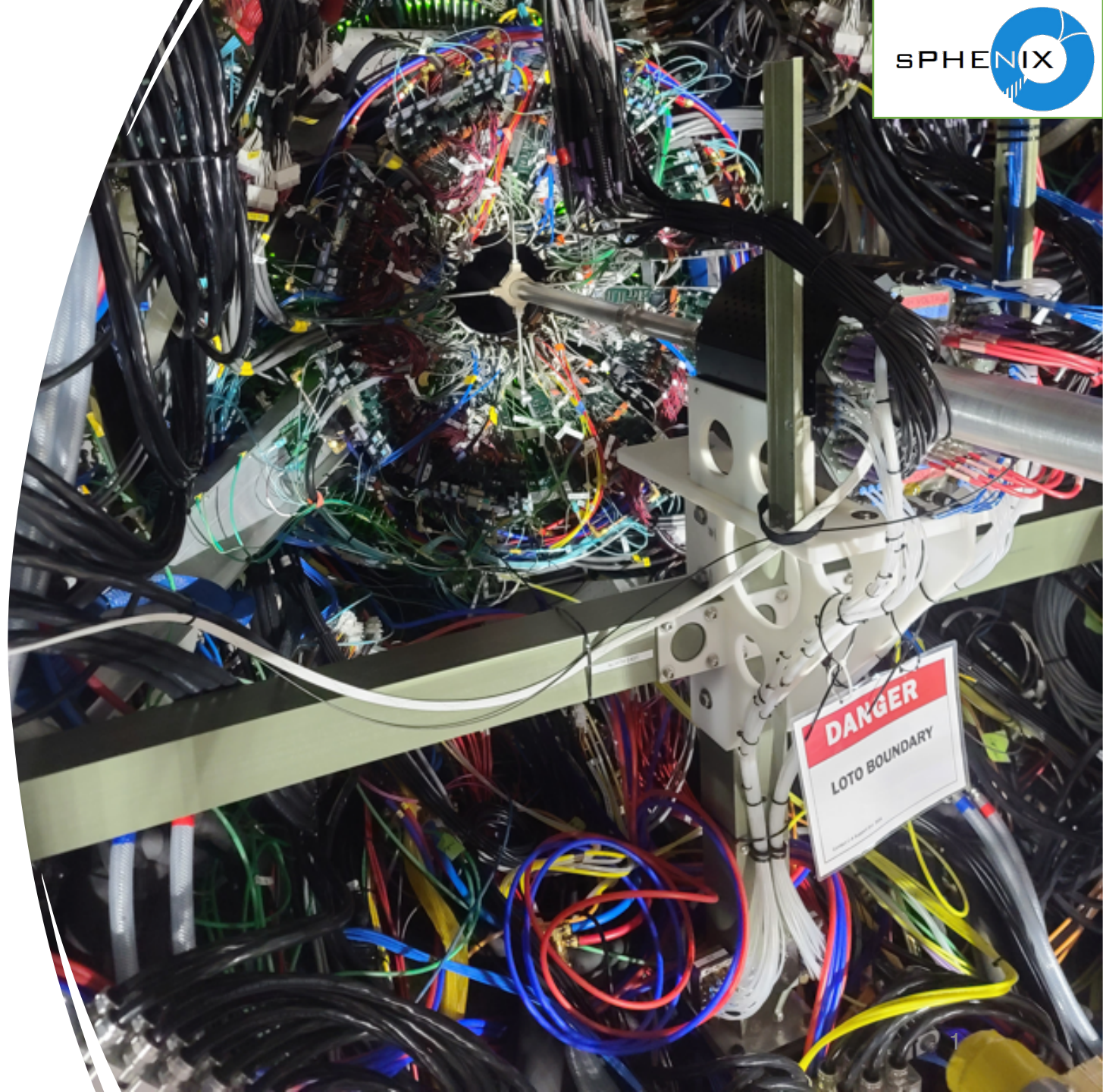


Intermediate Silicon Tracker for sPHENIX at RHIC

Jaein Hwang
Byungsik Hong



Center for
Extreme
Nuclear Matters



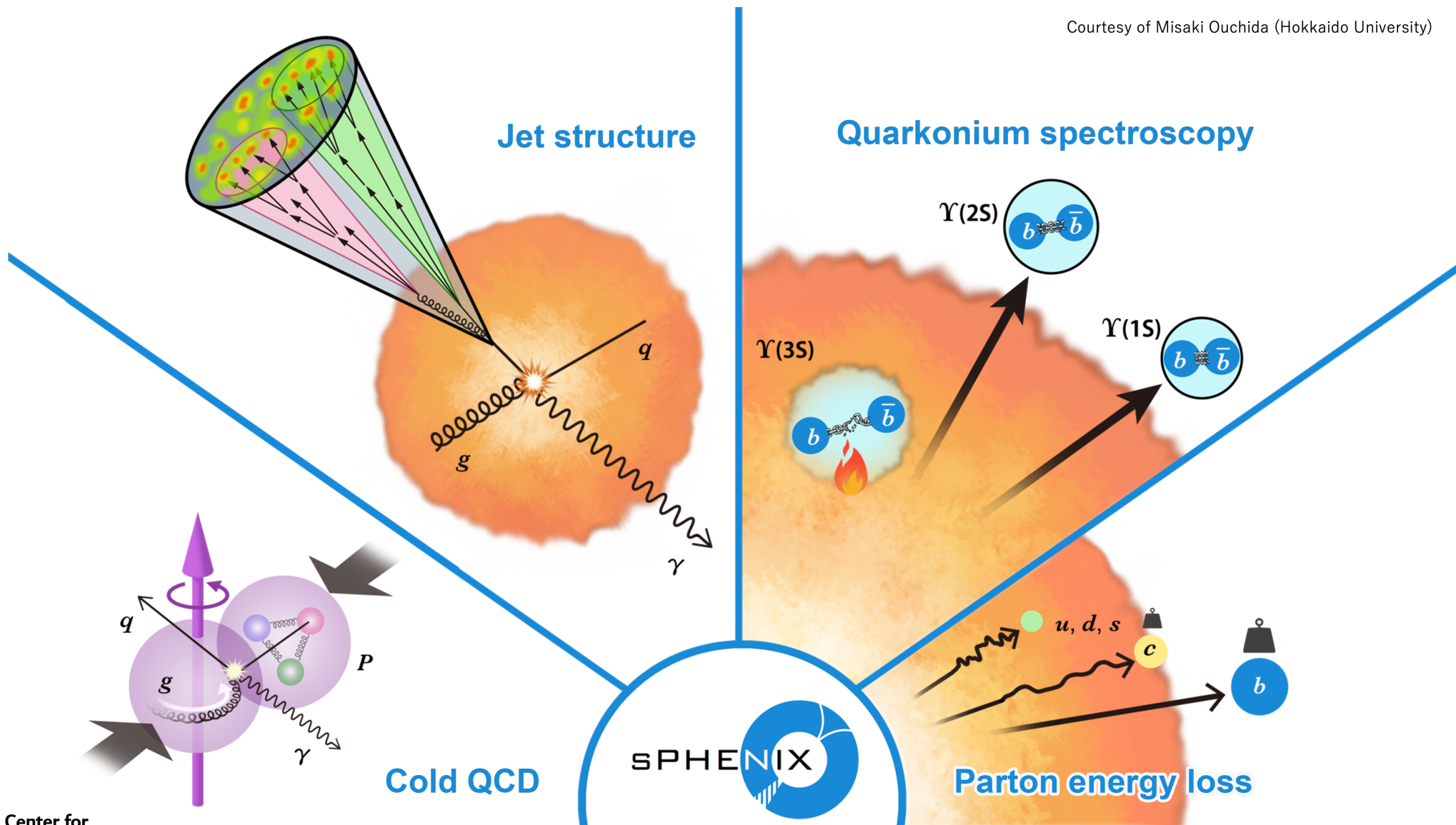
- sPHENIX experiment at RHIC
- Intermediate Silicon Tracker(INTT) at sPHENIX
- Ongoing Work related to INTT
- Summary

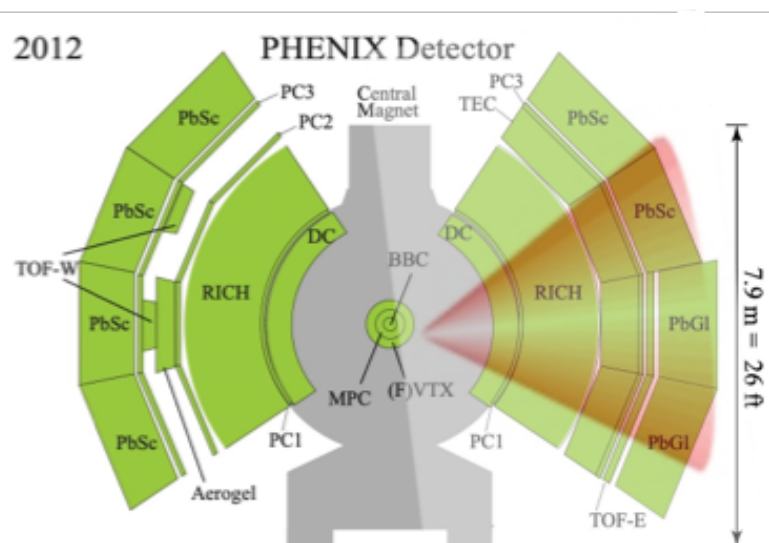
sPHENIX Experiment at RHIC



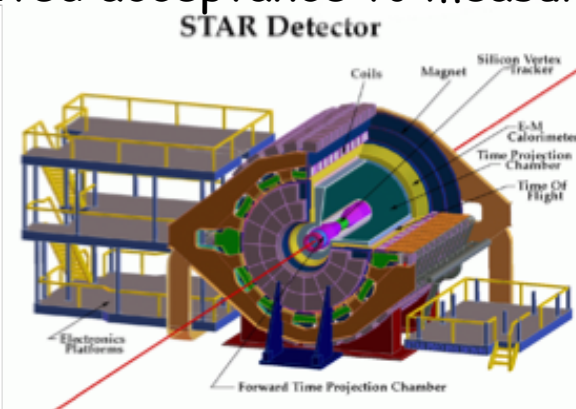
- ❖ The first new major detector at RHIC in over 20 years
- ❖ First Au+Au data was taken in Run-2023
- ❖ p+p data taking and Au+Au in Run-2024
- ❖ Preparation for Run-2025 data taking is ongoing

Courtesy of Misaki Ouchida (Hokkaido University)

