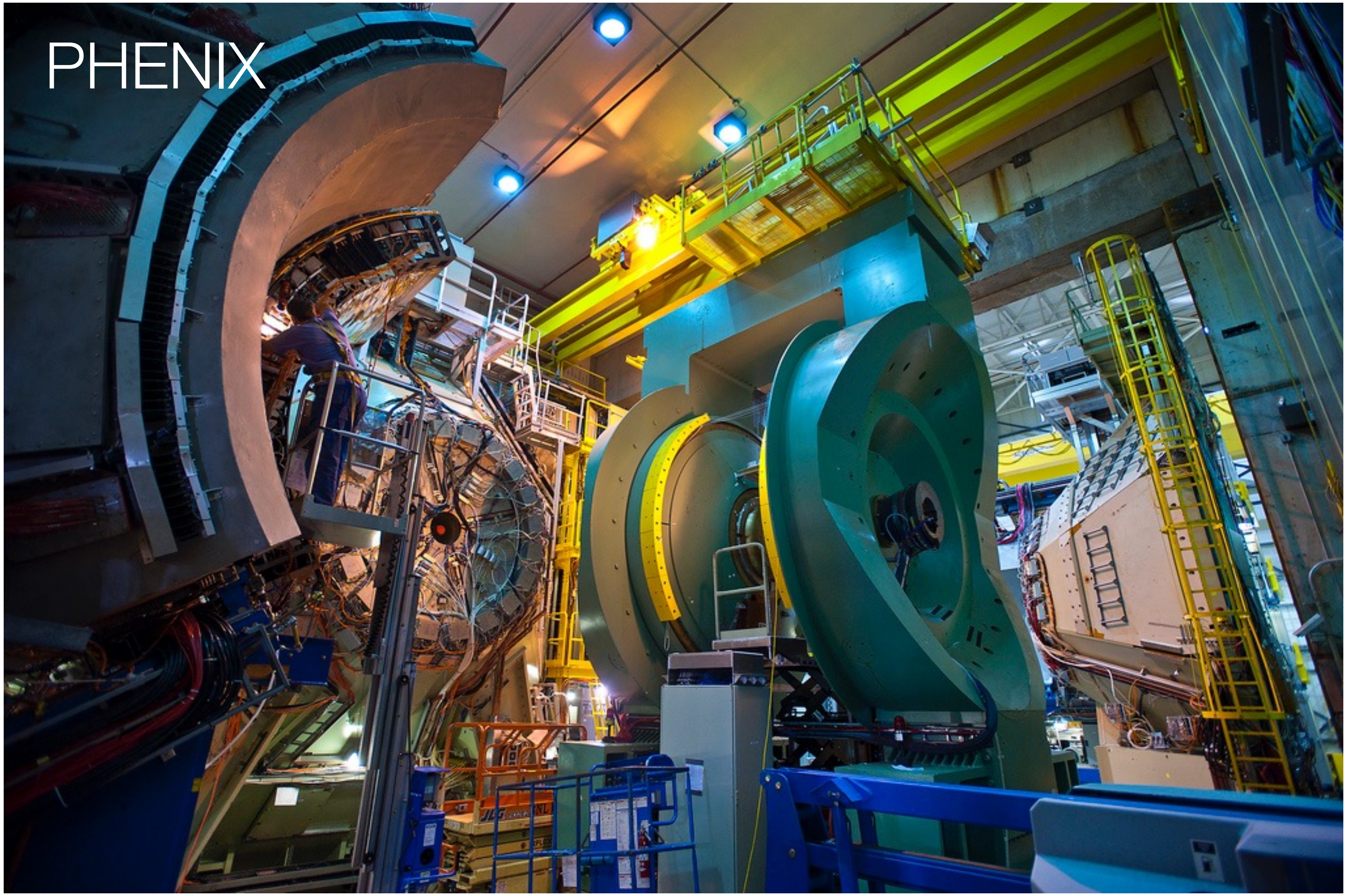
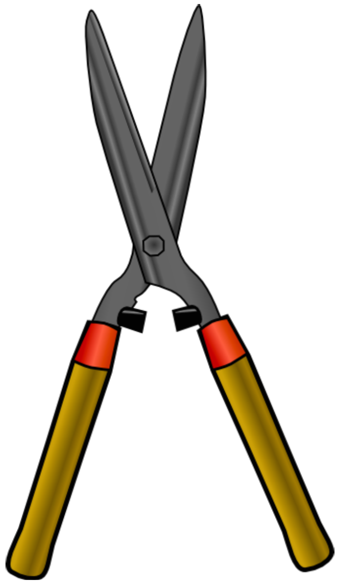
Future Jet and Heavy Flavor Measurements with sPHENIX

Dave Morrison (BNL) for the sPHENIX Collaboration



RHIC Run-16 (starts in 10 days):
- Au+Au @ 200 GeV
- d+Au beam energy scan

and then …



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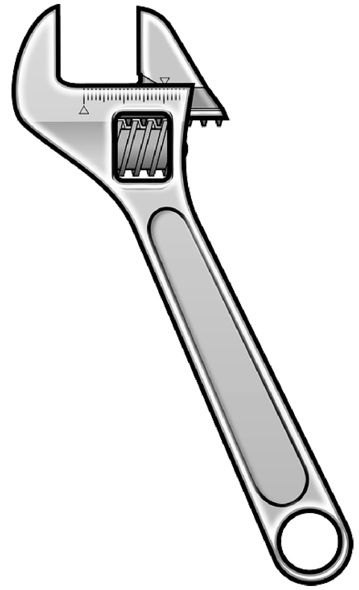

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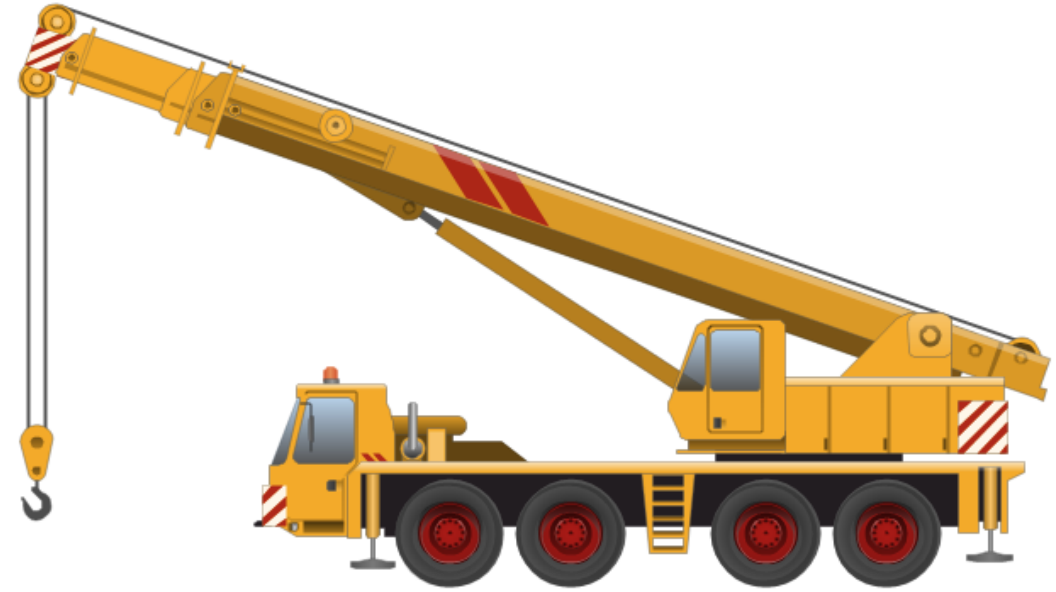
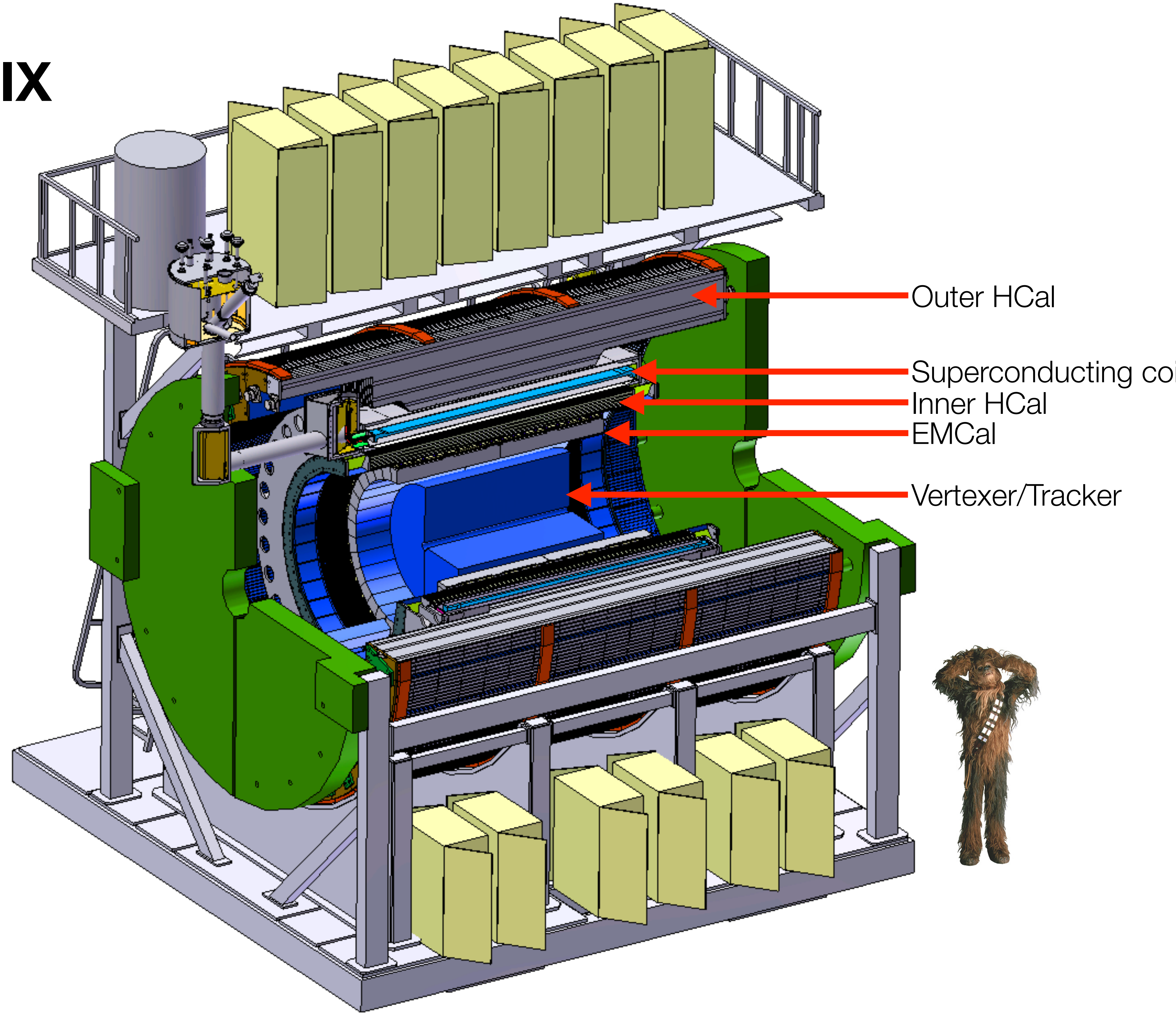
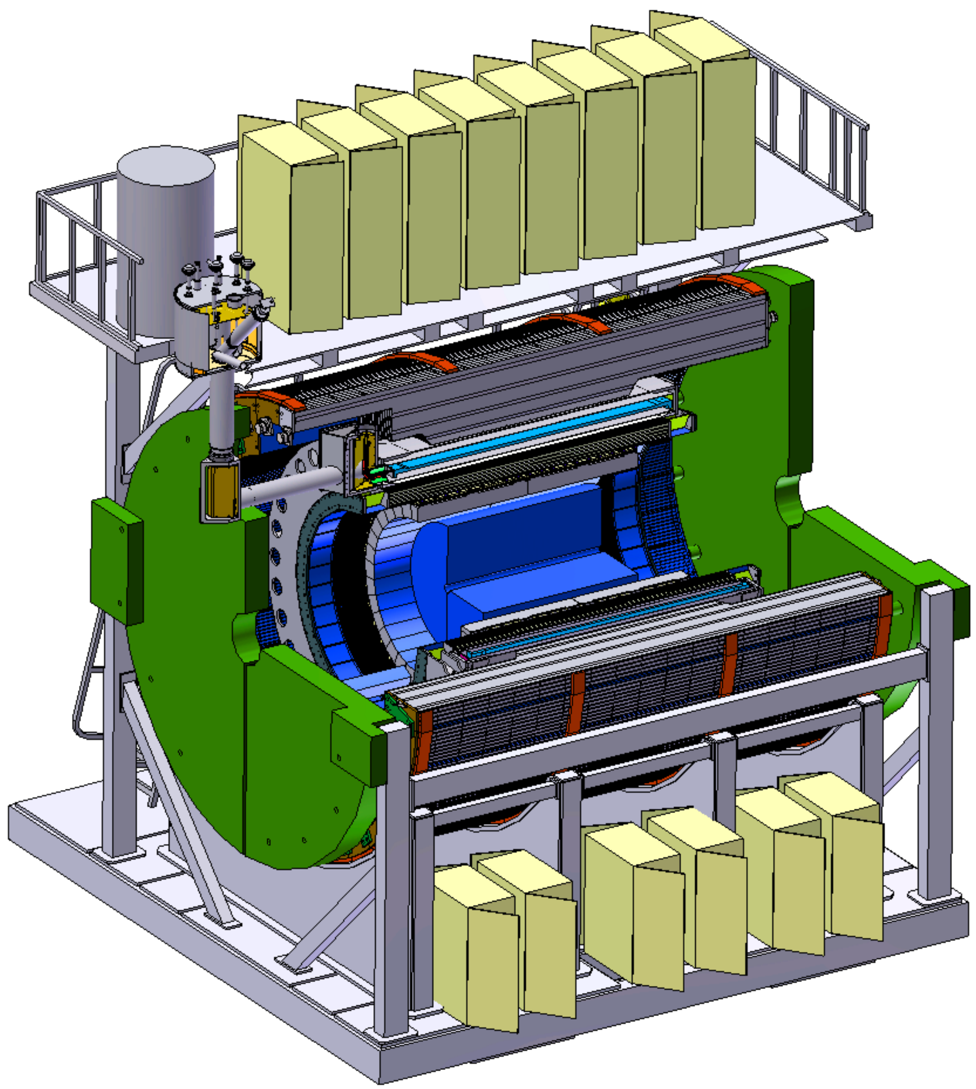


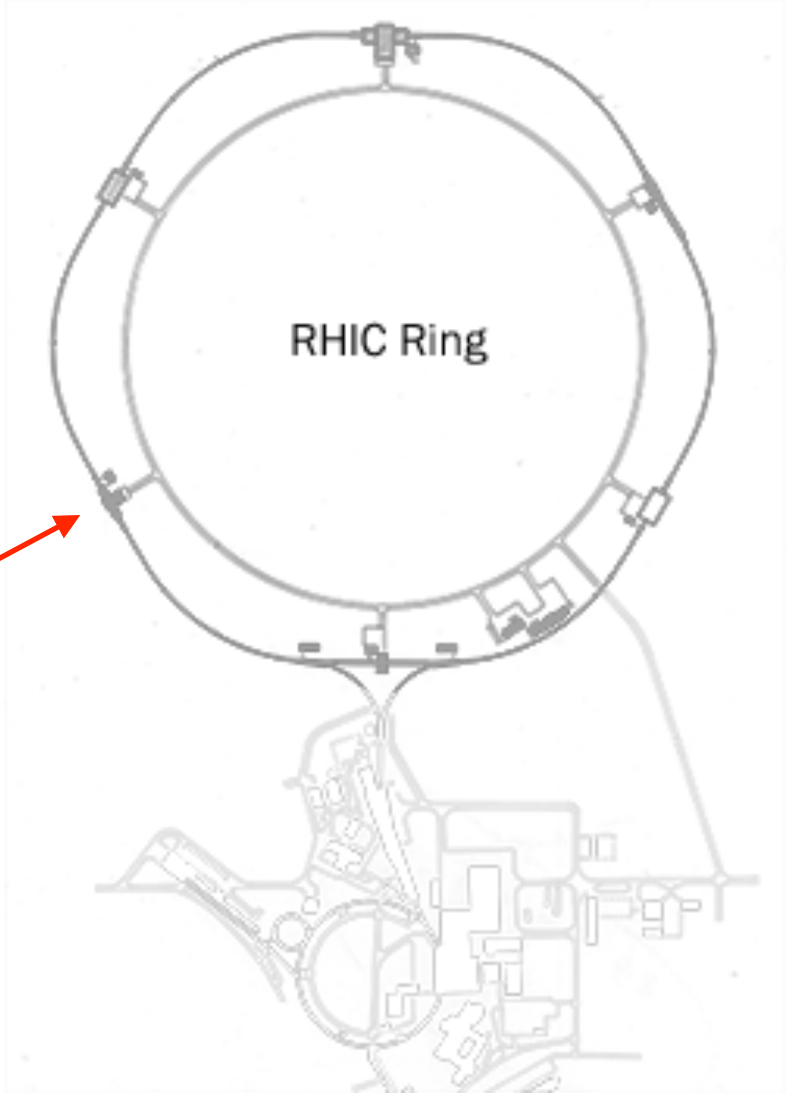

IP8 as it was June 1997
(will be even emptier)

sPHENIX


Outer HCal
Superconducting coil
Inner HCal
EMCal
Vertexer/Tracker

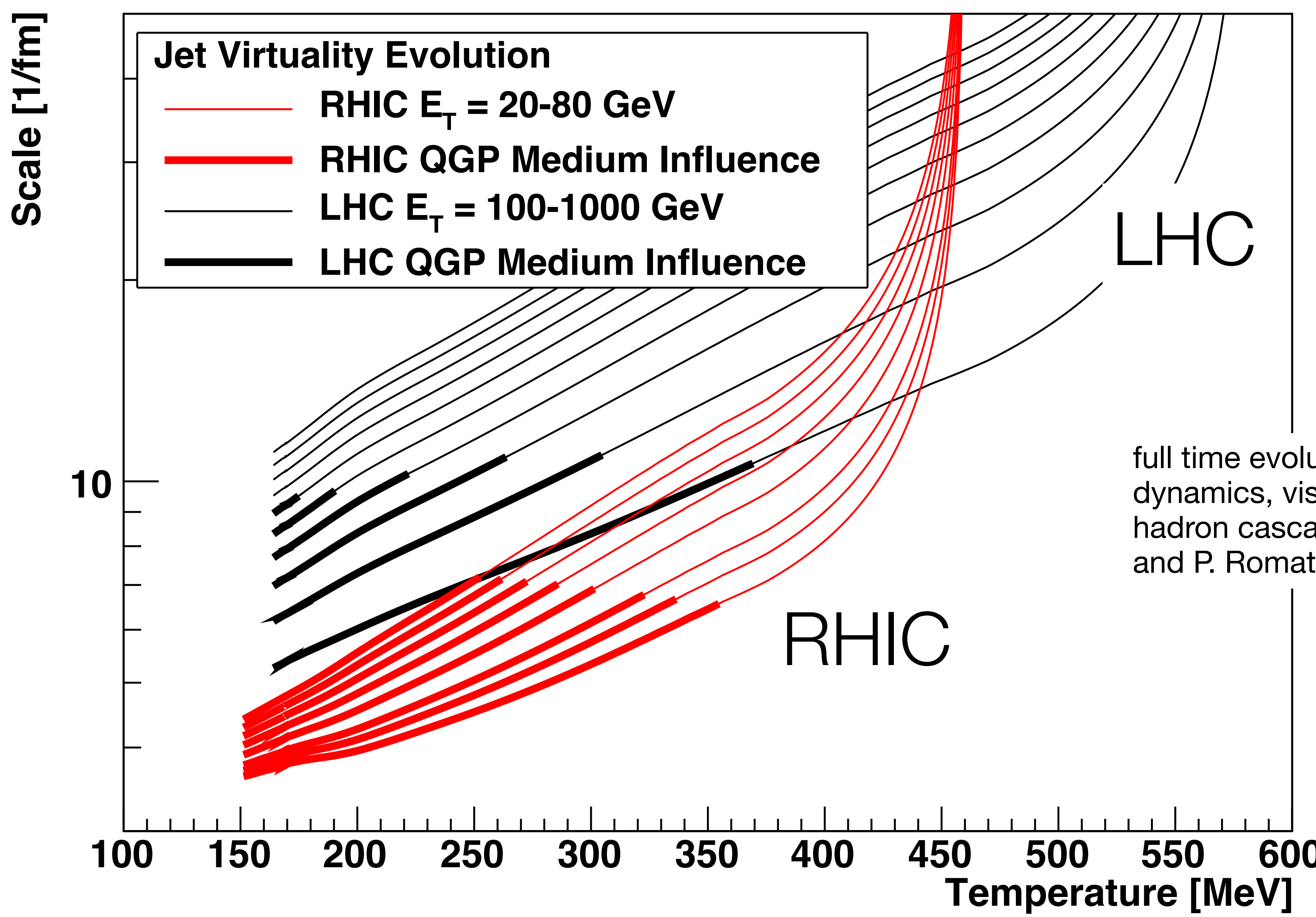
sPHENIX \es-ˈfē-niks\: A high-rate capable detector at RHIC IP8, built around the former BaBar 1.5 T superconducting solenoid, with full electromagnetic and hadronic calorimetry and precision tracking and vertexing, with a core physics program focused on light and heavy-flavor jets, direct photons, Upsilons and their correlations in p+p, p+A, and A+A to study the underlying dynamics of the QGP – physics delivered by 22 weeks of Au+Au, 10 weeks each of p+p and p+A (@ 200 GeV).





