The Heavy Flavor Tracker (HFT) of STAR experiment and its PIXEL prototype beam tests

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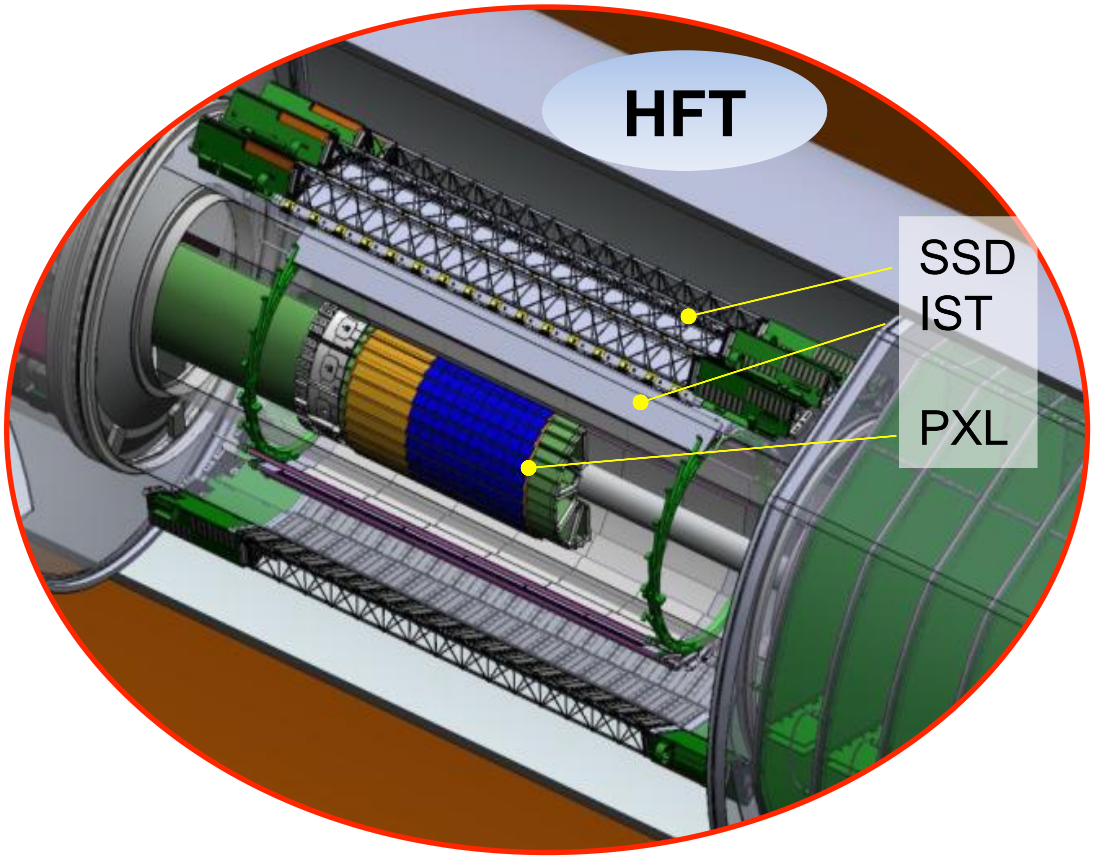
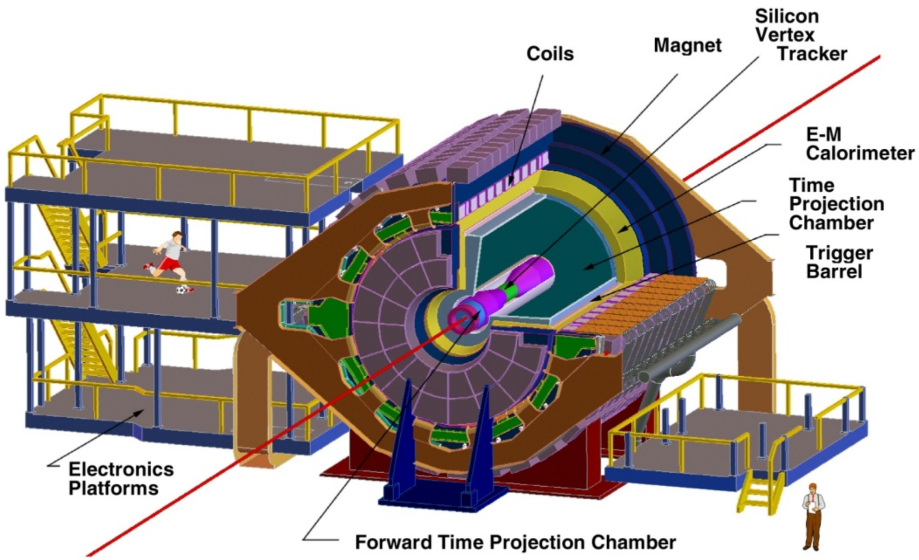
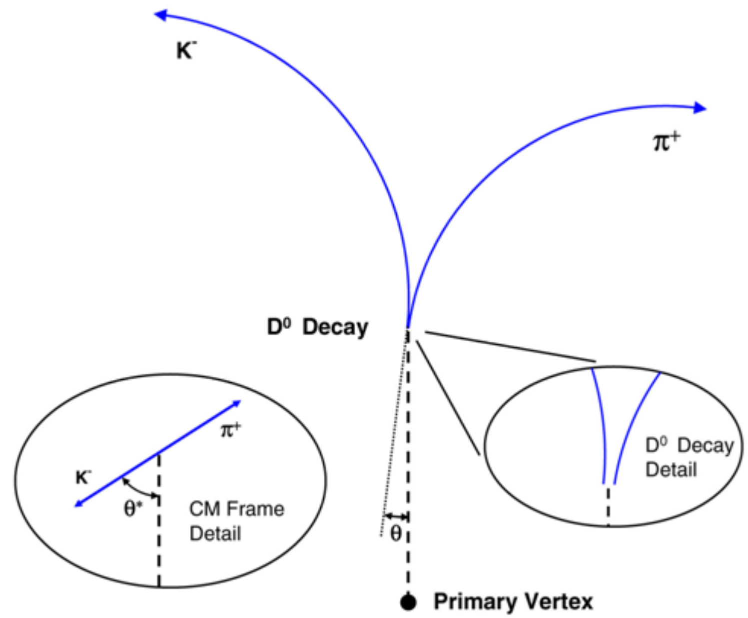


Talk Outline

- The HFT (Heavy Flavor Tracker) detector in the STAR experiment at RHIC facility of BNL
- HFT detector: physics goals, requirements, design and characteristics
- PIXEL detector prototype beam tests
- Summary.

HFT Detector Motivation





<u>Direct topological reconstruction of Charm</u>

Detect charm decays with small $c\tau$, including $D^0 \rightarrow K\,\pi$

Method: Resolve displaced vertices (50-100 microns)

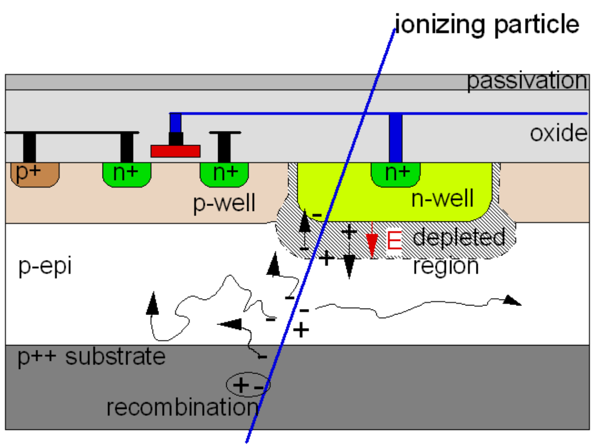
We track inward from the TPC with graded resolution:

TPC $\xrightarrow{\sim 1mm}$ SSD $\xrightarrow{\sim 300\mu m}$ IST $\xrightarrow{\sim 250\mu m}$ PXL $\xrightarrow{\sim 30\mu m}$ vertex

PXL Detector Requirements and Design Choices

Requirements

- -1 ≤ Eta ≤ 1, full Phi coverage (TPC coverage)
- ≤ 50 μm DCA pointing resolution required for 750 MeV/c kaon
  - Two or more layers with a separation of > 5 cm. Close to beam.
  - Pixel size of ≤ 30 μm
  - Radiation length as low as possible but should be ≤ 0.5% / layer (including support structure). The goal is ~0.4% / layer
- Integration time of < 200 μs
- Sensor efficiency ≥ 99% with accidental rate ≤ 10^{-4}.
- Survive radiation environment.

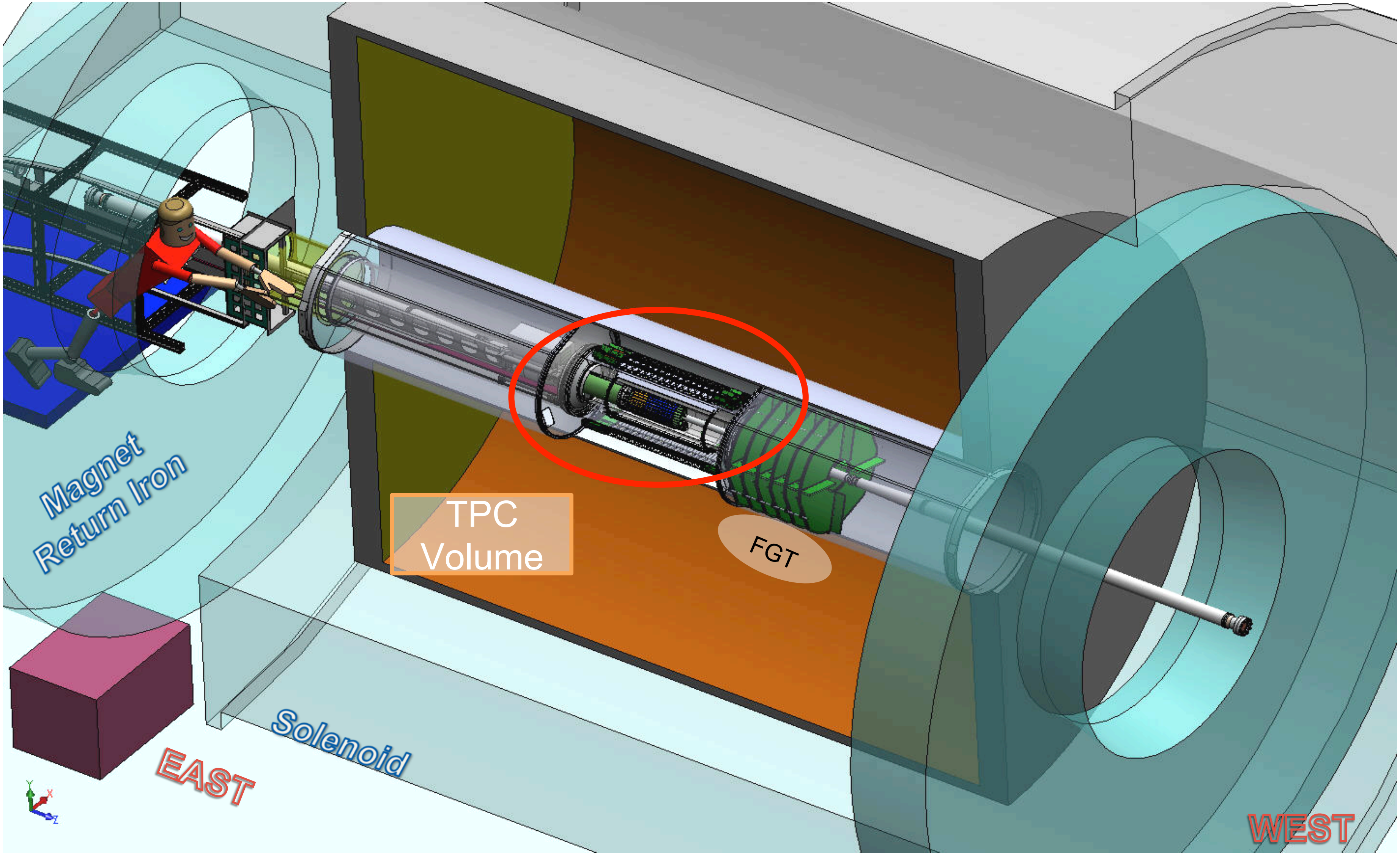


Design Choices

- **Standard CMOS technology**
- **Air** cooling – room temperature operation
- Thinned silicon sensors (**50 μm** thickness)
- MAPS (Monolithic Active Pixel Sensor) pixel technology
  - power dissipation ~170 mW/cm^2 (integration time <200 μs) [digital output]
- **Quick extraction/replacement (1 day) with 20 μm envelope [4 copies]**

