Performance and Plans for the Silicon Tracker Upgrade of the STAR Experiment at RHIC

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for the STAR Collaboration

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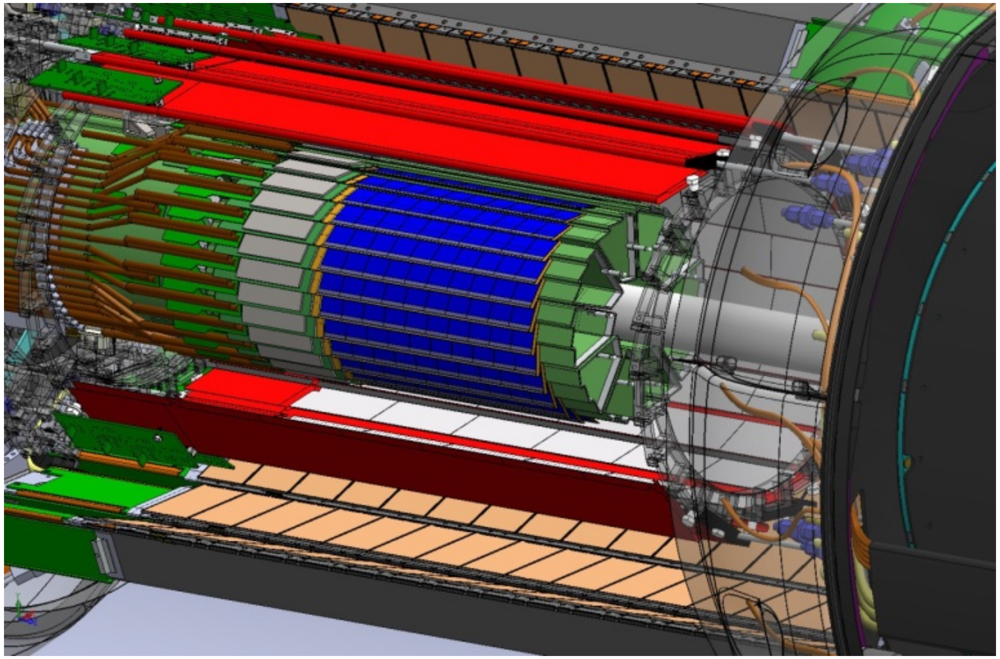
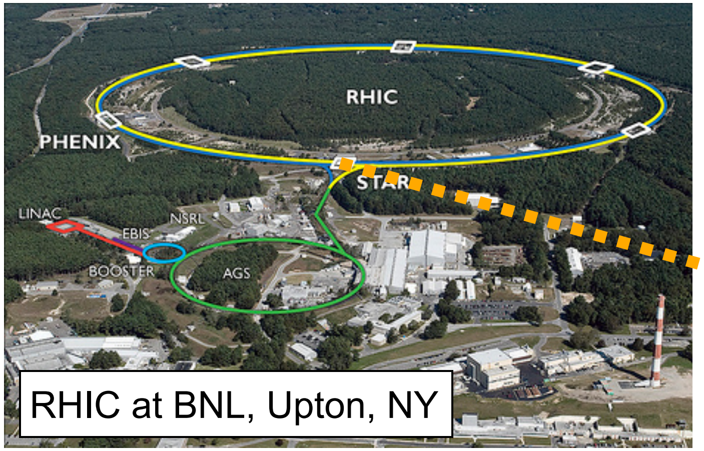
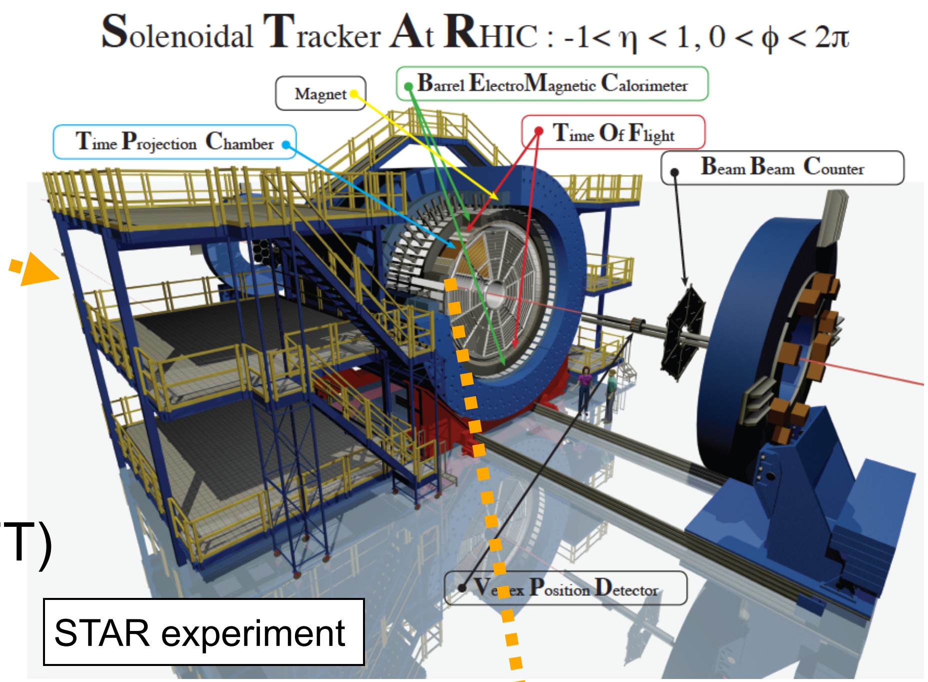


The 2015 International Conference on Applications of Nuclear Techniques
Crete, Greece
June 14-20, 2015

Outline

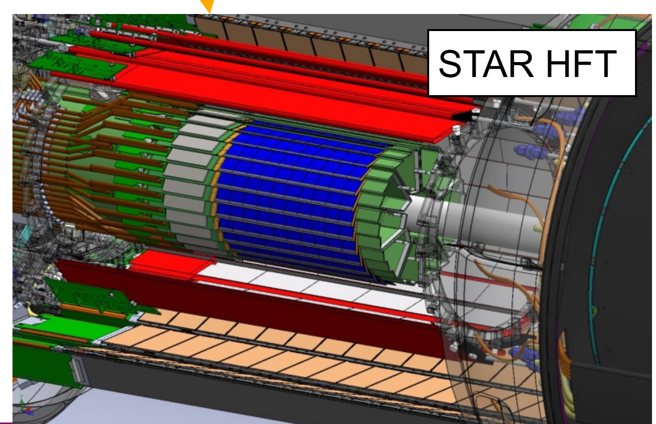


RHIC at BNL, Upton, NY



STAR experiment

- STAR Heavy Flavor Tracker (HFT)
  - 3 sub-detectors
- PXL Detector
  - First MAPS[1] - based vertex detector
- HFT status and performance
- Summary and Outlook

