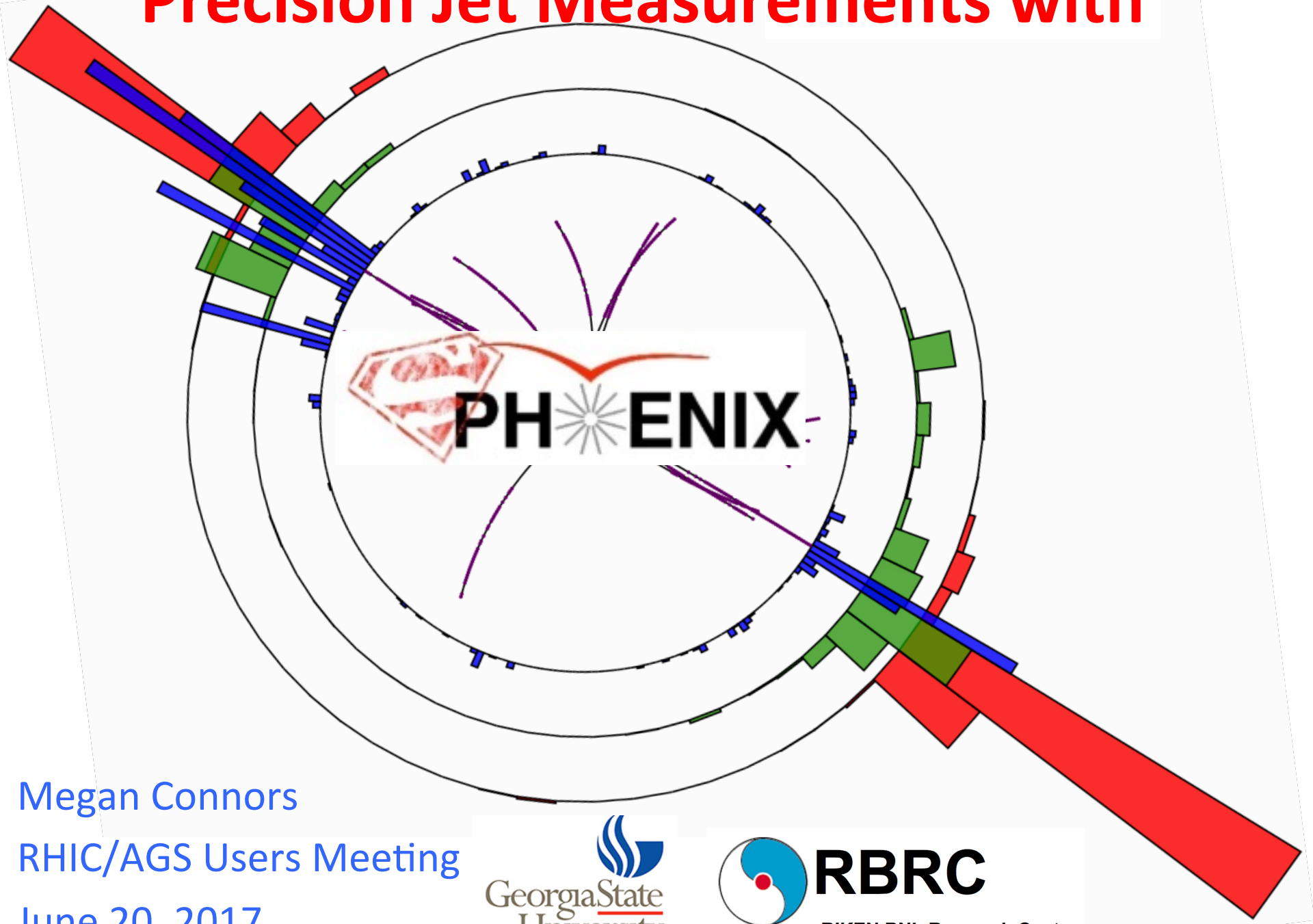
Precision Jet Measurements with



Megan Connors

RHIC/AGS Users Meeting

June 20, 2017

Georgia State University

RBRC

RIKEN BNL Research Center

Outline

- Goals and statistics of sPHENIX
- The sPHENIX detector
- Highlighting 2 sPHENIX Jet observables
  - b-tagged jets
  - jet structure

The need for sPHENIX

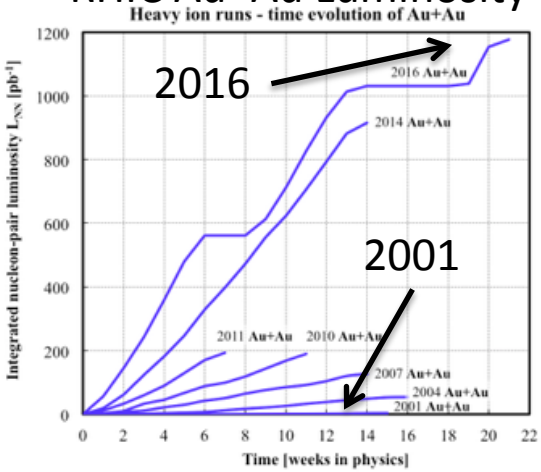
CD0 Approved

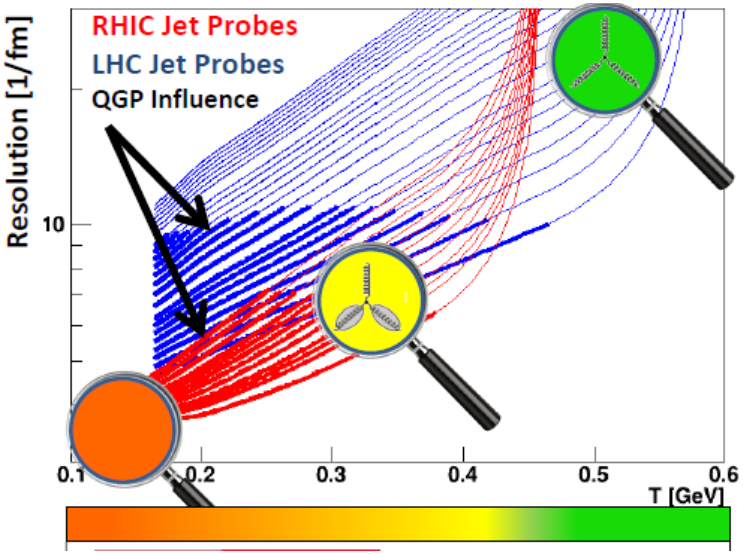
RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.

RHIC Au+Au Luminosity

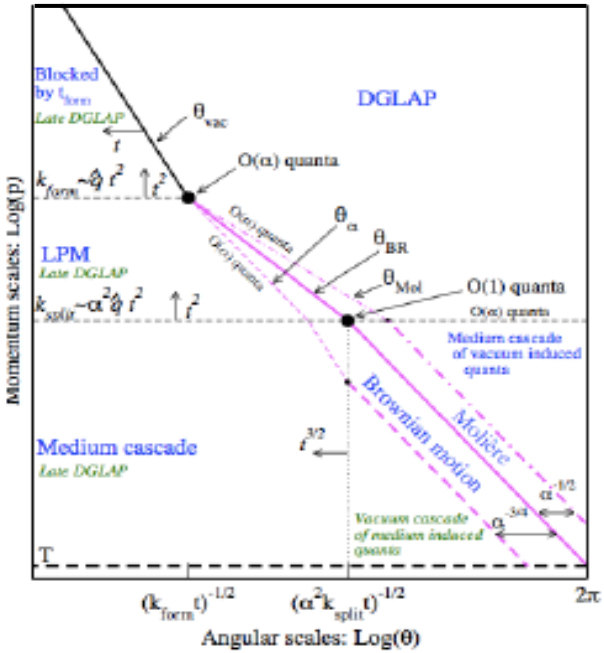




There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

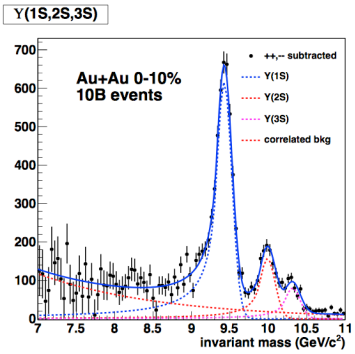
Probe QGP at Mutliple Scales

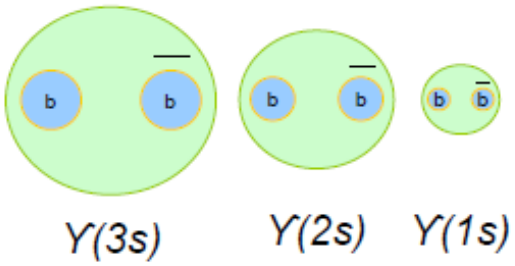
- Jet Structure



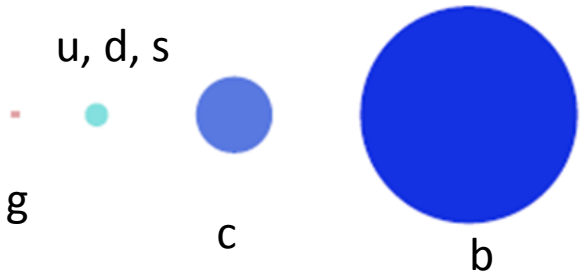
Phys. Lett. B 740 172 (2015)

- ϒ spectroscopy





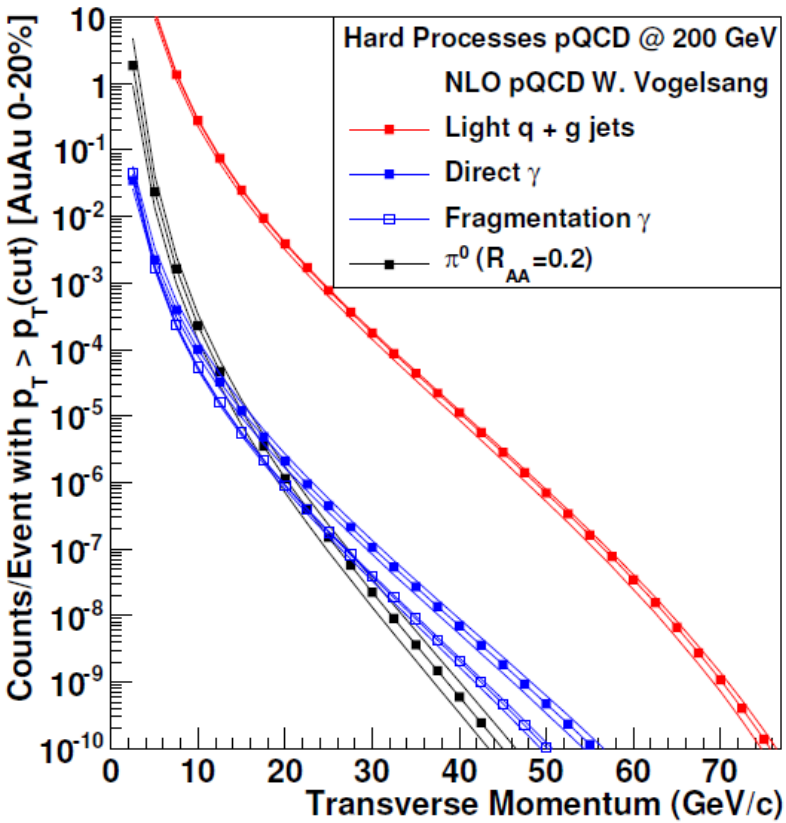
- parton mass/flavor

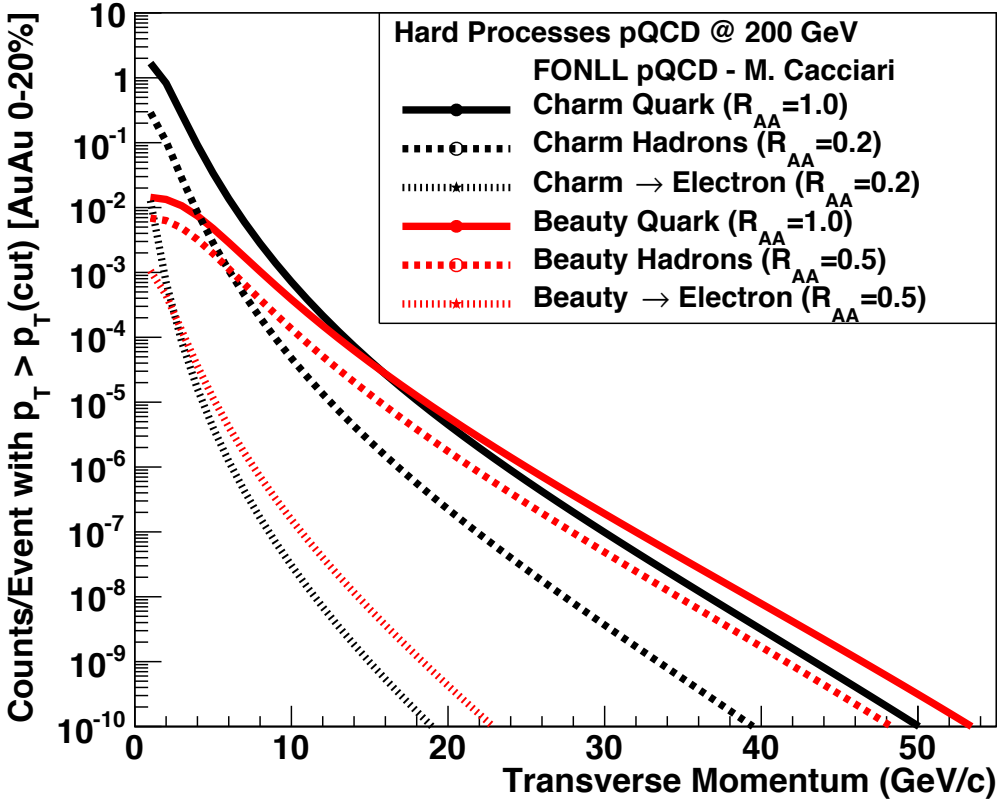


Statistics of sPHENIX

Original proposal projections assume
22 weeks of Au+Au at RHIC
→ 100B MB events
→ 20B 0-20% events

