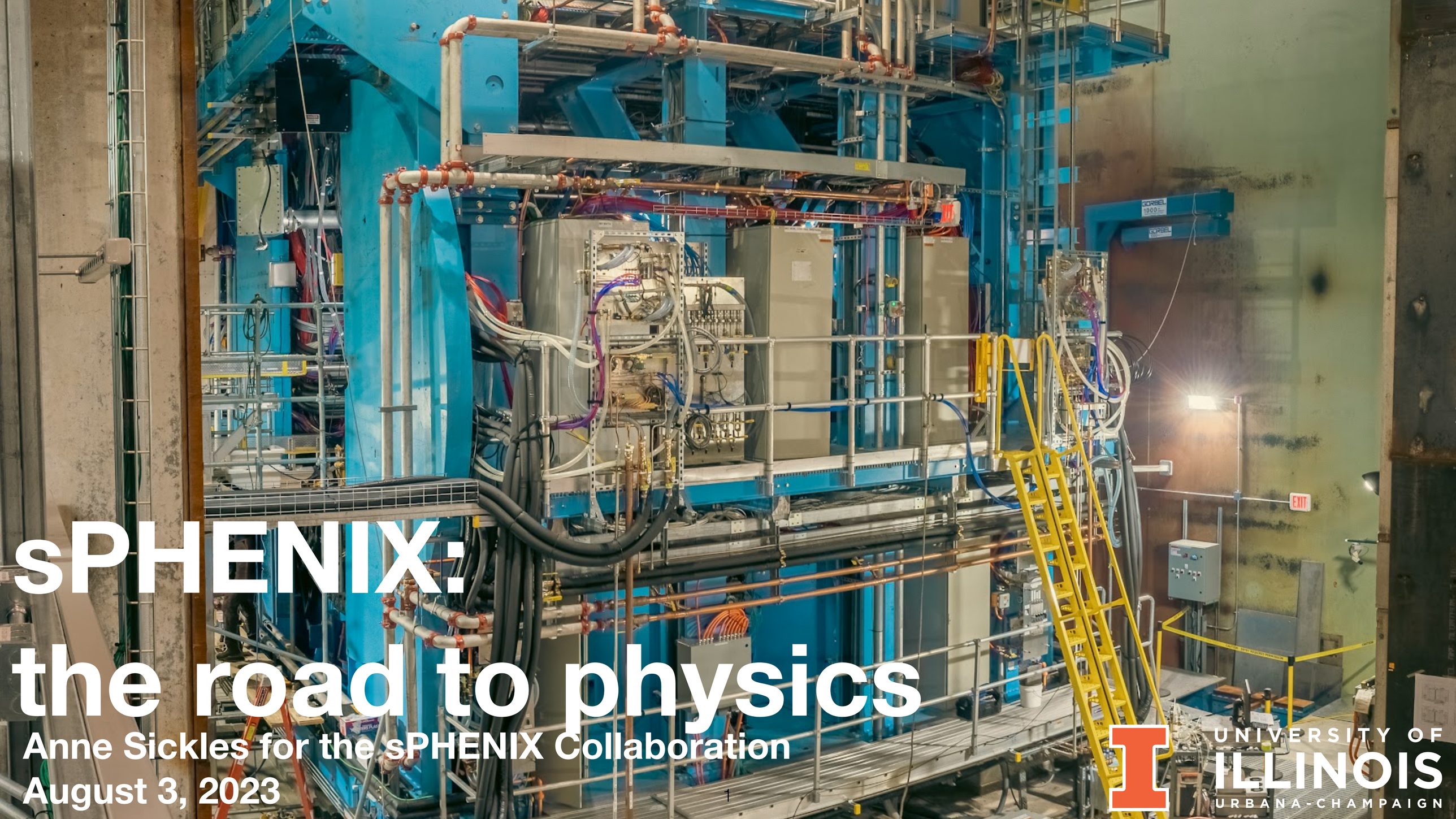


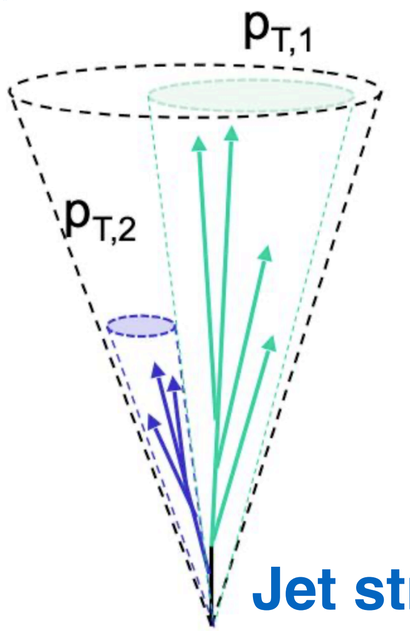
sPHENIX: the road to physics

Anne Sickles for the sPHENIX Collaboration

August 3, 2023

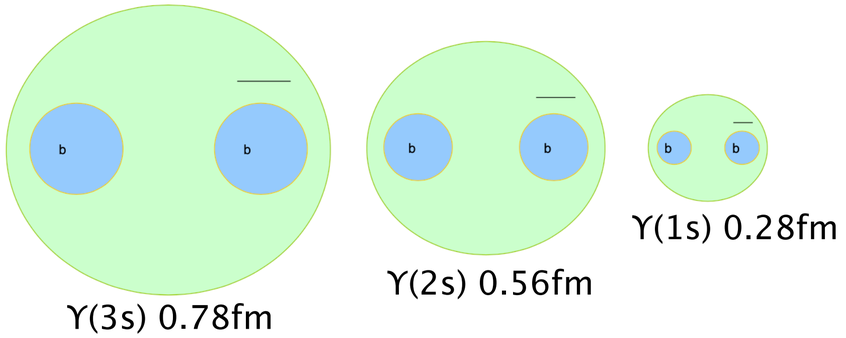
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

sPHENIX Program



Jet structure

vary momentum/angular scale of probe



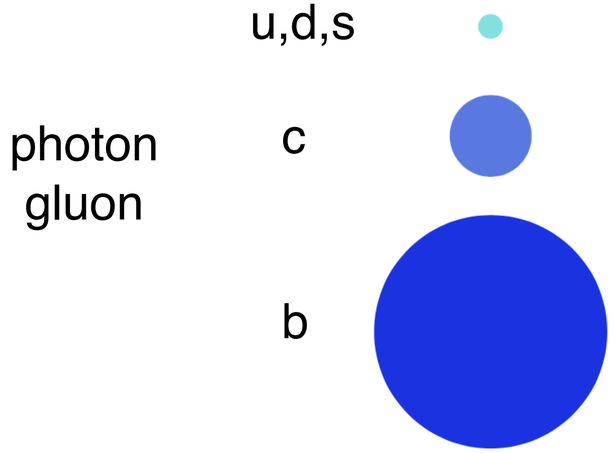
Quarkonium spectroscopy

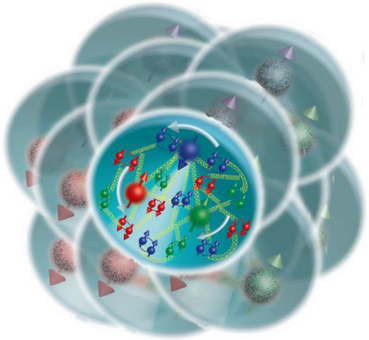
vary size of probe

sPHENIX

Parton energy loss

vary mass/momentum of probe

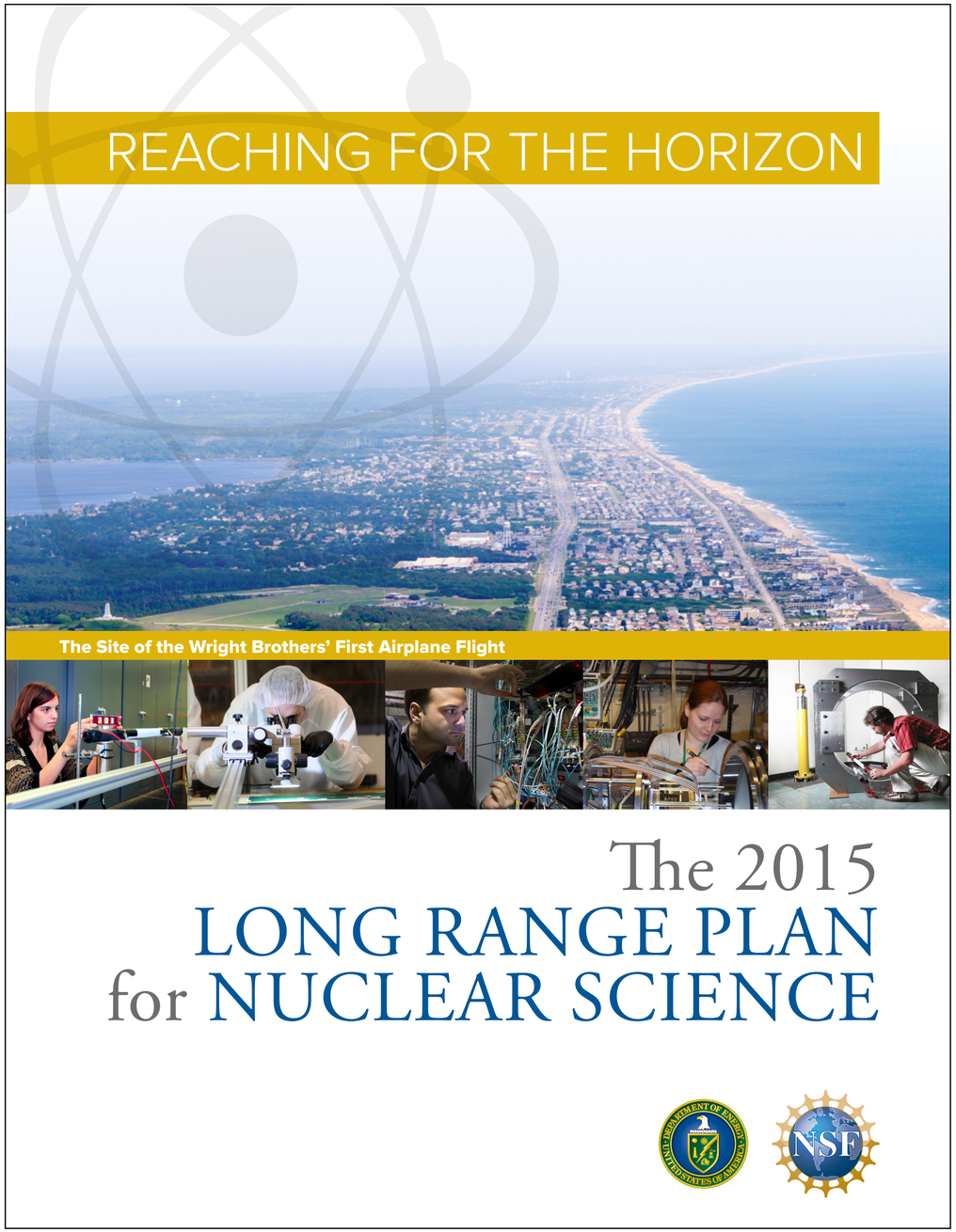




Cold QCD

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

sPHENIX



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.**

input to the 2023 Long Range Plan

The Present and Future of QCD

QCD Town Meeting White Paper – An Input to the 2023 NSAC Long Range Plan

arXiv: 2303.02579

Recommendation 1: Capitalizing on past investments *(Yes: 335; No: 3; No Answer: 4)*

The highest priority for QCD research is to maintain U.S. world leadership in nuclear science for the next decade by capitalizing on past investments. Maintaining this leadership also requires recruitment and retention of a diverse and equitable workforce.

We recommend support for a healthy base theory program, full operation of the CEBAF 12-GeV and RHIC facilities, and maintaining U.S. leadership within the LHC heavy-ion program, along with other running facilities, including the valuable university-based laboratories, and the scientists involved in all these efforts.

