UMassAmherst

The Commonwealth's Flagship Campus

Developments in Silicon Tracker Mechanics

Rafael Coelho Lopes de Sa

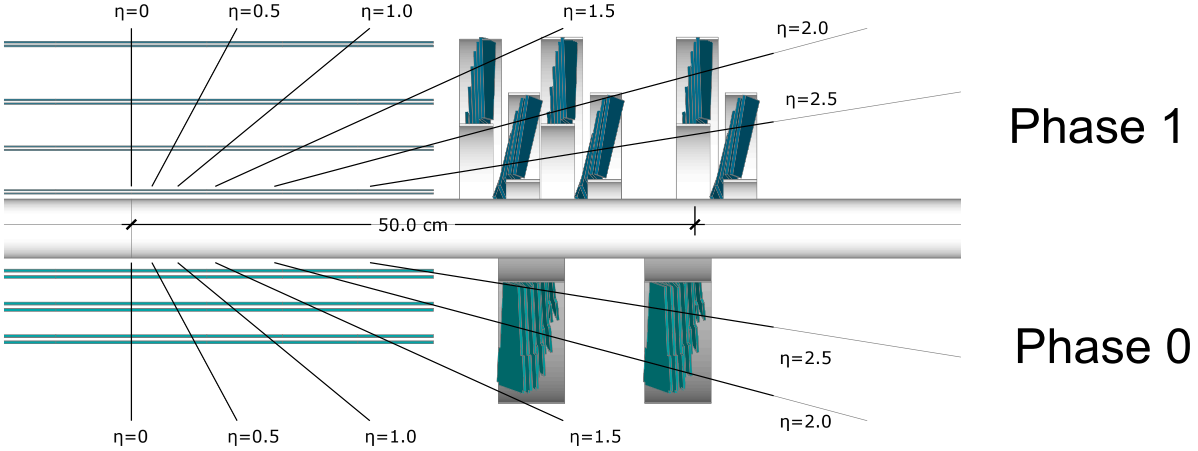
01/17/2018

Contents

- This talk is divided in three parts. The first two parts are projects that I have worked on (or I am currently working on). The last part is a gentle walk through some ideas being developed for other detectors.
  - [The past] The CMS Phase I FPIX upgrade
    - CO_2 cooling and 2PACL cycle
  - [The present] The ATLAS Phase II ITK Inner System upgrade
  - [The future] Some ideas from innovative detectors

[The past] The CMS Phase I FPIX Upgrade

New pixel detector for the CMS experiment successfully installed in the 2016 EoY shutdown

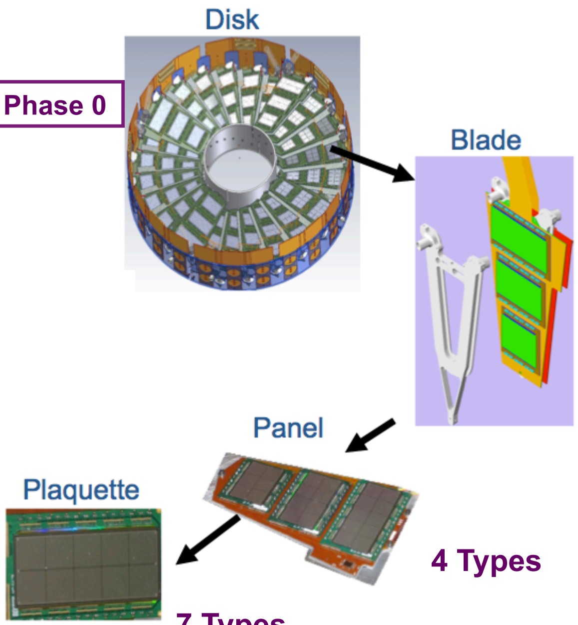


CMS FPIX - Mechanical Design Choices

- Reduction of material budget
  - Use carbon fiber and graphite support structure
  - CO_2 cooling with small stainless steel tubes
- Easy maintenance
  - Only one module type
  - Independent inner and outer disks (inner disk can be replaced)
  - Modules tilted to improve hit resolution

Improvements over original pixel detector

Phase 0

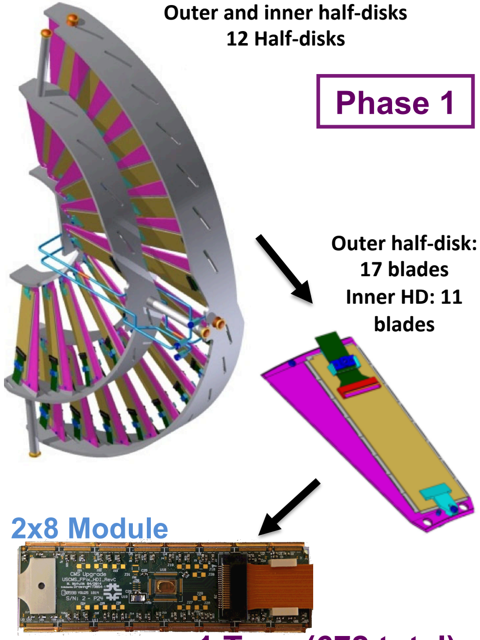


4 Types

7 Types

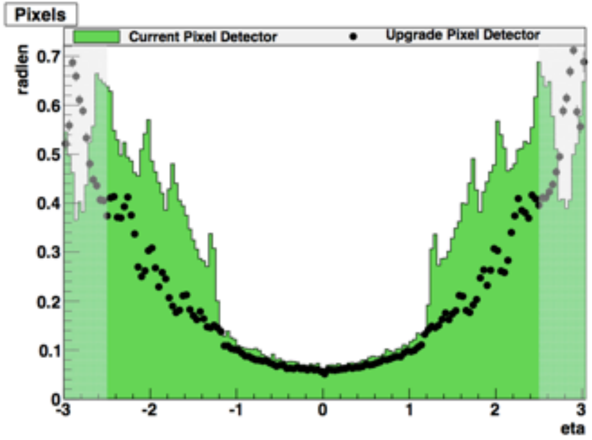
Outer and inner half-disks
12 Half-disks

Phase 1



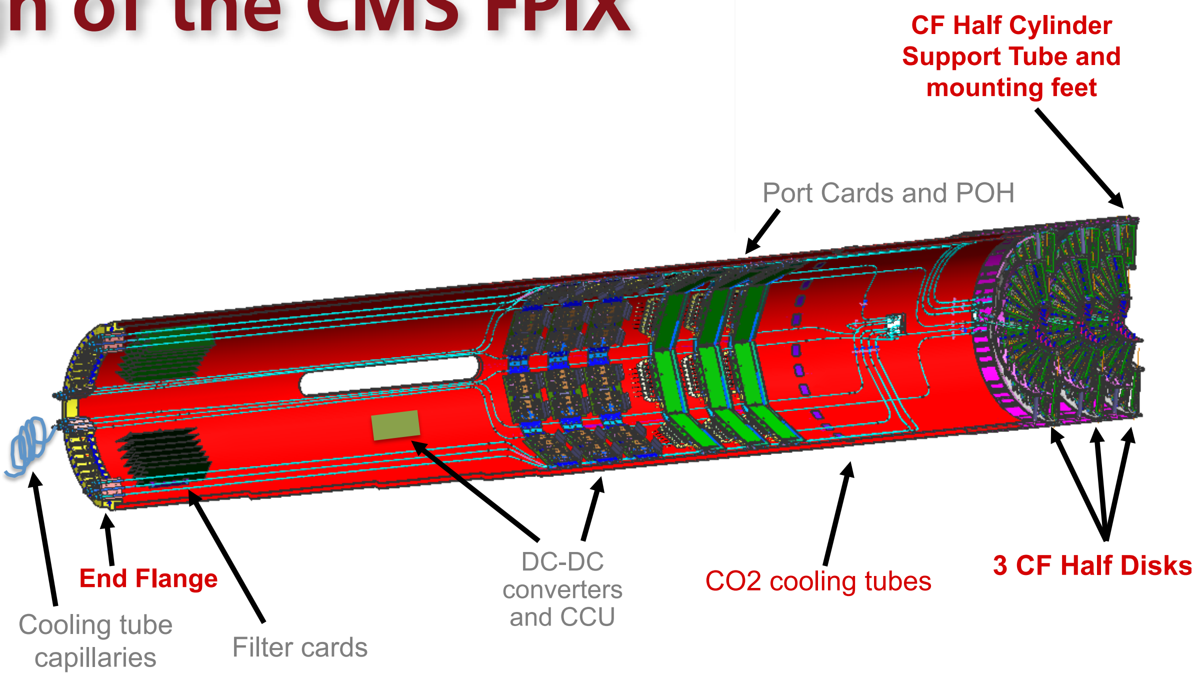
1 Type (672 total)

