Mechanical layout, services and integration

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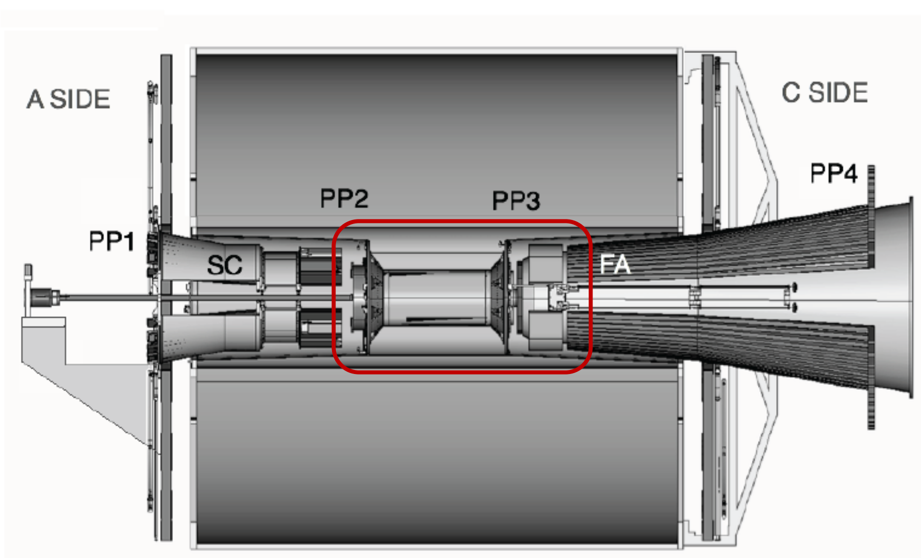
On behalf of the ITS upgrade WG4

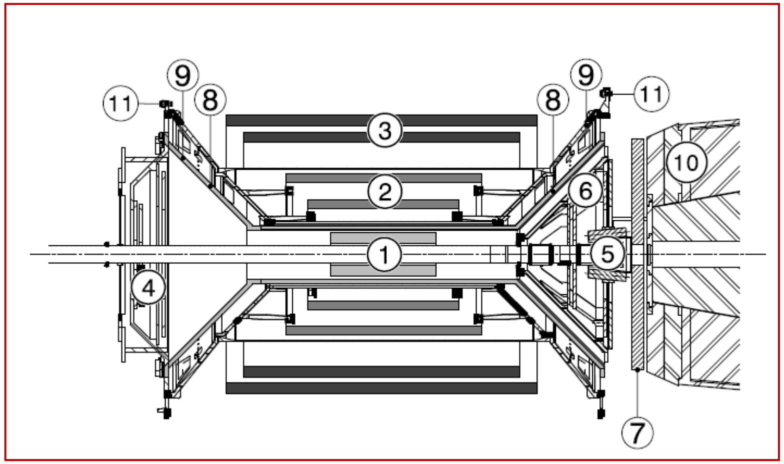
Outcome

- Contents of CDR chapter V (ver. 1.0)
- Requests for the CDR version 2.0

Introduction and system overview

- Description of the present scenario: ITS, TPC, Miniframe, patch panels etc.
- Basic considerations on the ITS accessibility and services connections
- Justification of one of the main requirement for the new detector: installation / removal from side A without moving miniframe and TPC to guarantee the detector accessibility during the winter shutdown
- Introduction of the 2 proposed options
  - New SPD (option 1)
  - New ITS (option 2)





Requirements

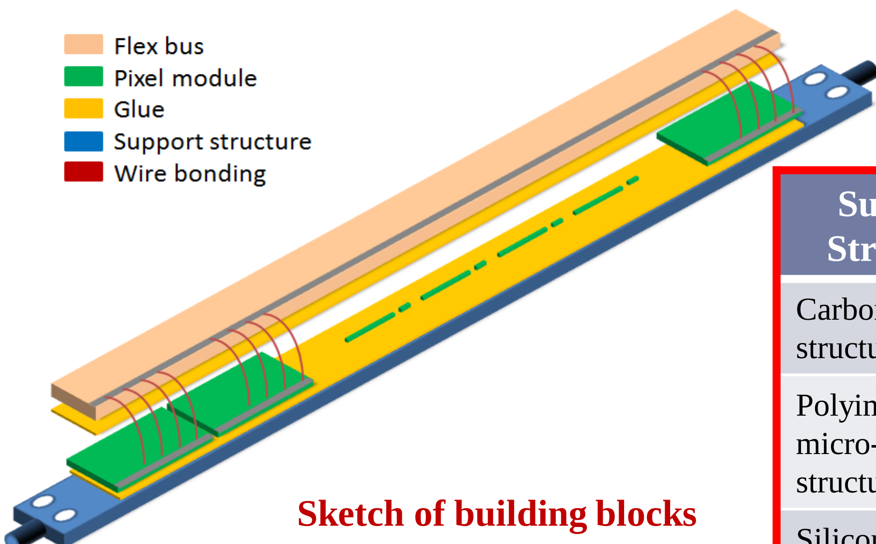
- 1^{st} layer as close as possible to the beampipe
  - 2 mm of clearance needed to move the detector along the beampipe during the installation
- Pseudo-rapidity coverage of 1.22 over the 90% of expected luminous region
- Demanding material budget (next Slide)

Parameters - Option 1		
Beampipe outer radius	mm	19.8
Number of pixel layers		3
Mean radial positions	mm	22, 47, 90
Stave length in z	mm	224, 300, 434
Power consumption	W/cm^2	$0.3 \div 0.5$
Total material budget per layer	X/X_0 (%)	≤ 0.5
Working temperature	°C	≈ 30
Deviation from nominal shape	μm	few hundreds

Parameters - Option 2		Pixel	Pixel–Strip
Beampipe outer radius	mm	19.8	19.8
Number layers		3	4
Mean radial positions	mm	22, 28, 36	200, 220, 410, 430
Stave length in z	mm	224, 242, 268	780, 836, 1424, 1486
Power consumption	W/cm^2	$0.3 \div 0.5$	≤ 0.5 mW/strip
Total material budget per layer	X/X_0 (%)	≤ 0.5	≤ 1.0
Working temperature	°C	≈ 30	≈ 30
Deviation from nominal shape	μm	few hundreds	few hundreds

Stave material budget

Component	Material budget X/X0 (%)	Notes
Support Structure	0.07 – 0.34	3 different structures are under discussion: carbon foam, polyimide and silicon
Glue	0.045	2 layers of glue 100 µm thick each
Pixel module	0.053 – 0.16	Monolythic (50 µm thick) – hybrid (150 µm thick)
Flex bus	1.5	Reasonable value if a singel layer flex bus is considered
Total	**0.32 – 0.7**	

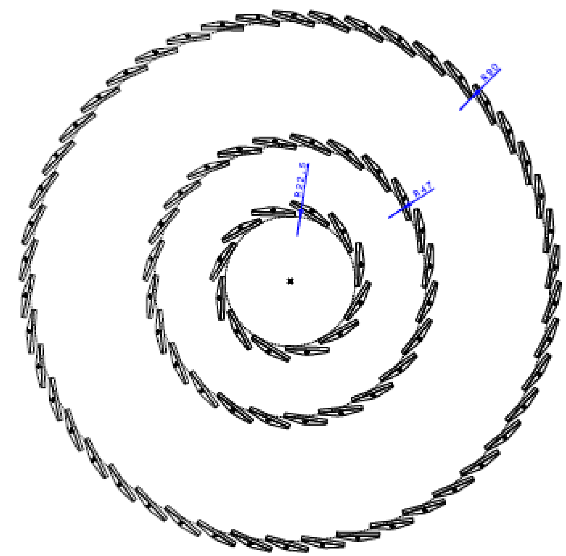


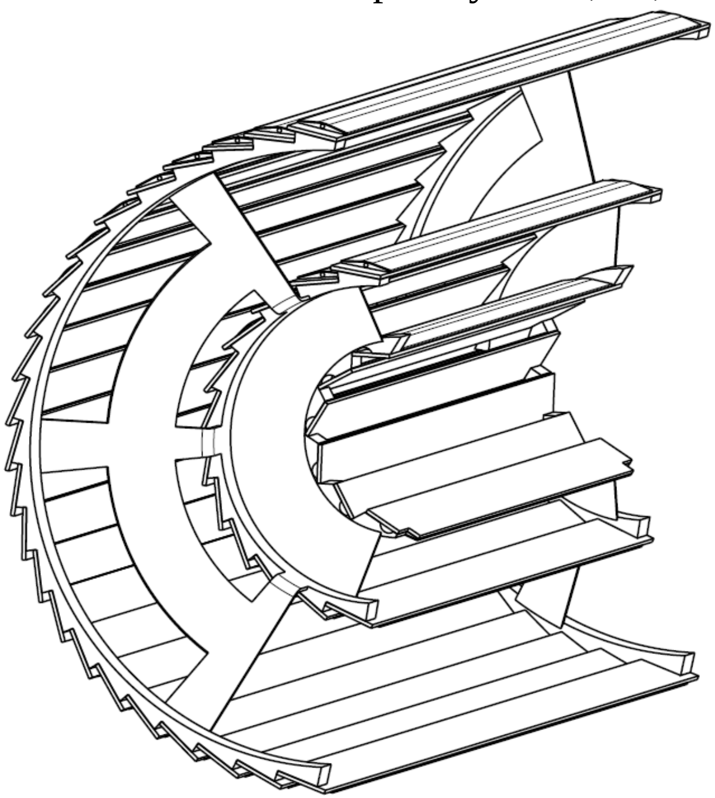
Sketch of building blocks constituting a generic stave