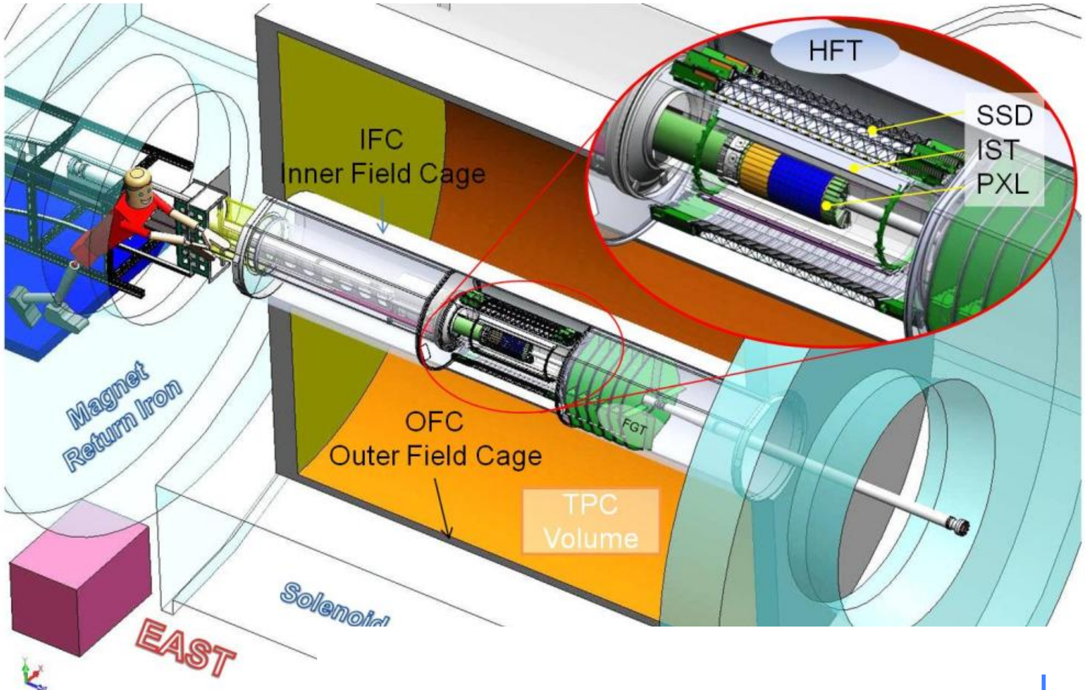

STAR HFT

[1]Monolithic Active Pixel Sensor

STAR Heavy Flavor Tracker (HFT) Upgrade

STAR HFT

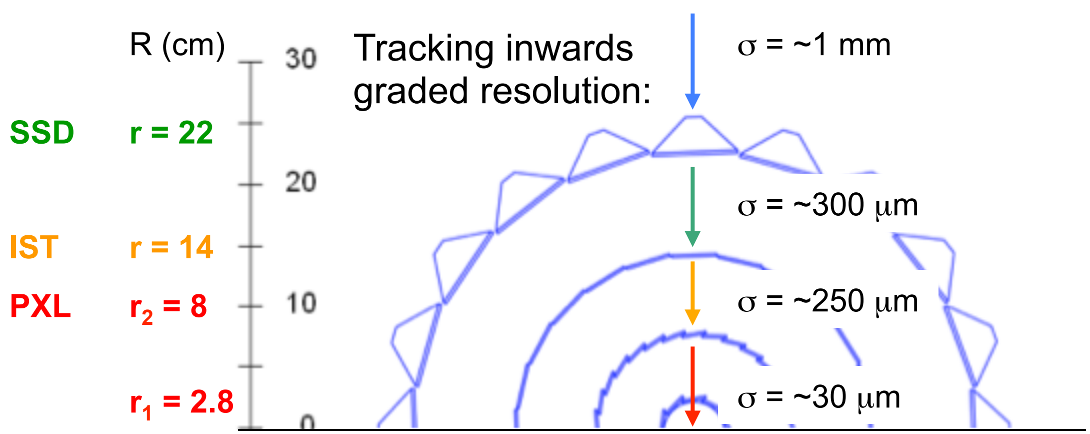
- Built to identify mid rapidity Charm and Beauty mesons and baryons through direct reconstruction and measurement of the displaced vertex with excellent pointing resolution.



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

HFT – Heavy Flavor Tracker

- **SSD – Silicon Strip Detector**
- **IST – Intermediate Silicon Tracker**
- **PXL – Pixel Detector**

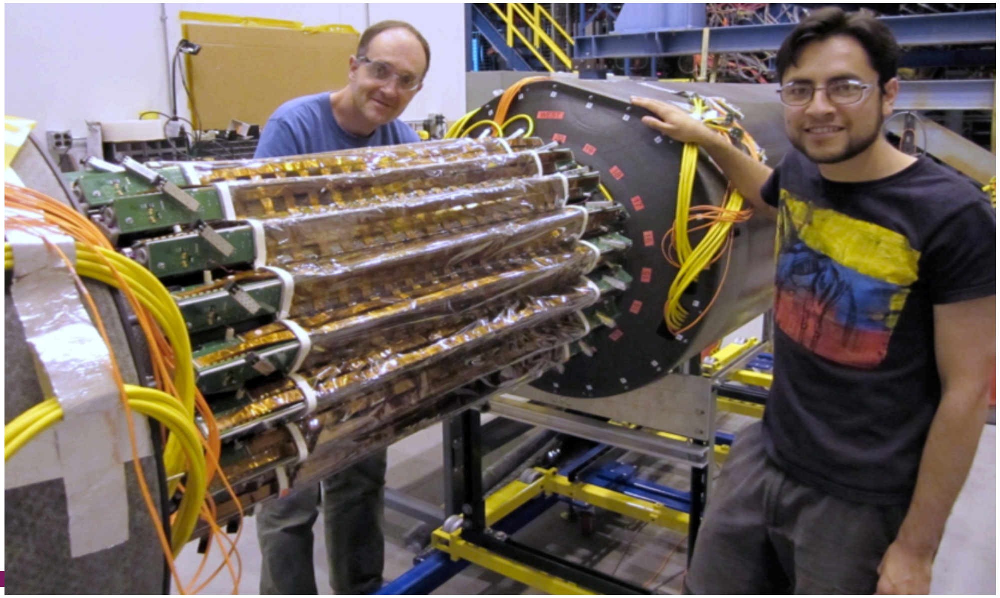


Silicon Strip Detector (SSD)

SSD radius	22 cm
SSD length	106 cm
$\|\eta\|$ coverage	< 1.2
Number of ladders	20
Number of wafers per ladder	16
Total number of wafers	320
Number of strips per wafer side	768
Number of sides per wafer	2
Total number of channels	491520
Silicon wafer size	75 × 42 mm
Silicon wafer sensitive size	73 × 40 mm
Silicon thickness	300 μm
Strip pitch	95 μm
Stereo angle	35 mrad
R-ϕ resolution	20 μm
Z resolution	740 μm

- Double sided silicon strip modules with 95 μm pitch
- Existing detector with new faster electronics
- Radius: 22 cm
- Radiation length 1% X_0

- 20 ladders from the old SSD detector
- Upgrade readout from 200 Hz to 1 kHz
- New:
  - 40 ladder cards on detector
  - 5 New RDO cards
  - Upgraded cooling system (air cooled)



Intermediate Silicon Tracker (IST)

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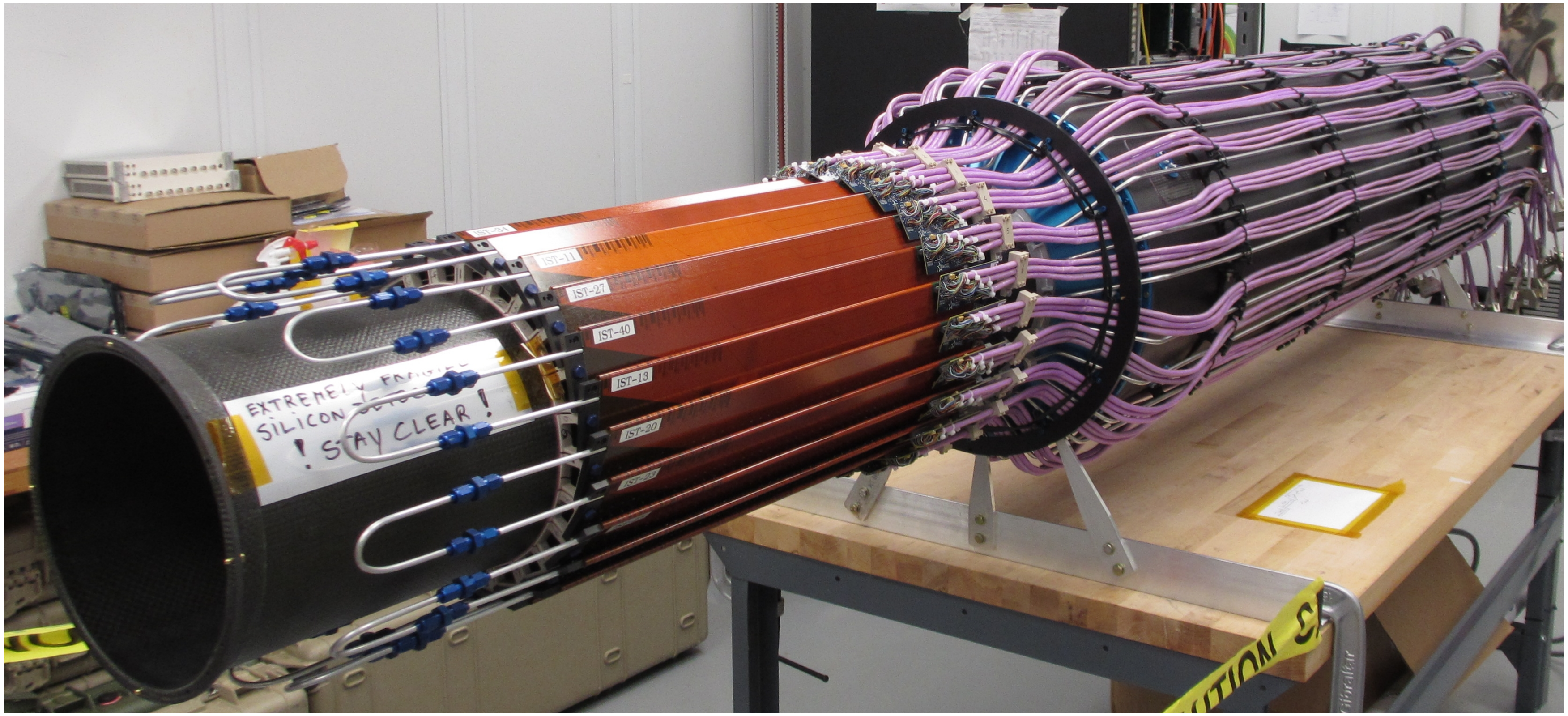
- Single sided double-metal silicon pad with 600 μm x 6 mm pitch
- Radius: 14 cm
- Liquid cooling
- Radiation length <1.5% X_0



- Conventional Si pad detector using CMS APV chip for ladders
- Readout system copy of STAR FGT detector system
  - G. Visser et al. A Readout System Utilizing the APV25 ASIC for the Forward GEM Tracker in STAR, IEEE Real Time Conference Record, Berkeley, CA, 2012

