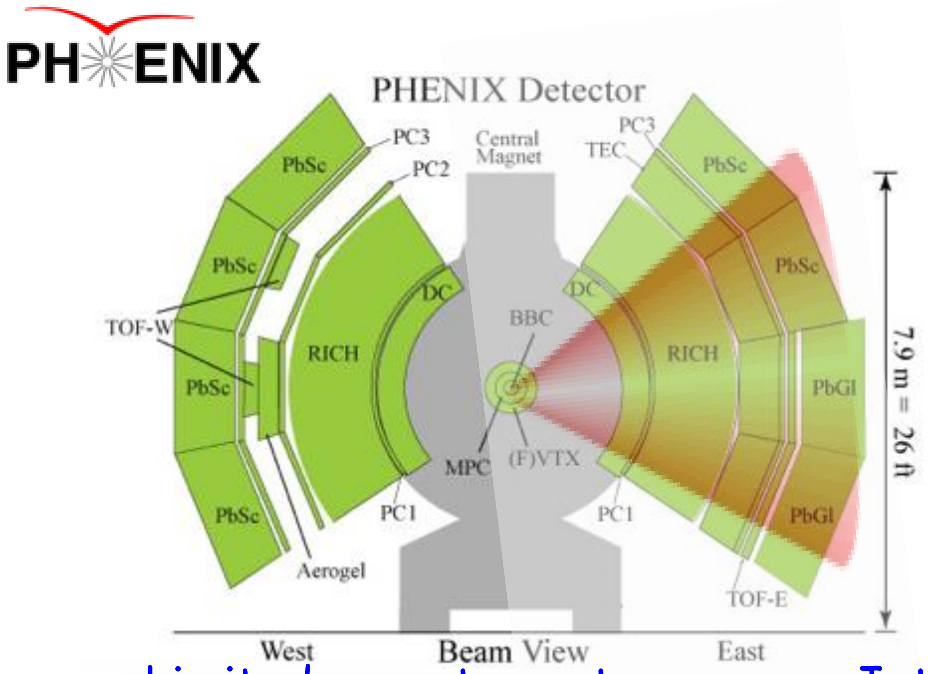
Introduction of sPHENIX & INTT

RIKEN/RBRC
Itaru Nakagawa

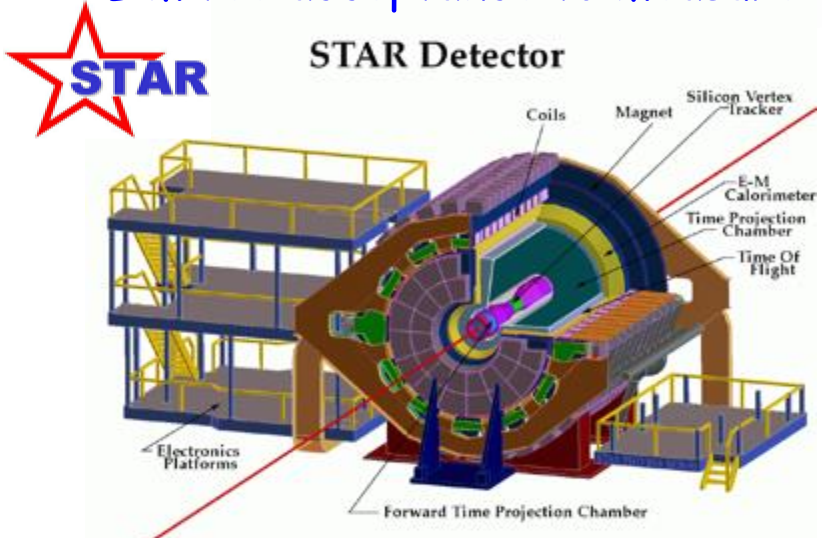
sPHENIX Detector


PHENIX ~2016
RHIC
sPHENIX
STAR
LINAC
EBIS
NSRL
BOOSTER
AGS

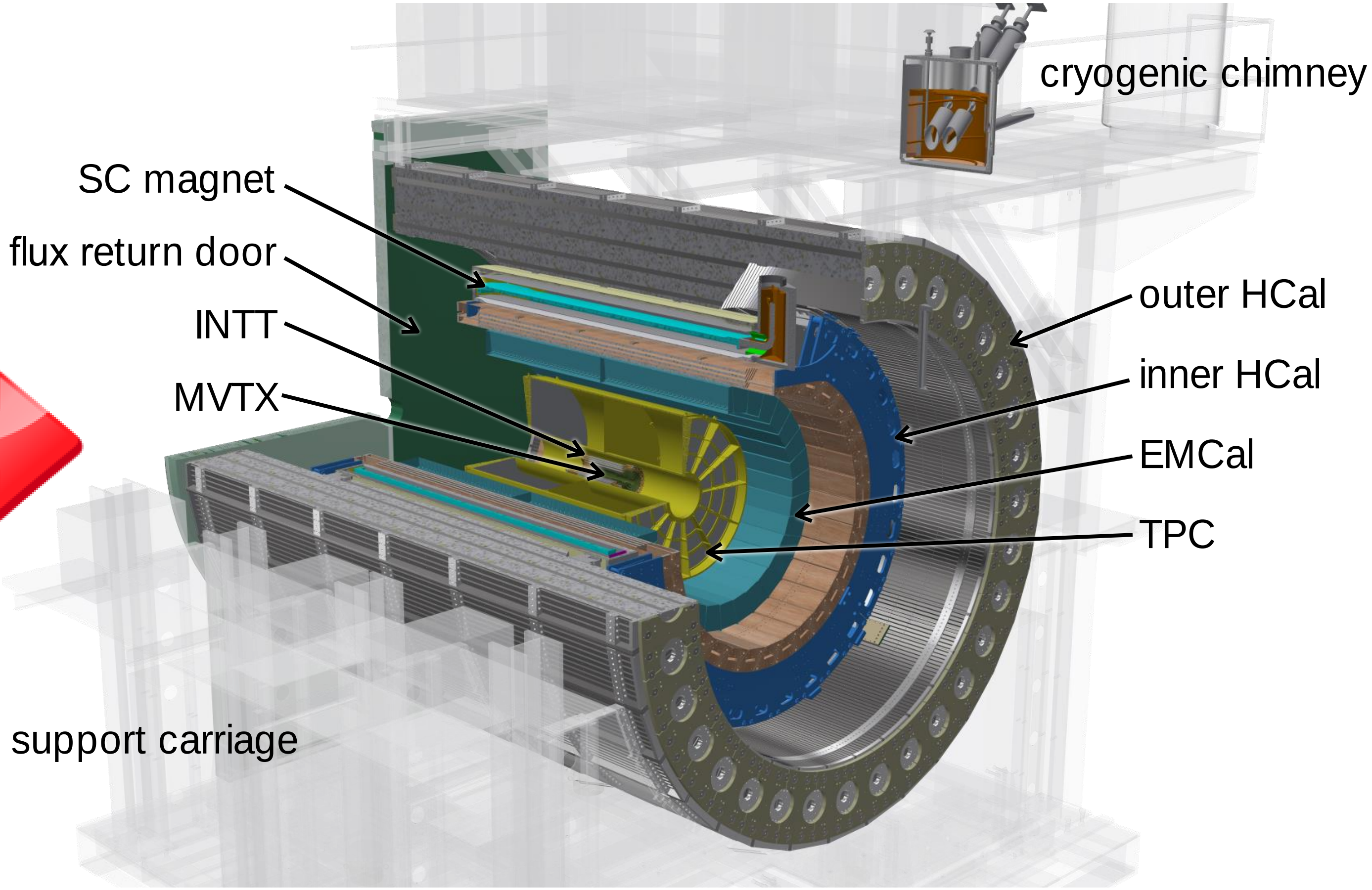
What's new about sPHENIX



Limited acceptance to measure Jet.



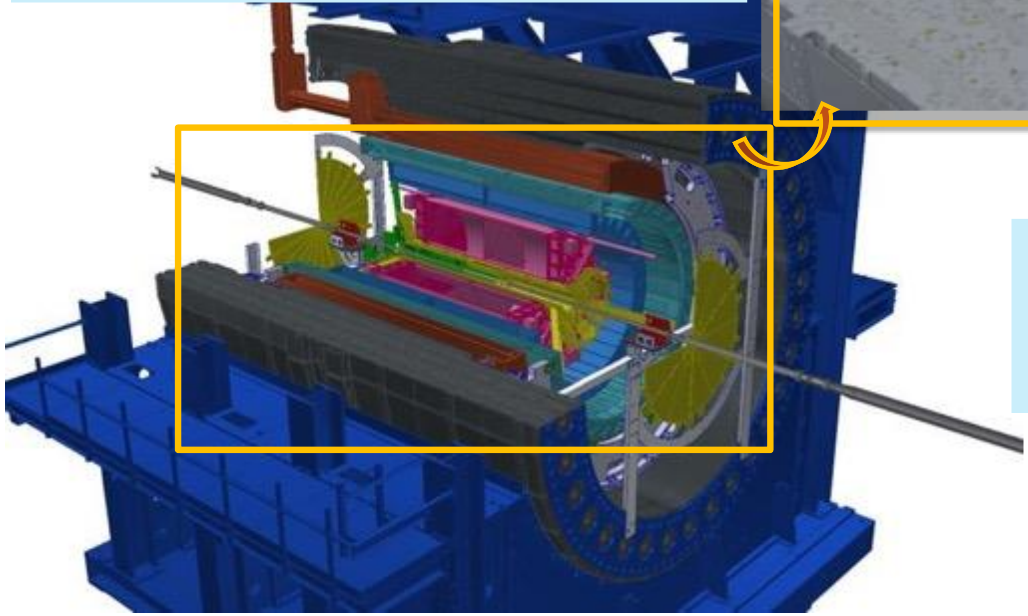
4π, but incomplete for jet without HCAL

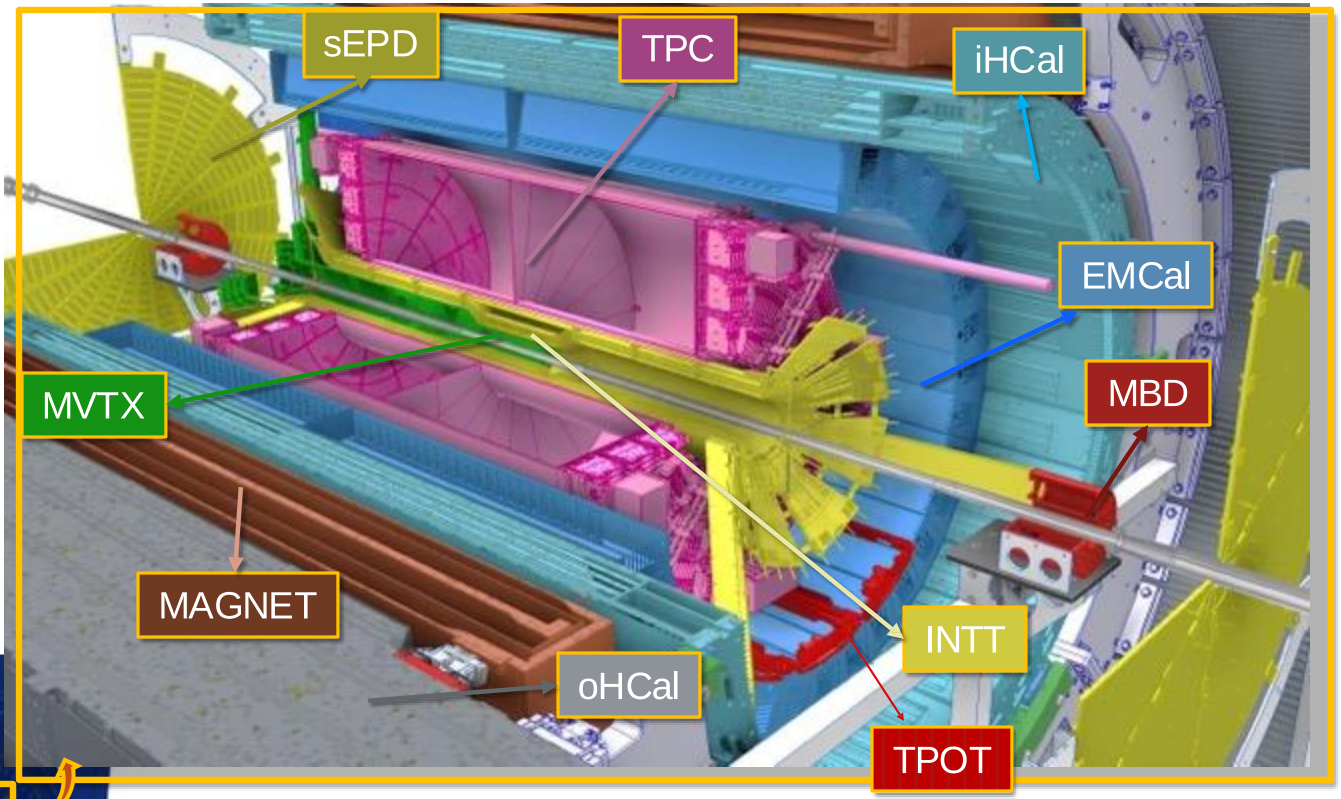


4π & -1<η<1 with HCAL
Designed to be ideal detector for Jet

sPHENIX Detector

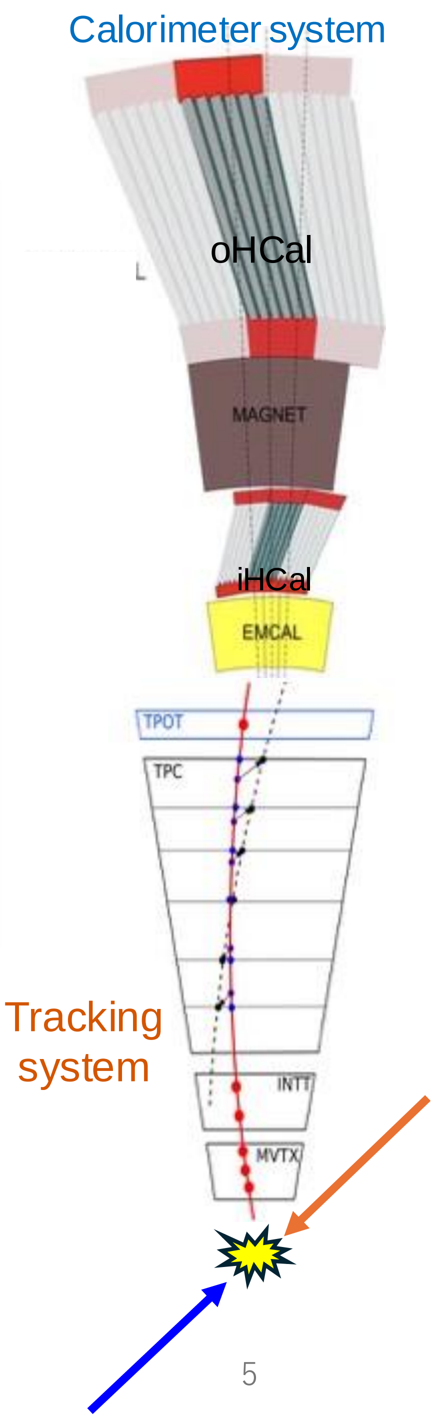
- 1.4T Solenoid from BaBar
- Hermetic coverage: |η|<1.1, 2π in φ
- Large-acceptance EM+H calorimeters: brings first full jet reconstruction & b-jet tagging at RHIC!!
- High data rates: 15 kHz for all subdetectors
- Precise tracking with tracking system in stream readout



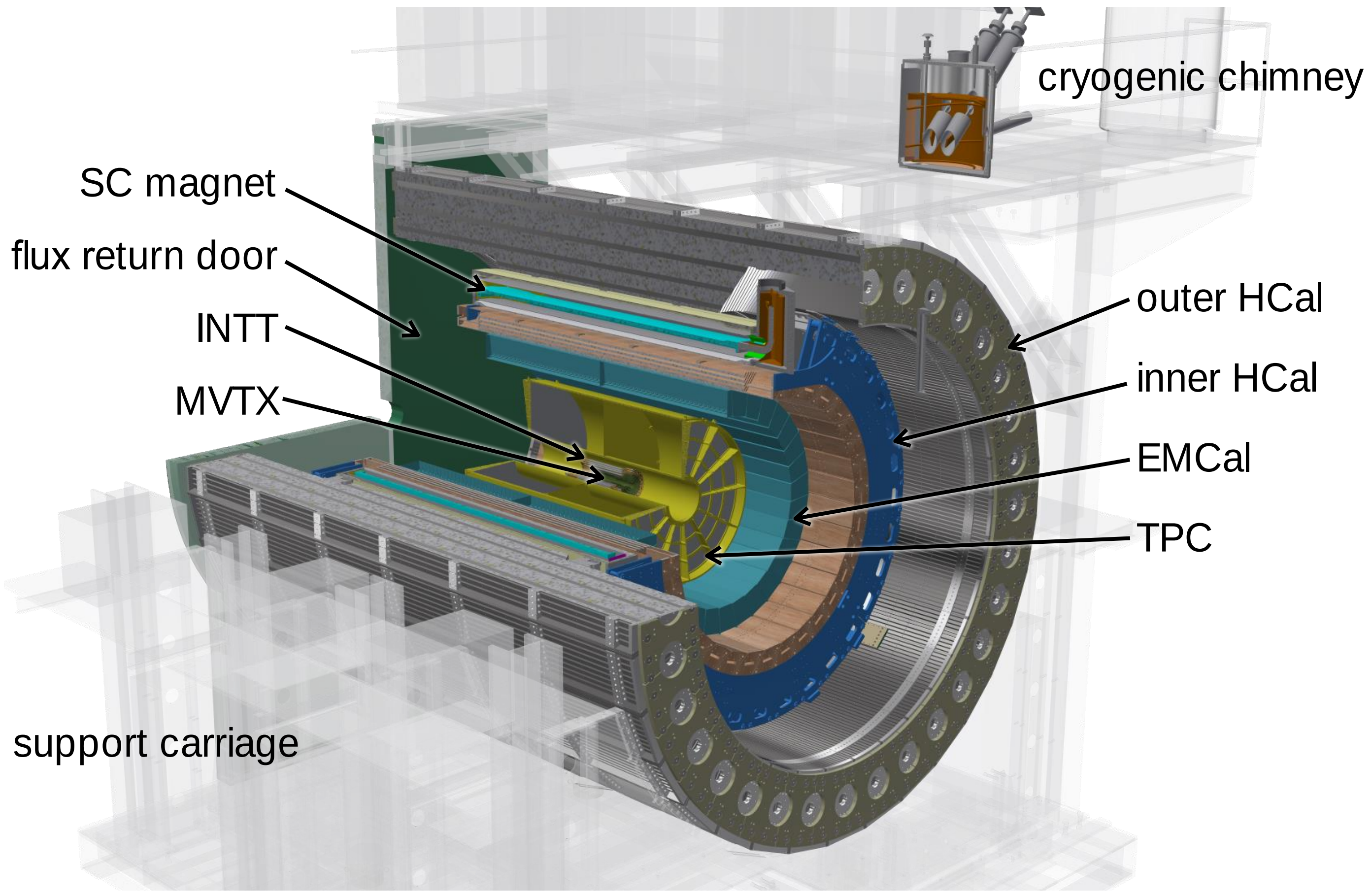


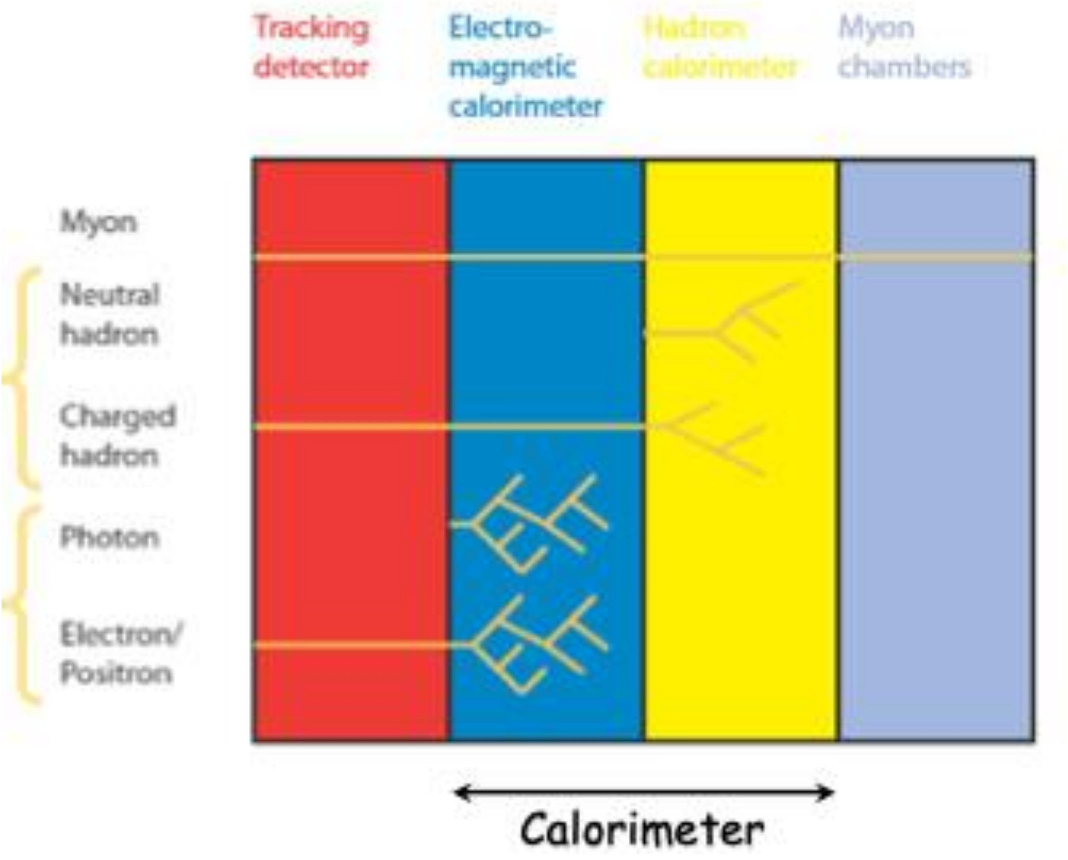
2023 : Commissioning Au+Au
2024 : p+p, Au+Au
2025 : Au+Au … p+A?

$\sqrt{s}$ =200GeV



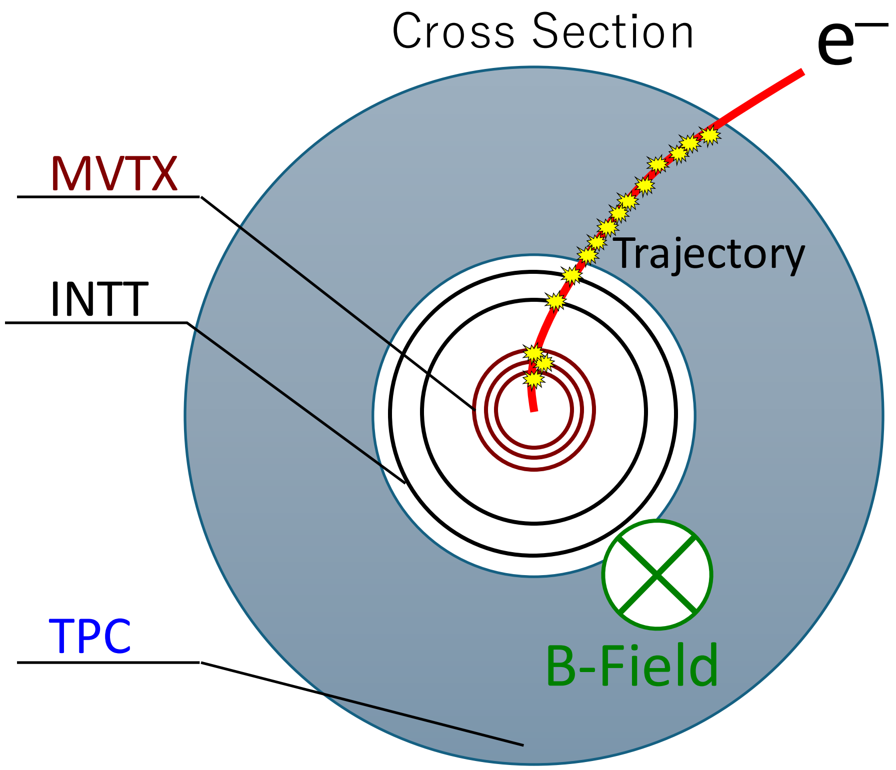
Modern Experimental Detector Layout

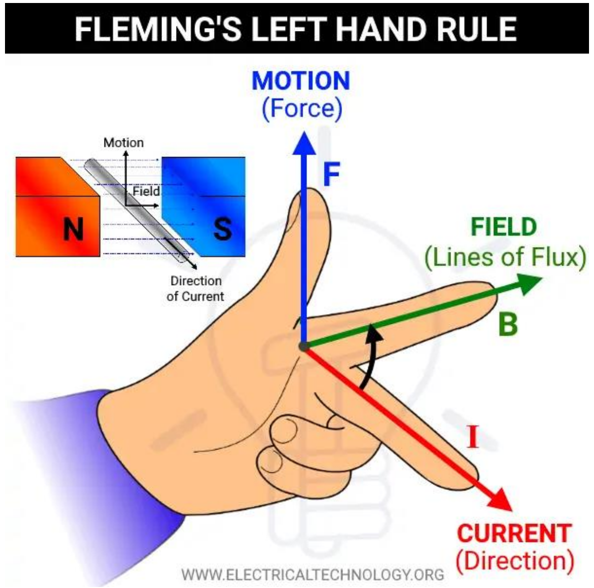


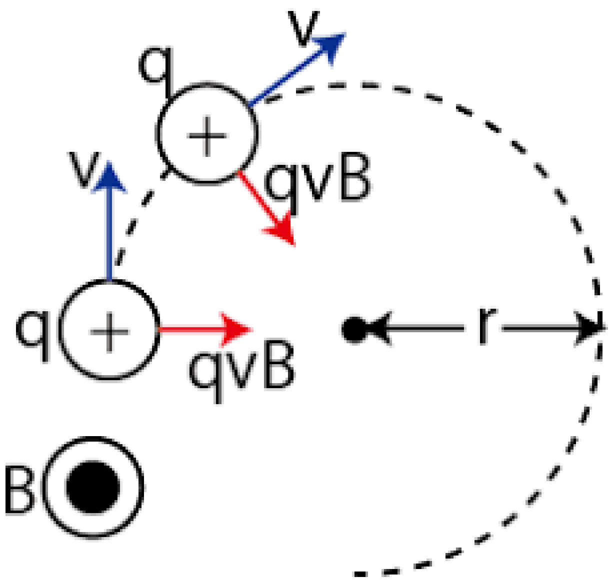


Tracking System

Tracking Particle Trajectory







Estimate Momentum of the particle trajectories by measure radius.

sPHENIX Tracking Detectors

MVTX (2.3 < r < 3.9 cm): precision vertexing

- 3 layers of Monolithic Active Pixel Sensors (MAPS) closely based on ALICE's ITS2
- 5 μm position resolution for tracks with p_T>1 GeV

INTT (7 < r < 12 cm): pileup separation

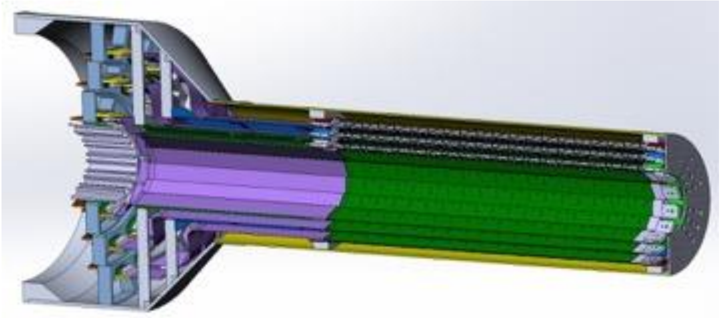
- 2 layers of silicon strips (78 μm pitch)
- single-beam-crossing timing resolution

TPC (30 < r < 78 cm): momentum measurement

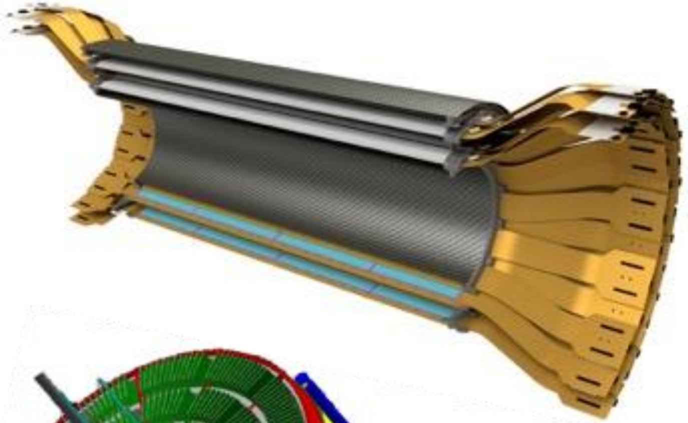
- Very compact GEM-based TPC: 48 layers with gateless and continuous readout.

TPC Outer Tracker (TPOT): calibration of beam- induced space charge distortions

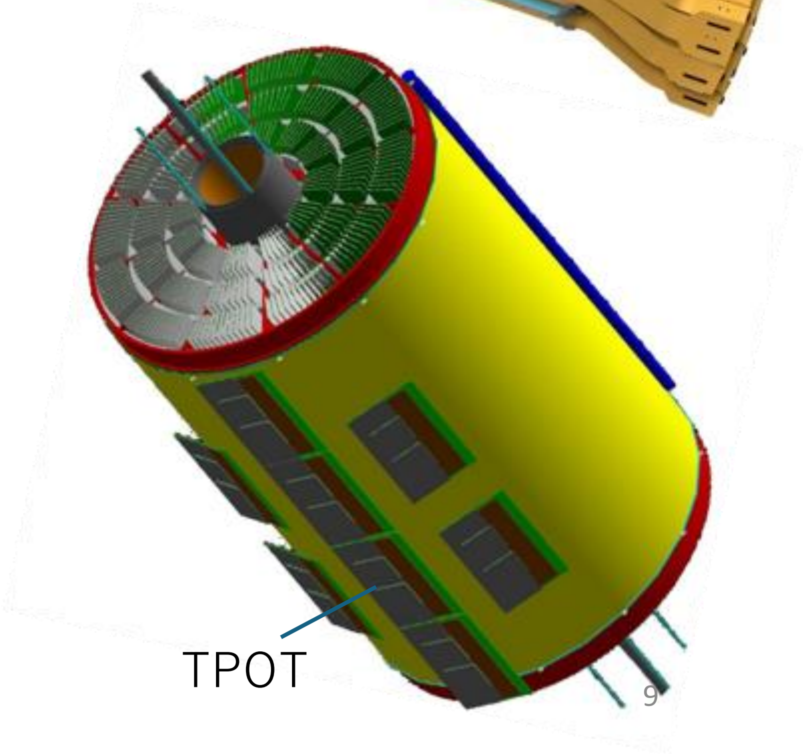
- 8 modules of Micromegas inserted between TPC and EMCal



MVTX



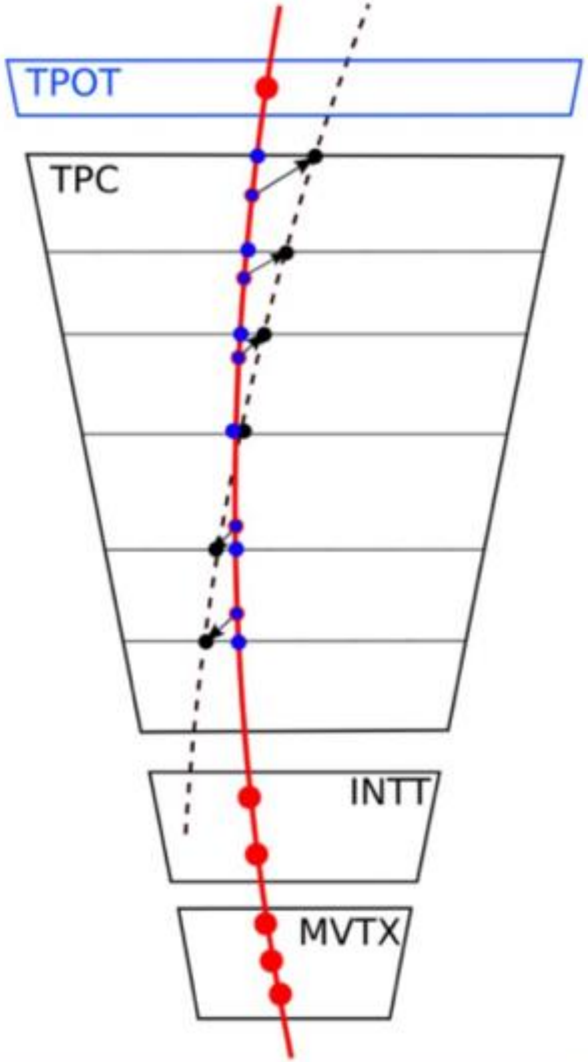
INTT

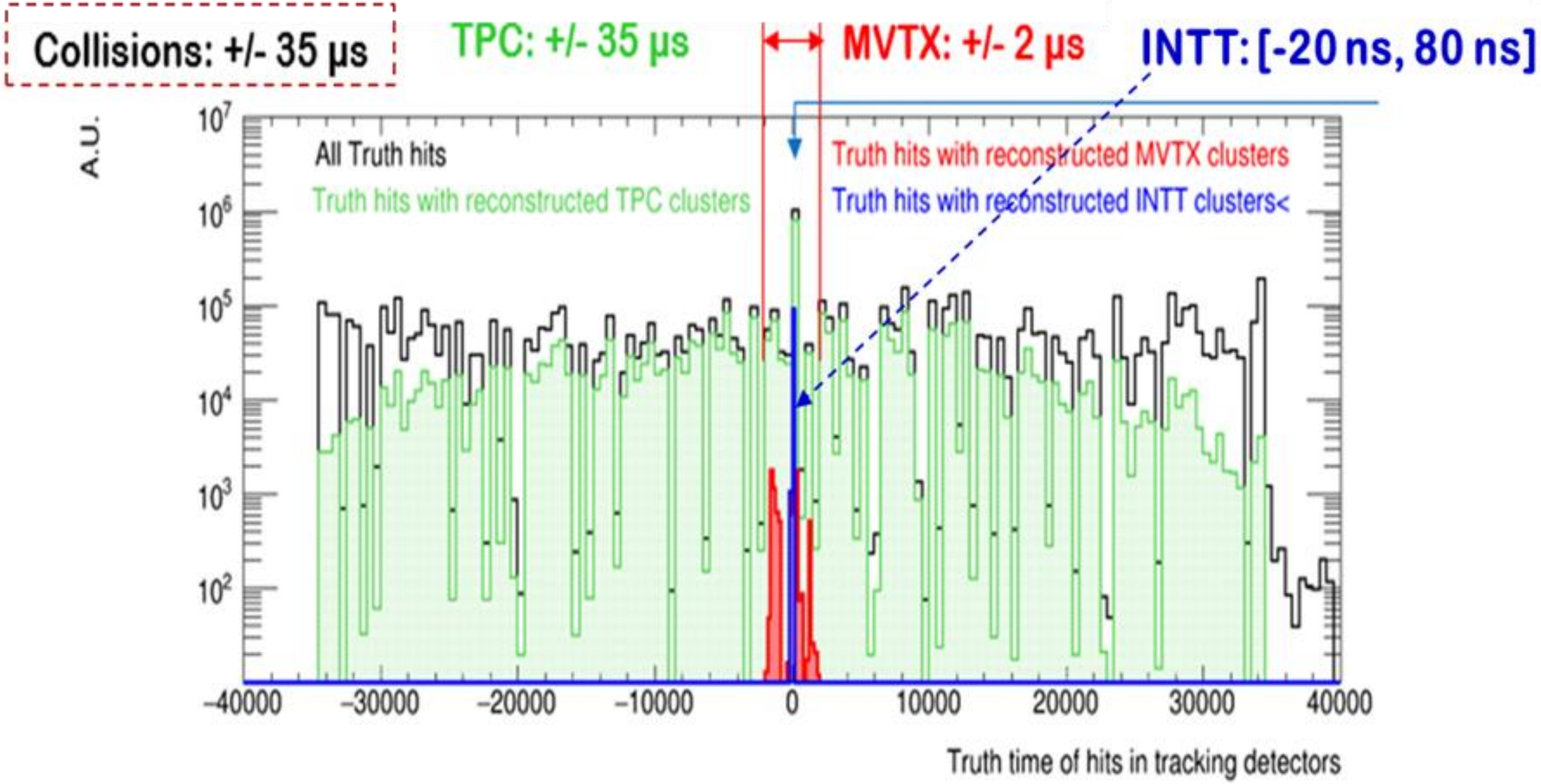


TPC

9

Tracking Points and Timing





Silicon Sensors

Design: Silicon and the Bethe-Bloch equation

- Doped silicon is our typical semiconductor
- A charged particle passing though a material releases energy and is measured by the Bethe-Bloch equation [PDG]:

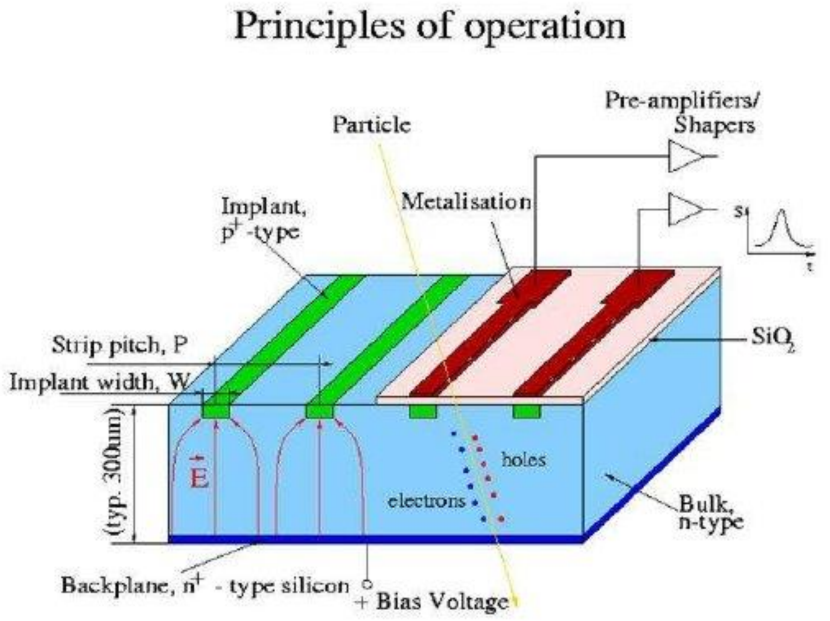
$$-\left\langle \frac{dE}{dx} \right\rangle \propto z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \left(\frac{2\gamma m_e c^2 \beta^2 K}{I^2} \right) - \beta^2 - \frac{\delta}{2} \right]$$

where K is the energy of the particle and I is the excitation energy

- It take 3.6 eV to make an electron-hole pair
- A 1 GeV pion passing through silicon releases ~400 eV/μm
- You get about 100 electrons produced for every micrometer of silicon in your detector

Design: The pn junction

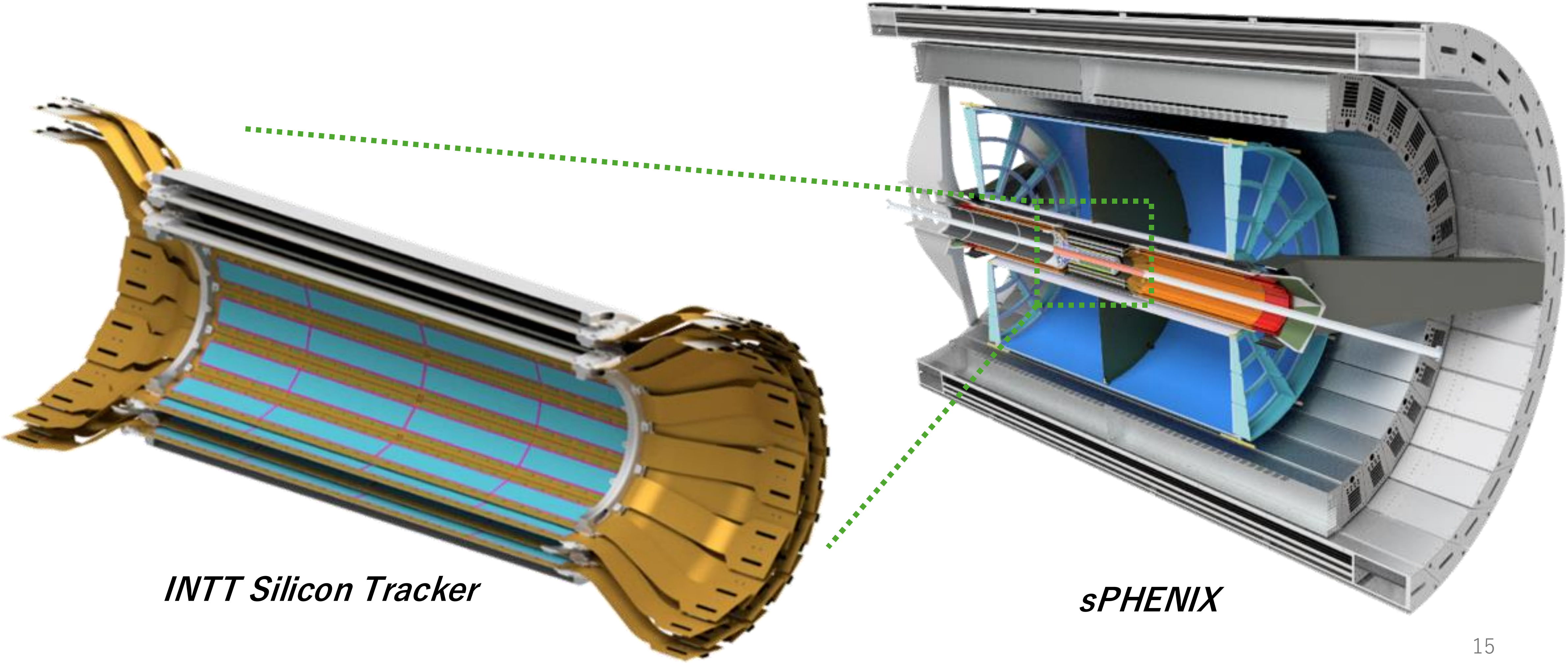
- Silicon has 4 valence electrons
- Dope with a 5 valence element and you make an n-type material (donors)
- Dope with a 3 valence element and you make an p-type material (acceptors)
- Combine a p and n material and you create a depletion zone at the boundary and a pn junction where there's an electric field
- Apply a positive voltage to the n material and a negative voltage to the p material and we have a reverse-biased diode



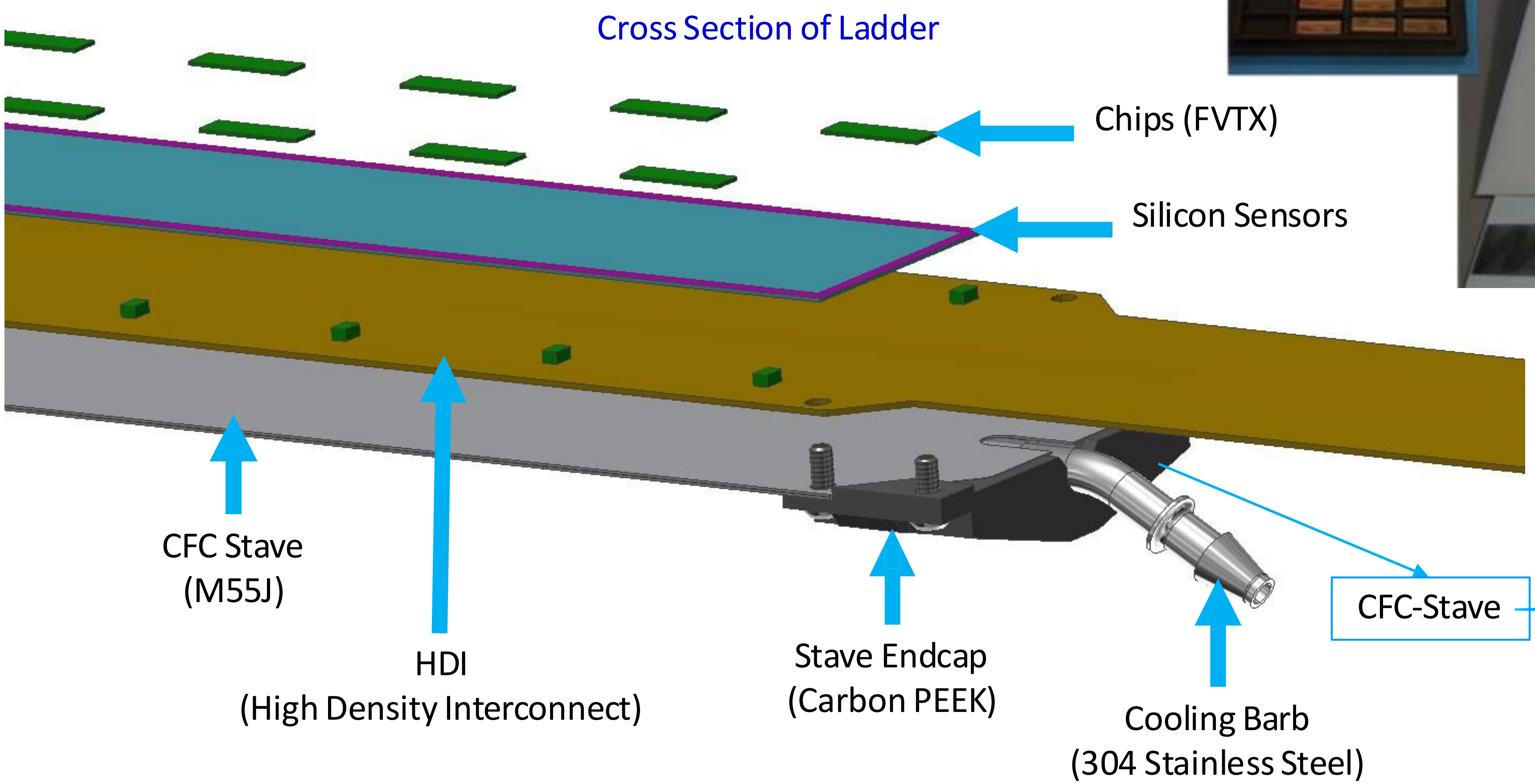
- If we fully deplete the region, no charge can flow without external influence (our particles)
- Particles release energy in the silicon, create electron-hole pairs which we can pick up in our strips or pixels
- Width (W) of the depletion region

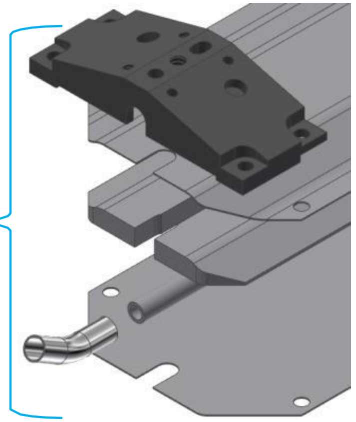
INTT

INTT Silicon Tracker



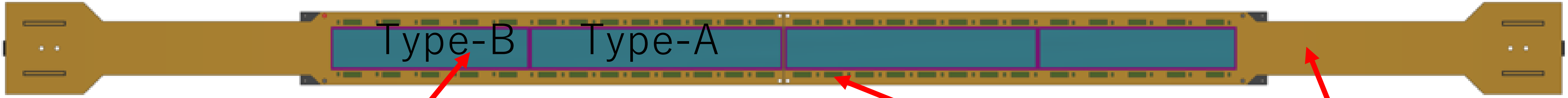
INTT Silicon Ladder





Assembled INTT Silicon Ladder

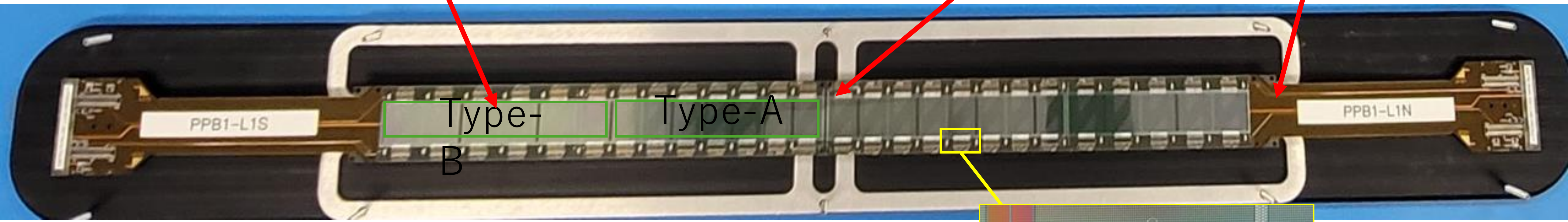
INTT Full Ladder



1. Silicon strip sensors

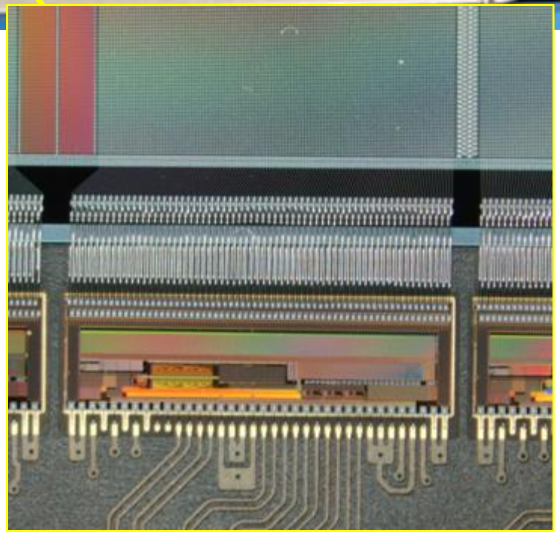
2. FPHX Chips

3. HDI Readout Cable



Wirebonding
(silicon-FPHX)

Wirebonding
(FPHX-HDI)

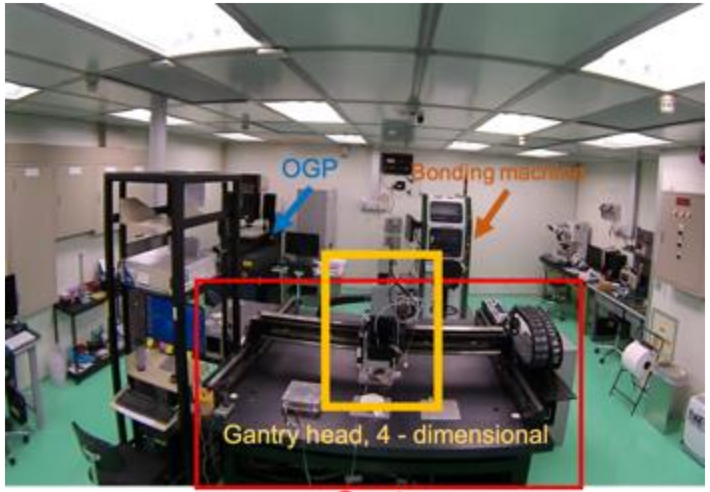


Silicon

FPHX Chip

HDI

INTT assembly in Taiwan



Taiwan Silicon Detector Facility (TSiDF)

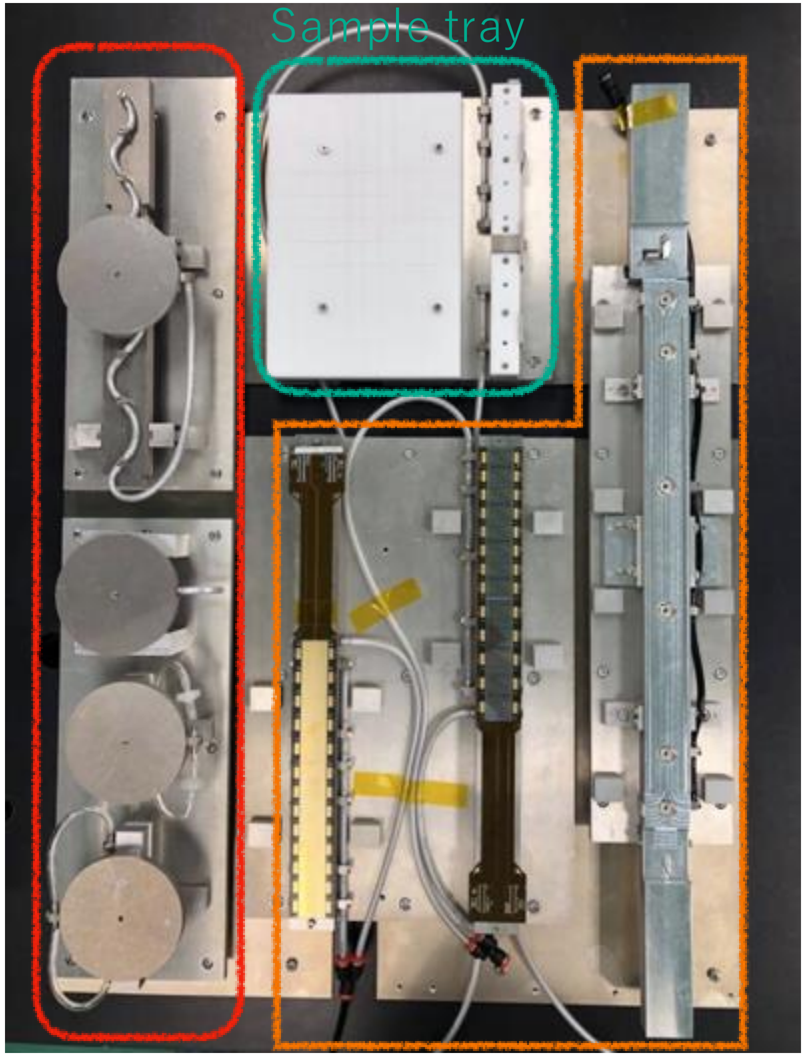
Assembly Unit : Half-ladder

Assembly procedures :

1. Chips glued on HDI then wire-bonded
2. Sensors glued on HDI then wire-bonded
3. Encapsulate all wire-bonds
4. Thermal cycles modules

Ladder assembly procedures :

- 2 half-ladder glued on stave



INTT assembly family on Gantry

Rong-Shyang Lu

Lian-Sheng Tsai

Wei-Che Tang

Jenny Huang

Kai-Yu Cheng

Cheng-Wei Shih

Ou-Wei Cheng

FPHX Chip/Produced by FNAL

Developed for Forward Vertex Detector for PHENIX at Fermi Lab.

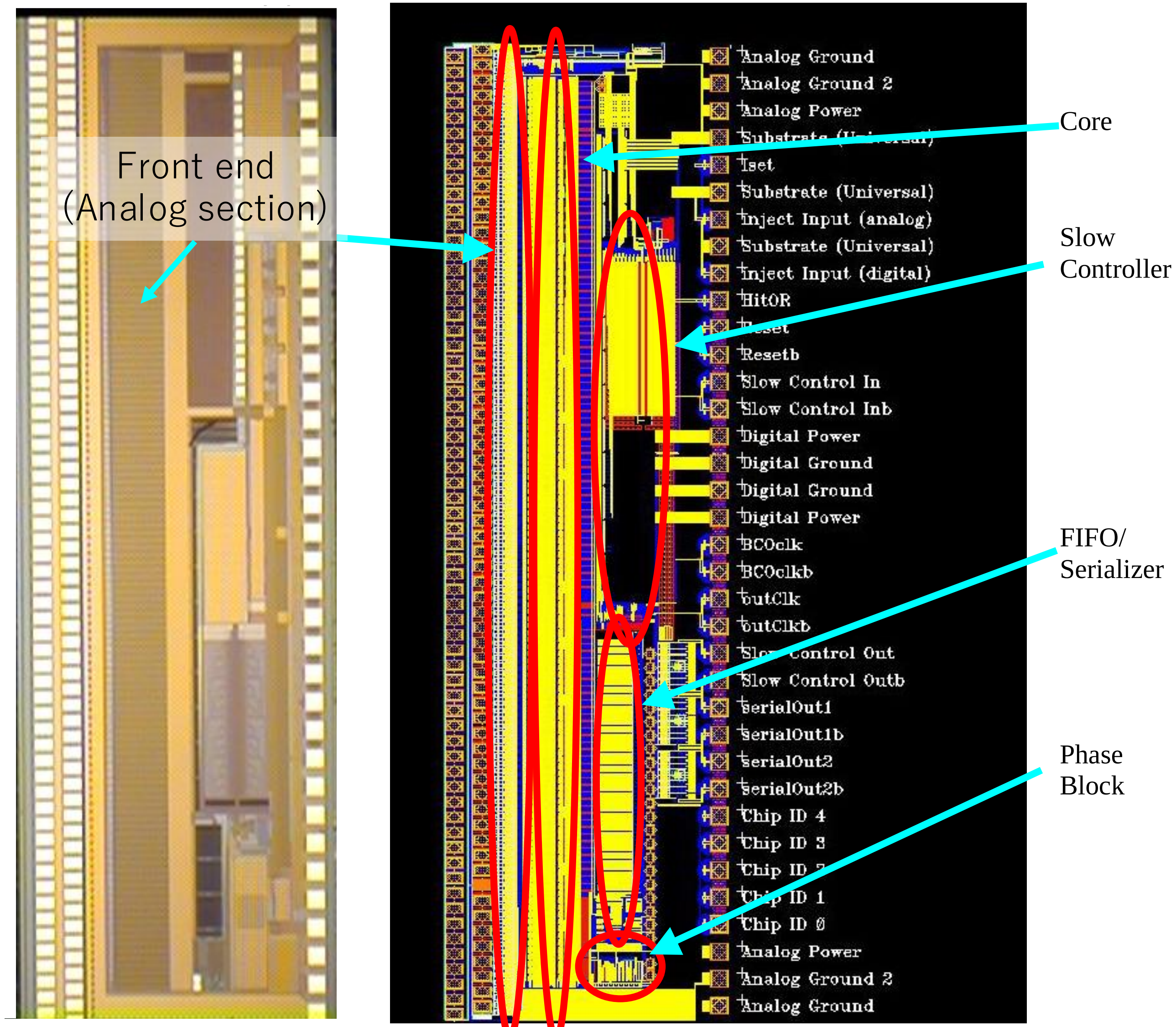
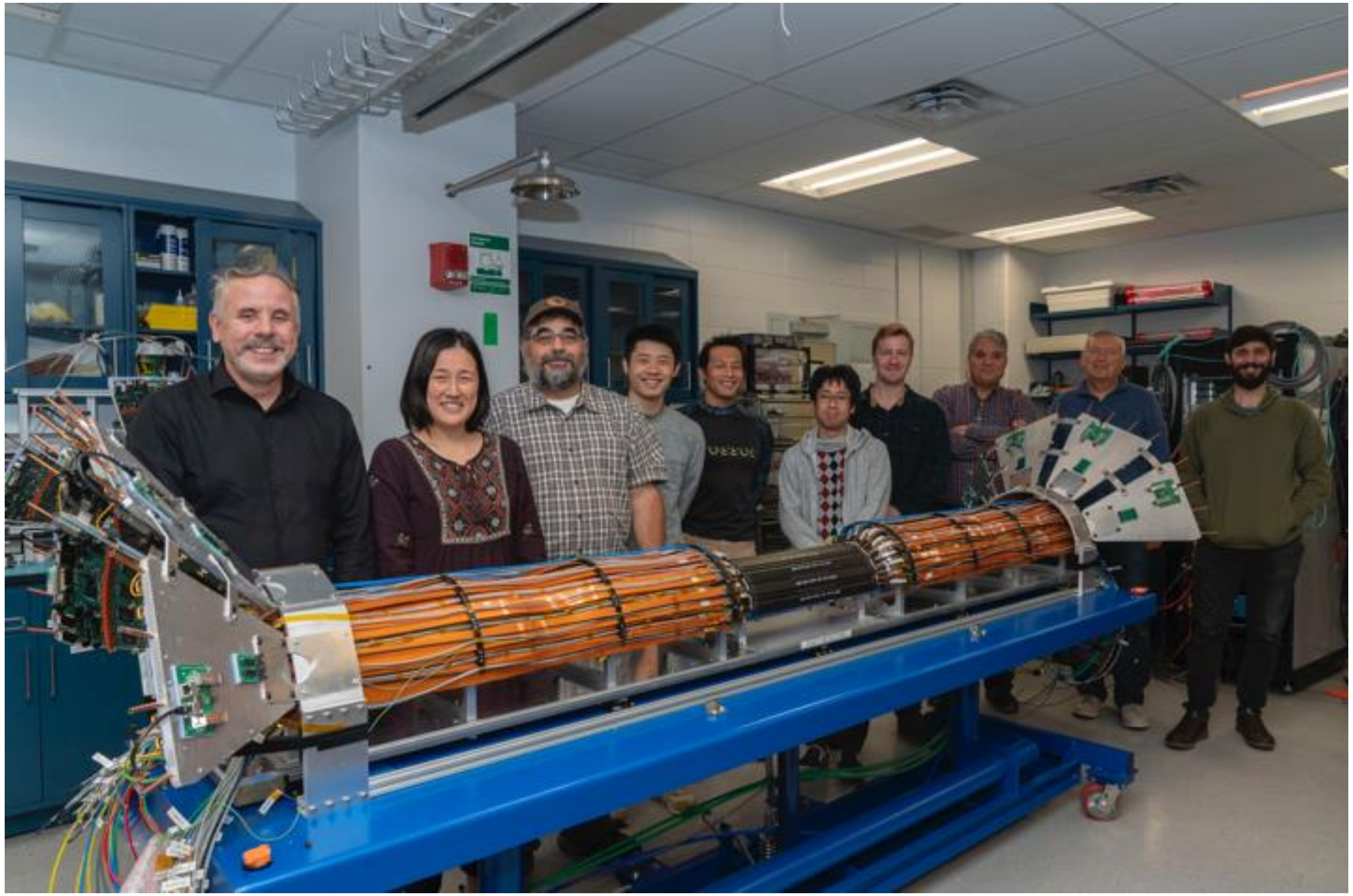


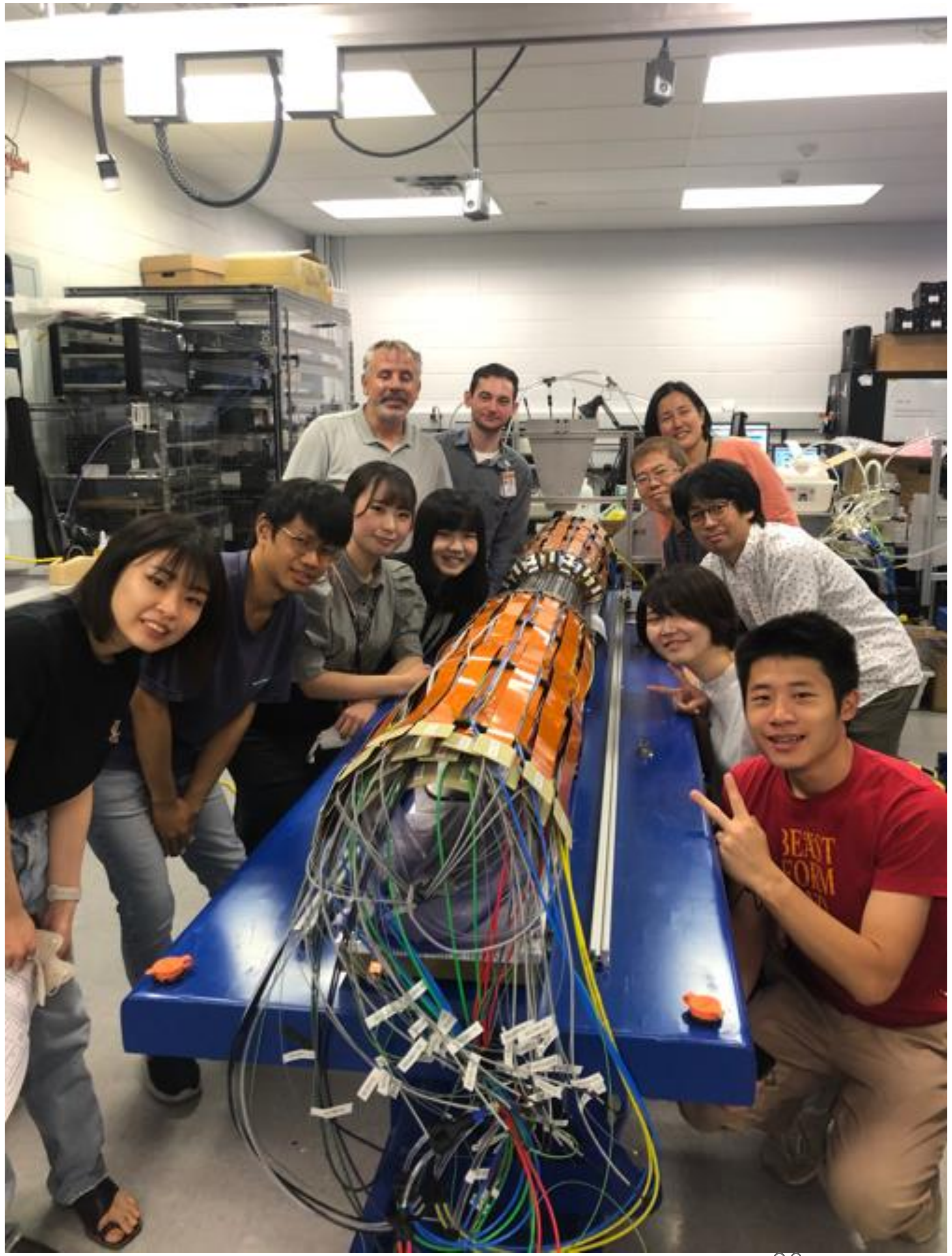
Figure 3 - The FPhx Layout

Specification	FPHX
ADC/channel	3 bits
Operation Voltage	2.5V
Power Consumption	64 mW
Number of channels	128
Data Transmission	200Mbps

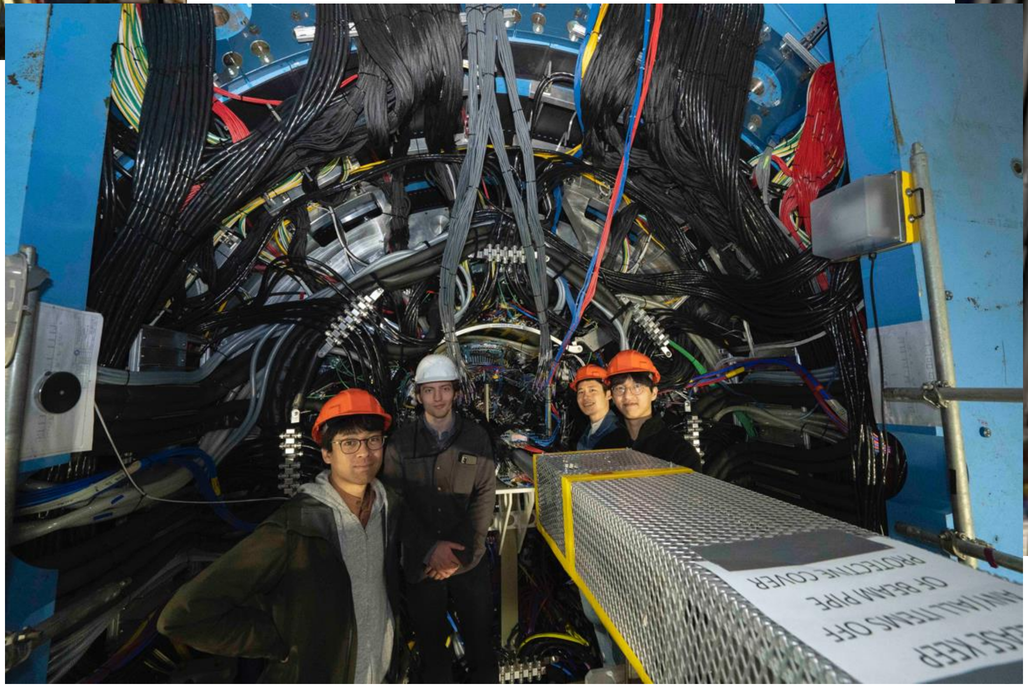
Each FPHX chip integrates and shapes (CR-RC) signals, digitizes and sparsifies the hit channels each beam crossing (106ns beam clock), and serially pushes out the digitized data.