Support Structure	Material budget X/X0 (%)	Notes
Carbon foam structure	0.22 – 0.34	Different cooling tubes: PEEK or Metal (MP35N)
Polyimide micro-channel structure	0.085 – 0.13	Different coolant: H20 or C6F14
Silicon micro-channel structure	0.07 – 0.11	Different layout: sideline or distributed micro-channels

Conceptual Design: Option 1

- 3 layers of SI-pixel sensors: 1st layer at ≈ 23 mm from the IP
- Full structure divided in 2 half, to be mounted around the beam pipe and to be moved along the beam pipe towards the final position
- Modules fixed to the 2 carbon fiber wheels
- All the services on side A
- Number of staves per layer: 12, 24, 46



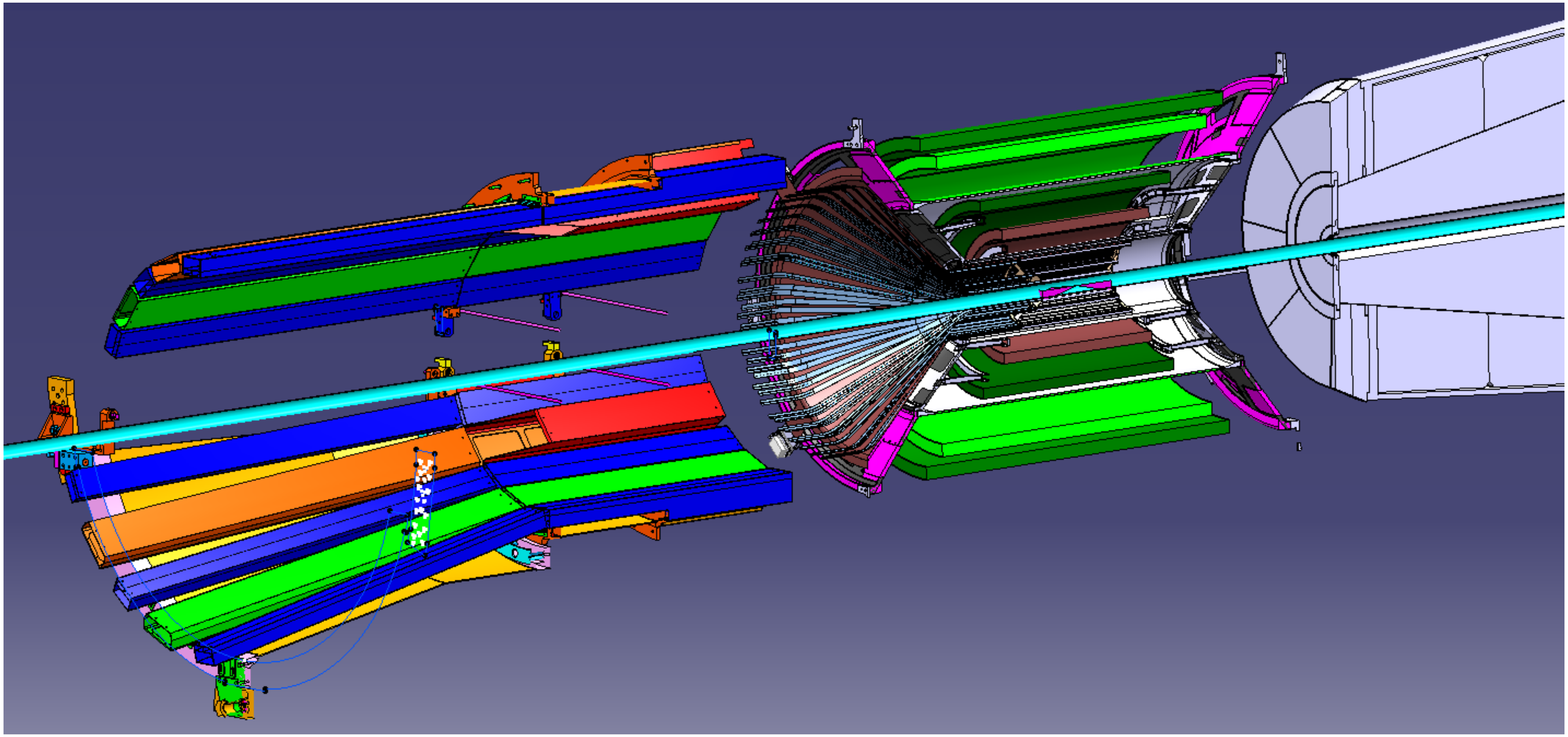


Constrains used in the drawings:

- Stave 15mm wide
- 2 mm dead area on one side
- Full azimuthally coverage plus overlaps
- 2 mm of clearance between neighboring staves
- Closest point to the beam pipe: 22.5mm (2 mm of clearance)

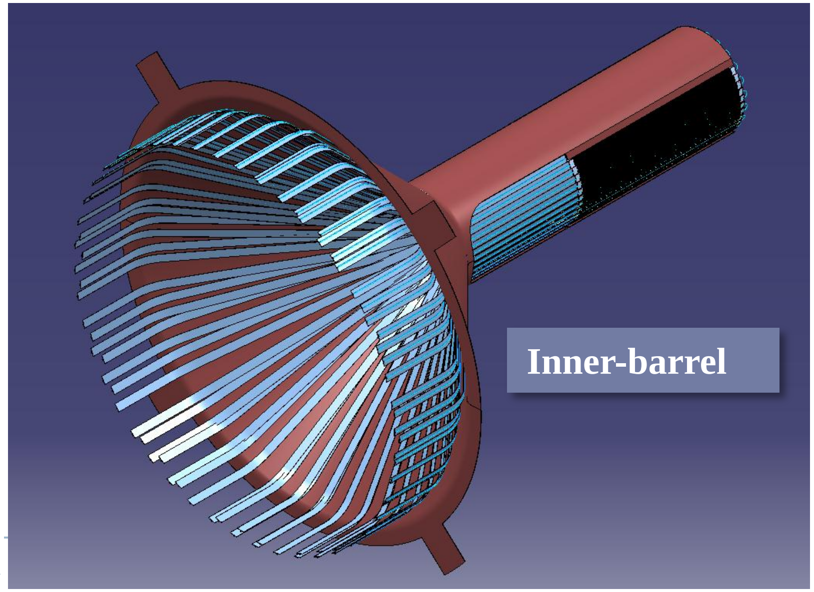
Conceptual Design: Option 1

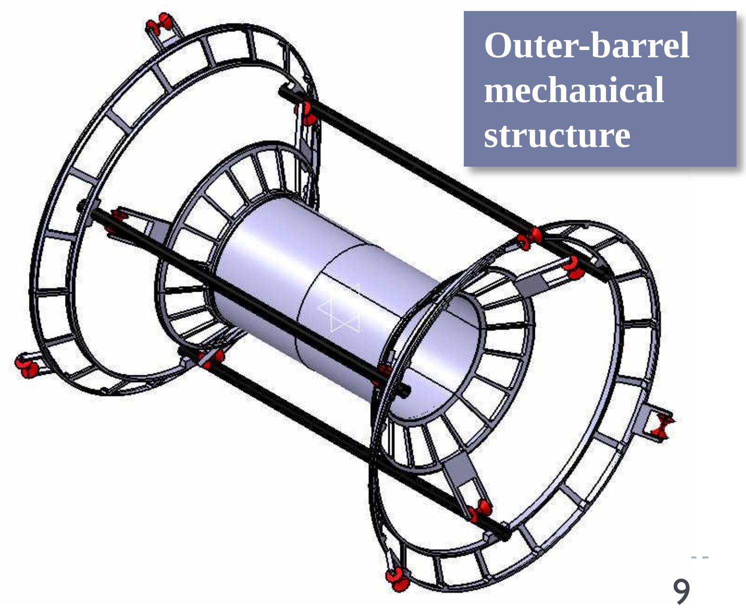
- The new detector will be integrated in the existing environment: SDD – SSD mechanical support
- The services will be connected only on PP1 because PP2 is not accessible when the TPC is in place (not shown in the drawing)



