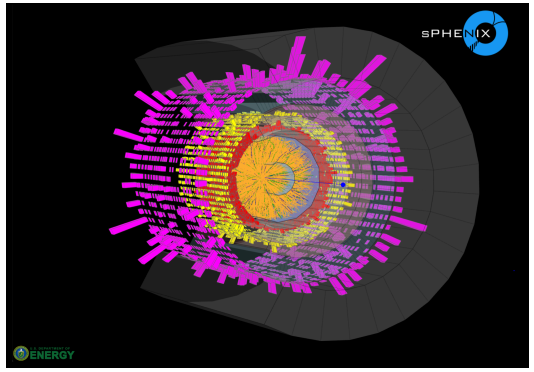
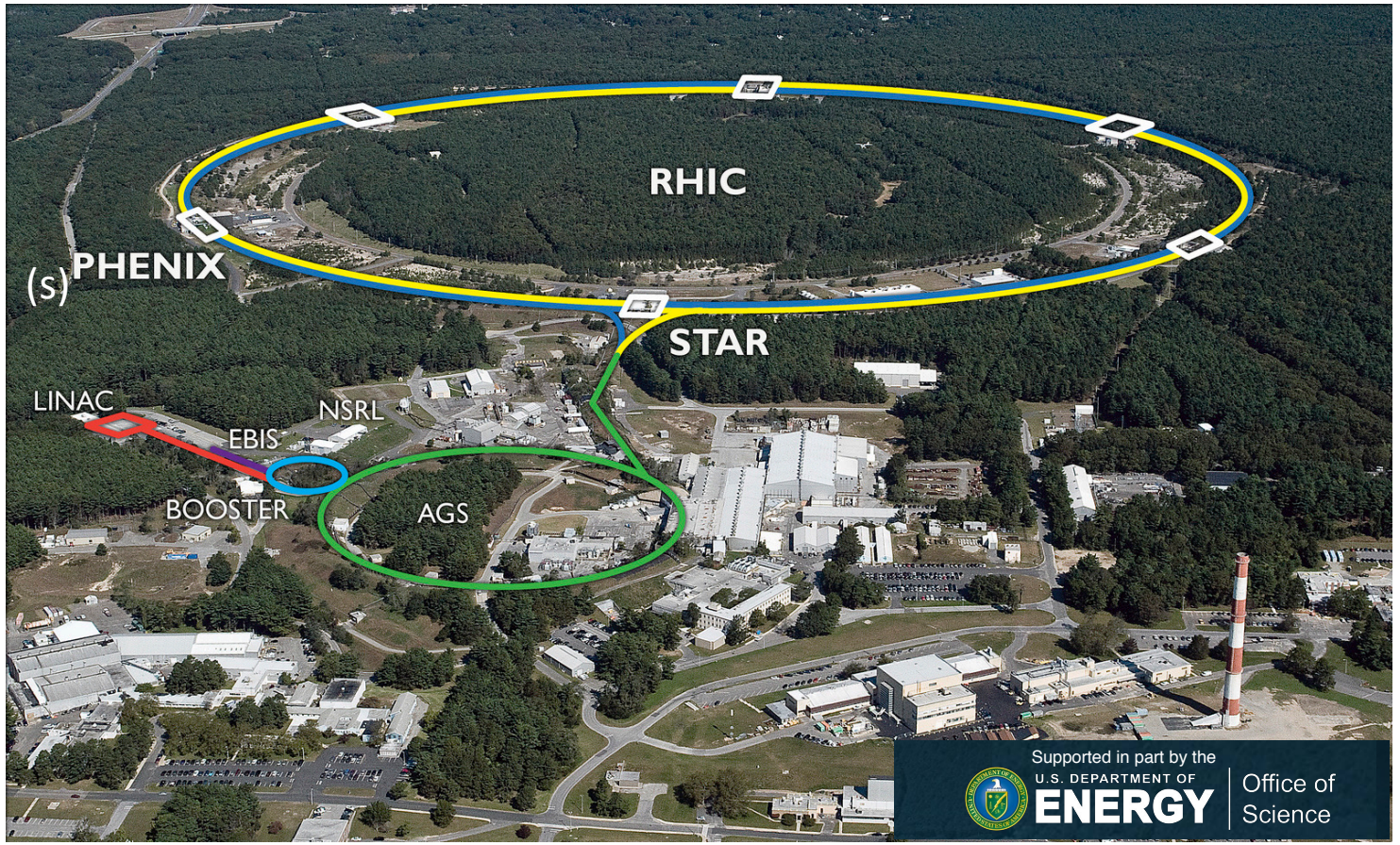
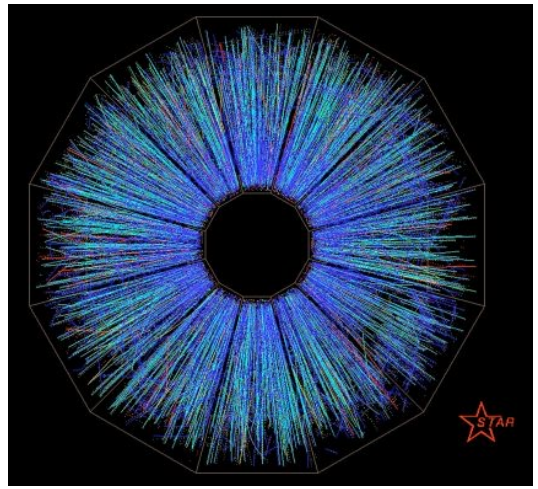
RHIC Highlights and Future I







Georgia State University

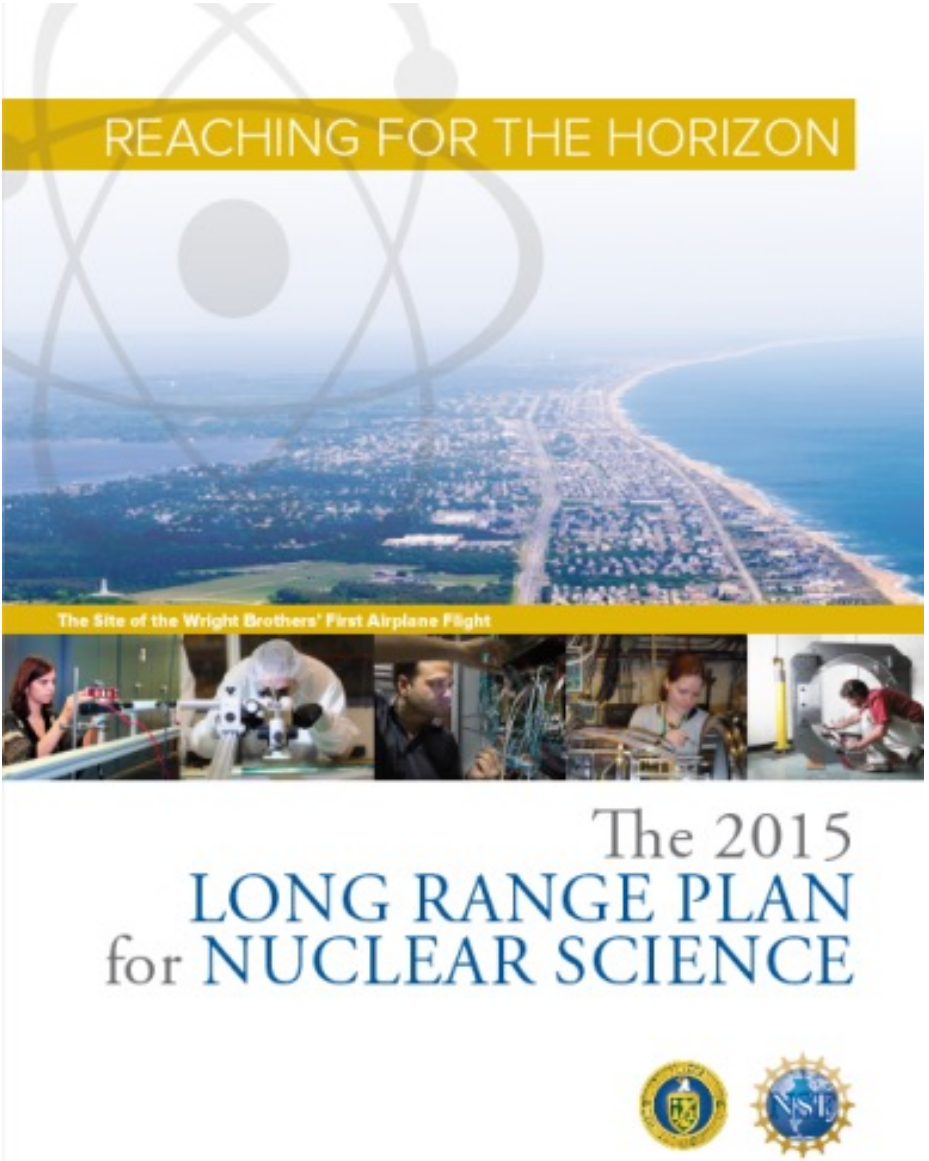
Megan Connors (GSU)

2022 Town Hall Meeting on Hot & Cold QCD

September 22, 2022

NSF

Recommendations in 2015 LRP: RHIC



RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

- *With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized.*
- *Expeditiously completing the Facility for Rare Isotope Beams (FRIB) construction is essential. Initiating its scientific program will revolutionize our understanding of nuclei and their role in the cosmos.*
- *The targeted program of fundamental symmetries and neutrino research that opens new doors to physics beyond the Standard Model must be sustained.*
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

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.**

RHIC is the only facility in the world designed specifically to create and study the QGP

Recommendations in 2015 LRP: RHIC

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This talk will focus on hard probes (1)

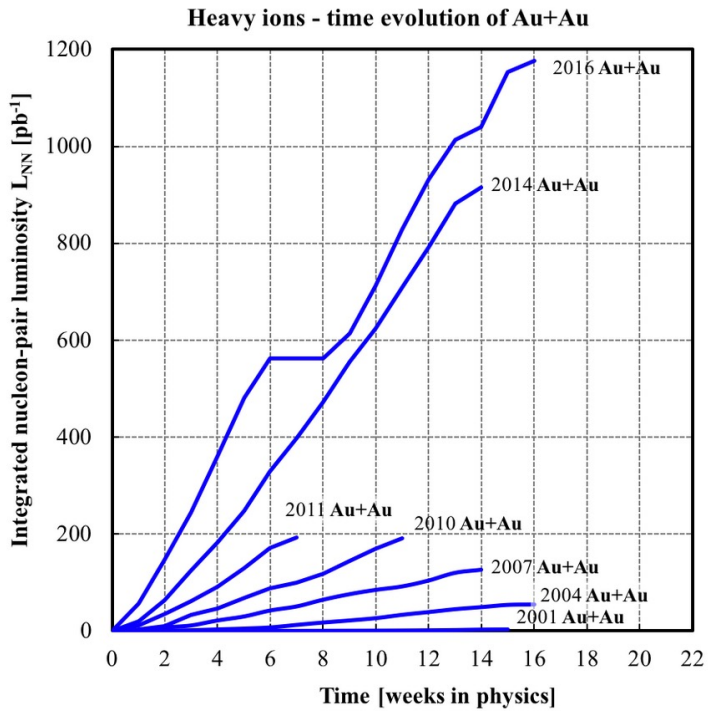
See talk RHIC Highlights/Future II by Prithwish Tribedy for (2)

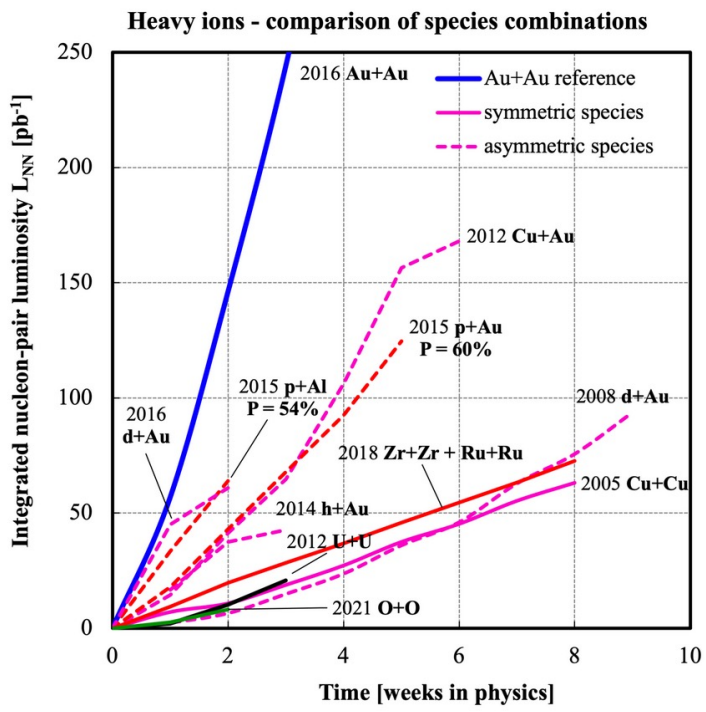
RHIC is the only facility in the world designed specifically to create and study the QGP

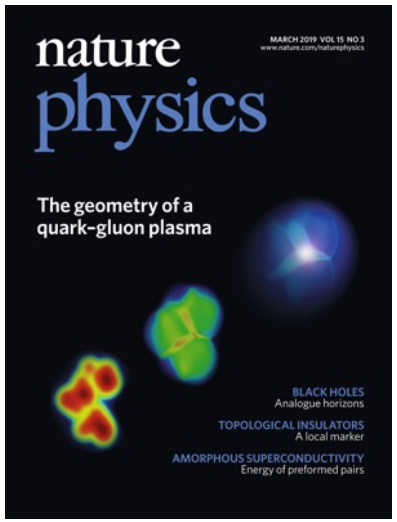
Some RHIC Highlights Since 2015

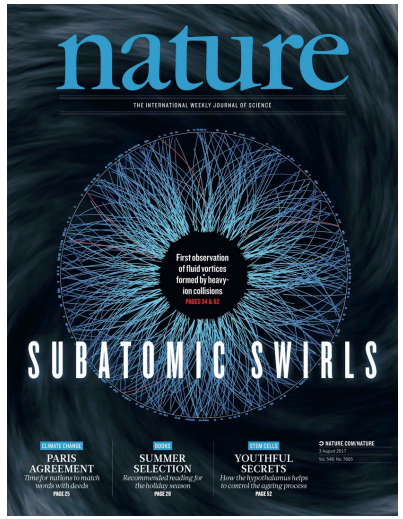
- ✓ Run 2016:
  - **dAu energy scan**
  - **Last Run for PHENIX**
- ✓ Isobar Runs
- ✓ Beam Energy Scan II
- ✓ sPHENIX construction

