STAR Heavy Flavor Tracker Upgrade --PXL Detector

Xiangming Sun

Lawrence Berkeley National Lab

L. Greiner,

H. Matis

J. Schambach

T. Stezelberger

M. Szelezniak

C. Vu

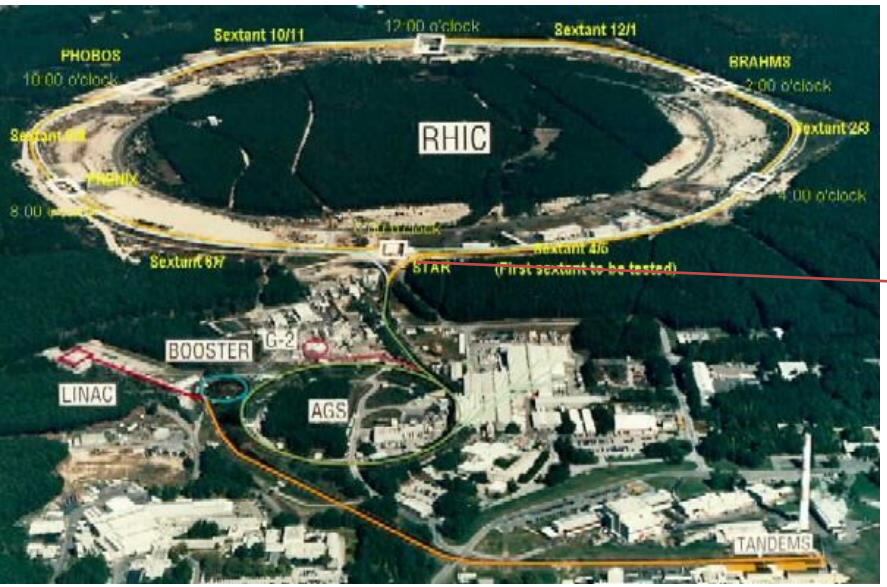
H. Wieman

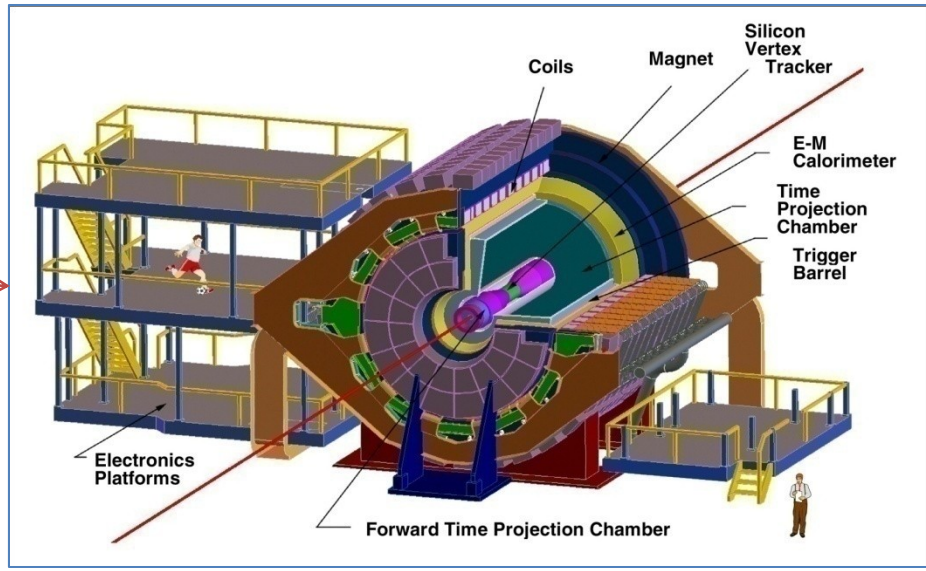
… …

Outline

- Heavy Flavor Tracker upgrade in STAR at RHIC
- PXL detector architecture
- Cooling and vibration testing
- Monolithic Active Pixel Sensor for PXL
- PXL Readout Electronics
- Summary

STAR Detector at RHIC

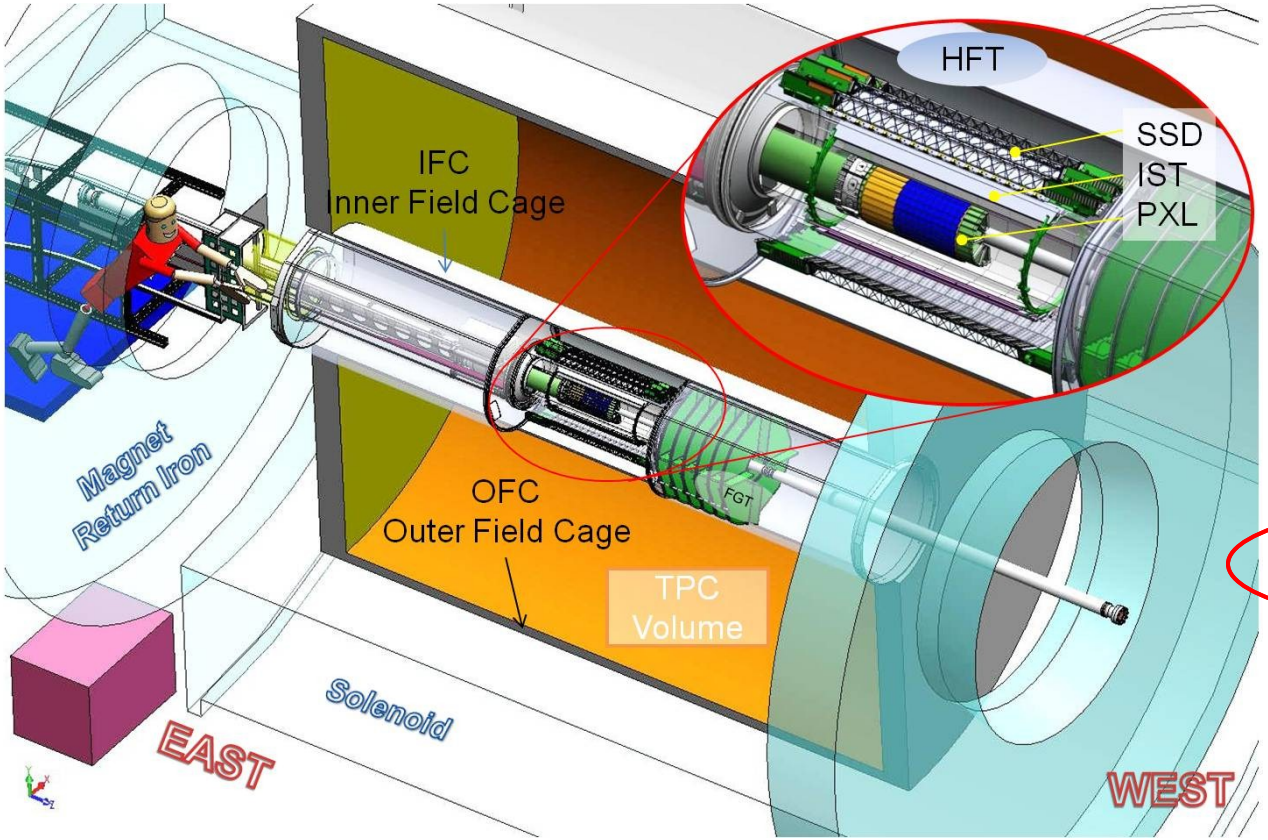




RHIC (Relativistic heavy ion collider)
Brookhaven National Lab
http://www.bnl.gov/rhic/

STAR(the solenoidal tracker at RHIC) is one of Detector at RHIC.
It specializes in tracking the thousands of particles produced by each ion collision

PXL in Inner Detector Upgrades



TPC – Time Projection Chamber (main tracking detector in STAR)

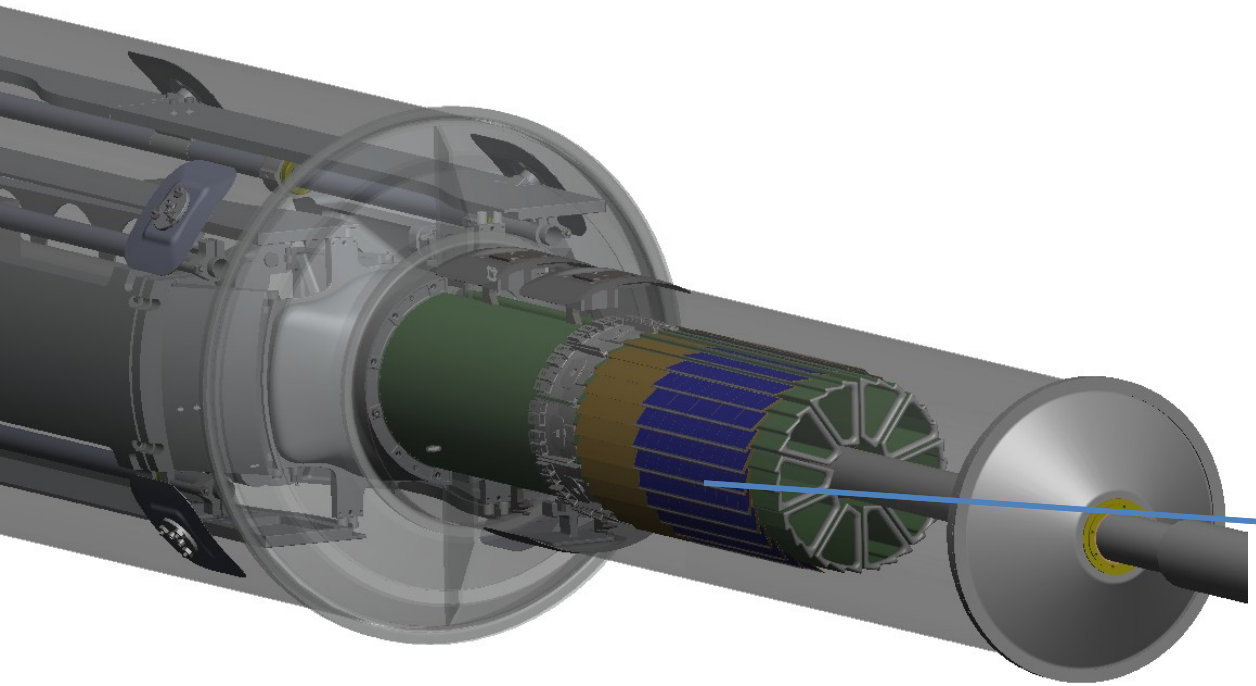
HFT – Heavy Flavor Tracker

- SSD – Silicon Strip Detector
  - r = 22 cm
- IST – Inner Silicon Tracker
  - r = 14 cm
- PXL – Pixel Detector
  - r = 2.5, 8 cm

