First year(s) results from sPHENIX

The 11th workshop of the APS Topical Group on Hadronic Physics - March 2025

Charles Hughes on behalf of the sPHENIX Collaboration

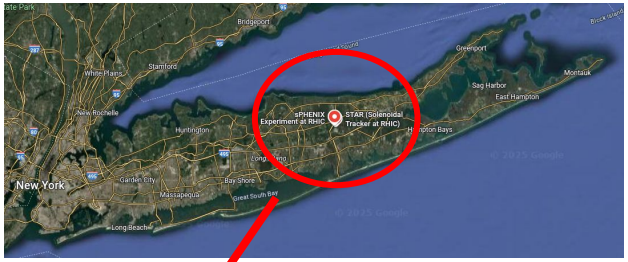
Outline

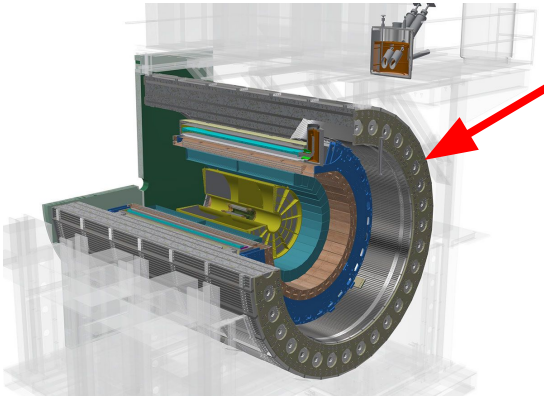
- sPHENIX Overview and Detector
- sPHENIX Physics Program
- sPHENIX Physics Results

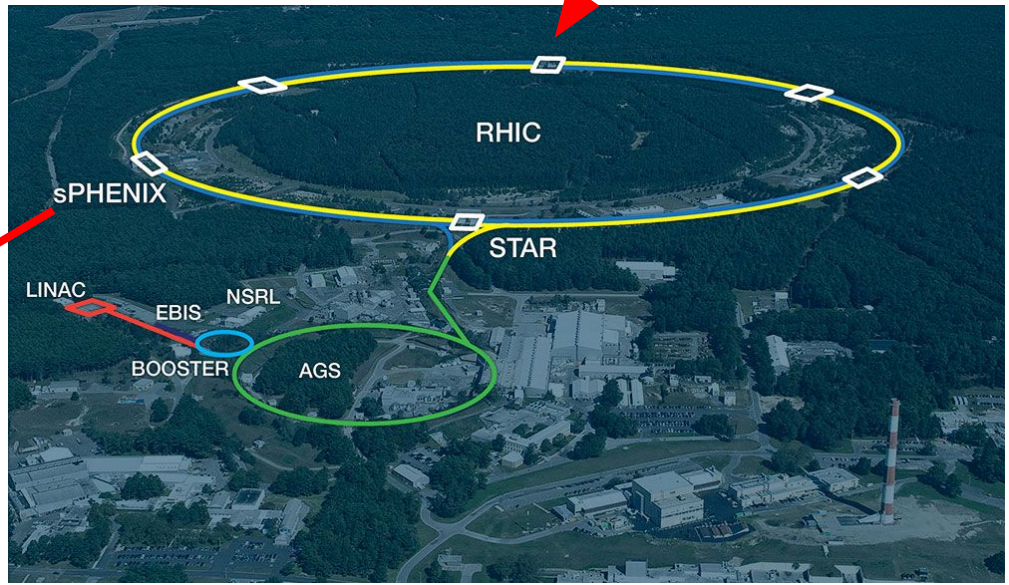
sPHENIX Overview

- sPHENIX: **s**uper **P**ioneering **H**igh **E**nergy **N**uclear phys**I**cs e**X**periment

- 322 members, 53 institutes
  - 11 countries







sPHENIX Overview Continued

Tracking Detectors

- MVTX
- INTT
- TPC
- TPOT

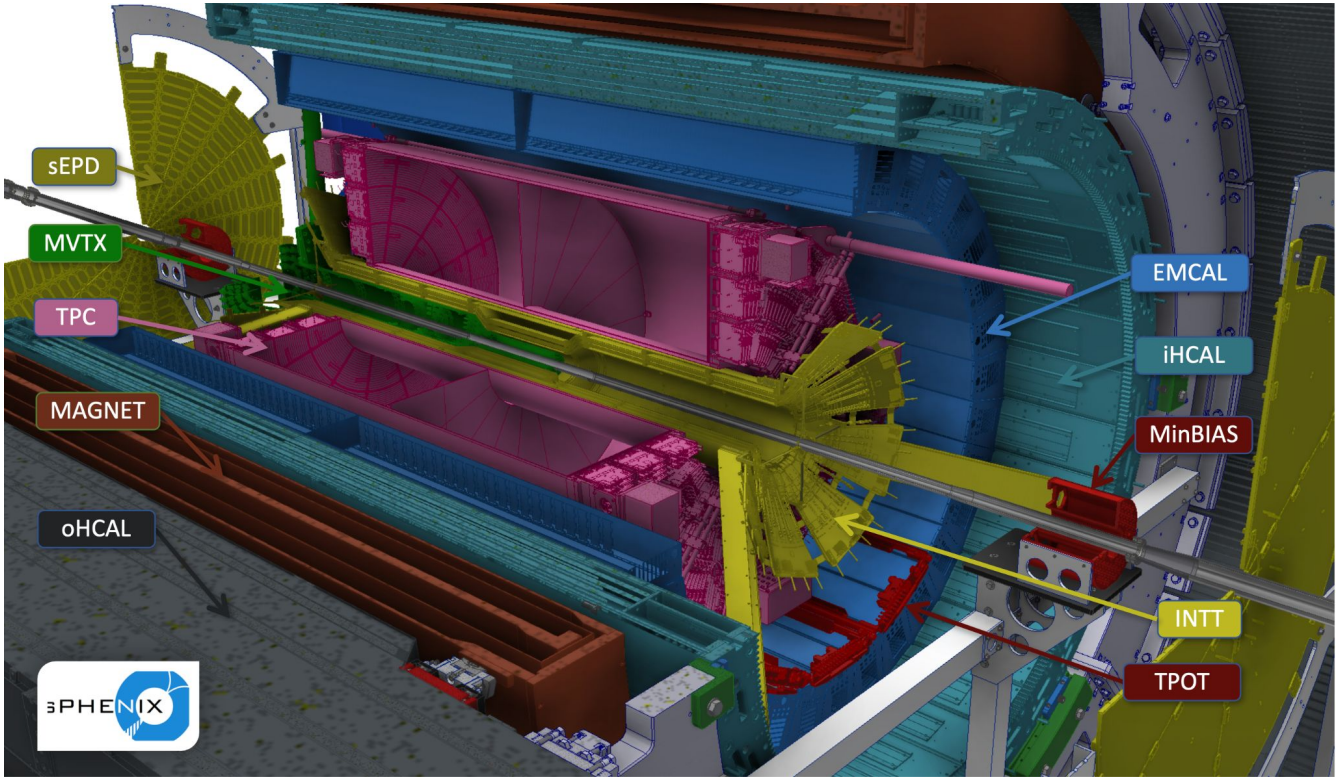
Calorimetry

- EMCAL
- HCAL (inner/outer)

Magnet

Forward Detectors

- sEPD
- MBD (minBIAS)
- ZDC/SMD (not shown)