RHIC: Increased luminosity and versatility of collision species







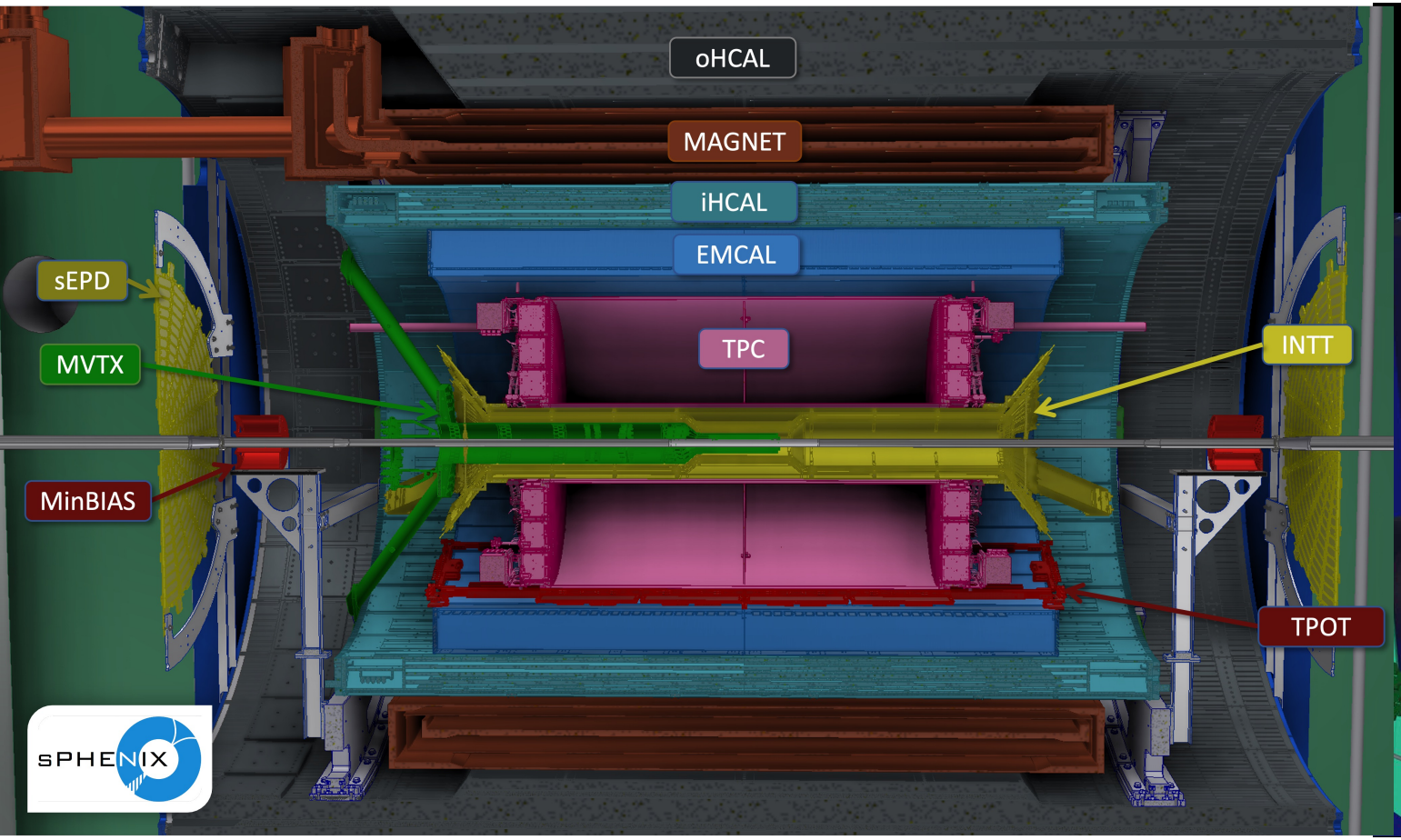


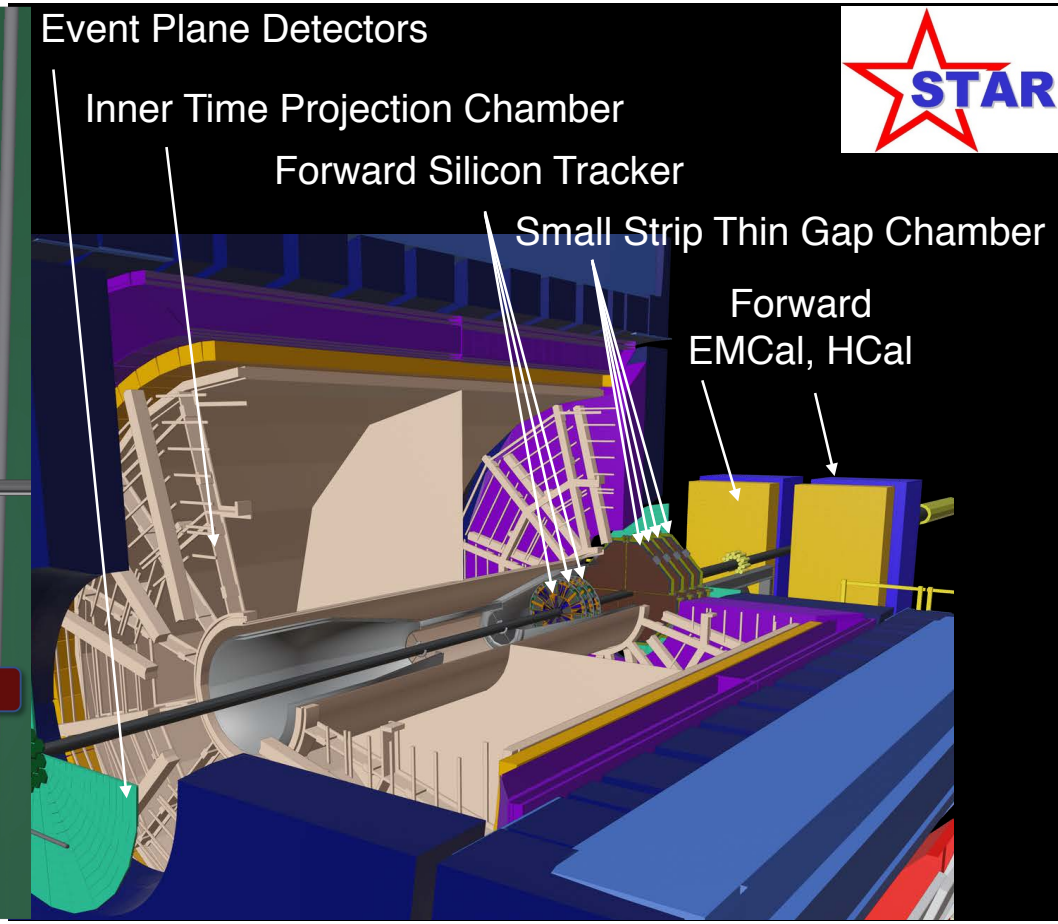
Impactful physics results

Plots/slides in this presentation denoted by experimental logos:

sPHENIX PHENIX STAR

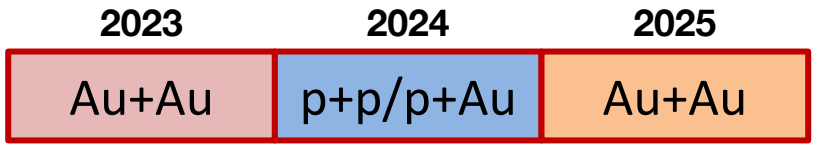
RHIC Detectors in 2023





RHIC Run Plan 2023-2025

Year	Species	$\sqrt{s_{NN}}$ (GeV)	Cryo Weeks	sPHENIX $\mathcal{L}_{samp}$ (|z|<10 cm)	STAR $\mathcal{L}_{samp}$
2023	Au+Au	200	28	6.9 nb^{-1}	20 nb^{-1}
2024	p+p	200	28	62 pb^{-1}	235 pb^{-1}
	p+Au	200		0.11 pb^{-1}	1.3 pb^{-1}
2025	Au+Au	200	28	25 nb^{-1}	20 nb^{-1}



Commissioning and calibration

Reference for HI measurements
Cold QCD measurements

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."

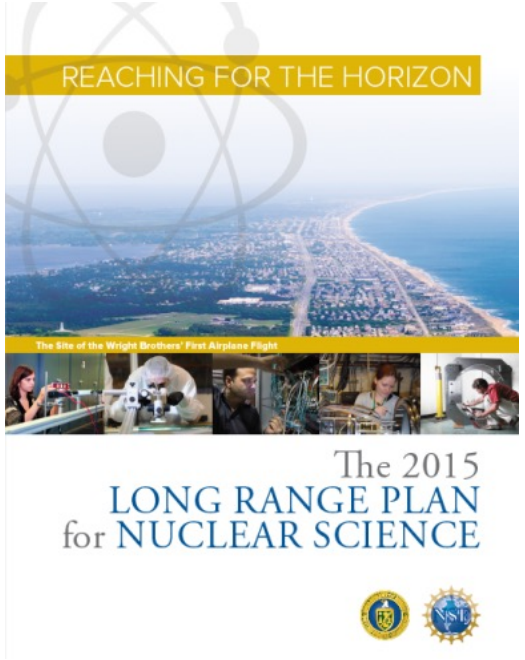
STAR Beam Use Report

sPHENIX Beam Use Proposal

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

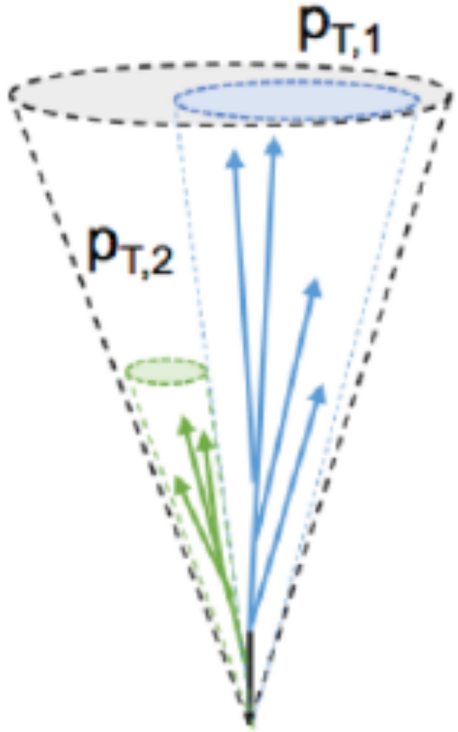
PAC Recommendations: https://www.bnl.gov/npp/docs/2022-npp-pac-recommendations-final.pdf

Probe QGP at Multiple Scales

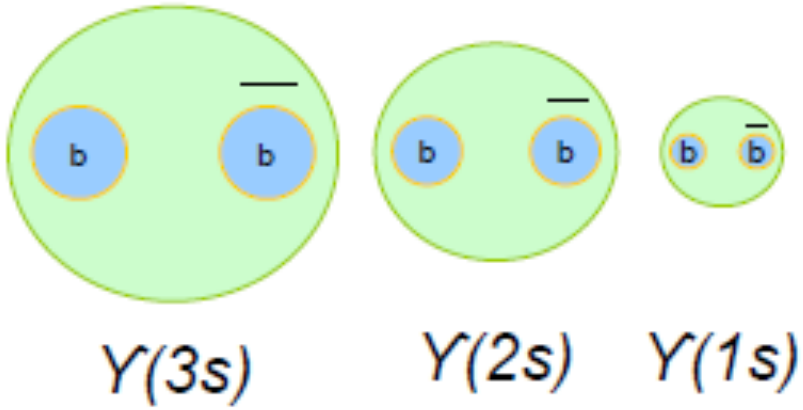


New instrumentation at RHIC in the form of a state-of-the-art jet detector (referred to as sPHENIX) is required to provide the highest statistics for imaging the QGP right in the region of strongest coupling (most perfect fluidity) while also extending the kinematic reach at RHIC (as illustrated in Figure 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.