Material budget



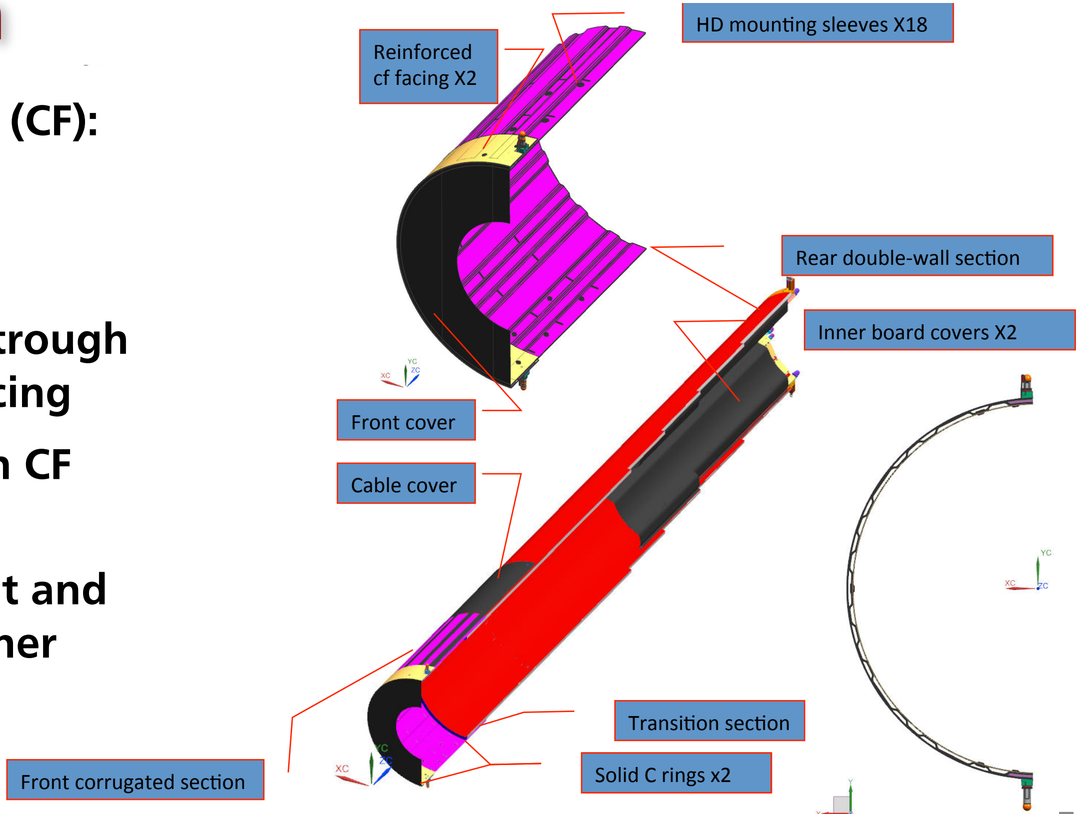
Mechanical design of the CMS FPIX

- **Half-cylinders (4)**
  - **Integration structure for modules, electronics, and cooling pipes**
- **Half-disks (24)**
  - **With integrated evaporators**
- **Modules (672)**
  - **Mounted on thermal pyrolitic graphite (TPG) blades**



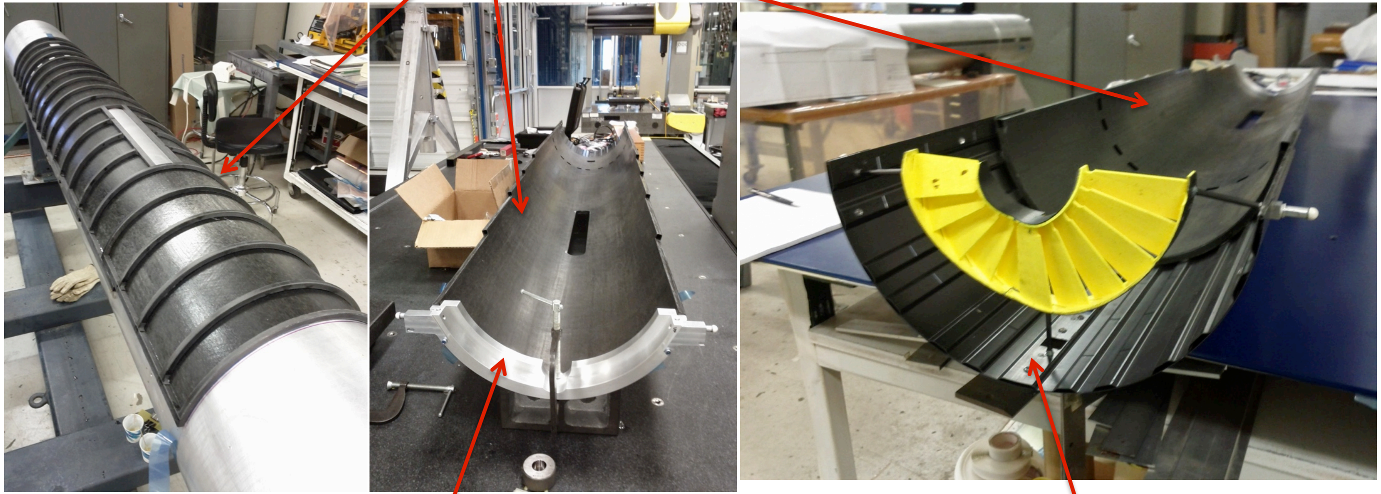
Half cylinder design

- Made of carbon fiber composite (CF):
  - Ultra High Modulus K13C2U
- Cylinder consists of 3 sections
  - Front corrugated single-wall trough section with reinforced CF facing
  - Rear double-wall section with CF ribs in between
  - Transition section where front and rear sections are glued together



Half cylinder construction

Double wall carbon fiber section

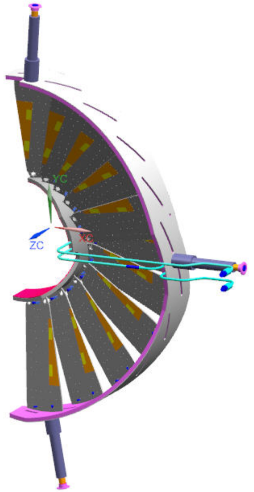


End flange

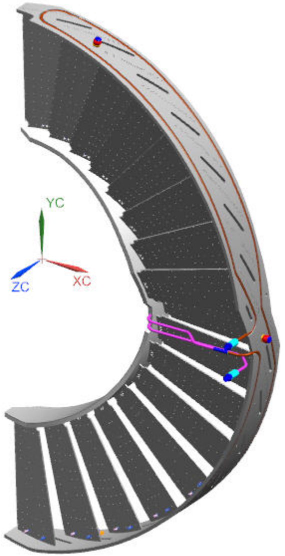
Carbon fiber front section

Local support - Half disk

Inner Assembly

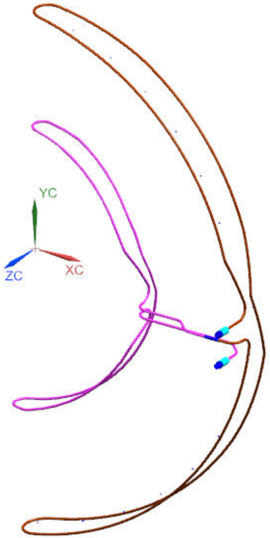


Outer Assembly

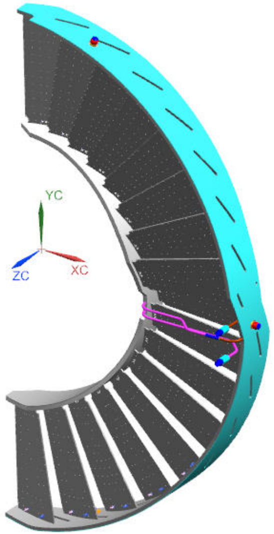


After blades bonded to graphite rings

SS Cooling Tubes



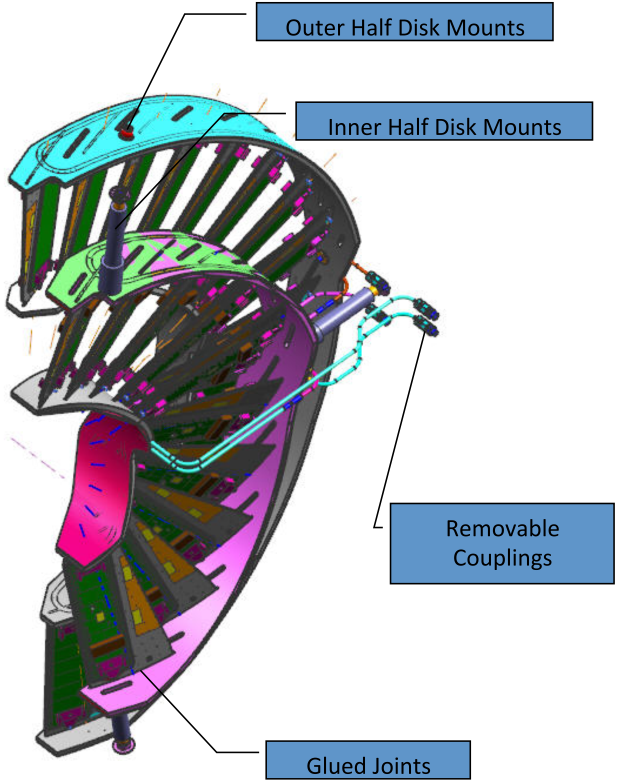
Outer Assembly with tubing and CF facing



After tubing and facing bonded to graphite rings

Half disk design

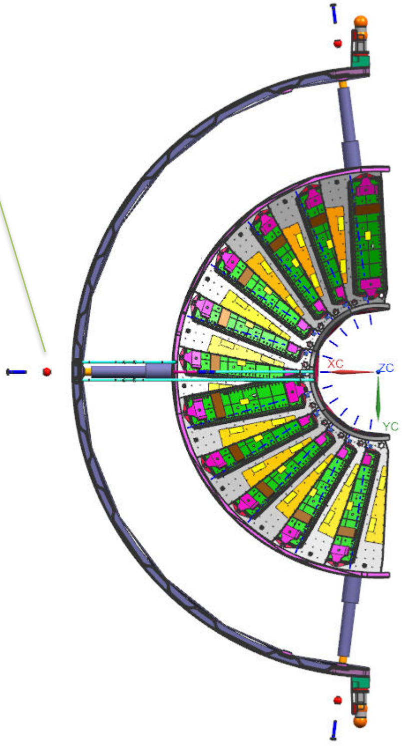
- Half disk consists of an inner blade and an outer blade assembly
- Both assemblies are fastened to the half cylinder with 3 mounts
- All blades are glued to 2 supporting half rings that work as heat sinks
- Cooling tubes are embedded within the rings with removable fittings

