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Probing QGP Properties at the sPHENIX Experiment

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for the sPHENIX Collabration

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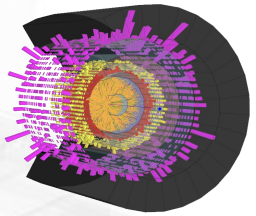
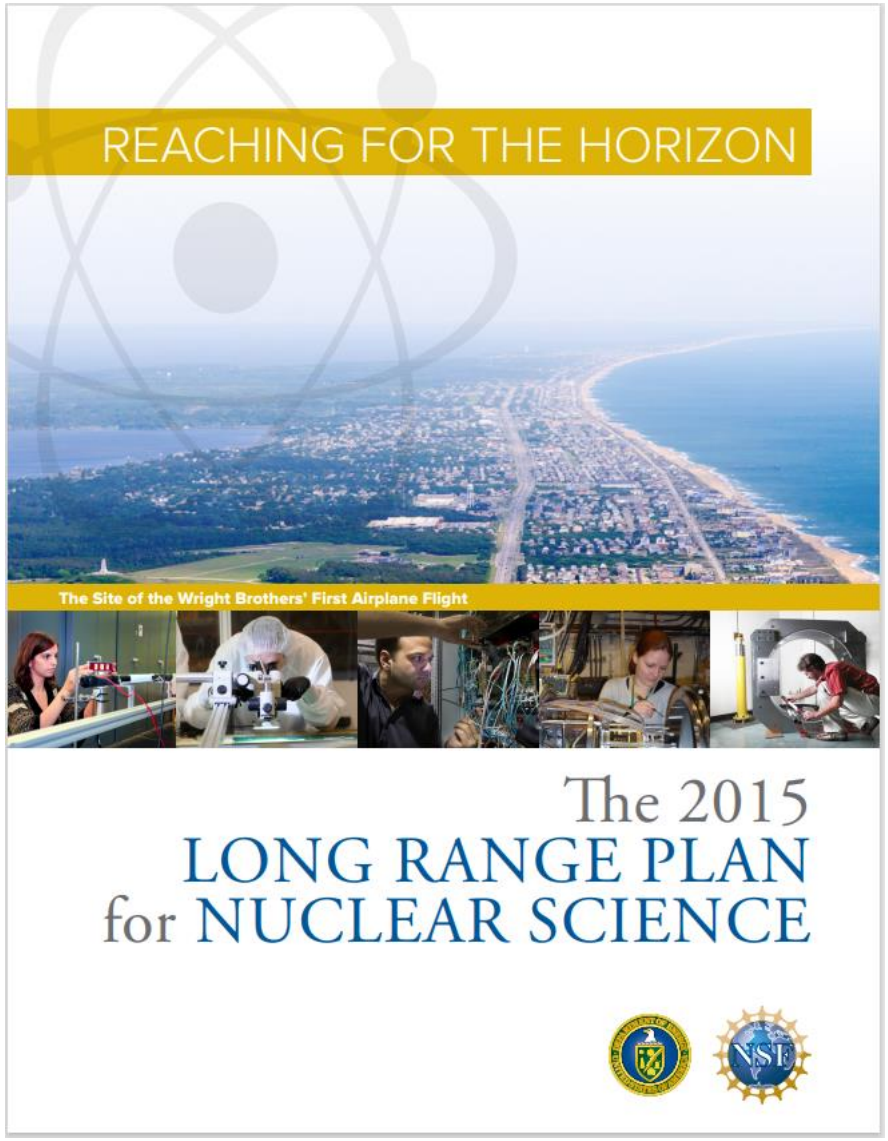
Sep. 8, 2022



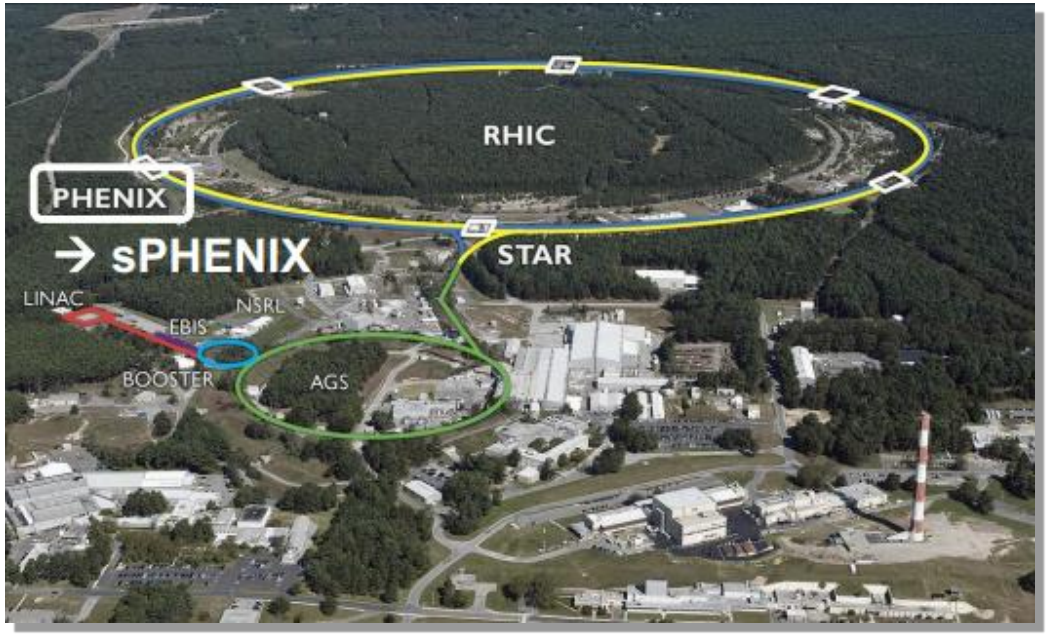
sPHENIX Science Mission



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.**

- ✓ sPHENIX will be the first new collider detector at RHIC in over twenty years;
- ✓ performing very high precision studies of jet production, jet substructure and open and hidden heavy flavor over an unprecedented kinematic range at RHIC;
- ✓ distinguished by high rate capability and large acceptance, combined with high precision tracking and electromagnetic and hadronic calorimetry.

sPHENIX Collaboration



- ✓ Replacement/upgrade of PHENIX. Proposed in 2010; collaboration formed in 2016.
- ✓ More than **360** members from **82** institutions in **14** countries as of 2022.
- ✓ Benefit from world-class expertise in physics, silicon, TPCs, calorimetry, electronics, computing, …

2016 2017 2018 2019

Berkeley, Temple University, Berkeley Lab, cea, IMP, SINAP, Peking University, UNC Greensboro, U. Sao Paolo, NCU, Taiwan, Sejong University, Florida AMU

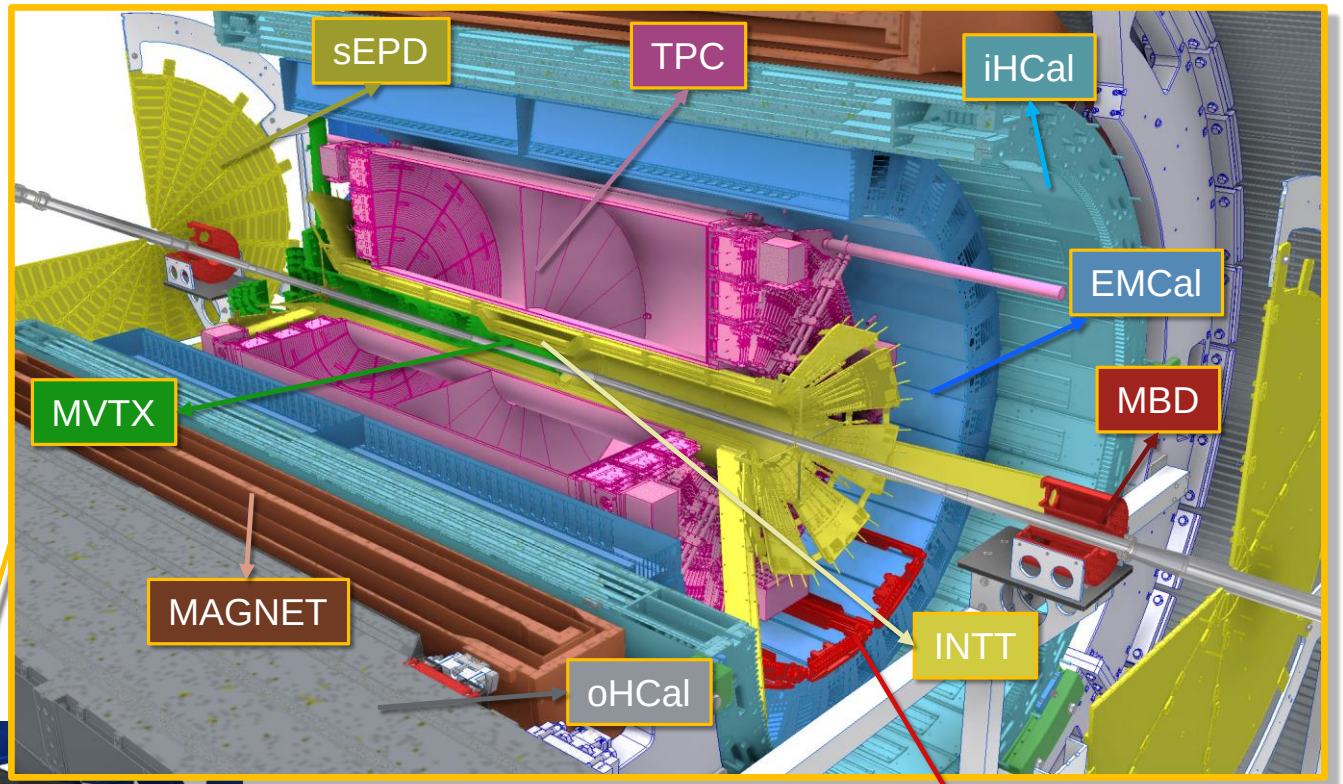
* shown here are institutions joined after CD-0

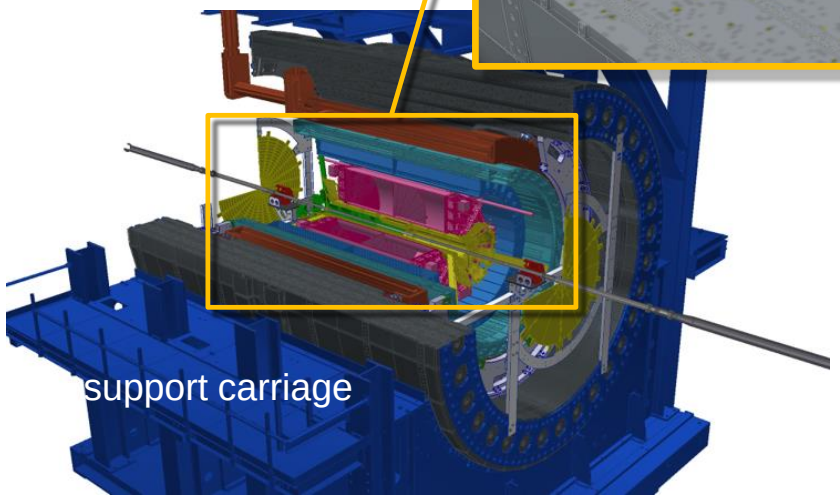
2020 2021

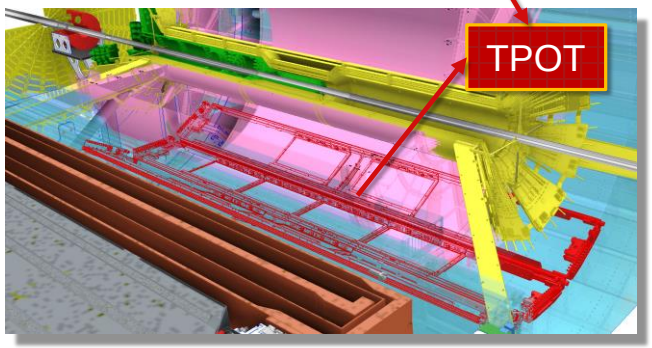
National Taiwan University, Hanyang University, Institute for Information Industry, Lund University, Pusan National University

sPHENIX Detector

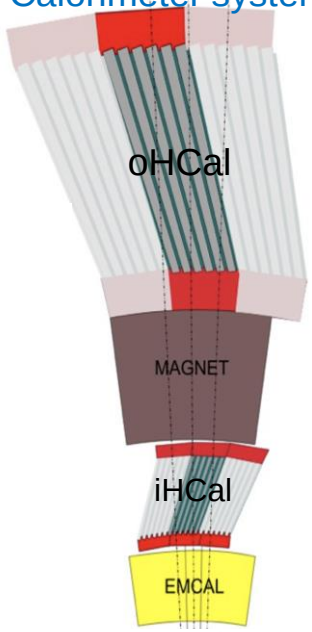
- High data rates: 15 kHz for all subdetectors
- Trigger capability also with streaming readout
- 1.4T Solenoid from BaBar
- Hermetic coverage: |η|≤1.1
- Precision tracking
- Large-acceptance EM+H calorimeters: brings first full jet reconstruction & b-jet tagging at RHIC!!