MVTX - Maps-based VerTeX detector

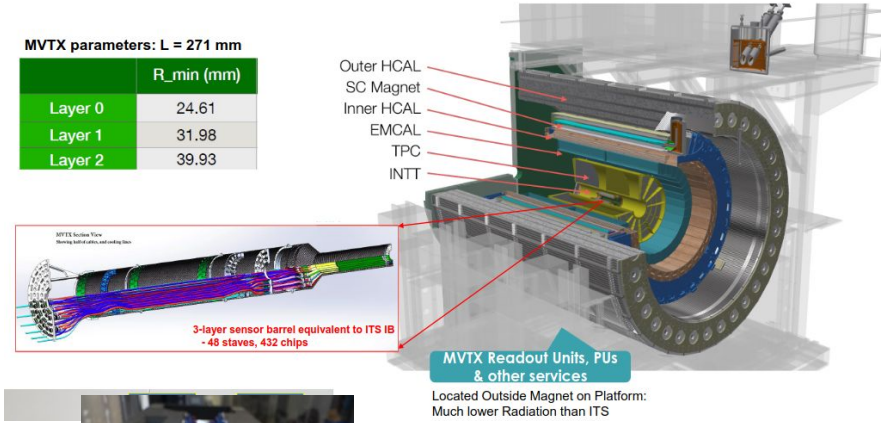
- **MAPS: Monolithic Active Pixel Sensors**
  - ALPIDE CMOS Pixel
  - 29 x 27 μm

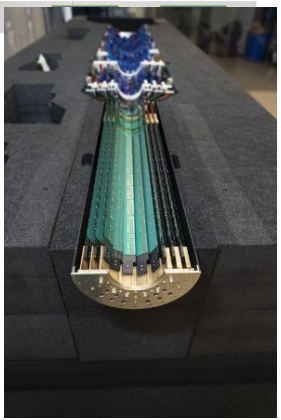
- **48 staves/3 layers**
  - 9 ALPIDE chips/stave
  - 2.4 < r < 4 cm, |η| < 1.1, full φ
  - Copy of ALICE ITS2 inner barrel

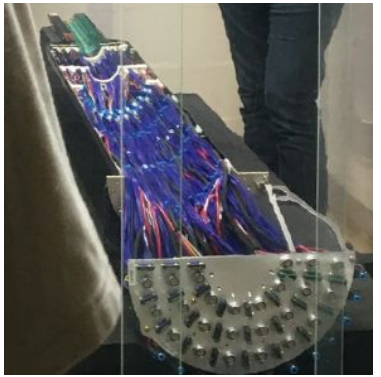
- **Identifies track vertex position**
  - O(10 μm) vertex position resolution
  - 4 μs integration time
  - Streaming or triggered readout
  - Key to sPHENIX Heavy Flavor Program

MVTX parameters: L = 271 mm

	R_min (mm)
Layer 0	24.61
Layer 1	31.98
Layer 2	39.93

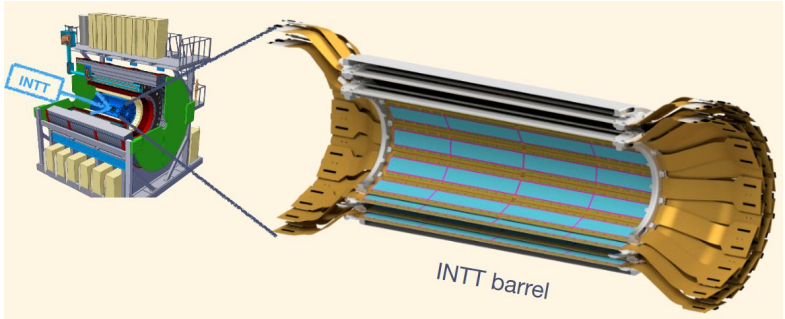


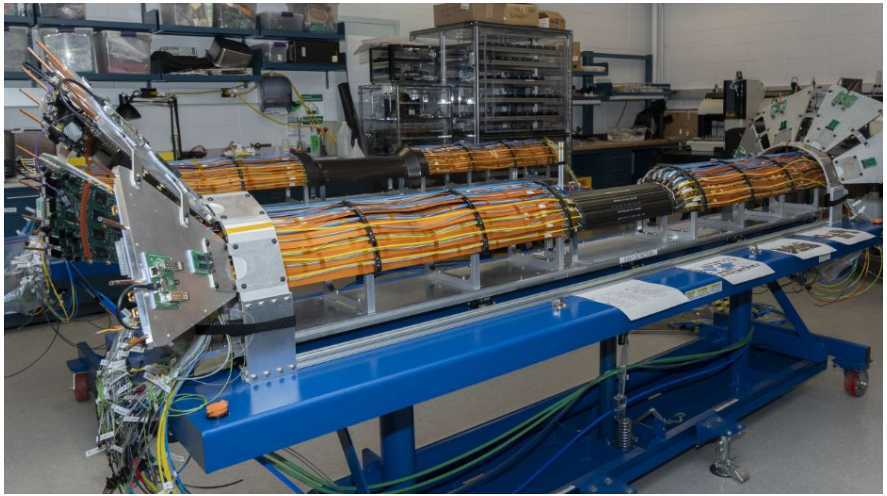




INTT - INTermediate silicon Tracker

- **Silicon Semiconductor Strip Detectors**
  - 2 kinds of Hamamatsu silicon modules
  - 78 μm x 16 or 20 mm
- **56 staves/2 layers**
  - 32+20 chips/stave
  - 7 < r < 11 cm, |η| < 1.1, full φ
- **Precision Timing + Hit Interpolation**
  - O(100 ns) - resolves bunch x-ing
  - O(10 μm) resolution in rφ
  - O(1 cm) resolution in z
- **INTT NIM-A Pre-print**: arXiv:2503.09105



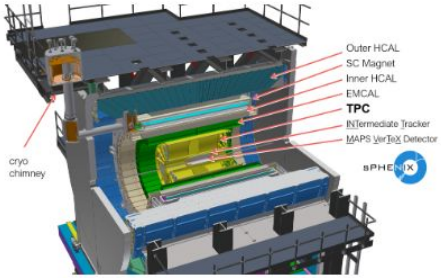


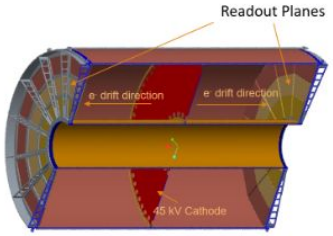
TPC - Time Projection Chamber

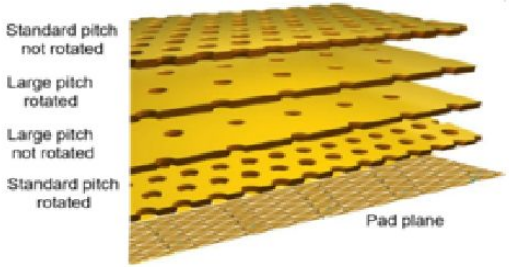
- **Gaseous Drift Detector**
  - $Ar/CF_4/iC_4H_{10}$ 75/20/5 % drift gas
    - 14 μs drift time
  - GEM (Gaseous Electron Multiplier) amplification
    - 4 Kapton + Copper GEMs / module
  - Un-gated like ALICE TPC
    - Allows for streaming readout
  - Zig/Zag segmented copper sensor pads
    - Improved position resolution

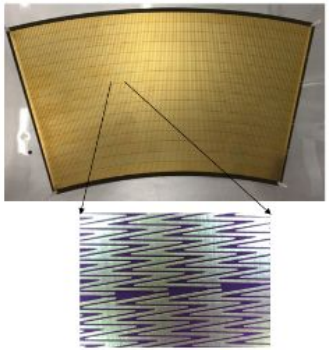
- **72 GEM modules/2 sides**
  - 36 modules / full φ
  - 3 modules / full r
  - 20 < r < 78 cm, |η| < 1.1, full φ

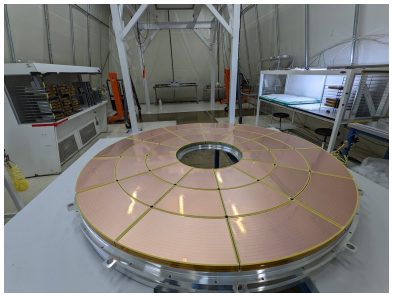
- **Measures Momentum**
  - Target momentum resolution:
    - Δp/p = 0.02 for p ~ 5 GeV
  - O(150 μm) spatial resolution

