The STAR Heavy Flavor Tracker (HFT) and Upgrade Plan

Quark Matter 2015 – Kobe, Japan

Session*: Future Experimental Facilities, Upgrades, and Instrumentation*

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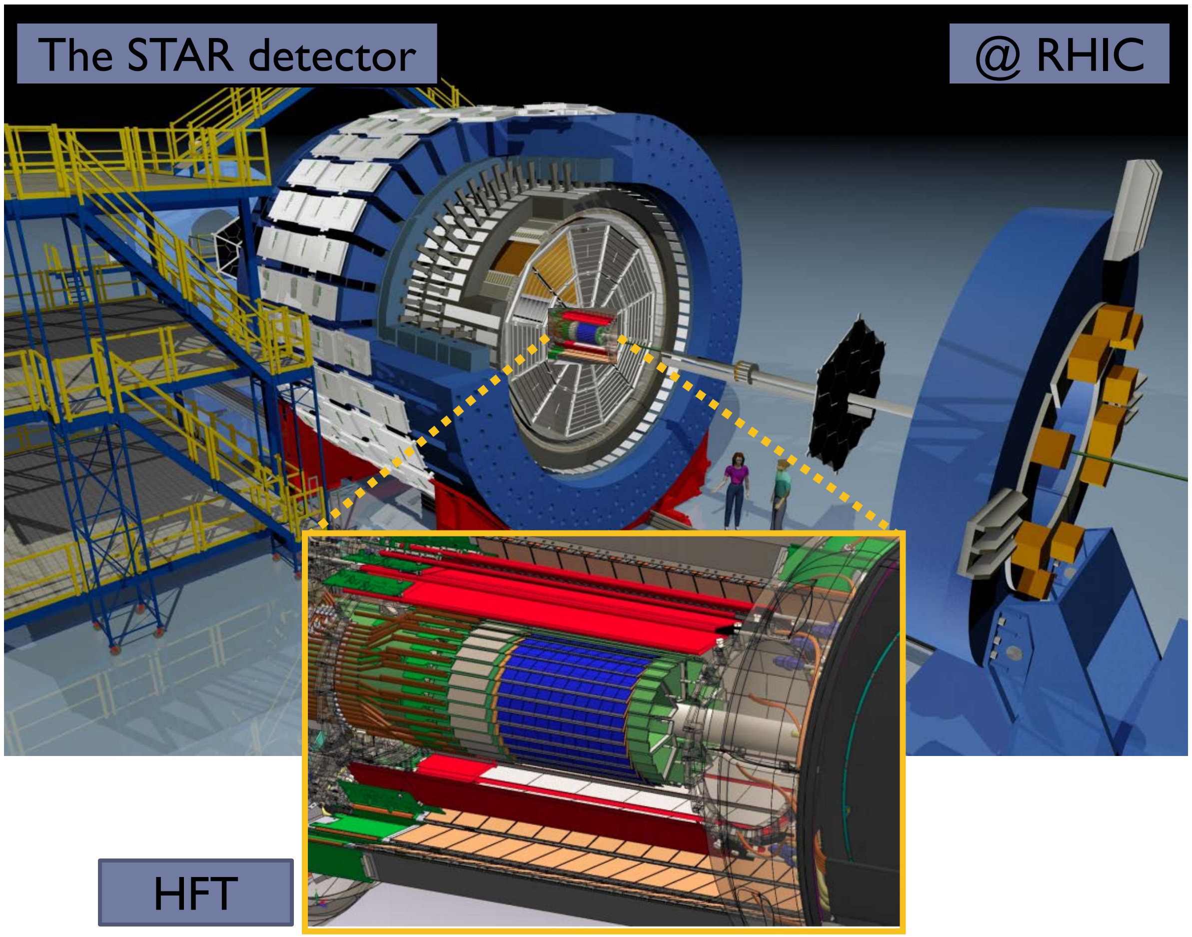
Outline

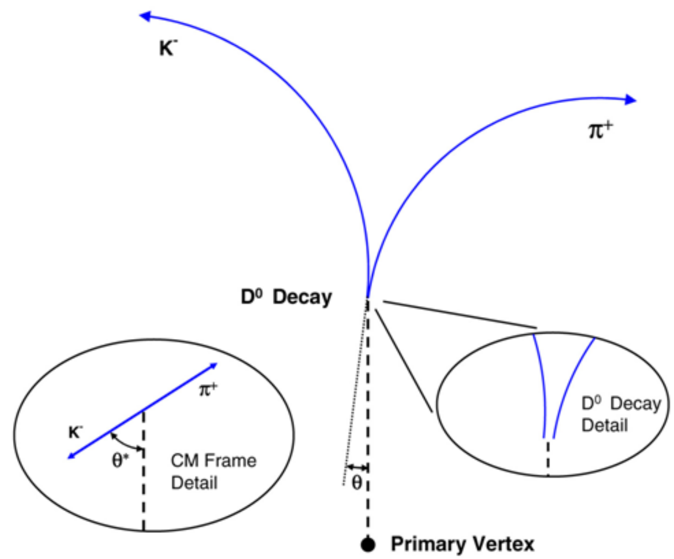
- Physics motivations
- The MAPS-based PXL detector
- HFT status and performance
- Future "HFT+" Upgrade plan
- Conclusions

STAR HFT Physics Motivation

Extend the measurement capabilities in the *heavy flavor* domain, good probe to QGP:

- Direct topological reconstruction of charm hadrons (small cτ decays, e.g. $D^0 \rightarrow K\ \pi$)



