ILLINOIS

sPHENIX

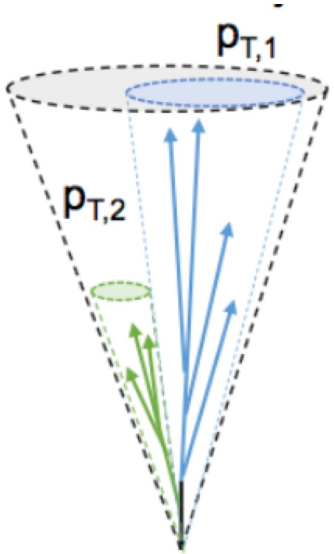
The jet physics program with sPHENIX

Virginia Bailey
for the sPHENIX Collaboration

March 1, 2022

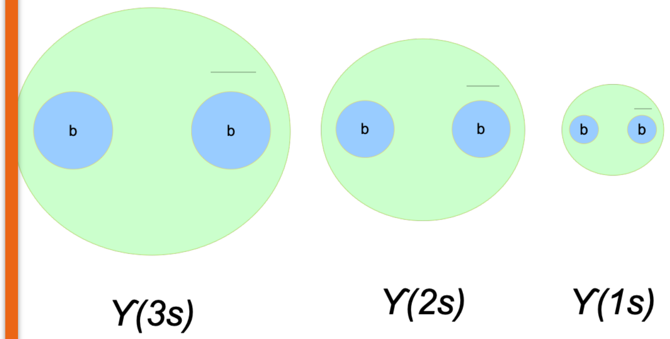
sPHENIX physics program

Jets and jet substructure



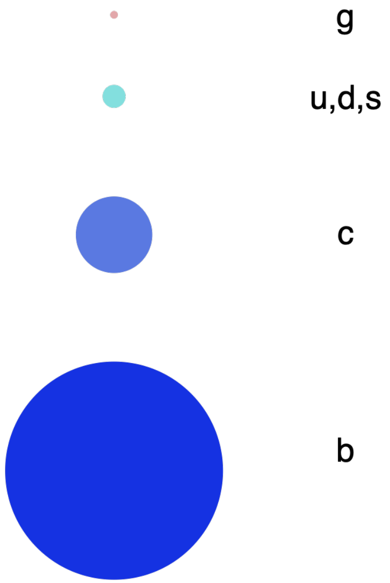
Vary momentum, angular scale of probe

Upsilon spectroscopy



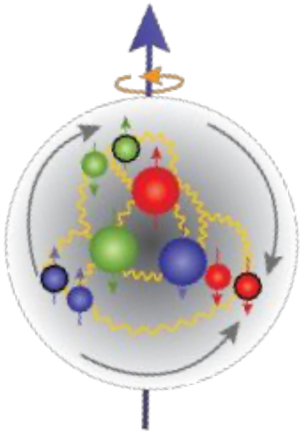
Vary size of probe

Open heavy-flavor



Vary mass of probe

Cold QCD



Study cold nuclear matter effects

See talk on heavy-flavor physics on Friday by Thomas Marshall

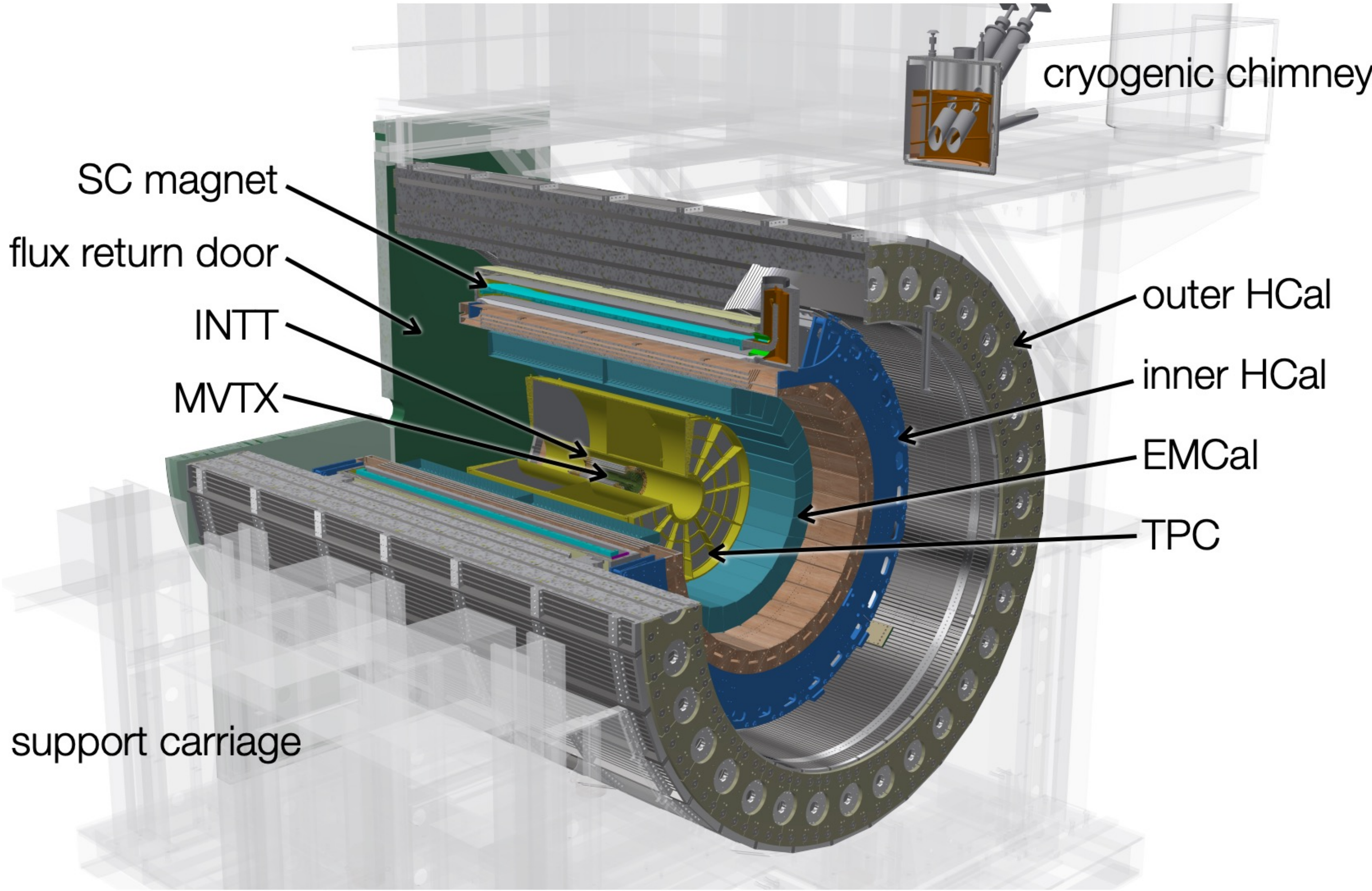
sPHENIX detector

Tracking detector:
- MAPS-based Vertex Tracker (MVTX)
- Intermediate Silicon Tracker (INTT)
- Time Projection Chamber (TPC)

Superconducting Magnet
- 1.4T solenoid magnet

Calorimeter:
- Electromagnetic calorimeter (EMCal)
- Inner hadronic calorimeter (inner HCal)
- Outer hadronic calorimeter (outer HCal)

High rate DAQ and trigger systems
- 15 kHz trigger



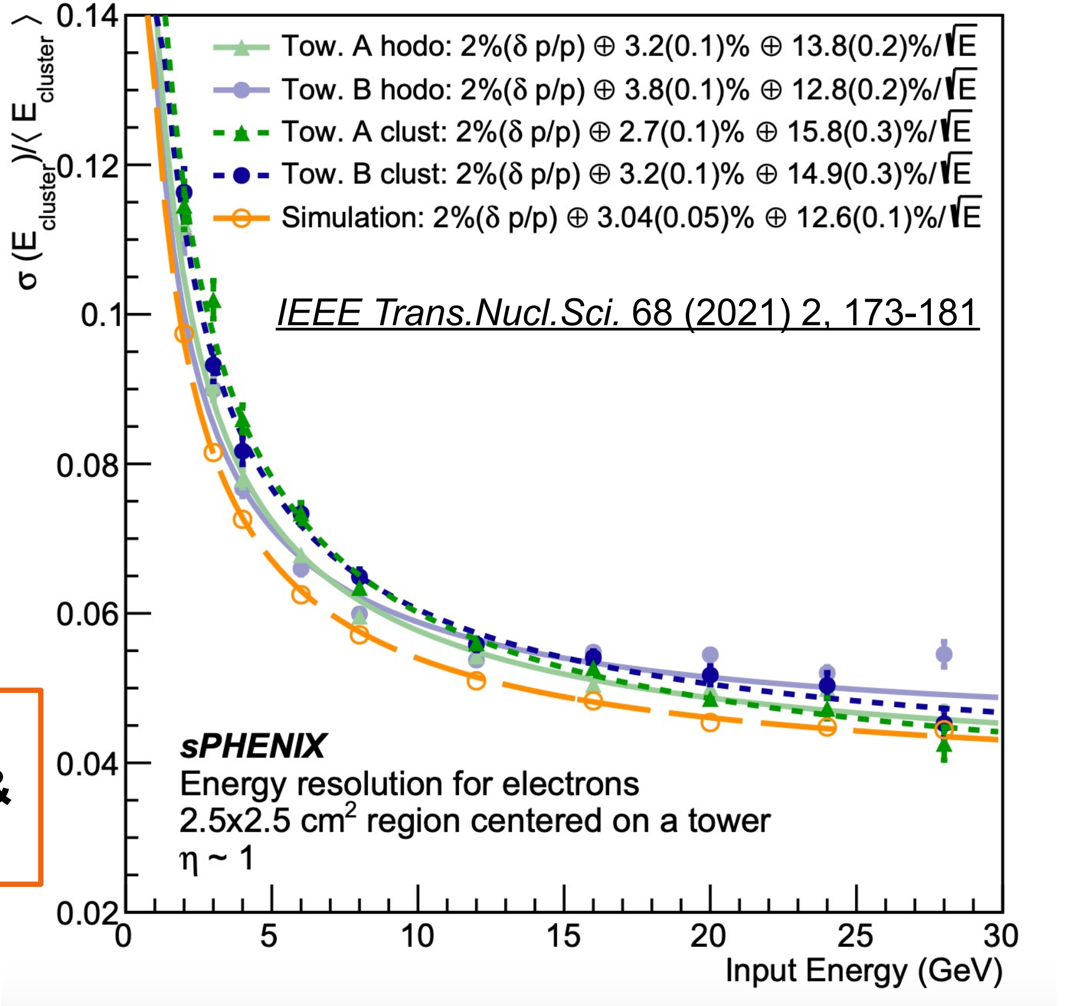
sPHENIX calorimeter

Full calorimeter covers 2π in azimuth and $|\eta| < 1.1$

EMCal:

