CERN
25 September 2018

DETECTOR MECHANICS R&D

EP R&D

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on behalf of Working Group 4 Detector Mechanics

https://indico.cern.ch/event/743661/

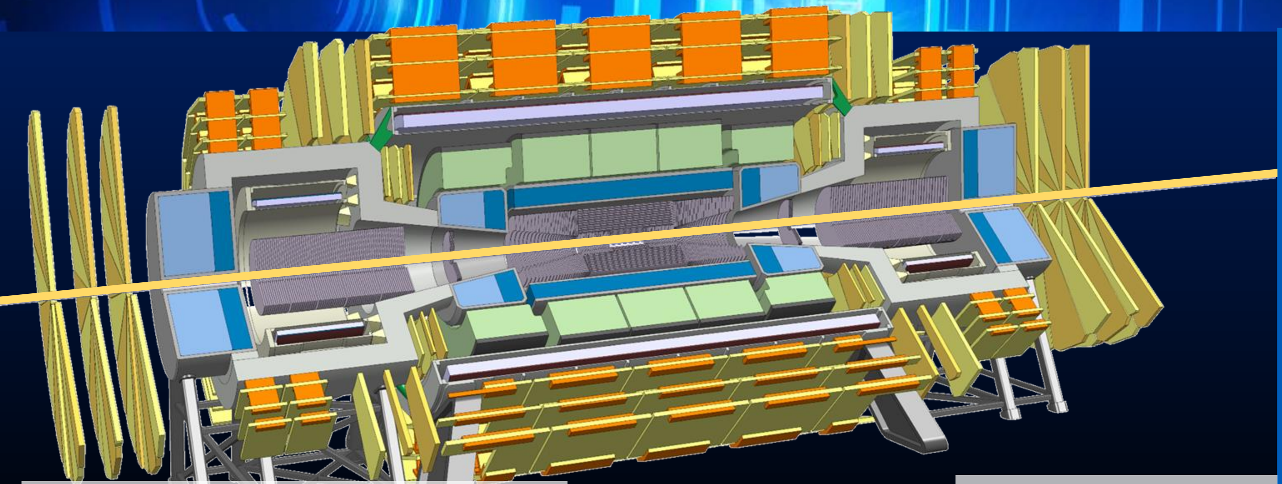
NEEDS

ON FUTURE DETECTOR MECHANICS

Large scale, high stability,
operate in high radiation level,
low material budget,…

FUTURE DETECTOR MECHANICS

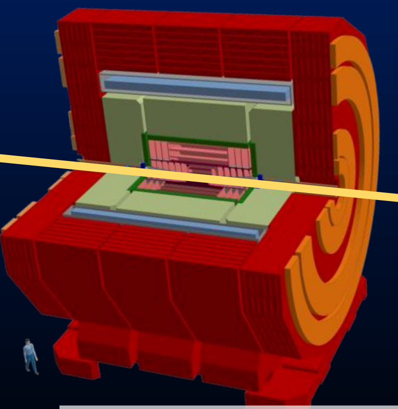
NEEDS



FCChh, HE-LHC, …

hh collisions

- **Large dimensions (50m)**
- **High radiation Level (up to 90MGy)**
- 4T 10m solenoid
- Forward solenoids 4T
- Silicon tracker **Tracker Radius 1.6m, Length 32m**
  radiation damage is a concern
- Barrel ECAL Lar/ Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr **2-4x better granularity than e.g. ATLAS**
  Silicon ECAL and ideas for digital ECAL with MAPS
- Muon system



e^+e^- collisions

CLIC, FCCee, ILC, CEPC,…

- Standard dimensions
- Low radiation Level
- 4T, 2T
- Silicon tracker **unprecedented spatial resolution**
  (1-5 µm point resolution)
  very low material budget (0.1X%)
  Dissipated power (vertex) (<50mW/cm^2)
  Radiation level NIEL (<4×10^{10} neq cm^{-2}/yr)
  Radiation level TID (<200Gy/yr)
- Barrel fine grained calorimeter
- Compact Forward calorimeter

➔ Future detector mechanics has to cope with large range of demanding requirements

➔ FCC-hh and HE-LHC have very similar detector technology requirements in terms of resolution and radiation hardness.

➔ FCC-hh, HE-LHC, FCC-ee have similar sensor technology requirements in terms of resolution and material budget.

R&D

WG4 DETECTOR MECHANICS: POSSIBLE DIRECTIONS, AS IN MARCH WORKSHOP

Structure Design	Ultra lightweight vertex detector structure; large scale composite structures,…
Cooling Design	New system design and coolants, polyimide micro tubes, microchannel 3D print, air cooling, …
Materials	Carbon materials, carbon nanotube, CVD diamonds, adhesive and composite for high radiation level, …
Processes	3D print micro and macro scale, large composite manufacturing and Out of Autoclave curing, …
Integration	High integrated system, low mass CNT power and signal cables, 3D tomography, …
Installation and Maintenance	Robotic Remote Manipulator System, service Umbilical Mechanism Assembly, alignment and survey, radiation shielding, augmented reality, …
Environment and Stability	High radiation level, vibration and hygro thermo elastic behaviour, …

WG4 DETECTOR MECHANICS: PROPOSED ACTIVITIES

- **Activity n.1** — **Low mass mechanical structures for…**
  - Task-1 — … future Tracking Detectors
  - Task-2 — … future cryostats for Calorimeters and Detector Magnets
- **Activity n.2** — **New detector interfaces and services architectures for automated installation and maintainability in future high radiation environments**
- **Activity n.3** — **High-performance cooling for future detectors**

ACTIVITY N.1

LOW MASS MECHANICAL STRUCTURES FOR…

Task 1. …future Tracking Detectors

LOW MASS MECHANICS: FOR FUTURE TRACKING DETECTOR

ACTIVITY N.1 TASK N.1

Description

Develop ultra **lightweight substrates** for the mechanical support and thermal management of the **tracking sensors** for future lepton and hadron collider detectors. New sensors technologies, air cooling solutions, microfabrication techniques and additive manufacturing processes will be explored.

Year Milestones → Deliverables

1 Identify new technologies for integrated thermo-mechanical substrates. → Report on identified technologies

Develop design of substrates based on identified technologies. → Design of different substrates options

2 Validate substrate design through analysis and breadboard models. → Report on design validation of substrate

3,4 Make substrate Engineering and Qualification models. → Substrates engineering models

5 Qualification test campaign on different substrates. Compare performances → Test report on substrates models

Cooperation with

WP1, CERN-EN-MME, EPFL, INFN, LBNL, Airbus, Forum on Tracker Mechanics,...

Potential co-fundings: AIDA 2020 extension, Marie Curie MSCA-ITN-2019; CERN & NTNU Collaboration, Horizon 2020-SPACE, ...

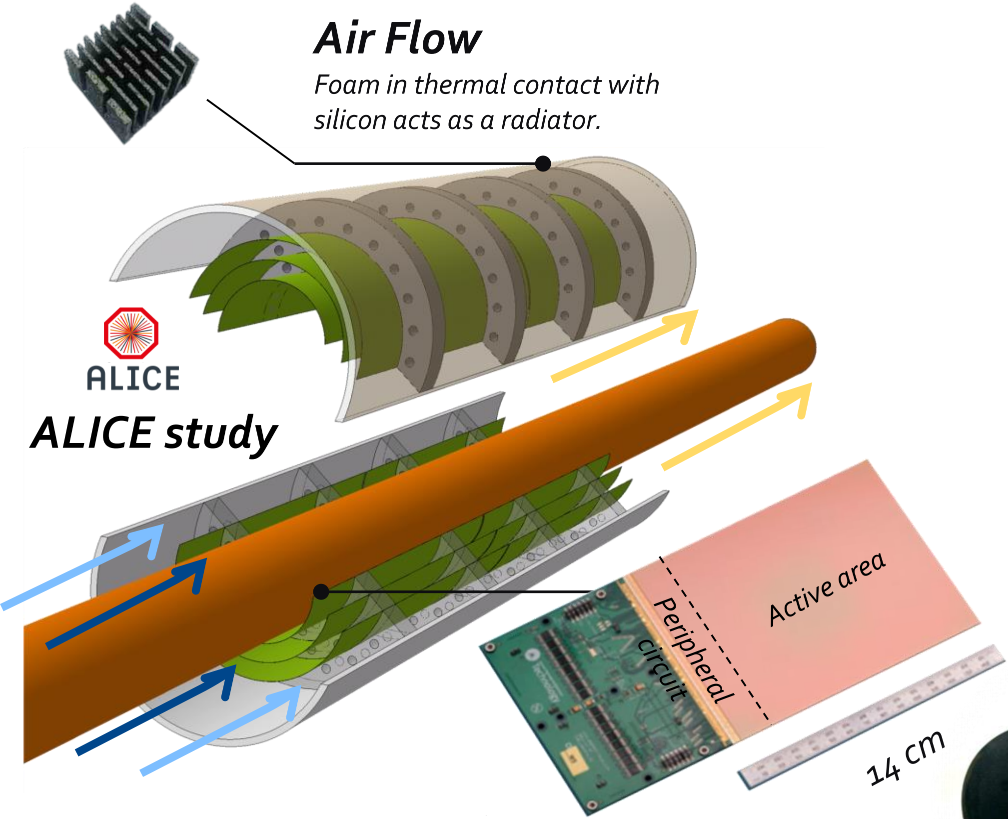
VERTEX DETECTOR: **GAS COOLING**

- ✓ The design of new vertex detectors in lepton collider will have to cope with unprecedented requirements on minimum material budget and dimensional stability

Air Flow

Foam in thermal contact with silicon acts as a radiator.