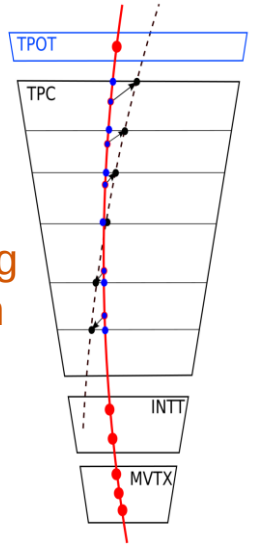




Calorimeter system



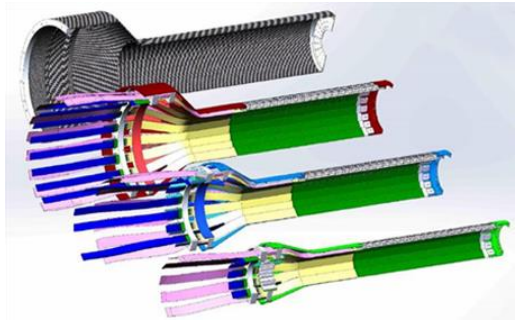
Tracking system



Tracking System

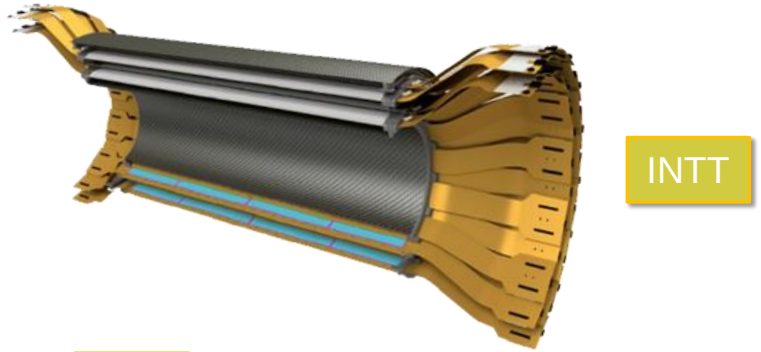
MAPS-based micro-VerTeX detector (MVTX)

- ✓ Based on ALICE ITS
- ✓ 3-layer Monolithic Active Pixel Sensors (MAPS).
- ✓ Excellent 2-D DCA resolution, < 10 μm for p_T > 2GeV/c
- ✓ Both half-detectors assembled at LBNL!



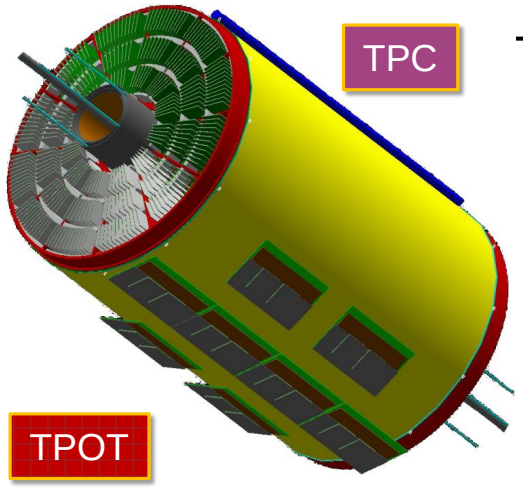
Intermediate Silicon Tracker (INTT)

- ✓ Two Barrels (four Layers) silicon strips
- ✓ Fast O(100 ns) integration time; can resolve one beam crossing
- ✓ Detector is under final construction.



TPC Outer Tracker (TPOT)

- ✓ 8 modules of Micromegas inserted between TPC and EMCal
- ✓ Calibration of beam-induced space charge distortions in the TPC
- ✓ TPOT module under test
- ✓ Installation in Oct.

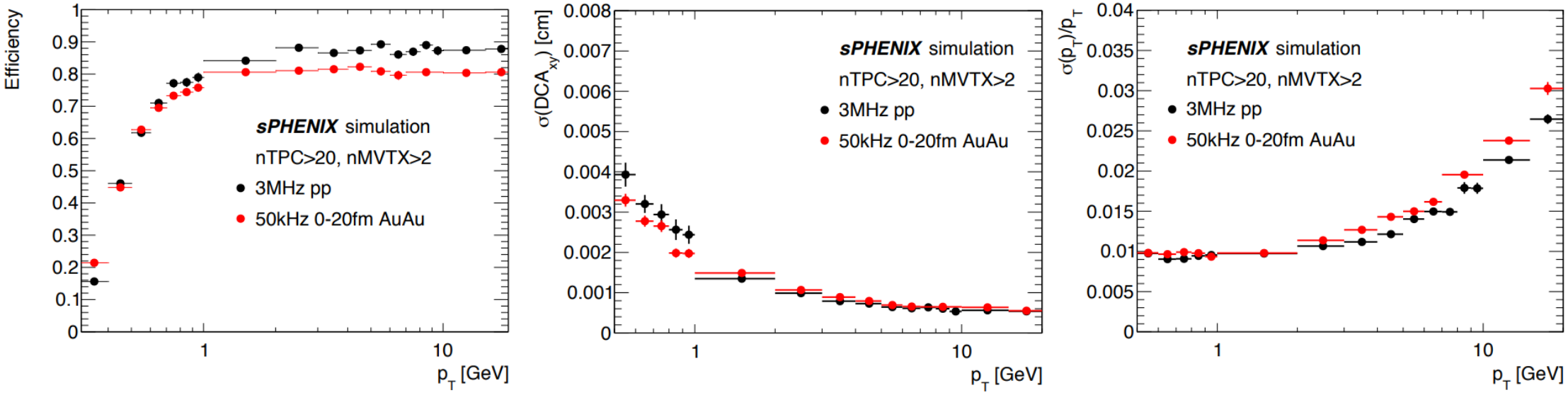


Time Projection Chamber (TPC)

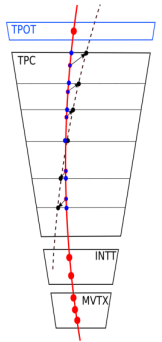
- ✓ Compact (1/30 volume of ALICE TPC)
- ✓ Gateless, continuous readout
- ✓ Quad GEM electron multiplier + chevron readout pads
- ✓ 48 layers (20-78 cm radius)
- ✓ Detector installation: middle of November

Tracking Performance

sPHENIX tracking performance



- ✓ Eff.~90% for pp at p_T>1 GeV. → promising to measure rare processes: e.g. Υ(nS).
- ✓ DCA resolutions in r-ϕ, 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.



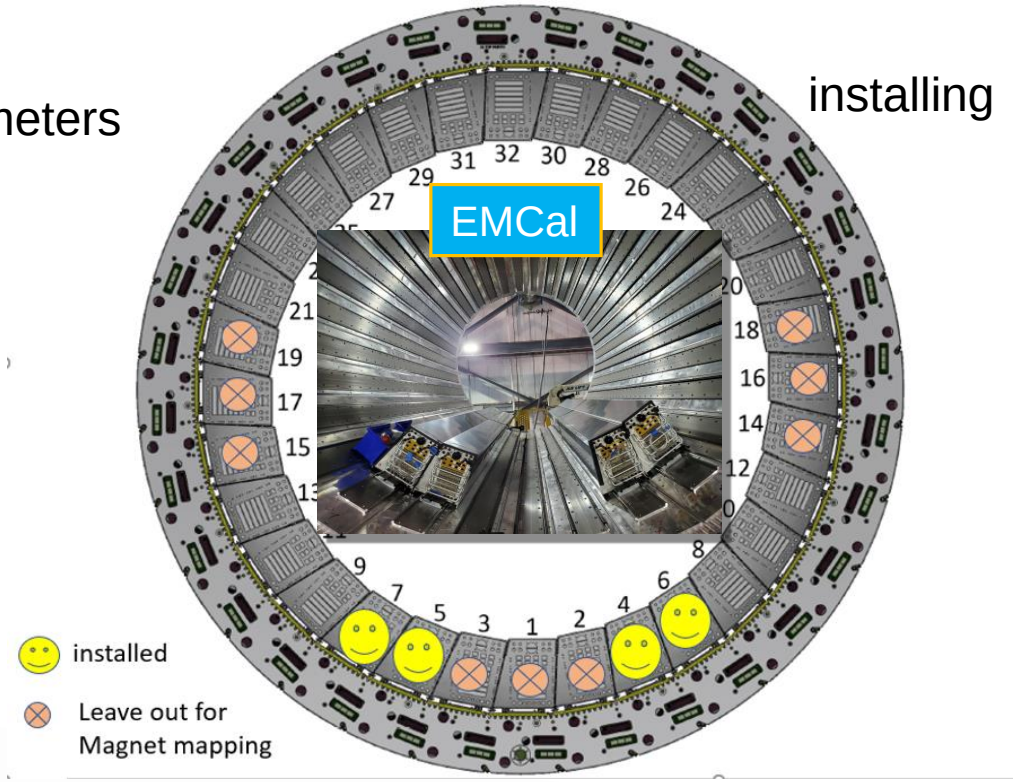
Electromagnetic Calorimeter (EMCal)

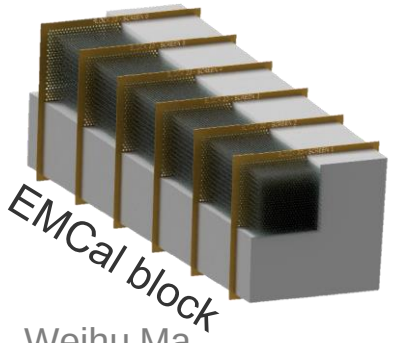
Calorimeter System(EMCal+iHCal+ oHCal)

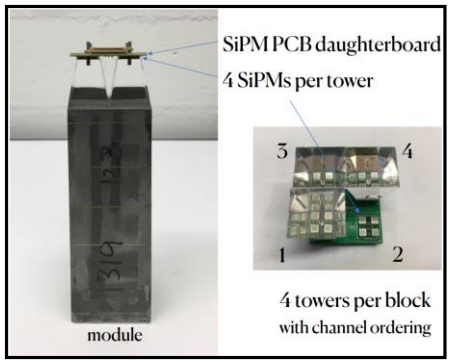
- ✓ Compact, hermetic, near-projective sampling calorimeters
- ✓ Coverage $|\eta| < 1.1$, 2π in φ
- ✓ SiPM readout for both EMCal and HCal
- ✓ Less-biased jet measurement
- ✓ All Calorimeter electronics complete!