sPHENIX in one plot

initial hard scattered parton virtuality in units of 1/fm as a function of the local temperature of the QGP medium

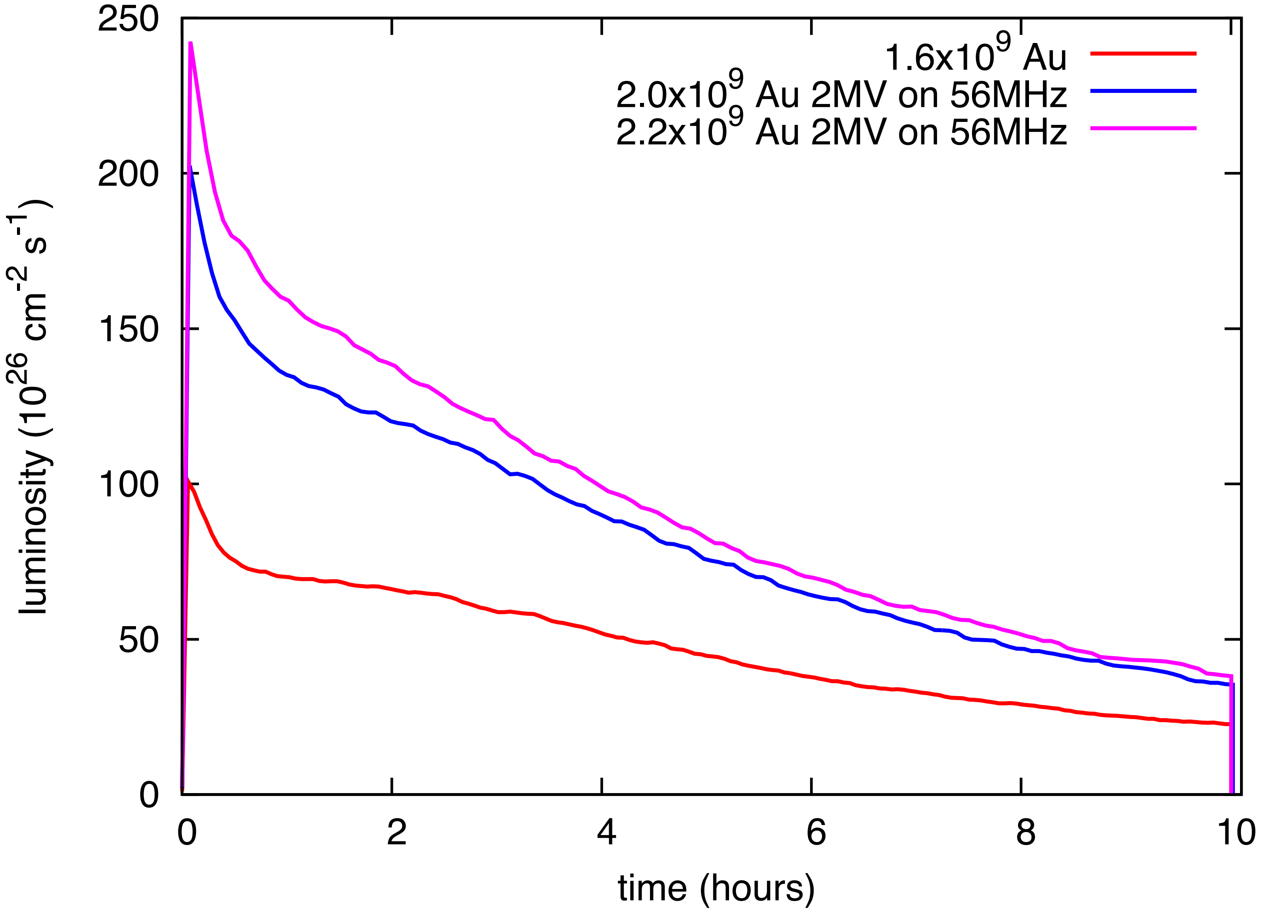


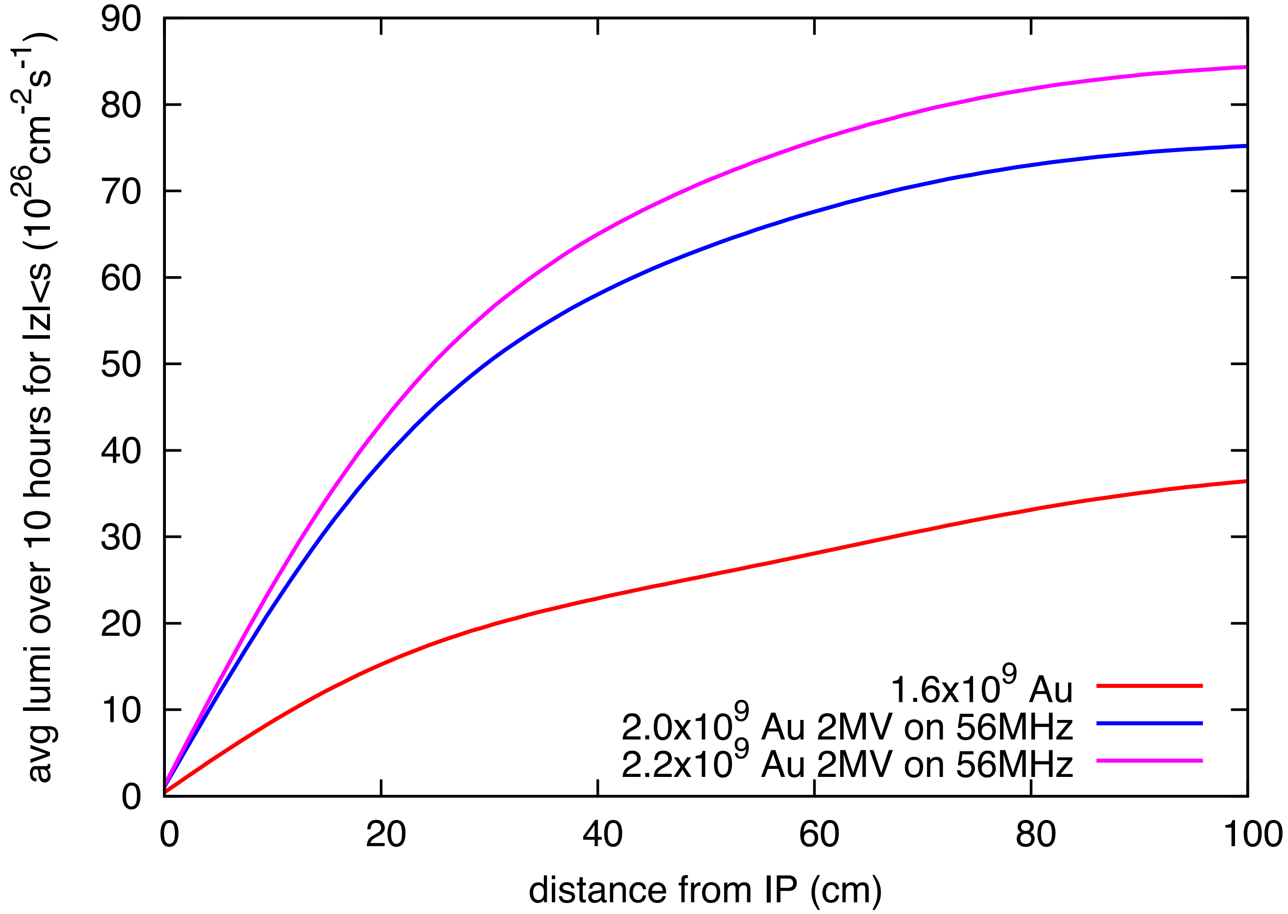
full time evolution of pre-equilibrium dynamics, viscous hydrodynamics, and hadron cascade from M. Habich, J. Nagle, and P. Romatschke, EPJC, 75:15 (2015)

Vacuum virtuality evolution initially, with medium influence becoming significant as virtuality of parton shower and medium become comparable


BaBar Magnet
OVERSIZE LOAD
VERSIZE LOAD
January 17, 2015

Au+Au luminosity projections from BNL Collider-Accelerator Department
(2.5x RHIC Run-14 in $|z| < 10$ cm vertex cut)



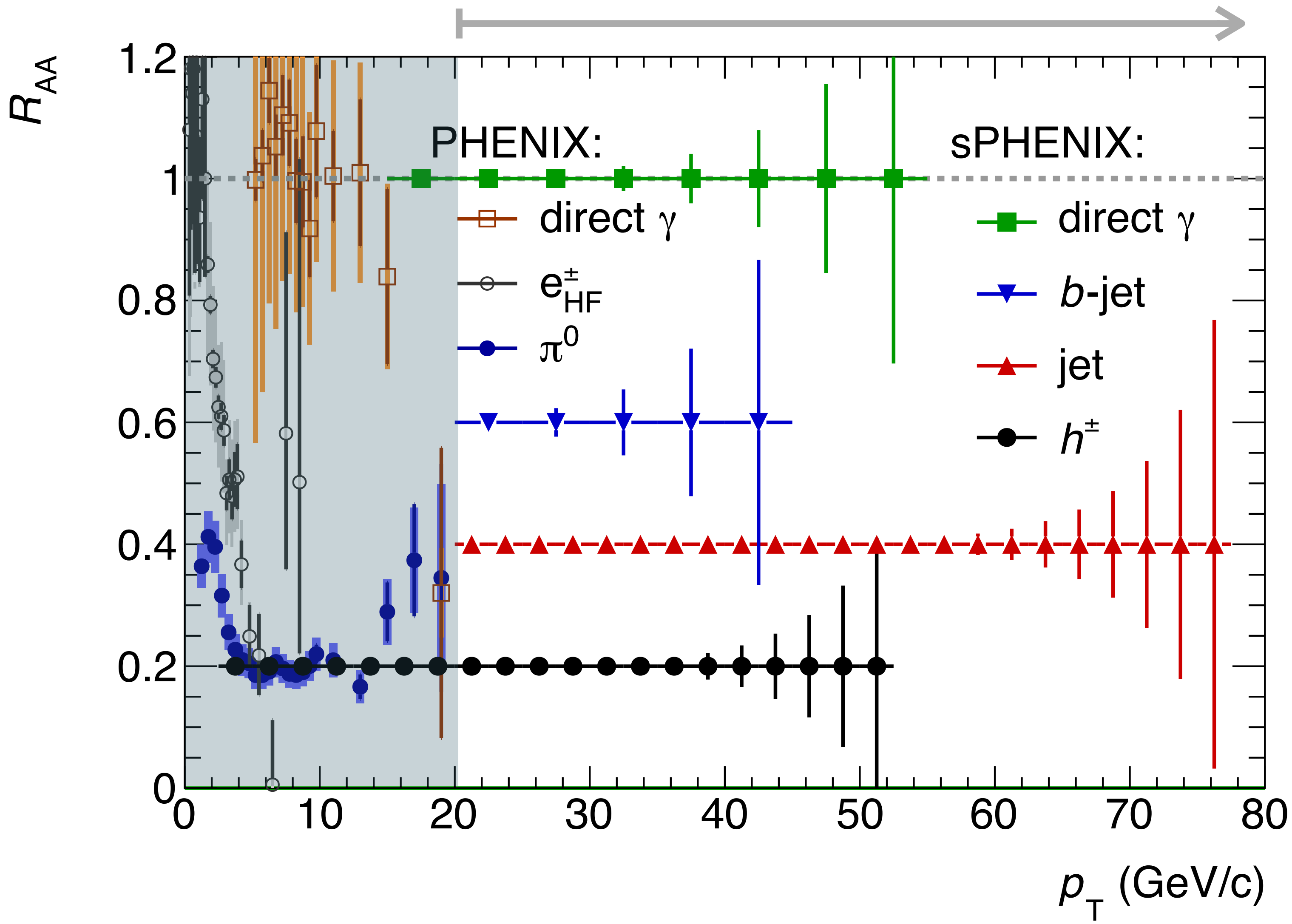


In nominal one-year Au+Au run, able to record **100 billion** Au+Au minimum bias events within $|z| < 10$cm

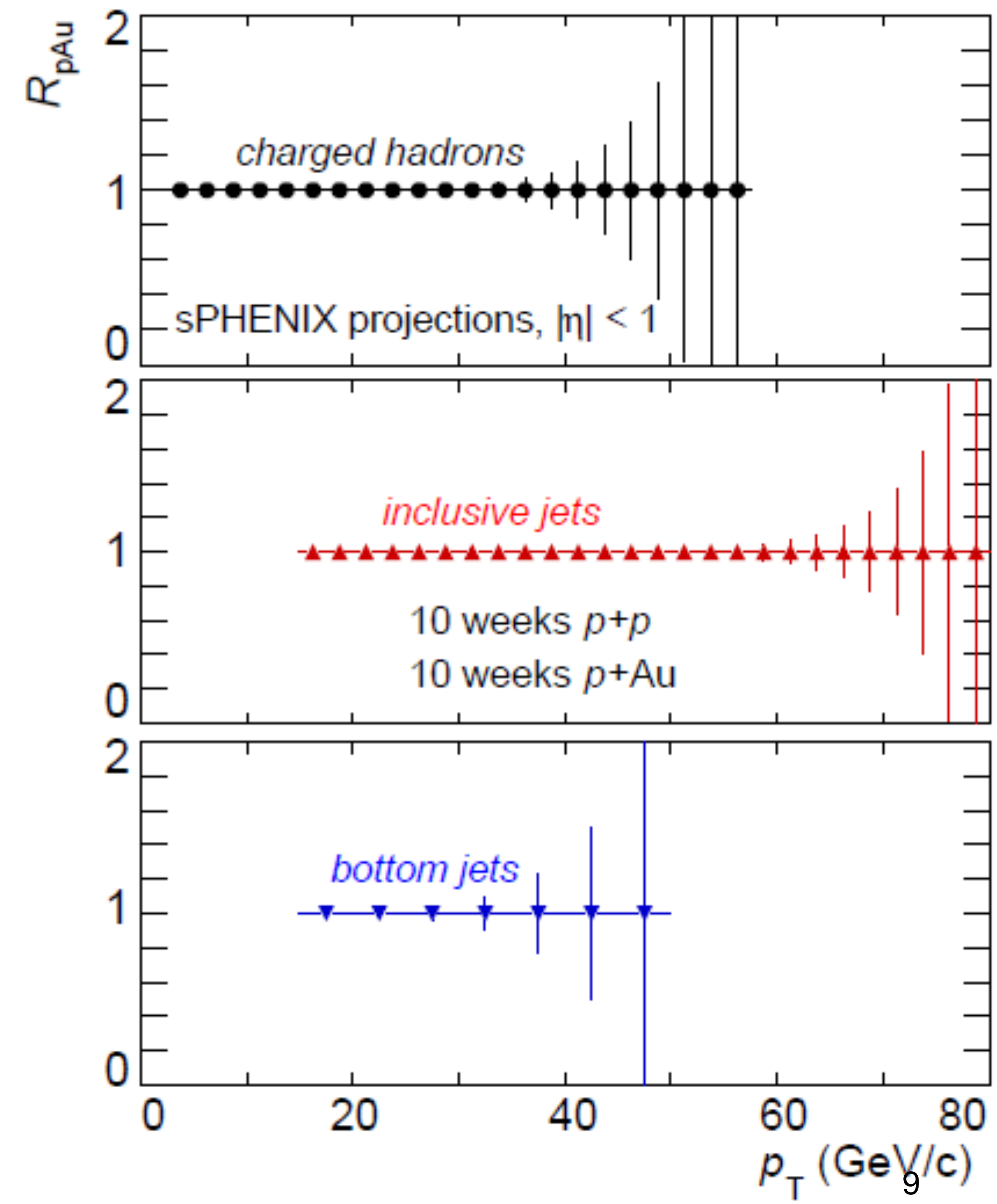
With Au+Au rare triggers for physics that can be measured just with the calorimeters (i.e. wider *z*-vertex range), and can sample **0.6 trillion** events.

PHENIX DAQ has been tested to 15 kHz – good match to these rates.

