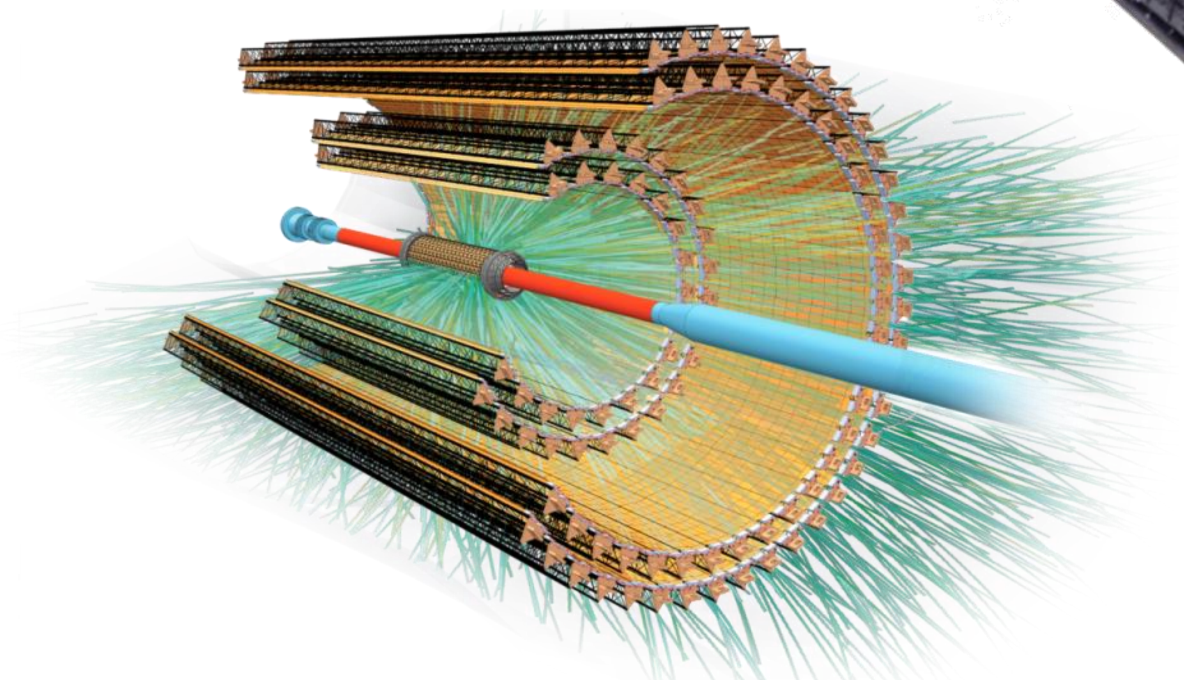
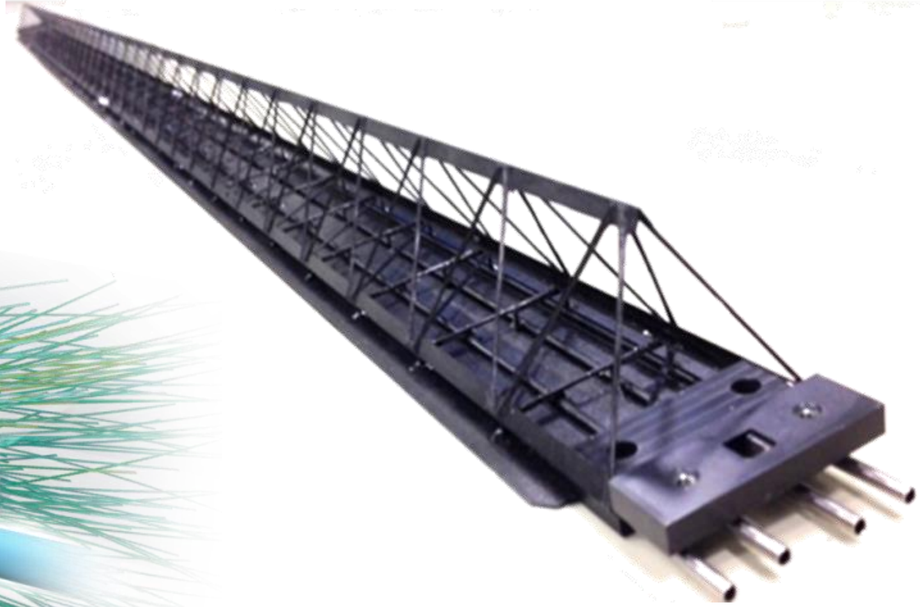




ALICE ITS UPGRADE
Mechanics and Cooling

C.Gargiulo
On behalf of Alice collaboration

28 May 2015

CLIC Tracker Technology Meeting

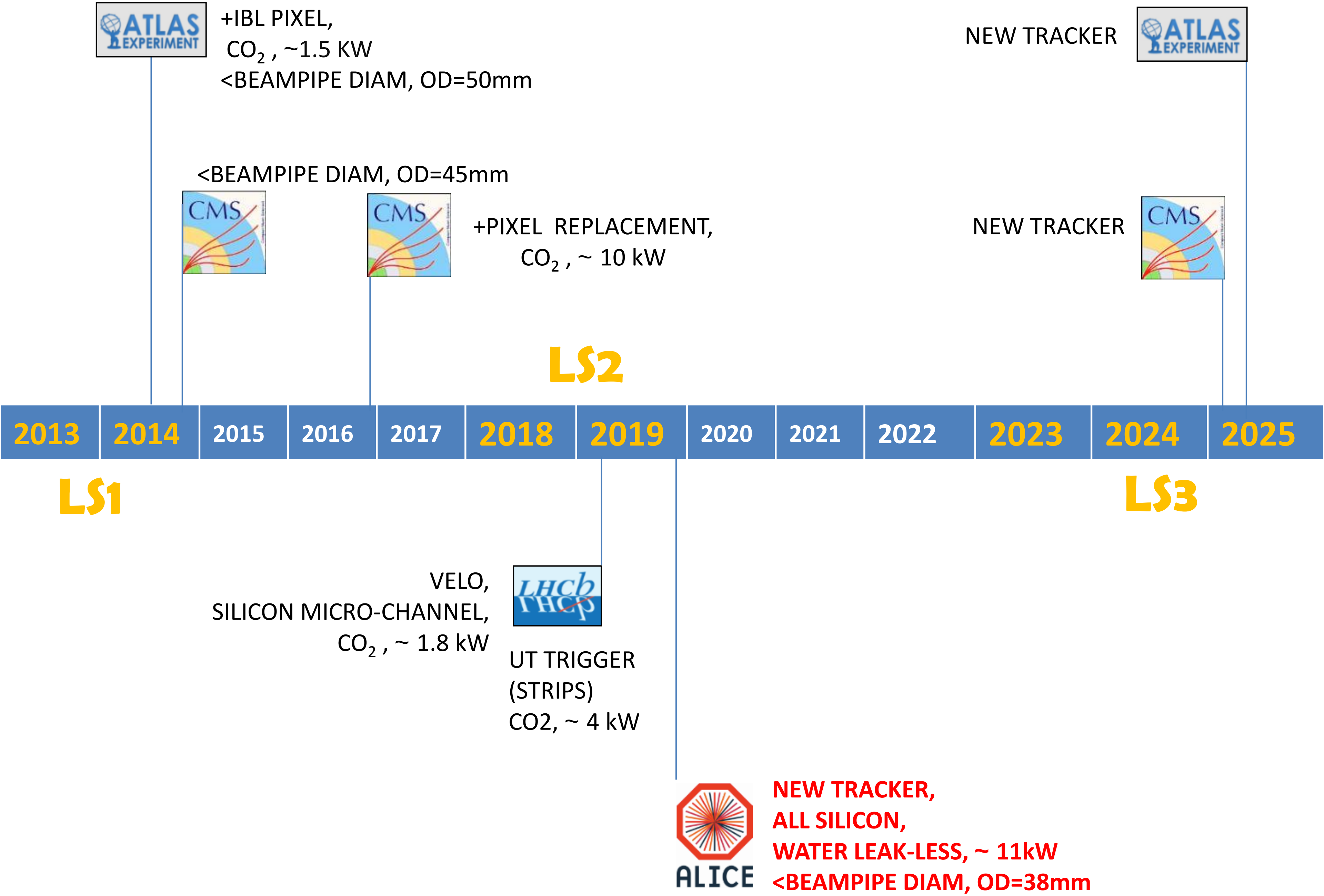
Outline

ALICE NEW INNER TRACKER SYSTEM

OBJECTIVES
LAYOUT
STAVE MECHANICS AND COOLING
    MATERIALS
    PRODUCTION PROCESSES
    MATERIAL BUDGET
    CHARACTERIZATION
        thermal, mechanical, thermoelastic
STAVE ASSEMBLY

LAYERS, BARRELS

INSTALLATION IN ALICE



ATLAS EXPERIMENT

+IBL PIXEL,
CO_2 , ~1.5 KW
<BEAMPIPE DIAM, OD=50mm

NEW TRACKER

ATLAS EXPERIMENT

<BEAMPIPE DIAM, OD=45mm

CMS

CMS

+PIXEL REPLACEMENT,
CO_2 , ~ 10 kW

NEW TRACKER

CMS

LS2

2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025

LS1

LS3

VELO,
SILICON MICRO-CHANNEL,
CO_2 , ~ 1.8 kW

LHCb

UT TRIGGER
(STRIPS)
CO2, ~ 4 kW

ALICE

NEW TRACKER,
ALL SILICON,
WATER LEAK-LESS, ~ 11kW
<BEAMPIPE DIAM, OD=38mm

Corrado Gargiulo, 28 May 2015

tracker mechanics and cooling

requirements

Towards HL-LHC: new tracker systems based on light thermomechanical structures

Boundary conditions

- -high radiation levels
- -external vibrations
- -temperature and humidity variations

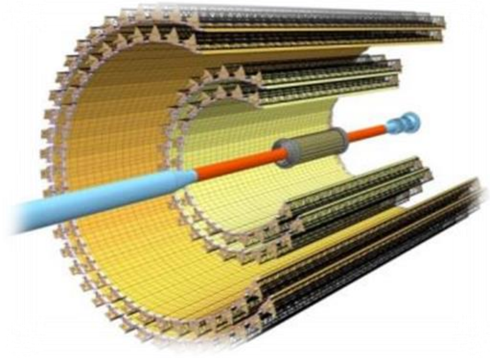
Requirements

- -support the sensor in position, with minimum mass, low x/X_0
- -provide high dimensional and dynamic stability
- -provide thermal control and stability

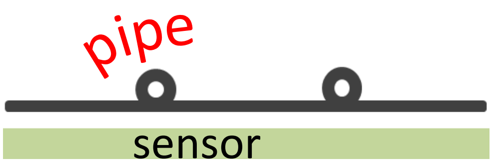
The design of the mechanical structure is inherently linked to the cooling requirements

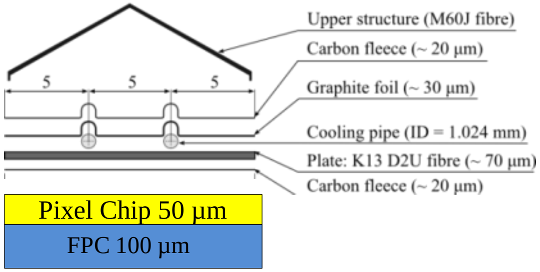
Trackers design baselines

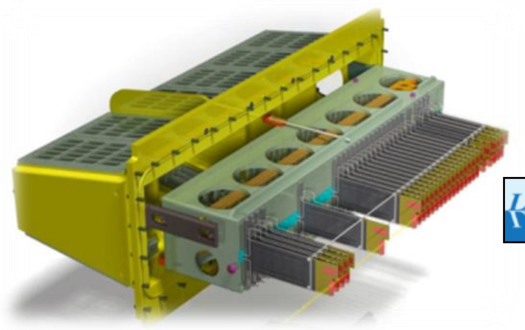
Different designs under study or already implemented to meet structural and thermal requirements



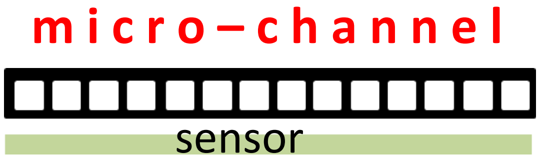
ALICE

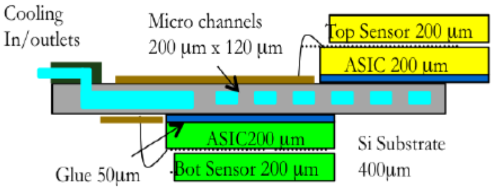


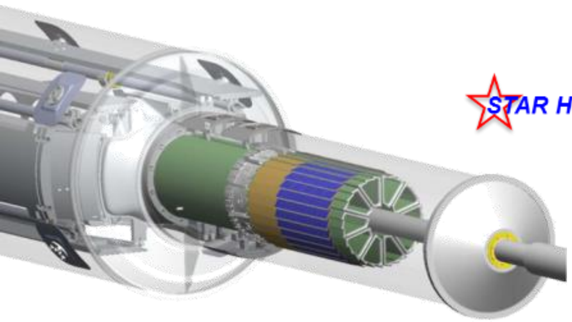




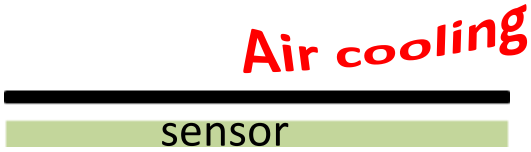
LHCb

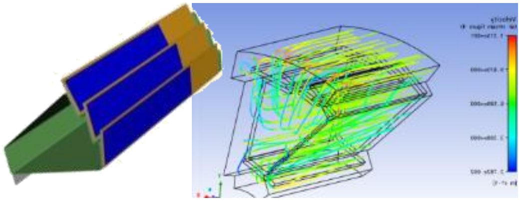




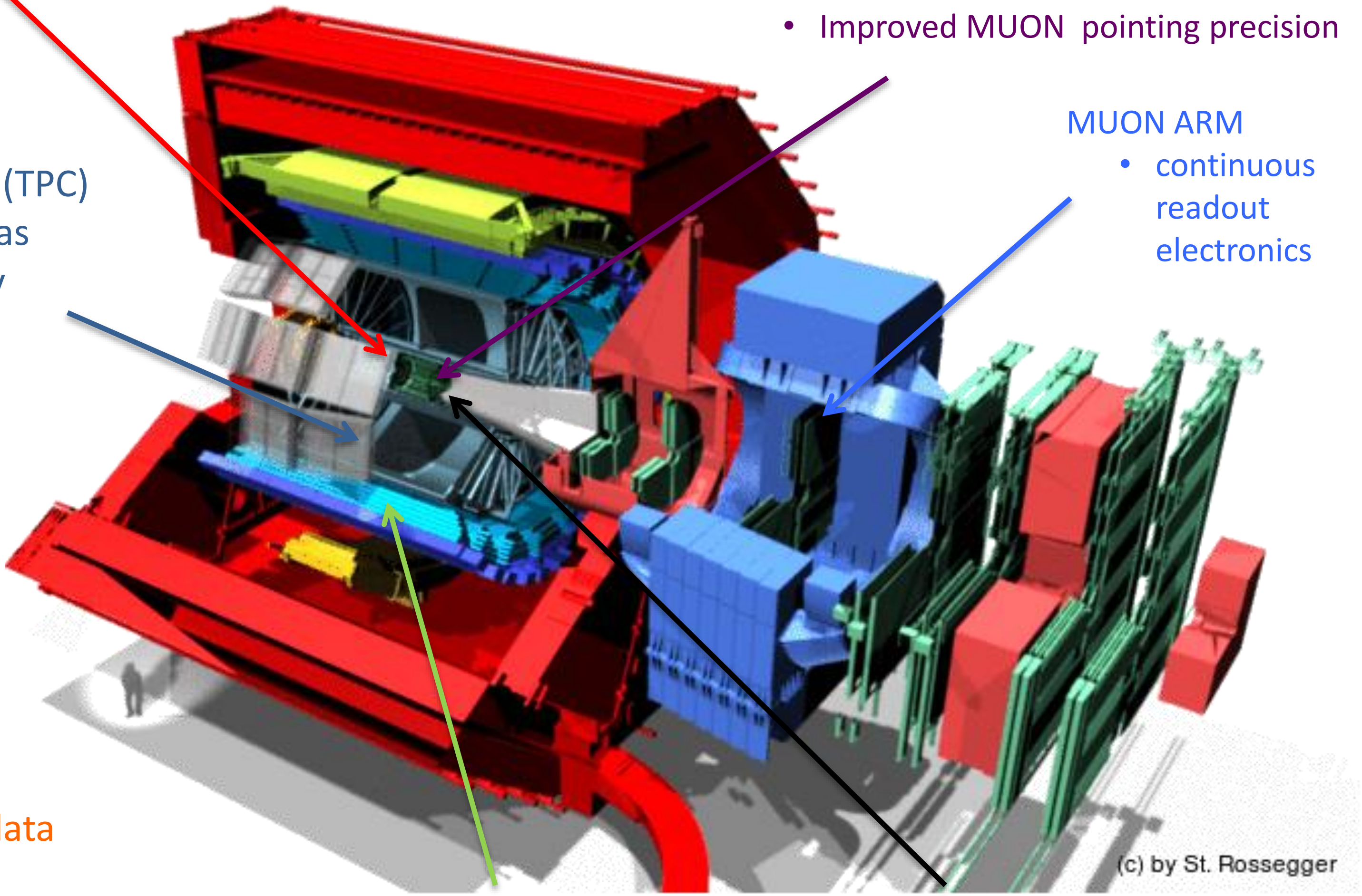


STAR HFT





ALICE upgrade



New Inner Tracking System (ITS)

Muon Forward Tracker (MFT)
- new Si tracker
- Improved MUON pointing precision

MUON ARM
- continuous readout electronics

Time Projection Chamber (TPC)
- New Micropattern gas detector technology
- continuous readout

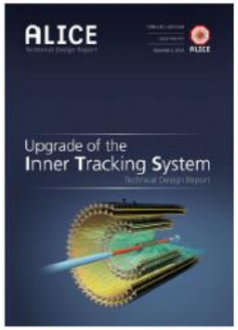
New Central Trigger Processor (CTP)

Data Acquisition (DAQ)/ High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate

TOF, TRD
- Faster readout

New Trigger Detectors (FIT)

ITS upgrade design objectives


ALICE

Upgrade of the Inner Tracking System

CERN-LHCC-2013-24

1. Improve impact parameter resolution by a factor of ~3

- Get closer to IP (position of first layer): 39mm ➡23mm
- Reduce x/X_0/layer: ~1.14% ➡~ 0.3% (for inner layers)
- Reduce pixel size: currently 50µm x 425µm ➡ O (30µm x 30µm)

2. Improve tracking efficiency and p_T resolution at low p_T

- Increase granularity:
  - 6 layers ➡7 layers
  - silicon drift and strips ➡pixels

3. Fast readout

- readout Pb-Pb interactions at > 100 kHz and pp interactions at ~ several 10^5 Hz (currently limited at 1kHz with full ITS)

4. Fast insertion/removal for yearly maintenance

- possibility to replace non functioning detector modules during yearly shutdown

Install detector during LHCC LS2 (2018-19)

ITS layout

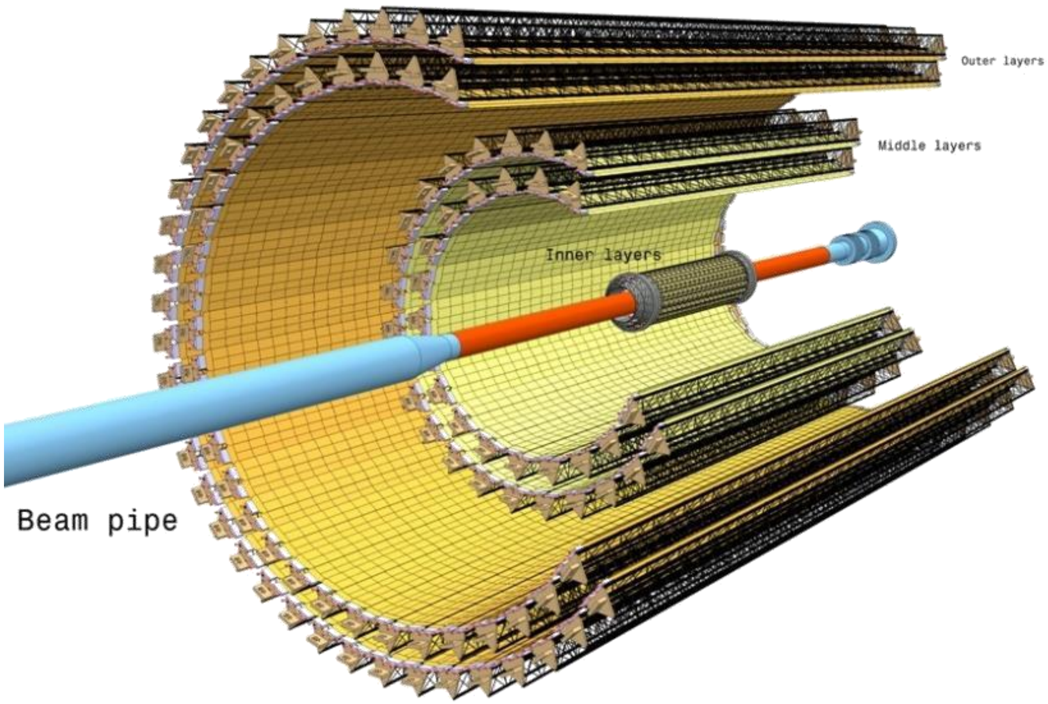
ITS layout

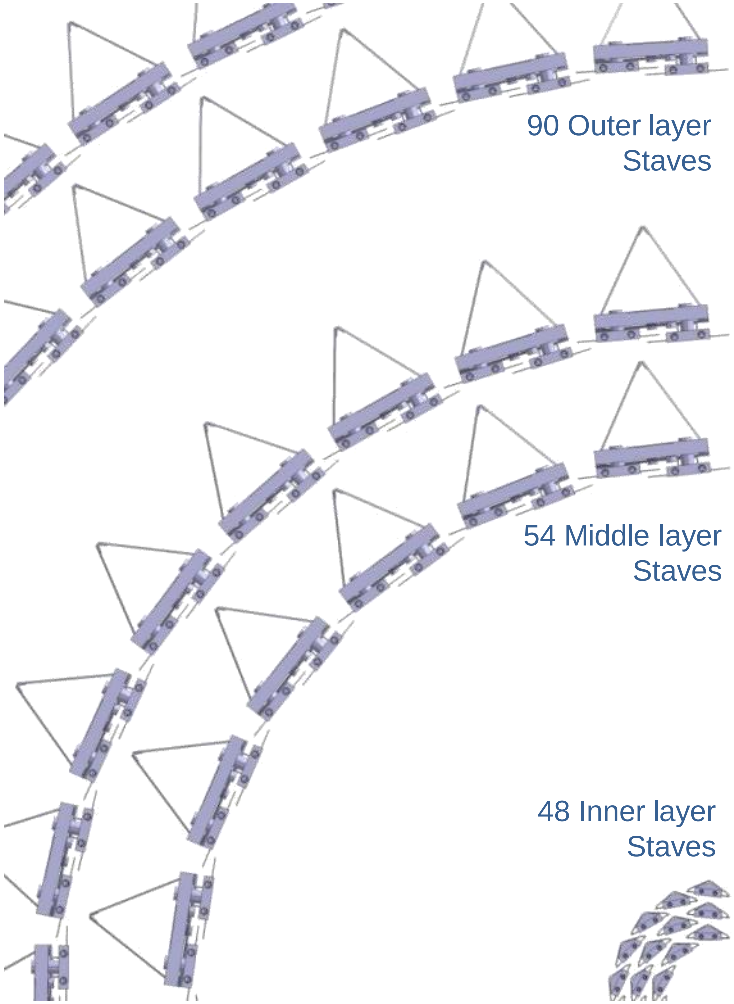
12.5 G-pixel camera (~10m^2)

