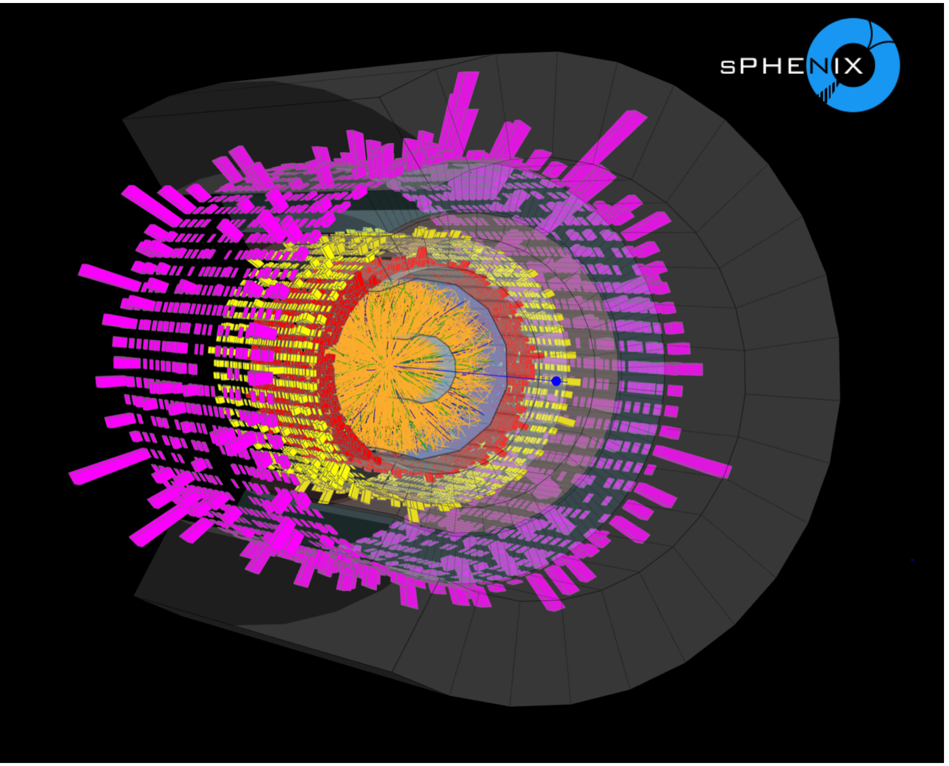
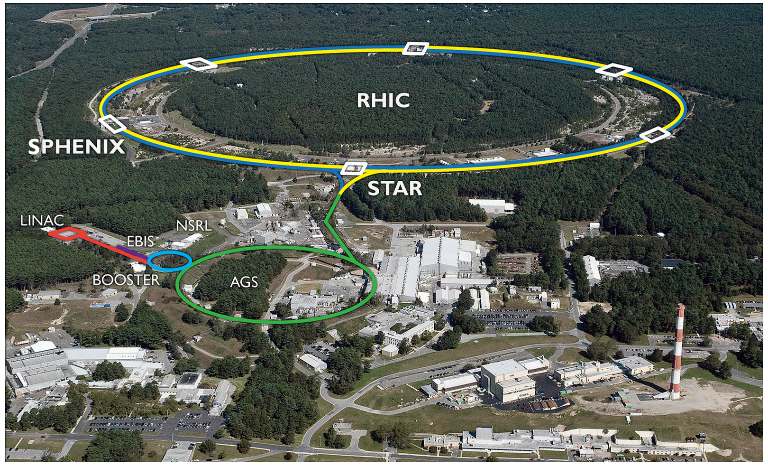
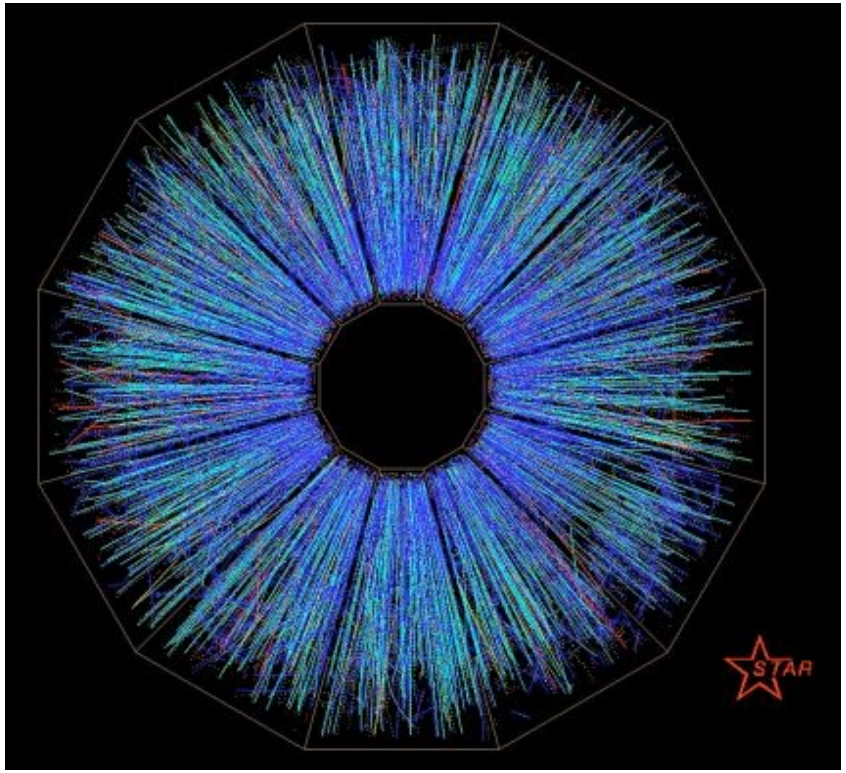
Future Facilities: RHIC







Megan Connors (GSU)

Hard Probes

March 30, 2023

Georgia State University

NSF

RHIC Run Plan 2023-2025

Year	Species	What's new
2023	Au+Au	sPHENIX: Commissioning, Calibration and 1st physics STAR: 1st results with new updates at 200 GeV Au+Au
2024	p+p	Precise reference for new HI measurements
	p+Au	Cold QCD/small system measurements
2025	Au+Au	High Statistics Au+Au

"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."

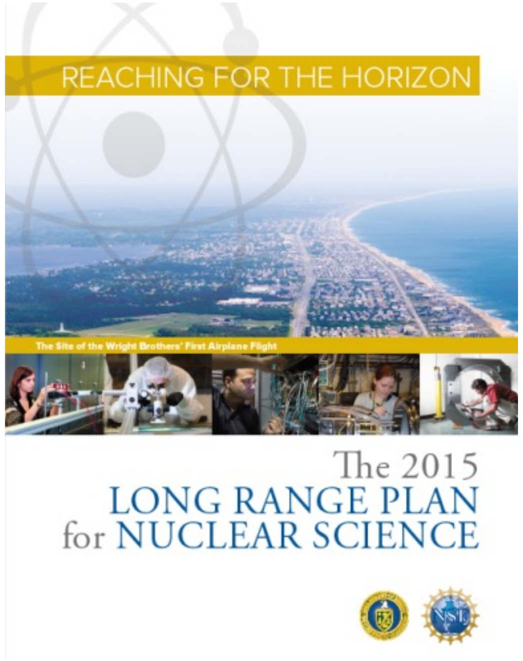
STAR Beam Use Report

sPHENIX Beam Use Proposal

PAC Meeting June 2022: https://indico.bnl.gov/event/15148/

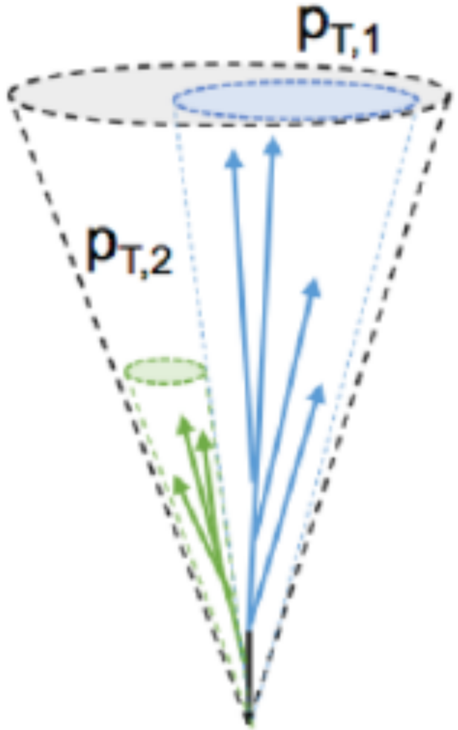
PAC Recommendations: https://www.bnl.gov/npp/docs/2022-npp-pac-recommendations-final.pdf

Probe QGP at Multiple Scales

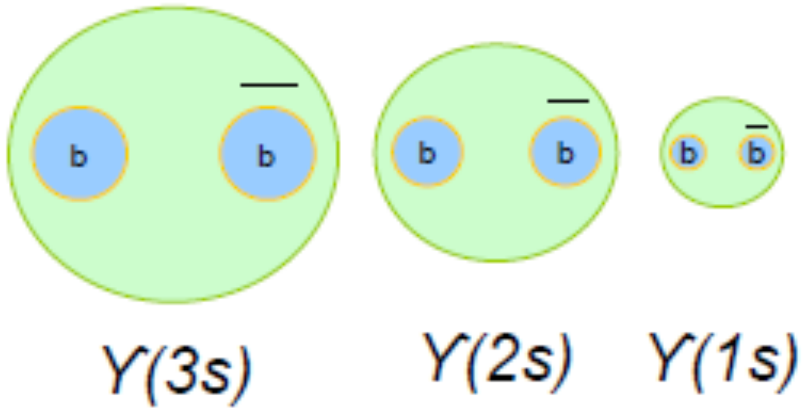


New instrumentation at RHIC in the form of a state-of-the-art jet detector (referred to as sPHENIX) is required to provide the highest statistics for imaging the QGP right in the region of strongest coupling (most perfect fluidity) while also extending the kinematic reach at RHIC (as illustrated in Figure 2.13) to overlap that for jets at LHC energies. Upgrades to the LHC luminosities and detector and measurement capabilities are keys to providing a complete picture, as are new experimental techniques being developed to compare how light quark jets, heavy quark jets, and gluon jets "see" QGP.

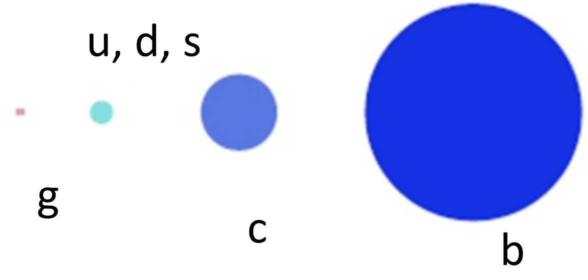
sPHENIX



Jet structure
Vary momentum/angular scale of probe

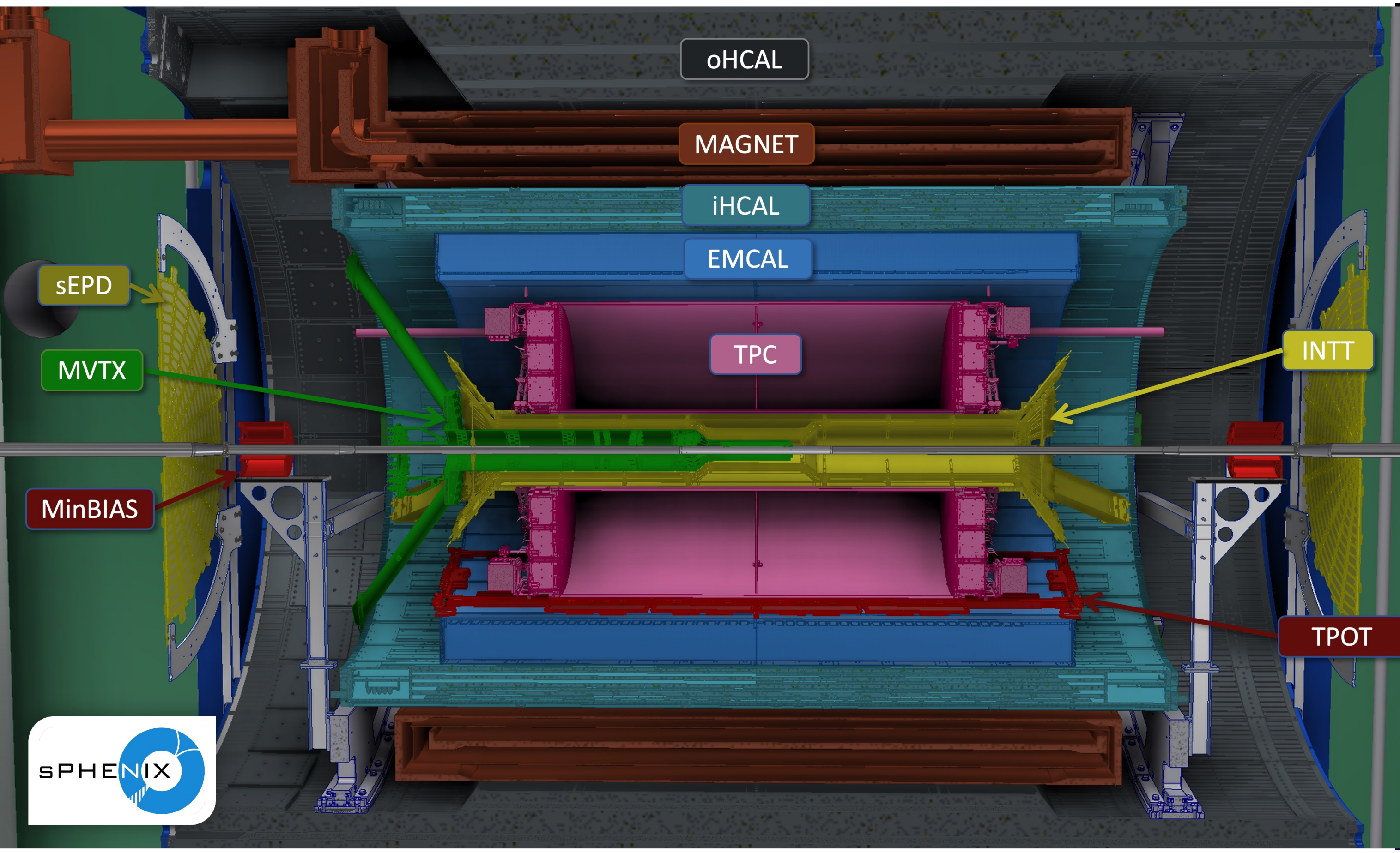


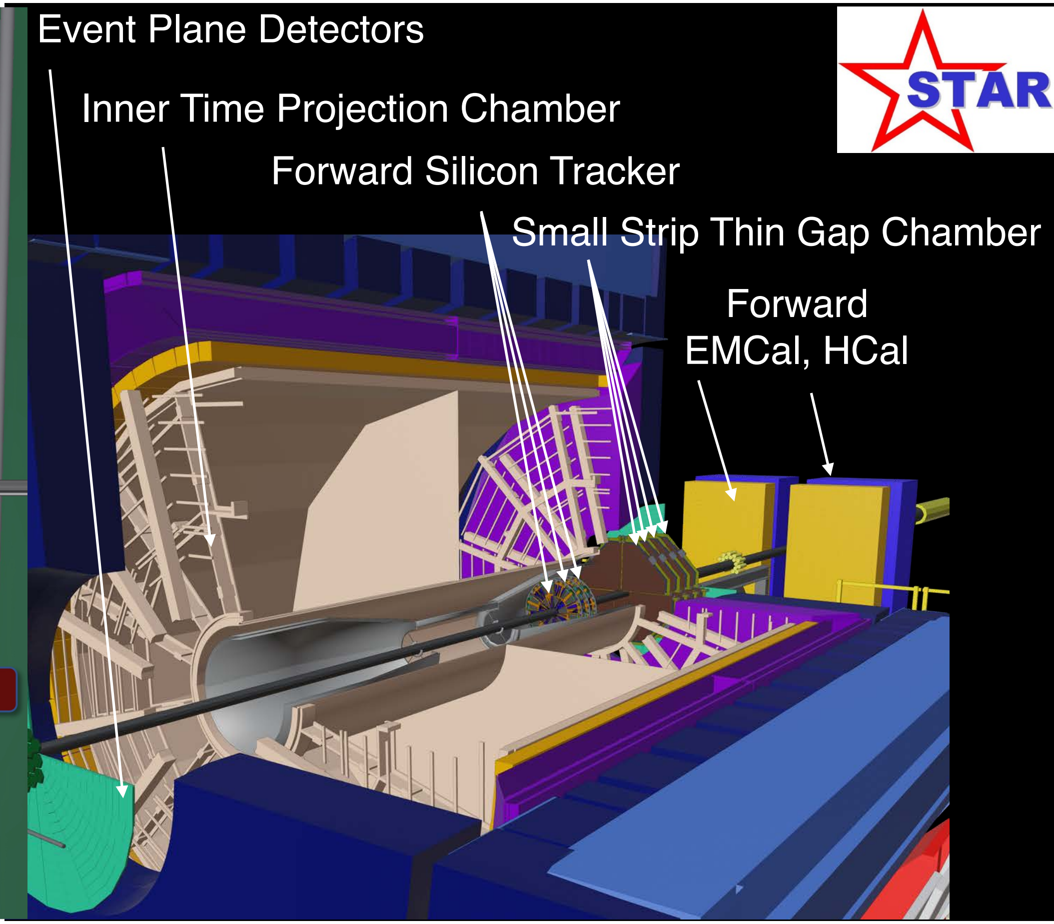
Quarkonium spectroscopy
vary size of probe



