The MAPS-based PXL detector for the STAR Experiment

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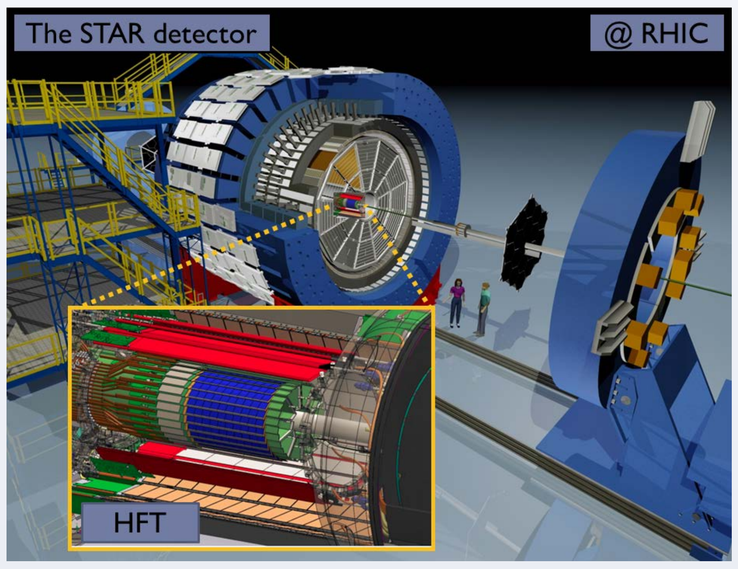
The STAR Experiment



The main goal of the STAR Experiment at RHIC is the systematic characterization of the dense medium created in heavy ion collisions, the so-called Quark-Gluon Plasma (QGP).

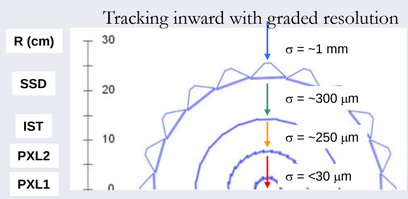
Heavy quarks, produced by hard processes early in the collision, are an ideal probe for studying the initial conditions of the produced QGP.

The Heavy Flavor Tracker has been designed to extend the STAR measurement capabilities in the heavy flavor domain to perform direct topological reconstruction of Charm

- Resolve displaced vertices from small $c\tau$ decays: $D^0 \rightarrow K\,\pi$ ($c\tau$ ~120 μm)
- Improve track pointing resolution from 1 mm to < 30 μm at the vertex

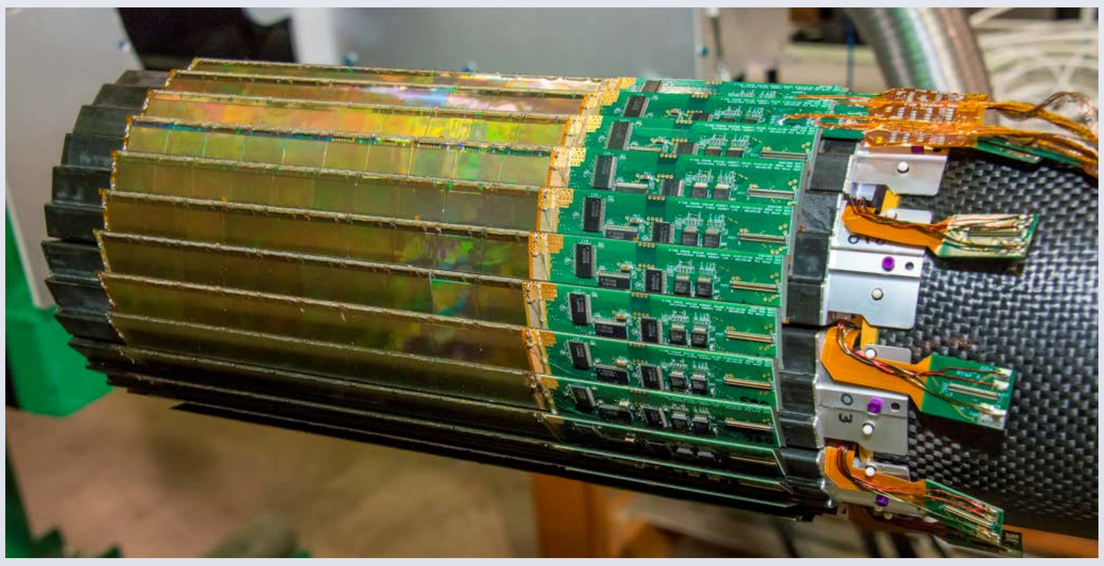
Inserted inside the Time Projection Chamber (TPC).
Composed of 4 cylindrical layers of silicon:

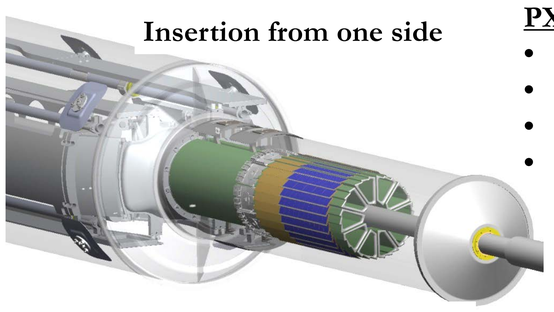
- Silicon Strip Detector (SSD) at 22 cm from the beam
- Intermediate Tracker Detector (IST) at 14 cm
- 2 Silicon PiXeL layers (PXL) at 8 and 2.8 cm



The PiXeL detector (PXL)

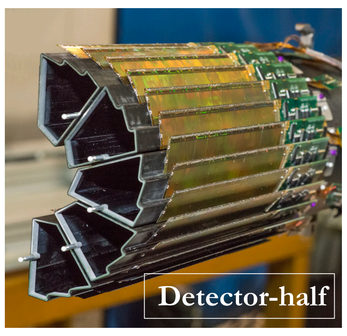
First vertex detector based on MAPS technology at a collider experiment





PXL System overview:

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

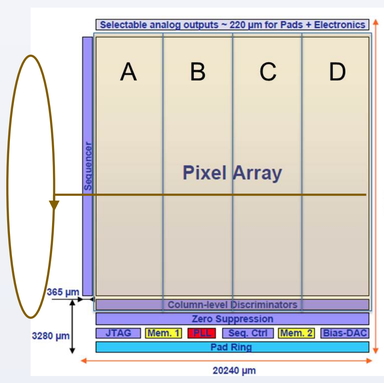


Ladder with 10 MAPS sensors

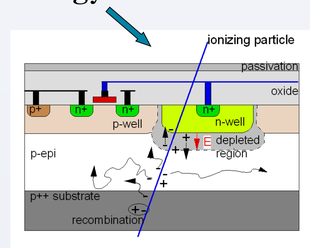
PXL Design Parameters

DCA pointing resolution	(10 ⊕ 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	5 μm rms (20 μm envelope)
Material budget 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	< 1 day

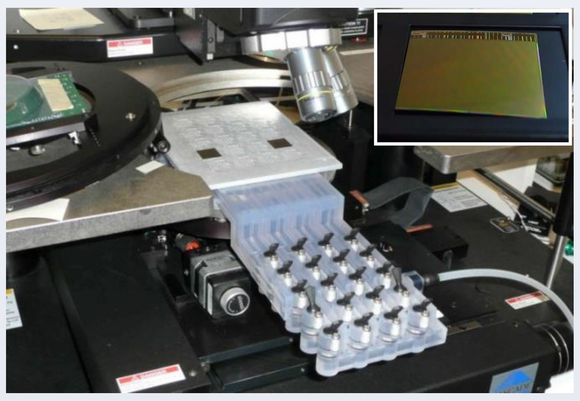
The MAPS sensor (*Ultimate-2* by IPHC Strasbourg):



- Monolithic Active Sensor Pixel technology
- High resistivity p-epi layer
- Rolling shutter readout
- End-of-column discriminators
- MIP Signal ~ 1000 e$^-$ - S/N ~ 30
- 185.6 μs integration time
- ~170 mW/cm^2 power dissipation
- 50 μm thick
- ~1M pixel on (2×2) cm^2
- in-pixel amplifier & Correlated Double Sampling



The PXL construction



Sensor probe testing

Thinned (50 μm) and curved sensors

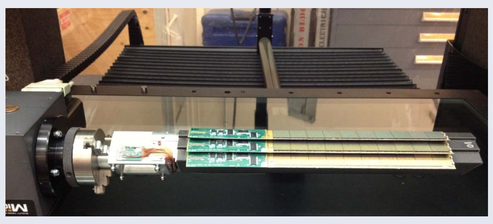
- probe pins optimized for uneven surface
- additional overdrive for contact reliability
- custom made vacuum chuck (20 chips)

Full automated sensor characterization

- Built-in test functionalities
- Full speed readout (160 MHz)
- Yield 46% - 60% (spare probe cards)
- Automated interface to a database

