

Mechanics and Cooling of Pixel Detectors

Pixel2000 Conference
Genoa, June 5th 2000

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From physics to reality

- Very demanding physicists community:
 - Detector has to be transparent
 - Detector has to be stable to a few microns
- these are two contradictory statements



- the engineers have always a hard job to move from “ideal” to “real” structures
- a long design optimization process is always required

Limits of the available electronics technology

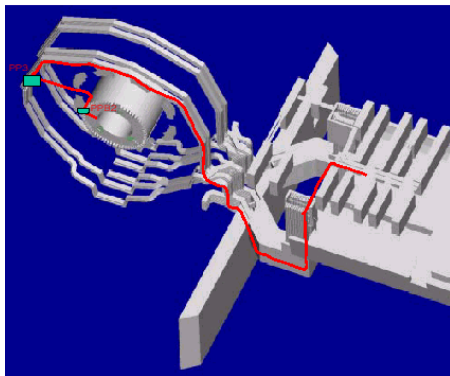
- Heat dissipation: **cooling is needed**
- High power density increasing systematically with performances: **very efficient cooling needed**
- radiation damage: **detector has to be operated at low temperature** (typically below 0 °C, to withstand the radiation dose)



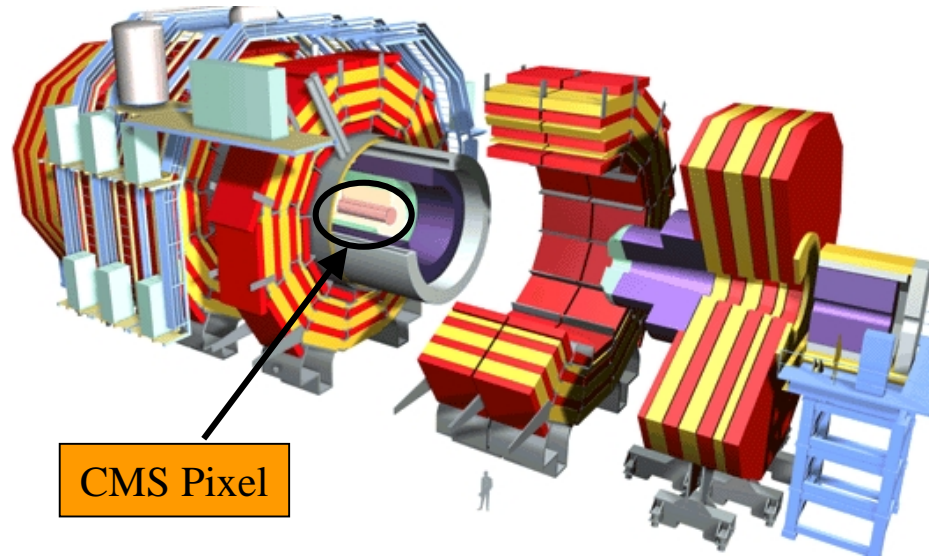
additional constraints to the mechanical structure

Further constraints on vertex detectors...

- Innermost structure: **remote control** more complex (limitations from services routing impacting all other detectors)
- Reliability: **access limitations**
- **Most vulnerable detector**: impact on maintenance scenarios (partial or total removal requirements)
- **ultra compact layout**: as close as possible to the interaction point



Typical service routing



CMS Pixel

... make the design really challenging

Summary of requirements

Mechanical structure

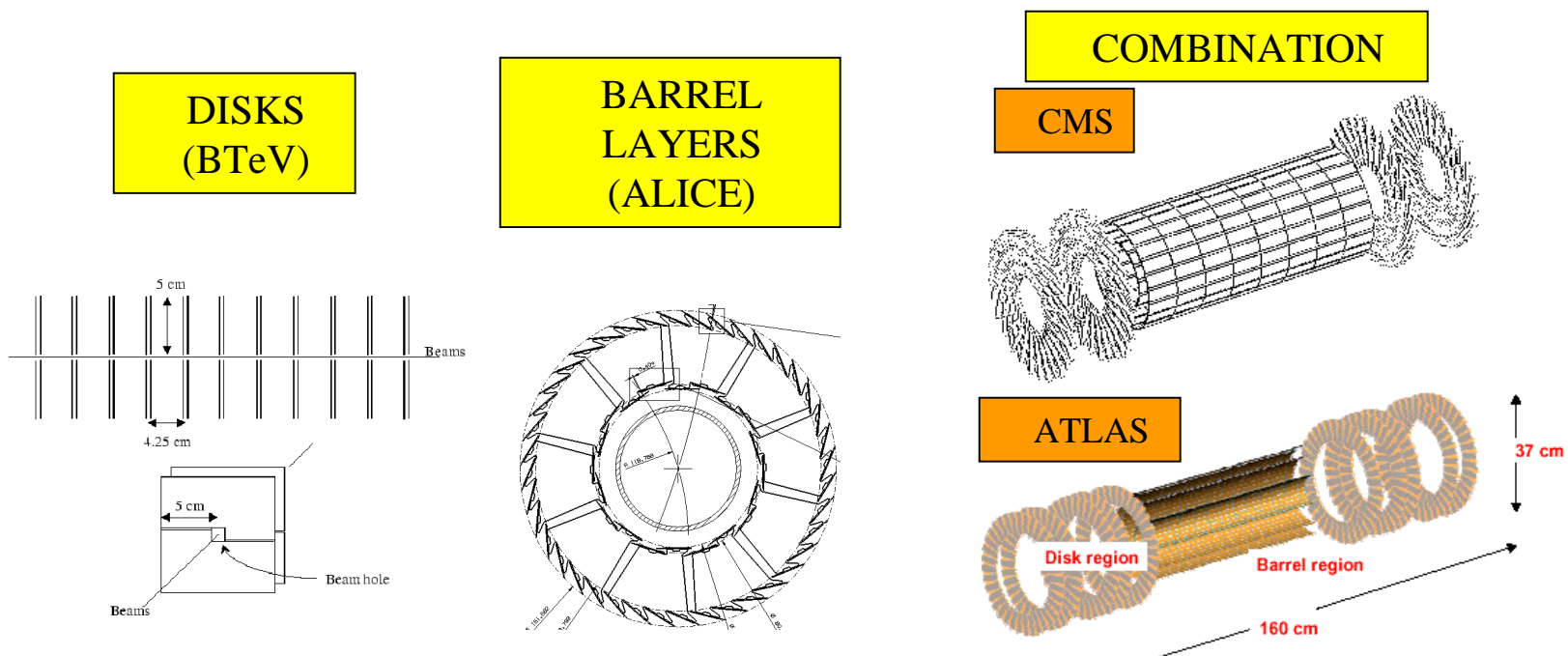
- **Lightweight** (low mass, low Z)
- **stiff** (low sag, less supports, higher natural frequency): UHM
- **stable** (low CTE and CME)
- **radiation hard**