7-layer barrel geometry based on MAPS

r coverage: 23 – 400 mm

η coverage: |η| ≤ 1.22
for tracks from 90% most luminous region





3 Inner Barrel layers (**IB**)

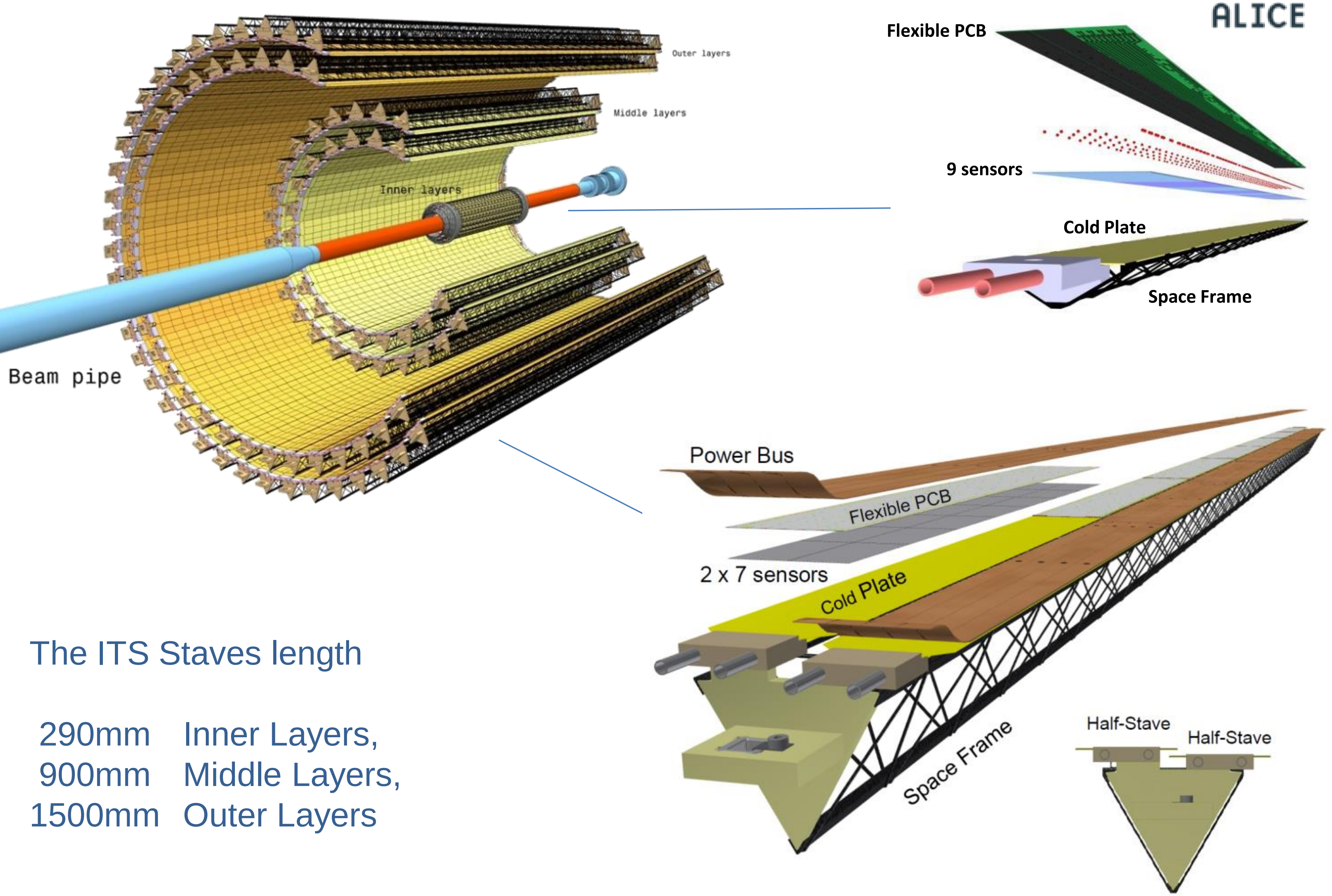
4 Outer Barrel layers (**OB**)

Material /layer : 0.3% X_0 (IB), 1% X_0 (OB)

	Inner Barrel	Outer Barrel
TID radiation hardness (*)	2700 krad	100 krad
NIEL radiation hardness (*)	1.7x10^{13} 1MeV n_{eq}/cm^2	10^{12} 1MeV n_{eq} / cm^2

(*) 10 x radiation load integrated over approved programme (~ 6 years of operation)

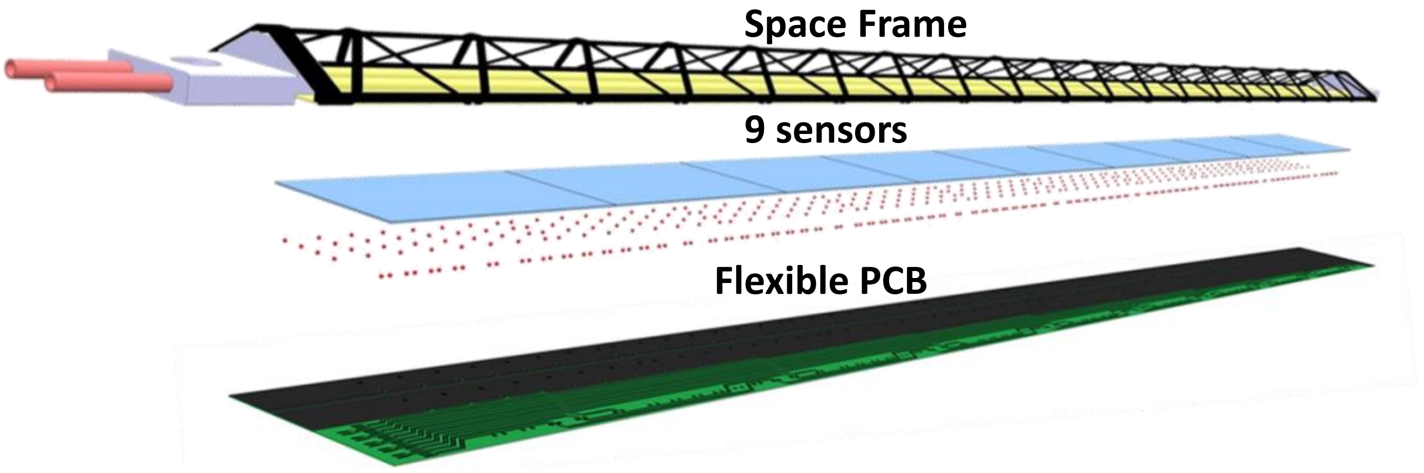
ITS staves



The ITS Staves length

290mm	Inner Layers,
900mm	Middle Layers,
1500mm	Outer Layers

ITS Inner Barrel (IB) staves



<Radius> (mm): 23,31,39

Nr. of staves: 12, 16, 20

Nr. of chips/layer: 108, 144, 180

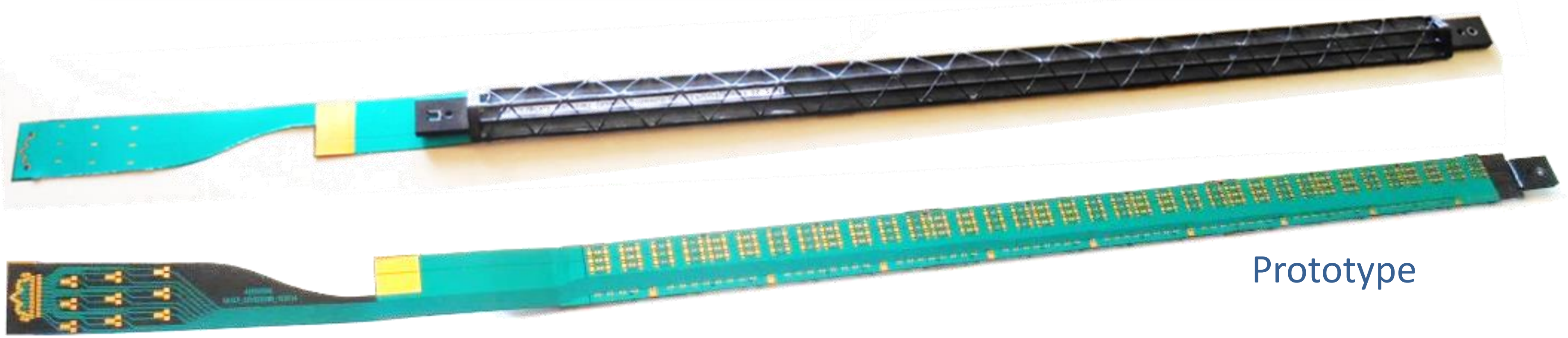
Power density: < 100 mW/cm^2

Length in z (mm): 290

Nr. of chips/stave: 9

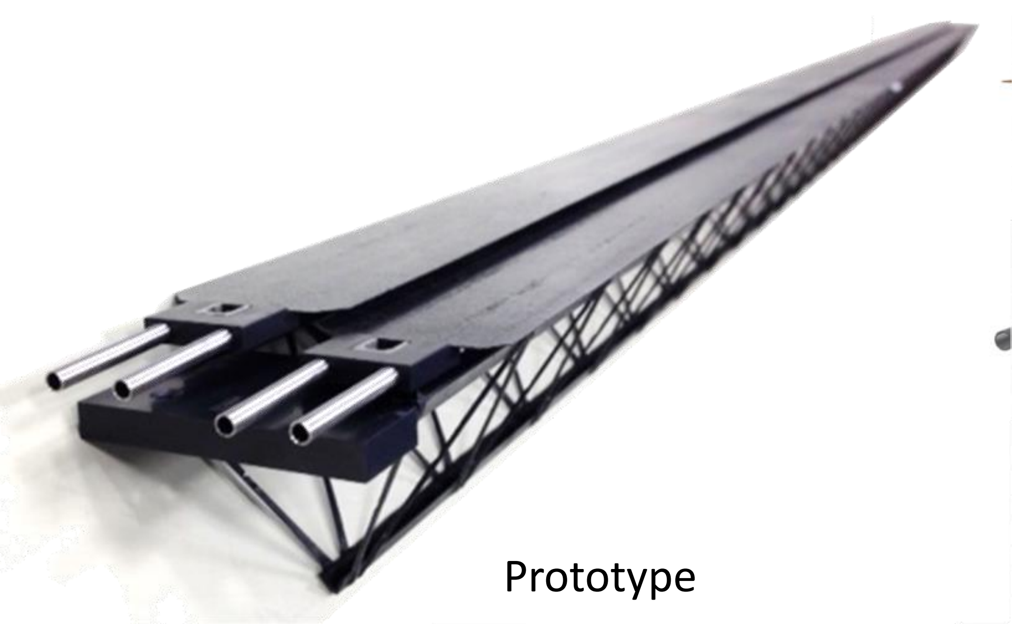
Material thickness: ~ 0.3% X_0

Throughput (@100kHz): < 80 Mb/s × cm^{-2}

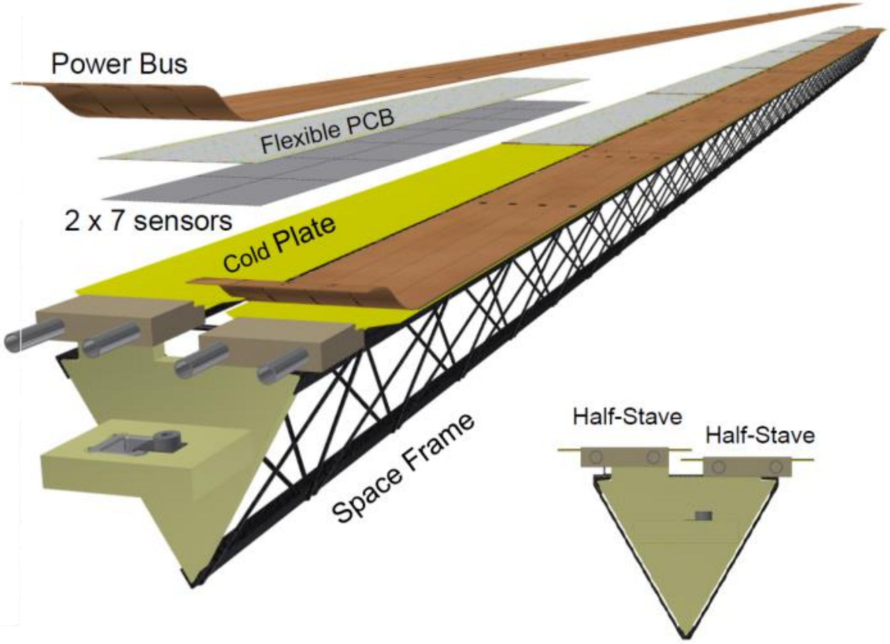


Prototype

ITS Outer Barrel (OB) staves



Prototype



Outer Barrel (OB)

<radius> (mm): 194, 247, 353, 405

Nr. staves: 24, 30, 42, 48

Nr. Chips/layer: 6048 (ML), 17740(OL)

Power density < 100 mW / cm^2

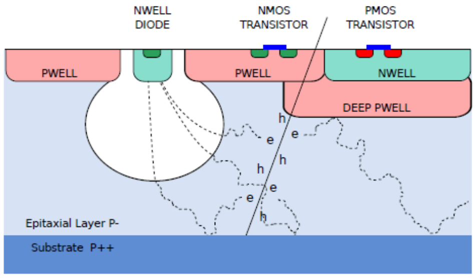
Length (mm): 900 (ML), 1500 (OL)

Nr. modules/stave: 4 (ML), 7 (OL)

Material thickness: ~ 1% X_0

Throughput (@100kHz): < 3Mb/s × cm^{-2}

Pixel chip

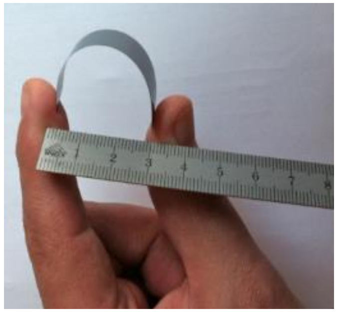


Schematic cross-section of CMOS pixel sensor (*ALICE ITS Upgrade TDR*)

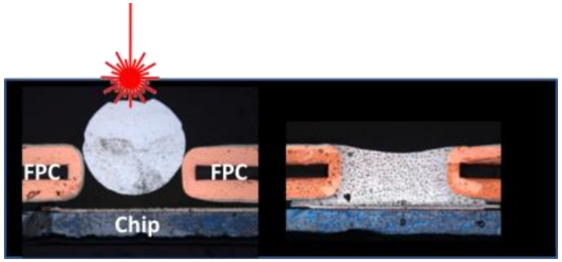
Schematic cross section of a Monholitic Active Pixel Sensor

Pixel Chip: CMOS TowerJazz 0.18 μm

- Chip size: 15 mm x 30 mm
- Pixel pitch ~ 30 μm
- Si thickness: 50 μm
- Spatial resolution ~ 5 μm
- Power density < 100 mW/cm^2



9 chips



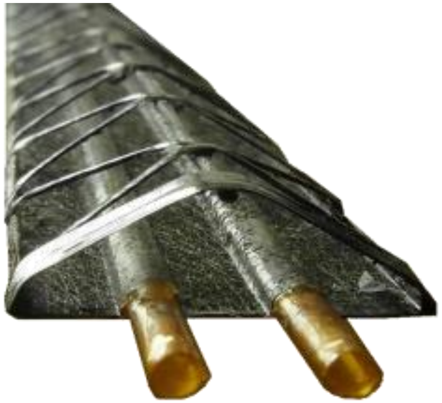
Laser soldering: Interconnecton of Pixel chip on flexible printed circuit

FPC

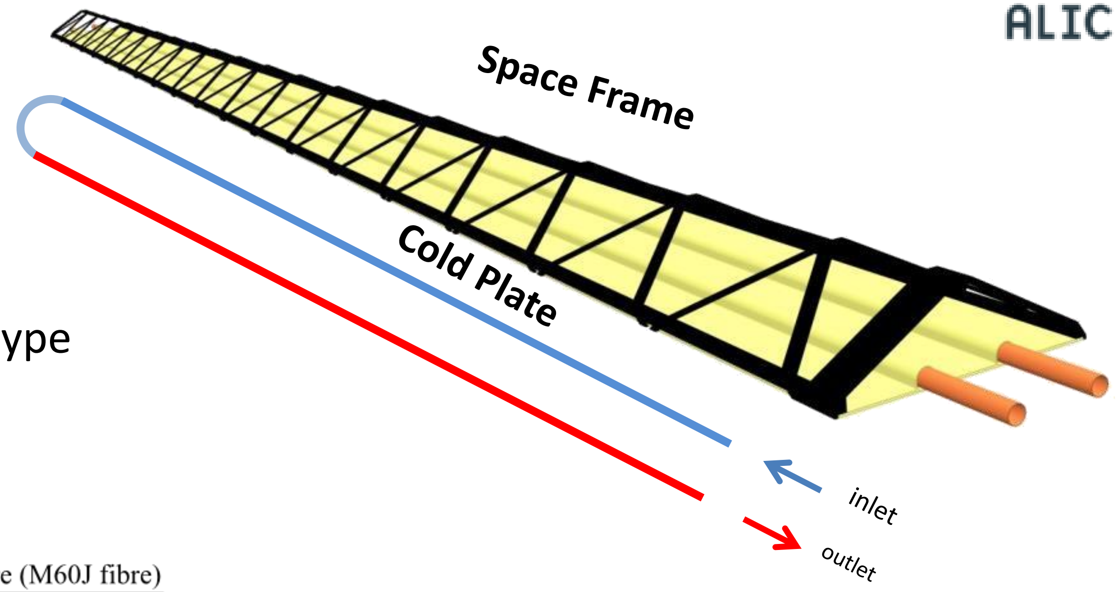
Layout for Inner Barrel

Flex Printed Circuit FPC

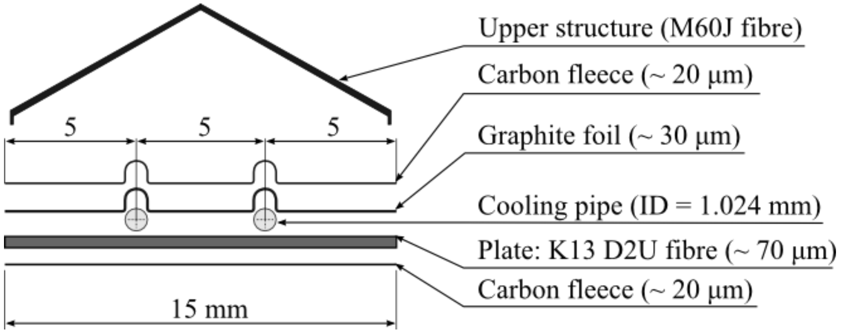
IB stave mechanics and cooling



Prototype



Transversal section:

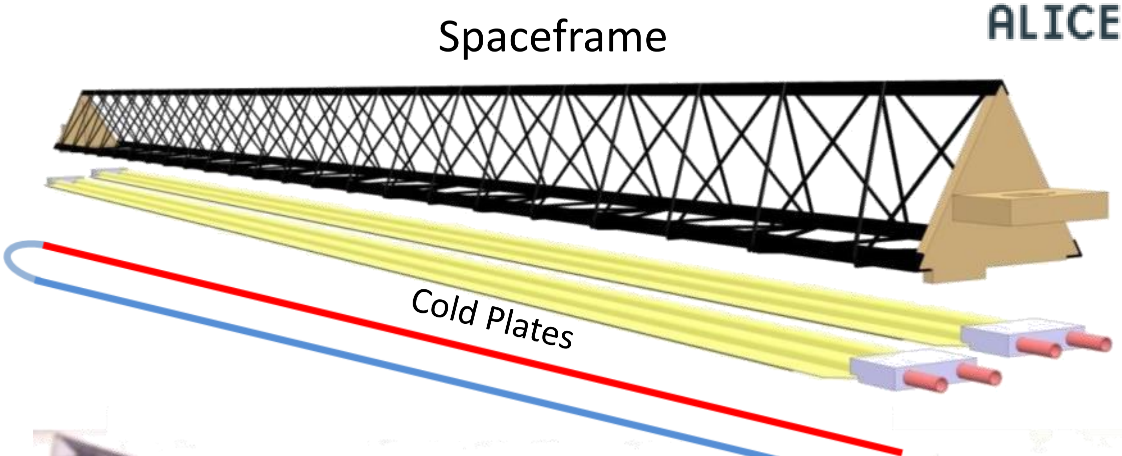


Coolant Single-phase H_2O leak-less
Pixel operational temperature < 30°C
Pixel max temperature non-uniformity < 5°C
Chip Power dissipation< 100mW/cm2

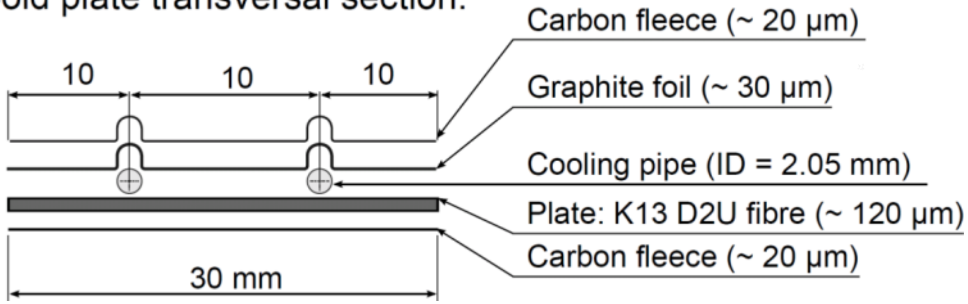
Prototype

290mm length, 1.5gram weight

OB stave mechanics and cooling



Cold plate transversal section:



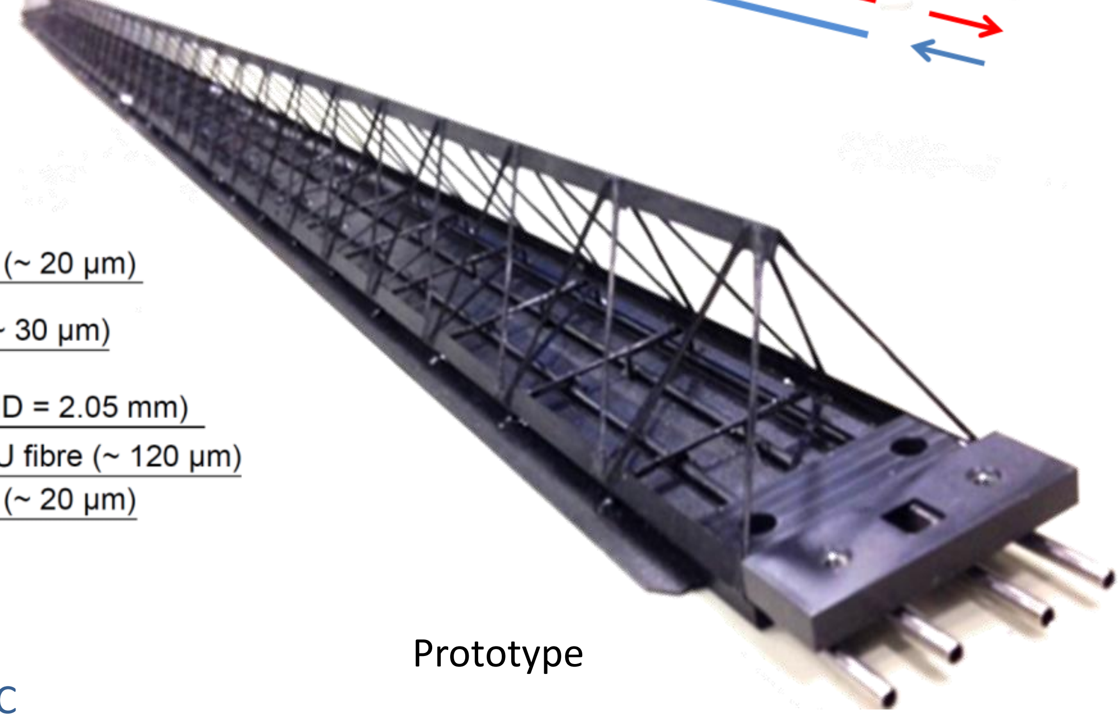
Carbon fleece (~ 20 µm)

Graphite foil (~ 30 µm)

Cooling pipe (ID = 2.05 mm)

Plate: K13 D2U fibre (~ 120 µm)

Carbon fleece (~ 20 µm)



Prototype

1500mm length, 80gram weight

Coolant Single-phase H_2O leak-less

Pixel operational temperature < 30°C

Pixel max temperature non-uniformity < 5°C

Chip Power dissipation< 100mW/cm2

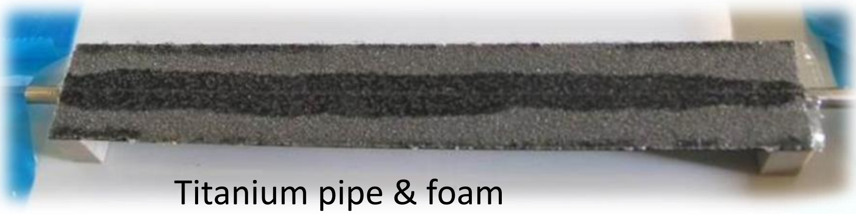
STAVE Mechanics and Cooling

- ✓ **materials**

ATLAS IBL stave operated @ -20°C, CO_2 evaporative

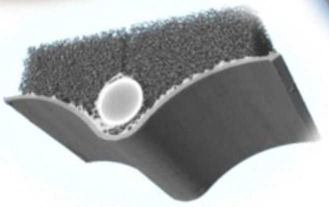
Titanium pipe

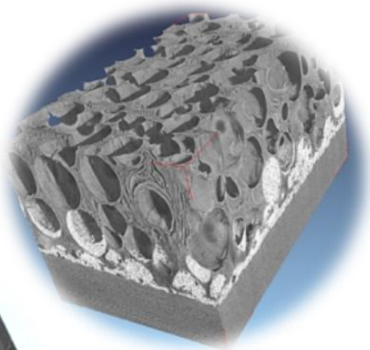
ID=2 mm, wall thick.= 0,12 mm



Titanium pipe & foam

«pipe» materials





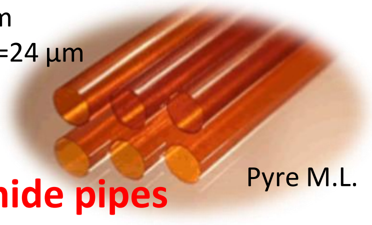
Tomography of
K9 carbon foam
40 W/mK

- ○ High Thermal Conductive (HTC) material carries the heat to a pipe with coolant.
- ○ Pipe embedded in carbon foam or graphite foil
- ○ Pipe can be either metallic or plastic

ALICE ITS stave upgrade, operated @ <30°C, water leakless

1.5 grams
(290mm length)

D=1.02 mm
wall thick.=24 µm

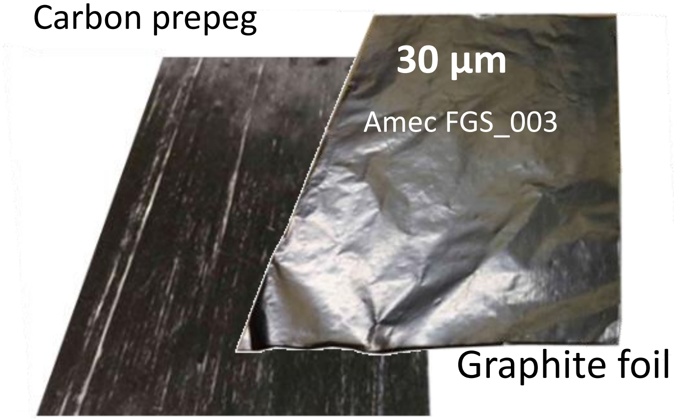


Polyimide pipes

Pyre M.L.

