Heavy flavor physics at the sPHENIX experiment

Xuan Li (xuanli@lanl.gov) on behalf of the sPHENIX collaboration

Los Alamos National Laboratory

The VII-th International Conference on the **Initial Stages** of High-Energy Nuclear Collisions (IS2023), Copenhagen.

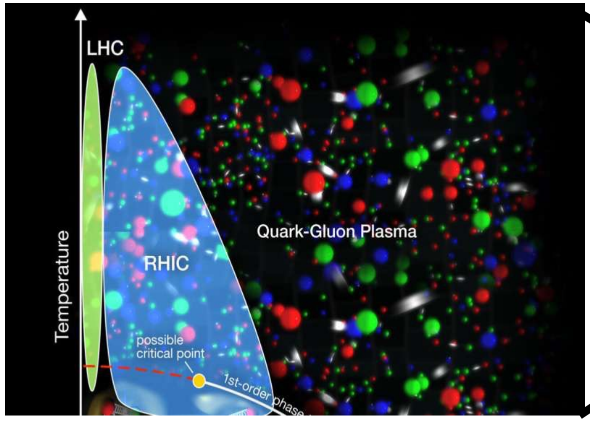
Outline

- Introduction of the sPHENIX experiment.
- sPHENIX detector and performance.
- sPHENIX heavy flavor physics highlight.
- Summary and Outlook.

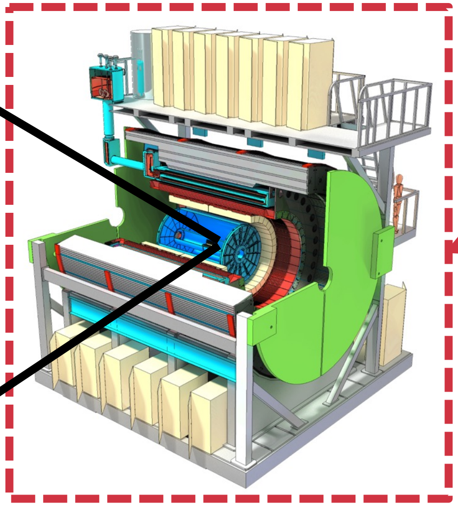
sPHENIX experiment introduction

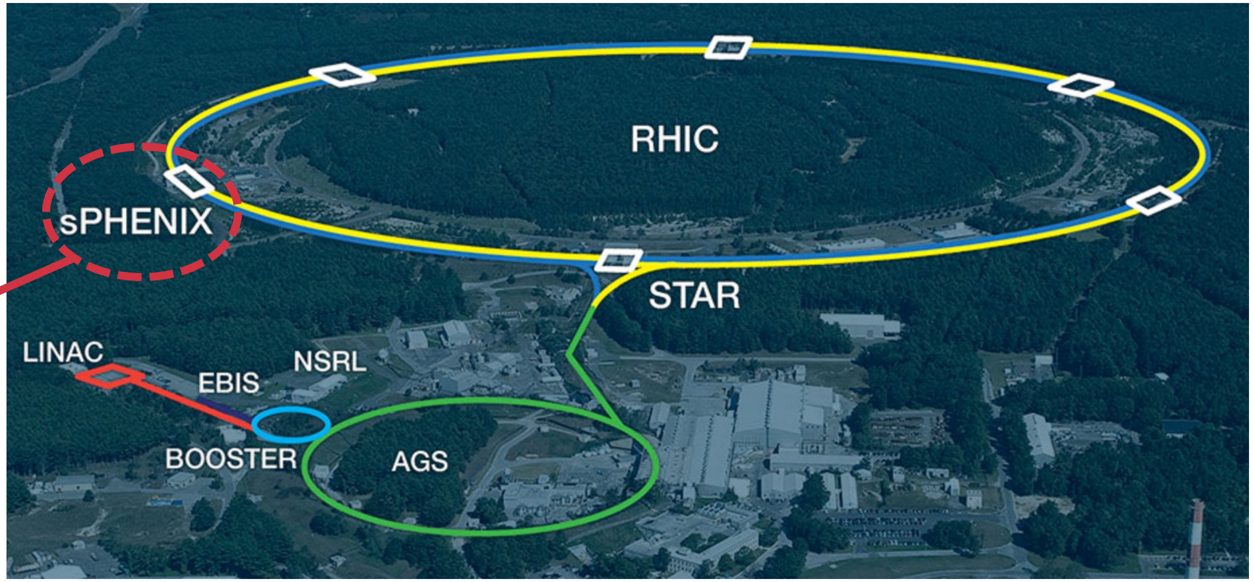
- The sPHENIX experiment at the 8 o'clock position of the Relativistic Heavy Ion Collider (RHIC) has started operation in April 2023.

Quark Gluon Plasma (QGP)



sPHENIX detector



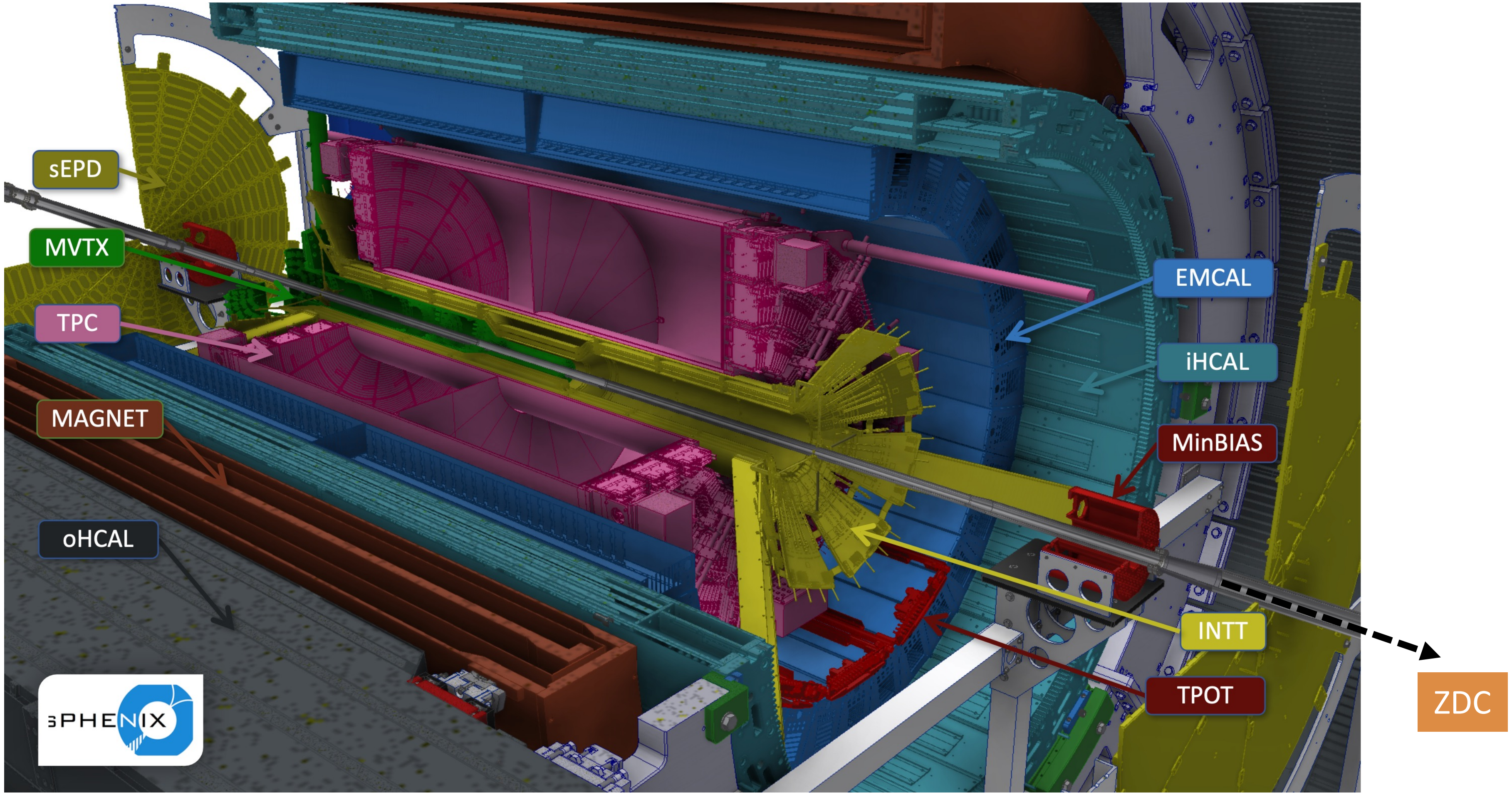


- The sPHENIX experiment will collect data of 200 GeV Au+Au collisions in 2023, 200 GeV p+p/Au collisions in 2024 and 200 GeV Au+Au collisions in 2025.
- The sPHENIX experiment will perform high precision jet, jet substructure, open and hidden heavy flavor measurements to explore the properties of the Quark Gluon Plasma (QGP), study the proton spin and cold medium effects.

sPHENIX detector overview

- The sPHENIX detector consists of high precision tracking (MVTX, INTT, TPC, TPOT), large acceptance electromagnetic (EMCAL) and hadronic calorimeters (iHCAL, oHCAL), event plane detector (sEPD) and minimum bias detectors (MBD, ZDC).