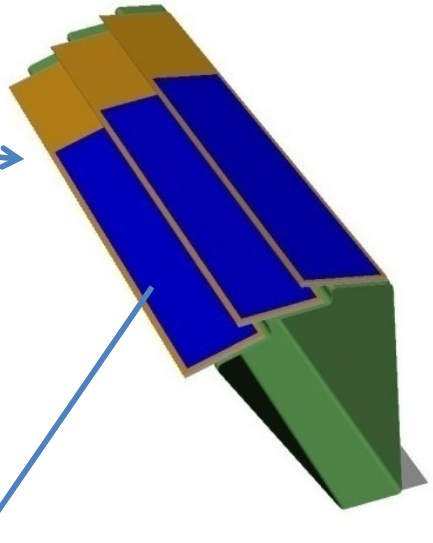
We track inward from the TPC with graded resolution:

TPC ~1mm SSD ~300μm IST ~250μm PXL <30μm vertex

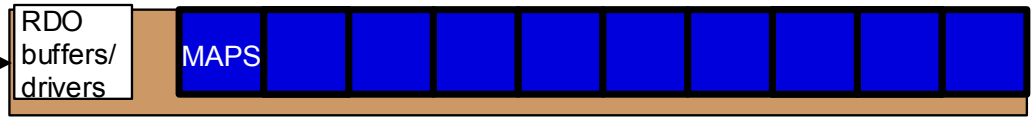
PXL Detector



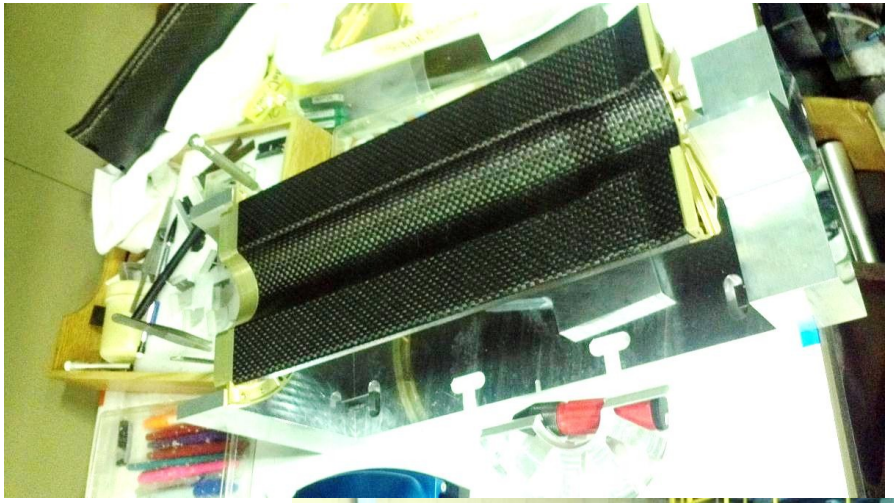
2 layers: 2.5,8 cm
10 sectors
1+3 ladders/ sector

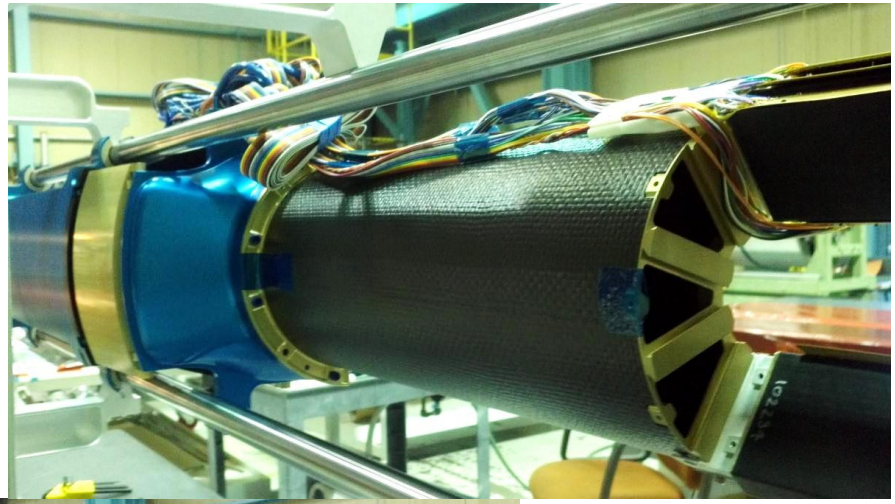


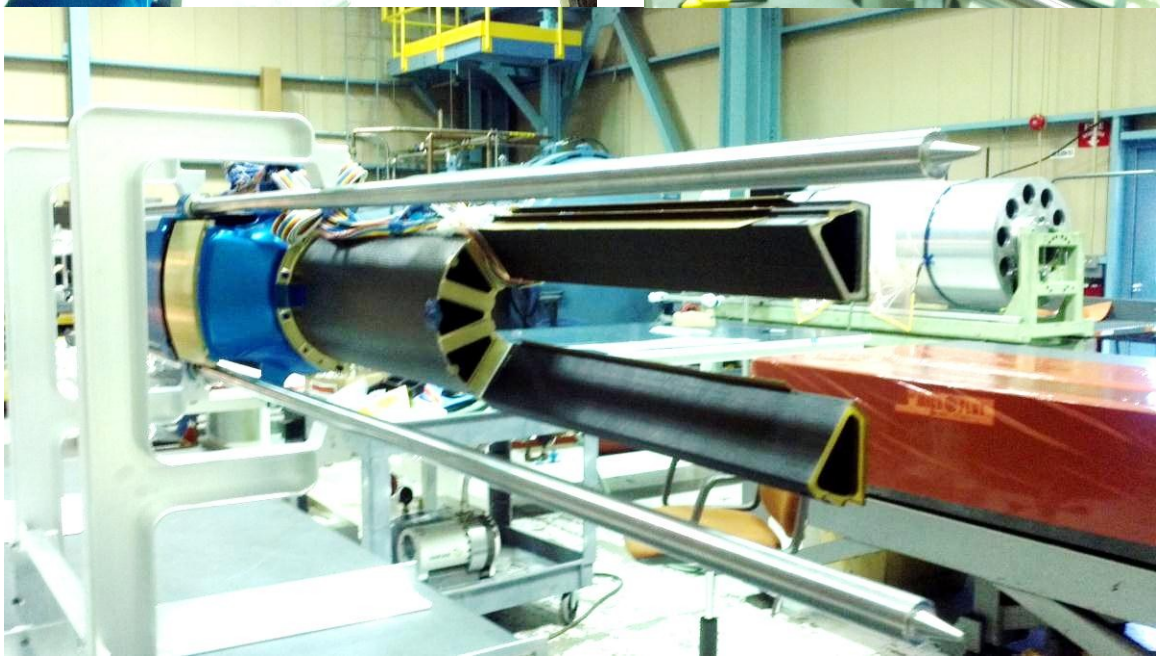
Ladder with 10
MAPS sensors
(~ 2×2 cm each)



PXL Mechanical Construction







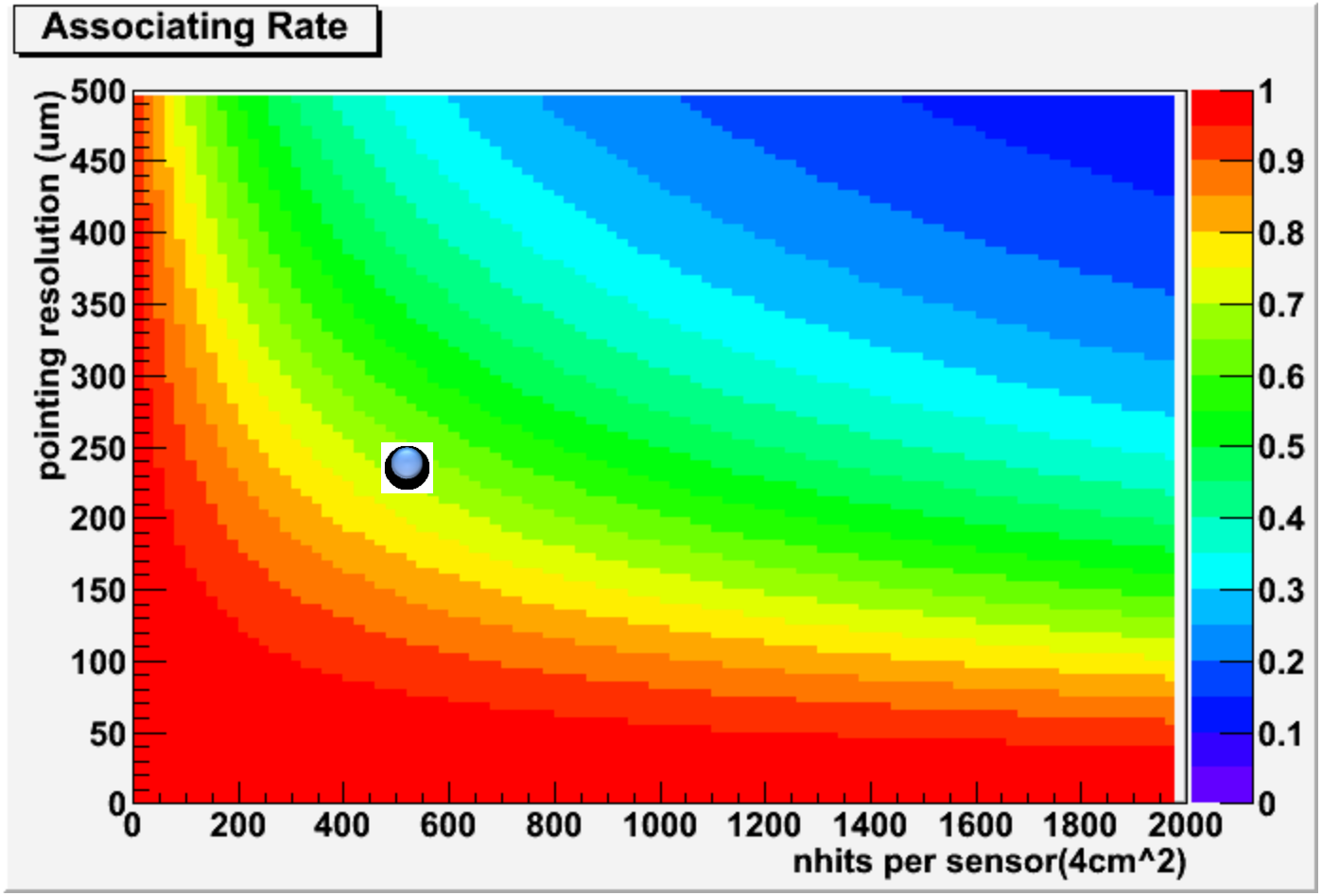
http://rnc.lbl.gov/hft/hardware/docs/ultimate/HFT_Mechanics_20110428.pptx

