# PHENIX Silicon Vertex Tracker (VTX)

Takashi HACHIYA

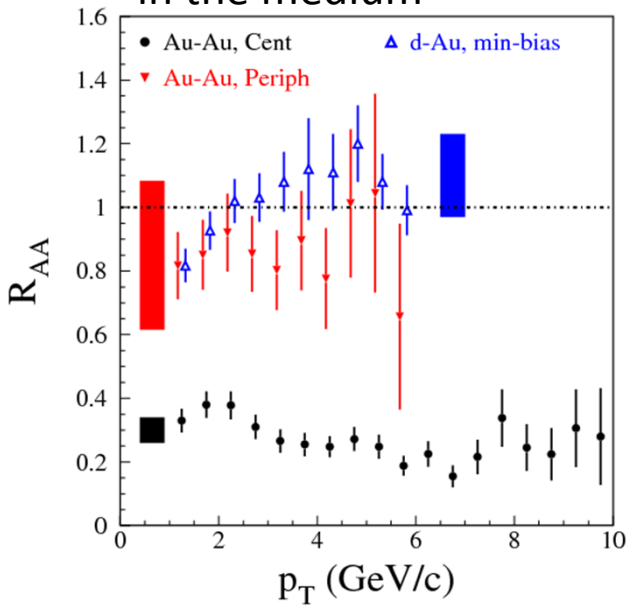
RIKEN

# Physics Motivation for Silicon Vertex Tracker (VTX)

## Heavy Ion Physics.

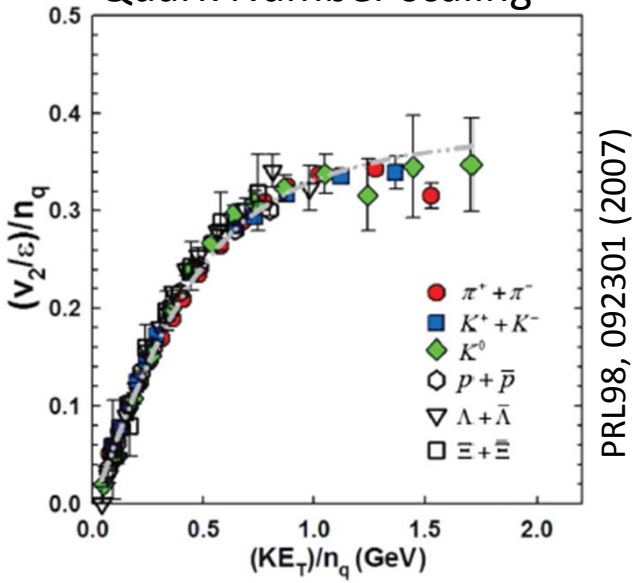
- We observed the strongly coupled QCD medium in Au+Au collisions.
  - Strong suppression of particle production at high pT and large v2 for light quarks

Parton Energy Loss
in the medium




NPA757, 184 (2005)

Early thermalisation time
Quark Number scaling




PRL98, 092301 (2007)

  - For heavy flavor, $R_{AA}$ of heavy flavor electrons shows the large suppression and non-zero flow.
    - Heavy Flavor Electrons are mixture of charm and bottom.

# Physics Motivation for VTX 2

## Heavy Ion Physics (cont.)

- To Study the property of the QCD medium by measuring c & b separately
  - $R_{AA}$ of single electrons from charm decays and bottom decays separately.
    - Flavor (mass) dependence of the energy loss
  - v2 of single electrons from charm and bottom decays separately.
    - Does bottom really flow?

- VTX provides clear separation of charm and bottom contribution.

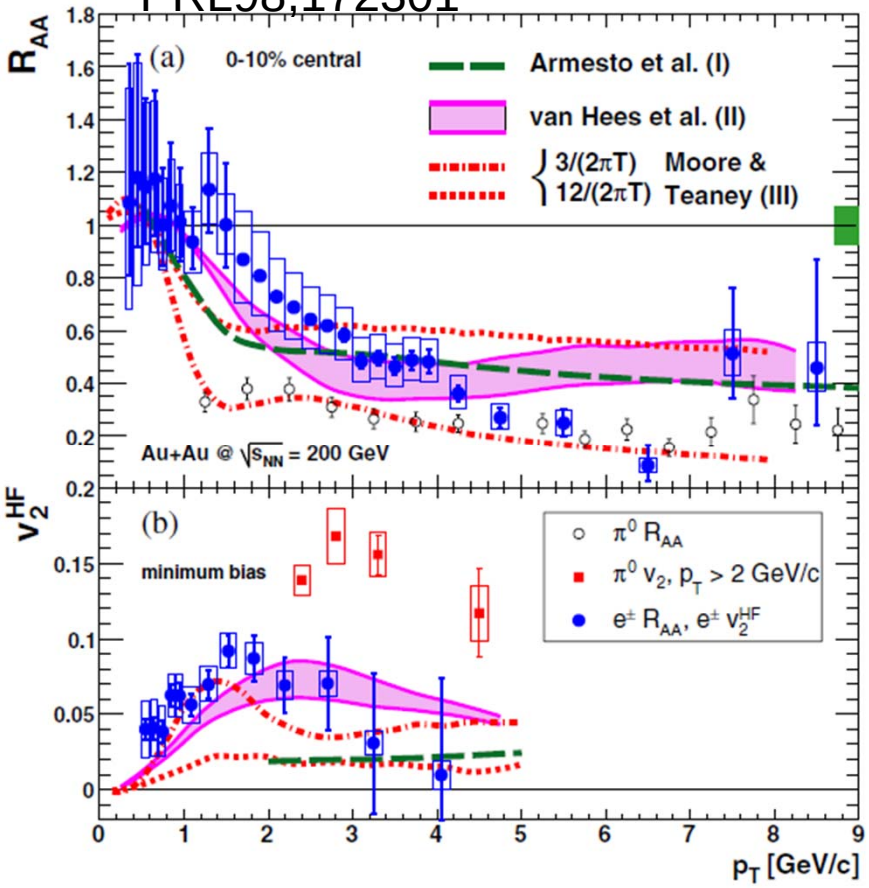
## Spin Physics.

- Gluon polarization $\Delta G(x)$ can be measured by heavy flavor.
  - Heavy flavor is mainly produced via gluon fusion ($gg \rightarrow c\bar{c}/b\bar{b}$)
- Improved W measurement.
  - Applying isolation cut  rejects the background for W measurement

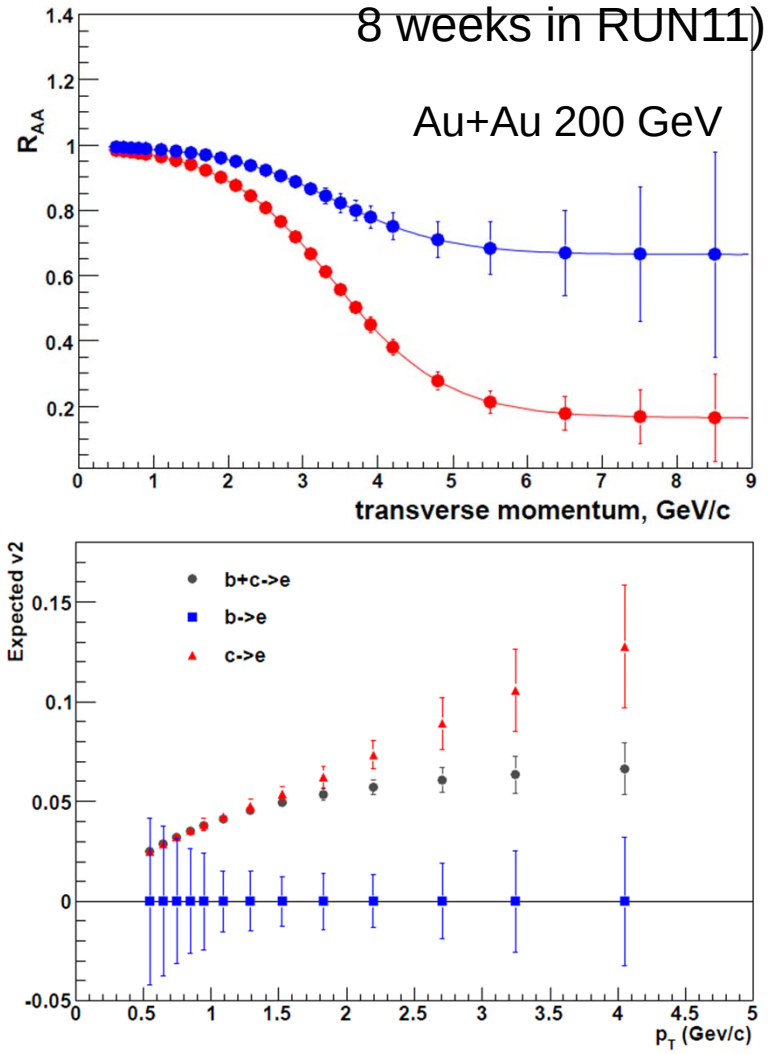
# Expected $R_{AA}$(b→e, c→e) and v2 with VTX

Current Measurement

RUN4 Au+Au 200 GeV
PRL98,172301




Expected with VTX (4.8B MB events 8 weeks in RUN11)



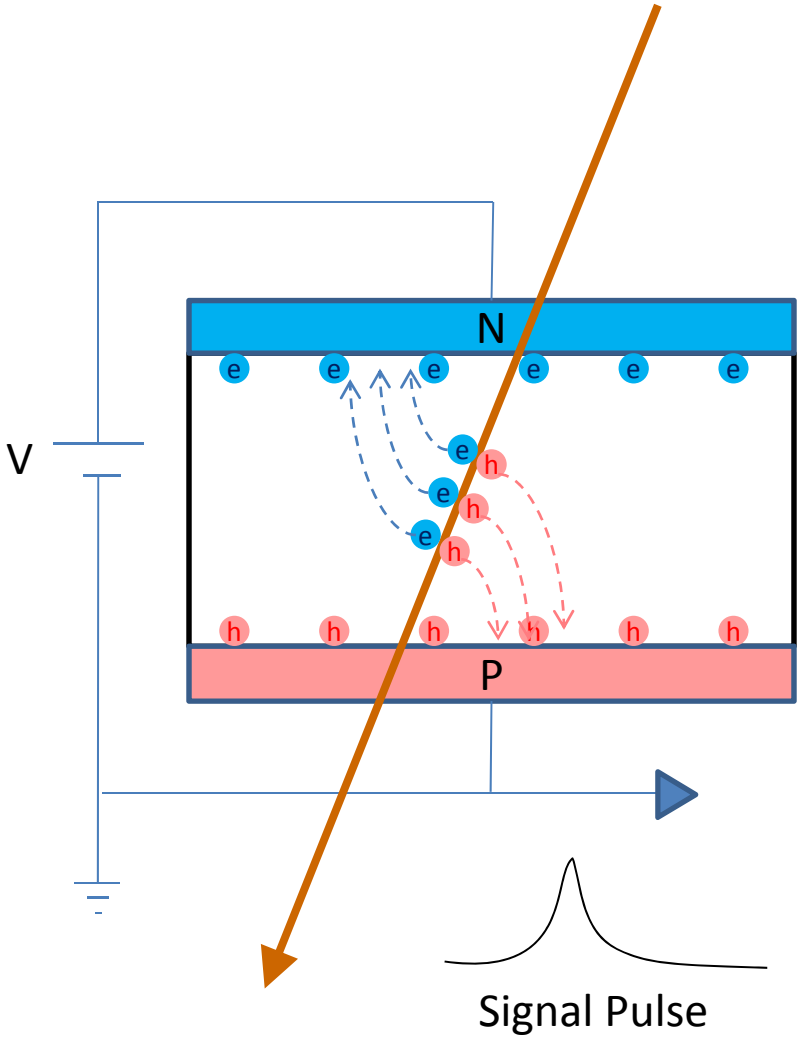

- The current measurement is mixture of b→e and c→e
- VTX can separately measure $R_{AA}$ and v2 of b→e and c→e

# VTX can approach the Physics topics

- Single Leptons:
  - Separation of charm and beauty
  - W background rejection improved
- Dileptons:
  - First direct bottom measurement via $B \rightarrow J/\psi$
  - Separation of $J/\psi$ from $\psi'$ with improved resolution and S/B
- Hadrons:
  - $D \rightarrow K\pi$
- Jet
  - Jet Reconstruction with wide acceptance coverage of VTX
  - Gamma-Jet Correlation
- Reaction Plane measurement
- Event Vertex reconstruction
  - Required to DCA measurement
  - Reconstruction of x-y vertex profile helps to monitor the luminosity

