The sPHENIX Open and Close Heavy Flavor Program

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on behalf of the **sPHENIX** collaboration

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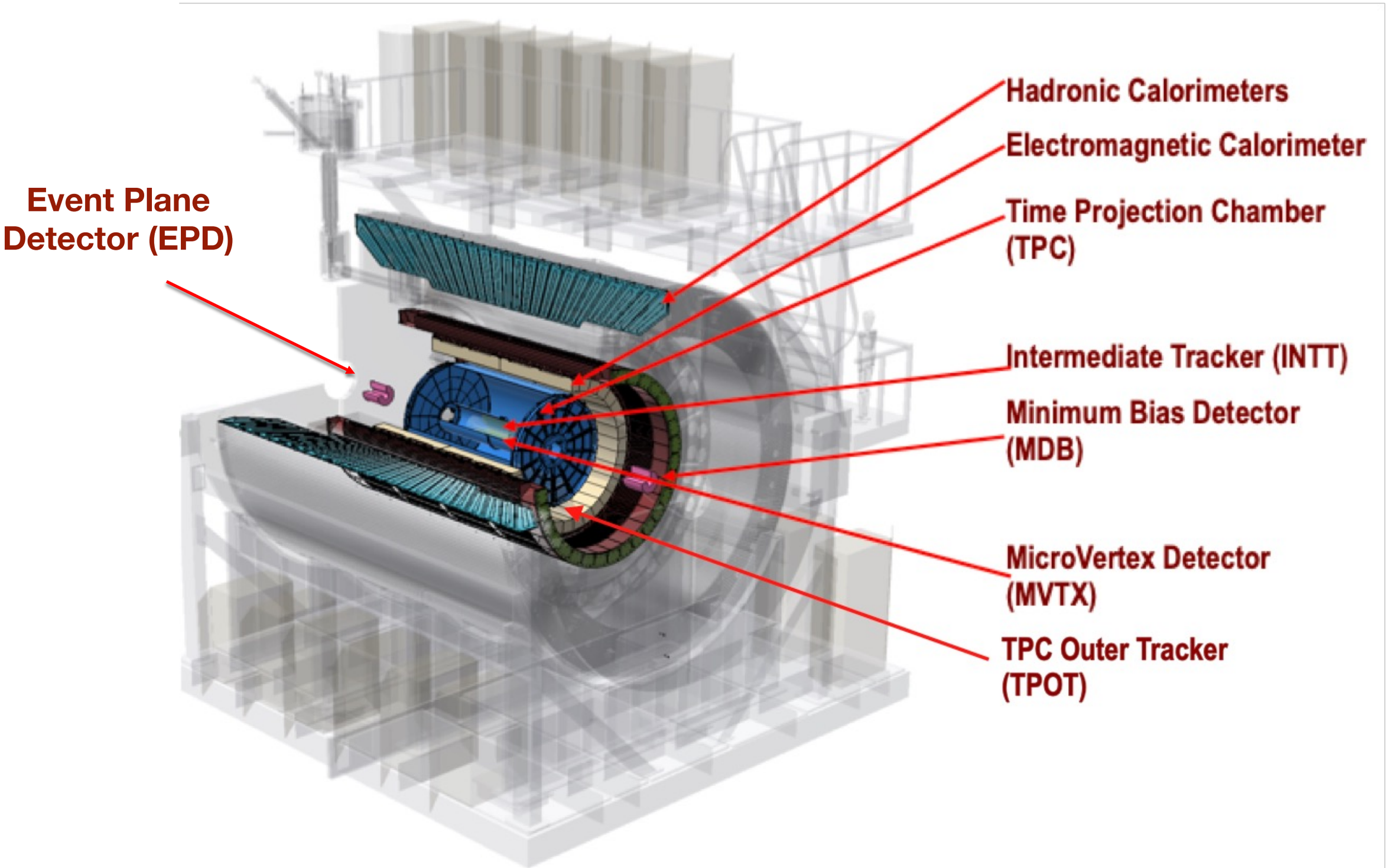
Los Alamos NATIONAL LABORATORY

sPHENIX

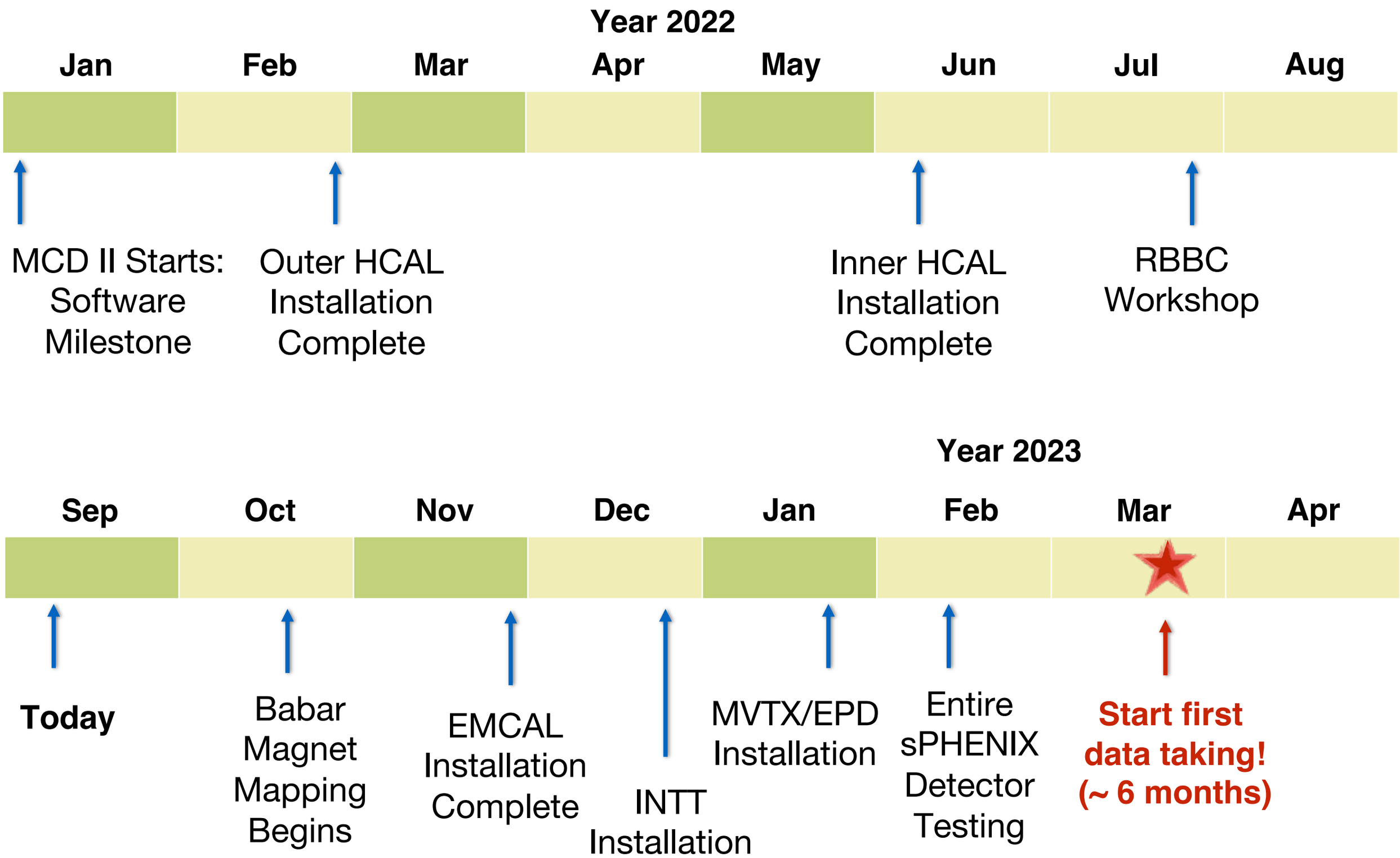
The sPHENIX Experiment at RHIC



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

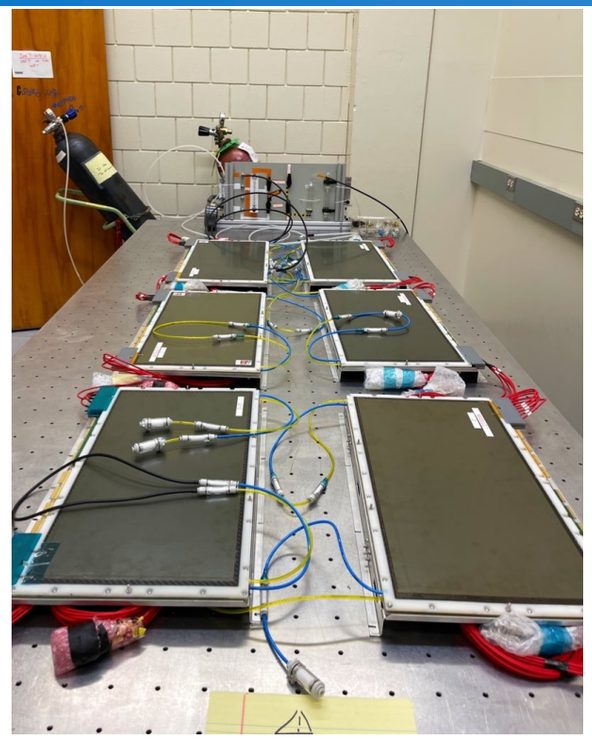
sPHENIX Recent Schedule and Milestones



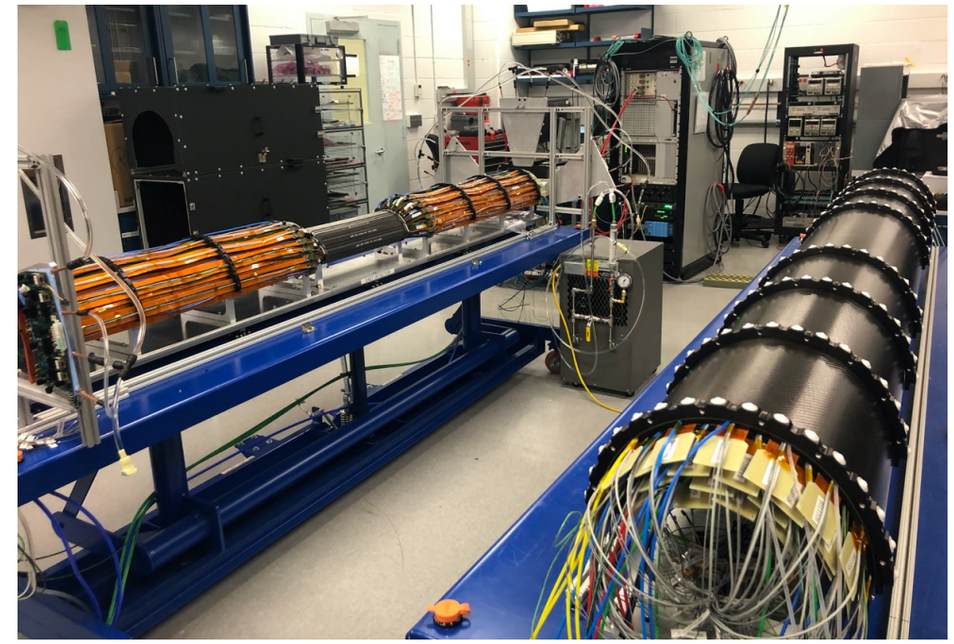
- Collective efforts of international collaboration from 85 institutions in 14 countries
- Intense preparation schedule to ensure timely and high-quality data taking in 2023

sPHENIX Detector Commissioning

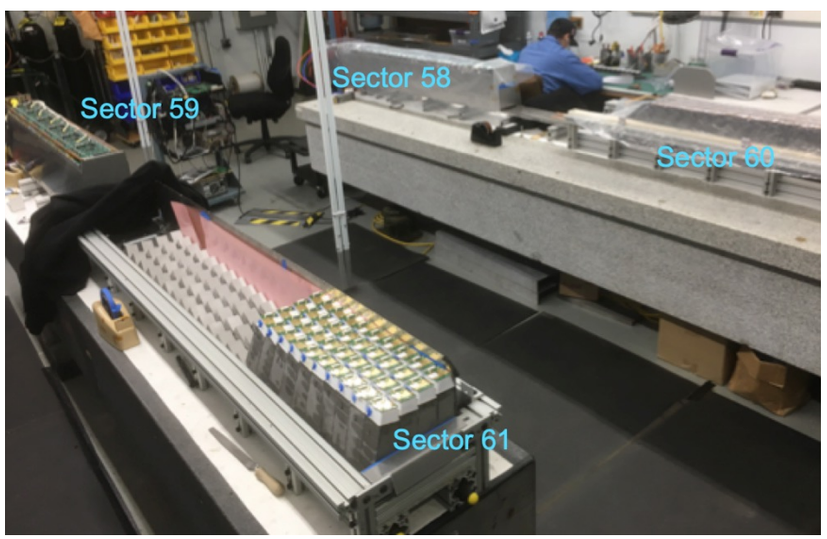
TPC construction at Stony Brook University