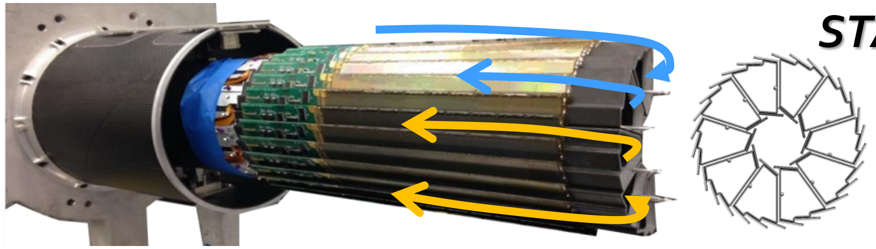
ALICE study



Stitched Silicon sensors

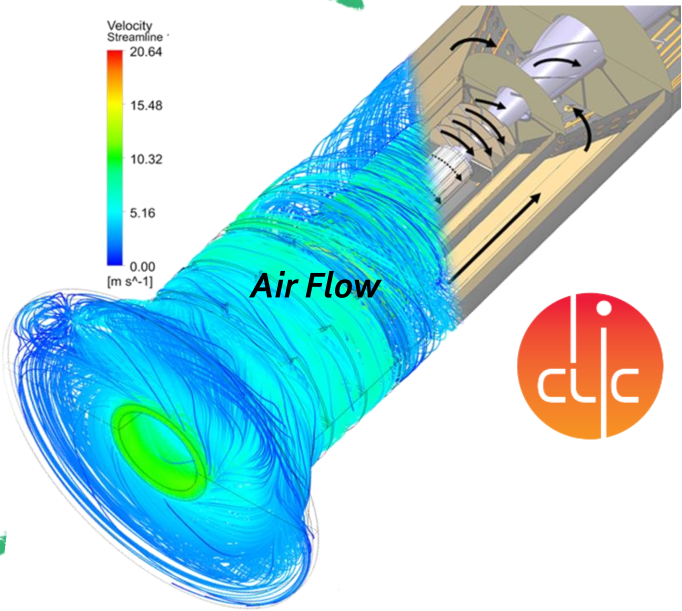
to achieve larger area pixel sensors beyond the typical mask reticule size of 2x2 cm2 or 2x3 cm2. Services at the sensor edge with a sensible reduction of material budget

STAR in operation @LBNL



R&D

CLIC study



R&D

Curved Silicon sensors

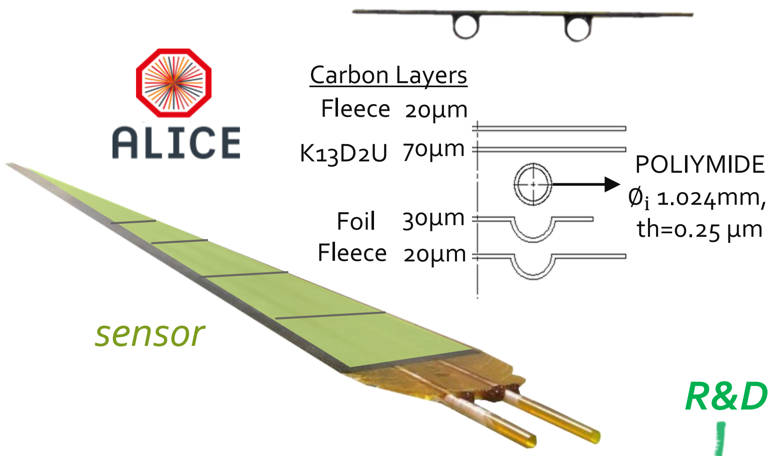
Reduction of thickness to about 20–40 μm open possibility of exploiting the flexible nature of silicon.

- ✓ Reduction of material in front of the sensor will be pursued by investigating new sensors technologies and air cooling solutions .

VERTEX DETECTOR: MICROFABRICATION

✓ In hadron collider vertex detectors stringent cooling requirements, driven by the minimisation of radiation damages, will require the development of new heat exchanger substrates to achieve better performance and lower temperatures.

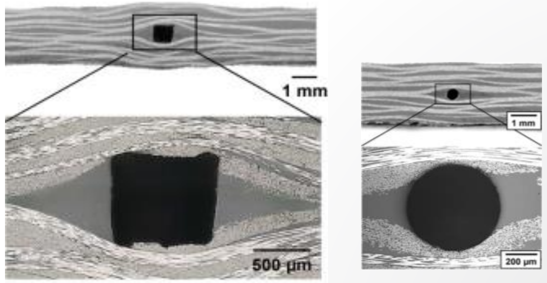
Cold plate: *Carbon vascular*



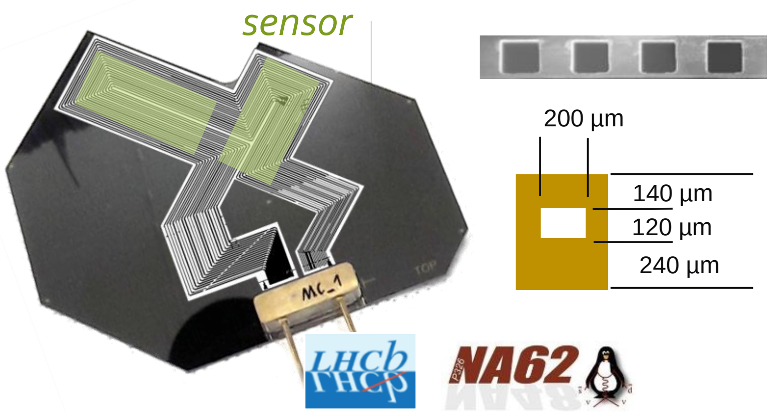
R&D

Carbon Microvascular

Ultralight pipes, reduce pipe size, higher pressure (>50 bar)



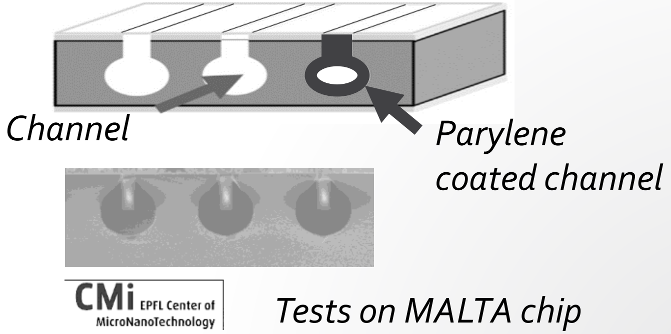
Cold plate: *silicon microchannel*



R&D

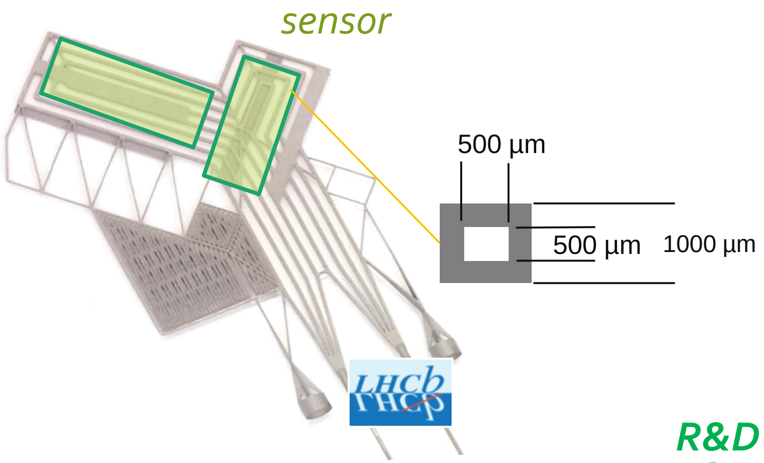
CMOS-compatible processes

Micro channel on the back of the sensor



Tests on MALTA chip

Cold plate: *3D print titanium*



R&D

3D printed ceramic, …

…different materials engineered for CTE compatibility

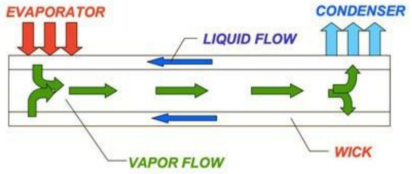
✓ Different microfabrication techniques will be studied for ultra lightweight coldplates.

TRACKER DETECTOR: **LARGE AREA COVERAGE**

✓ For the high levels of radiation and large surface coverage requirements, new approaches involving replaceable sensors

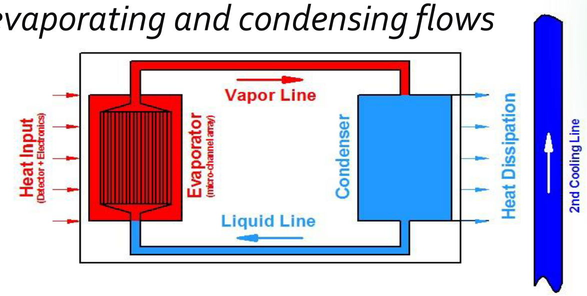
Heat Pipe

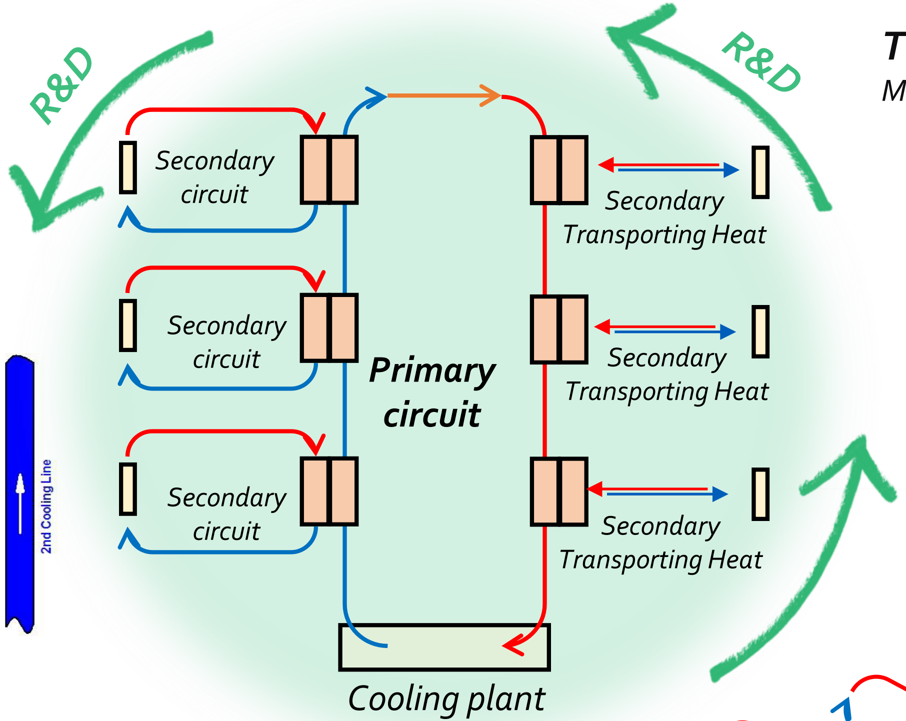
Passive heat transport device



Loop Heat Pipe:

