Jet physics measurements in sPHENIX

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on behalf of sPHENIX

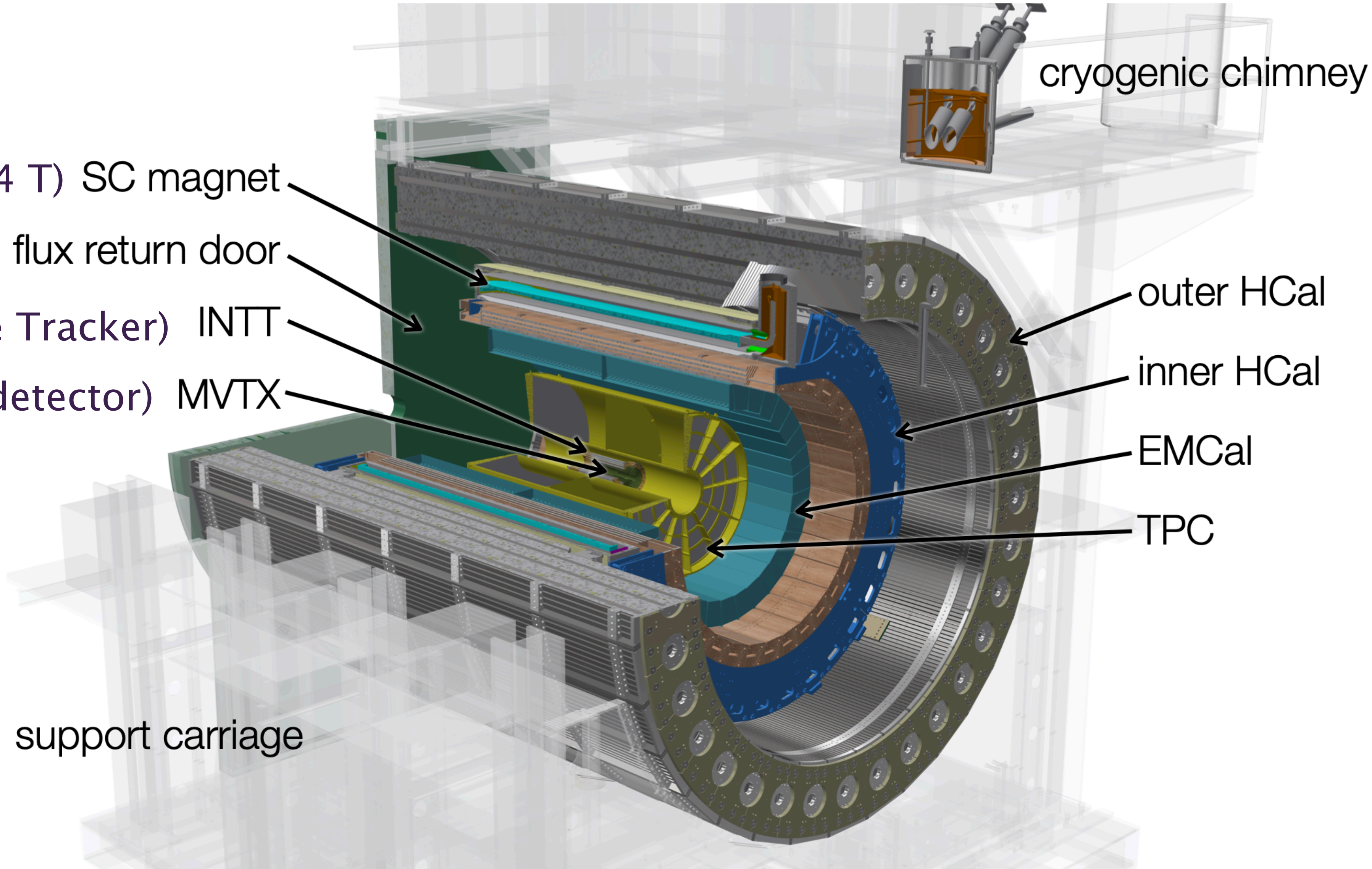
U.S. DEPARTMENT OF ENERGY

The 9th Workshop of the APS Topical Group on Hadronic Physics
13-16 April 2021, Virtual

University of Colorado **Boulder**

sPHENIX

sPHENIX Detector



- Jet Measurement with sPHENIX detector
  - ➡ **Large and hermetic** acceptance of EMCal + HCal out to $|\eta| < 1.1$
  - ➡ **Electromagnetic calorimeter**: high granularity of $\Delta\eta \times \Delta\varphi \sim 0.025 \times 0.025$
  - ➡ **Hadronic calorimetry**: $\Delta\eta \times \Delta\varphi \sim 0.01 \times 0.01$
  - ➡ **High-precision tracking**: silicon detectors (INTT + MVTX) + TPC
  - ➡ **High data readout rate** of 15 kHz for all subdetectors

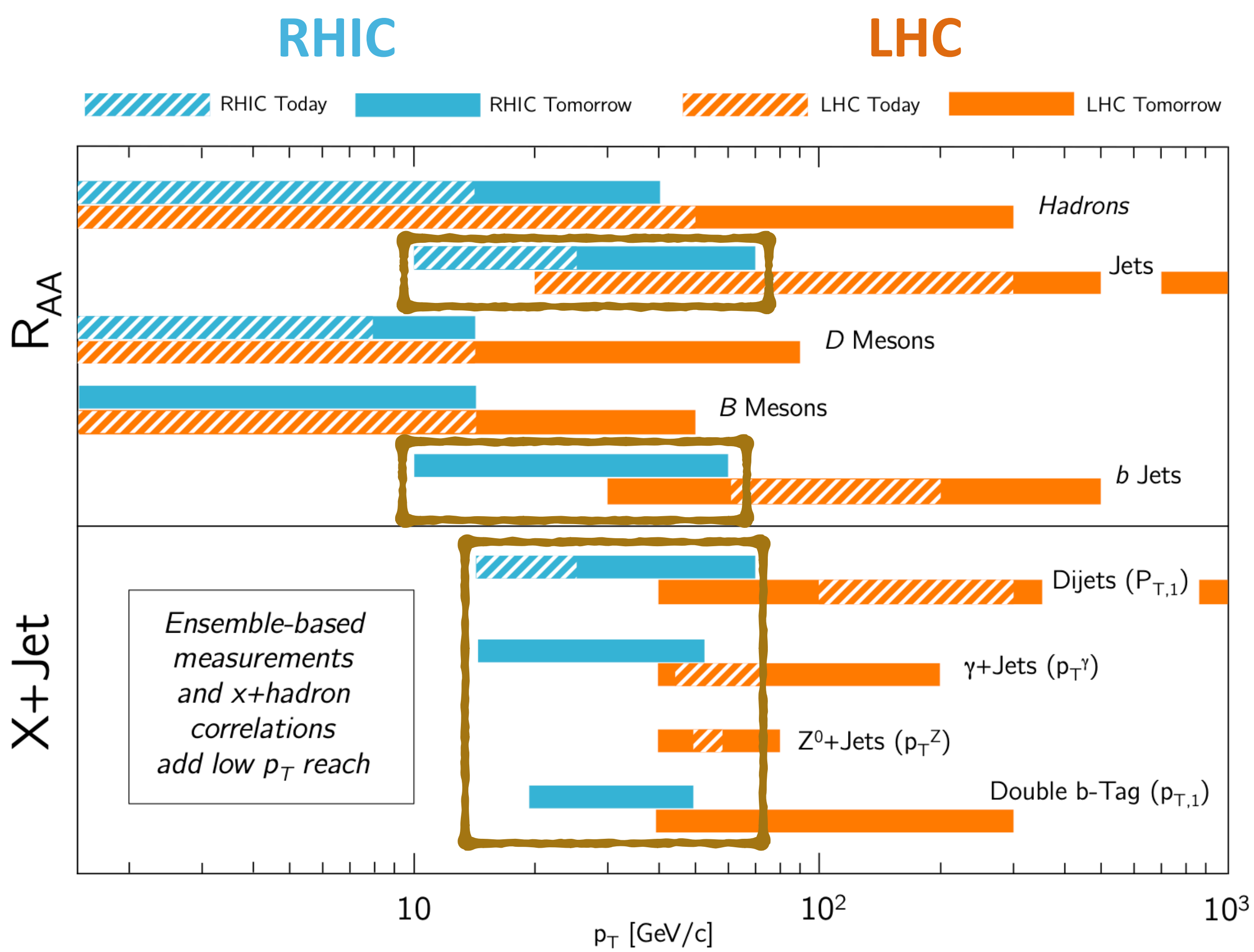
sPHENIX Run Plan

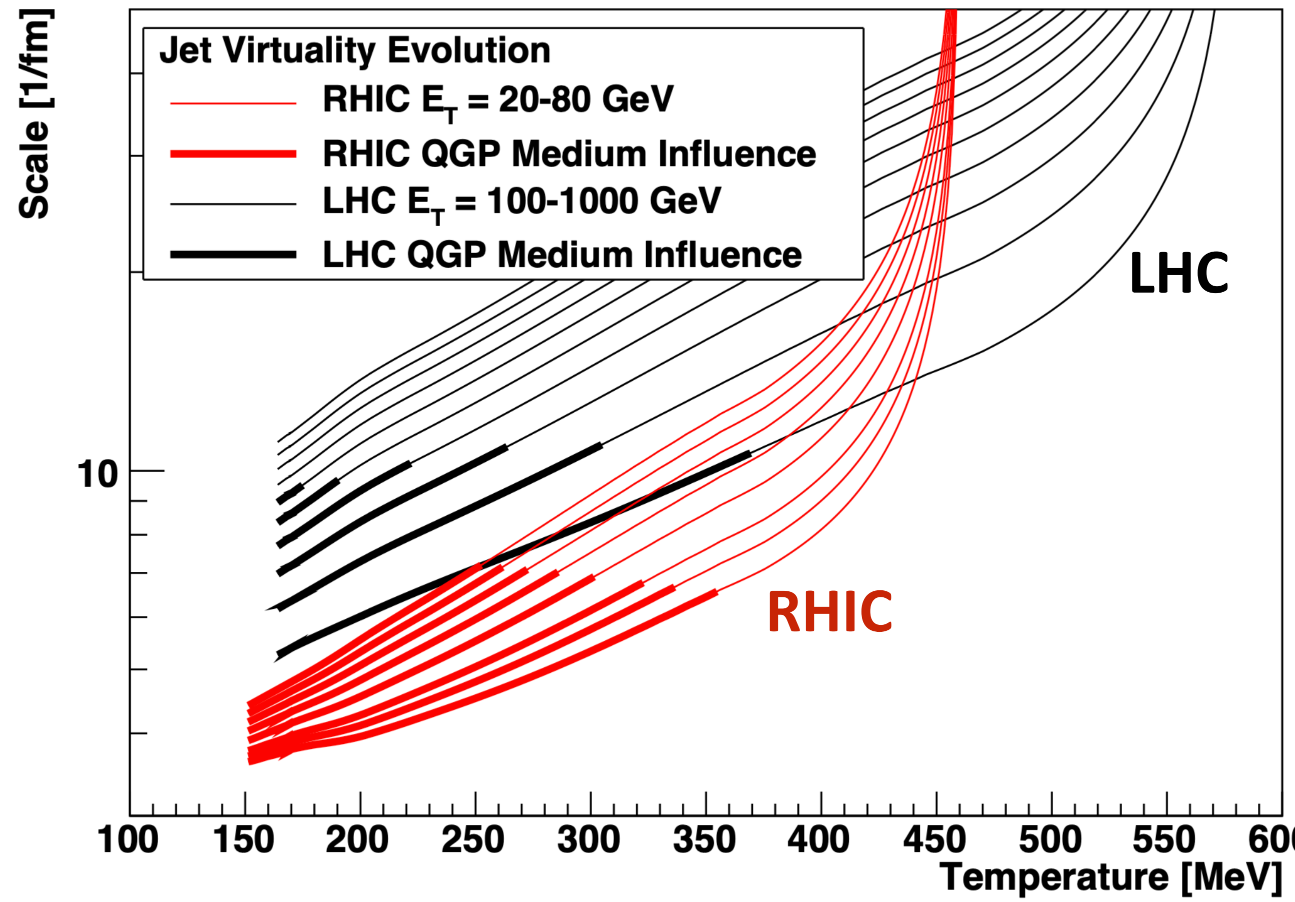
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z \rvert < 10$ cm	Samp. Lum. $\lvert z \rvert < 10$ cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-str]	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}

sPHENIX Beam Use Proposal
endorsed by the BNL NPP (Nuclear and Particle Physics) PAC (Physics Advisory Committee)

- Extensive **3-year** data taking staring from **2023**!
  - ➡ **Year-1**: commissioning, validating calibration and reconstruction
  - ➡ **Year-2**: p+p and p+Au runs for heavy-ion reference and cold QCD physics
  - ➡ **Year-3**: very large Au+Au dataset

Jet Kinematic Reach



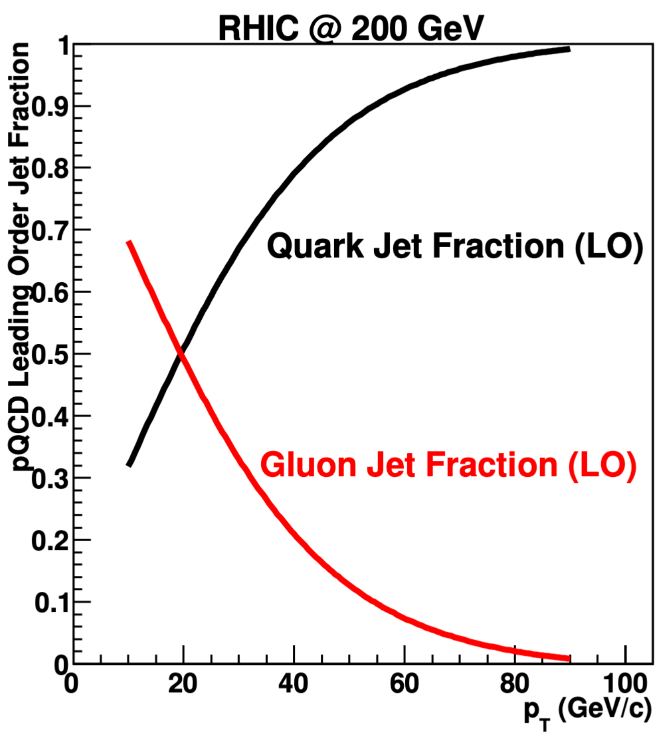


arXiv:1501.06197

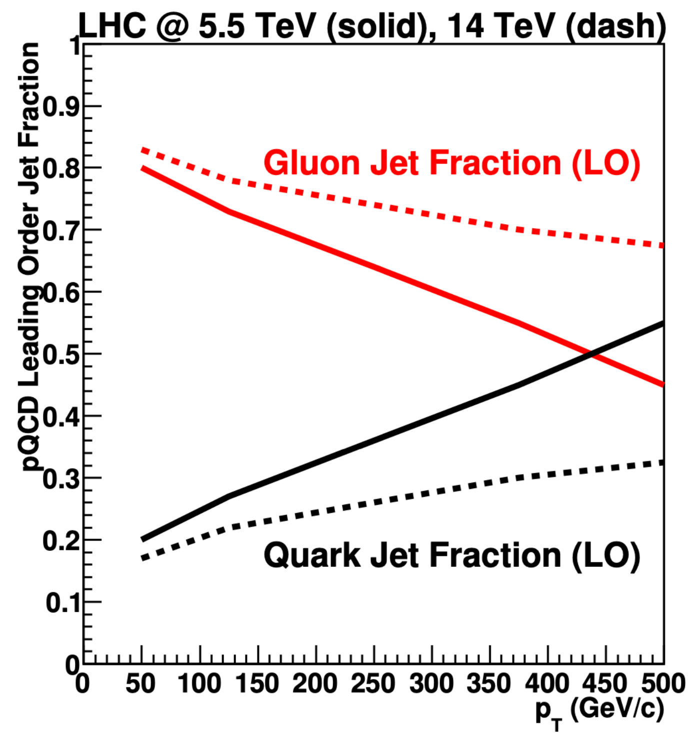
- Overlap with LHC kinematic range
  ➡ **complementary to the LHC**
- Extend measurements to **lower jet energy** (lower UE)
- **Opportunity for new probes** (b-jets) and **improved impression** (photon+jet) at RHIC
- Different initial conditions and evolution for QGP between RHIC and LHC
  ➡ allows study of **scale and temperature dependence**