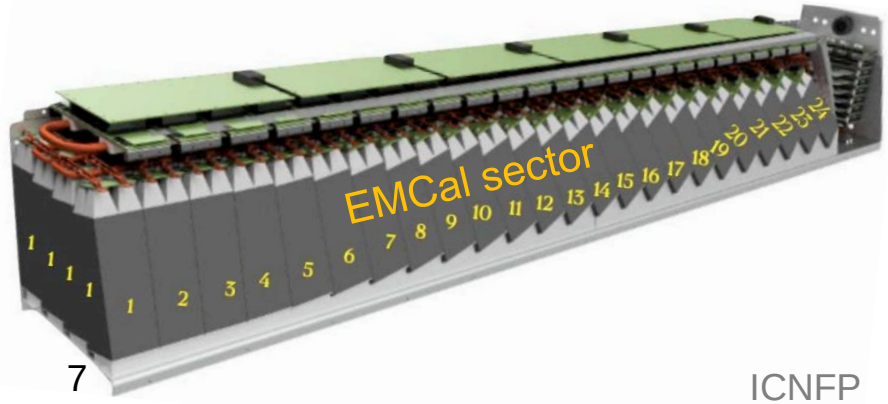
Electromagnetic Calorimeter (EMCal)

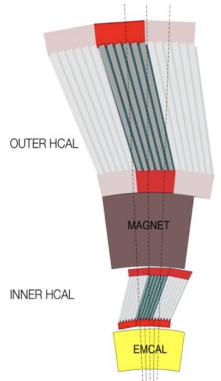
- ✓ Tungsten/scintillating fiber SPACAL
- ✓ ~7mm radiation length
- ✓ $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$
- ✓ Good energy resolution $\sigma_E/E \leq 16\%/\sqrt{E}$
- ✓ Sector Installation underway 10/64











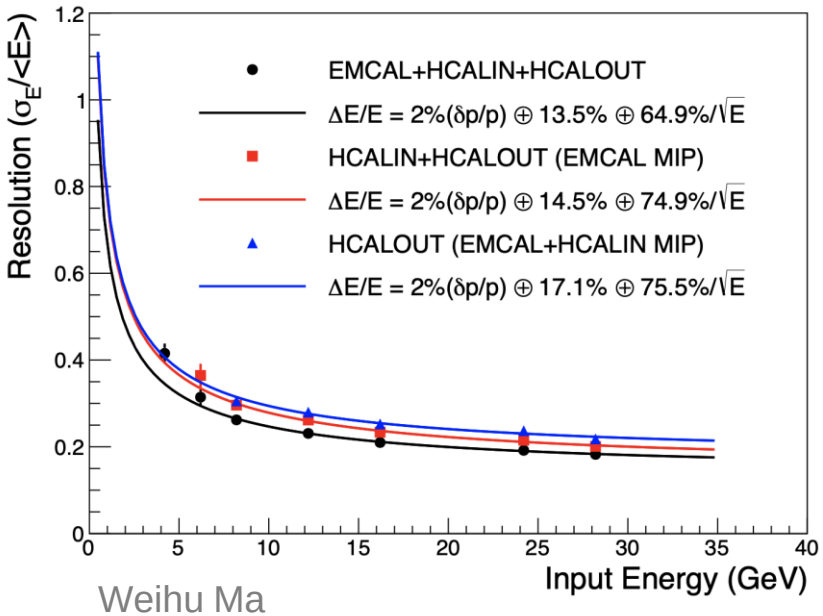
Hadronic Calorimeter (HCal)

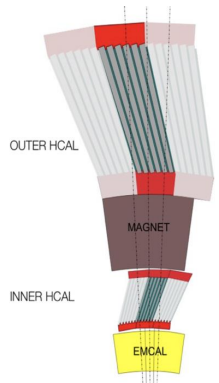
Inner Hadronic Calorimeter (iHCAL)

- ✓ Aluminum-scintillating tiles with embedded WLS fibers
- ✓ Installation complete!

Outer Hadronic Calorimeter (oHCAL)

- ✓ Tilted steel plates/scintillator tiles with embedded WLS fibers
- ✓ Δη x Δφ = 0.1 x 0.1 towers
- ✓ Installation complete!





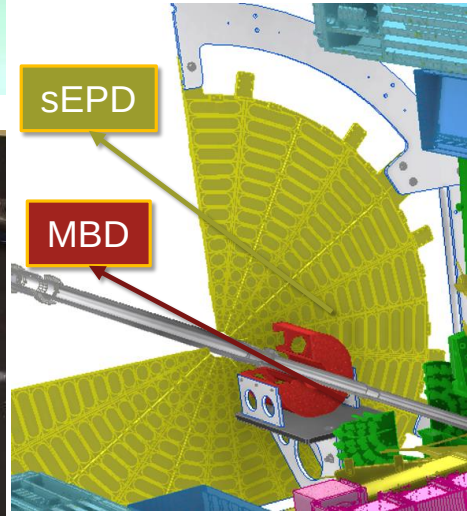
MBD and sEPD

Minimum bias detector (MBD)

- ✓ Provide minimum-bias trigger with high efficiency for heavy ion collisions (>90%)
- ✓ Contributes to centrality, reaction plane, start time, and interaction vertex
- ✓ Reuse of the PHENIX BBC(Beam-Beam counter)
- ✓ 128 channels of 3 cm thick quartz radiator on mesh dynode PMT
- ✓ $3.51 < |\eta| < 4.61$
- ✓ 120 ps timing resolution
- ✓ Detector complete!

sPHENIX Event Plane Detector (sEPD)

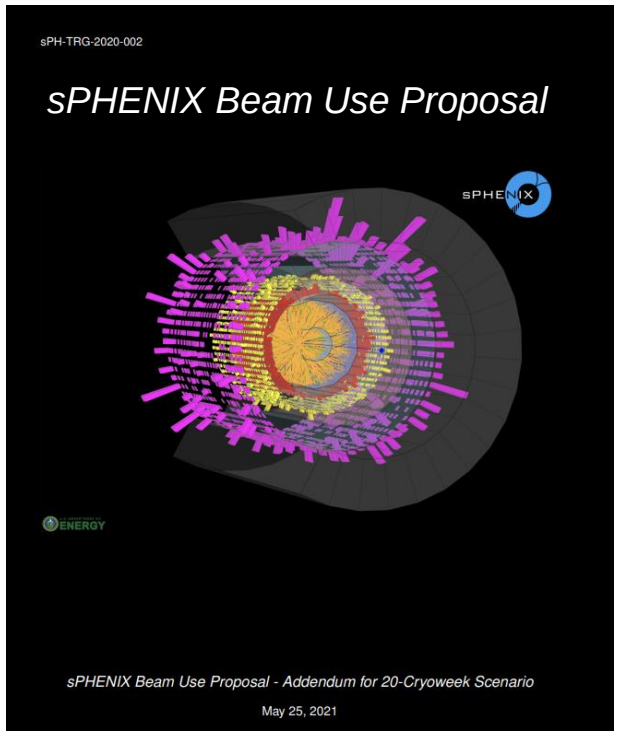
- ✓ Measure event plane and centrality outside of mid-rapidity
- ✓ 1.2-cm-thick scintillator with embedded WLS fibers
- ✓ 2 wheels of 12 sectors (31 tiles per sector)
- ✓ $2.0 < |\eta| < 4.9$



Run plan of sPHENIX

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023

- sPHENIX science collaboration
- DOE CD-0 "Mission need" approval
- DOE CD-1/3A Cost, schedule, advance purchase approval
- **Today** Installation and commissioning
- Start first data taking!

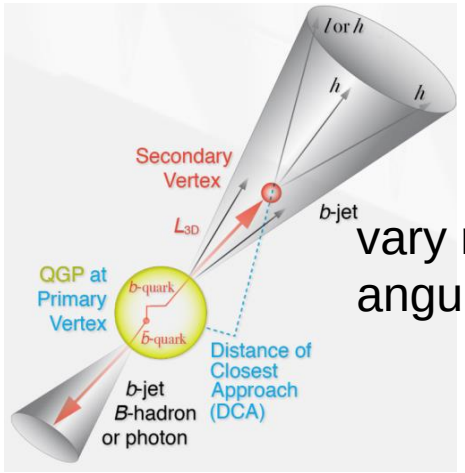


Summary of sPHENIX Beam Use Proposal for the years 2023–2025

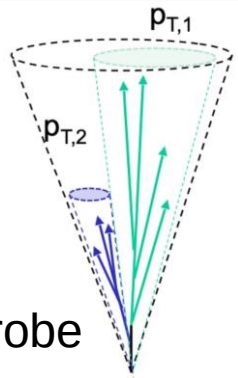
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	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}

- Year-1 (Au+Au): Commissioning, calibration, collection of a Au+Au data set.
- Year-2 (p+p & p+Au): Commissioning and p+p reference data & p+Au cold QCD Measurements.
- Year-3 (Au+Au): very large statistics data collection for jets and heavy flavor observables.