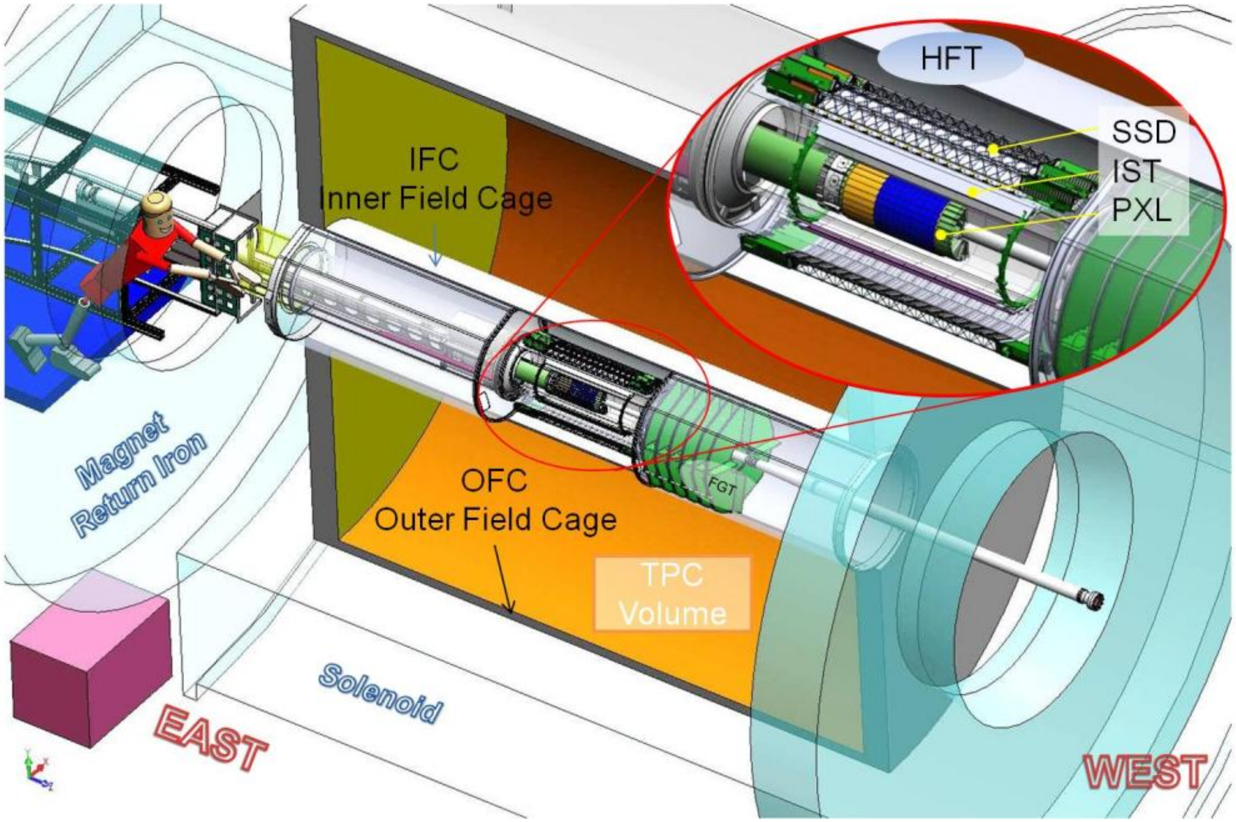


Method: Resolve displaced vertices (~120 μm)

200 GeV Au+Au collisions @ RHIC

- $dN_{ch}/d\eta$ ~ 700 in central events

STAR Heavy Flavor Tracker (HFT)



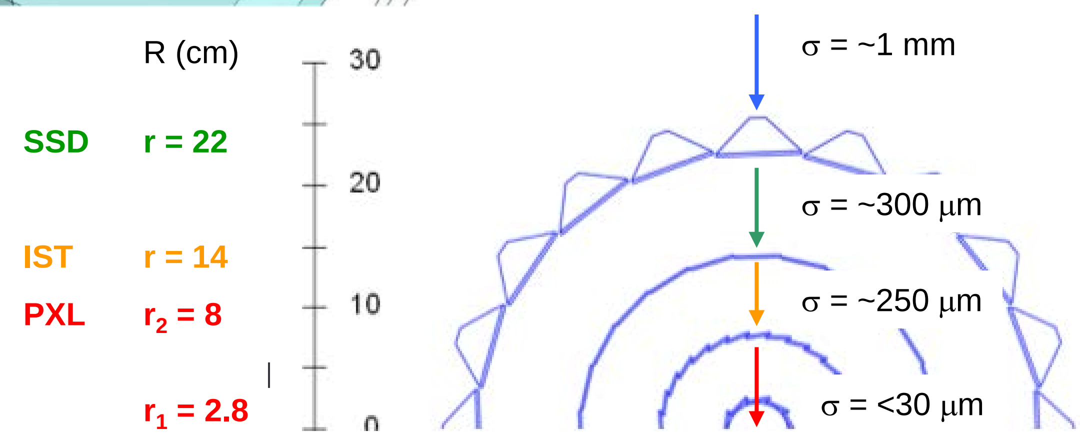
TPC – Time Projection Chamber (main tracking detector in STAR)

HFT – Heavy Flavor Tracker

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

Tracking inwards with gradually improved resolution:

Acceptance coverage:
$-1 < \eta < 1$
$0 < \phi < 2\pi$



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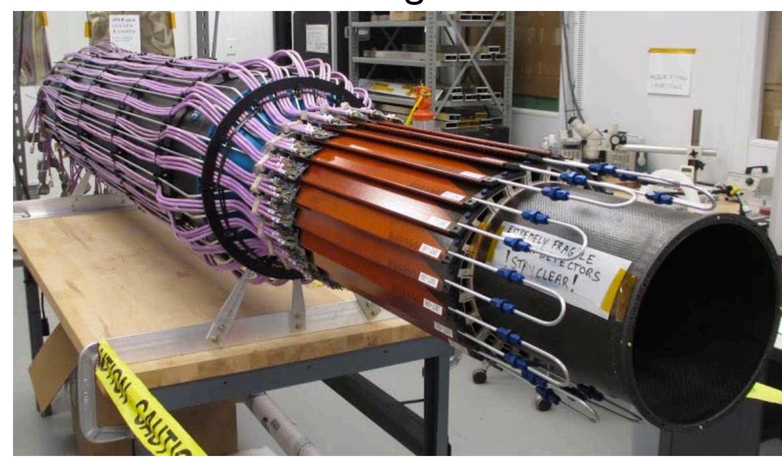
HFT Subsystems

Silicon Strip Detector (SSD)

- Double sided silicon strip modules with 95 µm pitch
- Existing detector with new faster electronics
- Radius: 22 cm – Length: ~106 cm

Intermediate Silicon Tracker (IST)

- Single sided double-metal silicon pad with 600 µm x 6 mm pitch
- Radius: 14 cm – Length: ~50 cm



PiXeL detector (PXL)

- *Monolithic Active Pixel Sensor* technology
- 20.7 µm pitch pixels
- Radius: 2.8 and 8 cm – Length: ~20 cm

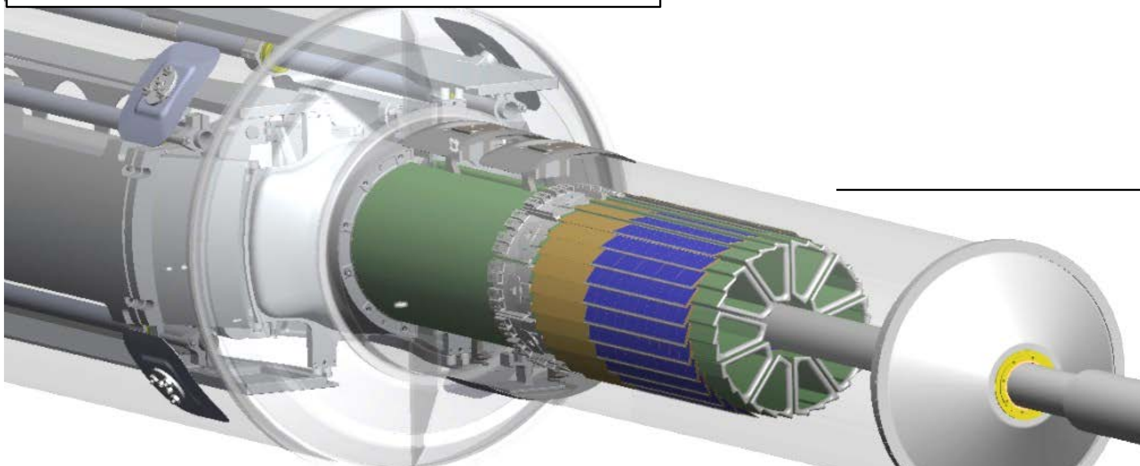
First MAPS-based vertex detector at a collider experiment

PXL System Overview

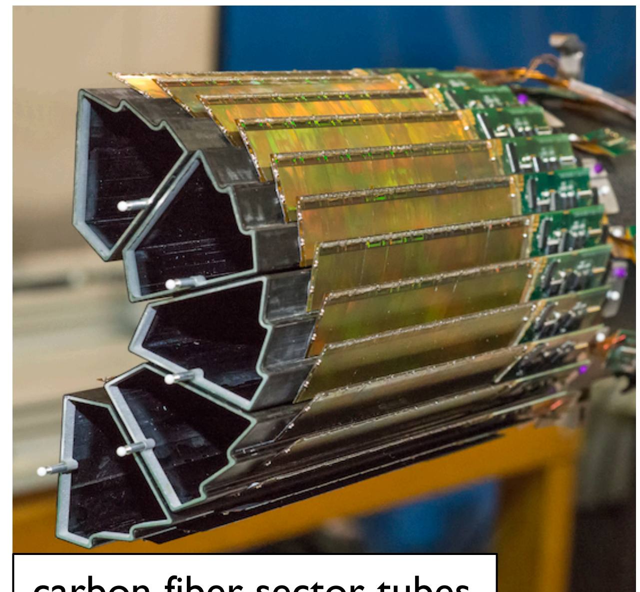
10 sectors total
5 sectors / half
4 ladders / sector
10 sensors / ladder

Highly parallel system

Mechanical support with kinematic mounts (insertion side)



Cantilevered support



carbon fiber sector tubes (~ 200 μm thick)