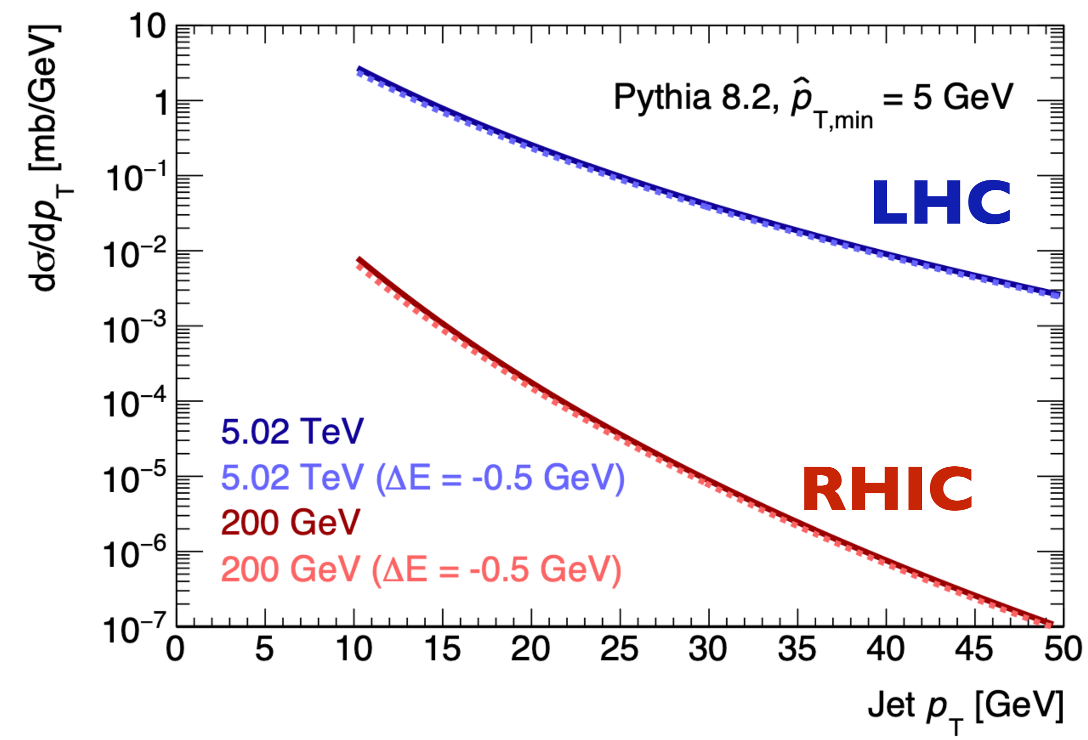
Complementarity with LHC

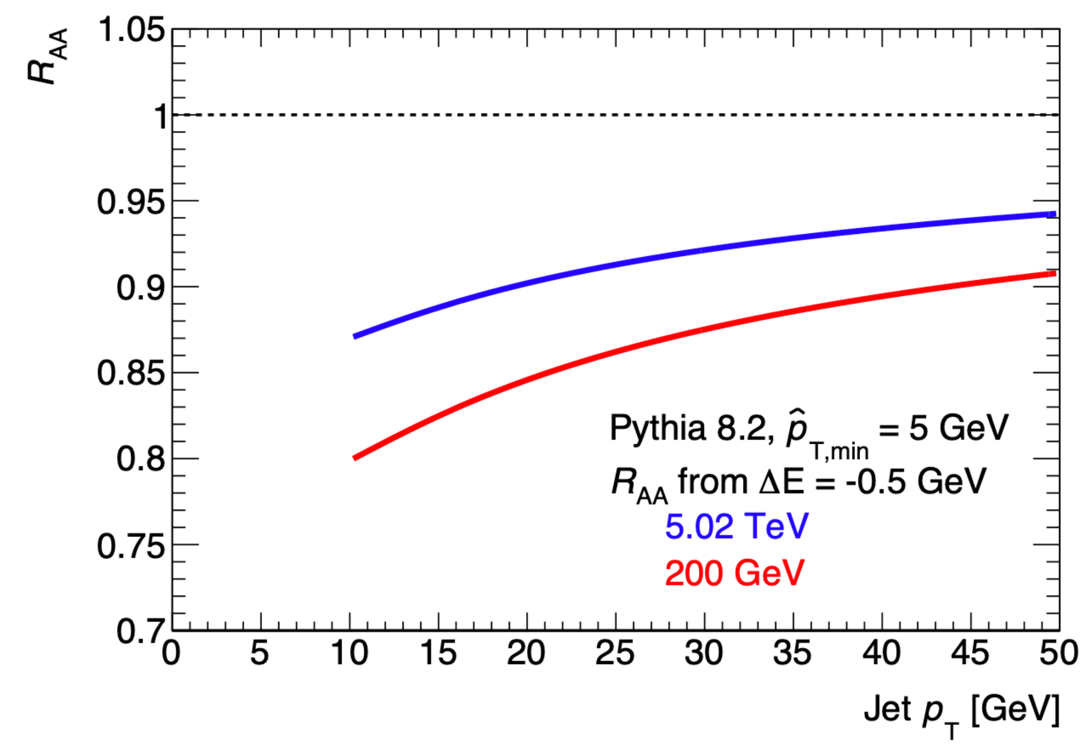
RHIC



LHC

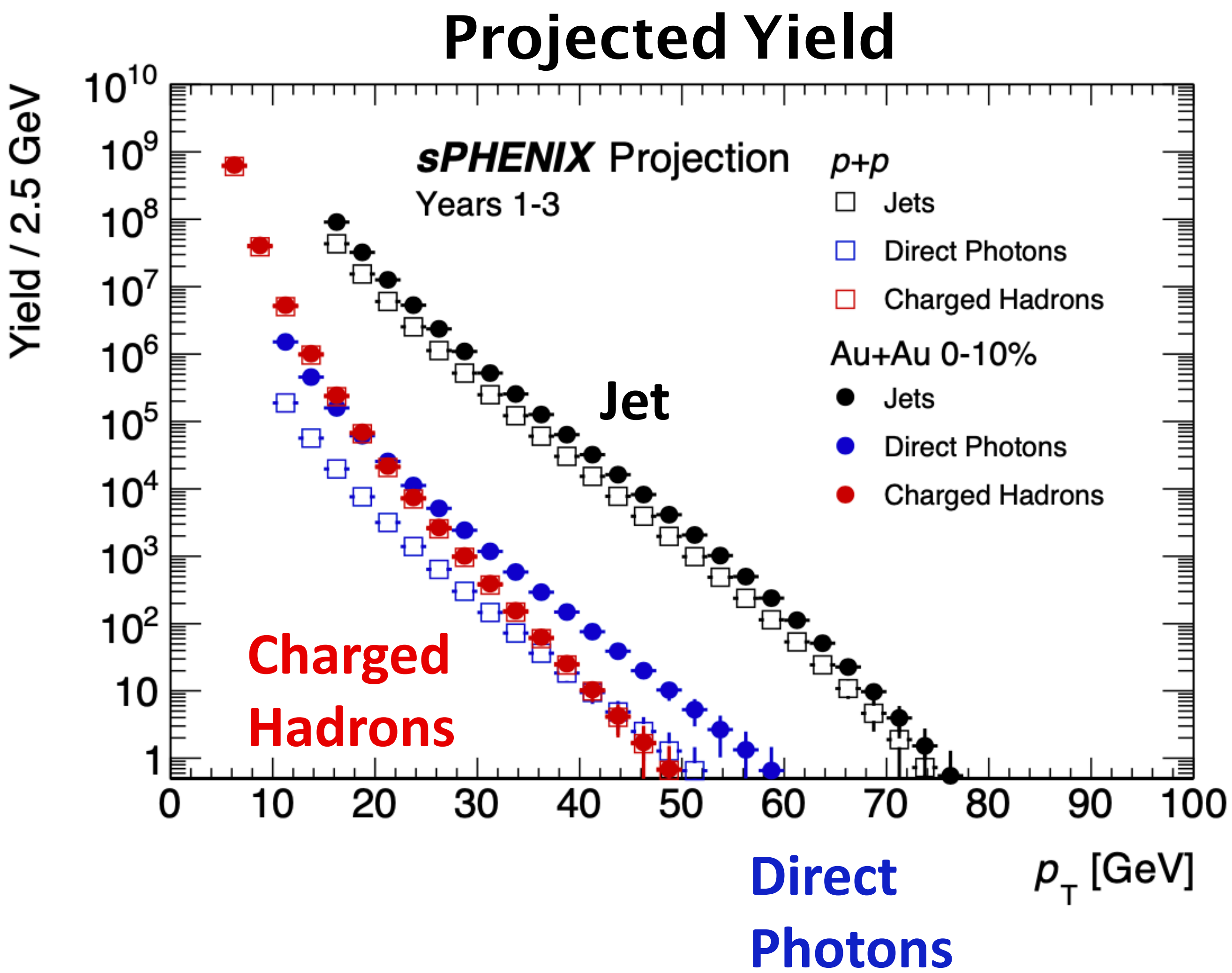


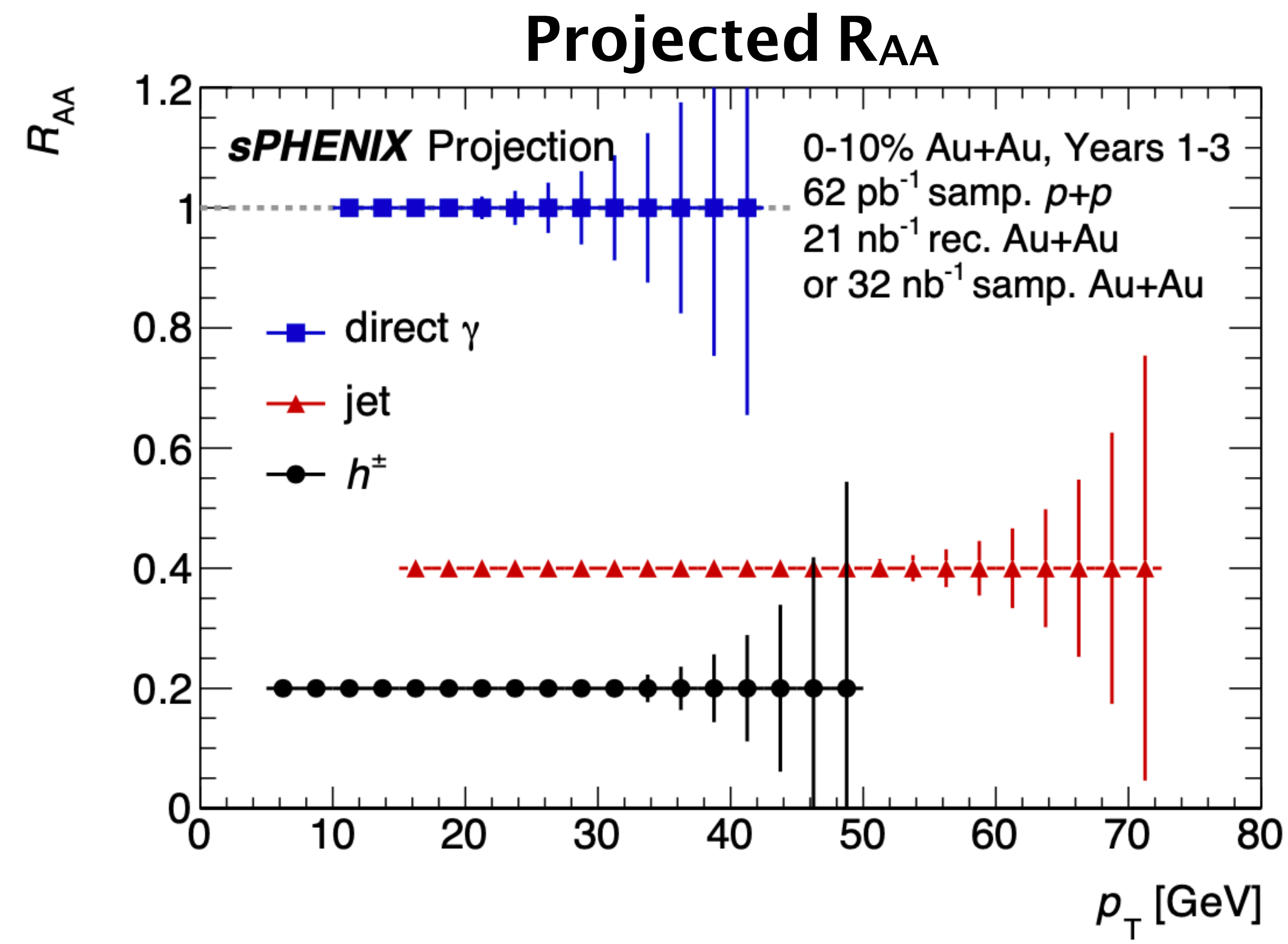




- Different composition of quark and gluon jets at available jet kinematic ranges for **RHIC** and **LHC**
  ➡ Study quark and gluon energy loss
- Steeper jet p_T spectra at **RHIC** than **LHC**
  ➡ more quenching (E-loss) effect