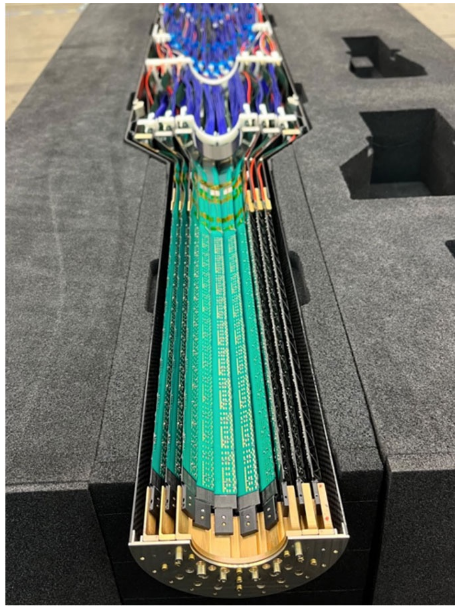
- Babar magnet: 1.4T
- Detector acceptance: $|\eta|<1.1$
- Collision rate:
  - Au+Au: 50kHz
  - p+p: 3MHz
- High rate DAQ:
  - 15kHz trigger rate
  - Streaming readout



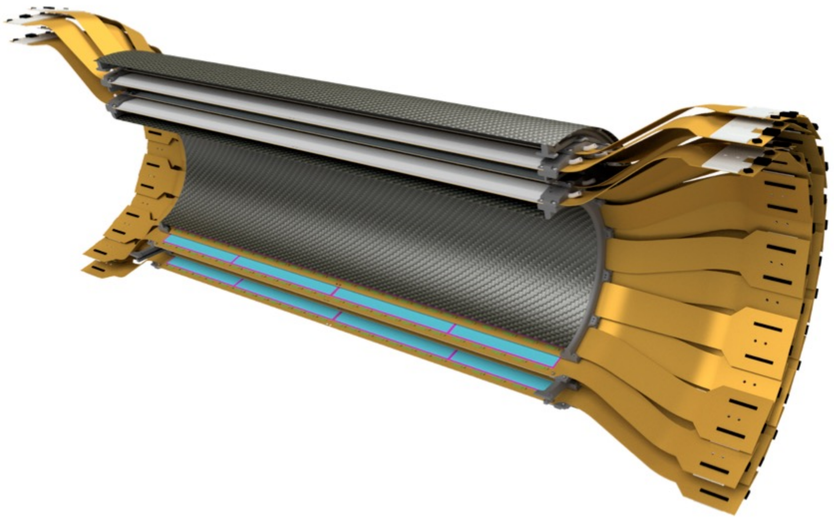
sPHENIX vertex and tracking detector

- The sPHENIX vertex and tracking detector can provide high precision primary vertex, displaced/decay vertex and track measurements for heavy flavor hadron and jet reconstruction/tagging.

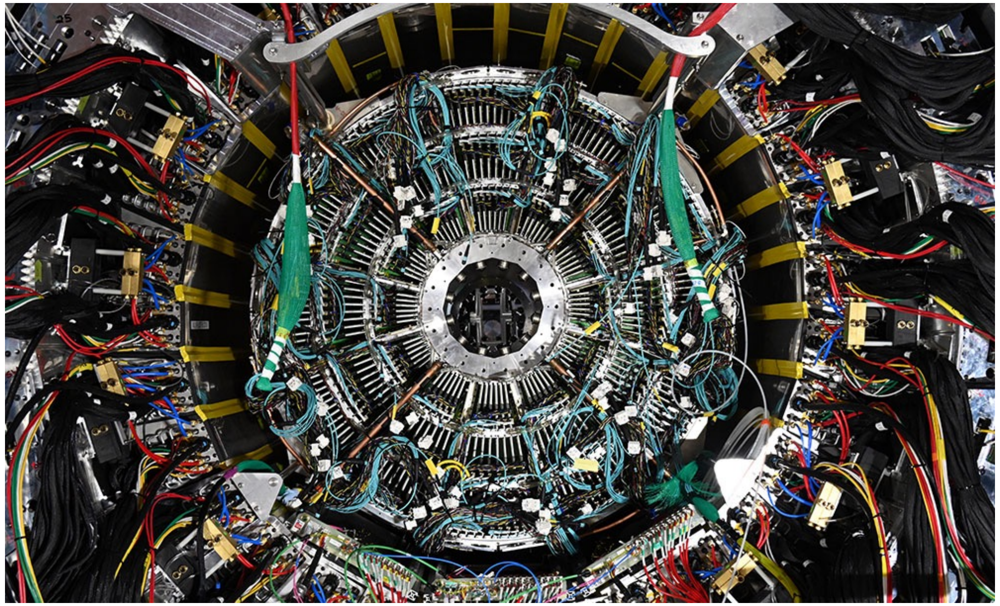
MAPS vertex detector (MVTX)



Silicon strip detector (INTT)



Time Projection Chamber (TPC)

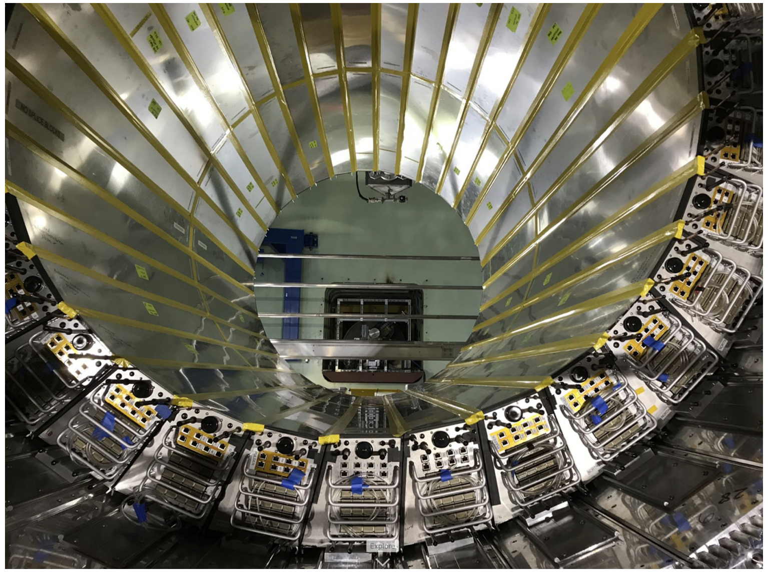


- MVTX: 3 layers of MAPS sensors (R=2.3-3.9cm), ~5 μm spatial resolution for track p_T > 1 GeV/c.
- INTT: 2 layers of silicon strips (R=6-12cm), fast timing, can identify single beam crossing.
- TPC+TPOT: ~150 μm rφ resolution (R=20-78cm), track momentum resolution ~1% at ~1 GeV/c.

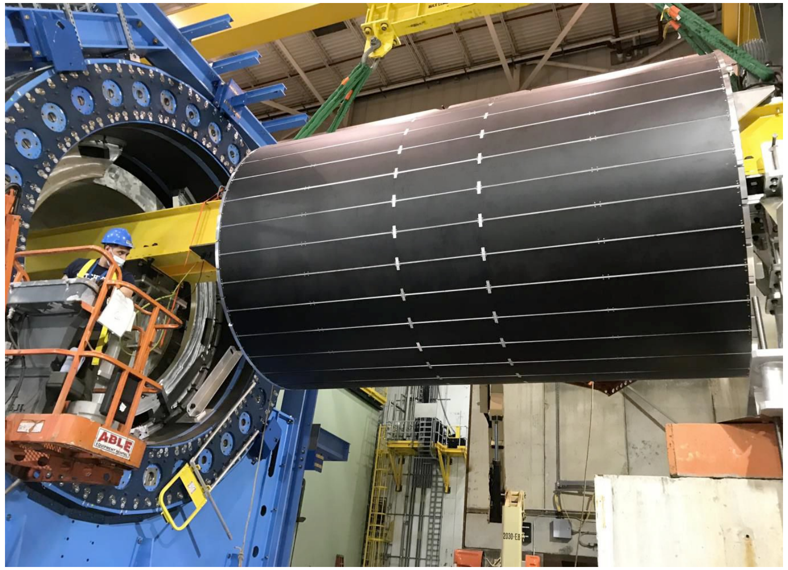
sPHENIX calorimeter detector

- The sPHENIX EMCal, inner and outer HCal calorimeters can provide good energy resolution for heavy flavor jet reconstruction and tagging.

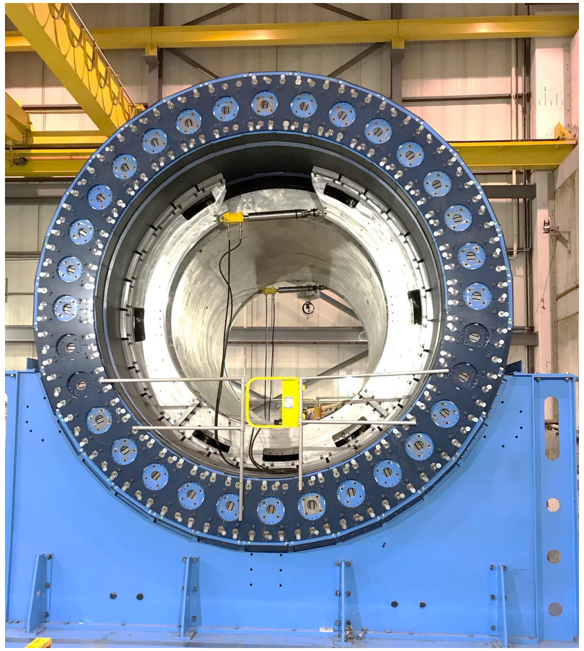
EMCal



Inner HCal



Outer HCal

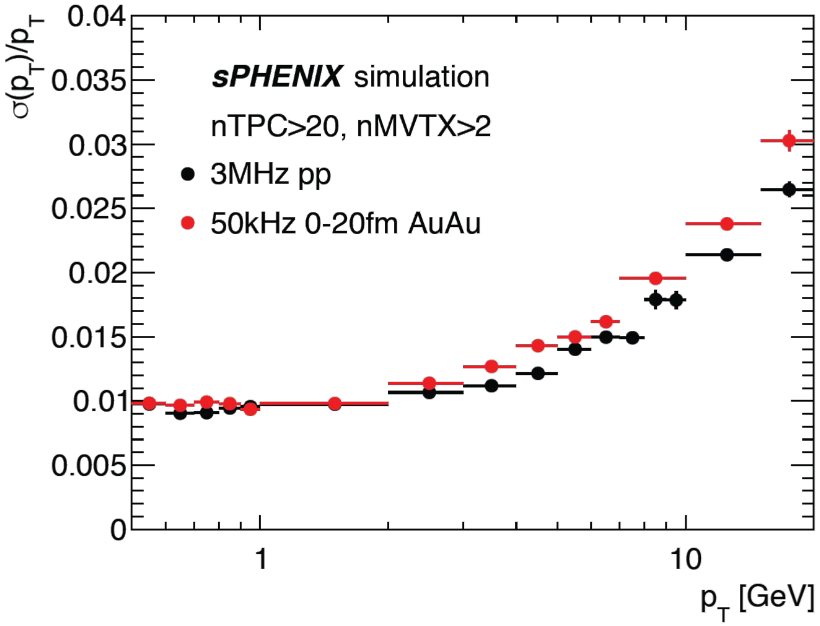


- EMCal: Tungsten-scintillating fiber sampling calorimeter, energy resolution: $16\%/\sqrt{E} \oplus 5\%$.
- Inner and outer HCal: Al (inner) & steel (outer) absorber plates, scintillating tiles w/ embedded WLS fibers, energy resolution: $88\%/\sqrt{E} \oplus 12\%$.