High thermal conductivity
1500 W/mK

Carbon prepeg



Graphite foil

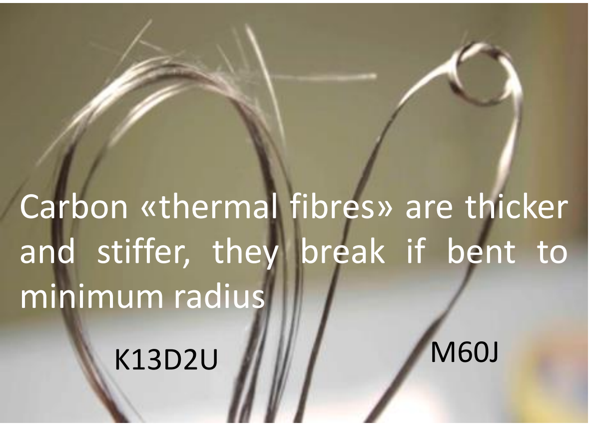
Carbon fibre filament wound

…carbon fibres

available in different shapes, offer a large range of properties

- ↑ High stiffness and strenght, fibre **E ~ 900GPa, X ~4 GPa**
- ↑ High thermal conductivity, fibre K ~ **1000 W/mK**
- ↑ Minimum thickness, prepreg ~ **45 µm**

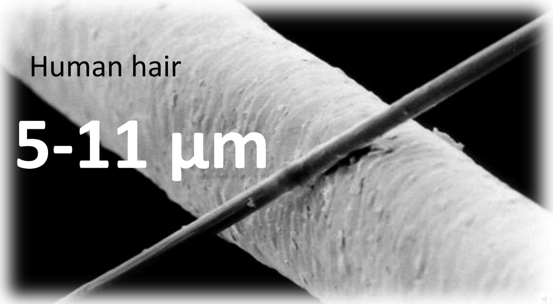
- ↓ Limitation on fibres minimum bending radius
- ↓ Poor mechanical and thermal properties ⊥ fibres



Carbon «thermal fibres» are thicker and stiffer, they break if bent to minimum radius

Thermal/ Structural fibres

materials

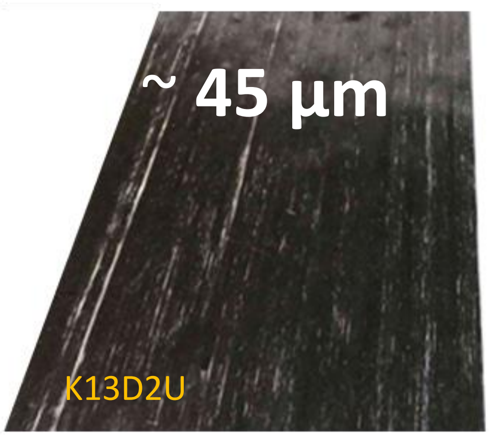


Carbon filament

Cyanate ester resin

Roving

3000 filaments



Unidirectional Prepreg

Fleece

Fabric

Carbon Structural

E [GPa]	X_t [GPa]	
240	4,4	**HT fiber**

Carbon Fleece

continuous-strand mat finished with a chemical binder to hold fibers in place

filament diameter= 5μm

t=20 μm, 8g/m2

	Filaments [K=1000]	Tex [g/km]	E [GPa]	X_t [GPa]	K [W/mK]	CTE [K^{-1}]
M60j	3K	110	588	3,9	140	$-1{,}1\times 10^{-6}$
M55j	6K	220	540	4,2	150	$-1{,}1\times 10^{-6}$

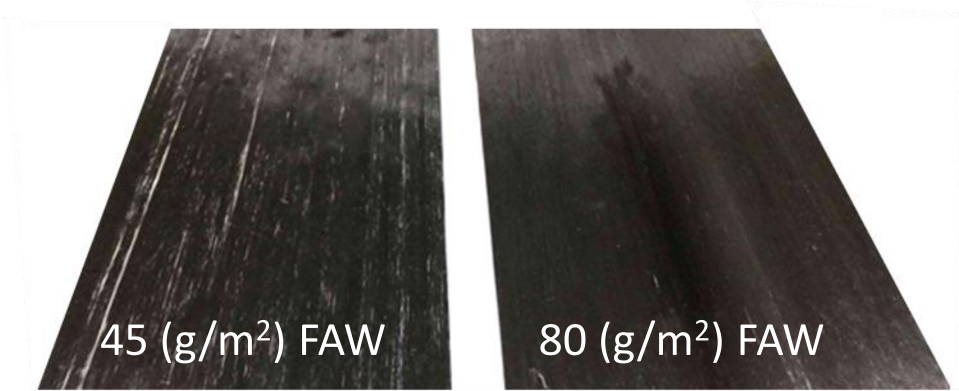
Carbon Roving

Bunches of filament parallel to each other

filament diameter= 5μm

Carbon Thermal

Carbon Unidirectional Prepreg



Prepreg: Ready to mold or cure material in sheet form which contains fiber all aligned in one direction

filament diameter= 11μm

	Filaments [K=1000]	E1 [GPa]	X_t /X_c [MPa]	E2 [GPa]	Y_t [MPa]	K [W/mK]	CTE [$10^{-6}K^{-1}$]
K13D2U [0] fibre	2K	935	3600			800	-1,2
K13D2U [0] prepreg	2K	560	1800/340	5,1	25	~450	-1 / 61

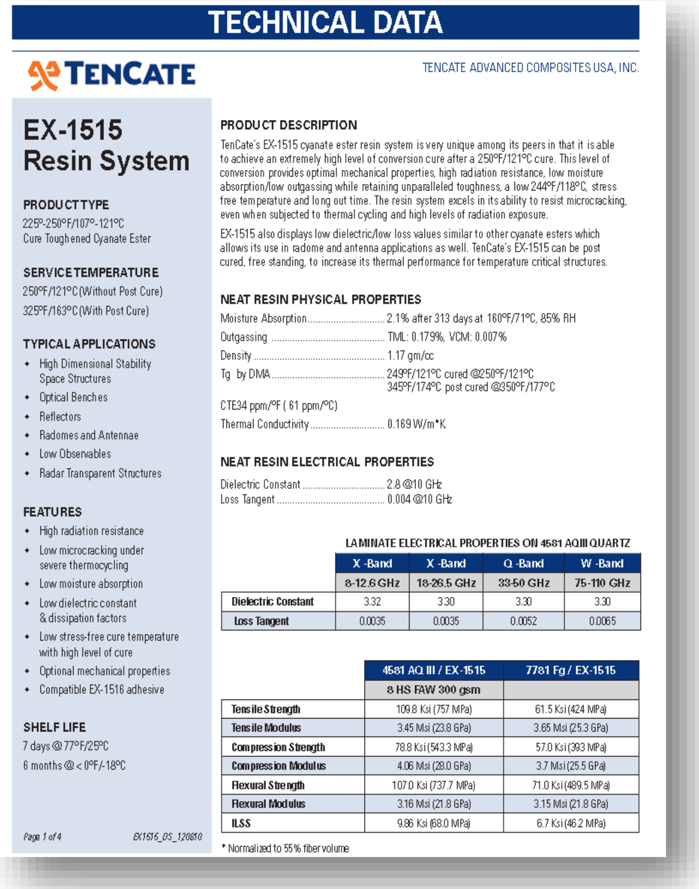
Carbon Paper

Thermal management material with very high thermal conductivity and flexibility

Thick. [μm]	Density [g/cm3]	K pl [W/mK]	K th [W/mK]
30	1.6	1500	15

Resin system: Cyanate Ester

Cyanate Ester (CE) resin to be prfered to epoxy
Optimal mechanical properties, high radiation resistance, low moisture absorption



TECHNICAL DATA

TENCATE

TENCATE ADVANCED COMPOSITES USA, INC.

EX-1515 Resin System

PRODUCT TYPE

225°-250°F/107°-121°C
Cure Toughened Cyanate Ester

SERVICE TEMPERATURE

250°F/121°C (Without Post Cure)
325°F/163°C (With Post Cure)

TYPICAL APPLICATIONS

- High Dimensional Stability Space Structures
- Optical Benches
- Reflectors
- Radomes and Antennae
- Low Observables
- Radar Transparent Structures

FEATURES

- High radiation resistance
- Low microcracking under severe thermocycling
- Low moisture absorption
- Low dielectric constant & dissipation factors
- Low stress-free cure temperature with high level of cure
- Optional mechanical properties
- Compatible EX-1516 adhesive

SHELF LIFE

7 days @ 77°F/25°C
6 months @ < 0°F/-18°C

PRODUCT DESCRIPTION

TenCate's EX-1515 cyanate ester resin system is very unique among its peers in that it is able to achieve an extremely high level of conversion cure after a 250°F/121°C cure. This level of conversion provides optimal mechanical properties, high radiation resistance, low moisture absorption/low outgassing while retaining unparalleled toughness, a low 244°F/118°C, stress free temperature and long out time. The resin system excels in its ability to resist microcracking, even when subjected to thermal cycling and high levels of radiation exposure.

EX-1515 also displays low dielectric/low loss values similar to other cyanate esters which allows its use in radome and antenna applications as well. TenCate's EX-1515 can be post cured, free standing, to increase its thermal performance for temperature critical structures.

NEAT RESIN PHYSICAL PROPERTIES

Moisture Absorption	2.1% after 313 days at 160°F/71°C, 85% RH
Outgassing	TML: 0.179%, VCM: 0.007%
Density	1.17 gm/cc
Tg by DMA	249°F/121°C cured @250°F/121°C 345°F/174°C post cured @350°F/177°C
CTE34 ppm/°F (61 ppm/°C)	
Thermal Conductivity	0.169 W/m*K

NEAT RESIN ELECTRICAL PROPERTIES

Dielectric Constant	2.8 @10 GHz
Loss Tangent	0.004 @10 GHz

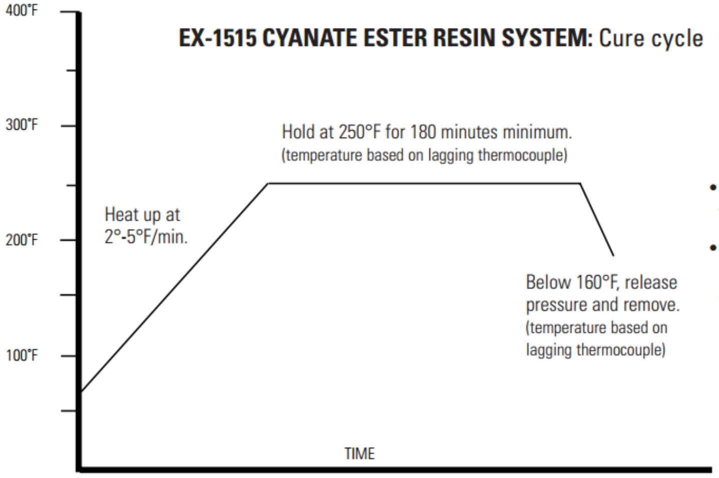
LAMINATE ELECTRICAL PROPERTIES ON 4581 AQIII QUARTZ

	X -Band	X -Band	Q -Band	W -Band
	8-12.6 GHz	18-26.5 GHz	33-50 GHz	75-110 GHz
Dielectric Constant	3.32	3.30	3.30	3.30
Loss Tangent	0.0035	0.0035	0.0052	0.0065

	4581 AQ III / EX-1515	7781 Fg / EX-1515
	8 HS FAW 300 gsm	
Tensile Strength	109.8 Ksi (757 MPa)	61.5 Ksi (424 MPa)
Tensile Modulus	3.45 Msi (23.8 GPa)	3.65 Msi (25.3 GPa)
Compression Strength	78.8 Ksi (543.3 MPa)	57.0 Ksi (393 MPa)
Compression Modulus	4.06 Msi (28.0 GPa)	3.7 Msi (25.5 GPa)
Flexural Strength	107.0 Ksi (737.7 MPa)	71.0 Ksi (489.5 MPa)
Flexural Modulus	3.16 Msi (21.8 GPa)	3.15 Msi (21.8 GPa)
ILSS	9.86 Ksi (68.0 MPa)	6.7 Ksi (46.2 MPa)

* Normalized to 55% fiber volume

Page 1 of 4 *EX1515_DS_120810*



EX-1515 CYANATE ESTER RESIN SYSTEM: Cure cycle

- Apply 25 inches Hg vacuum minimum.
- Apply 40 - 100 psig pressure to autoclave (optional).

EX-1515 TENCATE (127°C)

-radiation resistance

-extensive use at CERN

- Low curing temperature, 127°C

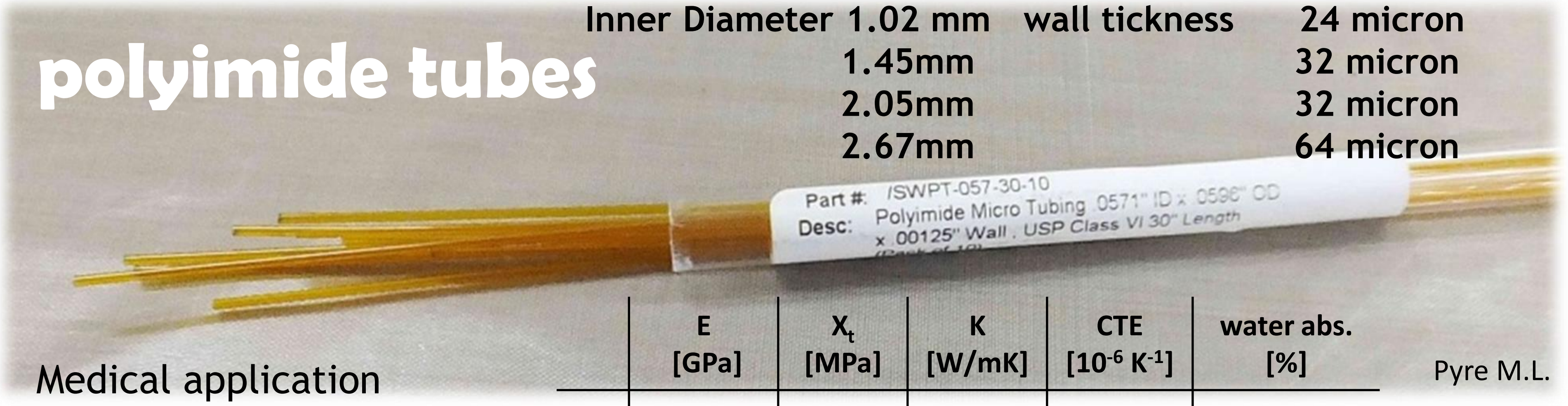
RS-3 TENCATE (177°C)

-the other predominant Cyanate Ester (CE) resin used at CERN.

Hexcel 954 (177°C)

-moderate use at CERN

polyimide tubes



Inner Diameter	wall tickness
1.02 mm	24 micron
1.45mm	32 micron
2.05mm	32 micron
2.67mm	64 micron

Medical application

	E [GPa]	X_t [MPa]	K [W/mK]	CTE [10^{-6} K^{-1}]	water abs. [%]
PI	2,5	305	0,205	40	0,841

Pyre M.L.

High radiation hardness: according to **CERN-98-01** report, **polyimide**:

No problem below 10^7 Gy, Mild damage between 10^7 to 5 10^7 Gy

1st layer of ITS Inner Barrel will be exposed to 700 krad/yr.=7000 Gy/yr.

Ageing: physical and chemical stability over time.

Plastic Pipe Institute states corrosion is not an issue in plastic pipes.

Fire Safety: Comply to LHC Fire Safety Instruction (IS-41)

Polyimide is allowed.

High radiation length material

Polyimide: X_0 = 29 cm, minimum wall thickness is 0.025 mm.

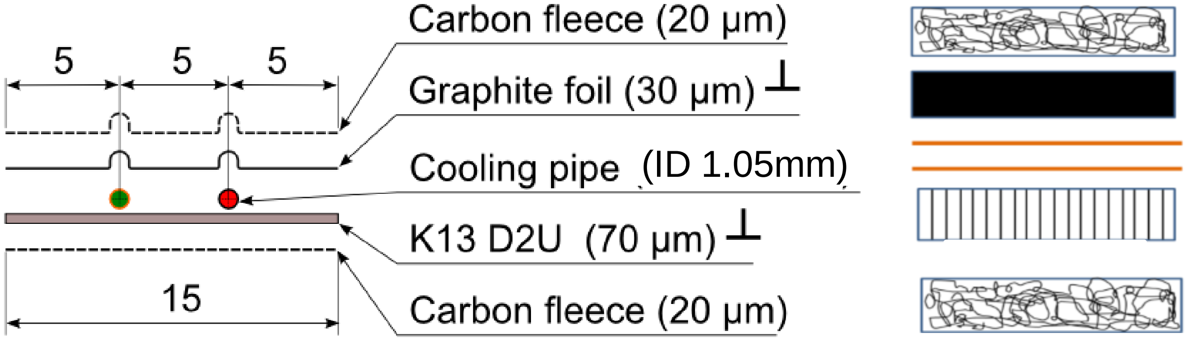
PEEK: X_0 = 31.45 cm, minimum wall thickness is 0.25 mm.

STAVE Mechanics and Cooling

✓ **production process**

IB Production Process: Manual Lay-up

New innovative design developed fo ALICE ITS Upgrade



Carbon fleece (20 μm)

Graphite foil (30 μm) ⊥

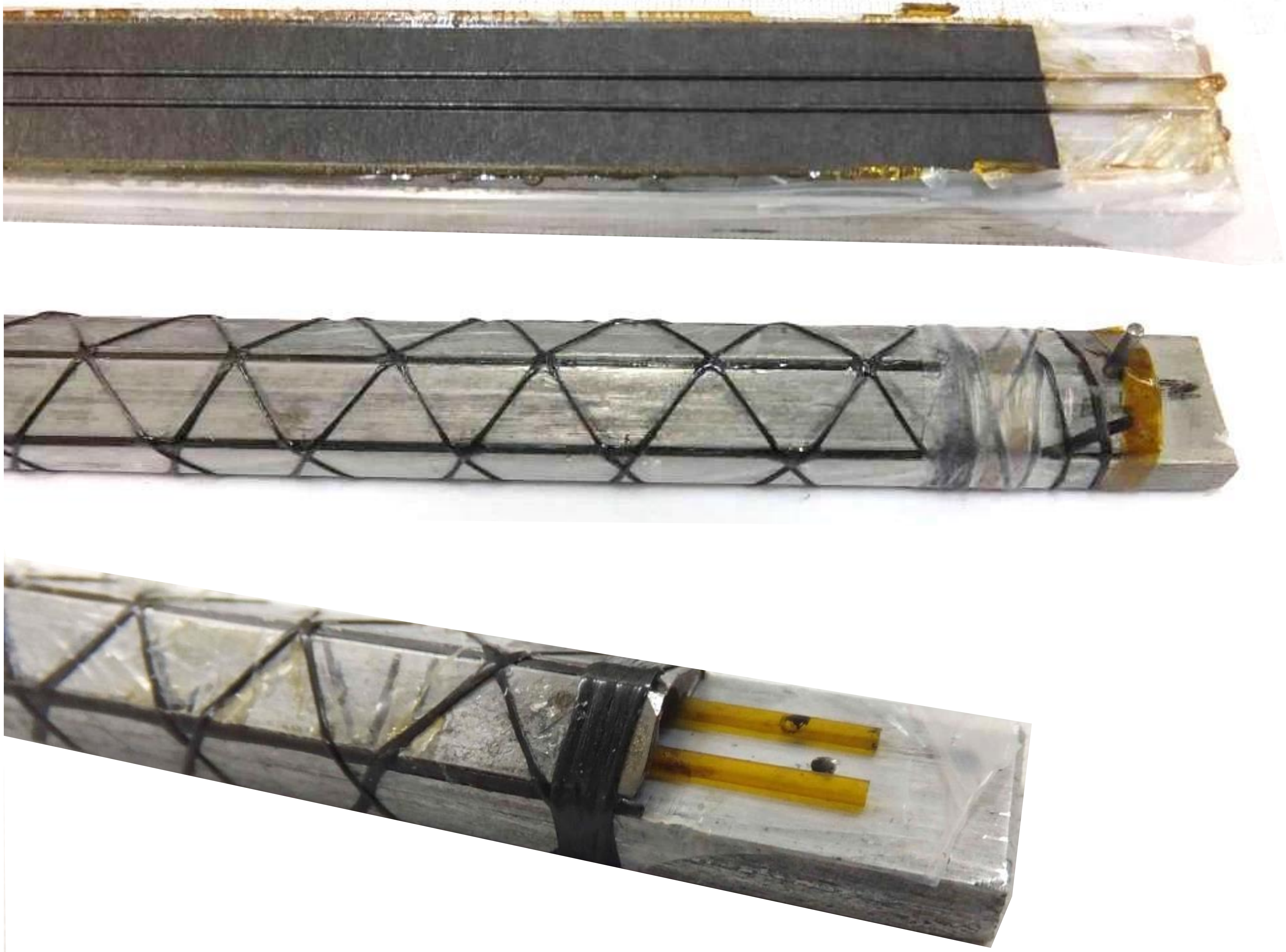
Cooling pipe (ID 1.05mm)

K13 D2U (70 μm) ⊥

Carbon fleece (20 μm)

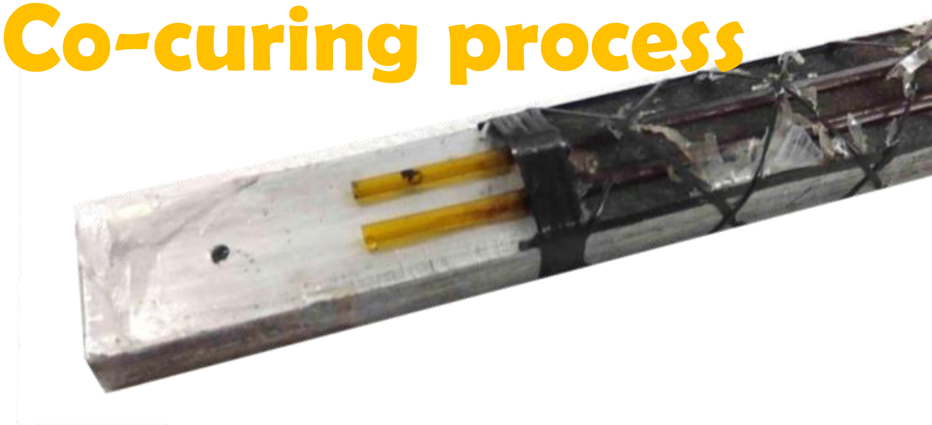
mandrels

(steel piano wires)



IB Production Process: Co-curing process

IB Production Process: Co-curing process



Inner mould extraction

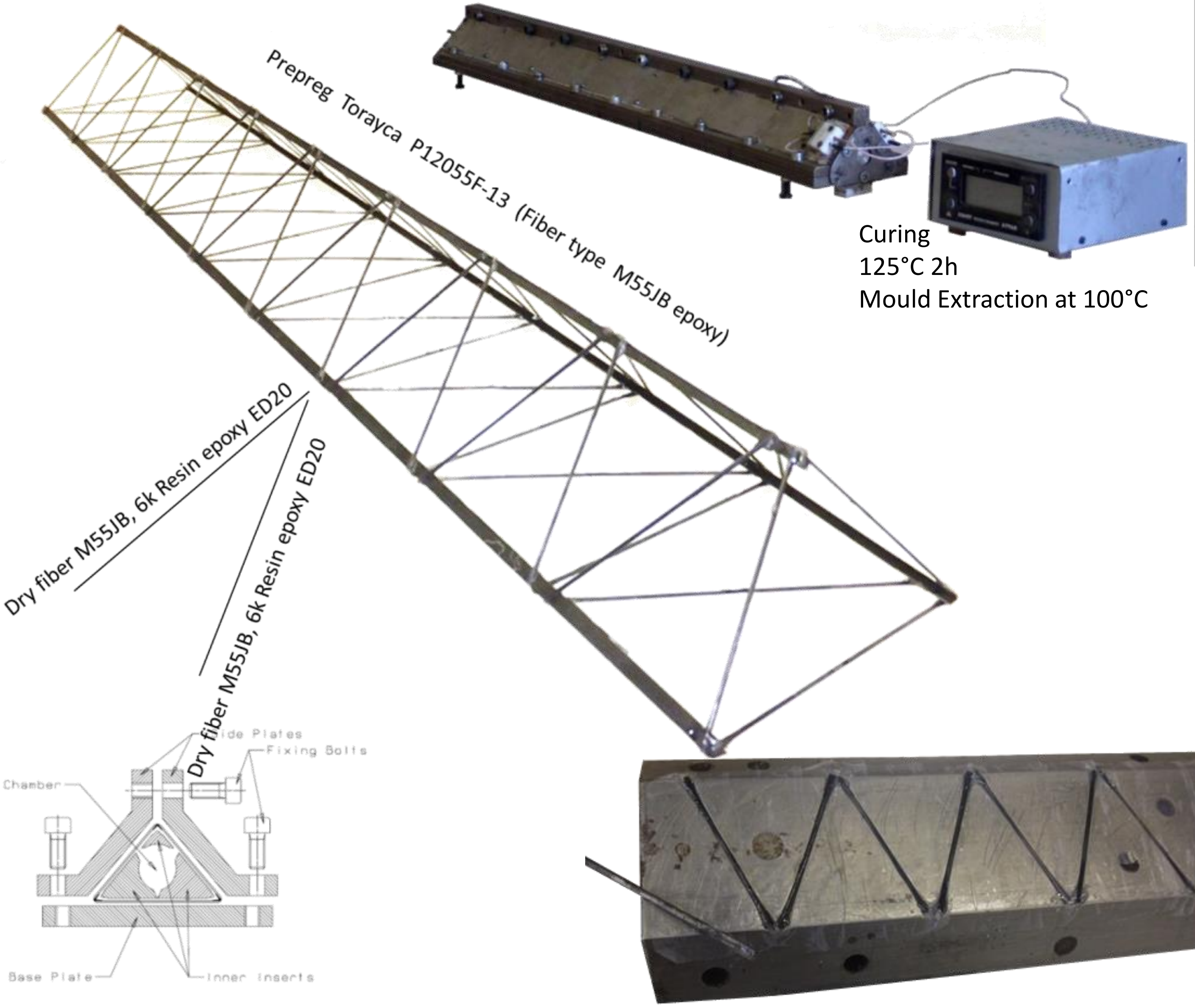
Cut and mould separation

290mm length, 1.5gram weight

OB Production Process: Spaceframe

Bassed on original design developed by St Petersburg University, Utrecth Univeristy and INFN Torino for the ALICE tracker now in operation.

