U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

sPHENIX Status

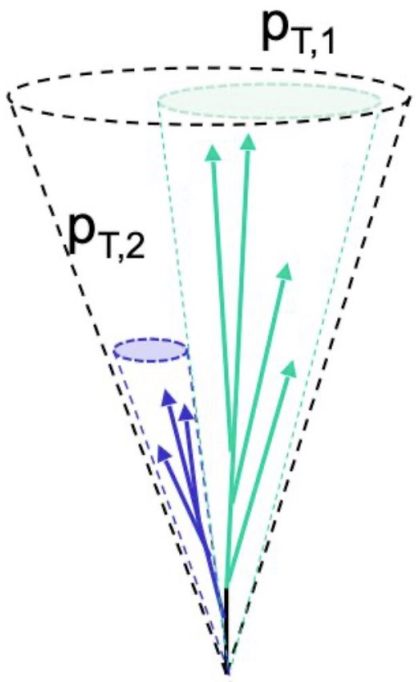
Virginia Bailey
Georgia State University
on behalf of the **sPHENIX** collaboration

JETSCAPE Summer School
July 28th 2023

Georgia State University

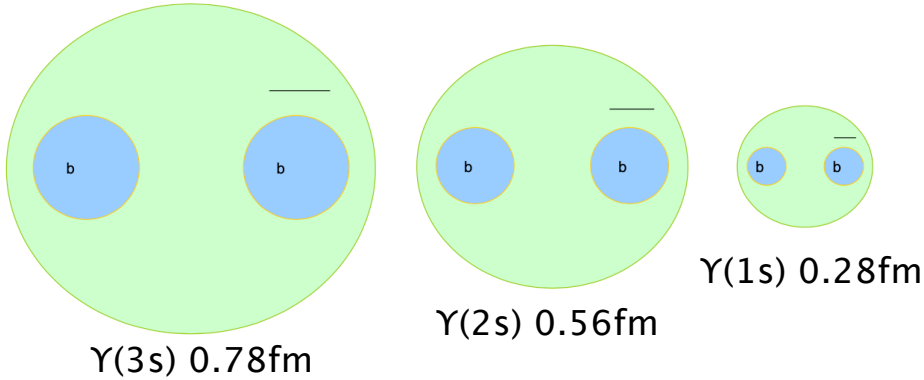
sPHENIX

The sPHENIX Physics Program



Jet structure

vary momentum/angular scale of probe

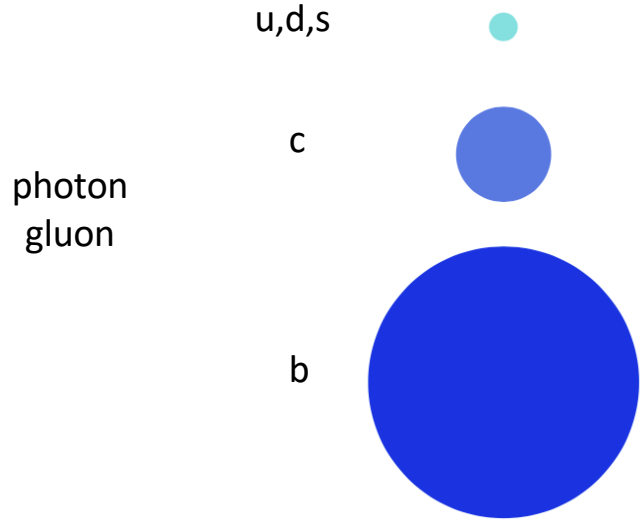


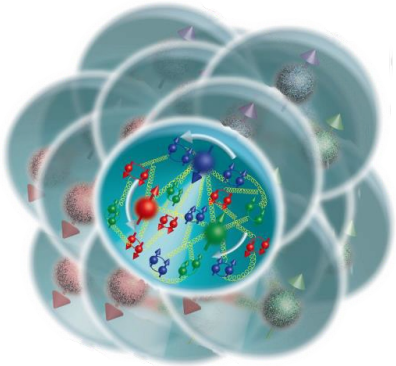
Quarkonium spectroscopy

vary size of probe

Parton energy loss

vary mass/momentum of probe





Cold QCD

study proton spin,
transverse-momentum,
and nuclear effects

sPHENIX Detector

First new detector at RHIC in 20 years!

Tracking:

- MAPS-based Vertex Tracker (MVTX)
- Intermediate Silicon Tracker (INTT)
- Time Projection Chamber (TPC)
- TPC Outer Tracker (TPOT)

Superconducting Magnet

- 1.4T solenoid magnet

Calorimetry:

- Electromagnetic calorimeter (EMCal)
- Inner hadronic calorimeter (IHCal)
- Outer hadronic calorimeter (OHCal)

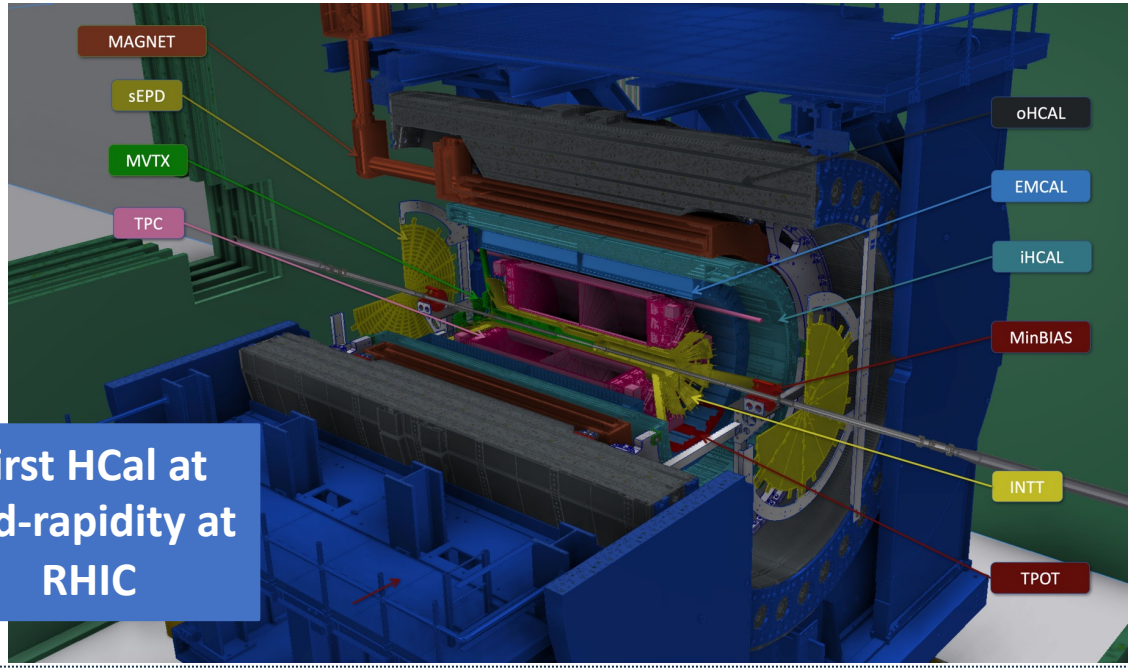
High rate DAQ and trigger systems

- 15 kHz trigger + ***streaming readout*** for tracking detectors

100x statistics for low p_T heavy flavor in *pp*

Event Characterization:

- Minimum Bias Detector (MBD)
- Event Plane Detector (sEPD)
- Zero Degree Calorimeter (ZDC)



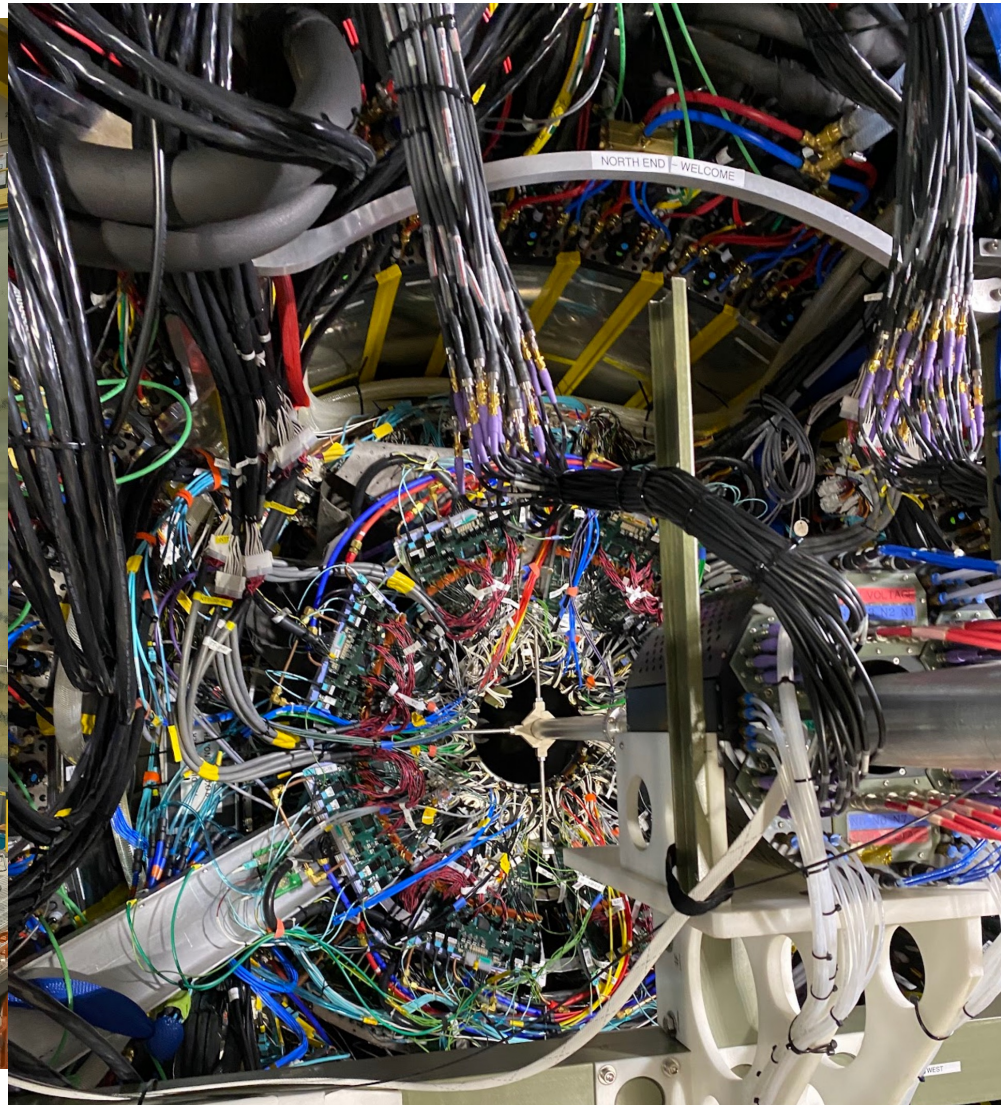
First HCal at mid-rapidity at RHIC

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}

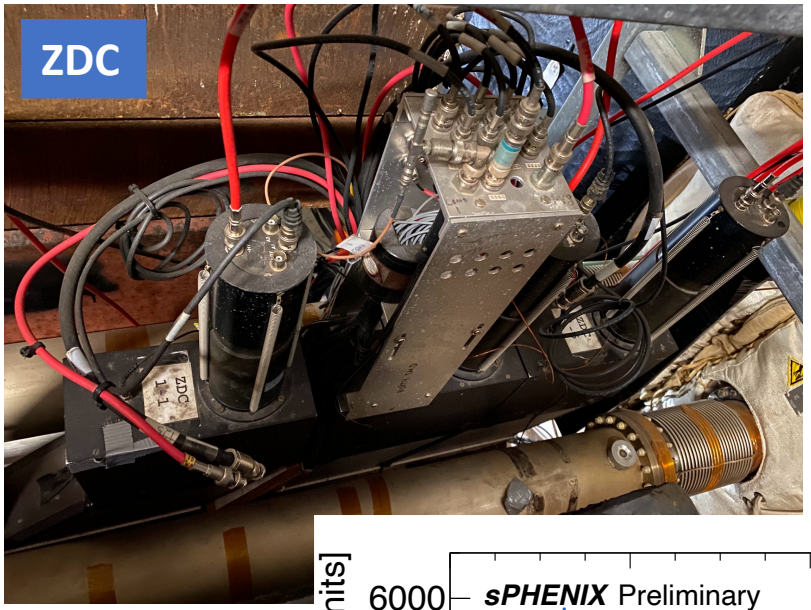
- 2023 - **commissioning** of detector, RHIC and data operations in **Au+Au**
- 2024 - **high statistics p+p** reference and **p+Au** cold QCD data
- 2025 - **high statistics Au+Au** data