Separated evaporating and condensing flows



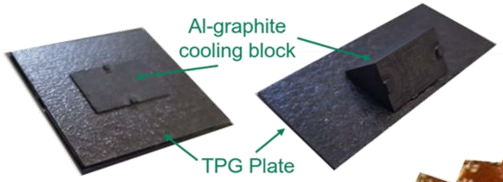


Thermal Straps

Material : Copper, Gold, Nickel, Carbon, Pyrolytic Graphite

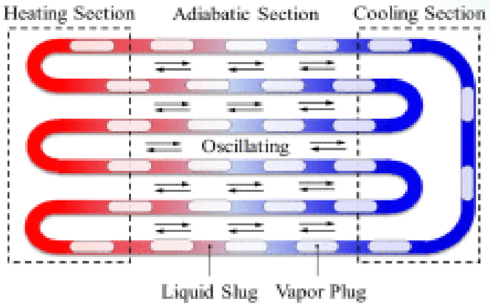
ATLAS Baseline, TPG and Cooling blocks:

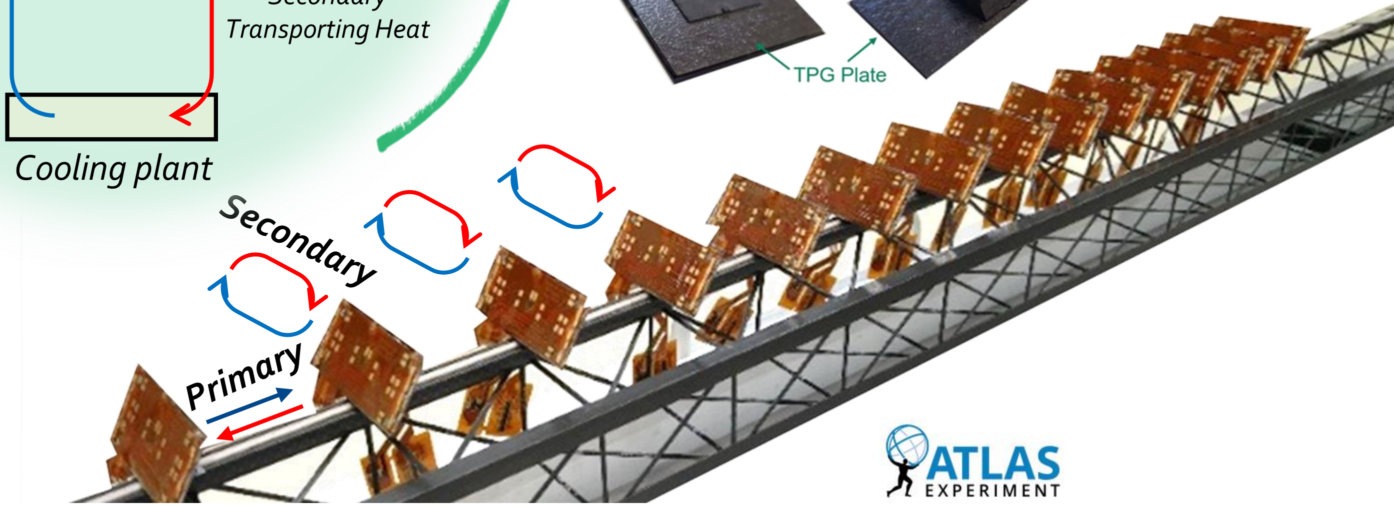
Thermal pyrolytic graphite (TPG) act as thermal link.



Oscillating Heat Pipe

Pulsating motion of liquid slug and vapour bubbles between the evaporator and the condenser.





in collaboration with
EPFL, CSEM, SSC

ATLAS EXPERIMENT

✓ Investigate cooling technologies that can be scaled to large areas without joints

✓ Study miniaturised closed loop device operated in stand alone mode to minimise connectors

ACTIVITY N.1

LOW MASS MECHANICAL STRUCTURES FOR…

Task 2. … future cryostats for Calorimeters and Detector Magnets

LOW MASS COMPOSITE CRYOSTATS: CALORIMETERS AND DETECTOR MAGNETS

EP R&D

Description

Cryostats in HEP are still the purview of metals. New detectors design aims to **Ultra Lightweight** (ULW) cryostats for both magnets and calorimeters. **Carbon Fibre Reinforced Plastic** (CFRP) will be explored and compared to advanced metal and hybrid honeycomb structures.

Year Milestones → Deliverables

Year	Milestones → Deliverables
1	Investigate status of cutting edge technologies developed for aerospace cryotanks. → Report on technologies
	Develop cryostats design based on carbon composite, compare to aluminium sandwich. → ULW Cryostat Design
2	Validate cryostat design through FEA and specific tests on critical interfaces. → ULW Cryostat Design Validation
	Evaluate production cost for an ultra lightweight cryostat . → ULW Cryostat Cost estimate
3,4	Build a scaled cylindrical ultra light weight cryostat engineering model. → ULW Cryostat demonstrator (~$1m^3$)
5	Qualification test campaign on demonstrator. → Test Report on $1m^3$ demonstrator.

Cooperation with

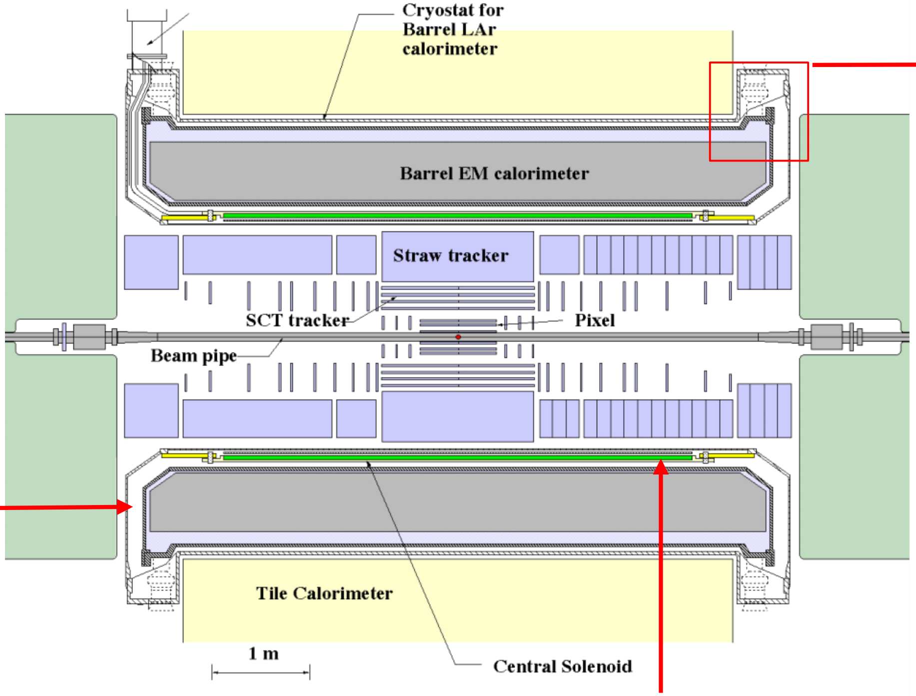
WP3, WP8, CERN-EN-MME, ESA, RUAG, DLR, …

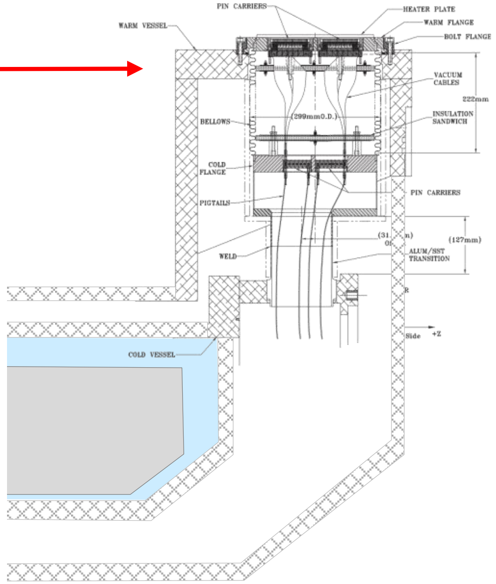
Potential co-fundings: AIDA 2020 extension, Marie Curie MSCA-ITN-2019

FUTURE DETECTOR CRYOSTAT: **ULTRA-THIN**

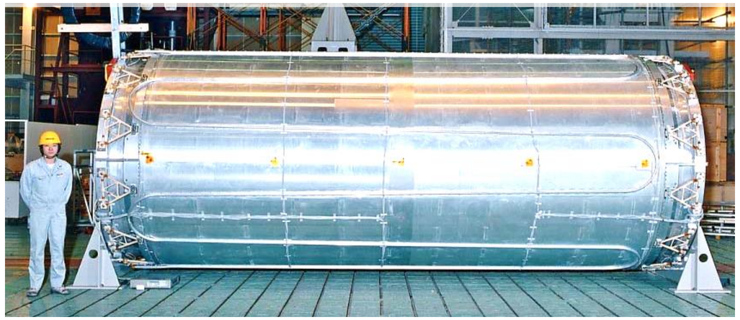
✓ Cryostats in HEP are still the purview of metals. New design aims to ultralight cryostats for both magnets and calorimeters