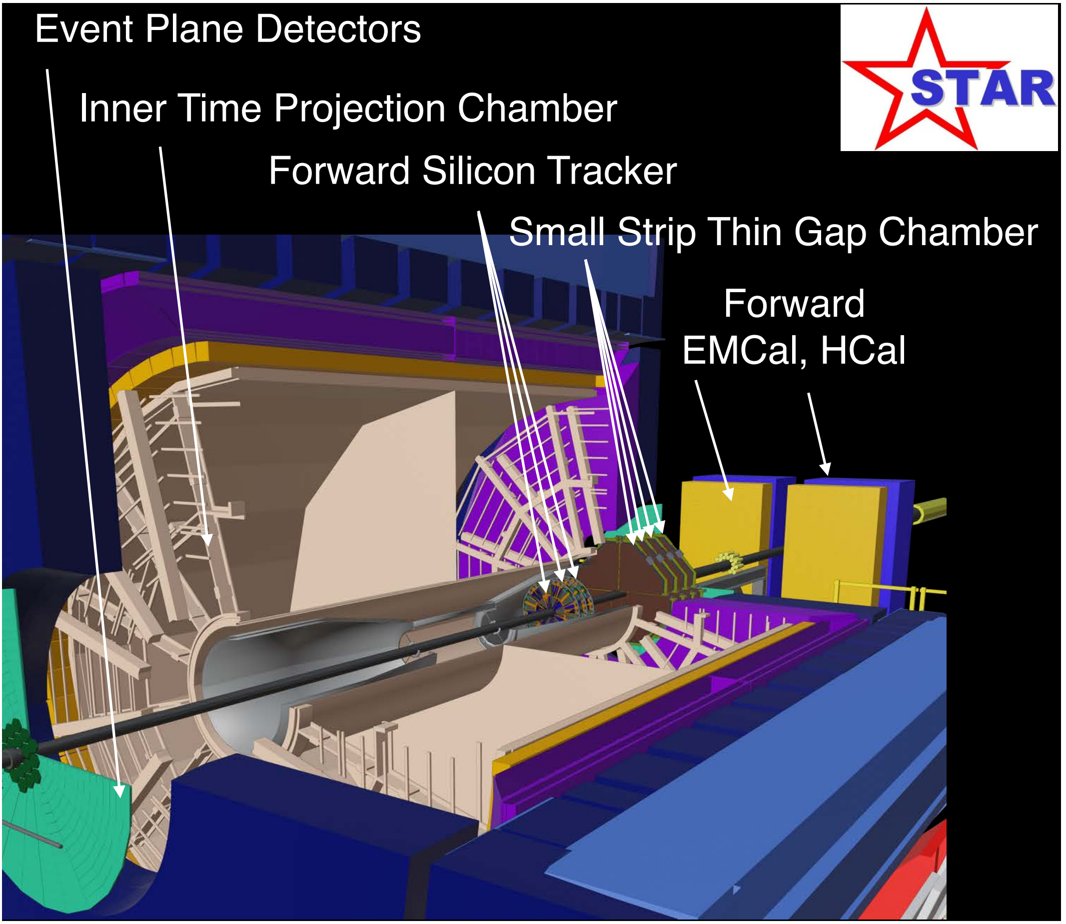
Parton energy loss
vary mass/momentum of probe

RHIC Detectors in 2023





Upgraded STAR



DAQ rate: 5000 Hz

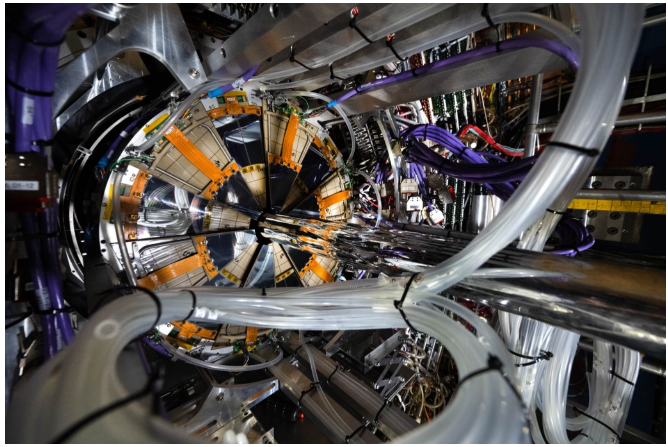
Forward jet detection $2.5 < \eta < 4.0$

FCS:

- **Emcal: refurbished PHENIX PbSc**
- **Hcal: FeSc Sandwich**

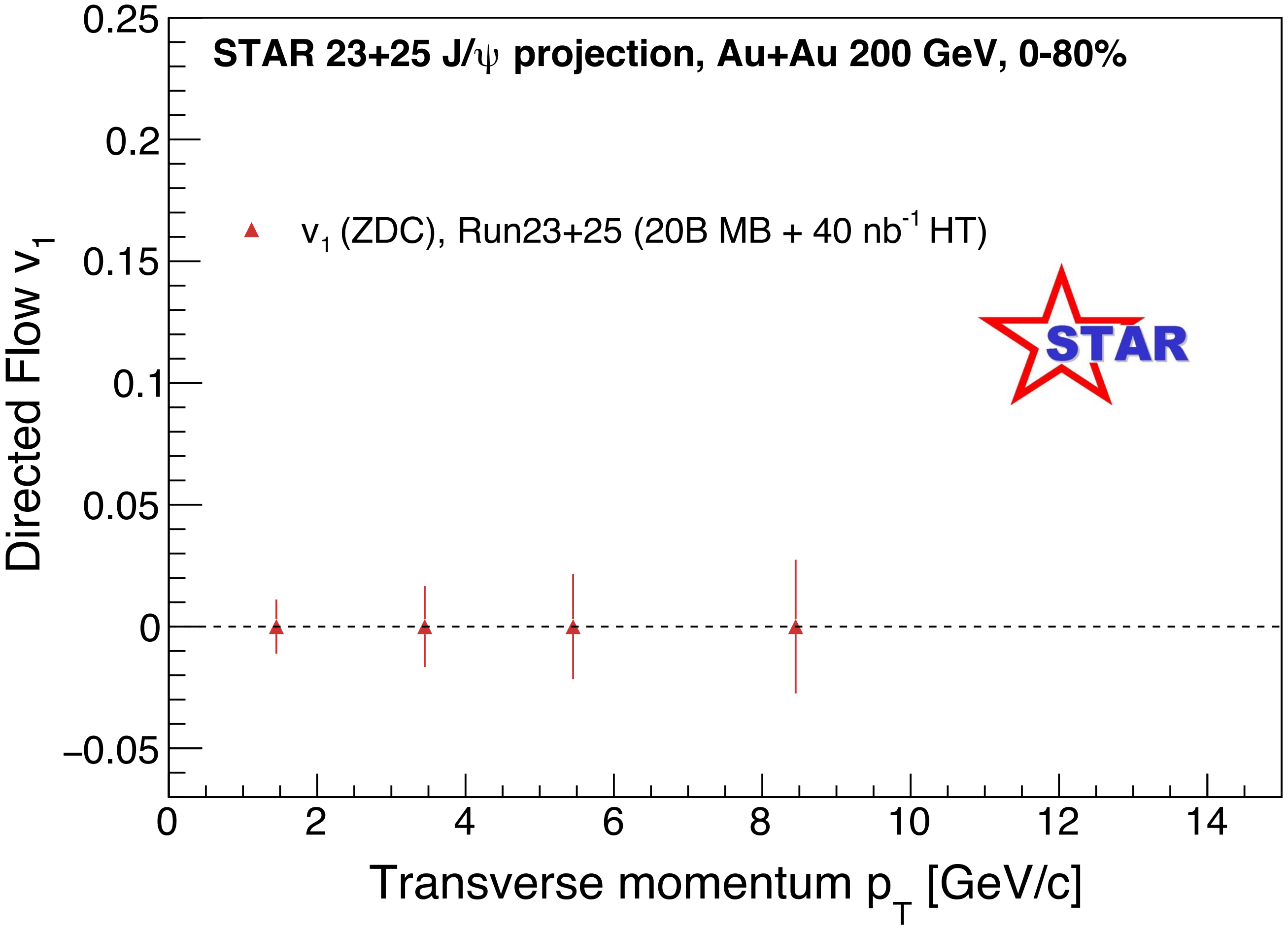
FTS:

- **3 Si mini-strip sensors**
- **four stations of small-strip thin gap chambers**



HF to study initial state

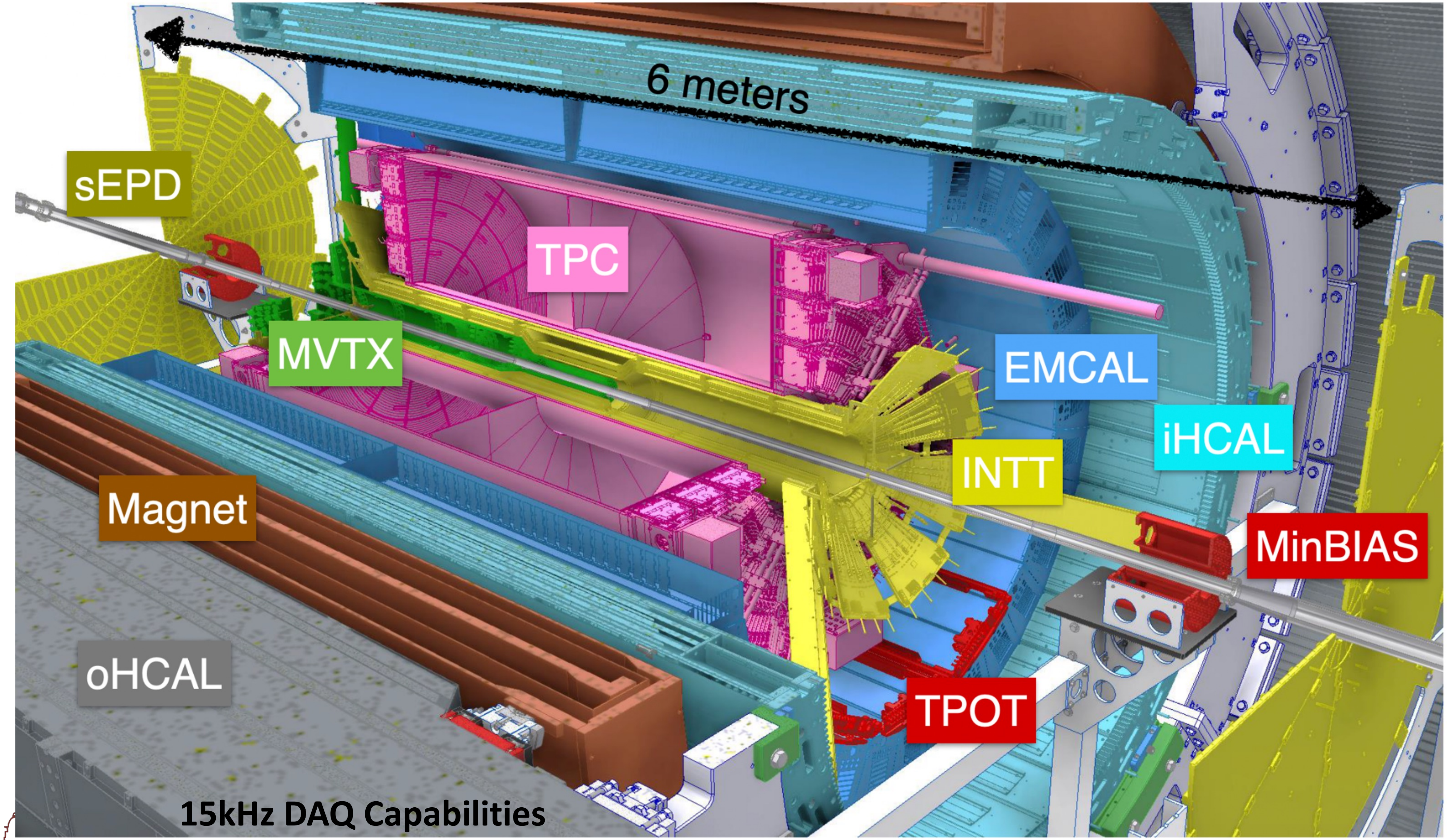
- J/ψ v_1 to study initial tilt
- iTPC:
  - **Improved momentum resolution**
  - **Extended η coverage**
  - **More precisely quantify directed flow**



List of anticipate HP results: [STAR Highlight Talk]

[STAR Beam Use Report]

sPHENIX



Antonio's talk Tuesday

ZDC

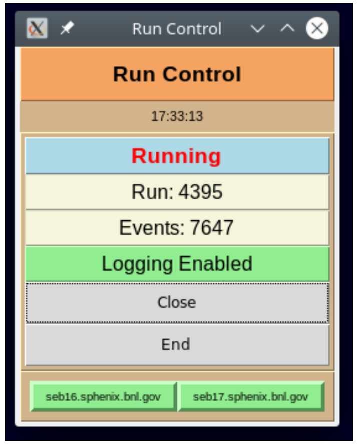
Calorimeters: HCal

oHCal installed
Feb 28, 2022!

Outer and Inner HCal:

- **First hadronic calorimeter at midrapidity at RHIC**
- Important for precise jet energy measurements
- Scintillator tiles between tilted absorber plates
- **$|\eta| < 1.1$, full azimuthal coverage**
- Hadron ΔE/E ~14% + 65%/√E

iHCal installed
in June 2022!

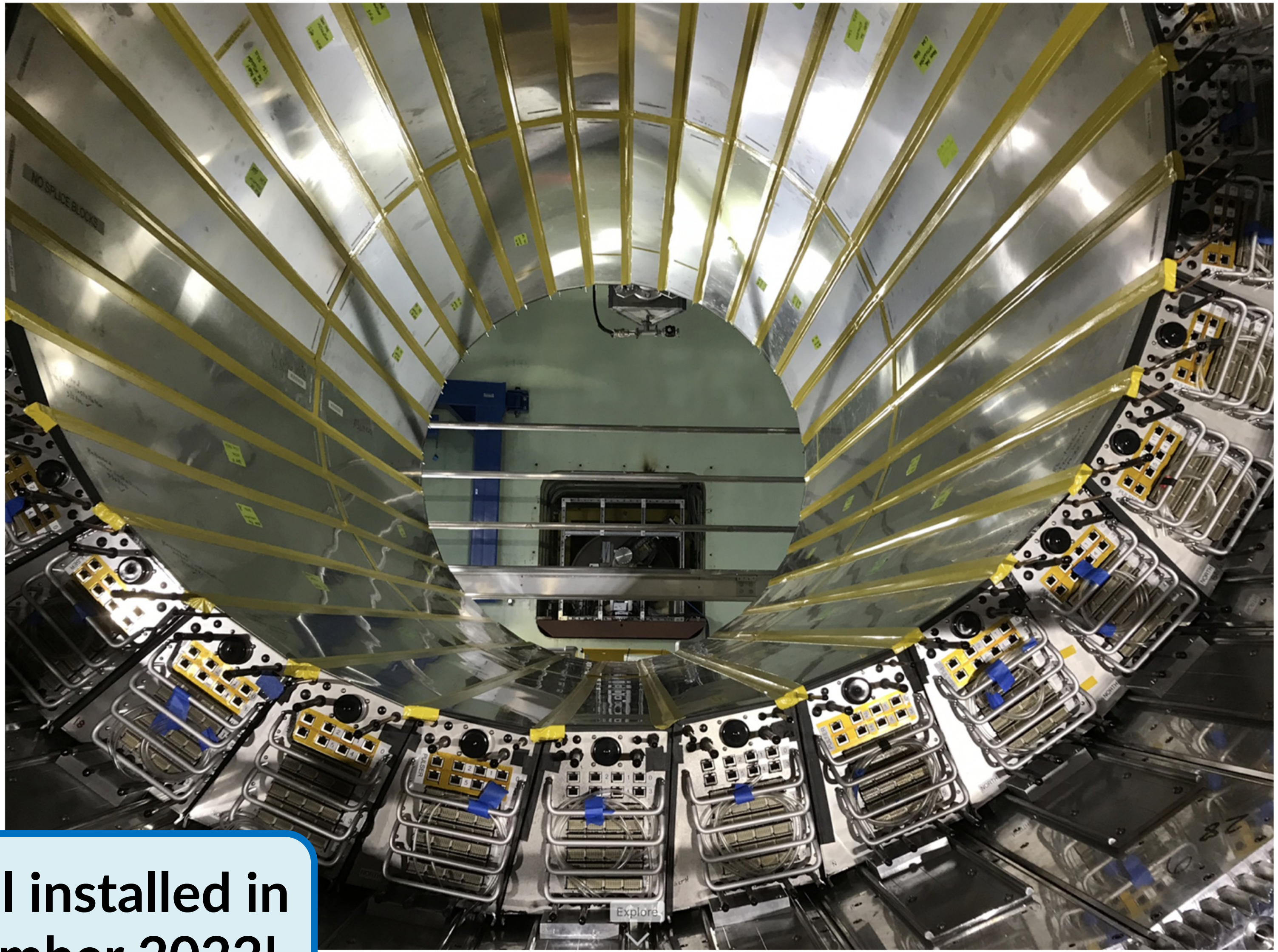


M. Connors

Calorimeters: EMCal

EMCal:

- Scintillator fiber tungsten sampling calorimeter
- Identification of photons and electrons
- Towers with ~0.025 x 0.025 in η x ϕ
- EM ΔE/E ~5% + 16%/√E