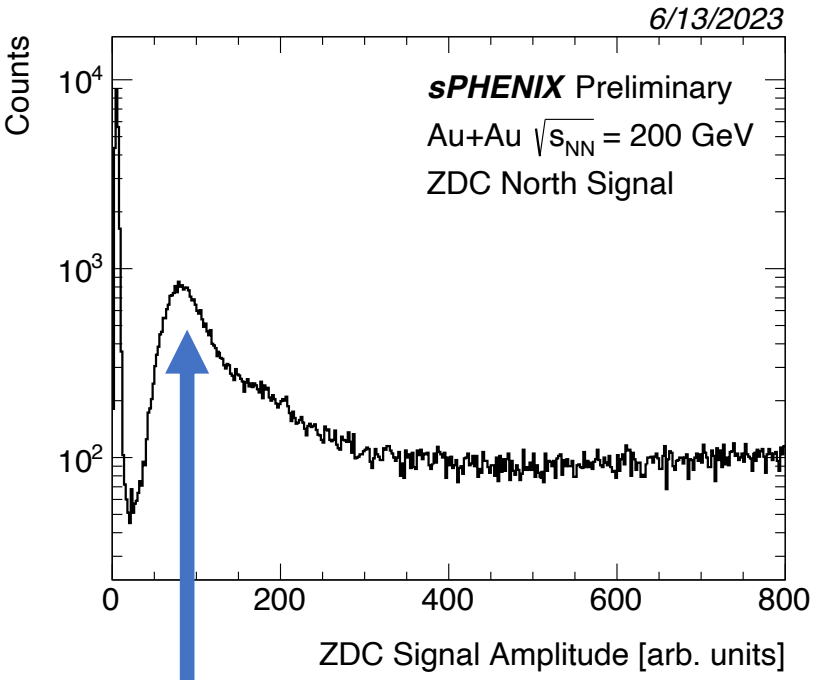
The Real sPHENIX Detector

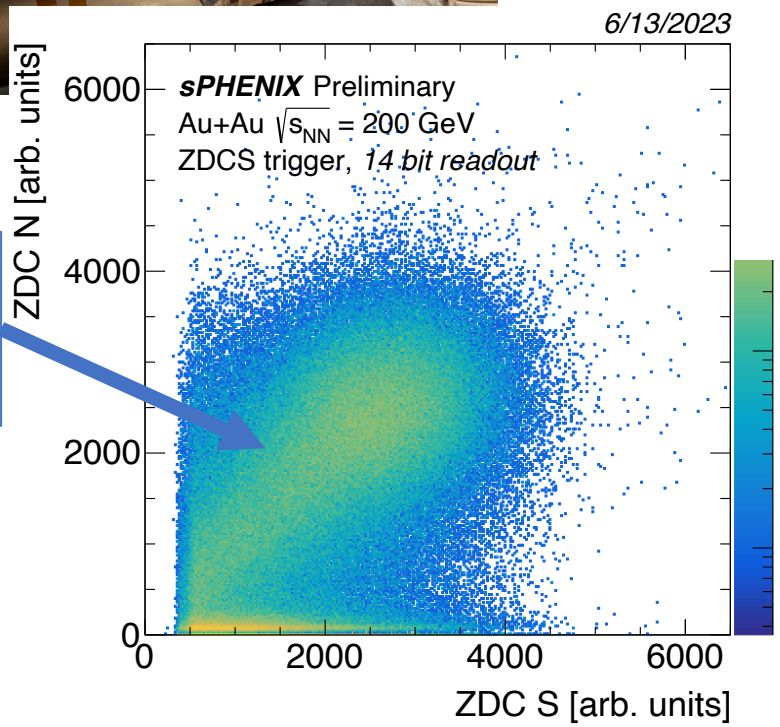


Detector assembled and commissioning underway at BNL- first looks at *real* sPHENIX data