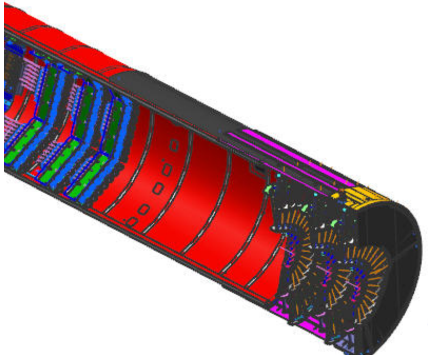


Half disk design

- **Half disk consists of an inner blade and an outer blade assembly**
- **Both assemblies are fastened to the half cylinder with 3 mounts**
- **All blades are glued to 2 supporting half rings that work as heat sinks**
- **Cooling tubes are embedded within the rings with removable fittings**

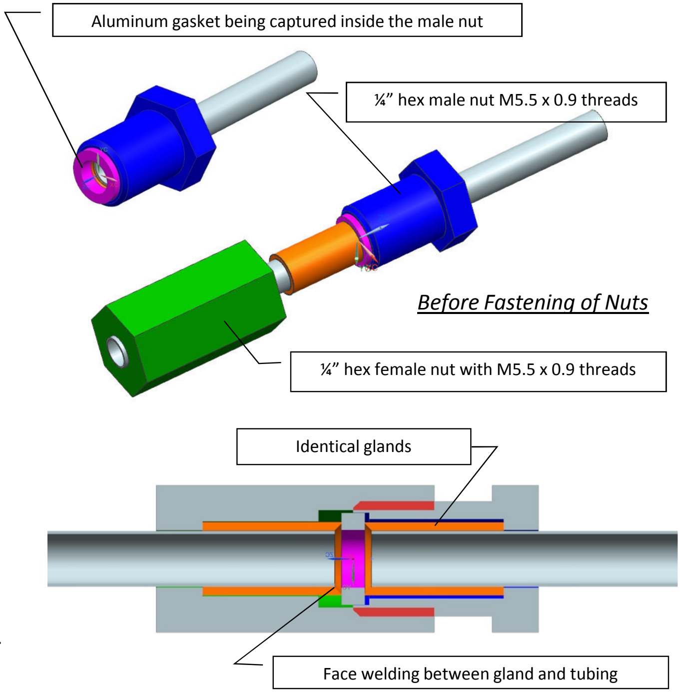
Sliding 5mm ruby balls inside HC inserts





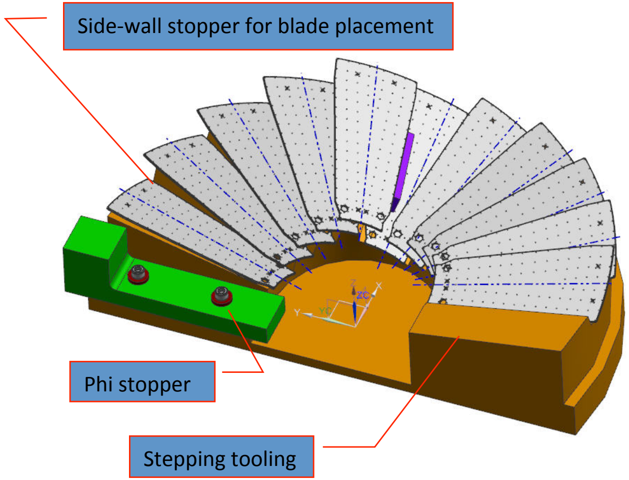
Custom designed fittings

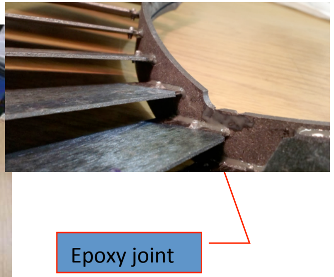
- No commercial solution for small diameter tubes (1.7mm diameter)
- Nuts are turned with minimal friction during fastening without the potential of twisting the tubing
- Gasket is seated properly within the male nut before fastening. Metal seal
- Glands is made of VIM-VAR 304 L SS (to avoid hot cracking) and welded to SS tube.
- Gasket is made of aluminum 6063 T6
- Nuts are also made of aluminium, but high-strength 2024 T4



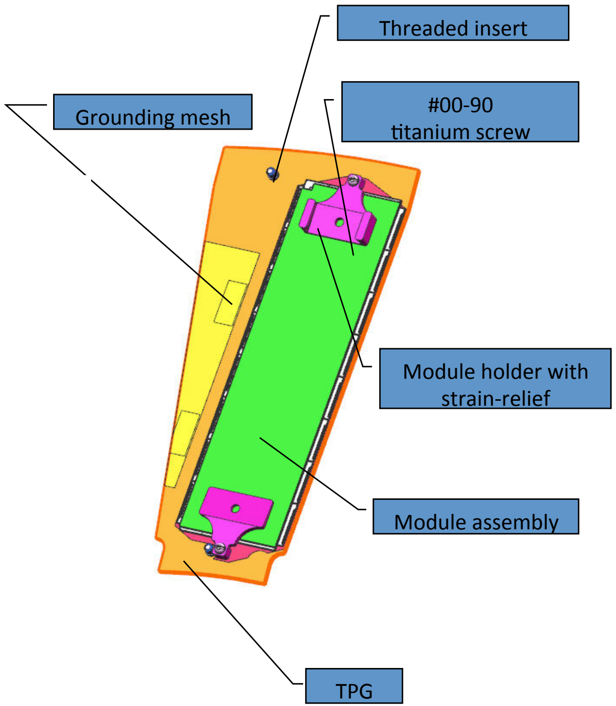
Half disk construction

- Use of fixtures sets precision of finished assembly
- TC 5022 thermal compound in blade-to-ring joints is sealed in by DP190 epoxy
- Exposed carbon edges of disk assembly sealed with epoxy



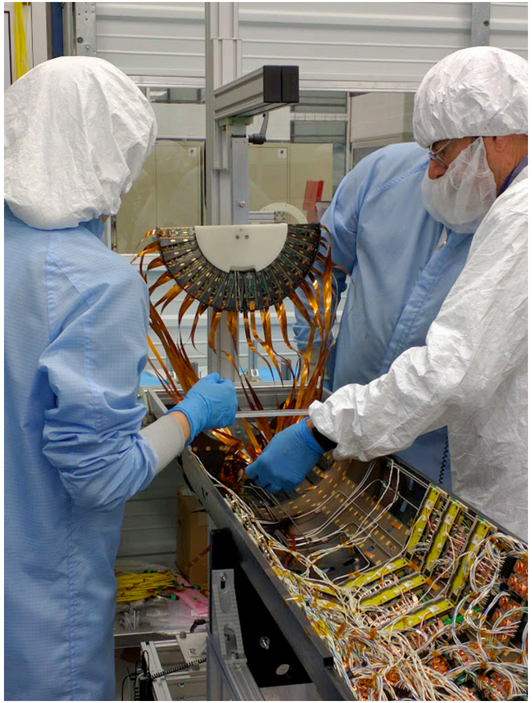


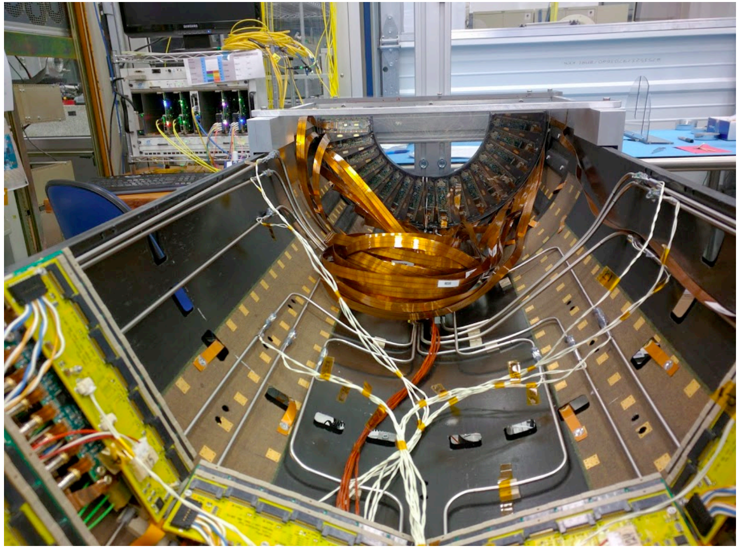
Design of the pixel blade



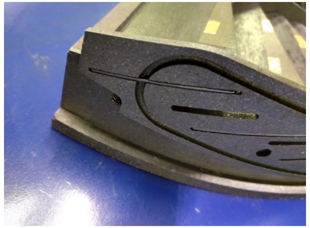
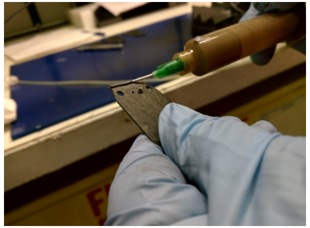
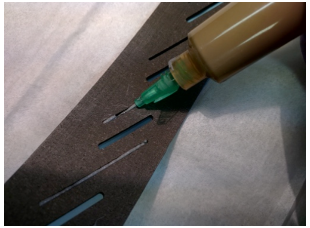
- Solid TPG (0.68 mm thick, highly thermally conductive with in-plane k = 1500 W/(m*K)) encapsulated with carbon-fiber facing (~60µm thick)
- All blades within the half disk are identical, with one module on each side.
- Cooling is arranged at the ends of the blade where blade is bonded to the cooling rings.
- Removable silicone thermal interface film with 4 W/(m*K) is used between the module and blade.
- Aluminum threaded inserts are glued on the blade for module mounting

