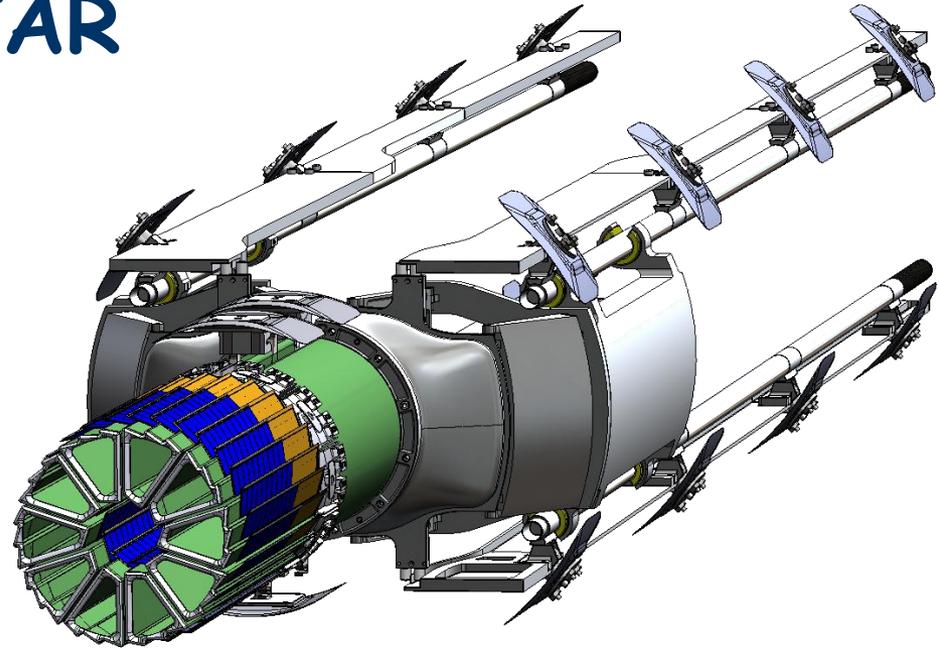


MAPS based vertex detector at STAR



Vertex 2010 - 19th International Workshop on Vertex Detectors, 6-11 June 2010, Loch Lomond, Scotland



*Michal Szelezniak*¹

on behalf of:

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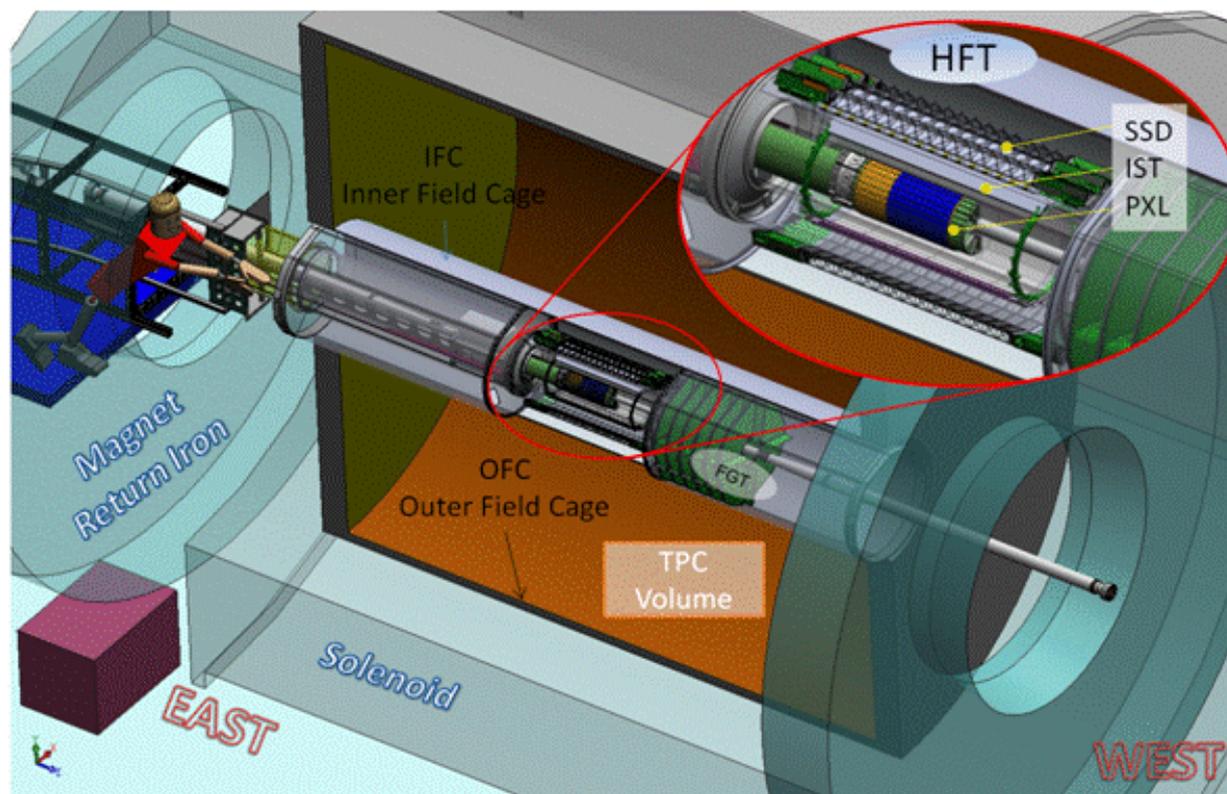
¹ LBNL, ² NPI ASCR, ³ KSU, ⁴ BNL

Outline

- STAR HFT Upgrade
- PIXEL (PXL) Requirements
- PIXEL Geometry
- PIXEL Development Path
 - Sensors
 - RDO electronics
 - Mechanical support – cooling tests
 - Readout cable development
- Summary and Outlook

STAR Heavy Flavor Tracker (HFT) Upgrade

The HFT is a tracking upgrade to the STAR detector to identify mid rapidity Charm and Beauty mesons and baryons through direct reconstruction and measurement of the displaced vertex with excellent pointing resolution.



TPC – Time Projection Chamber
(main detector in STAR)

HFT – Heavy Flavor Tracker

- SSD – Silicon Strip Detector
- IST – Inner Silicon Tracker
- PXL – Pixel Detector (PIXEL)

Graded resolution:

TPC → SSD → IST → PXL

~1mm ↘

~300μm ↘

~250μm ↘

<30μm

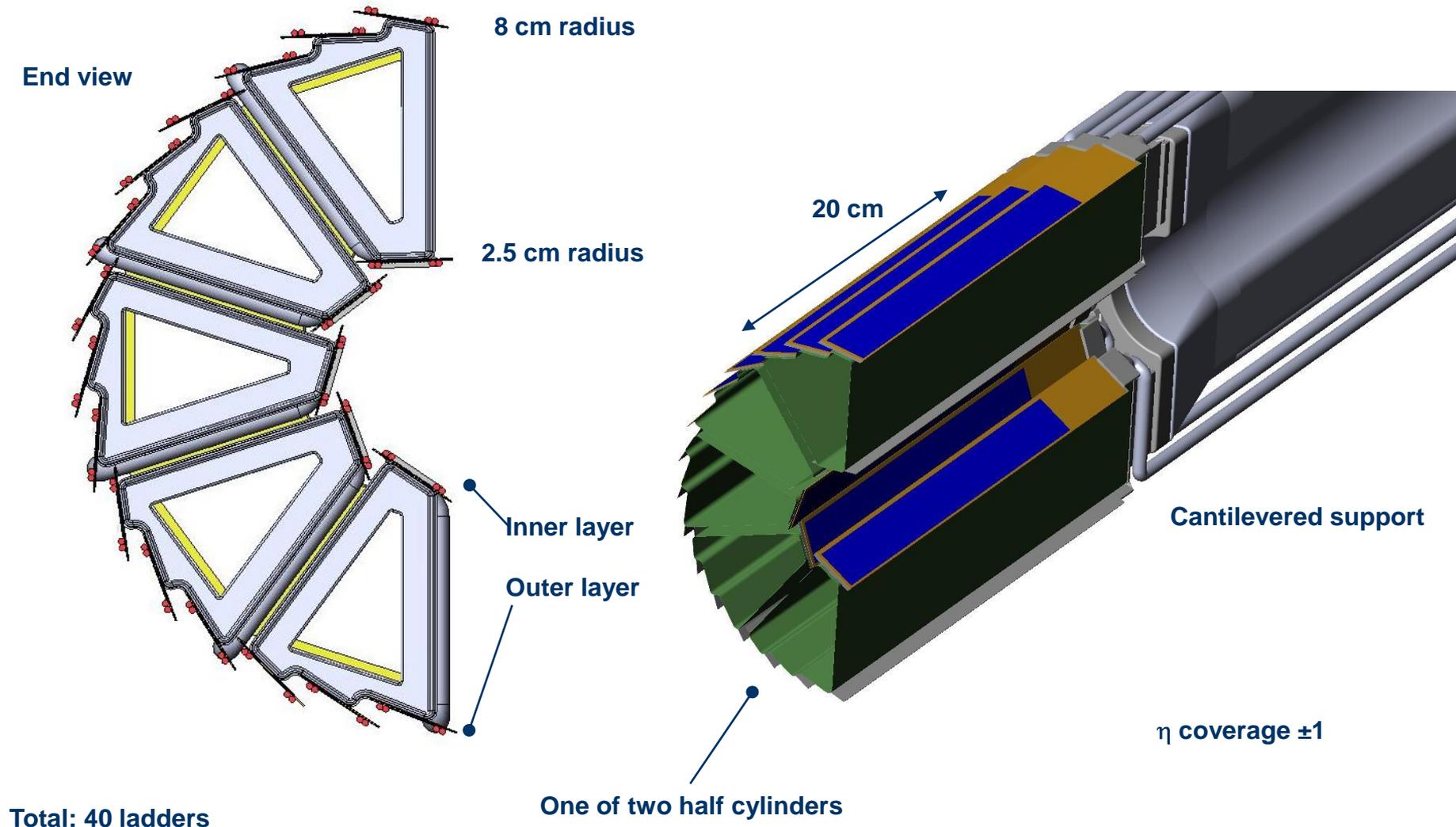
PIXEL Requirements

Pointing resolution	$(12 \oplus 19\text{GeV}/p\cdot c) \mu\text{m}$
Layers	Layer 1 at 2.5 cm radius Layer 2 at 8 cm radius
Pixel size	$18.4 \mu\text{m} \times 18.4 \mu\text{m}$
Hit resolution	$8 \mu\text{m}$
Position stability	$6 \mu\text{m rms}$ (20 μm envelope)
Radiation length per layer	$X/X_0 = 0.37\%$
Number of pixels	436 M
Integration time (affects pileup)	0.2 ms
Radiation requirement	20 to 90 kRad $2 \cdot 10^{11}$ to 10^{12} 1MeV n eq/cm ²
Rapid detector replacement	< 8 Hours

