The sPHENIX Open and Close Heavy Flavor Program

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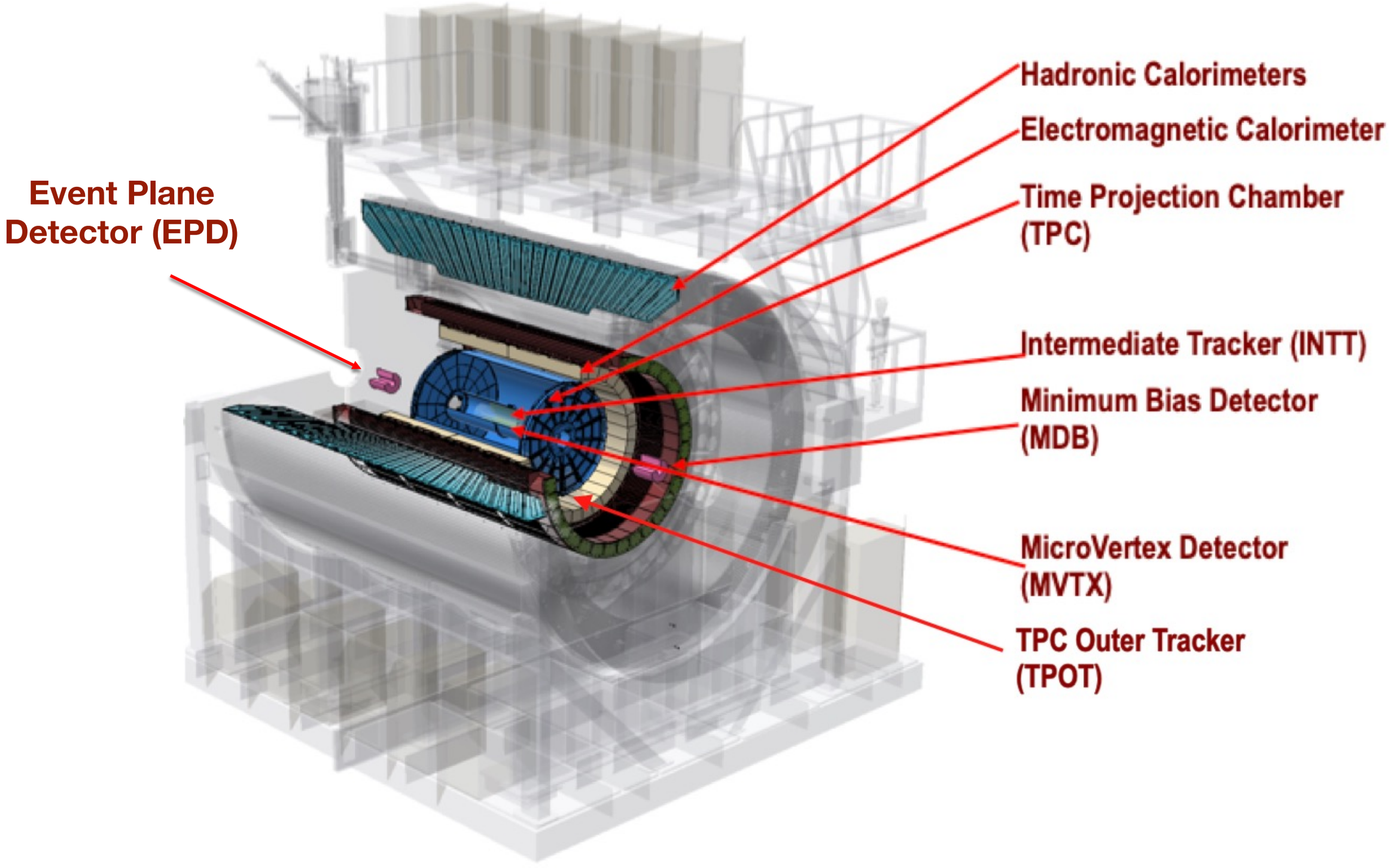
Los Alamos NATIONAL LABORATORY

sPHENIX

The sPHENIX Experiment at RHIC



2015 NSAC Long range Plan for Nuclear Science: sPHENIX Experiment at RHIC

- Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales
- Complementary to LHC experiments

sPHENIX Recent Schedule and Milestones

Year 2022

Jan | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug**

- MCD II Starts: Software Milestone
- Outer HCAL Installation Complete
- Inner HCAL Installation Complete
- RBBC Workshop

Year 2023

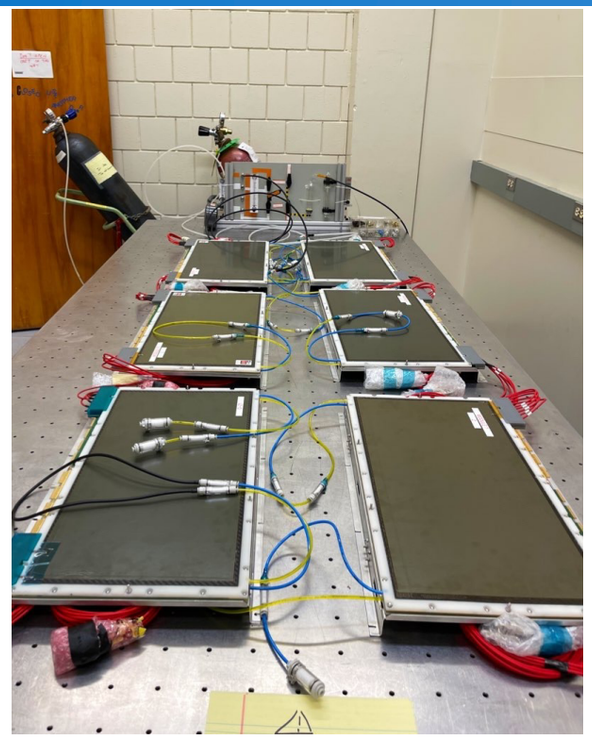
Sep | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr**

- **Today**
- Babar Magnet Mapping Begins
- EMCAL Installation Complete
- INTT Installation
- MVTX/EPD Installation
- Entire sPHENIX Detector Testing
- **Start first data taking! (< 6 months)**

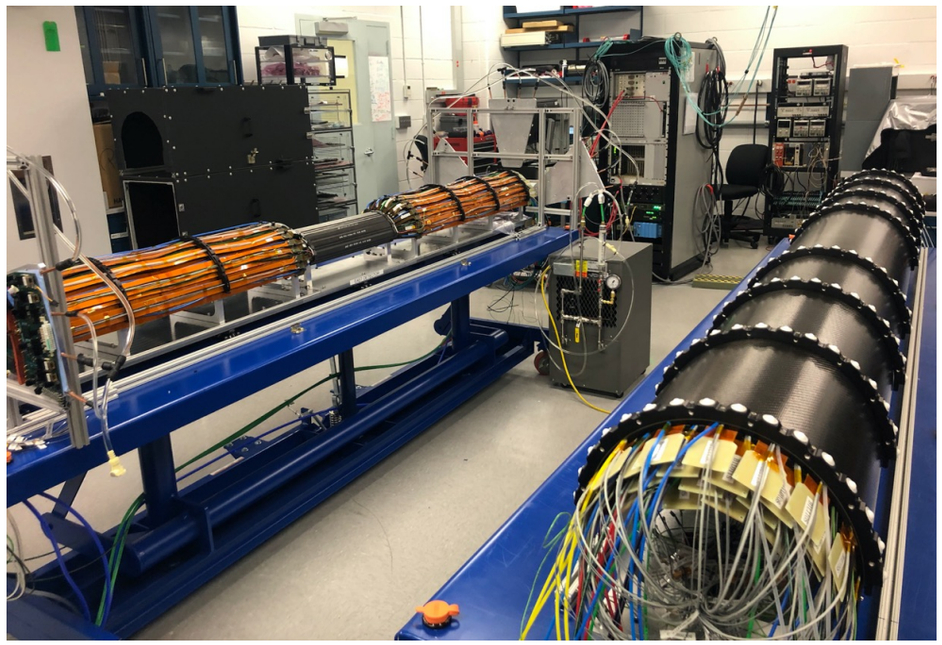
- Collective efforts of international collaboration from 85 institutions in 14 countries
- Intense preparation schedule to ensure timely and high-quality data taking in 2023

sPHENIX Detector Commissioning

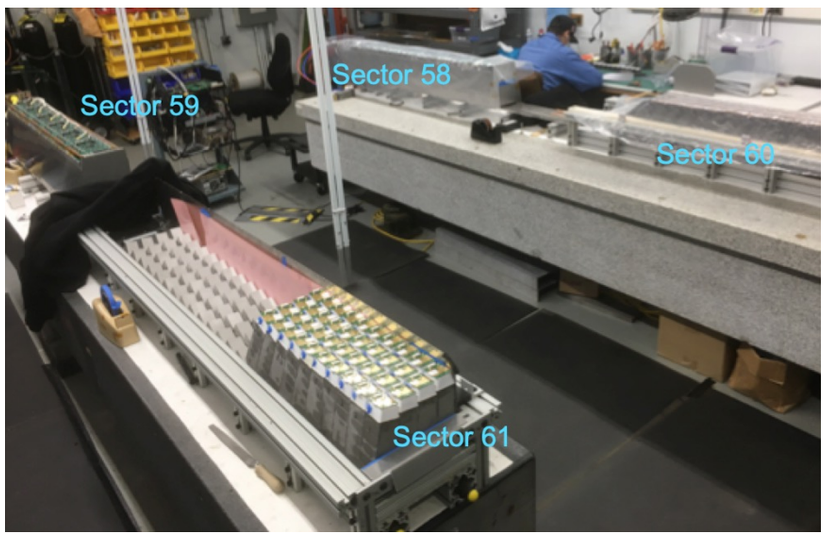
TPC construction at Stony Brook University



TPOT effort By LANL/Stony Brook

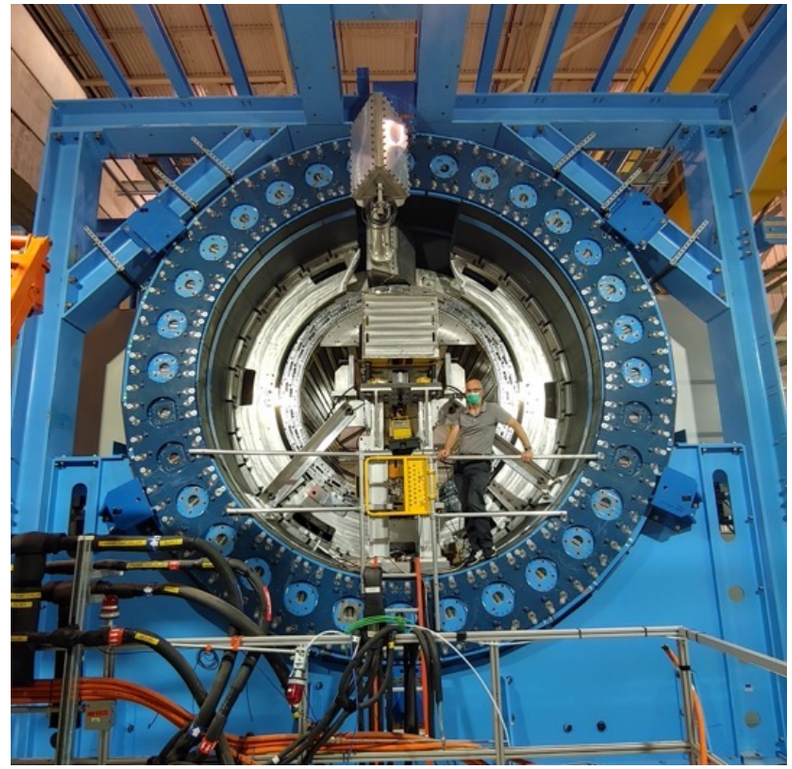


INTT half barrels completed and tested



EMCAL assembly at BNL

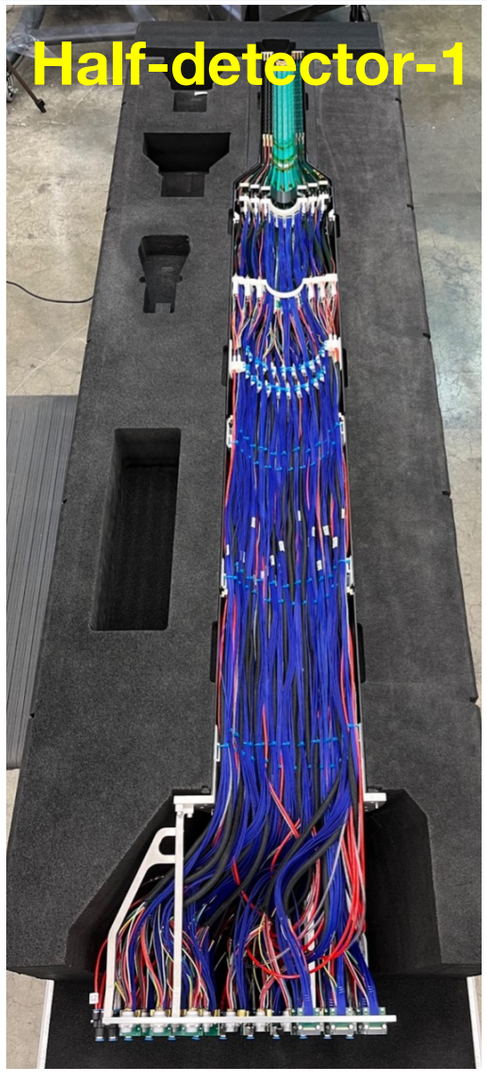
Commissioning task force

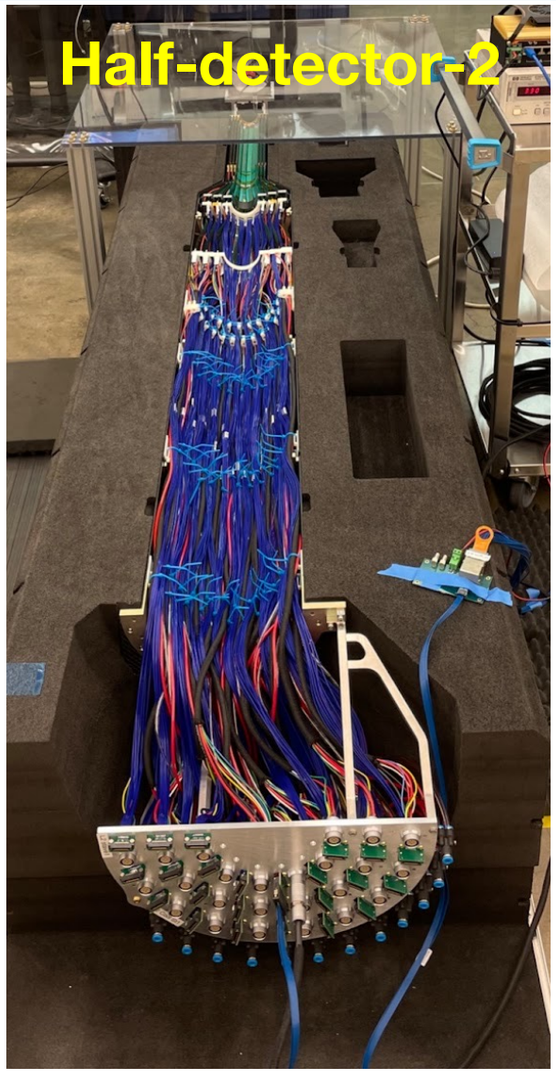


sPHENIX detector with HCAL in the PHENIX hall

- Lots of construction activities of detectors ongoing in many places
- Collaborative and diverse workforce of students, postdocs, staff, and faculty
- Install the sPHENIX detector from outermost to innermost in sPHENIX IP at BNL