Some PXL Parameters

Pointing resolution from outer detector	250μm(TPC,SSD, IST) (12 ⊕ 19 GeV/p·c) μm
Layers	Layer 1 at 2.5 cm radius Layer 2 at 8 cm radius
Pixel size	~20μm X 20 μm
Position stability	6 μm rms (20 μm envelope)
Radiation thickness per layer	X/X0 = 0.37%
Integration time (affects pileup)	186 μs
Number of pixels	400 M
Radiation tolerance	75 kRad/year 5*10^11-1*10^12 n_{eq}
Rapid detector replacement	< 8 hours

critical and difficult

Association Rate vs Pointing Resolution and Hit Density



Association rate: associating hits to tracks from outer detector

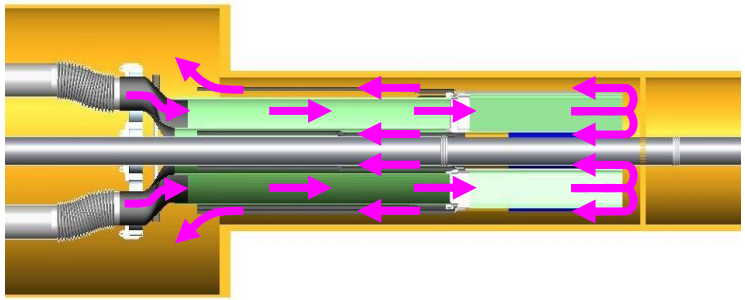
Nhits per sensor=500 for 200us integration time

Pointing resolution=250um

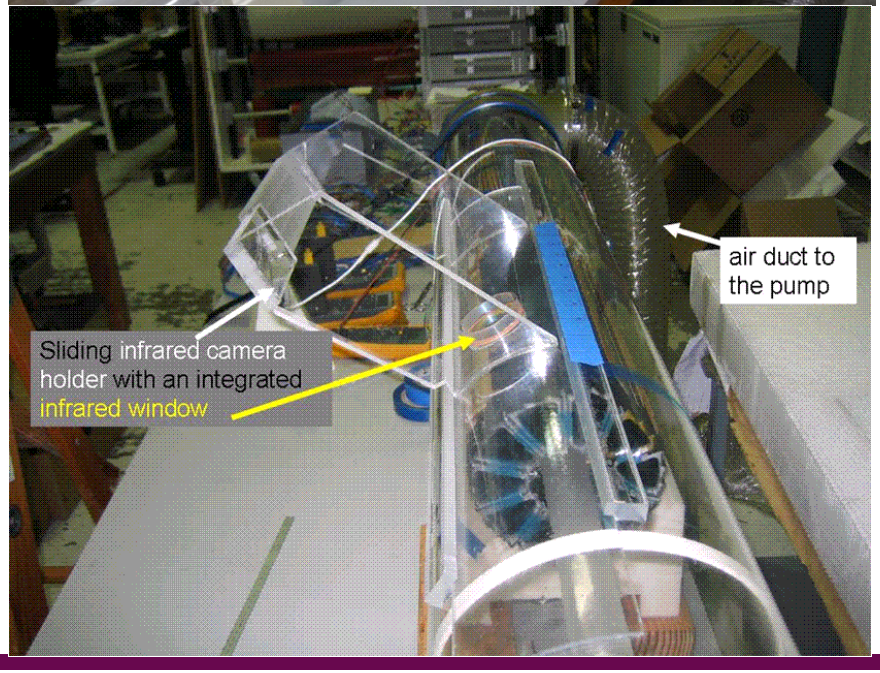
Association rate=67%

Cooling and vibration testing

- Sensor: 170 mW/cm^2 → 270 W for PXL sensors
- 2 W/drivers/cable → 80 W for PXL drivers



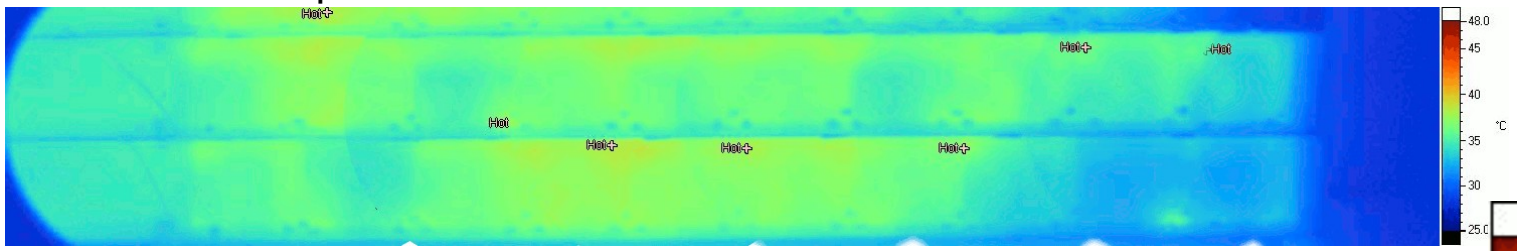
Silicon heater on 1 sector
PCB heaters on 9 sectors