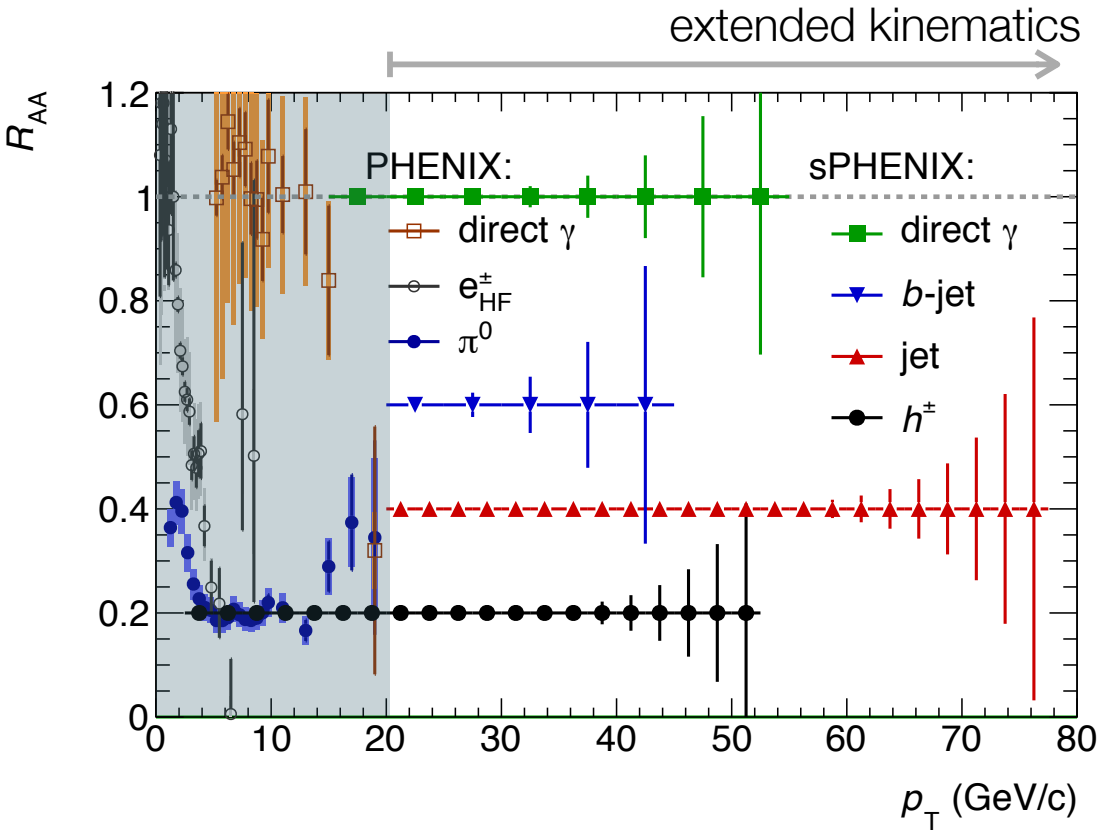
Central Yields	p_T Range
10^7 jets	> 20 GeV/c
10^6 jets	> 30 GeV/c
10^4 γ_{dir}	> 20 GeV/c
10^4 b-jets	> 20 GeV/c

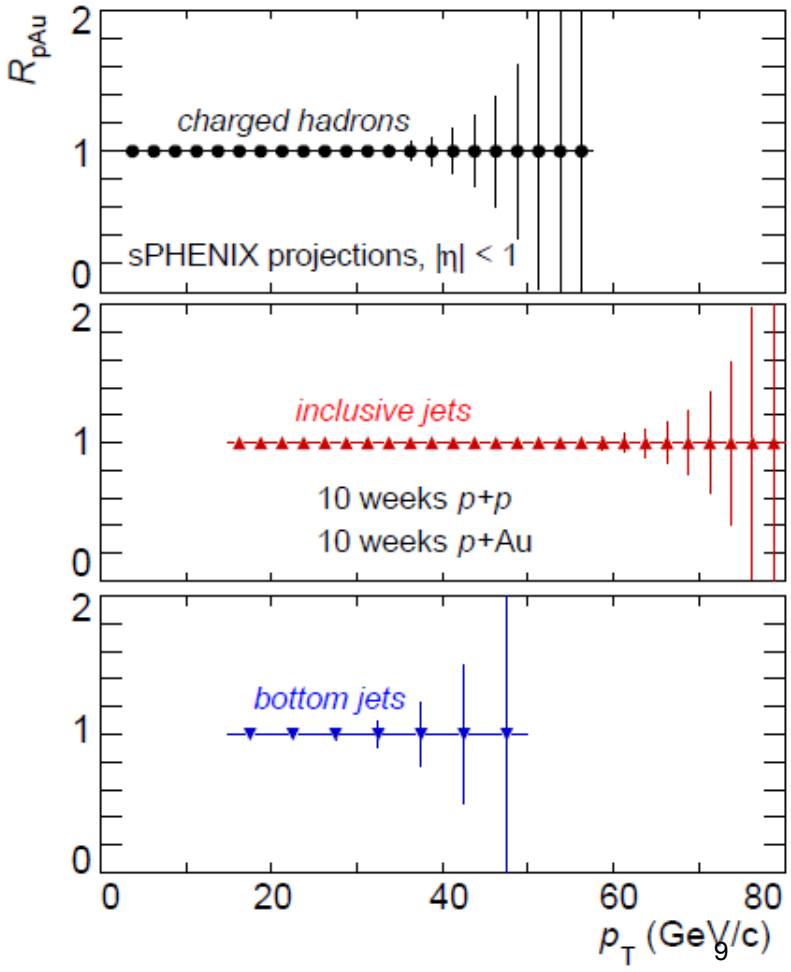




Extends the kinematic reach

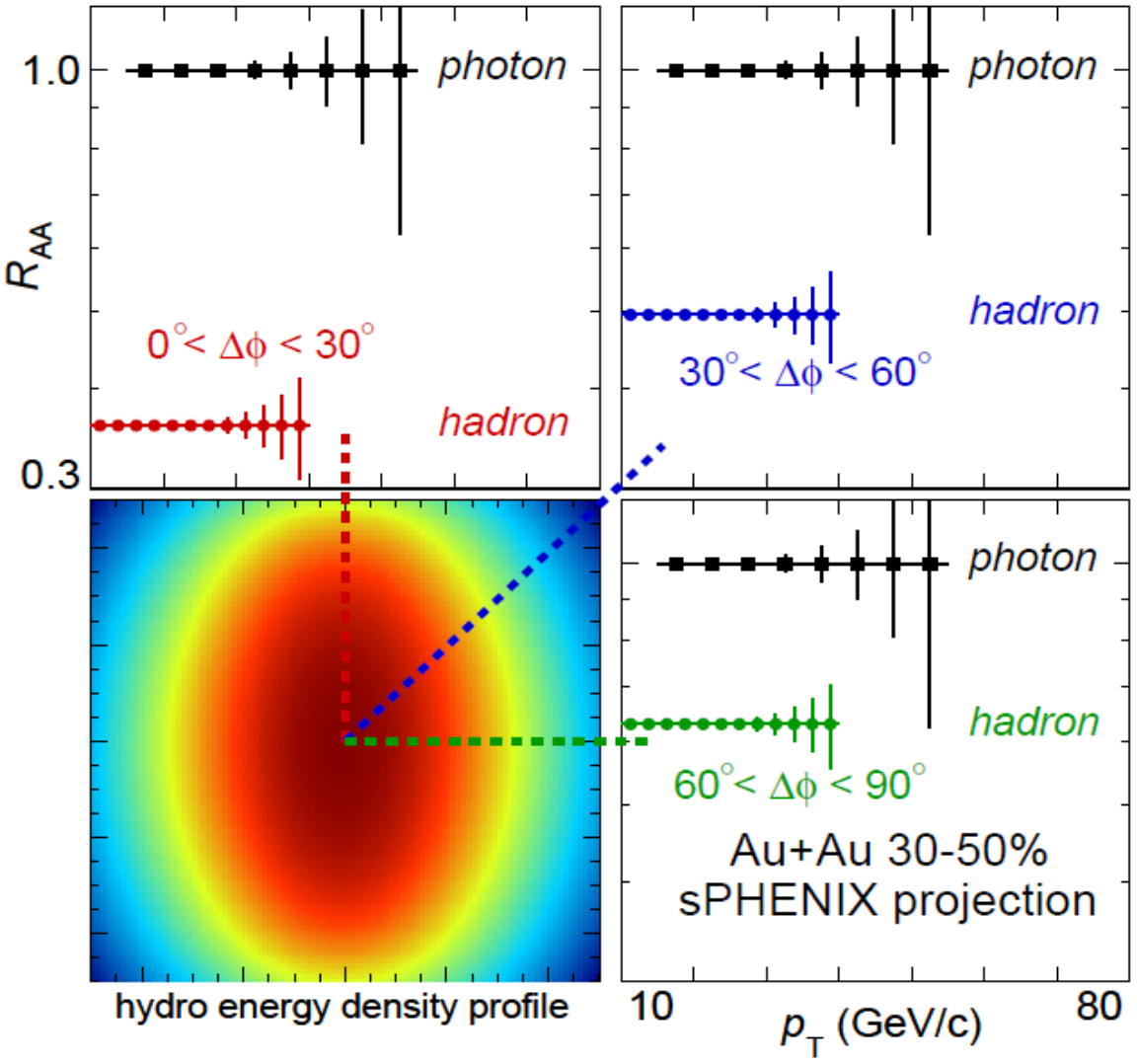
- R_{AA} for photons, HF and jets extended to higher p_T



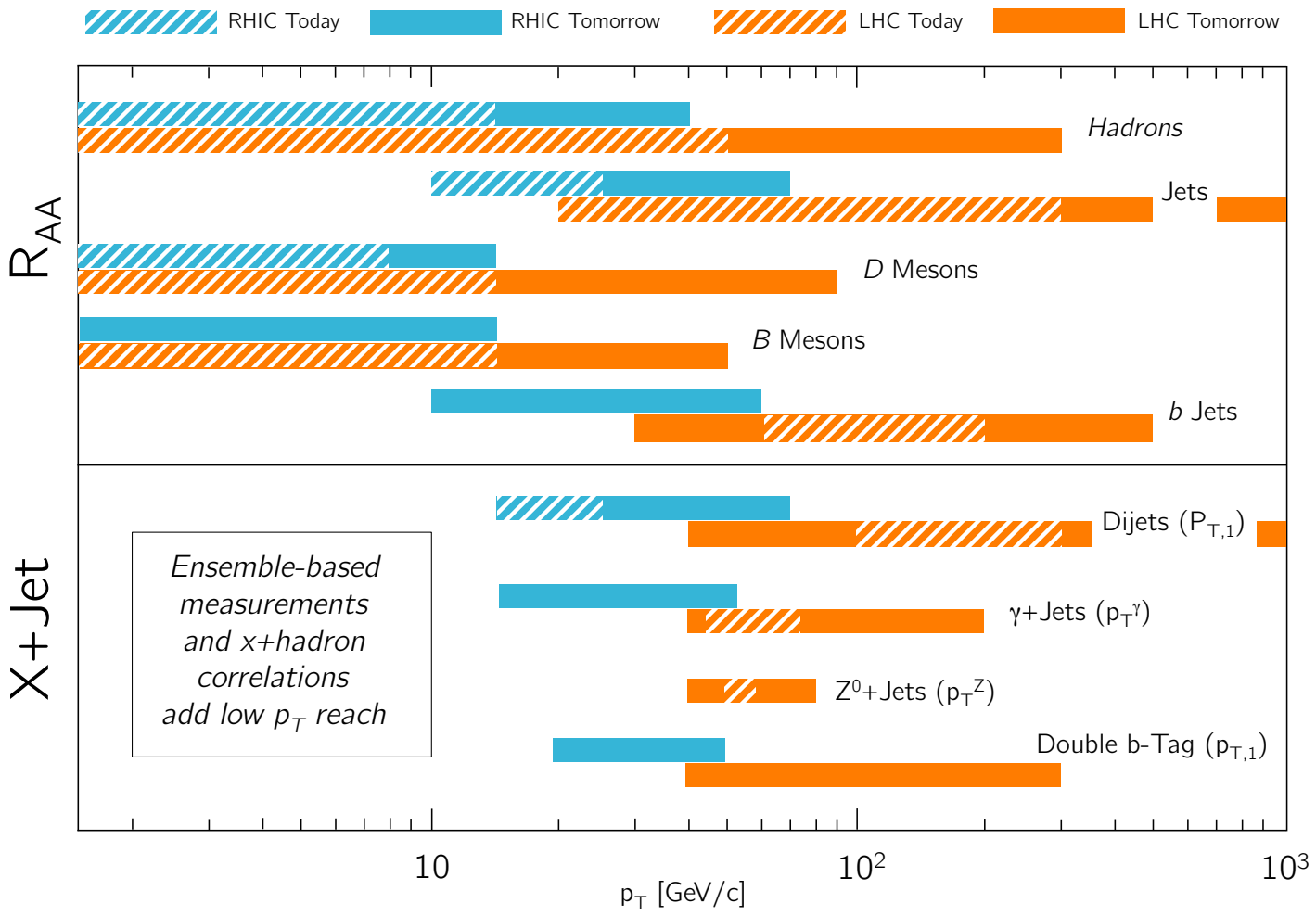


More Statistics = More Differential

- Pathlength studies
- Important constraints for models that describe inclusive R_{AA}