PXL detector

- MAPS sensors with 20.7 µm pitch
- Radius: ~2.8 and ~8 cm
- Radiation length <0.4% X_0 in inner layer

first MAPS based vertex detector at a collider experiment

PXL characteristics

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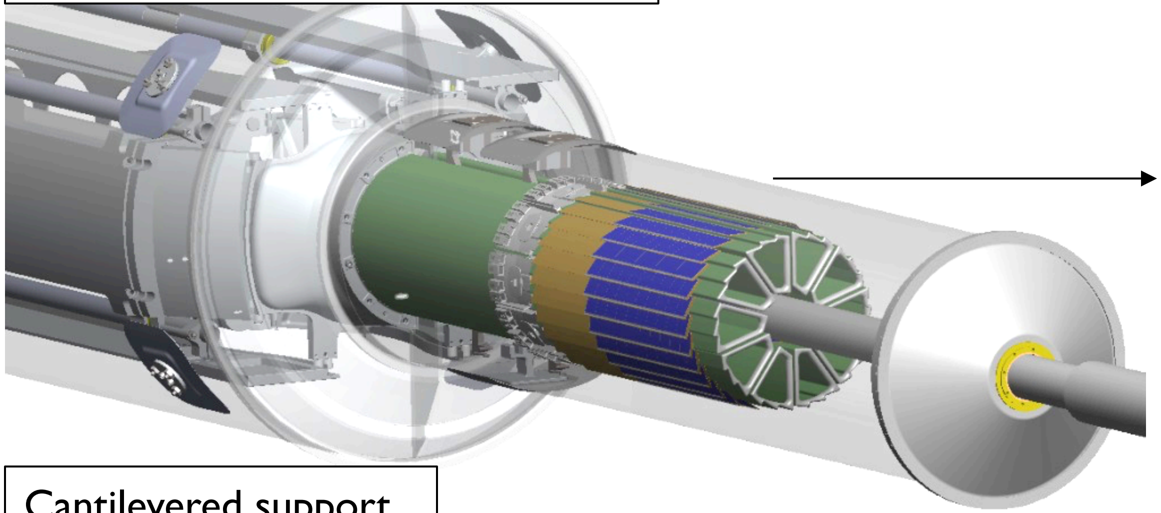
DCA Pointing resolution *	(12 ⊕ 24 GeV/p·c) μm
Layers	Layer 1 at 2.8 cm radius Layer 2 at 8 cm radius
Pixel size	20.7 μm X 20.7 μm
Hit resolution	3.7 μm (6 μm geometric)
Position stability	6 μm rms (20 μm envelope)
Radiation length first layer	X/X_0 = 0.39% (Al conductor cable)
Number of pixels	356 M
Integration time (affects pileup)	185.6 μs
Radiation environment	20 to 90 kRad / year $2*10^{11}$ to 10^{12} 1MeV n eq/cm^2
Rapid detector replacement (hot spare copy of the detector)	~ 1 day

356 M pixels on ~0.16 m^2 of Silicon

* Pointing resolution is limited by MCS and mechanical stability

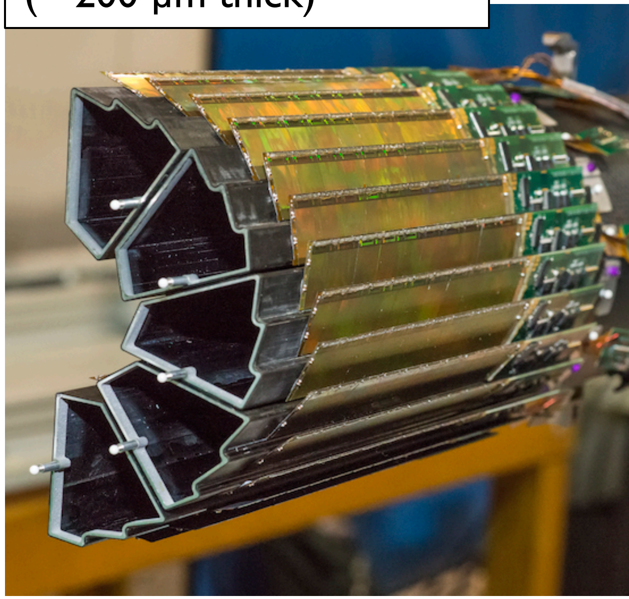
PXL architecture

Mechanical support with kinematic mounts (insertion side)



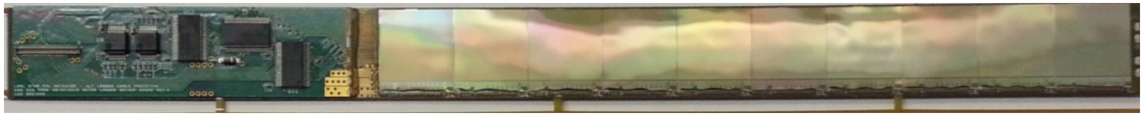
Cantilevered support

carbon fiber sector tubes (~ 200 μm thick)

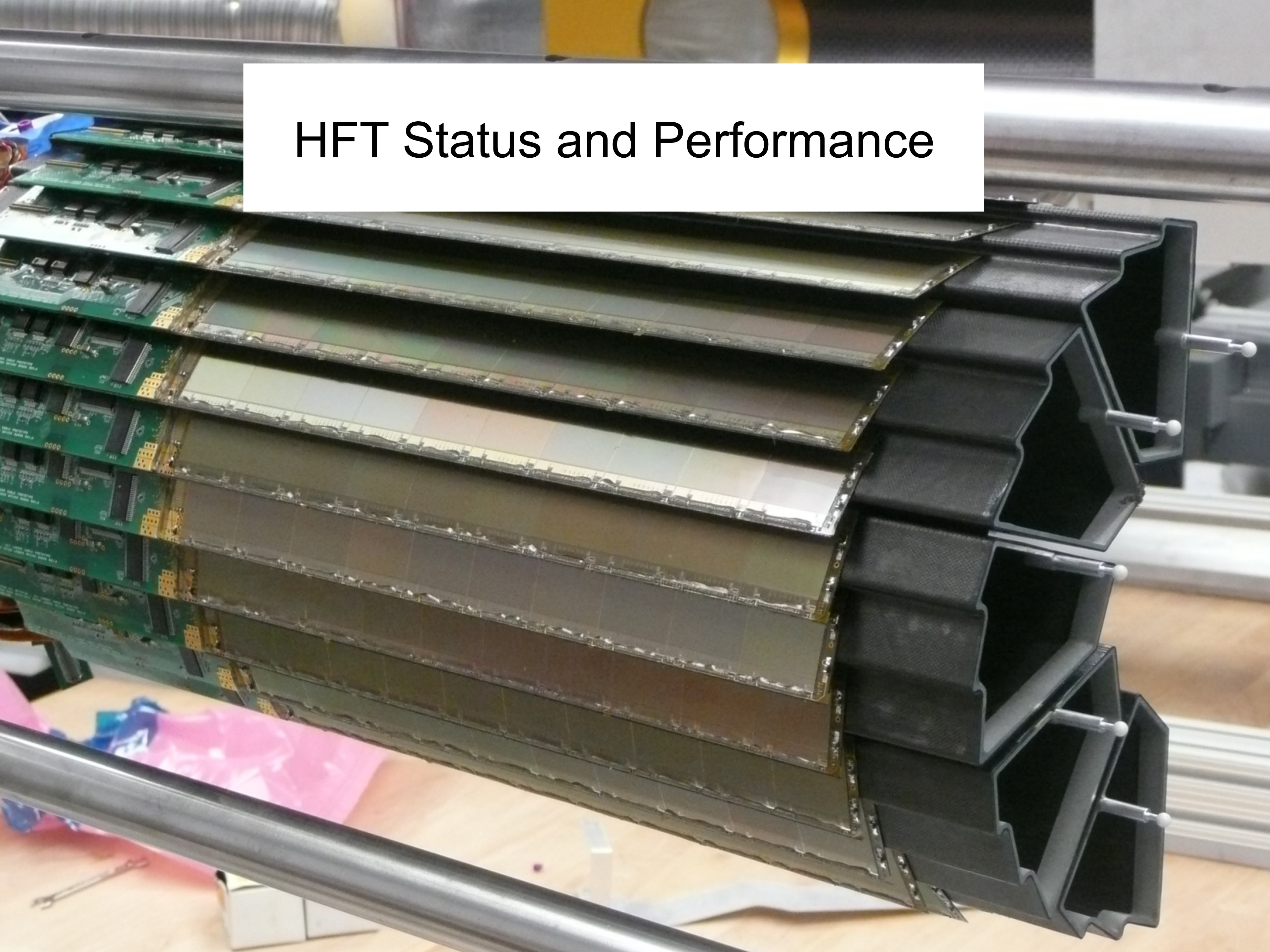


- Insertion from one side
- 10 sectors total
- 5 sectors / half
- 4 ladders / sector