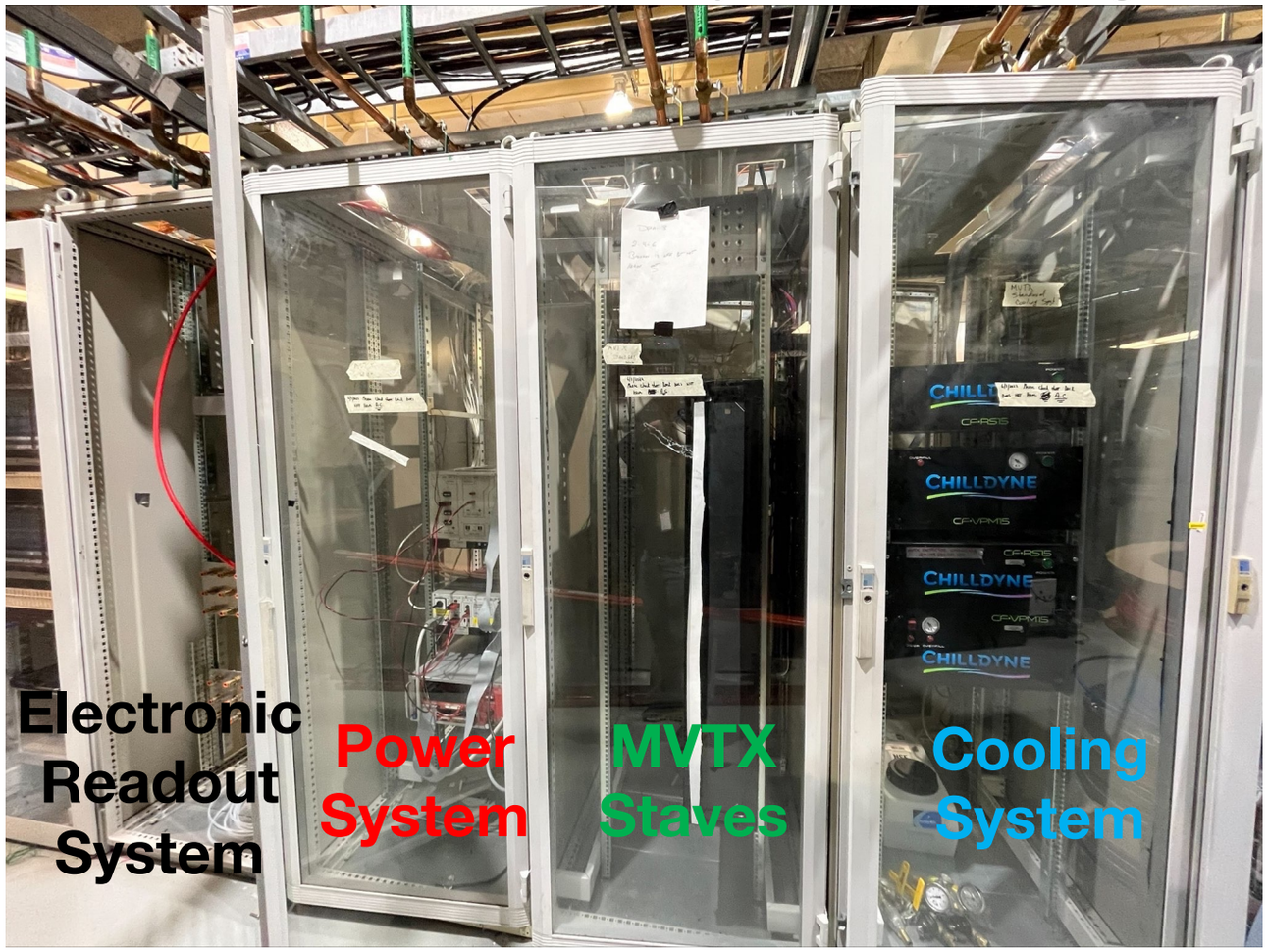
MVTX Commissioning Status





BNL Commissioning

- Clean tent setup
  - MOSAIC system to test the staves performance
- Entire MVTX system testing
  - Readout chain test
  - Detector alignment with cosmic ray data and machine learning
  - Online monitoring and slow control system
  - Ensure MVTX functionality for data taking



LBNL MVTX Detector Assembling

- Precision placement of staves at around 50 μm obtained by CMM
- Stave gluing to carbon structure
- Half detector fully assembled
- Power system and cabling preparation
- Readout mechanical structure

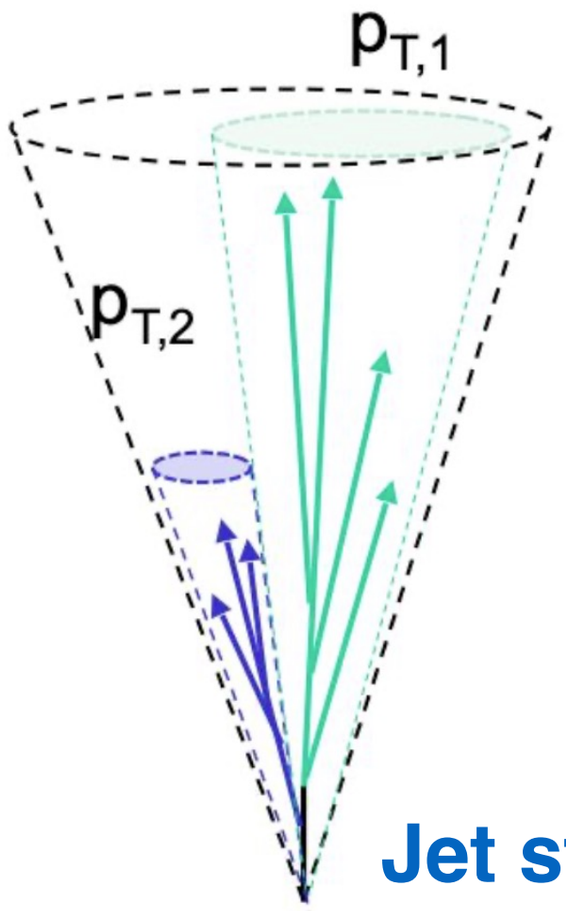
sPHENIX Beam Use Proposal

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <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}

sPHENIX Beam Use Proposal endorsed by the BNL NPP (Nuclear and Particle Physics) PAC (Physics Advisory Committee)

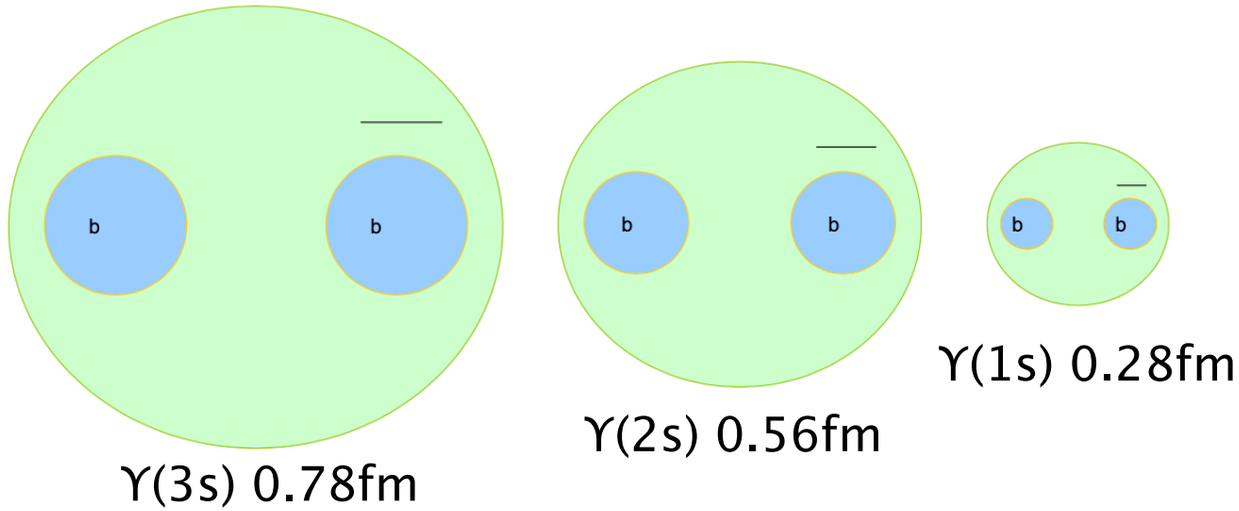
- Extensive **3-year** data taking starting in < 6 months
  - **Year-1**: commissioning and first physics in Au+Au
  - **Year-2**: p+p and p+Au runs for heavy-ion reference and cold QCD physics
  - **Year-3**: very large Au+Au dataset (141B events in total)

The sPHENIX Physics Program



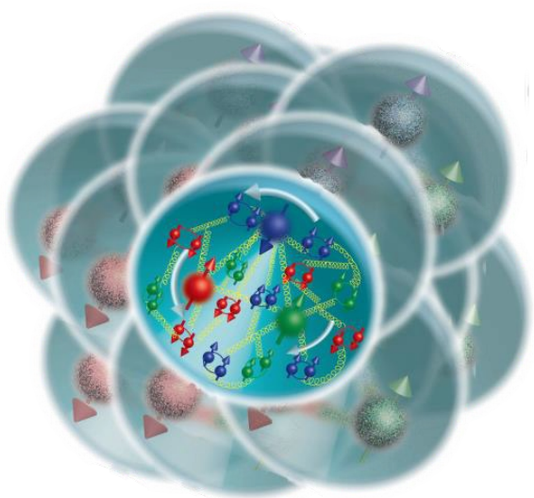
Jet structure

vary momentum/angular scale of probe



Quarkonium spectroscopy

vary size of probe

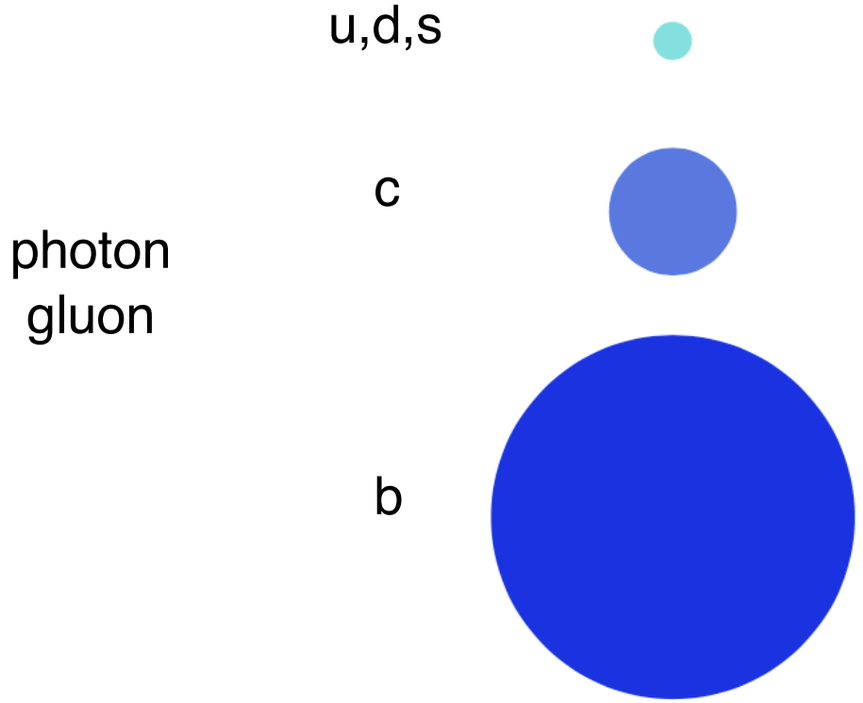


Cold QCD

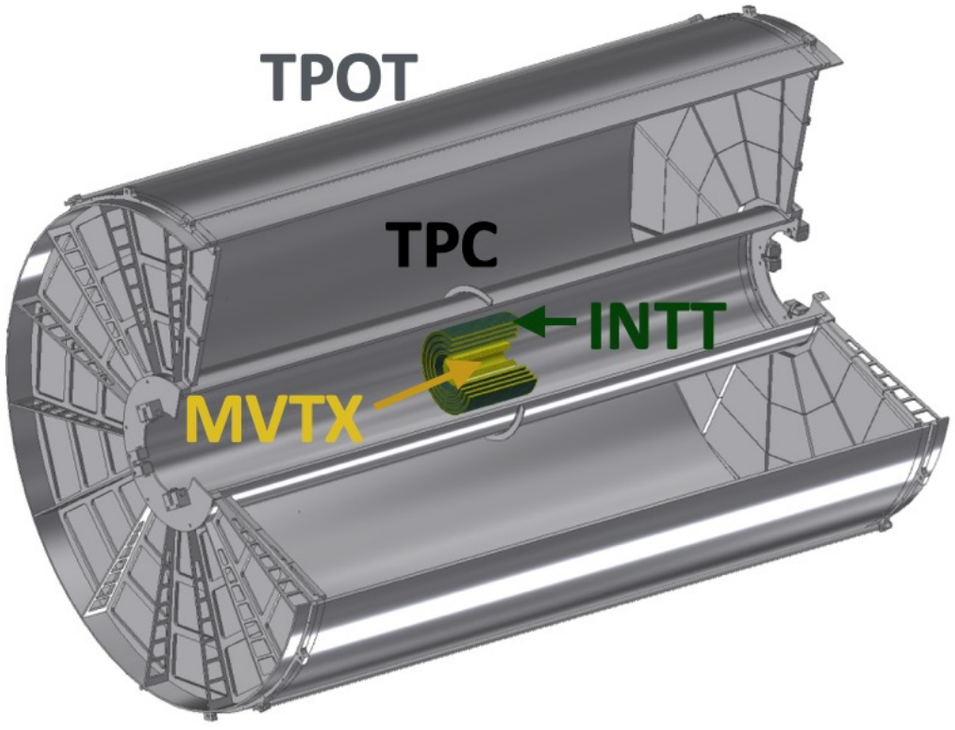
study proton spin, transverse-momentum, and cold nuclear effects