Conceptual Design: Option 2

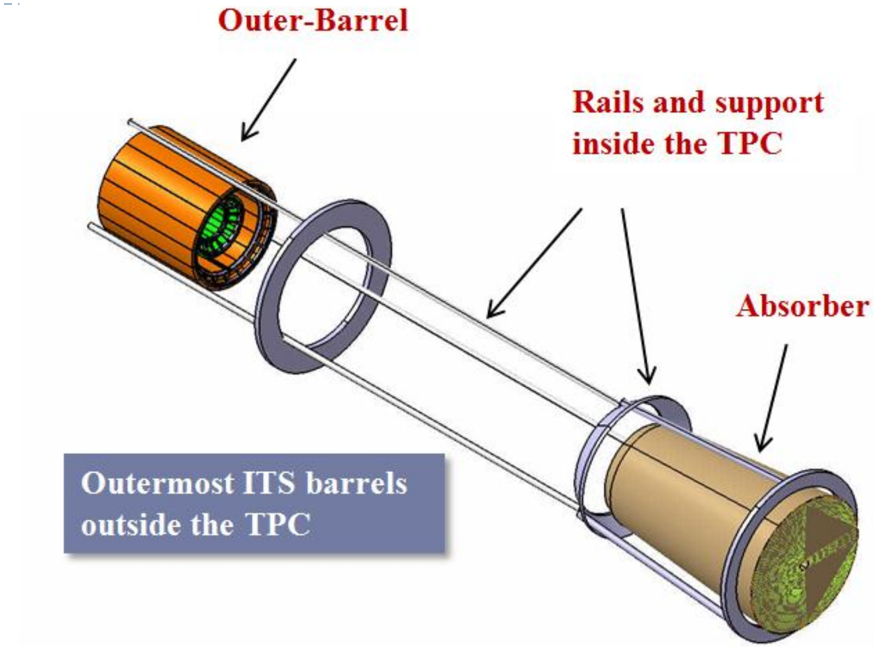
- Inner barrel: 3-layer structure
  - 3-pixel layers based on a similar mechanical structure used for the option 1
- Outer barrel: 4-layer structure
  - 4-detector layers (Pixel/strip) distributed on 2 barrels
  - Three tubes in carbon composite or beryllium are permanently fixed between the 2 structures both to rigidify it and to support - guide the inner part insertion

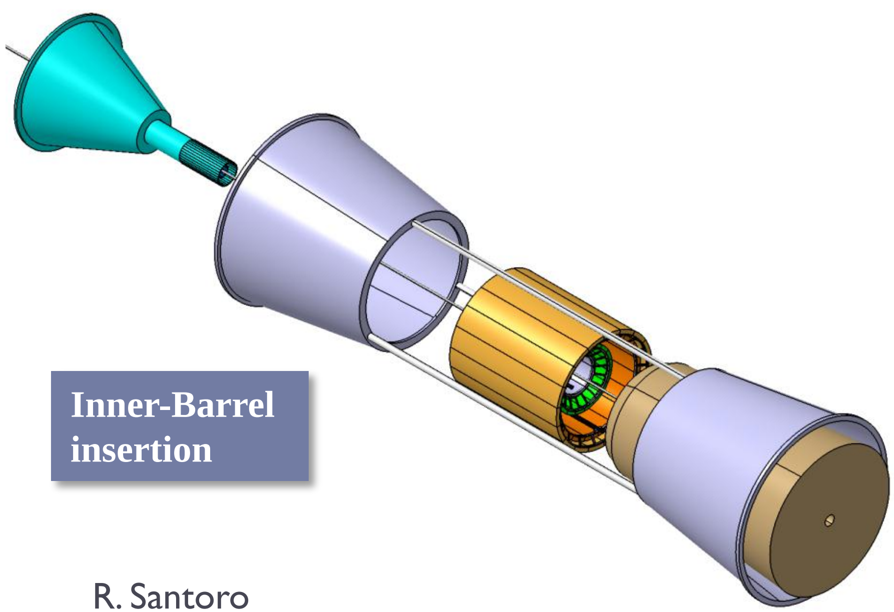


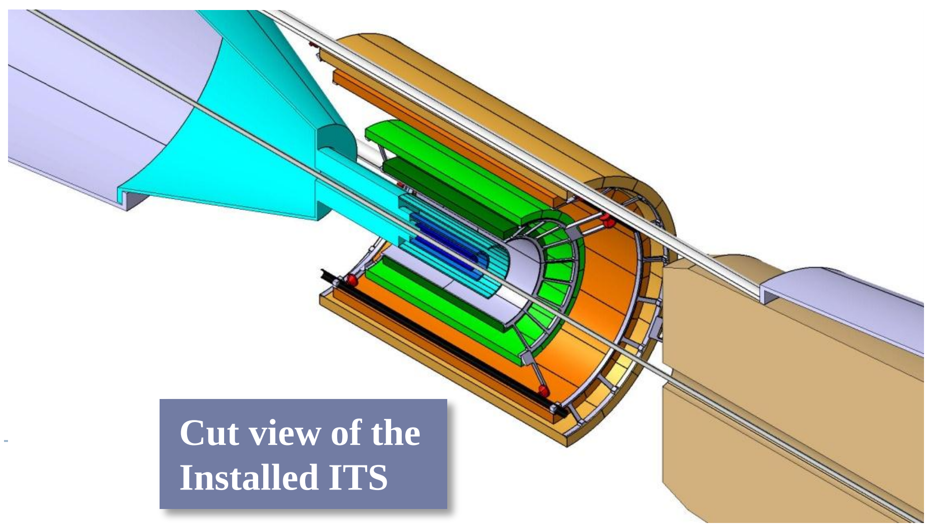


Conceptual Design: Option 2

- Three tubes in carbon composite or beryllium are permanently fixed in the inner surface of the TPC to support / guide the 4-layer Outer barrel insertion
- The Outer-Barrel is mounted outside the TPC before it is moved in the final position
- The Inner-Barrel is installed at the end







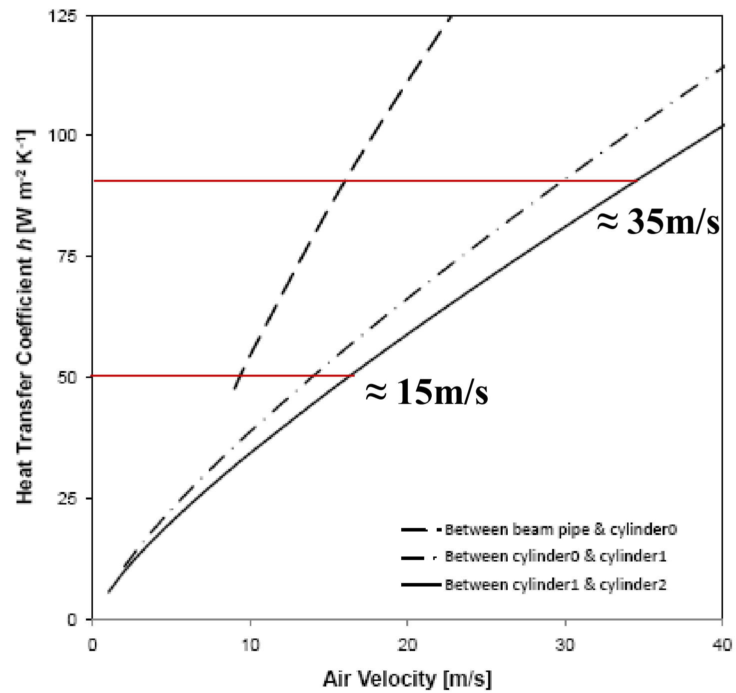
Cooling studies, R&D and prototypes

- At the moment we are studying different cooling options
  - Air cooling, carbon-foam, polyimide micro-channel and silicon micro-channel
  - The usage of high thermal conductivity plates based on APG (Annealed Pyrolytic Graphite) has been recently proposed. It is not include in the chapter although we decided to investigate also this option https://indico.cern.ch/getFile.py/access?contribId=0&resId=1&materialId=slides&confId=123827
- The input provided for all the studies are:
  - Low impact on the material budget (coolant, tubes, mechanical structures)
  - Cool down electronics with power consumption in the range of 0.3 – 0.5 W/cm^2
  - Working temperature around 30°C
- Accordingly with the progress of each option, we included simulations on simplified structure, R&D studies and test results on prototypes
- The possibility of having a different option for the inner layers will be considered if this will reduce the material budget

Air cooling

Preliminary considerations have been done using a simplified calculation for the inner barrel

$$q/2 = h(T_s - T_a)$$
$$q = 0.3W/cm^2 \Rightarrow h \approx 50Wm^{-2}K^{-1}$$
$$q = 0.5W/cm^2 \Rightarrow h \approx 90Wm^{-2}K^{-1}$$