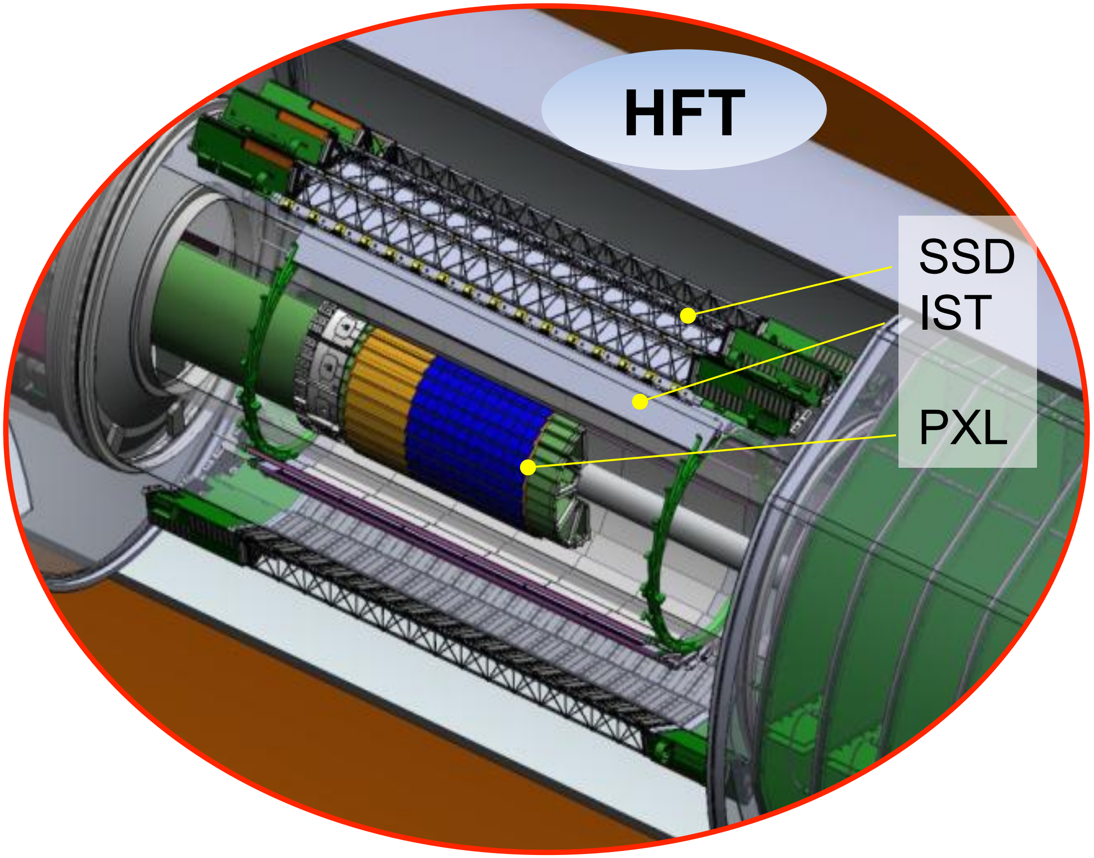
Heavy Flavor Tracker (HFT)

STAR HFT



Heavy Flavor Tracker (HFT)

STAR HFT



Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5 %X_0
PIXEL	8	12/ 12	~0.4 %X_0
	2.5	12 / 12	~0.4% X_0

PIXEL

- two layers
- 18.4x18.4 μm pixel pitch
- 10 sector, delivering ultimate pointing resolution that allows for direct topological identification of charm.
- **new monolithic active pixel sensors (MAPS) technology**

SSD

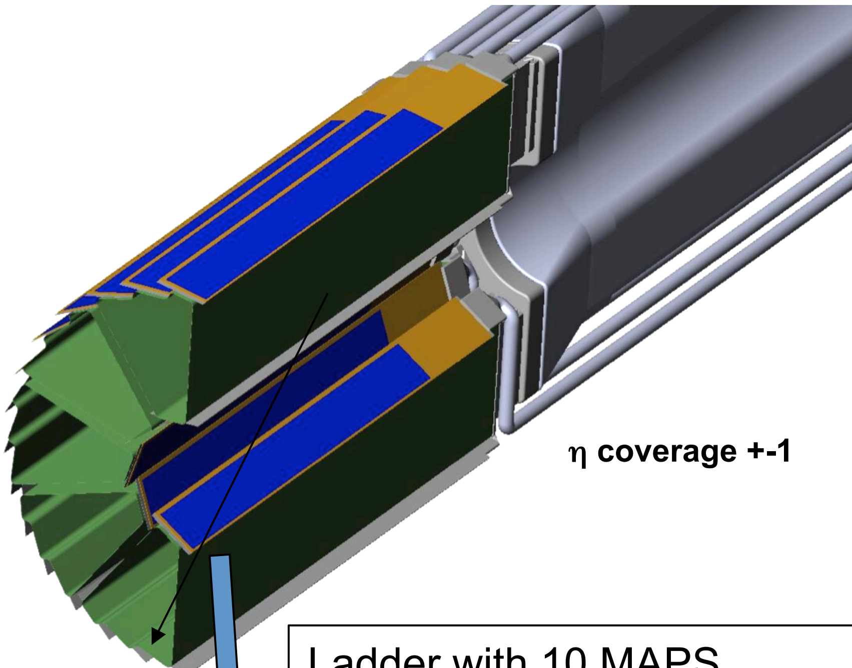
- existing single layer detector, double side strips (electronic upgrade)

IST

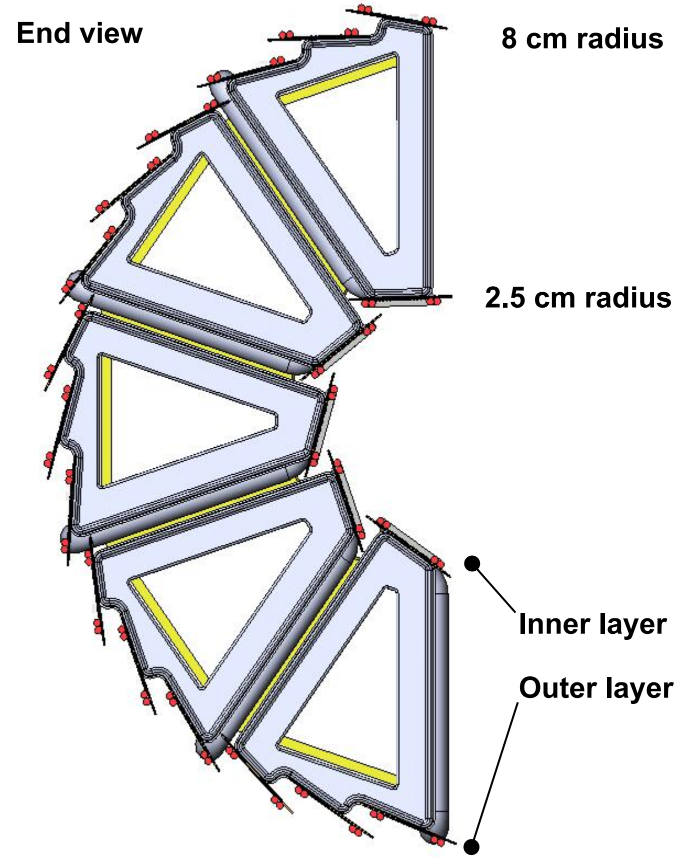
- one layer of silicon strips along beam direction, guiding tracks from the SSD through PIXEL detector. **- proven strip technology**

PXL Detector Design

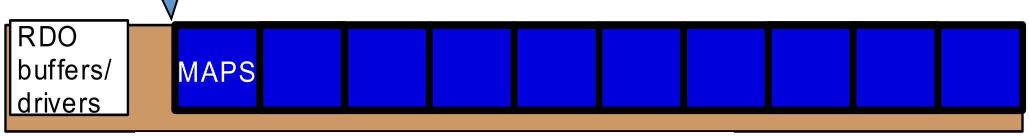
Carbon fibre sector tubes (~200μm thick)



η coverage +-1



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



Aluminum conductor Ladder Flex Cable

← 20 cm →

Expected track-pointing resolution

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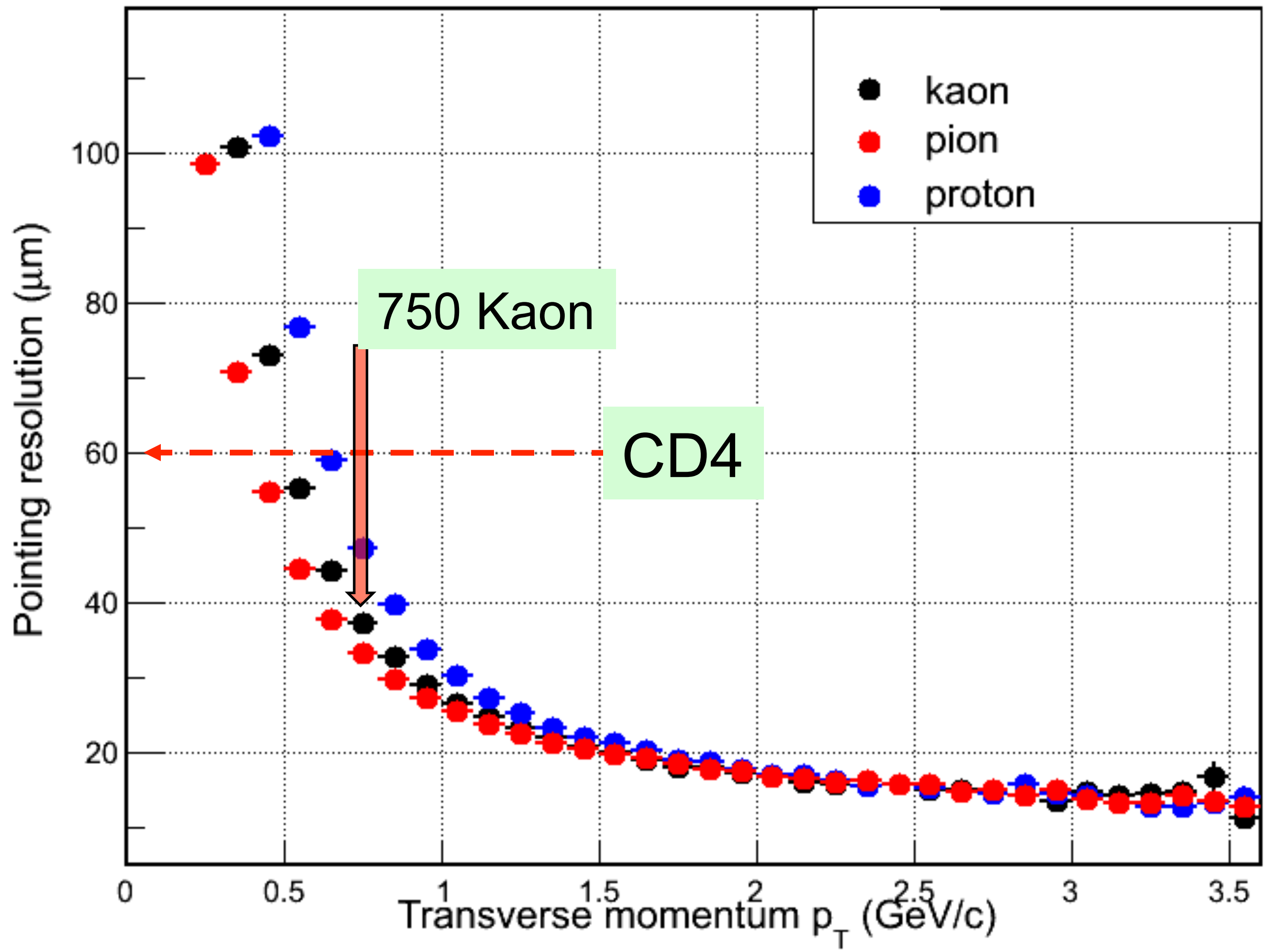
Pointing resolution of HFT system (750 MeV/c kaons)	≤60 μm in the r-phi plane



Intermediate Silicon Tracker (IST)

