Workshop Challenges on Additive Manufacturing for High Energy Physics
CERN, 5/11/14

Additive Manufacturing for Particle Detectors
POLYMERS

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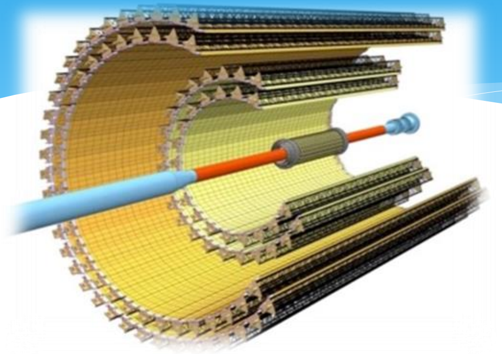
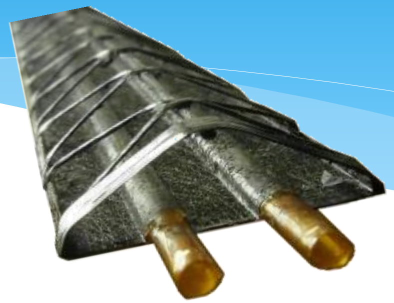
Structure of this 30’ block

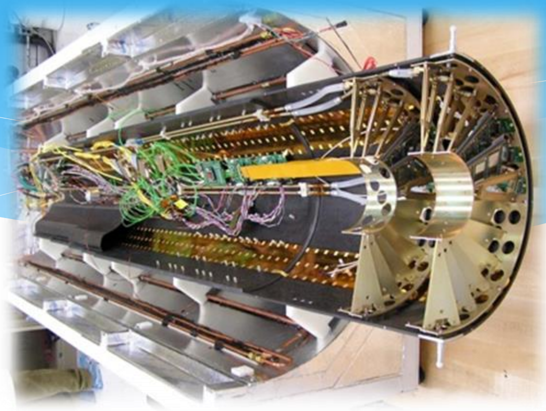
- **Rapid Prototyping for High Energy Physics**
  - High Energy Physics Environment
  - Range of Machines and Materials at CERN
  - Use Examples
    - Tooling
    - Prototypes
    - Functional parts

- **Challenges for Additive Manufacturing for Detector Technologies**
  - The Wish List
  - Breakthrough Technologies for the ALICE Inner Tracker System (ITS)

LHC Detectors' Environment







- Rad hard (several MGray)
- Large temperatures range (200°C, 20°C, -25°C, cryo regime)
- HV (1 - 30kV)
- Massless devices
- Material diversity (polymers, C-fiber materials, fiberglass, epoxy, light metals…)
- High accuracy (microm)
- Large dimensional range (micro to hundreds of meters)
- Full project cycles: prototypes to mass production

Polymer Printers at CERN Polymer lab

Project 4500
(Year 2014)

Accuracy : 0.1mm
Fast printing
Low cost
Multicolor

SLA® Viper si2 system
(Year 2013)

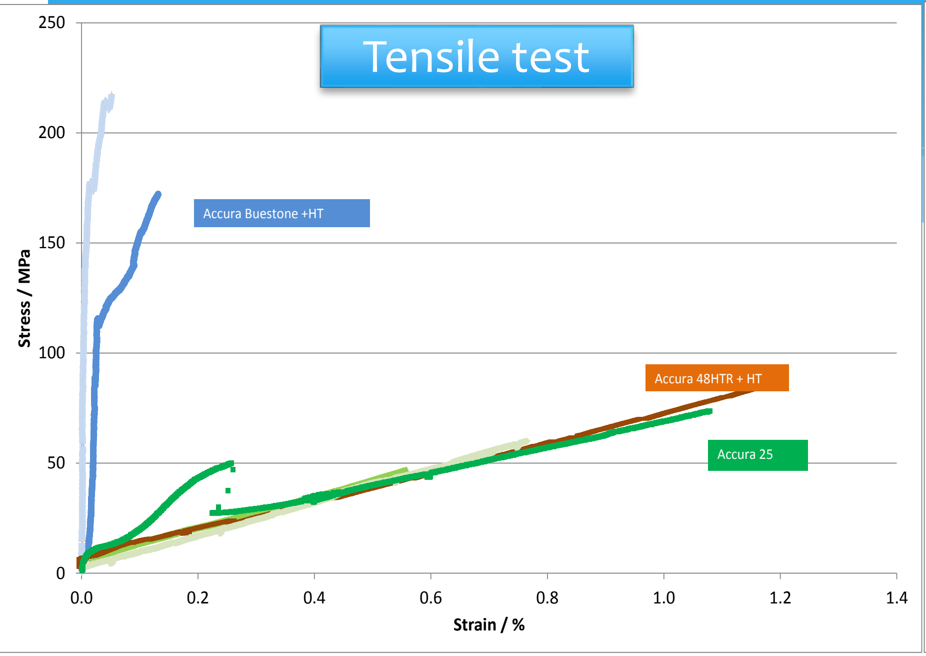
Accuracy 50 microns
3 resins available
Fast printing
Suitable Mechanical, Electrical, Cryogenic and Radiation Hardness resistance

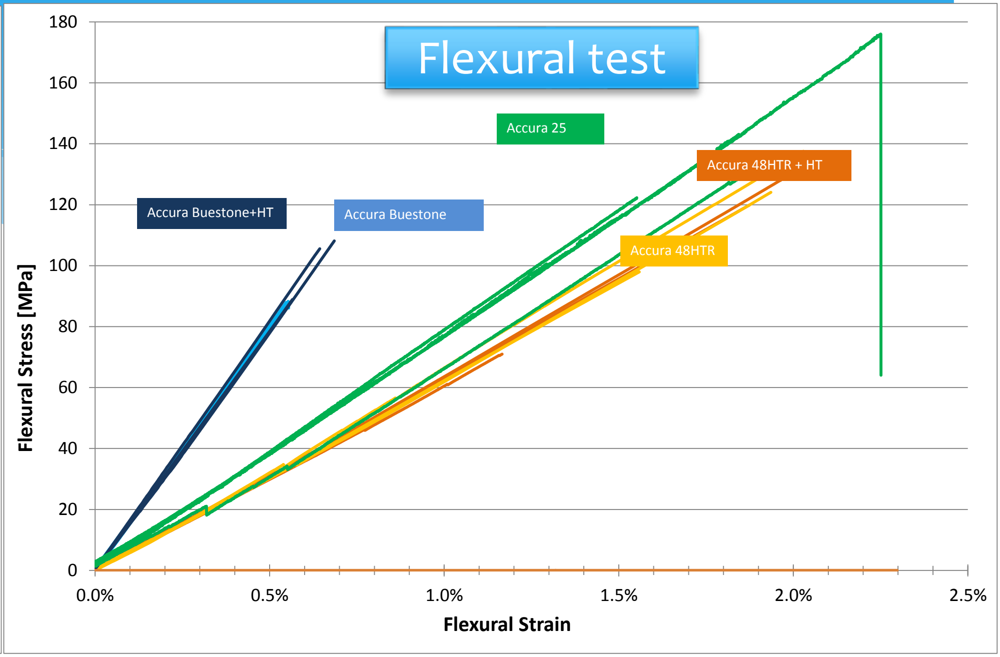
Polymer Printers at CERN

3d Dimension Elite (Fused Deposition Modeling)
Used since May 2013, ***~ 1200 hours***

- Material: ABS plus, different colors
- Deposition of soluble support
- Maxi part dimension: 203 x 203 x 305
- Layer thickness (Z movement): 0.178 or 0.254mm
- Solid part or «light» (massive external wall + structure like honey comb)
- Estimated accuracy: ~ +/- 0.1mm
- Mini thickness wall: 0.6mm