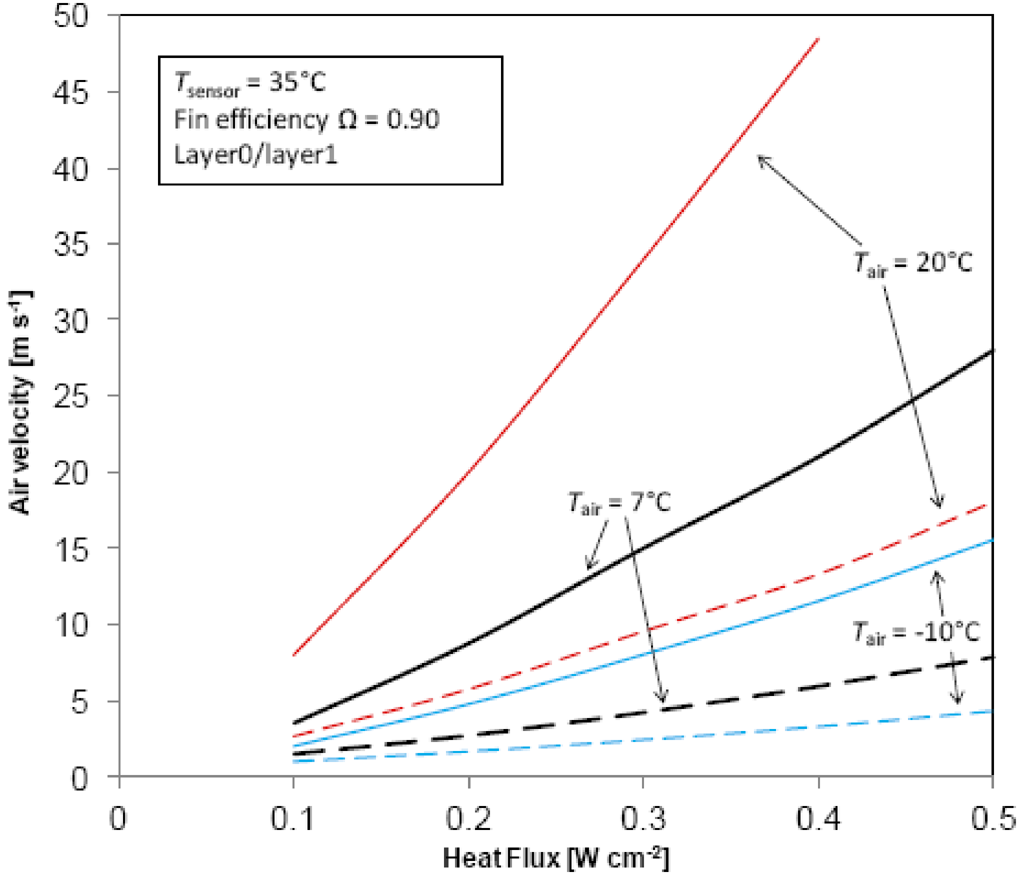
Assumptions

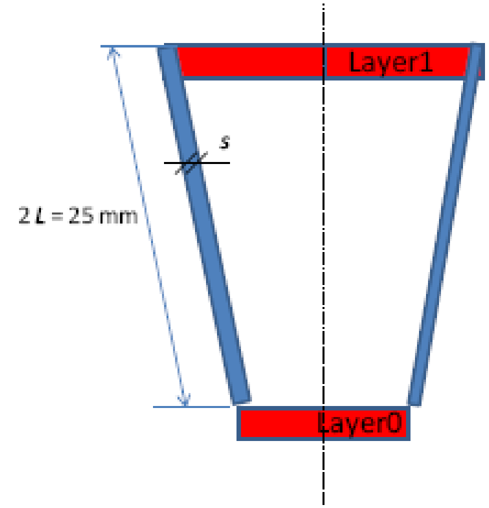
- Air flowing along the tubes with no air leakage
- 3 cylinders with the inner-barrel layout
- Power uniformly distributed along the surfaces (0.3 or 0.5 W/cm^2)
- Air inlet 7°C and temperature limit = 35°C

Considerations

- Those are only preliminary studies which show that we need very low power consumption to cool down the detector with reasonable air flow (less than 10 m/s)
- Further simulations and test are needed to better qualify this option
- With thermal conductivity fins, we should be able to reduce the air velocity (see next slide)

Air velocity reduction





D_h = 21 mm
(without fins D_h =50 mm)

- Heat transfer area (between layer0 and layer1) is increased by 140%
- The required heat transfer coefficient and air velocity decrease
- The lower hydraulic diameter also enhance the thermal performance

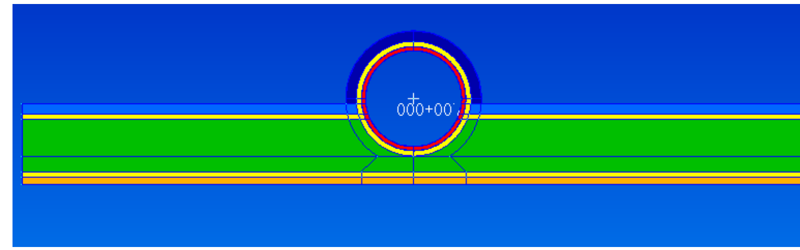
E. Da Riva APG thermal fins - ITS Upgrade 9/11/2011

For details:
https://indico.cern.ch/getFile.py/access?contribId=2&resId=0&materialId=slides&confId=123827

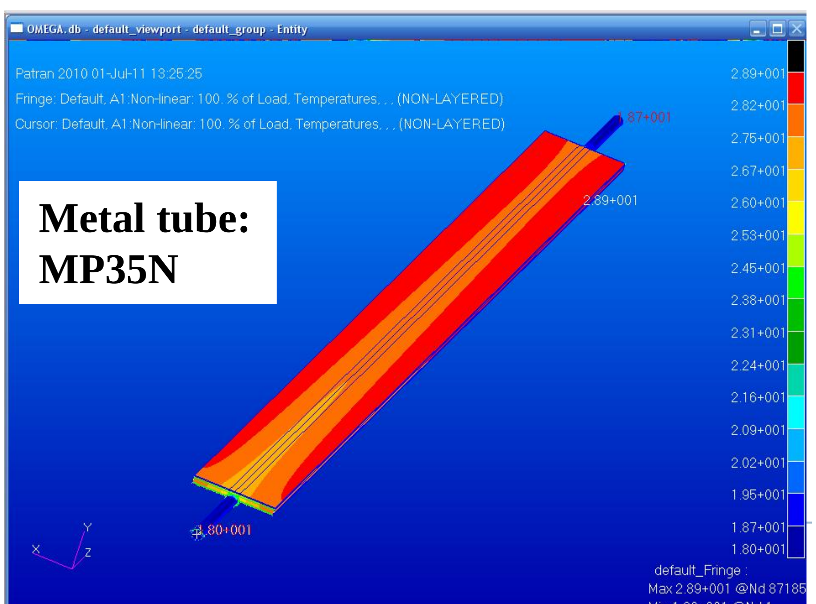
Carbon foam structure

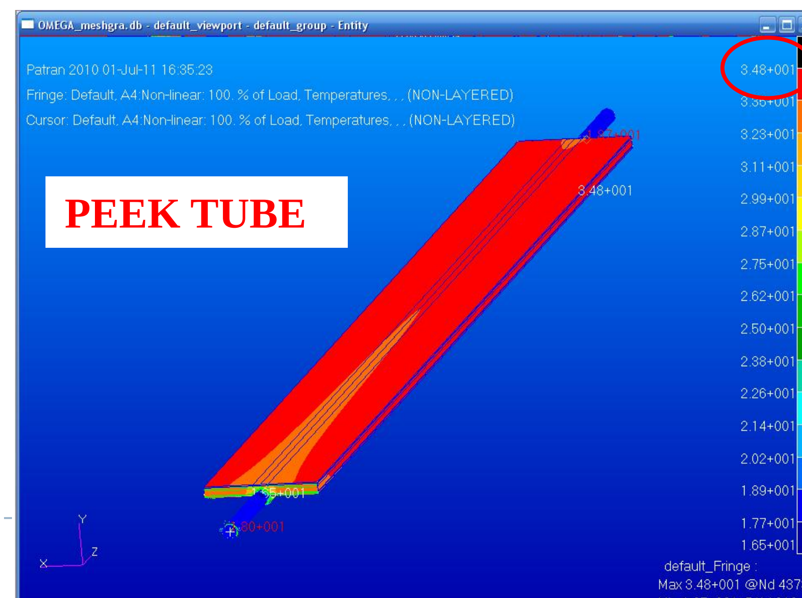
Preliminary simulations with resonable velues of material conductivity and thickness.
In these studies we assume surfaces with ideal contact

- Power consumption 0.5 W/cm2
- Cooling with water in leakless regime
- Inlet temperature = 18°C and flow rate 0.3 lit/min
- Glue conductivity 1 W/mK (100µm thick)
- Carbon foam conductivity 50 W/mK (1mm thick)



- **Glue** (yellow)
- **Tube 2mm diameter ext and wall 80µm thick** (red)
- **Omega in carbon fiber** (blue)
- **Carbon foam** (green)
- **Silicon detector** (orange)

