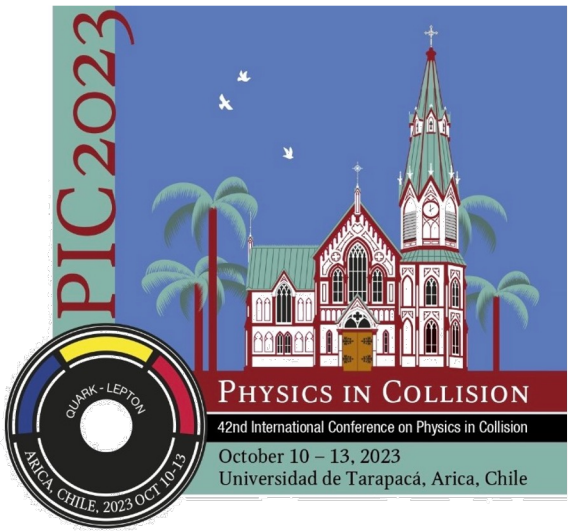
The sPHENIX Experiment at RHIC

Anthony Hodges *for* the sPHENIX Collaboration

Physics in Collision 2023

October 12th, 2023

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

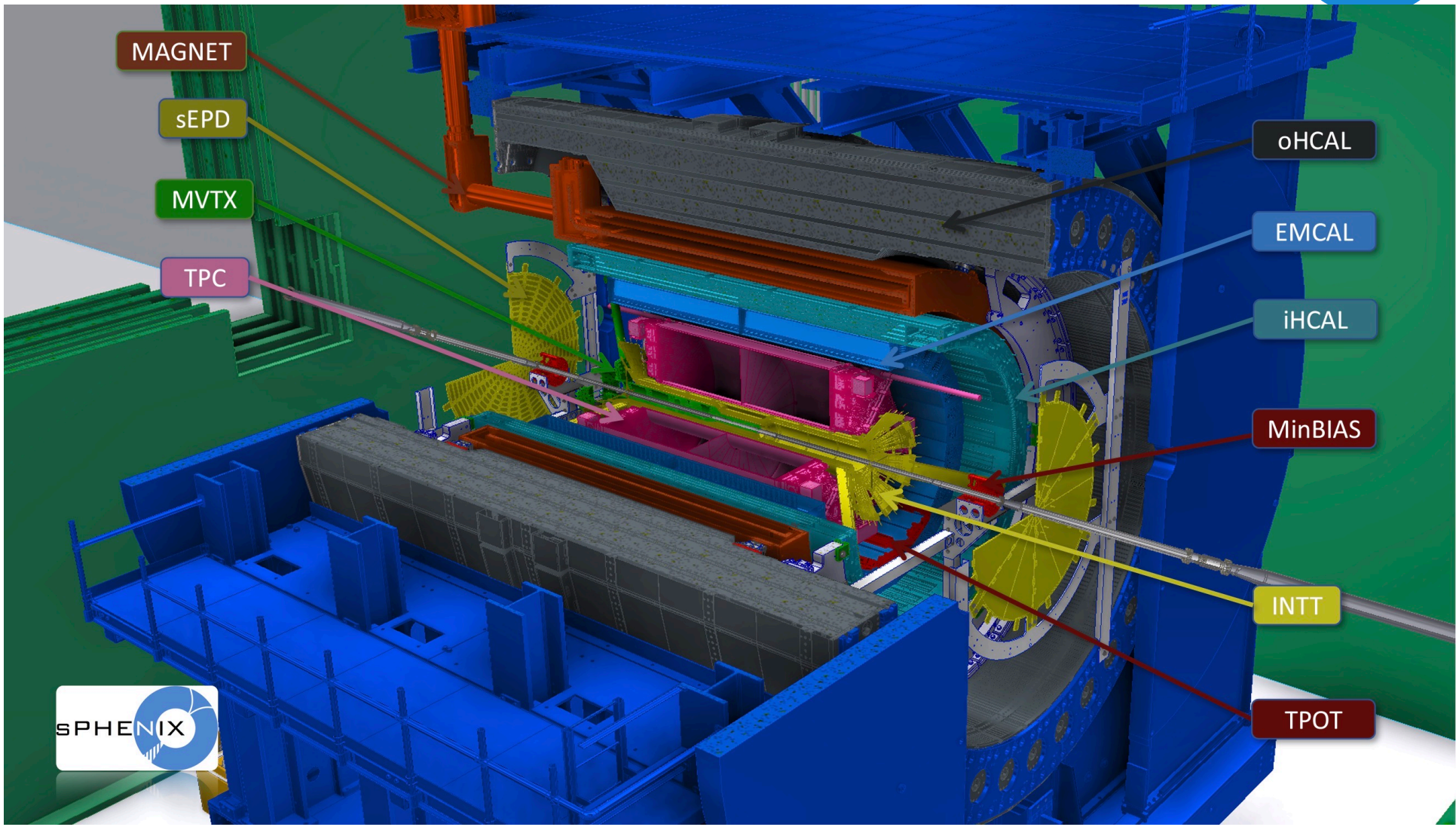


NSF Ascend Fellow

The sPHENIX Detector at RHIC

Features of sPHENIX:

- Large acceptance
  - 2π azimuth
  - $|\eta| < 1.1$
- Full EM and hadronic calorimetry
- Highly precise tracking, vertex, and DCA determination
- 1.4 T Superconducting solenoidal Magnet
- High-luminosity, build for rare probes measurements



The sPHENIX Science Mission

"The Present and Future of QCD"

- 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.

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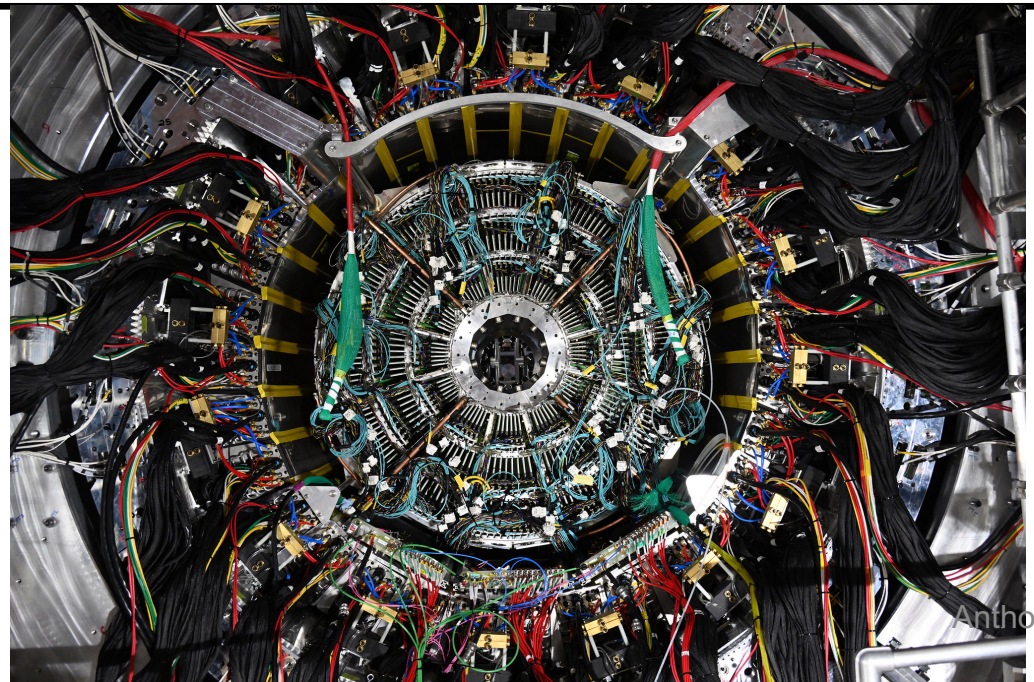

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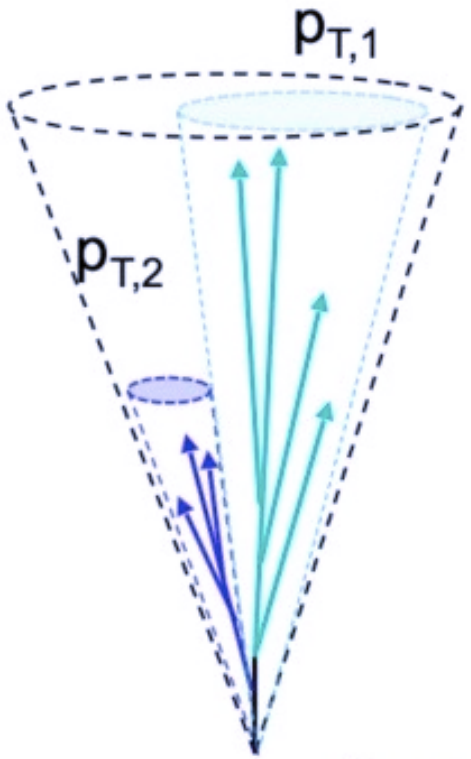
The sPHENIX Physics Program

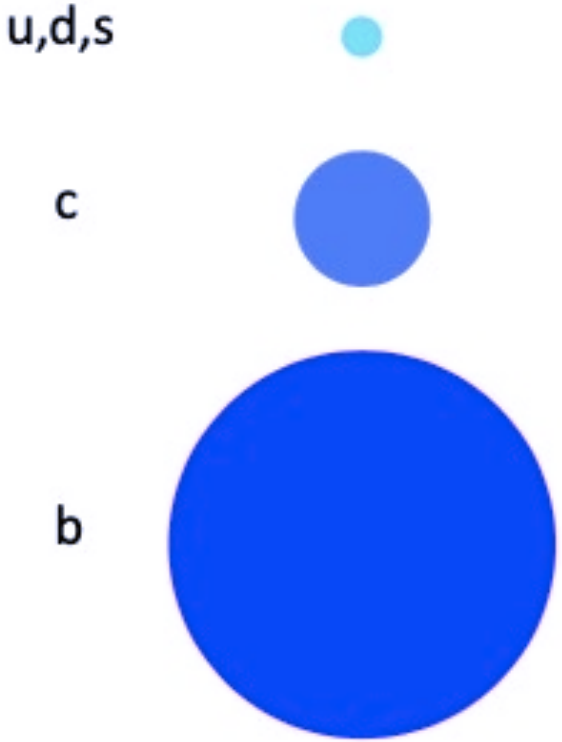
Jet structure

vary momentum/angular scale of probe



Parton energy loss

vary mass/momentum of probe

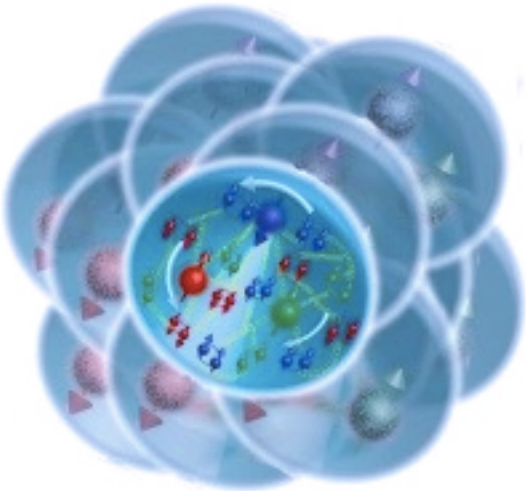


Quarkonium spectroscopy

vary size of probe

Cold QCD

study proton spin, transverse-momentum, and nuclear effects



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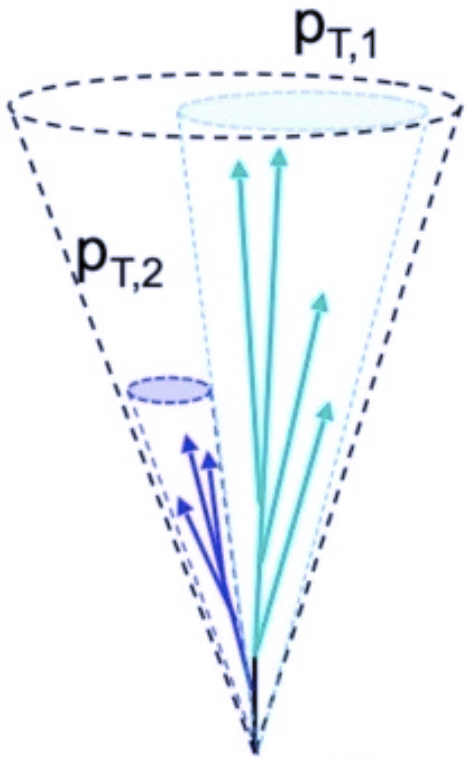

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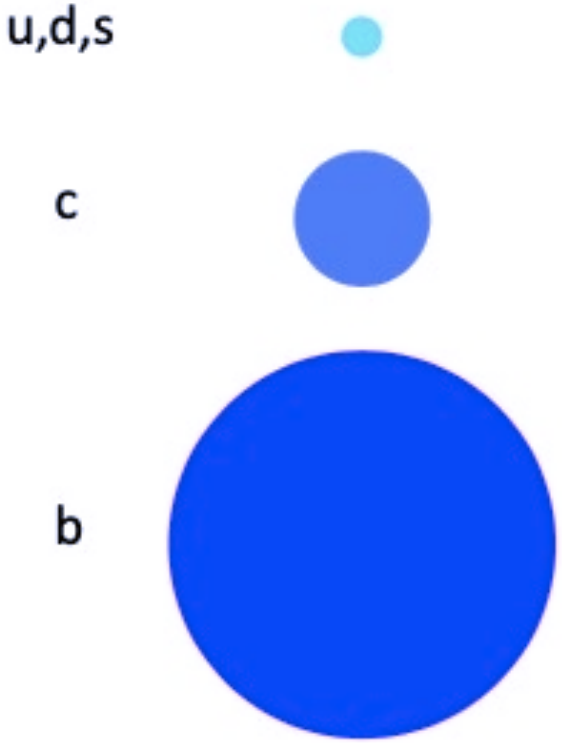

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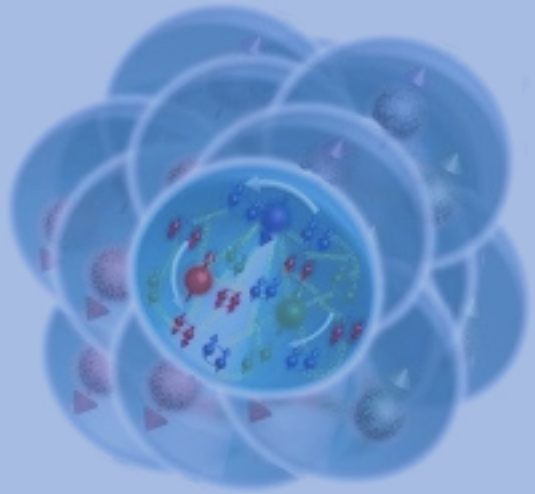
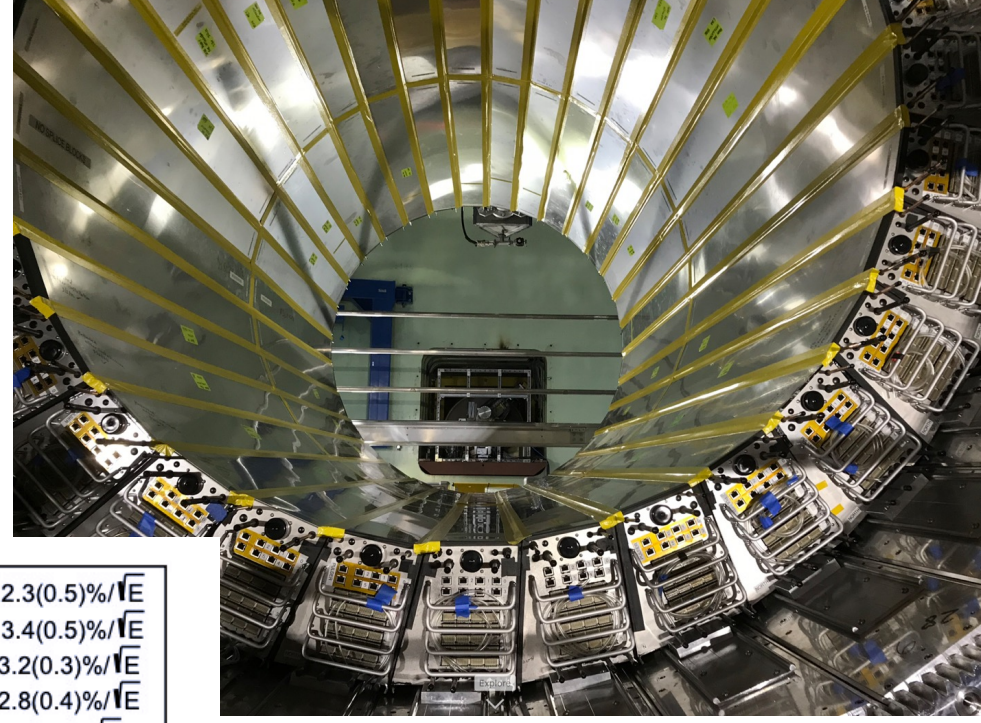
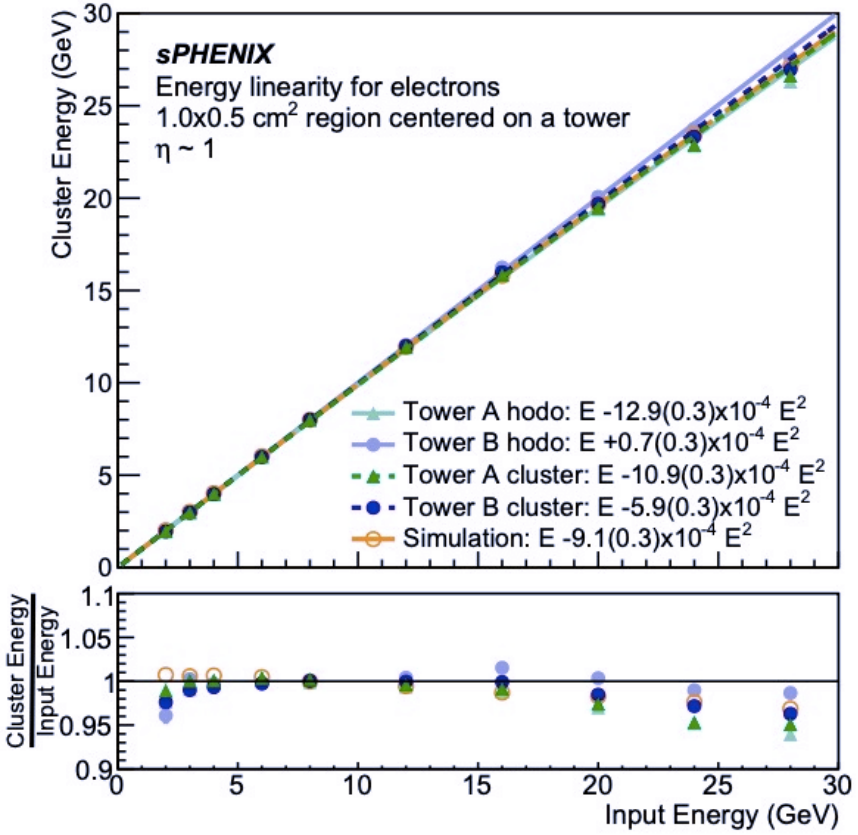
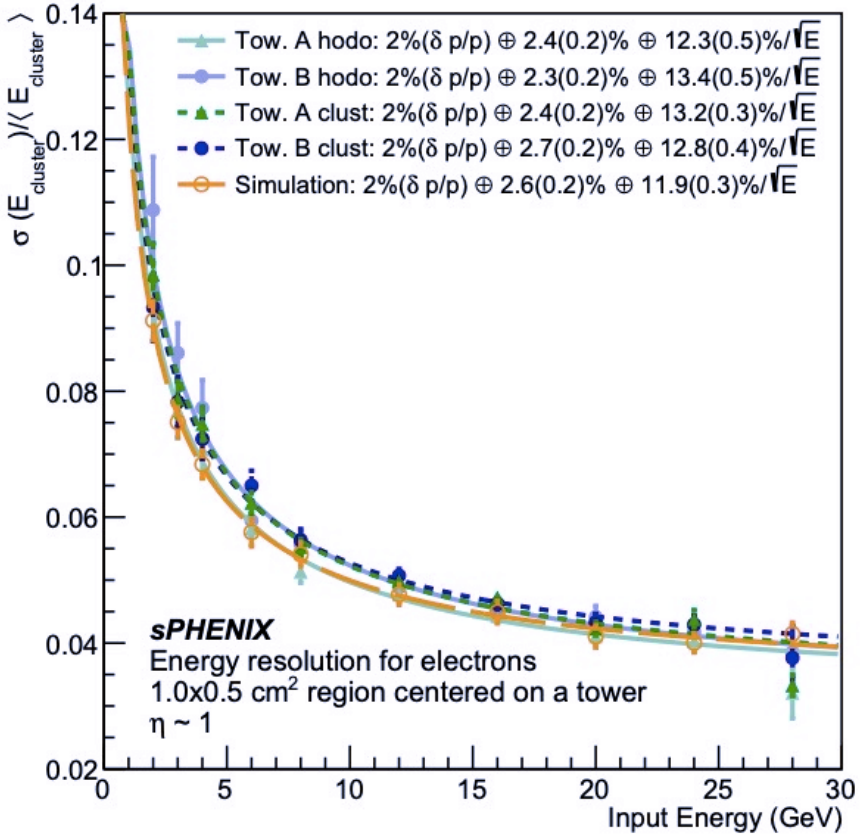


