FPIX Material Reduction & Module Development

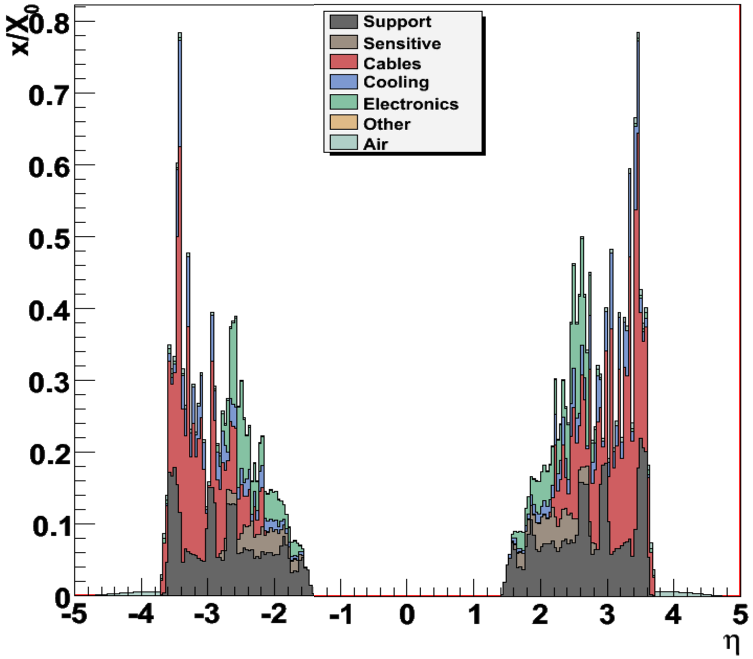
A few alternative layouts of modules on disks to spur discussion about optimal module design and material reduction (also think about electronics, cooling tube and cable routing schemes)

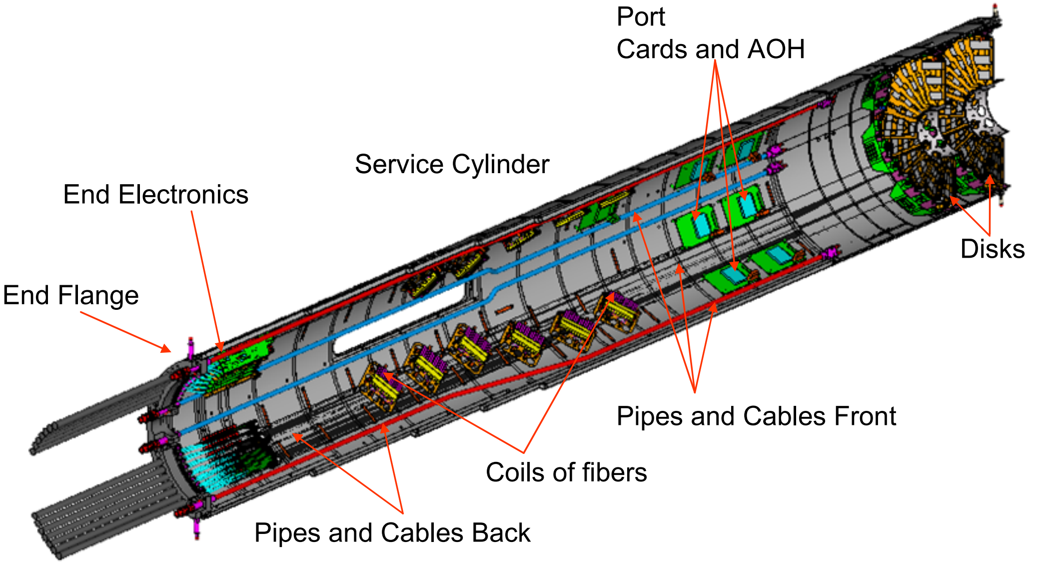
This work is part of our R&D plan described in:
Proposal for US CMS Pixel Mechanics R&D at Purdue and Fermilab *Daniela Bortoletto, Petra Merkel, Ian Shipsey, Kirk Arndt, Gino Bolla, Simon Kwan, Joe Howell, C.M. Lei, Rich Schmitt, Terry Tope, J. C. Yun with valuable input from Lucien Cremaldi, Mikhail Kubantsev, Vesna Cuplov* (http://indico.cern.ch/conferenceDisplay.py?confId=28746)

We've identified three objectives for the Phase 1 FPIX detector in order to reduce material significantly (and distribute more uniformly):

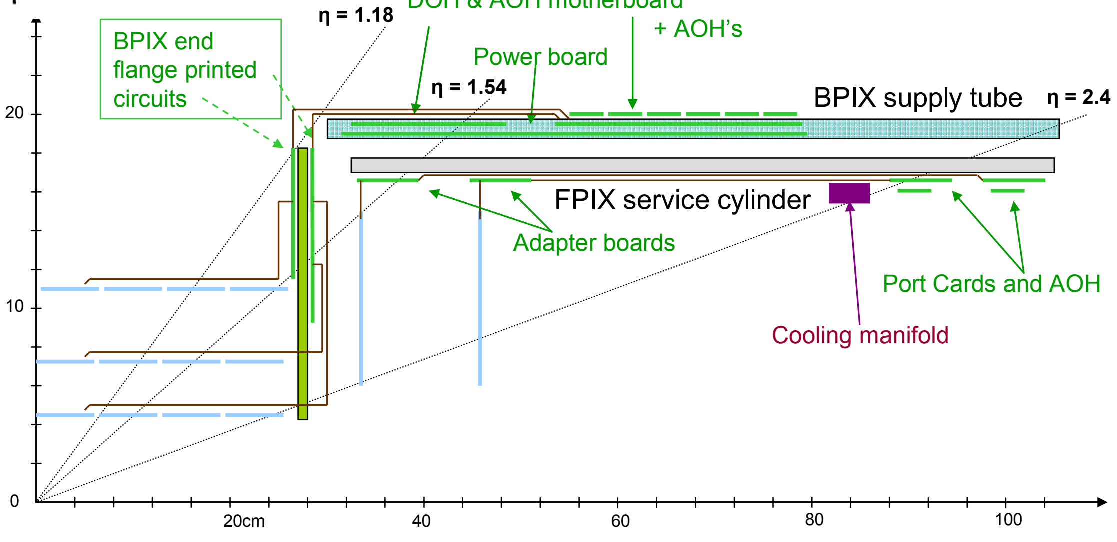
1) **Integrate CO2 cooling and lightweight support**
   - → slides today by T. Tope and S. Kwan
2) **Reduce # of module types and interfaces**
   - → these slides
3) **Improve cooling and cable routing, move control and optical hybrids out to higher η**

Present Material Distribution in FPIX Service Cylinder





Most material in the current Fpix detector between 1.2 < η < 2.2 is in Disks (brazed aluminum cooling loops) and electronics (connectors and adapter boards) and between 2.2 < η < 3.6 in cables and cooling