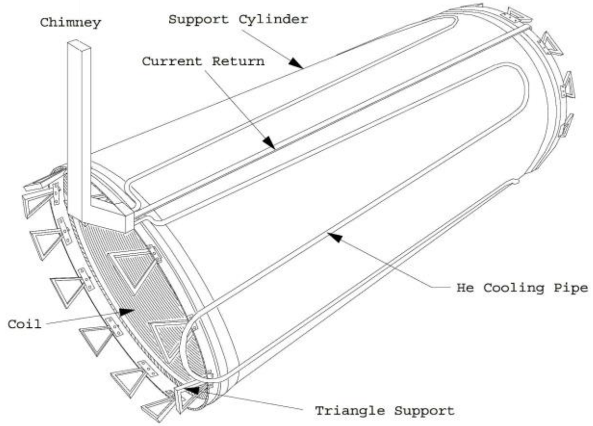
ATLAS barrel cryostat, *toroidal* Al 5083 *double wall, warm and cold vessel, with a feedthrough flange and a flexible bellows welded between them and pumped down to about* 10^{-3} *mbar vacuum.*





ATLAS Solenoid Magnet





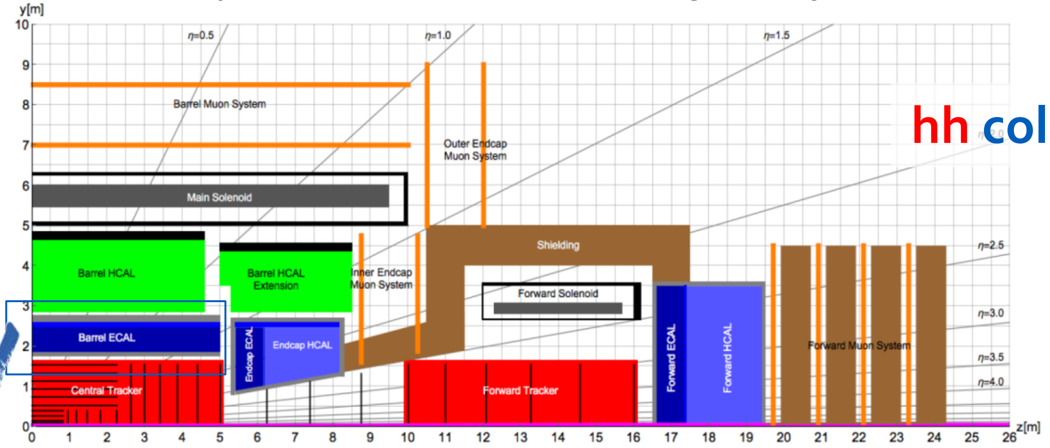
✓ In order to decrease the thickness and material budget, lightweight and strong composite materials will be considered

FUTURE DETECTOR CRYOSTAT: **ULTRA-THIN**

- ✓ Calorimeter and magnet requirements will drive the design of a thin carbon composite cryostat

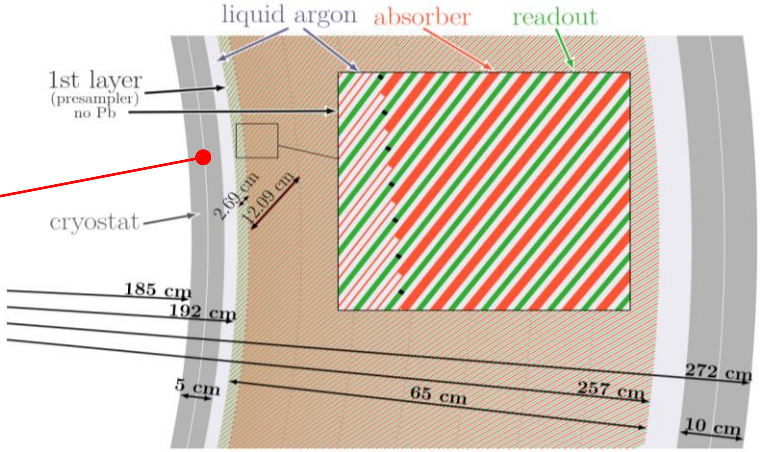
Baseline geometry, FCC-hh LAr barrel ECAL :

The aluminium cryostat is 5 cm thick, representing 56 % of Xo at η=0



hh collisions

Cryostat calorimeter (double vessel)



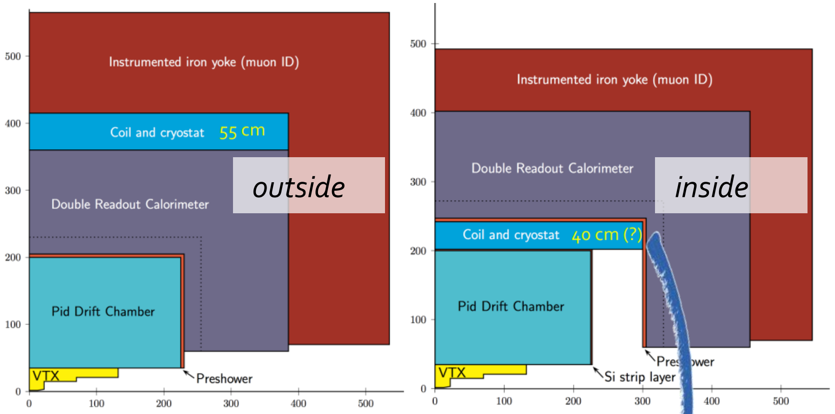
minimum material

Baseline geometry, FCC-ee :

a very challenging 2T solenoid "ultra-thin and transparent"

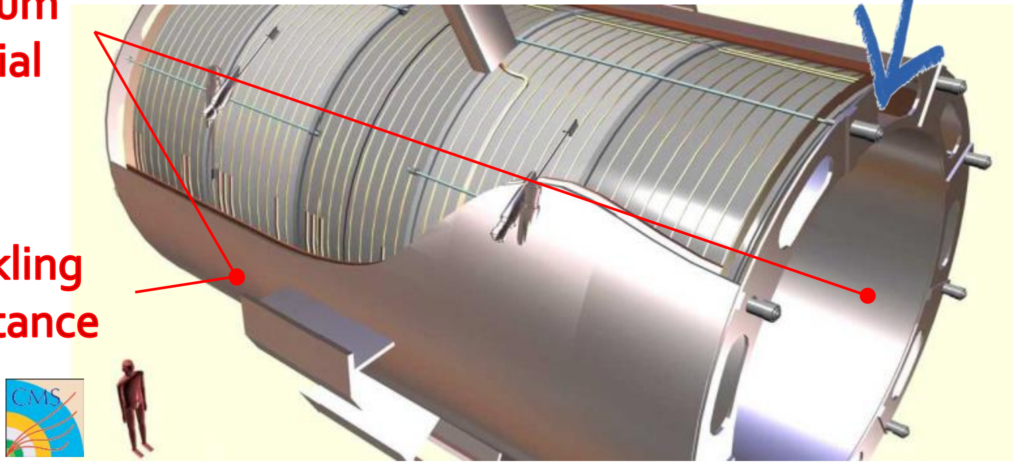
e^+e^- collisions

Solenoid outside or inside calorimeter



Cryostat magnet

minimum material

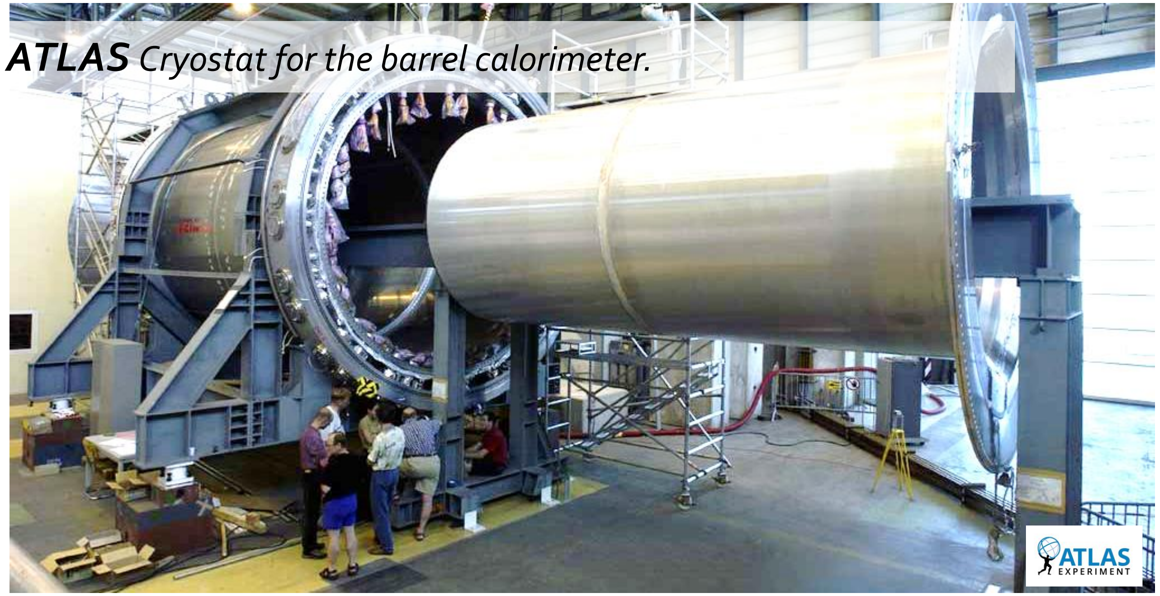


buckling resistance

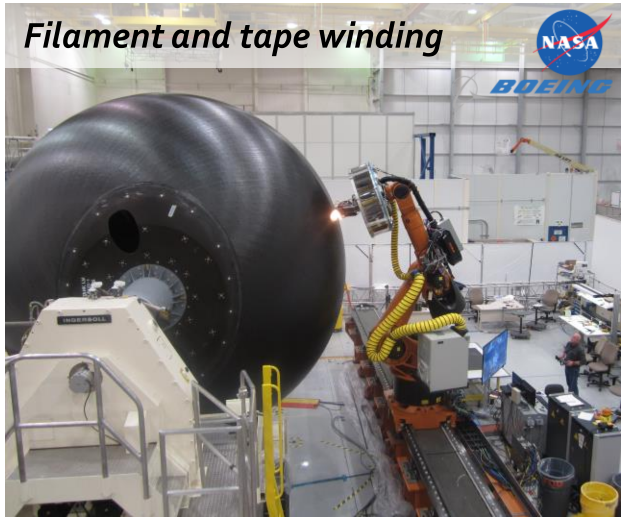
- ✓ Design solutions based on Carbon Fibre Reinforced Plastic will be investigated to fulfil specific HEP cryostat requirements