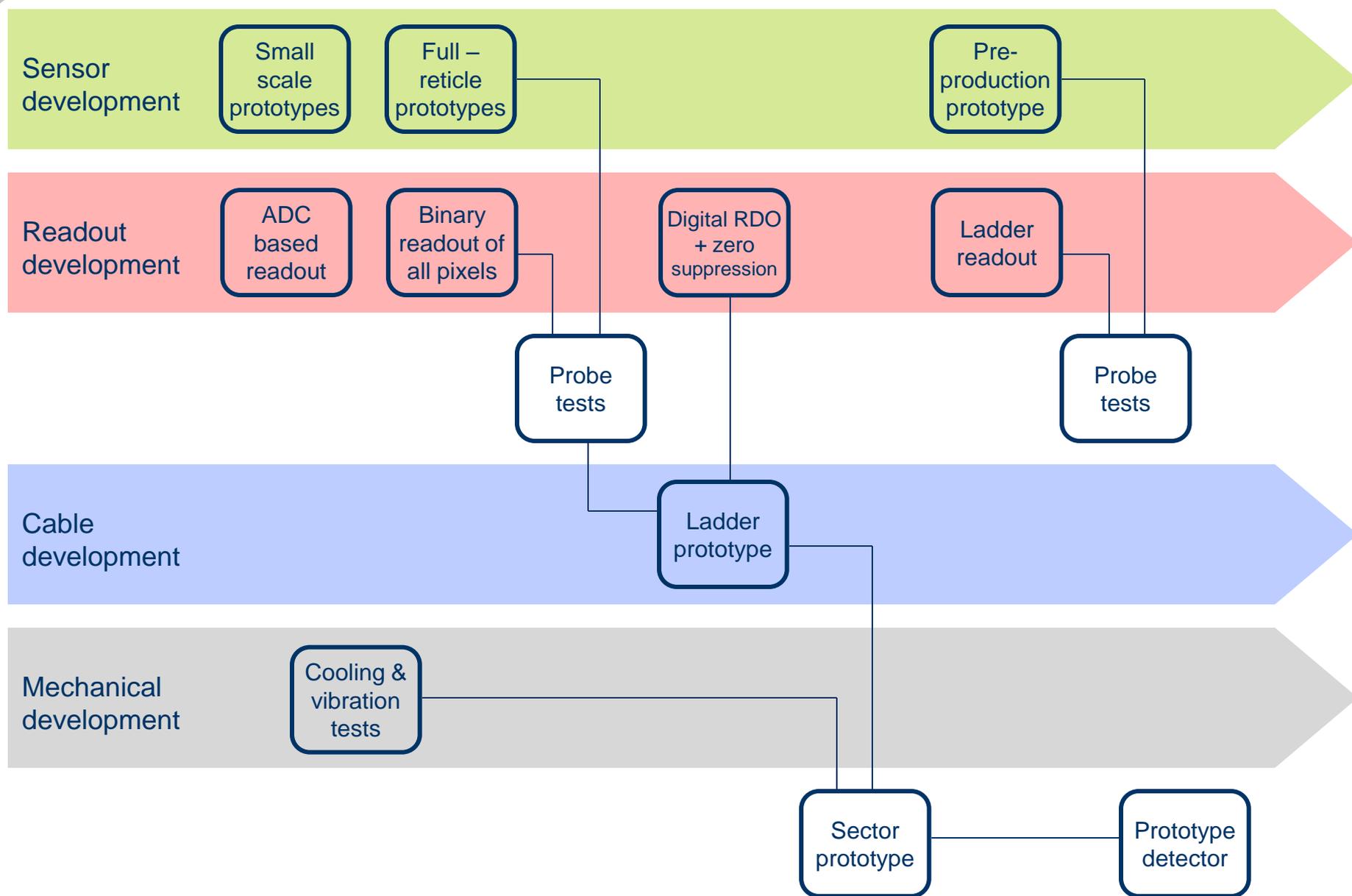
**critical
and
difficult**

PIXEL Geometry

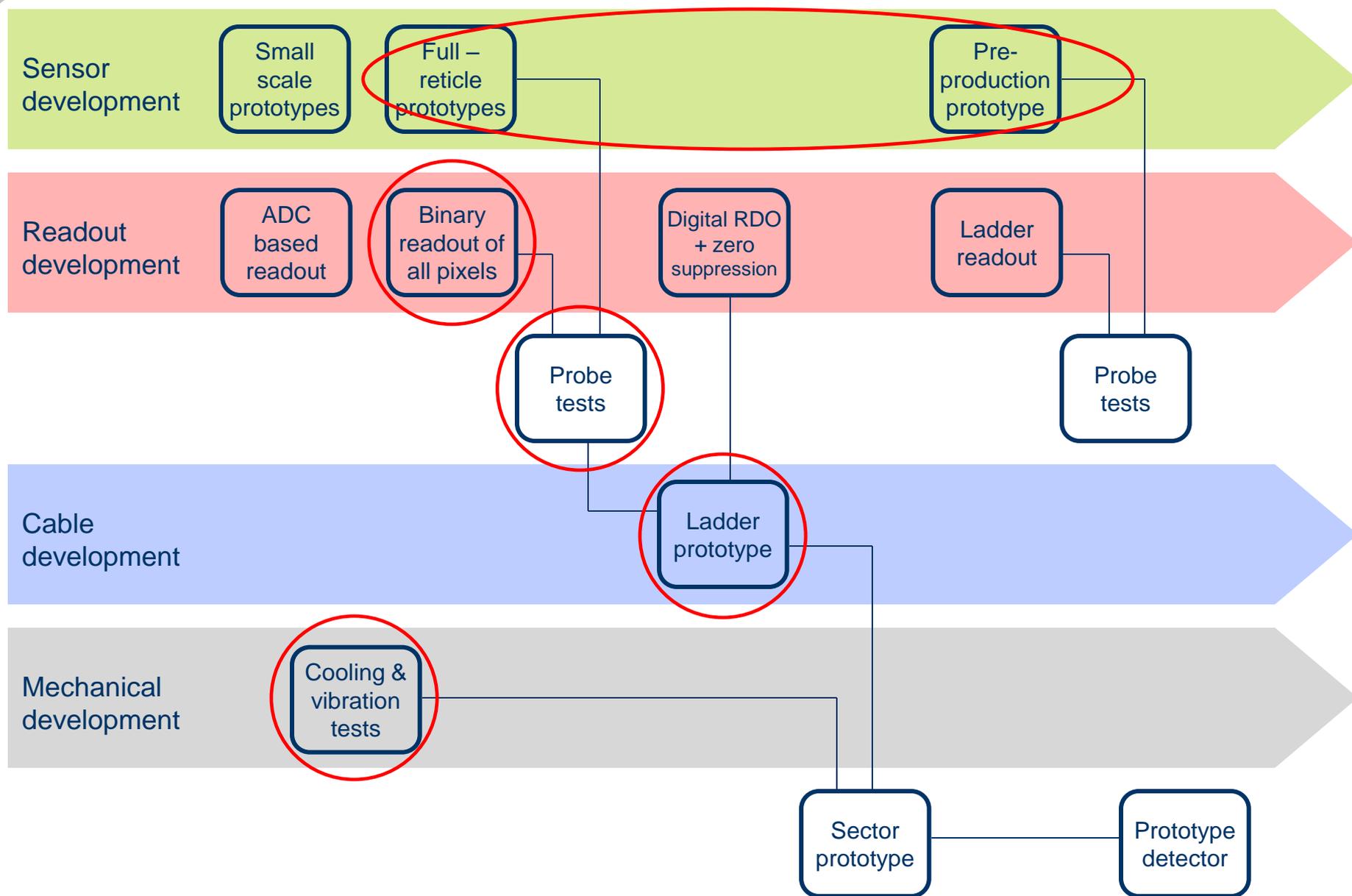
The detector ladders are 50 μm thinned silicon, on a flex kapton/aluminum cable.



PIXEL Prototype Development Path



PIXEL Prototype Development Path



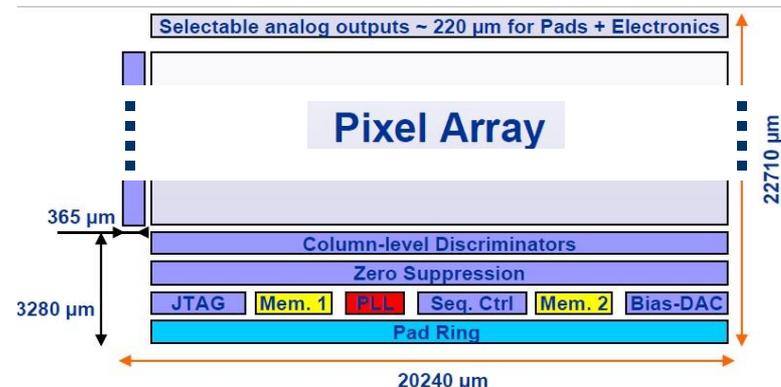
MAPS Prototypes For PIXEL Designed by IPHC

PIXEL benefits from the continuous MAPS development at IPHC.