TPOT effort by LANL/Stony Brook

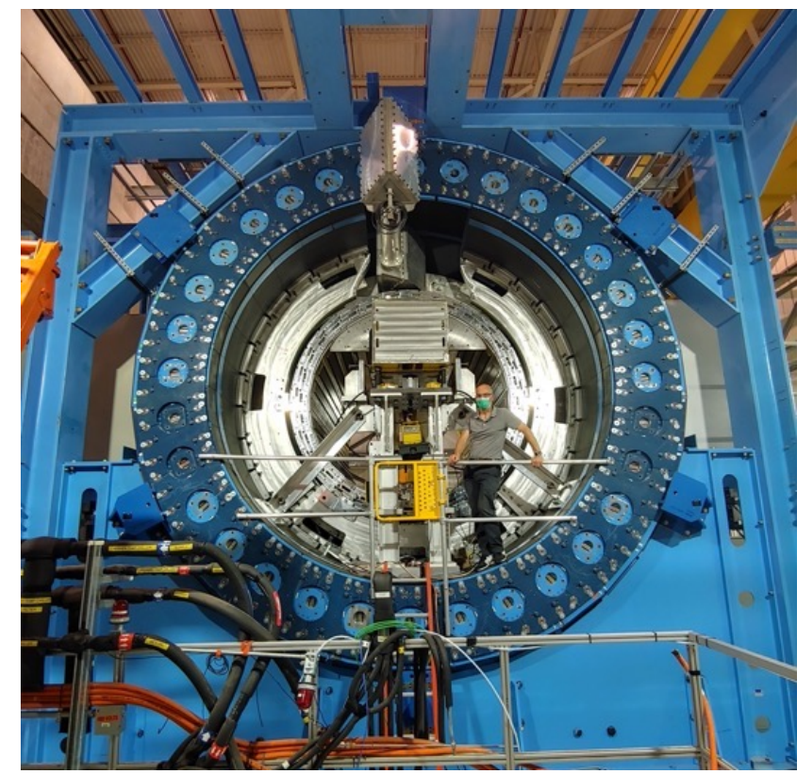


INTT half barrels completed and tested



EMCAL assembly at BNL

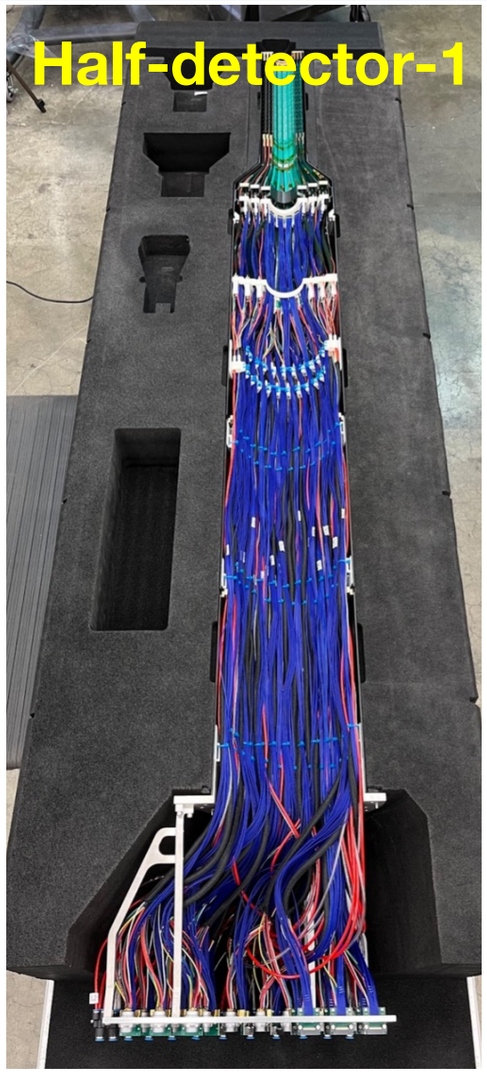
Commissioning task force

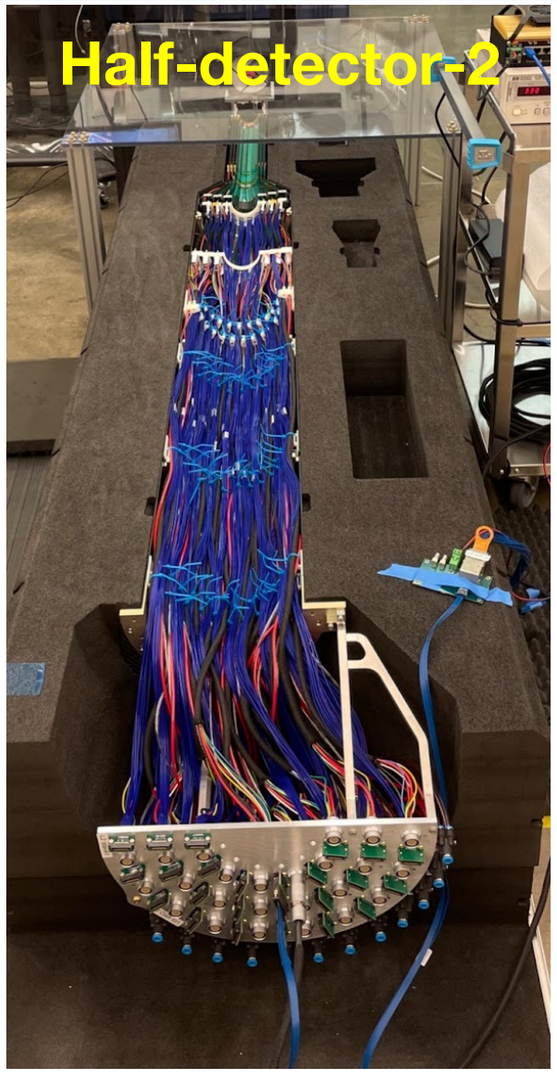


sPHENIX detector with HCAL in sPHENIX IP

- 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

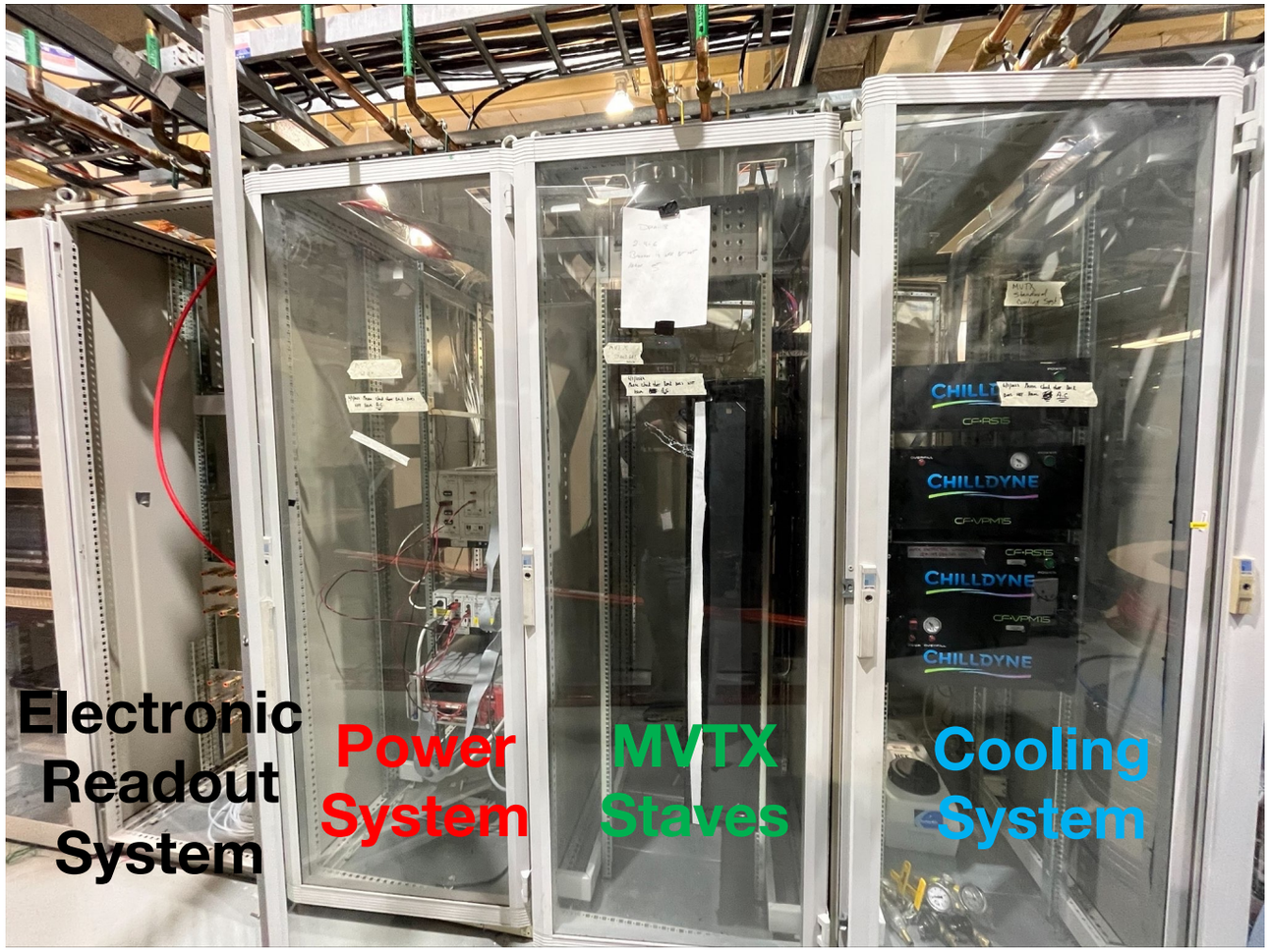
MVTX Commissioning Status





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
- Power system and cabling preparation
- Readout mechanical structure
- Half detector fully assembled

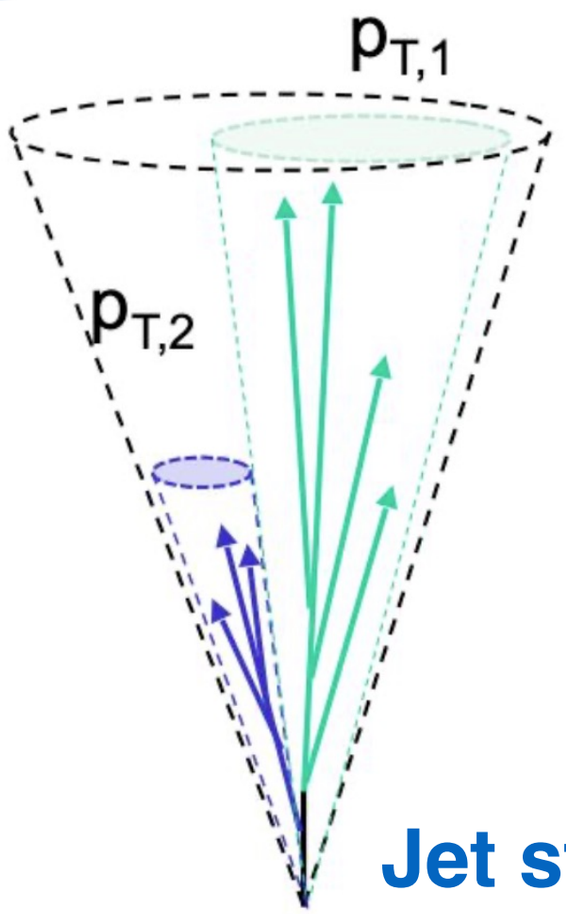
sPHENIX Beam Use Proposal

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)

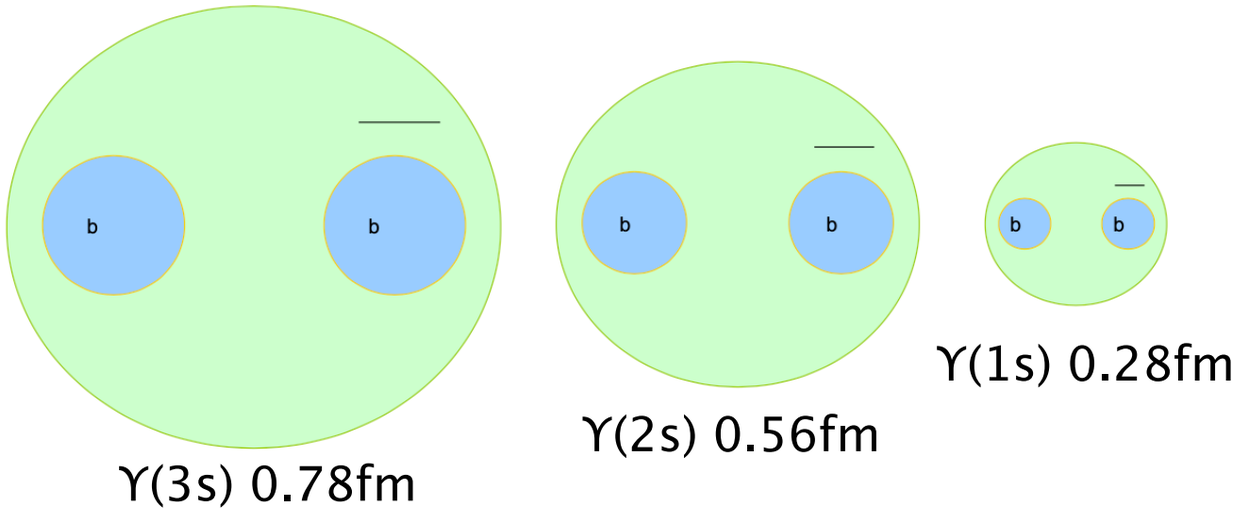
- Extensive **3-year** data taking starting in around 6 months
  - **Year-1**: commissioning and first physics in Au+Au
  - **Year-2**: p+p and p+Au runs for heavy-ion reference and cold QCD physics
  - **Year-3**: very large Au+Au dataset (141B events in total)