LOW MASS COMPOSITE : CALORIMETERS AND DETECTOR MAGNETS

✓ Cryostat in HEP detector should profit from similar development in aerospace cryotank: CHATT, CCTD, SpaceX Programs

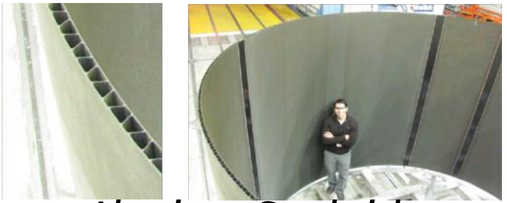


***ATLAS** Cryostat for the barrel calorimeter.*

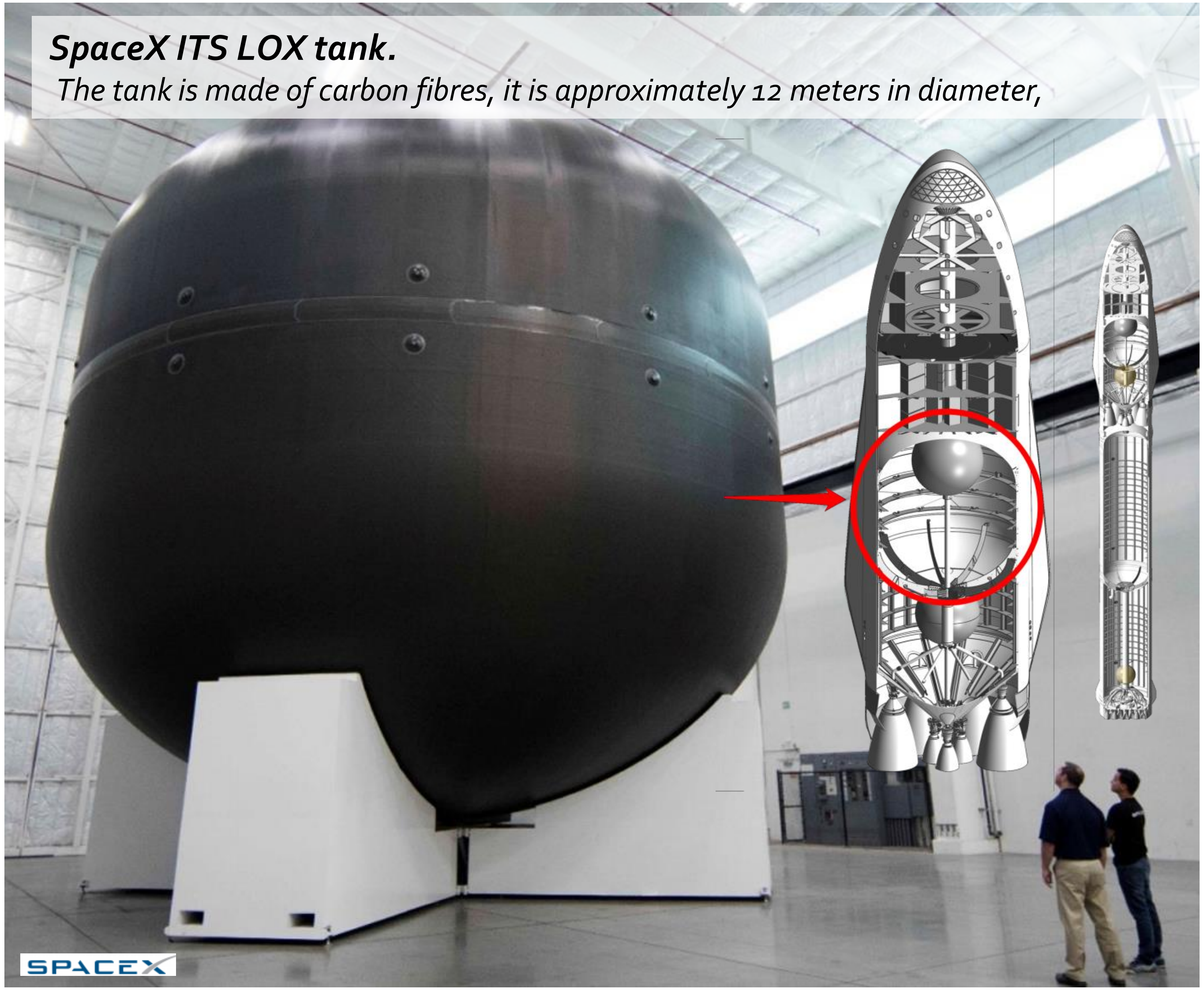


Filament and tape winding

OOA Out of Autoclave



Aluminum Sandwich



SpaceX ITS LOX tank.
The tank is made of carbon fibres, it is approximately 12 meters in diameter,

✓ Investigate how to tailor these new processes and materials for HEP cryostat: thermal insulation, feed through, rad loads

ACTIVITY N.2

NEW DETECTOR INTERFACES AND SERVICES ARCHITECTURES FOR AUTOMATED INSTALLATION AND MAINTAINABILITY

DETECTOR & SERVICES:
AUTOMATED INSTALLATION & MAINTAINABILITY

EP R&D

ACTIVITY N.2

Description

New HEP detectors must be designed to be easily maintained and possibly **robot friendly** to maximize detector accessibility and **decrease personnel exposures to hazards**. Layout and interface to automated systems/robots for maintenance and early intervention should be foreseen at the detector design level.

Year Milestones → Deliverables

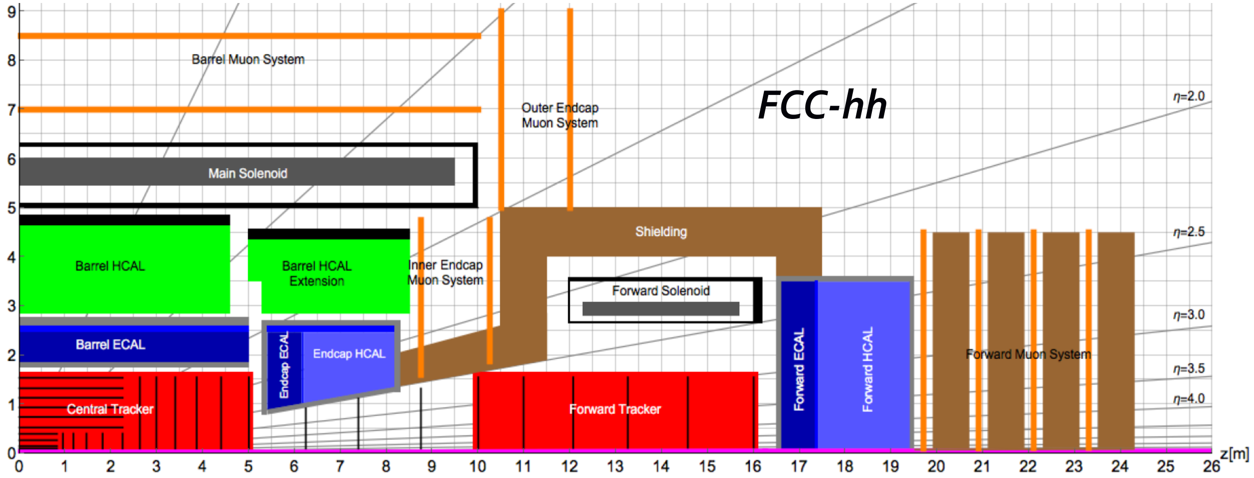
Year	Milestones → Deliverables
1	Identification of industrial solutions and cutting edge technologies of automated and robotic system compatible with the needs of future remote detector handling and maintenance→ Report on robotic solution
2	Development of standard detectors interfaces to automated systems/robots.→ Design of detector/robot I/F
3,4	Development of test articles for interface and automated systems/robots.→ Tests article for solution develop
	Construction of EP Robot Laboratory for solution testing → EP Rob Laboratory
5	Experimental validation on test articles of the proposed automated systems/robots solutions. → Report

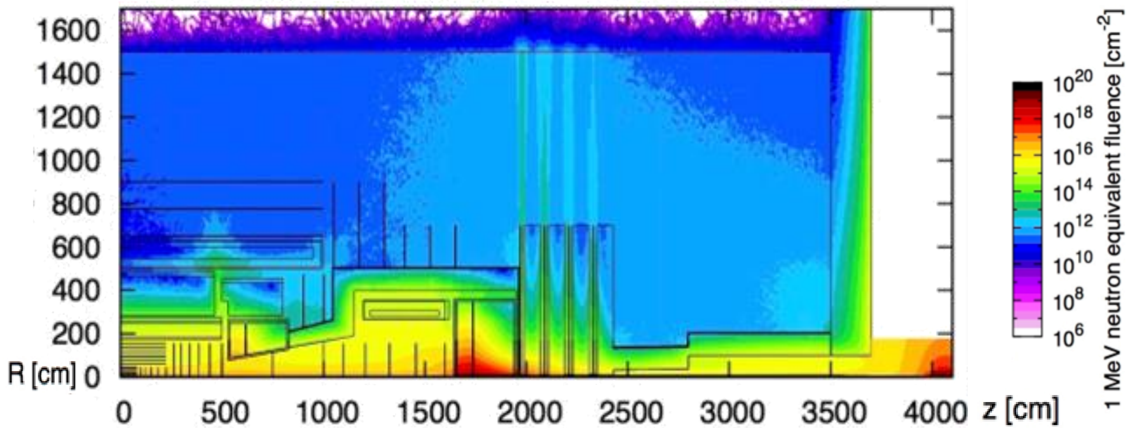
Cooperation with

CERN-EN-SSE, CERN-HSE, ETH, NASA, ESA,....

