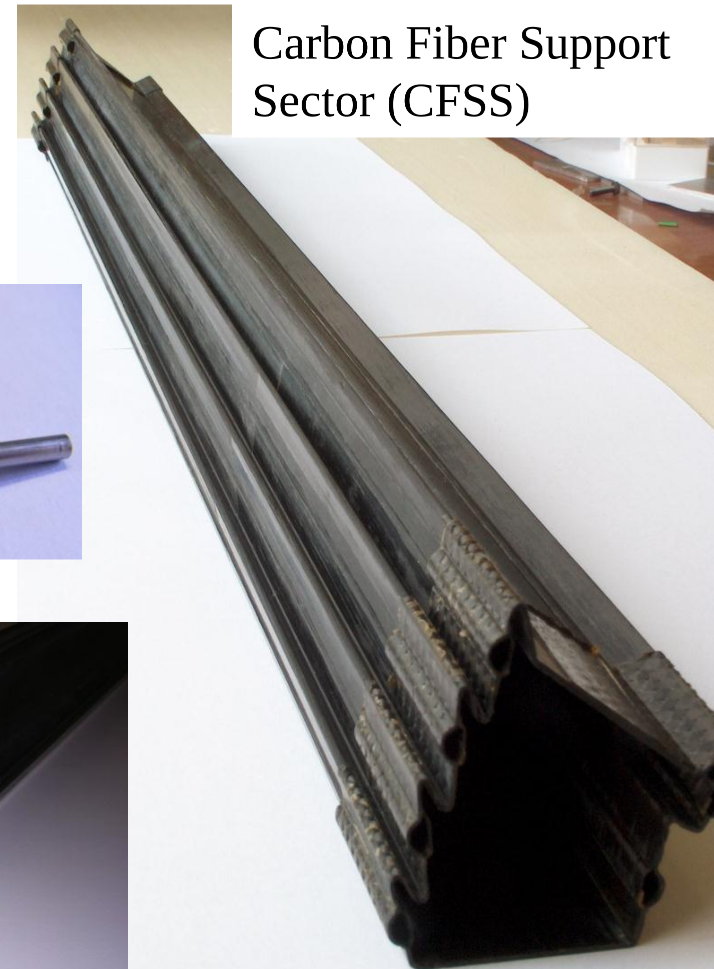
Sector components

6 Cooling pipes / sector (2 for layer 1 and 4 for layer 2)

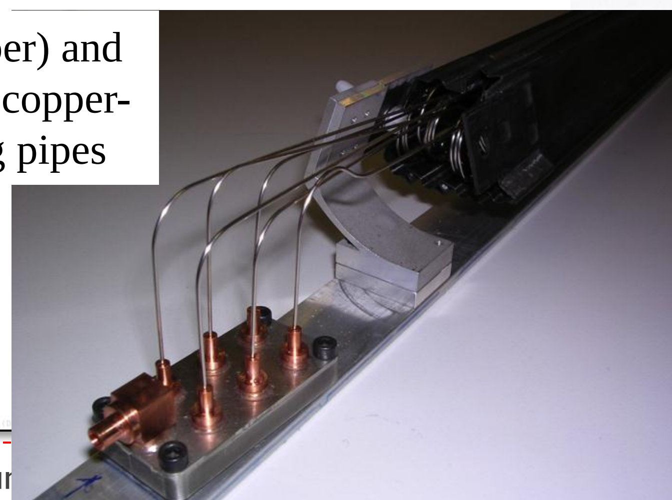
- Phynox pipes with 3mm diameter and 40μm wall
- Squeezed to 0.6 mm (inner size) to enlarge the thermal coupling surface
- Embedded to the CFSS



Carbon Fiber Support Sector (CFSS)



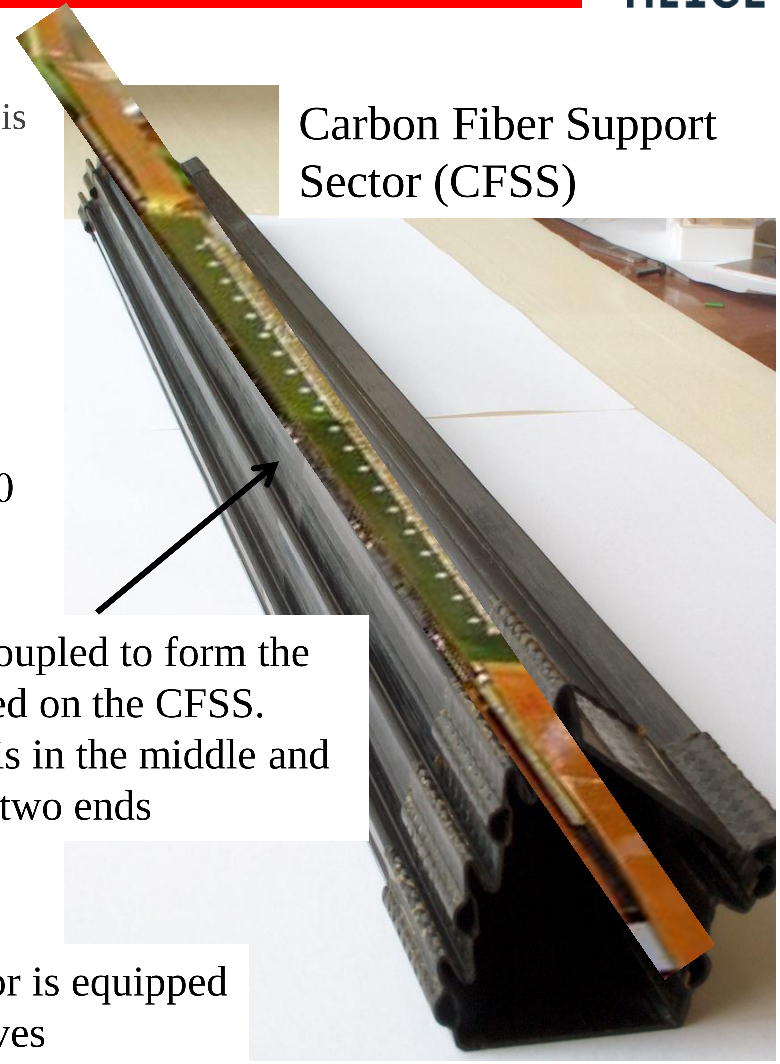
Manifold (steel), fittings (copper) and 6 capillaries (0.85 mm OD) in copper-nickel alloy to feed the cooling pipes



outside the barrel acceptance

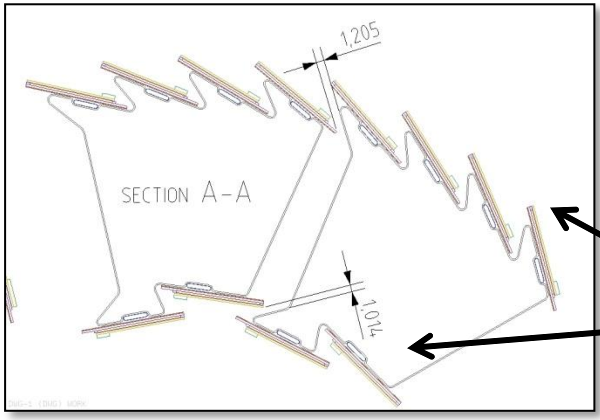
Sector components

- The Cooling is based on evaporative system with C4F10
  - Thermal contact between the cooling pipe and the FEE chips is performed with thermal grease (AOS 52029)
  - HS mechanical fixing to the CFSS with UV glue (NEA 123)
- Sector power dissipation ≈ 135 W
  - Working temperature ≈ 30°C
  - Due to the low mass of the SPD a cooling failure causes a temperature rise of ≈1°C/s
- Material budget contribution due to the mechanical support and piping in the central region is ≈ 0.19 % of X0



