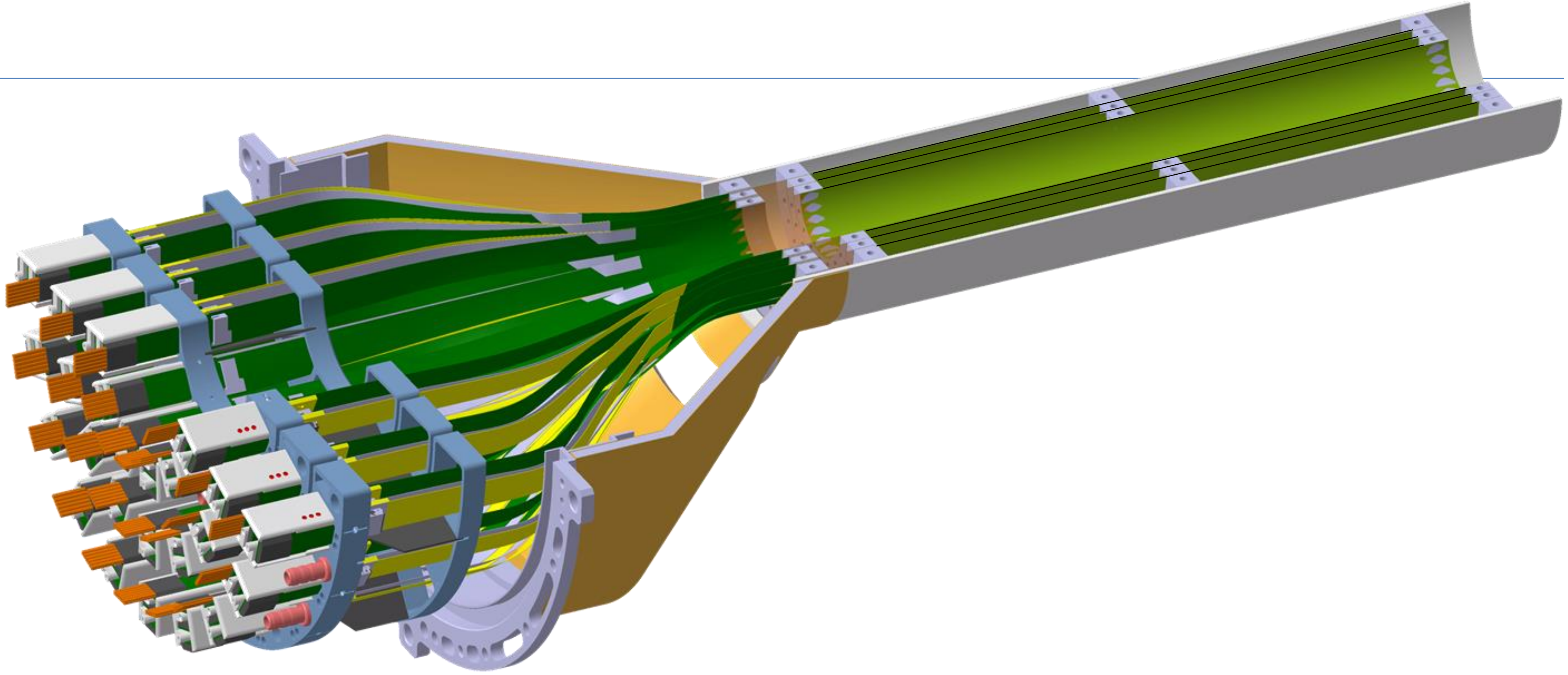
ITS3 mechanics and cooling



ITS 3 concrete example of R&D interest

ALICE-PUBLIC-2018-013
(https://cds.cern.ch/record/2644611)

ALICE proposal for a new vertex detector:

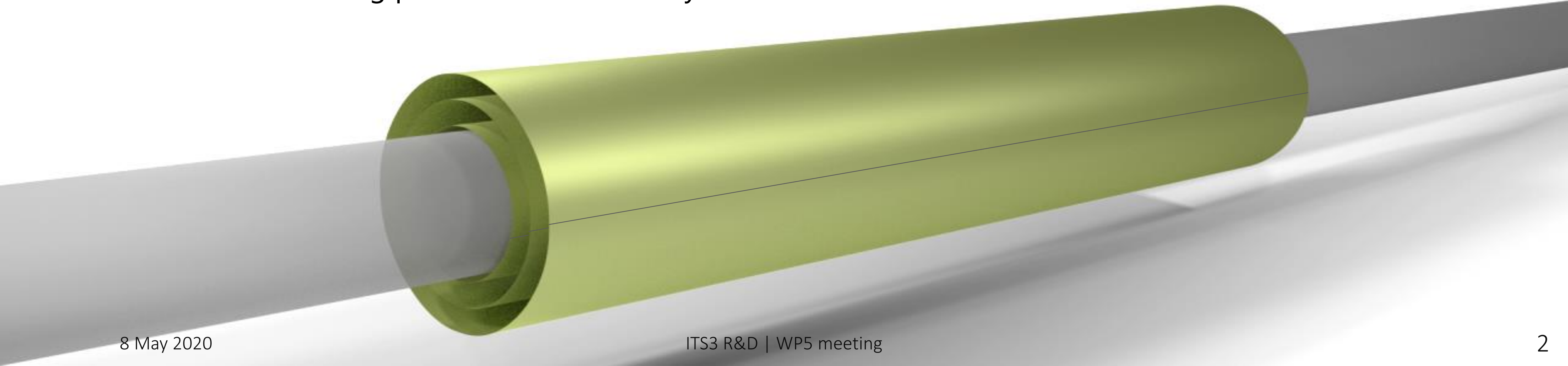
- new beam pipe with IR = 16 mm, ΔR = 0.5 mm
- three truly cylindrical Si-pixel layers based on ultra-thin, curved sensors
- material budget: X/X0 ≈ 0.05%
- inner-most layer: at R = 18 mm

Installation foreseen for LS3:

- replacing Inner Barrel of ITS2 (the upgraded ITS being installed now in LS2)
- Outer Barrel of ITS2 will stay in, Installation foreseen for LS3:

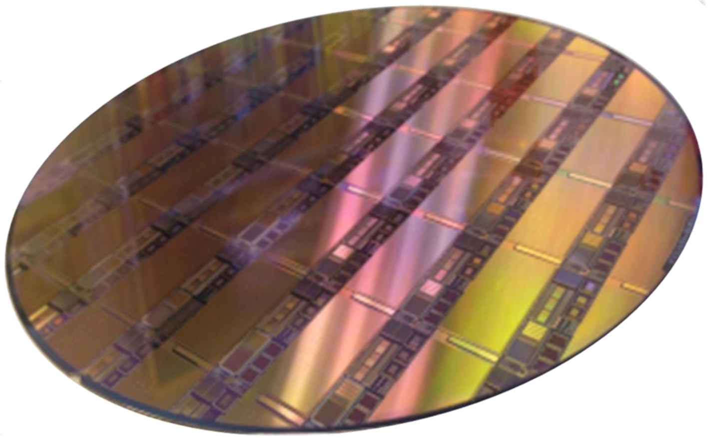
Key improvements:

- reduction of material budget (0.35% → 0.05% per layer) and equalisation of its homogeneities
- increase of tracking precision and efficiency at low transverse momenta



ITS 3 STICHING & BENDING

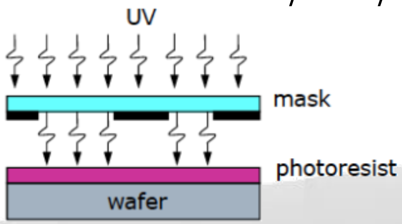
200 mm ALPIDE prototype wafer

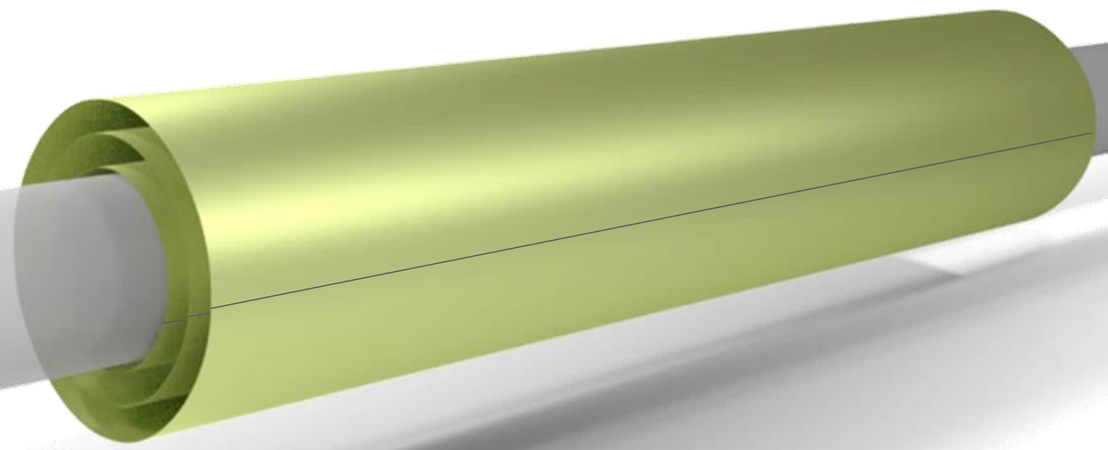


Courtesy: R. Turchetta, Rutherford Appleton Laboratory

- ➔ chip size is traditionally limited by CMOS manufacturing ("reticle size")
- ➔ new option: stitching, i.e. aligned exposures of given parts of a reticle to produce a larger circuit feasible, but needs specific design; on a 300 mm wafer (available in 65 nm technology node), a single chip fits a full half-layer