cooling

- **Efficient**: liquid (or two phase)
- **coolant**: **low density, low Z , low viscosity, stable, non flammable, non toxic, electrically insulator** (or leakless system)

From sensor topology to basic geometry

- layout basically driven by physics performances
- feasibility of support structure introduce minor constraints
- the sensitive elements are usually arranged in two **basic geometries**: **disk** and **barrel layer**



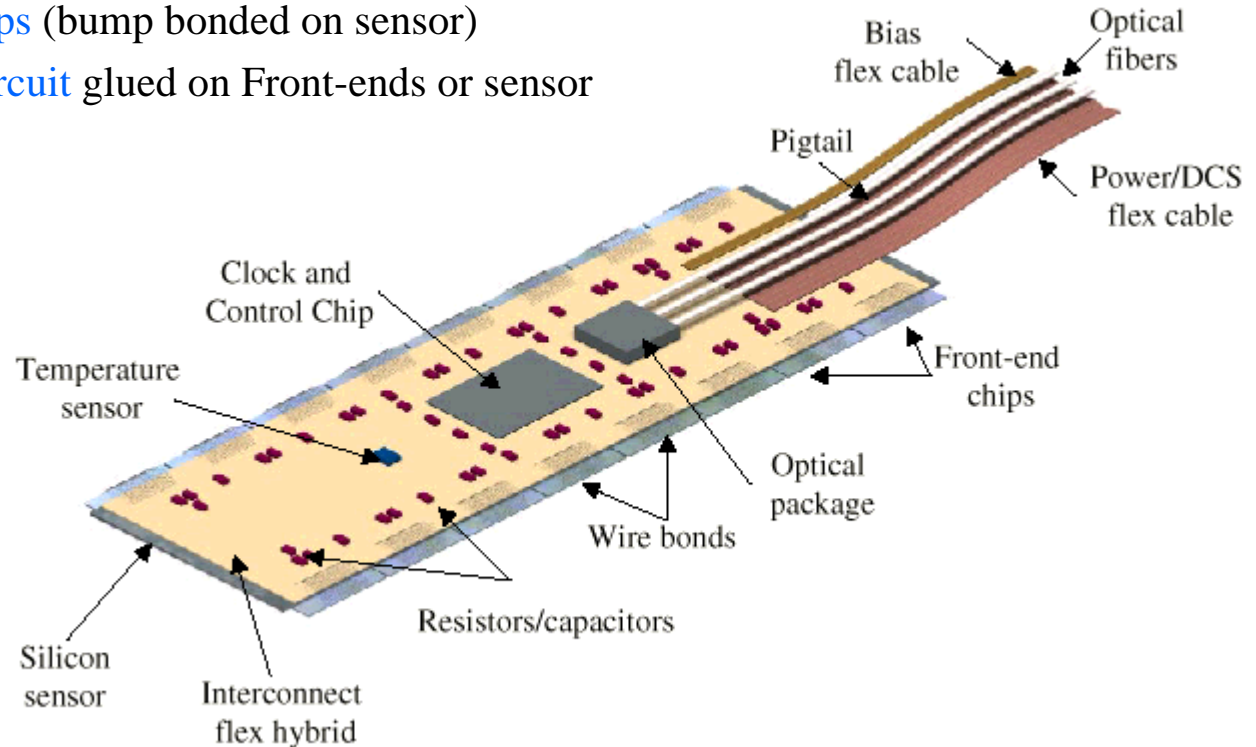
From basic geometry to support structure

In general the detector support structure can be split into:

- local support structures: actually the detector **core structure**
 - hold the chips in place
 - provide cooling (usually integrated)
- global support structures:
 - provide support to disk and barrel local supports and interfaces to the rest of the detector
 - basically passive structural elements

The electronic chip (pixel module)

- Different geometries but same concept
- Integrated Electro-mechanical sub-assembly:
 - silicon sensor
 - Front-end chips (bump bonded on sensor)
 - flex hybrid circuit glued on Front-ends or sensor