Overlap with LHC



- Significant overlap achievable with “tomorrow’s” RHIC-LHC jet measurements

Possible 5 year run plan

Multi-year run plan scenario for sPHENIX

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
2022	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
2023	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
2023	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
2024	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
2025	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
2026	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

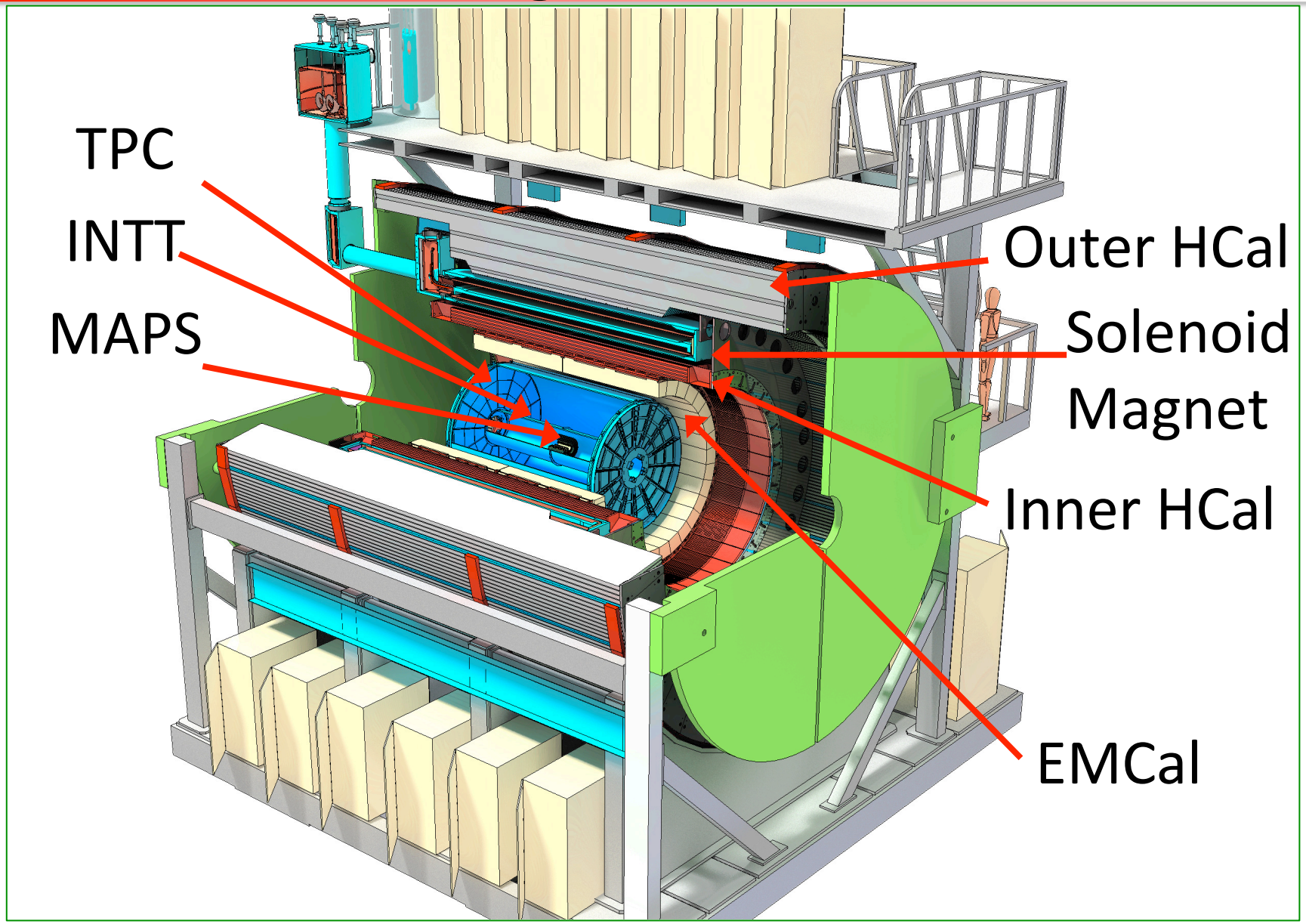
- Guidance from ALD to think in terms of a multi-year run plan
- Consistent with language in DOE CD-0 "mission need" document
- Incorporates updated C-AD guidance now officially documented
- Run plan relates to capabilities of full barrel detector
- Incorporates commissioning time in first year

Minimum bias Au+Au at 15 kHz for |z| < 10 cm:
47 billion (2022) + **96 billion** (2024) + **96 billion** (2026) = Total **239 billion events**

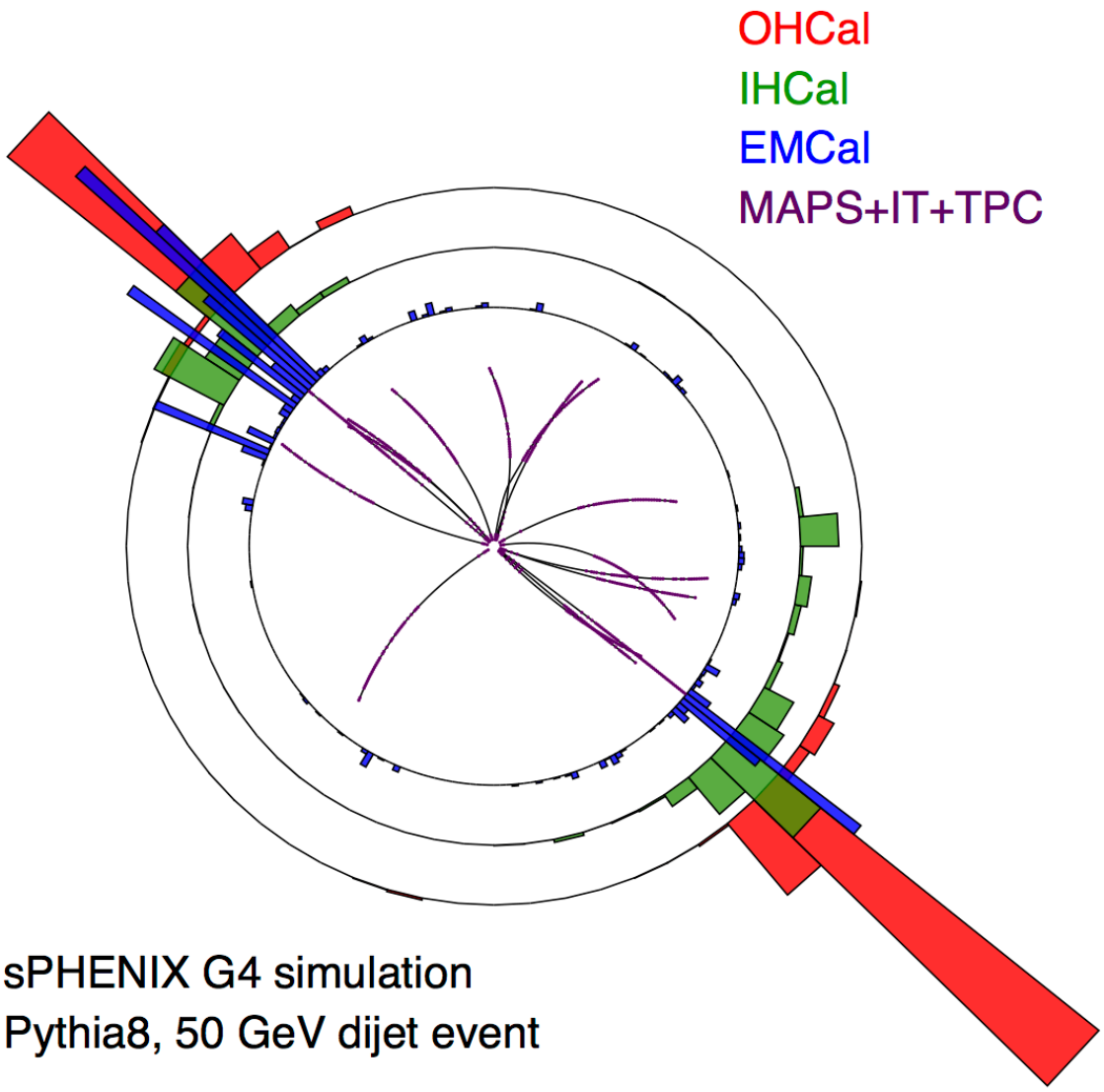
For topics with Level-1 selective trigger (e.g. high p_T photons), one can sample within |z| < 10 cm a total of 550 billion events. One could consider sampling events over a wider z-vertex for calorimeter only measurements, 1.5 trillion events.

Presented at the PAC Meeting 6/15/17 by D. Morrison

Detector Designed for Measurements



sPHENIX Event Display

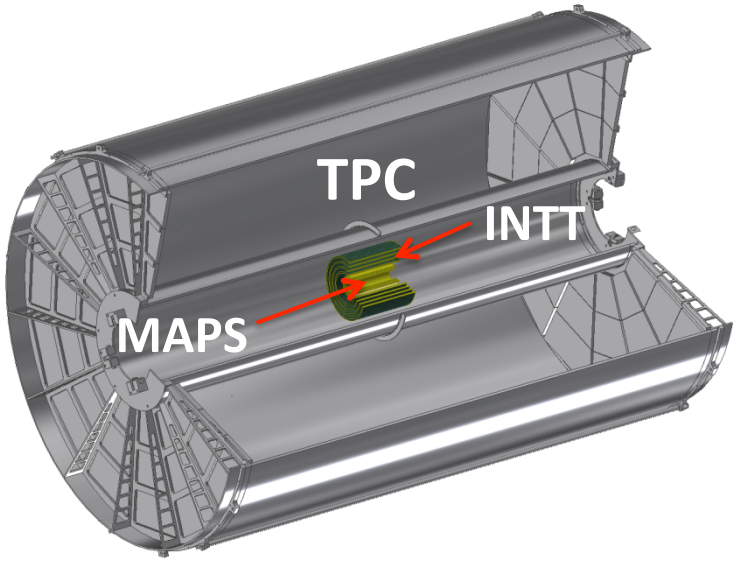


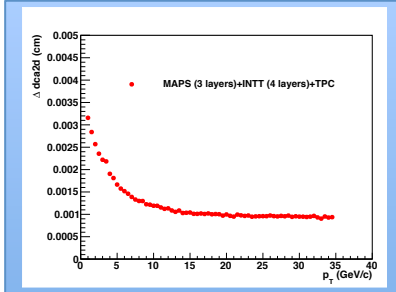
sPHENIX G4 simulation
Pythia8, 50 GeV dijet event

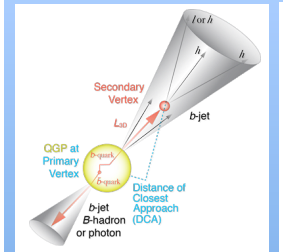
- Di-jet event highlights all detectors
- This talk will focus on b-jet and γ-jet substructure studies