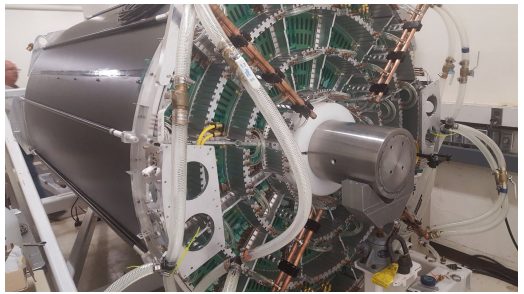












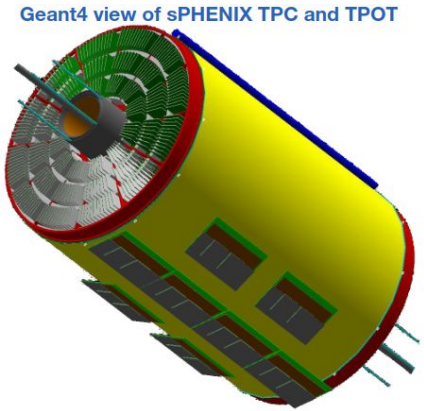
TPOT - Time Projection chamber Outer Tracker

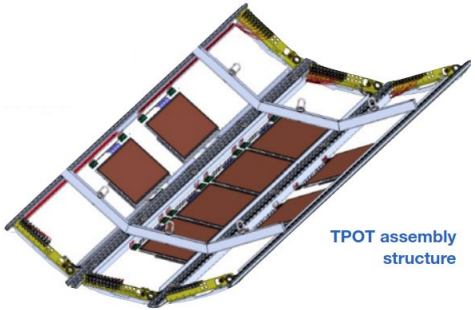
- **Gaseous Drift Detector**
  - Ar/iC_4H_{10} 95/5 % conversion gas
    - 3 mm conversion length
  - Micromegas amplification
  - Resistive layer w/ strips for readout

- **8 modules/bottom of TPC**
  - Partial coverage

- **Provides reference for TPC**
  - O(100 μm) spatial resolution
  - Calibrates Distortions

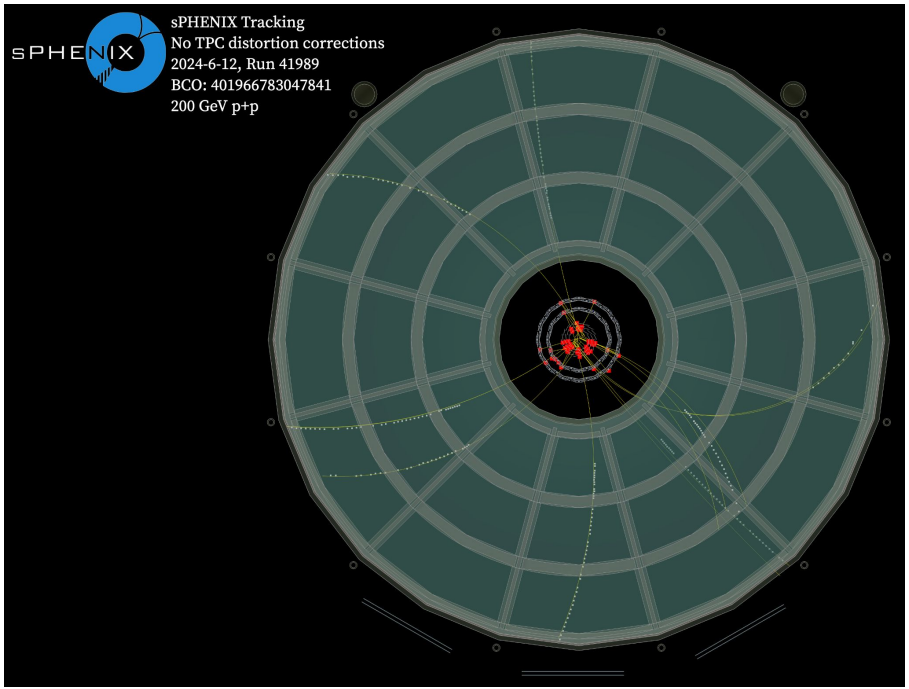
- **TPOT NIM Performance Paper**: [NIM-A 1066 (2024) 169615]



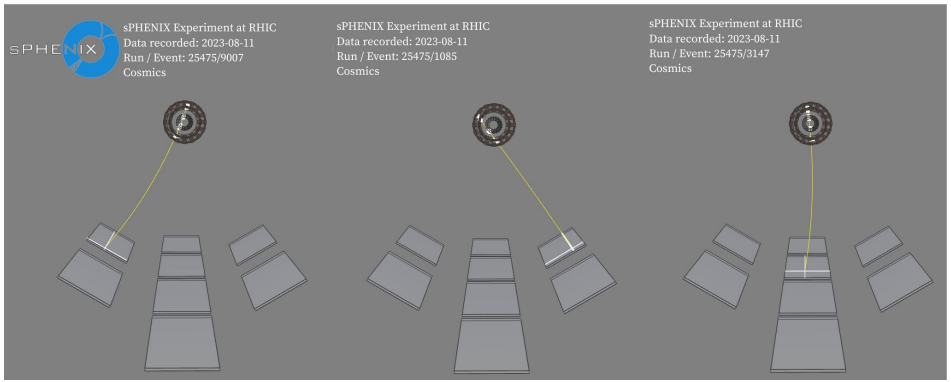


Tracking

MVTX + INTT + TPC - 200 GeV pp collision

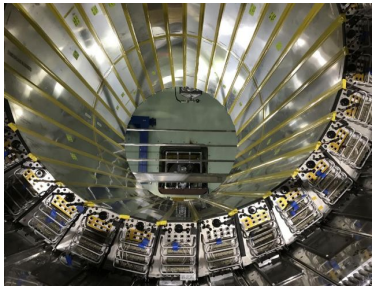


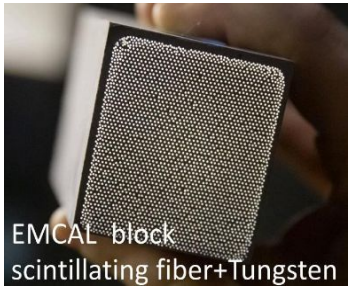
MVTX + INTT + TPOT - cosmic ray data



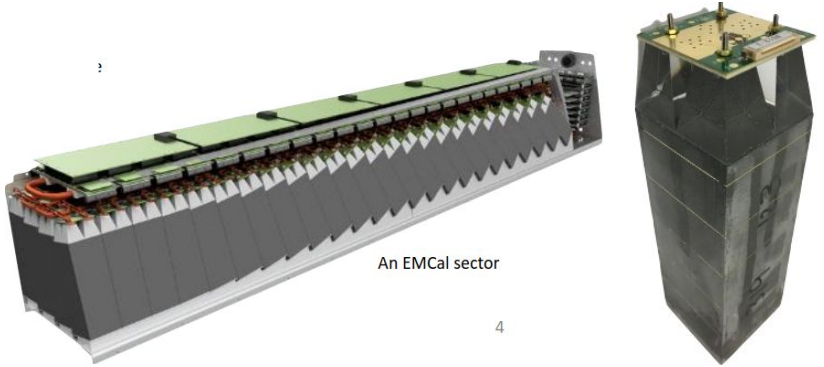
EMCAL - ElectroMagnetic CALorimeter

- **Tungsten-Scintillating Fiber Sampling Calorimeter**
  - Light guide + silicon photomultiplier (SiPM)
  - Pre-amp board sums signals from SiPMs





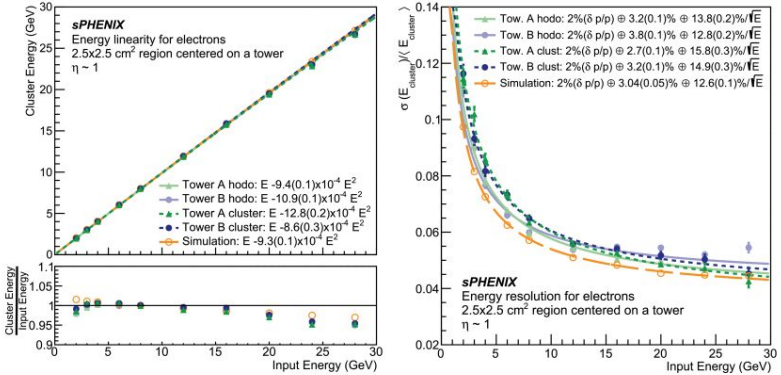
- **64 sectors: 32 azimuthal x 2 longitudinal**
  - $|\eta| < 1.1$, full φ
  - 96 modules / sector - 1 module = 2x2 towers
  - Towers have projective geometry
  - Each tower is $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$