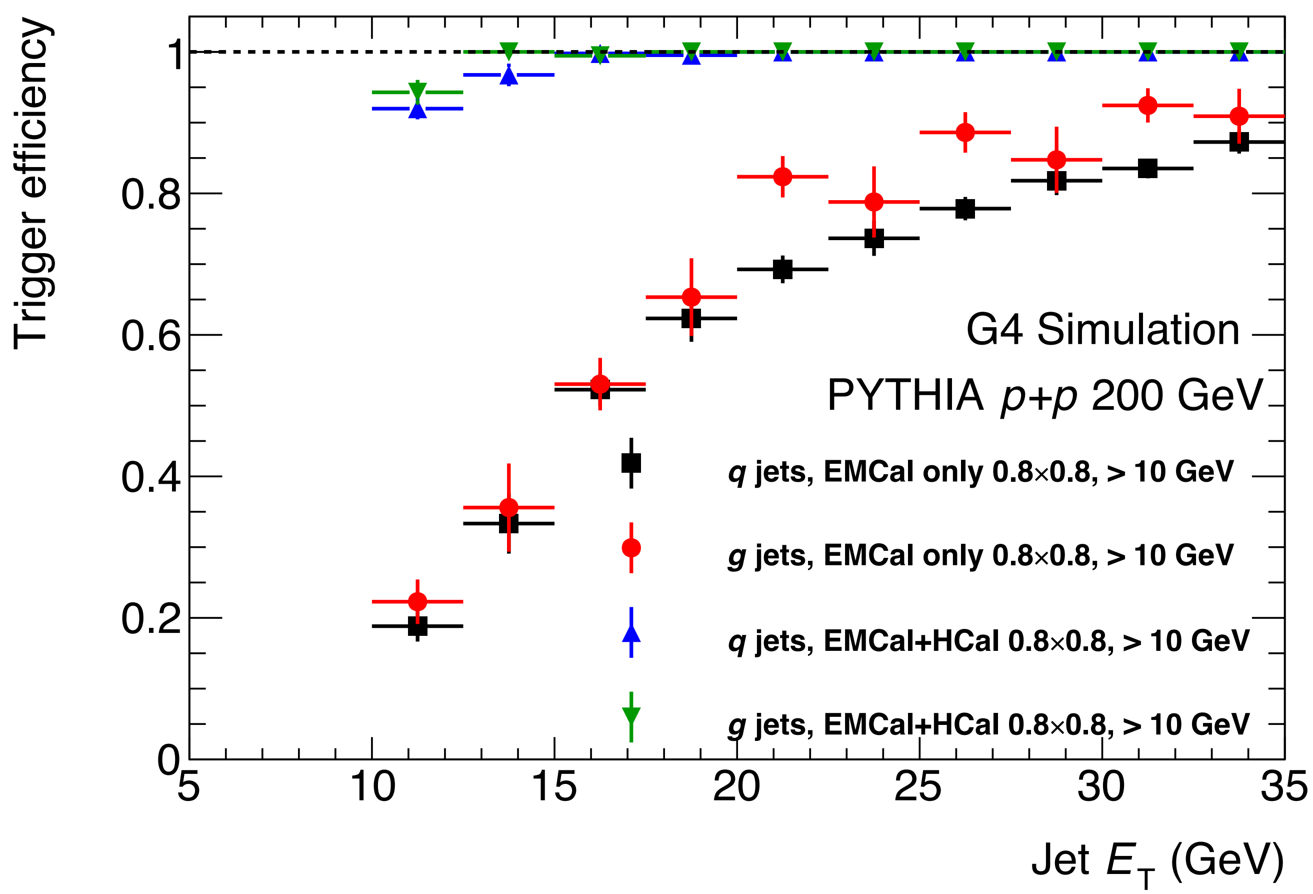
The benefits of rate

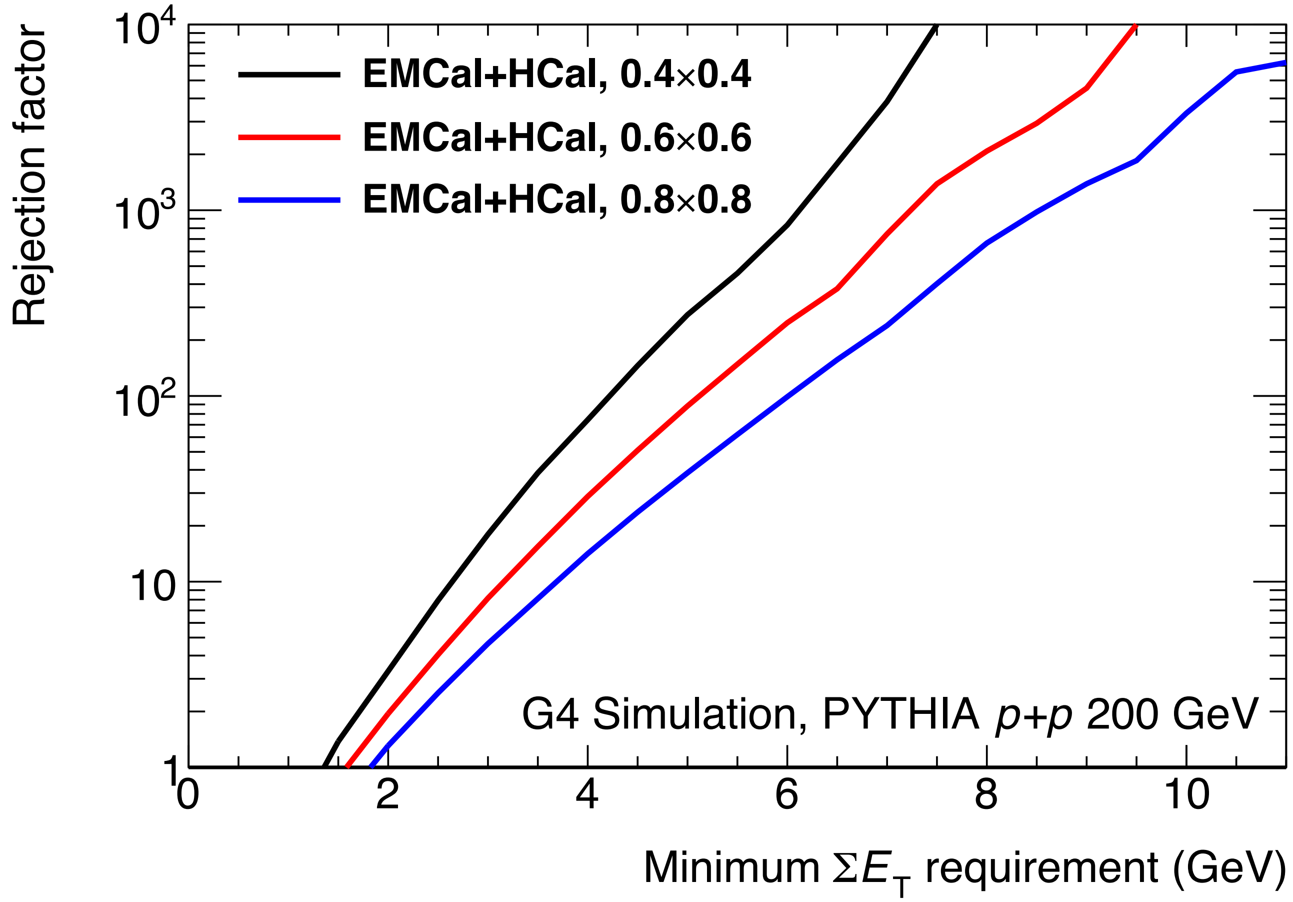


extended reach in p+Au also



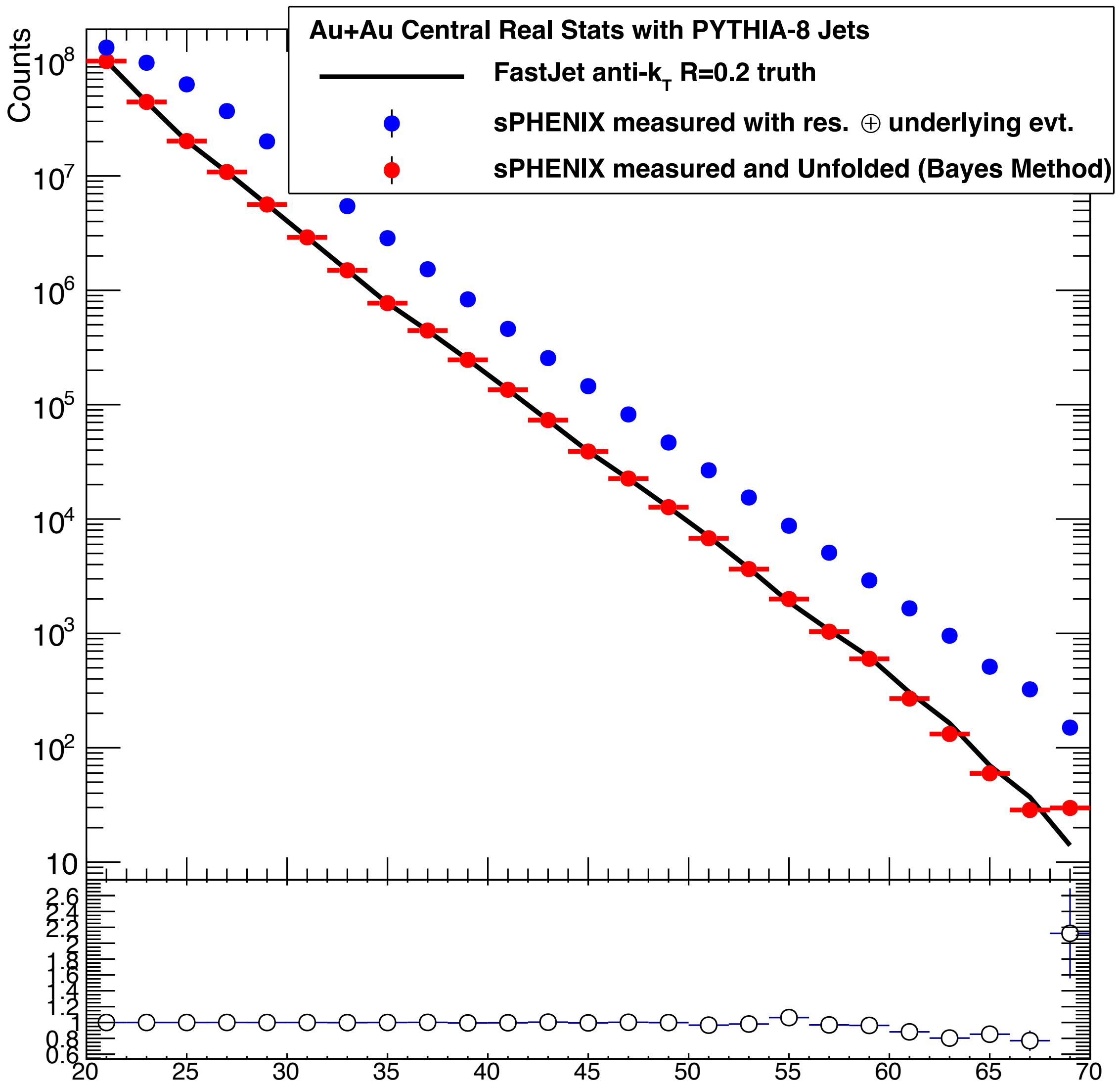
Hadronic calorimetry and triggering in p+p, p+Au

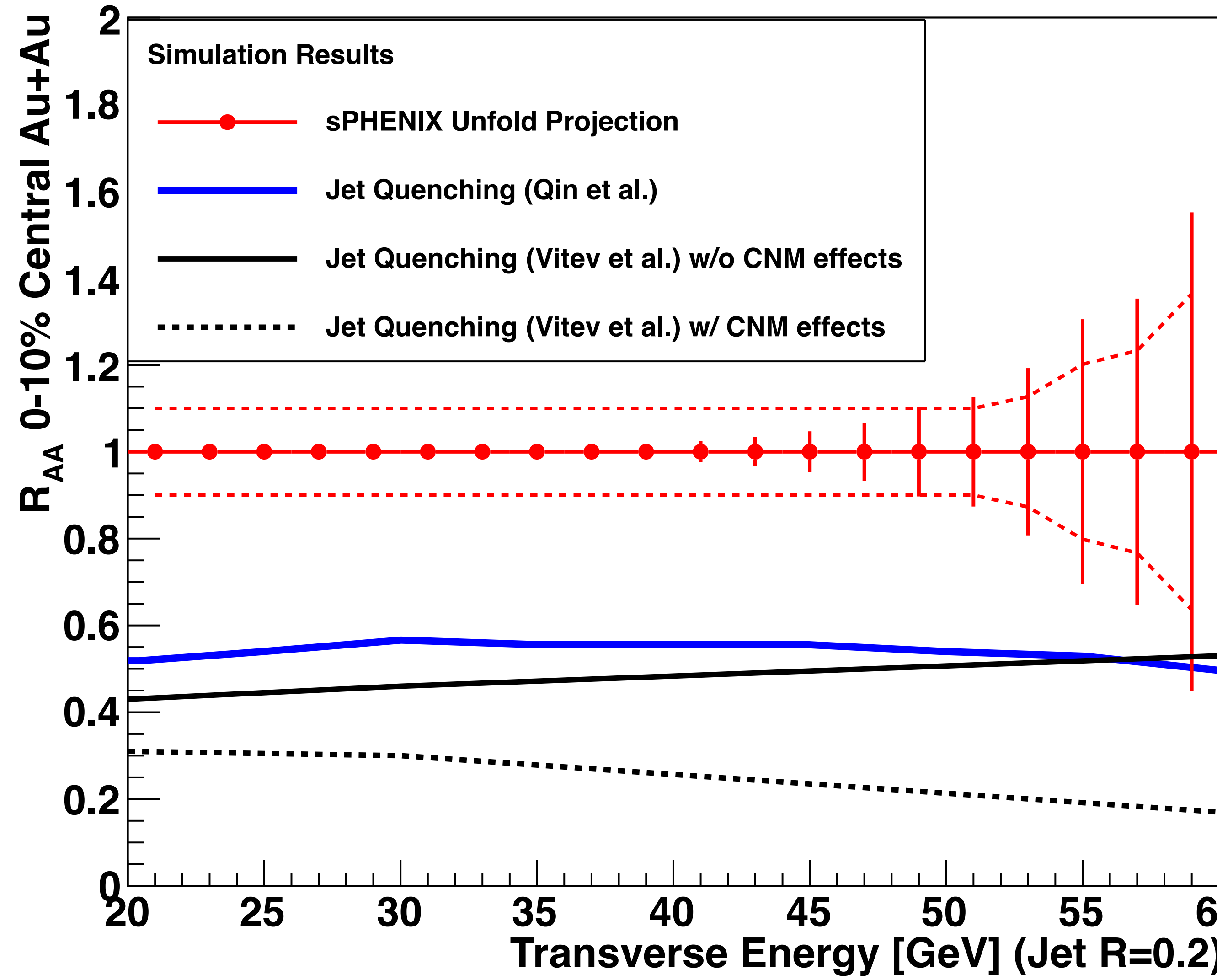




Jet trigger (EMCal + HCal) fully simulated in GEANT4.
Calorimeter electronics would enable fully digital trigger decisions.
Quark Jets and Gluon Jets sampled with very high efficiency for E_T > 10 GeV without strong bias.
Trigger threshold enables rejection of 100-1000, needed for p+p, p+A