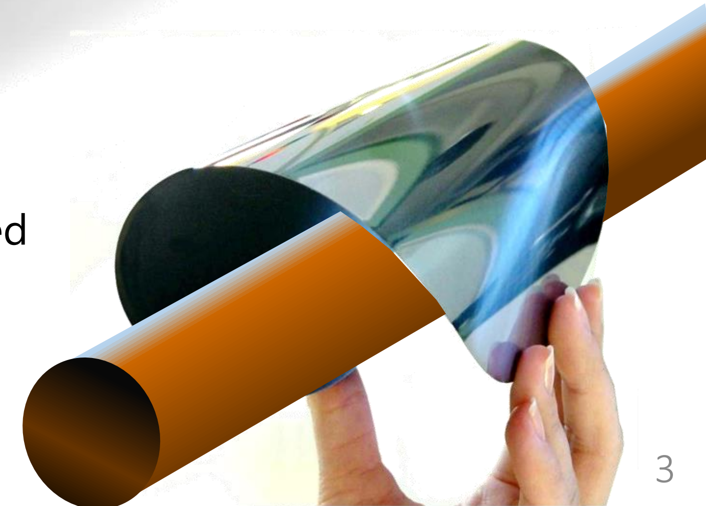
Principle of photolithography



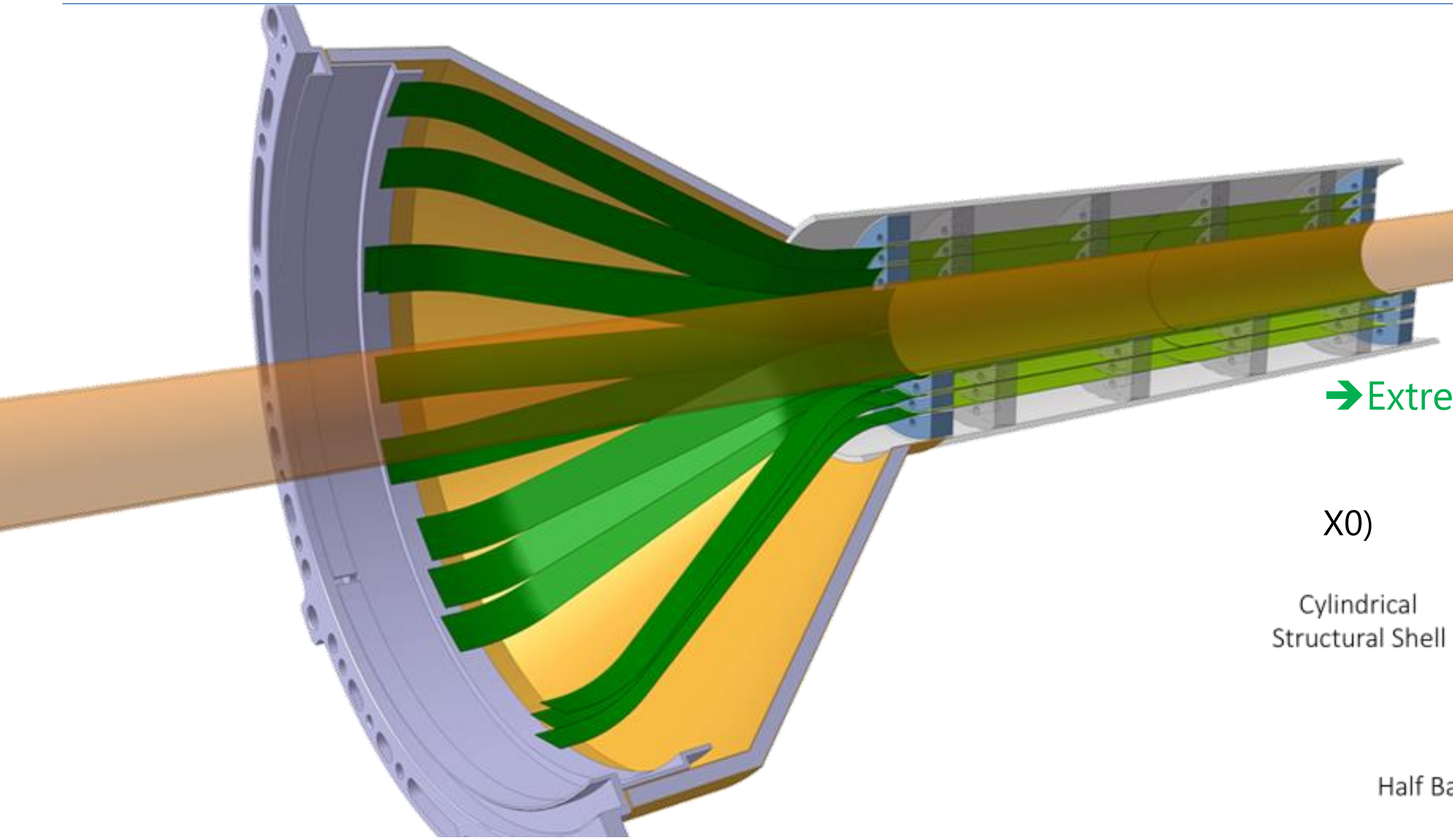


Chipworks: RF-SOI CMOS, 30µm-thick

- ➔ Bending Si wafers + circuits is possible!
- ➔ Radii much smaller than ALICE needs are obtained
- ➔ Circuit-specific R&D is needed
- ➔ Investigating options to start with existing ALPIDE chips + wafers

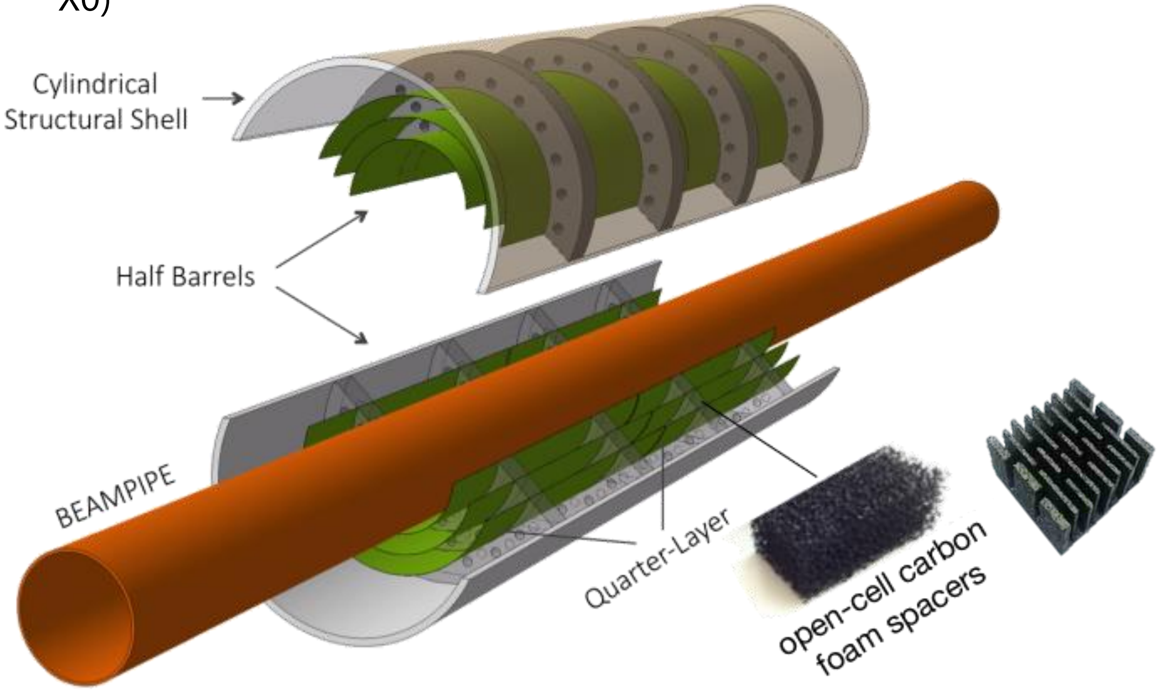


ITS3 LAYOUT



➔New beam pipe:
"old" radius/thickness: 18.2/0.8 mm
new radius/thickness: 16.0/0.5 mm