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

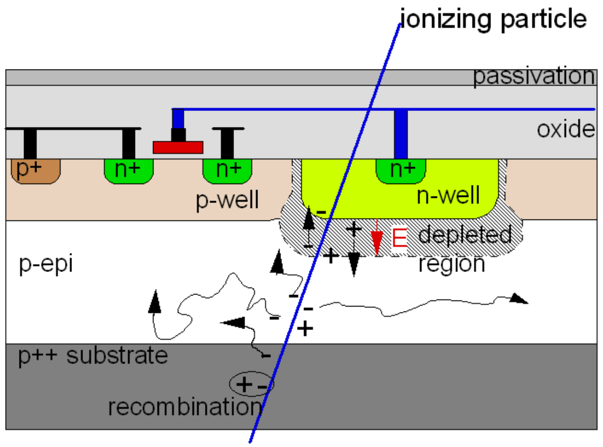
PXL Sensor

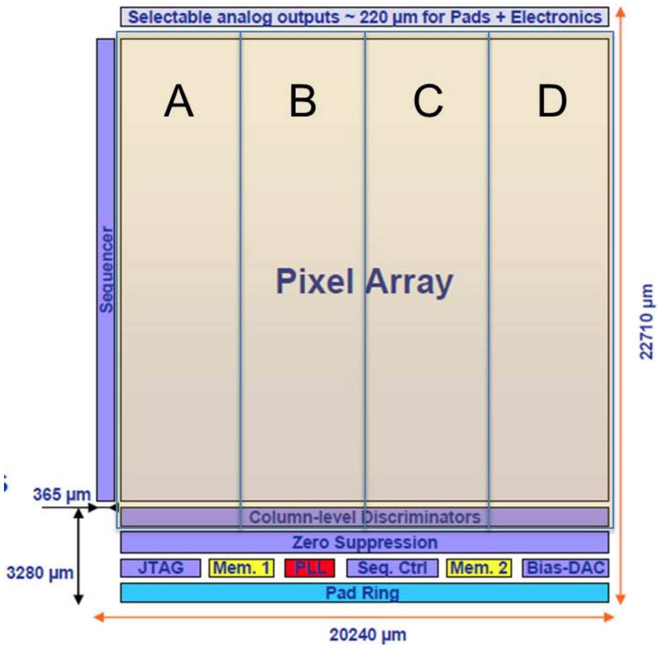
Monolithic Active Pixel Sensor technology

Ultimate-2: third generation sensor developed for the PXL detector by the PICSEL group of IPHC, Strasbourg

- High resistivity p-epi layer
  - Reduced charge collection time
  - Improved radiation hardness
    - 20 to 90 kRad / year - 2×10^{11} to 10^{12} 1MeV n eq/cm^2
- S/N ~ 30
- MIP Signal ~ 1000 e^-

- 928 rows * 960 columns = ~1M pixel
- Rolling-shutter readout
  - connects row by row to end-of-column discriminators
  - 185.6 μs integration time
  - ~170 mW/cm^2 power dissipation
- Configurable via JTAG
- 2 LVDS data outputs @ 160 MHz





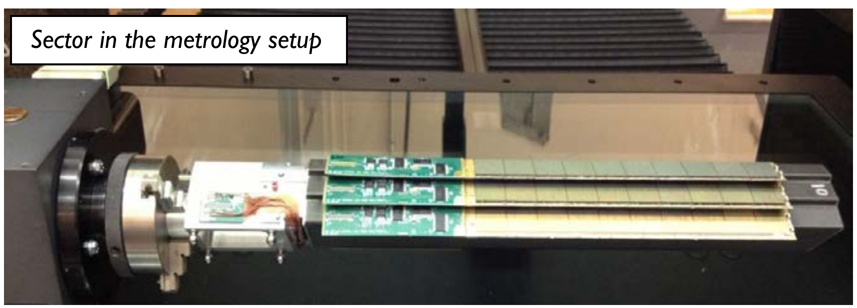
PXL Hit Position Resolution

- *Ultimate-2* sensor geometry
  - pixel size: 20.7 μm X 20.7 μm — ~6 μm geometrical resolution
  - 3-pixel av. cluster size — ~3.7 μm resolution on center-of-mass
- Position stability
  - Vibration at air cooling full flow: — ~5 μm RMS
  - *Stable displacement at full air flow:* — *~30 μm*
  - *Stable displacement at power on:* — *~5 μm*
- **Global hit resolution: $\Delta x \sim 6.2$ μm**

$\Delta x \sim 6.2$ μm
$r_1 = 2.8$ cm
$r_2 = 8$ cm

$$\Delta v = \Delta x \bullet \sqrt{\frac{r_2^2 + r_1^2}{(r_2 - r_1)^2}}$$

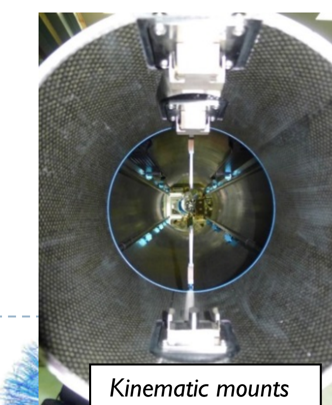
HFT DCA pointing resolution:
$(10 \oplus 24/p)$ μm


Sector in the metrology setup

- Metrology survey
  - 3D pixel positions fully mapped and related to kinematic mounts

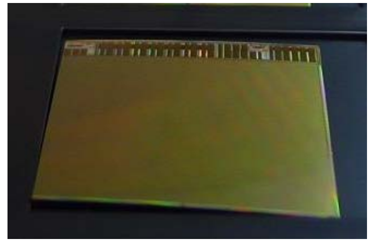
- Novel insertion approach
  - Inserted along rails and locked into a kinematic mount inside the support structure
  - Capability to fully replace PXL within 12 hour