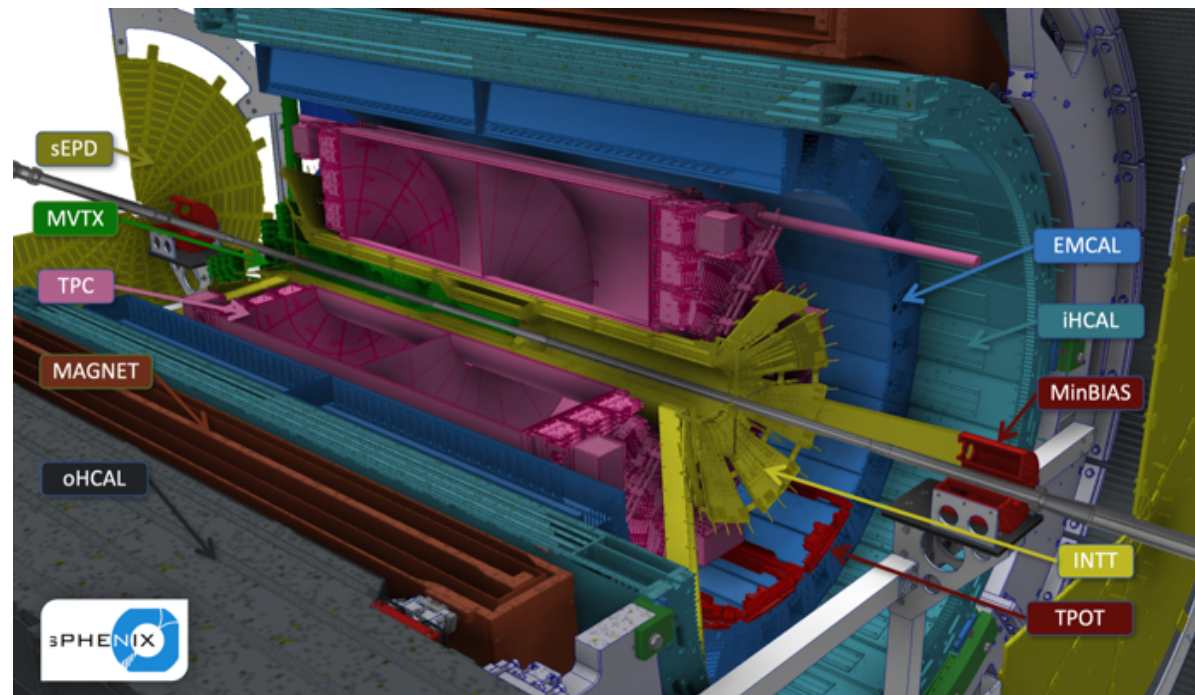




Limited acceptance to measure Jet.



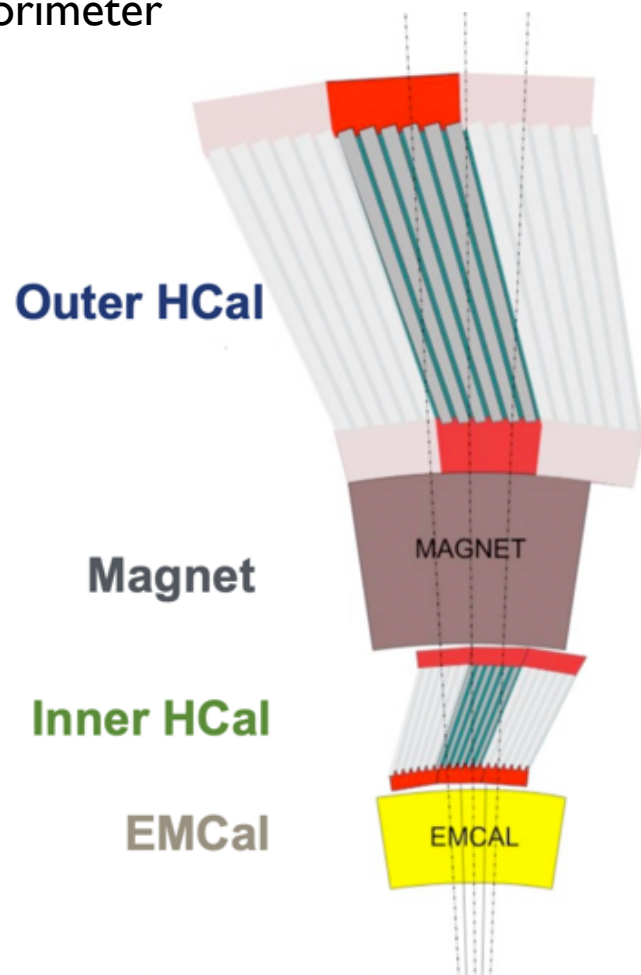
4π , but incomplete for jet without HCAL



- ❑ Designed to be ideal detector for Jet
A first hadron calorimeter in midrapidity at RHIC
- ❑ Acceptance of full azimuthal angle 2π and $|\eta| \leq 1.1$ in $|z| < 10$ cm
 $|\eta| < 0.35$ & 0.5π per arm for ϕ (PHENIX)

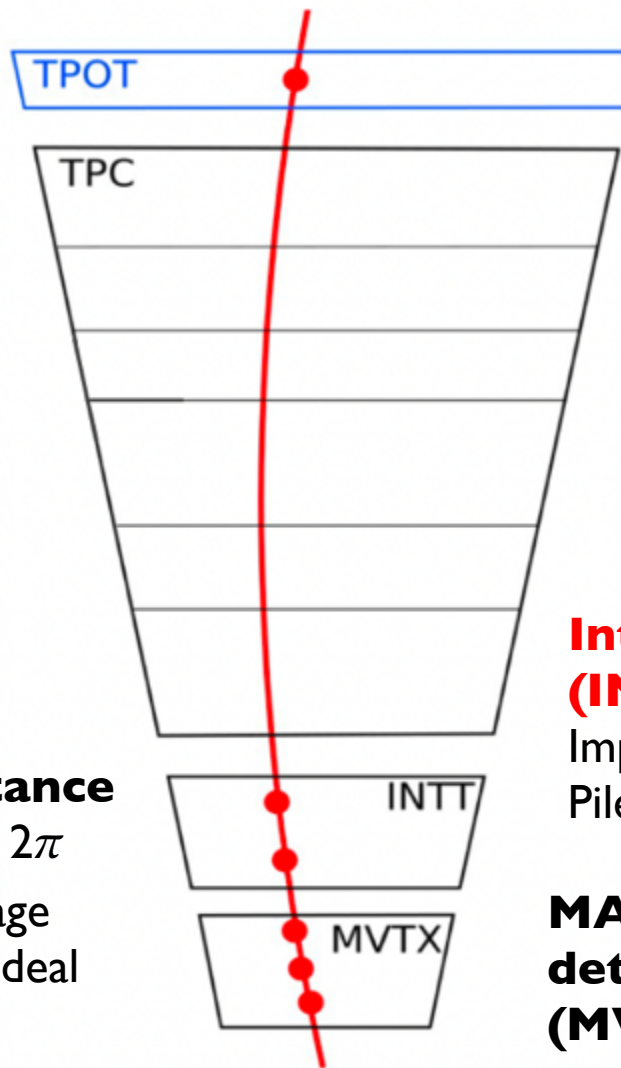
sPHENIX Calorimeters

Full Electromagnetic and Hadronic system calorimeter



Large Acceptance
 $|\eta| < 1.1$ and full 2π
 azimuthal coverage
 Designed to be ideal
 detector for Jet

sPHENIX Tracking Detectors



TPC Outer Tracker (TPOT)

calibration of space charge distortions

Time Projection Chamber (TPC) ($30 < r < 78$ cm)

Precise momentum measurement

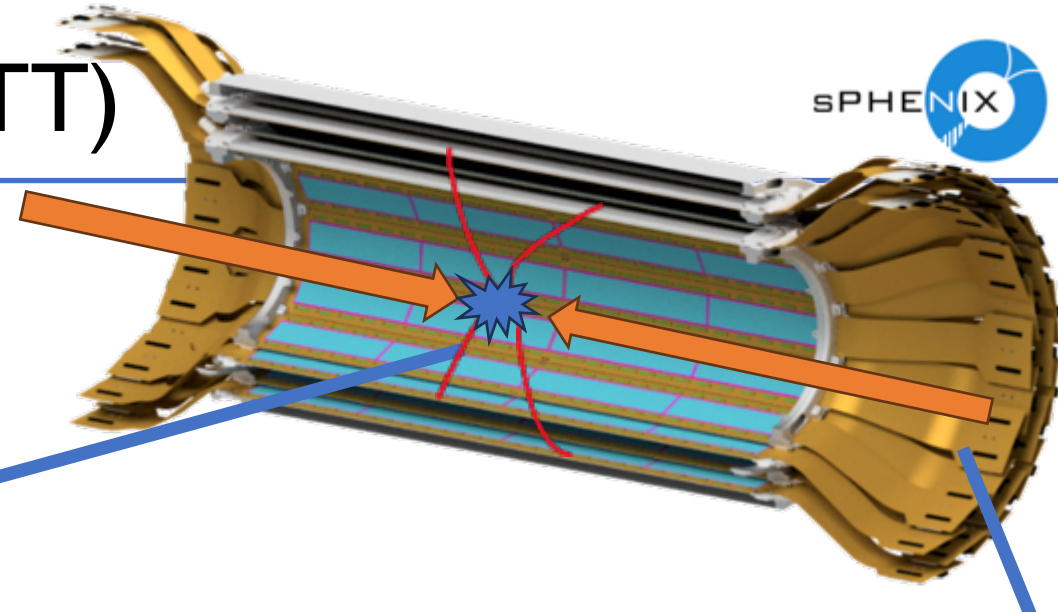
Intermediate Silicon Tracker (INTT) ($7 < r < 12$ cm)

Improving momentum resolution
 Pile-up separation

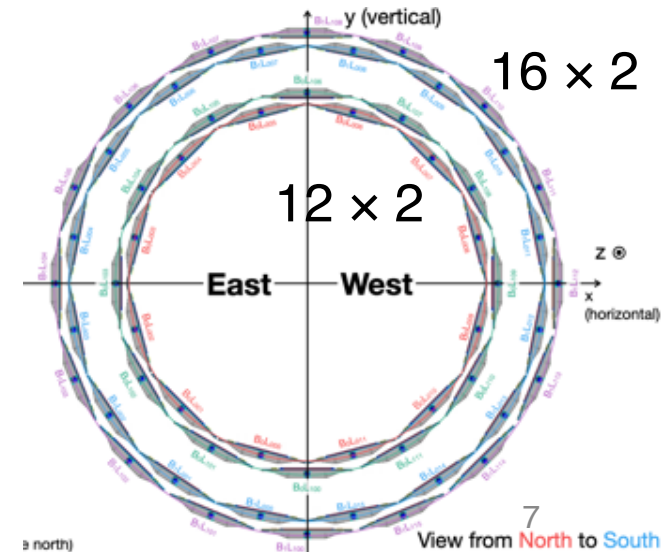
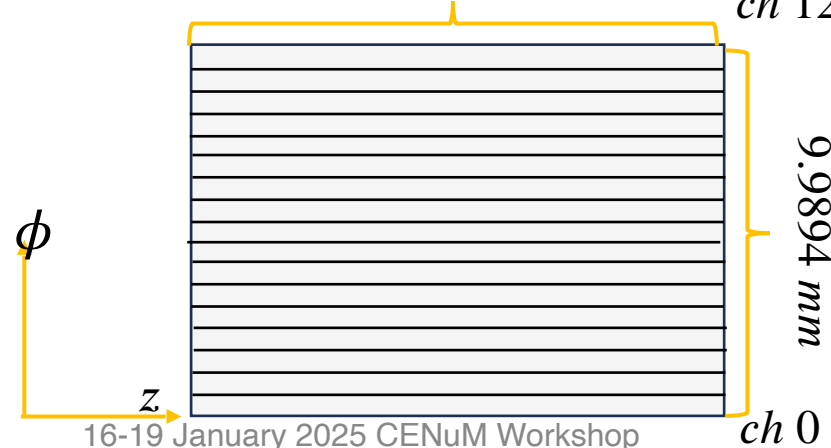
MAPS-based micro-VerTex detector (MVTX) ($2.3 < r < 3.9$ cm)

precision vertexing

Intermediate Silicon Tracker(INTT)



Type A Type B
Type A(B) : 16 mm (20 mm) ch 127



A group of 56 silicon ladders assembled in two layers in a barrel configuration.