- Sampling calorimeter of scintillating fibers embedded in tungsten blocks
- $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ towers

Block production finished at UIUC (80%) & Fudan/PKU/CIAE (20%)



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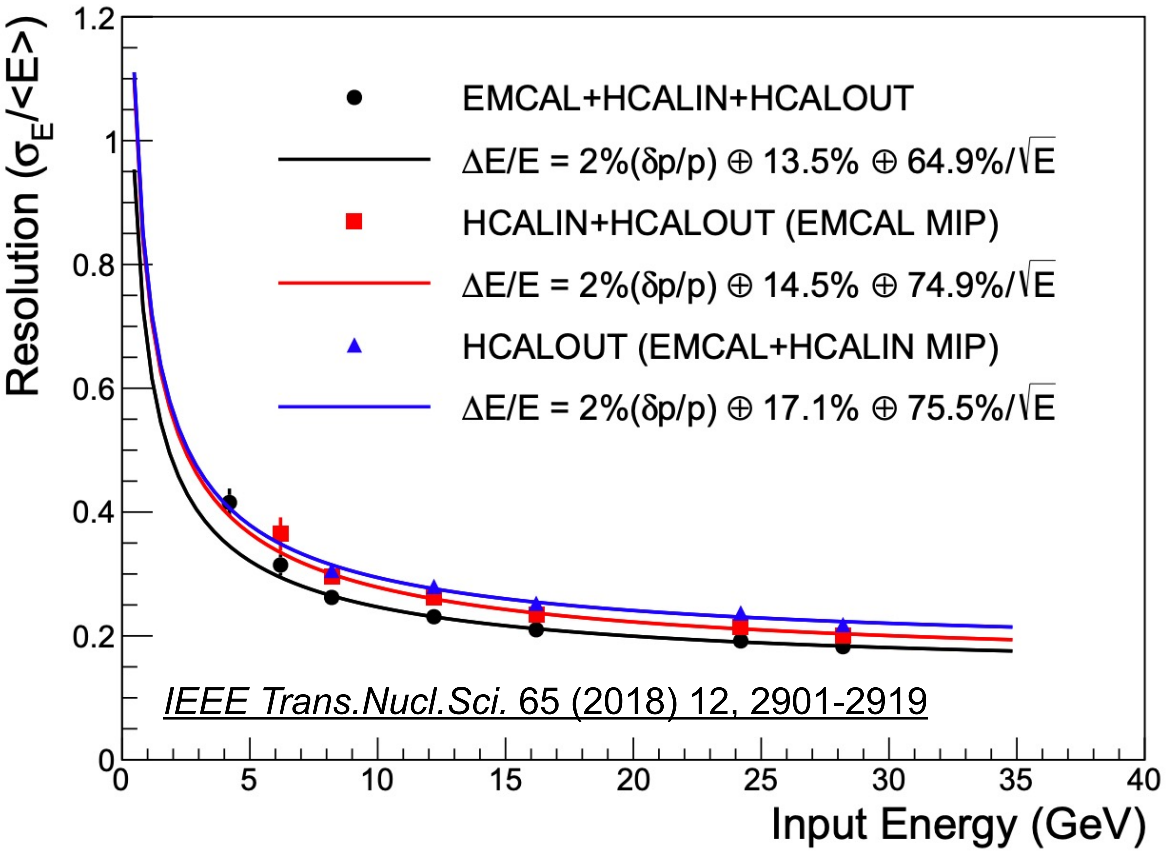
Inner and outer HCal:

- Sampling calorimeter of scintillating tiles and steel absorber plates
- $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ towers



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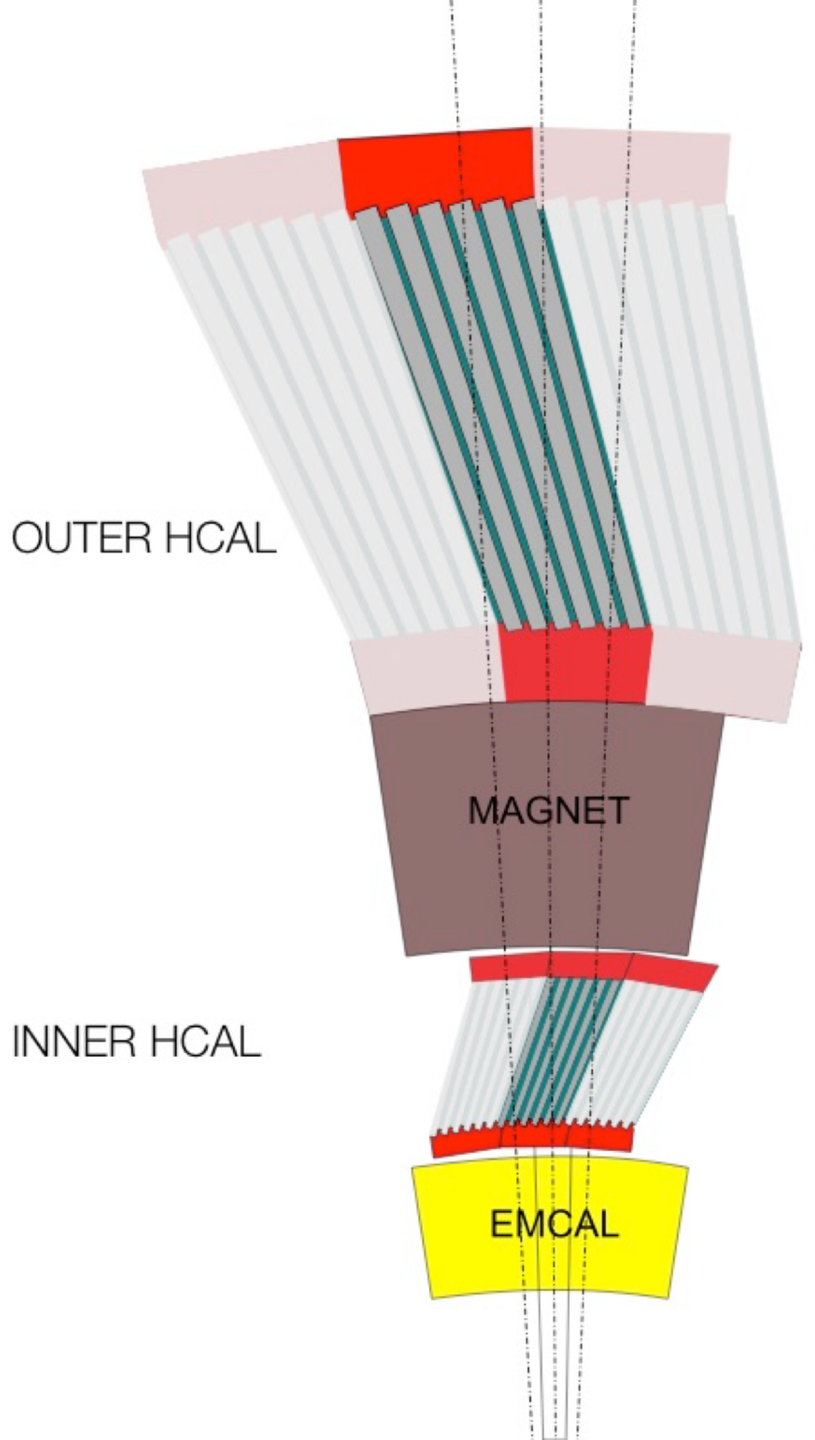
Calorimeters read out with SiPMs



sPHENIX run plan

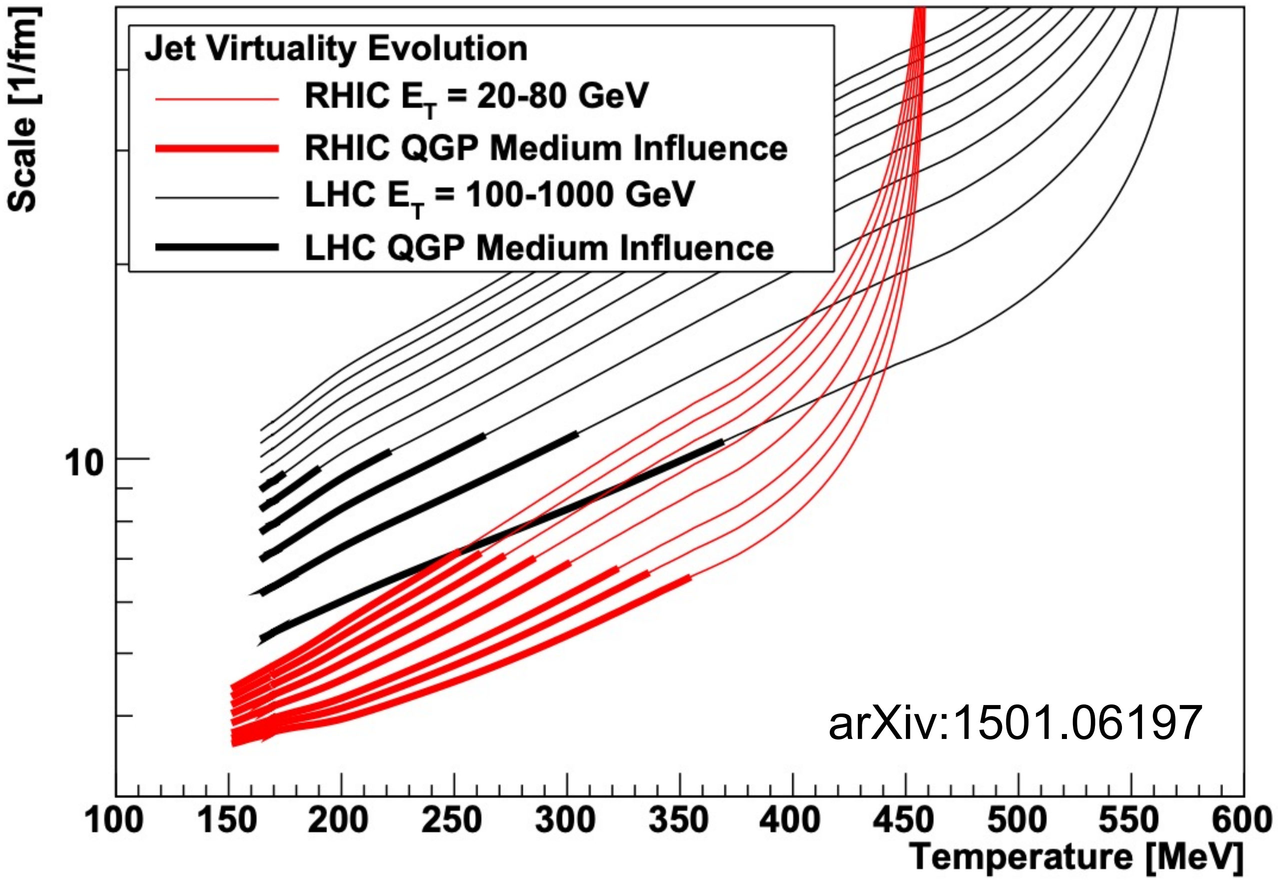
< 1 year until data

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\|z\| <10$ cm	Samp. Lum. $\|z\| <10$ 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}

Large luminosity in first year

Why jet measurements at RHIC?