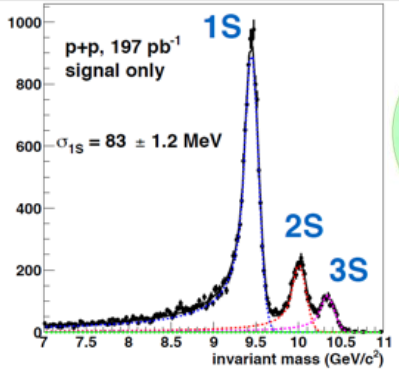
4 Core Physics Programs @ sPHENIX

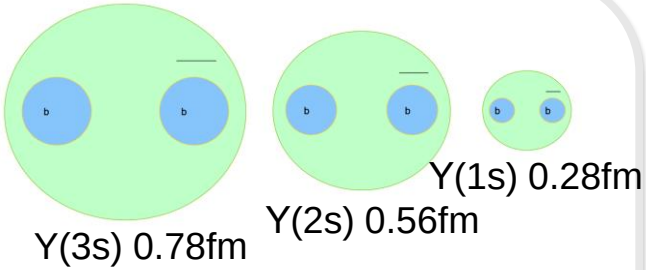


vary momentum & angular scale of probe



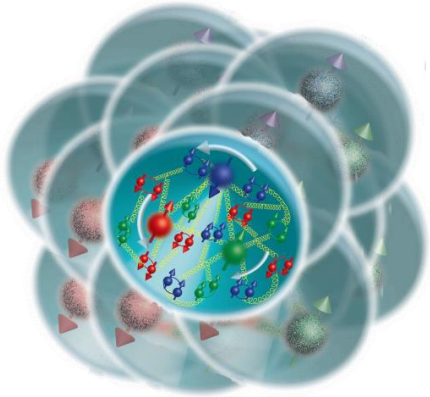
Jet physics





vary size of probe

Quarkonium spectroscopy



Cold QCD

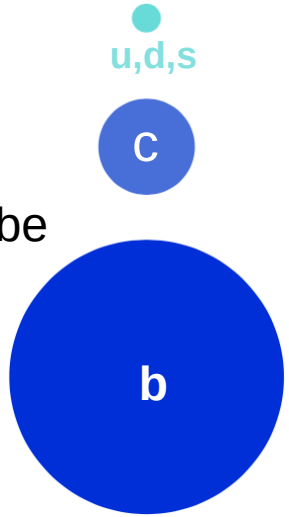
vary temperature of QCD matter

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

Parton energy loss

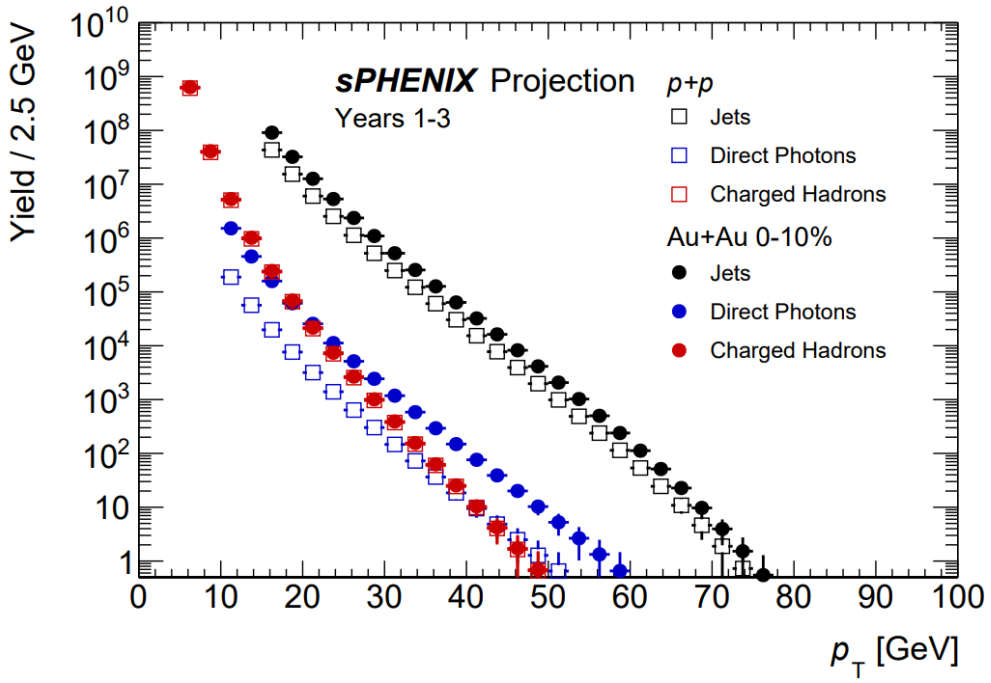
vary mass & momentum of probe

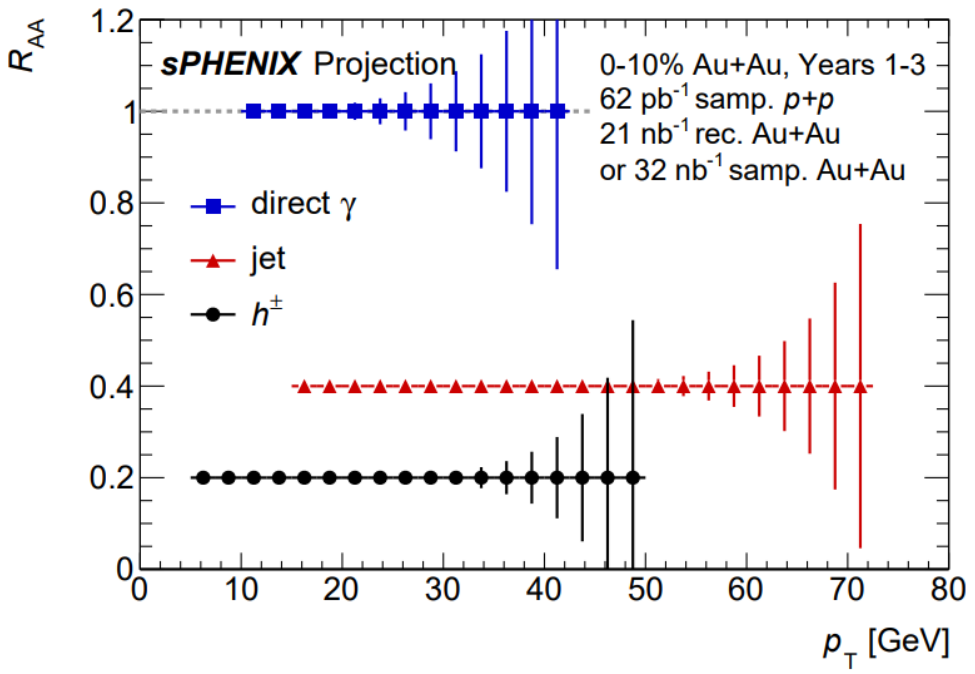
photon
gluon



High-p_T Probes

Probing the quark-gluon plasma with precise jet, direct photon, and hadron measurements is a core component of the sPHENIX scientific program.



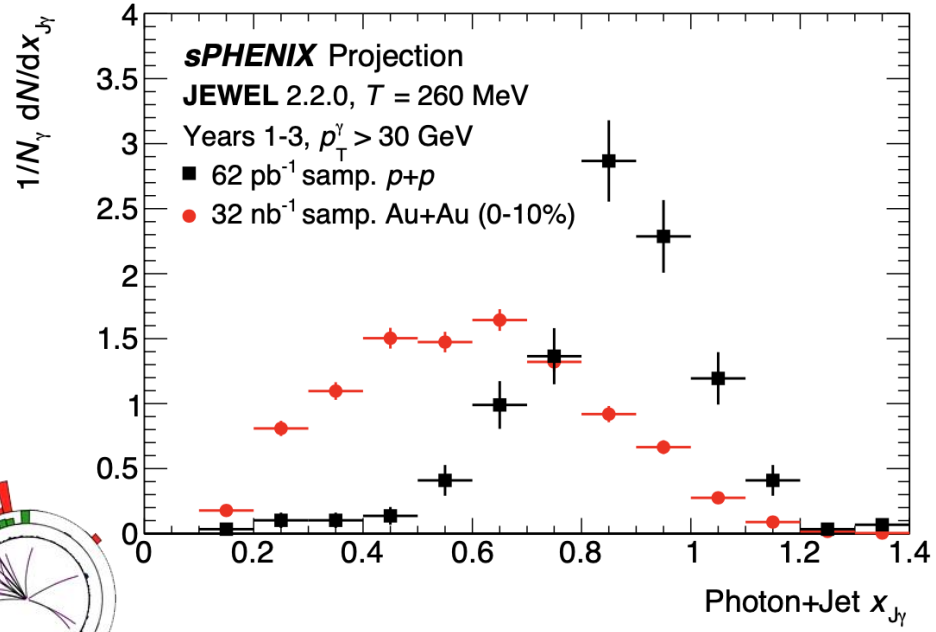


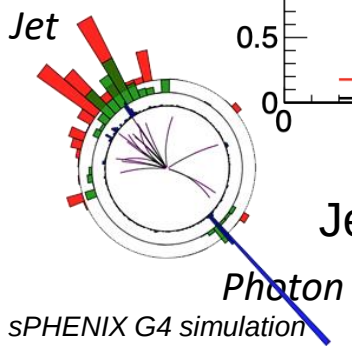
✓High data rates & hermetic EMCal+HCal offer wide p_T range for jet reconstruction.

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

✓sPHENIX will have kinematic reach out to ~ 70 GeV for jets, kinematic overlap with the LHC.