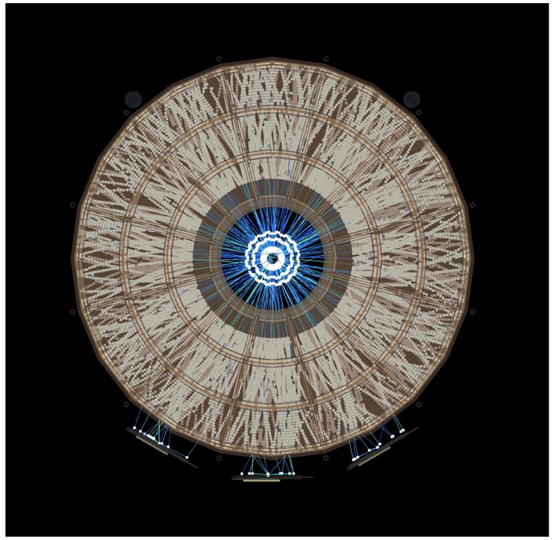


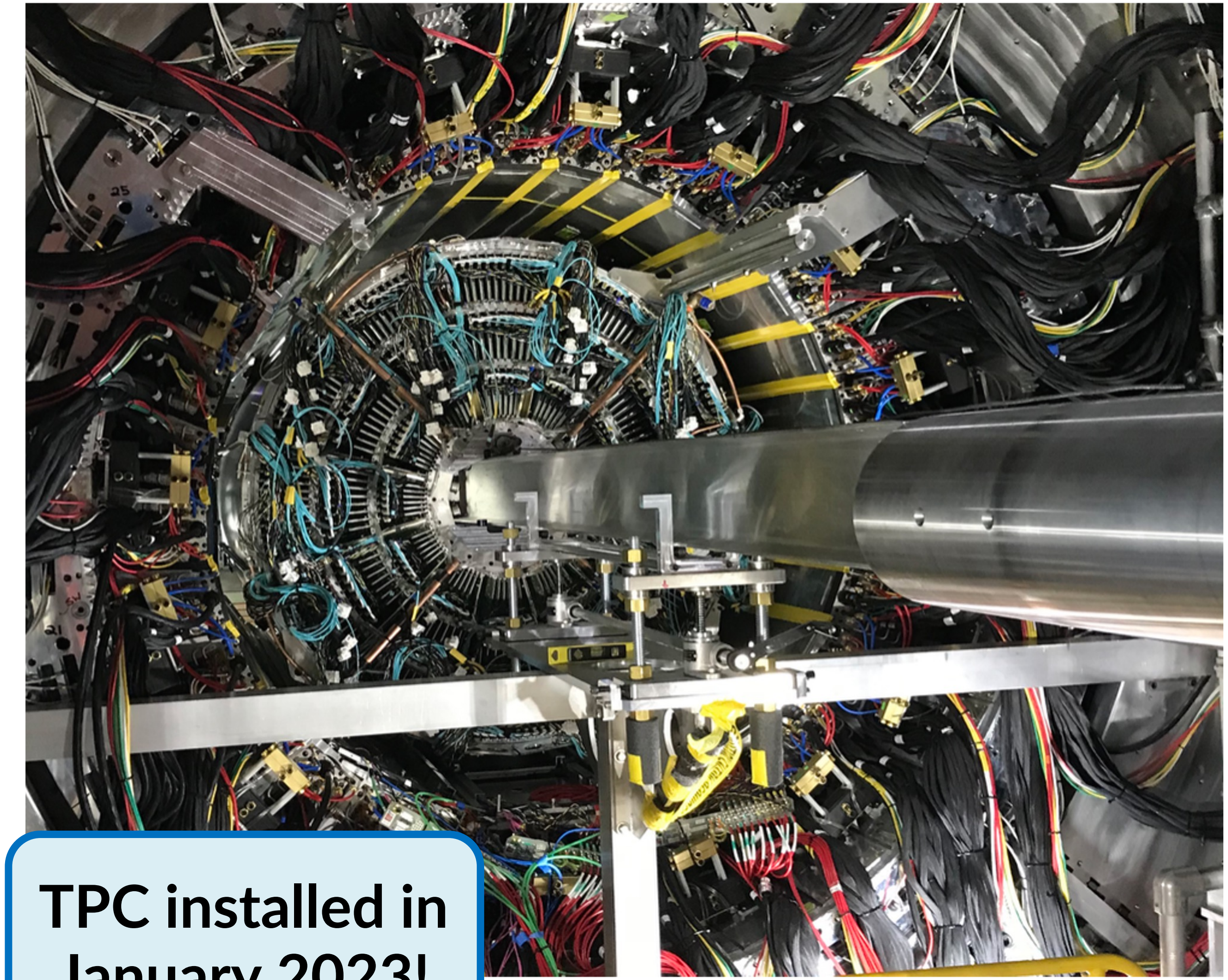
EMCal installed in November 2022!

Tracking: TPC

Time-projection chamber (TPC)

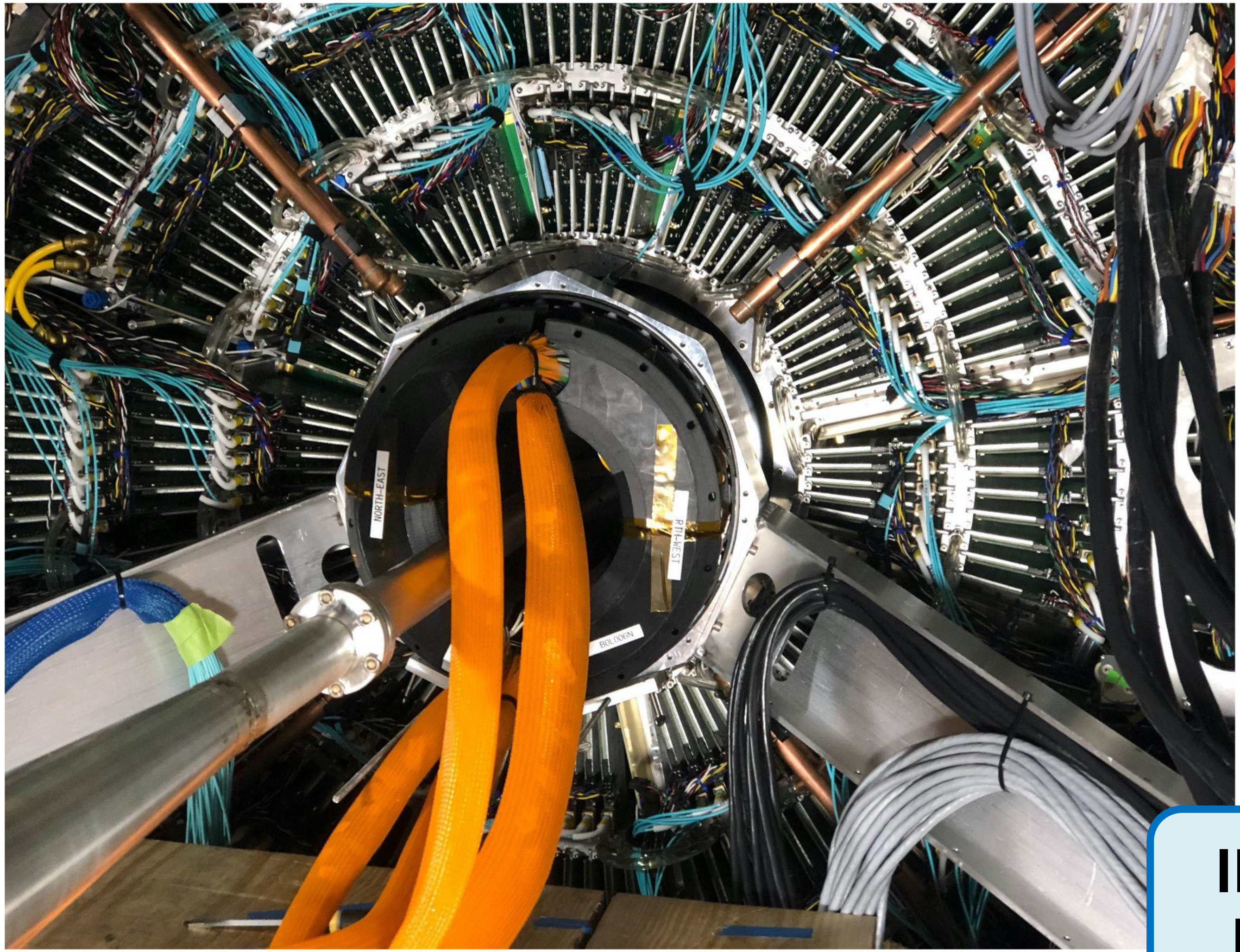
- **Ungated continuous readout**
- **Reconstruction of heavy-flavor decays**
- 150 µm rϕ resolution
- Δp/p ~1% at 5 GeV/*c* charged particles
- TPC outer tracker (TPOT) used for calibrations





TPC installed in January 2023!

Tracking: INTT

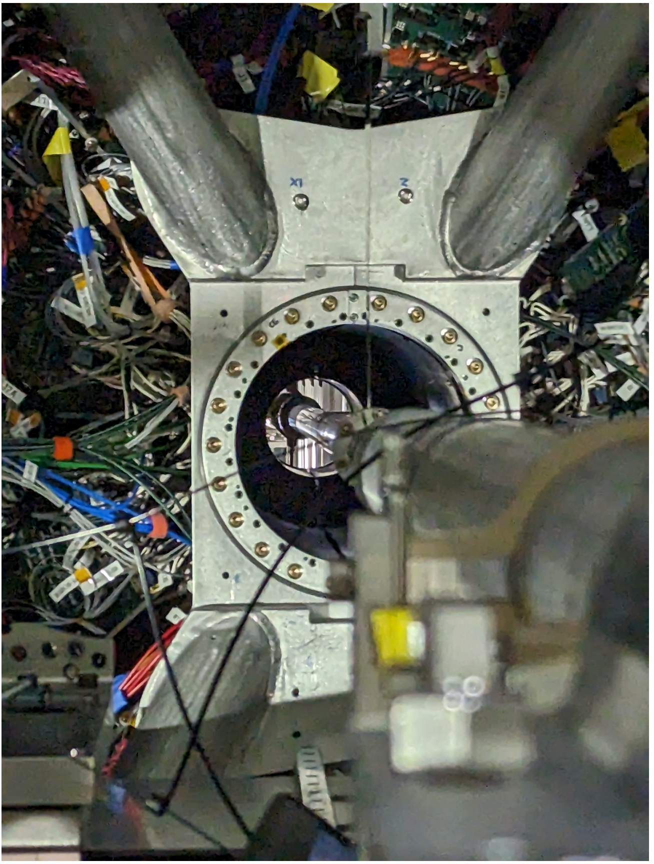


INTT:

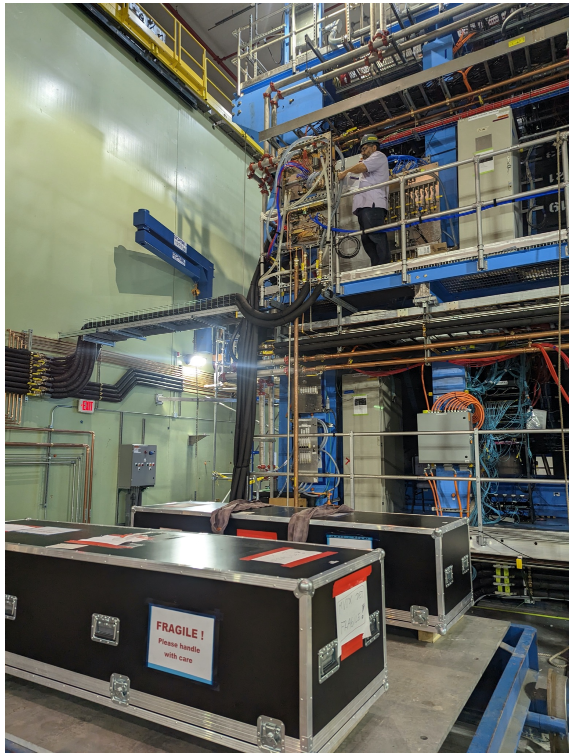
- silicon strip tracker
- Interpolation of tracks between MVTX and TPC
- 2 layers
- 78 µm pitch
- Low radiation length about $X/X_0 < 1.1\%$ per ladder

INTT installed March 2023!

Tracking: MVTX



X-wing support installed

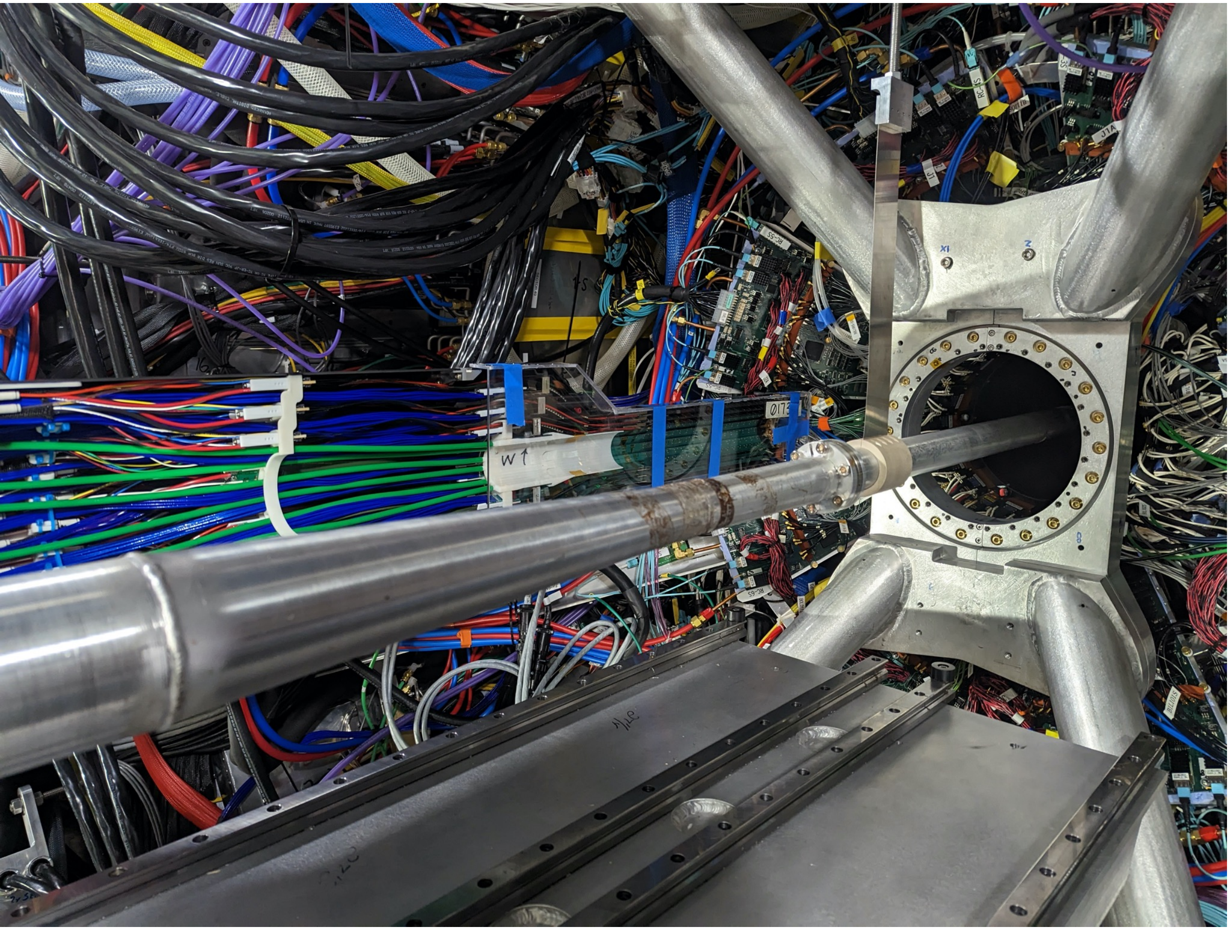


MVTX:

- MAPS based vertex tracker
- 3 layers
- ALPIDE chip - near copy of the ITS2 from ALICE
- Fine pixel pitch (27 µm x 29 µm)
    - ~5 µm position resolution
- Low material budget (~0.3% X_0 per layer)

MVTX installed this week...