- Different QGP:
  - Temperature/temperature evolution different between LHC and RHIC

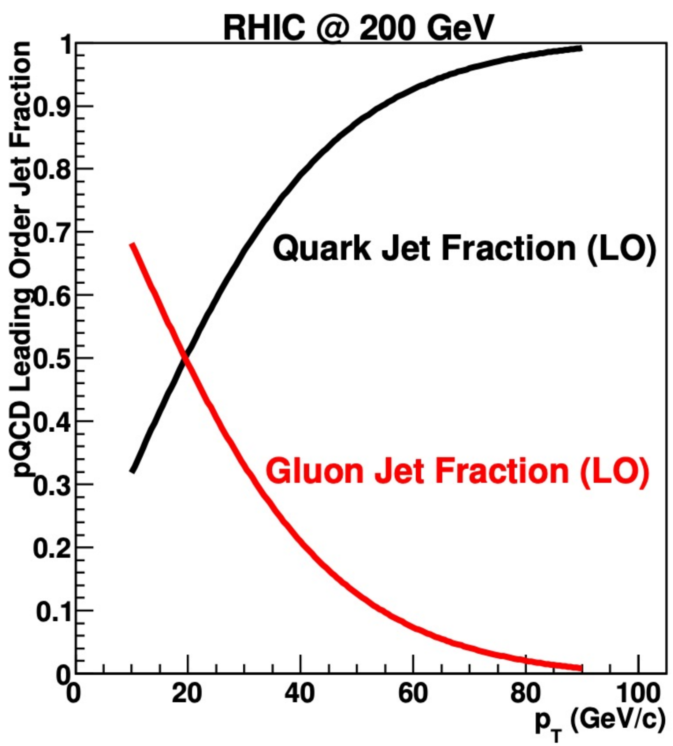


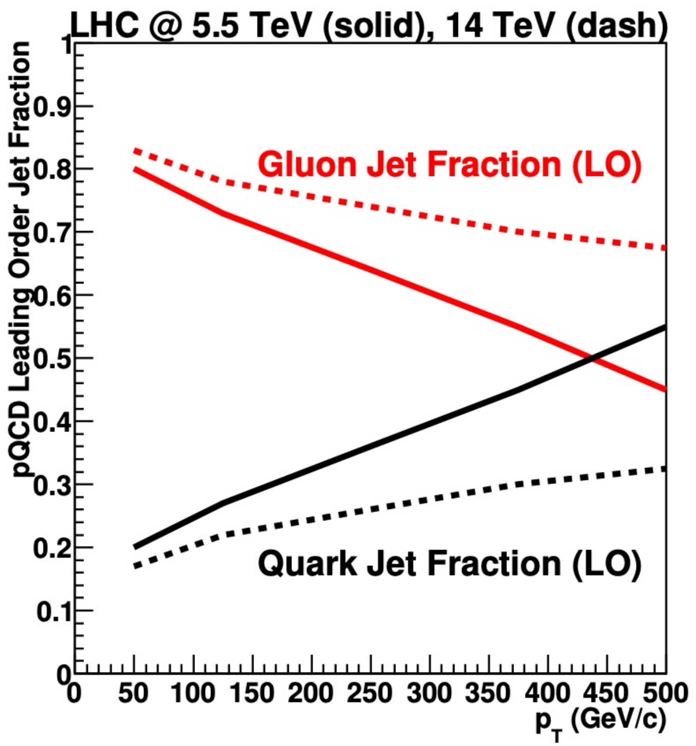
arXiv:1501.06197

Why jet measurements at RHIC?

- Different QGP:
  - Temperature/temperature evolution different between LHC and RHIC
- Different probes:
  - Different quark vs. gluon jet mixture
  - Lower kinematic range- radiation close to the QGP medium scale early in collision