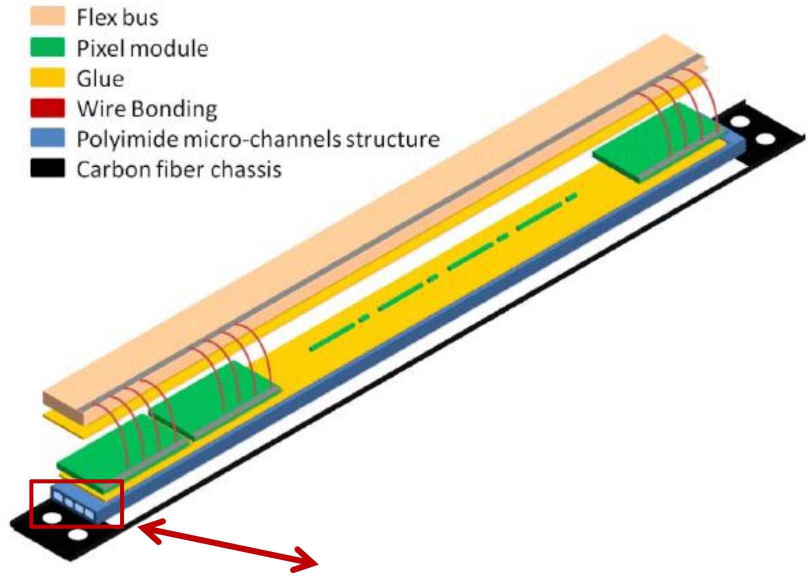


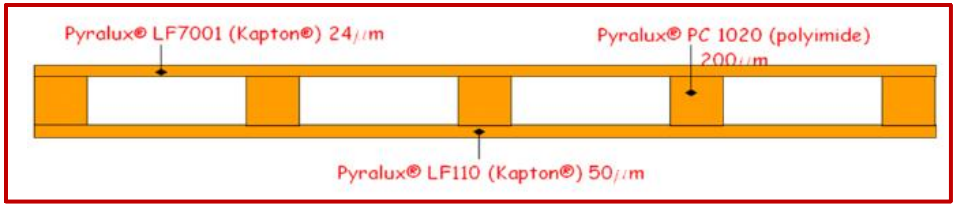


Polyimide micro-channel

Fabrication process

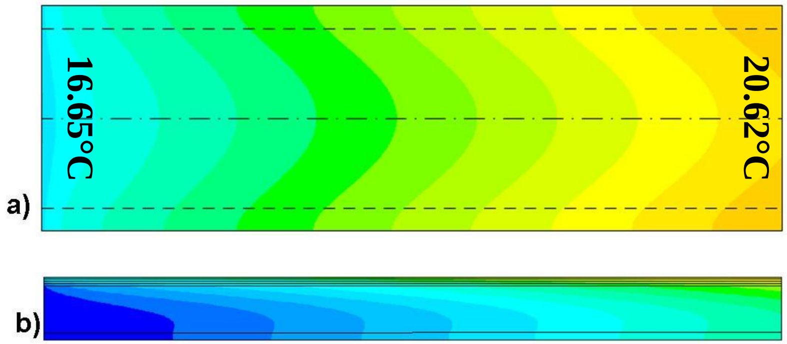
- Starting point: 1 layer of LF110 (50 µm thick) and 1 layer of PC1020 (50 µm thick)
- Grooves obtained with photolithography
- Cover lay hot pressed on the top and final cure @ 180°C for 10 Hours



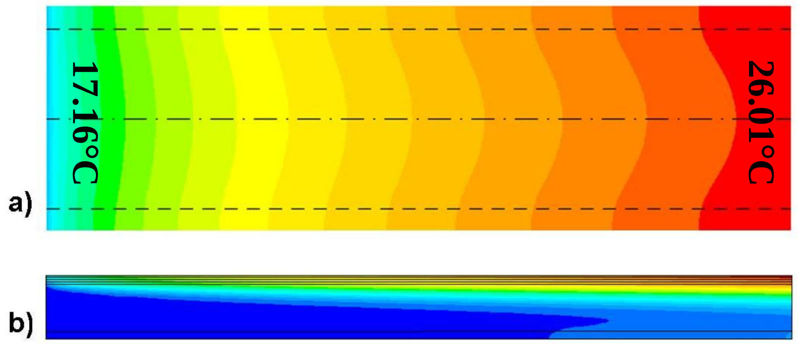


Simulation on micro-channel structures 200 x 800 µm^2

Water



C6F14



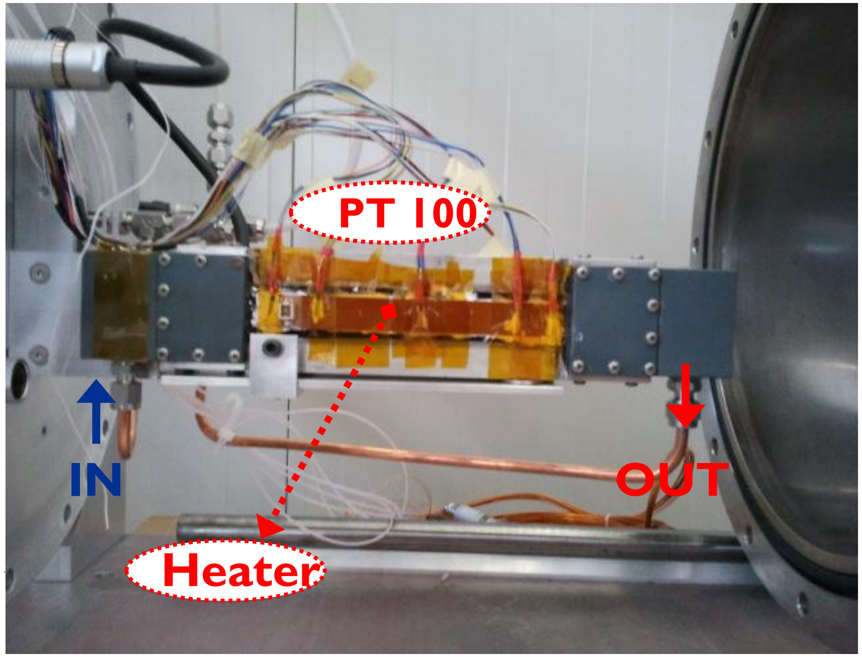
Simulated temperature distribution: polyimide surface and side view with 0.5 W/cm2

Polyimide micro-channel: tests with prototype

- Prototypes with simplified geometry: inlet and outlet at opposite sides (ready)
- Leak test and water compatibility (done)
- Thermo fluid dynamic test
  - First hydraulic and thermal test with C6F14 (done)
  - Test with water in leakless regime (soon)
- First connectors in polyimide (soon)

Prototype pressurized at 2 bar in water

Thermo fluid dynamic test set up



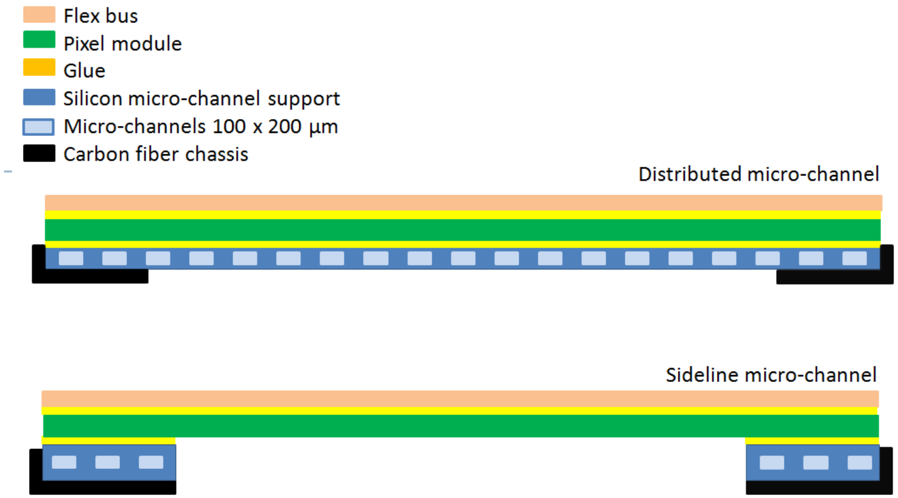
Test outcome:

- The hydraulic performance is in good agreement with the analytic estimation
- The prototype showed good thermal performance but it alighted the importance of having a good thermal contact

For details:
https://indico.cern.ch/getFile.py/access?contribId=1&resId=1&materialId=slides&confId=123825