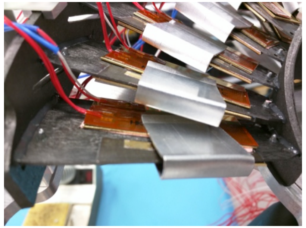
Assembly in the US (at Fermilab's SIDet)





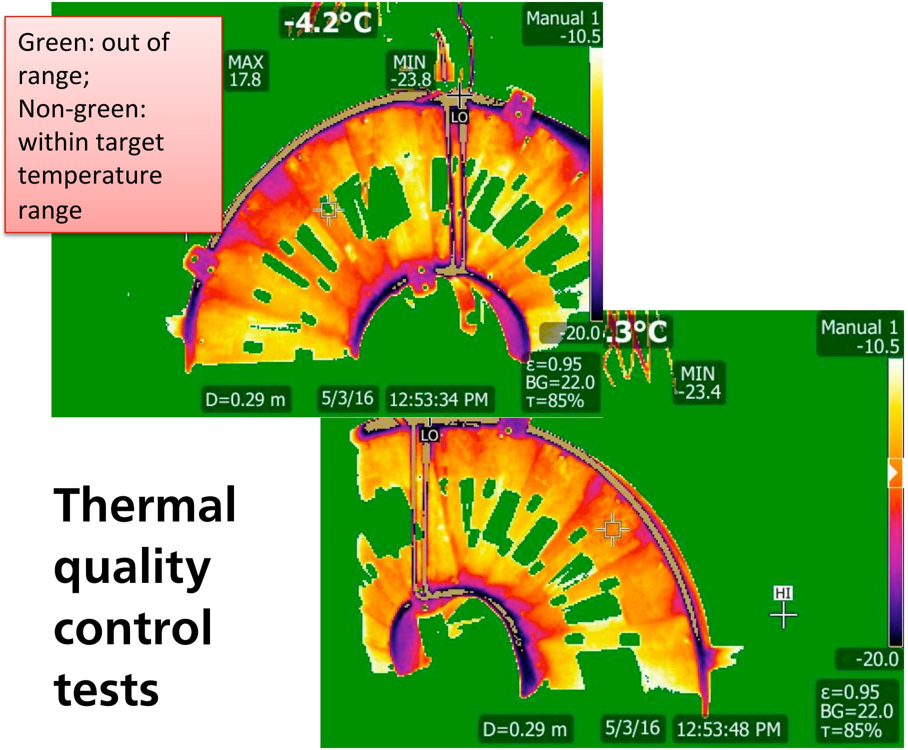
Thermal management

- To make tilted blade work, very tight control of tolerances in the joints are necessary (took a lot of R&D)
- Achieved ΔT(module, coolant) < 10^{o}C.
- Cooling loop is very conservative
  - Low heat load per loop (~100W).
  - CO_2 cooling with 30% vapor quality.
  - Pressure drop in manifold branches controlled by capillaries.

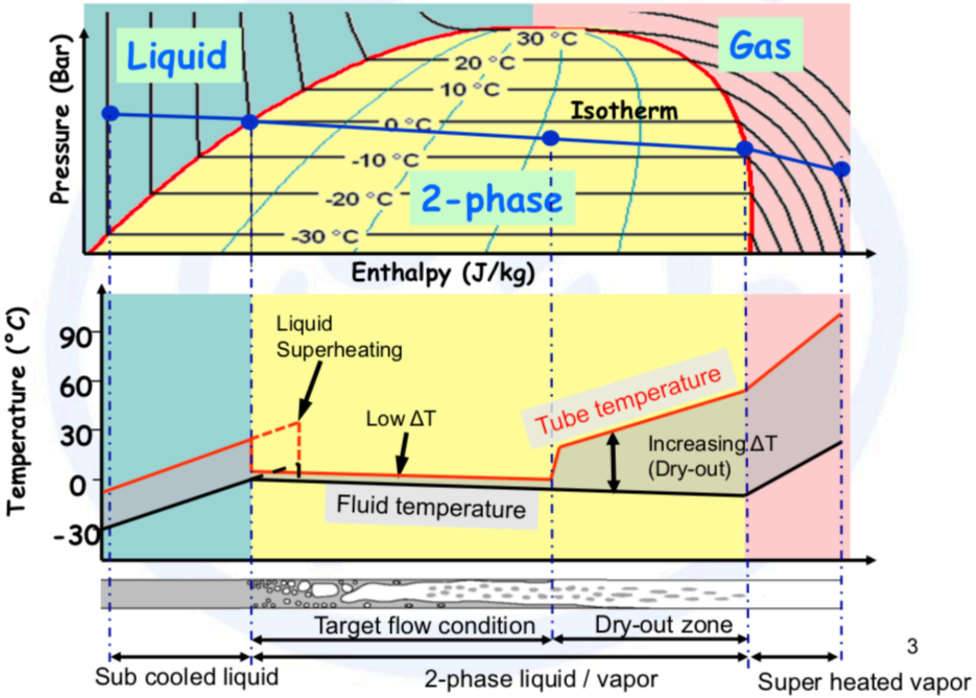
Thermal management

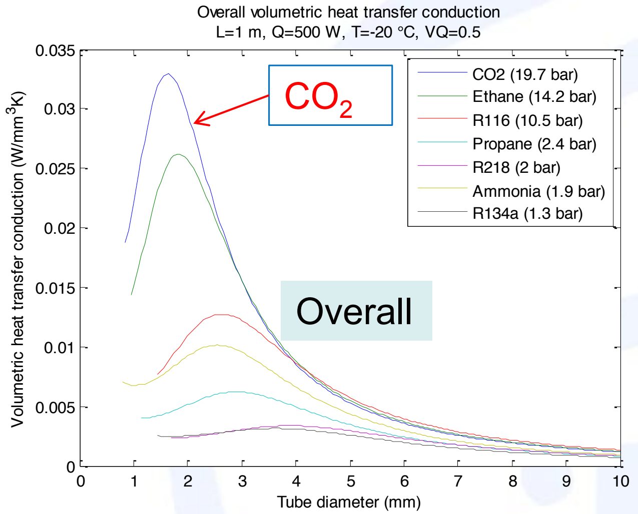


Thermal quality control tests

- To make tilted blade work, very tight control of tolerances in the joints are necessary (took a lot of R&D)
- Achieved ΔT(module, coolant) < 10°C.
- Cooling loop is very conservative
  - Low heat load per loop (~100W).
  - CO_2 cooling with 30% vapor quality.
  - Pressure drop in manifold branches controlled by capillaries.

2-phase cooling

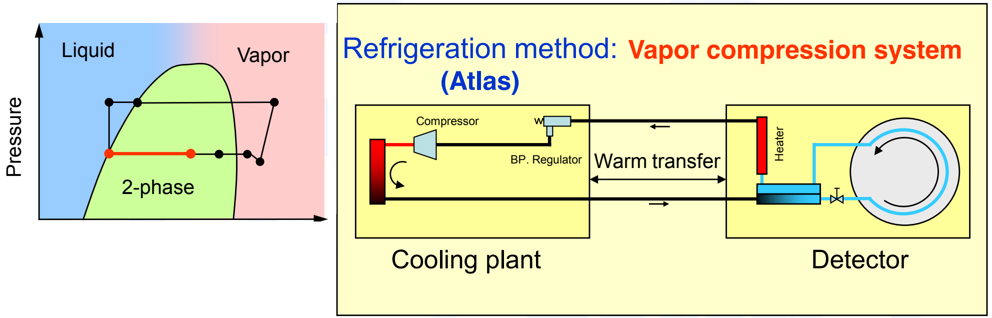


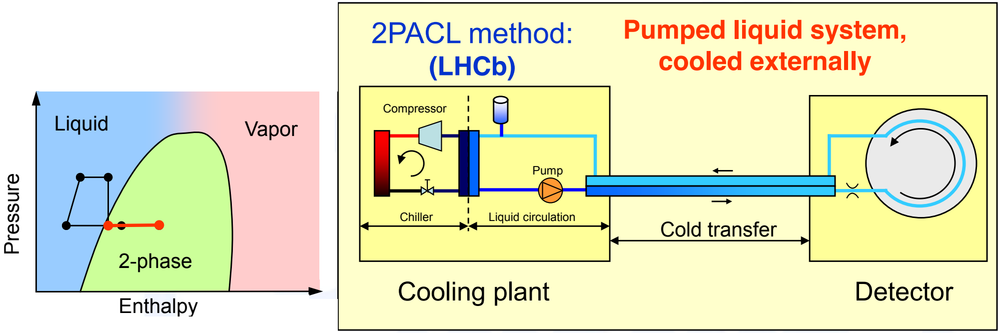


Plus:

High latent heat (less flow)
Low viscosity (low pressure drop)
Non-flammable
Radiation hard
….