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

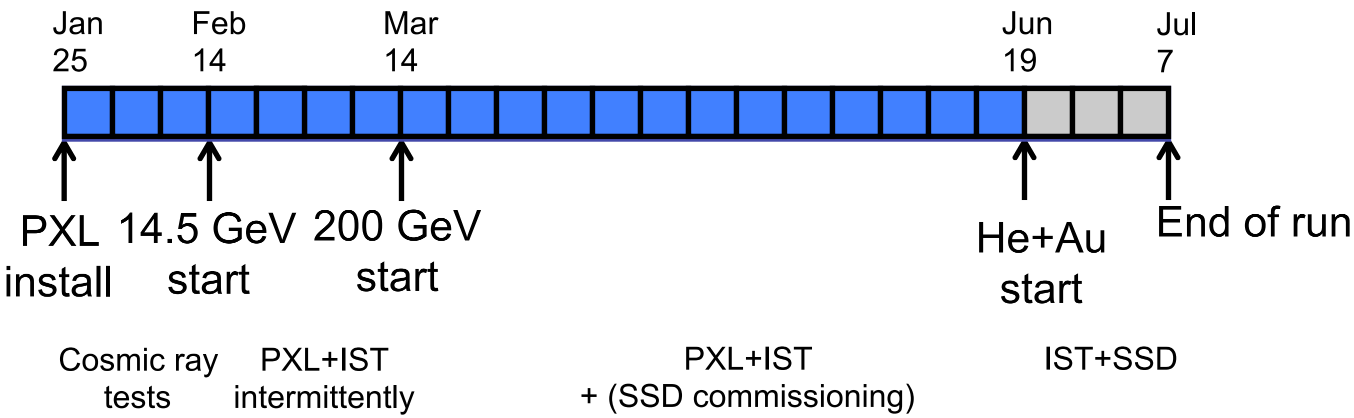


HFT Status and Performance



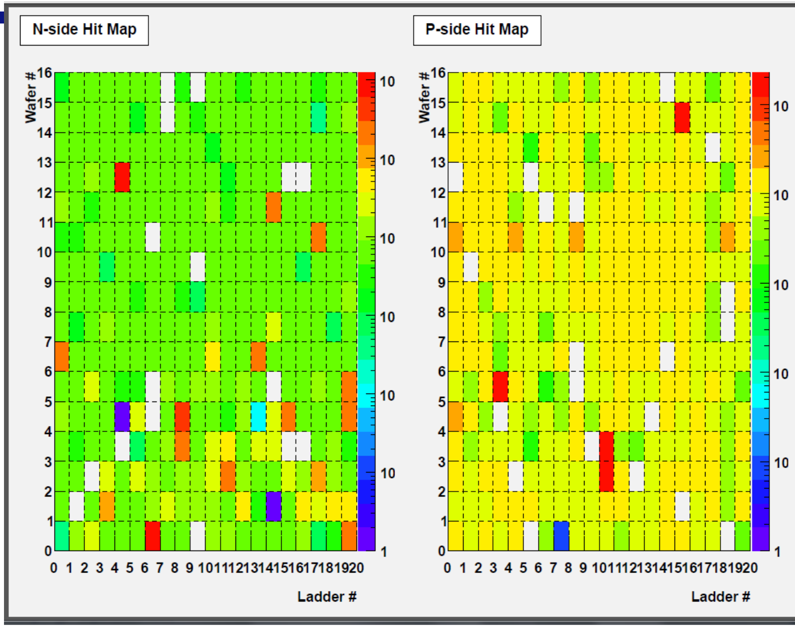
HFT in Run-14

- IST, SSD installed into STAR in the fall 2013
- PXL inserted into STAR at the end of January 2014
- Commissioning of HFT detectors in February and March including Cosmic Ray data taking (extended SSD commissioning)
- Physics data taking March - July
- Collected >1.2 Billion Au+Au @ 200 GeV events

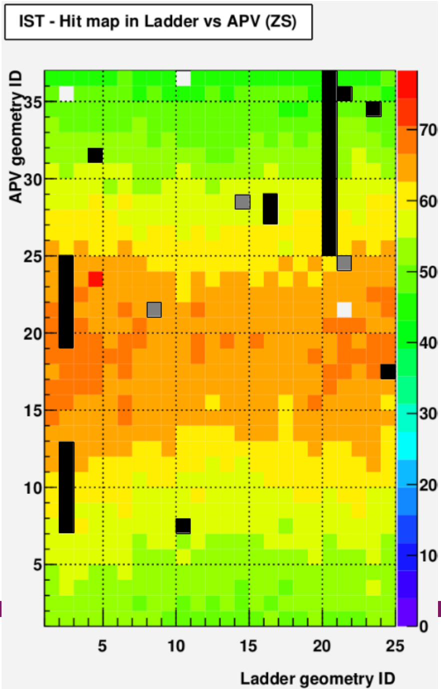


HFT Status – Run14

- SSD
  - The RDO runs at <20% dead-time at 1 kHz
    - The ultimate limit is due to old Si modules (circa 2000)
  - 6% dead wafers
  - 90 % of the strips are active in the remaining wafers
  - Collected 172 M Au+Au events and 57 M He3+Au events



- IST
  - 864 readout chips and 110592 channels total
  - More than 95% fully functional channels
  - Hit efficiency ~99%
  - S/N 15:1-30:1
  - Participated in data taking for Au+Au and He3+Au collisions



PXL damage in Run 2014

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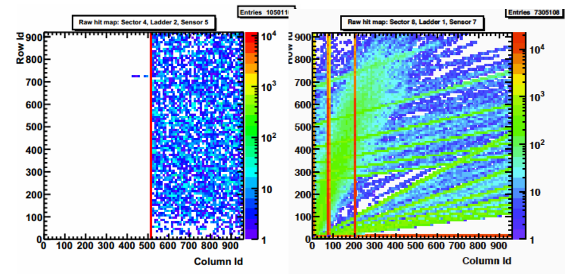
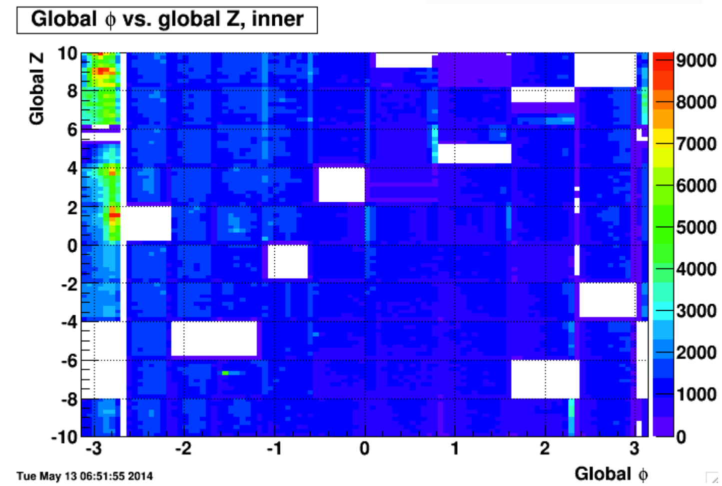
- Damage on multiple ladders in the first 2 weeks
  - Increased current in the digital power circuit
  - Sensor data corruptions
- Loss of detector efficiency
- Instability of the affected ladders
- Further damage stopped by tight over-current thresholds

  → latch-up as possible damage cause
- Post-run investigation: latch-up tests at the 88” Cyclotron @LBL
  - Measure latch-up cross-sections Vs over-current protection threshold
  - Reproduce damage seen during the run
  - Define a safe operation envelope for Runs 2015/2016:
    - over-current threshold ≤ 120mA above operating current

Examples of sensor data corruptions



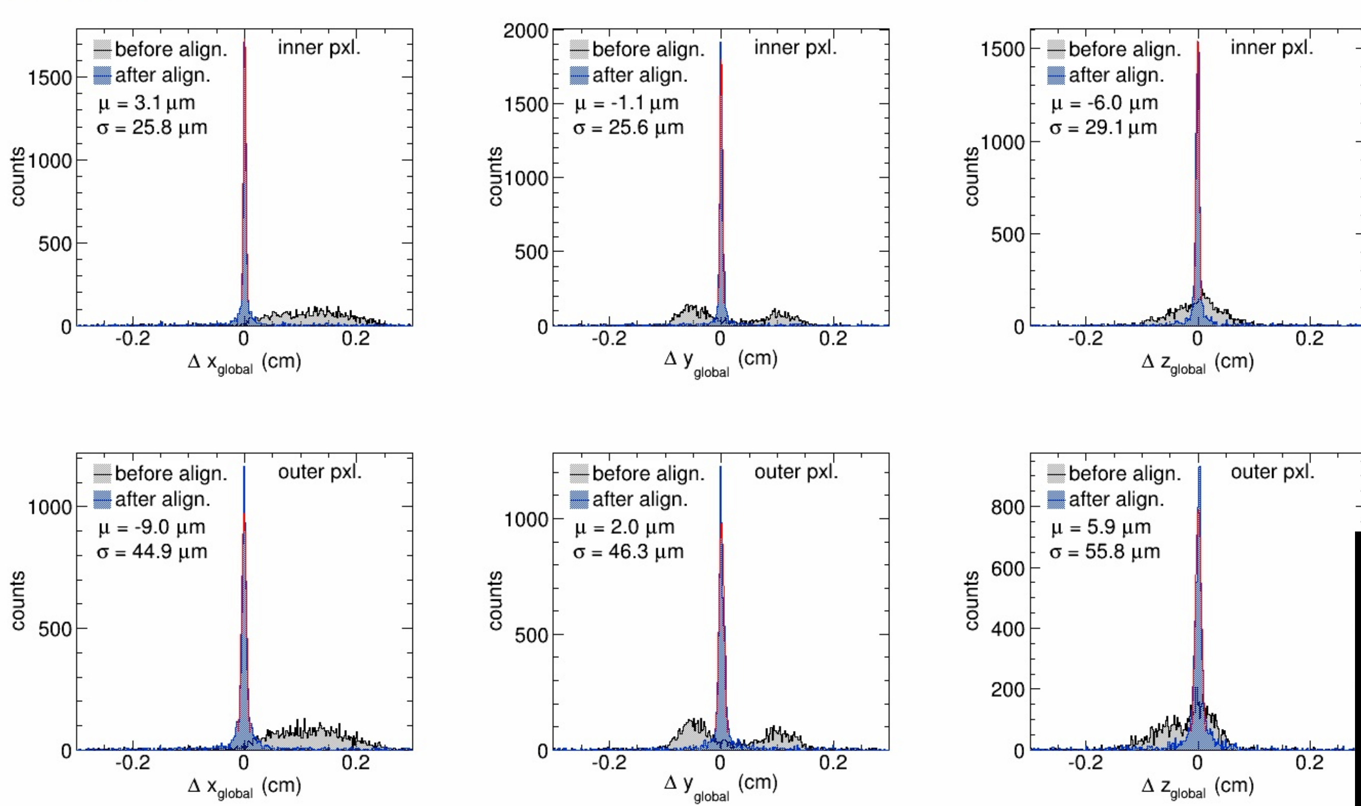


Inner Layer: 14% damage
(Outer layer: 1% damage)