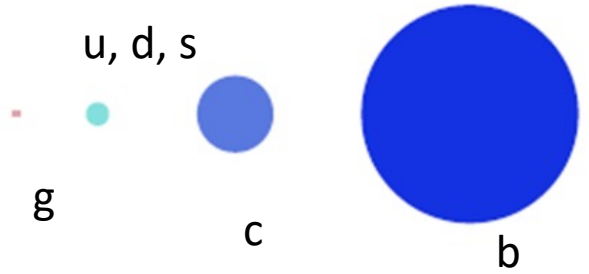
sPHENIX



Jet structure
Vary momentum/angular scale of probe

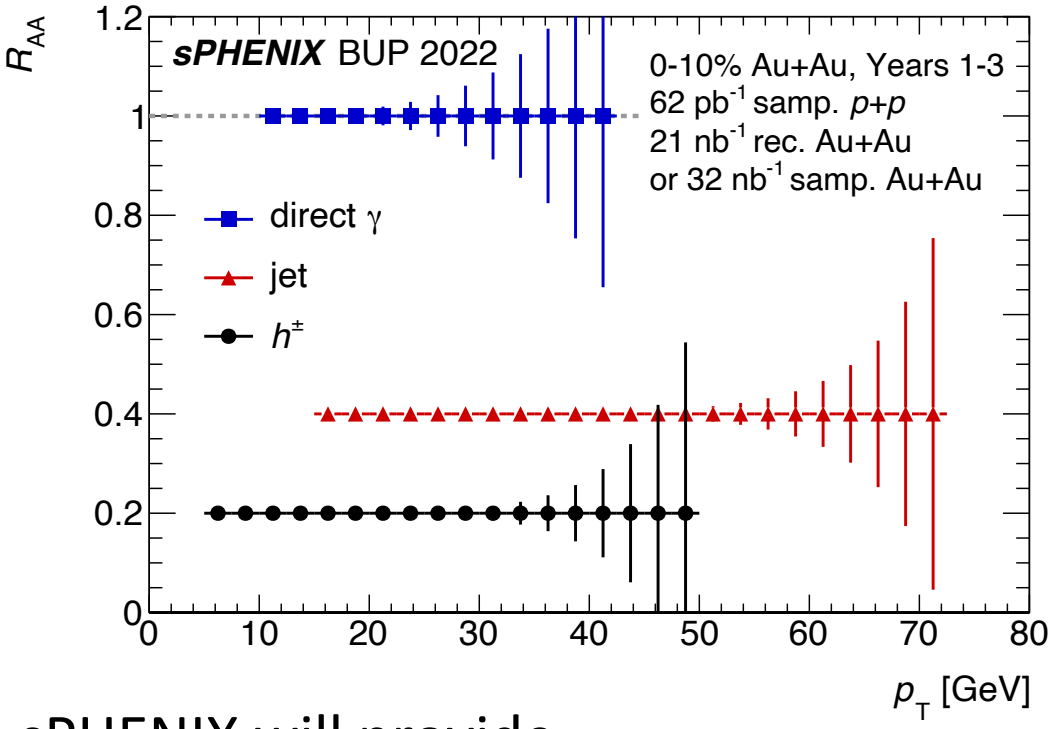


Quarkonium spectroscopy
vary size of probe



Parton energy loss
vary mass/momentum of probe

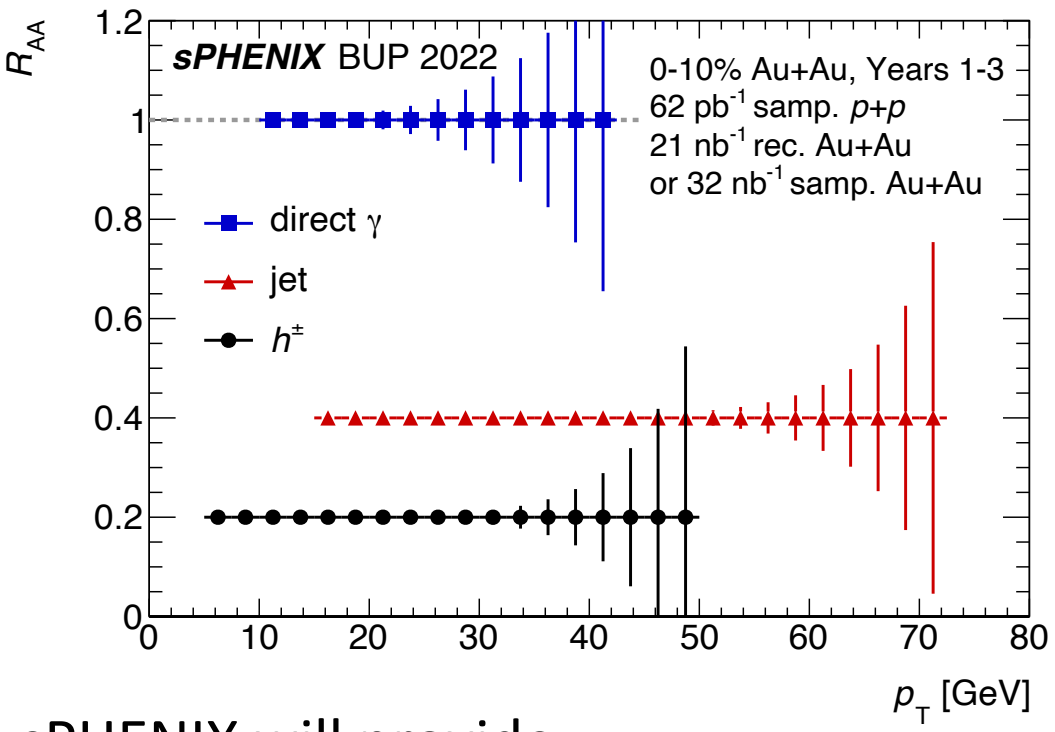
Kinematic Reach

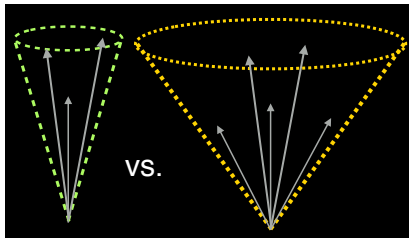


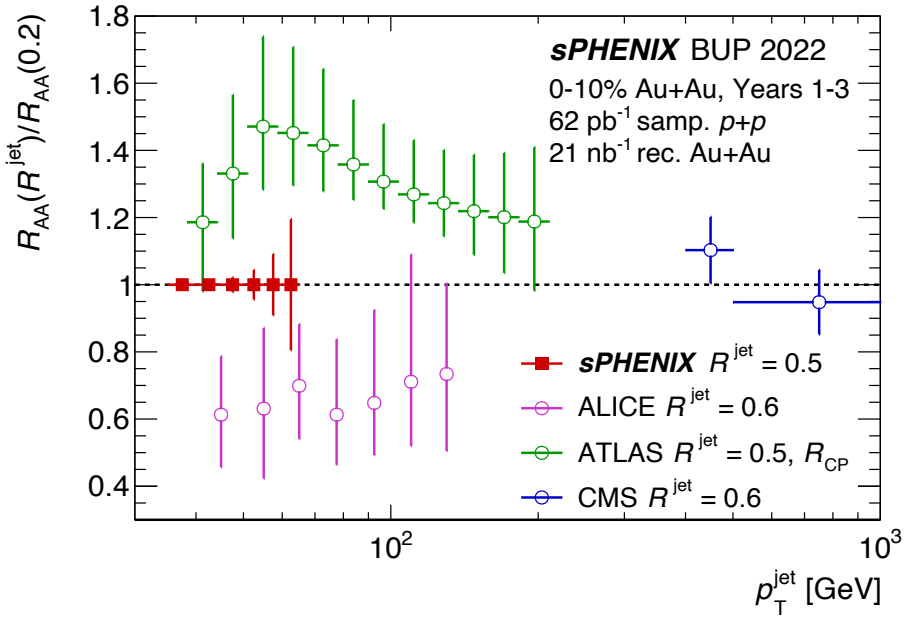
sPHENIX will provide

- significant extension in kinematics and overlap with LHC

Kinematic Reach



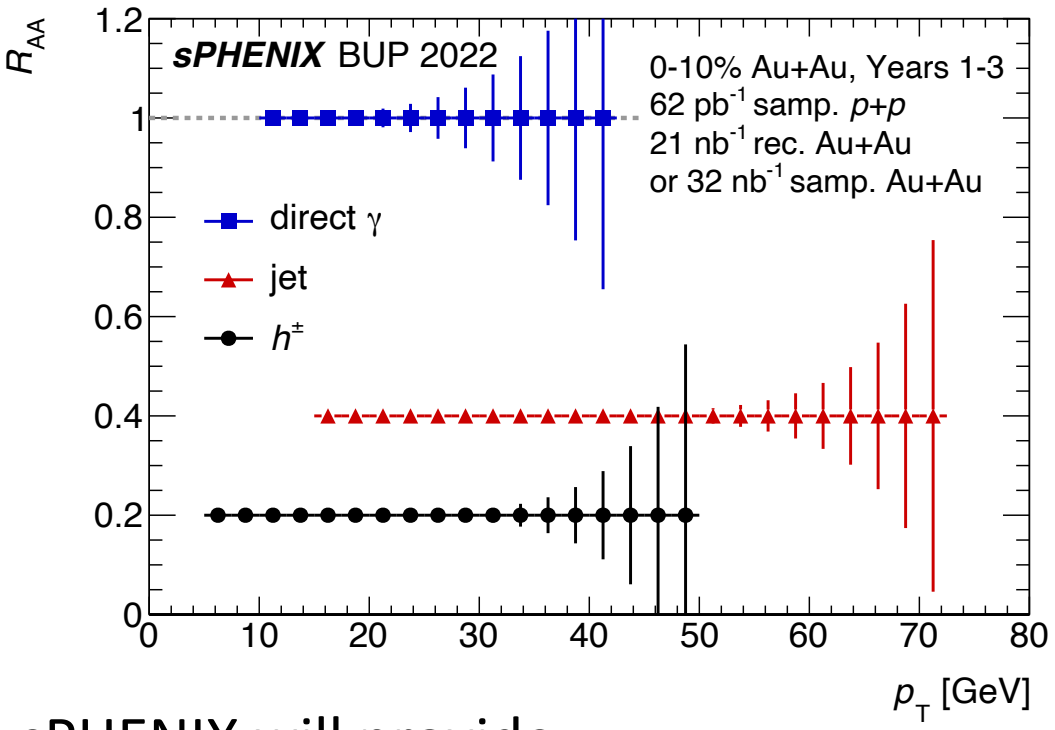


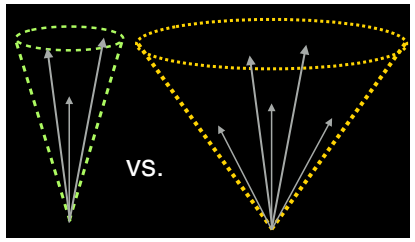


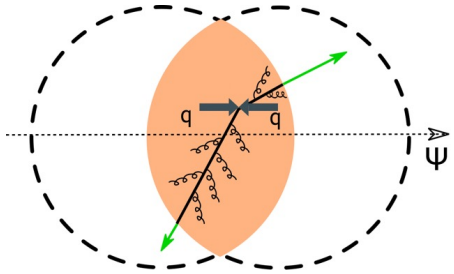
sPHENIX will provide

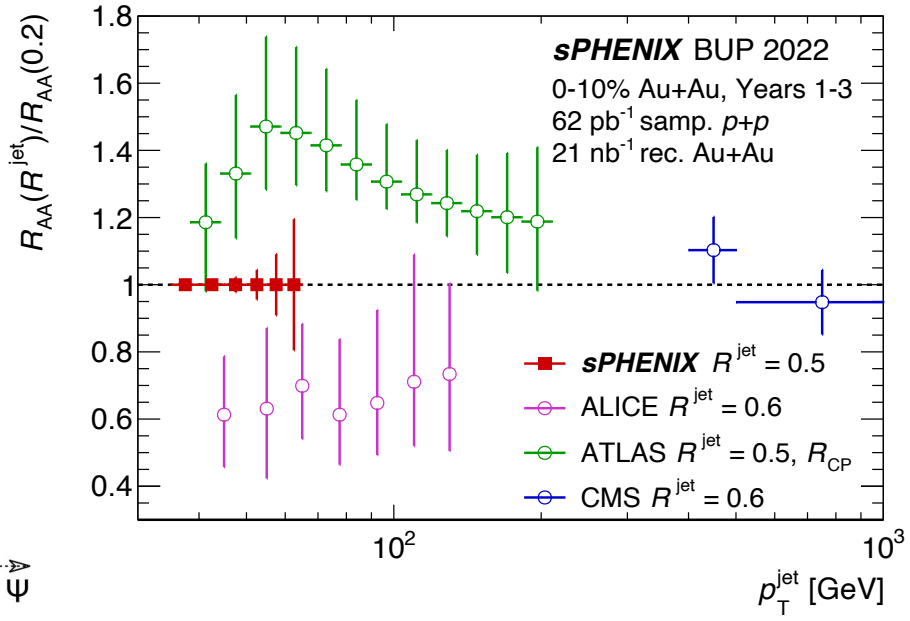
- significant extension in kinematics and overlap with LHC
- jet cone size R_{AA} comparisons at low p_T where differences at LHC experiments exist

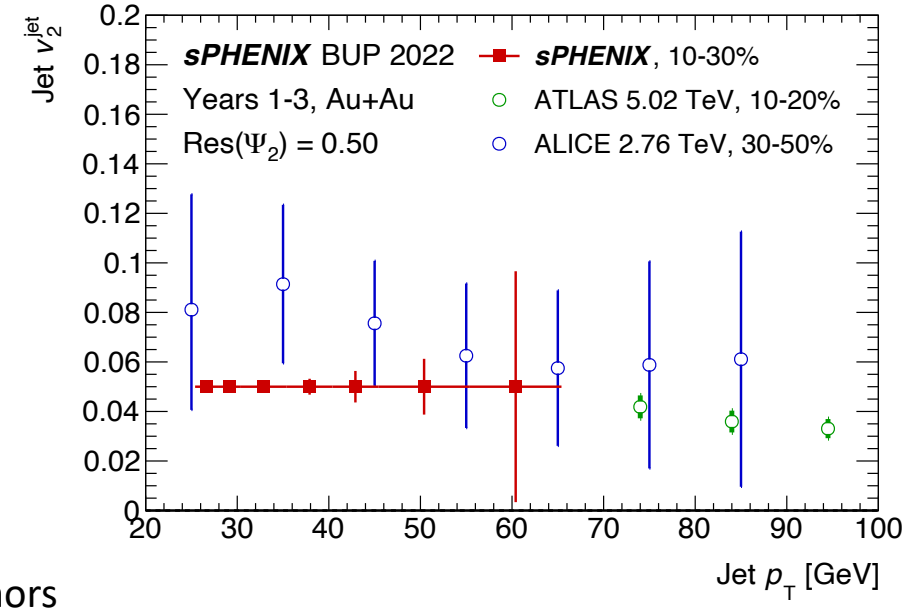
Kinematic Reach









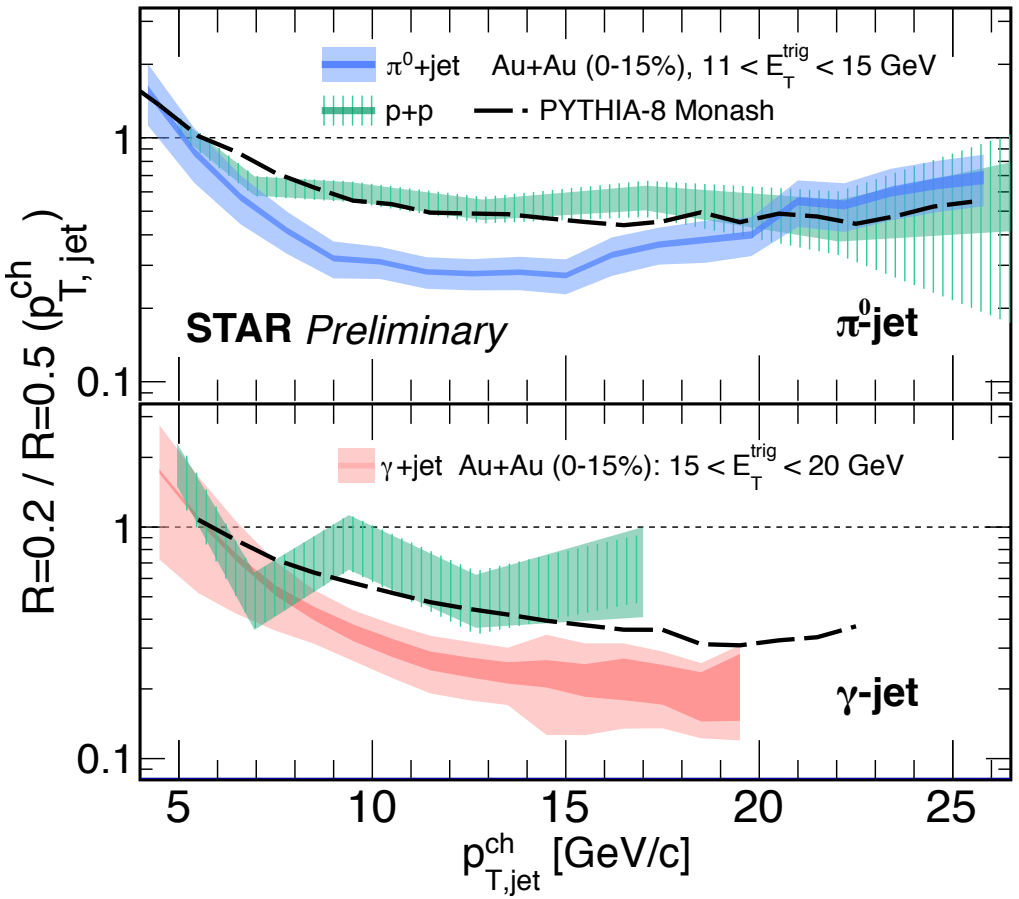


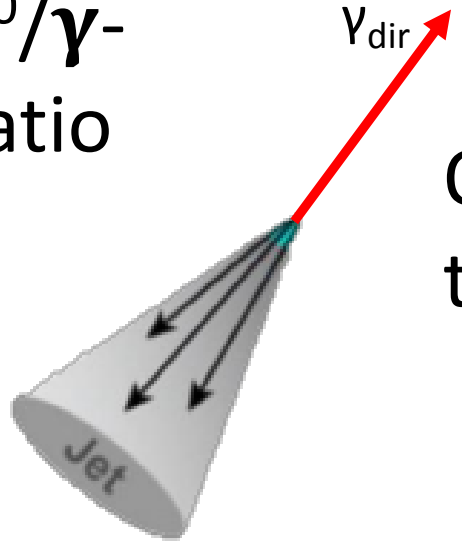
sPHENIX will provide

- significant extension in kinematics and overlap with LHC
- jet cone size R_{AA} comparisons at low p_T where differences at LHC experiments exist
- precise v_2 for low p_T jets

Photon-Tagged Jets

Preliminary STAR results for π^0/γ-tagged charged jets indicate ratio is lower in Au+Au than p+p





Quark jets dominate photon tagged jet samples

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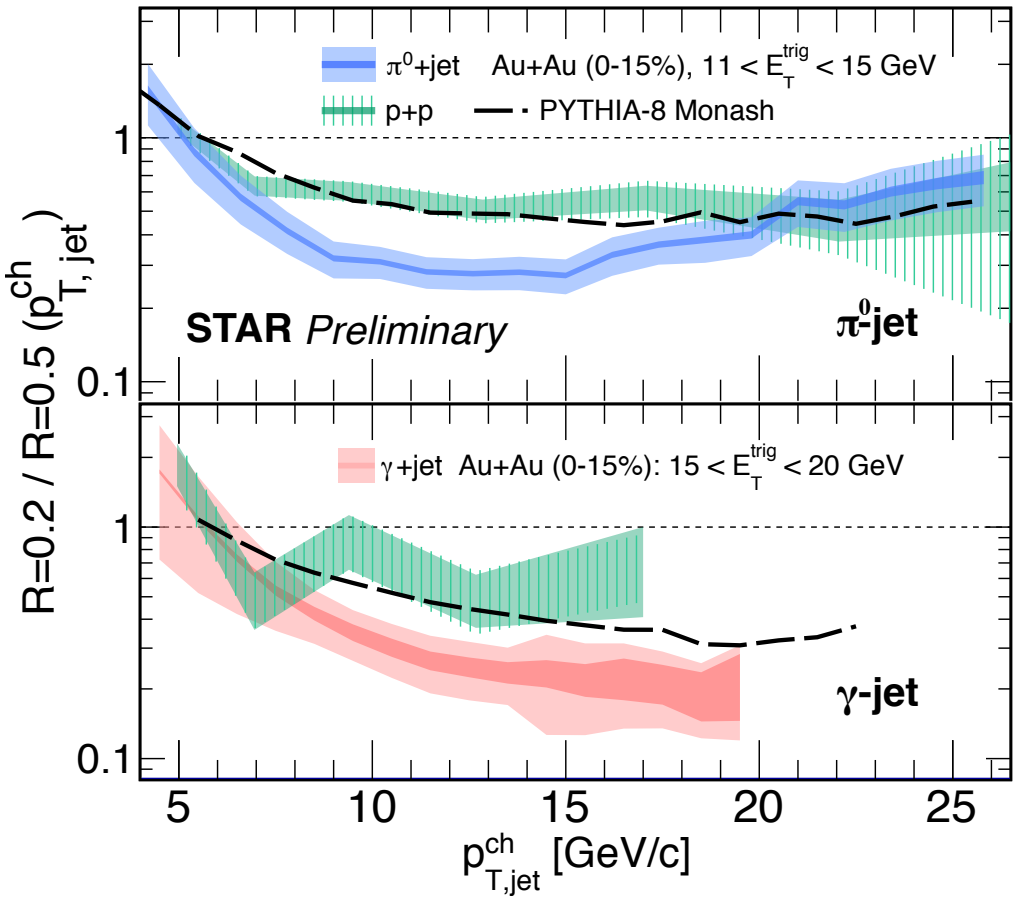

