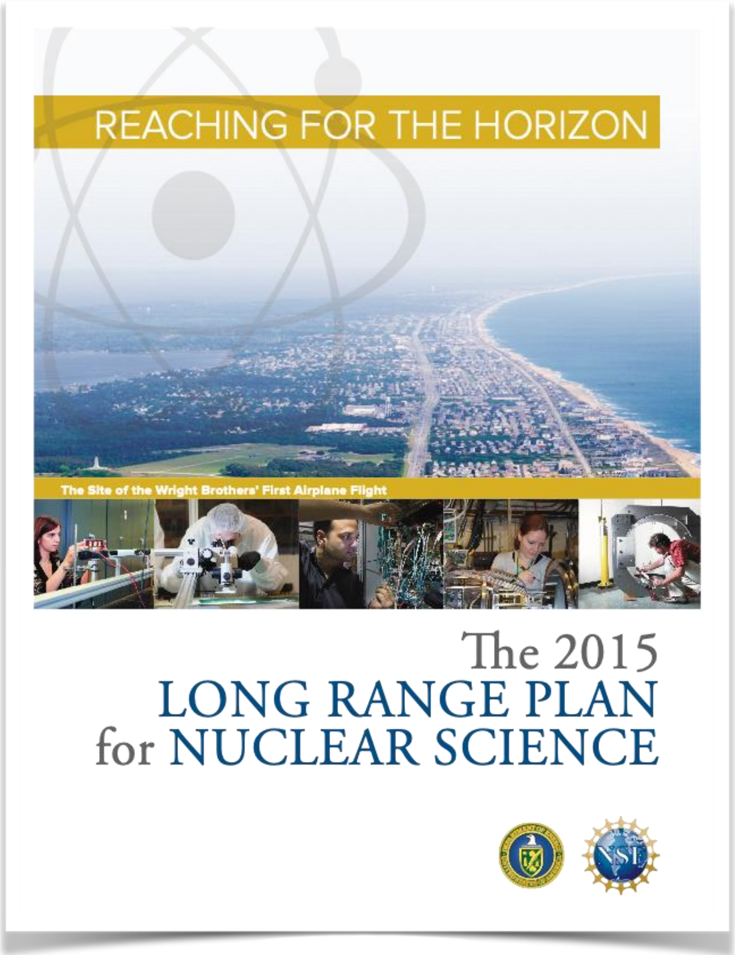
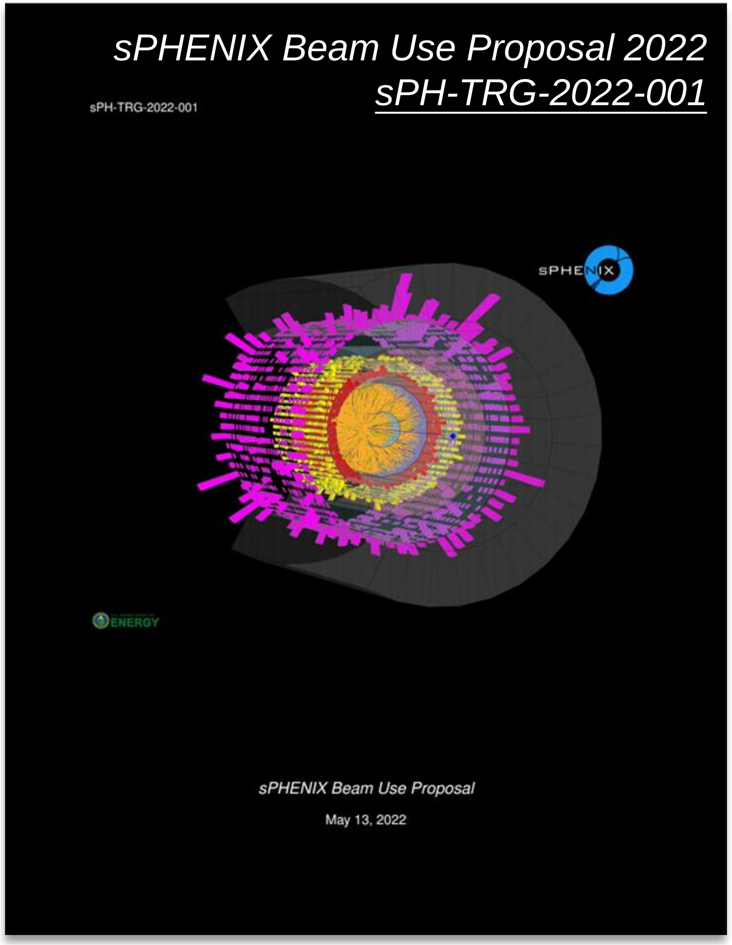
Status & Performance of sPHENIX Experiment

Strange Quark Matter 2022, June 13-17, 2021

Hideki Okawa for the sPHENIX Collaboration
Fudan University

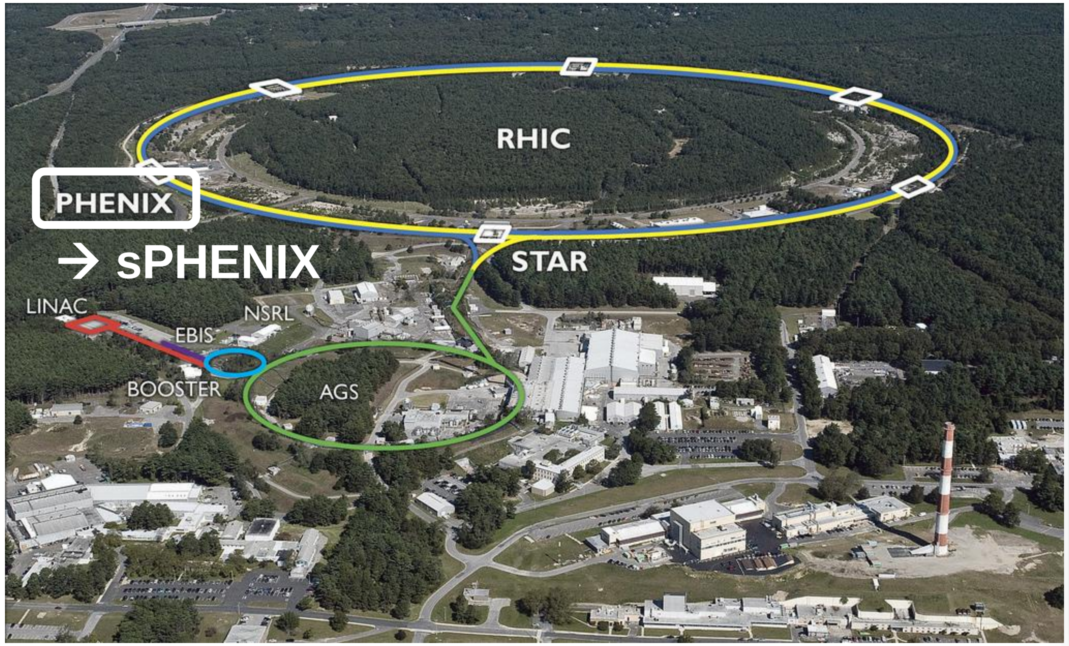
sPHENIX Mission





- **The first new detector at RHIC in >20 years.**
- Completing the scientific mission of RHIC.
- **Complementarity to LHC.**
- sPHENIX as the highest priority for Runs 2023-2025 (PAC Report, Sep. 2020)
- Beam Use Proposal 2022 submitted recently.

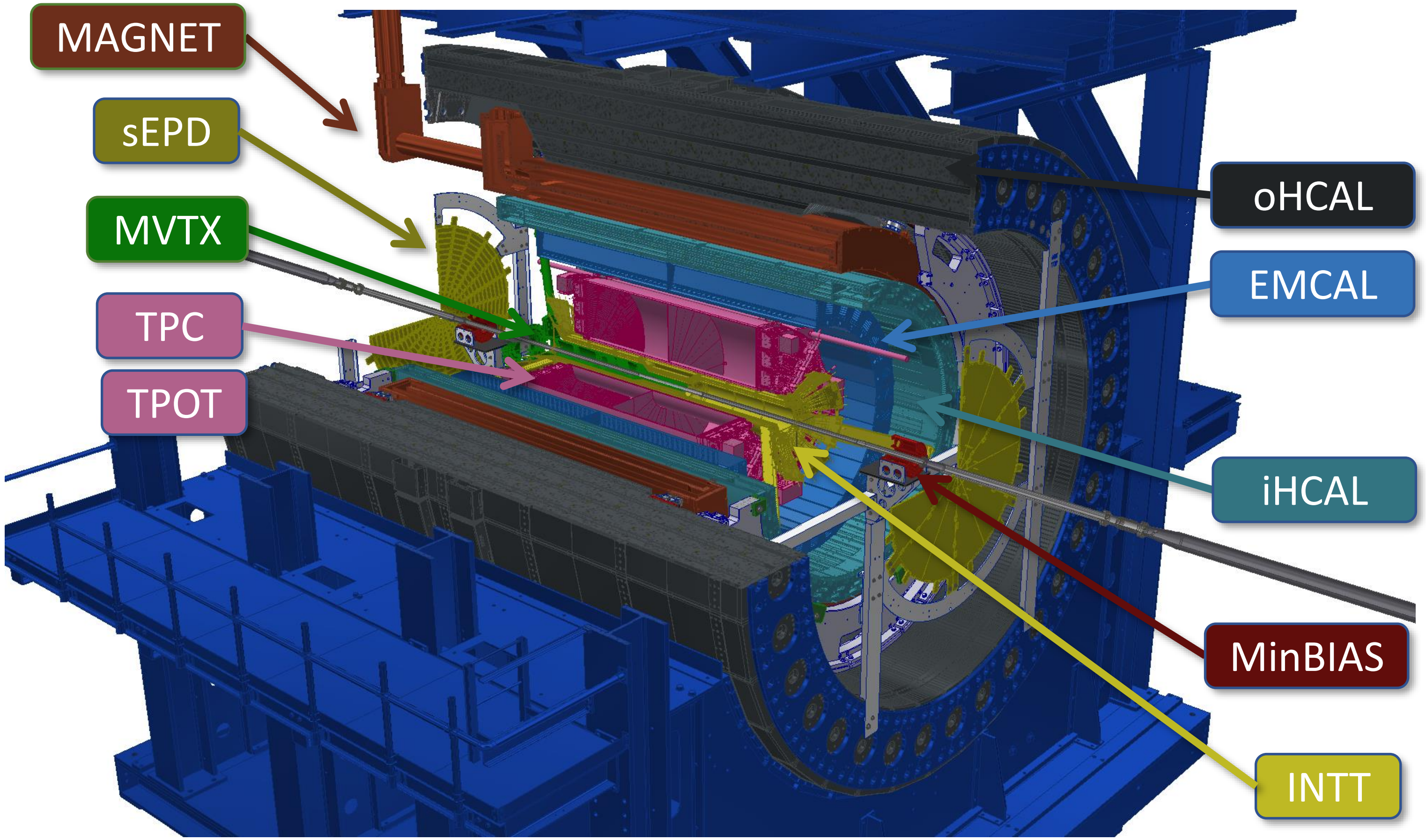
sPHENIX Collaboration



- Replacement/upgrade of PHENIX. Proposed in 2010; collaboration formed in 2016.
- Over 130 Collaboration General Meetings. (+13 Collaboration Workshops & 2 Asian regional meetings)
- **More than 360 members from 82 institutions in 14 countries (as of 2022)**

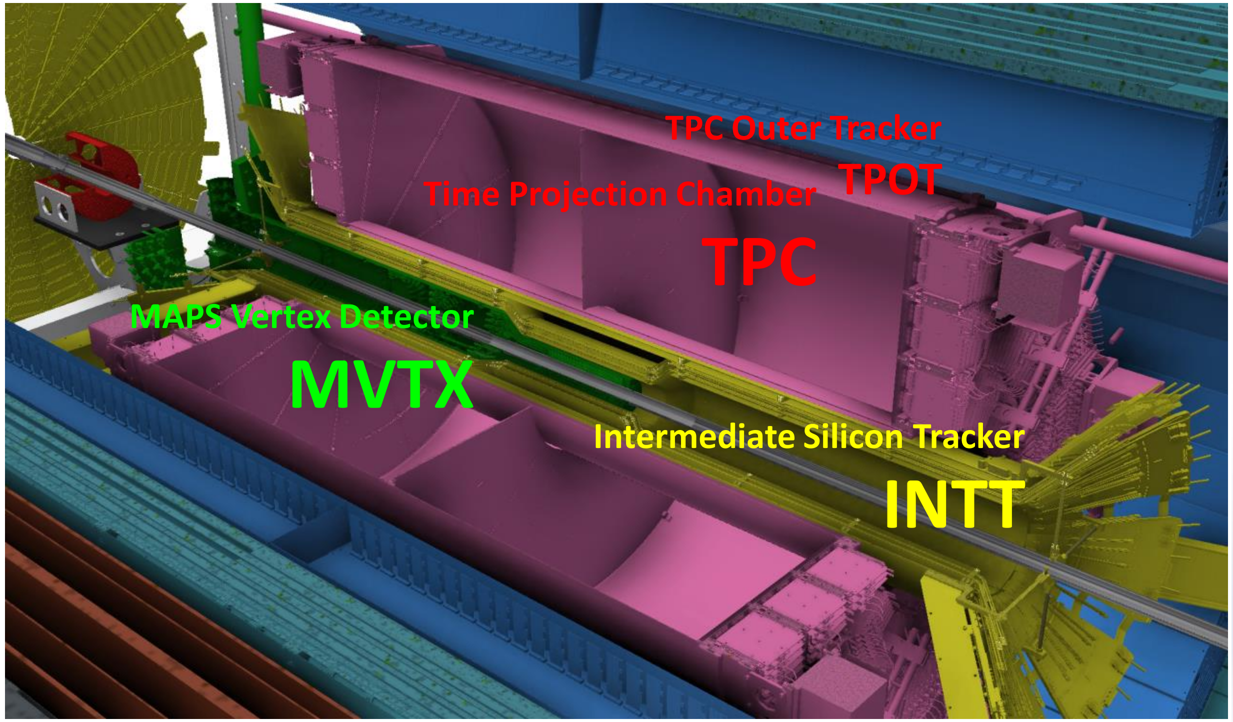
sPHENIX Detector

- High data rates: 15 kHz for all subdetectors
- Trigger capability also with streaming readout
- 1.4 T Solenoid from BaBar
- Hermetic coverage: |η|<1.1
- Precision tracking
- Large-acceptance EM+Had calorimeters



→ brings first full jet reconstruction & b-jet tagging at RHIC!!