Barrel Assembly Completion





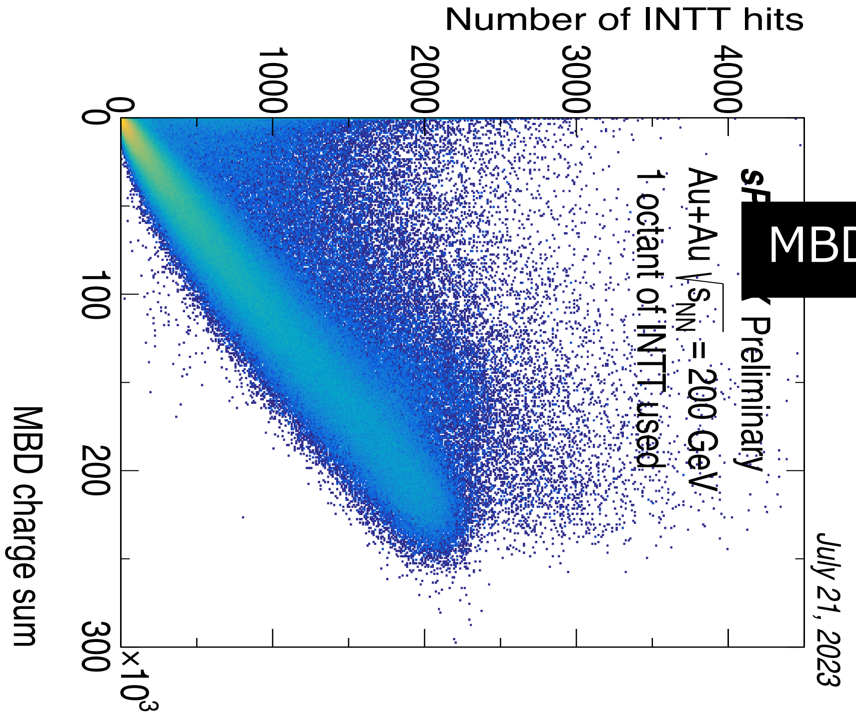
Installation to sPHENIX

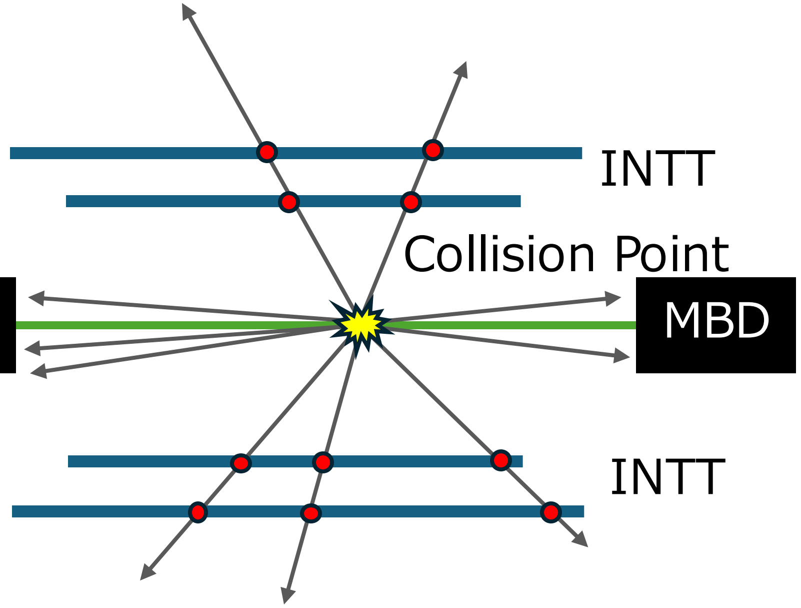


Performance of INTT Silicon Sensors

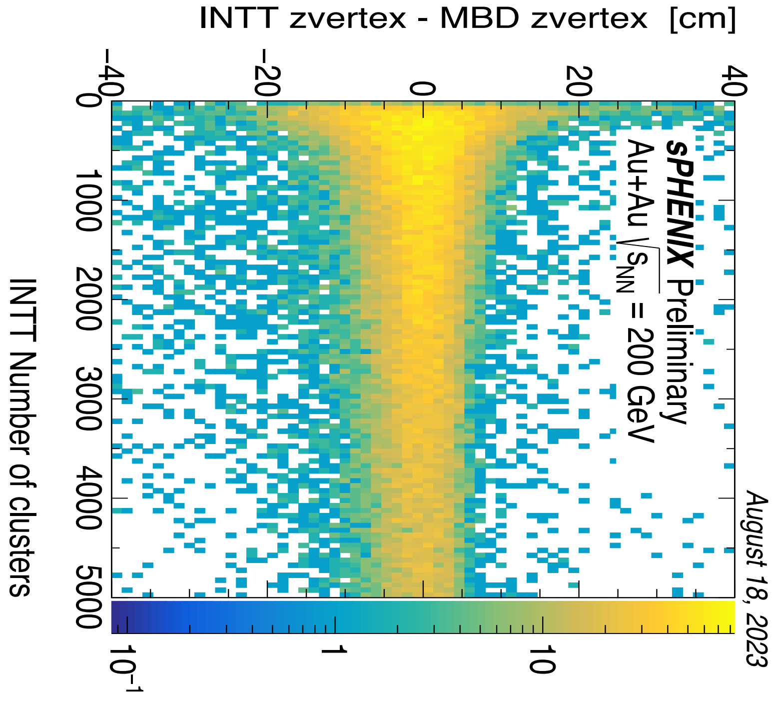
- Active Strips ~ 99%
- Moderate dark currents
- etc

Multiplicity

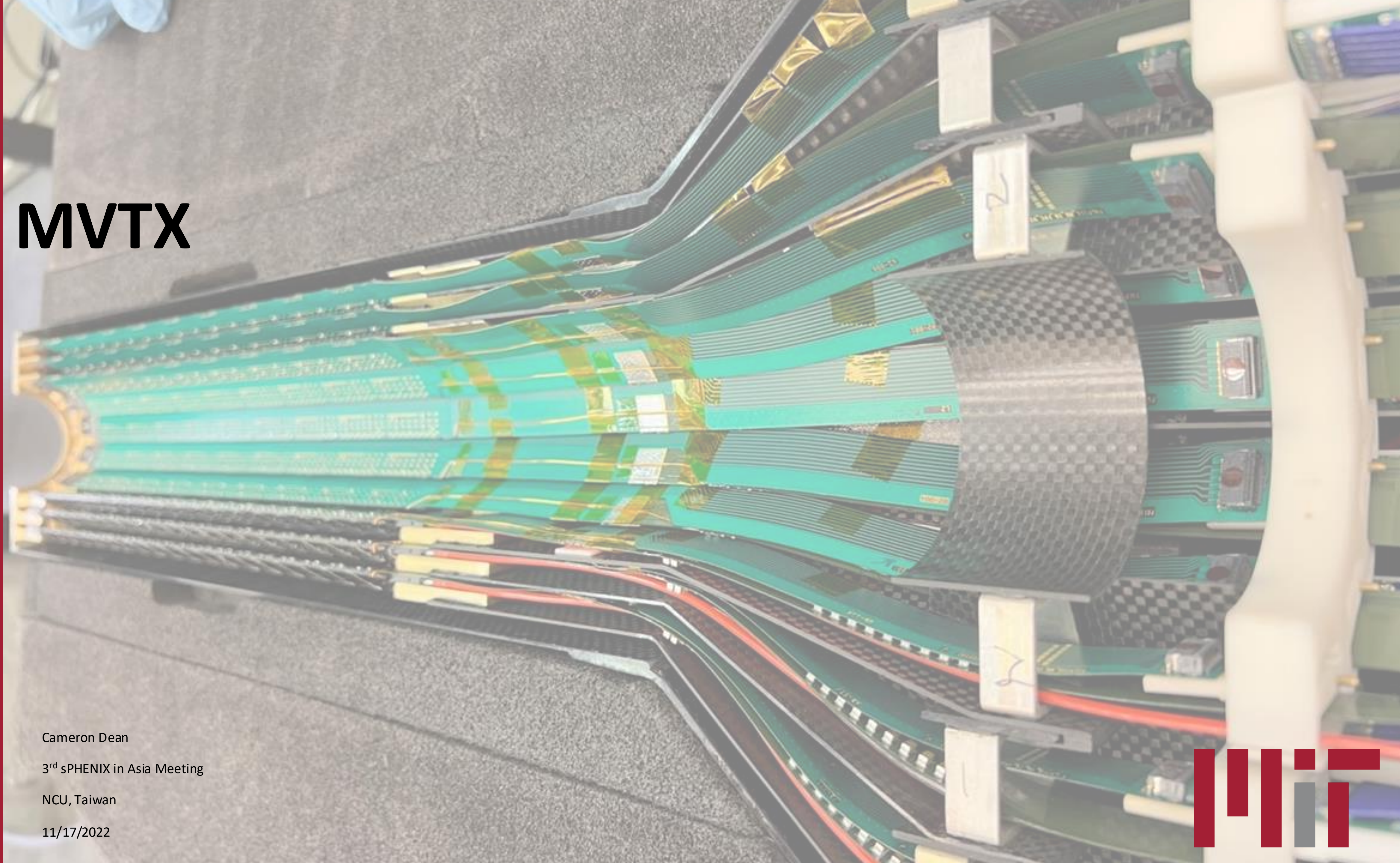




Reconstructed z-vertex



Reconstructed z-vertex proven to be consistent between MBD and INTT



MVTX

Cameron Dean

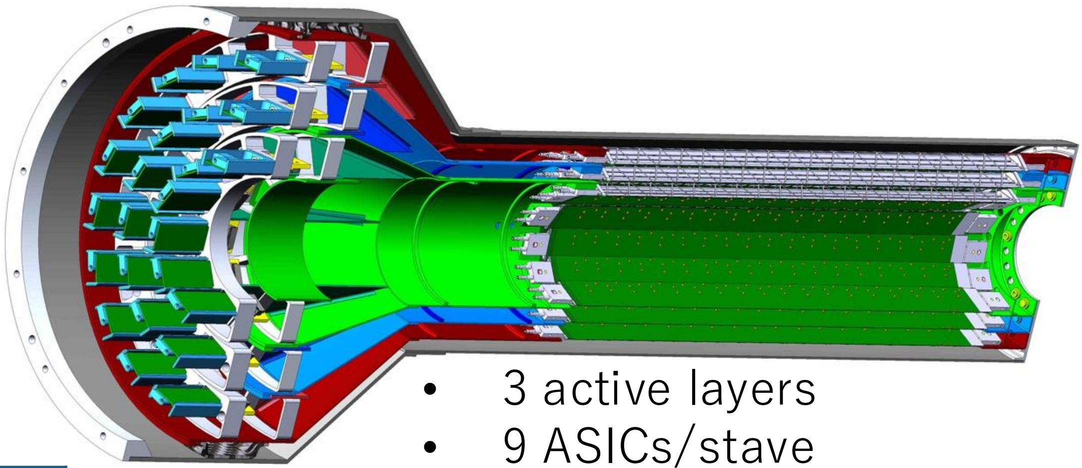
3rd sPHENIX in Asia Meeting

NCU, Taiwan

11/17/2022

The MAPS-based Vertex Detector

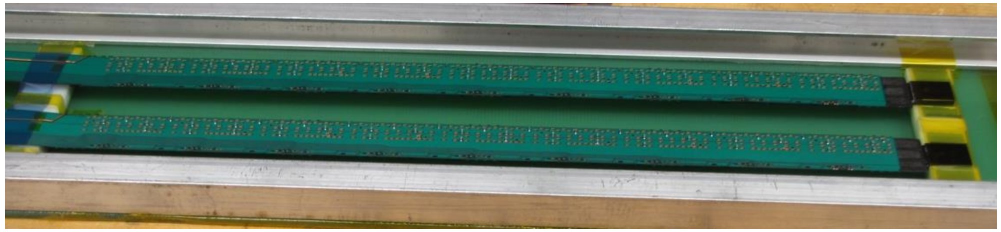
- Comprises of 3 layers of monolithic active pixe sensors using the ALICE ALPIDE
- The front-end readout uses the ALICE Readou
- The back-end uses the ATLAS FELIX
- Records from 2.5 cm to 4.5 cm, radially
- 226,492,416 pixels!



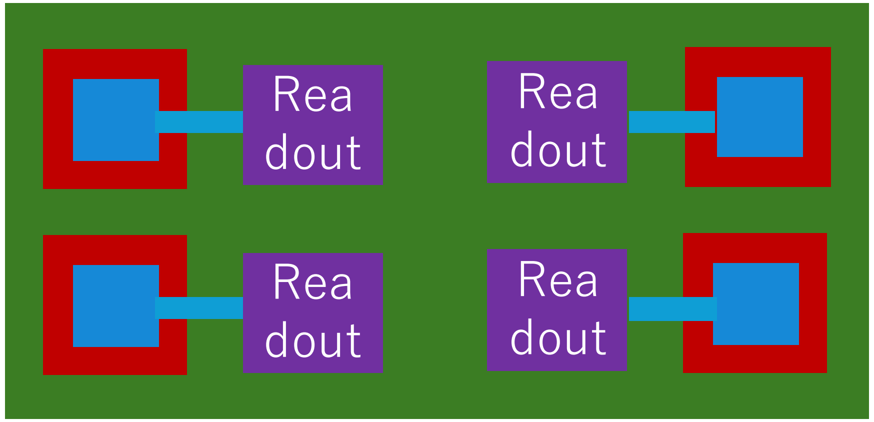
- 3 active layers
- 9 ASICs/stave
- 27 cm active length/stave

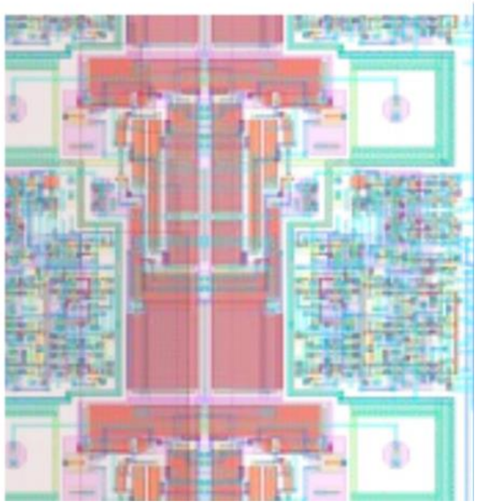
ALPIDE thickness [μm]	50
Pixel size [μm] / matrix	29 x 27 / 1024 x 512
Technology	180nm CMOS
Power Consumption [mW/cm^2]	40 (mean), 300 (peak)
Stave Material Budget	0.3% X_0
Timing resolution [μs]	~5 – 6
XZ spatial resolution [μm]	< 6

MVTX staves



Design: Monolithic active pixels sensors



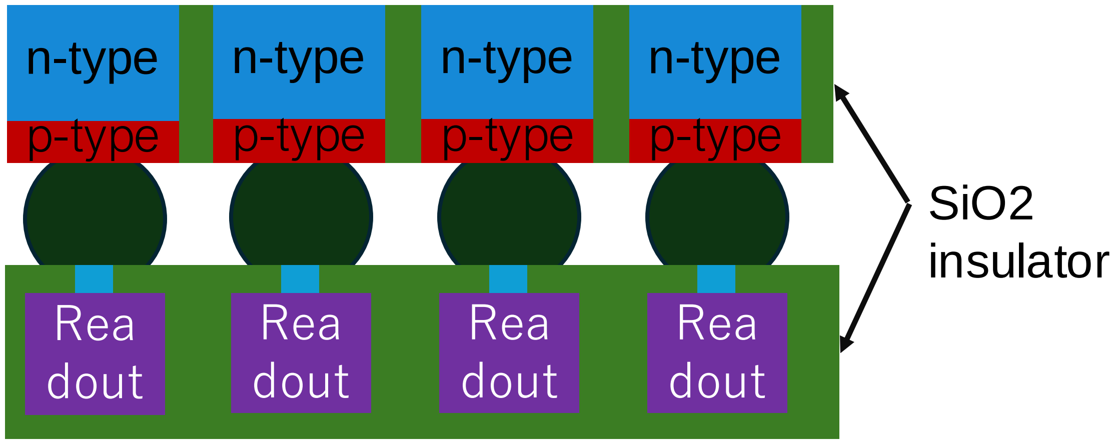


- Use Complementary Metal Oxide Semiconductor (CMOS) technology to build pixel directly on chip
- No bump bonding
- Small P-N width, no depletion voltage needed!
- Pixels can be small
  - Not driven by etching, bump size or placement precision
- Resolution is based on pixel size, p or pitch

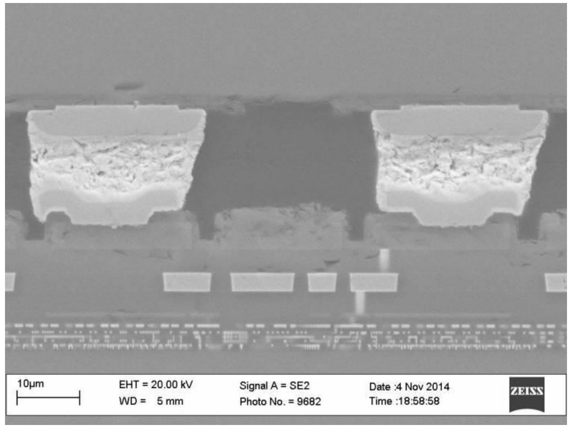
$\sigma_x = \sqrt{\langle \Delta x^2 \rangle} = \frac{\text{pitch}}{\sqrt{12}}$ where $\langle \Delta x^2 \rangle = \frac{1}{p} \int_{-p/2}^{p/2} x^2 \, dx$

ALPIDE design for ITS-2 and sPHENIX MVT

Design: Hybrid pixels



Timepix3 ASIC bump-bonded to a wafer, https://medipix.web.cern.ch/medipix3



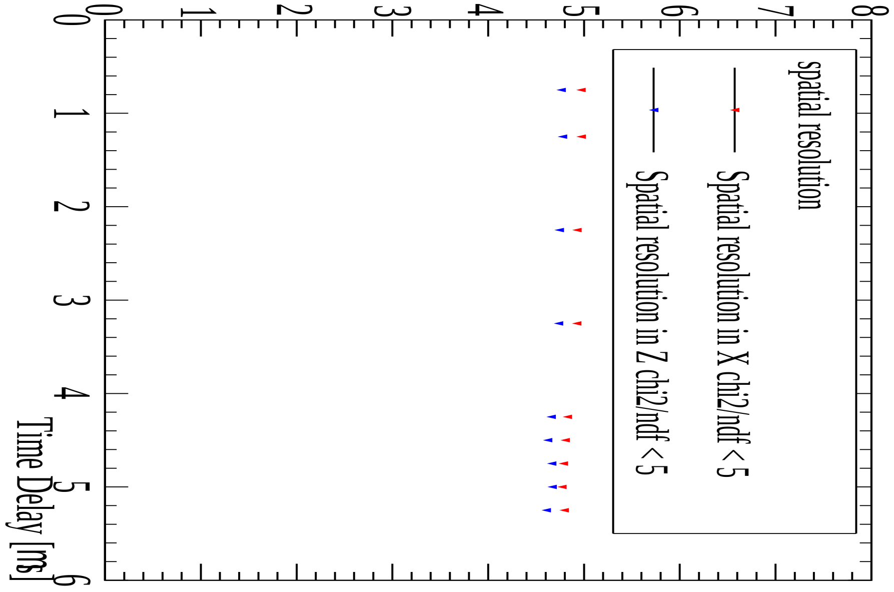
Medipix ASIC bump-bonded to a wafer, http://x-ray.camera/technology/flip-chip-bonding/

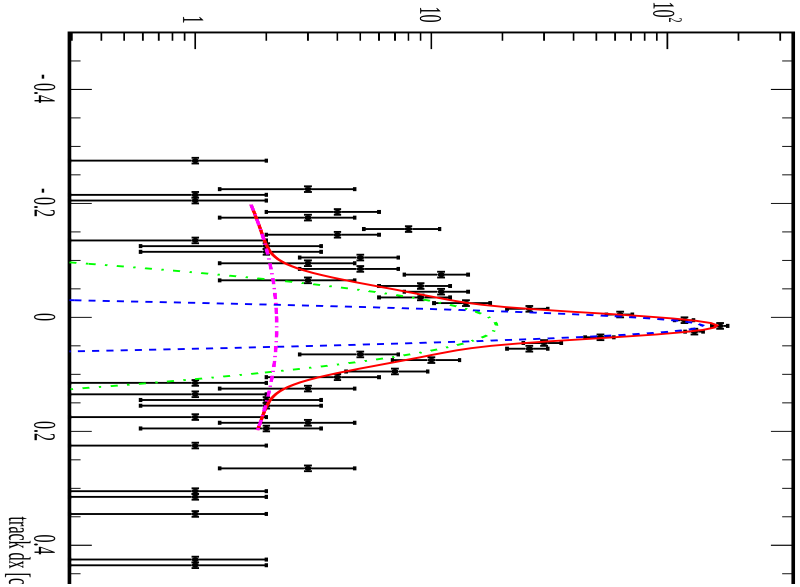
- Hybrid pixel detectors have 2 components
  1. A readout chip (typically ASIC for speed)
  2. A pixel matrix
- Each pixel must be bump-bonded to its chip readout
- Resolution is based on pixel size, p or pitch

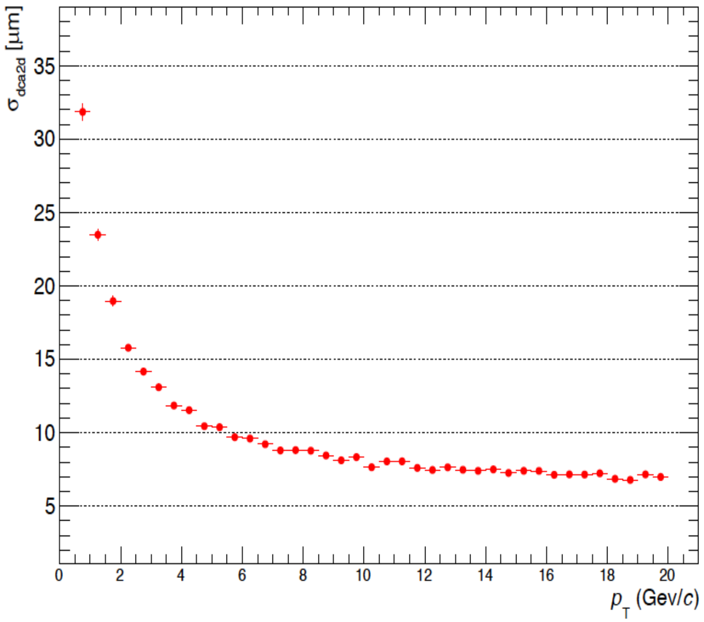
$$\sigma_x = \sqrt{\langle \Delta x^2 \rangle} = \frac{\text{pitch}}{\sqrt{12}} \text{ where } \langle \Delta x^2 \rangle = \frac{1}{p} \int_{-p/2}^{p/2} x^2 \, dx$$

- Pitch is typically 50 – 100 µm

Physics capabilities

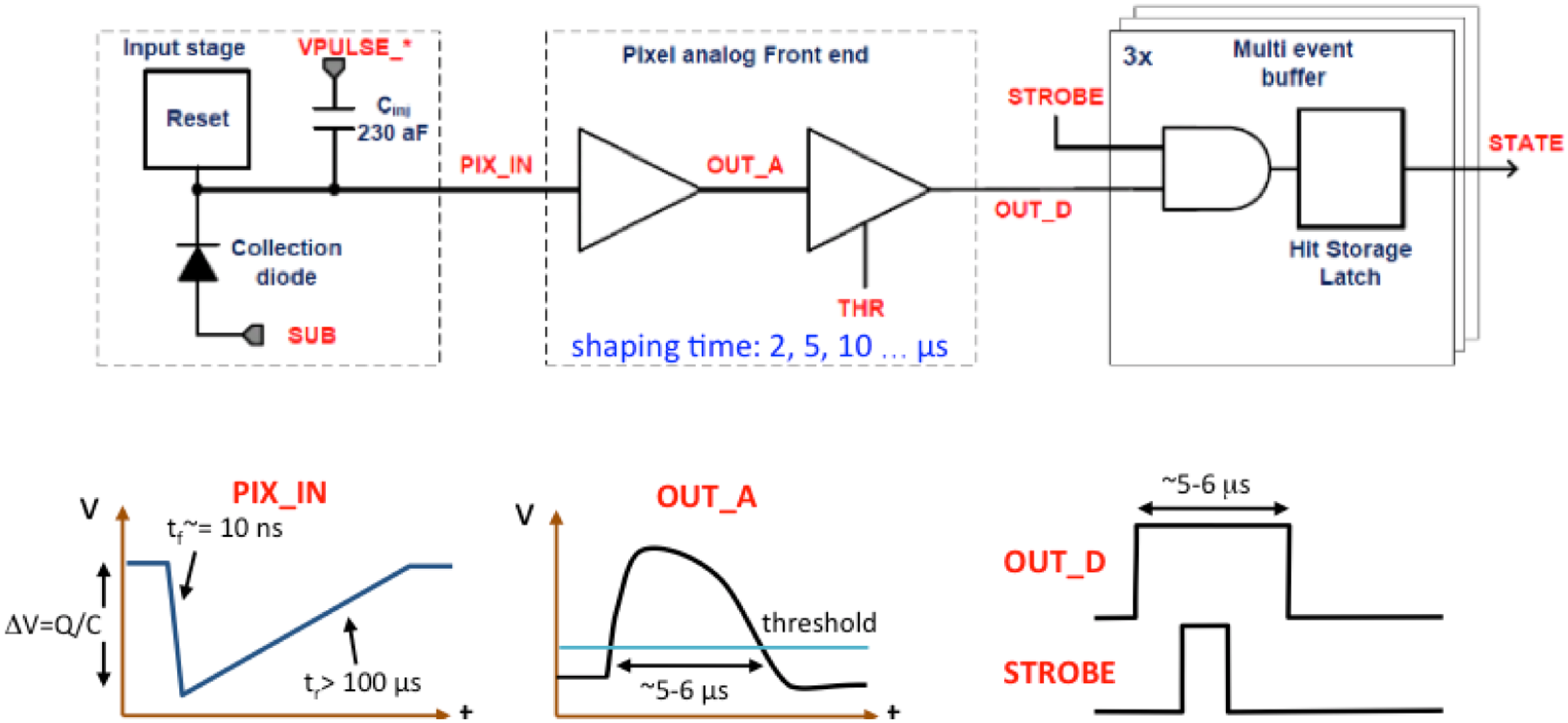




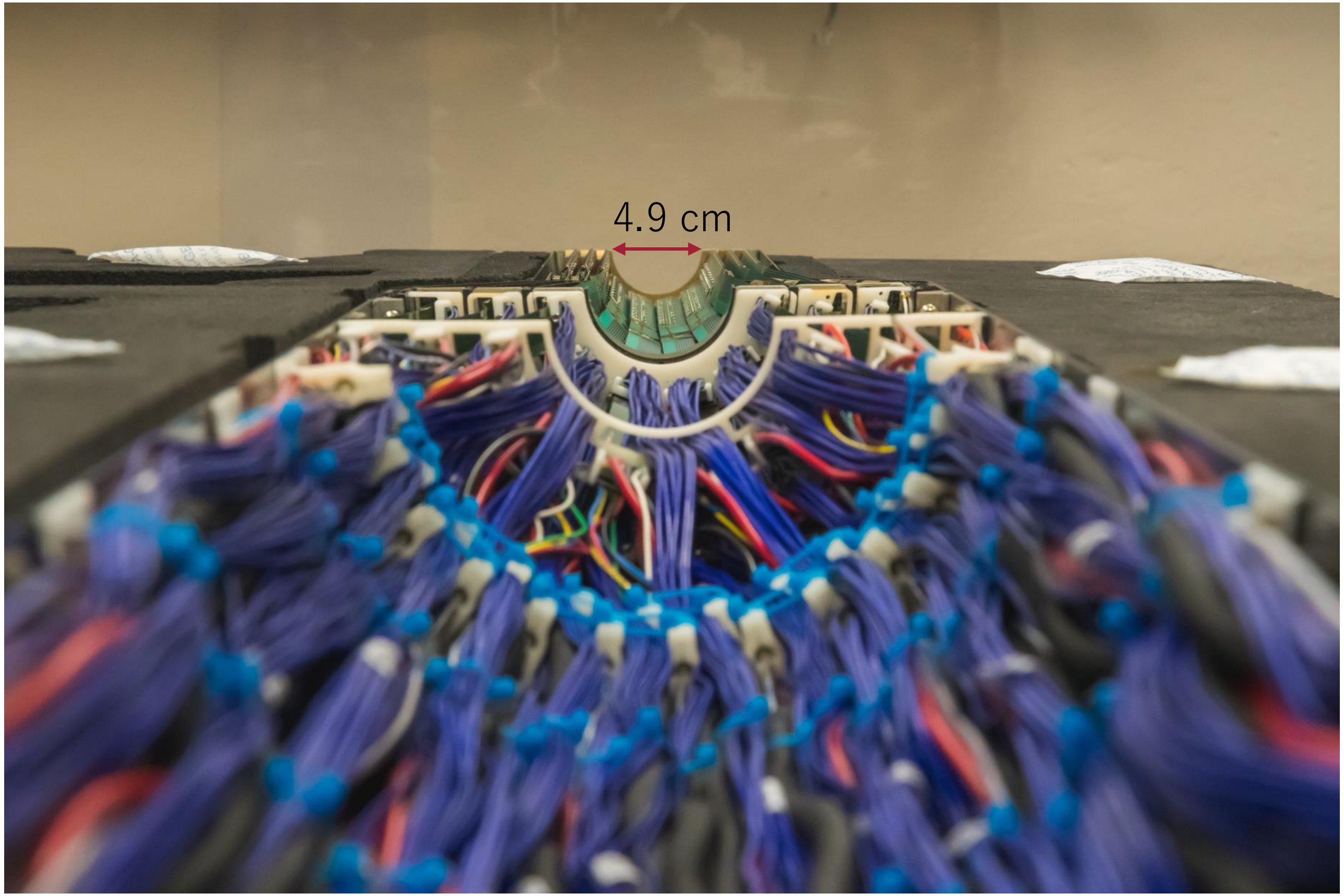


Left – MVTX spatial resolution as a function of trigger delay from test beam
Middle – MVTX track resolution from test beam
Right – sPHENIX DCA_{XY} resolution from simulation

MAPS Signal Processing Design



MVTX construction

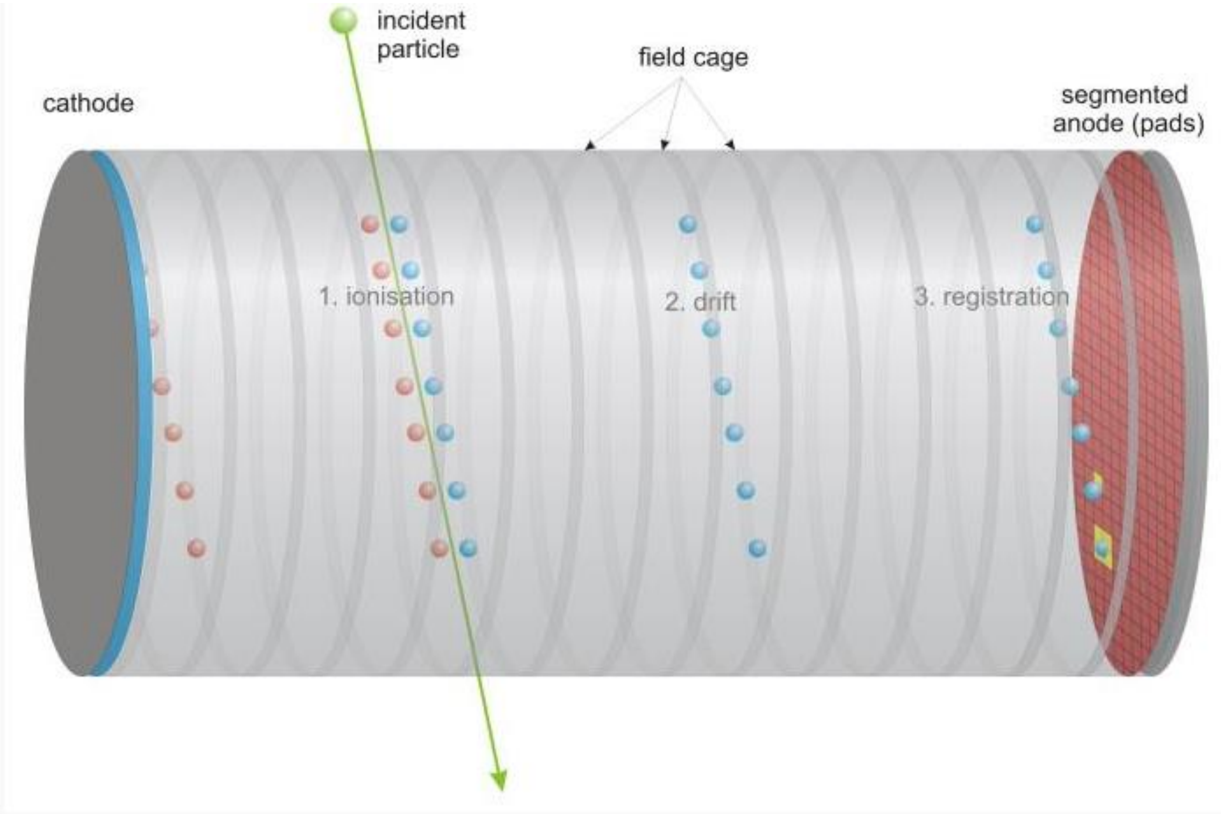


TPC

What's a Time Projection Chamber ?

- Time Projection Chamber (TPC)

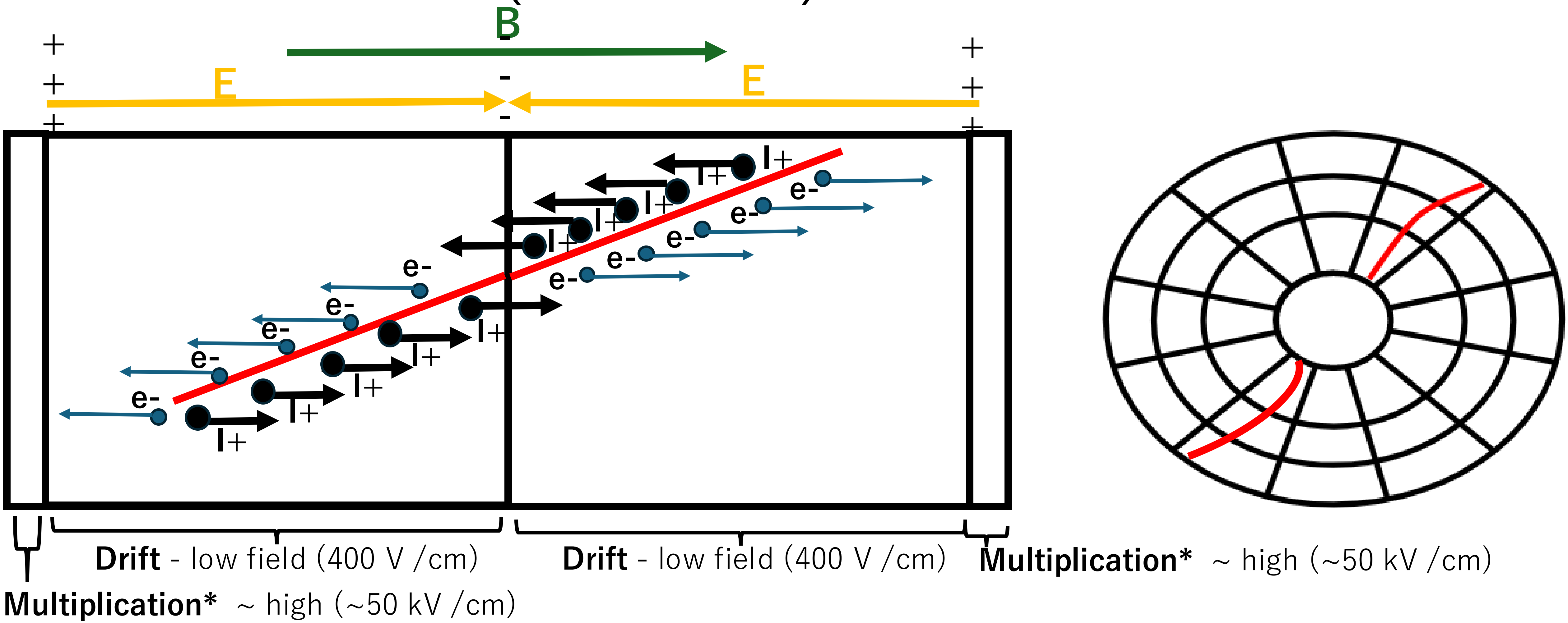
- Gaseous Drift Detectors
  - Big cylinder filled with (mostly) noble gas (Ne, Ar, etc...) and electric field
  - Particles come in, ionize gas, make electrons (and ions)
  - Electrons drift to anode plane – are read out



Source: https://www.lctpc.org/e8/e57671

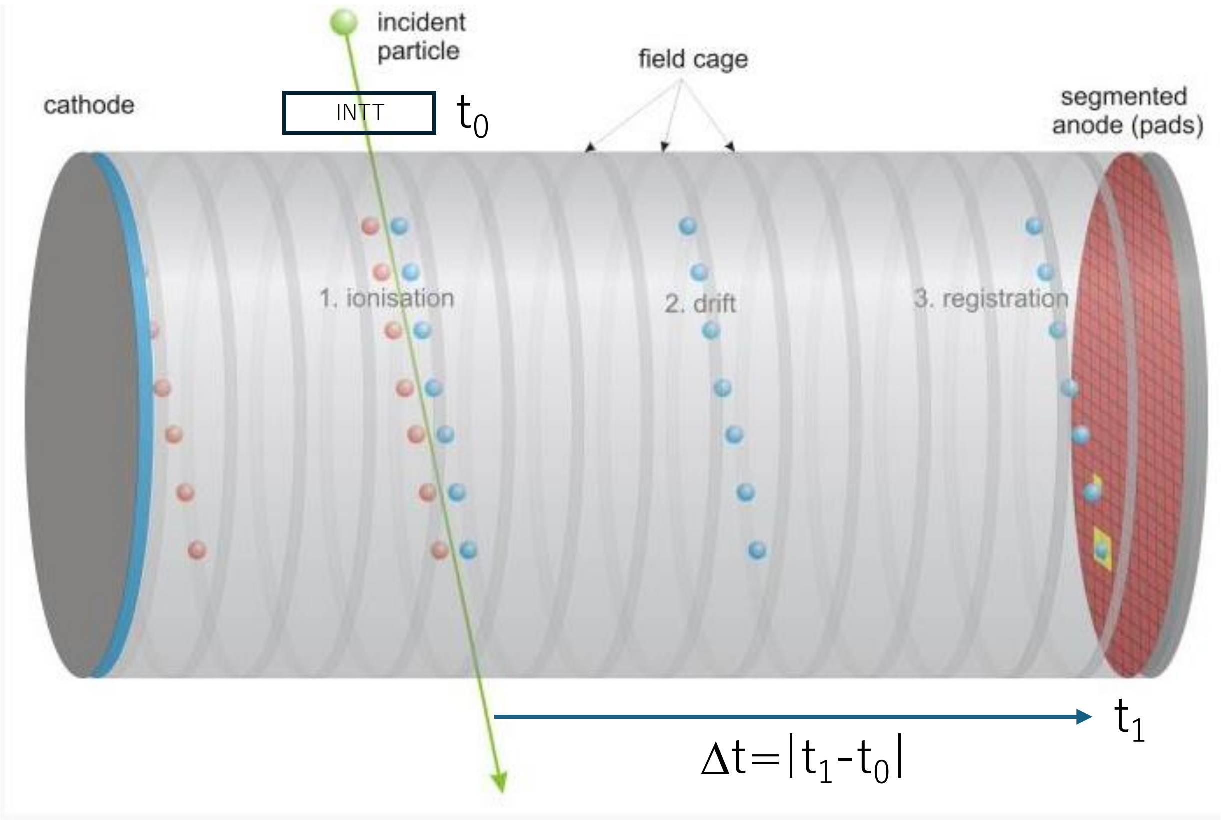
What's a Time Projection Chamber

- Double sided TPC (like sPHENIX)



How TPC Works?

