R_{AA} Measurements in PHENIX

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for the PHENIX Collaboration

Overview

Centrality Dependence of R_{AA}

System Size and Energy Dependence

Medium modification of jets

R_{AA}

"Ratio of measured particle yields to what would have been measured if a Heavy -Ion collision was just a superposition of independent p-p collisions"

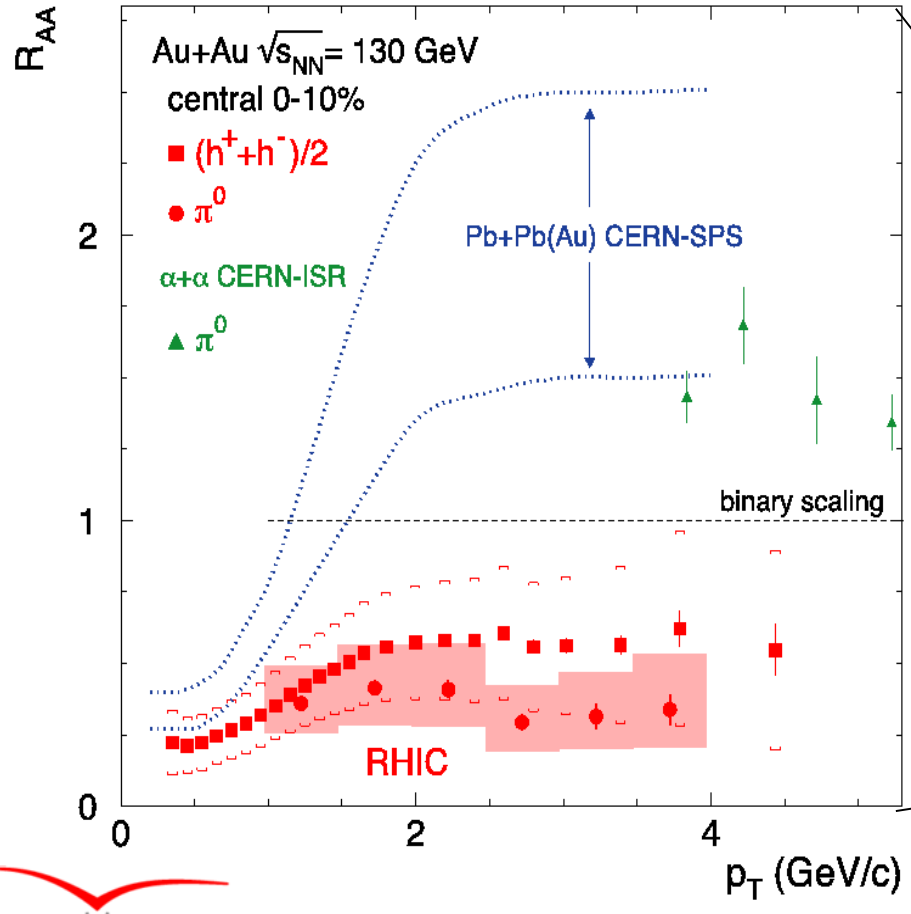
If it is just such a superposition, the ratio is 1, by definition

Any deviation denotes differences to a simple-minded superposition image

$$R_{AA}(p_T) = \frac{yield(AuAu)/N_{coll}}{yield(pp)}$$

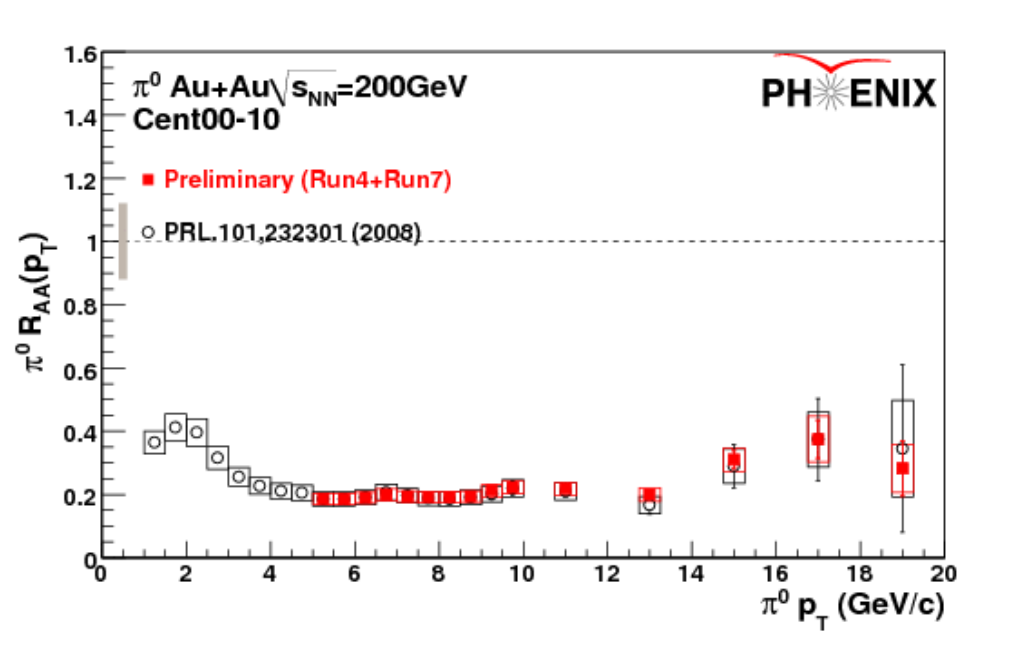
10 Years Ago - QM2001

10 Years ago we discovered π^0 suppression at RHIC



PHENIX

One Decade Later - QM2011

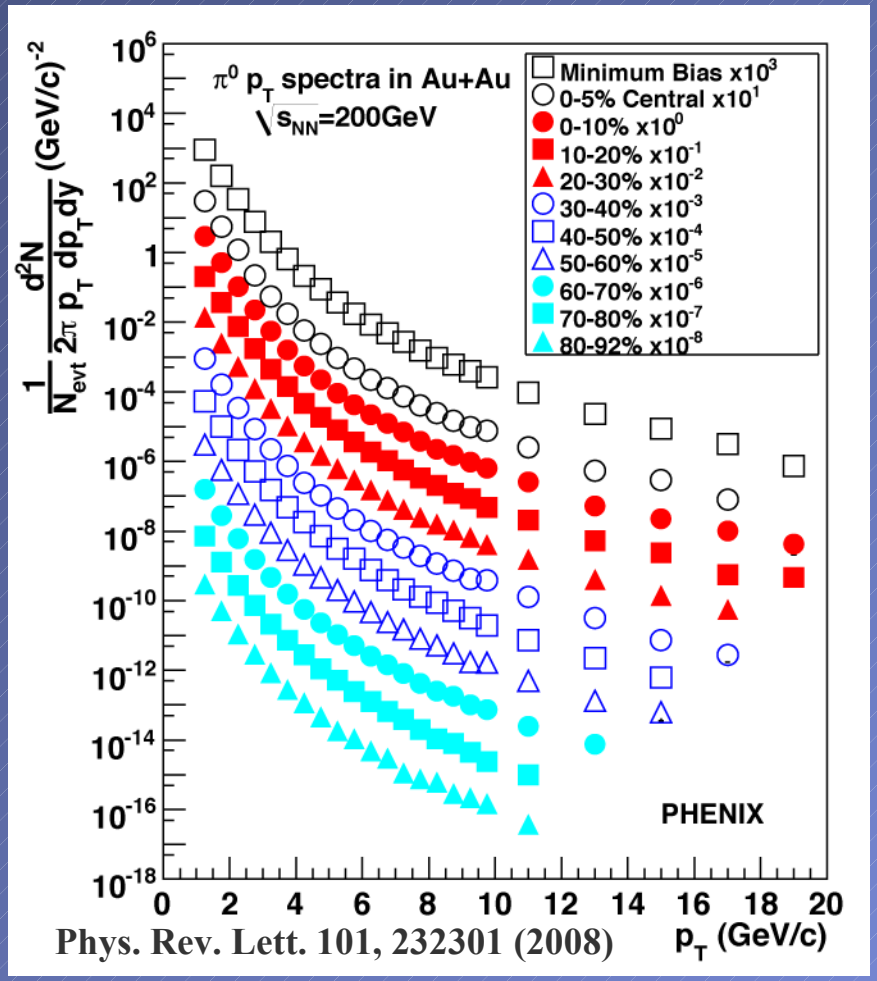


- 0-10% Au-Au central points suppressed across the whole p_T range
- PHENIX data reach out to 20GeV/c p_T