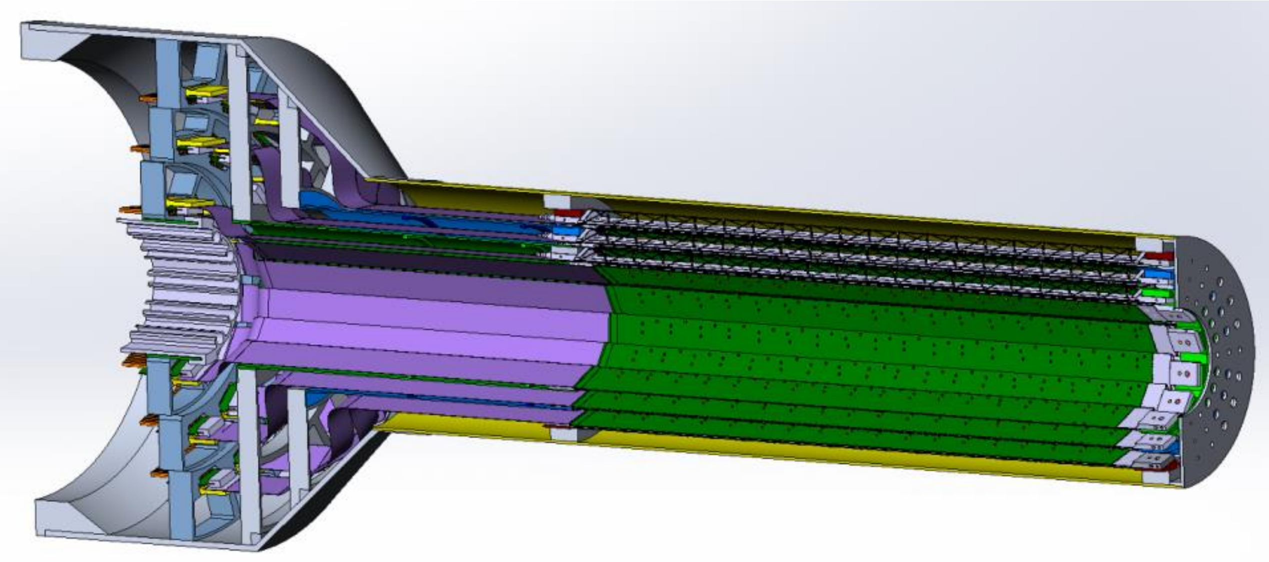
sPHENIX Tracking Detectors



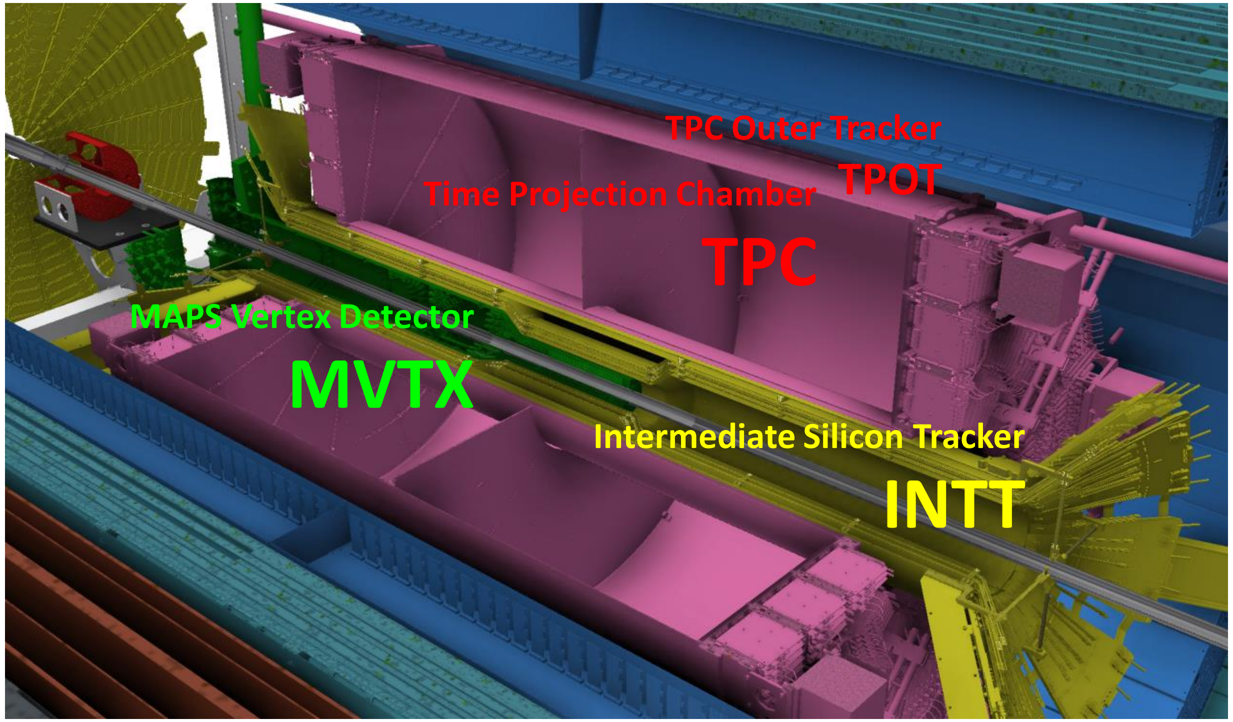
1/30 of ALICE TPC Volume

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

- 3 layers of Monolithic Active Pixel Sensors using ALICE ALPIDE. 30μm pitch.
- Nearest to collision point.



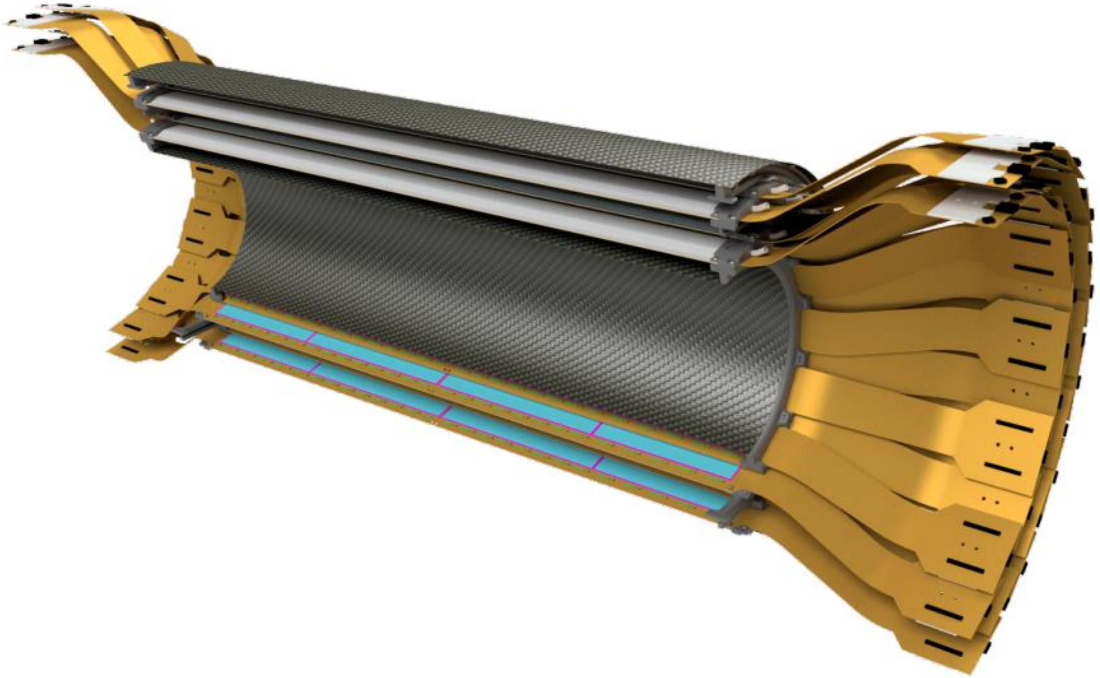
sPHENIX Tracking Detectors



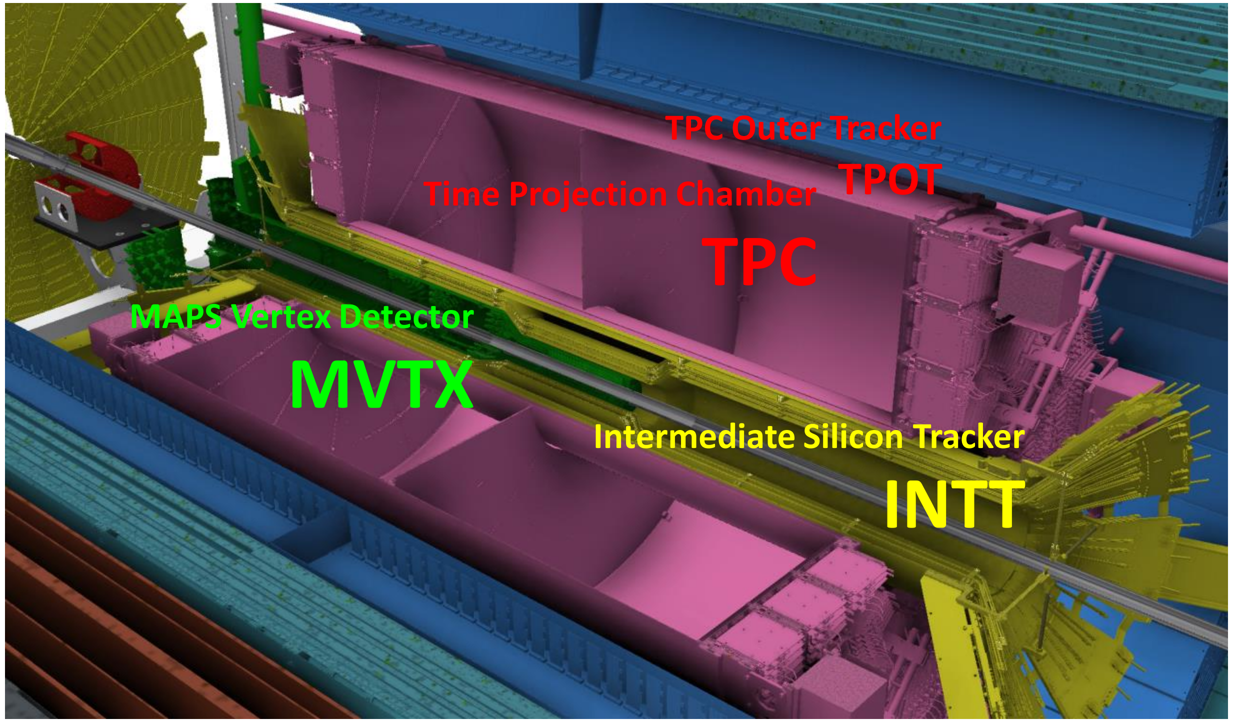
1/30 of ALICE TPC Volume

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

- 2 layers of silicon strips (86μm pitch)
- Fast integration time: O(100ns). Can resolve one beam crossing