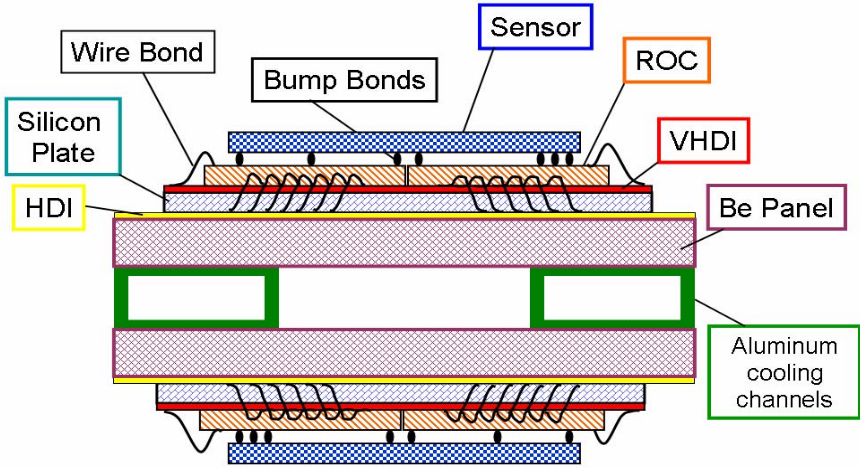


Mechanical R&D

Current FPIX blades have:

- **passive Si and Be substrates**
- **brazed aluminum (0.5mm wall thickness) cooling channels**

LARGE MATERIAL BUDGET



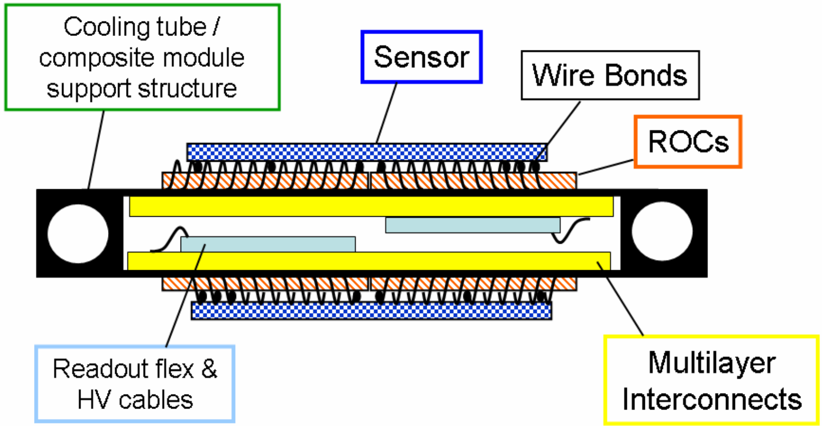
FPix blades have 7 different modules

(we assembled ~1000 modules to yield 672 for installation + spares)

Integrated modules concept

- **Flip chip modules mounted directly on low mass/high heat transfer/stiff material (ex. pyrolytic graphite)**

LOW MATERIAL BUDGET

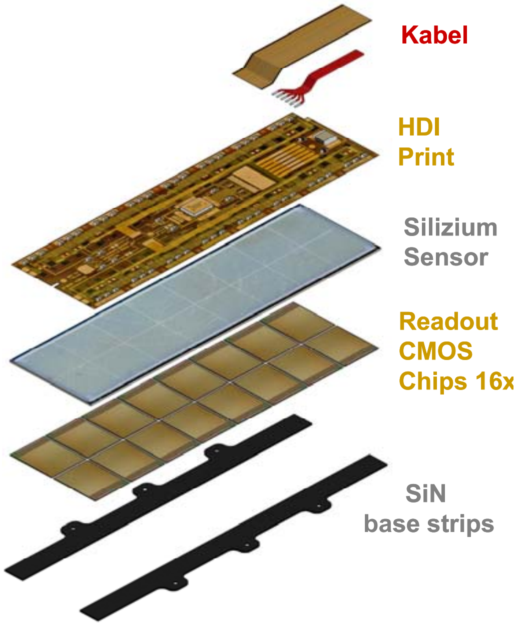


- **New system: fewer module types**
- **Lightweight support structure**
- **CO2 cooling**

Three alternative module designs

"BPIX"

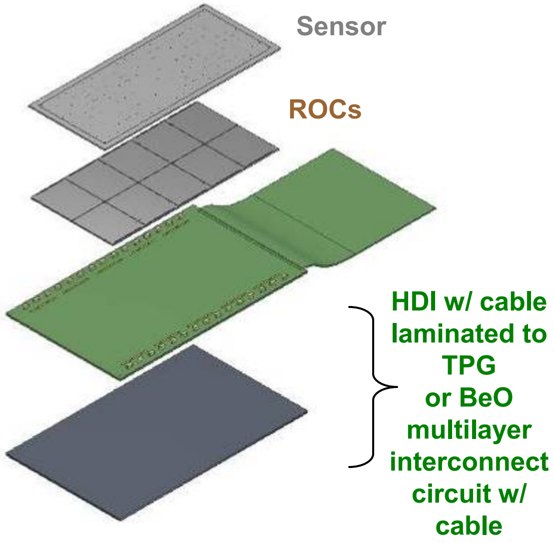
HDI flex on top of sensor



- \+ Only 1 thin passive layer between ROCs and cooling/support structure (or mount ROCs w/o strips)
- \+ Screw fastened to support structure
- \- Inhibits scanning with light for bump conductivity test
- \- Cable strain applies force on sensor

"FPIX"

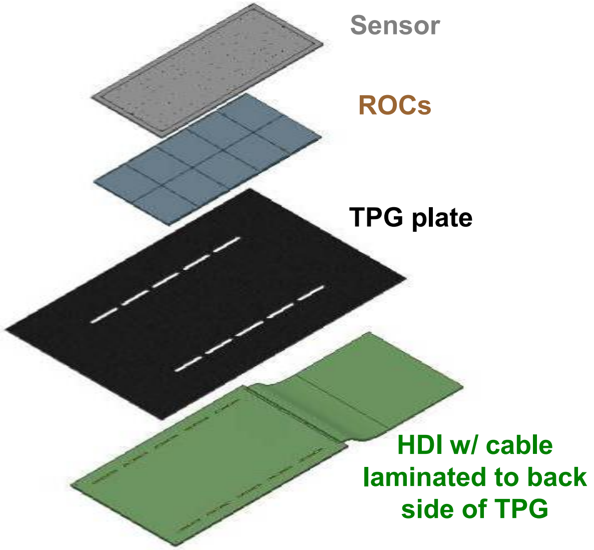
HDI under ROCs



- \+ Allows scanning sensor with light for dead channel/ bump connection tests
- \+ Allows for removal of flip chip module for ROC rework
- \+ Strain on cable not transferred to sensor or ROCs
- \- Multilayer interconnect layer between ROCs and cooling/support structure

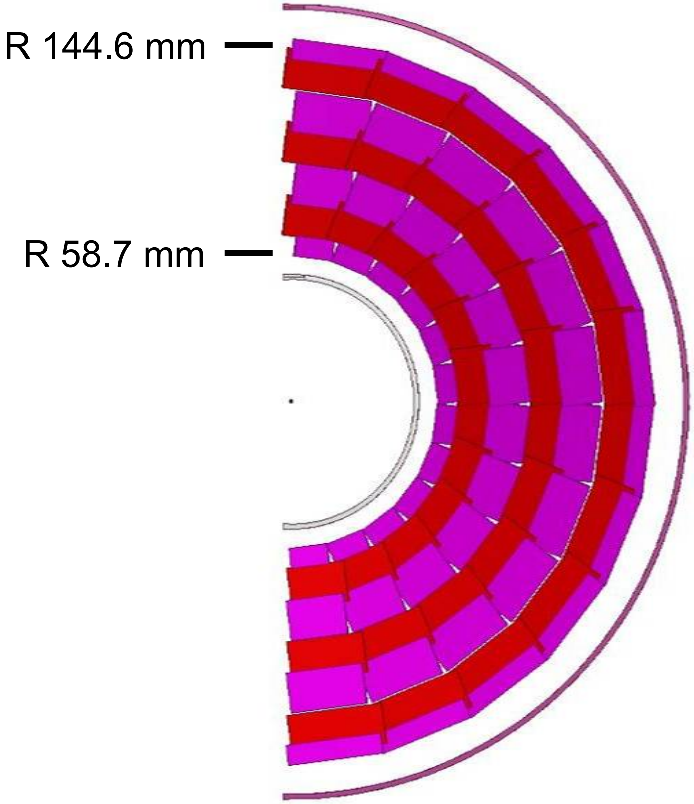
"Integrated Module"