Inclusive jet observables

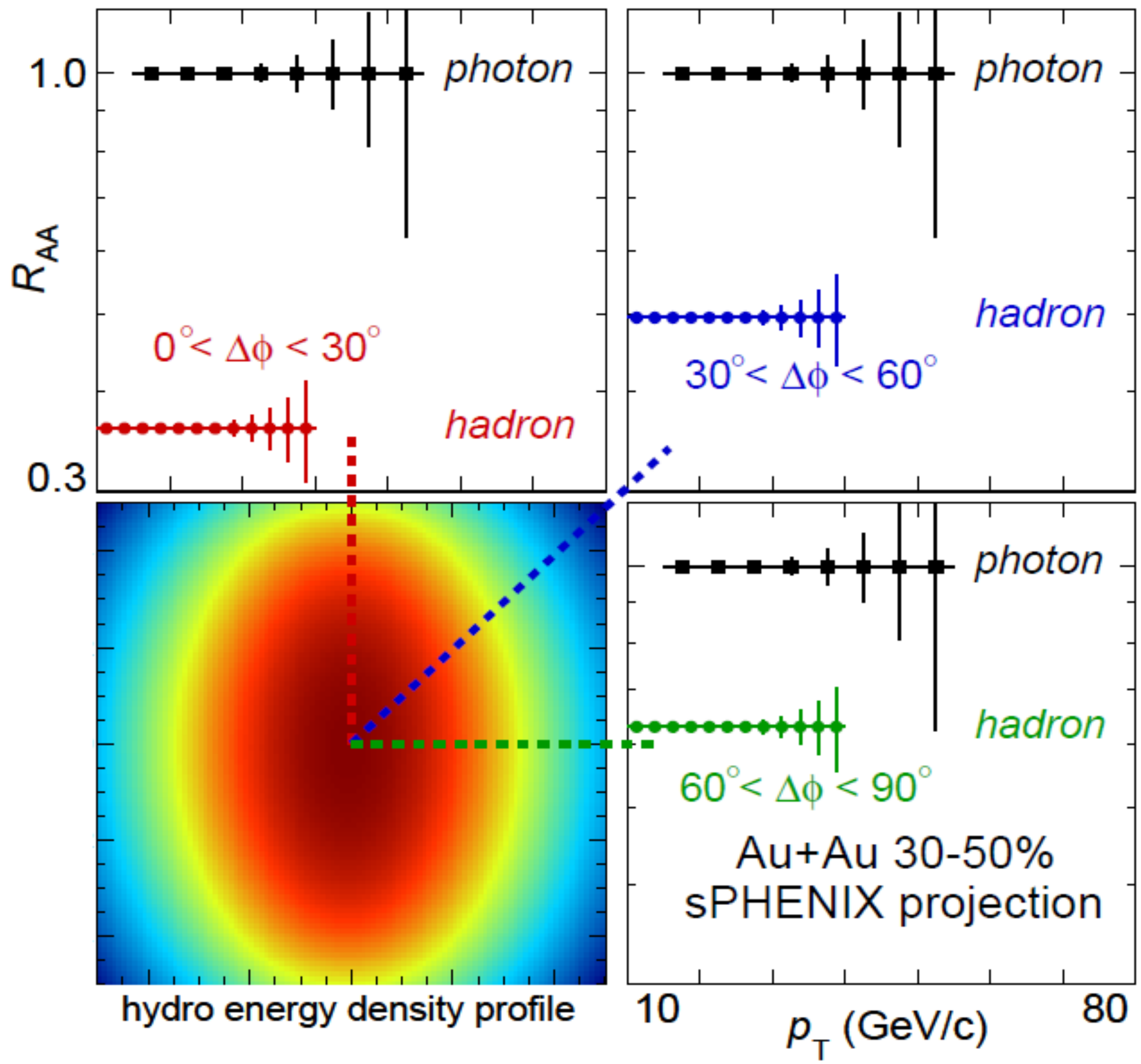




Stable unfolding to recover truth spectrum

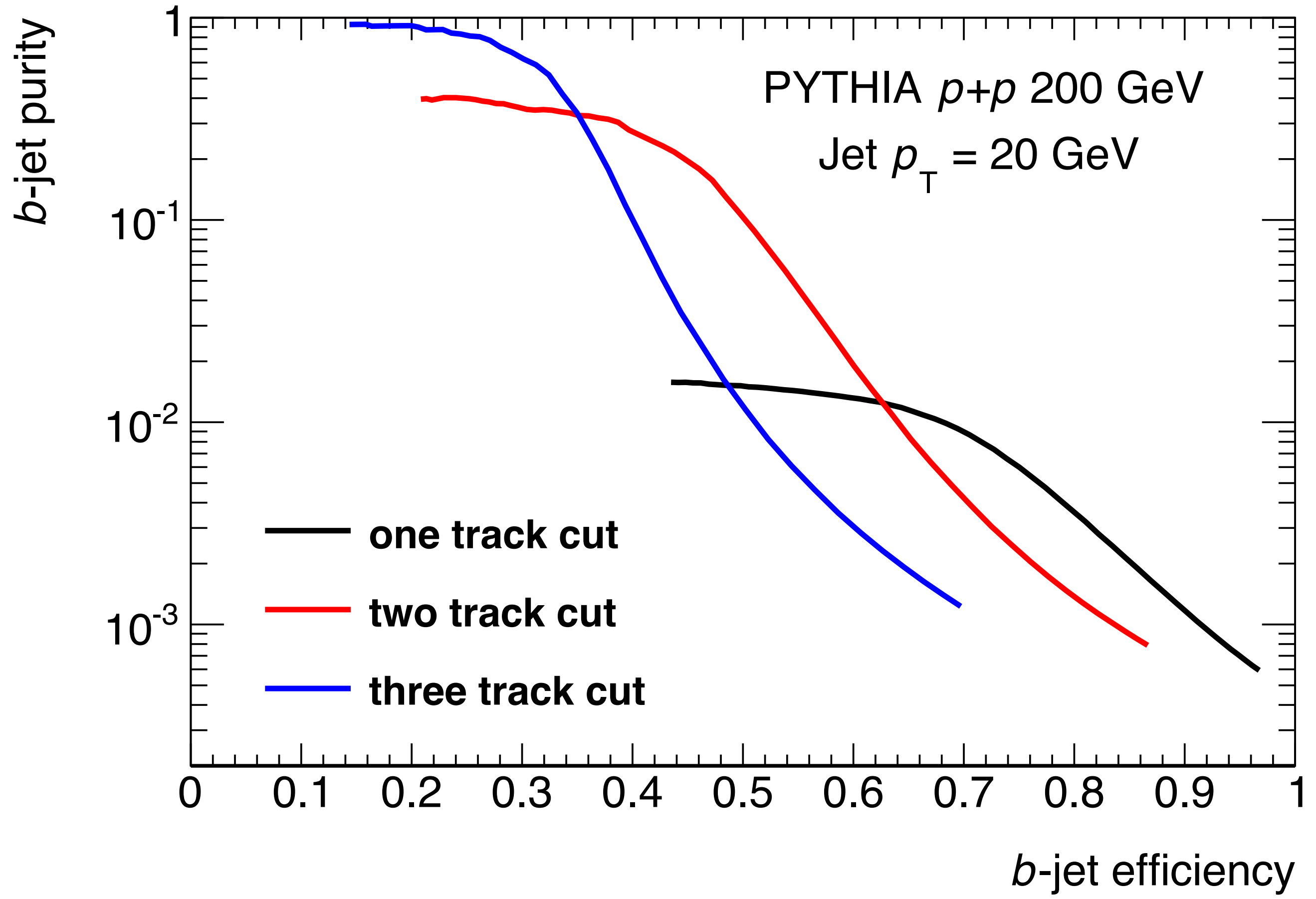
Statistics based on 22 weeks Au+Au, 10 weeks p+p

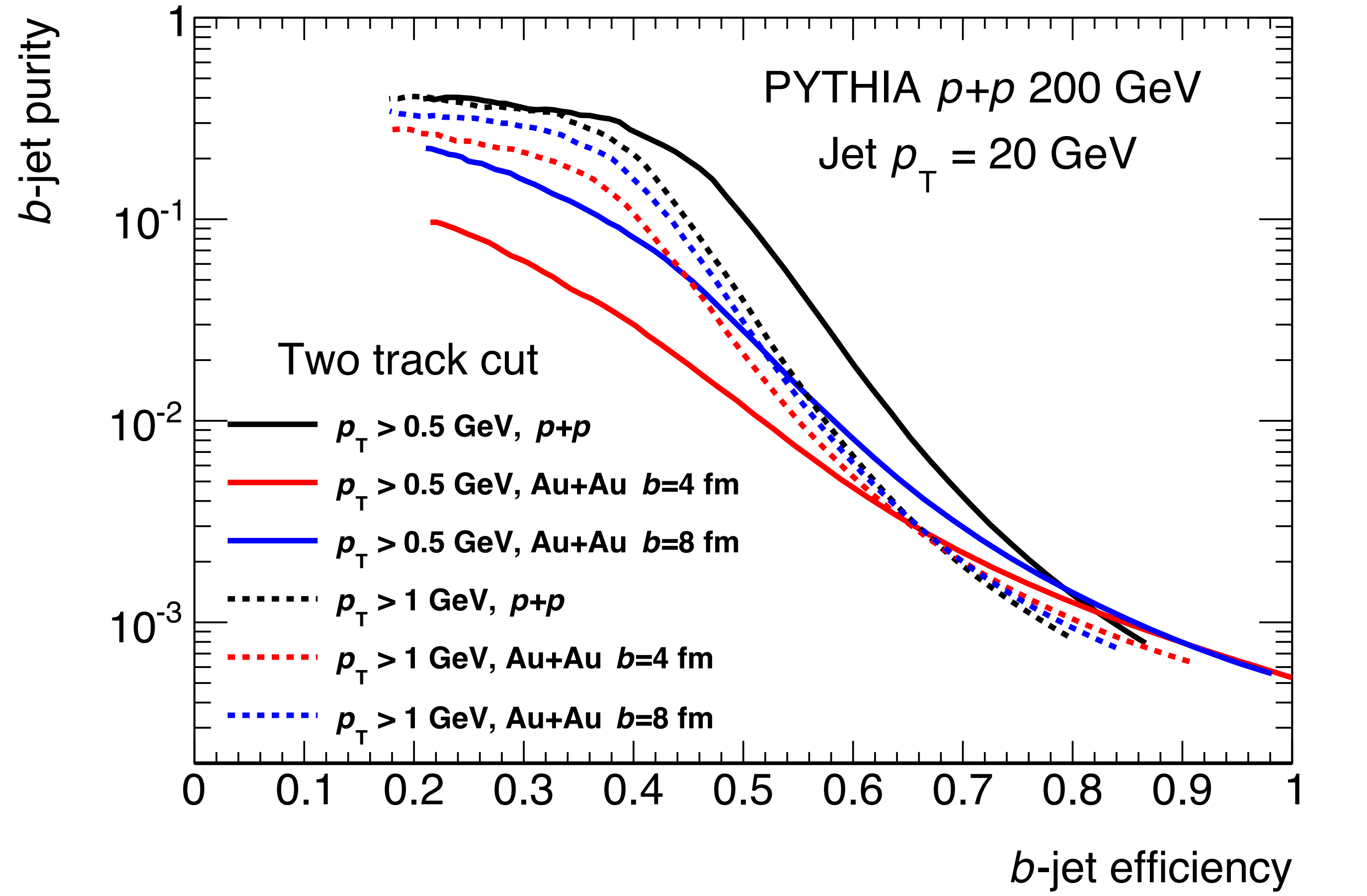
Large rates enable differential measurements



Heavy quark jets

Many algorithms for tagging heavy flavor jets – here, counting tracks with high DCA significance (i.e., don't point back to primary vertex)

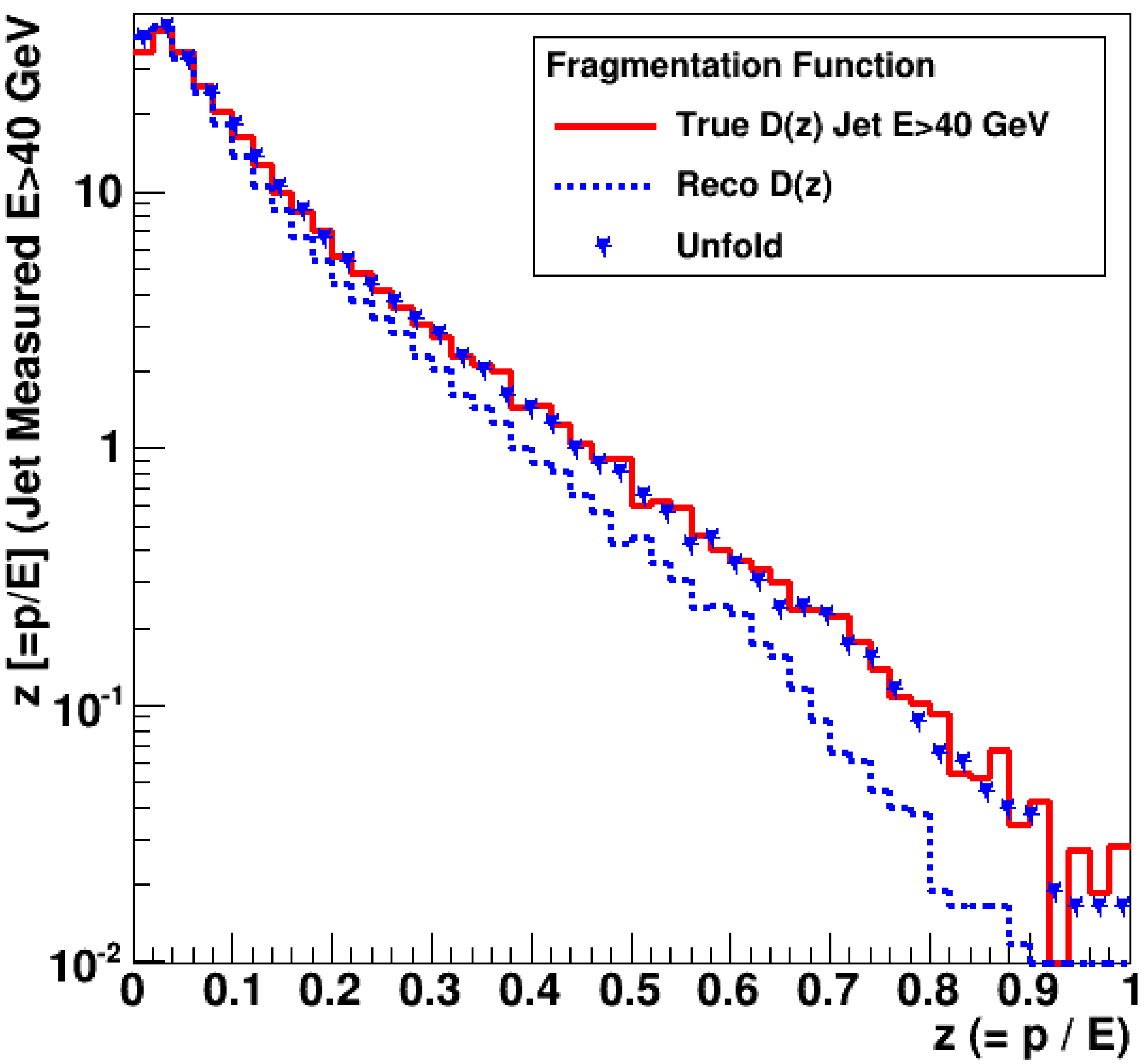




Choose working point with good efficiency and purity

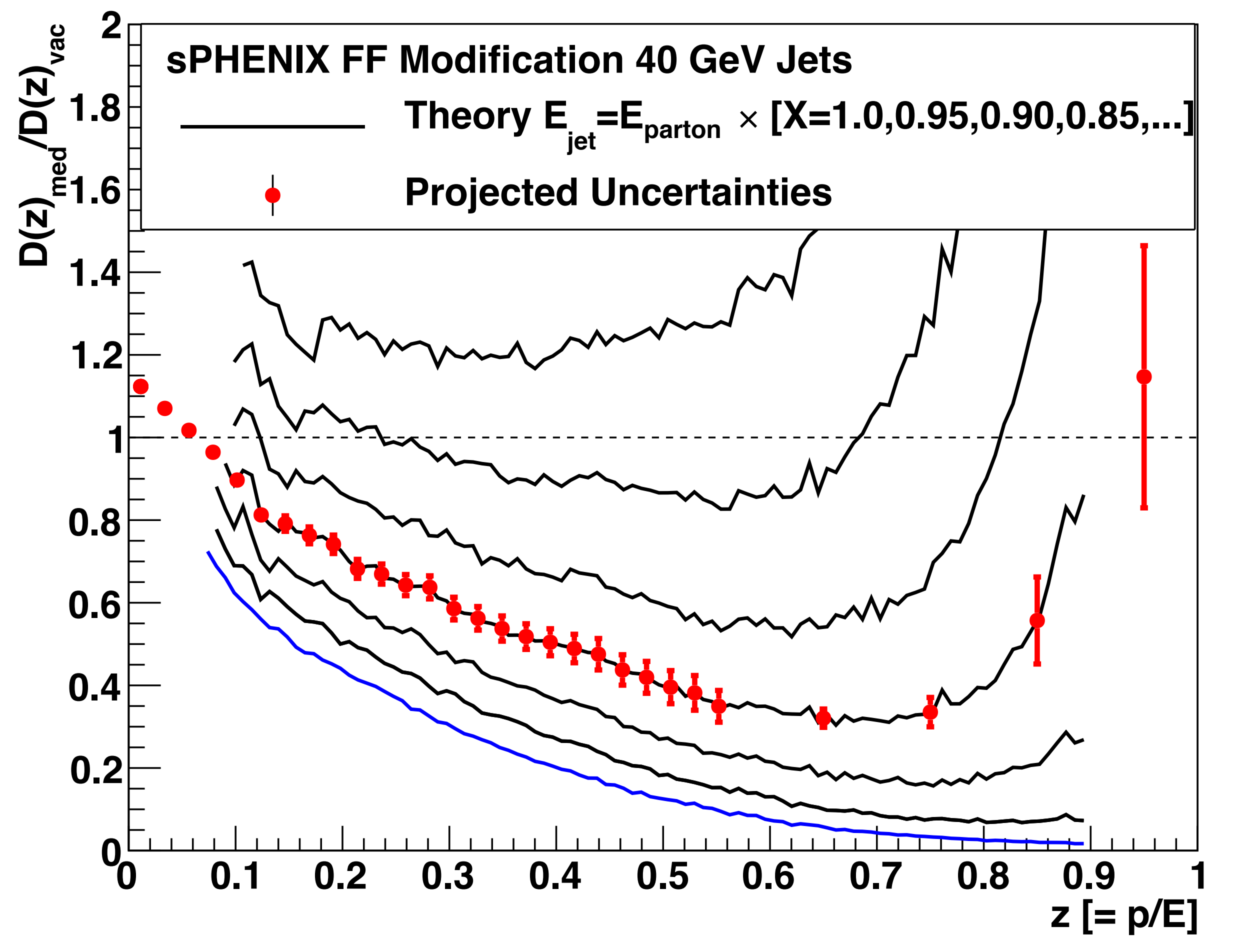
Low momentum cut on tracks works well for Au+Au case

Fragmentation functions and their modification



Reconstructed-level $D(z)$ is generally shifted towards lower values at fixed z – successfully unfolded to recover truth input

Armesto, Cunqueiro, Salgado, and Xiang. *JHEP*, 0802:048, 2008.



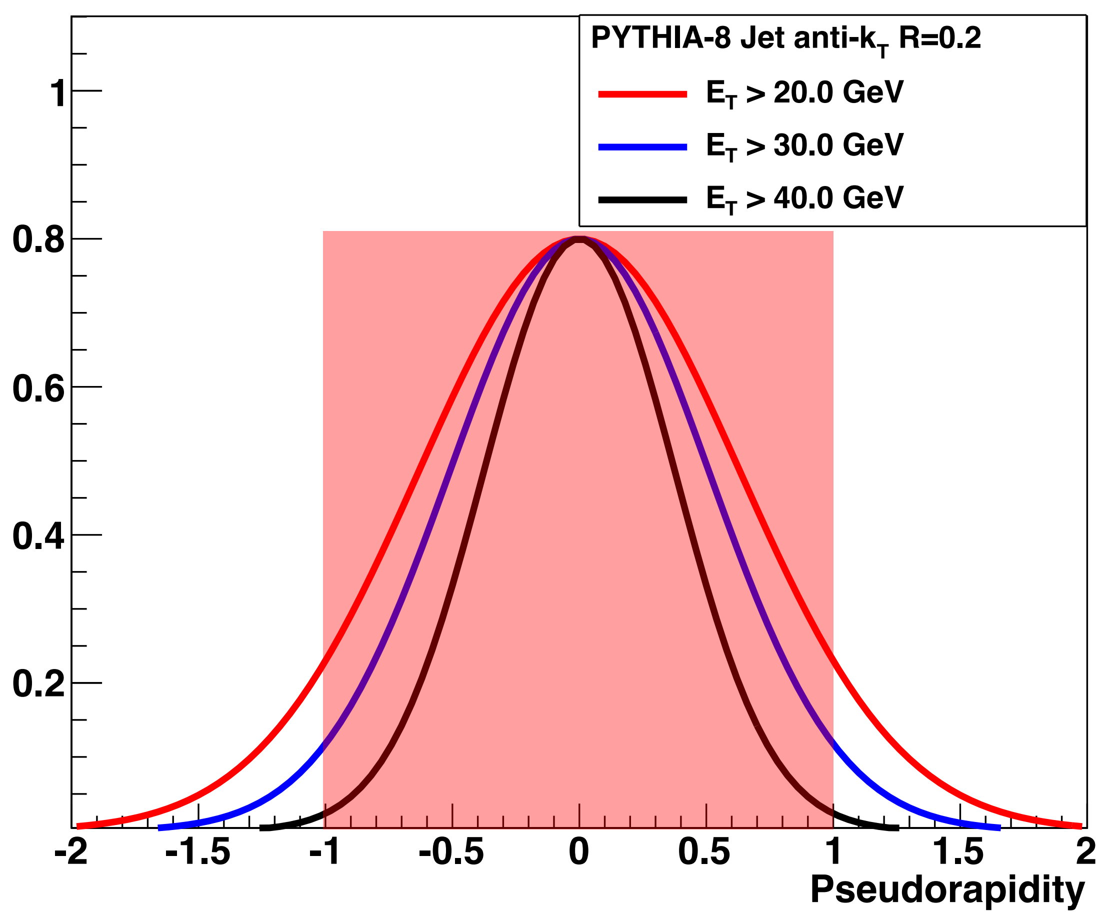
sPHENIX enables precision measurement

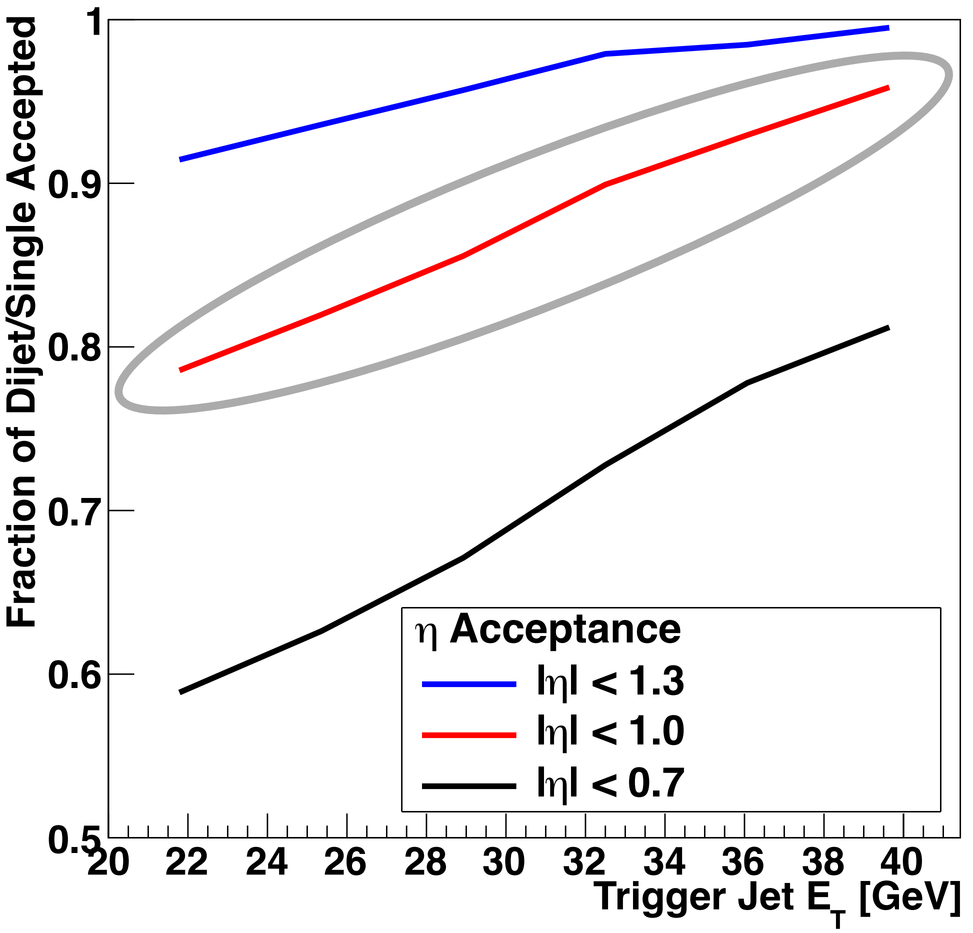
Cannot be done otherwise at RHIC

Coupled with precision measure at LHC across different jet energies and different QGP couplings