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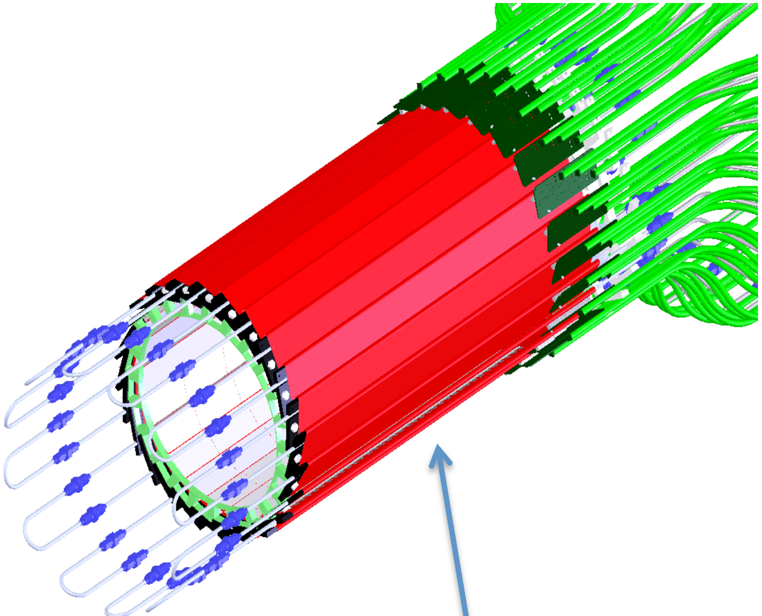
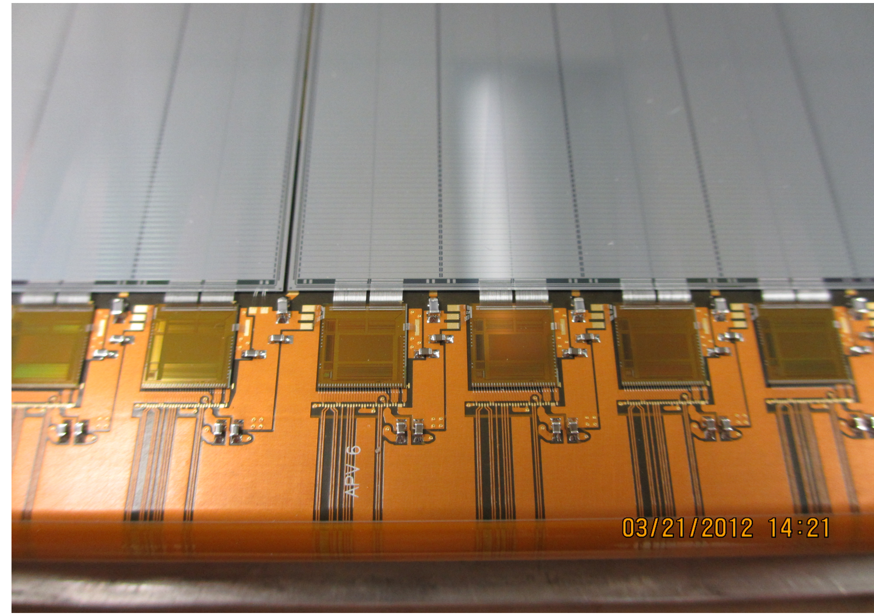
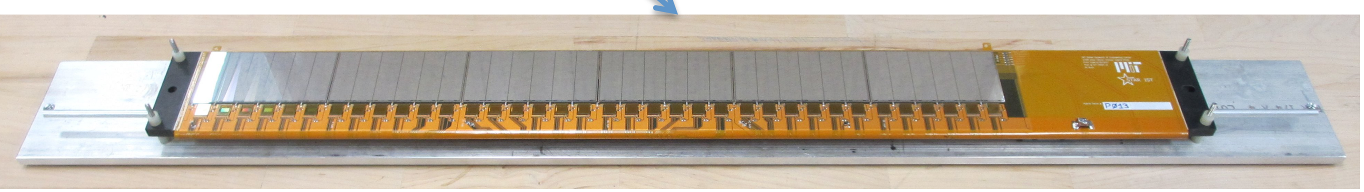


24 ladders, liquid cooling.



Detail



Prototype Ladder
S:N > 20:1
>99.9% live and functioning channels

Silicon Strip Detector (SSD)

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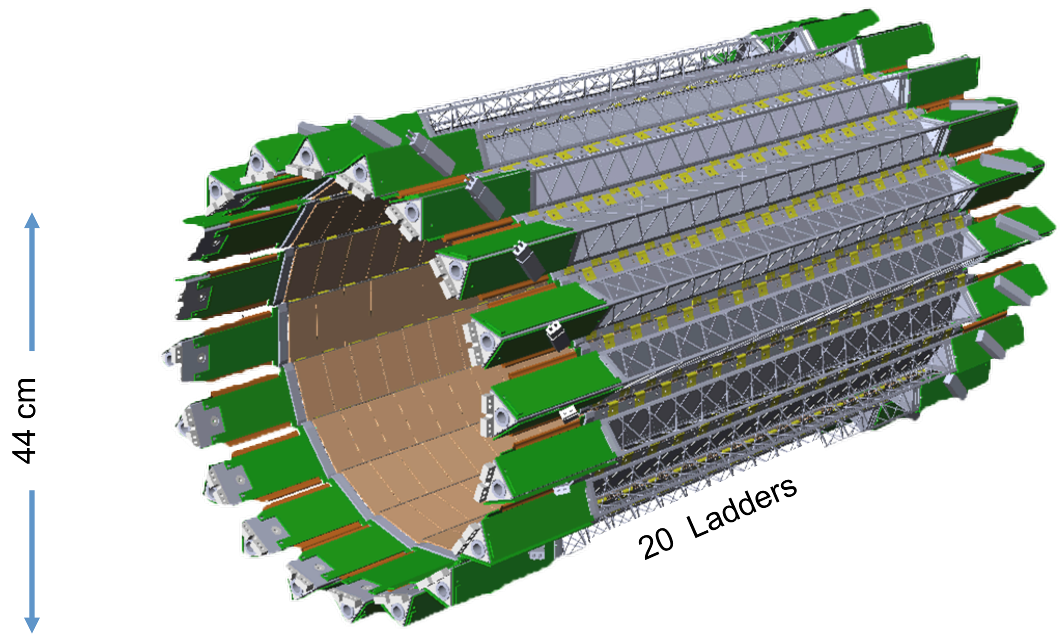

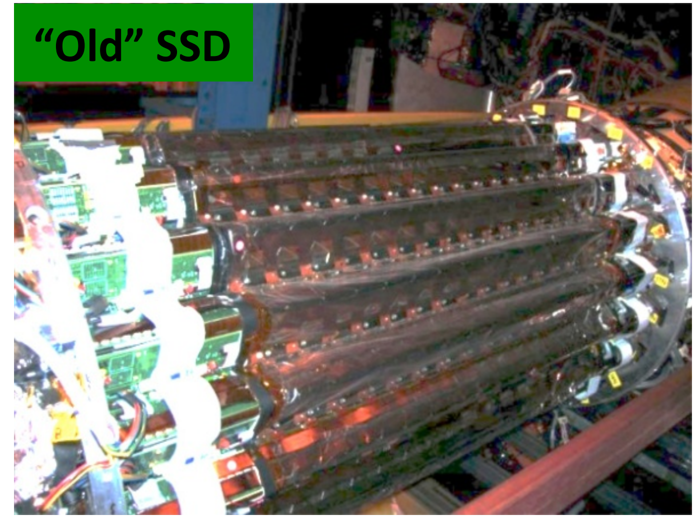

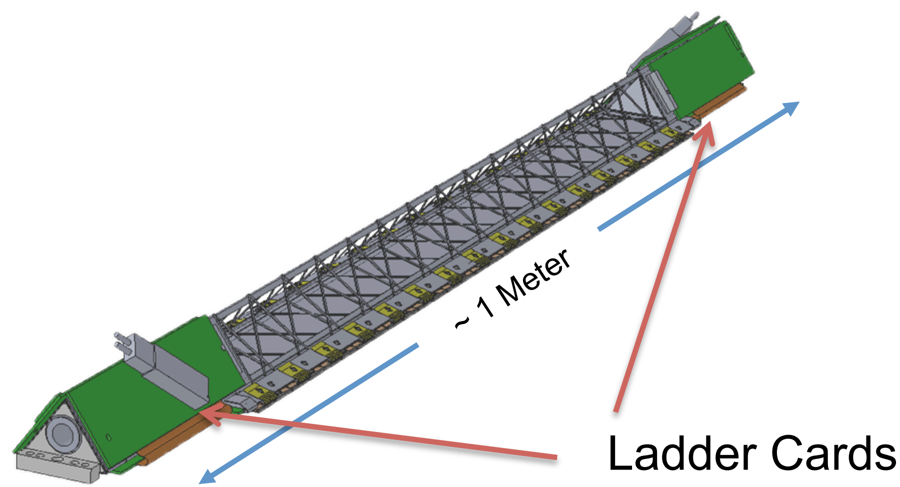

New/Faster Readout
"Old" Ladders, refurbished
New, direct mounting on support

Specific Engineering Goals for 2013 Run

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Run finished just two weeks ago!

- Test PXL system (3/10 sectors) in beam conditions before deployment of full system
- Integrate it with the STAR DAQ and Trigger system.
- Explore many configurations/settings to optimize response and identify problems

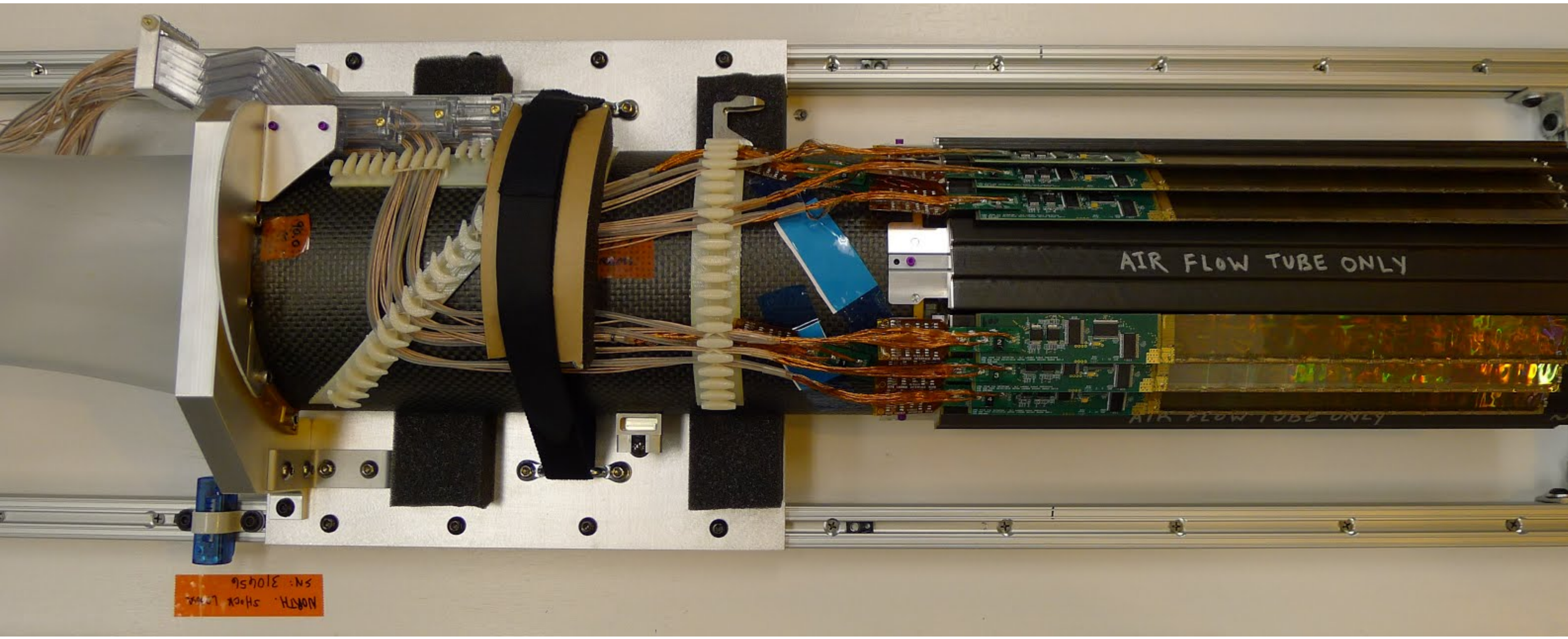
- Environment not optimal (p-p 500 GeV/c collisions at high luminosity) but still good for:
  - Offline/reconstruction chain development/testing
  - Calibration/Alignment code/procedures development/testing
  - limited physics results expected from this sample
- Most commissioning data are taken with the low-luminosity at STAR. De-steer beam to ~1-2% of full luminosity to reduce pile-up in TPC and PXL

Insertion into the experiment in May 2013

STAR HFT

- PXL sectors as they are being mounted on the insertion mechanism (sense of size)

Insertion into the experiment in May 2013



A PXL half holding two fully instrumented sectors (only the outer ladders can be seen) and three carbon (naked) sectors for efficient cooling. The other half had only one instrumented sector