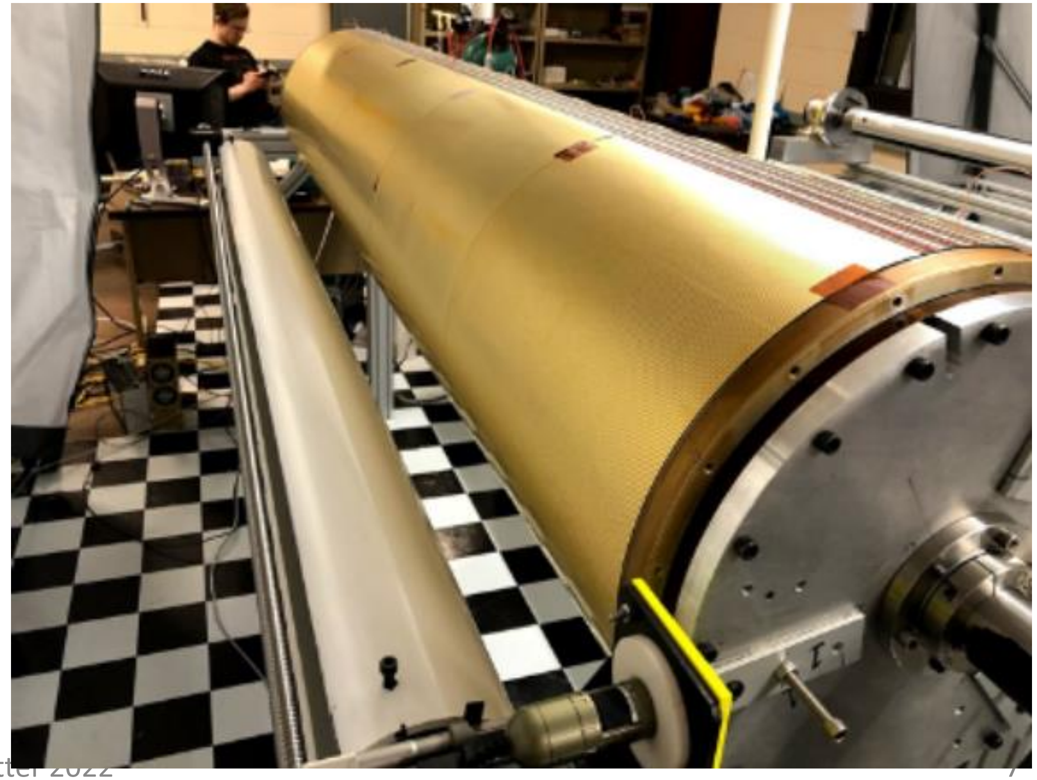
sPHENIX Tracking Detectors



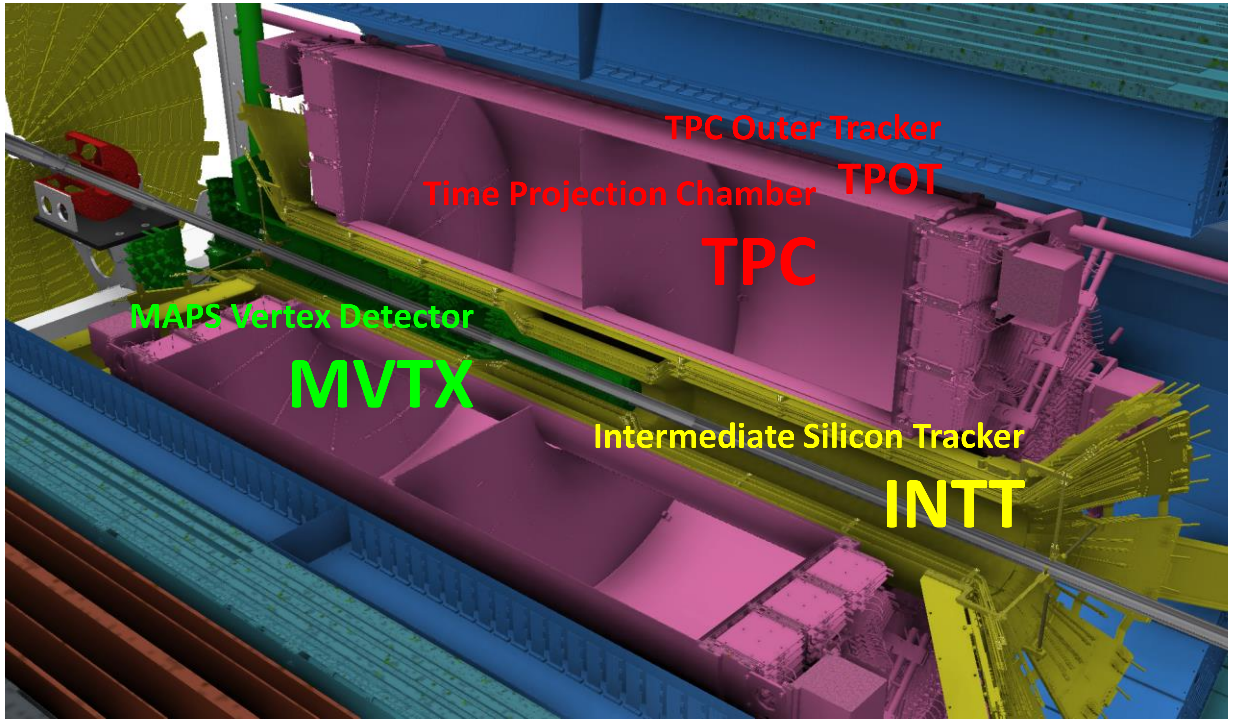
1/30 of ALICE TPC Volume

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

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



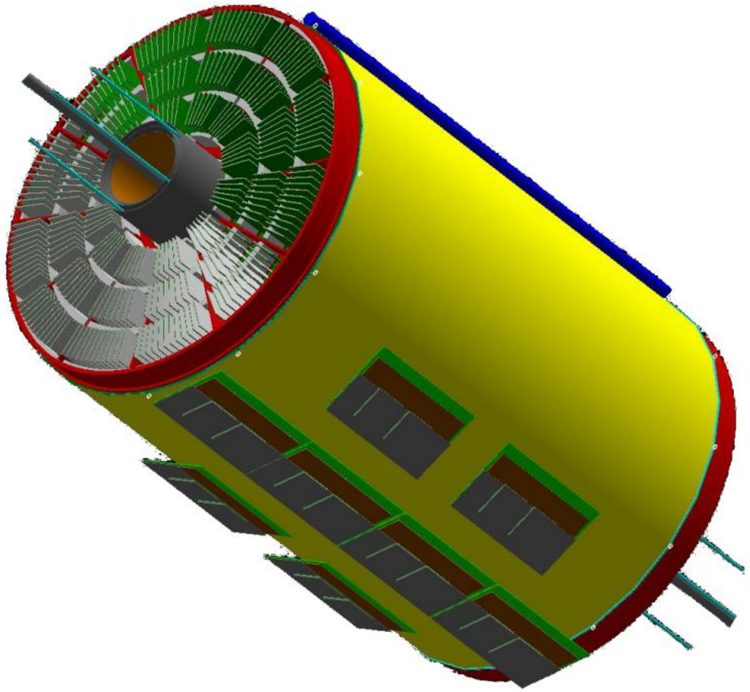
sPHENIX Tracking Detectors

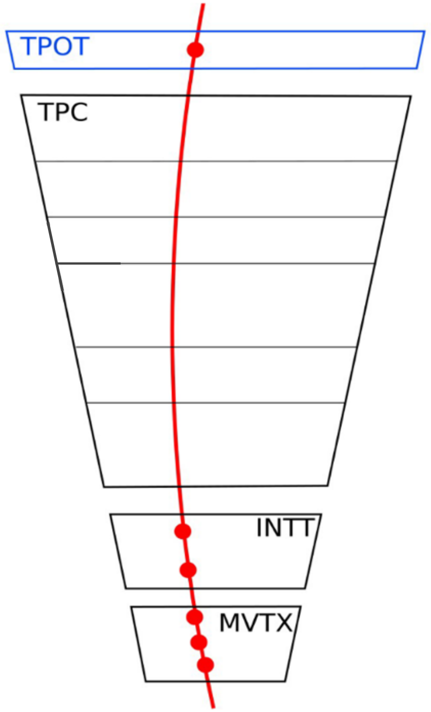


1/30 of ALICE TPC Volume

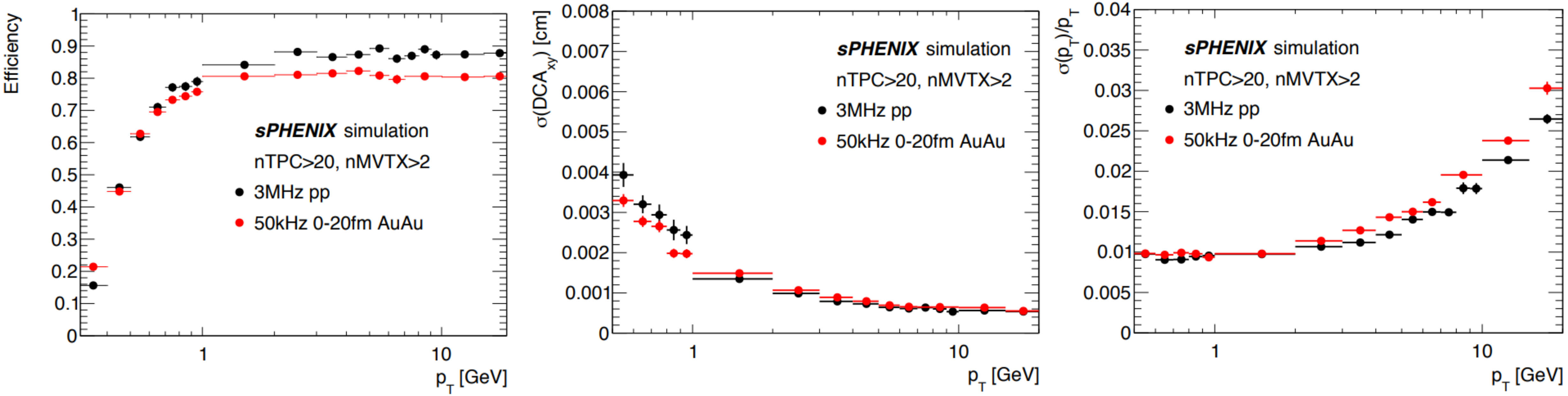
TPC Outer Tracker (TPOT): calibration of beam-induced space charge distortions

- 8 modules of Micromegas inserted between TPC and EMCal



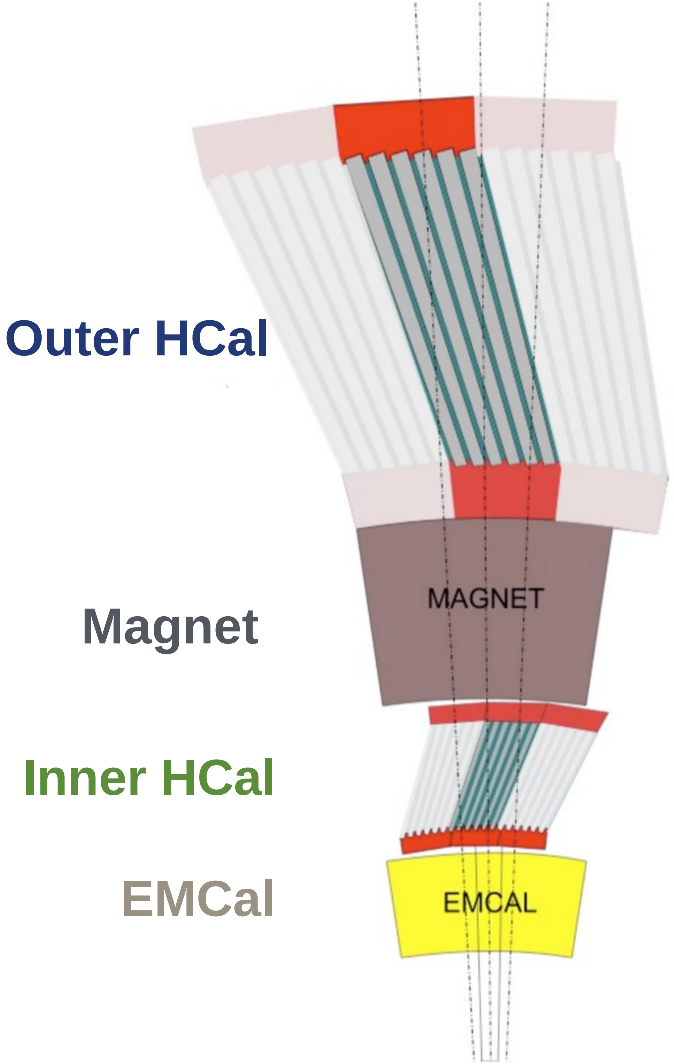


Tracking Performance



- Eff.~90% for pp at p_T>1 GeV. → promising to measure rare processes: e.g. Υ(nS)
- DCA resolutions in rϕ, z < 40μm at p_T>0.5 GeV. → crucial for open heavy-flavor
- p_T resolution < 2% for p_T < 10 GeV. → meets δM < 125 MeV for Υ(nS) separation