8

This includes the following, unordered, programs:

- The 12-GeV CEBAF hosts a forefront program of using electrons to unfold the quark and gluon structure of visible matter and probe the Standard Model. We recommend executing the CEBAF 12-GeV program at full capability and capitalizing on the full intensity potential of CEBAF by the construction and deployment of the Solenoidal Large Intensity Device (SoLID).
- The RHIC facility revolutionized our understanding of QCD, as well as the spin structure of the nucleon. To successfully conclude the RHIC science mission, it is essential to complete the sPHENIX science program as highlighted in the 2015 LRP, the concurrent STAR data taking with forward upgrade, and the full data analysis from all RHIC experiments.
- The LHC facility maintains leadership in the (heavy ion) energy frontier and hosts a program of using heavy-ion collisions to probe QCD at the highest temperature and/or energy scales. We recommend the support of continued U.S. leadership across the heavy ion LHC program.
- Theoretical nuclear physics is essential for establishing new scientific directions, and meeting the challenges and realizing the full scientific potential of current and future experiments. We recommend increased investment in the base program and expansion of topical programs in nuclear theory.

input to the 2023 Long Range Plan

The Present and Future of QCD

QCD Town Meeting White Paper – An Input to the 2023 NSAC Long Range Plan

arXiv: 2303.02579

Recommendation 1: Capitalizing on past investments *(Yes: 335; No: 3; No Answer: 4)*

The highest priority for QCD research is to maintain U.S. world leadership in nuclear science for the next decade by capitalizing on past investments. Maintaining this leadership also requires recruitment and retention of a diverse and equitable workforce.

We recommend support for a healthy base theory program, full operation of the CEBAF 12-GeV and RHIC facilities, and maintaining U.S. leadership within the LHC heavy-ion program, along with other running facilities, including the valuable university-based laboratories, and the scientists involved in all these efforts.

- The RHIC facility revolutionized our understanding of QCD, as well as the spin structure of the nucleon. To successfully conclude the RHIC science mission, it is essential to complete the sPHENIX science program as highlighted in the 2015 LRP, the concurrent STAR data taking with forward upgrade, and the full data analysis from all RHIC experiments.

This includes the following, unordered, programs:

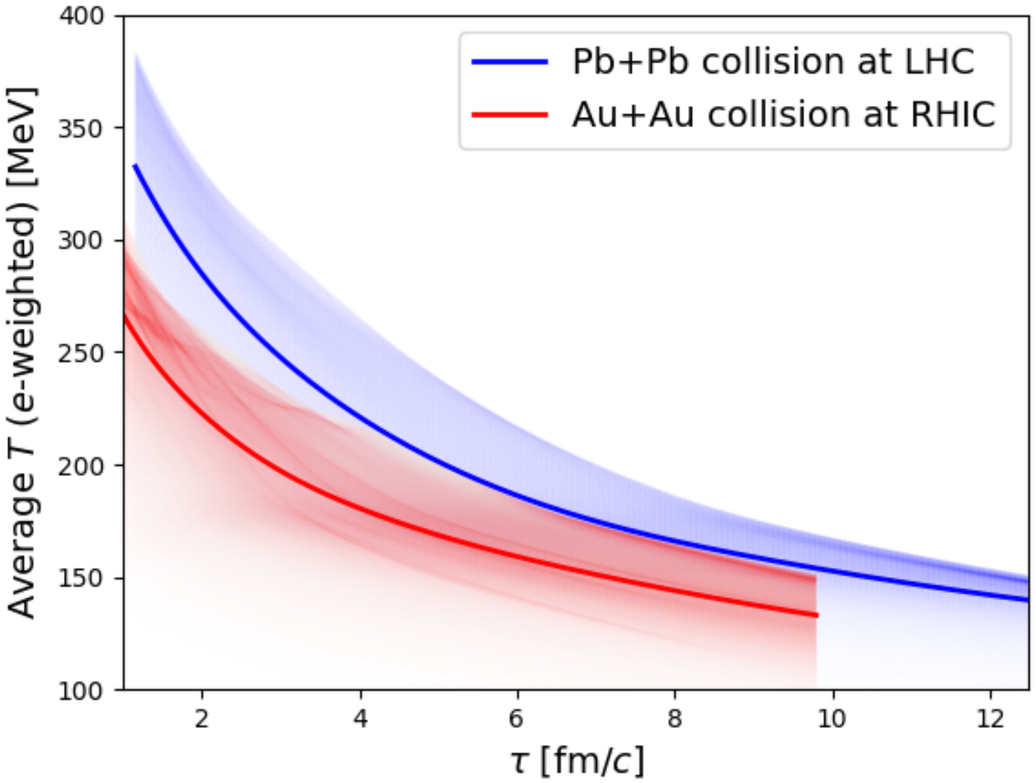
- The 12-GeV CEBAF hosts a forefront program of using electrons to unfold the quark and gluon structure of visible matter and probe the Standard Model. We recommend executing the CEBAF 12-GeV program at full capability and capitalizing on the full intensity potential of CEBAF by the construction and deployment of the Solenoidal Large Intensity Device (SoLID).
- The RHIC facility revolutionized our understanding of QCD, as well as the spin structure of the nucleon. To successfully conclude the RHIC science mission, it is essential to complete the sPHENIX science program as highlighted in the 2015 LRP, the concurrent STAR data taking with forward upgrade, and the full data analysis from all RHIC experiments.
- The LHC facility maintains leadership in the (heavy ion) energy frontier and hosts a program of using heavy-ion collisions to probe QCD at the highest temperature and/or energy scales. We recommend the support of continued U.S. leadership across the heavy ion LHC program.
- Theoretical nuclear physics is essential for establishing new scientific directions, and meeting the challenges and realizing the full scientific potential of current and future experiments. We recommend increased investment in the base program and expansion of topical programs in nuclear theory.

QGP at RHIC & the LHC

- different QGPs at RHIC & the LHC provide constraints on the temperature dependence of QGP properties

- the requires RHIC measurements which are as precise as at the LHC and which cover the widest possible kinematic range

QGP temperature (plot: Christopher Plumberg)



sPHENIX Run 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
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}

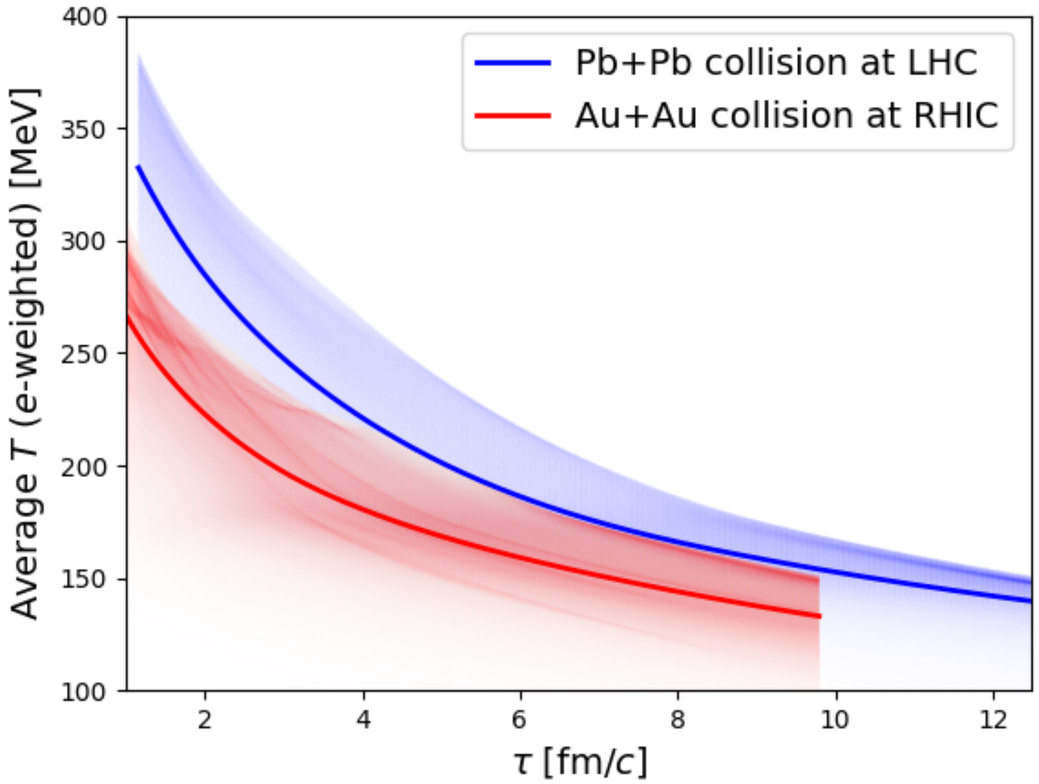
- 2023: Commissioning & first AuAu physics
- 2024:
  - pp data for HI reference and transverse spin measurements
  - pA data: cold QCD & small systems measurements
- 2025: High luminosity AuAu running, >140B MB AuAu collisions recorded

https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf

why jets at RHIC?

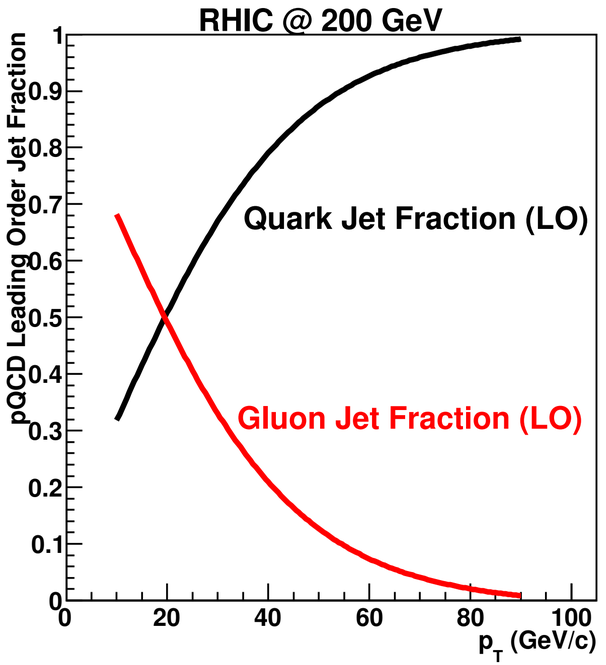
- Different QGP: lower temperatures, closer to the QGP transition

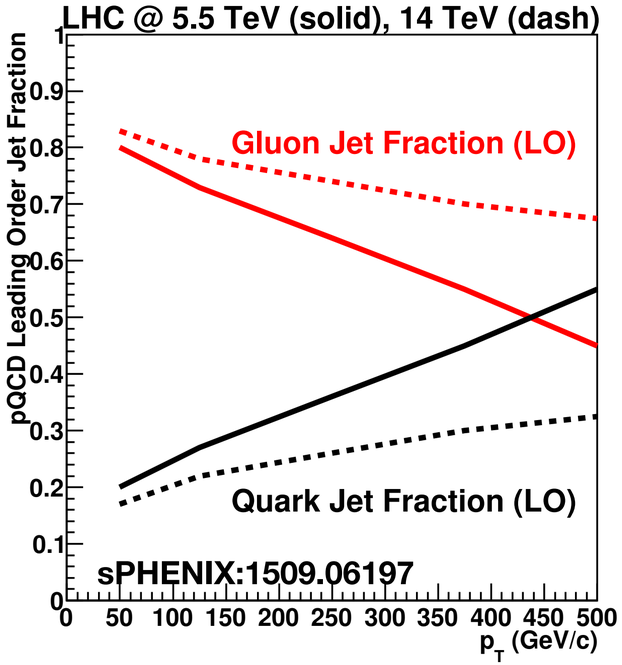
QGP temperature (plot: Christopher Plumberg)



why jets at RHIC?