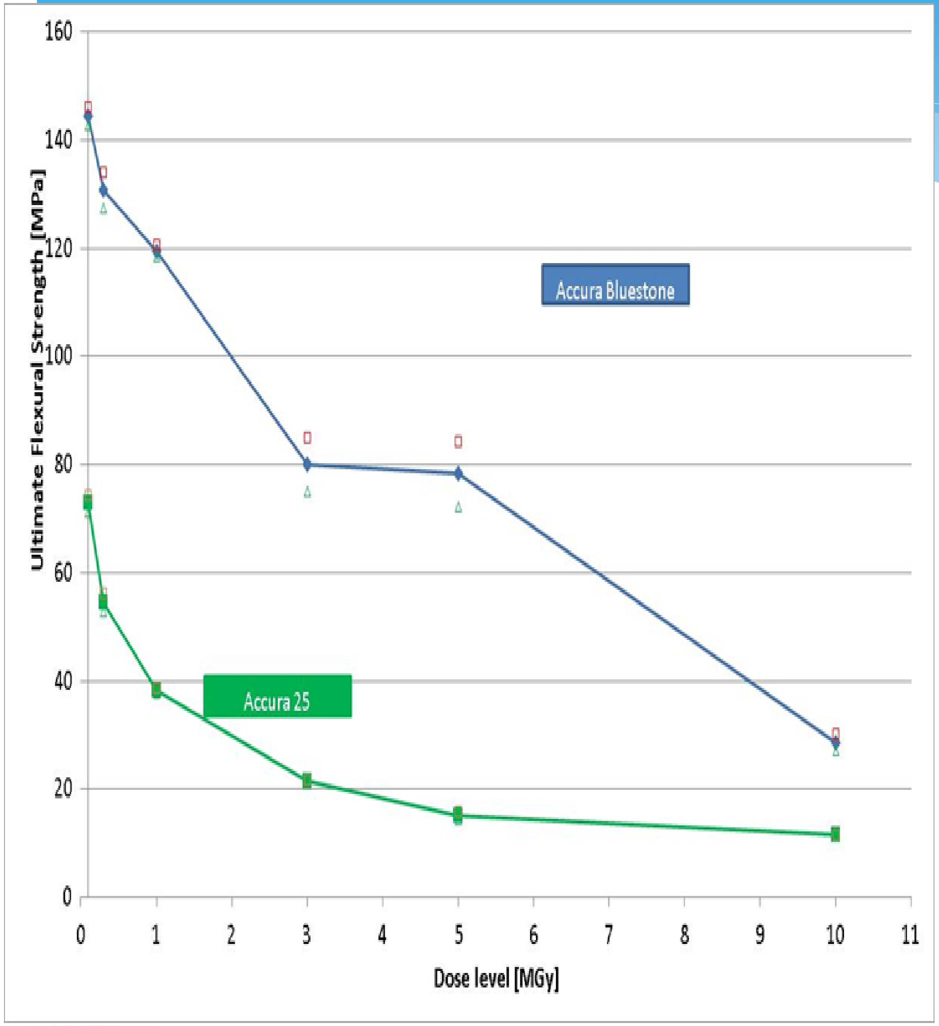
Mechanical test Properties 77K

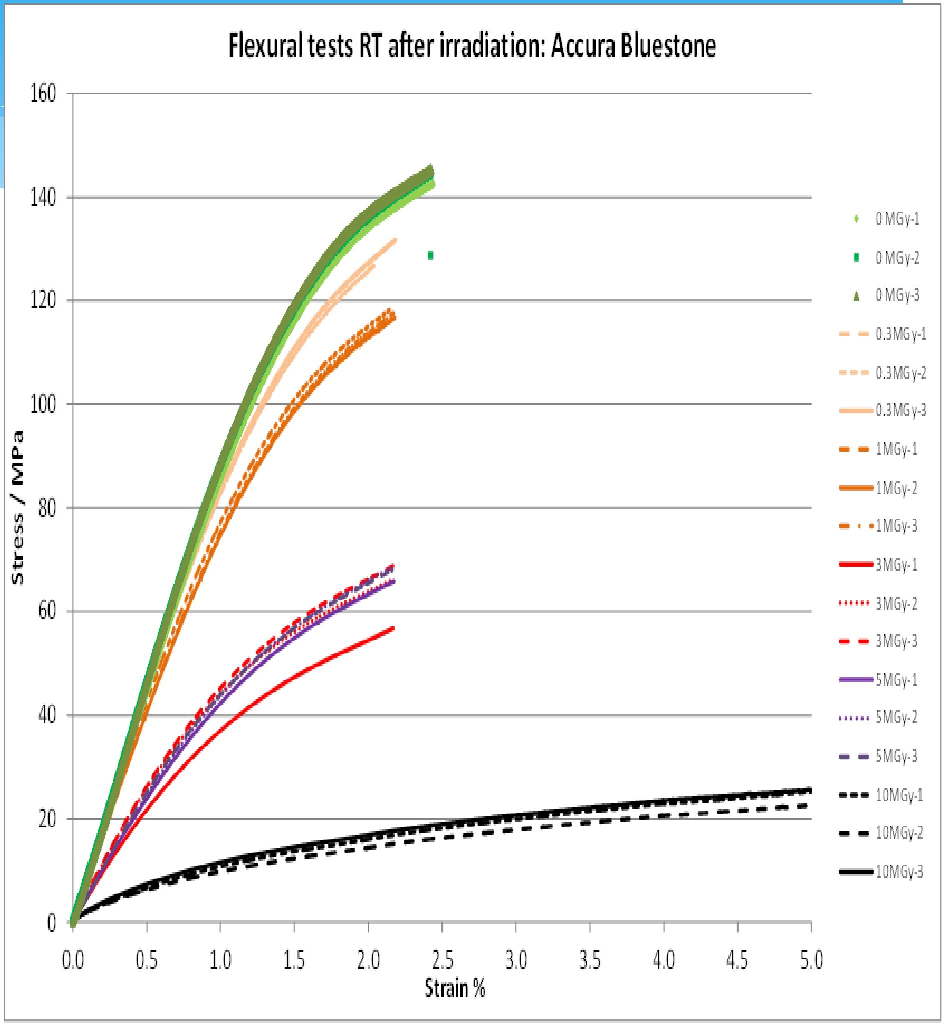




	Accura 25	Accura 48HTR	Accura 48HTR +HT	Accura Bluestone	Accura Bluestone +HT
Ultimate tensile strength [MPa]	70±8	NA	85	NA	190±25
Fracture tensile strain [%]	0.9±0.3	NA	1.2	NA	0.07±0.02
Ultimate flexural strength [MPa]	145±27	115±20	127±7	87±1	105±3
Fracture flexural strain [%]	1.9±0.35	1.8±0.2	2±0.1	0.53±0.03	0.8±0.03
Tensile E modulus [MPA]	8000±650	NA	7500±300	NA	15600±300

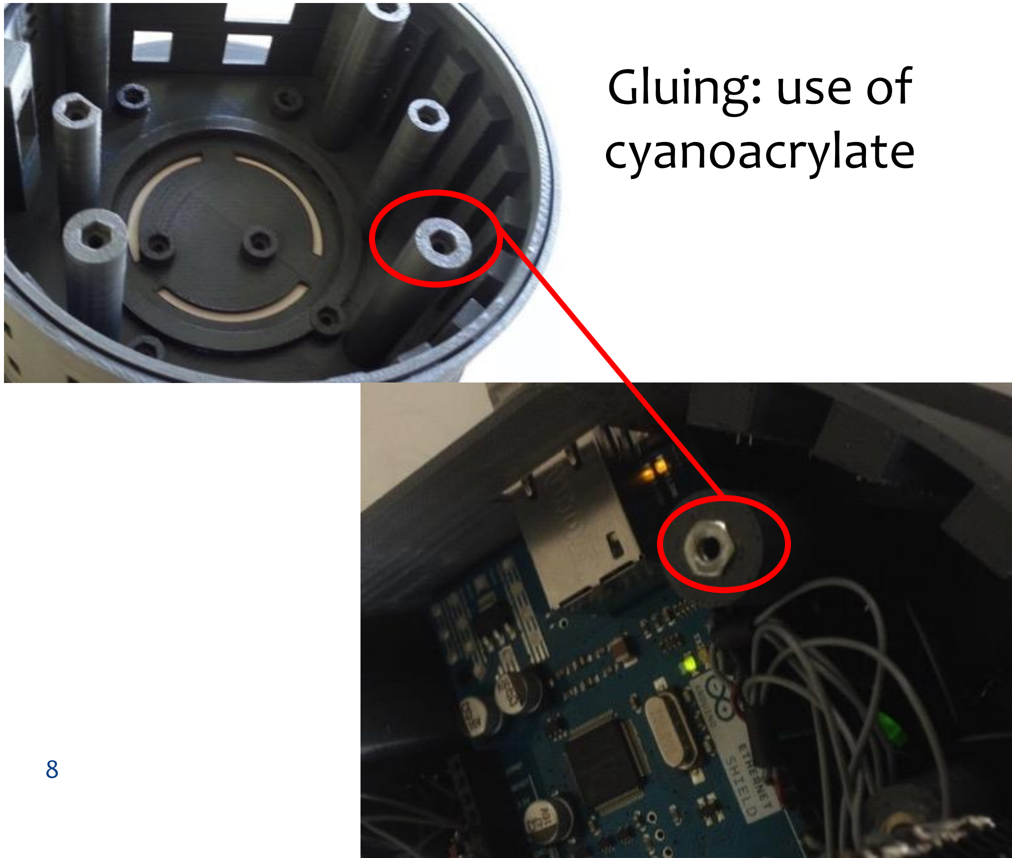
Radiation resistance materials test




Flexural tests RT after irradiation: Accura Bluestone

Research on Production Techniques

Threaded holes, holes machined, inserts…



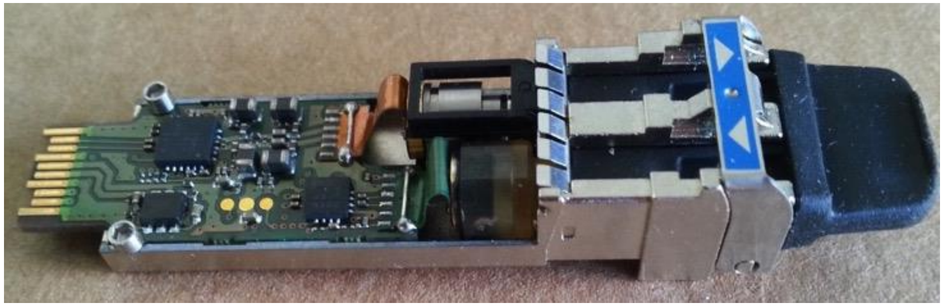
Gluing: use of cyanoacrylate

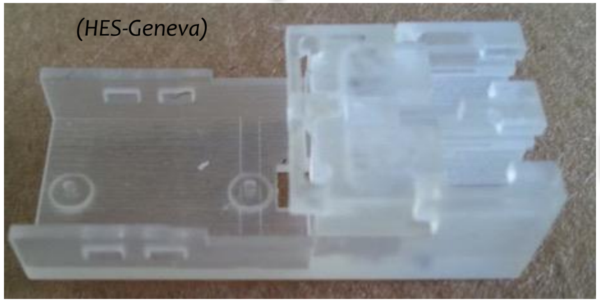
Use Examples
Opto-link Latch

Goal: Replacement of commercial metallic latch by low-mass ultem latch

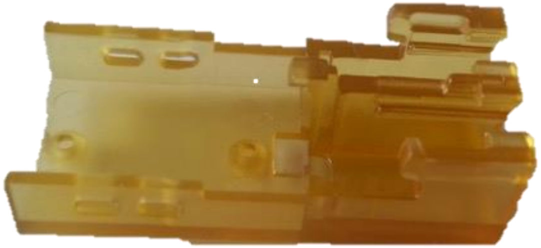
RP for **quick validation** of dimensional tolerances for final moulding process

Original Metallic latch





Final Ultem latch

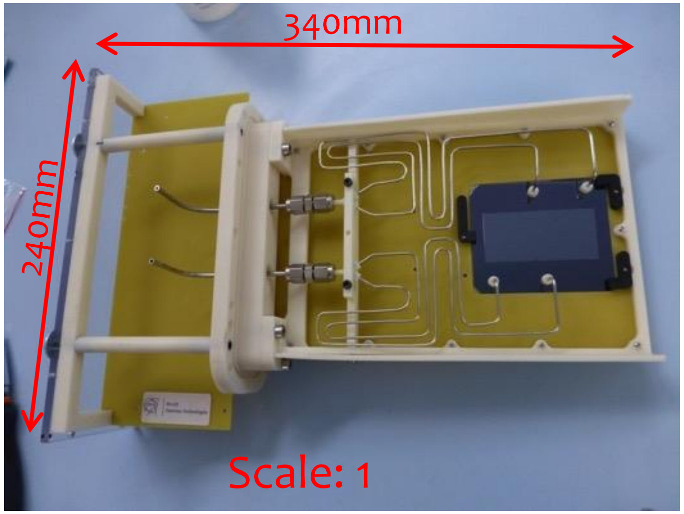


Use Examples: Tooling, Supports, Test fixtures

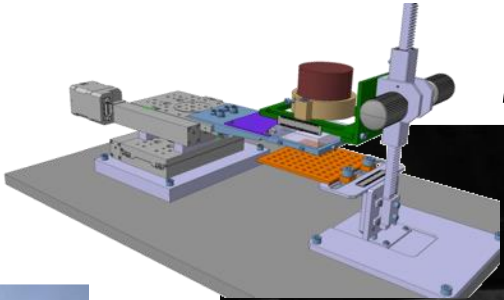
Achieved: Quick and cheap production of parts to enable tests of detectors assemblies and detector services and thus provide rapid feedback for final designs