# Introduction of Silicon Detector

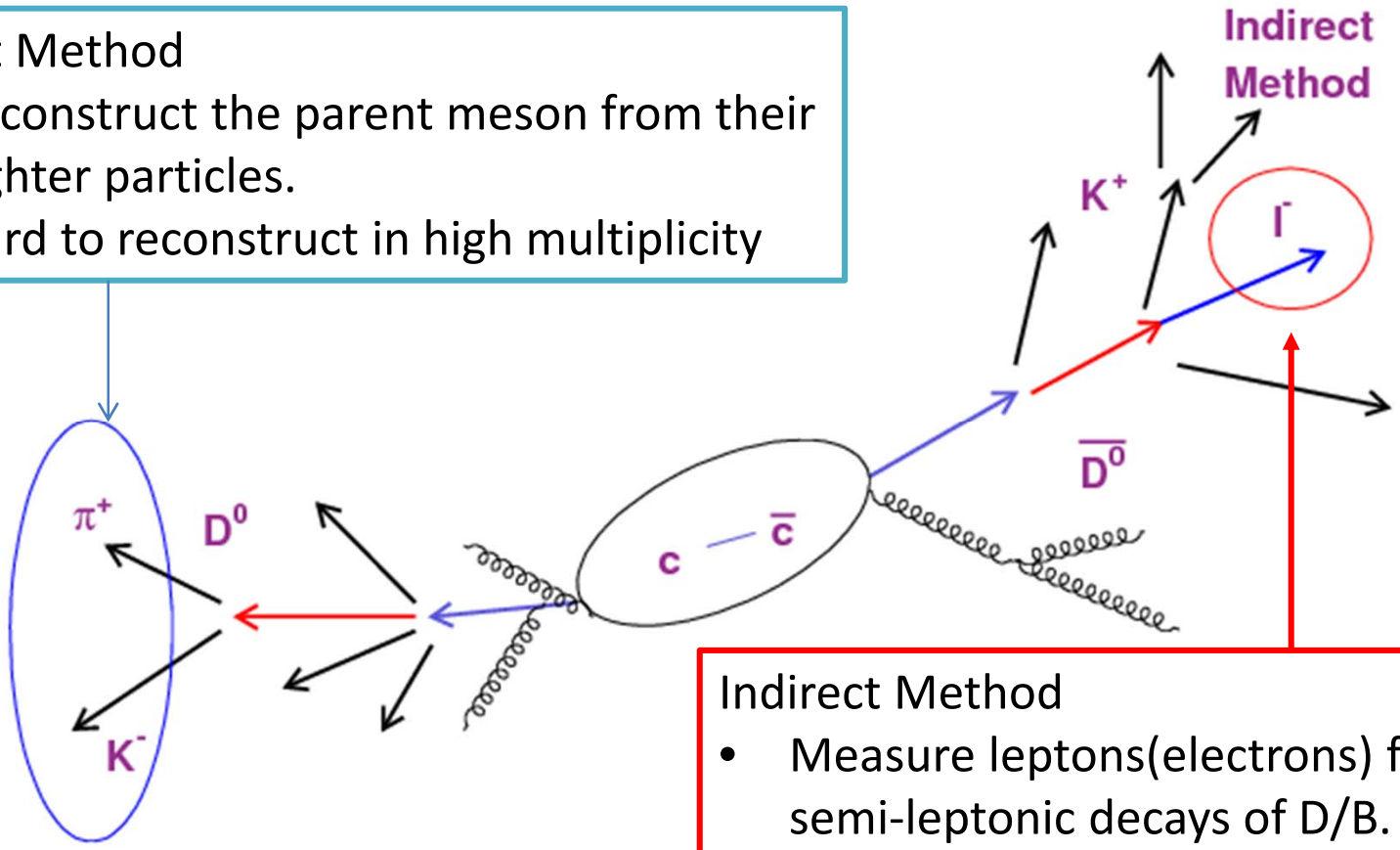
# Introduction of Silicon Detector




- Before the VTX detector…
- Silicon detector is made from P-N Junction.
- Apply the reversed bias voltage to P-N junction to make depletion region wider
  - Silicon Detector is Diode.
  - Careers are collected to the electrode.
- When a charged particle passes through the PN junction, it deposits the energy.
  - dE/dx can be calculated by Bethe-Bloch.
  - In case of 200μm depth, dE @ MIP is 56keV.
- The energy creates electron/hole pair (3.6eV/pair).
- Created Electron/Hole move to the electrode by electric field.
- Measure the corrected charge as a signal.

# Heavy Quark Measurement

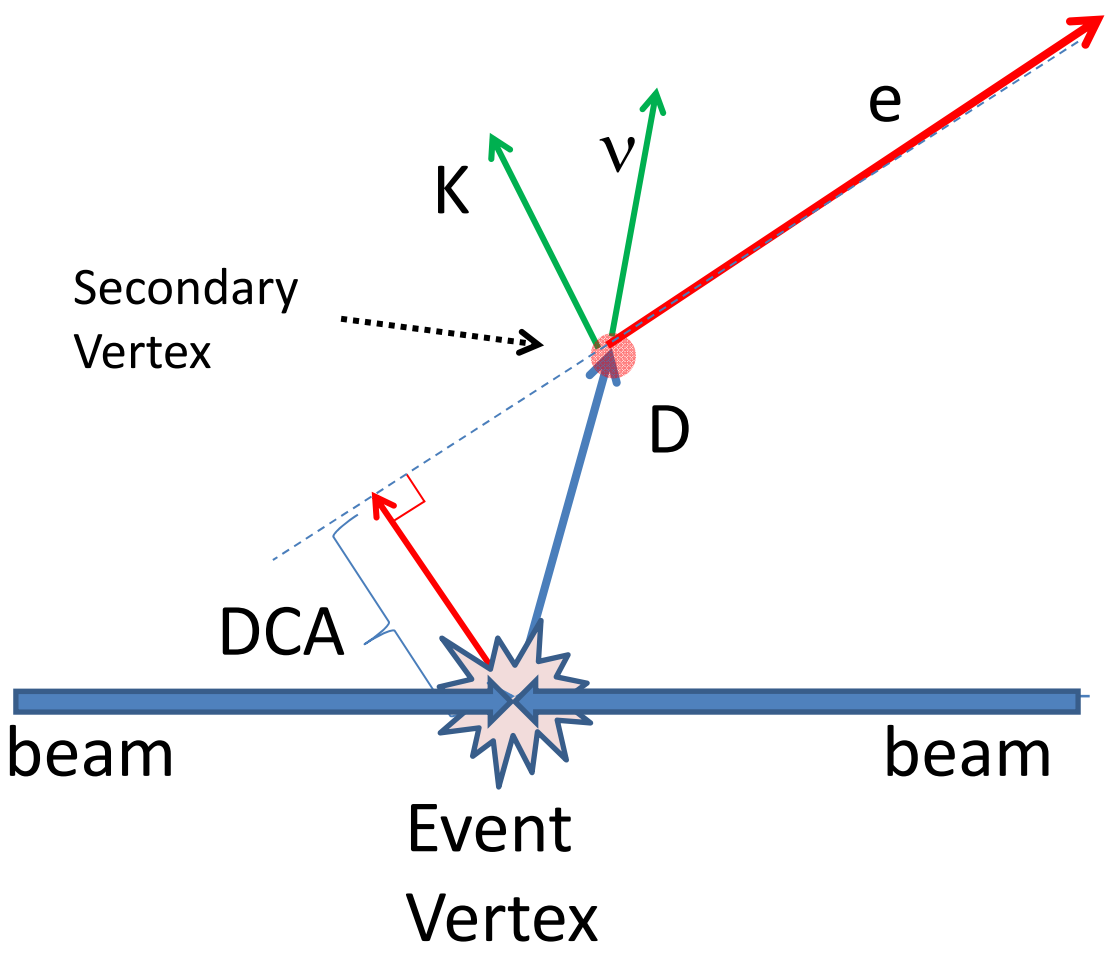
Direct Method
- Reconstruct the parent meson from their daughter particles.
- Hard to reconstruct in high multiplicity




Indirect Method
- Measure leptons(electrons) from semi-leptonic decays of D/B.
- Standard method in PHENIX

VTX can improve both Indirect and Direct method by DCA measurement.

# Distance of Closest Approach (DCA)




1. Collision happens
2. D meson is emitted from the event vertex
3. This D meson will decays in flight. Decay products are scattered at secondary vertex.
4. Electron is measured by VTX. The track is reconstructed.
5. DCA = Distance of Closest Approach of a reconstructed track to the event vertex

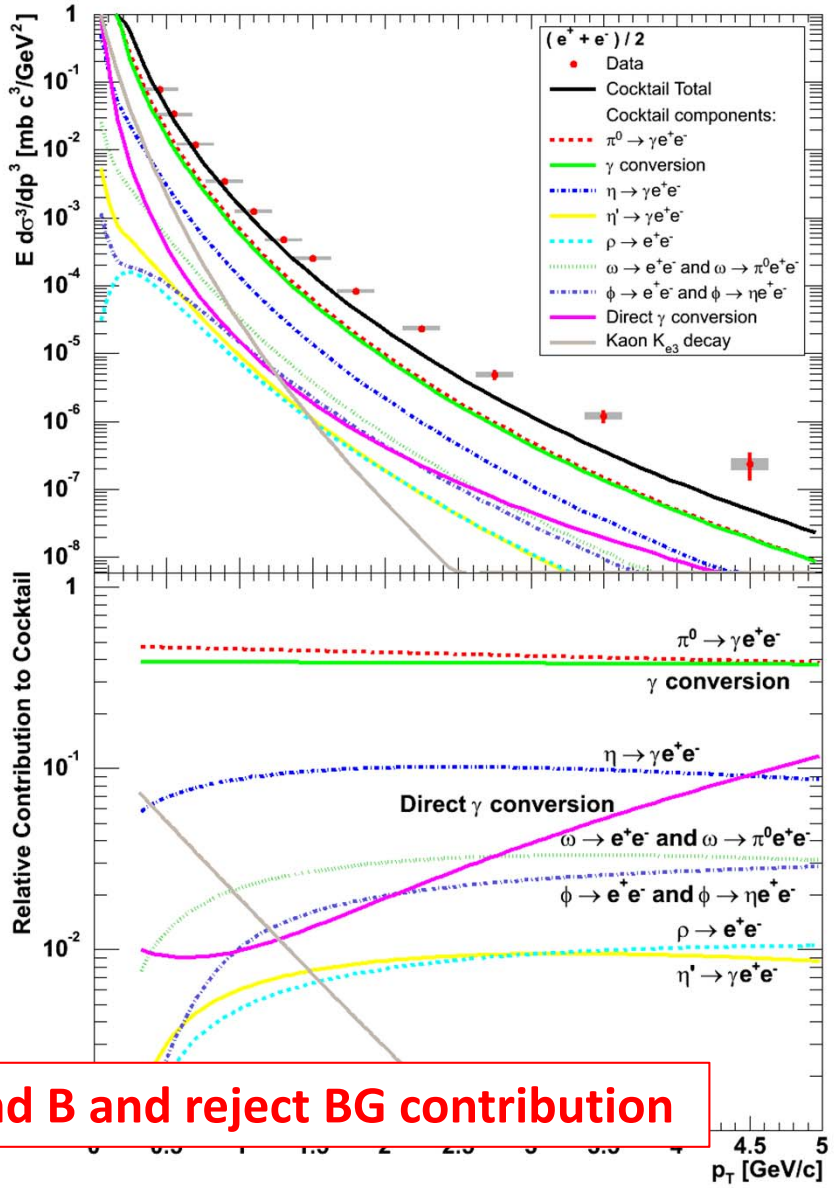
# DCA : Flight path length of Signal and Background

Back Ground

- π0 cτ = 25.1 nm
- η for Γ = 1.30 ± 0.07 keV
- ω for Γ = 8.49 ± 0.08 MeV
- ρ for Γ = 149.1 ± 0.8 MeV
- ϕ for Γ = 4.26 ± 0.04 MeV
- j/ψ for Γ = 28.6 ± 2.2 MeV
- K+/-e3 cτ = 3.712 m
- K0S cτ = 2.6842 cm
- K0L cτ = 15.34 m
- γ conv @ material

