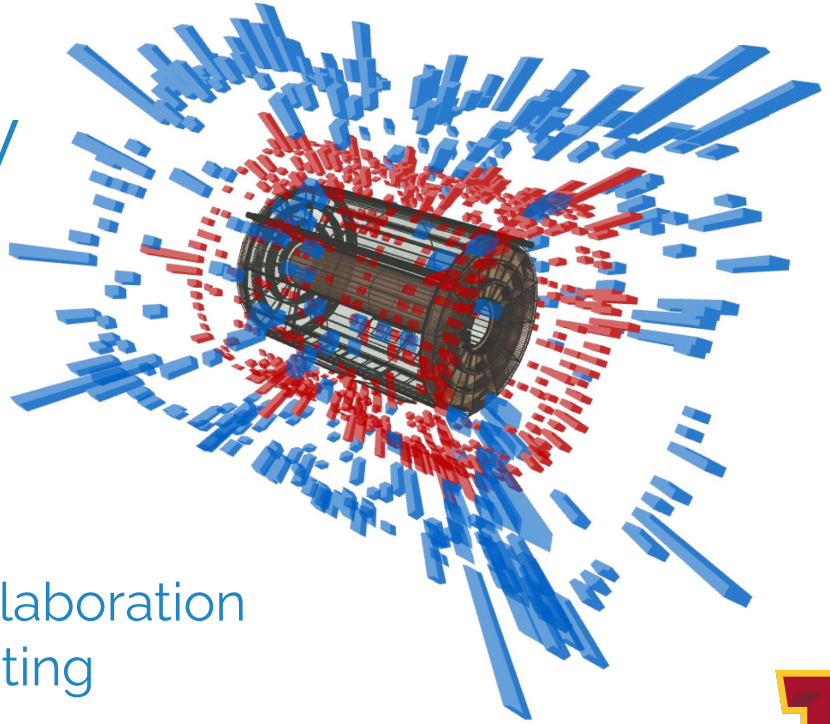
sPHENIX Experiment at RHIC
Data recorded: 2023-05-22, 02:07:00 EST
Run / Event: 7156 / 12
Collisions: Au + Au @ 200 GeV



Progress toward heavy flavor measurements in sPHENIX

Antonio Silva for the sPHENIX Collaboration

2023 RHIC/AGS Annual Users' Meeting

Aug 2nd, 2023

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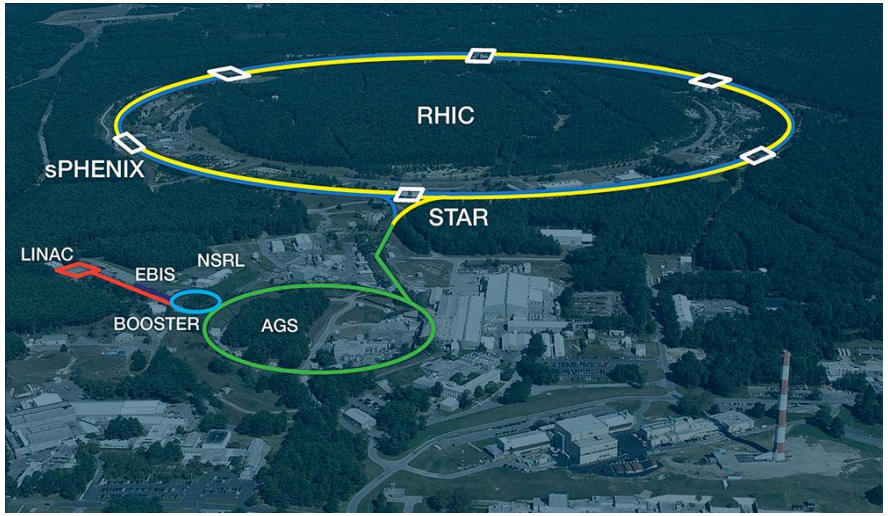
sPHENIX

The conclusion of a 20+ years scientific journey



There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

2015 US NP LRP

The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

- sPHENIX is the first new detector at any hadron collider in over a decade!
  - A compact detector with unique, purpose-built capabilities never before deployed at RHIC

- Different initial conditions and evolution for QGP at RHIC and LHC
  - Study of scale and temperature dependence

Heavy-flavor physics program

Open heavy flavor

Vary momentum/mass of the probe

Upsilon spectroscopy

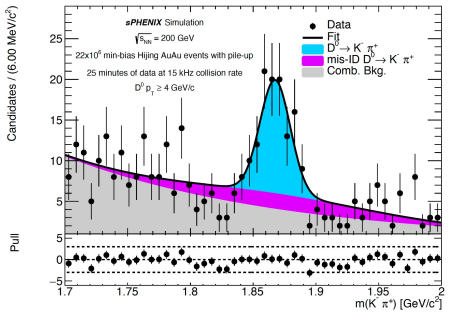
Vary size of the probe

Heavy-flavor jets

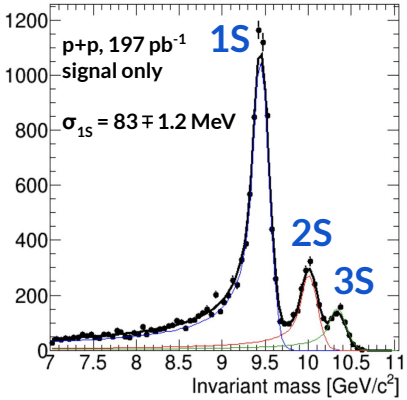
Vary momentum/angular size of the probe

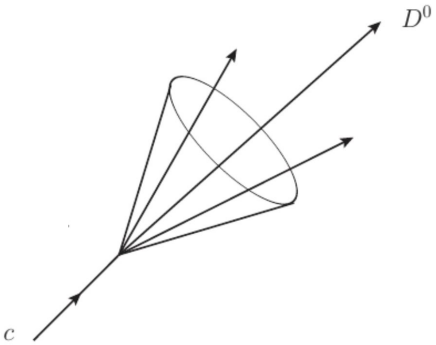
Cold QCD

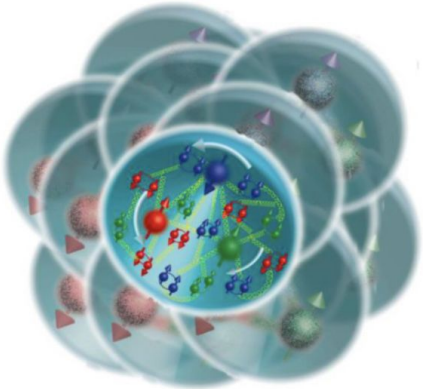
Vary temperature of QCD matter
HF spin asymmetry



Υ(3S) 0.78fm Υ(2S) 0.56fm Υ(1S) 0.56fm







RHIC run plan 2023-2025

Year	Beam	$\sqrt{s_{NN}}$ (GeV)	Cryo Weeks	Physics Weeks	$\mathcal{L}_{samp}$ (|z|<10cm)
2023	Au+Au	200	24	9	4.5 nb^{-1}
2024	p+p	200	24	12	45 pb^{-1}
	p+Au	200	-	5	0.11 pb^{-1}
2025	Au+Au	200	24	20.5	21 nb^{-1}