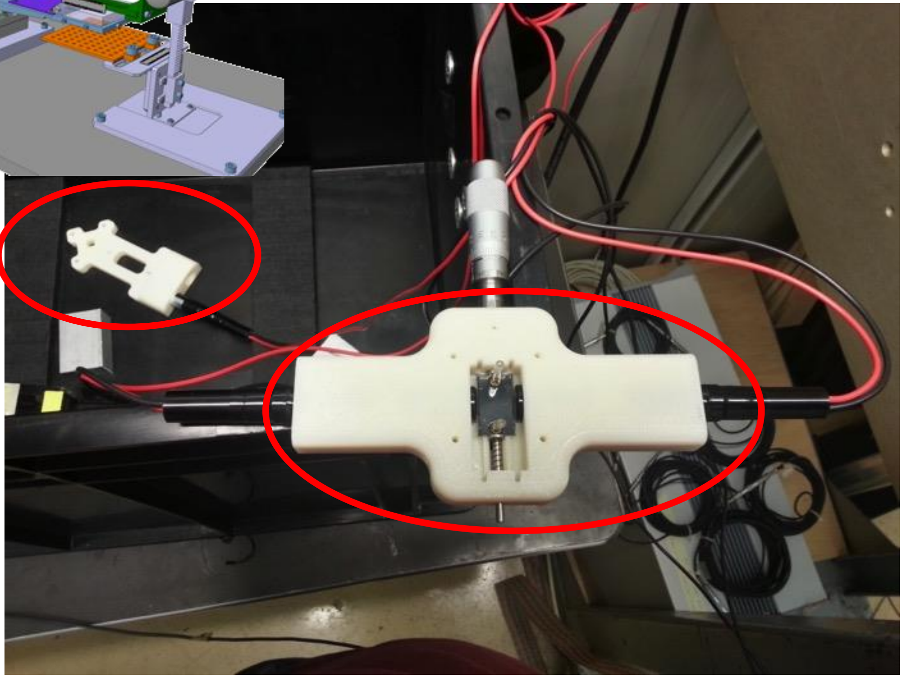
NA62 GTK Module

Sensor + microfluidic cooling plate + pipes + support



Microfluidic Scintillating detector

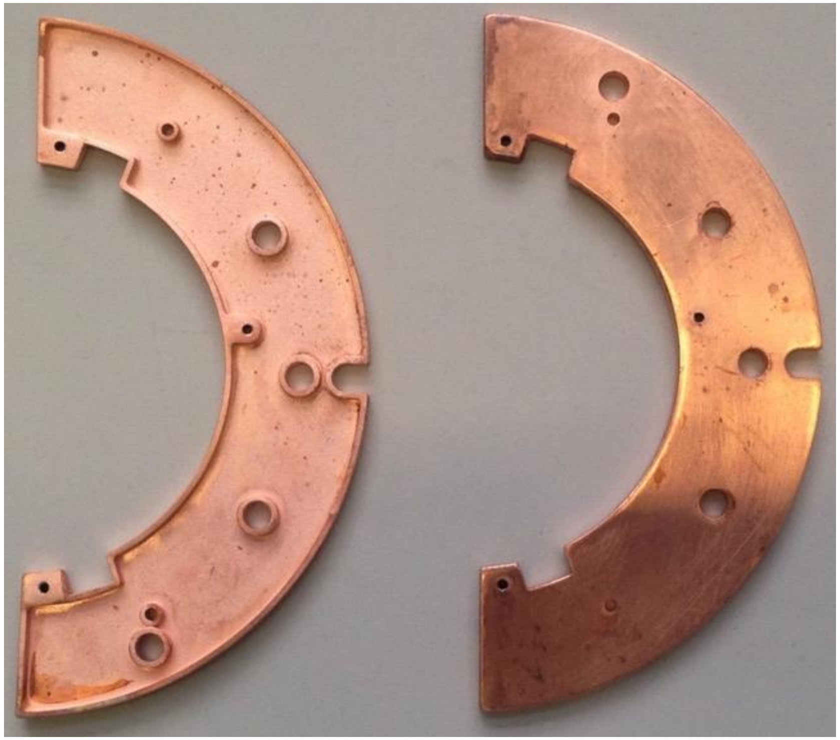




Use Examples: Functional Parts

PCB support covered by 10µm copper layer

Resin Accura Bluestone (resin with ceramic filler) because of radhard environment. Copper deposition is a first.

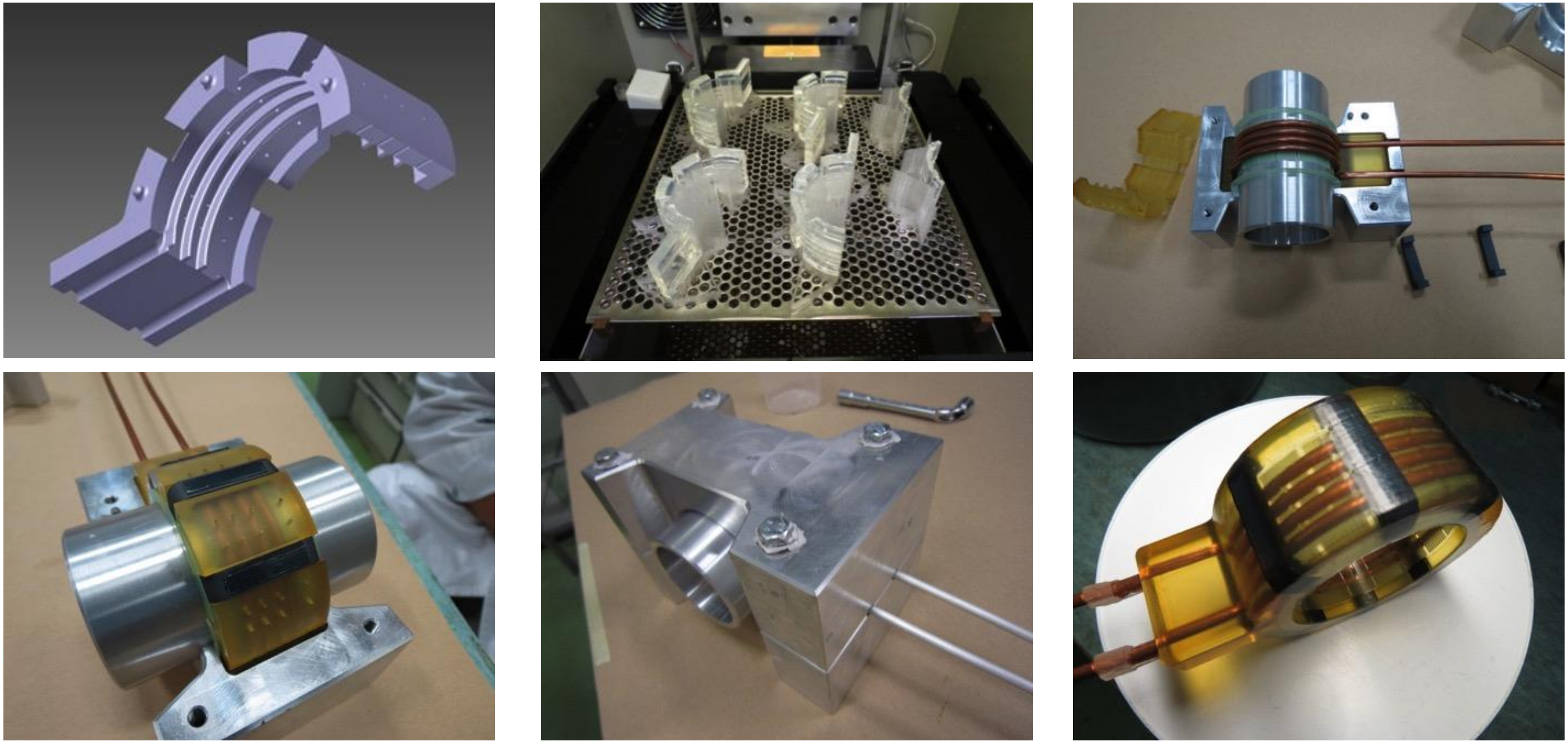


Use Examples: Functional Parts

RF Antenna For LINAC4 Ion Source

2 Supports made in 3D epoxy resin to replace 11 components previously machined in G11, Assembly, Epoxy vacuum impregnation, and demoulding

Achieved: gain in time, cost, assembly simplicity, and final performance

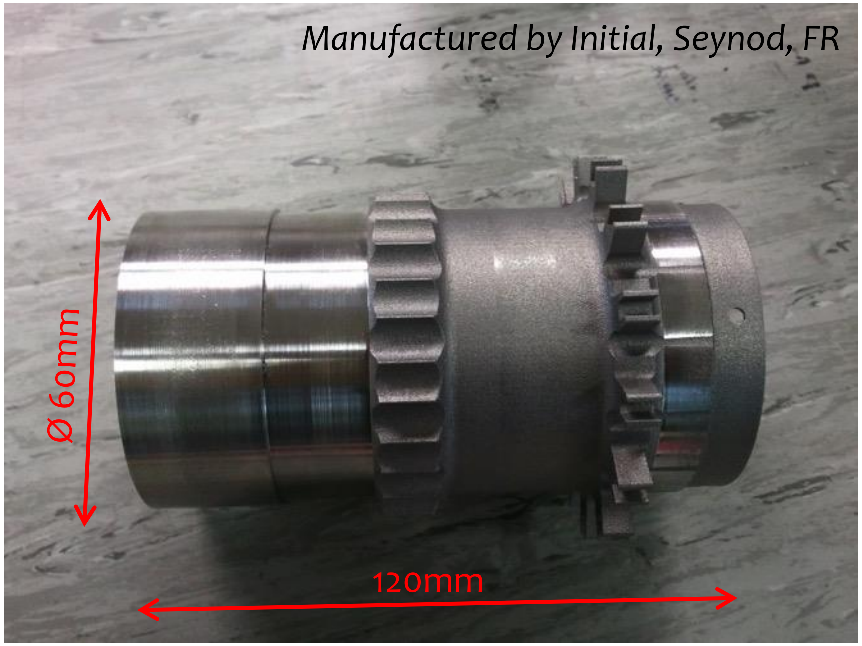


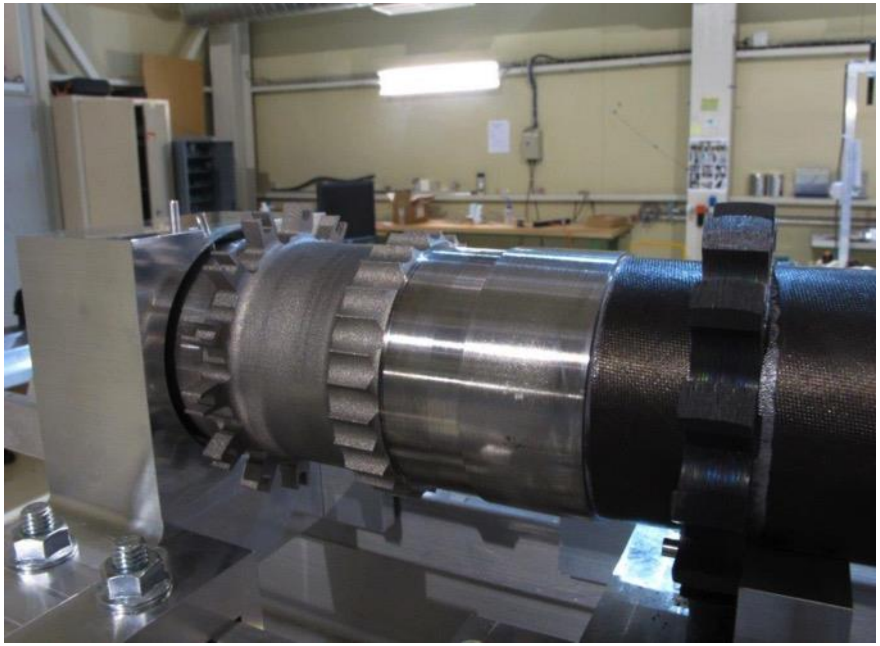
Use Examples: Functional Parts

Titanium extremity of Atlas IPT, glued on a carbon fibre pipe

Achieved: Complex shape piece impossible to obtain by std manufacturing process

(Only 4 parts manufactured. Internal diameter partially machined after DMLS process)