Dijets in sPHENIX

RHIC kinematics: for trigger jet of >20 GeV, 80% probability partner jet is in $|\eta| < 1$



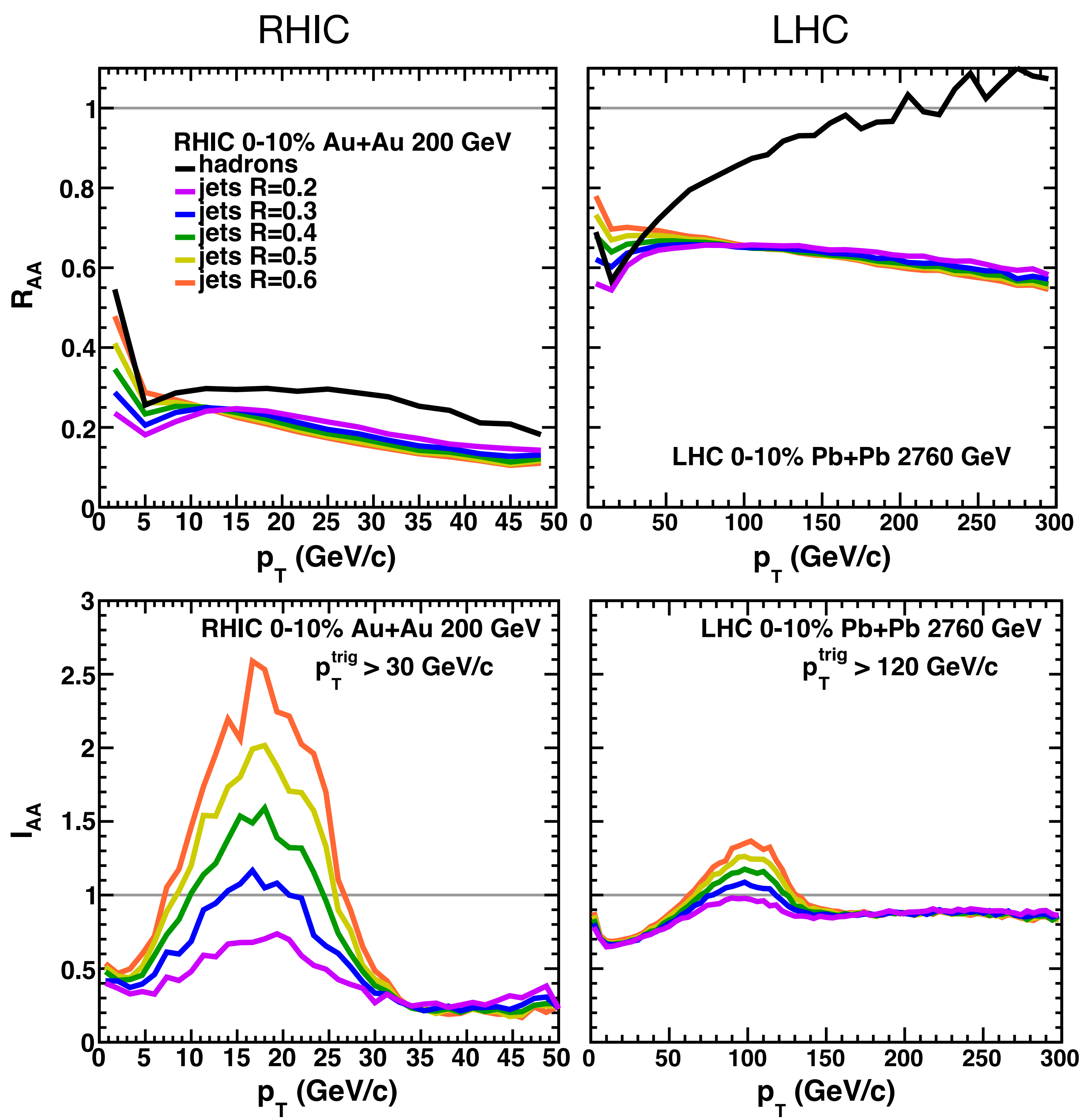


high rate capability of sPHENIX will enable the recording of over 10 million dijet events with $E_T > 20$ GeV, along with a correspondingly large γ+jet sample.

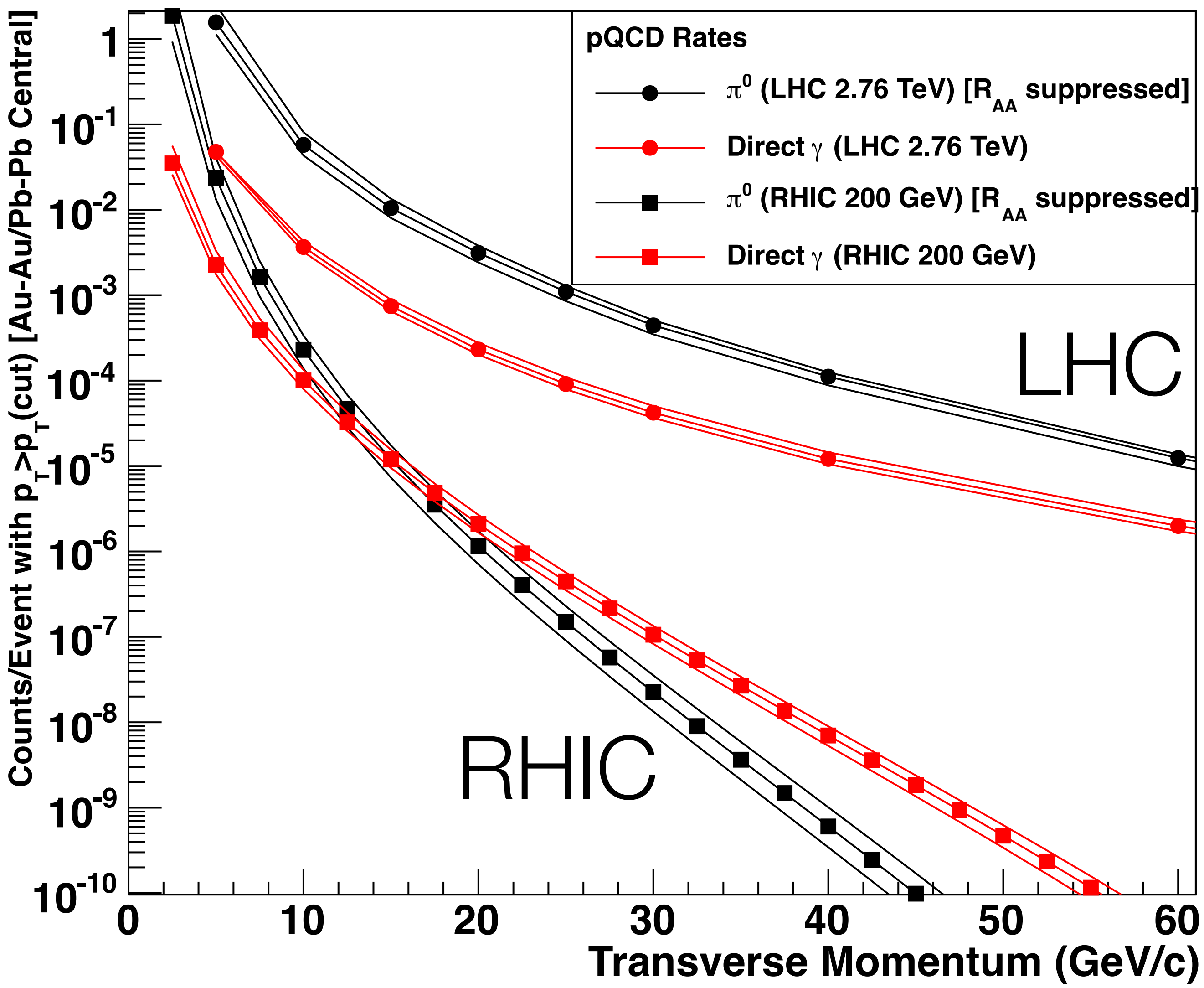
Di-jet sensitivity at RHIC energies

Simulations with JEWEL 2.0 at RHIC and LHC

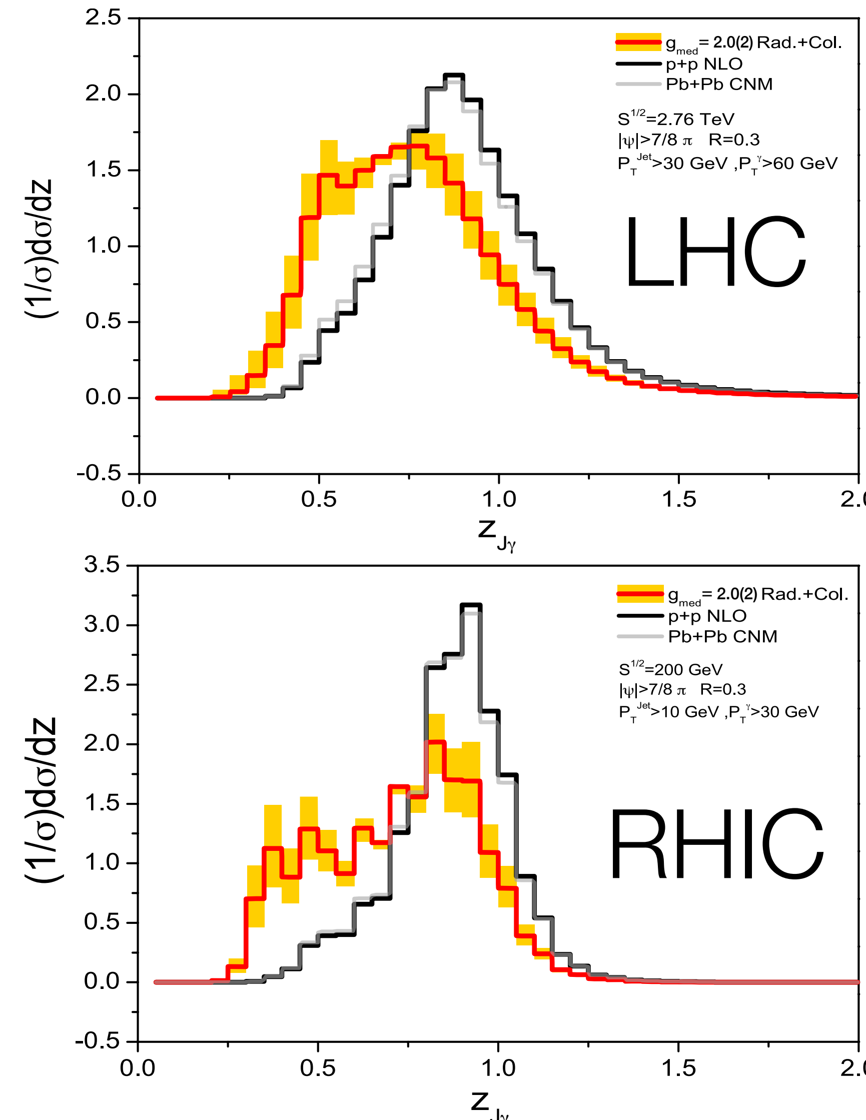
larger surface bias from the trigger jet and a bias for the away-side parton to be a gluon



Direct photons and photon triggered jets



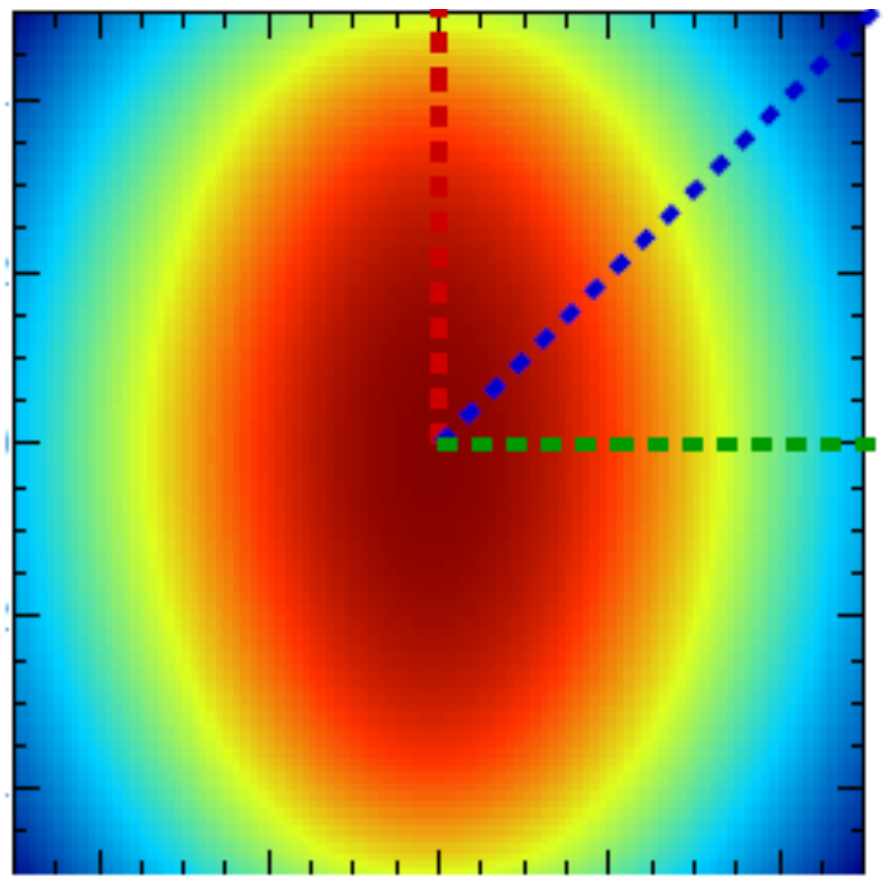
Dai, Vitev, Zhang, PRL 110 (2013) 14, 142001

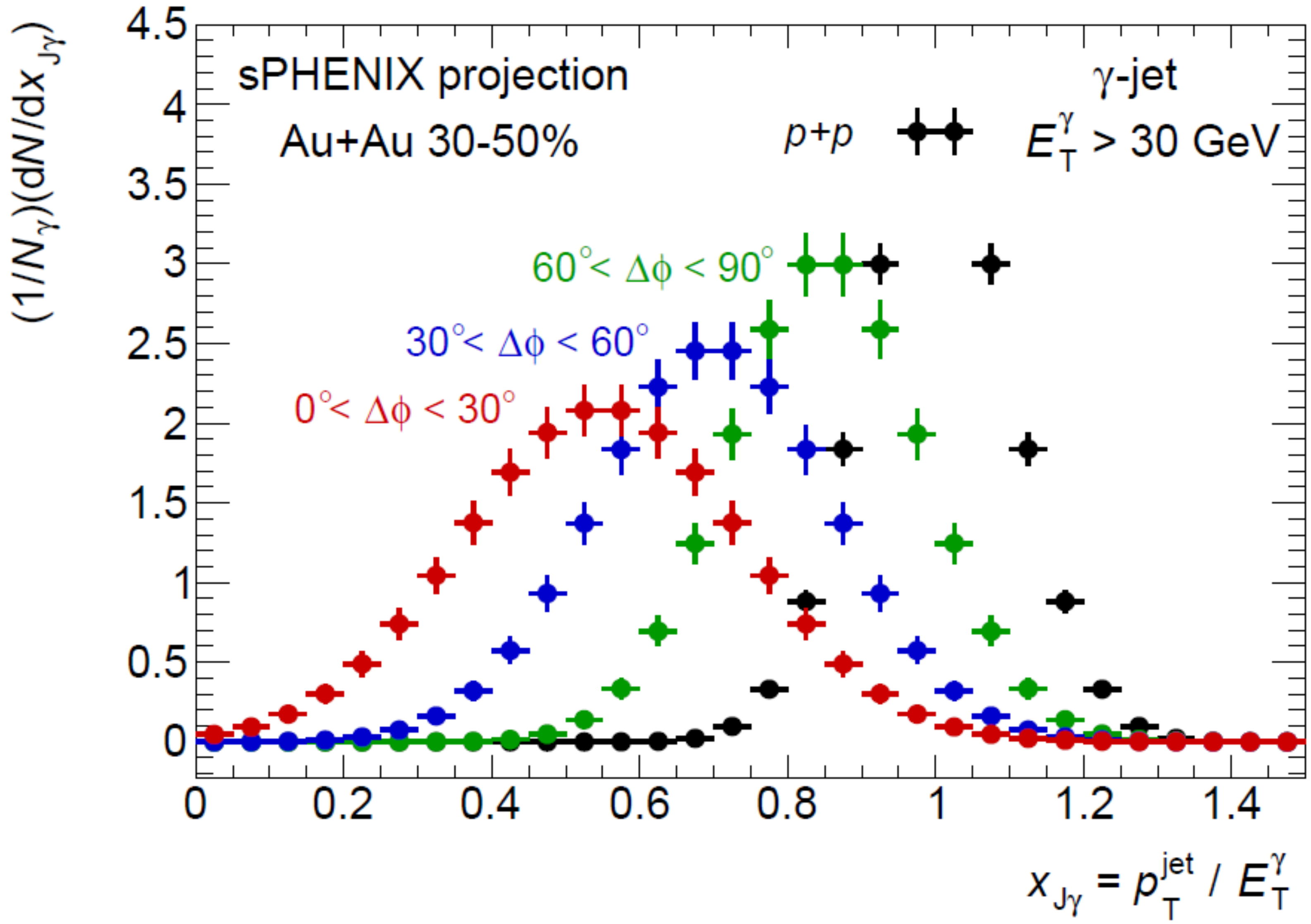


For γ (@ E = 20 GeV), S/B is 20x larger at RHIC; underlying event 2.5x smaller

"The steeper falling cross sections at RHIC energies lead not only to a narrower $z_{J\gamma}$ distribution in p+p collisions but also to larger broadening and shift in the $\langle z_{J\gamma} \rangle$. "