The sPHENIX Physics Program



Jet structure

vary momentum/angular scale of probe

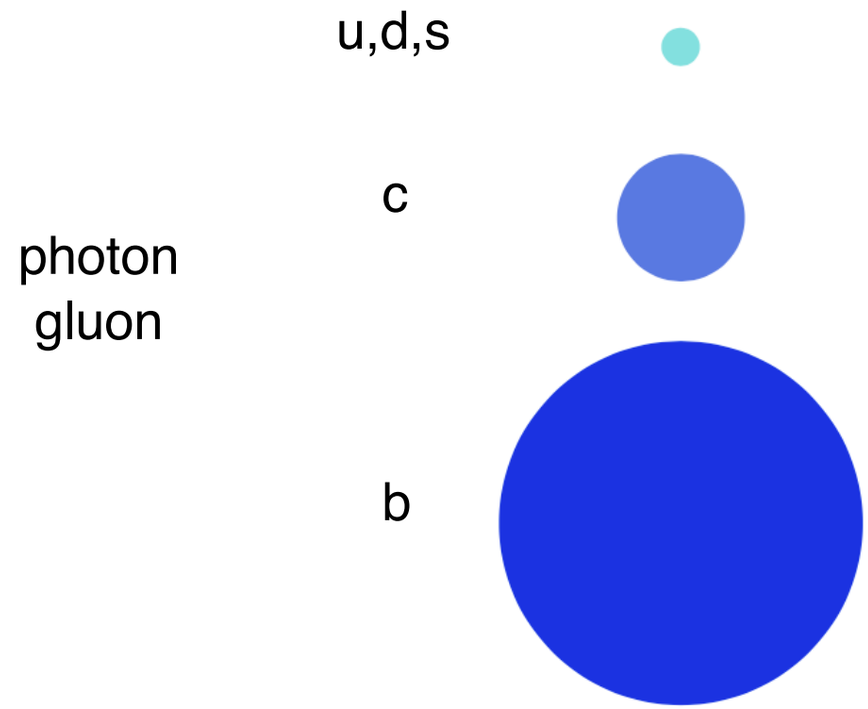


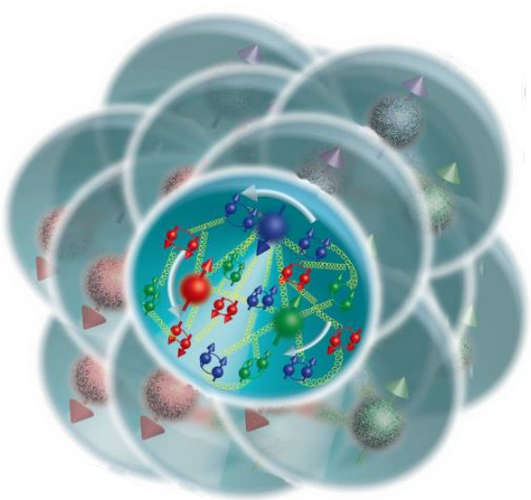
Quarkonium spectroscopy

vary size of probe

Parton energy loss

vary mass/momentum of probe

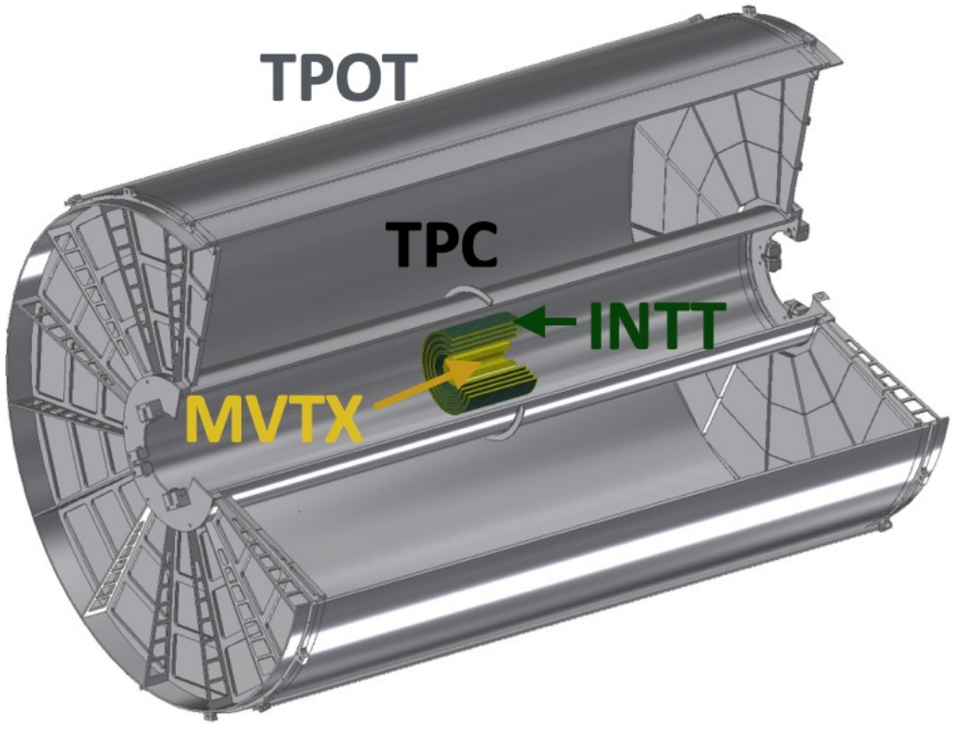


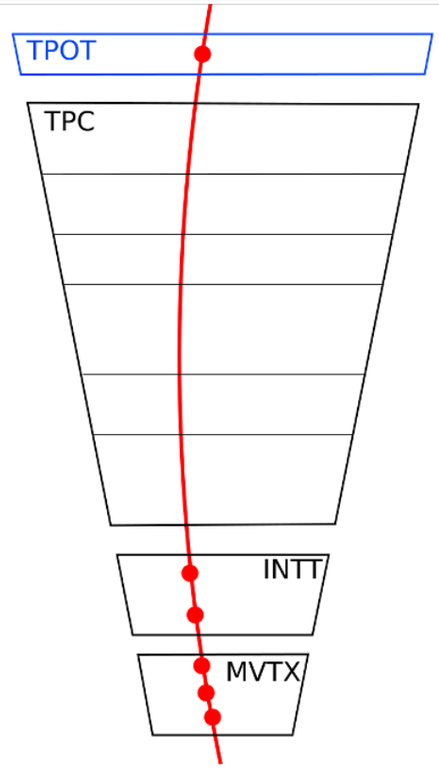


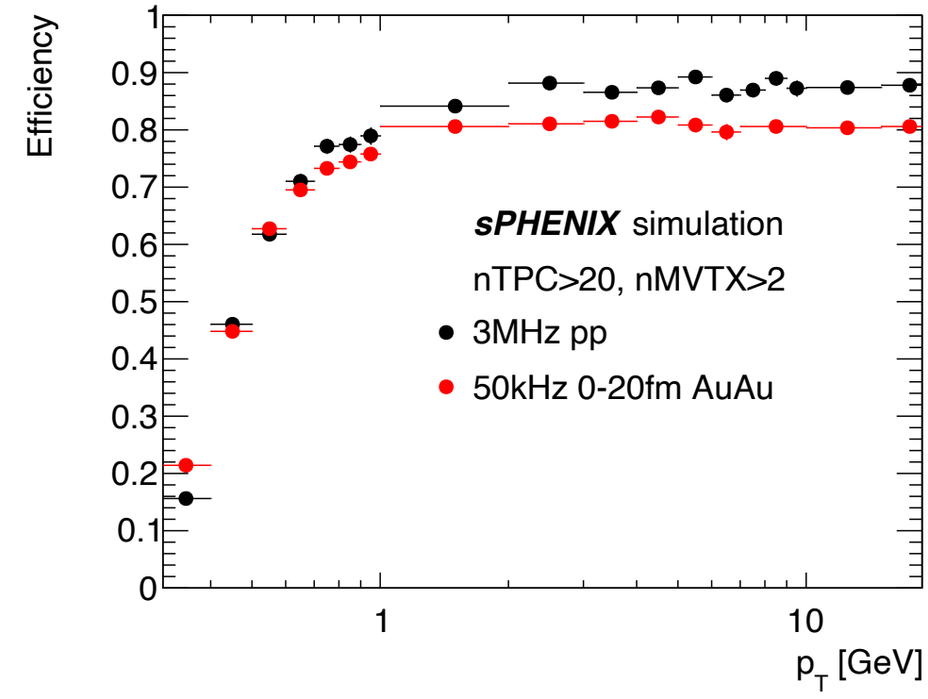
Cold QCD

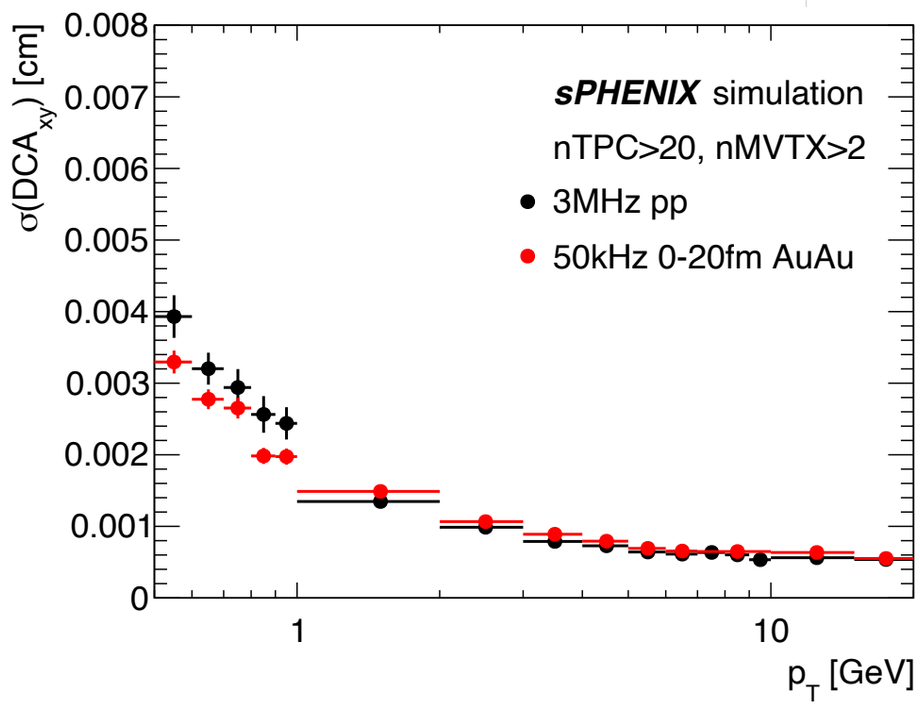
study proton spin, transverse-momentum, and cold nuclear effects

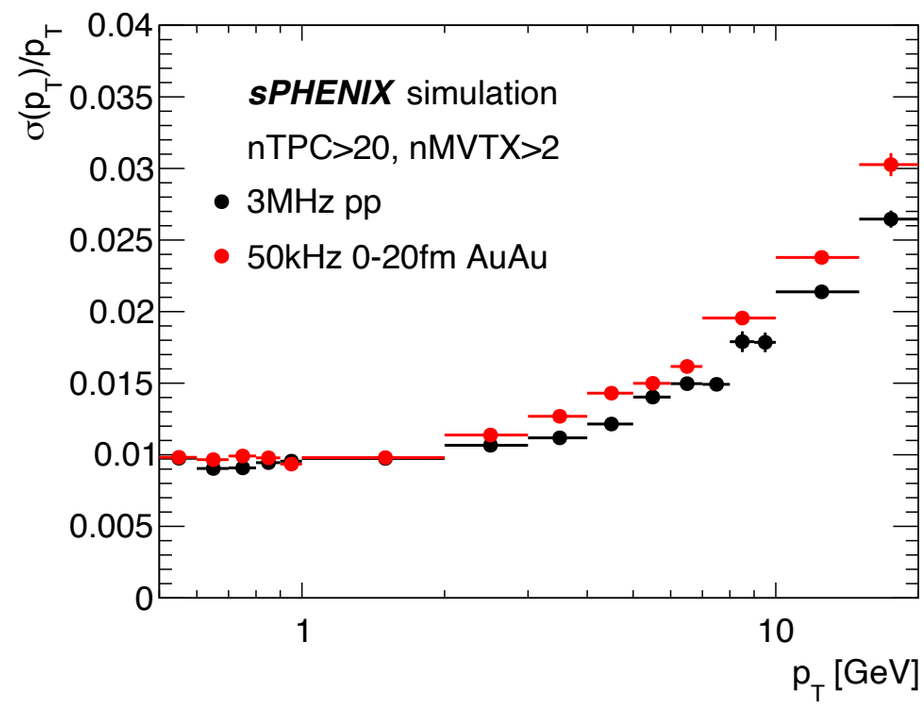
Tracking System and Performance





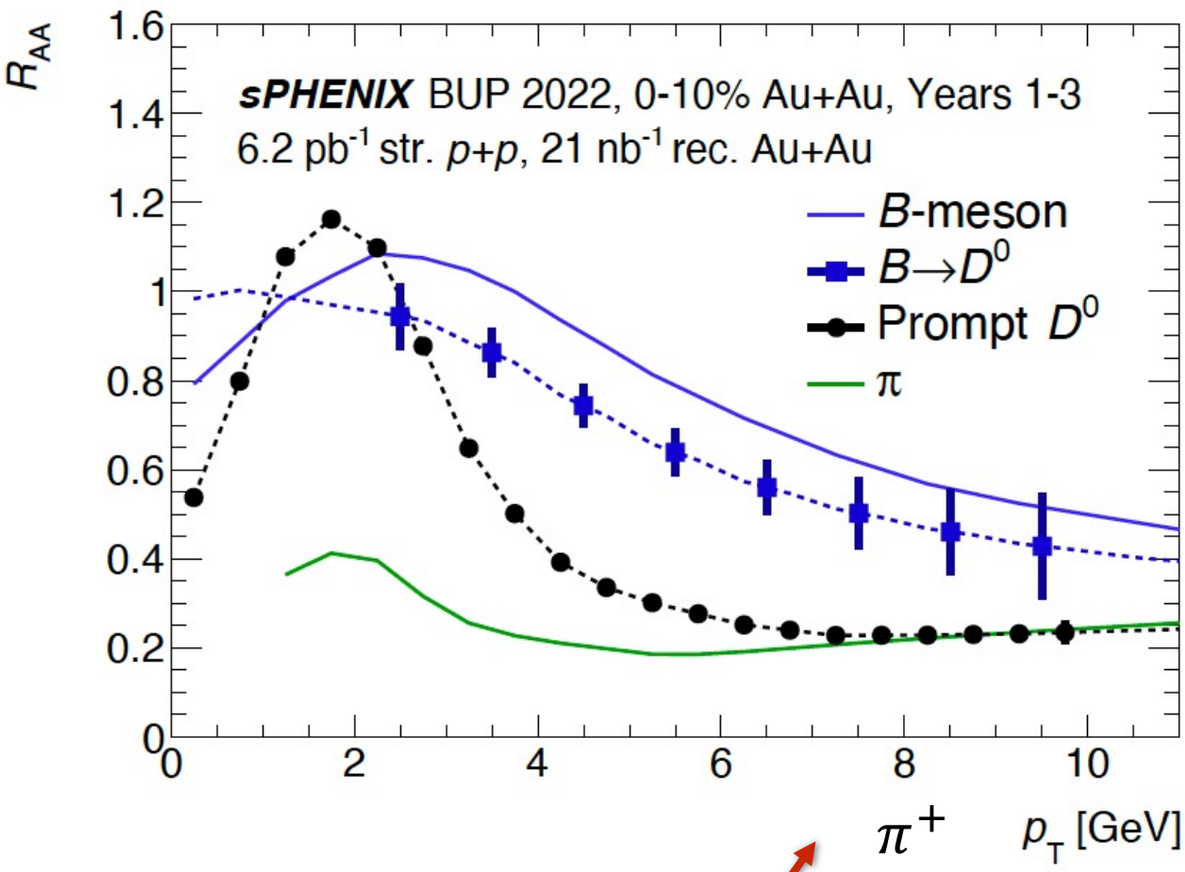


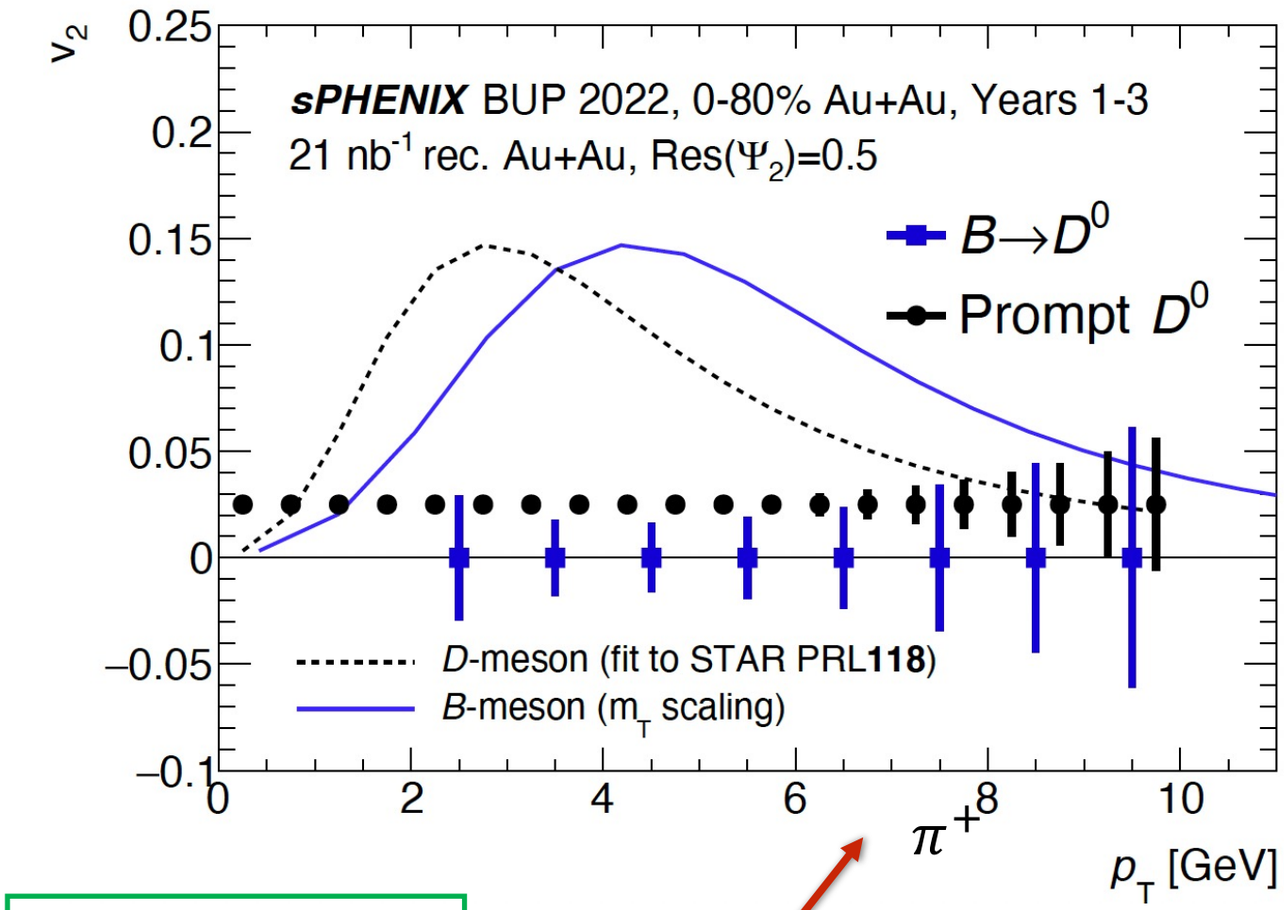




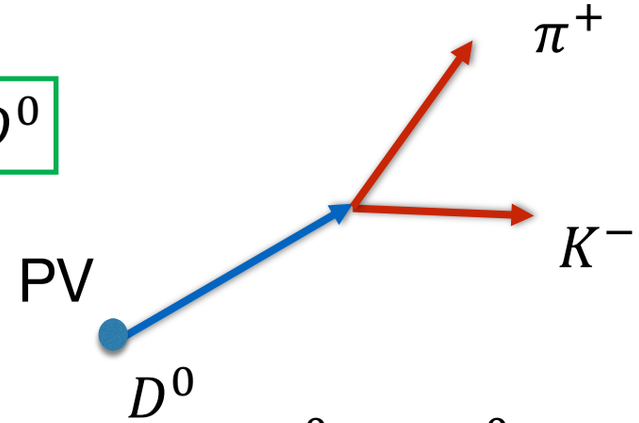
- MVTX and INTT operating in continuous streaming readout mode with advanced electronics
- TPC + TPOT as the outer tracking device for momentum determination
- Excellent tracking reconstruction and vertexing performance for HF physics studies