Design options

Given the constraints coming from:

- active area layout
- requirements

In principle

There seems to be enough design freedom

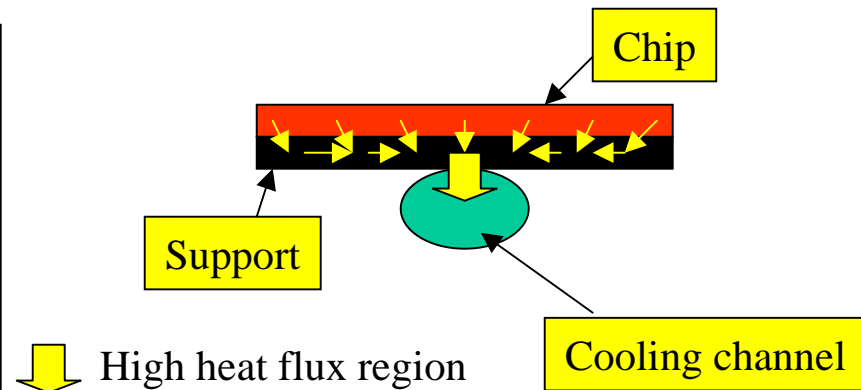
but

There are a few bottlenecks putting hard limits to the viable design options and material selection

Thermal management: fundamentals

The problem:

need to transfer uniform heat generated on a relatively wide chip area to a small cooling channel (tube and coolant material minimization)



Goals:

- uniform temperature on chip
- acceptable ΔT cooling channel-to-chip



Support material with **good thermal conductivity both in plane and in transverse directions:**

- CFRP cannot be used due to poor transverse heat conductivity



Good thermal contact support-to-channel:

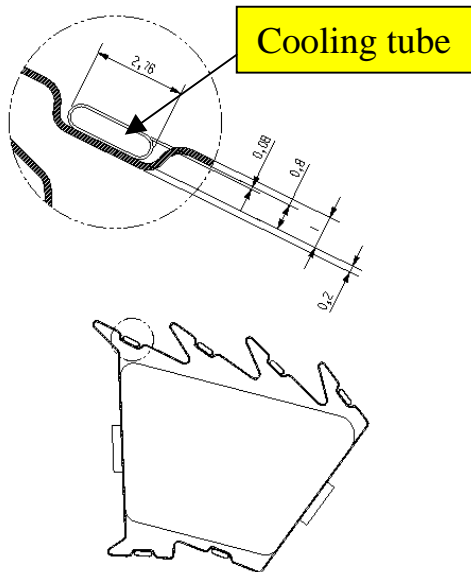
- materials with same CTE: hard bond possible
- materials with different CTE: soft but thermal efficient bond required: reliability
- need to maximize thermal contact area

Thermal management: barrel specific solutions

Common approach: cooling channel parallel to the chips sequence on local support

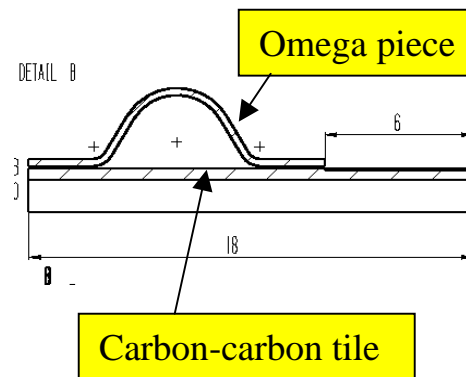
ALICE

Flattened stainless steel cooling tube, hosted in a groove, in direct contact with the chip carrier bus: thermal grease in-between



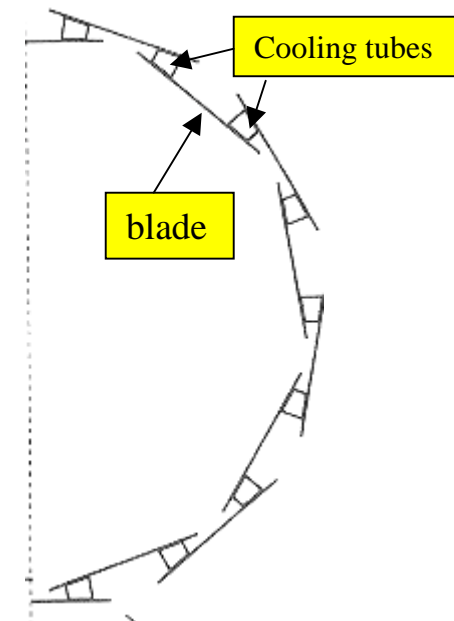
ATLAS

Worst case: one cooling channel collects 270W over 2 staves)
adopted **zero impedance baseline design**: fluid in direct contact to carbon-carbon tile