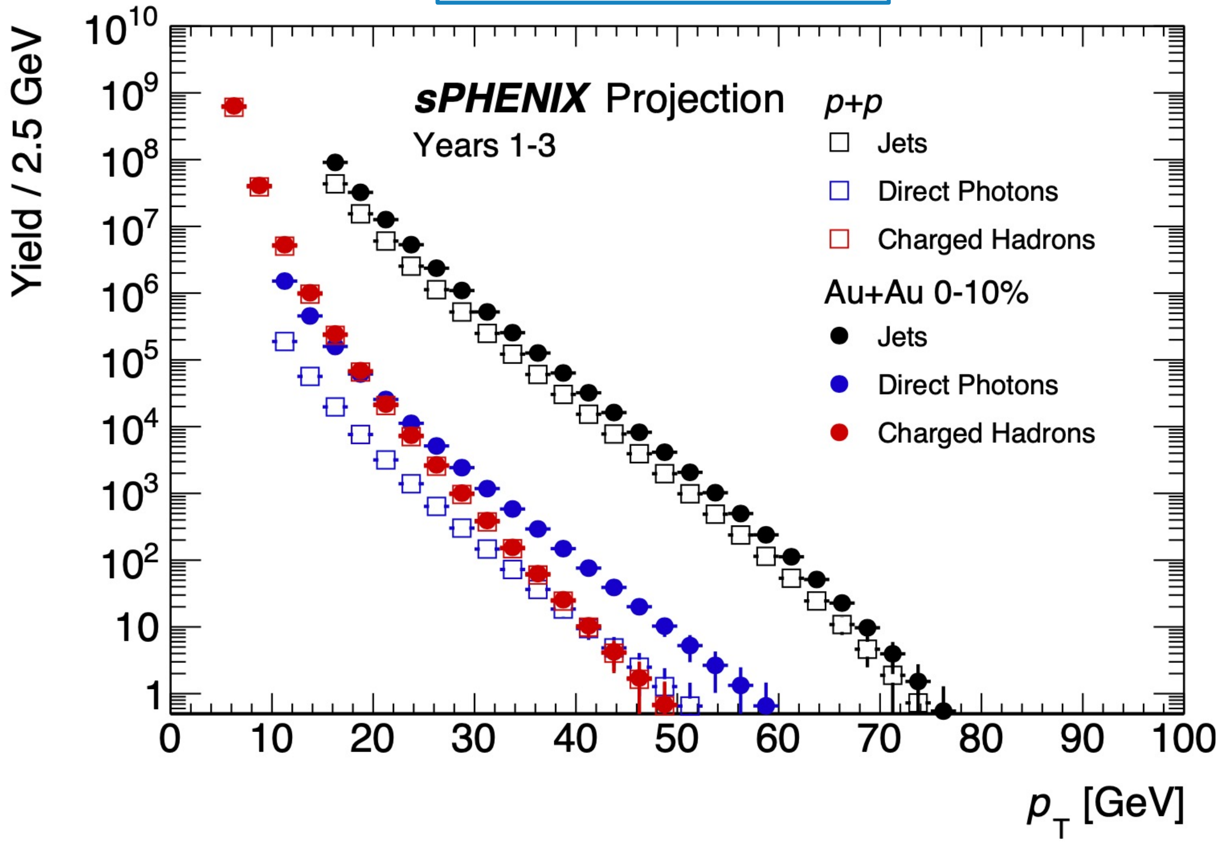
arXiv:1501.06197



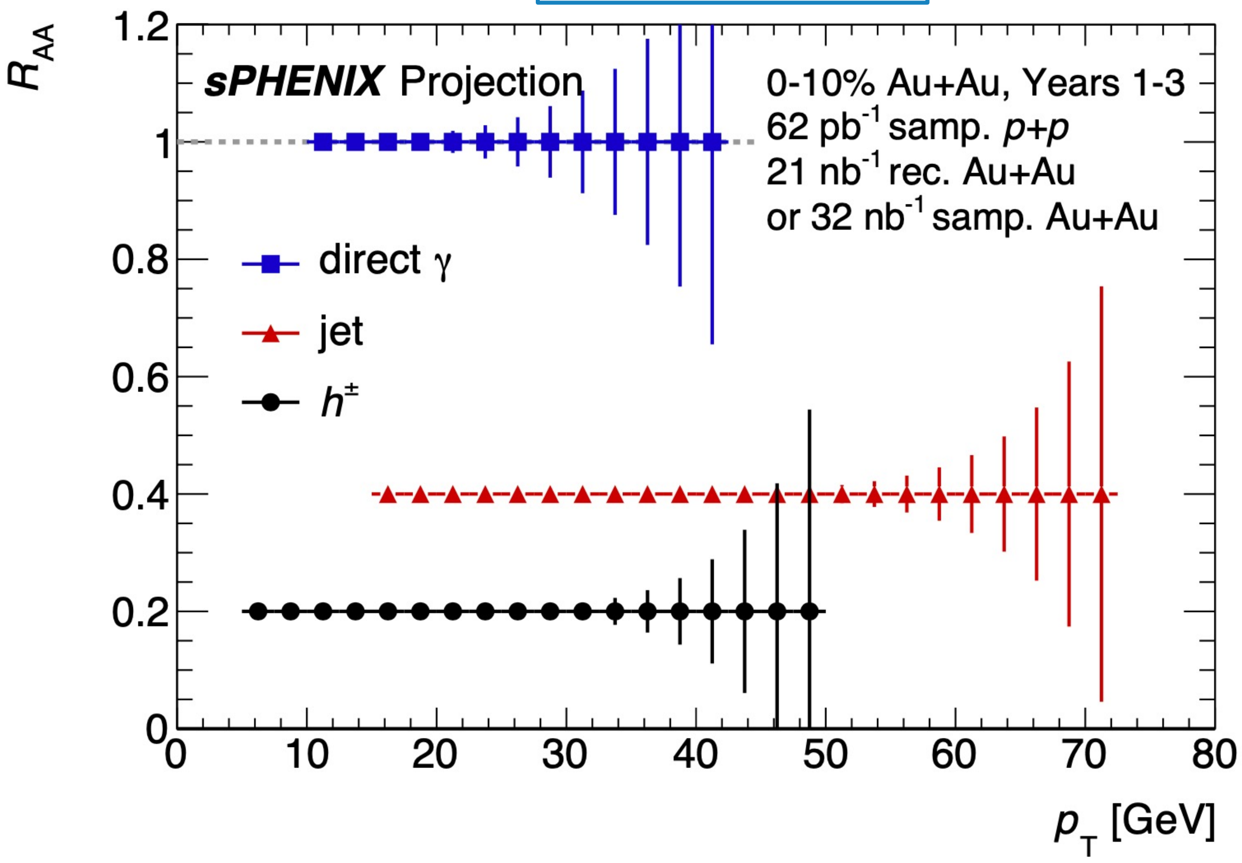


Jet kinematic reach

Projected yields

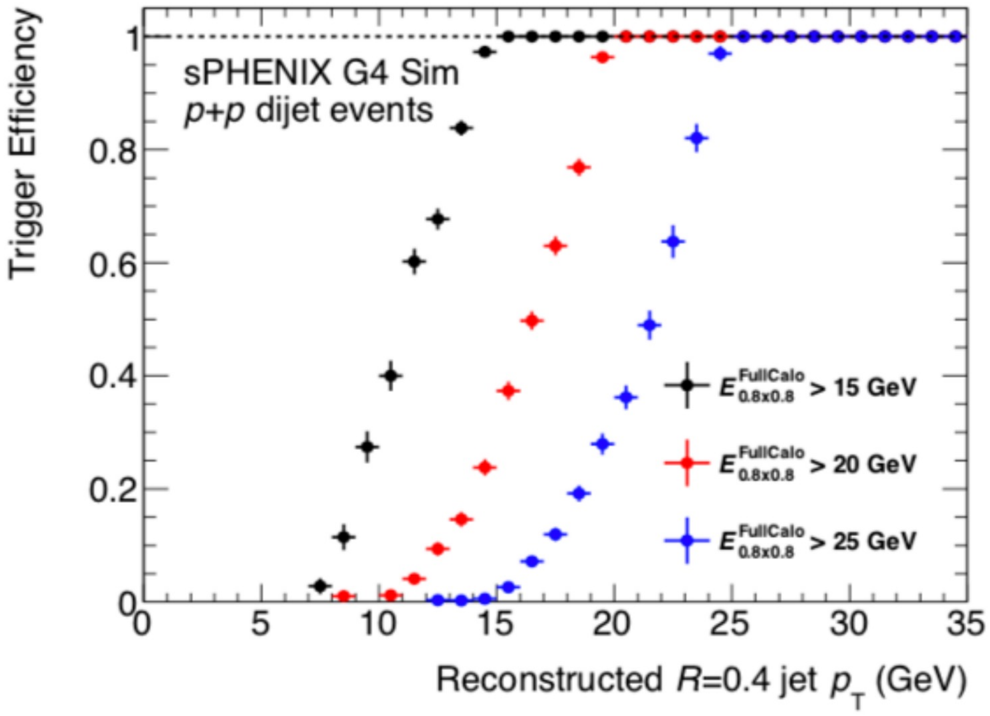


Projected R_{AA}



- Expect jet measurements out to 70 GeV- overlap with LHC measurements
- High stats for photons (γ-jet measurements) and charged hadrons (fragmentation functions, substructure)

Jet kinematic reach



3 year run plan projection

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

From: beam use proposal

Calorimeter jet trigger allows for high statistics, high p_T jet sample + unbiased *pp* reference

Calorimeter jets in sPHENIX

- Constituents: $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ towers (EMCal + HCals)
- UE subtraction: two iterations, subtract:

$$\frac{d^2 E_T}{d\eta d\phi} = \frac{dE_T}{d\eta}\left(1 + 2\sum_n v_n \cos\left(n\left(\phi - \Psi_n\right)\right)\right)$$

determined event-by-event

Method from: *Phys.Rev.C* 86 (2012) 024908

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Average energy density, excluding regions with jet candidates

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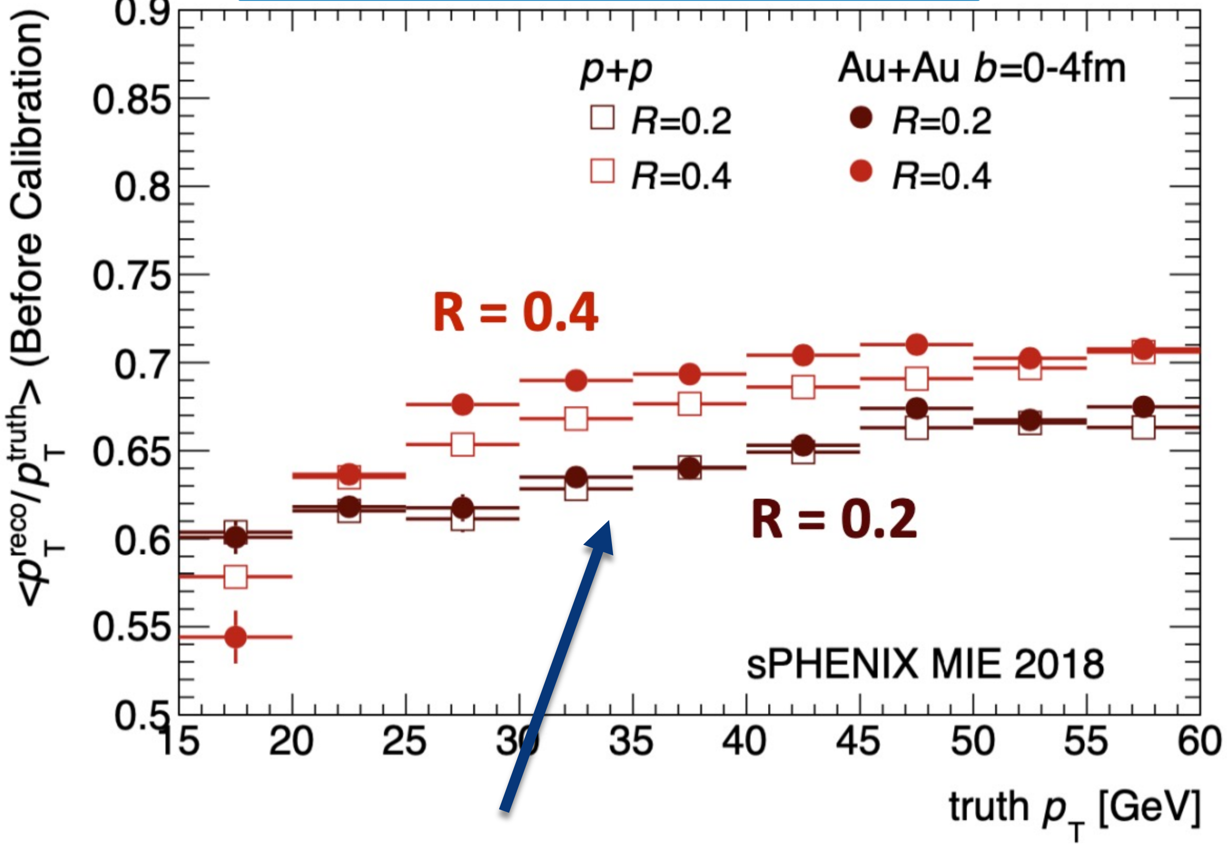
Average energy density, excluding regions with jet candidates

Flow modulation: v_2, v_3, v_4

Method from: *Phys.Rev.C 86 (2012) 024908*

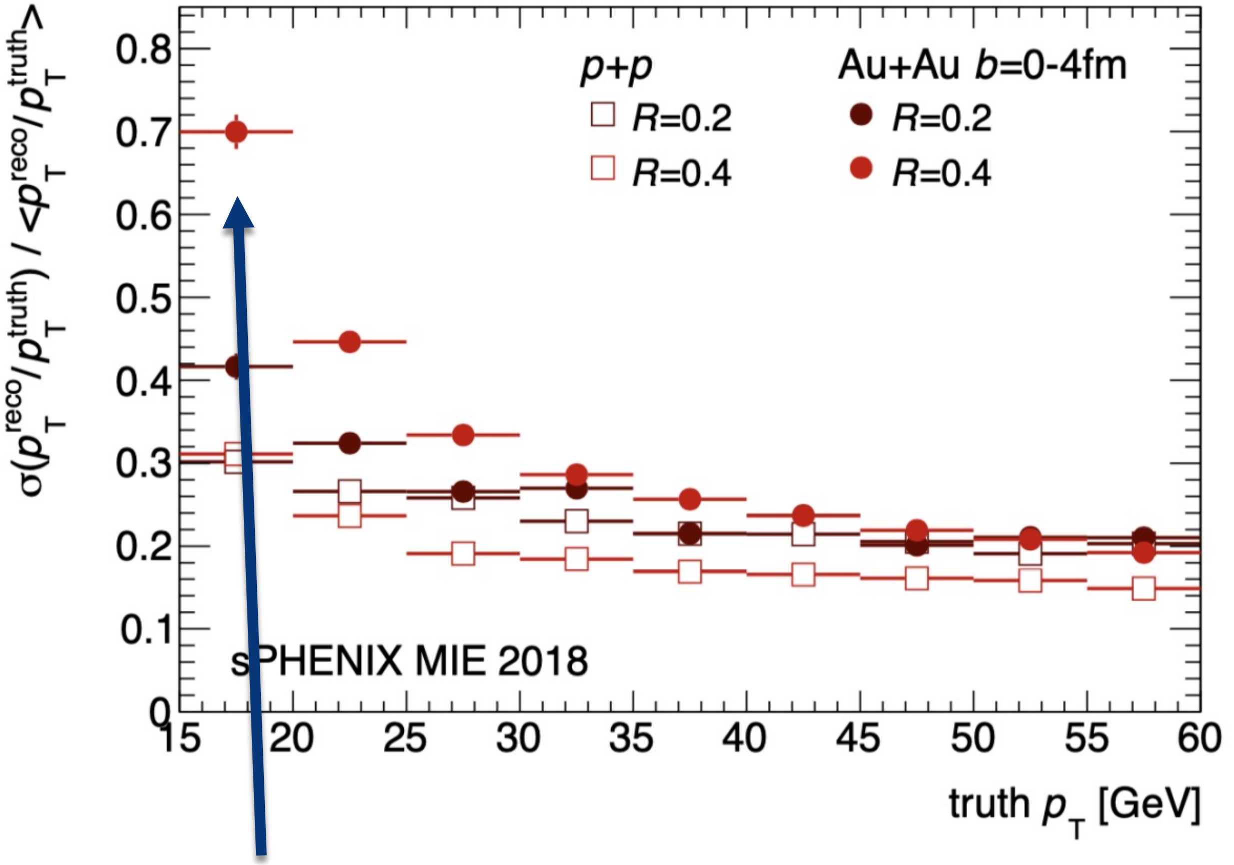
Calorimeter jets in sPHENIX

Jet energy scale (EM scale)



- high EM energy scale due to full (EM + hadronic) calorimetry
- similar JES in pp and Au+Au → good UE subtraction