HDI under and ROCs on top of high thermal conductive plate with thru holes for wirebonds



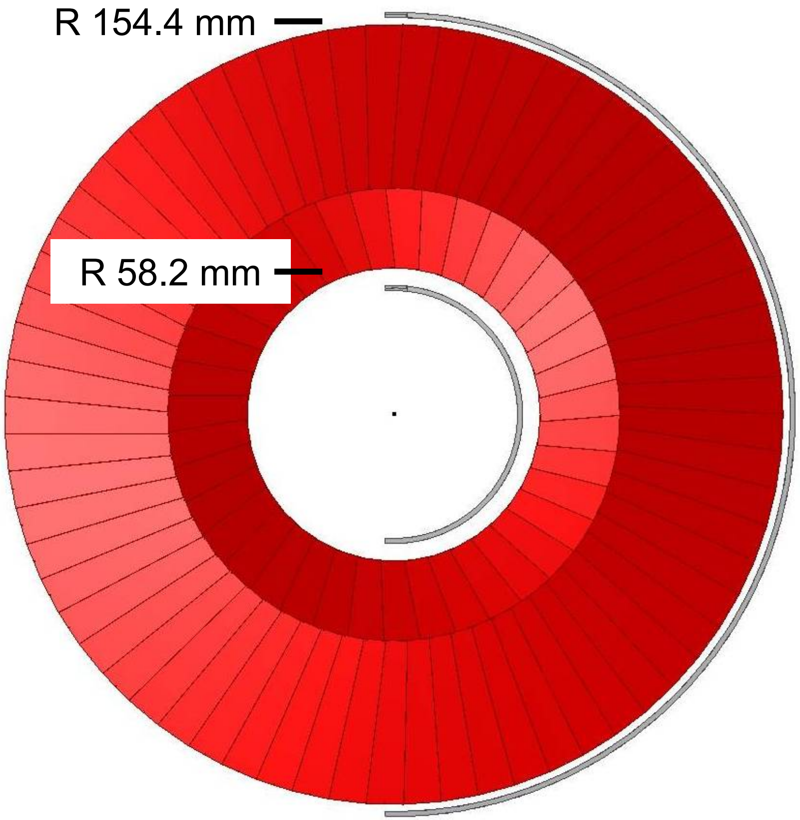
- \+ Flip chip modules mounted directly on high heat transfer material
- \+ Leaves sensors uncovered for scanning with light (pulsed laser)
- \+ Flip chip modules removable, leaving HDI intact for replacement modules
- \+ TPG provides cable strain relief

Conceptual Module Layout with radial and ϕ overlaps (and 20° tilt of sensors)



Current Fpix module layout

7 module geometries
168 modules per disk
(1080 ROCs per disk)



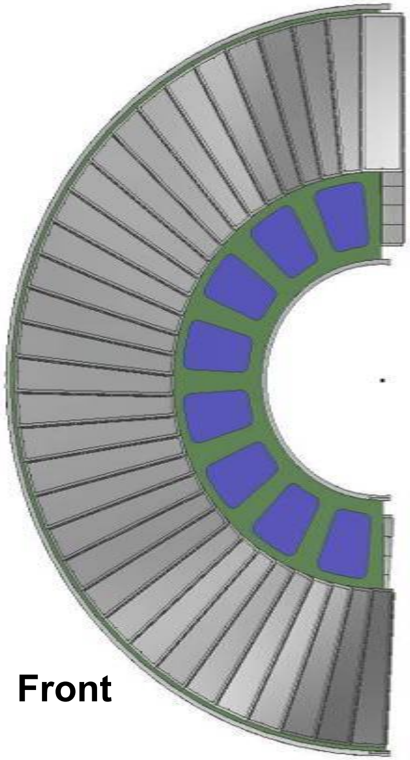
Radial layout of (65) 2x8 and (39) 2x4 modules

104 modules per disk
(1352 ROCs per disk)

NOTE: Inner and outer radii adjustable by varying length and # of modules

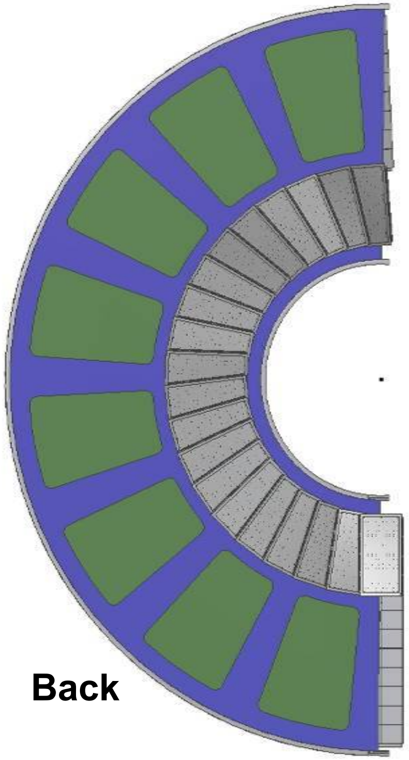
Disk Concept 1 - Shingles on single bulkhead

All 2x8 modules on "shingles" along outer radius on front side of half-disk

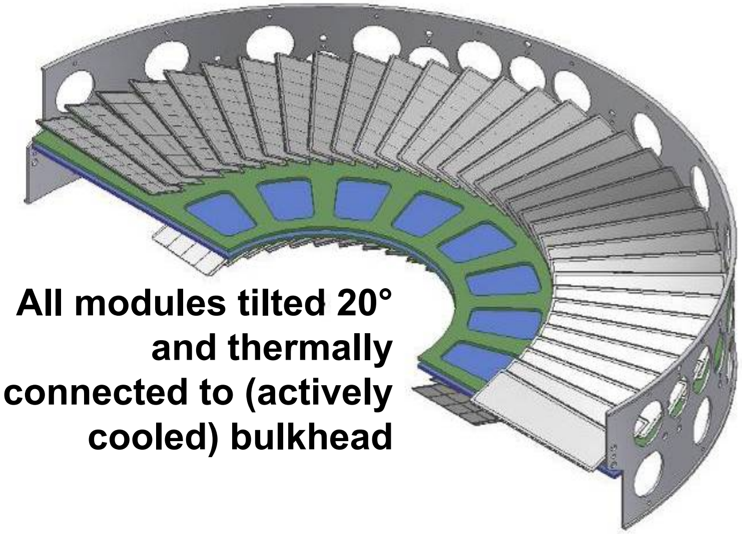


Front

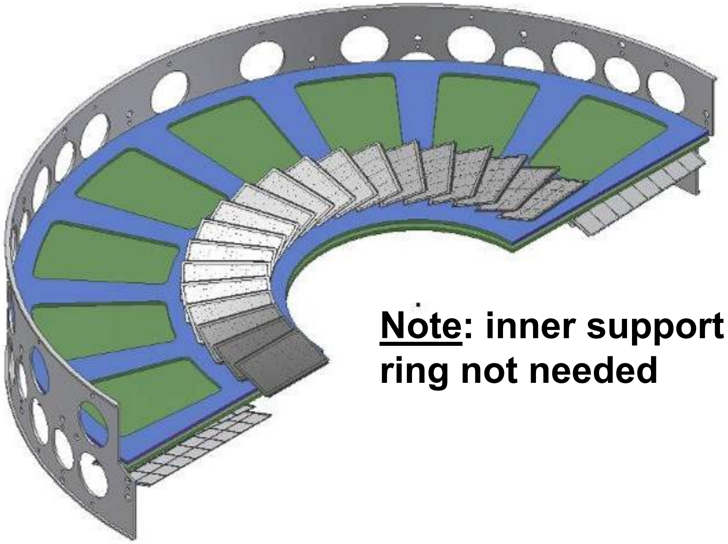
All 2x4 modules on "shingles" along inner radius on back side of half-disk



