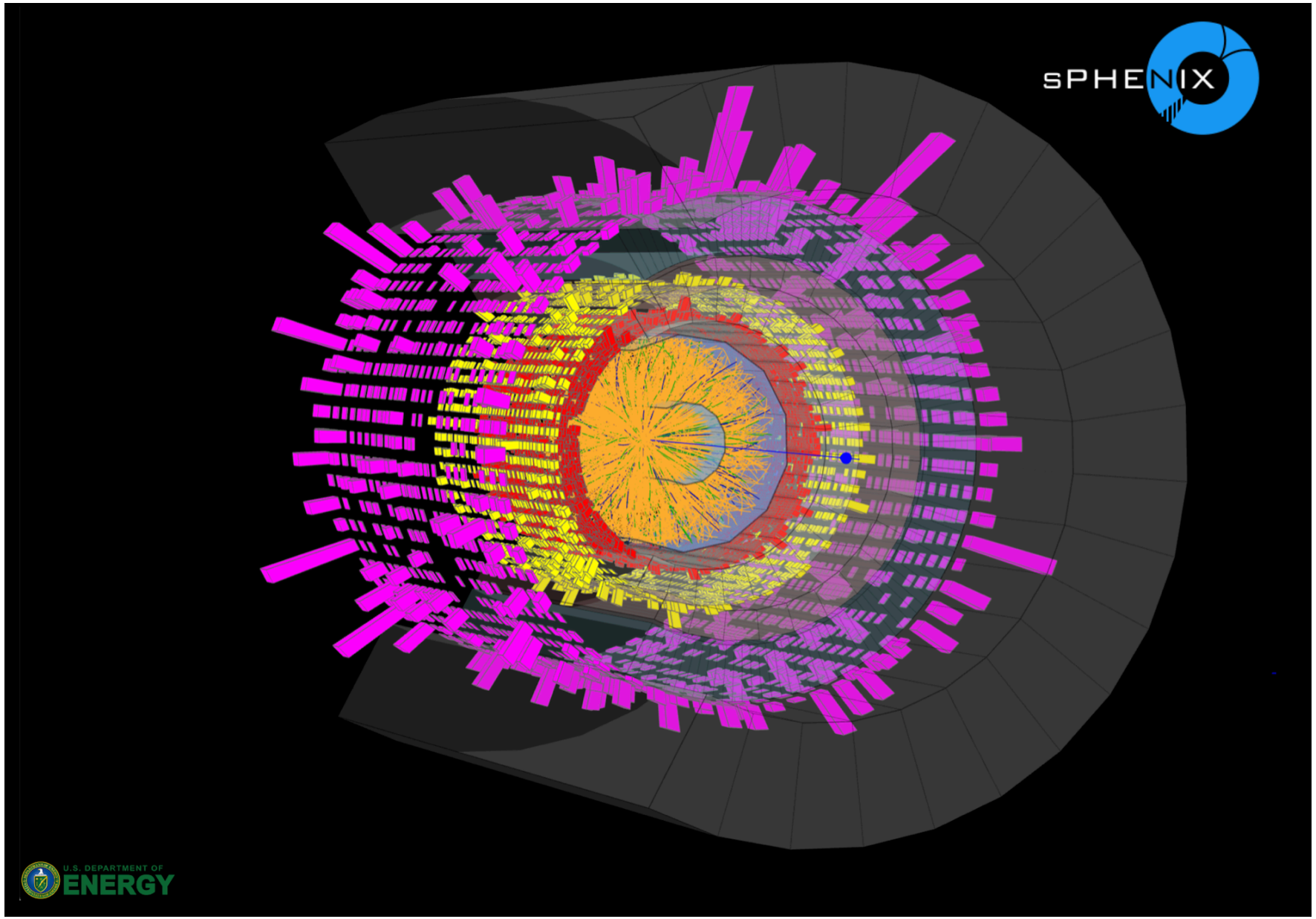
The Status and Anticipated Physics of sPHENIX

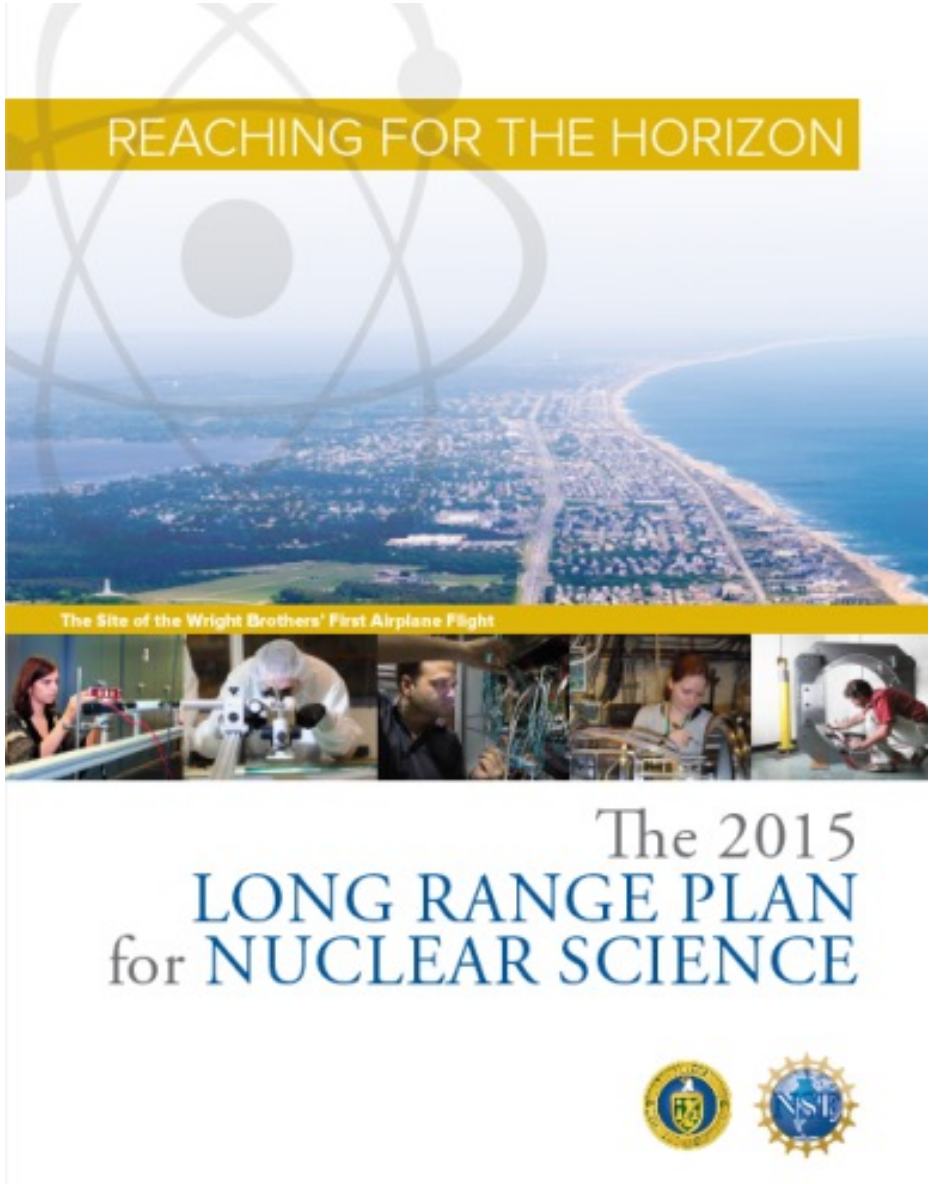


Megan Connors (GSU)

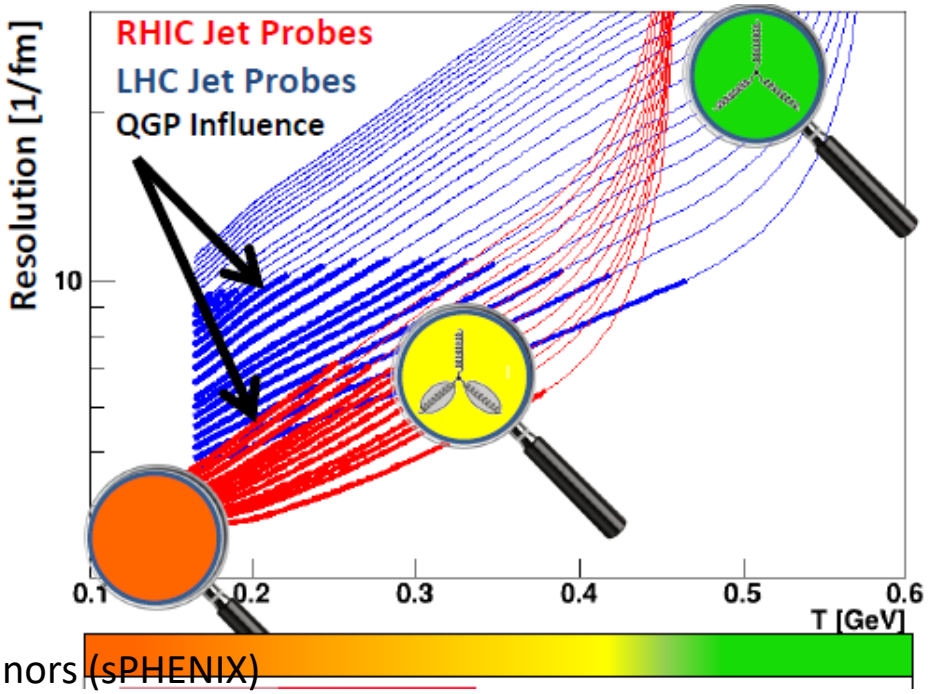
CIPANP

September 1, 2022

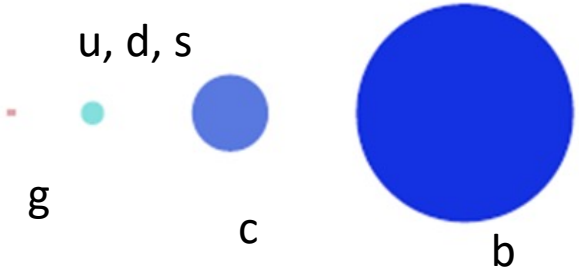
sPHENIX Mission



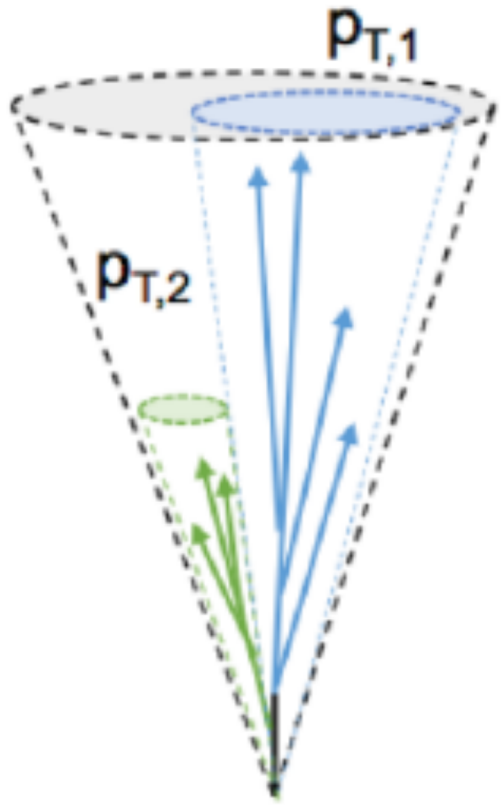
There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art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



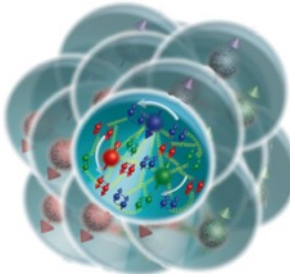
Probe QGP at Multiple Scales



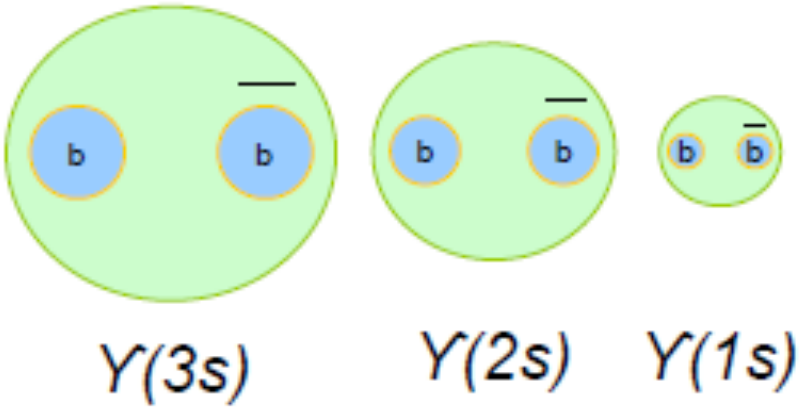
Parton energy loss
vary mass/momentum of probe