Emitted from Zvtx

Far from Zvtx



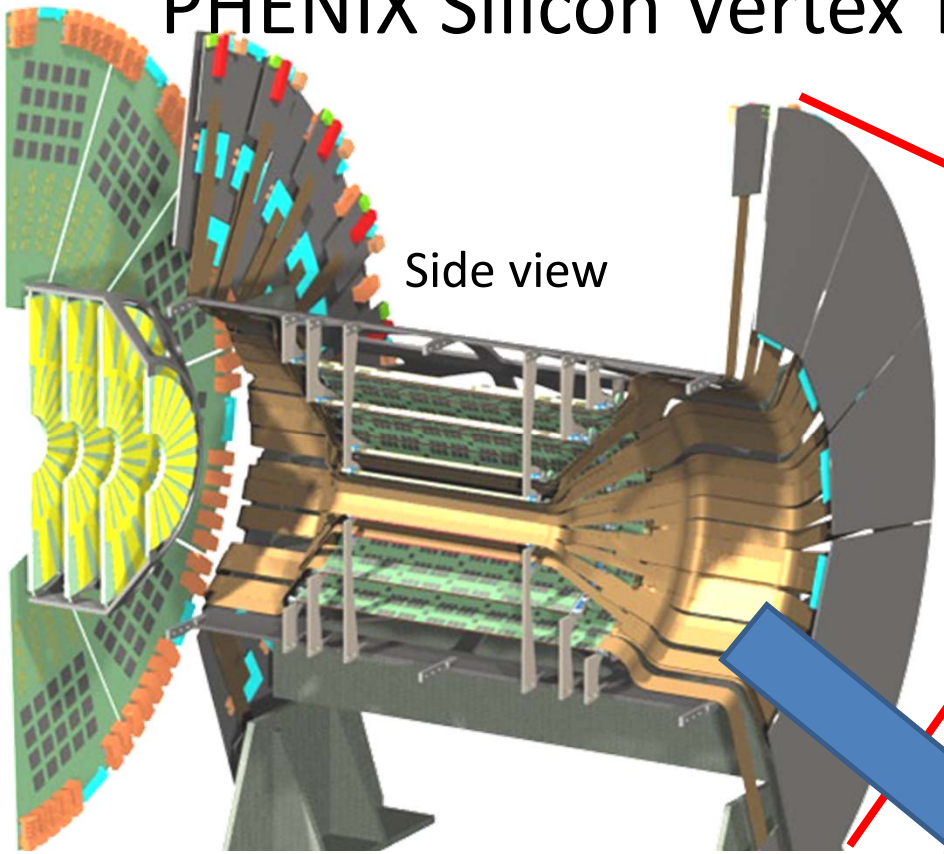

# Signal

- **D0 cτ = 122.9 μm**
- **D+ cτ = 311.8 μm**
- **B0 cτ = 457.2 μm**
- **B+ cτ = 491.1 μm**

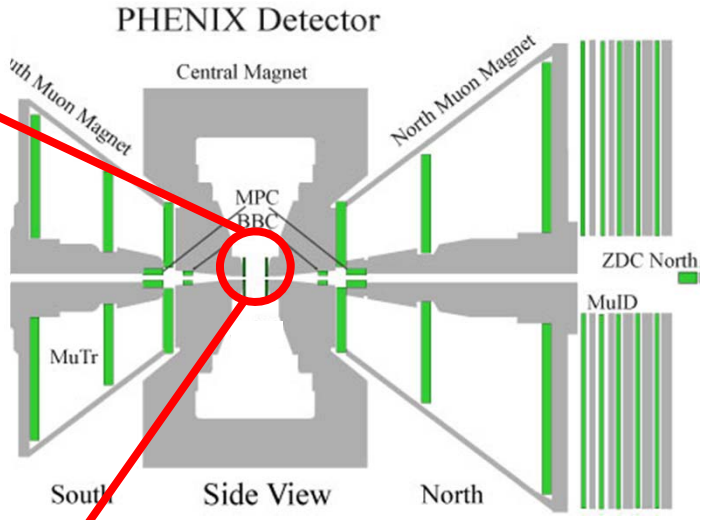
**With 50um resolution, VTX separate D and B and reject BG contribution**

# VTX overview

# PHENIX Silicon Vertex Tracker (VTX)

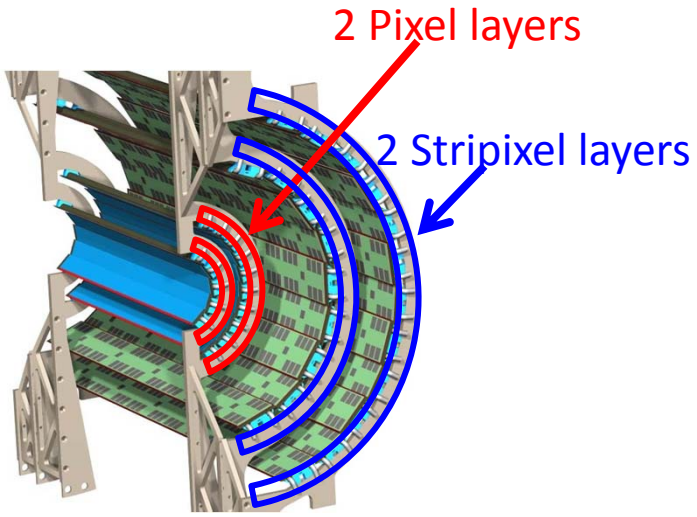


Side view



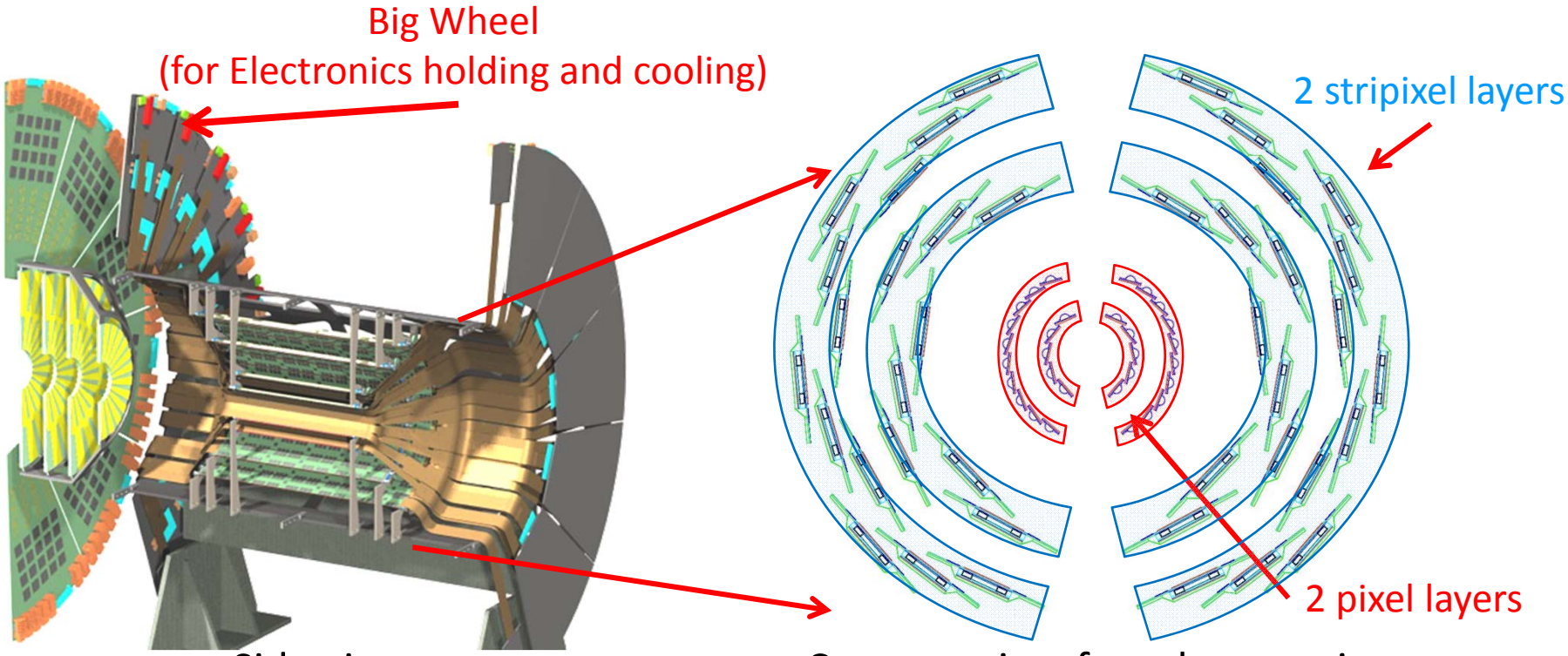

Silicon Vertex Detector (VTX)
Placed at the center of PHENIX

- Coverage: $|\eta| < 1.2$, $\Delta\phi \sim 2\pi$
- 4 Layers: 2 inner layers of Pixel detector
- 2 outer layers of Stripixel detector
- Spatial resolution:
  $\sigma$(DCA) ~ 100$\mu$m
  ~ 50 $\mu$m after alignment
- Material: $X/X_0$ ~ total 10%
- Stand-alone Tracking Capability




Beam view

# Parameters of VTX




Side view

Cutaway view from beam axis

Structure : 2 pixel layers, 2 stripixel layers

| Layer | Kind | R(cm) | Z(cm) | # ladder | RO Channel | Occupancy(Au+Au) |
|---|---|---|---|---|---|---|
| 0 | Pixel | 2.5 | ±10 | 10 | 1,310,720 | 0.53% |
| 1 | Pixel | 5 | ±10 | 20 | 2,671,440 | 0.16% |
| 2 | Stripixel | 11.7 | ±16 | 16 | 122,880 | 4.5% |
| 3 | Stripixel | 16.6 | ±19 | 24 | 221,184 | 2.5% |

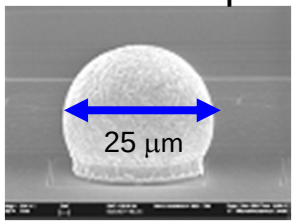
# Pixel Detector

## Pixel

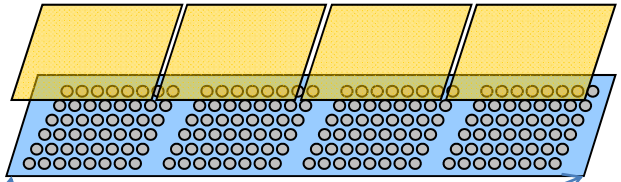
- Developed by ALICE experiment
- Pixel Size: 50 um ($\phi$) x 425 um (z)
- Ladder
  - sensor module is hybrid of a sensor + 4 readout chips.
  - Each pixel on sensor is connected to RO chip by bump bonding
  - 4 sensors modules/ladder
  - 2 buses
  - Stave with cooling tube
  - Electrically independent half ladder

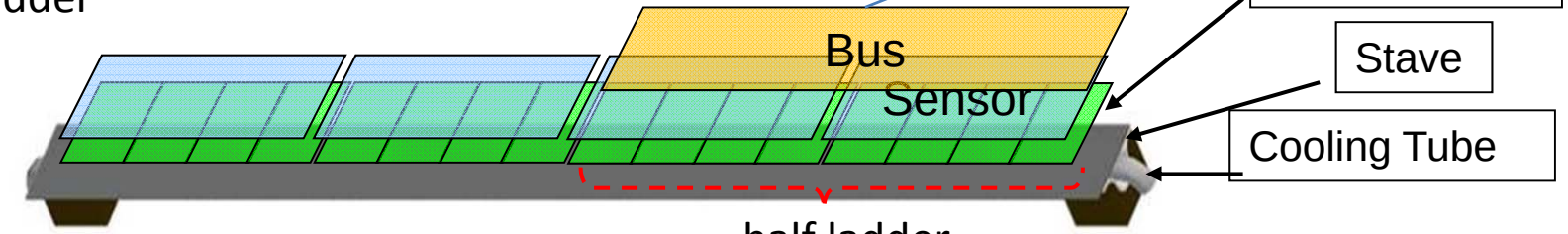
- Hit/No hit information (1ch = 1bit)
  - Hit is identified by the discr. channel by channel.