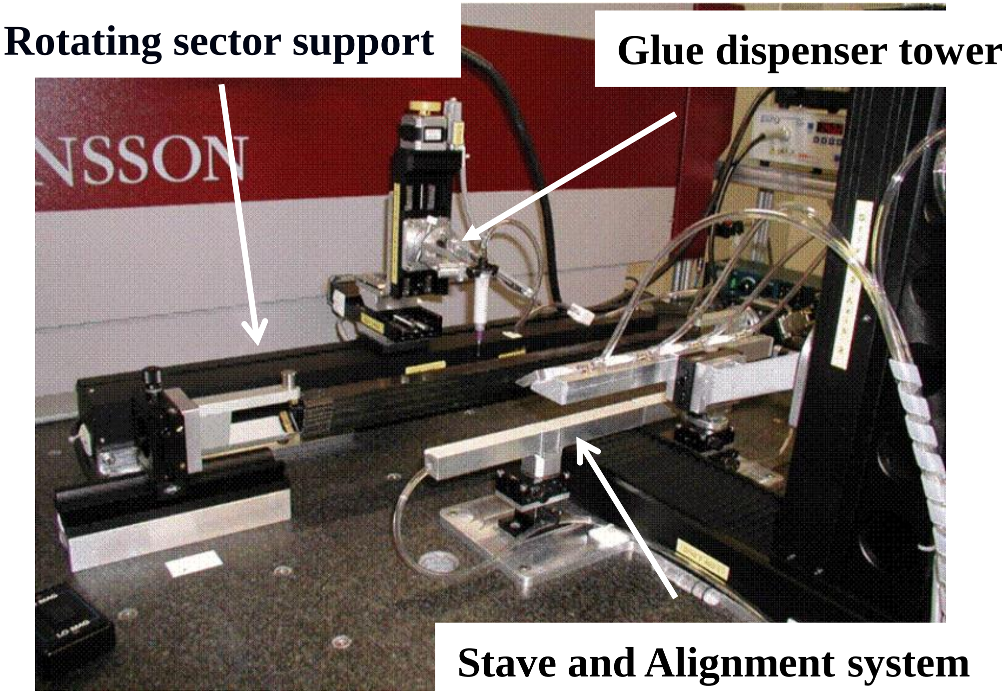
Carbon Fiber Support Sector (CFSS)

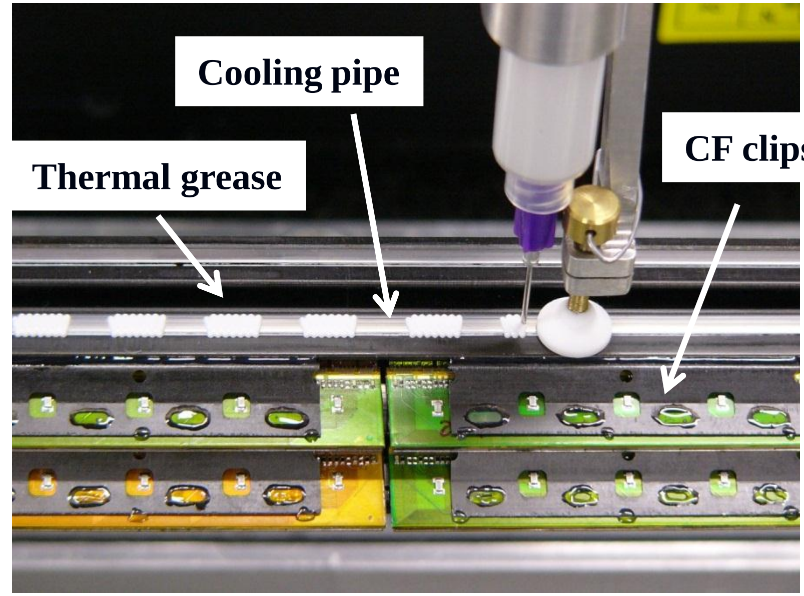
2 half-staves are coupled to form the stave and are placed on the CFSS. The active region is in the middle and the services at the two ends