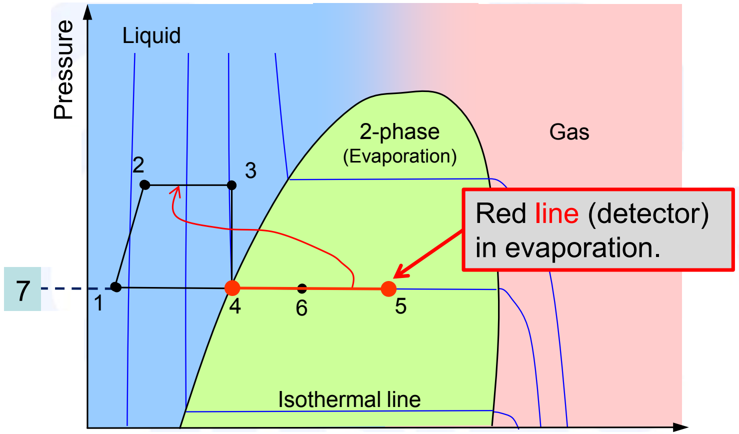
2 PACL cycle



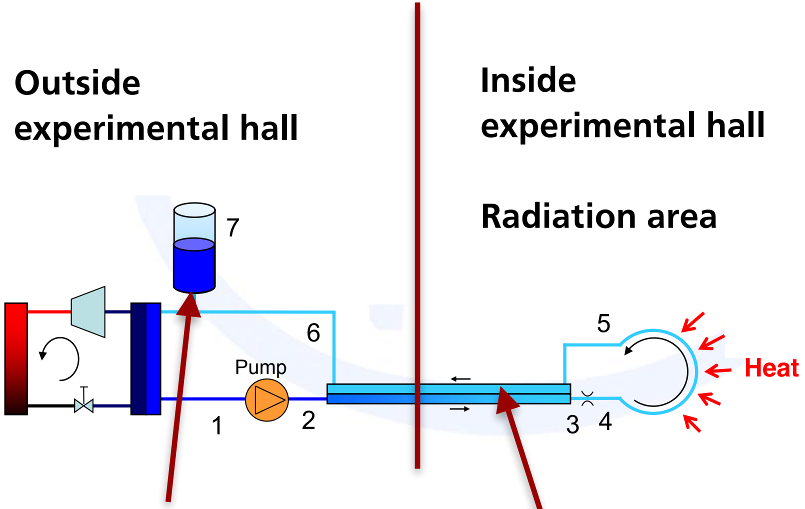


- Cycle stays on the liquid side, no heat required (experiment can be cooled unpowered)
- Primary cooling can be anything, no accurate temperature control needed as long as it is colder than the 2PACL 2-phase temperature.
- Large temperature range.

Advantages of 2PACL cycle



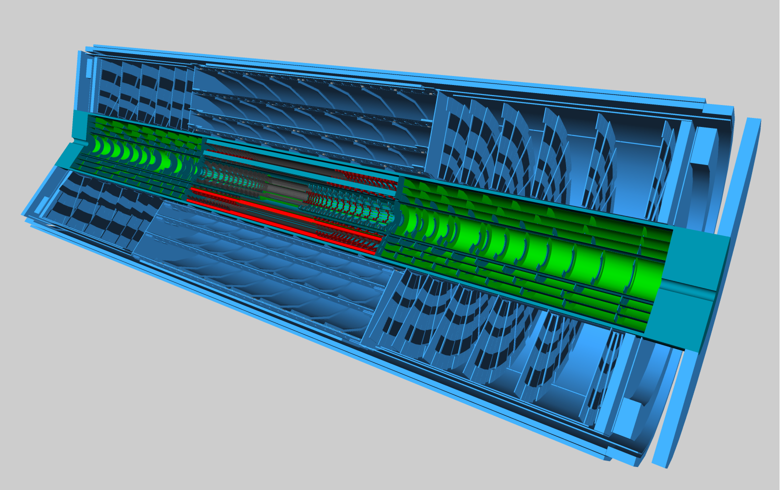
The only part of the system that need to be controlled is the temperature of the accumulator (heaters and chiller branch). But that’s far from the detector.



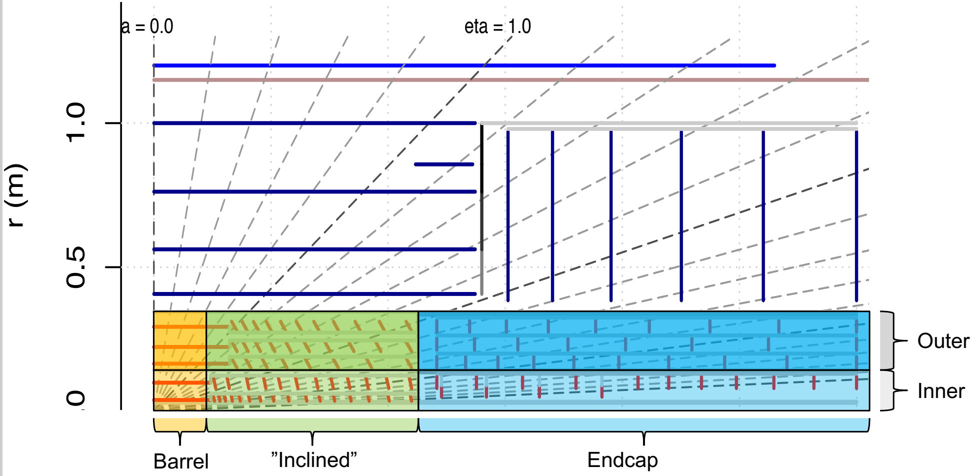
Inlet pressure defined by liquid and gas in equilibrium inside evaporator → always in saturation