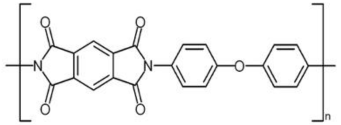
- The rϕ position (coordinates perpendicular to the cylinder axis) of the trajectory can be reconstructed directly from the coordinates of its projection on the pad plane.
- The z position (coordinate along the cylinder axis) is reconstructed from the drift time (time between particle passing the TPC volume and measured signal on the pads).
- Therefore an external timing information, e.g. from a silicon detector is needed.

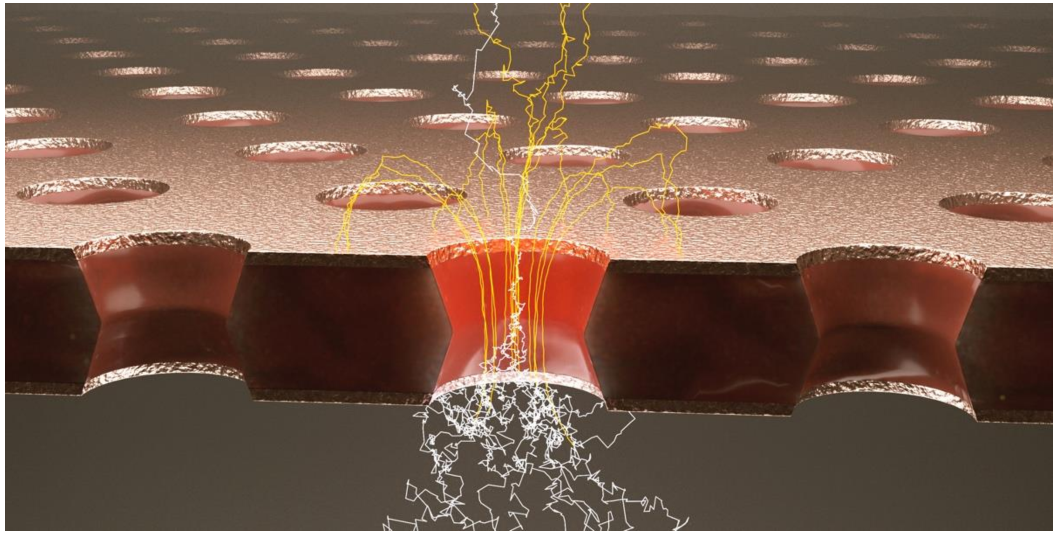


Multiplication Region – How do you get those high fields

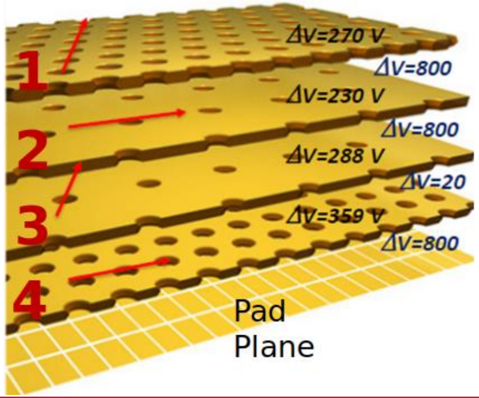
- Gaseous Electron Multiplier (GEM) Foils
  - Creates specific field shape in holes
  - Inside holes – Townsend Avalanche

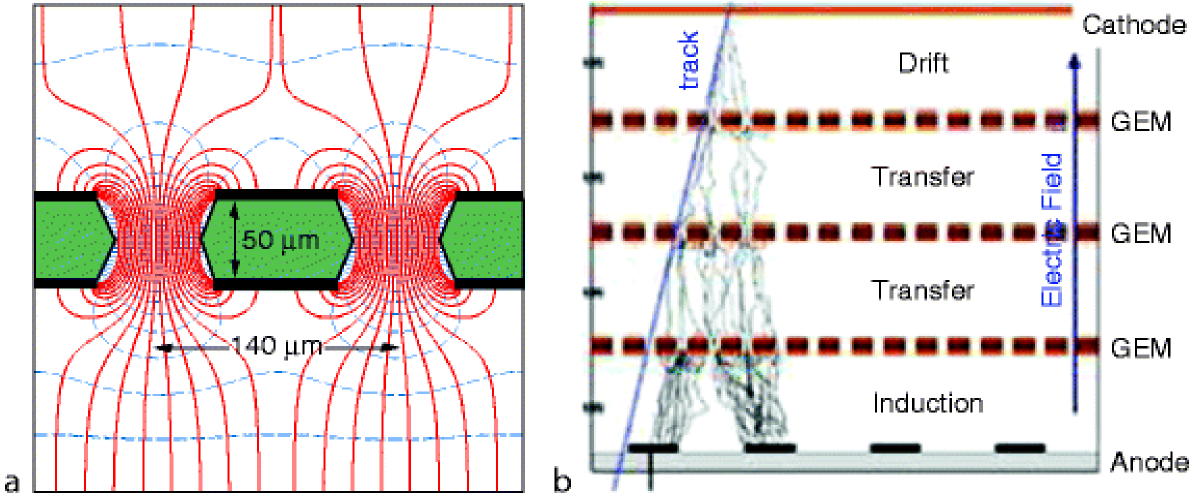
- Copper/Katpon/Copper w/ holes
  - 50 µm depth
  - 70 µm hole diameter





- Form stack with mutiple (4) foils
  - Each GEM in the stack has varying pitch between holes



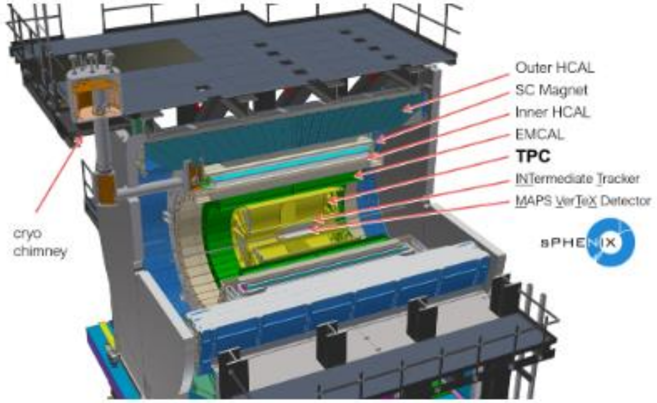


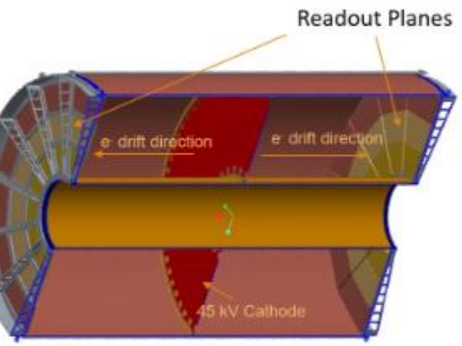
sPHENIX TPC Overview

- Gaseous Drift Detector
  - Ar/CF_4 60:40 % drift gas
    - O(13 μs) drift time
  - GEM (Gaseous Electron Multiplier) amplification
    - 4 Kapton + Copper GEMs / module
  - Un-gated like ALICE TPC
    - Allows for streaming readout
  - Zig-zag segmented copper sensor pads
    - Improves position resolution

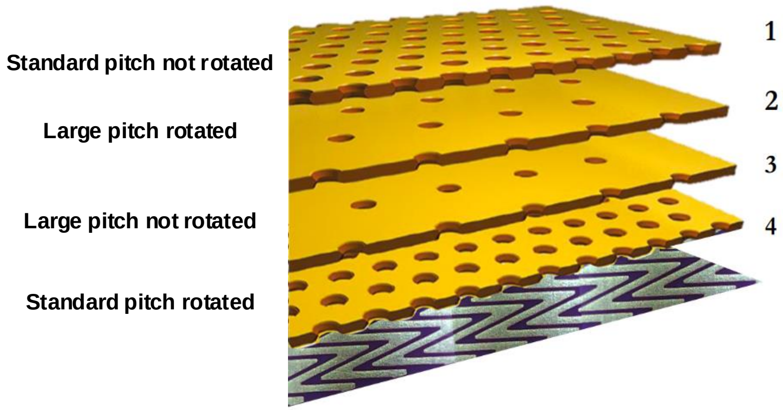
- 72 GEM modules/2 sides
  - 36 modules / full ϕ
  - 3 modules / full r
  - 20 < r < 78 cm, |η| < 1.1, full ϕ

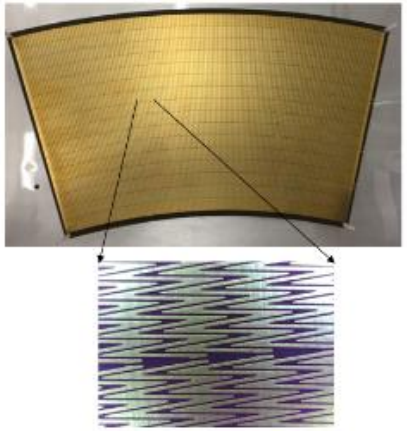
- Measures Momentum
  - Target momentum resolution:
    - Δp/p = 0.02 * p
  - O(150 μm) spatial resolution

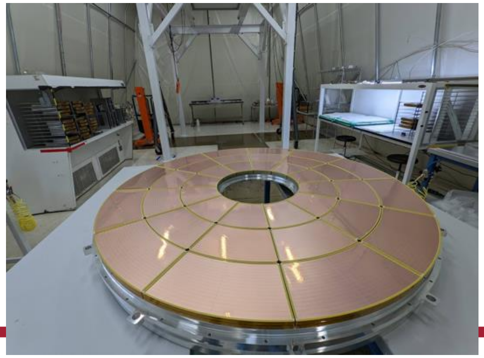


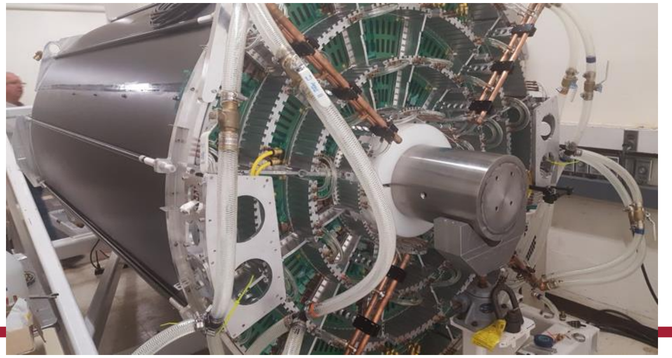


$E_{\mathrm{drift}} = 400\ \mathrm{V/cm}$

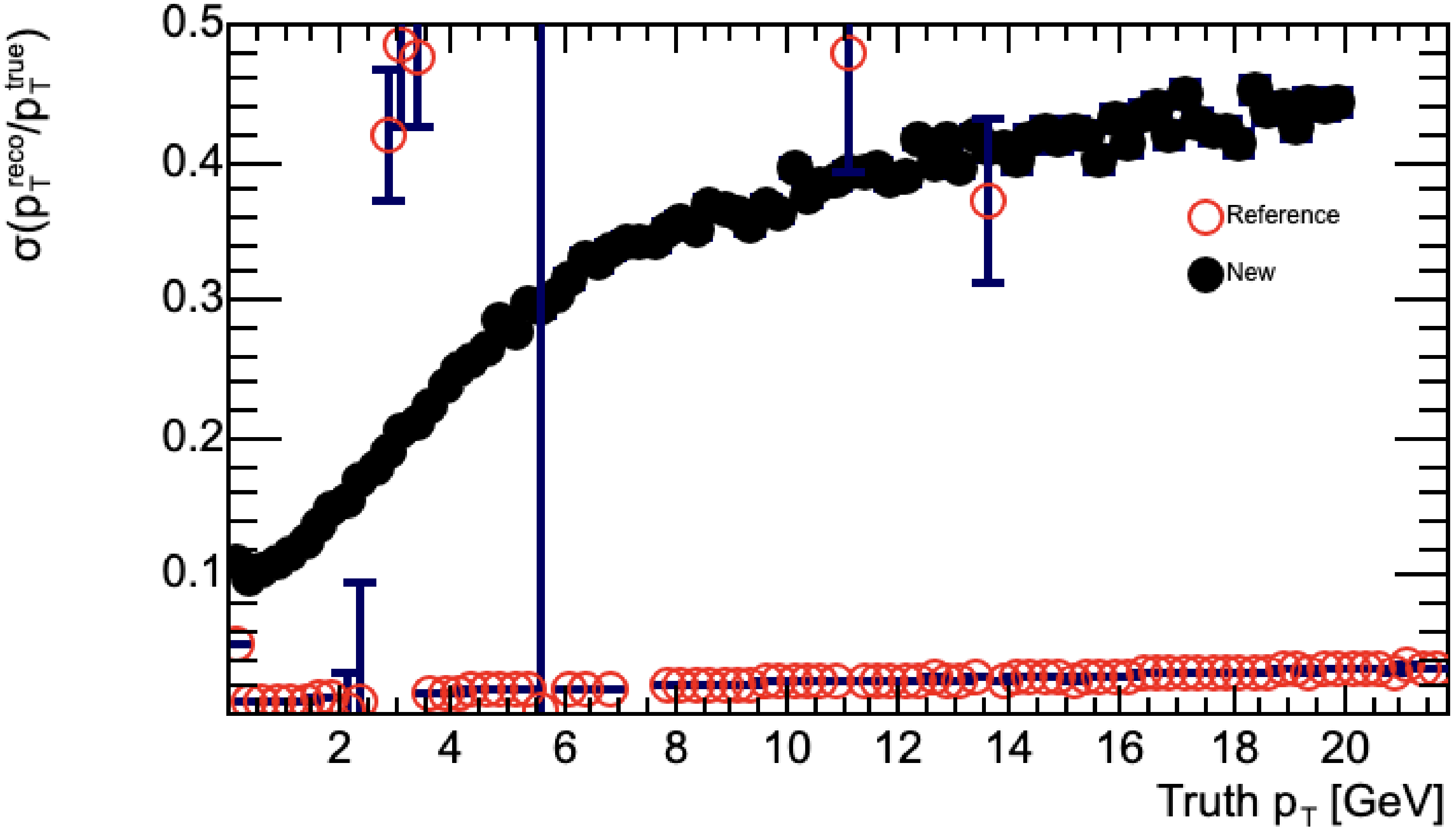








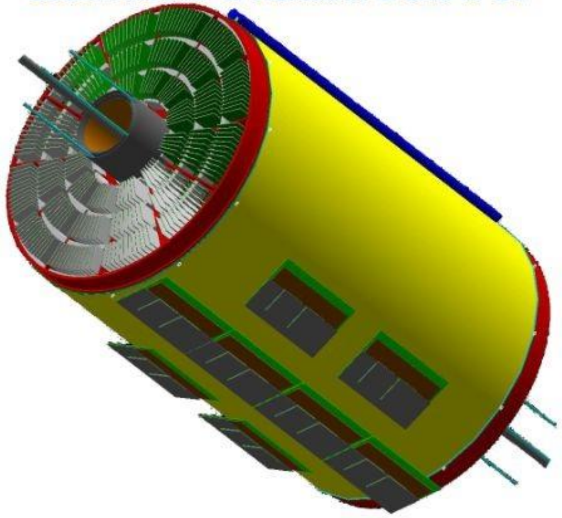
Momentum Resolution w and w/o TPC



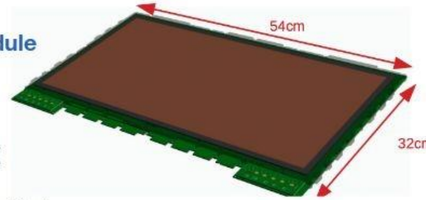
TPOT - Time Projection chamber Outer Tracker

- Gaseous Drift Detector
  - $Ar/HC(CH_3)_3$ 95:5 % drift gas
    - 3 mm drift length
  - Micromegas amplification
  - Resistive layer w/ strips for readout
- 8 modules/bottom of TPC
  - Fully covers 1 TPC sector/side
  - Partially covers 2 other TPC sectors/side
- Provides reference for TPC
  - O(100 μm) spatial resolution
  - Provides check for TPC calibration

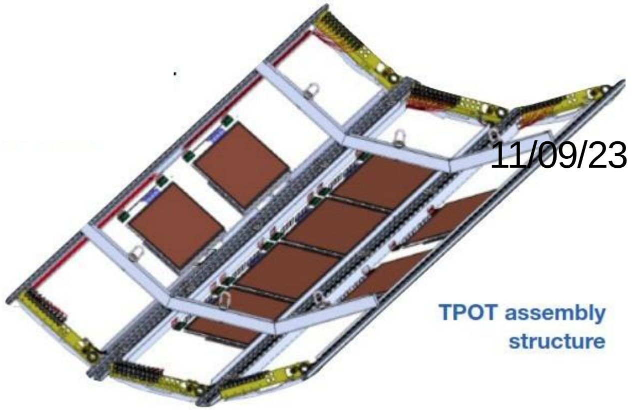
Geant4 view of sPHENIX TPC and TPOT



Each module = **2 bulk, resistive 1D-Micromegas detectors (back-to-back)**

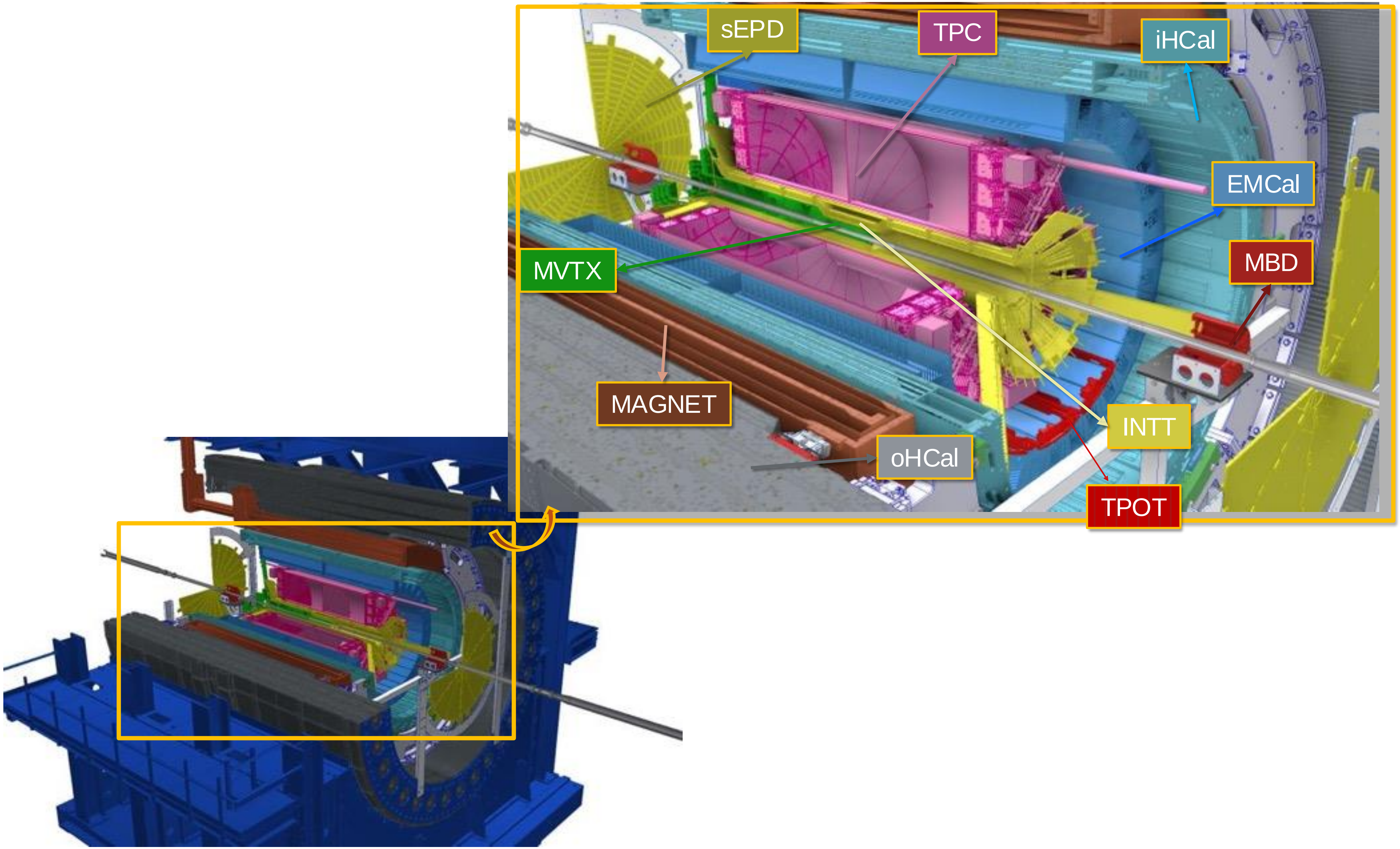


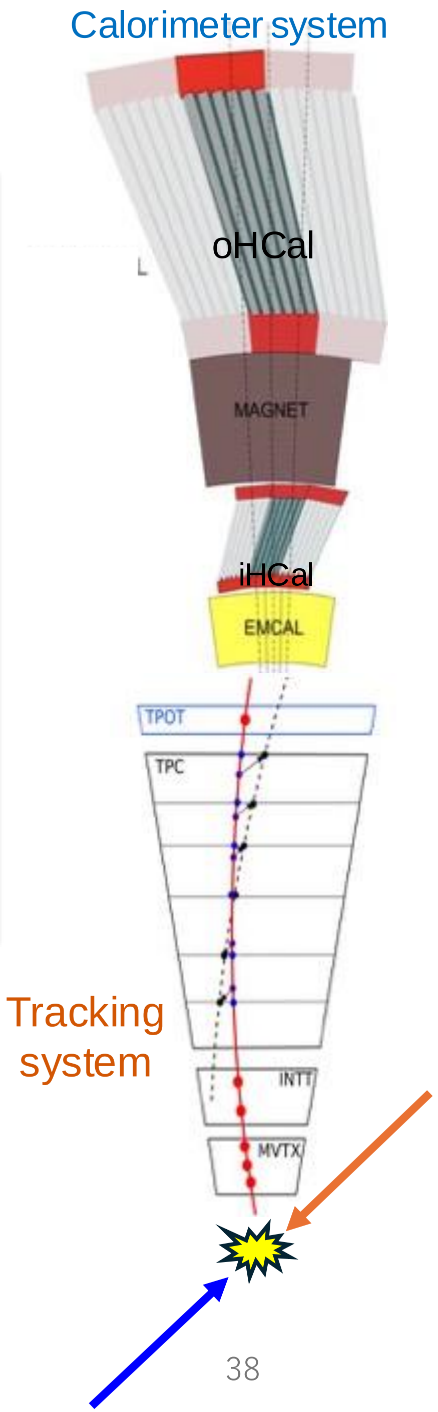
- Carbon drift
- 1mm/2mm pitch
- Ar/Isobutane (95/5)
- **Resistive** layer with strips



TPOT assembly structure

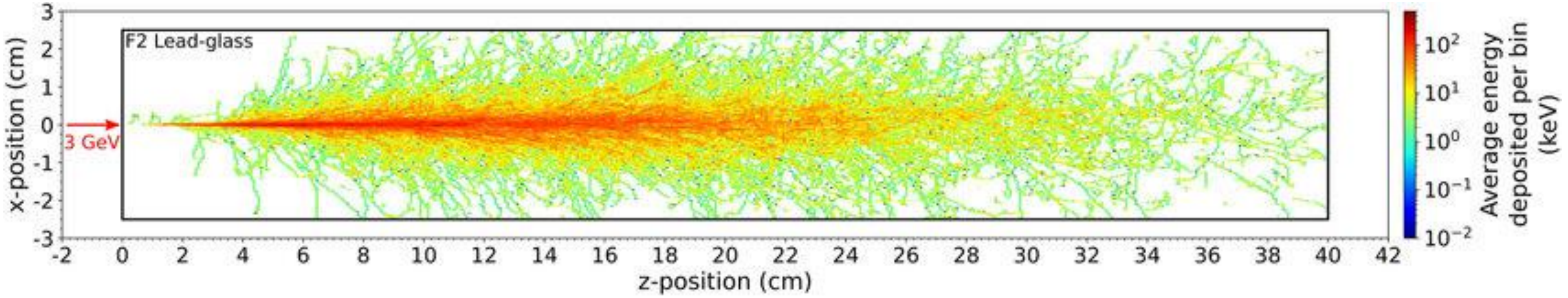
sPHENIX Detector



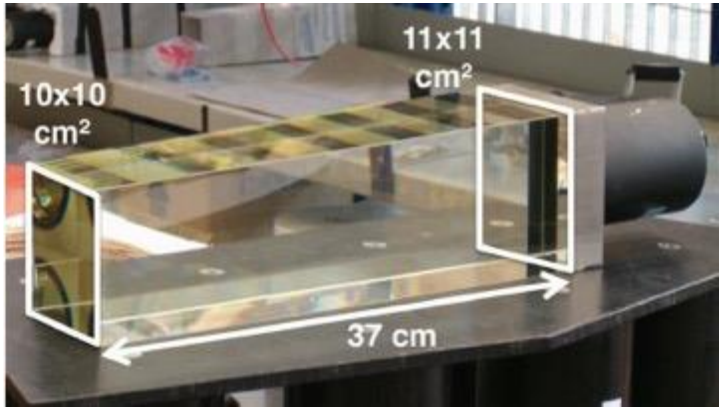


Calorimeter System

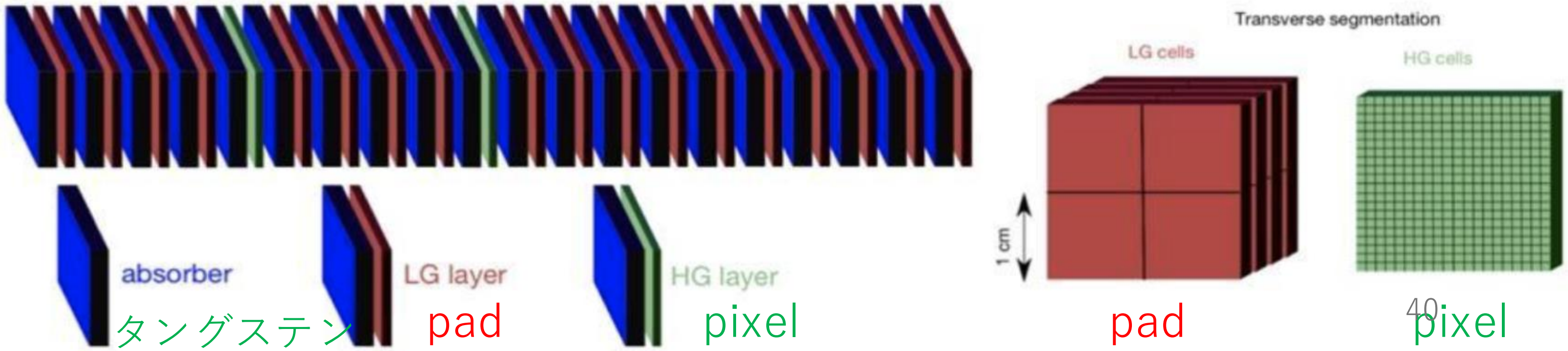
Calorimeters



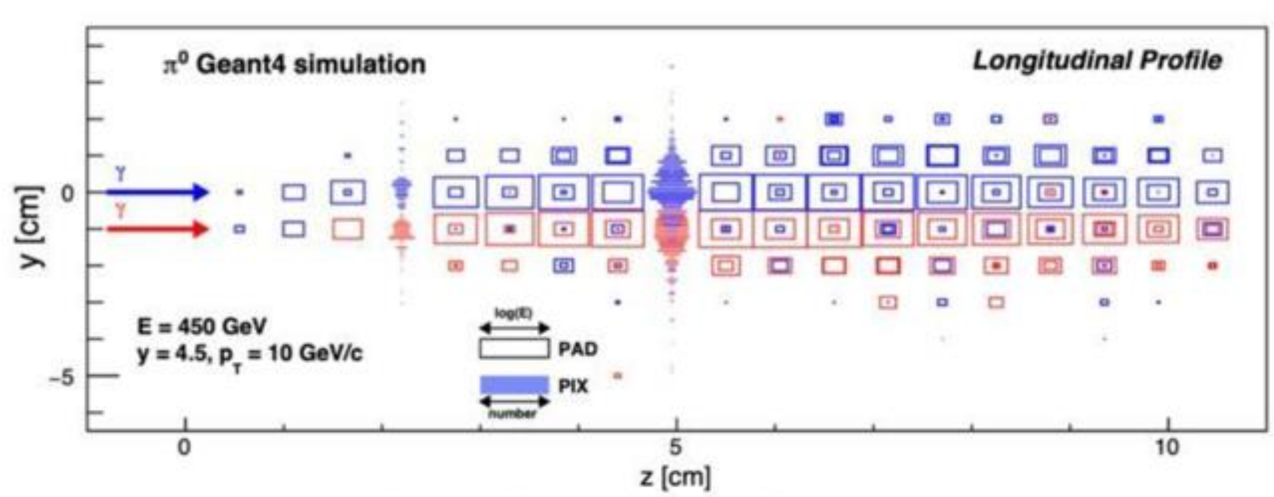
- Total absorption Type
  - High energy resolution
  - Low position resolution
  - Pb-Glass, etc.

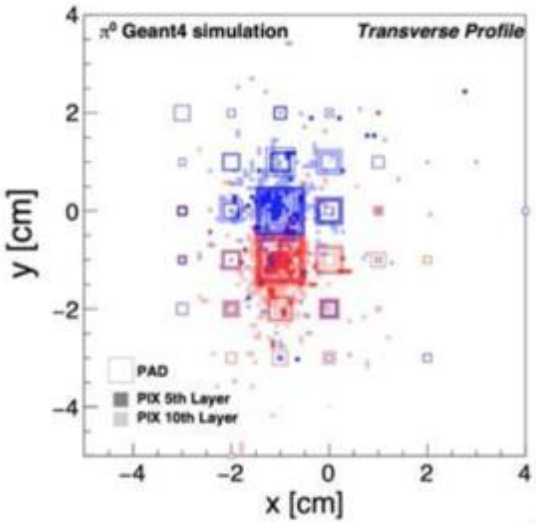


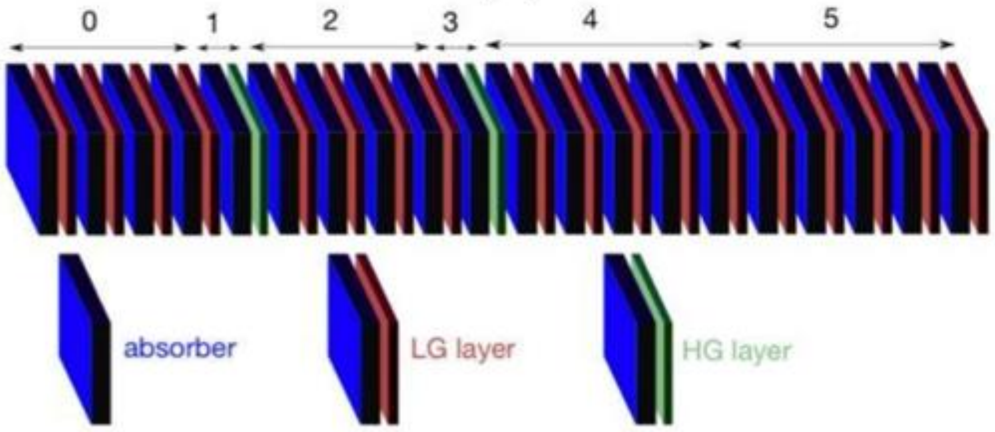
- Sampling Type
  - High position resolution as a trade off of lower energy resolution
  - Pb, W, Fe… as absorber
  - Sensors
    - Scintillation fibers, silicon sensors, etc
    - Pixel sensors for shower max

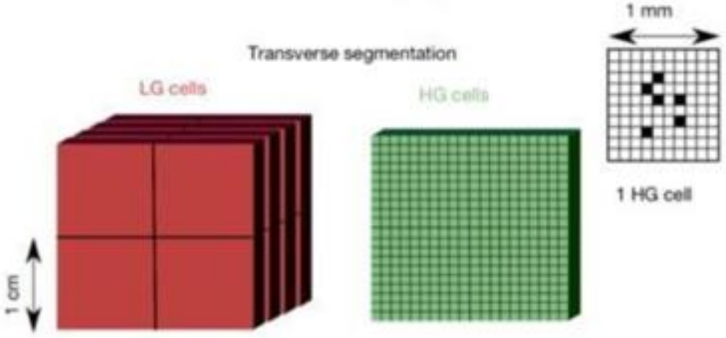


Sampling Type Calorimeters

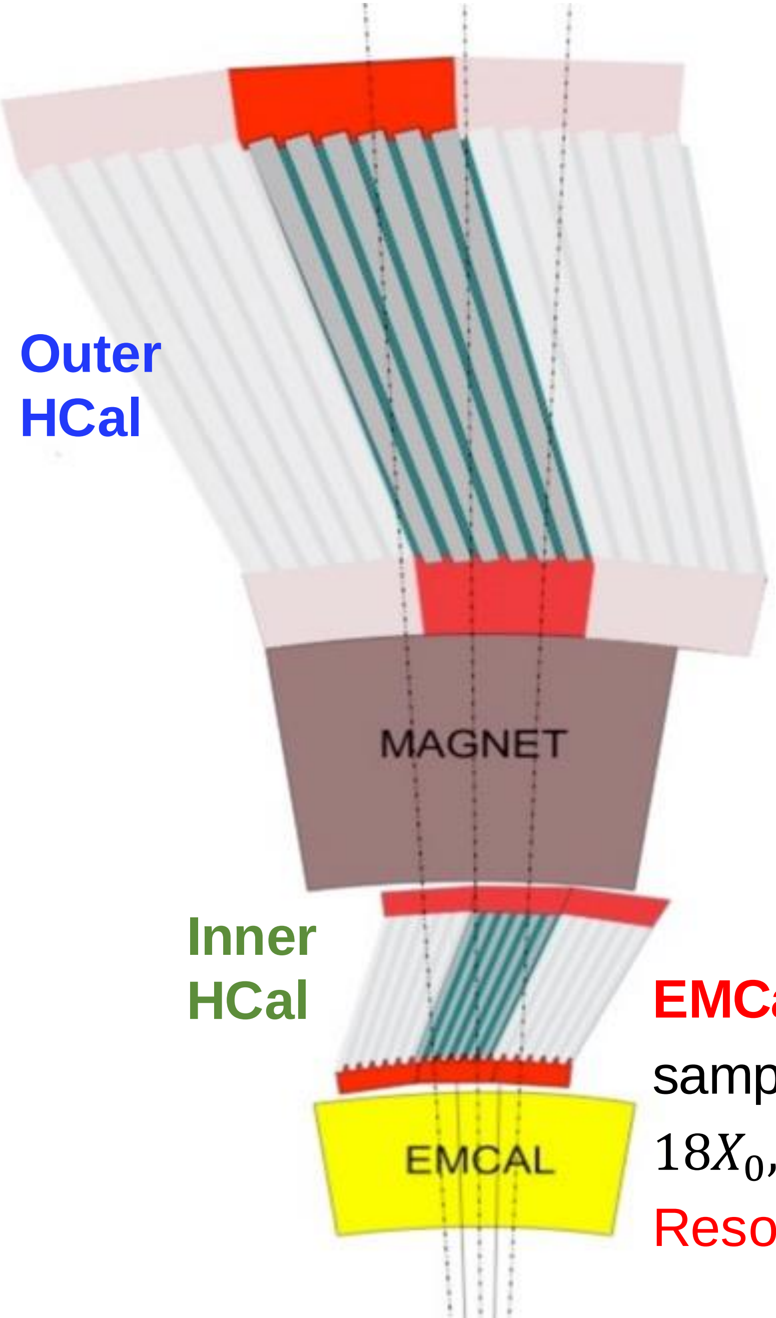








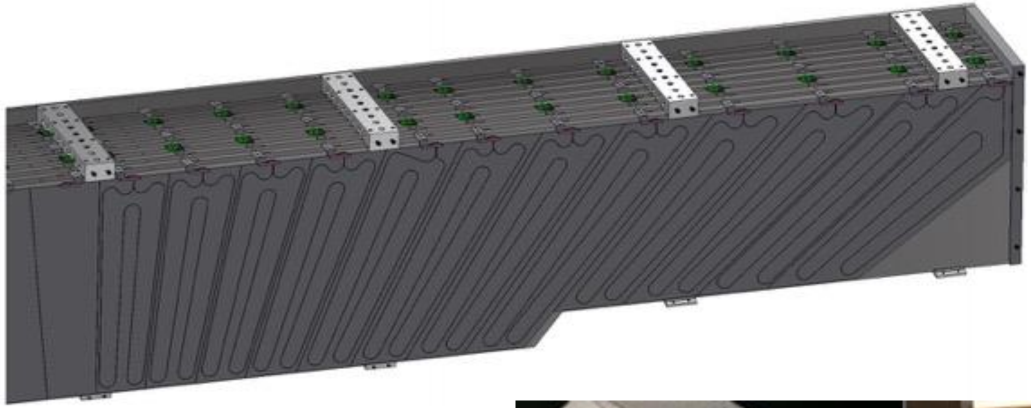
sPHENIX Calorimeters



Outer HCal: Steel absorber plates and scintillating tiles with embedded WLS fibers

Inner HCal: Al absorber plates and scintillating tiles with embedded WLS fibers

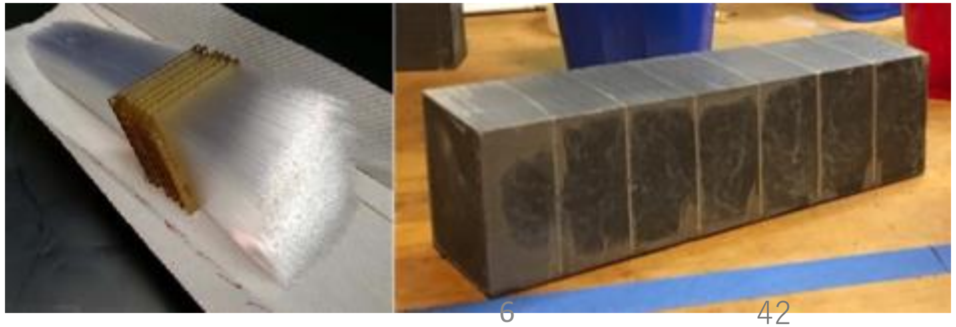
Resolution ~ 88%/√E⊕12% (single particle) for overall HCal.