Differential measurements of photon triggered jets





statistical uncertainties based on sPHENIX run plan

sPHENIX physics requires an excellent tracker

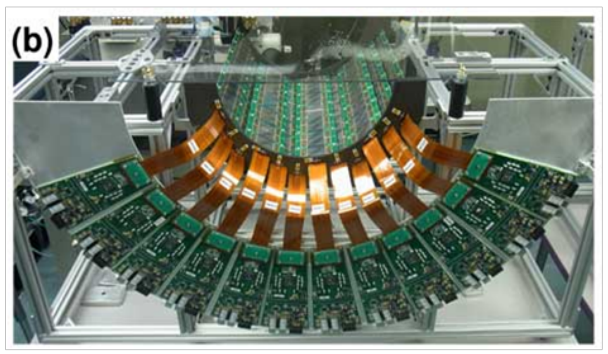
- Mass resolution to distinguish Upsilon states (σ_M < 100 MeV/c^2)
- Excellent (dp/p ~ 0.2%p) momentum resolution to > 40 GeV/c for fragmentation functions
- Precision DCA resolution (σ_{DCA} < 100 μm) for HF jet tagging
- Must handle full Au+Au @ 200 GeV multiplicity and full RHIC luminosity
- Best for all options to fully simulate their physics performance, and to engage experts to solidify an understanding of the technical, engineering and resources needed to realize them

Matrix of tracker technologies

Inner tracker

Reuse PHENIX VTX Components

- Momentum Resolution Limited by Multiple Scattering.
- Significant Dead Area (non-working & gaps)

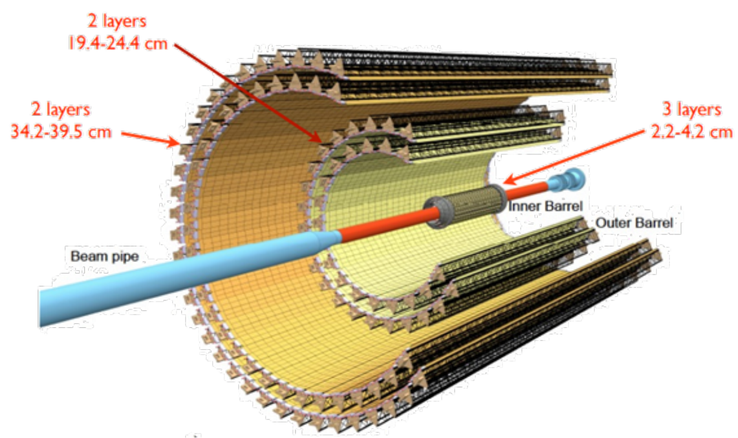


ALICE ITS upgrade detector

All layers composed of pixels.
- Inner three layers: 0.3% / layer
- Outer four layers: 0.8% / layer

Total thickness X/X_0 = 4.1%

Pixel sizes:
inner barrel 20-30 x 20-30 μm
outer barrel 20-50 x 20-50 μm



Existing PHENIX pixel detector currently achieves 60 μm @ p_T > 2 GeV/c DCA resolution (50 μm evt vertex; 30 μm pixel) – MAPS technology would improve this due to smaller pixels and less material.

Outer tracker

New PHENIX-like Components

- Straightforward technology.
- Fast (no event pileup).
- Multiple-Scat limited.
- Little PID capability

Compact TPC (ala ALICE?)

- Higher momentum resolution
- Smaller Bremsstrahlung tails.
- Leverage ALICE R&D
- PID via dE/dx & neutral V's.

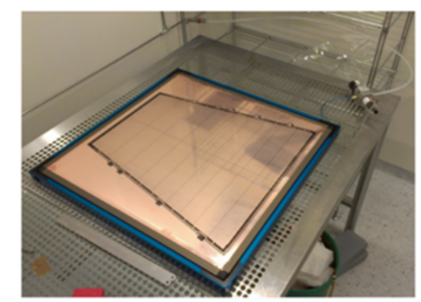
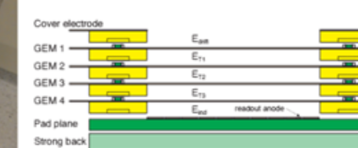


Figure 4.7: Photograph of an IROC GEM foil in the stretching frame.



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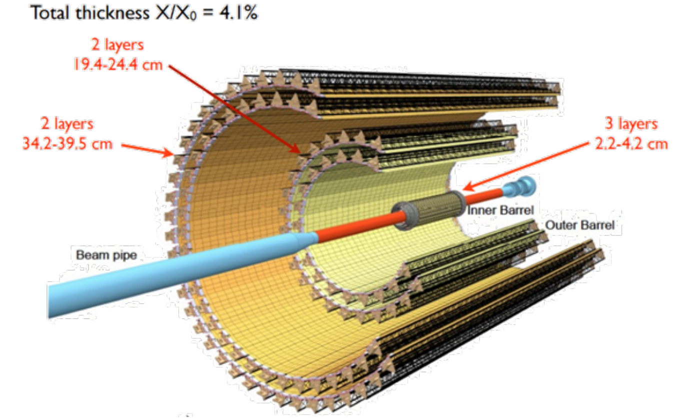
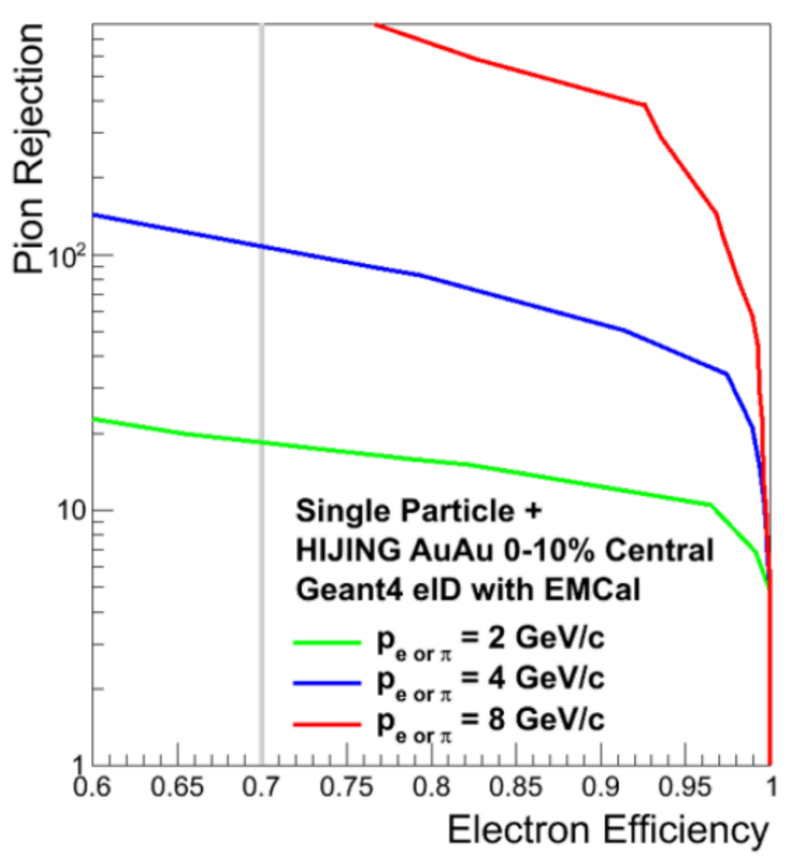
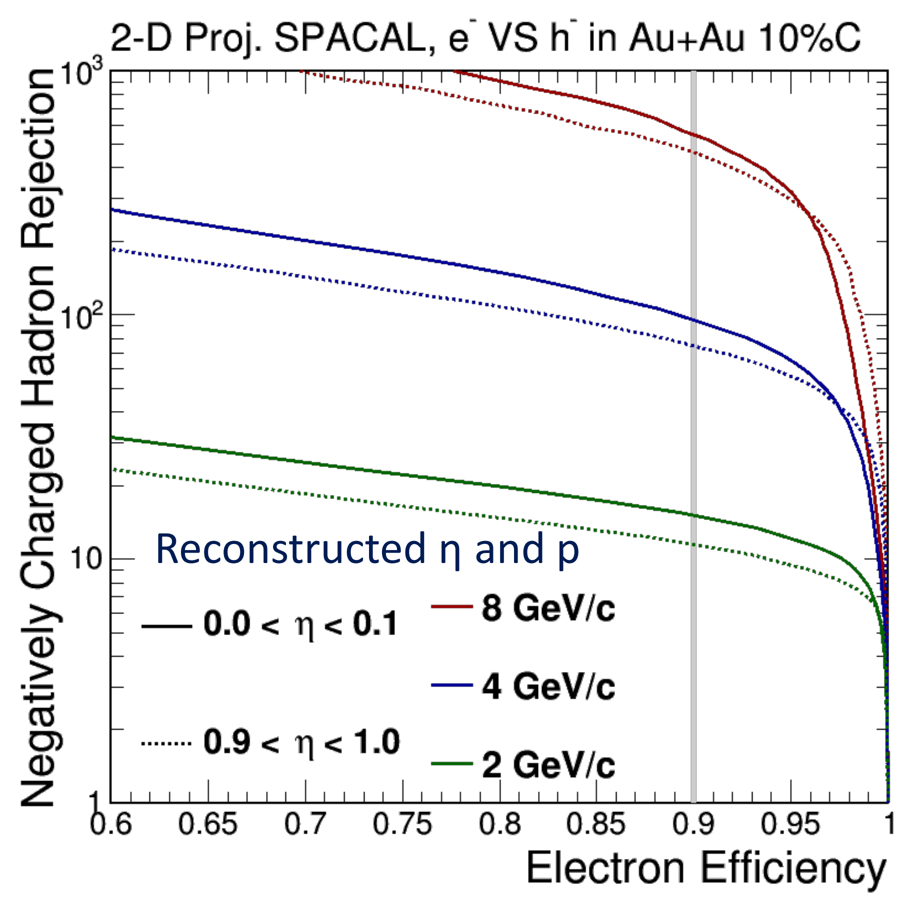
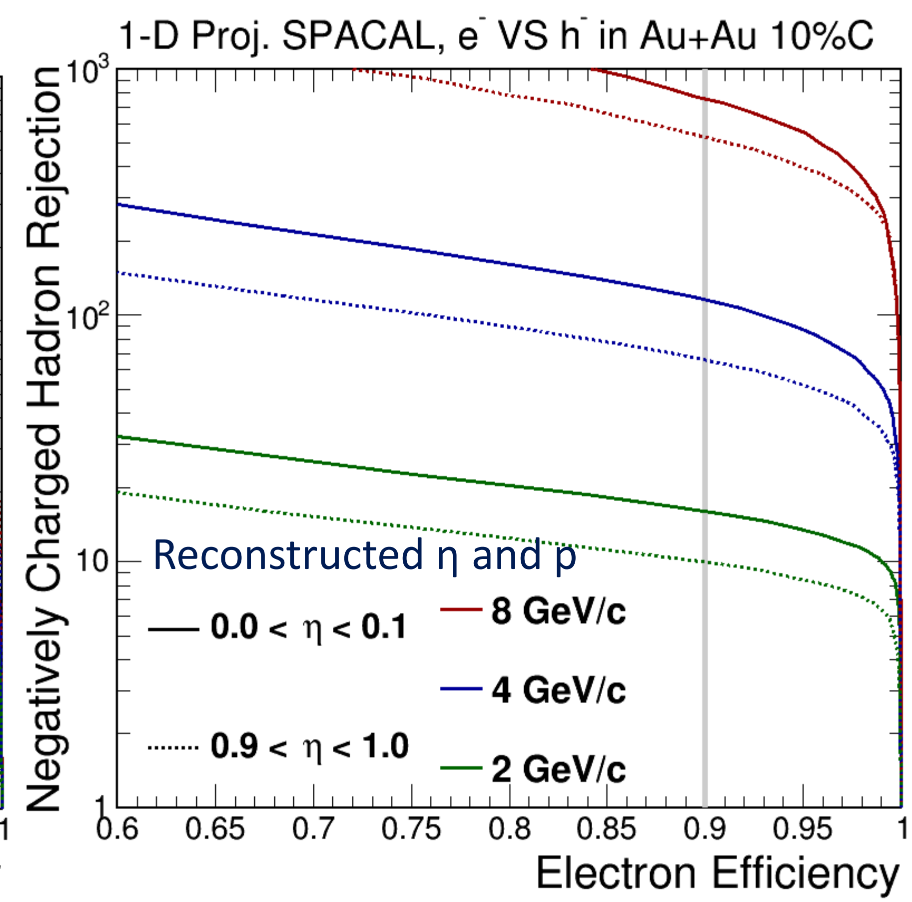


Performance : electron-ID in Au+Au

Updated and more detailed simulation show good safety margin on electron-ID performance on top of the baseline design (as required to reach Upsilon program physics goal)







Baseline performance,
design goals

- Sum all scintillator energy
- 1D SPACAL material with hits grouped into 2D SPACAL towers

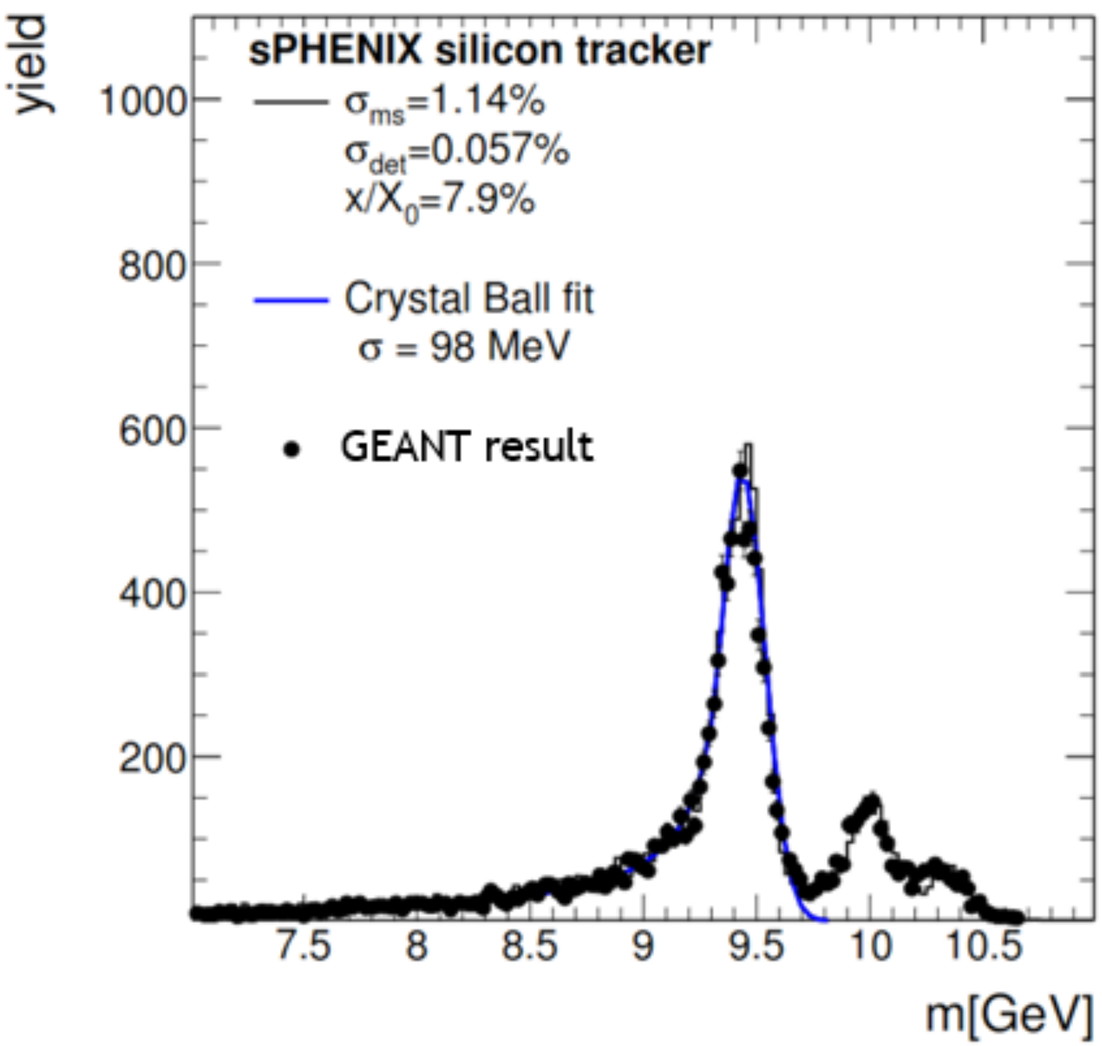
2D projective SPACAL

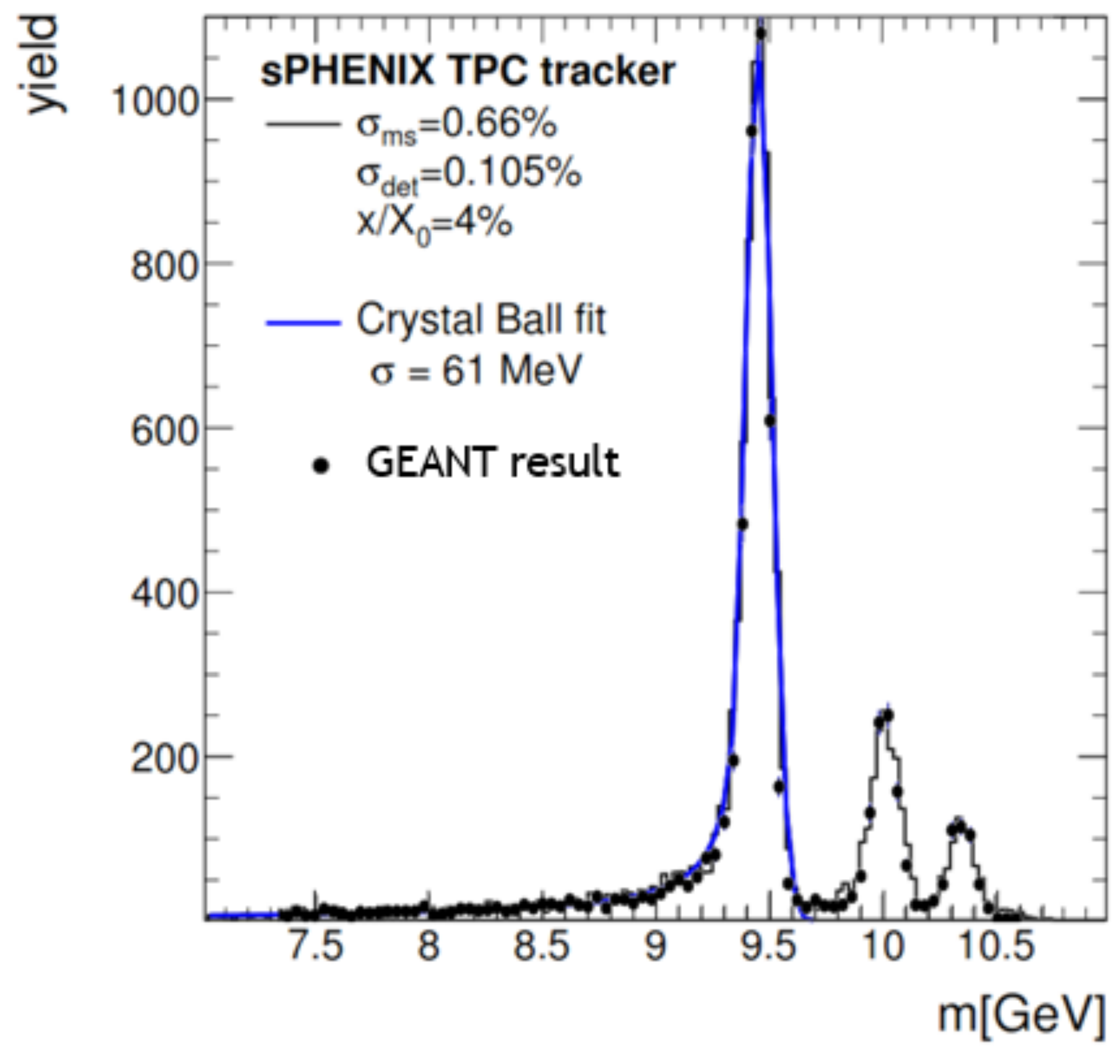
- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
- Full digitization (w/ Birk corrections)
- Full tracking with silicon opt.
- Fully implemented 2D SPACAL (tower/support structure)