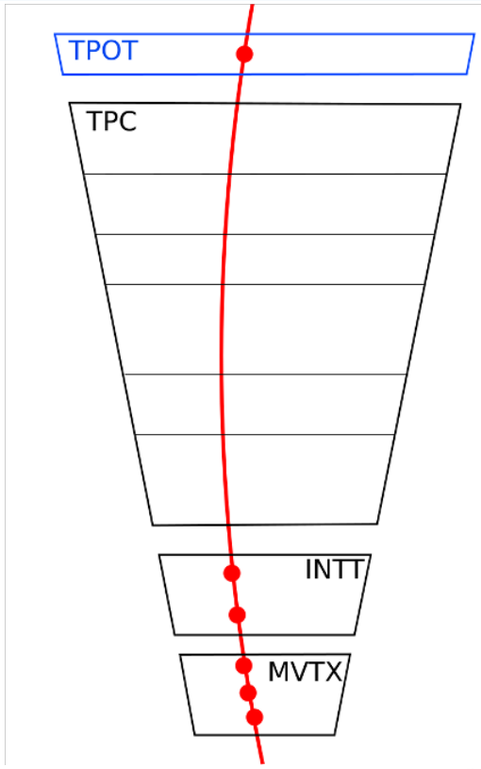
Parton energy loss

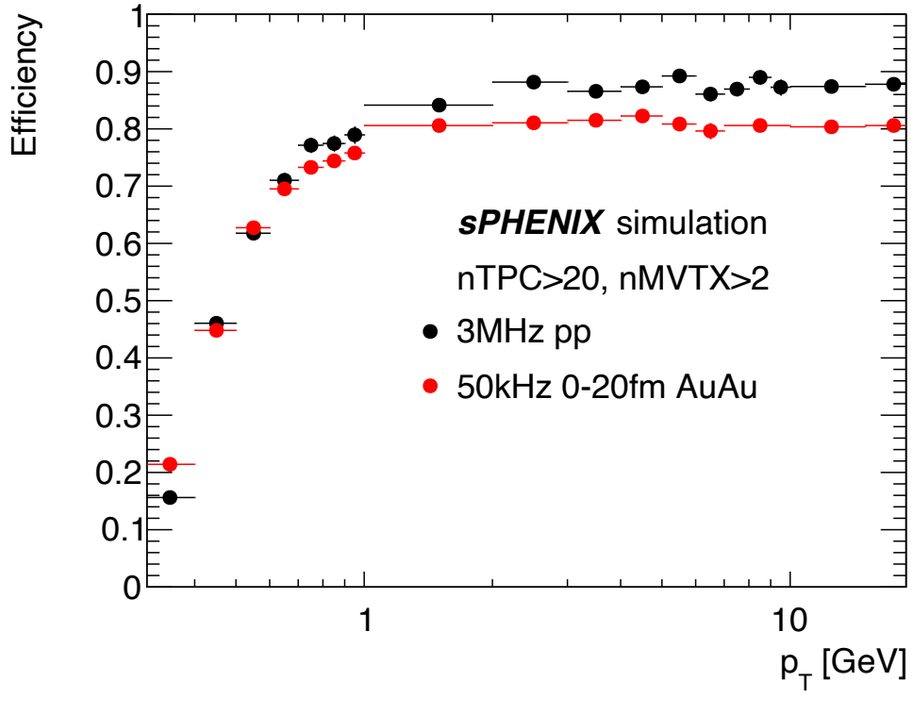
vary mass/momentum of probe

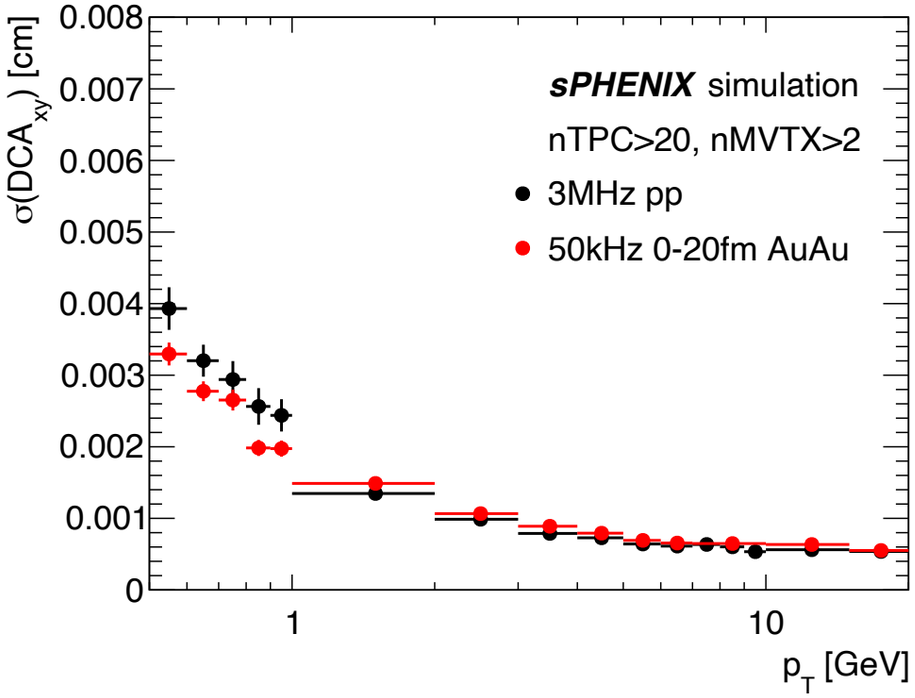


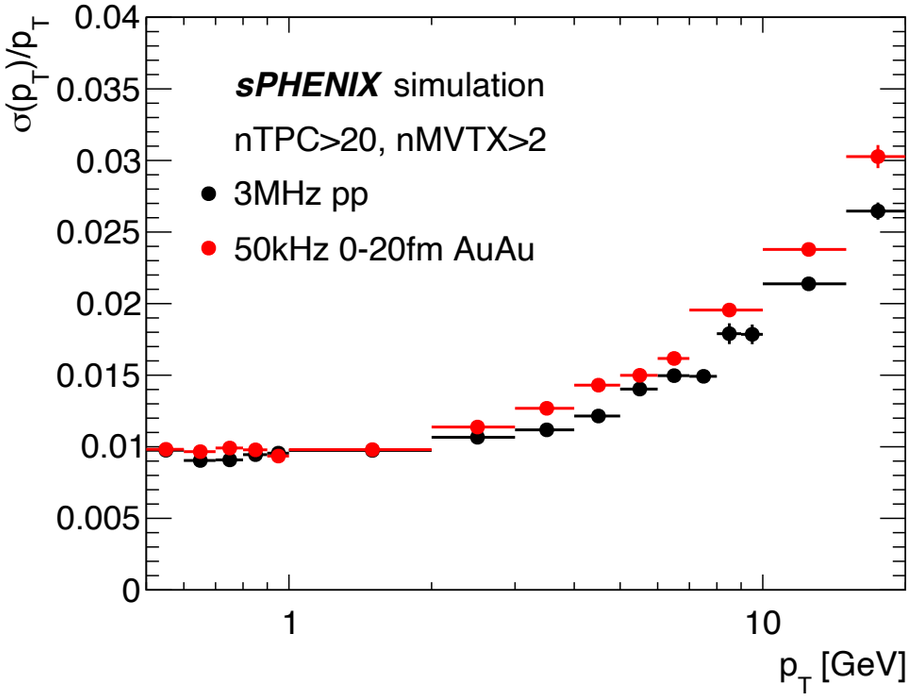
Tracking System and Performance





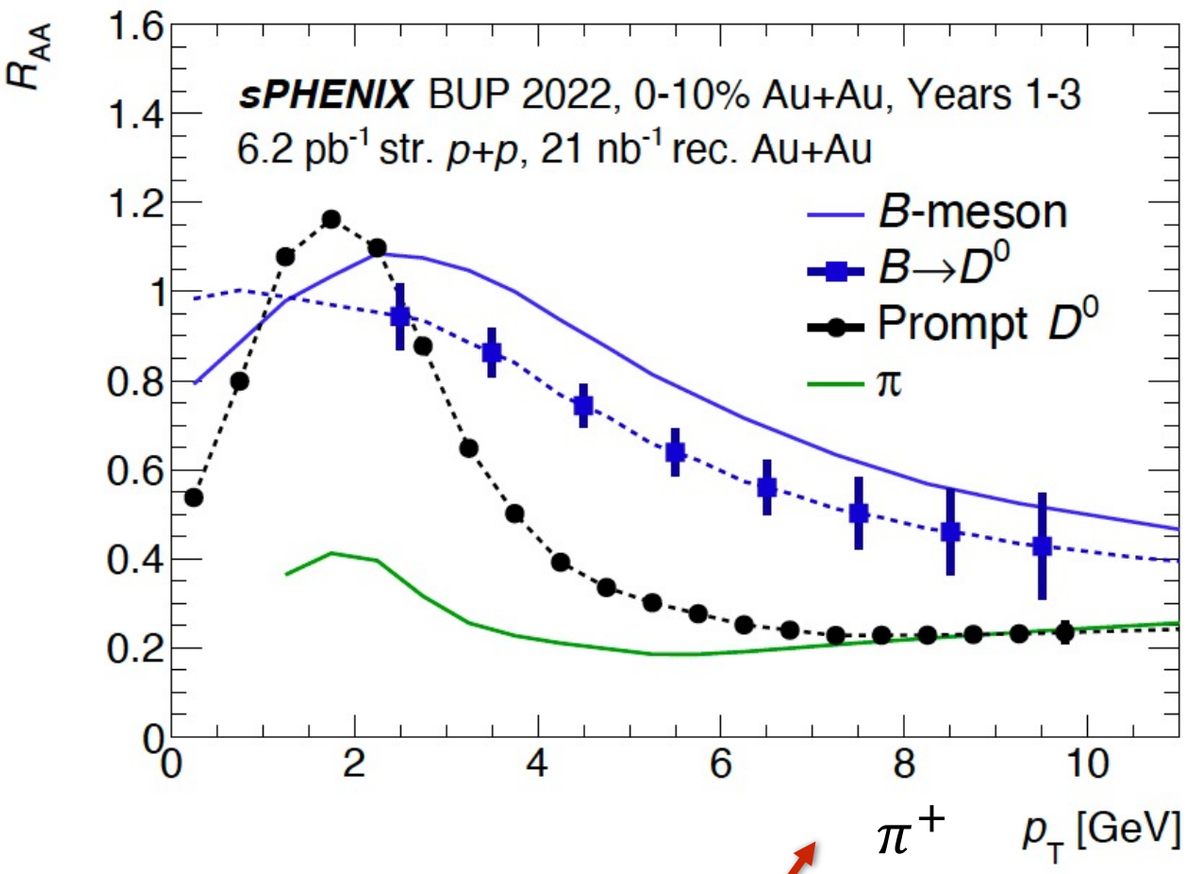


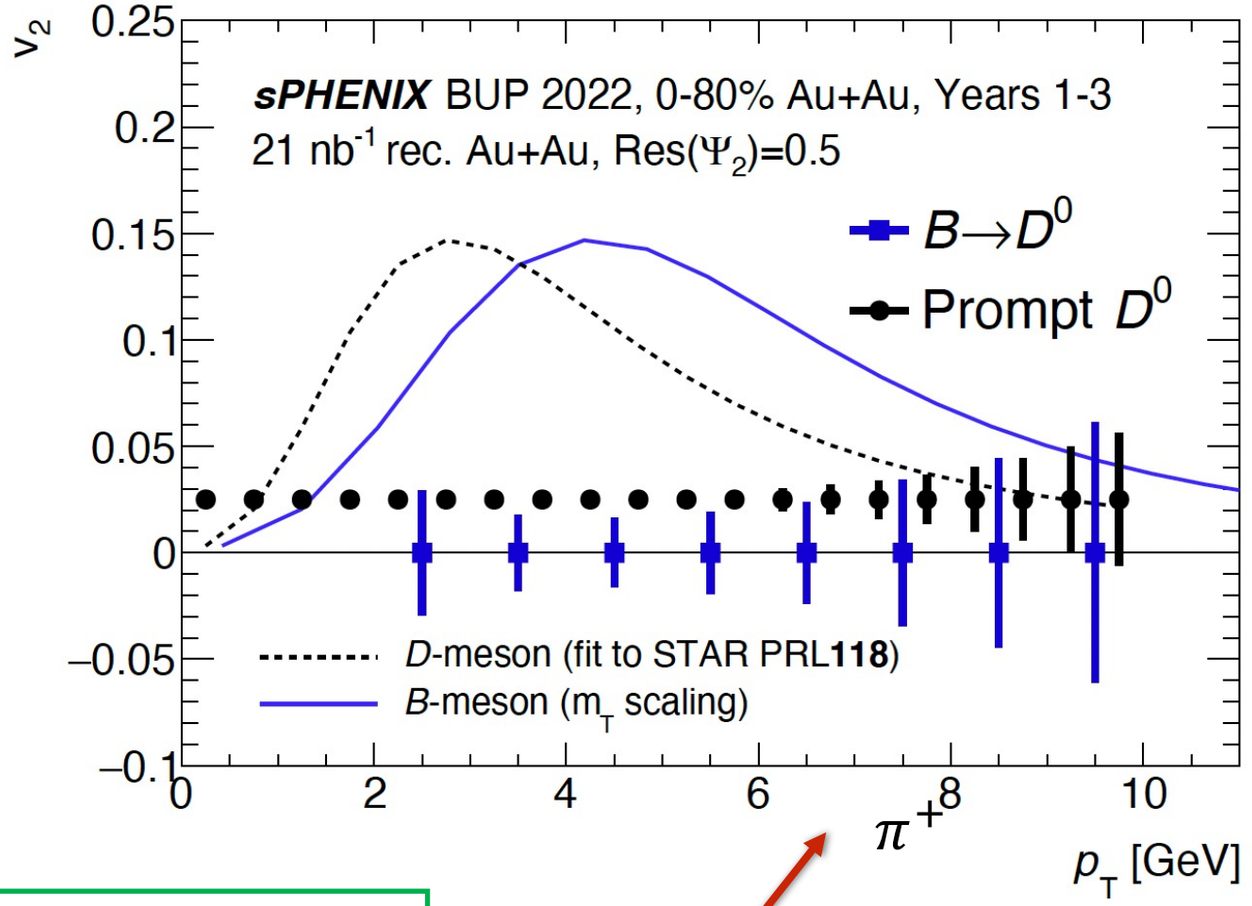




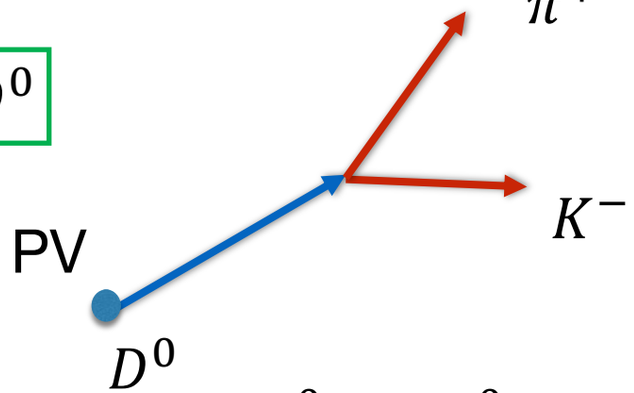
- MVTX and INTT operating in continuous streaming readout mode with advanced electronics
- TPC + TPOT for main for outer tracking for momentum determination
- Excellent tracking reconstruction and vertexing performance for HF physics studies