CMS

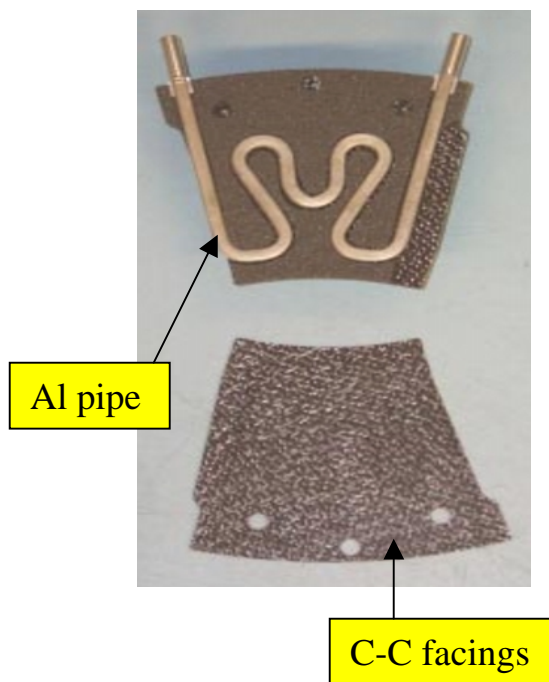
Aluminum cooling channel structurally active and shared by two adjacent blades (very high integration): each blade is cooled by two cooling channels (improve temperature uniformity)



Thermal management: disk specific solutions

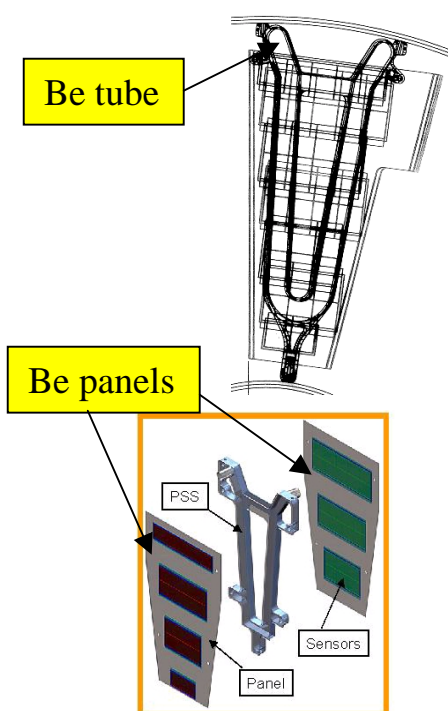
ATLAS

- flattened Al pipe embedded in between two carbon-carbon sheets
- thermal coupling by conductive grease



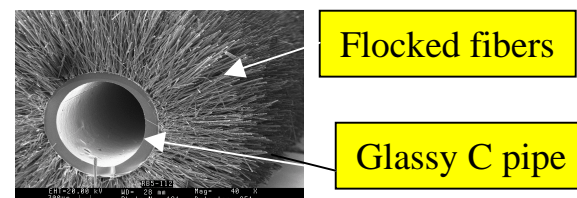
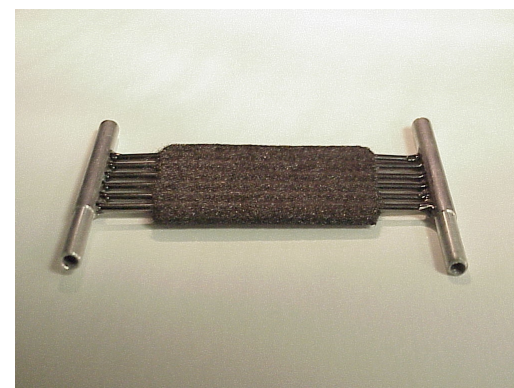
CMS

- Beryllium (Be) cooling tube in-between two Be plates (glue or thermal grease)
- chip integrated support blade (Si-kapton) connected to Be plates by soft adhesive



BTeV

- Glassy carbon pipe thermally coupled to chips with floaked carbon fibers
- CVD densification process to allow surface machining
- chips glued directly onto fuzzy surface shingle machined



Cooling systems

- fluorocarbon coolants are the best choice for pixel detectors:
 - excellent stability
 - good thermal properties
 - relatively low viscosity at low temperature
 - electrically insulator
- Alice and CMS adopted so far C_6F_{14} monophasic liquid cooling as baseline
- current ATLAS baseline is an evaporative system with C_3F_8 (due to high power dissipation: 19 kW inside a detector volume of about 0.3 m³)
- however careful attention has to be paid to:
 - material compatibility (diluting action on resins and corrosion under irradiation)
 - coolant purification (moisture contamination has to be absolutely prevented)

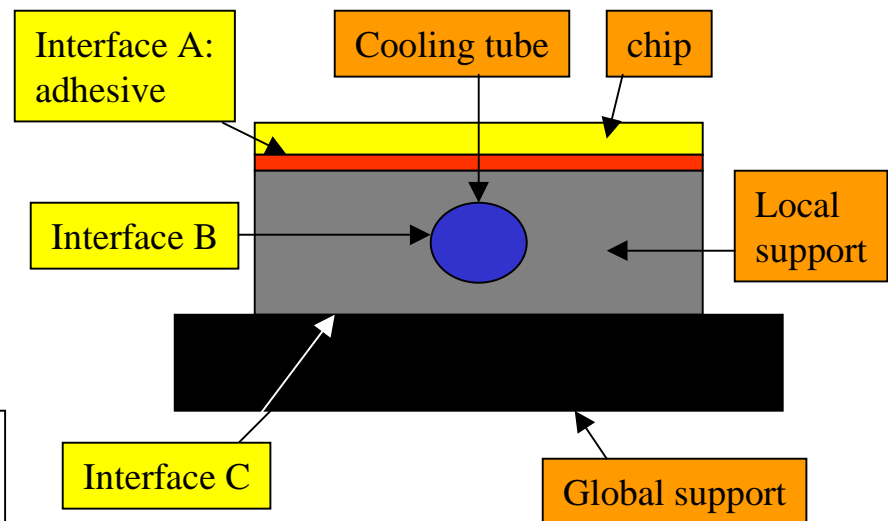
Thermal stability: fundamentals

background:

- detector fabricated at room temperature and operated below 0 °C (not true for Alice)
- local operating temperature gradients chips-to-cooling pipe on local supports

Goal: minimize by-metallic distortions due to

- CTE mismatches
- temperature gradients



Interface A

- chip CTE: fixed
- difficult to mate with support CTE
- either soft adhesive
- or very high rigidity of local support

Interface B

- same materials (small CTE)
- or flexible joint:
 - thermal grease
 - flocked fibers

Interface C

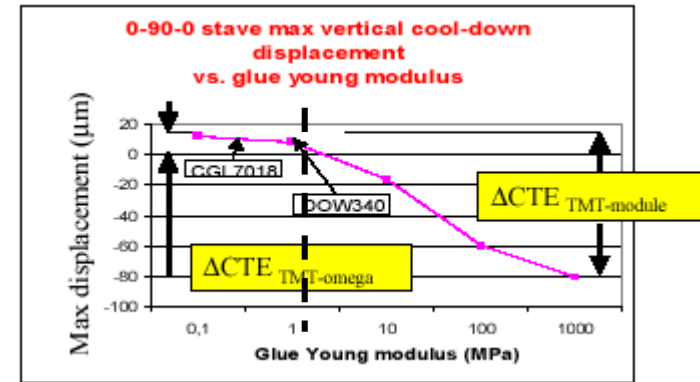
- same materials
- or kinematics joints

The thermal stability requirements impose very strong constraint on material selection

Thermal stability: chip-to-support interface

- Common problem for all detector
- adhesive has to be: soft, thermally conductive, rad-hard, room temperature curing
- difficult to find candidates meeting all specs
- modulus threshold depends on support stiffness and allowable stresses on chips

Typical effect on local support stability



Thermal pastes:

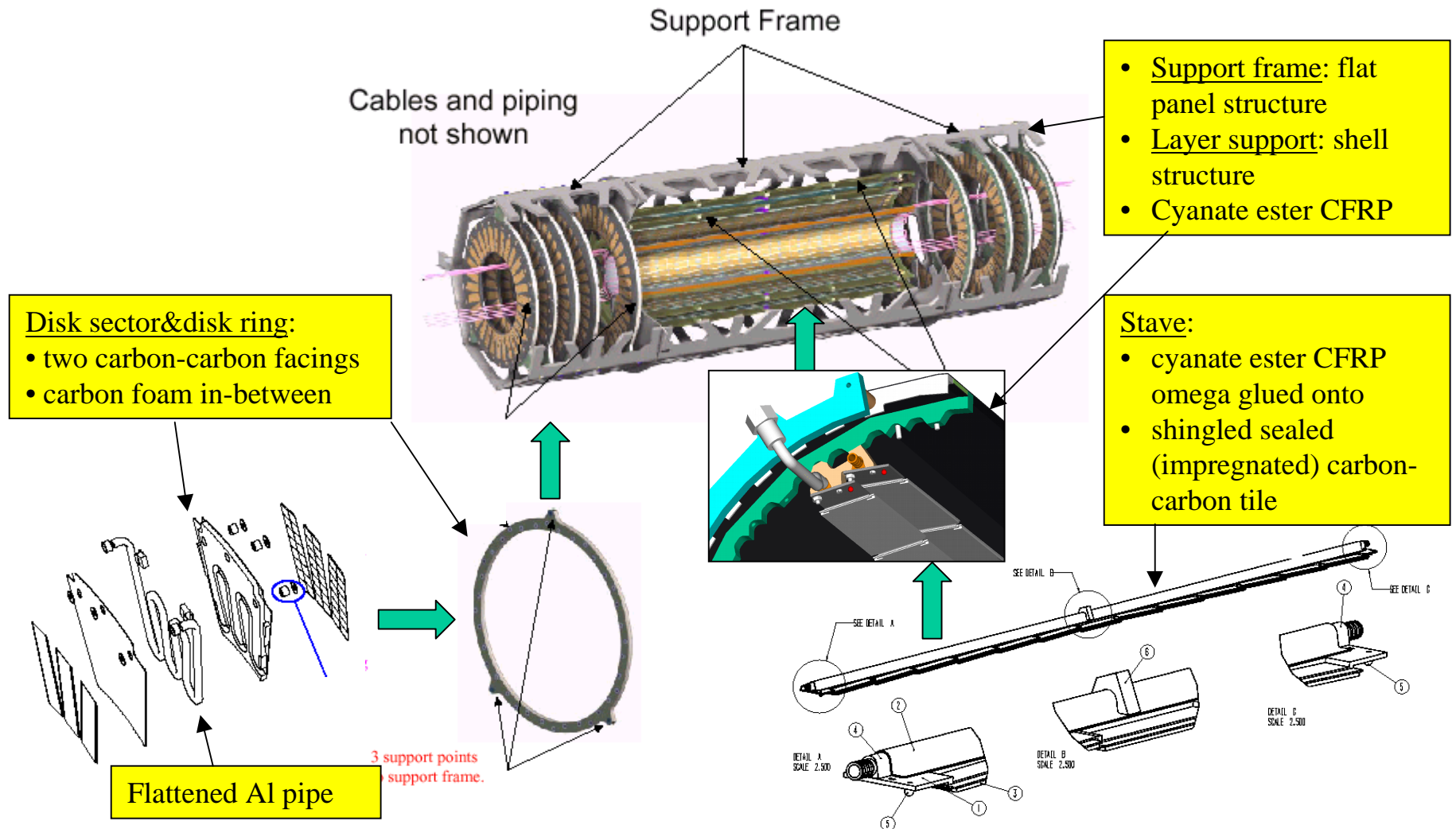
- need UV tags
- reliability?