Jet structure
Vary momentum/angular scale of probe

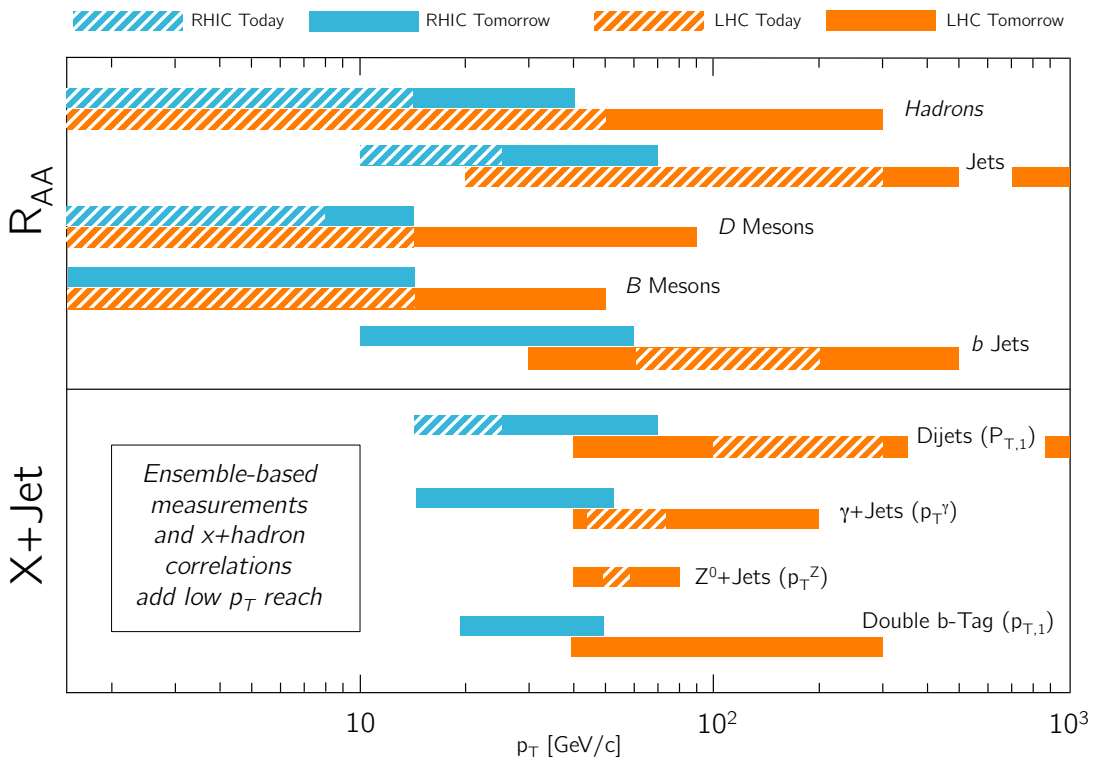


Cold QCD
vary temperature of QCD Matter

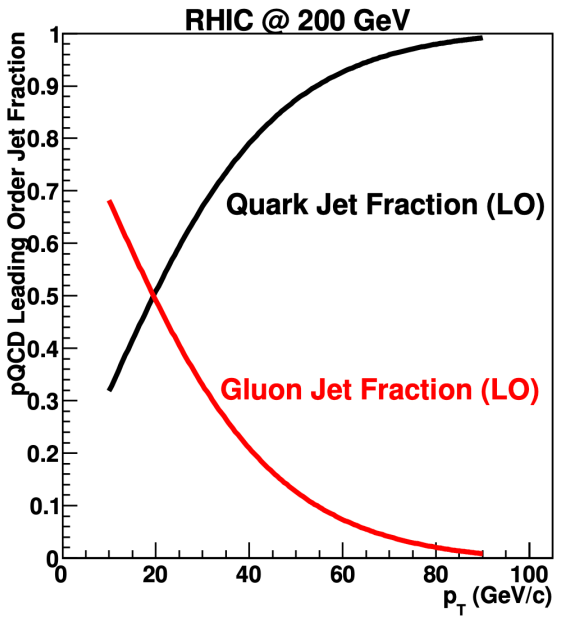


Quarkonium spectroscopy
vary size of probe

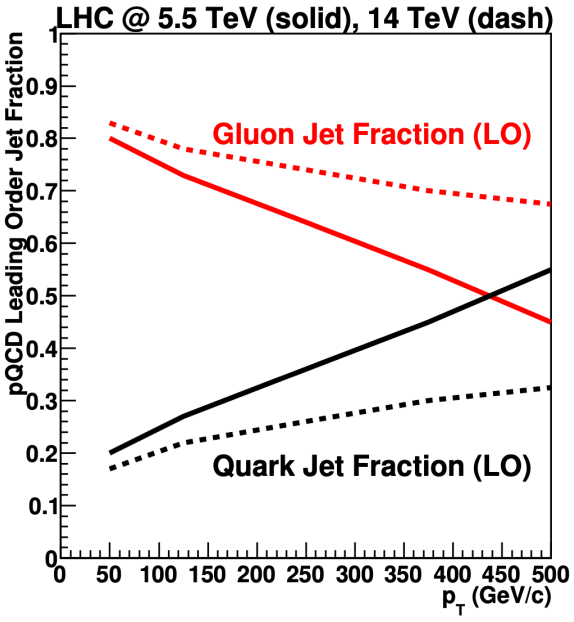
RHIC/LHC Complementarity



RHIC

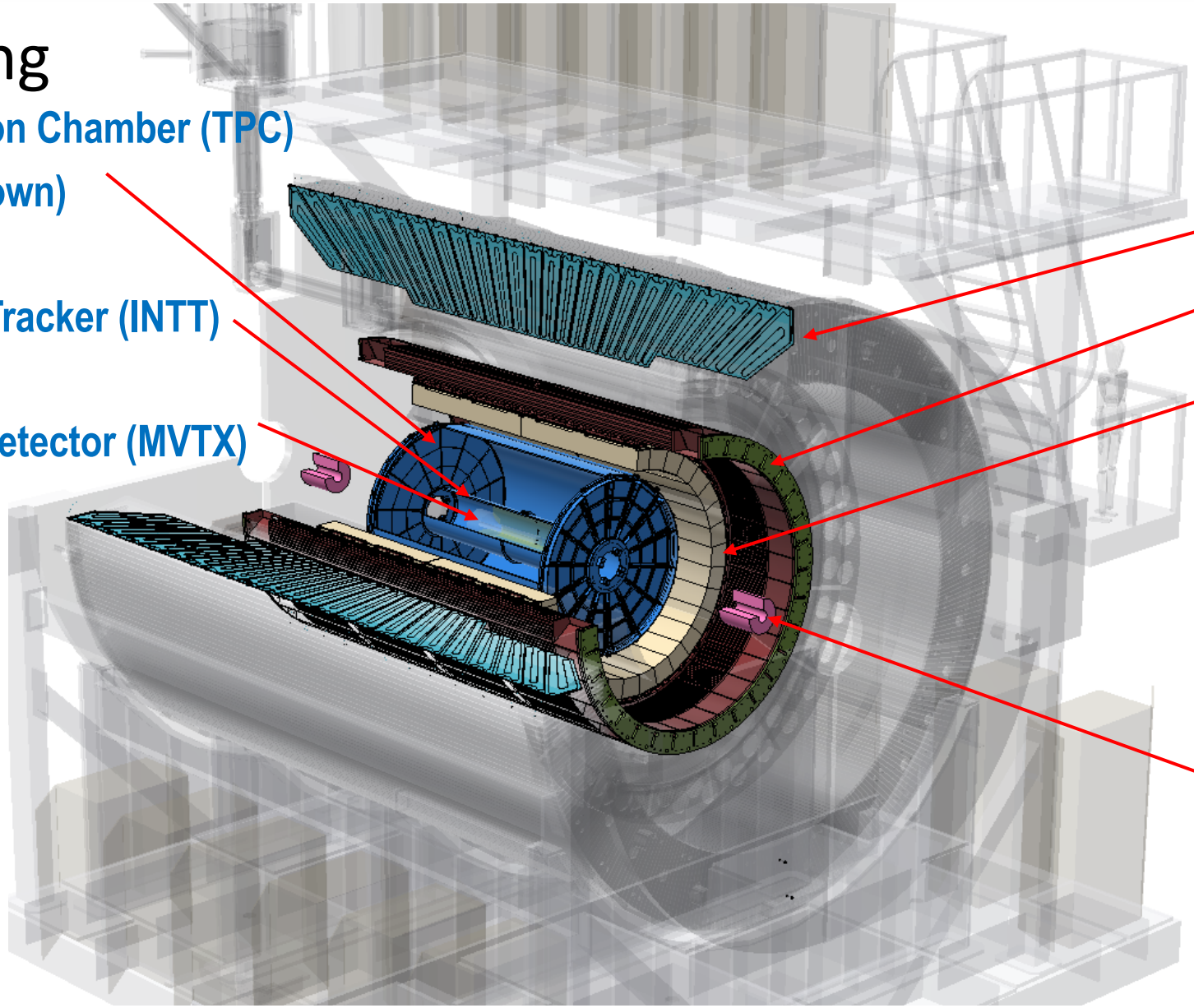


LHC



- Significant overlap achievable with “tomorrow’s” RHIC-LHC measurements
- Different mixture of quark and gluon jets at RHIC/LHC

sPHENIX Detectors



Tracking

Time Projection Chamber (TPC)

(TPOT not shown)

Intermediate Tracker (INTT)

MicroVertex Detector (MVTX)

Calorimetry

Hadronic Calorimeters

Outer

Inner

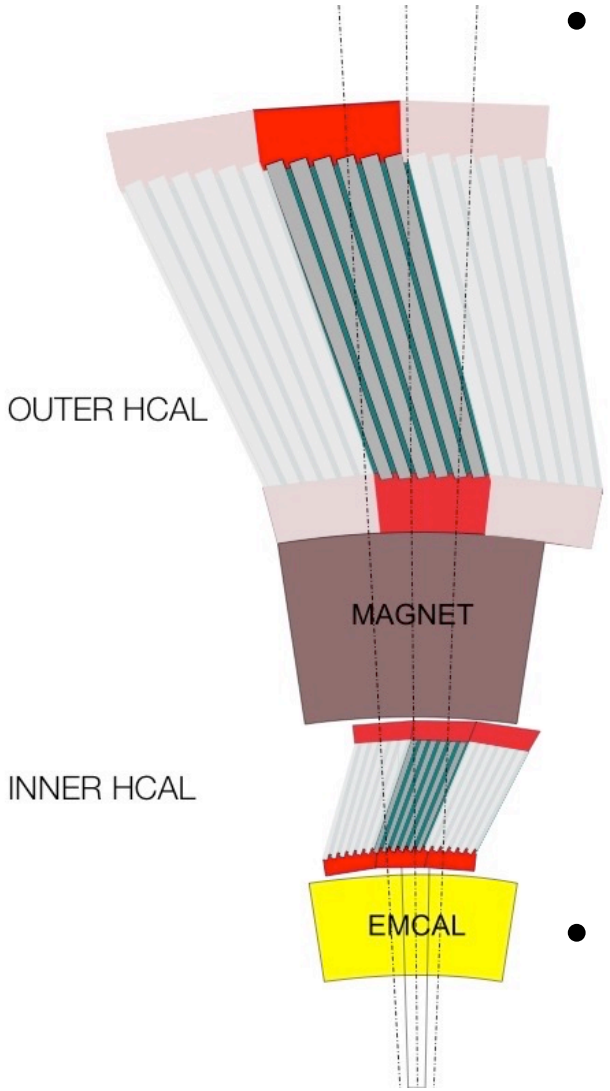
Electromagnetic Calorimeter

Trigger/event characterization:

Minimum Bias Detector (MBD)

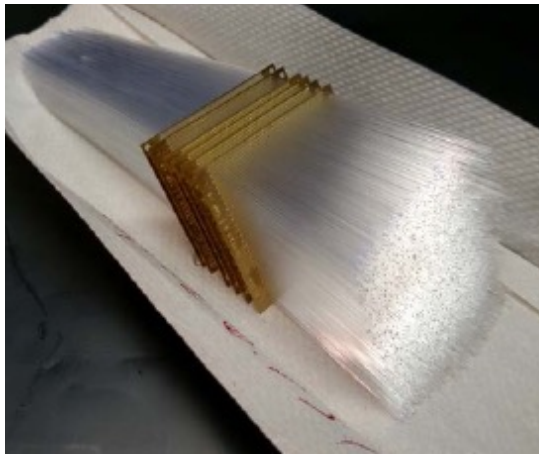
Event Plane (sEPD) (not shown)

sPHENIX Calorimeters



- Outer/Inner Hcals: Steel/Al absorber plates and scintillating tiles with embedded Wavelength shifting fibers

  Resolution ~ 88%/√E⊕12% (single particle)



- EMCal: Tungsten + scintillating fiber SPACAL

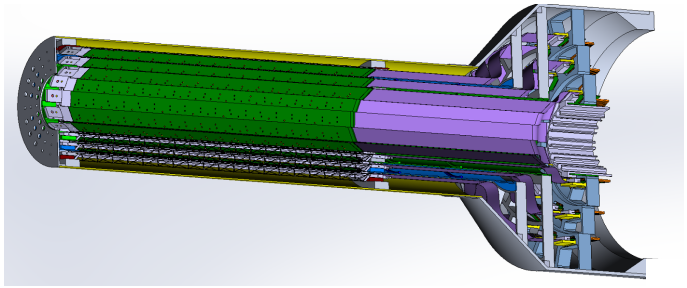
  18 X_0, 1 λ. Δη x Δϕ=0.025x0.025

  Resolution ~ 16%/√E ⊕5%

Tracking Subsystems

MVTX

- 3 layers Monolithic Active Pixel Sensors (MAPS)
- Based on ALICE ITS upgrade
- $DCA_{xy} < 70$ µm
- $|z_{vtx}| < 10$ cm

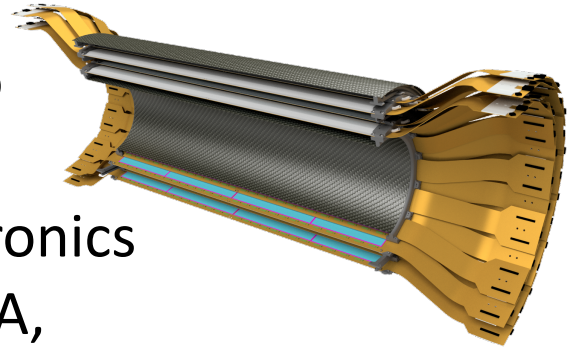


TPC

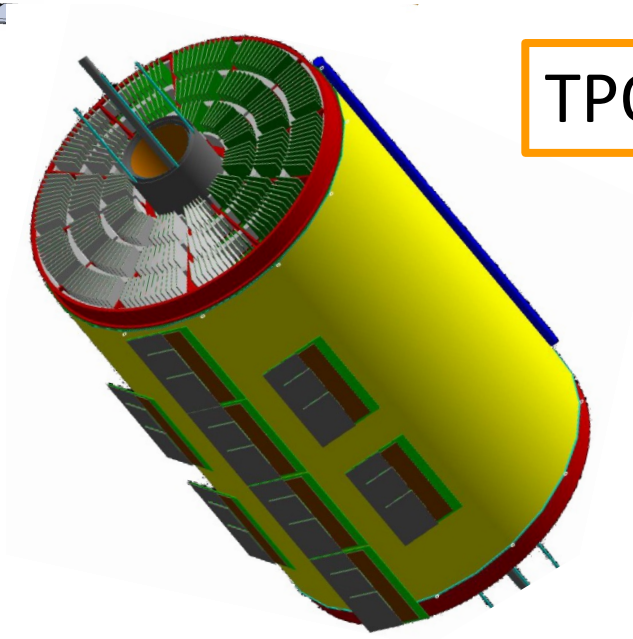
- Radius 20–78 cm
- ~250 µm effective hit resolution
- Continuous (non-gated) readout
- Pattern recognition, momentum resolution, p_T 0.2-40 GeV/c

INTT

- Four layers forming two barrels of Si strips
- Use PHENIX FVTX electronics
- Pattern recognition, DCA, connect tracking systems, reject pile-up



TPOT

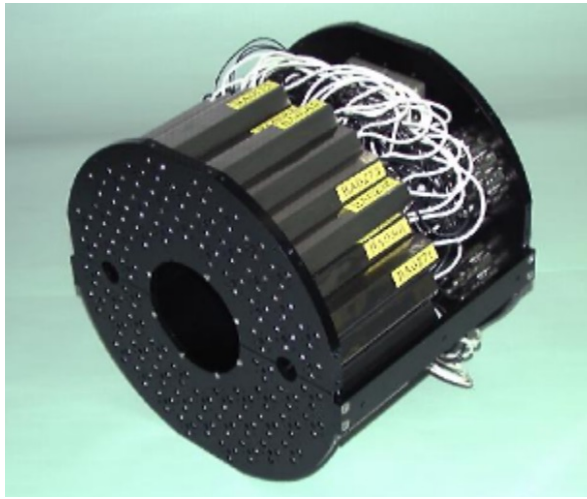


- TPC Outer Tracker
- Calibrate beam-induced space charge distortions
- 8 Micromega modules

Event Characterization Detectors

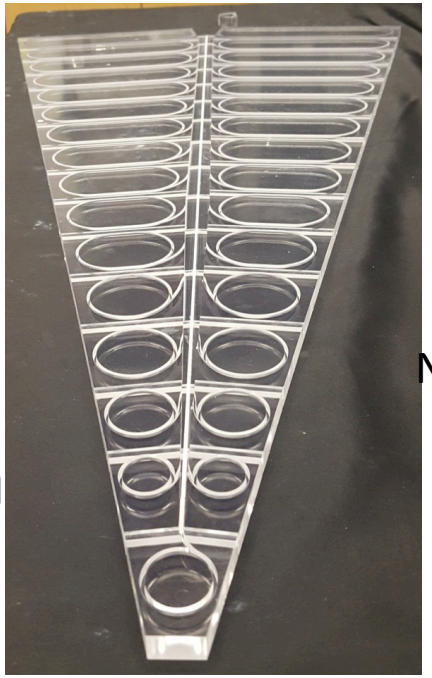
Minimum Bias Detector (MBD) [3.51 < |η| < 4.61]