Final State Probes



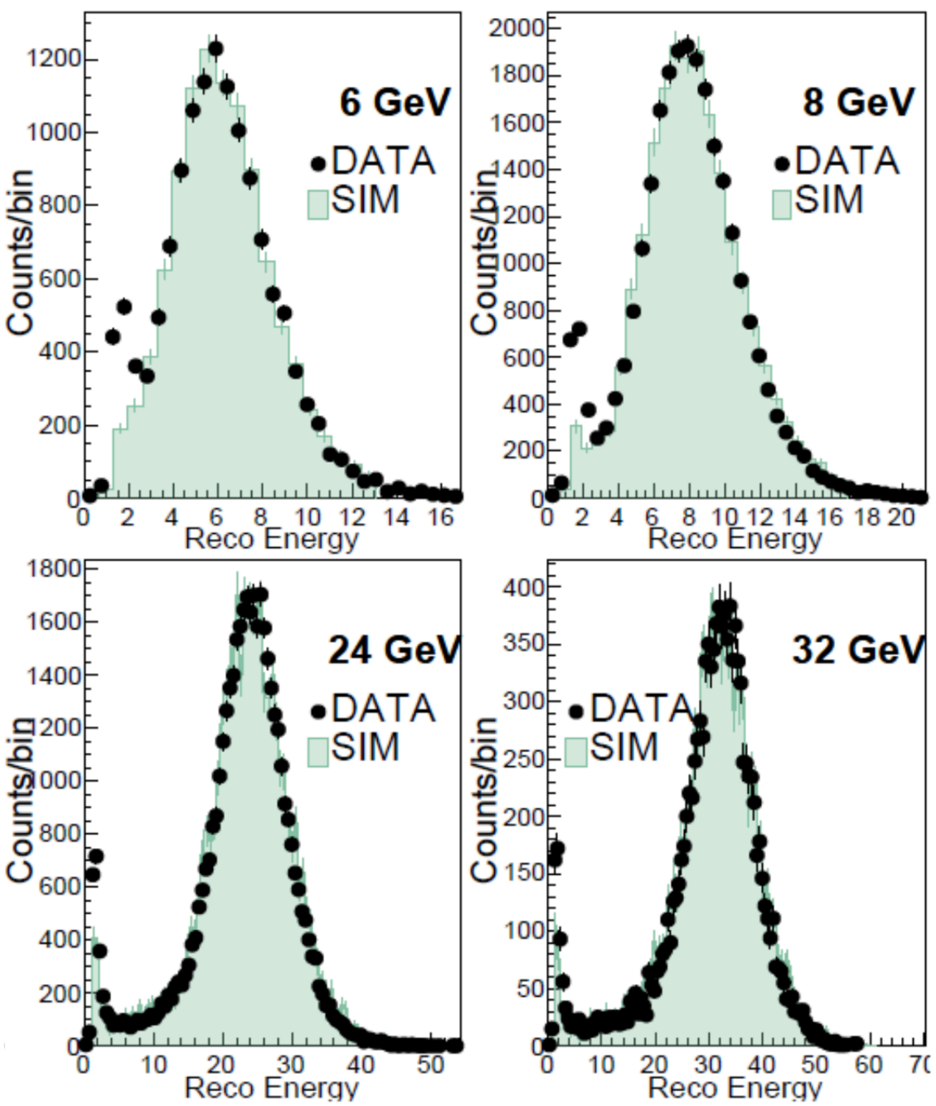


sPHENIX Beam Use Proposal

- **Statistical projection** for final state probes for 2023-2025 data
- Kinematic reach up to **70 GeV for jets**, **50 GeV for hadrons** and **40 GeV for photons**
  ➡ enabled **multi-differential** inclusive jet, photon+jet, jet+hadron measurements

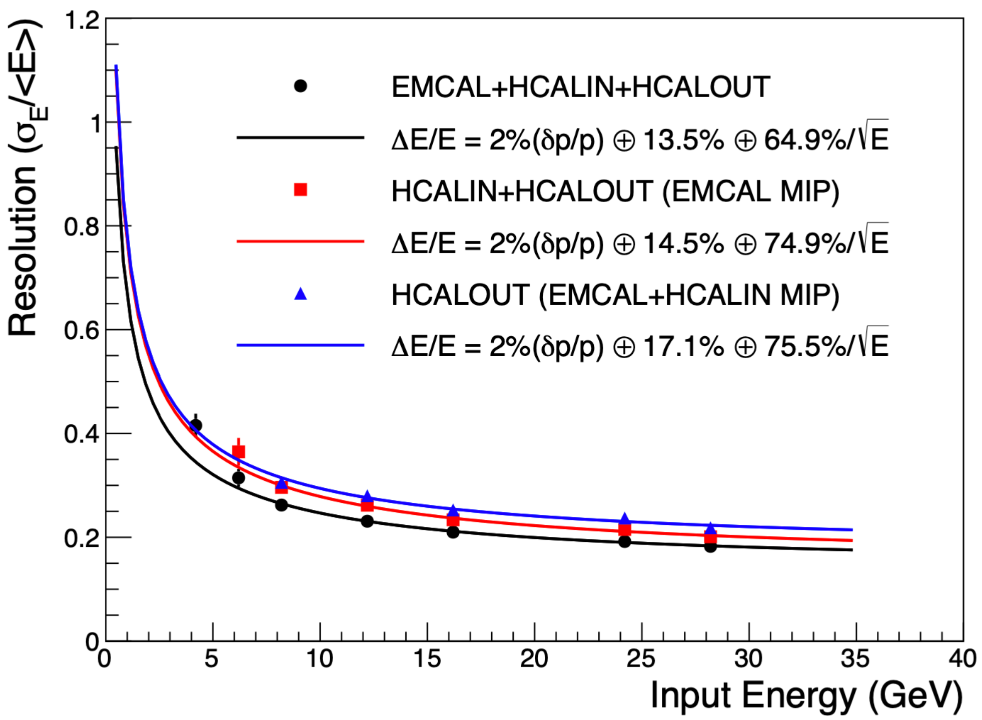
Calorimeter Energy Scale

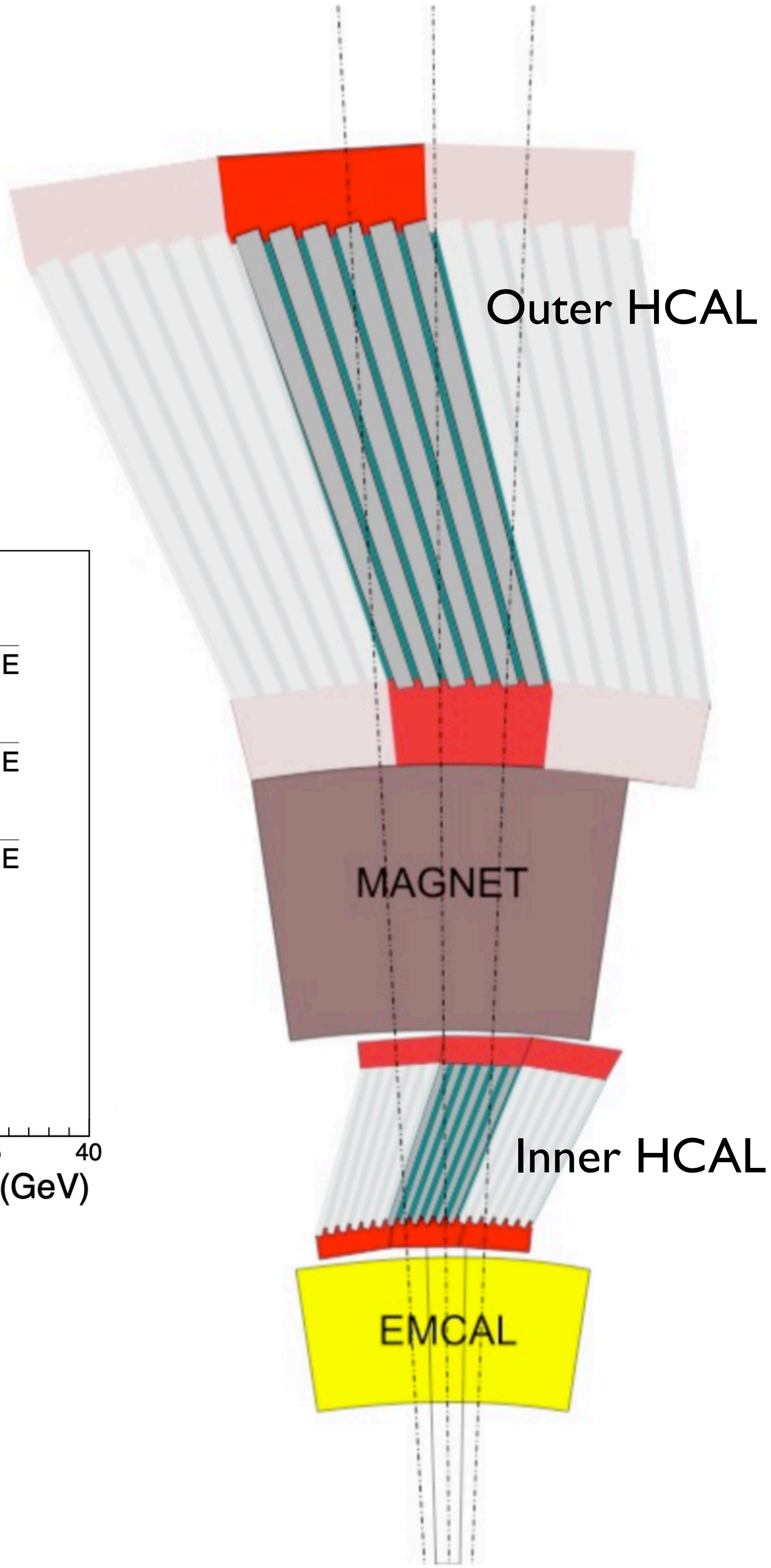
Hadron Energy



[arXiv:2003.13685](https://arxiv.org/abs/2003.13685), *IEEE Trans.Nucl.Sci.* 68 (2021) 2, 173-181

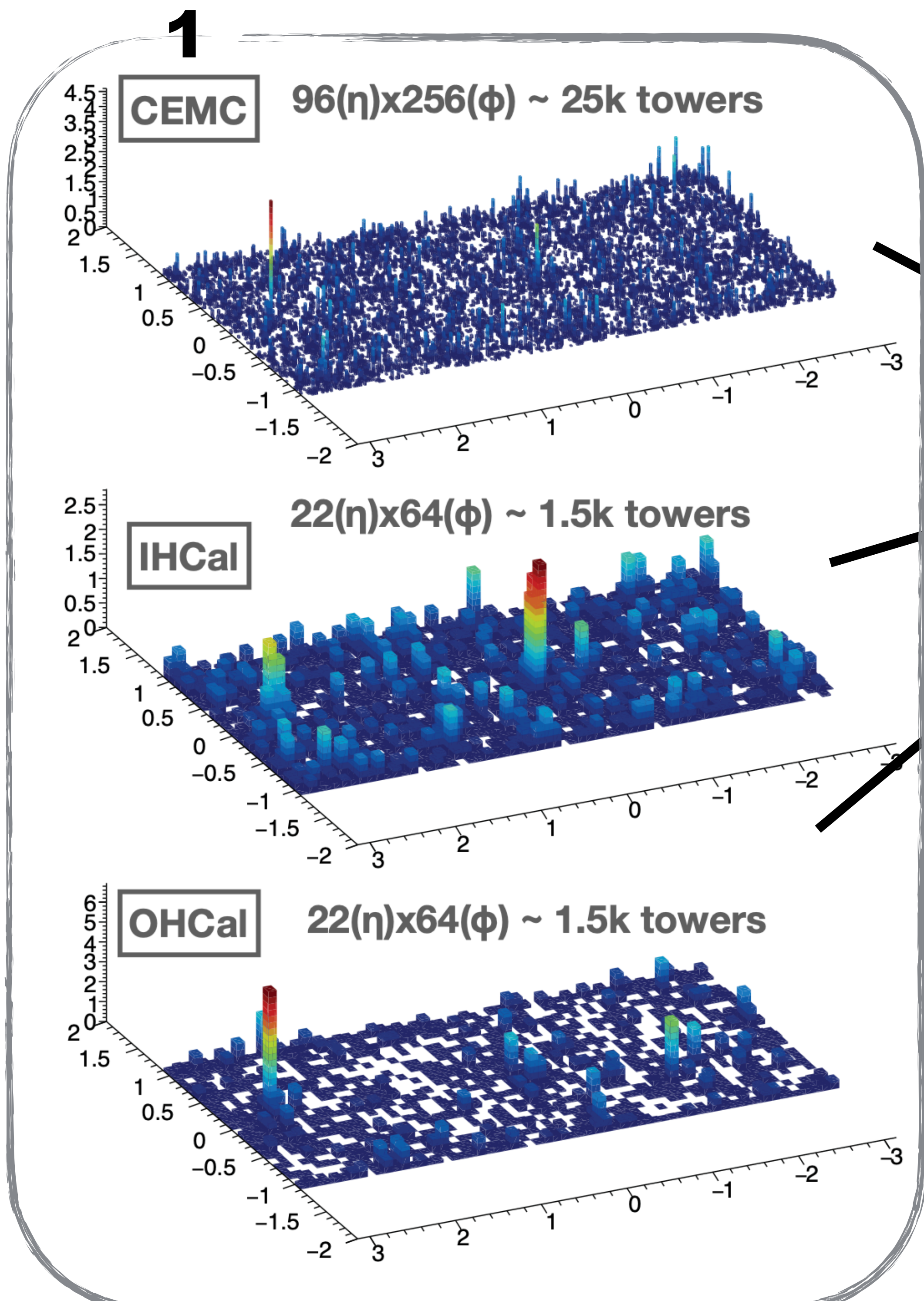
[arXiv:1704.01461](https://arxiv.org/abs/1704.01461), *IEEE Trans.Nucl.Sci.* 65 (2018) 12, 2901-2919



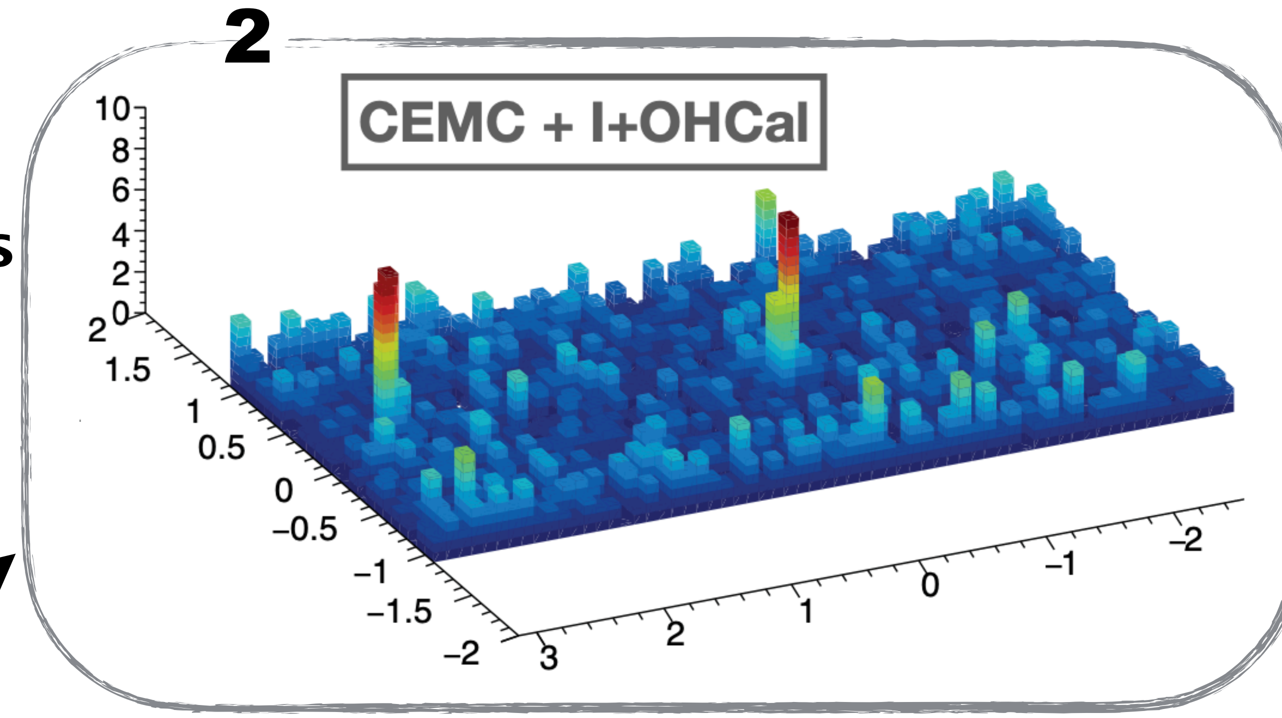


- Beam test performed with the full calorimetry at Fermilab
- Good agreement with the Geant4 simulations