Insertion into the experiment in May 2013

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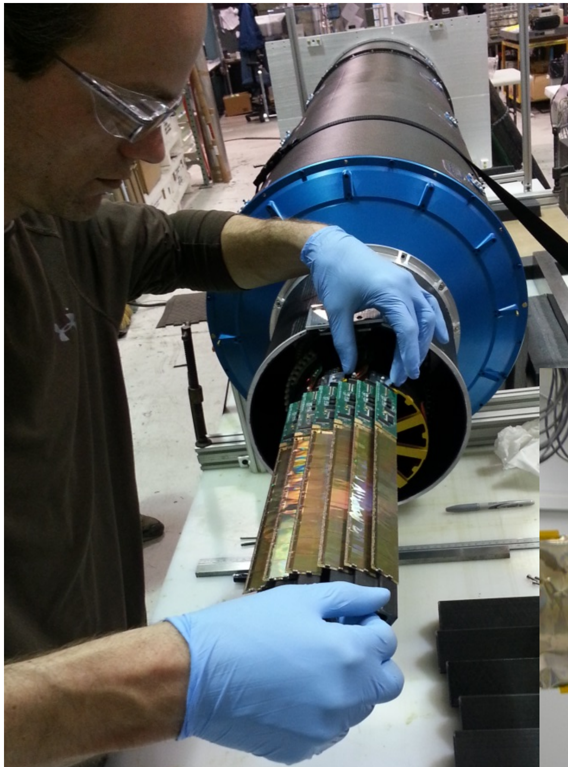
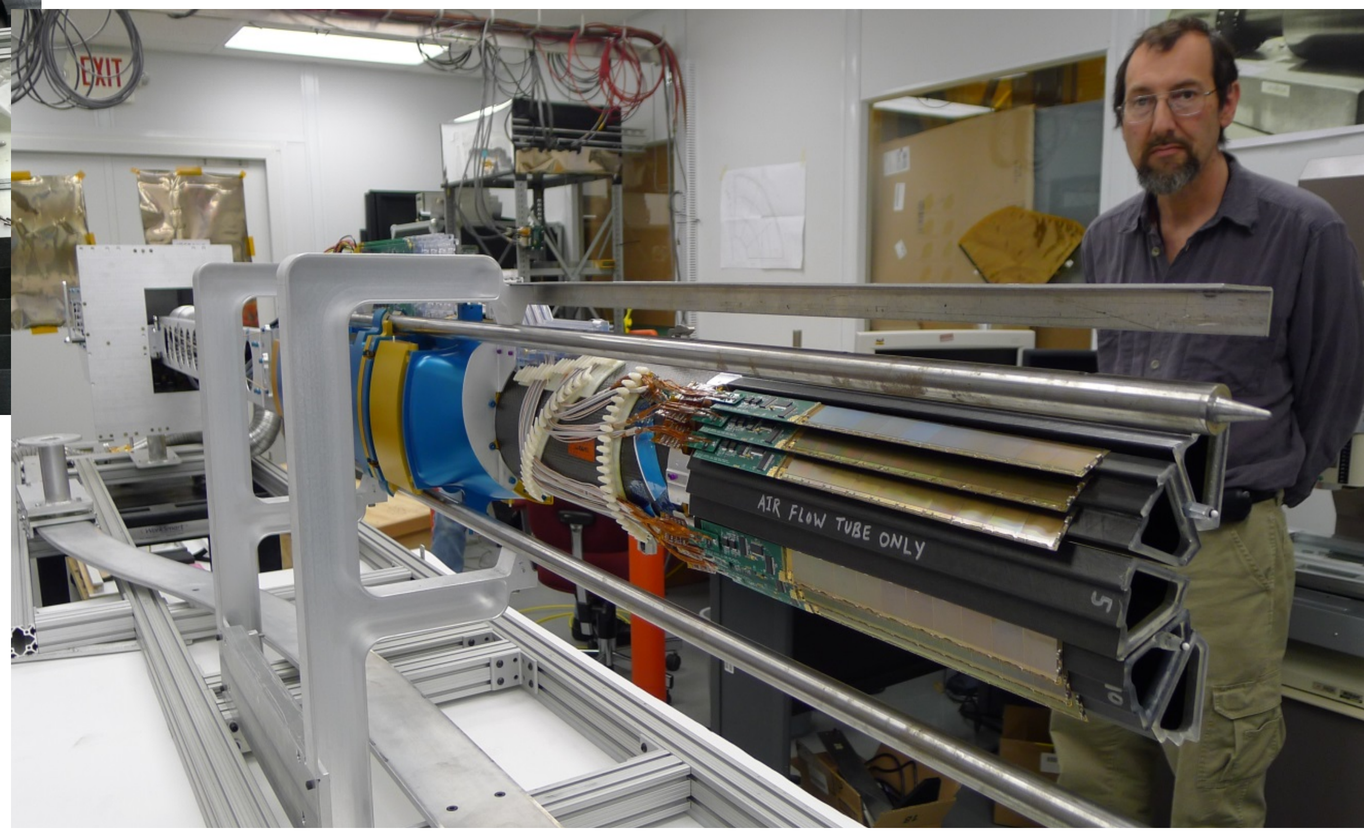
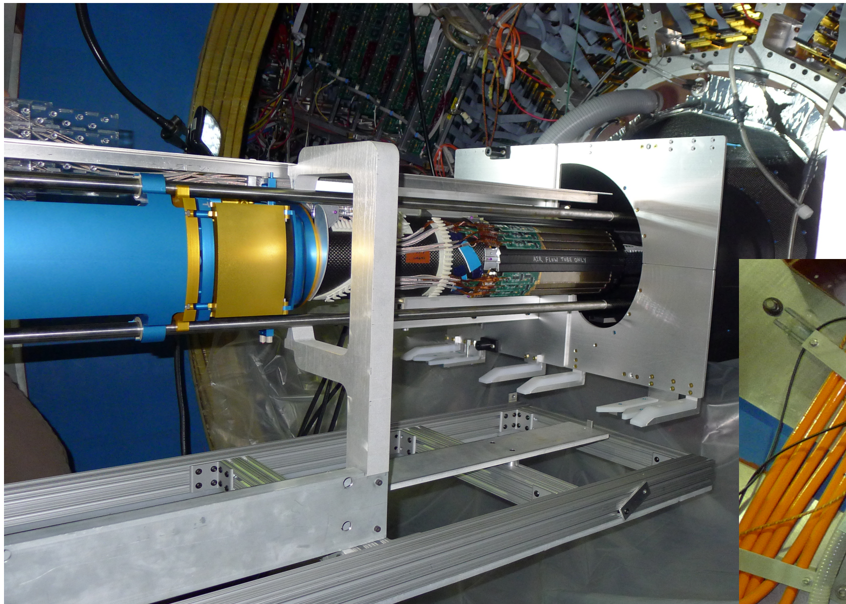
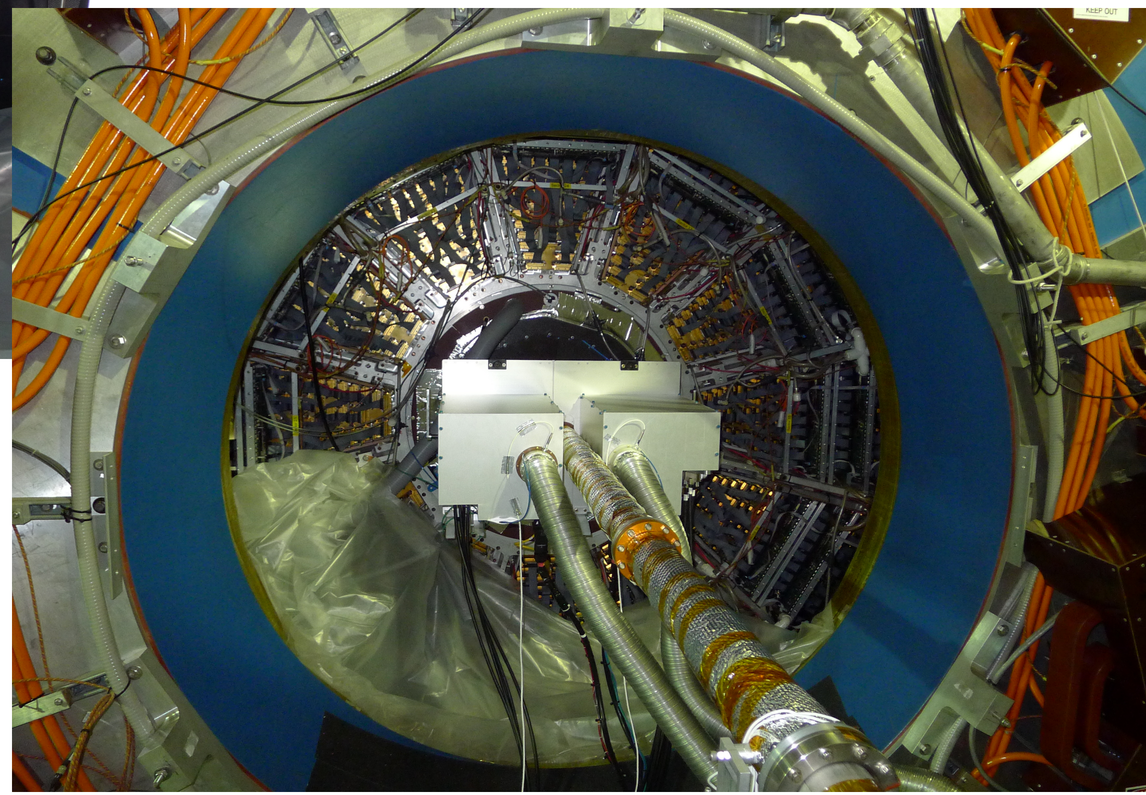
- Fabricated Assembled and tested at LBNL
- Shipped to BNL
- The PXL detector was assembled and tested in the STAR assembly area.





Insertion into the experiment in May 2013





- PXL being pushed in and after installation in the East end of STAR

Reducing Luminosity for suppressing Pileup events

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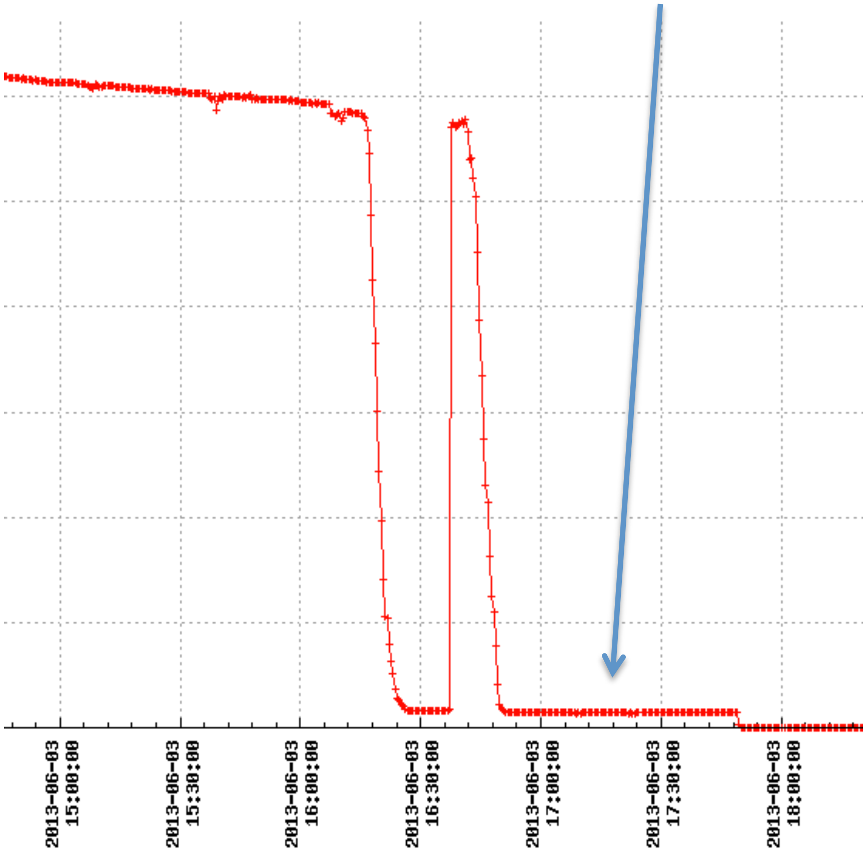
~8kHz ZDC rate – 2% of full luminosity of p-p 500 GeV/c



- The 0.2 ms readout makes the detector susceptible to non-triggered events (pileup)
- Beams were displaced to reduce the effective luminosity by a factor of ~50
- A special trigger was deployed to accept events where the event vertex was inside the useful acceptance of the detector. It also selected events with a total multiplicity above a certain threshold
  - Better event vertex determination
  - More tracks with Pxl hits