- Reuse the PHENIX Beam-Beam Counter
- 128 channels of 3cm thick quartz radiator on mesh dynode PMT
- 120 ps trigger level timing resolution



sPHENIX Event Plane Detector (sEPD) [2.0 < |η| < 4.9]

- 1.2-cm-thick scintillator w/ wavelength shifting fibers
- 2 wheels of scintillator tiles
- Significant improvement in the event plane resolution

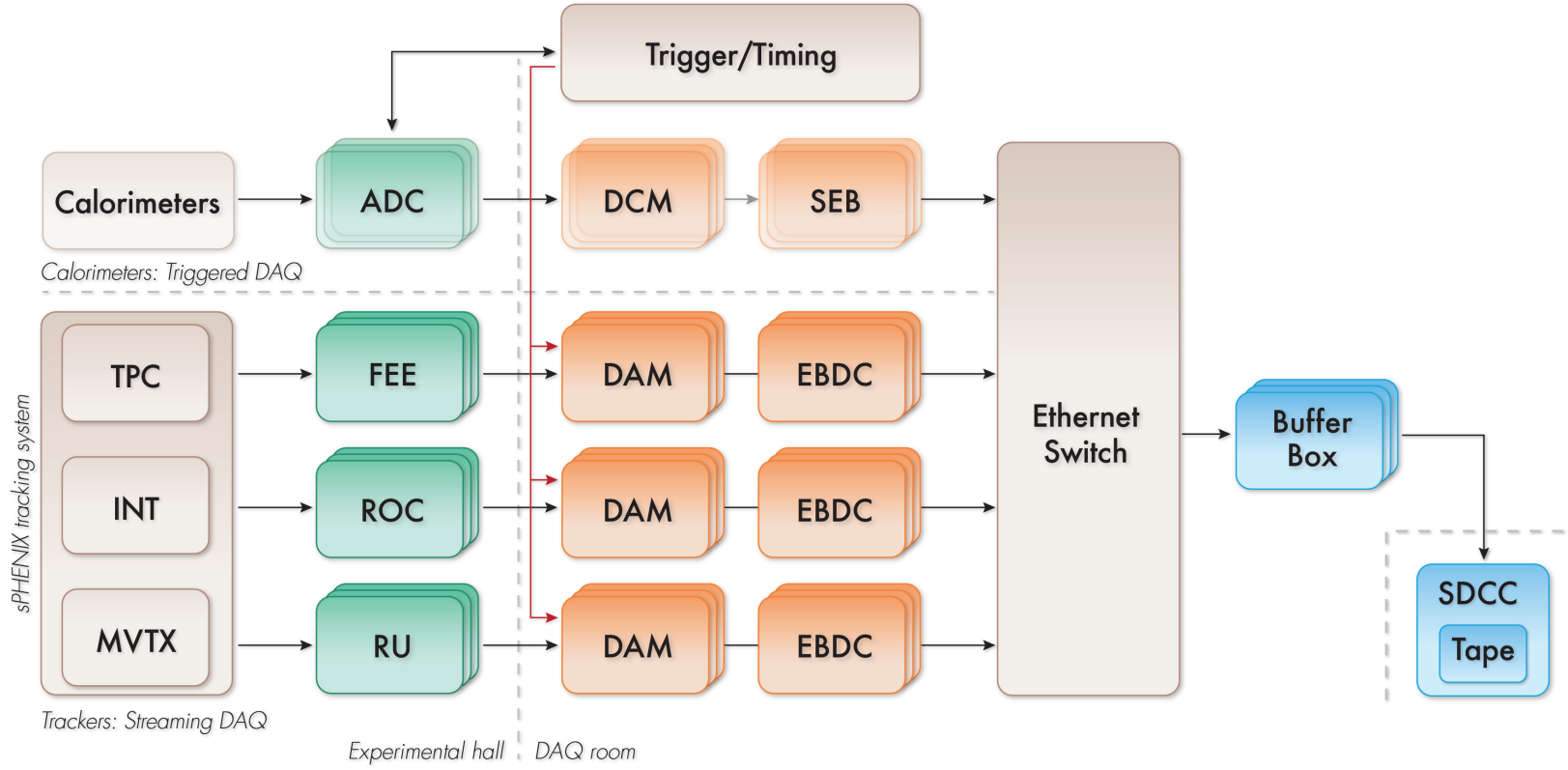


NSF-MRI

Hybrid DAQ & Streaming Readout

- Hybrid DAQ system: Triggered Calorimeters & streaming tracking
- Streaming tracking detectors planned for 2024 data collection
  - **Crucial for open HF and cold QCD measurements**
  - **Significantly increases p+p data collected**

Hybrid DAQ

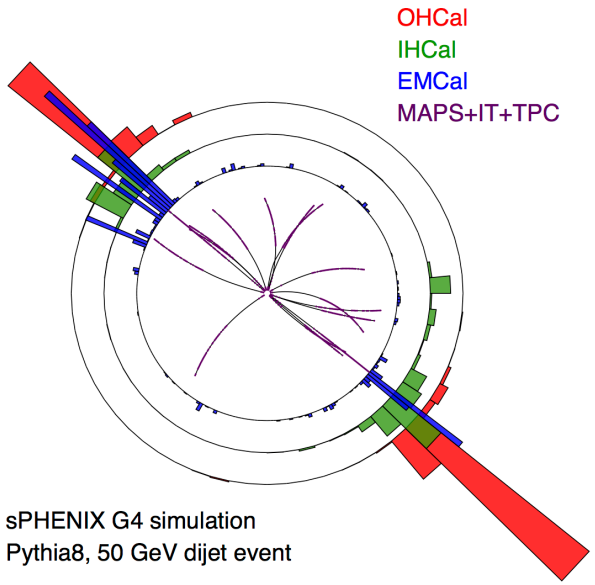


Proposed Plan

- First 3 years of data taking

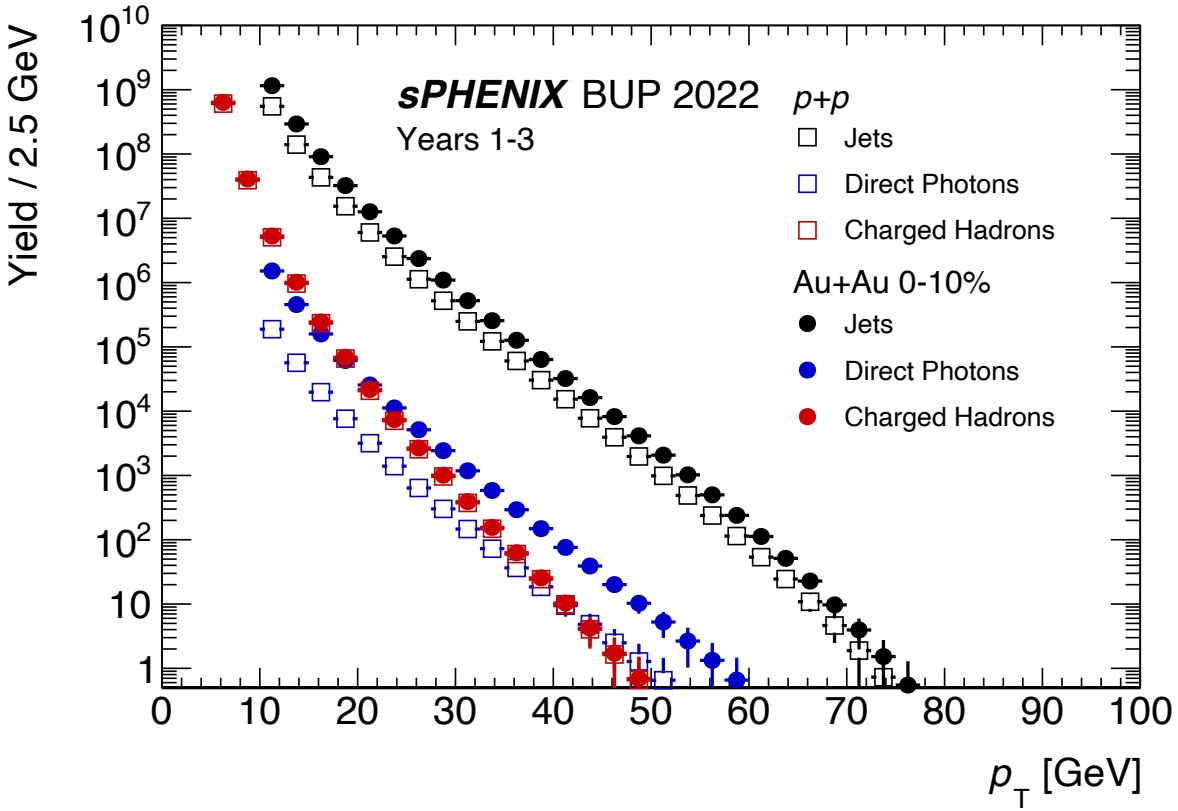
2023	2024	2025
Au+Au	p+p/p+Au	Au+Au

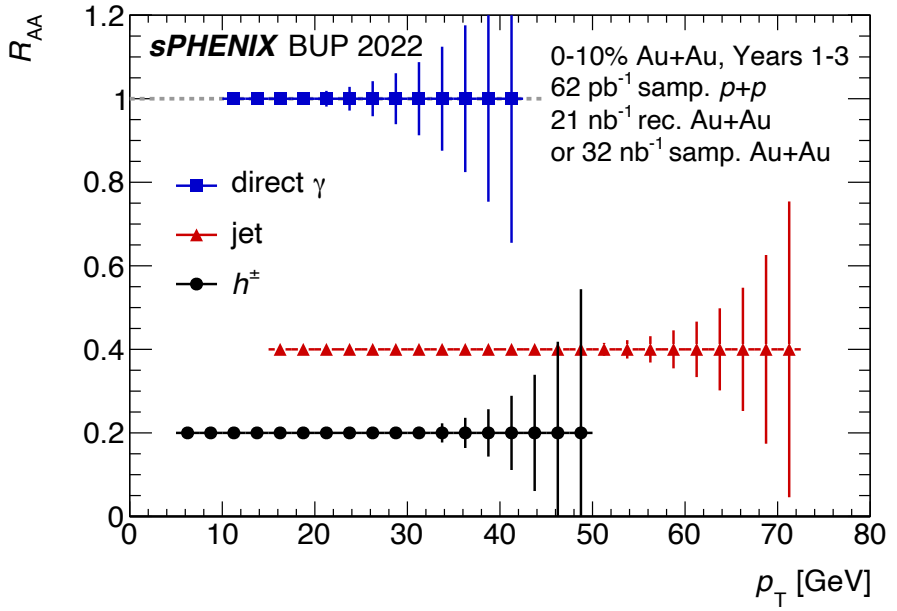
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]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

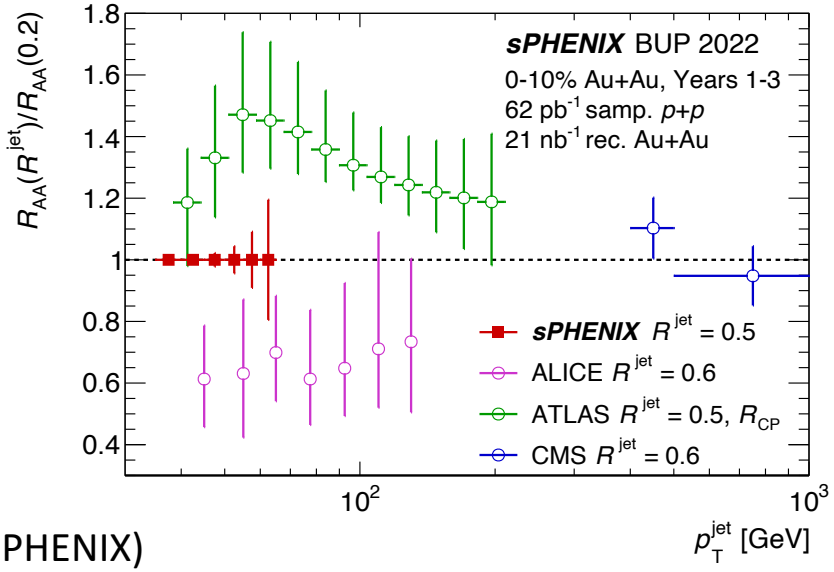


Beam Use Proposal: https://indico.bnl.gov/event/7881/attachments/30176/47160/sPH-TRG-2020-001.pdf

Jet Statistics with Heavy Ions

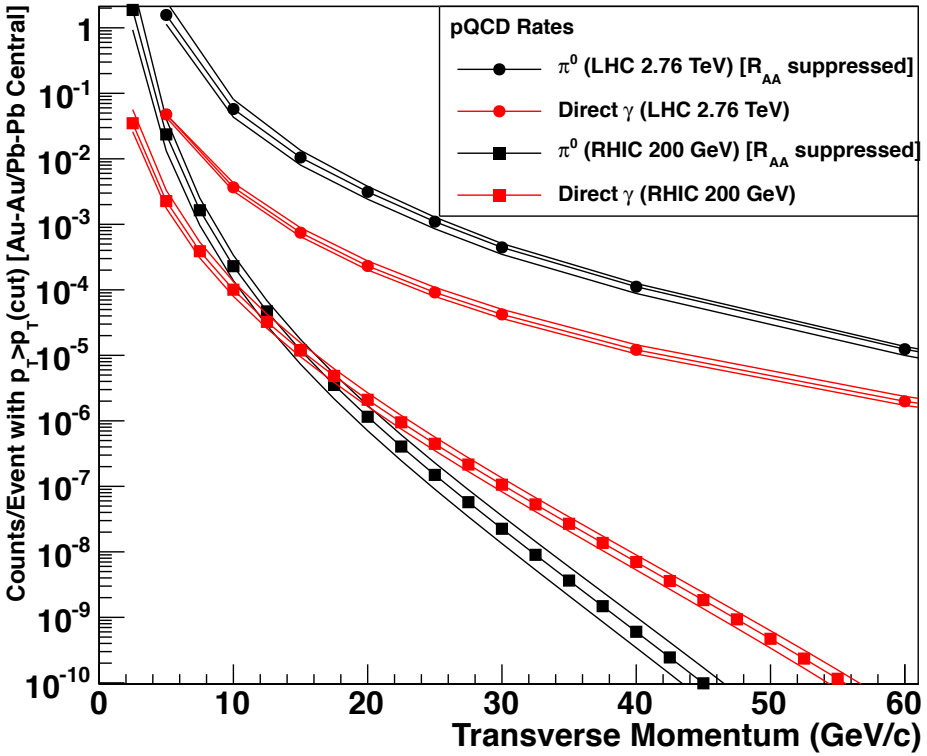




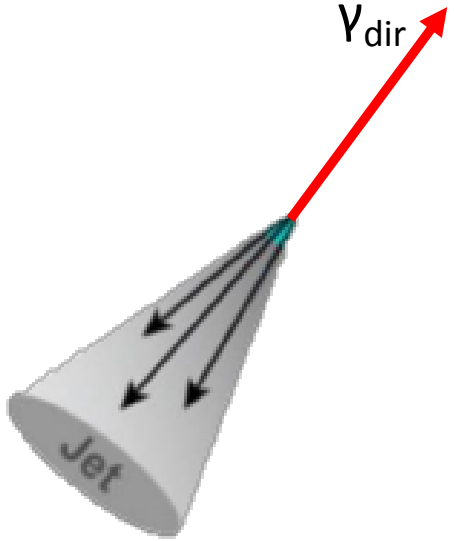


Central Yields	p_T Range
10^7 jets	> 20 GeV/c
10^6 jets	> 30 GeV/c
10^4 γ_{dir}	> 20 GeV/c
10^4 b-jets	> 20 GeV/c