Event Characterization



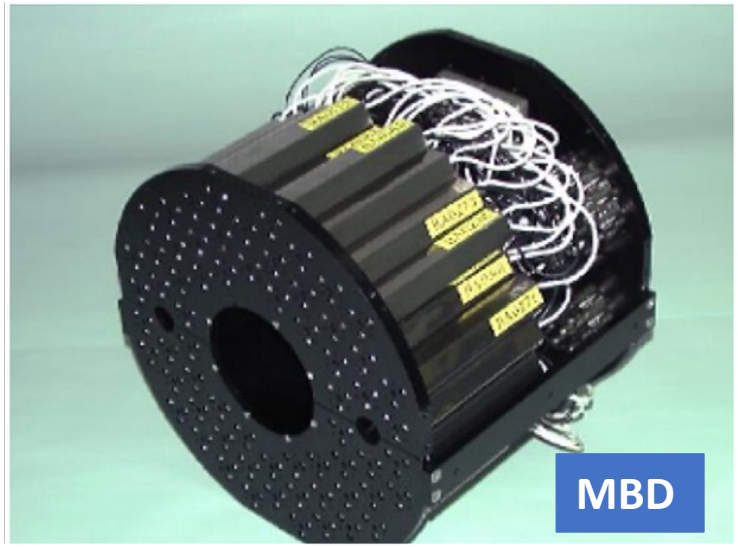


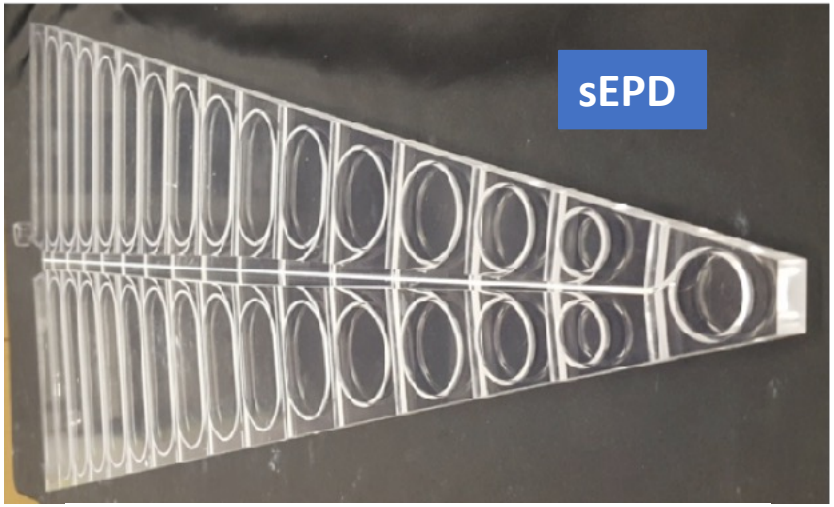


Correlation from collisions

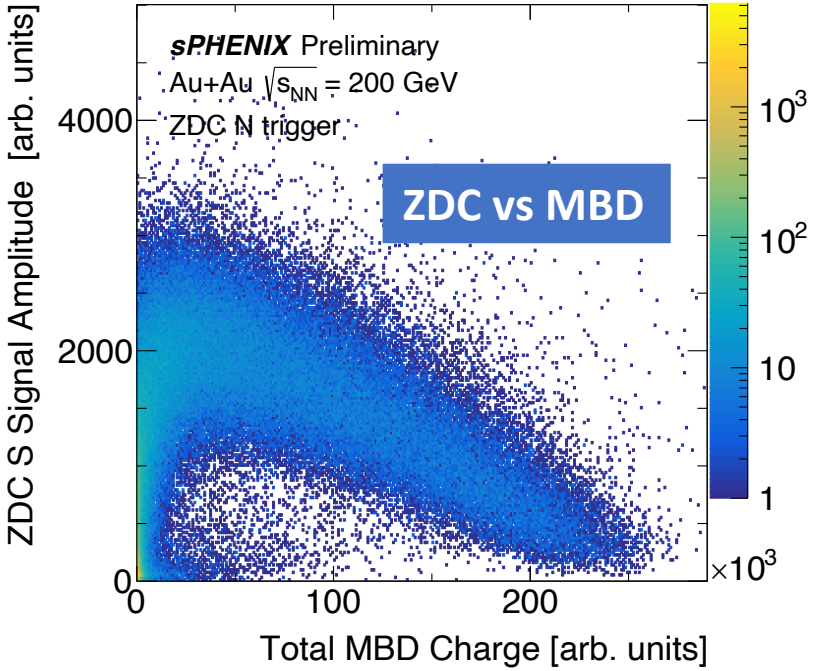
Single neutron peak

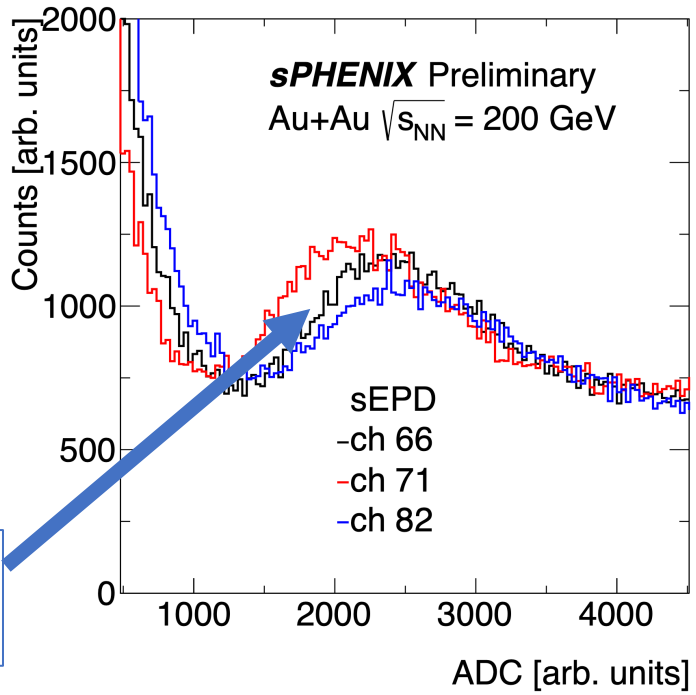
Event Characterization





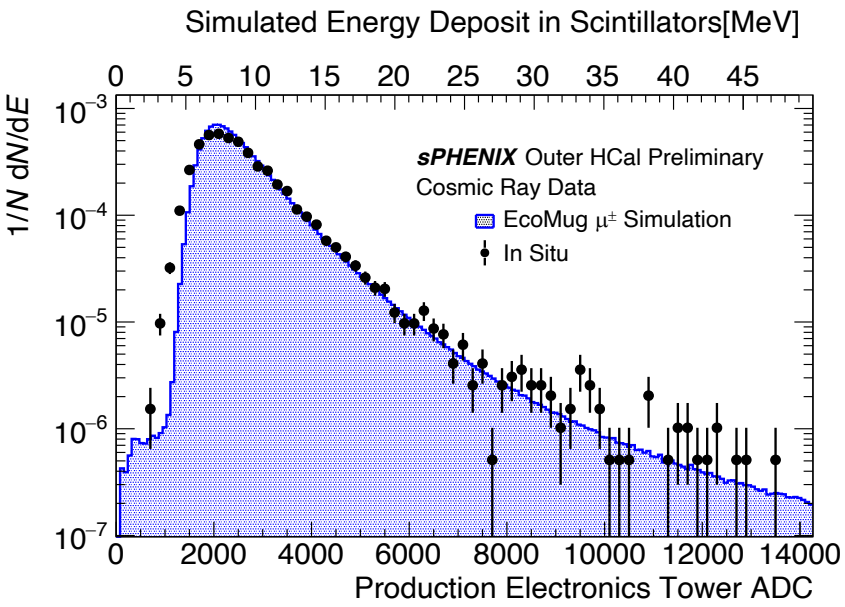
7/21/2023



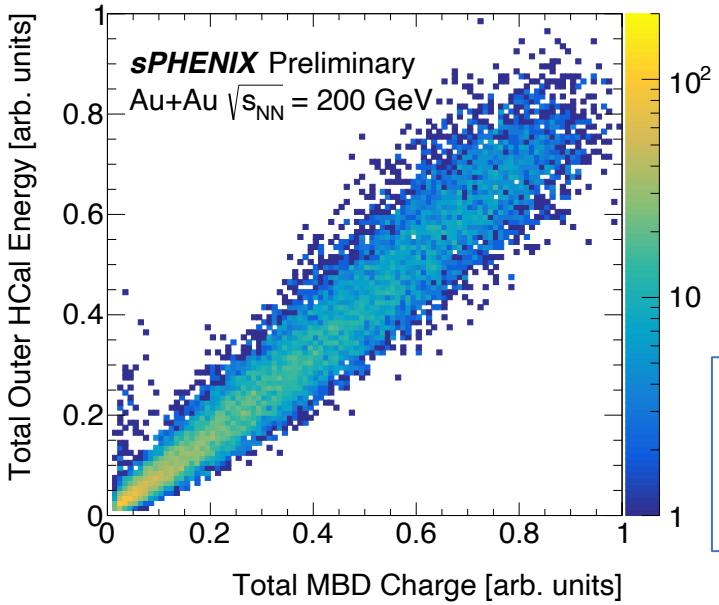


MIP peak in sEPD

Calorimetry: Outer HCal

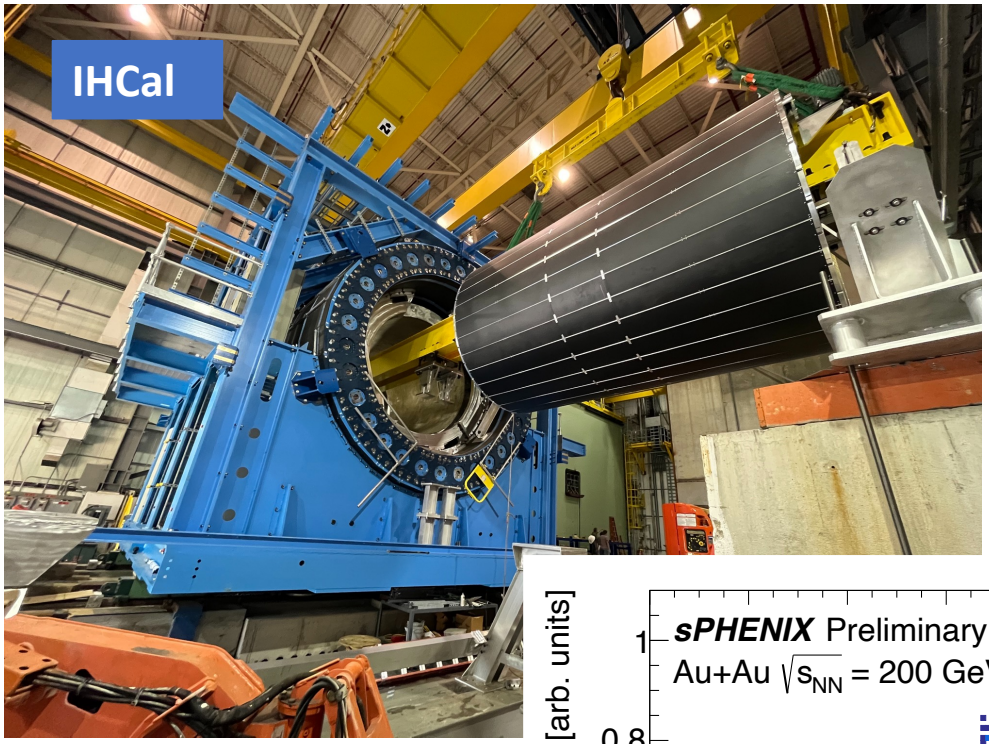


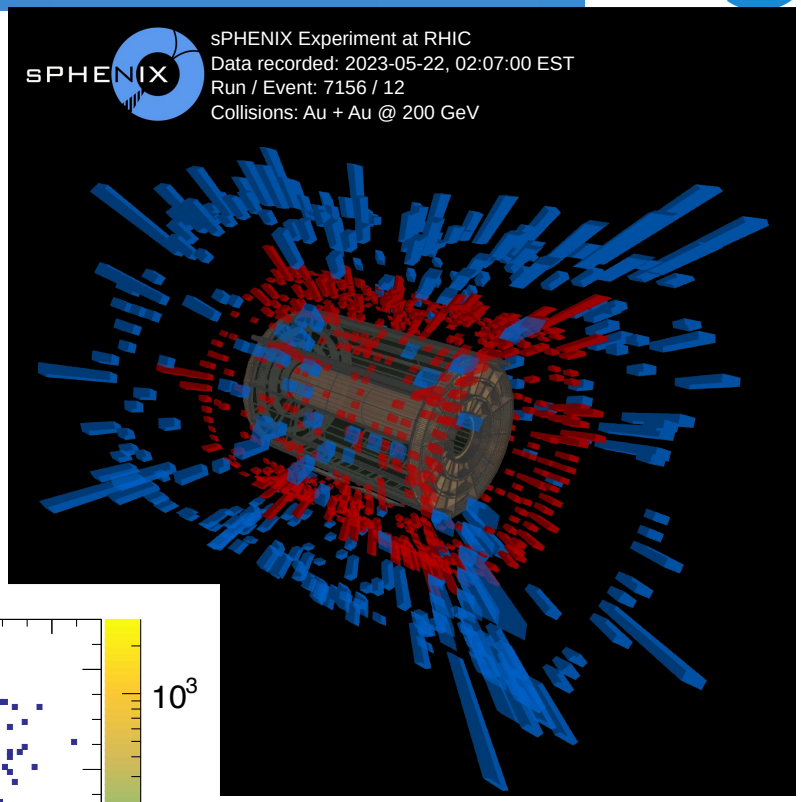
Cosmic ray data matches simulation

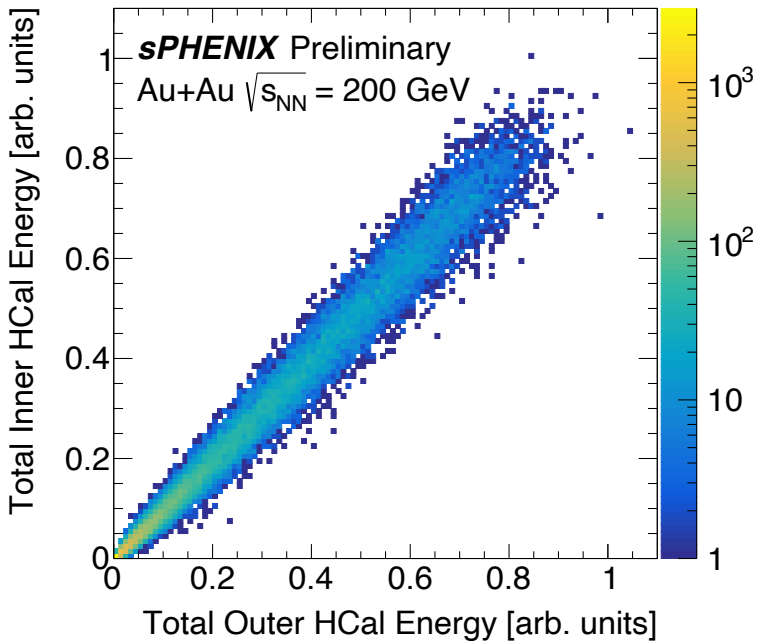


Good correlation with MBD

Calorimetry: Inner HCal

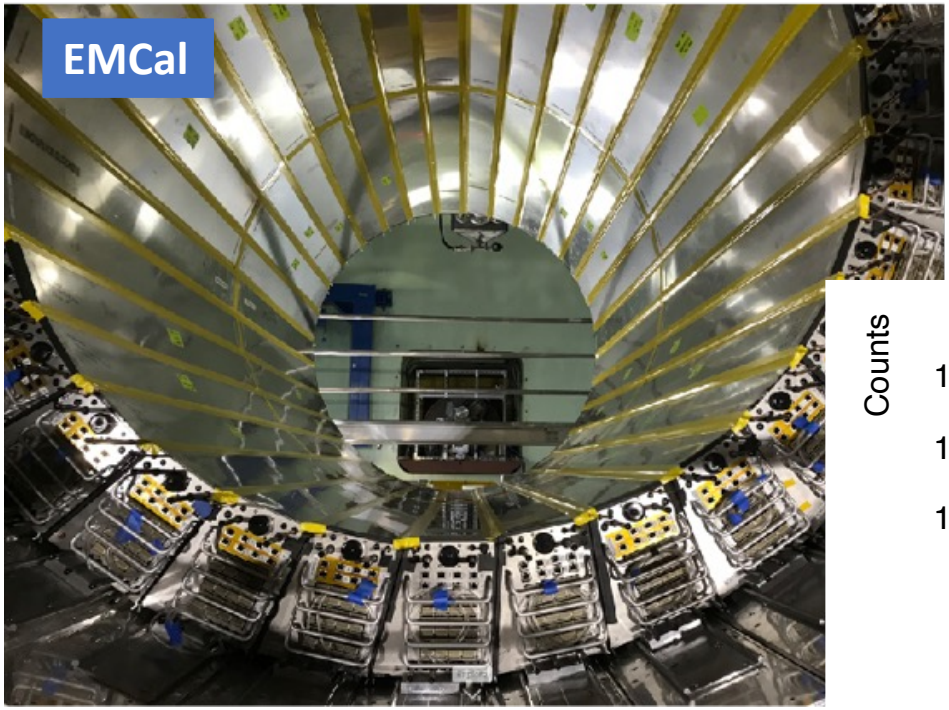


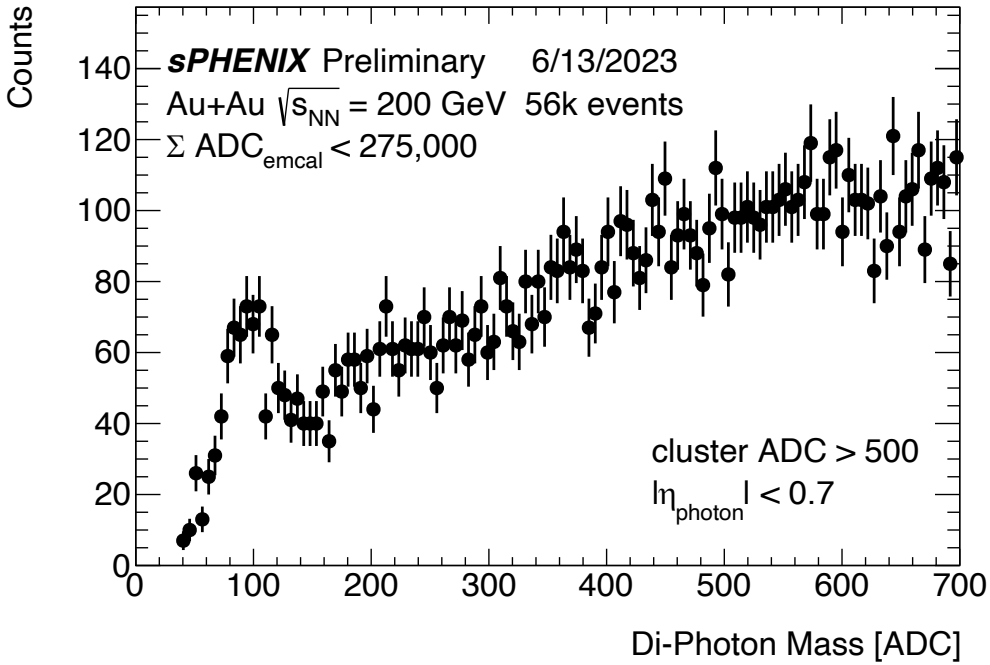