REMOTE MANIPULATOR SYSTEM- **RMS**

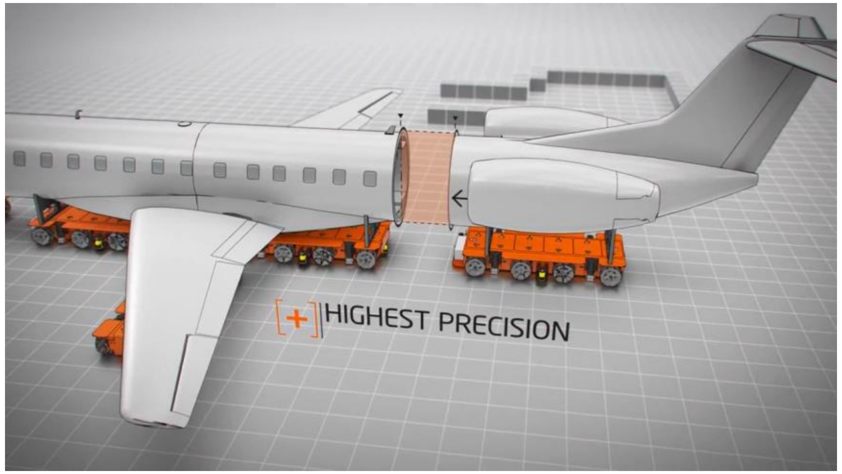
✓ High radiation level in hh will require design optimisation to allow remote installation, maintenance, repair and handling



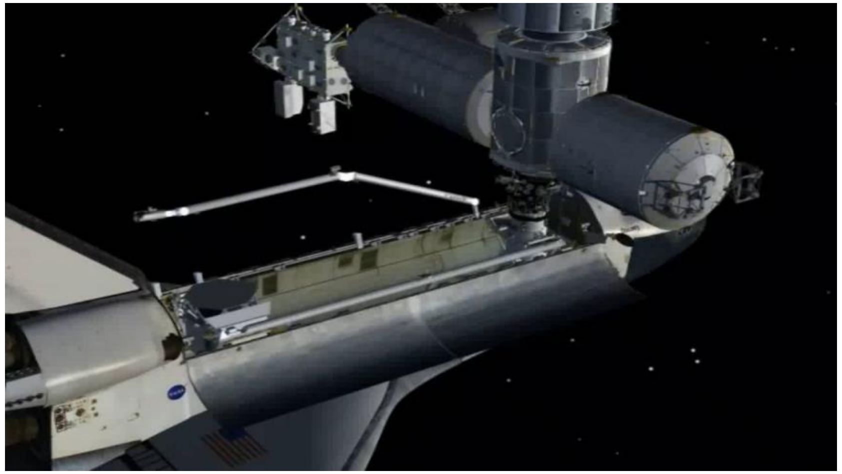


At at the end of the FCC-hh operation, the dose rate levels 1 mSv/h in the entire tracker cavity values do not decrease significantly for 1 month or 1 year of cooling time. This radiation comes mainly from the highly activated forward calorimeters, so an opening scenario must foresee an automated displacement of this object into a shielded garage or bunker in order to limit the dose for personnel.

KUKA robotics



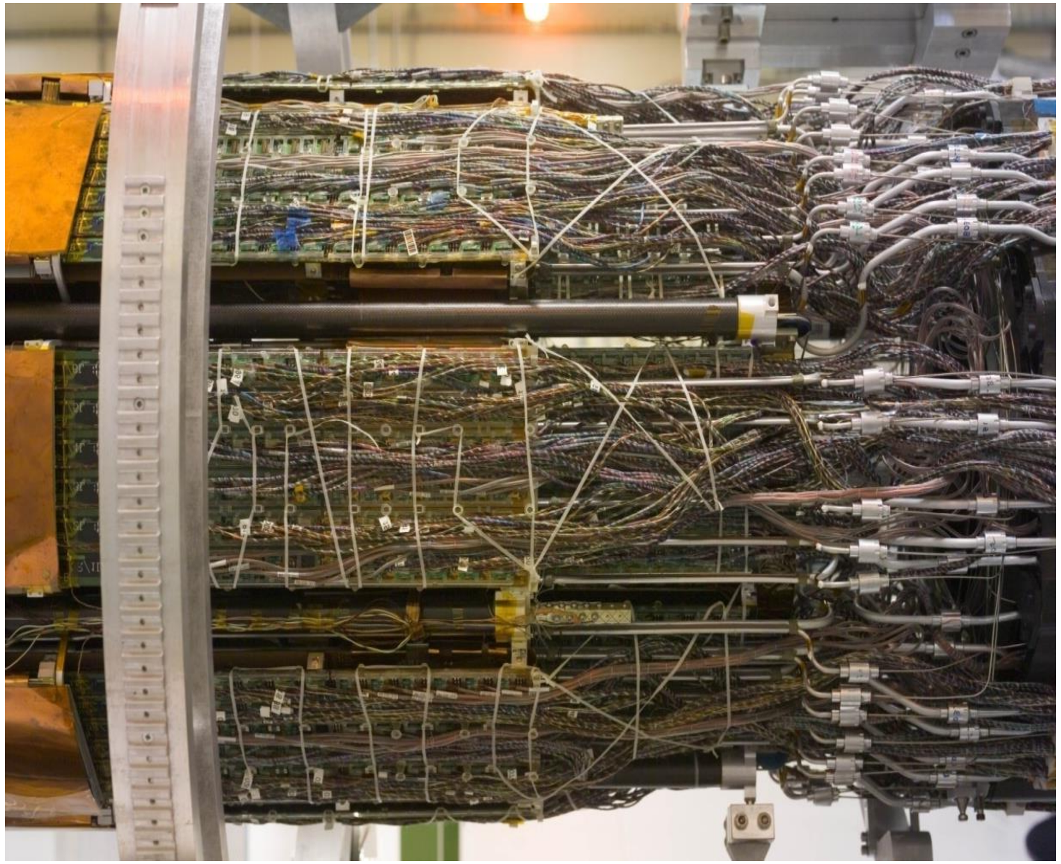
NASA



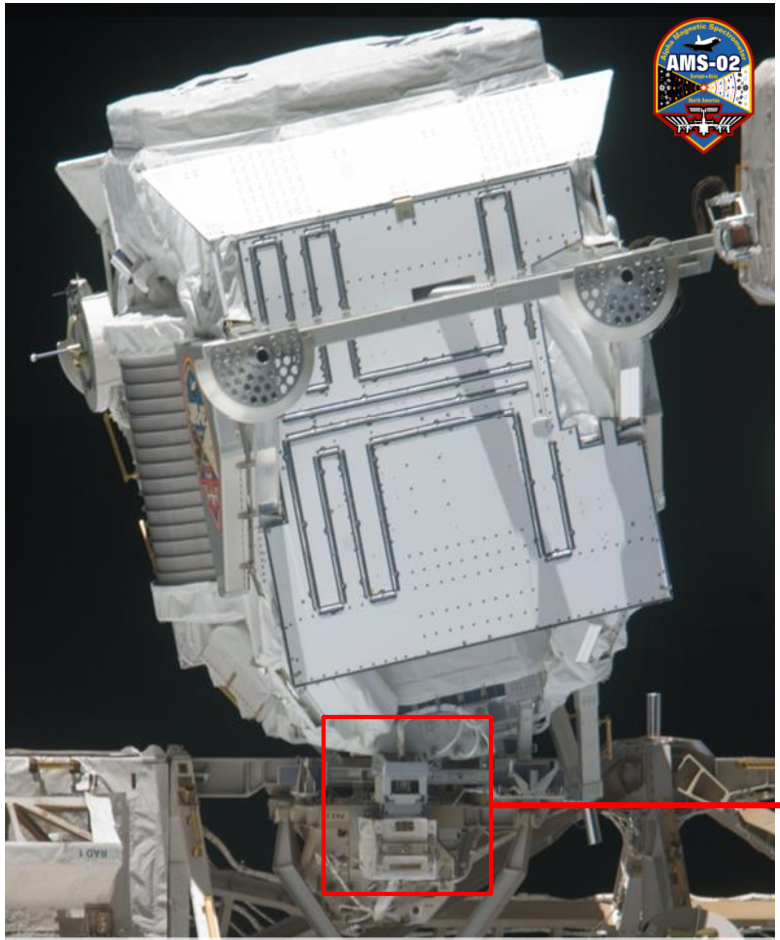
✓ Remote Manipulator System RMS, Automated Guided Vehicles AGV, will be investigated, detector I/F design developed

SERVICES UMBILICAL MECHANISM ASSEMBLY - **SUMA**

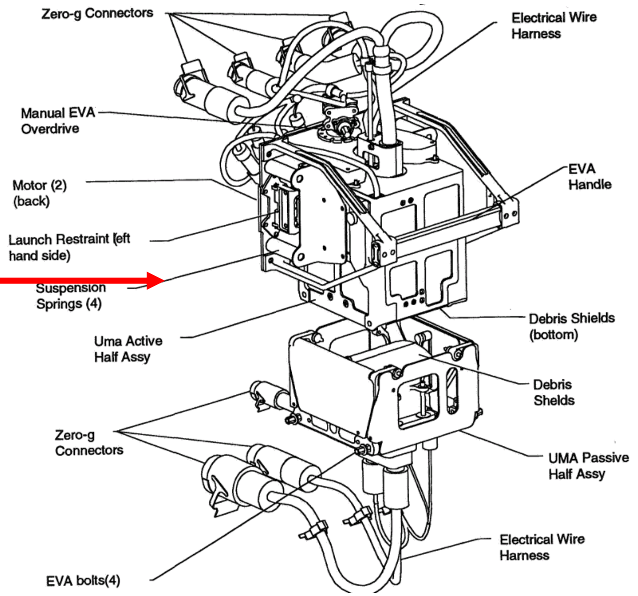
✓ Work in-situ will have tight limitations for future hh detectors. Simplify and minimize the services connections is a priority