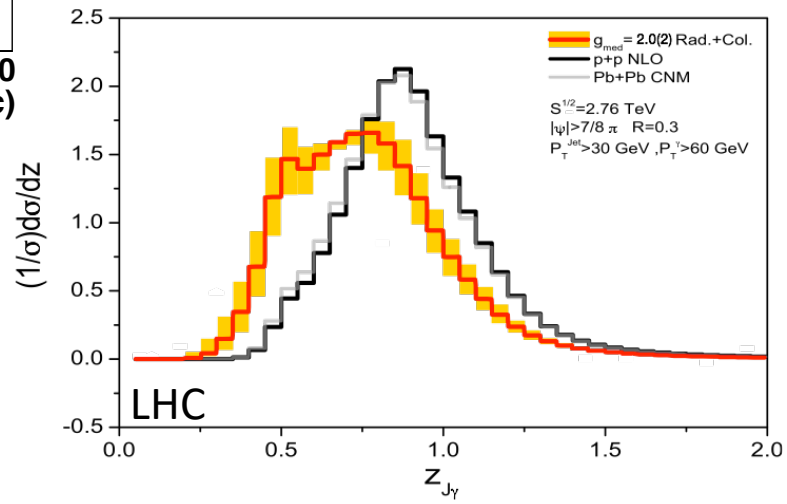
Photon-jets at RHIC

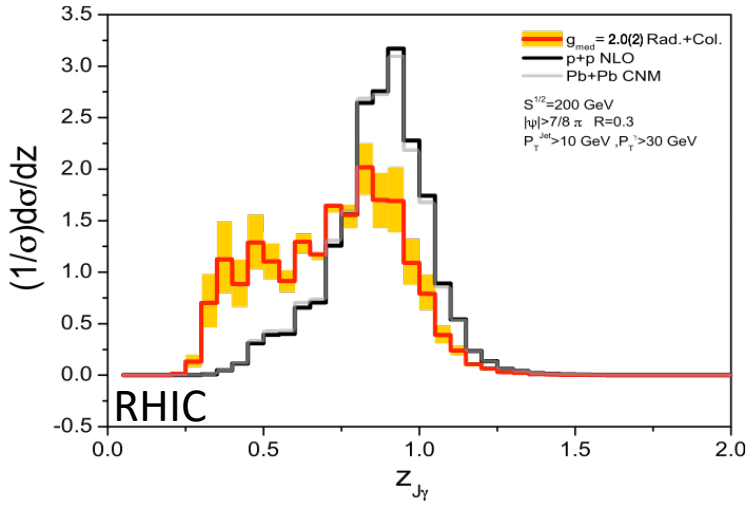


- RHIC is ideal for measuring direct photons
- $z_{J\gamma}$ may be more sensitive at RHIC

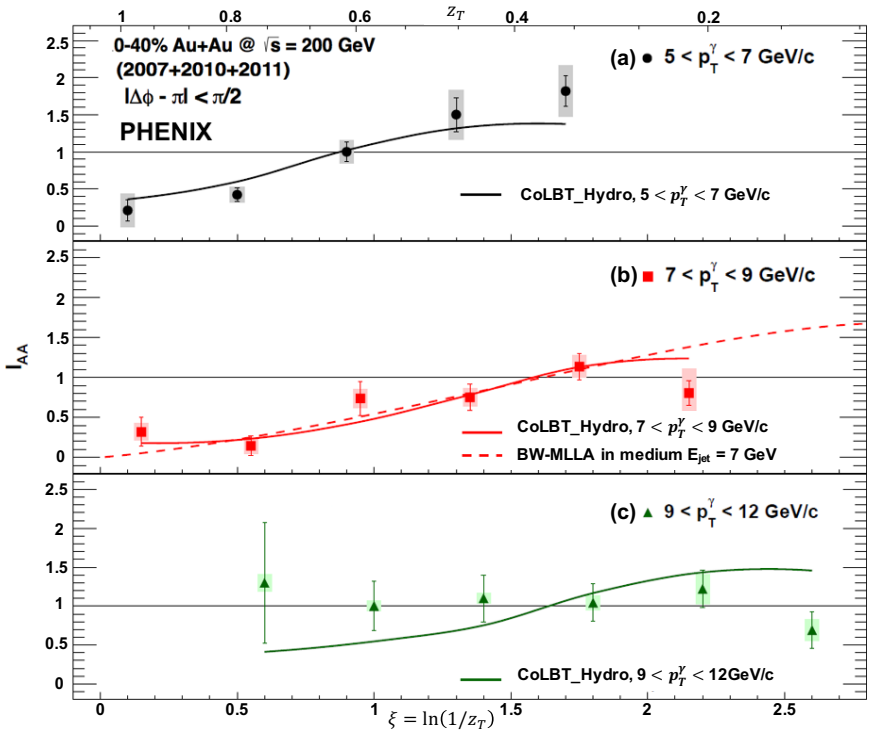


- Quark jets dominate photon tagged jet samples



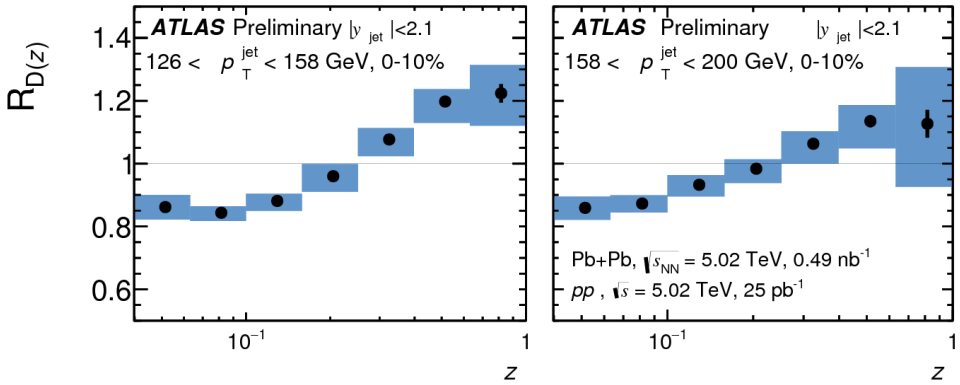


Photon-jet fragmentation functions

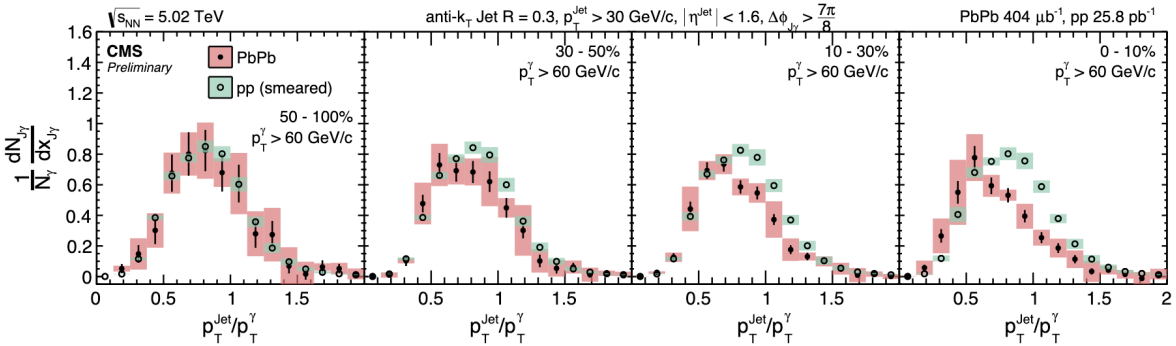


PRC 102, 054910

- Photon tags initial hard scattering kinematics $z = p_h / p^i_{jet}$
- Jet reconstructed after energy loss