EMCal: Tungsten-scintillating fiber sampling calorimeter (SPACAL type).

$18X_0, 1\lambda, \Delta\eta \times \Delta\phi = 0.025 \times 0.025$

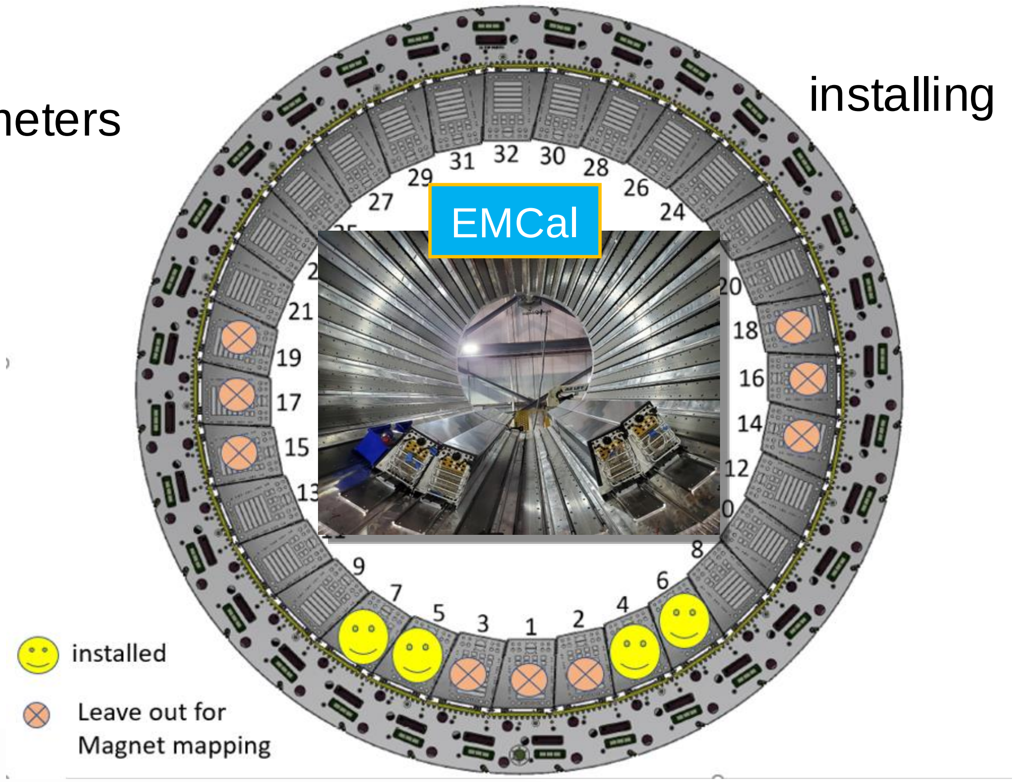
Resolution ~ 16%/√E ⊕5%.



Electromagnetic Calorimeter (EMCal)

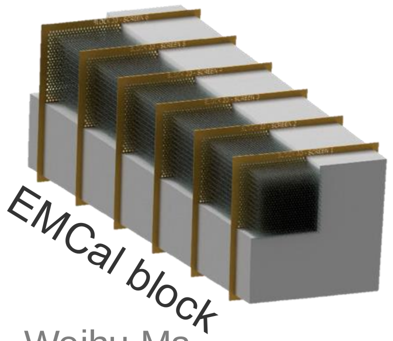
Calorimeter System(EMCal+iHCal+ oHCal)

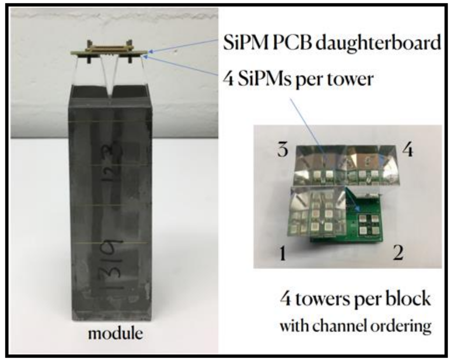
- ✓ Compact, hermetic, near-projective sampling calorimeters
- ✓ Coverage |η| <1.1, 2π in φ
- ✓ SiPM readout for both EMCal and HCal
- ✓ Less-biased jet measurement
- ✓ All Calorimeter electronics complete!

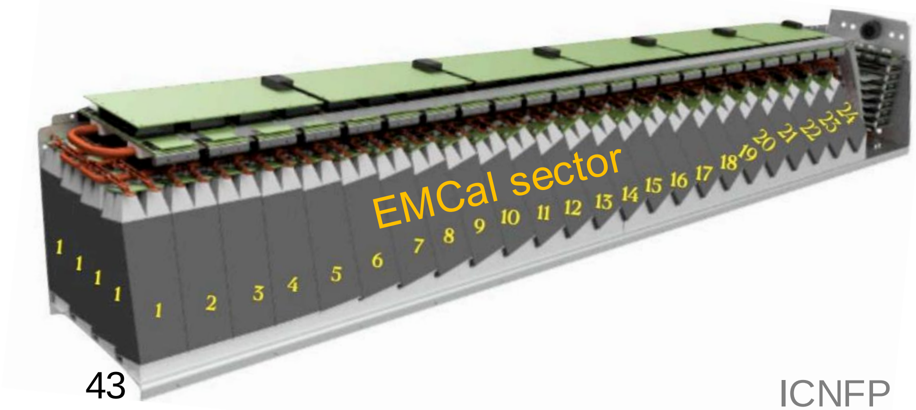


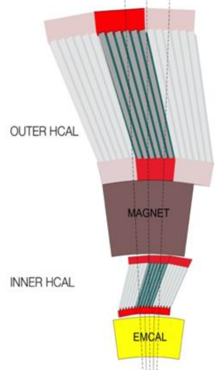
Electromagnetic Calorimeter (EMCal)

- ✓ Tungsten/scintillating fiber SPACAL
- ✓ ~7mm radiation length
- ✓ $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$
- ✓ Good energy resolution $\sigma_E/E \leq 16\%/\sqrt{E}$
- ✓ Sector Installation underway 10/64



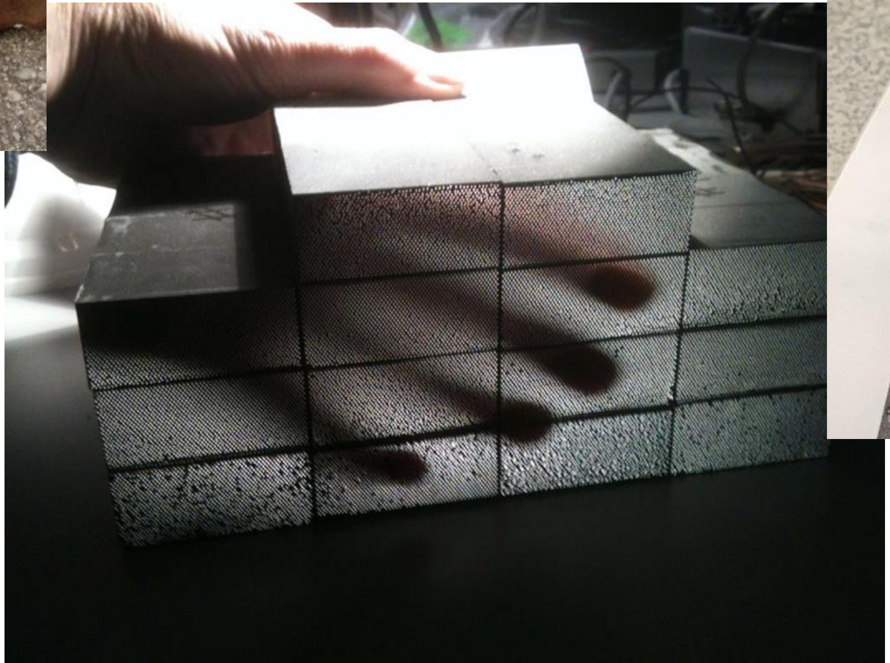


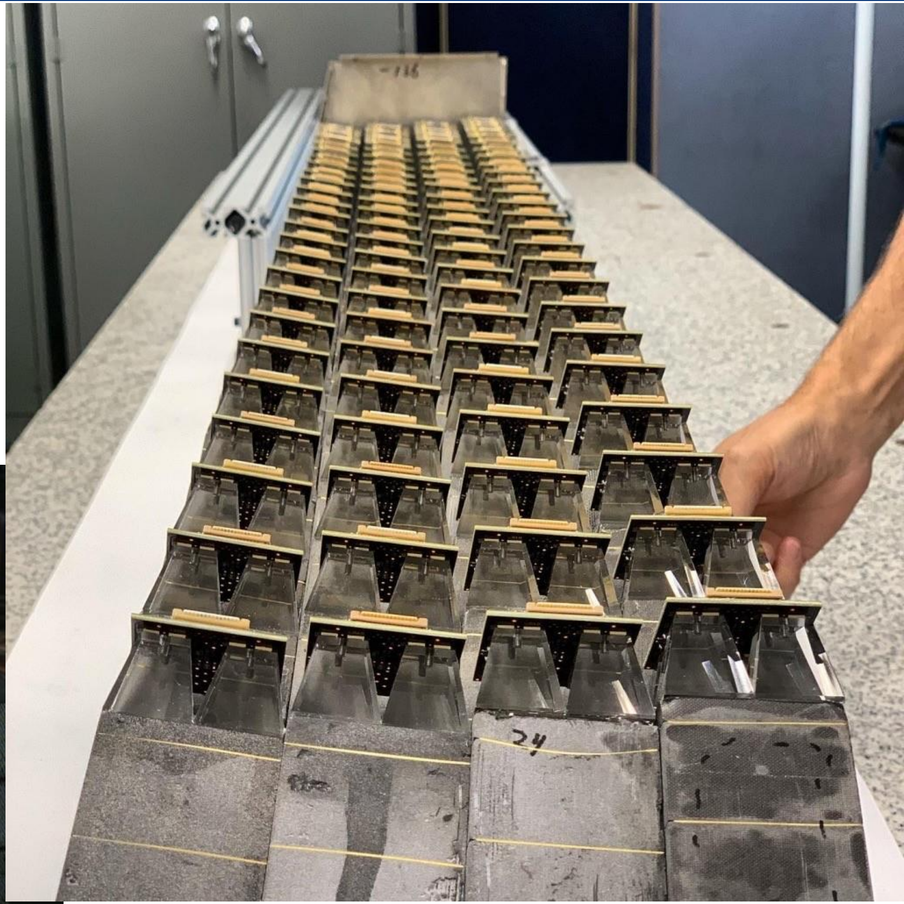




sPHENIX EMCal

59





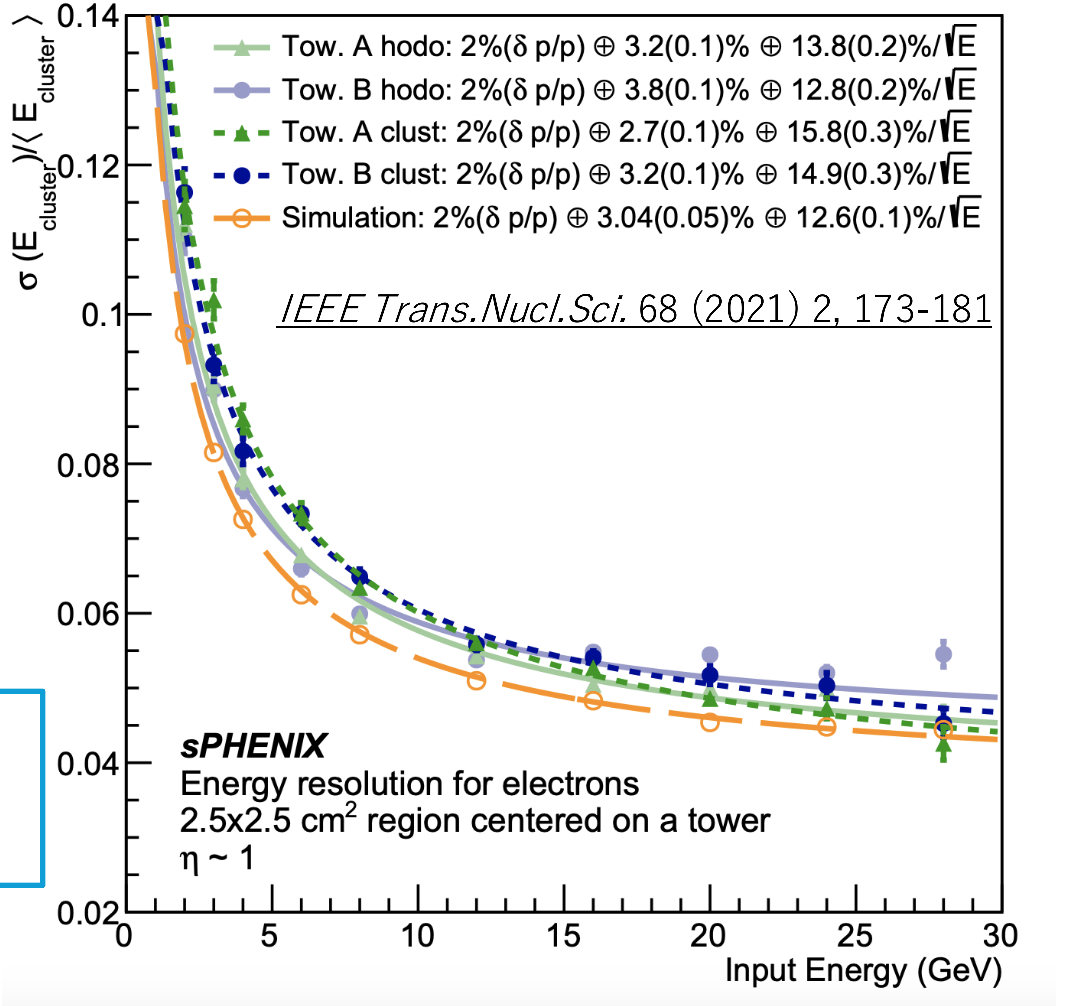
sPHENIX EM calorimeter

Full calorimeter covers 2π in azimuth and $|\eta| < 1.1$

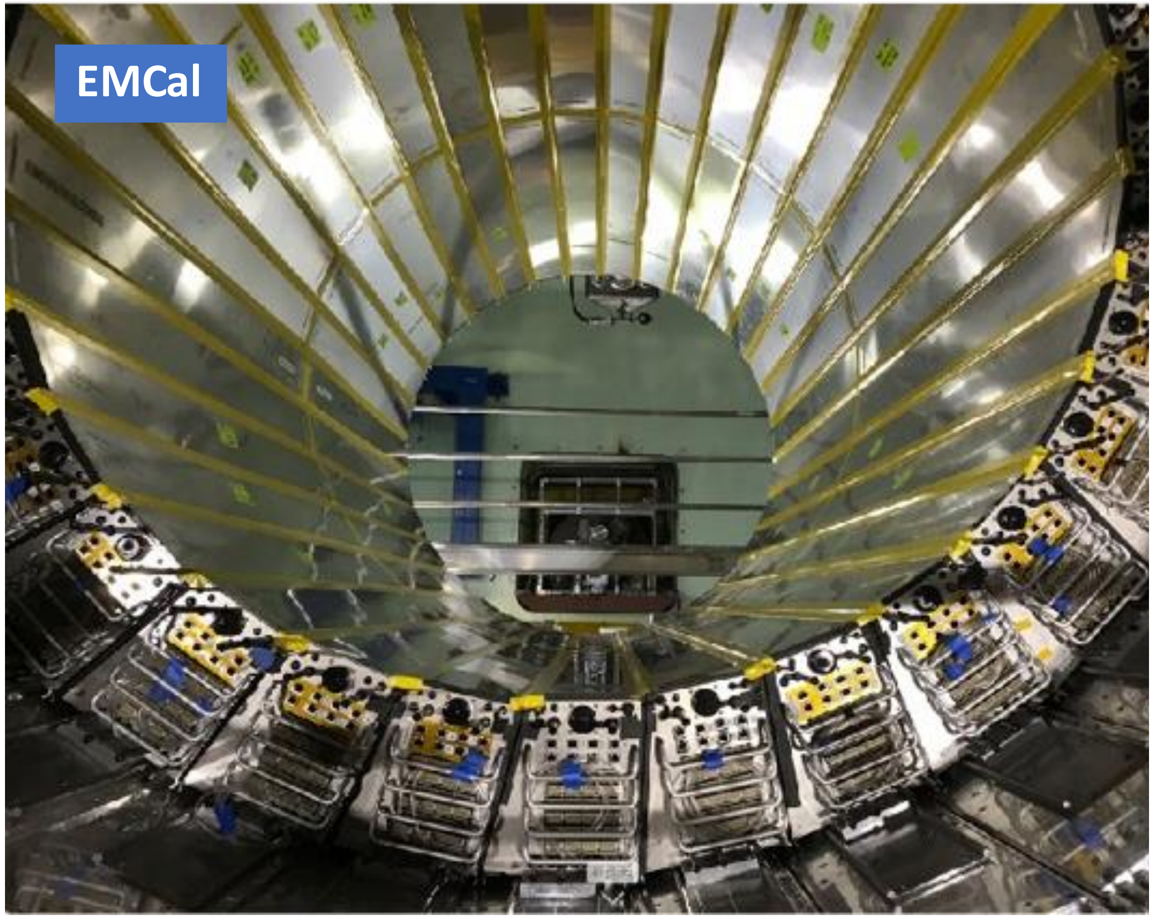
EMCal:

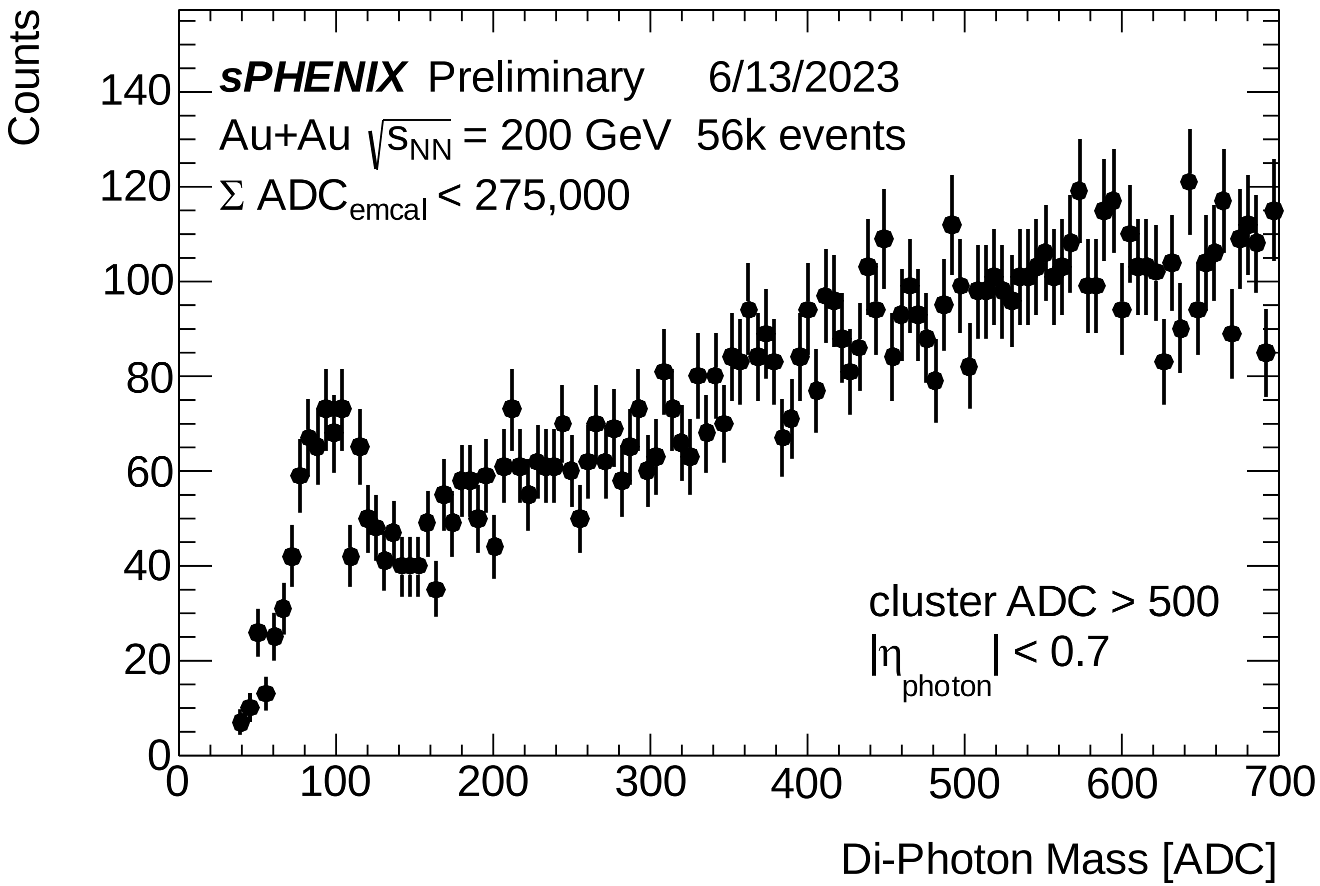
- Sampling calorimeter of scintillating fibers embedded in tungsten blocks
- $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ towers

Block production finished at UIUC (80%) & Fudan/PKU/CIAE (20%)



Calorimetry: EMCal





Di-photon mass distribution shows expected π^0 peak

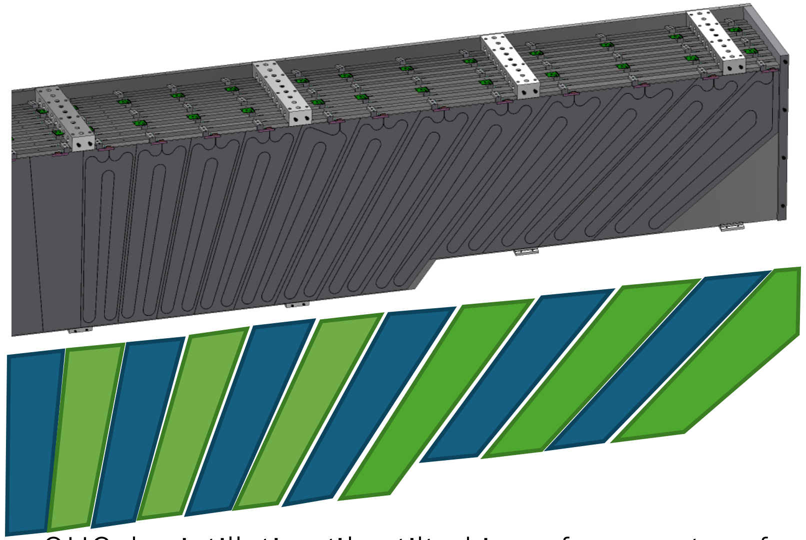
46

What the HCal is

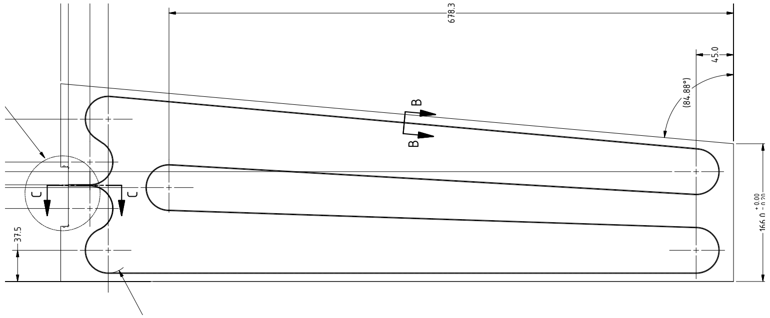
sPHENIX School

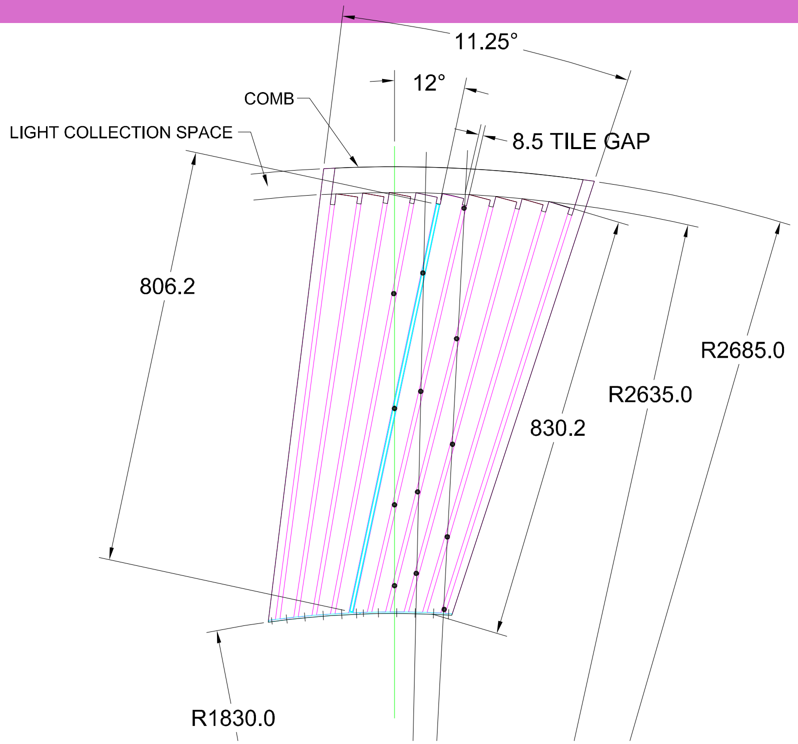
Tiles, Segmentation, and Tilt

- Fanning out radially from nominal collision vertex
- tilted away from radius so that a radial particle would go through multiple tiles/sector
- Tilt in phi is different for inner/outer
- Sector boundaries between



OHCal scintillating tiles tilted in η from center of barrel

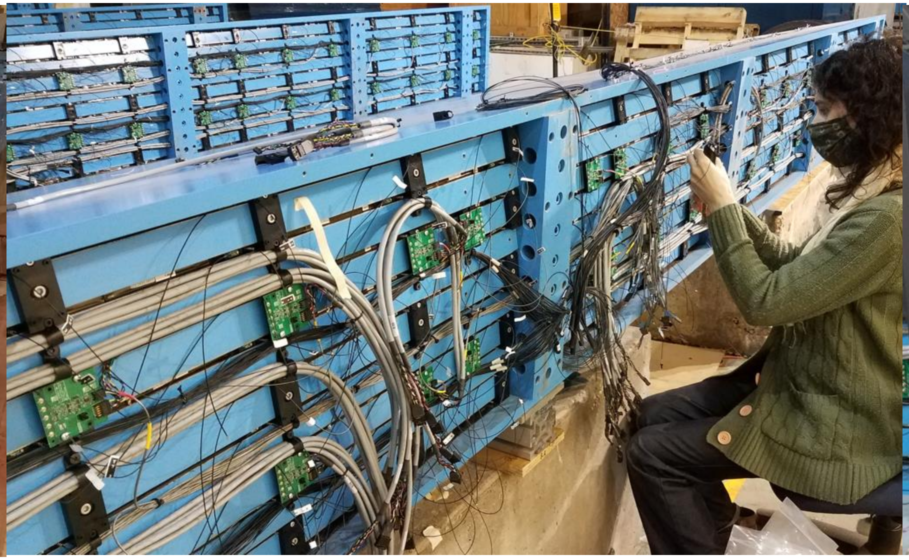


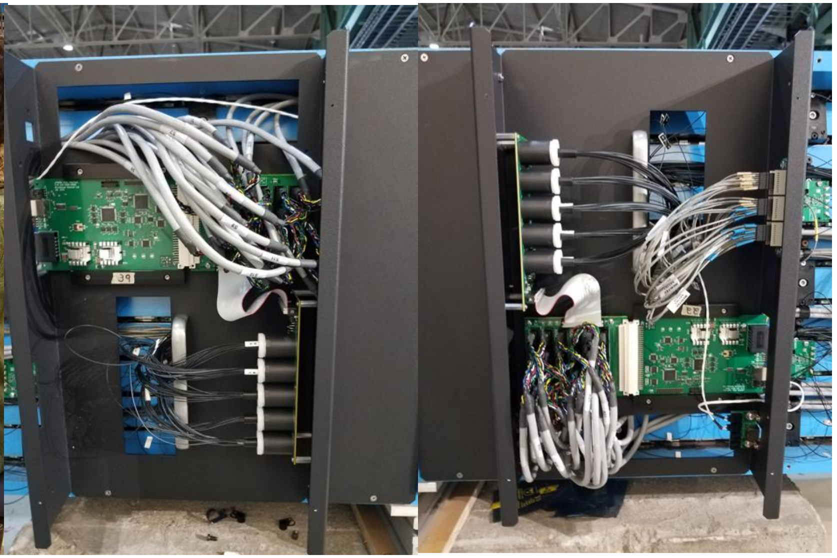


OHCal scintillating tiles tilted in ϕ from radius

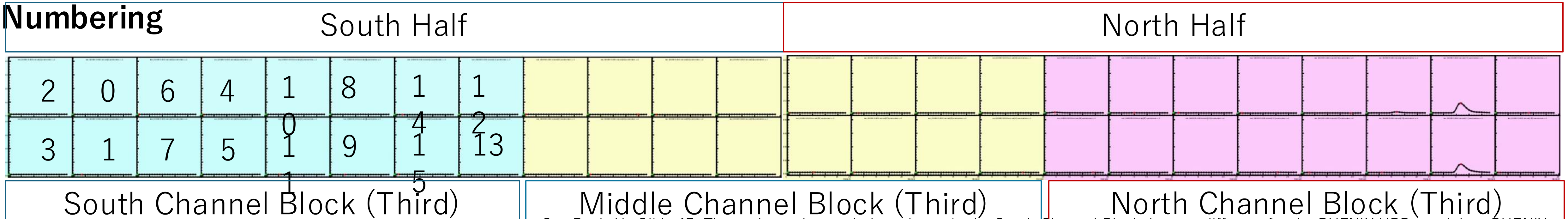
What the HCal is

Assembly pictures





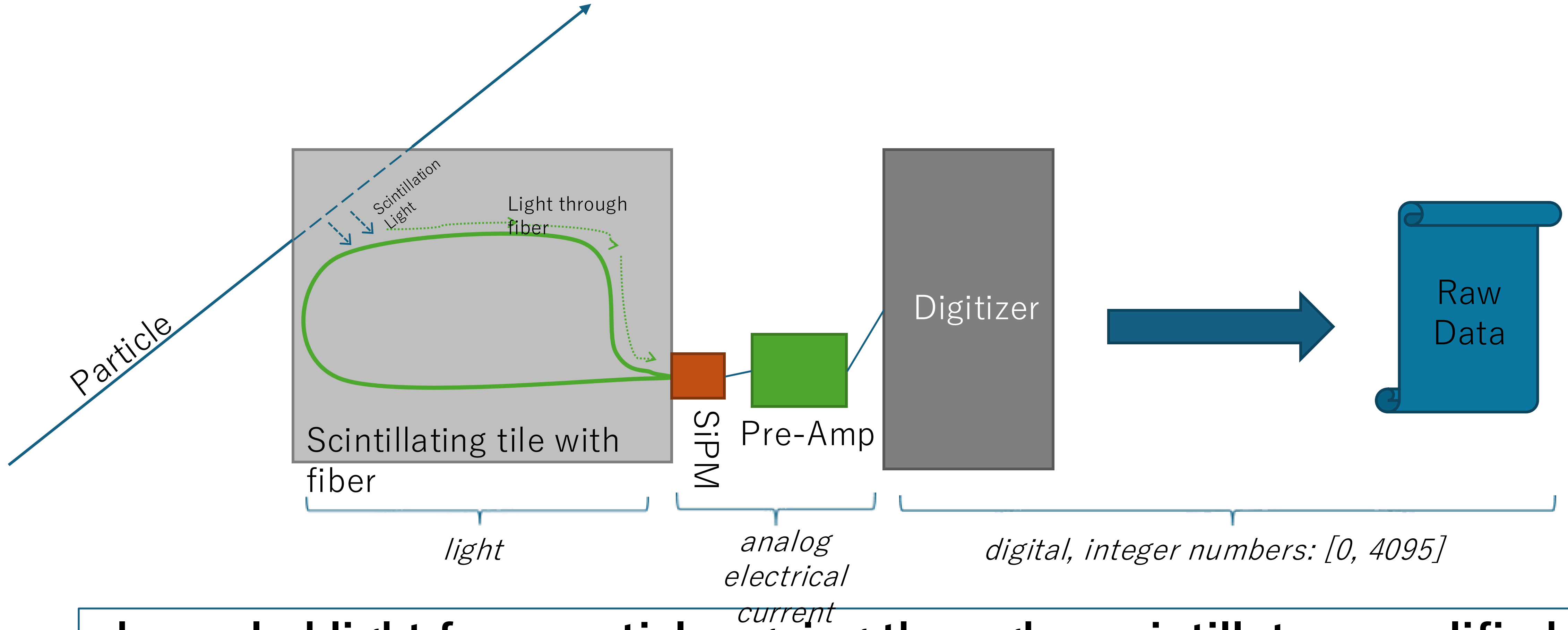
Schematic & Channel Numbering



See Back-Up Slide 47: These channels match the scheme in the South Channel Block, but are different for the PHENIX HBDs and the sPHENIX electronics