Jet energy resolution

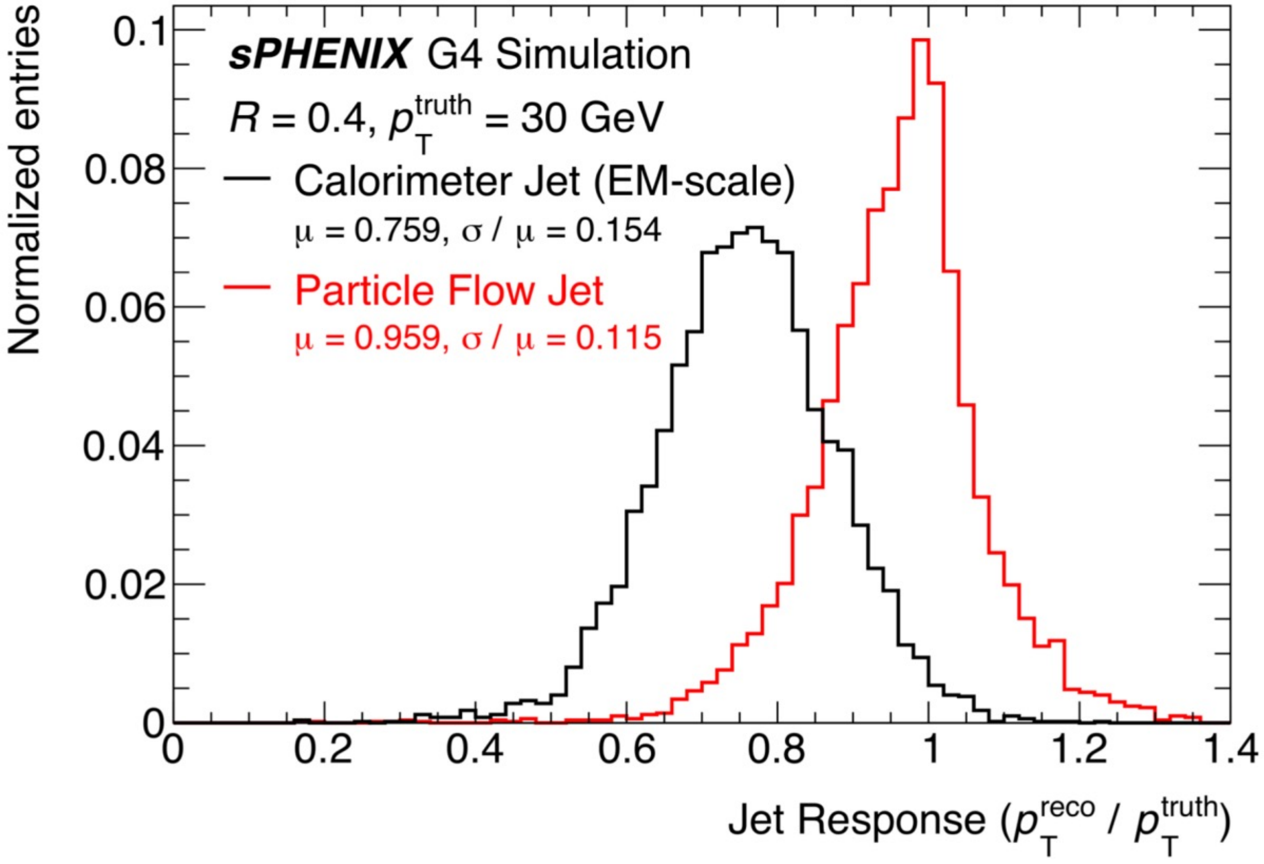


low p_T Au+Au JER high due to UE fluctuations

- ongoing study to quantify these

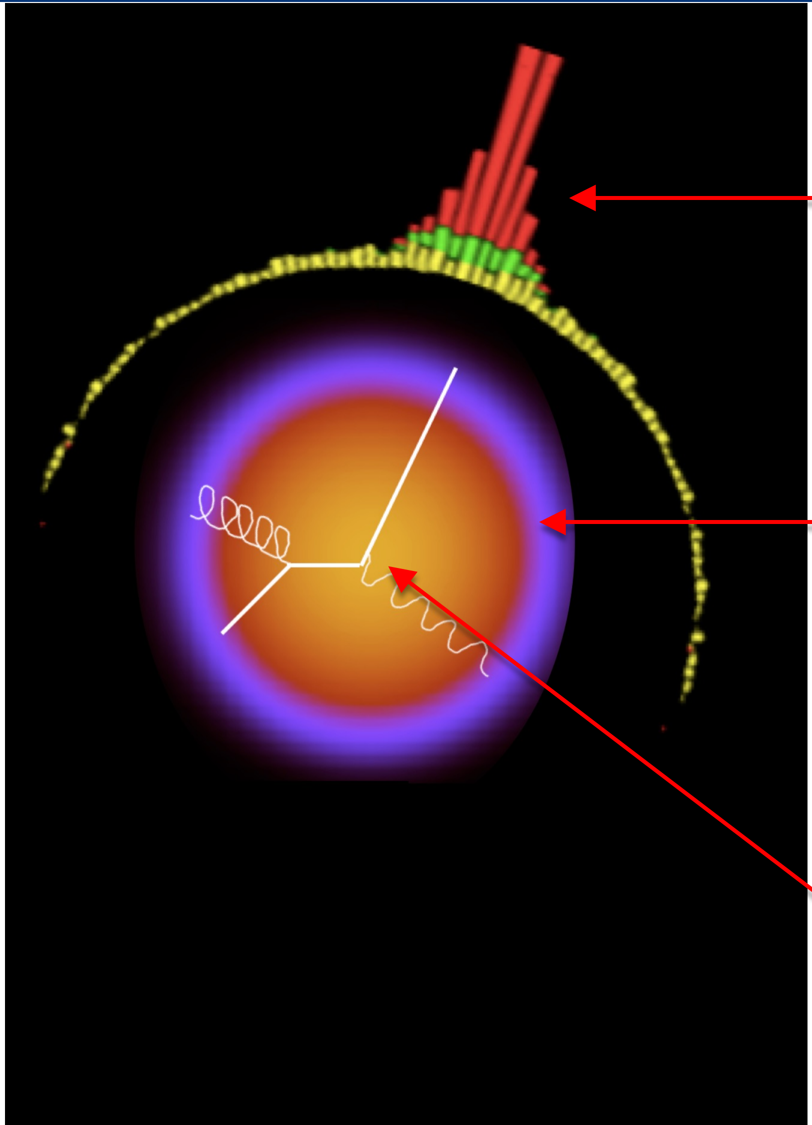
Particle flow jets in sPHENIX

- Ongoing work to implement particle flow jets in sPHENIX
- Takes advantage of calorimeter + precision tracking
- Excellent energy response in *pp* simulations
- Use for substructure measurements



Jet measurements in sPHENIX

- Study at RHIC:
  - Path-length dependence of energy loss
  - Mass dependence of energy loss (light vs. heavy flavor jets)
  - Flavor dependence of energy loss (quark vs. gluon jets)
  - How does medium resolve jet substructure?