- Each ladder has 26 readout FPHX chips
- Each silicon chip has 128 channels resulting in a total of ~370k ch

- Fine strip width : 78 μm in ϕ
For high spatial resolution

- Thin sensors 320 μm ($\sim 0.34\% X_0$)
For less multiple scattering

- Timing resolution less than 106 ns
For pile-up separation

Intermediate Silicon Tracker(INTT)

A group of 56 silicon ladders assembled in two layers in a barrel configuration.

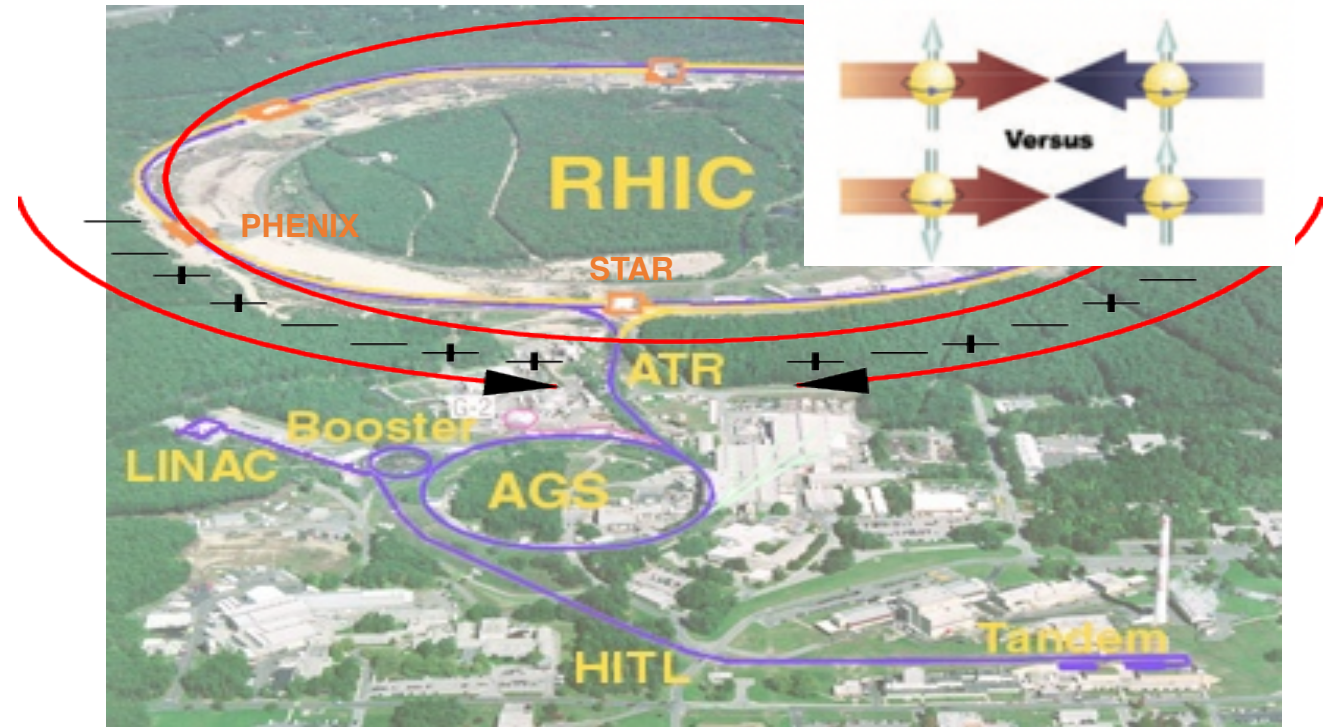
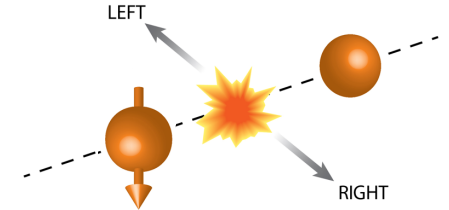
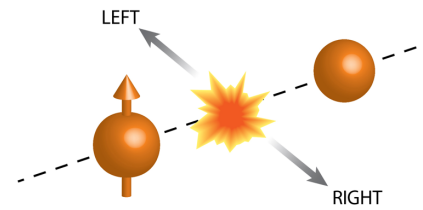
- Each ladder has 26 readout FPHX chips
- Each silicon chip has 128 channels. resulting in a total of ~370k channels

Its precise timing resolution allows us to reconstruct the tracks bunch by bunch

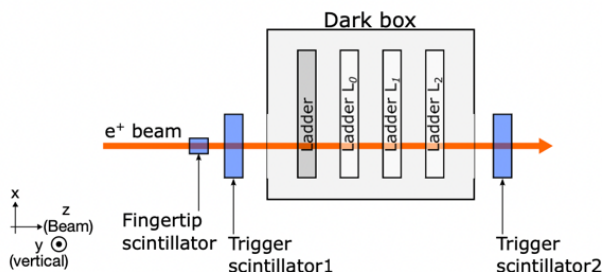
-> Necessary for Cold-QCD spin physics programs

- Timing resolution less than 106 ns

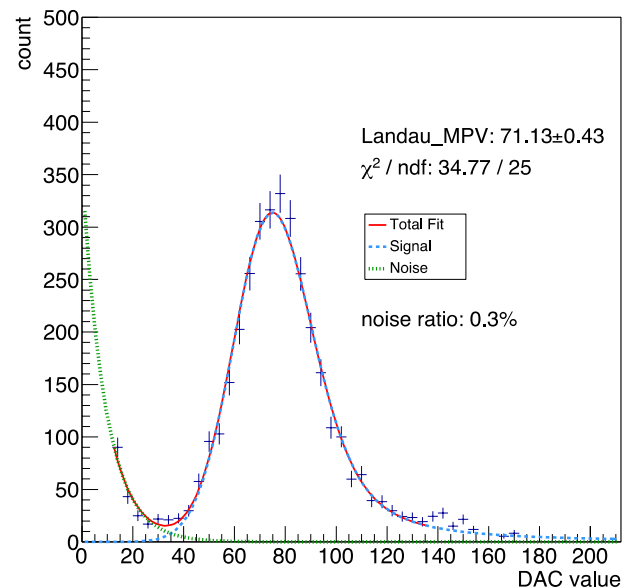
For pile-up separation



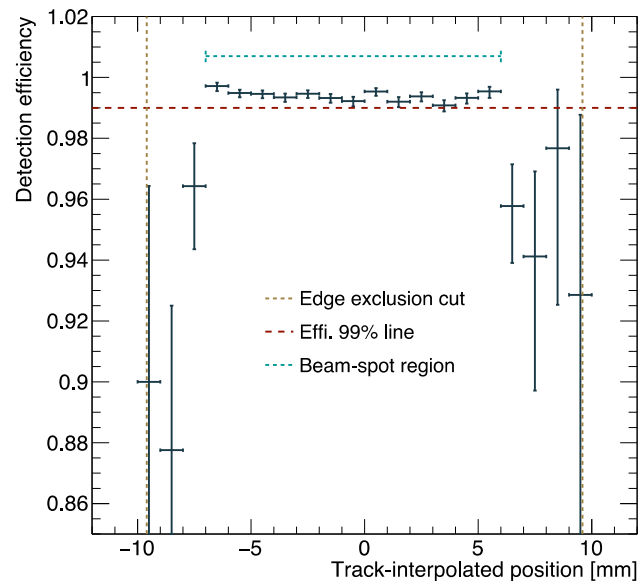
Test beam Experiment in 2021



- 1 GeV positron beam at Tohoku University
- 3 INTT ladders, L0, L1, and L2 were used.
- Two plastic scintillators were installed upstream or downstream of the dark box.



Energy deposit distribution
Signal : 99.7% noise : 0.3%

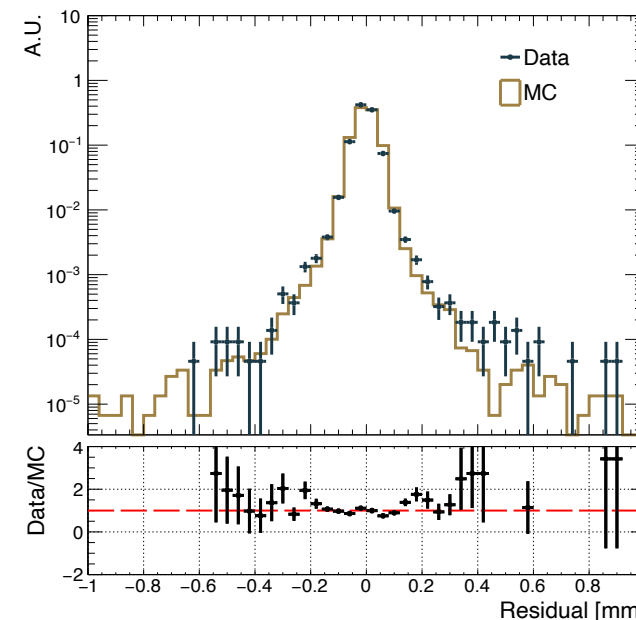
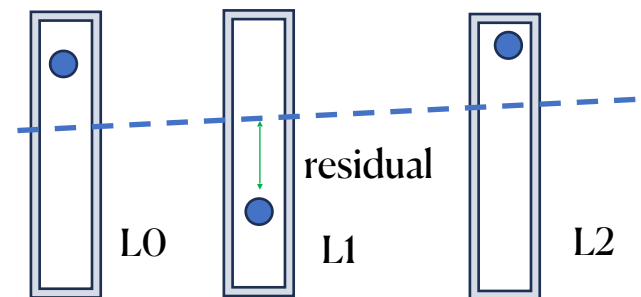