- Current generation



- Next generation (in design)



- Phase-1 prototype
 - Reticle size (~ 4 cm²)
 - Pixel pitch 30 μm
 - ~ 410 k pixels
 - Column parallel readout
 - Column discriminators
 - Binary readout of all pixels
 - Data multiplexed onto **4 LVDS outputs @ 160 MHz**
 - **Integration time 640 μs**
- Functionality tests and yield look very good.
 - Measured ENC is 15 e⁻.
 - Beam test to measure MIP efficiency planned for 2010.
- Phase-2 prototype
 - Small mask adjustments to improve discriminator threshold dispersion

- Design based on Mimosa26 architecture
- Reticle size (~ 4 cm²)
 - Pixel pitch 20.7 μm (recent change)
 - 890 k pixels
- Reduced power dissipation
 - **Vdd: 3.0 V**
 - Optimized pixel pitch vs. Non-ionising radiation tolerance
 - Estimated power consumption ~134 mW/cm²
- **Short integration time 185.6 μs**
- Improved pixel architecture
- Optimized discriminator timing
 - Improved threshold uniformity
- **on-chip zero suppression**
- **2 LVDS data outputs @ 160 MHz**

Probe Tests

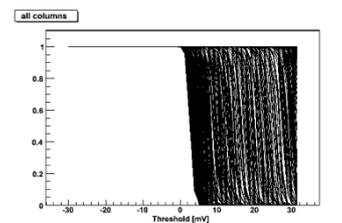
Testing diced and thinned sensors to meet yield requirements for ladder assembly

- Sensors designed with dedicated probe pads in the sensor pad ring.
- Automated test system allows for a qualitative analysis of probed sensors.
 - Including identification of dead/stuck pixels
- 13 full-thickness, diced sensors probe tested.
- Results are very promising.
- Up to 3 probe tests on a sensor.
- We will begin testing thinned sensors within the next few days

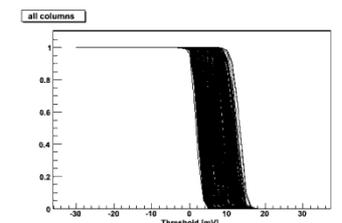


Vacuum chuck for probe testing 50 μm thick MAPS

Phase-1 discriminator transfer functions $f(\text{threshold voltage})$ observed on two of the probed sensors :



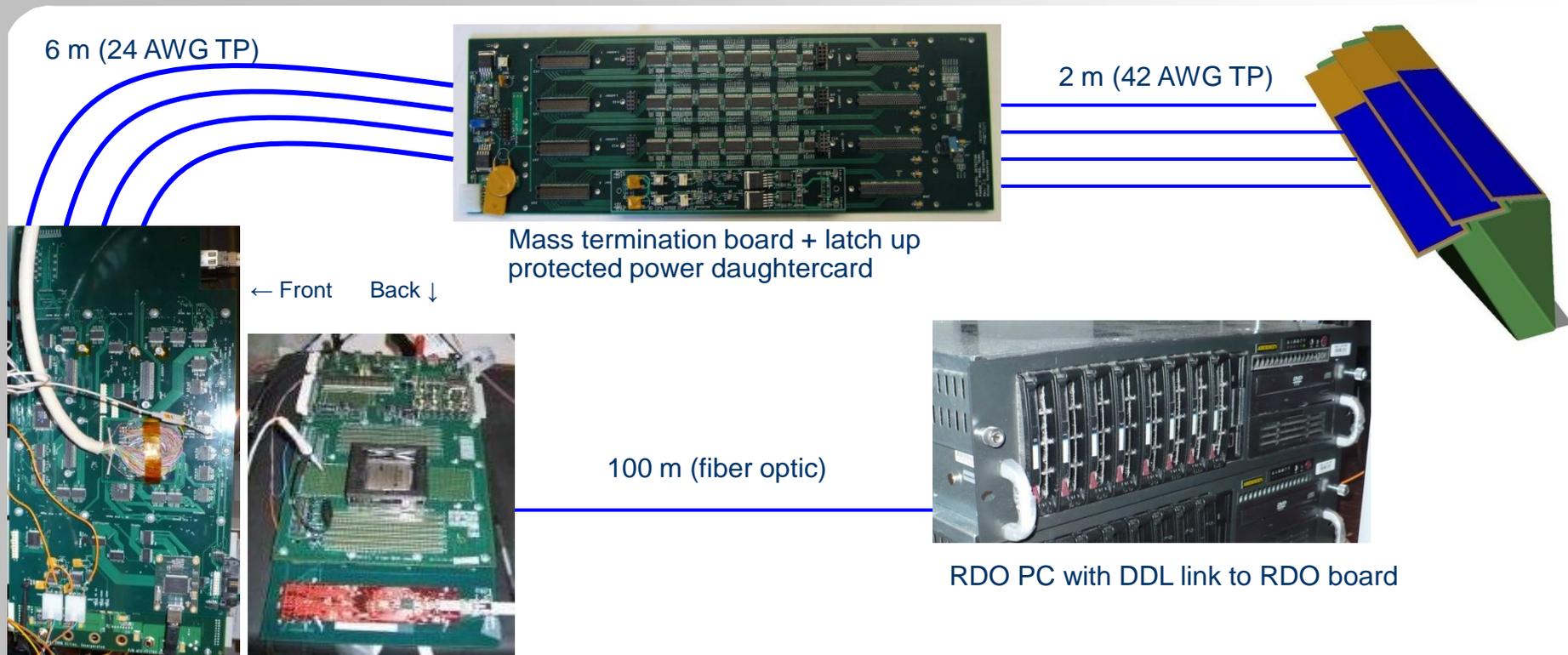
Initial testing with $\sim 75 \mu\text{m}$ travel past touchdown



30 μm additional lowering of probe pins

We are considering possibility of using pad protection diodes to verify good contacts

PIXEL RDO Basic Unit



- 4 ladders per sector
- 1 Mass Termination Board (MTB) per sector
- 1 sector per RDO board
- 10 RDO boards in the PIXEL system

PIXEL RDO architecture validated with data path test

Measured BER (bit error rate)
of $< 10^{-14}$

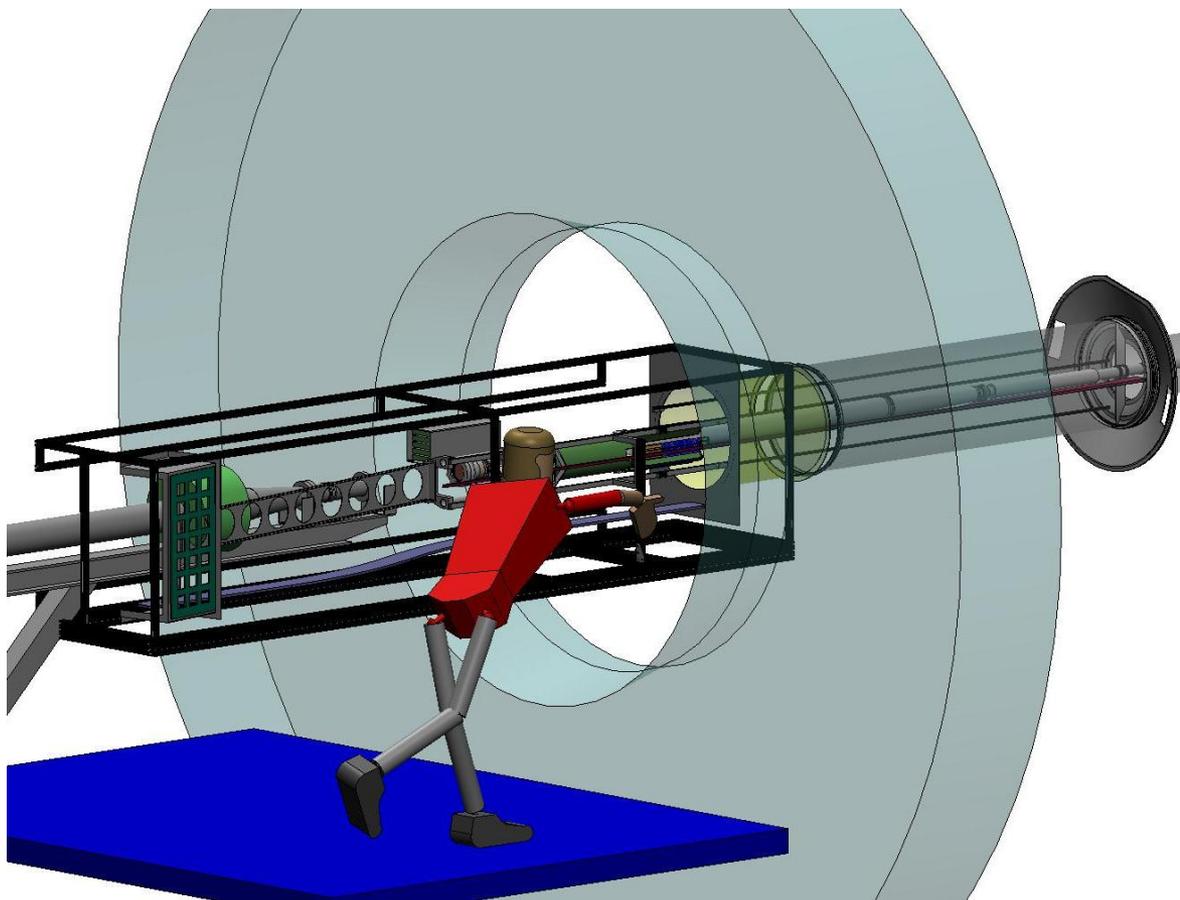


PIXEL Mechanical Support

Mechanical stability within a 20 μm window is required.

other requirements:

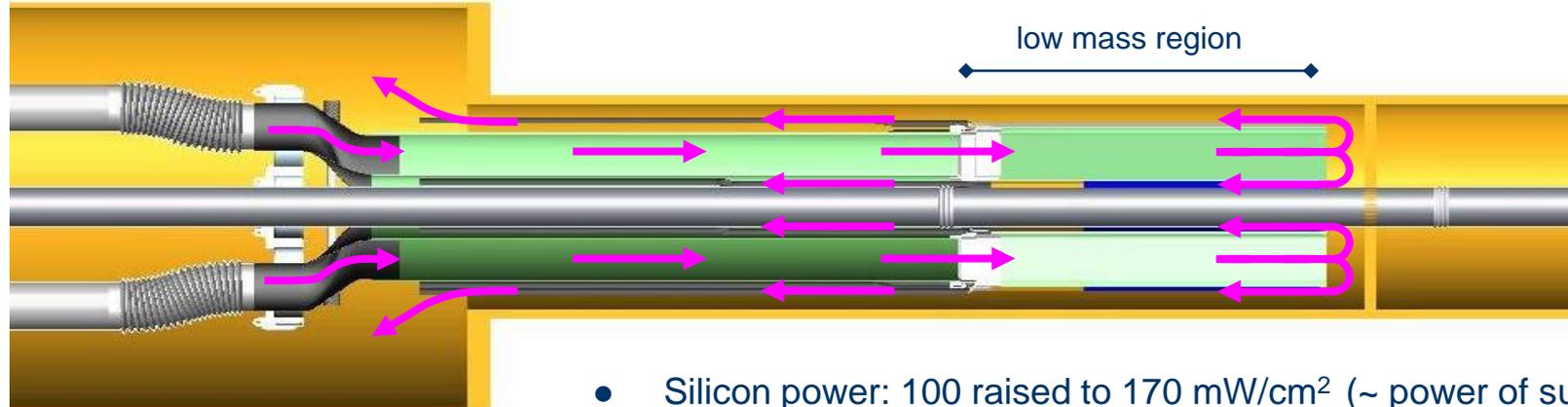
- Fast detector replacement capabilities
- Air cooling



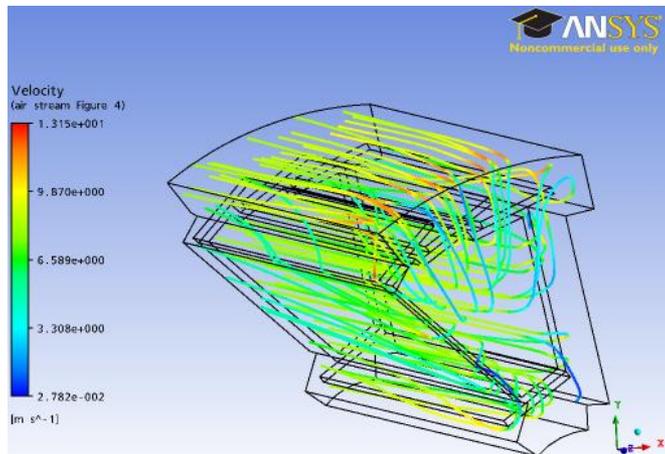
- A well controlled method for installation of the pixel detector has been developed with emphasis on ease of operation and avoidance of detector risk
- Insertion mechanism to guide detector around beam pipe and beam pipe support uses track and carriage with hinge and cam to guide into final docking position defined by locking kinematic mounts

PIXEL Thermal Analysis and Testing

The large CTE difference between silicon and kapton is a potential source of thermal induced deformation. An air-flow based cooling system has been chosen for PIXEL to minimize material budget.



- Silicon power: 100 raised to 170 mW/cm² (~ power of sunlight)
- 350 W total in the low mass region (Si + drivers)



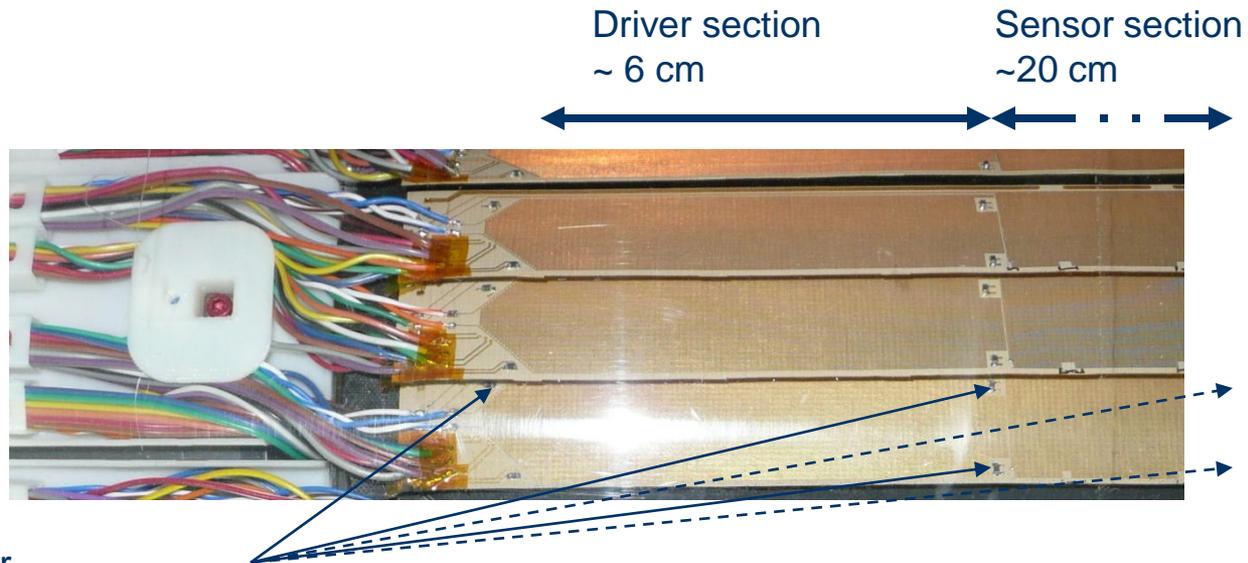
CFD computational fluid dynamics



Detector mockup to study cooling efficiency

Detector Mockup

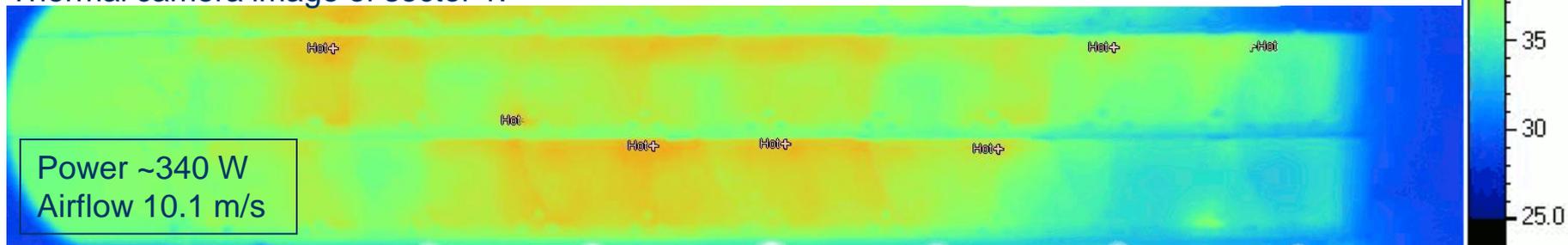
- Kapton cables with copper traces forming heaters allow us to dissipate the expected amount of power in the detector



- 6 thermistors on each ladder
- One of the sectors (sector 1) was equipped with 10 dummy silicon chips per ladder, with Pt heaters deposited on top of silicon

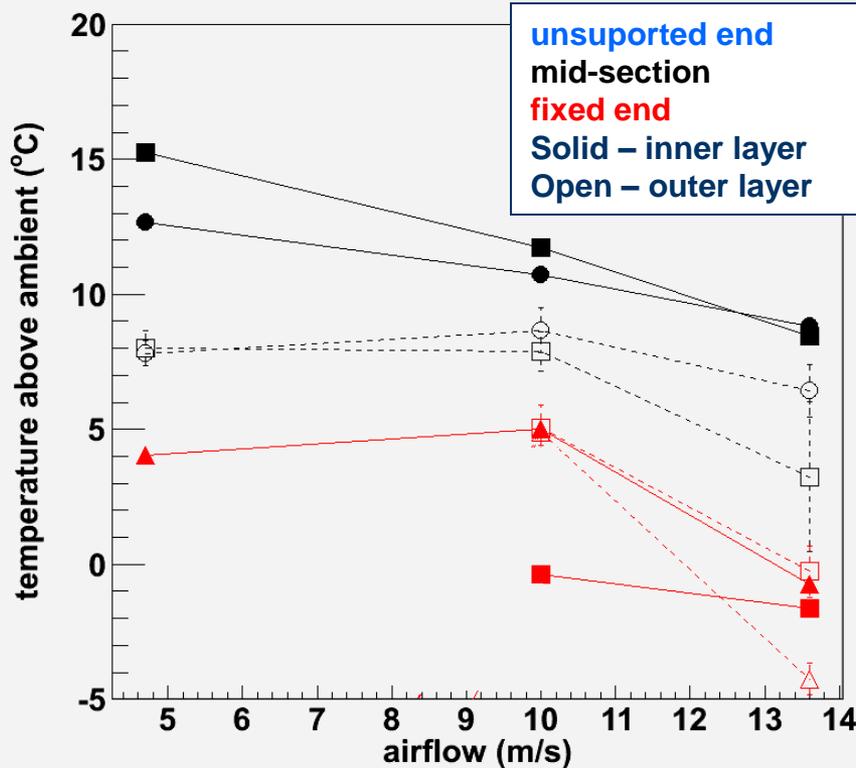


Thermal camera image of sector 1:

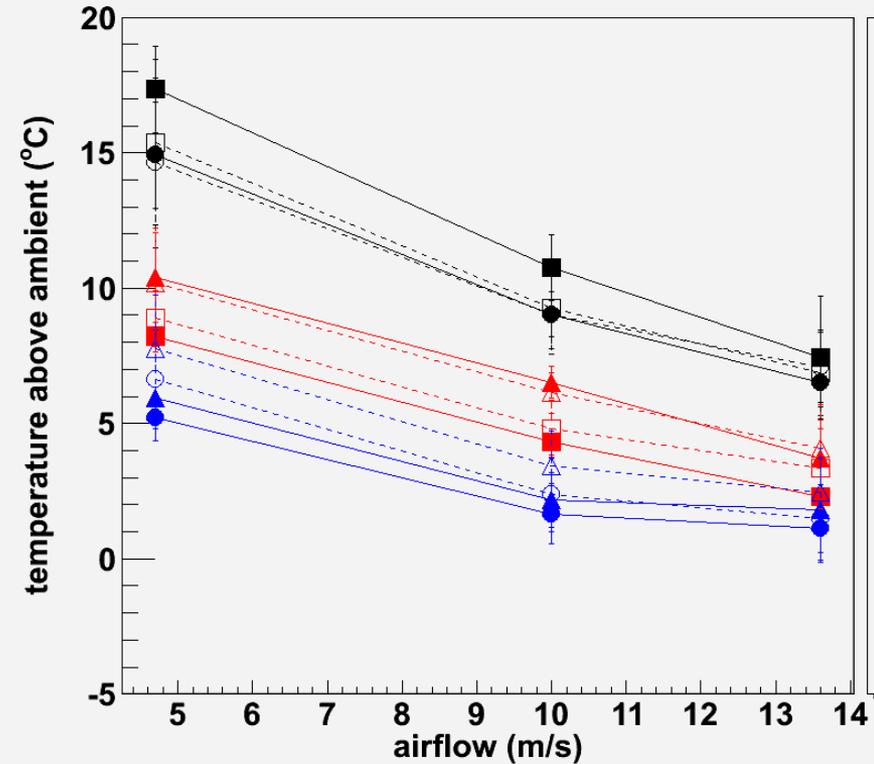


Cooling Tests at ~340 W

thermistor temperature at 340W, sector 1, ambient air @~26.8 °C



thermistor temperature at 340W, sectors 2-10, ambient air @~26.8 °C



- Measurement results agree with simulations
- Air flow-induced vibrations (@ < 10 m/s) are within required stability window

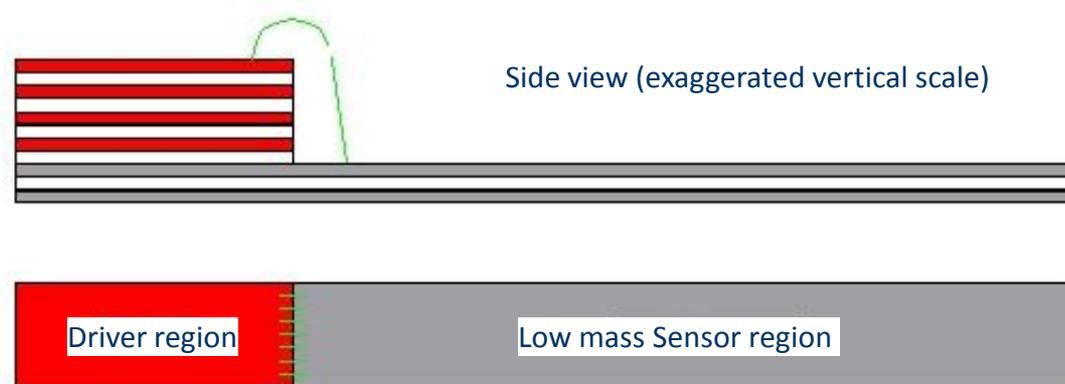
Sensor RDO Cable Development

Al based cable is needed for low radiation length in the low mass region.

PIXEL Cable development stages:

1. Infrastructure testing board
2. Prototype detector cable FR-4 with Cu traces
3. Prototype detector cable Kapton with Cu traces
4. Prototype detector cable Kapton with Al traces

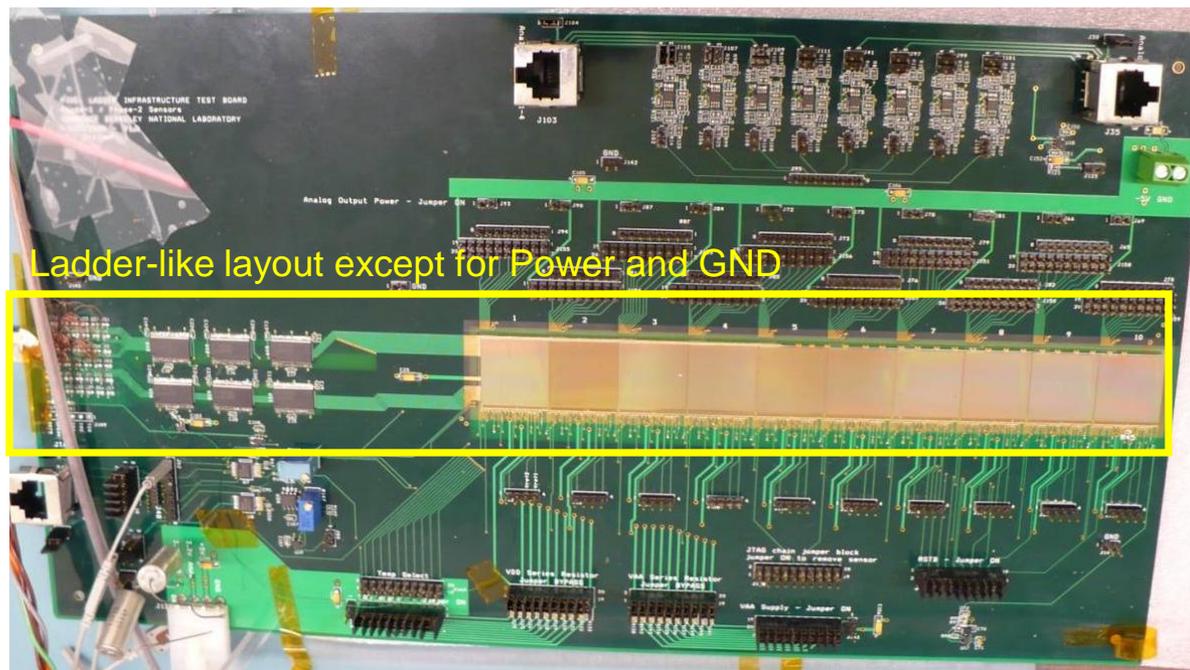
Preliminary Design:
Hybrid Copper / Aluminum
conductor flex cable



Low mass region calculated X/X_0 for Al conductor = 0.073 %
 Low mass region calculated X/X_0 for Cu conductor = 0.232 %

Infrastructure Test Board

- This is a ladder level system test
 - complete chain of RDO system that has never been fully tested (MTB, RDO, long cables)
- Multidrop clock working
- JTAG daisy chain working (with caveats)
- Just started taking data



Very preliminary results with full thickness Phase-1 prototypes:

	Noise
One sensor at a time	100 %
All sensors on (high discriminator threshold → low switching/output activity) – expected running configuration	Up to 125 % (122 % on average)
All sensors on (low discriminator threshold → high switching/output activity)	Up to 145 % (138 % on average)

- Coupling mechanism is under investigation.
- Next board with 50 μ m Phase-2 prototypes is being assembled.

Summary and Outlook

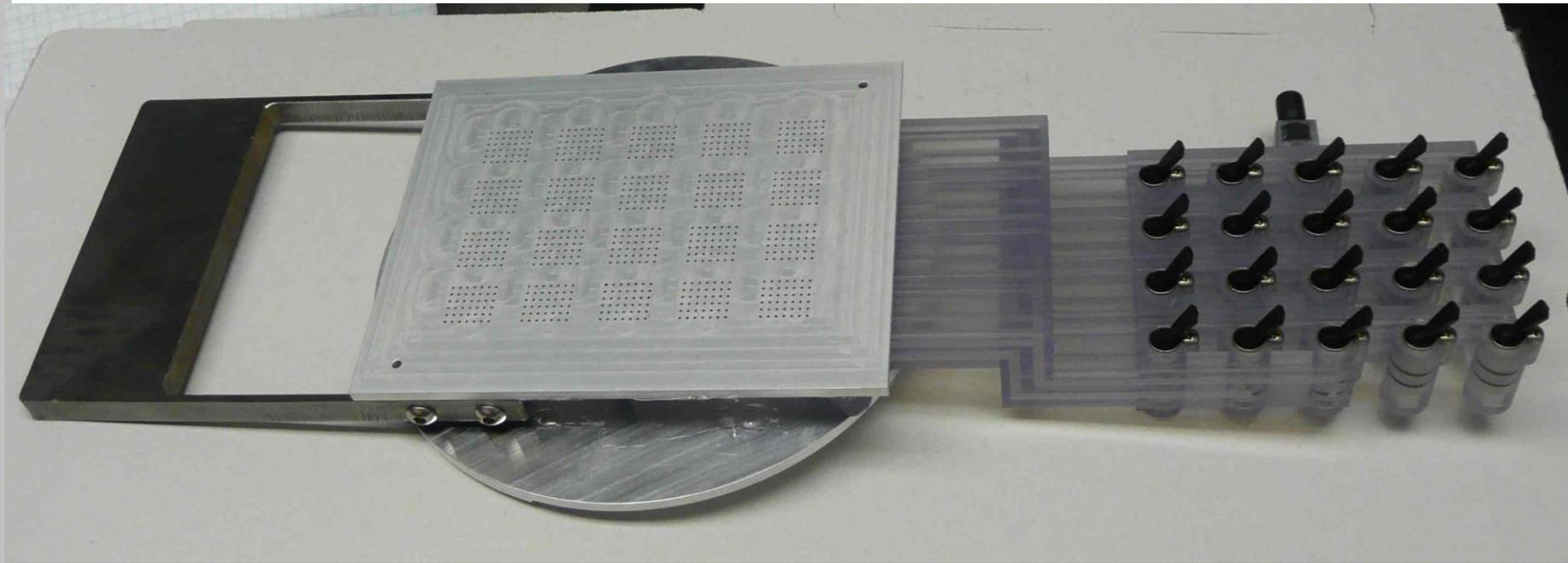
- Development of the detector's mechanical support is well advanced
 - Very low mass detector support designs have passed multiple analysis tests and prototype tests addressing cooling and position stability.
 - Prototype tooling is in place and tested for sector/ladder production.
 - Concept designs for installation and insertion are well advanced .
- MAPS technology development at IPHC is well advanced and on schedule
- The RDO data path architecture has been validated and hardware prototypes have been produced
 - Testing of individual sensors works well.
 - We have just started reading out 10 sensor ladders.
- Test plans:
 - Beam test with Phase-2 @ Fermilab
- HFT is headed for CD2/3 in Q4 FY2010
- HFT completion scheduled for Q3 FY 2013

Thank you for your attention!