State of the Prototype - Example of QA plots

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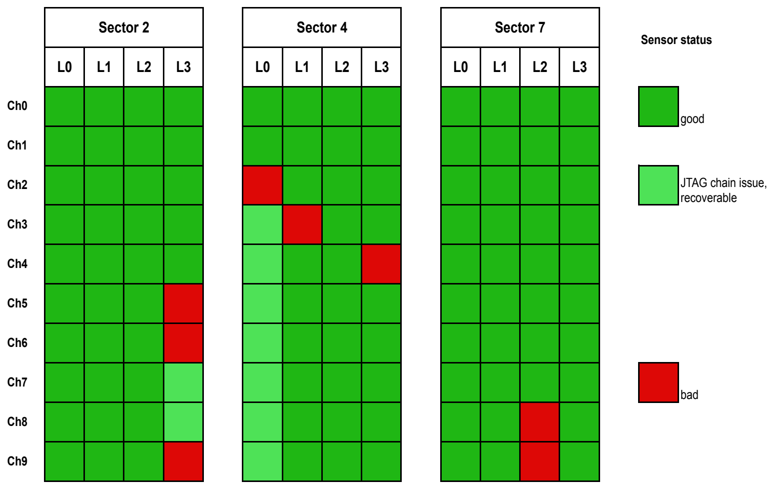
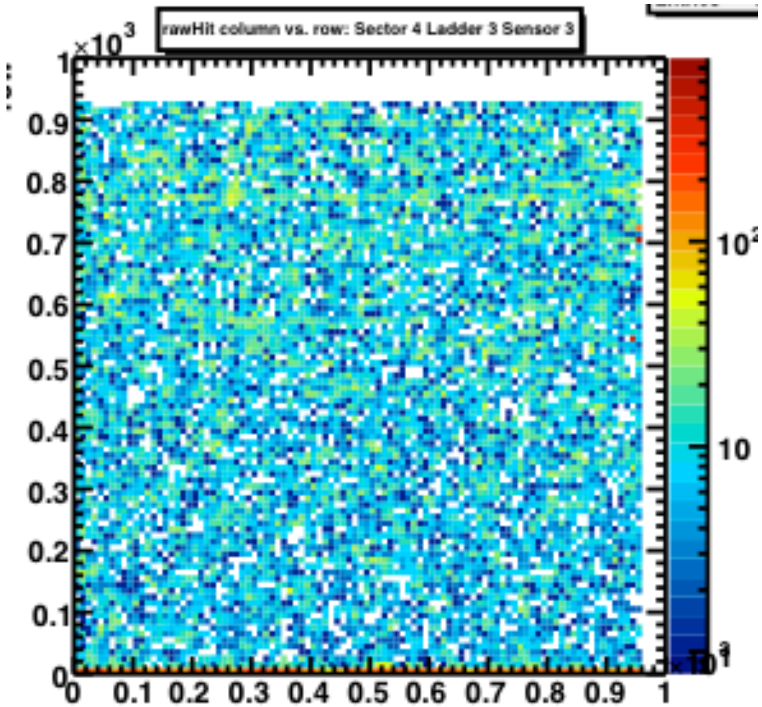
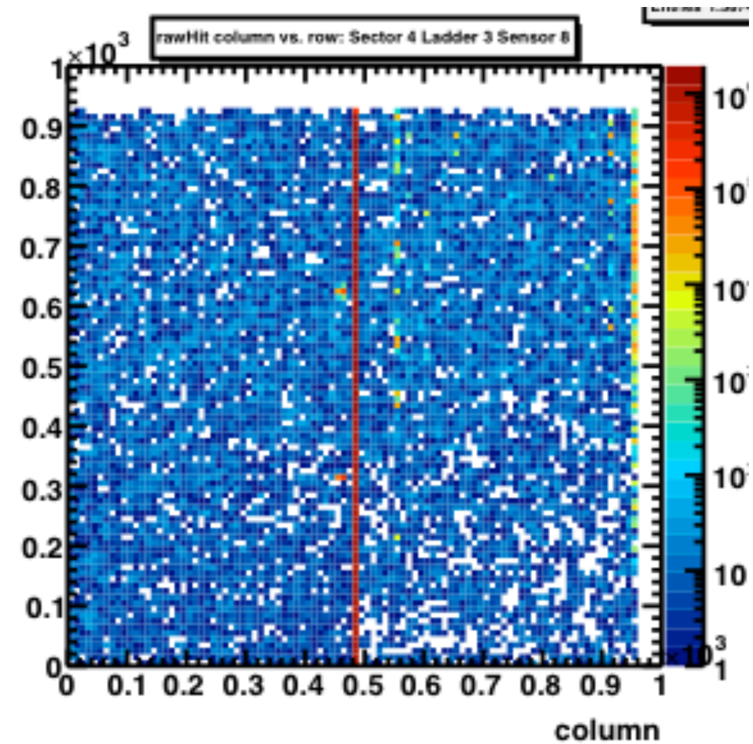




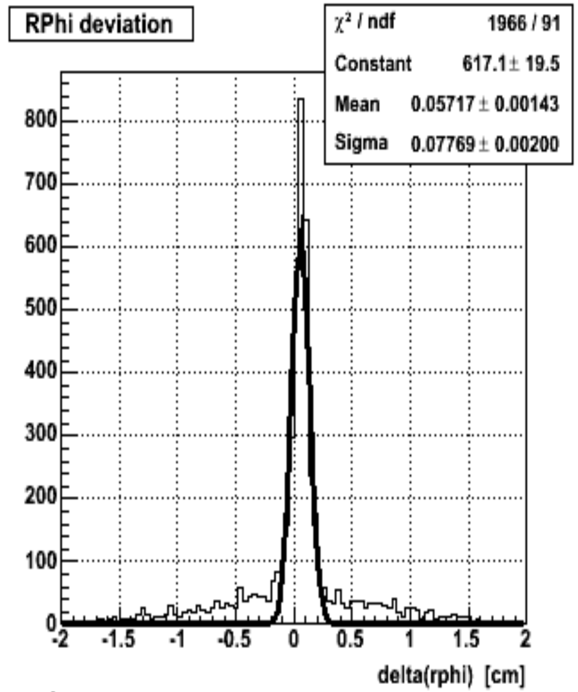


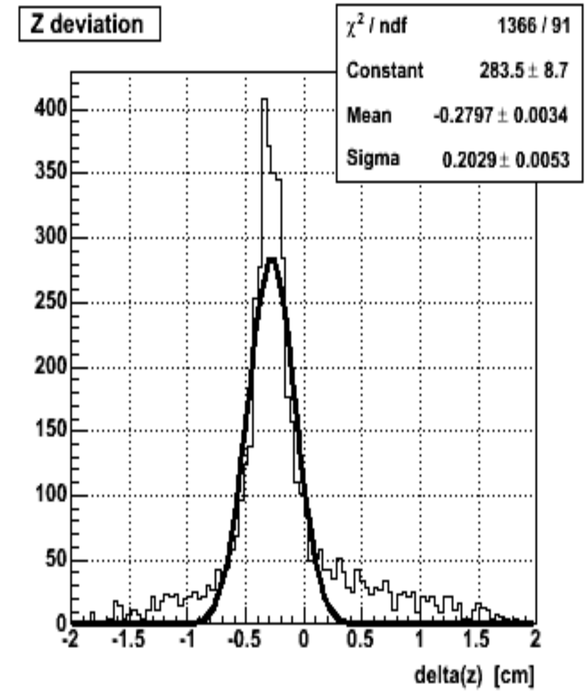
- Several sensors were damaged during construction (red squares) and several were having hot pixels/column/rows (red dots and line)
- A method to catalog and remove these noisy parts during production is being developed
- Data will be used to address/correct issues in full system

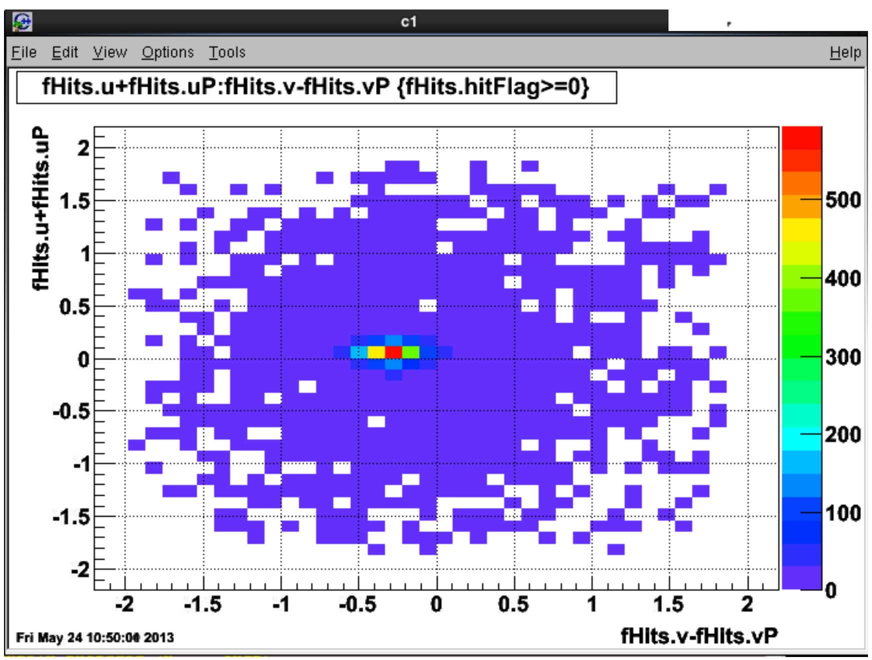
First look at Data

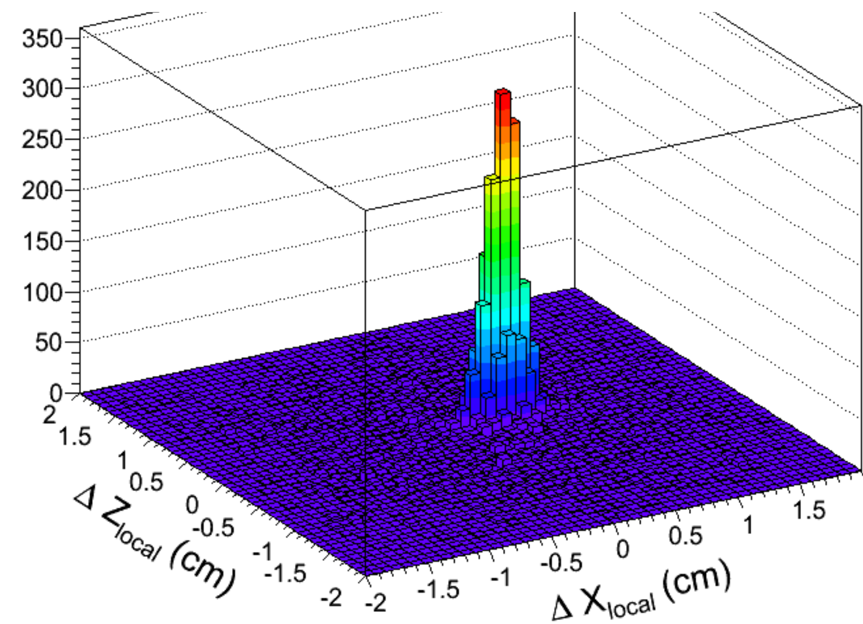
First tracking results show matching of TPC tracks to hits on sensors with residuals compatible with TPC-track resolutions on the sensors (~1-2 mm)

A beam (z) shift of ~3mm of the relative position of PXL and TPC is also observed









First look at Data

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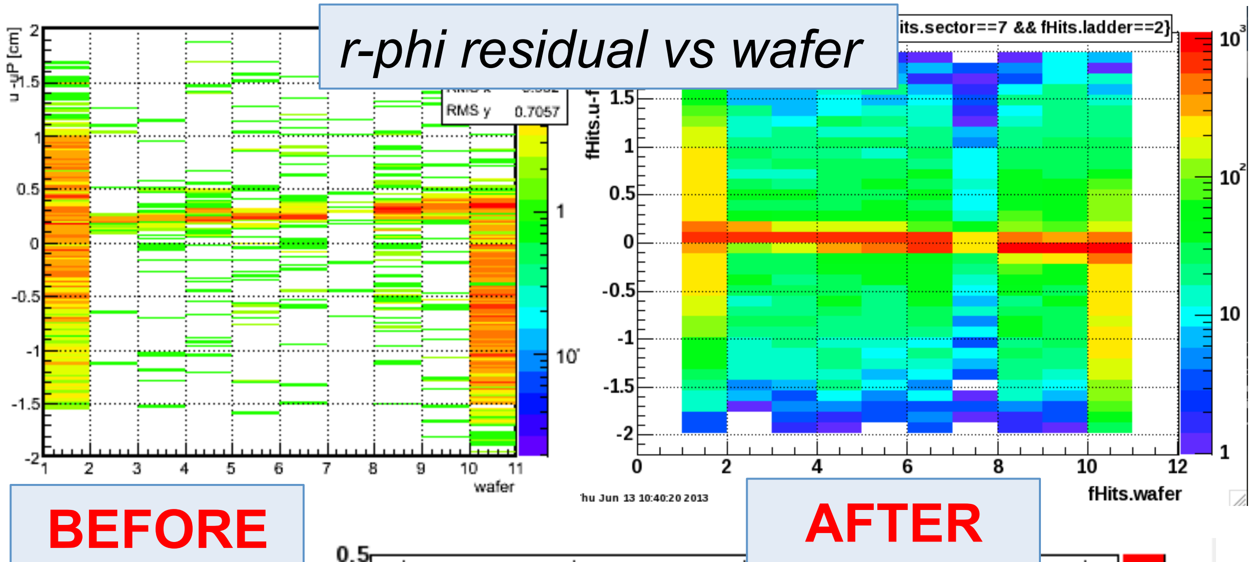
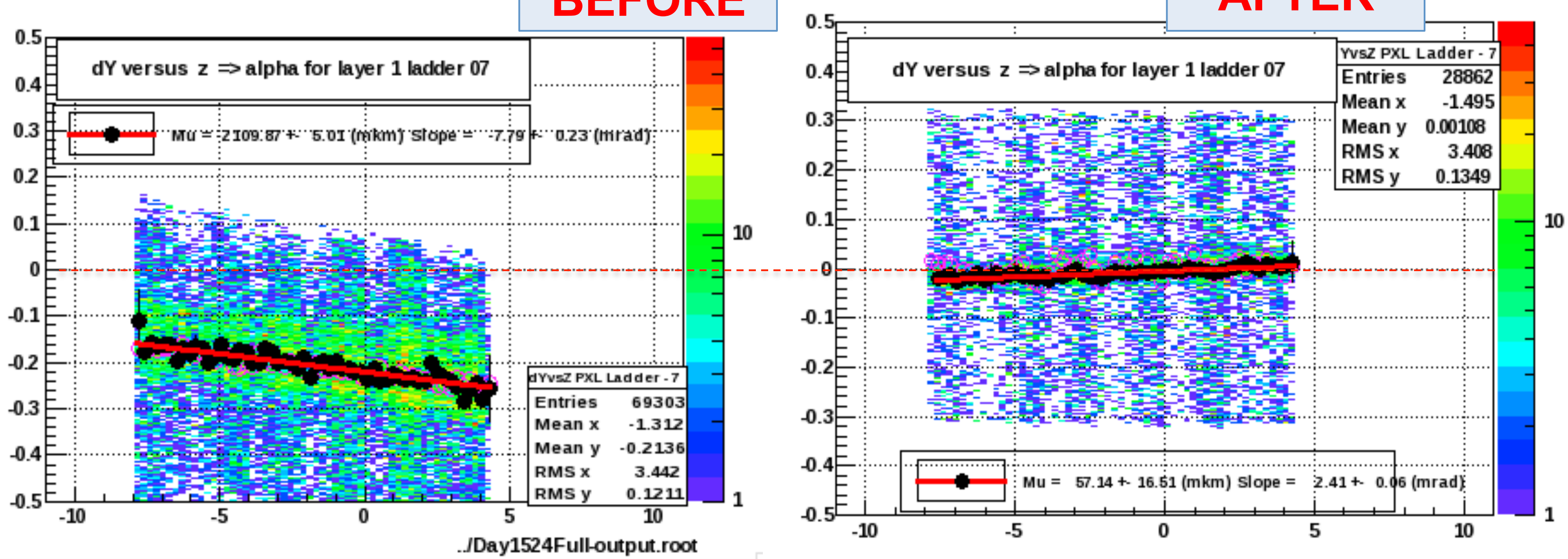
First look at alignment showed one sector (#4) being placed in almost ideal position and one (#7) deviating a few mm with some rotations (“before” plots)