Good correlation between inner and outer HCals

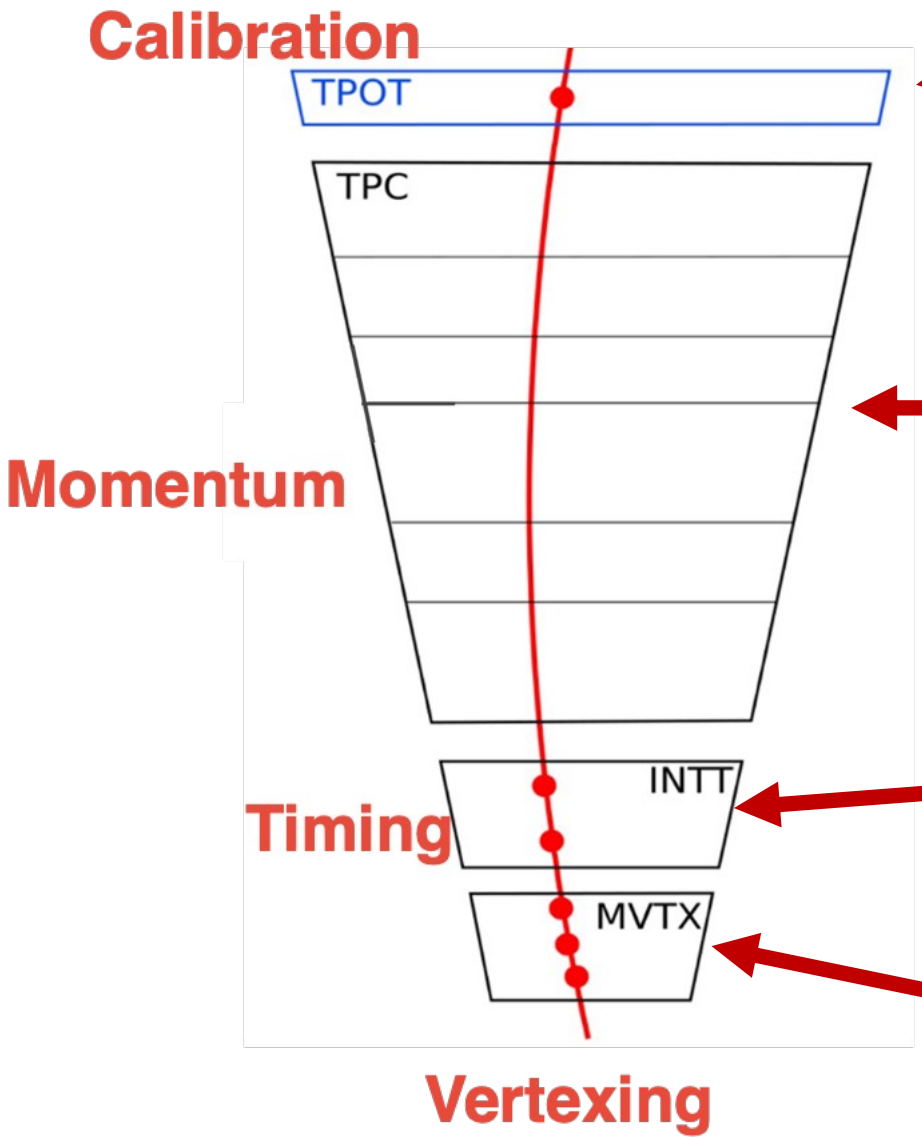
Calorimetry: EMCal

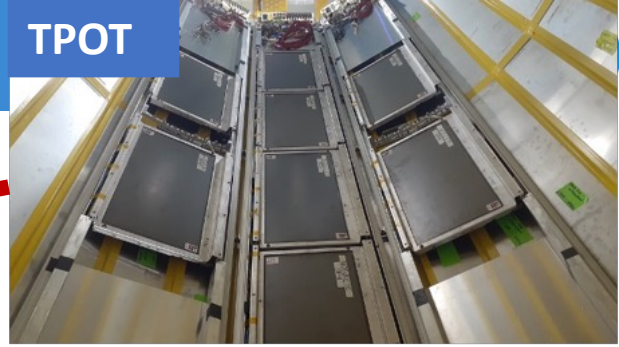


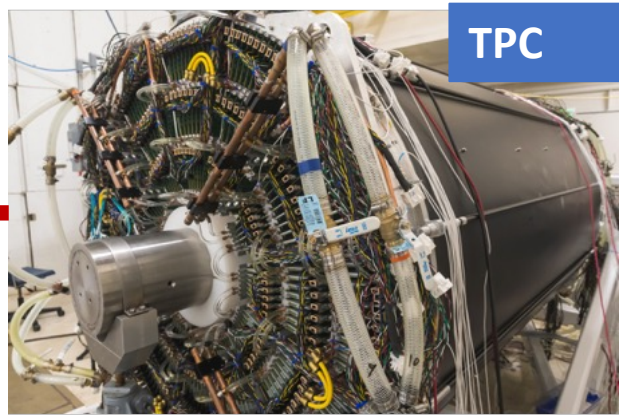


Di-photon mass distribution shows expected π^0 peak

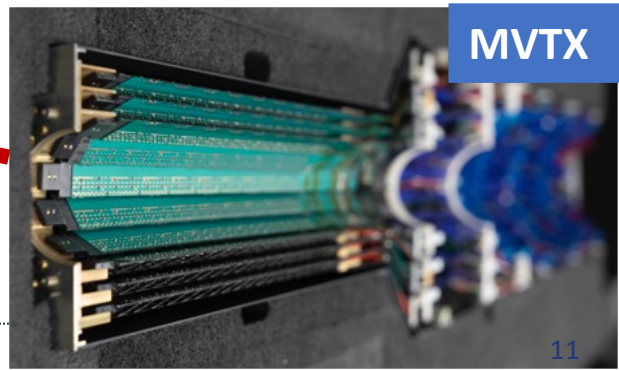
Tracking


Calibration
TPOT
TPC
Momentum
INTT
Timing
MVTX
Vertexing


TPOT

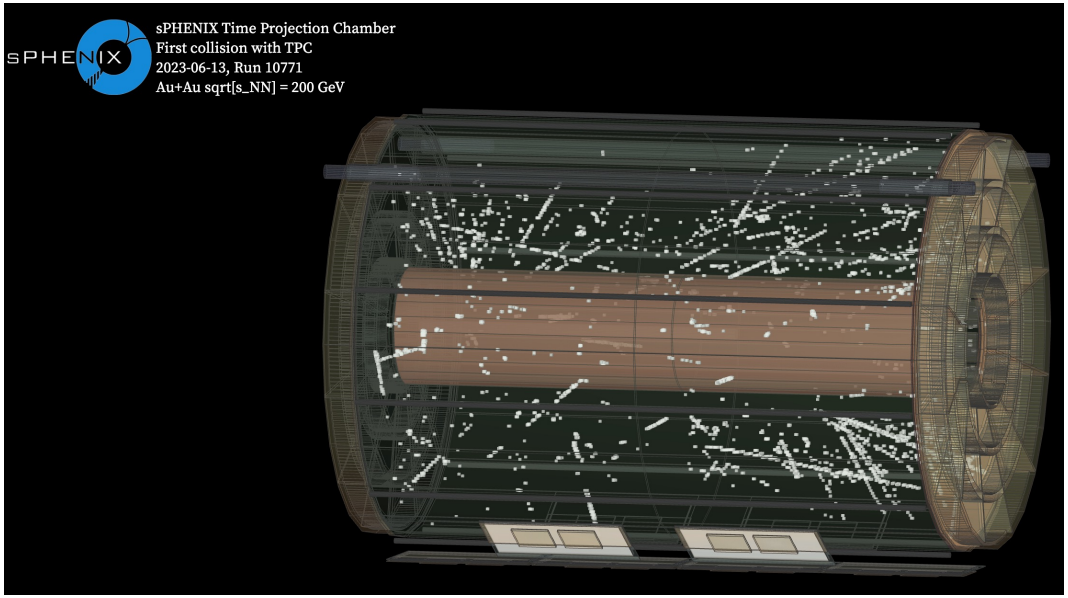

TPC

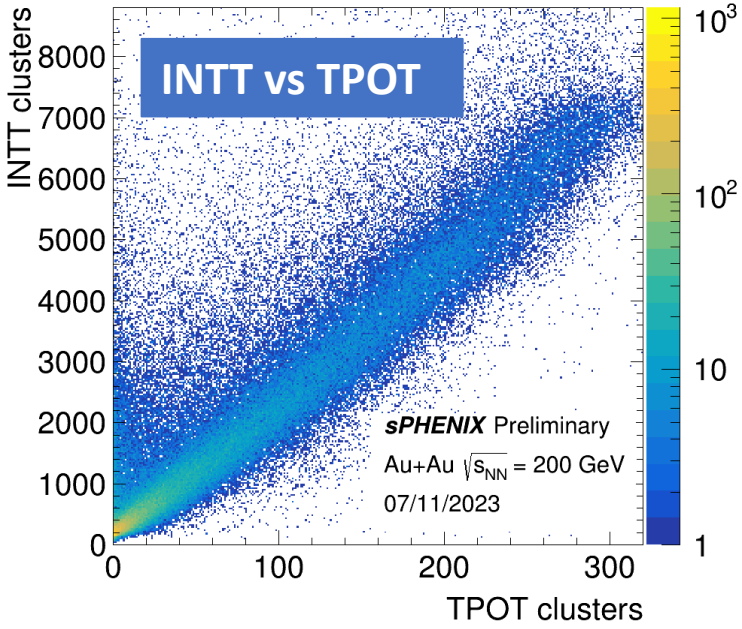

INTT

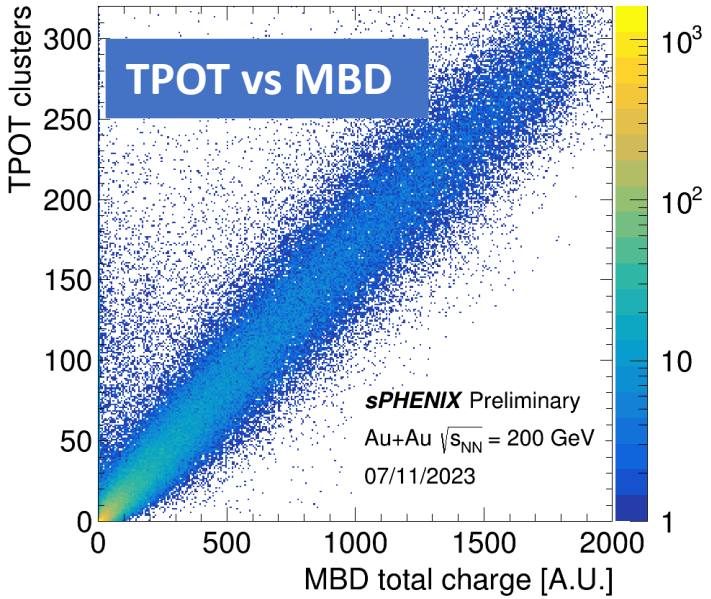

MVTX

Tracking

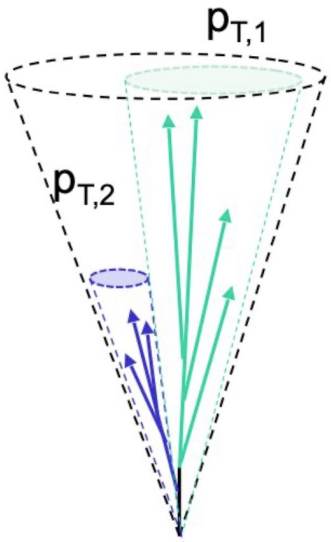
Hits in the TPC

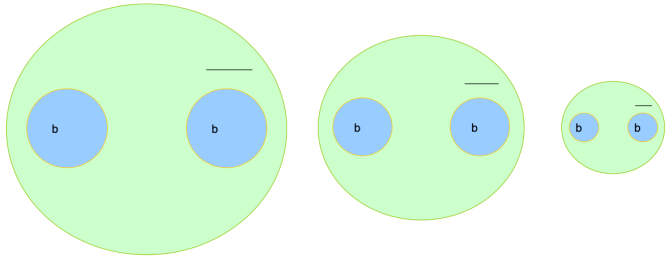




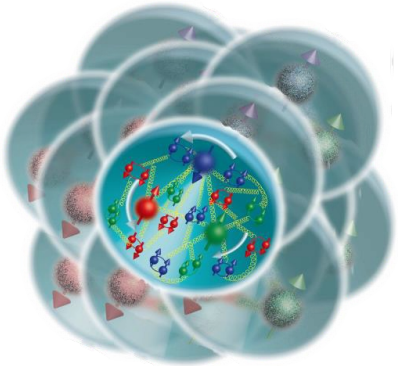


Correlation between systems with different readouts

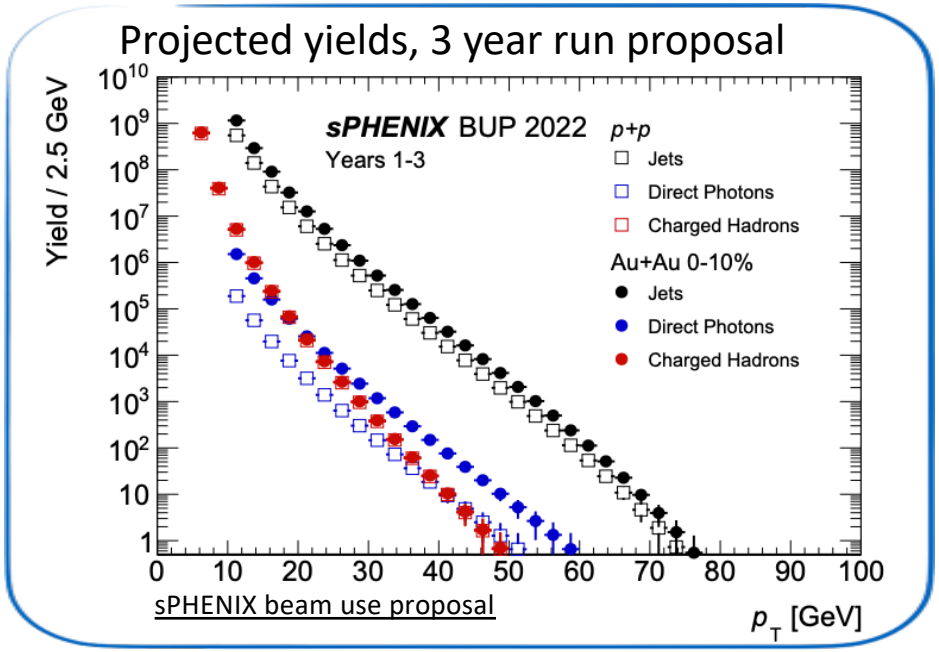