What the HCal measures

sPHENIX School



channeled light from particles going through a scintillator, amplified and digi

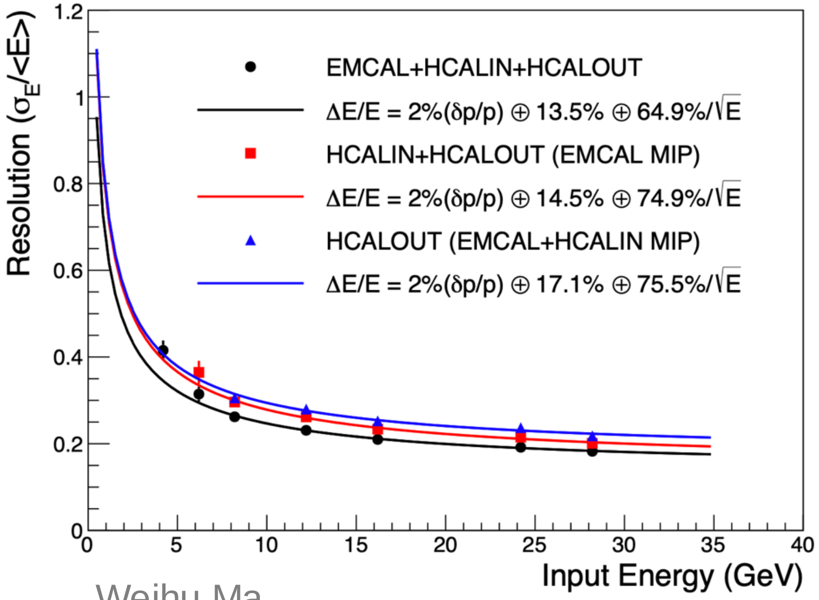
Hadronic Calorimeter (HCal)

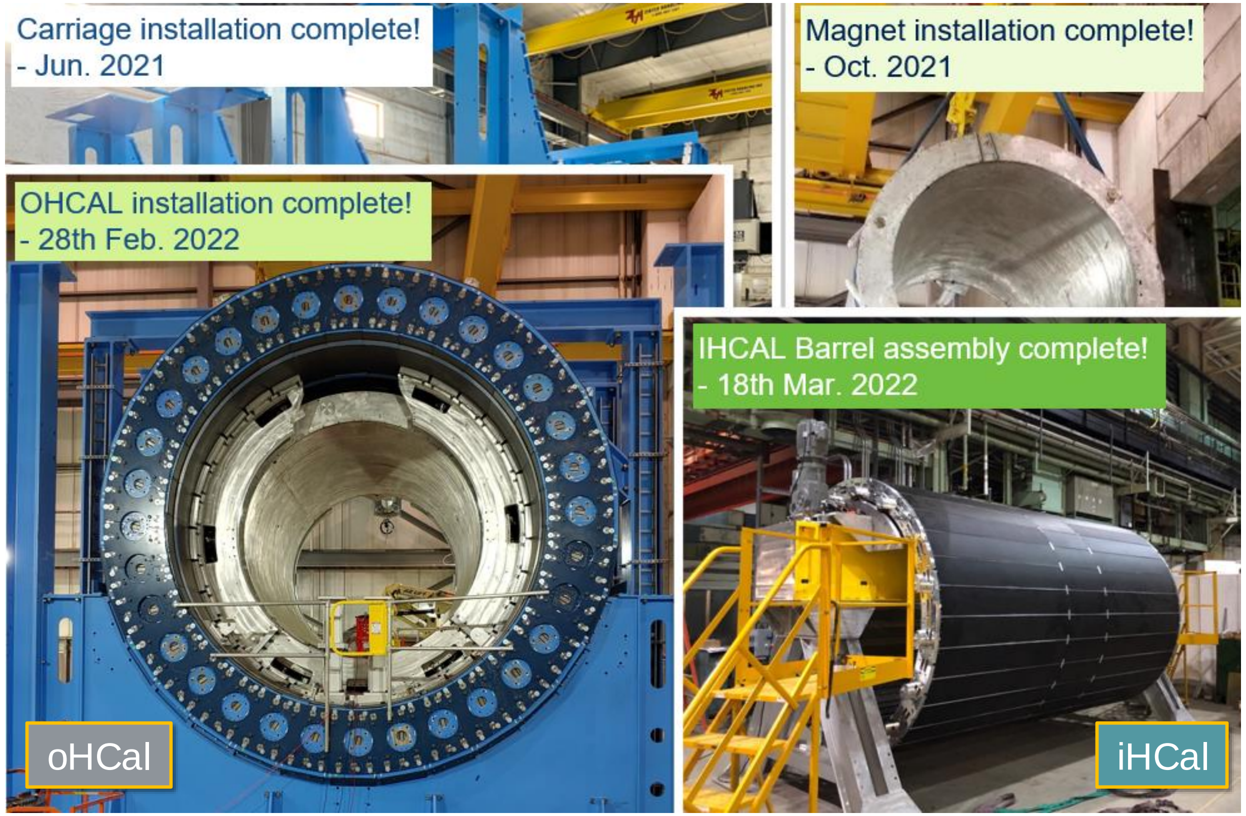
Inner Hadronic Calorimeter (iHCAL)

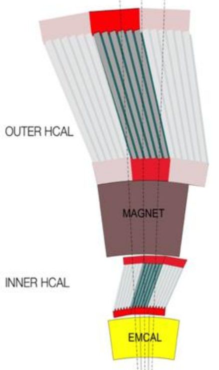
- ✓ Aluminum-scintillating tiles with embedded WLS fibers

Outer Hadronic Calorimeter (oHCAL)

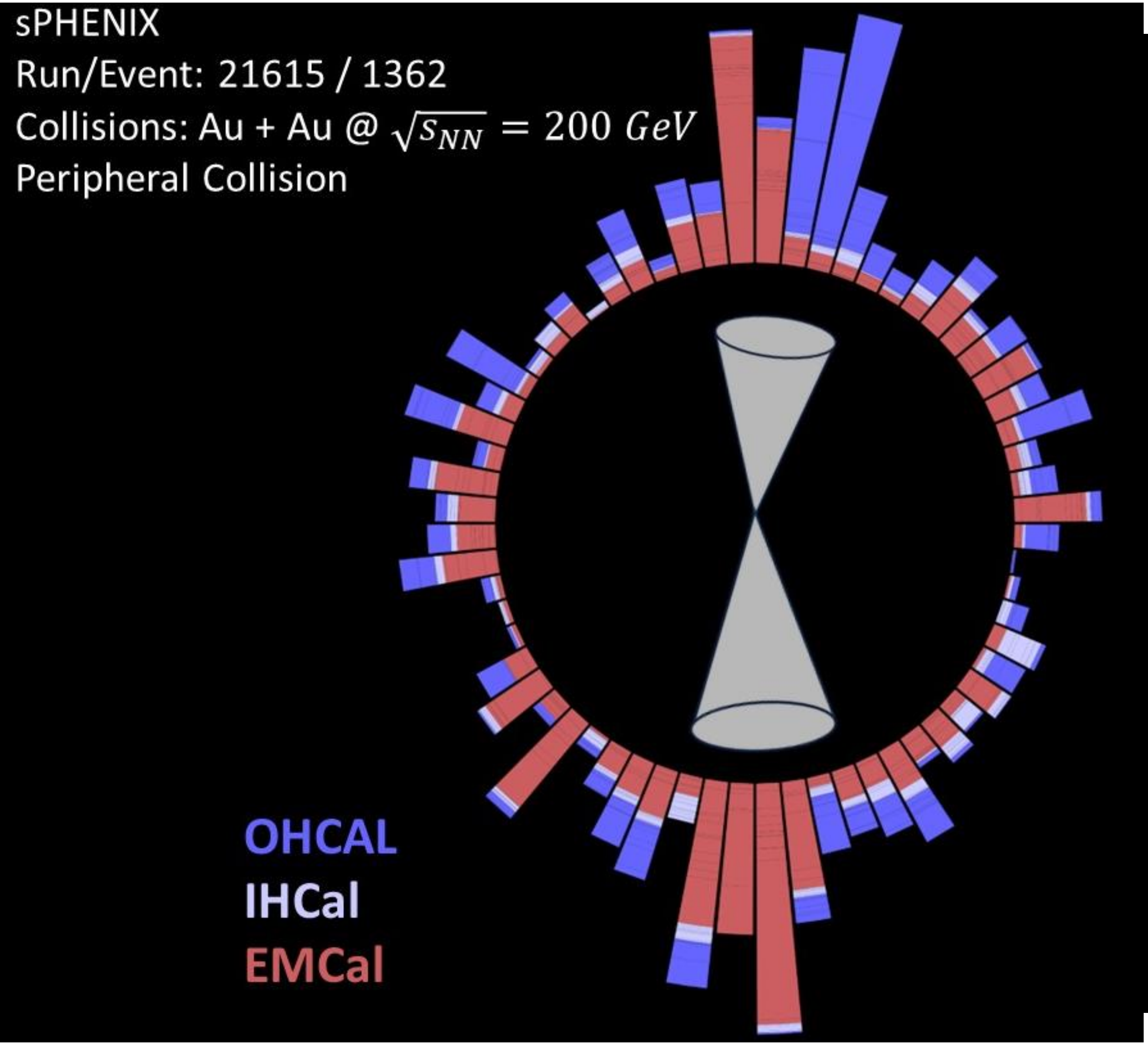
- ✓ Tilted steel plates/scintillator tiles with embedded WLS fibers
- ✓ $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ towers
- ✓ Installation complete!

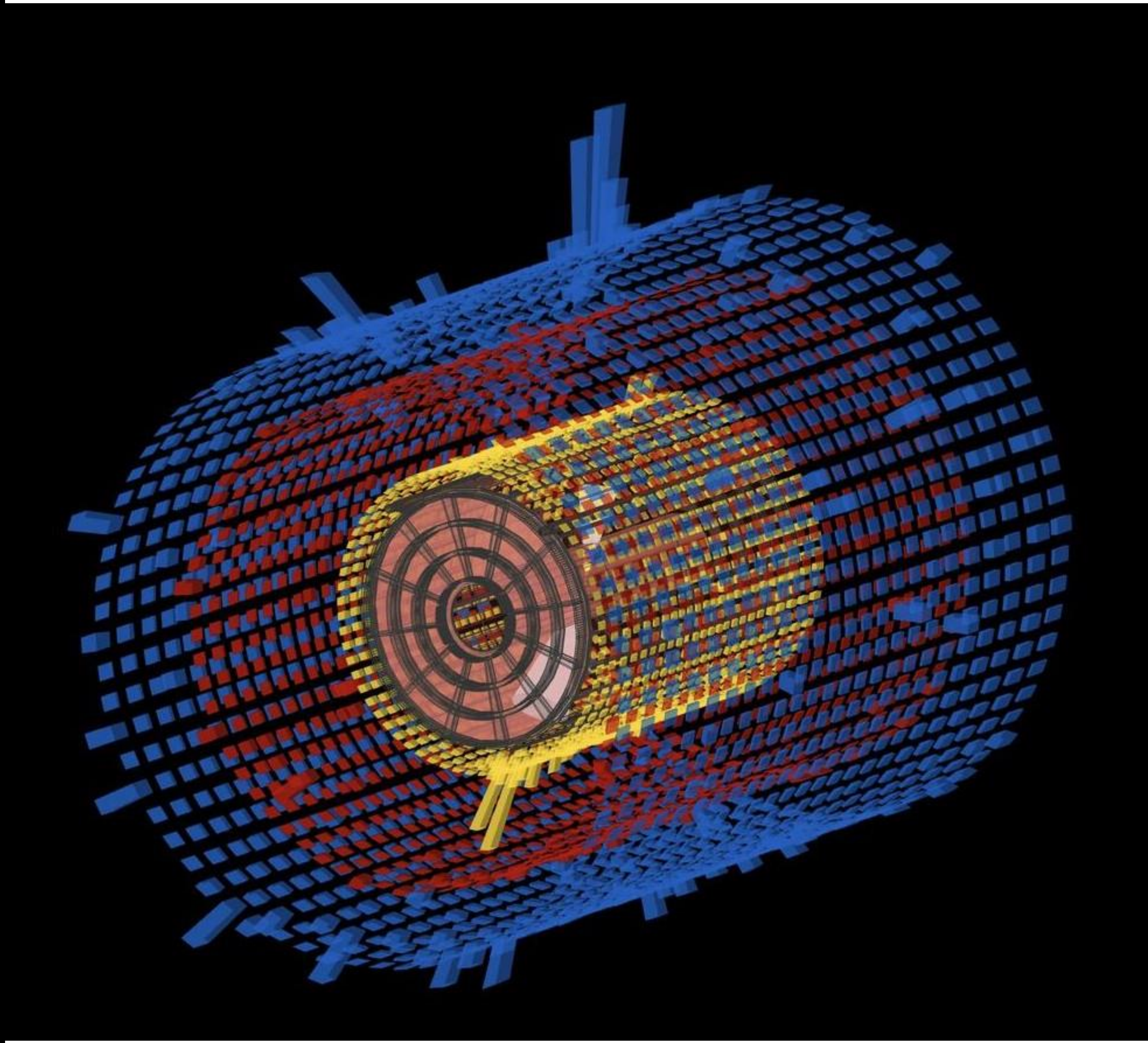






Dijet Event in Run 2023 Au+Au Data

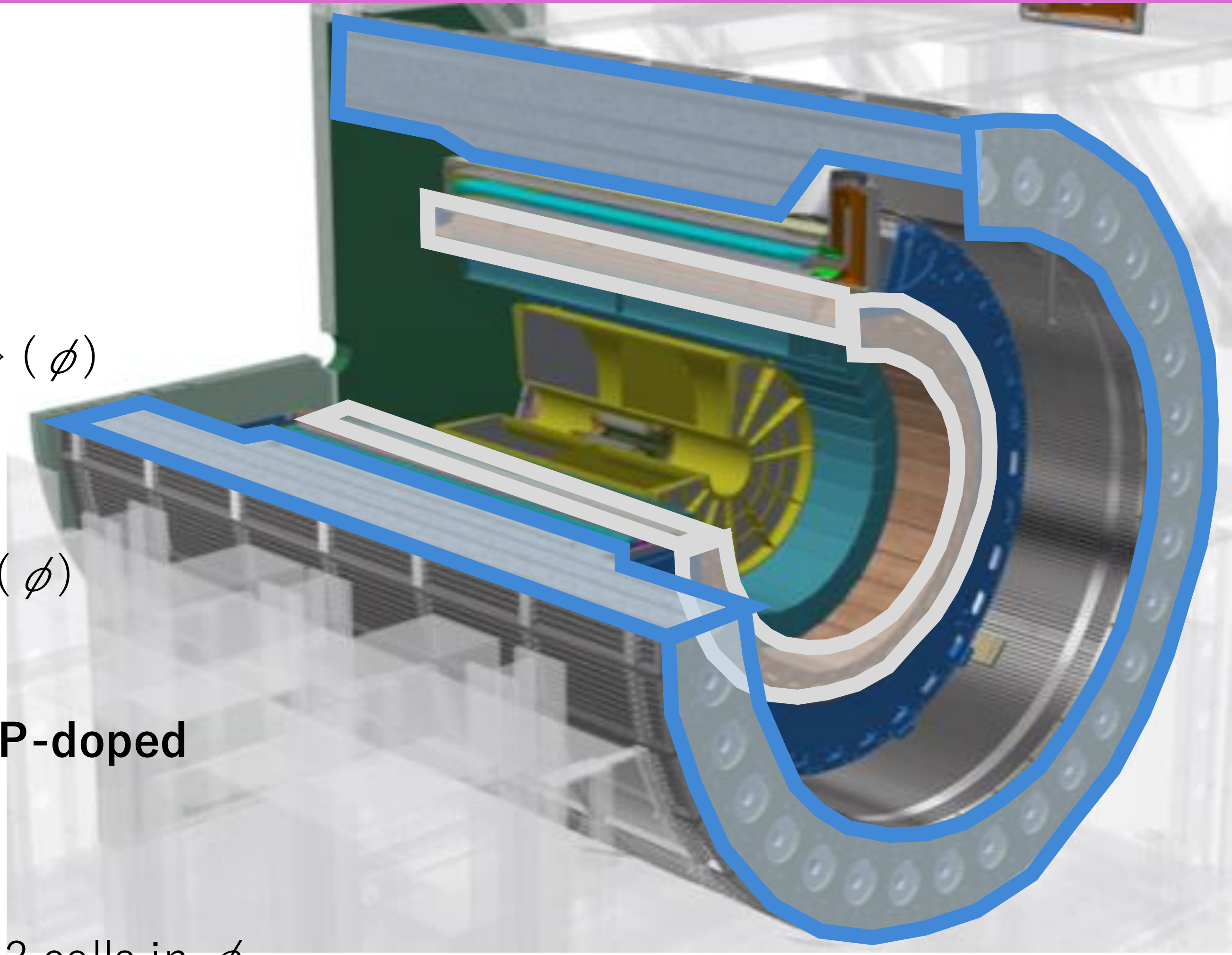




What the HCal is

sPHENIX School

- **Acceptance**
  - **$-1.1 < \eta < 1.1$**
  - **$0 \leq \phi < 2\pi$**
- Details
  - OHCal
    - **low-carbon, magnet steel absorber**
    - 7.22m (z) × 0.865m (r) × {0.357 m, 0.527m} (ϕ)
    - 12,105.5 kg x 32 modules (sectors)
  - IHCal
    - **aluminum absorber**
    - 4.35m (z) × 0.235m (r) × {0.223 m, 0.27m} (ϕ)
    - 907.2 kg x 32 modules (sectors)
- Sampling detector
  - **7,680 (O) + 6,144 (I) scintillating tiles (POPOP-doped polystyrene)**
  - tapered, tilted metal plates
  - Arrangement of each sector
    - 5 (O) or 4 (I) tiles per cell, 24 cells in η by 2 cells in ϕ
    - **Segmentation: $\Delta\eta/\eta_{total} \sim 0.1$, $\Delta\phi/2\pi = 0.1$**

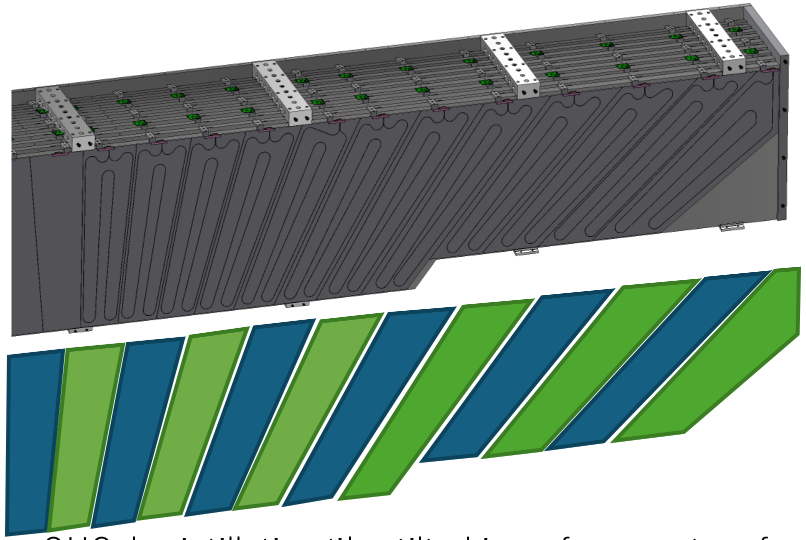


What the HCal is

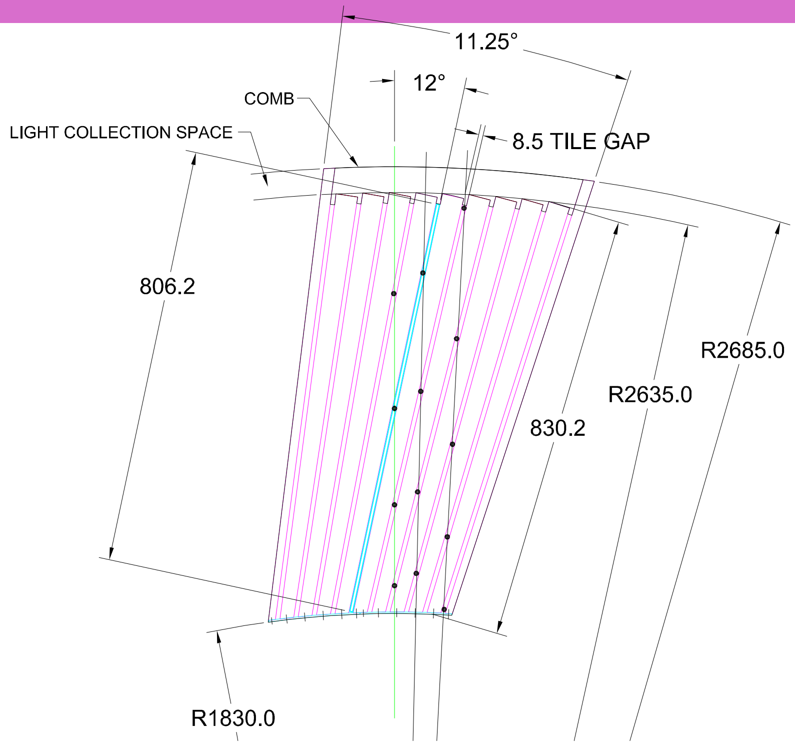
sPHENIX School

Tiles, Segmentation, and Tilt

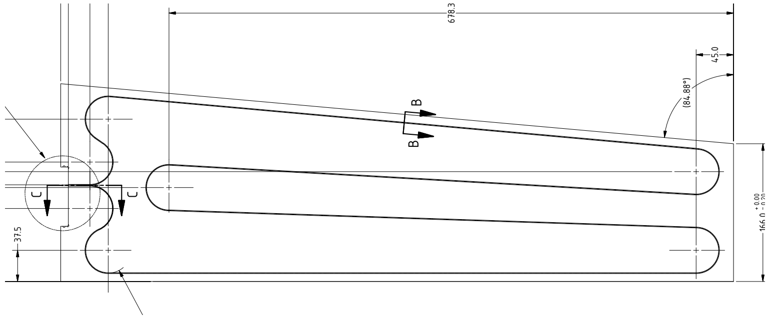
- Fanning out radially from nominal collision vertex
- tilted away from radius so that a radial particle would go through multiple tiles/sector
- Tilt in phi is different for inner/outer
- Sector boundaries between



OHCal scintillating tiles tilted in η from center of barrel



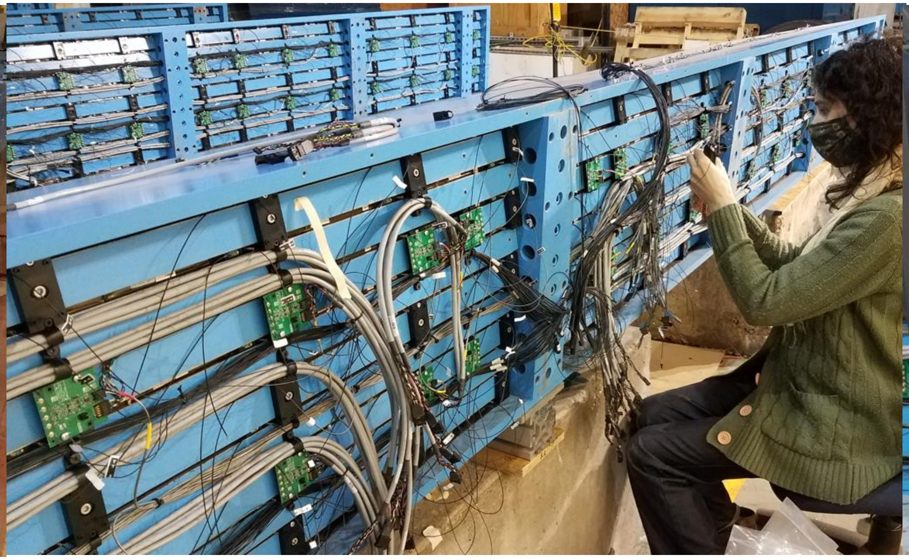
OHCal scintillating tiles tilted in ϕ from radius

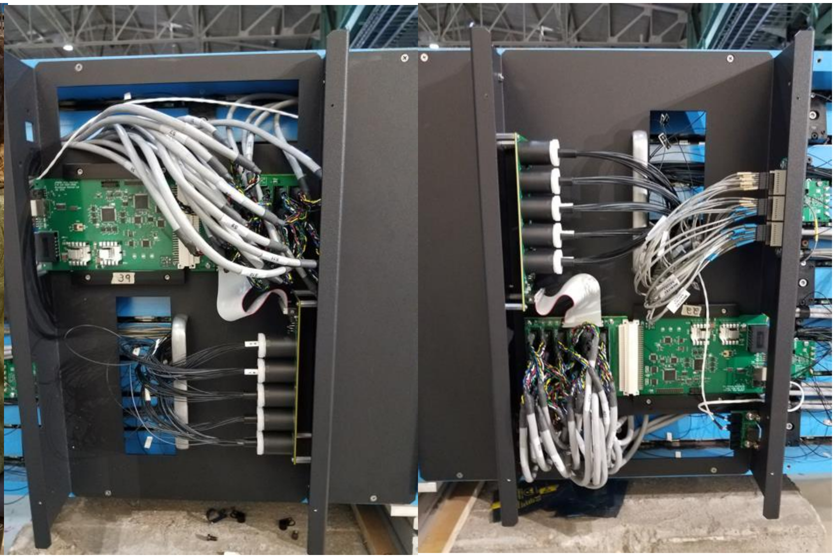


What the HCal is

sPHENIX School

Assembly pictures

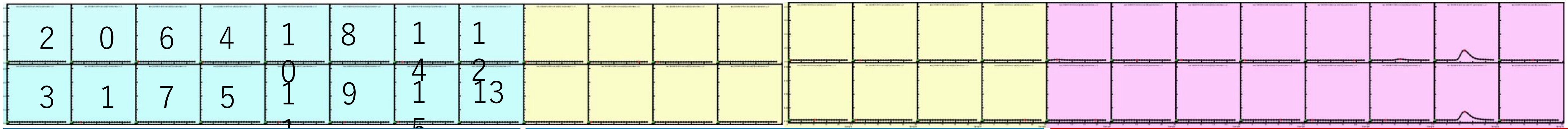




Schematic & Channel Numbering

South Half

North Half



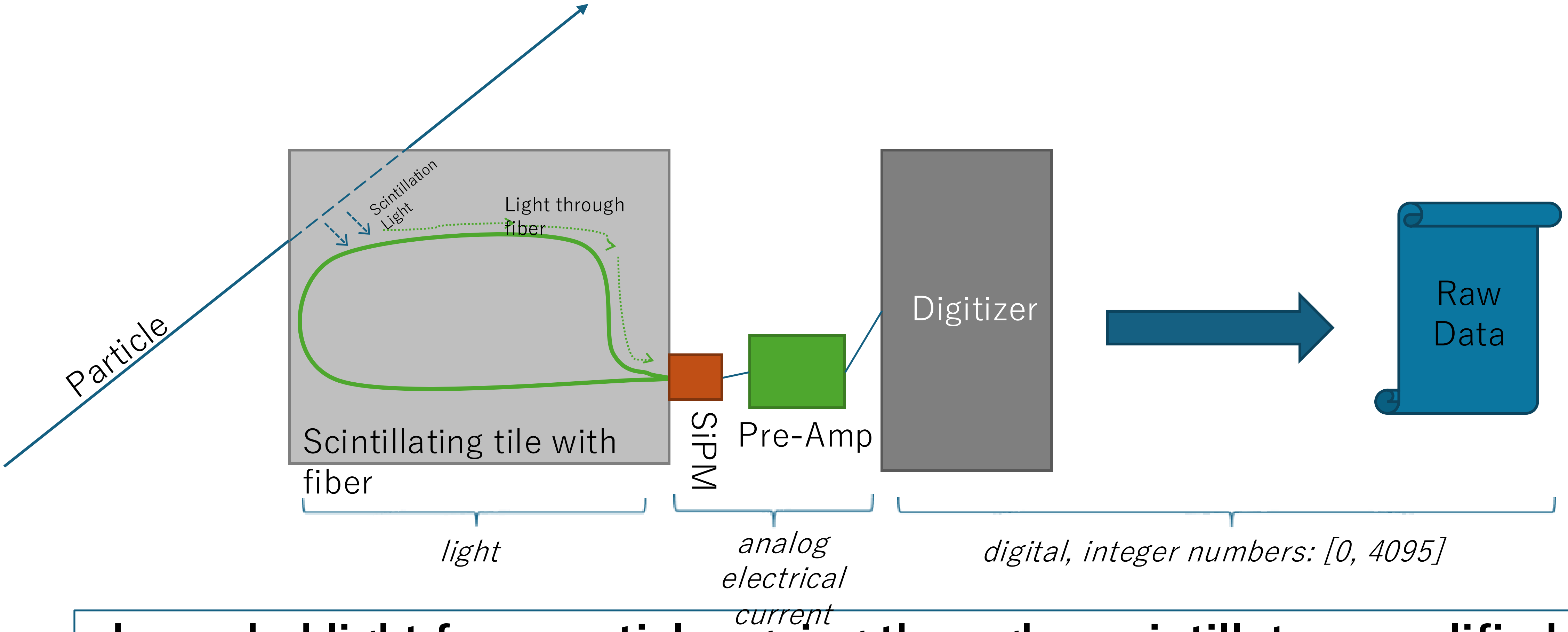
South Channel Block (Third)

Middle Channel Block (Third)

North Channel Block (Third)

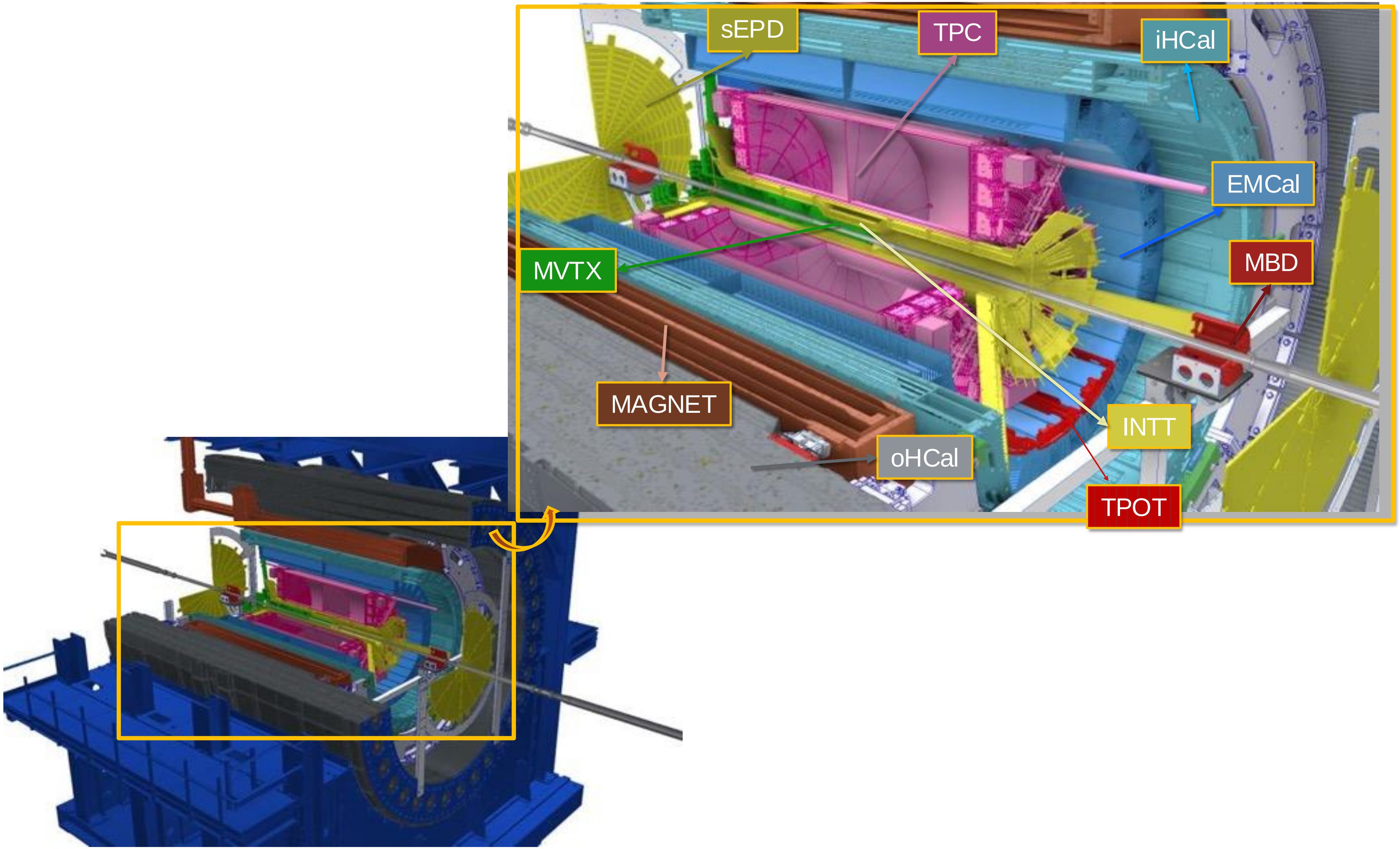
See Back-Up Slide 47: These channels match the scheme in the South Channel Block, but are different for the PHENIX HBDs and the sPHENIX electronics