sPHENIX Beam Use Proposal

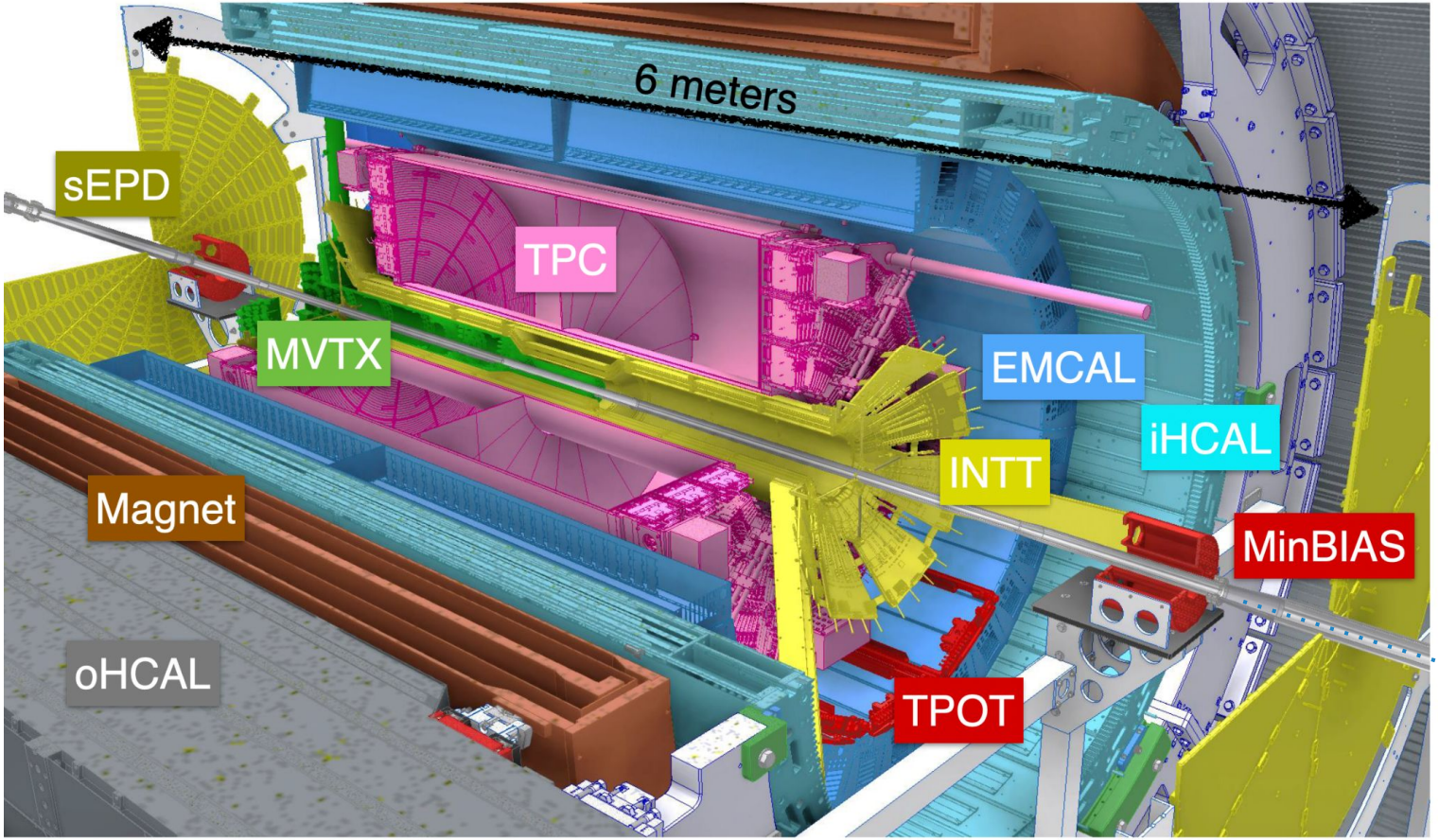
- **Year 1:** Commissioning, calibration and first physics
- **Year 2:** Cold QCD and heavy-ion reference
- **Year 3:** Large Au+Au dataset

➔ High rate DAQ (15 kHz): trigger capability with streaming readout

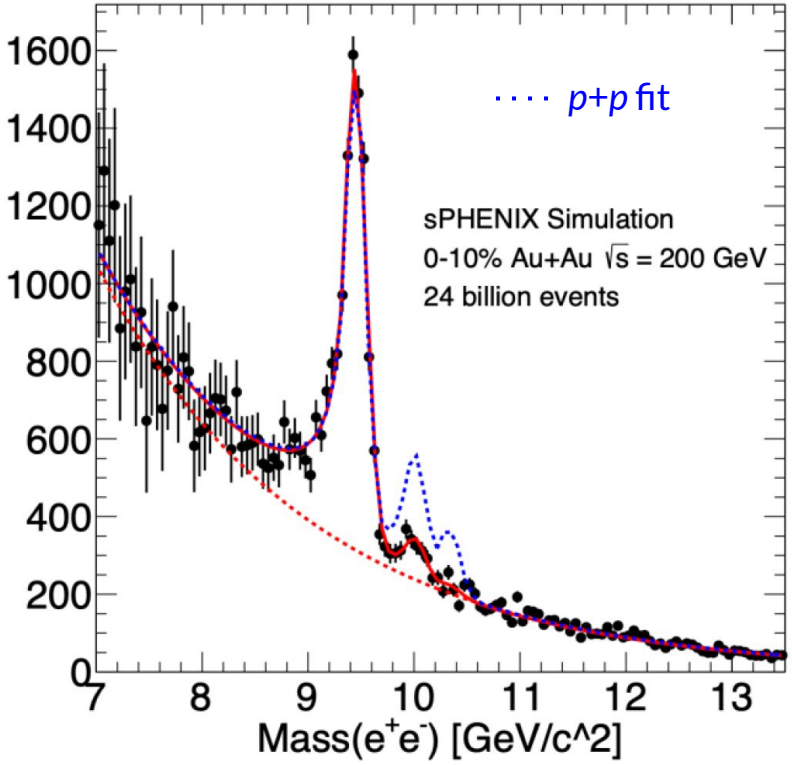
"The PAC urges BNL Management and the DOE to do everything possible to ensure sufficient beamtime to accomplish the physics goals in Runs 23, 24, 25 set out for sPHENIX in the 2015 NSAC Long Range Plan."

PAC Meeting June 2022: https://indico.bnl.gov/event/15148/
PAC Recommendations:
https://www.bnl.gov/npp/docs/2022-npp-pac-recommendations-final.pdf