Detection efficiency of L1 was defined as

$$\frac{N(L0 \cap L1 \cap L2)}{N(L0 \cap L2)} \times 100\%$$

$$= 99.33 \pm 0.04 (stat) \pm 0.06 (sys) \%$$

16-19 January 2025 CENuM Workshop

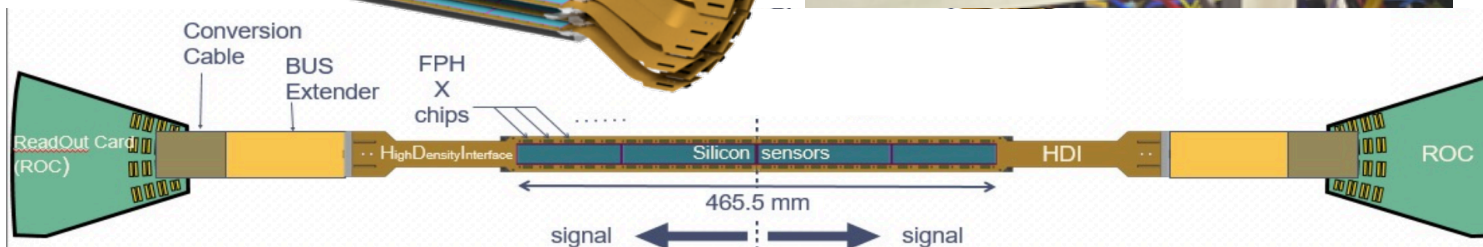
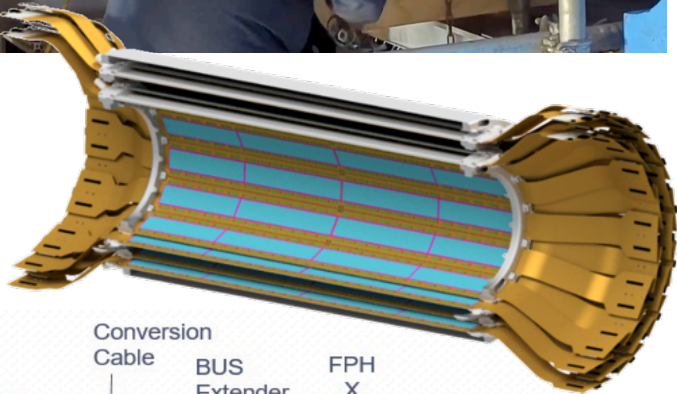


Residual distribution

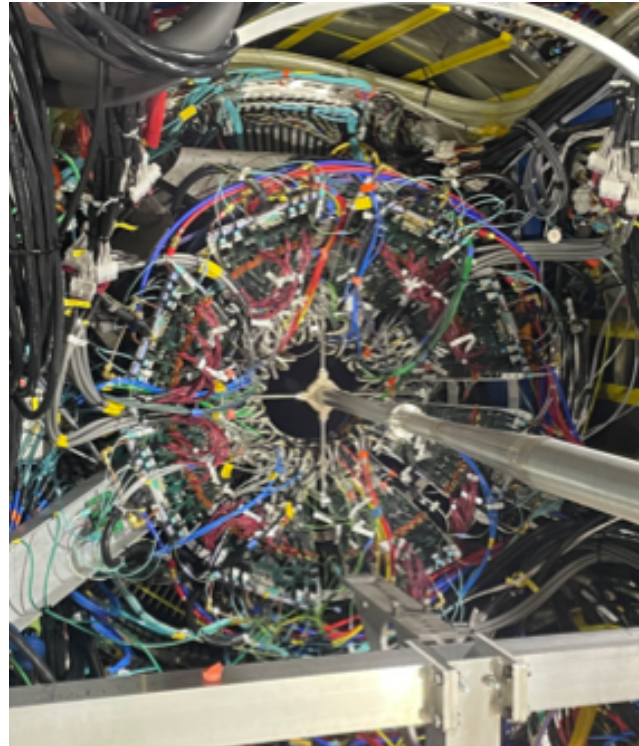
Good Agreement with MC

Installation was done at Feb 28, 2023

INTT Barrel insertion



INTT ROCs



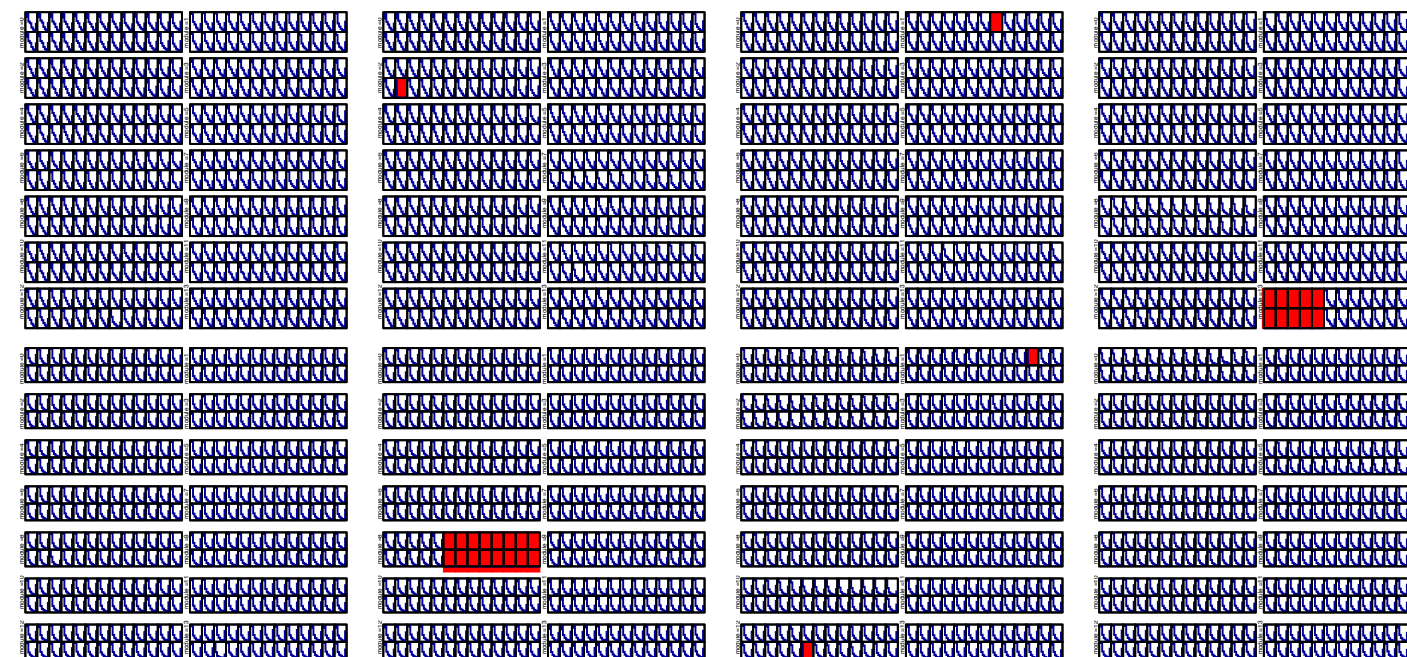
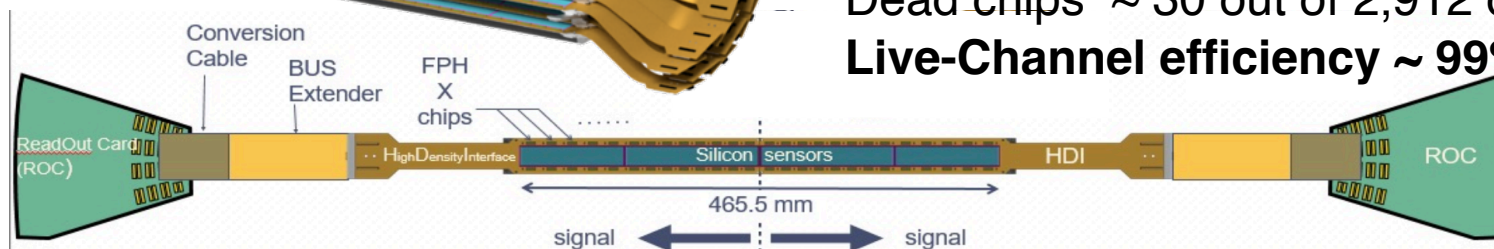
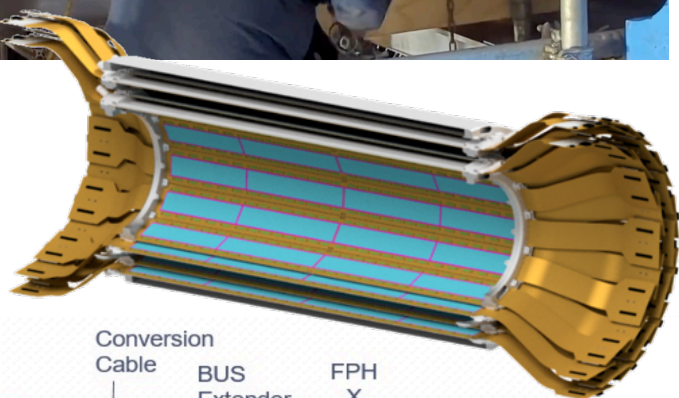
ROC(Readout Card) from PHENIXVTX

- Signal processing
- Applying LV for FPHX chips
- Applying Bias voltage on Silicon sensors



Installation was done at Feb 28, 2023

INTT Barrel insertion



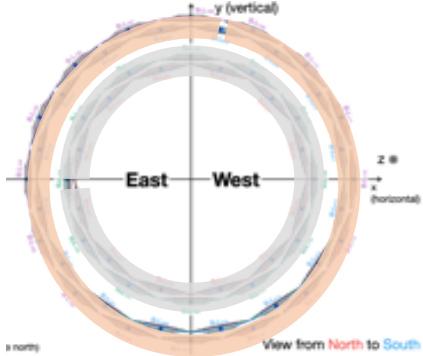
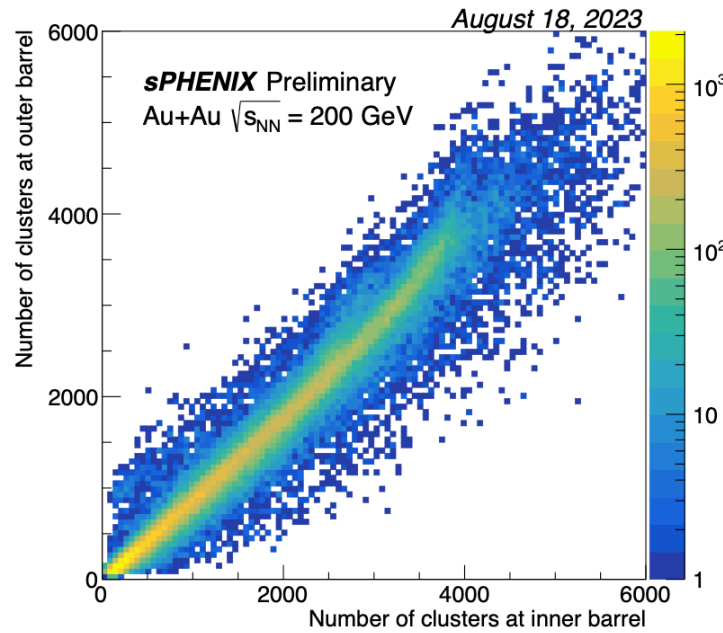
ADC distribution for the entire silicon chips