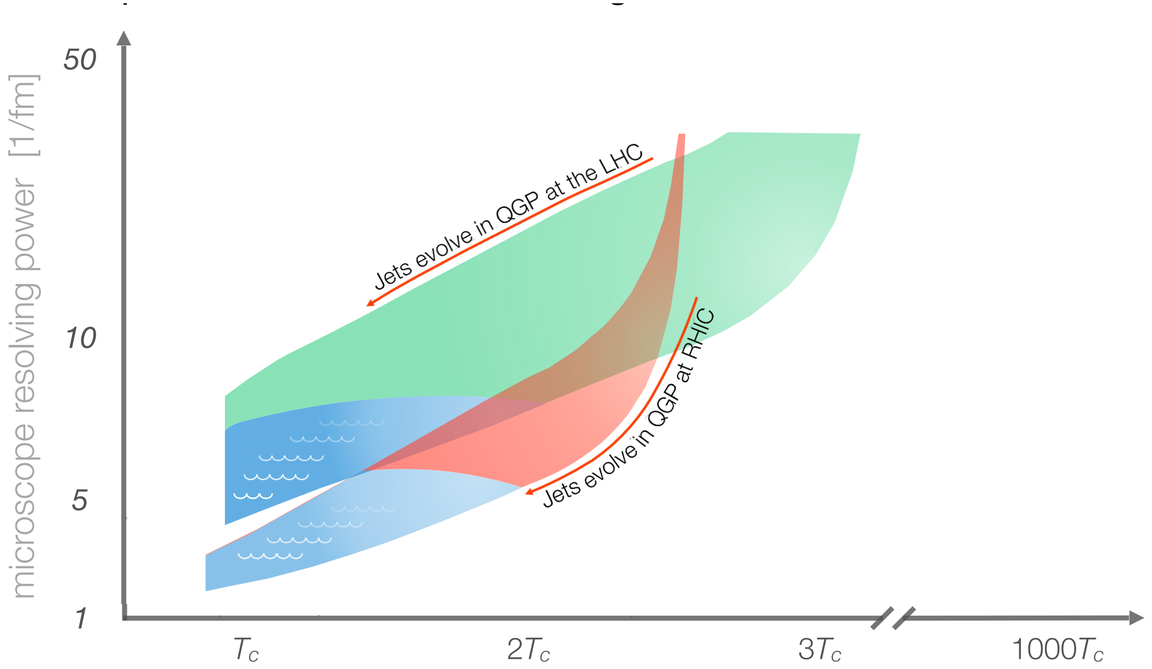
- Different QGP: lower temperatures, closer to the QGP transition
- Different jets: jet flavor composition at the lower collision energy





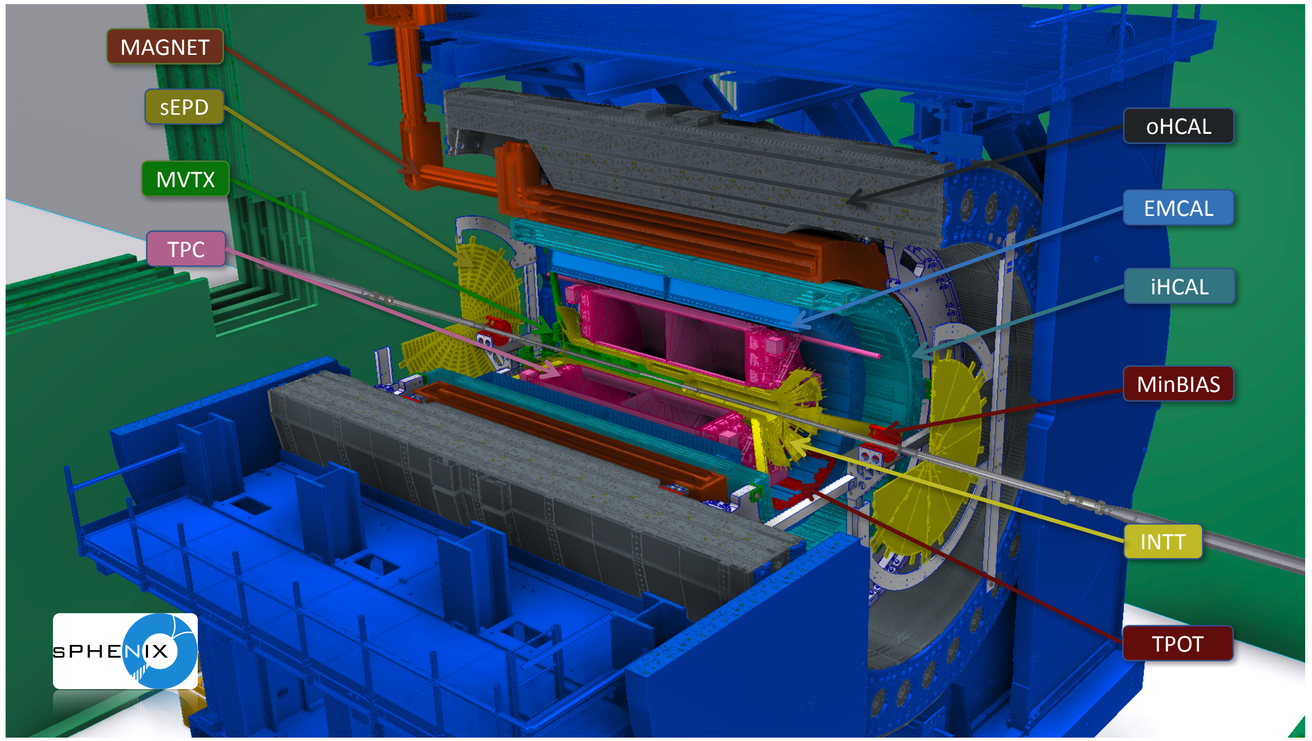
why jets at RHIC?

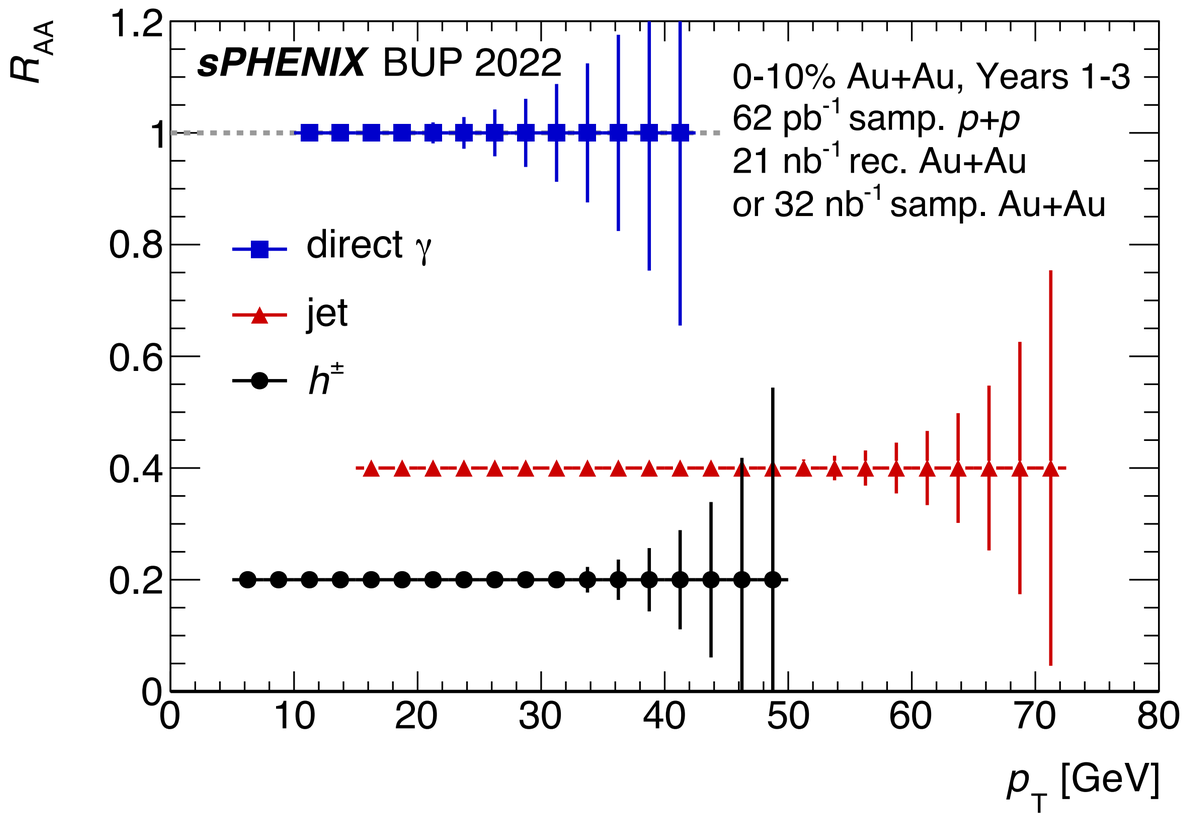
- Different QGP: lower temperatures, closer to the QGP transition
- Different jets: jet flavor composition at the lower collision energy
- Different QGP/jet interaction: lower energy jets are expected to spend more of their evolution interacting at QGP scales



jets evolve at **QGP scales** for a larger fraction of their evolution at **RHIC** than the **LHC**

jet measurements

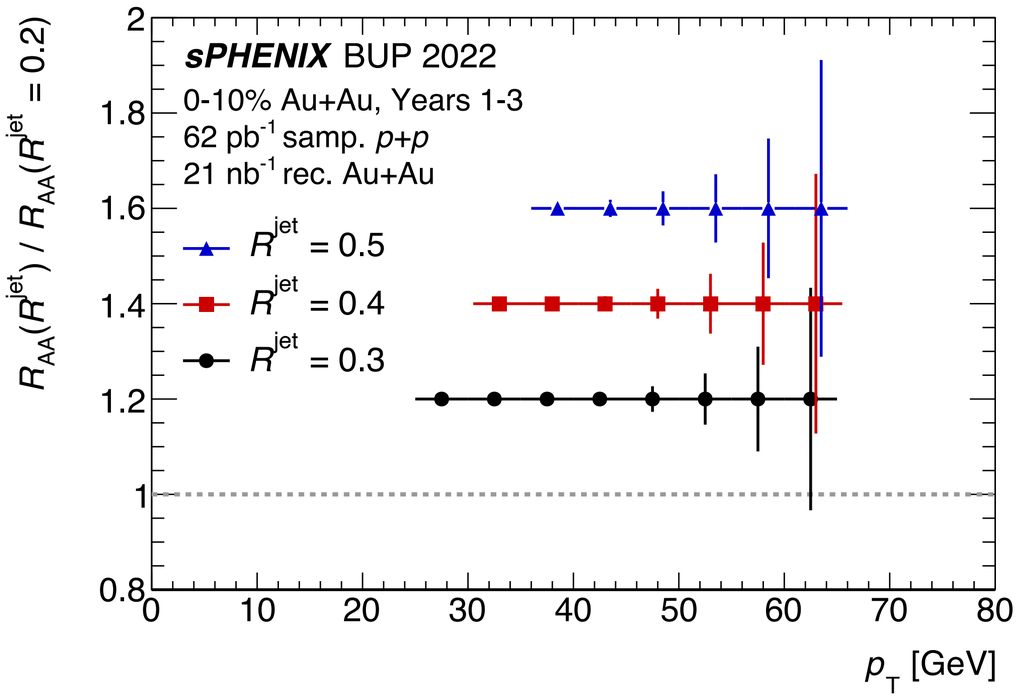


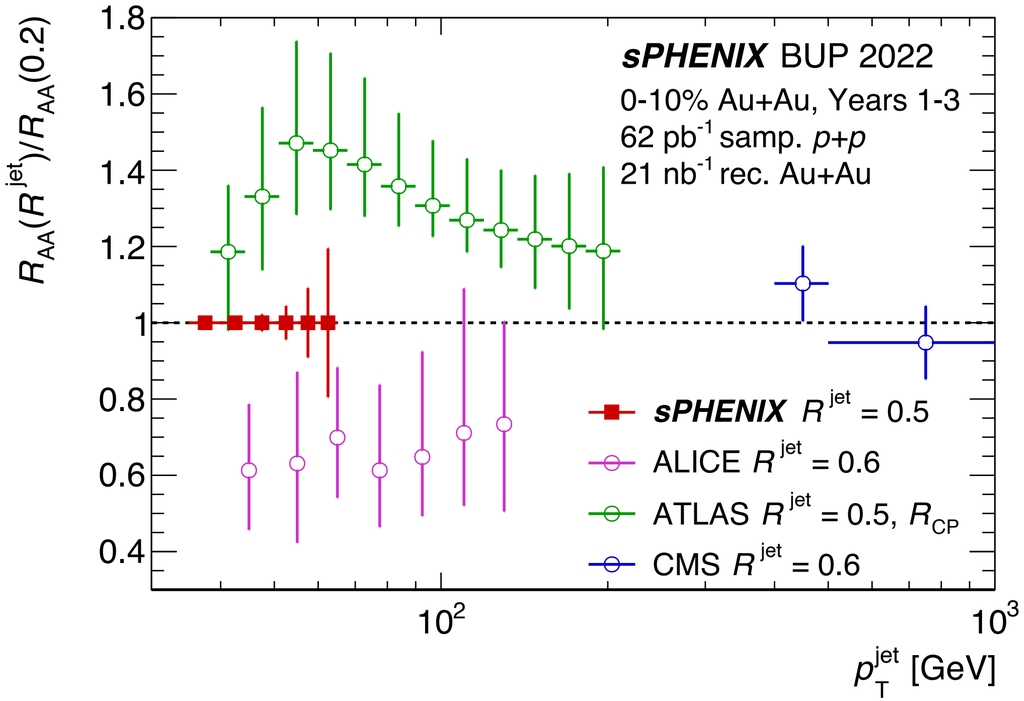


- calorimeter based jets allow for unbiased triggering and measurement of the full jet energy; access to nearly all the kinematic range at RHIC