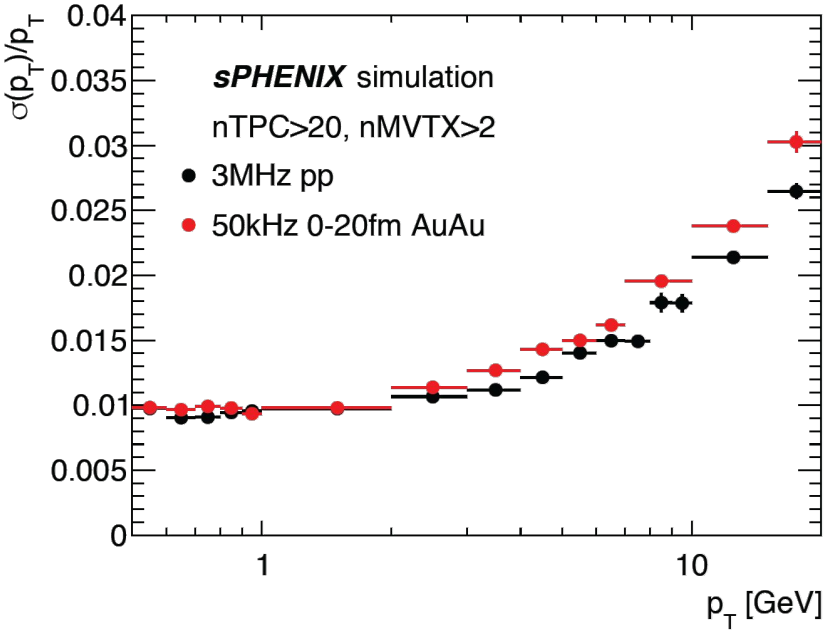
The sPHENIX detector



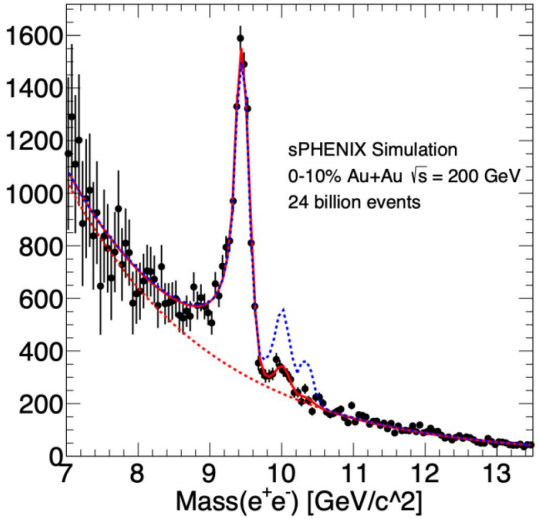
Upsilon and track resolution

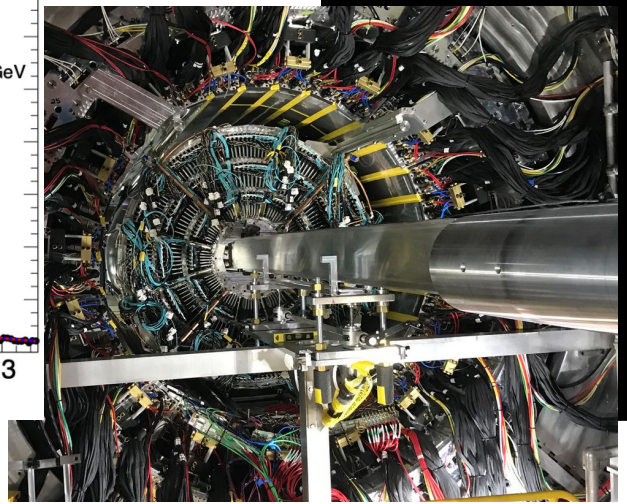


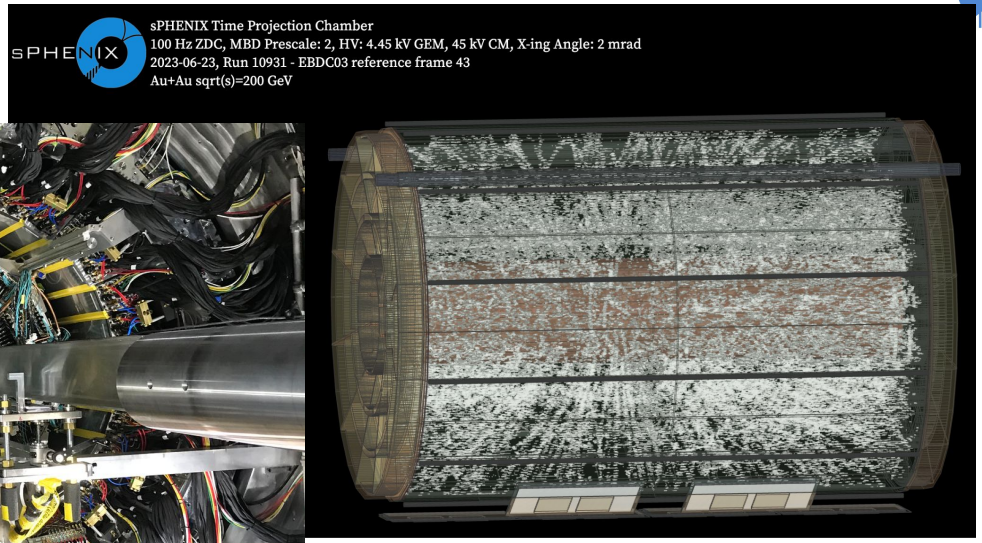
- p_T resolution < 2% for p_T < 10 GeV/c
- Meets invariant mass resolution <125 MeV/c^2 for **Υ(2S) and Υ(3S) direct separation for the first time at RHIC**



Upsilon and track resolution





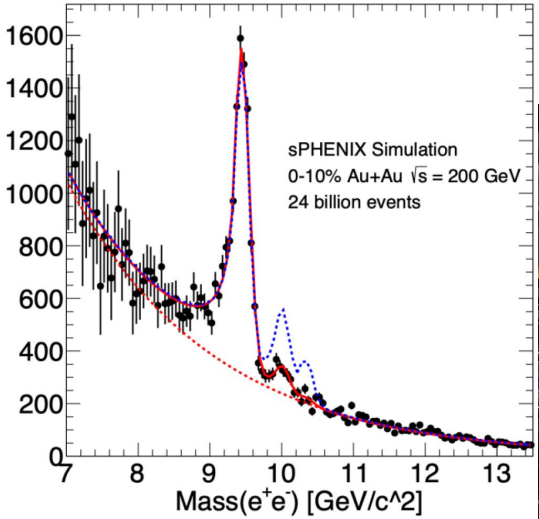


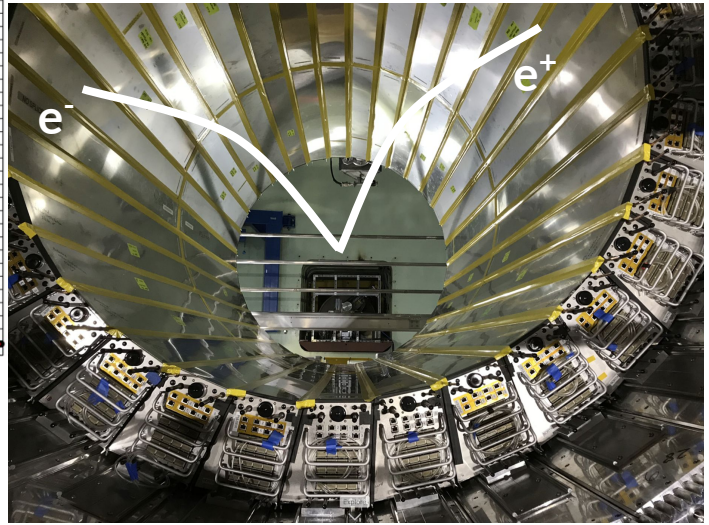
Time-projection chamber (TPC)

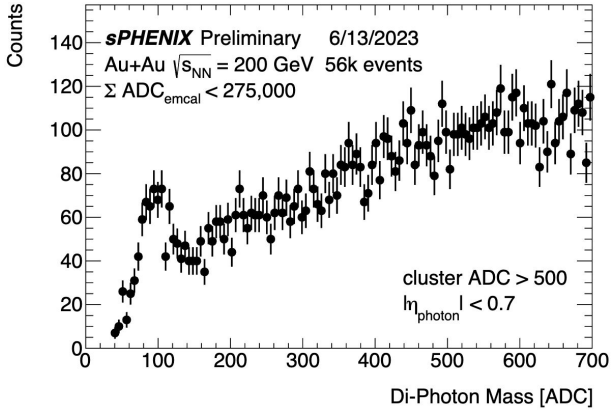
- Ungated continuous readout
- Reconstruction of heavy-flavor electrons and hadron decays
- 150 μm rϕ resolution
- $\Delta p/p$ ~1% at 5 GeV/c charged particles
- TPC outer tracker (TPOT) used for calibrations