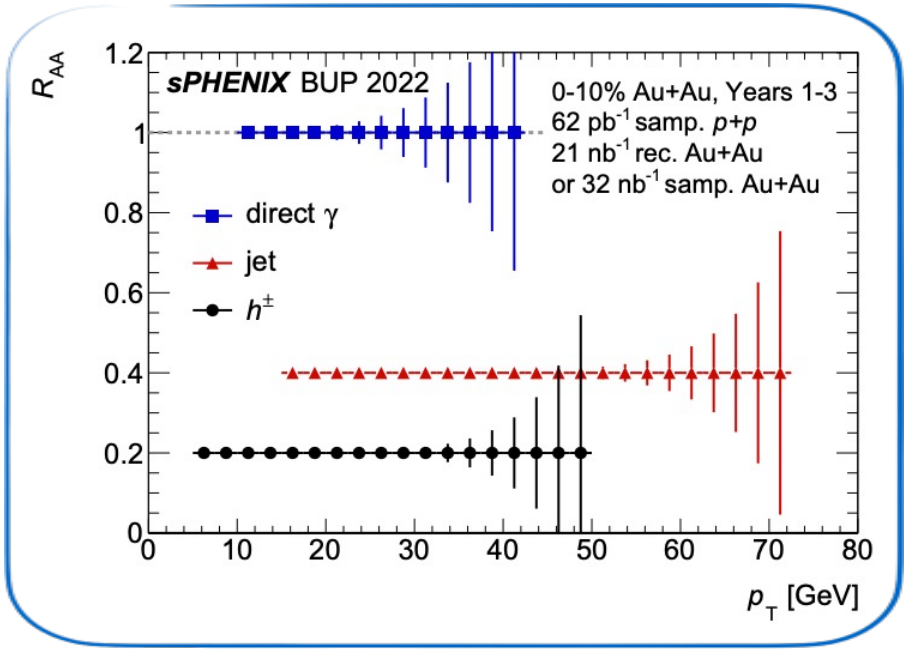


sPHENIX Physics Projections



Jet Physics





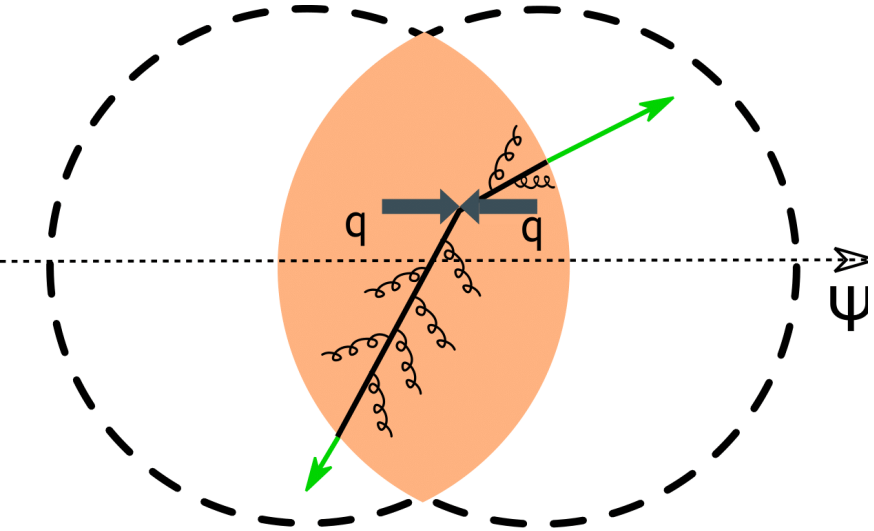
- Jet measurements up to high p_T
  - overlap with LHC measurements
- Precision measurements at low p_T
- High stats also for
  - photons (γ-jet measurements)
  - charged hadrons (fragmentation functions, substructure)

3 years

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

What we can learn at sPHENIX: Jet v_2

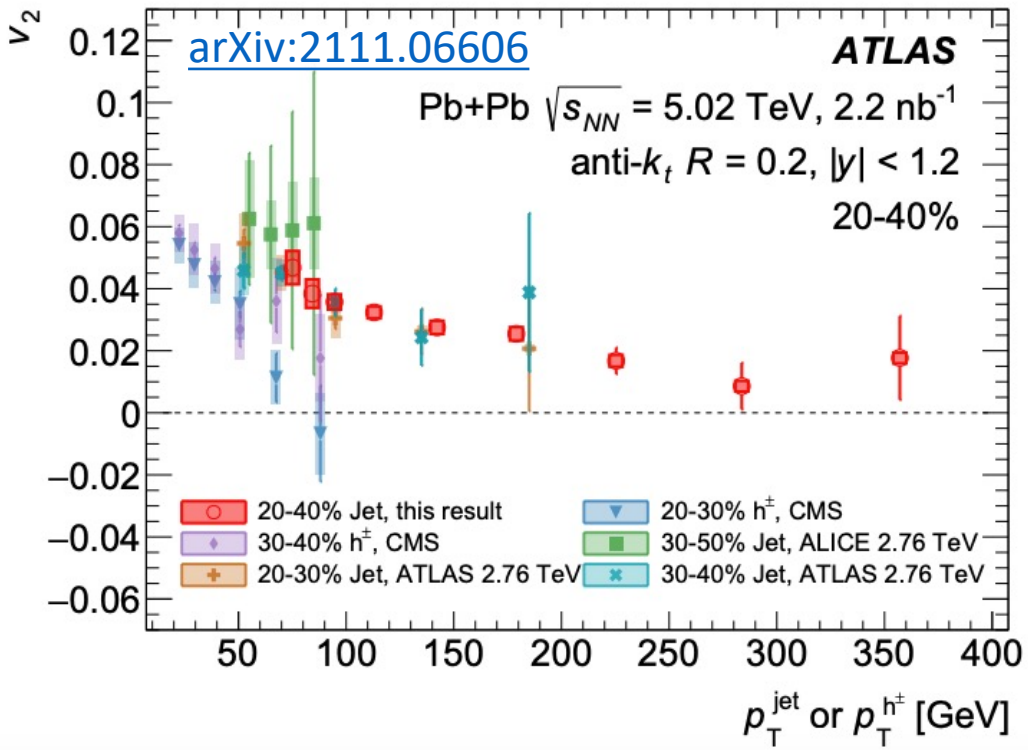
Open question: What is the path-length dependence of energy loss?



Cartoon from M. Rybar

- v_2 at low p_T → flow
- v_2 at high p_T (i.e. jet v_2) → energy loss correlations with initial geometry
  - path-length dependence of energy loss