The sPHENIX EMCal

- High-granularity Electromagnetic Calorimeter for precision neutral meson, direct photon, and Υ measurements







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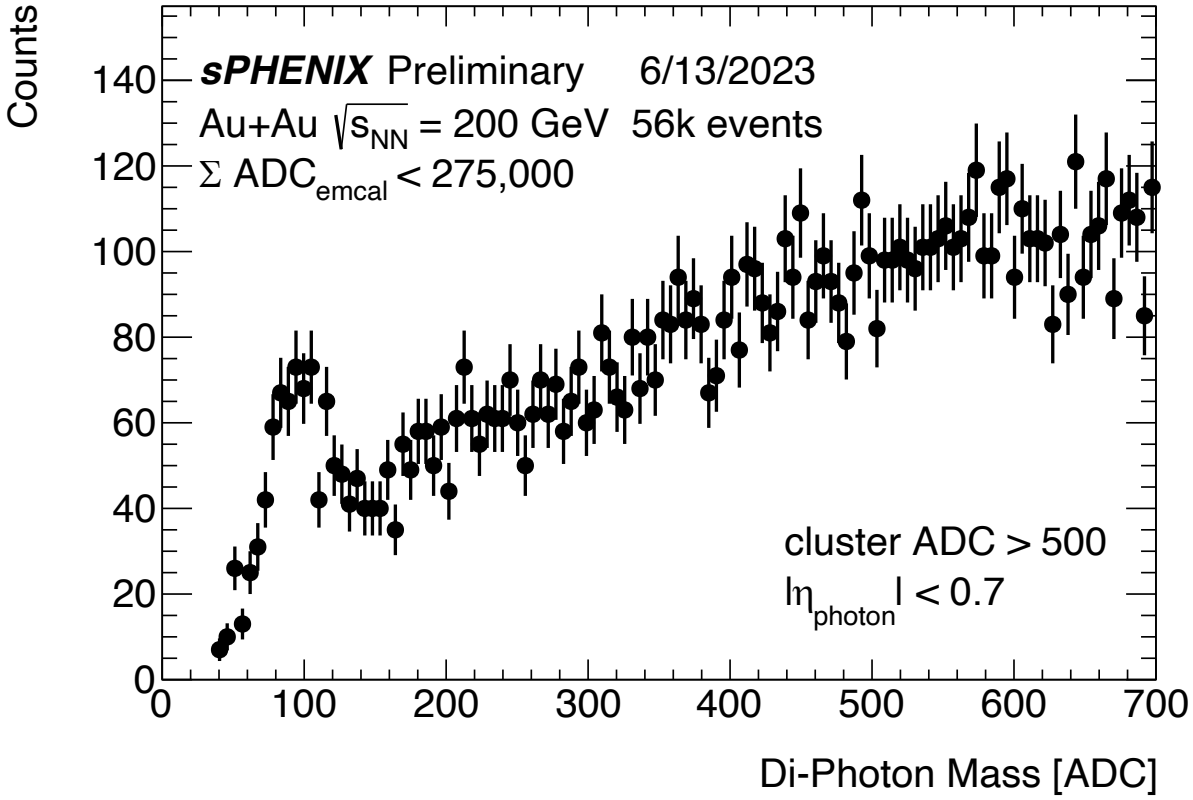
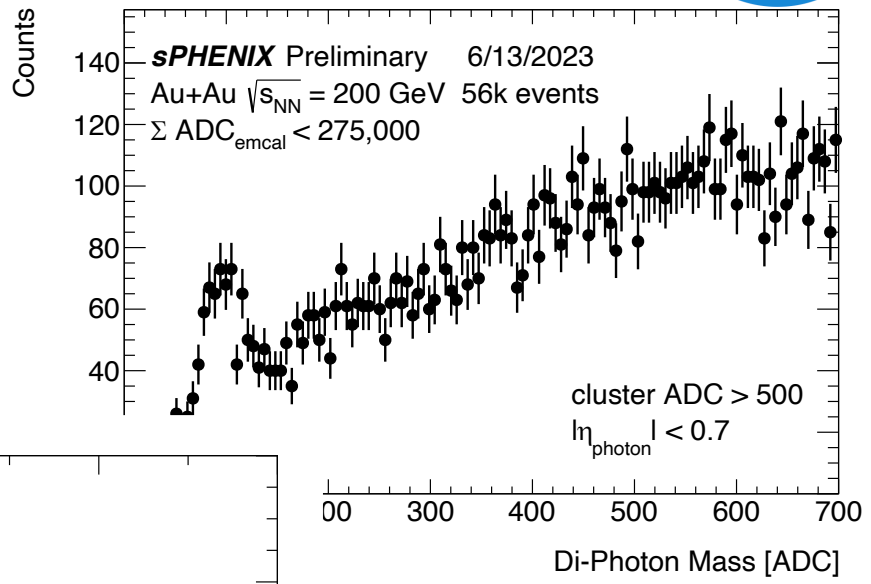
Early Calorimeter Measurements

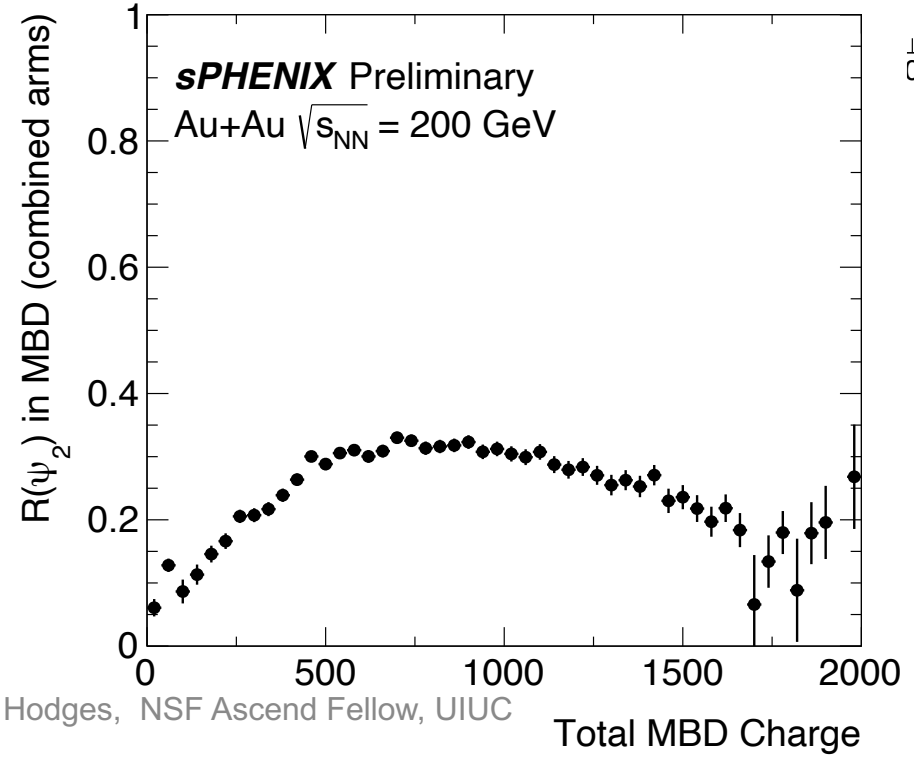
- π^0's successfully reconstructed in sPHENIX EMCal
- Important for calorimeter calibration as well as first sPHENIX physics results



Early Calorimeter Measurements

- Important for calorimeter calibration as well as first sPHENIX physics results
- Measurement of π^0 v_n will make use of EMCal and MBD (Minimum Bias Detector) for event categorization and event plane determination



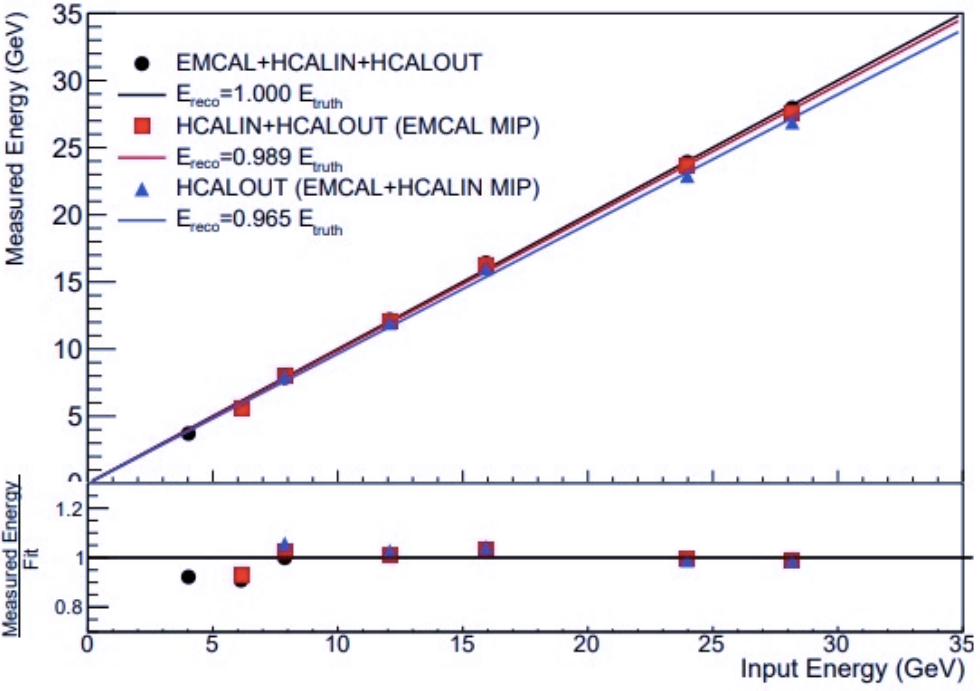


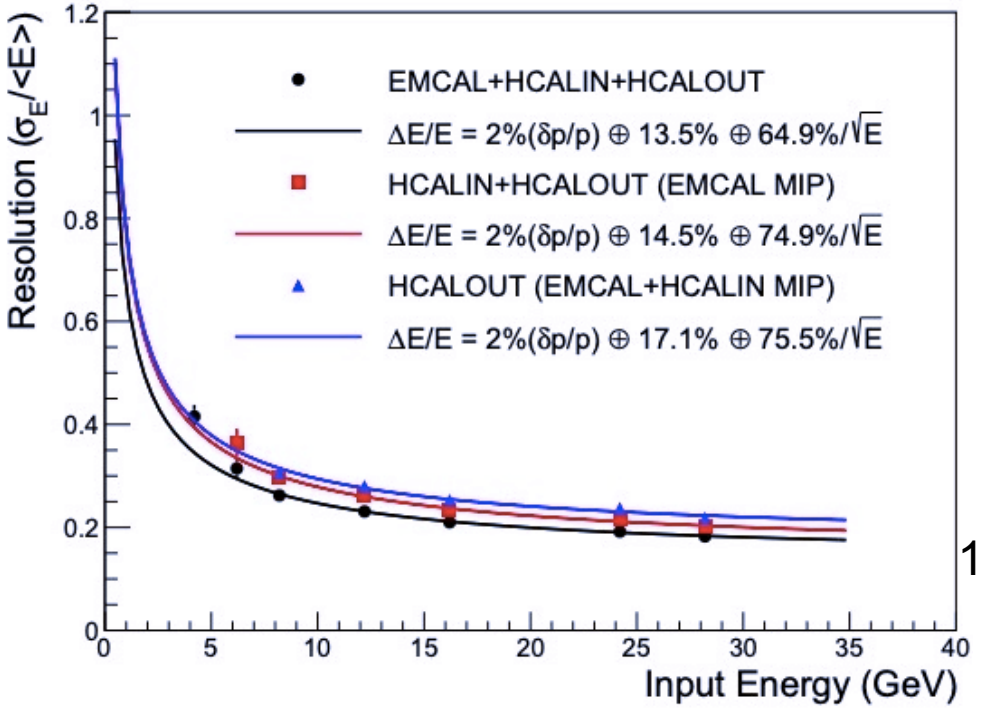
The sPHENIX HCals

- EMCal complemented by first HCal at mid-rapidity at RHIC!
- Powerful tool for full-jet reconstruction

Inner Hadronic Calorimeter

Outer Hadronic Calorimeter





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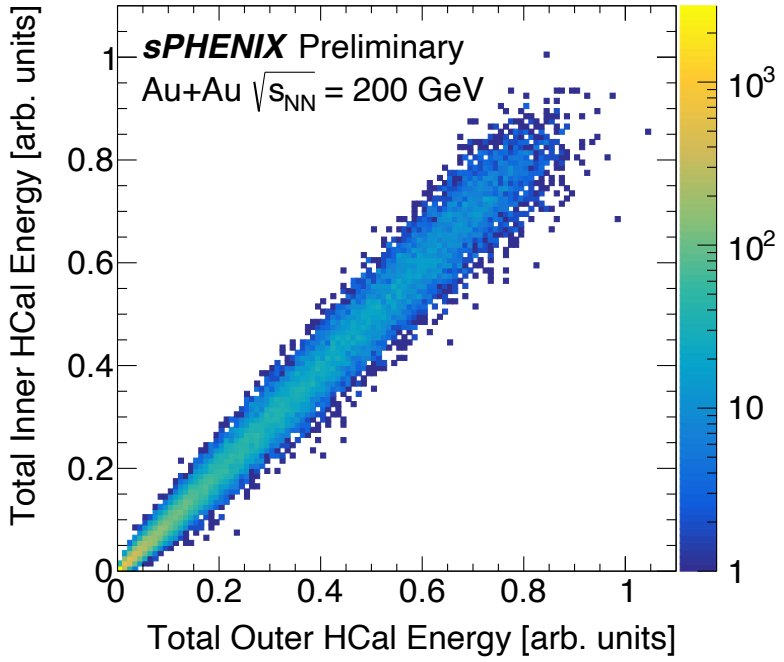
Preparing for First Jet Measurements

- Early jet measurements will be fully calorimeter-based
- Access to full jet energy and less susceptible to fragmentation bias
- Commissioning focused on tight correlation between calorimeters and other critical subsystems



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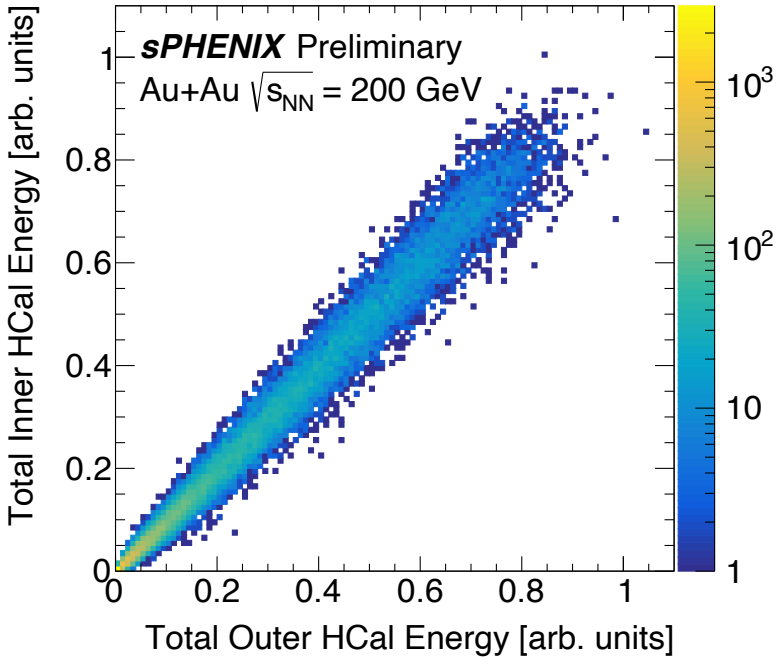
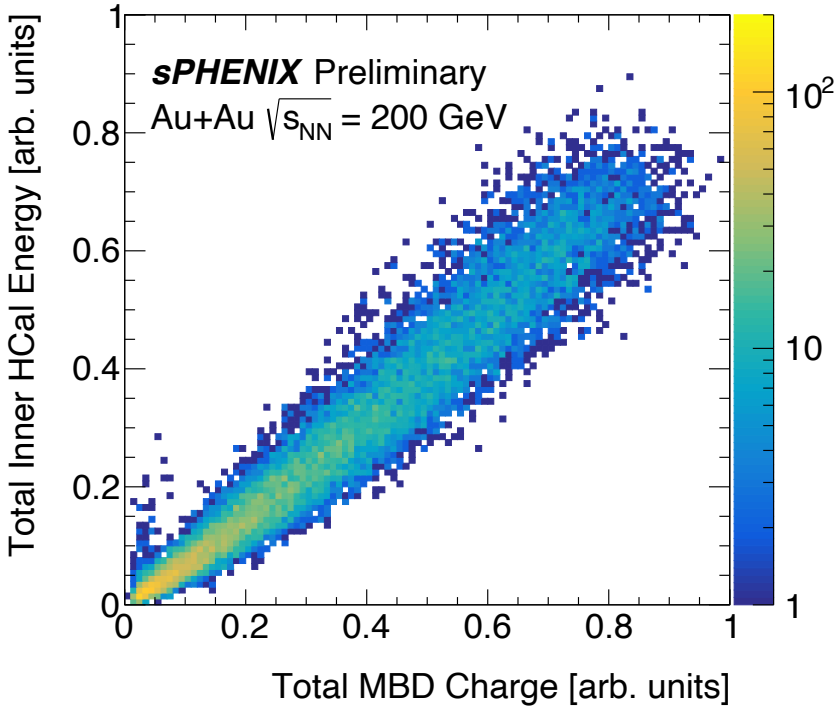
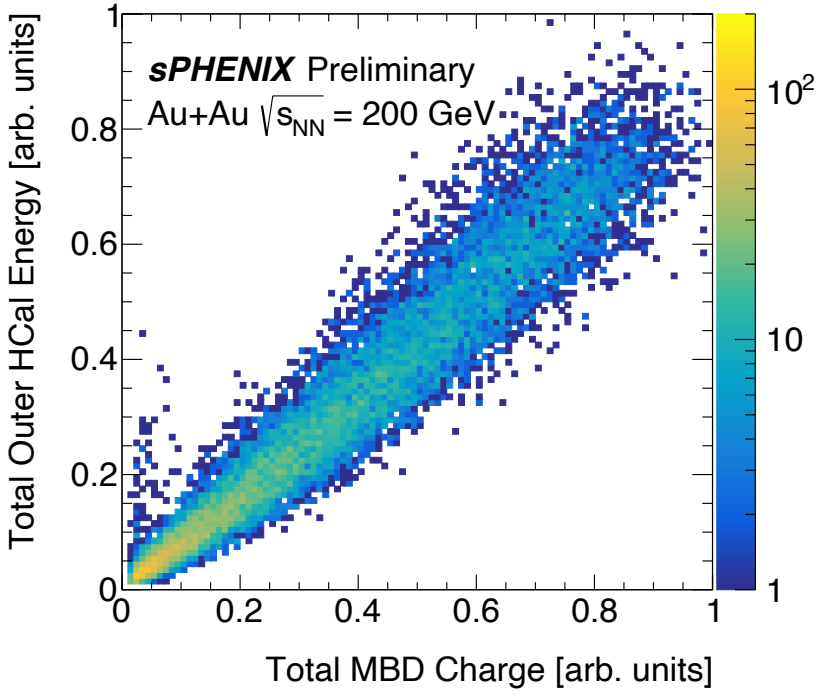
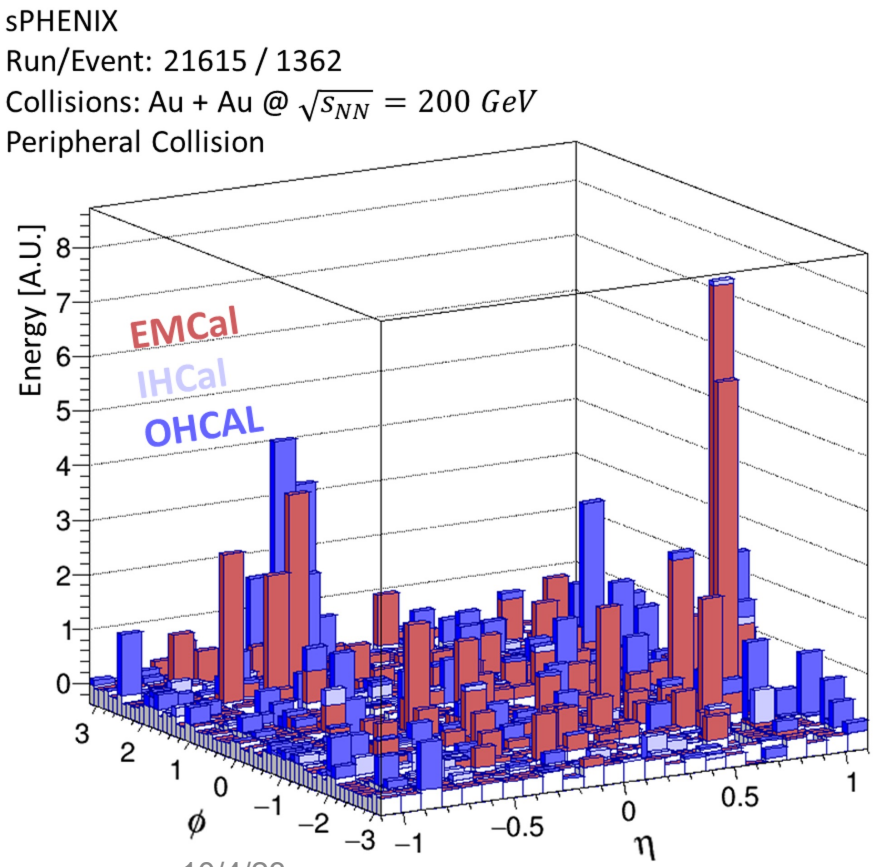