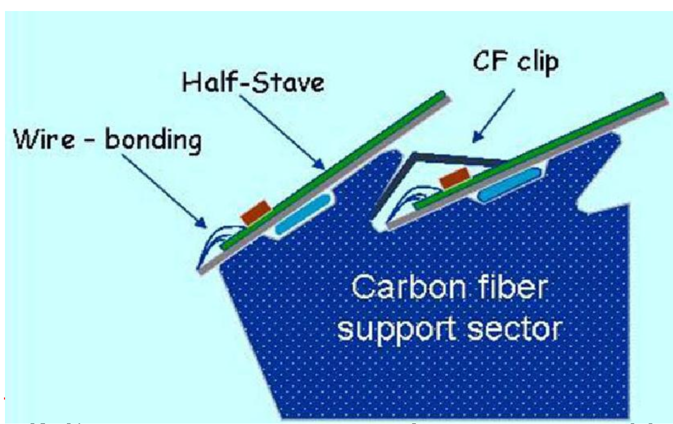


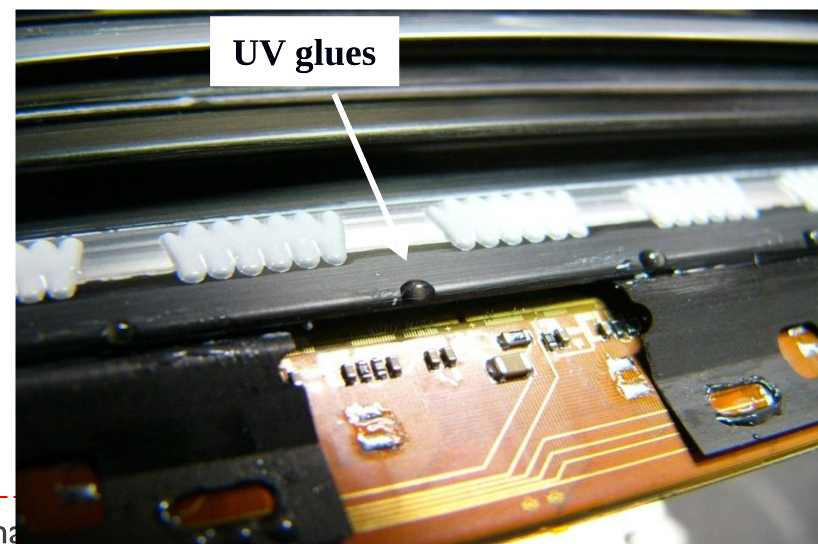
Each sector is equipped with 6 staves

Sector set up

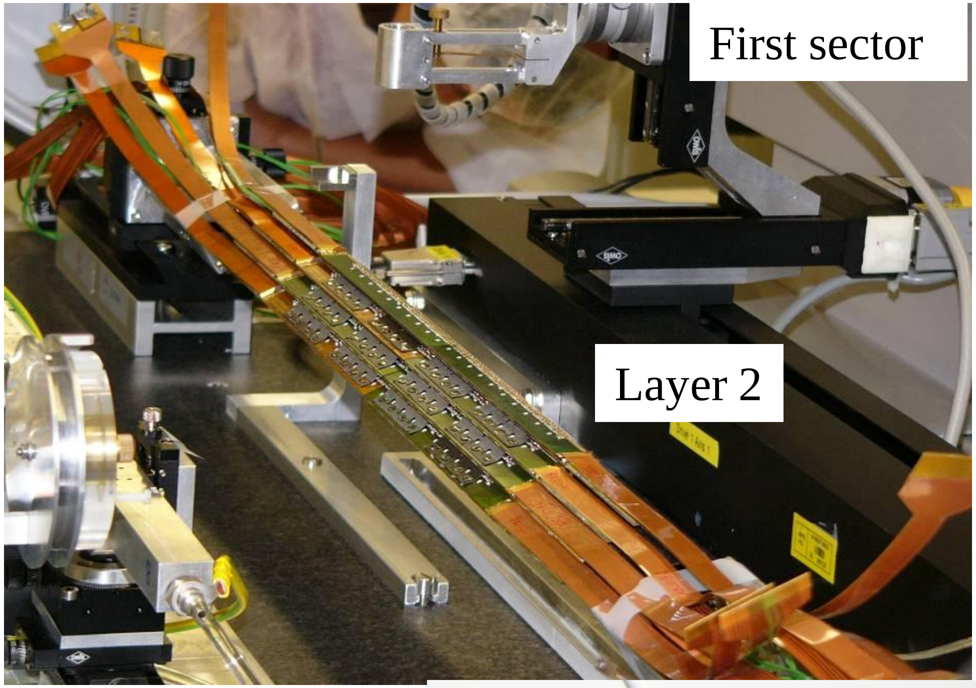


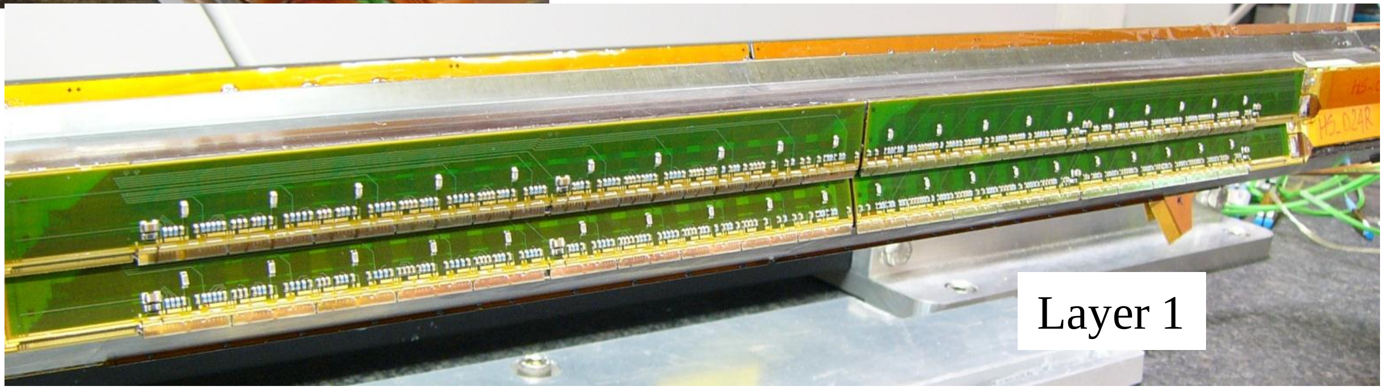




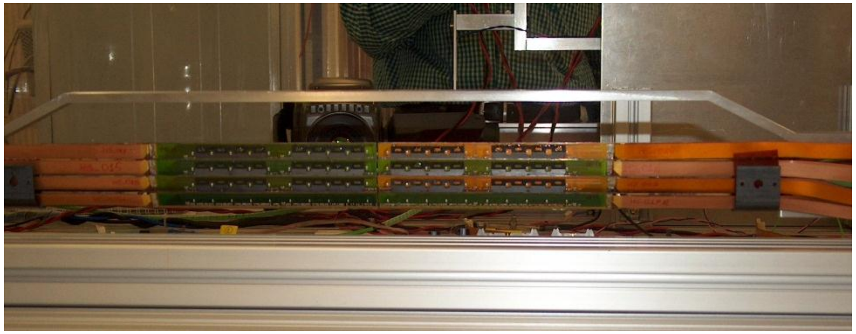


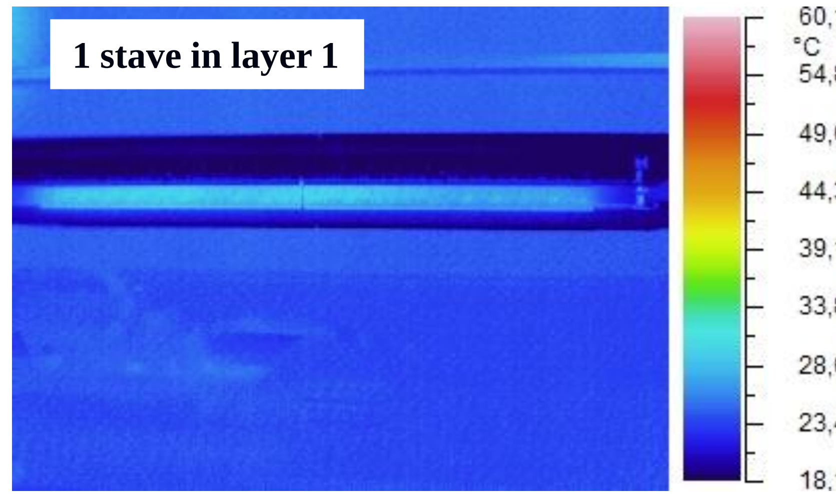
The first sector fully equipped