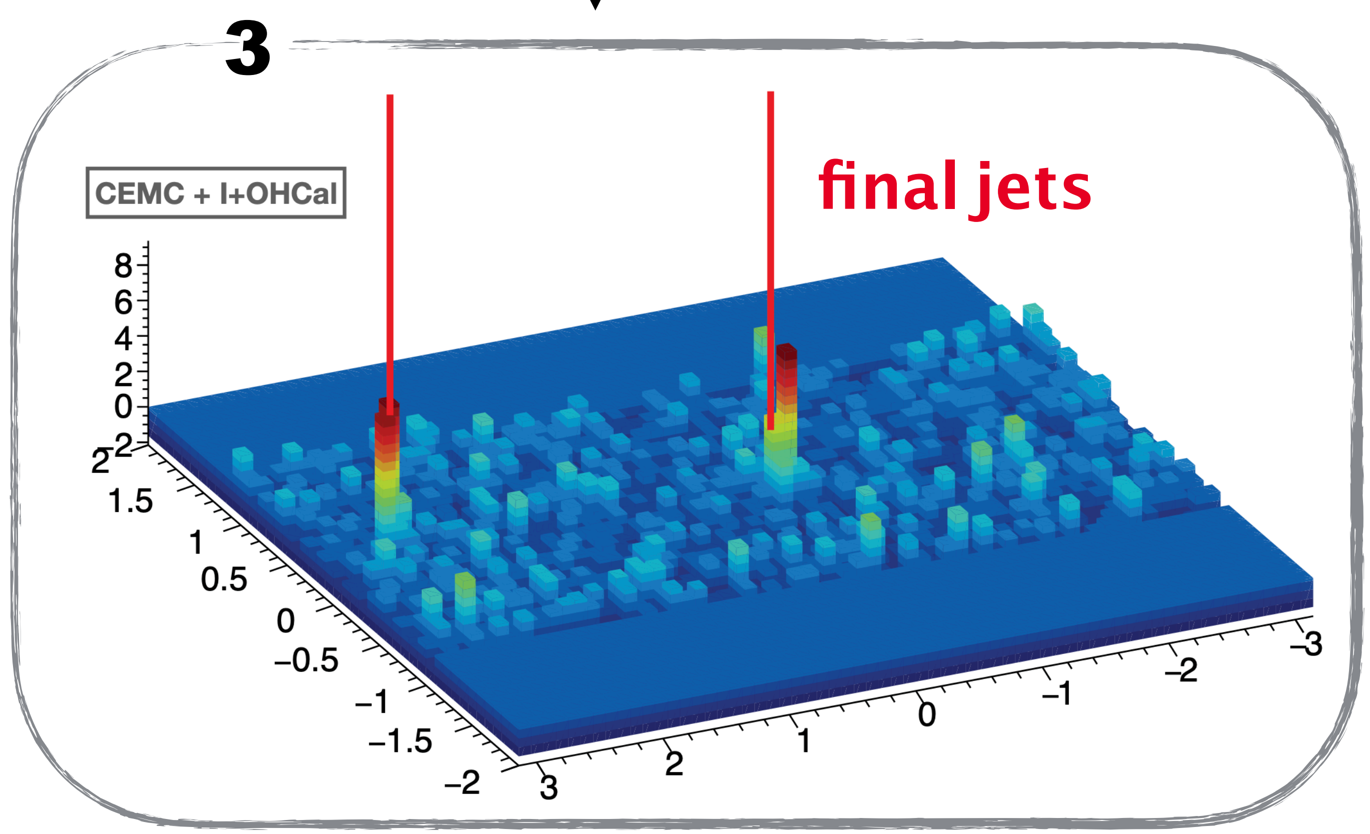
Calorimeter Jet Reconstruction



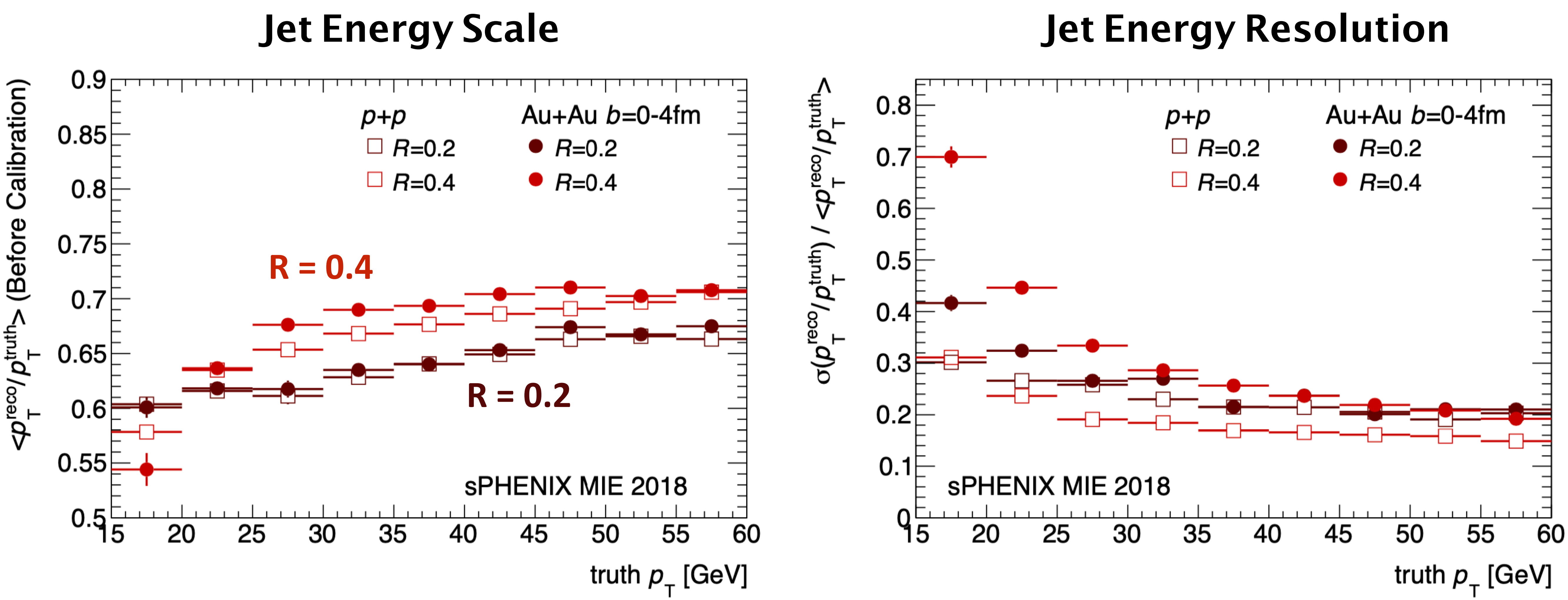
Combine energies in all layers



Iterative UE subtraction



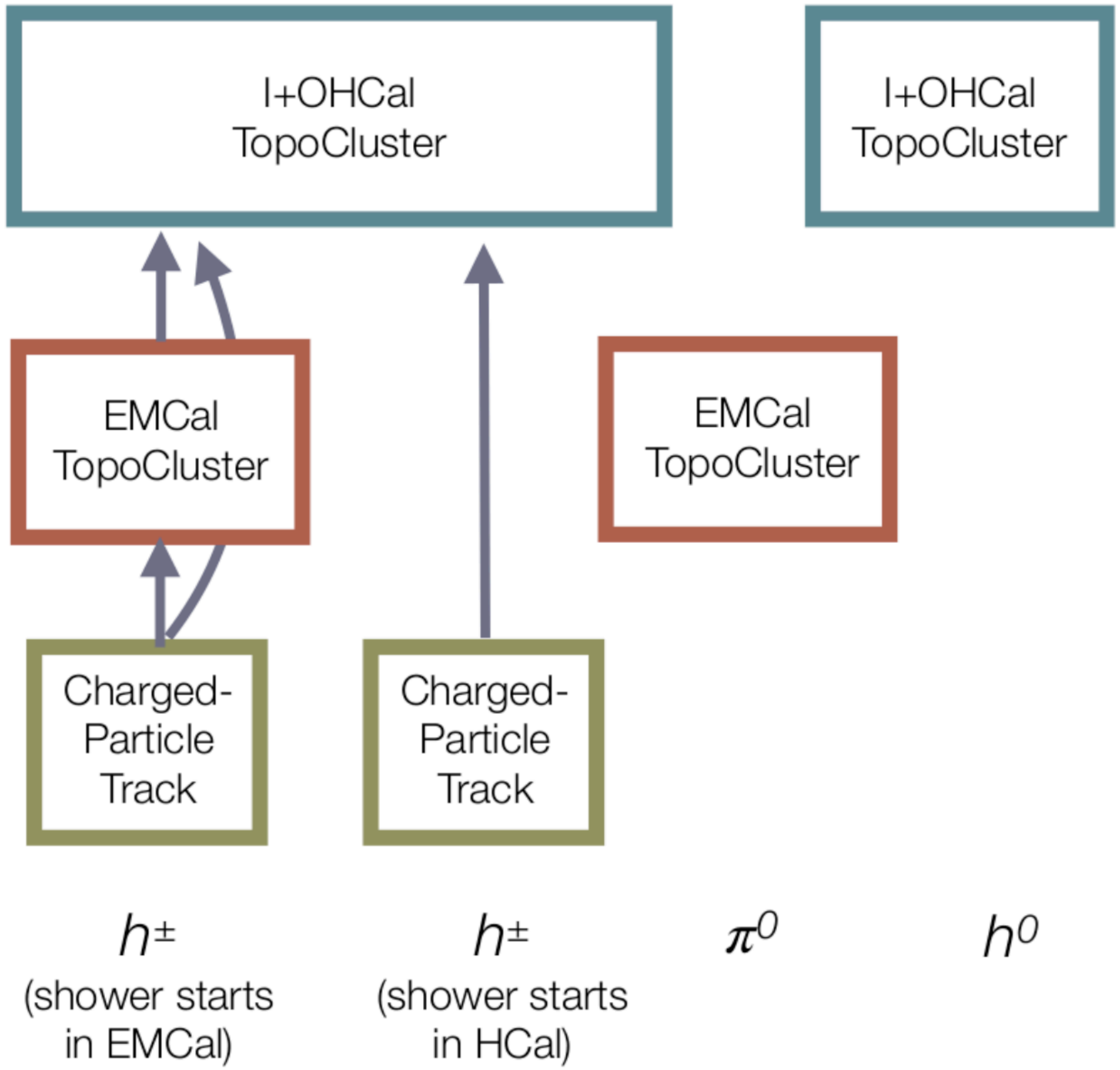
Calorimeter Jet Performance

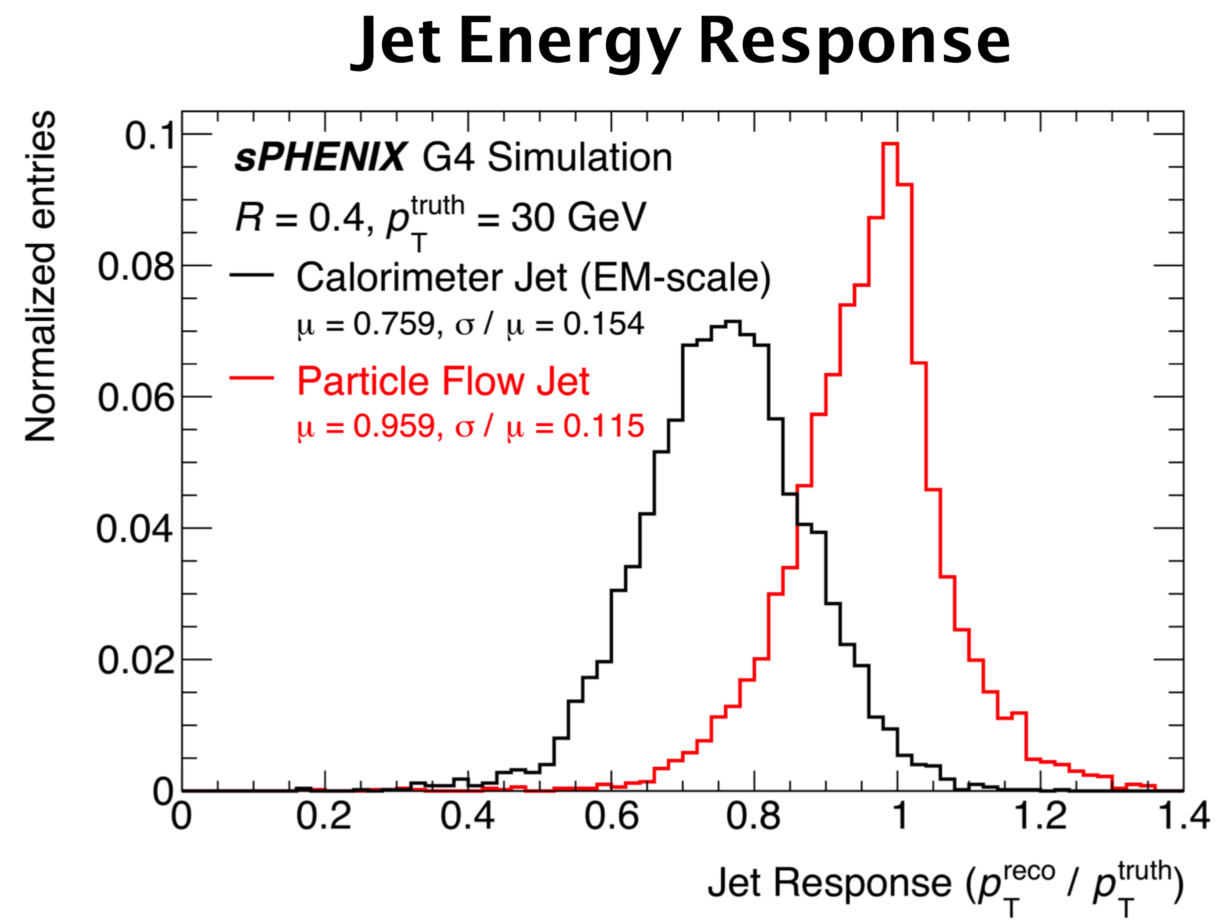


- p_T response at EM scale (before jet-level calibration) is independent of UE level
- Expected ordering in jet radius
- UE fluctuation at low p_T for large R jets