Manufactured by Initial, Seynod, FR



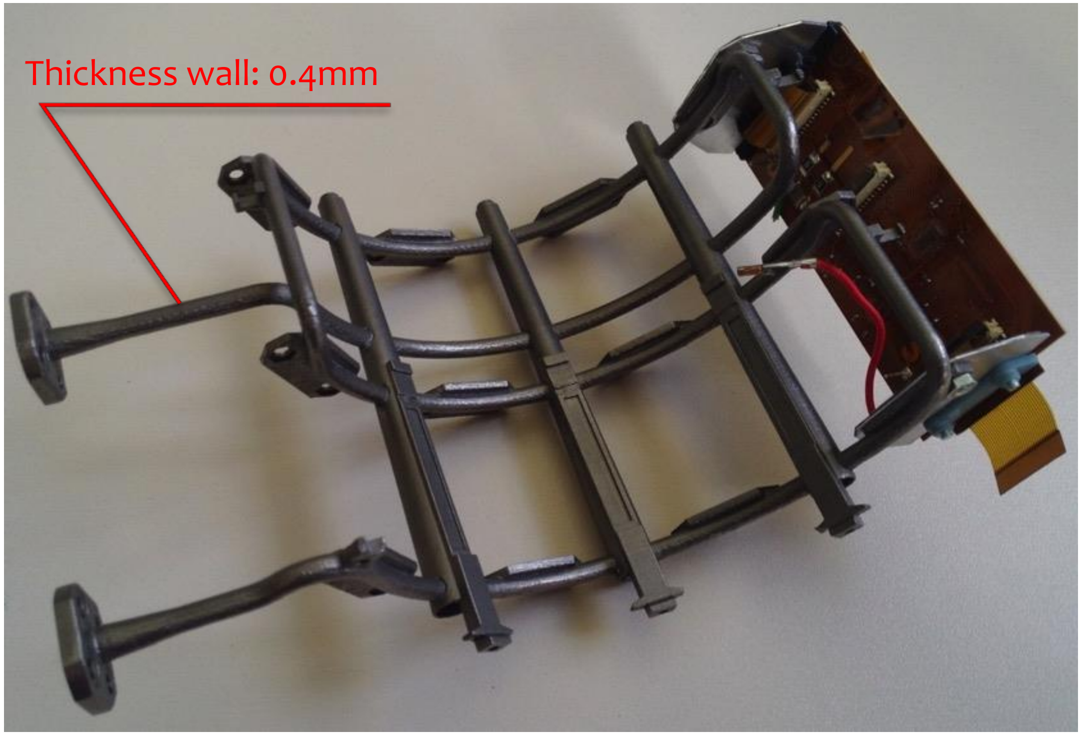
Courtesy: R.Loos
PH-DT

Use Examples: Functional Parts

Cooling pipes and support structure

Titanium module support made by SLM process. To improve cooling performance, and decrease pressure drop, a special finishing process (SILC) was applied inside the pipes (made by LayerWise)

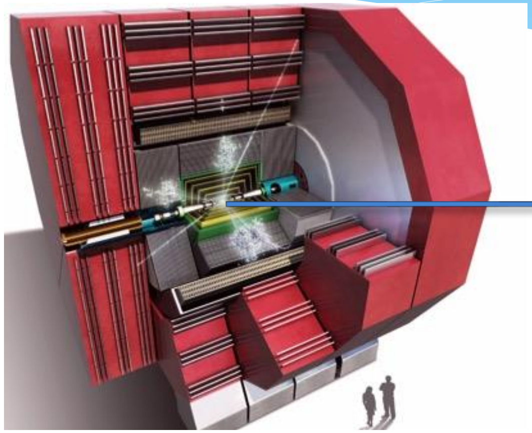
Several functionalities included in 1 structure: electronic cards support, complex cooling pipes with inlet and outlet connections, tested at 15 bar

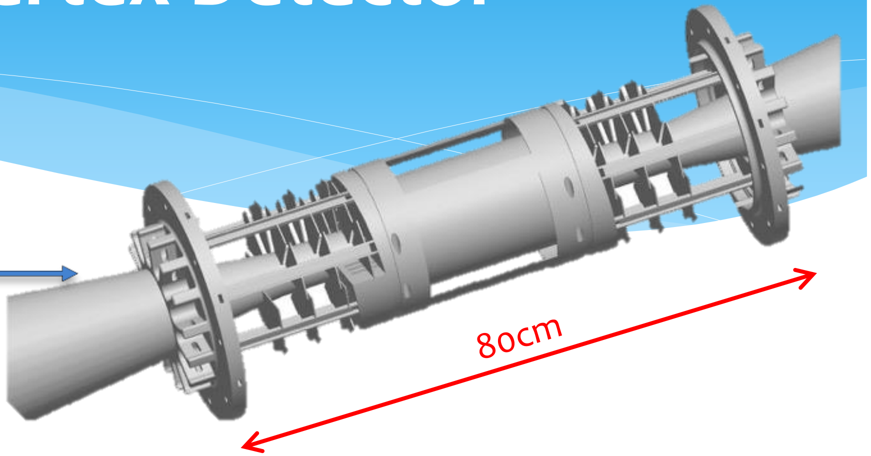


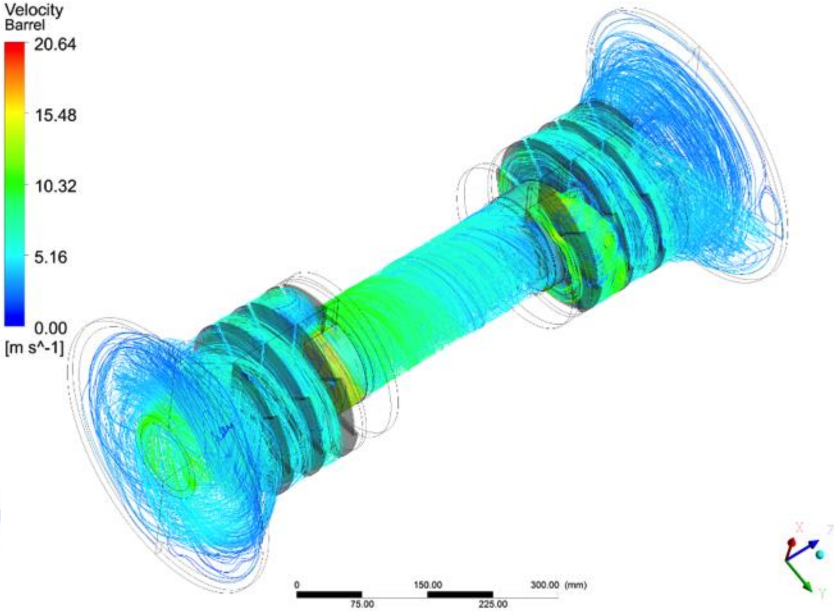
Courtesy: F. Duarte Ramos; F. Nuiry
PH-DT