Fully Reconstructed D^0 R_{AA} and v_2

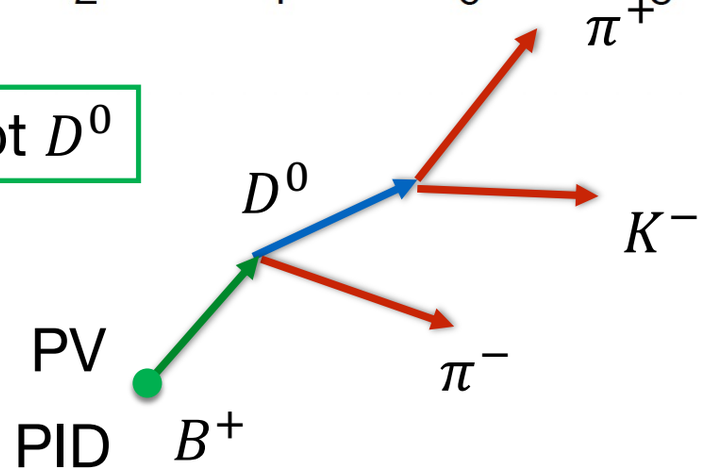




Prompt D^0

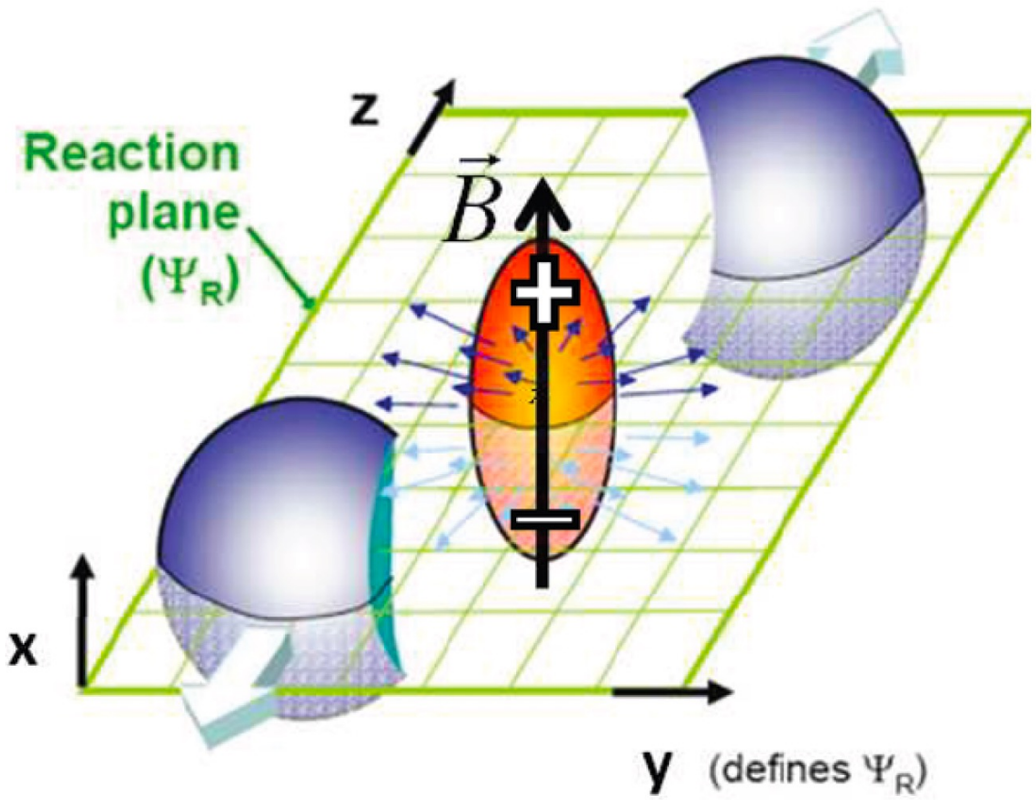


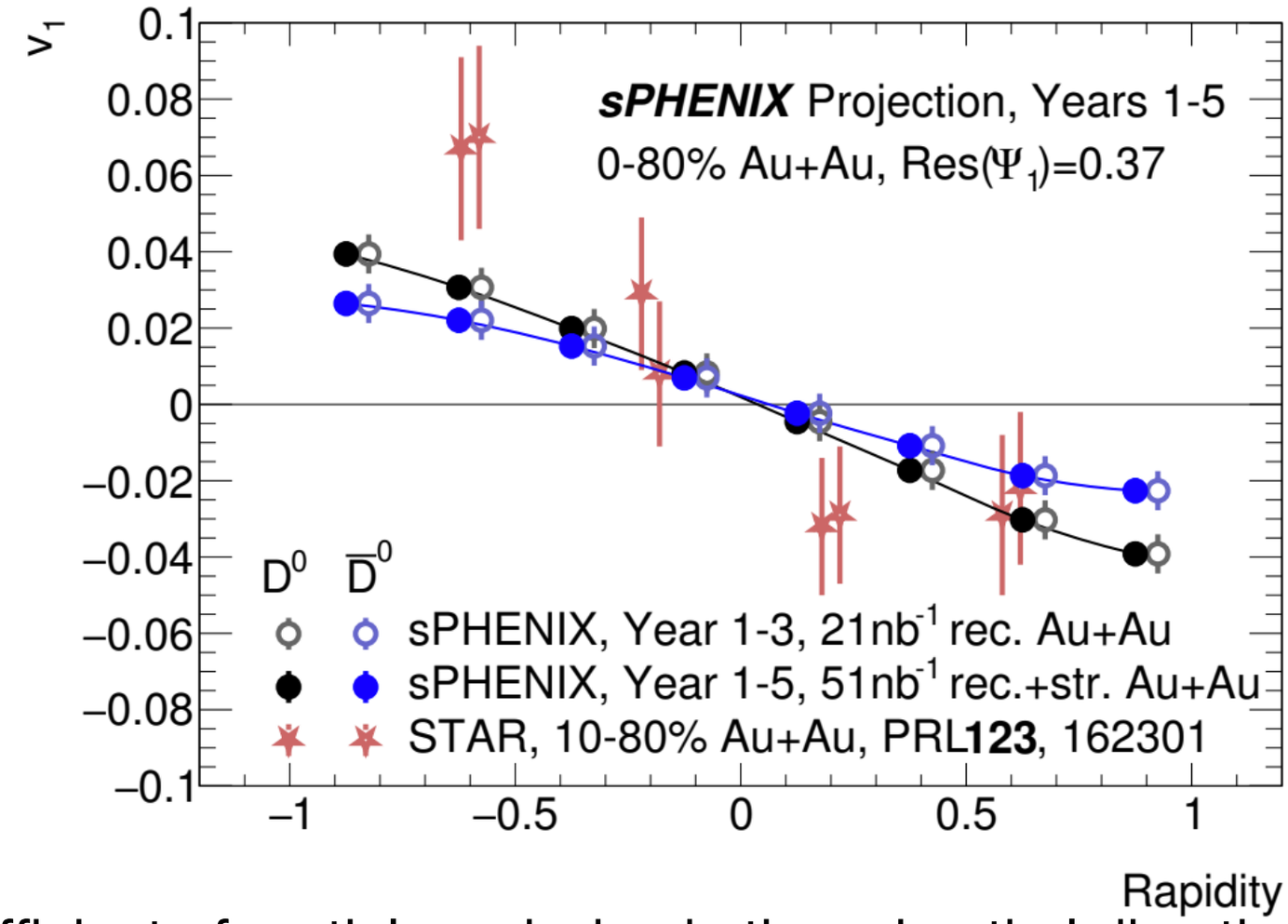
Non-Prompt D^0



- 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

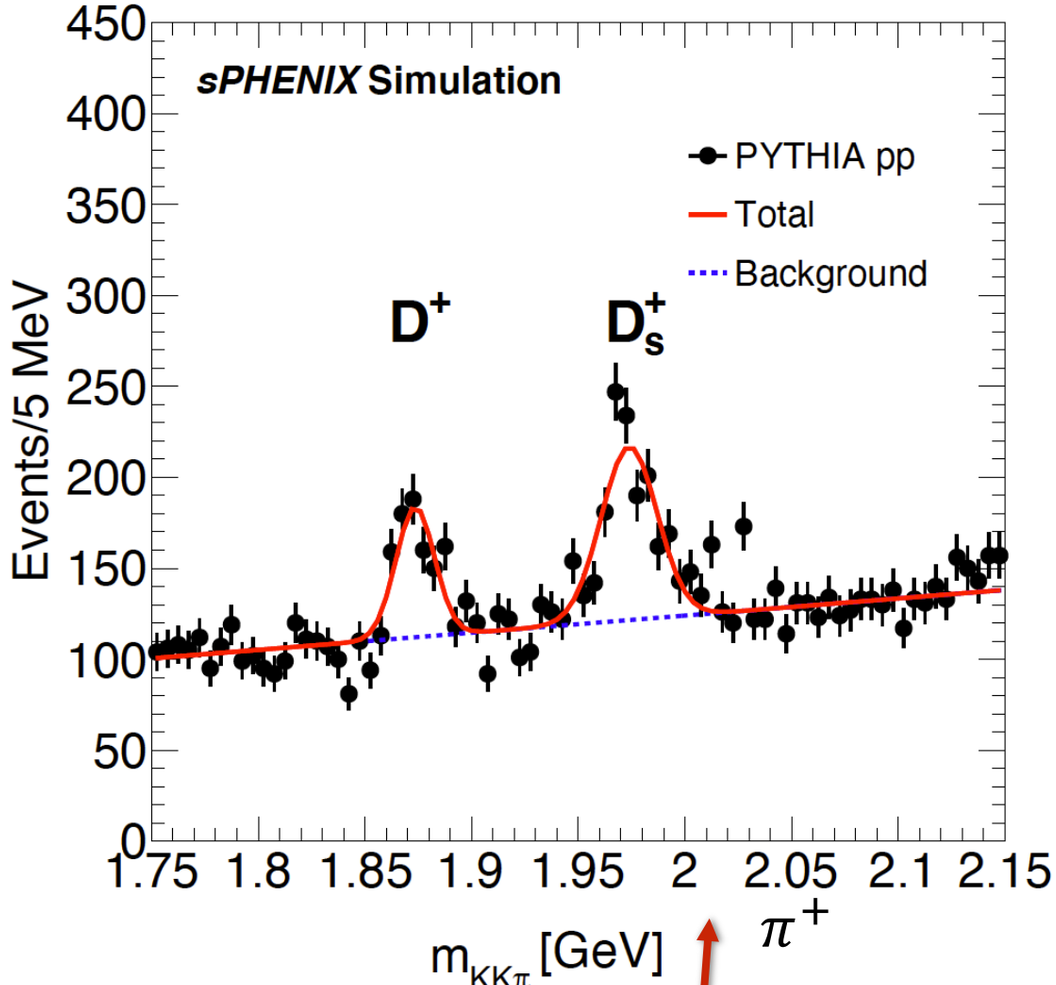
D-meson Directed Flow v_1

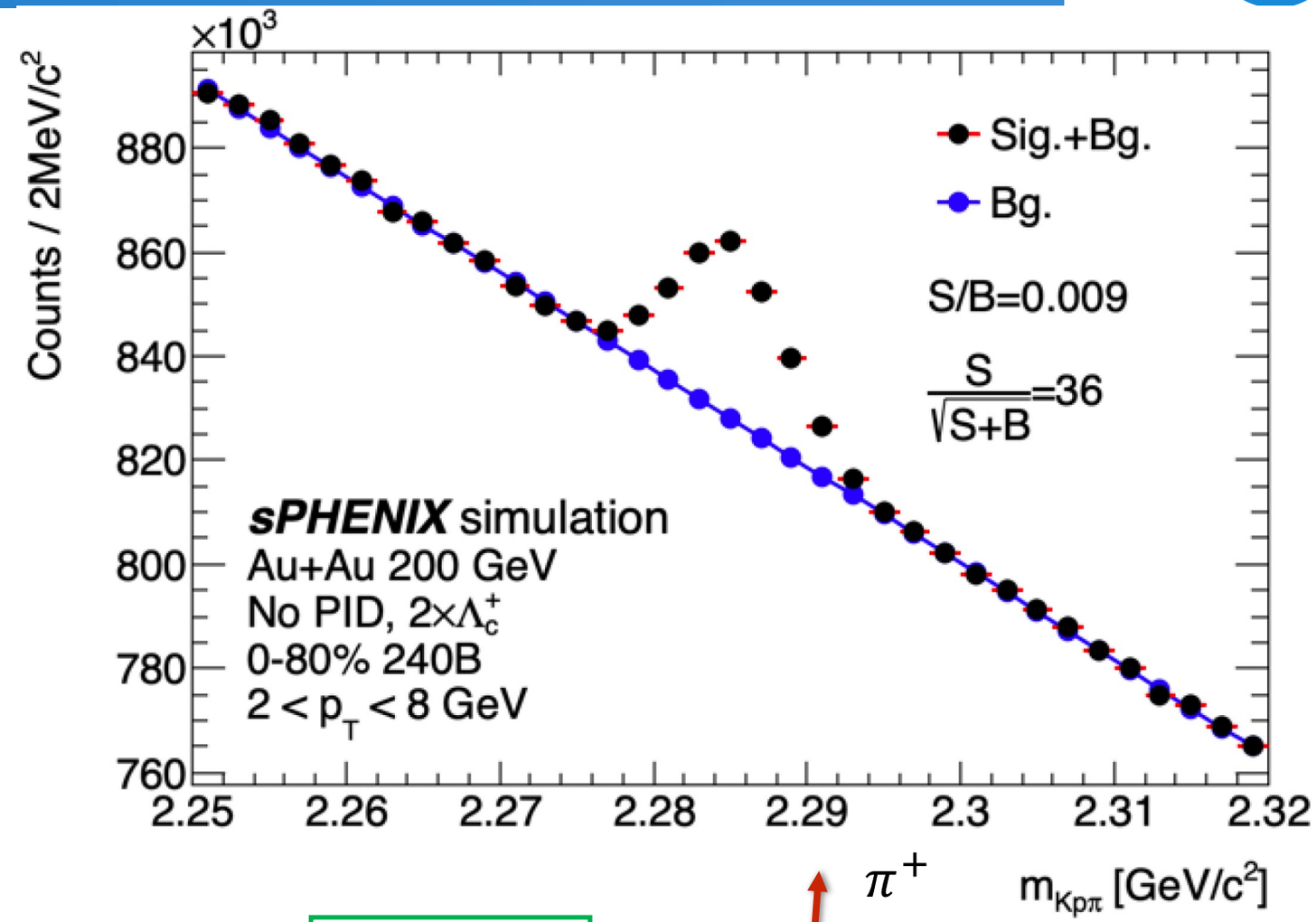




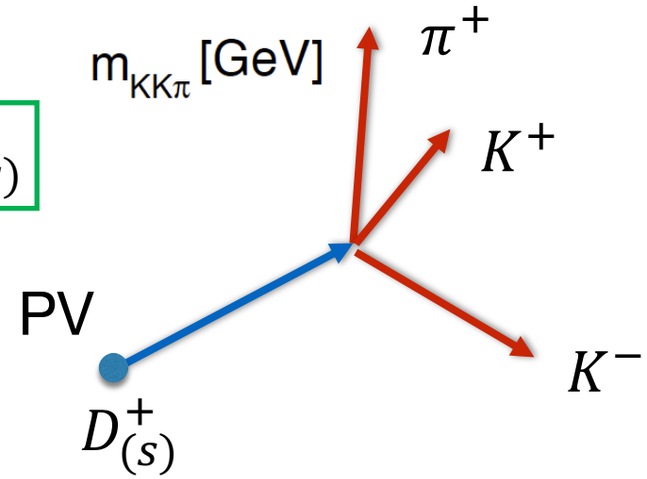
- Directed flow v_1: first order Fourier coefficient of particle emission in the azimuthal direction with respect to the reaction plane in heavy-ion collisions
- Relatively large mass of charm quark
  - Predominantly produced in early hard scattering processes
  - Long thermal relaxation time
  - Induce larger v_1 due to the Lorentz force
- D-meson v_1 sensitive the initial tilt and pressure asymmetry due to non-equilibrium effects in the initial stage of heavy ion collisions
  - Novel probe of the spacetime evolution of the initial magnetic field in heavy-ion collisions