Uses outlet fluid to increase the temperature of sub-cooled liquid

[The present] ATLAS Phase 2 ITk Inner System



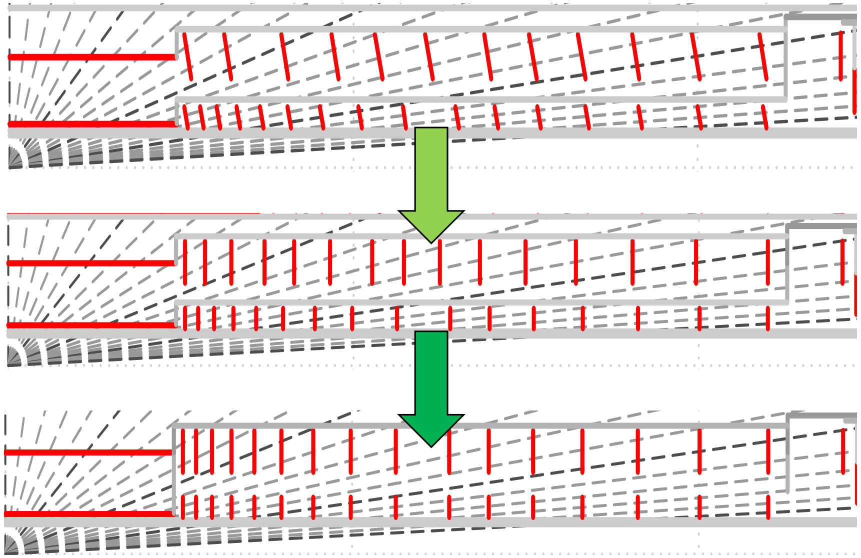
Layout presented in the pixel TDR

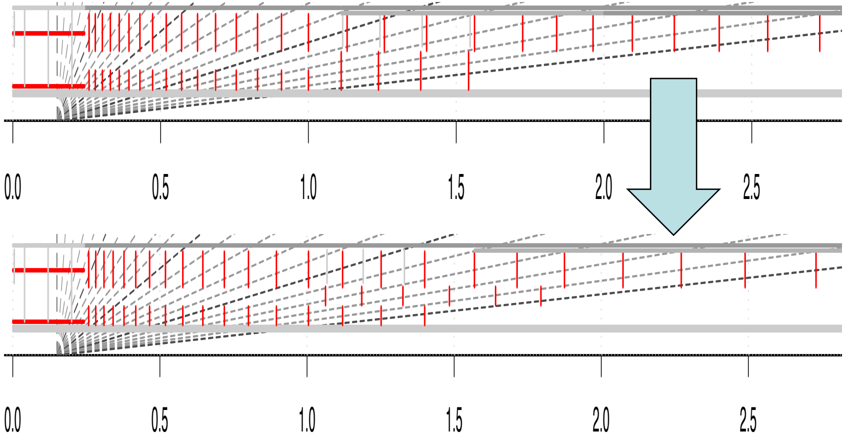


Very small staves minimize amount of services at high η in the first layers

Evolution of the design

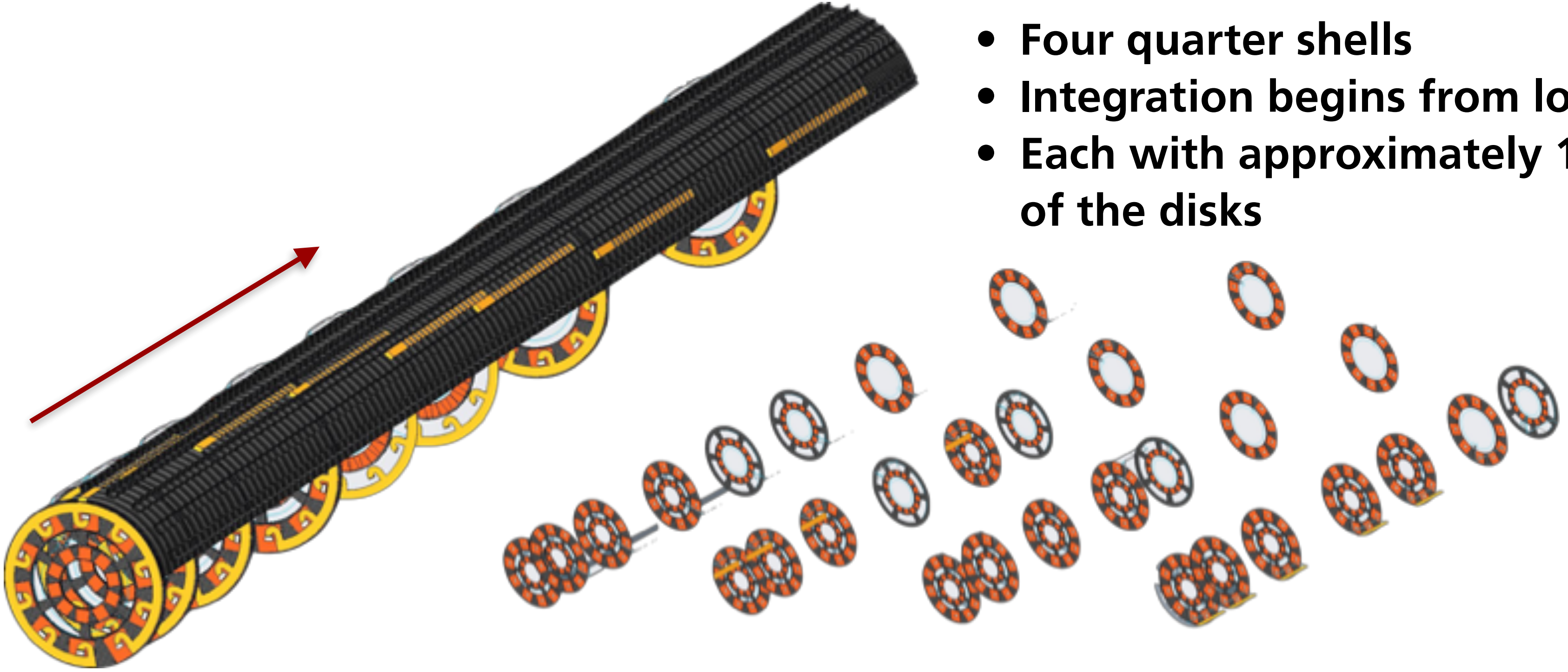
Optimization of individual layers
Angles chosen to minimize material





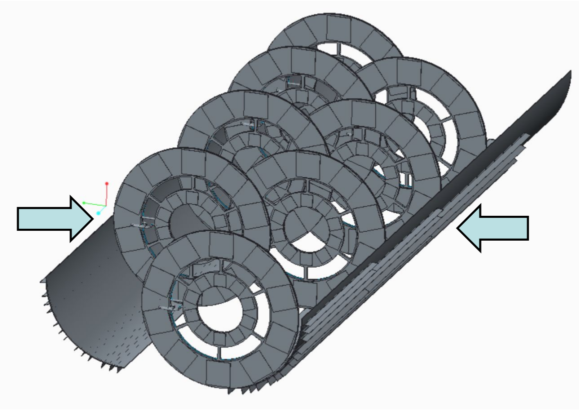
Less is more: simplify design. Greatly improves thermal performance and simplifies mechanical integration.

Integration structure - quarter shell

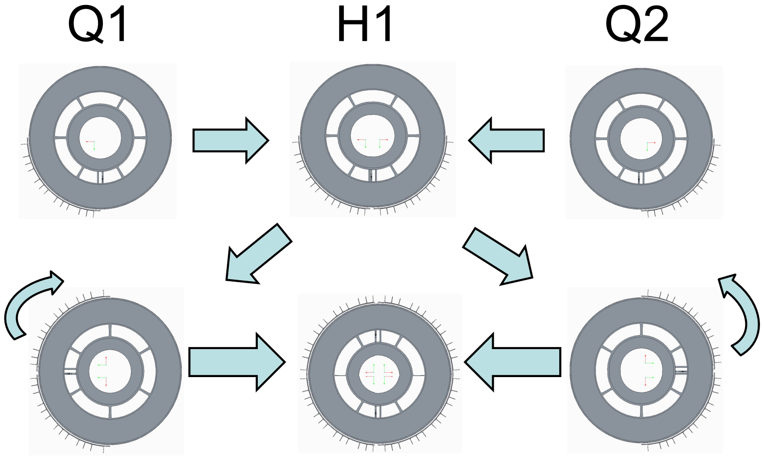


- Four quarter shells
- Integration begins from low z
- Each with approximately 1/4 of the disks

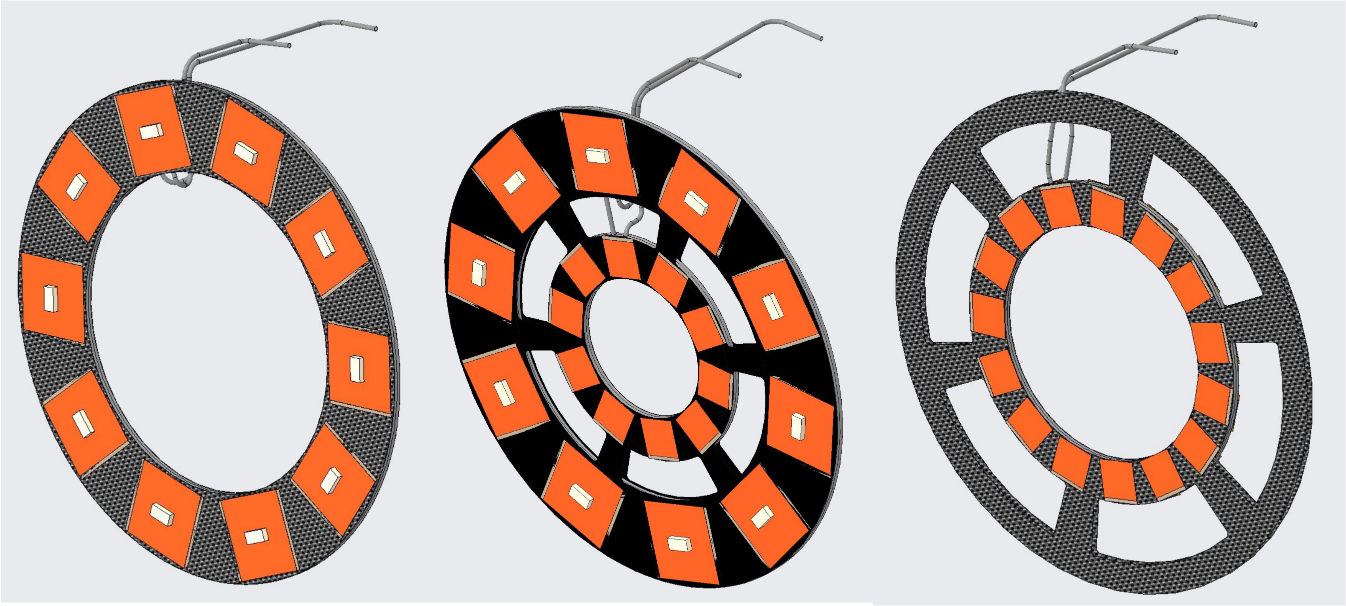
Integration strategy



Radial
Assembly
Of Quadrants



Local support: barrel rings

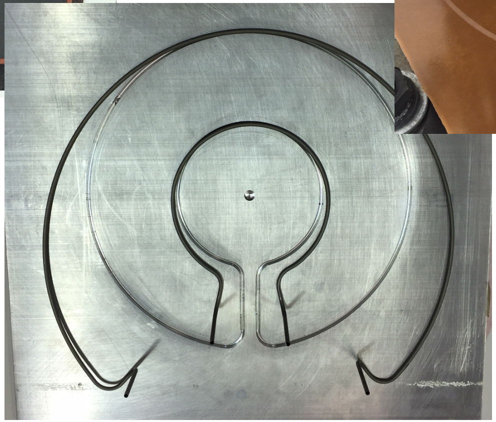


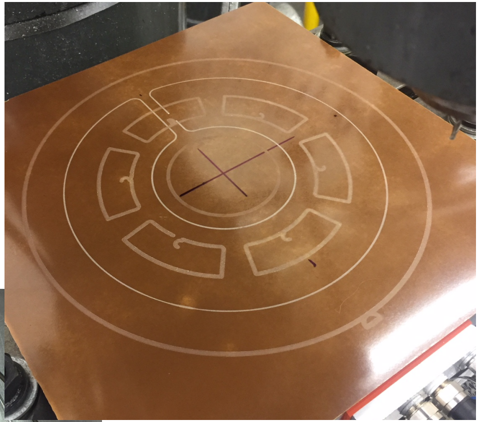
L1 ring L0-L1 coupled ring L0 intermediate ring