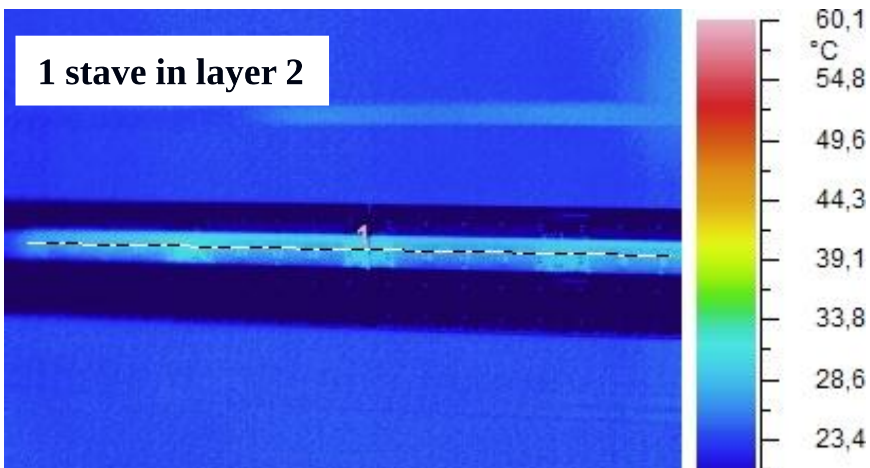


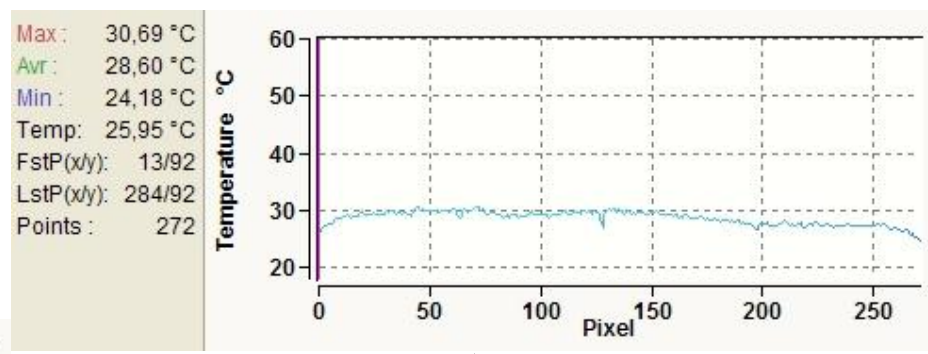


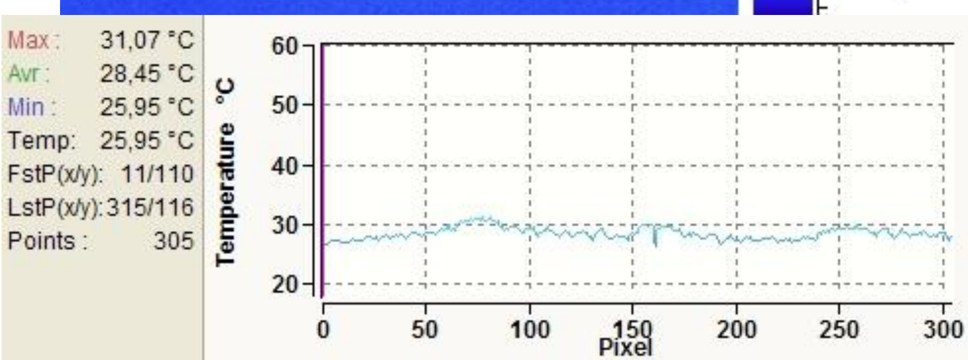
Cooling thermal qualification







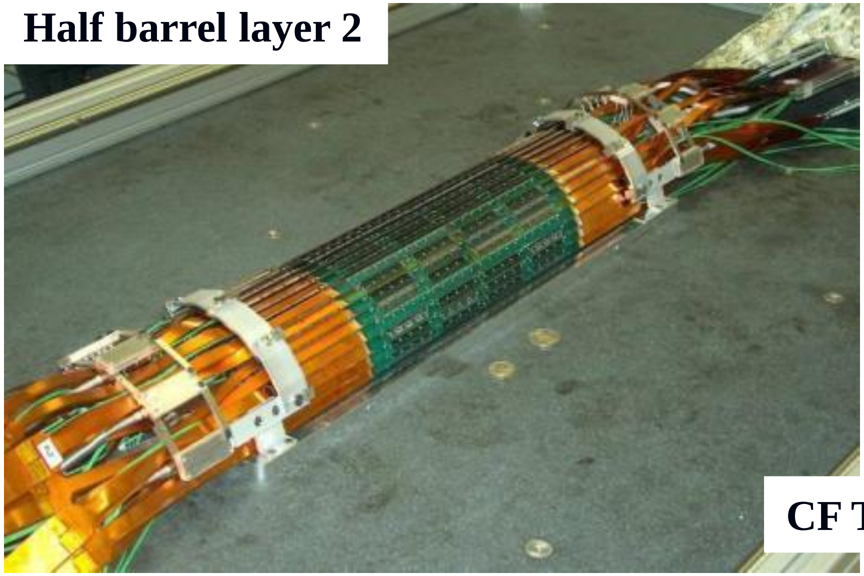




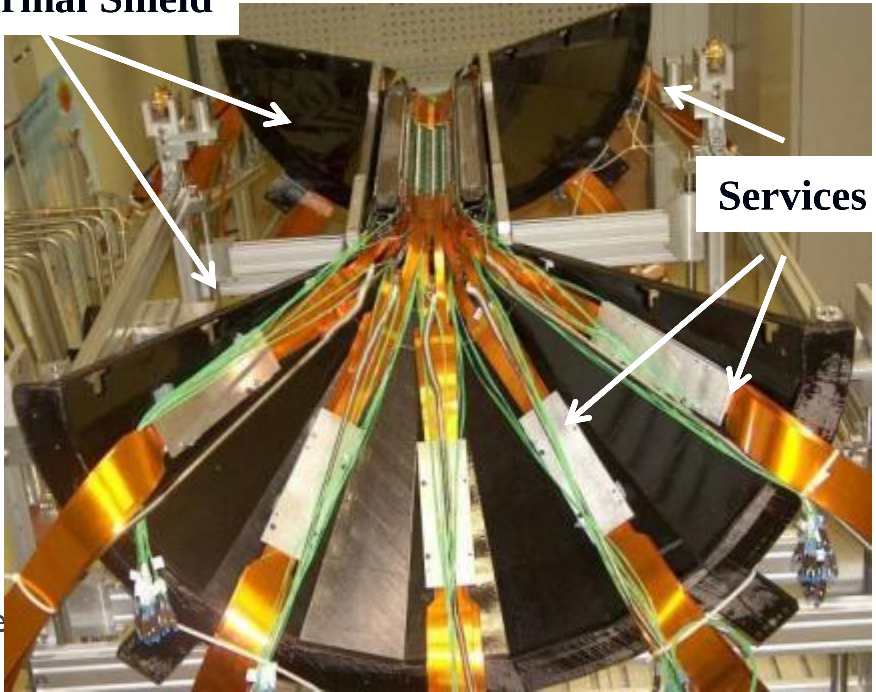
Stave temperature profile

Half-barrel integration

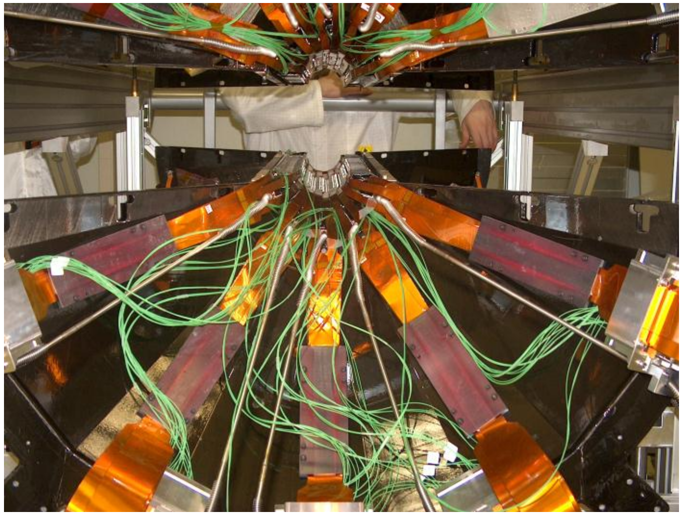