Spaceframe <1m



Prepreg Torayca P12055F-13 (Fiber type M55JB epoxy)

Curing
125°C 2h
Mould Extraction at 100°C

Dry fiber M55JB, 6k Resin epoxy ED20

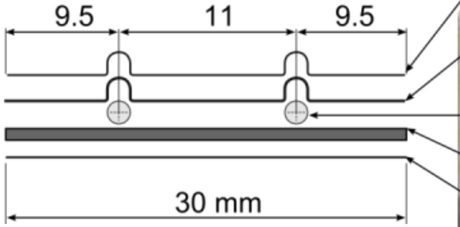
Dry fiber M55JB, 6k Resin epoxy ED20

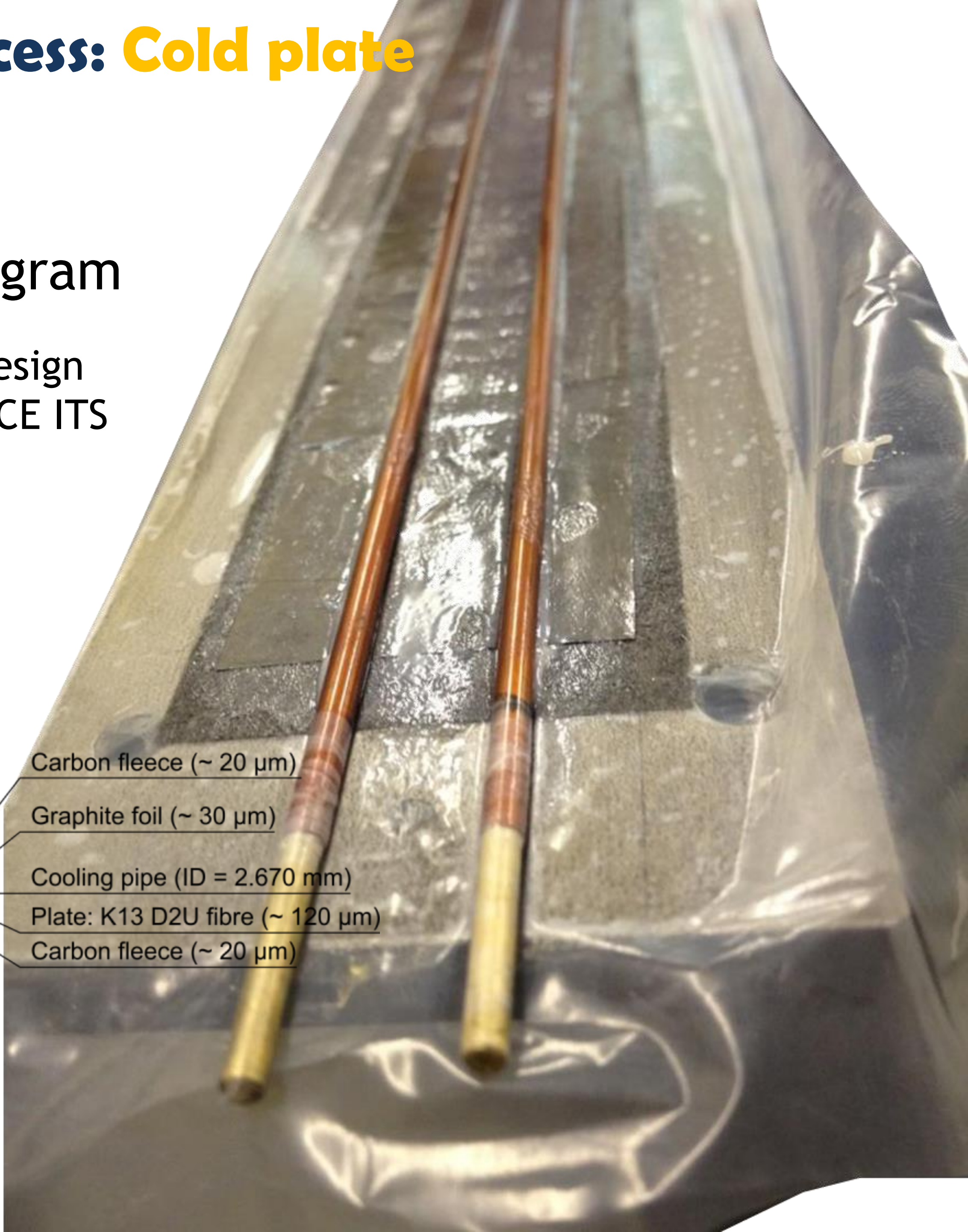
OB Production Process: Cold plate

1500mm ~22 gram

New innovative design developed for ALICE ITS Upgrade

Cold plate transversal section:



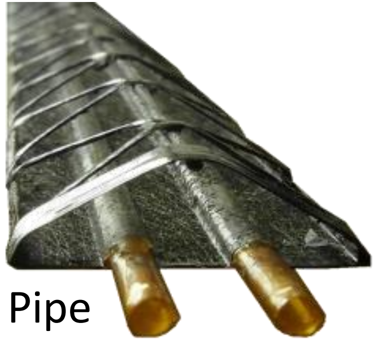


STAVE Mechanics and Cooling

- ✓ **material budget**

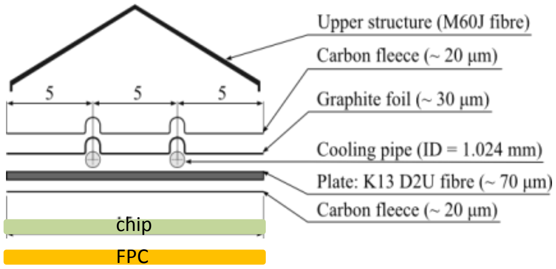
material budget

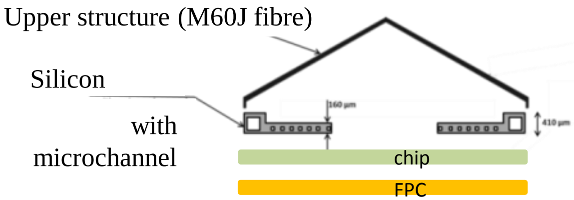
...very stringent requirements

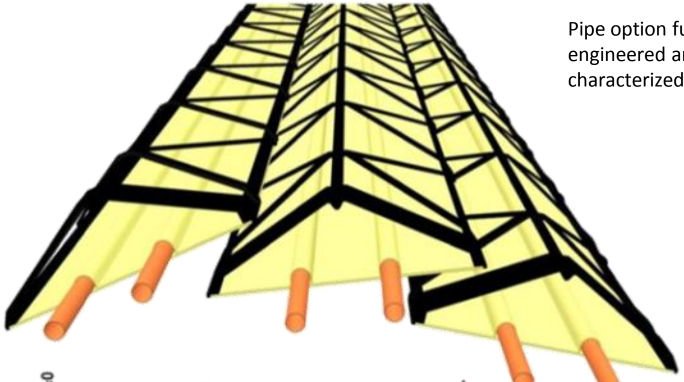


X_0 E is used as figure of merit for all the structural material of a detector. With this criterion, the best materials are beryllium and carbon fibre.

Material	Be	CFC	Al-Be	Al	Ti	Fe
E (GPa)	290	200	193	70	110	210
X_0 (m)	0.353	0.271	0.253	0.089	0.036	0.018







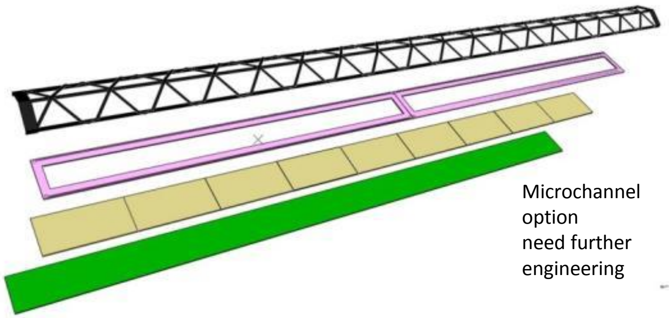
Pipe option fully engineered and characterized

mean

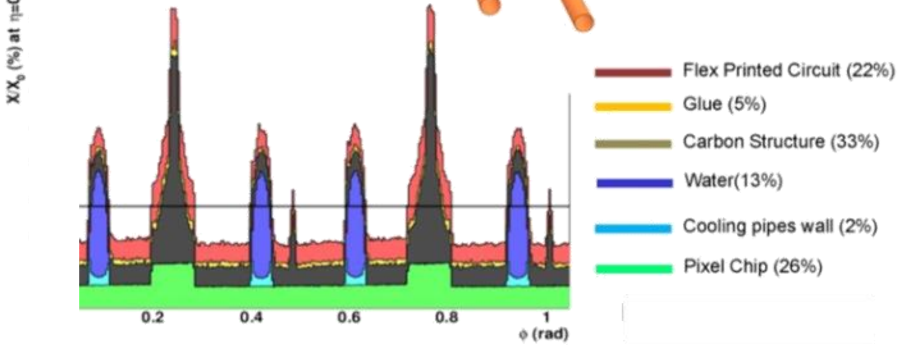
X/X_0~ 0.3%

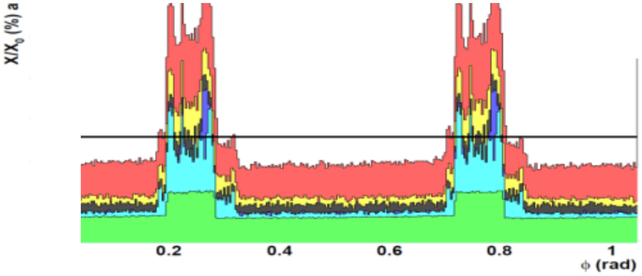
per layer

Includes:
Structure,
Pixel Chip, Flex Printed Circuit, Coolant



Microchannel option need further engineering



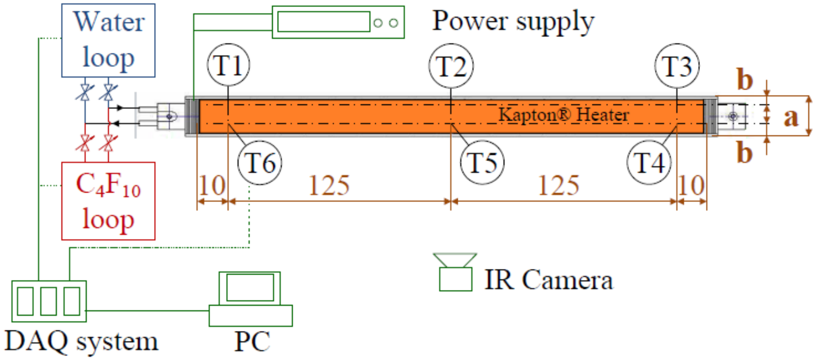


STAVE Mechanics and Cooling

- ✓ thermal characterization

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

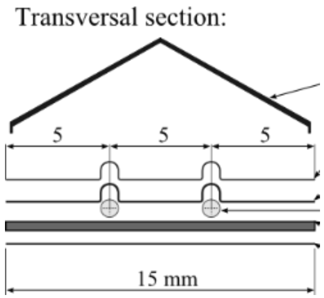
Water in 15°C--->Tchip <30°C

Pixel max temperature non-uniformity < 5°C

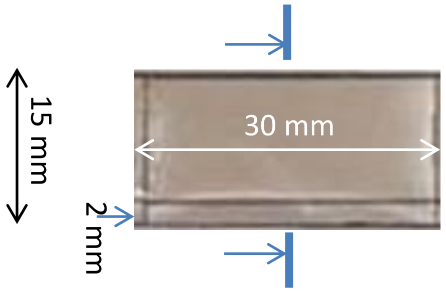
Pressure drop ΔP below 0.3 bar

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

Chip non uniform power dissipation



dummy metalized chip acts as heater



Chip Power dissipation concentrated at periphery: 83% of total power

P_{in}= 1 bar
T_{in}=15.8° C

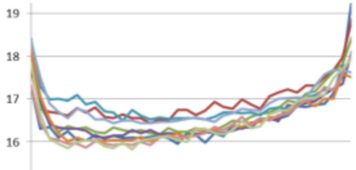
Q= 3 L/h

T_{out}=16.6 °C
P_{out}= 0.7 bar

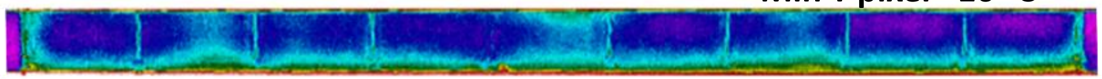
Heating is provided by dummy metalized chip : thickness= 50 µm chip + 20/200 nm Titanium /Platinum

~40mW/cm2

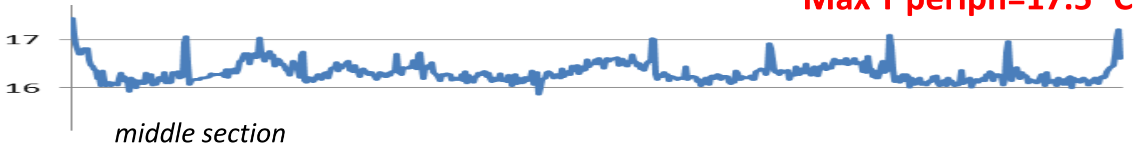
Periphery: 0.145 W/chip
Pixels: 0.03 W/chip



Min T pixel =16° C

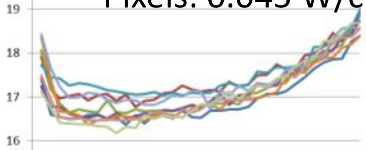


Max T periph=17.5° C

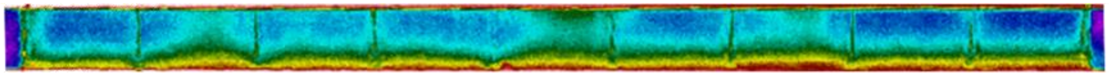


~60mW/cm2

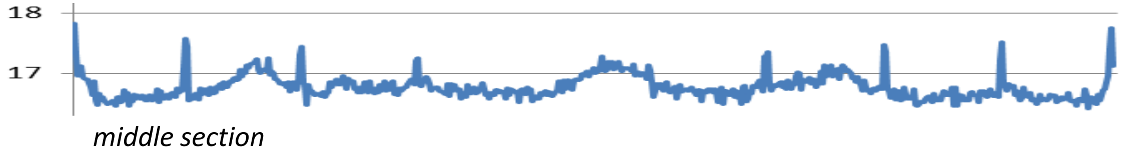
Periphery: 0.217 W/chip
Pixels: 0.045 W/chip



Min T pixel =16.5° C

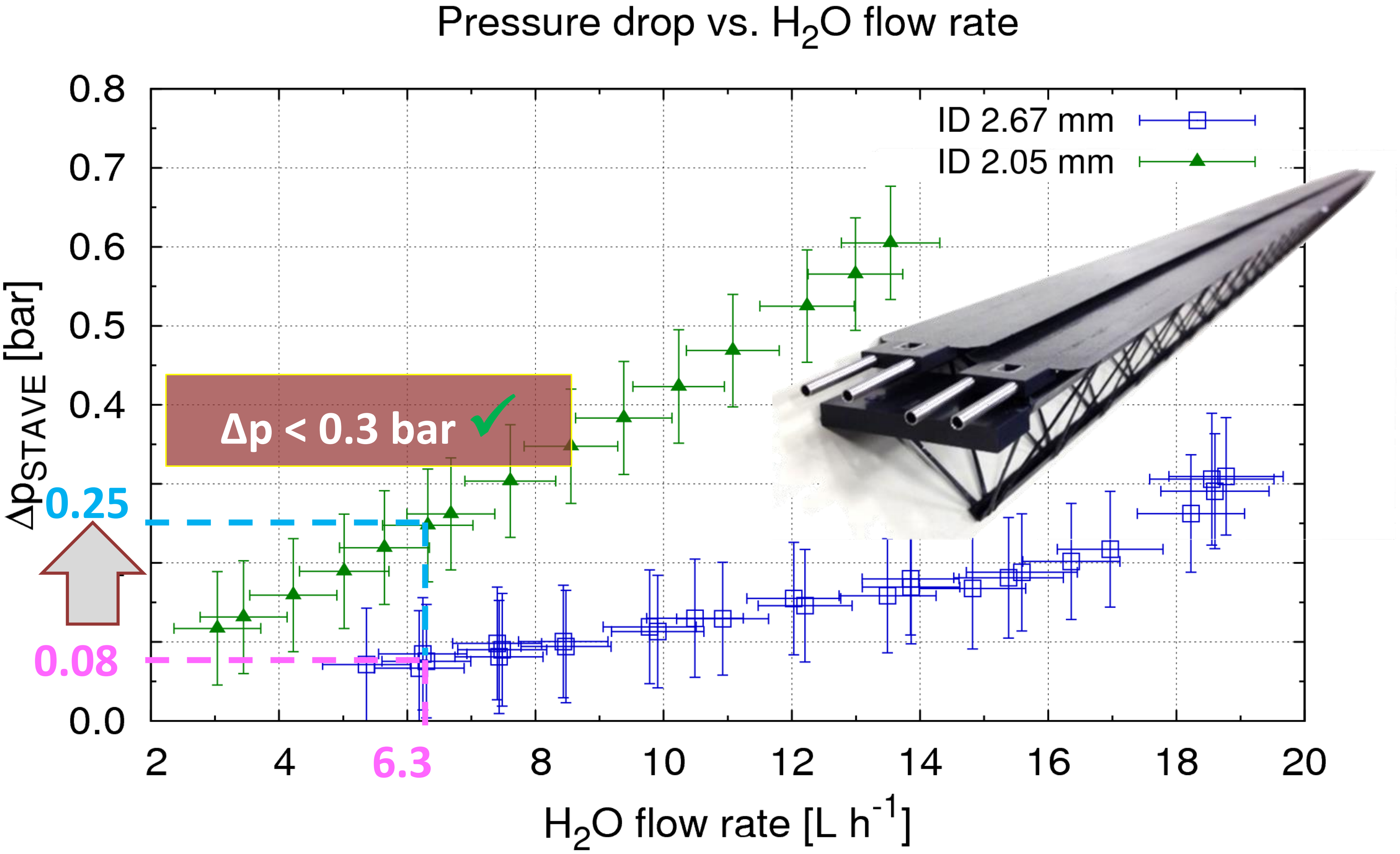


Max T periph=18.5° C



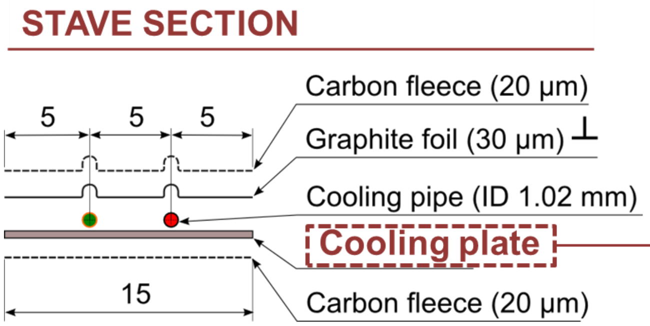
pressure drop for 1,5m OB stave

Pressure drop for leak less system to be below 0,3 bar



Corrado Gargiulo, 28 May 2015

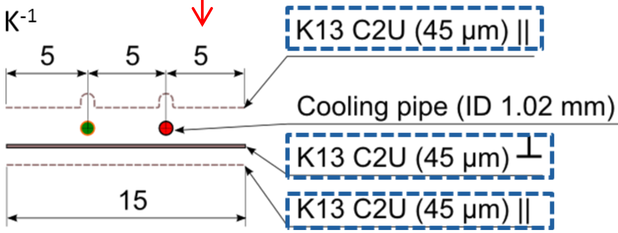
Studies: different carbon layup

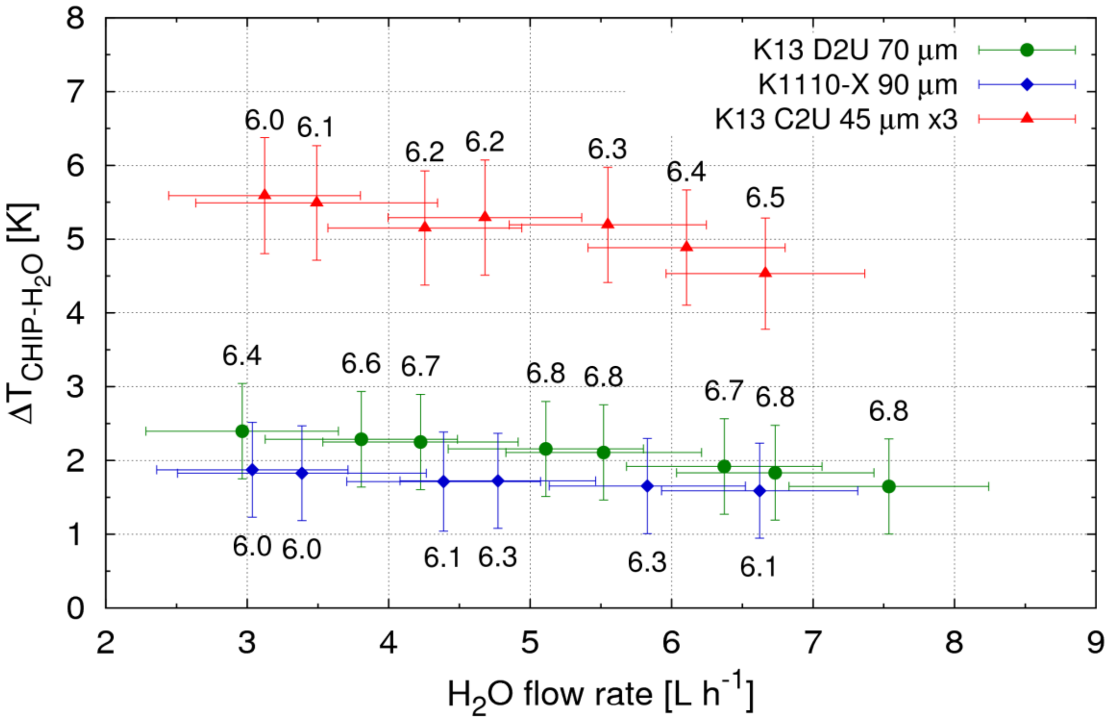


1. K13 D2U 70 µm ⊥
   - $k_{K13D2U} \sim 800\ W\ m^{-1}\ K^{-1}$

2. K1100-X 90 µm ⊥
   - $k_{K1100} \sim 1000\ W\ m^{-1}\ K^{-1}$

3 (alt). K13 C2U 45 µm x3
   - $k_{K13C2U} \sim 620\ W\ m^{-1}\ K^{-1}$

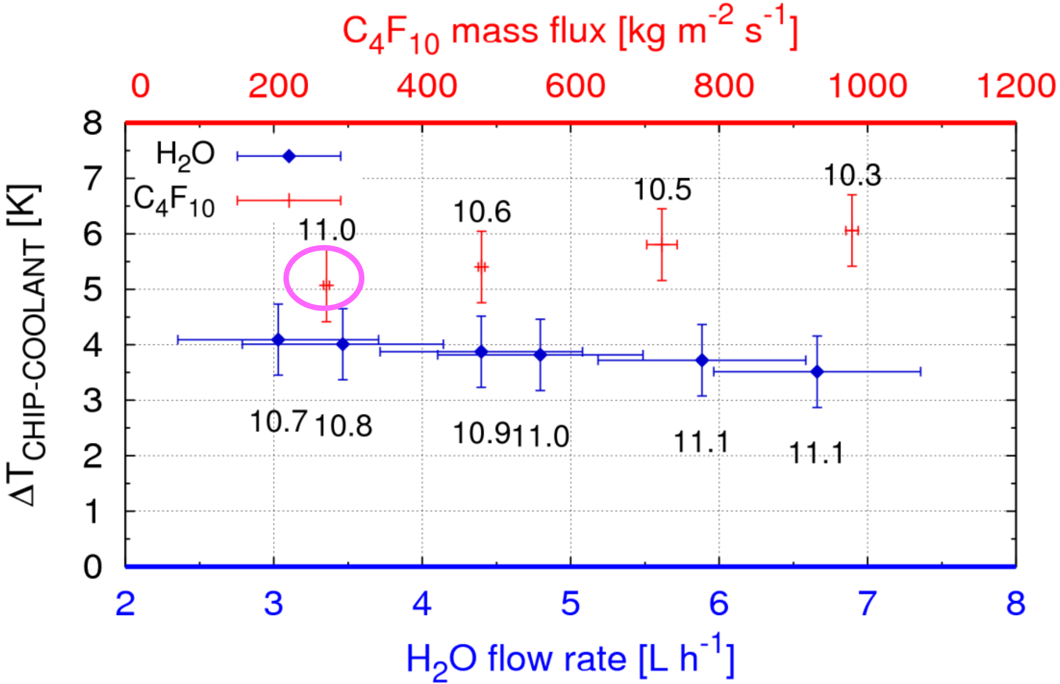




Studies: evaporative C4F10

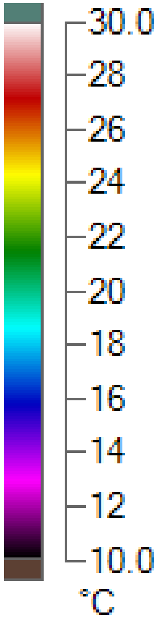
IB K1100-X 90 µm,
50mW/cm2

Almost no difference in thermal performance H2O vs C4F10



Cold plate performance driven by cold plate minimum thickness

G [kg m^{-2} s^{-1}]	Δp [bar]	ΔT_{C4F10} [K]	T_{C4F10} [°C]	T_{Chip} [°C]	x_{In} [-]	x_{Out} [-]
271	0.29	3.1	13.9	19.0	0.14	0.40