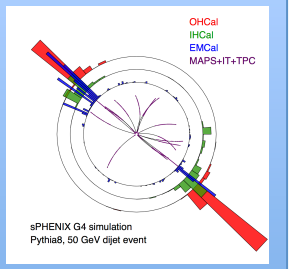
Importance of Tracking

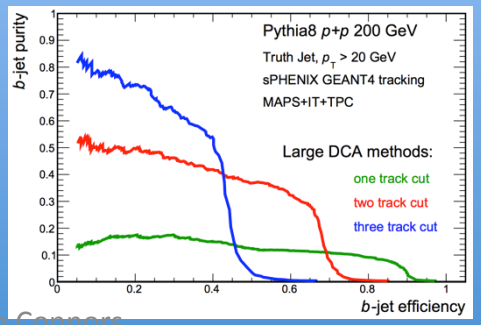
Physics Goal	Detector Requirement
Fragmentation Functions	Excellent Momentum Resolution: dp/p ~ 0.2%p to > 40 GeV/c
Jet Substructure	Excellent track pattern recognition
Distinguish Upsilon States	Mass resolution: $\sigma_M < 100$ MeV/c^2
HF jet tagging	Precise DCA resolution $\sigma_{DCA} < 100$ μm
High Statistics Au+Au 200 GeV	Handle multiplicity and full RHIC luminosity

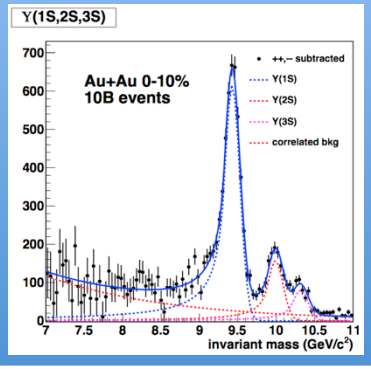








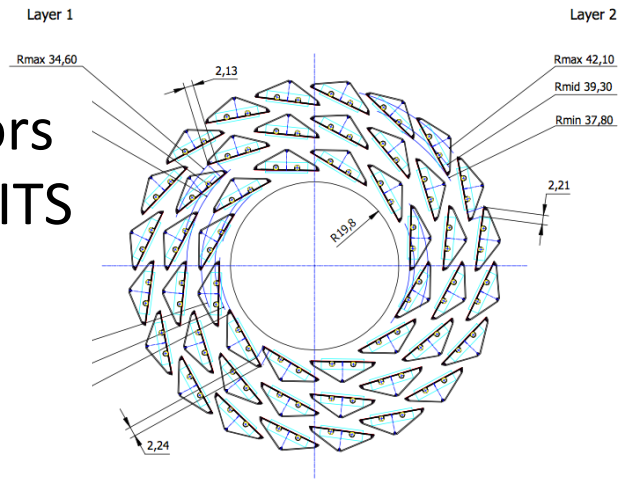


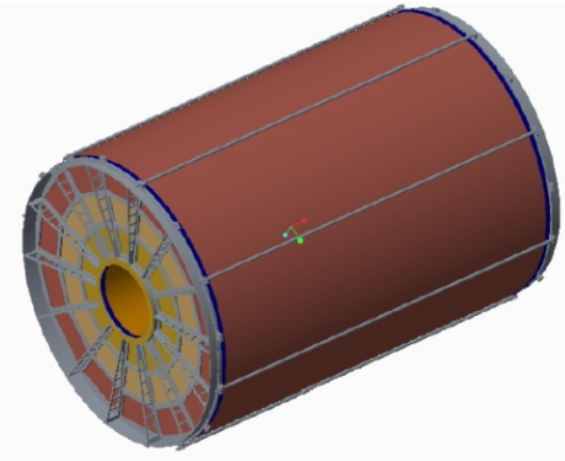


Tracking Subsystems

MAPS

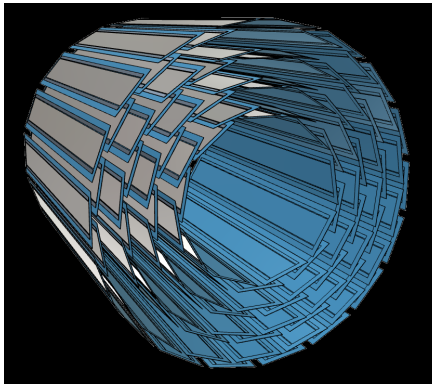
- 3 layers Si sensors
- Based on ALICE ITS upgrade
- $DCA_{xy} < 70$ µm
- $|z_{vtx}| < 10$ cm





INTT

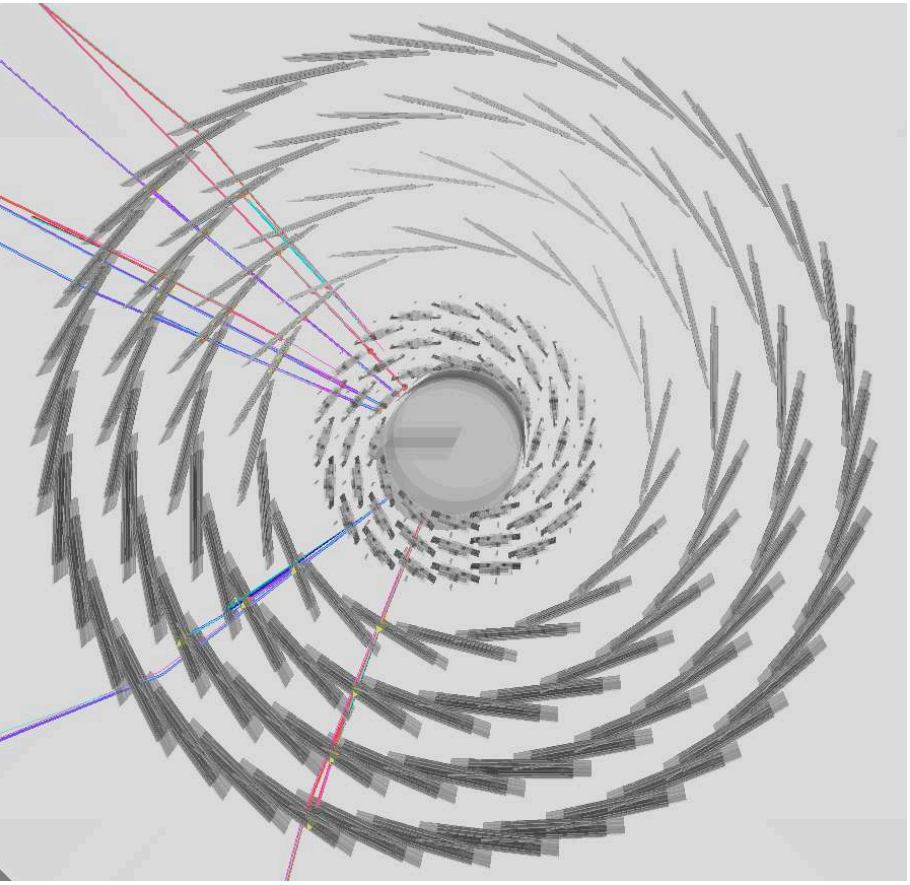
- 4 layers Si strips
- Use PHENIX electronics
- Pattern recognition, DCA, connect tracking systems, reject pile-up



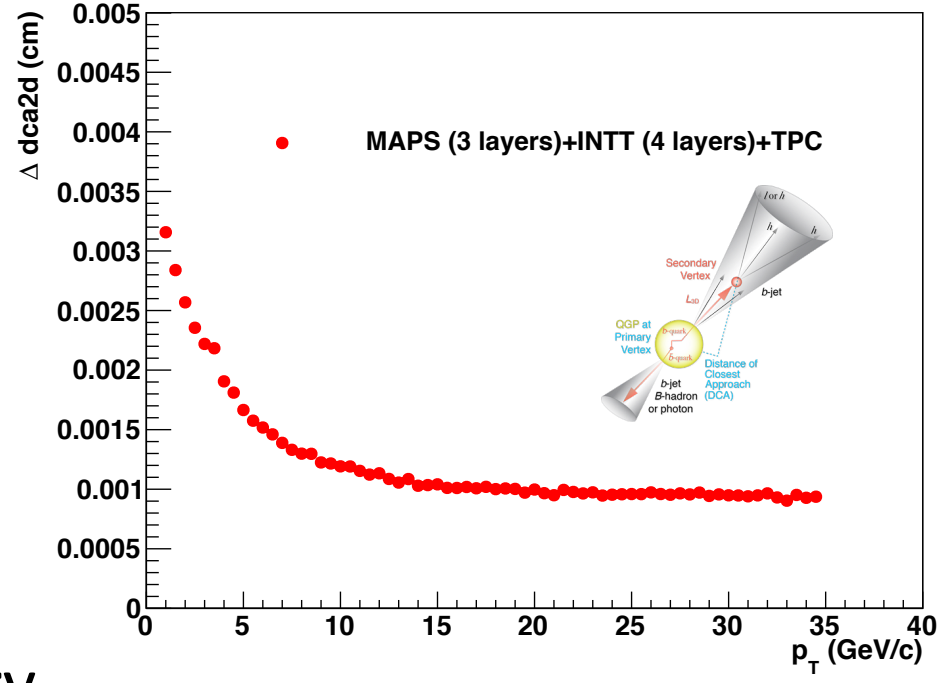
TPC

- Radius 20–78 cm
- ~250 µm effective hit resolution
- Continuous (non-gated) readout
- Pattern recognition, momentum resolution, p_T 0.2-40 GeV/c

Designed to Measure b-jets



- Outstanding DCA resolution
  - 25 μm for p_T 1-2 GeV/c

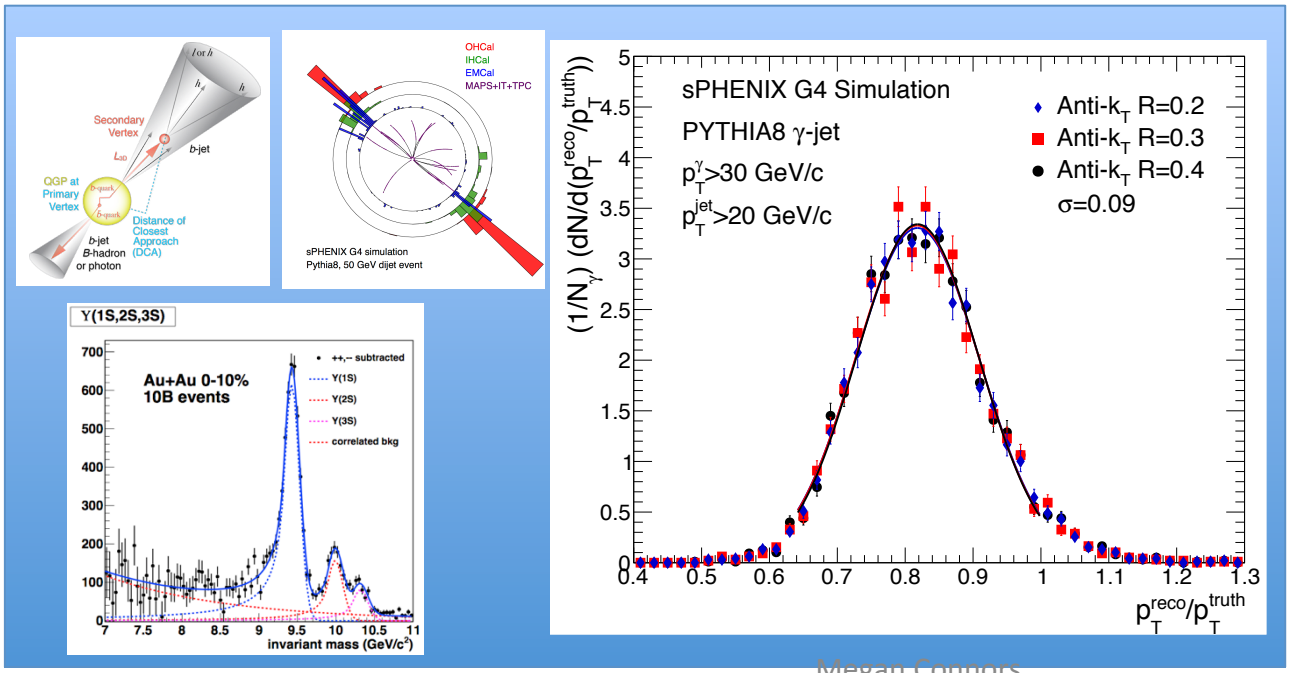


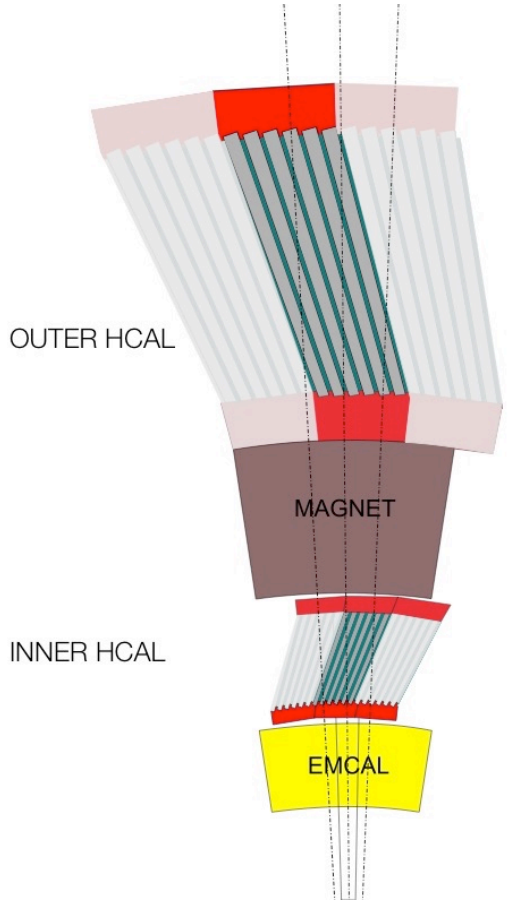
- Simulation Improvements:
  - Realistic ladder geometry