https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf

jet radius dependent suppression





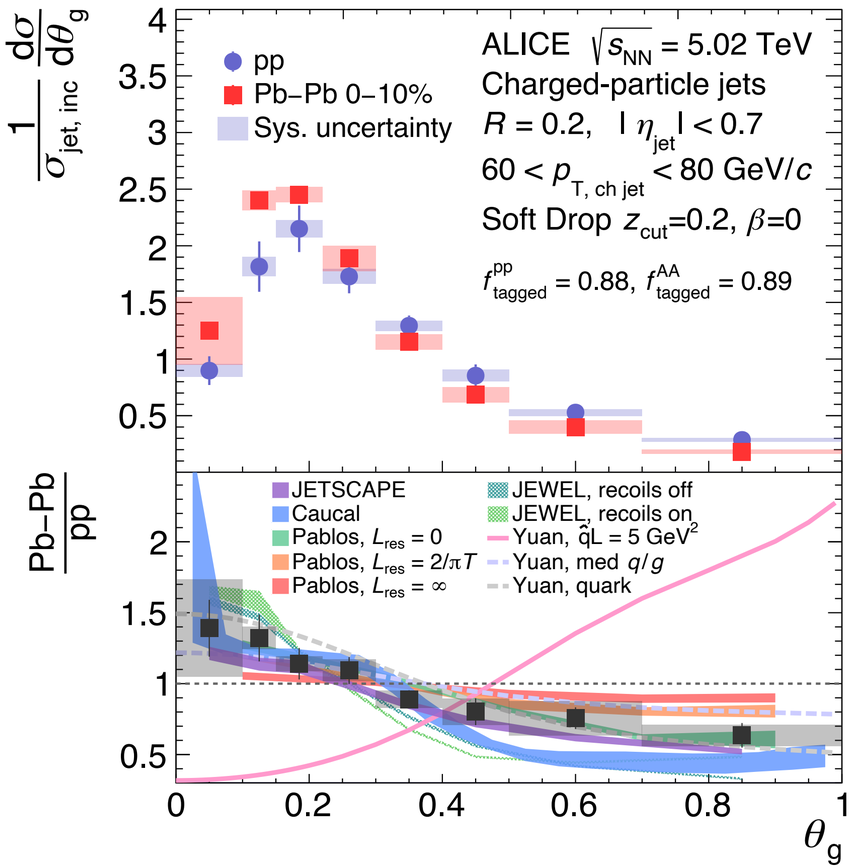
smaller UE event at RHIC helps the low p_T jet radius scan—an area where LHC measurements currently disagree

huge min-bias AuAu samples allow unbiased jet samples

https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf

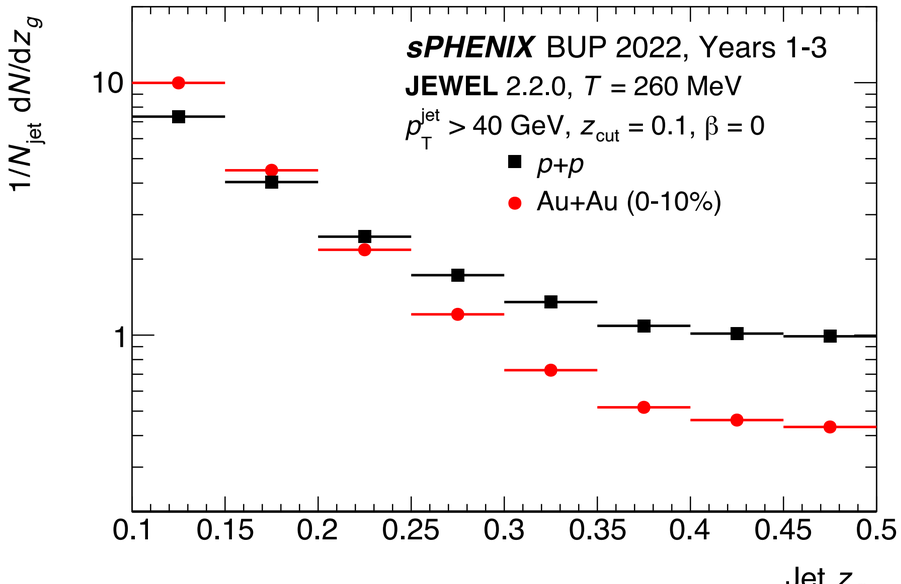
jet substructure

ALICE:2107.12984



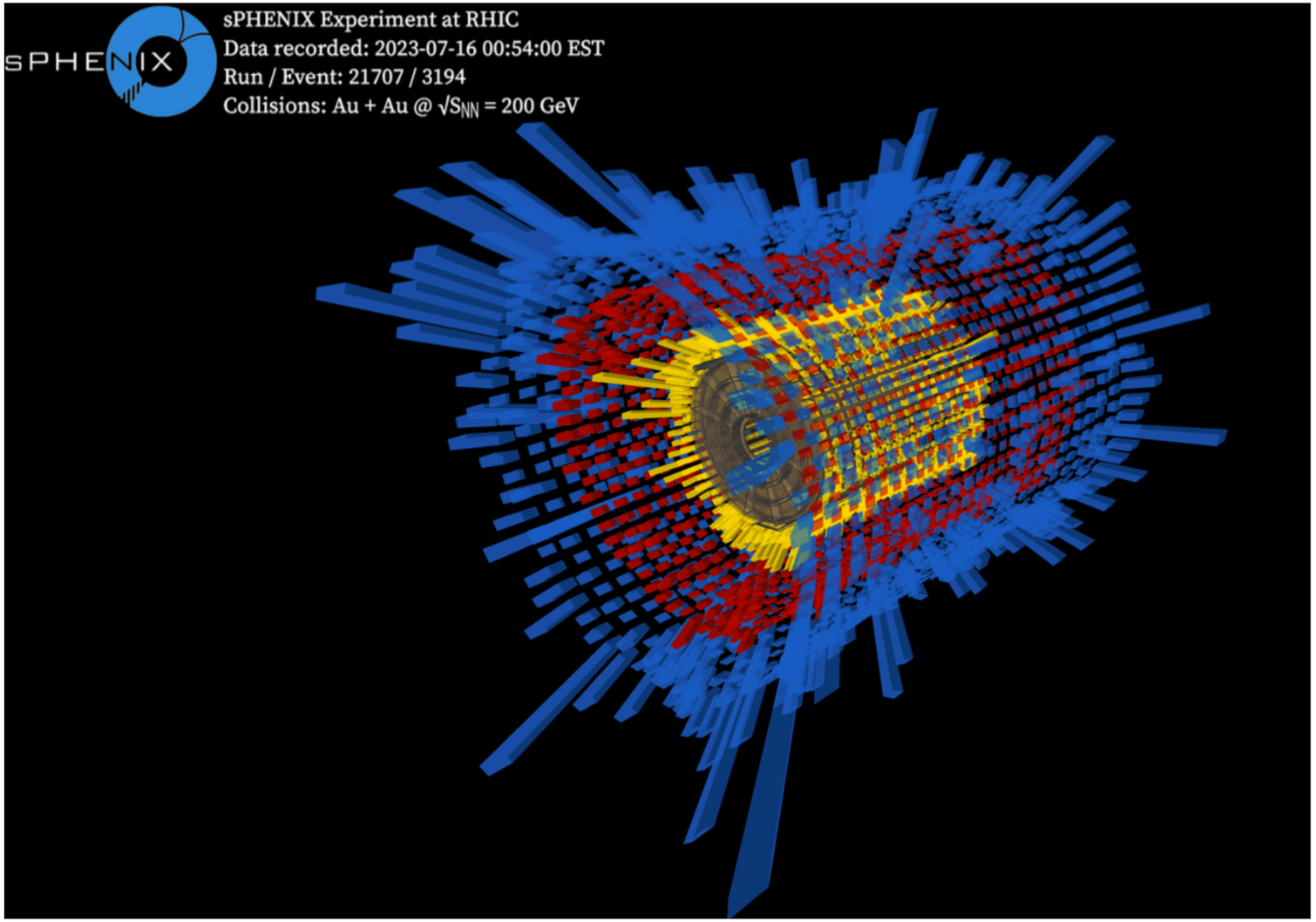
measurements of jet substructure provide information on how the QGP sees the developing parton shower

sPHENIX will be able to make a wide variety of substructure measurements with large data samples, excellent tracking & calorimetry