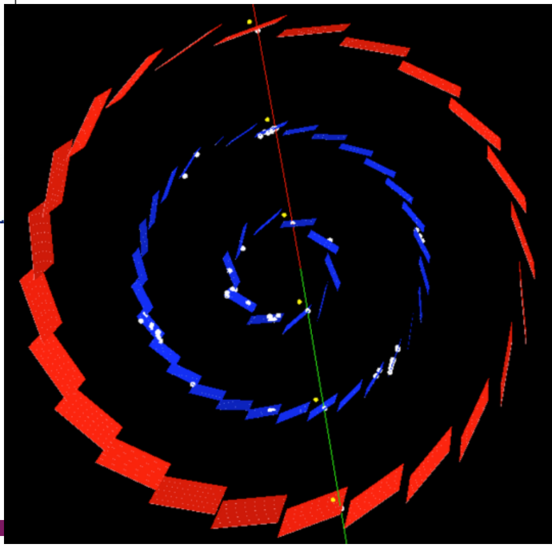
PXL Alignment

- PXL hit residual distributions before and after PXL alignment

(analysis by A. Schmah, LBL)



Cosmic ray event (PXL + IST), Magnet-OFF



- Consistent with expectations for alignment and momentum of muons
- σ ~ 25μm for inner layer and 50μm for outer layer

HFT Pointing Resolution Performance- Run 14

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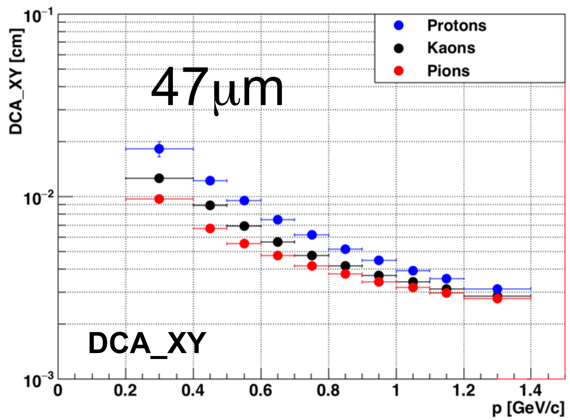
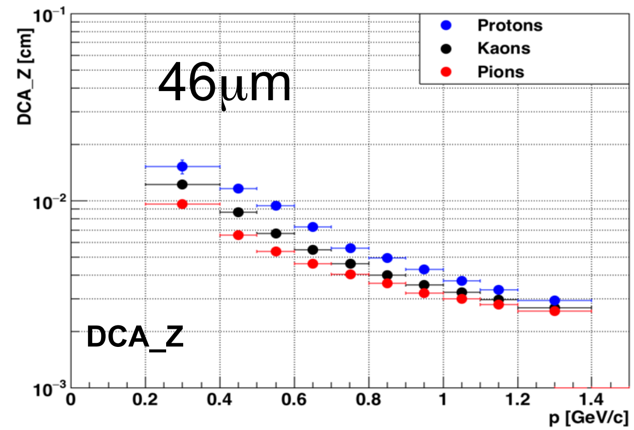
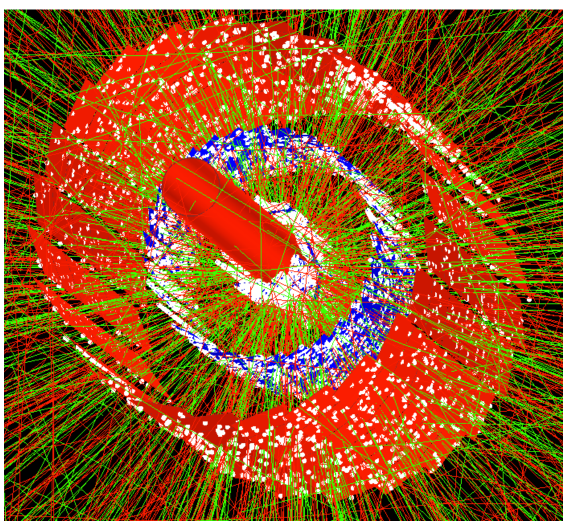
- DCA pointing resolution
  - Design requirement: 60μm for 750 MeV/c Kaons
  - 2 Al cables on inner layer
  - From 2015: all Al cables

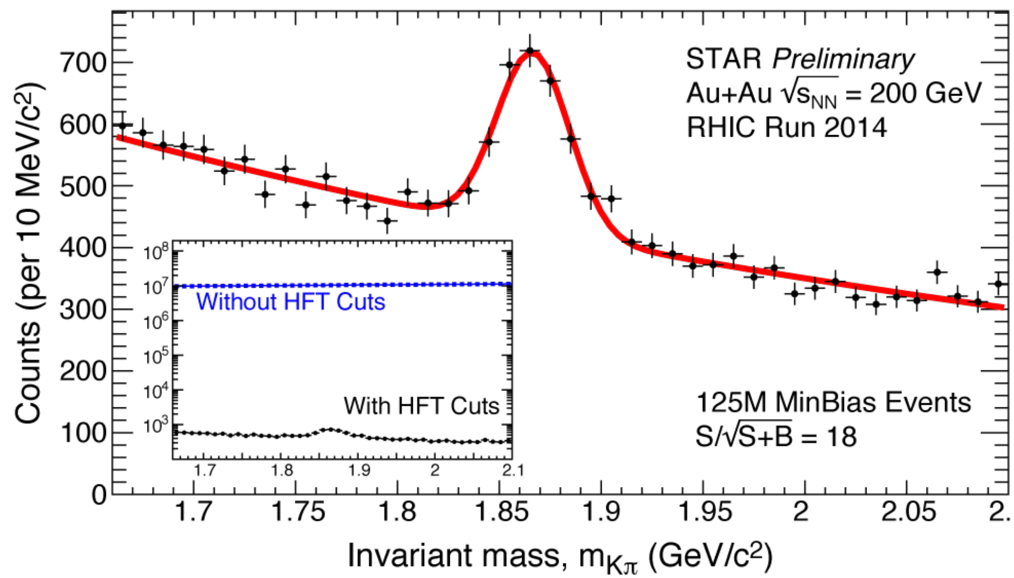




- D0 analysis in Run 14 data (ongoing)

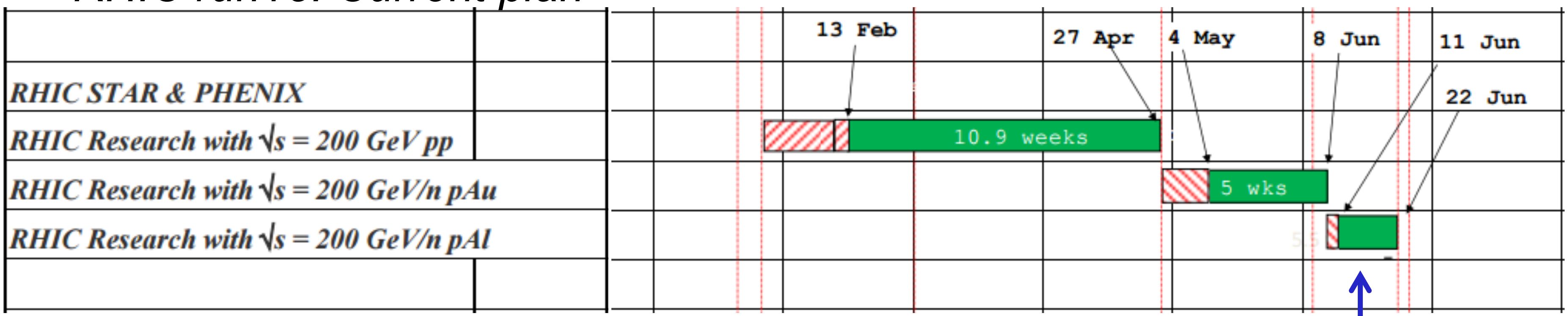


200 GeV Au+Au event



HFT in Run-15

RHIC run15: Current plan



Now

- Main goal is to collect p-p and p-A (reference) data
- Used the refurbished PXL Run14 detector
  - All aluminum cable ladders on Inner layer
  - Improved protection against latch-up damage
  - Only ~5% damage per layer in Run15