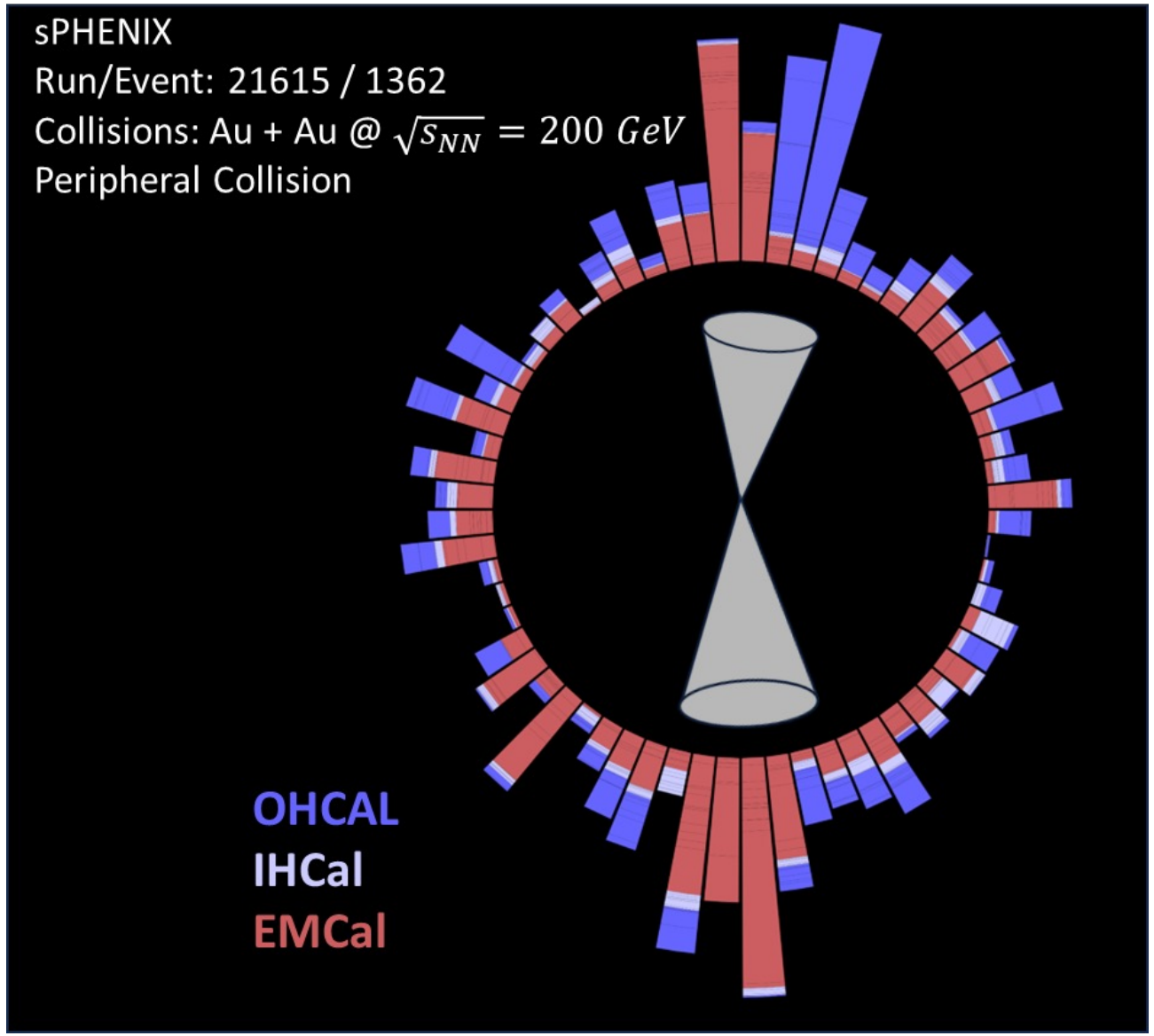




First sPHENIX Dijets!

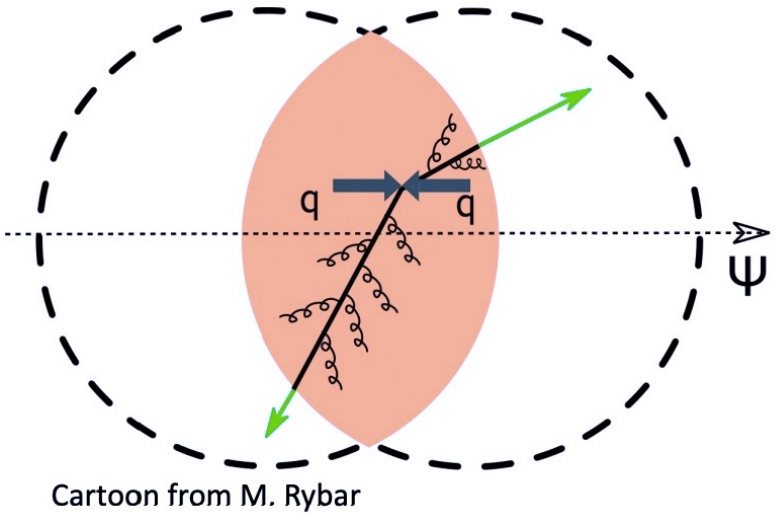
- R=0.4 anti-k_T calorimeter jets
- First measurement of calorimetric dijet at RHIC!



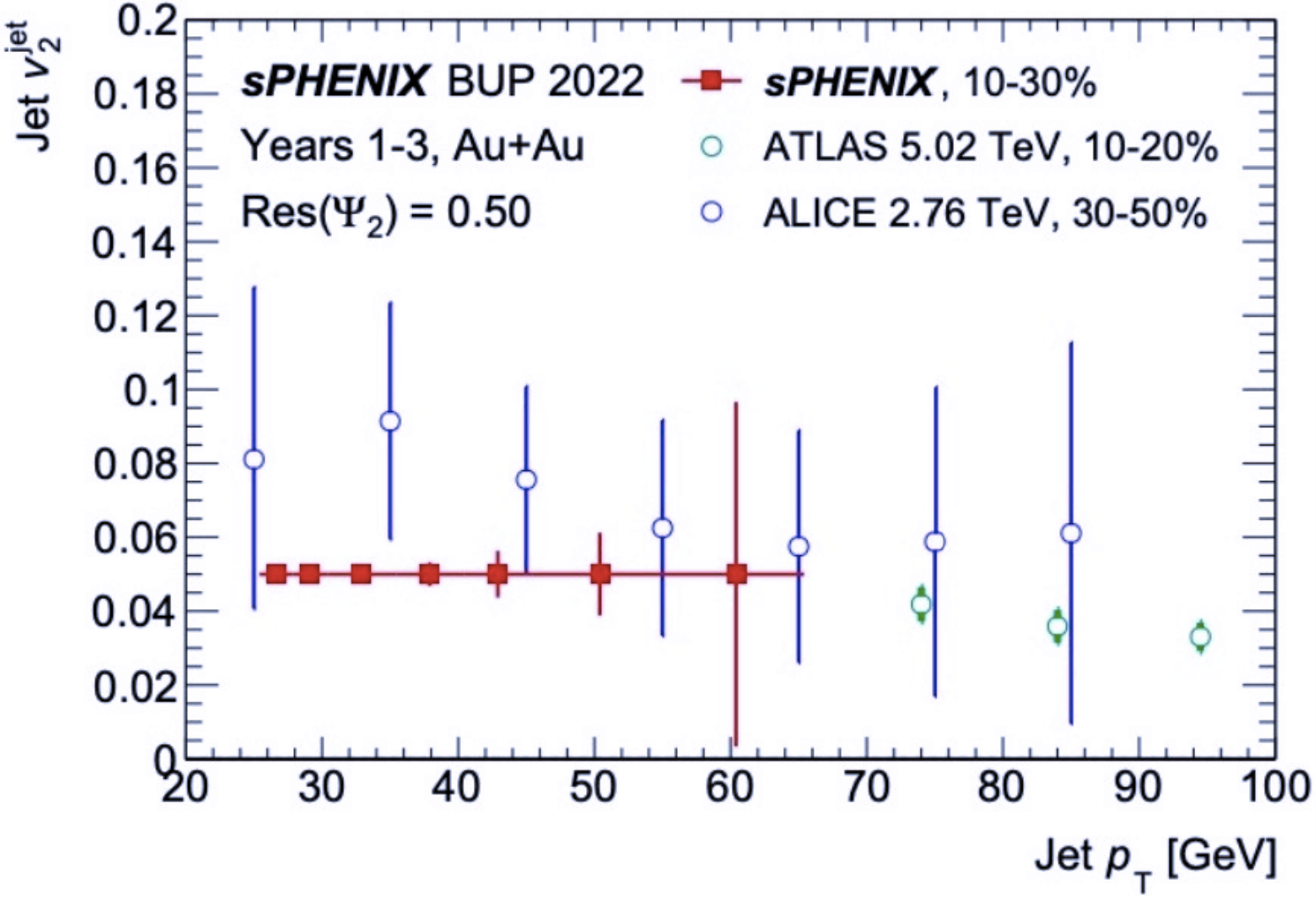


Future sPHENIX Measurements

- Statistics from future measurements will allow for precision measurements of jet v_2



Cartoon from M. Rybar



Future sPHENIX Measurements

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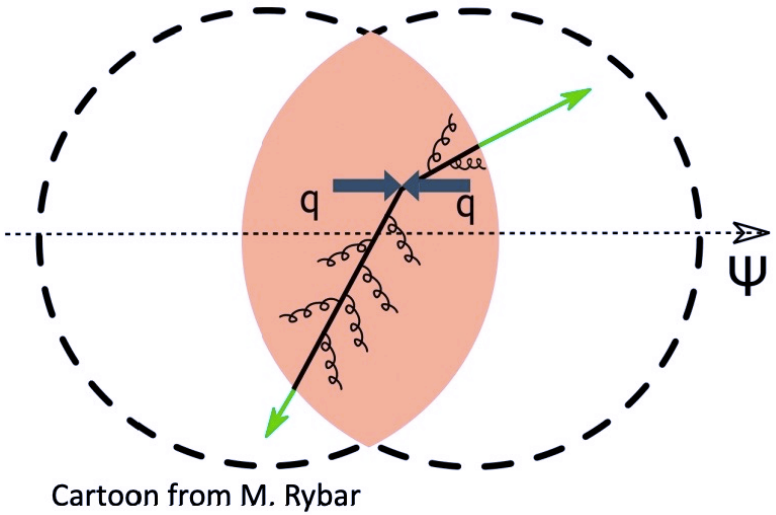
- sPHENIX kinematic range offers complementarity with LHC results



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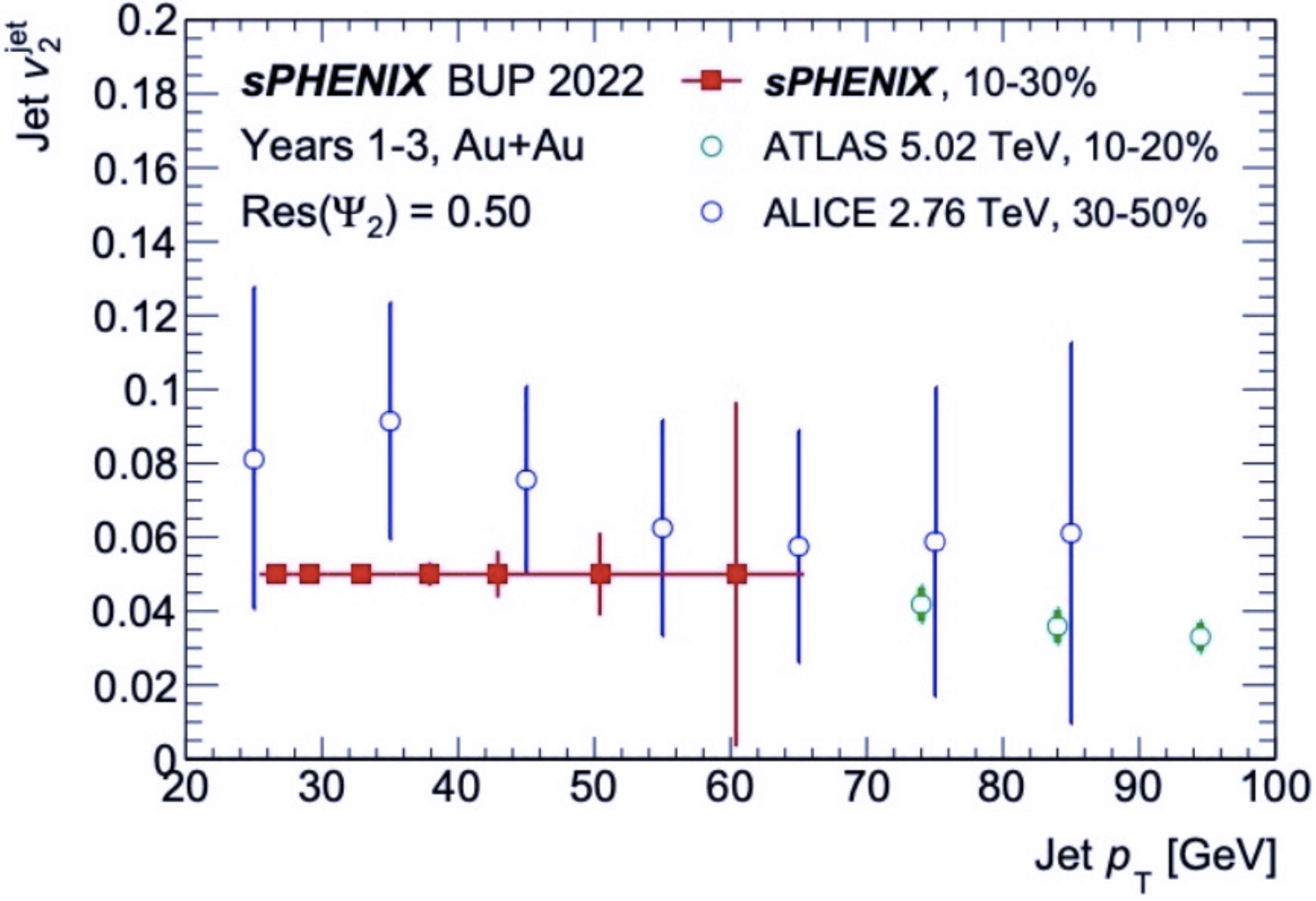
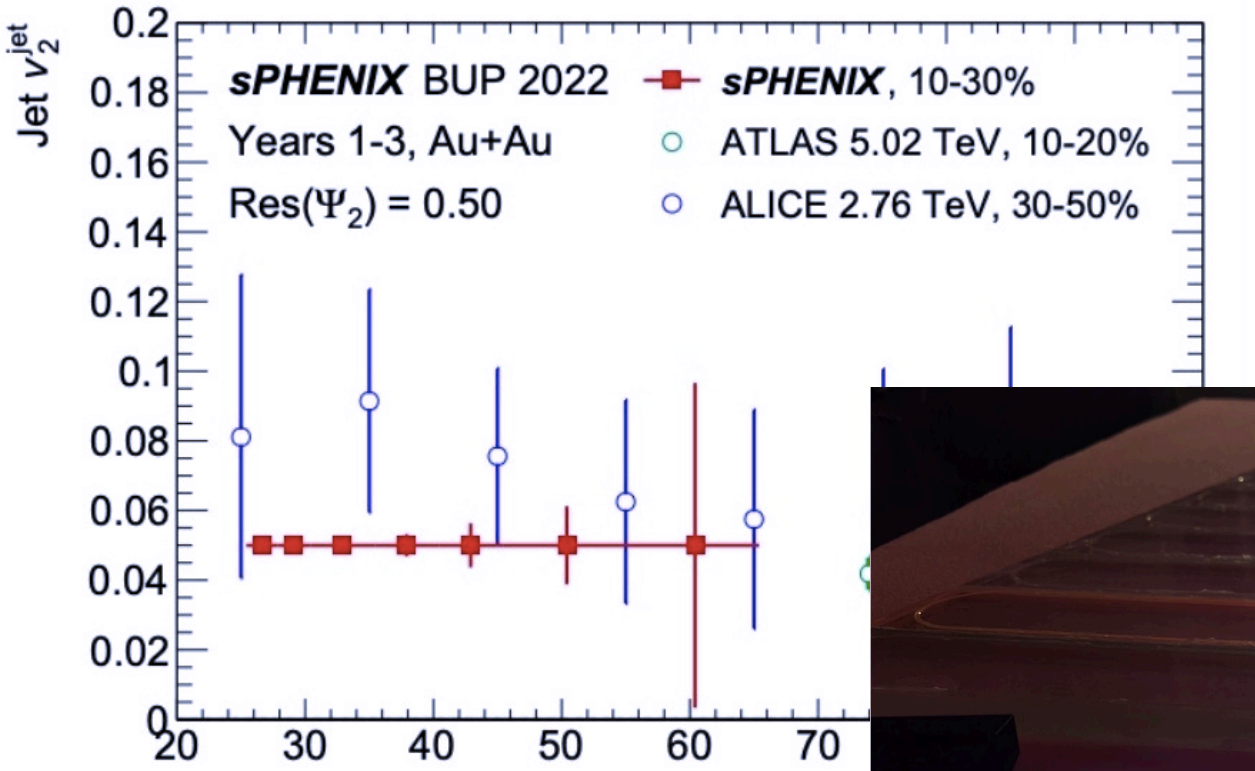
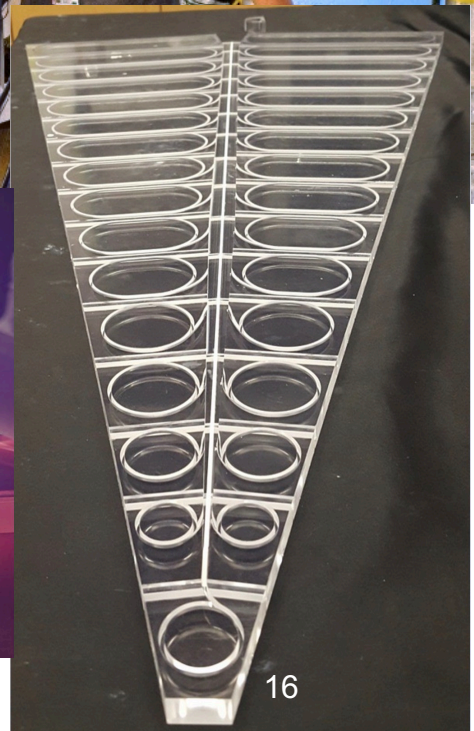