Back



All modules tilted 20° and thermally connected to (actively cooled) bulkhead

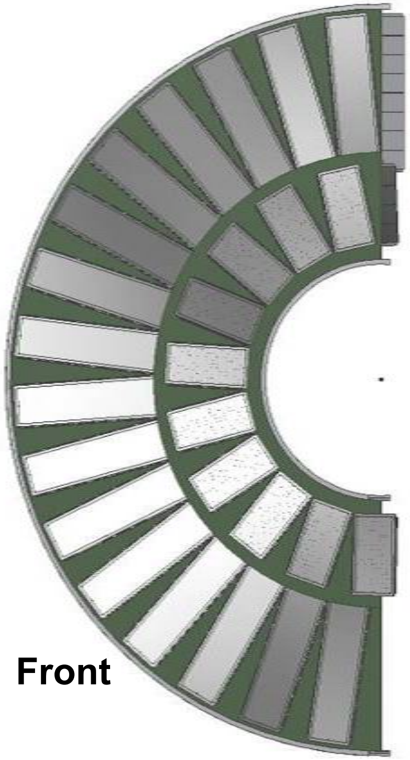


Note: inner support ring not needed

This disk concept lends to the integrated module or FPIX module designs, where TPG provides high heat transfer from ROCs to actively cooled bulkhead

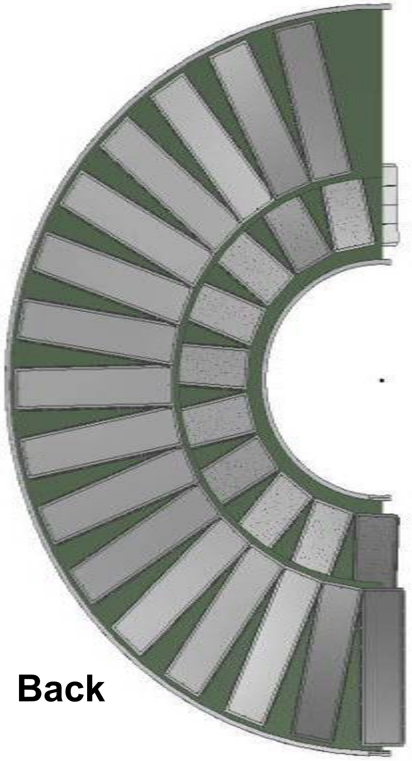
Disk Concept 2 – shingles on two bulkheads

2x8 modules “shingles” on outer radius bulkhead alternate on both sides of half-disk



Front

2x4 modules “shingles” on inner radius bulkhead alternate on both sides of half-disk



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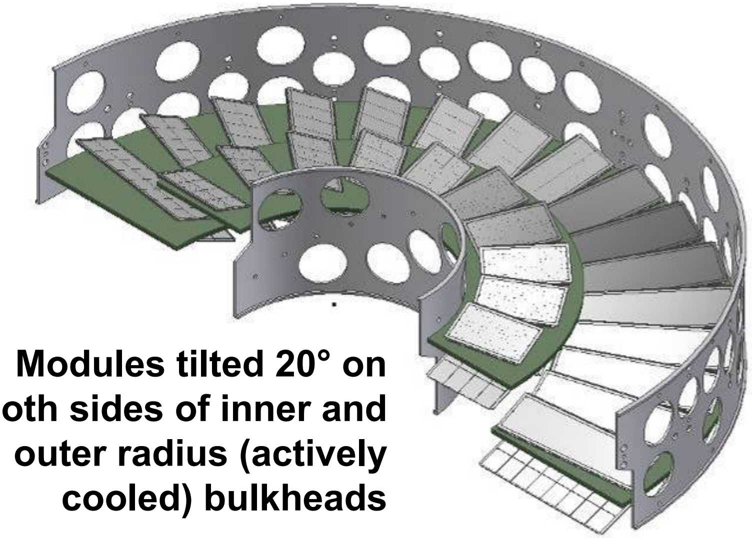
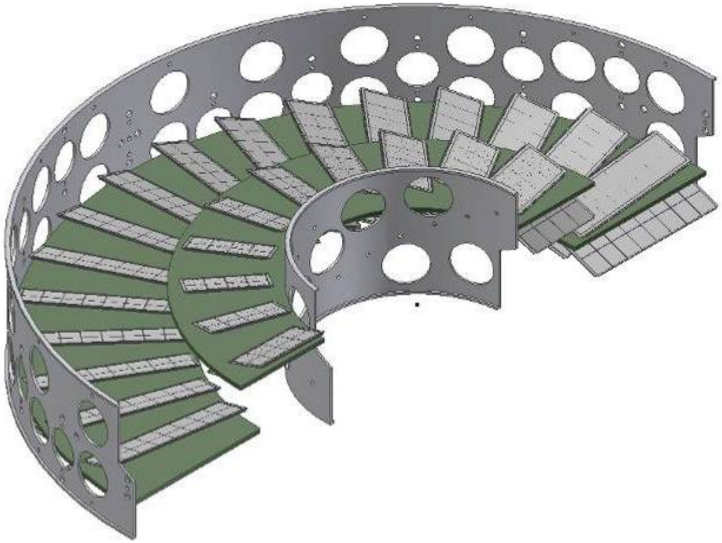


Modules tilted 20° on both sides of inner and outer radius (actively cooled) bulkheads



This disk concept lends to the integrated module or FPIX module designs, where TPG provides high heat transfer from ROCs to actively cooled bulkheads

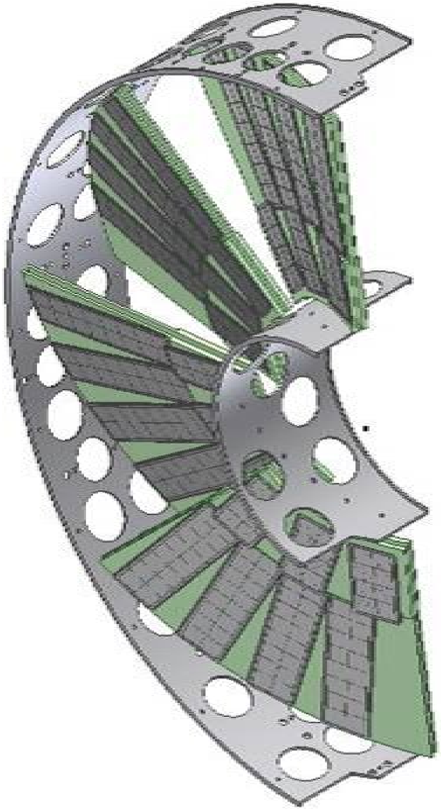
AND

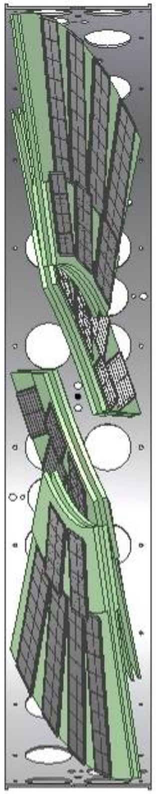
the BPIX module design as there is room to access screws for fastening modules to “shingle supports”