For the past decade, R_{AA} has been one of the workhorse variables

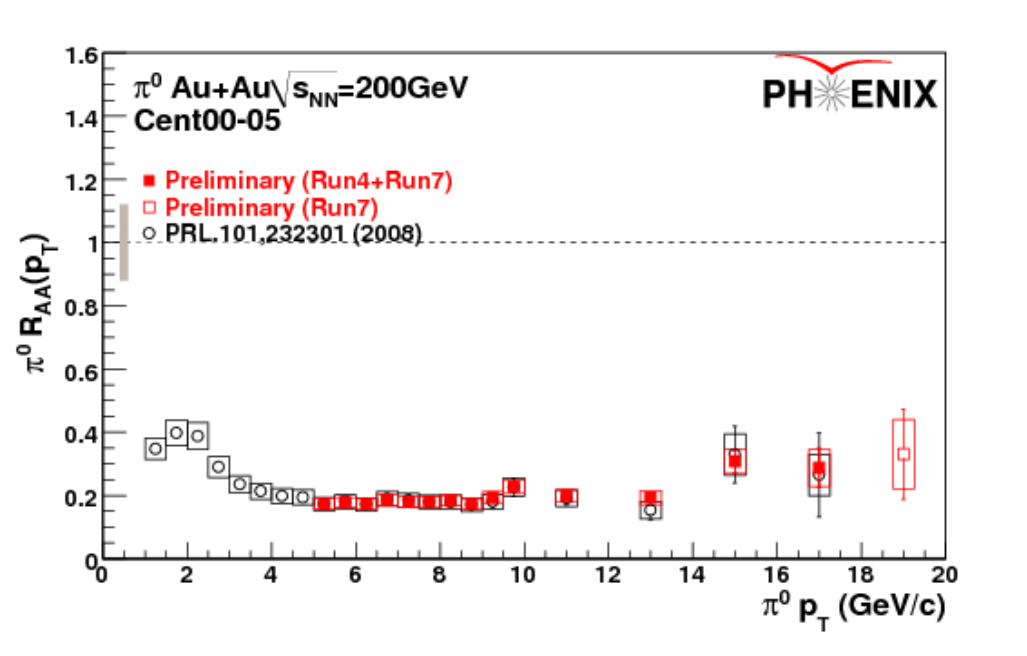
A wealth of results available from different probes

π^0 p_T Spectra $\sqrt{s_{NN}}$ = 200 GeV



Spectra show the reach of the PHENIX data up to 20GeV/c

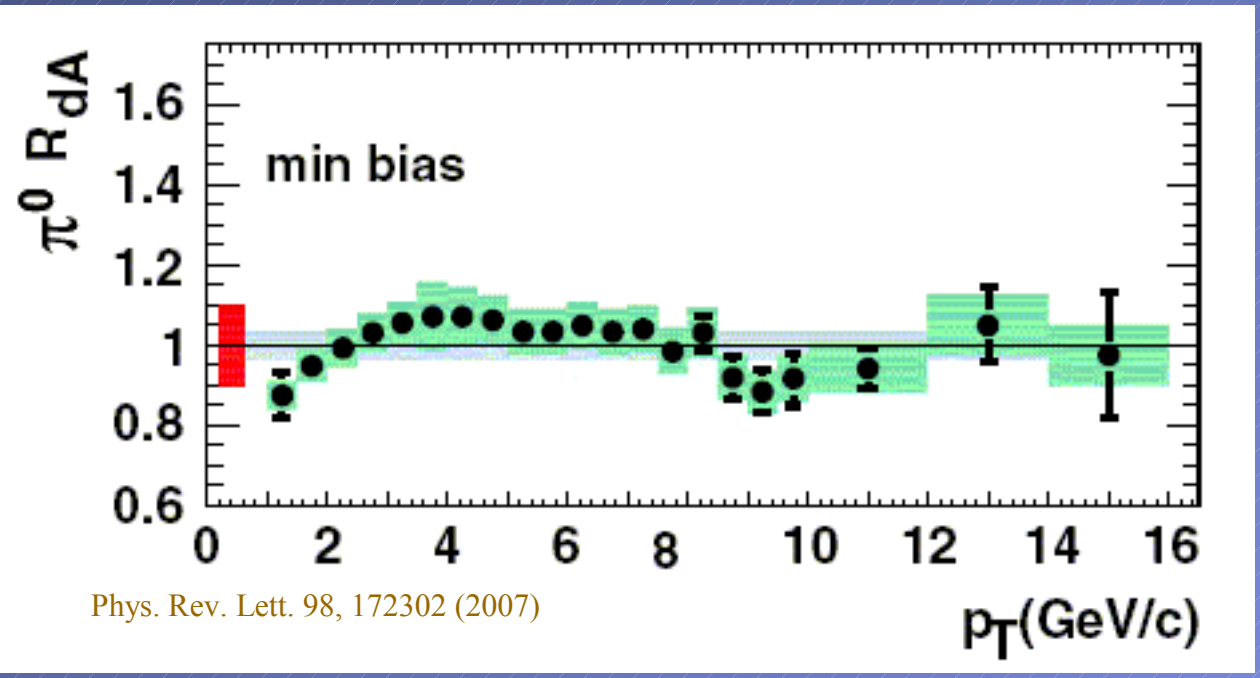
Centrality Dependence $\sqrt{s_{NN}}$ = 200 GeV



- π^0 R_{AA} measured up to p_T = 20 GeV/c (central Au+Au)
- Constant $R_{AA} \approx 0.2$ in central Au+Au up to highest p_T ($5 < p_T < 20$ GeV/c)