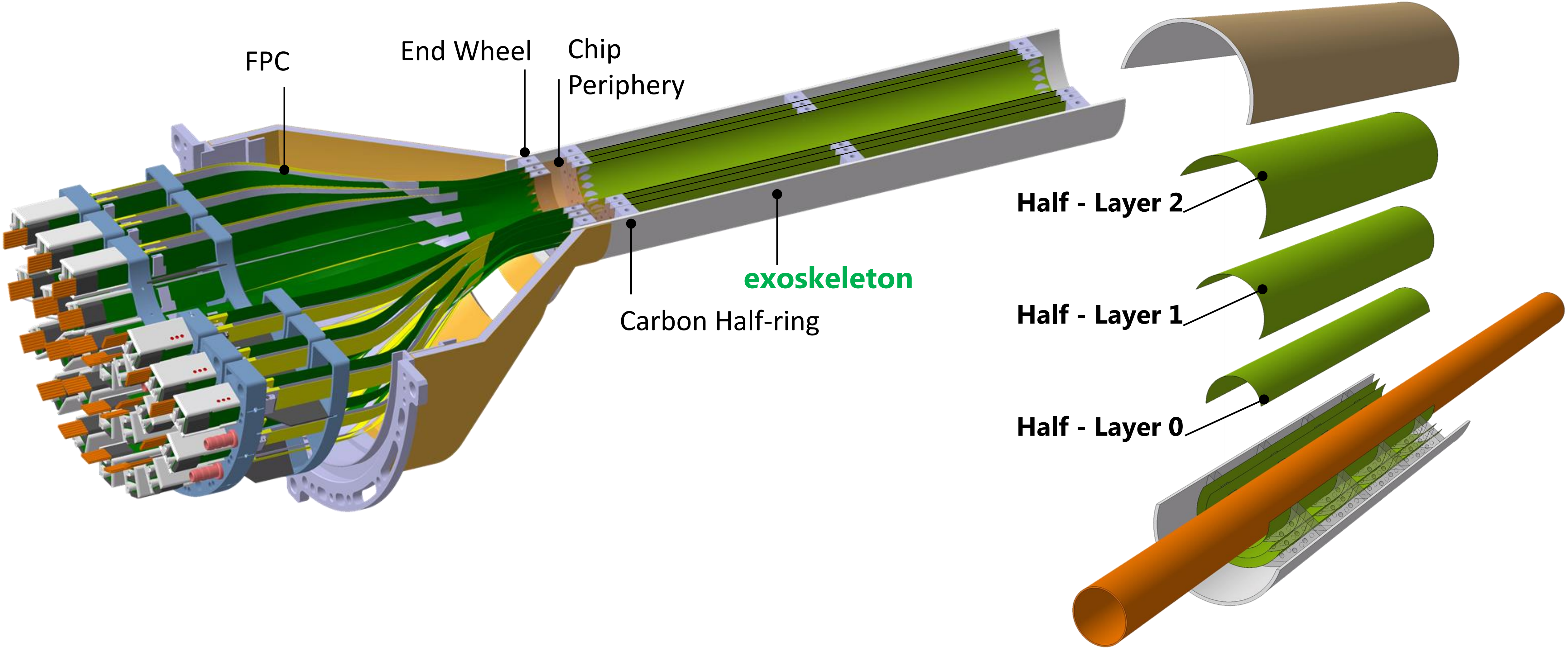
➔Extremely low material budget:
Beam pipe thickness: 500 μm (0.14% X0)
Sensor thickness: 20-40 μm (0.02-0.04% X0)



- ➔ Possible layout based on air-cooling
- ➔ Sensors hold in place with low-density carbon foam.
- ➔ Fixation into the experiment by surrounding support structure, as well as at both ends.
- ➔ Cooling at the extremities (chip peripheries)

R&D mechanics

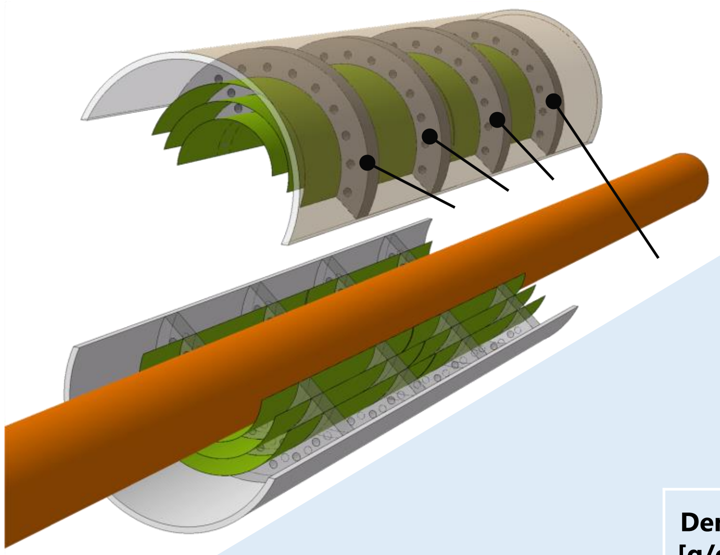
The mechanical design of the ITS3 is based on an external carbon shell (CYSS), used as exoskeleton, and ultralight carbon supports that keep the layers bended in position. R&D is needed to identify materials, develop assembly procedures and jigs for layers bending and positioning, perform structural verification and test validation for detector stability assessment.



R&D mechanics

Materials

Identify carbon foam that can fulfill the structural and thermal function. Find optimum compromise between carbon foam stiffness, thermal heat spread, cell size and impedance to air flow. Optimise glued interface between carbon foam and silicon half-layer.



Convective heat transfer enhancement by bonding foam rings to sensors and allowing air to ßow across the foam surface.

Convective heat transfer enhancement then occurs in two ways: first due to the roughness of the exposed surface, and second due to the additional surface area exposure to fluid that infiltrates the foam.

Carbon foam

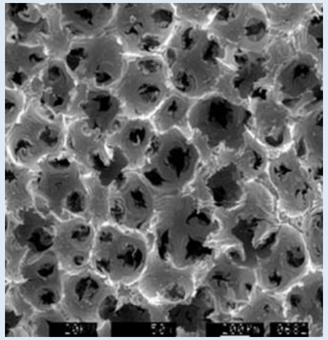
Properties are porosity and process dependent . Choice to be made on the base of:

- *Density,*
- *Thermal conductivity*
- *Stiffness*
- *Machinability*
- *Particle release*
- *Long term behaviour, ….*

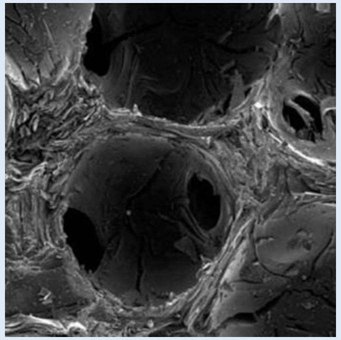
Surface to volume ratio as large as 5000 m^{-1} to 50000 m^{-1}

	Density [g/cm3]	CTE [ppm/ºC]	K In plane [W/mK]	K Out of plane [W/mK]	Pore volume	Mean pore size [µm]	Elastic modulus [MPa]
POCO HTC	0.9	~1	70	245	61%	400	>100 (Compr)
POCOFoam	0.5	~0.6	45	135	75%	400	>100 (Compr)
CFOAM 35 HTC	0.4-0.5	1.9-2.1	140-180	140-180	>70%	1200	100 (Compr.)
CFOAM 25	0.4	5	0.3	0.3	>60	1000	1665 (Compr.)
RVC Carbon Foam	0.045	2.2	<0.08	<0.08	90-97%	255- >3000	58.6 (Flexur.)