Half barrel layer 2

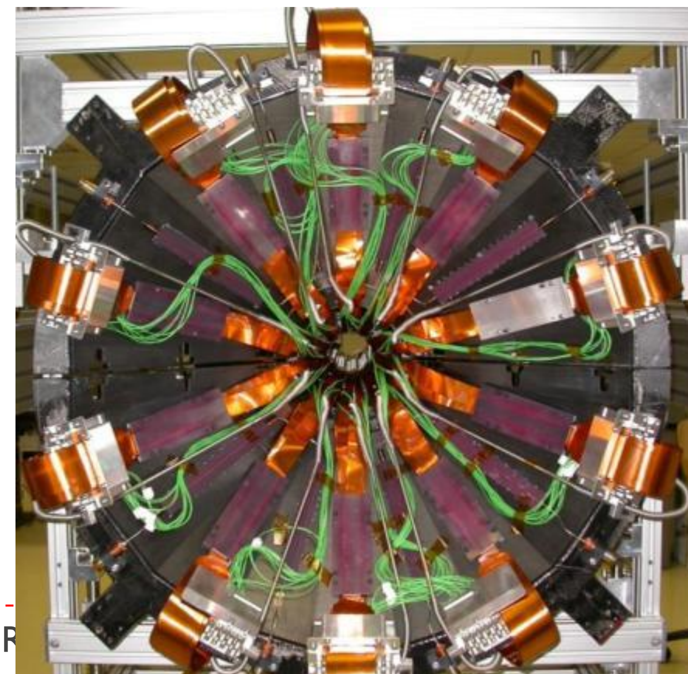


Half barrel layer 1

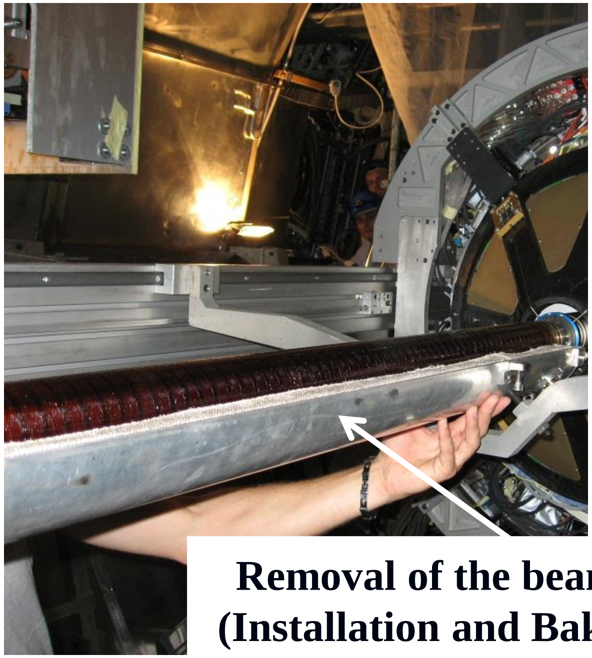


Barrel integration test

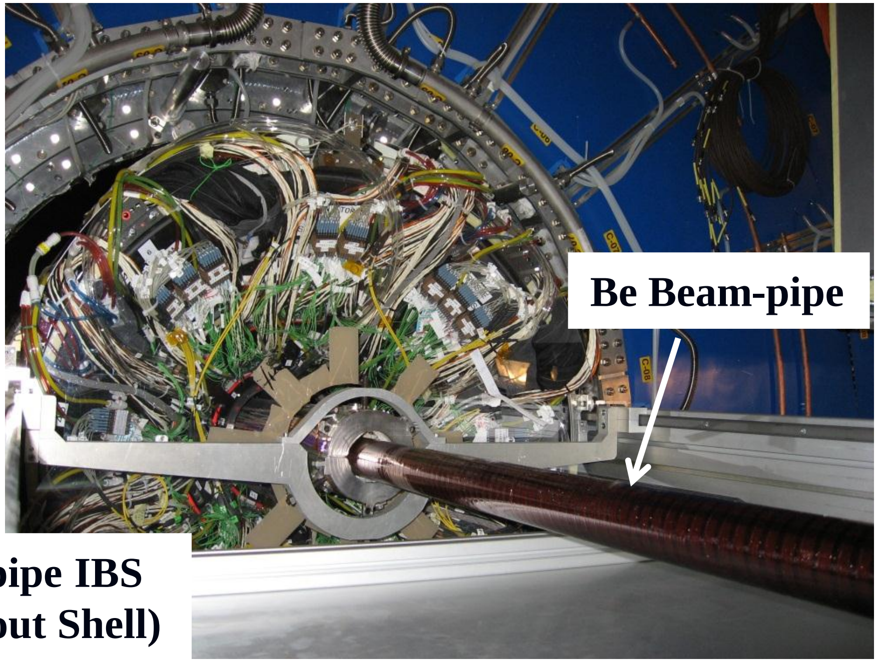




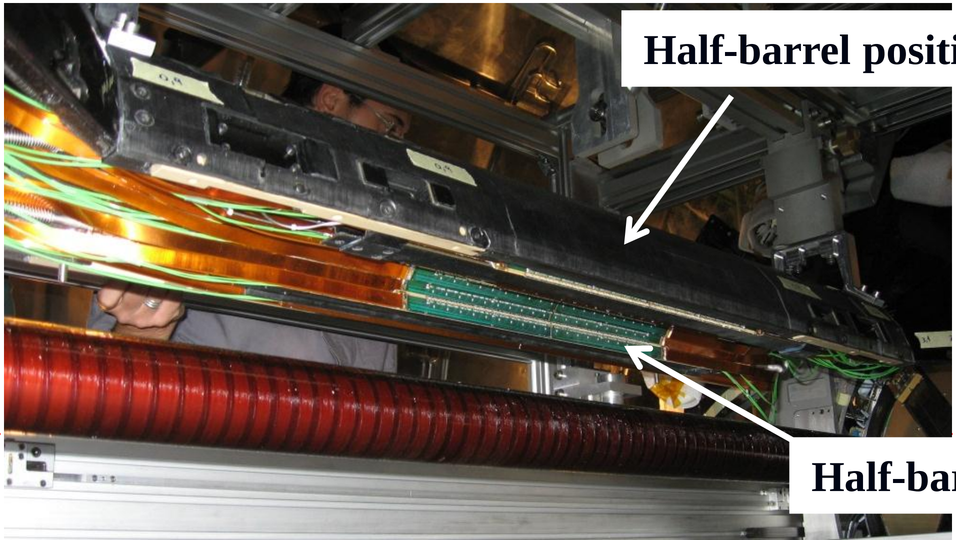
SPD installation in ALICE



Removal of the beam-pipe IBS
(Installation and Bake-out Shell)