PXL insertion


Kinematic mounts

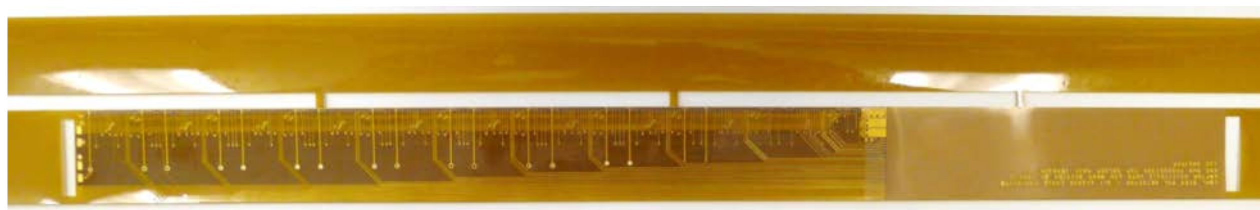
PXL Material Budget

- Thinned Sensor
  - 50 µm
  - 0.068% X_0

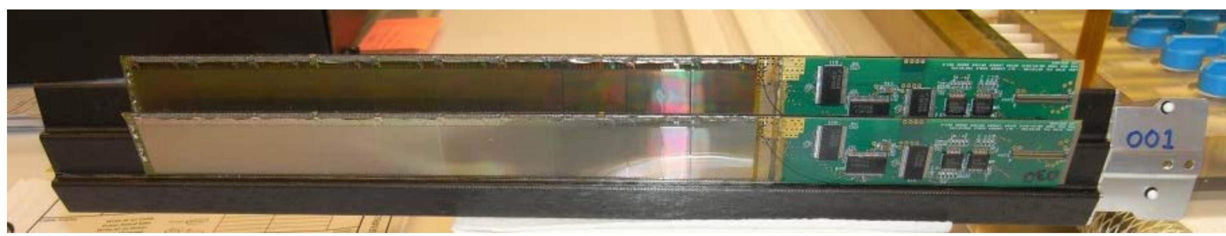


- Curved sensor
- 40-60% yield after thinning, dicing and probe testing

- Flex Cable
  - Aluminum-Kapton
  - two 32 µm-thick Al layers
  - 0.128% X_0
    - *Copper* version → 0.232% X_0



- Carbon fiber supports
  - 125 µm stiffener
  - 250 µm sector tube
  - 0.193% X_0



- Cooling
  - Air cooling: negligible contribution

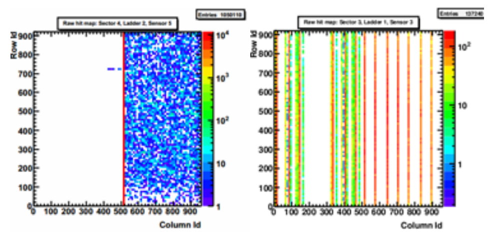
- **Total material budget on inner layer: 0.388% X_0**

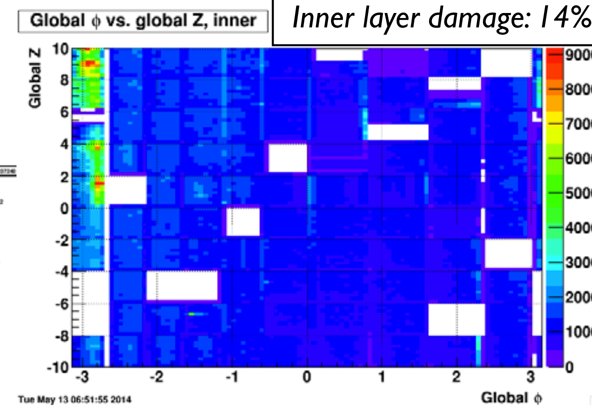
(0.492% X_0 for the Cu conductor version)

HFT DCA pointing resolution:
(10 ⊕ 24/p) µm

Lessons learned: Latch-up damage on PXL

- Unexpected damage seen on 15 ladders in the STAR radiation environment in 2014 Run first 2 weeks
  - Digital power current increase
  - Sensor data corruption
  - Hotspots in sensor digital section
  - Related to latch-up events