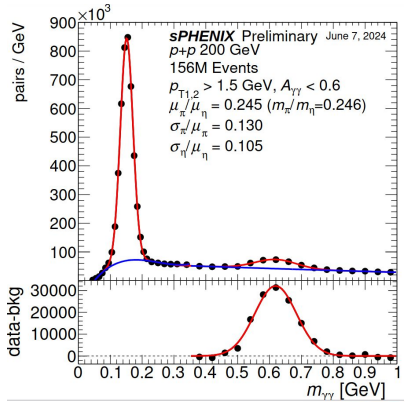
- **Performance Specs**
  - 0.83 λ_{int}, 20 X_0
  - Moliere Radius: 2.3 cm, Absorber Depth: 14 cm
  - Energy Resolution: = 5 % ⊕ 16 % / √E

EMCAL - ElectroMagnetic CALorimeter

- **EMCAL (test beam) performance:**
  - [IEEE Trans.Nucl.Sci. 68 (2021) 2, 173-181]
  - Linearity and resolution for 2.5 x 2.5 cm^2 cut centered on a tower



- **EMCAL reconstruction:**
  - Proton-proton data show good invariant mass peaks for π^0 and η



HCAL - Hadronic CALorimeter(s)

- **Inner + Outer**
  - Al (inner) and steel (outer) absorber plates
  - Scintillating tiles w/ embedded WLS fibers

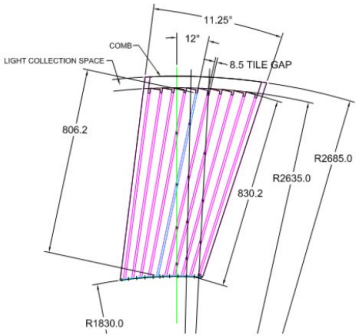
- **32 sectors (both inner & outer HCAL)**
  - $|\eta| < 1.1$, full φ
  - 48 towers / sector
  - (1 tower = 4/5 tiles (I/O))
  - Towers have projective geometry
  - Each tower is $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

- **Performance Specs**
  - 5 λ_{int} for both calos combined
  - Energy Resolution: = 14 % ⊕ 81 % / √E for hadrons

- **First mid-rapidity HCAL at RHIC**


Half of oHCal sector. oHCal scintillating tiles tilted in η from center of barrel

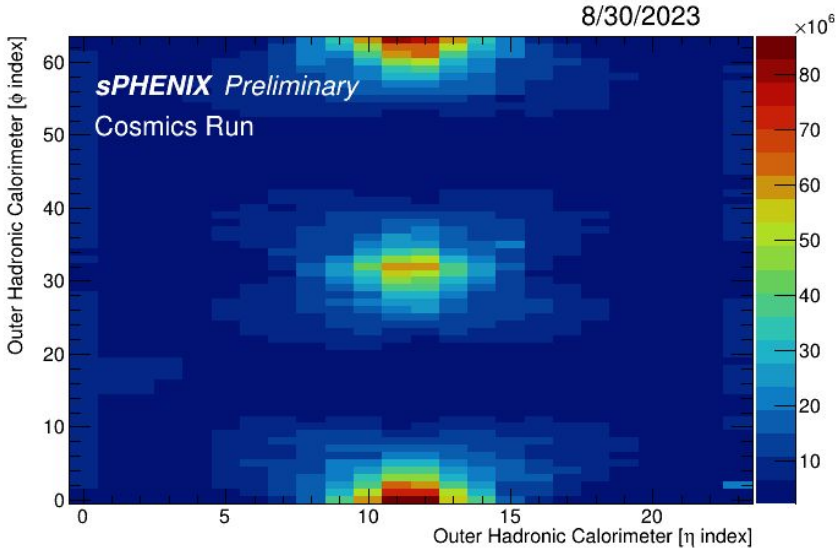

IHCal scintillating production

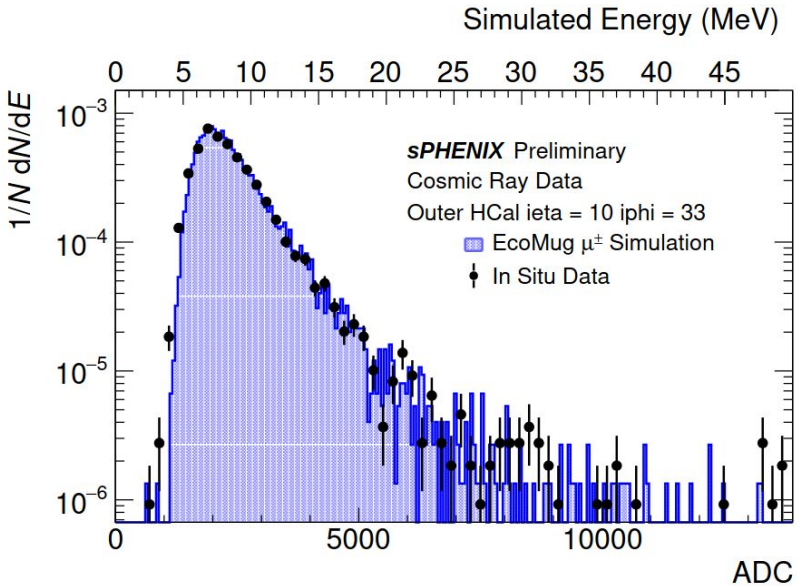


OHCal scintillating tiles tilted in φ from radius

HCAL - Hadronic CALorimeter(s)

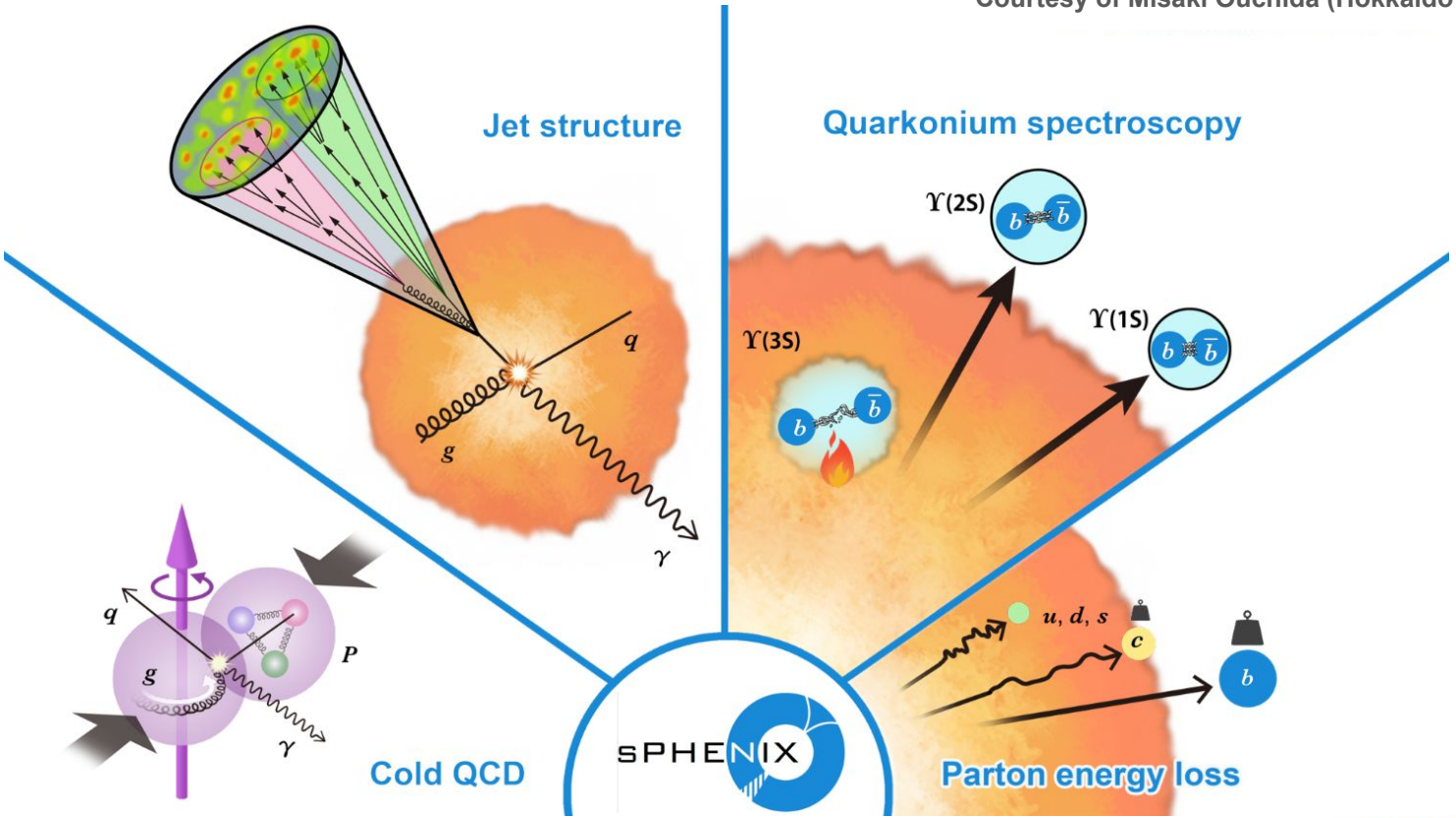
- **Cosmic ray data in OHCAL**
  - Shows good agreement to simulation