Final-State Effect

PHENIX π^0 d+Au 200 AGeV



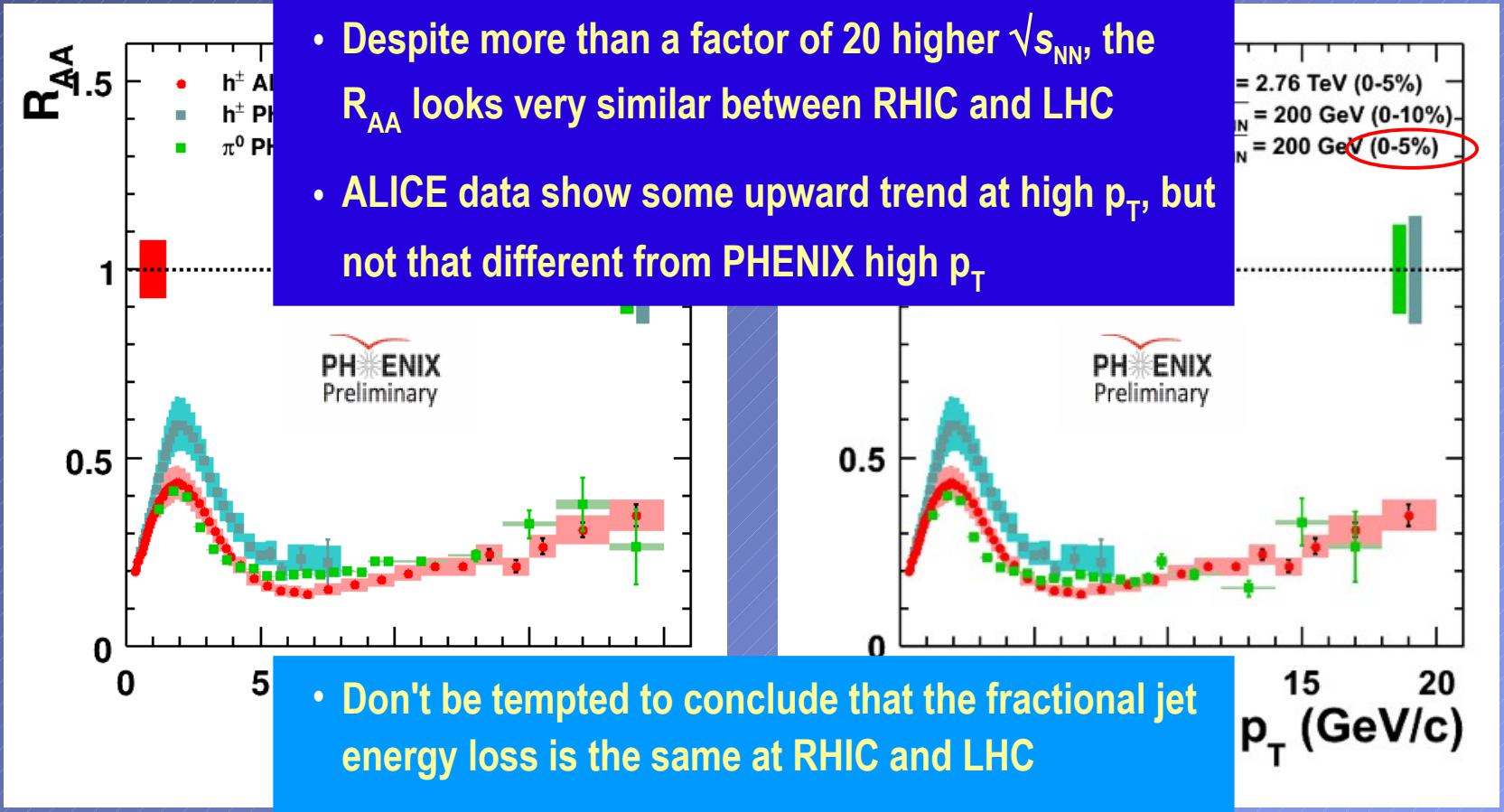
Phys. Rev. Lett. 98, 172302 (2007)

- d-Au data show no or very little suppression
- Evidence that this is a final-state effect

How does this look at LHC Energies?

0-5% ALICE with 0-10% PHENIX Centrality

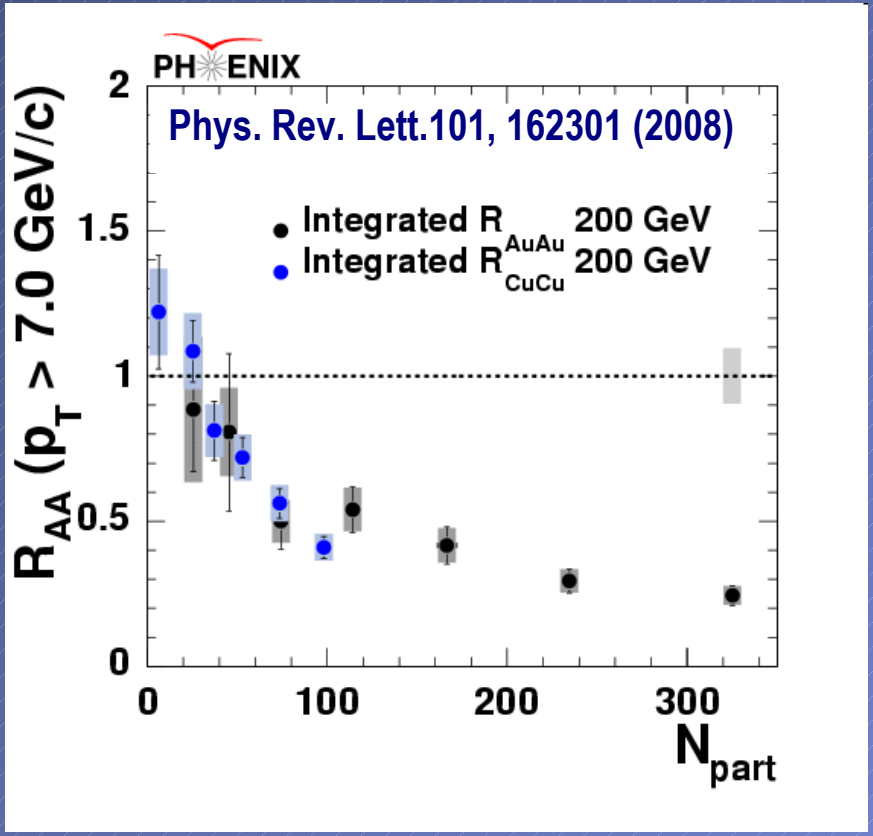
0-5% ALICE with 0-5% PHENIX Centrality



- Despite more than a factor of 20 higher $\sqrt{s_{NN}}$, the R_{AA} looks very similar between RHIC and LHC
- ALICE data show some upward trend at high p_T, but not that different from PHENIX high p_T

- Don't be tempted to conclude that the fractional jet energy loss is the same at RHIC and LHC
- See poster by Mike Tannenbaum to see why not

System Size and Energy Dependence



We can, up to a point, control the system size by varying the species and the collision energy

CuCu at 200, 64, 22.4

AuAu at 200, 62.4, 39, {19.6}

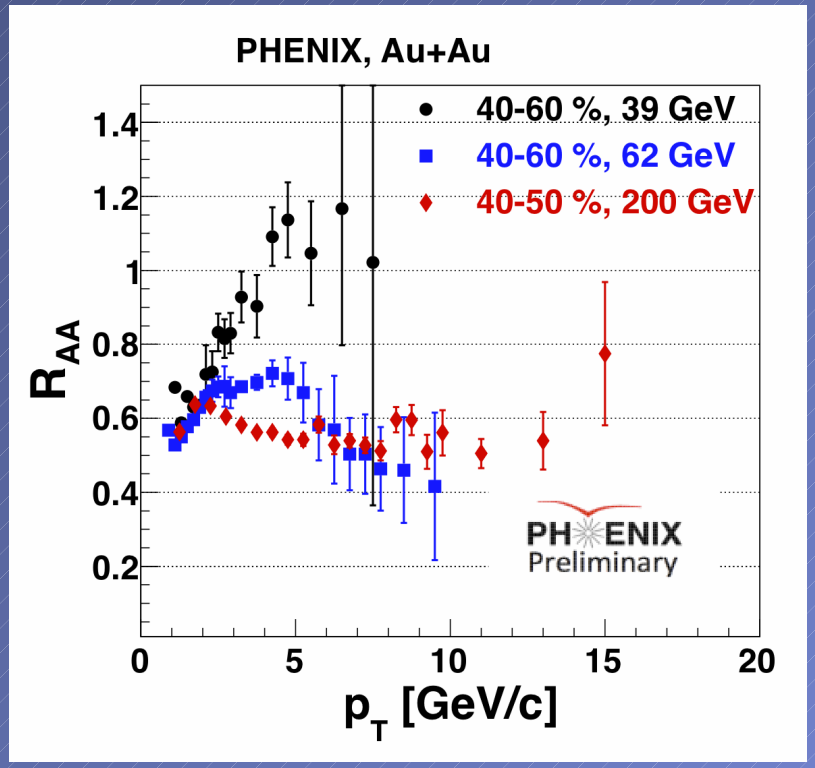
Different-sized systems with the same number of participants look very similar