Importance of Calorimetry

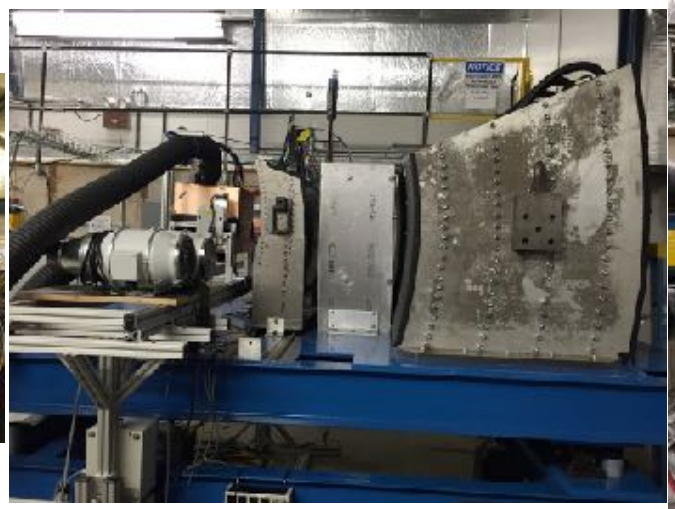
Physics Goal	Detector Requirement
Jets/Fragmentation Functions/ jet substructure	Single particle Resolution: $\sigma/E < 100\%/\sqrt{E}$
Distinguish Upsilon States	Good e/π separation
HF jet tagging	Electron ID

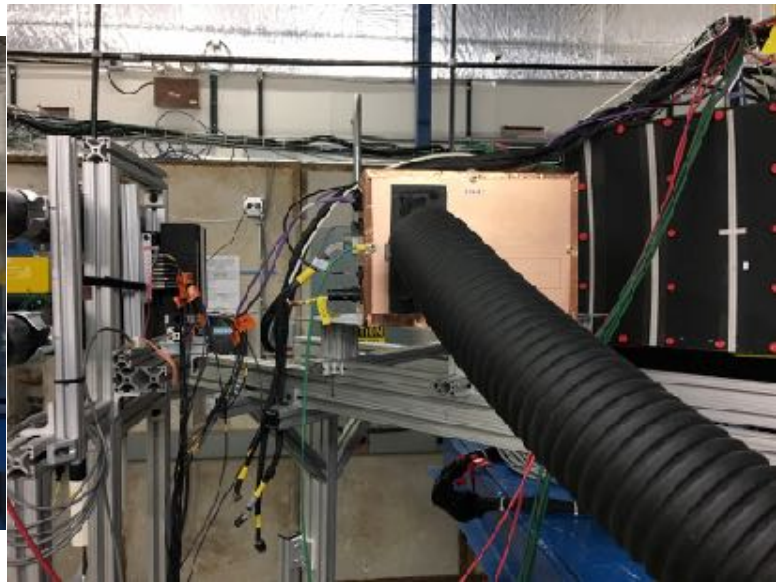
- Designed to Measure Jet energy





Calorimeter Beam Tests





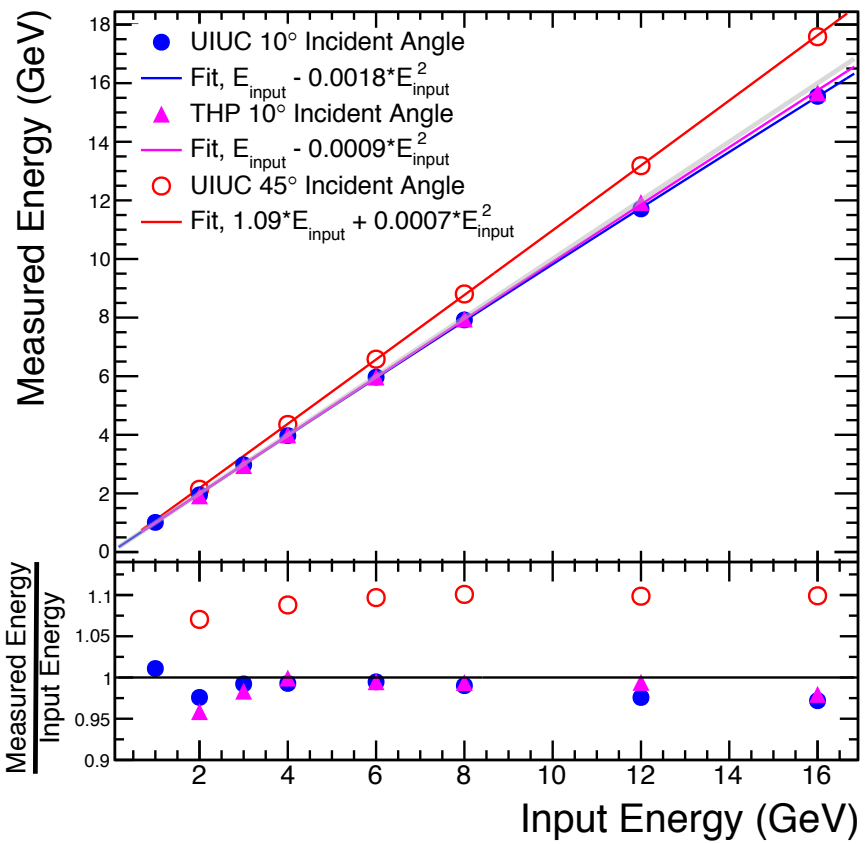
February 2014
Proof of principle

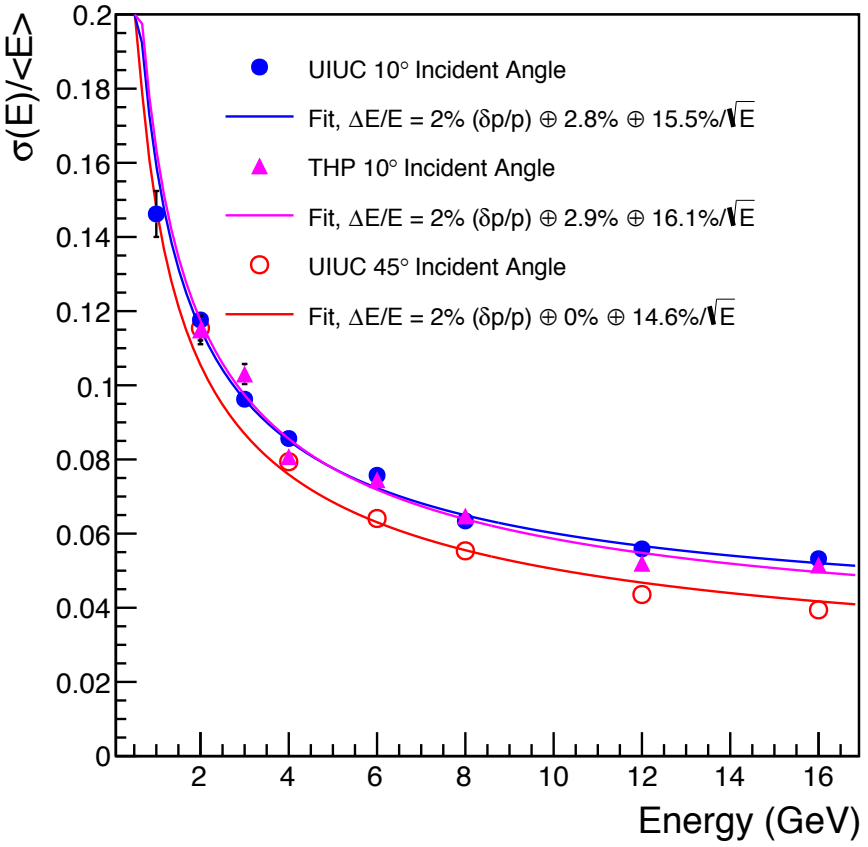
April 2016
η~0
sPHENIX geometry

February 2017
η~0.9

- 2016 results submitted (arXiv:1704.01461)
- 2017 results coming soon!

EMCal Electron Energy Resolution

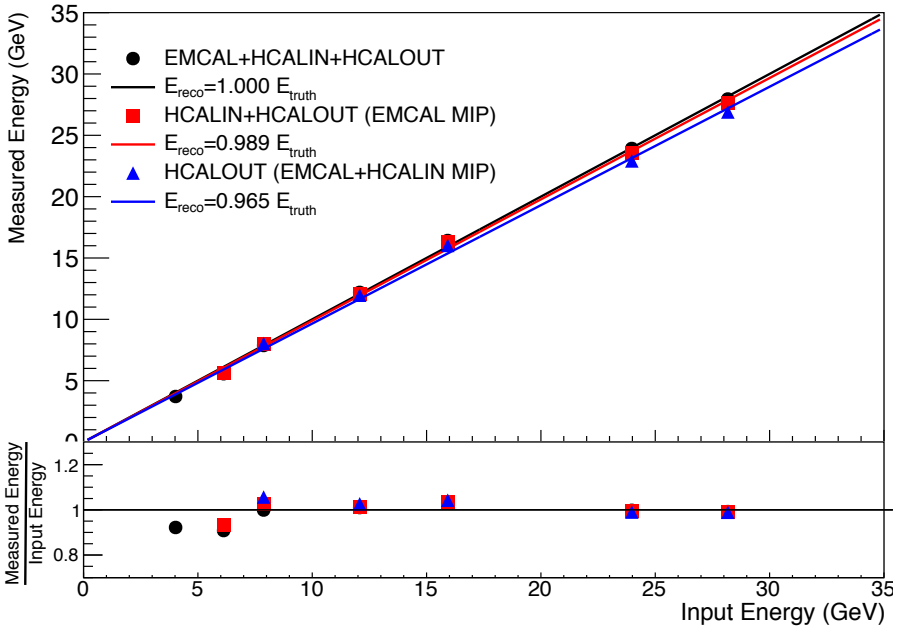


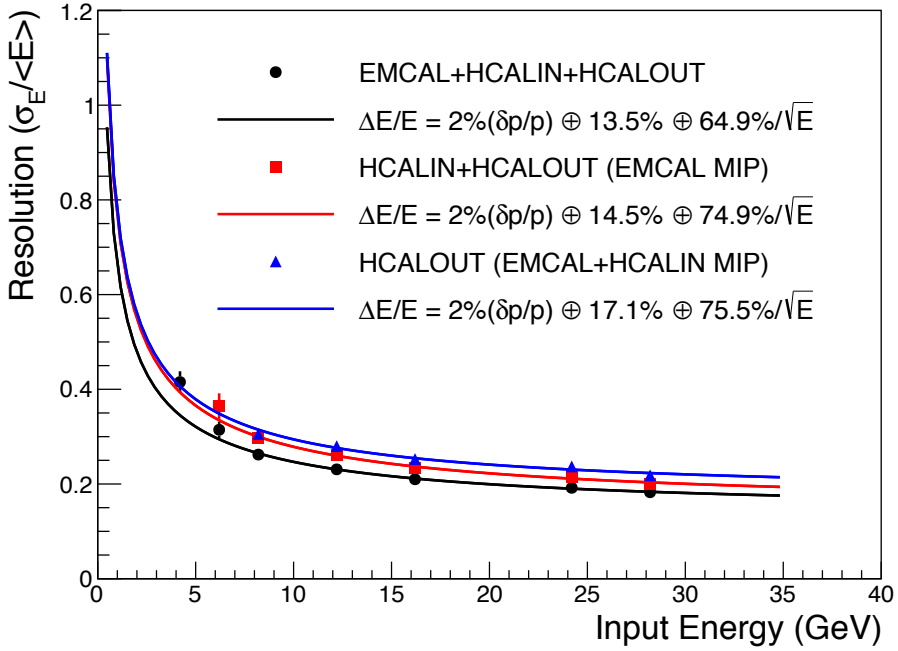


- Consistent with simulations
- Satisfies sPHENIX requirement

sPHENIX Hadron Energy Resolution

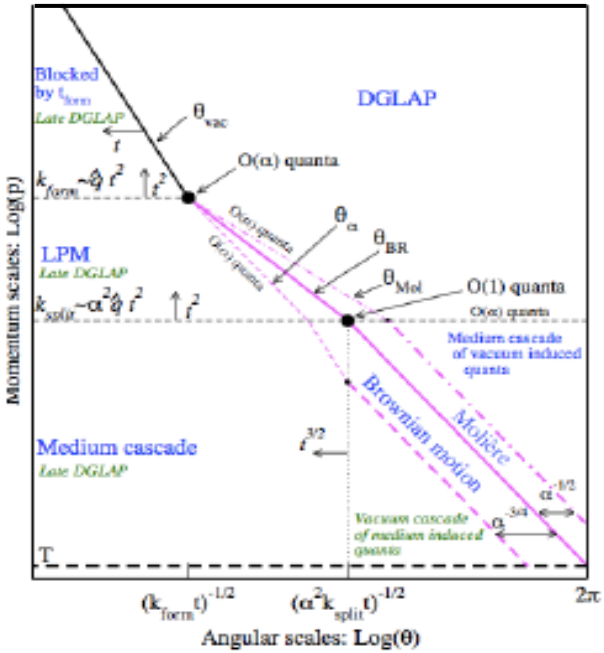
- Combined system takes into account where the particles shower develops
- Satisfies the single particle energy resolution needed for sPHENIX program