Assembly

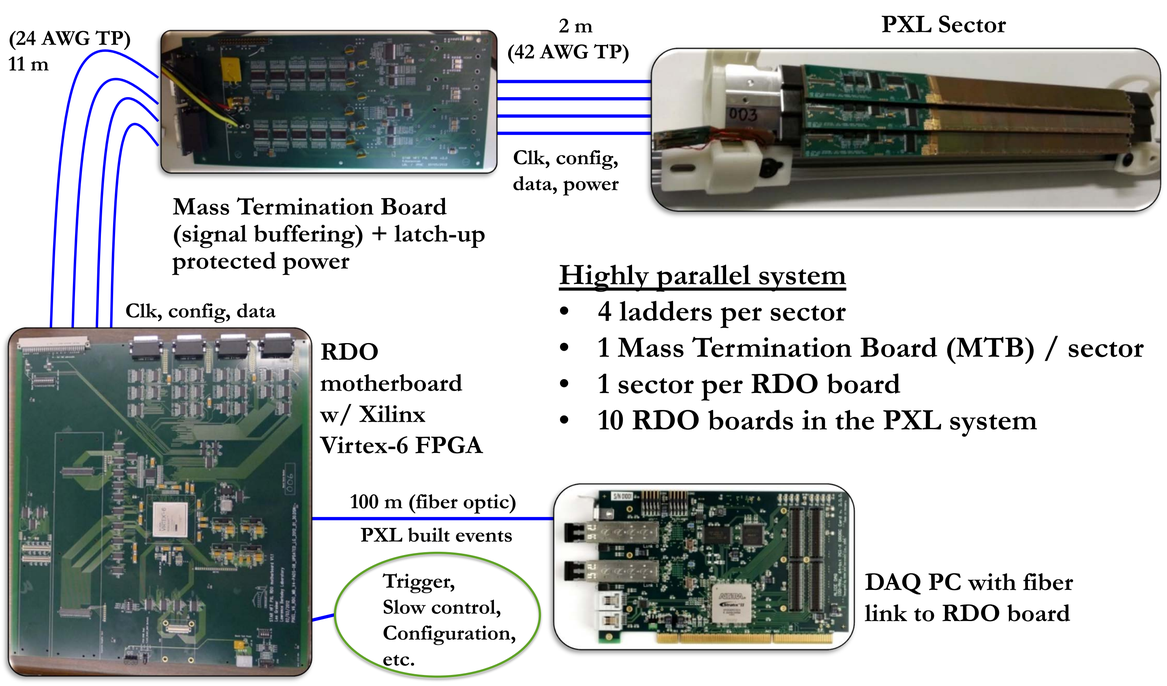
- Precision vacuum chuck fixtures to position sensors by hand
- Sensors are positioned with butted edges. Acrylic adhesive prevents CTE difference based damage
- Ladders are glued on carbon fiber sector tubes in 4 steps



Survey

- Pixel positions measured and related to tooling balls on sectors
- After detector-half assembly and survey, pixel positions known to an accuracy of approximately 10 μm

The PXL Powering, Control and Readout Chain



Highly parallel system

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

- PXL spin-off technology: RDO boards, testing boards and ladders have been adapted for testing by other LBL projects (*ALICE ITS Upgrade, Topmetal, …*)

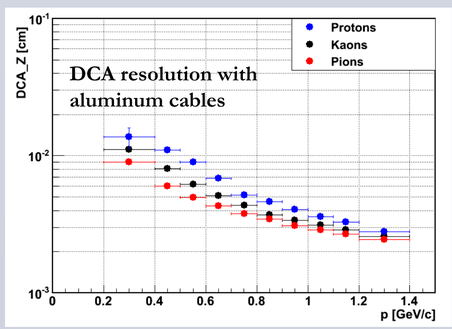
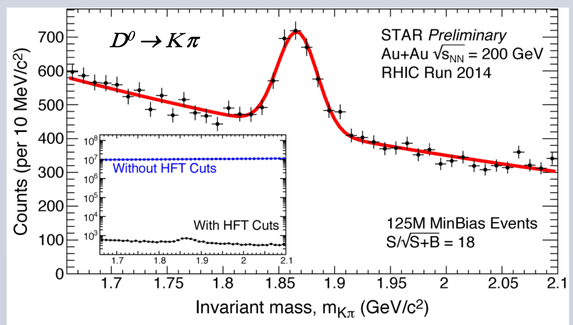
HFT Performance

Minimum bias events in HFT acceptance @ $\sqrt{s_{NN}}$ = 200 GeV, 0.8-1 kHz, deadtime ~6%:

- 2014 Run: 1.2 Billion Au+Au ← *PXL: latch-up induced damage studied and limited*
- 2015 Run: 1 Billion p+p / 0.6 Billion p+Au ← *PXL inefficiency due to firmware bug*
- 2016 Run: 2 Billion Au+Au / 0.3 Billion d+Au ← *Higher rates: up to 1000 hits/sensor*

DCA pointing resolution: design requirement exceeded:

- < 50 μm for 750 MeV/c Kaons
- ~ 30 μm for p > 1 GeV/c

Physics of D-meson productions:

- High significance signal
- Nuclear modification factor R_{AA}
- Collective flow v_2