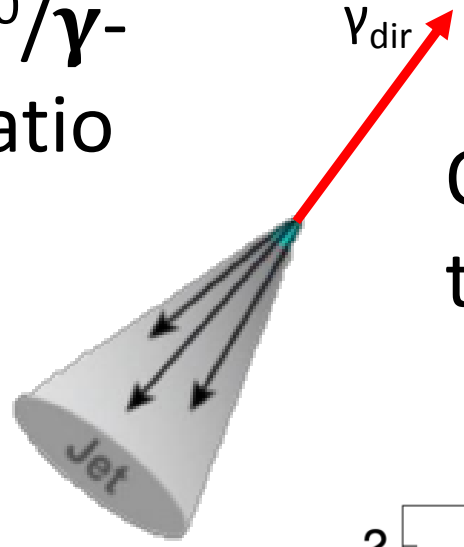

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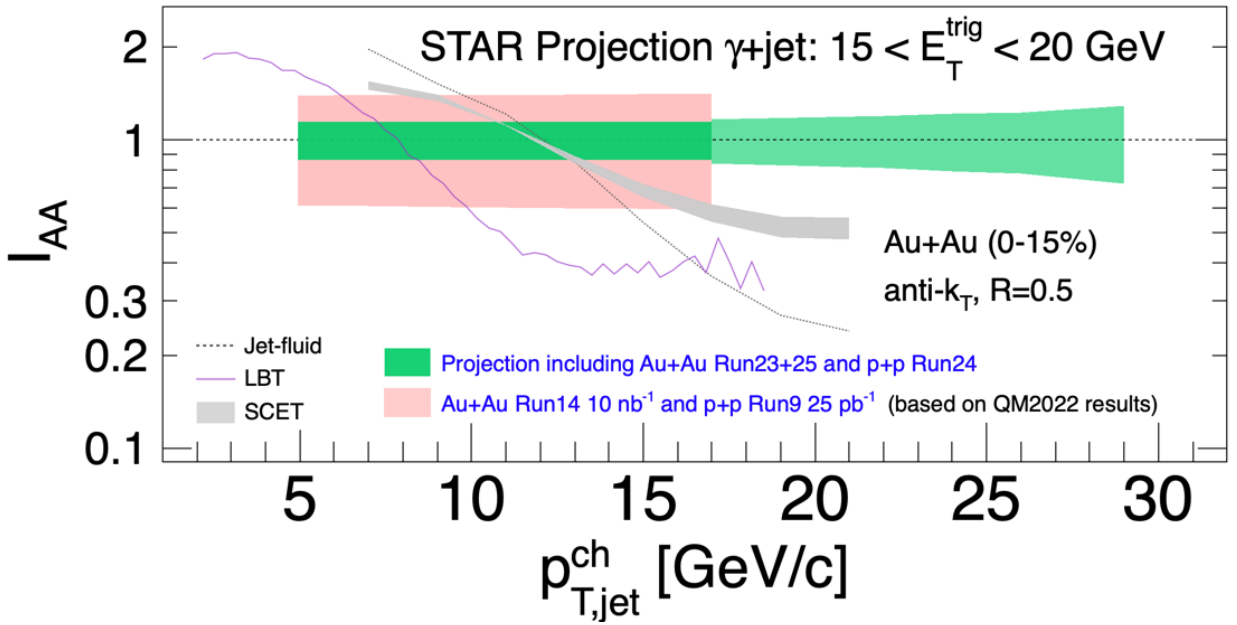
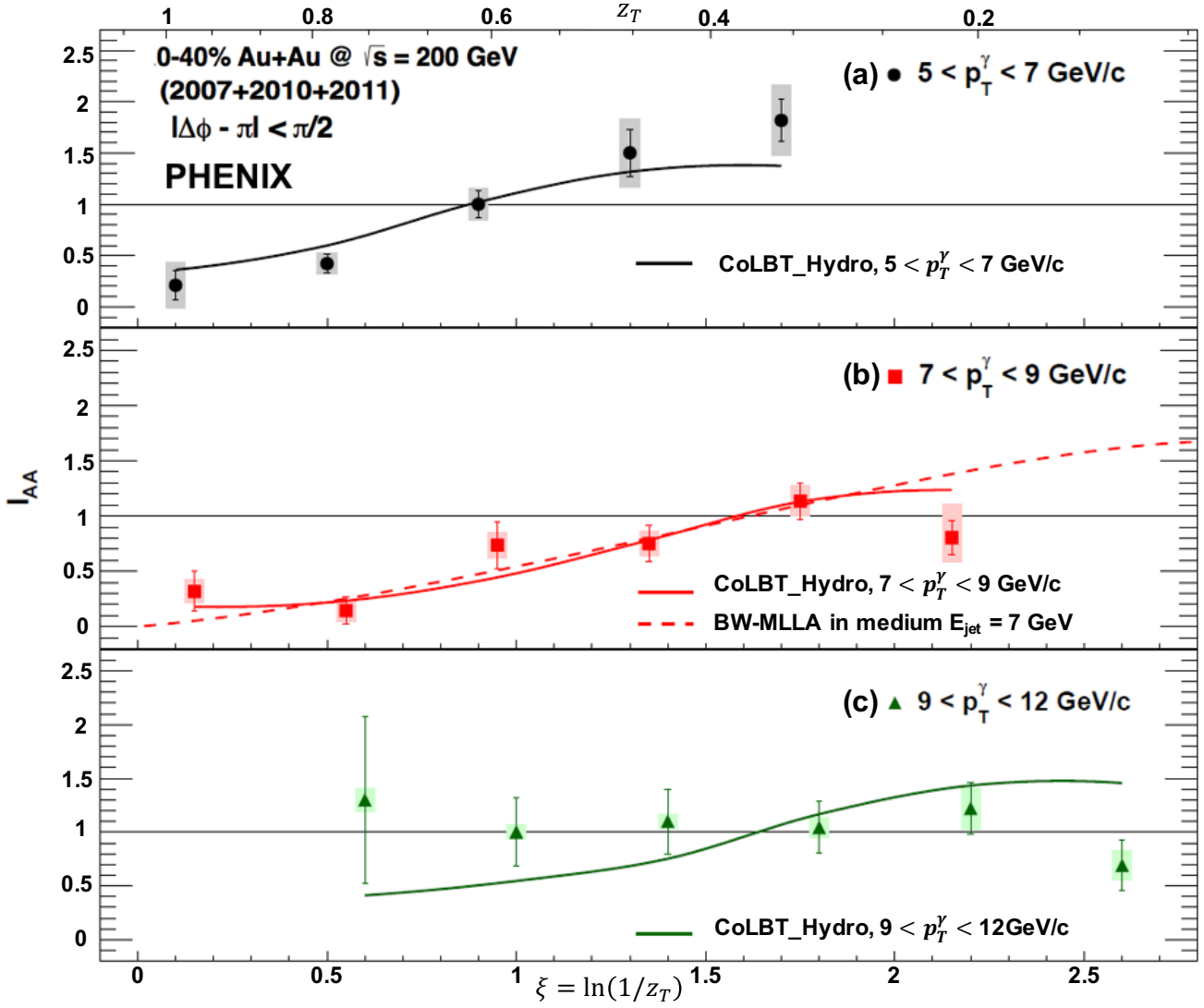


Photon-Tagged Jets at RHIC



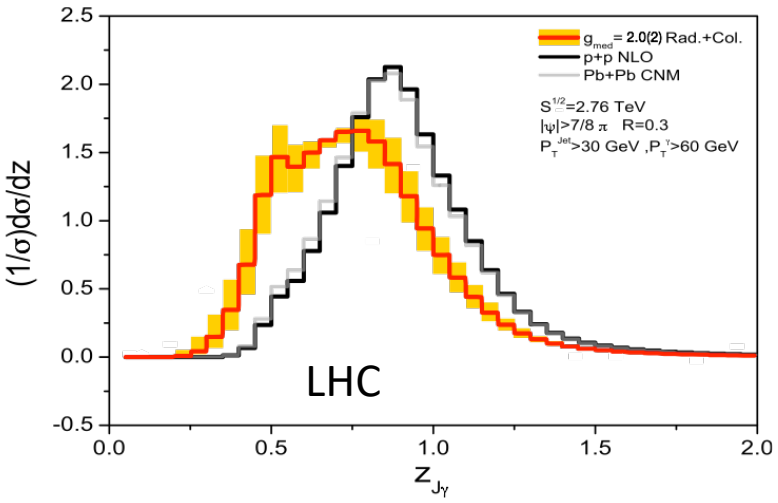
- "Golden Channel" for studying energy loss in the QGP
- Photon tags initial hard scattering kinematics

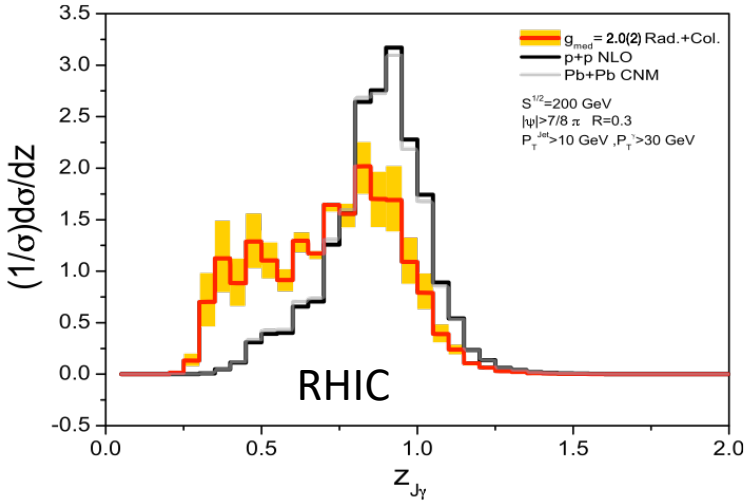
$$z = p_h / p^i_{jet}$$

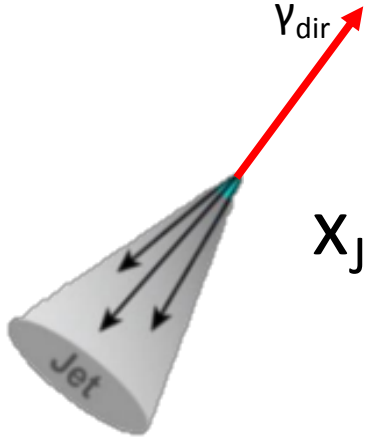
- $I_{AA}=Y_{AA}/Y_{pp}\sim D_{AA}(z)/D_{pp}(z)$
- Medium response effects
- Because of $\boldsymbol{\gamma/\pi^0}$ RHIC is ideal for measuring direct photons