- Hadronic calorimetry offers a much higher jet energy scale than has been available mid-rapidity at RHIC

Particle Flow Jet

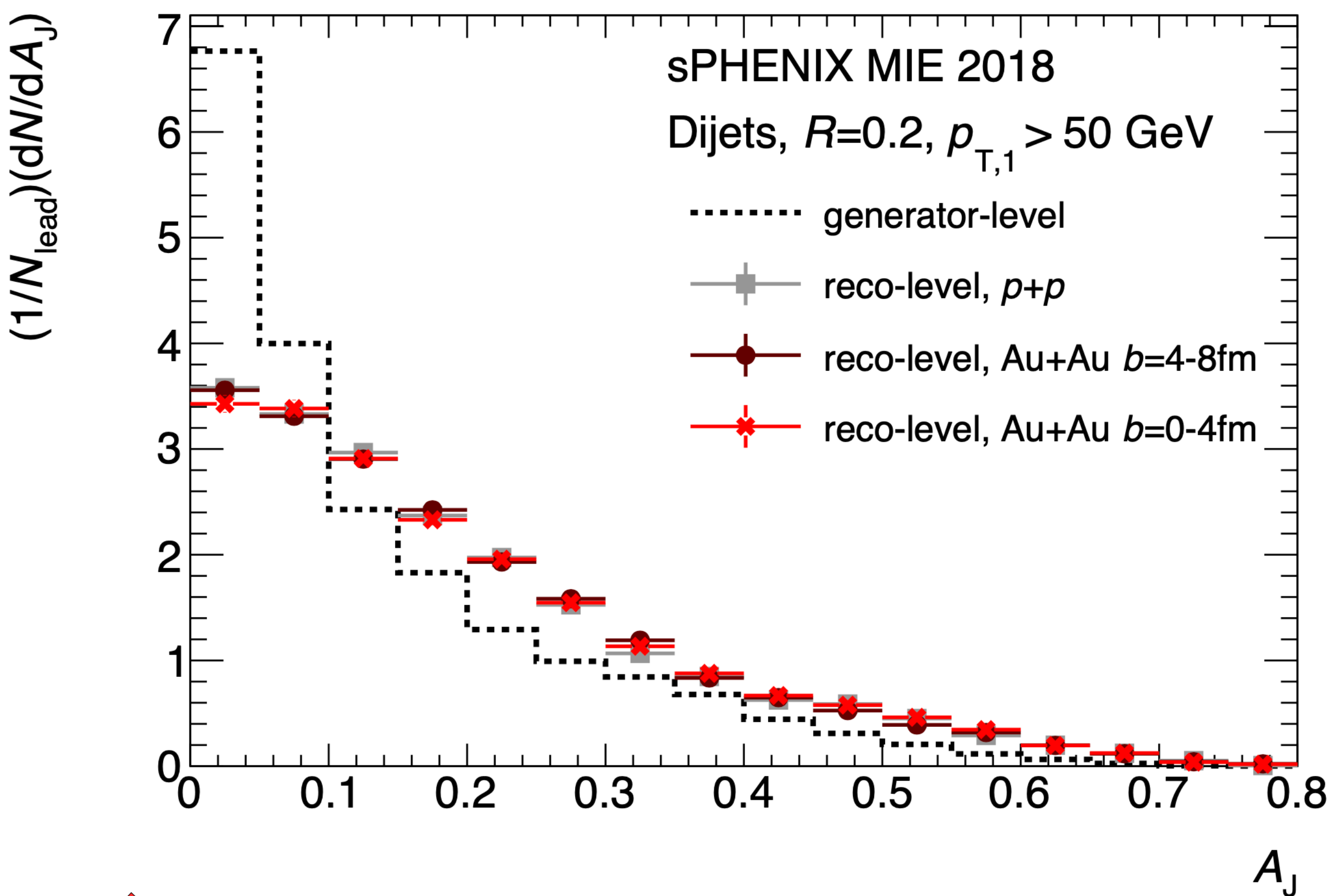


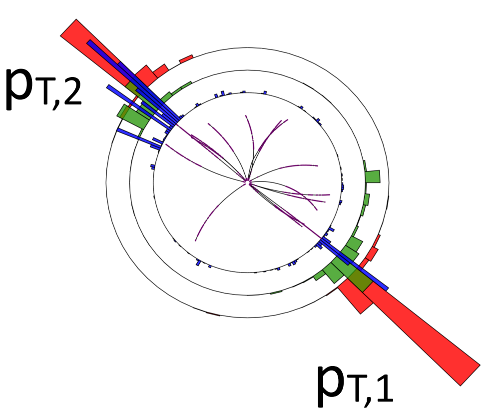


- **Particle Flow Jet (PF Jet)**
  - ➡ Use charged-particle track energy whenever matched
  - ➡ Combine ideas from ATLAS & CMS experiences
- Excellent energy response for **PF jets** with precision tracking system

Dijet and Jet Structure

Dijet Momentum Imbalance

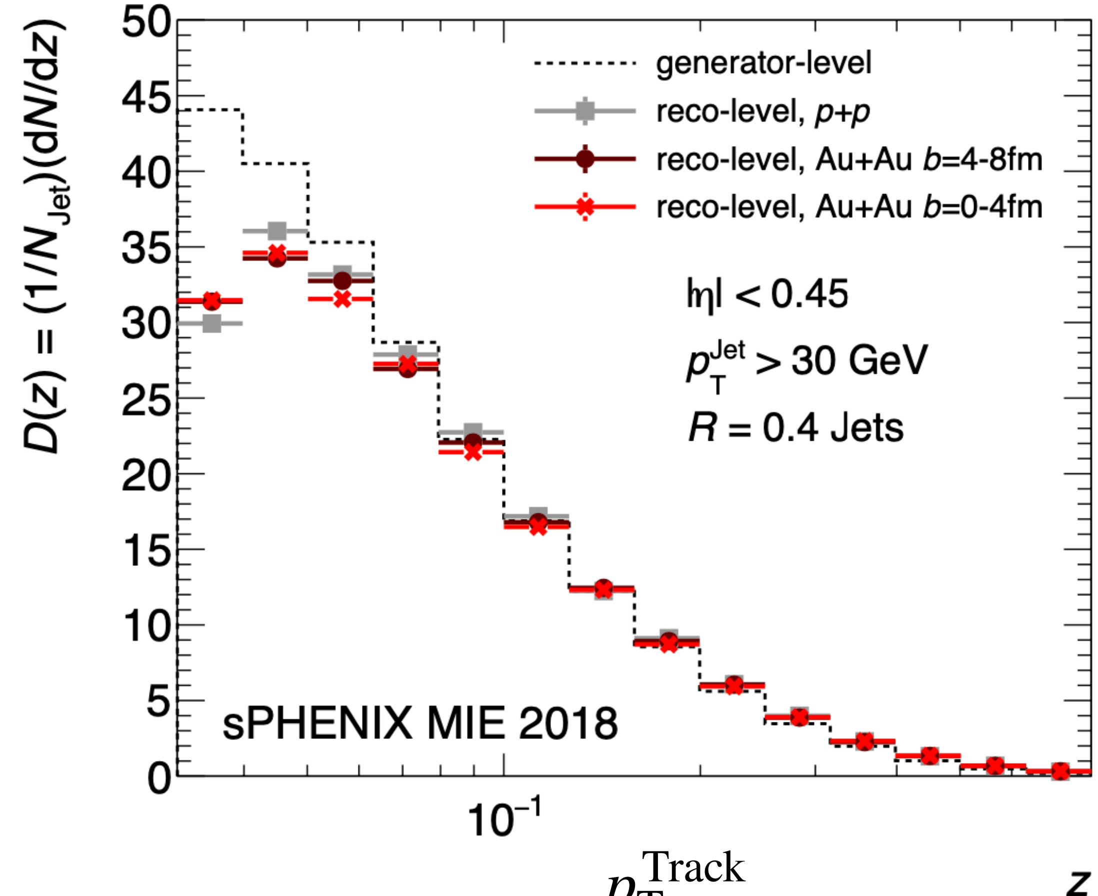




$$A_J = \frac{(p_{T,1} - p_{T,2})}{(p_{T,1} + p_{T,2})}$$

- **Good first observables** to understand jet quenching mechanisms at lower scale than LHC

Fragmentation Function

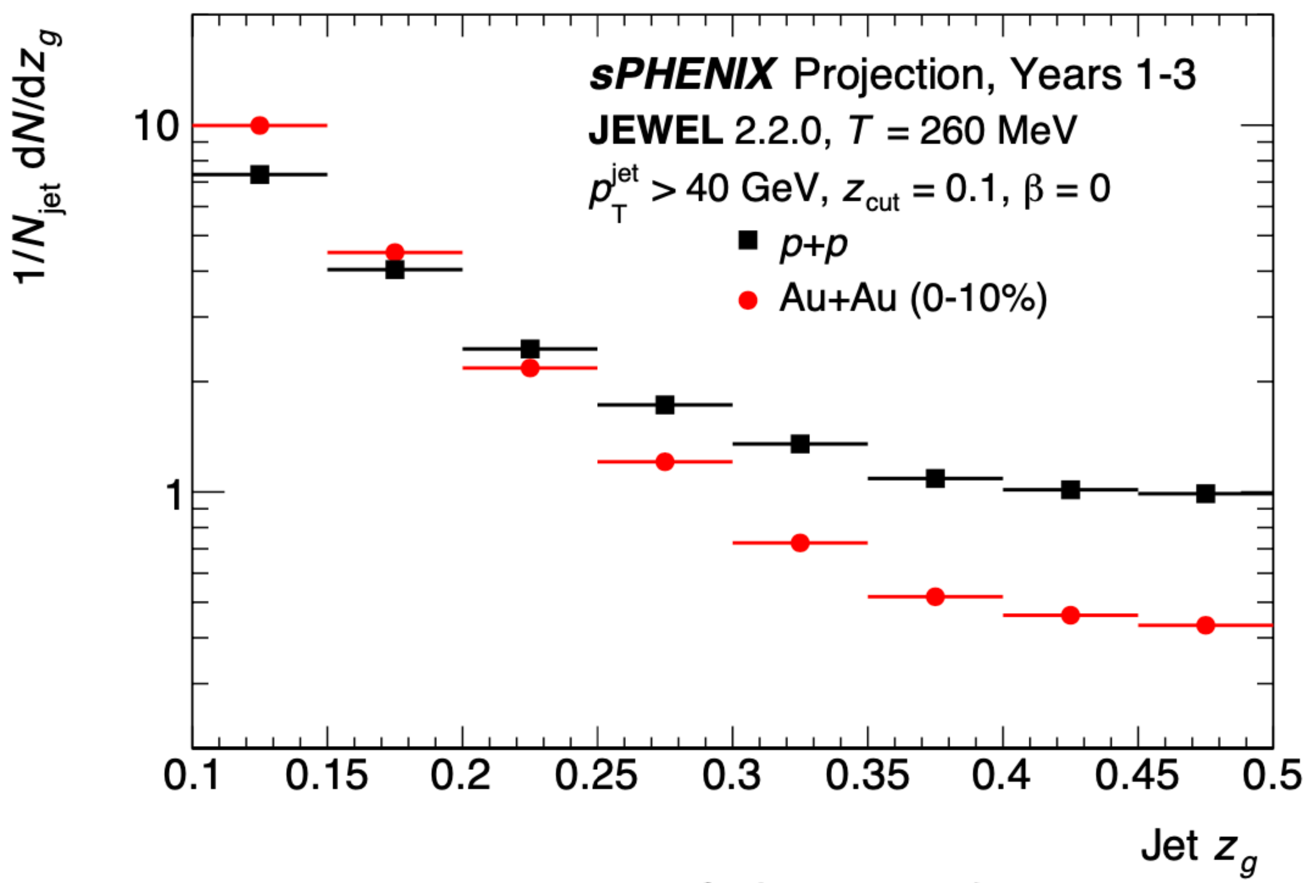


$$z = \frac{p_T^{\mathrm{Track}}}{p_T^{\mathrm{Jet}}}$$

- Improved jet reconstruction (i.e. UE subtraction, PF jets) give opportunities to better study **jet tomography** in medium
- Remove autocorrelations between calorimeter jet + tracking-based substructure