R_{AA} shows similar behavior at AuAu, CuCu at 200GeV

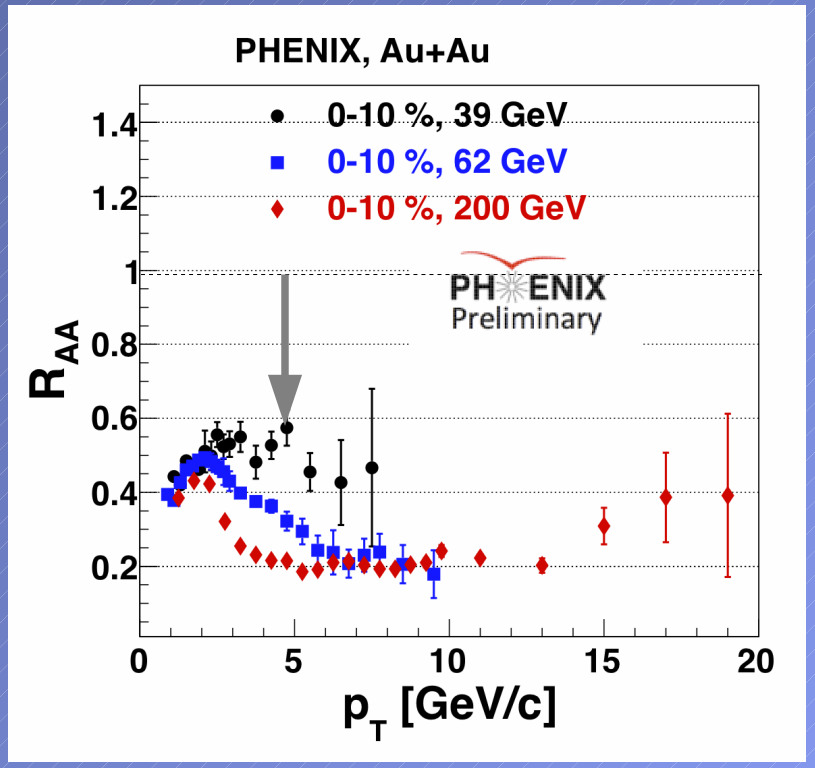
39 GeV Au+Au data added to the 22.4GeV Cu+Cu data

Au-Au at various energies

Medium Peripheral

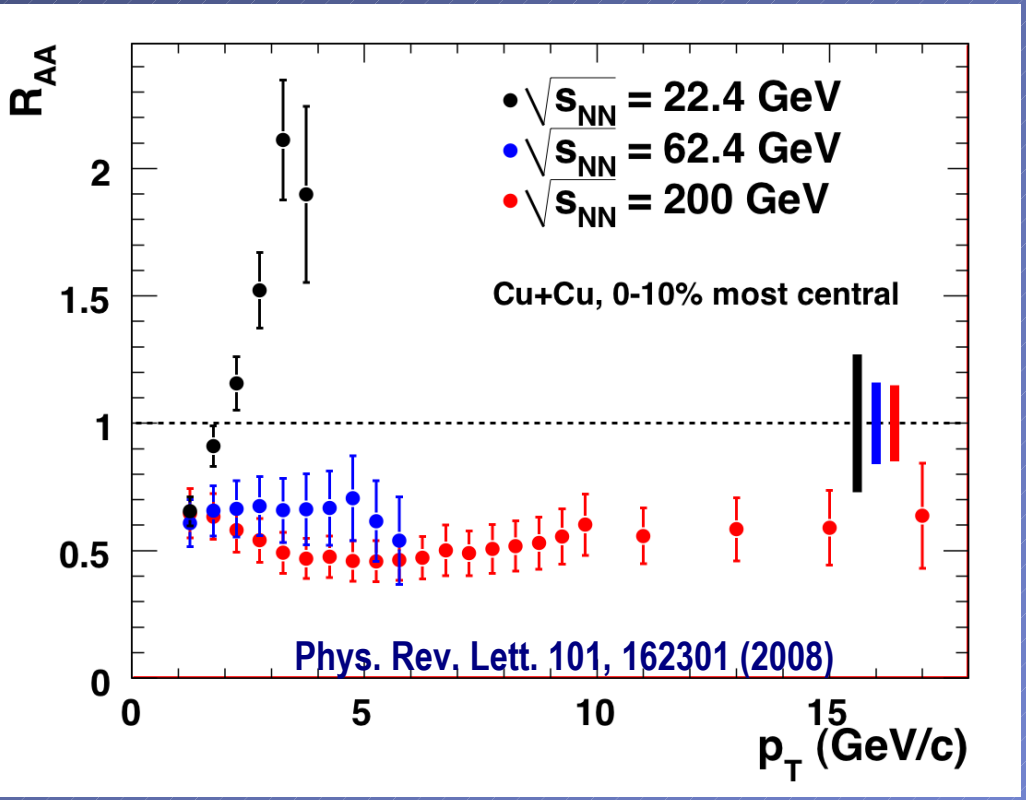


Central



No transition away from suppression seen at 39GeV yet

Transition between 22.4 GeV CuCu and 39 GeV Au+Au

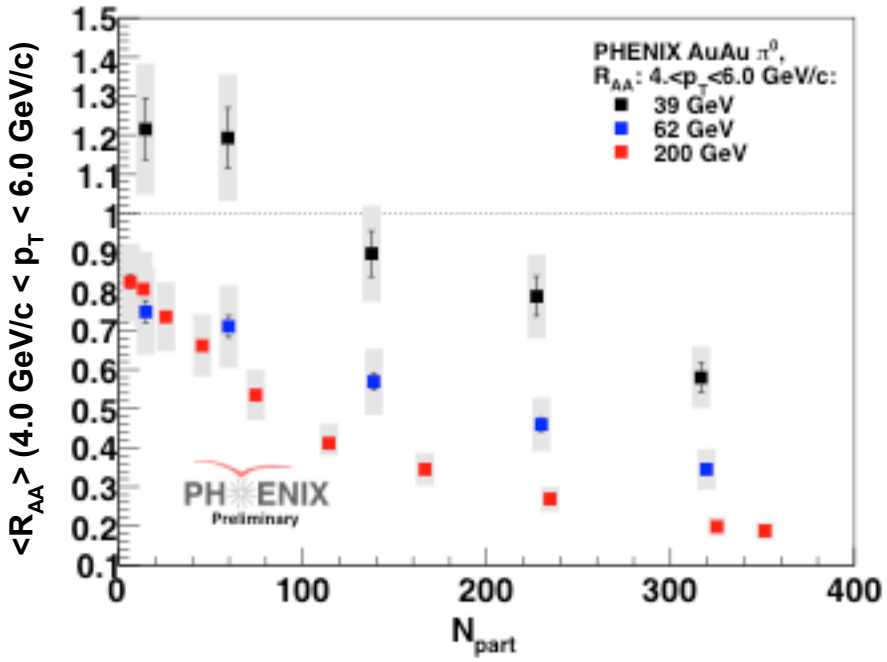


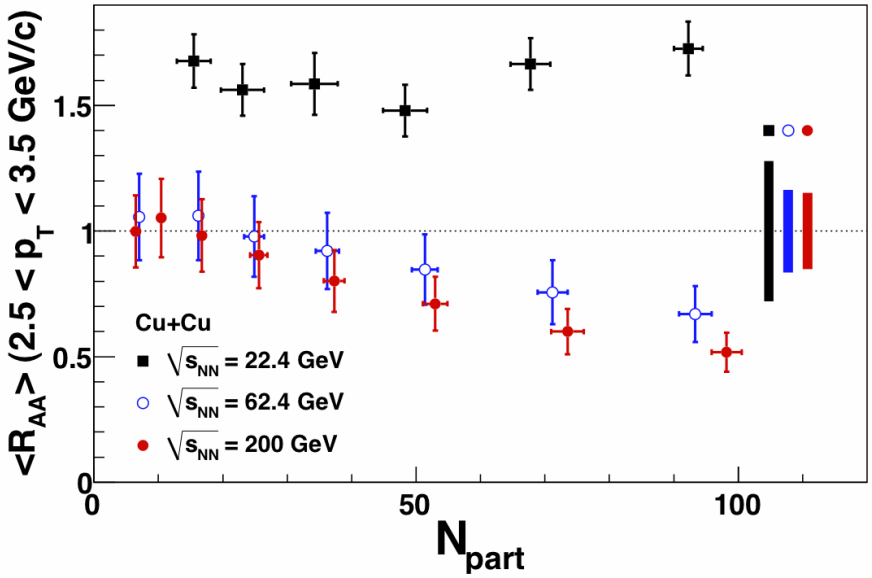
Here, at long last, we see some enhancement instead of suppression at 22.4 at the most central collisions

The quest for the transition point is on right now... Stay tuned.