- TPC event display during commissioning phase
- High voltage and magnet are on

Upsilon and electron identification





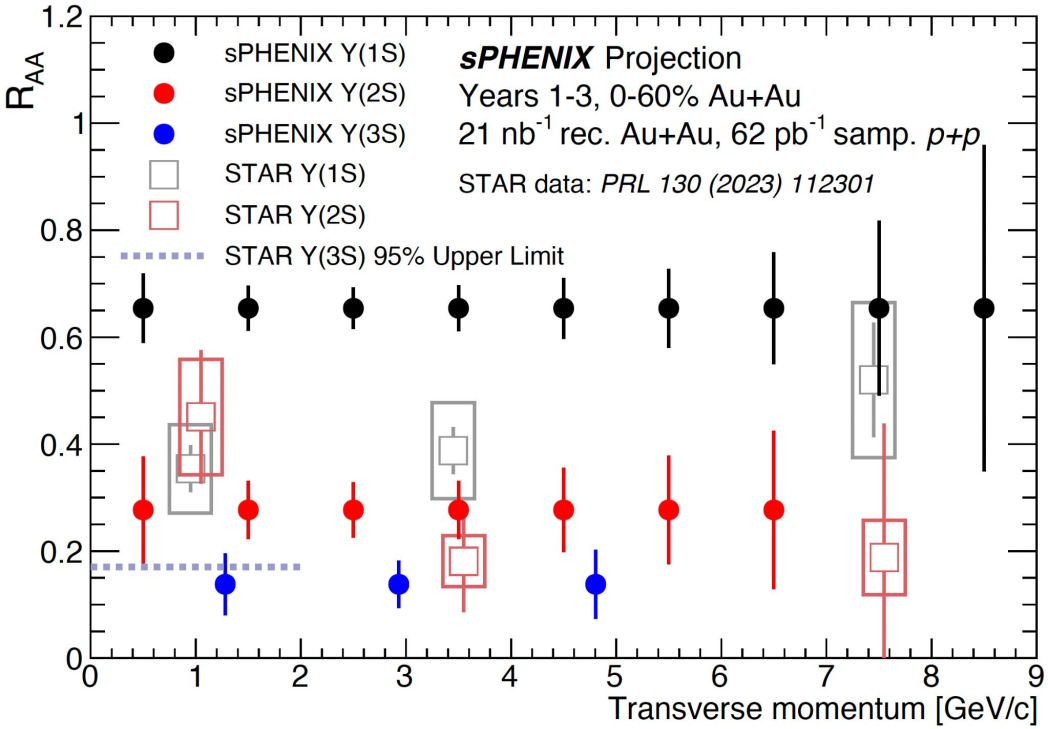


- EMCal commissioning
  - Di-photon invariant mass distribution
  - No energy calibration

EMCal: Scintillator fiber tungsten sampling calorimeter

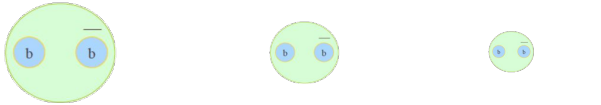
- **$|\eta| < 1.1$, full azimuthal coverage**
- [Identification of electrons from HF decays and HF-jets]
- Towers with ~0.025x0.025 in ηxϕ
- EM $\Delta E/E$ ~5% + 16%/$\sqrt{E}$

Quarkonium



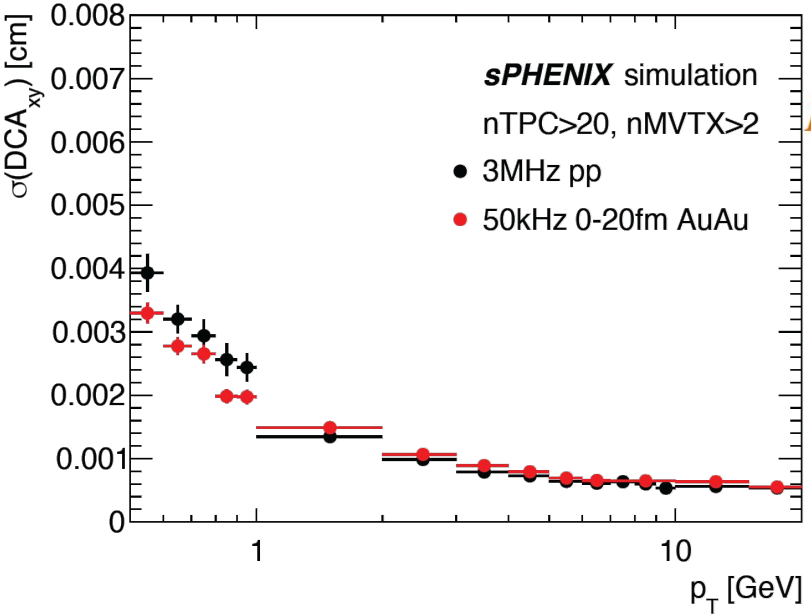
*Considering the Y(3S) suppression observed at the LHC.
Nucl. Phys. A879 25, (2012).

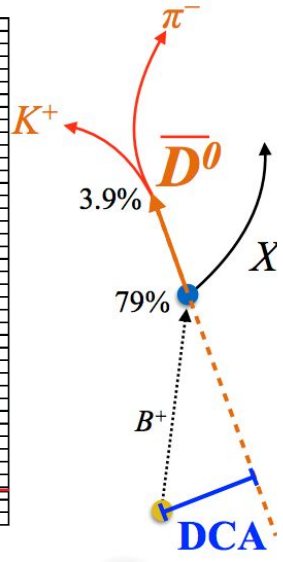
- Centrality- and p_T-differential R_{AA} measurements
- Clear **distinction of three Upsilon states**
  - Probing the QGP with color dipoles at three length scales
- Kinematic range allows for **comparison between RHIC and LHC** measurements



Y(3S) - 0.78fm Y(2S) - 0.56fm Y(1S) - 0.56fm

Open heavy flavour: DCA resolution





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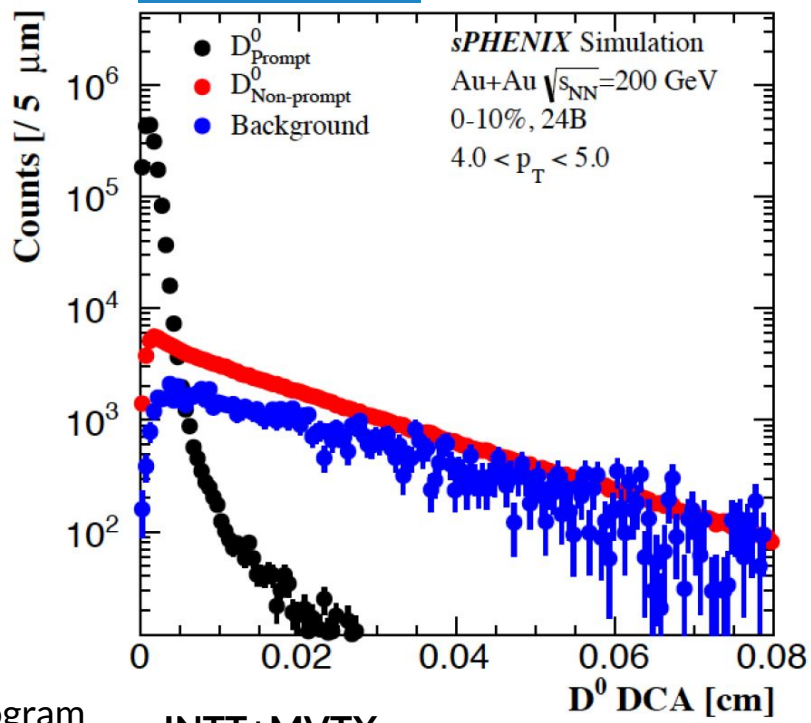


- **DCA resolution in $r\phi$ < 40 μm** for p_T > 0.5 GeV/c
- Crucial for the open heavy flavor and heavy-flavor jets program
- Separation of **prompt and non-prompt D^0**
  - Proxy for B mesons

INTT+MVTX

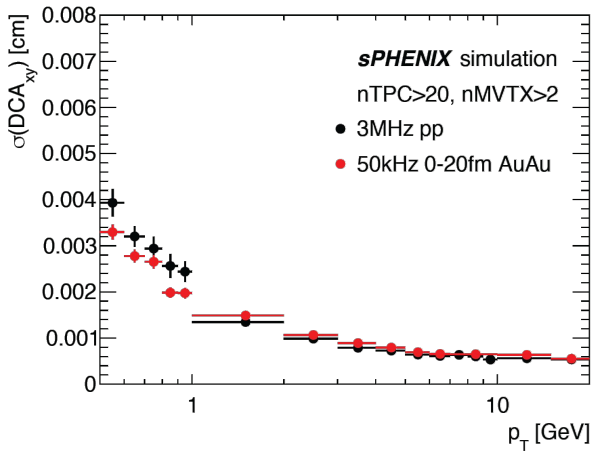
- **Reconstruction of heavy-flavor decay topology**