Solder bump

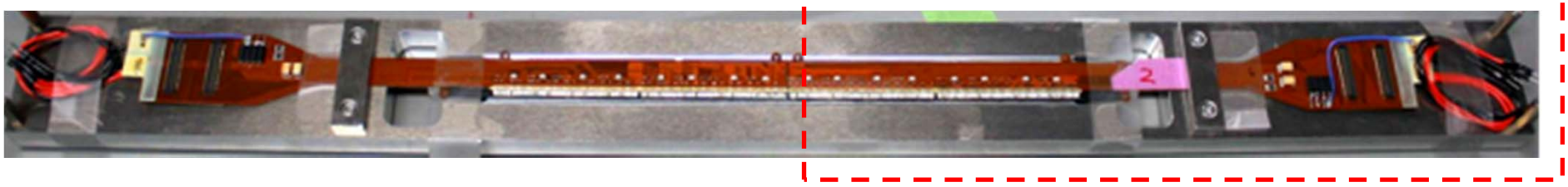



Sensor module (Sensor+4ROchip)



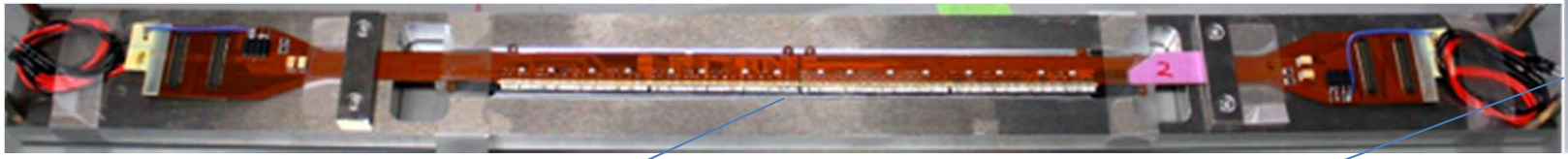


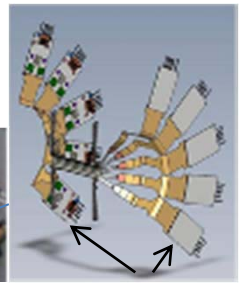

half ladder



Pixel Full ladder

# Pixel Ladder Readout System



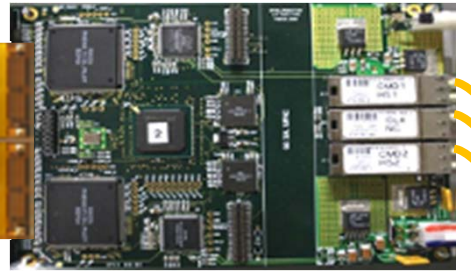


SPRIO

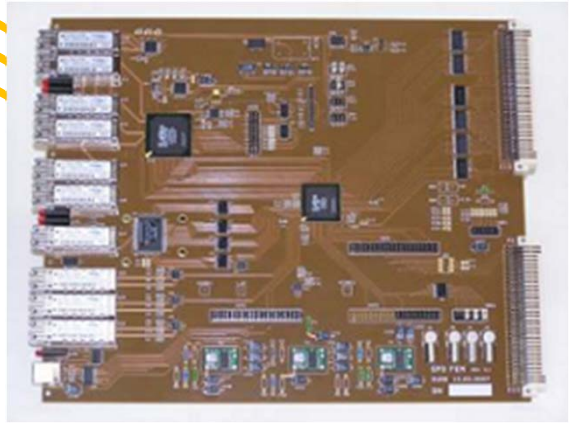
Half Ladder

Bus Extender

SPIRO Board



Optical link



FEM in rack room

Signal :

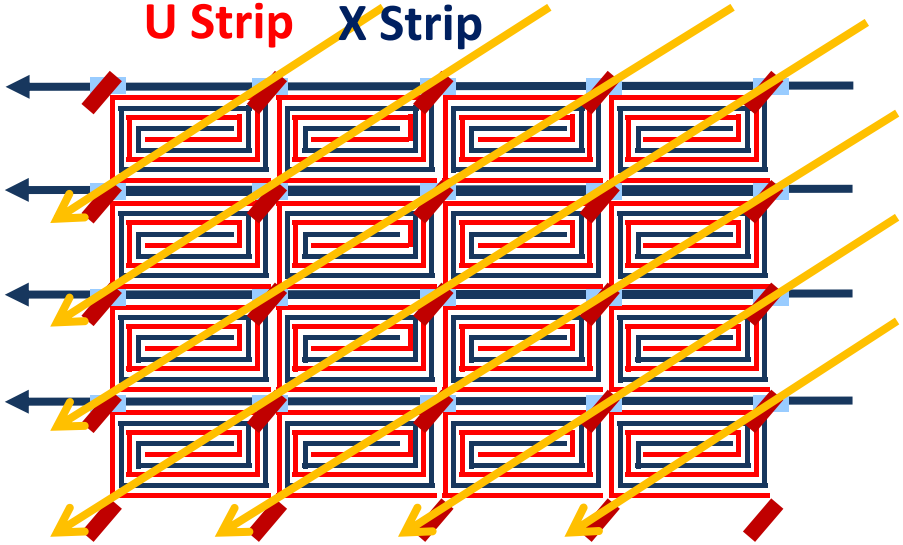
- Readout by Readout Chip (Alice) on the ladder.
- Sent through the BUS extender
- Collected by SPIRO
- Formatted by FEM

# Stripixel Detector

## Stripixel Detector

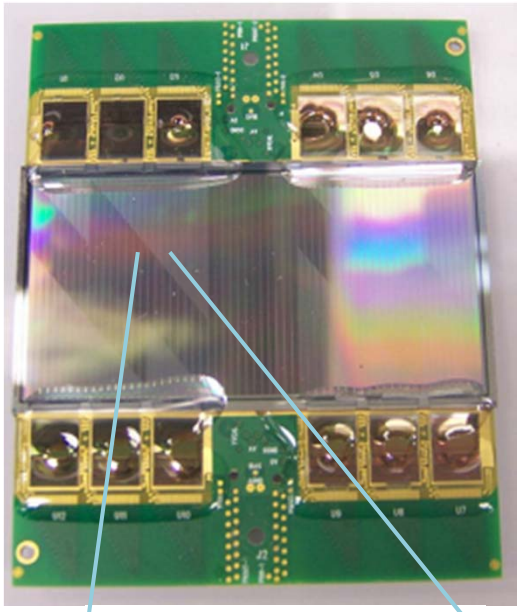
### New Technology at BNL

- Stripixel Size : 80 um ($\phi$) x 1000 um (z)
- X-strip and U-strip is made by connection of the stripixel
- Charge information is readout from each strip for dE/dx measurement

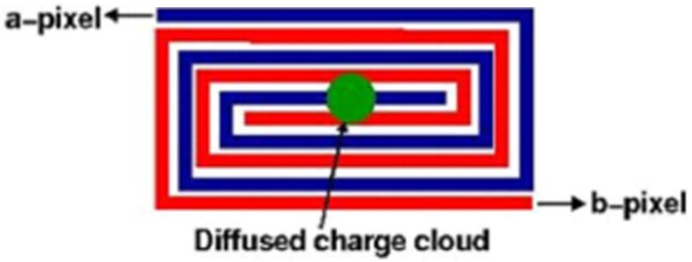



Stereo Angle of U strip is 4.6 degree w.r.t X strip

Stripixel Module

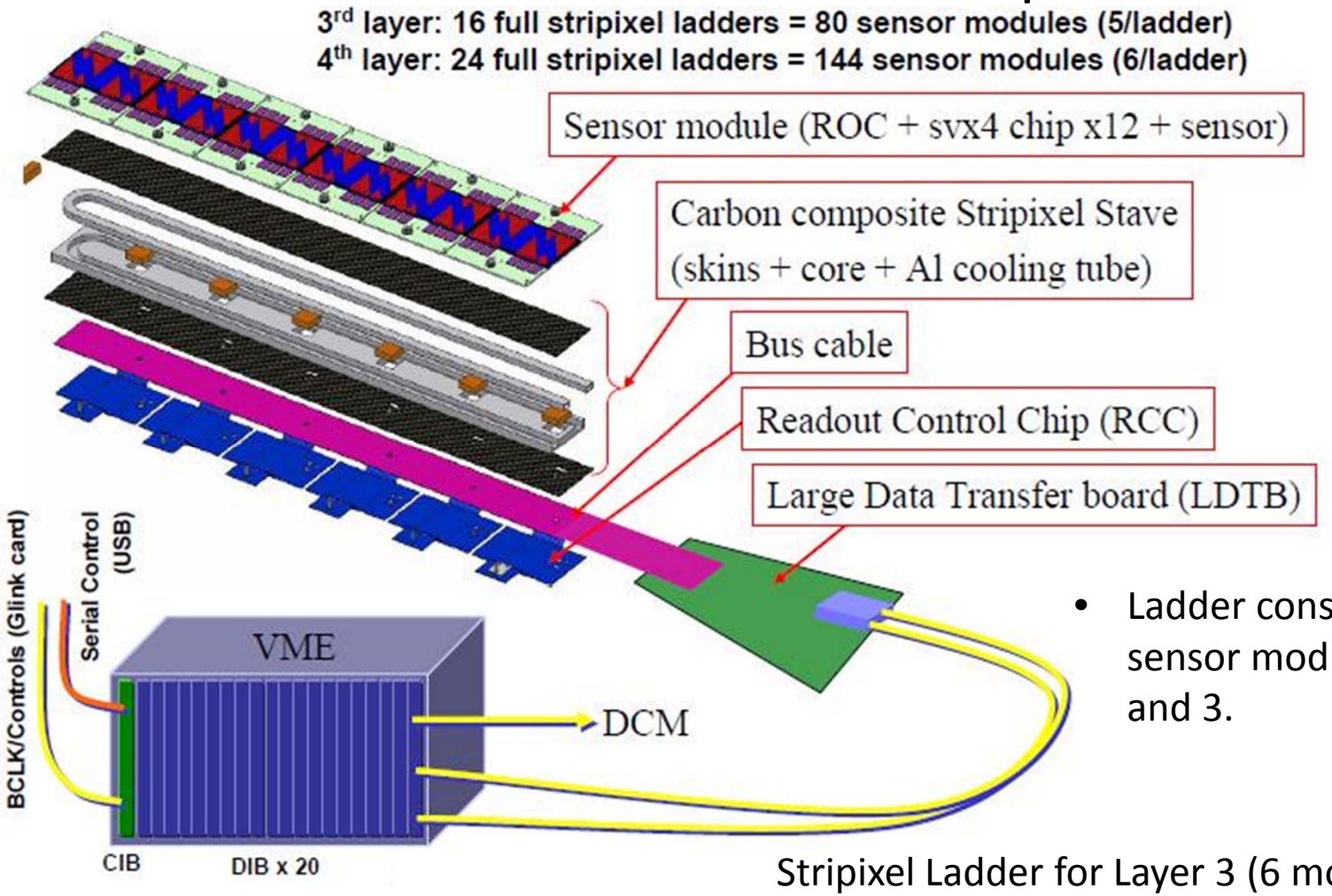


80 x 1000 $\mu m^2$



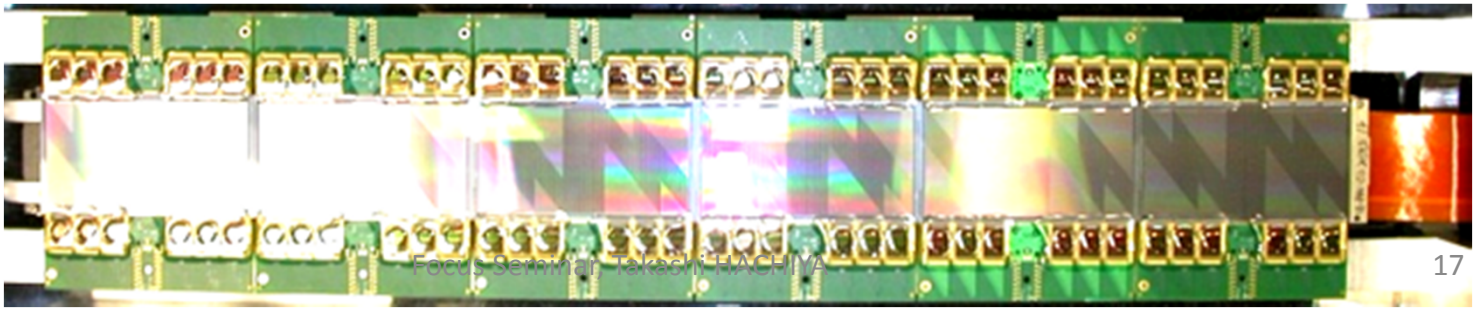

- 2-dimensional position can be measured by charge sharing.
- Spiral structure gives smaller material than the normal Si strip detector

# Mechanical Structure of Stripixel Ladder



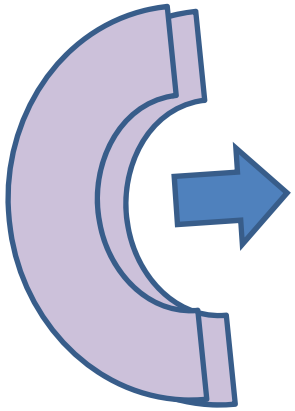

- Ladder consists of 5 and 6 sensor modules for layer 2 and 3.