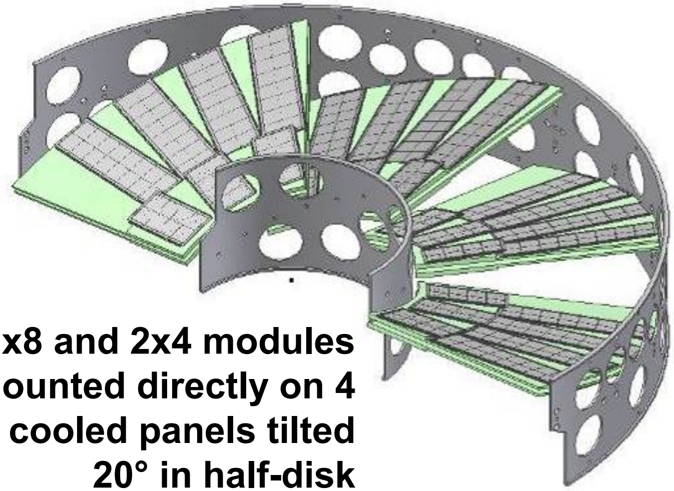
Disk Concept 3 - Modules on 4 tilted panels

2x8 modules along outer radius and alternate on both sides of panels

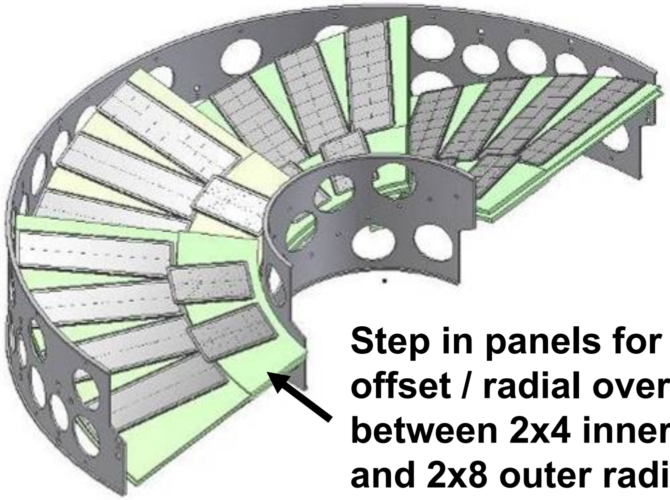
2x4 modules at inner radius on steps on panels, and alternate on both sides of panels







2x8 and 2x4 modules mounted directly on 4 actively cooled panels tilted 20° in half-disk



Step in panels for Z-offset / radial overlap between 2x4 inner and 2x8 outer radius mounted modules

<u>This disk concept lends to the BPIX module design, as there is minimal space between neighboring modules for ROC wirebonds, and a minimum of passive material between ROCs and actively cooled panels</u>

Mass and Radiation Length estimates for replacement/upgrade FPIX Disk

	Present Fpix		**New Fpix**		
	Mass(g)	Rad L%	Mass(g)	Rad L%	Comments
Flip chip modules	117.6	0.50	103.2	0.46	use thinner adhesive or rails with screws to fasten to HDI
VHDI	208.8	0.93	0.0	0.00	mount modules directly on HDI
HDI	300.0	0.80	338.4	1.02	combine function of VHDI and HDI, TPG with CF facing instead of Be
Support Hardware	179.9	0.76	124.4	0.34	CF instead of Alum for Inner and Outer Rings
Cooling channel	322.6	1.17	**6.1**	**0.12**	**CO2 coolant + small diameter SS pipes** instead of brazed Alum channels
Total per disk	1129	4.16	**572**	**1.94**	

50% less mass per disk

2X reduction in %RL per disk

Mechanical Design optimization

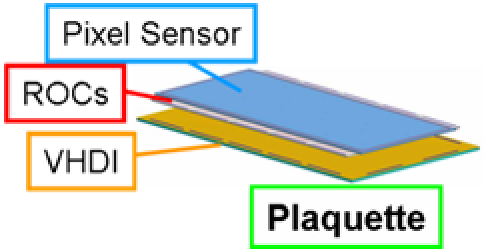
- Goals
  - Early conceptual design
  - Model thermal gradients and distortions
  - Minimize material and meet thermal requirements
  - Overall optimal design (mechanics, power and readout)
- Small mechanical prototypes for measurements of thermal performance vs. material
  - Module prototypes – to evaluate adhesives, interconnects, develop assembly tooling and procedure
  - Support prototypes – to evaluate
    - TPG and facing materials - none (just epoxy), carbon fiber, carbon-carbon
    - Mix of low (i.e. Pocofoam) and higher density materials
  - CO2 cooling – to evaluate tube types and size, number of tubes per module
- Ambitious goal would be to build full-scale disk prototype for thermal and mechanical tests by Fall 2009 based on design and small prototype studies

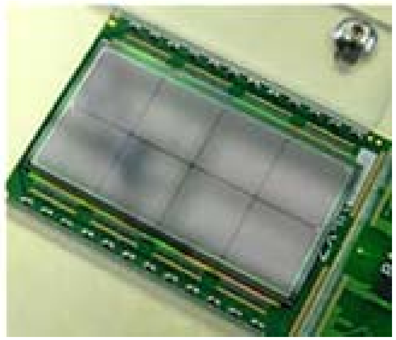
Summary

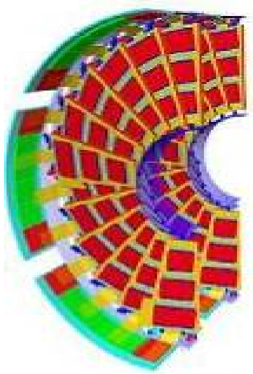
- Reduction in # of module types, components and interfaces + integration with lightweight support and CO2 cooling reduces material *SIGNIFICANTLY* *(and may simplify assembly)*
- Module and disk conceptual design and studies have begun
- Small prototype development for testing will follow
- Goal to build full-scale prototype for thermal and mechanical tests in ~1 year from now