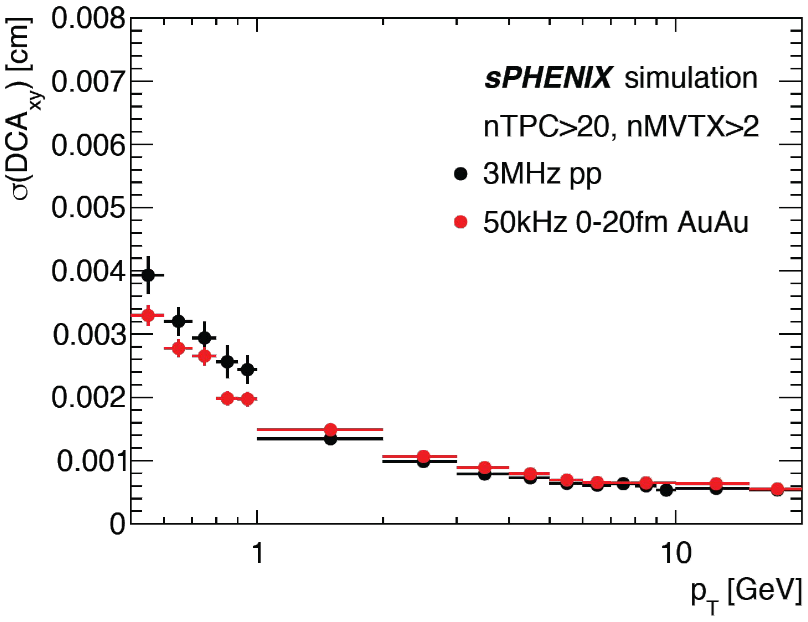
sPHENIX detector performance for heavy flavor related studies

- The sPHENIX detector performance was initially evaluated in 200 GeV p+p and Au+Au simulation, has been confirmed in beam test data, and is under study with the collision data.

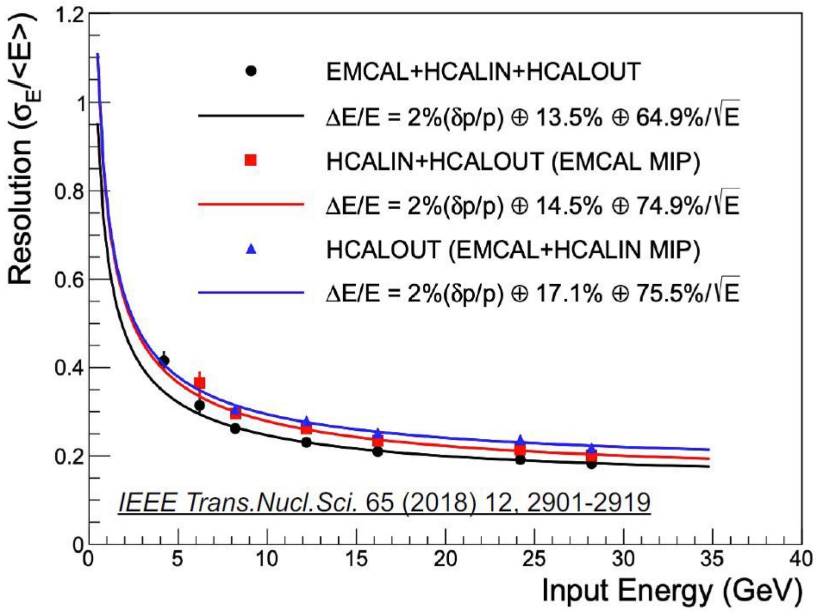
Track p_T resolution



Track transverse DCA (DCA_{xy}) resolution



Charged particle energy resolution

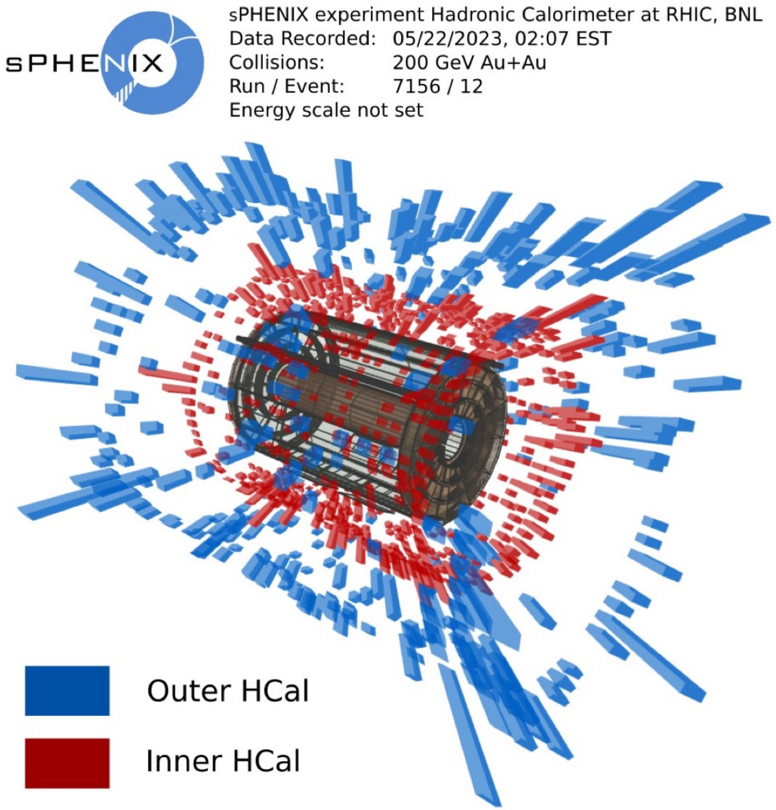


- Better than 2% p_T resolution for track p_T < 10 GeV/c.
- Better than 40 μm DCA_{xy} resolution for track p_T > 0.5 GeV/c.
- Integrated calorimeter energy resolution meets the detector design goals.

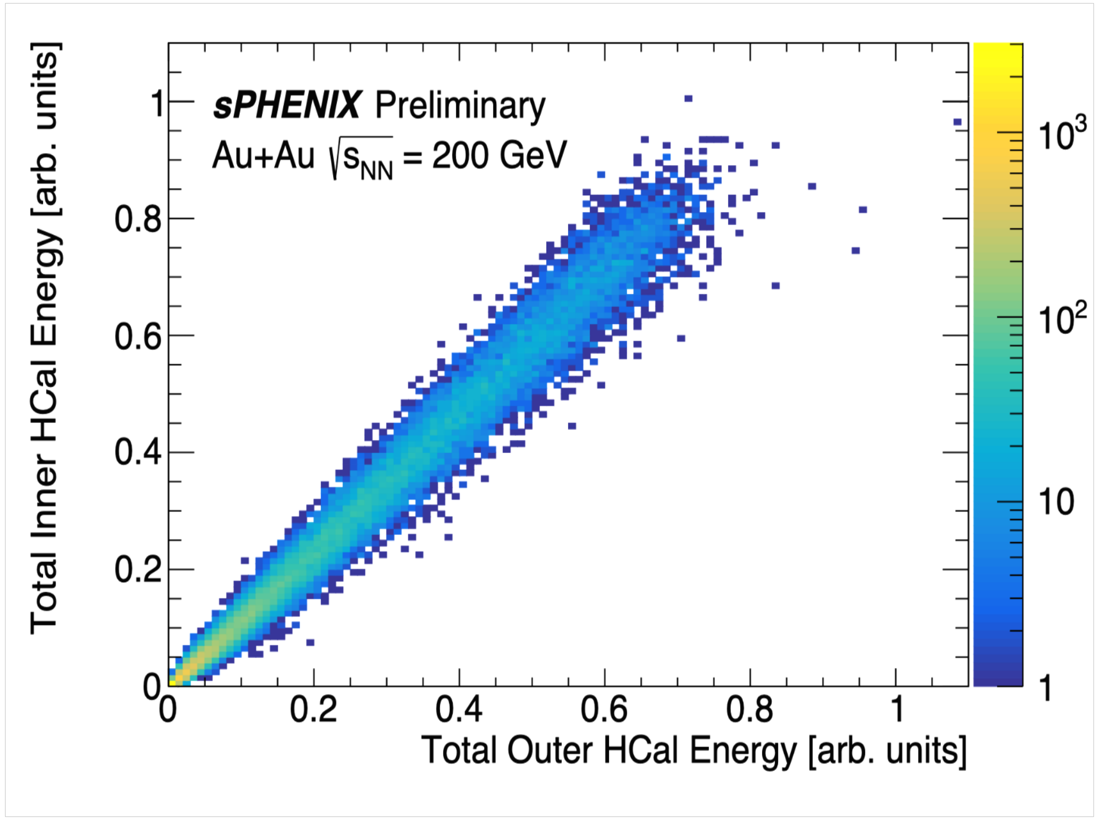
First sPHENIX data in 200 GeV Au+Au collisions

- Commissioning and calibration of the sPHENIX detector is ongoing.
- Initial 200 GeV Au+Au data look promising.