- backup

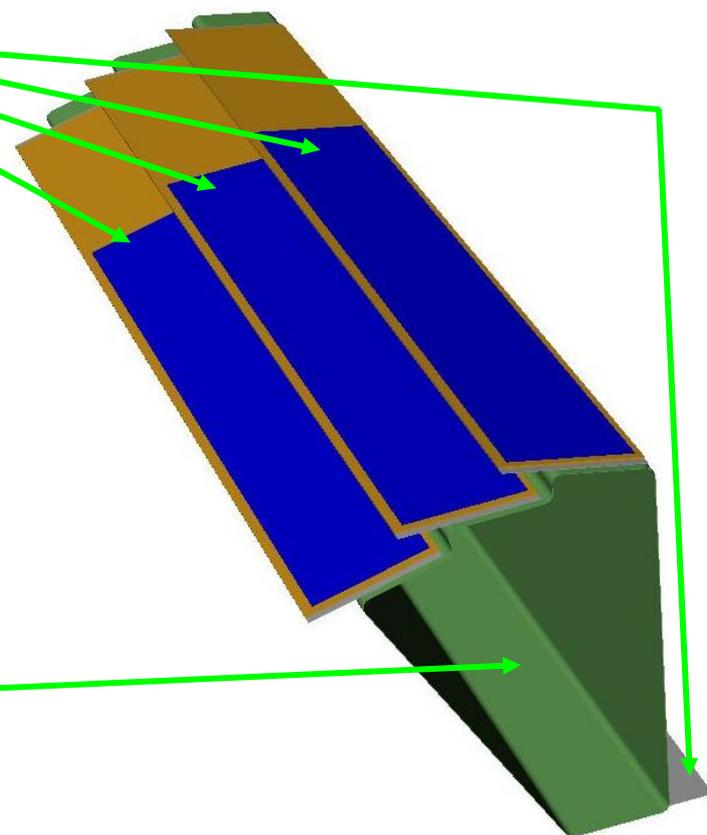
Vacuum chuck

Vacuum chuck for probe testing 50 μm thick MAPS



Stability requirement drives design choices

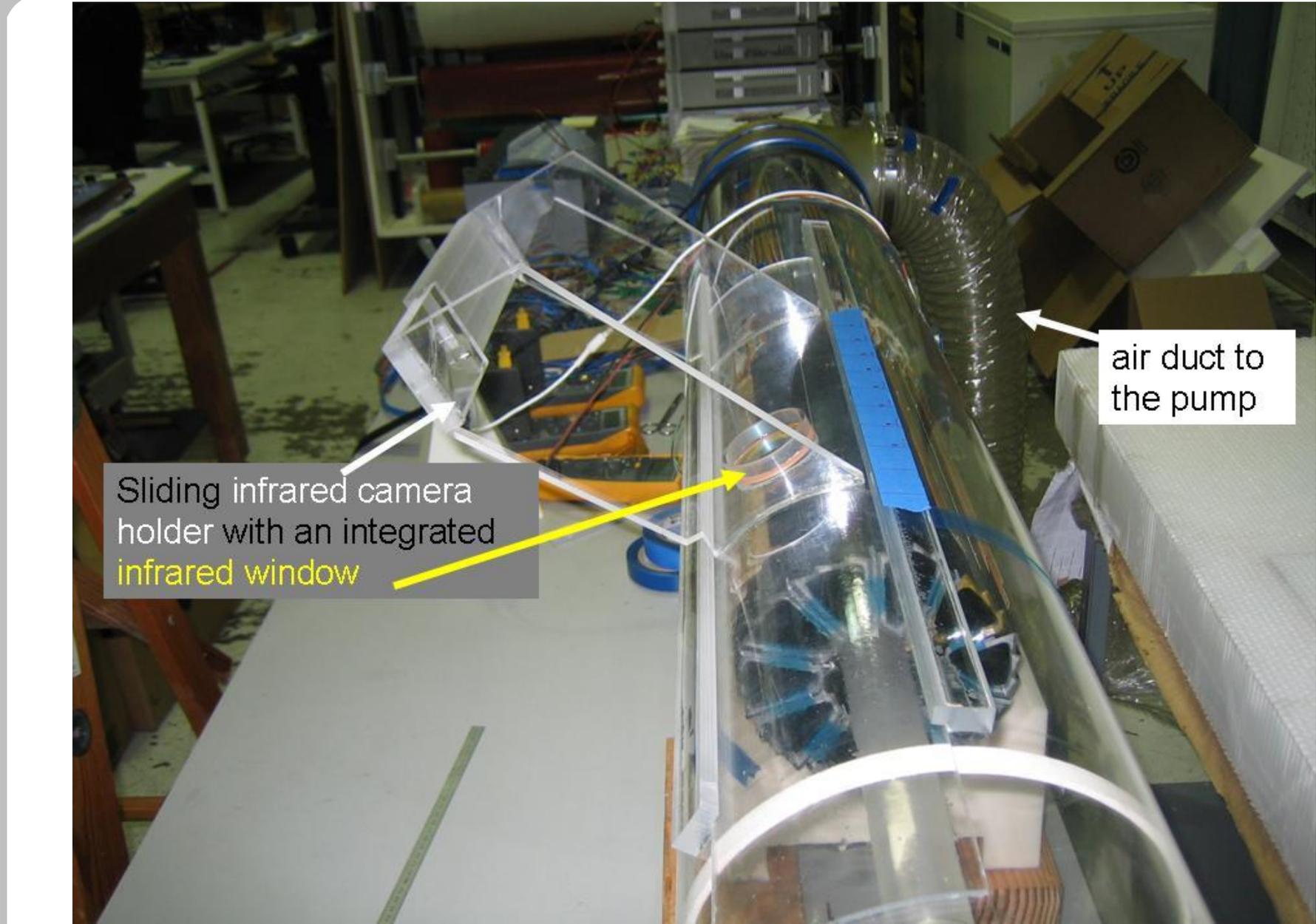
- The detector ladders are thinned silicon, on a flex kapton/aluminum cable
- The large CTE difference between silicon and kapton is a potential source of thermal induced deformation even with modest 10-15 deg C temperature swings
- Two methods of control
 - ALICE style carbon composite sector support beam with large moment of inertia
 - Soft decoupling adhesive bonding ladder layers



RDO requirements

- Triggered detector system fitting into existing STAR infrastructure (Trigger, DAQ, etc.)
- Deliver full frame events to STAR DAQ for event building at approximately the same rate as the TPC (1 kHz for DAQ1000).
- Have live time characteristics such that the Pixel detector is live whenever the TPC is live.
- Reduce the total data rate of the PXL detector to a manageable level (< TPC rate of ~1MB / event).
- Contain additional functionality for full sensor characterization including production probe testing.

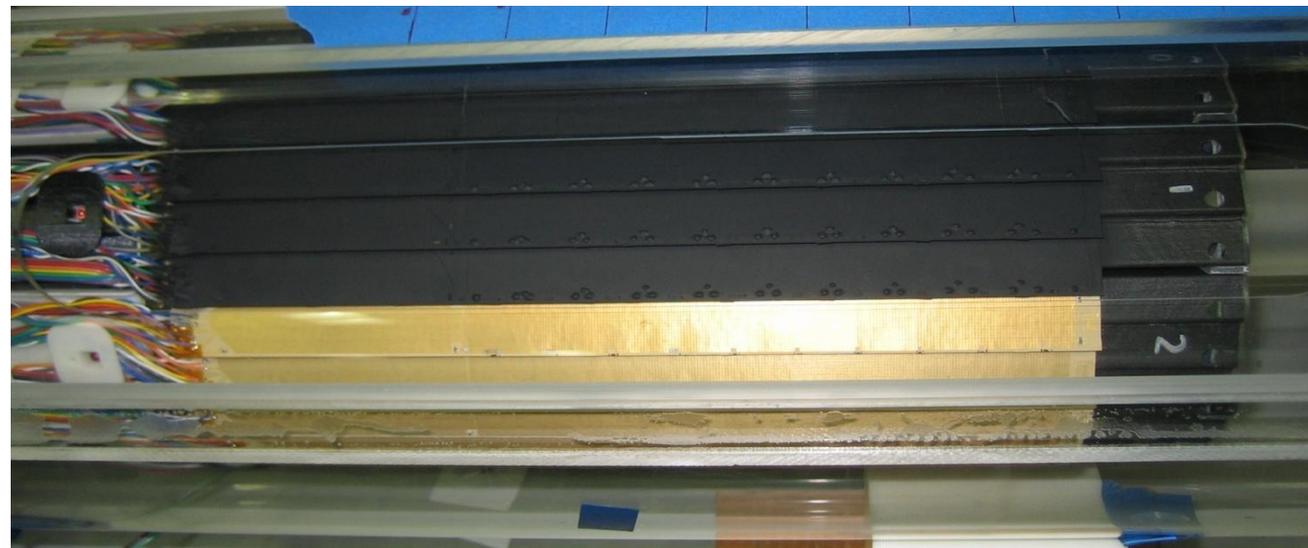
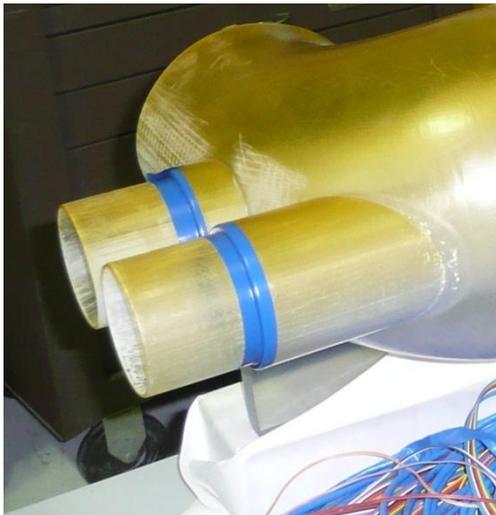
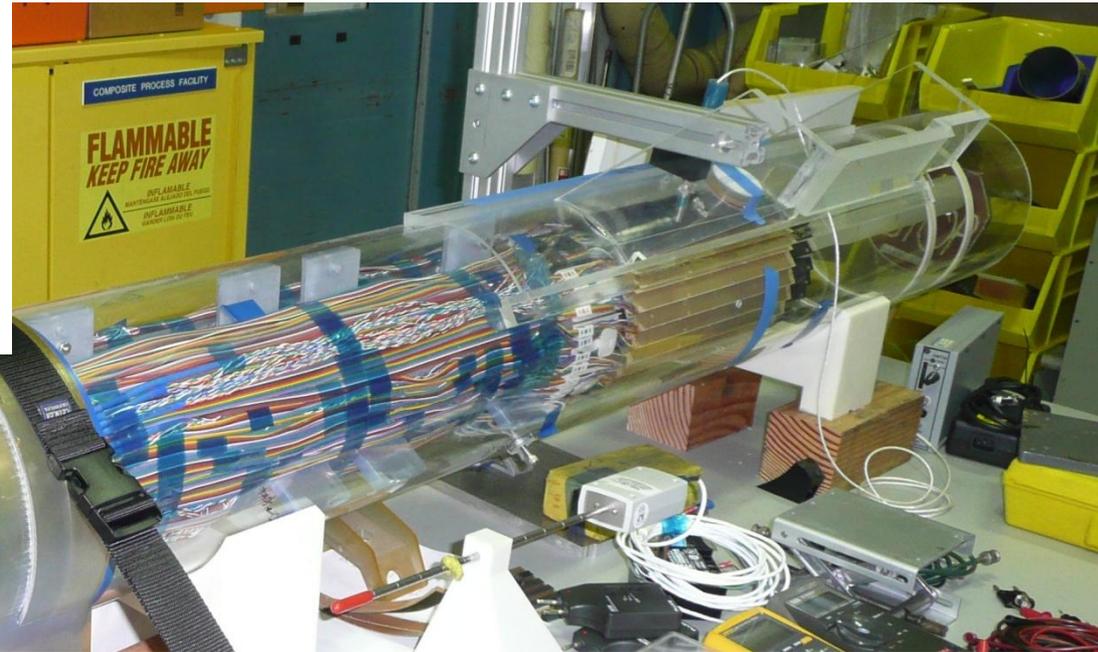
Cooling Test Setup