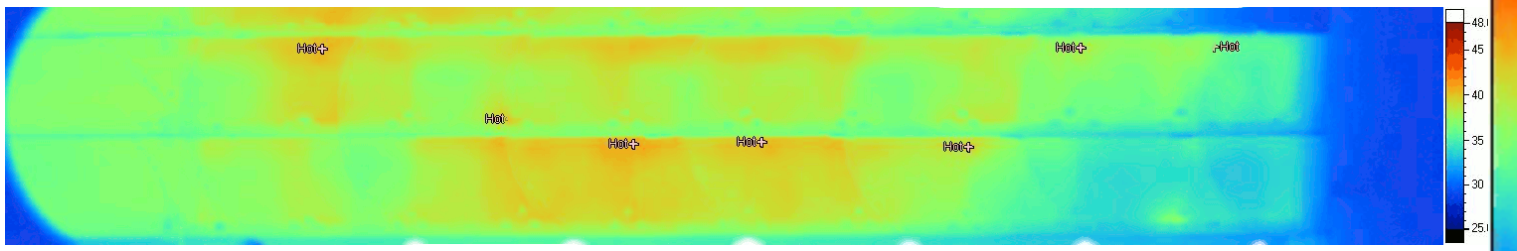
Cooling Tests at ~360 W – IR Images

From infra-red camera

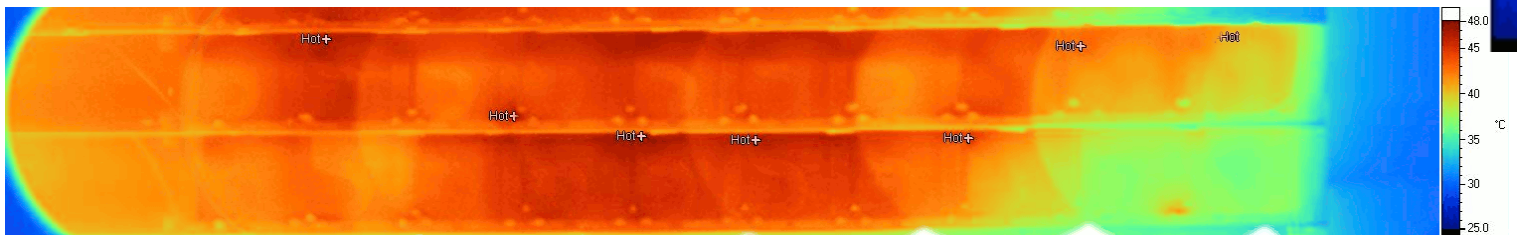
Air 13.8 m/s Hot spots ~37 °C



Air 10.1 m/s Hot spots ~41 °C

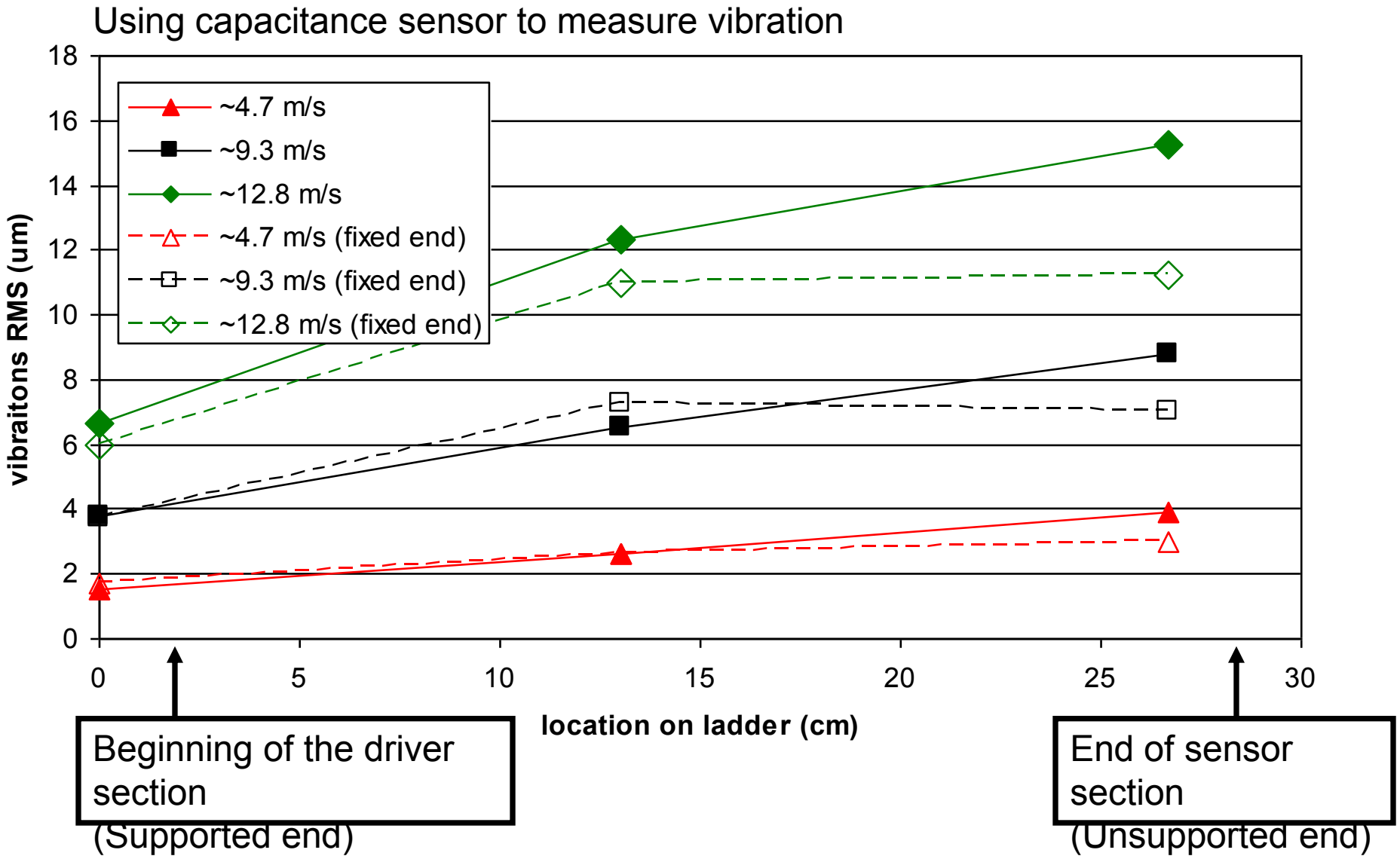


Air 4.7 m/s Hot spots ~48 °C

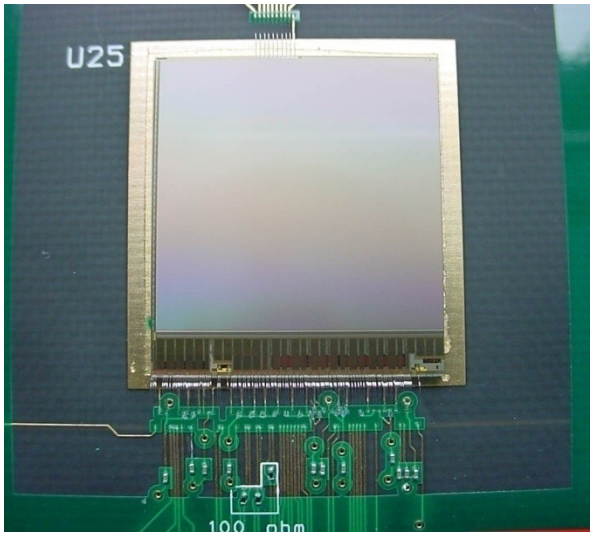


Air temperature ~27 °C

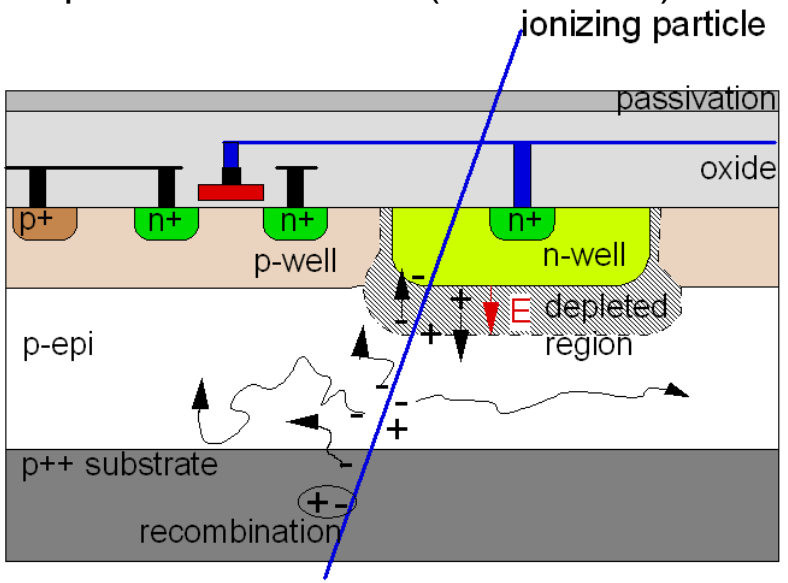
Vibrations Caused by Airflow



Monolithic Active Pixel Sensors



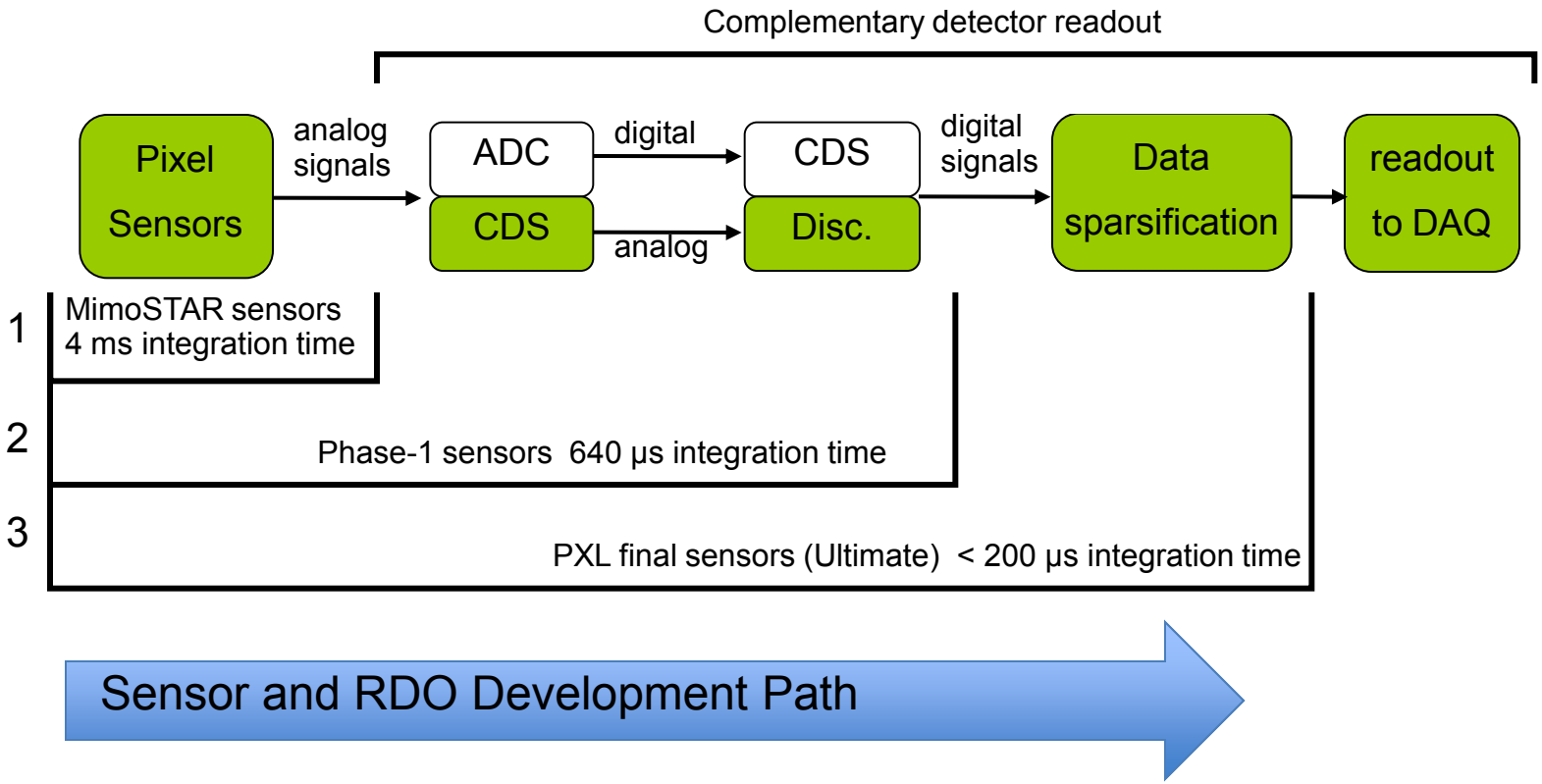
MAPS pixel cross-section (not to scale)