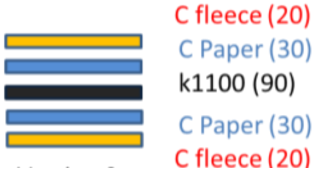


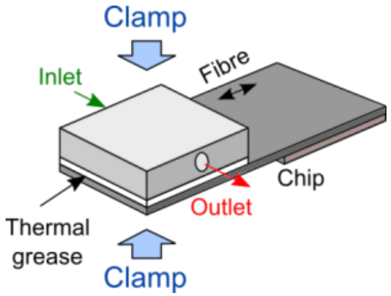
studies: peripheral cooling, no pipes on the stave

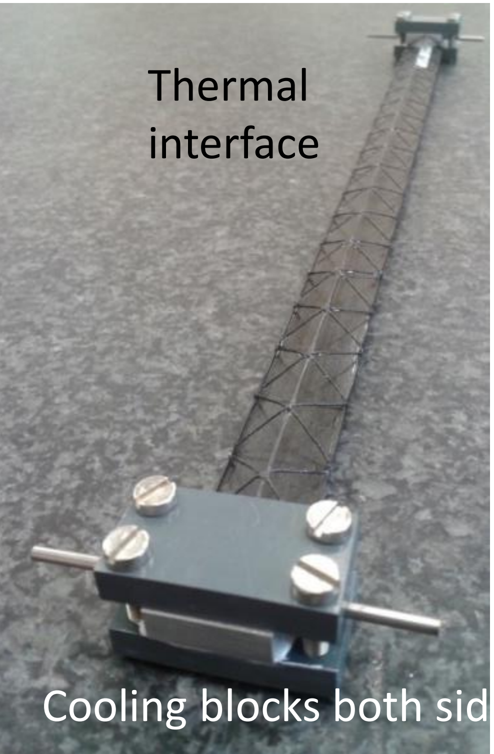
↔

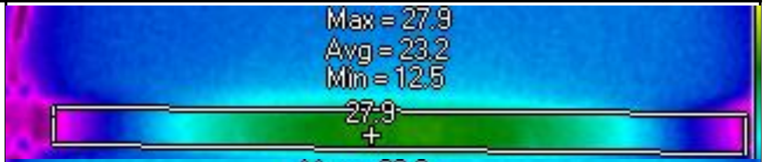
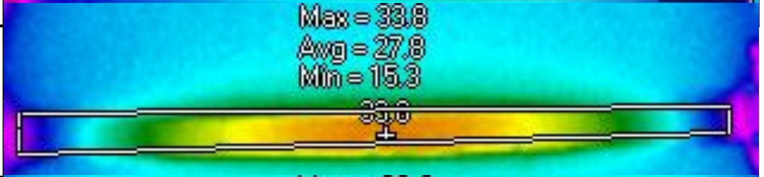
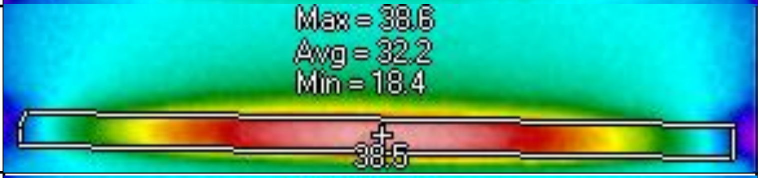
Carbon Fibre orientation

Cold plate section





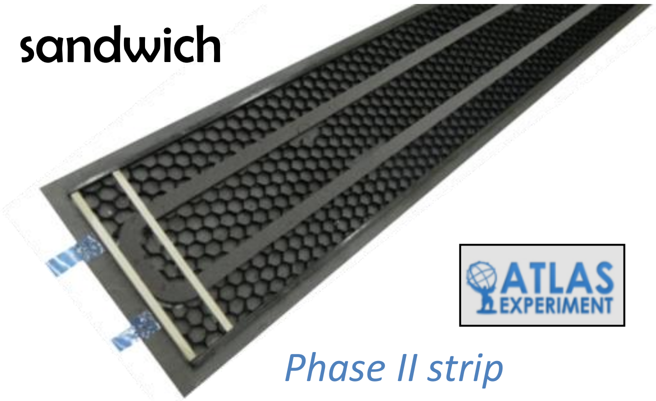


q [W cm^{-2}]	Power input [W]	Estim. power to flow [W]	T water [°C]	T map [°C] 
0.02	0.82	0.56	12.6	
0.03	1.25	0.71	12.7	
0.04	1.64	0.80	12.9	
0.05	2.02	0.86	12.9	

STAVE Mechanics and Cooling

✓ **mechanical characterization**

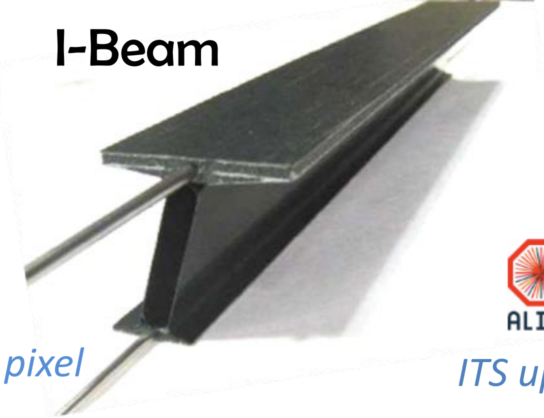
sandwich



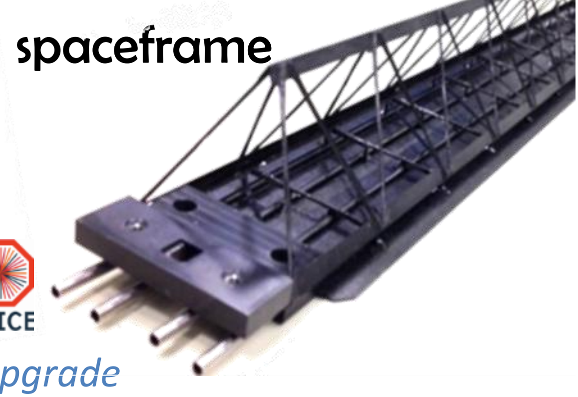
Phase II strip

Phase II pixel

I-Beam

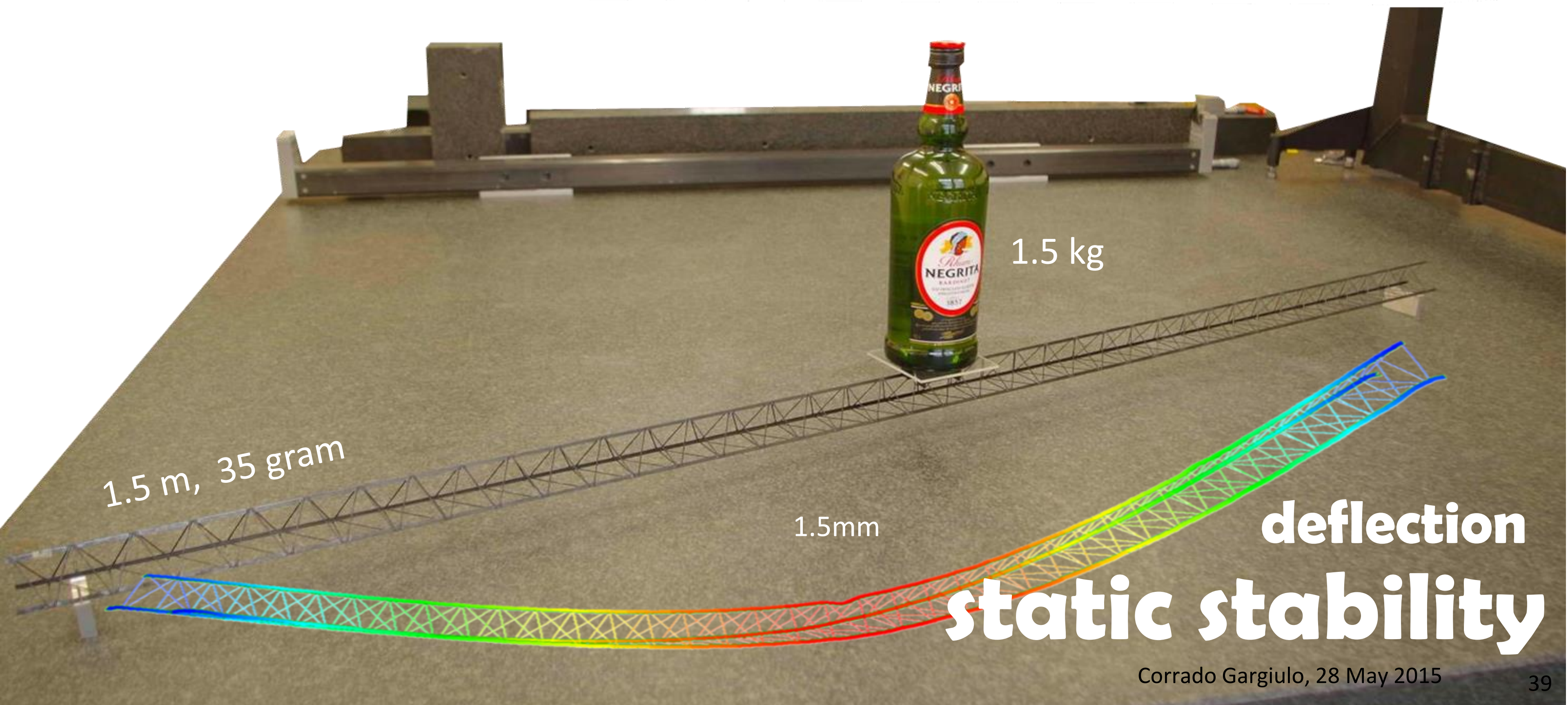


spaceframe



ITS upgrade

Stiffness is provided not only by the choice of high modulus material but also by large inertia section, different options proposed



deflection

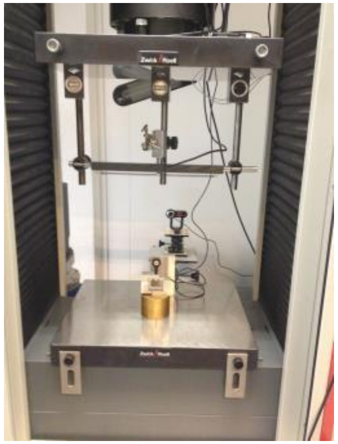
static stability

static stability: deflection

Objective: evaluate stave sag under Chip+FPC load

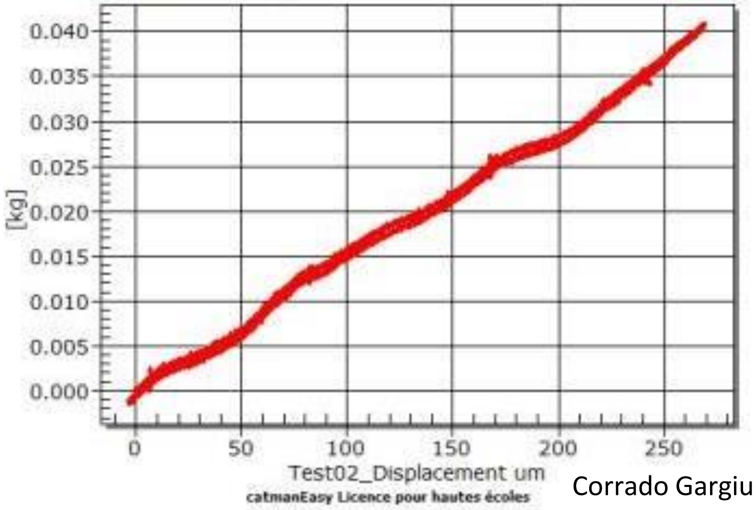
3 point bending test results

Displacement sensor:
HEIDENHAIN (MT 1201),Accuracy: ± 0.2 µm
Force transducer:
HBM (S2M-10),Accuracy: 0.002 N



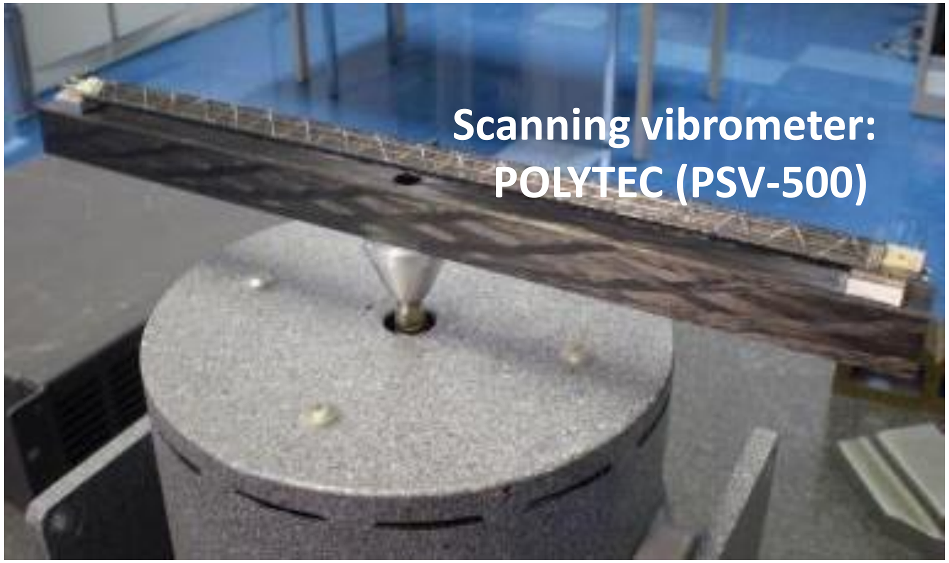
INNER Barrel stave
HIC (chip + FPC) mass estimate =2 gr

predicted sag 4-9 µm



static stability: natural frequencies

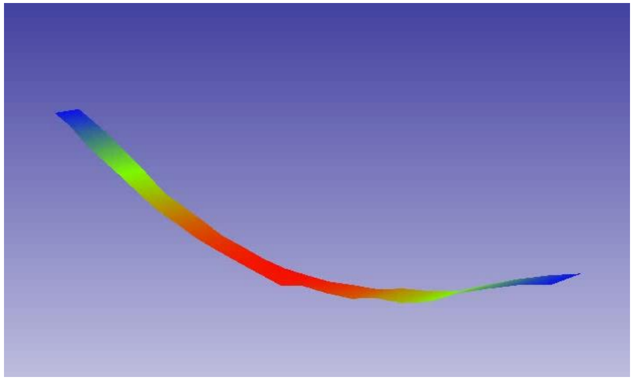
Objective: Determine the natural frequencies of the Inner tracker stave.

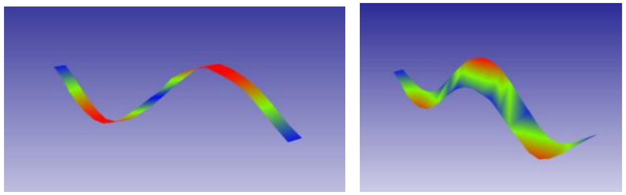


Scanning vibrometer: POLYTEC (PSV-500)

Test results

167 Hz





461 Hz **764 Hz**

Laser non-contact vibration measurement

Mechanical Measurements Laboratory
EN-MME-EDM

Corrado Gargiulo, 28 May 2015

static stability: deflection

Objective: evaluate stave sag under Chip+FPC+Bus load

OUTER Barrel stave

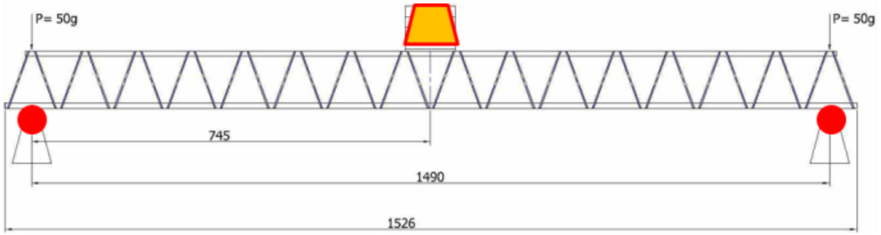
HIC (chips + FPC)+Bus mass estimate =170 gr