D_s^+/D^+ and Λ_c^+/D^0 Ratios

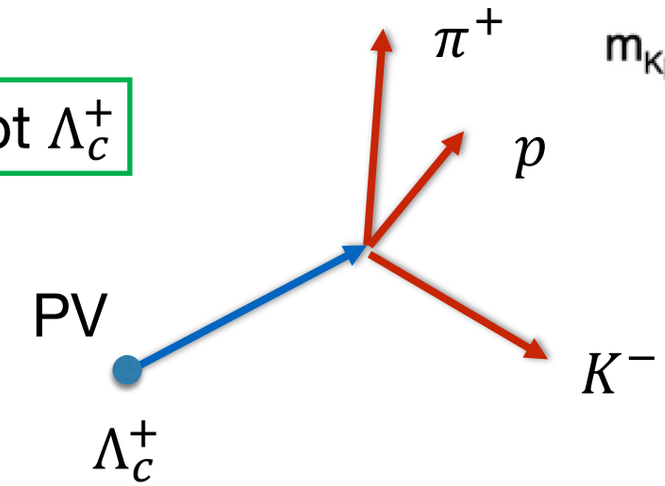




Prompt $D_{(s)}^+$



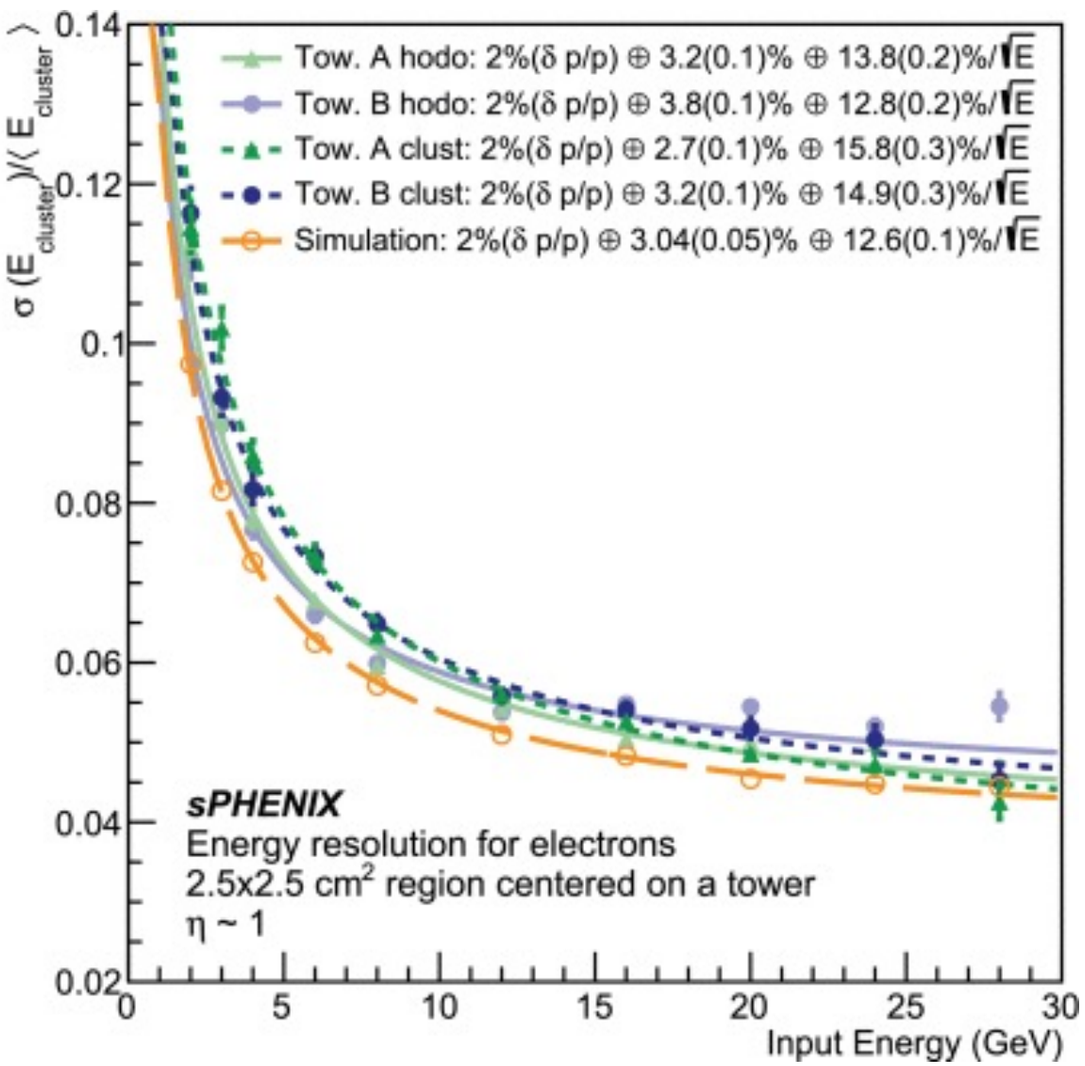
Prompt Λ_c^+



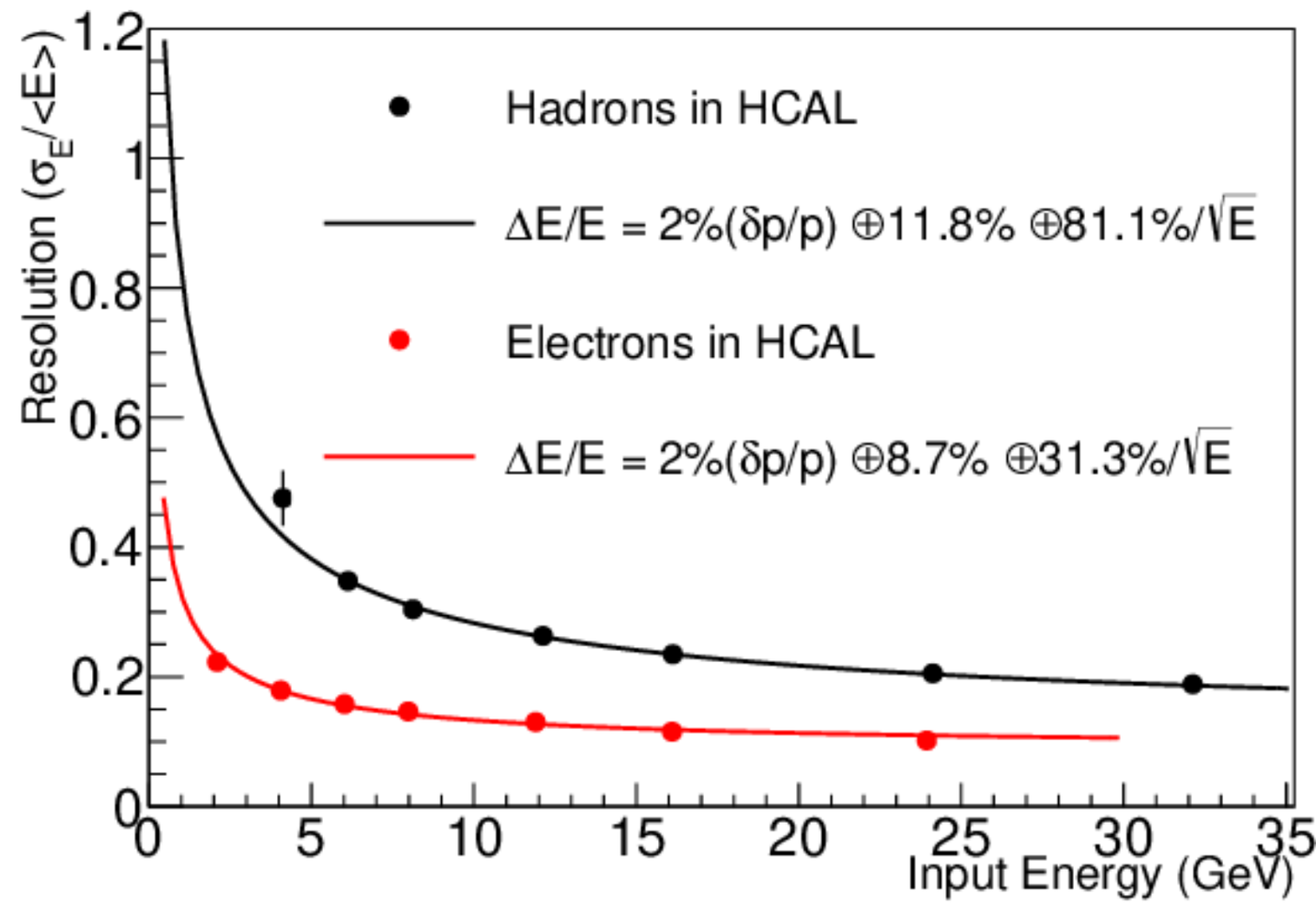
- More complex 3-prong decays
- High precision measurement thanks to streaming readout data taking and tracking
- Study charm hadronization from vacuum to QGP via the measurements of D_s^+/D^+ and Λ_c^+/D^0 as a function of event multiplicity

Calorimeter System Performance

EMCAL



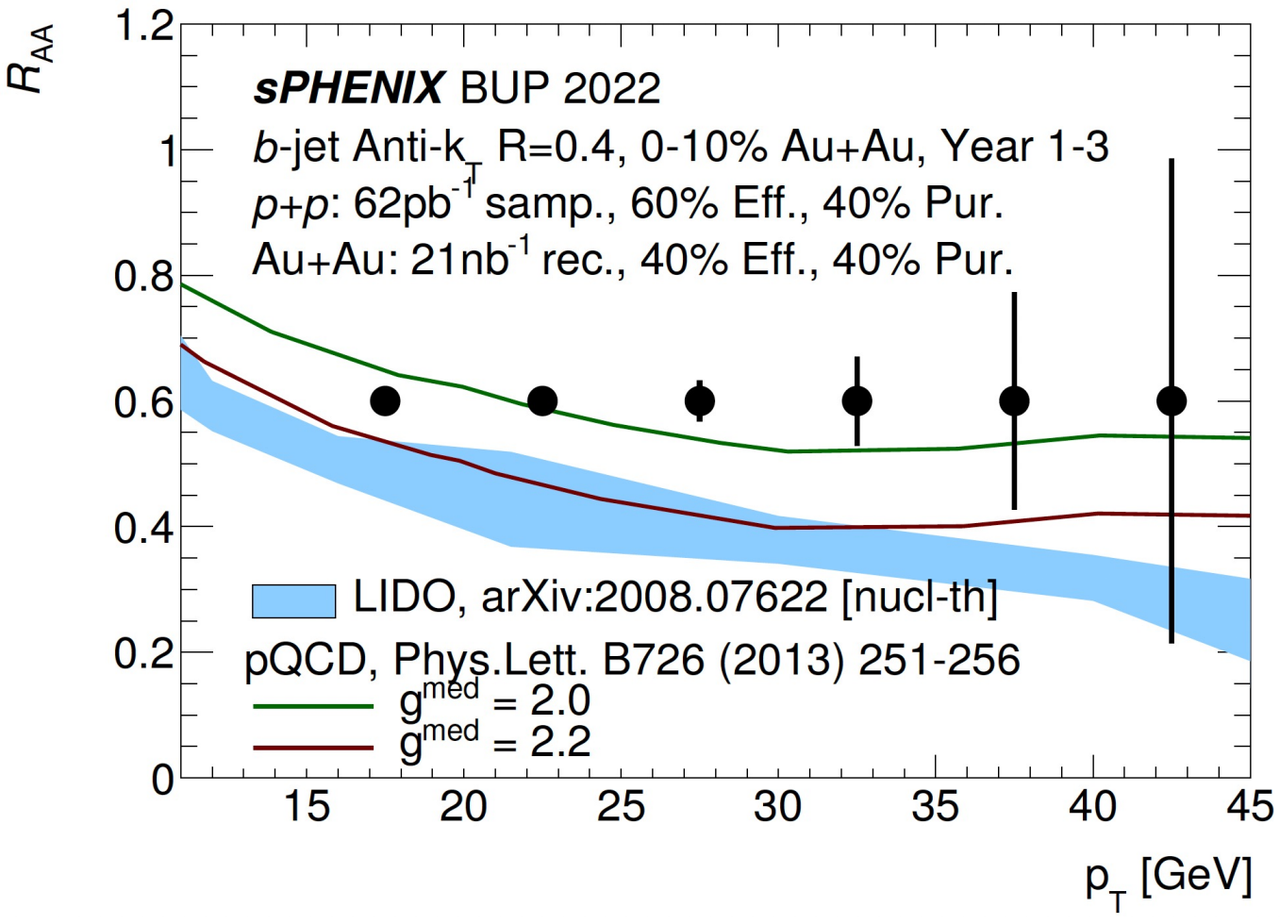
HCAL

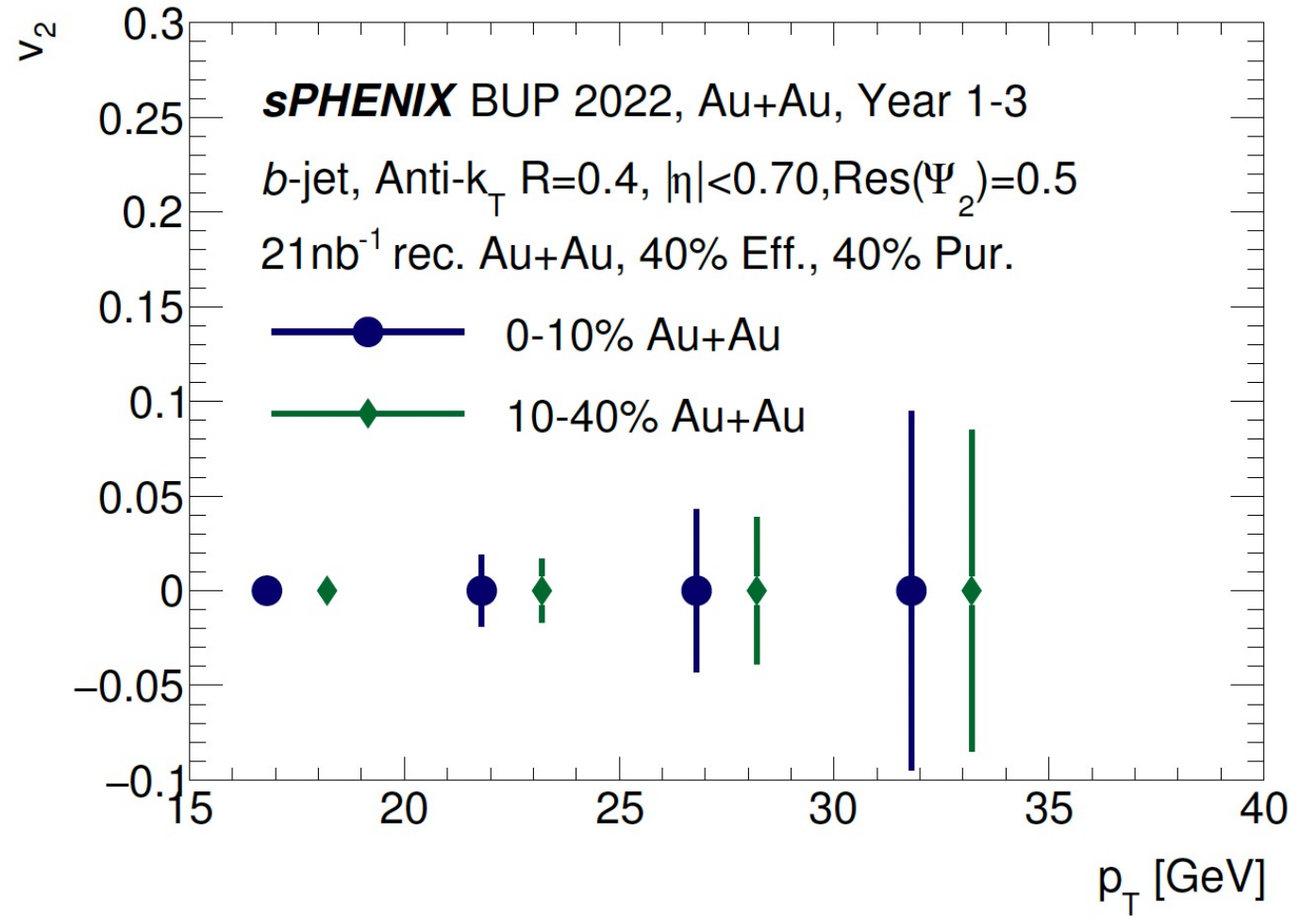


(b)