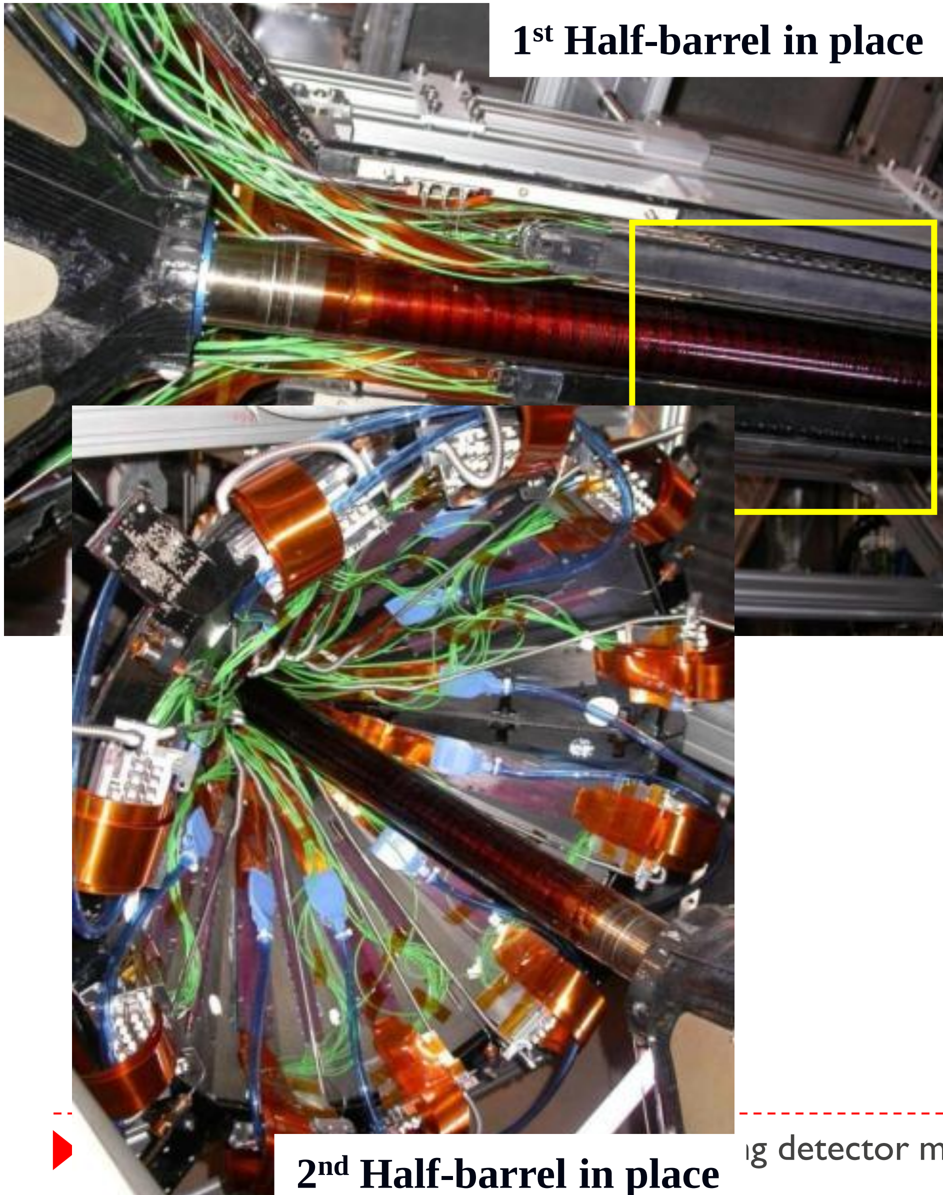
Be Beam-pipe



Half-barrel positioning

Half-barrel layer 1

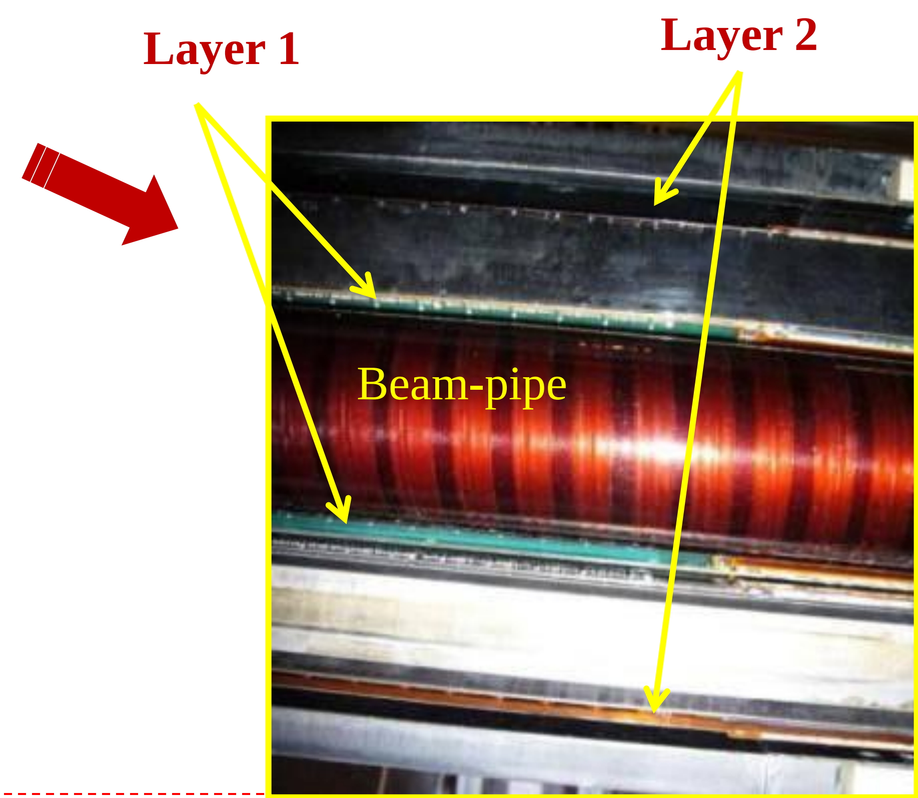
SPD installation in ALICE



1st Half-barrel in place

2nd Half-barrel in place

SPD Internal mean radius ≈ 39 mm
Beam pipe outer radius = 29.8 mm



Material budget summary table

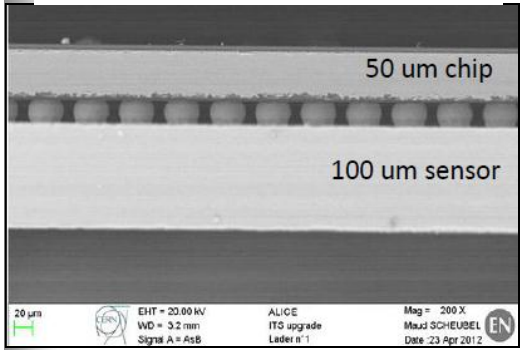
ALICE

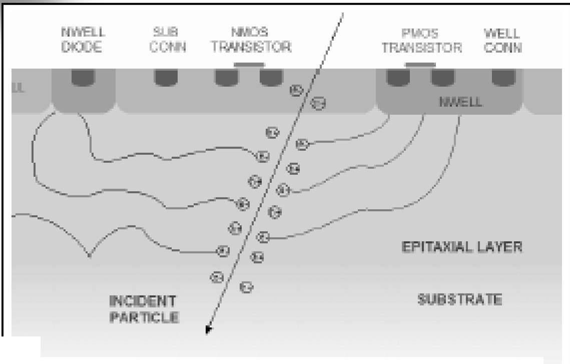
SPD Component	Some details	Thickness (μm)	X/X0 (%)	Contribution to the total X/X0 (%)
Silicon	Sensor + FEE + interconnection	350	0.38	33
Electrical bus	5 Al/polyimide layers + SMD components	280	0.48	42
Mechanical support and cooling	Carbon fiber + tube	200	0.19	17
Others	Glue (assembly / thermal contact) and grounding foil		0.09	8
Total			**1.14**	**100**

Towards the upgraded pixel layers

SPD Component	Some details	Thickness (μm)	X/X0 (%)	Contribution to the total X/X0 (%)
Silicon	Sensor + FEE + interconnection	350	0.38	33
Electrical bus	5 Al/polyimide layers + SMD components	280	0.48	42
Mechanical support and cooling	Carbon fiber + tube	200	0.19	17
Others	Glue (assembly / thermal contact) and grounding foil		0.09	8
Total			**1.14**	**100**