Inner layer damage: 14%

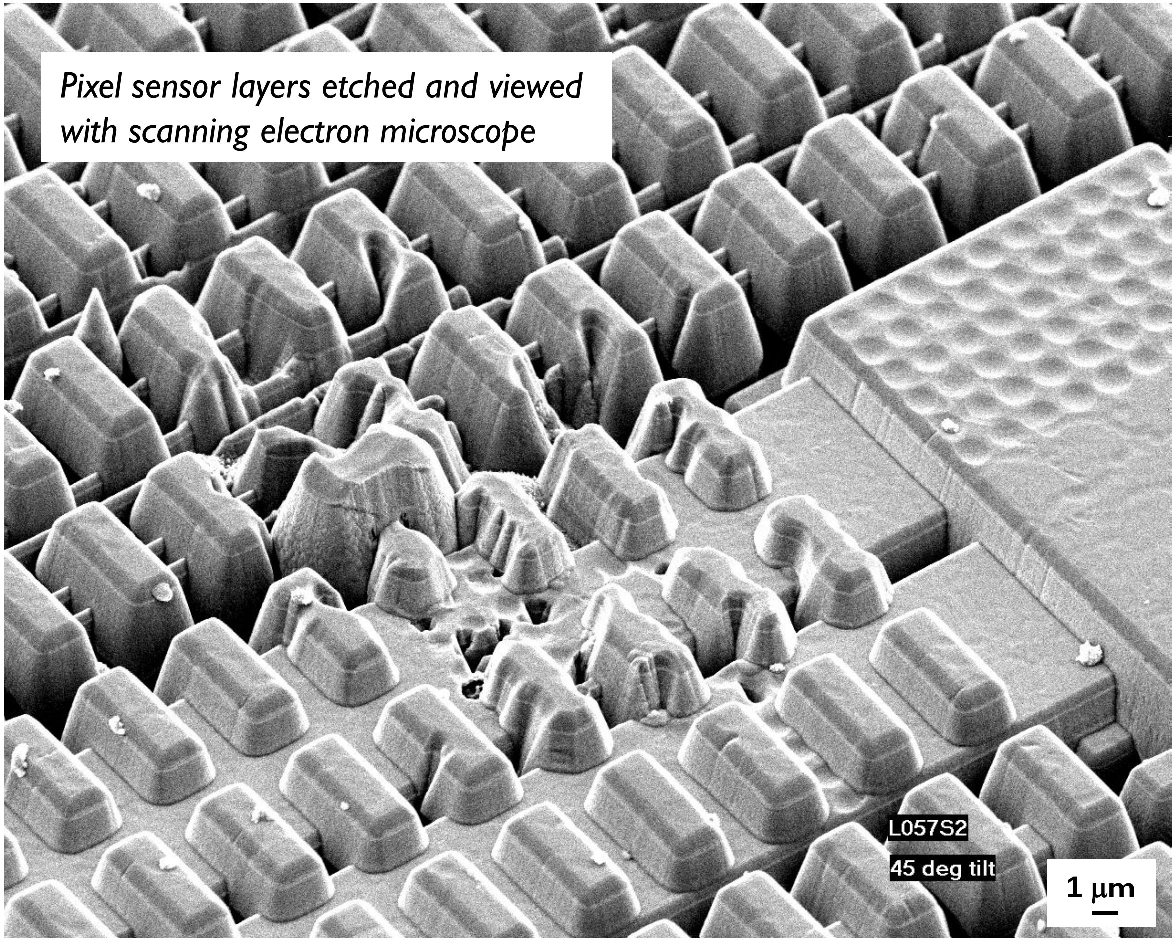
- Latch-up tests at *BASE facility* (LBL) to measure latch-up cross-section and reproduce damage
  - 50 μm & 700 μm thick, low and high resistivity sensors; PXL ladders
  - Irradiation with heavy-ions and protons
- Results and observations
  - Current limited latch-up states observed (typically ~300 mA)
  - Damage reproduced only with HI on PXL 50 μm thinned sensors
- Safe operations envelope implemented
  - Latch-up protection at 80 mA above operating current
  - Periodic detector reset

Latch-up phenomenon:

- Self feeding short circuit caused by single event upset
- Can only be stopped by removing the power

Latch-up damage: Sensor Deconstruction

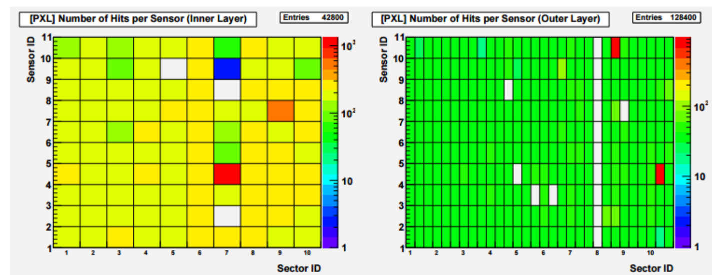
- Deconstructing damaged sensor through a plasma etching technique
- The metal layer appears to be melted



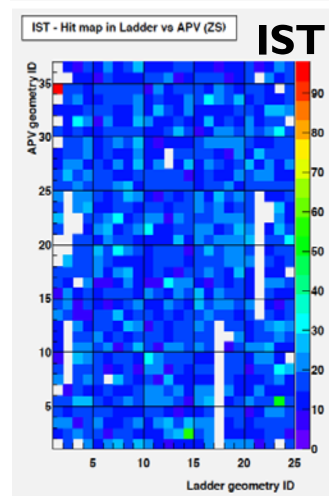
HFT Status in 2014 and 2015 Run

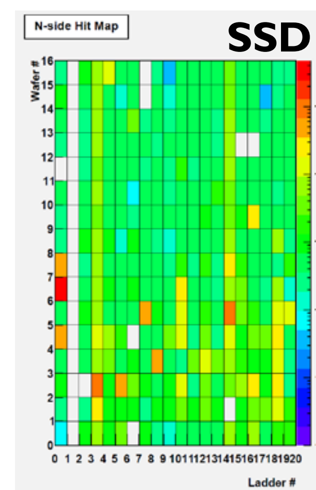
- Collected minimum bias events in HFT acceptance:
  - 2014 Run — 1.2 Billion Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV
  - 2015 Run: → { ~ 1 Billion p+p; ~ 0.6 Billion p+Au } @ $\sqrt{s_{NN}}$ = 200 GeV
- Typical trigger rate of ~0.8kHz with dead time <5%
- Sub-detector active fraction
  - PXL
    - > 99% operational at the delivery
    - 2015 Run ended with 5% dead sensors (6 damaged sensors + 1 outer ladder off)
  - IST
    - 95% channels operational, stable
  - SSD
    - 80% channels operational (one ladder off)