POCOGRAPHITE An Entegris Company | FOAM | ULTRAMET …



Scanning electron micrograph of the carbon foam surface

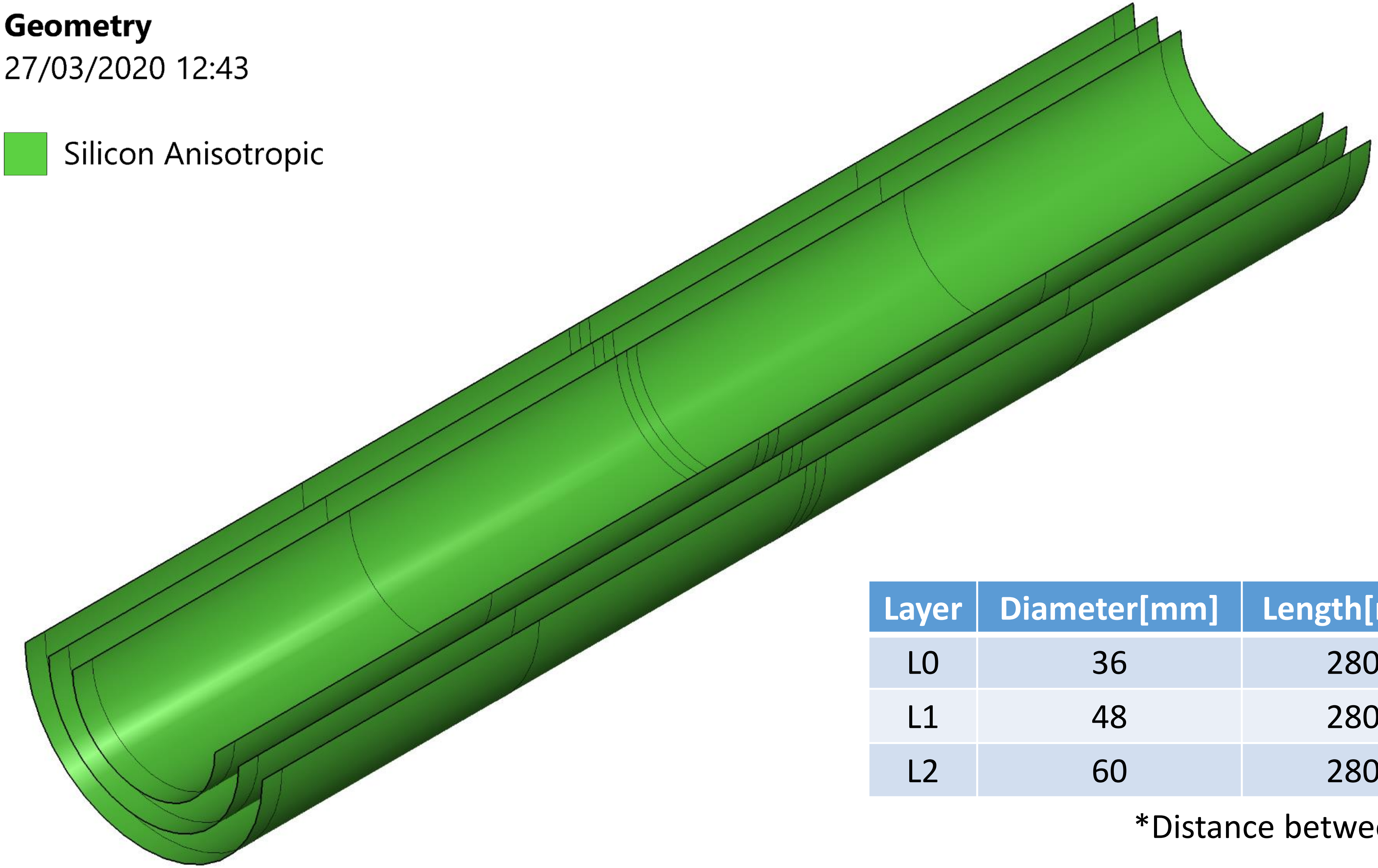


Scanning electron micrograph of the surface of a single pore.

ITS3 Mechanical analysis (Preliminary): Overall

Geometry
27/03/2020 12:43

Silicon Anisotropic



Layer	Diameter[mm]	Length[mm]	Thickness[µm]
L0	36	280	50
L1	48	280	50
L2	60	280	50

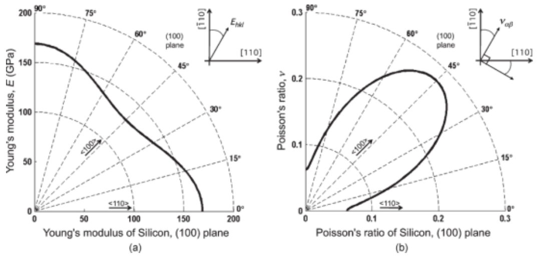
*Distance between layer = 3 mm

ITS3 WP5 Engineering model: FEA analysis stiffness and modal

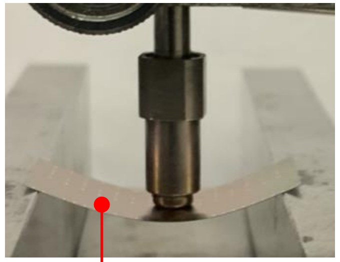
For a fist assessment of the behaviour of a large chip, the mechanical properties of a pure Si material has been considered. Young modulus theorical values are in good agreement with specific bending test.

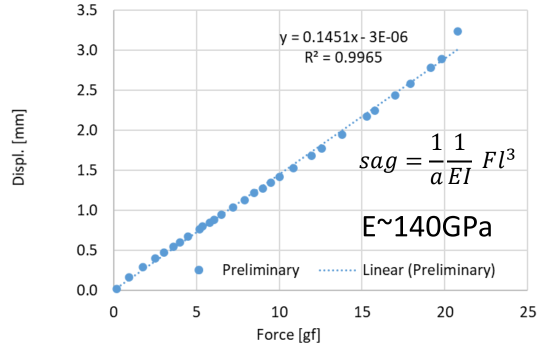
- **Si material:** Anisotropic crystalline material, (100) Oriented silicon wafer.

$$E_x = E_y = 169\ \text{GPa} \qquad E_z = 130\ \text{GPa}$$
$$\nu_{yz} = 0.36 \qquad \nu_{zx} = 0.28 \qquad \nu_{xy} = 0.064$$
$$G_{yz} = G_{zx} = 79.6\ \text{GPa} \qquad G_{xy} = 50.9\ \text{GPa}$$



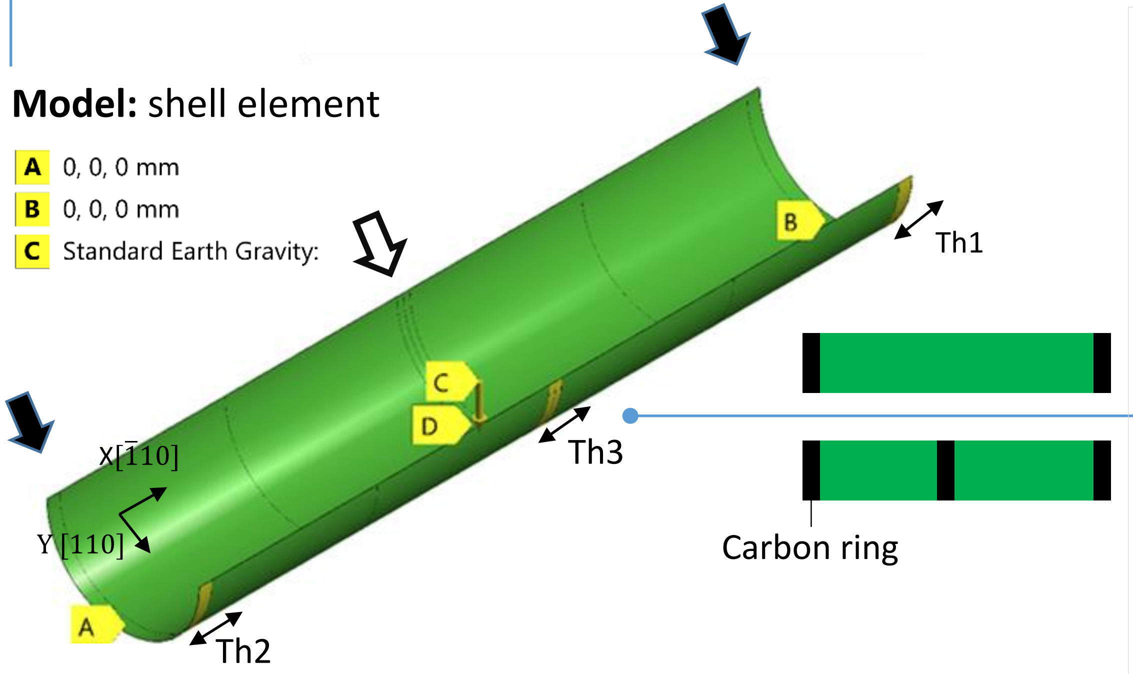
Preliminary 3 point bending test

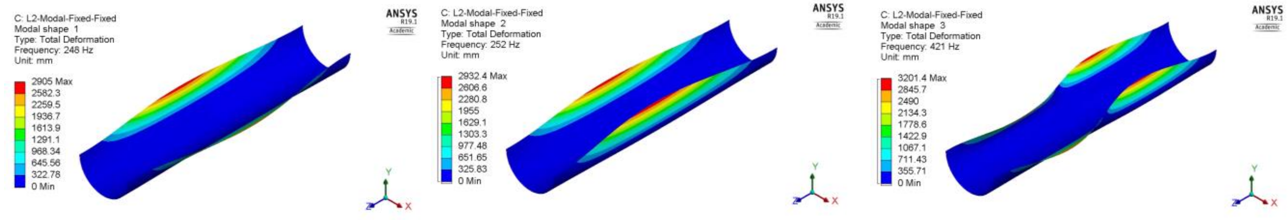




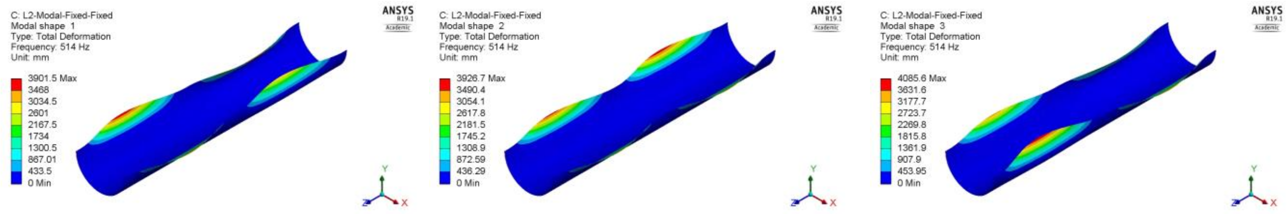
Model: shell element

- **A** 0, 0, 0 mm
- **B** 0, 0, 0 mm
- **C** Standard Earth Gravity:





Case	Th1[mm]	Th2[mm]	Th3[mm]	Sag[µm]	F1[Hz]	F2[Hz]	F3[Hz]	F4[Hz]	F5[Hz]	F6[Hz]
	INPUT			OUTPUT						
2 Carbon rings	5	5	//	1.2	248	252	421	422	599	599
3 Carbon rings	5	5	5	0.21	514	514	514	514	877	877