$z = p_h / p^f_{jet}$



- Photon-tagged jets directly probe ΔE

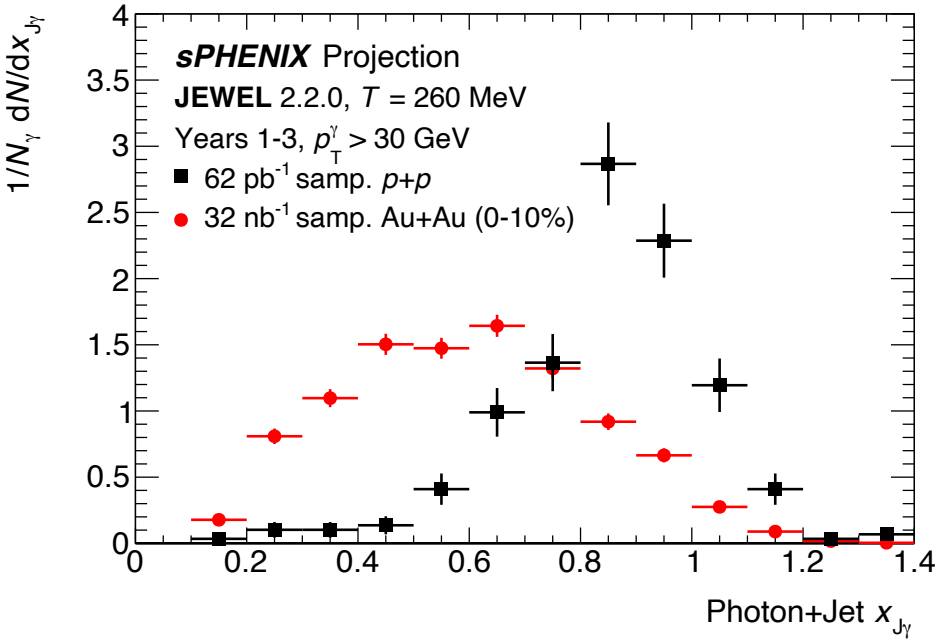
p^f_{jet} / p^i_{jet}

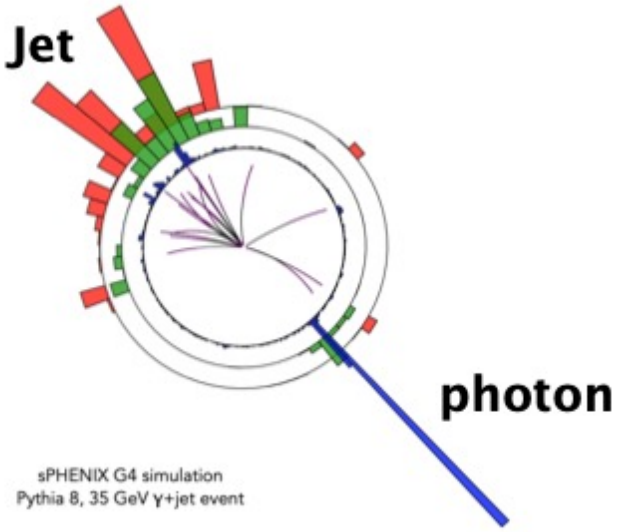
Increasing centrality

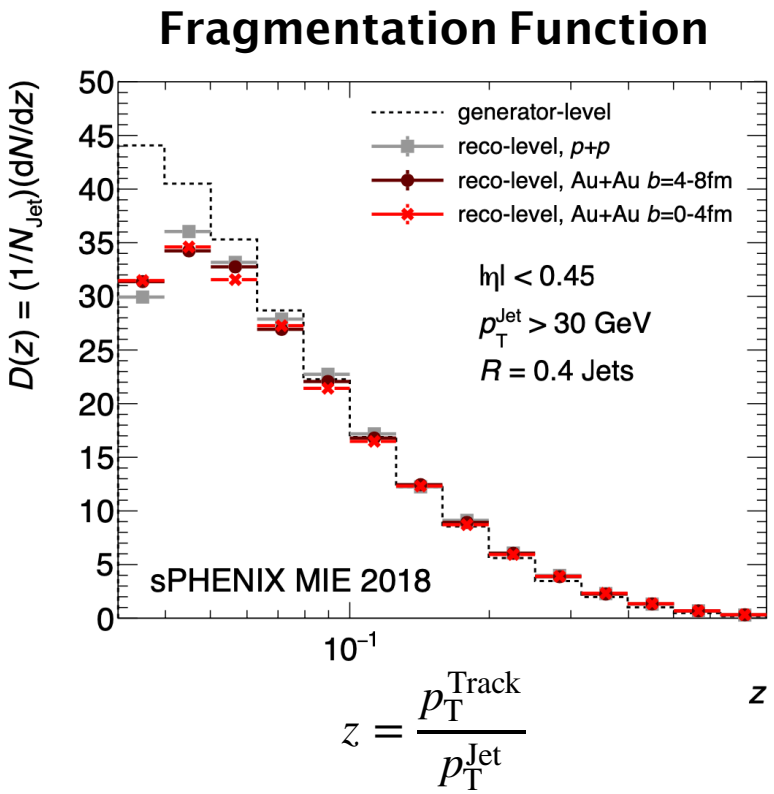
CMS-PAS-HIN-16-002

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)**



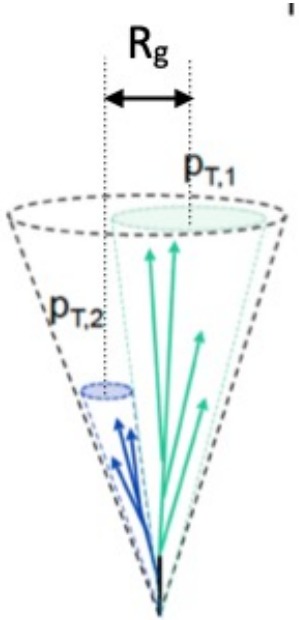


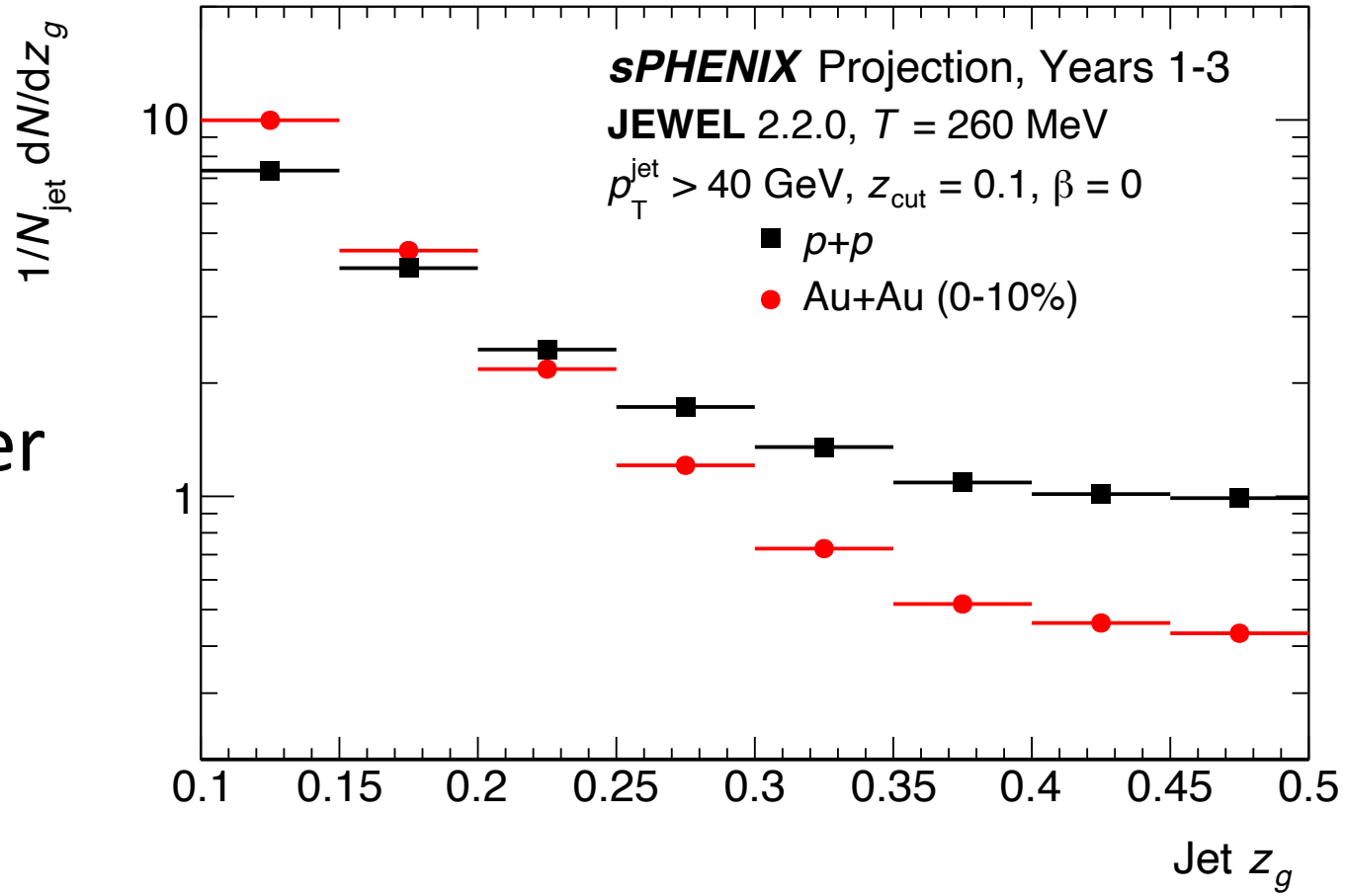


Jet Substructure

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

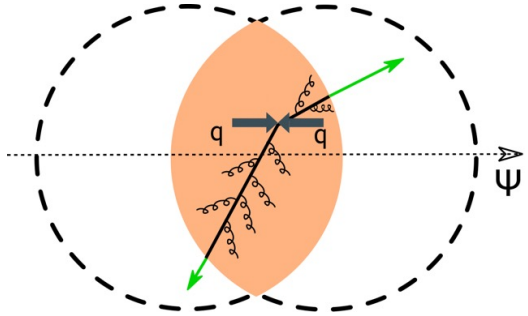
$$z_g = \frac{\min(p_{\perp,1}, p_{\perp,2})}{p_{\perp,1} + p_{\perp,2}}$$

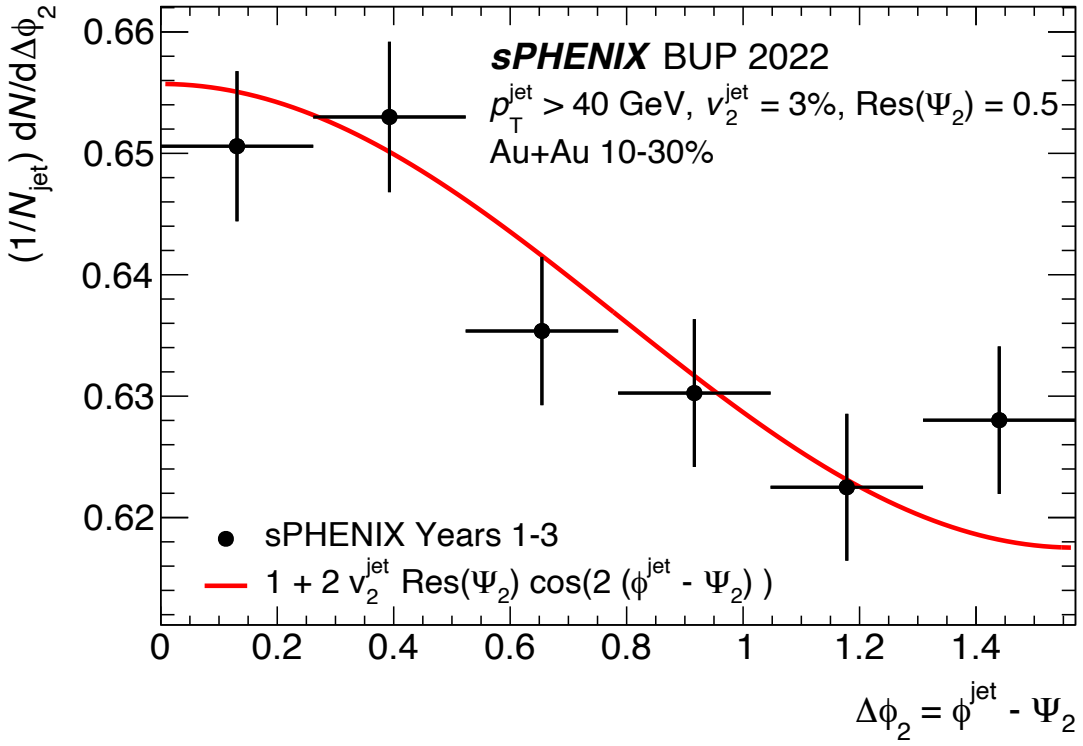


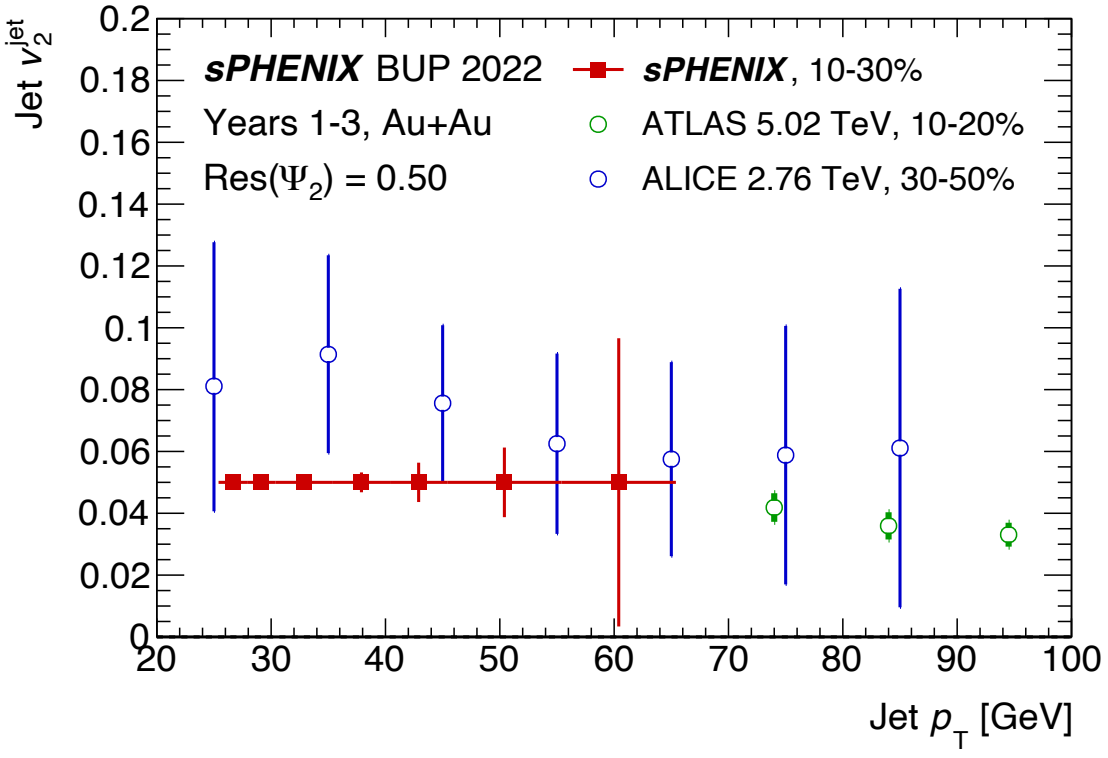


Event Plane Studies

- Event Plane Detector will improve resolutions to enable more precise jet v_2 studies
  - **Address R_{AA} v_2 puzzle in heavy ions**
  - **Jet v_2 in p+Au to deepen understanding of small systems**

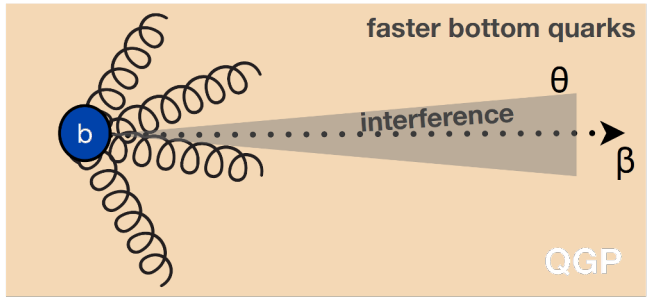


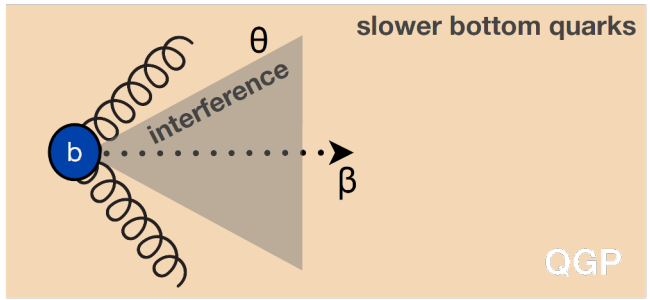


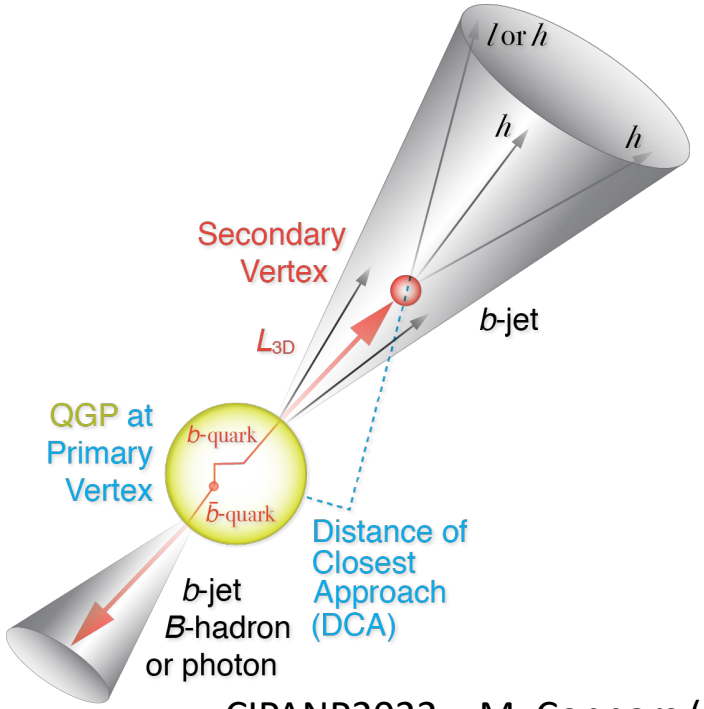


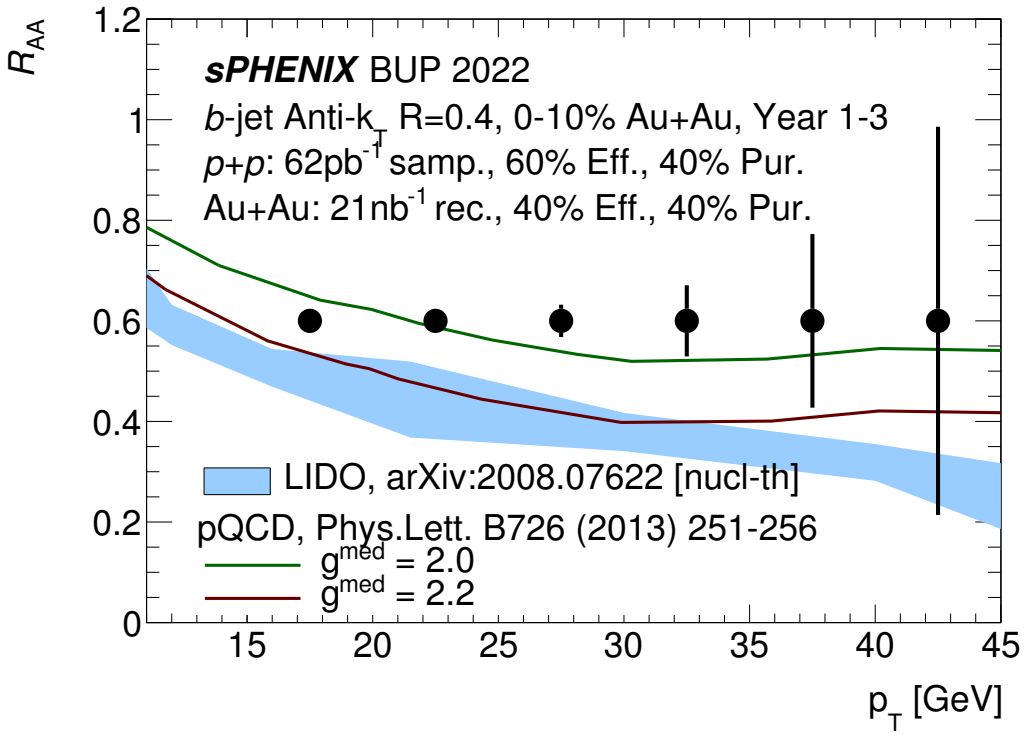
b-tagged Jets

- Sensitivity to collisional vs radiative energy loss
- First b-jet measurement at RHIC
- Complimentary to LHC jets, accessing lower p_T region with larger heavy quark mass effect.