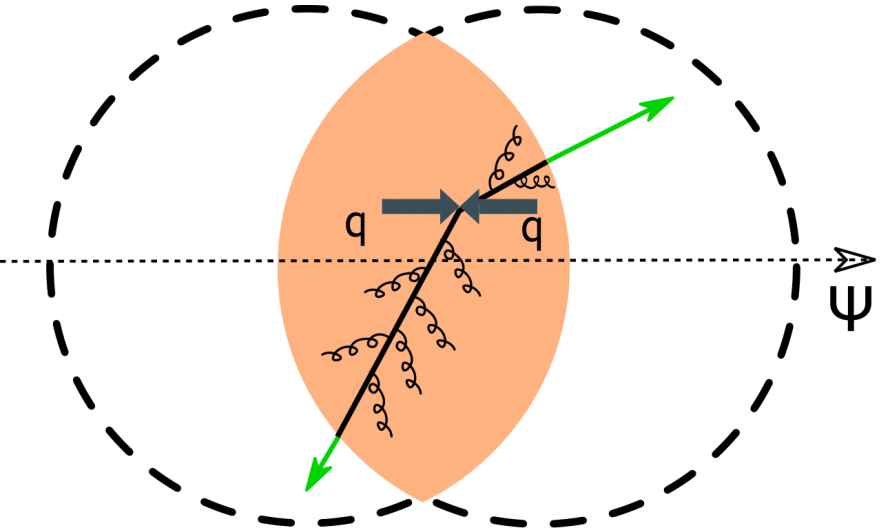
From the LHC



- Precision measurements of jet v_2 at ***high*** p_T

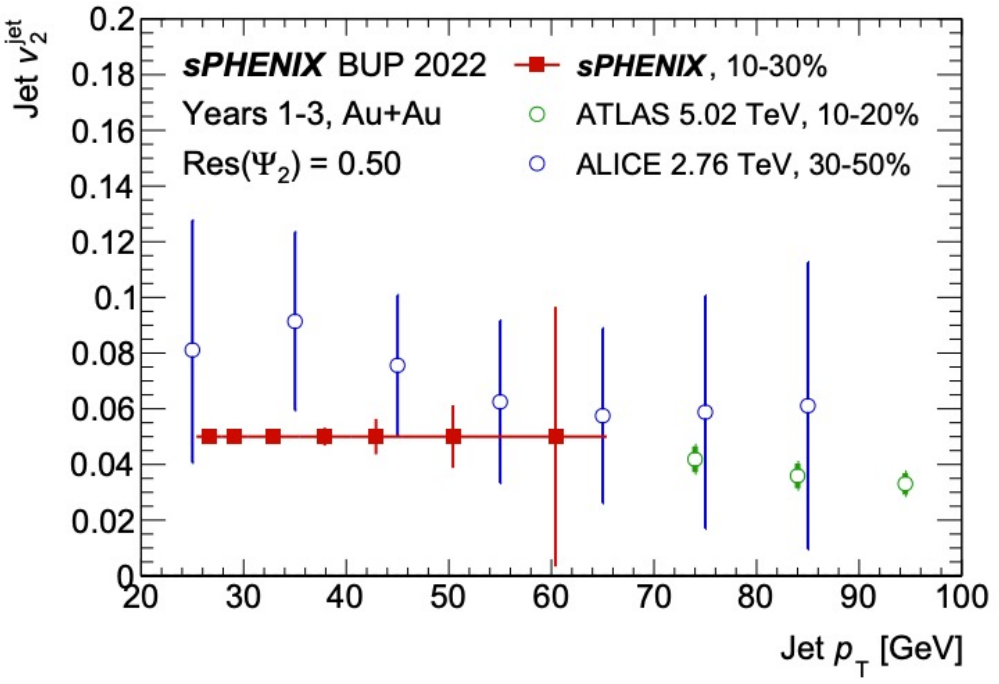
What we can learn at sPHENIX: Jet v_2

Open question: What is the path-length dependence of energy loss?



Cartoon from M. Rybar

In sPHENIX



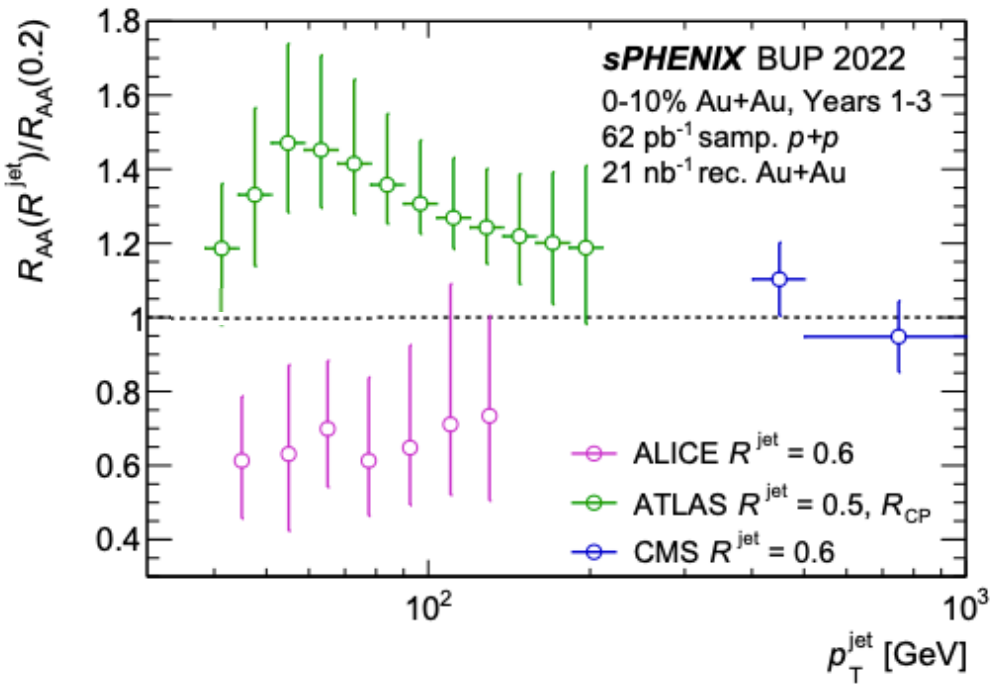
- v_2 at low p_T → flow
- v_2 at high p_T (i.e. jet v_2) → energy loss correlations with initial geometry
  - path-length dependence of energy loss

- Precision measurements of jet v_2 at ***low*** p_T
  - Constrain models of path-length dependence of energy loss for jets near QGP medium scale

What we can learn at sPHENIX: *R* dependence

Open question: What is the interplay between out of cone energy loss and medium response vs. jet structure dependence?

From the LHC

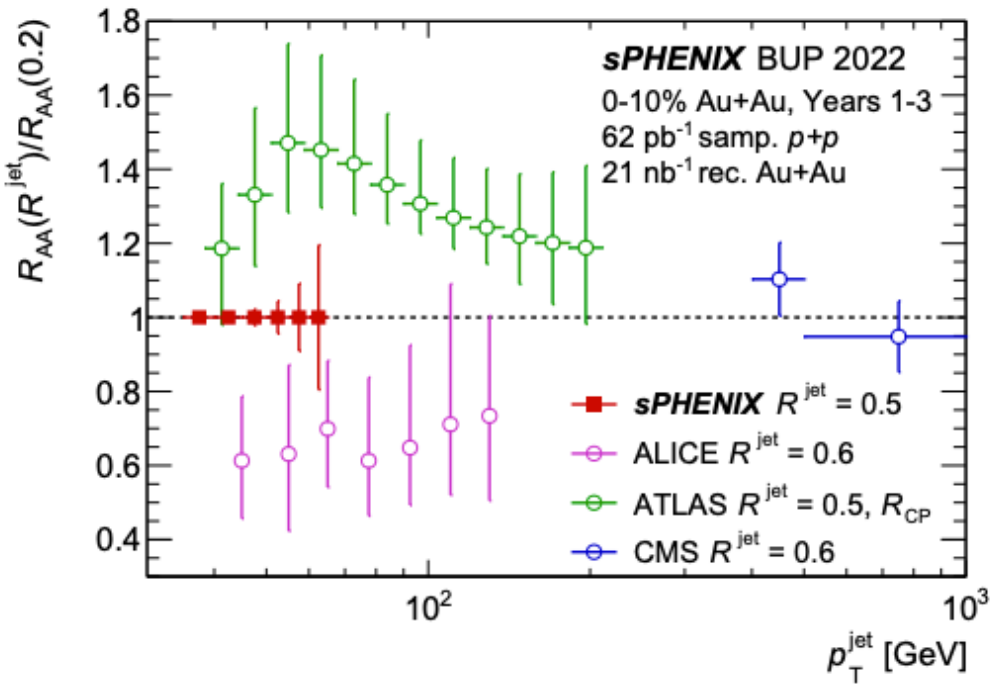


- Competing effects can lead to larger or smaller suppression for large R jets:
  - Recovery of out of cone energy
  - Inclusion of medium response
  - Jets with wider splittings lose more energy
- Models need input from experiment to balance these effects
- Tension in LHC results at low p_T

What we can learn at sPHENIX: *R* dependence

Open question: What is the interplay between out of cone energy loss and medium response vs. jet structure dependence?

In sPHENIX



Precision measurement in region of tension from LHC

- Competing effects can lead to larger or smaller suppression for large R jets:
  - Recovery of out of cone energy
  - Inclusion of medium response
  - Jets with wider splittings lose more energy
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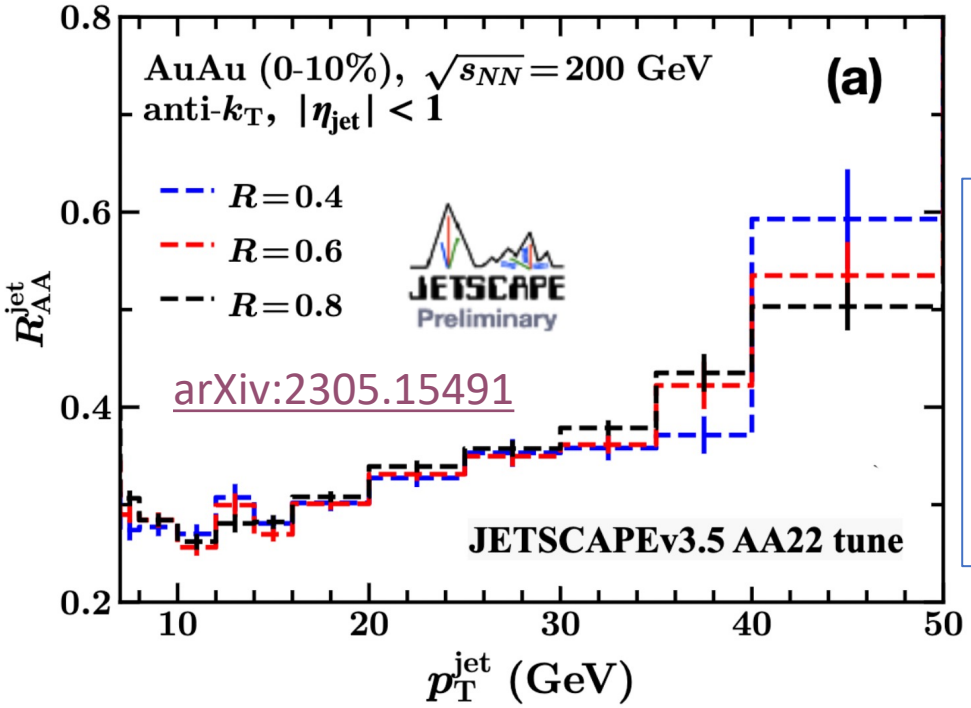
- Tension in LHC results at low p_T

What we can learn at sPHENIX: *R* dependence

Open question: What is the interplay between out of cone energy loss and medium response vs. jet structure dependence?