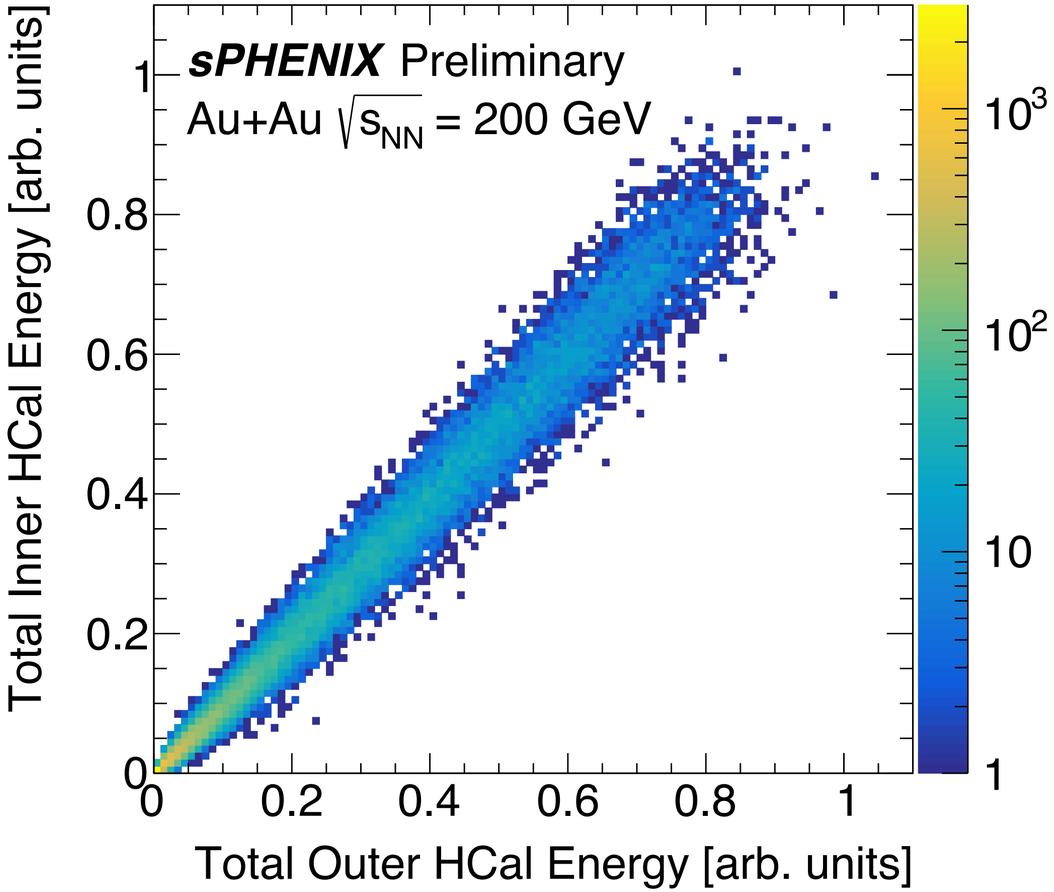


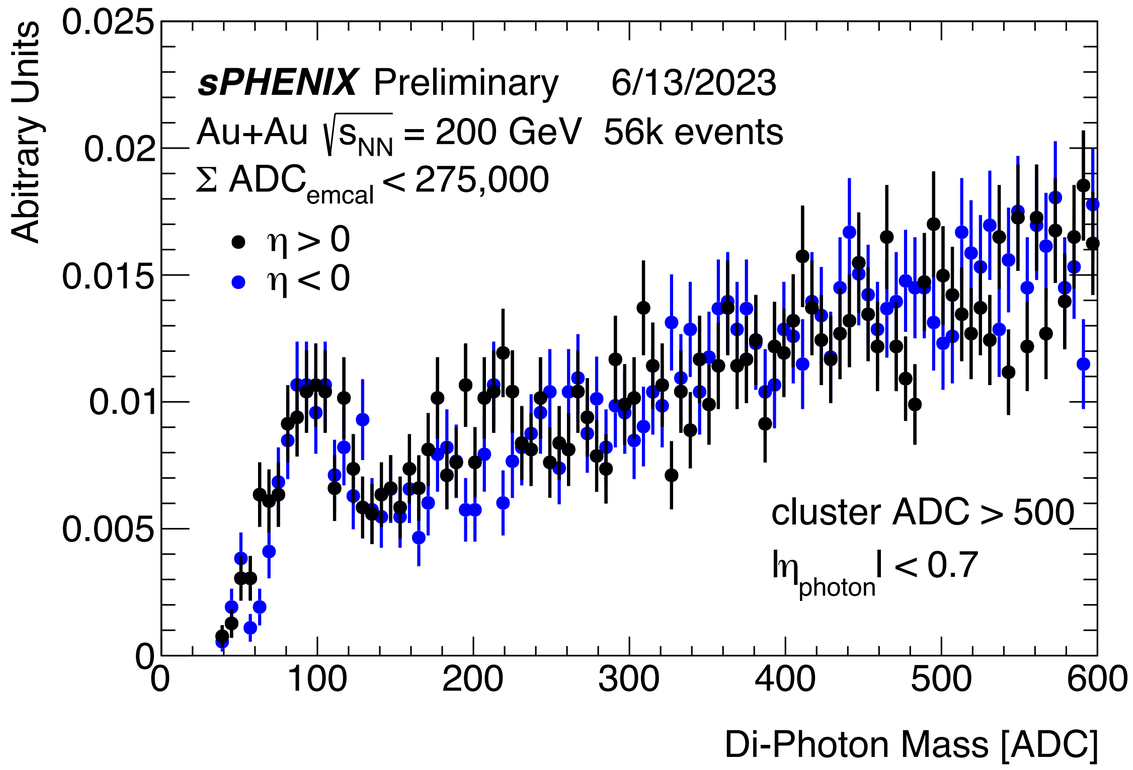
https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf

a AuAu collisions in the calorimeter



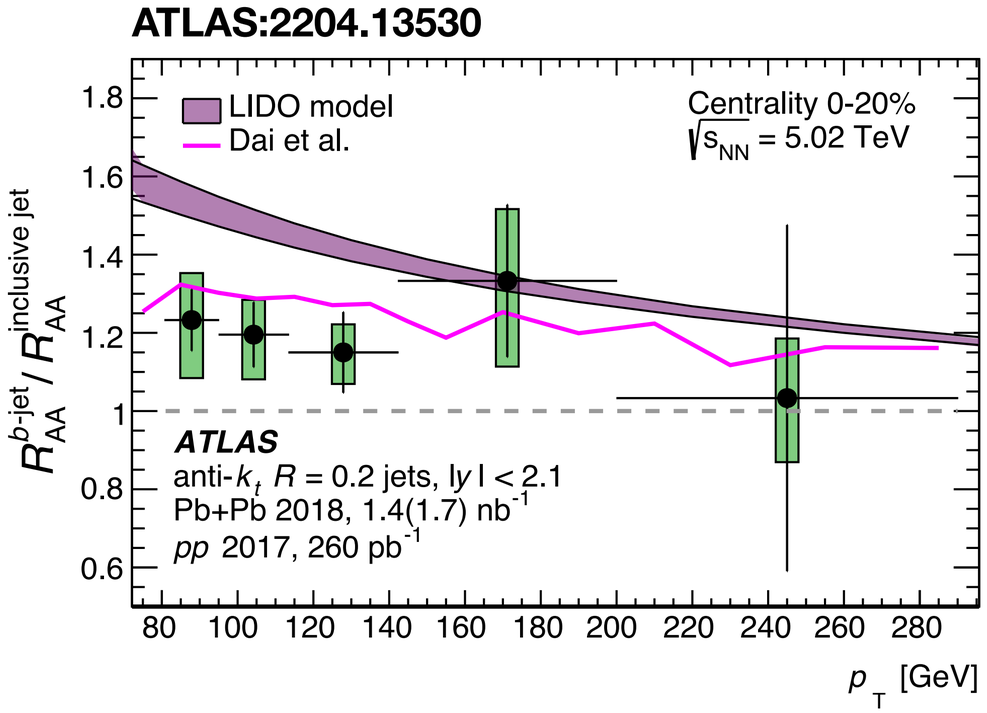
first calorimeter data

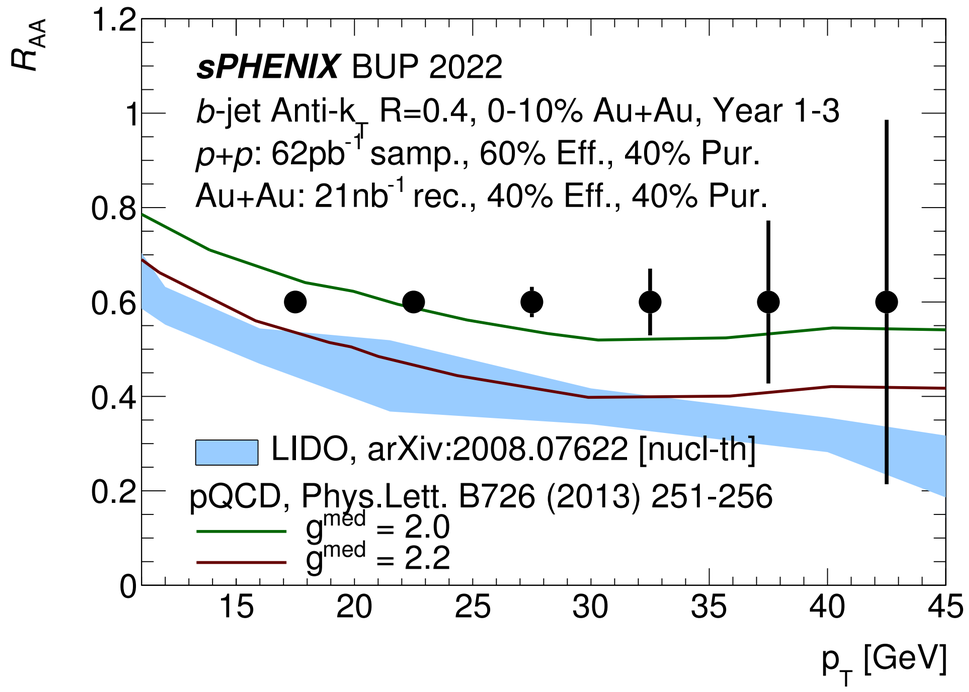




next steps: calibration & jet finding!

b-jet R_{AA}





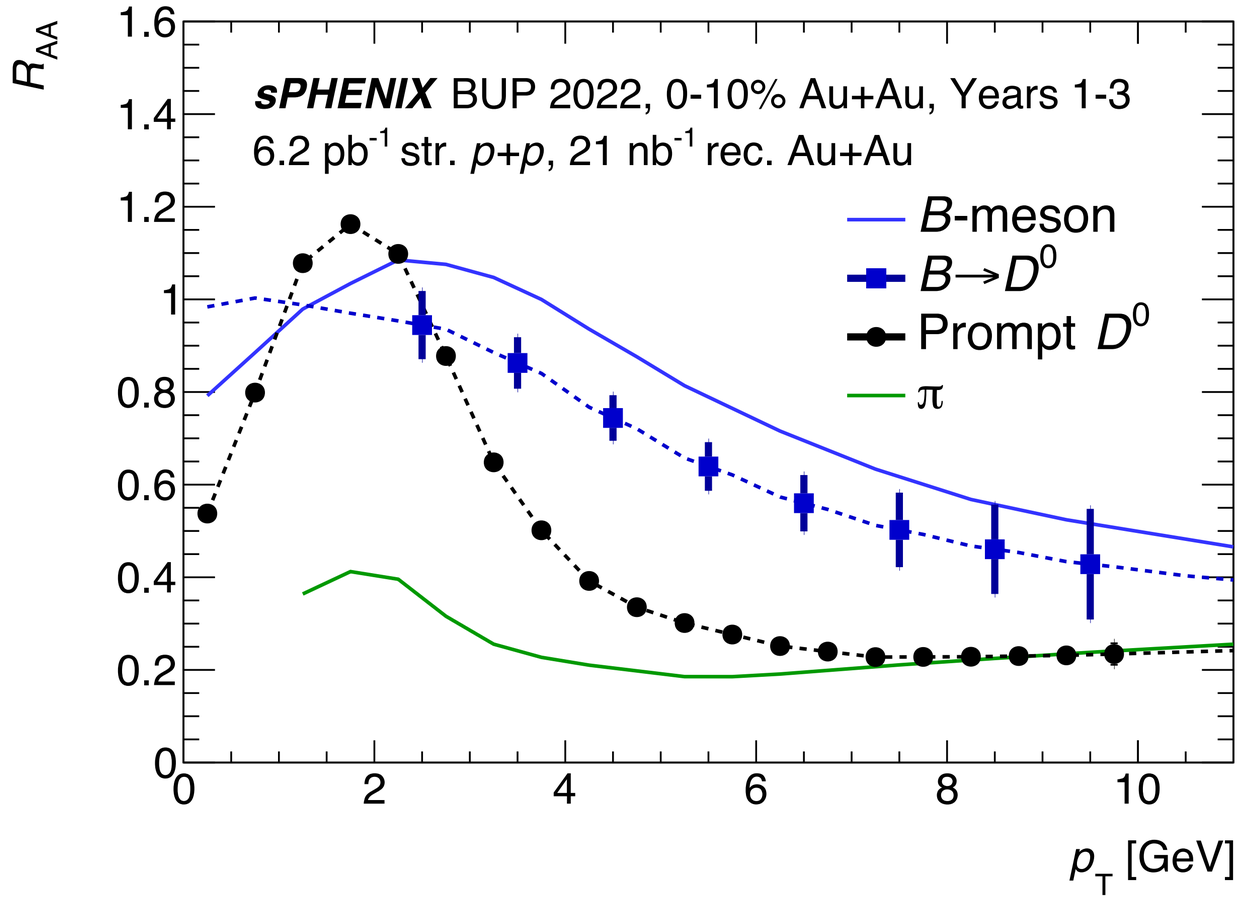
at the LHC, differences between inclusive and b-jet R_{AA} are expected from flavor effects (b-jets from gluon splitting) and mass effects (at the lower p_T end of the measurement)

sPHENIX data at much lower p_T will isolate the mass effects

open heavy flavor

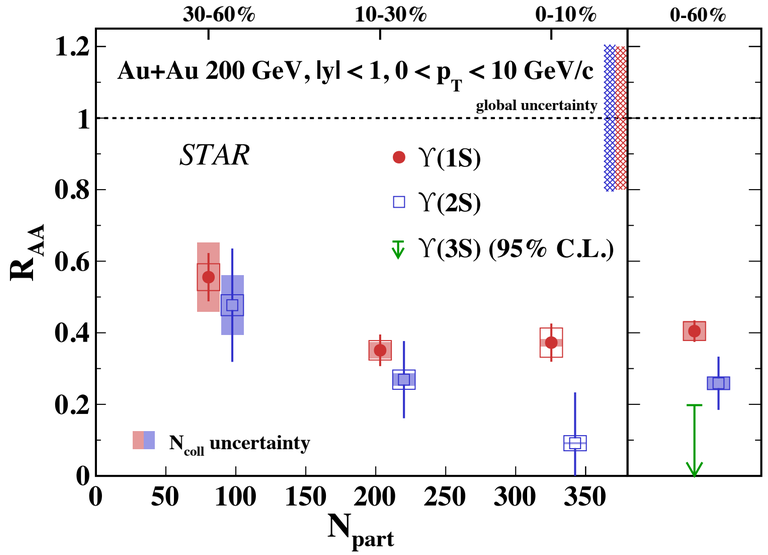
- reconstructed D0 measurements based on pp data available with **the streaming readout of the tracking detectors**.