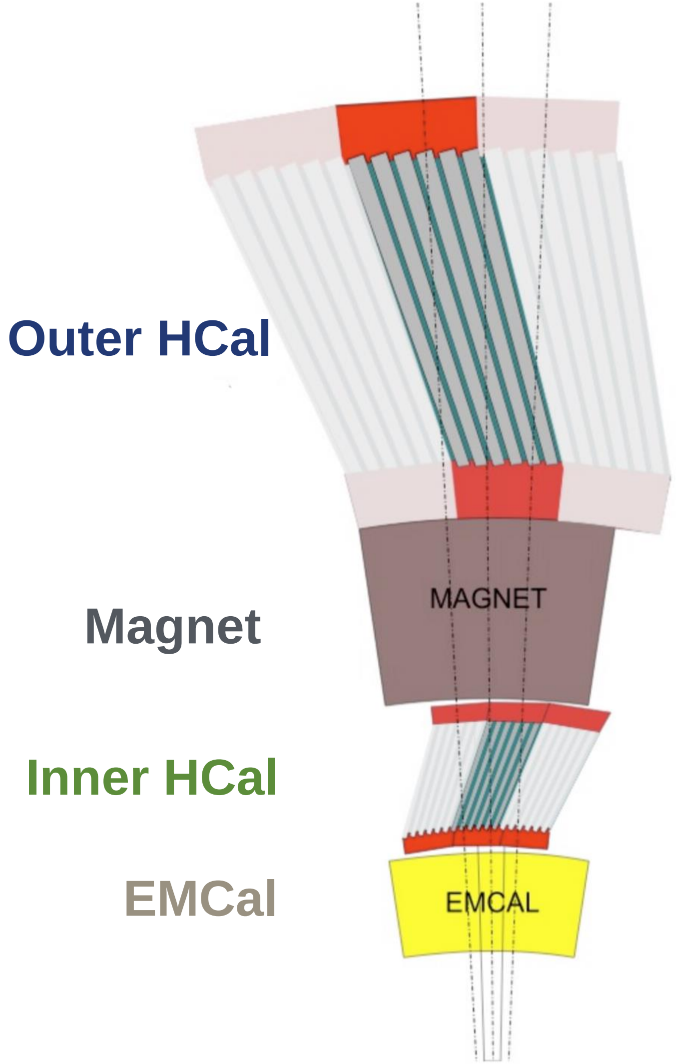
sPHENIX Calorimeters



Full Electromagnetic and Hadronic calorimeter system

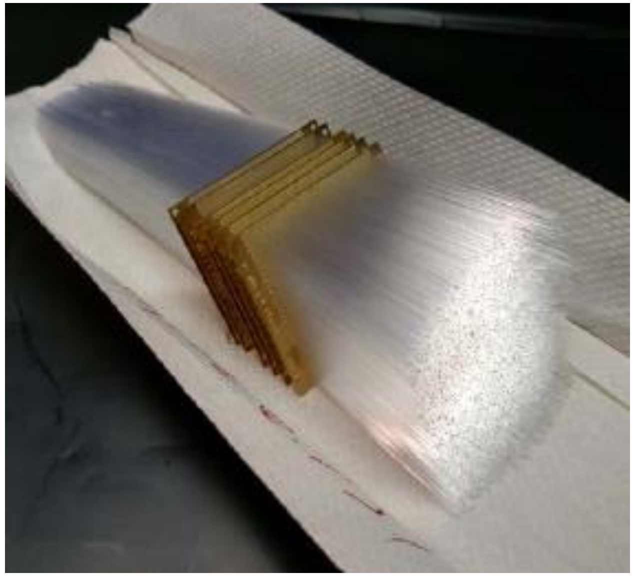
- Large Acceptance: $|\eta| < 1.1$ and full 2π azimuthal coverage
- SiPM used for light collection & readout

sPHENIX Calorimeters

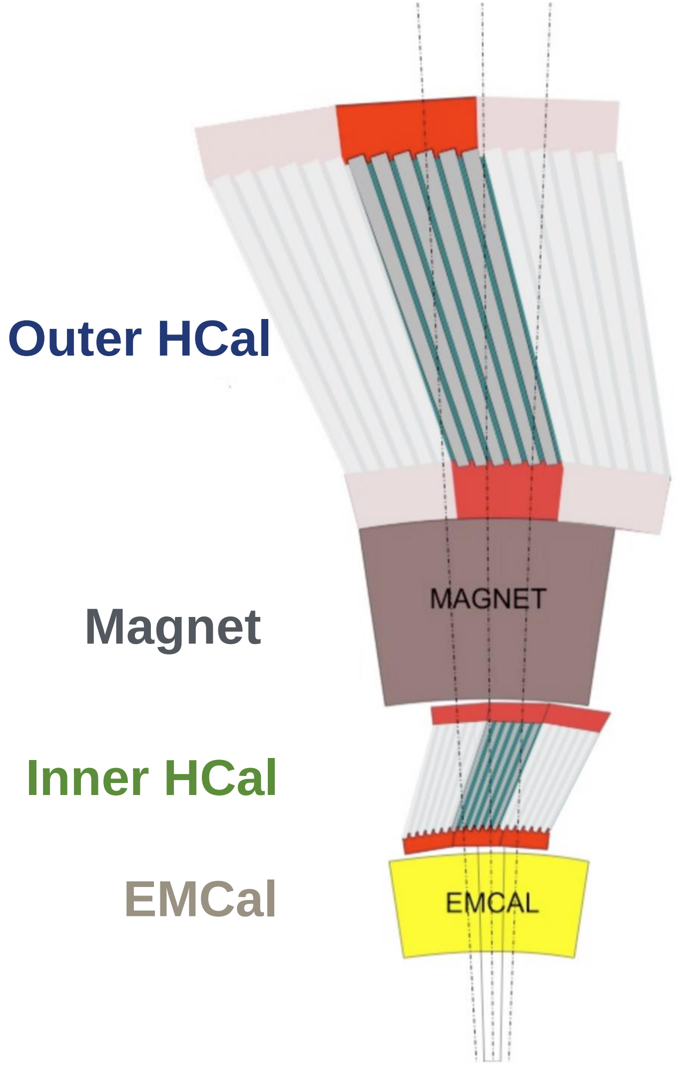


EMCal

- Tungsten-scintillating fiber sampling calorimeter (SPACAL type). 18 X_0, 1 λ. Tower size: $\Delta\eta \times \Delta\phi$=0.025x0.025. Resolution ~ 16%/$\sqrt{E}$ $\oplus$5%.



sPHENIX Calorimeters



Inner HCal

- Al absorber plates and scintillating tiles with embedded WLS fibers

Outer HCal

- Steel absorber plates and scintillating tiles with embedded WLS fibers

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

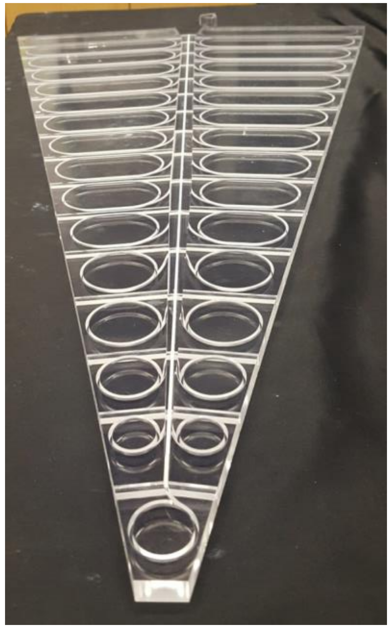
Minimum Bias & Event Plane Detectors

Minimum Bias Detector (MBD)
[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

sPHENIX Event Plane Detector (sEPD) [2.0 < |η| < 4.9]

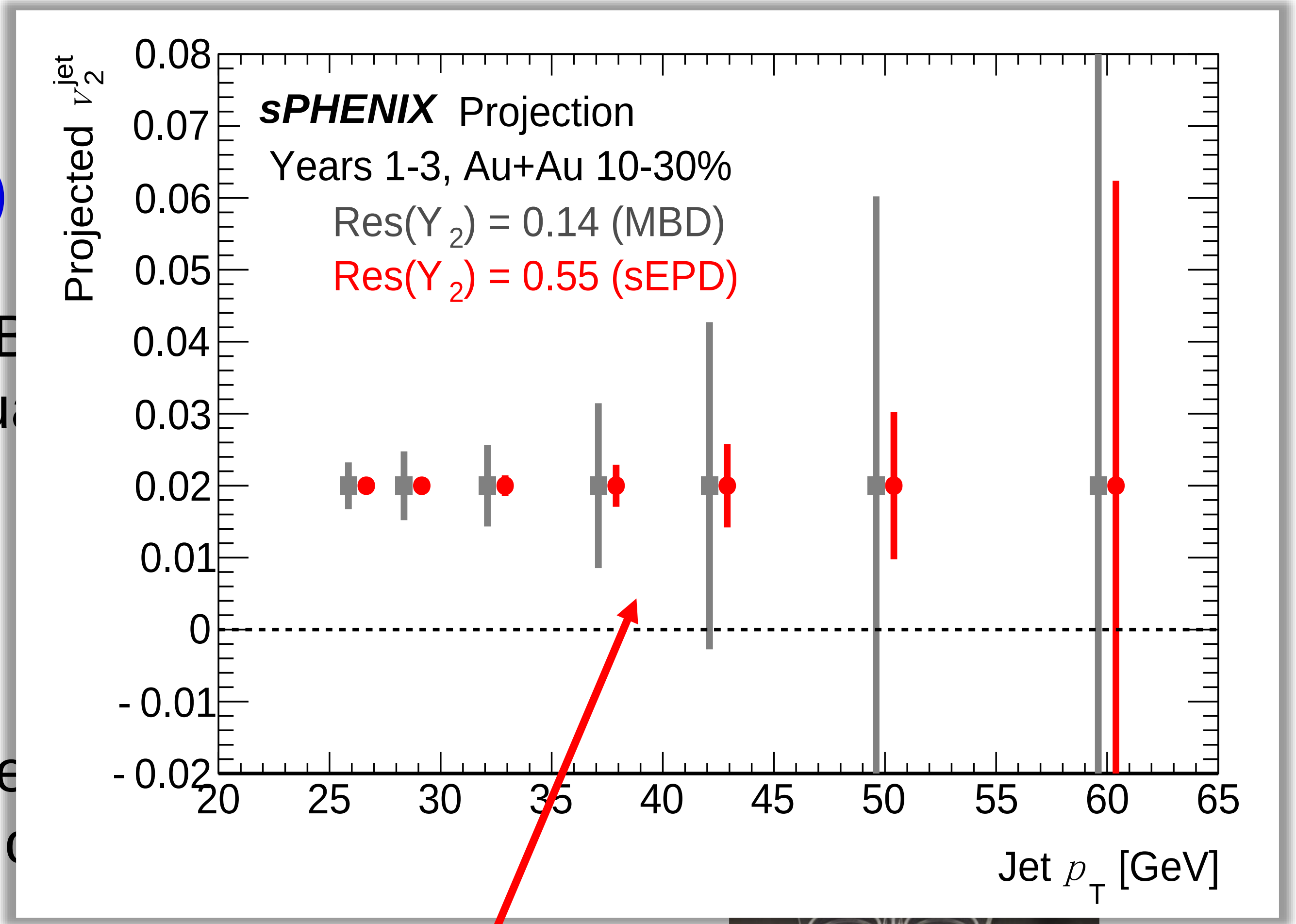
- 1.2-cm-thick scintillator w/ wavelength shifting fibers
- 2 wheels of 12 sectors with 31 optically-isolated tiles = 744 channels
- Provides significant improvement in the event plane resolution



MBD & sEPD

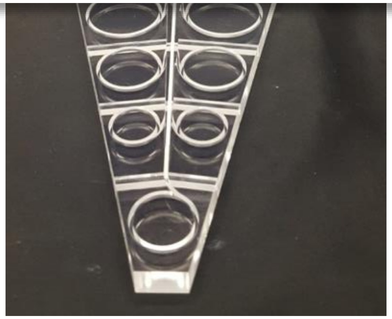
Minimum Bias Detector (MBD)
[3.51 < |η| < 4.61]

- Reuse of the PHENIX Beam-B
- 128 channels of 3 cm thick qu
  on mesh dynode PMT
- 120 ps timing resolution