In JETSCAPE



JETSCAPE predicts no strong R dependence to R_{AA}

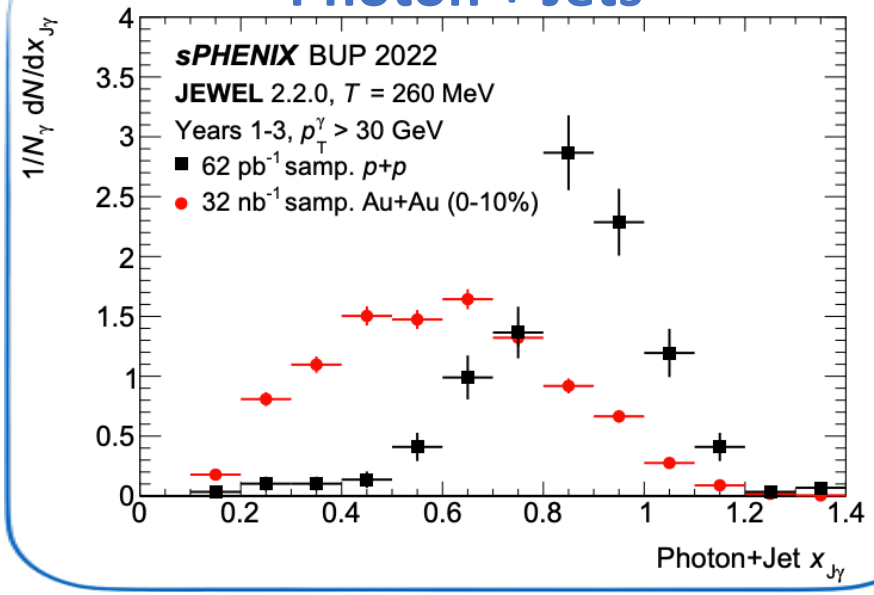
From July 2022 RBRC Predictions for sPHENIX workshop paper

Predictions for the sPHENIX physics program

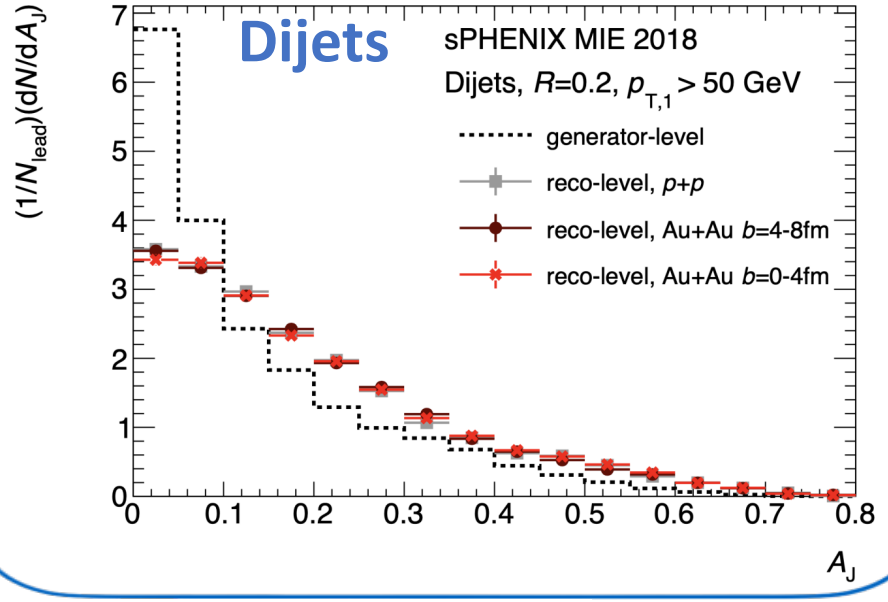
Ron Belmont[a], Jasmine Brewer[b], Quinn Brodsky[c], Paul Caucal[d], Megan Connors[e,1], Magdalena Djordjevic[f], Raymond Ehlers[g,y,2], Miguel A. Escobedo[h,i], Elena G. Ferreiro[h], Giuliano Giacalone[j], Yoshitaka Hatta[k,l], Jack Holguin[m], Weiyao Ke[n], Zhong-Bo Kang[o], Amit Kumar[p,2], Aleksas 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]