- 62.4, 200 GeV:
  - Suppression consistent with parton energy loss for p_T > 3 GeV/c
- 22.4 GeV:
  - No suppression
  - Enhancement consistent with calculation that describes Cronin enhancement in p+A
- Parton energy loss starts to compensate Cronin enhancement between 22.4 and 62.4 GeV

The Upshot - Energies & System





Phys. Rev. Lett.101, 162301 (2008)

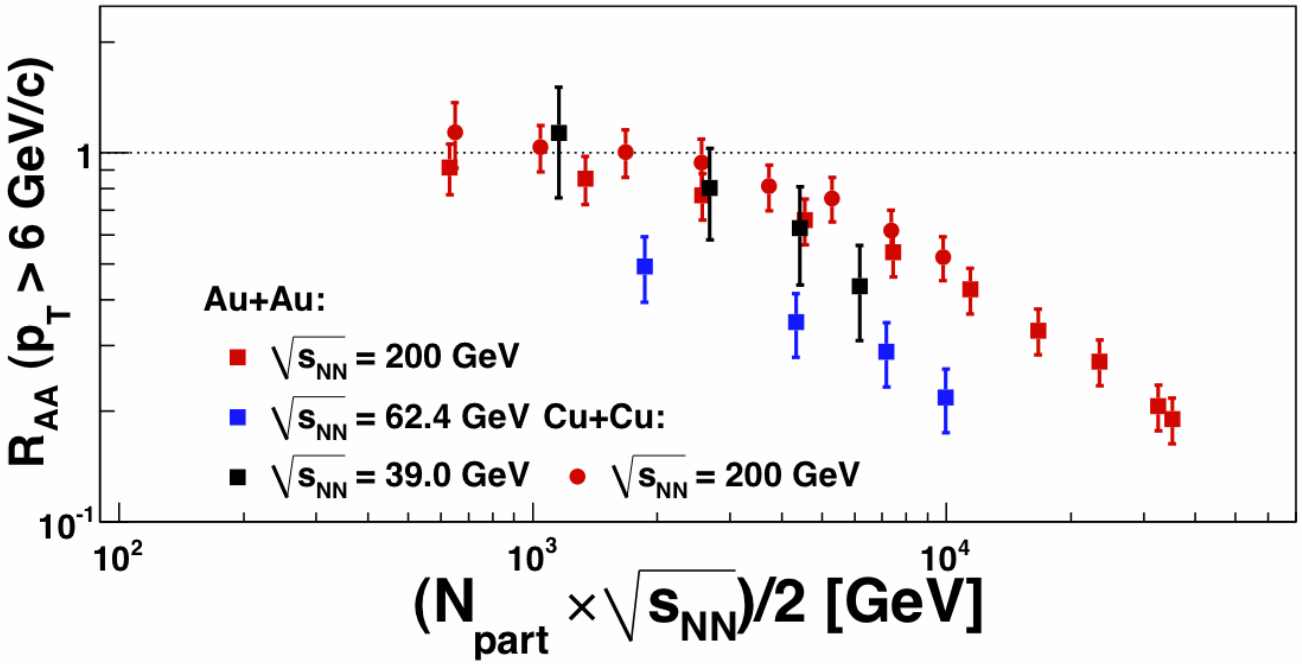
The next task is to describe the behavior with a universal function

We'll show one approach which transforms the x axis only

Extracting Common Behavior

Total energy available in the collision:

$$E_{AA} \equiv \left(N_{part} \cdot \sqrt{s_{NN}}\right) / 2$$



System:
- **Circles: Cu+Cu**
- **Squares: Au+Au**

Energy:
- Red: 200 GeV
- Blue: 62.4 GeV
- Black: 39.0 GeV
- Orange: 22.4 GeV

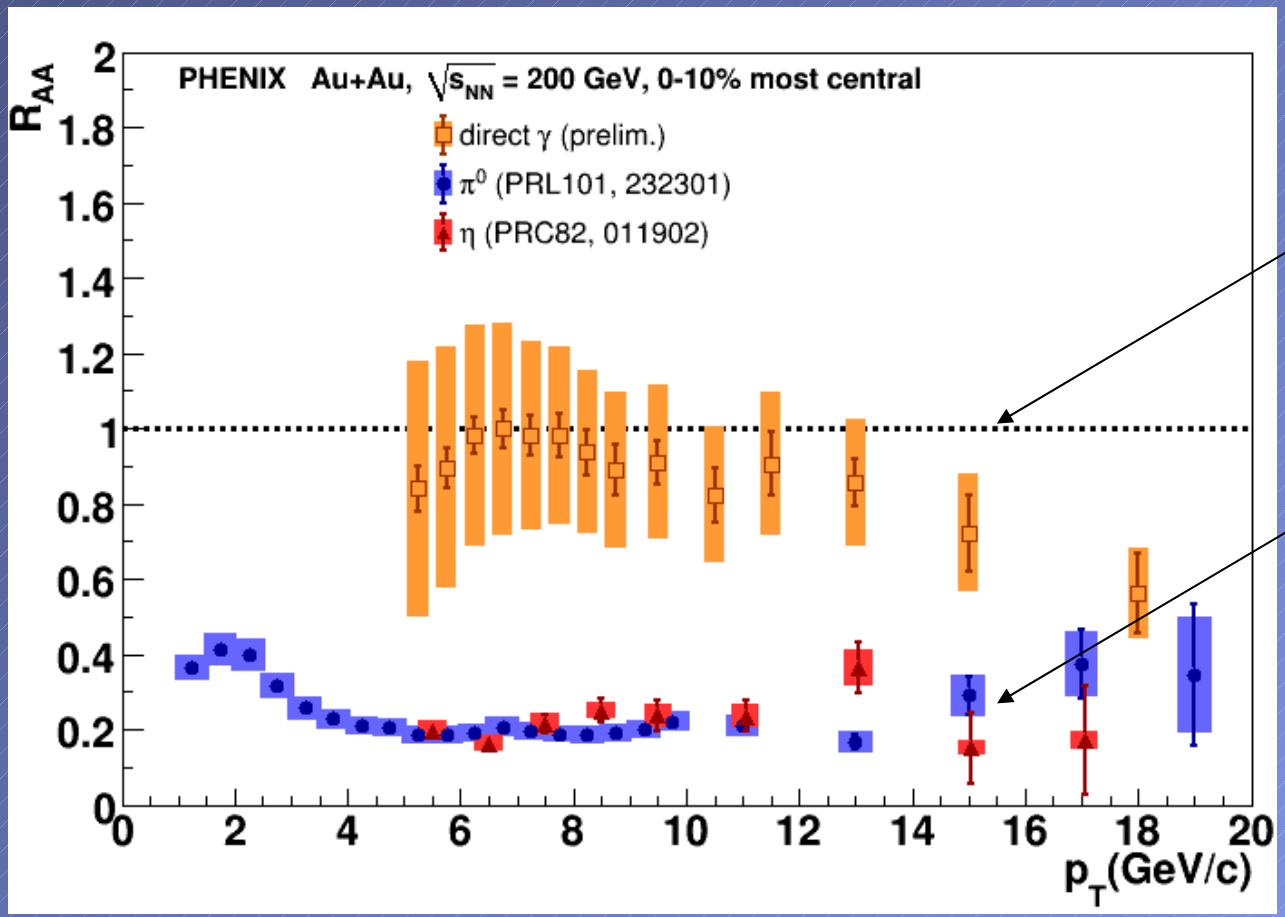
The suppressed systems show a similar trend in this variable