PRC 102, 054910

Photon-Jet Imbalance



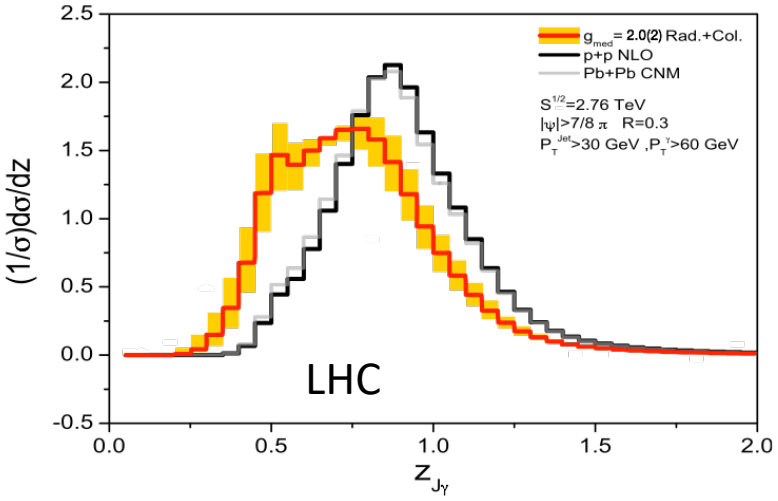


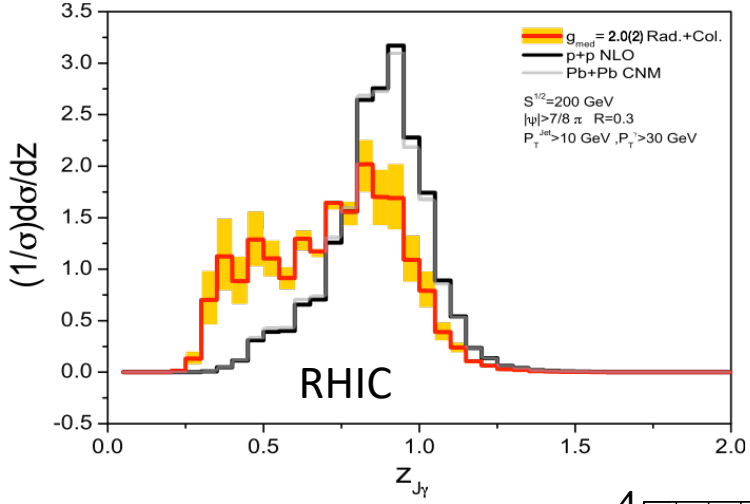


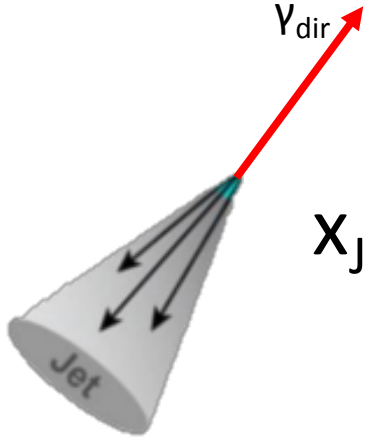
$x_{J\gamma} = p_{Tjet}/p_{T\gamma}$

- $x_{J\gamma}$ may be more sensitive at RHIC
- directly probes energy loss

Photon-Jet Imbalance

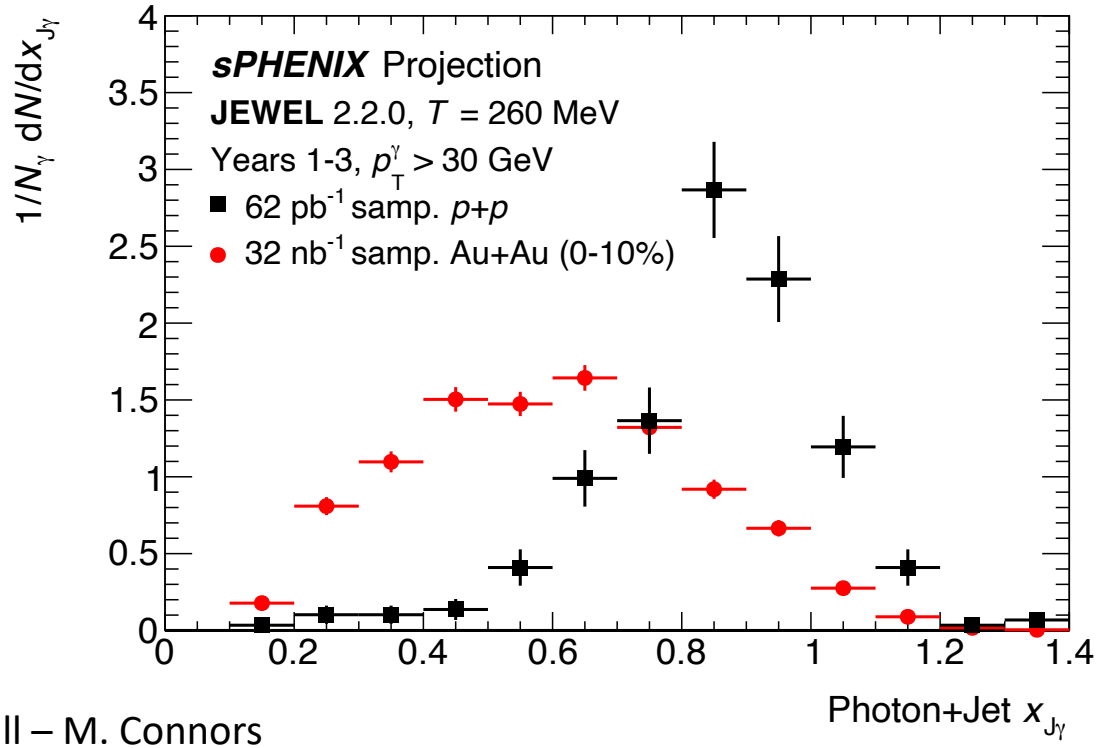






$x_{J\,\gamma} = p_{Tjet}/p_{T\gamma}$

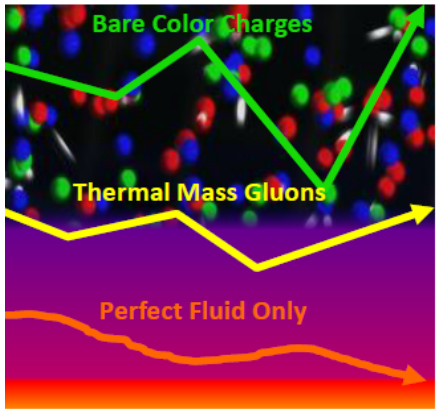
- $x_{J\gamma}$ may be more sensitive at RHIC
- directly probes energy loss
- Photon tagged jets are a key component to the sPHENIX program

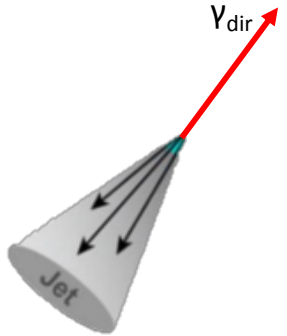


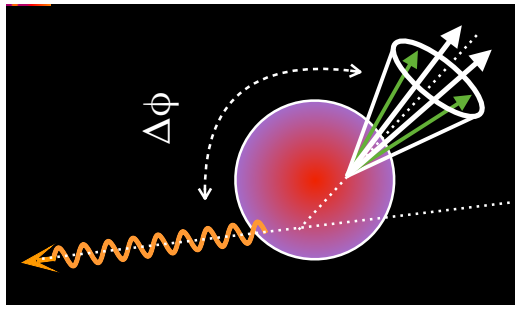
Acoplanarity of Photon-Jets

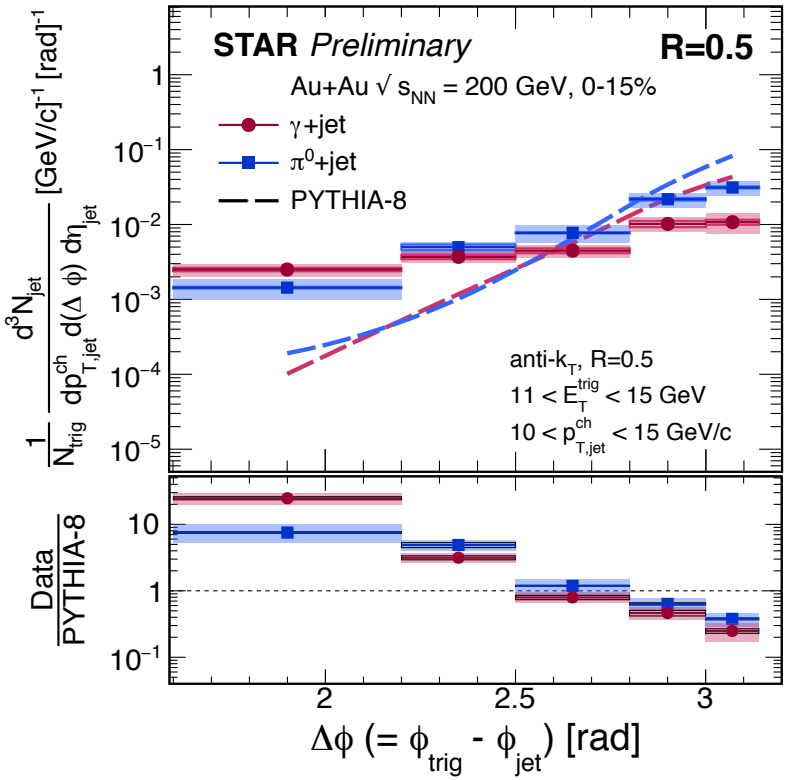
The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

The simplest way to "see" pointlike quarks and gluons within QGP is, as Rutherford would have understood, to look for evidence of jets, or partons within jets, scattering off individual quarks and gluons as they plow through QGP. As the top-right panel illustrates,

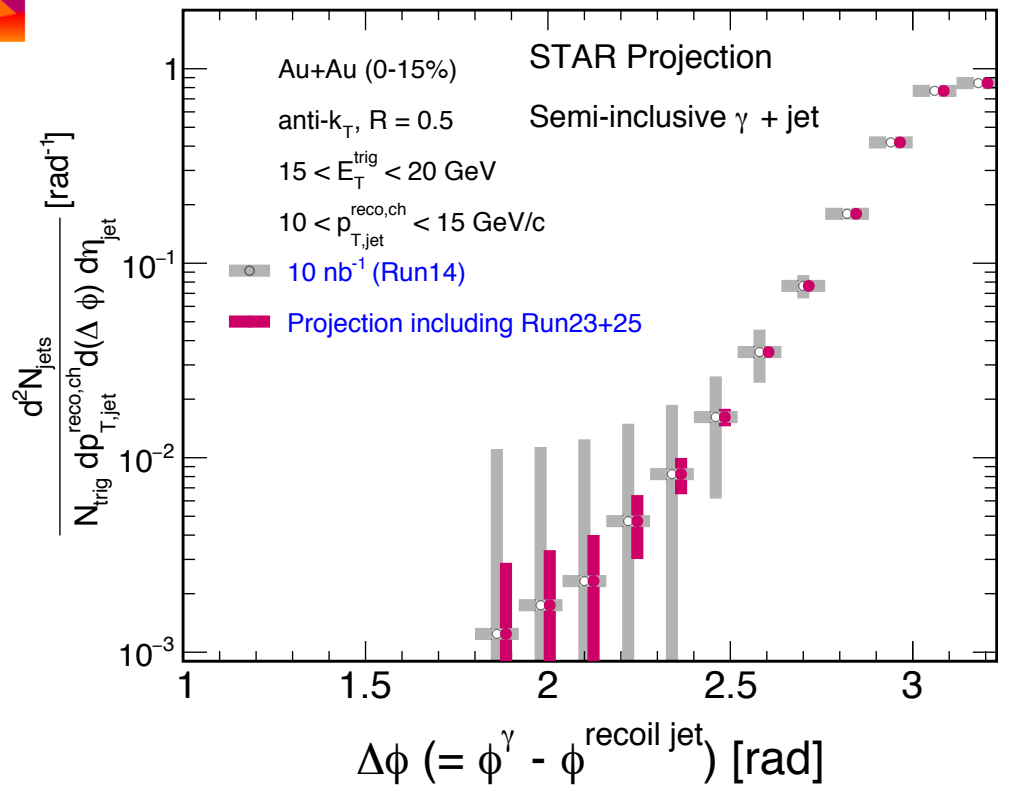








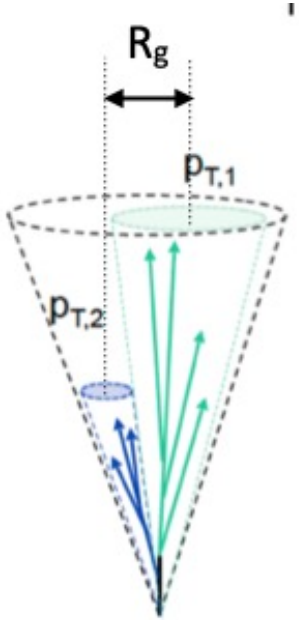
- Excess yield at large angles in Au+Au compared to PYTHIA
- 1st signature of medium-induced acoplanarity in the central Au+Au collisions

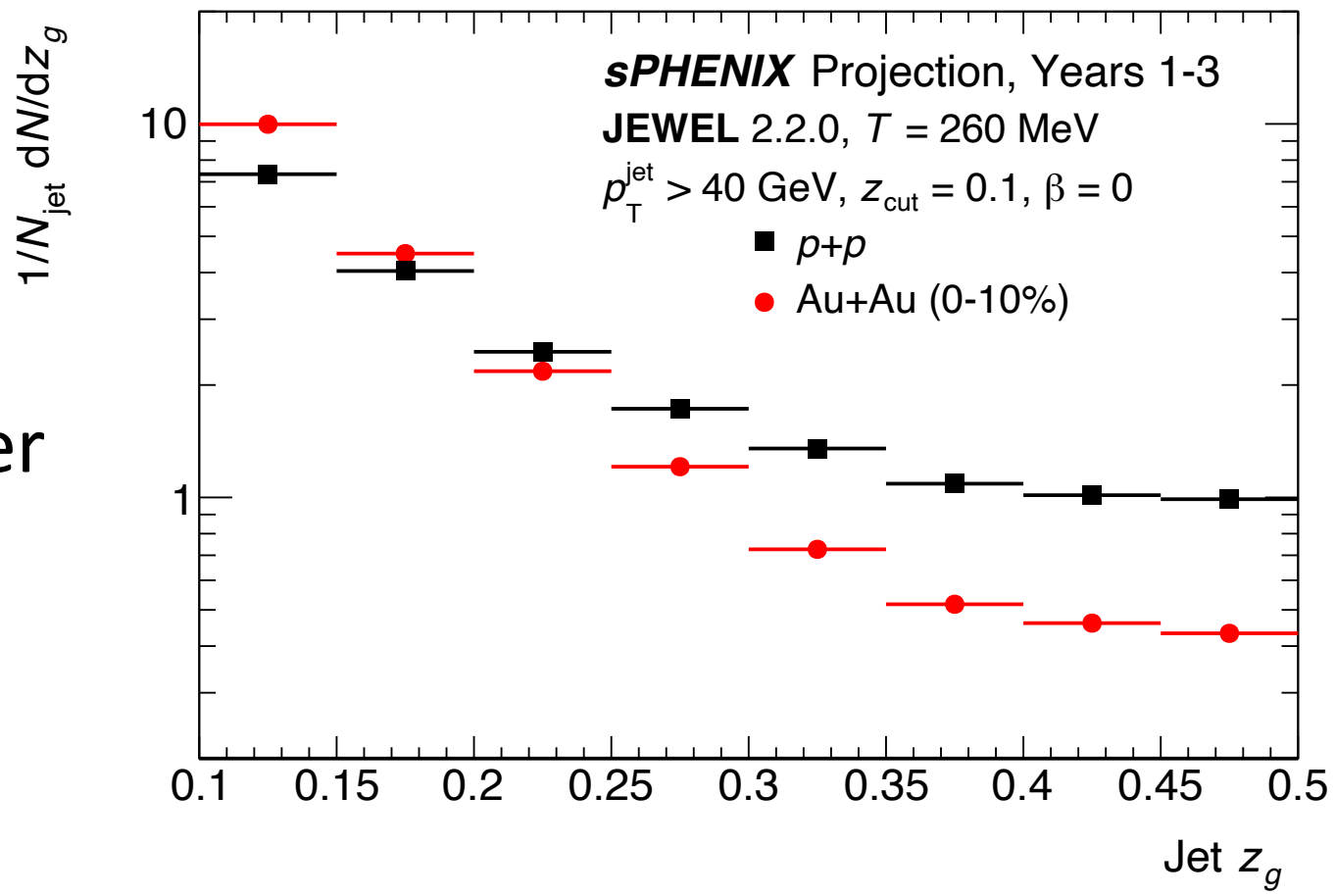


Jet Substructure

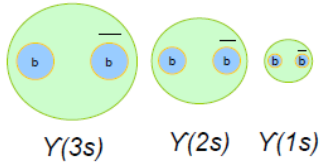
- Jet grooming one of many techniques to explore substructure of jets
- Groomed jets explore the evolution of the parton shower