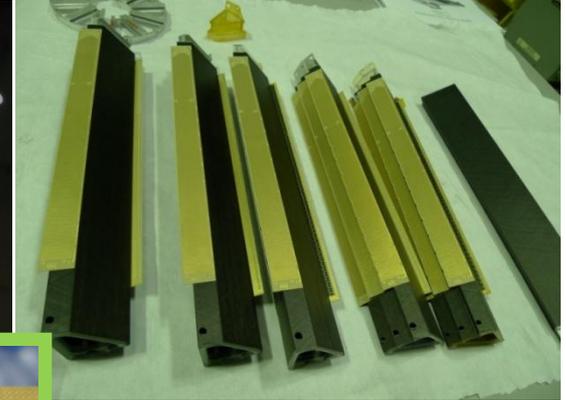
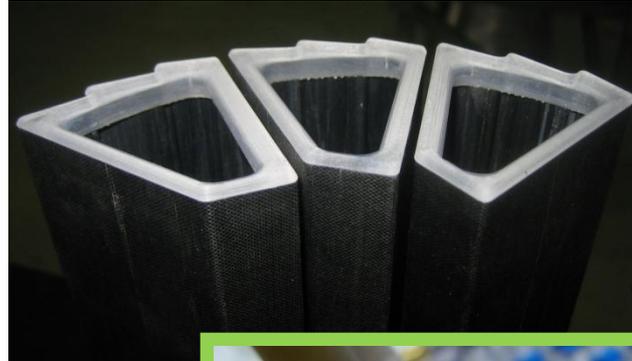
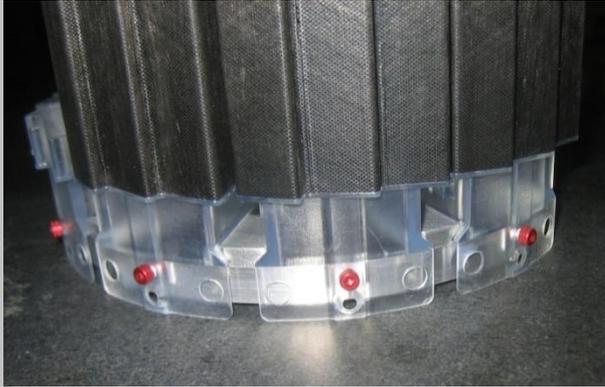
Sliding infrared camera holder with an integrated infrared window

air duct to the pump

Cooling Test Setup

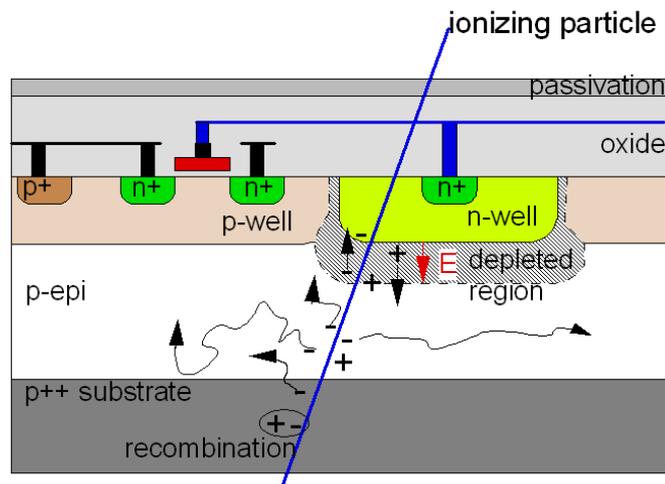


HFT PXL status - fabrication and tooling



Monolithic Active Pixel Sensors

MAPS pixel cross-section (not to scale)

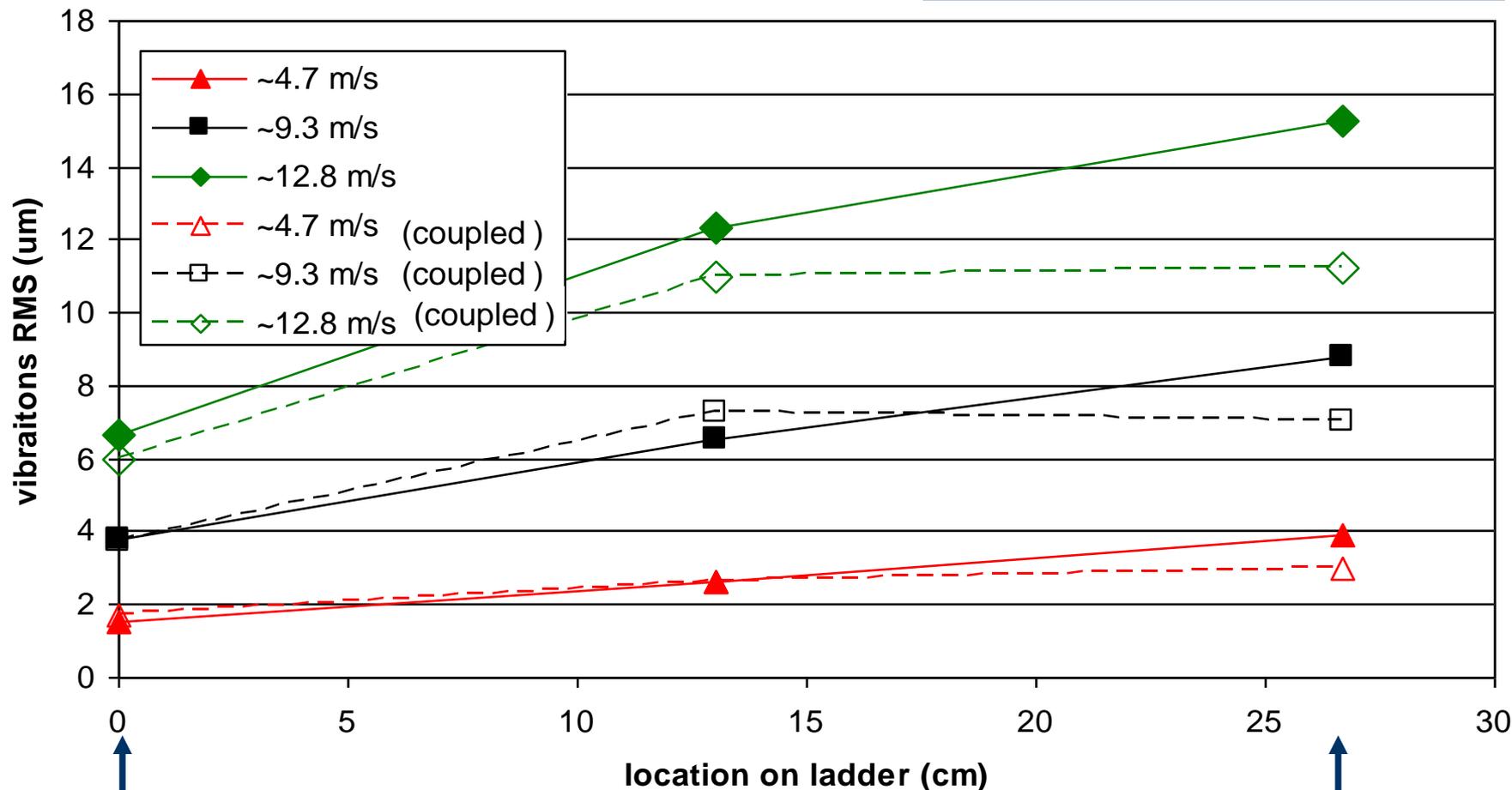


- Standard commercial CMOS technology
- Room temperature operation
- Sensor and signal processing are integrated in the same silicon wafer
- Signal is created in the low-doped epitaxial layer (typically $\sim 10\text{-}15\ \mu\text{m}$) \rightarrow MIP signal is limited to <1000 electrons
- Charge collection is mainly through thermal diffusion ($\sim 100\ \text{ns}$), reflective boundaries at p-well and substrate \rightarrow cluster size is about ~ 10 pixels ($20\text{-}30\ \mu\text{m}$ pitch)
- 100% fill-factor
- Fast readout
- Proven thinning to 50 micron