1D projective SPACAL

- Updated studies (Preliminary)
- Sum all hadron taking account of hadron ratio
- Full digitization (w/ Birk corrections)
- Full tracking with silicon opt.
- Ideally towering (no-tower boarder, no enclosure structure)

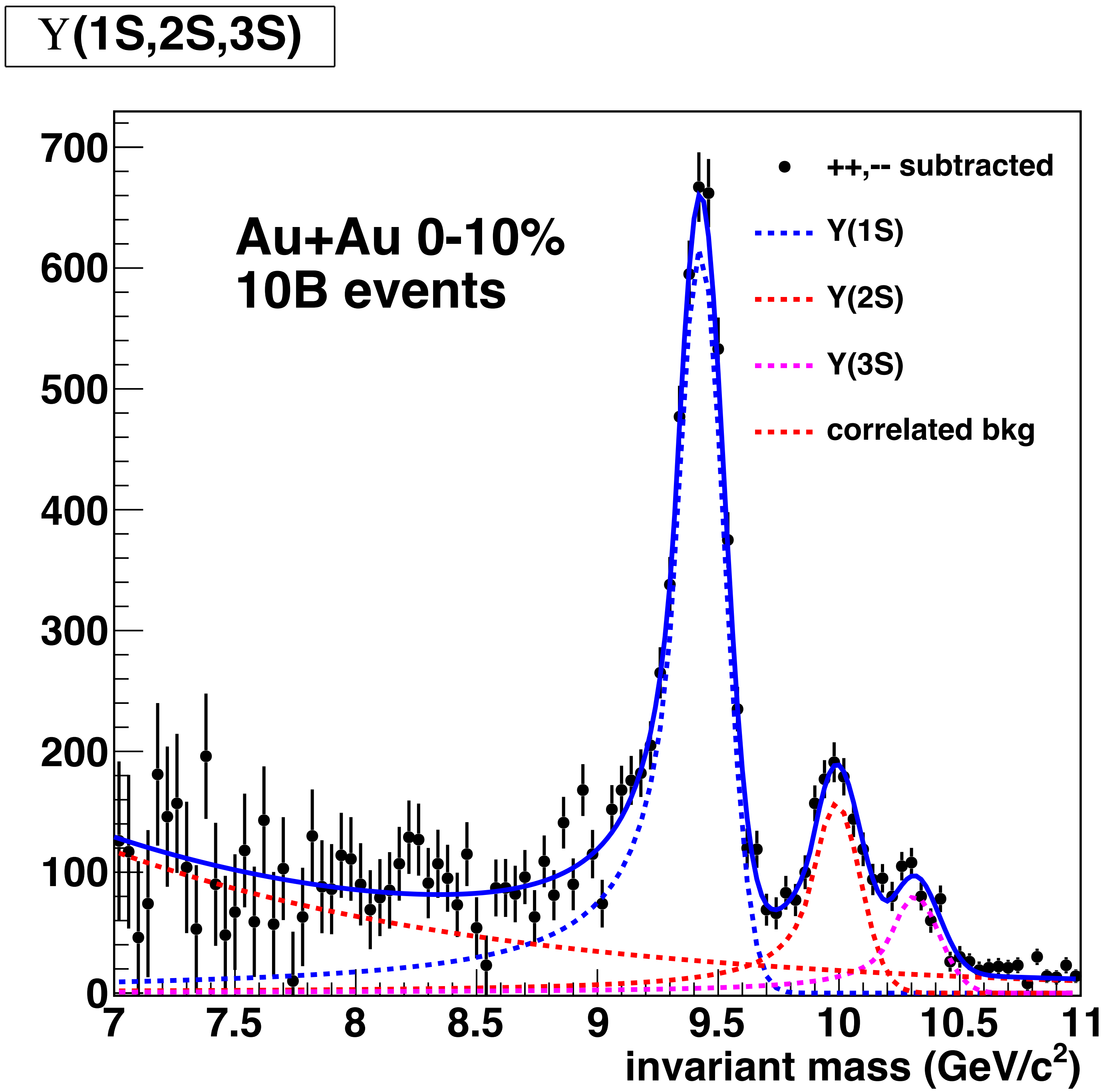
Upsilon mass resolution in *p+p*





Silicon strip outer tracker (reference design from proposal) and a modern compact TPC provide excellent separation of Upsilon states

Resolving the Upsilon states in Au+Au

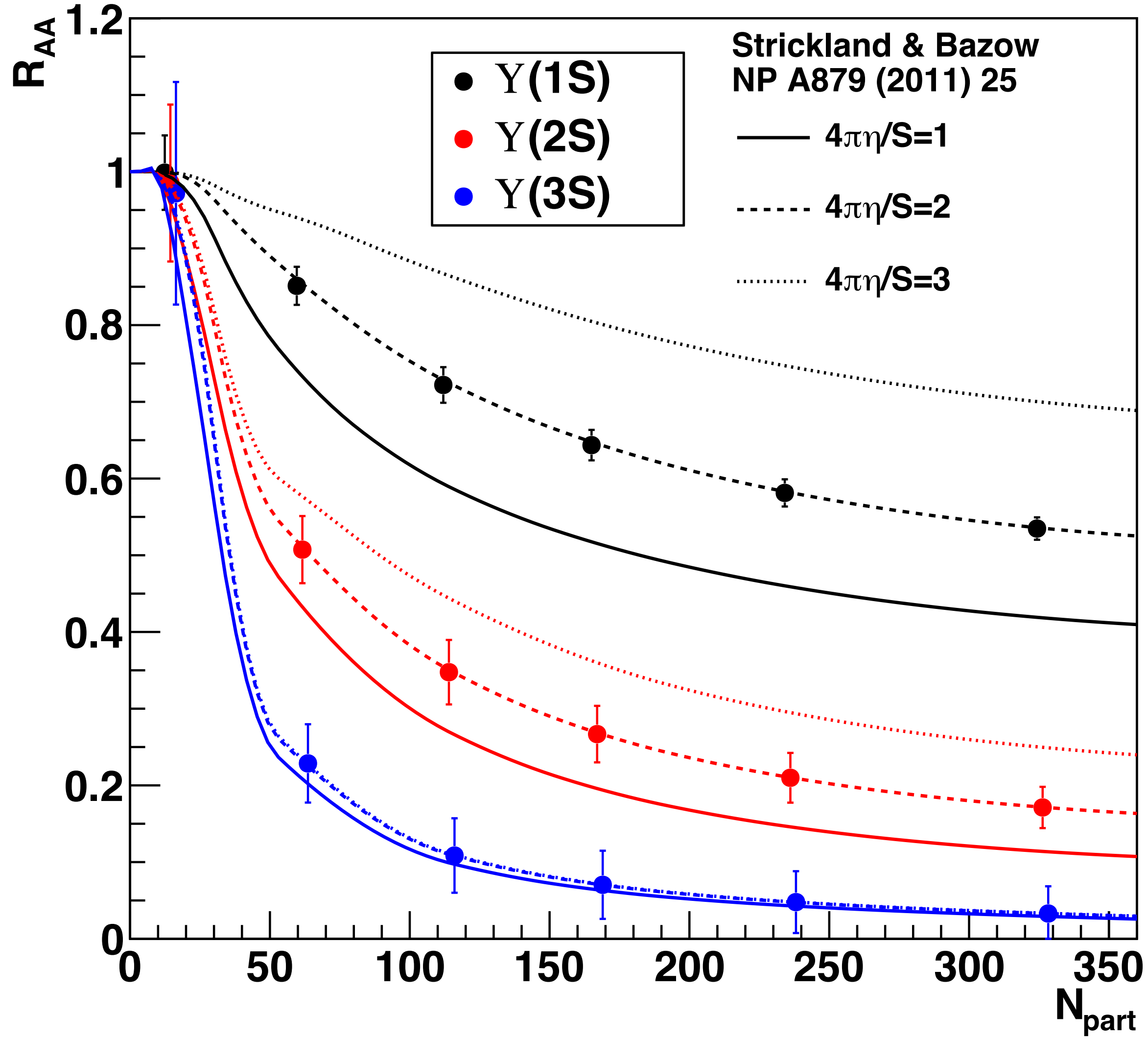


combinatorial background from misidentified charged pions (removed by like sign or mixed event subtraction)

correlated charm and bottom di-electron invariant mass distributions predicted by PYTHIA normalized to the PHENIX measured charm and bottom cross-sections in Au+Au collisions.

Upsilon measurement in Au+Au

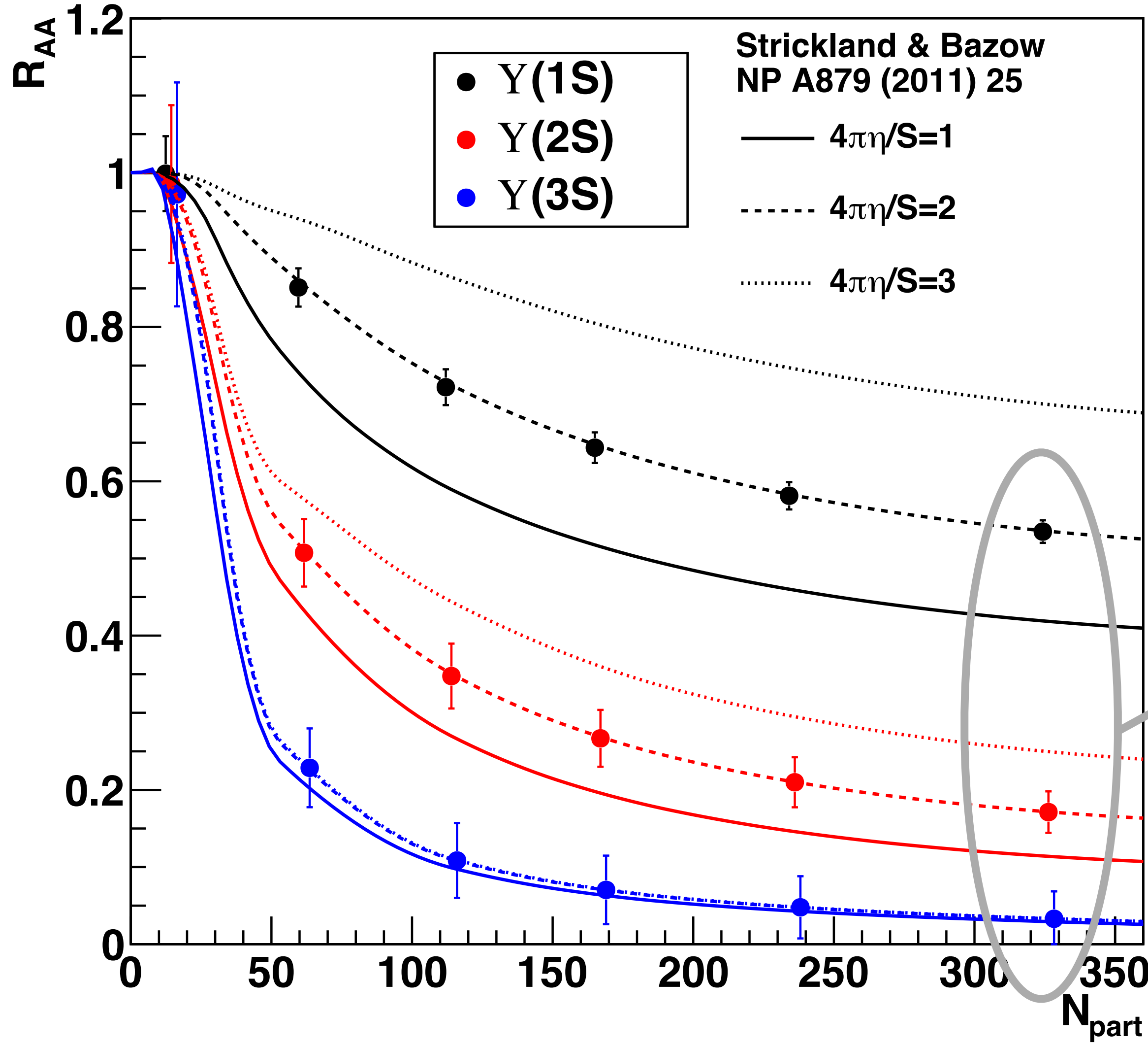
centrality dependence of
separated states



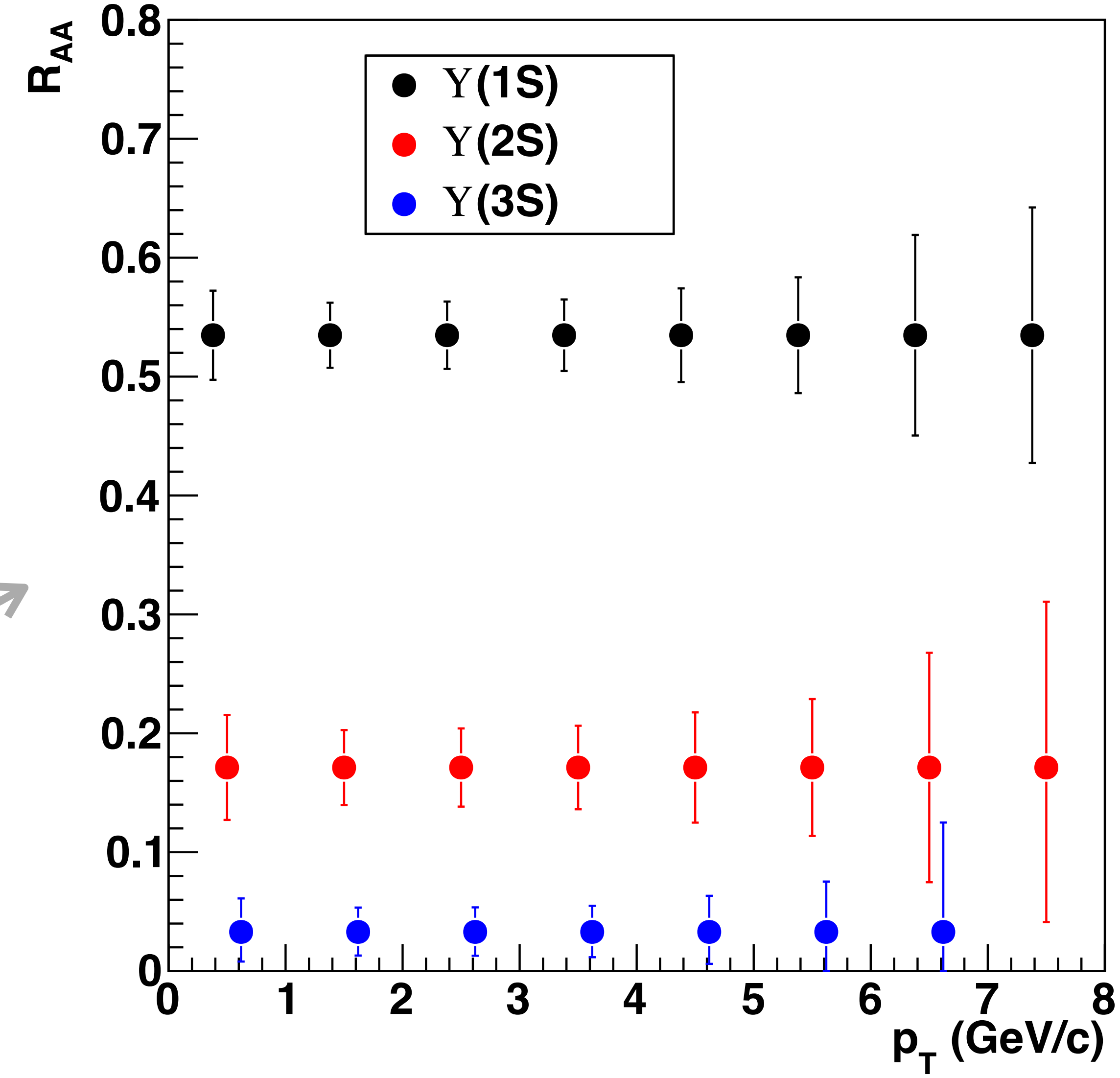
statistical uncertainties based on 22 weeks Au+Au, 10 weeks p+p