predicted max sag 80 µm

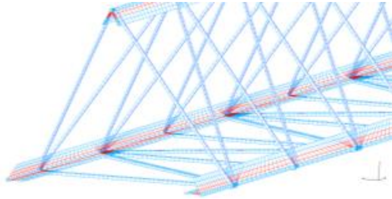
test

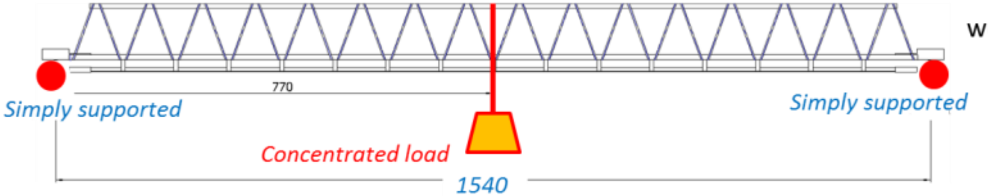
FEA

spaceframe



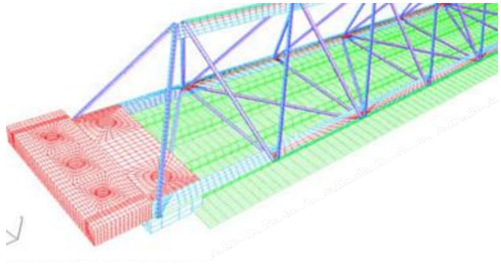
weight 170g, sag=160um*

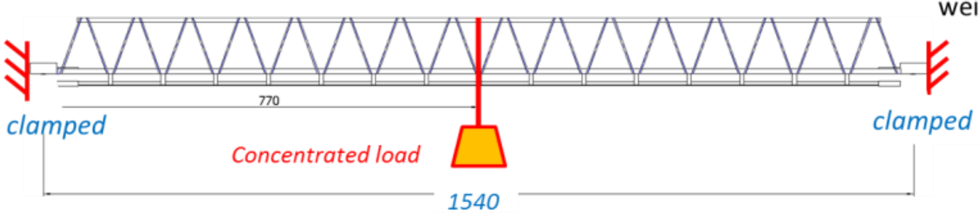




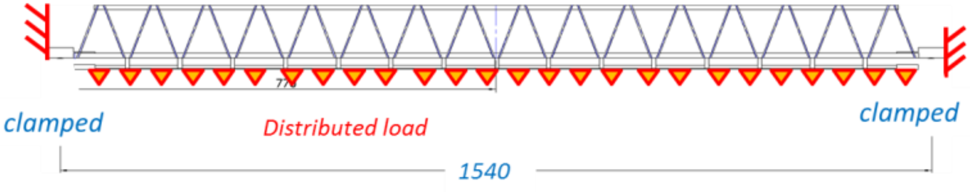
weight 170g, sag=153um

Spaceframe+ coldplate





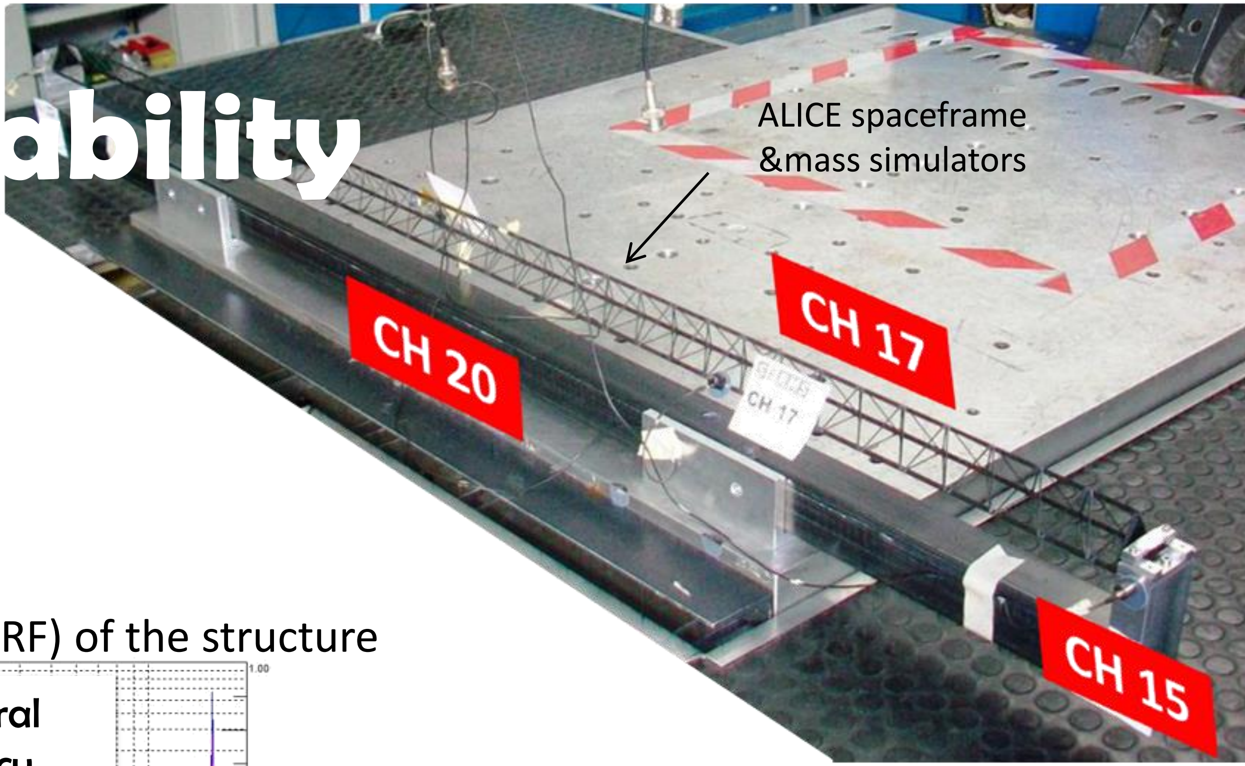
weight 170g, sag=123um



weight 170g, sag=80um

TEST do not account for HIC/PWBus stiffness

dynamic stability



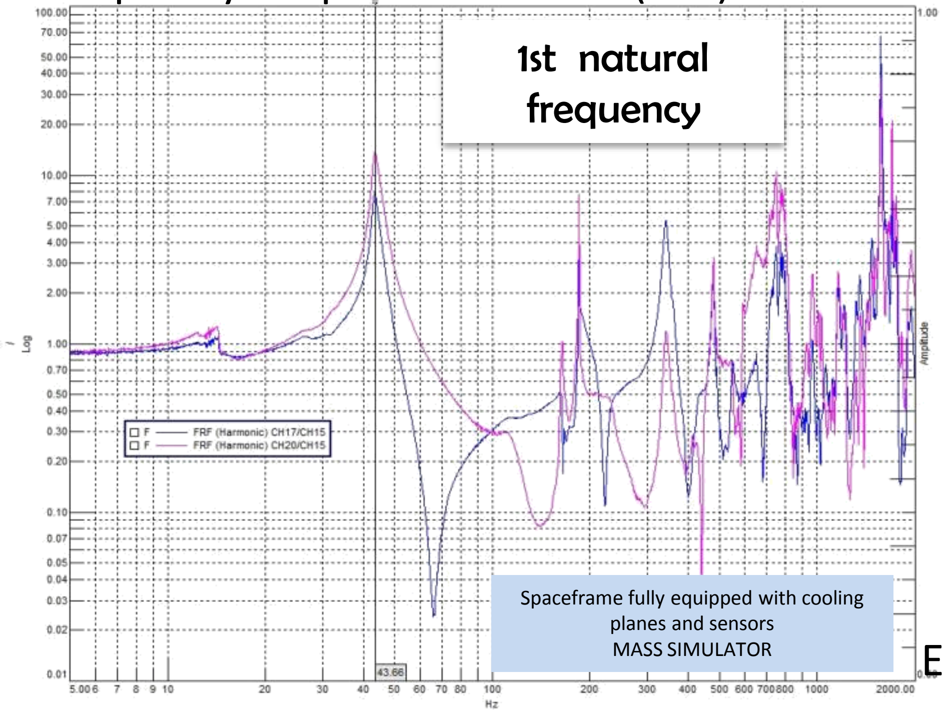
ALICE spaceframe
&mass simulators

-natural frequencies

-modal **damping** coefficients

-modal **shapes**

Frequency Response Function (FRF) of the structure



1st natural frequency

Spaceframe fully equipped with cooling planes and sensors
MASS SIMULATOR

Determine vibrational input

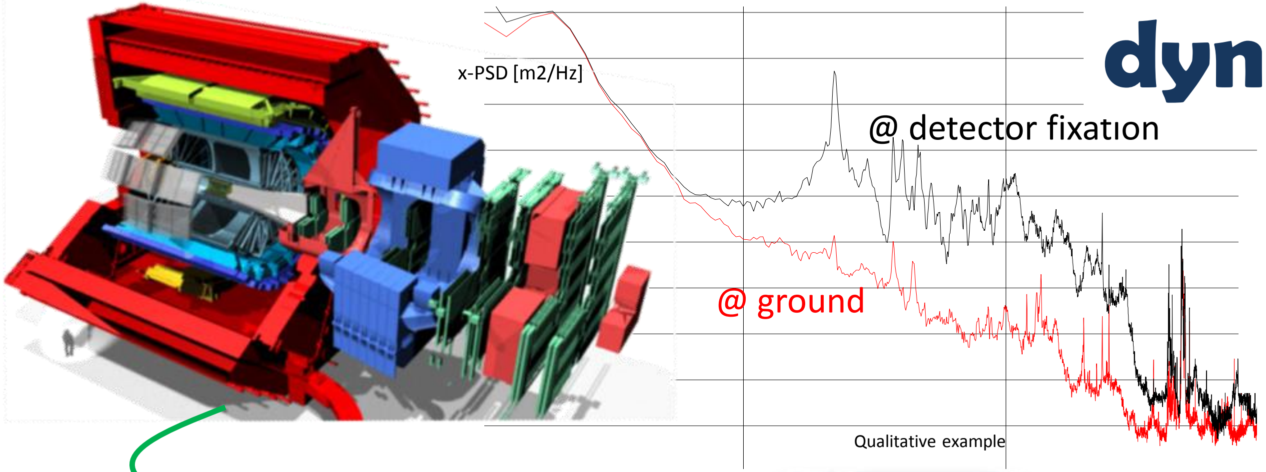
↓

Determine structure FRF

↓

Evaluate output in term of sensors (chip) stability

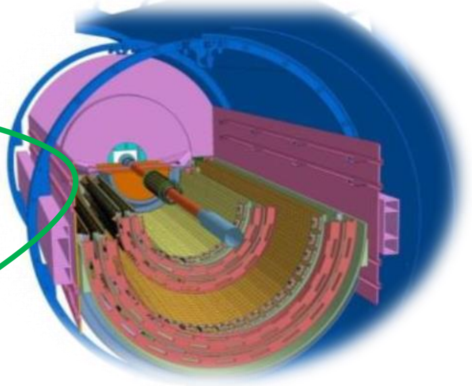
dynamic stability

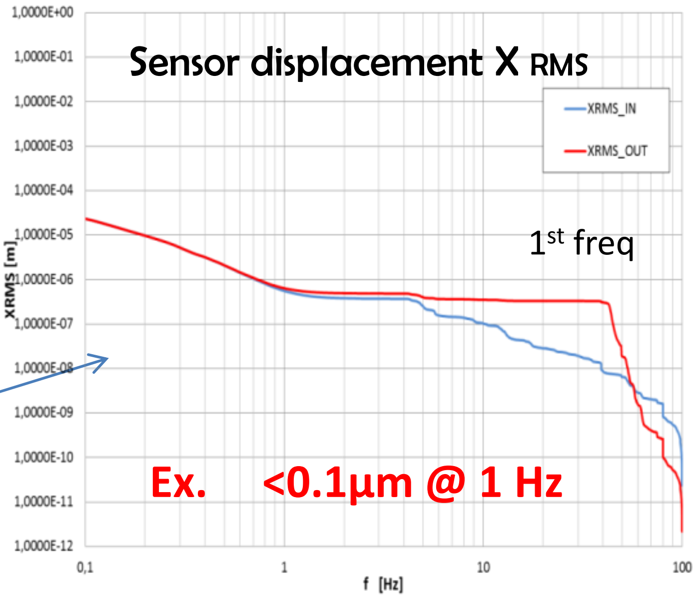


The first source of vibration comes from the ground

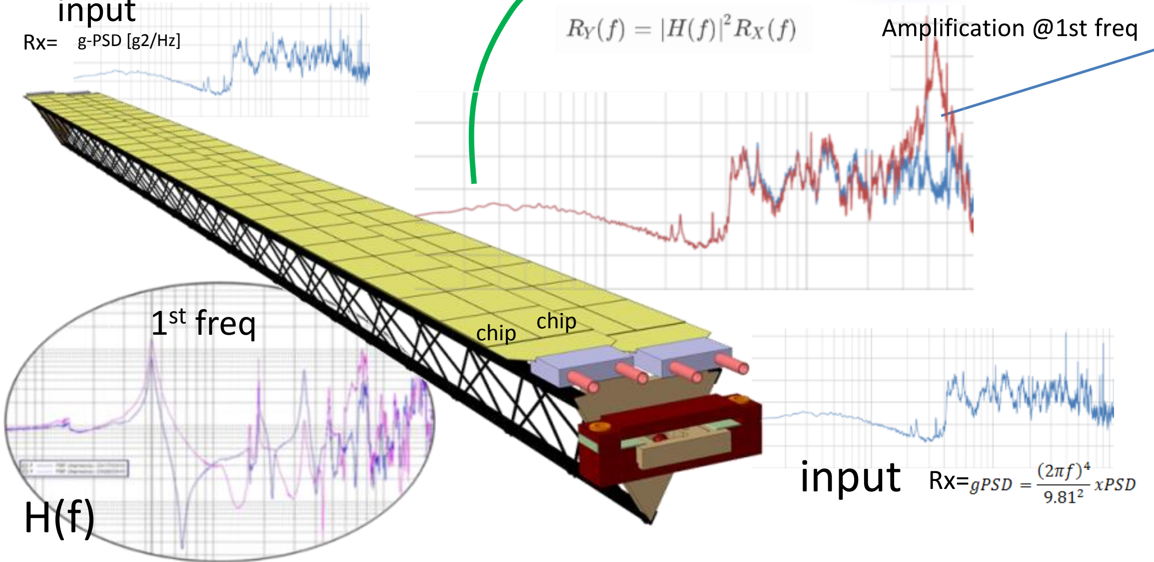
Seismic (<1Hz, cultural>1Hz)

The Experiments amplify the ground motion at frequencies above 1Hz





Ex. <0.1µm @ 1 Hz



$R_Y(f) = |H(f)|^2 R_X(f)$

Rx= $gPSD = \frac{(2\pi f)^4}{9.81^2} xPSD$

Vs

pixel stability requirement

5-10µm

Corrado Gargiulo, 28 May 2015

STAVE Mechanics and Cooling

✓ mechanical characterization

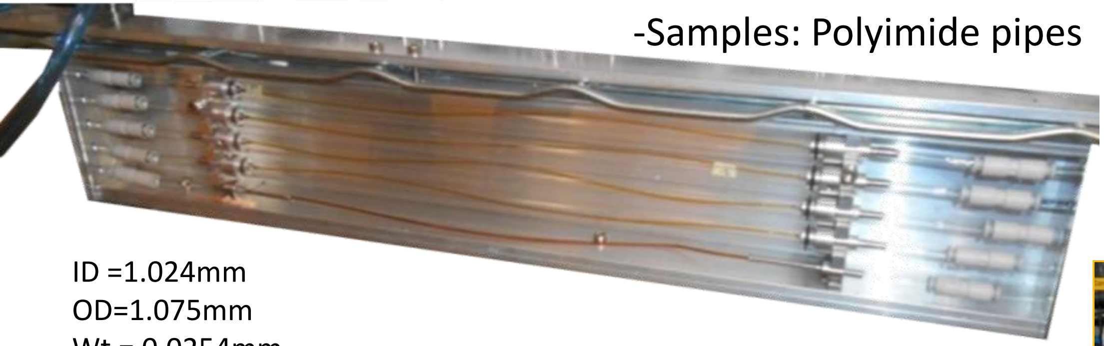
erosion test

erosion test

-**Objective:** Long term test with water flow to evaluate erosion effects on polyimide pipes

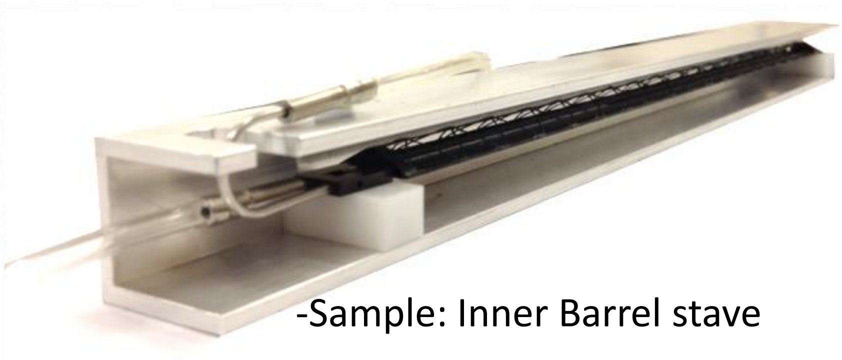
SEM (surface damage)
AFM (surface roughness change)

-Test set up in the ALICE cavern



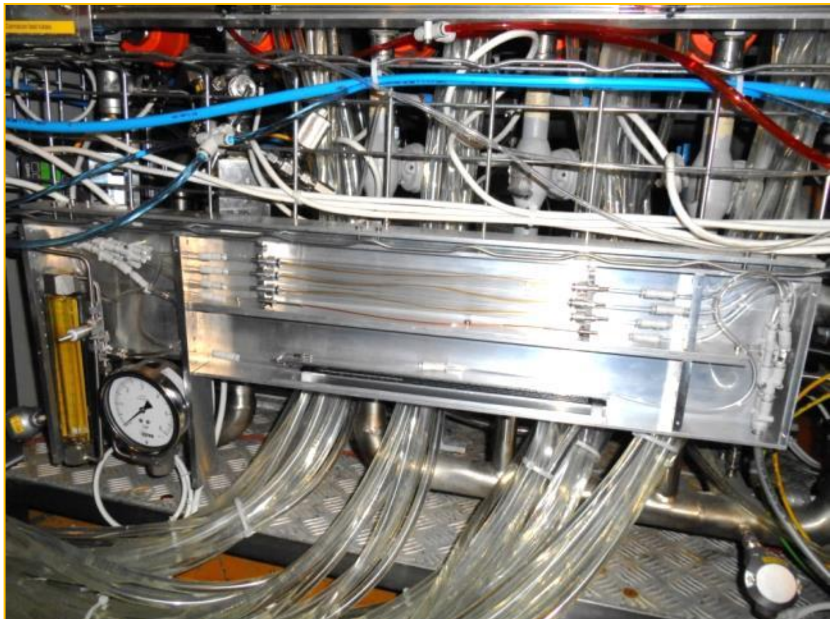
-Samples: Polyimide pipes

ID =1.024mm
OD=1.075mm
Wt = 0.0254mm
L= 300mm



-Sample: Inner Barrel stave

-Flow rate: 0.3 l/min
-P inlet: 2.30 bar
-T= 20°C



erosion test

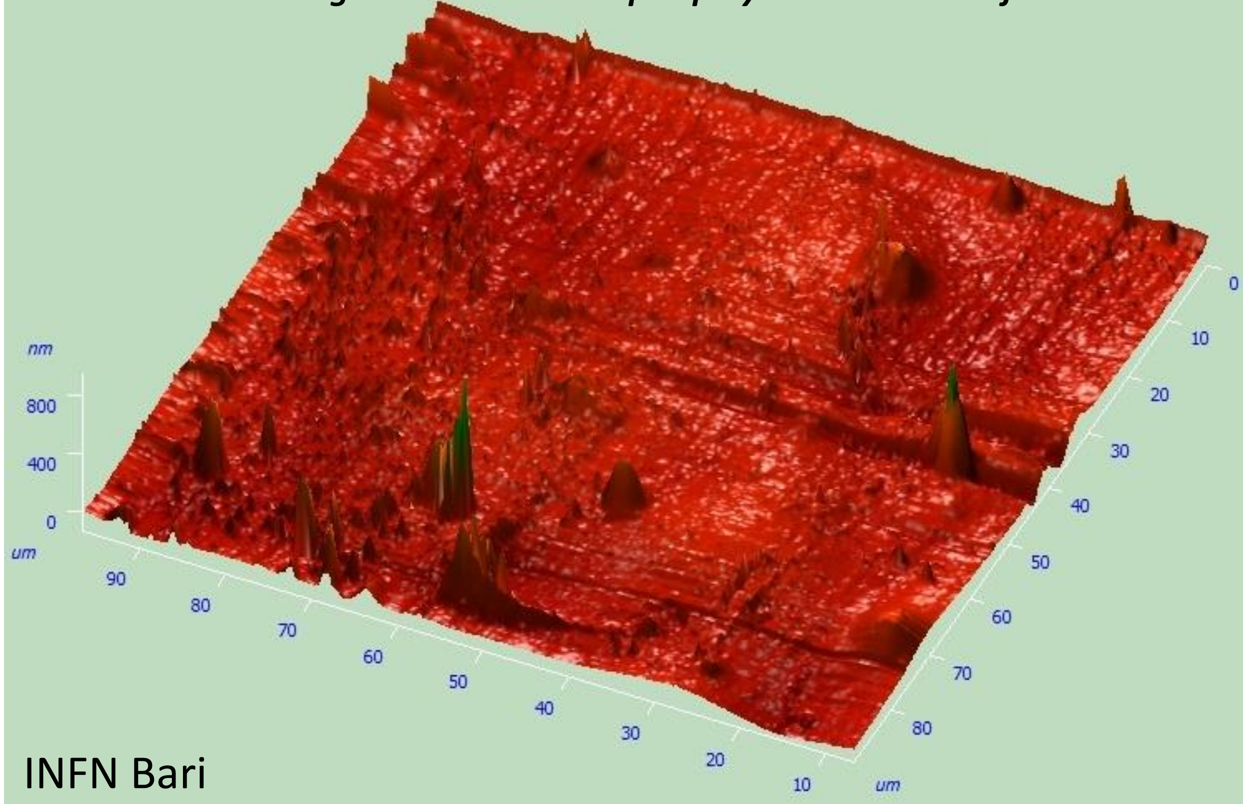
Water erosion effects: surface roughness measurement

A surface roughness measurement was carried out before and after the water erosion test on Polyimide:

The statistical average roughness, on an area of 100 x 90 µm^2 with 256 x 256 points is 34.94 nm.

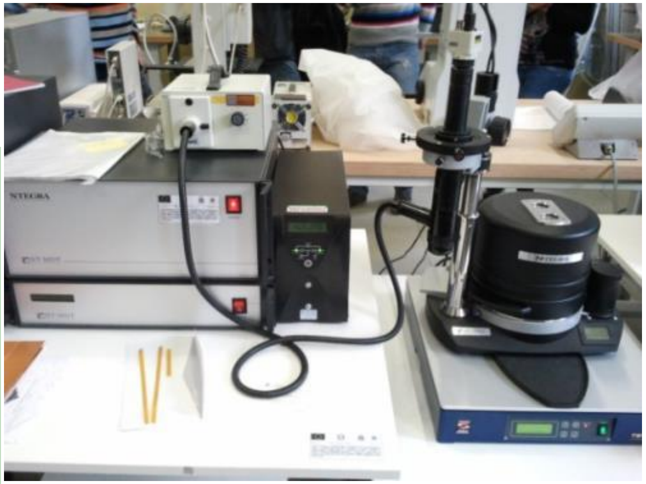
Measure after 10 months of testing : no difference on the average value

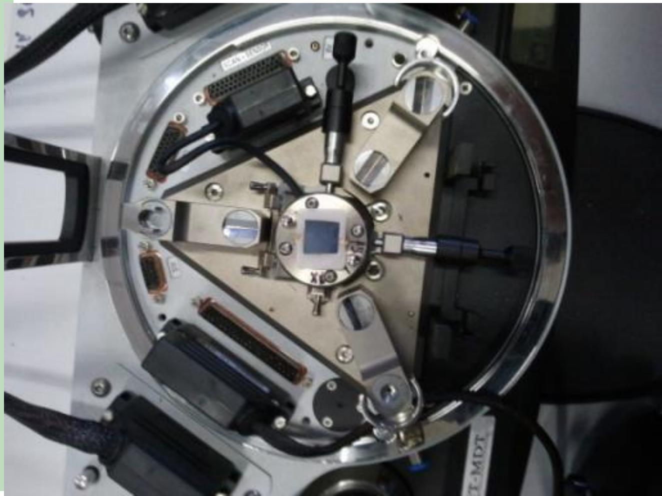
3D reconstructed roughness on 100 x 90 µm^2 polyimide MCHS surface



INFN Bari

Atomic Force Microscope



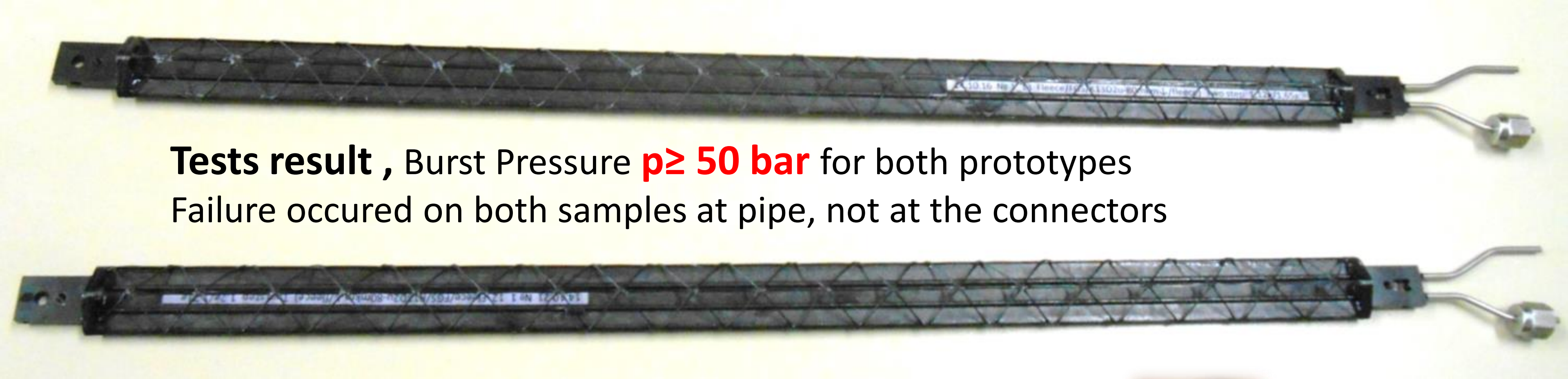


STAVE Mechanics and Cooling

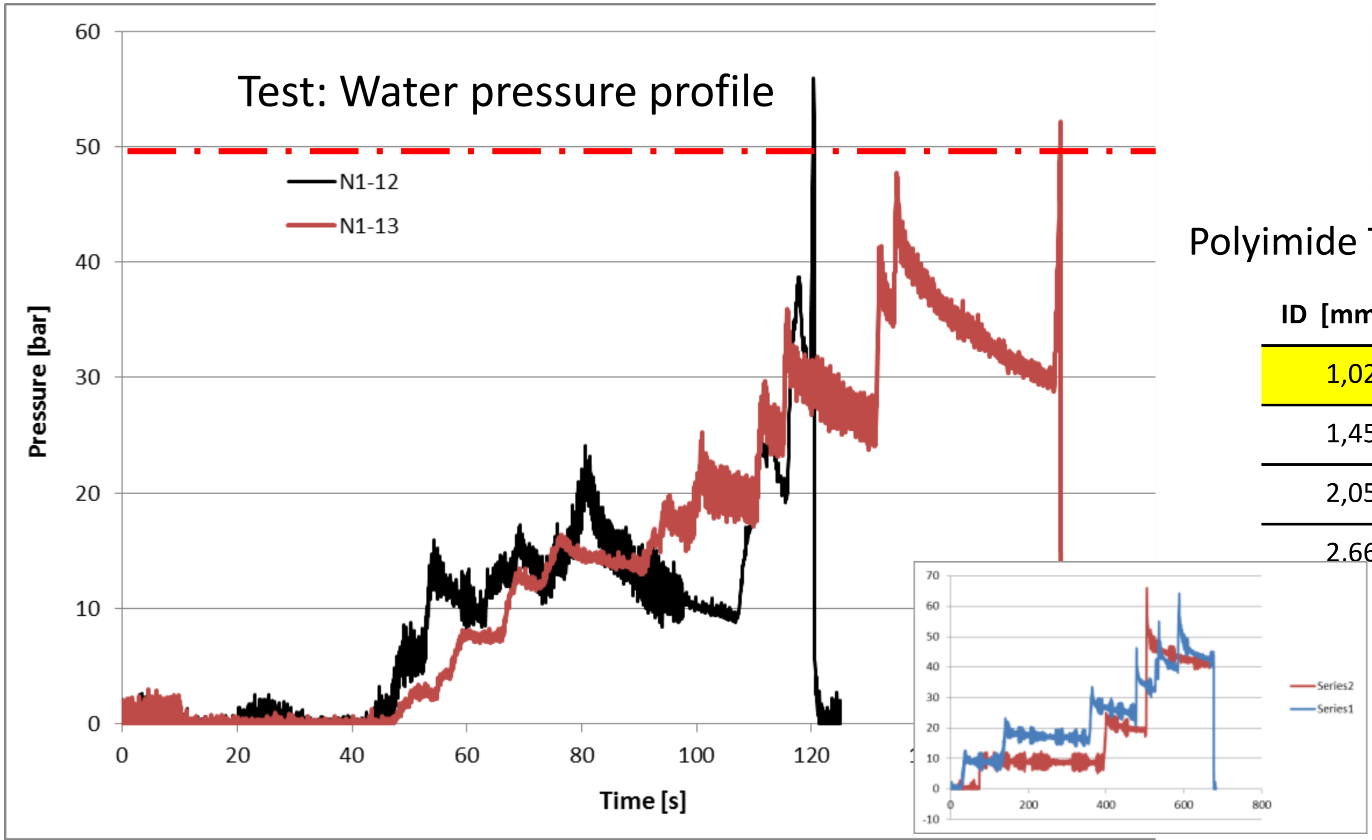
✓ mechanical characterization

Pressure test

Pressure test



Tests result , Burst Pressure **p≥ 50 bar** for both prototypes
Failure occured on both samples at pipe, not at the connectors