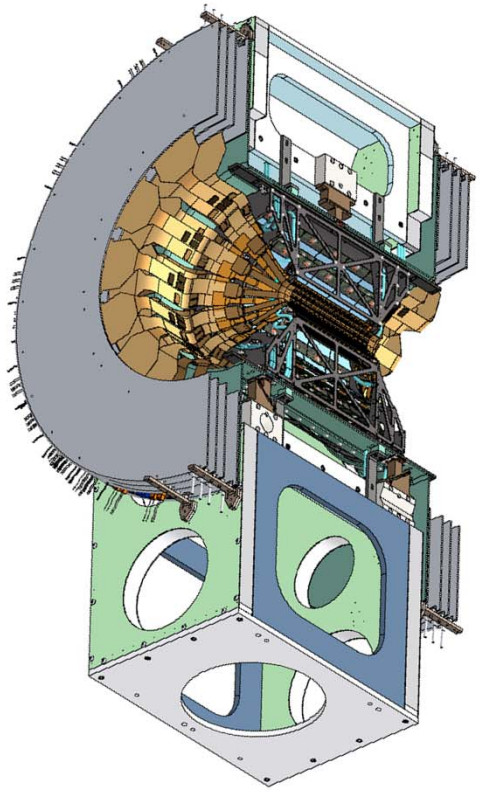
Stripixel Ladder for Layer 3 (6 modules)



# VTX Detector Structure

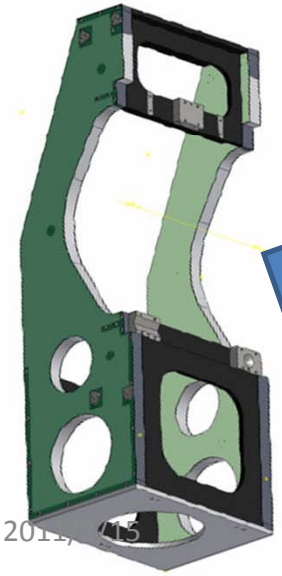
Big Wheel



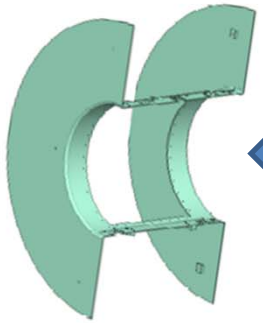


- Space Frame – hold the ladders
- Gas Enclosure – make inside gas tight
- Support Structure
  - Support the entire VTX detector
- BigWheel – hold the Readout PCB

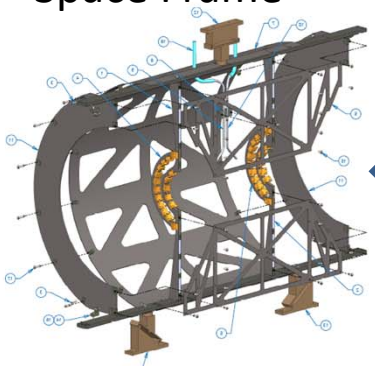
Support Structure



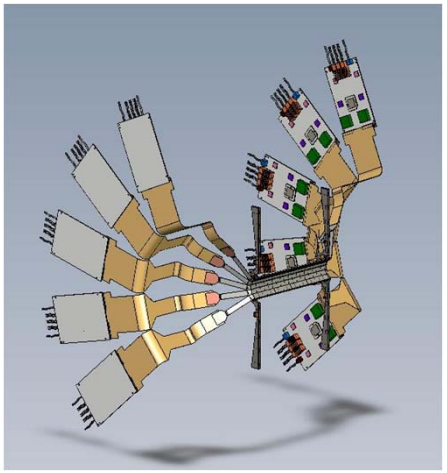
Gas Enclosure



Space Frame



Detector (Ladder)



# Analysis Method

# Analysis Method for Indirect Method (electron)

## DATA analysis

Central Arm data in DST

VTX data In DST

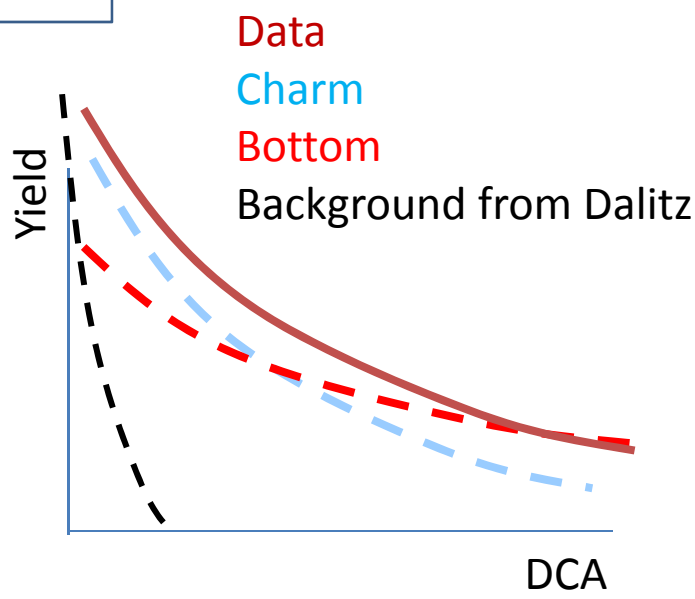
Electron ID by RICH and EMCAL

DCA measurement By VTX

## Simulation Analysis

Determine DCA shape for charm and bottom

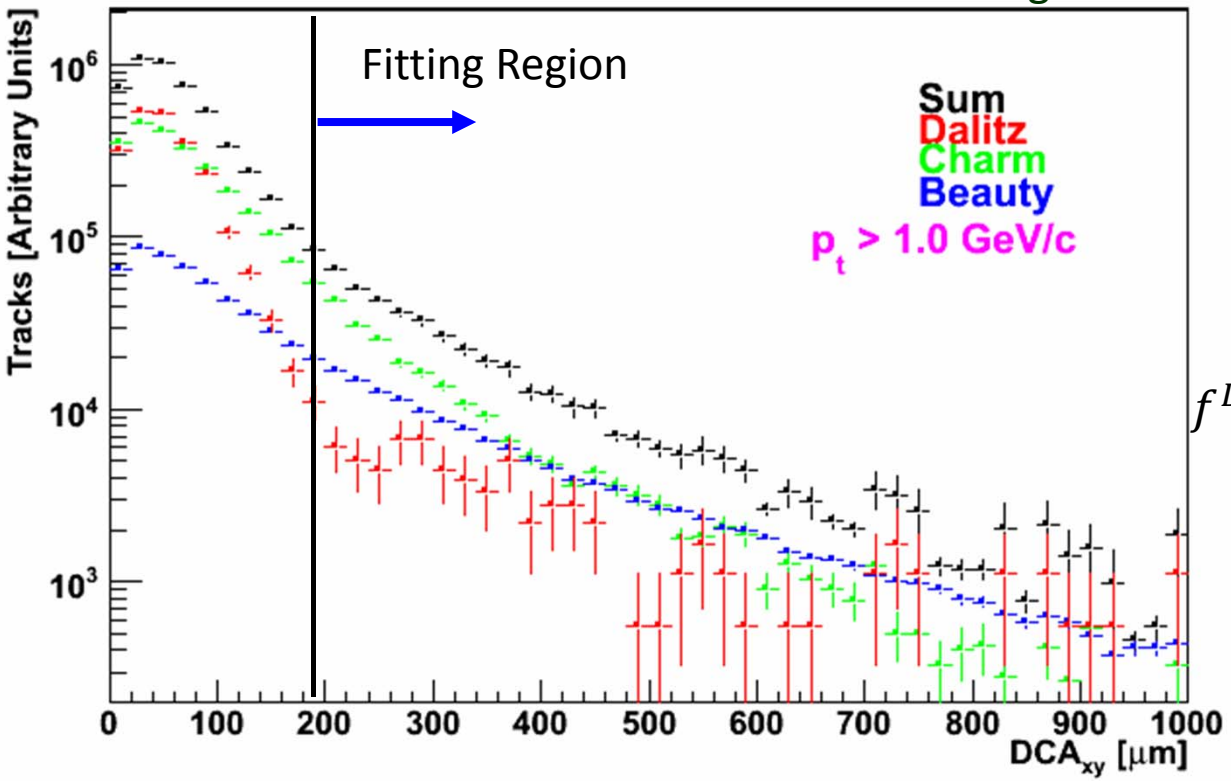
DCA for charm and bottom have different shape (different **cτ)** (also background)




Simultaneous Fit of the DCA by charm and bottom to obtain the charm and bottom yield

# DCA distribution from Simulation (Pythia+PISA)

Plot from S. Baumgart JPS slide




DCA distribution is fit to obtain the shape

$$f^{D/B}{}_{DCA}(x) = Ae^{-\omega_{D/B}x^{2/3}}$$

Real data is :

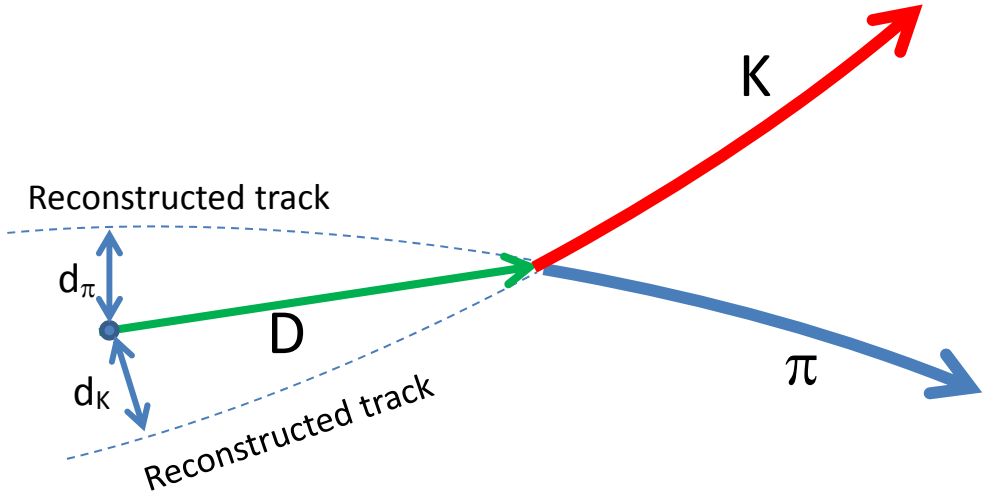
$$f^{D}{}_{DCA}(x) = N_D f^D + N_B f^B + N_{bg} f^{bg}$$

Fitting for real data is performed above smaller BG.

Using $N_D$ and $N_B$,
The charm and bottom yield can be obtained

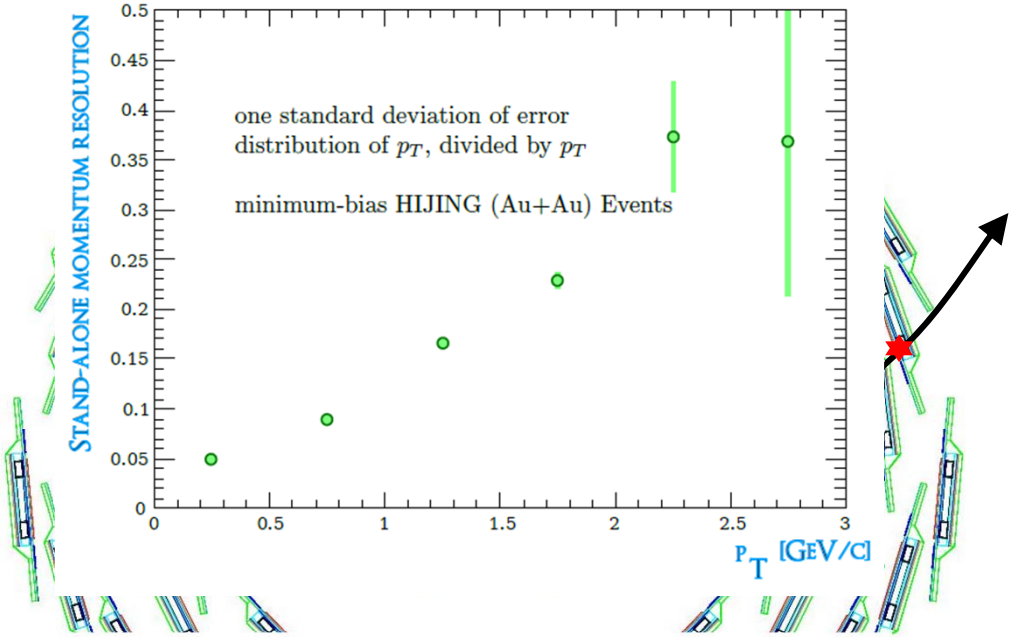
Spatial resolution can smear the DCA distribution.
Therefore, we need to calibrate the detector alignment.
For the realistic simulation, we must implement realistic DCA resolution to obtain the DCA shape of charms and bottoms .