ATLAS Pixel has 1 connector per module at PP0
AMS_02 has 1 connector for the entire Experiment



***Umbilical Mechanism Assembly** (UMA)*
The UMA is the way the power is supplied from the ISS to AMS-02



✓ Investigate Mechanism for dis/engaging electrical and fluid line connectors in hazardous or remote locations

ACTIVITY N.2

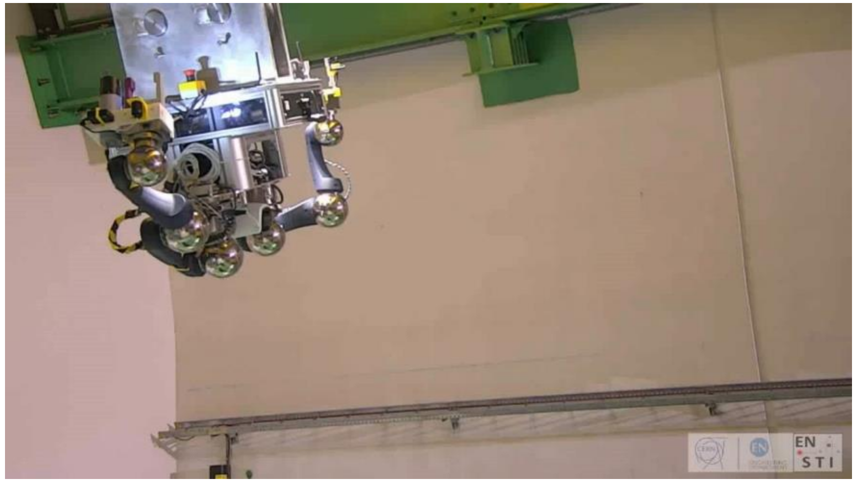
ON DETECTOR ROBOT SYSTEMS - **ODRS**

✓ New detector must be designed to be easily maintained such to decrease personnel exposures to hazards

Limit
human intervention
for
Detectors' maintenance

Robots at CERN
(EN-SMM-MRO)

TIM: *Built at CERN, used for inspection, radiation mapping of LHC*



Telemax: *environment inspection, teleoperation.*
Un/screwing
LHC TDE inspection
SPS TIDVC

✓ Designing Detectors that can be maintained by robots using appropriate and easily accessible interfaces

✓ Tele-manipulation system, Virtual and augmented reality, Learning by demonstration

ACTIVITY N.3

HIGH-PERFORMANCE COOLING FOR FUTURE DETECTORS

HIGH-PERFORMANCE COOLING FOR FUTURE DETECTORS

ACTIVITY N.3

Description

Environmental friendly, radiation resistant, single-phase and phase-changing coolants for **new operative requirements** of future detectors. **Cooling pipework and instrumentation** for large distributed systems adapted to the different challenges posed by detectors at future hadron or lepton colliders.

Milestones → Deliverables

Year	Milestones → Deliverables
1	Selection of candidate fluids (synthetic and natural) for single/ two-phase applications→ Report candidate fluids
2	Selection of candidate instruments and insulated pipework.→ Report on pipework solutions
3	Analysis and modelling of thermo-fluid properties suited for detectors.→ Analysis Report on fluids performance
4,5	Build and test reduced scale prototypes of the future cooling systems. → Tested demonstrator cooling system
	Investigation on fluids' limits of applicability in different detector classes → Tests Report fluid limits in detector

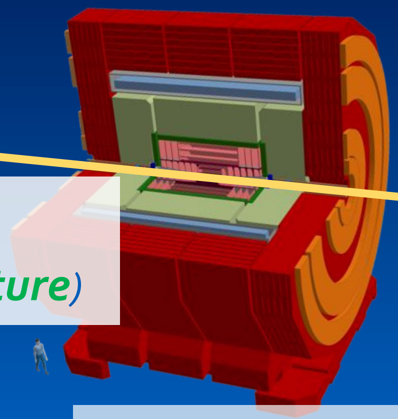
Cooperation with

WP1, WP3, CERN-EN-CV, 3M, Honeywell Fluids, NTNU, GE, NTO, MPI Munich,…

Potential co-fundings: AIDA 2020 extension, Marie Curie MSCA-ITN-2019; CERN & NTNU Collaboration, CEPS.

HIGH-PERFORMANCE COOLING: FOR FUTURE DETECTORS

Remove heat generated on the detector (→ *power*)
Keep detectors cold to limit leakage currents (→ *temperature*)



FCChh, HE-LHC, …	hh collisions	e^+e^- collisions	*CLIC, FCCee, ILC, CEPC,…*

- *High radiation dose (~ 100 MGy/10years)*

Very Low Temperature
High Pressure

- *Unprecedented spatial resolution (1-5 μm point resolution)*
- *Low dissipated power (<50mW/cm2)*

Room Temperature
Minimum Material budget

gas ***AIR*** *suitable only for very low on-detector dissipation*

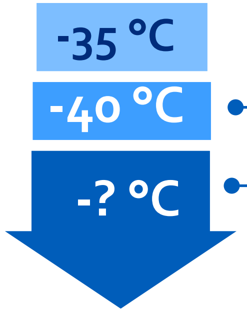
mono phase ***WATER*** *"leakless"* ***, FKs, NOVEC***

two phase ***CO_2/N_2O, HFOs***

✓ Future lepton collider ambient temperature viable solution: air cooling or liquid cooling for complex detector geometry
✓ Future hadron collider, more powerful cooling and also lower coolant temperature: CO_2/N_2O?

HIGH-PERFORMANCE COOLING: **FOR FUTURE DETECTORS**

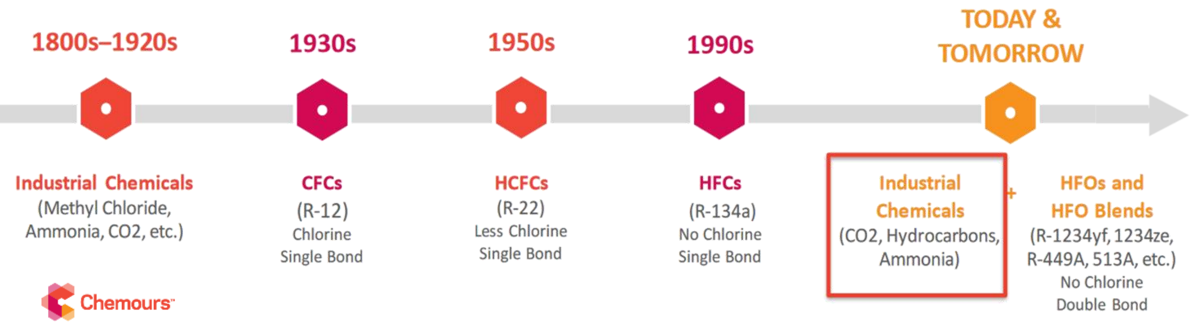
✓ Effective substitution refrigerants of new generation for very low temperatures are still an issue of active R&D



Current state-of-the-art in hh is two phase evaporative cooling with CO_2 fluid for inner tracking detectors.

Due to its intrinsic limitation on freezing point -56.6 °C , pure CO2 may not be a viable option anymore and replacements need to be found. Among these, CO2/N2O mixtures seem to be extremely promising, but basic studies about the boiling properties of these mixtures are still missing.

Ozone Depletion Potential (ODP)
The potential for substances to reduce the amount of ozone in the atmosphere which blocks harmful radiation from the sun.



Molecule	Structure	Atmospheric Lifetime	GWP
PFC-116	CF3-CF3 (No H)	10.000 y	11100
HFC-134a	CH2F-CF3	13 y	1300
HFO-1234yf	CH2=CF-CF3	11 days	<1

As a more general long-term perspective, the use of environmental friendly cooling fluid must be investigated. Hydrofluorocarbon (HFC) and Perfluorocarbons (PFC) are being progressively substituted in industries by ***Hydro fluoro olefeins (HFOs)*** *and* ***Fuoroketons (FK)****, which have a very low Global Warming Potential (GWP).*

Global Warming Potential (GWP)
The potential for a gas to trap heat in the atmosphere, resulting in climate change.

✓ For these synthetic refrigerants R&D effort of EP will focus on the cooling requirements and thermal performance validation

COOLING FOR FUTURE DETECTORS

✓ Once the cooling power is generated in the plant, the coolant has to be efficiently transferred to the detector.

Cooling lines

- ***Cold transfer lines*** *in hadron collider detectors need to be* ***insulated*** *from the surroundings and installed in congested spaces.*
- ***Minimal material budget pipework*** *compatible with the selected refrigerant are also to be qualified for lepton collider detectors. New layout architecture shall be studied*
- *In all cases, the large detector dimensions will call for an* ***increased integration*** *of the cooling system to* ***minimise number of parallel lines****.*

Instrumentation

R&D on ***cheap and rad hard sensors*** *for pressure and flow readings, on large number of instrumented lines*

✓ Minimise number of dismountable connections, provide reliable solution, mitigate failure and leak through QA

✓ Cheap and radiation hard sensors for cooling system pressure and flow readings.