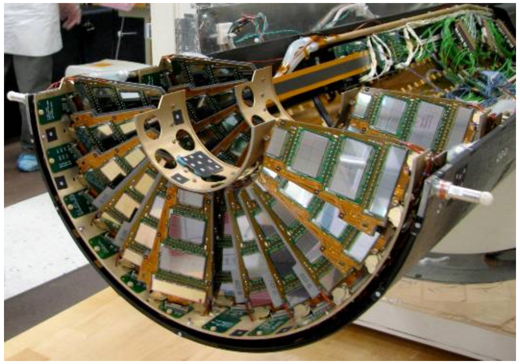
Backup slides

CMS Forward Pixels at Purdue and FNAL









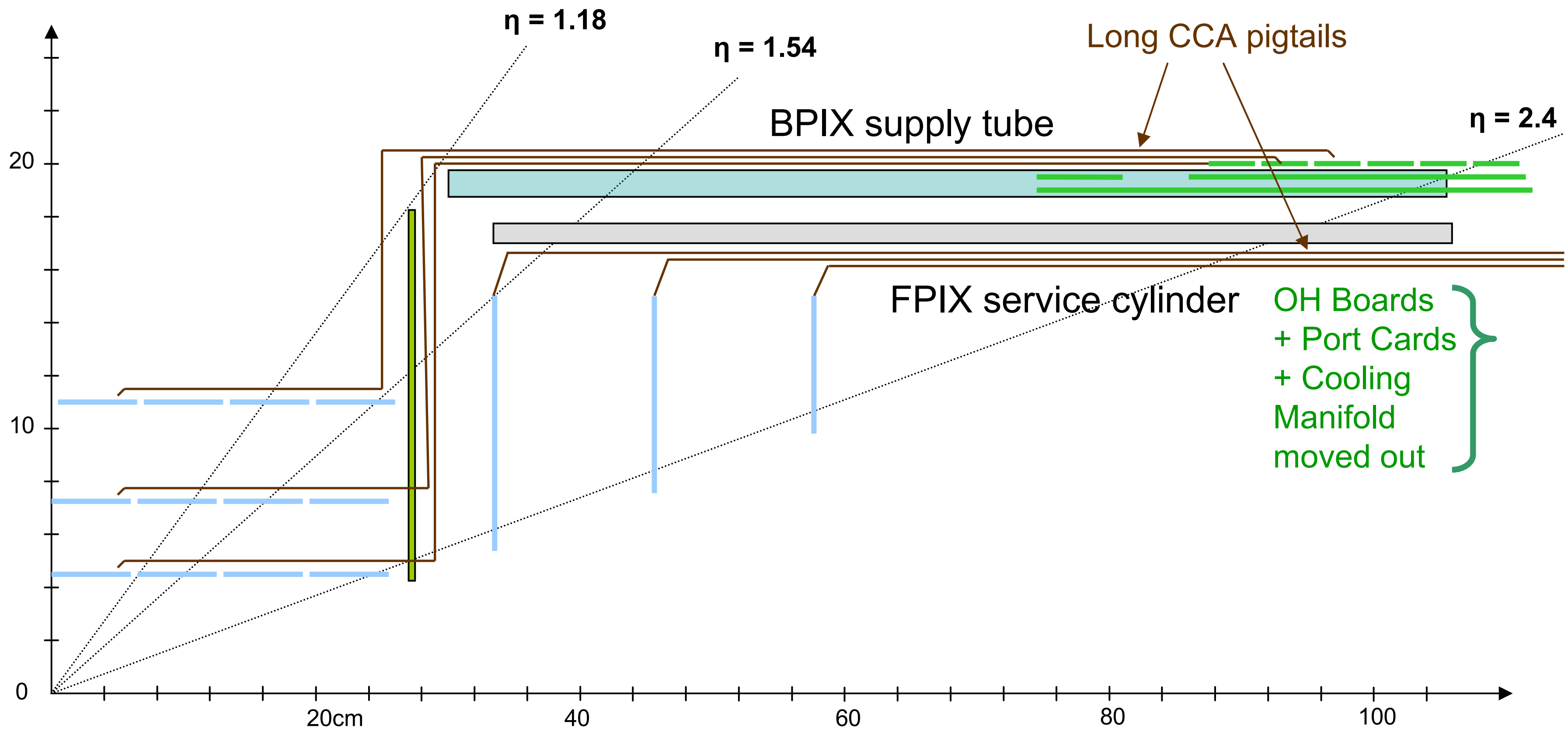
- The Purdue group developed the tools, materials & techniques for assembly, testing and delivery of ~1000 Pixel modules for the CMS FPIX (~250,000 wirebonds and >25 million pixels) at the planned assembly rate of 6 modules per day.
- Rework techniques were also developed at Purdue to recover faulty modules and maximize the final yield.
- The Fermilab group designed, assembled and tested ~250 Panels on 8 Half-Disks (for Pixel module support and cooling), in 4 Half-Cylinders (with cooling and electronics services) for FPIX.
- Fermilab had overall management responsibility for the construction of FPIX, as well as the transportation of detector assemblies to CERN and commissioning of the detector at CERN.

Goals for US CMS Pixel Mechanics R&D at Purdue and Fermilab

- In view of the recent Phase 1 upgrade plan, we have ***revised*** our mechanics R&D toward a Forward Pixel replacement / upgrade detector in 2013 = ***3 disks + CO2 cooling***
  - Reduce material significantly (and distribute more uniformly)
  - Reduce # of components and interfaces = simplify assembly
  - Study alternatives to current disks for detector geometry (i.e. fewer module types)
  - Improve routing of cooling, cables, location of control and optical hybrid boards
- A CO2 cooling system may lead to a design that uses significantly less material, and acts as a "pilot system" for implementation in a Phase 2 full CMS (and ATLAS) tracker upgrade.
- Mechanics R&D compatible with new detector layout and technologies required to maintain or improve tracking performance at higher luminosity + triggering capability
  - Serial powering (or other powering scheme)
  - Longer (possibly thinner) ROC with double buffer size for higher data rate and HV-cap
  - MTC (Module Trigger Chip) for pixel-based trigger at Level 1

Phase 1 Pixel System Concept

- Replace C6F14 with CO2 Cooling
- 3 Barrel Layers + 3 Forward Disks (instead of 2)
- Pixel integrated modules with long Copper Clad Aluminum pigtail cables
- Move OH Boards and Port Cards out



Revised Mechanics R&D Proposal

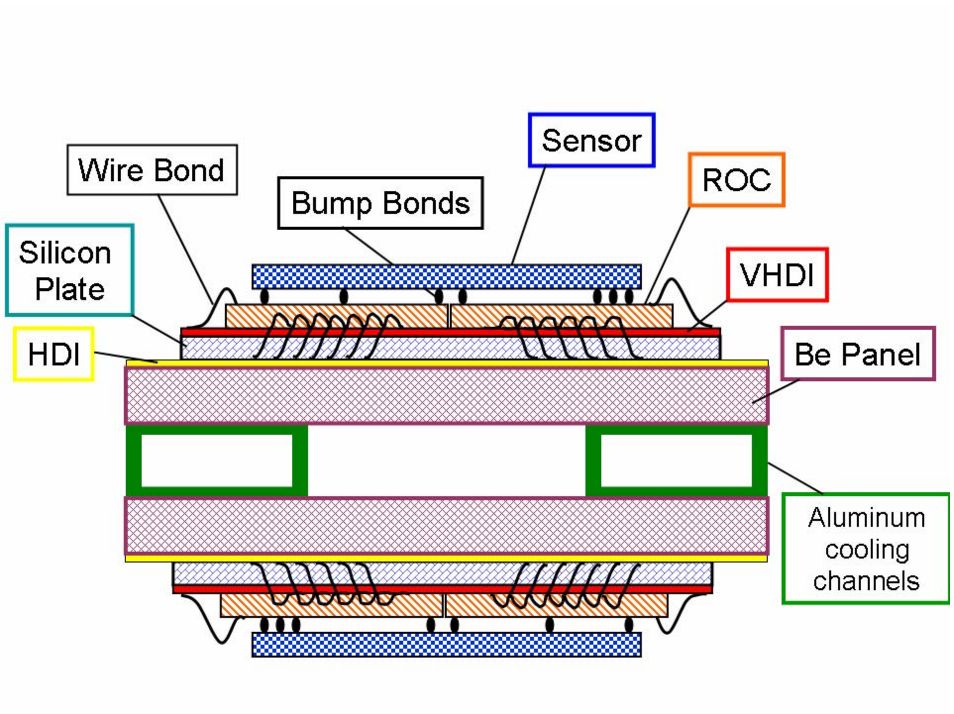
1. **Conceptual design**
   - Integrate cooling/support structure into an overall detector package and eliminate redundant features
2. **Cooling/Support development**
   - Study CO2 cooling, including construction of a CO2 cooling system for lab bench testing of prototype integrated cooling/support structure and prototype pixel detector integrated modules
     - Improved C6F14 is backup cooling solution
   - Investigate new materials and designs for support/cooling structure to lower the material budget
     - Study suitability of composites with high thermal conductivity for fabrication of low mass support frame and thermal management scheme
     - Finite Element Analysis of mechanical stability and thermal performance
     - Composite material combinations (ex: Thermal Pyrolytic Graphite vs. C-F laminate) for integrated module support
     - Investigation of alternative cooling channel materials
     - Design cooling structure in a sparse arrangement that minimizes the number of fluid connection joints
     - Measurements of cooling performance of prototype integrated module-on-support structures, and evaluation of radiation hardness of alternative materials