PXL1



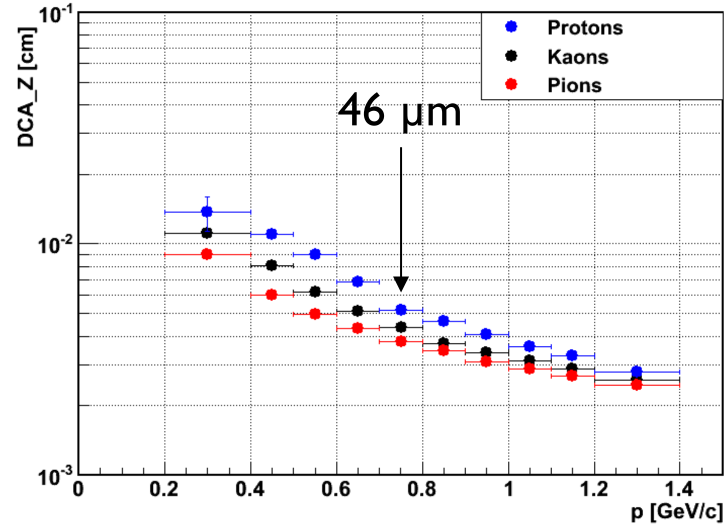
PXL2



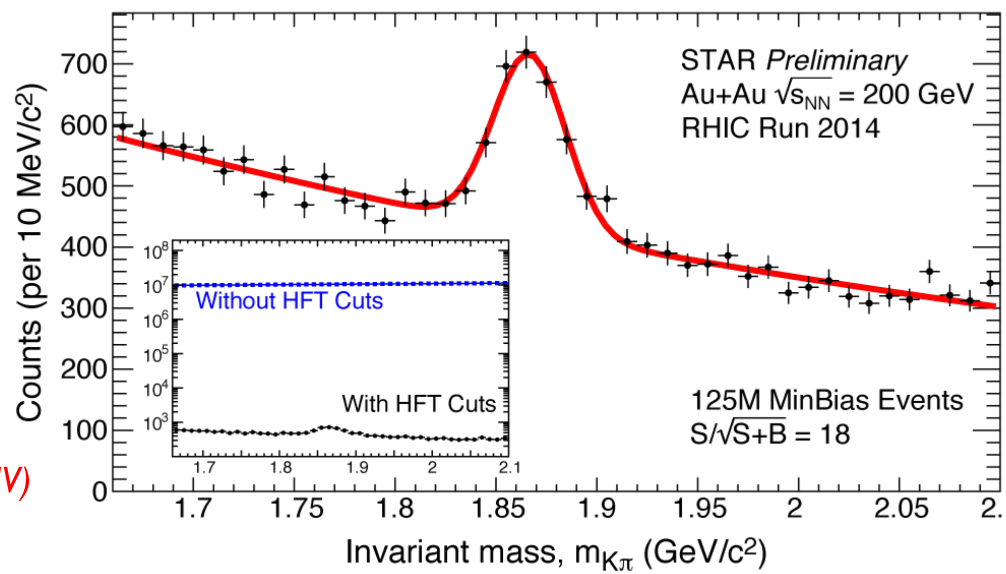


HFT Performance in 2014 Run

- DCA pointing resolution
  - Design requirement exceeded: 46 μm for 750 MeV/c Kaons for the **2 sectors** equipped **with aluminum cables on inner layer**
  - ~ 30 μm for p > 1 GeV/c
    - From 2015: all sectors equipped with aluminum cables on the inner layer



***$D^0 \to K\pi$ production** in*
*$\sqrt{s_{NN}}$ **=** 200 GeV Au+Au collisions*
(partial event sample)

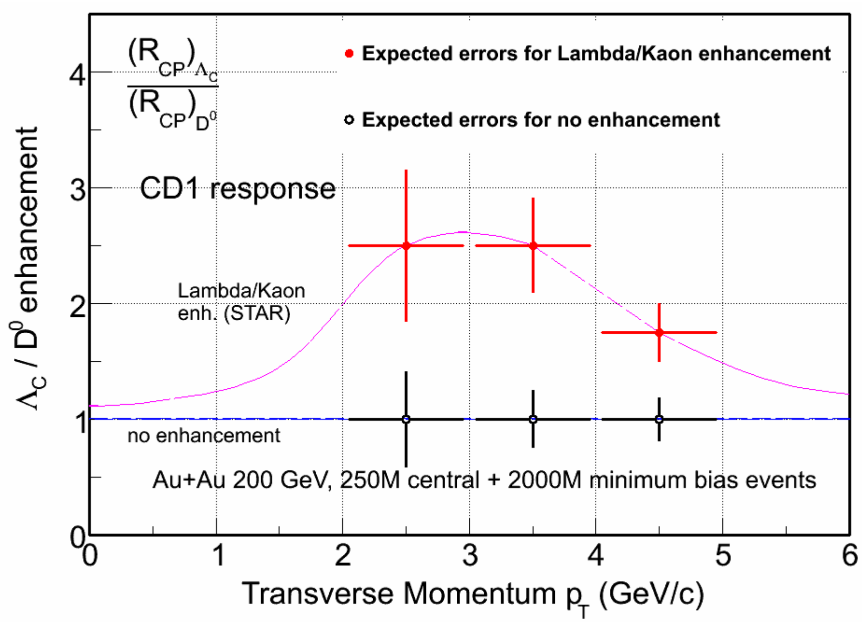


- Physics of D-meson productions
  - See QM15 contributions by:
    - G. Xie (*Sept. 28th - Open HF and Strangeness II)*
    - M. Lomnitz (*Sept. 29th - Collective Dynamics I)*
    - Md. Nasim *(Sept. 29th - Open HF and Strangeness IV)*

HFT goals for Au+Au data-taking in 2016

- STAR/RHIC improvements with respect to 2014 Run
  - PXL equipped with all aluminum cables on inner ladders 0.49%→0.38% X_0
  - SSD at full speed → better track matching / ghosting rate reduction
  - Increased luminosity fraction within $|V_z|<5$ cm
- RHIC beam for 2016 Run:
  - ~10 weeks Au+Au 200 GeV run
  - 2 B minimum bias events
  - Physics goals:
    - Λ_c and B→J/ψ measurements
    - More differential studies on charmed hadron production