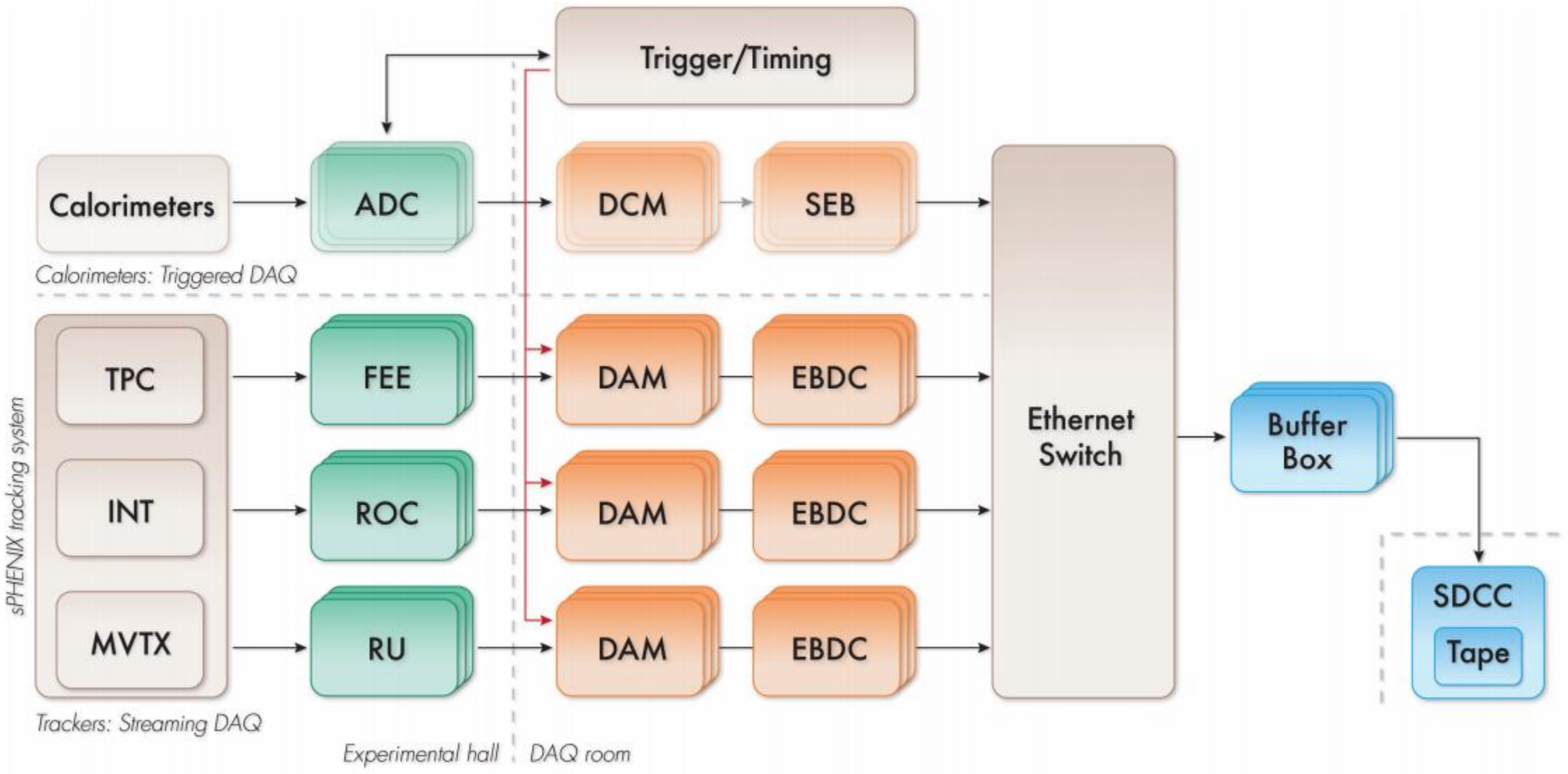
sPHENIX Event Plane Detector

- 1.2-cm-thick scintillator w/ wave
- 2 wheels of 12 sectors with 31 c
  = 744 channels
- Provides significant improvement in the event plane resolution



Hybrid DAQ Structure

- **A hybrid of TPC/INTT/MVTX streaming & calorimeter triggers**
- **Streaming readout:** triggerless configuration recording 10% of all collisions.
  → increases amount of Run-24 pp data by orders of magnitude
- **Crucial for open heavy flavor physics** as well as cold QCD measurements.



Run Plan (2023-2025)

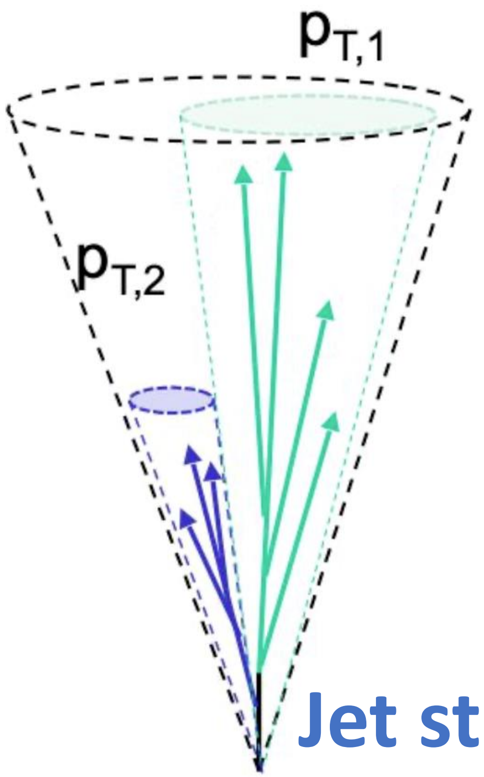
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\|z\|$ <10 cm	Samp. Lum. $\|z\|$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

Year-1 (Au+Au): Commissioning, calibration, HI standard candle

Year-2 (pp & pAu): Reference for HI measurements & cold QCD measurements

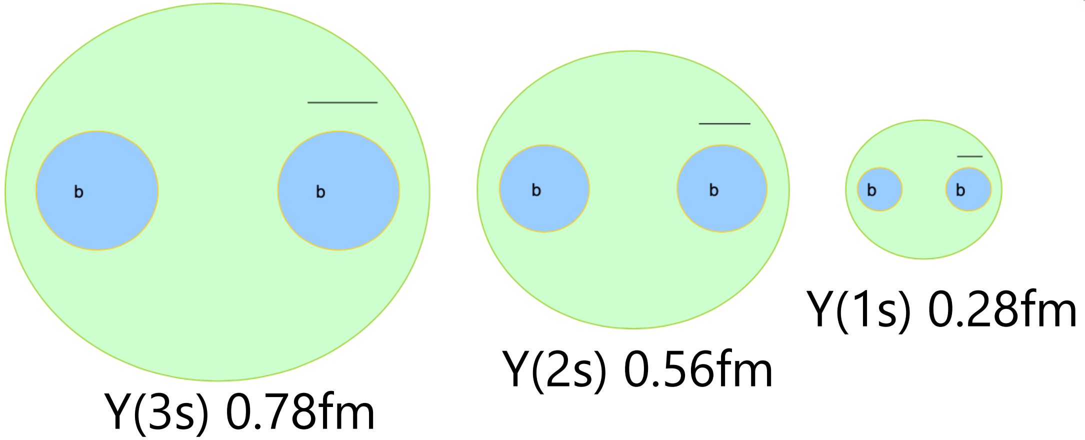
Year-3 (Au+Au): High statistics HI

- **Scientific mission of sPHENIX can be achieved with 3 years of running.**
- Consistent with the currently envisioned **Electron Ion Collider (EIC) schedule.**
- If opportunity arises, additional runs would continue to recoup benefits from sPHENIX investment.