Dead chips ~ 30 out of 2,912 chips

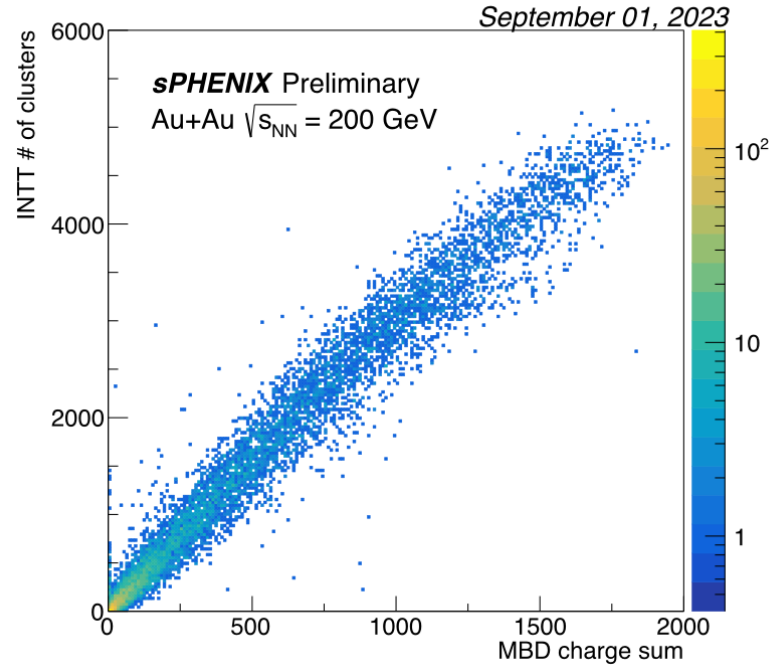
Live-Channel efficiency ~ 99%

sPHENIX Preliminary
Au+Au $\sqrt{s_{NN}} = 200$ GeV

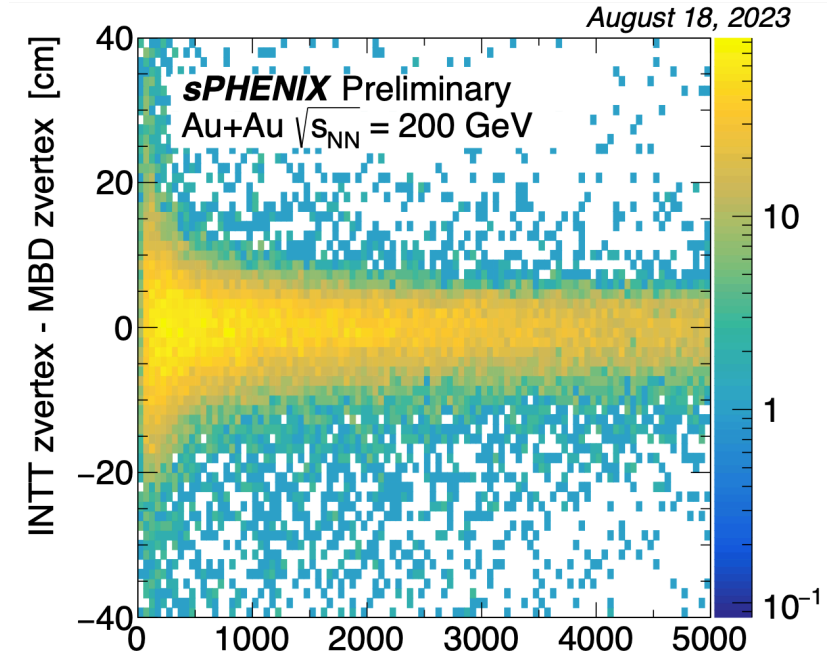
Cluster multiplicity Correlation between the Inner and the Outer Barrel



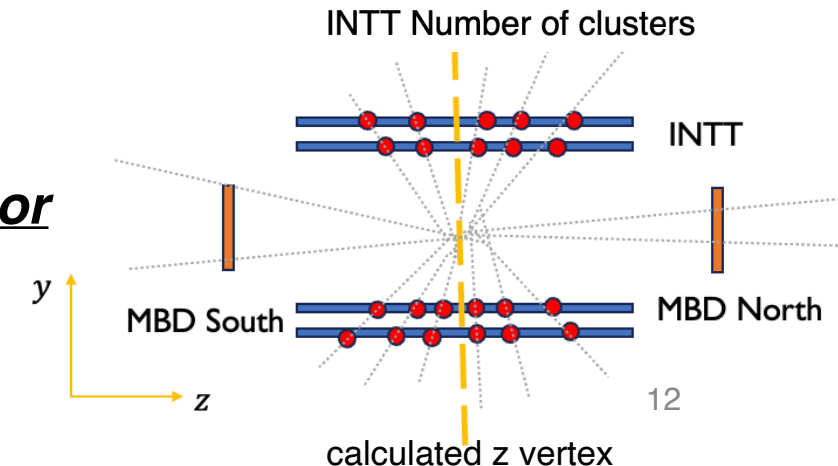
Multiplicity Correlation between INTT clusters and MBD charge



The difference of Z vertex measured by INTT and MBD

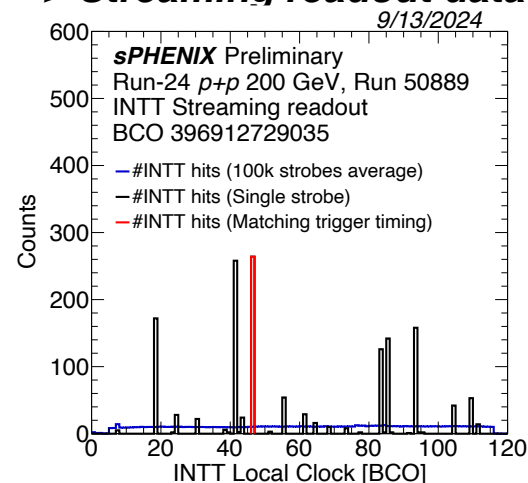


- Evidence of collision data
- Well synchronized with Trigger detector



sPHENIX trackers operated in Trigger mode(w/o TPC) and streaming readout(with TPC) during pp runs

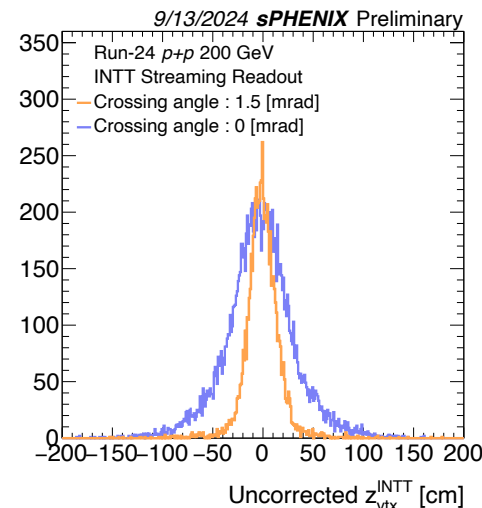
-> Streaming readout data QA must be done



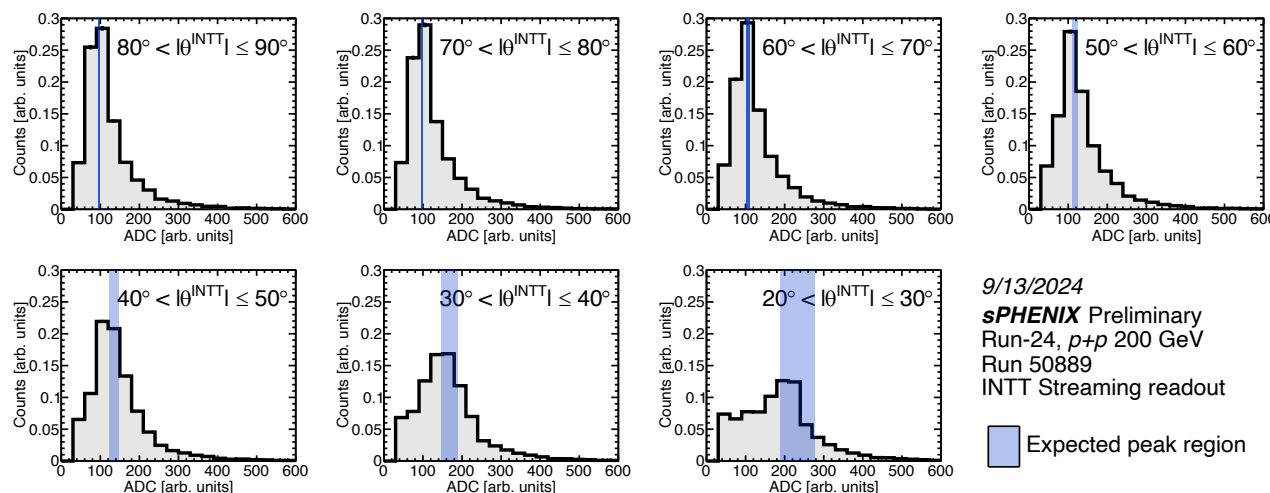
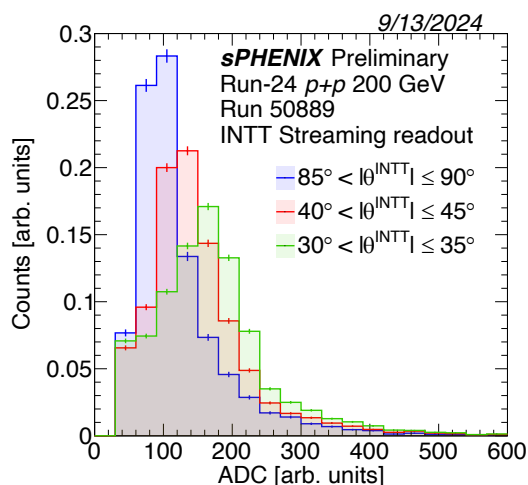
of hits for different INTT internal clock (BCO)