Statistical error estimations on the Λ_c/D_0 enhancement factor measurement



Future HFT+ Upgrade plan (2021-2022)

HFT+ upgrade motivation:

- Measure **bottom quark hadrons** at the RHIC energy
- Take data in **higher luminosity** with high efficiency

HFT+ detector requirements:

- **Faster** frame readout of 40 μs or less
- **Similar or better** pointing resolution, S/N ratio, total power consumption, radiation length

→ **ALICE ITS Upgrade** MAPS sensor

- P. Riedler *(Sept. 29th - Future Upgrades)*

- **Compatible** with the existing insertion mechanism, support structure, air cooling system

→ **STAR HFT** mechanics and services

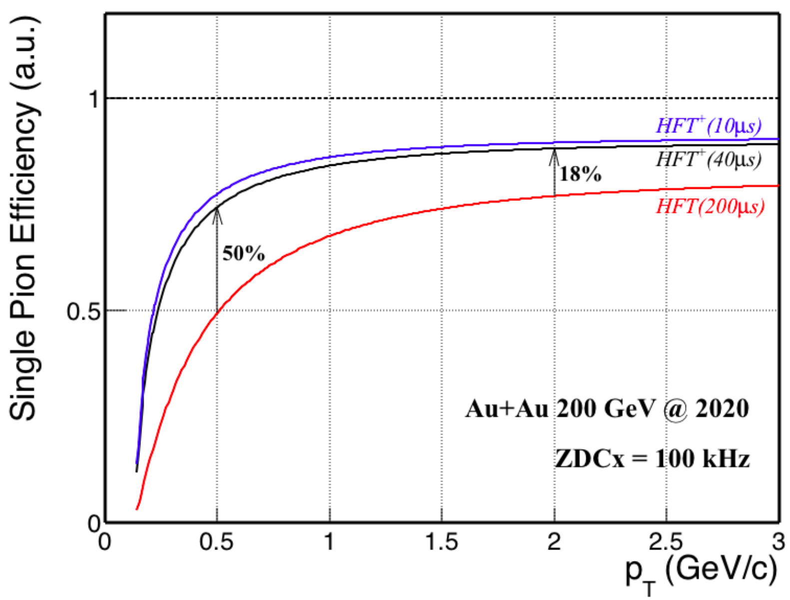
HFT+ read-out electronics requirements:

- **Compatible** with STAR DAQ system and trigger

→ **STAR + ALICE** new development

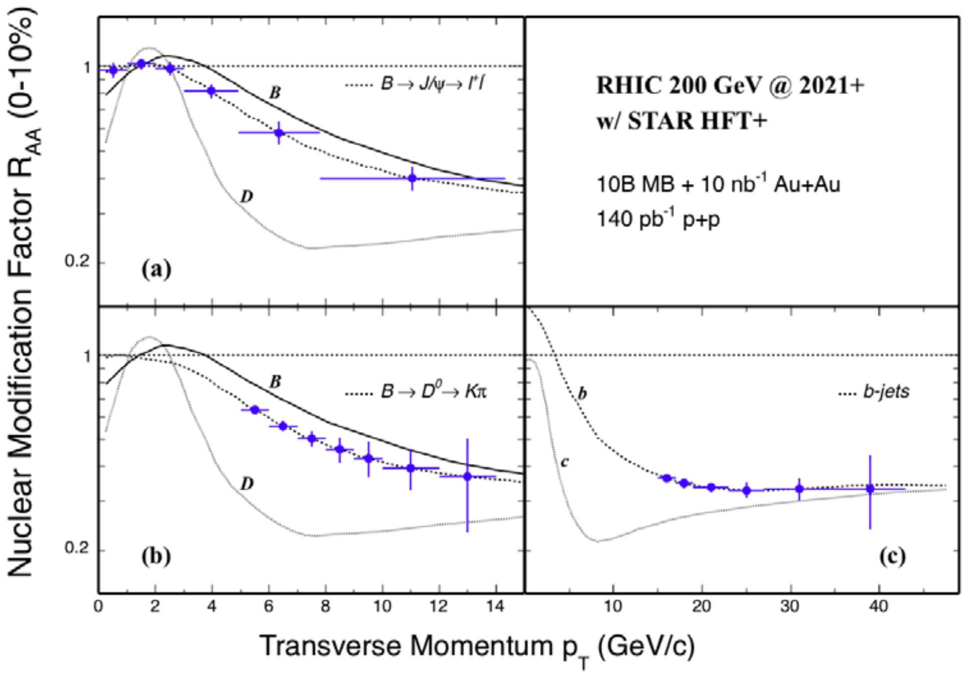
HFT+ simulation

Efficiency: fast vs. slow HFT



- HFT (~200 μs) → HFT+ (≤40 μs)

HFT+ flagship measurements



- R_{AA} for *J/ψ* and *D^0* from *B*, and *b-jets*

- The planned HFT+ program (2021-2022) is complementary to sPHENIX at RHIC and ALICE HF program at LHC

Conclusions

- The STAR HFT has been successfully taking data in 2014 and 2015
- State-of-the-art MAPS technology proved to be suitable for vertex detector application
- The HFT enabled STAR to perform a direct topological reconstruction of the charmed hadrons
- A faster HFT+ has been planned in order to measure the bottom quark hadrons at the top RHIC energy

Thank you for your attention!