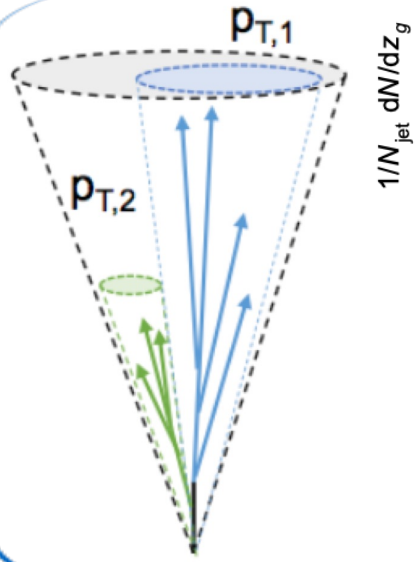
Other jet measurements in sPHENIX

Photon + Jets

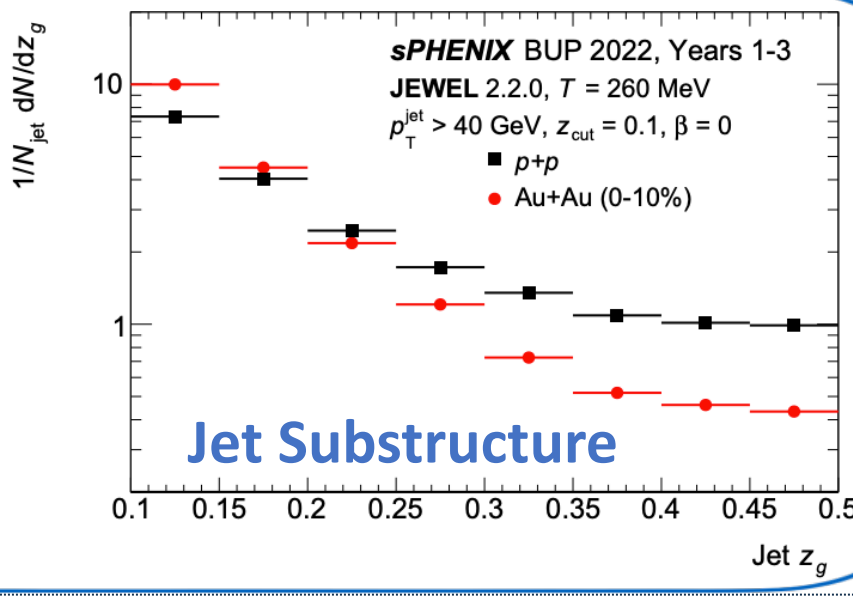


Dijets



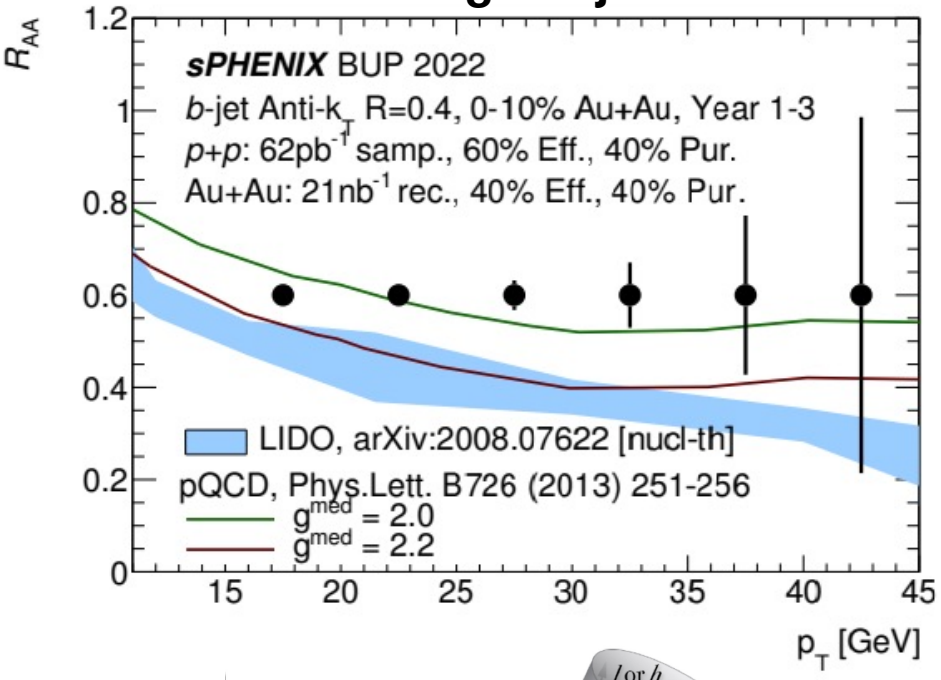


Jet Substructure

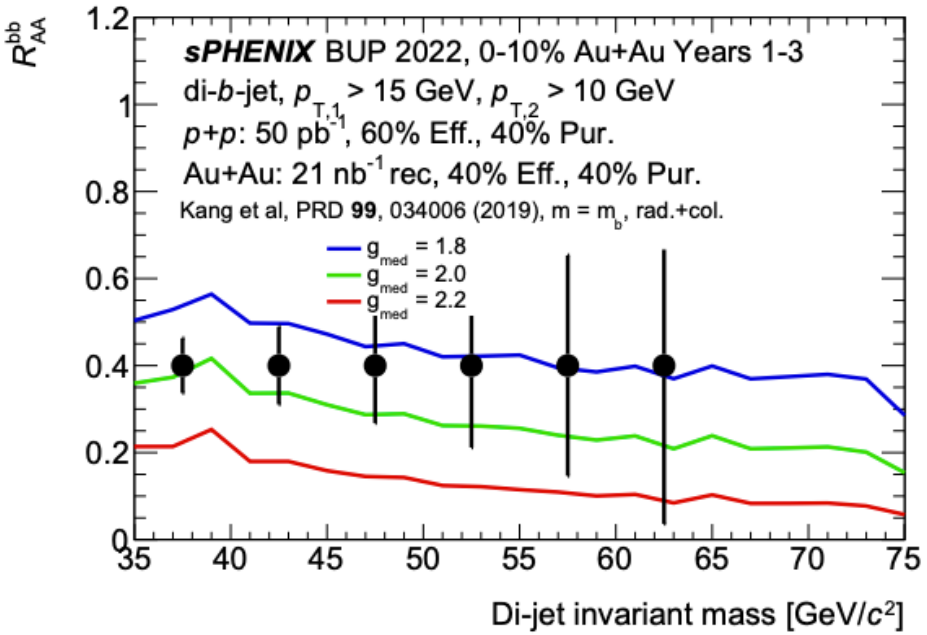


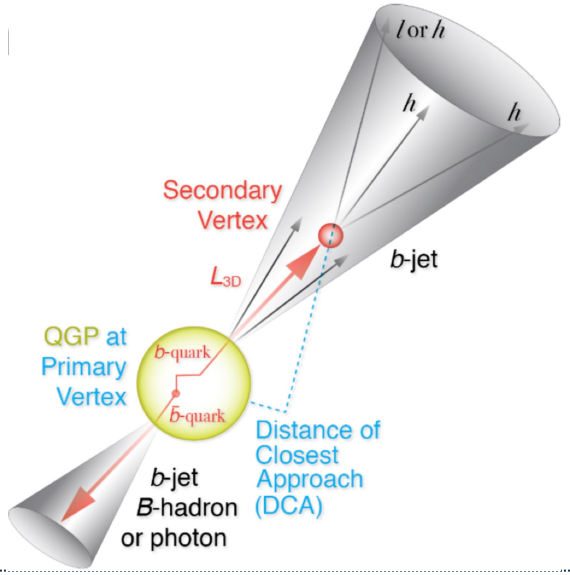
Heavy Flavor Jets

Single b-jets



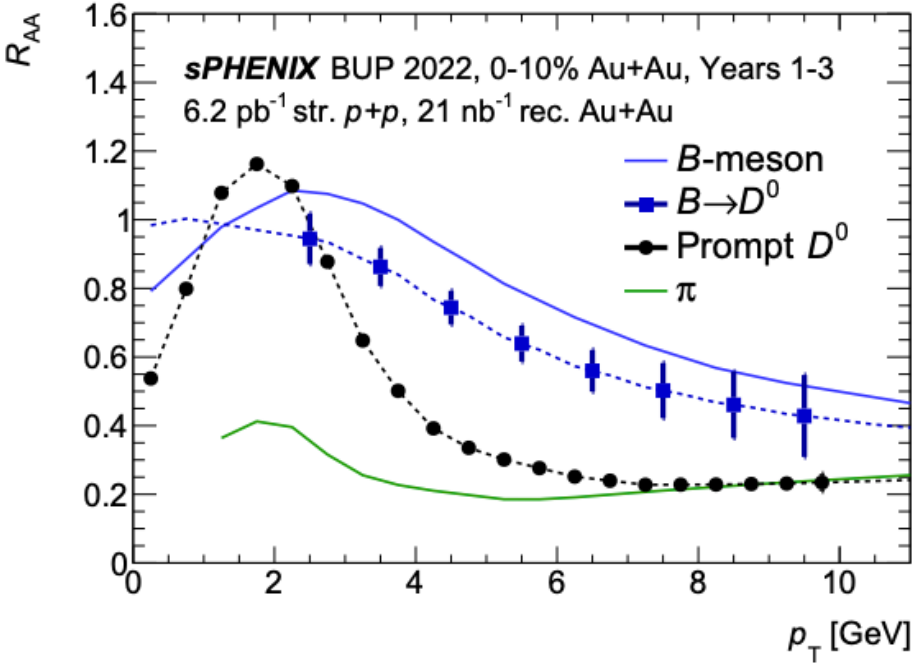
di-b-jets

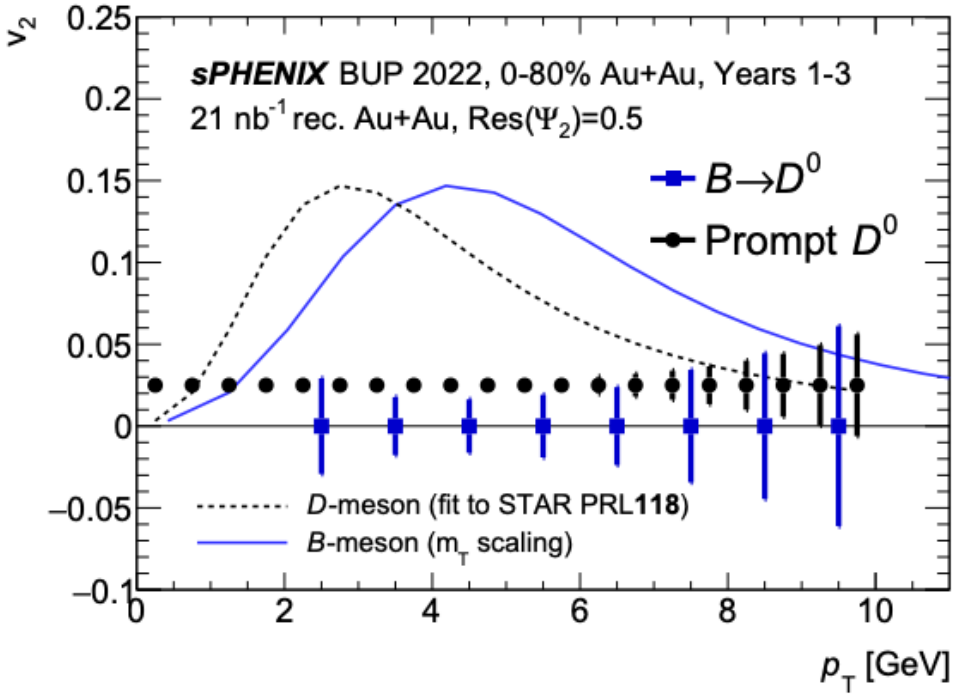




- b-jet tagging using DCA tagger for secondary vertices
  - mass dependence of energy loss
  - back-to-back b-jet measurement reduces contribution from gluon splitting

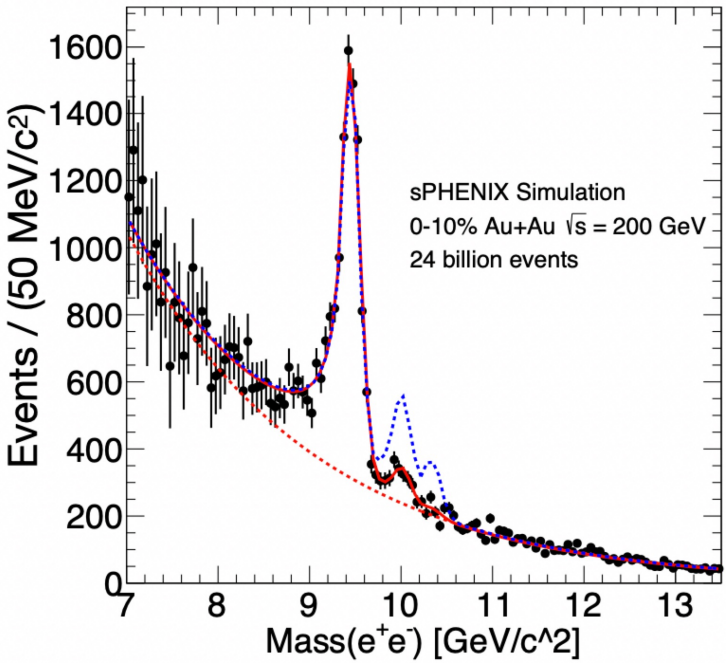
Open Heavy Flavor Physics

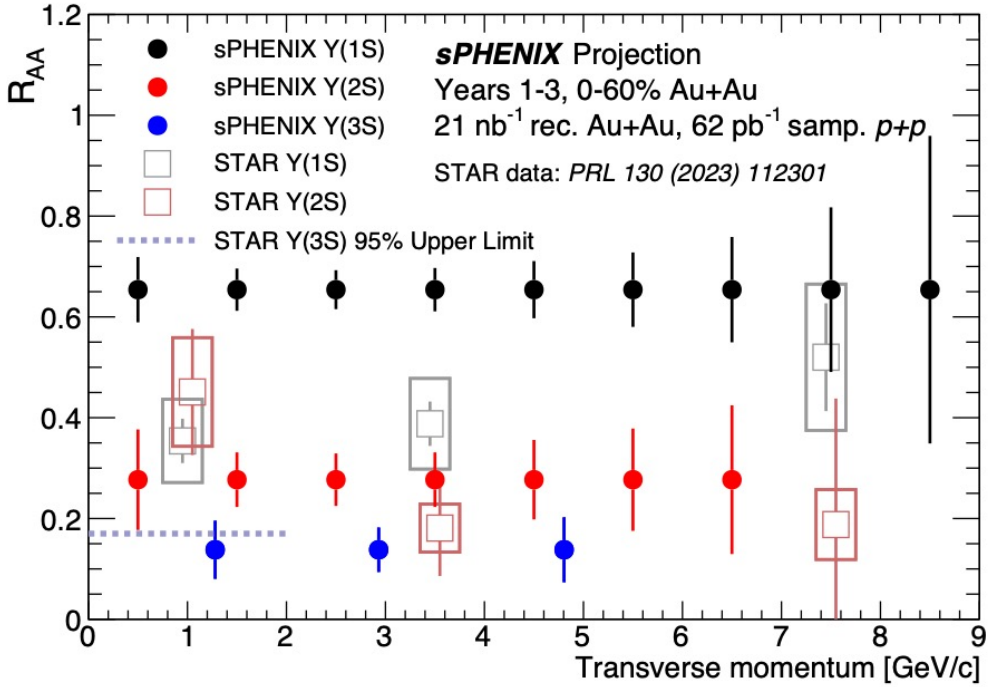




- Measure using sPHENIX precision track and vertex reconstruction
- Vary the mass of QGP probes:
  - $m_{c,b} >> \Lambda_{QCD}$ → produced primarily in early hard scatterings
  - Study mass dependence of collectivity and energy loss
  - Provide constraints on diffusion transport parameter of the QGP

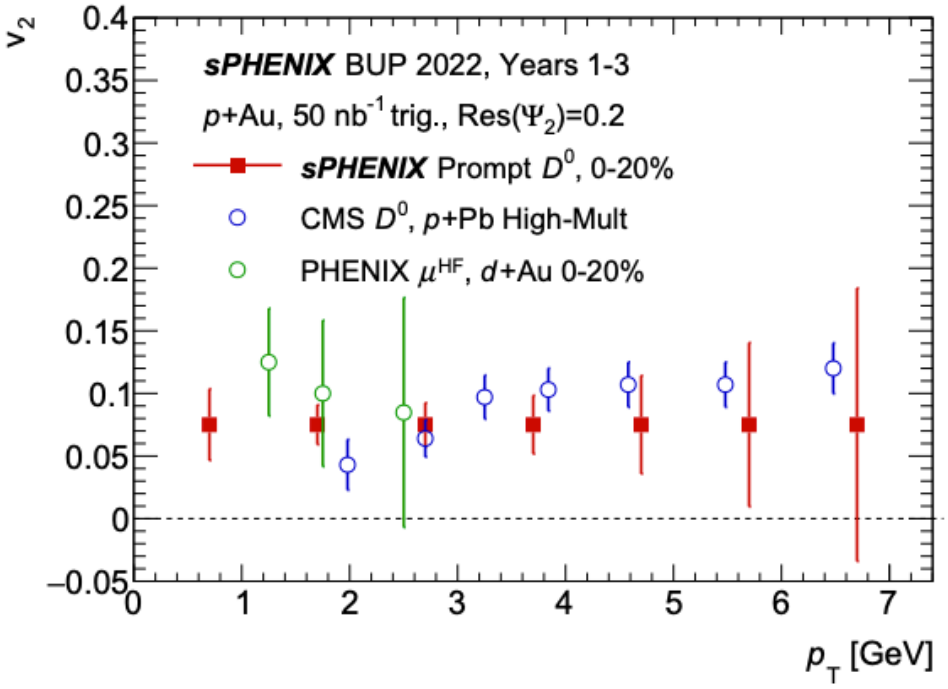
Quarkonia

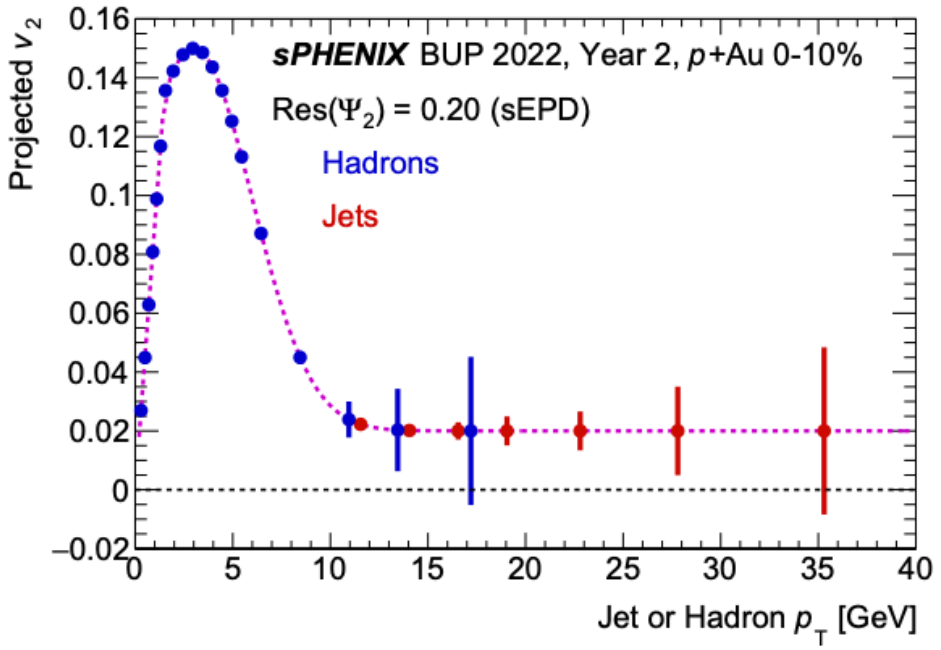




- Excellent mass resolution will allow for separation of three upsilon states
- Measurement of ϒ(3S) suppression allows for test of models

Small Systems





- Heavy flavor flow in p+Au:
  - Collectivity in small systems
- Jet/high p_T hadrons p+Au:
  - Cold nuclear matter effects
  - Potential for energy loss in small systems
  - Cold QCD spin measurements

Summary

- sPHENIX detector provides:
  - Electromagnetic and hadronic calorimetry with full azimuthal coverage out to $|\eta| < 1.1$
  - High precision tracking and vertexing
  - Fast readout rate

- Design allows for:
  - High statistics samples of hard probes (jets, photons, high p_T charged hadrons, heavy-flavor)
  - Complimentary measurements to LHC

- Measurements will improve our understanding of small-scale behavior of the QGP

- Commissioning with beam began May 18th
  - Significant progress in just 10 weeks!

- Looking forward to first physics measurements soon!