- **All HFT detectors operated well in Run15**

HFT dataset goals for run15

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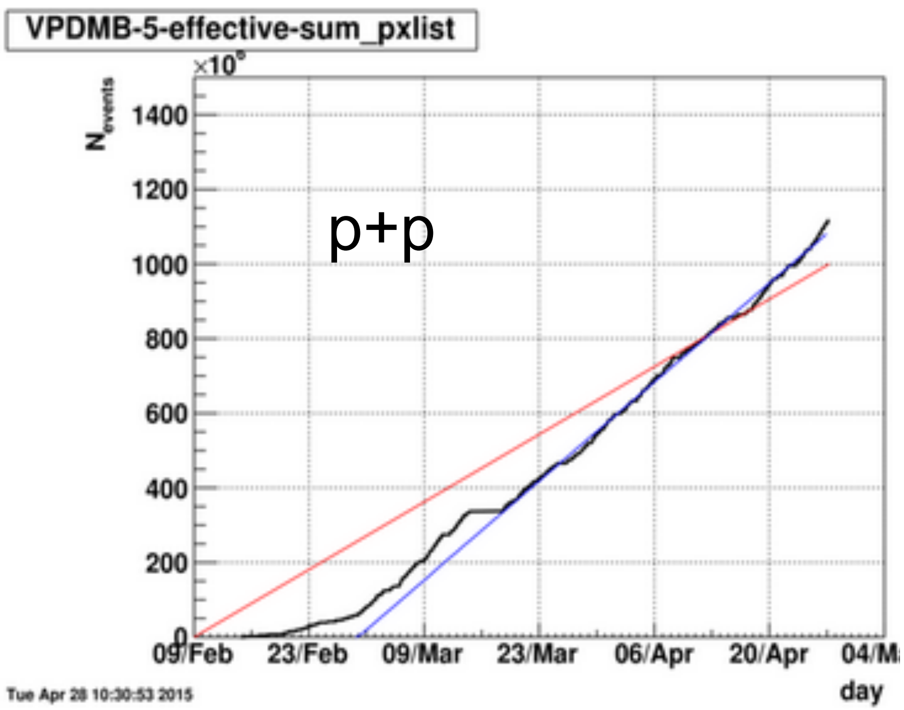
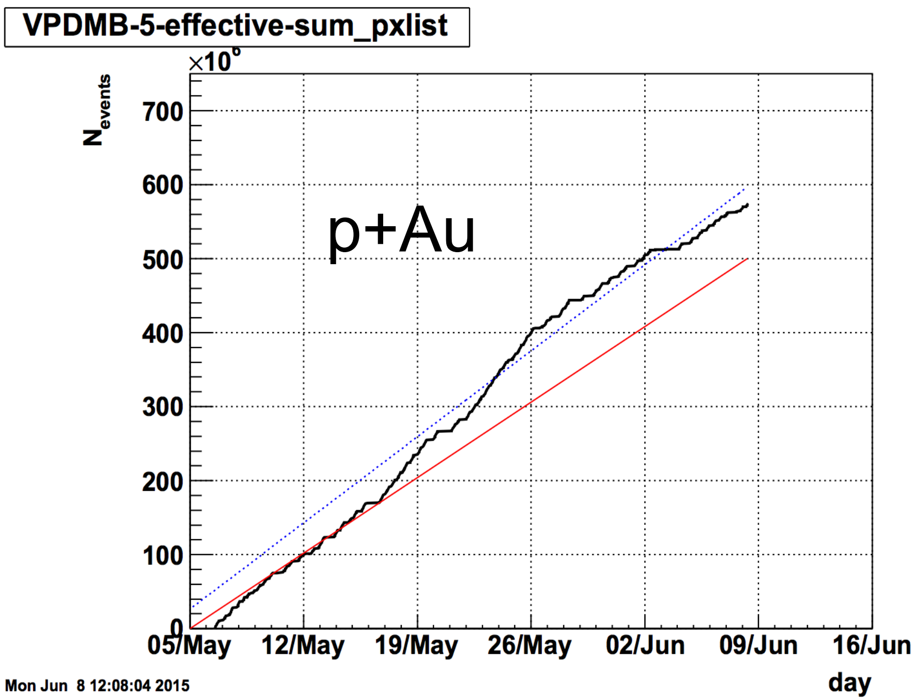
HFT minimum bias





HFT goals for Run 16

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- STAR/RHIC improvements vs. Run 14
  - PXL equipped with the Aluminum (Al) cable for inner ladders 0.52%→0.38% X_0
  - SSD at full speed → better track matching
  - Increased luminosity fraction within |Vz|<5cm
- Beam request for Run 16:
  - 13 weeks Au+Au 200 GeV run
  - 2 B minimum bias events

Physics goals:

- More differential studies on charmed hadron production
- Λ_c measurement
- Open bottom measurements through B->e and B->J/psi

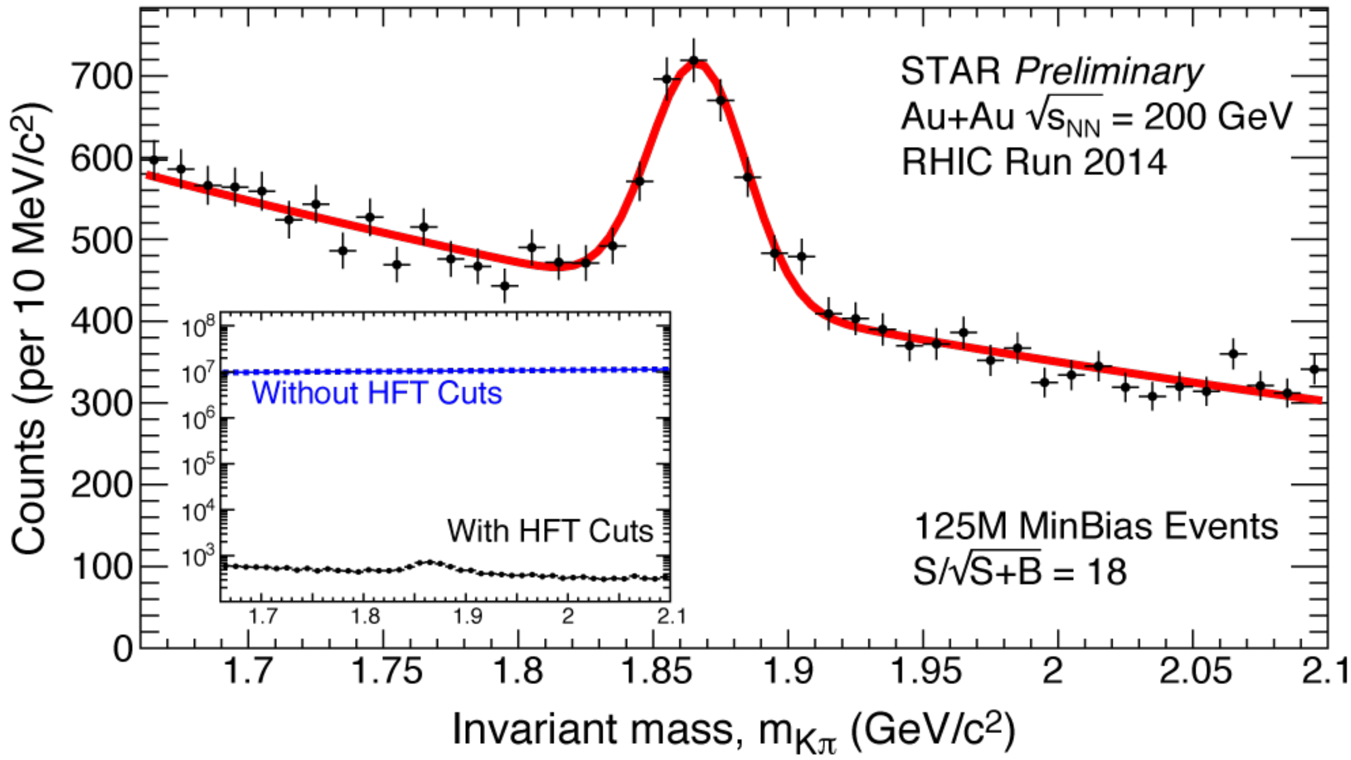
Summary and Outlook

STAR HFT

- STAR Heavy Flavor Tracker was first fully installed and commissioned for the 2014 Au+Au RHIC run. This data set is now in production for physics analysis.
- The (preliminary) DCA pointing resolution performance of the installed HFT detectors appears to be as expected and meets the design goals
- Observed radiation related damage in the PXL detector appears to be halted by using operational methods
- A spare detector (with Al conductor cable on the inner ladders) is complete and ready to be deployed as needed.
- **<u>MAPS is working well as a technology for vertex detectors</u>**
- The PXL detector is the first MAPS based vertex detector and as such leads the way for future vertex detectors based on MAPS technology (such as the ALICE ITS, etc.)

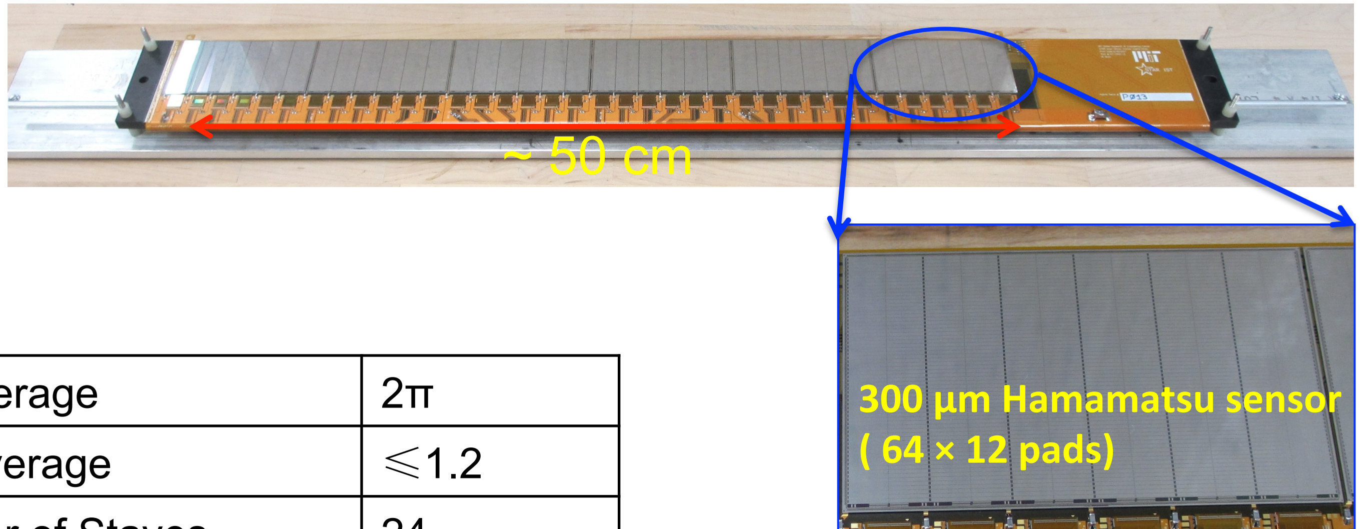
Thank you!