ITS3 Mechanical analysis (Preliminary): Dynamic analysis

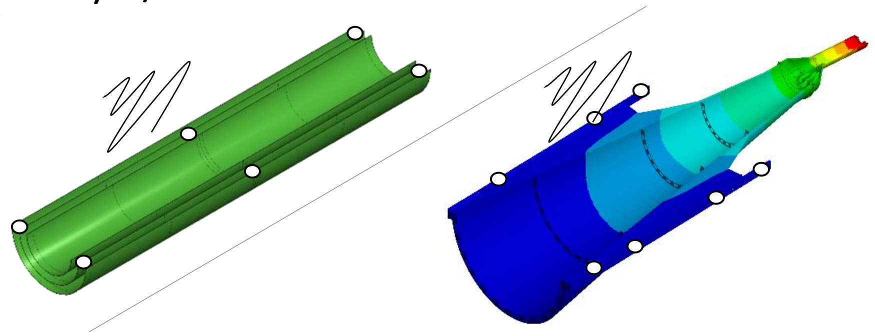
- **Approach:** same followed for ITS2

Input

PSD [m^2/Hz]
RMS [m]

Structural analysis and modal analysis

Step1 H-layer/ H-detector* level

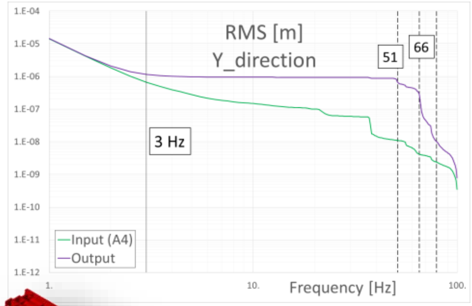


Step2 H-barrel* level

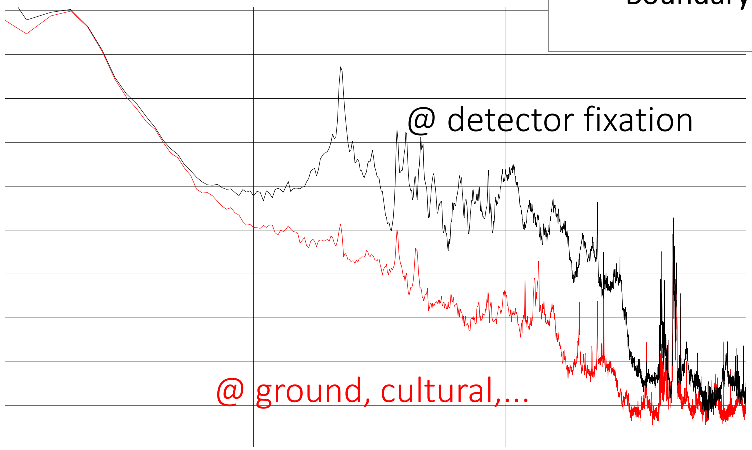
○ = Boundary condition

Output

PSD [m^2/Hz]
RMS [m]



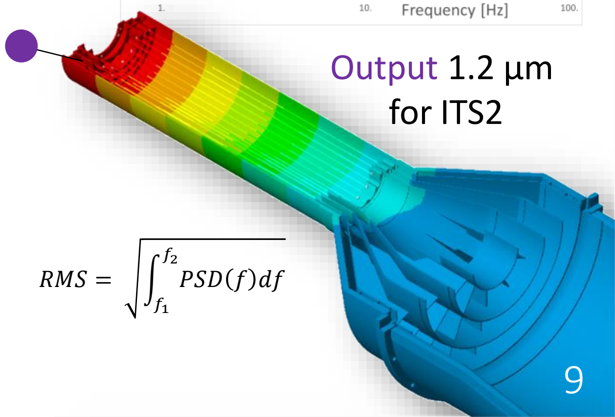
Measured



*once the design is consolidated

$$|H(f)|^2$$

- Conservative Damping factor 1%
- Cage considered rigid
- All B.C. excited



Output 1.2 µm for ITS2

$$RMS = \sqrt{\int_{f_1}^{f_2} PSD(f)df}$$

Material availability and purchased

Mechanical properties of carbon foam ordered:

Company	Material	Density [g/cm3]	CTE [ppm/°C]	K In plane [W/mK]	K Out of plane [W/mK]	Pore volume	Mean pore size [μm] / PPI	Elastic modulus [MPa]
ERG Material & Aerospace	**Duocel® Carbon Foam**	0,03	2,2 μm/m°C	< 0,05	< 0,05	97%	5 to 100 PPI	101,84
Allcomp	**K9 Hi-K**	0,20-0.26 / 0.45-0.68		20 / 60	20 / 60		130 PPI	
CFOAM	**CFOAM 35 HTC**	0.4-0.5	1.9-2.1	140-180	140-180	>70%	1200	100 (Compr.)
ENTEGRIS	**POCO HTC**	0.9	~1	70	245	61%	400	>100 (Compr)

Company	Material Ordered	Order status	Total value (CHF)
ERG	3 sets of rings + 1 sample	Approved on 24.04.2020	2087
ALLCOMP	1 set of rings + 1 sample for 2 different density (0.20-0.26 and 0.45-0.68)	Approved on 29.04.2020	5360
CFOAM	3 sets of rings + 1 sample	Approved on 07.05.2020	1500
ENTEGRIS	3 sets of rings + 1 sample	Awaiting for approval	2735

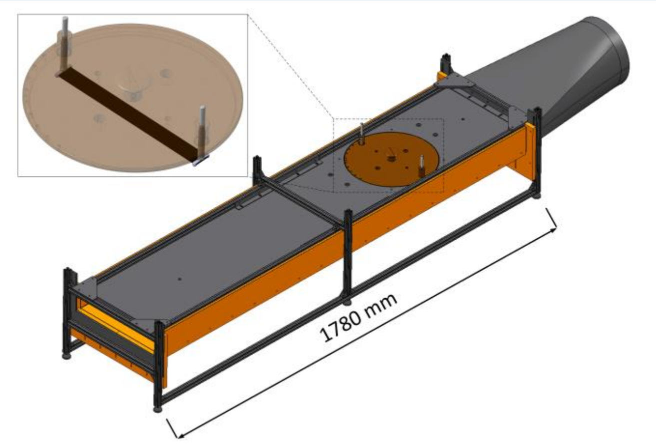
R&D cooling

Wind tunnel thermal tests

Both thermal and vibrational behavior of the detector under a gas flow will be tested in a benchtop wind tunnel

As a first step, in the validation of the gas cooling solution, the behavior of a single curved silicon half-layer, under the action of a gas cooling stream will be tested in the wind-tunnel. As a second step, a 1:1 scale thermal-mechanical mock-up of the vertex detector, with the three layers, will be built and tested.

Test will start using CLIC benchtop wind tunnel, (already in ALICE in composite lab)

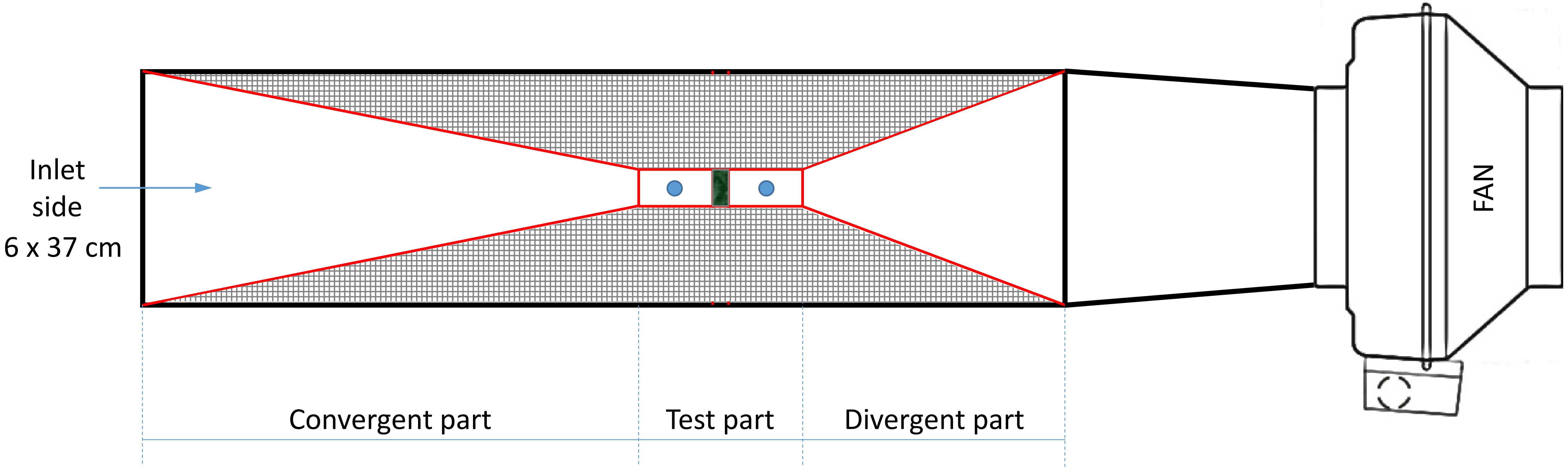


The test setup will consist in a tunnel, where gas is forced through the test section. The volumetric flow of air going through the test-section will be controlled through a flow restrictor with an adjustable diameter. Openings at different locations on the wind tunnel will allow measuring the air temperature and air flow.