Caveat: Does not work equally well for all p_T ranges

N. Novitzky
Friday afternoon

Overview of R_{AA} results

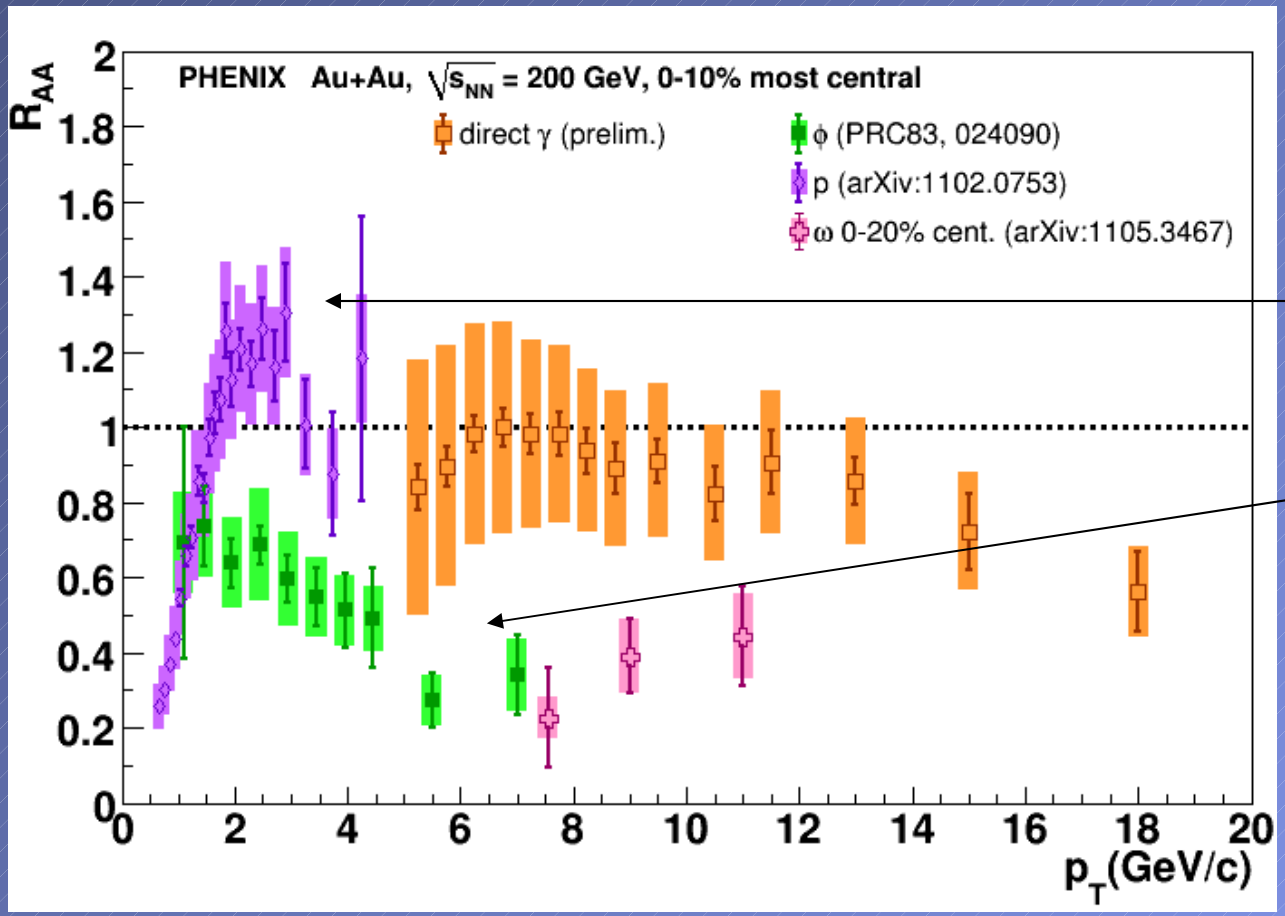
R_{AA} results in various channels



The direct photon data are consistent with 1 up to about 14 GeV/c

π^0 and η is suppressed

Proton, ϕ and ω

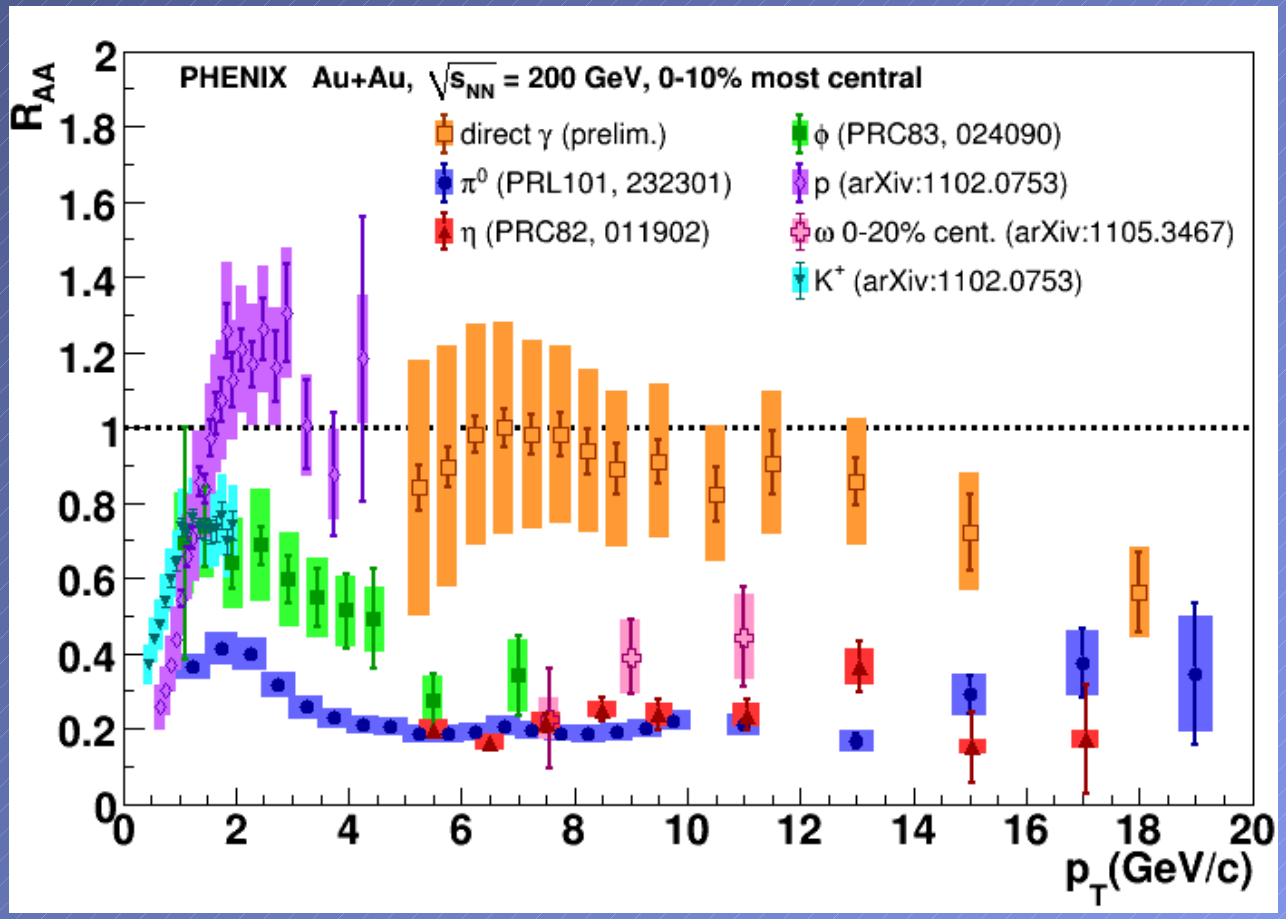


The proton is not suppressed

The ϕ behaves like a meson, not a baryon. It's not the mass that counts but the quark composition