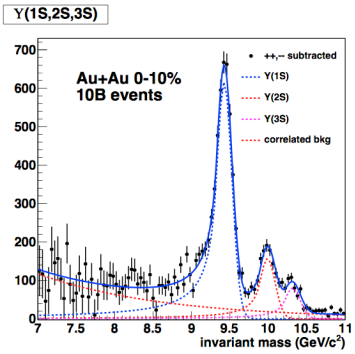
Probe QGP at Mutliple Scales

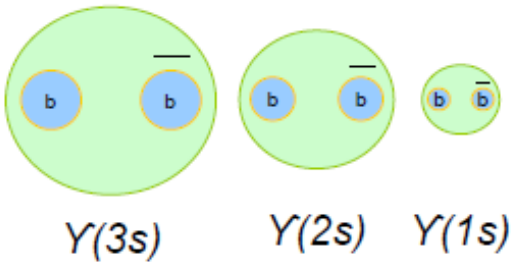
- Jet Structure



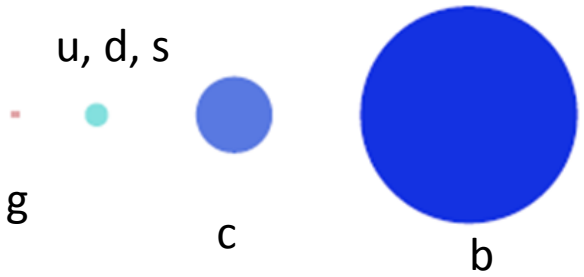
Phys. Lett. B 740 172 (2015)

- ϒ spectroscopy



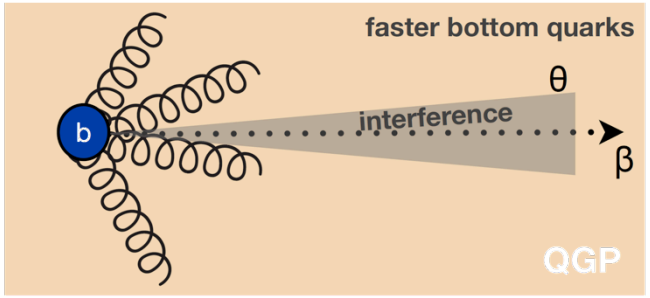


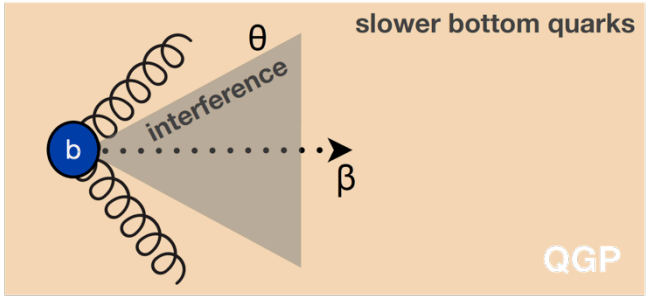
- parton mass/flavor

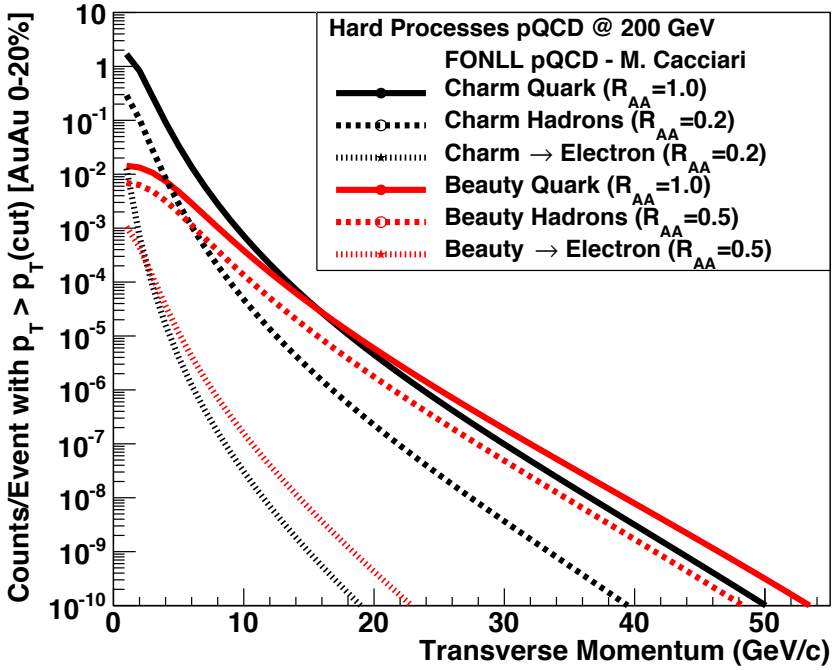


b-tagged Jets

- Sensitivity to collision vs radiative energy loss
- First b-jet measurement at RHIC
- Complimentary to LHC jets, accessing lower p_T region with larger heavy quark mass effect.

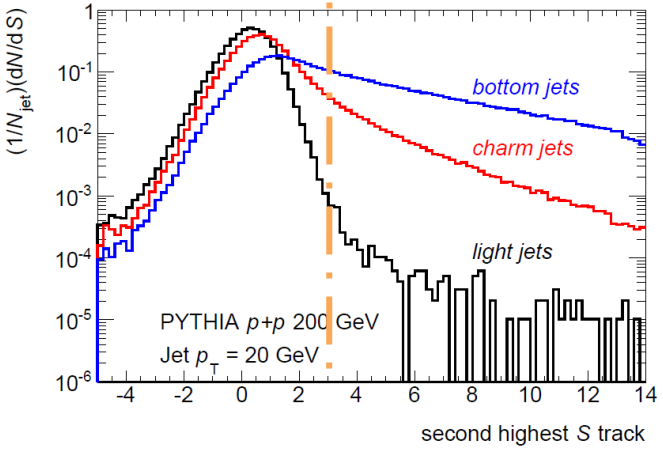




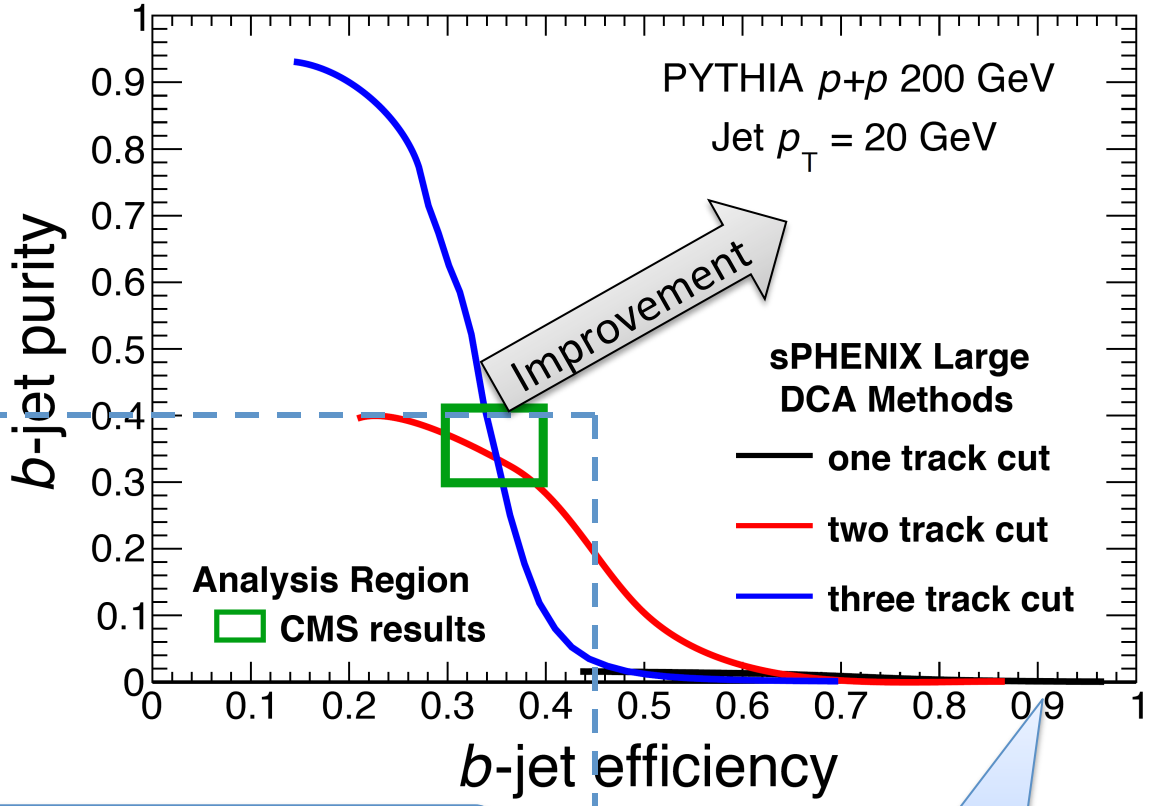


Important Factors in b-jet tagging

Cut



sPHENIX-proposal projection based on fast sim.
(already updated to Geant4 simulation)



Saturate efficiency at level determined by

- Light decay-background
- Fake high DCA (mismatching, alignment) → realistic sim.

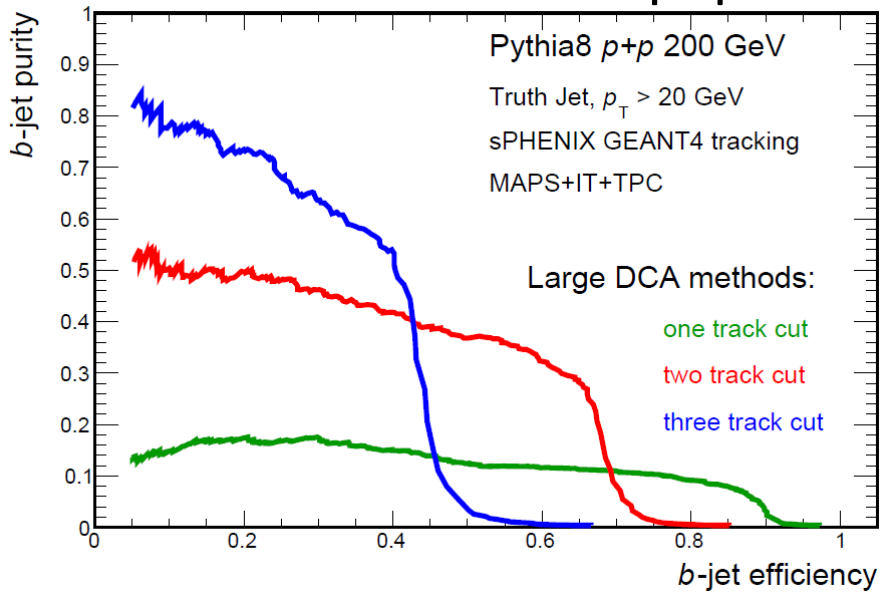
Performance turn-on at primary particle's DCA peak
Efficiency improve w/ higher DCA precision and tracking eff.