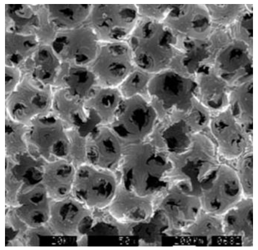
Silicon dummies will be developed, with equivalent dimensions and thickness of the final half-layer sensors, and with embedded heating and temperature sensor features to simulate the power dissipated in the detector. The power will be varied within a meaningful range, based on the chip final consumption. Several measurements will be performed with different detector layouts, while setting different values for the maximum gas velocity. The influence of the number and shape of the ultralight carbon foam supports acting as heat spread radiator, will be tested.

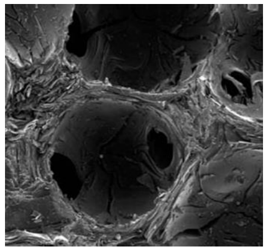
Wind channel studies

The wind channel used for the development of the cooling system for CLIC experiment is being arranged for fluid dynamics studies on carbon foams.



- New Plexiglas walls
- Carbon foam sample
- Pressure/velocity detection point





Wind channel studies

Current situation (VERSION 1):

- the pc with LABView is now working
- 2 anemometers have been connected to the DAQ system
- 1 fan has been connected to the pc and placed in the wind channel
- more complex LABView DAQ software: **ongoing**
- the material for the convergent/divergent part (Plexiglas foils) alignment in the wind channel: **DONE**

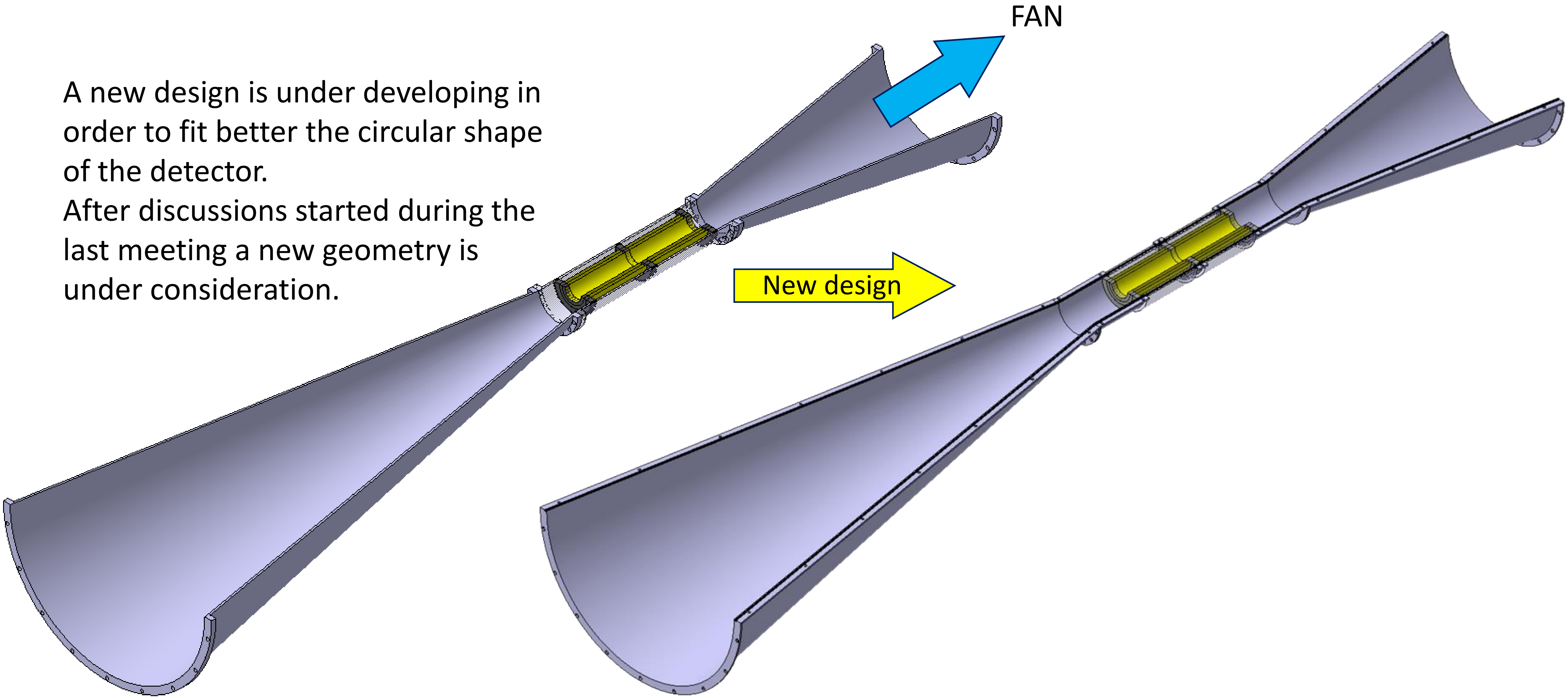
VERSION 2:

Cad design ongoing (development of best solution for tests on bent chip): SEE NEXT SLIDES

Wind channel studies

Preliminary design VERSION 2

A new design is under developing in order to fit better the circular shape of the detector.
After discussions started during the last meeting a new geometry is under consideration.

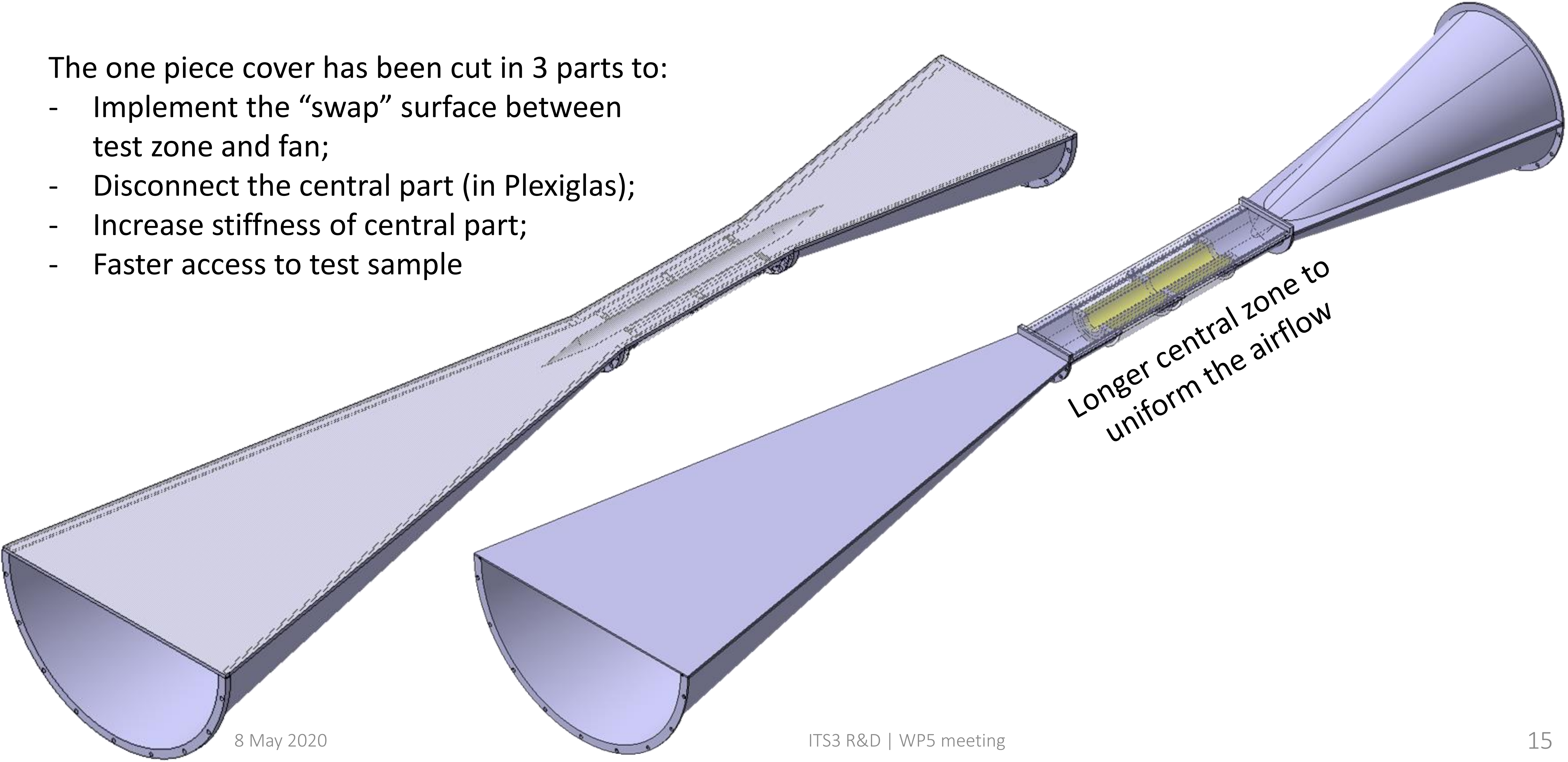


Wind channel studies

Preliminary design VERSION 2

The one piece cover has been cut in 3 parts to:

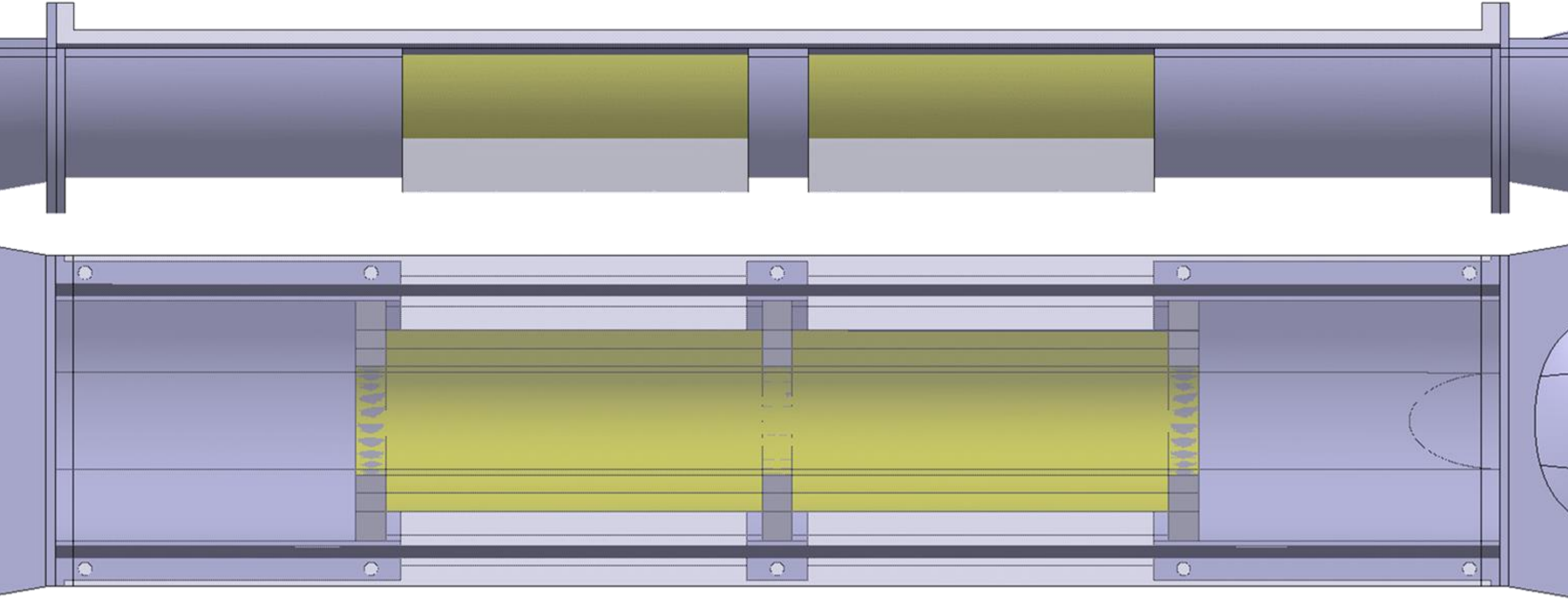
- Implement the “swap” surface between test zone and fan;
- Disconnect the central part (in Plexiglas);
- Increase stiffness of central part;
- Faster access to test sample



Wind channel studies

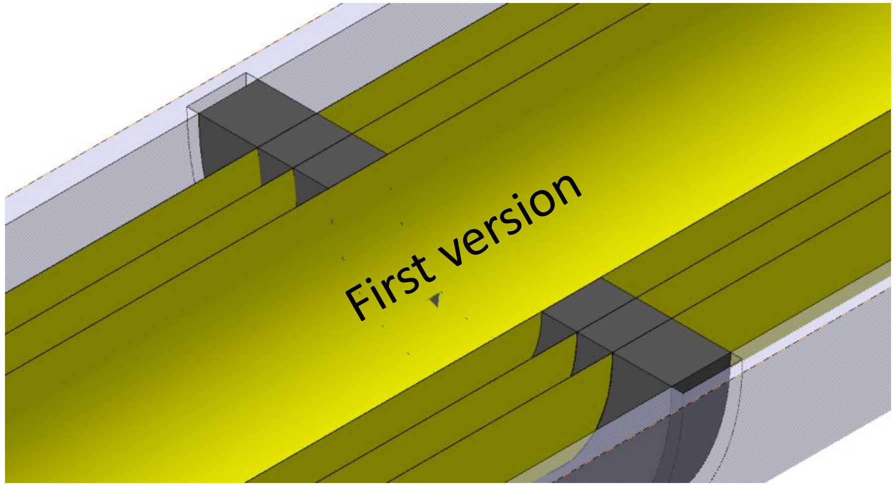
Preliminary design VERSION 2

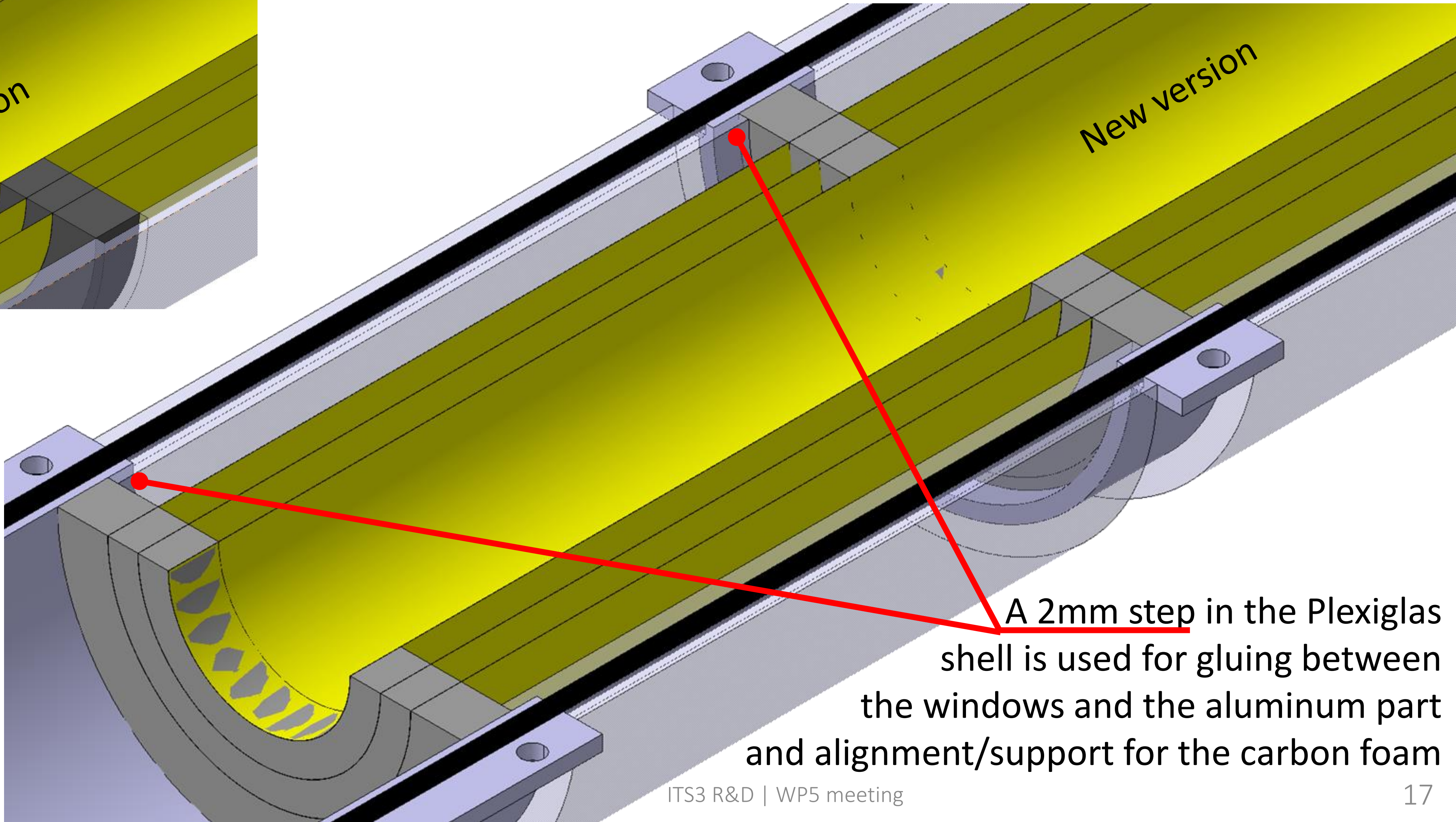
2 windows replace the full central barrel in Plexiglas