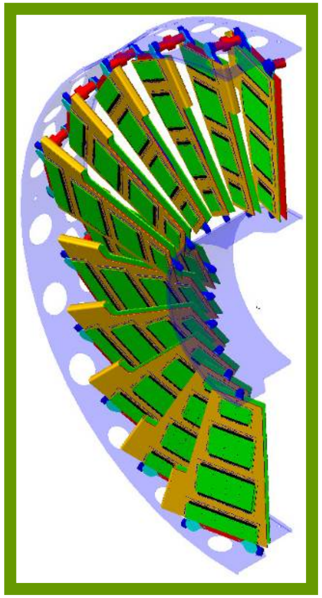
Revised Mechanics R&D Proposal

3. Integrated Module Development

- Evaluation of adhesives for integrated module assembly and rework
- Evaluate state-of-the-art alternatives (ex: ceramic vs. flex-laminated-on-rigid substrates) for dense multilayer interconnects for readout and power circuits
- Development of (semi-robotic) tooling to assemble prototype integrated modules
- Testing of mechanical, thermal and electrical properties of prototype integrated modules with radiation

Current Fpix components stack-up

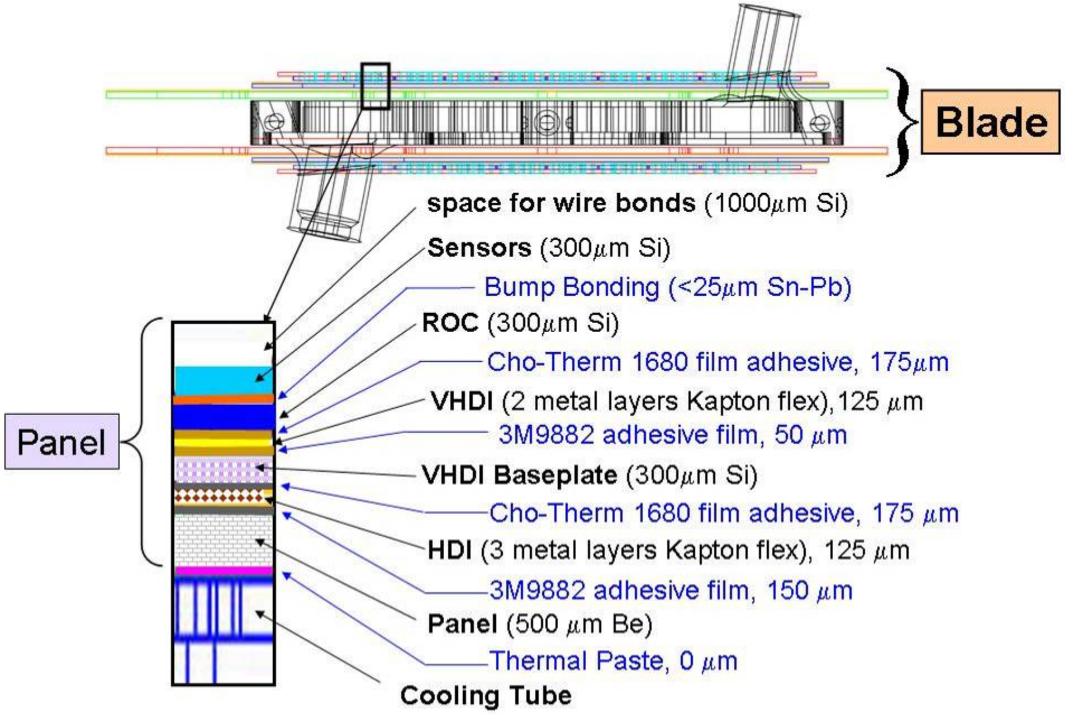




Currently, FPIX Disks have a lot of material in:

- passive Si and Be substrates
- flex circuits with Cu traces
- thermal conductive (BN powder) adhesive interfaces
- brazed aluminum (0.5mm wall thickness) cooling channels

Fpix Blade components and thermal interfaces



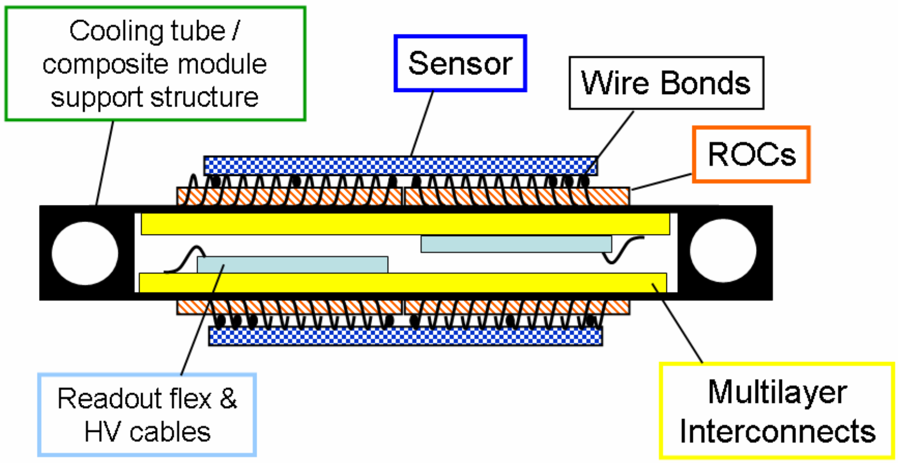
Blade

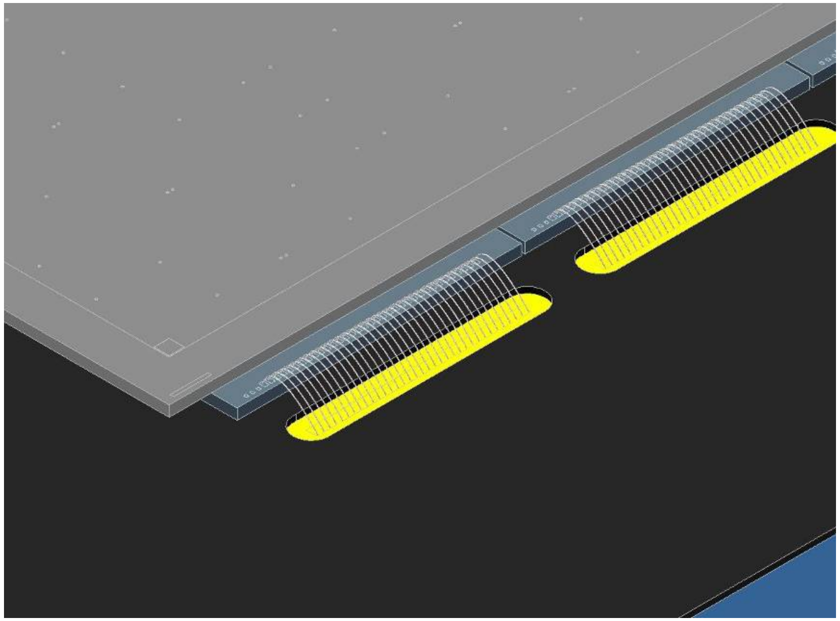
Panel

space for wire bonds (1000µm Si)
Sensors (300µm Si)
Bump Bonding (<25µm Sn-Pb)
ROC (300µm Si)
Cho-Therm 1680 film adhesive, 175µm
VHDI (2 metal layers Kapton flex),125 µm
3M9882 adhesive film, 50 µm
VHDI Baseplate (300µm Si)
Cho-Therm 1680 film adhesive, 175 µm
HDI (3 metal layers Kapton flex), 125 µm
3M9882 adhesive film, 150 µm
Panel (500 µm Be)
Thermal Paste, 0 µm
Cooling Tube