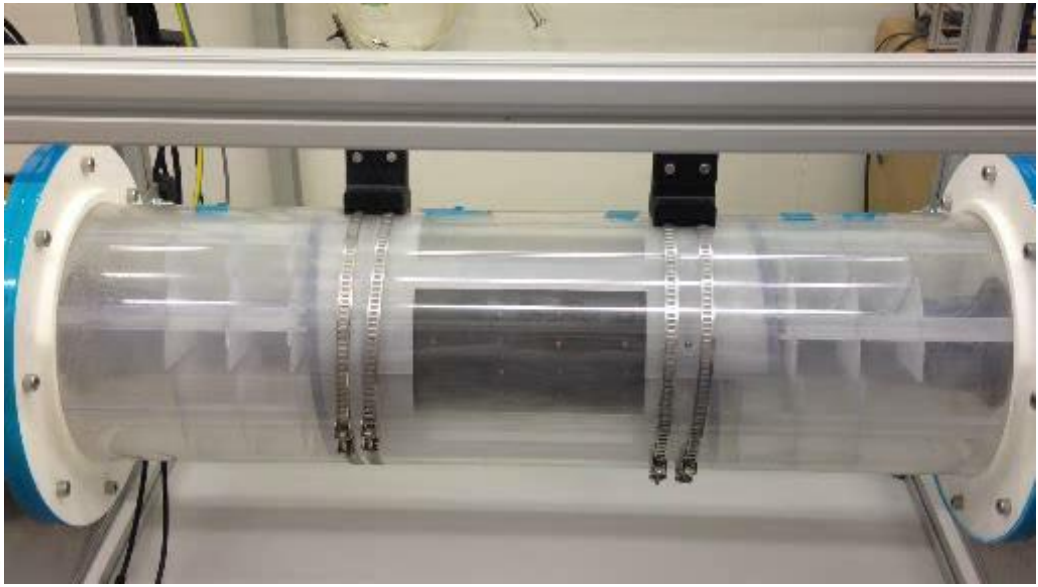
Use Examples: 1 to 1 Mockups

Linear Collider Vertex Detector

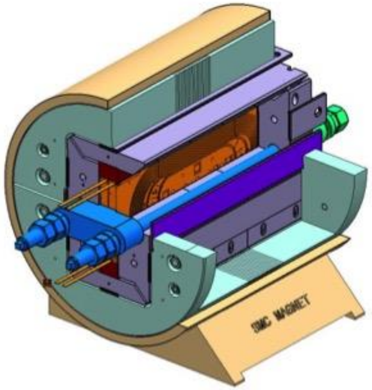




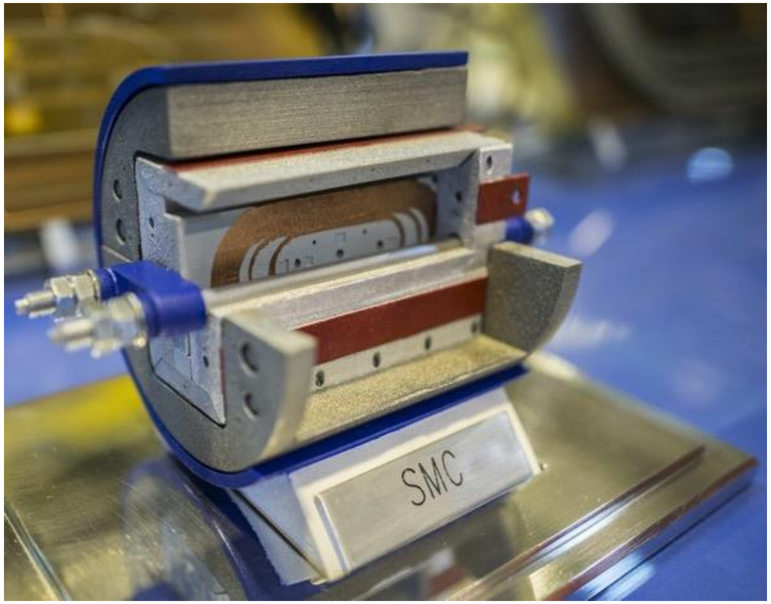




Use Examples: Models



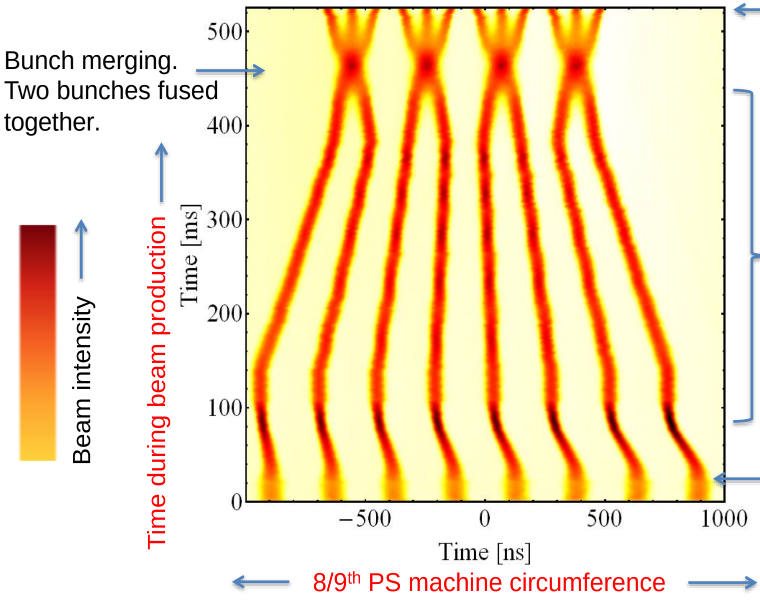
Magnet prototype
Short Model Coil (SMC)
25% reduction scale
120mm x130mm



Use Examples: Dreams

3DModel of RF gymnastics for LHC-beam production (BCMS scheme in PS)

BCMS full RF gymnastics



Bunch merging. Two bunches fused together.

Triple splitting. Every bunch divided in 3

Batch compression Distance between reduced

8 bunches injected from the PSB to the PS

The Obvious Advantages

- Economical and quick production of parts and tools
- Reduction of assembly steps
- Reduce waste (economy for raw materials)
- Quick feedback at design and proto phases (less design flaws)
- Increased visualization capabilities
- Manage impossible geometries
- Produce multifunctional devices: reducing mass, space…
- …

The Wish List

From present 3D-aided design …

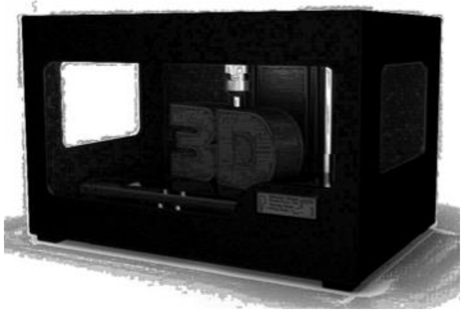
… to future 3D Manufacturing

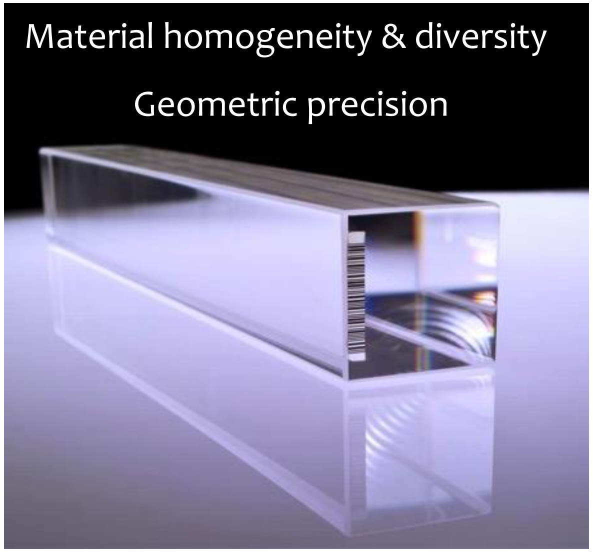
Modelling

⇨

⇦

Prototyping



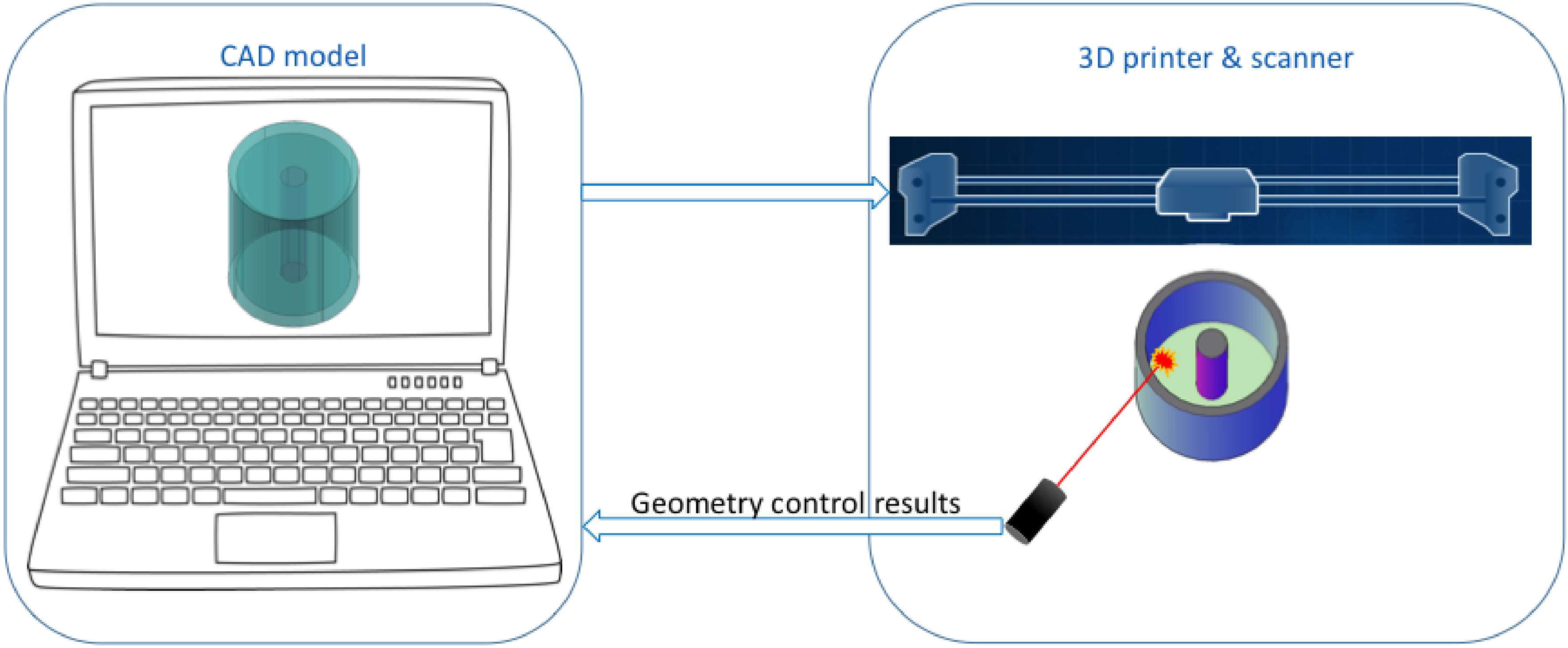


Material homogeneity & diversity

Geometric precision

Physical creation brings a new dimension to the design process

The Wish List
Integrated design, manufacturing & QA



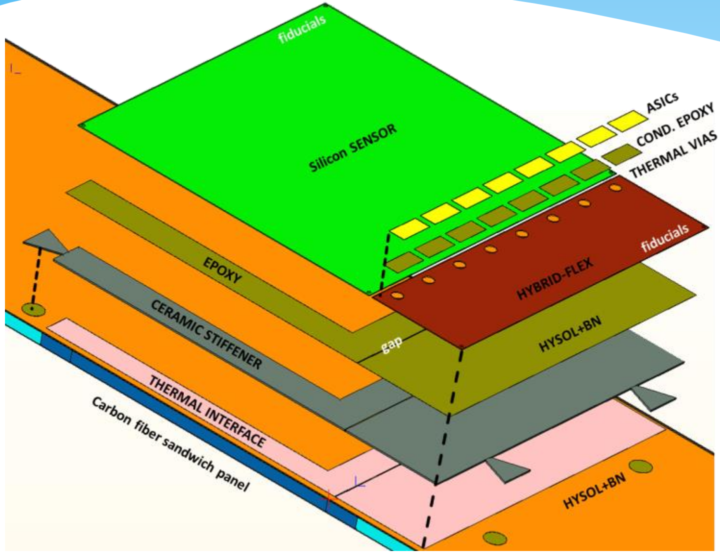
CAD model

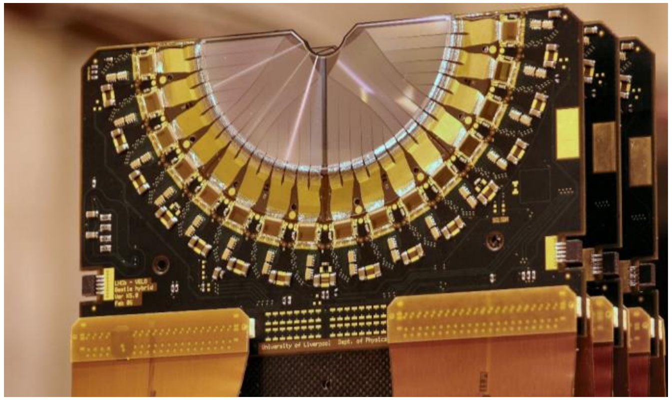
3D printer & scanner

Geometry control results

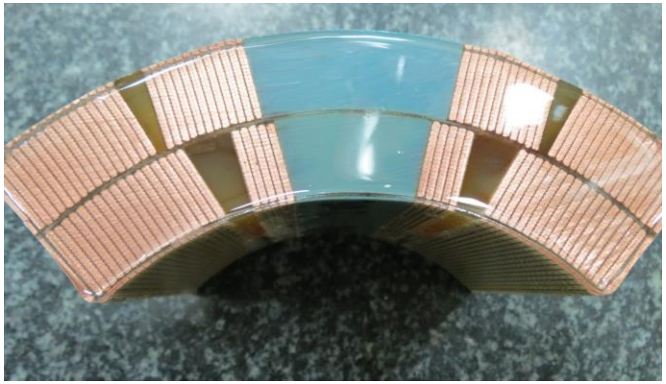
The Wish List

Multi-Materials for Manufacturing





Cutting view of a coil: cable in copper winding around head spacer in insulating materials (epoxy). The assembly is impregnated by liquid epoxy on vacuum and curing.