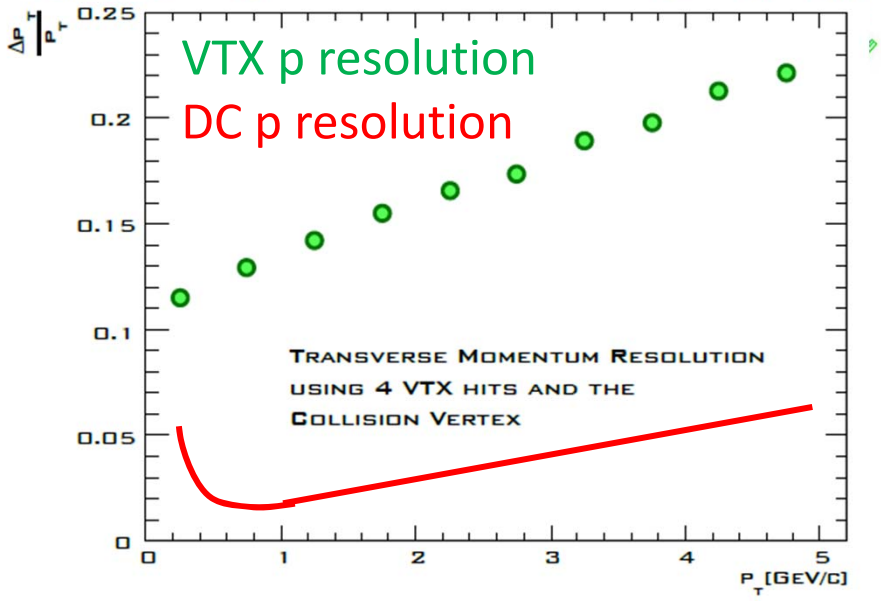
# Analysis for Direct Method




- In the direct method, we have non-trivial combinatorial background in the invariant mass distribution of D meson
- However, applying DCA cut to both π and K track, the combinatorial background can be much reduced.
  - Even applying DCA cut to single track(π or K), it must be useful for p+p and d+Au collisions.
  - dE/dx info. can be used to PID in addition to central arm.
- Simulation work does not start yet.

# Momentum Reconstruction from Standalone Tracking



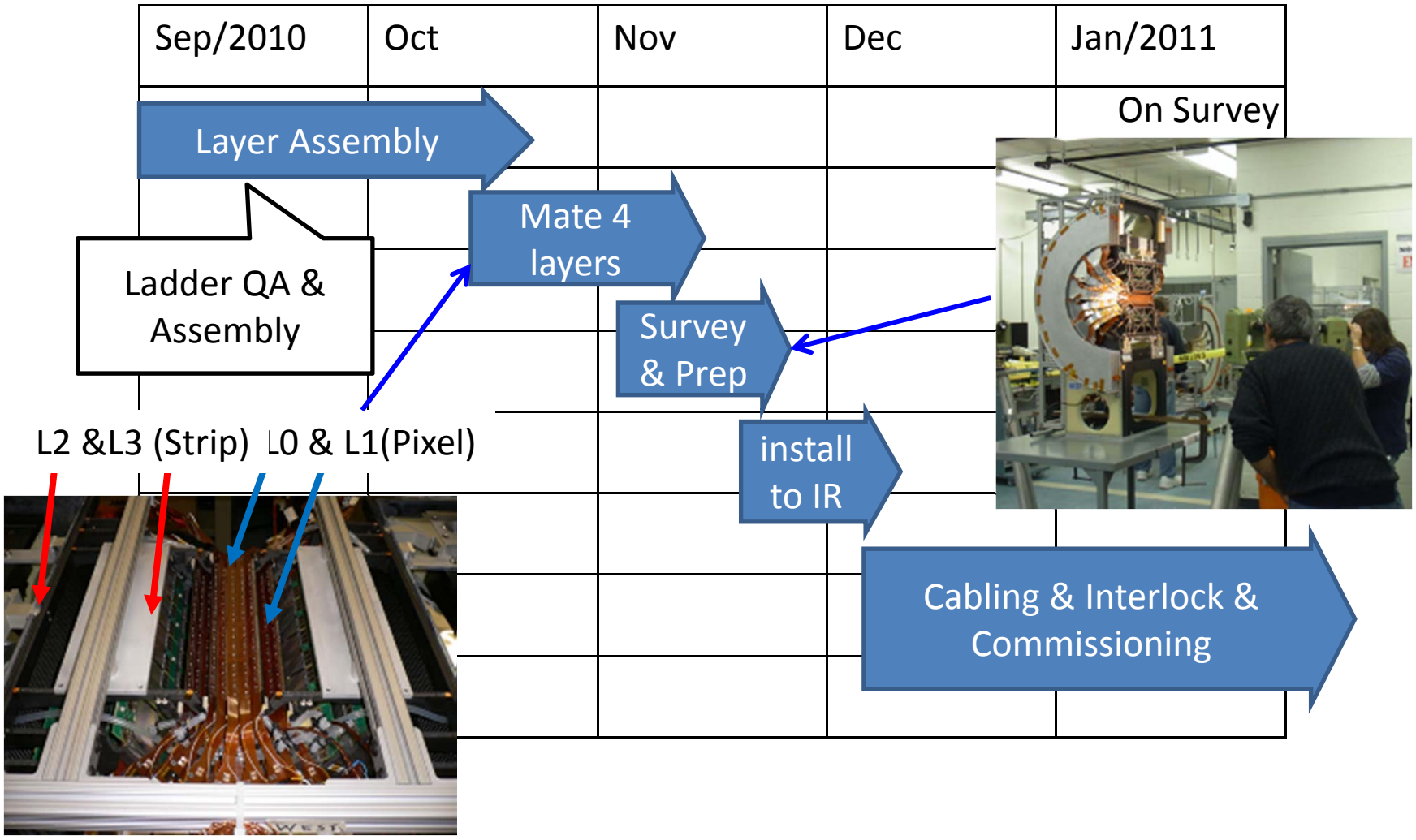

VTX can determine the track momentum by measuring the curvature of the track.

→ Kalman Filter method

- Momentum resolution of VTX is 13% at pT= 1GeV (in simulation).
  - Small bending from B-field
  - Multiple Scattering
- DC resolution is much better than VTX.
  - 1.5% @ pT=1GeV
- But we have small room to improve the resolution
- Tuning the parameter can modify the mom-resolution
  - Good resolution at low pT
- We need to tune the parameter carefully

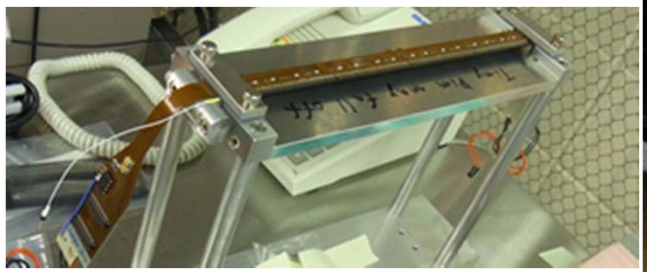
# Assembly and Installation

# Assembly & Installation History

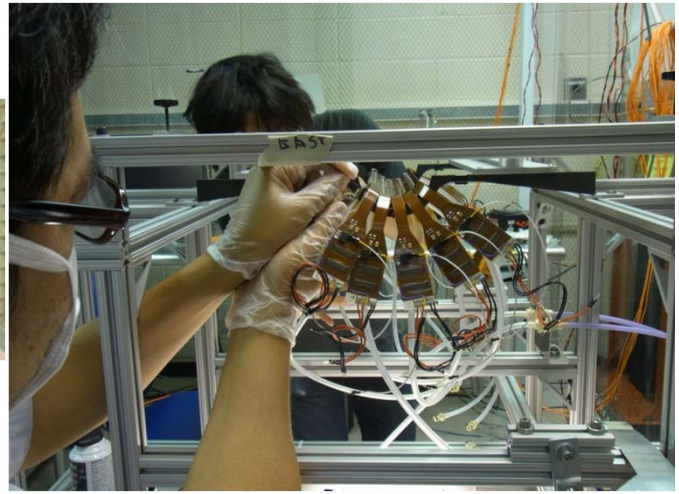


# Layer Assembly
## (Ladder Installation to Frame)

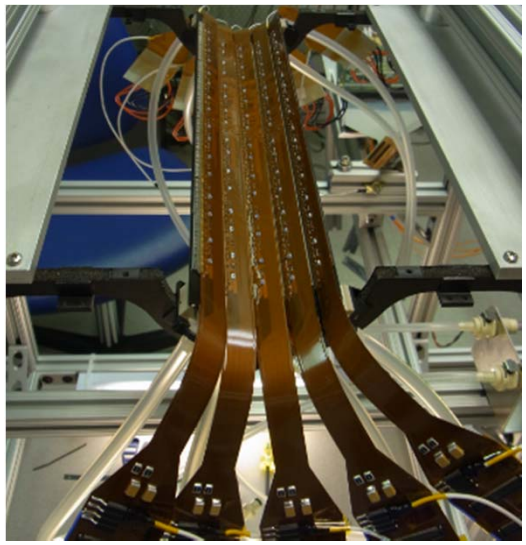
## Pixel



Installing to the frame

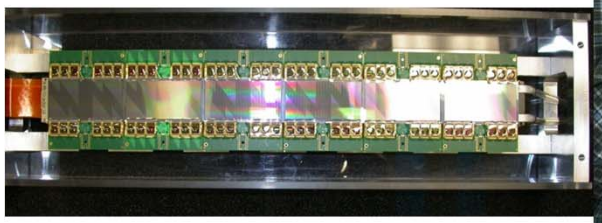


Complete!!



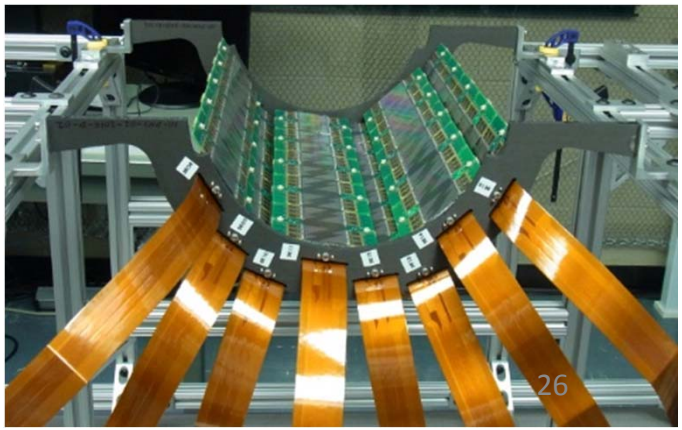
## Stripixel

Ladder

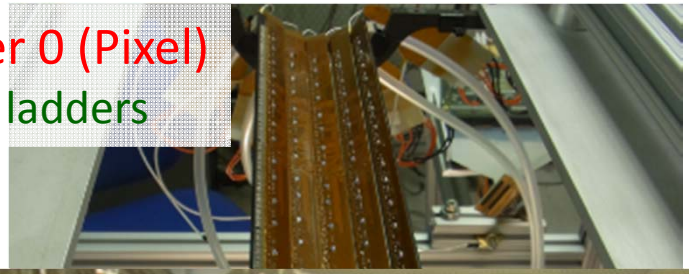


Installing to the frame

Complete!!

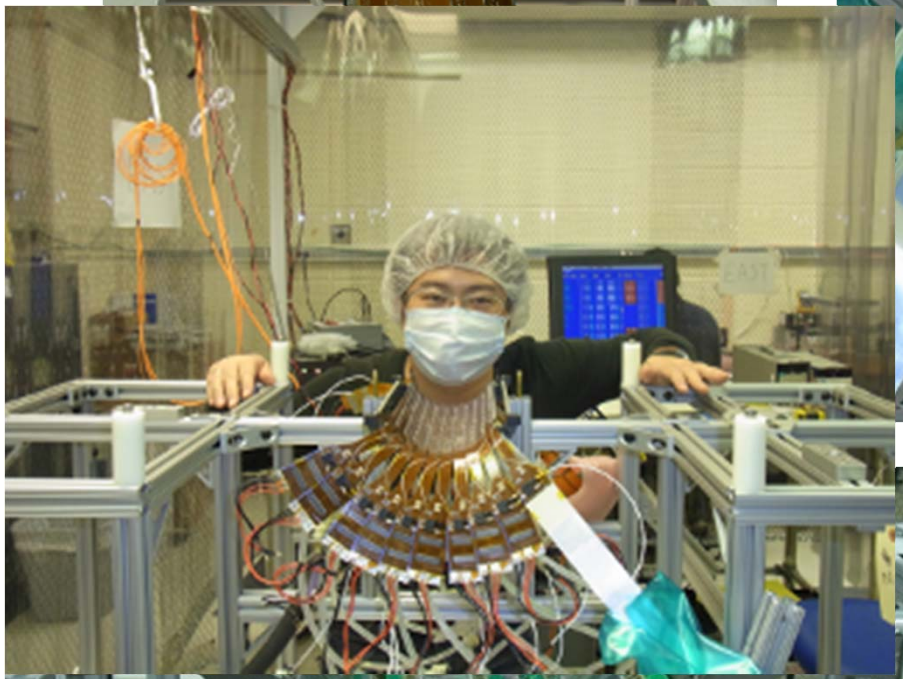


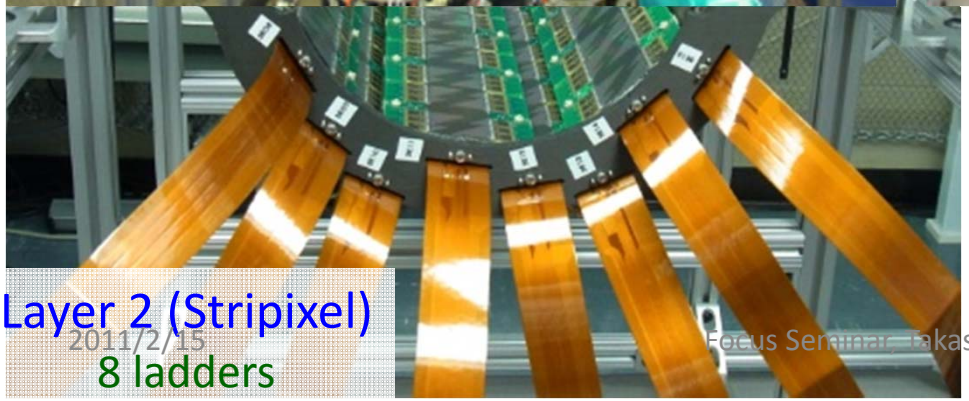
# Pixel and Stripixel Layers are completed