Future sPHENIX Measurements

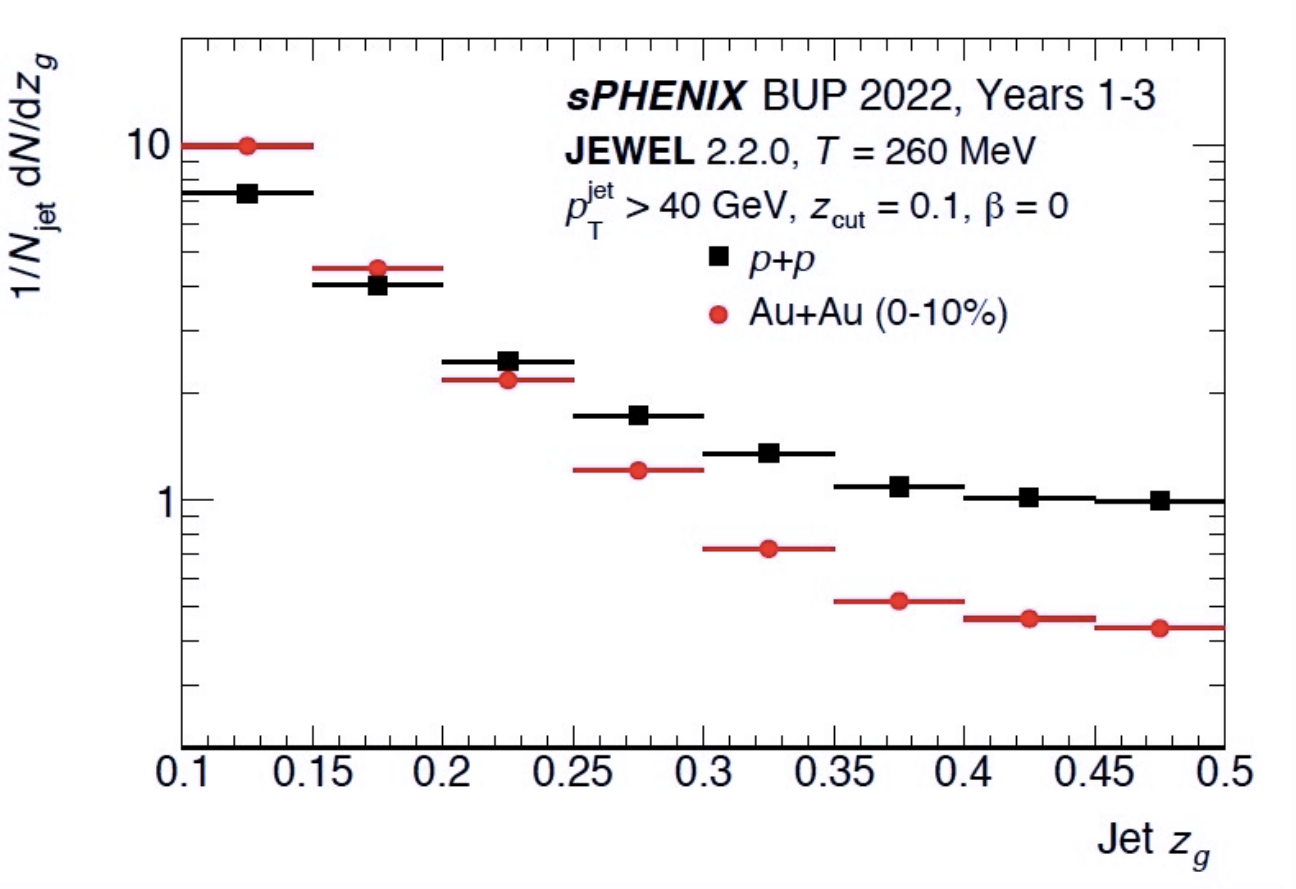
- Jet v_2 will make use of newly installed sPHENIX Event Plane Detector (sEPD)

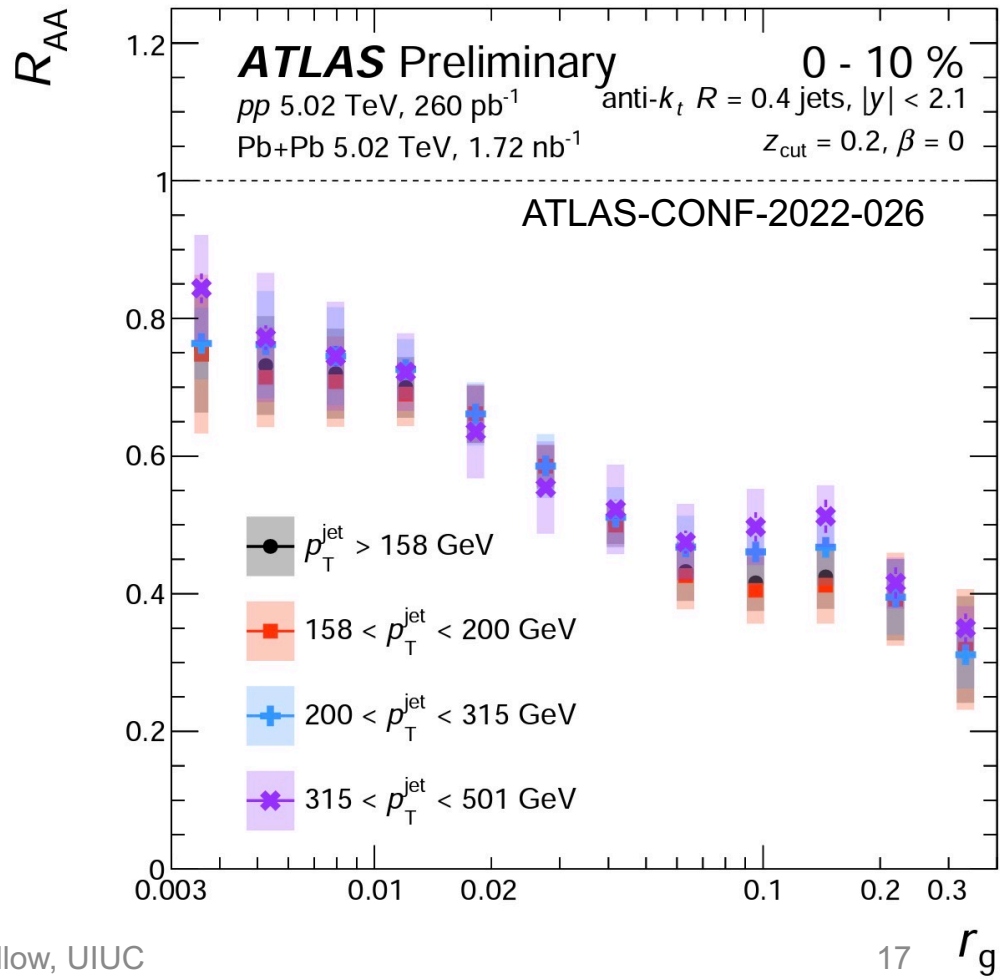




Calorimeter + Track Jet Measurements

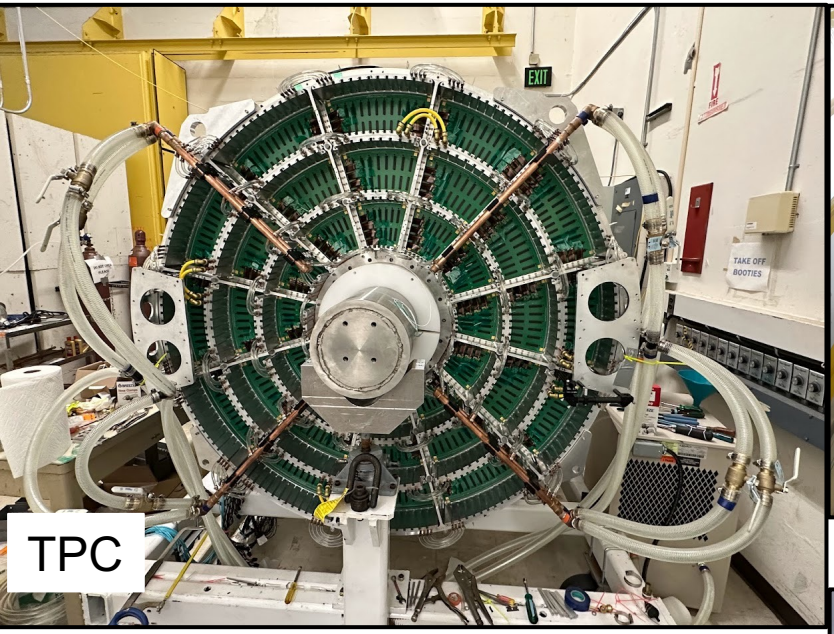
- Marriage of tracking and calorimeter information will yield high statistics jet (sub)structure measurements complementary of recent LHC results

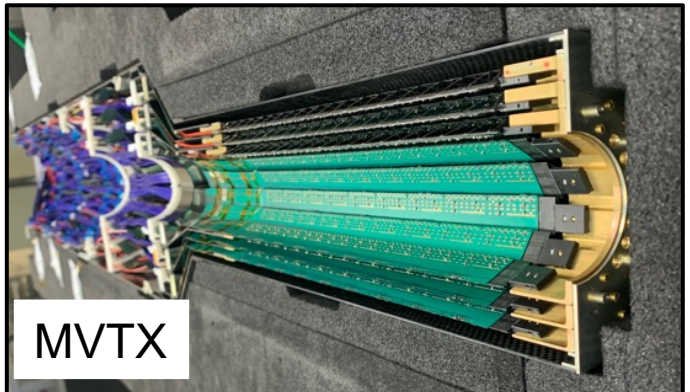


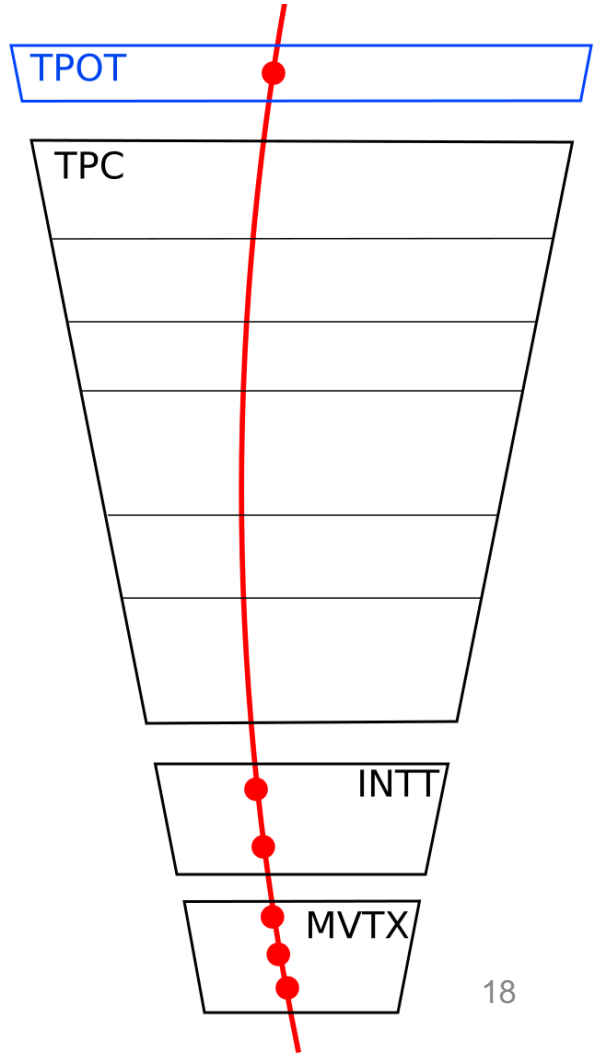


sPHENIX Tracking

- State-of-the-art tracking system critical for heavy-flavor physics program

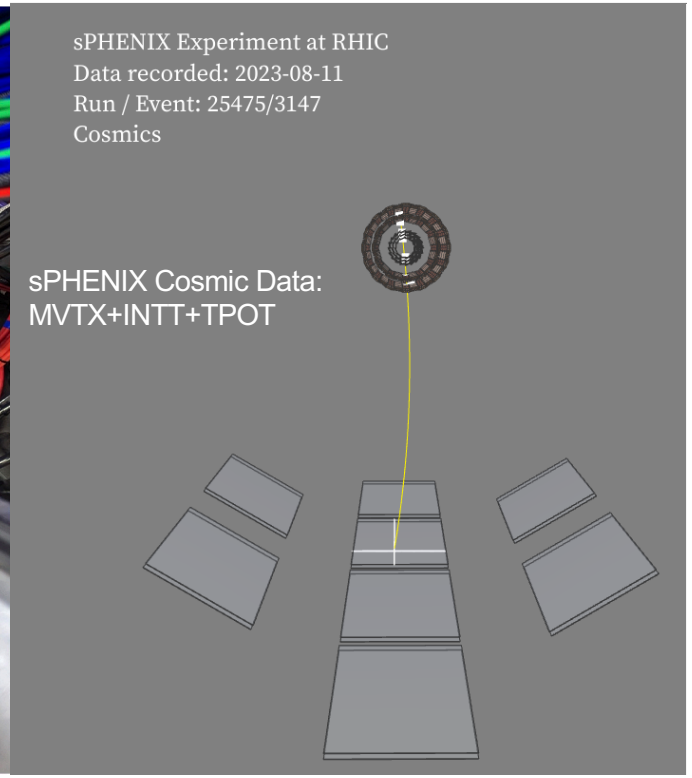


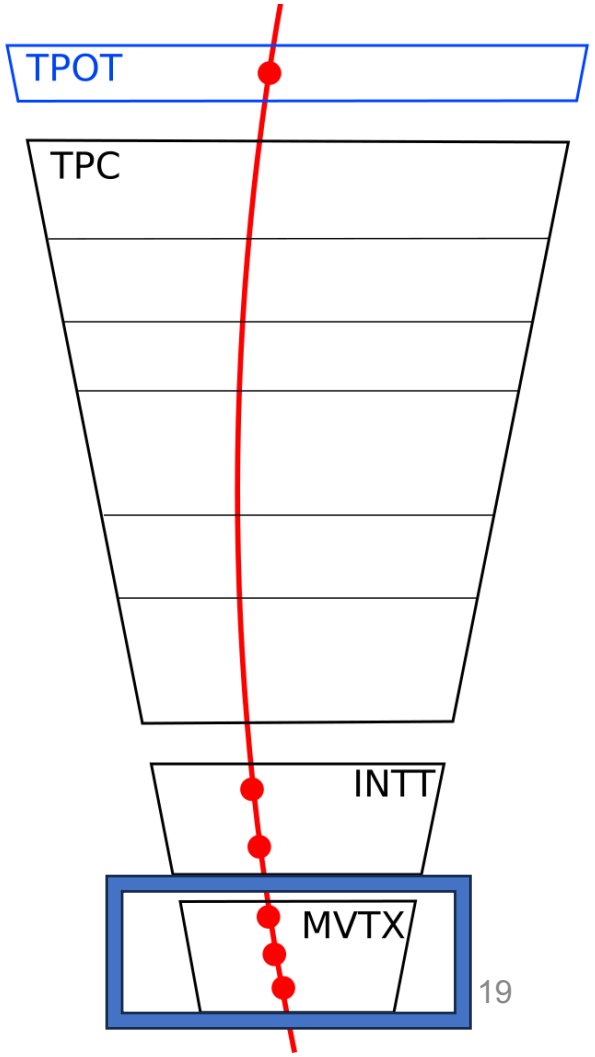




MAPs–Based Vertex Detector (MVTX)

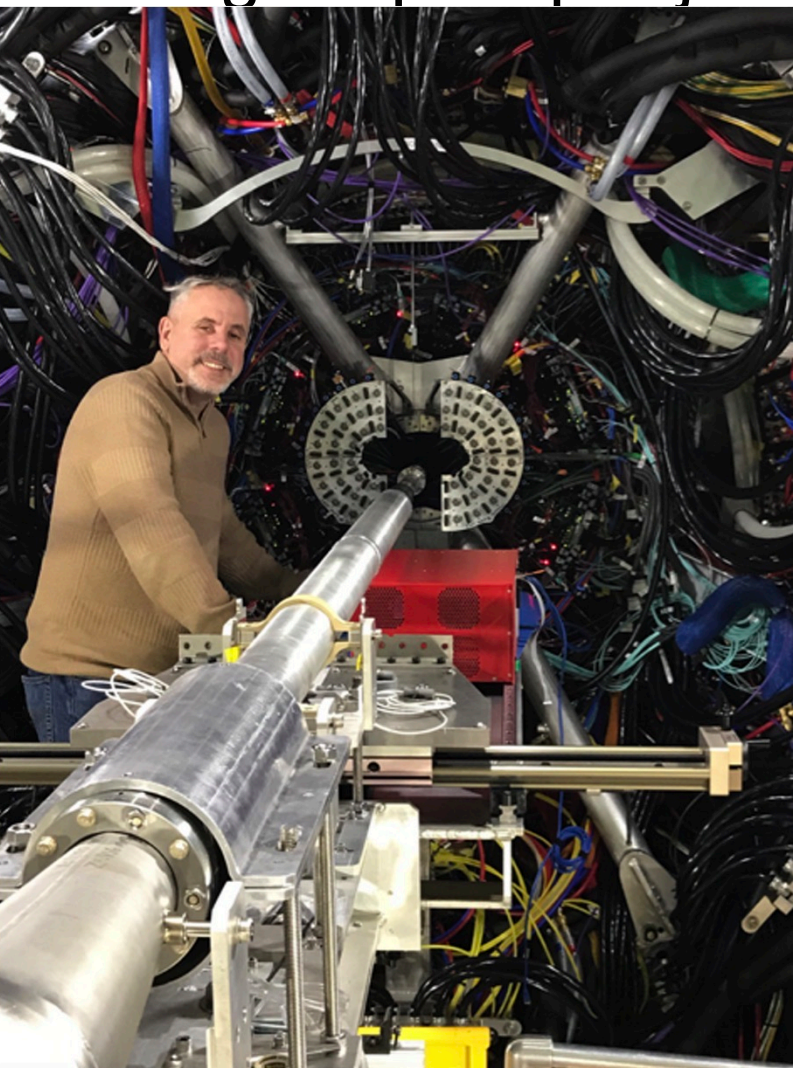
- 230M channel, 3-layer MAPS-based pixel detector
- Provides precision primary and secondary vertex determination (~5μm precision)