Jet Physics

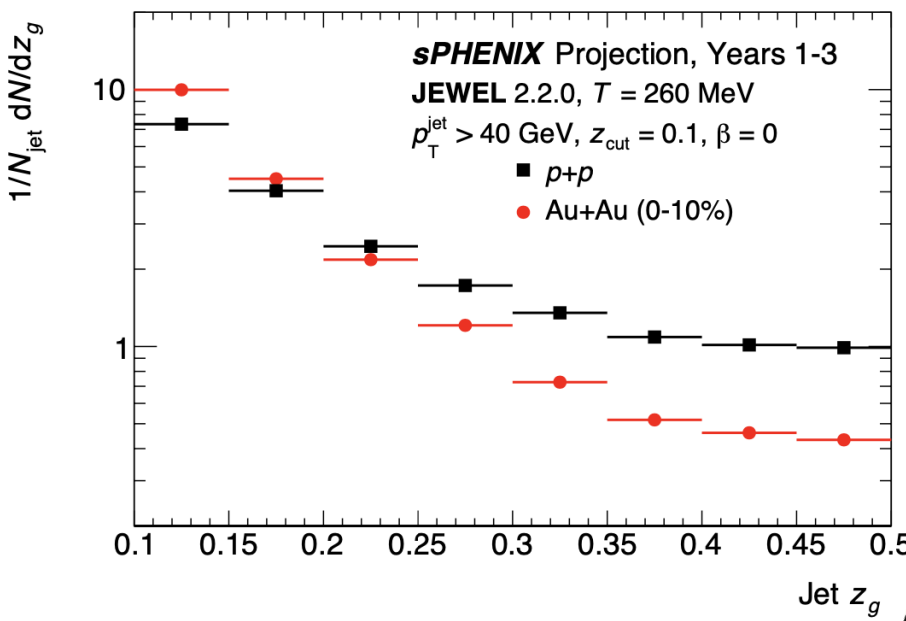


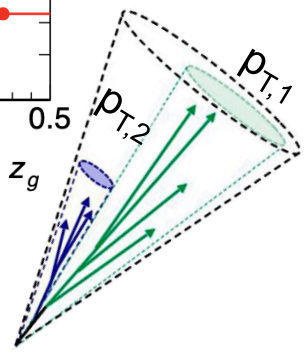


sPHENIX G4 simulation
Pythia8, 35 GeV γ+jet event

Jet-to-photon momentum balance

$$X_{J\gamma} = p_T^{jet}/p_T^{\gamma}$$





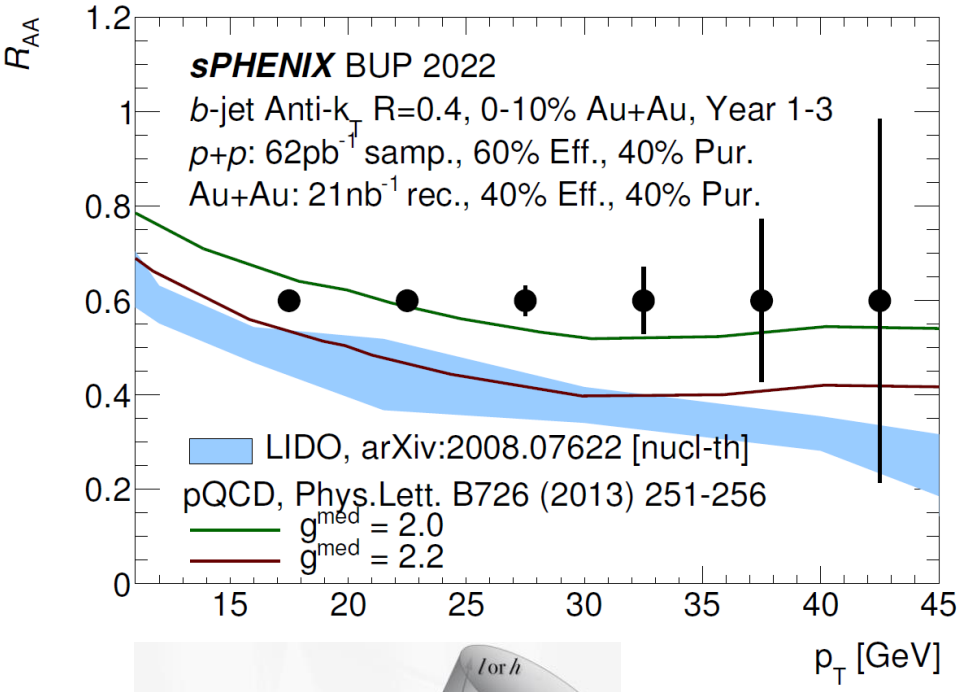
Groomed momentum fraction

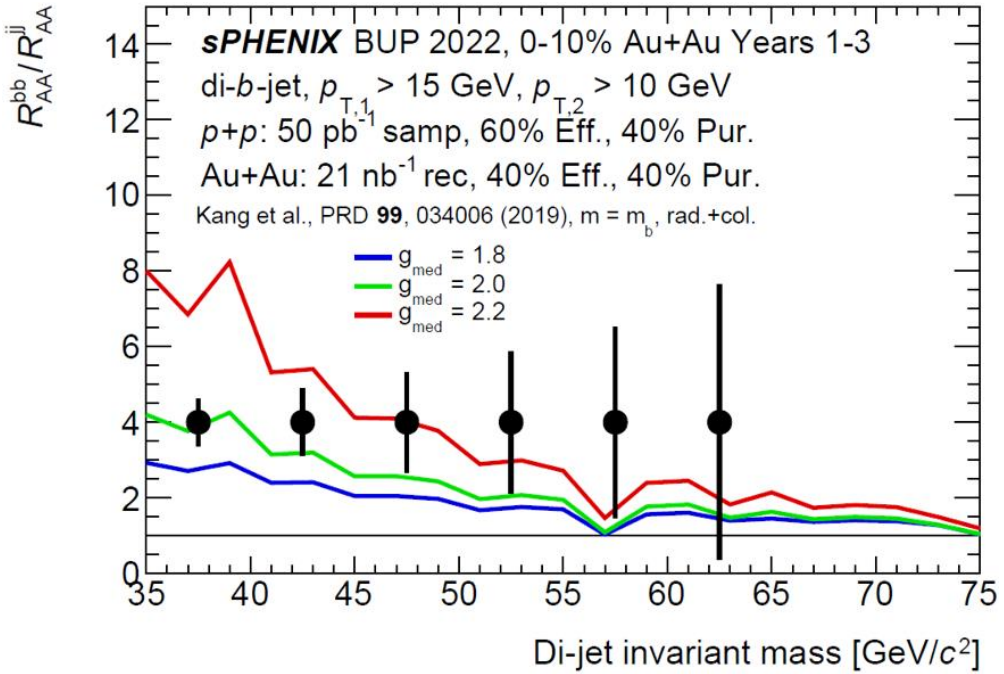
$$z_g = \frac{\min(p_{\perp,1}, p_{\perp,2})}{p_{\perp,1} + p_{\perp,2}}$$

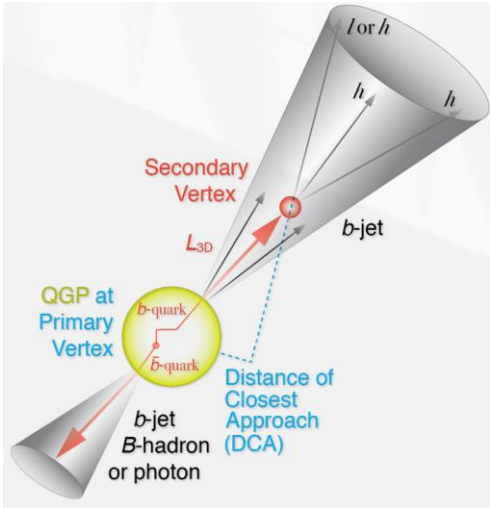
- ✓ A “flagship” measurement.
- ✓ Photon+jet measurements with high statistics.
- ✓ A direct measure of the jet energy loss.

- ✓ Jet substructure measurements thanks to the fine segmentation of calorimeter + good tracking resolution.
- ✓ Providing a glimpse into fundamental splittings at parton level.

b-Jet Physics

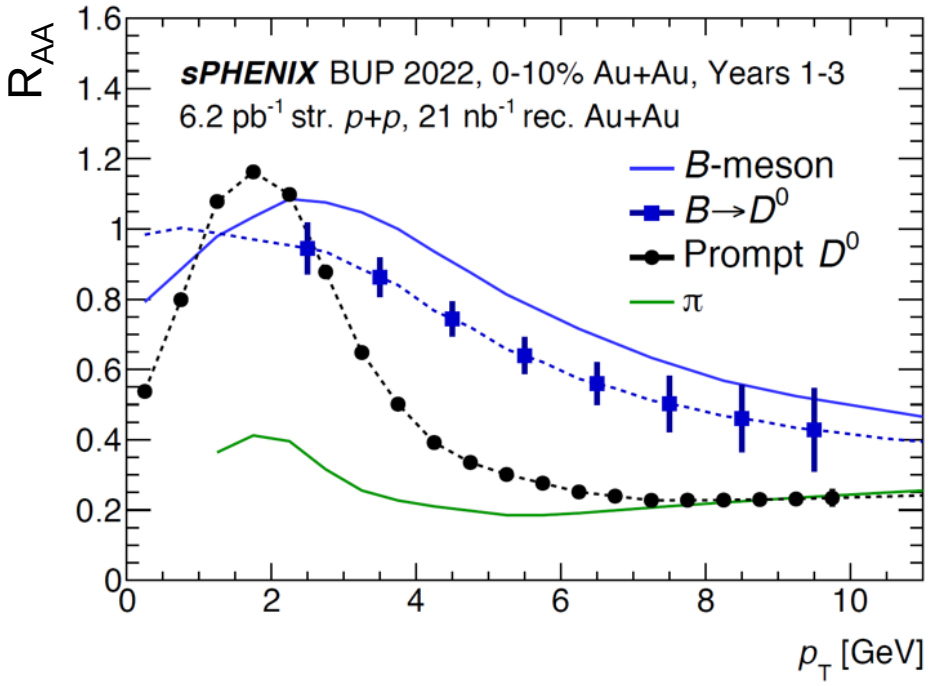


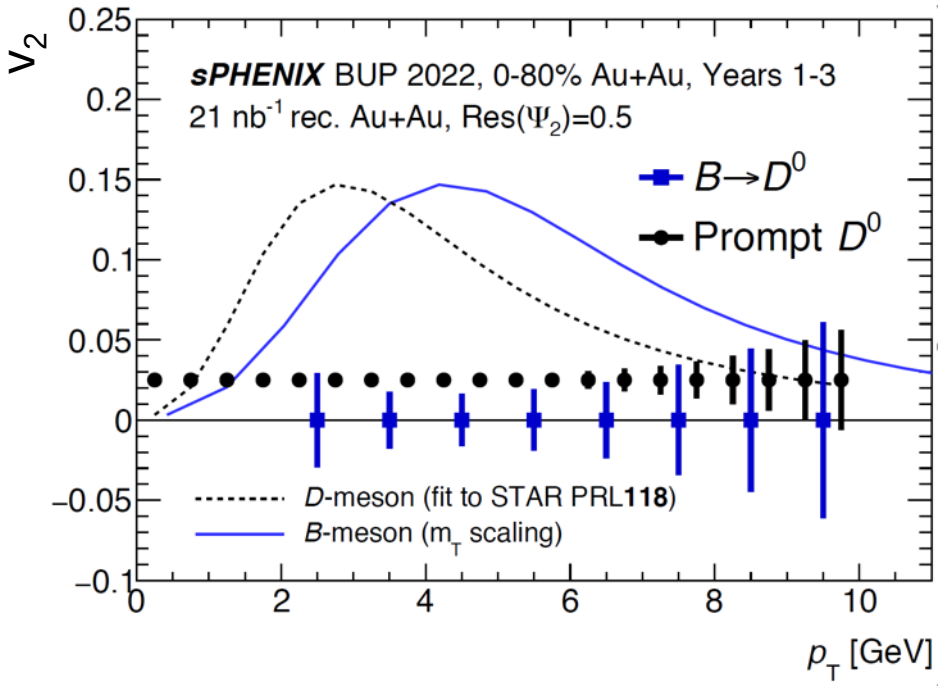




- ✓ New for RHIC, enabled by precision tracking and full calorimetric jet.
- ✓ First b-jet tagging at RHIC using precision-DCA track and secondary vertices tagger.
- ✓ Study mass dependence of energy loss mechanisms.
- ✓ sPHENIX data will place stringent constraints on the b-quark coupling to the QGP.
- ✓ Back-to-back heavy-flavor jet pairs studying the propagation of quarks in the QGP.

Open Heavy Flavor

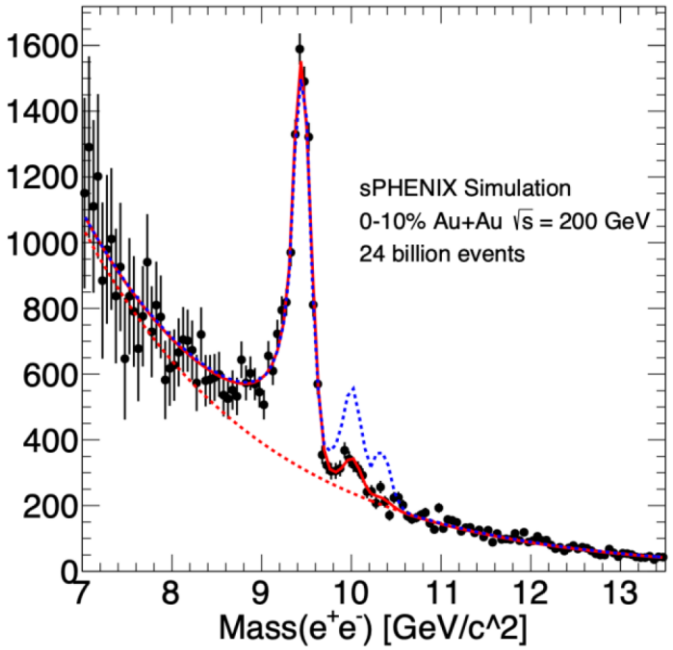


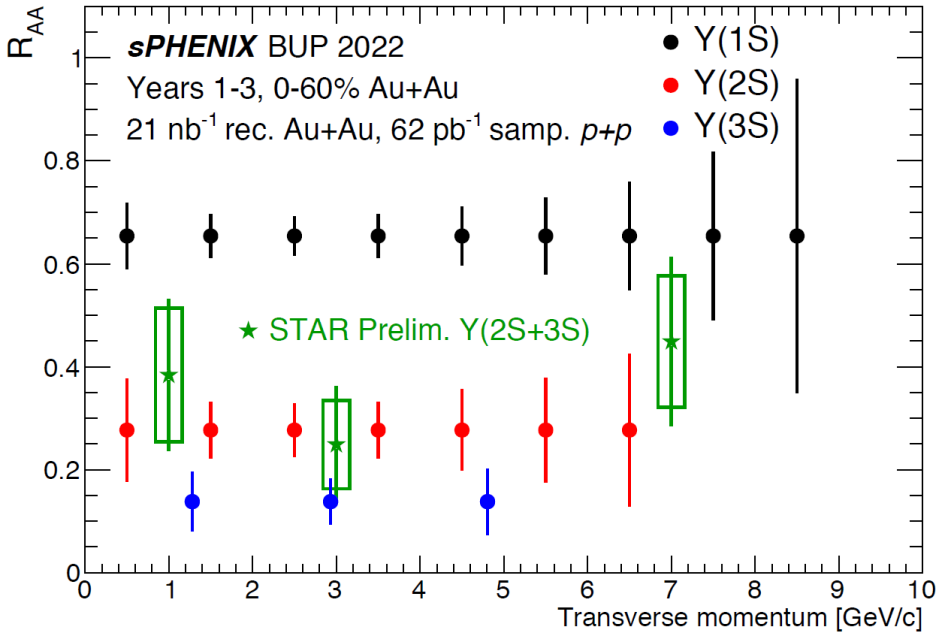


- ✓ Cleanly separate open bottom via DCA.
- ✓ Bottom quarks and light quarks are expected to be different for R_{AA} and v_2 for $p_T \lesssim 15$ GeV.
- ✓ Study mass dependence of energy loss and collectivity.