Initial b-jet fraction

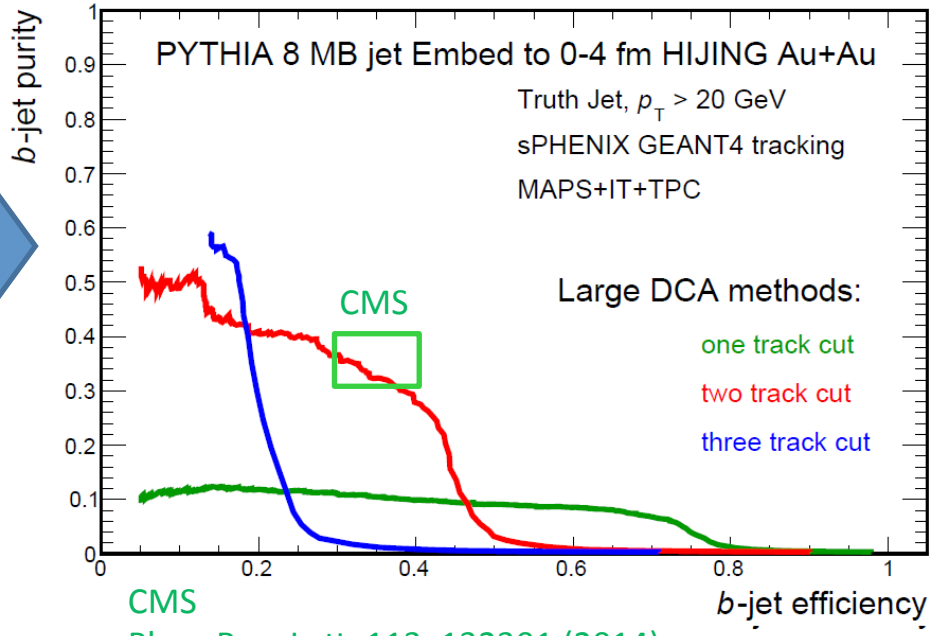
b-jet tagging in GEANT4

- Moved from fast simulation to GEANT4
- Embedded in 0-10% Au+Au

Full Geant4 Sim: p+p



Embedded to Central Au+Au



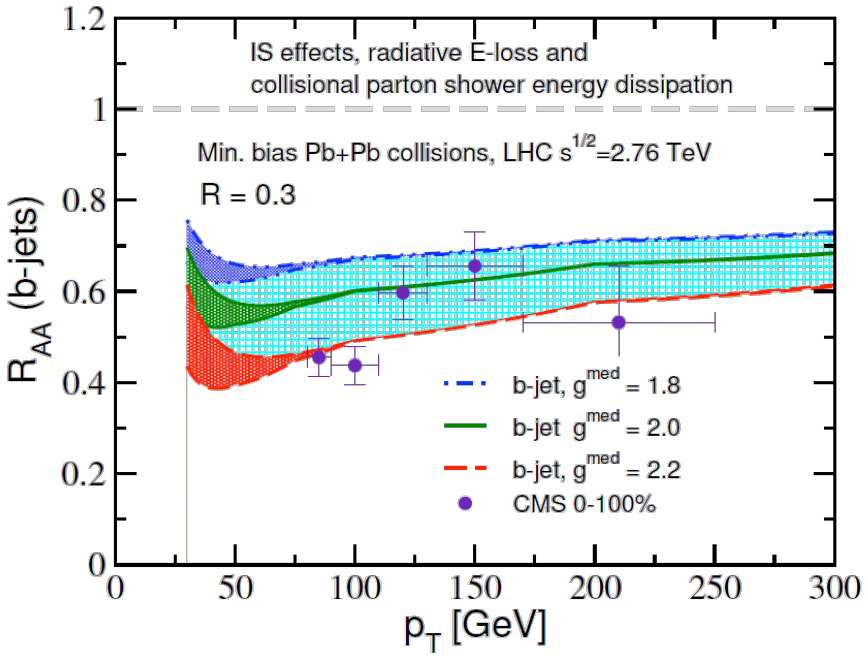
CMS
Phys. Rev. Lett. 113, 132301 (2014)

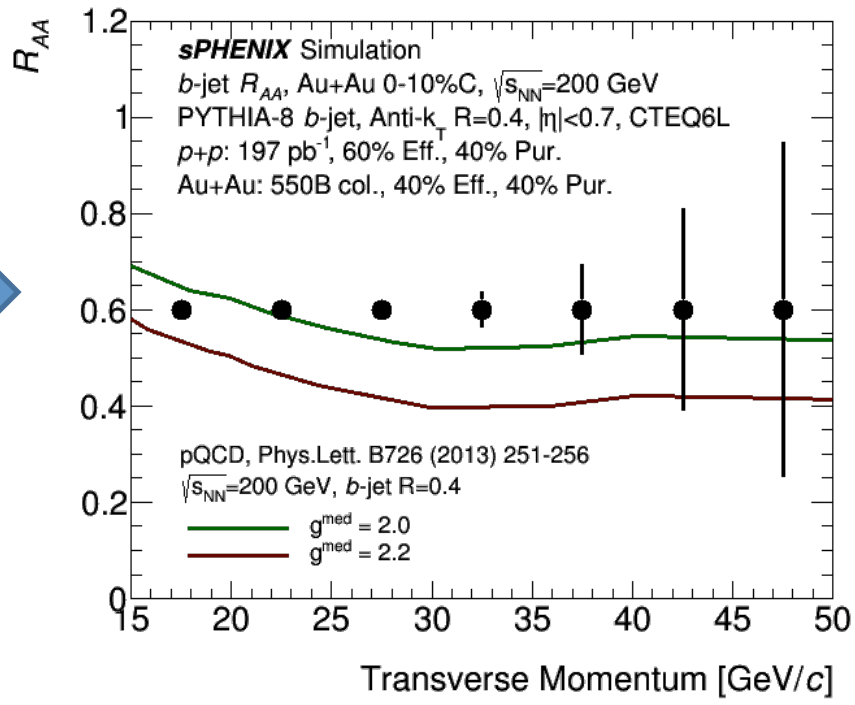
- Improving tracking and pattern recognition software are ongoing…

b-jet Theory Predictions

- Updated pQCD calculations for b-jet R_{AA} from Vitev et al
- sPHENIX statistics here from a 5 year run plan

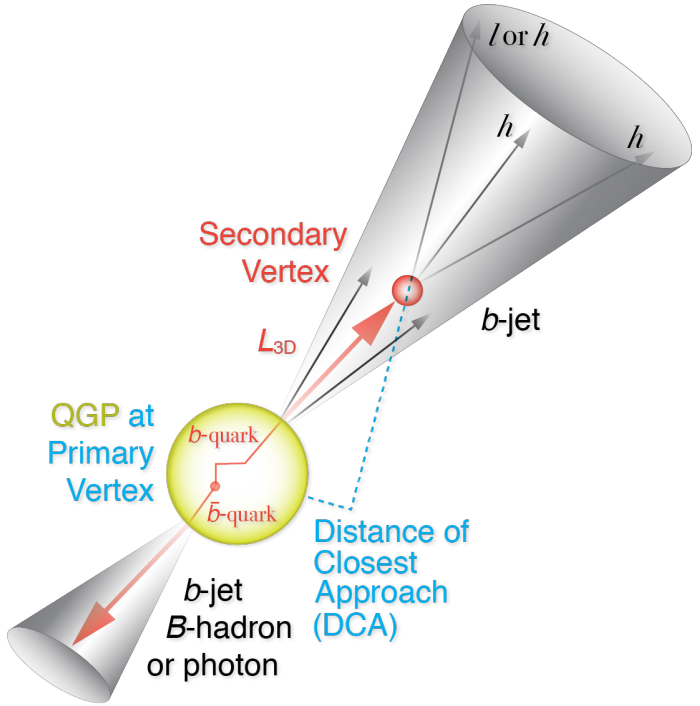
Phys. Lett. B726 (2013) 251-256
Phys.Rev.Lett. 113 (2014) no.13, 132301





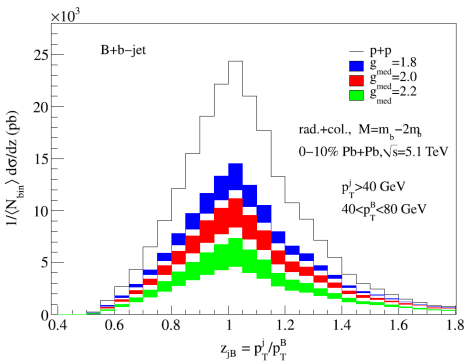
b-jet and Beyond

- b di-jet and b-jet-non-prompt D correlations possible with sPHENIX acceptance
- Studies are ongoing
- Also helps purity of jet and b-tagging



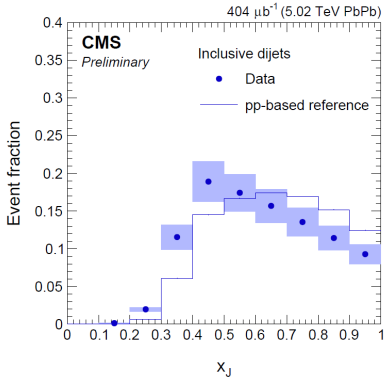
b-jet + *B*-hadron, model

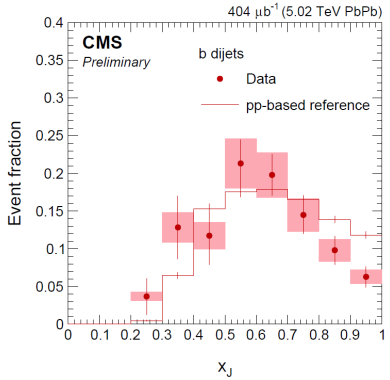
Physics Letters B750 (2015) 287–293



b di-jet, CMS 2016

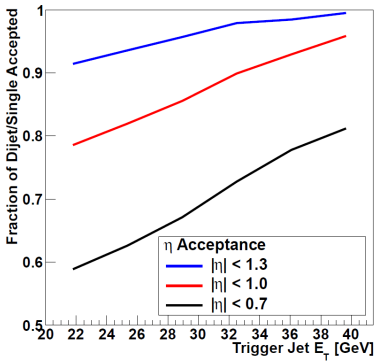
CMS PAS HIN-16-005





di-jet acceptance in sPHENIX

sPHENIX scientific proposal



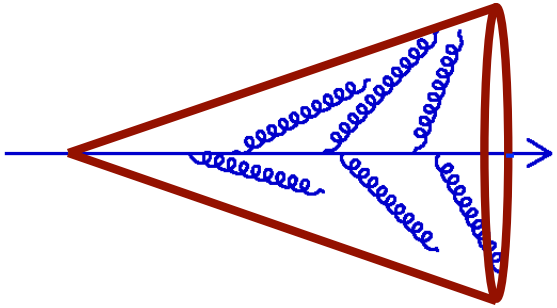
Jet Substructure

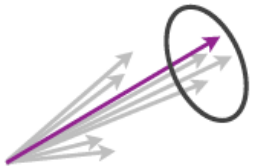
- Hot topic at QM17

What is jet substructure?

Dynamics of particles inside the jet

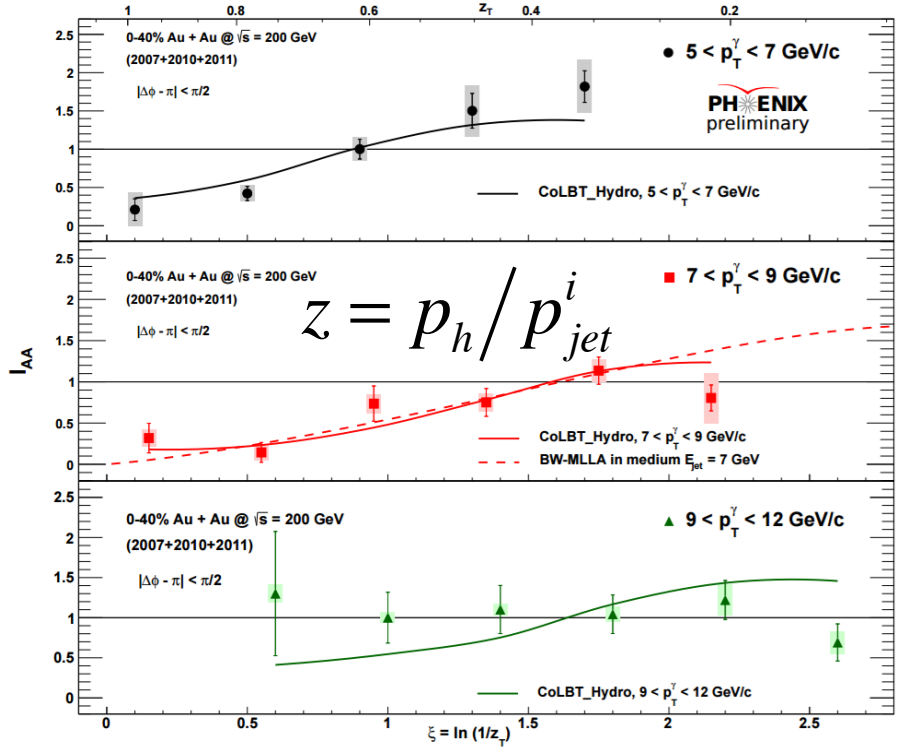
Two scales: angular + momentum space



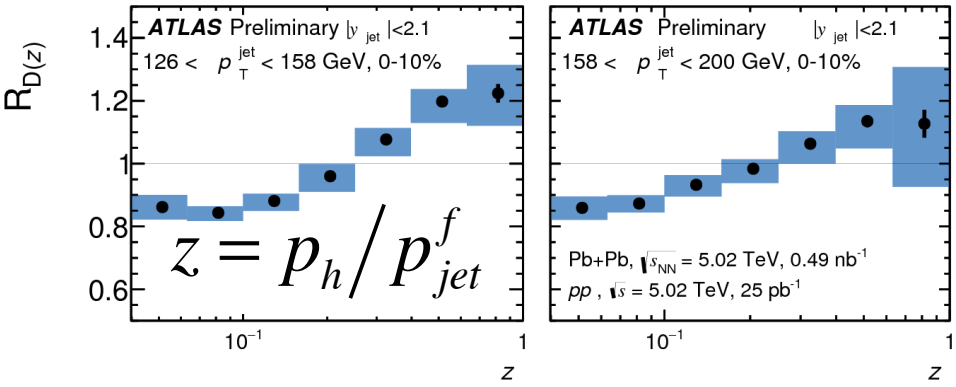
Fragmentation Functions	Classic Jet Shapes	Groomed Observables
		