Hybrid thinned to 150 μm (0.16 % of X0)



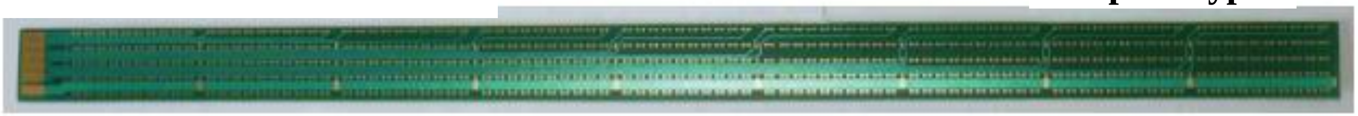


Monolithic thinned to 50 μm (0.053 % of X0)

See C. Gargiulo's talk

Electrical Bus: double Al/polyimide layer (0.075 % of X0)

1st prototype



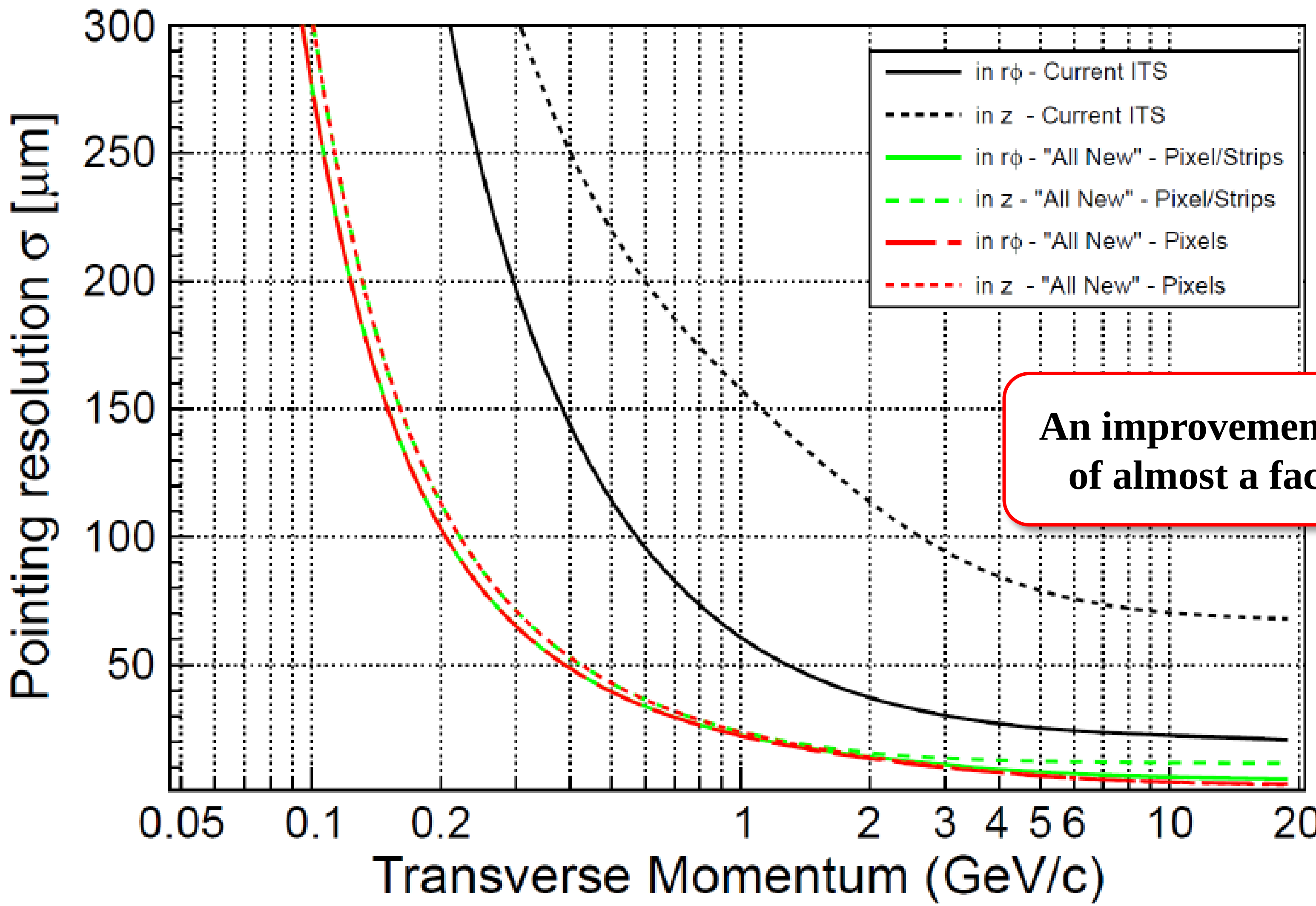
Back to the previous considerations

- The key requirements to obtain good tracking performance are:
  - Small channel dimension
  - Low material budget
  - First layer as close as possible to the interaction point

- The silicon pixel detector in ALICE
  - Channel dimension: 50 μm (rφ) x 425 μm (z)
  - Material budget: 1.14 % of X0
  - Mean sensor position of the first layer = 39 mm
    - Beam pipe outer radius = 29.8 nm

- Target for the first layers of the upgraded ITS
  - Channels dimension: 20 μm x 20 μm (monolithic option)
  - Material budget: 0.3% of X0 (See C. Gargiulo's talk)
  - First tracking point: 22 mm
    - This will be possible by reducing the beam-pipe outer radius to 19.8 mm