-> Clear peak matched with sPHENIX global trigger timing

Streaming data can be matched with Calo system
Necessary for Particle-flow jet



INTT Z vertex distribution depending on beam crossing angle

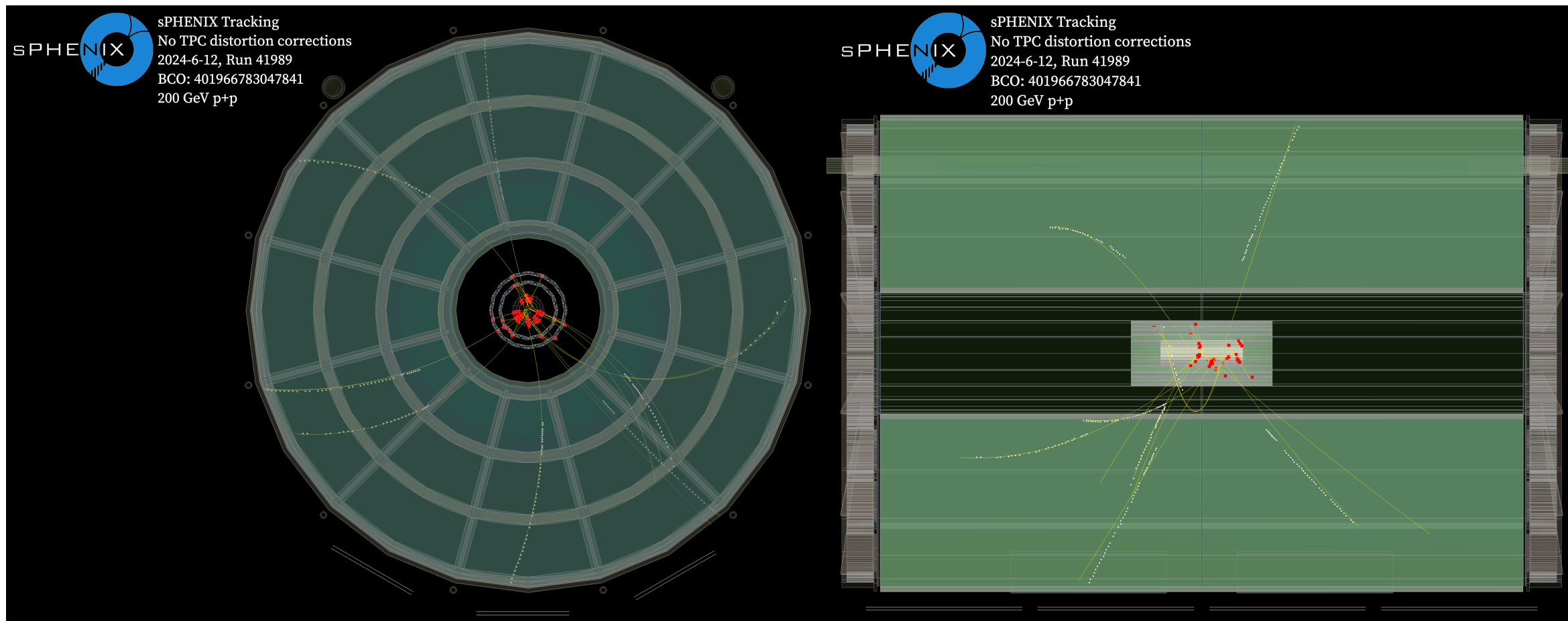


MIP peak position depending on different incident angle

9/13/2024
sPHENIX Preliminary
Run-24, p+p 200 GeV
Run 50889
INTT Streaming readout

Expected peak region

Event Display with entire tracker system at sPHENIX



Several calibrations are ongoing with TPC

Alignment with whole tracker & TPC spare charge distortion correction

sPHENIX is the first detector at RHIC with full calorimeter system.

INTT detector is crucial for pile-up separation which is necessary especially for Cold-QCD Spin Physics program.

INTT took Au+Au and p+p data , and working properly.

Run2025 preparation and various analysis with several calibrations are parallel ongoing.



Thank you!



On site BNL crew (Post-Doc, Students)

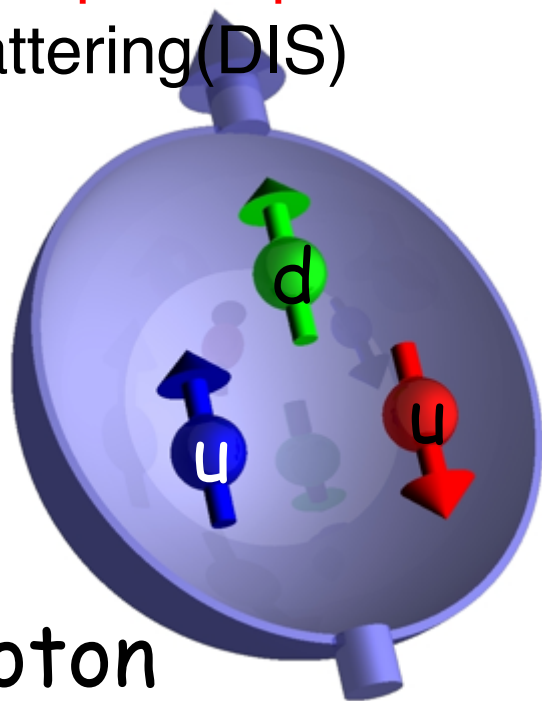
Backup

Proton spin sum-rule

$$Proton\ Spin = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \dots$$

Total quark spin $\Delta\Sigma \sim 25\%$ of proton spin measured by Deep Inelastic Scattering(DIS)

Nucl Phys B 1989; **328**: 1–35
at SLAC



Proton

mass →	≈2.3 MeV/c ²	u up
charge →	2/3	
spin →	<u>1/2</u>	
QUARKS	≈4.8 MeV/c ²	d down
	-1/3	
	<u>1/2</u>	

$$\frac{1}{2} = \frac{1}{2} + \frac{1}{2} + \left(-\frac{1}{2} \right)$$

Proton spin sum-rule

$$Proton\ Spin = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_g + L_q$$

Total quark spin $\Delta\Sigma$ + gluon spin contribution ΔG + partons Angular Momentum L_g, L_q

$\Delta\Sigma \sim 25\%$ of proton spin / $\Delta G \sim 40\%$ of proton spin

Nucl Phys B 1989, 328: 1-35
at SLAC

PRD93,011501R (2016)

PRD102,042001 (2020)

at RHIC

L_g, L_q These are crucial points to investigate the proton spin puzzle
How to measure ?

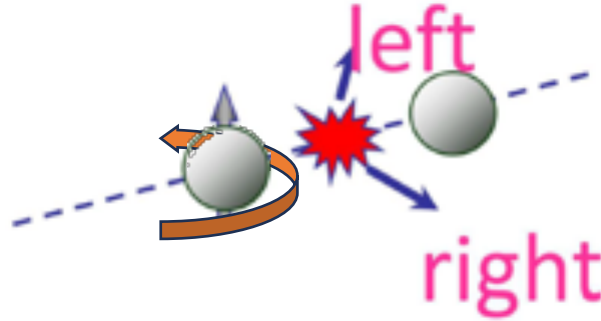
We need some special tools for the spin structure of the proton!

Transverse single spin asymmetry(TSSA) A_N

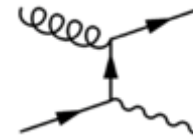
$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

Left-Right Asymmetry

(One proton is polarized in the collision)



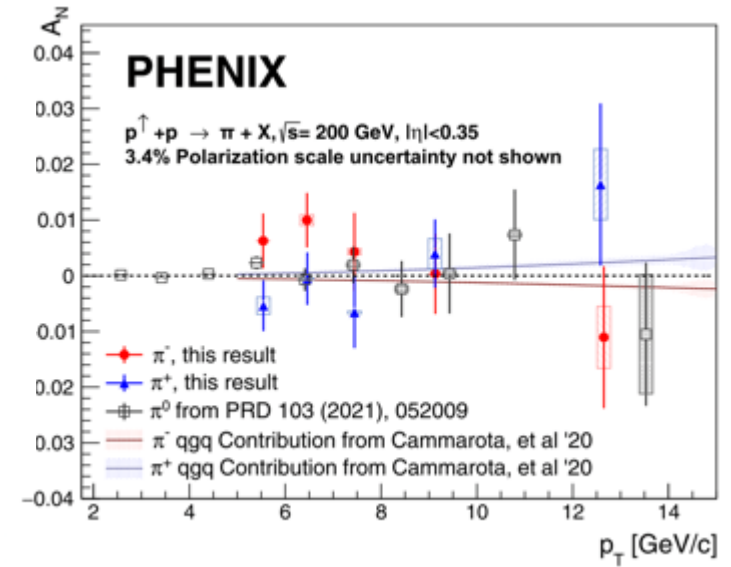
$\pi^{+/-}$ A_N are consistent with theoretical predictions in measured range, but there is an indication that $\pi^{+/-}$ behave differently



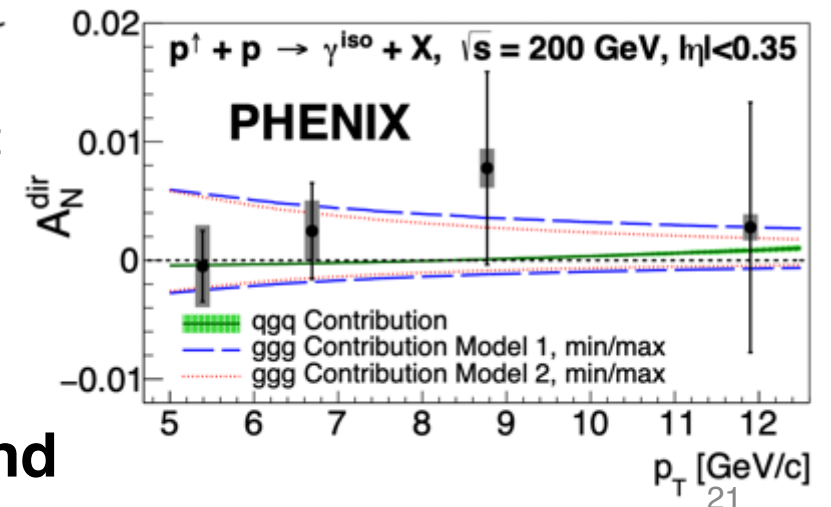
TSSA of Direct Photon from QCD Compton Scattering($qg \rightarrow \gamma q$)

The photons originate in the hard scattering subprocess and do not interact via strong interaction.

Direct photon should be sensitive to the initial state!

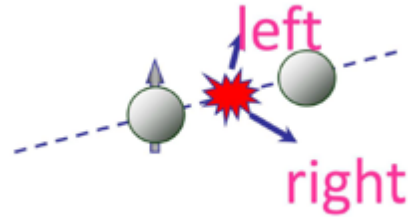


Phys. Rev. Lett. 127, 162001 (2021)



We still need more various measurements to understand

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



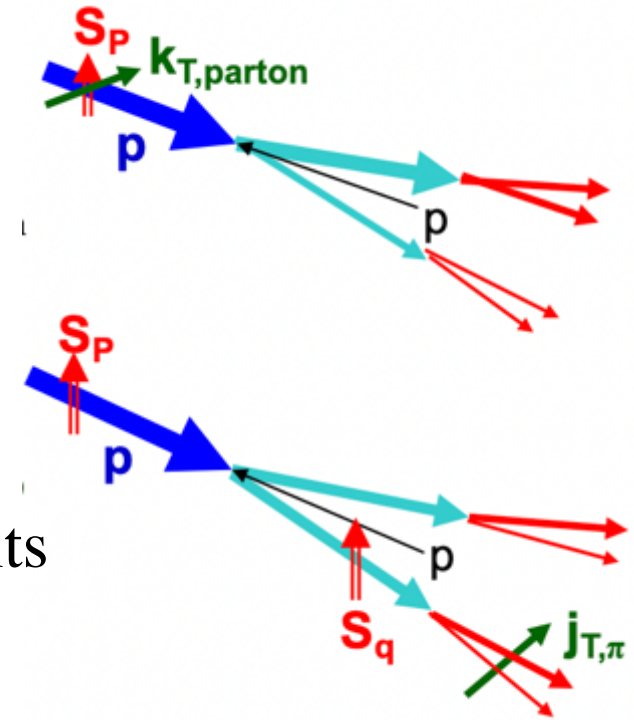
Left-Right Asymmetry

Initial State Effect (Sivers effect)

Distribution of partons inside a polarized proton depends on the parton's transverse momentum and spin direction of proton.