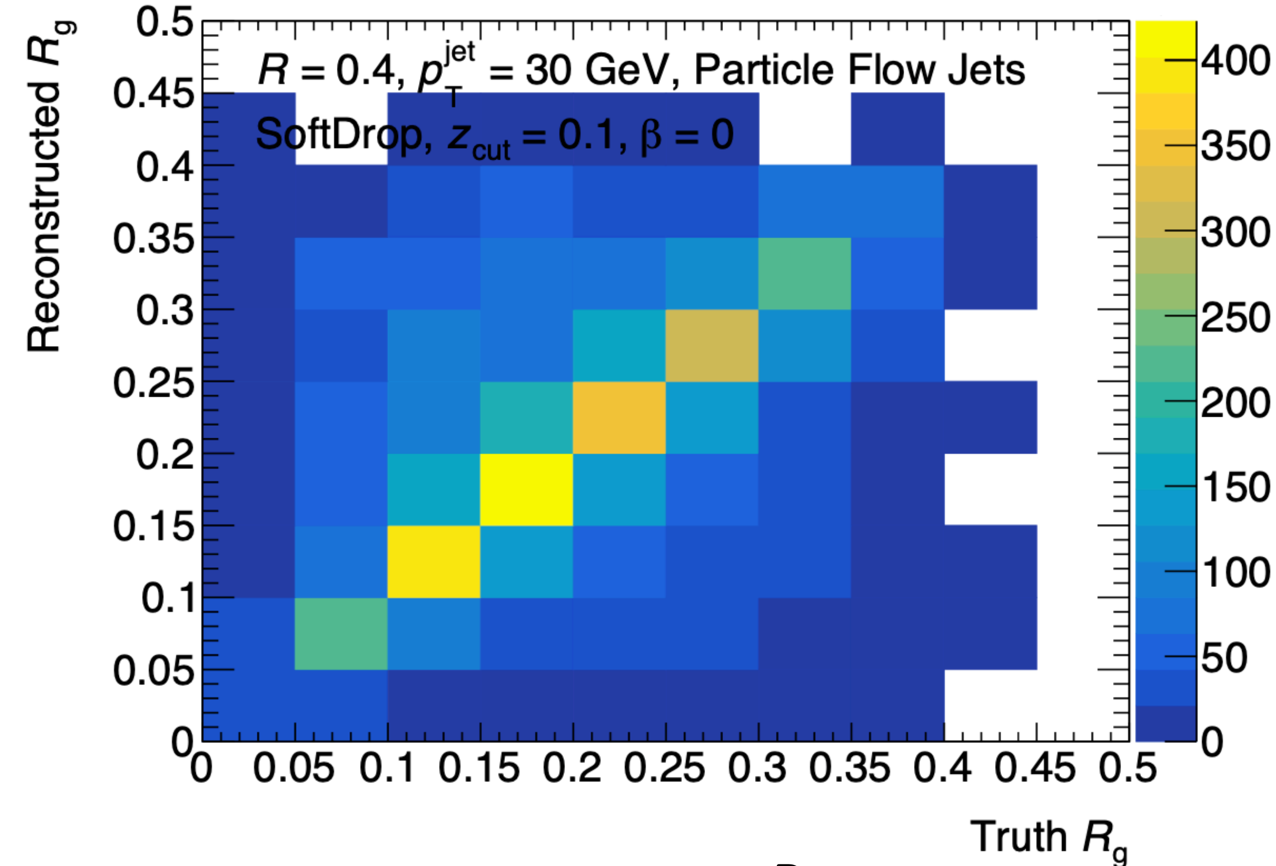
Jet Substructure

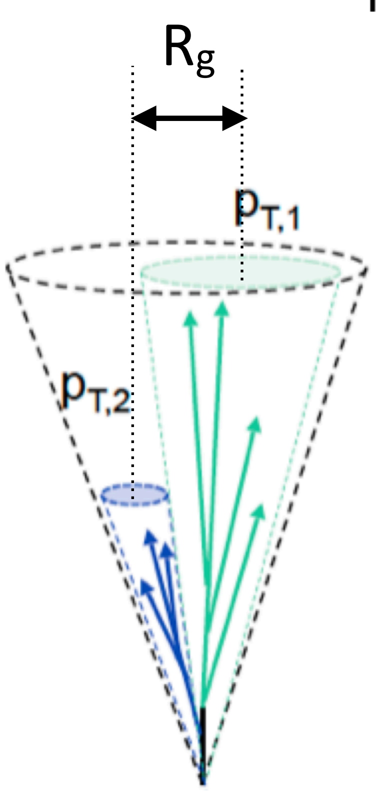
Groomed Momentum Fraction



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

Groomed Jet Radius

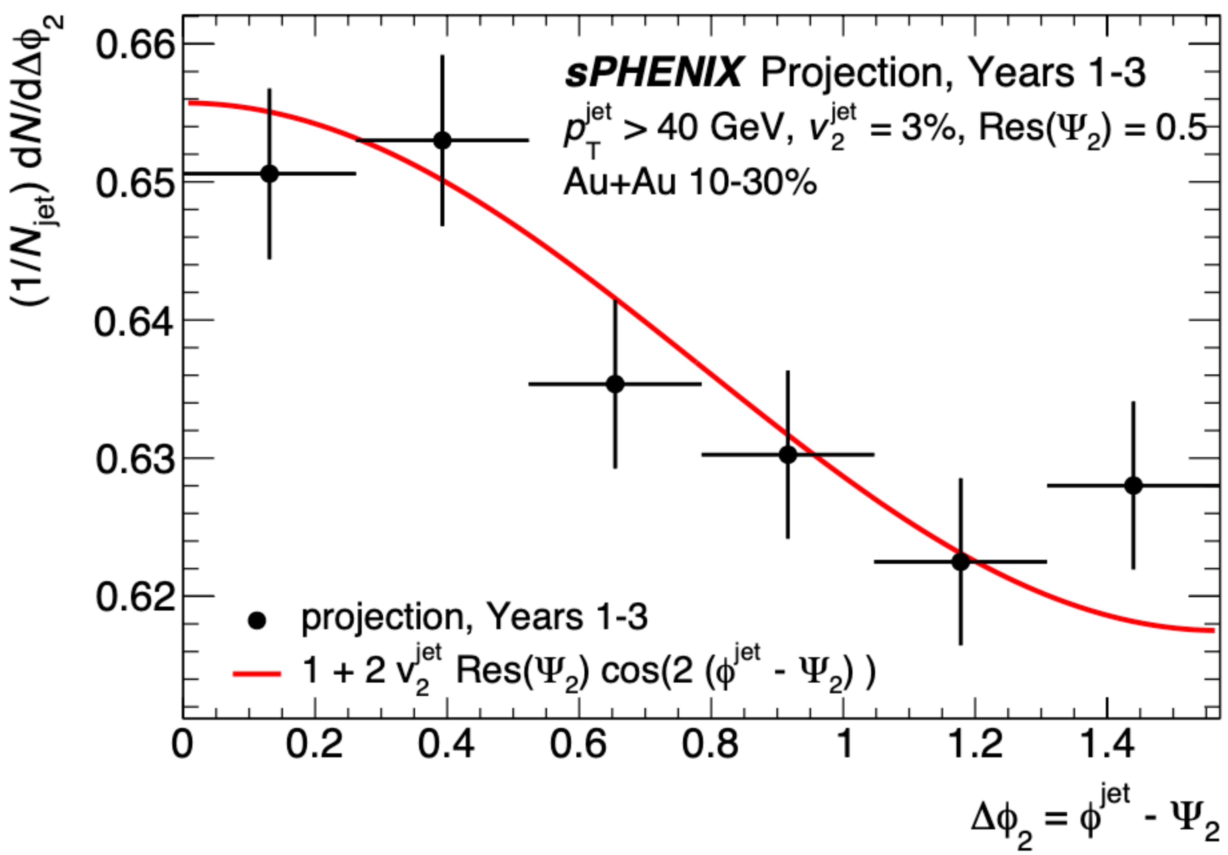




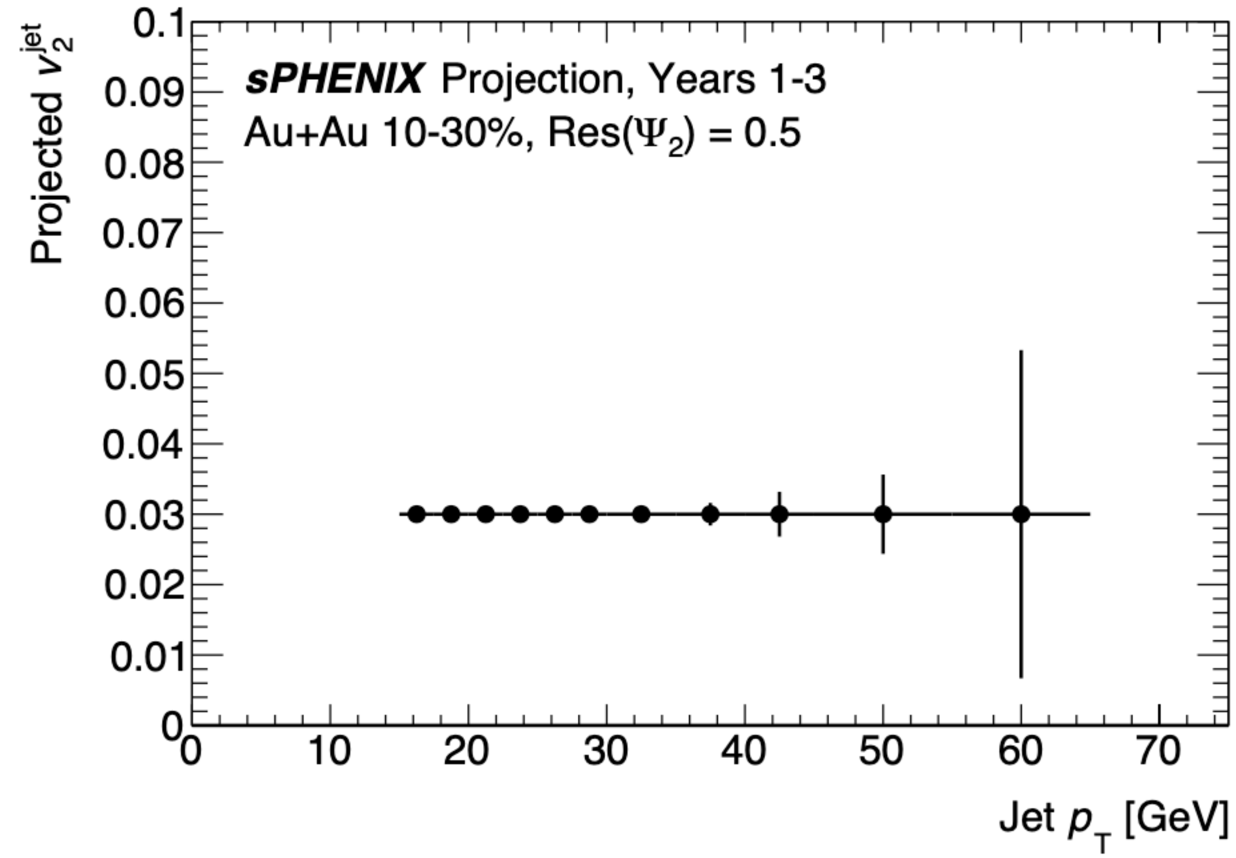
- **Jet grooming technique**: remove soft components and leave hard substructure in a jet
  ➡ study final state to evolution of parton shower (e.g., “splitting function”)

Jet Flow

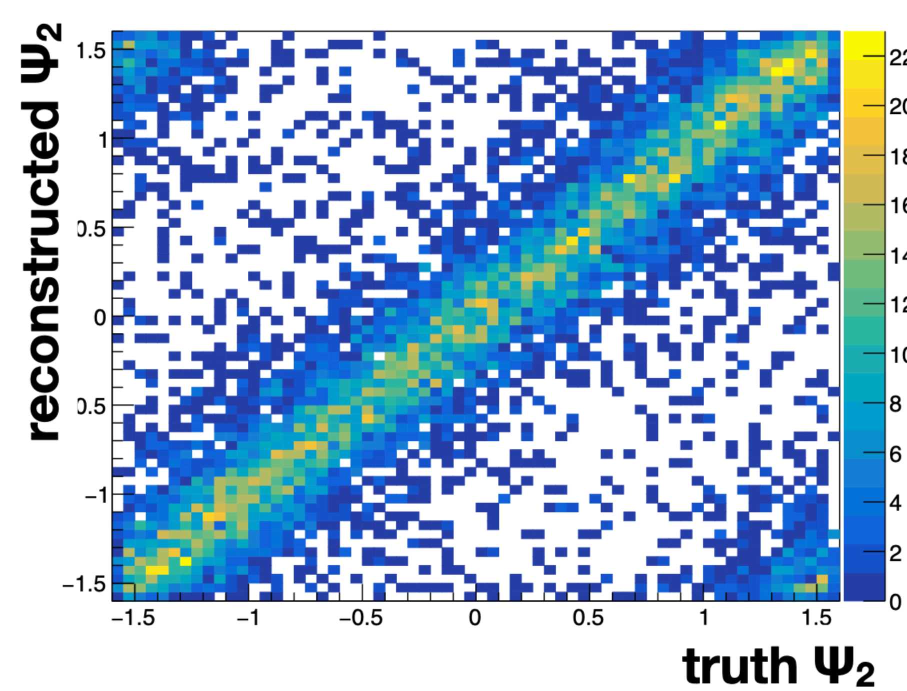
Azimuthal distance from event plane



Elliptic Flow

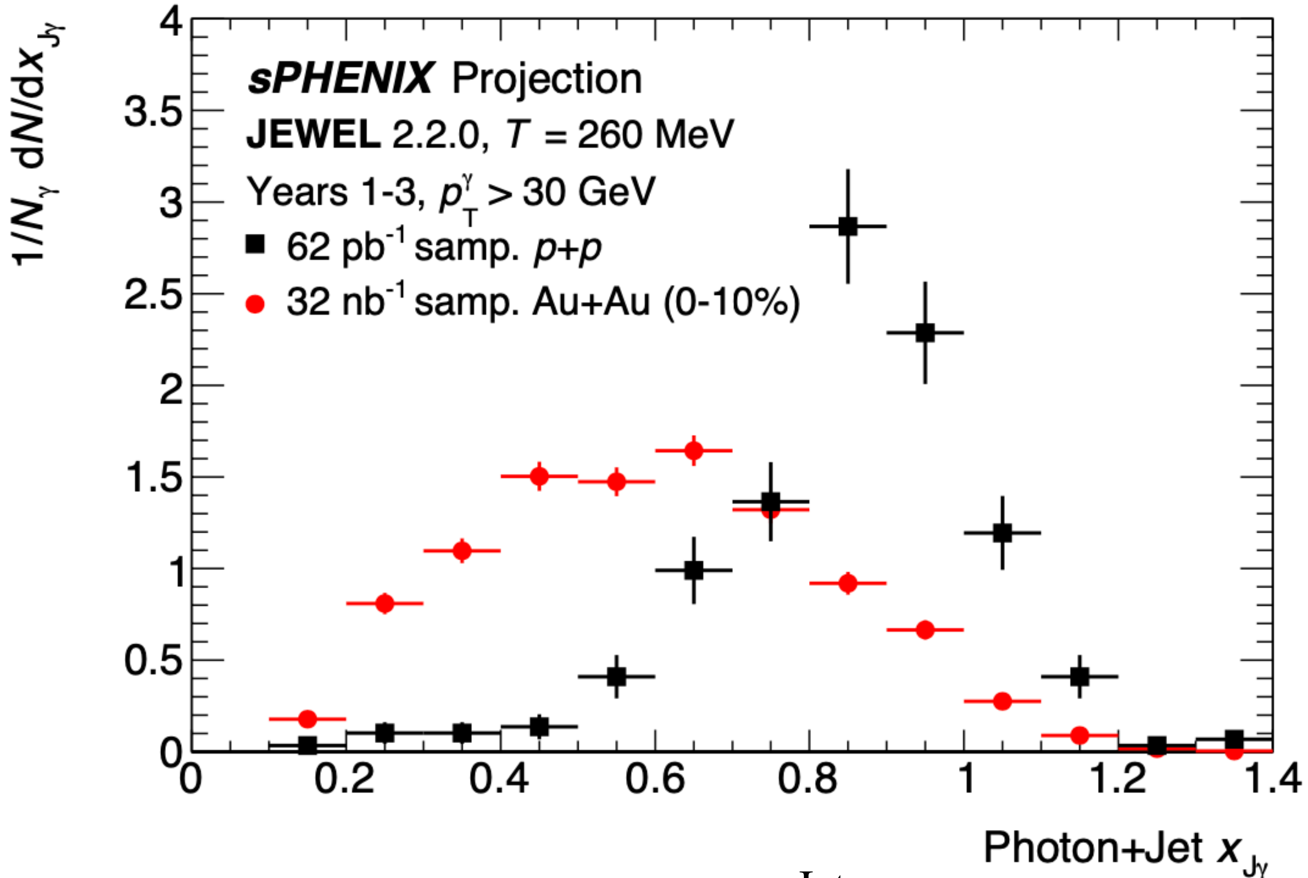


- **EPD (Event Plane Detector)** allows to measure event plane far from the mid-rapidity jet measurement
- describe suppressed yield and anisotropy together (i.e. the v_2-R_{AA} "puzzle")