Tracking: MVTX



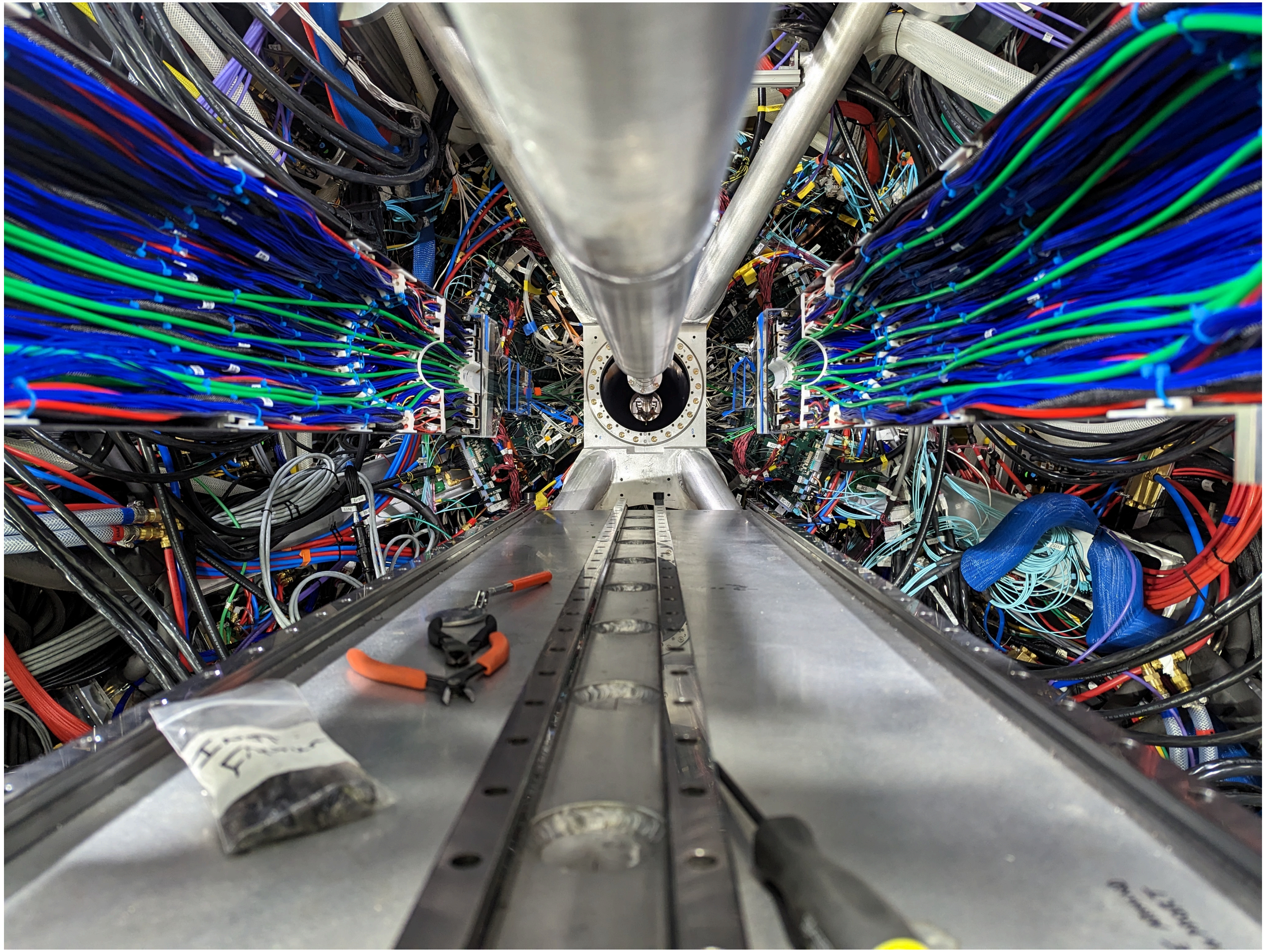
2:55pm MVTX west on insertion table

MVTX:

- MAPS based vertex tracker
- 3 layers
- ALPIDE chip - near copy of the ITS2 from ALICE
- Fine pixel pitch (27 µm x 29 µm)
  - ~5 µm position resolution
- Low material budget (~0.3% X_0 per layer)

MVTX installation underway!

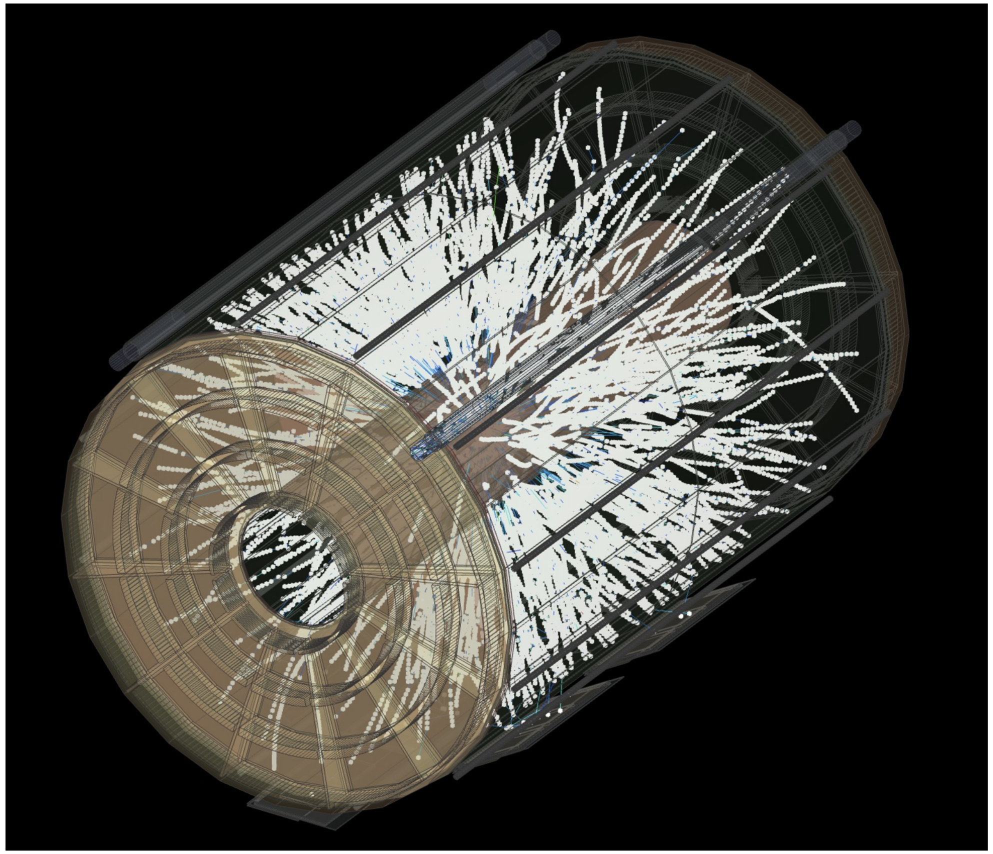
Tracking: MVTX



MVTX installation underway!!!!

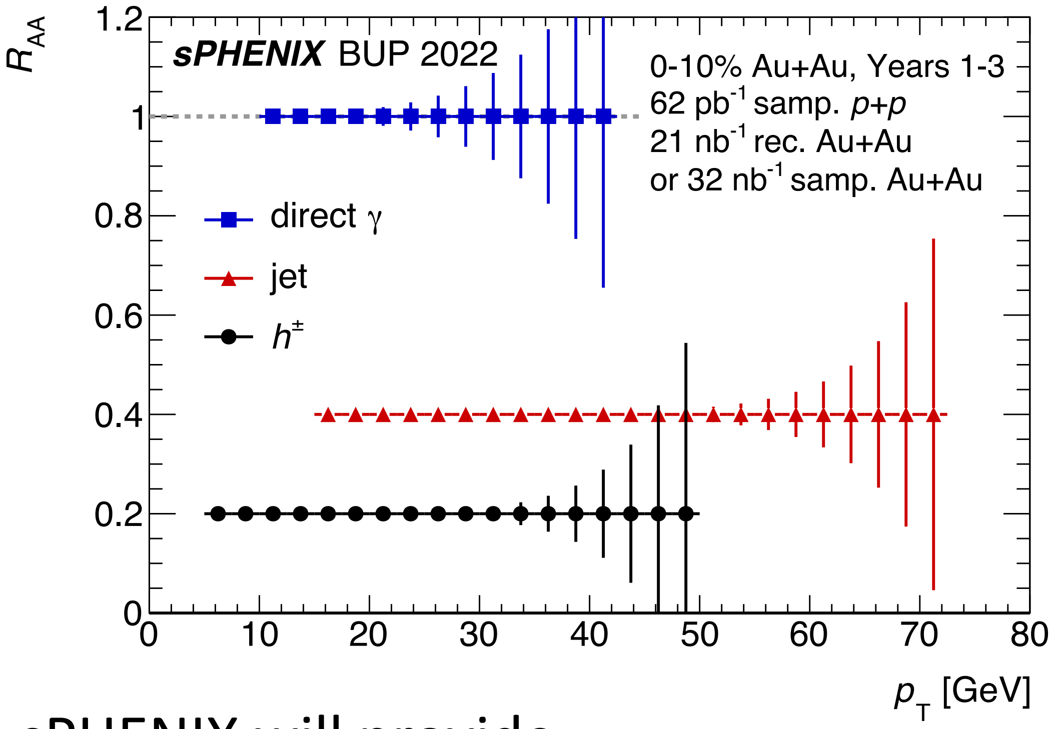
3:57pm update:
Both halves are on insertion table!!

RHIC Run 2023



Starting next month…

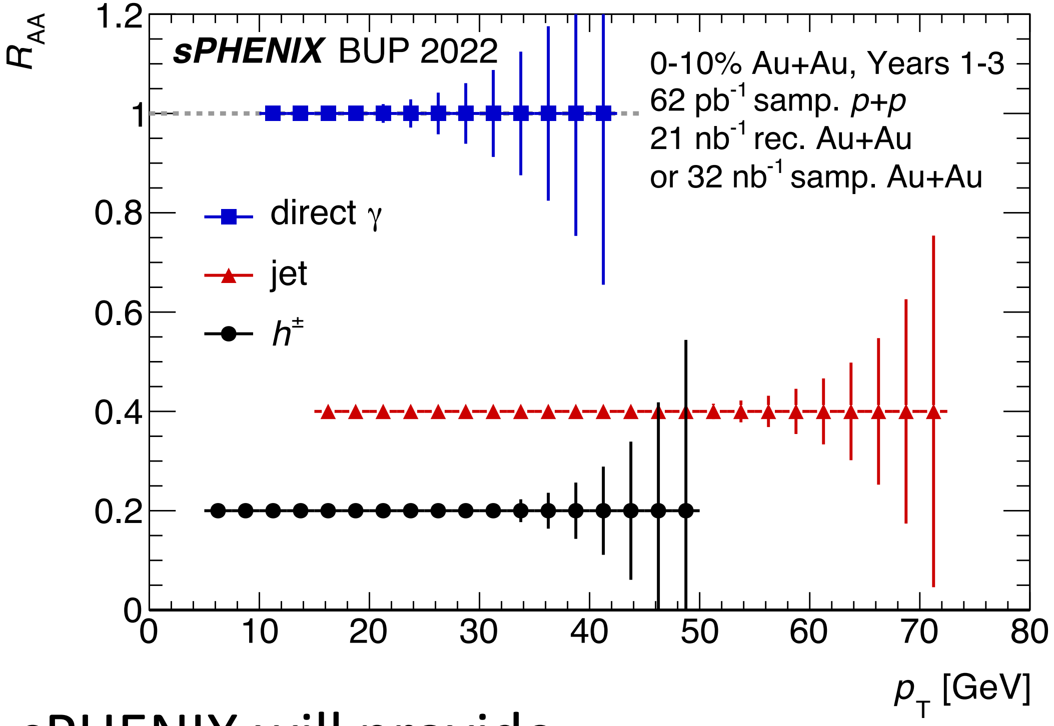
Kinematic Reach

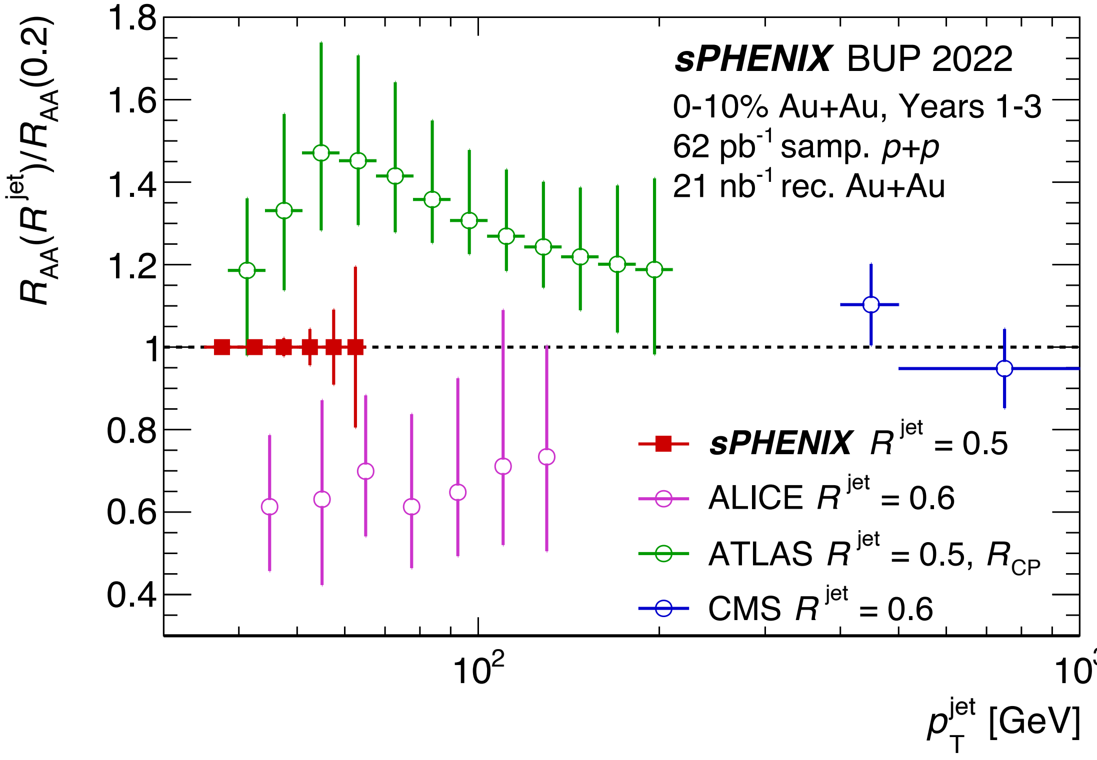


sPHENIX will provide

- significant extension in kinematics and overlap with LHC

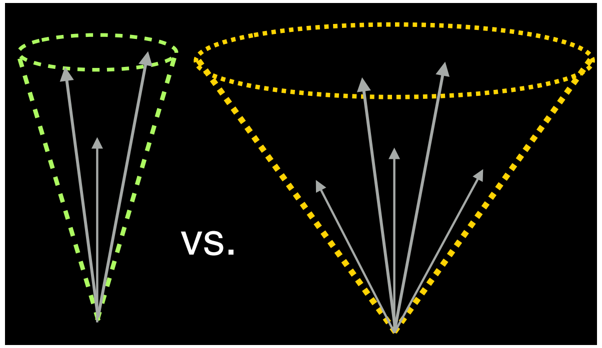
Kinematic Reach





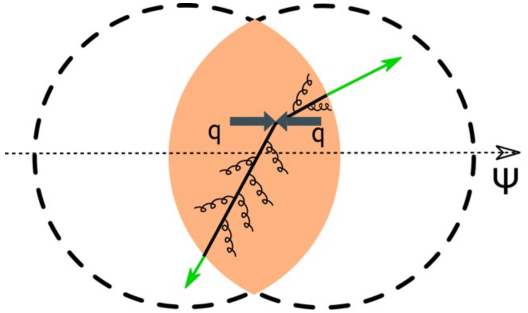
sPHENIX will provide

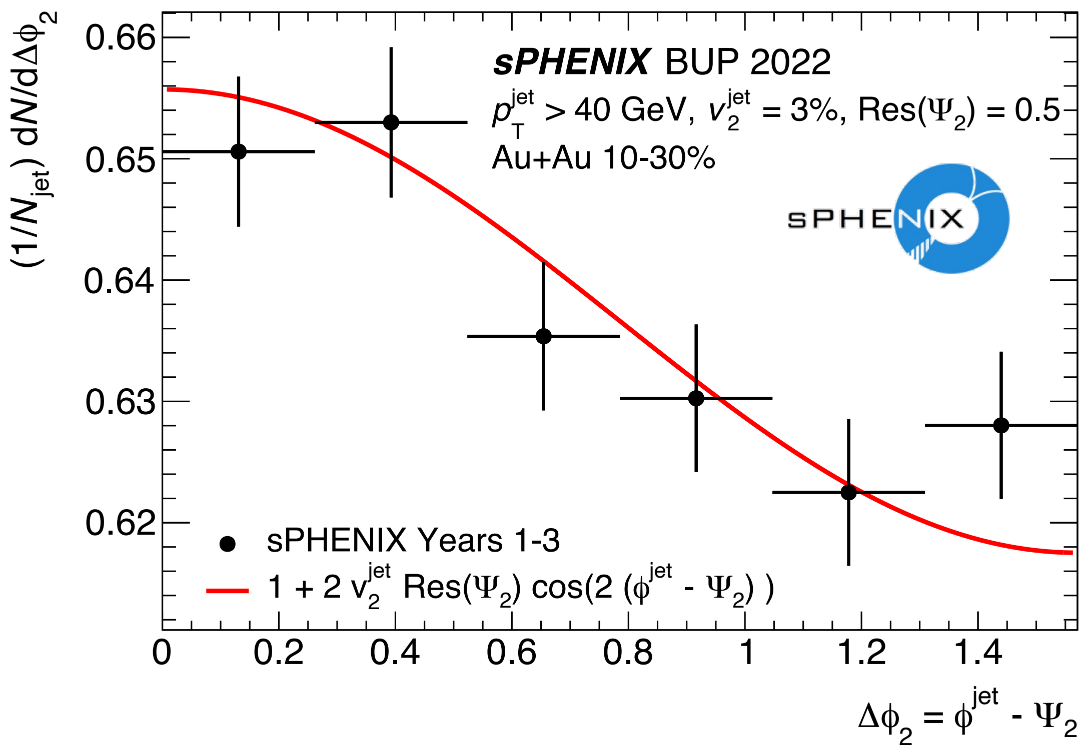
- significant extension in kinematics and overlap with LHC
- jet cone size R_{AA} comparisons at low p_T where differences at LHC experiments exist