Silicon Trackers at LHC

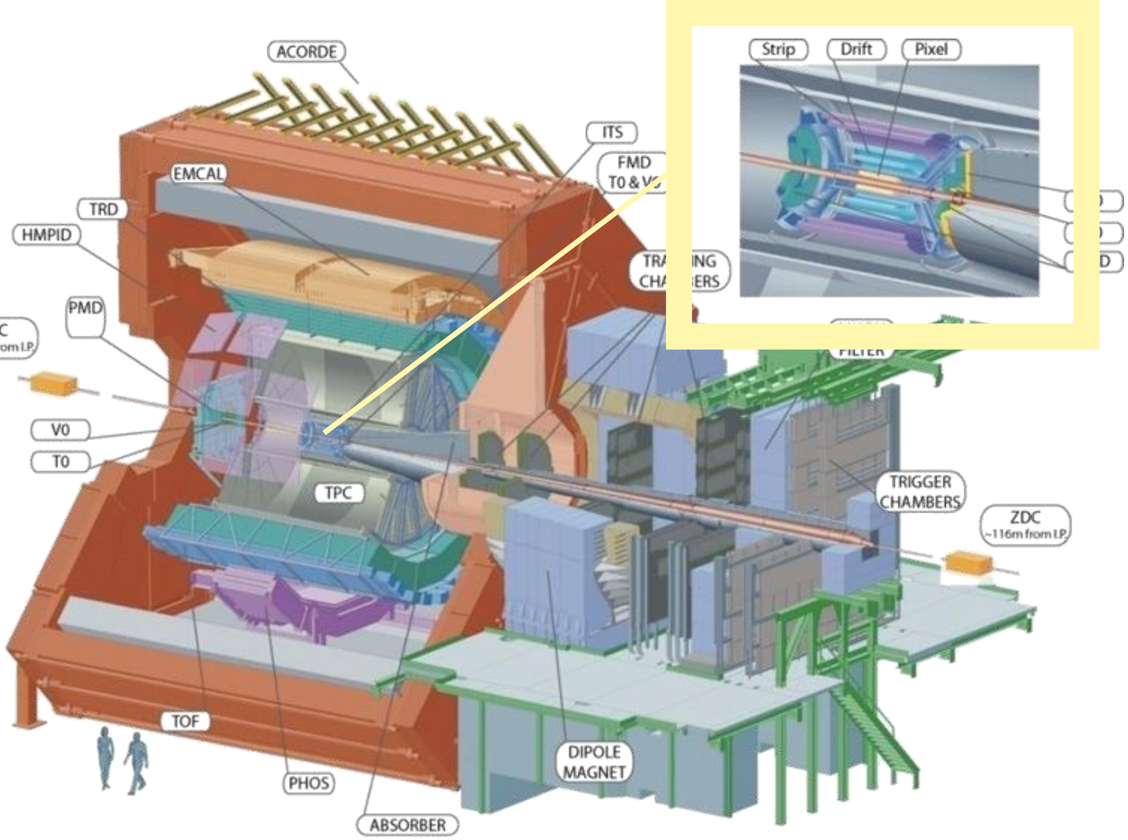
Catalog of today's technologies for a particle detector (operational in 2018), and basis for reflection about how/if these technologies and production/assembly technologies could evolve for future tracker systems

- Silicon tracking detectors are used in all LHC experiments
- **Upgrades of the present tracker systems, which will have to meet more stringent requirements,** are planned for the LHC shutdown periods 2018 and 2023
- Project R&D and production time is typically in the range of several years → **upgrades for 2018 present todays state of the art technologies**
- **Upgrades planned for 2023 will strongly profit from new developments starting now**
- **Example** presented: **ALICE ITS Upgrade (2018)**

Upgrades	**~Area**	
ALICE ITS	10.3 m^2	2018
ATLAS Pixel	8.2 m^2	2023
ATLAS Strips	193 m^2	2023
CMS Pixel	4.6 m^2	2023
CMS Strips	218 m^2	2023
LHCb VELO	0.15 m^2	2018
LHCb UT	5 m^2	2018

ALICE Experiment
Inner Tracking System Upgrade

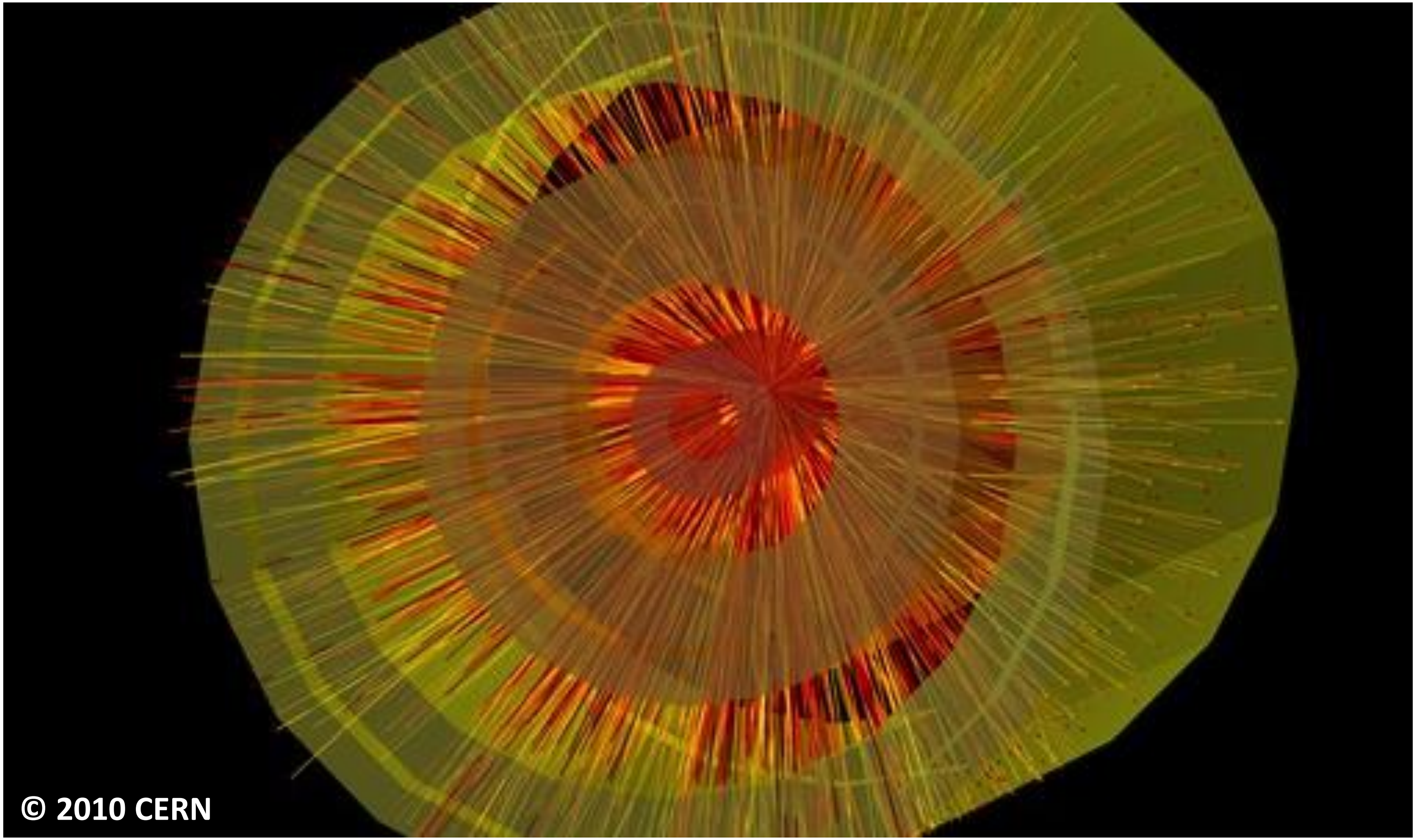
- **ALICE** is an experiment at the LHC dedicated to study heavy ion collisions.
- At the center of the experiment, closest to the interaction point, is the **Inner Tracking System (ITS)**.
- The ITS is based on **silicon tracking detectors**, using presently three different technologies.
- In 2018/19 the entire ITS (~10 m^2) will be replaced with CMOS monolithic silicon pixel detectors.



Size: 16 m high, 26 m long
Weight: 10,000 tons

Collaboration:
1200 members
131 institutes
36 countries

Operation of silicon tracking detectors in dense particle track environment:

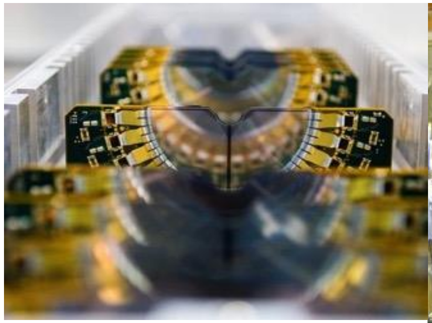

© 2010 CERN

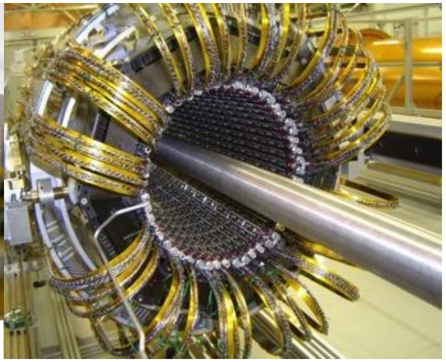
Events recorded by the ALICE experiment from the first lead ion collisions, at a centre-of-mass energy of 2.76 TeV per nucleon pair.

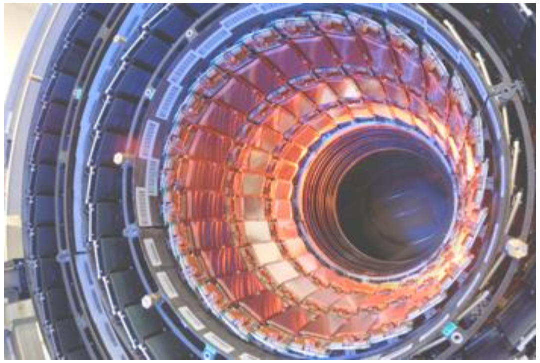
Silicon Tracking Detectors

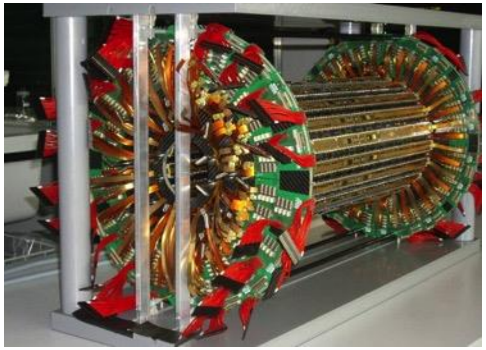
- Complex systems operated in a challenging high track density environment
- **Stringent requirements** on **radiation hardness**, cooling, **material budget**, etc.
- Innermost regions usually equipped with pixel detectors