Upsilon R_{AA}

Mass reconstruction

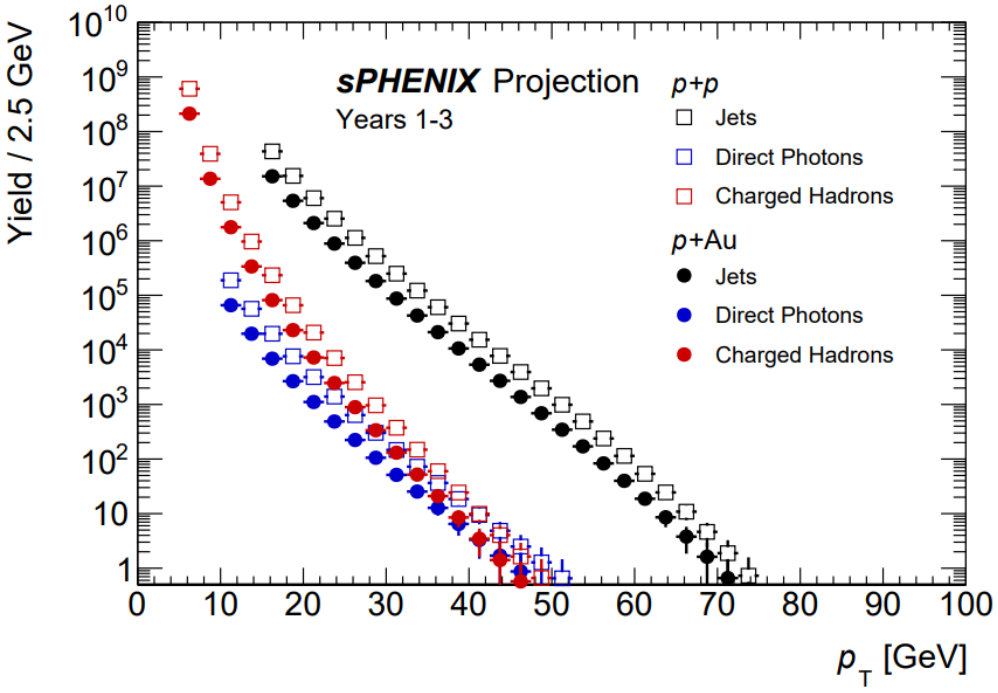




- ✓ Suppression with clear distinction of three Upsilon states. Color dipoles probing the QGP at three length scales.
- ✓ The centrality dependence and particularly the p_T dependence are critical measurements for comparison between RHIC and the LHC.
- ✓ sPHENIX is developing ML algorithms to reject hadronic background.

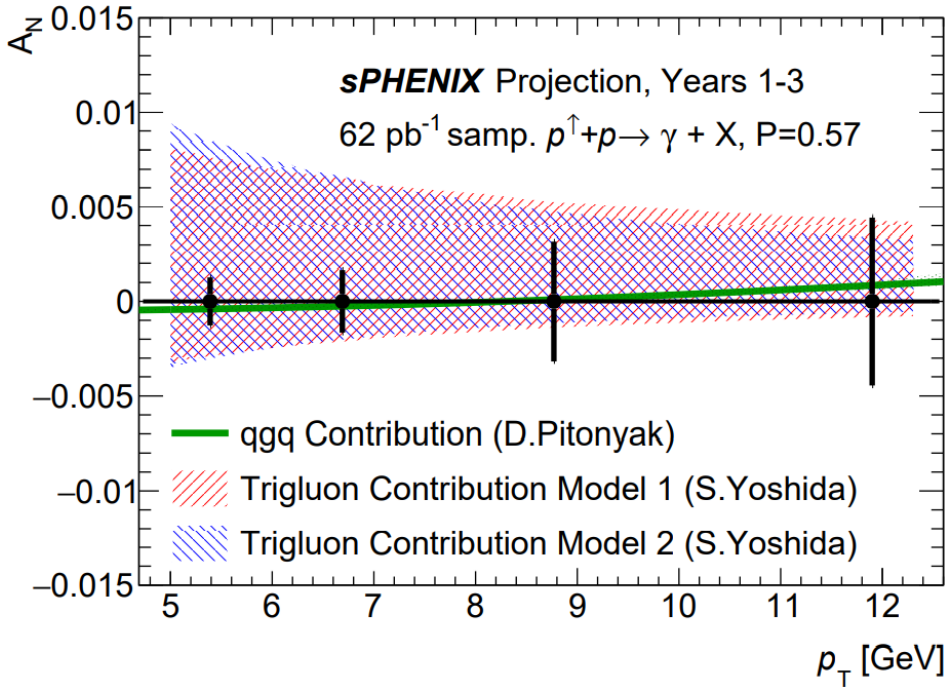
Cold QCD

Hard probes in p+Au



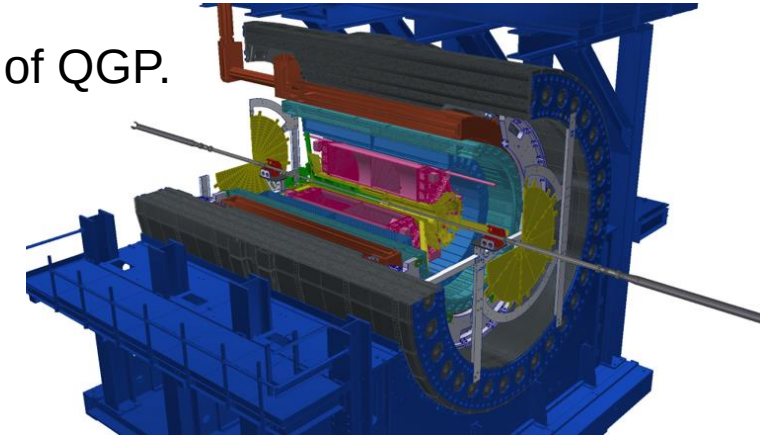
- ✓ Study of nuclear modifications using unpolarized p+Au measurements.
- ✓ Provide information on the nuclear modification of hadronization processes.

TSSA for direct photon



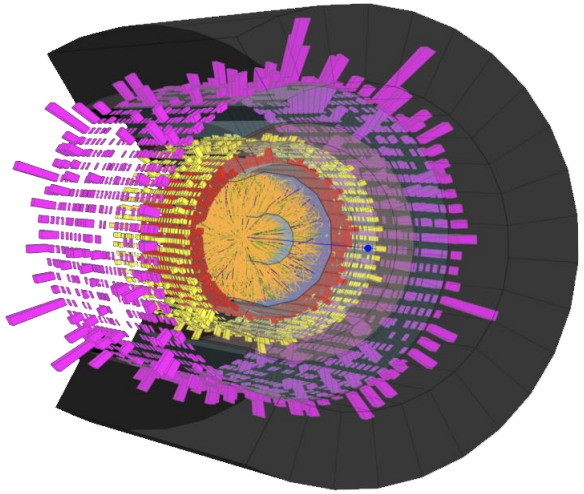
- ✓ Spin measurements such as transverse single spin asymmetry (TSSA) can be achieved using the beam polarization.
- ✓ Study the nucleon spin structure and parton dynamics.

Summary



- ✓ sPHENIX enable new measurements of the microscopic nature of QGP.
- ✓ Large and hermetic electromagnetic and hadronic calorimetry.
- ✓ Highly precise tracking.
- ✓ High DAQ and trigger rate.

- ✓ 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, Upsilon spectroscopy, open heavy flavor & cold QCD.
- ✓ Detector construction & data taking preparation on schedule!
- ✓ Preparing for the first data taking in 6 months!



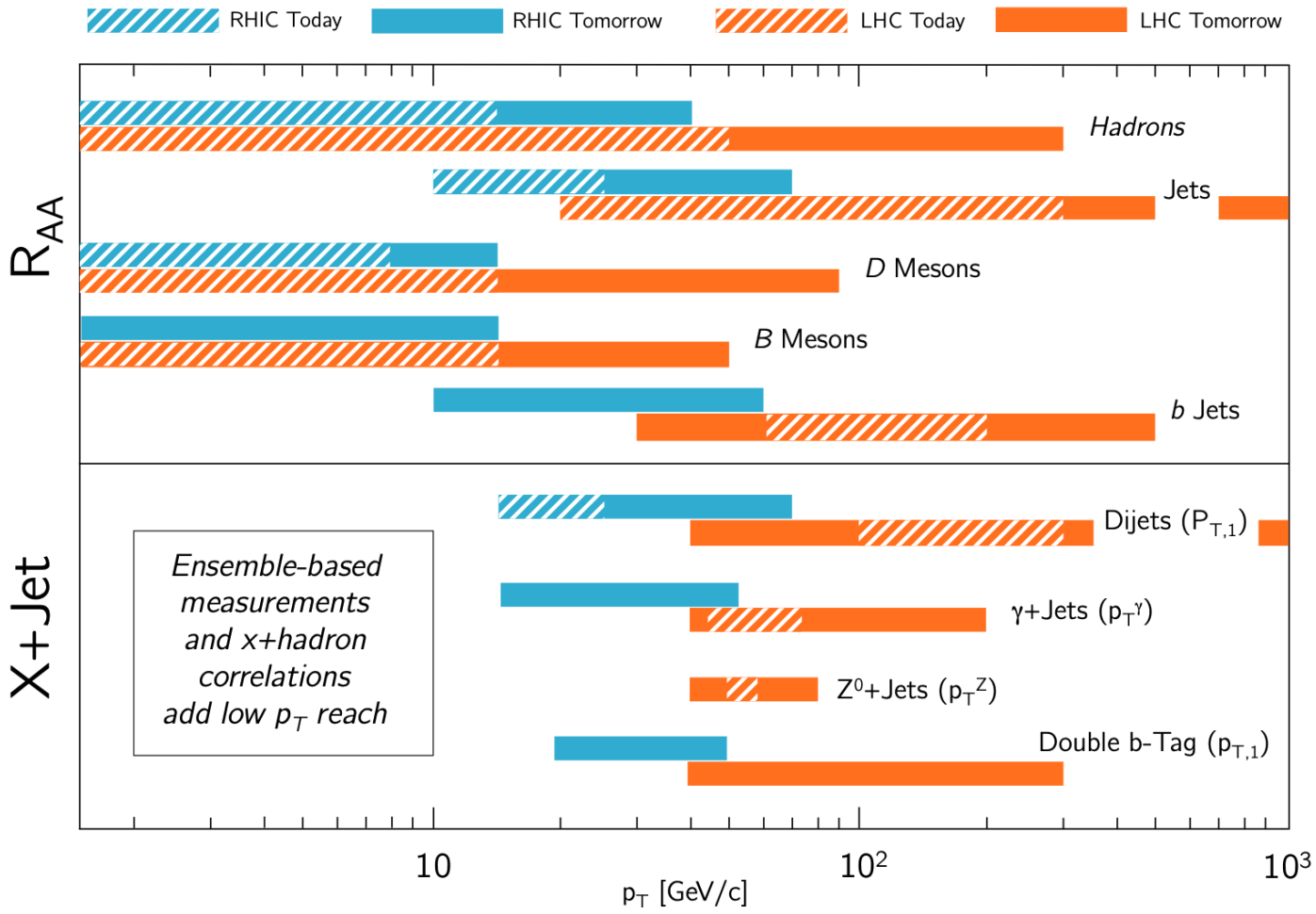
Thanks !