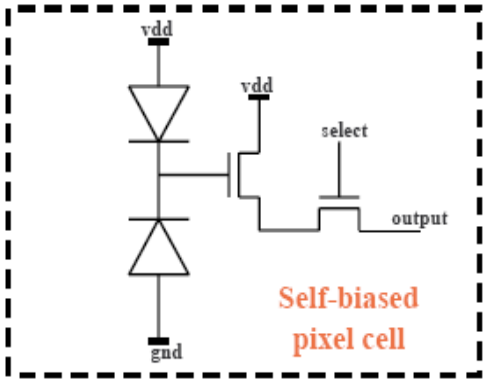
- IPHC-DRS (former IRES/LEPSI) proposed using MAPS for high energy physics in 1999
- Standard commercial CMOS technology
- Sensor and signal processing are integrated in the same silicon wafer
- Proven thinning to 50 micron
- Signal is created in the low-doped epitaxial layer (typically ~10-15 μm) → MIP signal is limited to <1000 electrons
- Charge collection is mainly through diffusion (~100 ns), reflective boundaries at p-epi and substrate → cluster size is about ~10 pixels (20-30 μm pixel pitch)
- Room temperature operation

PXL Sensor generation and RDO attributes

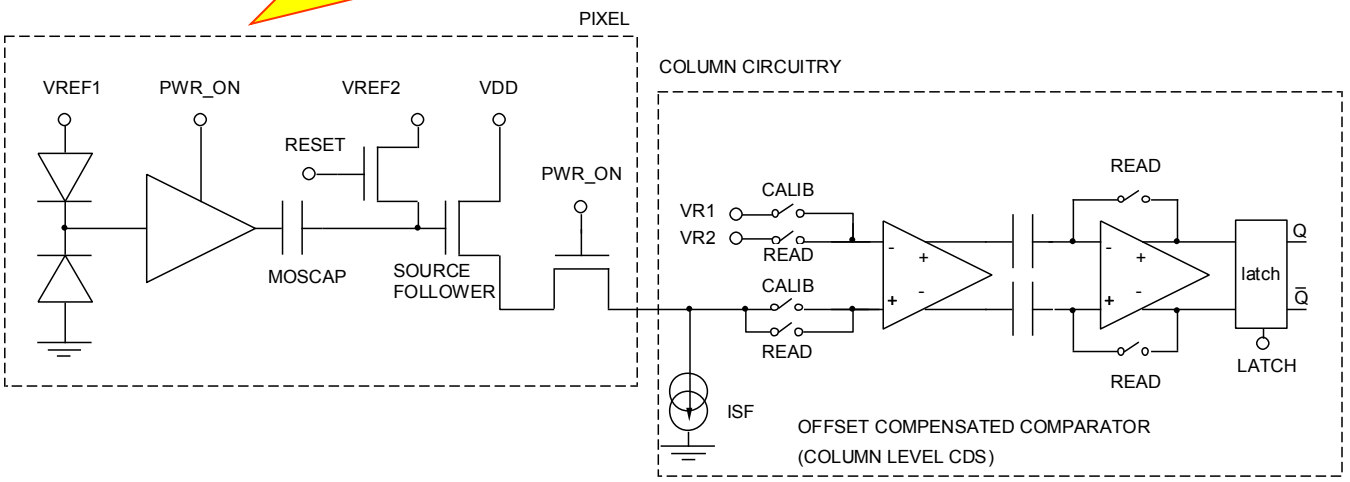
3 generation program with highly coupled sensor and readout development



From Analog to Binary Readout

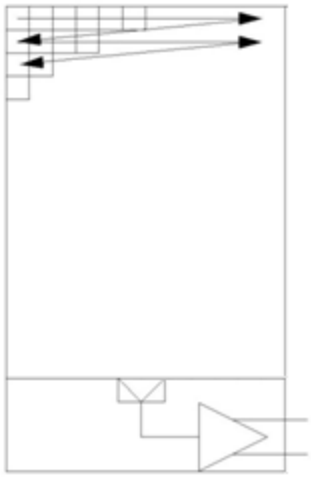


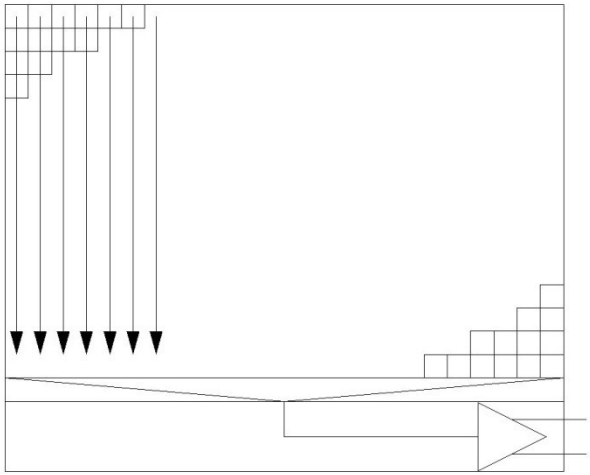
Analog readout – simpler architecture but slower readout



Digital readout – offers increased speed but requires on-chip discriminators or ADCs and increased S/N for on-chip signal processing

MAPS Integration Time = Readout Time

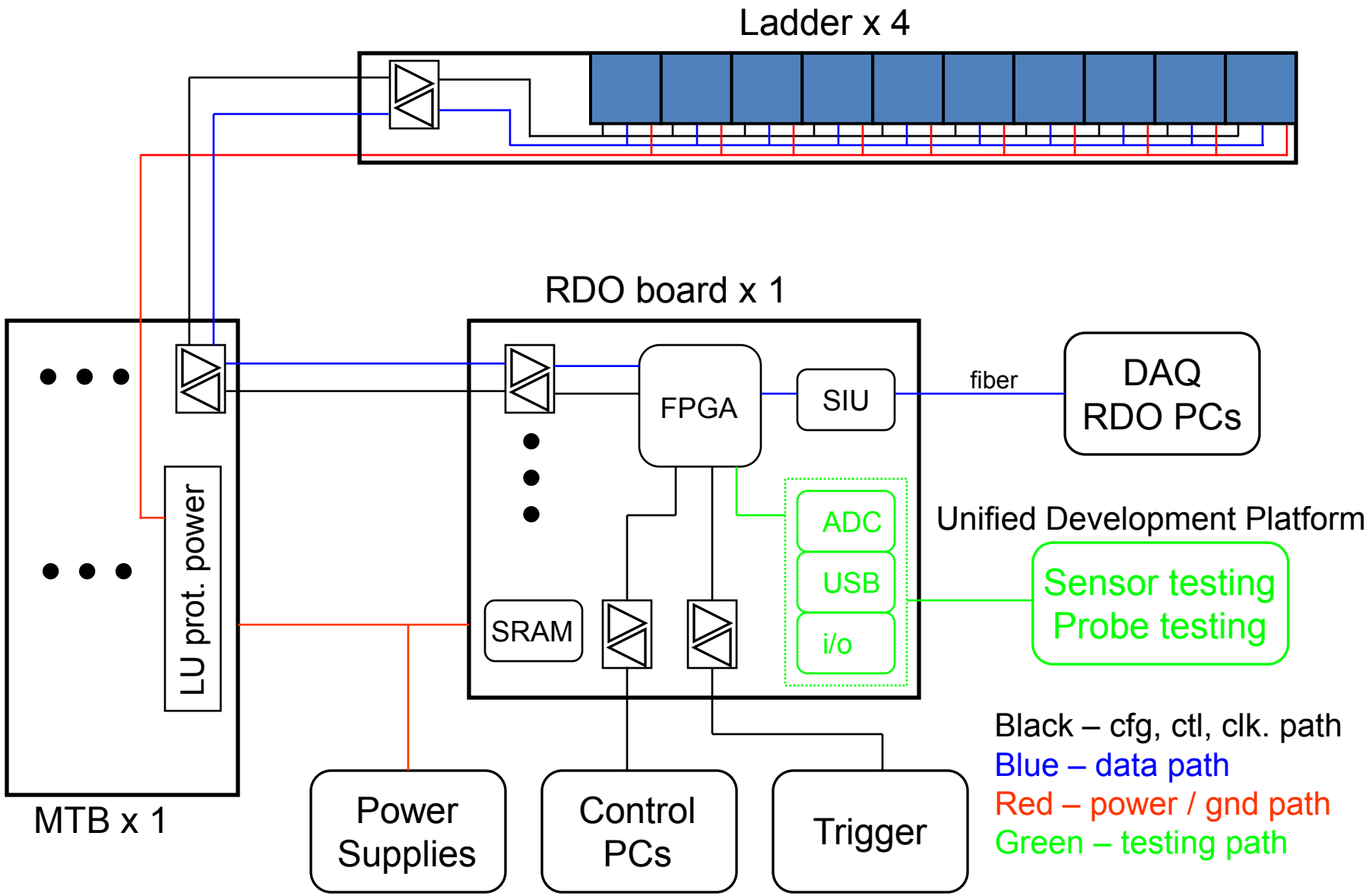




- Typical sensor readout
  - "rolling shutter" mode.
  - Integration time = array readout time

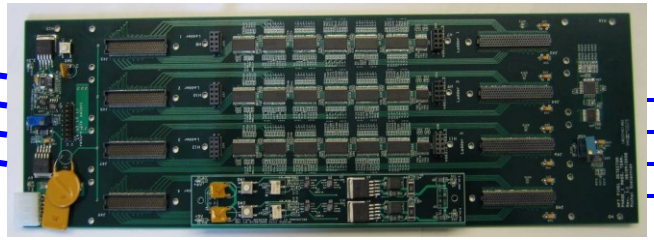
- Column parallel readout architecture
  - All columns readout in parallel and then multiplexed to one output
  - Integration time = column readout time
  - Integration time = 200 us