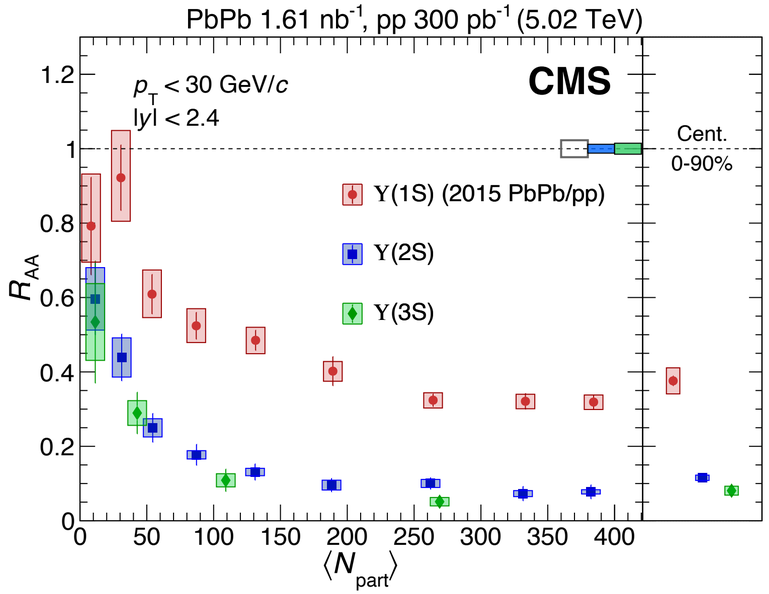
- big improvement in precision available at RHIC!

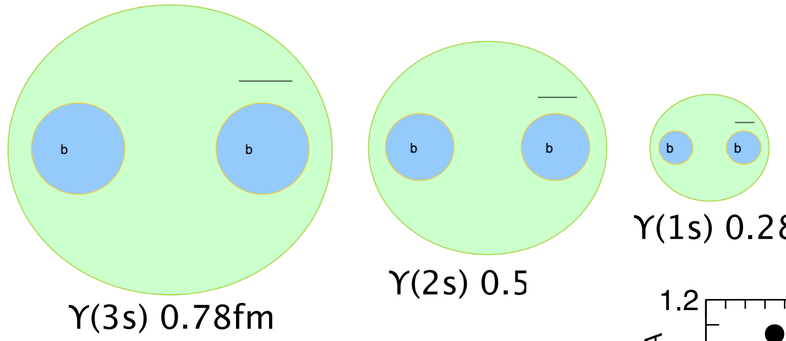


https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf

upsilons



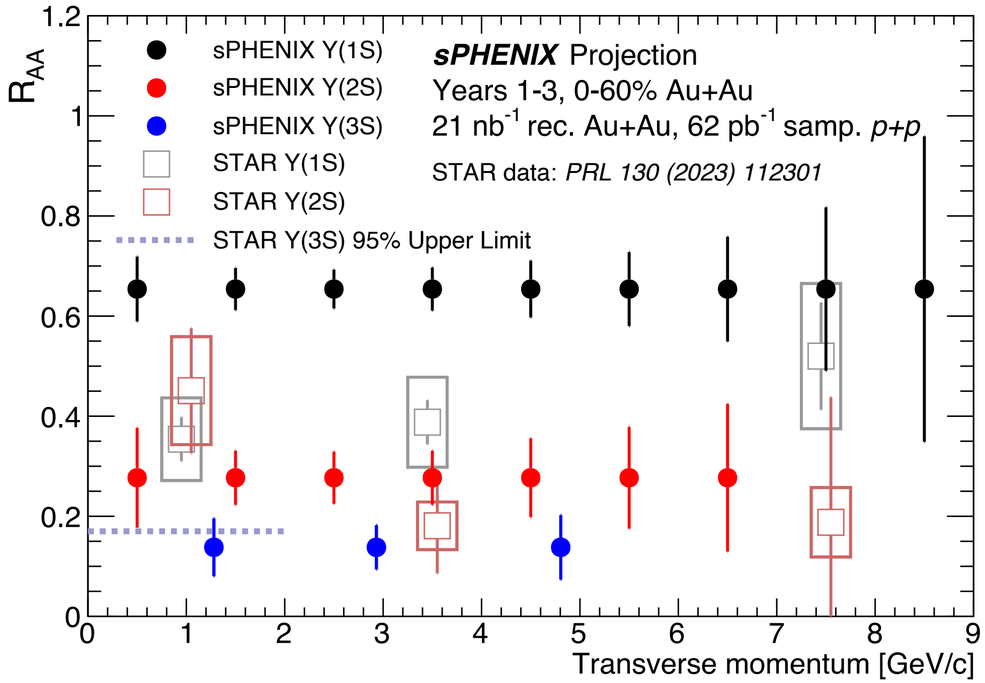




different suppression patterns observed at RHIC & the LHC

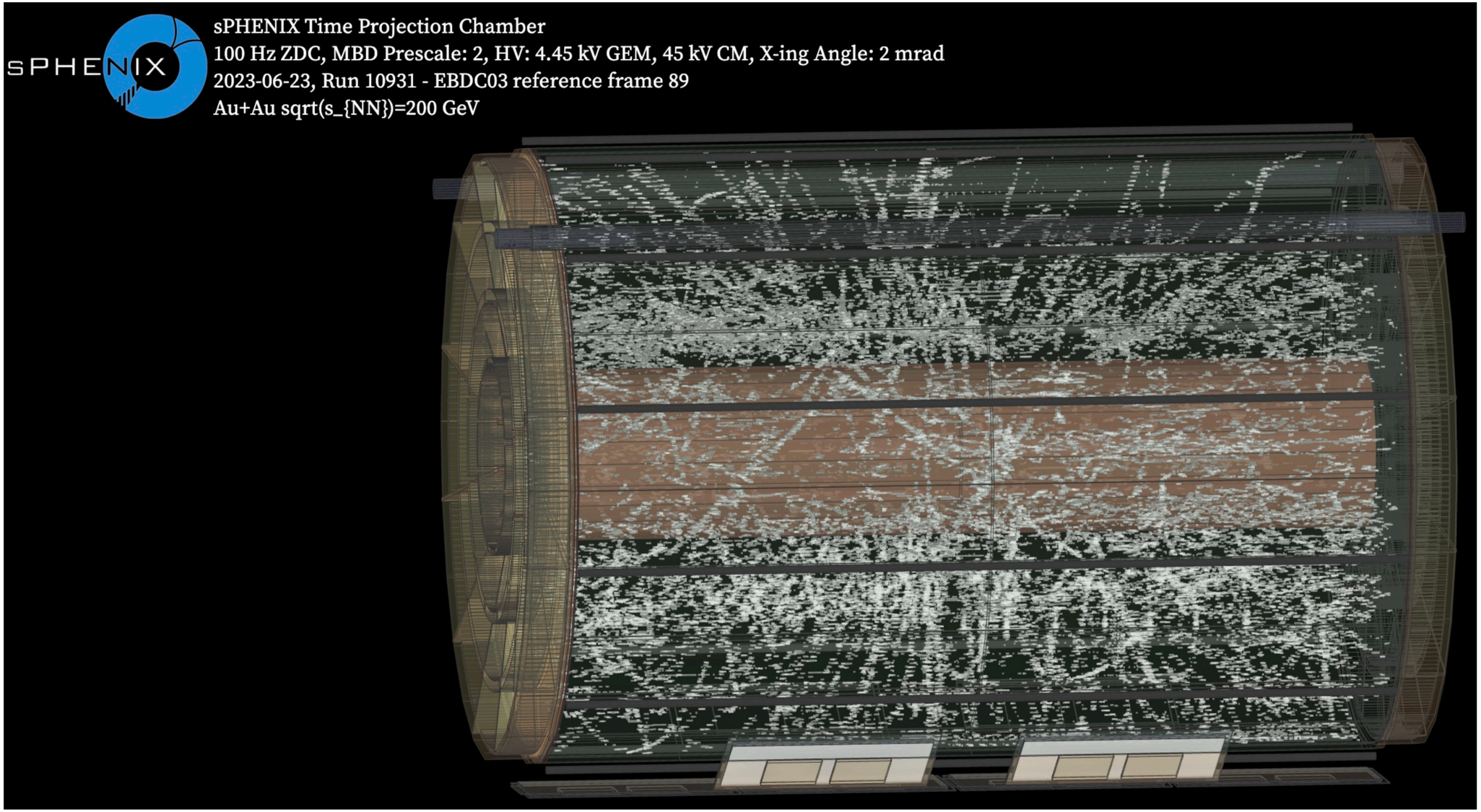
key to have full luminosity to fully exploit this channel!

suppression of the upsilon states sensitive to the QGP screening length



STAR:2207.06568, 2303.17026

TPC tracks from AuAu collision



pp running: essential hot QCD reference

BUP 2022: Years 1-3, 28 weeks/year

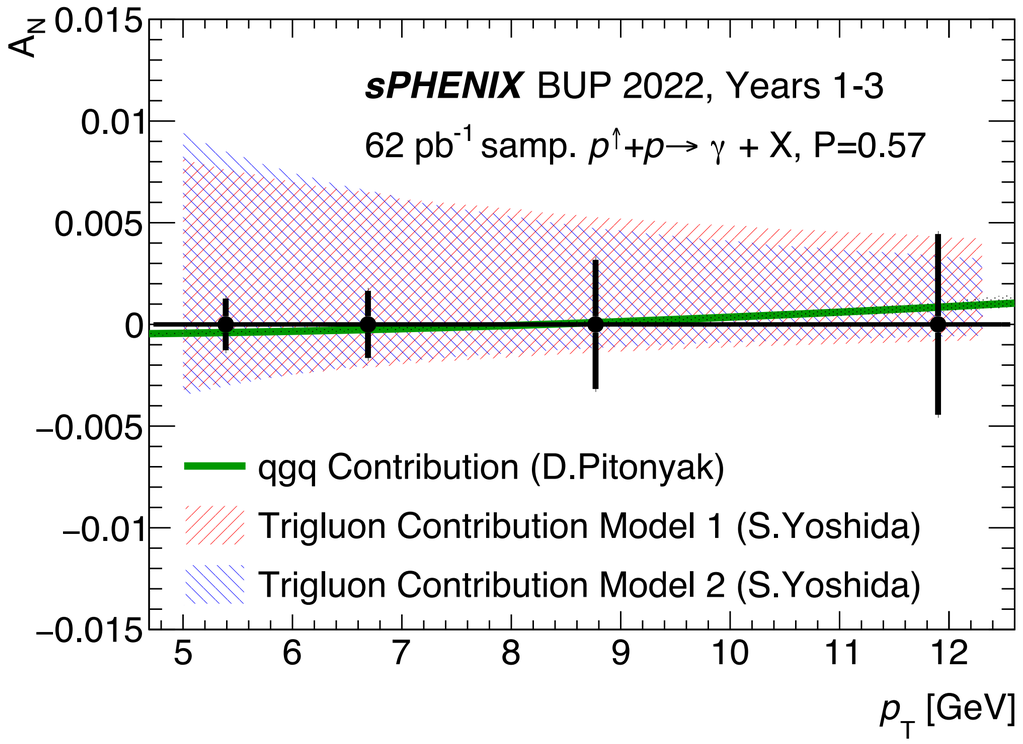
Signal	Au+Au 0–10% Counts	$p+p$ Counts
Jets $p_{\mathrm{T}} > 20$ GeV	22 000 000	11 000 000
Jets $p_{\mathrm{T}} > 40$ GeV	65 000	31 000
Direct Photons $p_{\mathrm{T}} > 20$ GeV	47 000	5 800
Direct Photons $p_{\mathrm{T}} > 30$ GeV	2 400	290
Charged Hadrons $p_{\mathrm{T}} > 25$ GeV	4 300	4 100

in many cases pp integrated luminosity drives the uncertainty in AuAu measurements
essential to make sure that this run is successful to enable precision hot QCD measurement