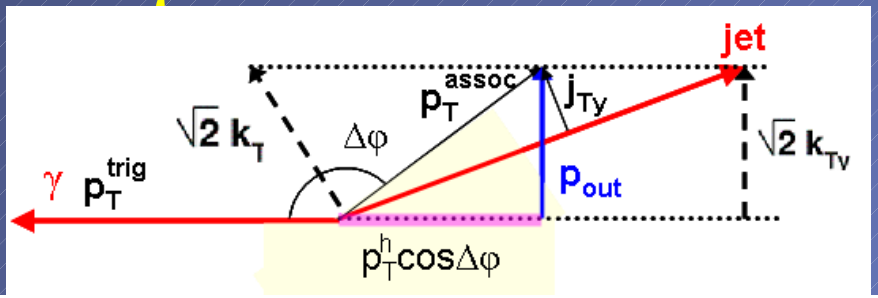
All together now

Summary of R_{AA} results in various channels, with references



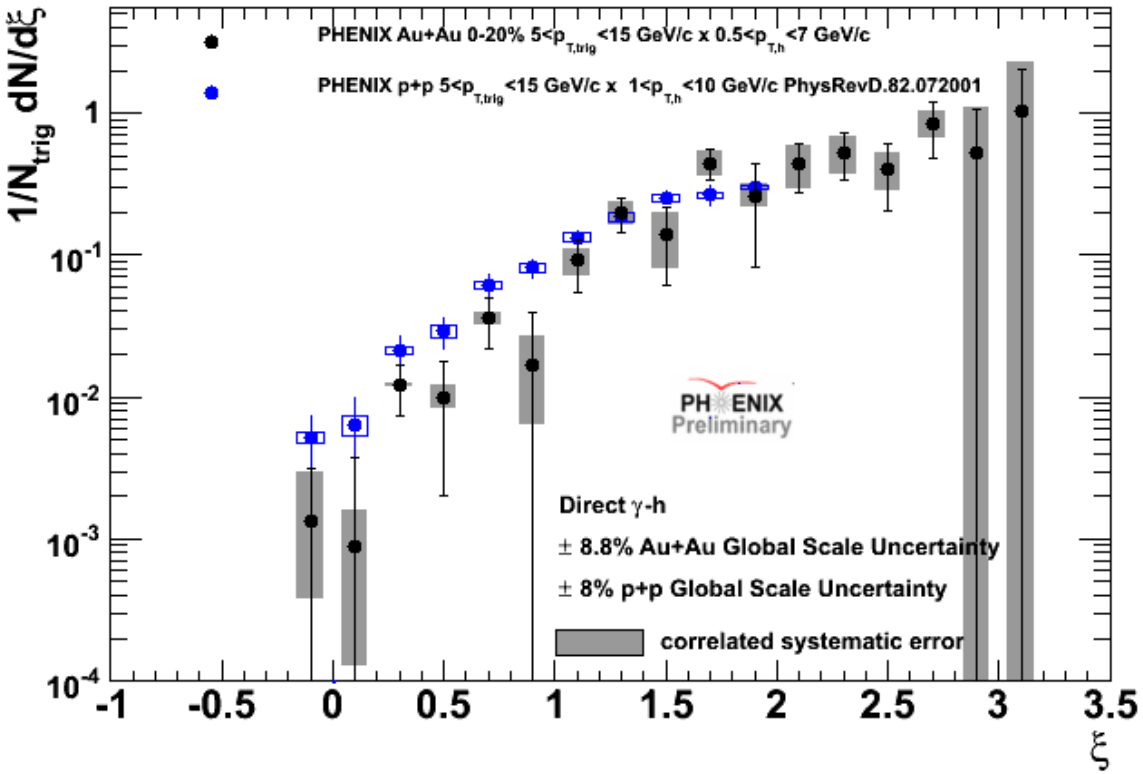
Measuring Fragmentation via γ-hadron

γ-hadron correlation



Direct γ defines jet kinematics precisely

Plot fragmentation function in ξ rather than z (basically shows z distribution logarithmically)



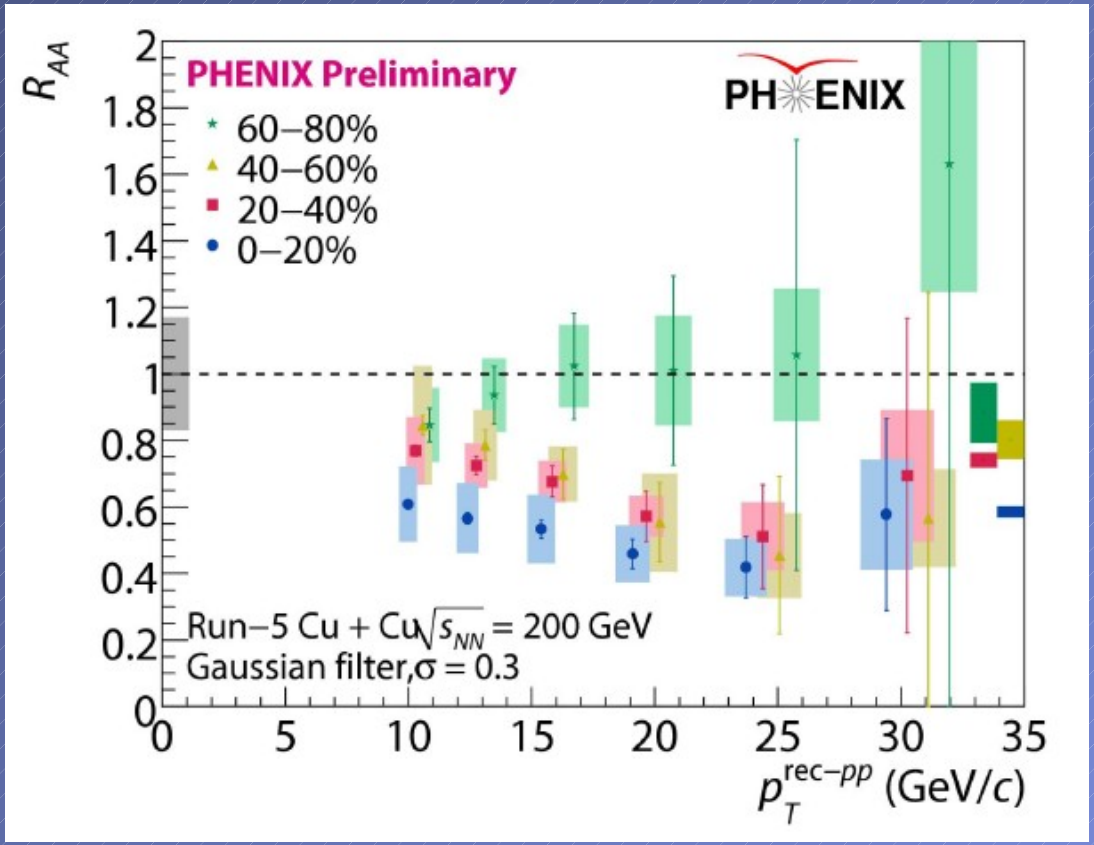
Further detail in slides of N. Grau's talk (yesterday)

First direct measurement of in-medium fragmentation via γ-tagged jets

In addition to its fundamental importance, this results further underscores the need to measure full jets

Jet R_{AA} in 200 GeV Cu-Cu

R_{AA} of fully reconstructed jets



Centrality-dependent suppression of jet yields observed.