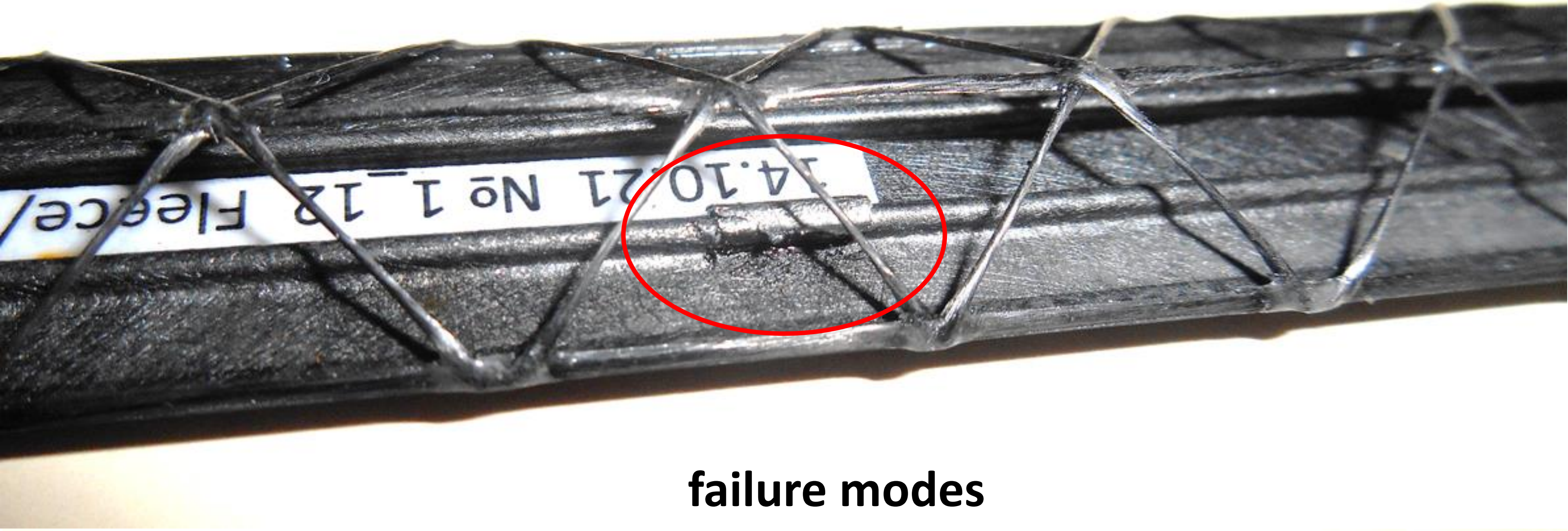
by design

Polyimide Tubing Pressure resistance

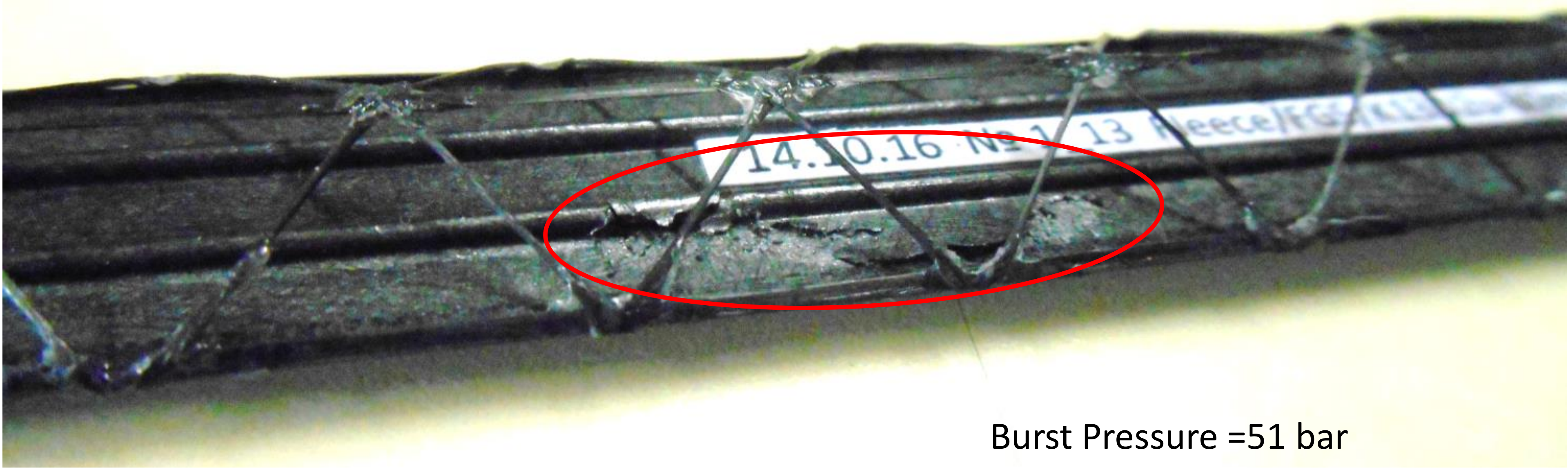
ID [mm]	Wt [mm]	P [bar]
1,024	0,0254	40
1,450	0,032	35
2,050	0,032	25
2.667	0,0635	38

Closed circuit= presssure losses due to internal pump circuit

Pressure test



failure modes



Burst Pressure =51 bar

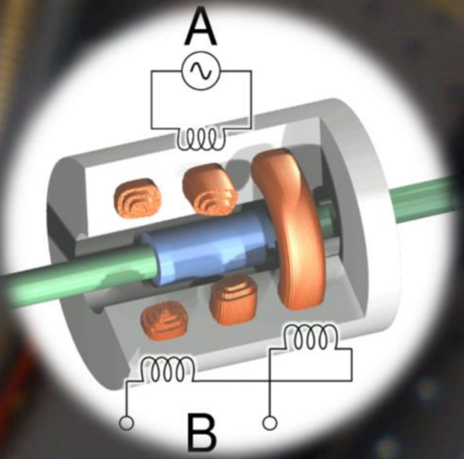
STAVE Mechanics and Cooling

- ✓ **thermo elastic characterization**

thermoelastic characterization

measured by LVDT

An LVDT Displacement Transducer comprises a primary (A) and two secondaries (B) coils

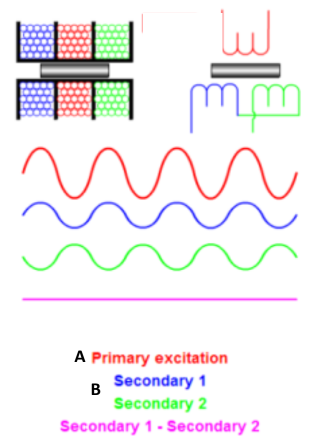


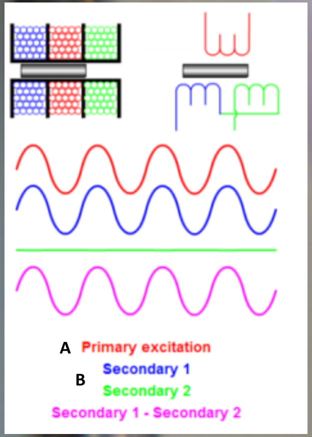
The transfer of current between the primary and the secondaries of the LVDT displacement transducer is controlled by the position of a magnetic core

The magnetic core is in contact with the specimen.

Specimen thermoelastic deformation induce a displacement of the magnetic core

Dilatometer DIL 402 E





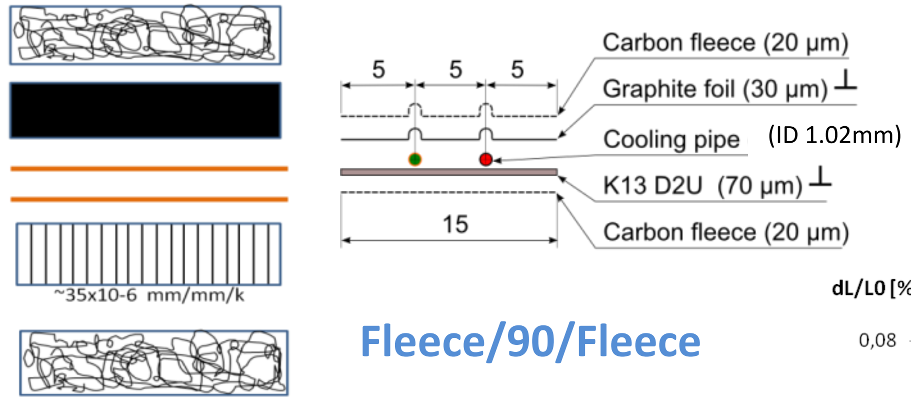
Mechanical Measurements Laboratory

EN-MME-EDM

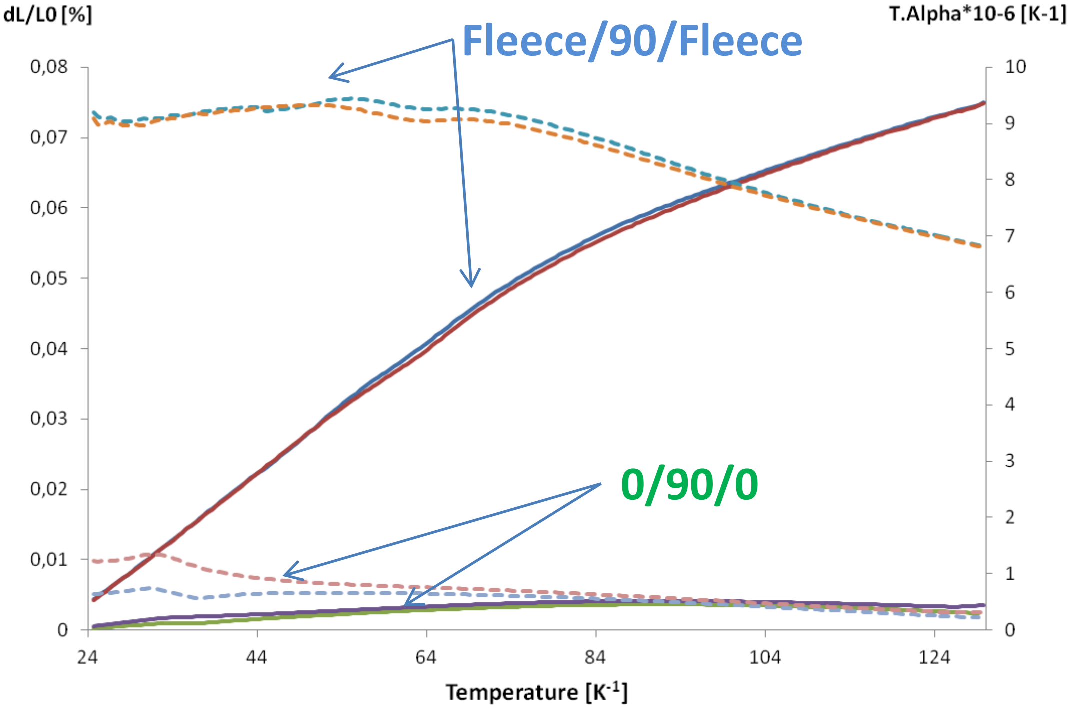
thermoelastic characterization

Baseline stave layout

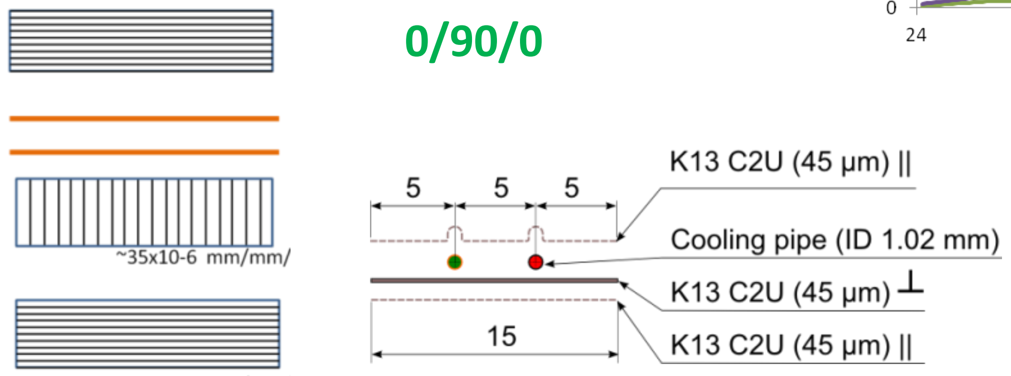
CTE< $10*10^{-6}$ [K^{-1}]



Fleece/90/Fleece



0/90/0



Alternative option to reduce CTE

CTE= $0*10^{-6}$ [K^{-1}]

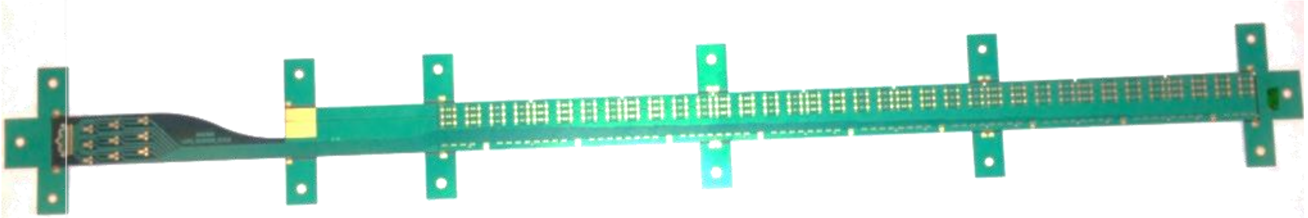
STAVE
assembly

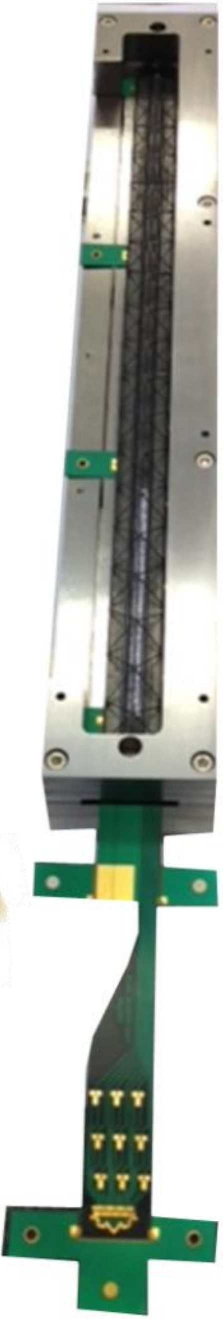
Stave assembly

HIC gluing to spaceframe

HIC=FPC+ soldered dummy CHIPs with pads

✓ **Precise alignment** defined by accurate jig and assembly procedures

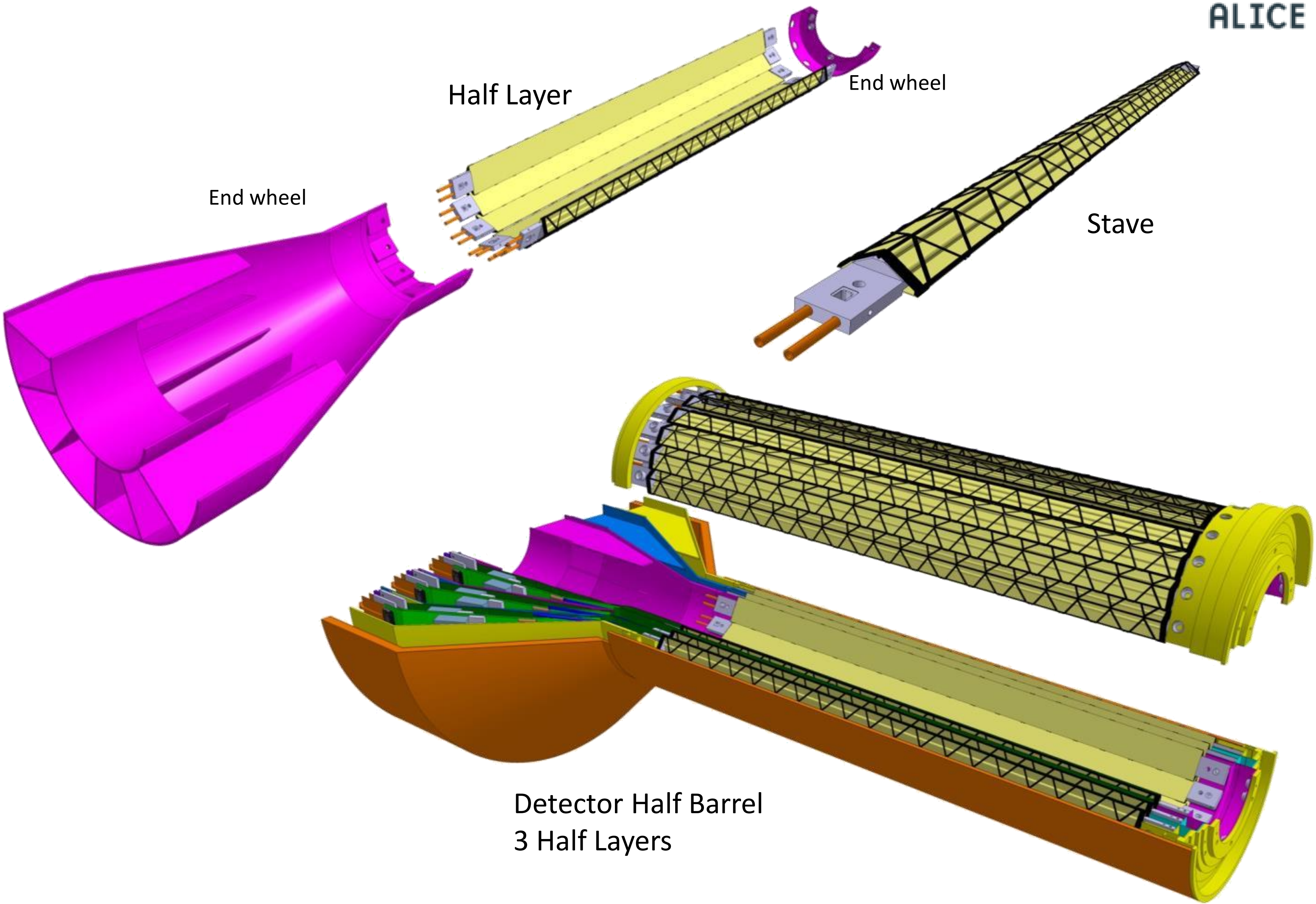




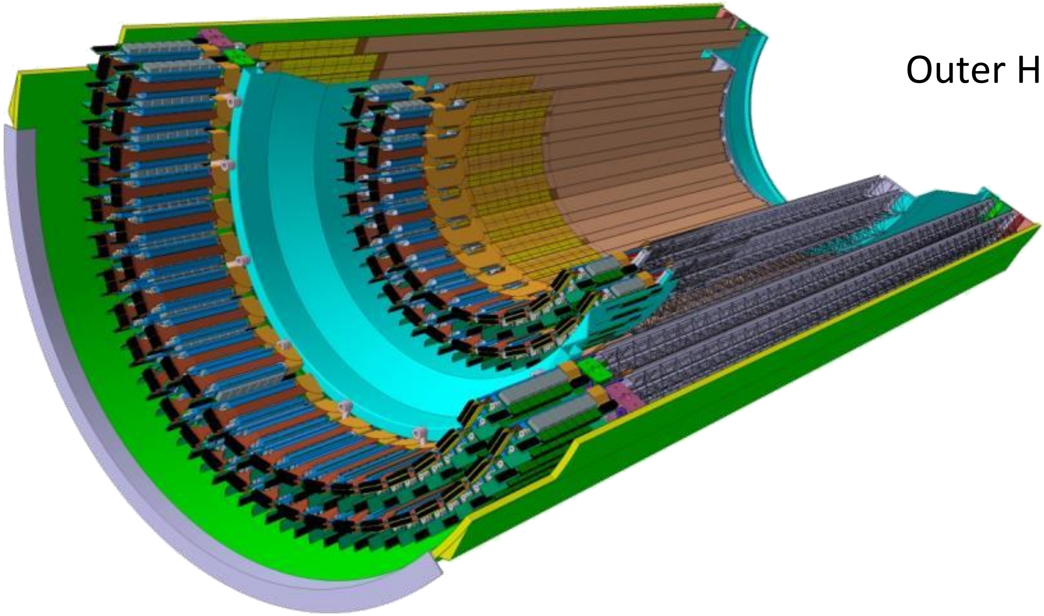
✓ **non-rigid bond** preferred to minimize possible structure bending deformation due to differential thermal deformation
Eccobond 45/ catalyst 15 (100/100) semirigid formulation