Jet structure

vary momentum/angular scale of probe



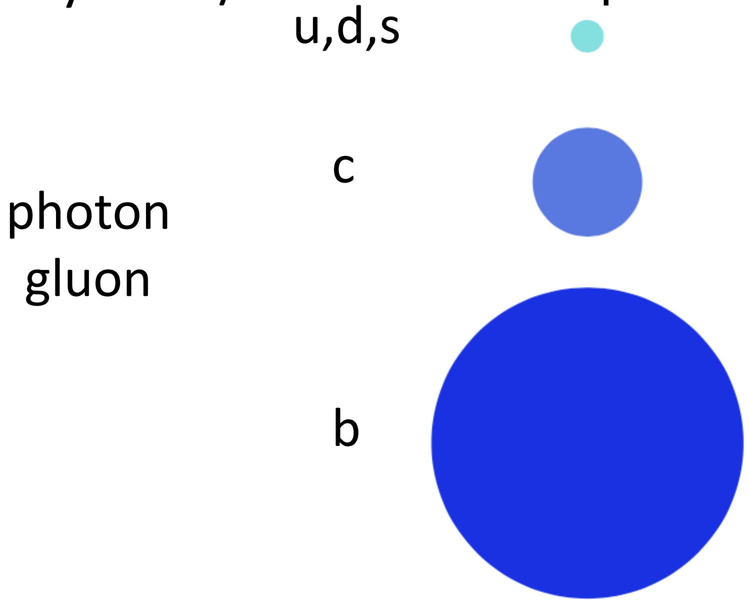
Quarkonium spectroscopy

vary size of probe

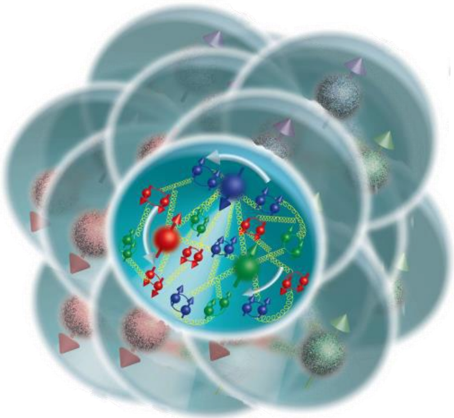
Physics sPHENIX Programs

Parton energy loss

vary mass/momentum of probe



Cold QCD

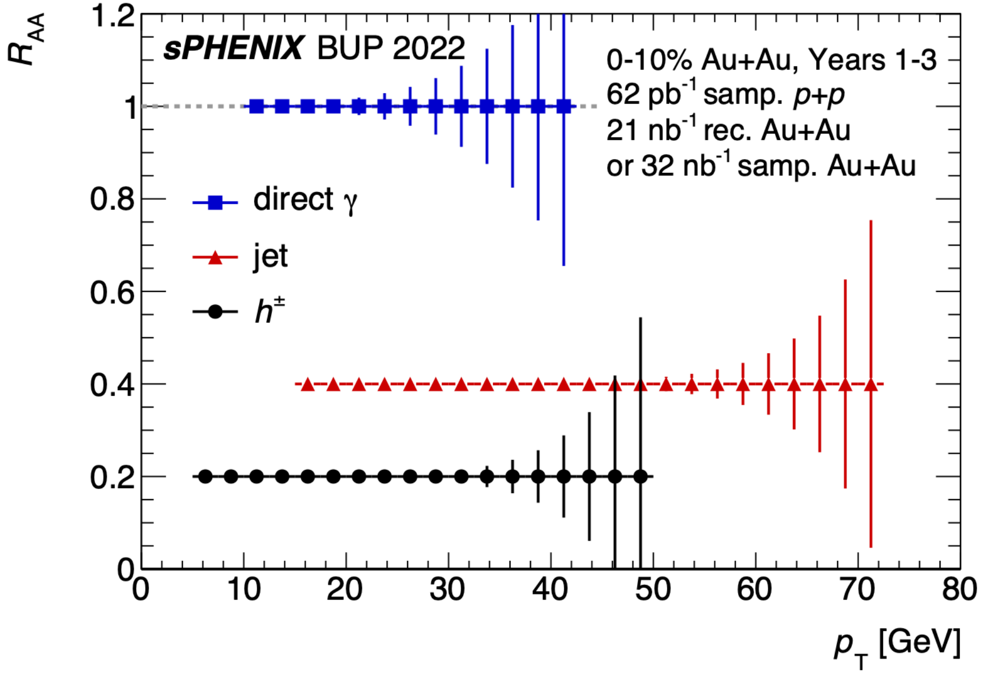


study proton spin, transverse-momentum, and cold nuclear effects

High p_T Probes

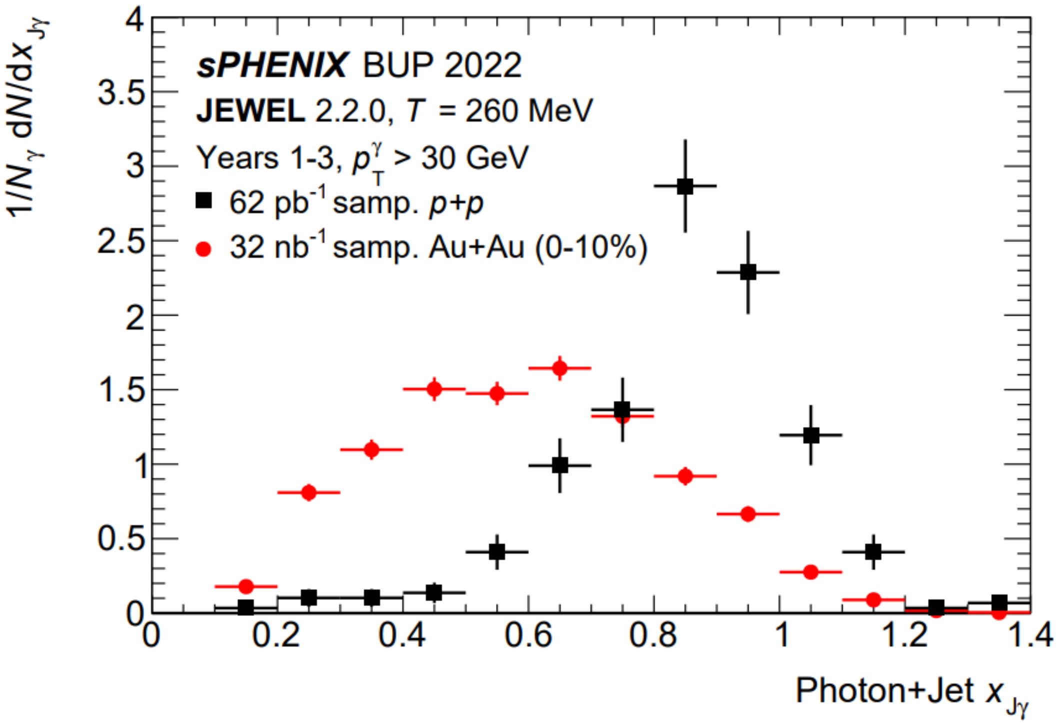
Projected counts for 2023-2025

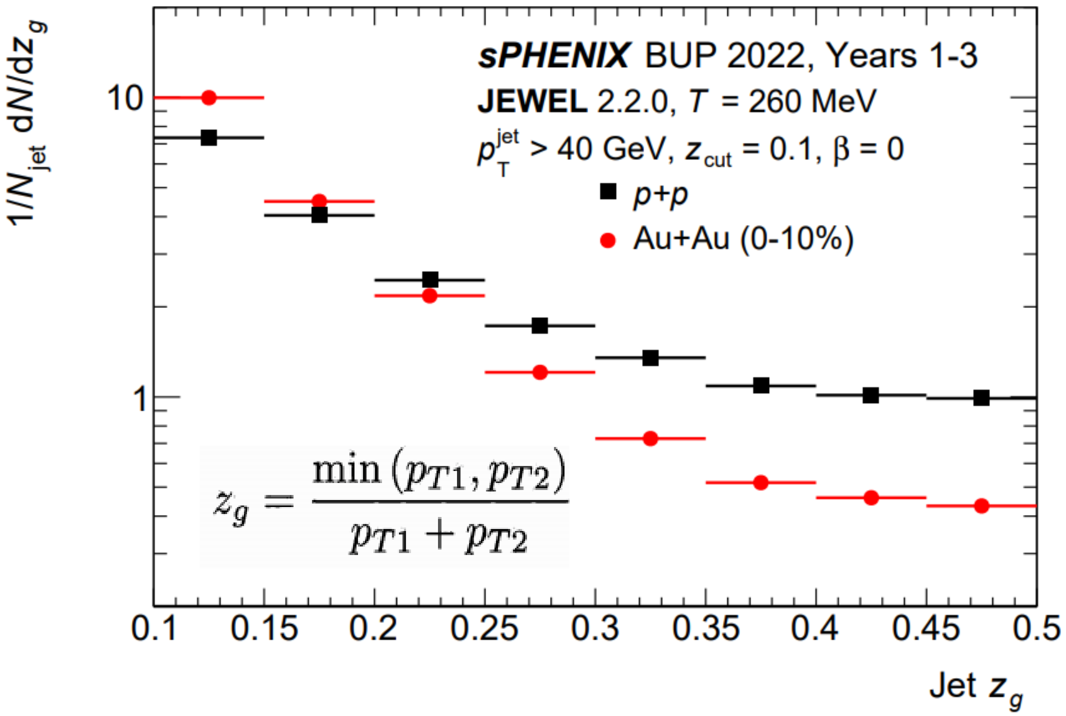
Signal	Au+Au 0–10% Counts	$p+p$ Counts
Jets $p_T > 20$ GeV	22 000 000	11 000 000
Jets $p_T > 40$ GeV	65 000	31 000
Direct Photons $p_T > 20$ GeV	47 000	5 800
Direct Photons $p_T > 30$ GeV	2 400	290
Charged Hadrons $p_T > 25$ GeV	4 300	4 100



- **High data rates & hermetic EMCal+HCal offer wide p_T range for jet reconstruction.**
- Low p_T: crucial for precise measurements of QGP properties
- High p_T (up to ~70 GeV for jets, ~50 GeV for hadrons): kinematic overlap with the LHC; possible for the first time at RHIC.

Jet Correlations & Substructure

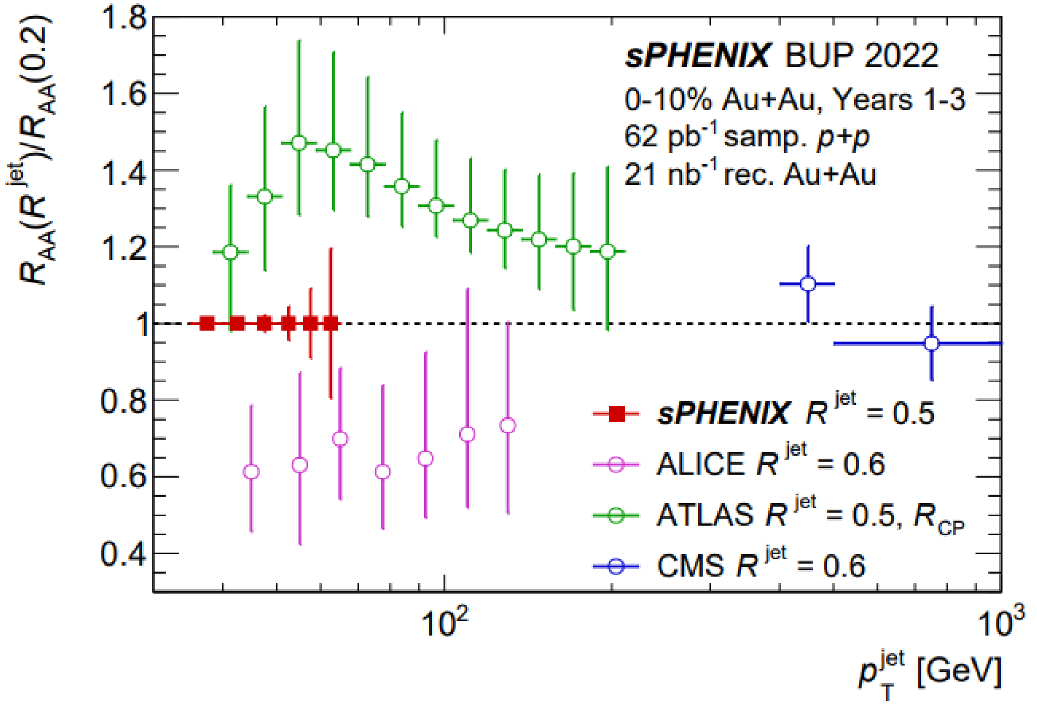


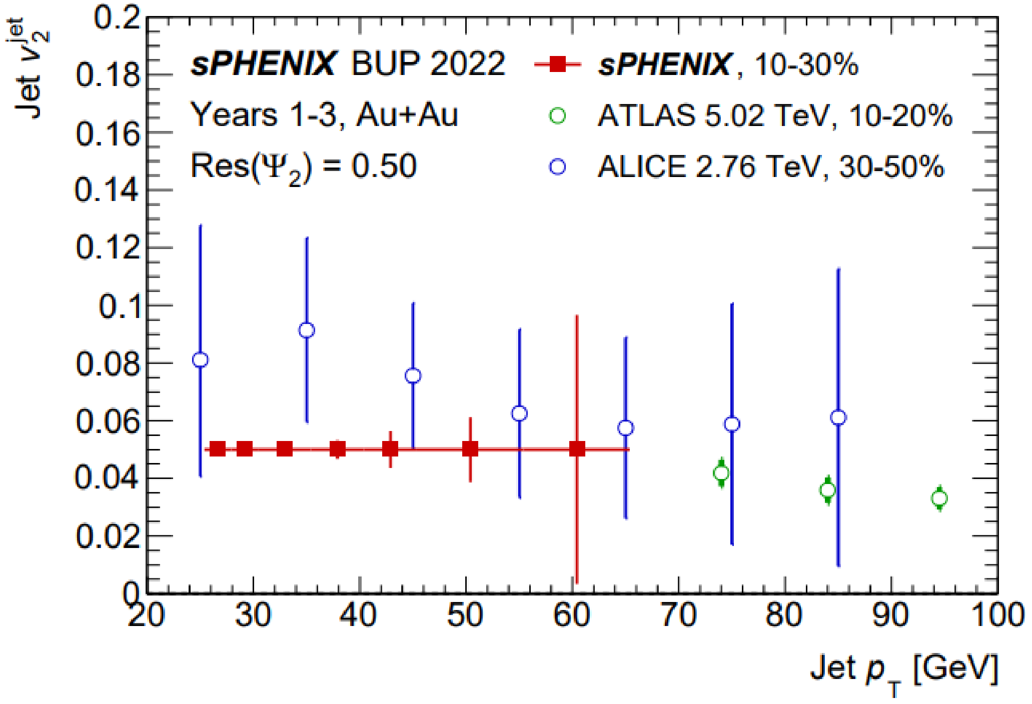


- A "flagship" measurement.
- Dramatic difference expected b/w RHIC & LHC energies (W. Dai, I. Vitev, and B.-W. Zhang PRL 110, 142001)

- Groomed momentum sharing: explore parton shower development in QGP.
- Connection to fundamental QCD & a probe to measure the QGP properties.

Unique Jet Opportunities



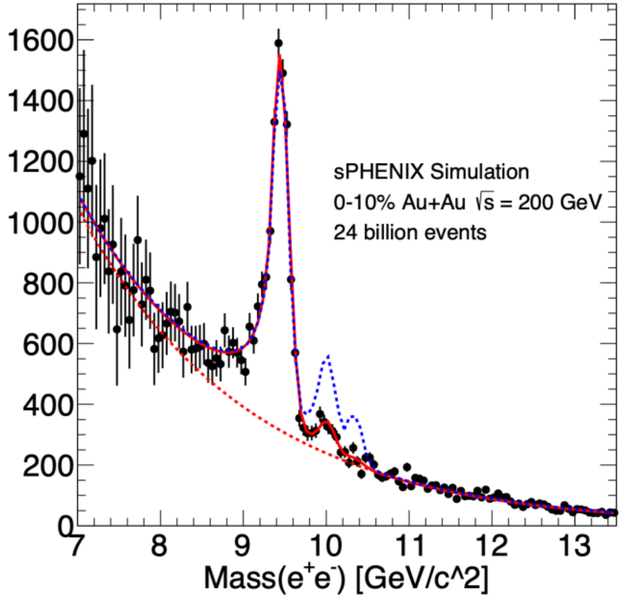


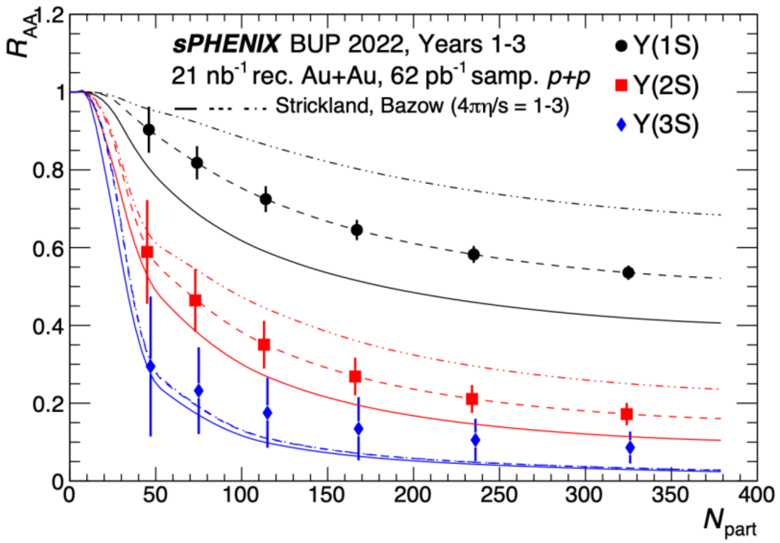
- R-dependence: probe interplay of out-of-cone energy loss & medium response.
- Jet v_2: unable to simultaneously model with the suppression in most models.