Upsilon measurement in Au+Au

centrality dependence of separated states

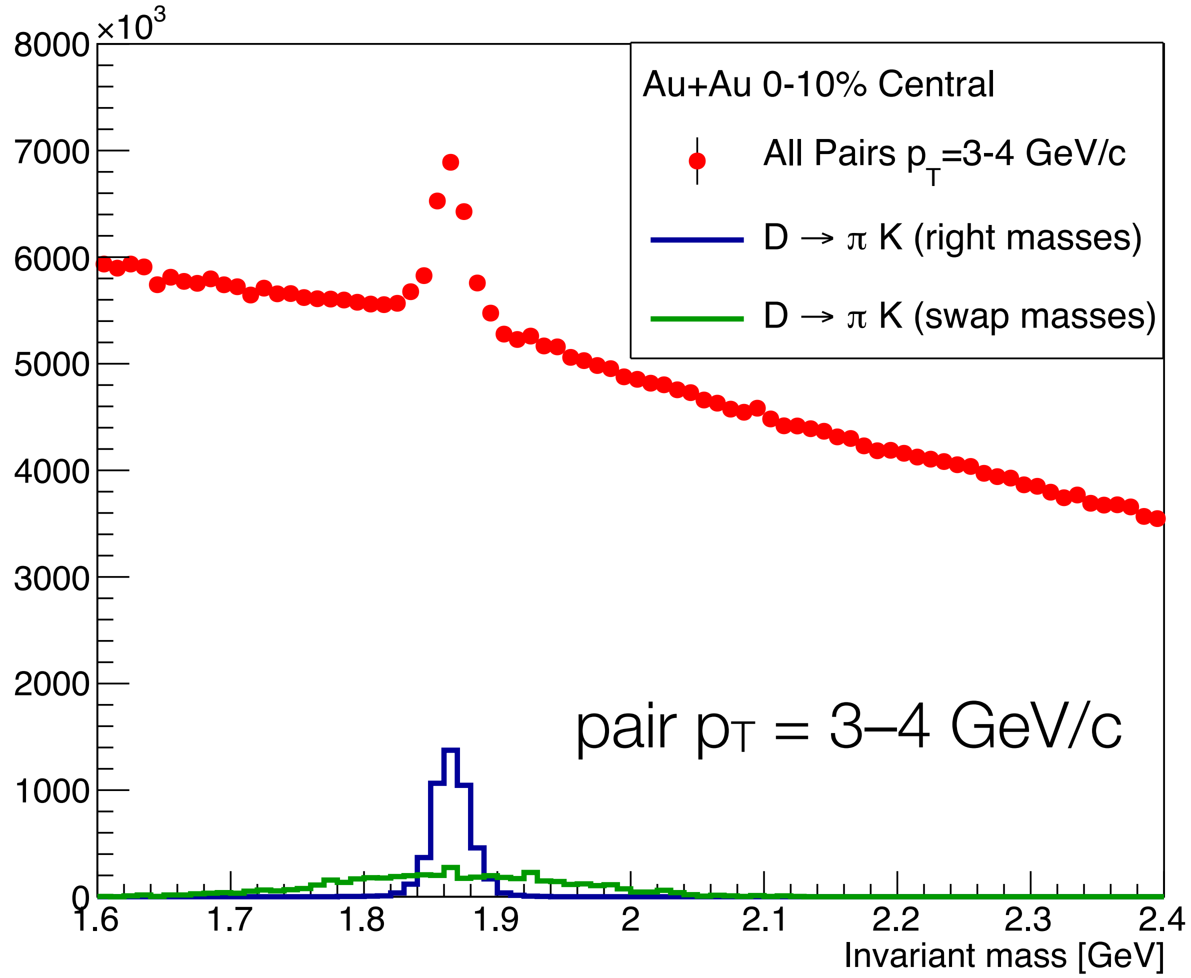


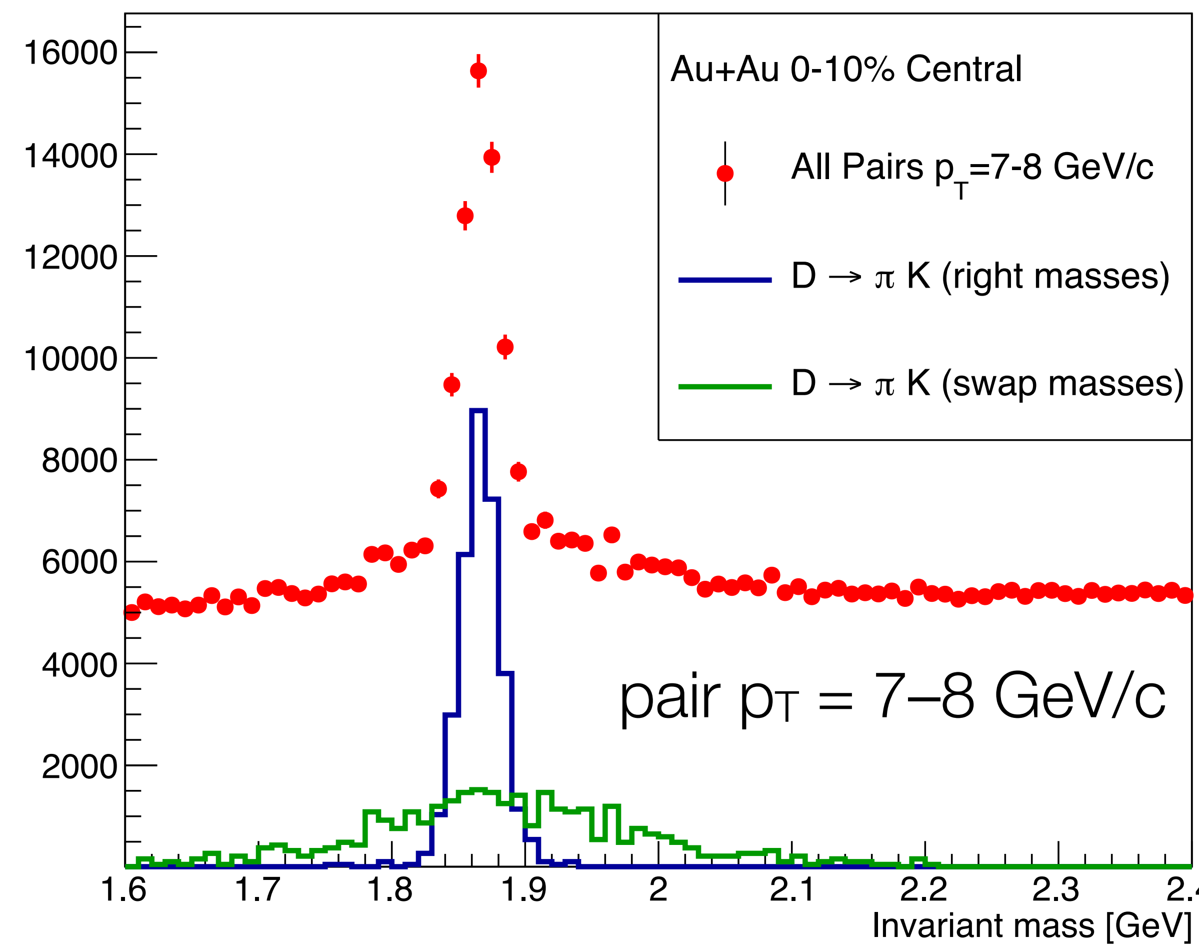
p_T dependence of centrality selected data



statistical uncertainties based on 22 weeks Au+Au, 10 weeks p+p

High p_T D mesons

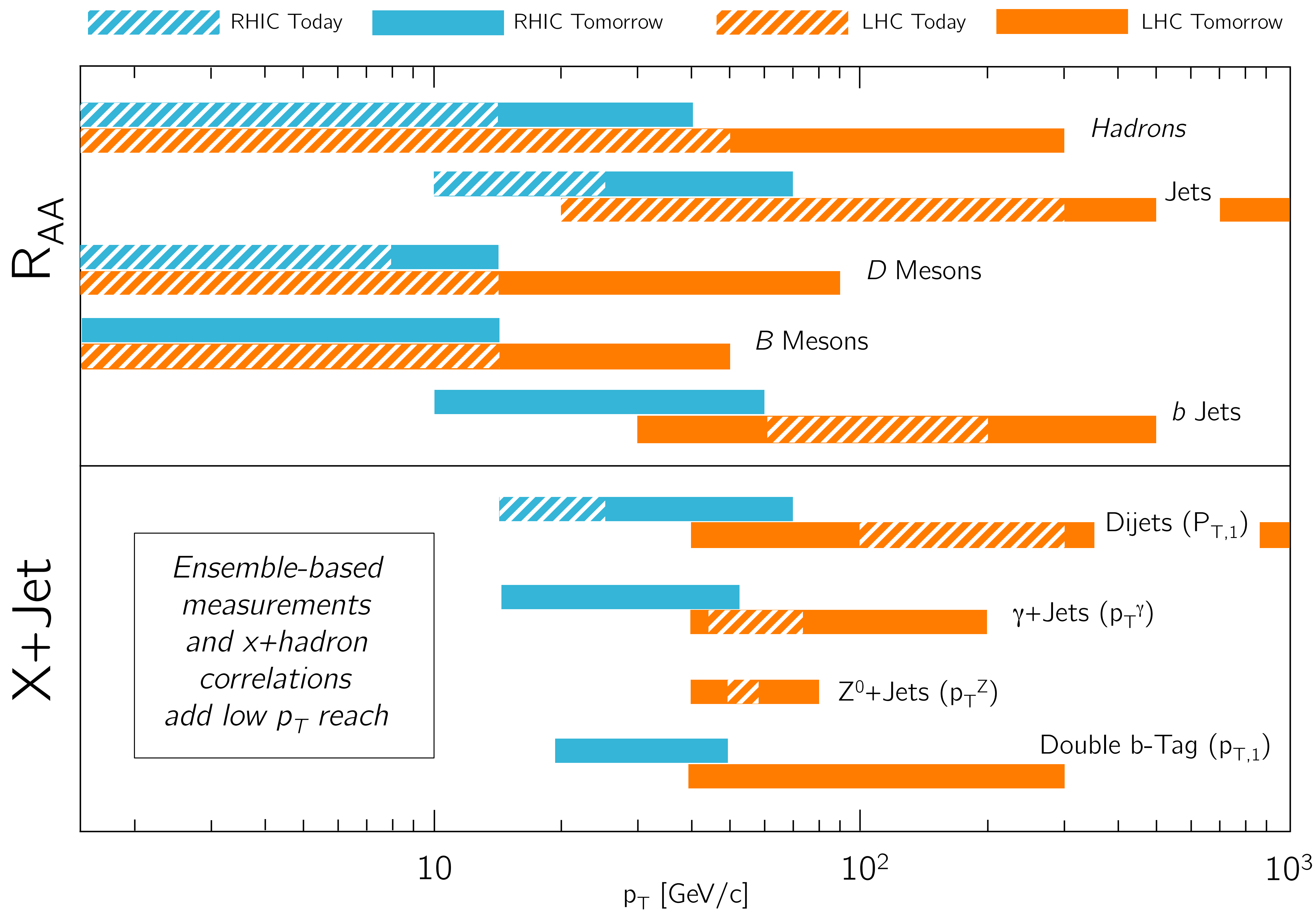




each track DCA > 100 µm, pair displaced vertex: 200 – 800 µm, pair direction angle < 1 (angle between D^0 momentum and the direction to displaced vertex)

similar to CMS approach described by Yen-Jie Lee

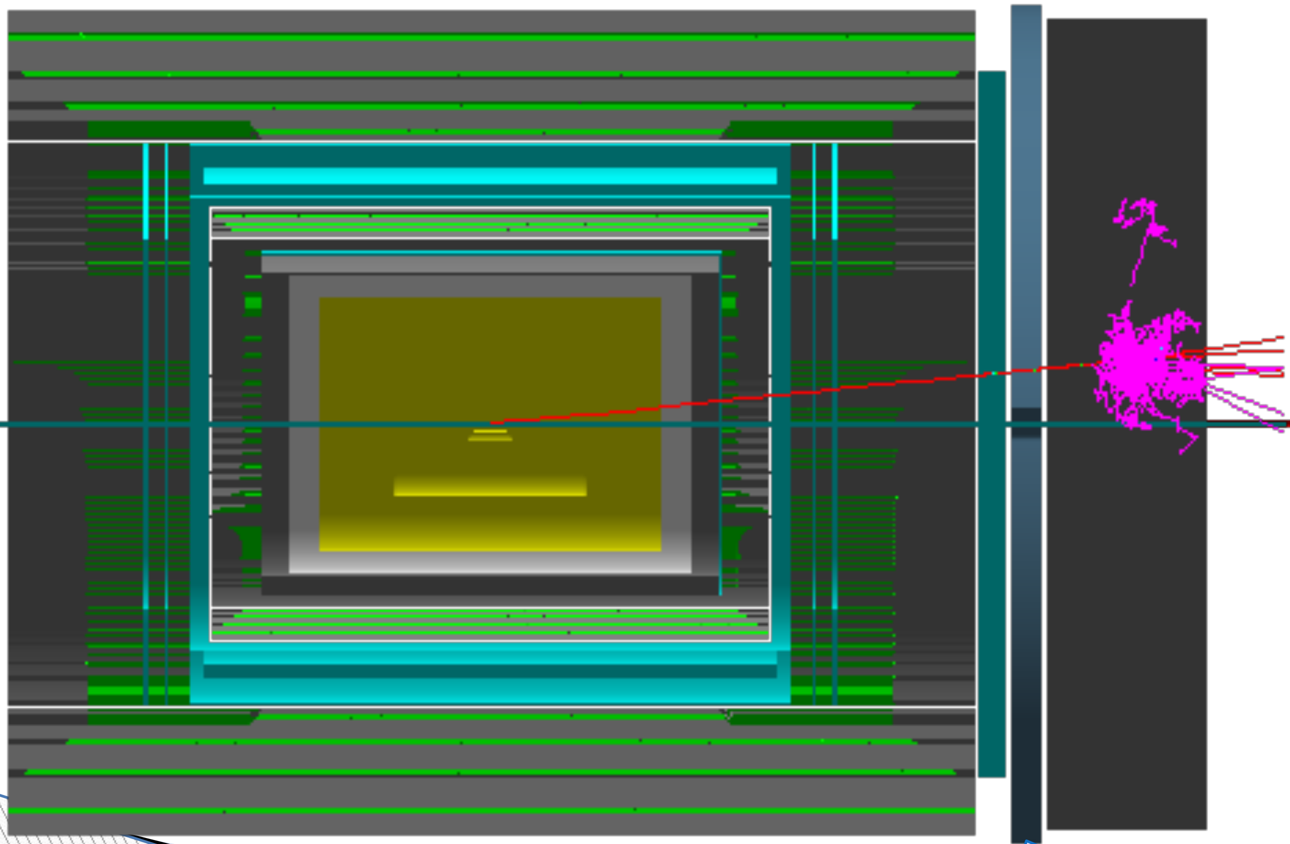
sPHENIX will complement LHC measurements



Forward calorimeters and towards EIC

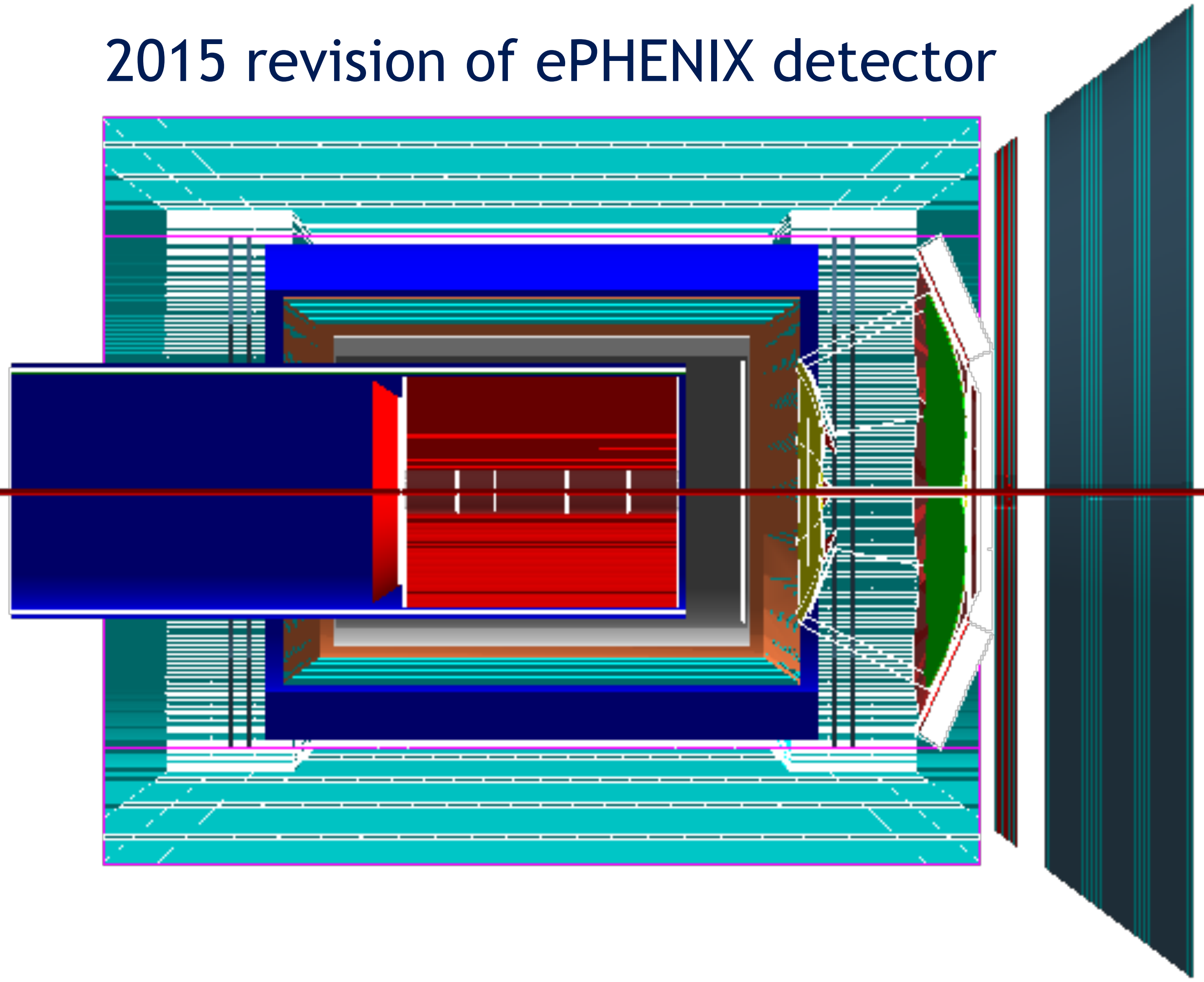
- Calorimeter simulation also extends to forward under the same framework
- fsPHENIX/EIC series of meetings: https://indico.bnl.gov/categoryDisplay.py?categId=93

30 GeV/c pion shower in forward EMCal + HCal



sPHENIX magnet end door

2015 revision of ePHENIX detector



Where do things stand?

- Successful DOE review of sPHENIX science case April 2015 – hopeful that DOE will make a positive “CD-0” decision soon
- In any case, “pre-conceptual” activities underway
  - EMCal and HCal design, engineering and prototyping progressing
  - Inspection of BaBar magnet, planning for magnetic field tests
  - Engineering concept for installation and infrastructure well along
  - BNL-convened review of cost and schedule took place November 9–10, 2015

You need more than a detector …

Inaugural sPHENIX Collaboration meeting December 10–12, 2015 at Rutgers University — 90 participants (in person plus participating remotely), 60 institutions.

You also need workshop like this one … many thanks to Ivan Vitev, Cesar da Silva, Zhongbo Kang, Chris Lee, Mike McCumber.