Event display of the sPHENIX hadronic calorimeter in 200 GeV Au+Au data

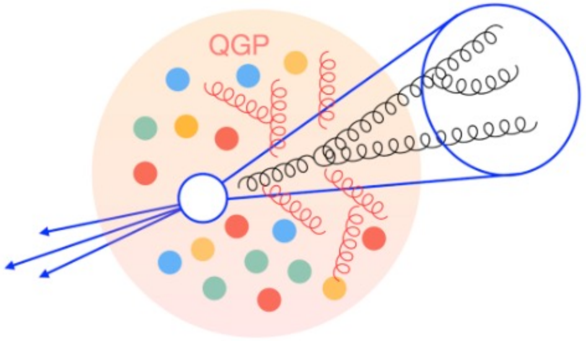


Correlation of iHCAL and oHCAL at sPHENIX in 200 GeV Au+Au data

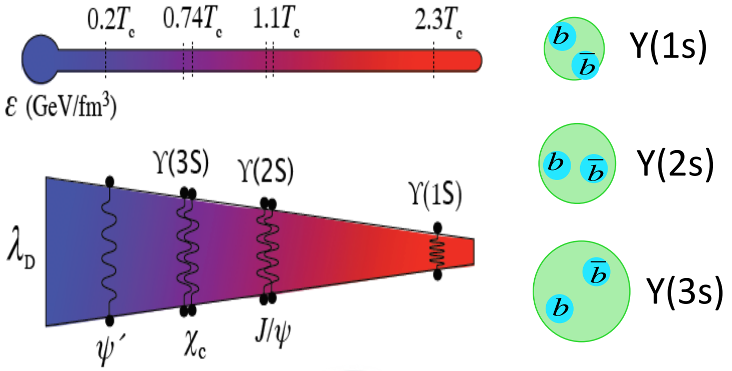


sPHENIX heavy flavor physics overview

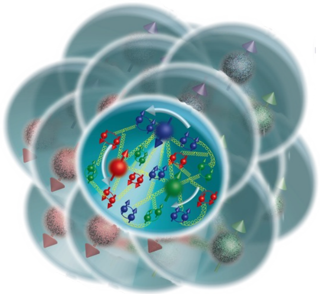
- The sPHENIX experiment will utilize open and closed heavy flavor products to
  - Explore the parton energy loss mechanism and study the collective behavior in medium by varying the mass/momentum of the probe (e.g., charm and bottom jet R_{AA} and v2).
  - Perform the upsilon spectroscopy to study the QGP thermal properties by varying the probe sizes.
  - Study the cold nuclear medium effects and the proton spin origin.



Parton energy loss



Sequential melting of γ in QGP

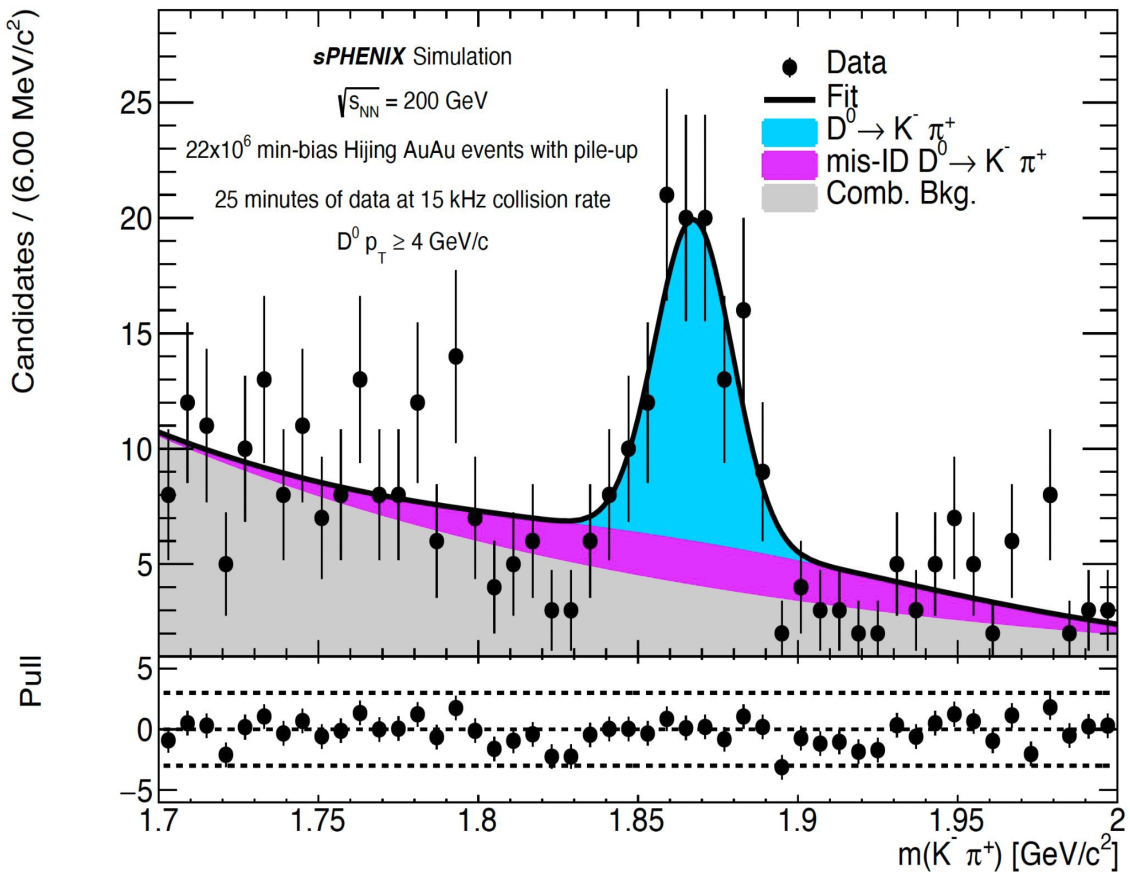


Cold QCD

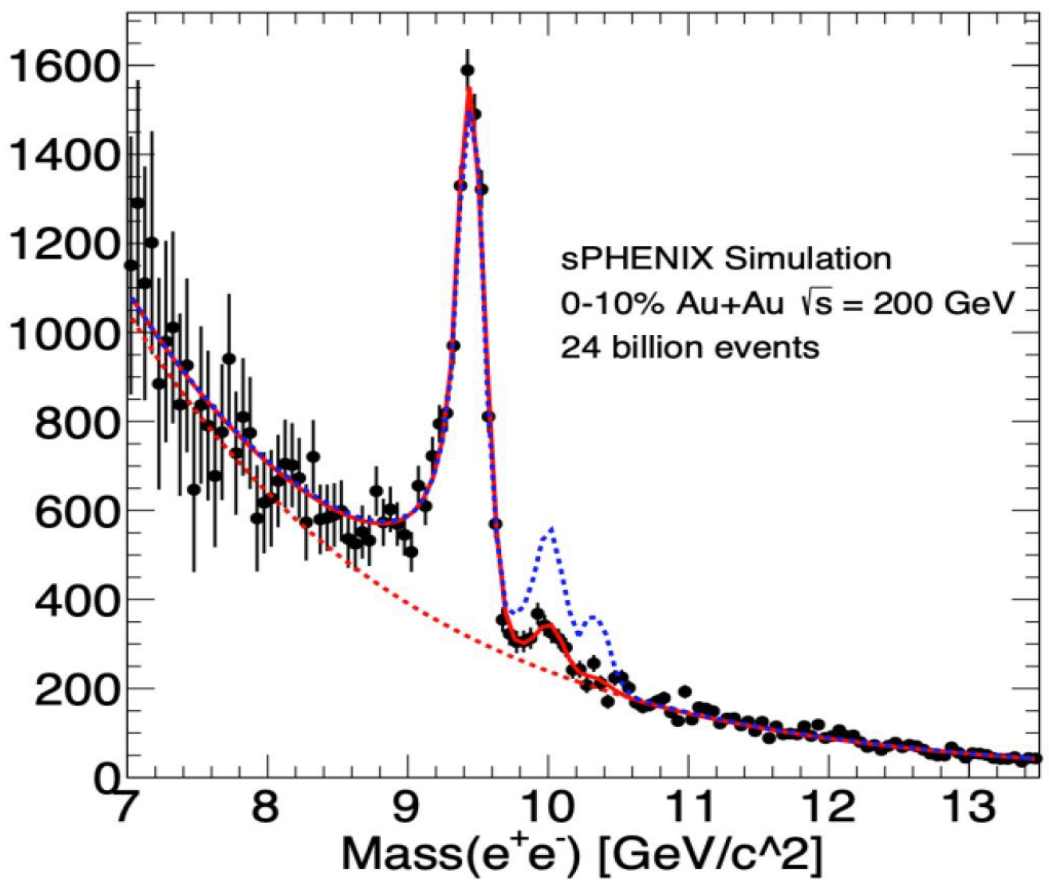
sPHENIX heavy flavor hadron reconstruction capability

- In Au+Au simulation with the sPHENIX detector configuration and performance, clear and pronounced D^0 and $\Upsilon(1s, 2s, 3s)$ signals can be fully reconstructed.