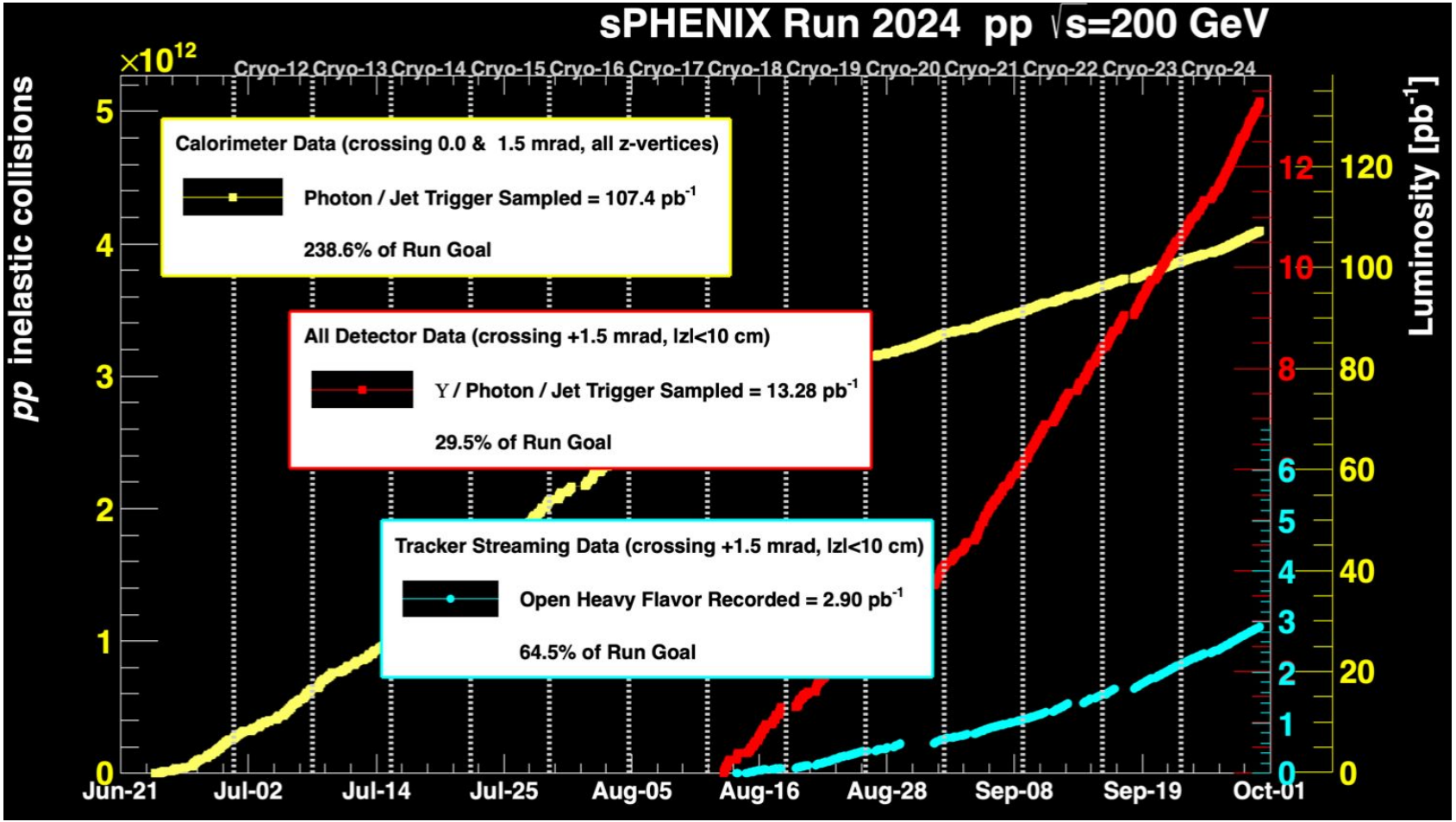




sPHENIX Physics Program

Courtesy of Misaki Ouchida (Hokkaido University)

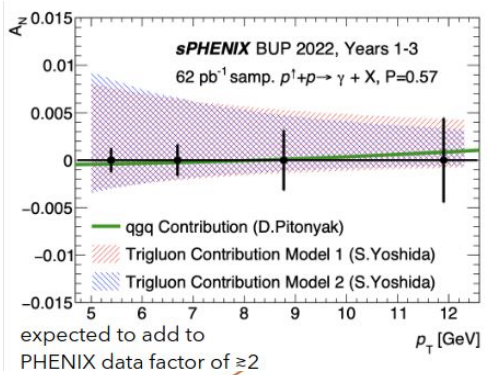



sPHENIX Run 2024 pp √s=200 GeV
×10^12
Cryo-12 Cryo-13 Cryo-14 Cryo-15 Cryo-16 Cryo-17 Cryo-18 Cryo-19 Cryo-20 Cryo-21 Cryo-22 Cryo-23 Cryo-24
pp inelastic collisions
Luminosity [pb^-1]
Calorimeter Data (crossing 0.0 & 1.5 mrad, all z-vertices)
Photon / Jet Trigger Sampled = 107.4 pb^-1
238.6% of Run Goal
All Detector Data (crossing +1.5 mrad, |z|<10 cm)
Υ / Photon / Jet Trigger Sampled = 13.28 pb^-1
29.5% of Run Goal
Tracker Streaming Data (crossing +1.5 mrad, |z|<10 cm)
Open Heavy Flavor Recorded = 2.90 pb^-1
64.5% of Run Goal
0 1 2 3 4 5
0 1 2 3 4 5 6 8 10 12
0 20 40 60 80 100 120
Jun-21 Jul-02 Jul-14 Jul-25 Aug-05 Aug-16 Aug-28 Sep-08 Sep-19 Oct-01

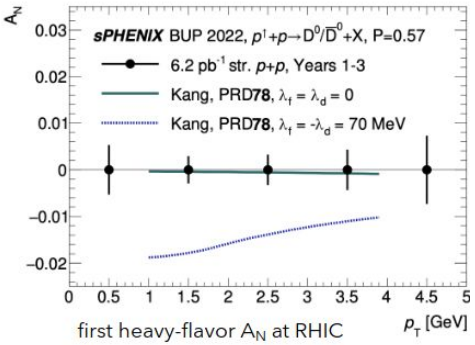
sPHENIX Physics Program - Cold QCD

- **RHIC can provide polarized proton beams**

- **Planned Measurements (e.g.):**
  - A_N -> neutral meson transverse single-spin asymmetry