- Current design has ~20 component layers for a blade. This allows for “standalone module” testing, but at a material price
- Reduce # of thermal (adhesive) interfaces = less material and thermal impedance
- Need method to evaluate bump bond connections before next assembly step = ***probe testing BBMs before module assembly***

Upgrade Integrated Module Concept





- Flip chip modules mounted directly on high heat transfer/stiff material (ex. pyrolytic graphite).
- Wirebond connections from ROCs to high density interconnect/flex readout cables through holes in rigid support / heat spreader
- Leaves pixel sensors uncovered for scanning with pulsed laser
- Flip chip modules REMOVABLE, leaving multilayer interconnect bus intact for replacement modules.

CO_2 Cooling

- A CO2 cooling system was designed and constructed for the VELO detector in LHCb and will run in conditions (silicon detector, high radiation) that are comparable to CMS and ATLAS conditions
- CO2 properties are good for silicon detector applications
  - Low viscosity and low density difference between liquid and vapor is ideal for micro channels (d<2.5mm)
  - Ideal for serial cooling of many distributed heat sources
  - High system pressure makes sensitivity to pressure drops relatively small
  - High pressure (up to 100 bar) no problem for micro channels
  - Radiation hard
  - Environment friendly, ideal for test set-ups
  - Optimal operation temperature range (-40°C to +20°C)
- "No showstoppers" foreseen using existing CMS pipes for CO2 cooling, but modifications will have to be made to the LHCb CO2 system to reduce the pressure for CMS pipes
- CO2 cooling may be the best coolant for any upgrade in the CMS and ATLAS inner detectors

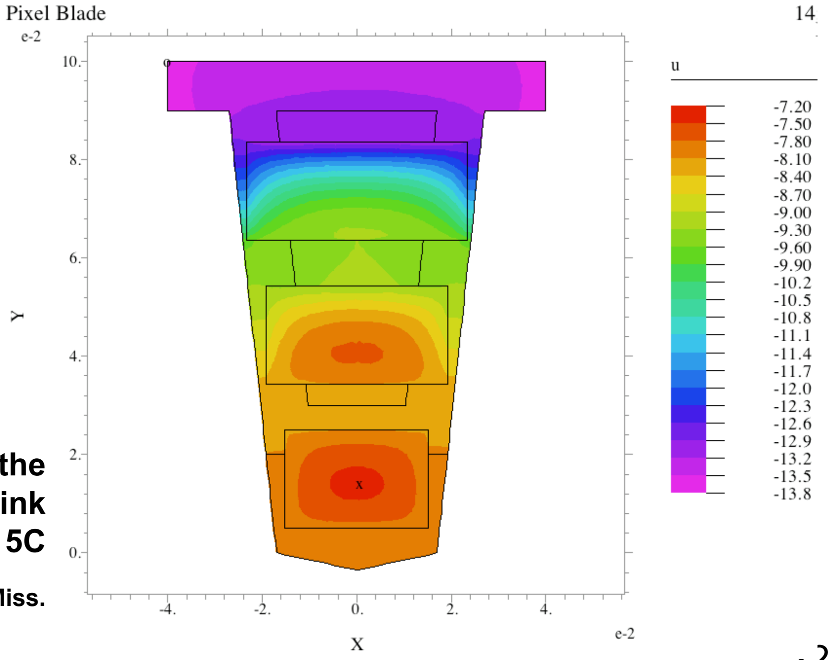
CO$_2$ Cooling

Small diameter (1mm) pipes for CO2 cooling:

- much less mass ~1/10
- small area for heat transfer - have to route enough tubes for sufficient thermal contact with pixel modules
- lends to design similar to current FPIX - flat substrates for module support and tubing loops

→ need for material budget optimization -- passive high thermal conductive panels vs. routing small diam. CO2 cooling tubes to heat sources

Consider cooling tube at edge of panel with pixel modules mounted on heat spreader



2D FEA model of the FPIX blade heat sink coolant temp of -15C

L. Cremaldi, U. Miss.

Resolution of Flat Disk VS Turbine at 20°

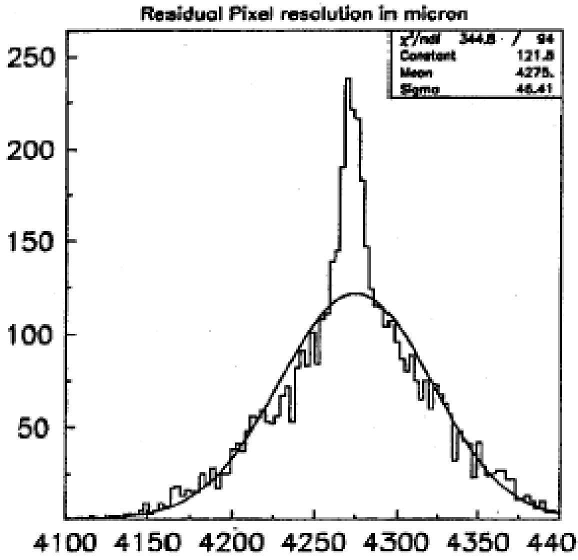


Fig. 18. A resolution of 46 μm is found along columns for $\alpha = 0°$ using charge sharing. The peak at the center indicates a higher resolution in case charge was shared with neighboring pixels.

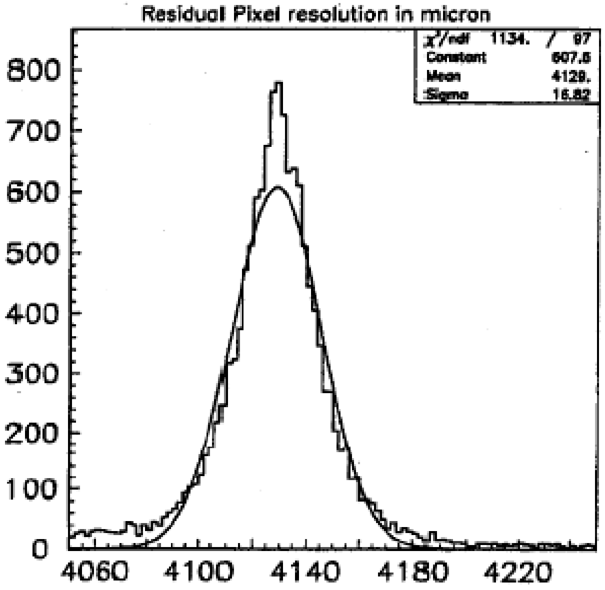


Fig. 19. An average resolution of 17 μm is found along columns for $\alpha = 20°$ using charge sharing.

- 20° angle of sensors improve resolution from 46 to 17 microns according year 2000 CERN measurements.
- Improved vertex resolution by factor of ~2 (raw estimation)