STAR HFT



Backup Slides

IST characteristics



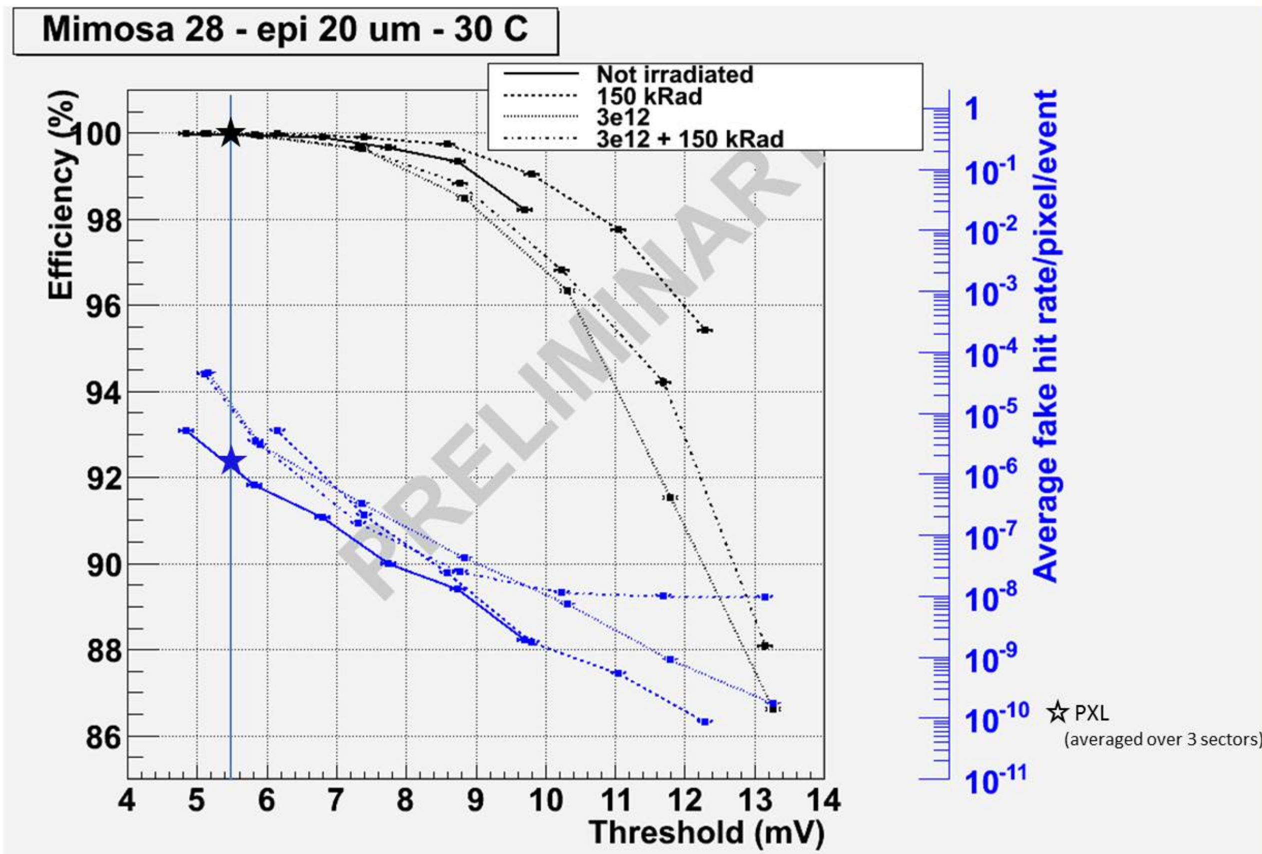
ϕ-Coverage	2π
|η|-Coverage	⩽1.2
Number of Staves	24
Number of hybrids	24
Number of sensors	144
Number of readout chips	864
Number of channels	110592
r-ϕ resolution	172 µm
Z resolution	1811 µm
R-ϕ pad size	594 µm
Z pad size	6275 µm

IST stave = Carbon fiber ladder
+ Kapton flex hybrid
+ Passive components
+ 6 silicon pad sensors
+ 3 x 12 APV25-S1 readout chips
+ Aluminum cooling tube
+ Liquid coolant (3M Novec 7200)

IST staves were assembled/tested/surveyed at UIC/FNAL and MIT/BNL sites (18 staves produced at each site).

PXL sensor threshold operation point

- The noise level was set at ~2 x 10^{-6} for the cosmic ray run. At this noise rate, the measured operating point (taken from beam tests) is shown above.



Threshold = $Th_{1.5*10E\text{-}6\ fake\ hit\ rate}$ – Offset $_{from\ labThScan}$

σ_{noise} = 1.33 mV

Threshold = 5.48 mV = 4.12 σ_{noise}

Engineering run 2013

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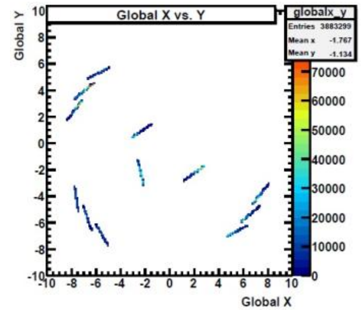
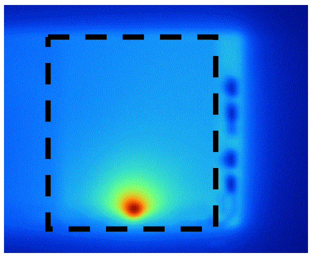
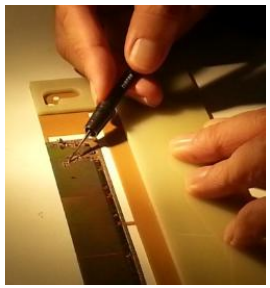
- PXL Engineering Run assembly crucial to deal with a number of unexpected issues



Engineering run geometry



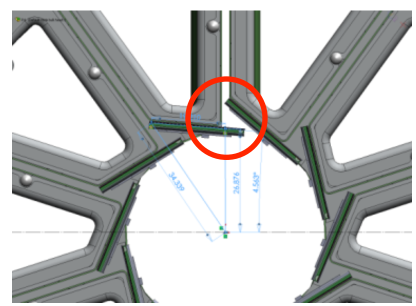
Sensor IR picture



Flawed ladder dissection: searching for shorts

- Shorts between power and gnd, or LVDS outputs
- Adhesive layer extended in both dimensions to increase the portion coming out from underneath the sensors
- Insulating solder mask added to low mass cables

- Mechanical interference in the driver boards on the existing design.
- The sector tube and inner ladder driver board have been redesigned to give a reasonable clearance fit
- Inner layer design modification: ~ 2.8 cm inner radius



Inner layer design

- After the engineering run added functionality to the MTB:
  - remote setting of LU threshold and ladder power supply voltage + current and voltage monitoring

PXL hit efficiency

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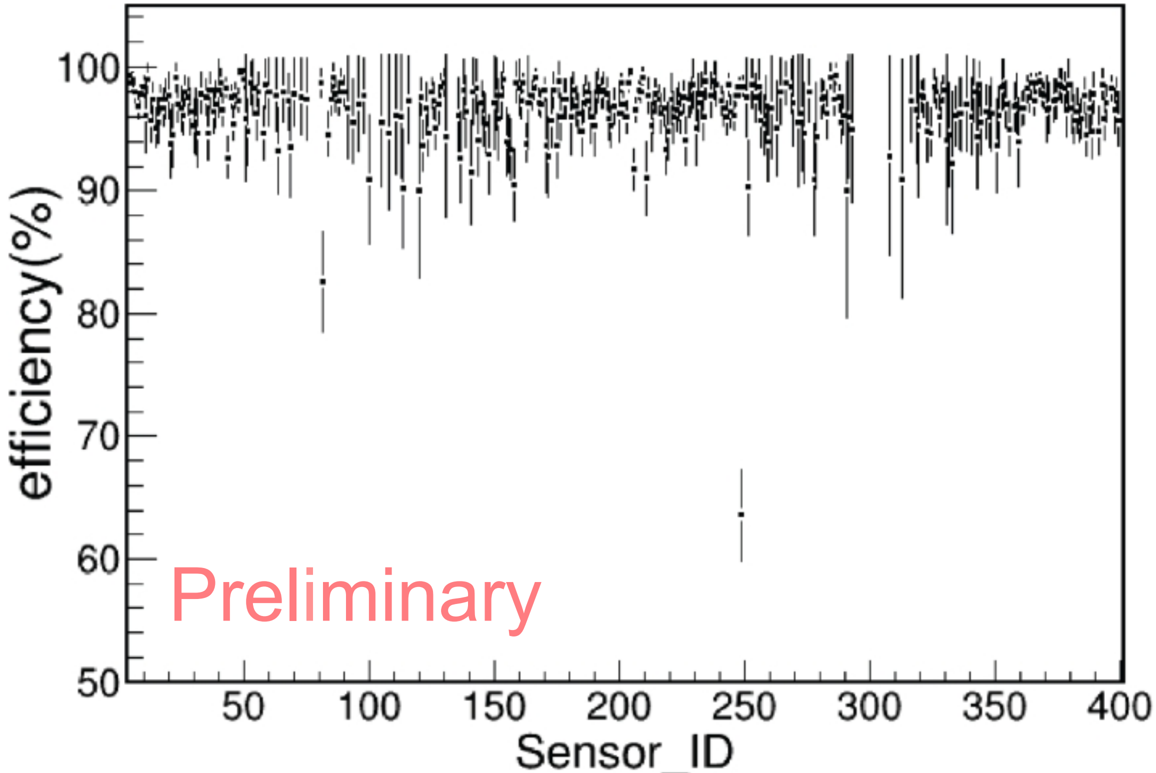
preliminary results based on the cosmic ray data