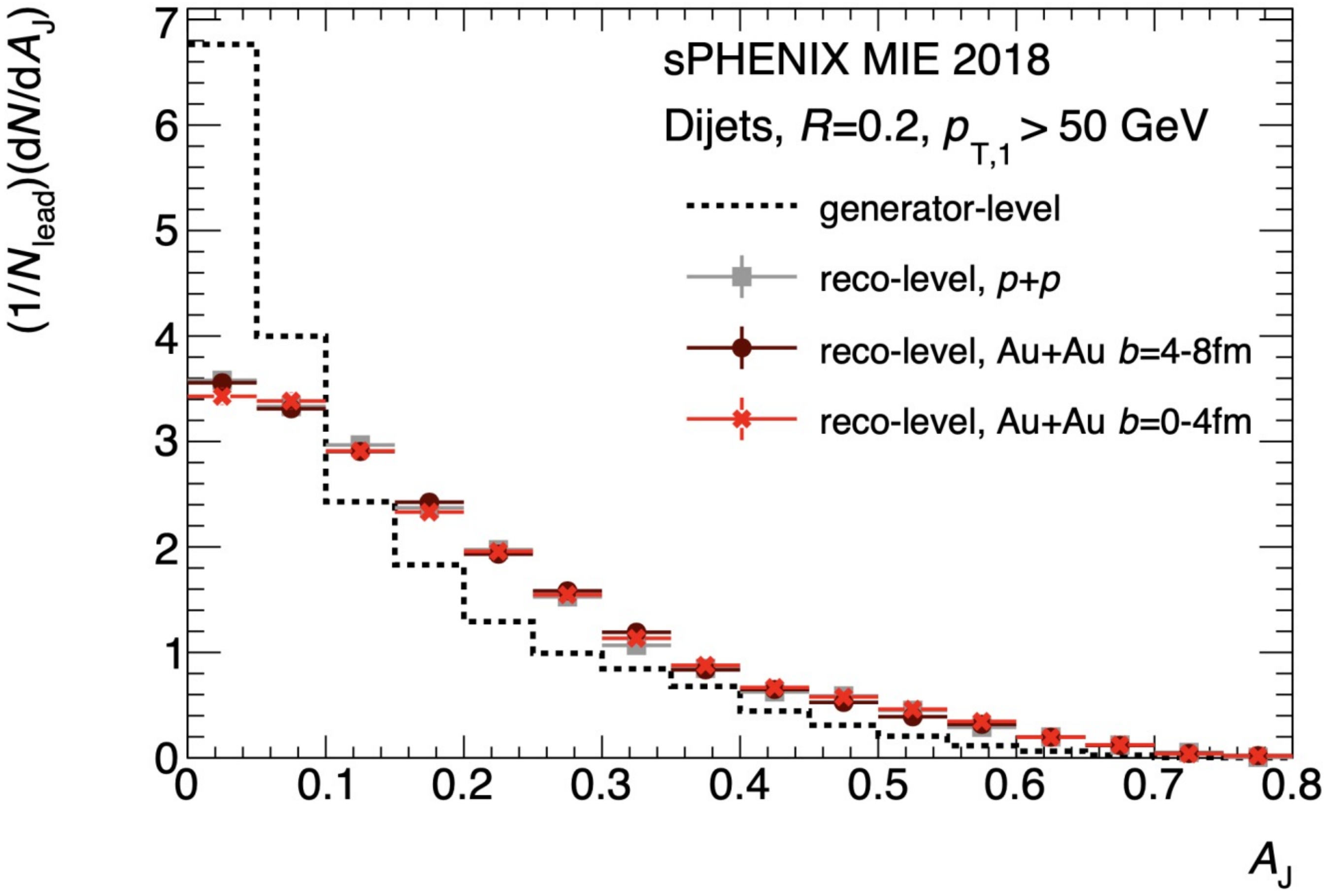


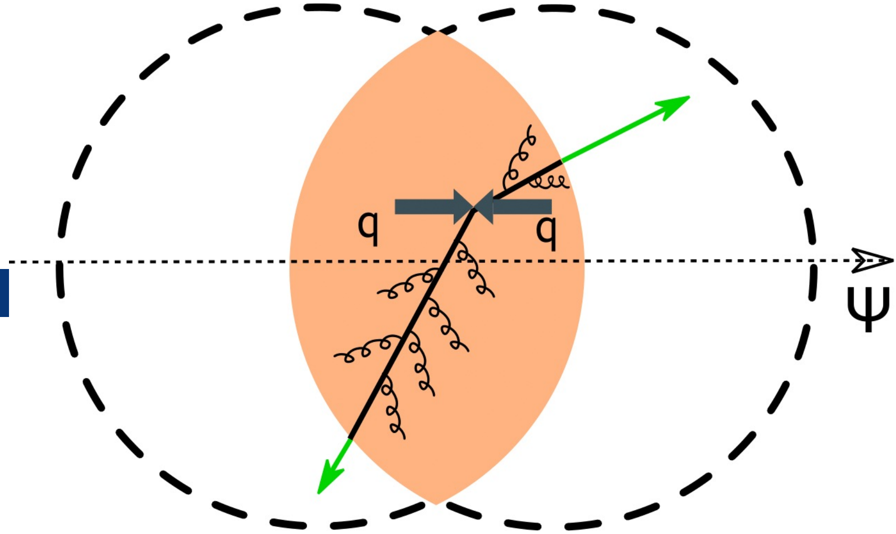
Full characterization of final state

Different QGP initial conditions and evolution at RHIC and LHC

Same hard process

Dijet asymmetry



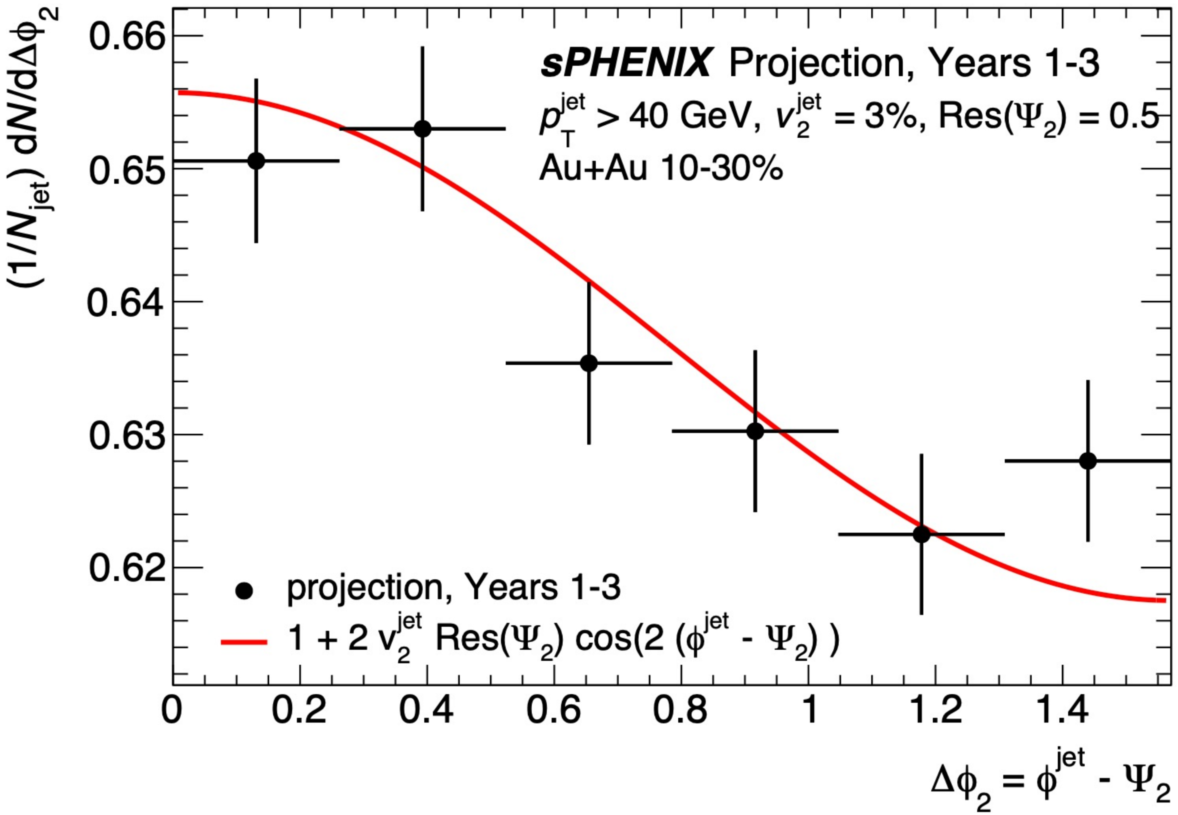


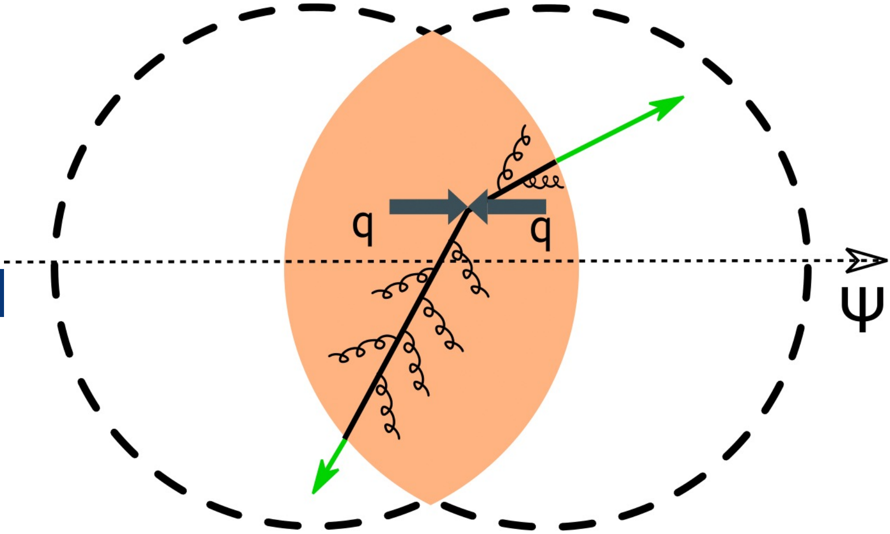
- Study path-length dependence of energy loss
- Potential early measurement of jet quenching at RHIC energies

$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

Jet v_2

Projected yields

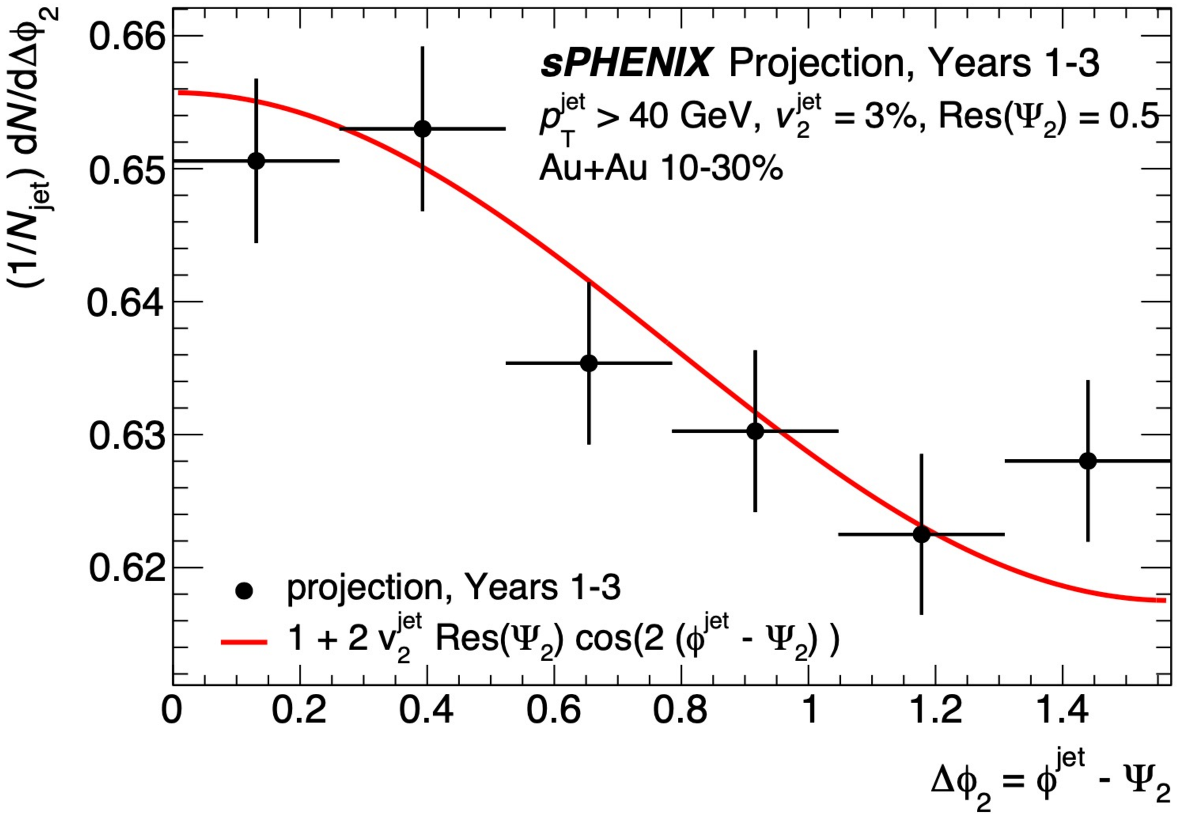




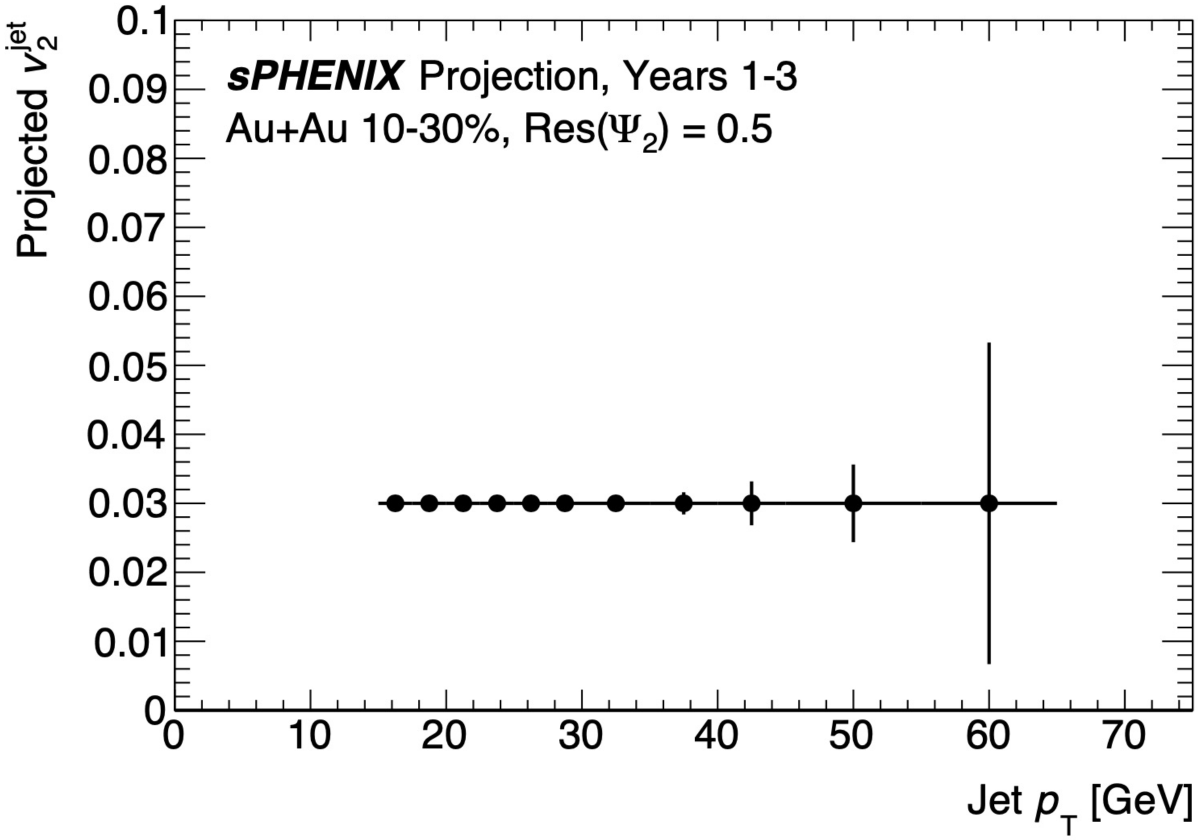
- Correlations between energy loss and initial state → path-length dependence of energy loss
- sPHENIX event plane detector (sEPD) allows for measurements of event planes away from jets of interest (see talk by Rosi Reed on Thursday)