Fully reconstructed D^0 mesons

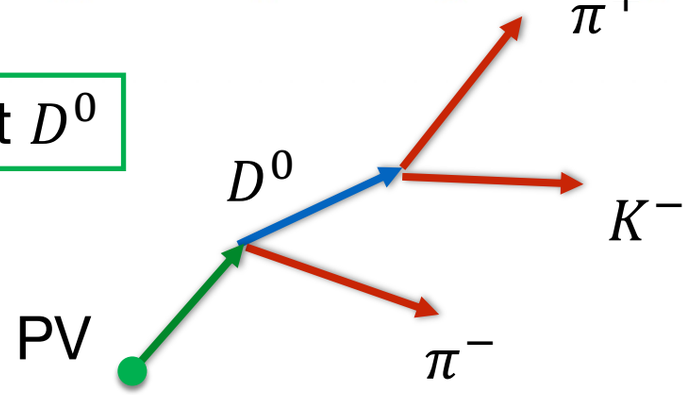




Prompt D^0

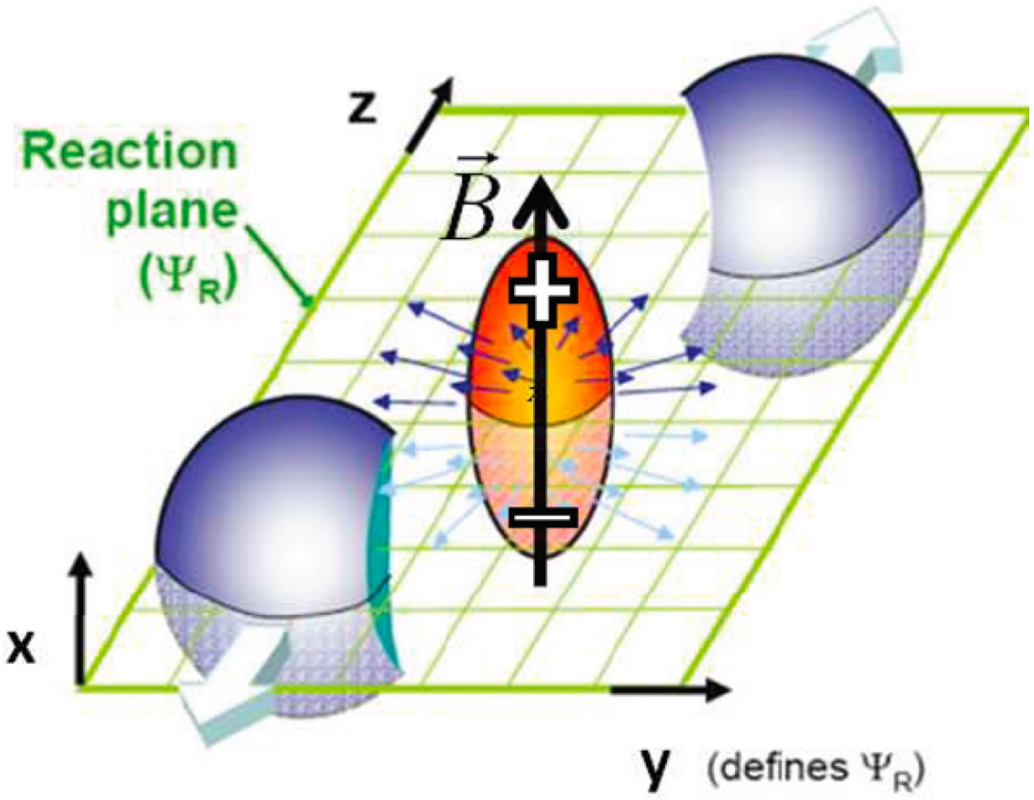


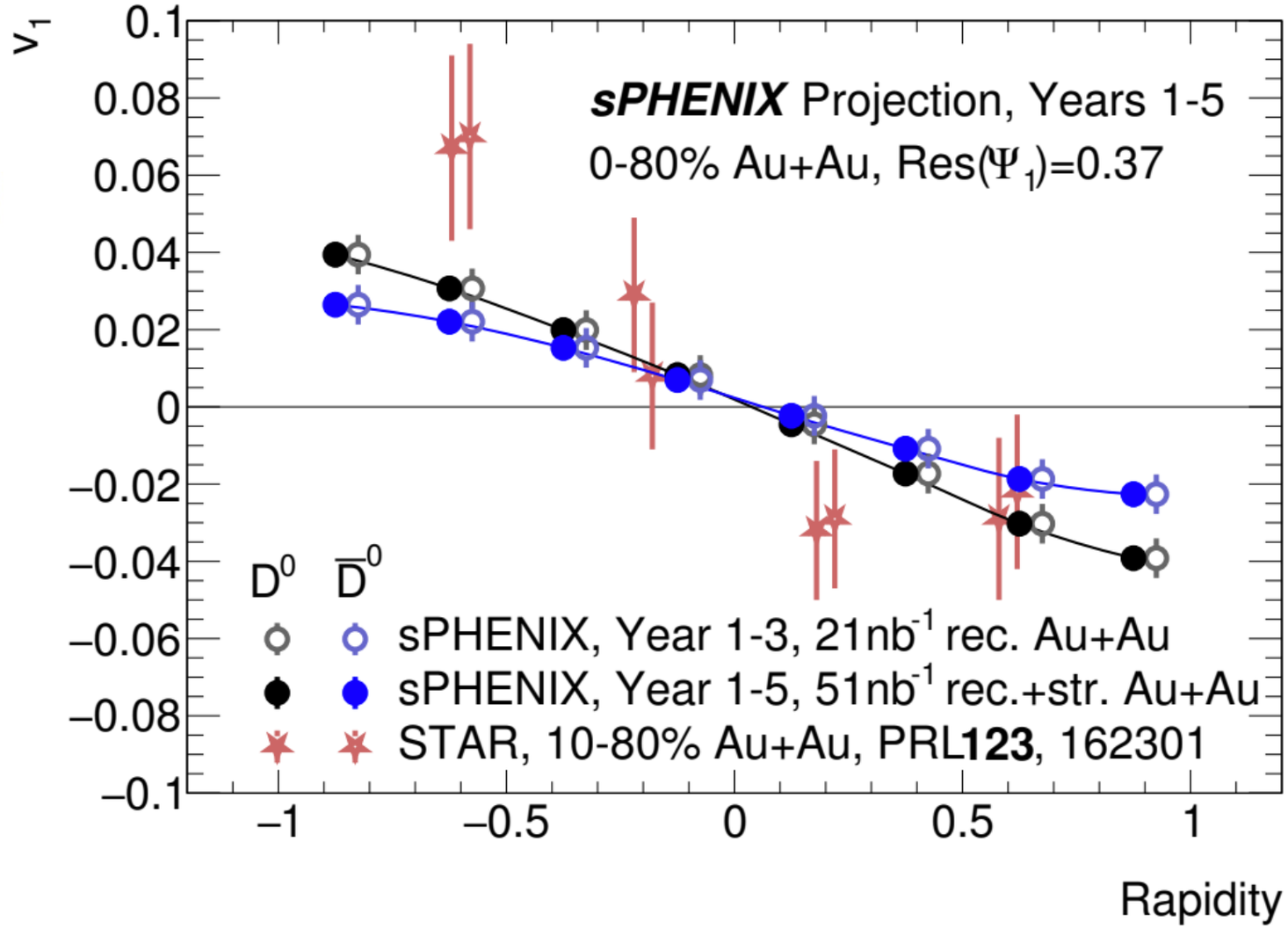
Non-Prompt D^0



- Fully reconstructed D^0 via $D^0 \rightarrow K^-\pi^+$ without hadronic PID
- High precision D-meson thanks to dataset size and tracking system
- Data-driven method: separation of prompt and non-prompt D^0 via $B \rightarrow D^0$ decay with DCA
  - Constrain beauty quark diffusion coefficient in QGP medium
  - Flavor dependence of energy loss
  - Investigate charm quarks thermalization

D-meson Directed Flow

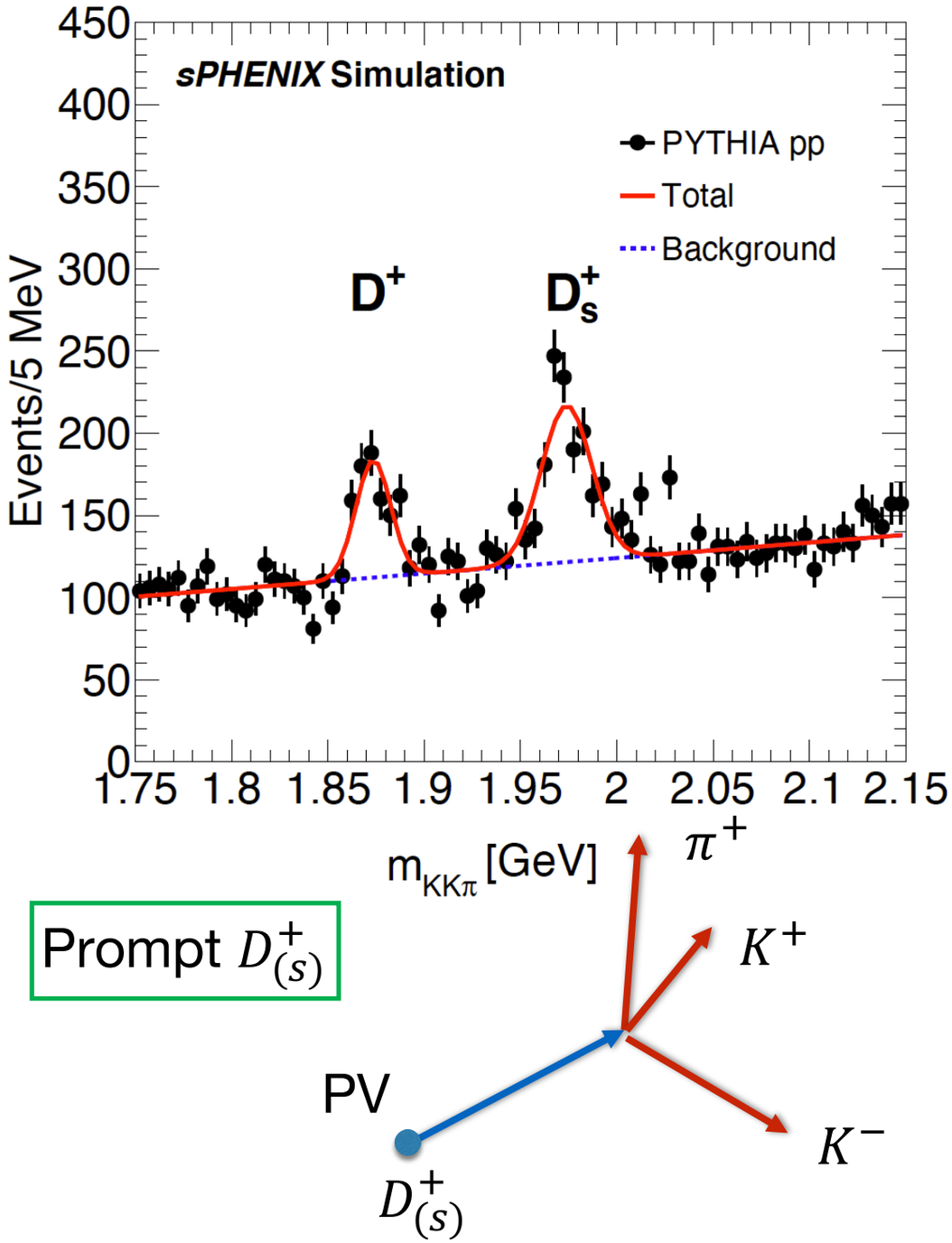




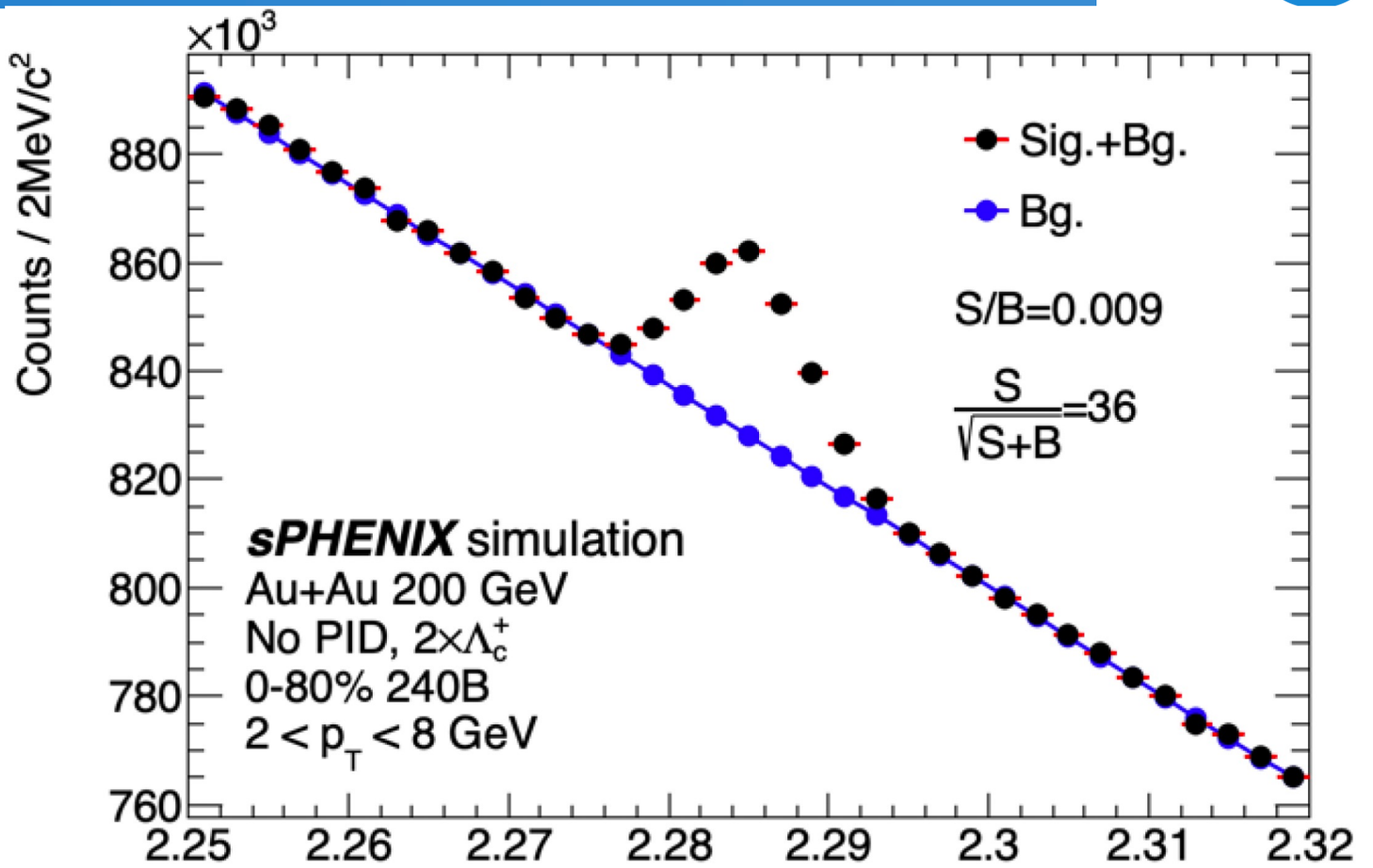
- Directed flow v_1: first order Fourier coefficient of particle emission with respect to the reaction plane in heavy-ion collisions
- Charm quarks predominantly produced in early hard scattering processes
- D-meson $v_1$sensitive the initial tilt and pressure asymmetry due to non-equilibrium effect in the early stage of heavy ion collisions
- Novel probe of the spacetime evolution of the initial magnetic field in heavy-ion collisions