Wind channel studies

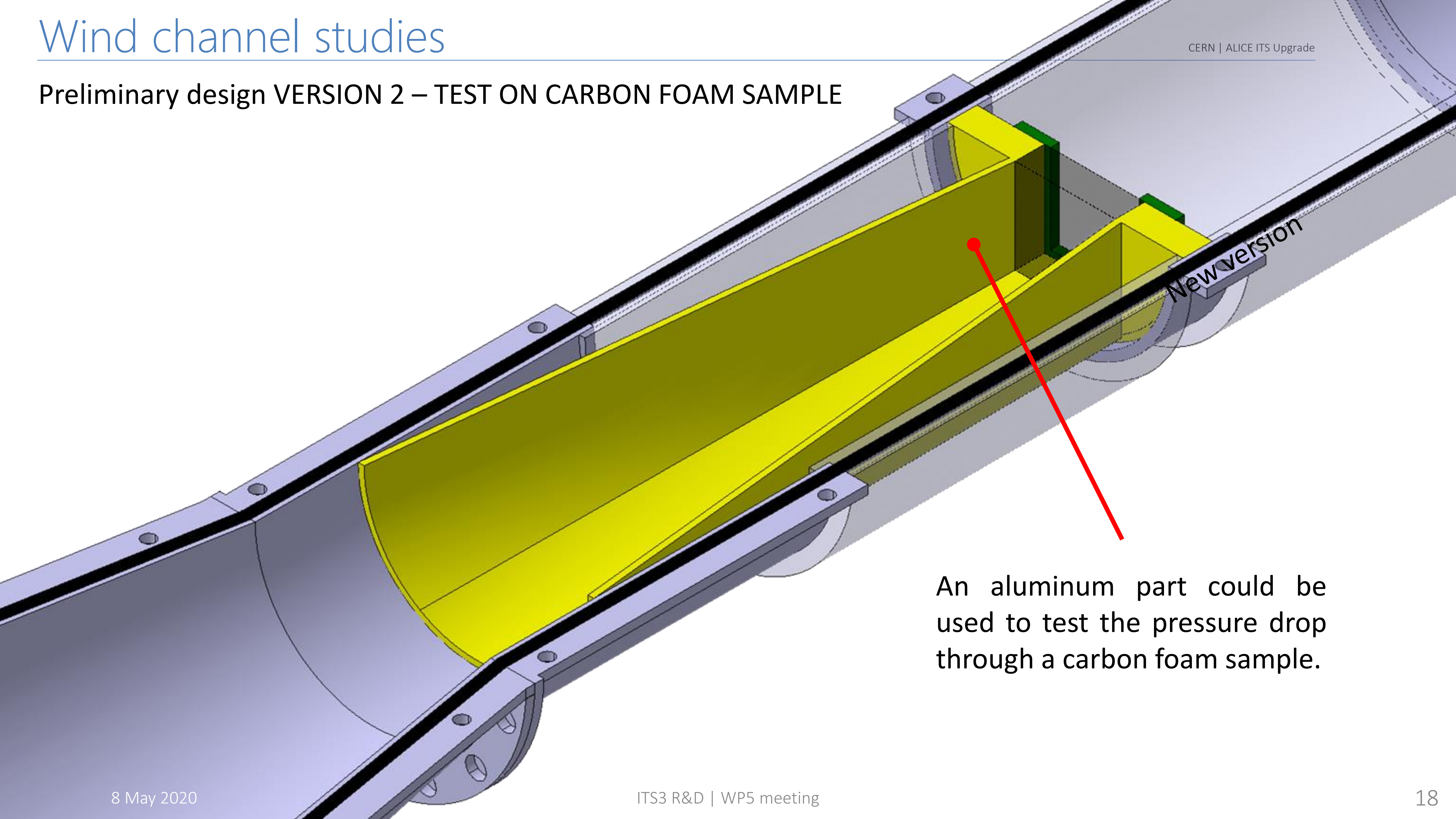
Preliminary design VERSION 2





Wind channel studies

Preliminary design VERSION 2 – TEST ON CARBON FOAM SAMPLE

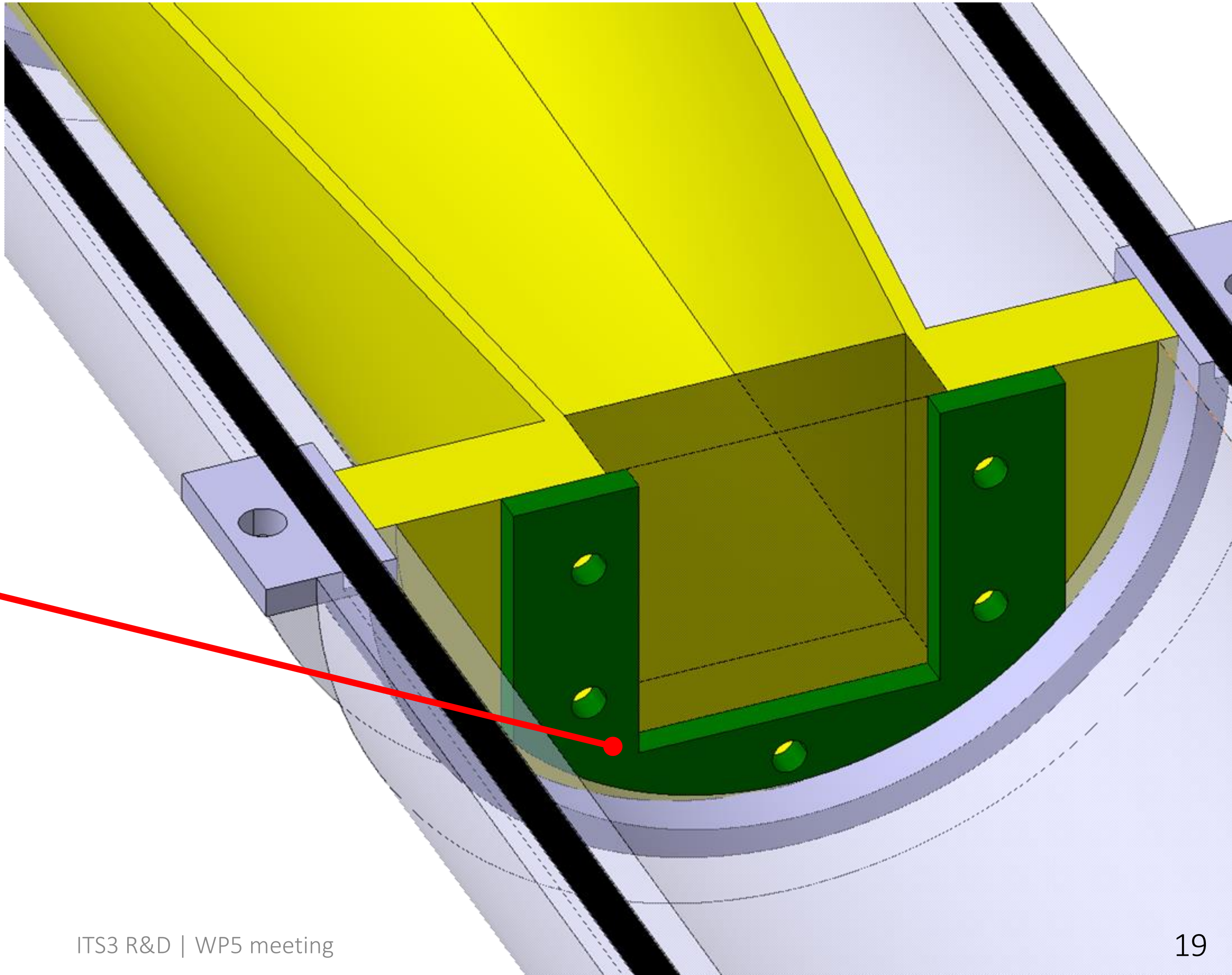


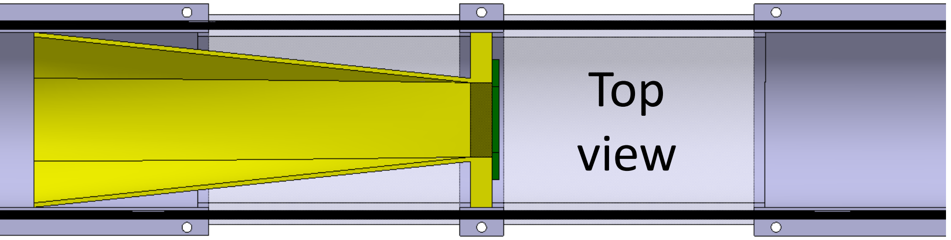
An aluminum part could be used to test the pressure drop through a carbon foam sample.

Wind channel studies

Preliminary design VERSION 2 – TEST ON CARBON FOAM SAMPLE

Maximum carbon foam dimension 32mm x 32mm with and a surface lost of 2mm on 3 sides for the support frame





Wind channel studies: LDV

Micro Epsilon

Different quotation respect to the measuring system:

System	Model	Max. Measuring Freq. (kHz)	Signal output	Resolution (nm)	Cost (CHF)
Laser triangulation	ILD 2300	49	Digital*	30	4563
	ILD 1750	7.5	Analog/Digital**	100	2606
Laser Line (LL)	ILD 2300 -LL	49	Digital*	30	4731
	ILD 1750 -LL	7.5	Analog/Digital**	100	2855
Confocal	IFS 24xx	25	Analog/Digital***	4	18133

* Signal output (switchable): RS422, Ethernet and EtherCAT
** Analog 0 … 5 V,; 0 … 10V; 4 … 20 mA; Digital (RS422)
*** Analog: 0 – 10 V for distance and intensity; Digital (Ethernet, EtherCAT and RS422

Confocal system can also be used for the measure of thin transparent films but works in almost perfect perpendicular position