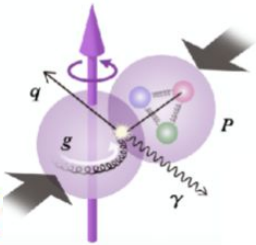
expected to add to PHENIX data factor of ≥2



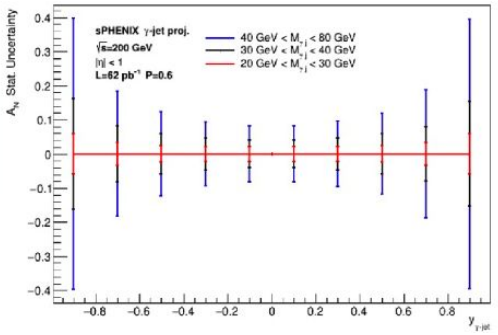
first heavy-flavor A_N at RHIC

planned sPHENIX cold QCD measurements:

physics	channel
tri-gluon correlator	neutral mesons, direct γ
tri-gluon correlator	mesons
transversity PDF, IFF	di-hadrons
Collins effect	hadrons-in-jets
Sivers TMD PDF (valence q)	di-jets
Sivers TMD PDF (g)	jet-γ
tri-gluon correlator	inclusive jets



qg scattering @ LO



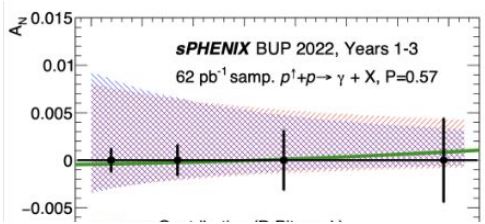
sPHENIX Physics Program - Cold QCD

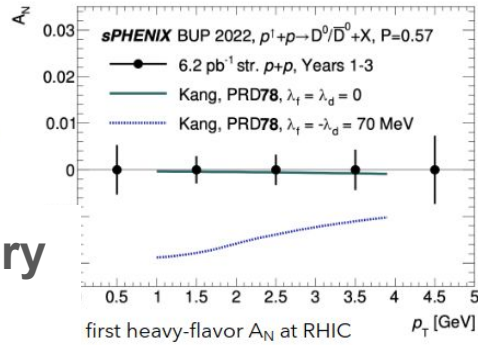
- **RHIC can provide polarized proton beams**

- **Planned Mea**

  - **A_N -> ne**
    single-sp

See 03.19 talk at Global Summit by Gregory Mattson:

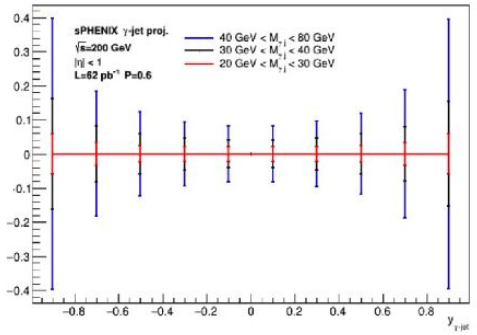




planned sPHEN

physics		
tri-gluon correlat		
tri-gluon correlat		
transversity PDF,		
Collins effect		
Sivers TMD PDF (valence q)		
Sivers TMD PDF (g)	jet-γ	qg scattering @ LO
tri-gluon correlator	inclusive jets	

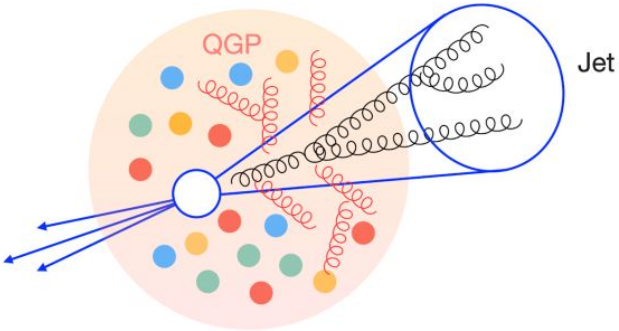
"Transsverse Single-Spin Asymmetries in Neutral Meson Production with sPHENIX"

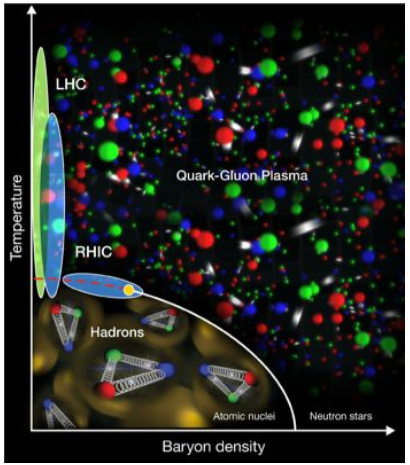


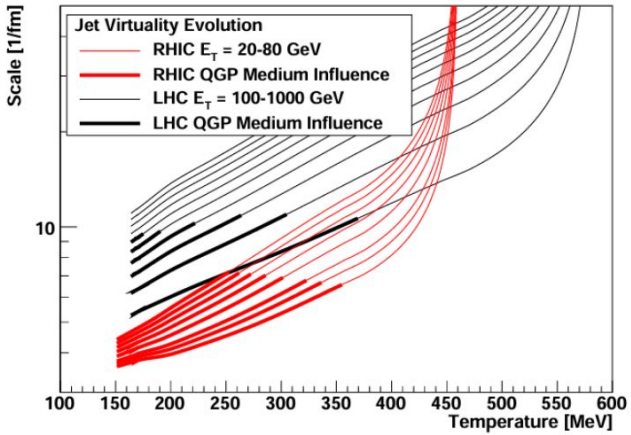
sPHENIX Physics Program - Jets

- Jets are collimated showers of particles from initial hard scattering before Quark Gluon Plasma (QGP) formation