  Search for Chiral Magnetic Effect

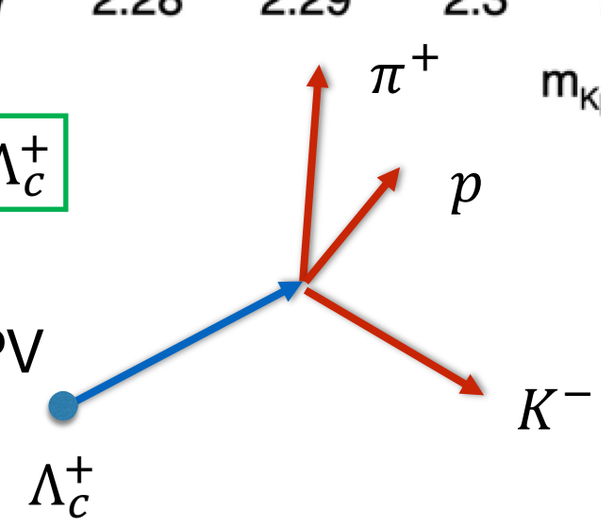
Charm Hadronization



Prompt $D^+_{(s)}$

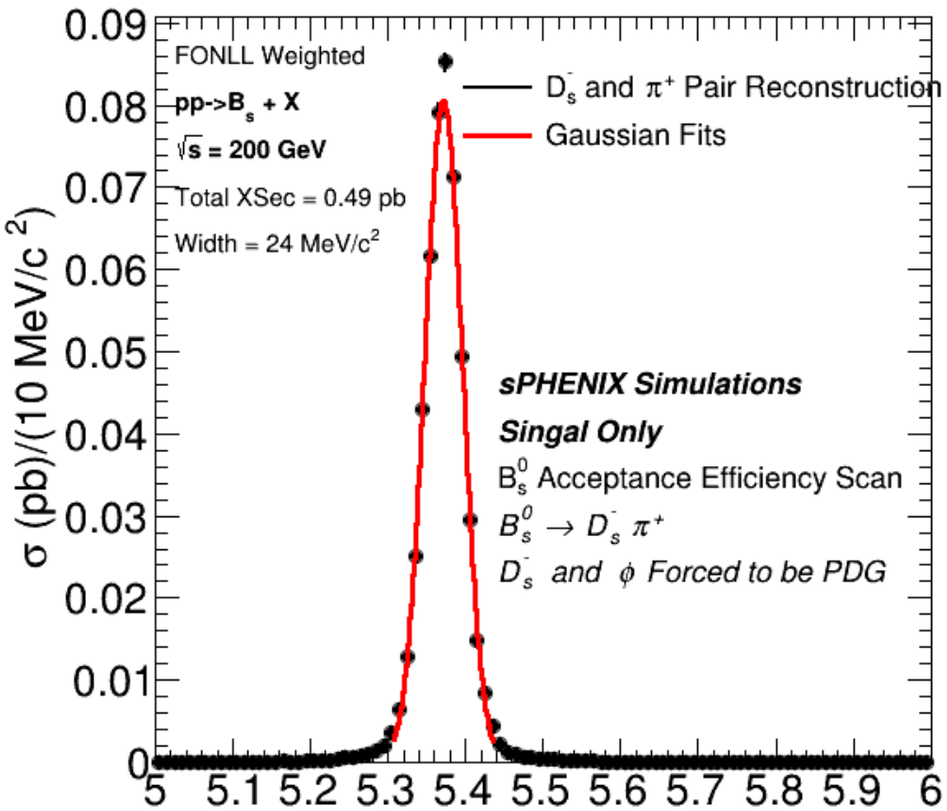


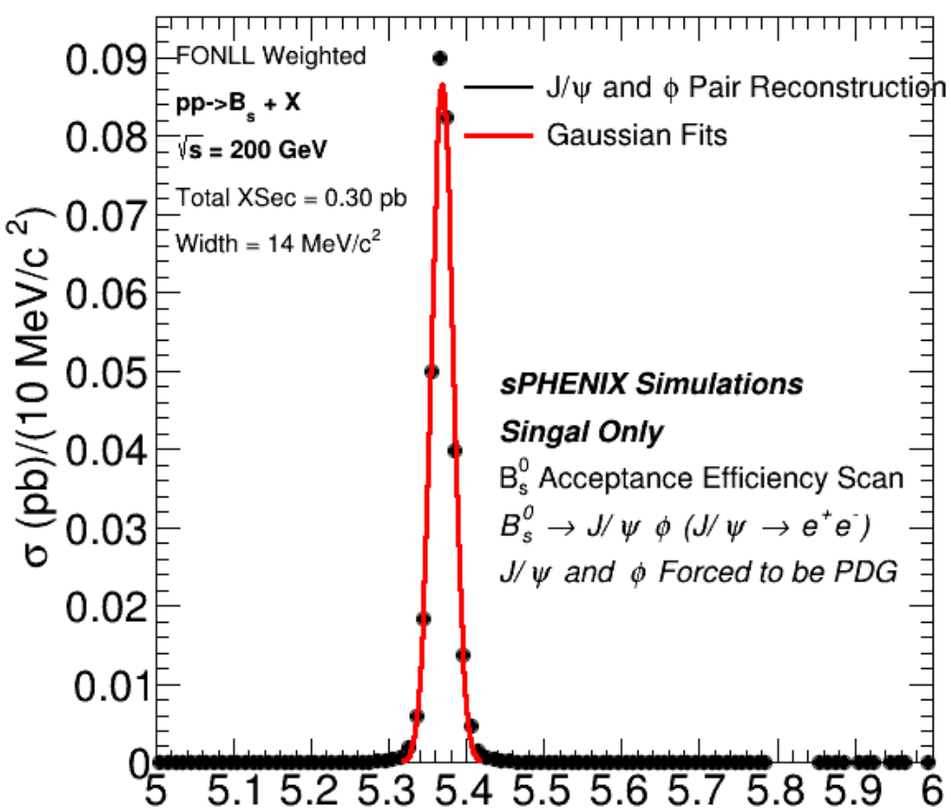
Prompt Λ_c^+

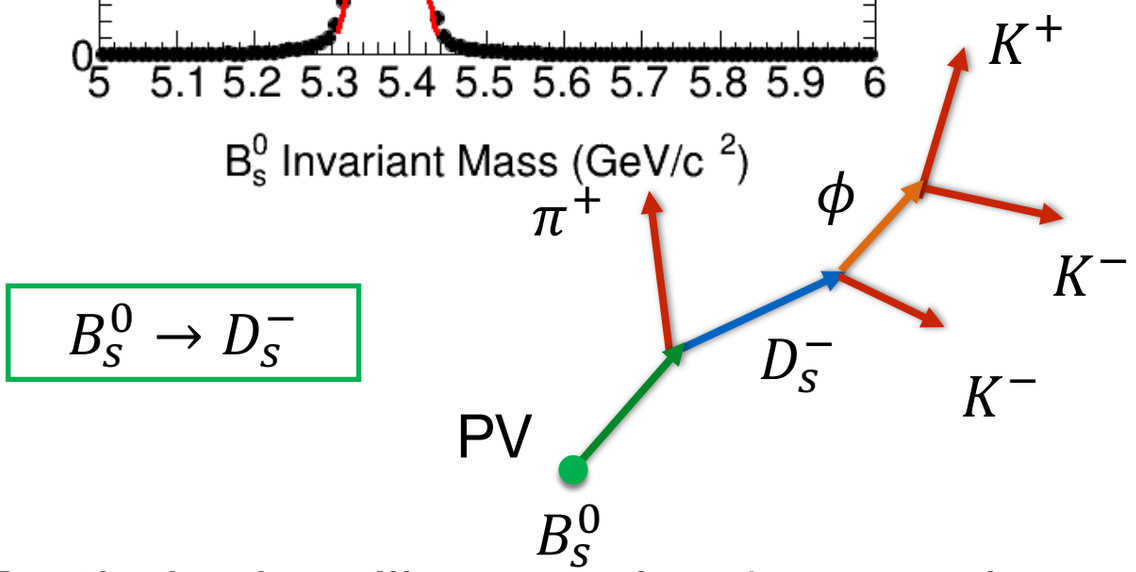


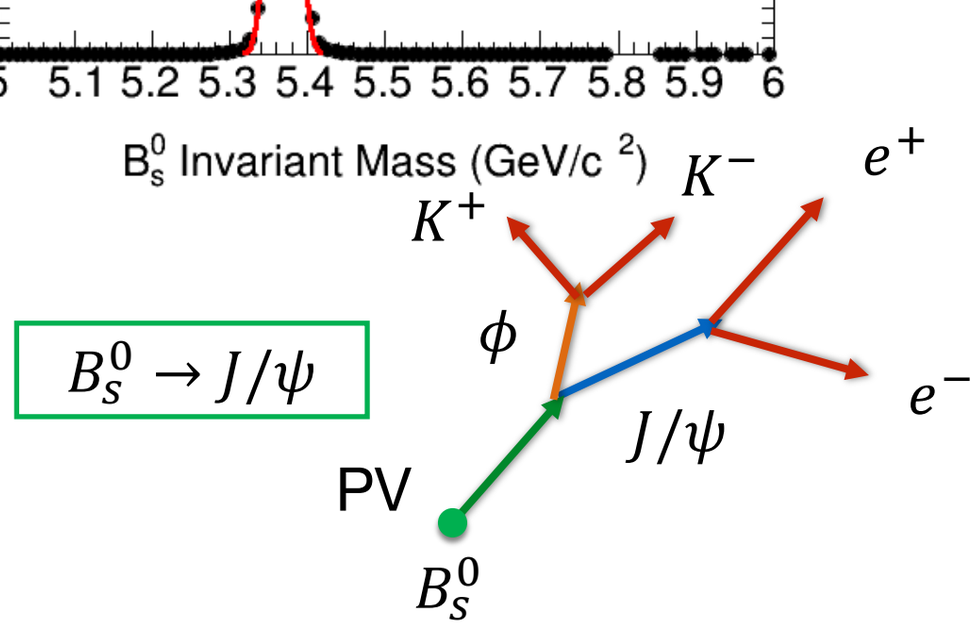
- More complex 3-prong decays
- High precision measurement thanks to streaming readout data taking and tracking
- Study charm hadronization from vacuum to QGP via the measurements of D_s^+/D^+ and Λ_c^+/D^0 as a function of event multiplicity