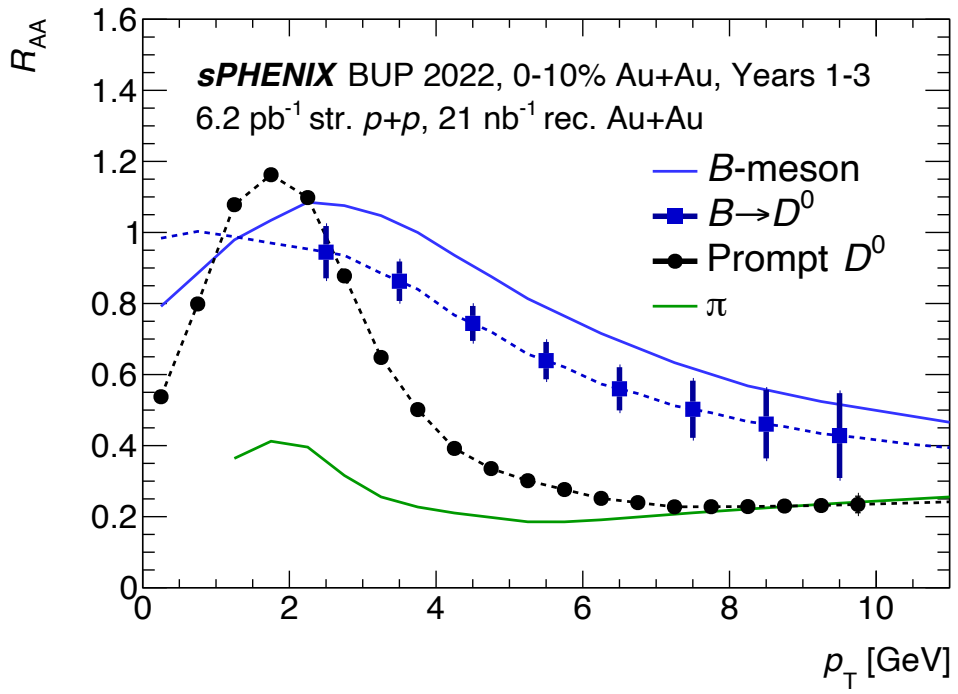


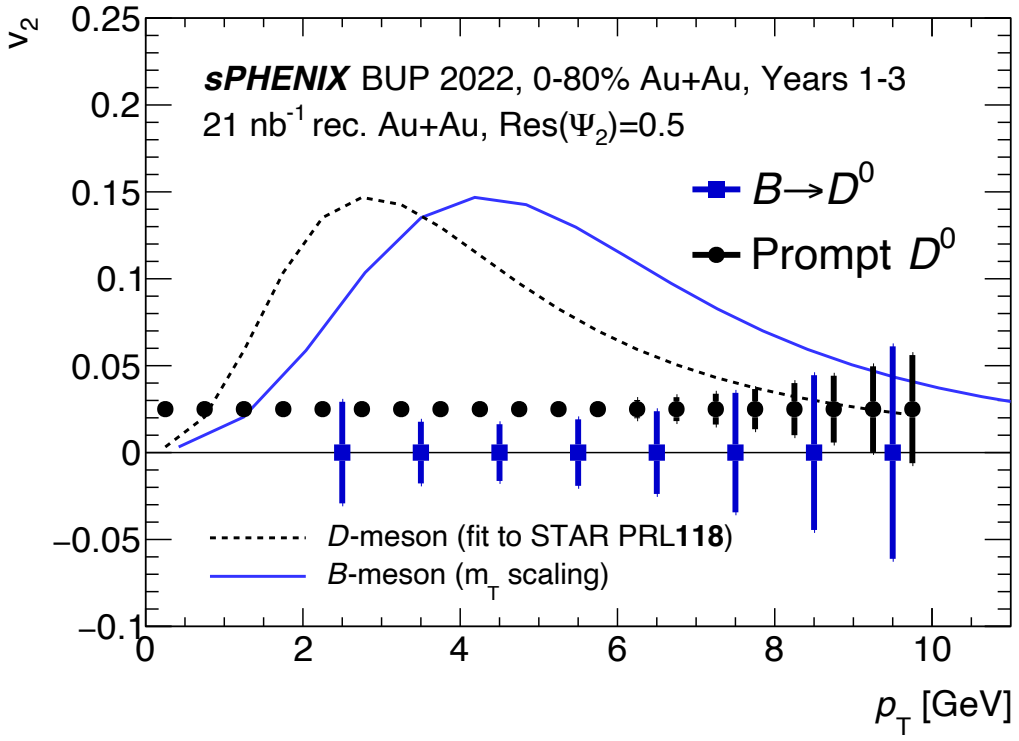




Heavy Flavor

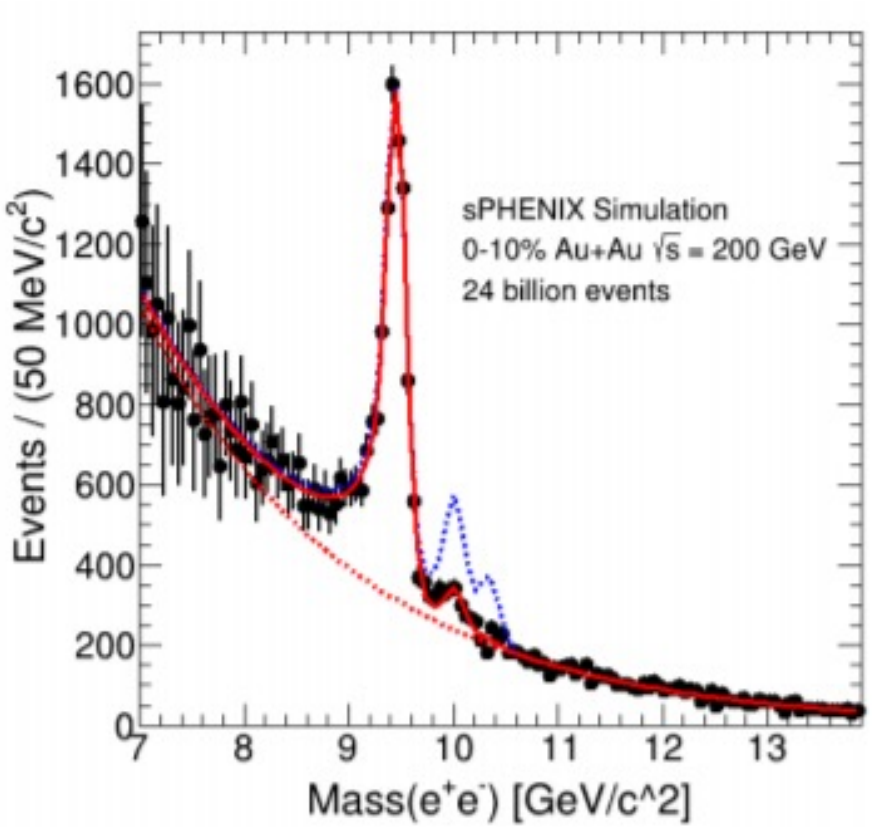
- Streaming readout enables huge MB data for unbiased HF measurements in p+p collisions
- High precision non-prompt D suppression and flow at RHIC

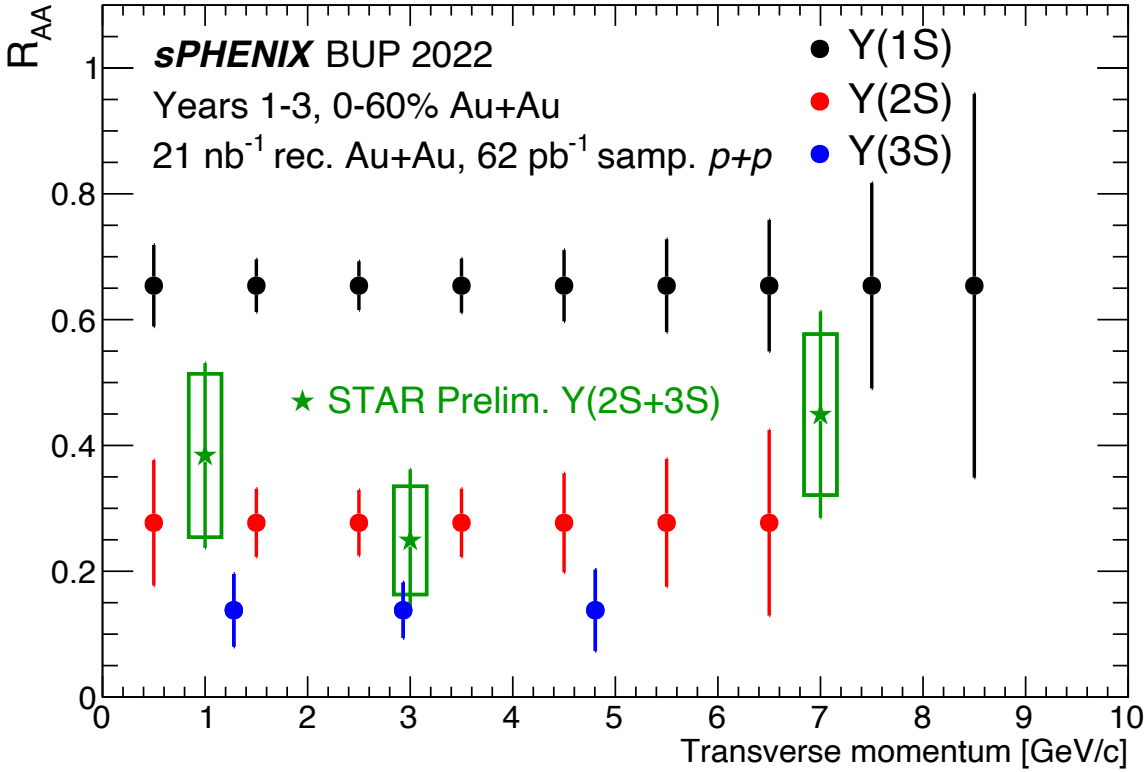




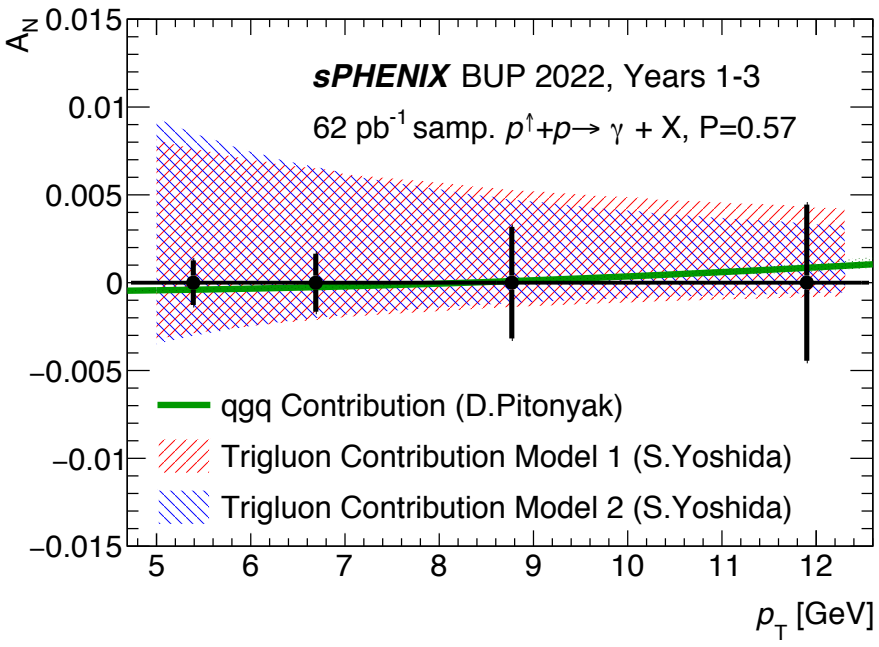
Upsilon R_{AA}

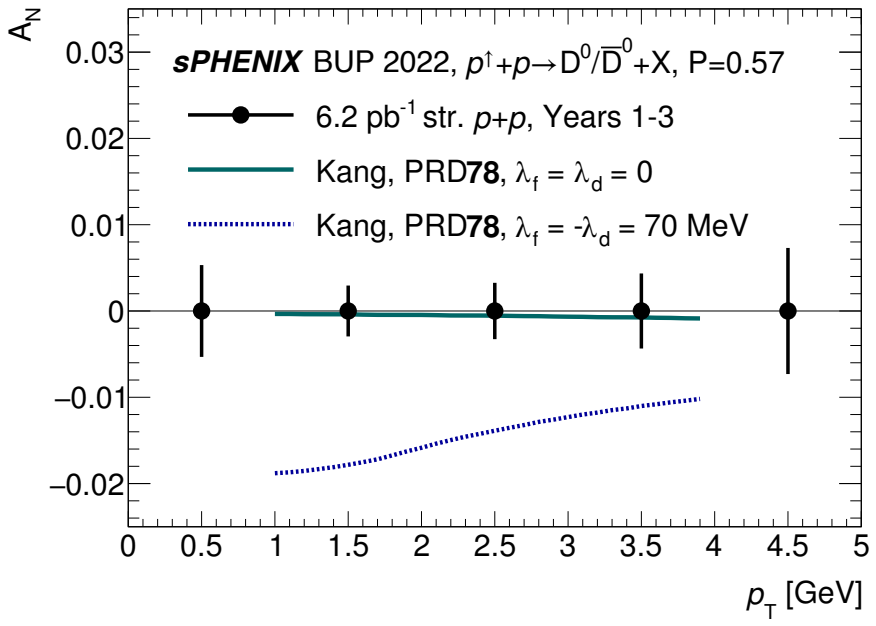
- Separate 3 Upsilon states at RHIC
- Potential to discover Υ(3S) suppression at RHIC