First pass corrections on sector #7 (“after” plots) seem to rectify most of the misalignment. A few iterations are expected to align sensors to <10 microns





Plans

- We took a large data set of tracking data, ~ 6-10Mevents at end of fills (low luminosity runs).
- A few runs were taken at full luminosity
- We started systematic calibration/alignment studies
- We are starting adding the Pxl information on tracks
- We are starting looking into matching efficiency issues

- The engineering run has been tremendously valuable and will allow to identify problems, and make next year's startup smoother.

The rest of HFT: the IST mounting

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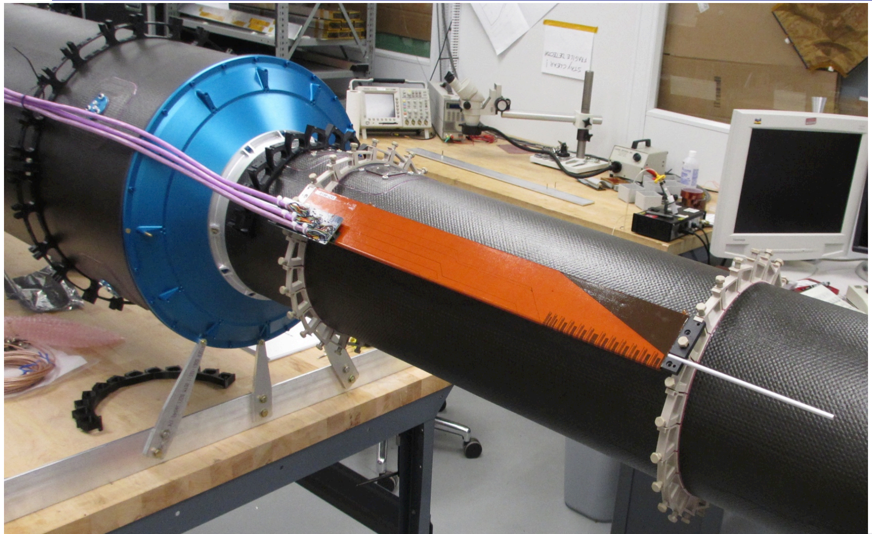

- The IST mounting on the MSC cone
- Also the SSD will begin soon

STAR BUR for Runs 14 and 15

Run	*	Beam Energy	Time	System	Goals
14	2	$\sqrt{s_{NN}}$ = 15 GeV	3-week	Au + Au	1) 150M M.B. events for CP search 2) Fixed-target data taking(3)
14	1	$\sqrt{s_{NN}}$ = 200 GeV	14-week	Au + Au	HFT & MTD heavy flavor hadron measurements $L=10\ nb^{-1}$, 1000M M.B.
15	1	$\sqrt{s}$ = 200 GeV	12-week	1) p + p 2) $p_\uparrow + p_\uparrow$ (6-week) 3) $p_\rightarrow p_\rightarrow$ (6-week)	1) Heavy ion reference data $L= 90\ pb^{-1}$, 500M M.B. 2) A_N, $L= 40\ pb^{-1}$, 60% pol. 3) Study $\Delta g(x)$ $L=50\ pb^{-1}$, 60% pol.
15	2	$\sqrt{s_{NN}}$ = 200 GeV	5-week	$p_\uparrow$ + Au	Study saturation physics, pA-ridge and heavy ion reference $L=300\ pb^{-1}$

- 22 cryo-week.
- 15 cryo-week run, we request the top priority item for both runs.

* Physics priorities

Expected Physics performance of HFT system - Examples

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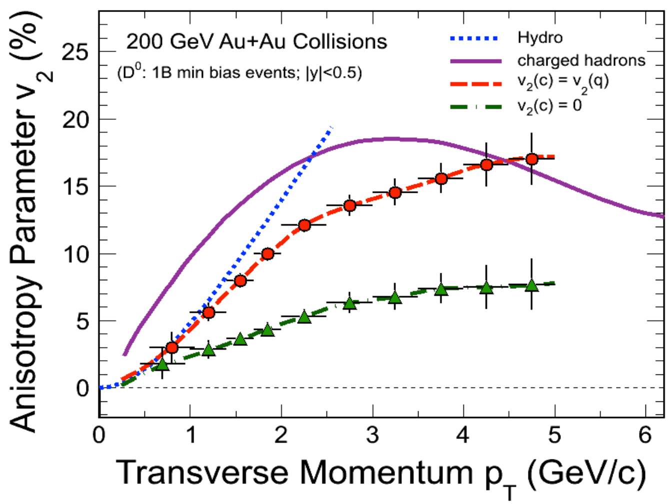
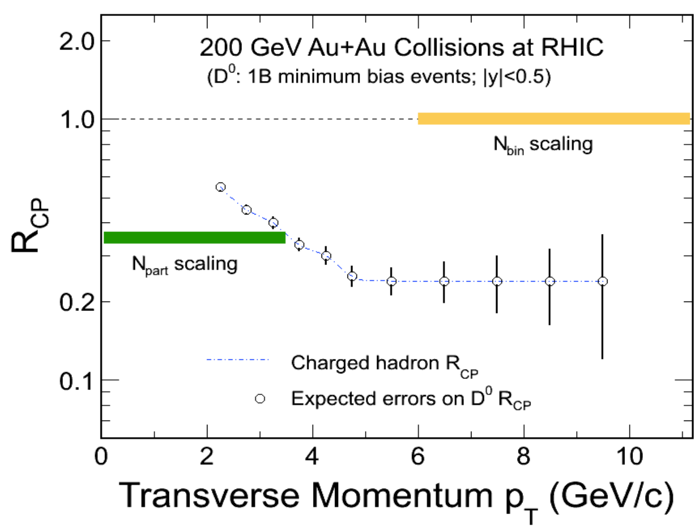
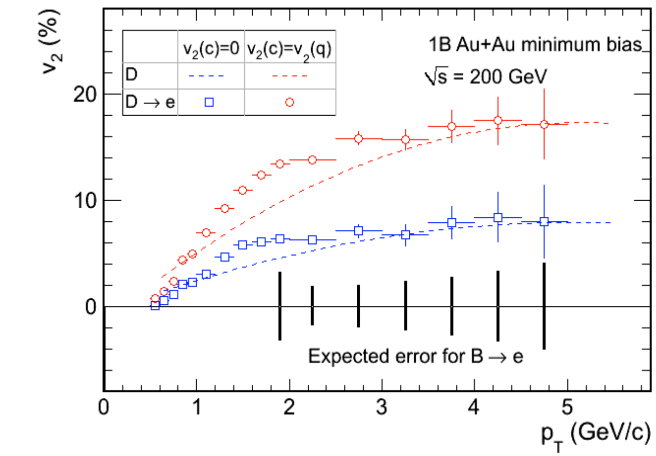
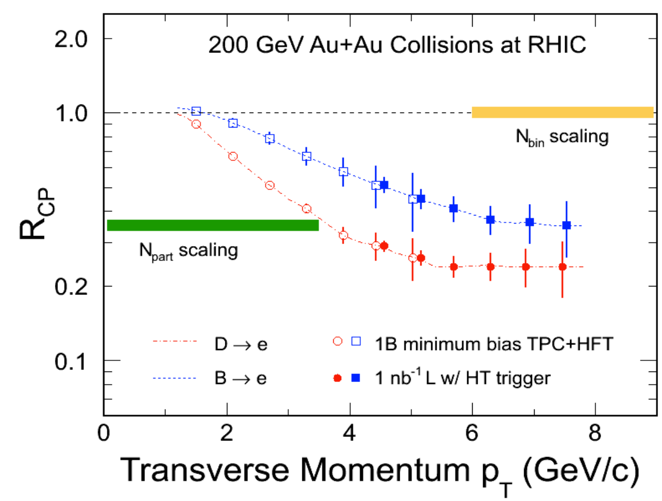
D^0 mesons





HF decayed electrons





Summary

- The HFT upgrade for STAR is in its final construction phase
- The PXL detector will achieve a new standard in low radiation length vertex detectors
- The prototype run of the heart of HFT, the PIXEL system, is a valuable step toward the success of the system and will insure quick physics results after first physics run
- The final PXL detector along with the rest of the HFT upgrades will be installed for the November 2013 run.

BACKUP SLIDES

Detector Characteristics

Pointing resolution	$(12 \oplus 19\ \mathrm{GeV}/p\cdot c)\ \mu m$
Layers	Layer 1 at 2.5 cm radius Layer 2 at 8 cm radius
Pixel size	20.7 μm X 20.7 μm
Hit resolution	6 μm
Position stability	6 μm rms (20 μm envelope)
Radiation length per layer	$X/X_0 = 0.37\%$
Number of pixels	356 M
Integration time (affects pileup)	185.6 μs
Radiation environment	20 to 90 kRad $2*10^{11}$ to 10^{12} 1MeV n eq/cm^2
Rapid detector replacement	~ 1 day

356 M pixels on ~0.16 m^2 of Silicon

Monolithic Active Pixel Sensors

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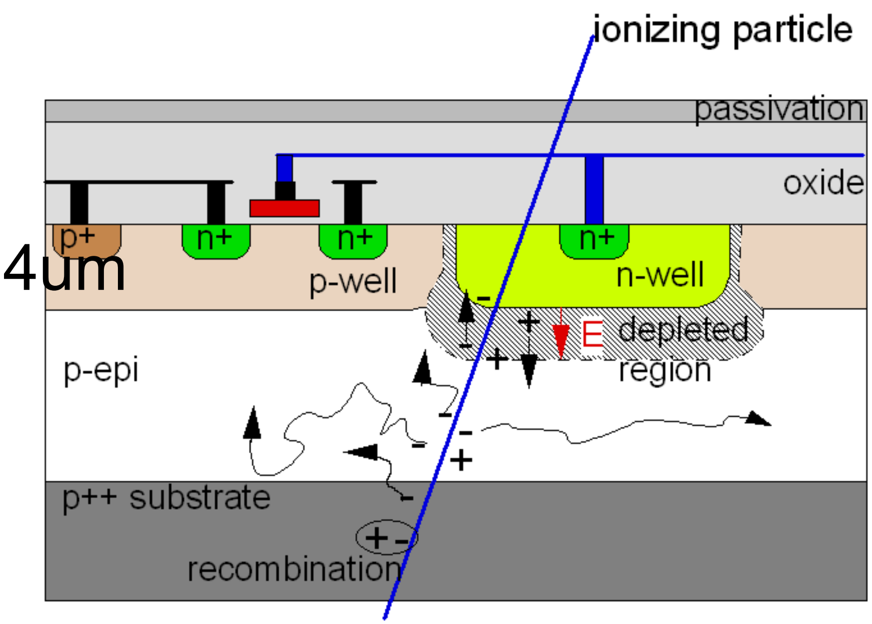
MAPS pixel cross-section (not to scale)