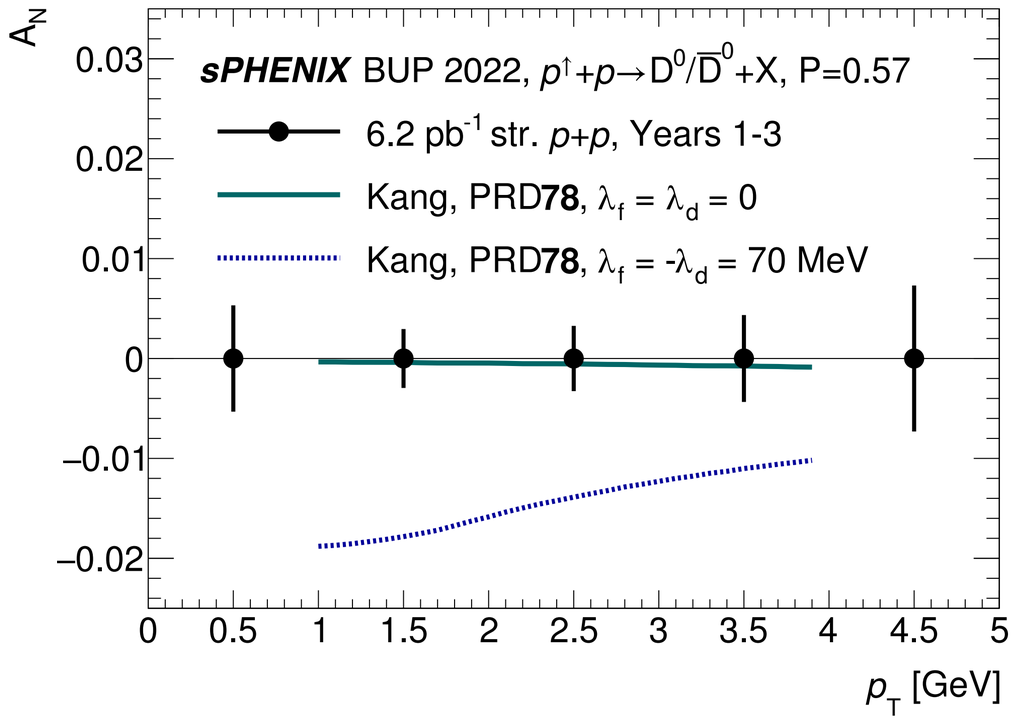
https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf

pp running: cold QCD physics

direct photons



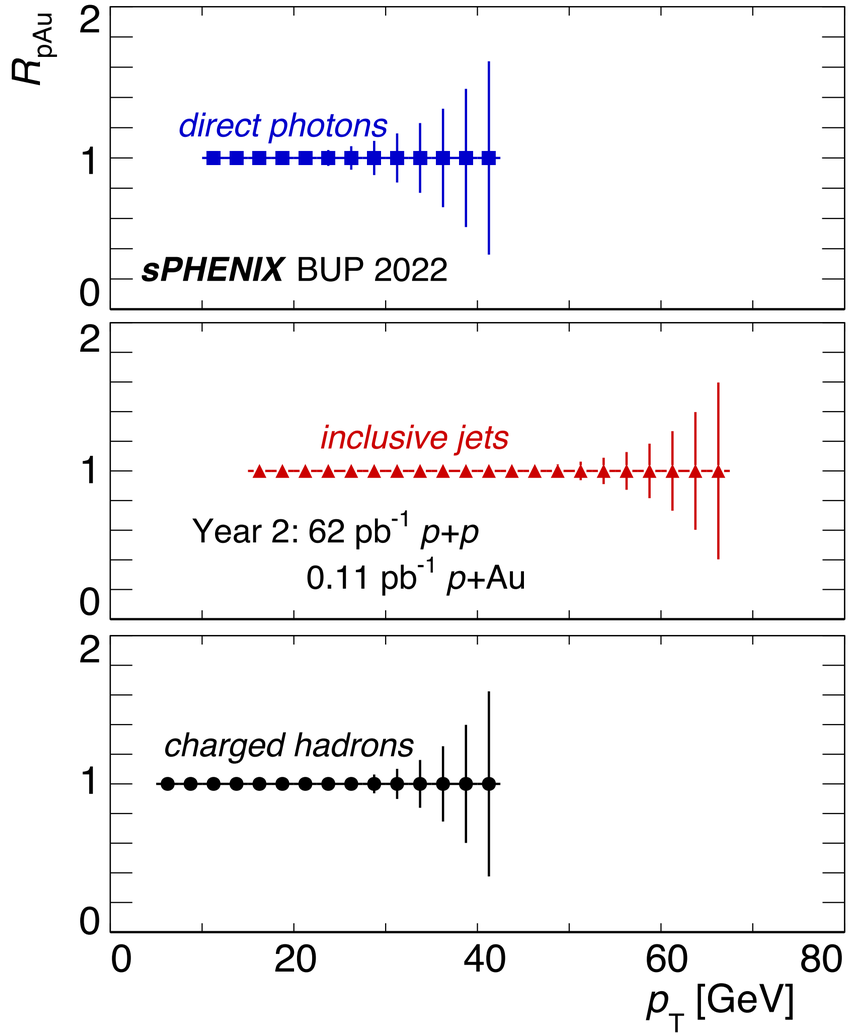
D-mesons



Use sPHENIX capabilities for transverse single spin asymmetries of direct photons and heavy flavor hadrons to probe gluon dynamics in transversely polarized nucleons through tri-gluon correlation function

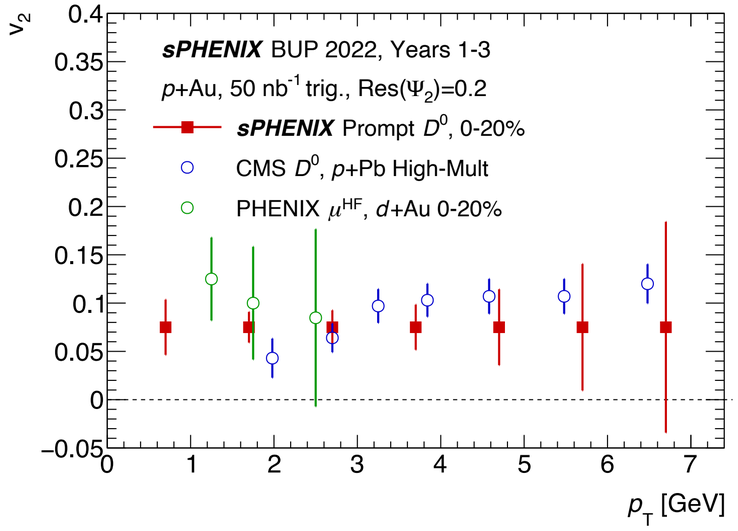
many other measurements planned in pp collisions!

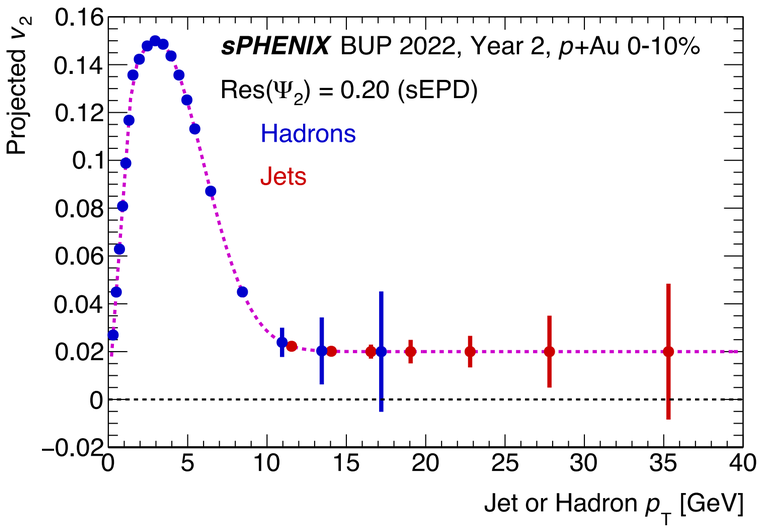
pA physics



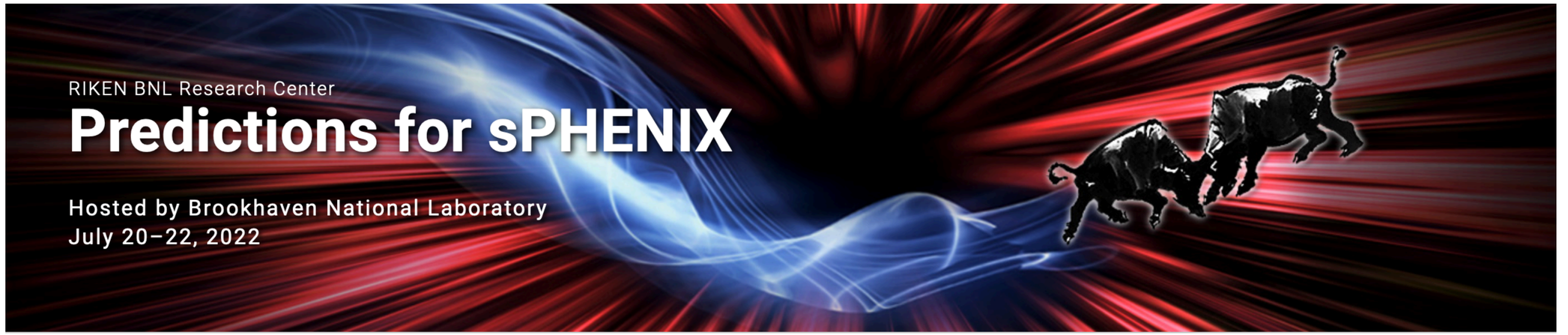
pA data has been very exciting over the last decade at both RHIC & the LHC

one highlight (out of many) for sPHENIX, high p_T v_2 for jets, hadrons & heavy flavor hadrons





https://indico.bnl.gov/event/15148/attachments/40846/68568/sPHENIX_Beam_Use_Proposal_2022.pdf



https://www.bnl.gov/sphenix2022/

experimentalists & theorists discussing how to maximize the sPHENIX physics program

2305.15491

Predictions for the sPHENIX physics program

Ron Belmont[a], Jasmine Brewer[b], Quinn Brodsky[c], Paul Caucal[d], Megan Connors[e,1], Magdalena Djordjevic[f], Raymond Ehlers[g,y,2], Miguel A. Escobedo[h,i], Elena G. Ferreiro[h], Giuliano Giacalone[j], Yoshitaka Hatta[k,l], Jack Holguin[m], Weiyao Ke[n], Zhong-Bo Kang[o], Amit Kumar[p,2], Aleksas Mazeliauskas[b,j], Yacine Mehtar-Tani[k,l,1], Genki Nukazuka[l,1], Daniel Pablos[q,r,s], Dennis V. Perepelitsa[t,1,*], Krishna Rajagopal[c], Anne M. Sickles[u,1], Michael Strickland[v], Konrad Tywoniuk[w], Ivan Vitev[n], Xin-Nian Wang[y], Zhong Yang[x], Fanyi Zhao[o]

workshop summary available! looking forward to comparing the predictions to data soon!

sPHENIX

summary

- sPHENIX collaboration is excited to be in the midst of our first data taking period
- the collaboration working hard to commission the detector and begin our physics program
- please go talk to the young people doing the work at the poster session!

more sPHENIX talks/posters

- sPHENIX Run 23 Report—Stefan Bathe—today, 10am
- sPHENIX Jet program (workshop talk)--Anthony Hodges
- Heavy flavor physics (workshop talk)—Antonio Carlos Oliveira da Silva
- sPHENIX Detector (workshop talk)—Ejiro Umaka
- sPHENIX Calorimeters (workshop talk)—Hanpu Jiang
- sPHENIX Tracking (workshop talk)—Joseph Bertaux
- Construction and Installation of sEPD (poster)—Micah Meskowitz—today, 6:00pm
- Tracking in Jets for the sPHENIX cold-QCD Program (poster)—Athira Vijayakumar—today, 6:00pm
- Performance and Commissioning of sPHENIX MBD (poster)—Lameck Mwibanda—today, 6:00pm
- Heavy Flavor Physics in sPHENIX (poster)—Antonio Carlos Oliveira da Silva—today, 6:00pm
- Commissioning of sPHENIX Intermediate Silicon Tracker (poster)—Jaein Hwang—today, 6:00pm
- Commissioning Status of the sPHENIX EMCal (poster)—Abraham Holtermann—today, 6:00pm