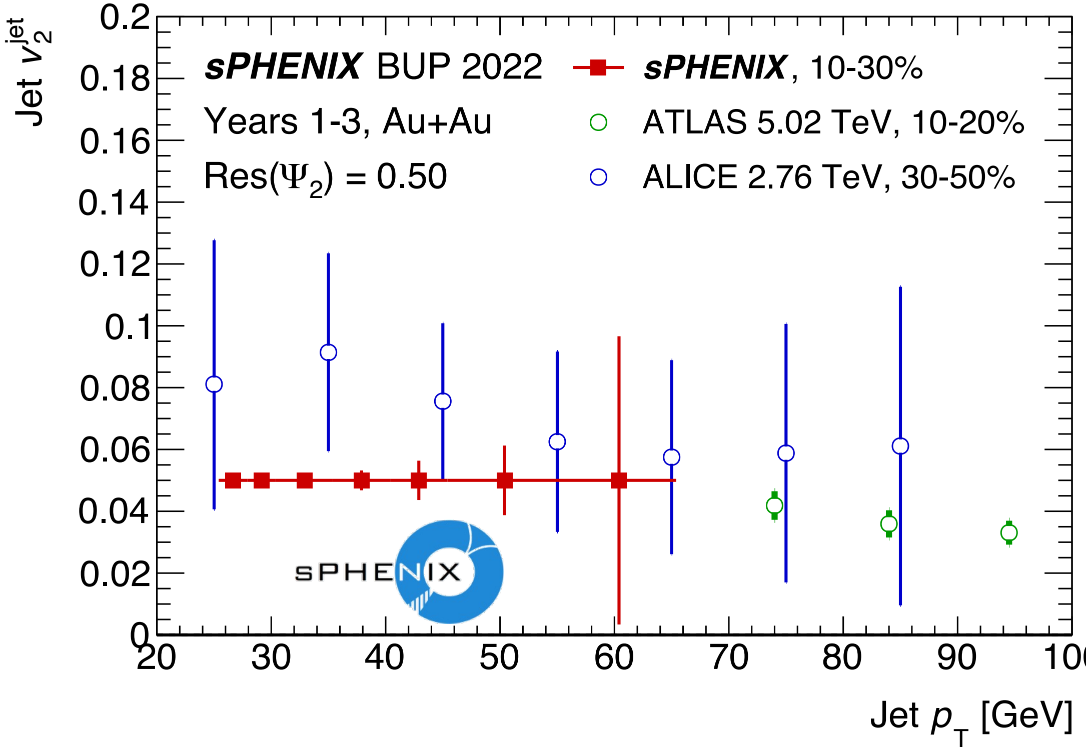


Event Plane Studies

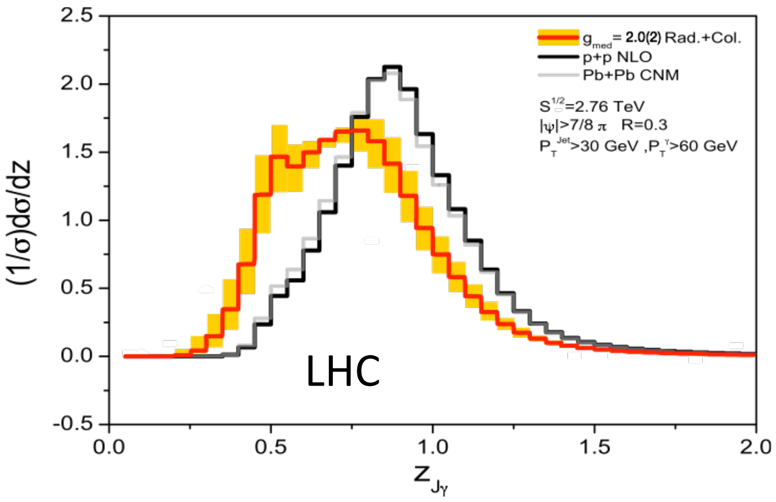
- Event Plane Detector will improve resolutions to enable more precise jet v_2 studies
  - **Pathlength dependence of energy loss**
  - **Jet v_2 in p+Au to deepen understanding of small systems**

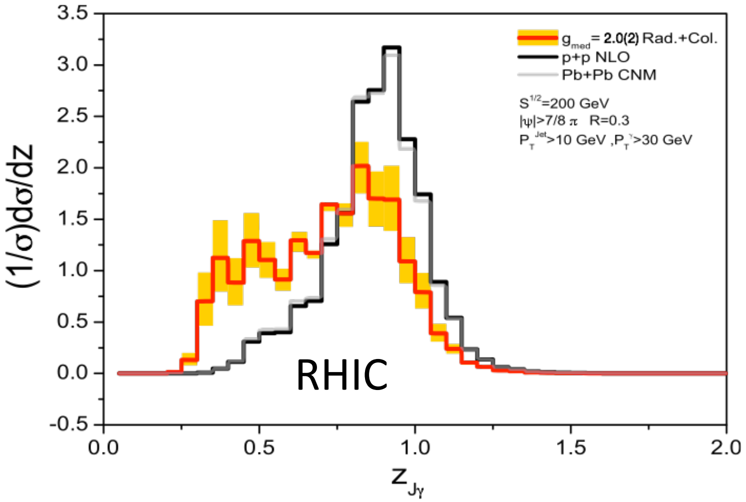


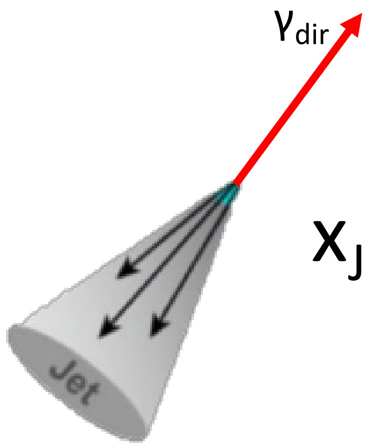




Photon-Tagged Jets at RHIC





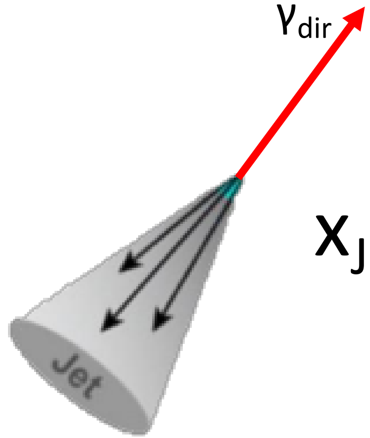


$x_{J\gamma} = p_{Tjet}/p_{T\gamma}$

- "Golden Channel" for studying energy loss in the QGP
- Photon tags initial hard scattering kinematics directly probes energy loss
- Dominated by quark jets
- Because of γ/π^0 RHIC is ideal for measuring direct photons
- $x_{J\gamma}$ may be more sensitive at RHIC

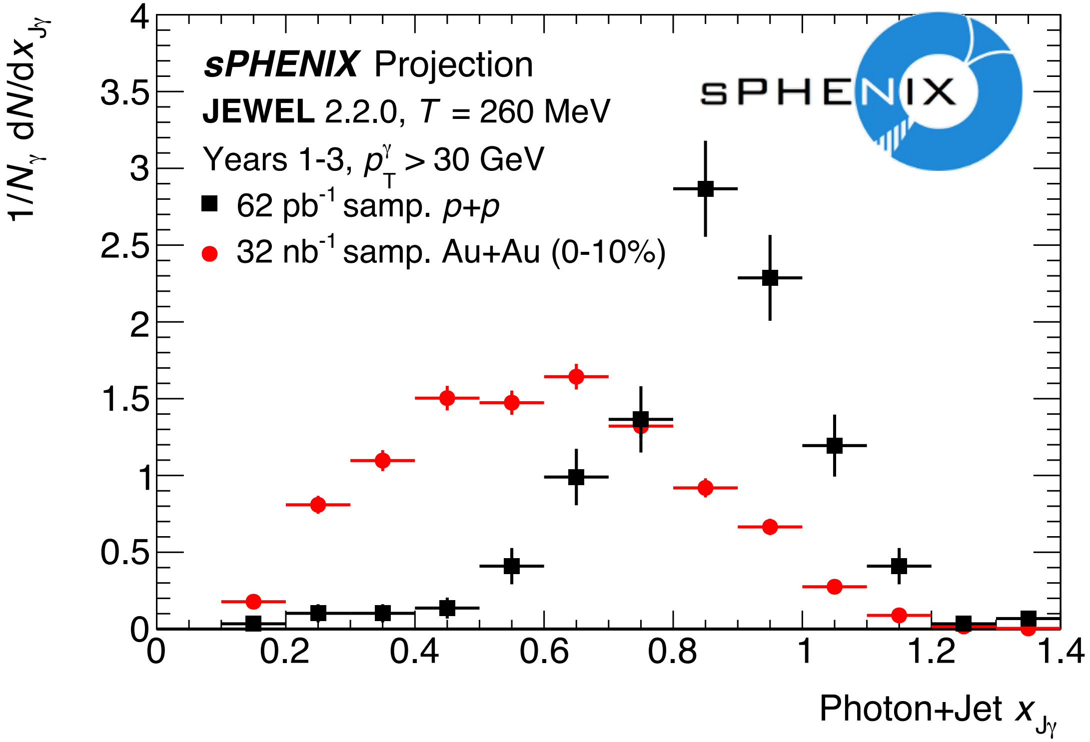
PRC 102, 054910

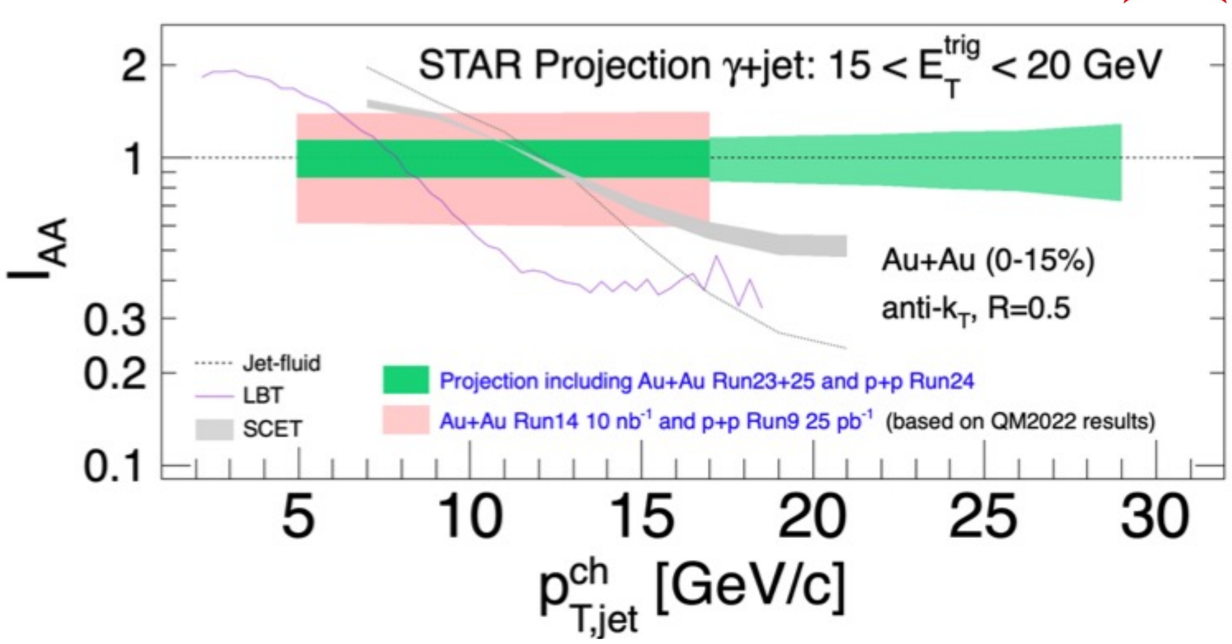
Photon-Jet Imbalance



$x_{J\gamma} = p_{Tjet}/p_{T\gamma}$

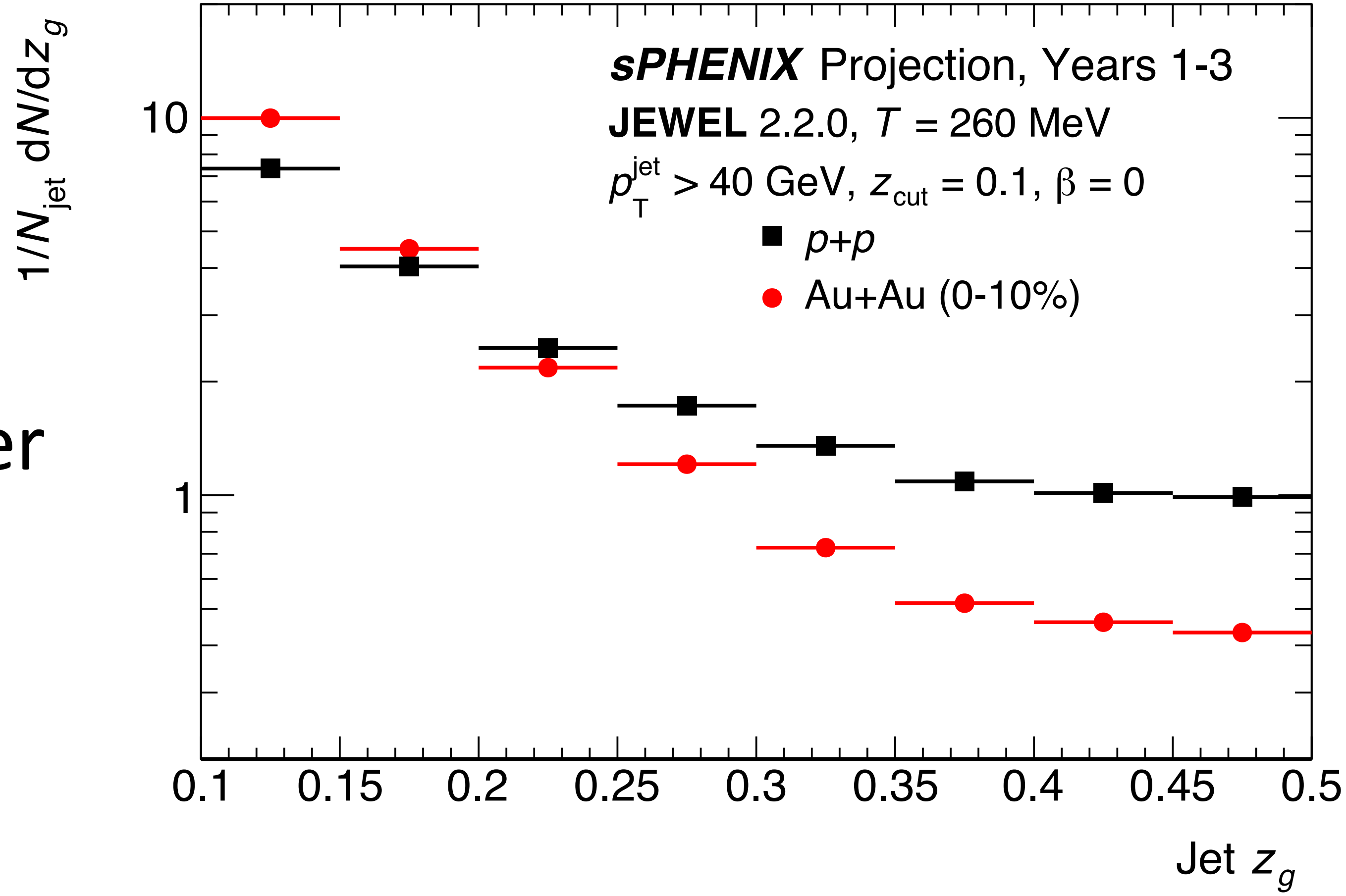
- Photon tagged jets are a key component to the sPHENIX program
- Statistical precision improves systematic uncertainties



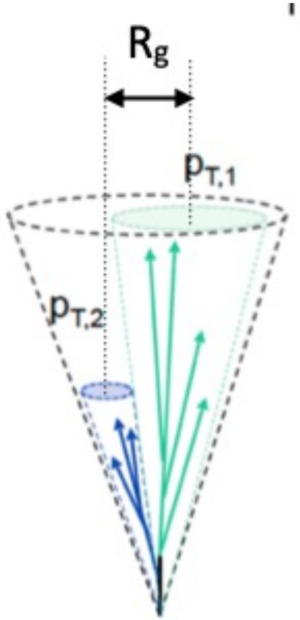


Jet Substructure

- Jet grooming one of many techniques to explore substructure of jets
- Groomed jets explore the evolution of the parton shower

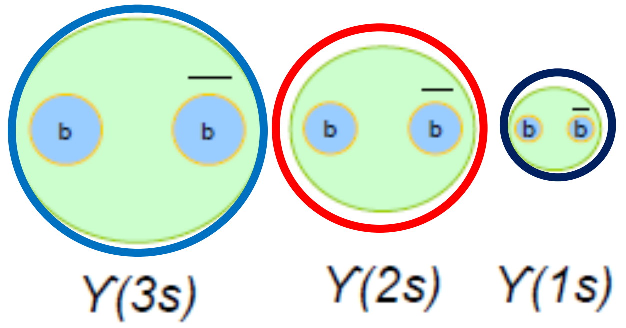


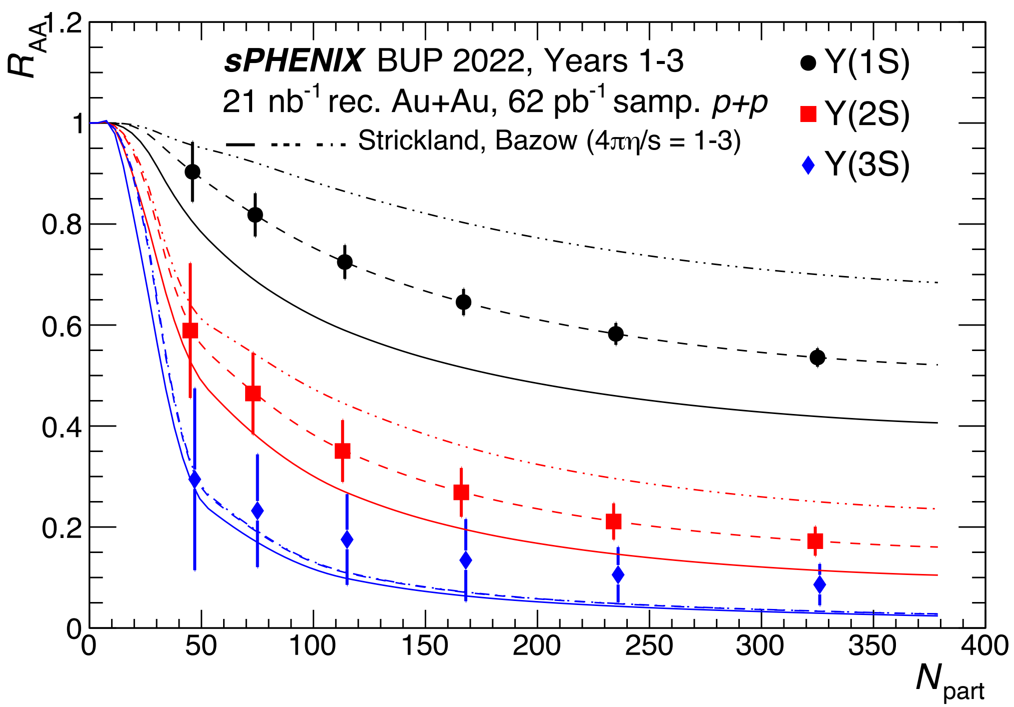
$$z_g = \frac{\min(p_{\perp,1}, p_{\perp,2})}{p_{\perp,1} + p_{\perp,2}}$$