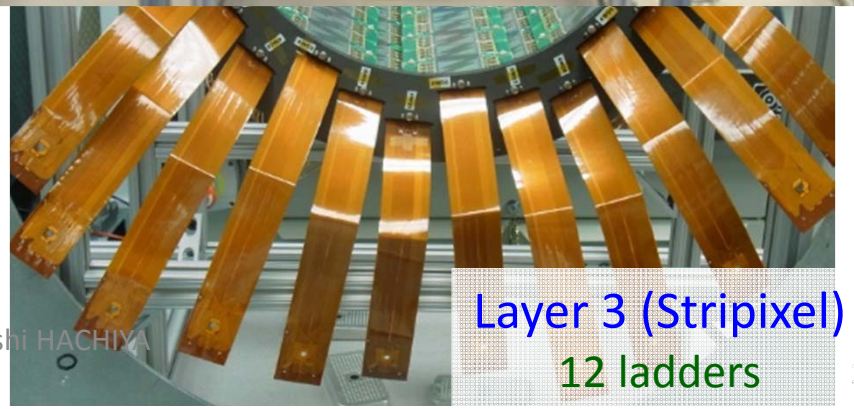
Layer 0 (Pixel)
5 ladders

Layer 1 (Pixel)
10 ladders



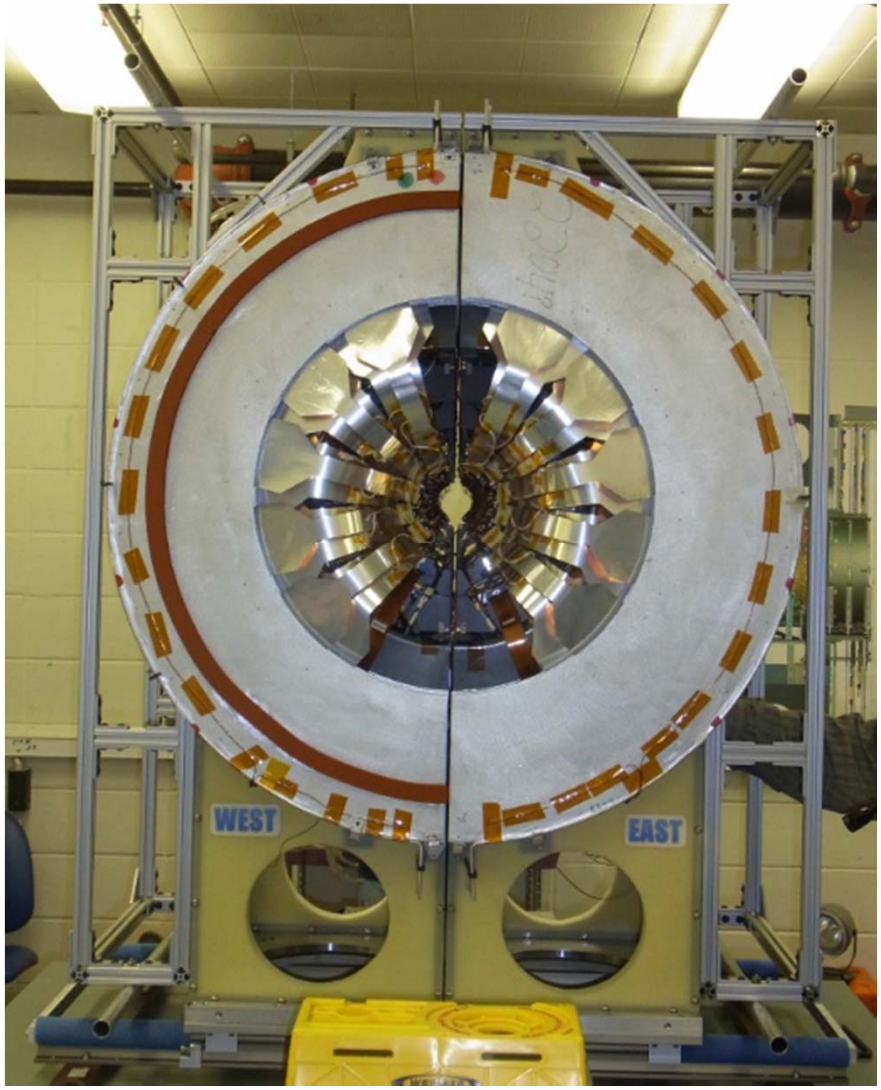


Layer 2 (Stripixel)
8 ladders

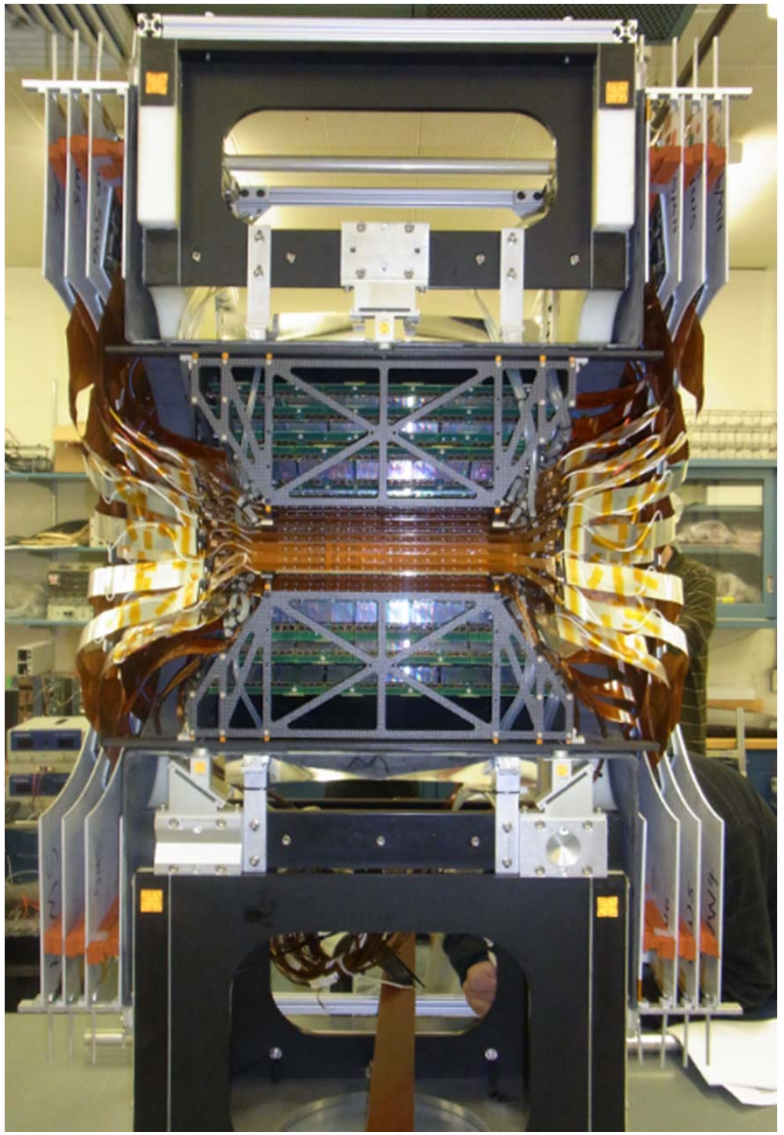


Layer 3 (Stripixel)
12 ladders

# East and West VTX are completed!!



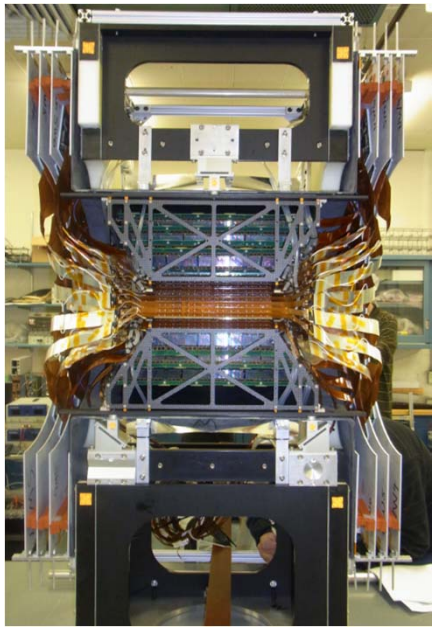

Beam view



Side view

# Installation of VTX to IR

Half barrel at Chem.

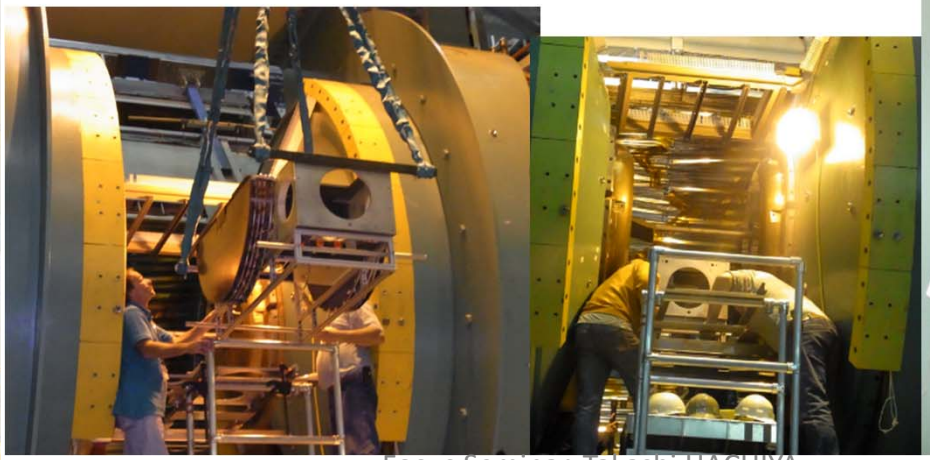


Moving to IR

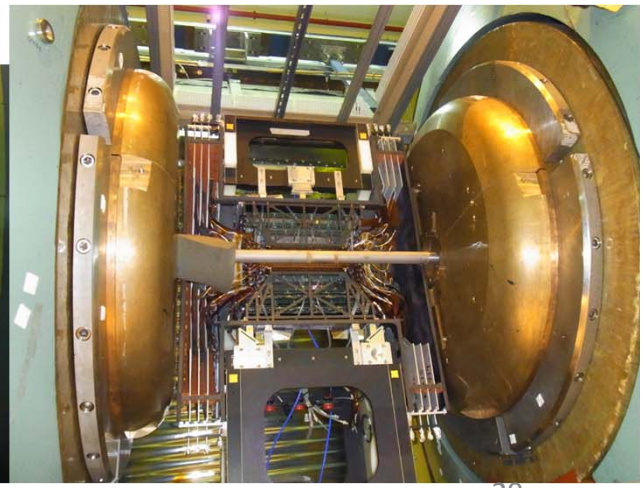
Waiting for installation

Lifting up

Sliding under the beam pipe



INSTALLED !!