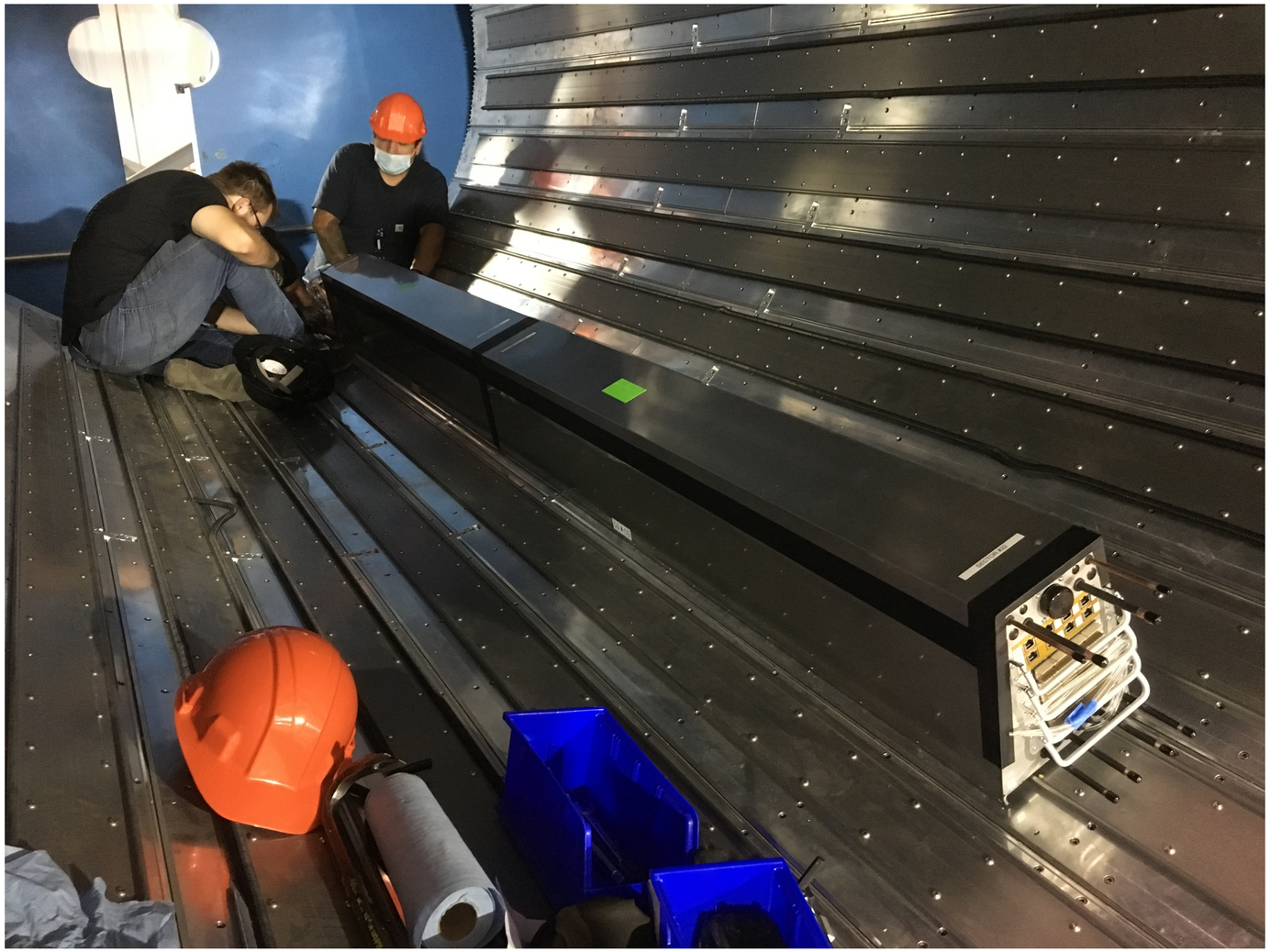
backup

possible extra running

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}

should the opportunity arise, sPHENIX could increase the pp luminosity, explore light ions and take a lot more AuAu data

EMCal insallation

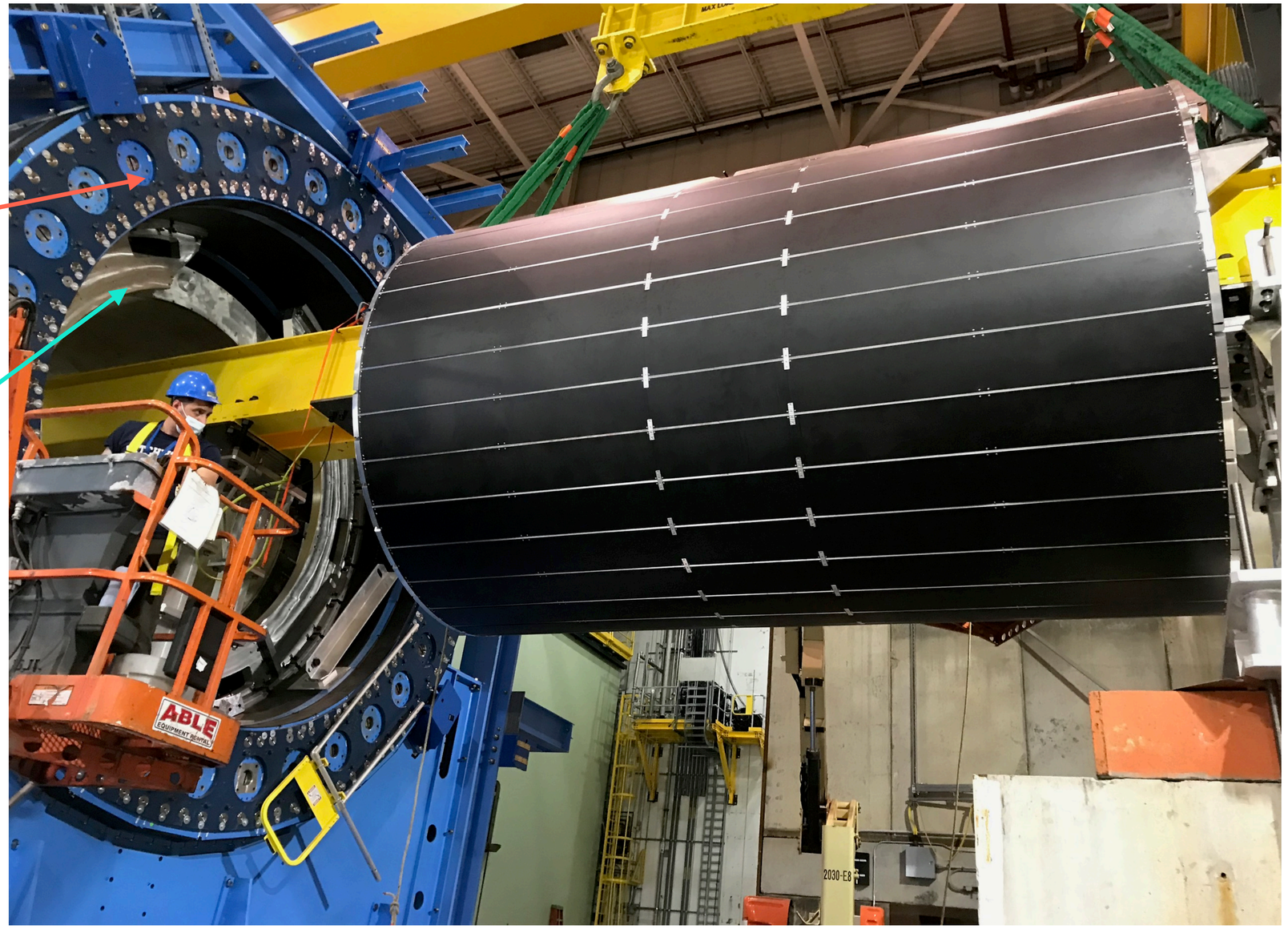


First 2 EMCal sectors installed into the Inner HCal earlier this week!

Inner HCal installation

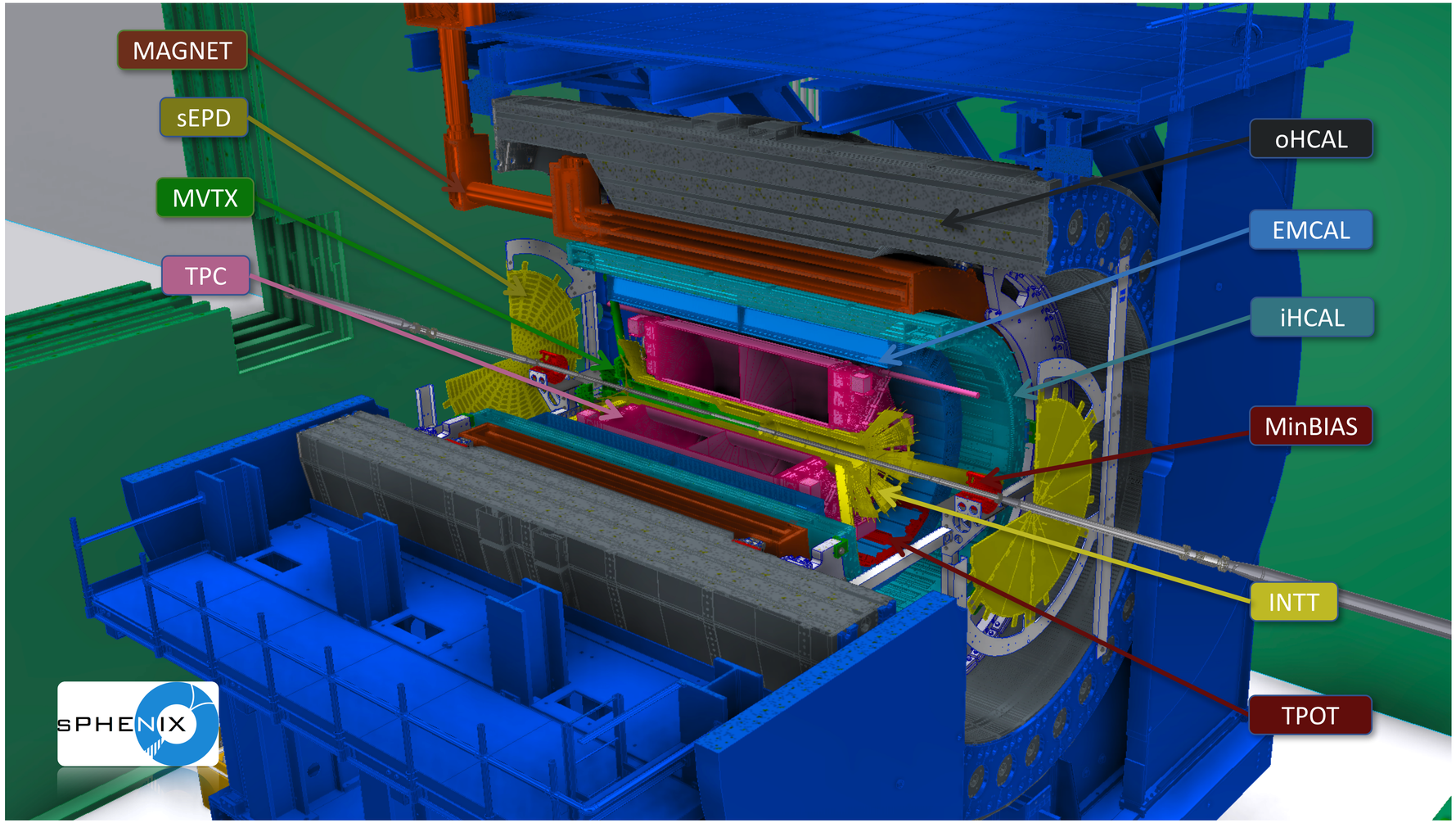
Outer HCal

Solenoid



June 2022

sPHENIX Detector



- large, uniform acceptance
- full electromagnetic and hadronic calorimetry
- high precision tracking/ vertexing
- huge AuAu samples, without biased triggered

optimized for hard probes and unique among RHIC experiments!

sPHENIX