Si-Micro-channel

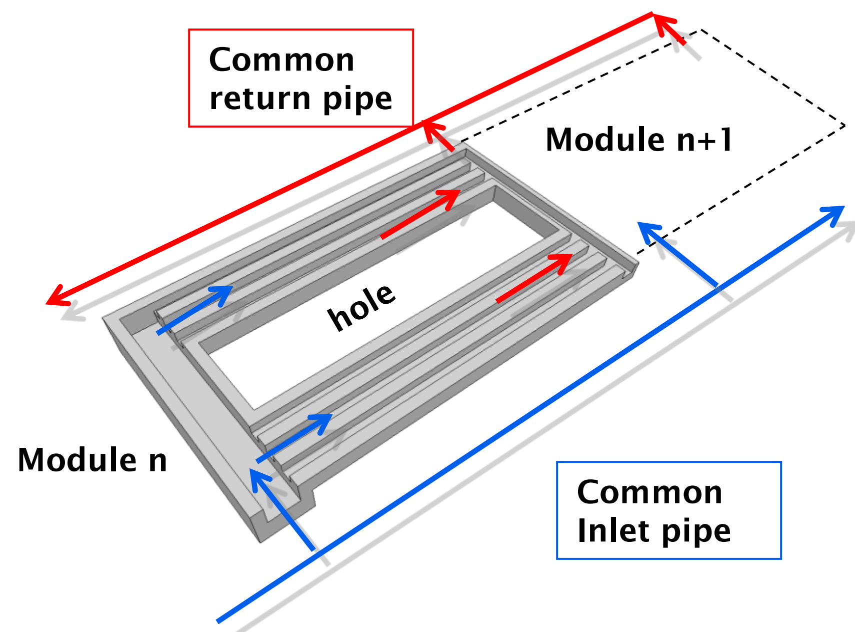
- Micro-channels made on etched silicon plates covered with Si-plate by fusion bonding
- Two layouts are under discussion
  - Distributed micro-channels: material budget equally distributed below the sensitive area
  - Sideline micro-channels: micro-channels confined at the chip’s border



Further considerations

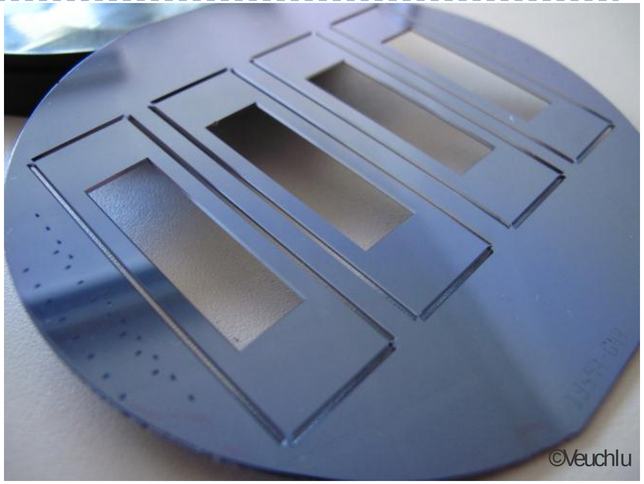
- This is actually an option considered for the NA62 Experiment at CERN
- Suitable with double-phases cooling (C02 or fluorocarbons)
  - Simulation and R&D are needed
- Limitation: the standard process is actually performed on 4” wafer although…
  - CEA-LETI is trying to manufacture 8” silicon wafer
  - There are some ideas to have micro-channels interconnections (next slides)

Sideline micro-channels

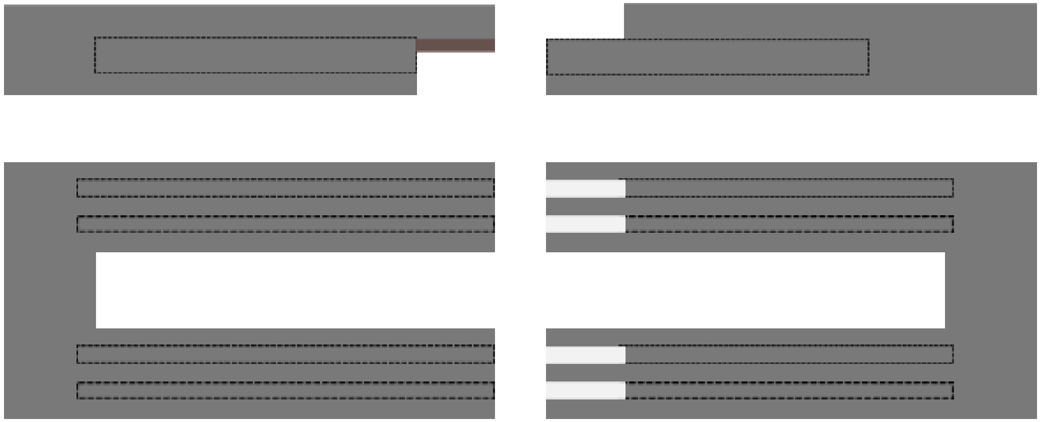


Silicon cooling frames

- First prototypes of micro-structured full silicon cooling frame have been successfully produced in 4” wafers.
  - First tests with C_4F_{10} will start soon

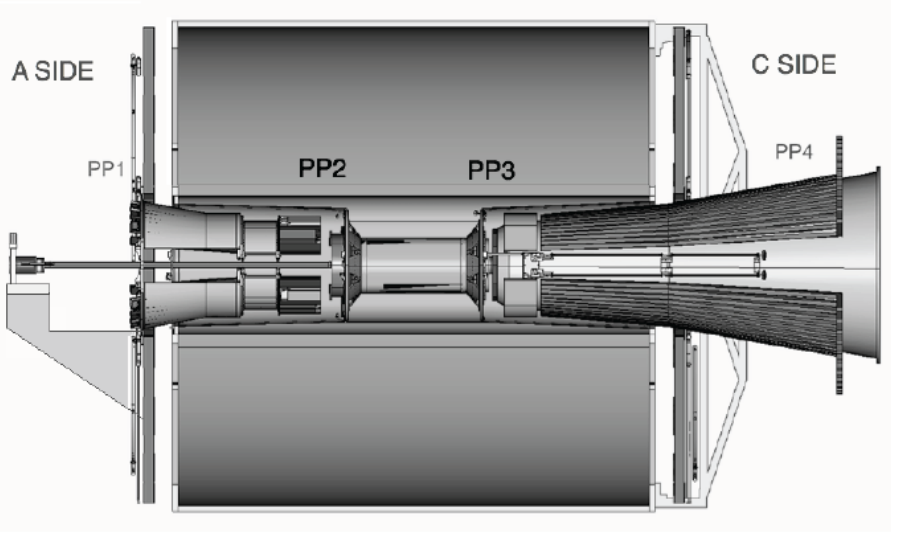


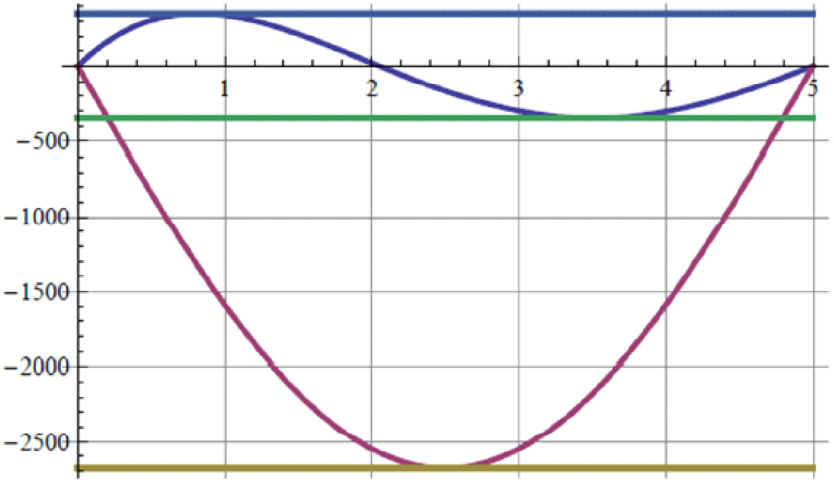
- There are some ideas on how to develop microfluidic interconnections between short frames of 4” or 6” wafers (benefiting from low pressure operation)



Beam pipe considerations

- The beampipe is actually hold in 3 points (FMD2, FMD3 and service support wheels)
- To permit the insertion of the ITS from the A side, the central support has to be removed
- The sagitta of a beampipe 5m long with the wall 800µm thick has been studied
  - The sagitta can be reduced applying a moment along the beam axis on one end (8Nm)
  - Almost the same result has been calculated with a thinner wall (500µm)
- In the section are described all the considerations used to justify the inner radius of the beam pipe (i.e. fabrication tolerance, sag, alignment etc.)
  - At the moment we are assuming to have a beam pipe with radius = 19.0 / 19.8 mm (inner/outer)
- Beam pipe with 500µm wall seems to be feasible although R&D is needed
  - The worry is the "porosity" and the vacuum tightness
  - Prototypes are needed





Requests for the CDR version 2.0

- Remove any reference to the 2 upgrade options and keep only the replacement of the full ITS (option 2 in the previous nomenclature)
- New target for the material budget and for the mean radius of the first layer
  - Beam pipe
    - Minimum possible radius: first discussions with the technical coordination just started
    - 500μm beam pipe wall
  - Further reduction of material budget: 0.1% of X0 in total
    - A preliminary idea will be shown in the next slide

Options for the new ALICE beampipe

	RI/RO [mm/mm]	Tolerance [mm]	N1 [σ]
1)	19/19.8	6	16
2)	17.2/17.7	6	11.8
3)	16.2/16.7	5	11.8