Jet v_2

Projected yields

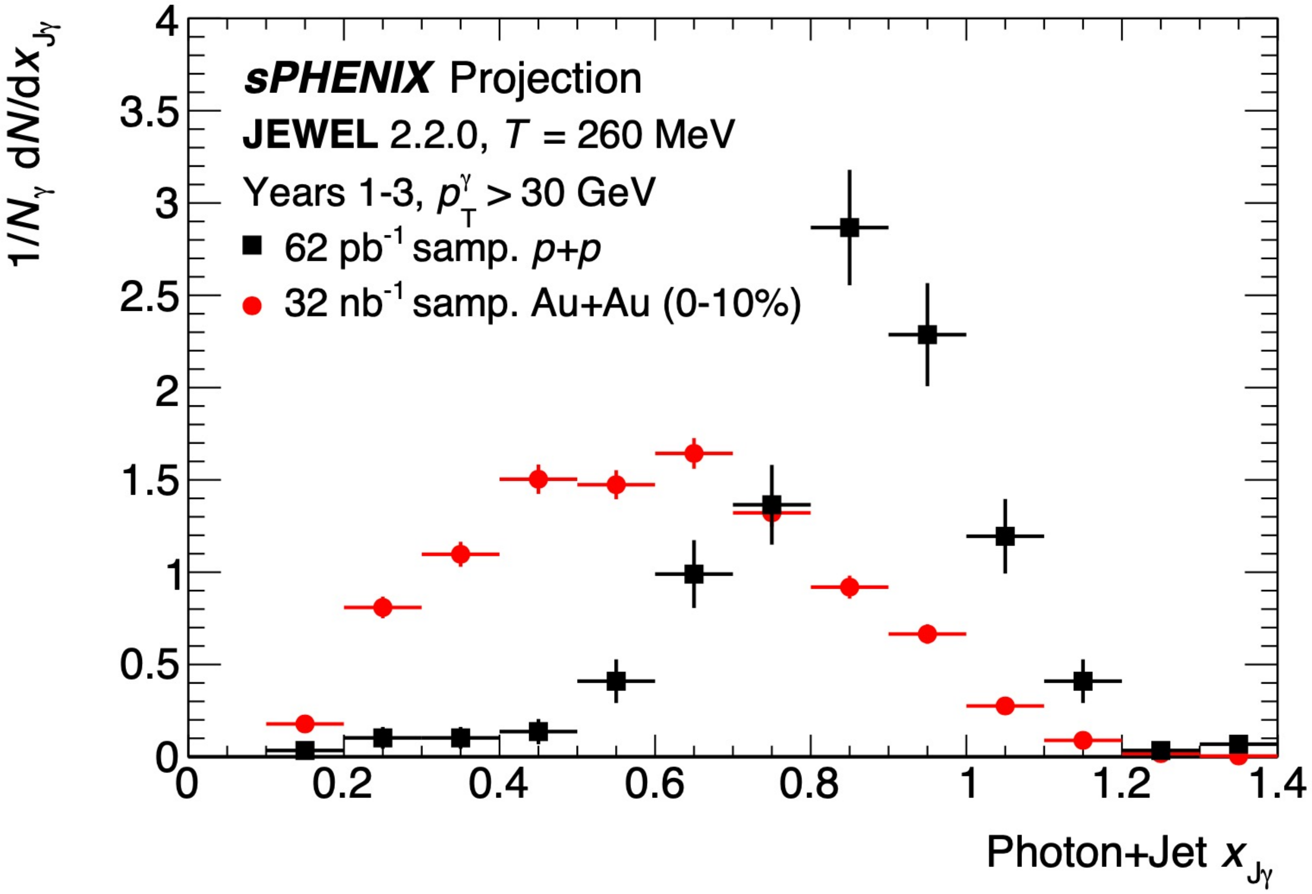


Projected v_2



Simultaneous explanation of R_{AA} and v_2 ongoing "puzzle”

Photon + jet

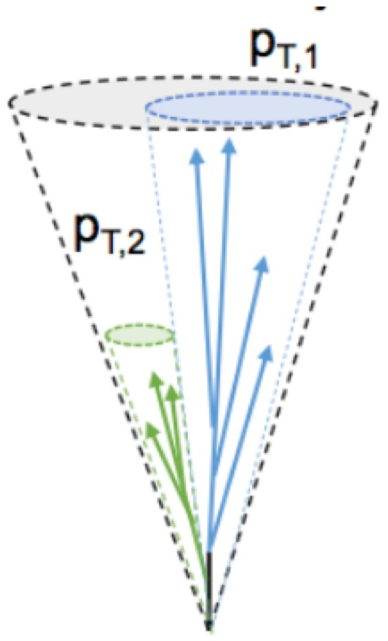


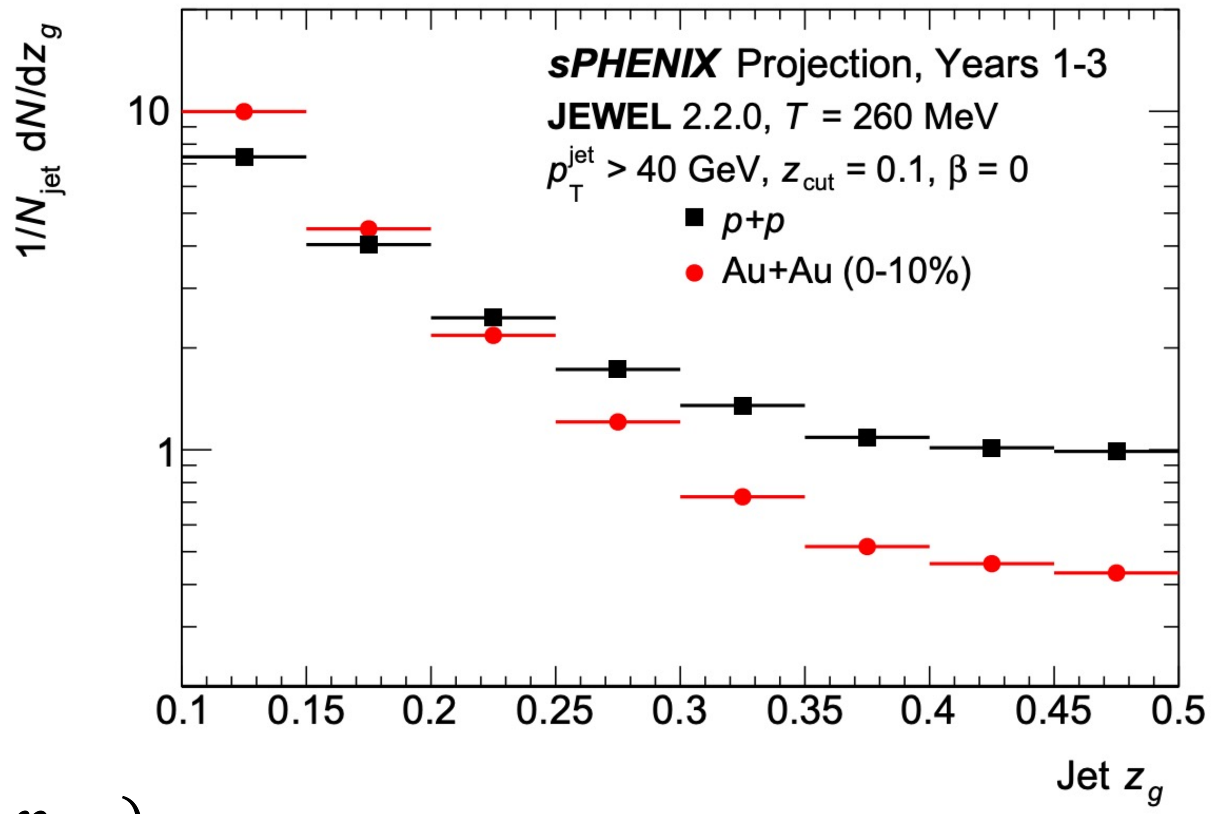
- High statistics allow for photon + jet measurements
- Photon provides unquenched tag of jet momentum
- Flavor dependence of energy loss

$$x_{J\gamma} = \frac{p_T^{jet}}{p_T^{\gamma}}$$

Jet substructure

- Fine segmentation of calorimeter + good tracking resolution allows for substructure measurements
- Study how the medium resolves jet substructure