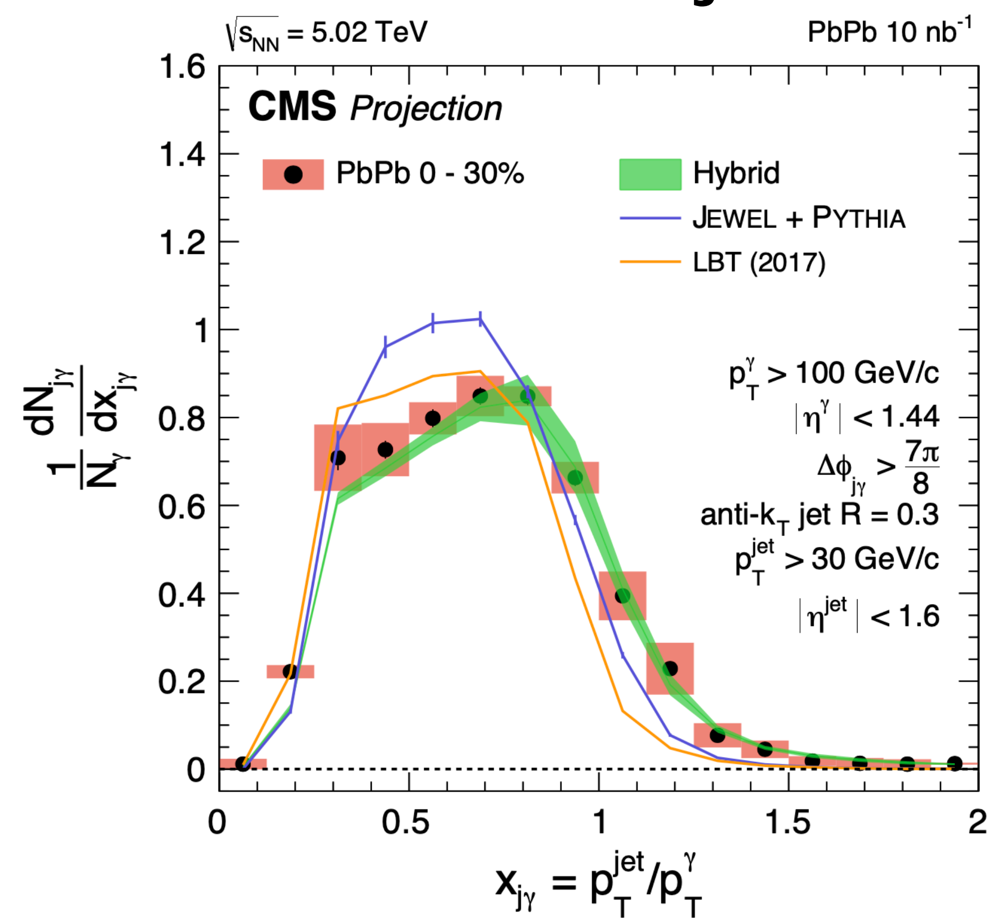
Photon+Jet Correlations

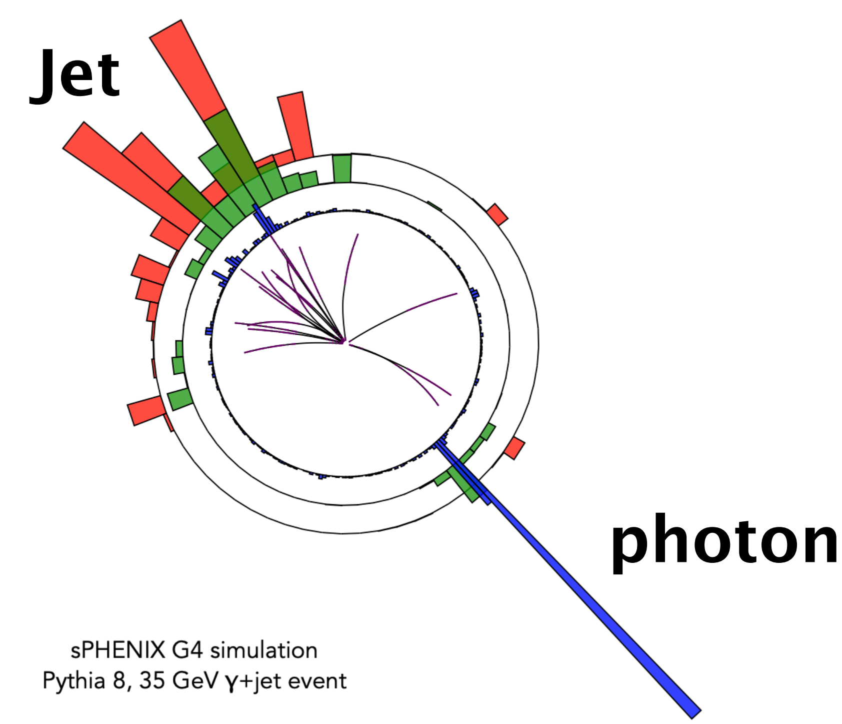
Photon+Jet Momentum Imbalance



$$x_{J\gamma} = \frac{p_T^{\mathrm{Jet}}}{p_T^{\gamma}}$$

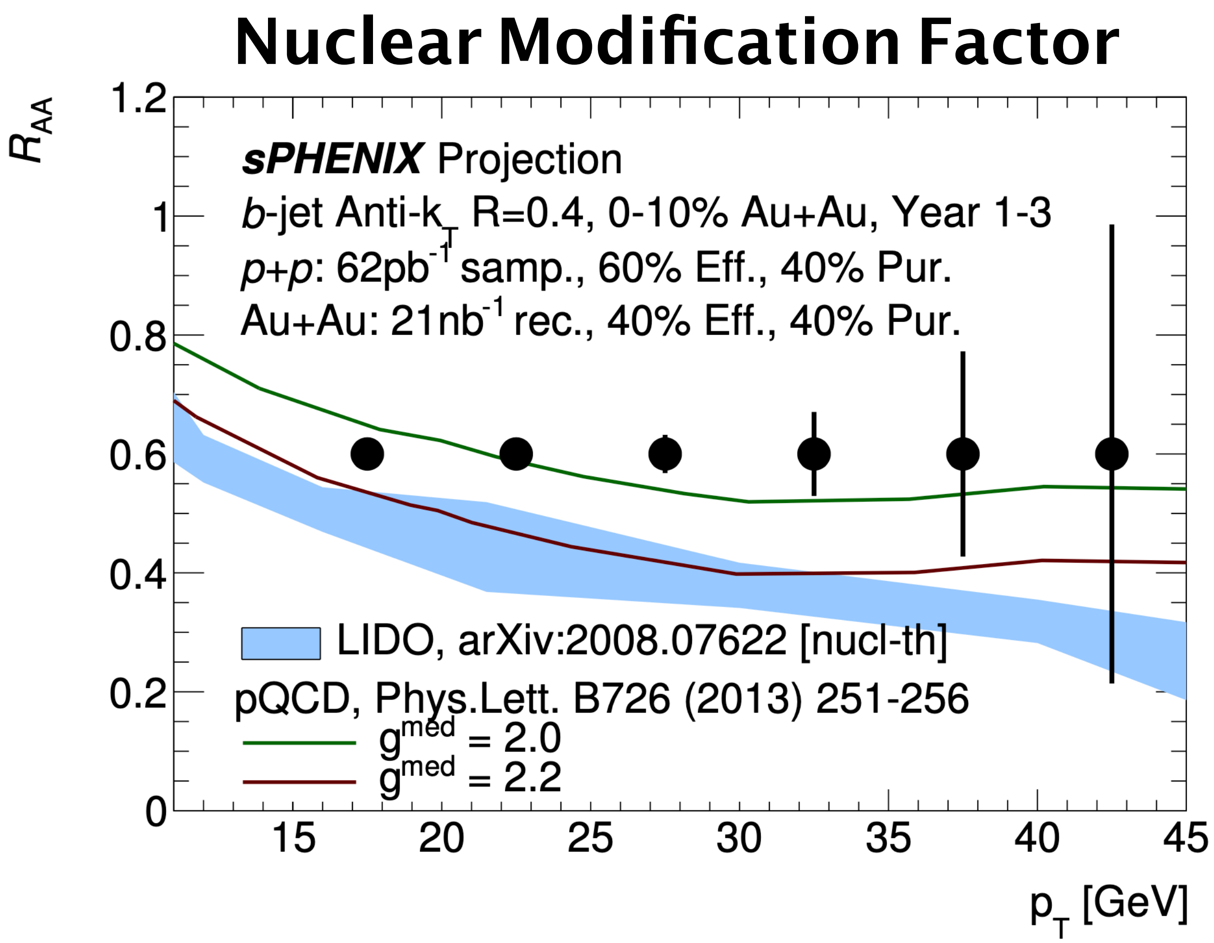
LHC Run III Projection

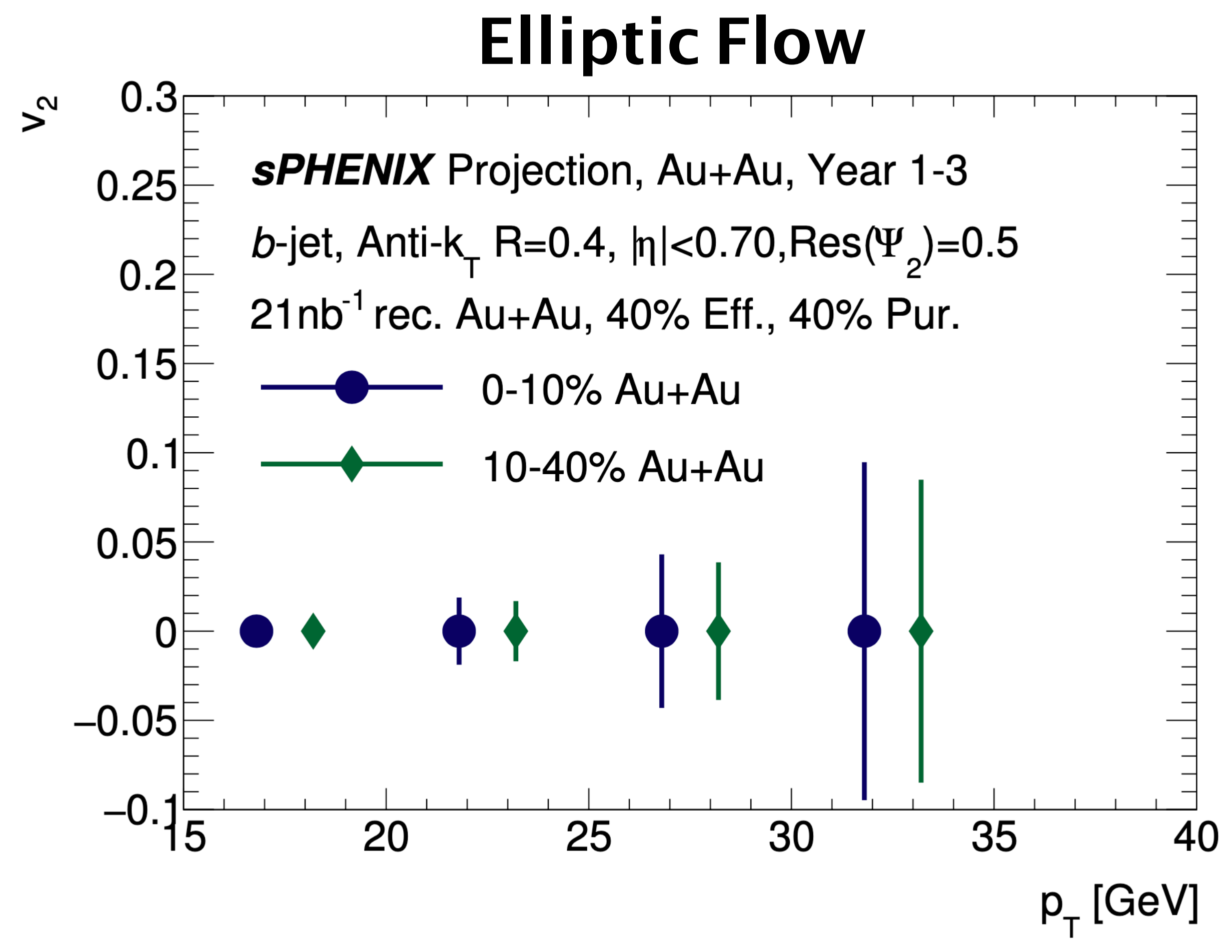




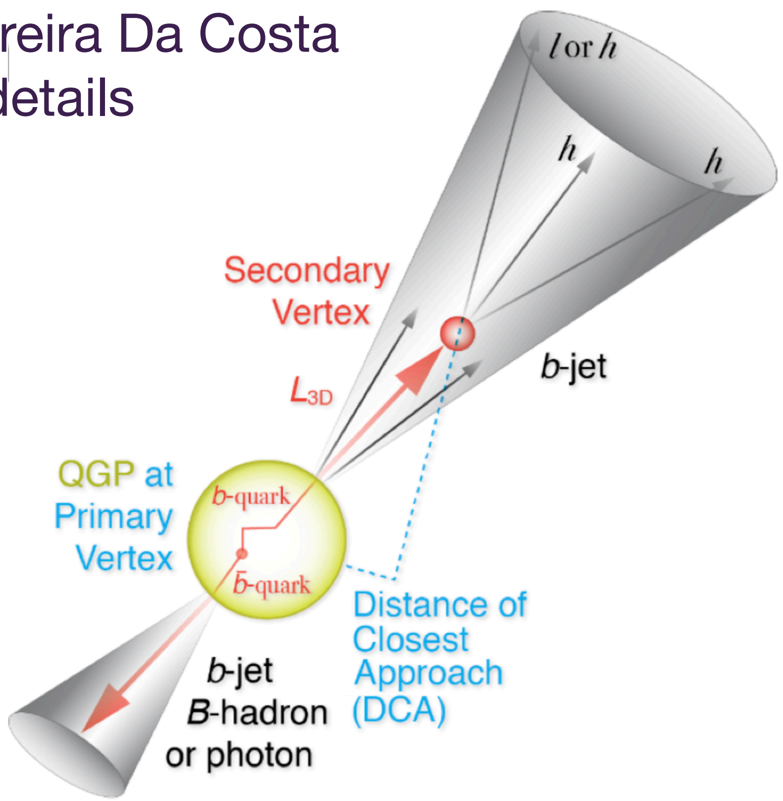
- **Photon+jet**: powerful tool to study jet quenching
  - ➡ **Photon** provides **initial** hard-scattered parton energy information of counterpart jet
  - ➡ Jets in photon+jet events are dominated by quark jets; **flavor-dependent energy loss** mechanism
  - ➡ calibrating the calorimeters