Single hadron	*All hadrons*	*Subset of hadrons*

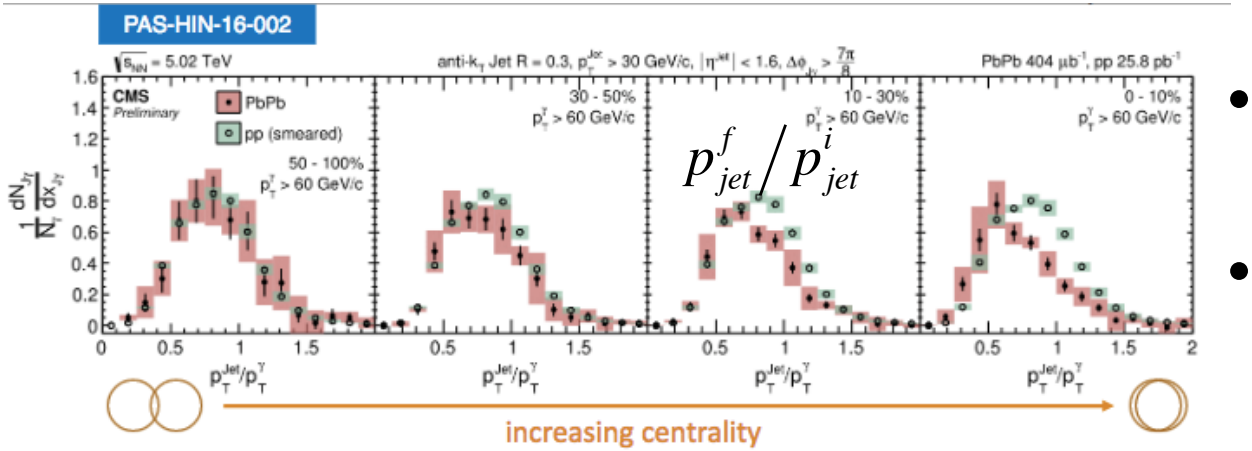
Sketches by J. Thaler

Photon tagged jet fragmentation functions



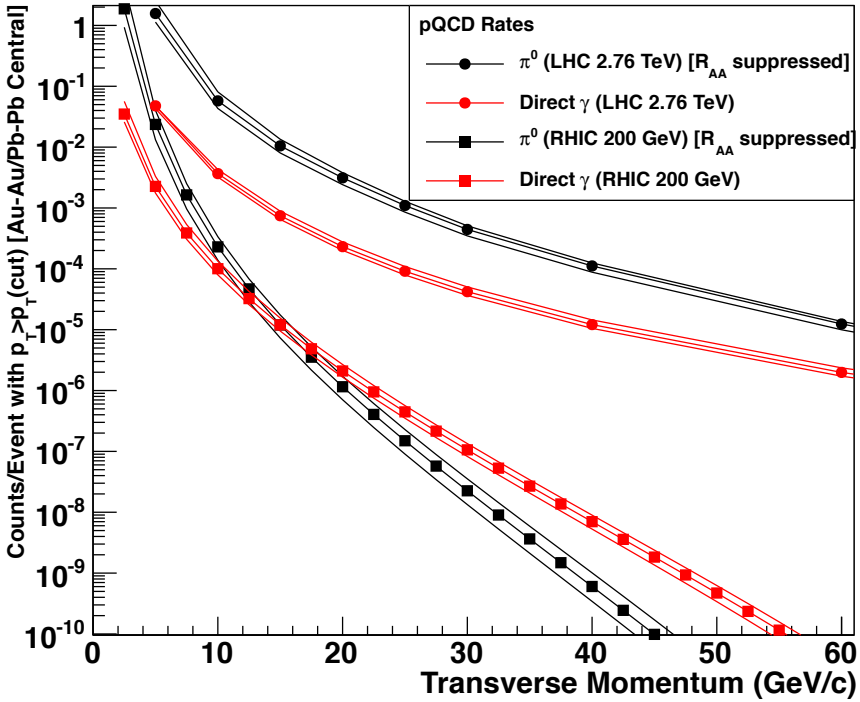
- Photon tags initial hard scattering kinematics
- Jet reconstructed after energy loss



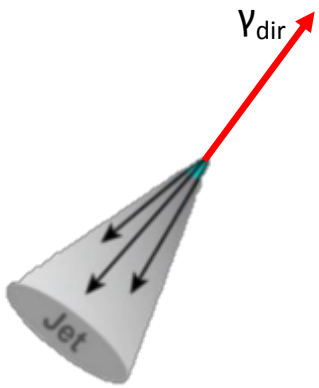


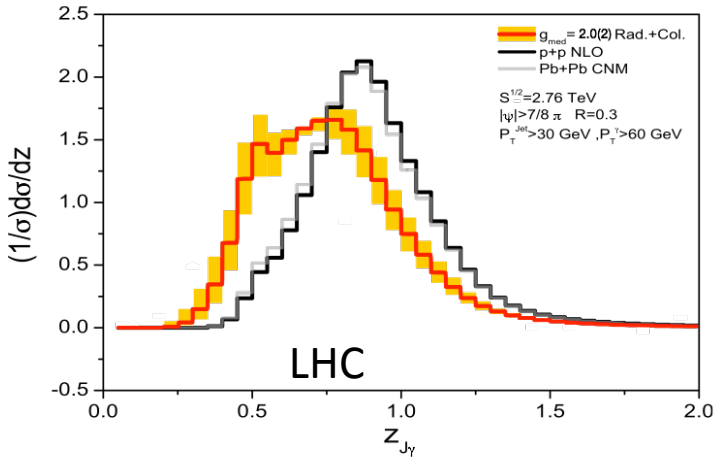
- Photon-tagged jets directly probe ΔE
- Is the fragmentation function modified?

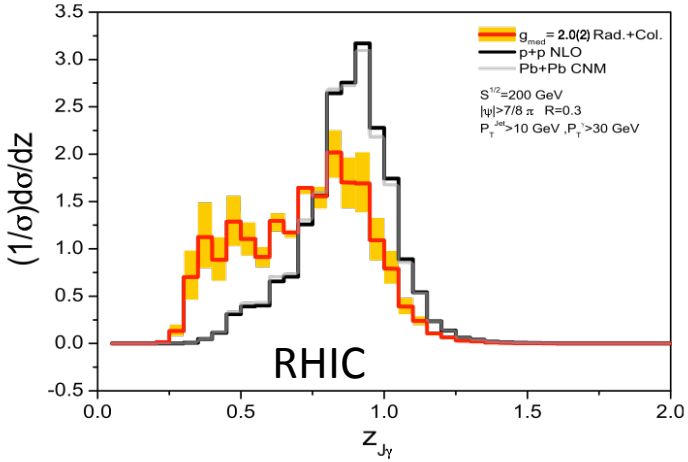
Photon-jet FF at RHIC



- RHIC is ideal for measuring direct photons
- $z_{J\gamma}$ may be more sensitive at RHIC

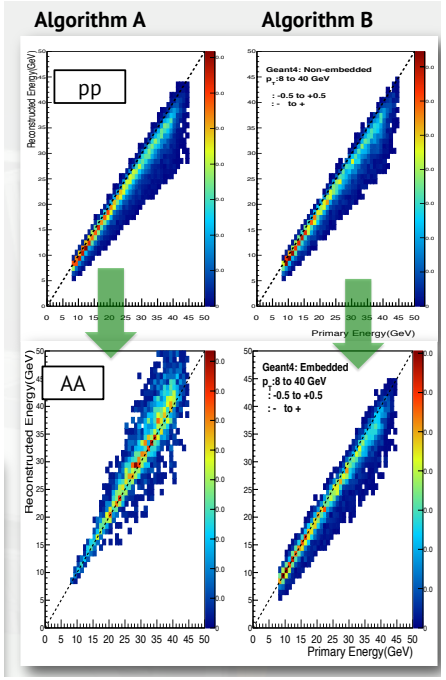


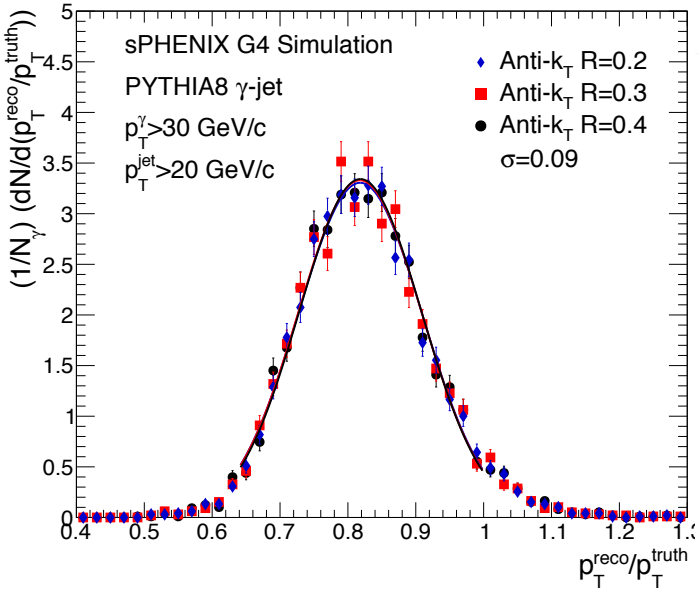


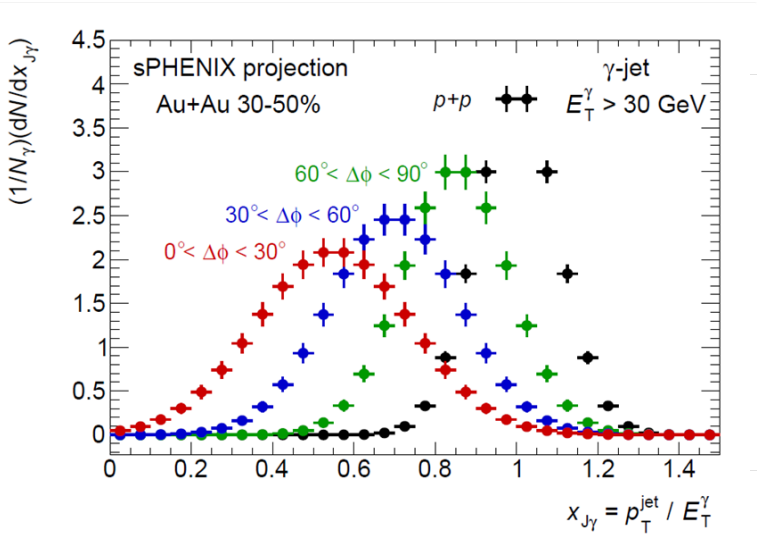


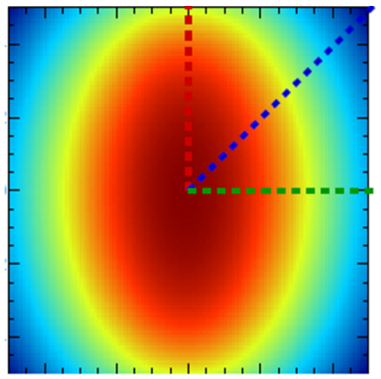
Photon-jet in sPHENIX

- EMCal clustering studies ongoing
- Good jet energy resolution for p+p γ-jet events
- Enough statistics to explore reaction plane dependence of $z_{J\gamma}$
- γ-jet fragmentation functions require:
  - Photon reconstruction in EMCal
  - Jet reconstruction (EMCal+HCals)
  - Tracking (MAPS+INTT+TPC)









Summary

- sPHENIX has CD0 and preparing for CD1 review
- A lot of physics opportunities for jet, jet structure and HF jets
- Continue to improve software framework
  - Realistic tracking in place
- Prototype testing confirms simulations

Growing collaboration:
Bi-annual collaboration meetings

Bi-weekly general meeting

Topical Groups:
-Jet structure
-HF jets
-Quarkonia
-Cold QCD