Silicon adhesives:

get much harder after irradiation

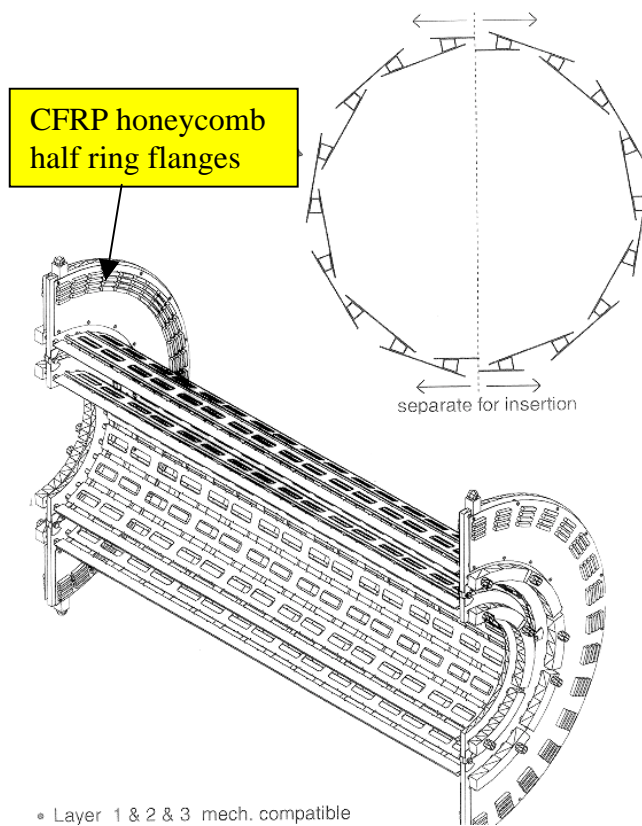
Long term test program always needed to qualify the specific adhesive joint

Specific design features : ATLAS pixel



Specific design features : CMS pixel

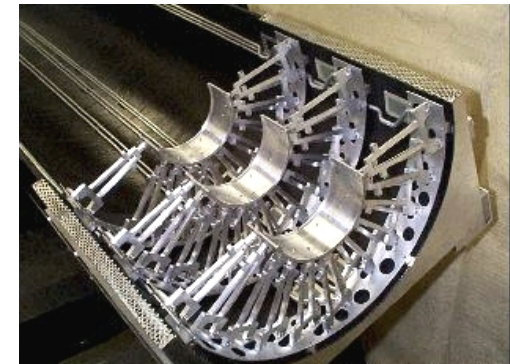
Barrel half section assembly



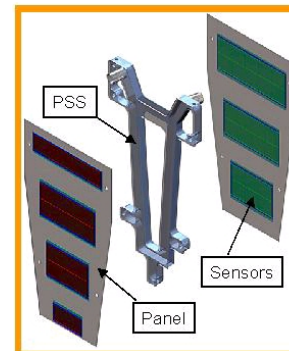
CFRP service tube

CFRP space frame
(sandwich structure)