sPHENIX Au+Au simulation: $D^0 \to K^- + \pi^+$

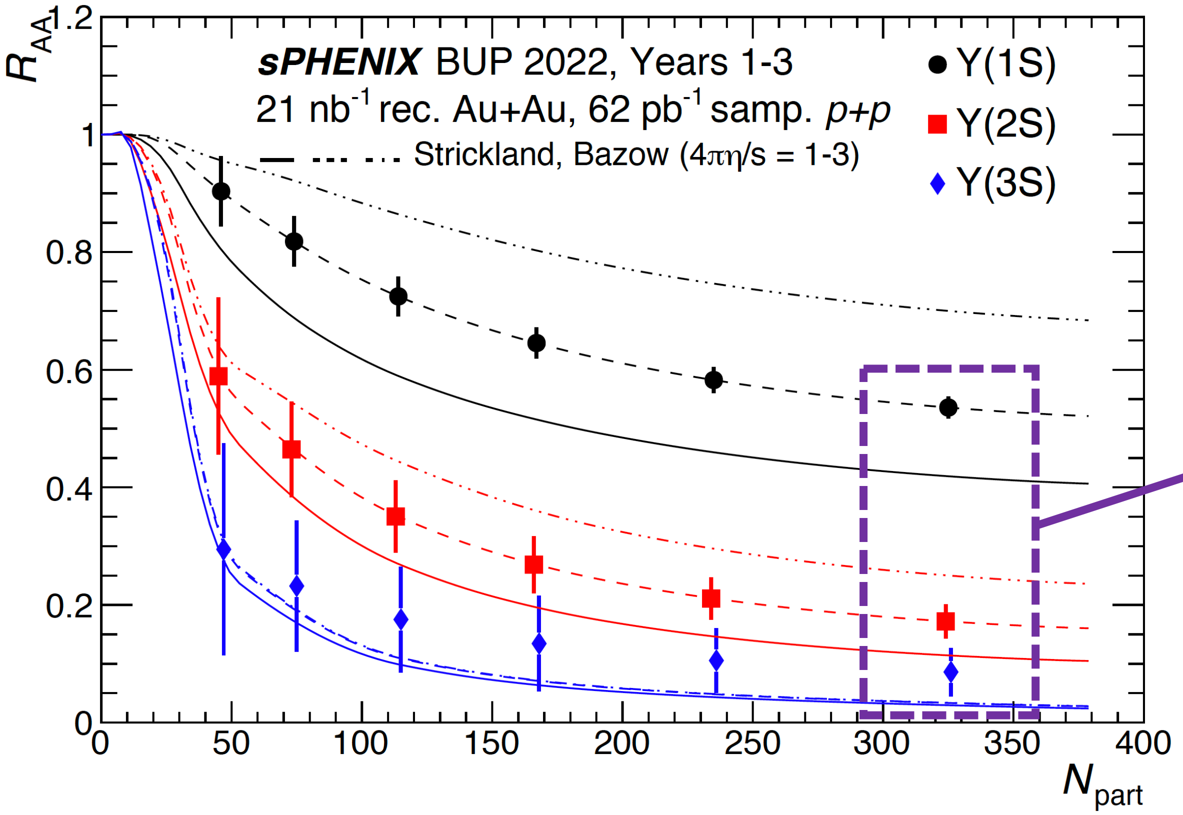


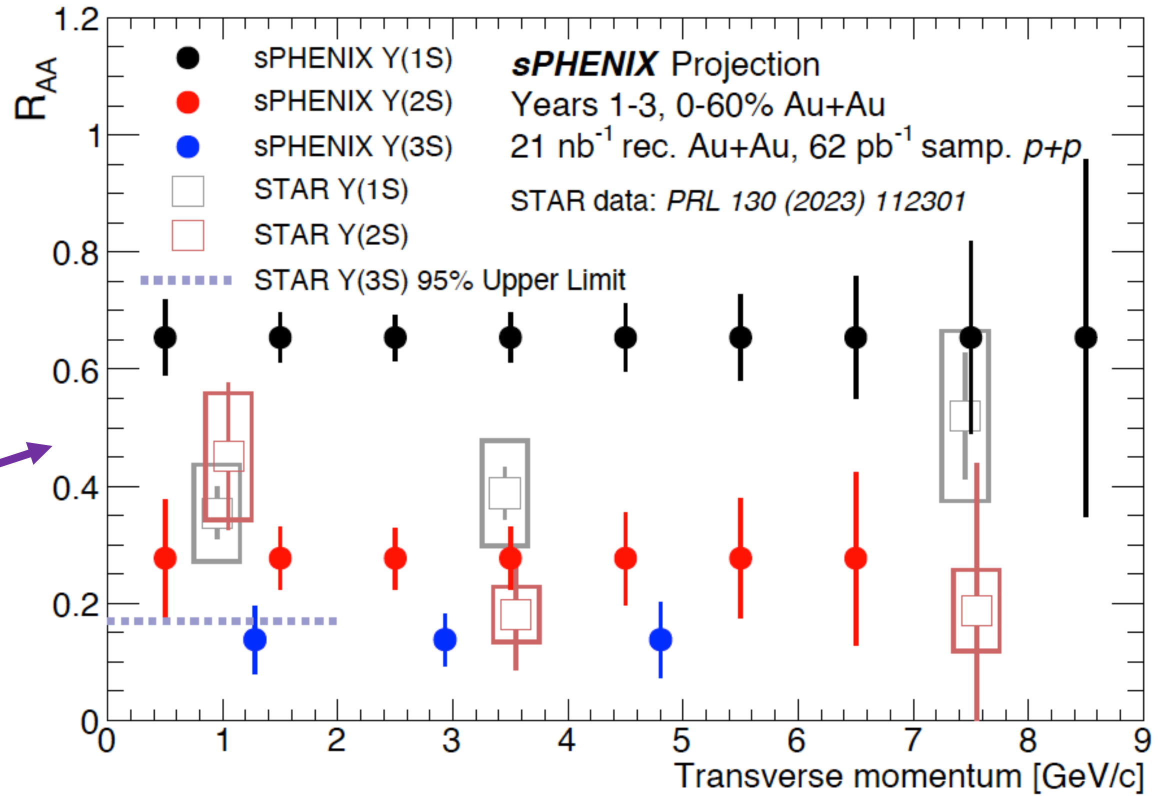
sPHENIX Au+Au simulation: $\Upsilon \to e^+ + e^-$



Upsilon R_{AA} projection at sPHENIX

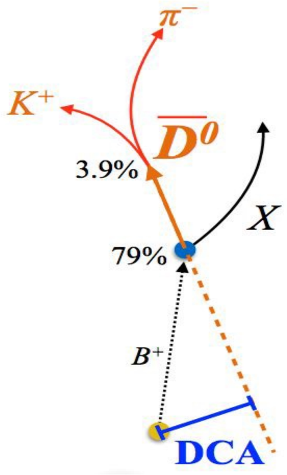
- Expect to achieve clear separation of three upsilon states for the first time at RHIC.
- The multiplicity and transverse momentum dependent R_{AA} of $\gamma(1s), \gamma(2s)$ and $\gamma(3s)$ has great sensitivity to explore the QGP thermal properties.