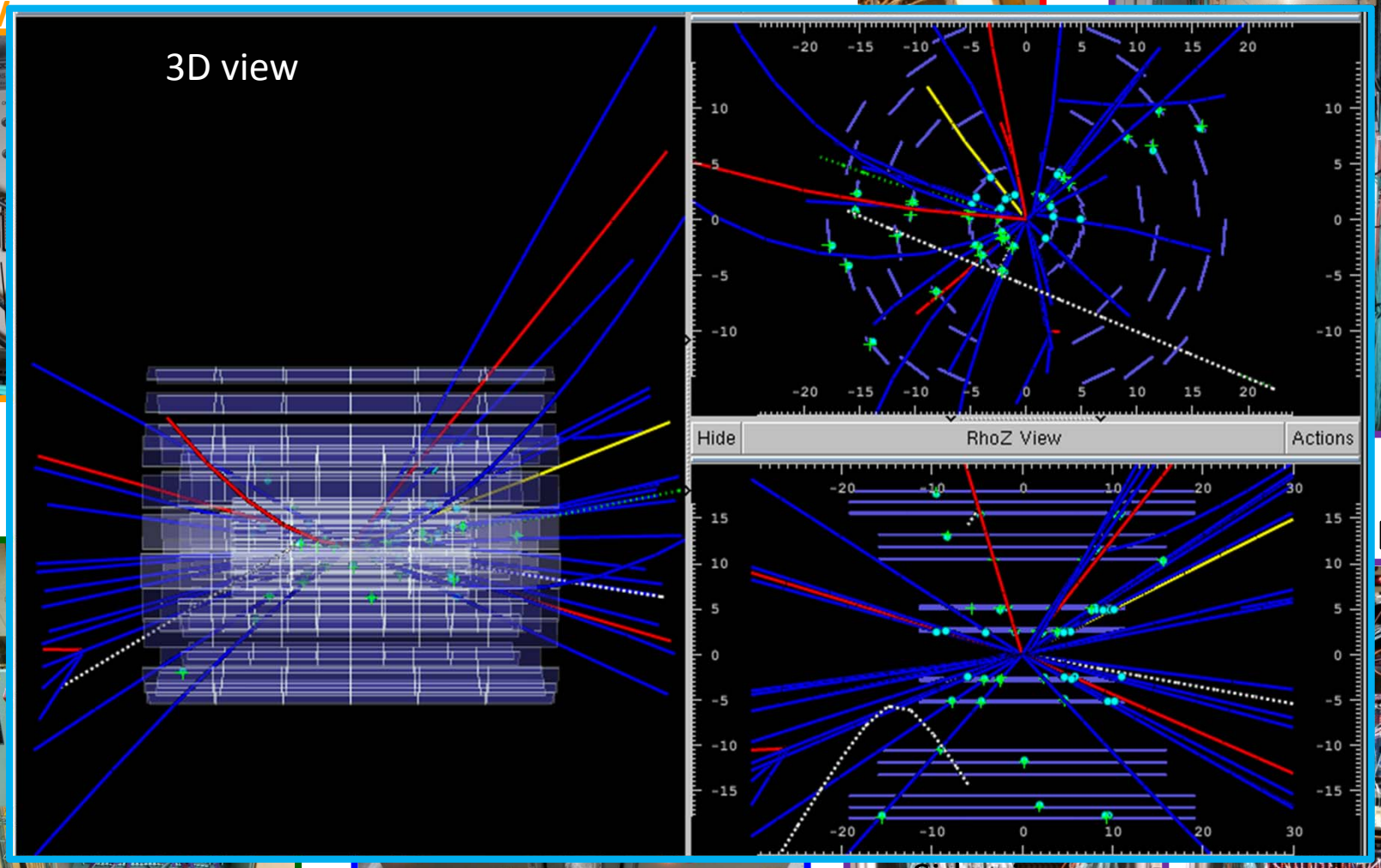
# Picture of Hardware

VTX in IR

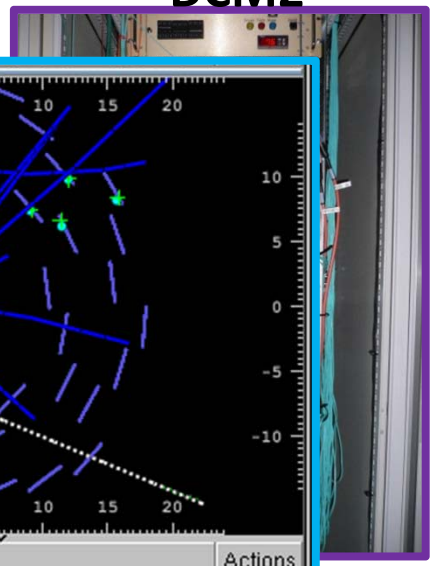
Beam view

High V (Bias V

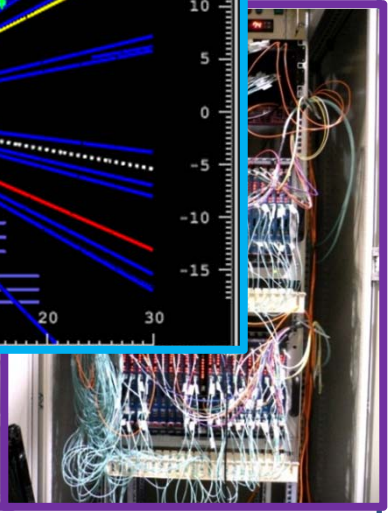
Event Display : Simulation



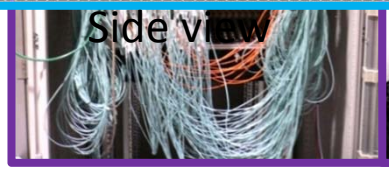

DCM2

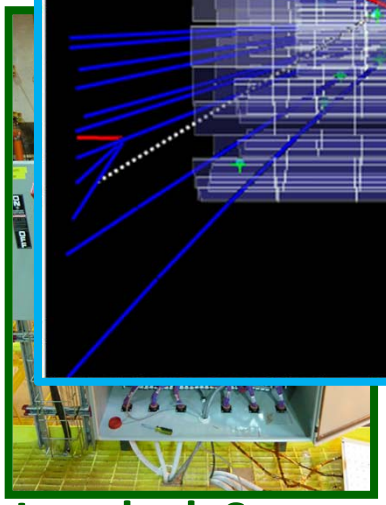


B/CIB



Side view





Interlock System

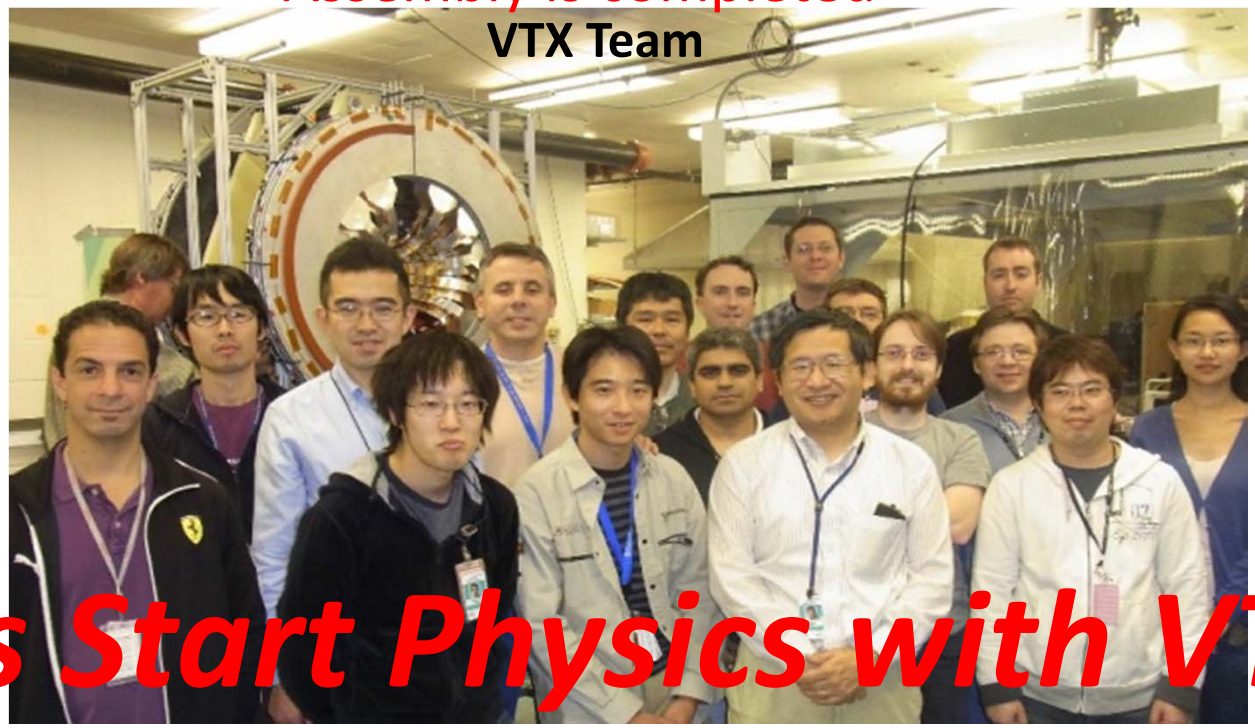
Chiller1 Chiller2

# Summary

- VTX provides new and precise measurement of heavy flavor.
  - Charm and bottom can be separate by DCA measurement of VTX.
  - Flavor dependence of Energy loss and Flow

- VTX was successfully constructed and installed into PHENIX-IR for RUN11.
  - Hardware works are mostly completed.
  - 96% of both Pixel and Stripixel is working.
  - Software works need to be done.

Assembly is completed

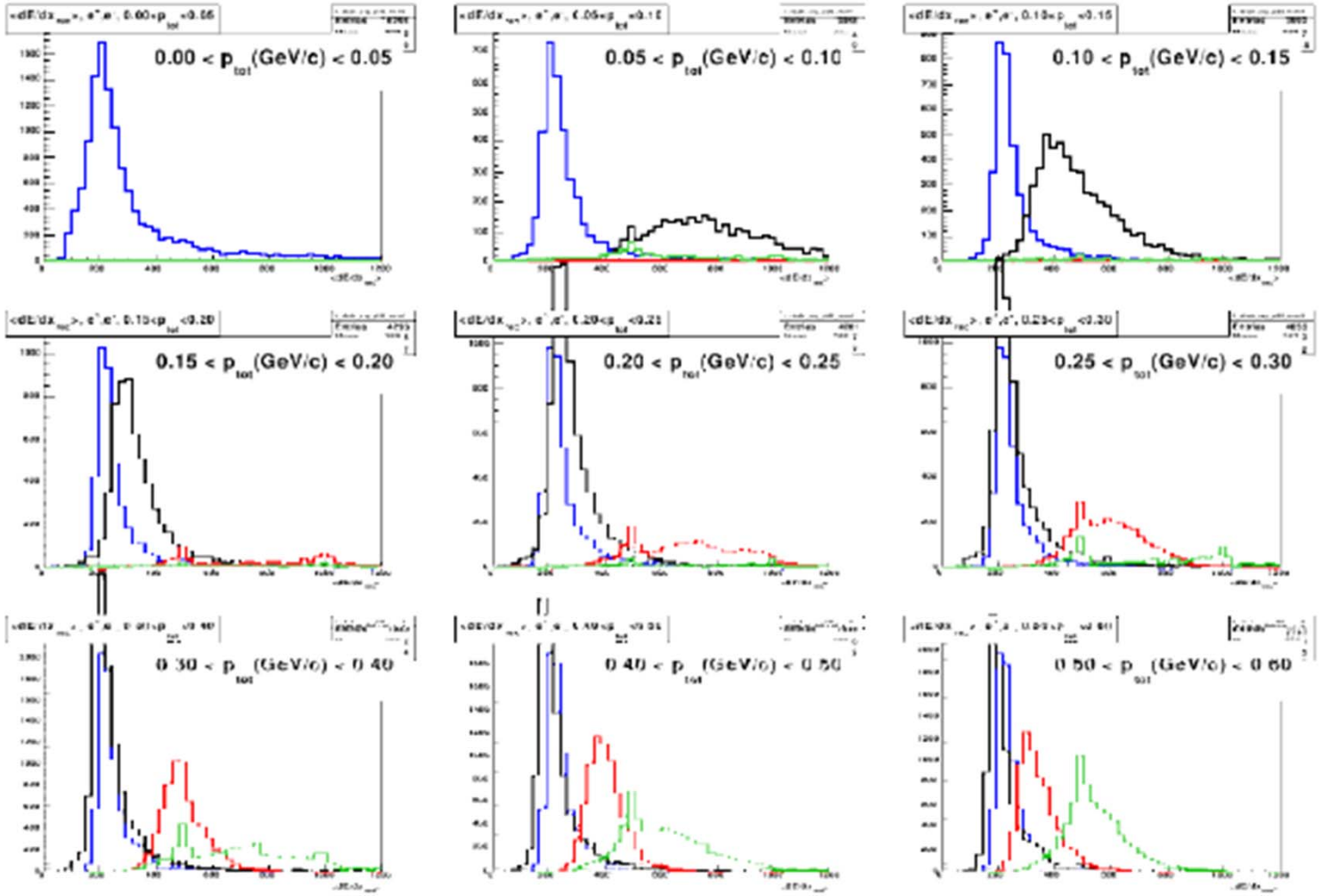



# *Let's Start Physics with VTX*

West and East VTX Installation is completed

# backup

# PID at Low pT




Electron
Pion
Kaon
Proton

Plot from Alan's slide