sPHENIX is supported by U.S. DEPARTMENT OF ENERGY | Office of Science

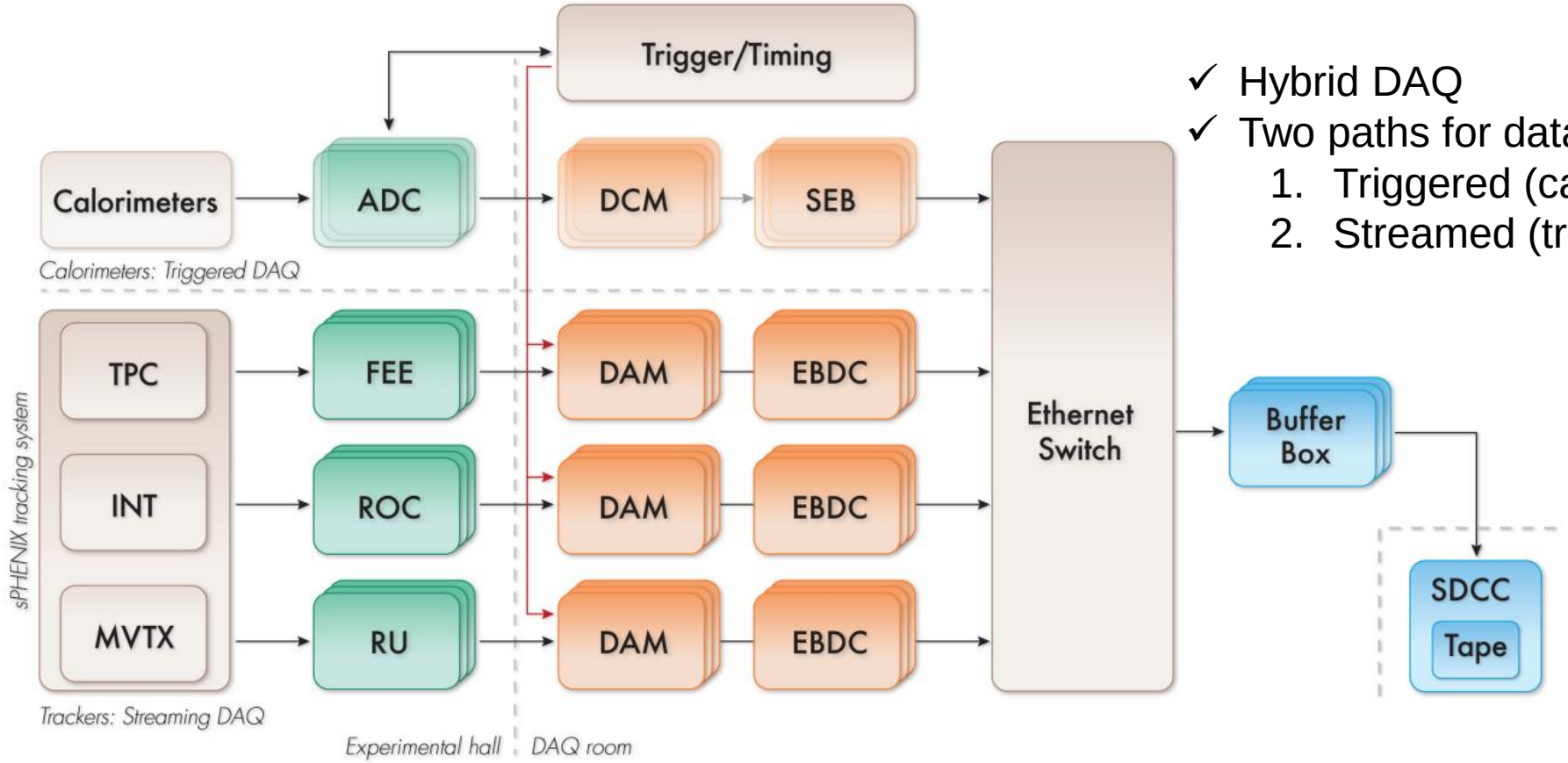
RHIC & LHC Complementarity

Different initial conditions and evolution for QGP between RHIC and LHC, allows study of scale and temperature dependence.

- ✓ Same hard probes at RHIC overlap with LHC kinematic range
- ✓ Opportunity for new probes at RHIC at the lower energy scale



sPHENIX Readout



- ✓ Hybrid DAQ
- ✓ Two paths for data
  1. Triggered (calorimeters)
  2. Streamed (trackers)

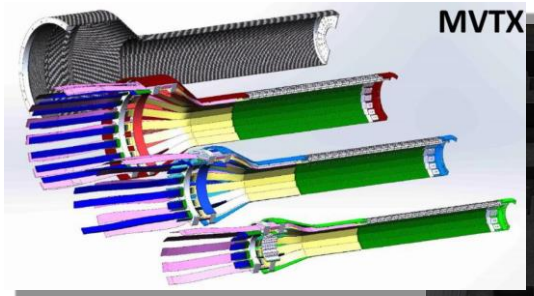
Streamed trigger:

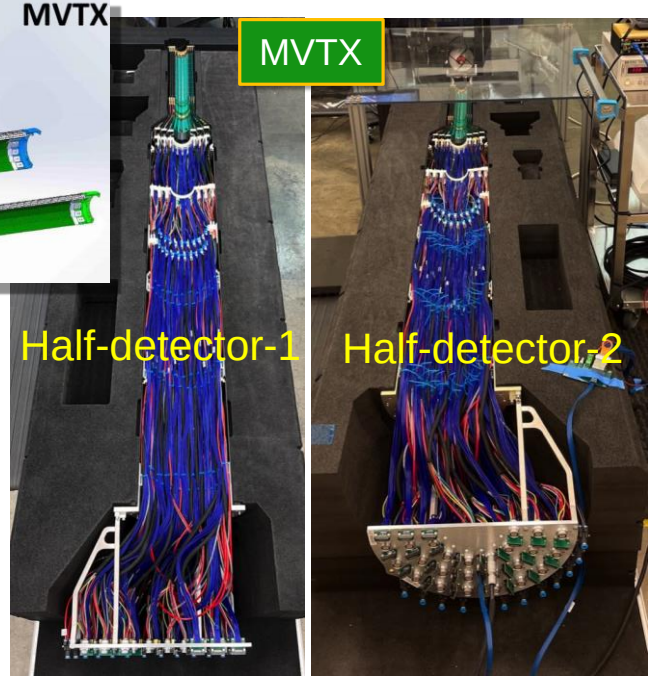
- ✓ Records ~10% of all collisions
- ✓ Significantly increases p+p data collected
- ✓ Crucial for open heavy flavor physics as well as cold QCD measurements

Precision Vertex Trackers

MAPS-based micro-VerTeX detector (MVTX)

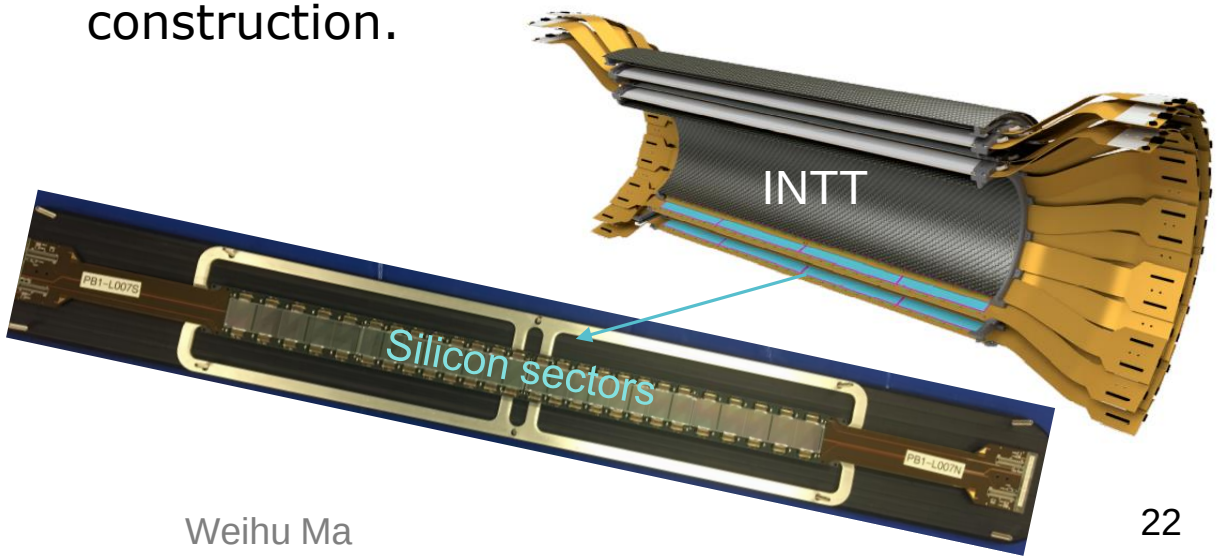
- ✓ Nearest the collision point
- ✓ Based on ALICE ITS
- ✓ Covering 2.3<r<3.9 cm radius.
- ✓ 3-layer Monolithic Active Pixel Sensors (MAPS).
- ✓ Excellent 2-D DCA resolution, < 10 μm for p_T > 2GeV/c
- ✓ Both half-detectors assembled at LBNL!

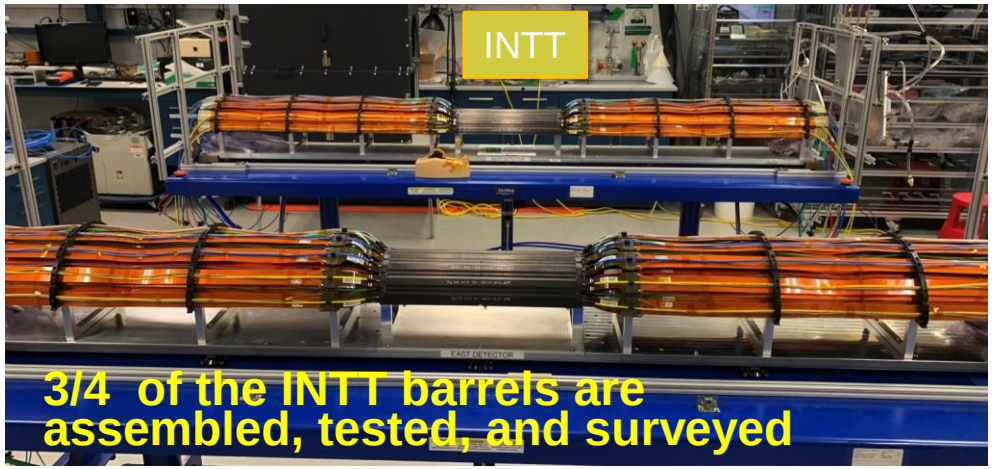




Intermediate Silicon Tracker (INTT)

- ✓ 2 layer (7-10 cm radius) silicon strip detector
- ✓ Fast O(100 ns) integration time; can resolve one beam crossing
- ✓ All ladders are produced, detector is under final construction.