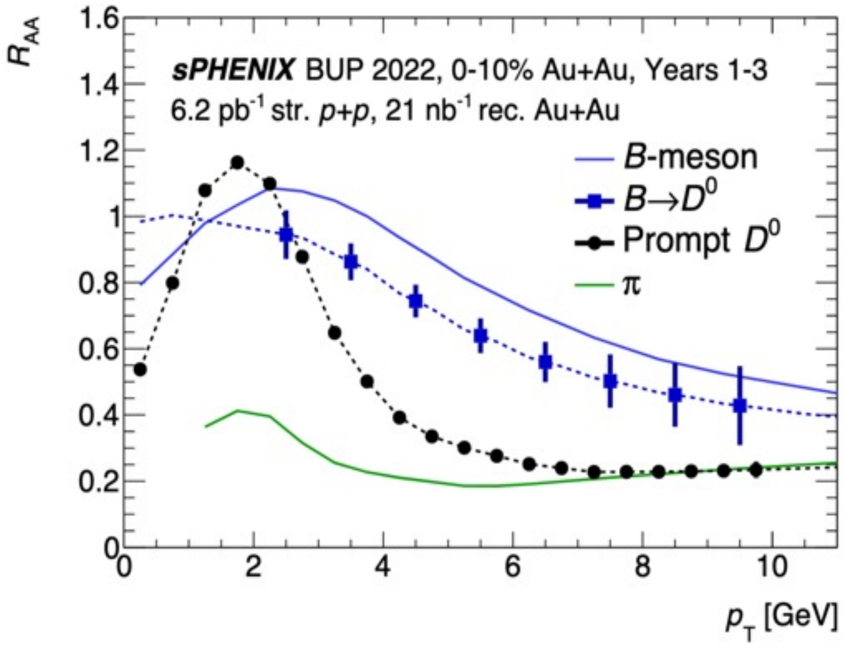


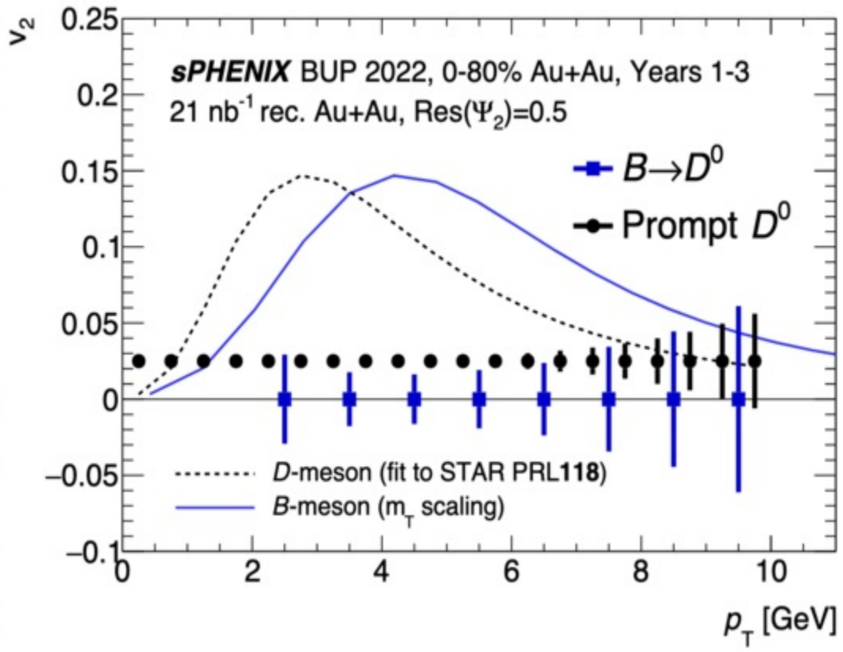


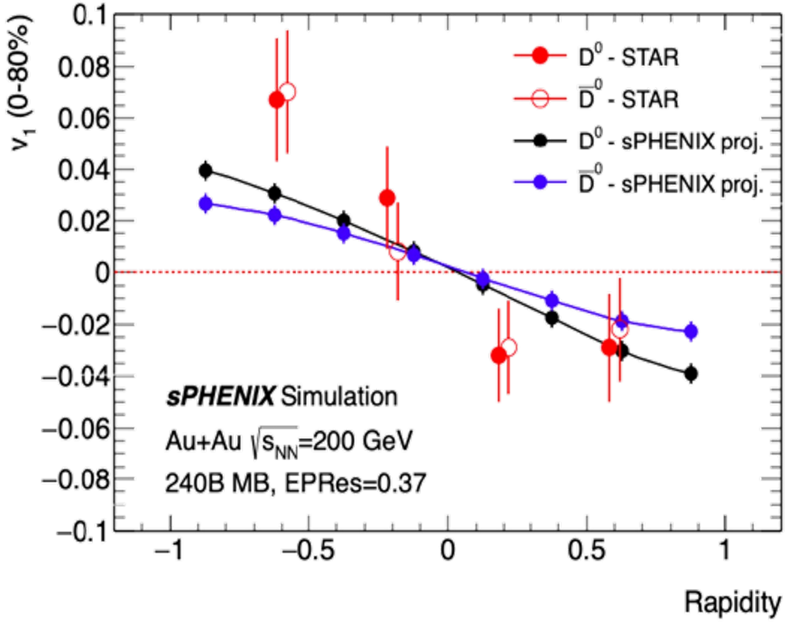
Open heavy flavor hadron R_{AA} and v2 projection at sPHENIX

- The sPHENIX streaming readout enables high statistics open heavy flavor hadron measurements down to $p_T = 0$.
- The prompt and non-prompt D^0 R_{AA} and v2 measurements will help map out the mass/flavor dependent parton energy loss and collectivity.
- The prompt D^0 ($\overline{D^0}$) v1 has good sensitivity to access the geometry and initial magnetic field of the QGP.



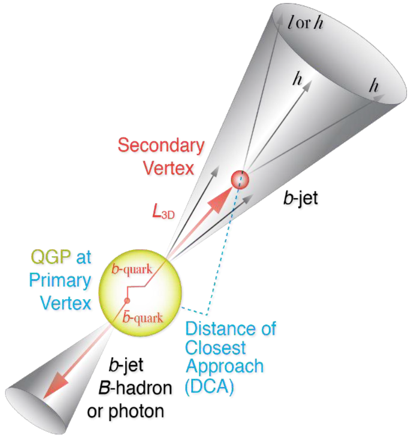


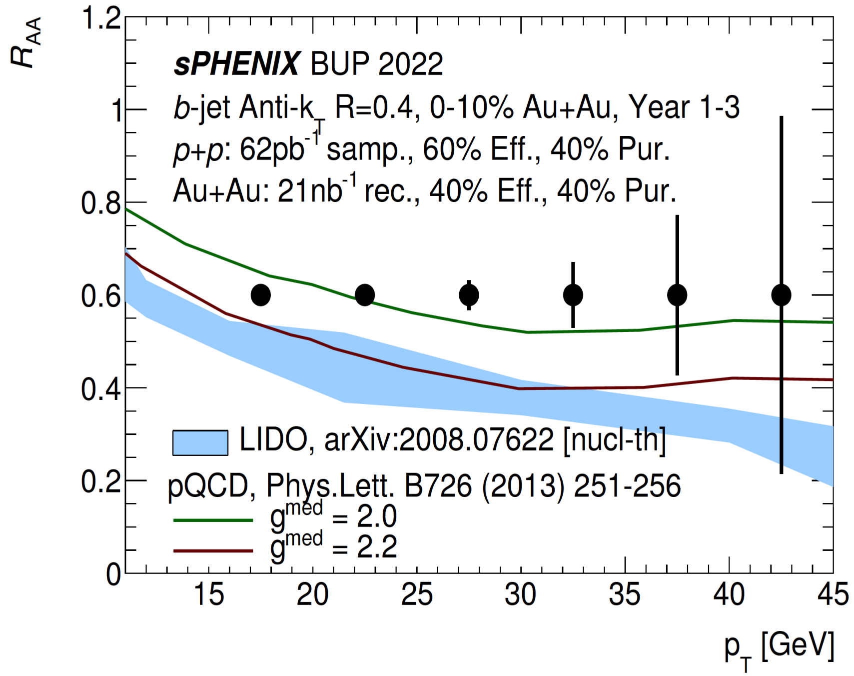


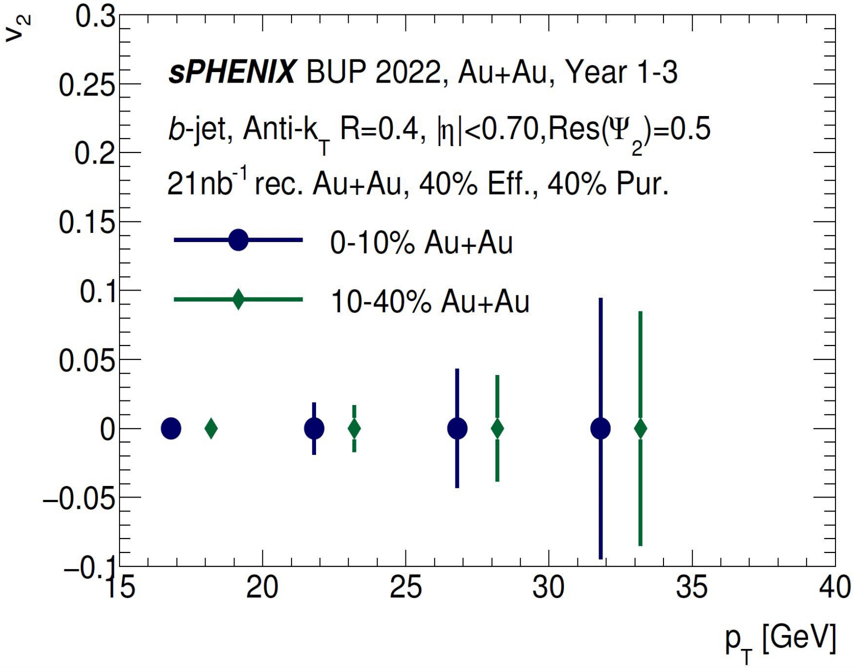


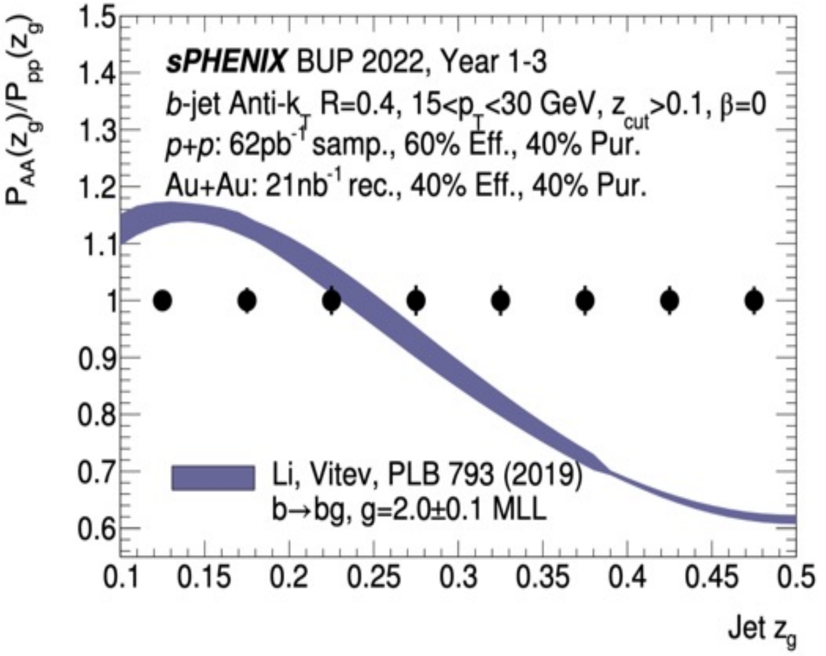
Open heavy flavor jet R_{AA} and v2 projection at sPHENIX

- First bottom jet measurements at RHIC will be carried out at sPHENIX.
- The heavy flavor jet R_{AA} (low p_T), contains interplay of the collisional and radiative energy loss. The heavy flavor jet v2 will help constrain the heavy quark diffusion coefficient in QGP.
- The bottom jet substructure measurements will help study the bottom quark splitting function with great precision.