Length: 4820mm– All numbers assumed for 2σ

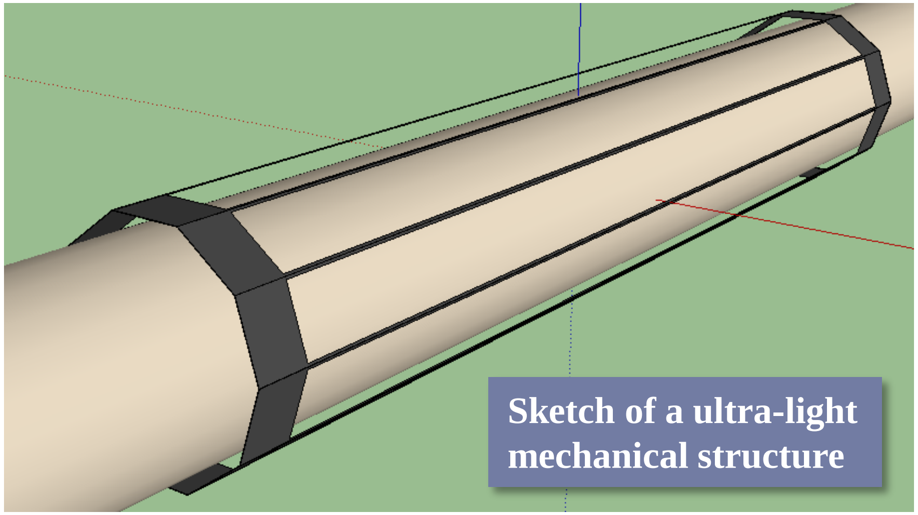
Solution 1: present proposal

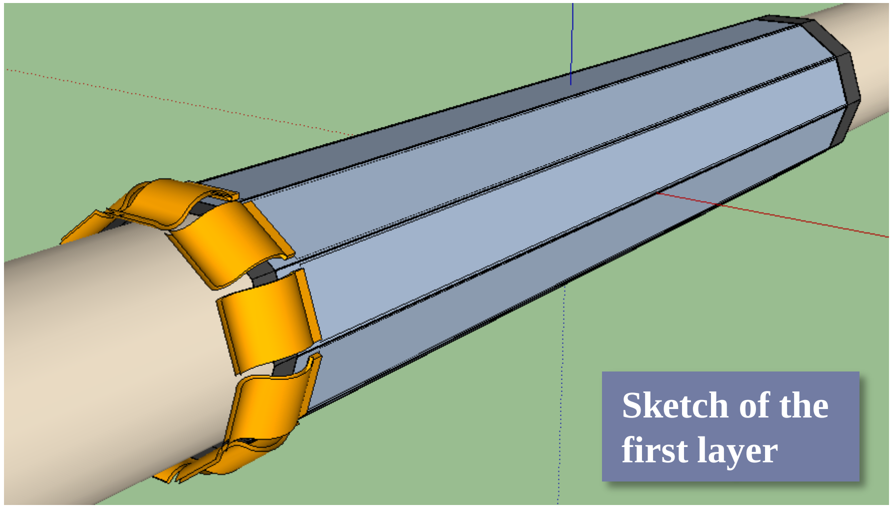
Solution 2: same n1 as ATLAS and CMS, and 500µm thickness

Solution 3: very challenging in term of tolerance

Ultra-light layer: preliminary considerations

- Very light structure with almost no material in the active area
- No overlap to simplify the geometry
- Air cooling looks to be the only option to avoid the extra material due to coolant, tubes and micro-channels structure
- Very light stave without glue layers, bus to bring signals at the periphery etc.
  - In first approximation, it looks to be "viable" only if we use large silicon structures ≈ 50μm thick with the integrated bus



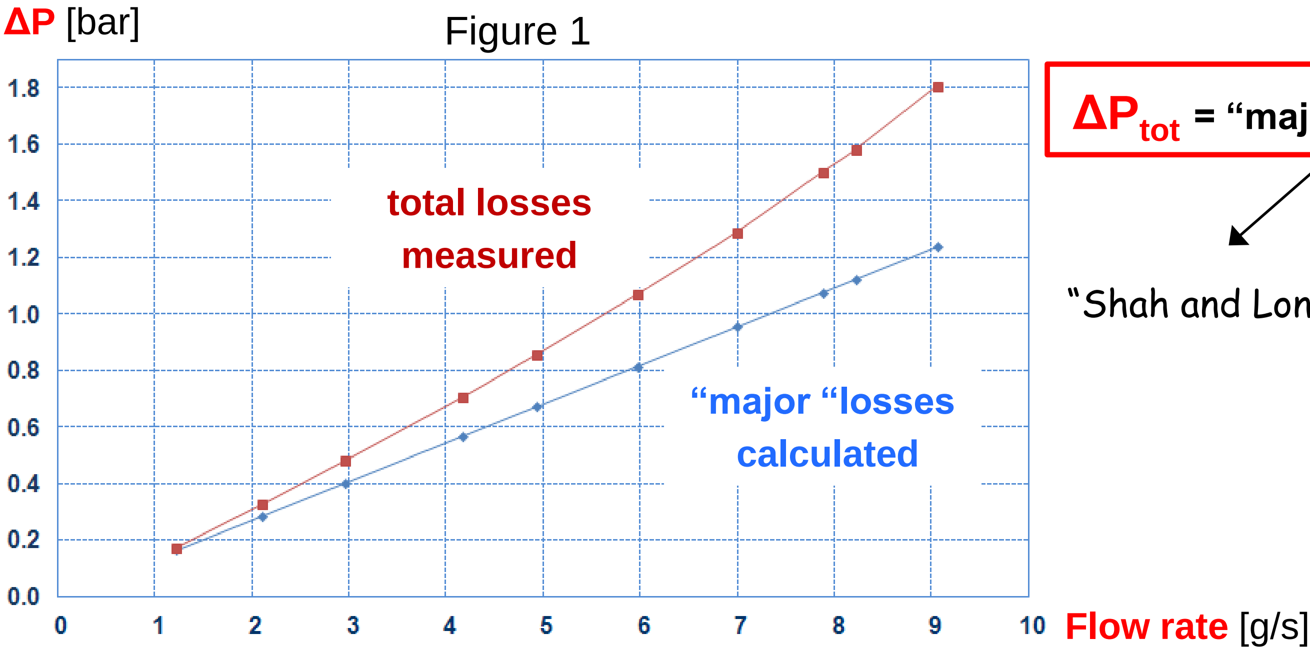


A special thanks to all the people who regularly contributed to the WG

Spares

Hydraulic test results

Figure 1



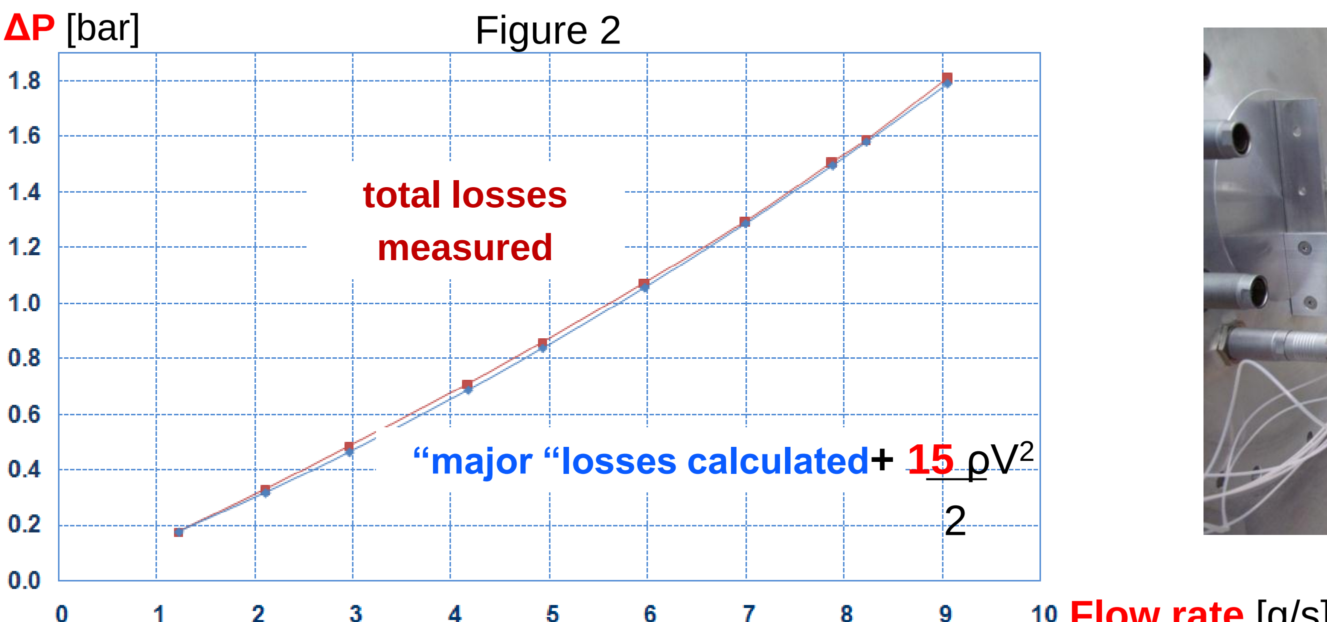
ΔP_{tot} = "major" losses + "minor" losses