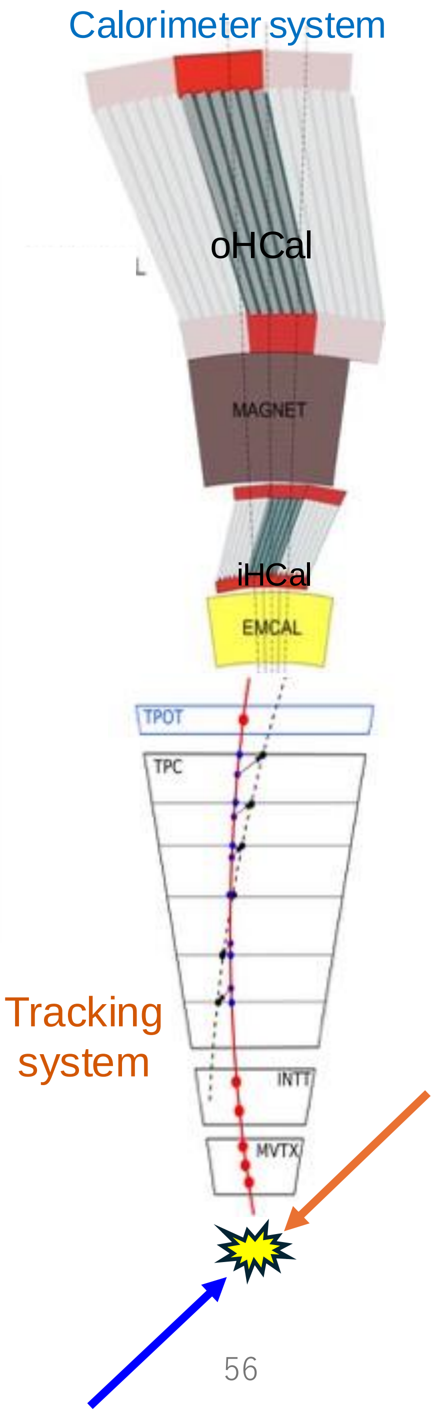
What the HCal measures



channeled light from particles going through a scintillator, amplified and digi

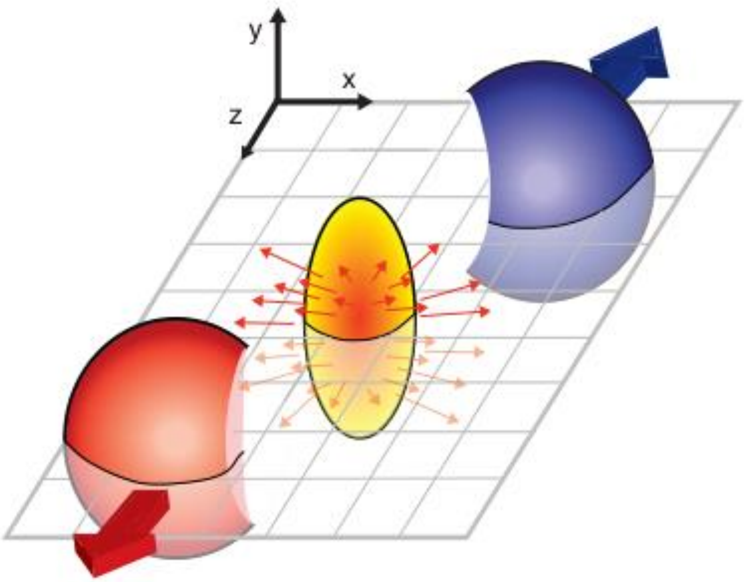
sPHENIX FORWARD Detector

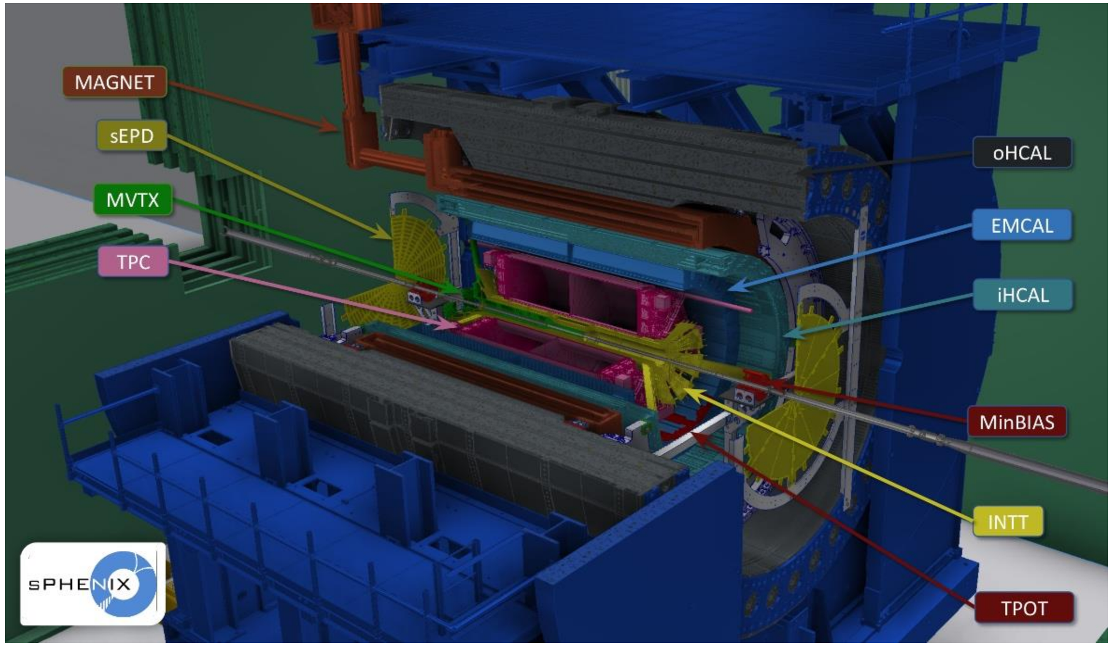




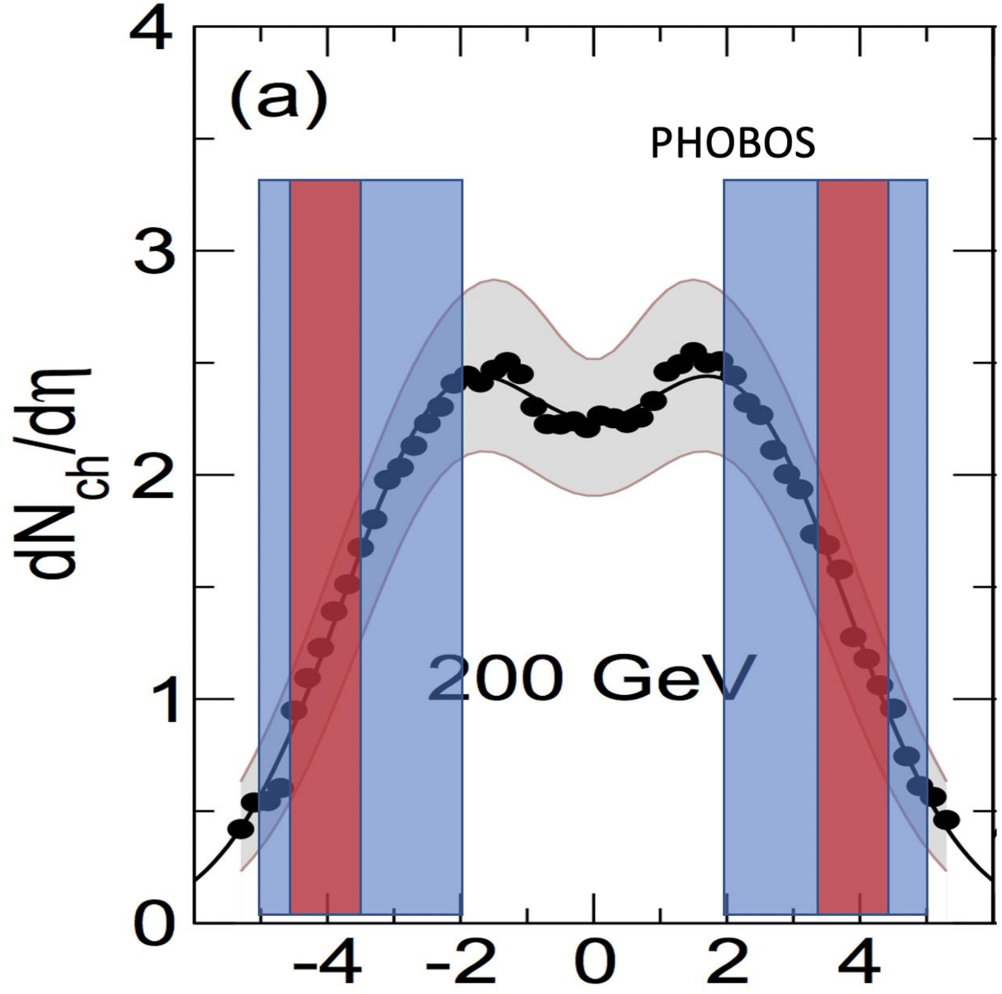
sPHENIX Event Plane Detector (sEPD)

Built to determine the collision geometry → Impact Parameter



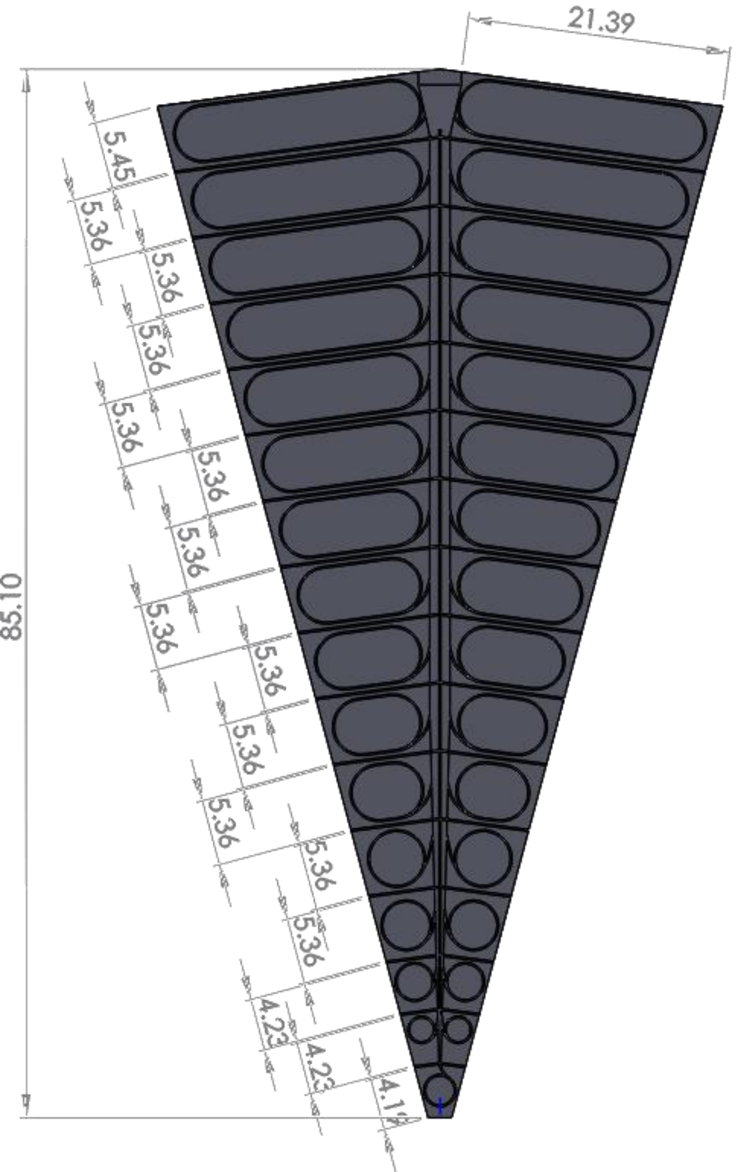


Forward Particle Distributions



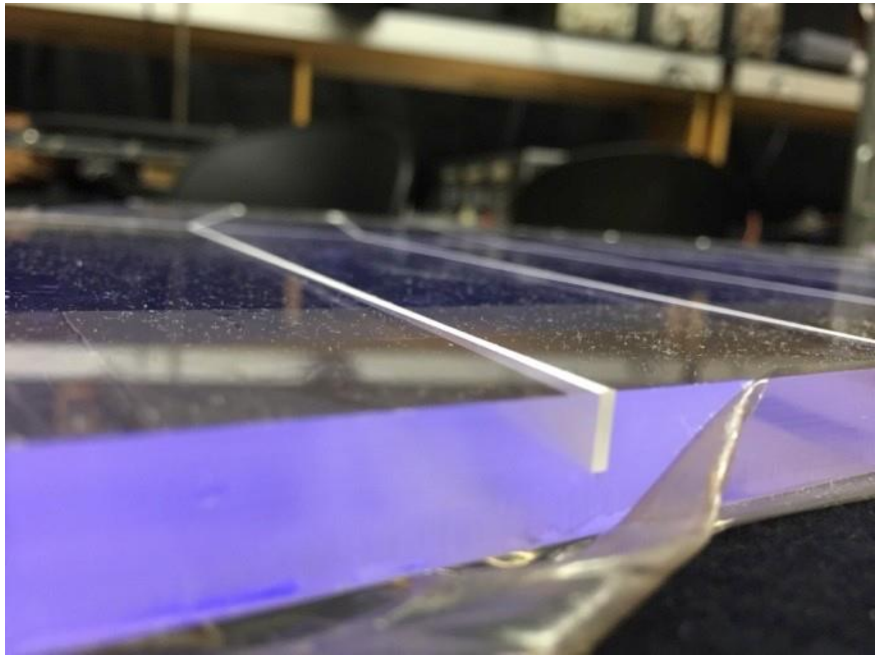
- **sEPD 2.0 < |η|< 4.9**
- **MBD: 3.51 < |η| < 4.61**
- Large acceptance with azimuthal symmetry with h gap from mid-rapidity is very useful for many analyses
  - Especially important for small systems

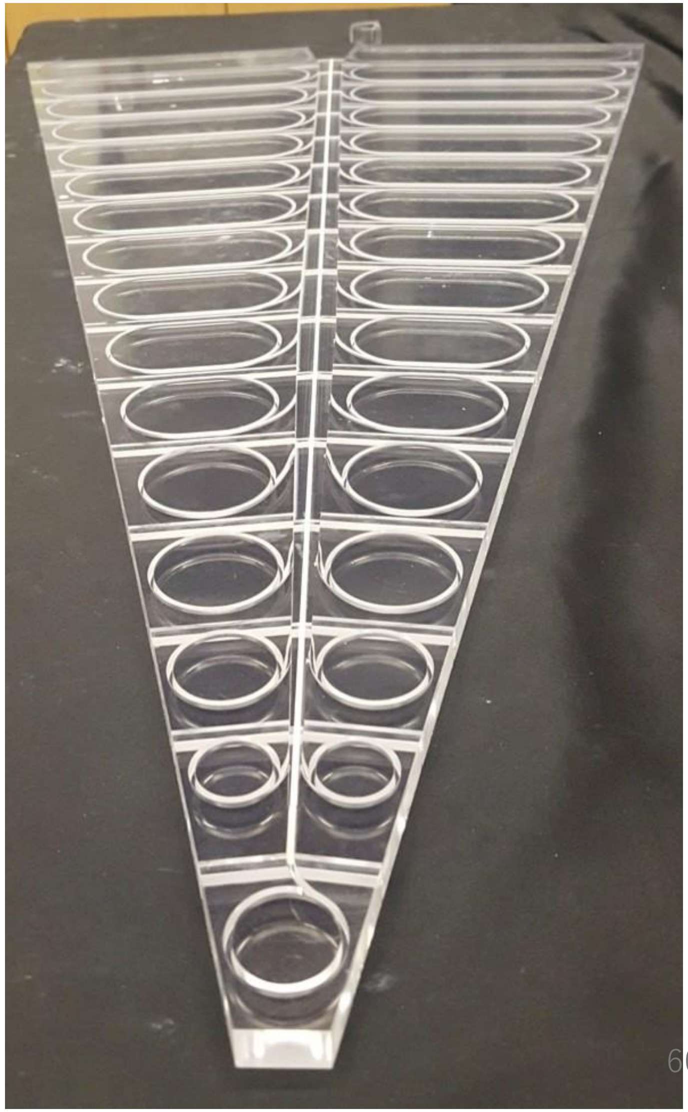
Sector Design



- 2 Wheels of 12 sectors with 31 optically-isolated tiles
  - **1.2-cm-thick scintillator**
- Total of 12x31x2=**744 channels**
- R_{outer} = 0.9 m, R_{inner} = 4.6 cm
- Planned location of ~z = 319 cm
  - **2.0 < |η|< 4.9**
  - STAR: 375 cm (2.1 < |η|< 5.1)
  - PHENIX BBC: (3.1 < |η|< 3.9)
  - sPHENIX MBD: 250 cm (3.51 < |η| < 4.61)
- Wavelength shifting fibers (3x loops) glued into tiles
- Machined out of a single piece of scintillator

Isolation Grooves



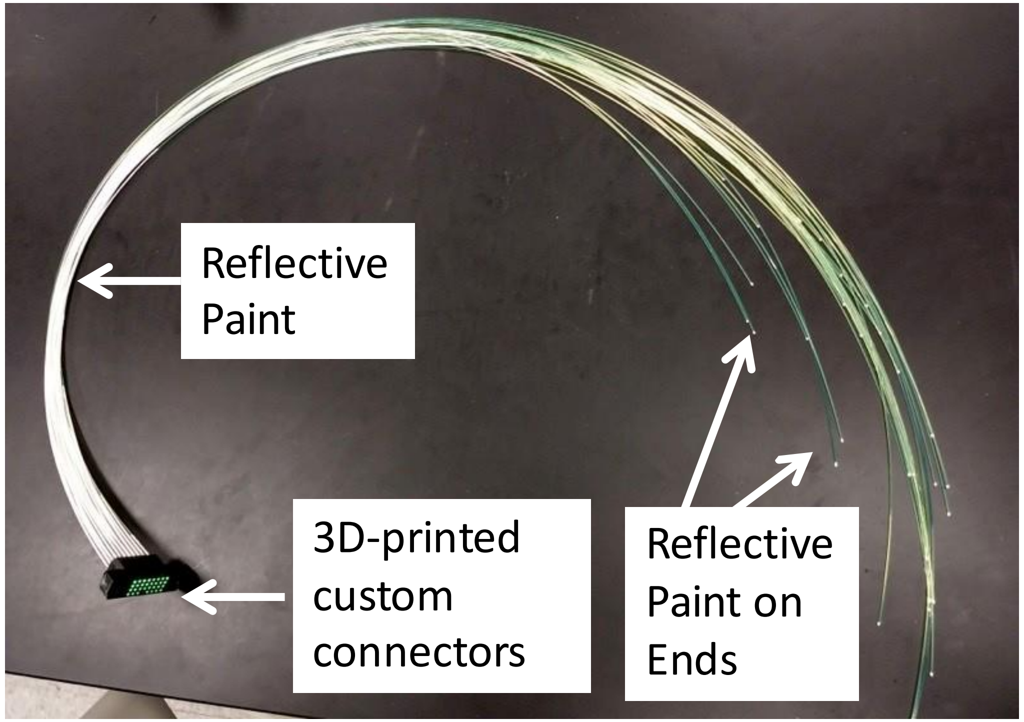


Mill "half-way" and fill groves with TiO_2 + epoxy mixture (reflective epoxy)

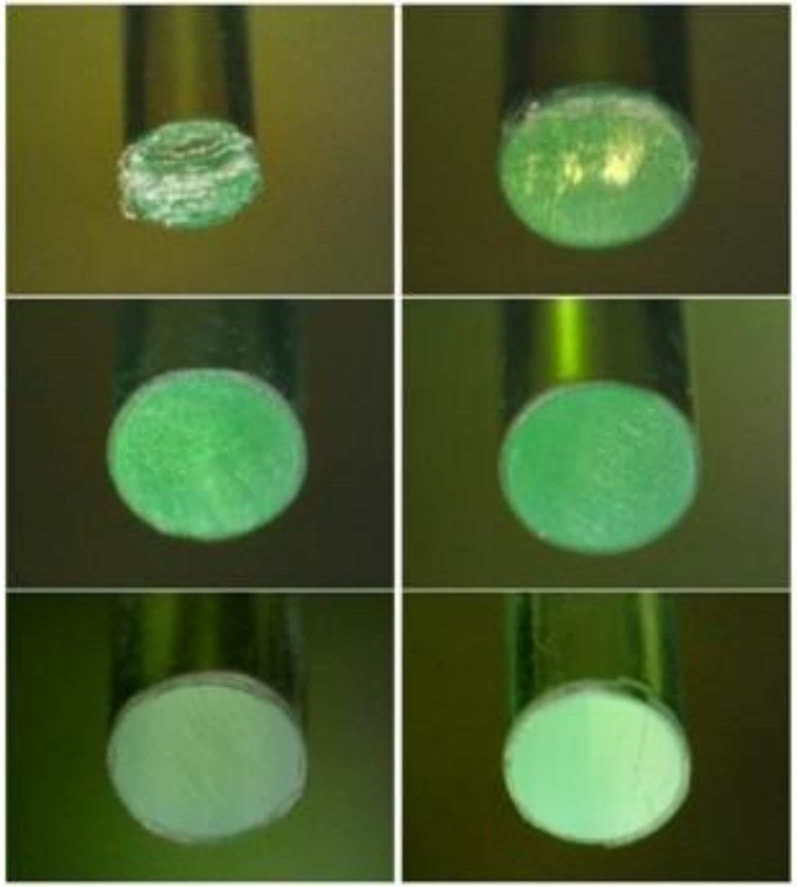
- **Optical isolation!**

Flip over and finish milling the groves + Fiber channels

WLS Fiber Preperation



Connectors polished prior to gluing, inserts for panel screws

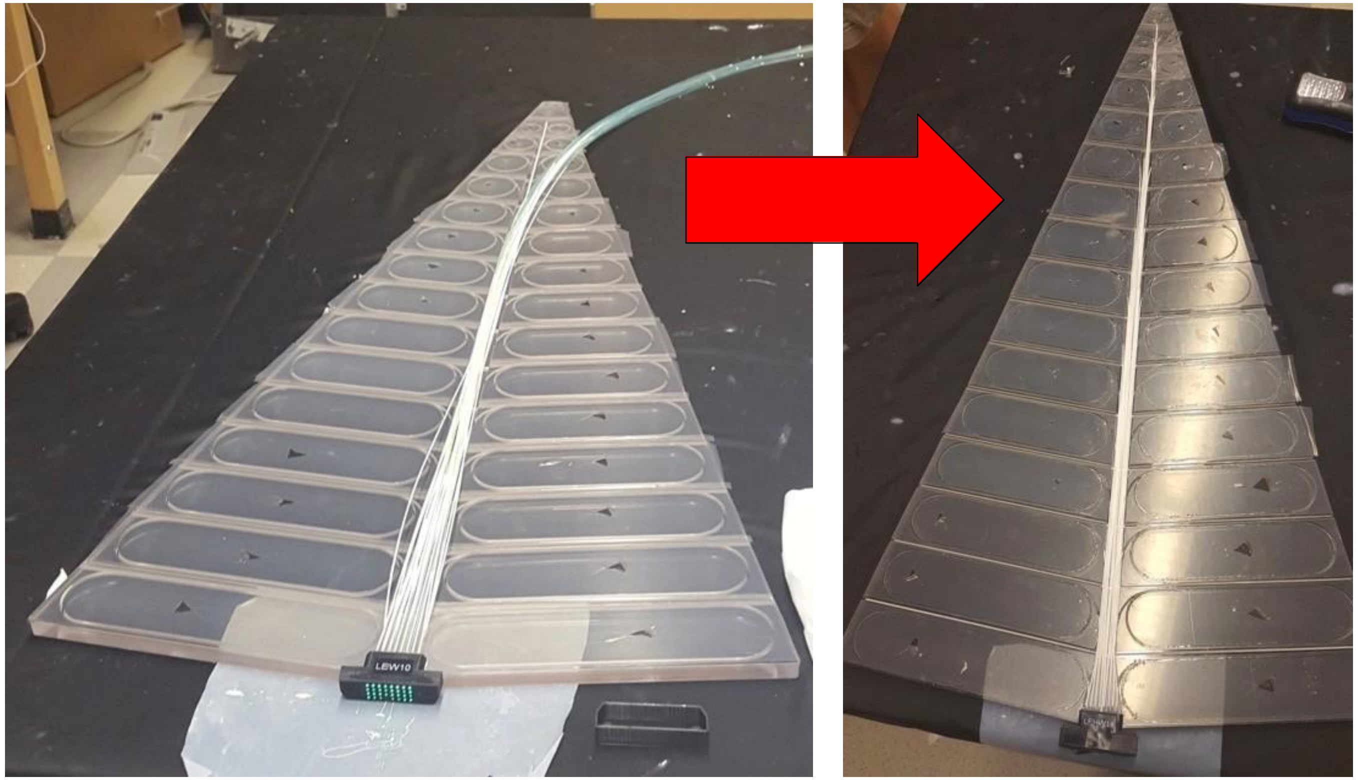


Reflective paint for "Central Channel"

- **Decreases cross-talk**

Fiber ends painted→ Increases light yield by ~30-50%

sEPD Sector Construction

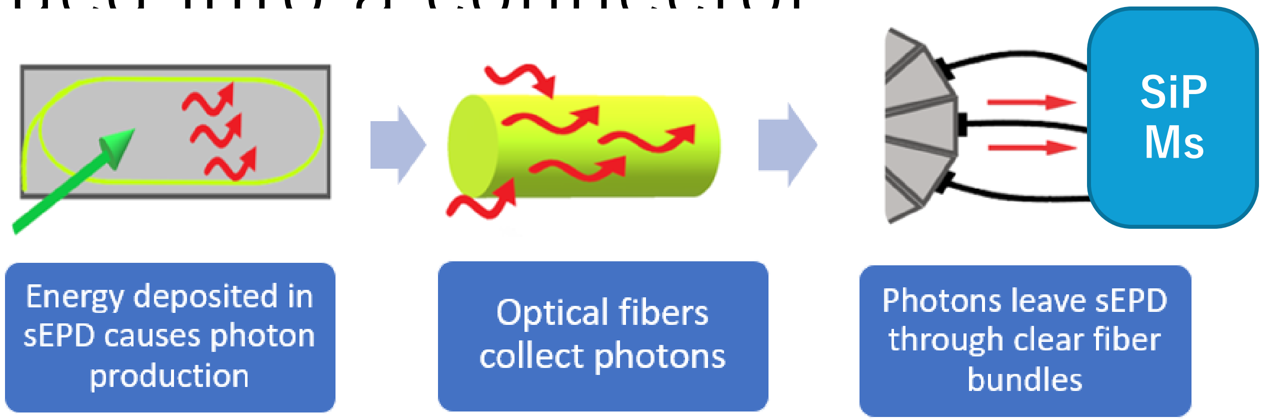


Optical Isolation is important! Sectors will be checked after construction

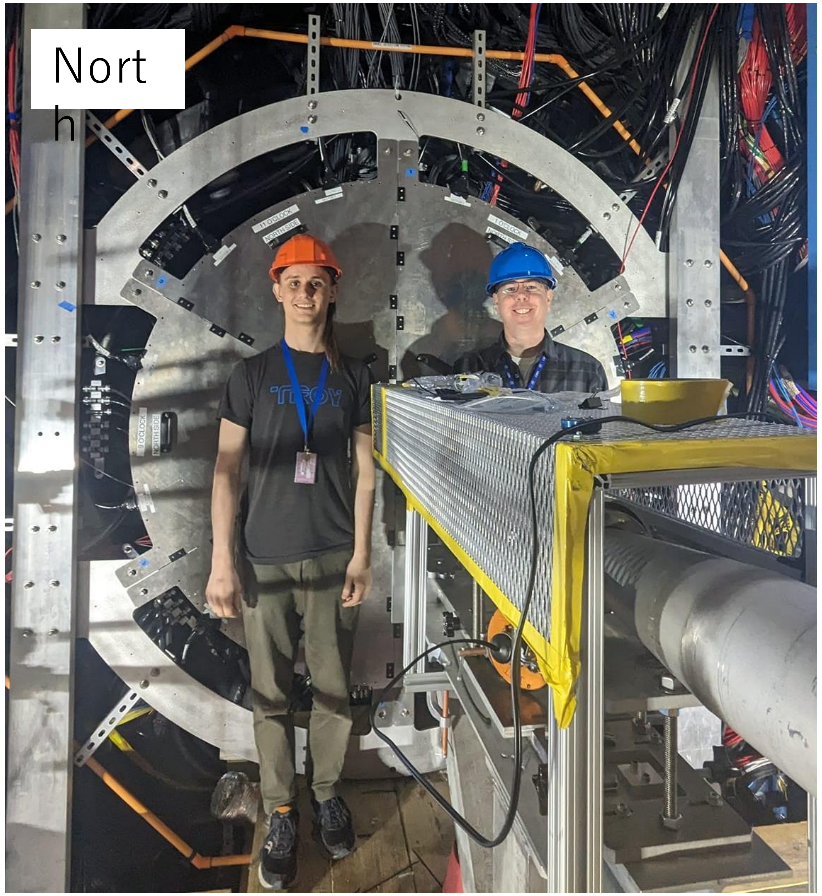
- Connector glued into place (reflective epoxy), then fibers (optical epoxy)
- Central channel and front grooves filled with reflective epoxy
- Tape removed and scintillator polished

Clear Fiber Bundles

- Purpose: carry signal to the electronics
- Clear fibers were cut to a length of 6.8 meters
- The fibers were put into thick tubing measuring 4.4 meters
- Fibers glued into a connector

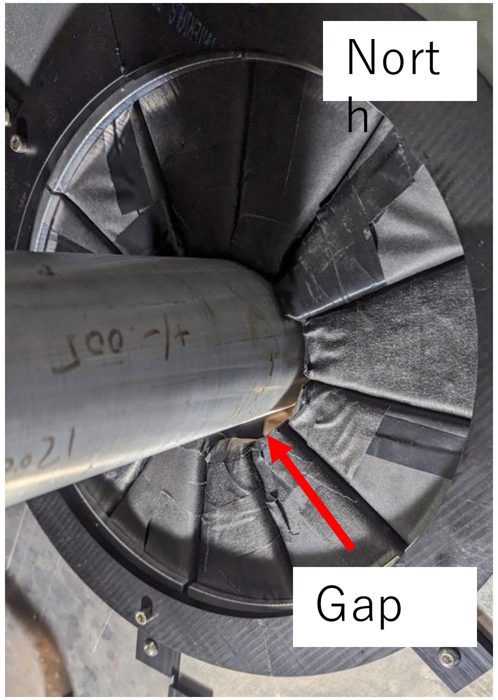


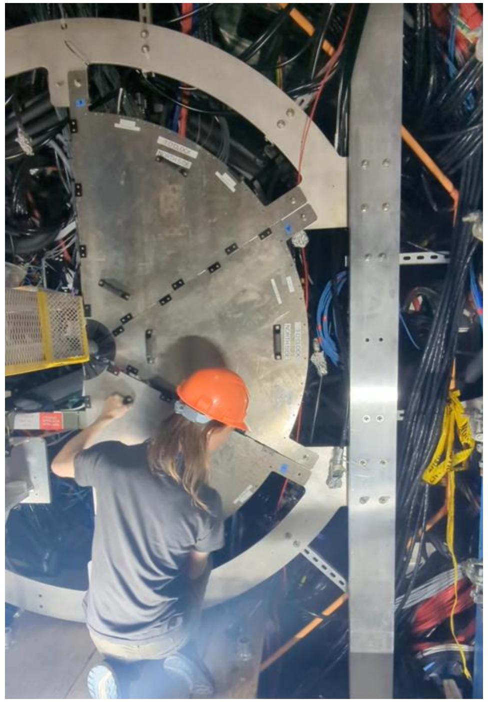
sEPD Install 2024



Tristan Protzman

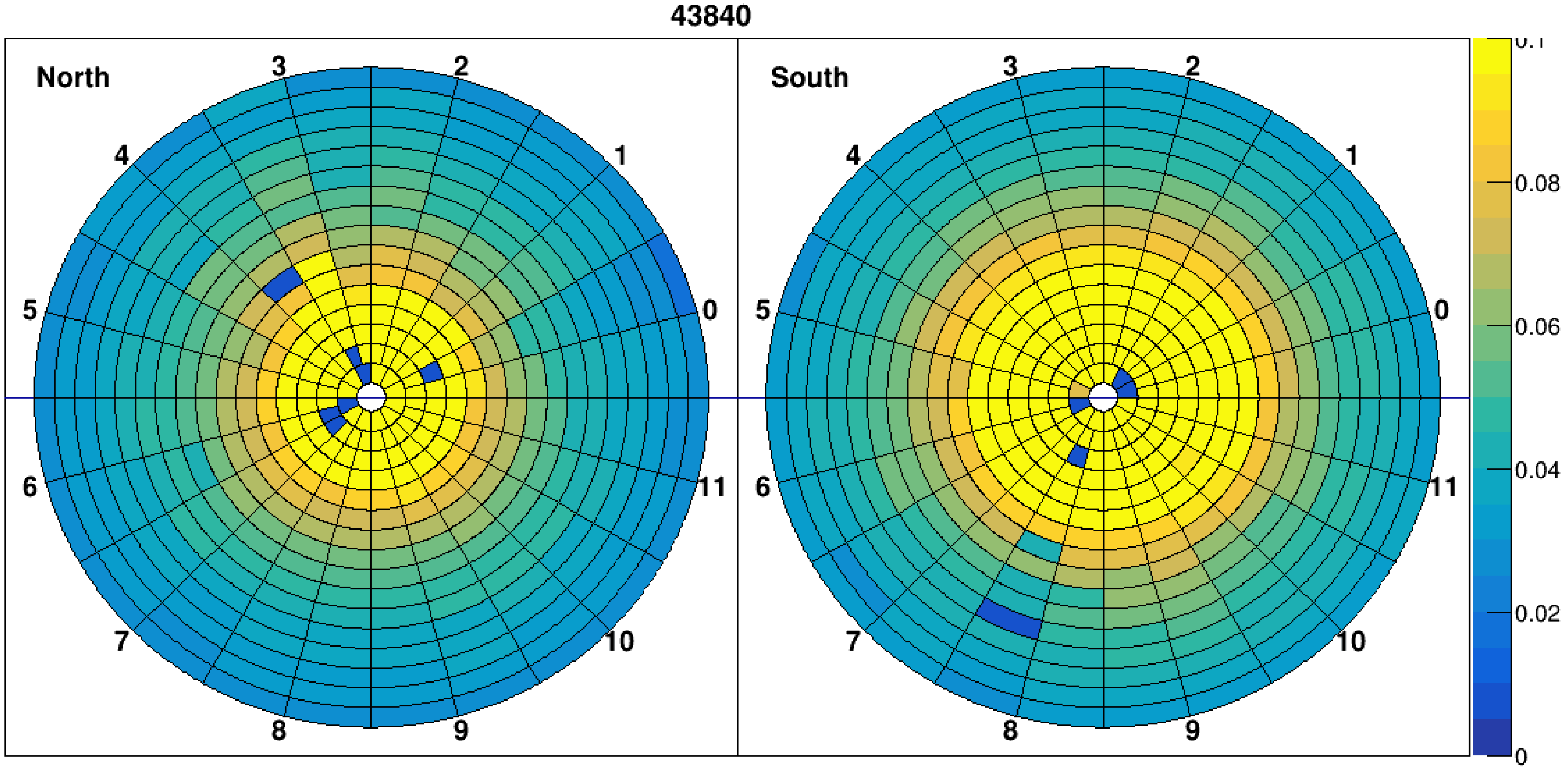
Ron Belmont





- South installed during an earthquake
- North installed during an eclipse

First data



Number of “hits” per tile divided by # of collisions in the run

Further calibration and data processing in progress

Event plane resolution matches simulation!