- QGP temperature & evolution different at RHIC than LHC

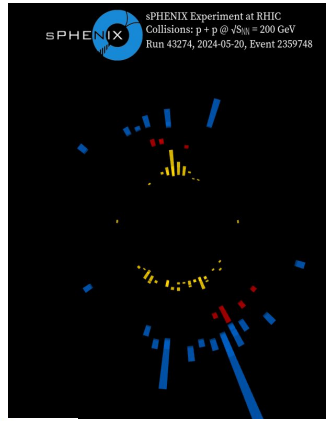


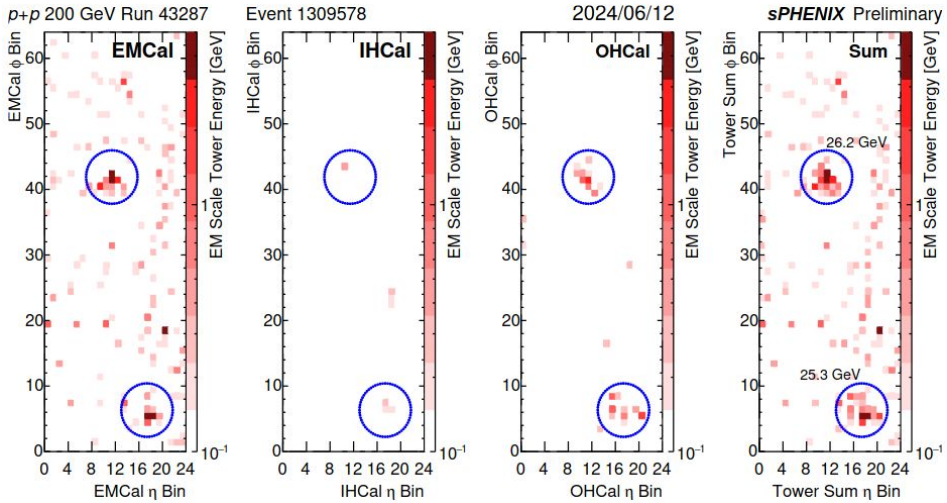


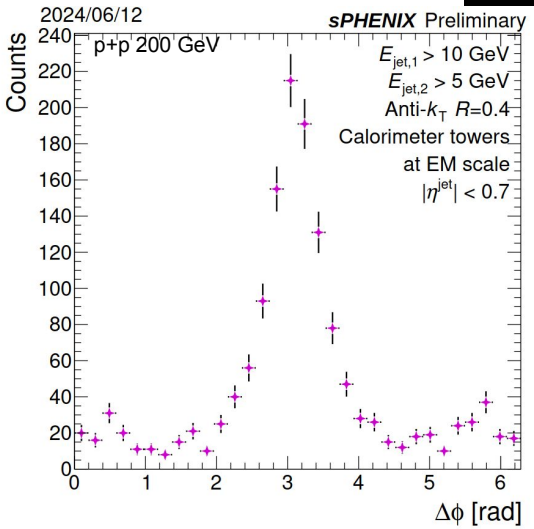


sPHENIX Physics Program - Jets

- Early check showing energy deposits in calorimeters are back-to-back

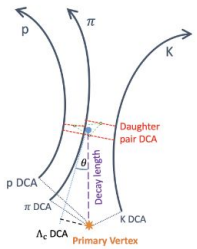


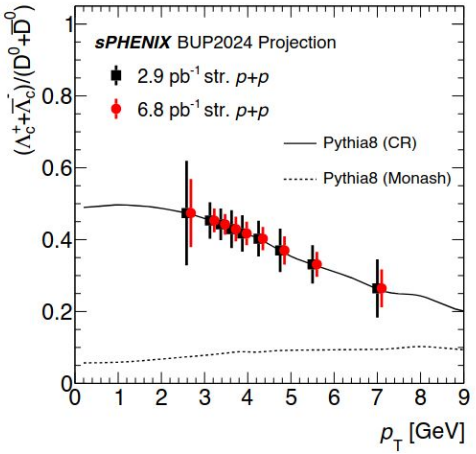




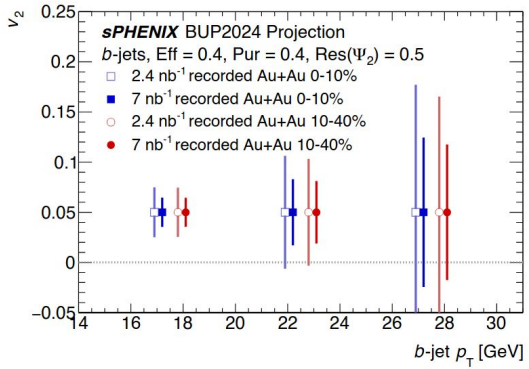
sPHENIX Physics Program - Heavy Flavor

- **RHIC and LHC see enhancement of Λ_c baryon to D^0 meson production**
  - Future sPHENIX measurement will help discriminate between models



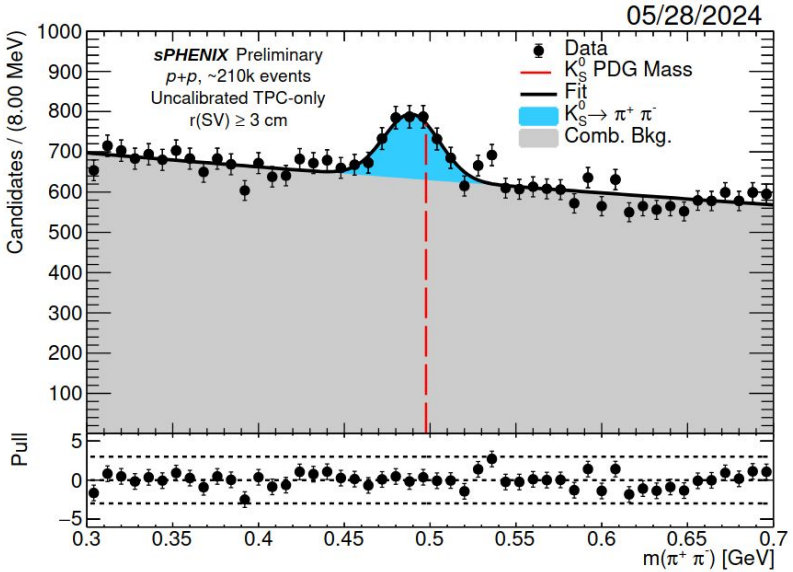


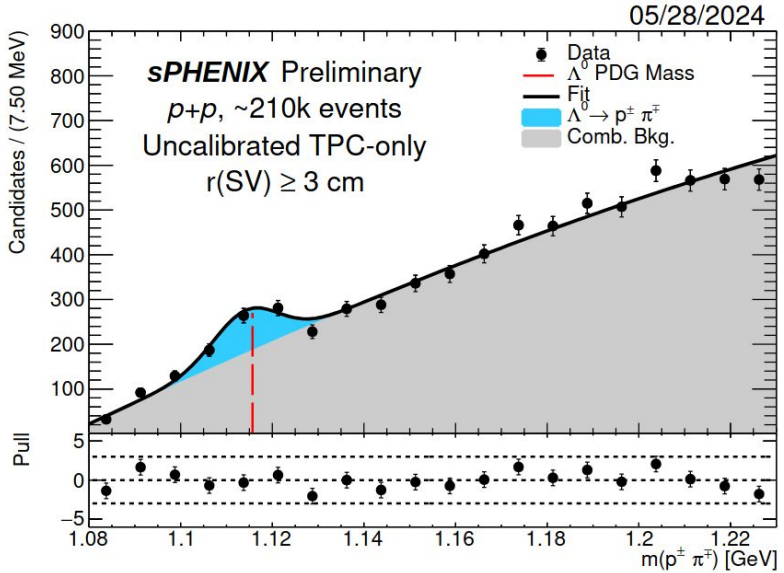
- **sPHENIX collects high luminosity p+p data in extended readout and Au+Au data in triggered mode**
  - Can help understand this enhancement and hadronization in QGP
  - Streaming capability necessary for HF Jet



sPHENIX Physics Program - Heavy Flavor

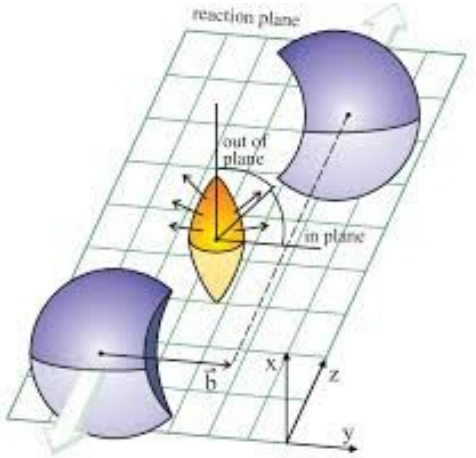
- **Initial Results for K^0_s and Λ^0 in proton-proton data**
  - (Uncalibrated) TPC Only Tracks
  - KFParticle is used for resonance reconstruction



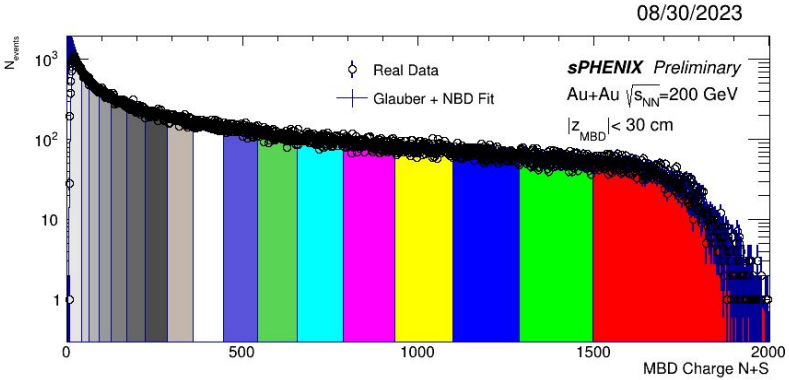


sPHENIX Physics Program - Bulk

- **Measurement of bulk properties**
  - E_T, v_2, Ψ_2, centrality, etc…



- **Also provides categories for differential hard probes measurements**
  - e.g. exploring jet quenching in different event geometries
  - e.g. measuring centrality