LAYERS and BARRELS

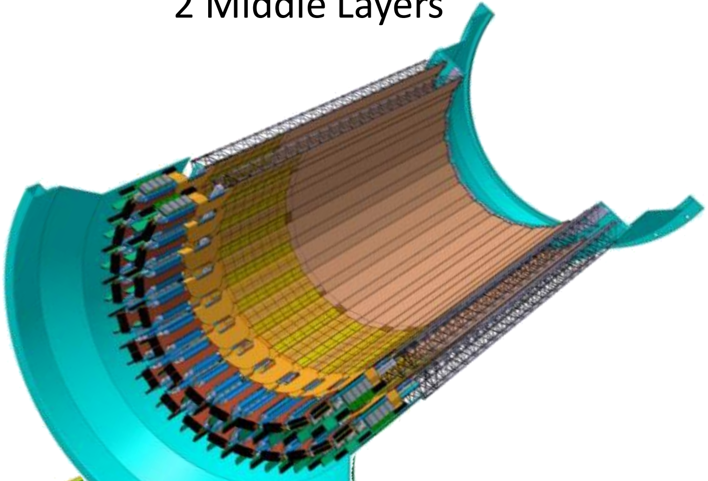
Inner Barrel layers and barrel



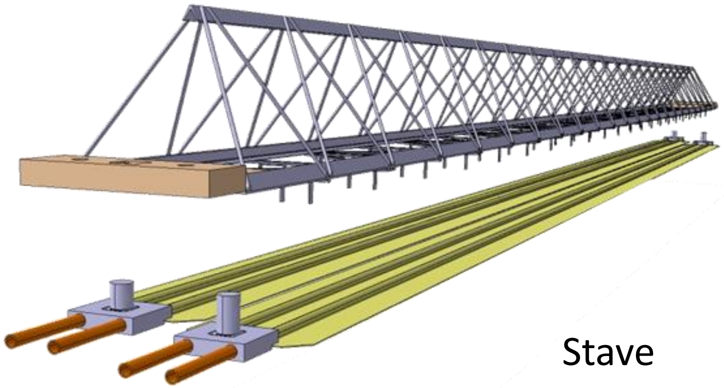
Outer Barrel layers and barrel



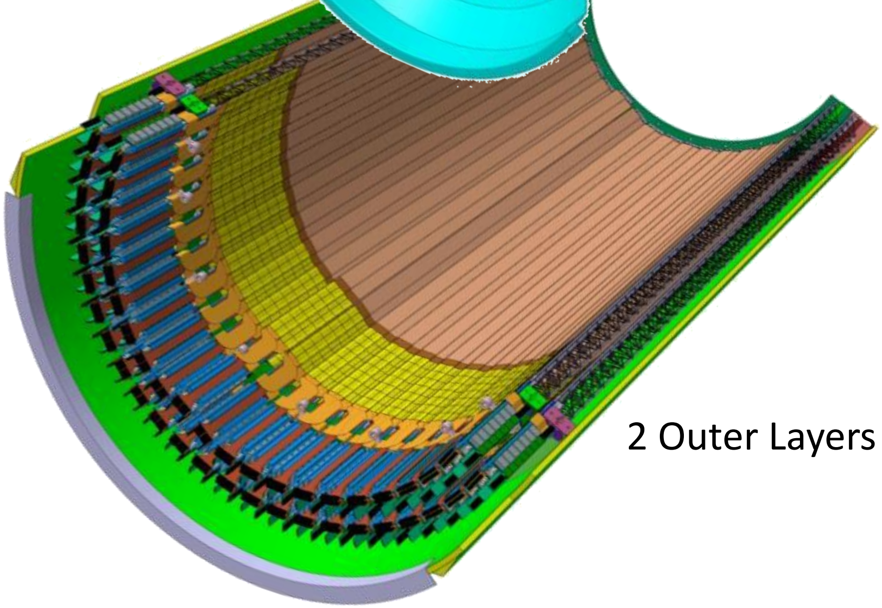
Outer Half Barrel



2 Middle Layers

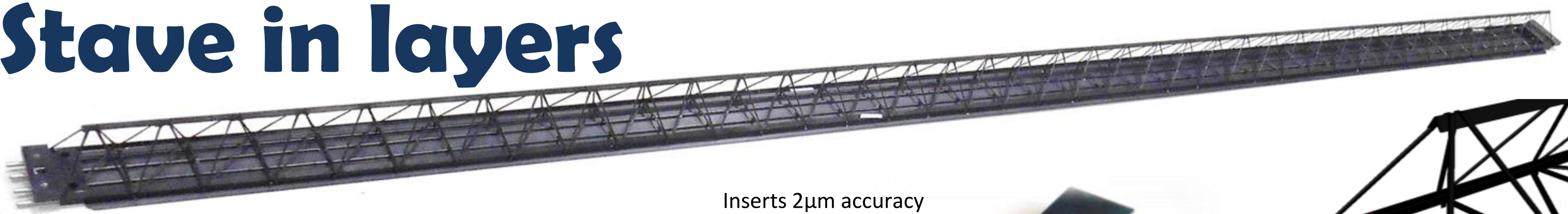


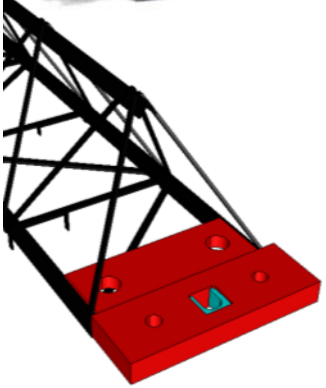
Stave



2 Outer Layers

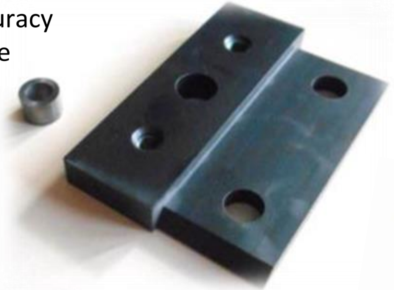
Stave in layers

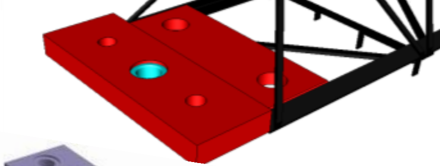




Carbon peek

Inserts 2µm accuracy
tungsten carbide

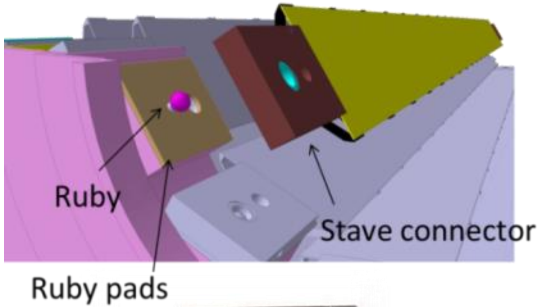


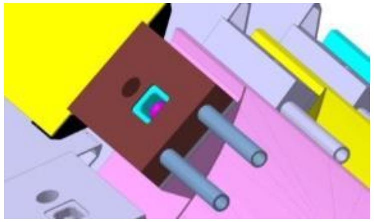


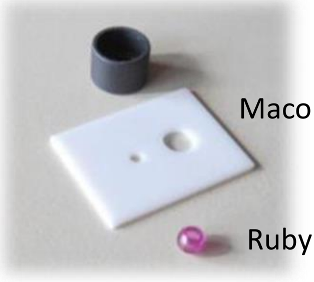
Outer Barrel stave

Inner Barrel stave

Precise locating ruby sphere and inserts







Carbon peek

Inserts 2µm accuracy
tungsten carbide

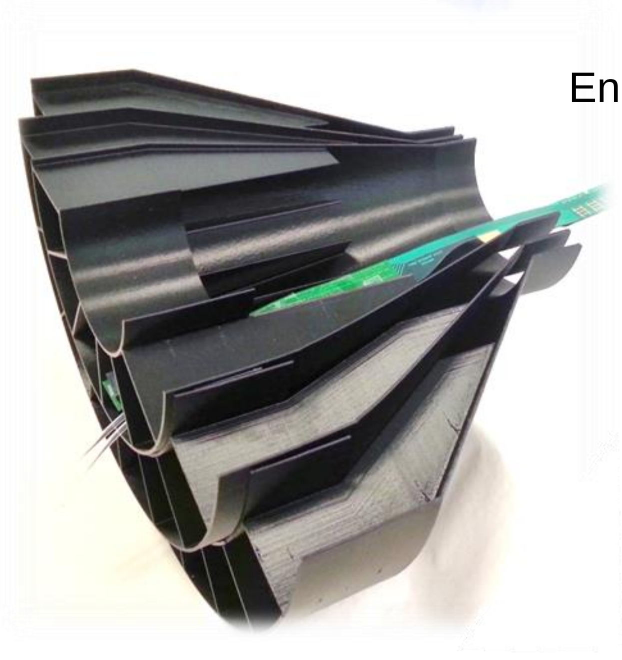
IB layers and barrel prototype

Cylindrical Structural Shell

Layer 0

Layer 1

Layer 2

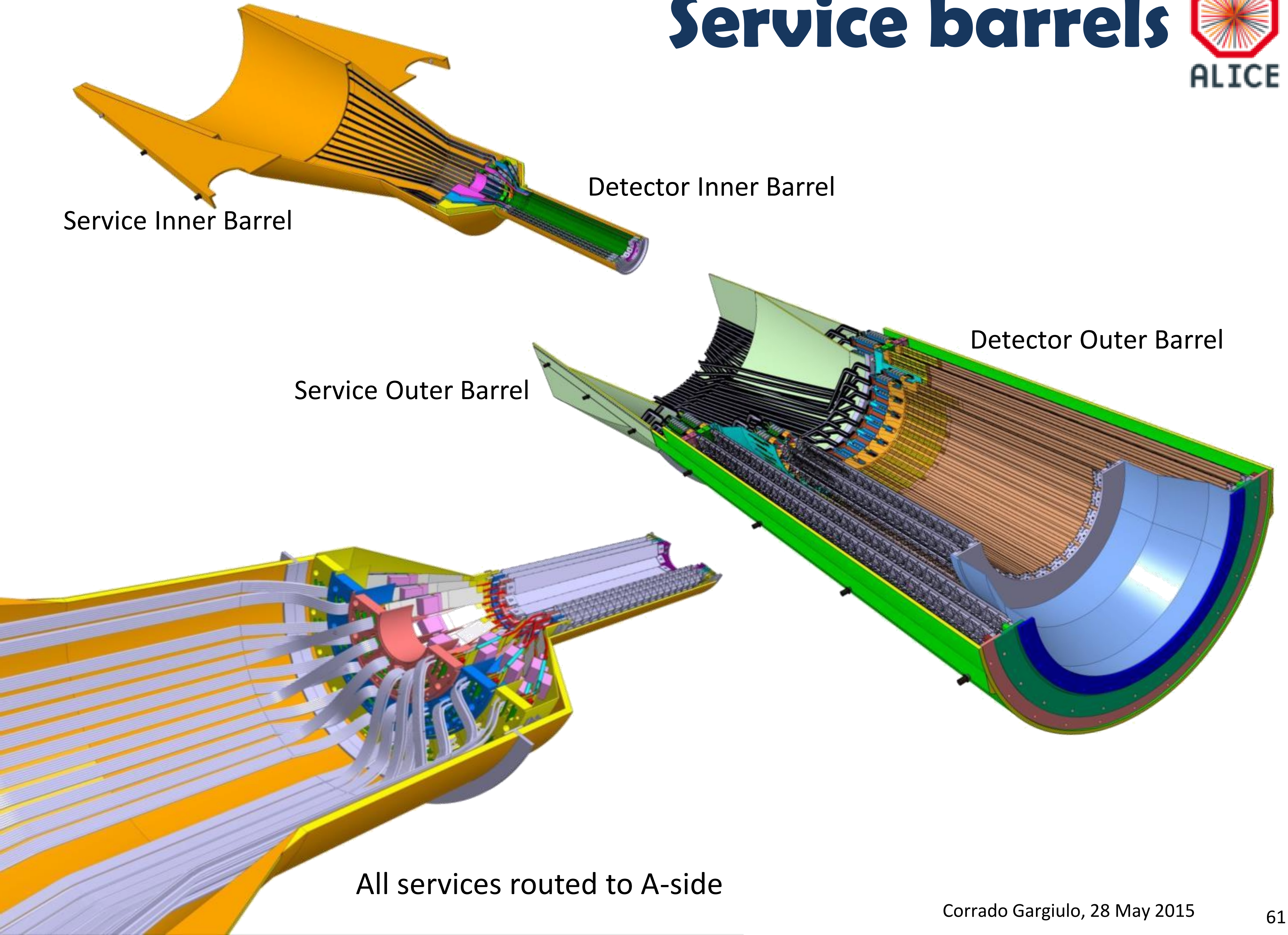


End wheel

Half Barrel

Stave

Service barrels



Detector Inner Barrel

Service Inner Barrel

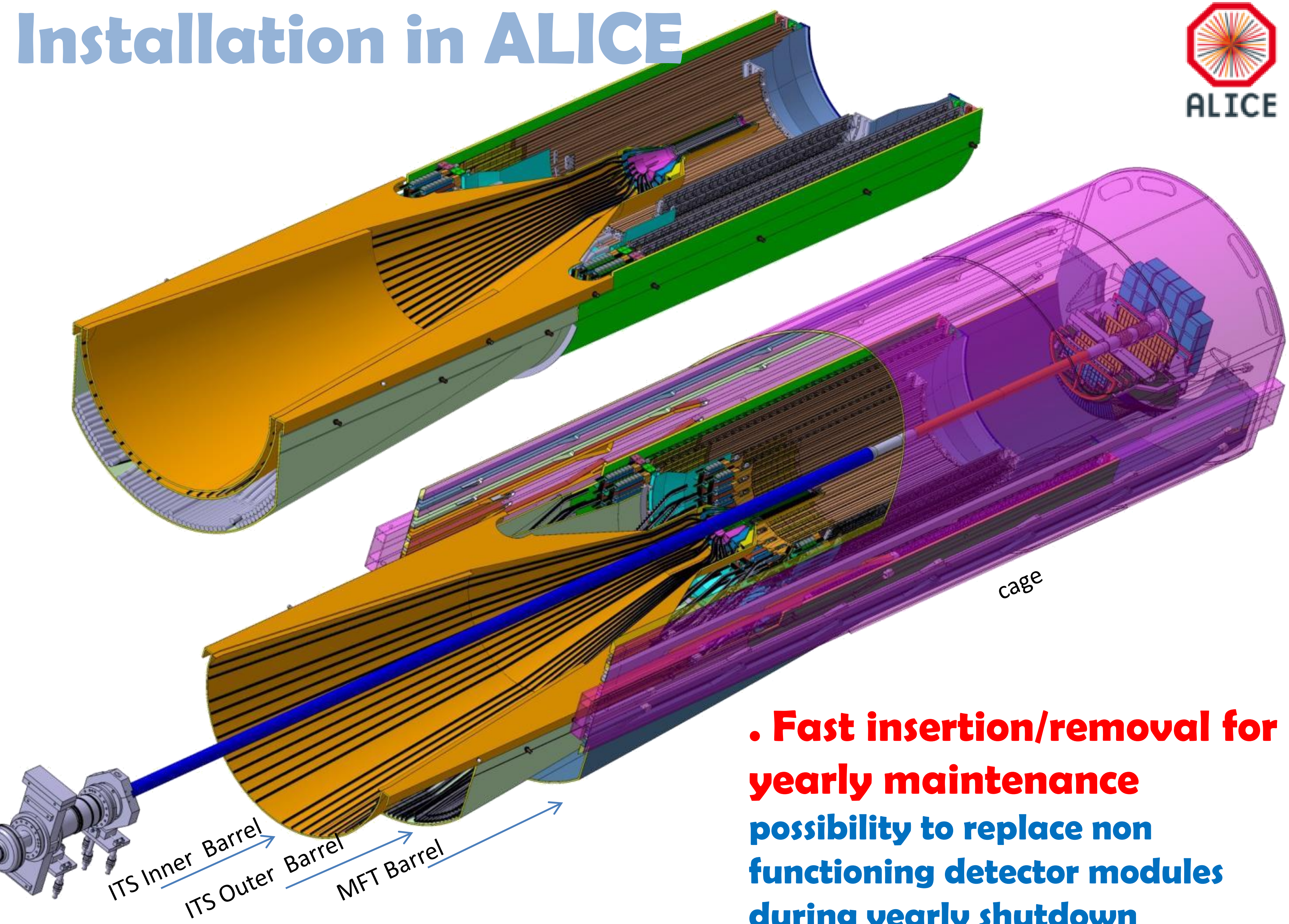
Detector Outer Barrel

Service Outer Barrel

All services routed to A-side

Installation in ALICE

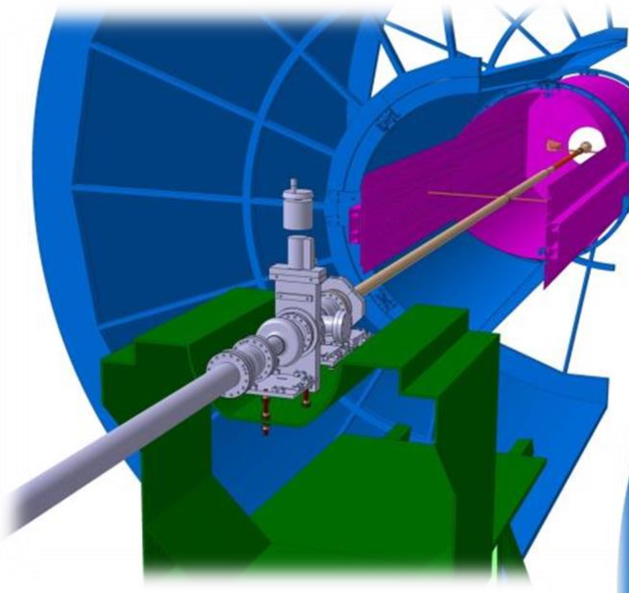
Installation in ALICE



. Fast insertion/removal for yearly maintenance

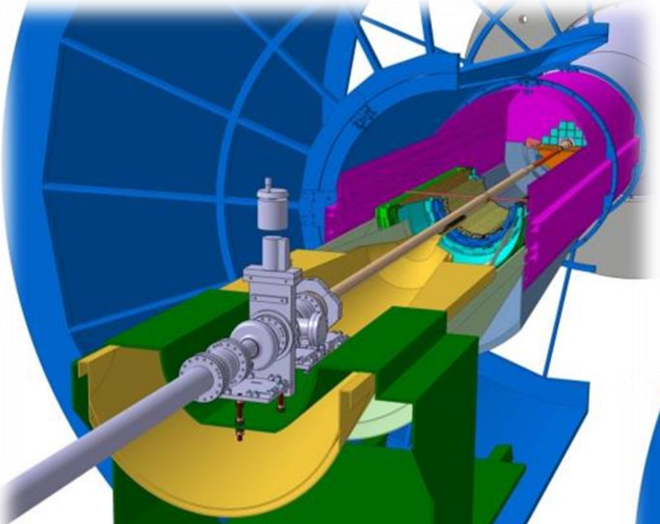
possibility to replace non functioning detector modules during yearly shutdown

Installation in ALICE

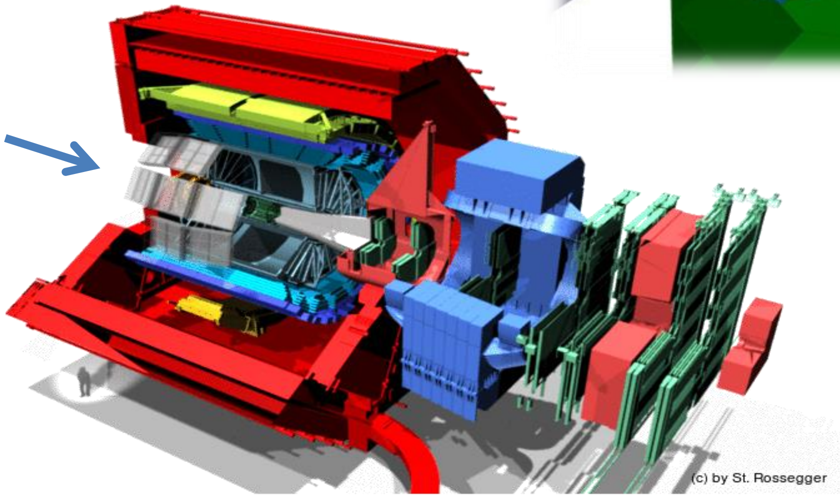


- The cage is inserted in the TPC bore
  The cage support in position the beam pipe

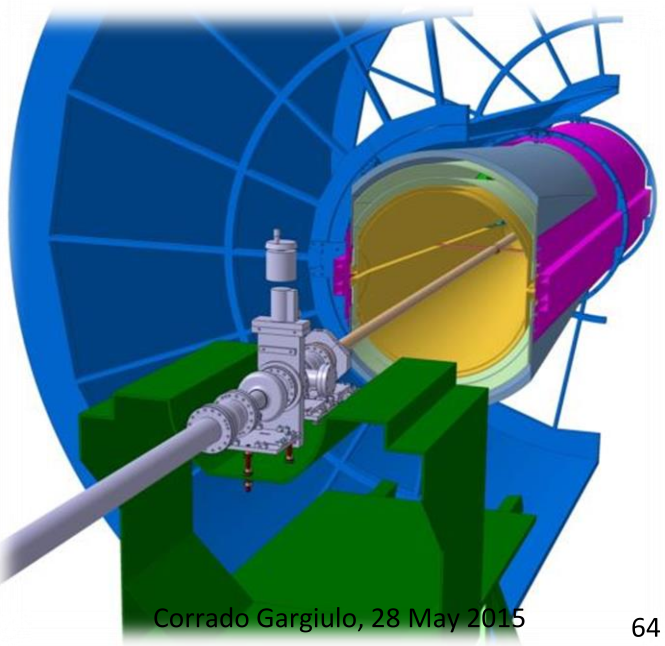
•ITS Outer Barrel, and ITS Inner Barrel are inserted in the cage, one half barrel at the time



•The detector barrels and the BP realtive position is guaranteed by the cage



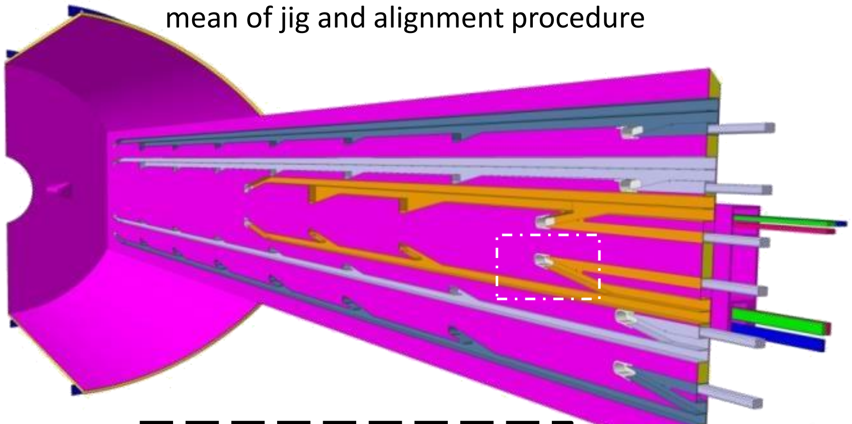
(c) by St. Rossegger

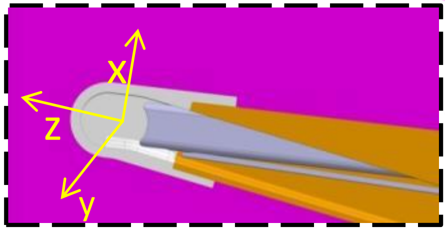


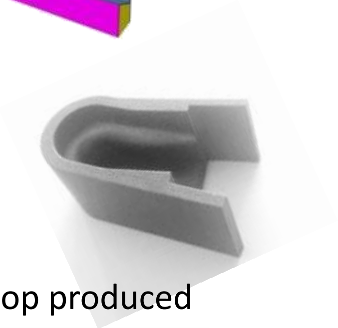
Cage

rails

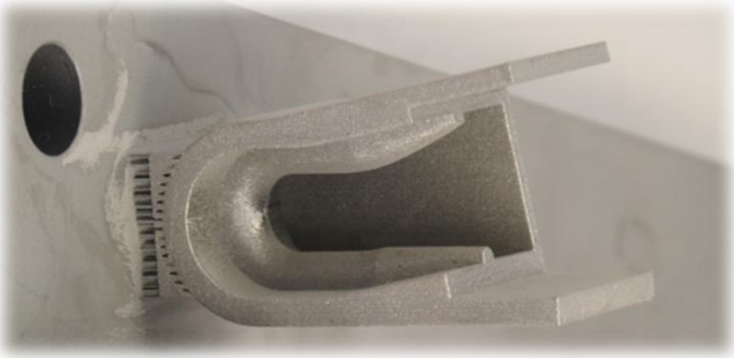
Rails end-stop, providing detector final position, are glued in the cage in a precise relative position by mean of jig and alignment procedure



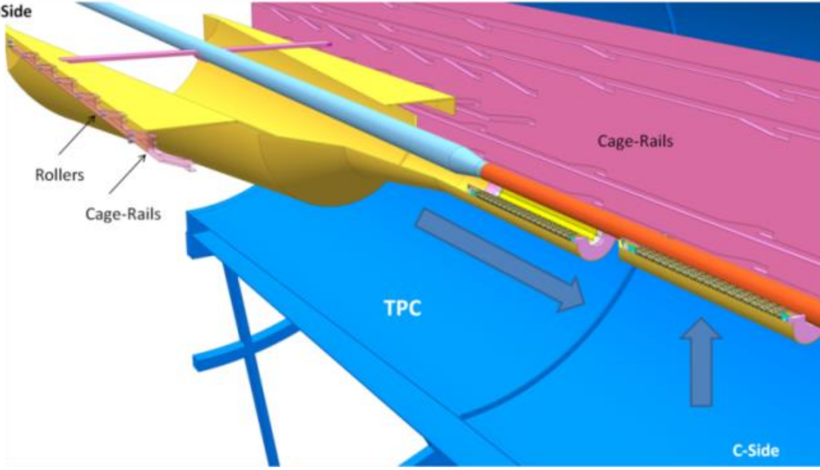




3D Printed prototype of rail end stop produced



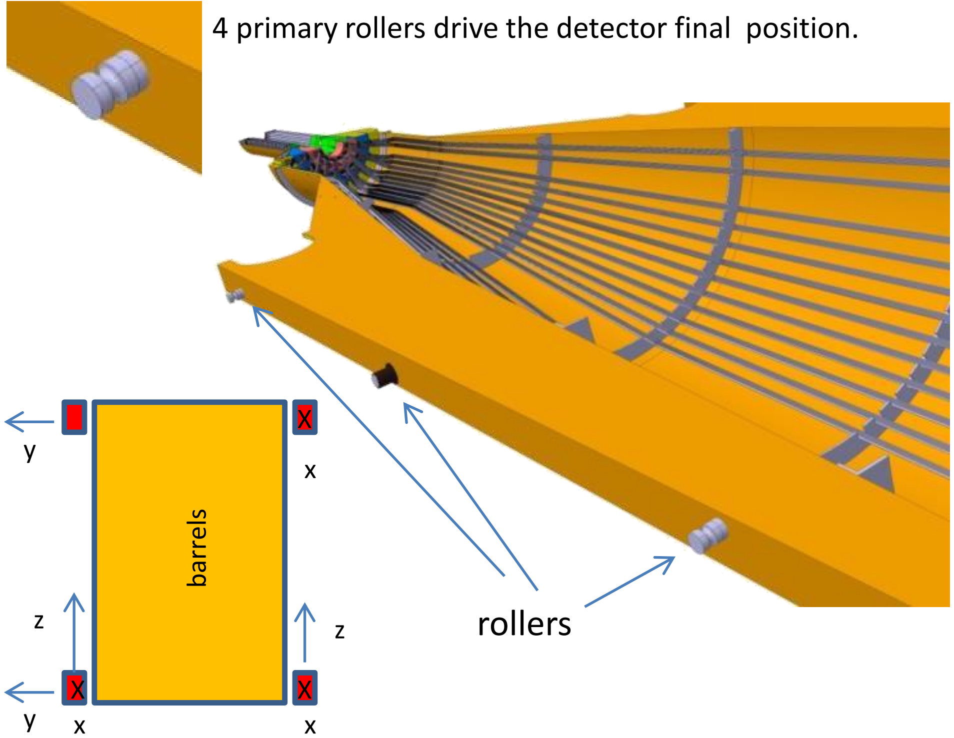
prototype: Titanium CL42Ti

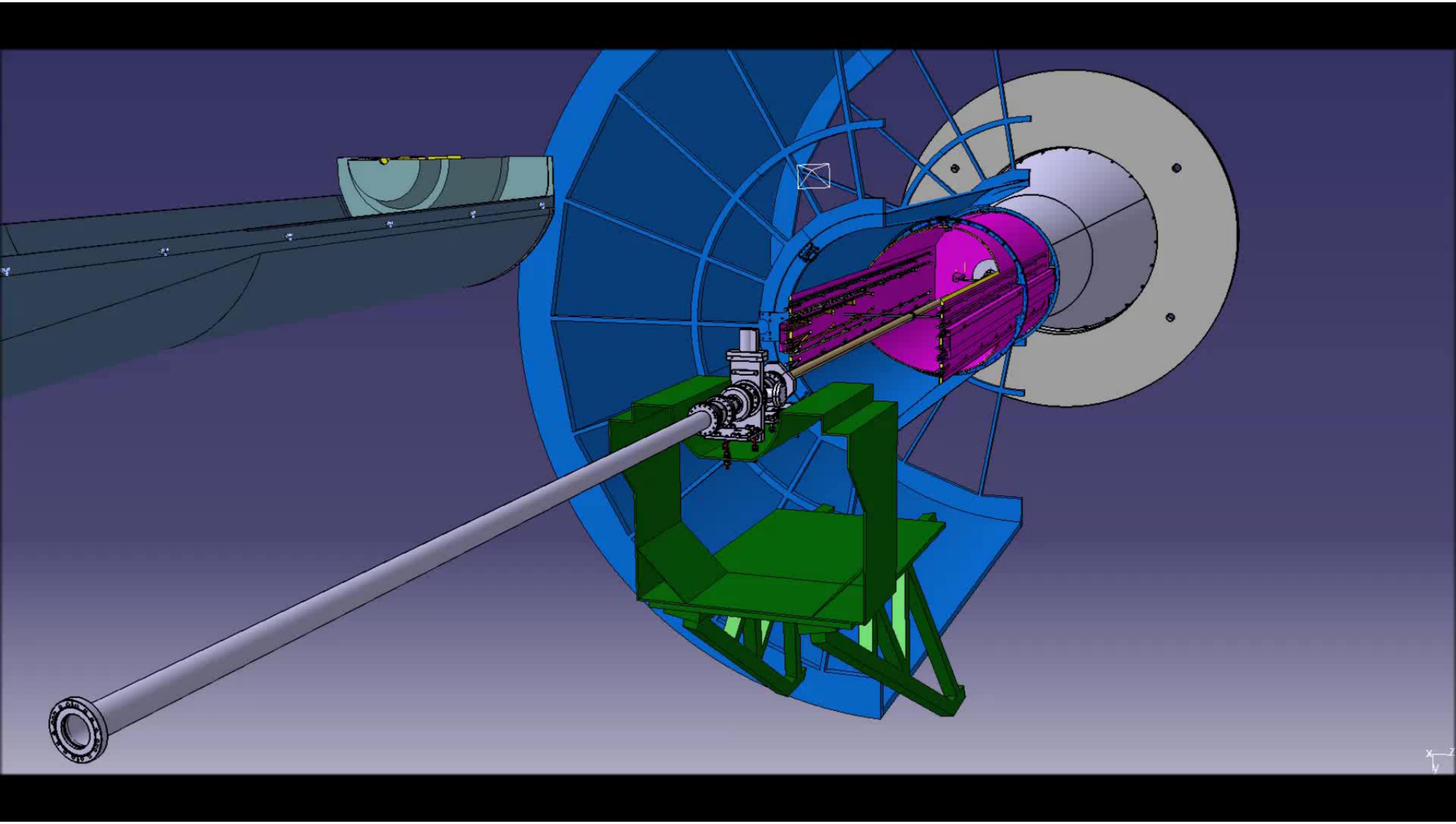


rollers

Rollers, engaging Cage rails, are aligned respect to the Detectors.

4 primary rollers drive the detector final position.





Insertion (and Removal)