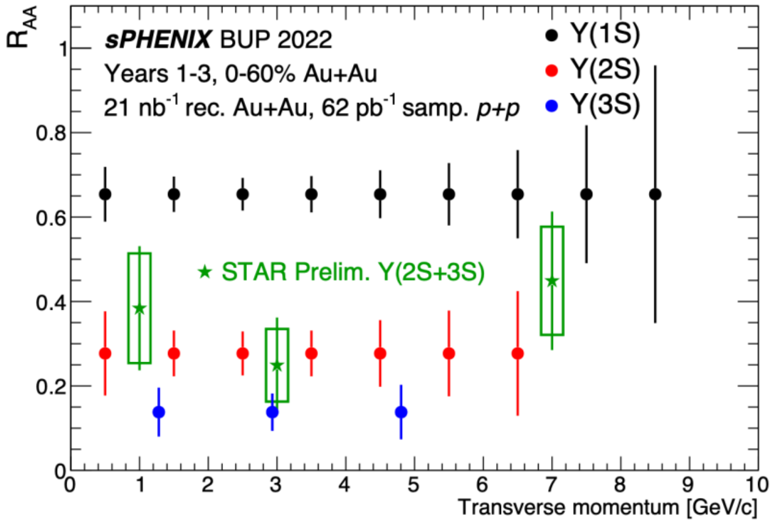
→ sPHENIX can precisely measure low p_T region, which is challenging at the LHC.

see Jin Huang's parallel talk

Upsilon R_{AA}



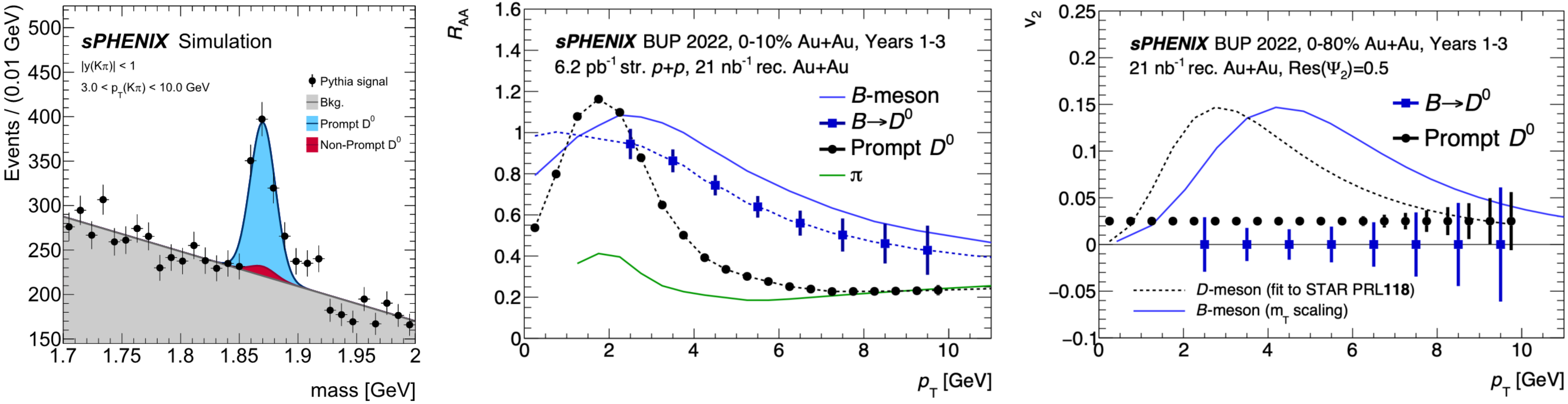




- Measuring centrality & p_T dependence of R_{AA} is crucial to compare with LHC.
- Υ(3S) projected, given the observation of $R_{AA}(3S)/R_{AA}(2S)$ ~ 0.5 at the LHC.
- sPHENIX has the unique opportunity to discover the Υ(3S) suppression at RHIC.

see Jin Huang's parallel talk

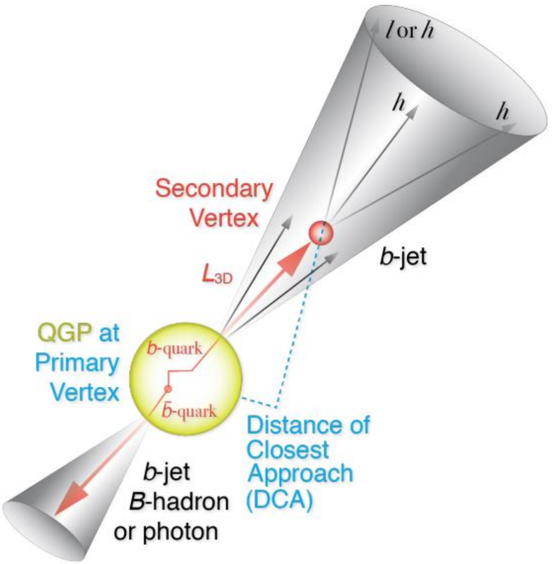
Heavy Flavor R_{AA} & Flow

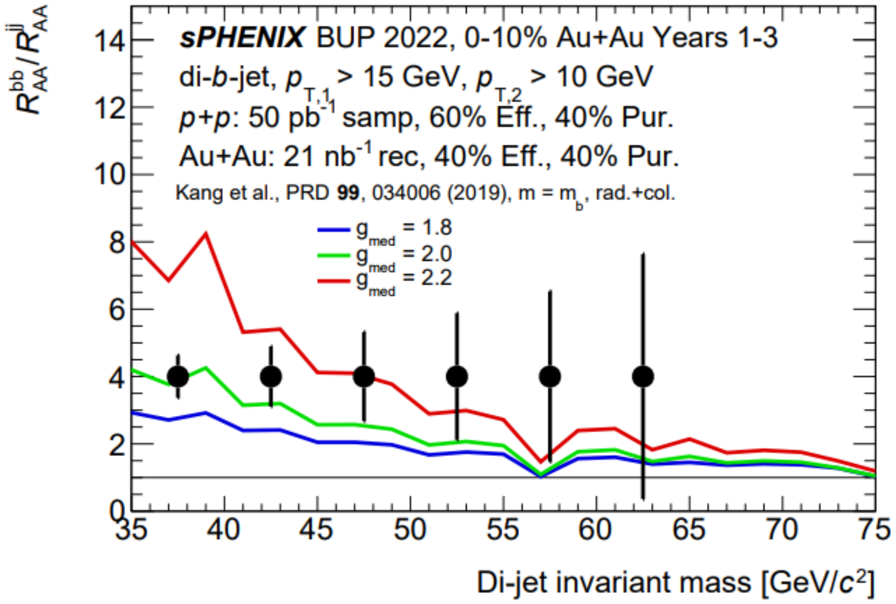


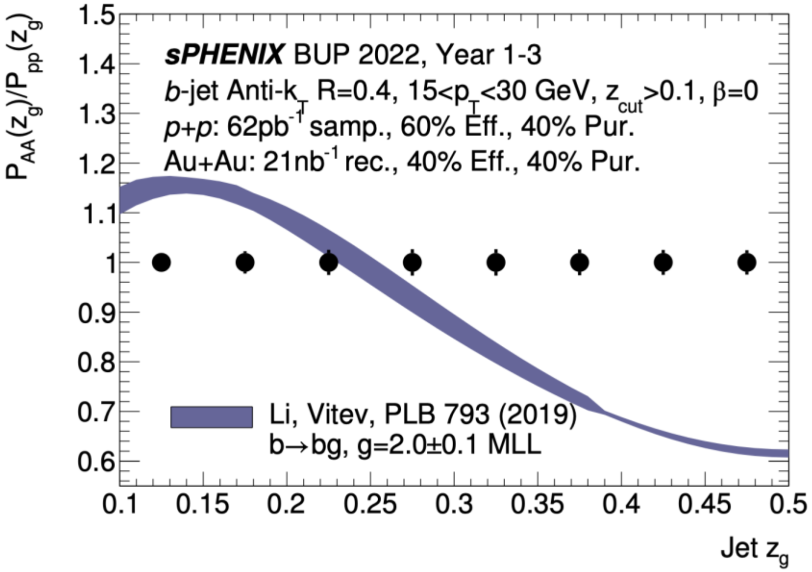
- Heavy flavors are unique probes as they are conserved from the initial production.
- Streaming readout allows us to collect a huge MB data for unbiased HF down to p_T~0 GeV.
- Precise measurement of non-prompt-D^0 suppression thanks to MVTX performance.
- Determination of b-quark R_{AA} → clean access to diffusion at RHIC

see Jin Huang's parallel talk

Heavy Flavor Jets R_{AA}

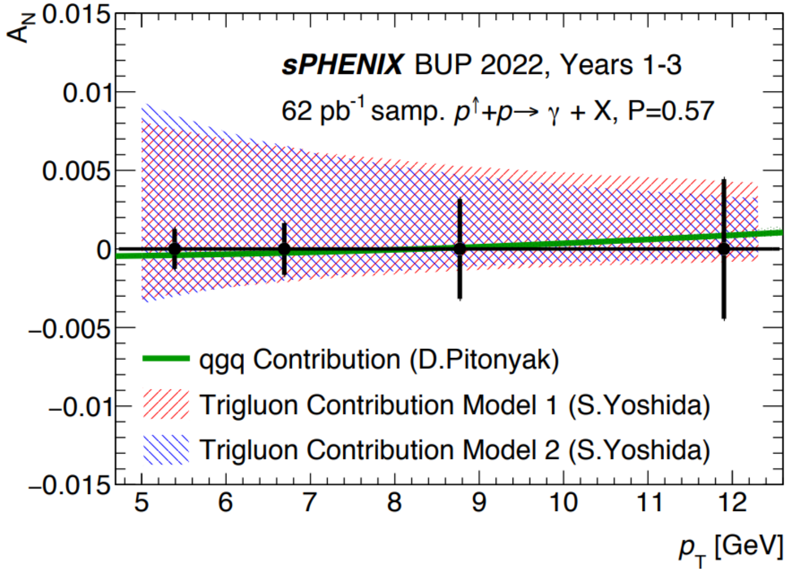


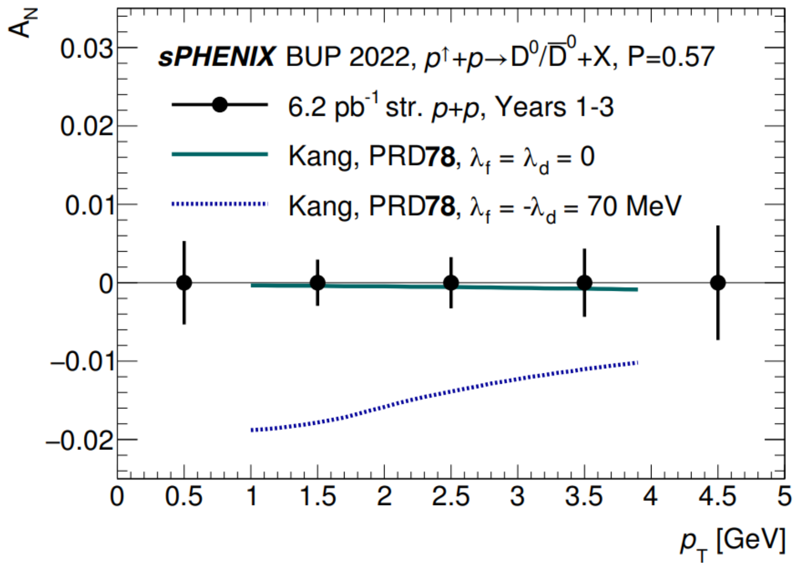


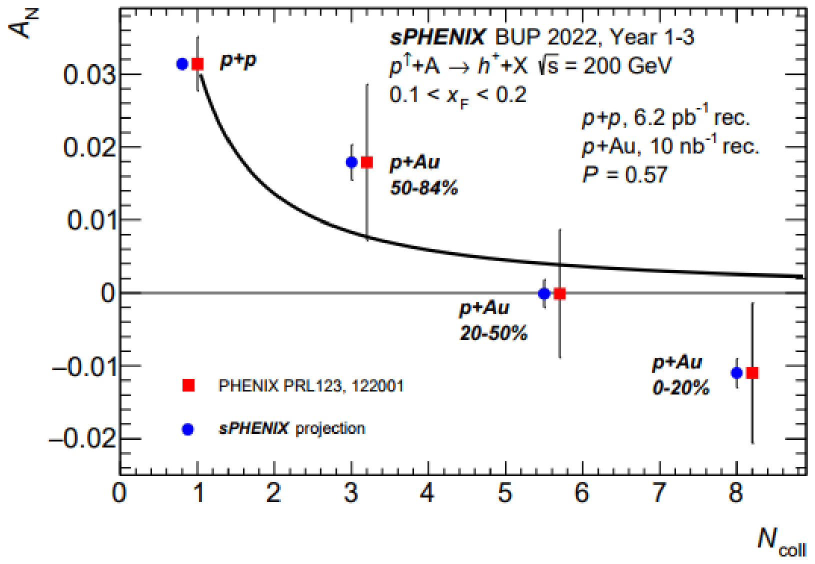


- **First b-tagging at RHIC** thanks to MVTX & full calorimeter implementation. **Performance compatible with CMS** using track DCA or secondary vertices.
- Outstanding precision in low-p_T region. Enhanced sensitivity with dijet mass & ratio to the inclusive jet measurement.
- Sufficient statistics to measure b-jet substructure: **sensitive to the role of parton mass.**