Final State Effect (Collins effect)

The correlation between the transverse polarization of a quark and its transverse momentum is related to the fragmentation direction.



TSSA of Direct Photon

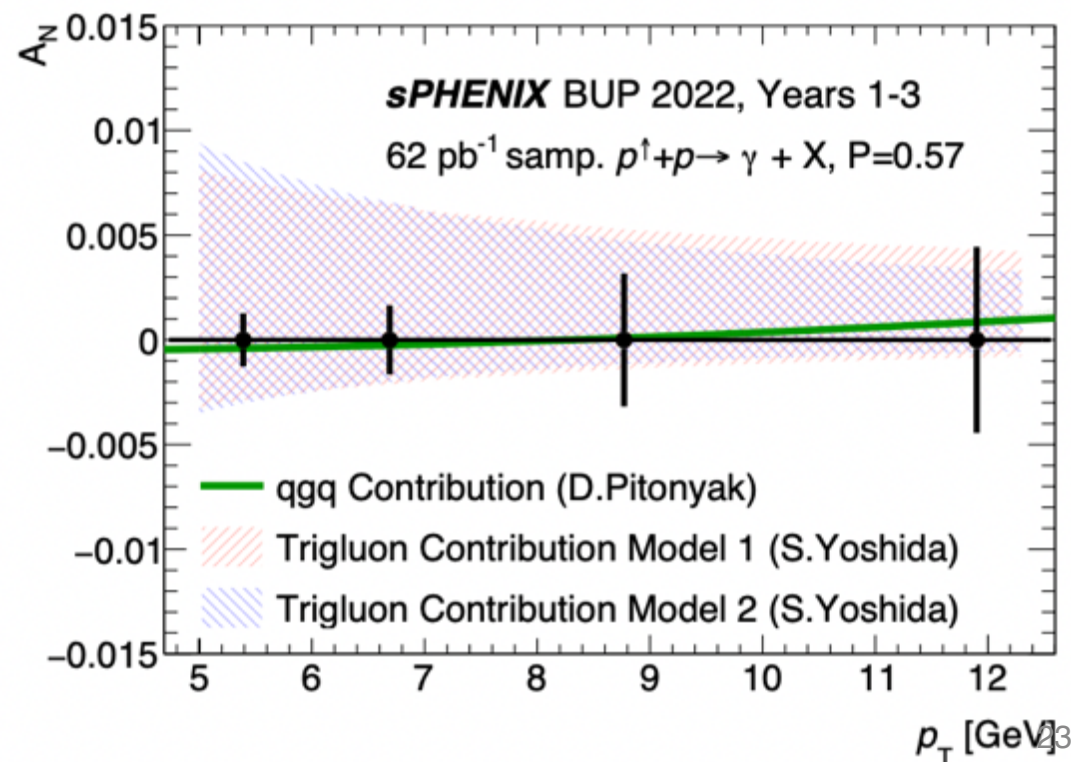
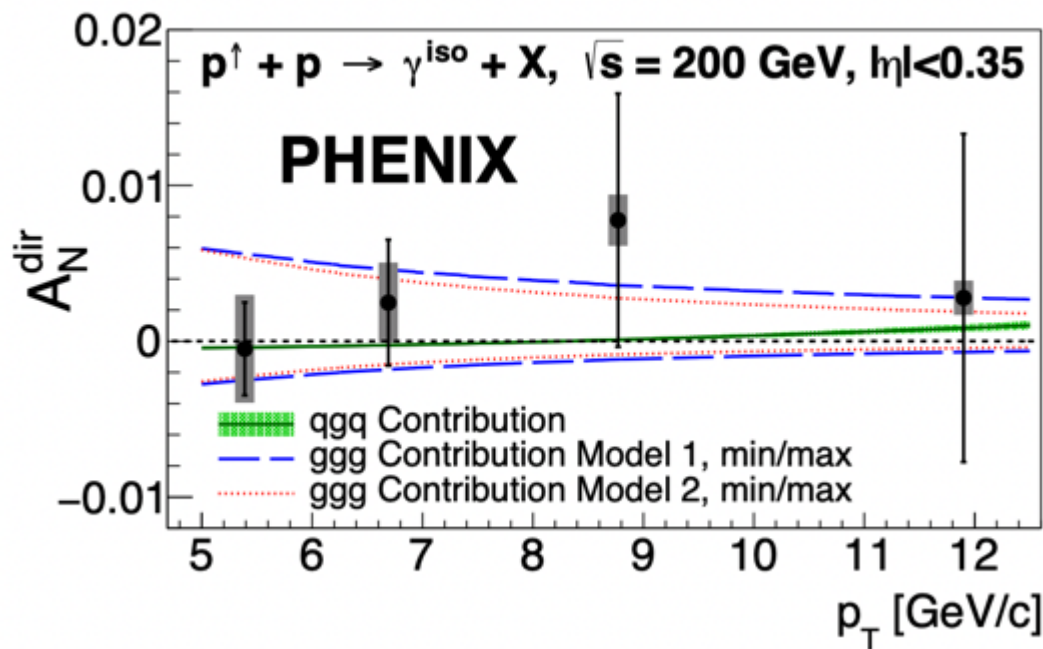
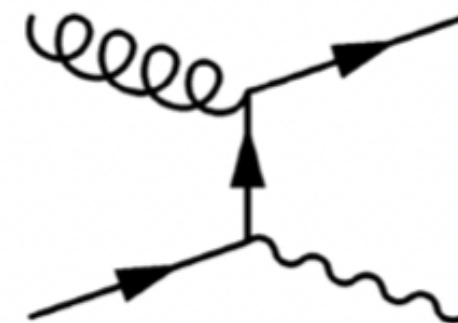
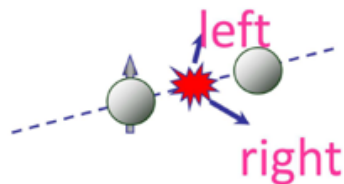
$$qg \rightarrow \gamma q$$

The photon originates in the hard scattering subprocess and does not interact via strong interaction, which means that the final state effect is not present.

(Only initial state effect)

Direct photon is a clean probe of gluon structure within the proton

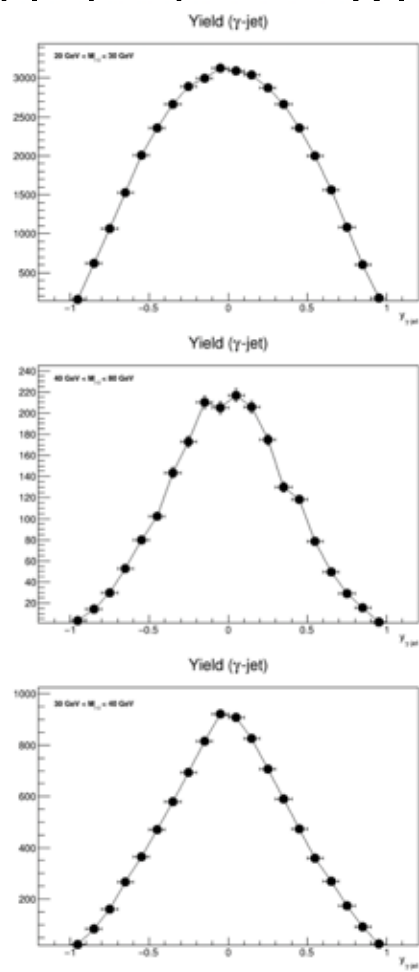
Phys. Rev. Lett. 127, 162001



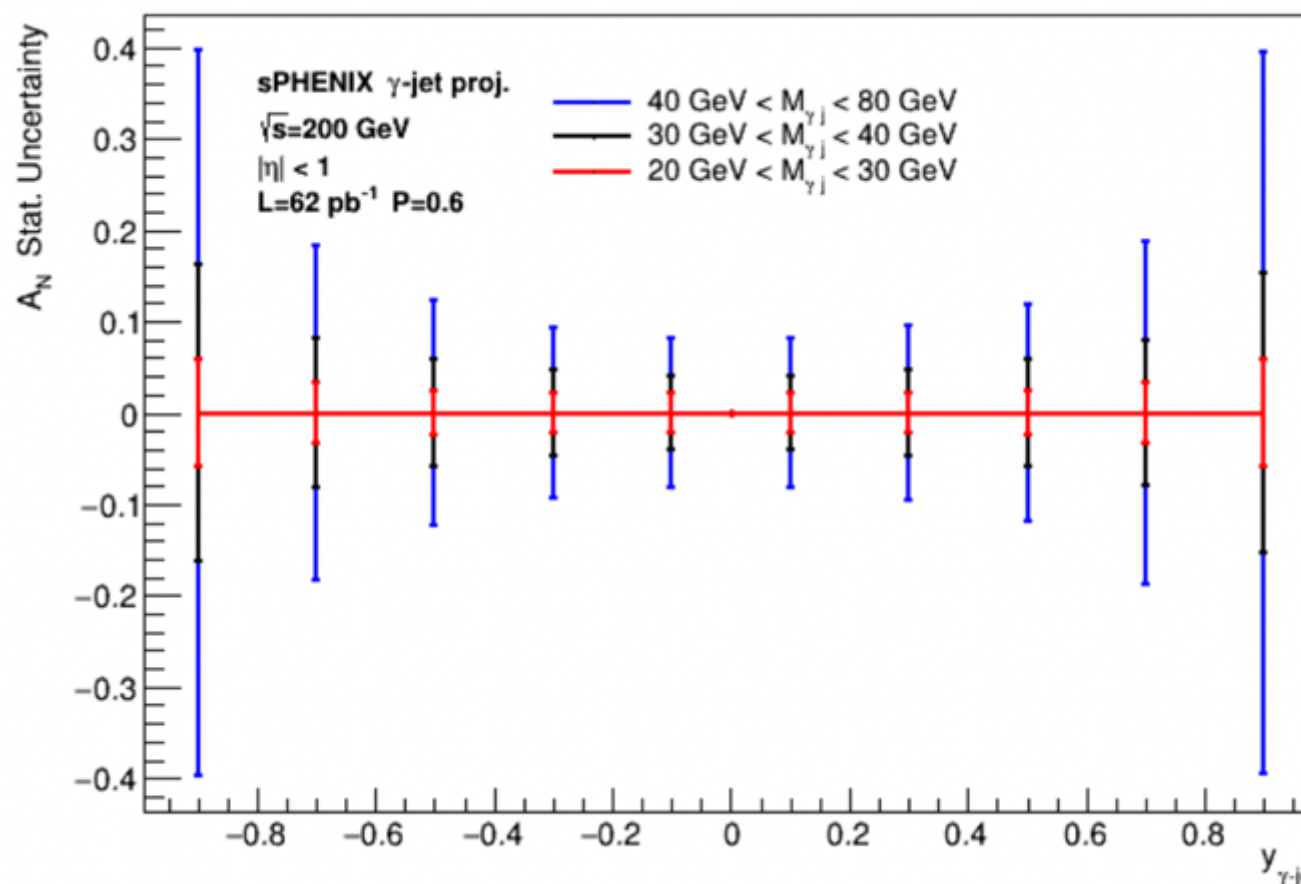
Detecting both photon and jet simultaneously can give more specific constraint for theoretical expectation.