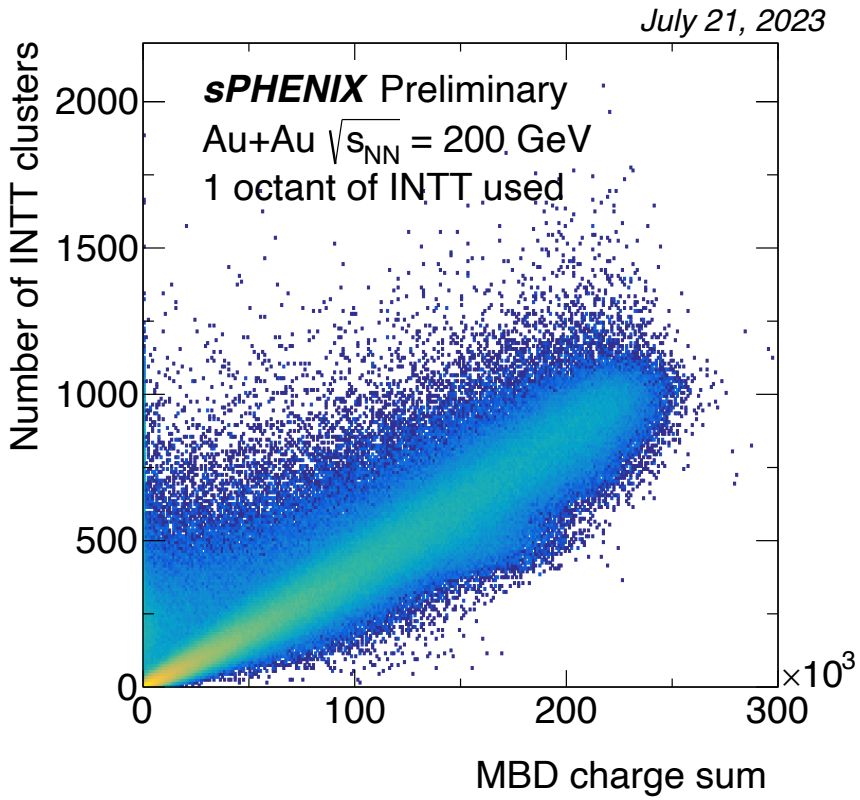


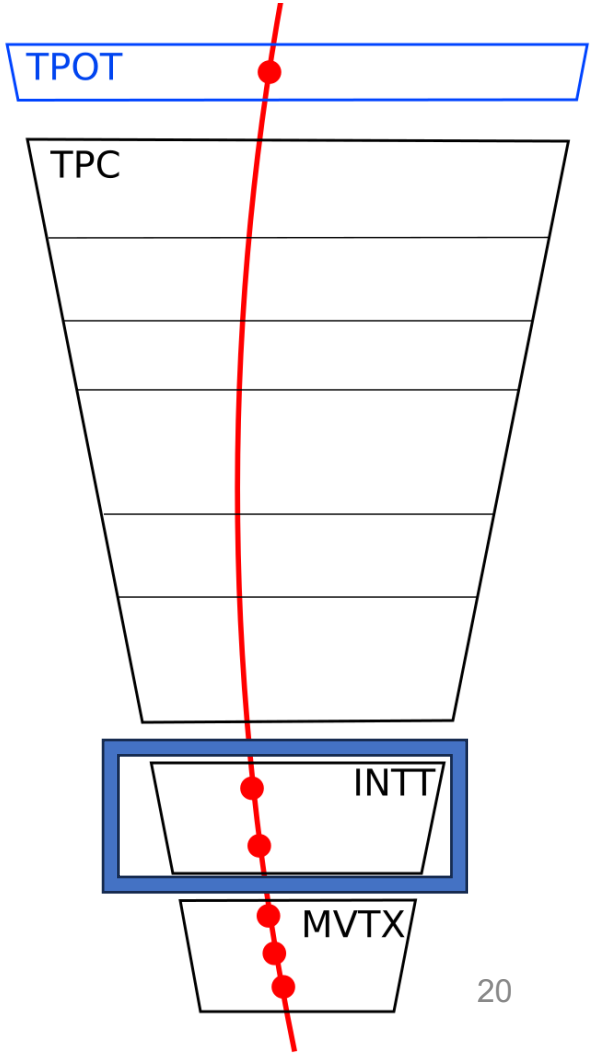


Intermediate Tracker (INTT)

- Two-layer silicon detector with single beam-crossing timing for pileup rejection

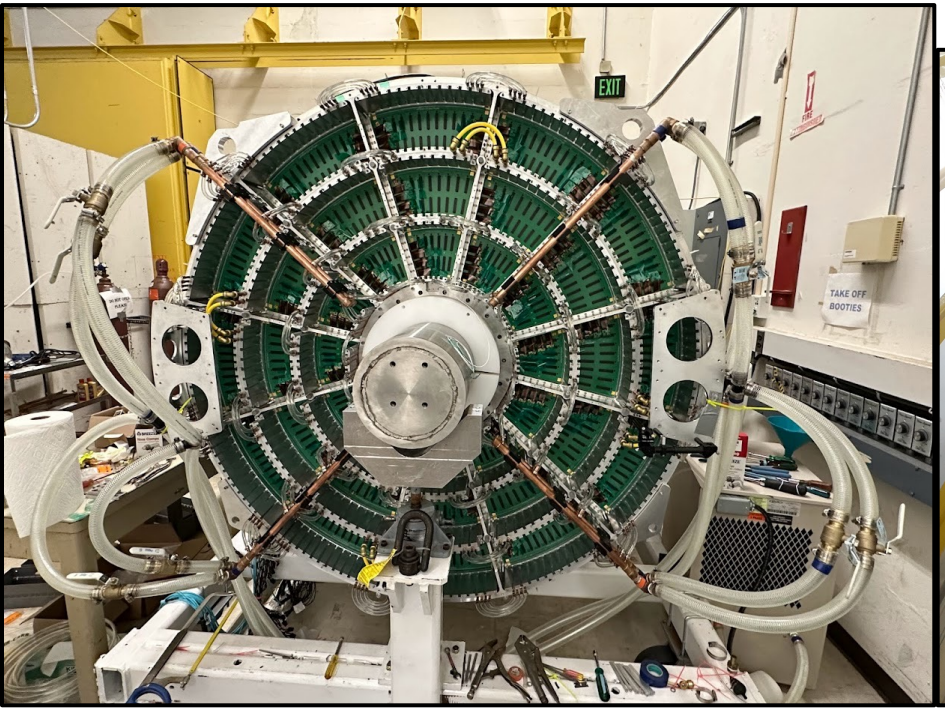


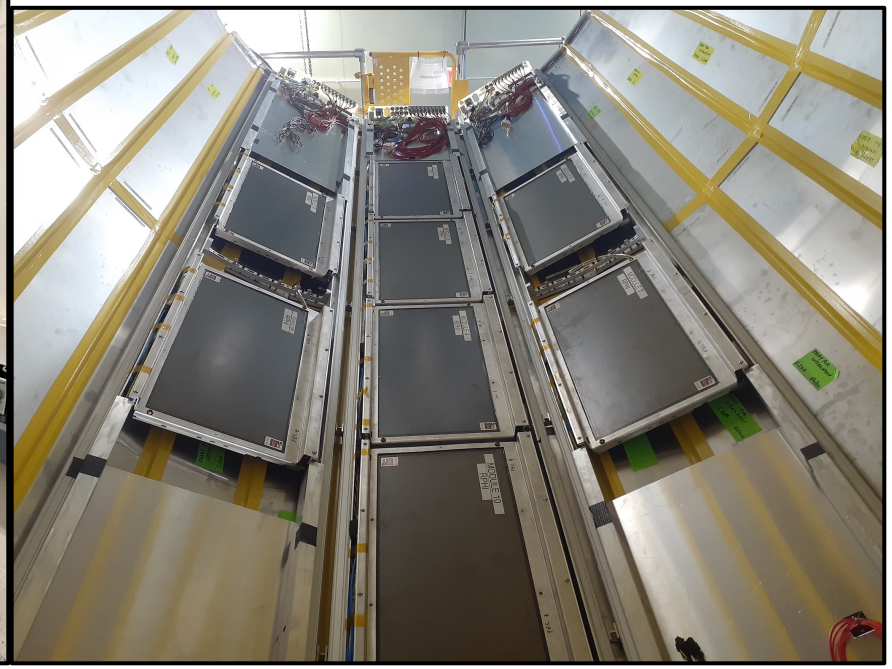


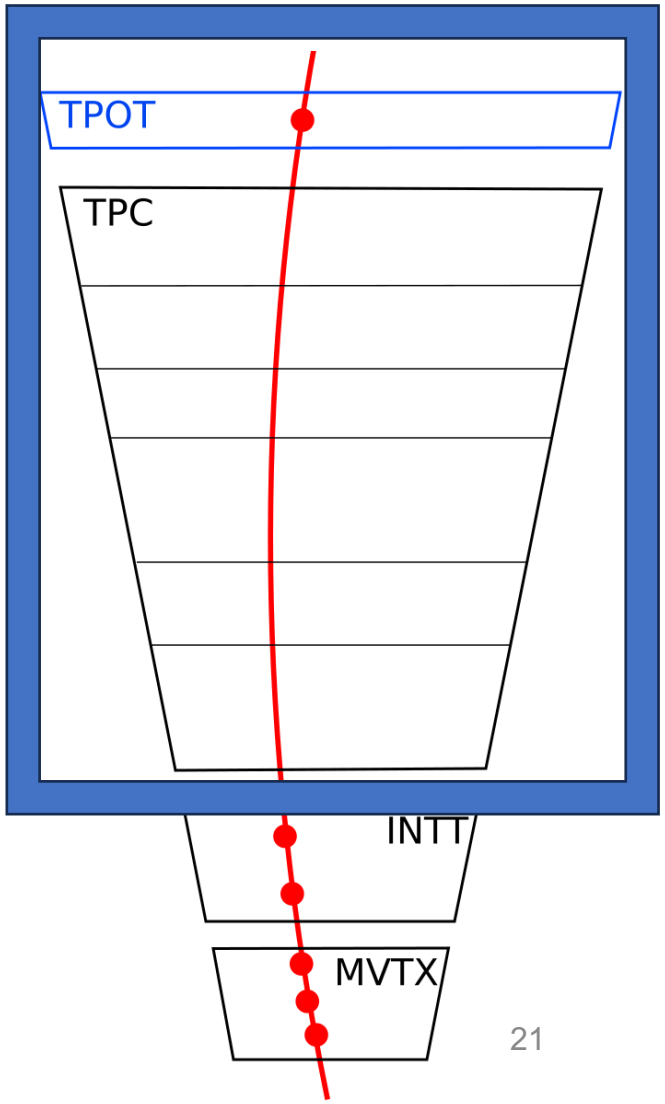


Time Projection Chamber (TPC)

- Ungated, continuous readout tracking volume provides primary lever-arm for momentum-resolution
- TPC Outer Tracker (TPOT) provides extra spatial point for calibration







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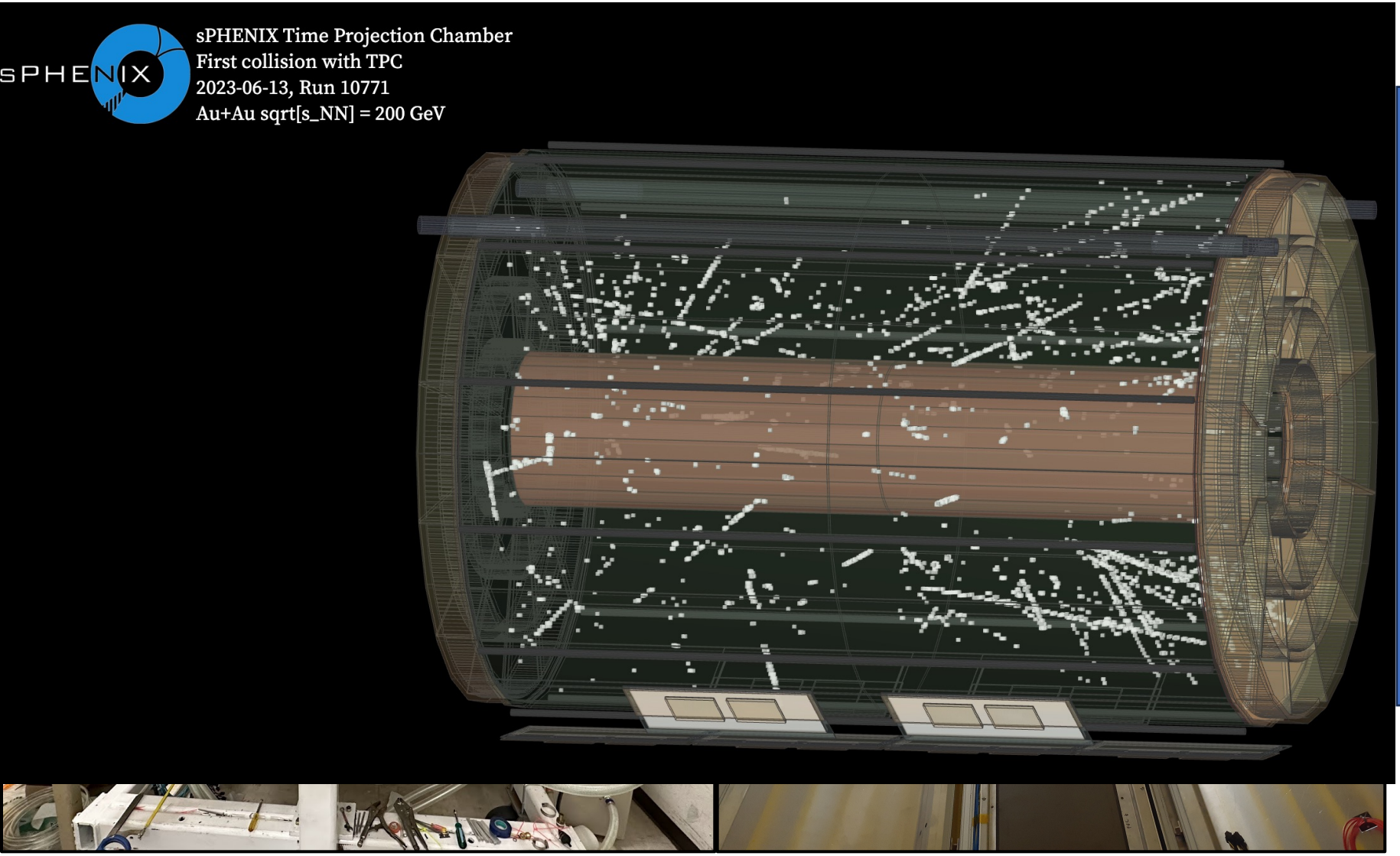
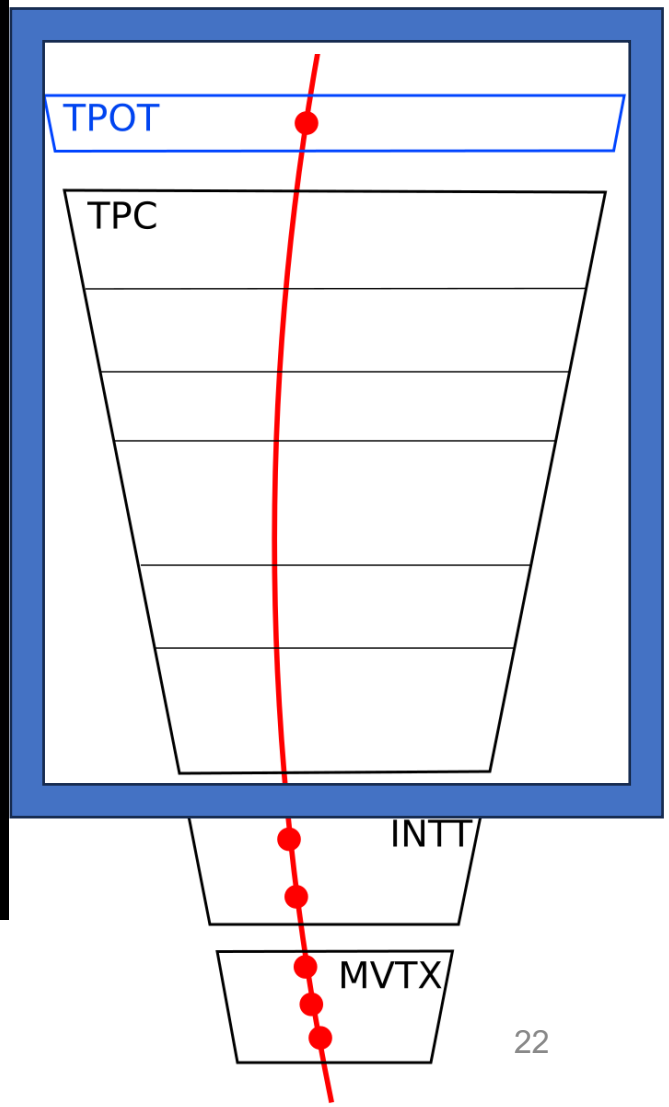
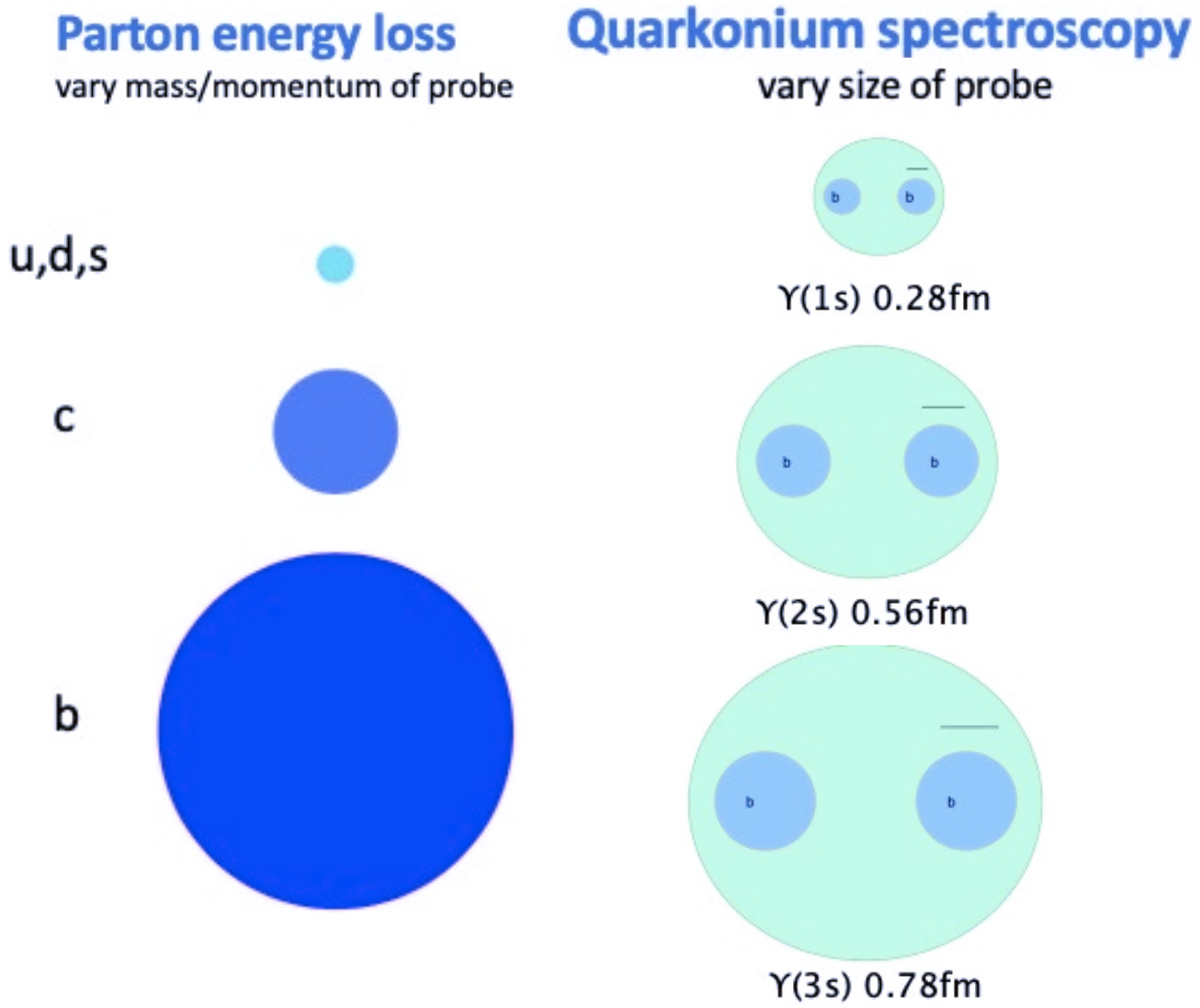