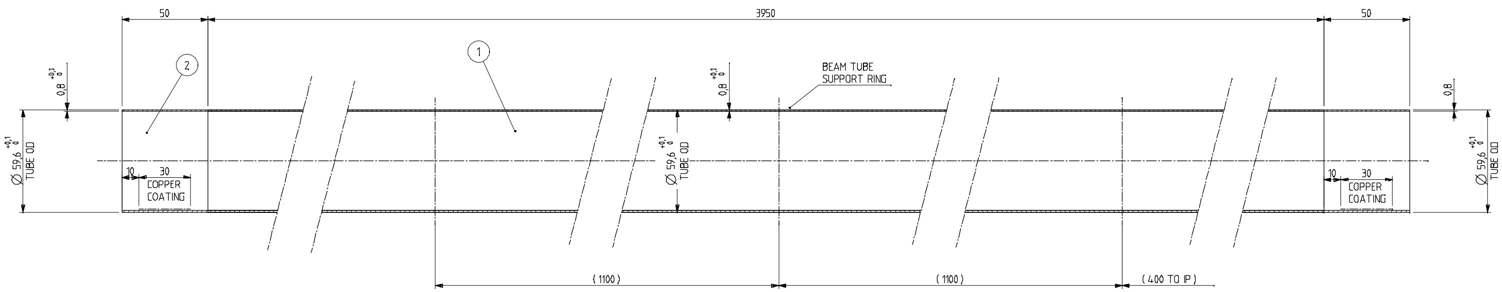
Back to the previous considerations



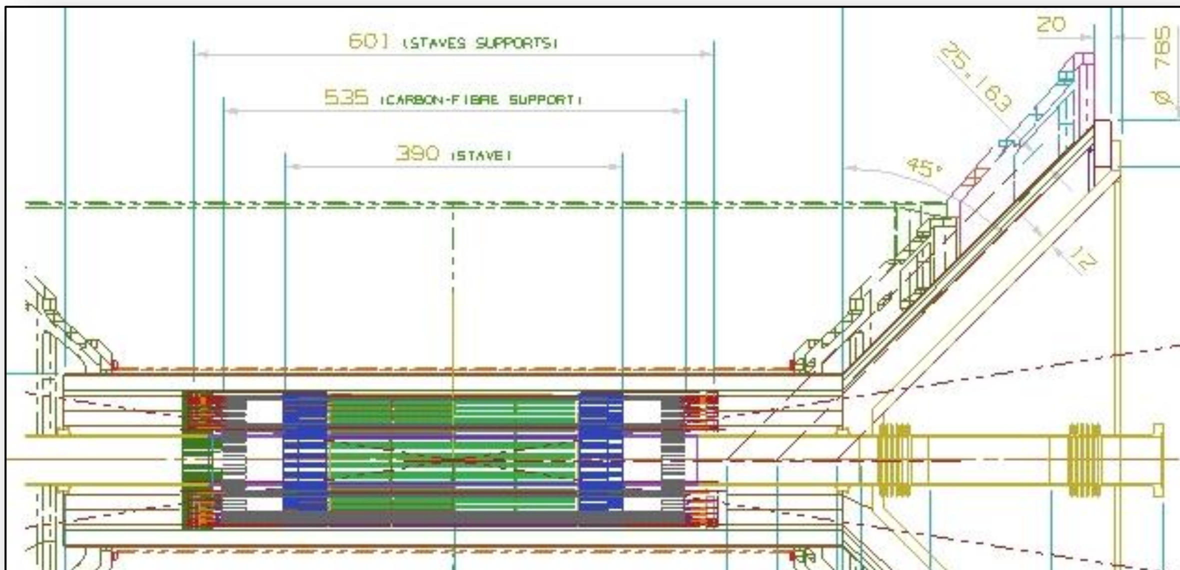
An improvement in rφ of almost a factor 3

Thanks for your attention

Spare

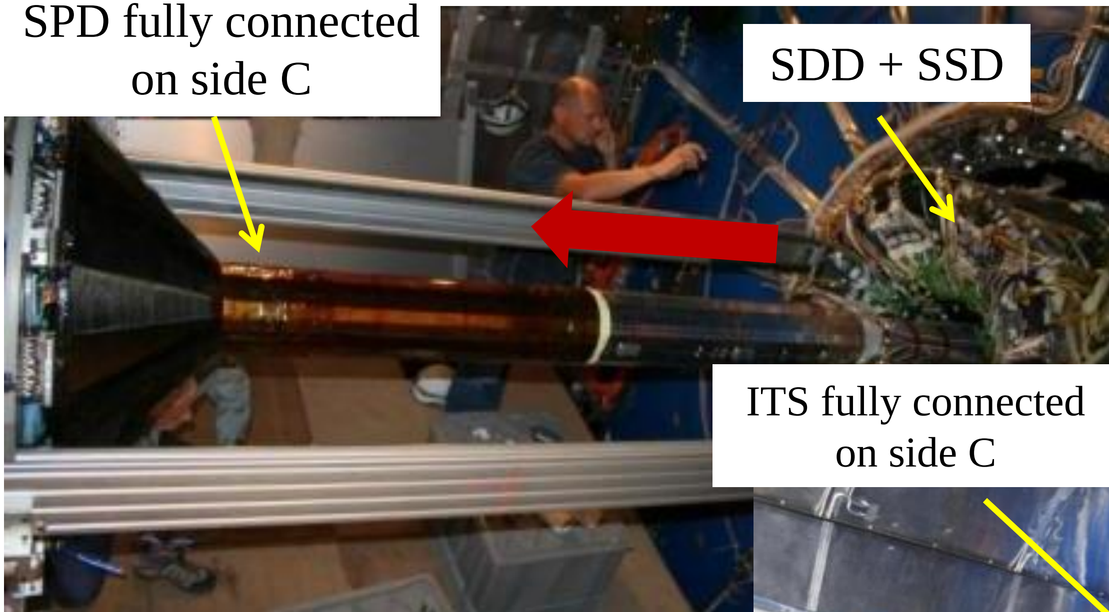


CP/1

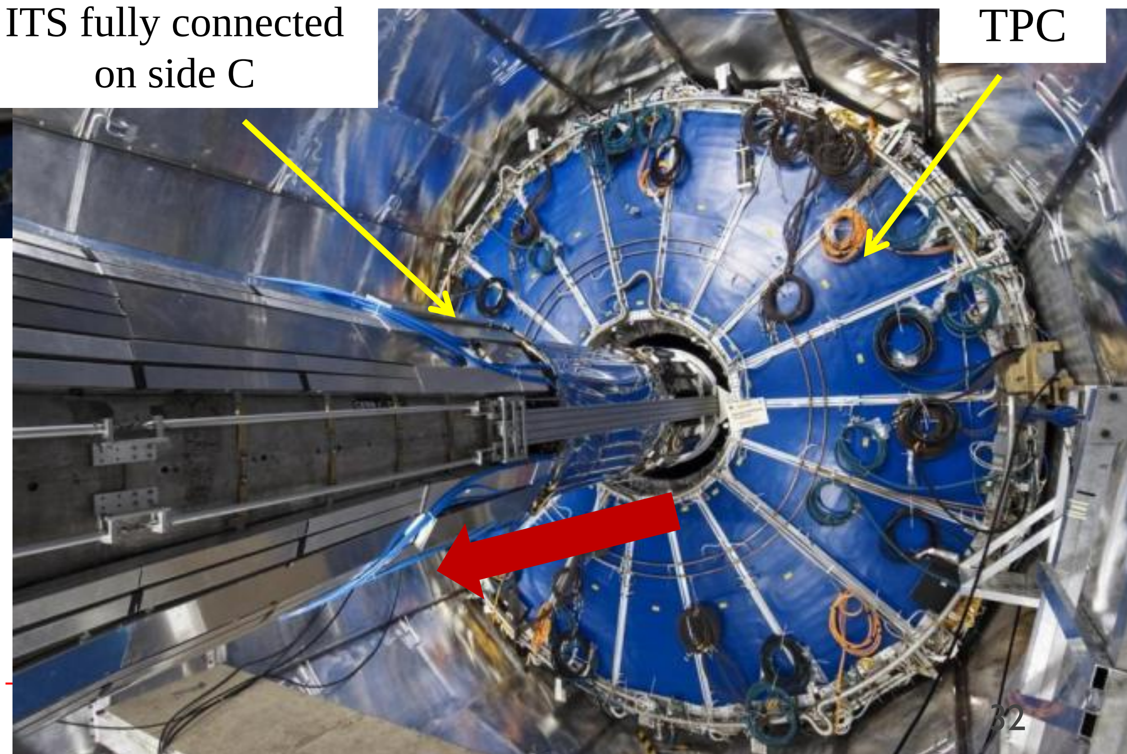


	current ALICE	ALICE upgrade	ATLAS upgrade	CMS upgrade
innermost point (mm)	39.0	22.0	25.7	30.0
x/X_0 (innermost layer)	1.14%	0.3%	1.54%	1.25%
d_0 res. $r\phi$ (μm) at 1 GeV/c	60	20	65	60
hadron ID p range (GeV/c)	0.1–3	0.1–3	–	–

ITS installation: summer 2007 (phase 2)



SDD+SSD moved over the SPD to form the ITS



TPC moved over the ITS