Note: this data was taken before the final detector optimizations



PXL sensor efficiency measured with cosmic ray

Average = 97.2 %

PXL insertion

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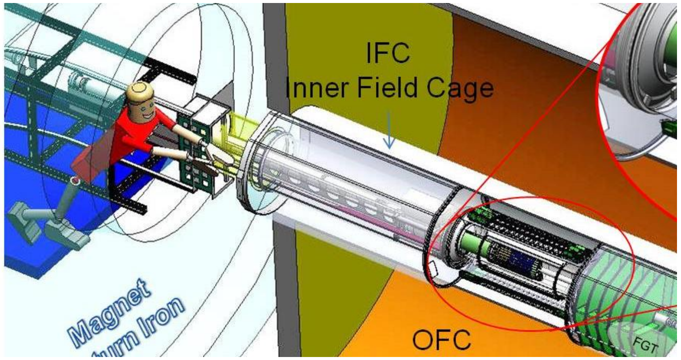
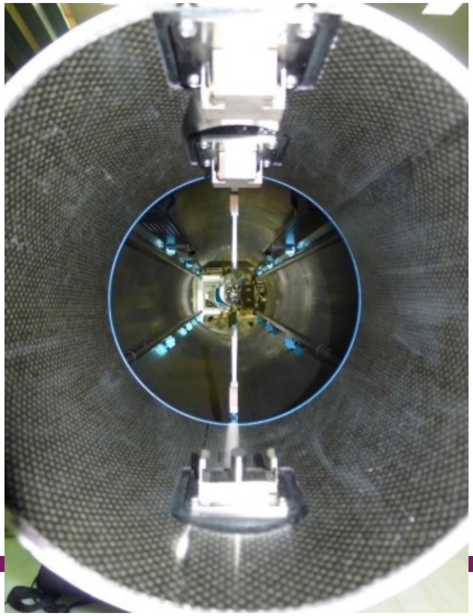
Yes – we push it in by hand



Unique mechanical design:

- detector is inserted along rails and locks into a kinematic mount on the insertion end of the detector
- Allows for rapid (1 day) replacement with a characterized spare detector

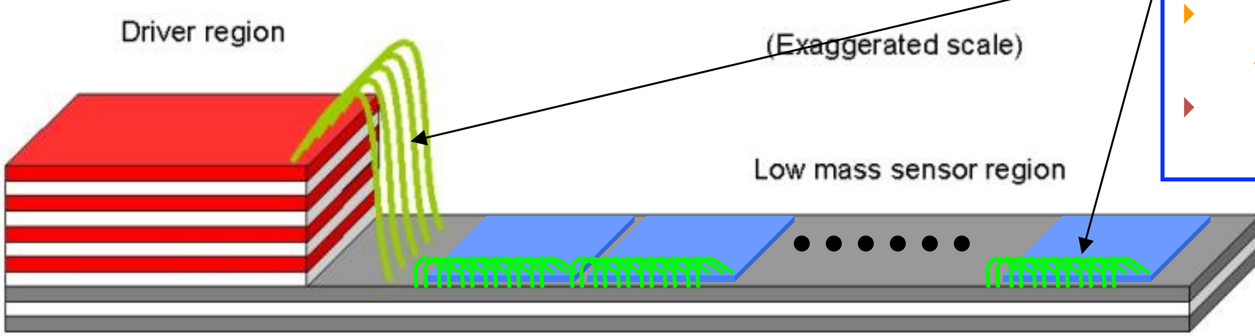
Kinematic mounts

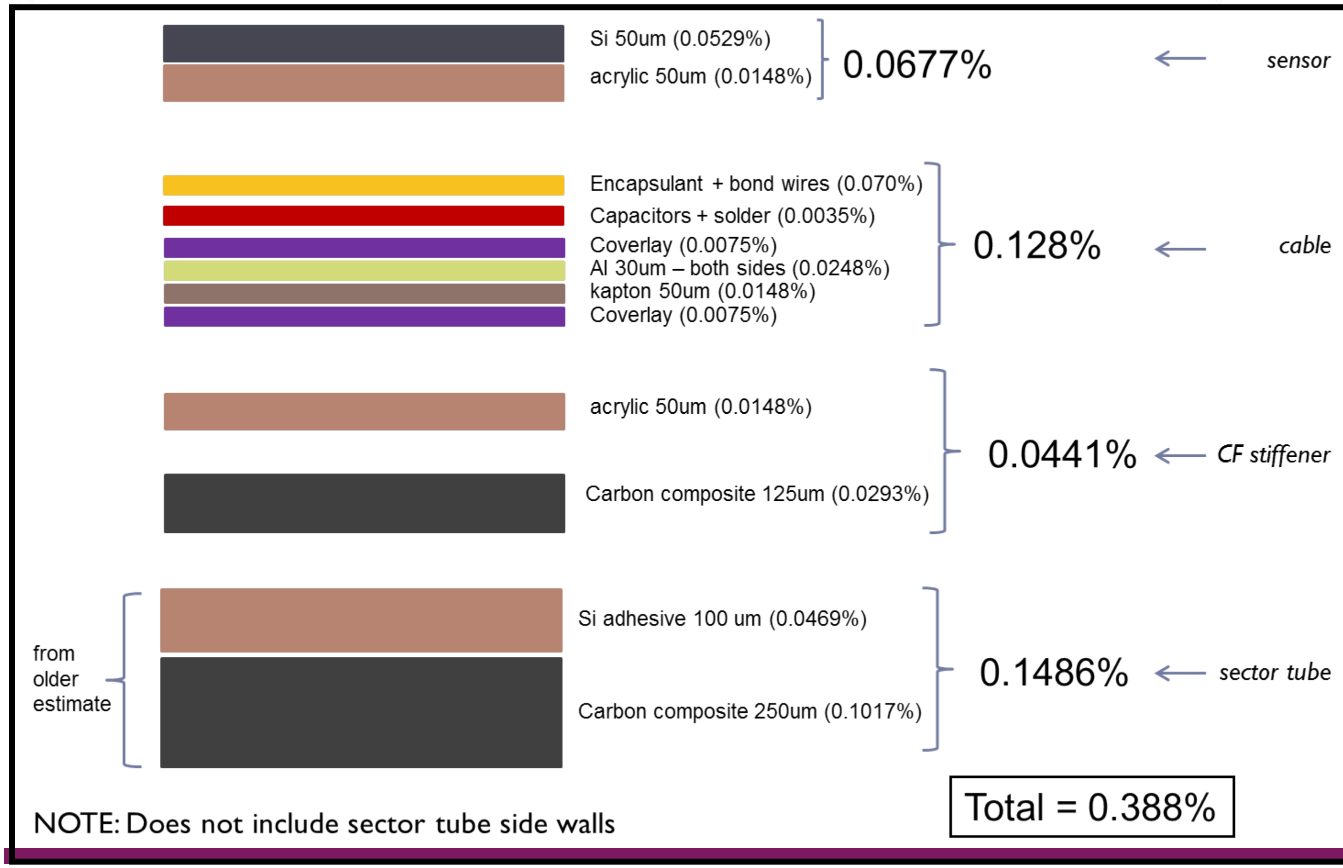


Insertion of PXL detector

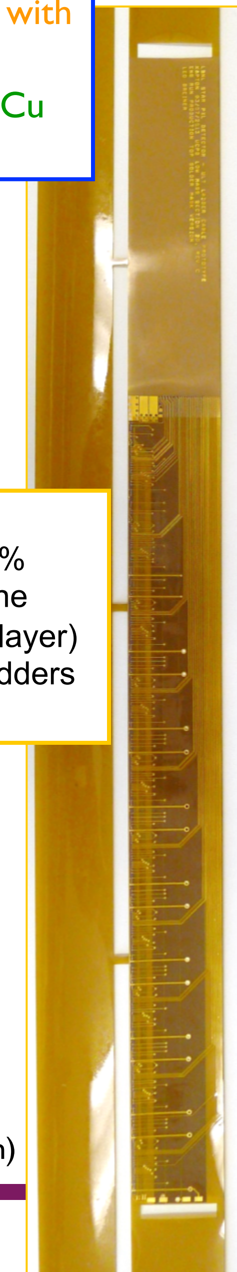
PXL ladder

- Classic wire bonding
- Difficulties and delays with Al cable production
- Backup solution with Cu cables





Cu conductor:
$X/X_0 \uparrow$ to 0.129% (corrected for the thinner copper layer)
$\Rightarrow$ Cu based ladders $X/X_0 = 0.492\%$



Flex cable
(Copper version)