PXL Readout Schematics



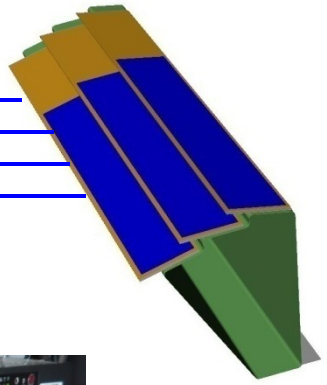
PXL Readout Electronics

6 m (24 AWG TP)



Mass termination board + latch up protected power daughtercard

2 m (42 AWG TP)



← Front Back ↓

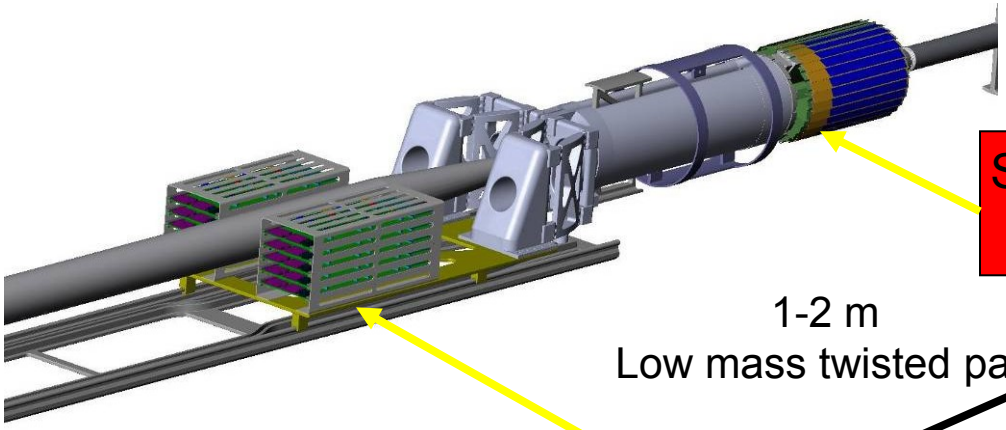
RDO motherboard + Xilinx Virtex-5 Dev Board

100 m (fiber optic)

RDO PC with DDL link to RDO board

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

RDO System Design – Physical Layout



Sensors / Ladders / Sectors (interaction point)

1-2 m
Low mass twisted pair

LU Protected Regulators, Mass cable termination

Platform

Power Supplies

30 m

6 m - twisted pair

30 m

Control PCs

30 m USB

RDO Boards

(Low Rad Area)

100 m - Fiber optic

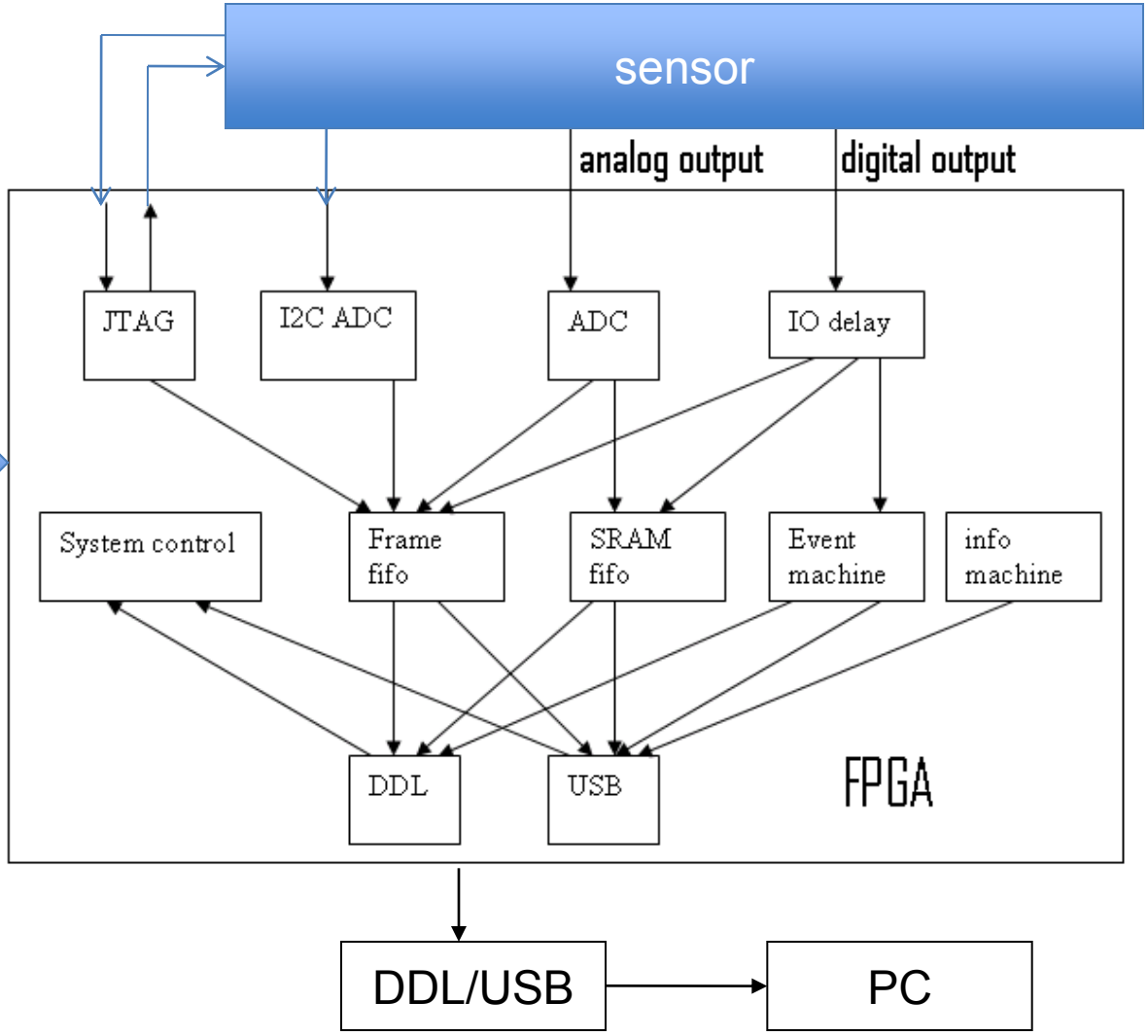
DAQ Room

400MB/s

DAQ PCs

Firmware Structure

Xilinx Virtex-5 Dev Board

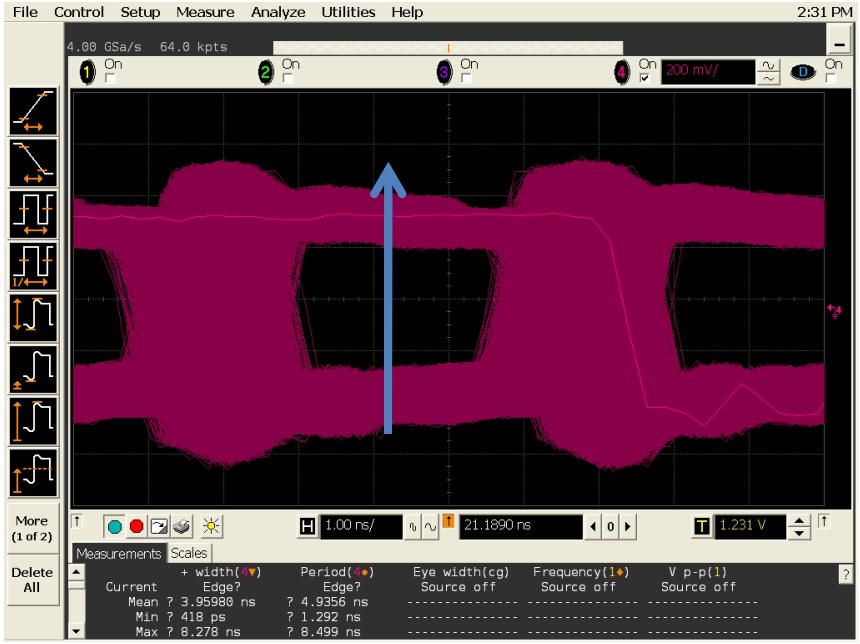


IO Delay for Digital Data Alignment

800 channels, 160 MHz digital signals pass 8 meters before arriving FPGA.

digital need to be aligned in FPGA end.