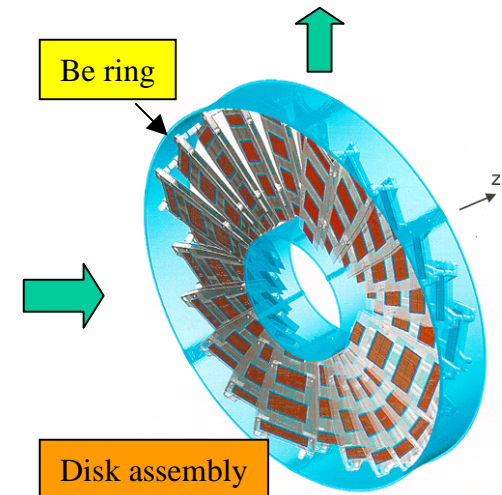
Disk section assembly



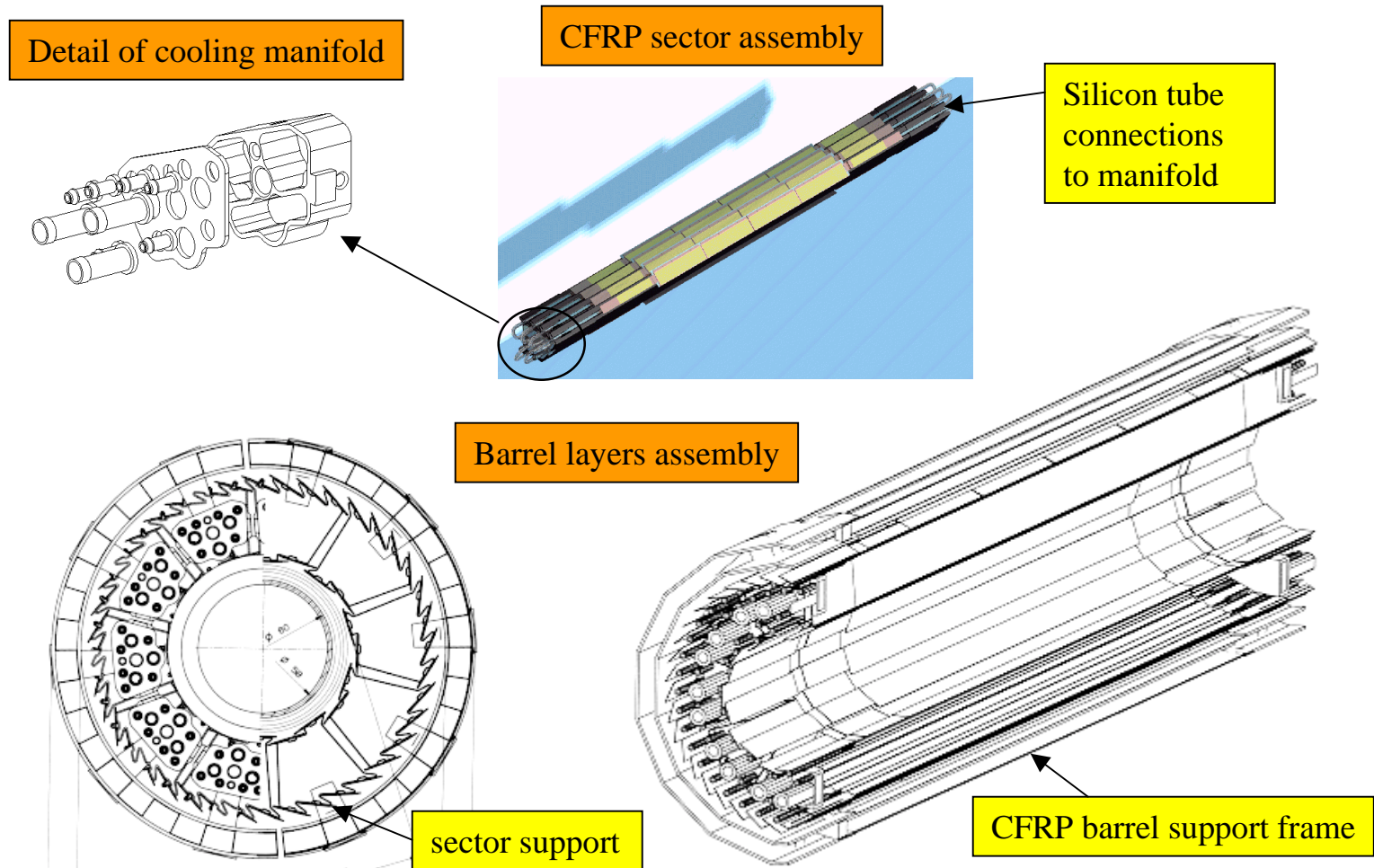
Disk blade



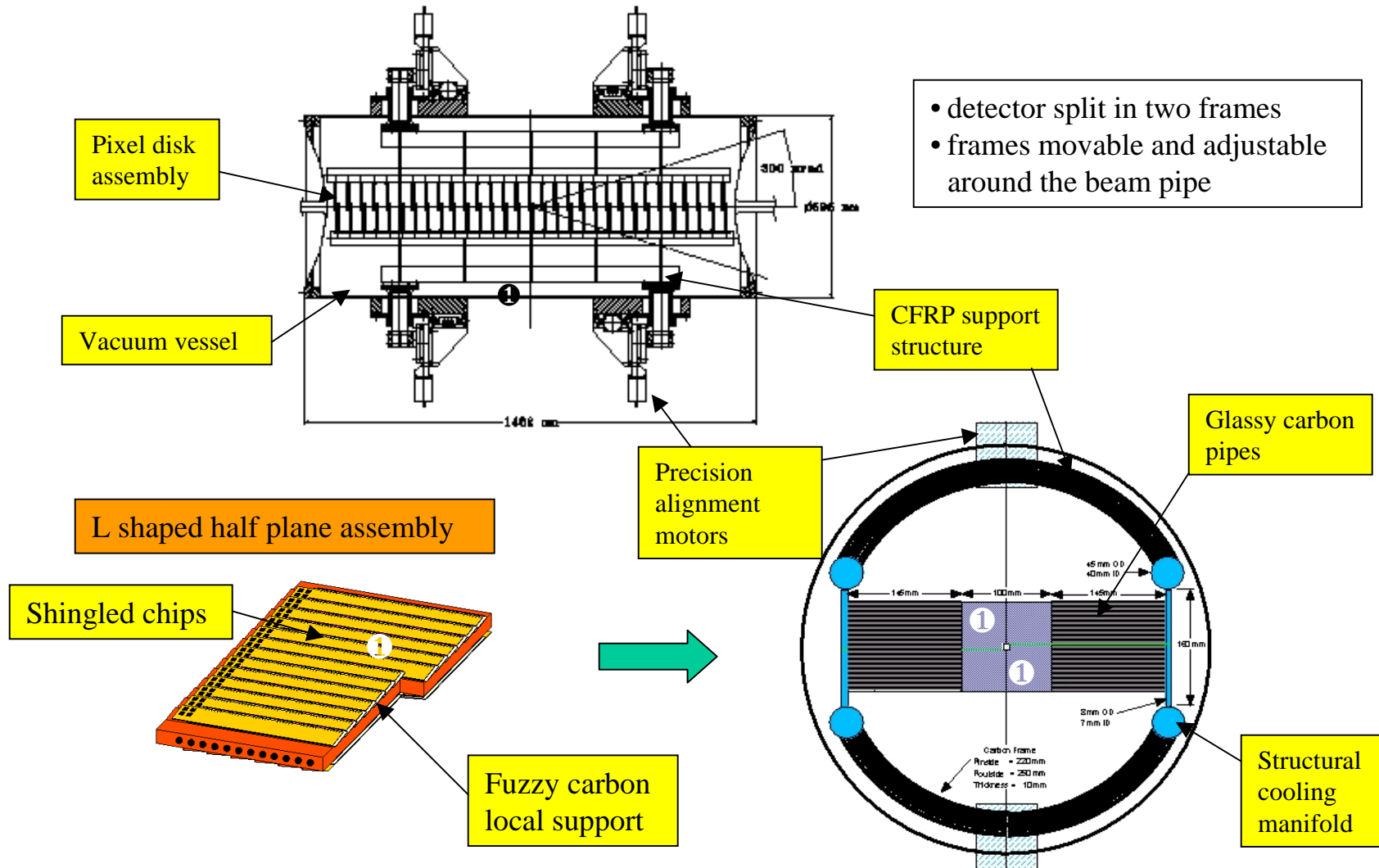
Be ring



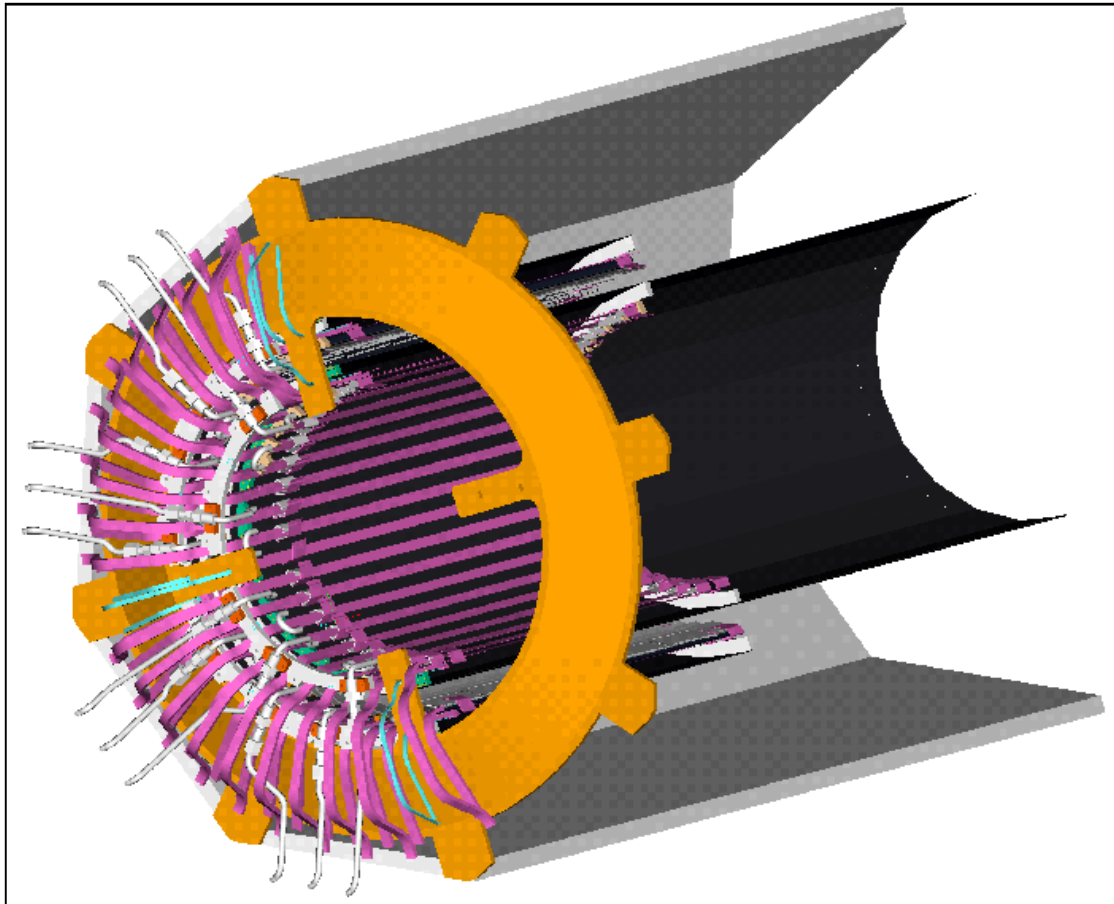
Specific design features : ALICE pixel



Specific design features: BTeV pixel



On top of that.....



- Services integration has a big impact on pixel detector:
 - routing
 - clearances
 - additional loads to the structure
 - actions due to cool down
- it is vital for the detector stability to minimize any load on local supports
- strain relieves, bellows elastic joints design needs to be carefully assessed: reliability

Final remarks

- Mechanics and cooling design of new generation pixel detectors are status of the art technologies and push some of them a bit further: same level of aerospace industry standards
- careful material selection allows to meet the thermal and stability requirements
- very hostile environment vs ultra light structures: long term performances are the crucial issue as well as the QA/QC policy