b-Jet





* See talk by Hugo Pereira Da Costa on 14 Apr. (Wed.) for details

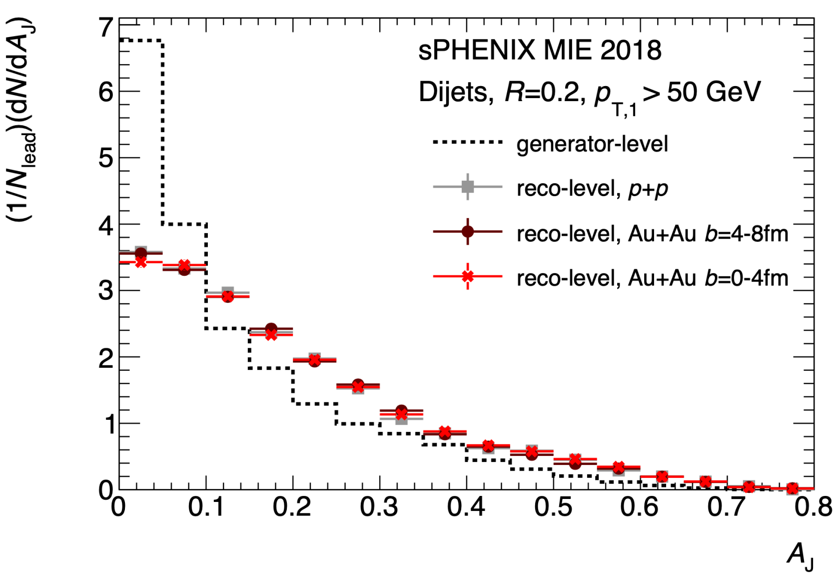


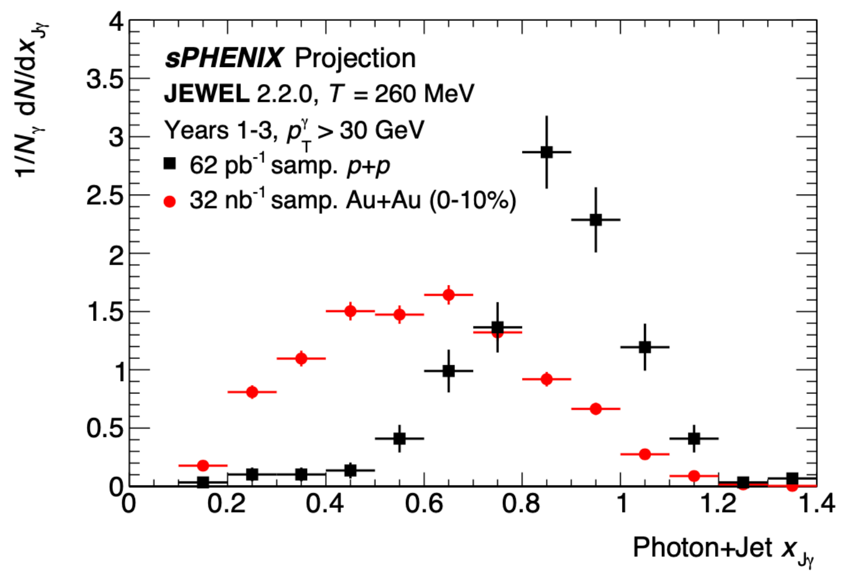
- **First b-jet tagging** at RHIC
- Precision DCA using excellent tracking system: MVTX and INTT, TPC
  - ➡ DCA resolution < 25 μm at p_T > 1 GeV
- Study **heavy quark energy loss** mechanisms in QGP

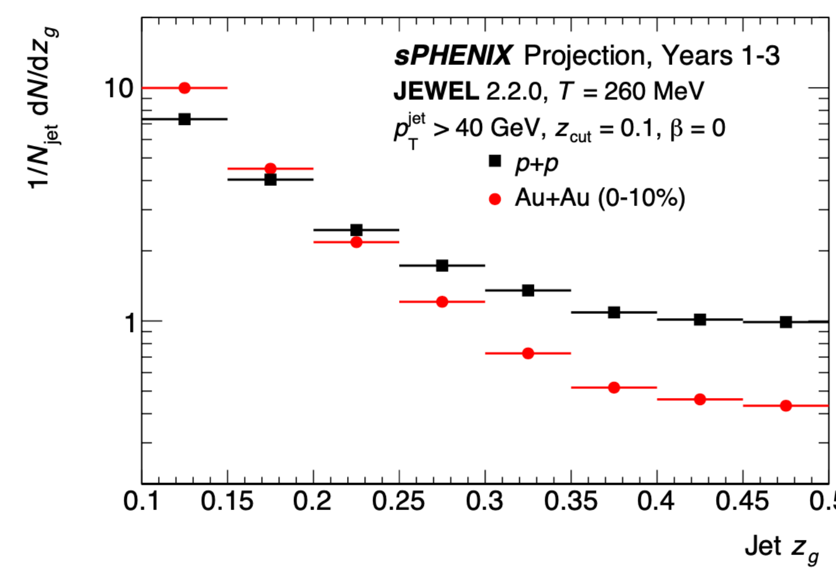
Summary

- **sPHENIX** will be the first new collider detector at RHIC in over 20 years
  - ➡ enable new measurements of the microscopic nature of QGP
  - ➡ large and hermetic electromagnetic and hadronic calorimetry
  - ➡ high precision tracking
  - ➡ kinematic overlap with LHC and unique opportunities for lower energy
    - complementary to the LHC

- Robust **jet measurements** are achievable with **sPHENIX**
  - ➡ jet, dijet, photon-jet, b-jet, fragmentation function, …
  - ➡ performing high precision studies of jet production, jet substructure
  - ➡ great opportunities to understand parton energy loss mechanism



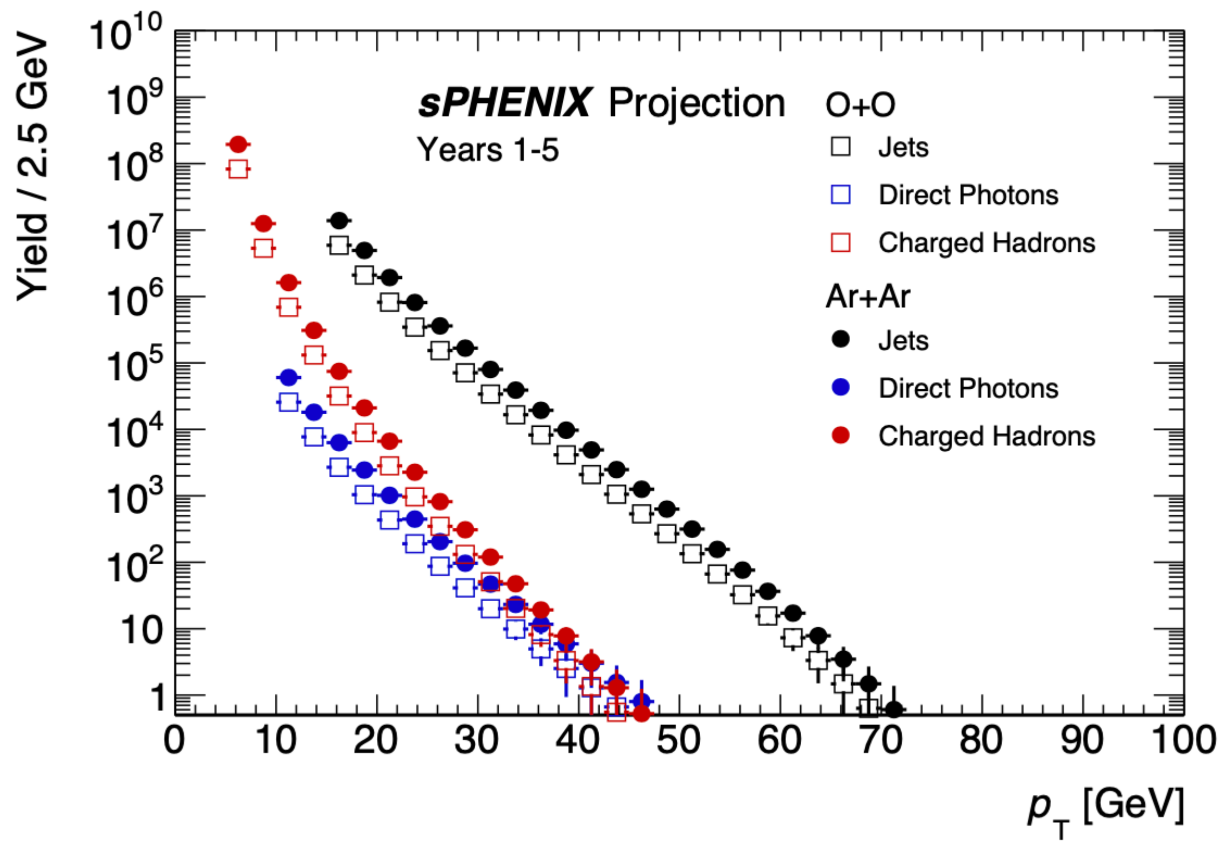


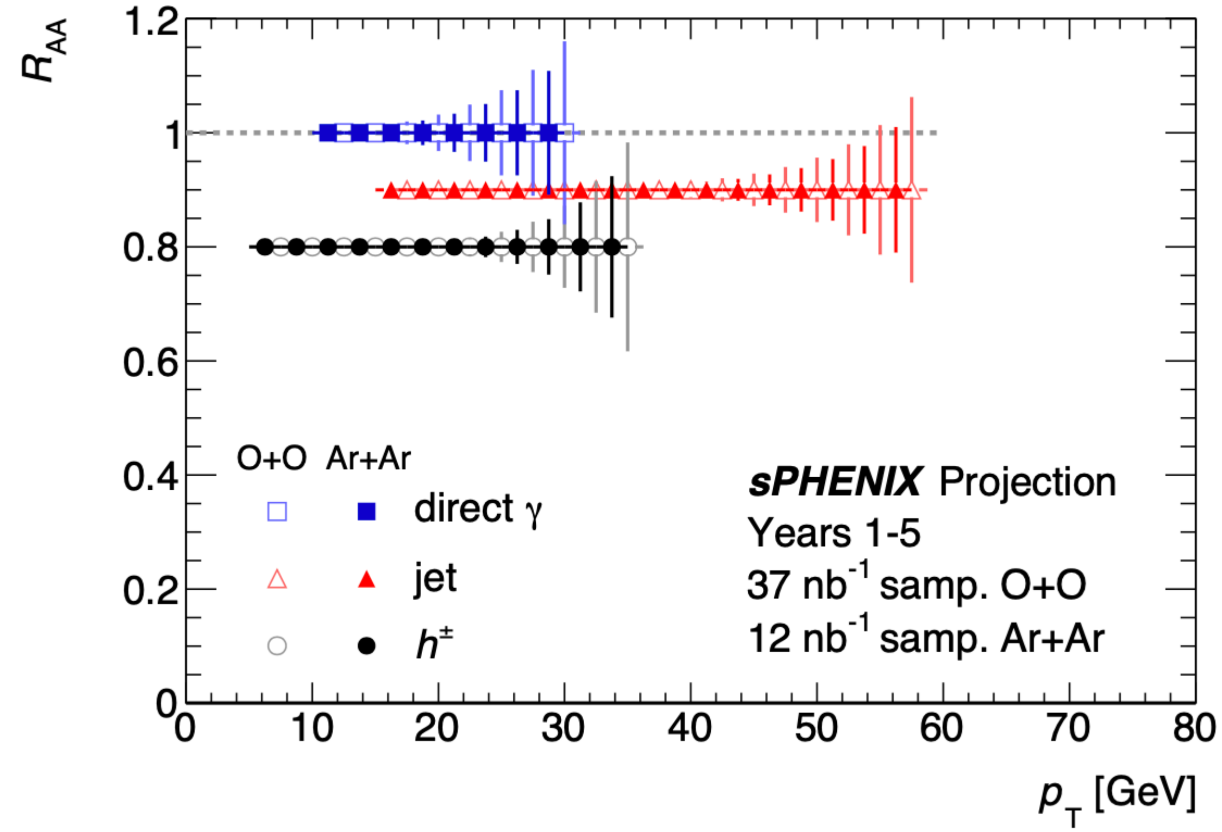


THANK YOU FOR YOUR ATTENTION!

BACK UP

Jets in O+O and Ar+Ar collisions





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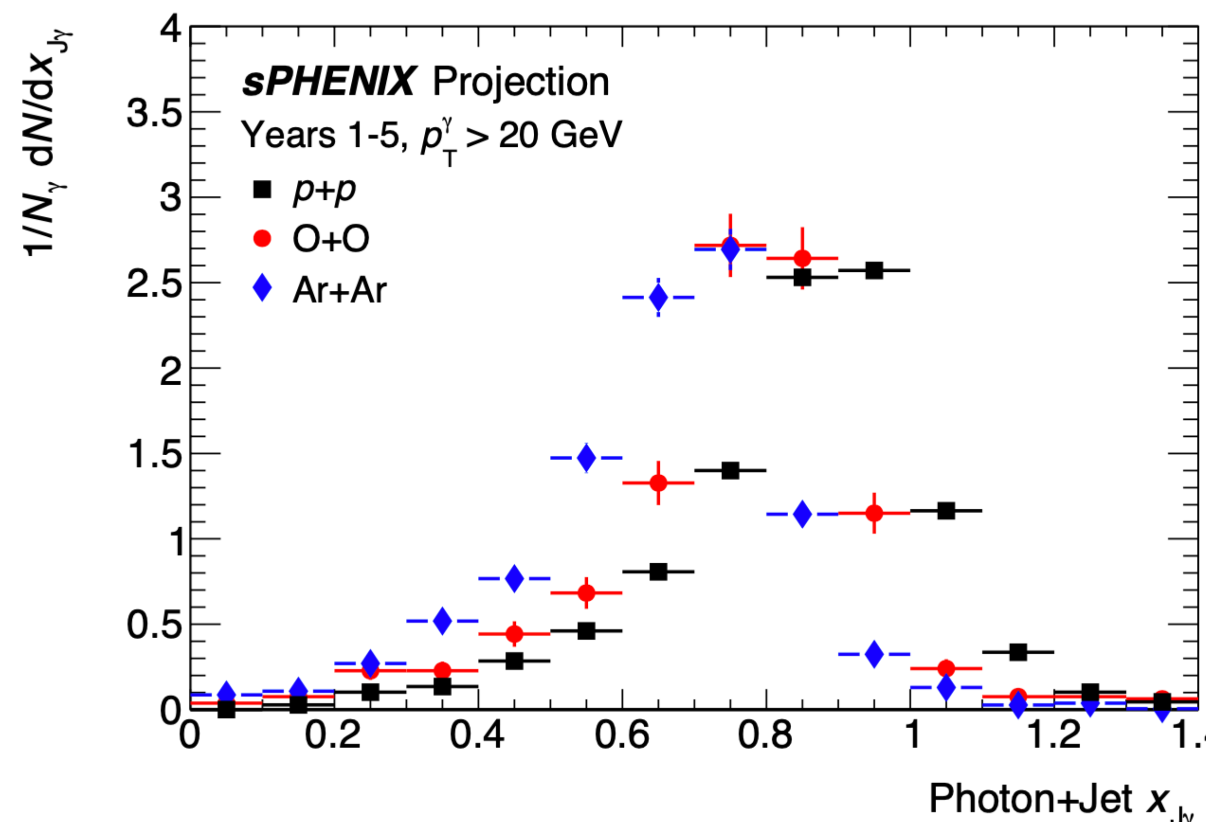
2026	$p^{\uparrow}p^{\uparrow}$	200	28	15.5	1.0 pb^{-1} [10 kHz] 80 pb^{-1} [100%-*str*]	80 pb^{-1}
–	O+O	200	–	2	18 nb^{-1} 37 nb^{-1} [100%-*str*]	37 nb^{-1}
–	Ar+Ar	200	–	2	6 nb^{-1} 12 nb^{-1} [100%-*str*]	12 nb^{-1}
2027	Au+Au	200	28	24.5	30 nb^{-1} [100%-*str*/DeMux]	30 nb^{-1}



- Additional O+O and Ar+Ar runnings proposed in case the EIC program delays