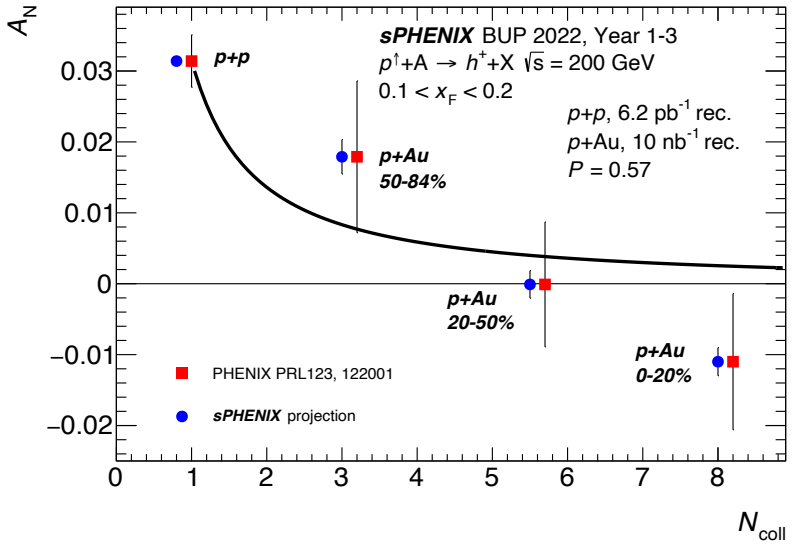


Cold QCD Studies





- Transverse Single Spin Asymmetry (TSSA) via prompt photons and D^0

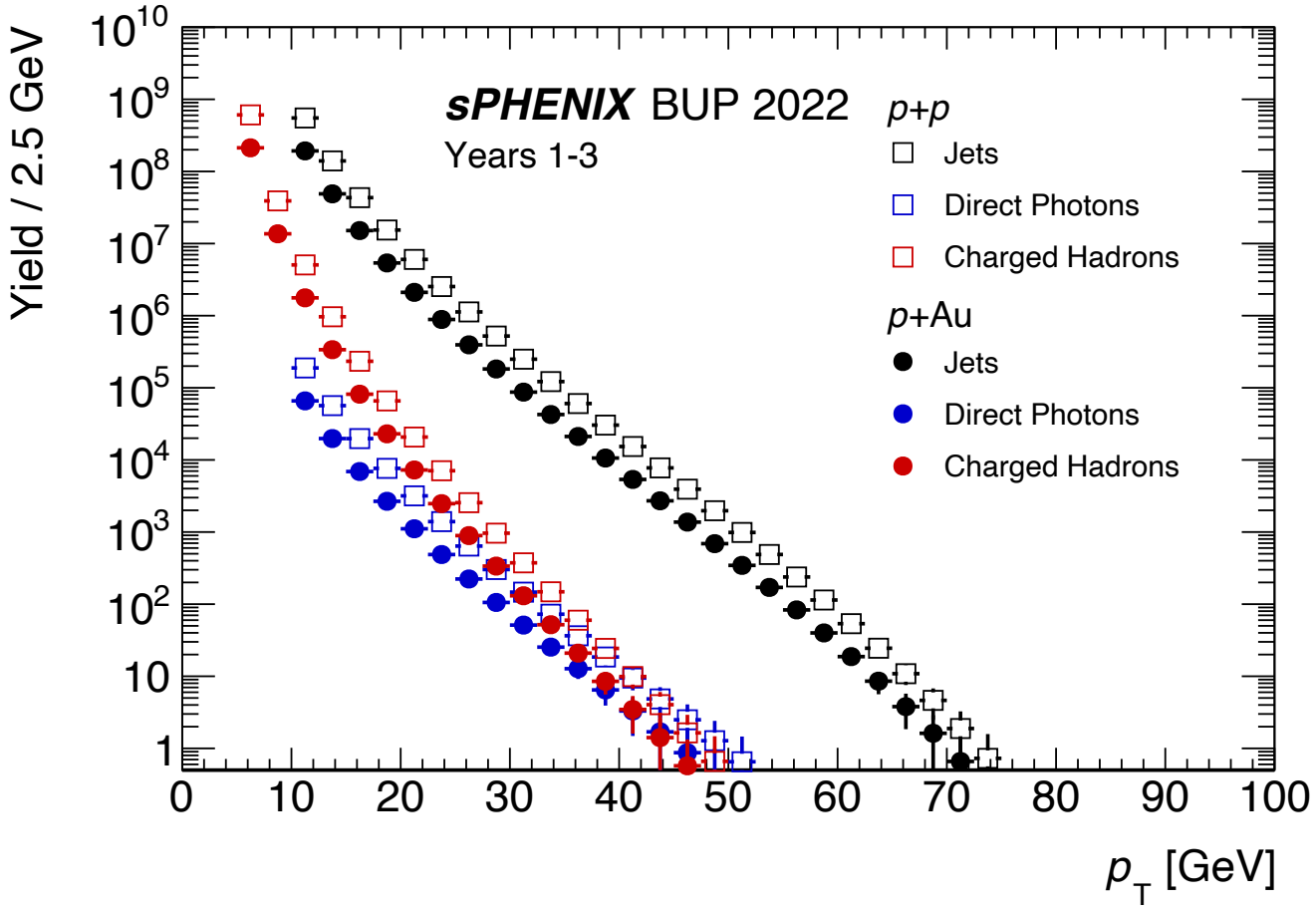


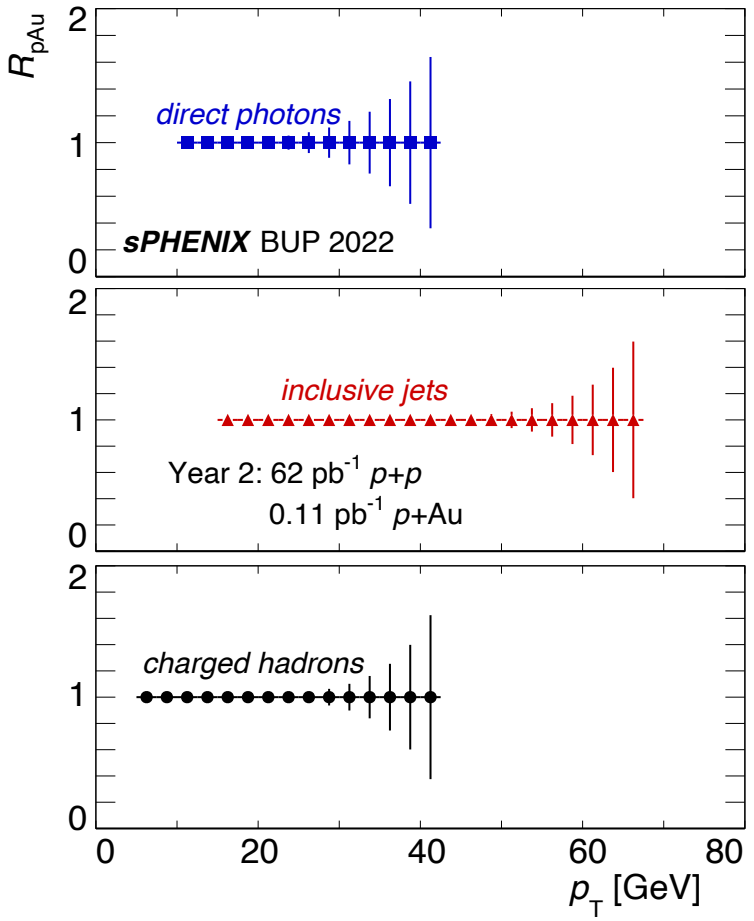
- Nuclear dependence of TSSA for hadrons
- Improved precision from previous PHENIX measurement

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

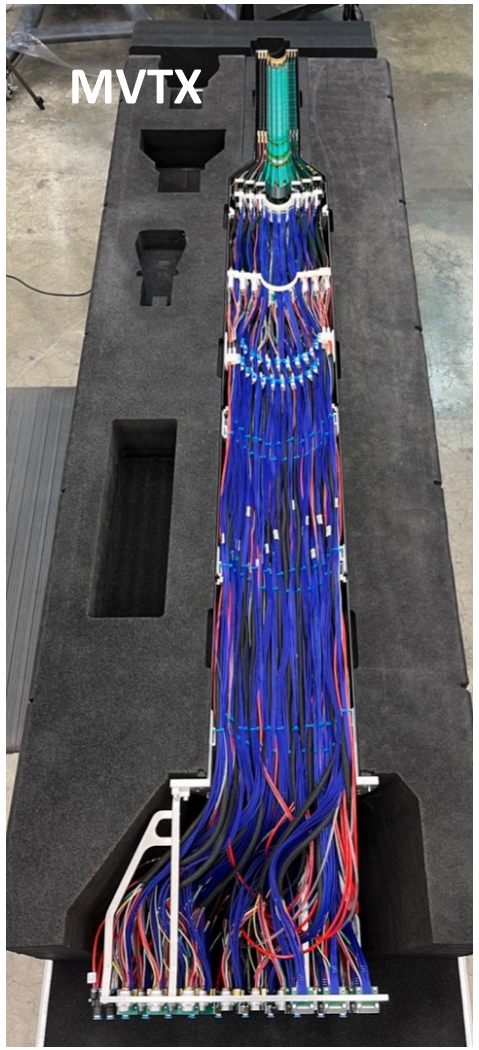


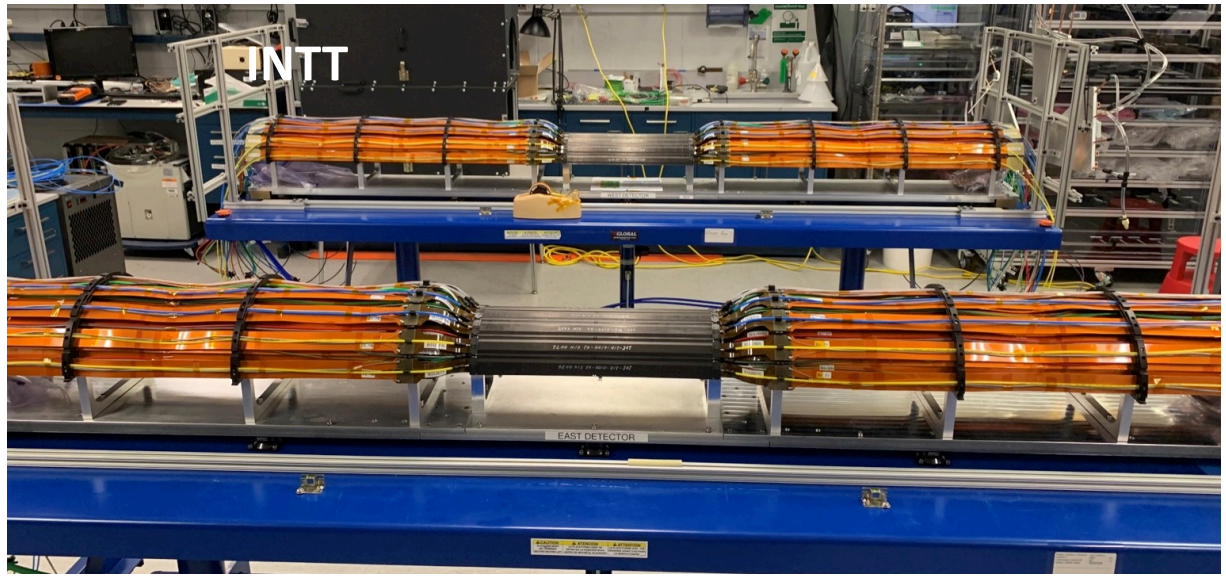


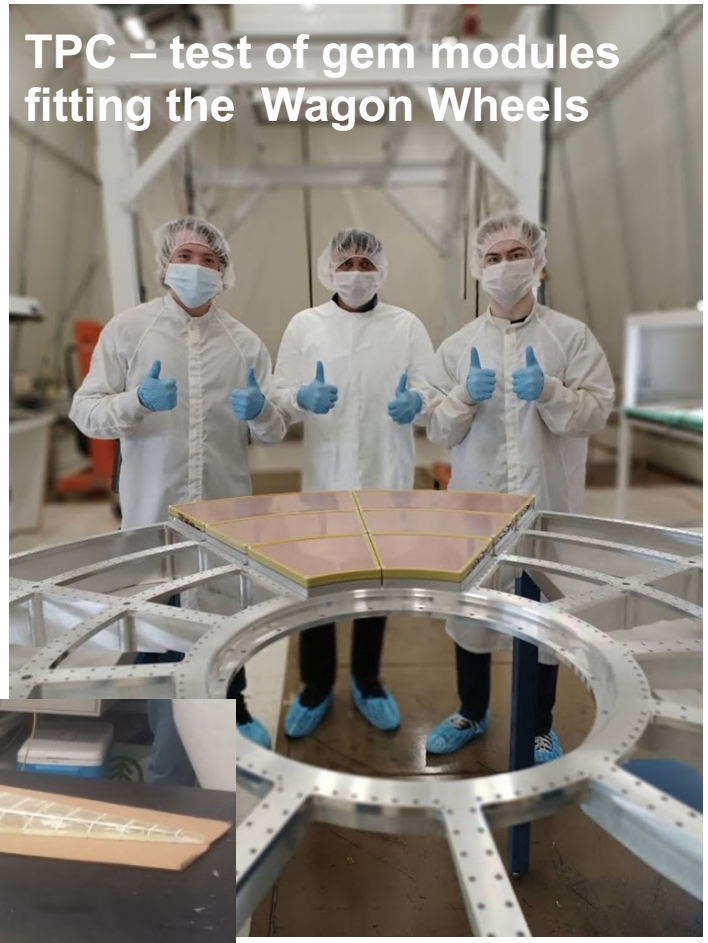
From Projections to Measurements

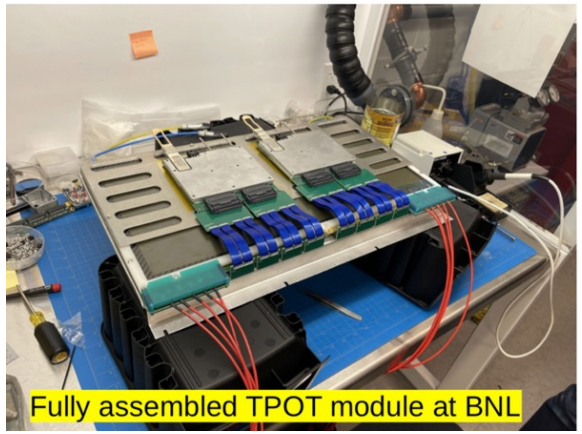
- Outer Hcal installed
- Magnet installed
- Inner Hcal installed
- Emcal installation underway

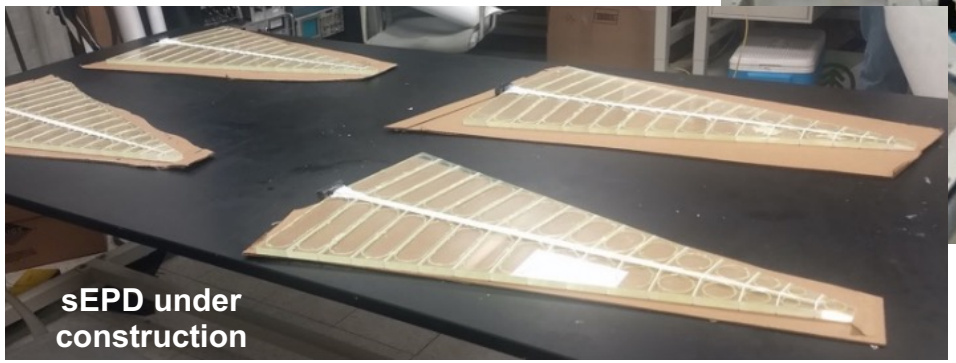
sPHENIX Construction











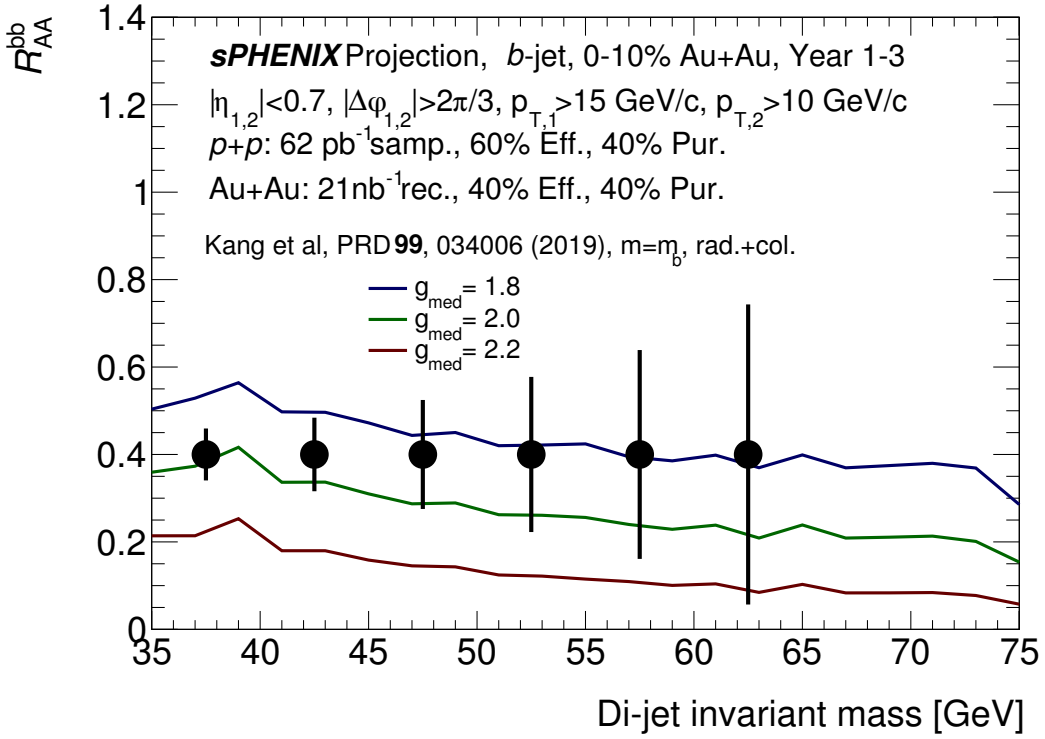
Summary

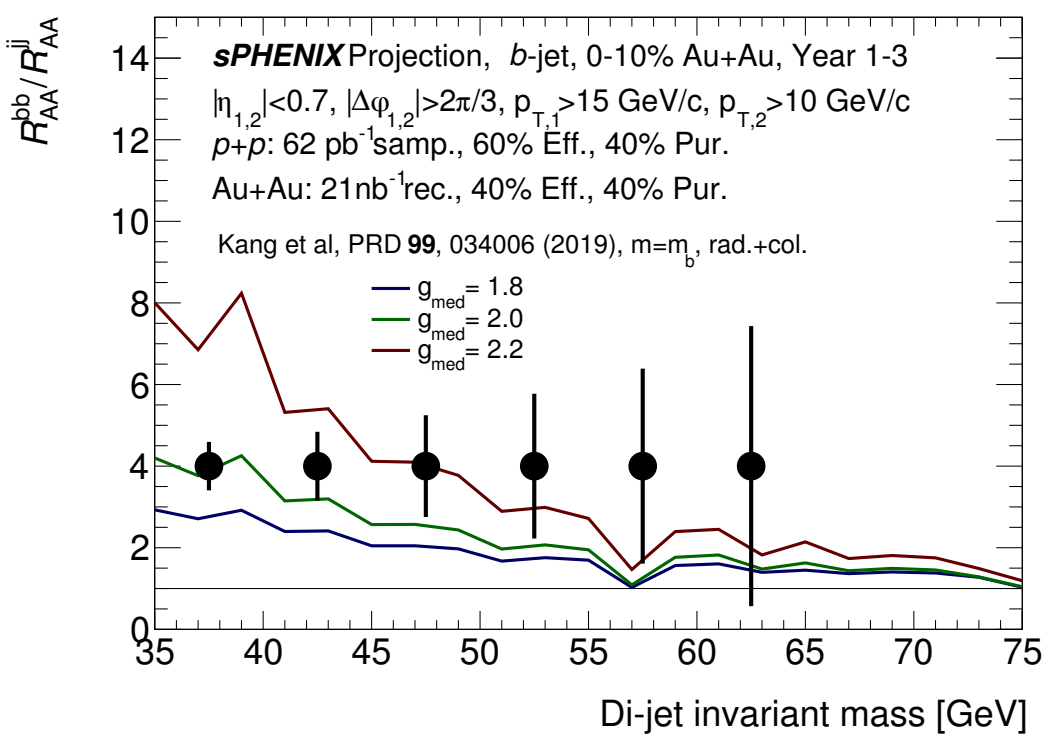
- sPHENIX will usher in new suite of precise jet, heavy flavor, quarkonia measurements probing the QGP and cold nuclear matter at RHIC
- sPHENIX will provide an overlap of kinematic reach between RHIC & LHC to further constrain theoretical models
- sPHENIX is on schedule to start data collection in 2023!