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

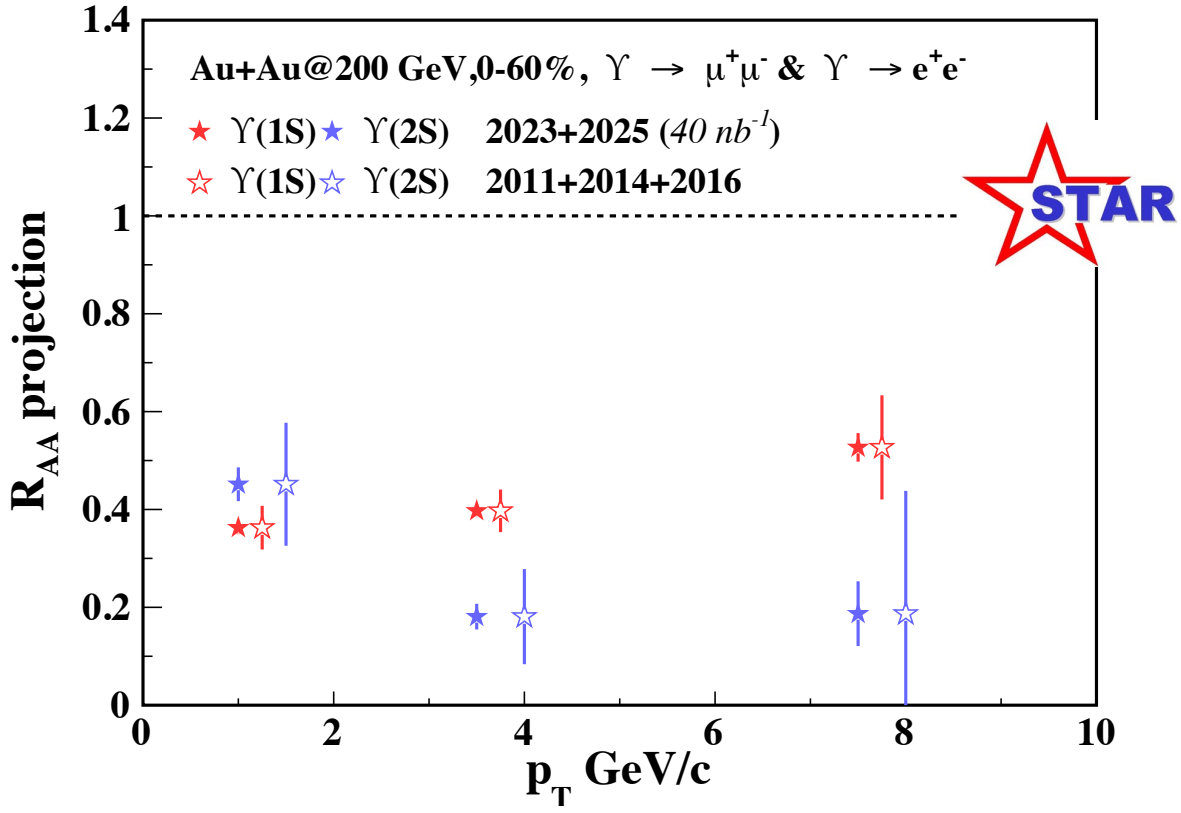




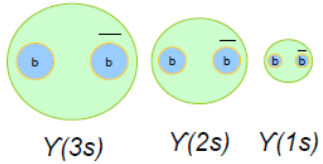
Upsilon R_{AA}

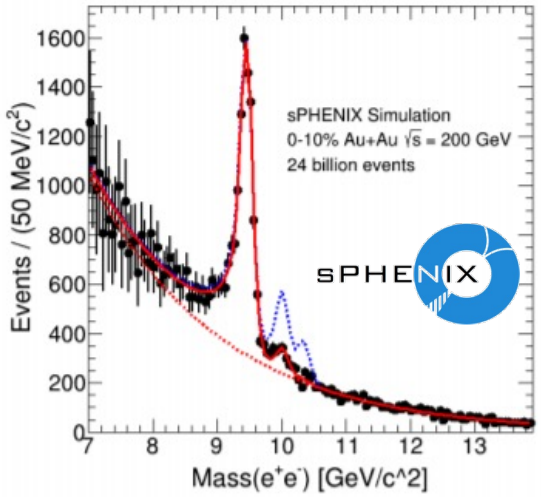


- Current STAR results use combined STAR/PHENIX p+p

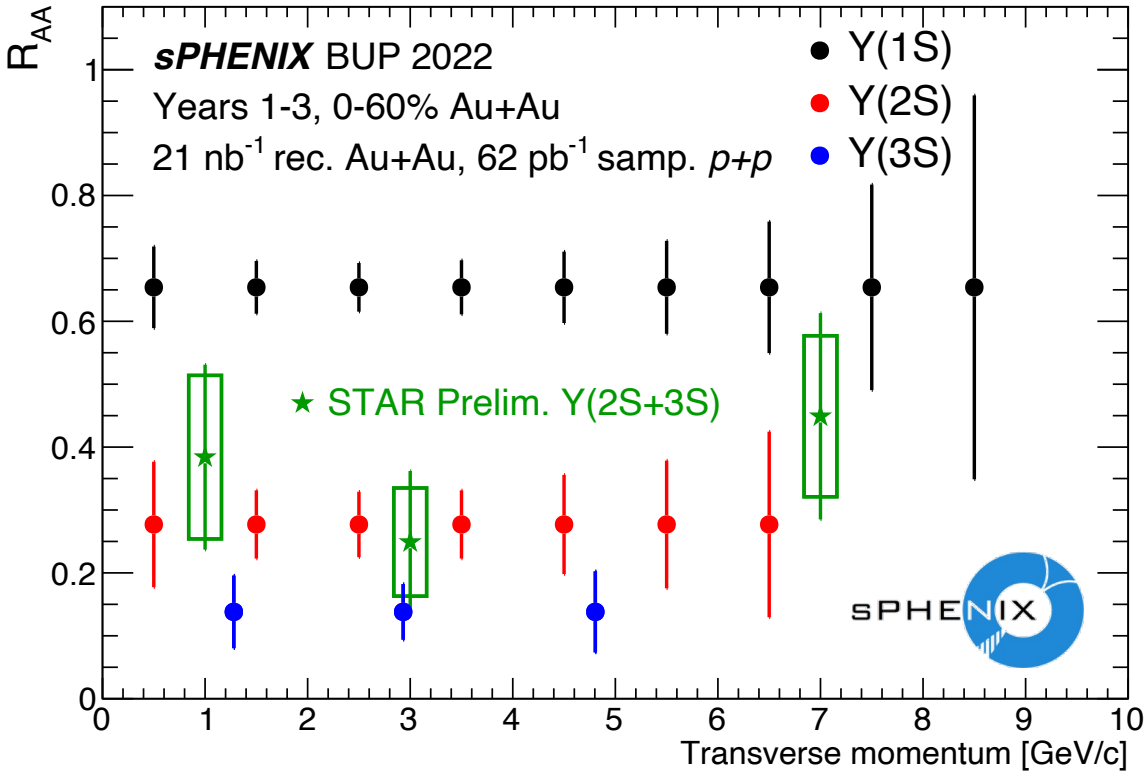


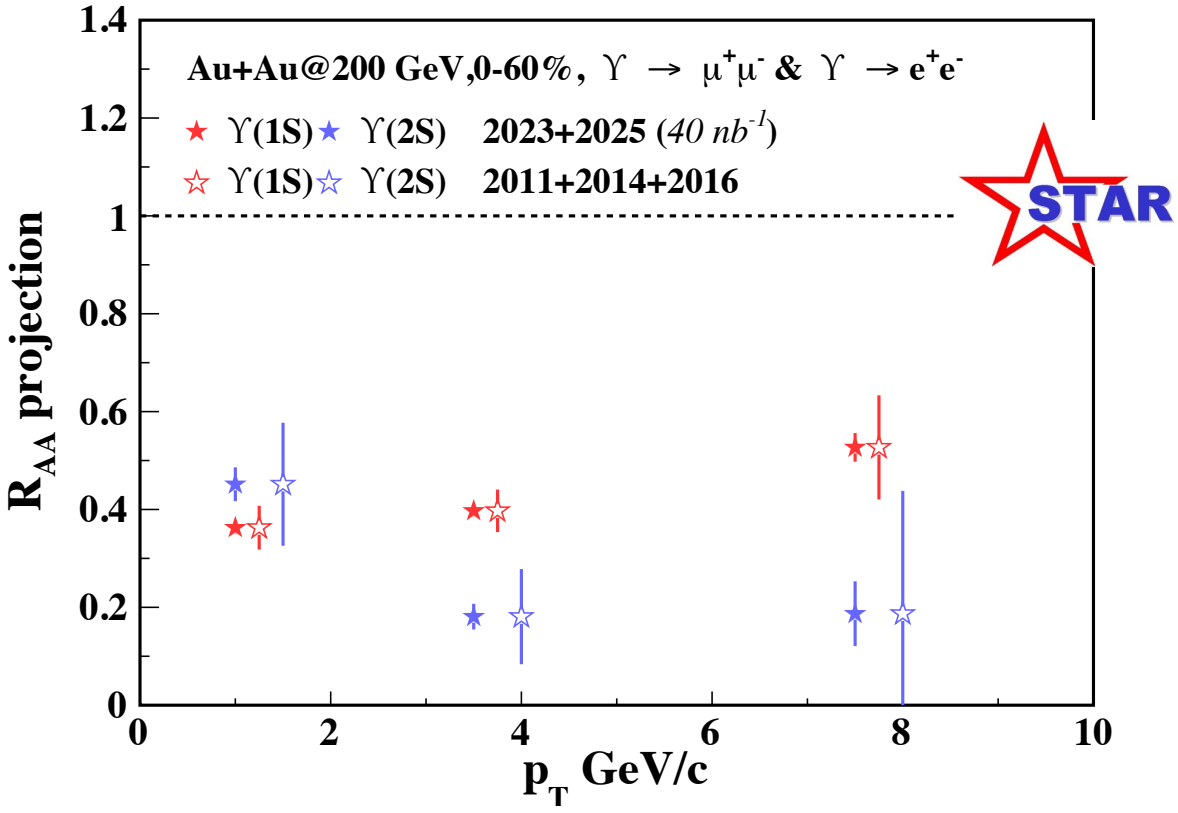
Upsilon R_{AA}





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

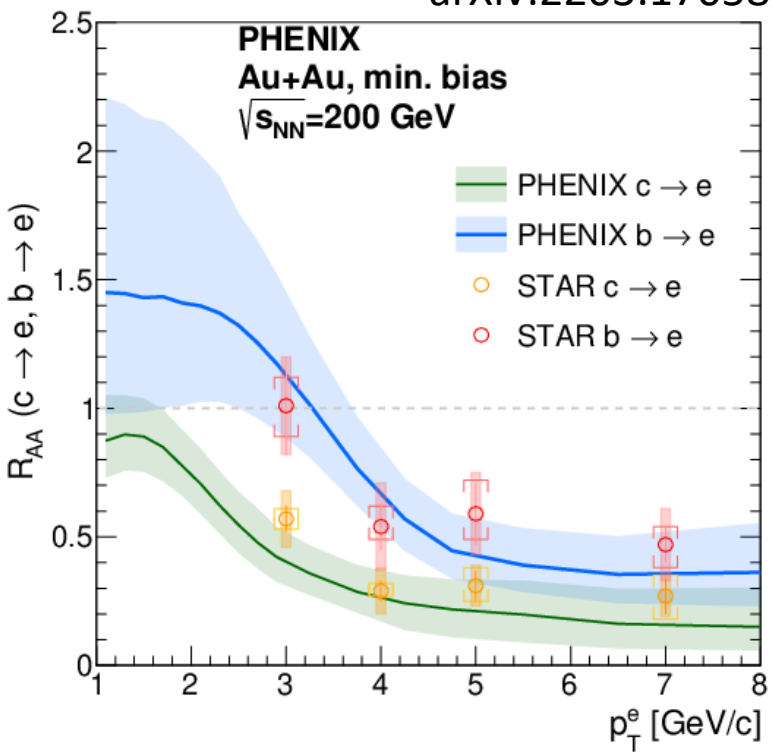




Quark Mass Dependent Energy Loss

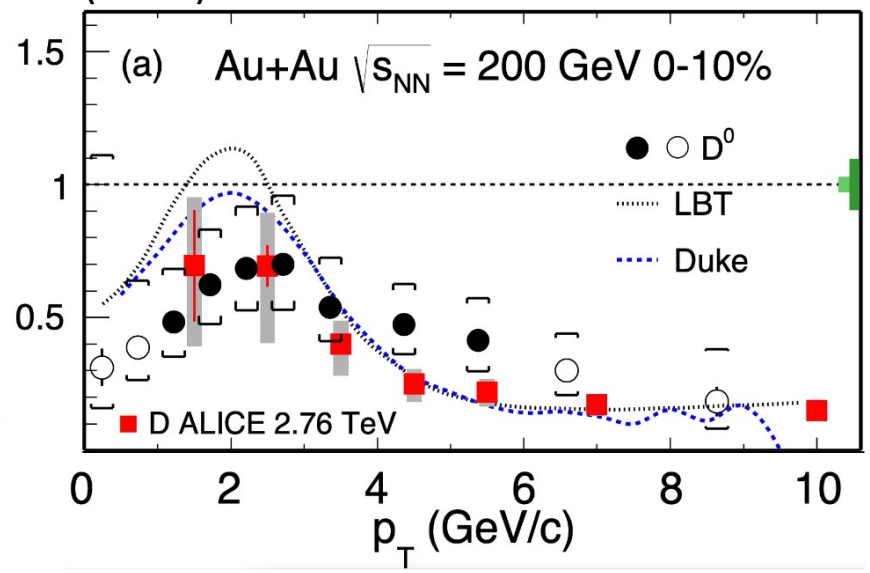
PHENIX

arXiv:2203.17058

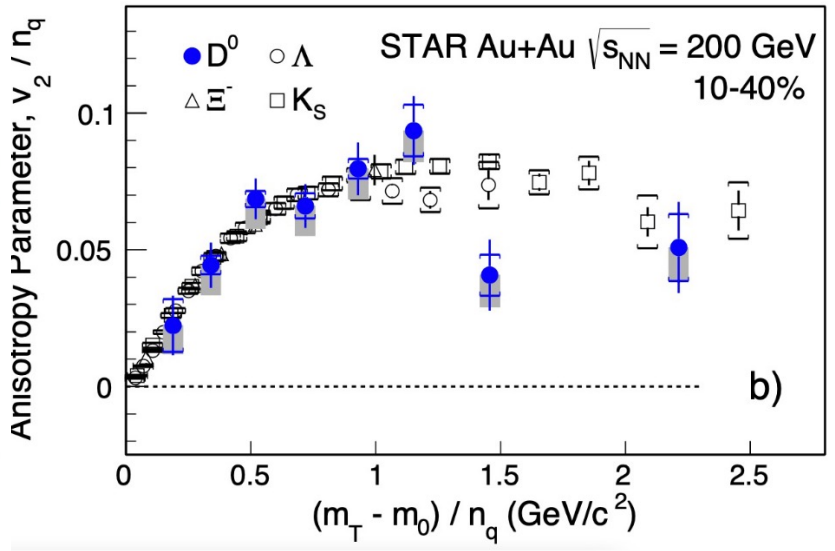


- Measurements enabled by Upgrades at PHENIX and STAR
- Beauty is less suppressed than charm
- Studies of charm via D^0 suppression and v_2