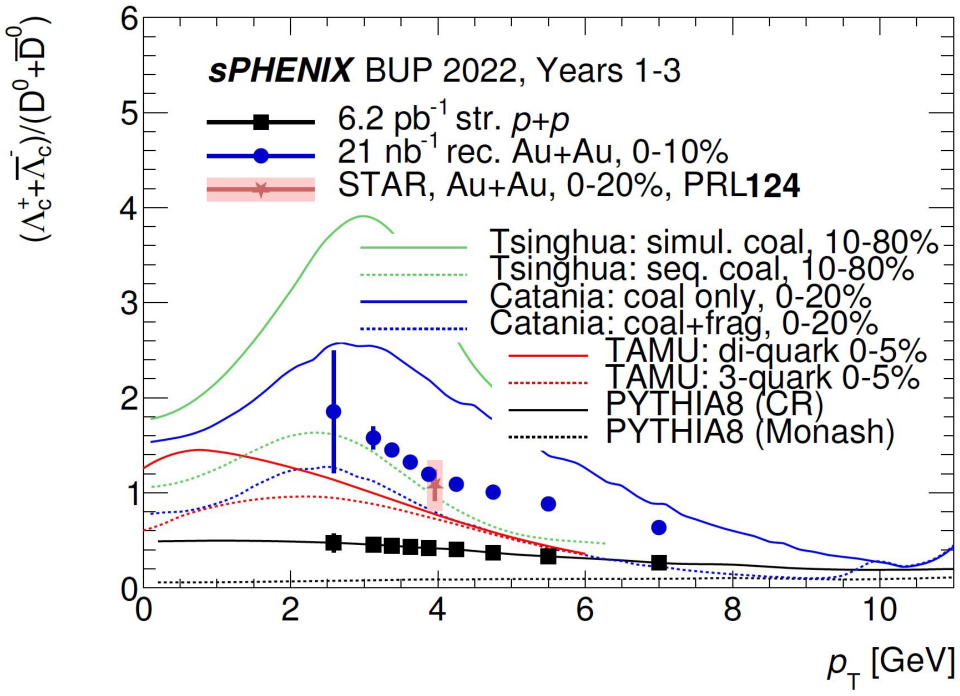


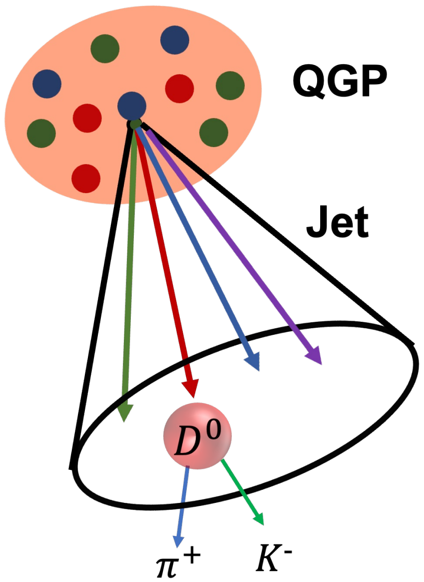


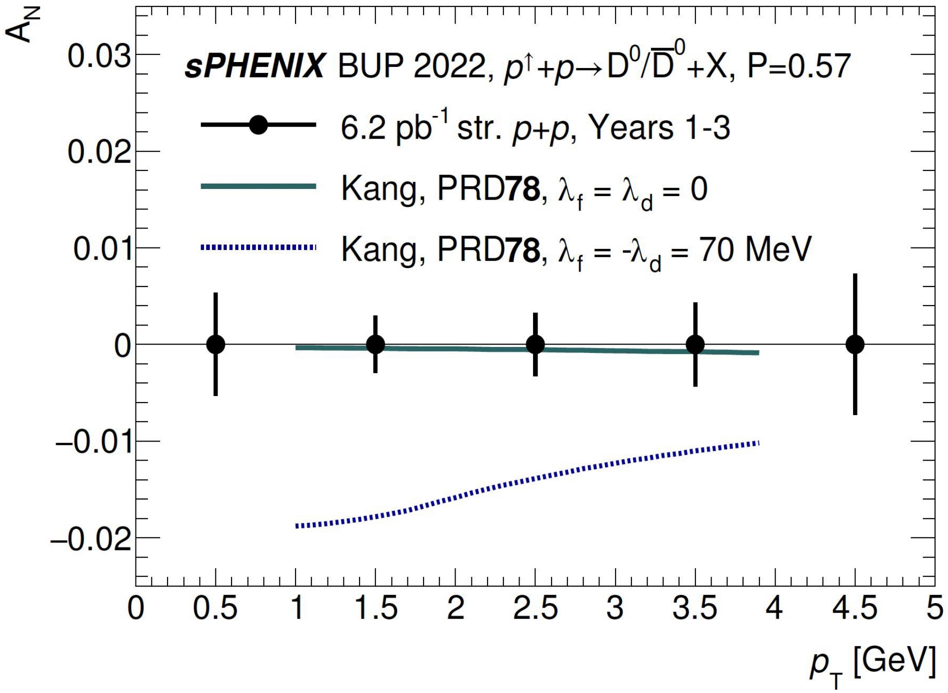


Physics to be covered by the sPHENIX HF measurements

- Check the universality of heavy quark fragmentation via the p_T dependent Λ_c/D^0 in 200 GeV p+p and Au+Au collisions (less recombination at RHIC compared to LHC).
- Exploration of the heavy quark hadronization expanded by including the D meson inside jet measurements.
- Study the gluon Sivers TMD by measuring the D^0 ($\overline{D^0}$) transverse spin asymmetry, A_N.

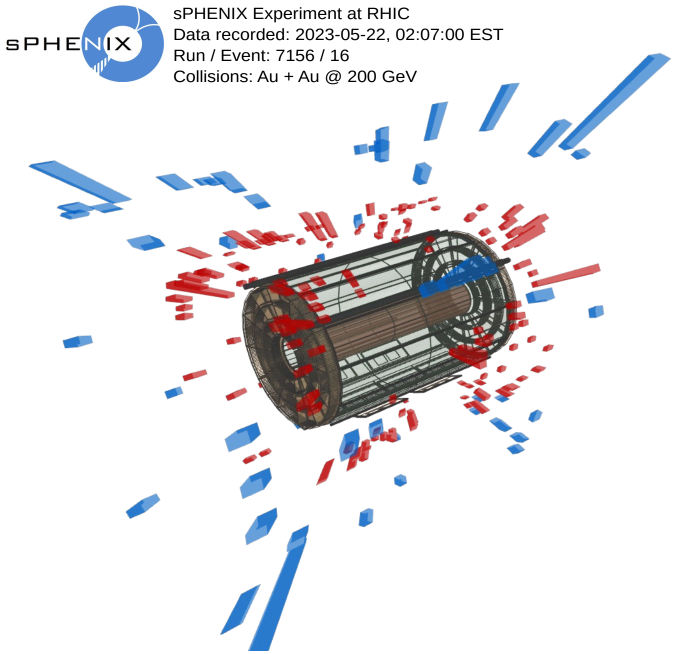






Summary and Outlook

- The sPHENIX experiment has started collecting 200 GeV Au+Au data with fully installed detector subsystems in May 2023.
- The planned sPHENIX open and closed heavy flavor measurements will
  - include first b-jet and $\Upsilon(3s)$ measurements at RHIC;
  - systematically explore the QGP properties within their unique/complementary kinematic coverage compared to existing RHIC/LHC measurements;
  - provide good precision to study a broad range of physics topics.
- Stay tuned!



Backup

sPHENIX run schedule

- The sPHENIX scientific program consists of 3-year running period:

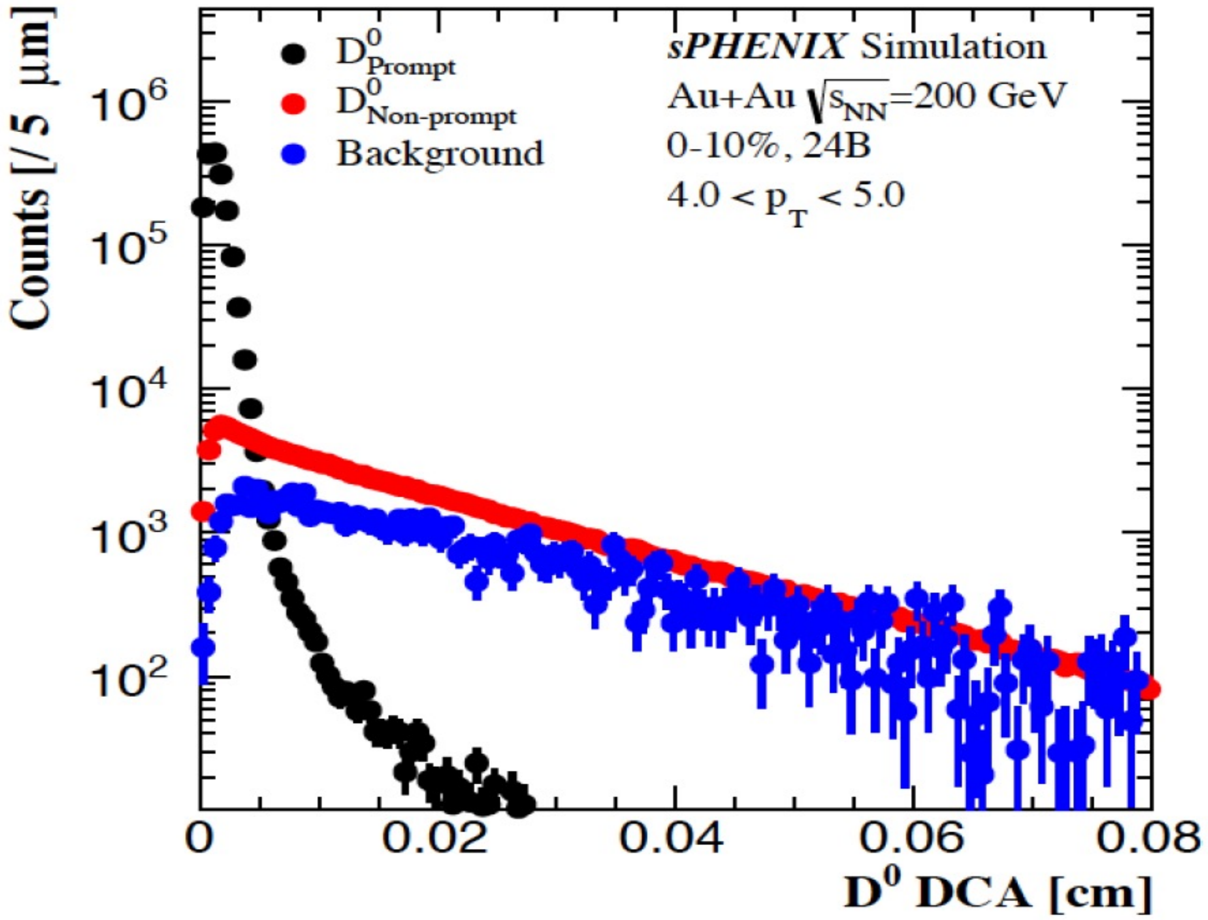
sPH-TRG-2022-001

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}

- 200 GeV Au+Au in 2023: Commissioning & Calibration, benchmark measurements, first physics results at sPHENIX.
- 200 GeV p+p/Au in 2024: Cold QCD physics, baseline for heavy ion measurements.
- 200 GeV Au+Au in 2025: High statistics, sPHENIX physics milestones.