Fully Reconstructed B_s^0 Meson





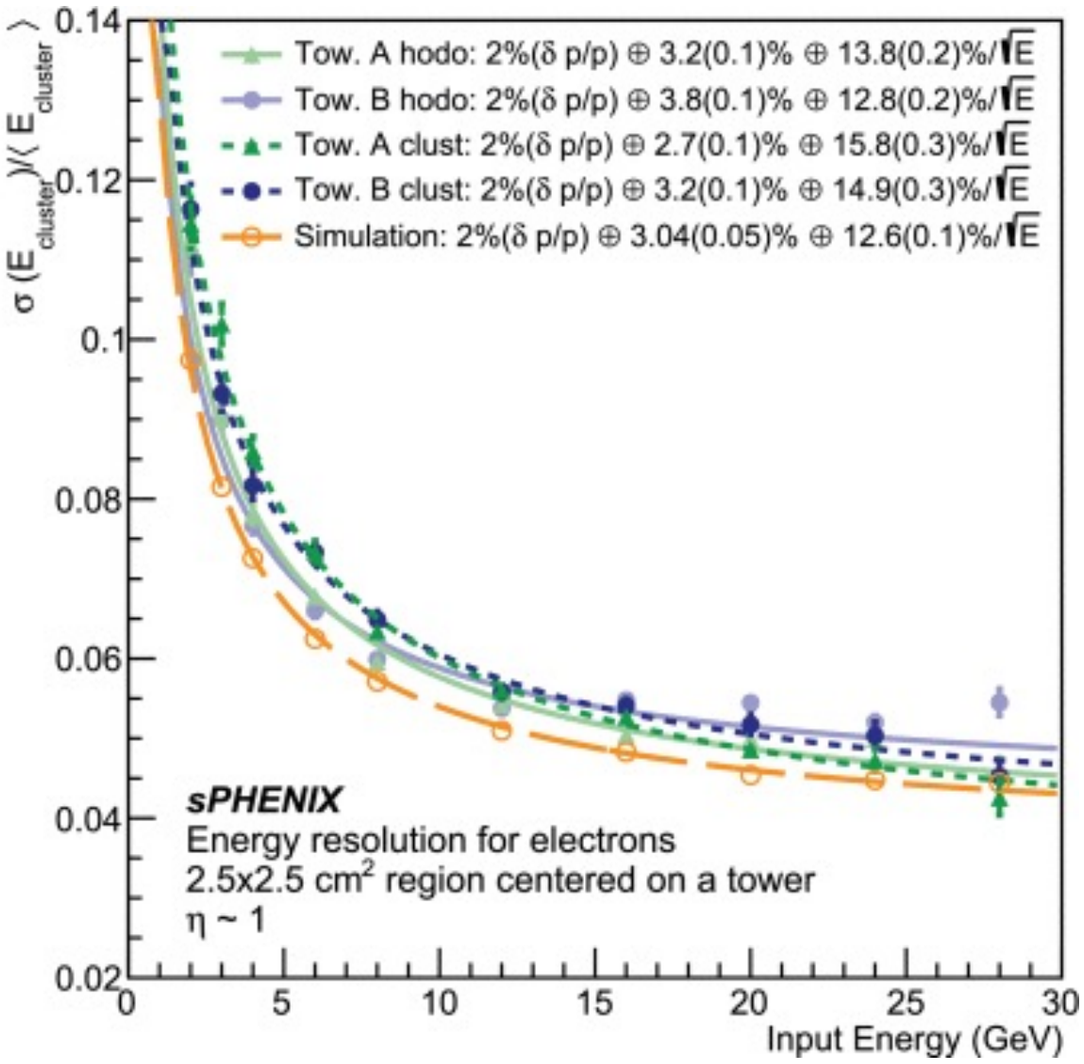




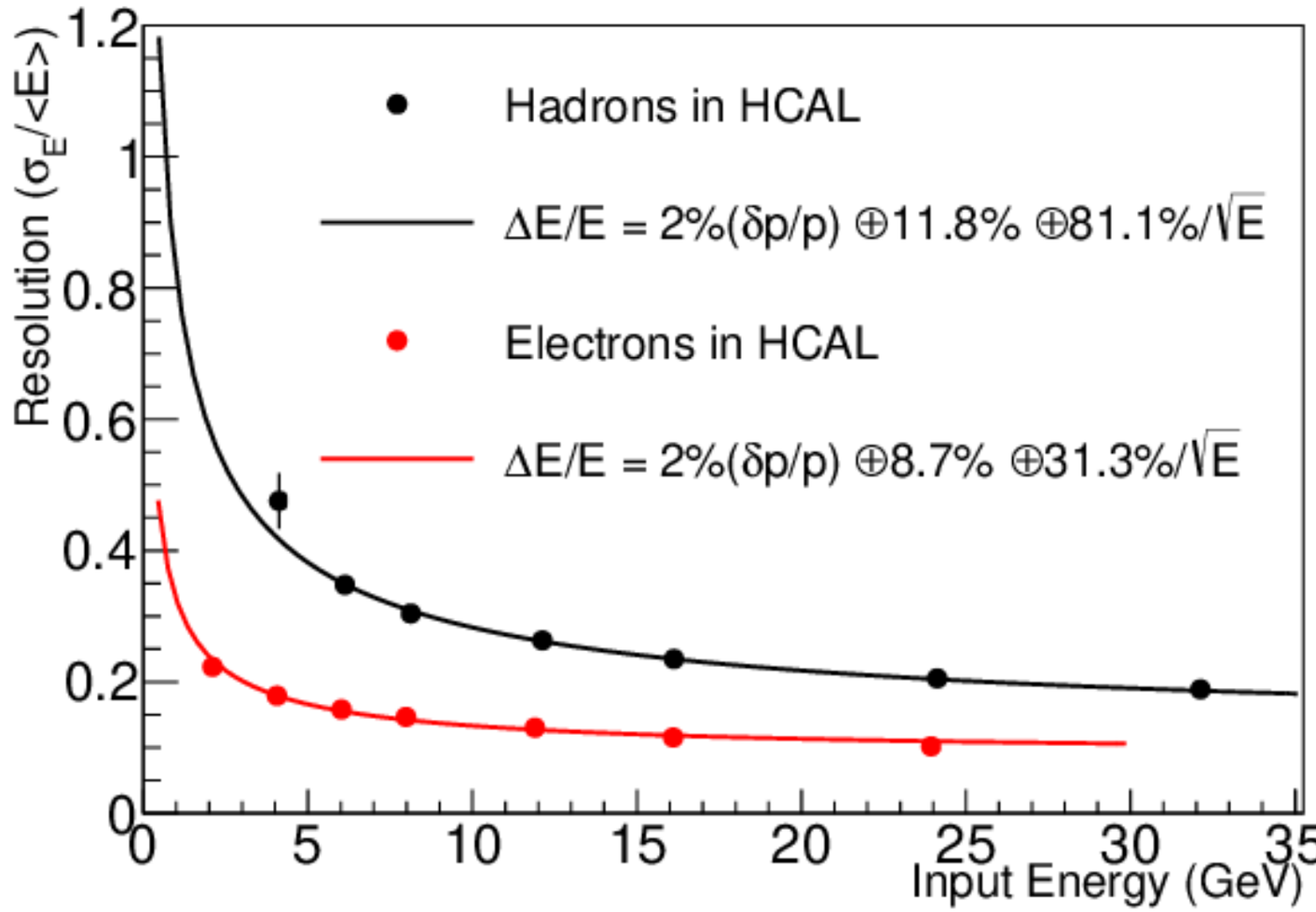
- Exotic-hadron like complex 4-prong decays
- FONLL weighted B_s^0 in GEANT simulation for signal only prediction
- First observation of fully reconstructed B-meson in nuclear collisions at RHIC
- Study beauty quark hadronization mechanism with B_s^0/B^+ ratio
- Test QCD factorization theorem at RHIC energy in the beauty sector

Calorimeter System Performance

EMCAL



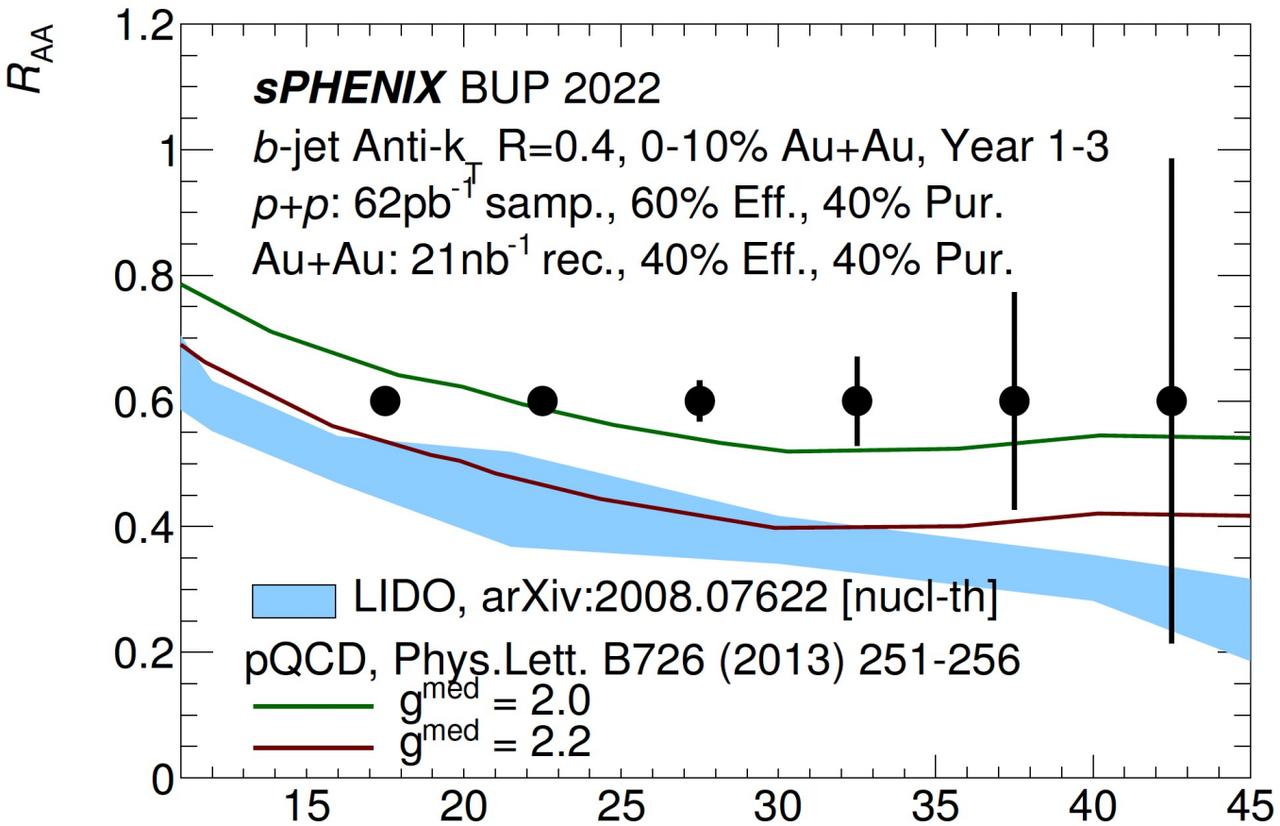
HCAL

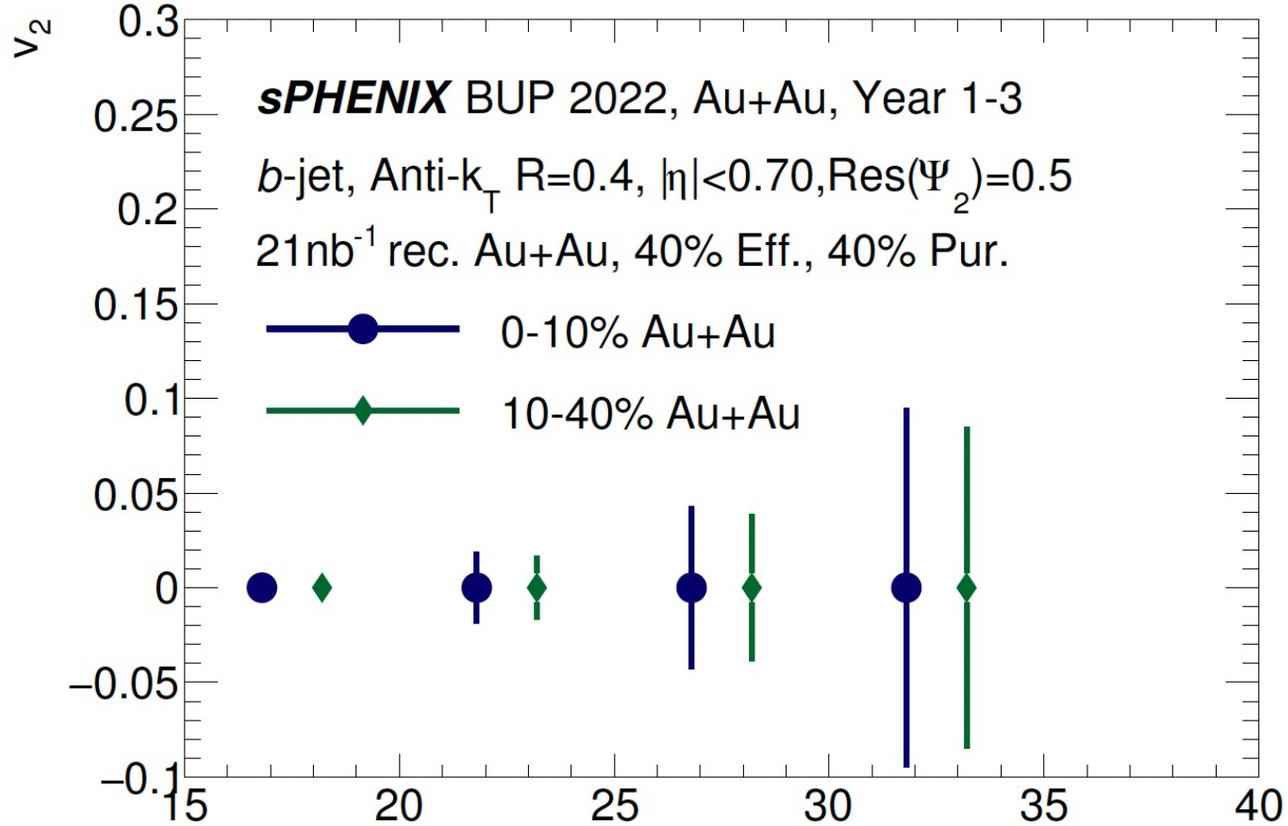


(b)

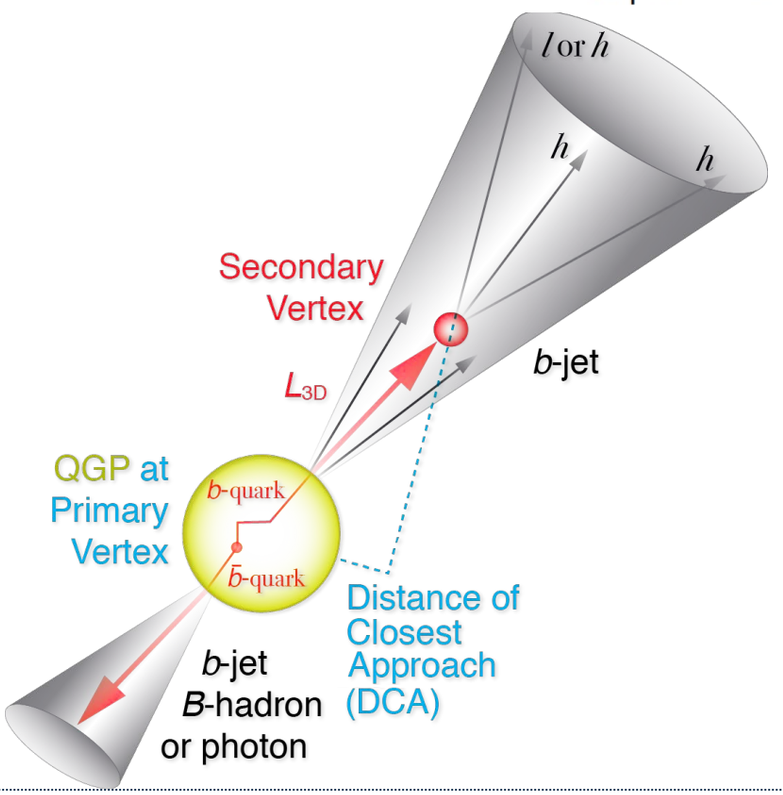
- Excellent EMCAL and HCAL energy resolutions
- High p_T trigger implemented to the calorimeter system dedicated for jet physics studies
- Advanced 3D topological jet reconstruction algorithm
- Capable of performing precision calorimetric jet measurements