- Low mass mechanics for detectors support and thermal management
- Automated-robotic detectors maintenance
- New cooling solutions

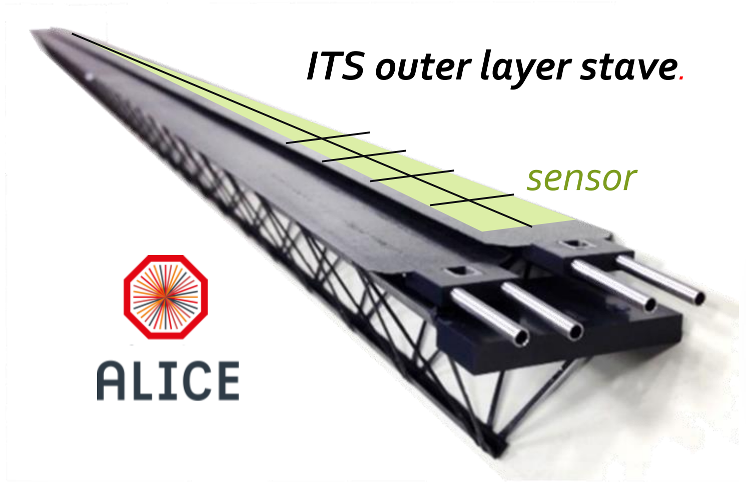
Cooperation with external teams is welcome,
…often essential, to strengthen the EP R&D program

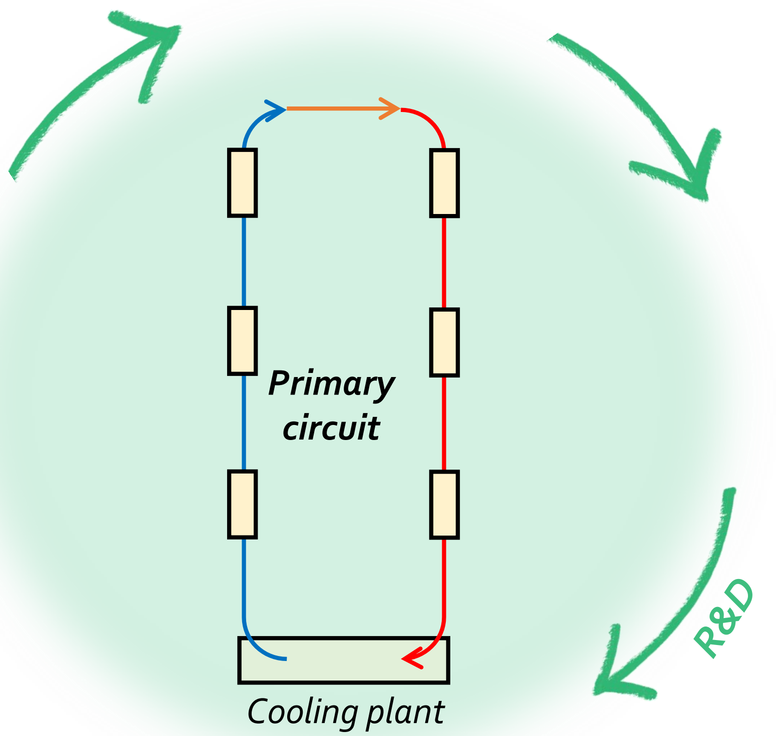
https://ep-dep.web.cern.ch/rd-experimental-technologies
http://cern.ch/ep-rdet-wg4-mech

BACK-UP

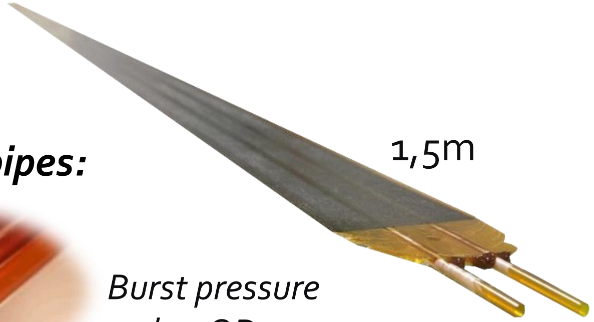
TRACKER DETECTOR: LARGE AREA COVERAGE

✓ Find best compromise between minimum material, cooling performance and cost for large surface coverage





Polyimide pipes:



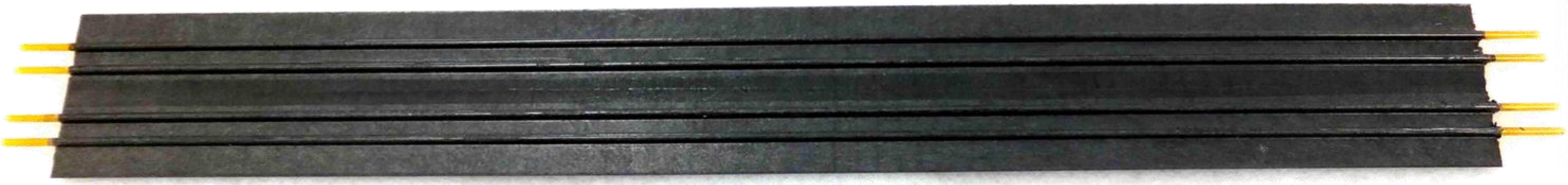
Burst pressure 50 bar OD=1mm

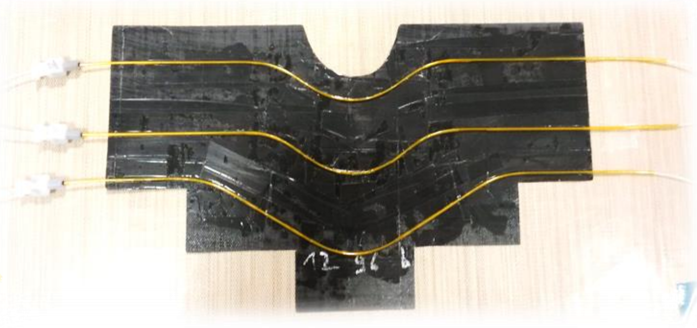
BRAIDED-COILED Polyimide pipe

Investigate burst pressure increase with braided reinforced polyimide pipes

Large surface carbon vascular substrate:

(steel, fibre,..) tube, available on the market, allow for larger pressure value, (hoop strength almost double), and smaller bending radius'.





✓ Cheap and disposable large substrate such as carbon fibre structures embedding polyimide pipes will be exploited.

hh collisions

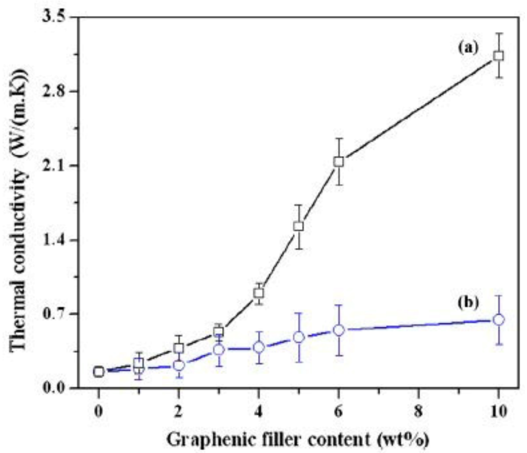
COMPOSITE: CARBON NANOTUBE & HIGH RADIATION

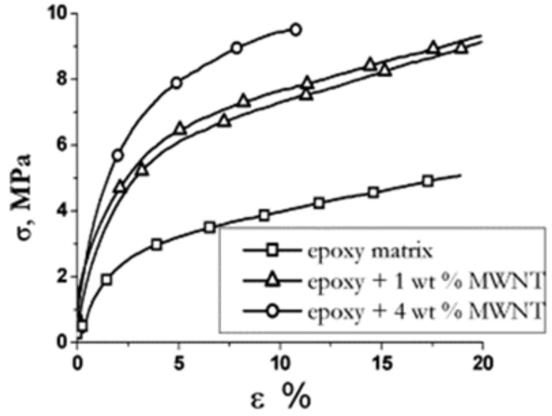
✓ In future high radiation environments, organic materials used in mechanical structure can suffer from their loss of properties

Composite enhanced properties

Carbon Nanotubes and/or Graphene + Epoxy

Graphene shows outstanding mechanical and thermal performance at microscale level. The ultimate goal of epoxy nanocomposites is to extrapolate the exceptional intrinsic properties of the nanoparticles to the bulk matrix.





Composite radiation hard

Organic materials used in mechanical structure can suffer from their loss of mechanical, electrical, optical and chemical properties as a result of accumulated radiation dose

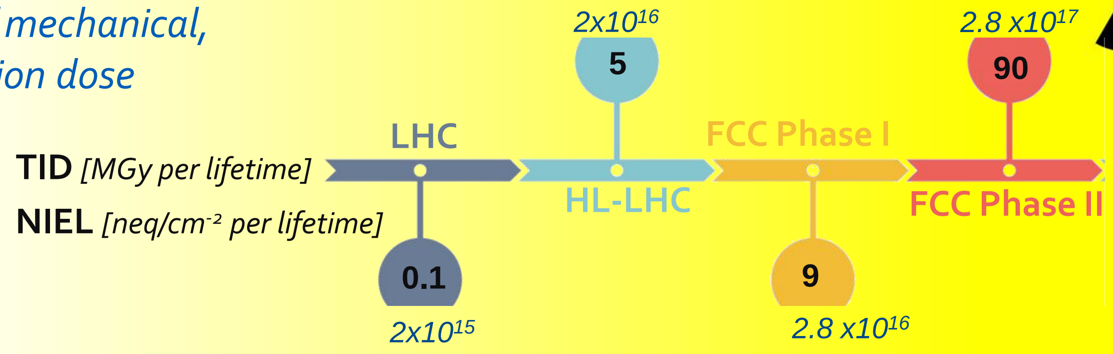
Resin with better resistance to radiative environment

Cyanate Ester *(CE) Tencate EX1515, Tencate RS3, and Hexcel 954.*

Cyanate Siloxane *Hexcel 996.*

CFR-Polyimide*, Tencate TC890*

CFR-PEEK



Lifetime: LHC, HL-LHC: 7 years; FCC: 10 years

...many times the radiation load of LHC

✓ Investigate new composite materials to improve thermomechanical and radiation hardness properties.