sPHENIX D^0 DCA in Au+Au simulation

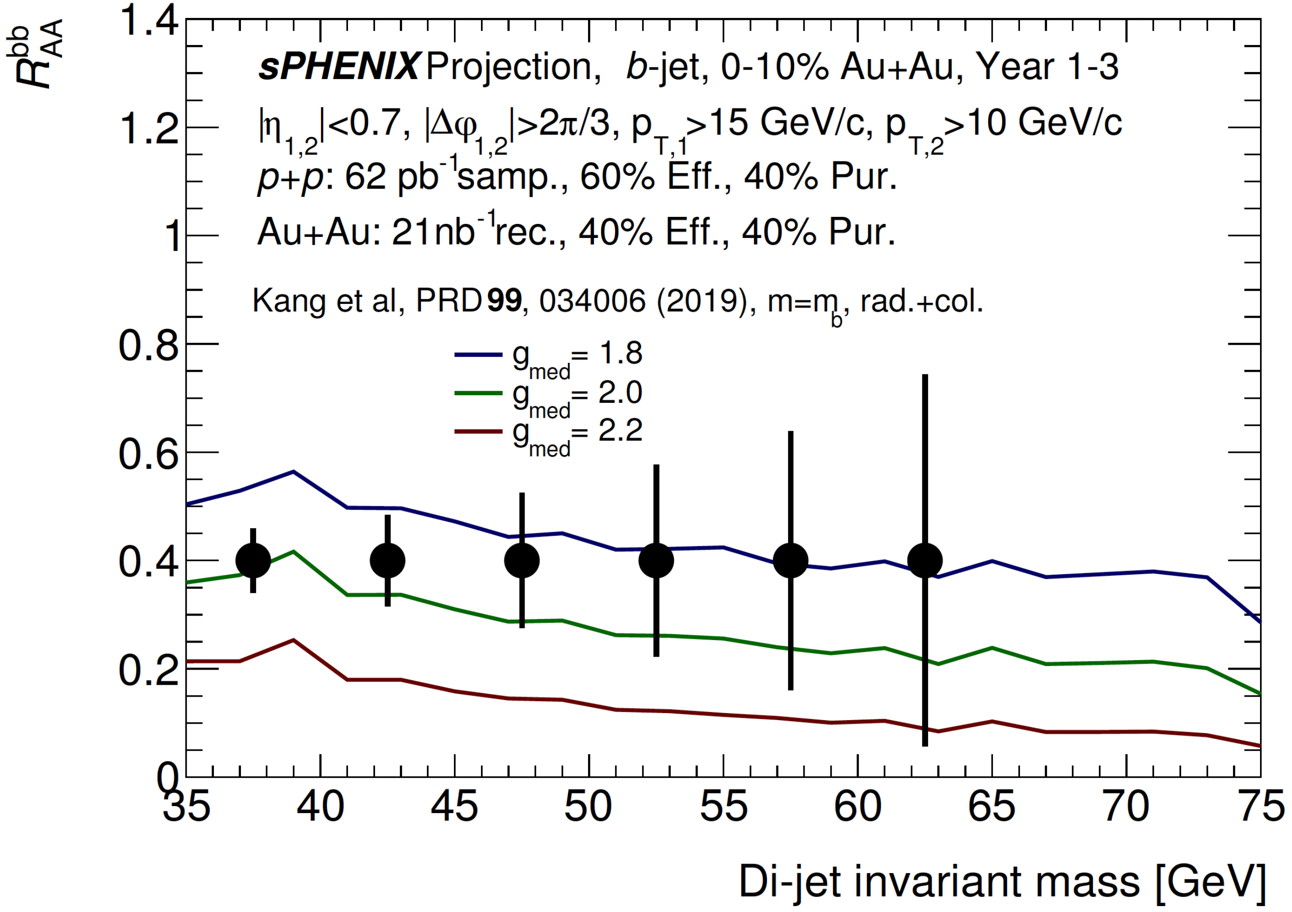
- Prompt and non-prompt D^0 Distance of Closest Approach (DCA).



[sPH-HF-2017-002]

sPHENIX di b-jet R_{AA}

- The sPHENIX di b-jet RAA will provide good constraints on the transport coefficients in the QGP.

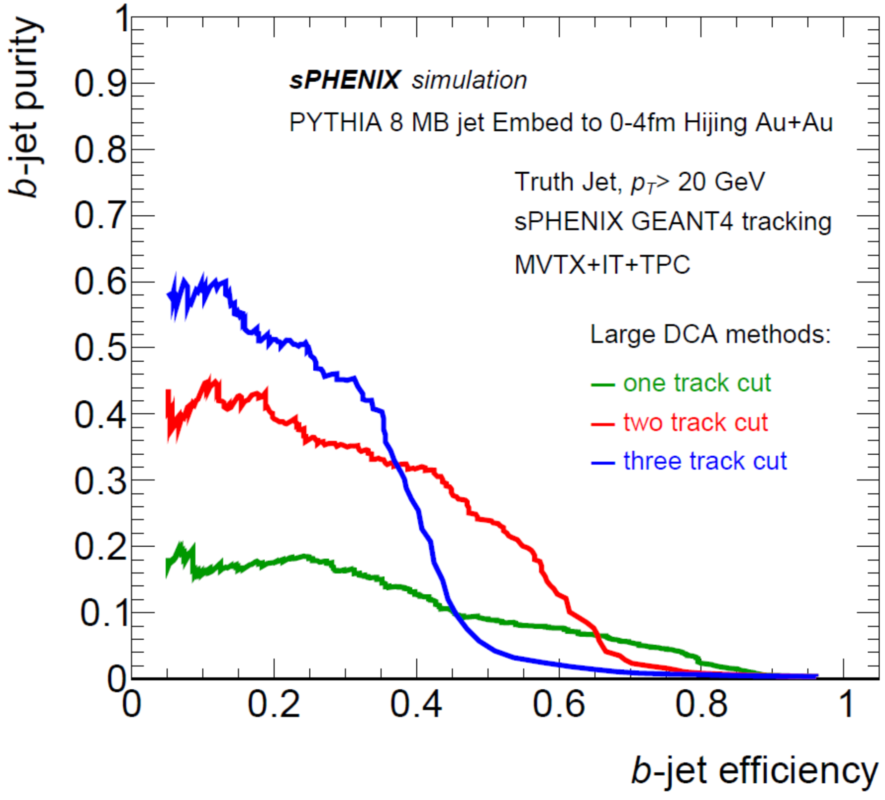


sPHENIX Heavy Flavor Jet tagging methods

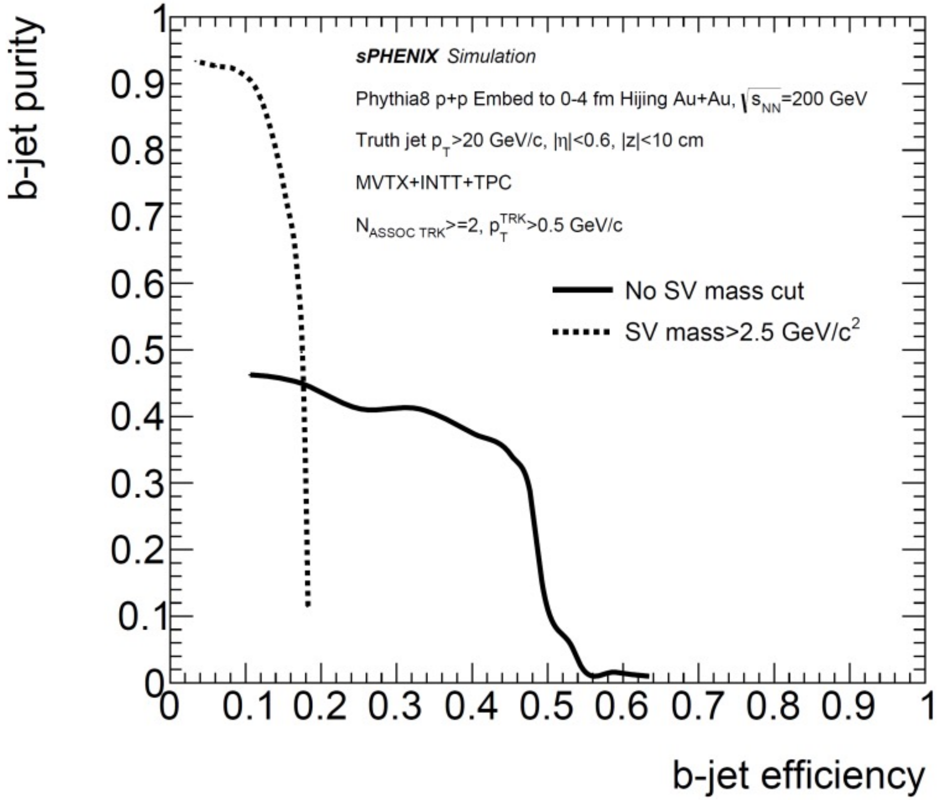
- Large DCA track counting
- Displaced vertex tagging
- Displaced lepton

[sPH-HF-2018-001]

Large DCA track counting tagging



Displaced vertex tagging



Comparison between the RHIC and LHC kinematics

- RHIC tomorrow will be realized by the sPHENIX measurements.