Barrel ring assembly

Foam/face co-cured

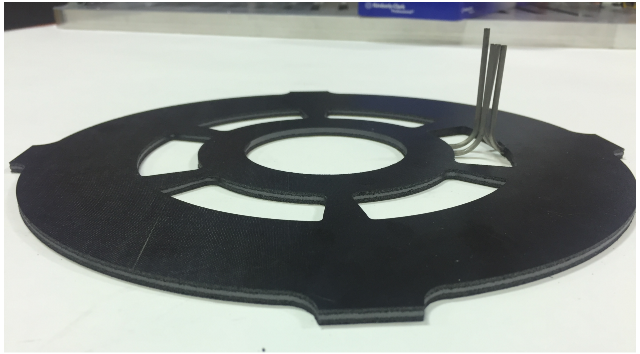
Titanium pipes



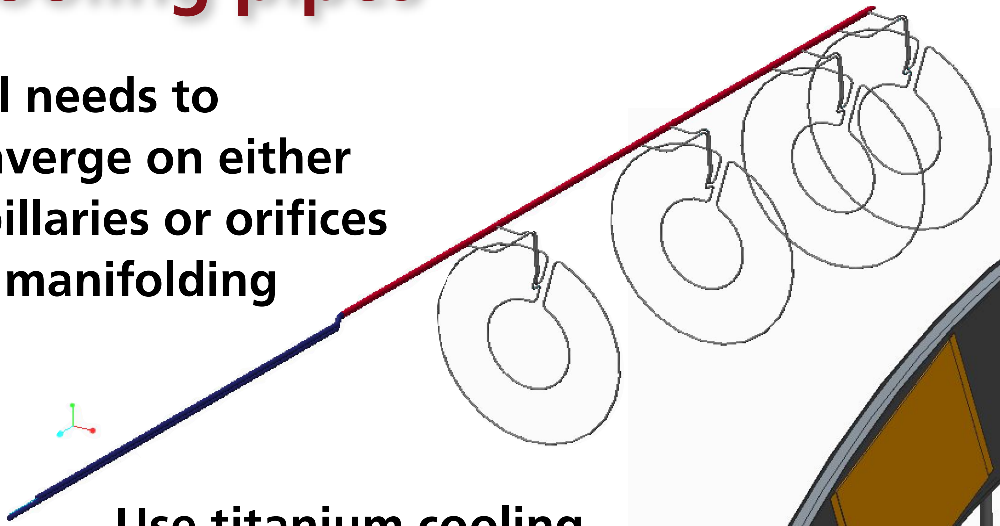


Pipe and shape machined

Bonded assembly

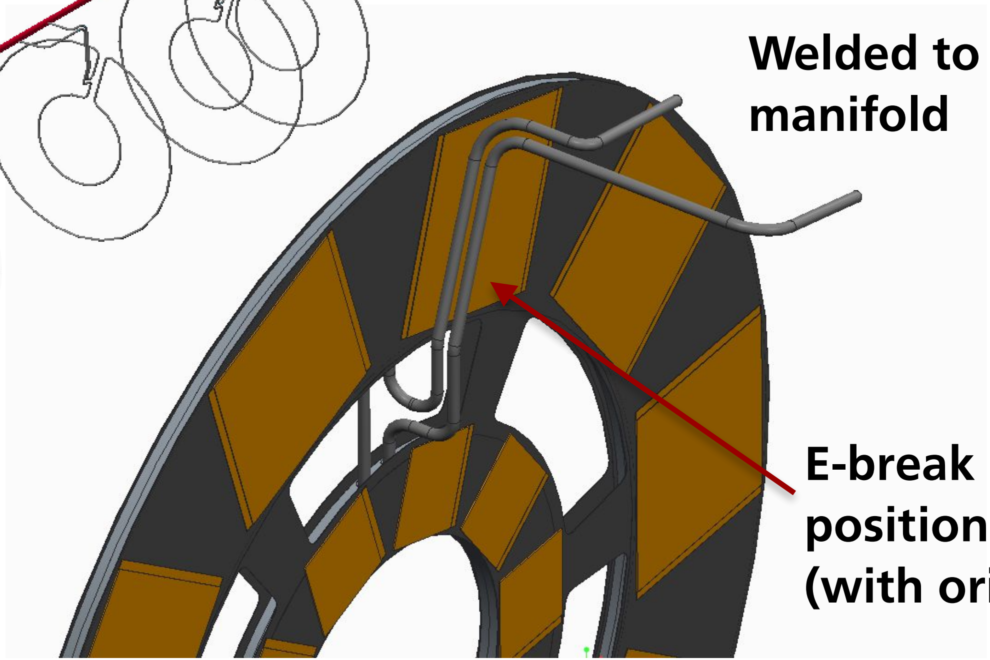


Cooling pipes



Still needs to converge on either capillaries or orifices for manifolding

Use titanium cooling pipes to minimize CTE difference

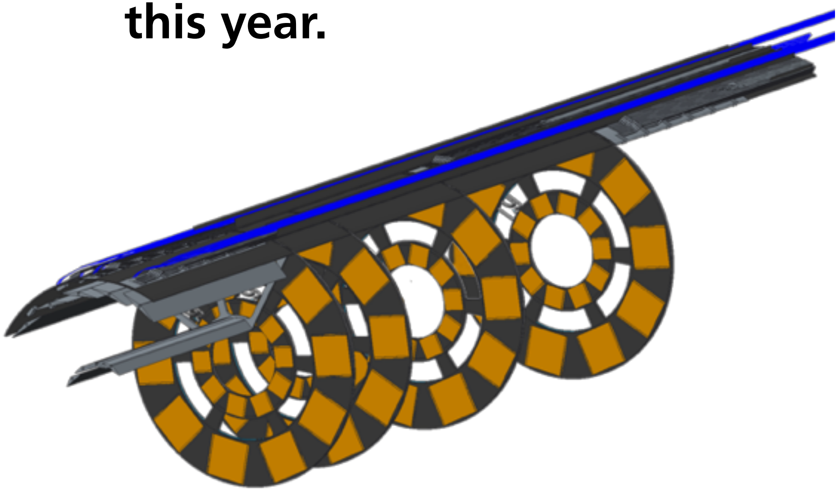


Welded to manifold

E-break position (with orifices?)

Prototype example

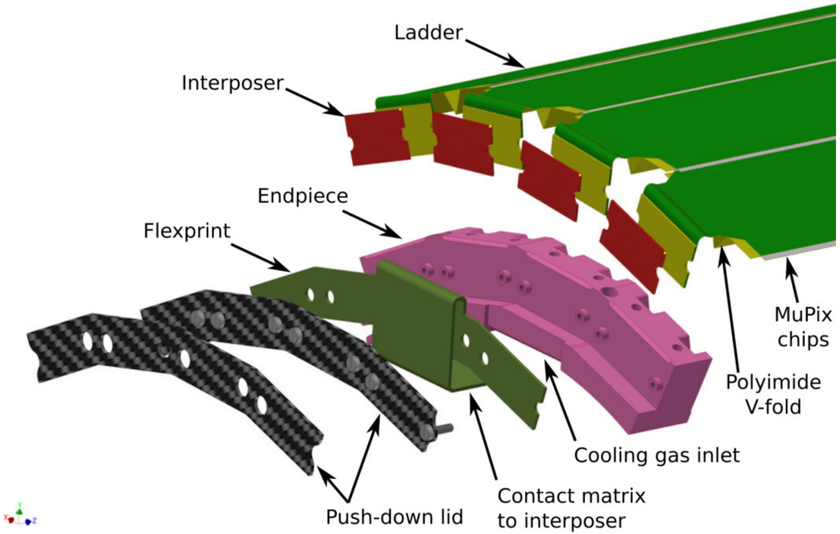
We plan to build a larger “Integration prototype” this year.

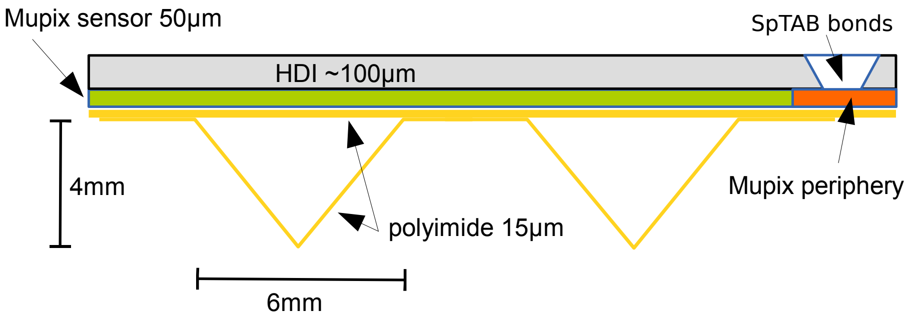


[The future] Some new ideas

- Disclaimer: the next slides cover projects that I have not participated in.
- However, those are nice ideas that are being explored for some unique detectors right now and that can also be used in future detectors.
- I will present two case studies. The information I have about them is a bit limited, but I think they are interesting to discuss here.
- Both were presented in last year's Forum on Tracker Detector Mechanics. This is a superb conference to learn new ideas about tracker mechanics.
  - In 2019 the conference will be in Cornell (NY, USA) [https://indico.cern.ch/event/775863/]

The mu3e ultra-low mass tracker



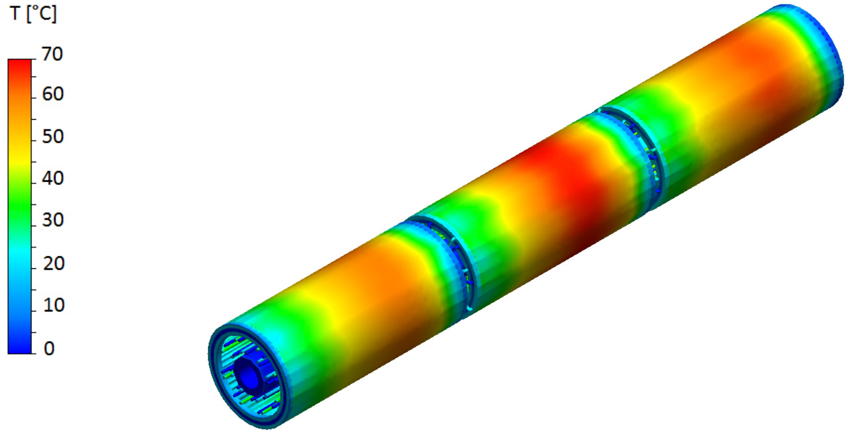


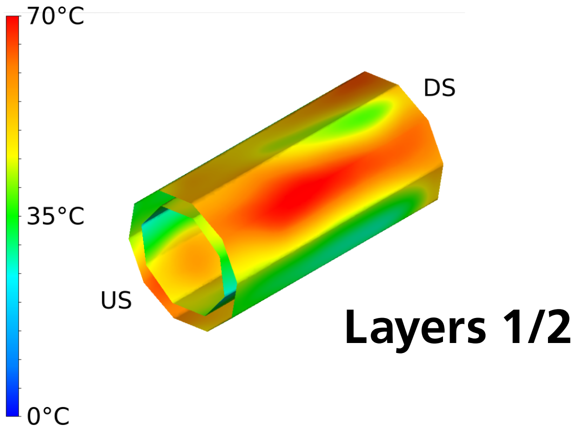
The V-shape is used not only for mechanical strength, but also for cooling with gaseous helium