Back up Slides

b-jet Projections

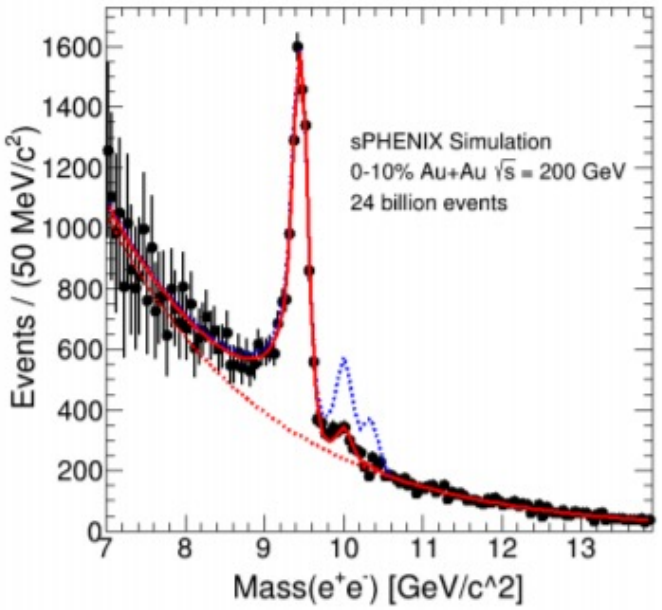
- sPHENIX b-tagged di-jets compared to calculations from $SCET_{MG}$ framework
  - **Precision capable of constraining medium coupling**

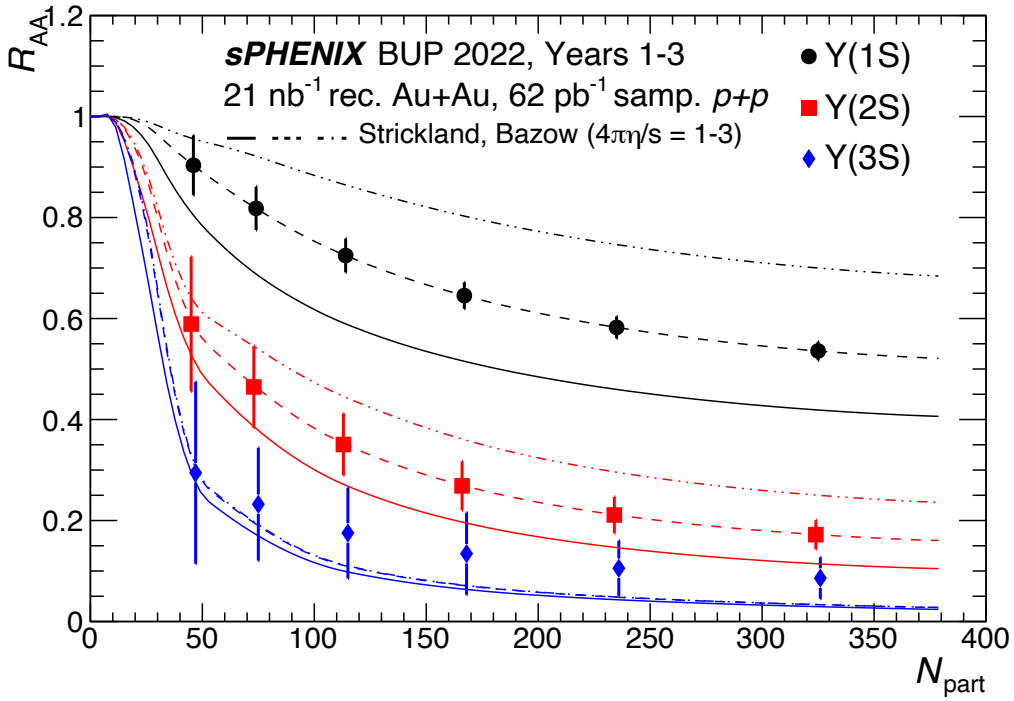


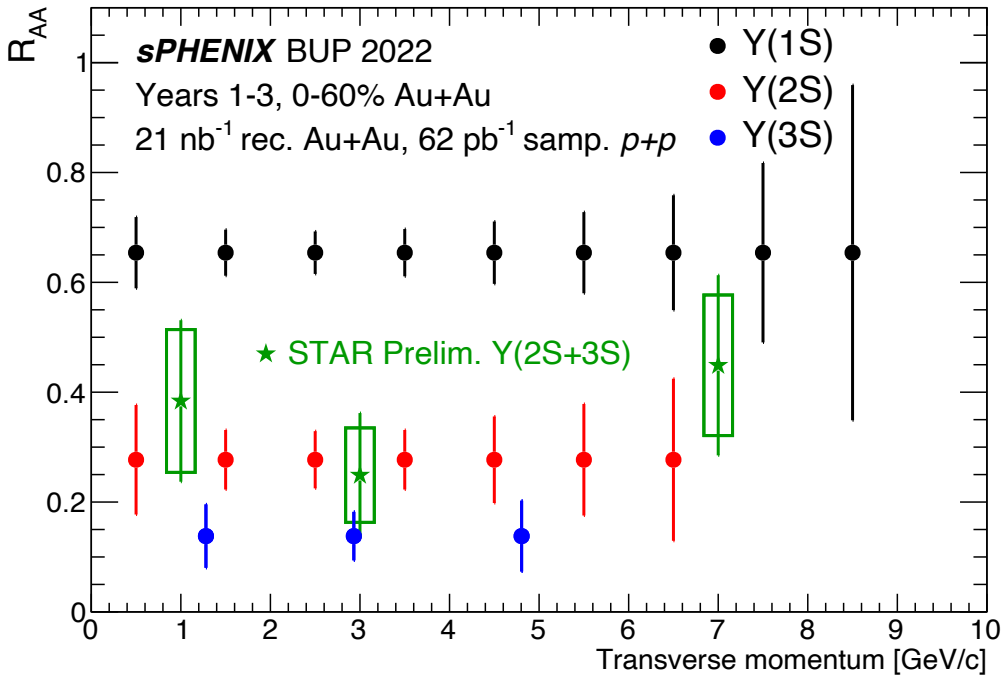


Upsilon R_{AA}

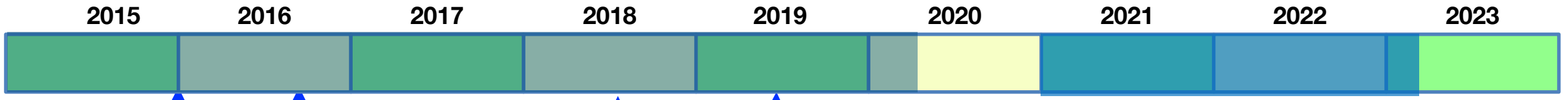
- Separate 3 Upsilon states at RHIC
- Potential to discover Υ(3S) suppression at RHIC

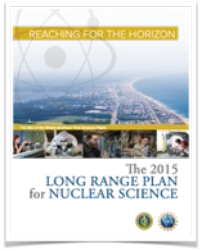






sPHENIX Timeline





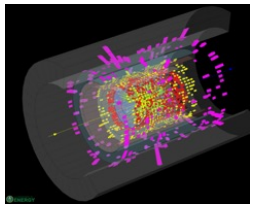
sPHENIX science collaboration

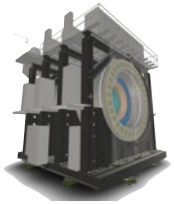
DOE CD-0 "Mission need" approval

DOE CD-1/3A Cost, schedule, advance purchase approval

BNL PD-2/3 Final project design approval

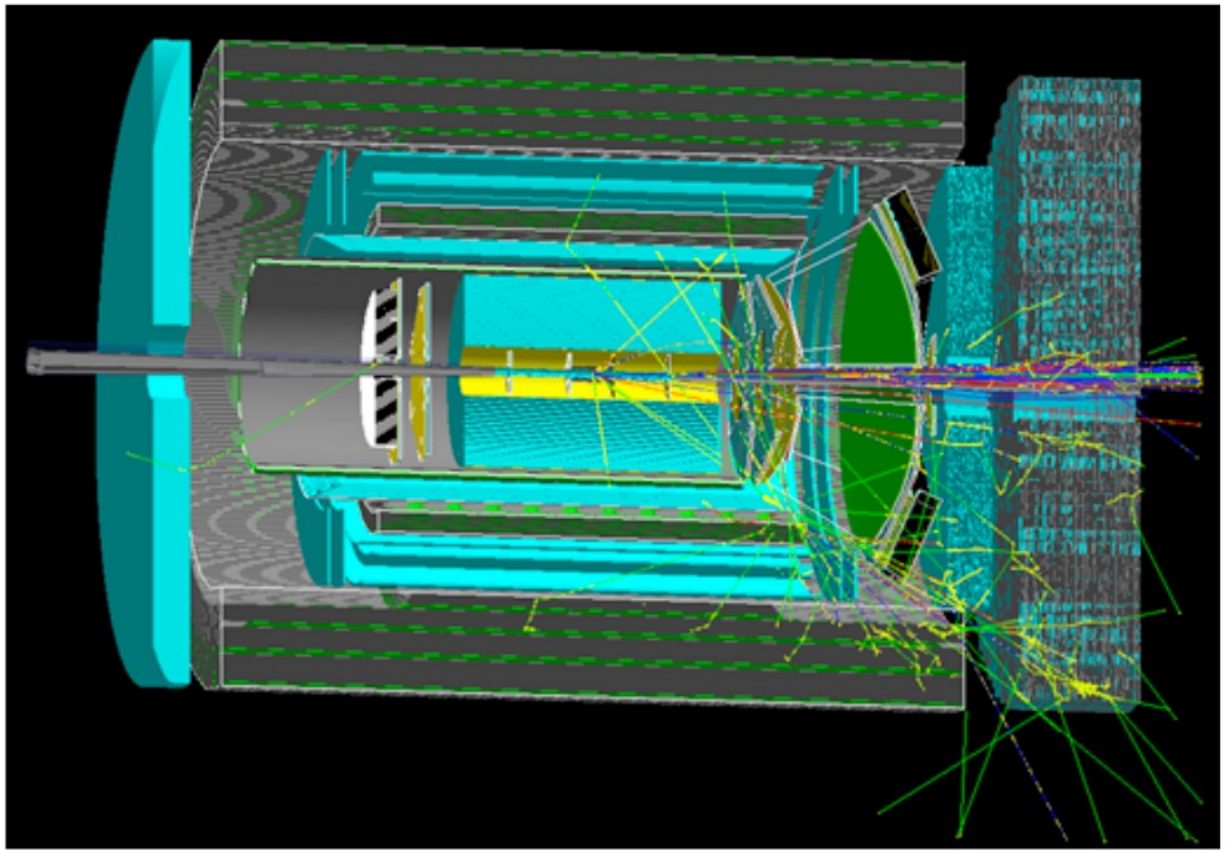
Installation & commissioning



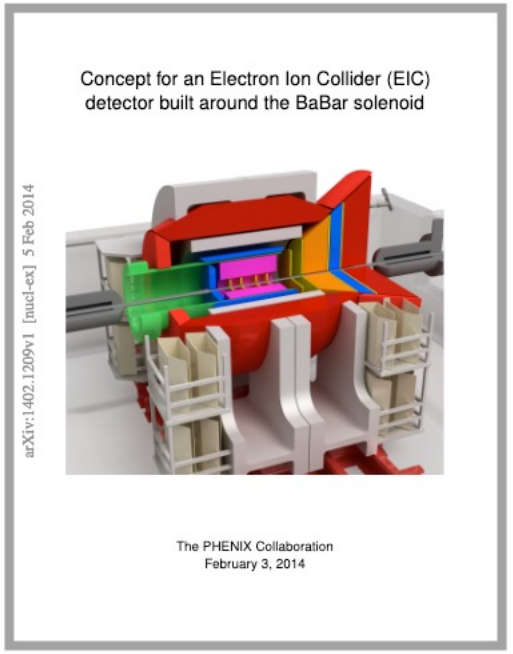


sPHENIX → data taking in early 2023

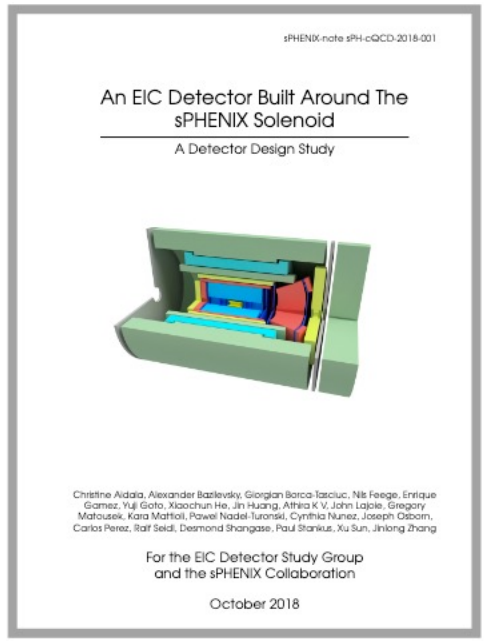
From RHIC to EIC



G4 Simulation, DIS *e+p* event @ 18 on 275 GeV,
25mrad crossing, x ~ 0.5, Q^2 ~ 5000 GeV^2



2014 white paper



2018 design study

EPIC

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. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <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}