b-jet R_{AA} and v_2 Measurement

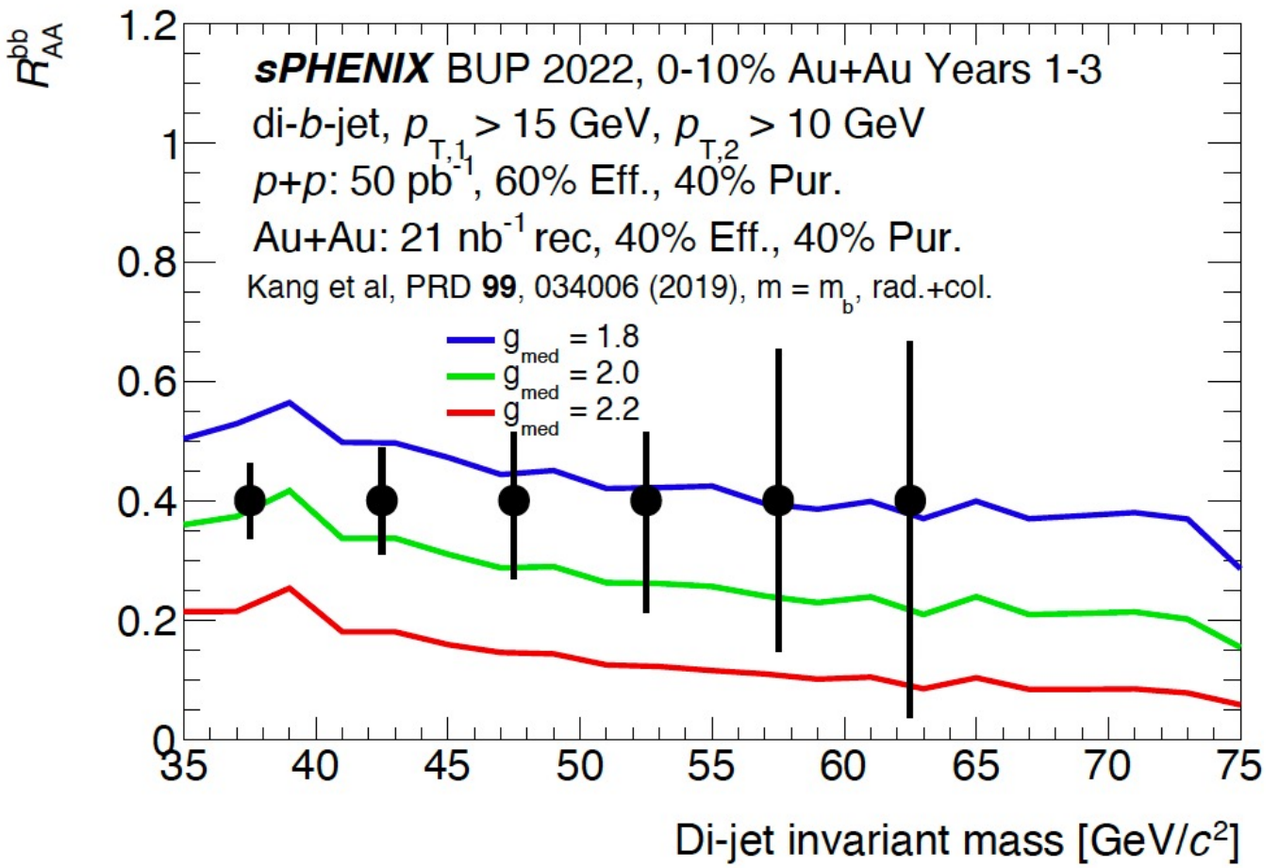


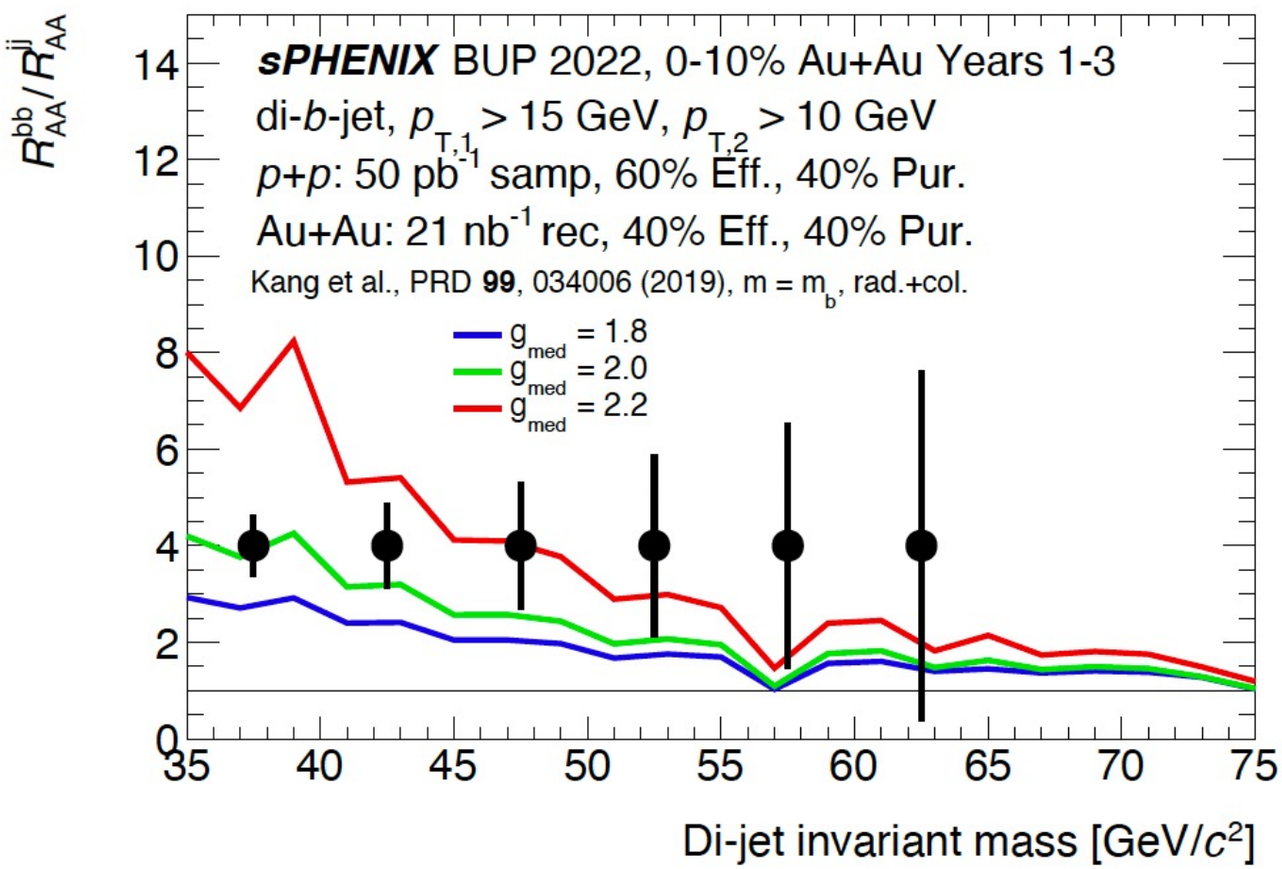


- Utilization of MVTX to reconstruct secondary vertex within the jet cone
  - Identify jets with displaced vertices to tag the b quarks
  - Inclusive measurement with better statistics
- First b-jet measurement at RHIC
- Sensitive to heavy-quark collisional and radiative in-medium energy loss
- Pathlength dependence of beauty energy loss in QGP
- Complementary to LHC with better measurements at lower p_T



Di-b-jet Invariant Mass

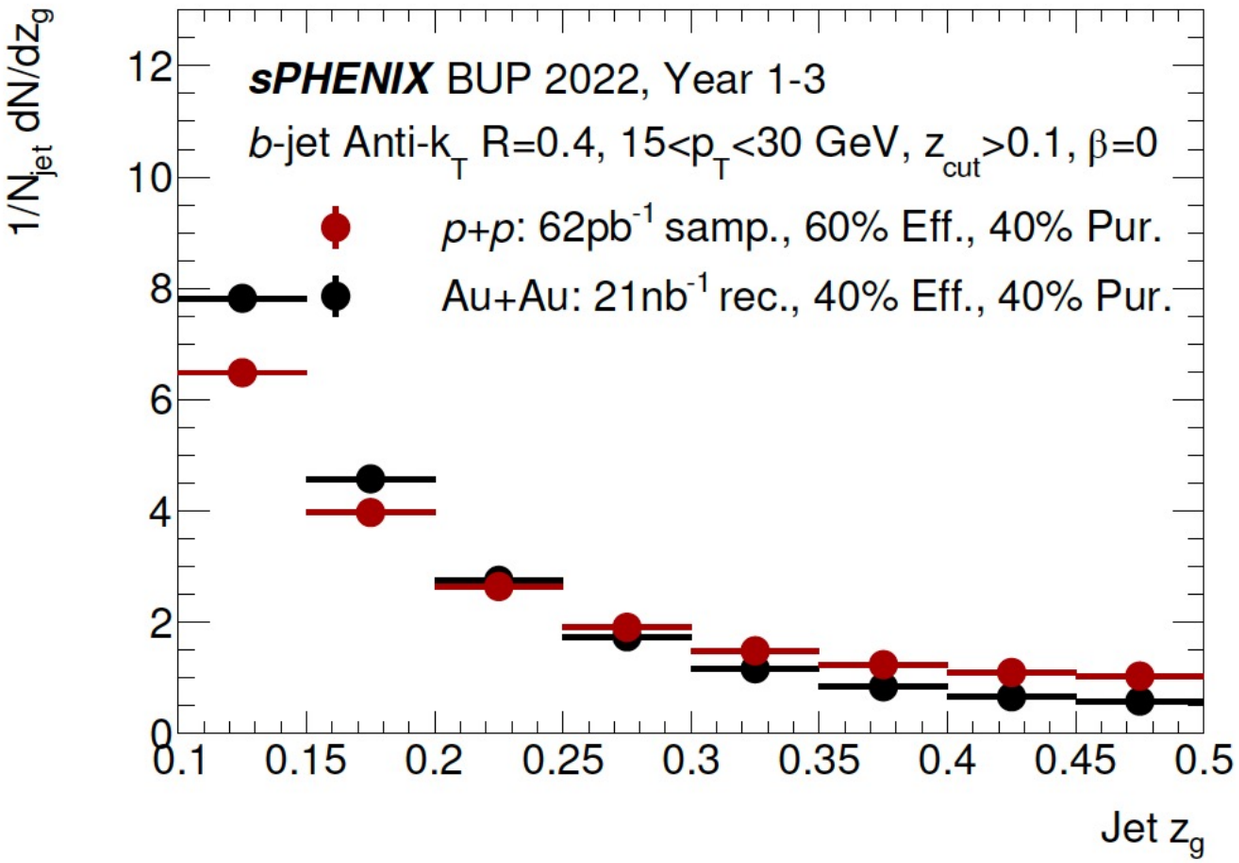


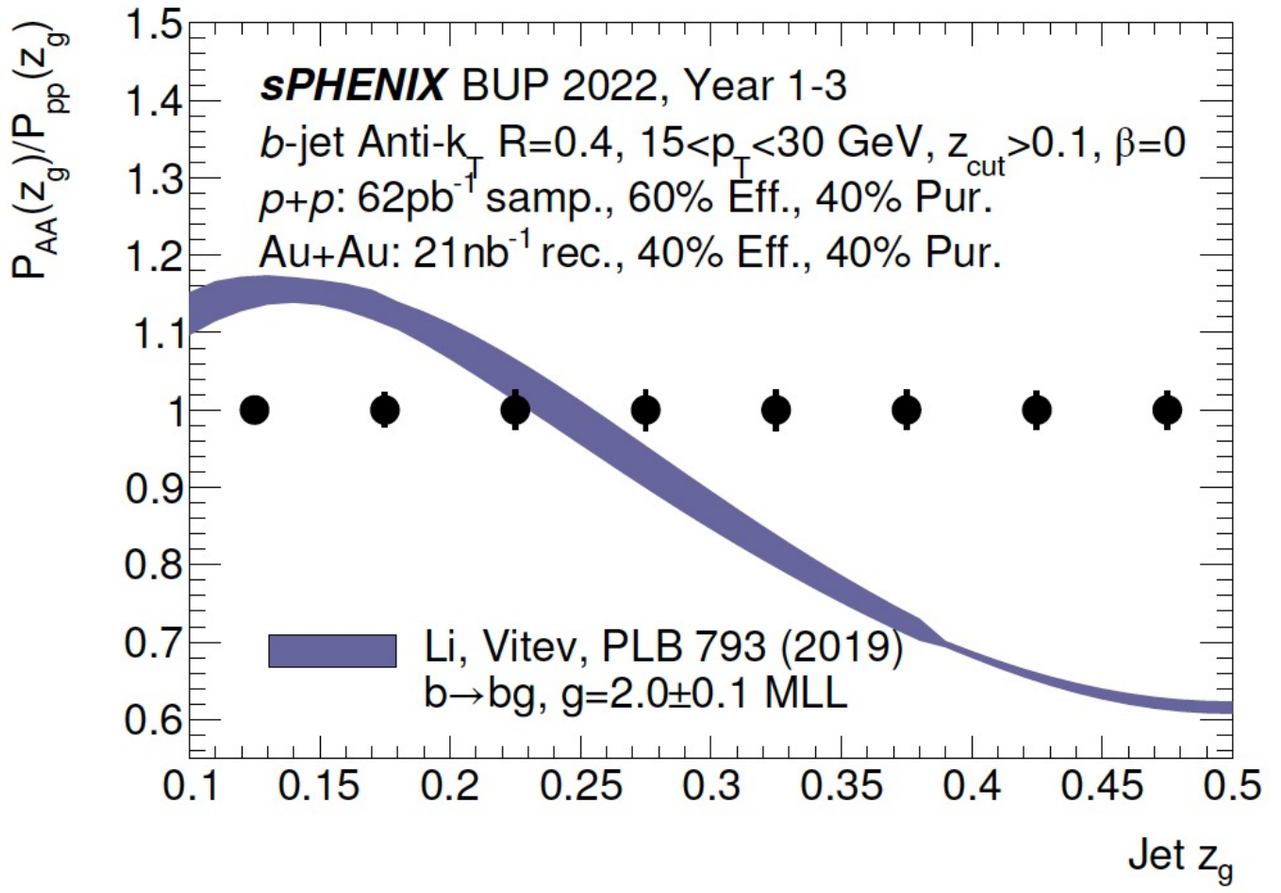


- Back-to-back b-jet pairs studies enabled by the large detector acceptance and multi-observable capabilities

  Precision di-b-jet R_{AA} as a function of di-jet invariant mass measurement
- Pinpoint the propagation of beauty quarks in the QGP
- Extract beauty quark coupling parameter to the medium
- Complementary to LHC di-b-jet imbalance measurements