Solution: FPGA iodelay function



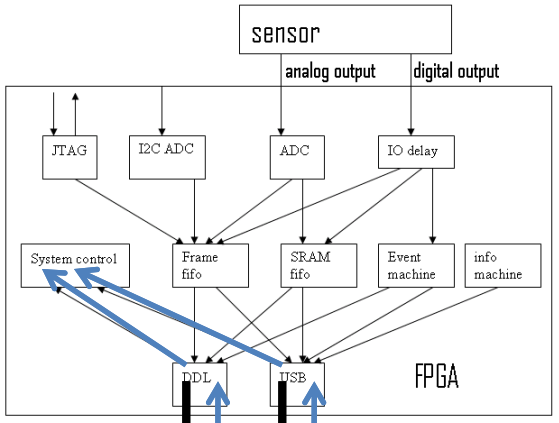
Status

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

System Control

Command generator:
command.exe

Hex file



download_data_block_to_FEE

USB upload

0x0402fffd
0x1d82ff3f
0x1502ffcf
0x2642ffff
0x2642fdff
0x2202feff
0x0c03fff0
0x1547ffff
0x1547ffff
0x1547ffff
0x1547ffdf
0x0cc7ffff
0x0cc7ffff
……

rorc_receive

USB download

DAQ PC

Control PC

Summary

Our current status:

Layer thickness	X/X0=0.37%
Air speed	~10 m/s
Senor temp arise	14 °C
Vibration	<8 um rms
The integration time	186 us
Readout Electronics	prototyped and works as required

The PXL is expected to be fully installed in 2013 for RHIC Run14

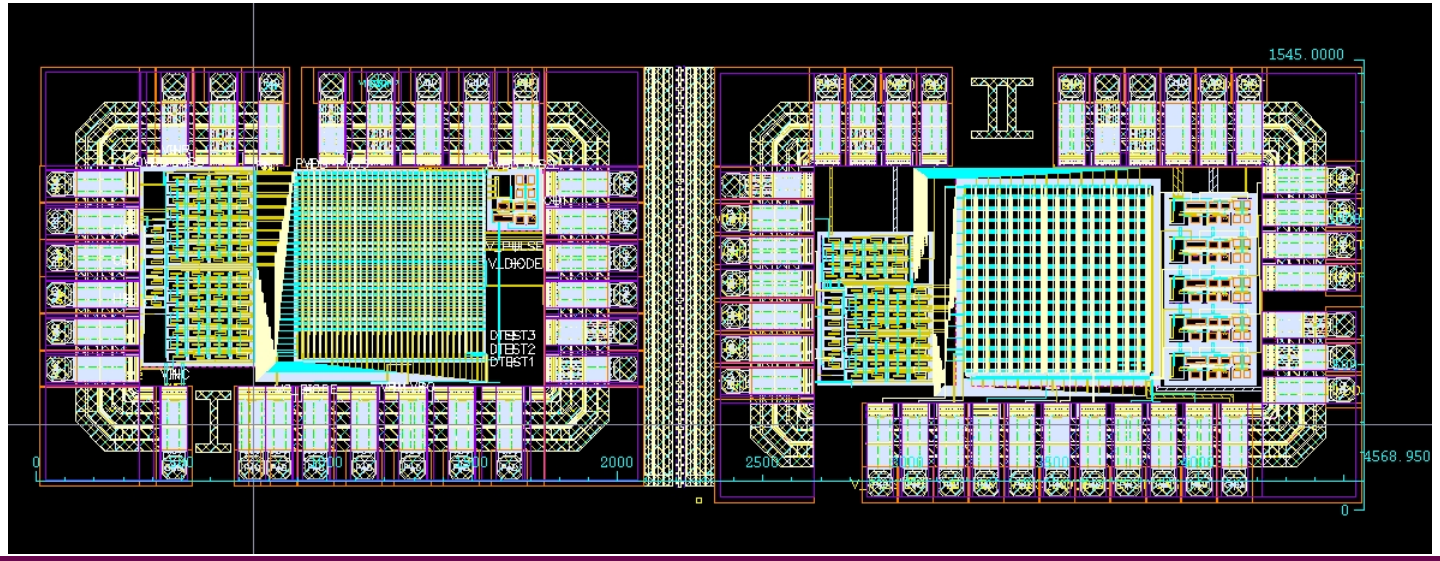
Activity in Wuhan

CCNU plans to in study Pixel sensor. (Nu Xu proposed)

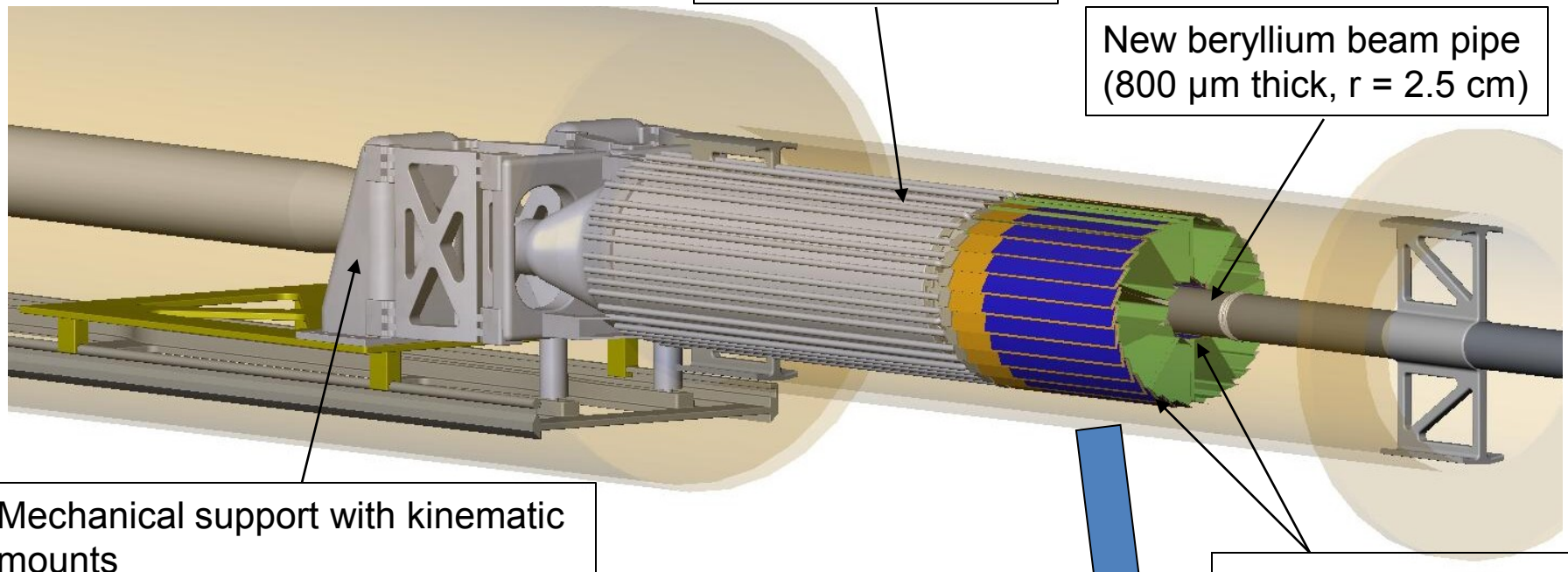
Pixel sensor in high energy physics is a good opportunity for CCNU to start

Try to be familiar with IC design environment(2 student)
Try to be familiar with XFAB technology

0.35 MPW in May 20 in XFAB.



PXL Detector



Radiation Environment

Direct measurement has not been done so far.

Based on estimates (http://rnc.lbl.gov/~wieman/radiation dose straus oct 2007 HW.ppt) and TLD projection.

- For the radius of 2.5 cm:
  - Ionizing radiation:
    - Total dose: 155 kRad
    - TLD projection: 300 kRad
  - Non-ionizing radiation
    - average pion count for 1 Yr: 3x1012 cm-2
    - TLD projection (pion assumption): 12x1012 cm-2

Ionizing Radiation Tolerance

MIMOSA-22 Testing in 10 KeV X-Rays in Lab

▷ ex. of S6 (M22) variants at 20°C

- before irradiation $\gtrsim$ 9.5 e^- ENC
- after 50 kRad $\gtrsim$ 11 e^- ENC
- after 150 kRad $\gtrsim$ 13 e^- ENC
- after 300 kRad $\gtrsim$ 15 e^- ENC

MIMOSA-22ter

- after 300 kRad $\lesssim$ 15 e^- ENC

Signal/noise ratio >=20 after 300 kRad Ionizing radiation (300 e+e- pairs)
Non-ionizing radiation is under investigation

- The Heavy Flavor Tracker (HFT) is an upgrade project for the STAR detector at RHIC, It will allow the topological reconstructions of the heavy flavor hadrons via their hadronic decays . The HFT consists of three coaxial detectors: SSD(Silicon Strip Detector), IST(Intermediate Si-Tracker) and PIXEL(a pixel detector). The PIXEL is the inner-most and highest precision detector in HFT. The sensor chip we use to build PIXEL is developed in Monolithic Active Pixel Sensor(MAPS) technology. Each sensor has 1024X1188 pixels with 18.4 micron pitch and 50 micron thickness. The integration time is 200 us. Correlated double sampling (CDS) and digitization are performed on the sensor chip. The readout electronics is designed to handle 400 sensors which are grouped in 10 sectors. In this talk, we discuss the relation between the physics goals and sensor characteristics, such as pixel size, sensor thickness, integration time, radiation tolerance and power consumption. We introduce the on-chip electronics design to perform CDS and digitization. We also show the readout electronics designed to handle R&D tests and physics data acquisition. The PIXEL is expected to be fully installed in 2014 for RHIC Run14

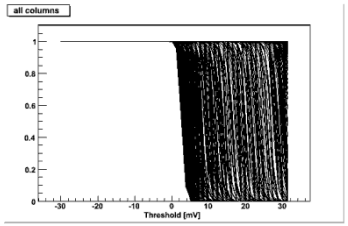
Probe Tests

Status

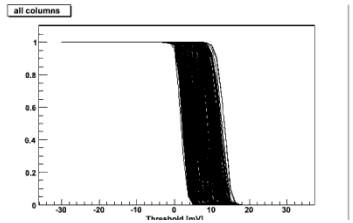
- Automated and scripted system for sensor testing is in place.
- Vacuum chuck for handling up to twenty 50 μm thick sensors is being tested
- Ongoing sensor testing

- Sensors designed with dedicated probe pads in the sensor pad ring.
- 13 full-thickness, diced sensors probe tested.
- Up to 3 probe tests on a sensor.
- We will begin testing thinned sensors within the next few days

Phase-1 discriminator transfer functions f(threshold voltage) observed on two of the probed sensors :



Initial testing with ~75 μm travel past touchdown



30 μm additional lowering of probe pins

Cooling tests at ~360 W

- Initially: 100 mW/cm^2 → 160 W for PXL sensors
- Updated: x1.7 → 270 W for PXL sensor
- 2 W/drivers/cable → 80 W for PXL drivers