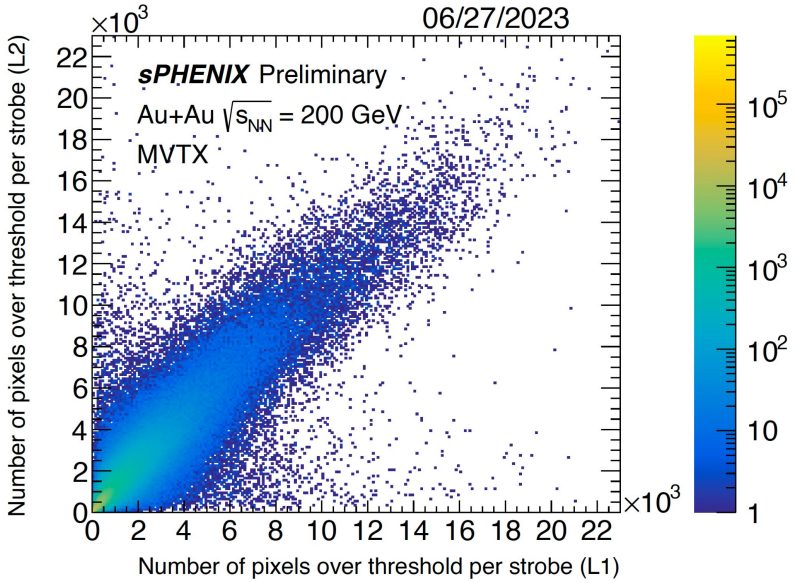
Open heavy flavor: MVTX

MVTX: MAPS based vertex tracker

- ALPIDE chip - near copy of the ITS2 inner layer from ALICE
- **~5 μm position resolution**

Critical for reconstruction of the open heavy-flavor decay topology



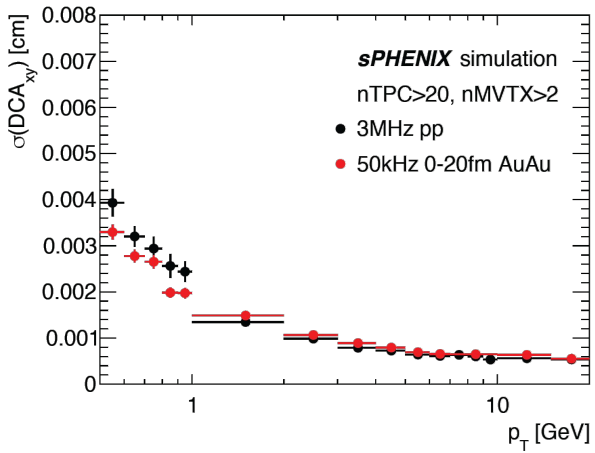


- Correlation between layer 1 and 2 of the MVTX

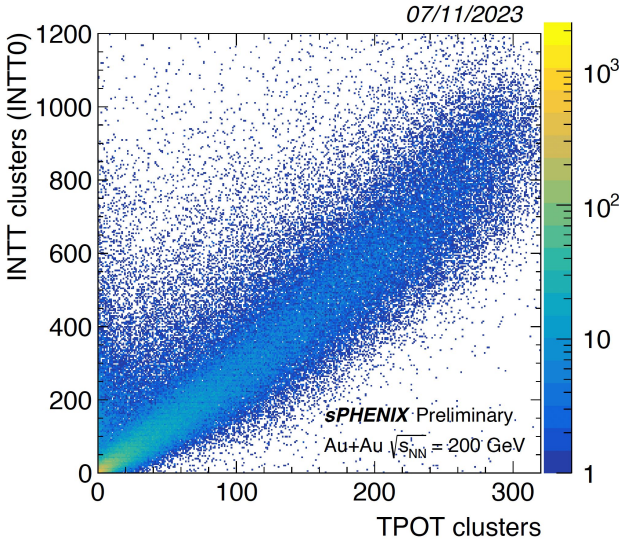
Open heavy flavor: INTT

INTT: silicon strip tracker

- 78 μm pitch
- **Single beam-crossing timing**



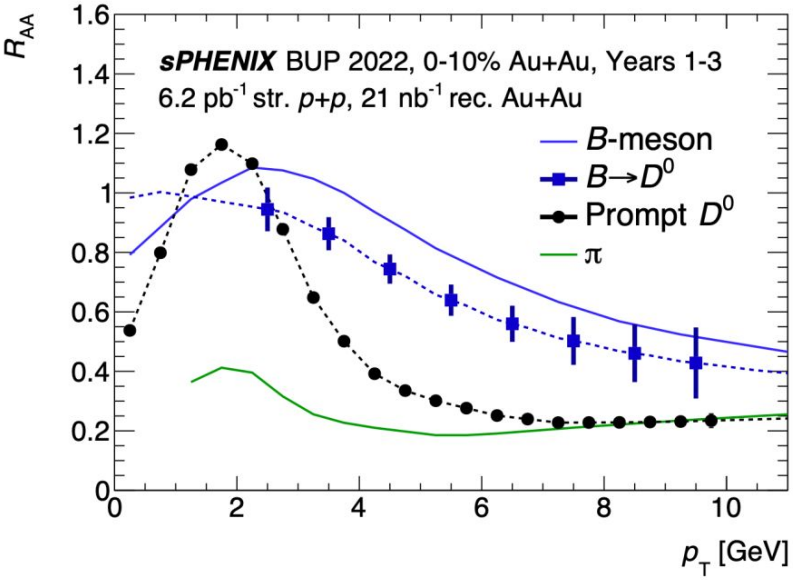
Critical for reconstruction of the open heavy-flavor decay topology



- Correlation between INTT and TPOT clusters

Antonio Silva

Open heavy flavour measurements



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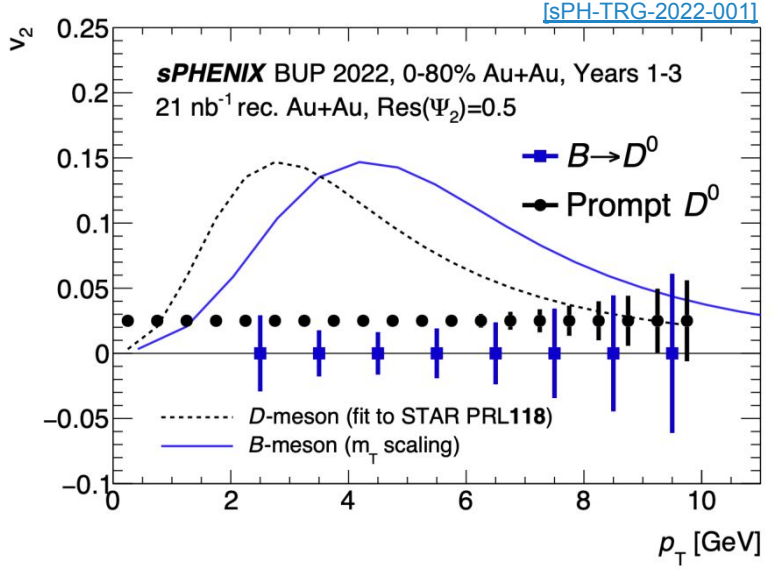
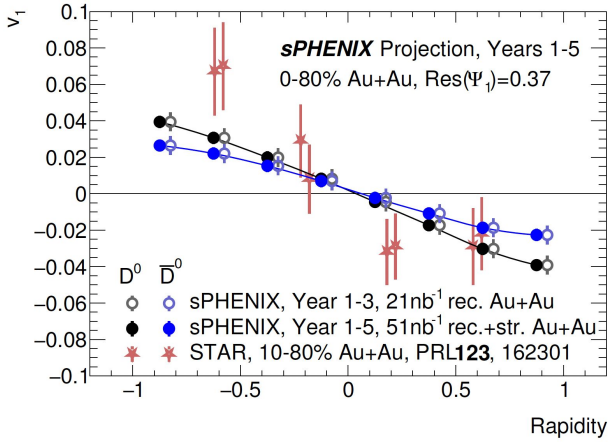
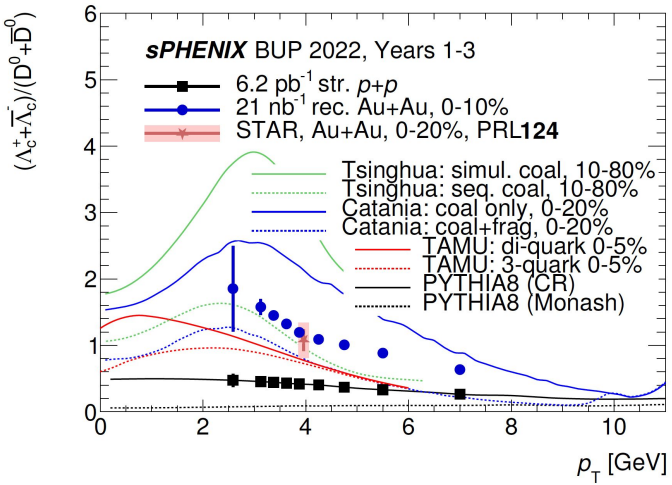