Cold QCD



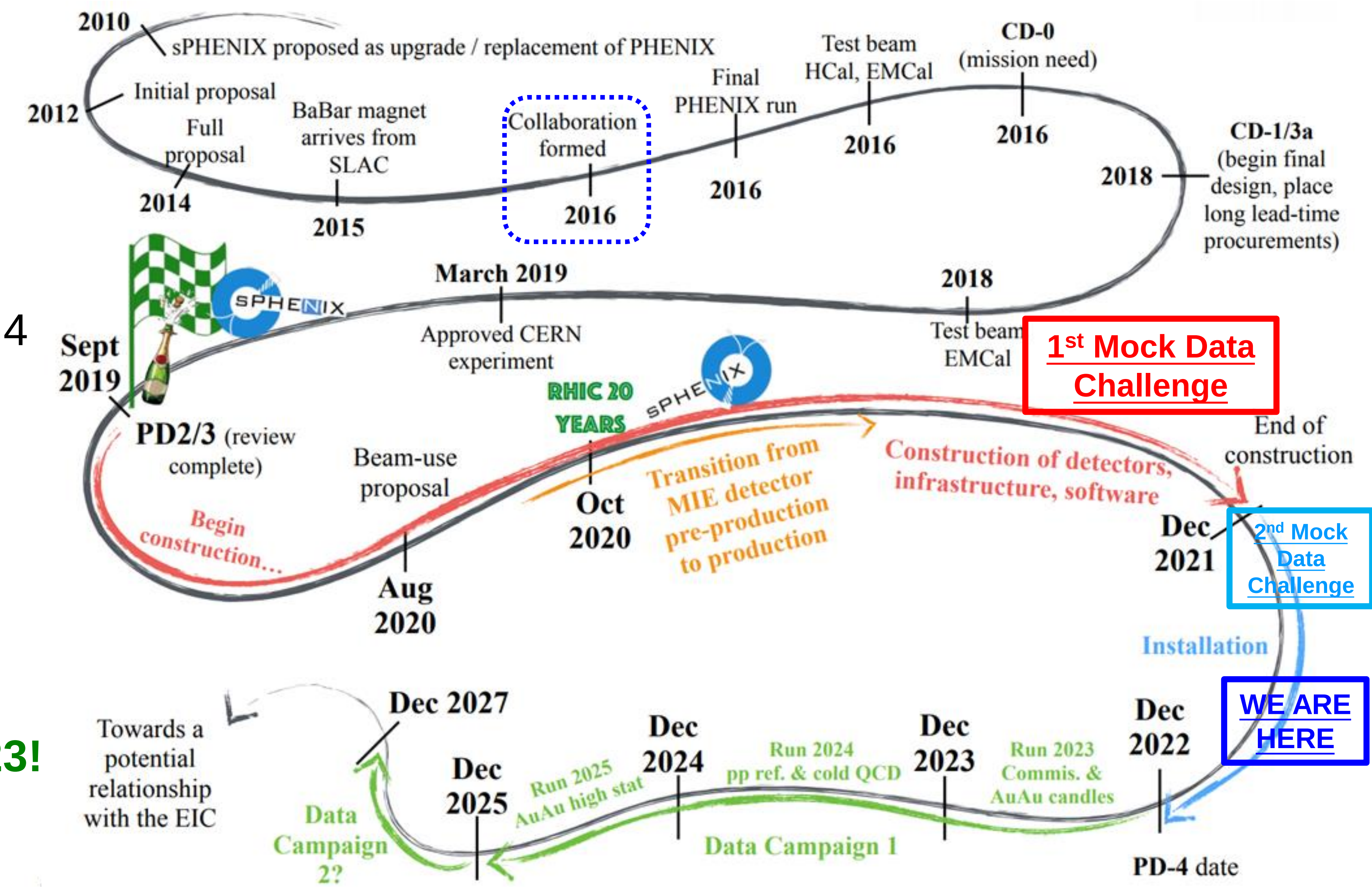




- Complementary measurements to the upcoming EIC.
- Access to transverse single spin asymmetry (TSSA) via prompt photon & D^0.
  → gluon dynamics in transversely polarized nucleons w/ tri-gluon correlations.
- In pAu, measuring nuclear dependence of TSSA will offer insight to its origin (much improved precision from PHENIX).

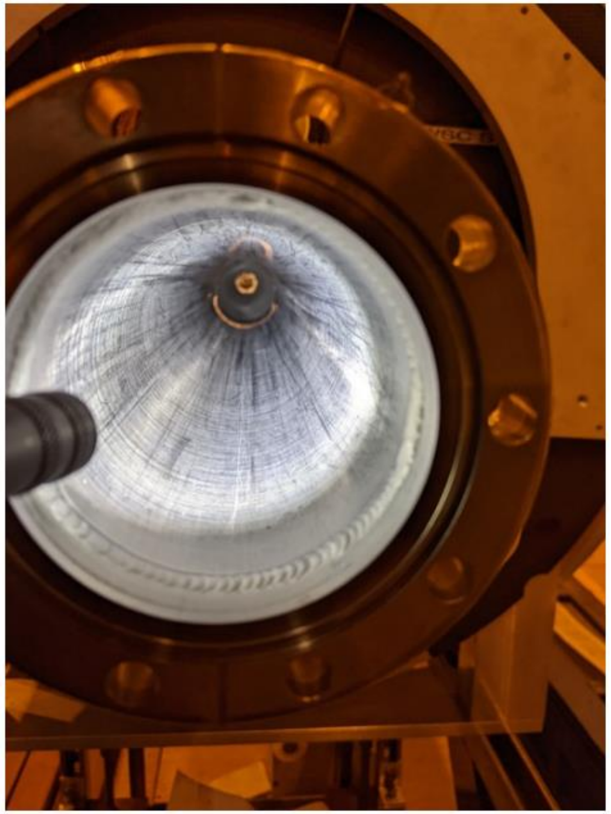
Schedule

- **Successful 1st Mock Data Challenge in 2021:** testing the full chain of generation, G4 sim, reconstruction & analyses.
- **Detector installation & 2nd Mock Data Challenge ongoing!**
- **Data taking from 2023!**

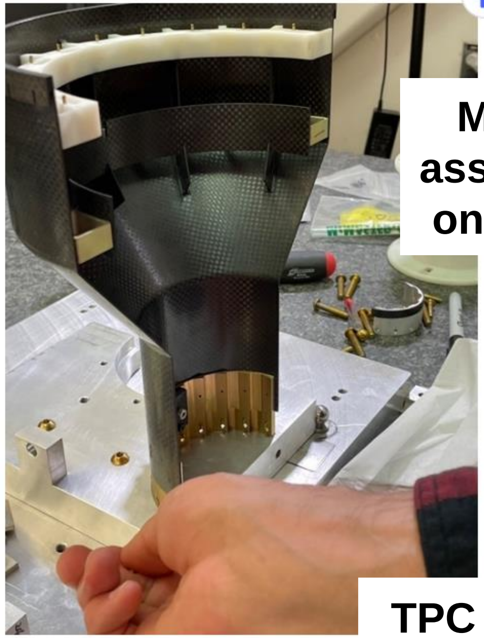


From Caroline Riedl

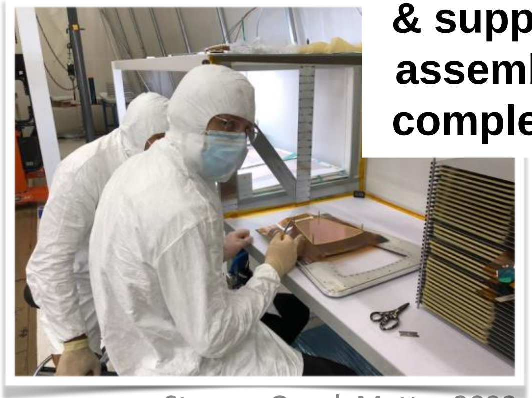
Toward the First Data Taking



Beam pipe from STAR (sPHENIX one was lost in the warehouse fire)

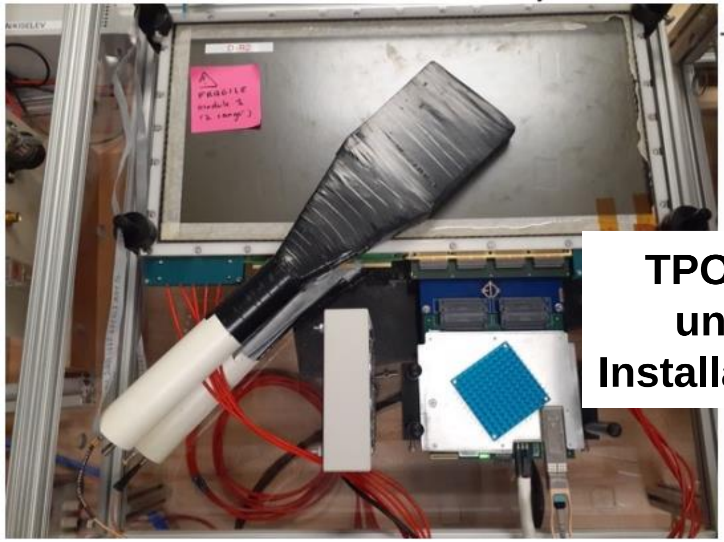


MVTX assembly ongoing



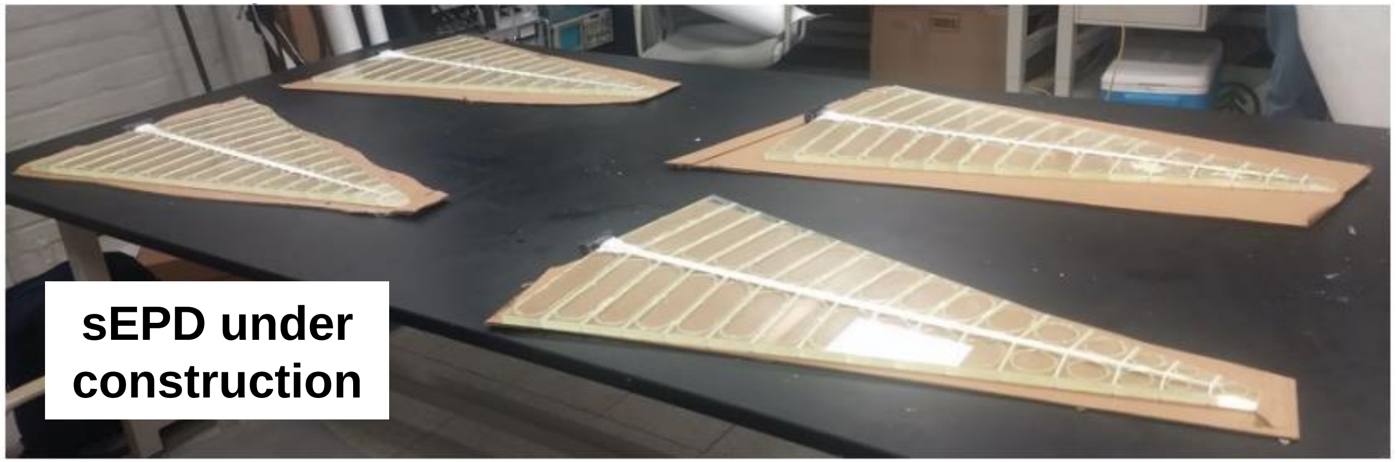
TPC GEM & support assembly complete!

INTT ladder placement (2022.6)



TPOT module under test. Installation in Oct.

Toward the First Data Taking



Summary

- sPHENIX is the first new detector at RHIC in >20 years.
- sPHENIX provides unique opportunities in low energy & offer kinematic overlap with the LHC.
- Wide range of physics covered in sPHENIX: jet correlations & substructure, Υ spectroscopy, open heavy flavor & cold QCD.
- Detector construction & data taking preparation on schedule!
- **Preparing for the first data taking in 8 months**!