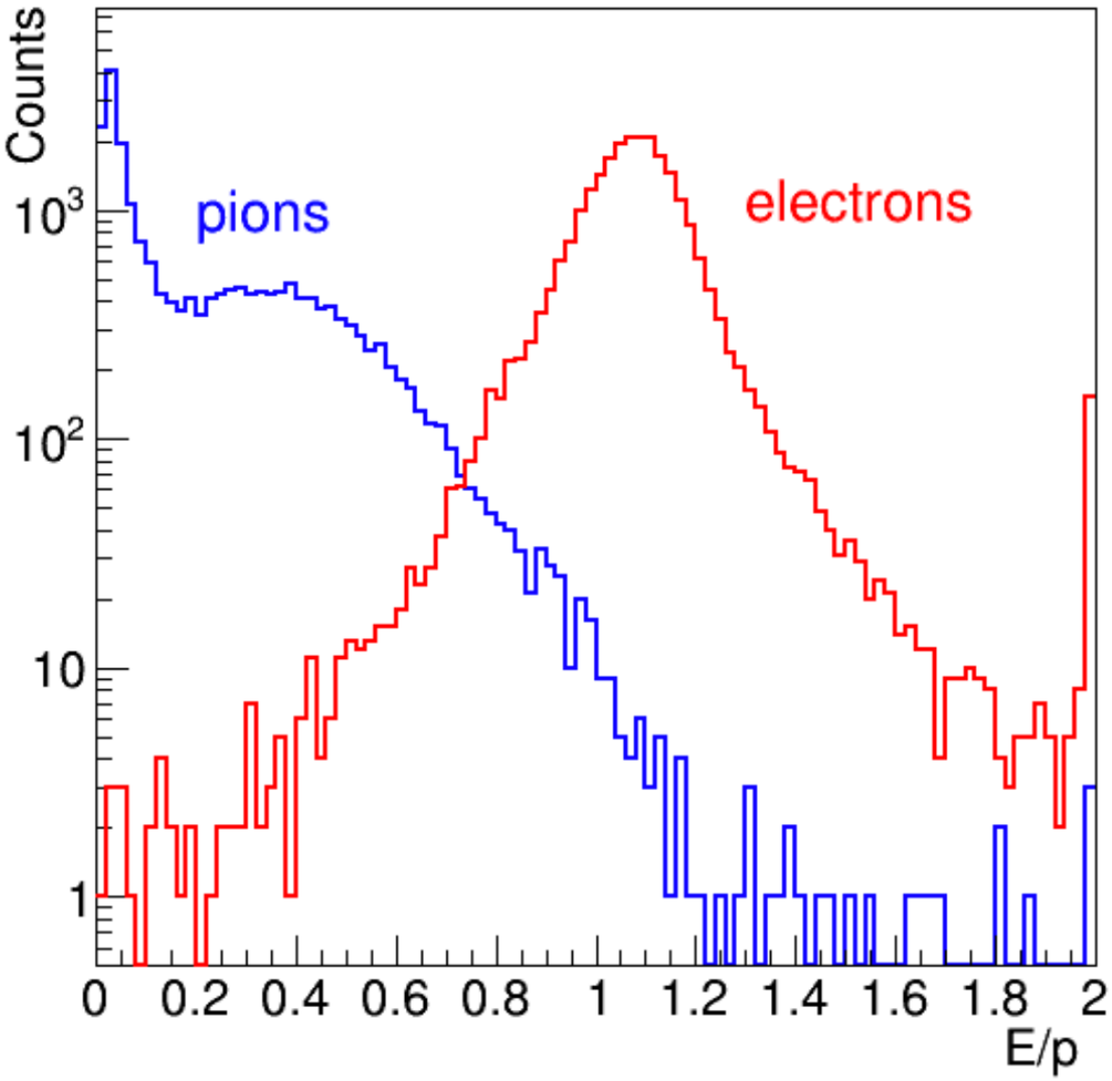
b-jet Substructure Observable

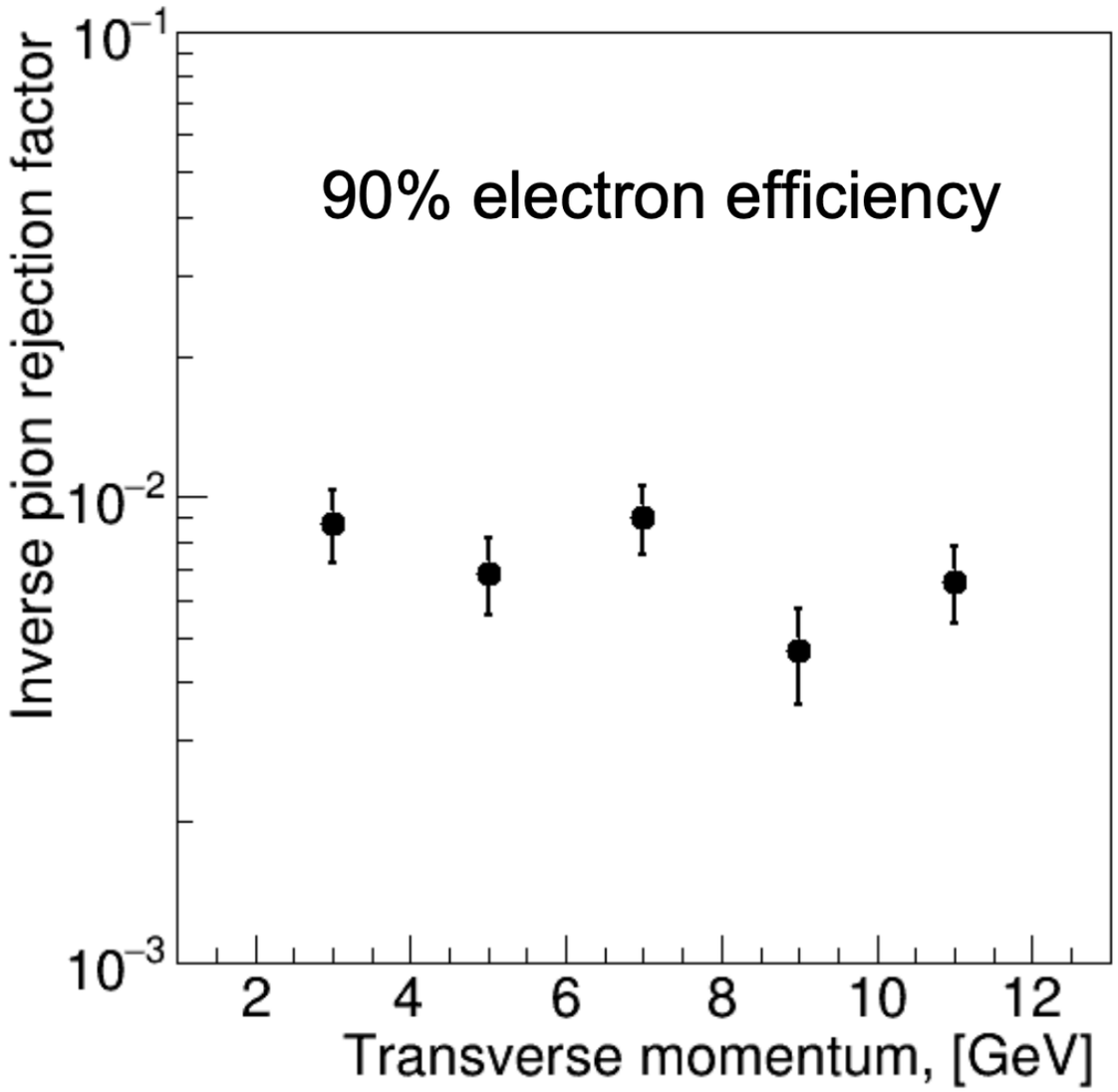




- Differential subjet splitting function measurements thanks to the large dataset statistics
- Test pQCD model calculations in $p + p$ collisions
- Quantify the medium modification of b-jets in the sPHENIX kinematic region
- Complementary to LHC jet substructure measurements

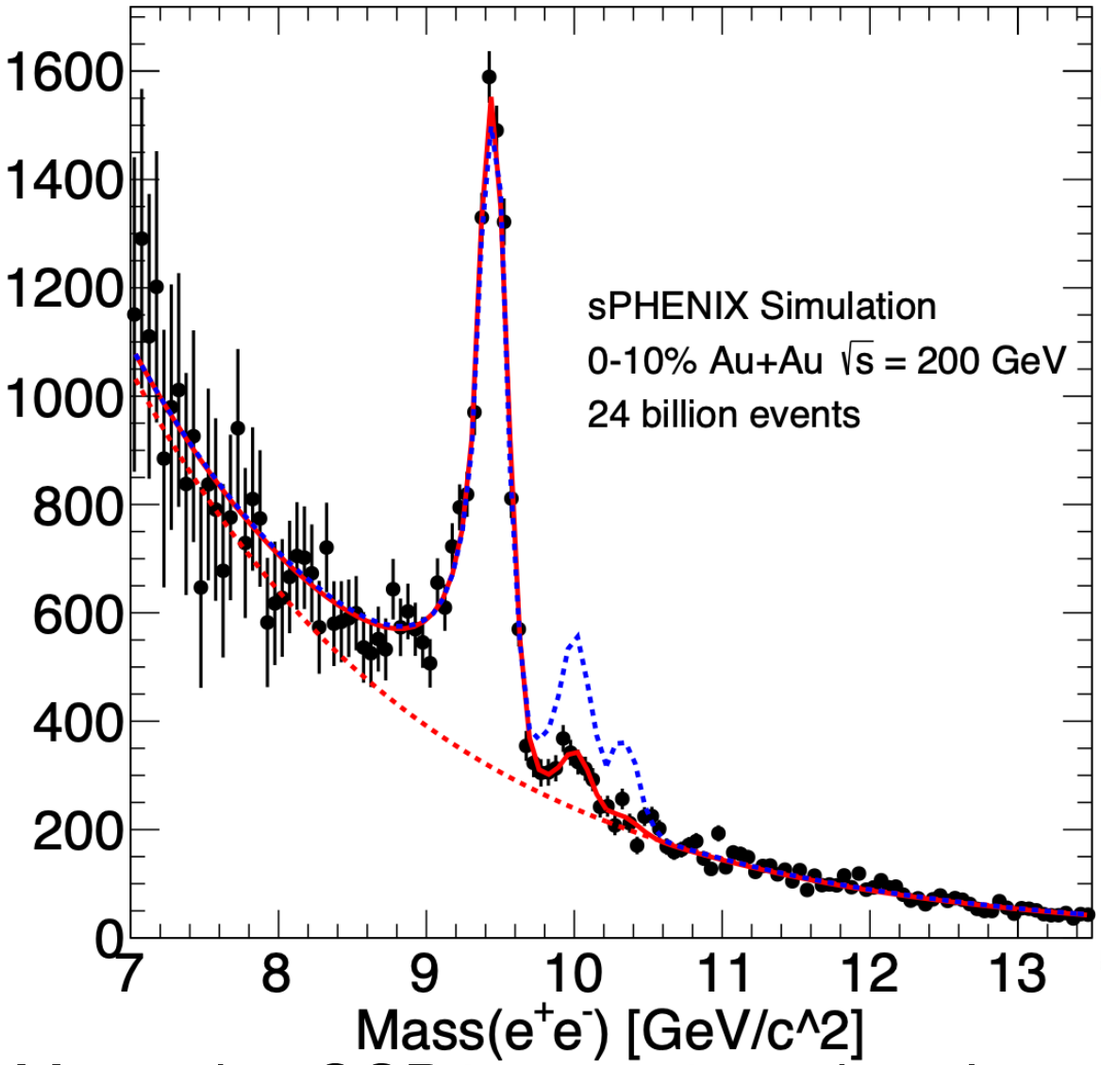
Electron Identification Capabilities

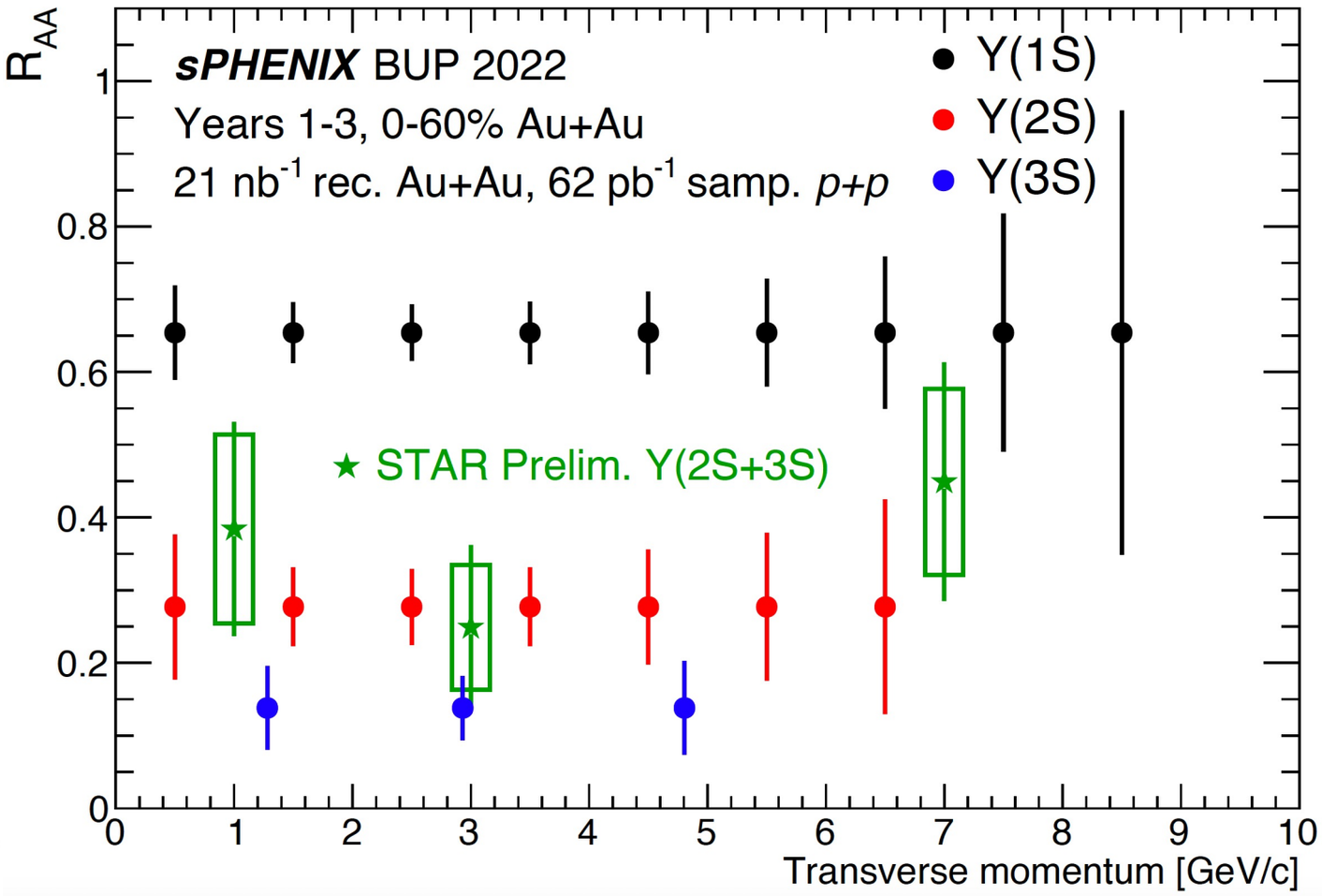




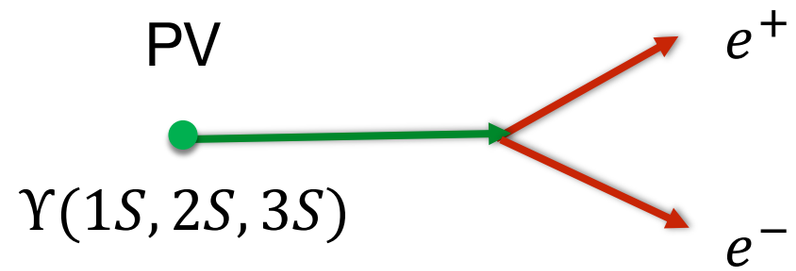
- Use shower core energy information from central EMCAL and HCAL for e/h separation
- Working point: EMCAL/p > 0.9 and iHCAL/EMCAL < 0.2 to maintain 90% electron efficiency
- Excellent electron identification capabilities for quarkonia background rejection
- Improvement with machine learning techniques in development
- Ongoing muons identification studies with machine learning techniques

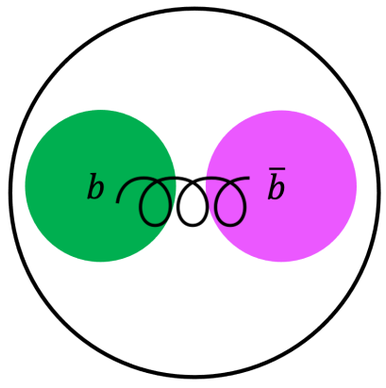
Upsilon Spectroscopy

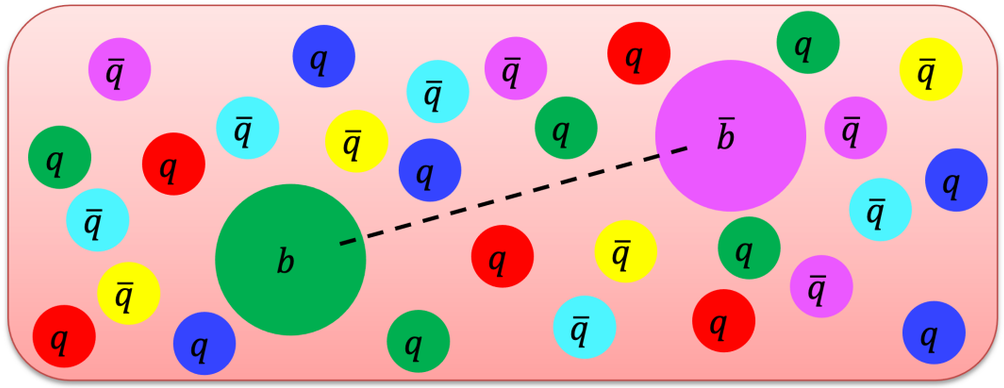




- Measuring QGP temperature via color screening effect
- Excellent mass resolution in the dielectronic decay channel
- R_{AA} measurement with high precision
- Potential observation of $\Upsilon(3S)$ at RHIC, complementary with CMS $\Upsilon(3S)$ measurement at the LHC







Summary

The sPHENIX Experiment at RHIC

- Physics program: jet, **open heavy flavor**, **quarkonia**, cold QCD
- Detector commissioning: lots of activities ongoing right now

Detector Performance

- Excellent tracking and vertexing capabilities for heavy flavor physics measurements
- Outstanding calorimetric jet performance for heavy flavor jet studies
- Good electron identification performance for quarkonia background rejection

Open Heavy Flavor Physics Program

- Fully reconstructed charm and beauty hadron measurements
  - Heavy quark diffusion
  - Heavy quark energy loss
  - Heavy quark hadronization
- First inclusive b-jet measurements at RHIC
  - High precision at low p_T
  - Complementary to LHC experiments

Hidden Heavy Flavor Physics Program

- Upsilon Spectroscopy
  - measure the temperature of QGP
  - Potential observation of $\Upsilon(3S)$ at RHIC

First data taking starts in around 03/2023: STAY TUNE!

Thank You

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- **Thank you very much for your attention!**

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