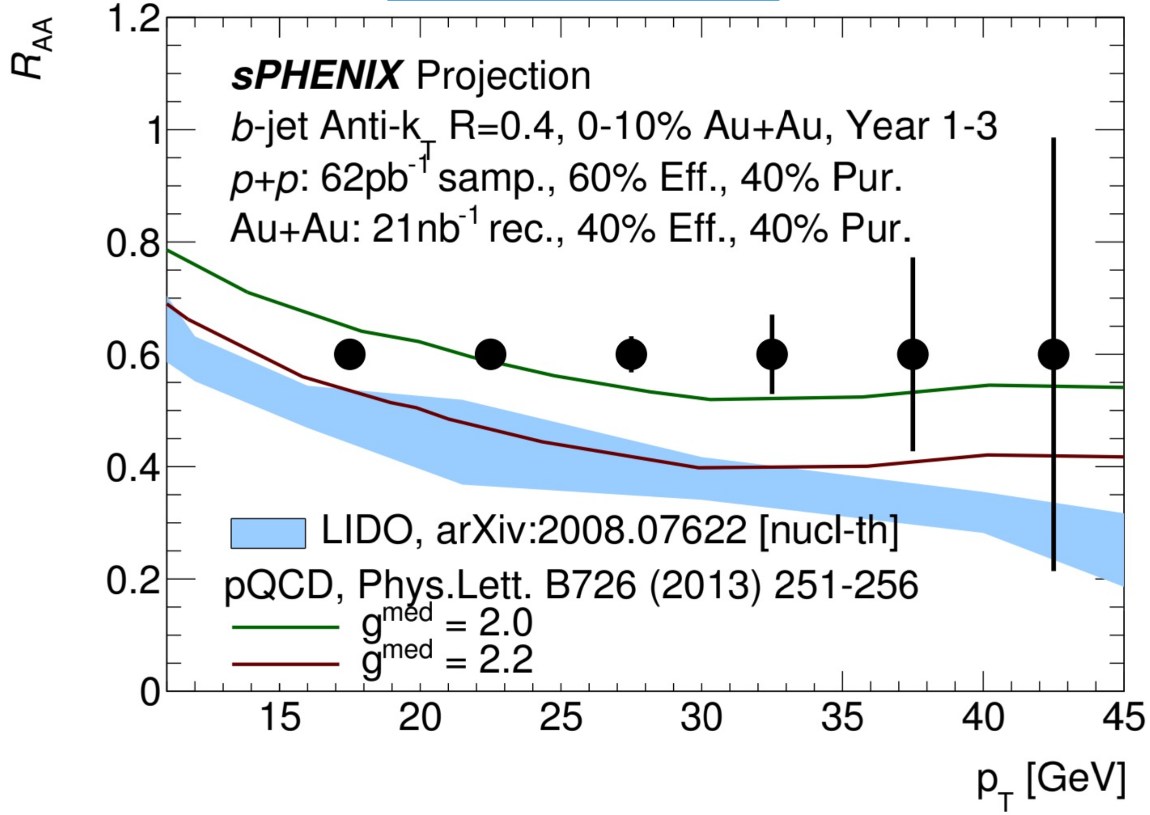




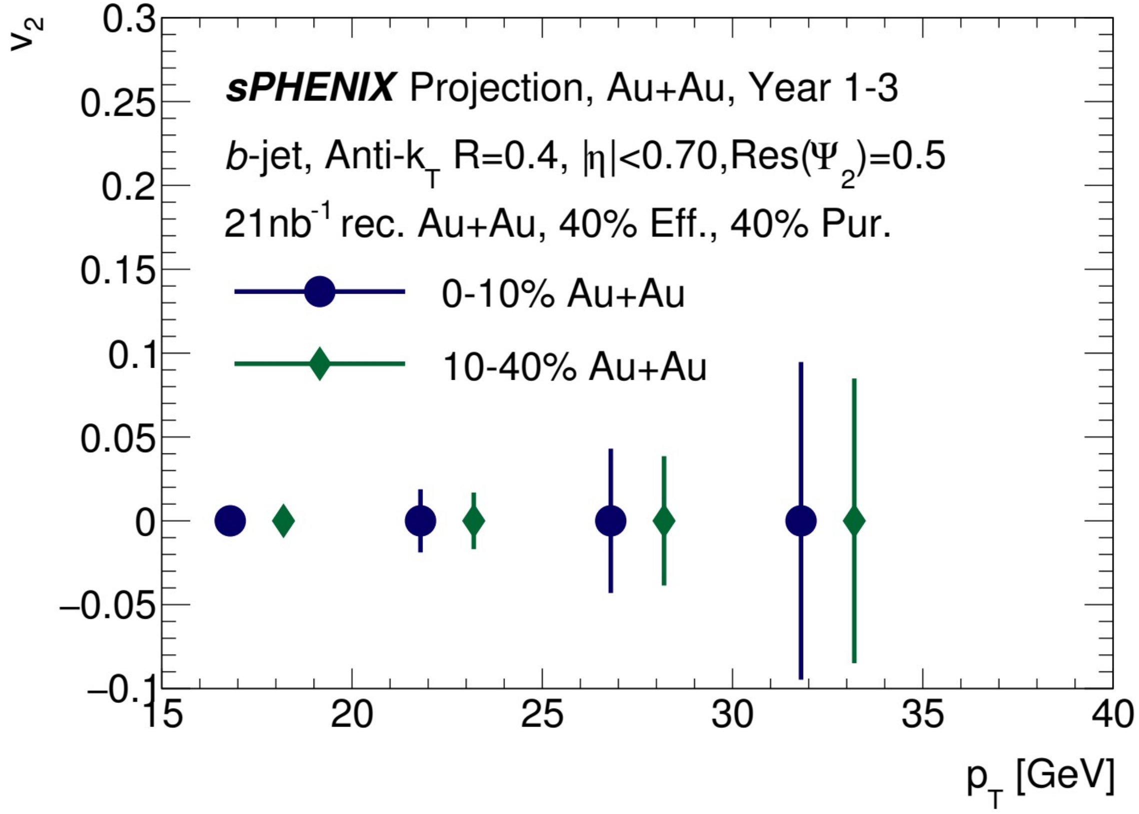
$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

b-jets

Projected R_{AA}

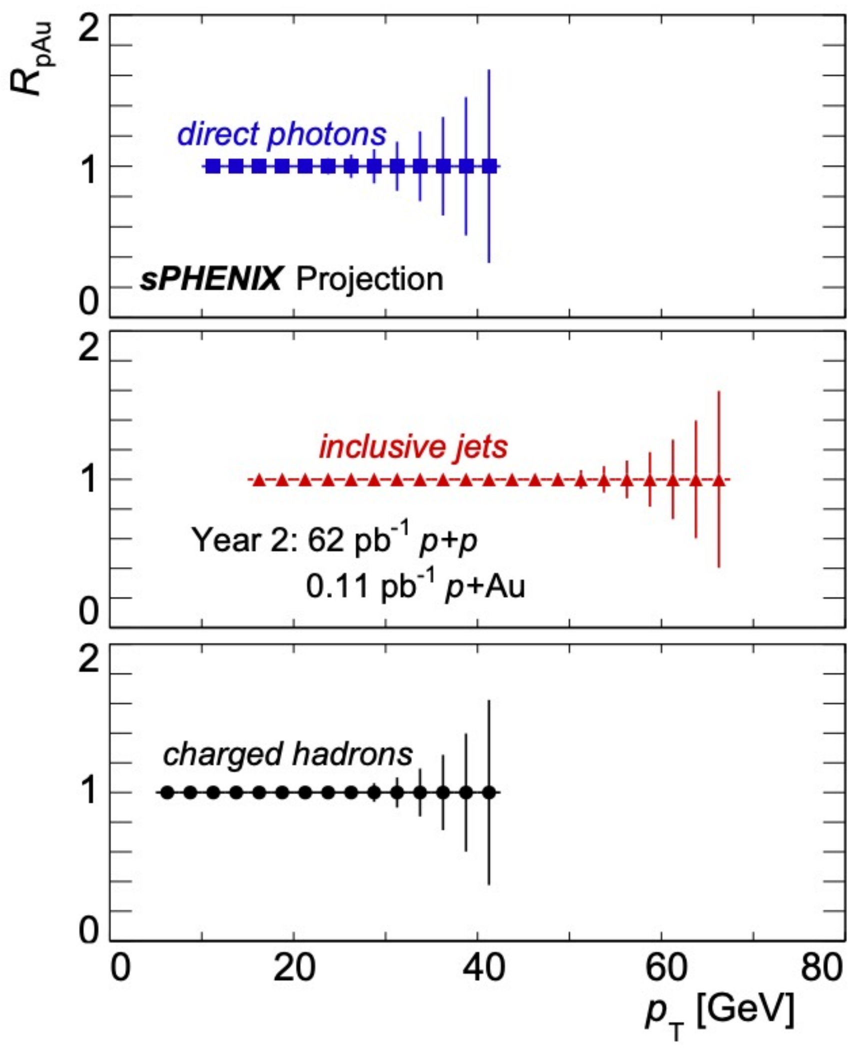


Projected v_2

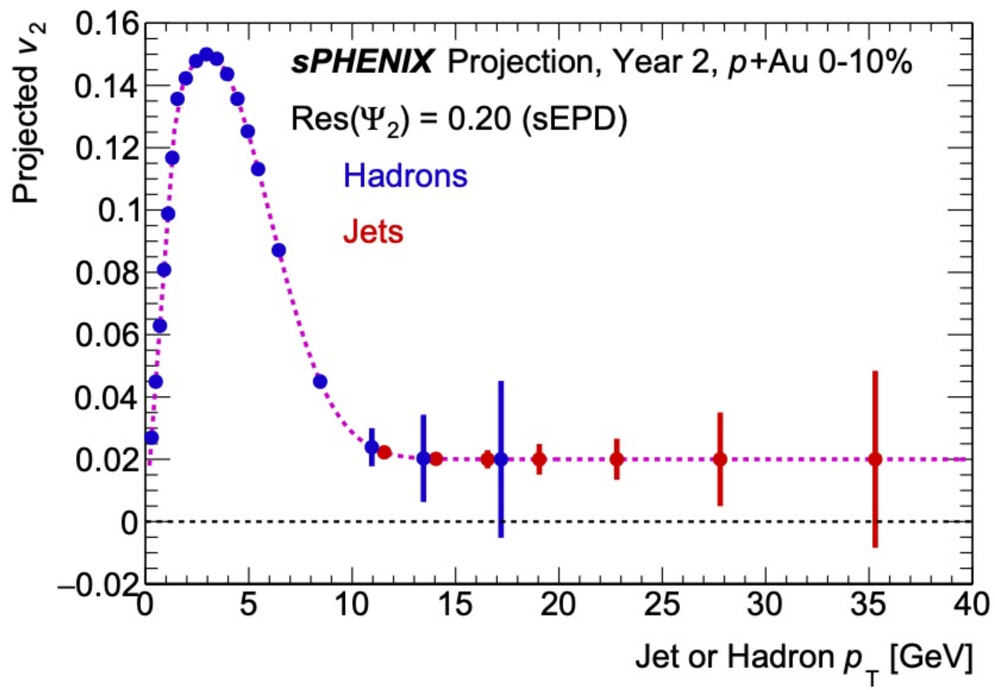


- MVTX allows for tagging of heavy-flavor decays
- Study mass dependence of energy loss

Jets in small systems



- p+Au data:
  - Cold nuclear matter effects
  - Potential for energy loss in small systems
  - + cold QCD spin measurements



Status and timeline

- Detector assembly ongoing at BNL
  - Magnet installed in October
  - Outer HCal installation complete
  - Inner HCal and EMCal construction ongoing
- High statistics simulation campaign ongoing
  - Prep for processing real data + use for performance studies
- Data taking to being in Feb. 2023

Summary

- sPHENIX detector will provide:
  - Full coverage electromagnetic and hadronic calorimetry
  - High precision tracking
  - Fast readout rate

- Design allows for:
  - High statistics samples of hard probes (jets, photons, high p_T charged hadrons)
  - Full jet reconstruction → complimentary jet measurements to LHC

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