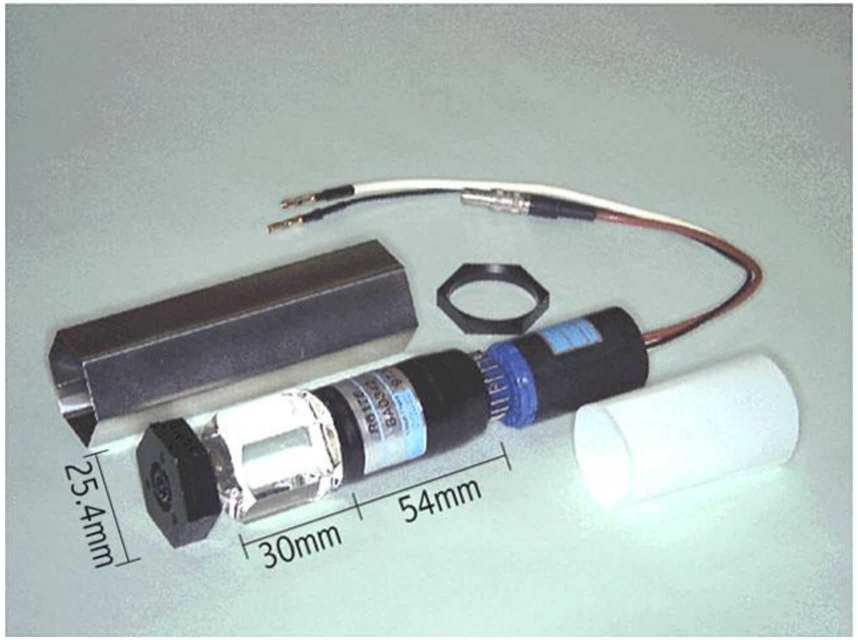
Minimum Bias Detctor (MBD)

Charged Particle Detector

Minimum Bias Detector

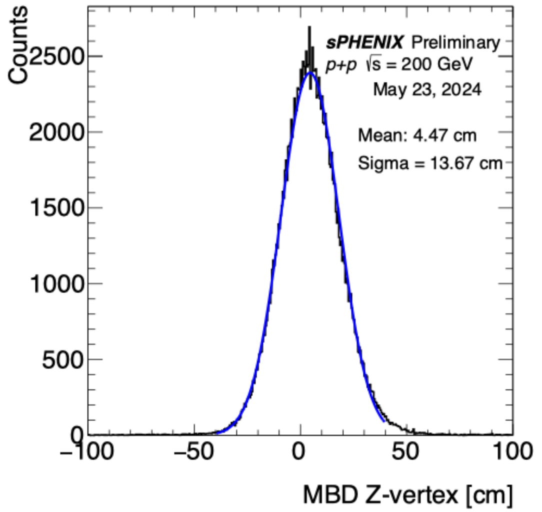
Rapidity Coverage
[3.51 < |η| < 4.61]

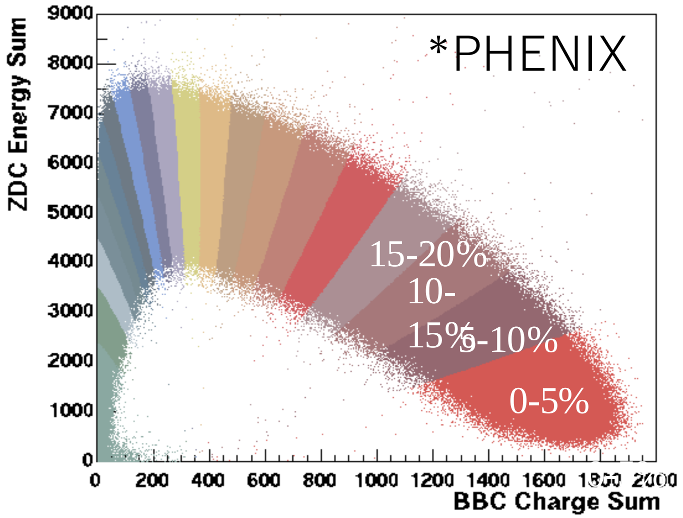
- Reuse of the PHENIX Beam-Beam Counter
- 128 channels of 3 cm thick quartz radiator on mesh dynode PMT
- 120 ps timing resolution



- Each element is assembled by Quartz Cherenkov radiator(β_{th}=.7) and meshed dynode PMT.

Role of MBD





Collision Vertex
initial point of charged particle tracking

Centrality Determination
Impact Parameter Determination with ZDC

Minimum Bias Trigger
Level1 Trigger with Online Vertex Cut

Time-Zero Determination
Start Timing for ToF Measurements

Reaction Plane Determination
Direction of Impact Parameter

BBC Guys

DC : Toru Sugitate

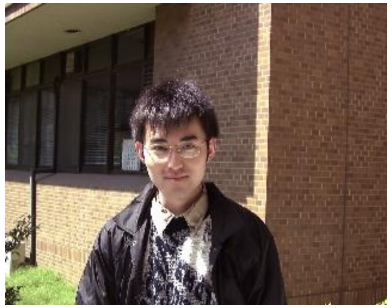
contact person
Kensuke Homma

Tomoaki Nakamura

Takashi　Hachiya

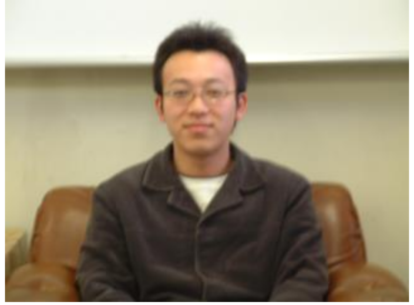
Kenta Shigaki

Yuji
Tsuchimoto



Akitomo Enokizono
enoki@hepl.hiroshima-u.ac.jp

Kota Haruna



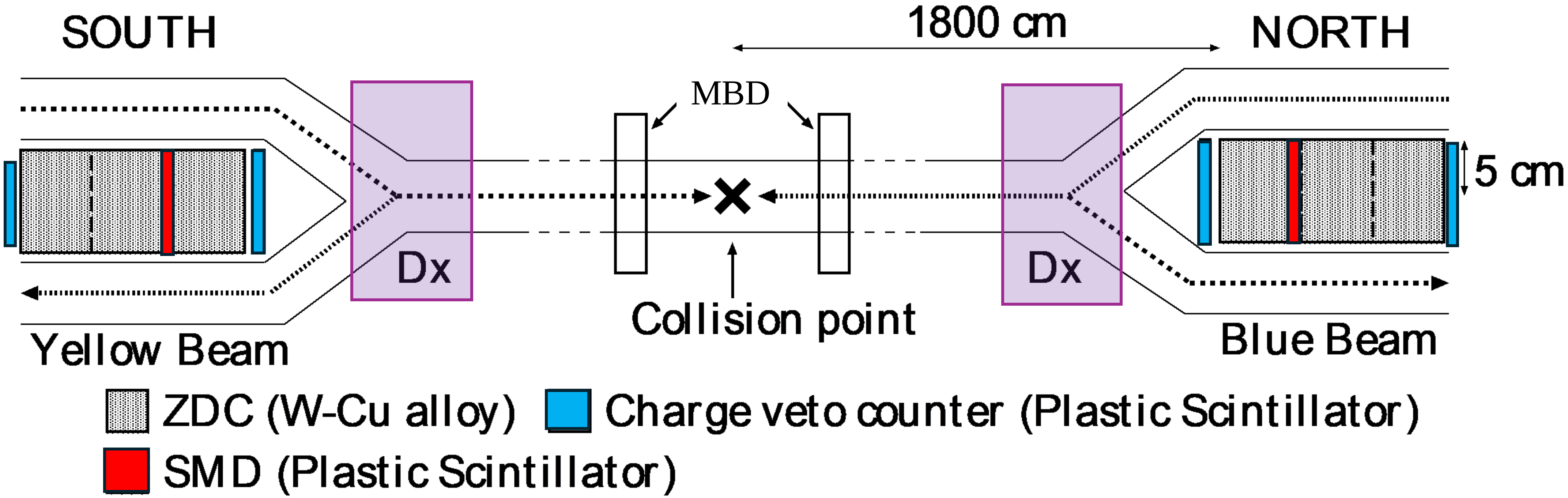
Hiroyuki Harada

Ryota Kohara

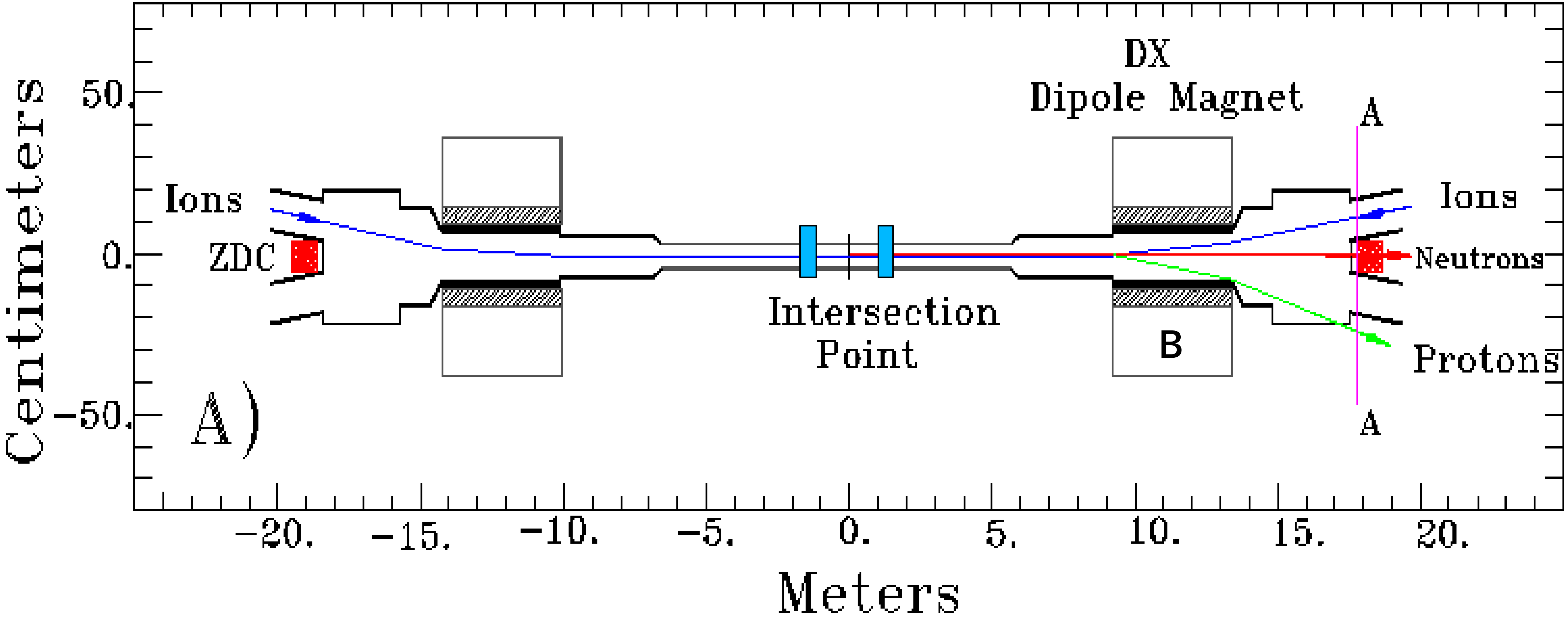
Zero Degree Calorimeter (ZDC)

Neutron Detector

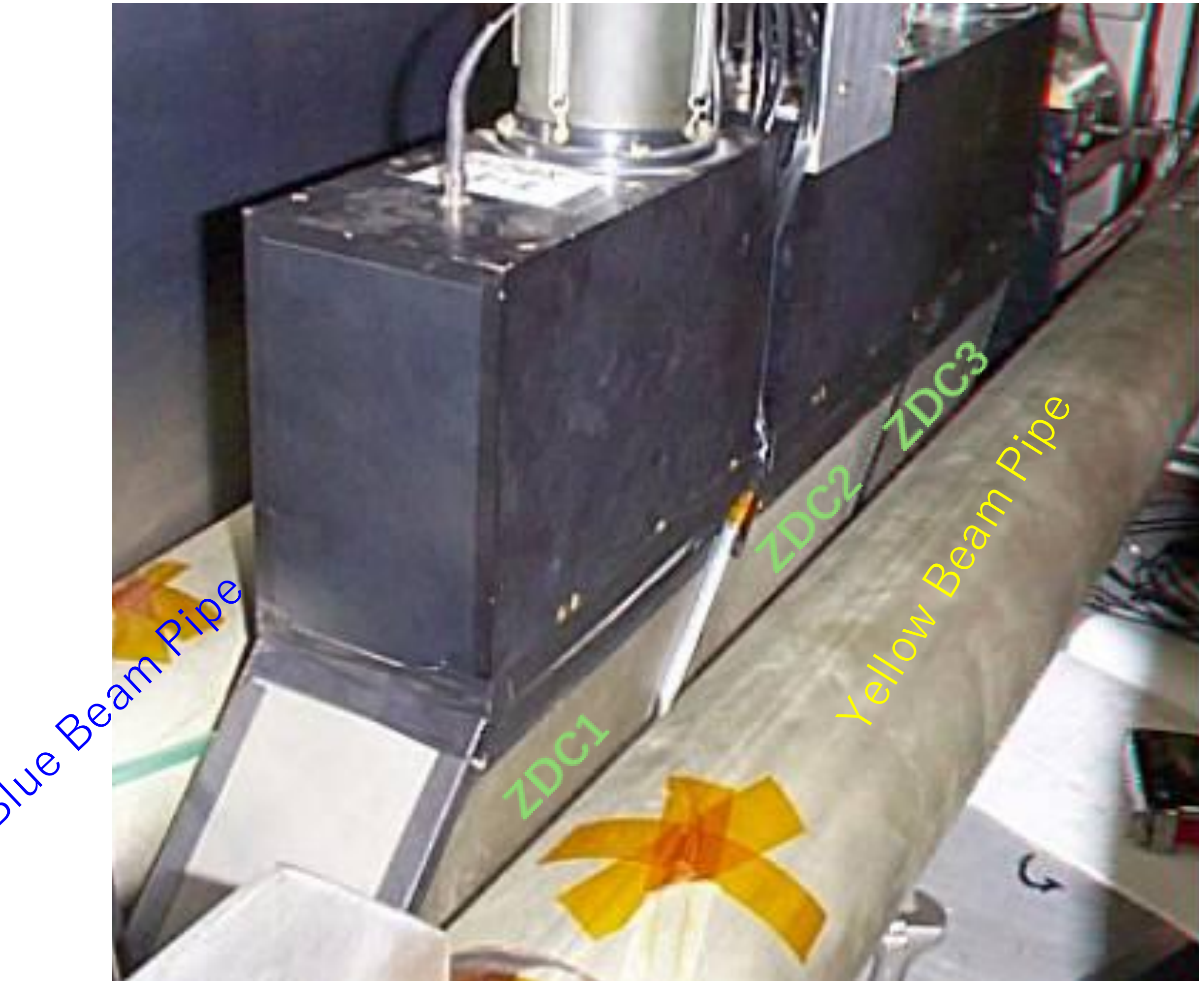
ZDC Location

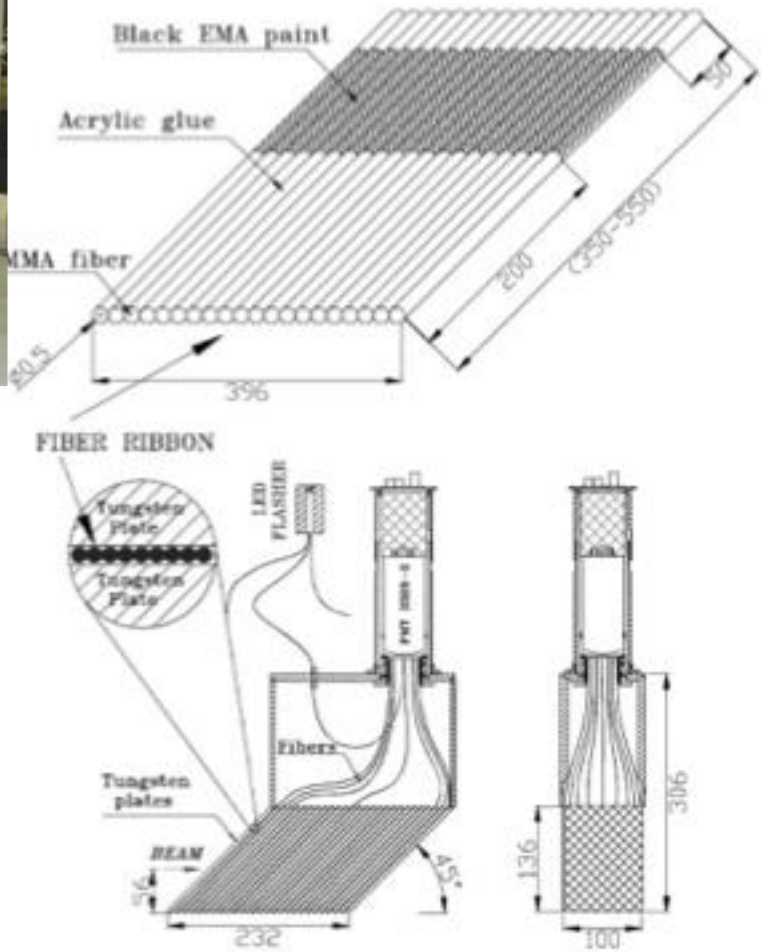


ZDC as Neutron Detector



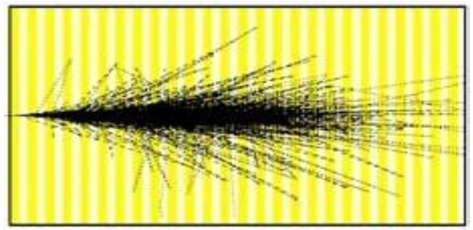
ZDC Compartments

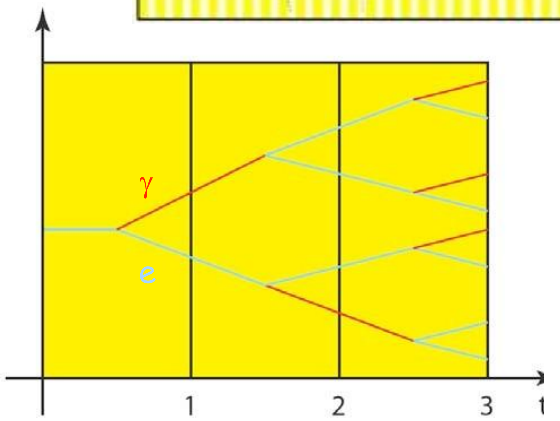


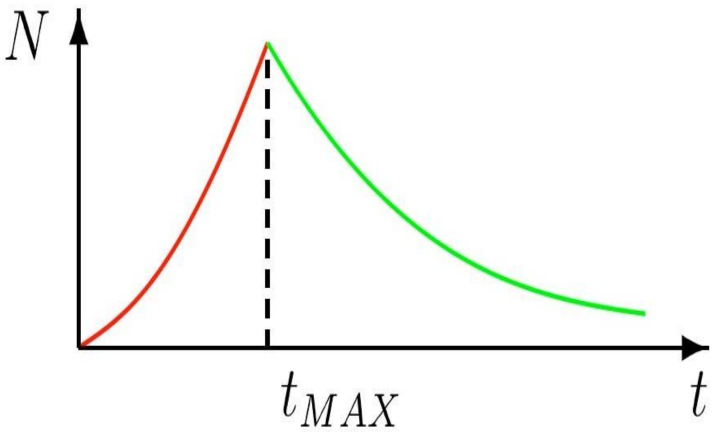


Shower Max Detector (SMD)

- Electromagnetic shower development
  - Simple qualitative model for shower development (Heitler)
    - Consider only: bremsstrahlung and pair production
    - Each electron with $E > E_c$ travels $1X_0$ and then gives up half of its energy to a bremsstrahlung photon
    - Each photon with $E > E_c$ travel $1X_0$ and then undergoes pair production with each created particle receiving half of the energy of the photon
    - Electrons with $E < E_c$ cease to radiate and lose remaining energy through ionization
    - Neglect ionization losses for $E > E_c$







Total number of particles after t X_0:

$$N(t) = 2^t = e^{t \ln 2}$$

Average energy of shower particle at depth t:

$$E(t) = E_0/2^t = E_0/e^{t \ln 2} \qquad t_{max} = \ln(E_0/E_c)/\ln 2 \propto \ln(E_0)$$

$$E(t) = E_c$$

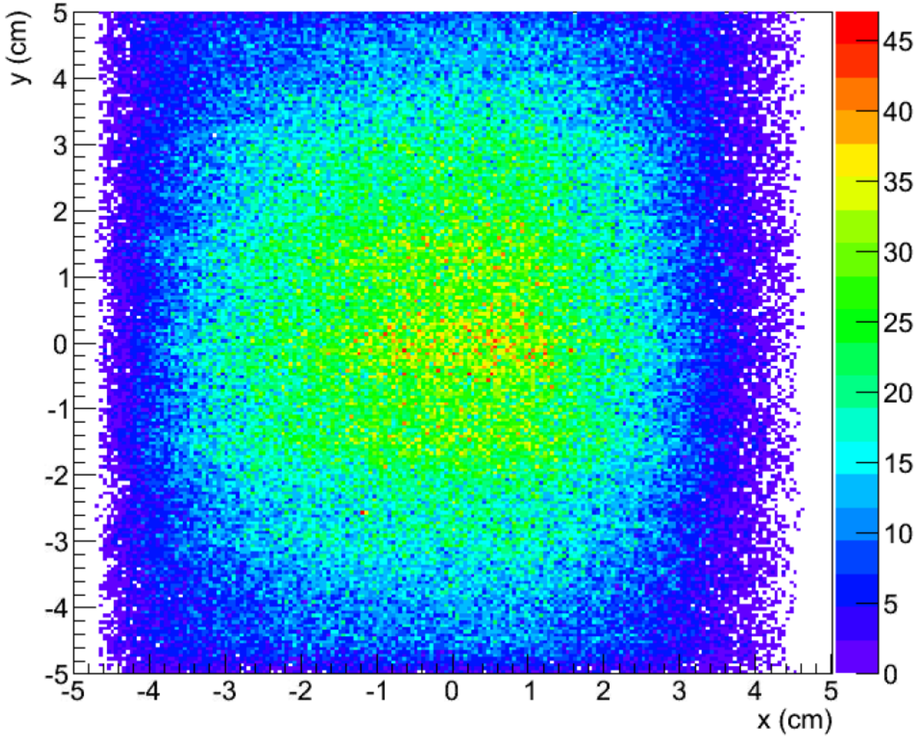
$$N_{max} = e^{t_{max} \ln 2} = E_0/E_c$$

After $t=t_{max}$: ionization, compton effect and photoelectric effect!

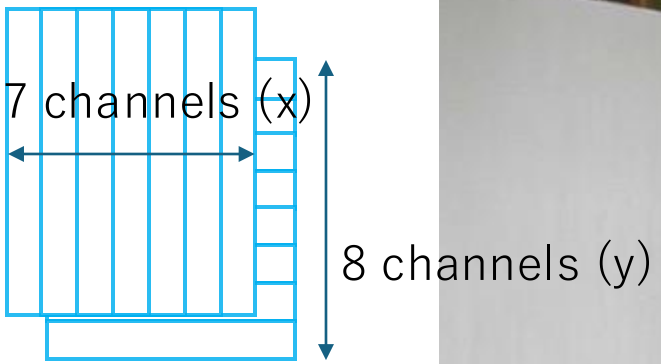
Shower Max Detector (SMD)

- X-Y plastic strip scintillator hodoscopes ($\Delta x, \Delta y$ ~1 cm)
- $x, y = \frac{\sum_i^{\#SMD} E(i) \times pos(i)}{\sum_i^{\#SMD} E(i)}$

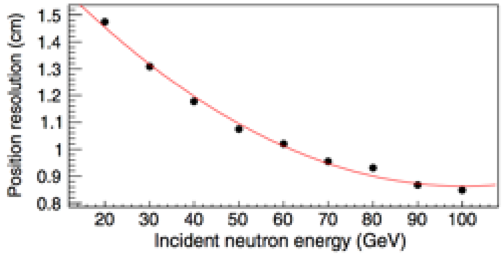
Reconstructed x,y Position of Neutrons

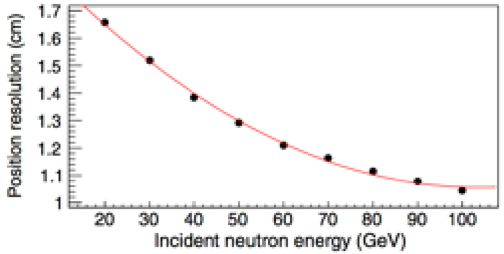


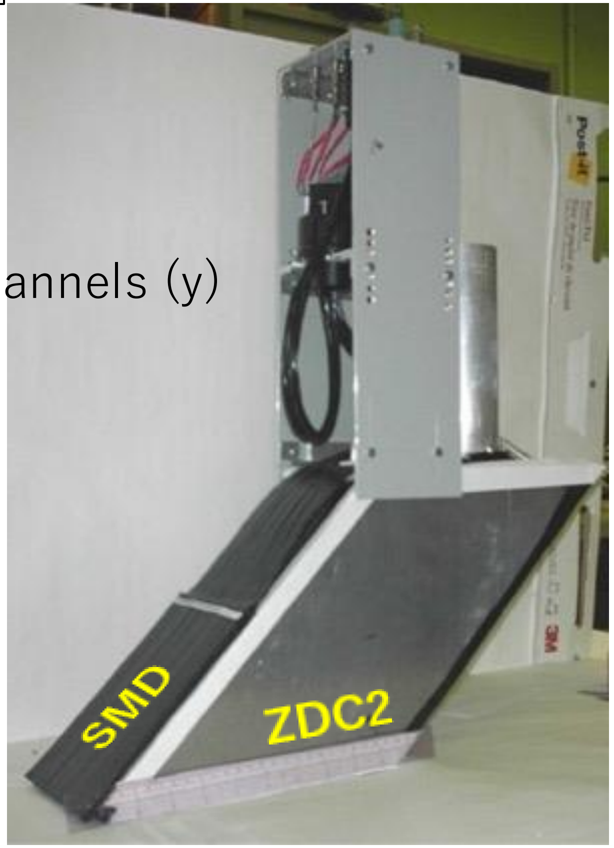
11 cm x 17 cm
Tilted by 45°



SMD Scintillator Paddles



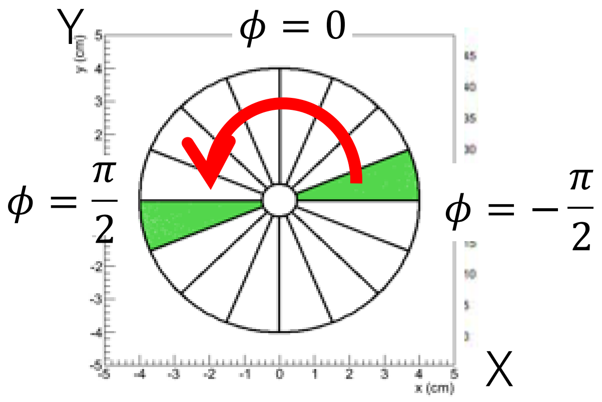


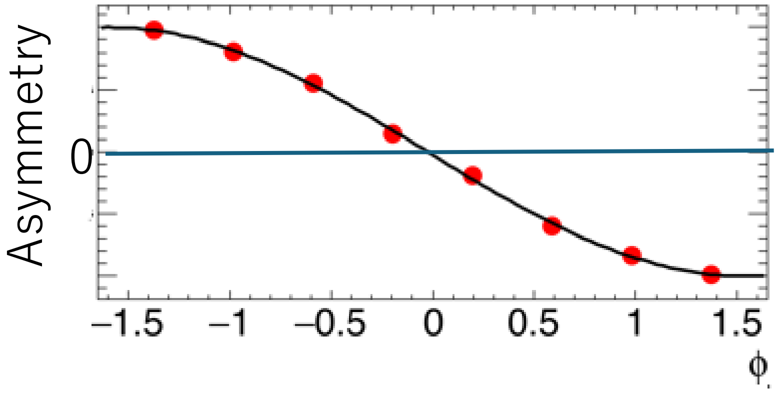


Local Polarimeter

- Raw asymmetry of neutron yields

$$e_N(\phi) \equiv \frac{\sqrt{N_\phi^\uparrow N_{\pi-\phi}^\downarrow} - \sqrt{N_\phi^\downarrow N_{\pi-\phi}^\uparrow}}{\sqrt{N_\phi^\uparrow N_{\pi-\phi}^\downarrow} + \sqrt{N_\phi^\downarrow N_{\pi-\phi}^\uparrow}}$$





- Normalization by polarization P
- Correction C_ϕ

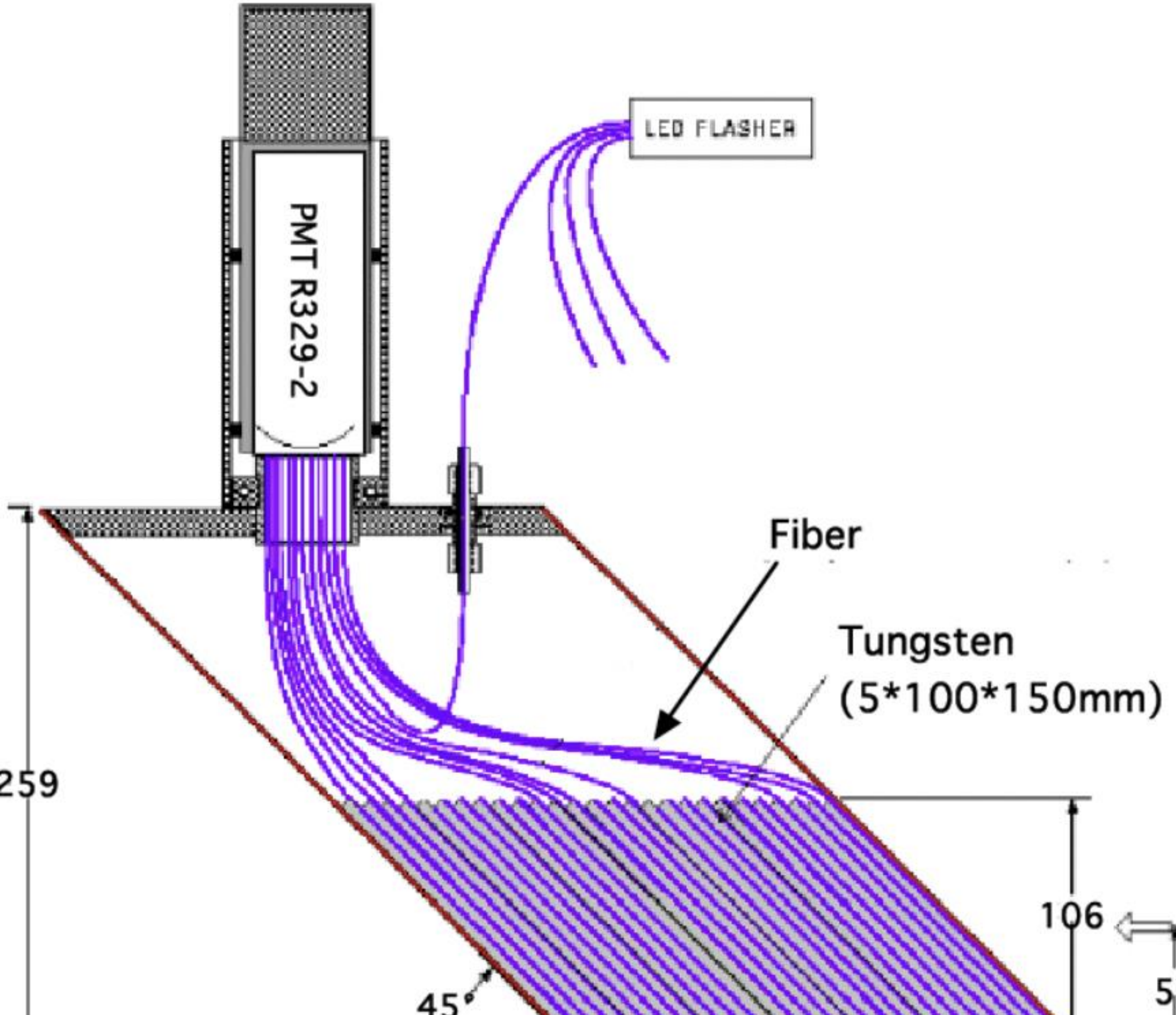
$$A_N = \frac{\sqrt{\sigma_L^\uparrow \sigma_R^\downarrow} - \sqrt{\sigma_L^\downarrow \sigma_R^\uparrow}}{\sqrt{\sigma_L^\uparrow \sigma_R^\downarrow} + \sqrt{\sigma_L^\downarrow \sigma_R^\uparrow}}$$

$$A_N = \frac{e_N(\phi)}{\sin(\phi - \phi_0)} \frac{1}{C_\phi} \frac{1}{P}$$

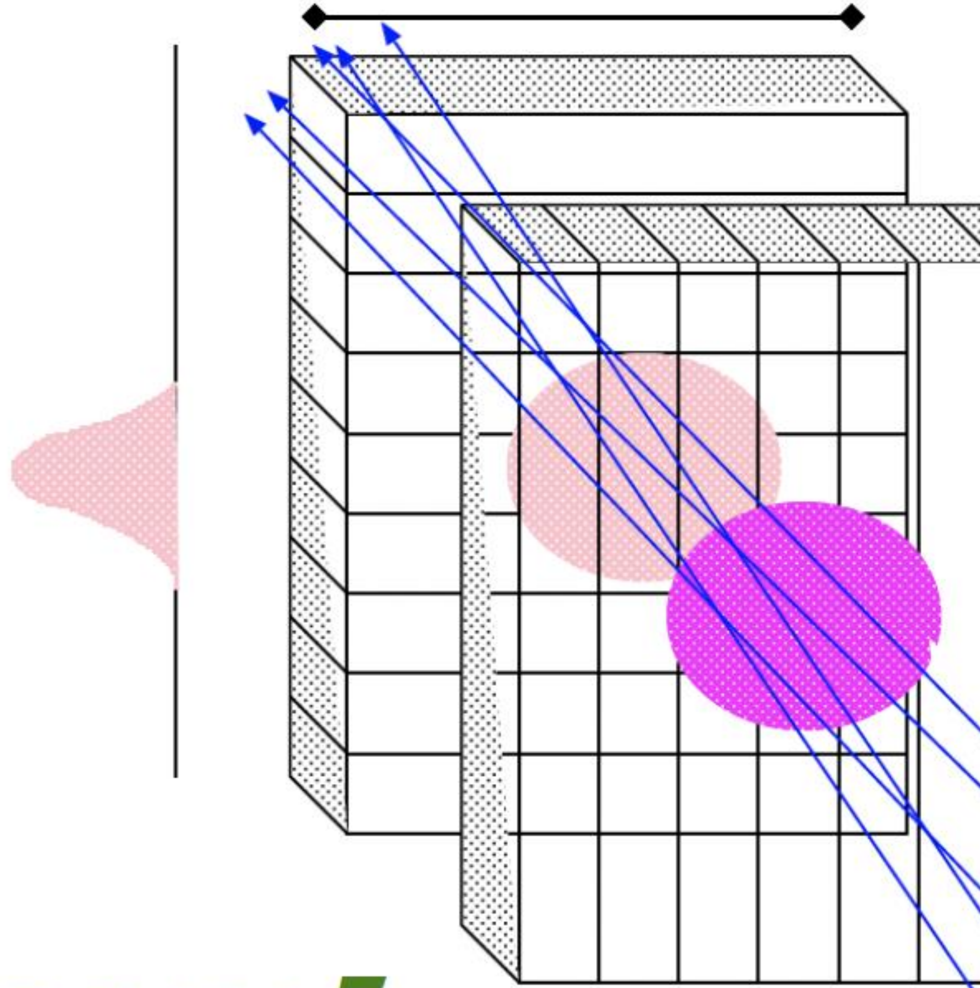
Local Polarimeter

RHIC polarimeters from IP12

ZDC (Zero Degree Calorimeter)



MD (Shower Maximum Detect



or x pos : 7