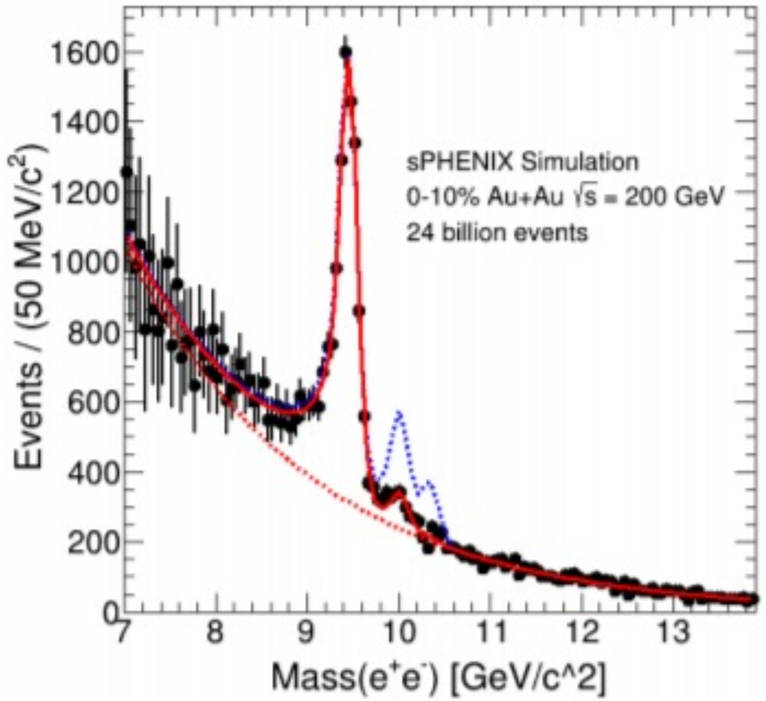


Upsilon R_{AA} vs N_{part}

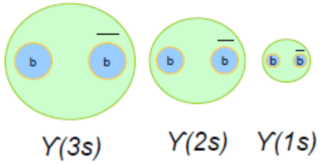
- Separate 3 Upsilon states at RHIC
- R_{AA} from peripheral to central collisions

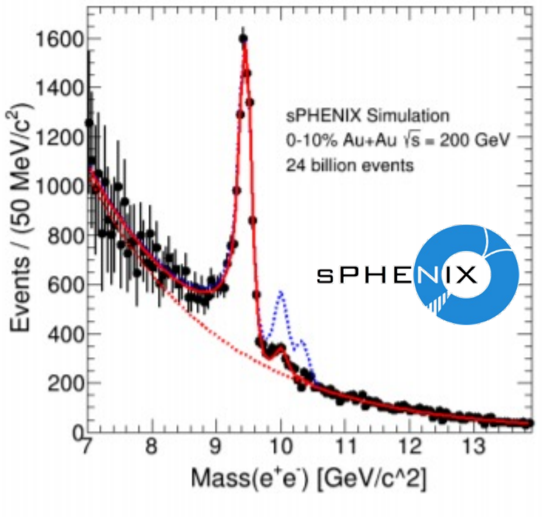




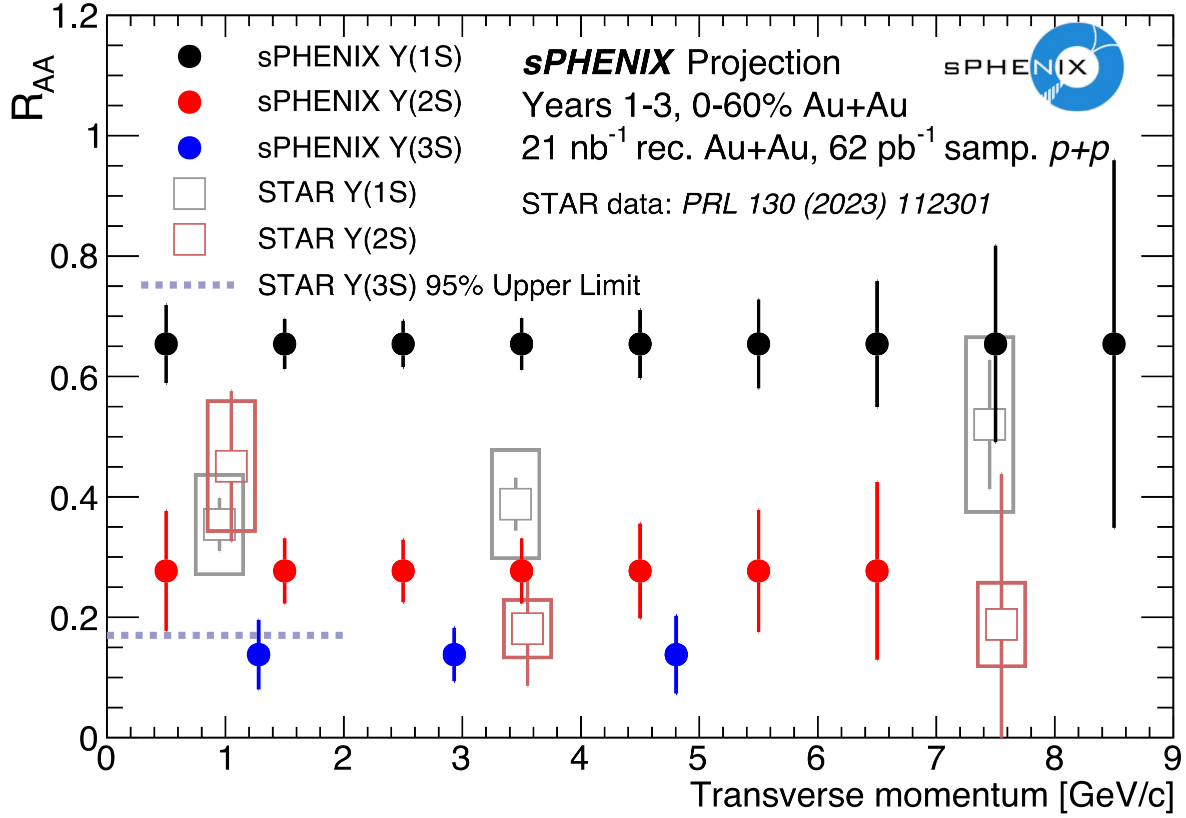


Upsilon R_{AA} vs p_T

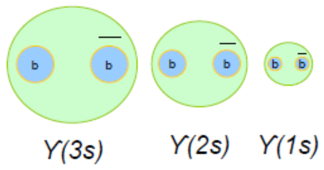


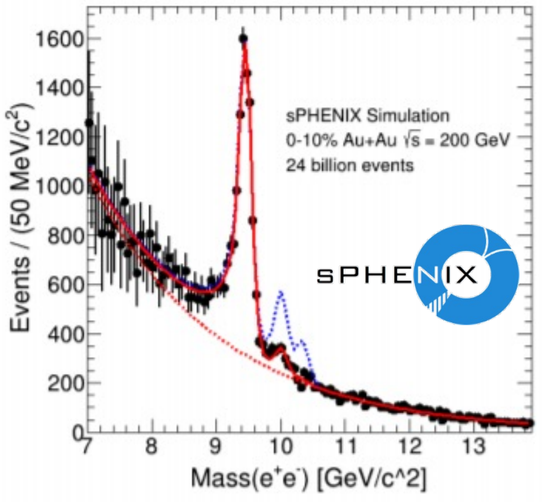


- Separate 3 Upsilon states at sPHENIX
- Potential to quantify Υ(3S) suppression at RHIC energies

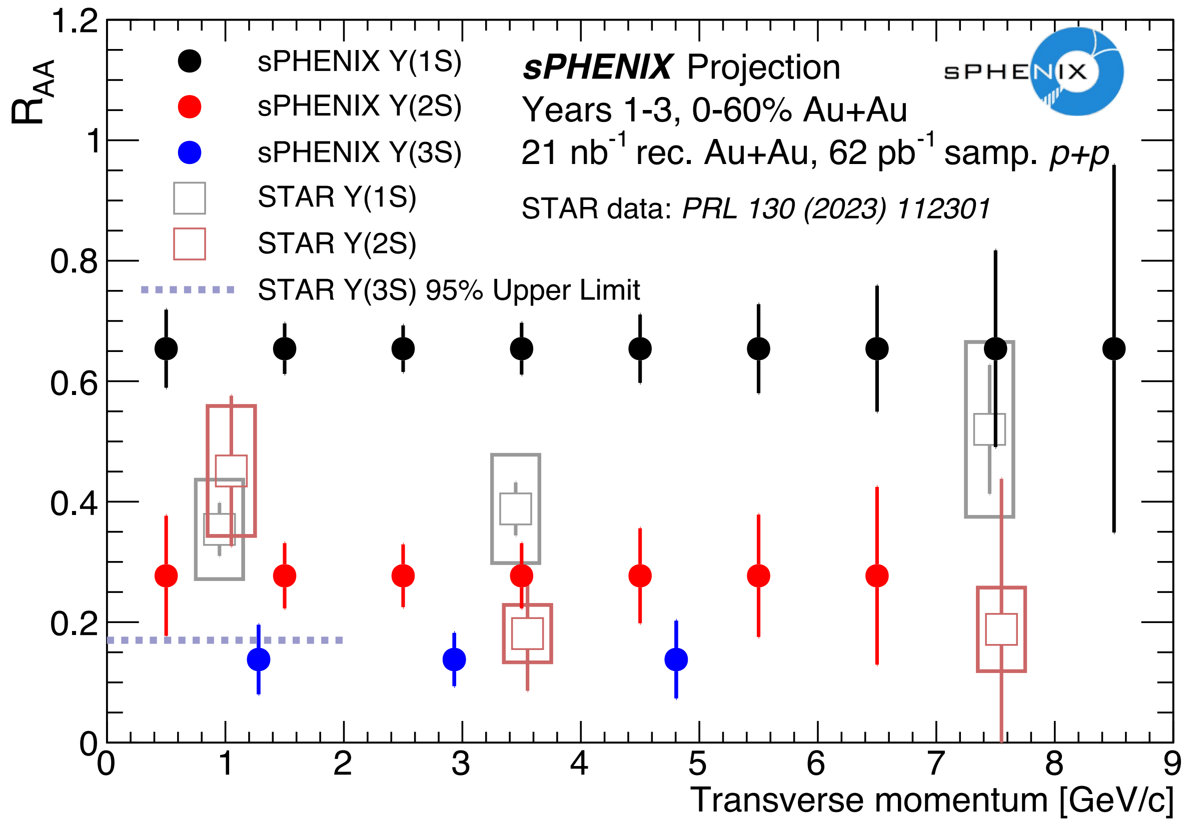


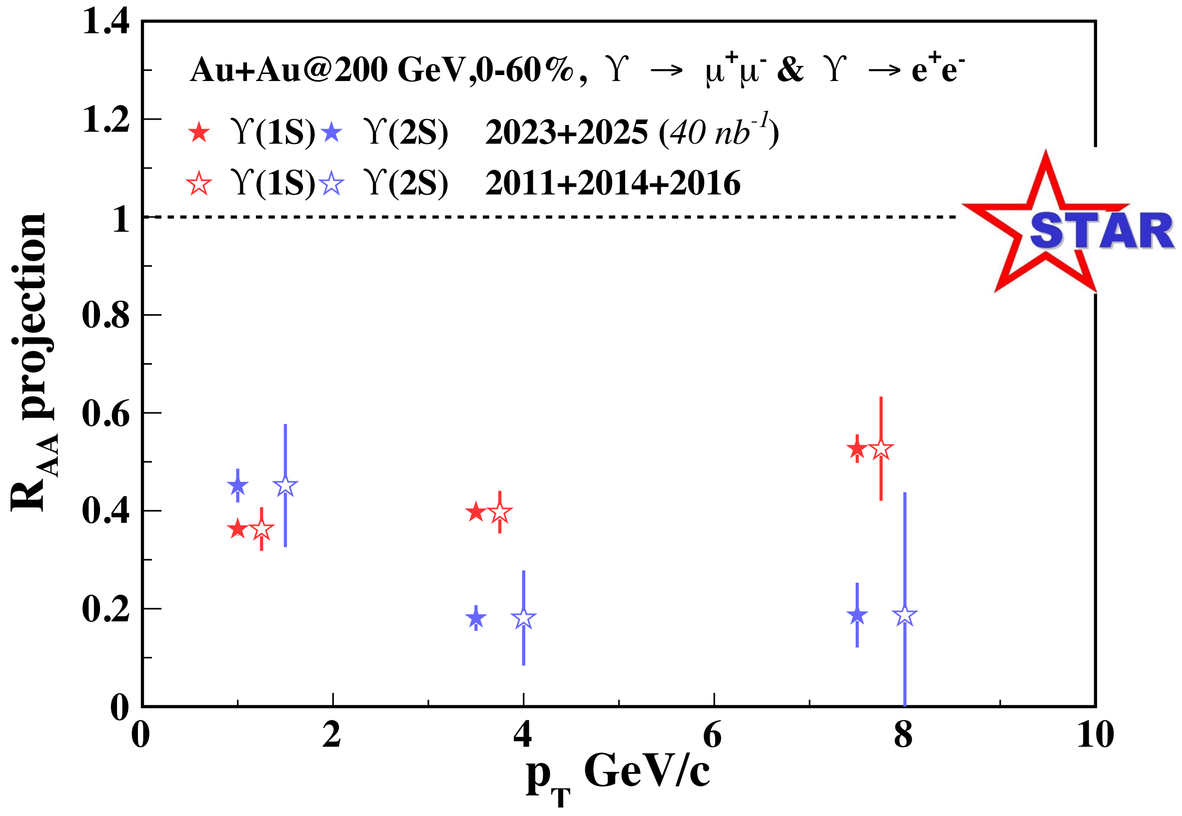
Upsilon R_{AA} vs p_T





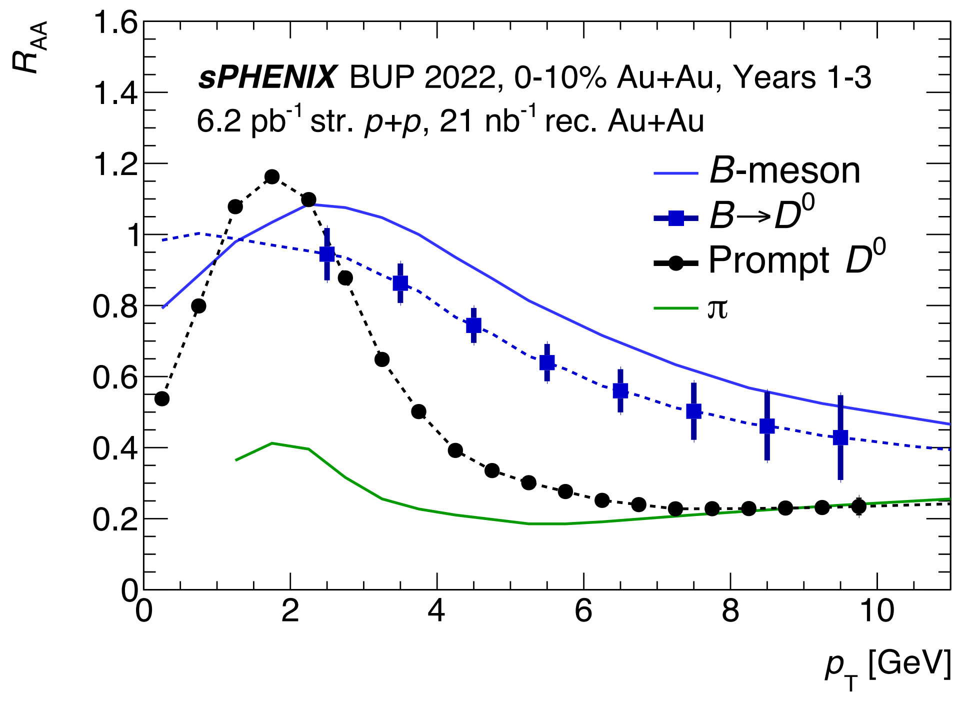
- Separate 3 Upsilon states at sPHENIX
- Potential to quantify Υ(3S) suppression at RHIC energies
- Current STAR results use combined STAR/PHENIX p+p