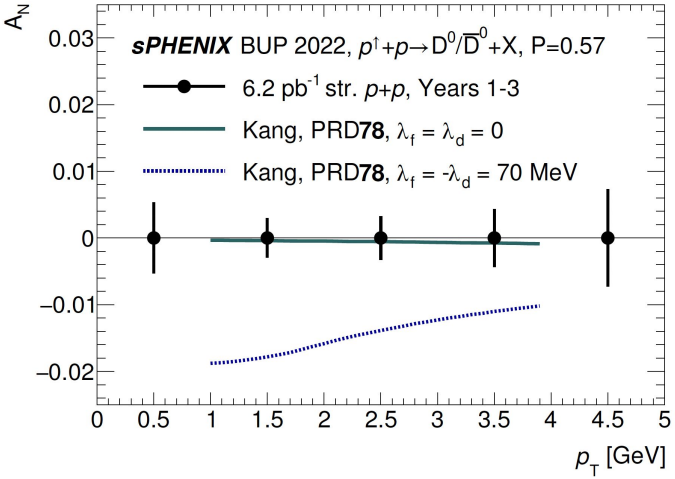
- Study of **heavy-flavor energy loss** (R_{AA})
  - Interplay between collisional and radiative energy loss
- Study of **collective effects** (v_2)
  - Access to the **bottom quark collectivity**
- **High precision measurements** → deeper understanding of the interaction mechanisms between heavy-quarks and the QPG

HF flow, baryons, and spin asymmetry

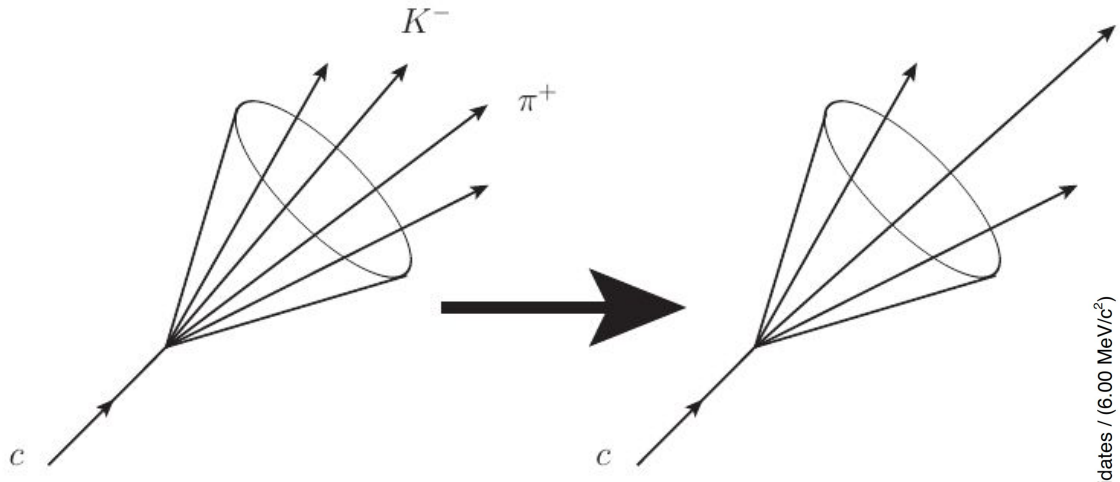


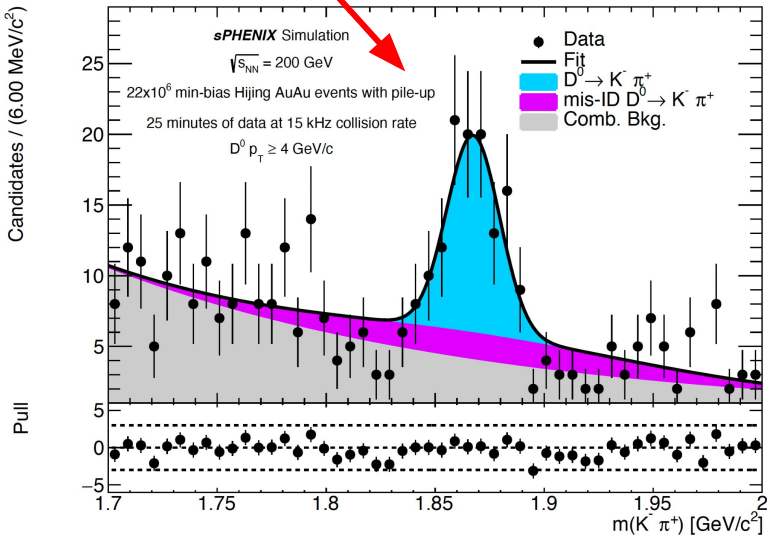


- Heavy-flavor flow: D^0 v_1
  - Separated for D^0 and $\overline{D}^0$
- Charmed baryon Λ_c
  - Λ_c/D ratio for central Au+Au and p+p
- D^0 transverse single spin asymmetry in p+p at $\sqrt{s}$ = 200 GeV



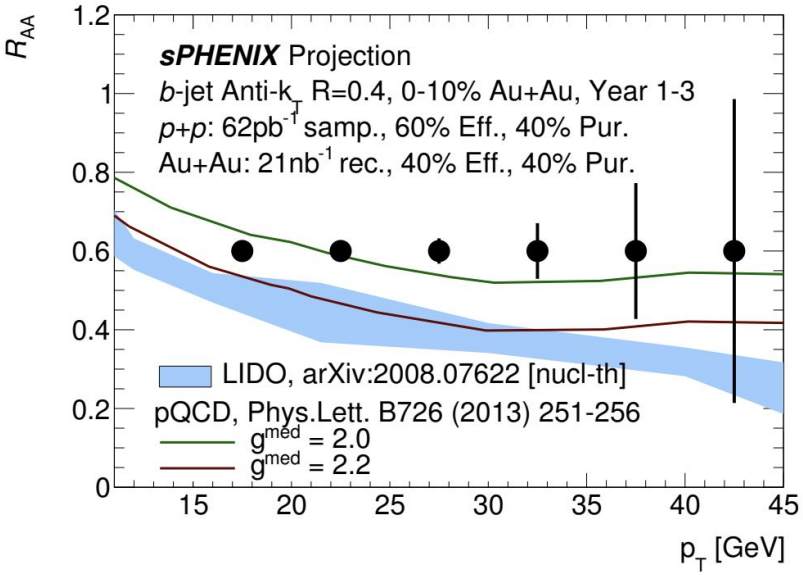
Heavy-flavor jets: D-tagged jets





- Jets reconstructed with a **D meson as one of the constituents**
  - **Full jet reconstruction → tracking + calorimeters**
  - Strong rejection of combinatorial jets at low momentum
- Wide range of jet structure measurements
- Interesting comparison to b-jets and inclusive jets