- 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 ~10-15 μm) → MIP signal is limited to <1000 electrons
- Charge collection is mainly through thermal diffusion (~100 ns), reflective boundaries at p-well and substrate.
- 100% fill-factor
- Fast readout
- Digital output
- Proven thinning to 50 micron

Pixel signal extraction and operation

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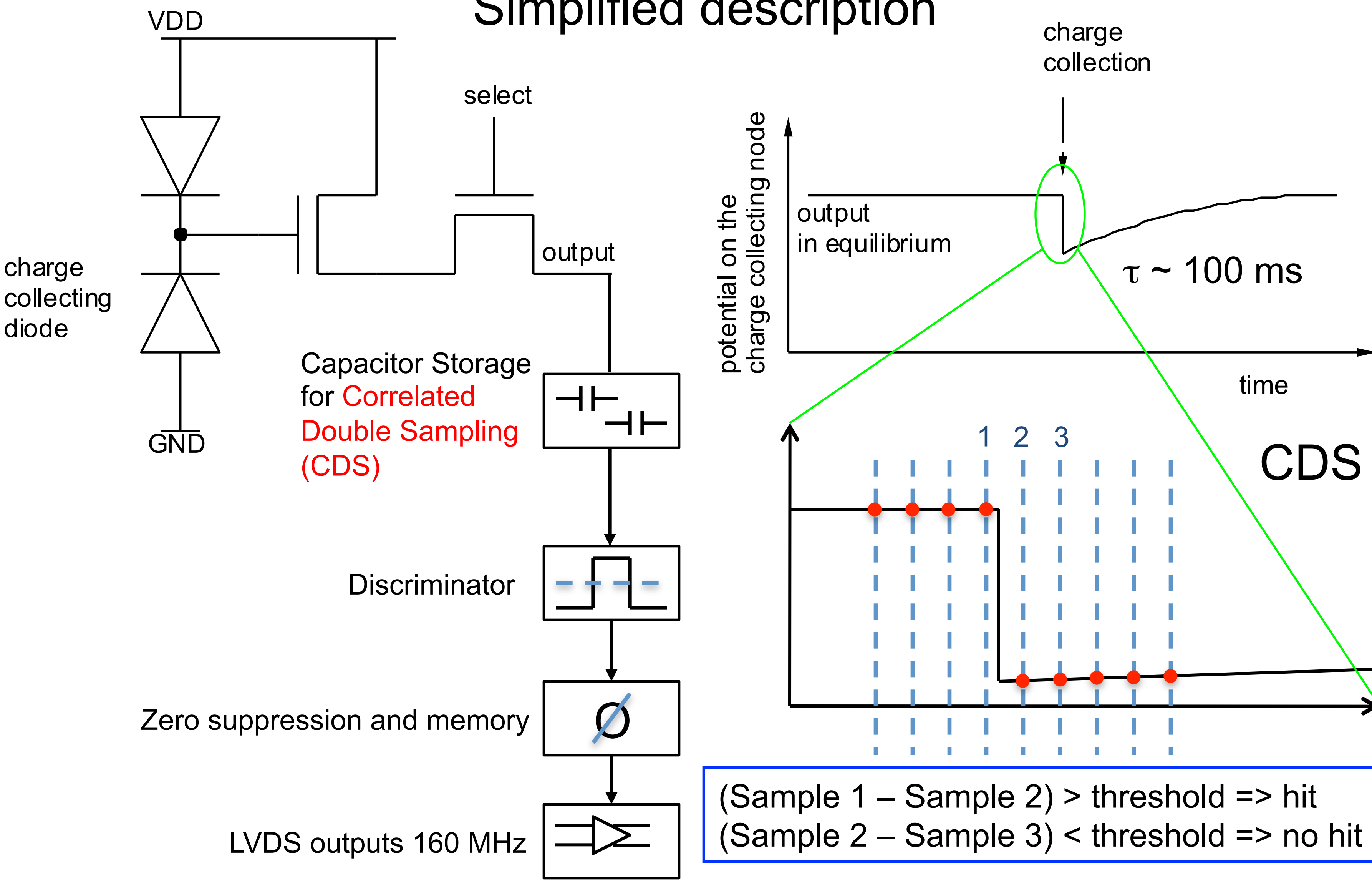
Simplified description



(Sample 1 – Sample 2) > threshold => hit
(Sample 2 – Sample 3) < threshold => no hit

Mimosa-26HR eff vs. fake hit rate

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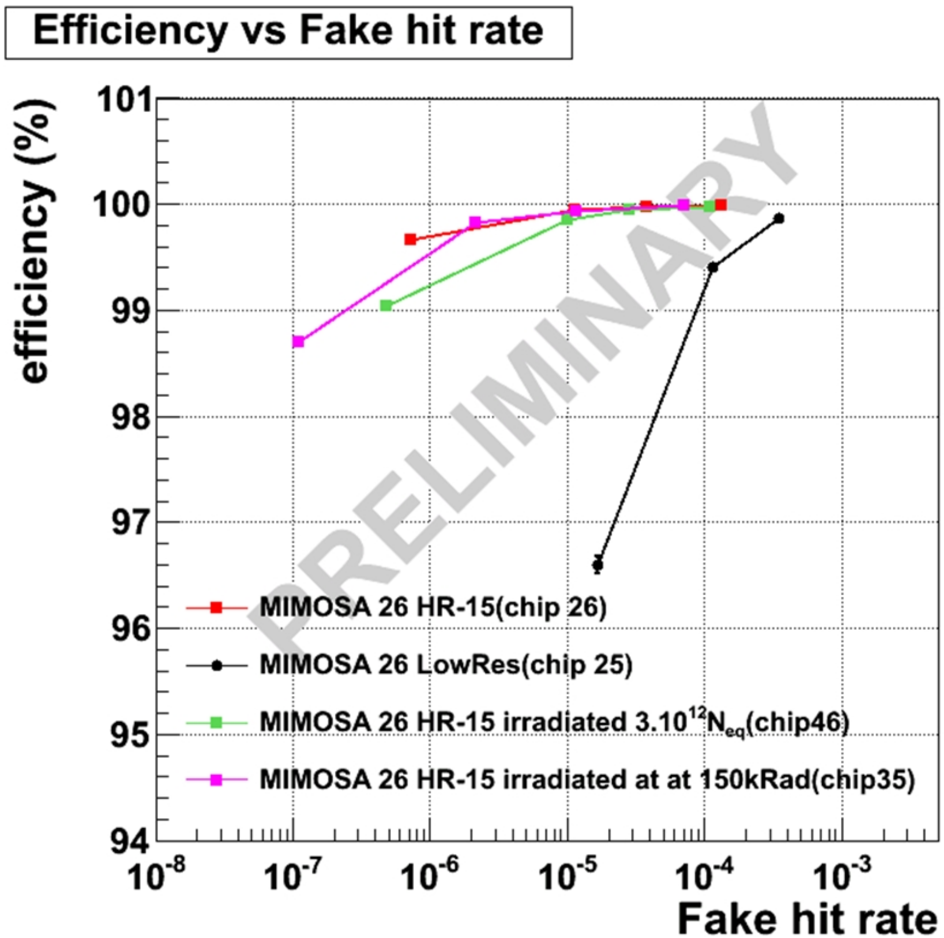
Mimosa26 sensor in a high-resistivity epitaxial layer



Tested for STAR Operating conditions

resolution < 5um

14

Pixel2010, September 6 – 10, Grindelwald, Switzerland

A. Dorokhov, IPHC, Strasbourg, France

Mimosa-26 in HR

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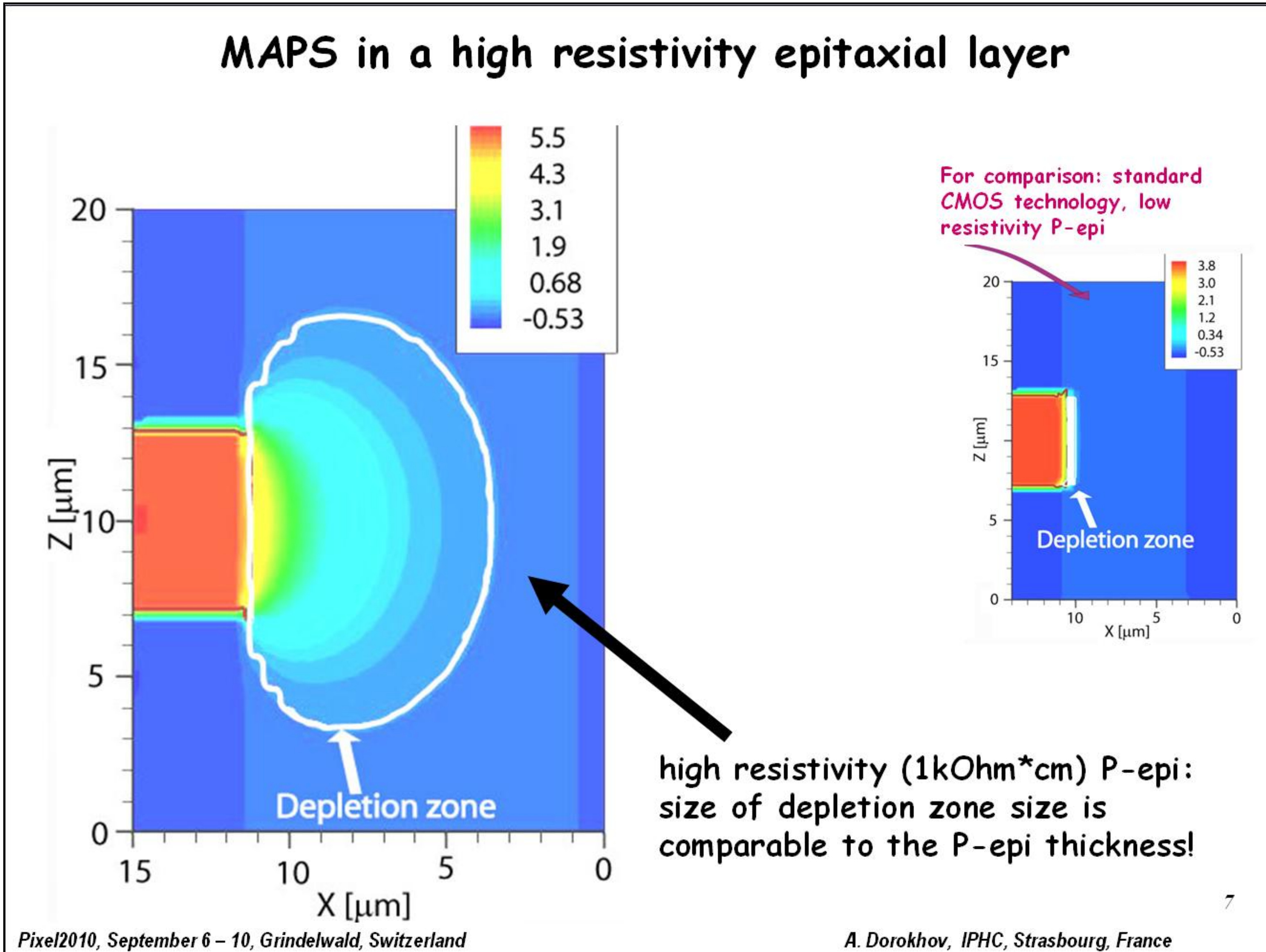
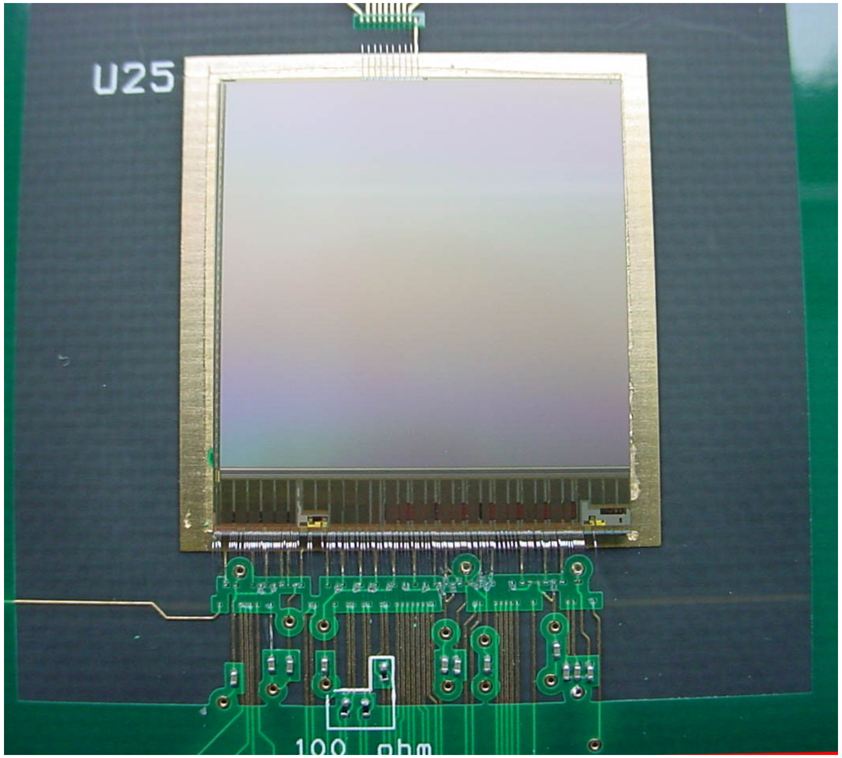
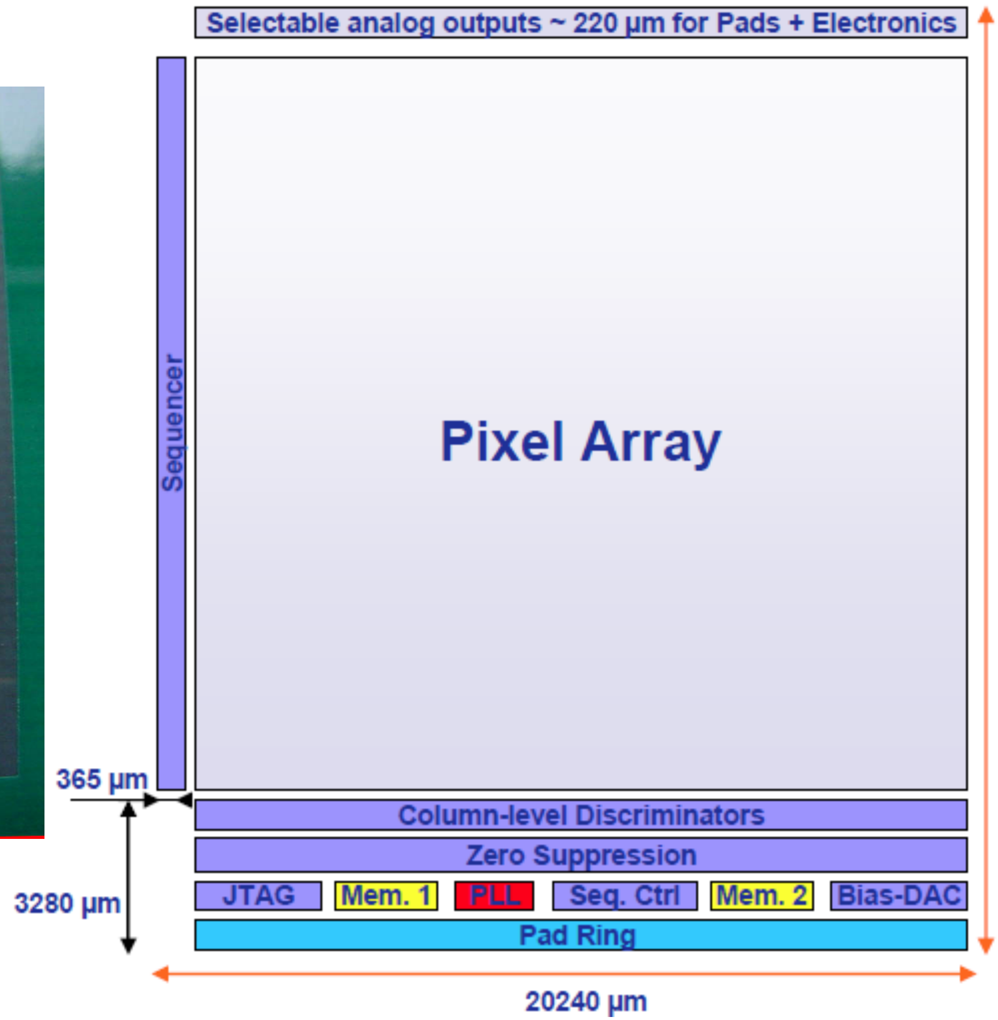