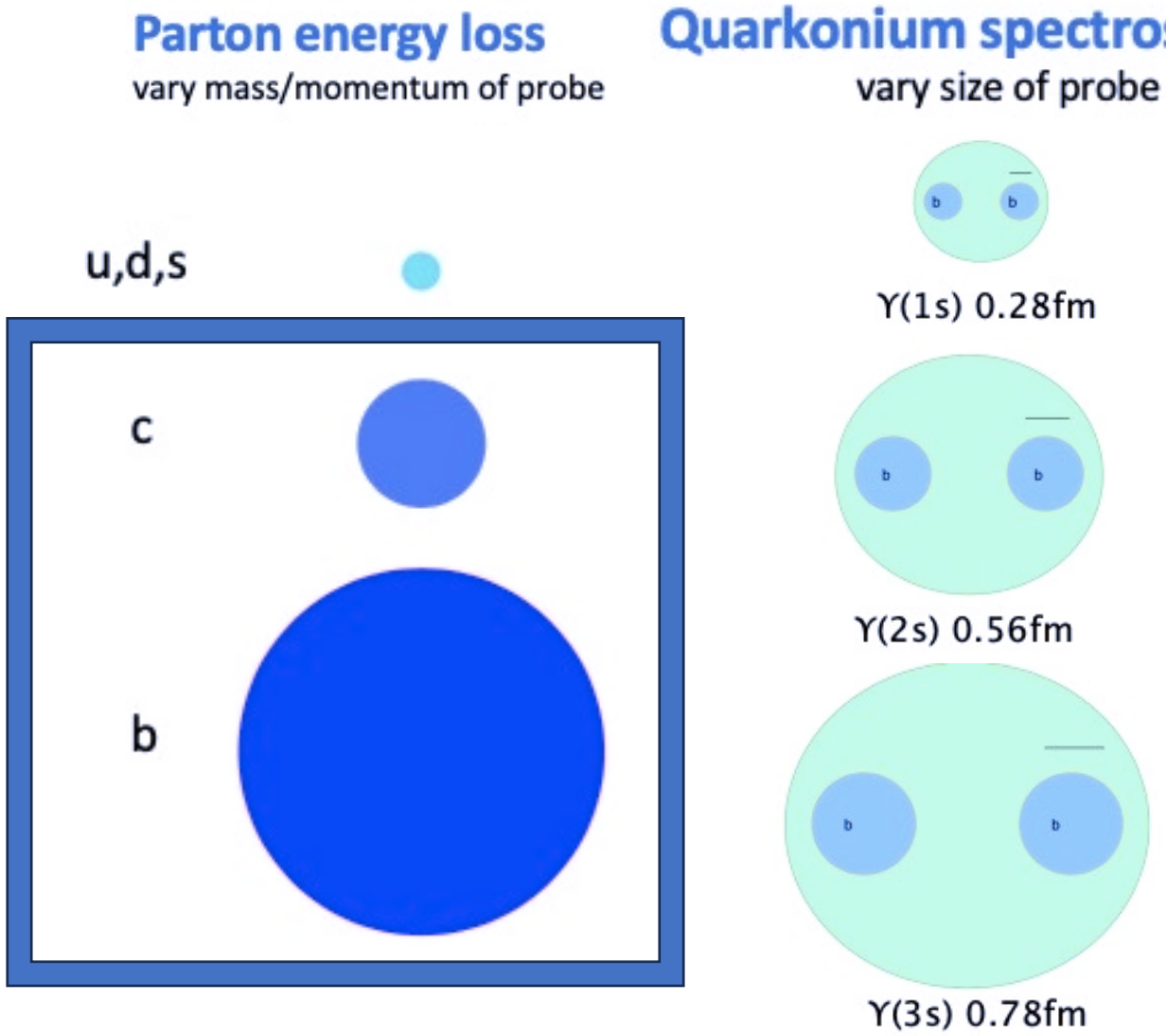


The sPHENIX Heavy Flavor Program



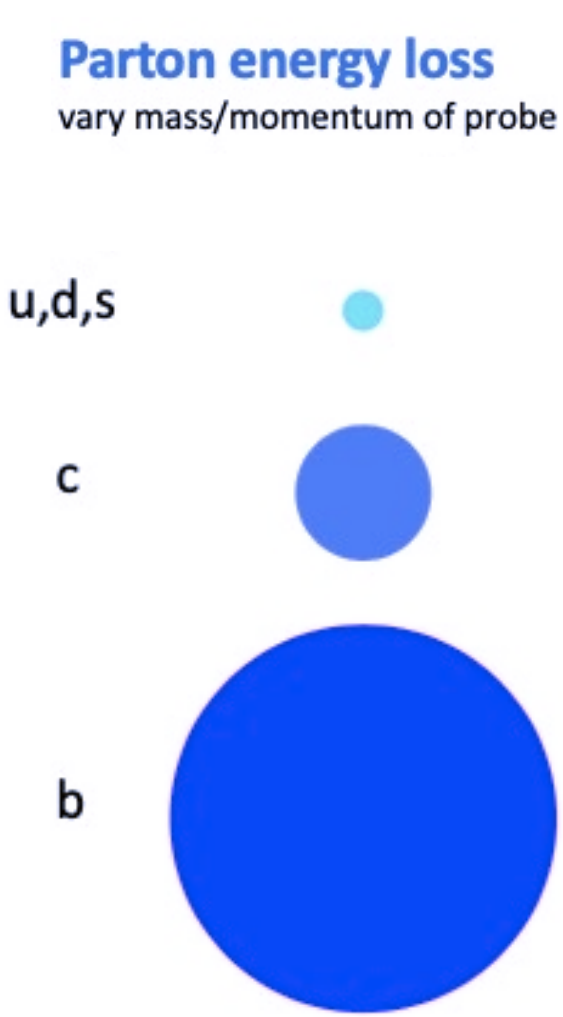
The sPHENIX Heavy Flavor Program

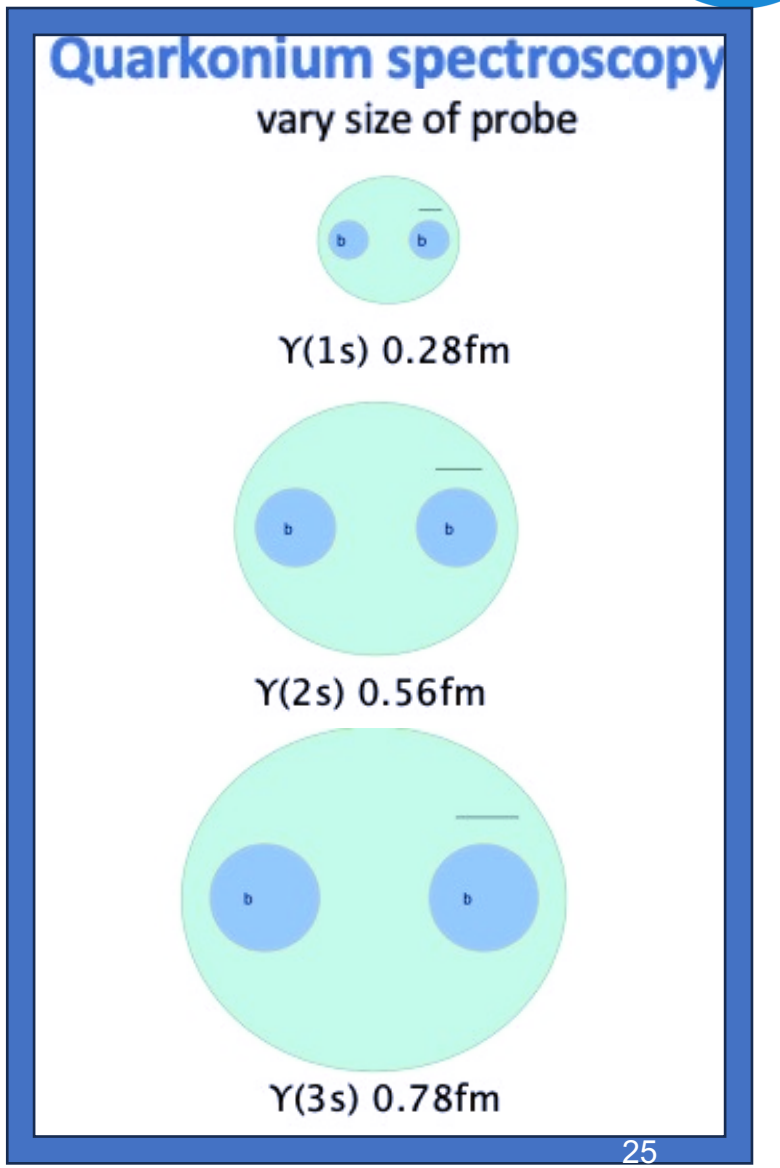
- Heavy flavor quarks probe mass dependence of partonic energy loss



The sPHENIX Heavy Flavor Program

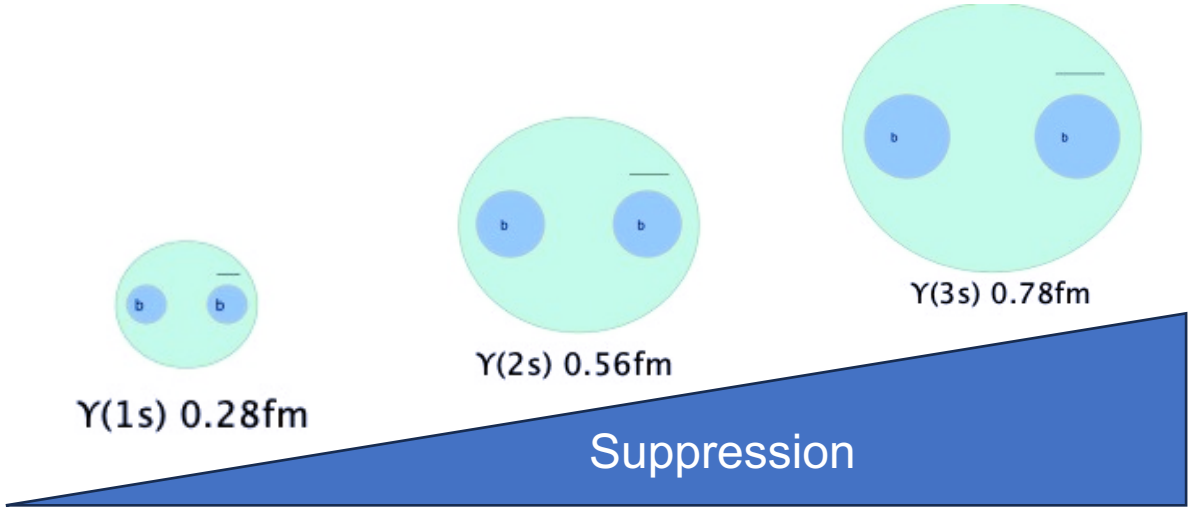
- Heavy flavor quarks: probe mass dependence of partonic energy loss
- Upsilon spectroscopy: probe medium properties such as screening length

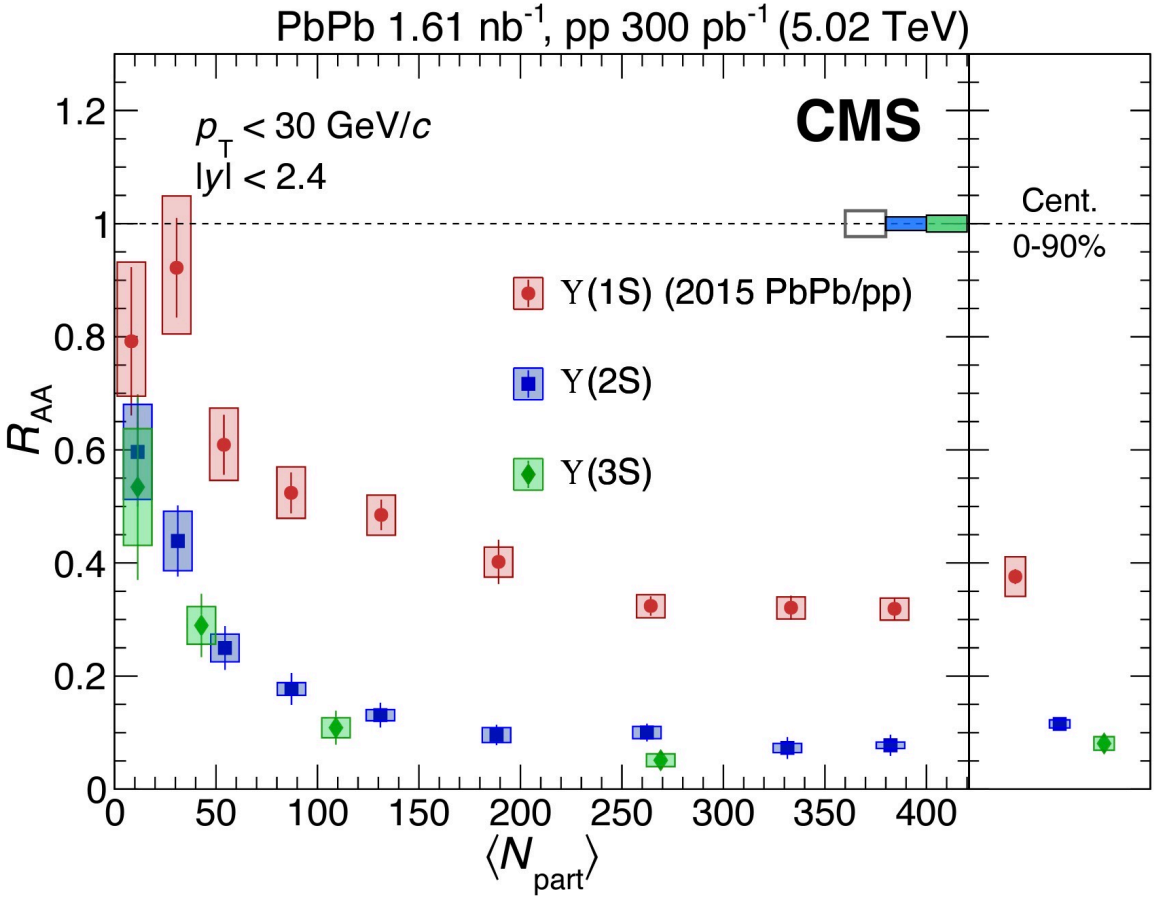




Upsilon Spectroscopy

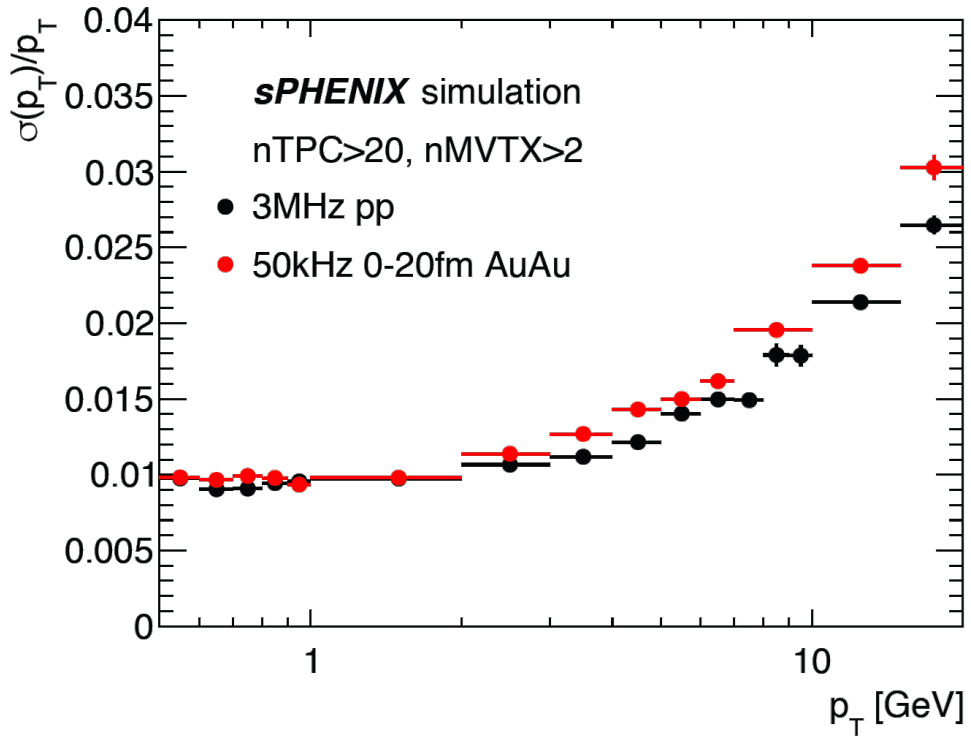
- LHC measurements of ϒ 1s, 2s, 3s, shows separation in suppression levels

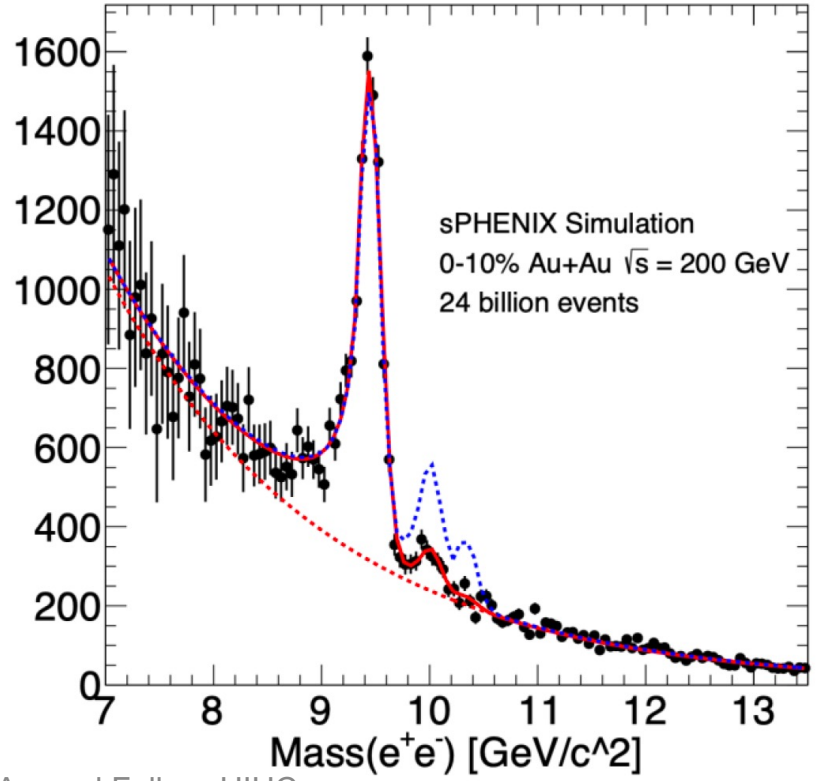




Tracking Performance: Momentum Resolution

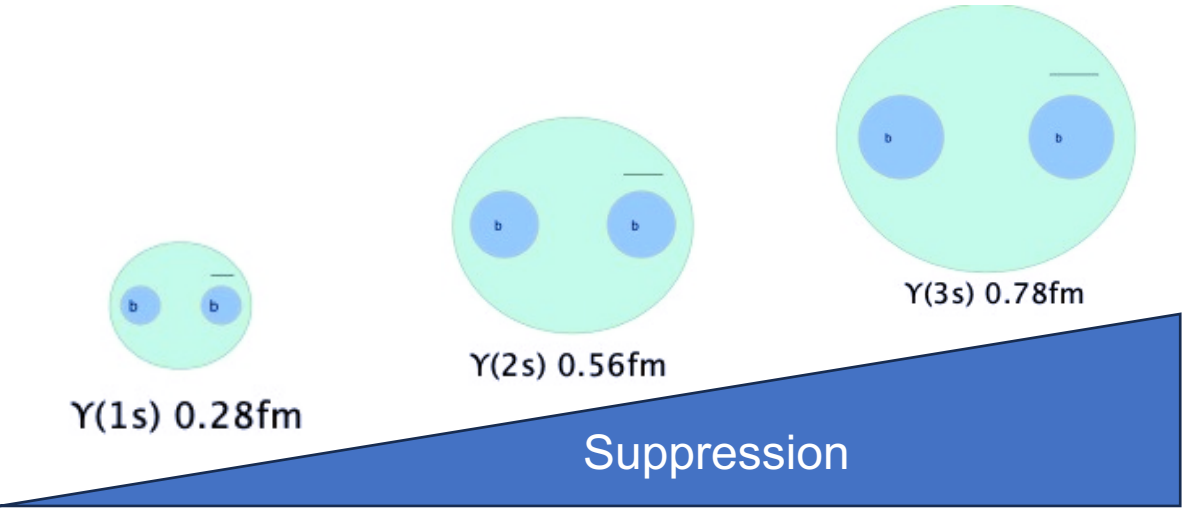
- sPHENIX tracking resolution < 2% for $p_T < 10$GeV/c
- Translates to invariant mass resolution <125 MeV/c^2 required to separate $\Upsilon(2s)$ and $\Upsilon(3s)$ states