Heavy-flavor jets: b-jets



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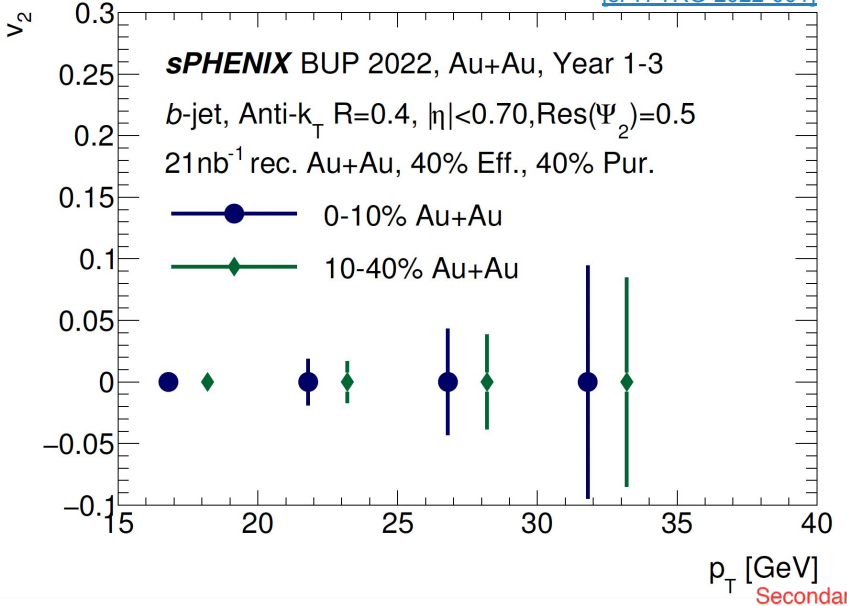
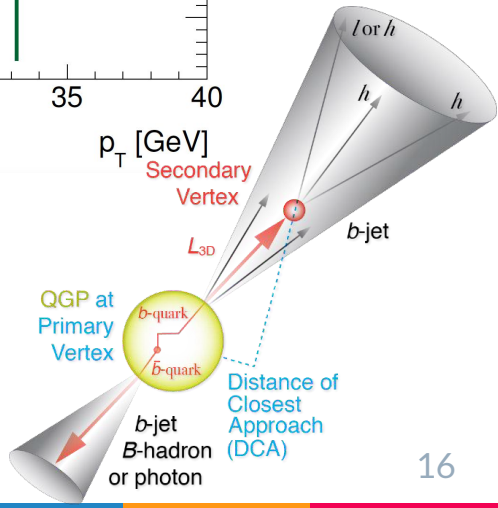
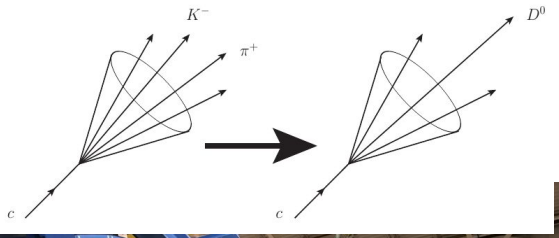
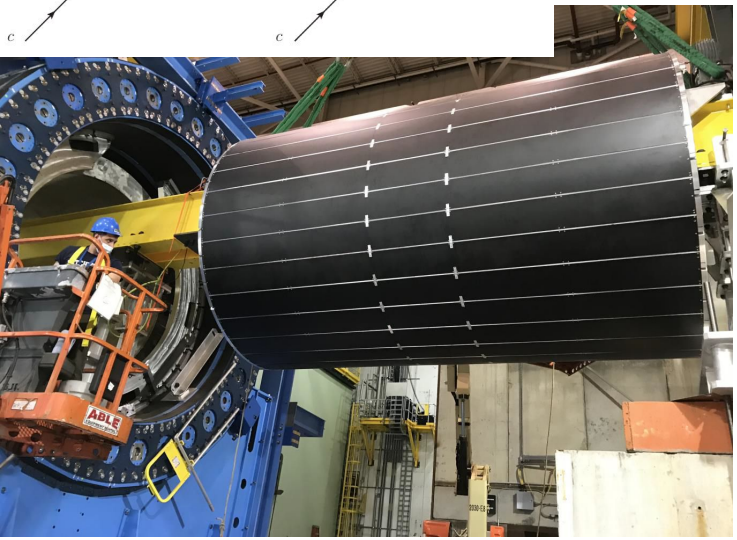


- **First b-jet tagging at RHIC**
  - Track DCA based tagger
  - Secondary vertices tagger
- **Full jet reconstruction → tracking + calorimeters**

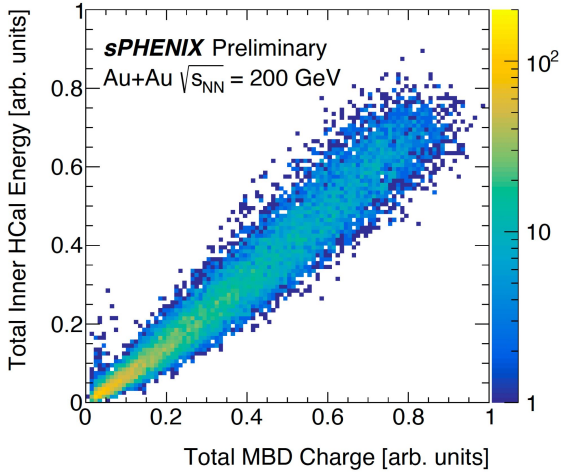


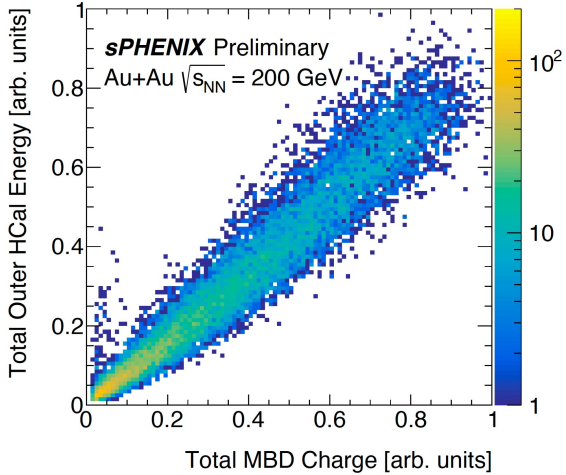
Heavy-flavor jets: HCal





- Heavy-flavor jet reconstruction
  - Combination of tracking and calorimeters
  - Implementation of particle flow





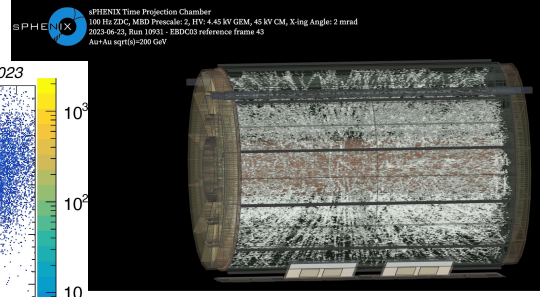
- Inner and Outer HCal commissioning
  - Inner (left) and Outer (right) HCal total energy as a function of MBD charge

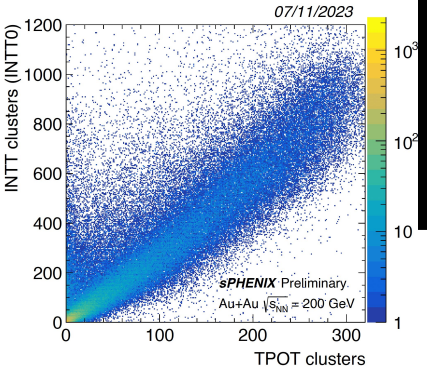
Outer and Inner HCal

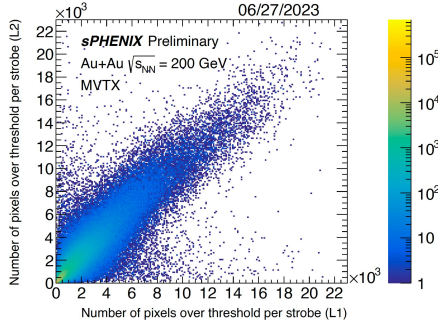
- **First hadronic calorimeter at midrapidity at RHIC**
- **$|\eta| < 1.1$, full azimuthal coverage → HF-jets**