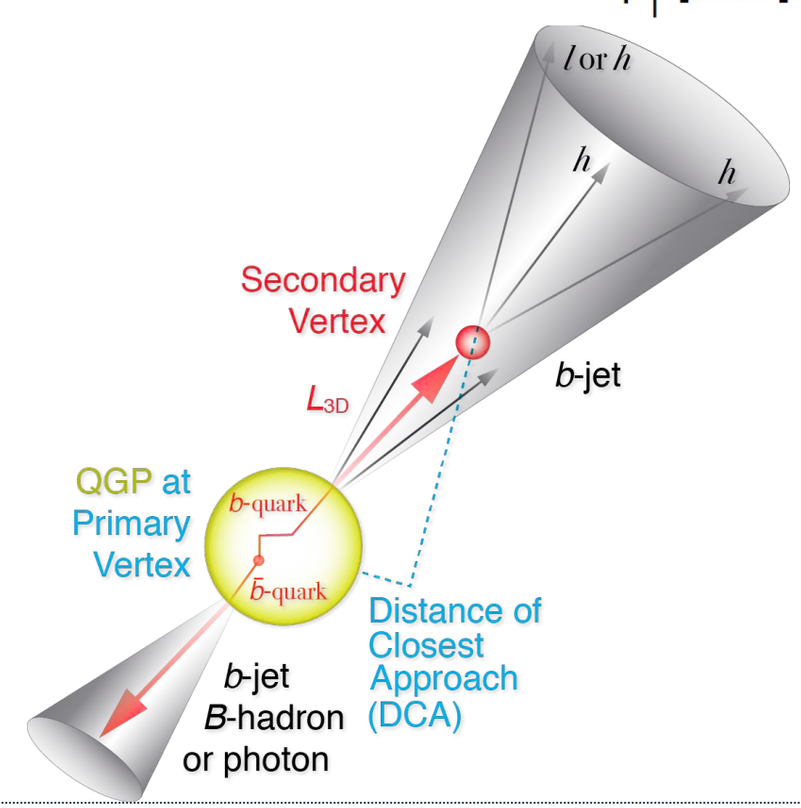
- High p_T trigger implemented to the calorimeter system dedicated for jet physics studies
- Advanced 3D topological jet clustering algorithm
- Capable of performing precision calorimetric jet measurements
- First mid-rapidity calorimetric jet measurements at RHIC

b-jet R_{AA} and v_2

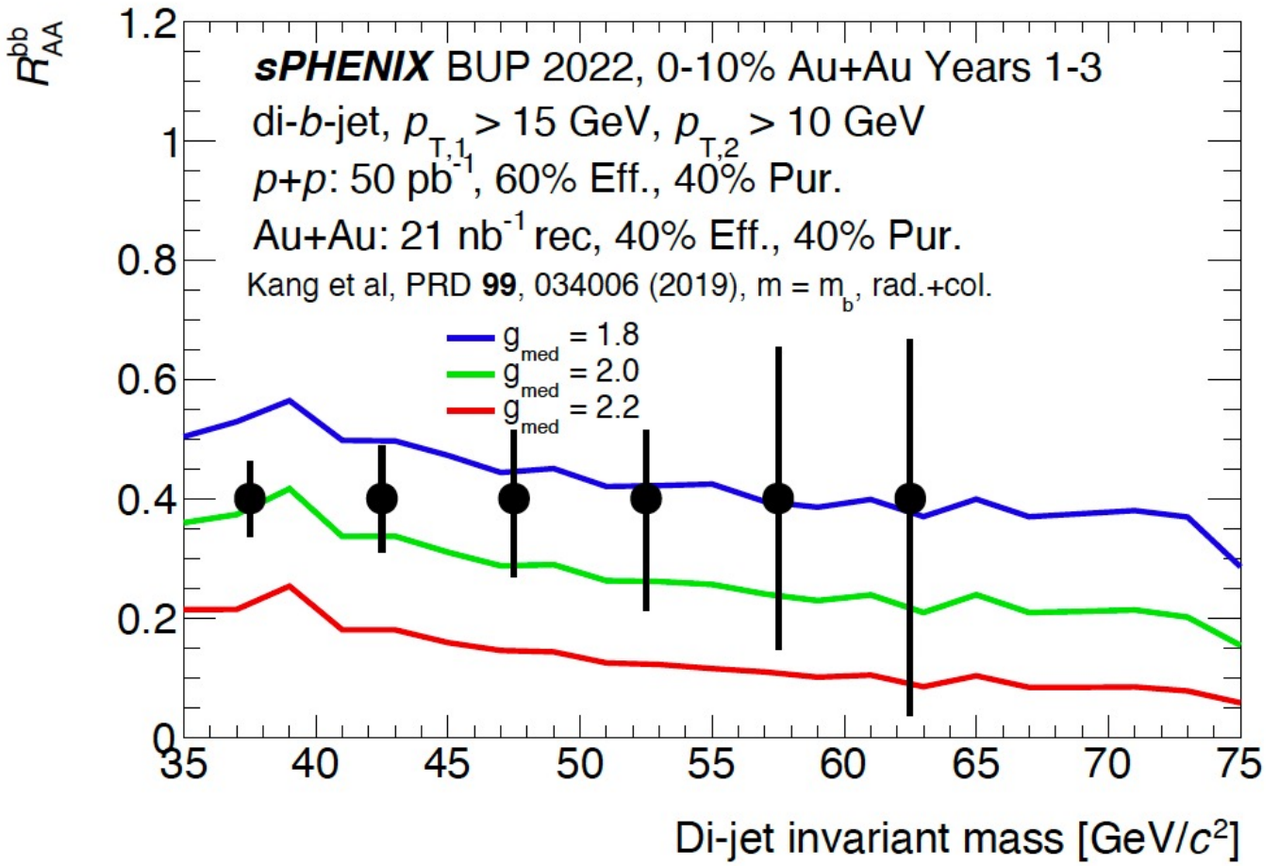


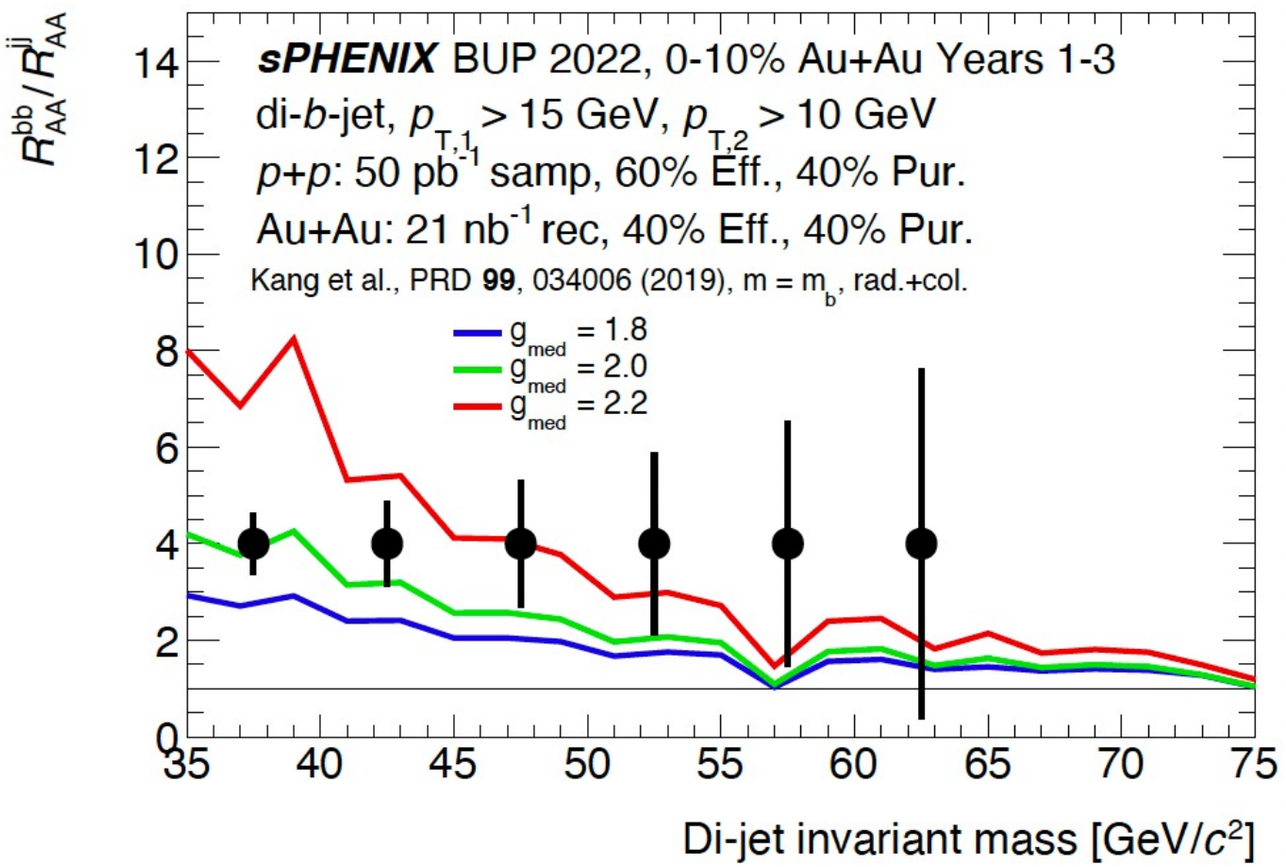


- Utilization of MVTX to reconstruct secondary vertex within the jet cone
  - Identify jets with displaced vertices to tag the b quarks
  - Inclusive measurement with better statistics
- First b-jet measurement at RHIC
- Sensitive to heavy-quark collisional and radiative in-medium energy loss
- Pathlength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