Enabled by high stat. calorimetric jet/photon detection provided by sPHENIX

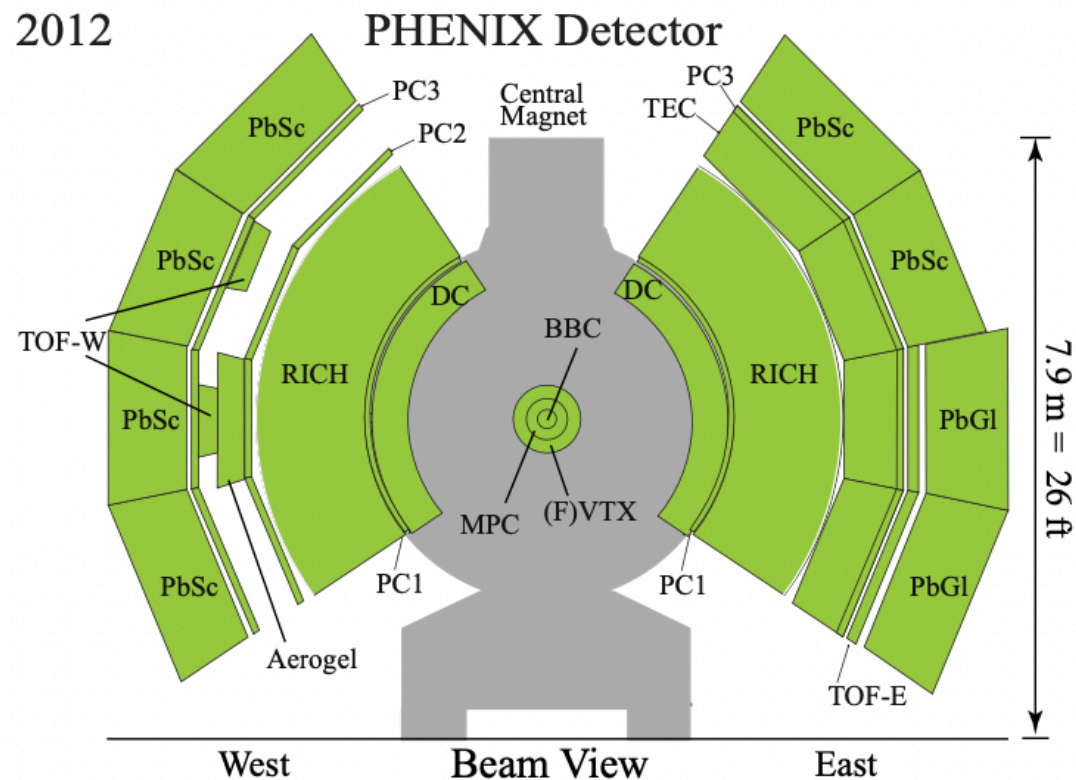
It should be $\epsilon \sim 1\%$ for gluons.



RHIC/AGS AUM 2022



- $|\eta| < 0.35$ and π coverage for ϕ .
- EMCal: primary detector for photons.
- EMCal trigger: select high energy particles.
- DC: measure charged particles.
- PC3: track matching.
- RICH: PID from Čerenkov light.

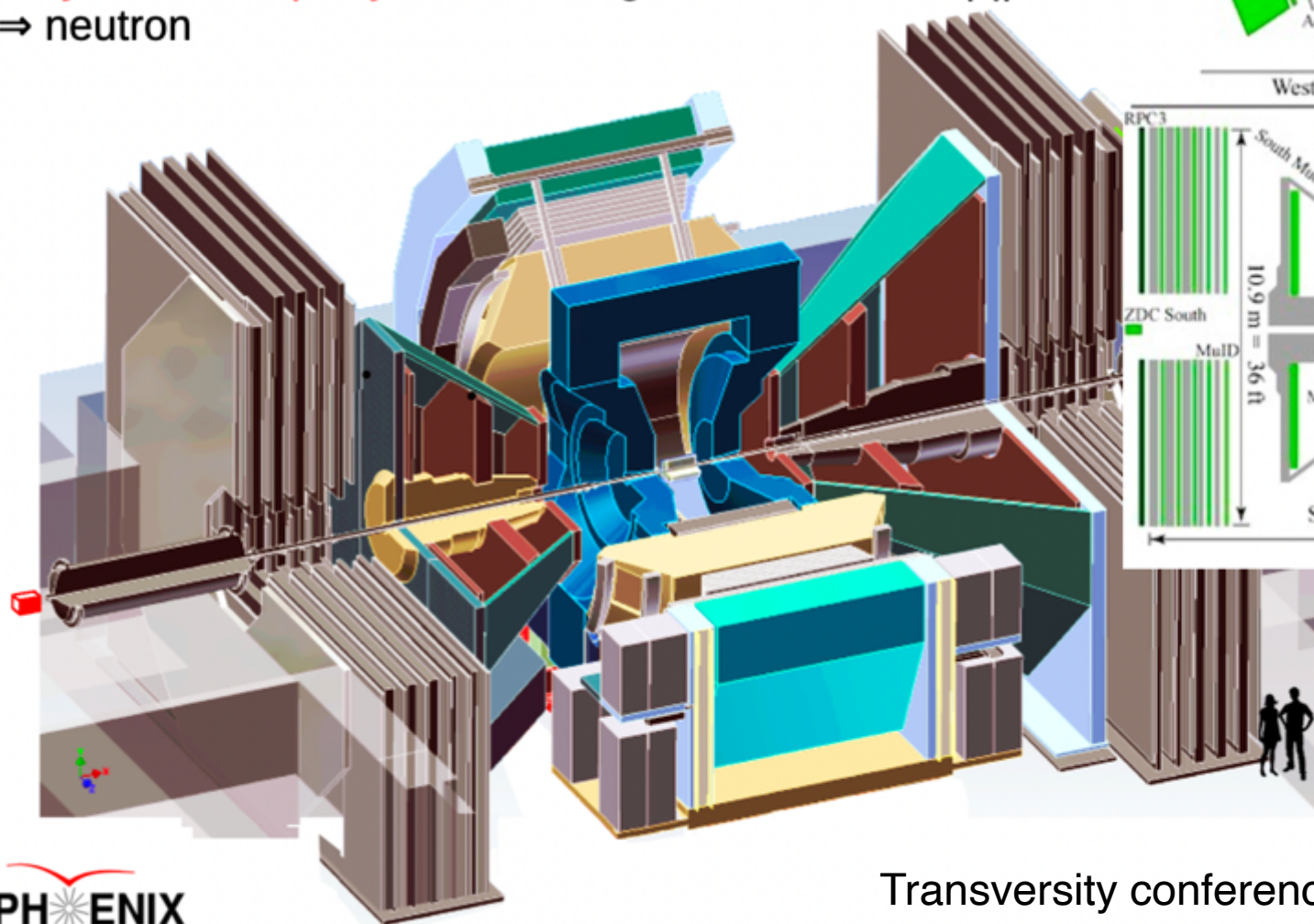
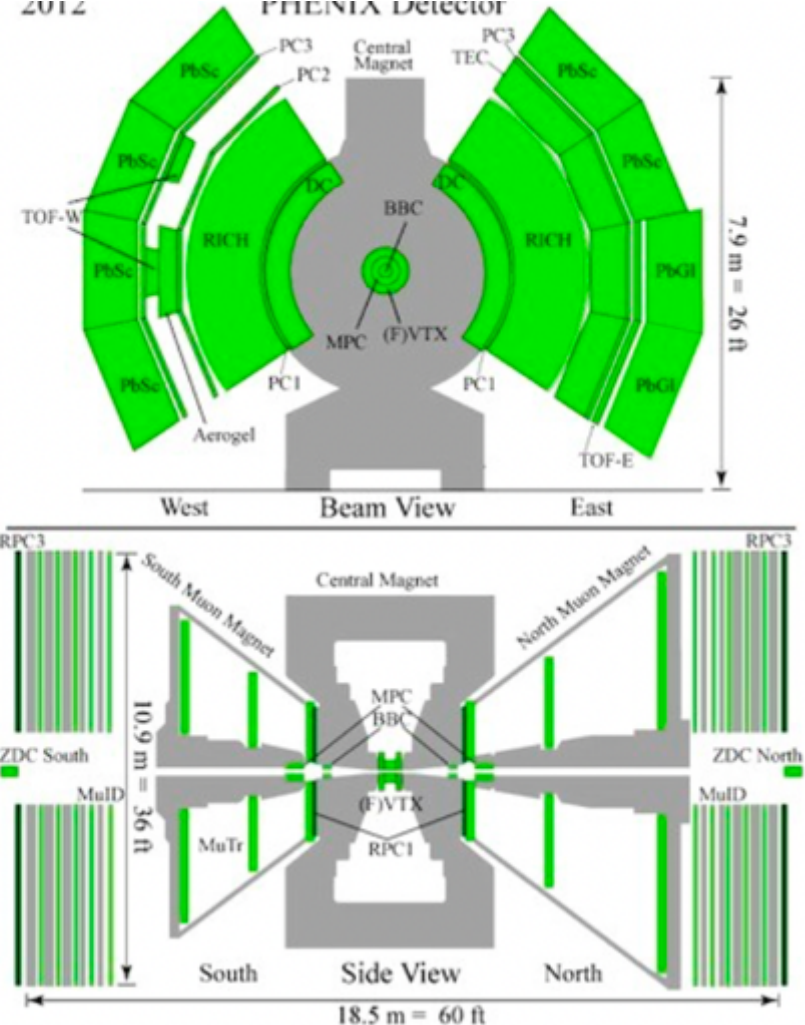


Mid rapidity, central arm: $|\eta| < 0.35 \Rightarrow$ charged hadrons with PID, π^0 , η ...

Forward rapidity, muon arms: $1.2 < |\eta| < 2.4 \Rightarrow$ charged hadrons, muons, J/ψ ...

Forward rapidity, muon Piston Calorimeters: $3.1 < |\eta| < 3.9 \Rightarrow \pi^0$, η

Very forward rapidity, in Zero Degree Calorimeter: $|\eta| > 6.8 \Rightarrow$ neutron



(Marie Boër)

Transversity conference, December 11 - 15, 2017, Erice, Italy