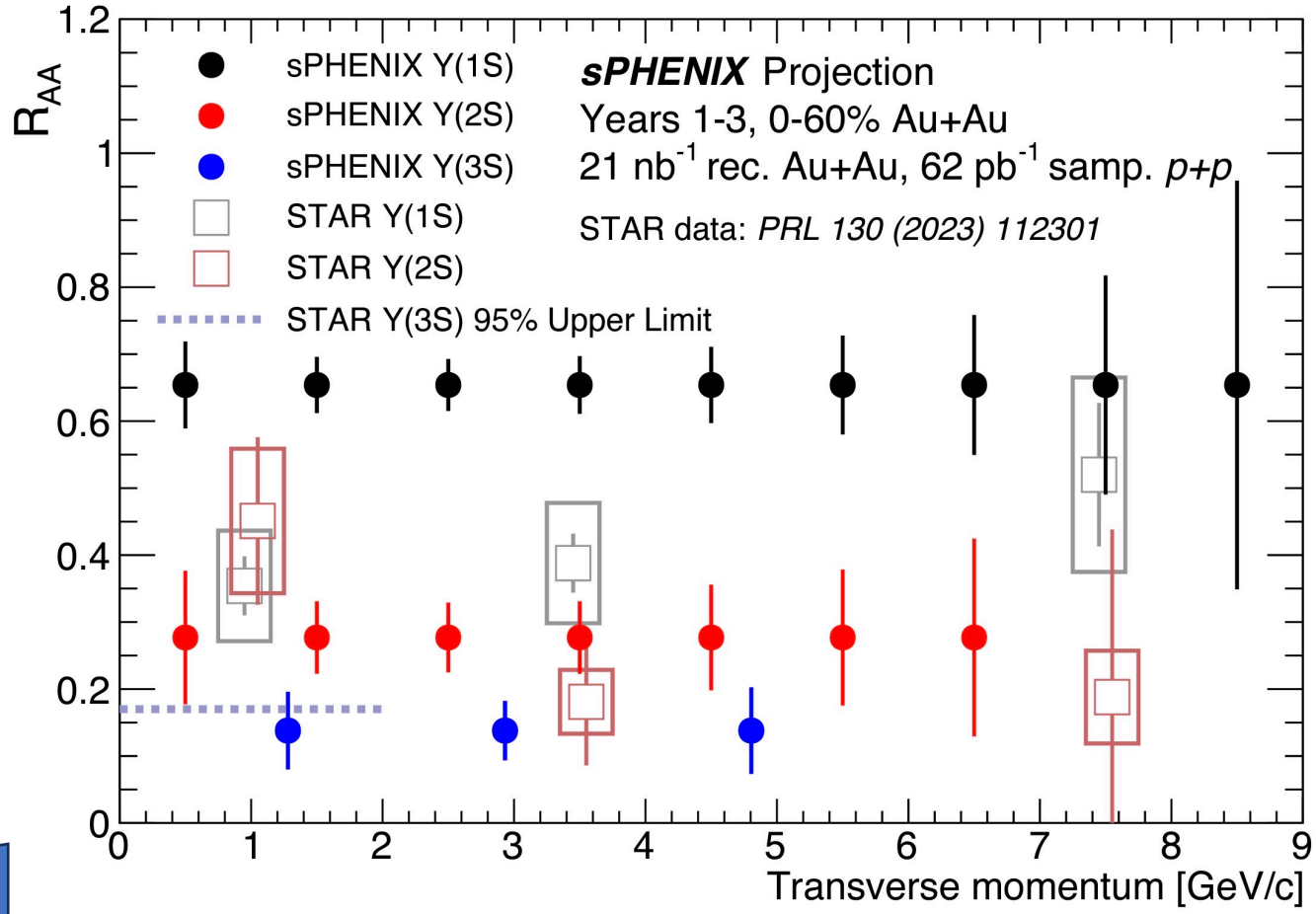




Upsilon Spectroscopy

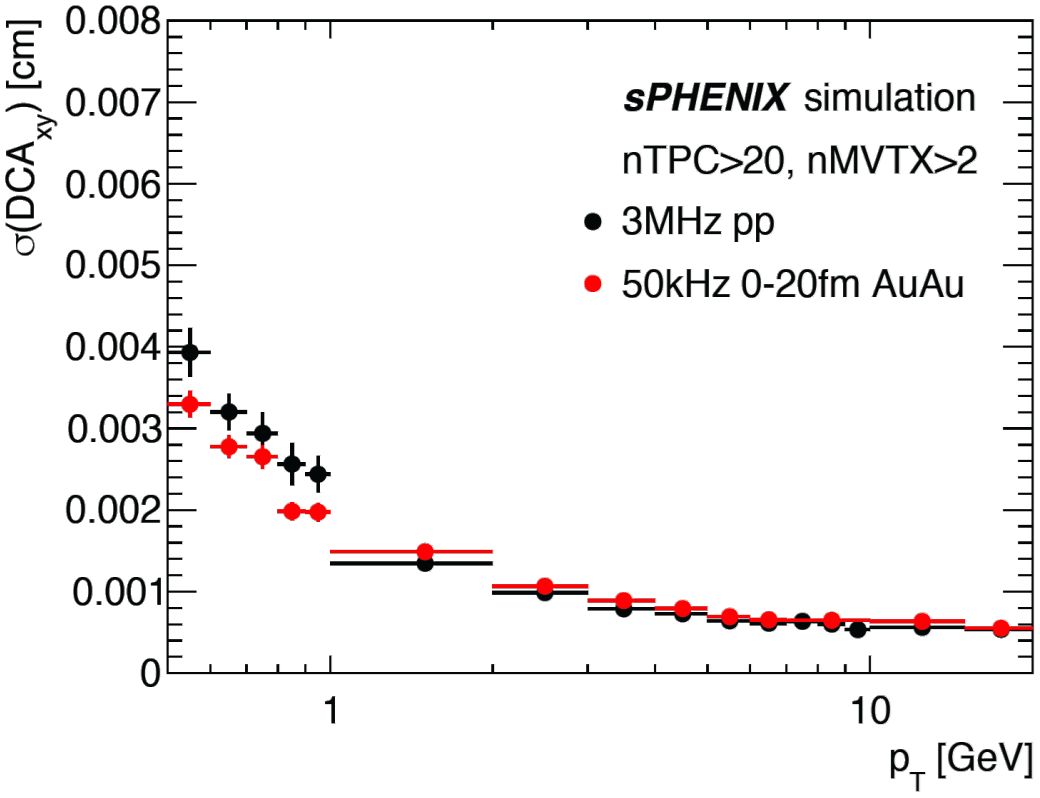
- sPHENIX will able to simultaneously resolve 1S, 2S, and 3S states
- Offers possible insight into medium screening length

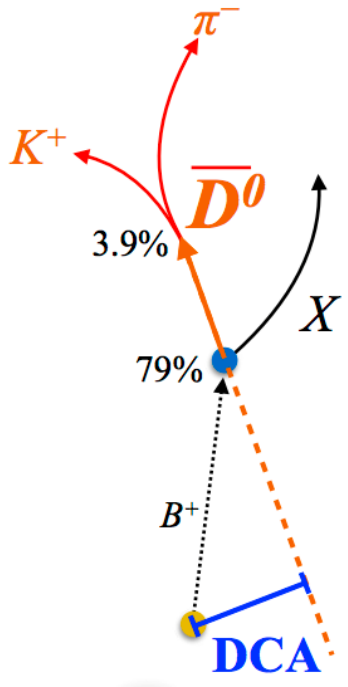


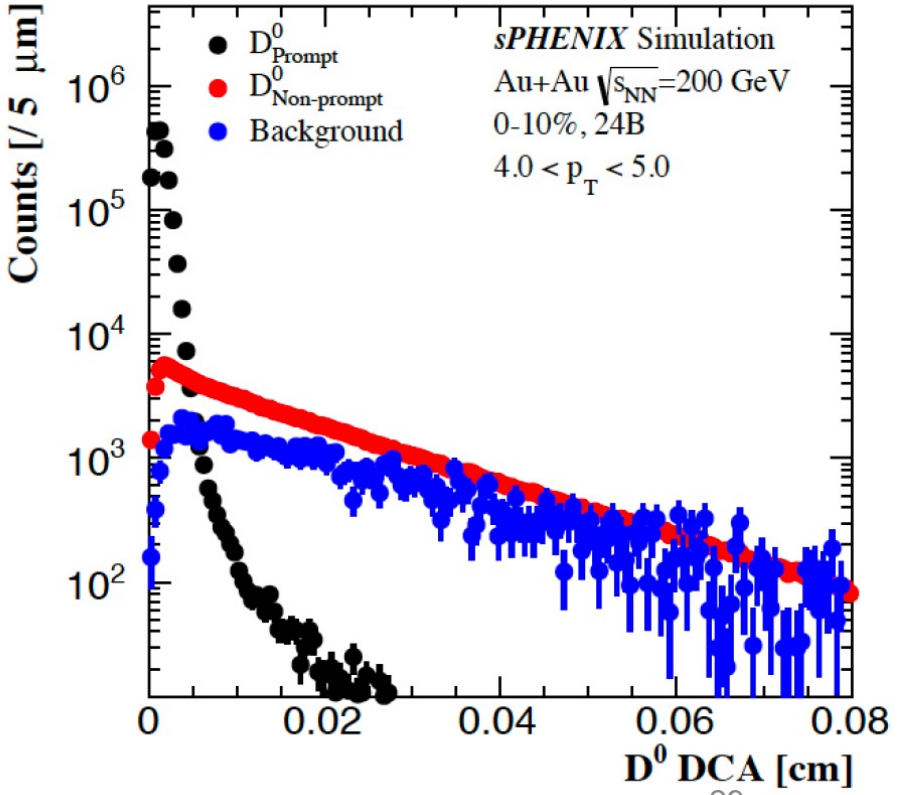


Tracking Performance: DCA Resolution

- DCA resolution delivered by tracking < 40μm for $p_T > 0.5$GeV/c
- Allows for separation of prompt and non-prompt D^0 candidates

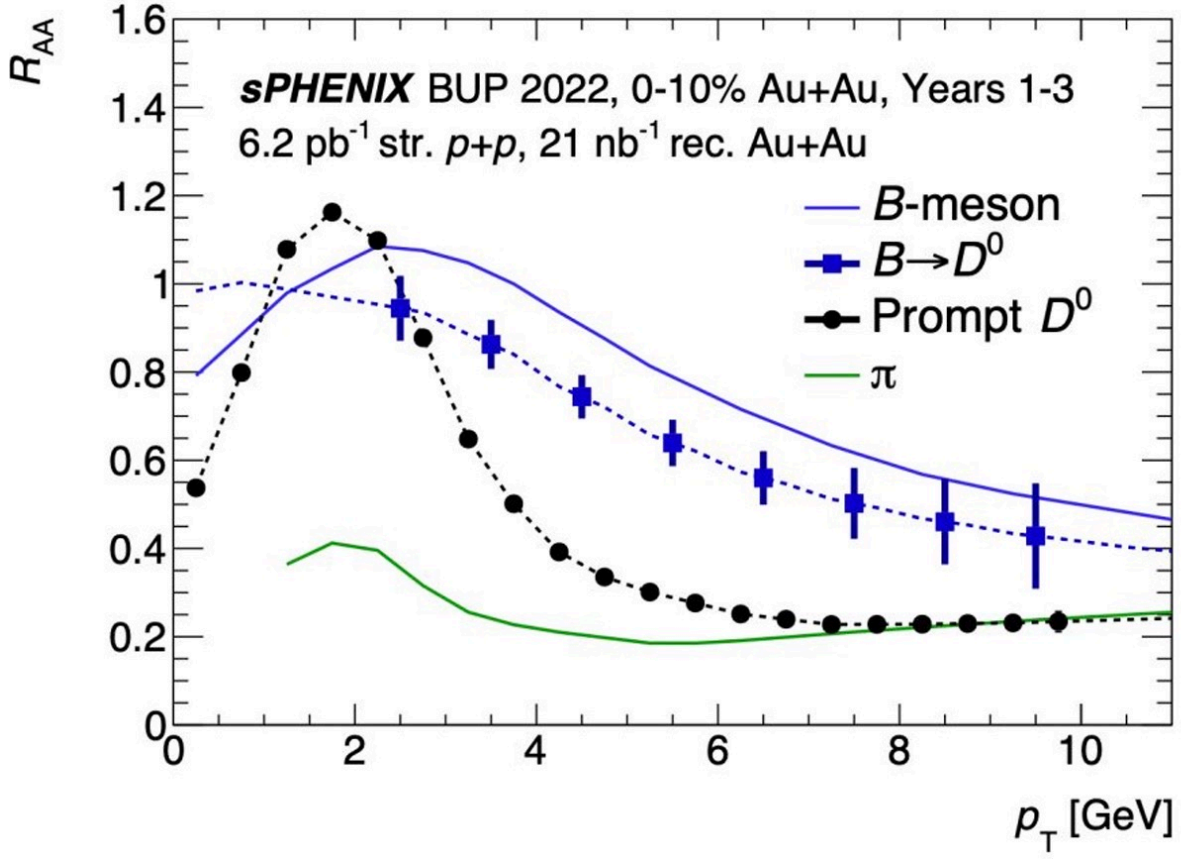


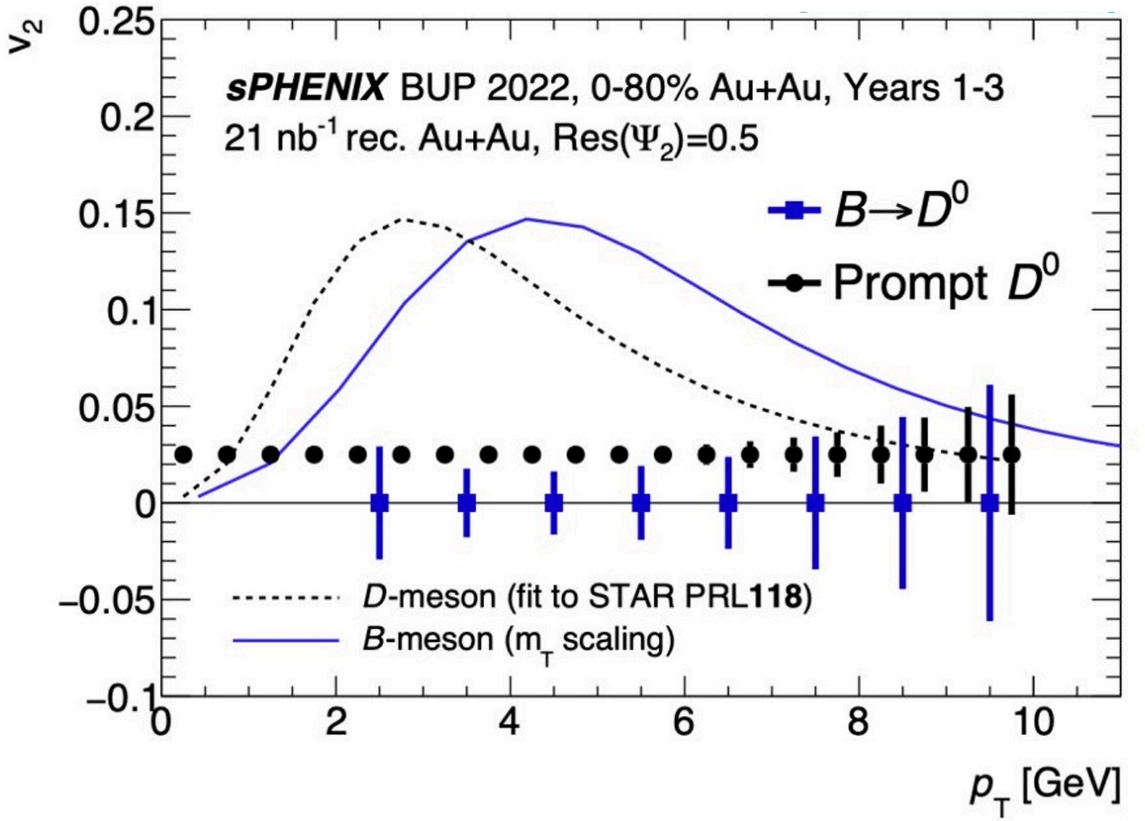




Open Heavy-Flavor Measurements

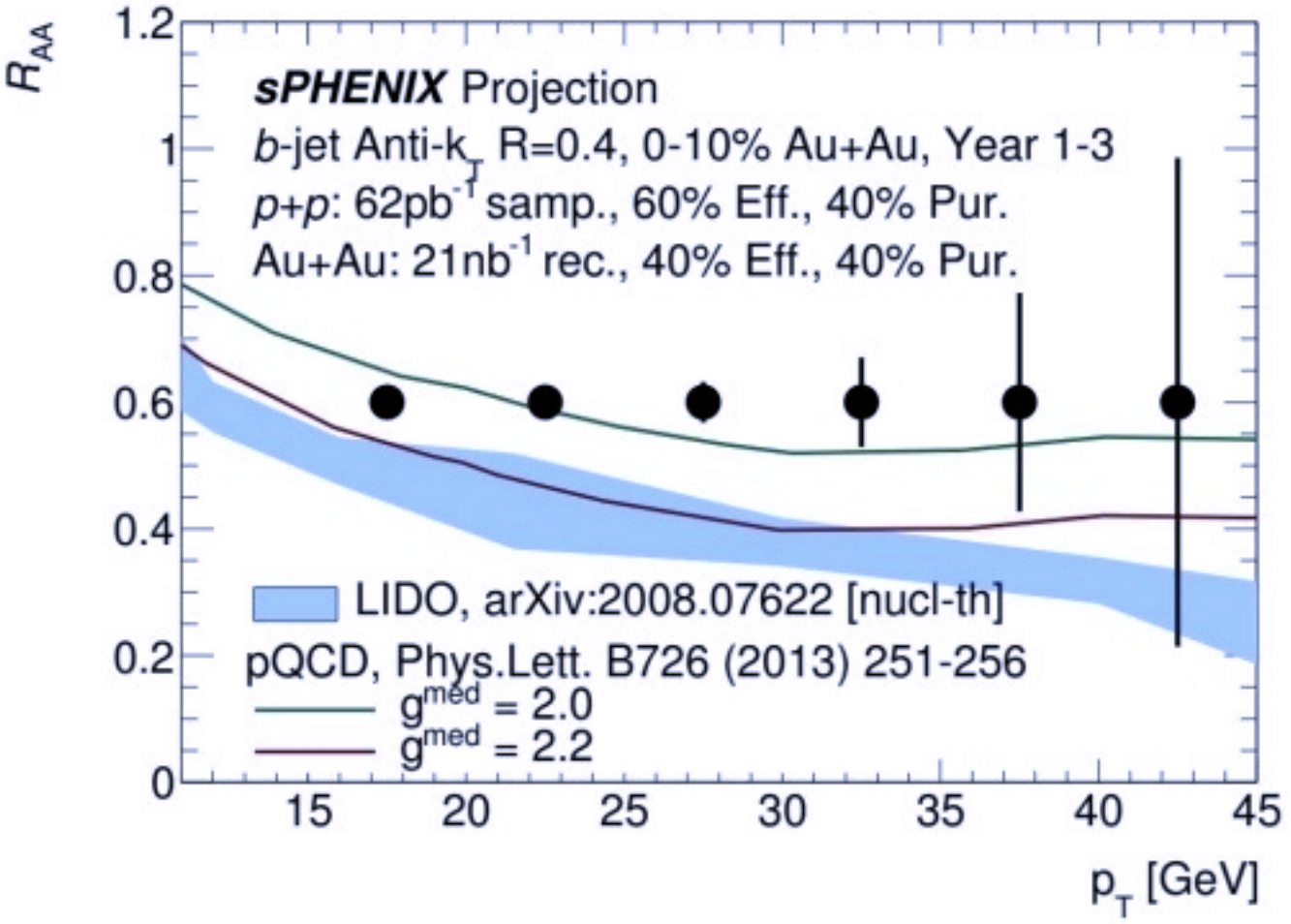
- R_{AA} of heavy flavor hadrons illuminates interplay between radiative and collisional energy loss
- Study of v_2 assess bottom quark collectivity