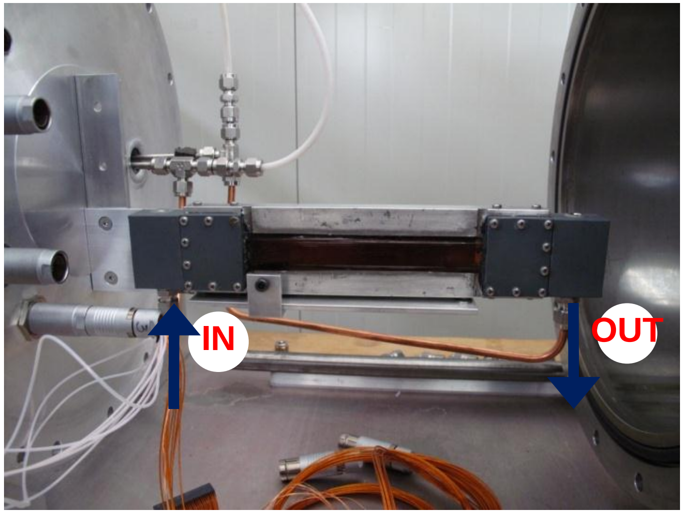
"Shah and London (1978)"

$\sum_i \frac{K \rho V^2}{2}$

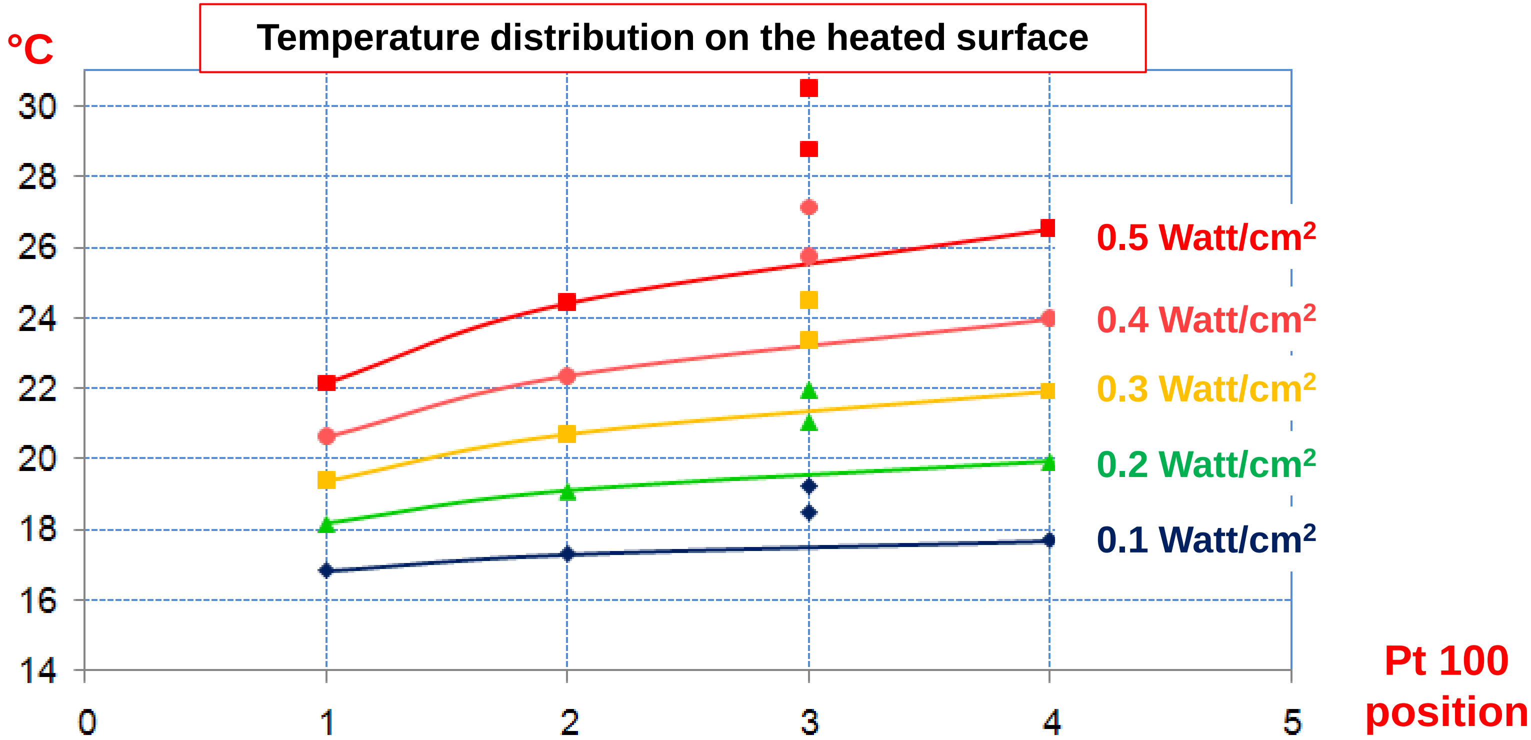
K= k(geometry)

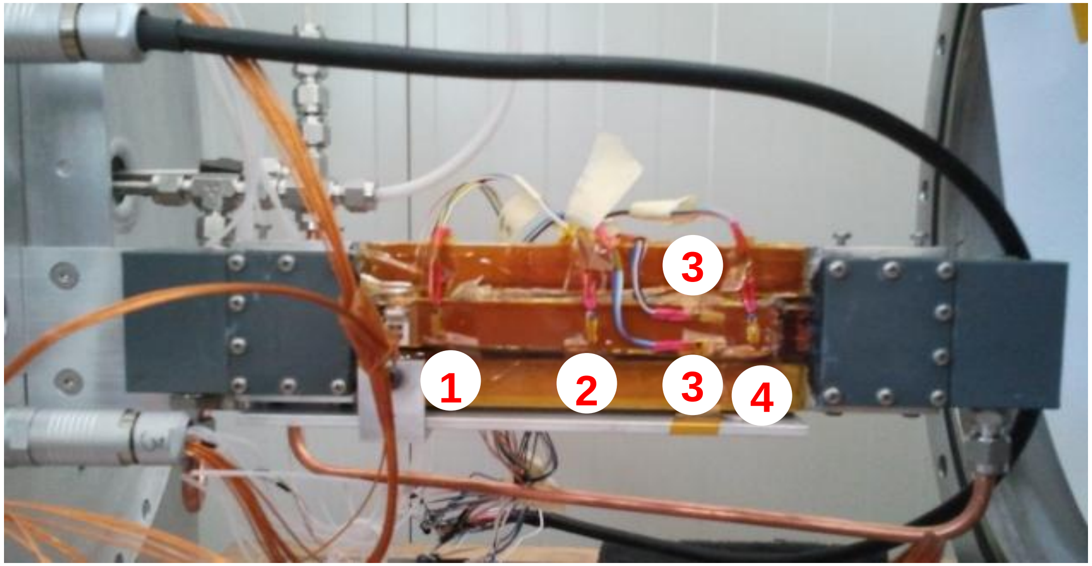
Figure 2





3° Thermal test : results





Option 1

Quantity	Value	Comment
Fabrication tolerance	0.5mm	CMS quotes 0.4mm
Sag	0.5mm	Unsupported length 4335mm + **counterweight**
Mechanical adjustment precision	2.0mm	
Survey to beamline uncertainty	1.5mm	Provided by survey
Quad fiducial to beamline uncertainty	0.5mm	
L3 movement	<0.5mm	
B field movement	<0.5mm	Measured values
Linear sum	**6.0mm**	
RI/RO	**19/19.8mm**	Thickness 800um
n1	**16**	**2.36σ/mm**

Length: 4820mm

Option 2

Quantity	Value	Comment
Fabrication tolerance	0.5mm	CMS quotes 0.4mm
Sag	0.5mm	Unsupported length 4335mm + **counterweight**
Mechanical adjustment precision	2.0mm	
Survey to beamline uncertainty	1.5mm	Provided by survey
Quad fiducial to beamline uncertainty	0.5mm	
L3 movement	<0.5mm	
B field movement	<0.5mm	Measured values
Linear sum	**6.0mm**	
RI/RO	**17.2/17.7**	Thickness 500um
n1	**11.8**	**2.36σ/mm**

Length: 4820mm

Option 3

Quantity	Value	Comment
Fabrication tolerance	0.5mm	CMS quotes 0.4mm
Sag	0.5mm	Unsupported length 4335mm + **counterweight**
Mechanical adjustment precision	**1.0mm**	Very demanding!
Survey to beamline uncertainty	1.5mm	Provided by survey
Quad fiducial to beamline uncertainty	0.5mm	
L3 movement	<0.5mm	
B field movement	<0.5mm	Measured values
Linear sum	**5.0mm**	
RI/RO	**16.2/16.7**	Thickness 500um
n1	**11.8**	**2.36σ/mm**

Length: 4820mm