ALICE Pixel Detector


LHCb VELO

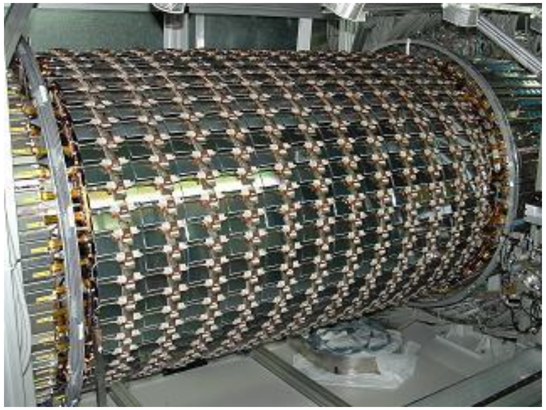

ATLAS Pixel Detector


CMS Strip Tracker IB


CMS Pixel Detector


ALICE Drift Detector

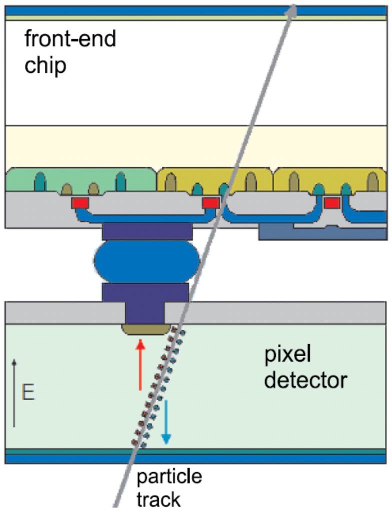

ALICE Strip Detector


ATLAS SCT Barrel

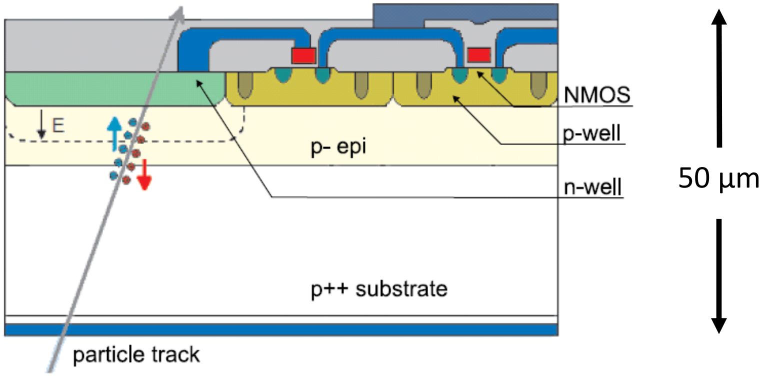
Hybrid and Monolithic Silicon Pixel Detectors

- Present LHC experiments are using **hybrid pixel detectors**, composed of a silicon sensor connected to a front-end chip.
- The **ALICE ITS upgrade** will use **monolithic silicon pixel detectors**, which will include the sensing part inside the electronic chip --> **50 µm thin silicon chip**

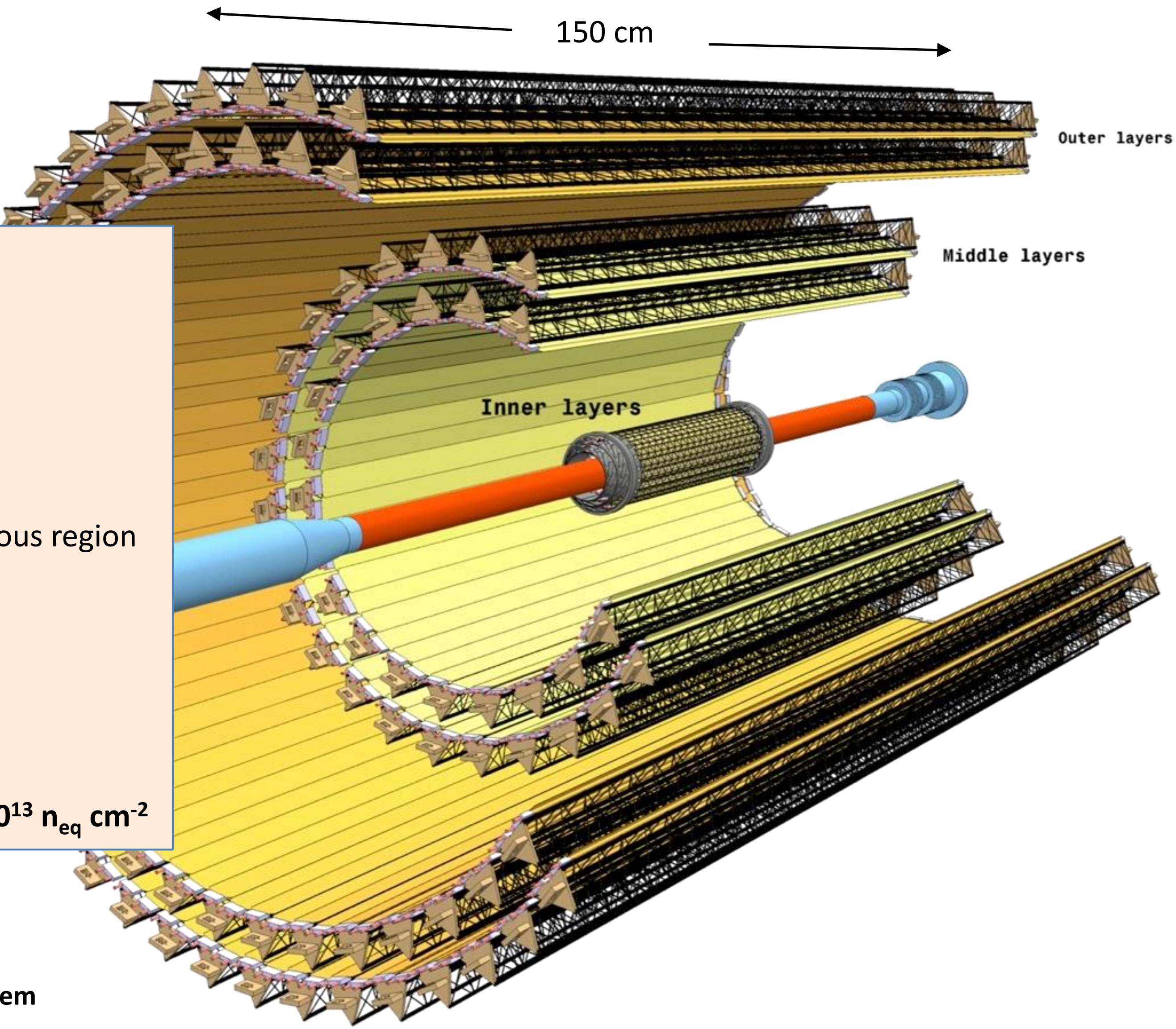
Hybrid Pixel Detector



Monolithic Pixel Detector (example)



ALICE ITS Upgrade



3 Inner Barrel layers (IB)
4 Outer Barrel layers (OB)

Radial coverage: 2.1-40 cm

~ 10 m^2

$|\eta|<1.22$ over 90% of the luminous region

0.3% X_0/layer (IB)
0.8 % X_0/layer (OB)

12.5 Giga-pixel tracker

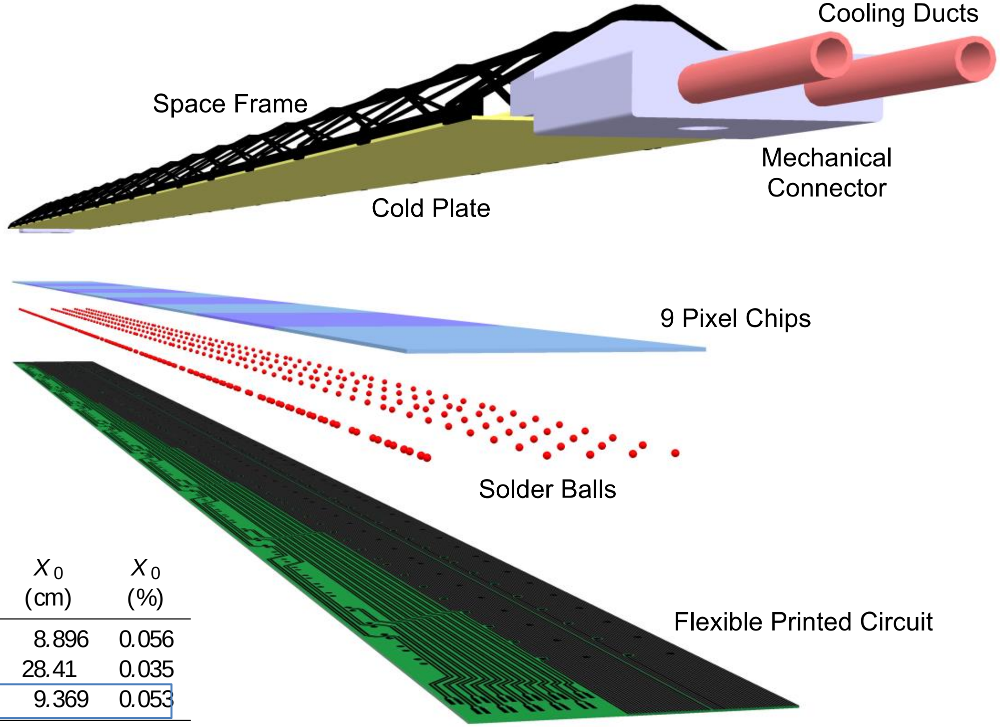
Radiation level (L0): 700 krad/10^{13} n_{eq} cm^{-2}

Upgrade of the ALICE Inner Tracking System
CERN-LHCC-2013-024 ; ALICE-TDR-017

ALICE ITS Upgrade: Inner Layer Stave

Light weight, compact modules to minimize material budget:

- 50 µm silicon sensors connected via solder points to a 2-layer Al(Cu)-polyimide flex cable
- Mechanical support and cooling
- Power and signal connections to each chip

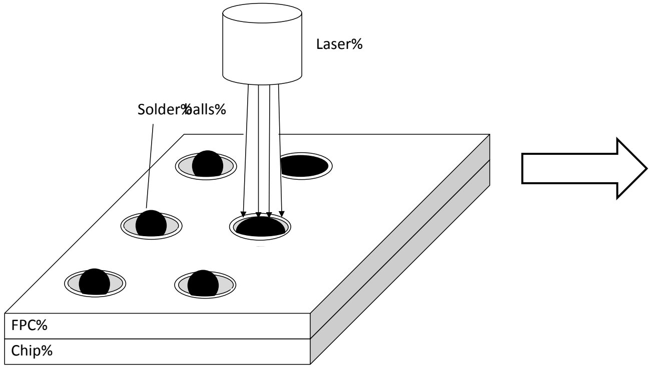


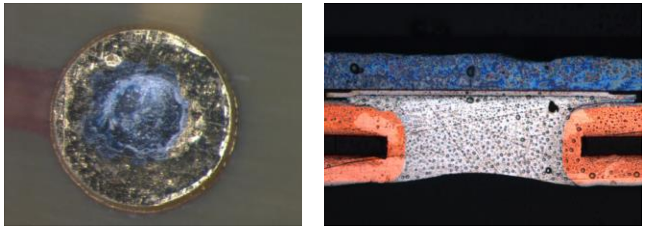
Inner barrel stave
ALICE ITS TDR

Stave element	Component	Material	Thickness (µm)	X_0 (cm)	X_0 (%)
HIC	FPC Metal layers	Aluminium	50	8.896	0.056
	FPC Insulating layers	Polyimide	100	28.41	0.035
	Pixel Chip	Silicon	50	9.369	0.053
Cold Plate		Carbon fleece	40	106.80	0.004
		Carbon paper	30	26.56	0.011
	Cooling tube wall	Polyimide	25	28.41	0.003
	Cooling fluid	Water		35.76	0.032
	Carbon plate	Carbon fibre	70	26.08	0.027
	Glue	Eccobond 45	100	44.37	0.023
Space Frame		Carbon rowing			0.018
Total					0.262