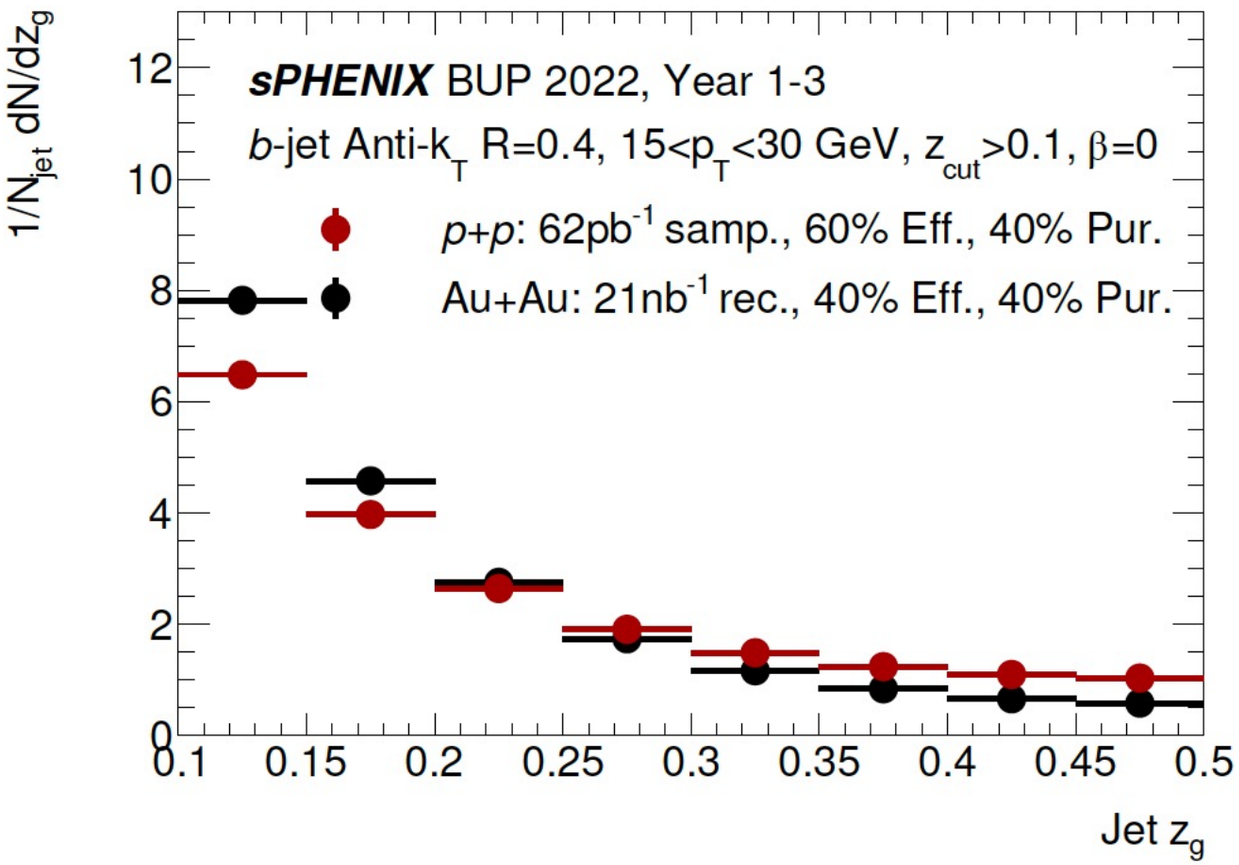
Di-b-jet Invariant Mass

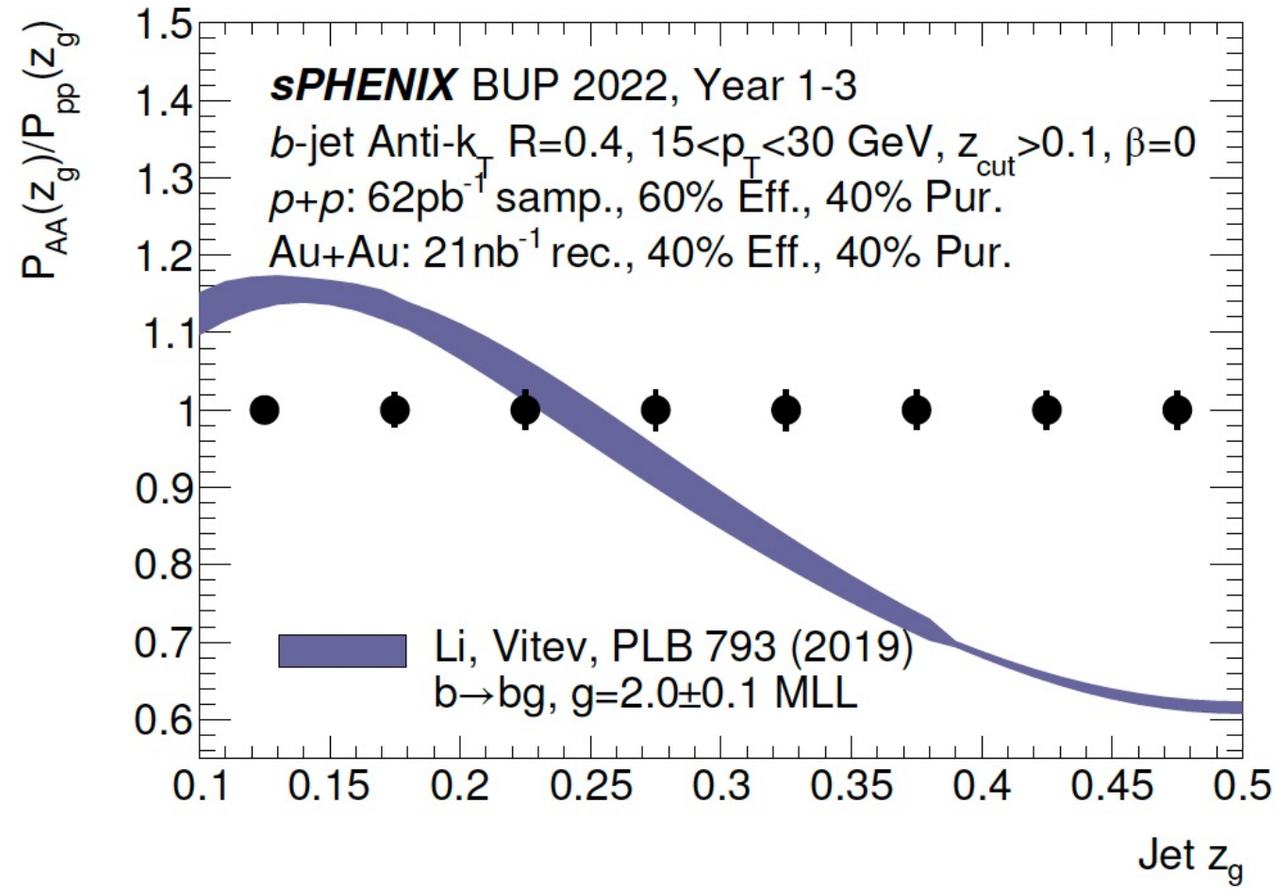




- Back-to-back b-jet pairs studies enabled by the large detector acceptance and multi-observable capabilities
  - Precision di-b-jet R_{AA} as a function of di-jet invariant mass measurement
- Pinpoint the propagation of beauty quarks in the QGP
- Extract beauty quark coupling parameter to the medium
- Complementary to LHC di-b-jet balance measurements

b-jet Splitting Function z_g

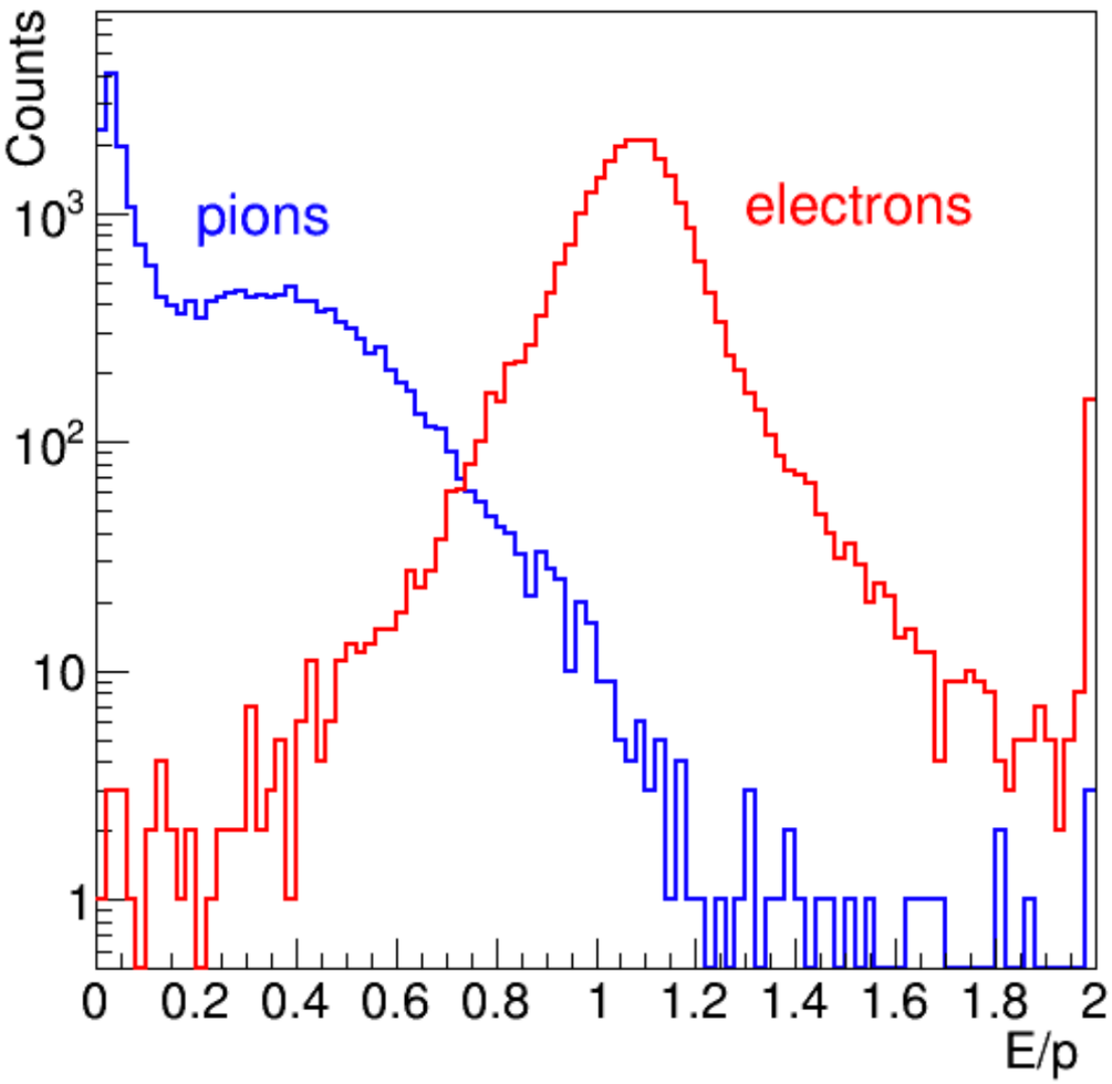


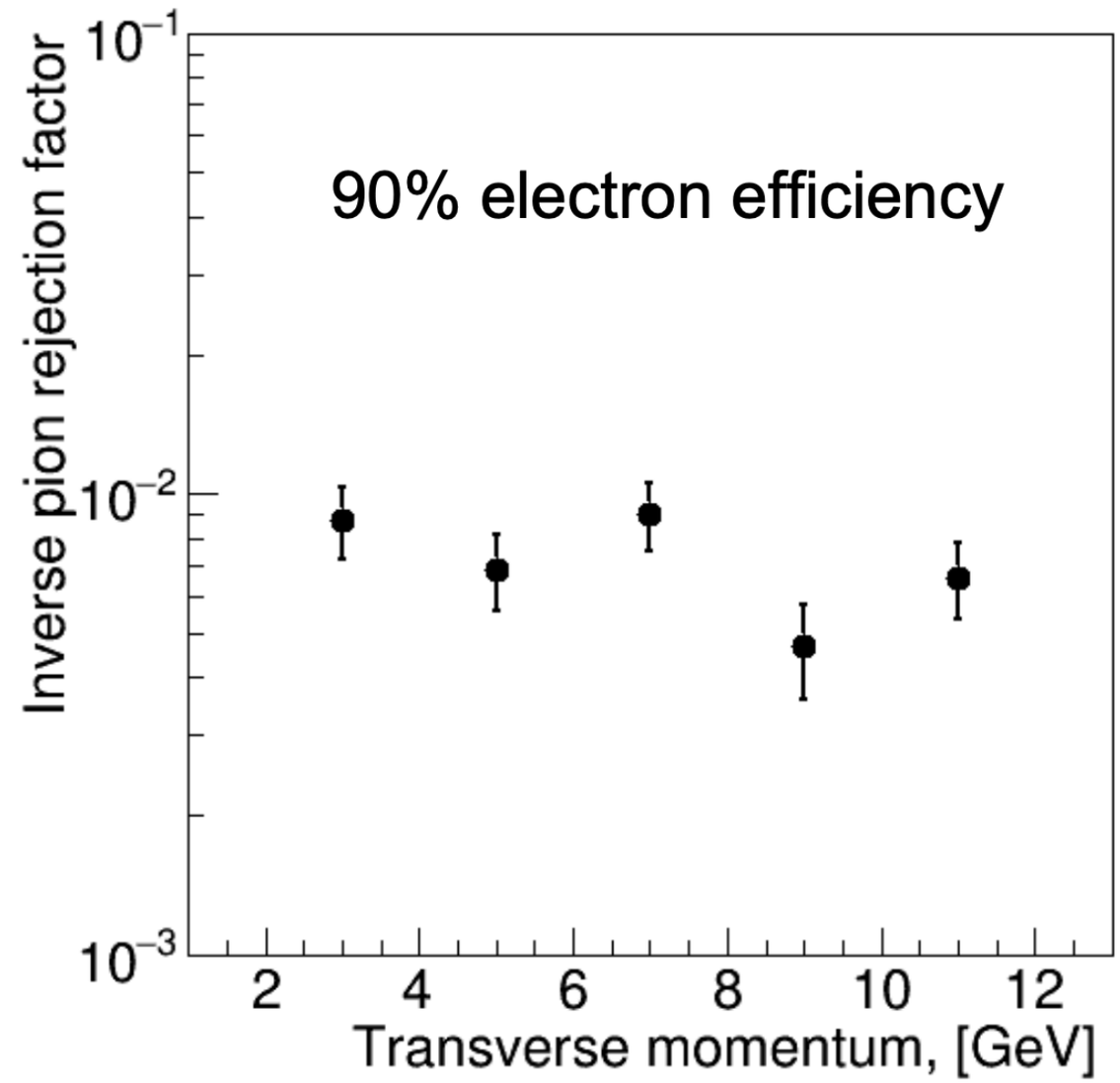


- Differential subjet splitting function measurements thanks to the large dataset statistics
- Test pQCD model calculations in $p + p$ collisions
- Quantify the medium modification of b-jets in the sPHENIX kinematic region
- Complementary to LHC jet substructure measurements

Electron Identification Capabilities

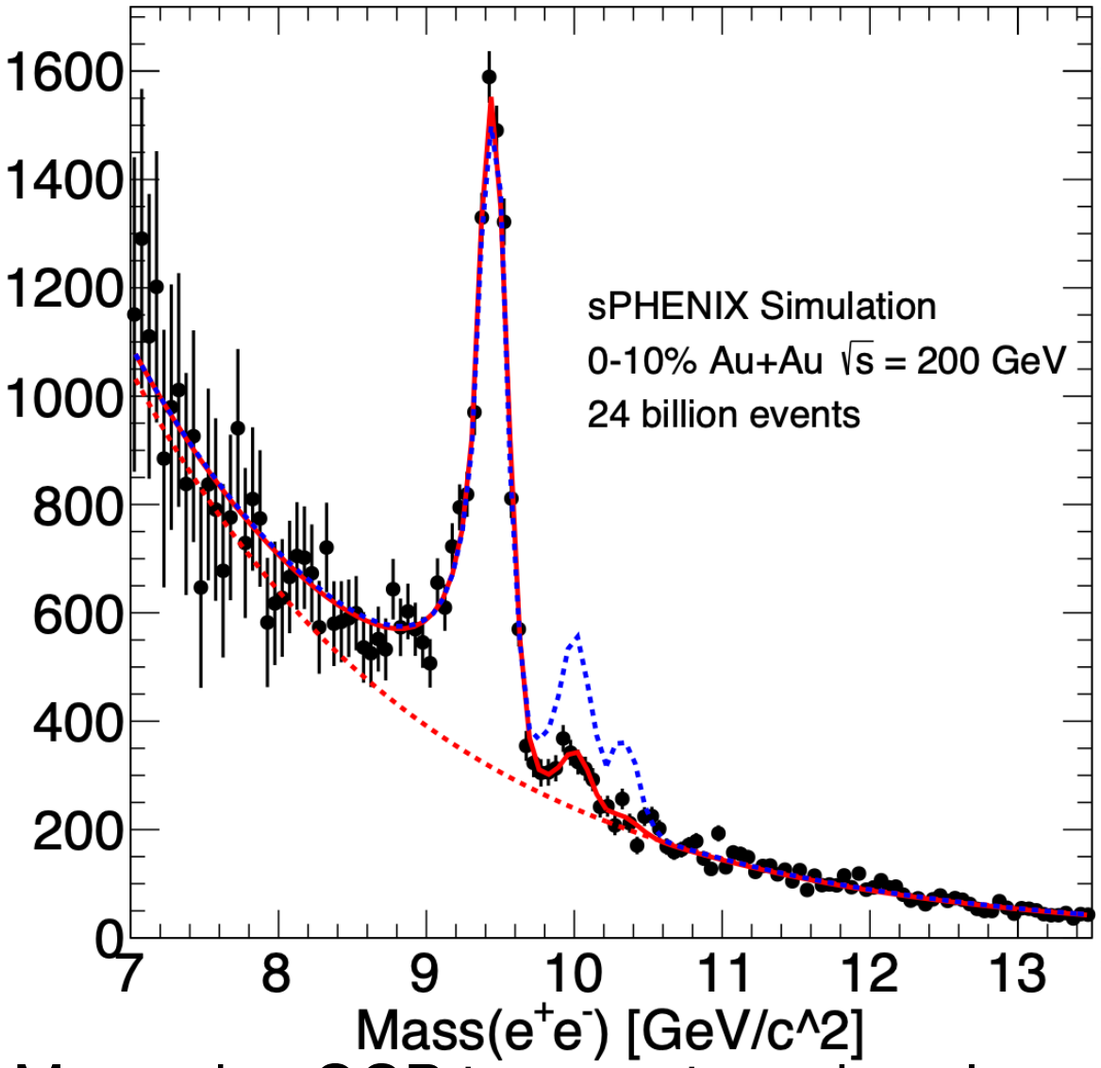
Minimum Bias $\sqrt{s} = 200$ GeV Au + Au Events