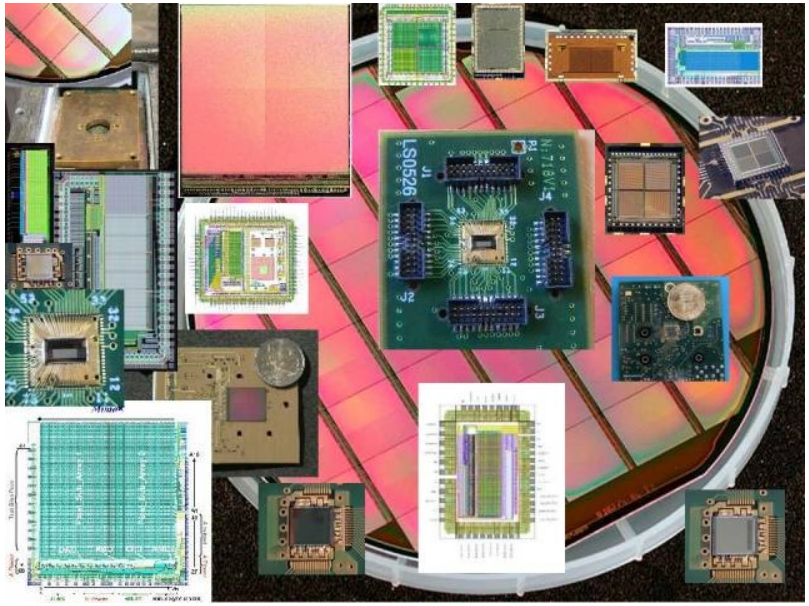
Ladder section		Measured resistance (Ω)	Current (A)	Voltge (V)	Power (I·V) (W)
sensors	Sector 1 (Pt heaters)	6.6	2.06	6.97 + 7.96	30.7
	Sectors 2-10	4.6 || 3.7	10.6	23.1	244.8
drivers	Sectors 1-5	1.4	5.3	8.23	43.6
	Sectors 6-10	1.4	5.3	8.03	42.5
	Total Power				**~361**

MAPS @ Institut Pluridisciplinaire Hubert Curien

- IPHC-DRS (former IRES/LEPSI) proposed using MAPS for high energy physics in 1999

- CMOS & ILC group today
  - 6 physists
  - 9 microcircuit designers
  - 6 test engineers
  - 7 PhD students

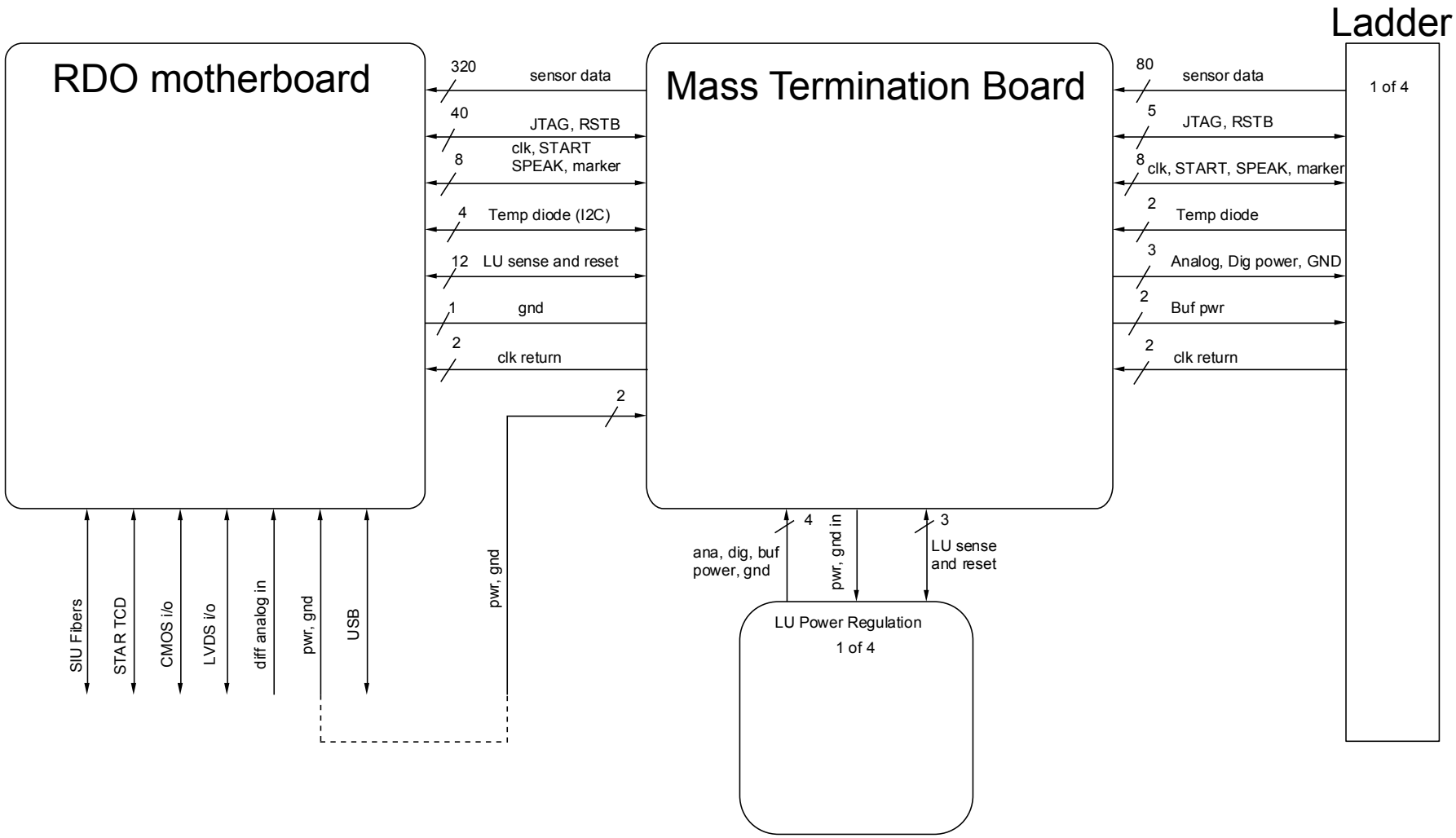
CNRS - IPHC, Strasbourg-Cronenbourg



MIMOSA (Minimum Ionizing particle MOS Active sensor)

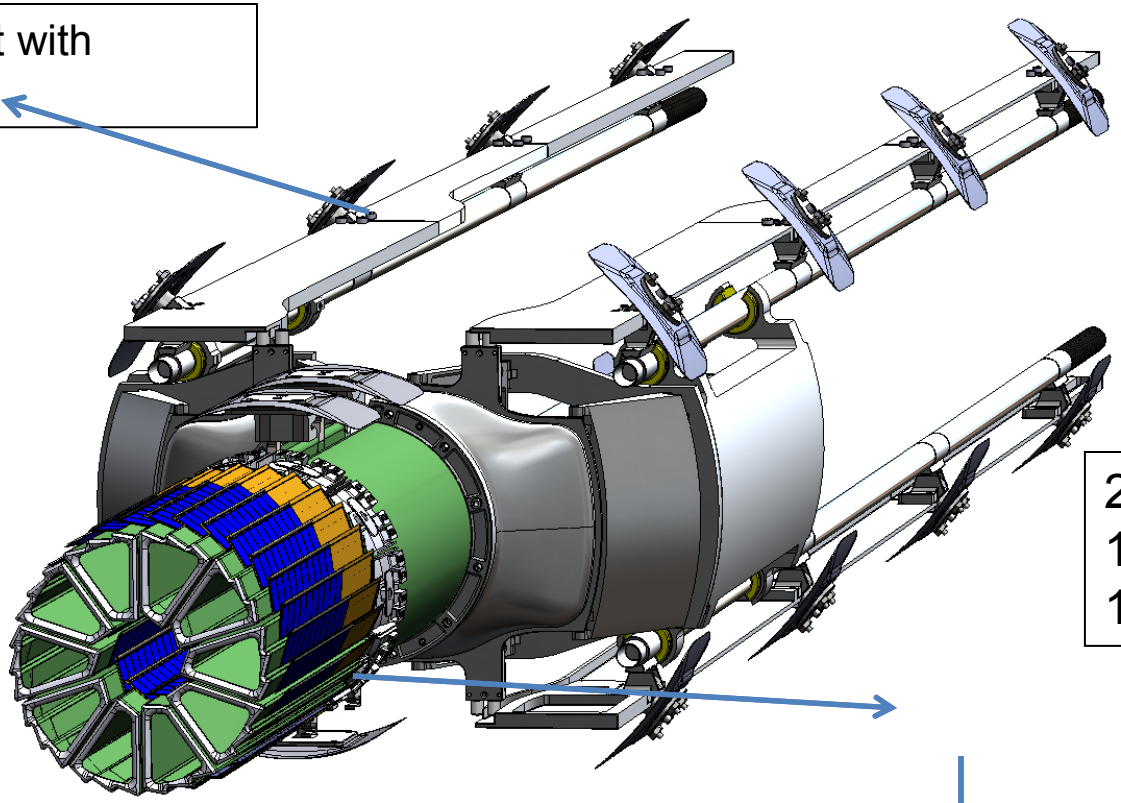
- More than 30 prototypes developed
  - several pixel sizes and architectures (simple 3-transistor cells, pixels with in-pixel amplifiers and CDS processing)
  - different readout strategies (sensors operated in current and voltage mode, analog and digital output)
  - Large variety of prototype sizes (from several hundreds of pixels up to 1M pixel prototype with full-reticule size)

PXL Hardware Architecture

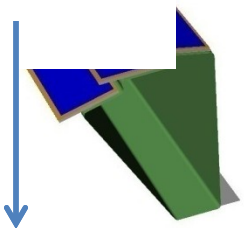


PXL Detector

Mechanical support with kinematic mounts



2 layers: 2.5,8 cm
10 sectors
1+3 ladders/ sector



Ladder with 10 MAPS sensors (~ 2×2 cm each)