PRC 99 (2019) 034908

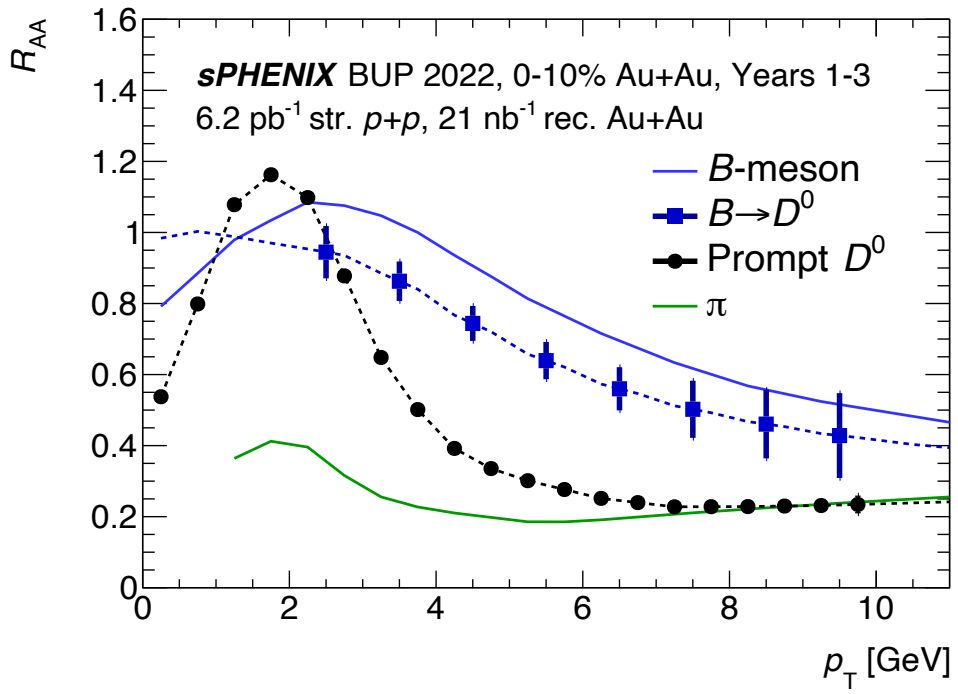


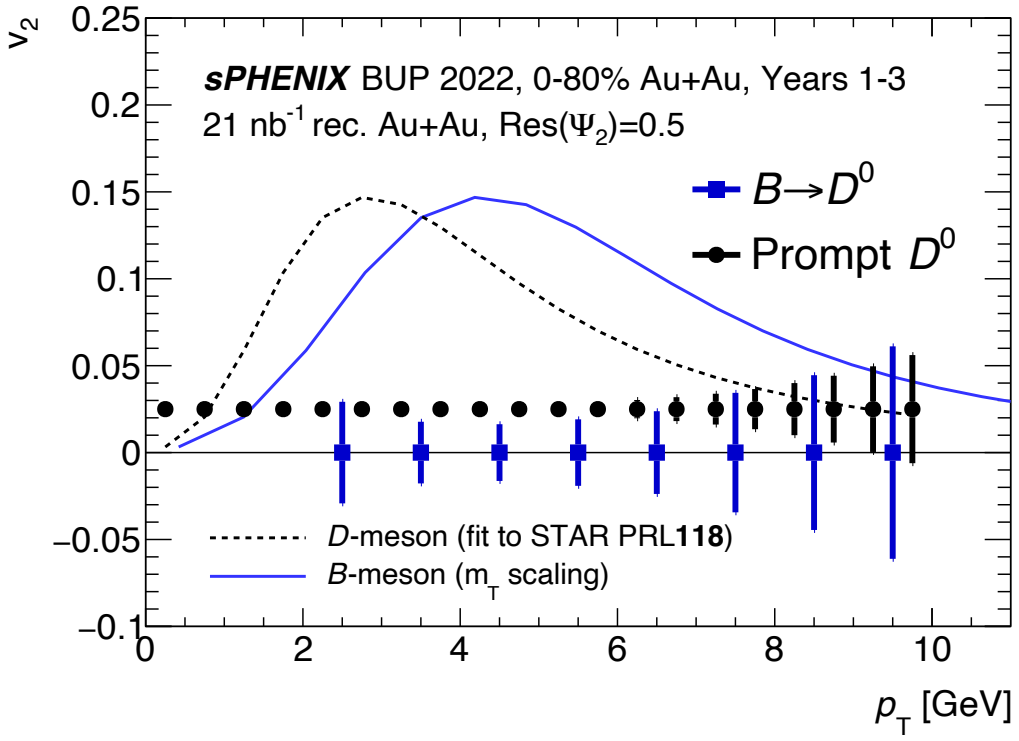
PRL 118 (2017) 212301



Heavy Flavor in sPHENIX

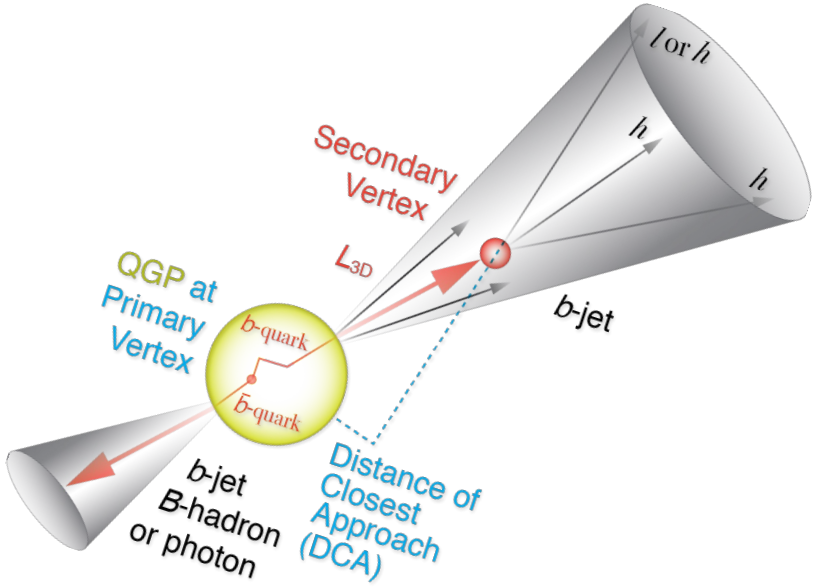
- Streaming readout enables huge MB data for unbiased HF measurements in p+p collisions
- High precision non-prompt D suppression and flow at RHIC