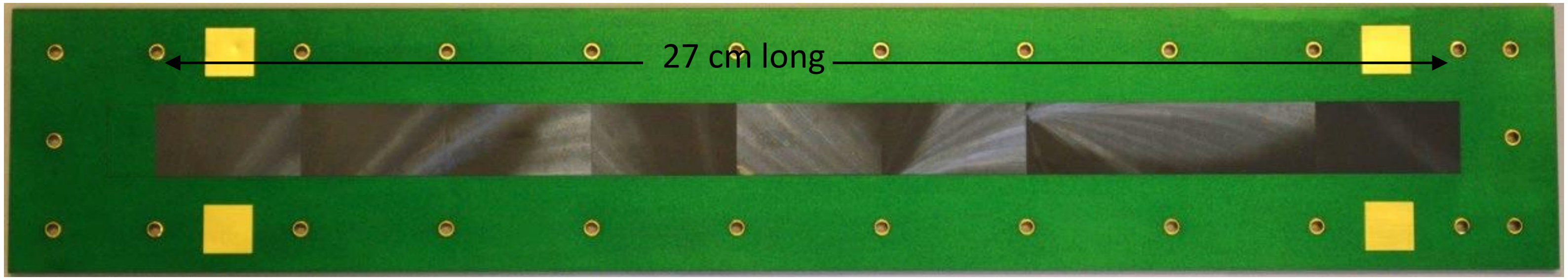
Example: ALICE ITS Inner Layer Stave

Sandwich structure: Silicon + flex cable and interconnection + cooling plate + mechanical support

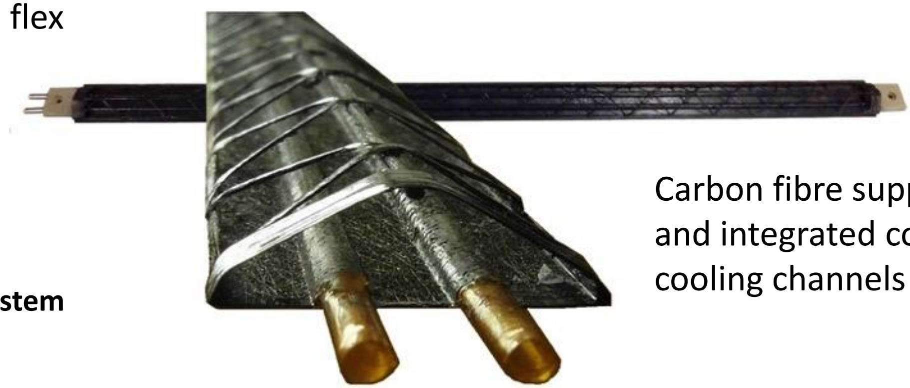




Direct on chip laser soldering



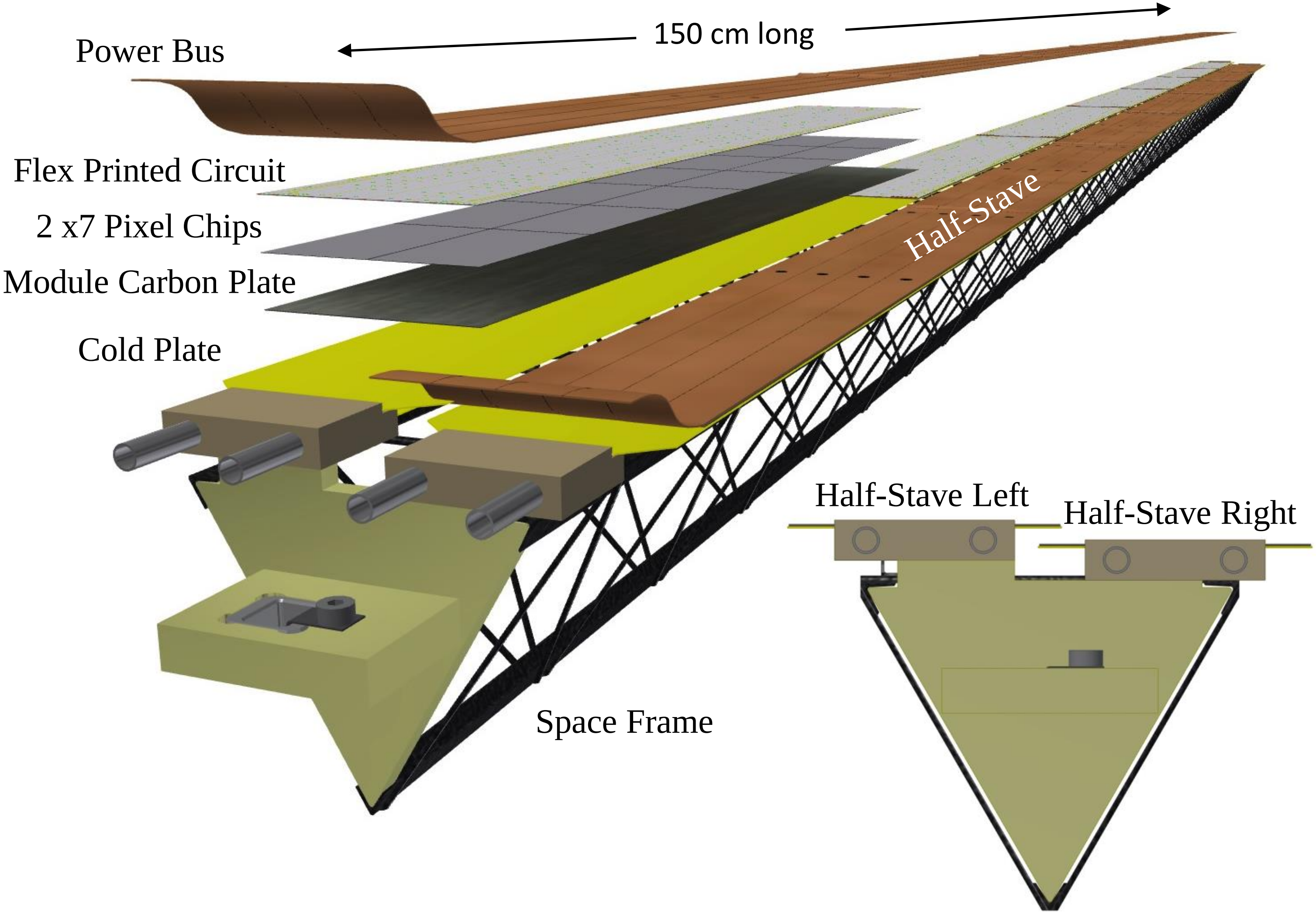
50 µm chips soldered to flex



Carbon fibre support structure and integrated cooling plate with cooling channels

Upgrade of the ALICE Inner Tracking System
CERN-LHCC-2013-024 ; ALICE-TDR-017

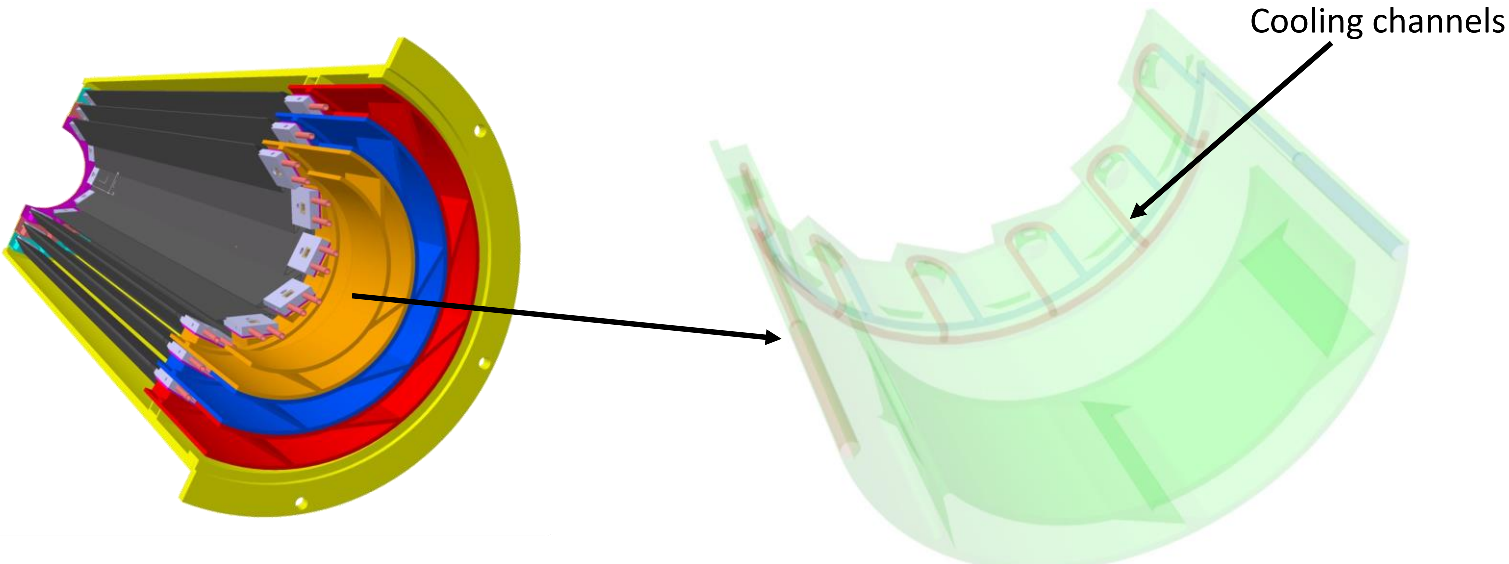
Example: ALICE ITS Outer Barrel Stave



Upgrade of the ALICE Inner Tracking System
CERN-LHCC-2013-024 ; ALICE-TDR-017

ALICE ITS Upgrade

Additive manufacturing techniques used for rapid prototyping and for building parts of the mechanics and cooling of the ITS Upgrade:



Inner Barrel End Wheel Mechanics
including cooling channels being produced in Accura Bluestone (3D printing)
C. Gargiulo/PH-DT

Conclusions

- Very satisfactory use of additive manufacturing technologies to support particle detector R&D and assembly (even with a 40k printer!)
- Advantages demonstrated… by the book: creation of impossible shapes, visualization, fast turnaround, cost reduction, democratized manufacturing (students!), etc
- Further development passes by
  - Using materials that are standard in HEP (carbon, silicon, kapton…) i.e. radhard, light, outgassing-free, thermomechanically suitable, non-magnetic…
  - Using multi-materials to print detectors and services (power, readout, cooling) at once
  - Combining design, manufacturing and QA in one machine