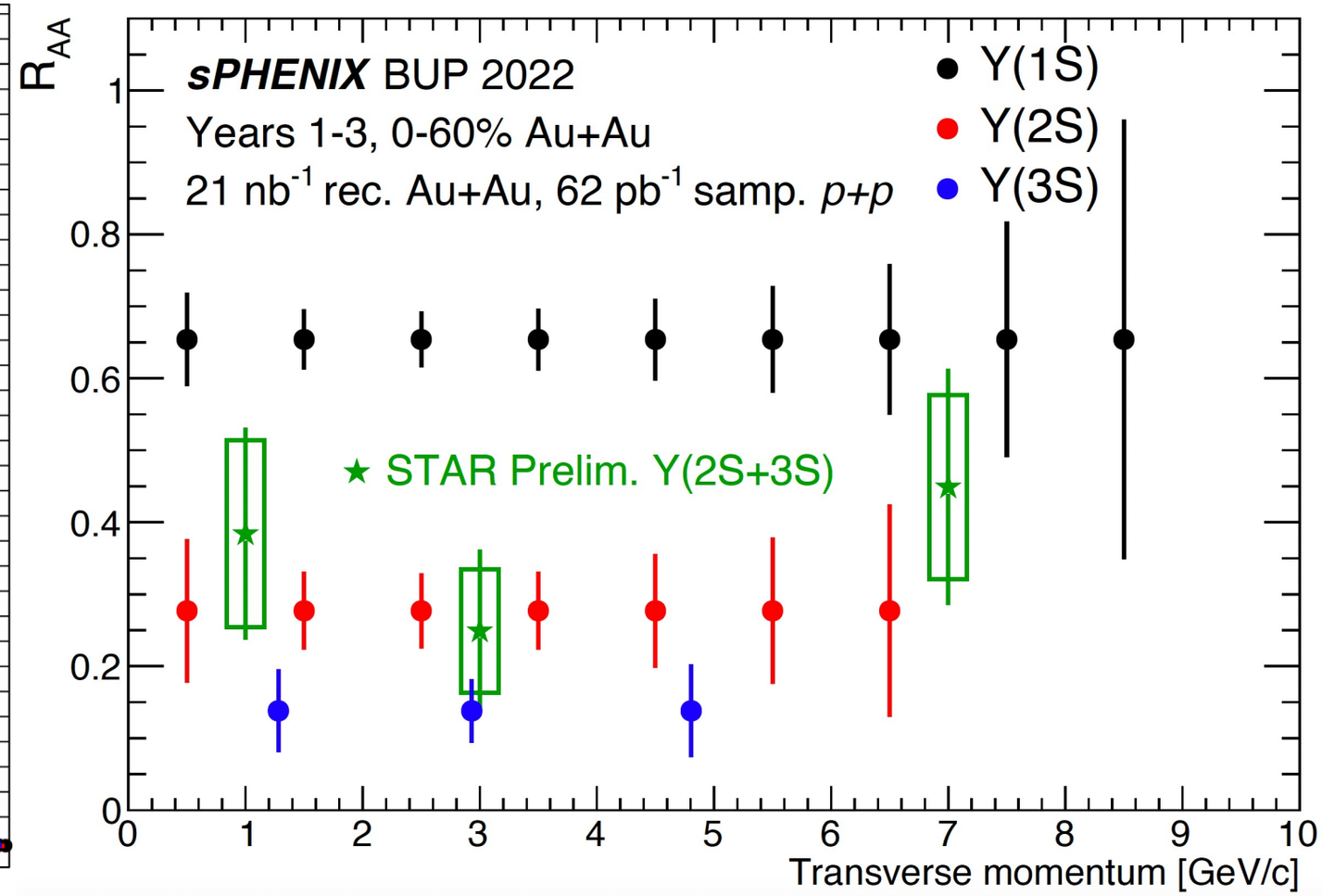


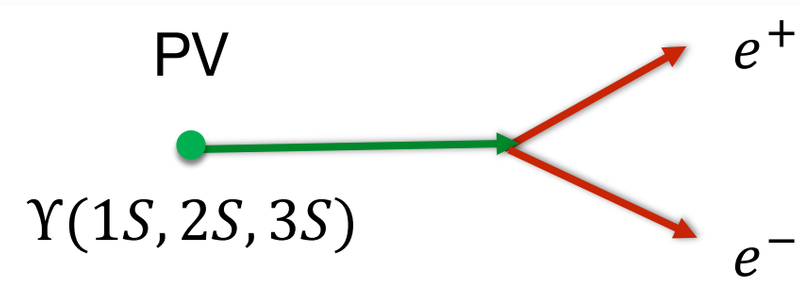


- Use shower core energy information from central EMCAL and HCAL for e/h separation
- Working point: EMCAL/p > 0.9 and iHCAL/EMCAL < 0.2 to maintain 90% electron efficiency
- Excellent electron identification capabilities for quarkonia background rejection
- Improvement with machine learning techniques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

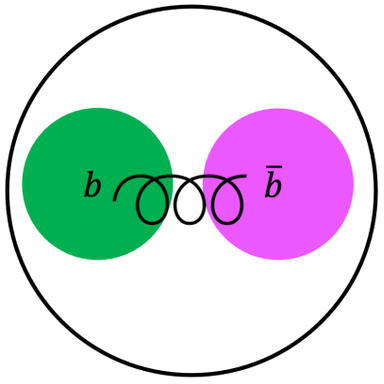
Upsilon Spectroscopy

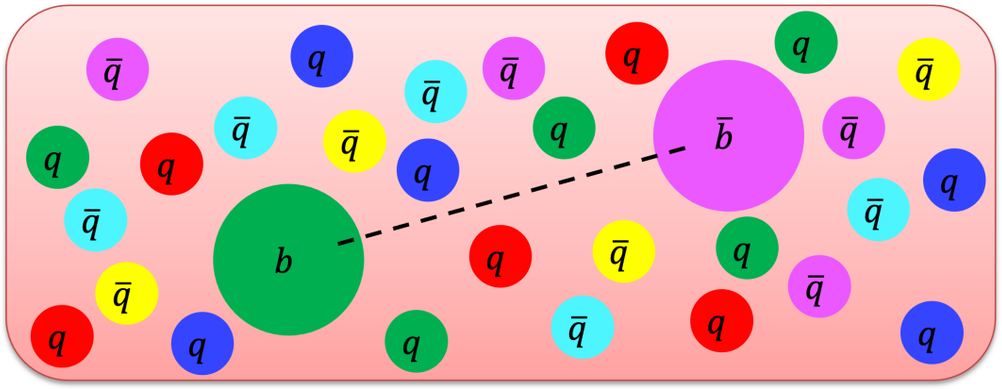






- Measuring QGP temperature via color screening effect
- Excellent mass resolution in the dielectronic decay channel
- R_{AA} measurement with high precision
- Potential observation of $\Upsilon(3S)$ at RHIC, complementary with CMS $\Upsilon(3S)$ measurement at the LHC





Summary

The sPHENIX Experiment at RHIC

- Physics program: jets, **open heavy flavor**, **quarkonia**, cold QCD
- Detector installation in interaction region in progress

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 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
  - Thermometer of QGP
  - Potential observation of $\Upsilon(3S)$ at RHIC

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

Thank You

- This work is supported by the United States Department of Energy Office of Science and Los Alamos National Laboratory Laboratory Directed Research & Development (LDRD)

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

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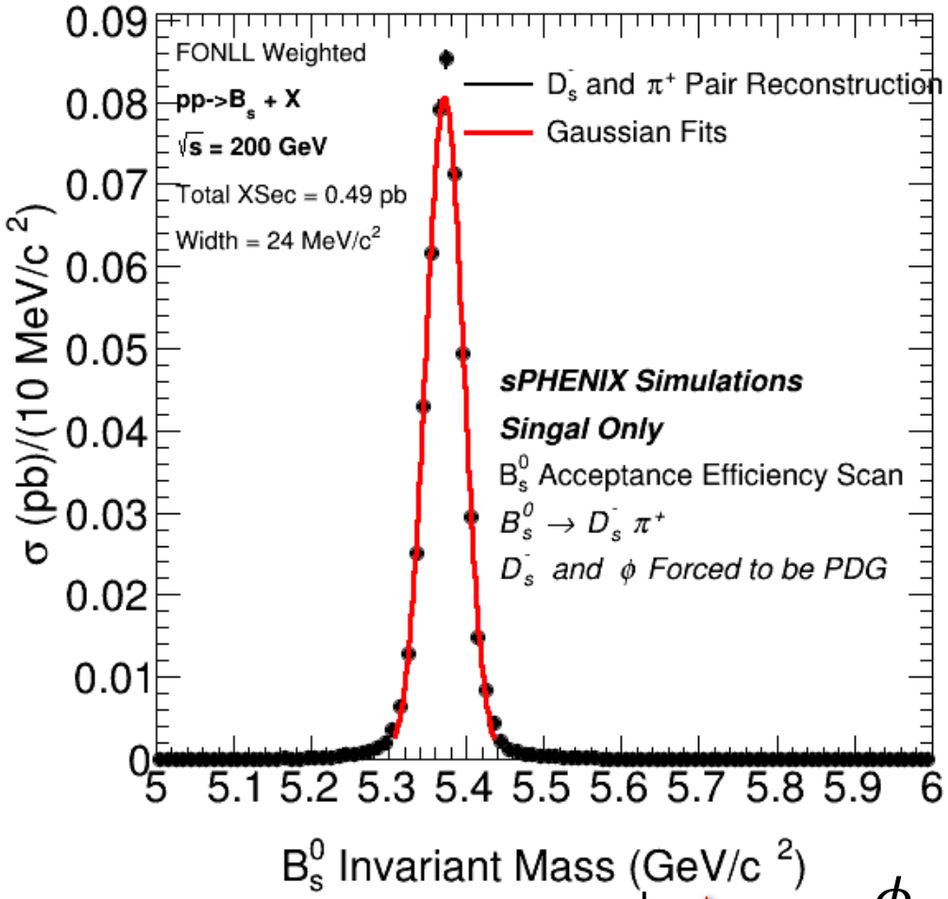
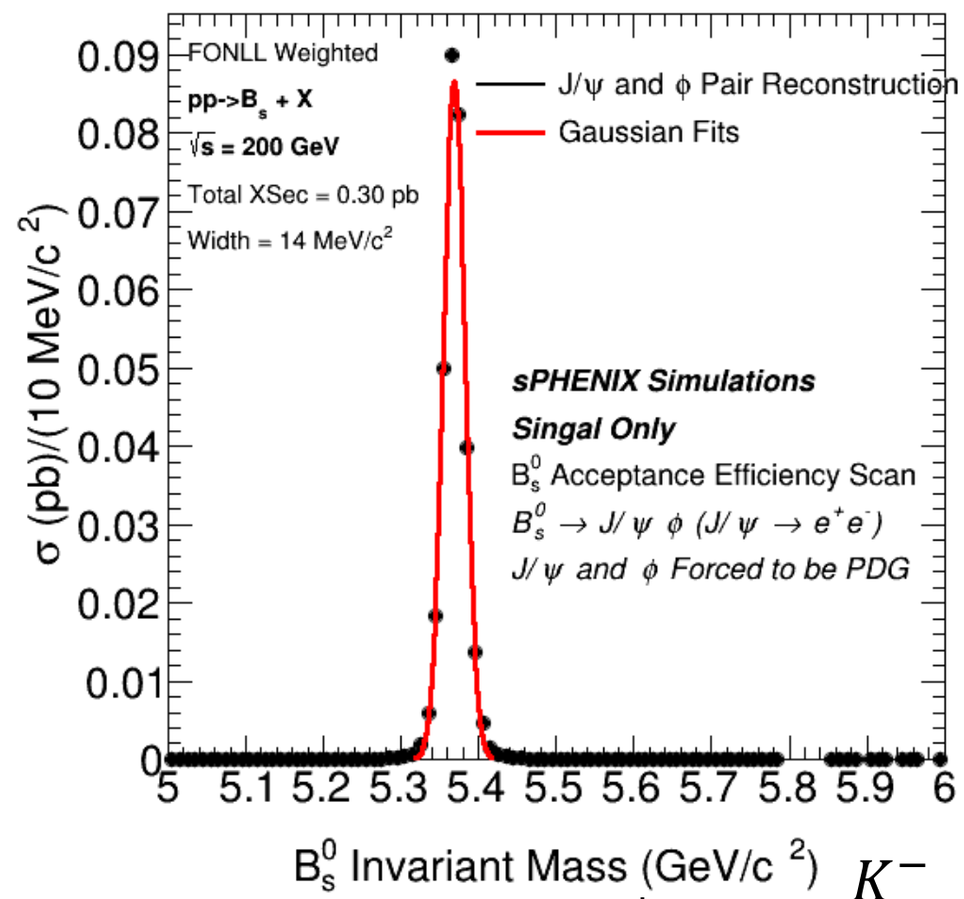
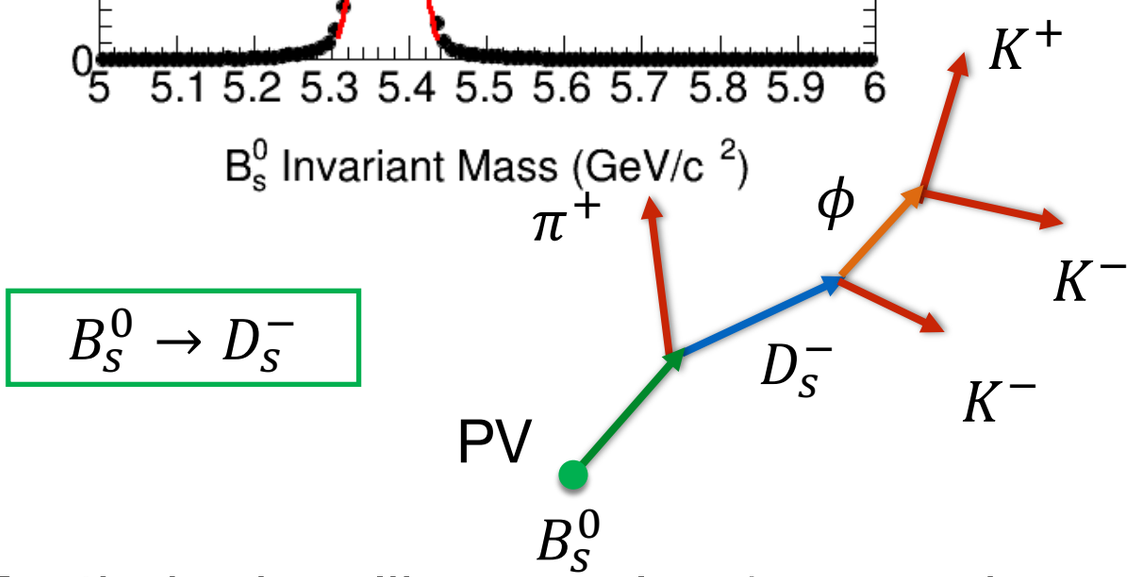
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

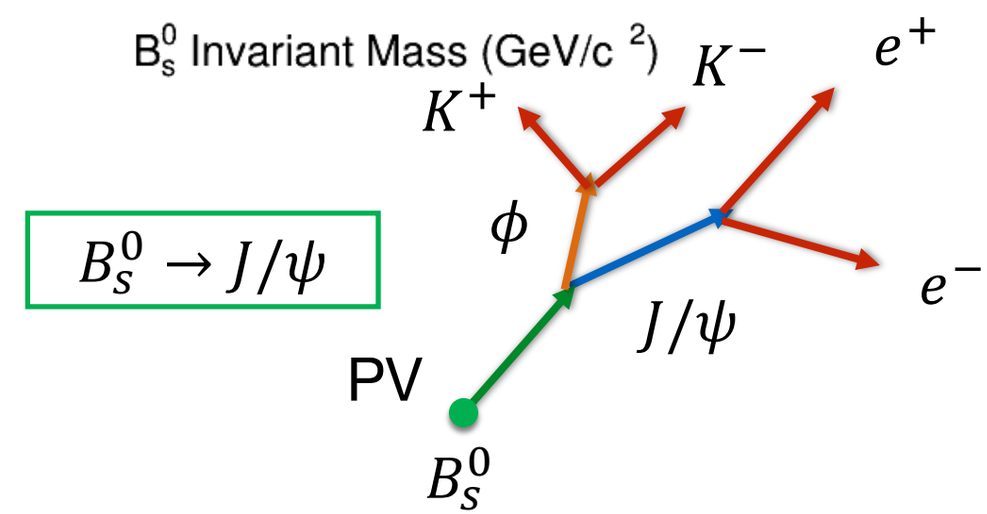
Back Up

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