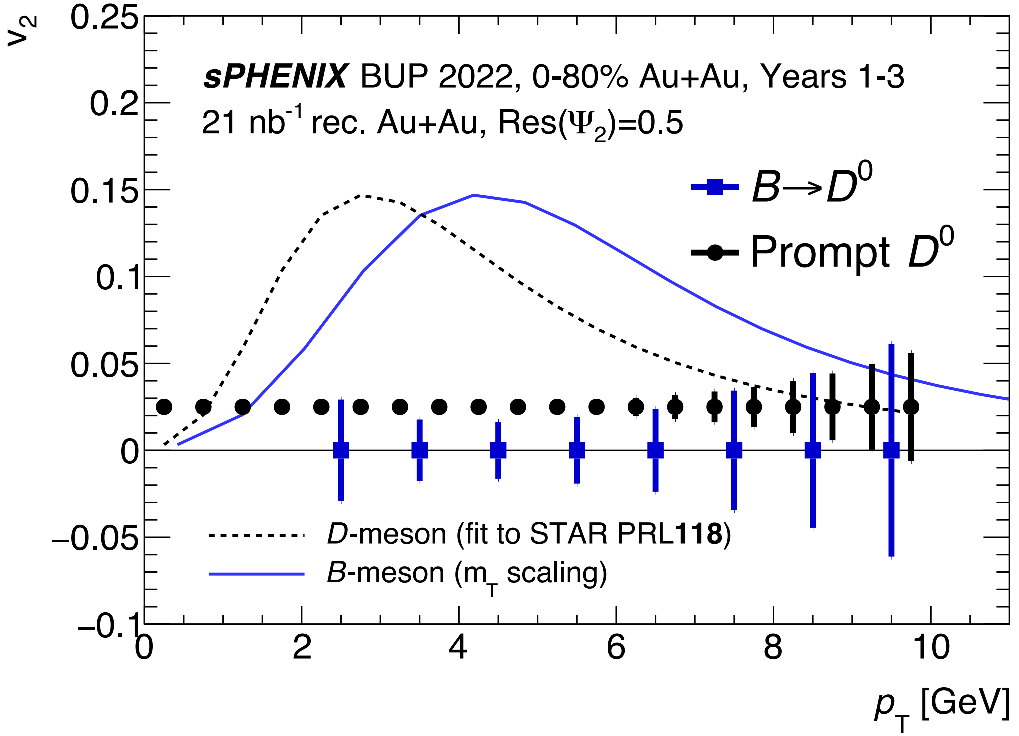




Heavy Flavor in sPHENIX

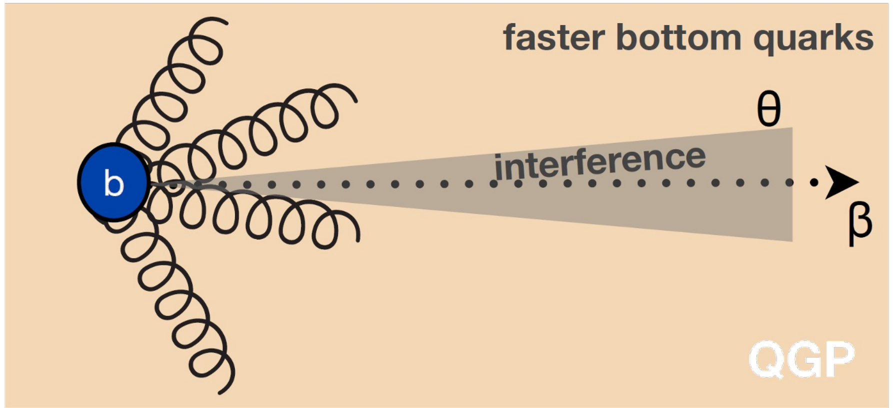
- Streaming readout enables huge MB data for unbiased HF measurements in p+p collisions
- High precision non-prompt D suppression and flow at RHIC

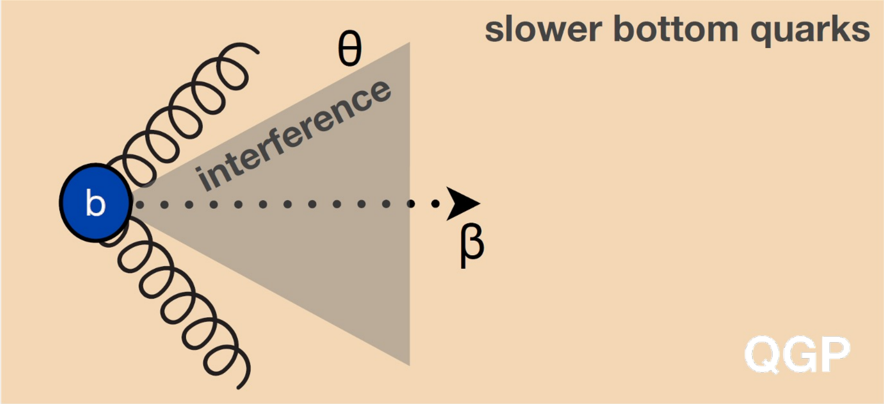


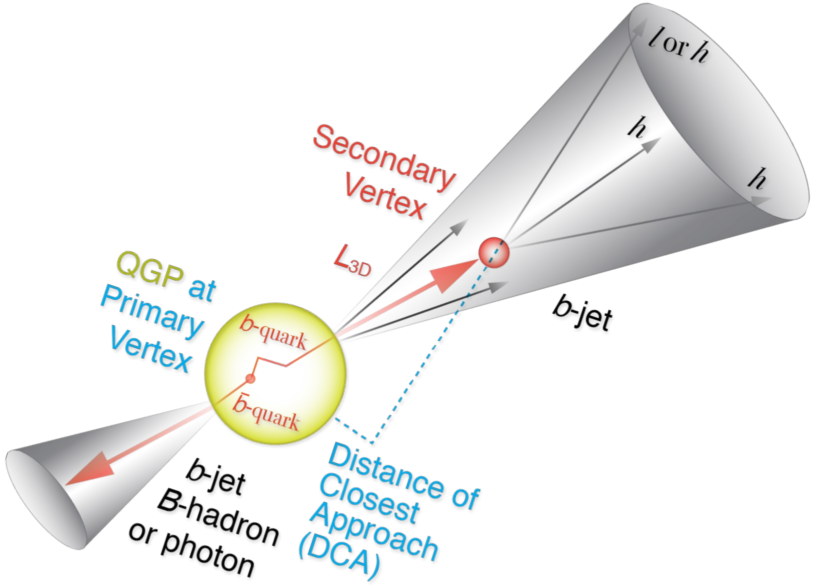


b-tagged Jets at RHIC

- Sensitivity to collisional vs radiative energy loss
- Complimentary to LHC jets, accessing lower p_T region with larger heavy quark mass effect.

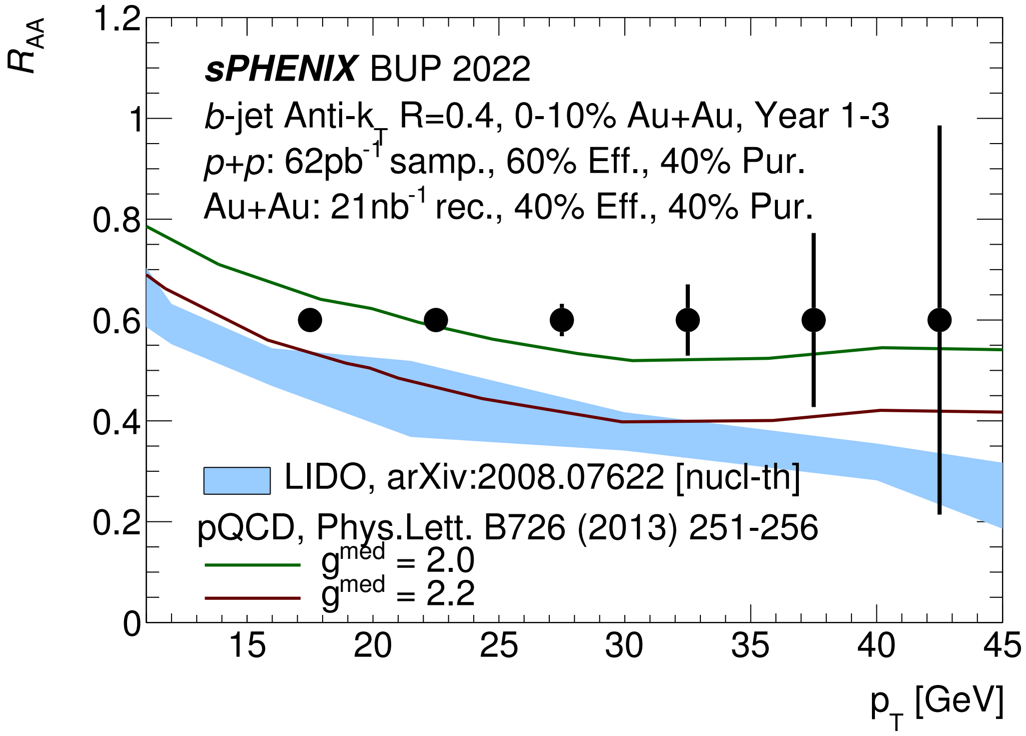


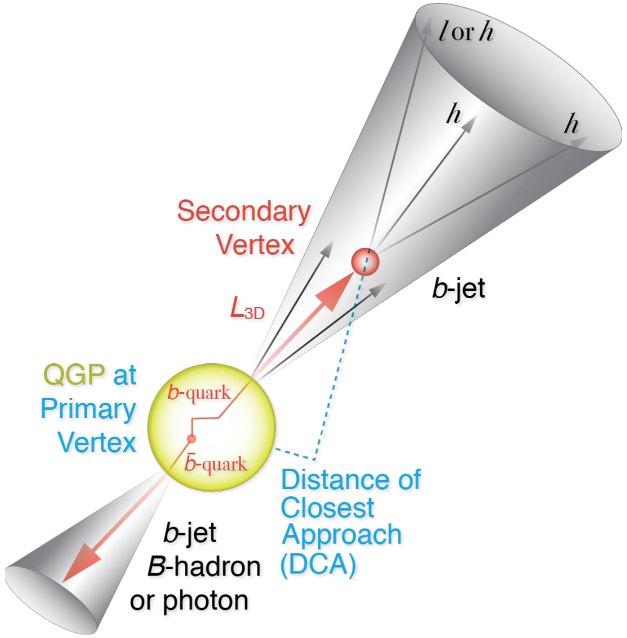


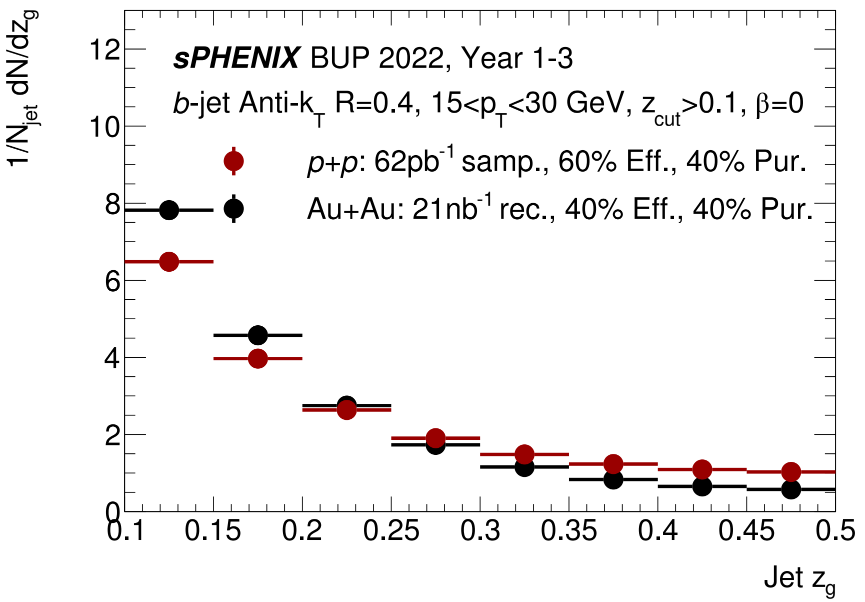


b-tagged Jet Projection

- First b-jet measurement at RHIC
- Power to constrain medium coupling parameters in models

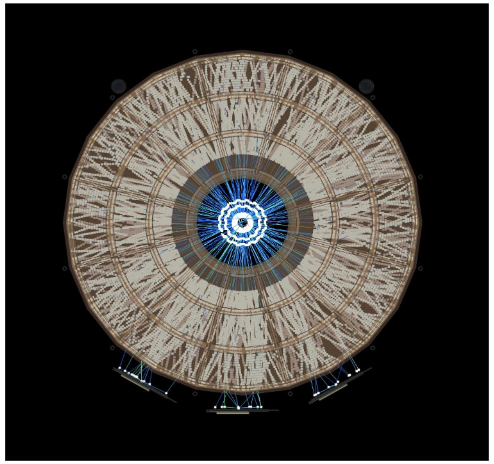






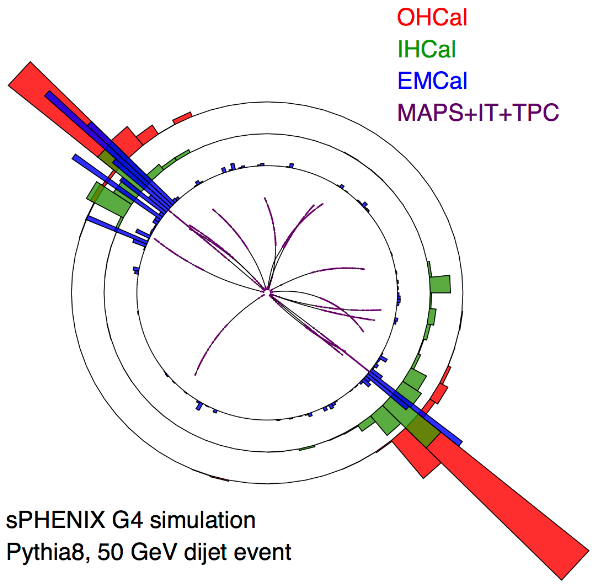
Summary

- STAR measurements with increased rapidity and statistics
- The sPHENIX era is upon us
  - **First ever b-jet measurements at RHIC**
  - **Measurement of upsilon 3S suppression**
  - **Precise imbalance & substructure measurements with jets and γ–tagged jets**
- Achieve the goals established in the 2015 US LRP to complete the scientific mission of RHIC
- Looking forward to interesting results at the next HP!