PXL detector production prototype





Mechanical Development

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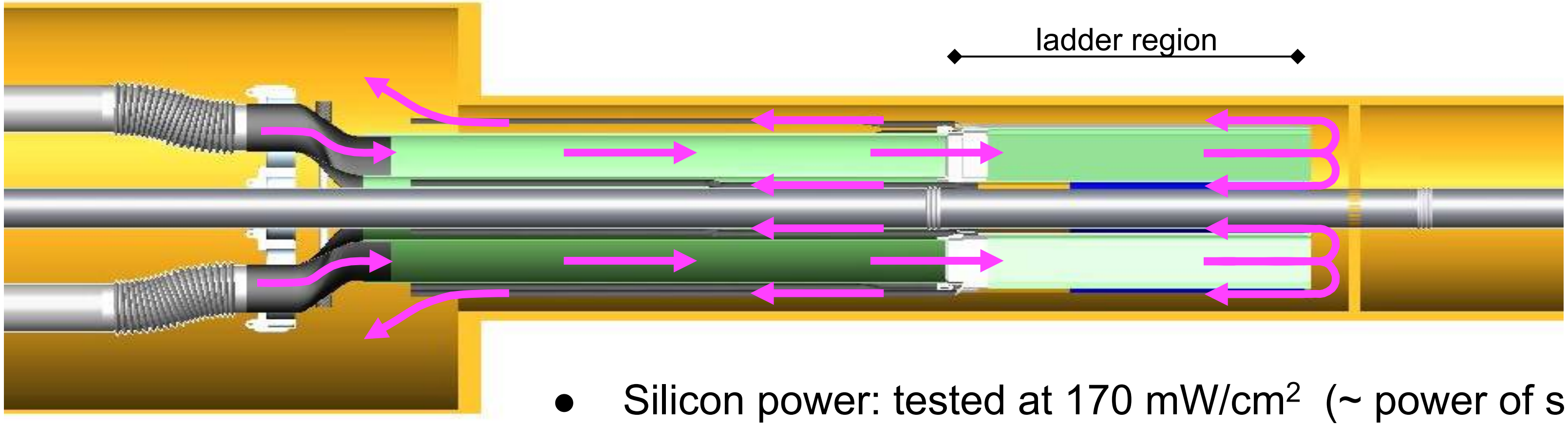
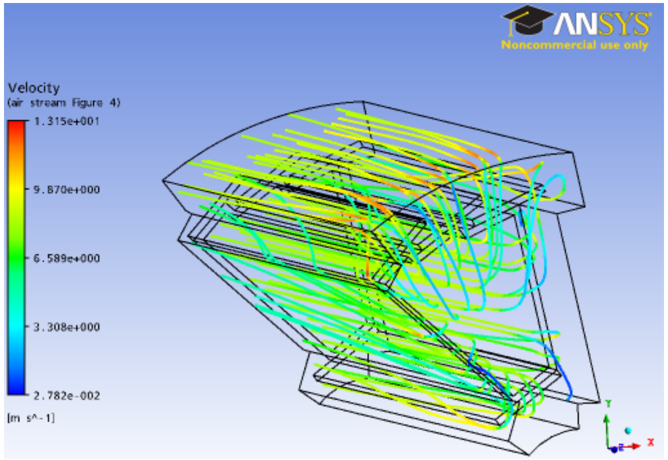
Air-flow based cooling system for PXL to minimize material budget.



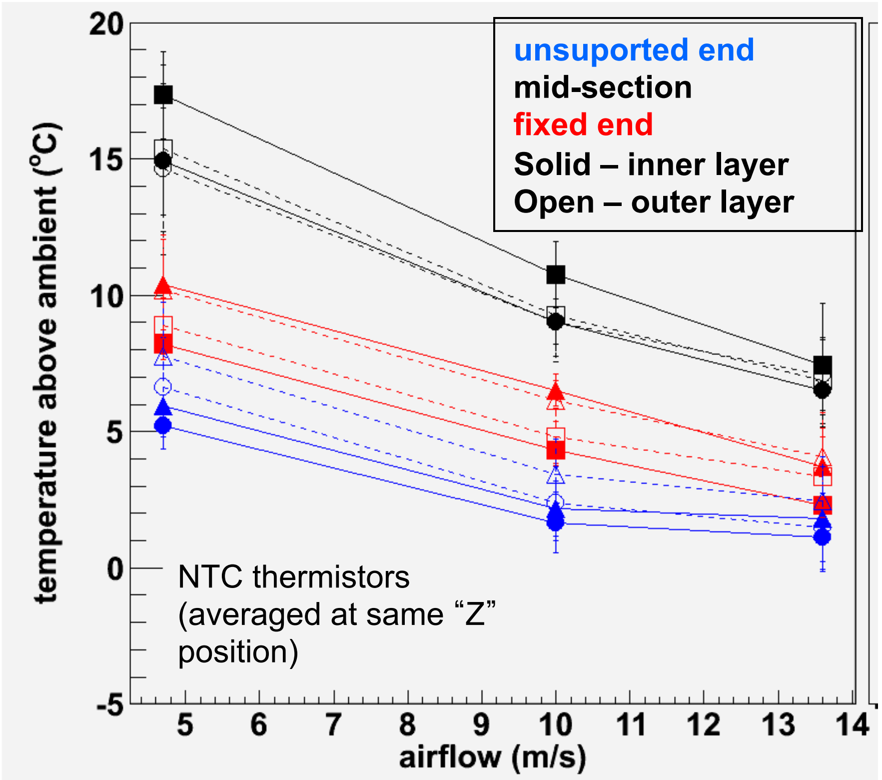
- Silicon power: tested at 170 mW/cm^2 (~ power of sunlight)
- 350 W total in the ladder region (Si + drivers)



computational fluid dynamics

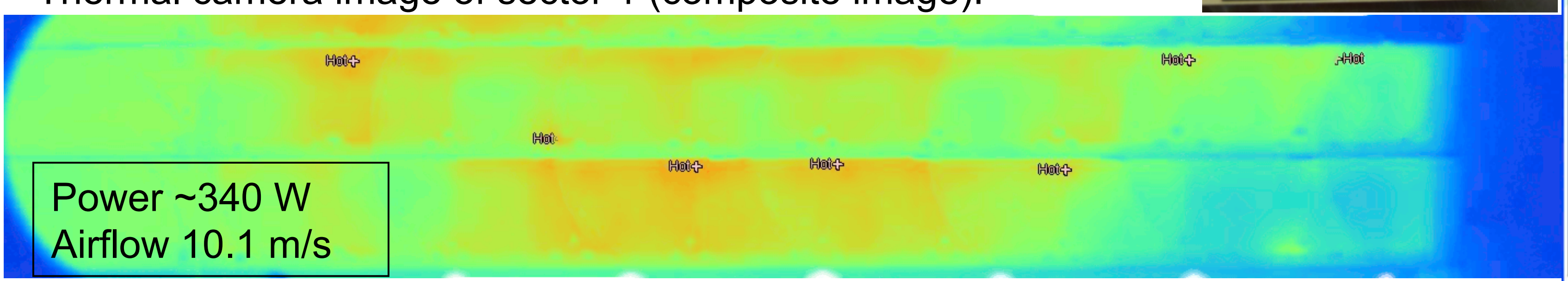
Mechanical Development

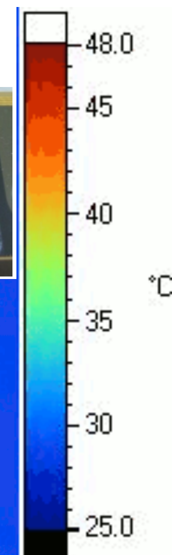
340 W with ambient air = 26.8 C



- Measurement results agree with simulations and meets calculated stability envelope tolerance.
- Air flow-induced vibrations (≤ 10 m/s) are within required stability window.

Thermal camera image of sector 1 (composite image):





CD-4 performance parameters

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Low-level CD-4 key performance parameters: experimentally demonstrated at Project Completion

1	Thickness of first PXL layer	< 0.6% X_0 (0.37% in the baseline design)	Measured during construction
2	Internal alignment and stability PXL	< 30 μm (This requirement is met in the baseline mechanical design, verified by simulation and prototype testing)	Measure during prototype testing and with test beam or cosmic rays after construction.
4	PXL integration time	< 200 μs (Current generation sensors have an integration time of 185.6 μs)	This is a design parameter of the sensor. This can be demonstrated with oscilloscope measurements.
5	Detector hit efficiency PXL	95% sensor efficiency and noise from all sources < 10^{-4} (Prototype sensors measured in beam tests to be > 99% with noise < 10^{-4})	The sensor efficiency will be measured in beam tests as a function of bias settings and threshold. This will be established prior to construction.
7	Live channels for PXL and IST	95% (The measured good sensor live channel yield fraction is > 99% for over 90% of sensors on a wafer. We will select good sensors for production ladders)	The number of bad pixels will be measured on each mounted sensor during probe testing and verified after ladder and sector construction. The numbers will be saved to a database.
8	PXL and IST Readout speed and dead time	<5% additional dead time @ 500 Hz average trigger rate and simulated occupancy	This can be measured in real time with simulated data for verification.

Our current design meets (and exceeds) these requirements.