Typical heat dissipation 0.25 W/cm²

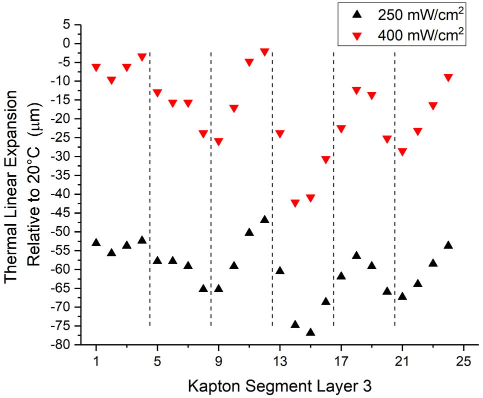
https://indico.cern.ch/event/695767/contributions/3014935/attachments/1674108/2686948/praesMu3eValencia2018.pdf

Thermal simulation

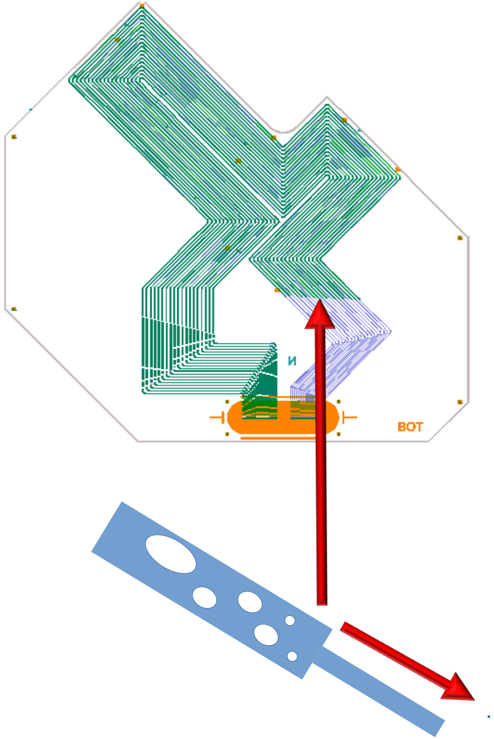




Very large temperature gradients!
And O(10μm) thermal expansion!
Many more studies needed.



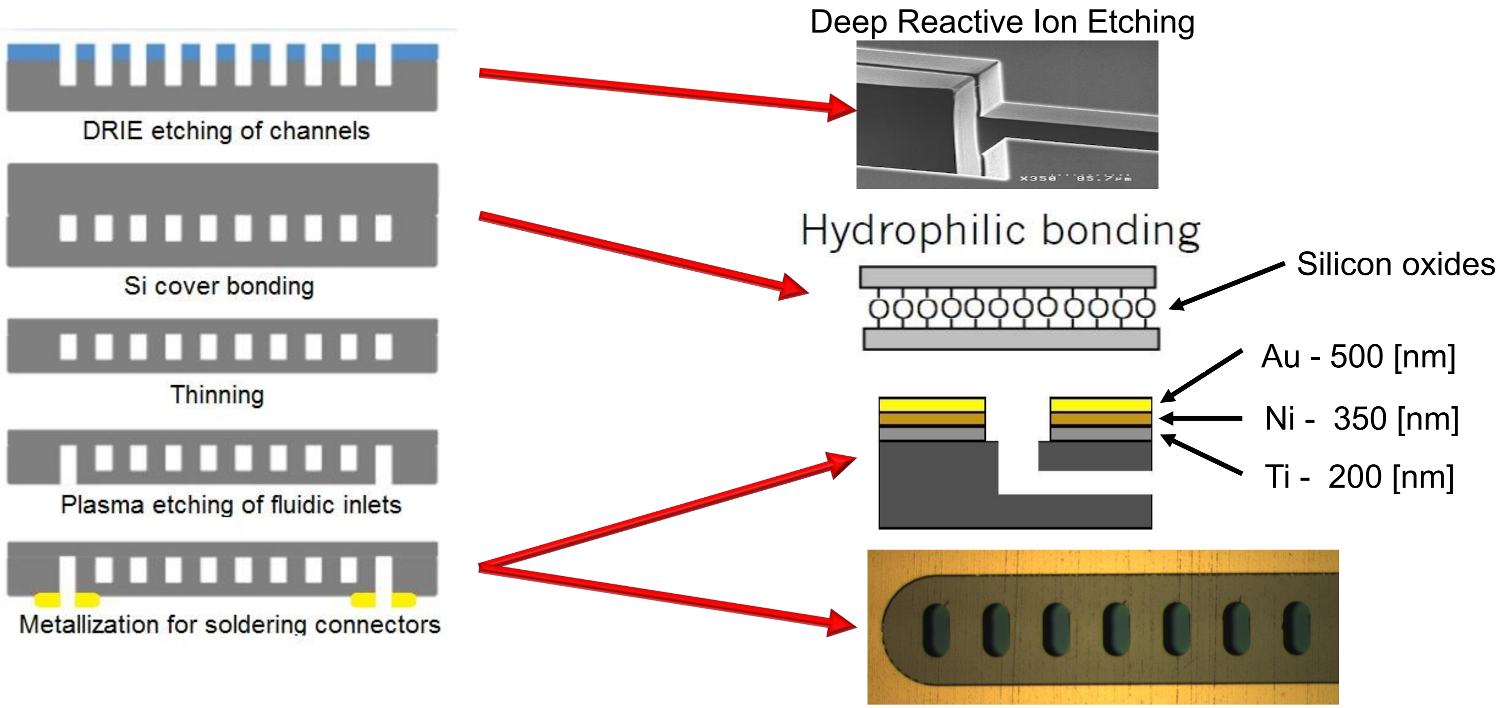
The LHCb VELO upgrade cooling



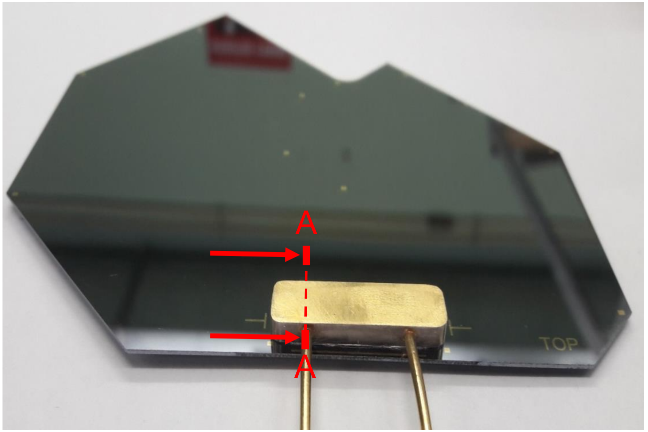
- The LHCb VELO upgrade will use silicon microchannels to cool down the detector.
- 500 µm thick silicon substrate
- Input restrictions
  - 60µm x 60µm, 40mm long
  - thin capillary, dominant pressure drop
- Main channels
  - 120µm x 120µm, 260mm long
  - sudden increase in cross section triggers boiling

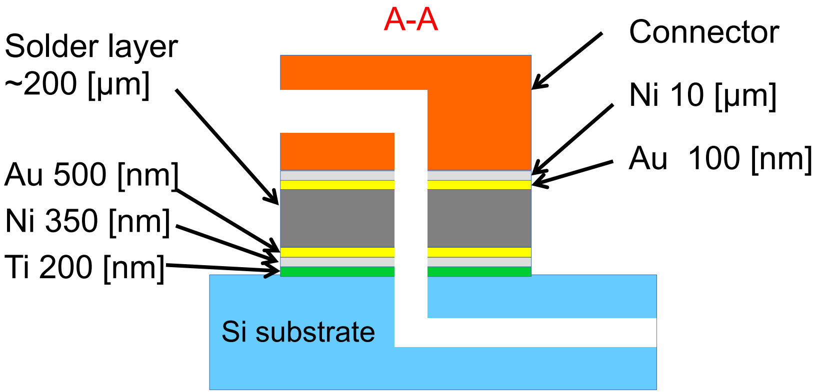
https://indico.cern.ch/event/695767/contributions/3014925/attachments/1674339/2687417/FOTDM2018_Byczynski_v3.pdf

Microchannel fabrication



The connector is a big challenge





Very hard to obtain leak tightness and high pressure qualification so that it can be operated with CO_2

Conclusions

- **Many lessons were learned with the CMS Phase I FPIX**
- **The ATLAS ITk Pixel is currently being designed with new ideas that minimize the amount of material in the two first layers and simplify the mechanical structure of the detector.**
- **New detectors are being designed with ideas that have never been used in particle detectors before but that may find applications in future detectors.**