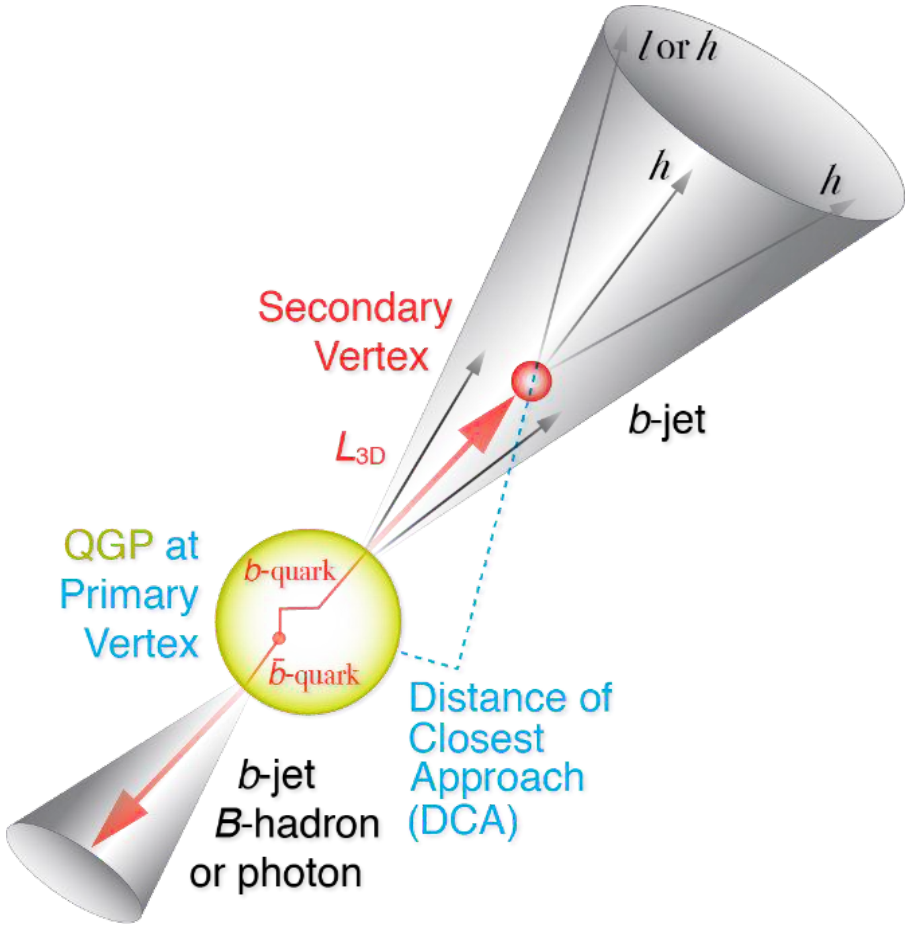




Heavy Flavor-Tagged Jets

- Track+calorimeter jets allow reconstruction of heavy flavor tagged jets
- Precision measurements offer discrimination power between model parameters

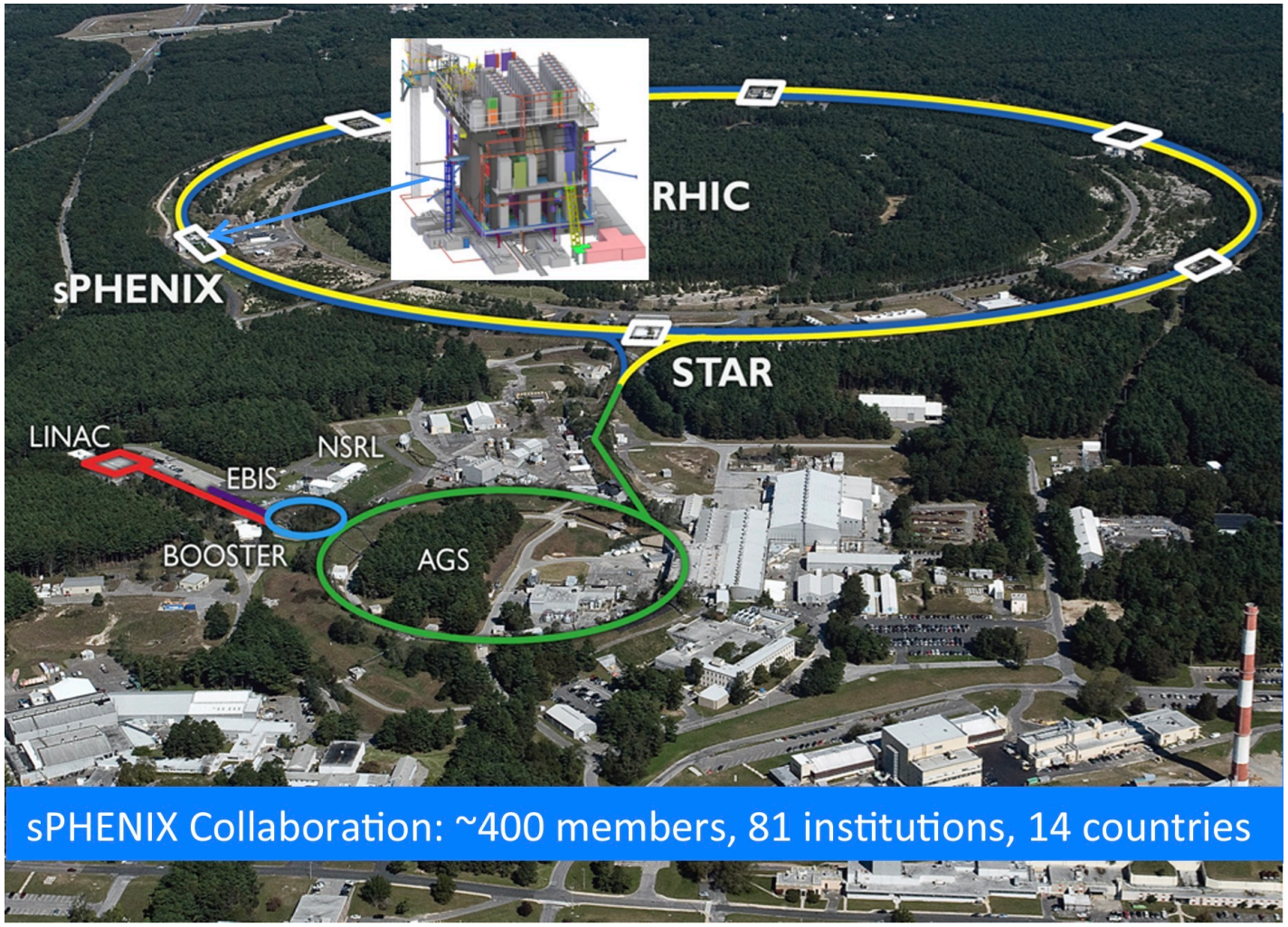




Summary

- sPHENIX is a new, state-of-the-art detector that has just begun taking data at RHIC
- sPHENIX is designed to make precise measurements of jet and heavy flavor observables
- These measurements are made possible by;
  - The first full-coverage electromagnetic and hadronic calorimeters at mid-rapidity at RHIC
  - A highly precise tracking system incorporating years of technical expertise from both RHIC and LHC experiments
- First physics is already coming from our commissioning run, expect results early 2024!

Conclusion: The sPHENIX Detector



- A novel, state-of-the-art particle detector at RHIC
- Designed to make precision measurements of jet and heavy flavor final states
- sPHENIX is the first new detector at RHIC in 20 years!

Thank you!


uark Matter 2023
The 30th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions
Houston, Texas
3-9 September 2023
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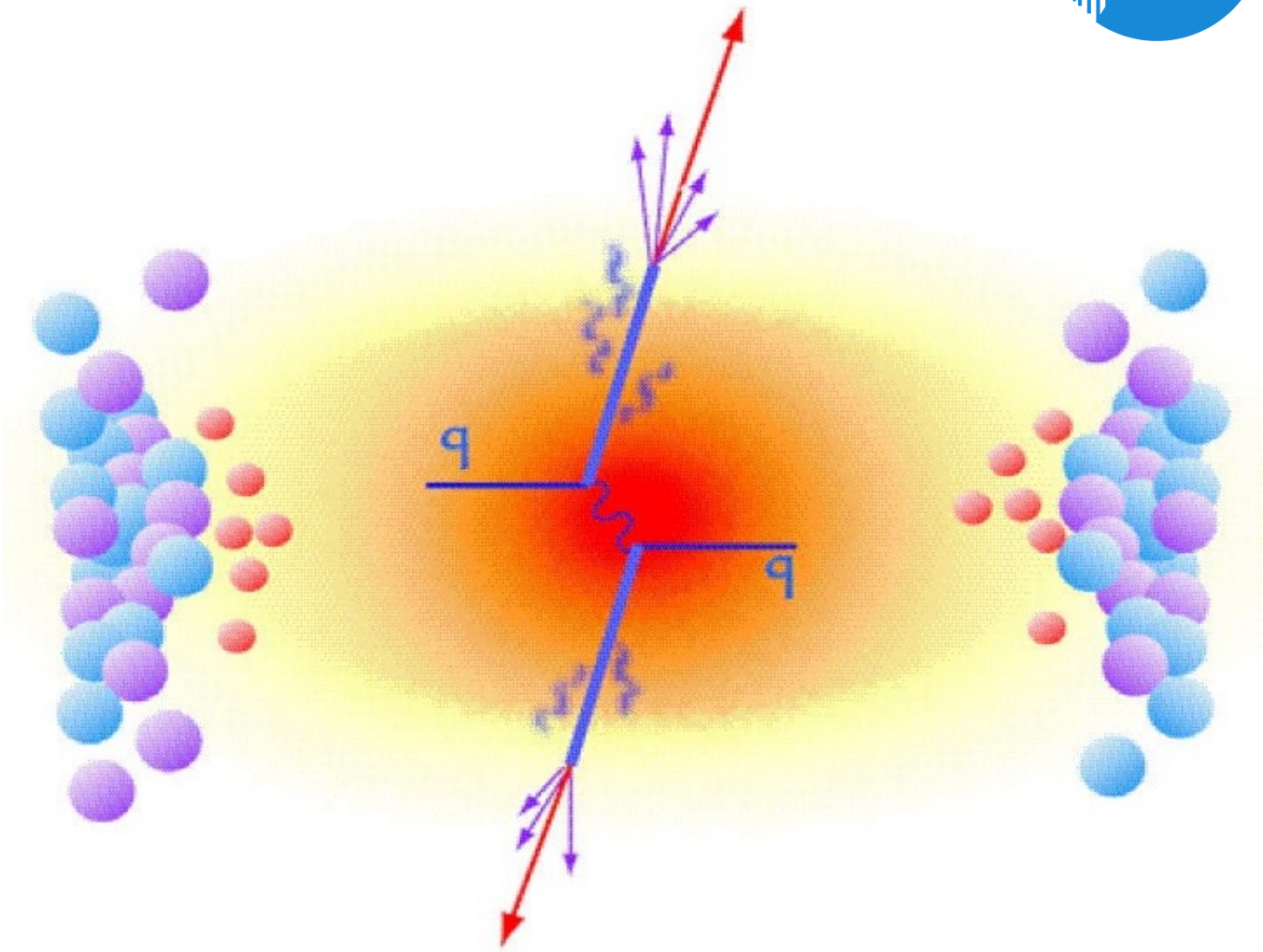
Back-up

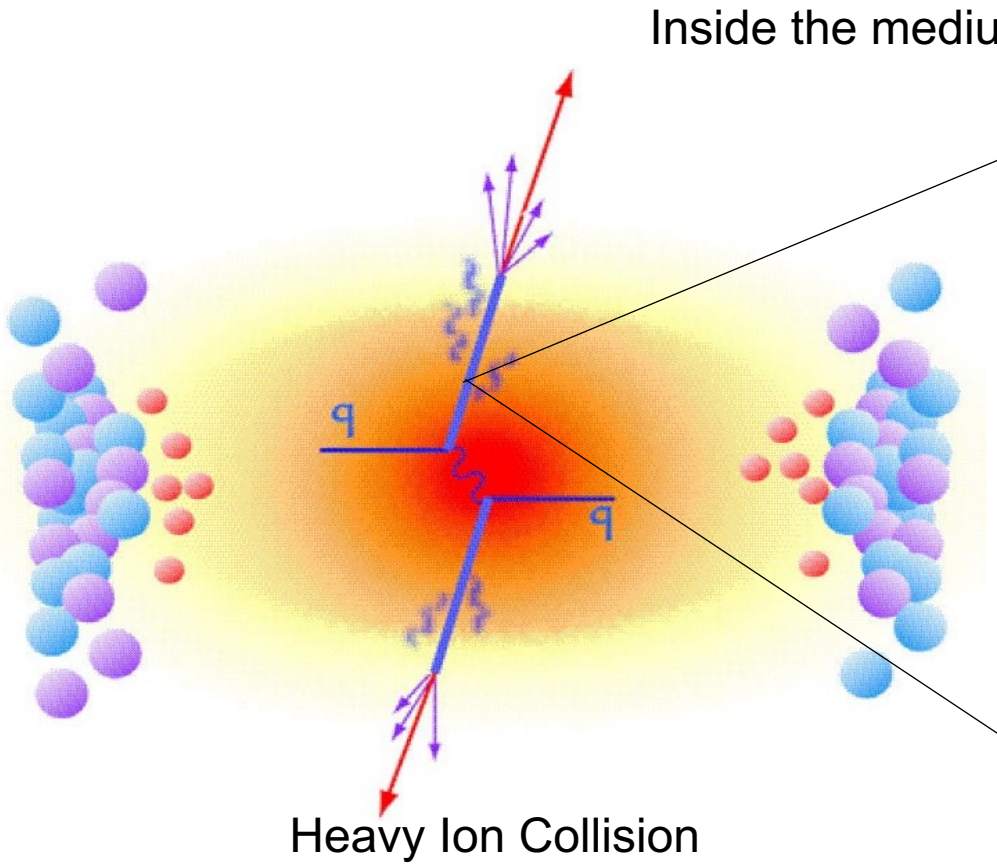
Jets in Heavy-Ion Collisions

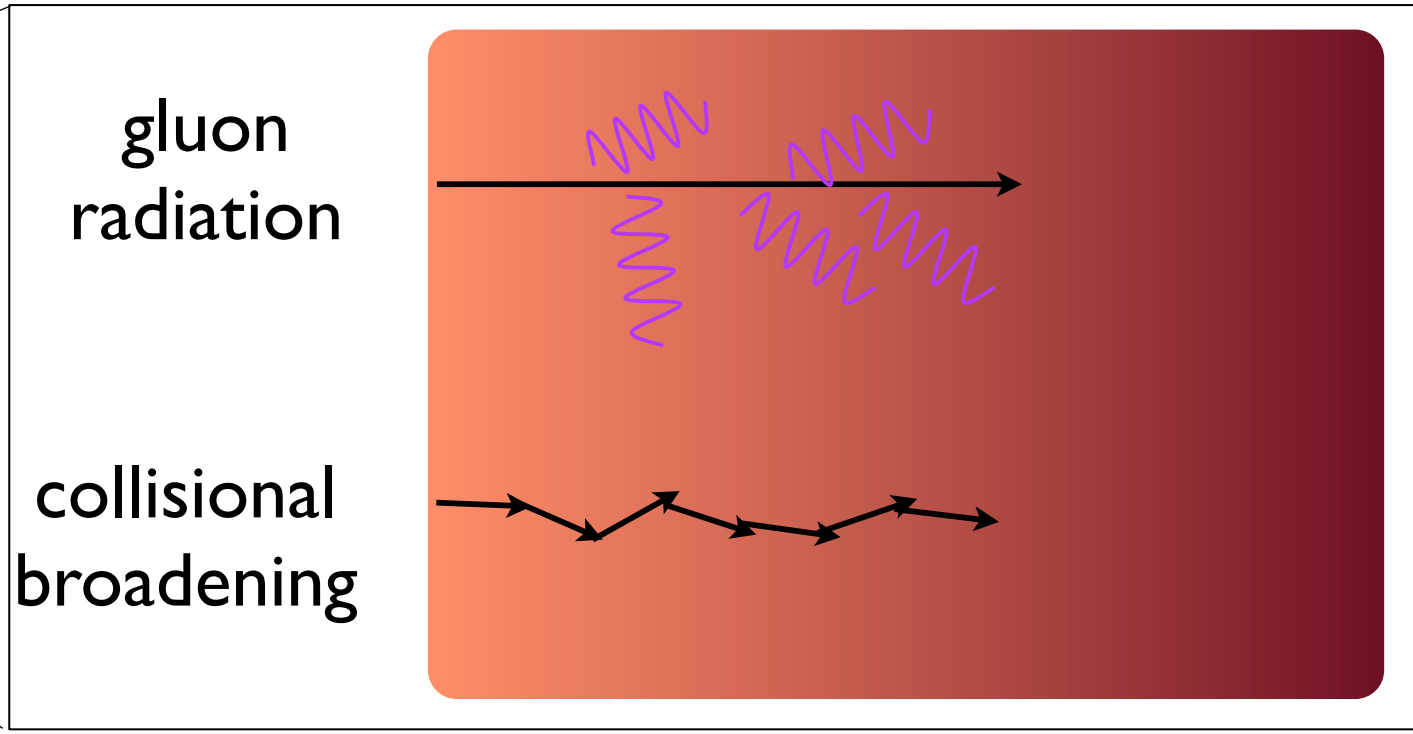
- Jets – valuable probe of partonic energy and parton-medium interactions



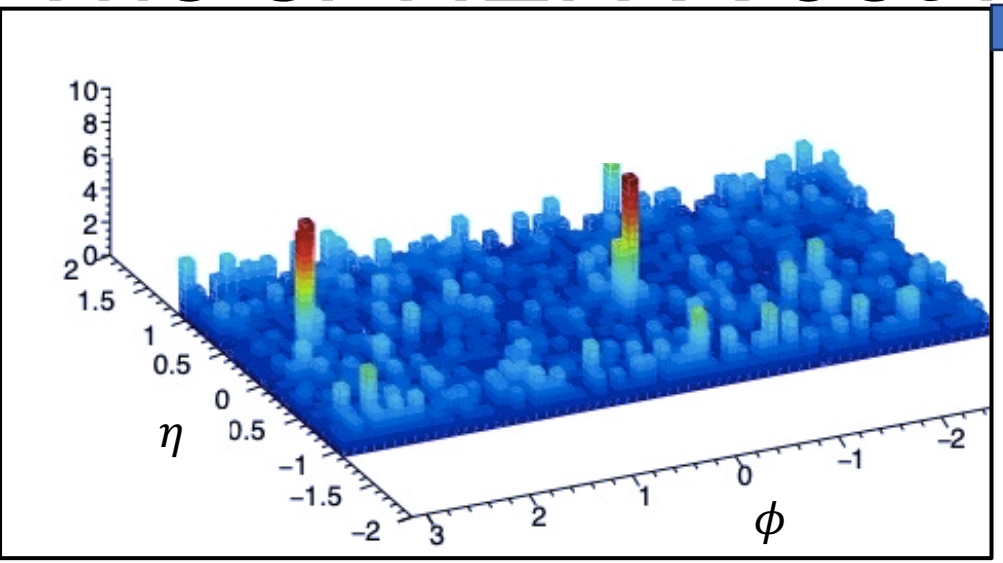
Heavy Ion Collision

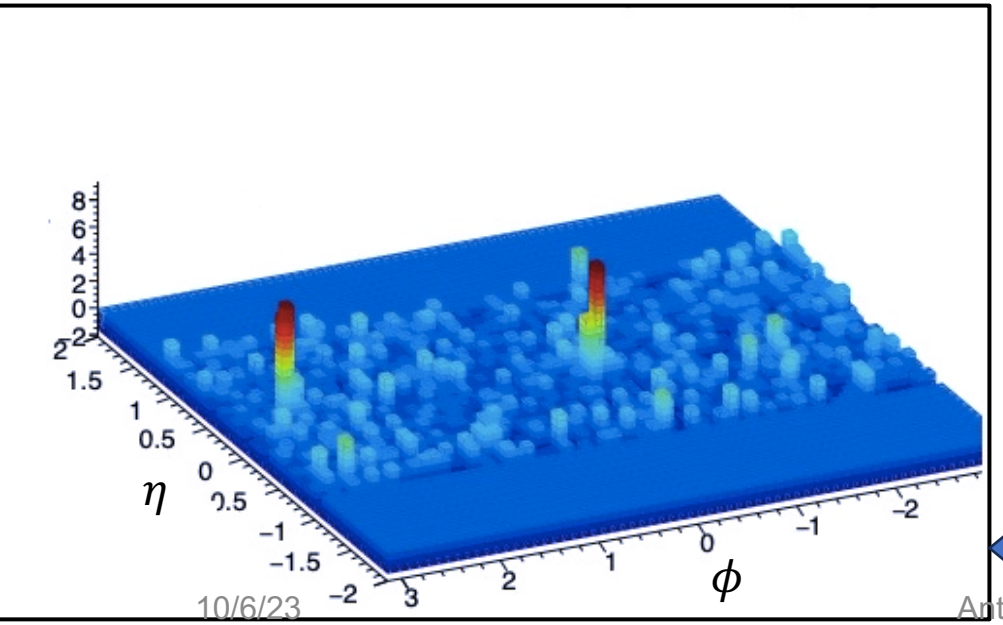
Jets in Heavy-Ion Collisions





The sPHENIX Jet Reconstruction Process





Iterative Subtraction Procedure

1) Reconstruct R = 0.2 Seed Jets

2) Determine event v_n excluding regions near seeds

3) Determine UE $\langle E \rangle$ away from seed jets and Subtract with flow modulation

4) Repeat (1-3) with new seed jets from subtracted towers

5) Run jet reconstruction on subtracted towers