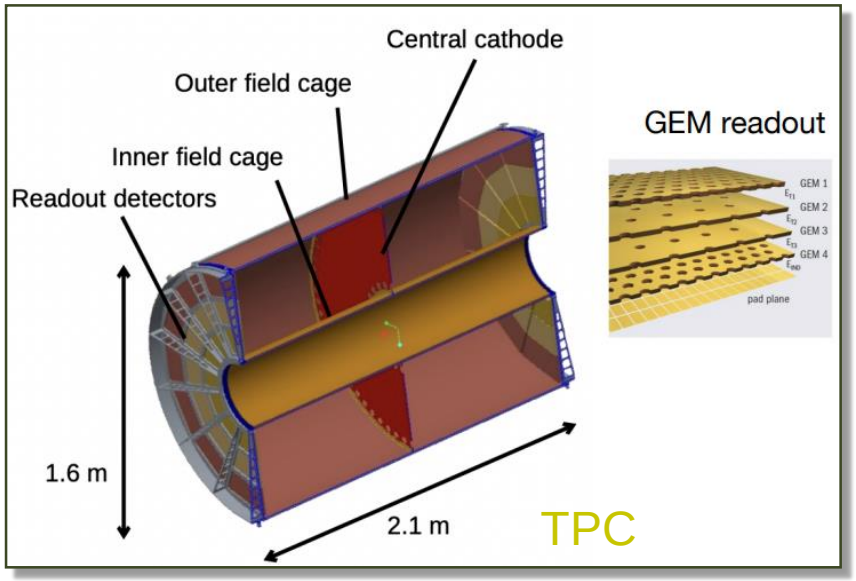


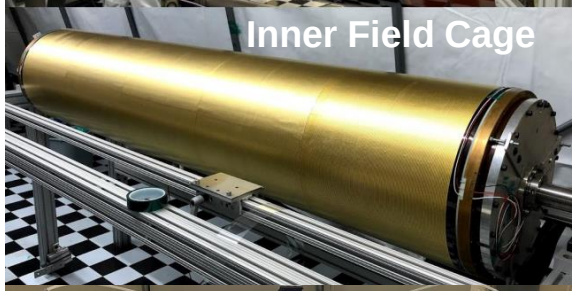


Time Projection Chamber (TPC)

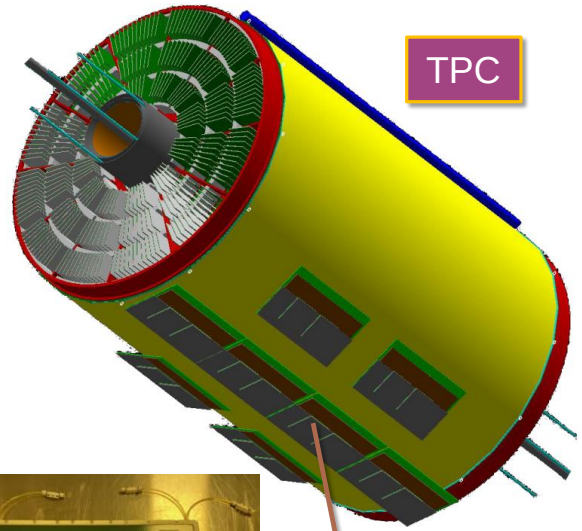
Time Projection Chamber (TPC)

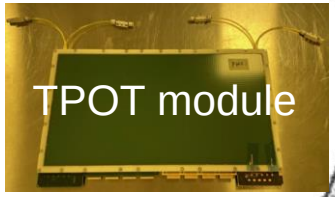
- ✓ Compact (1/30 volume of ALICE TPC)
- ✓ Gateless, continuous readout
- ✓ Quad GEM electron multiplier + chevron readout pads
- ✓ Δp/p~1% at 5 GeV/c
- ✓ R-φ resolution ~ 150 μm
- ✓ 48 layers (30-78 cm radius)
- ✓ Detector installation: middle of November





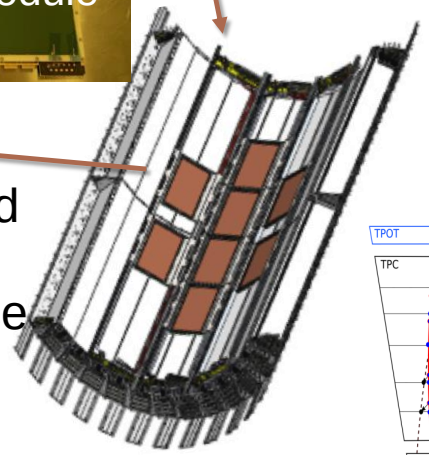
Geant4 view of sPHENIX TPC and TPOT

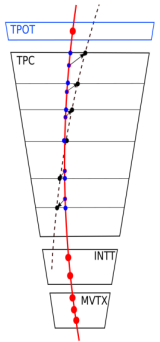




TPC Outer Tracker (TPOT)

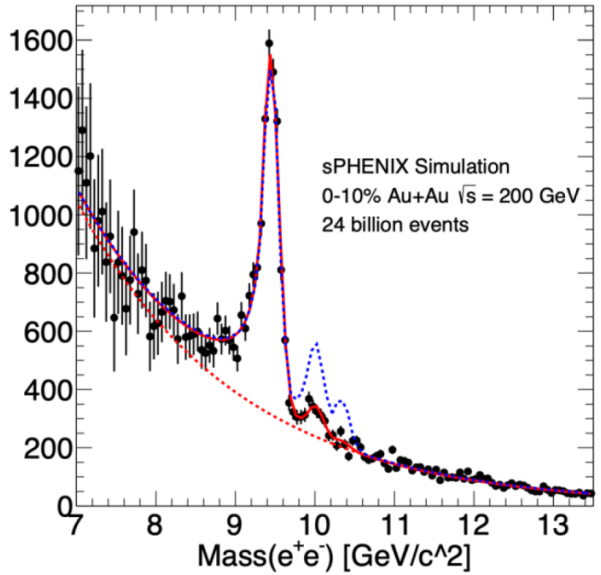
- ✓ 8 modules of Micromegas inserted between TPC and EMCal
- ✓ Calibration of beam-induced space charge distortions in the TPC
- ✓ TPOT module under test
- ✓ Installation in Oct.

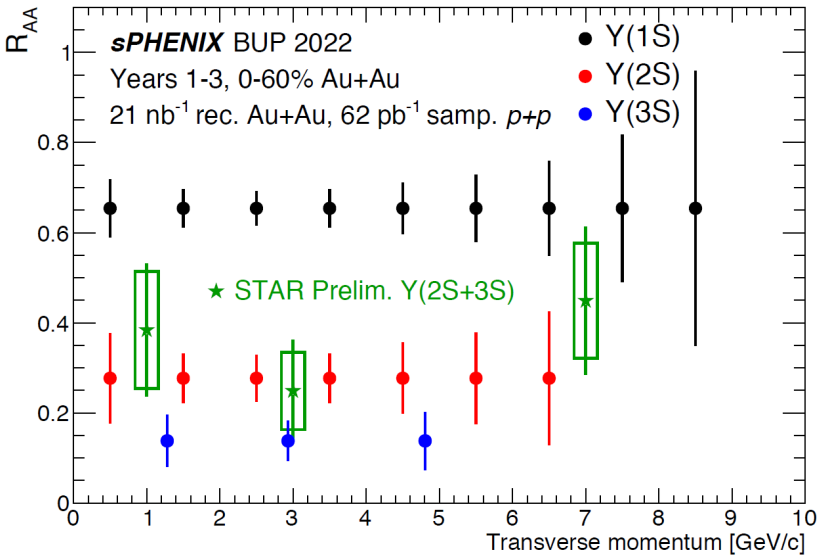


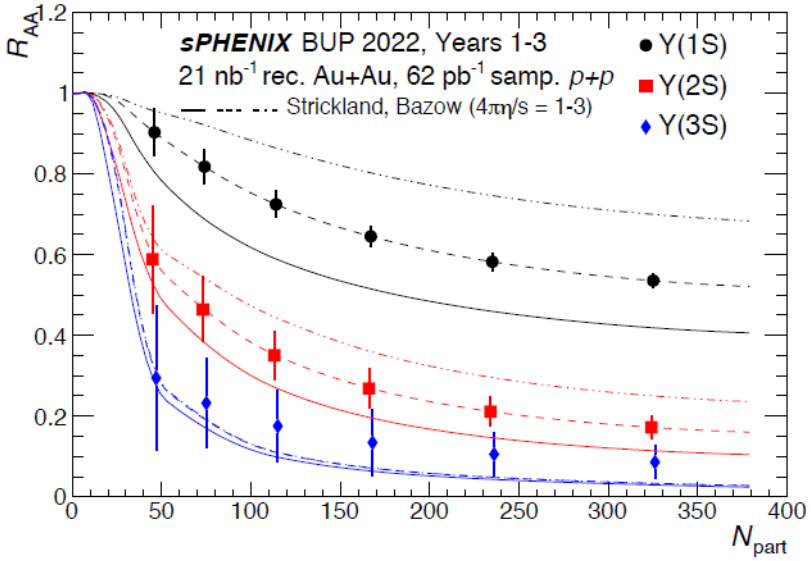


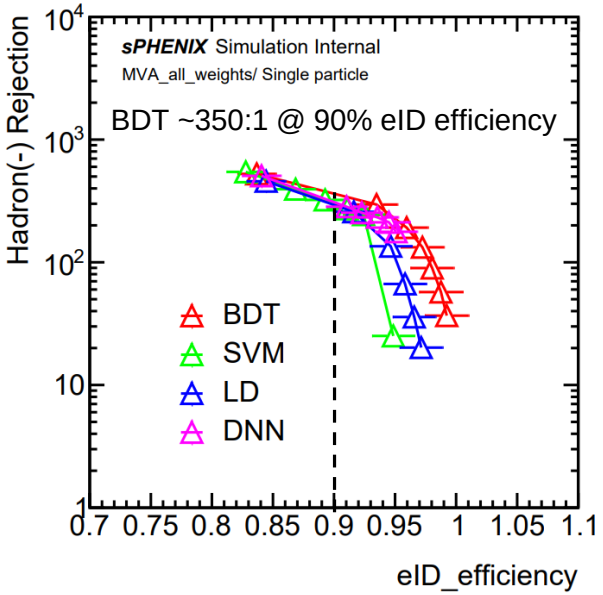
Upsilon R_{AA}

Mass reconstruction



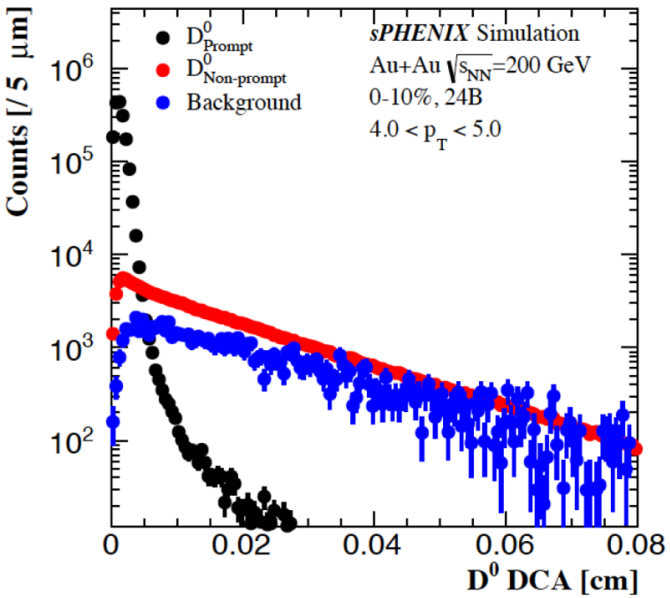


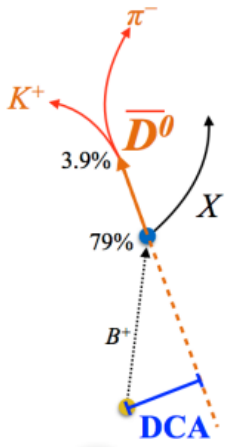




- ✓ Suppression with clear distinction of three Upsilon states.Color dipoles probing the QGP at three length scales.
- ✓ The centrality dependence and particularly the p_T dependence are critical measurements for comparison between RHIC and the LHC.
- ✓ sPHENIX is developing ML algorithms to reject hadronic bkg.

Open Heavy Flavor





- ✓ Cleanly separate open bottom via DCA.
- ✓ Bottom quarks and light quarks are expected to be different for R_{AA} and v_2 for $p_T \lesssim 15$ GeV.
- ✓ Study mass dependence of energy loss and collectivity.
- ➢ sPHENIX will enable the precision measurement of the Λ_c/D at RHIC for understanding charm hadronization.