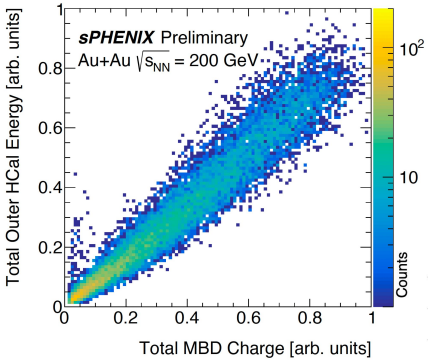
Summary

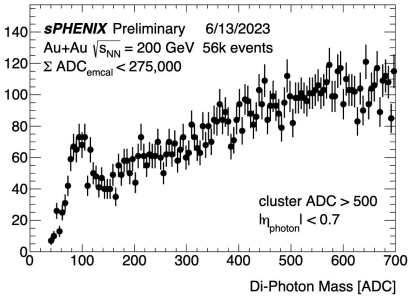
- All sPHENIX subsystems are progressing well during the commissioning phase
- The conclusion of a scientific mission to probe the inner workings of the QGP and resolving its properties
  - Heavy flavor is an important part of this mission
- Unique capabilities to probe the QGP at distinct length and mass scales at RHIC
  - Υ(2S) and Υ(3S) measurements at RHIC
- Open heavy flavor and heavy-flavor jet physics programs
  - Precision tracking
    - Including hadrons originating from b quarks
  - Full jet reconstruction
    - b-jets and HF-hadron tagged jets









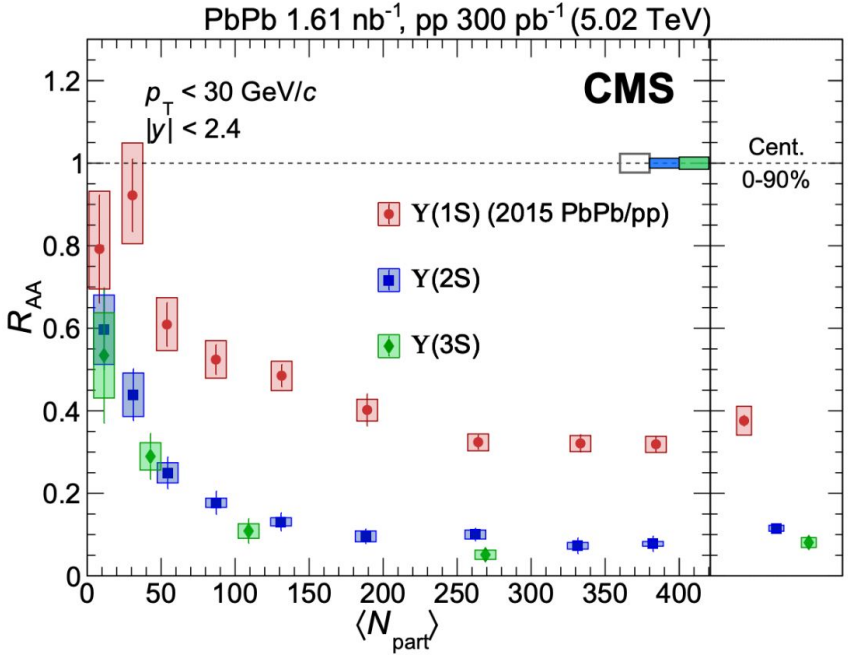


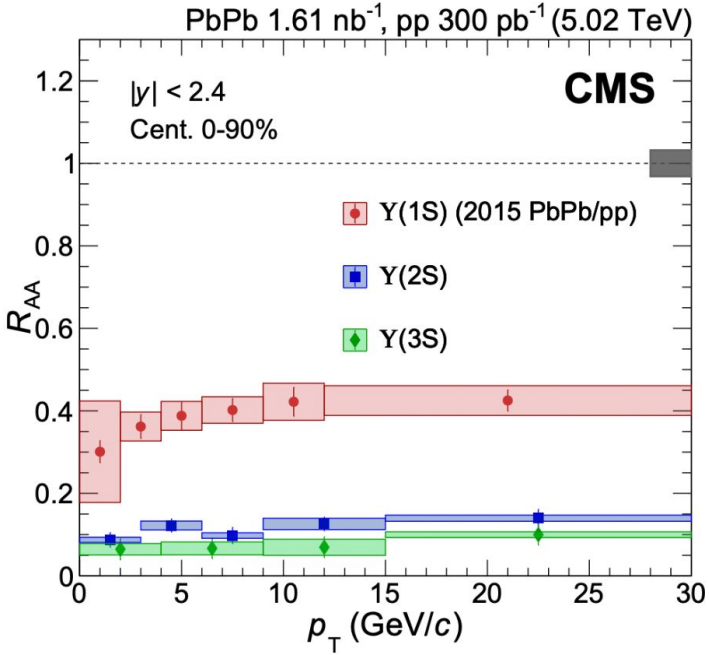
Backup slides

Potential 2 more years run 2026-2027

Year	Beam	$\sqrt{s_{NN}}$ (GeV)	Cryo Weeks	Physics Weeks	$\mathcal{L}_{samp}$ (|z|<10cm)
2026	p+p	200	28	15.5	80 pb^{-1}
	O+O	200	-	2	37 nb^{-1}
	Ar+Ar	200	-	2	12 nb^{-1}
2027	Au+Au	200	28	24.5	30 nb^{-1}

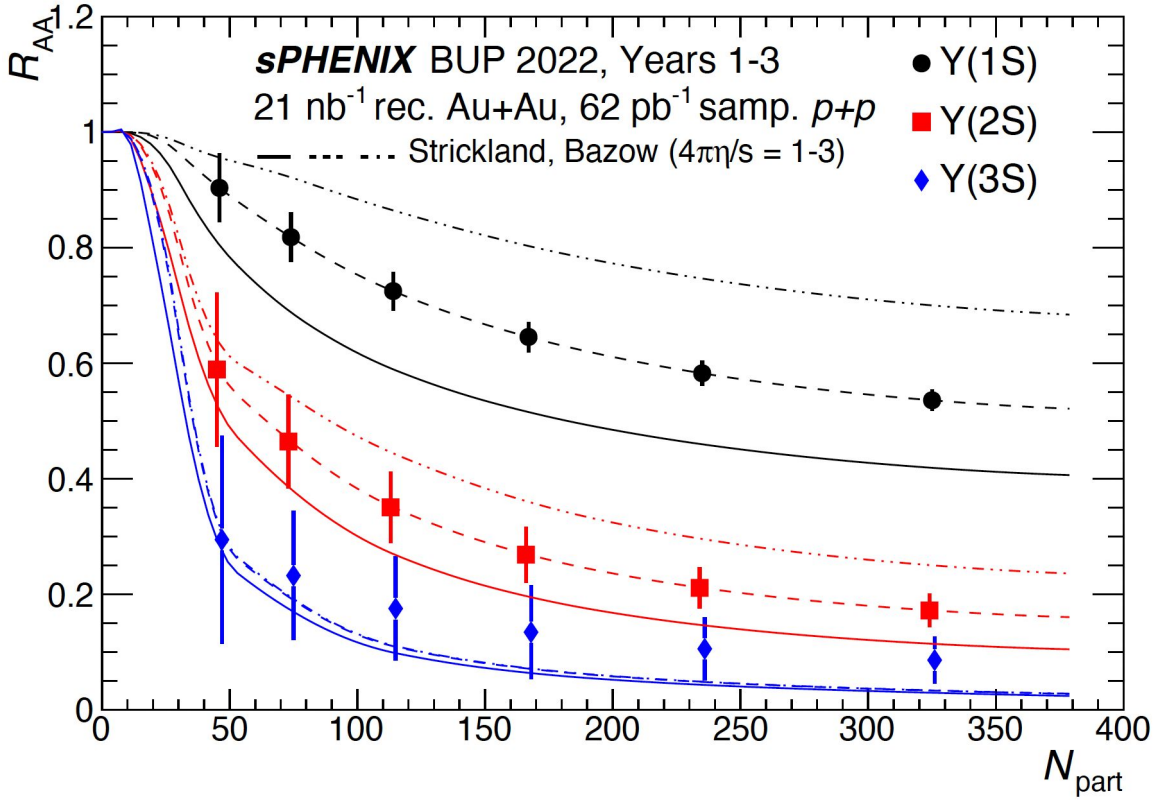
Quarkonium measurements





- CMS measurement
- CMS-HIN-21-007, CERN-EP-2023-011

Quarkonium measurements



Y(1S), Y(2S) and Y(3S) R_{AA} as a function of centrality

- Comparison to LHC measurements