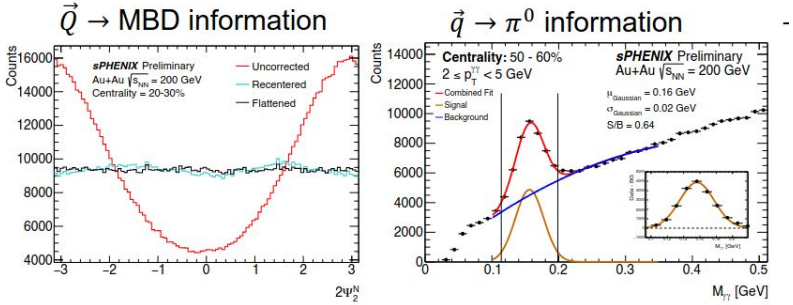


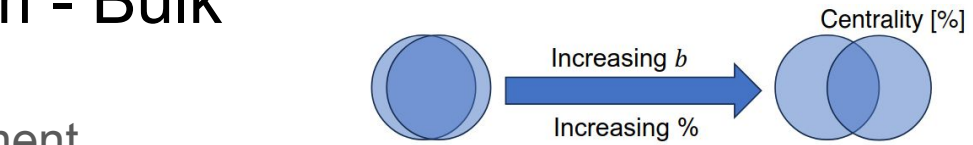
sPHENIX Physics Program - Bulk

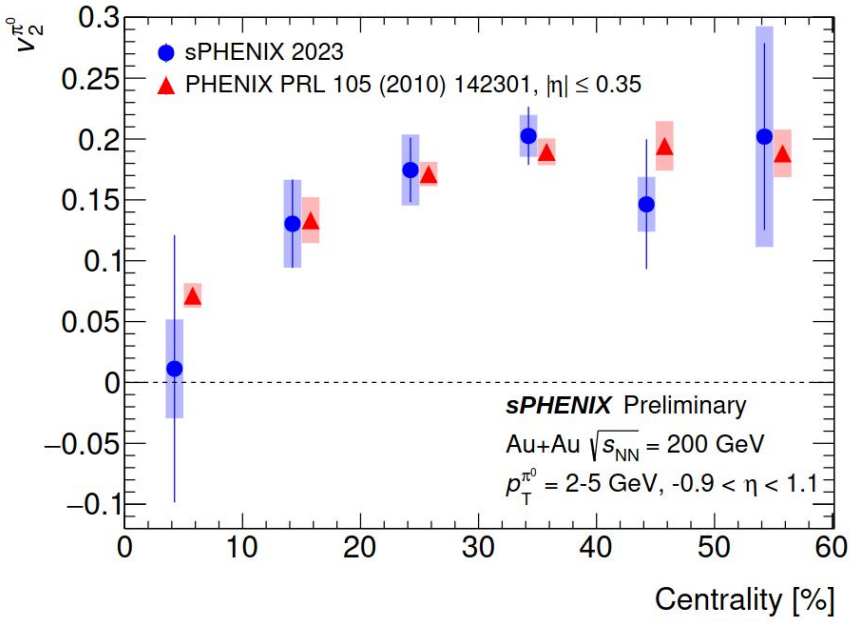
- π^0 v_2 vs centrality - good agreement to previous RHIC measurements

- scalar product method

$$v_n\{SP\} \equiv Re\frac{\left\langle \vec{q}_{n,j}\vec{Q}_n^{S|N^*}\right\rangle}{\sqrt{\left\langle \vec{Q}_n^S\vec{Q}_n^{N^*}\right\rangle}}$$



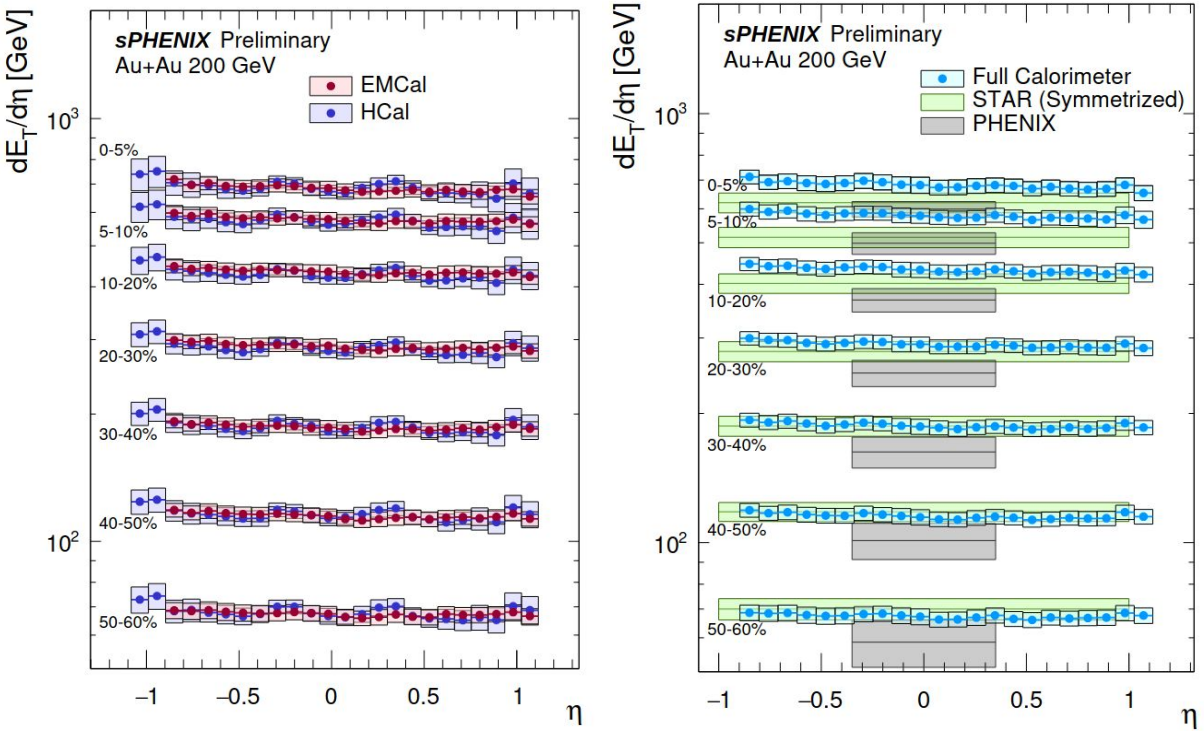




Neutral pion v_2 via scalar product method (sPH-CONF-BULK-2024-01)

sPHENIX Physics Program - Bulk

- Fully corrected transverse energy
- Good agreement between HCAL and EMCAL
- Good agreement to previous RHIC measurements



Corrected $dE_T/d\eta$ (sPH-CONF-BULK-2024-02)

Conclusions

- **sPHENIX is a unique detector:**
  - Optimized for hard probes, but provides good opportunity for cold QCD and bulk !
- **sPHENIX has already taken data in 2023 and 2024:**
  - Run 2023 was a AuAu commissioning run - still useful for early measurements
  - Run 2024 was a pp physics run - achieved more than double its target luminosity for calorimetric photon/jet triggered data
  - Many good initial results (jets/heavy flavor/bulk)
    - (All current and future sPHENIX results available here: https://www.sphenix.bnl.gov/PublicResults)
  - Many more to come (e.g. APS Global Summit & Quark Matter 2025)
- **sPHENIX will take data again in 2025**
  - First AuAu collisions ~ end of month

More to Come at the APS Global Physics Summit

- Virginia Bailey - 03.17.25 11:21 AM PT:
  - "Early results from the sPHENIX calorimeter jet program"
- Evgeny Shulga - 03.17 11:57 AM PT:
  - "sPHENIX Tracking performance and Related Physics Studies"
- Gregory Mattson - 03.19 11:57 AM PT:
  - "Transverse Single-Spin Asymmetries in Neutral Meson Production with sPHENIX"
- Lameck Mwibanda - 03.20 5:36 PM PT:
  - "New Submission Design and performance of MBD in sPHENIX"

(All current and future sPHENIX results available here: https://www.sphenix.bnl.gov/PublicResults)