sPHENIX

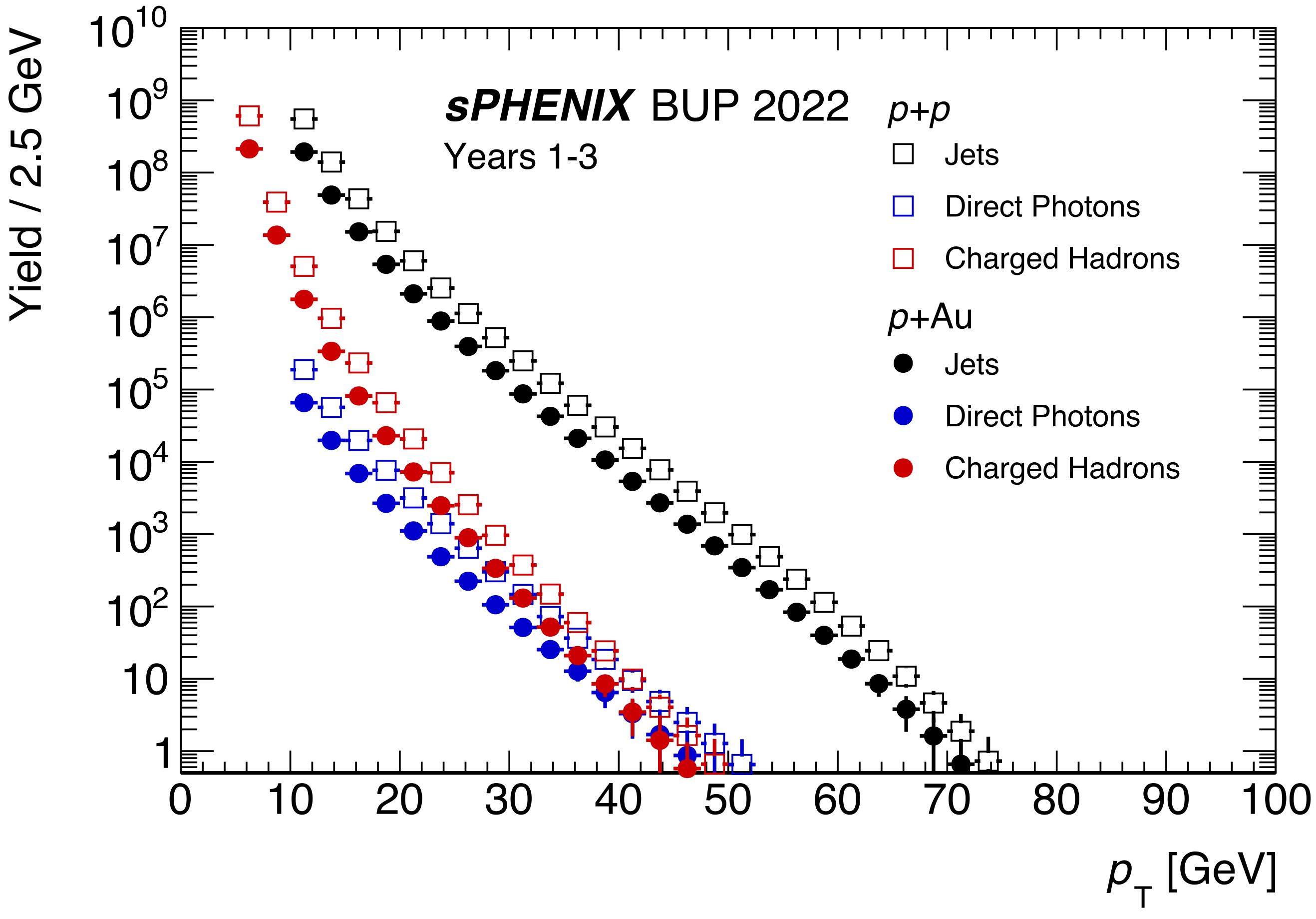
Back up Slides

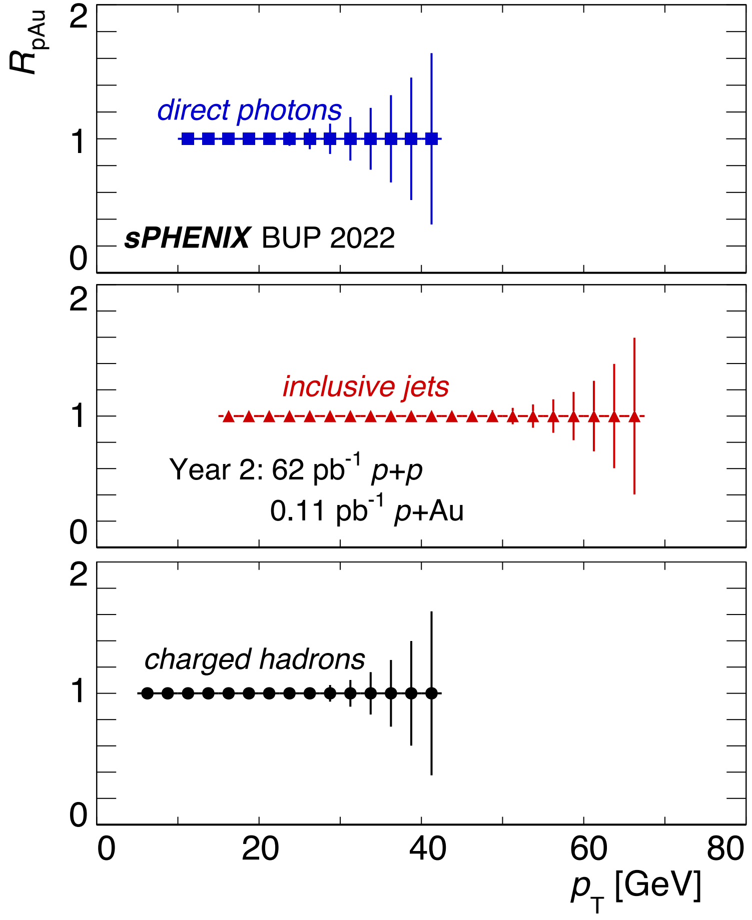


Jets Statistics with Cold QCD

Utilizing p+Au and p+p data from year 2

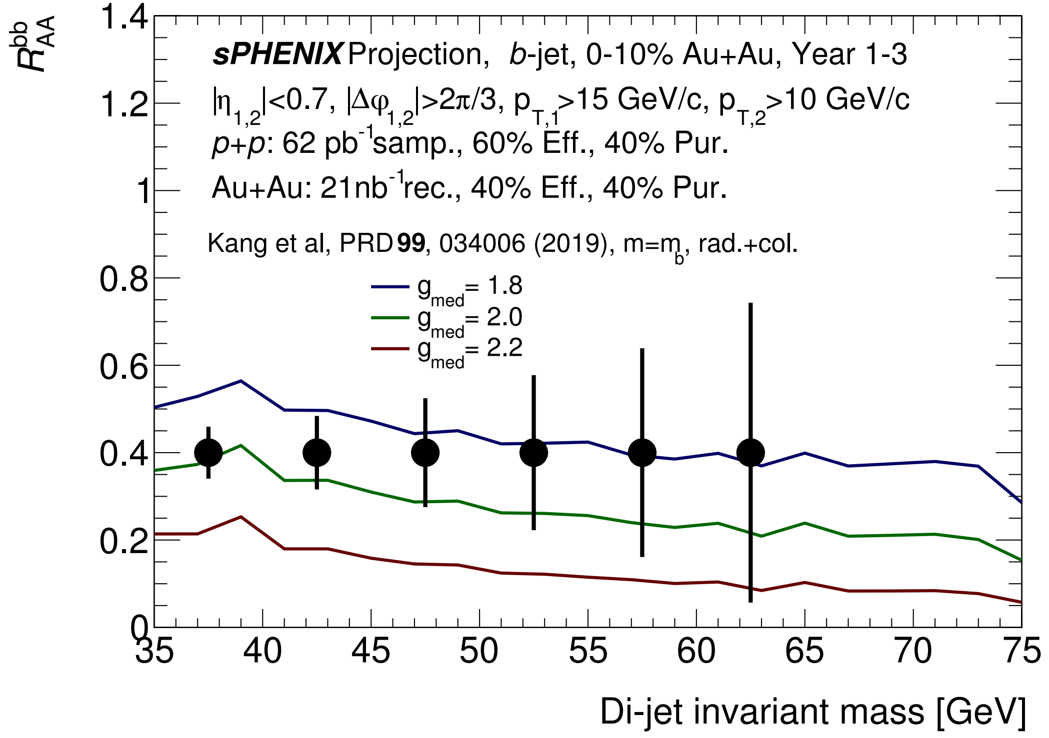
Extends previous RHIC photon/hadron measurements beyond 20 GeV/c

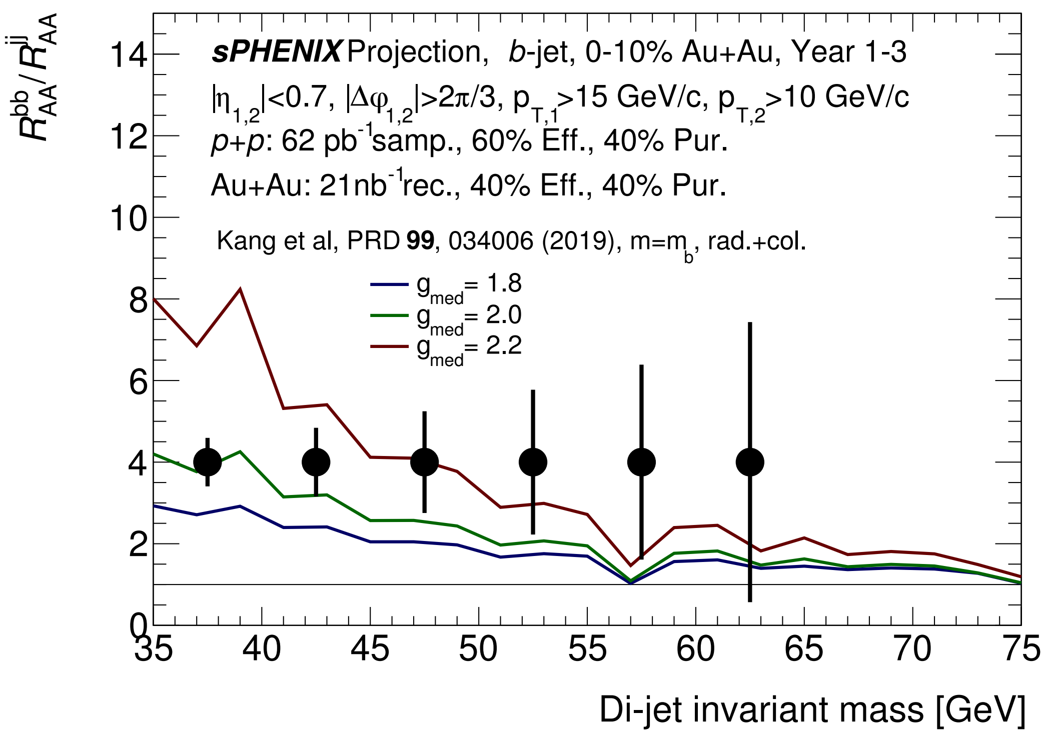




b-jet Projections

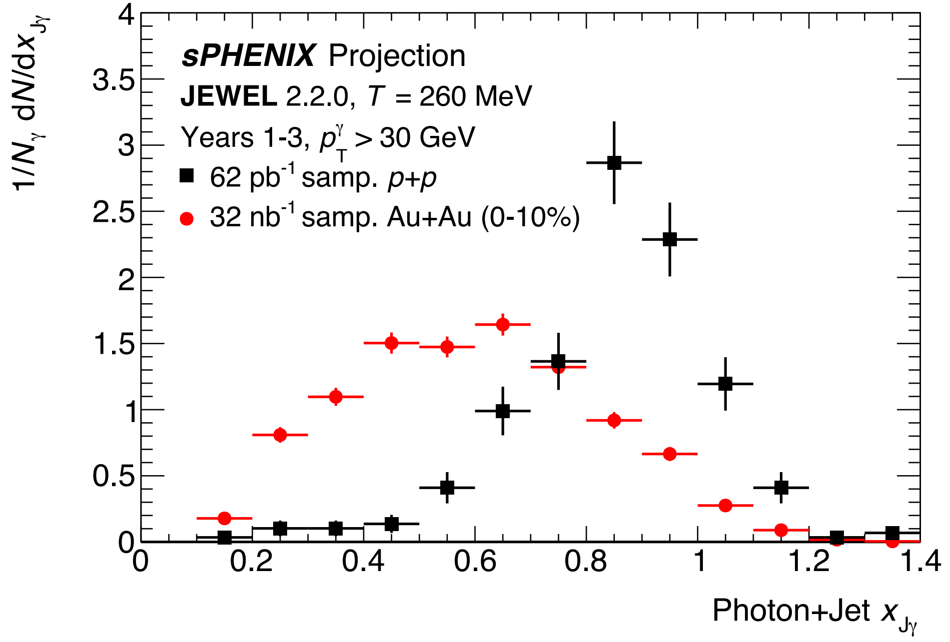
- sPHENIX b-tagged di-jets compared to calculations from $SCET_{MG}$ framework
  - **Precision capable of constraining medium coupling**

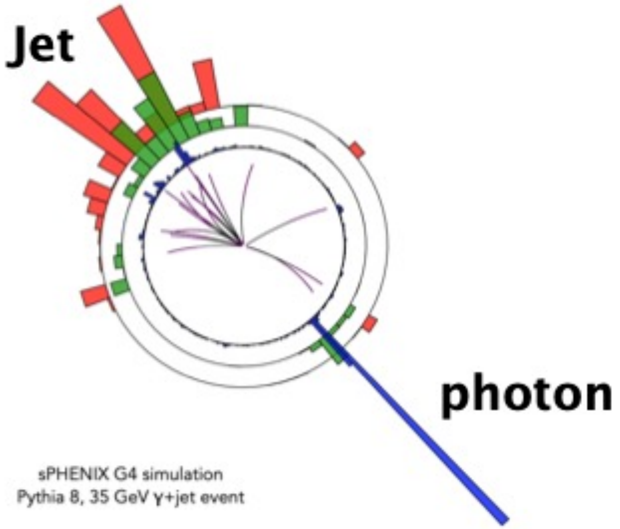




Photon-jet in sPHENIX

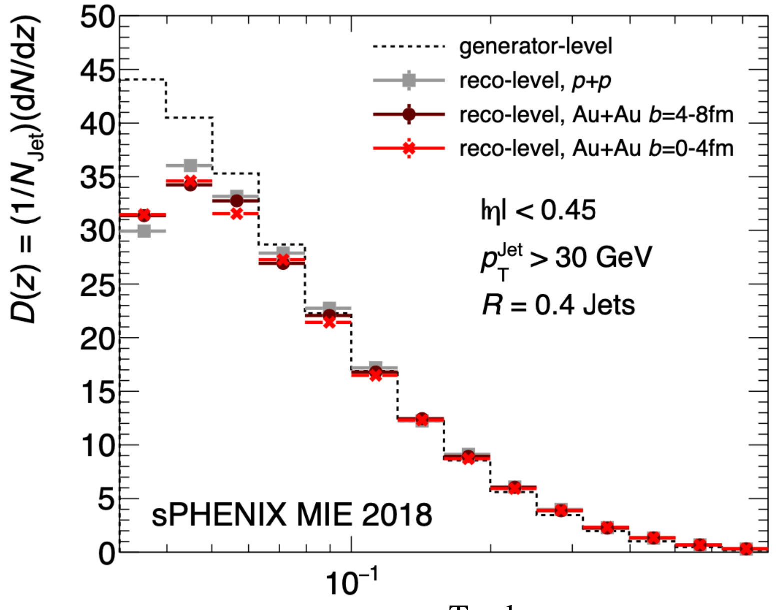
- Photon-jets are a powerful tool for studying jet quenching and medium response effects with sPHENIX
- γ-jet fragmentation functions require:
  - **Photon reconstruction in EMCal**
  - **Jet reconstruction (EMCal+HCals)**
  - **Tracking (MAPS+INTT+TPC)**





M. Connors

Fragmentation Function



$$z = \frac{p_T^{Track}}{p_T^{Jet}}$$

sPHENIX Detectors

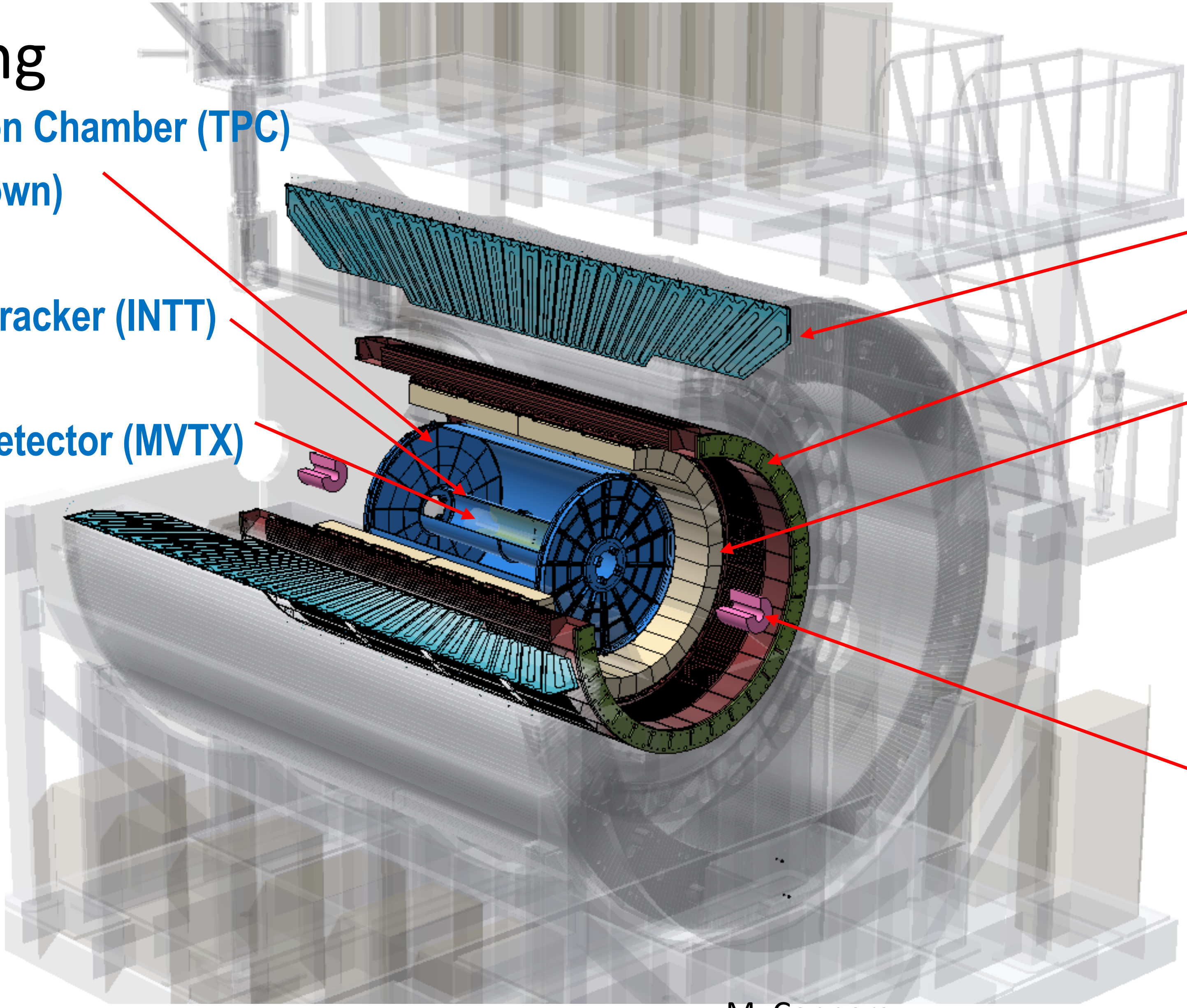
Tracking

Time Projection Chamber (TPC)

(TPOT not shown)

Intermediate Tracker (INTT)

MicroVertex Detector (MVTX)



Calorimetry

Hadronic Calorimeters

Outer

Inner

Electromagnetic Calorimeter

Trigger/event characterization:

Minimum Bias Detector (MBD)

Event Plane (sEPD) (not shown)

Run Plan 2023-2025

2023	2024	2025
Au+Au	p+p/p+Au	Au+Au

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}

$\sqrt{s_{NN}}$ (GeV)	Species	Number Events/ Sampled Luminosity	Year
200	Au+Au	20B / 40 nb^{-1}	2023+2025
200	p+p	235 pb^{-1}	2024
200	p+Au	1.3 pb^{-1}	2024

Opportunities beyond 3-year plan

- sPHENIX goals accomplished with 3 year plan
- Additional physics opportunities achievable beyond 3 year plan

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $|z| <$10 cm	Samp. Lum. $|z| <$10 cm
2026	$p^{\uparrow}p^{\uparrow}$	200	28	15.5	1.0 pb^{-1} [10 kHz] 80 pb^{-1} [100%-*str*]	80 pb^{-1}
–	O+O	200	–	2	18 nb^{-1} 37 nb^{-1} [100%-*str*]	37 nb^{-1}
–	Ar+Ar	200	–	2	6 nb^{-1} 12 nb^{-1} [100%-*str*]	12 nb^{-1}
2027	Au+Au	200	28	24.5	30 nb^{-1} [100%-*str*/DeMux]	30 nb^{-1}