Vibrations caused by airflow

● Sector 1, Ladder 2

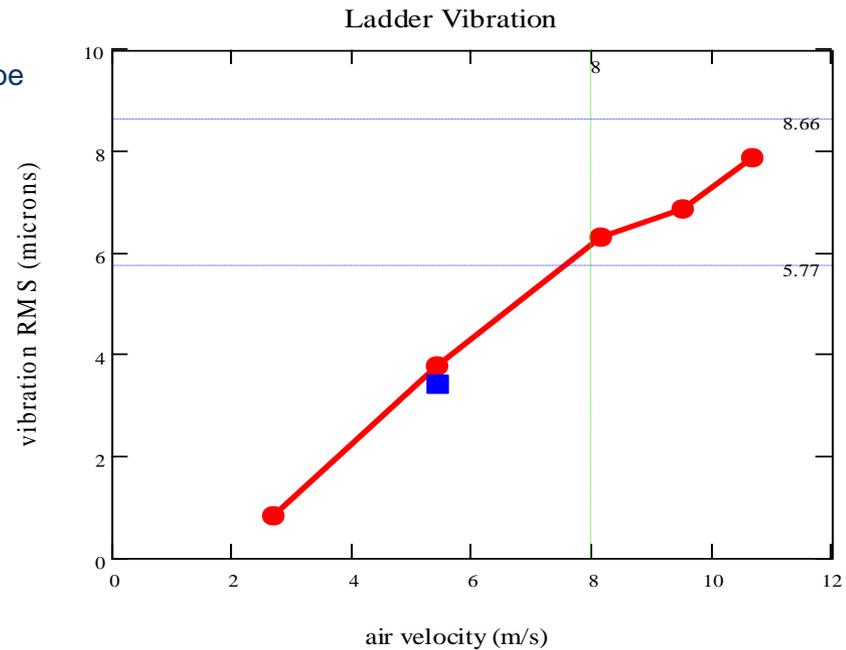
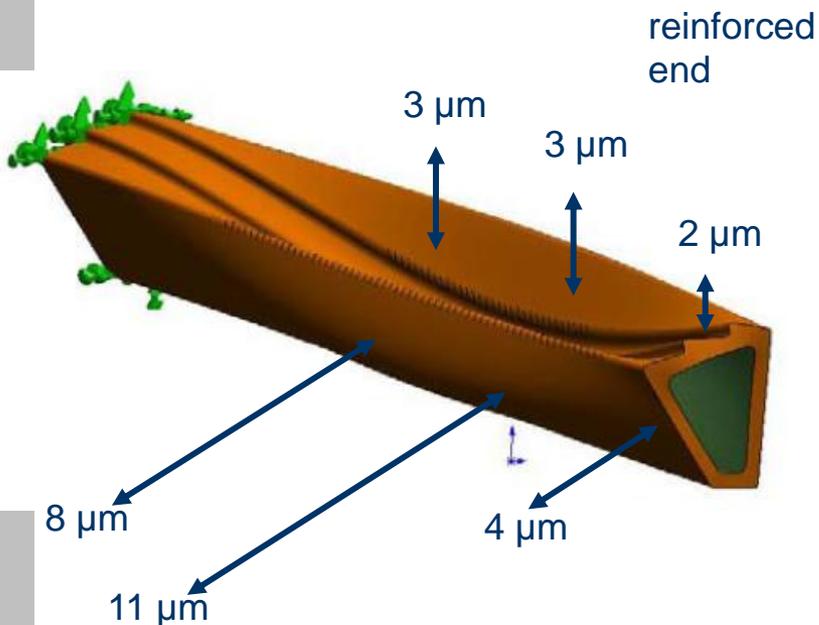
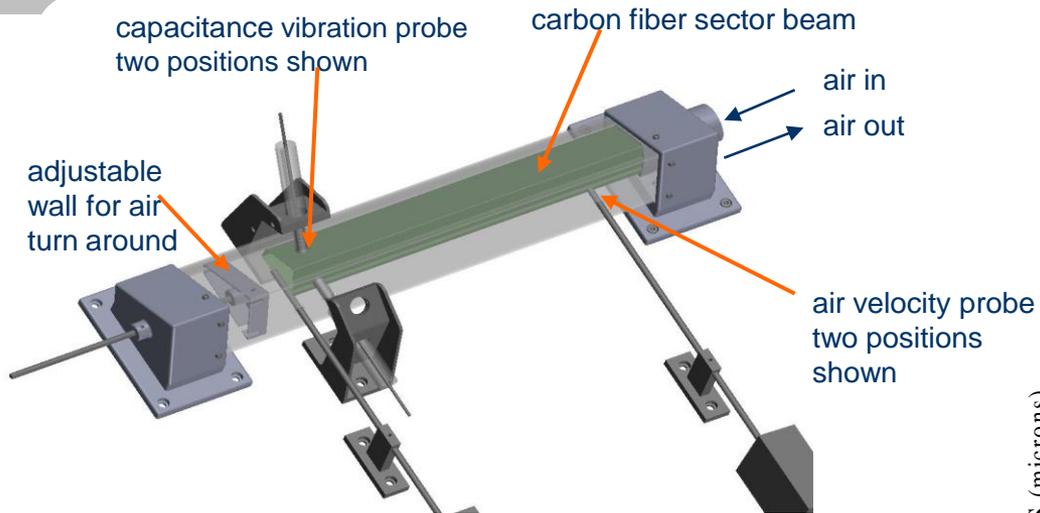
coupled means that the unsupported end is tied to sector 2



Beginning of the driver section
(Supported end)

End of sensor section
(Unsupported end)

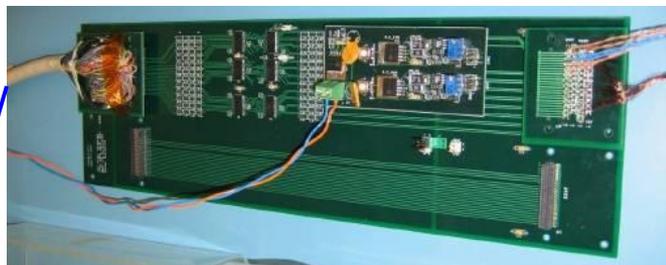
HFT PXL status - air flow vibration tests



- measured vibration with negative pressure mode
- measured vibration with positive pressure mode

no reinforcement at the end

LVDS Data Path Testing at 160 MHz



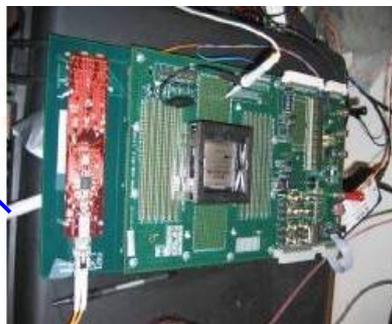
Mass termination board + LV monitoring

42 AWG wires



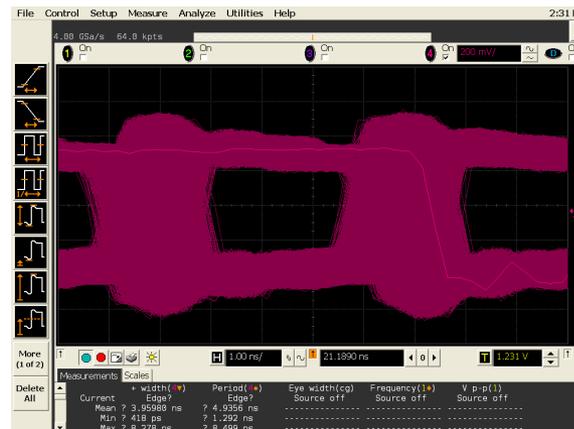
Ladder mock-up with 1-to-4 LVDS fanout buffers

24 AWG wires



Vertex-5 based RDO system with DDL link to PC

2 ns eye pattern opening for 1 m 42 AWG cables at 200 MHz



- Data Path Architecture Validated
- Measured BER (bit error rate) of $< 10^{-14}$

Sensor RDO Cable Development

- A detailed description of the challenge is available here http://rnc.lbl.gov/hft/hardware/docs/PXL_RDO_cable_options_1.doc
- A single sided test cable design has been produced for fabrication at Datex to assess capability and quality.
- Some delay due to material issues. It is difficult to find anyone willing to fabricate kapton/Al.
- We have located some 1 mil Al on 1 mil mylar and shipped it to Datex. They are evaluating the suitability.
- Datex is about to start first attempt at fabrication.
- Other vendors (SE SRTIIE, Kharkov,Ukraine and CERN?) will be contacted.

Project status

Formal Department of Energy (DOE) milestones:

- CD-0 (Critical Decision-0, Mission Need) approved in Feb 2009
- CD-1 review in Nov 2009. (“One of the alternatives proposed in the CD-0 is selected and a credible cost range is established”)
 - CD-1 homework sent to DOE, waiting for approval
- Ready for CD 2/3 in Q4FY10 (Performance Baseline / Start of Construction)
 - Next step in DOE approval process. HFT will become a full construction project and construction funds will be released upon successful completion.
 - Requires a significant amount of technical and management documentation to be generated.
- HFT completion scheduled for Q3 FY 2013

	Noise	FPN (~0.55 noise)
One sensor at a time	100 %	100%
All sensors on (high discriminator threshold → low switching/output activity) – expected running configuration	Up to 125 % (122 % on average)	Up to 140 % (128 % on average)
All sensors on (low discriminator threshold → high switching/output activity)	Up to 145 % (138 % on average)	Up to 160 % (138 % on average)