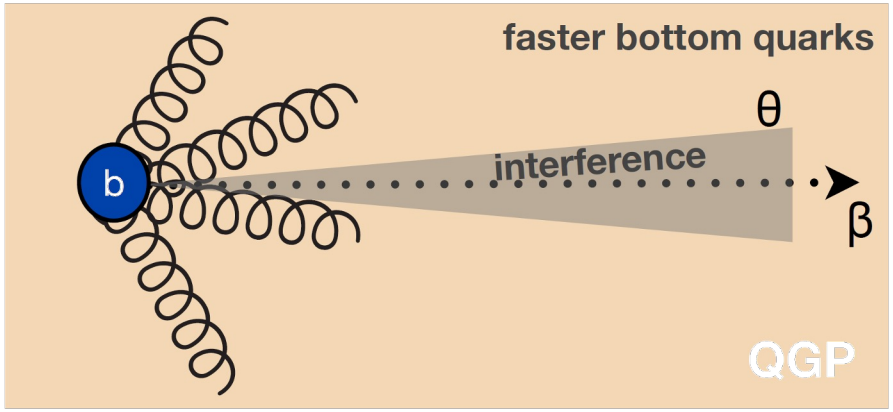


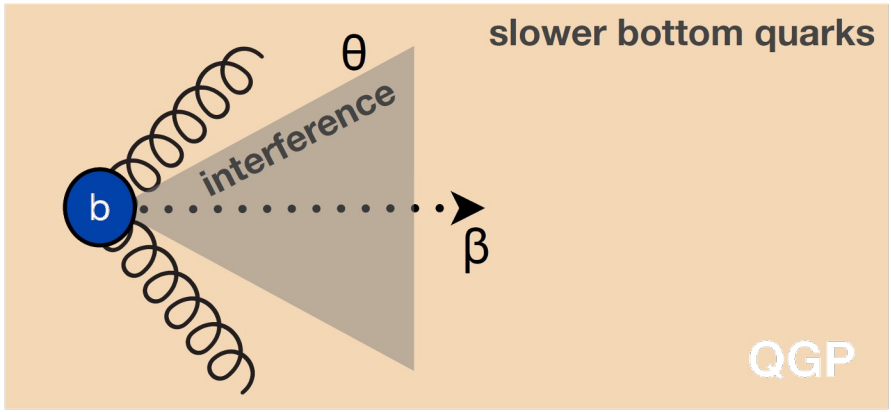


b-tagged Jets at RHIC

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

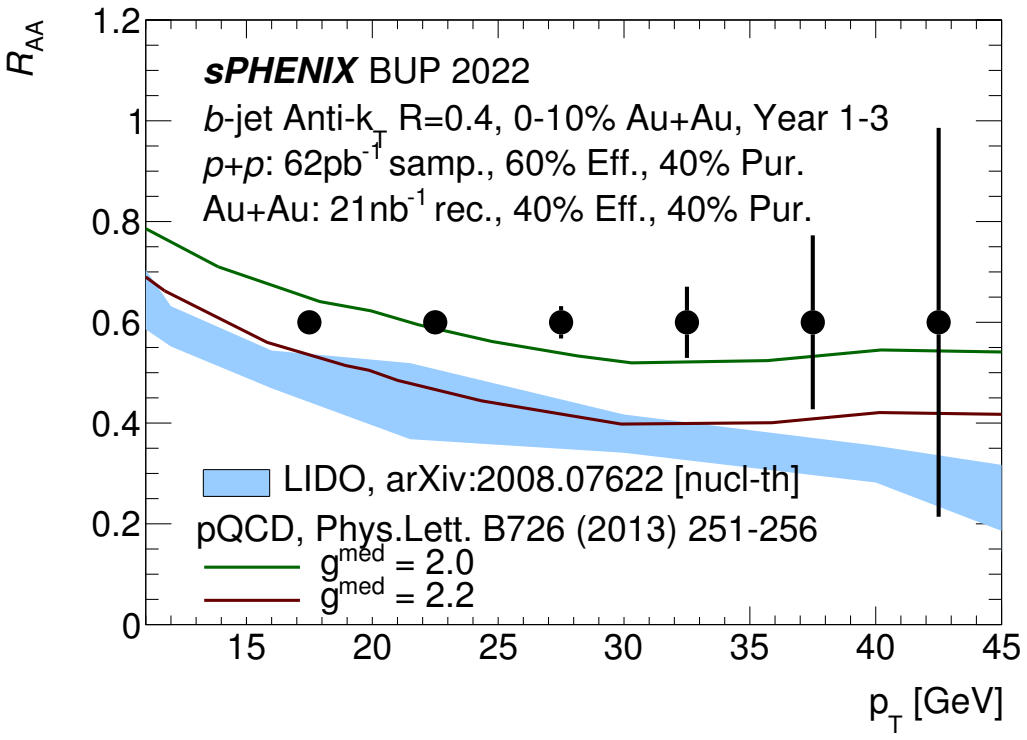


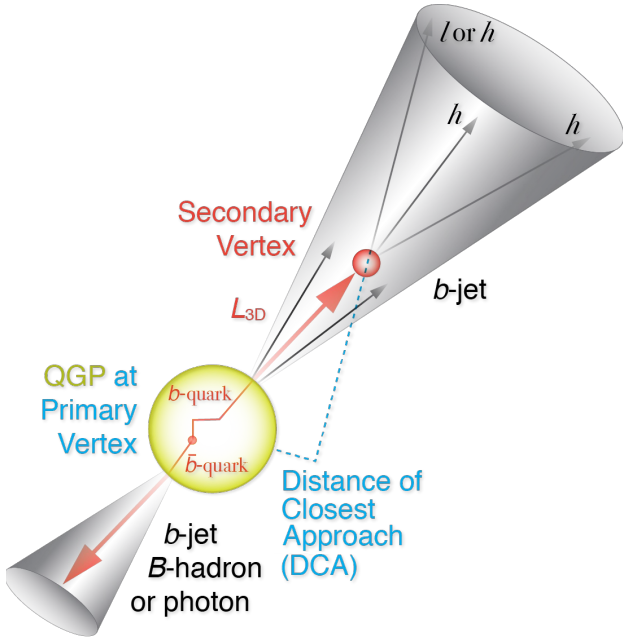


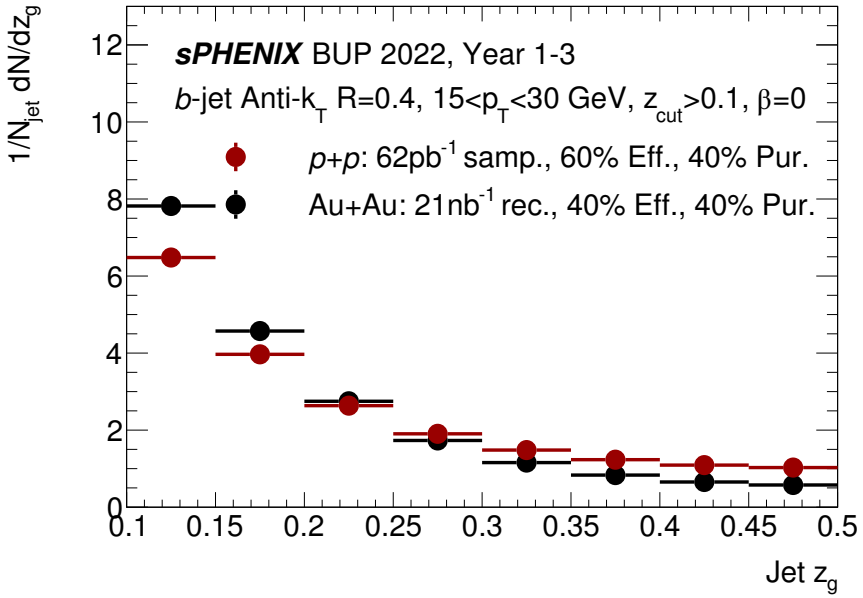


b-tagged Jet Projection

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



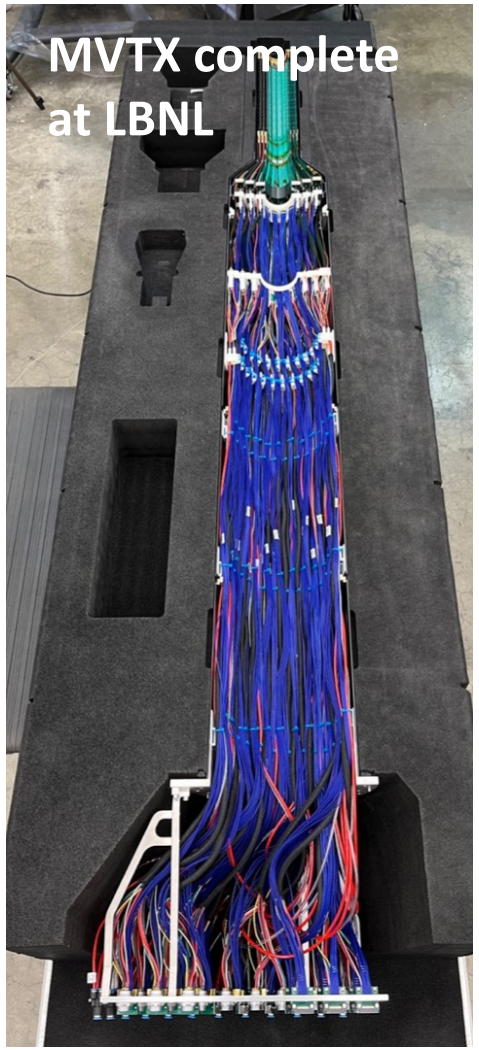




From Projections to Measurements

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

sPHENIX from Construction to Assembly



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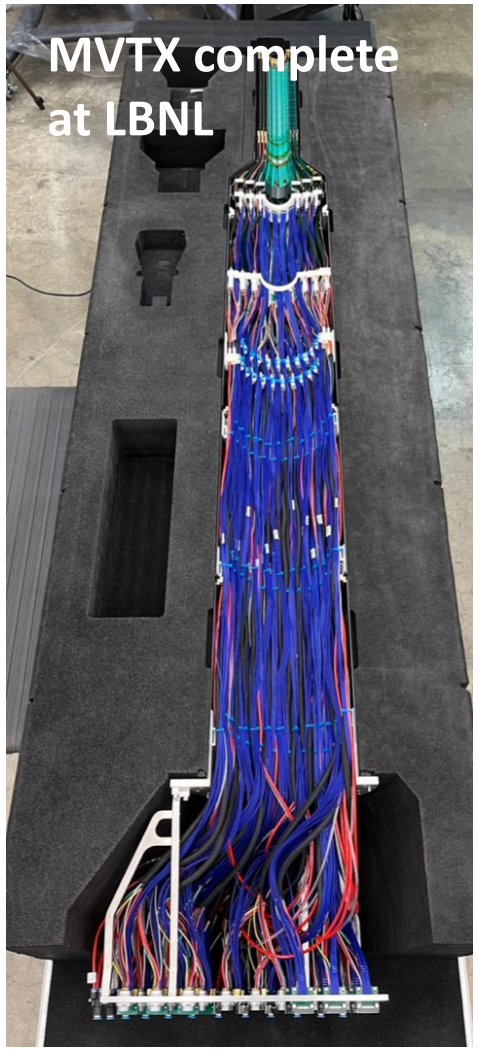
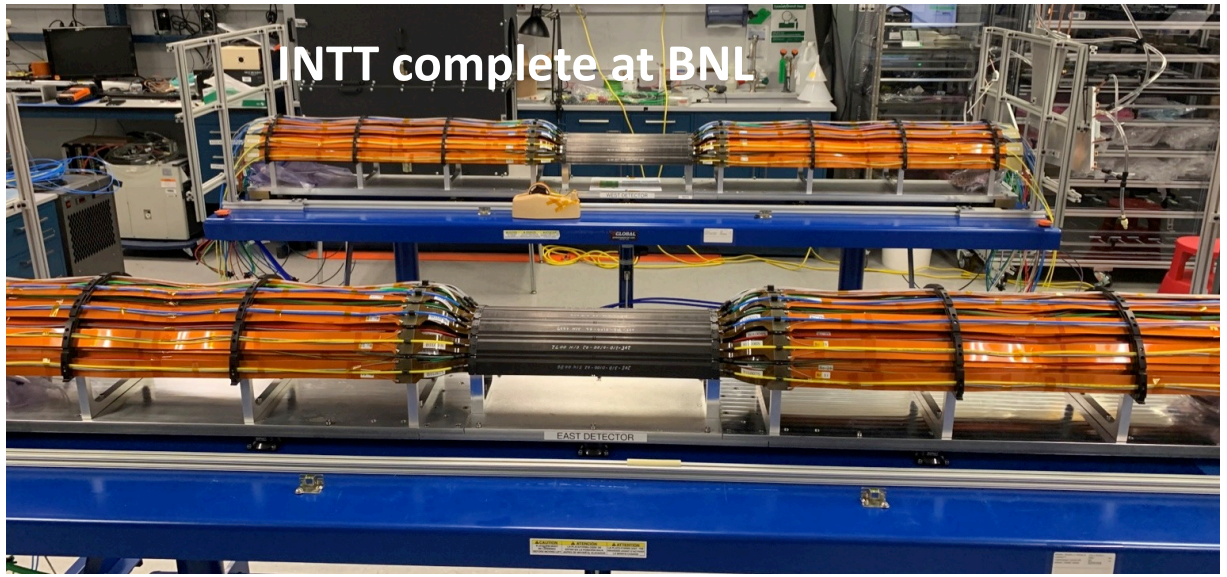
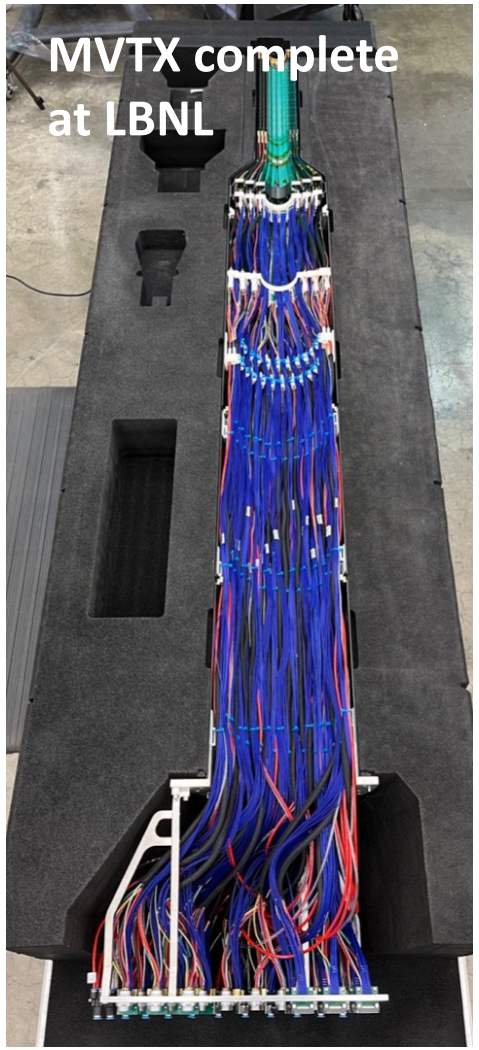
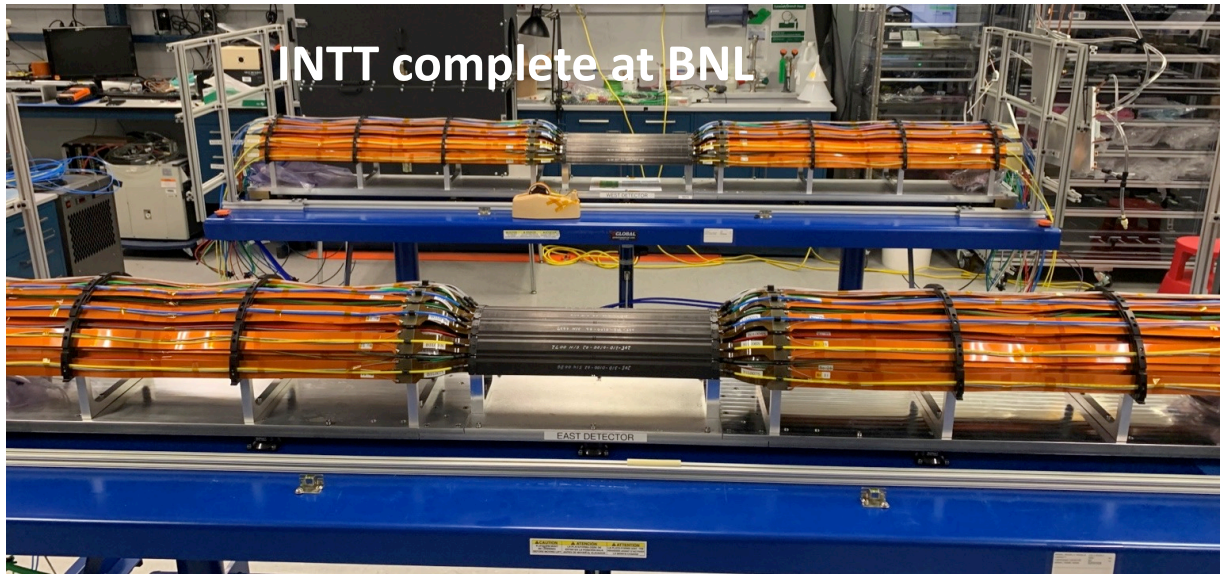
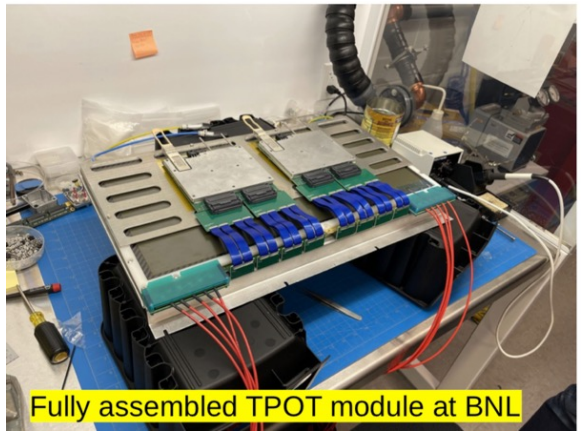




sPHENIX from Construction to Assembly







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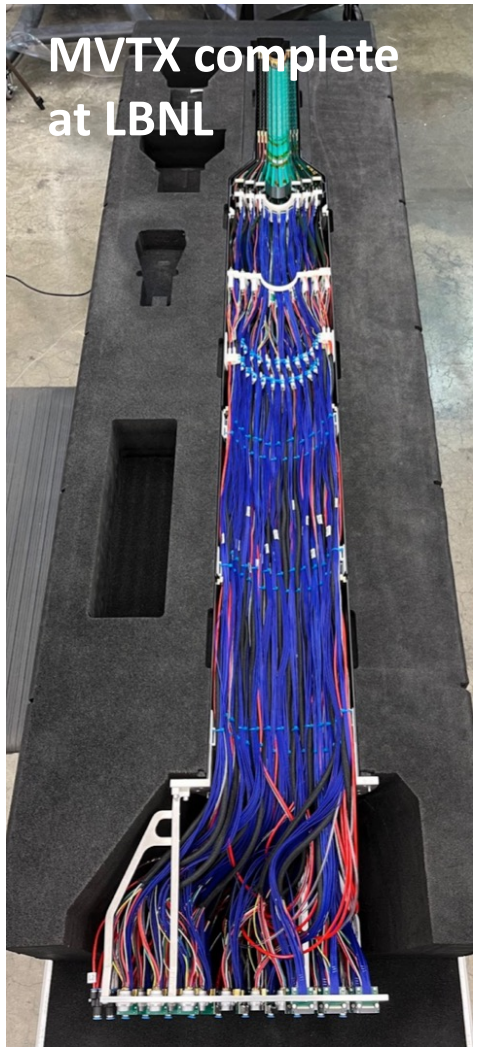

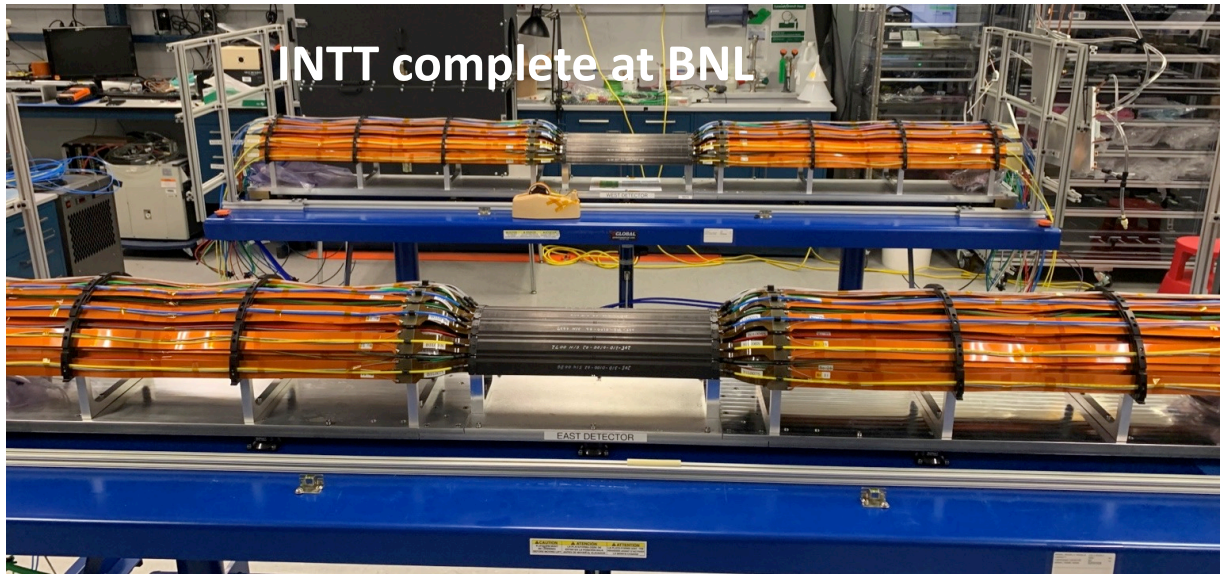

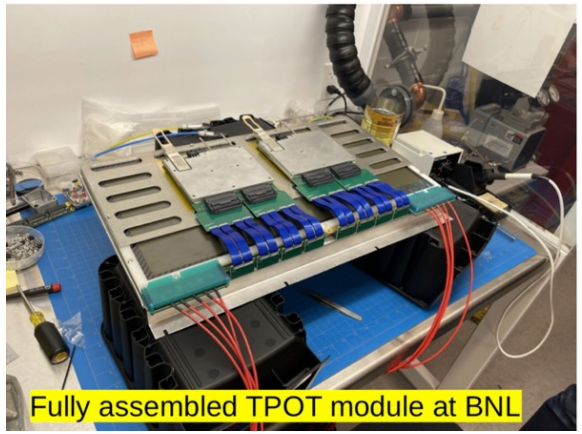

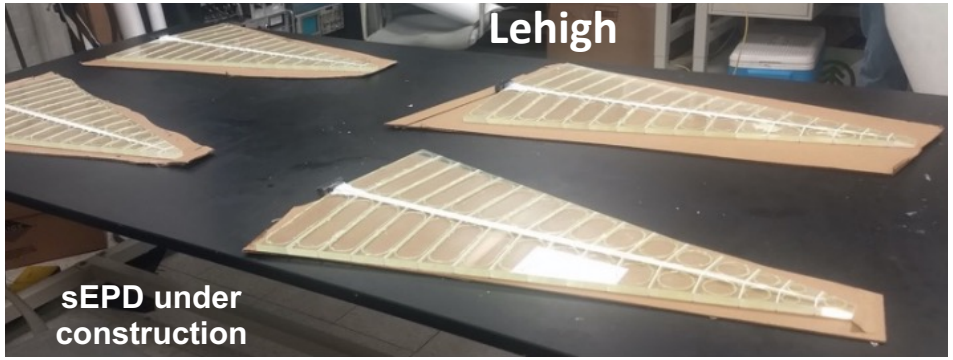

Completing Scientific Mission Means

There are two central goals of measurements pl
at RHIC, as it completes its scientific mission and
LHC: **(1) Probe the inner workings of QGP by re**

Completing its scientific mission does not end when heavy ion collisions at RHIC cease

Wealth of data to analyze!

After the 2016 RHIC run, PHENIX has submitted over 50 papers for publication and 40 PhD students completed their theses.

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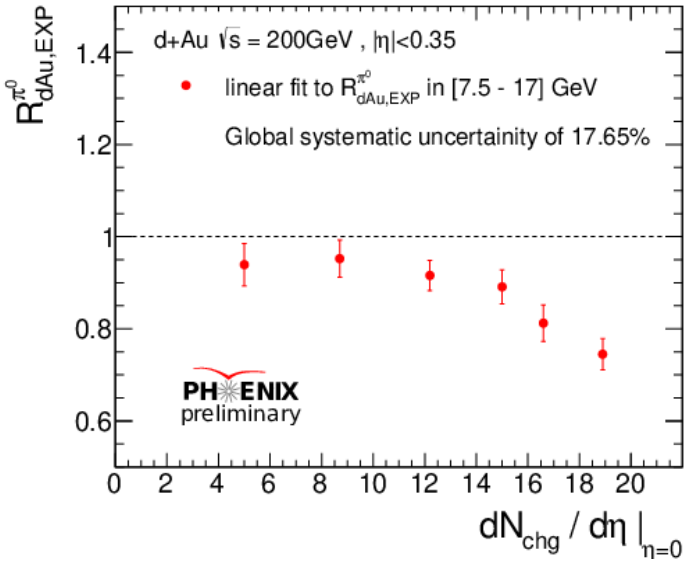
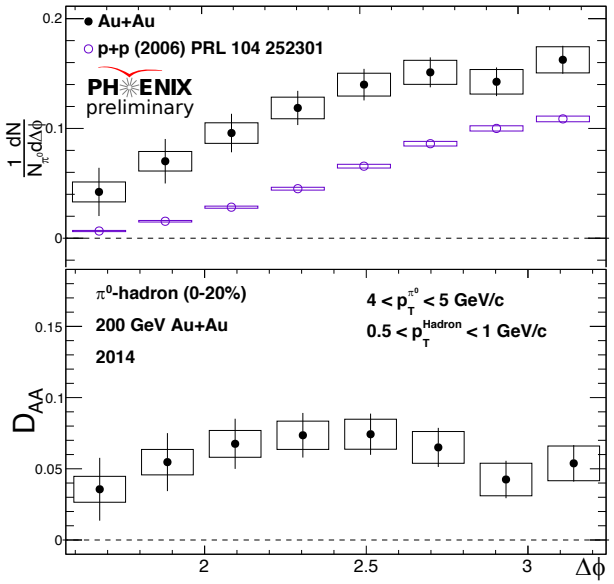
Recent PHENIX theses include impactful results that inform our understanding of small and large collision systems



Niveditha Ram (SBU PhD 2021)

$$D_{AA} = Y_{AA} - Y_{pp}$$



A. Hodges (GSU PhD 2022)

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Data and Analysis Preservation (DAP)

PHENIX

To ensure reproducibility of published results:

- **Standardized analysis notes**
- **All analysis code, macros, relevant files stored in HPSS**
- **Upload published data to HEPData**

Ideal Goal: re-analysis possible "forever" by "everyone"

- **Tools: Docker/REAna; Github and Zenodo; CERN OpenData for the general public; RIVET**

Find out more at the Analysis tab on the phenix website:

https://www.phenix.bnl.gov/

Summary

Highlighted Results/Projections:

- Unique capabilities of the RHIC facility/Achievable precision
- Upsilon 1S and 2S suppression observed/3S suppression to be discovered at RHIC
- Jet quenching results/precise acoplanarity, imbalance & substructure measurements
- Bottom less suppressed than charm/b-jet measurements

Goal:

- Achieve the goals established in the 2015 LRP to complete the scientific mission of RHIC

Need:

- Continued RHIC operations necessary to collect p+p, p+Au and Au+Au data to achieve required precision with sPHENIX
- Continued support beyond RHIC running necessary to complete the analysis of the necessary datasets to fulfill the goal envisioned in 2015 NSAC LRP