Could be out-of cone radiation from medium interaction

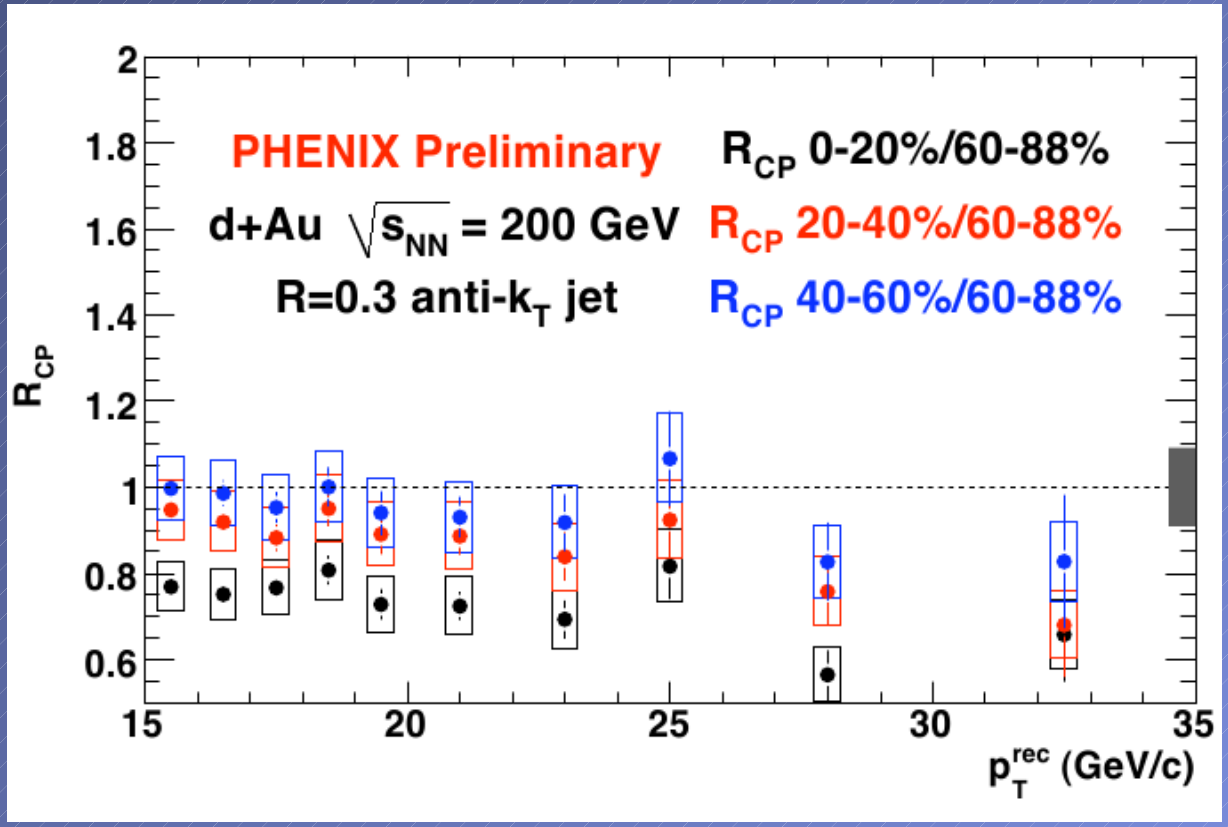
Or the jet shape or other properties are modified and makes the jet fail the rejection cut

Either one would be a *really* interesting result

N. Grau

Caveat: Know your Reference

R_{CP} of fully reconstructed jets from d+Au



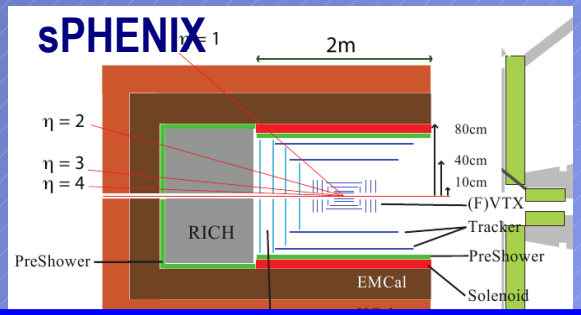
All R_{AA} measurements need a corresponding R_{dA} measurement as crosscheck

The data are presently R_{CP} but may indicate that CNM effects should not be ignored.

Stay tuned.

Summary

- R_{AA} has been a very versatile workhorse variable for the past 10 years
- Large variety of probes with large p_T reach available
- Hadrons are suppressed except for CuCu at 22.4GeV/c
- No suppression of direct photons up to 14GeV/c
- First measurement of the fragmentation function in Au+Au
- Full reconstructed Jet R_{AA} shown
- For the next decade, the focus will be on full jets
- Stay tuned for exciting new results from the next 10 years of PHENIX



A. Sickles (PHENIX Upgrades) Thursday Afternoon

More PHENIX Presentations

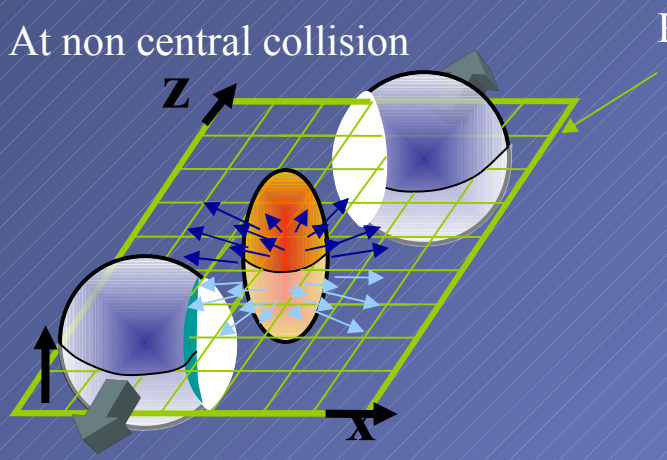
Plenary: S. Bathe (PHENIX Overview) Monday Morning
Parallel: R. Lacey (v3, jet shape) Monday Afternoon
Parallel: D. Sharma, LightVector Mesosns, Monday afternoon
Plenary: S. Esumi, Tuesday Morning
Parallel: A. Sen (quarkonia) Tuesday Afternoon
Parallel: N. Grau (gamma-hadron, jets) Tuesday Afternoon

Parallel: E. Kistenev (direct photons) Thursday Afternoon
Parallel: M. Chiu (small x dAu correl) Thursday Afternoon
Parallel: A. Sickles (PHENIX Upgrades) Thursday Afternoon
Plenary: C. Luiz da Silva, Friday Morning
Parallel: J. Kamin (dAu dileptons) Friday Afternoon
Parallel: X. Gong (energy scan: bulk) Friday Afternoon
Parallel: M. Durham (open heavy flavor) Friday Afternoon
Parallel: N. Novitzky (energy scan) Friday Afternoon

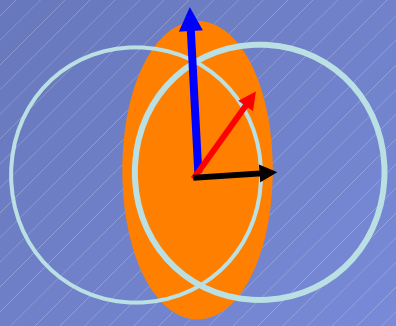
Poster: S. Mizuno (PID v3)
Poster: Z. Citron (small x dAu correlations)
Poster: D. Perepelitsa (Jets in d+Au)
Poster: S. Withaker (Upsilon RAA)
Poster: A. Takahara (J/psi photoproduction)
Poster: M. Tannenbaum (E loss RHIC vs. LHC)

Reserve Slides

Path Length Dependence



Geometrical anisotropy



The almond shape of the collision region provides a built-in way to look at different path lengths through the medium in the same collision system, type, centrality

Much better than varying energy, size

Gives a handle on energy loss per path length

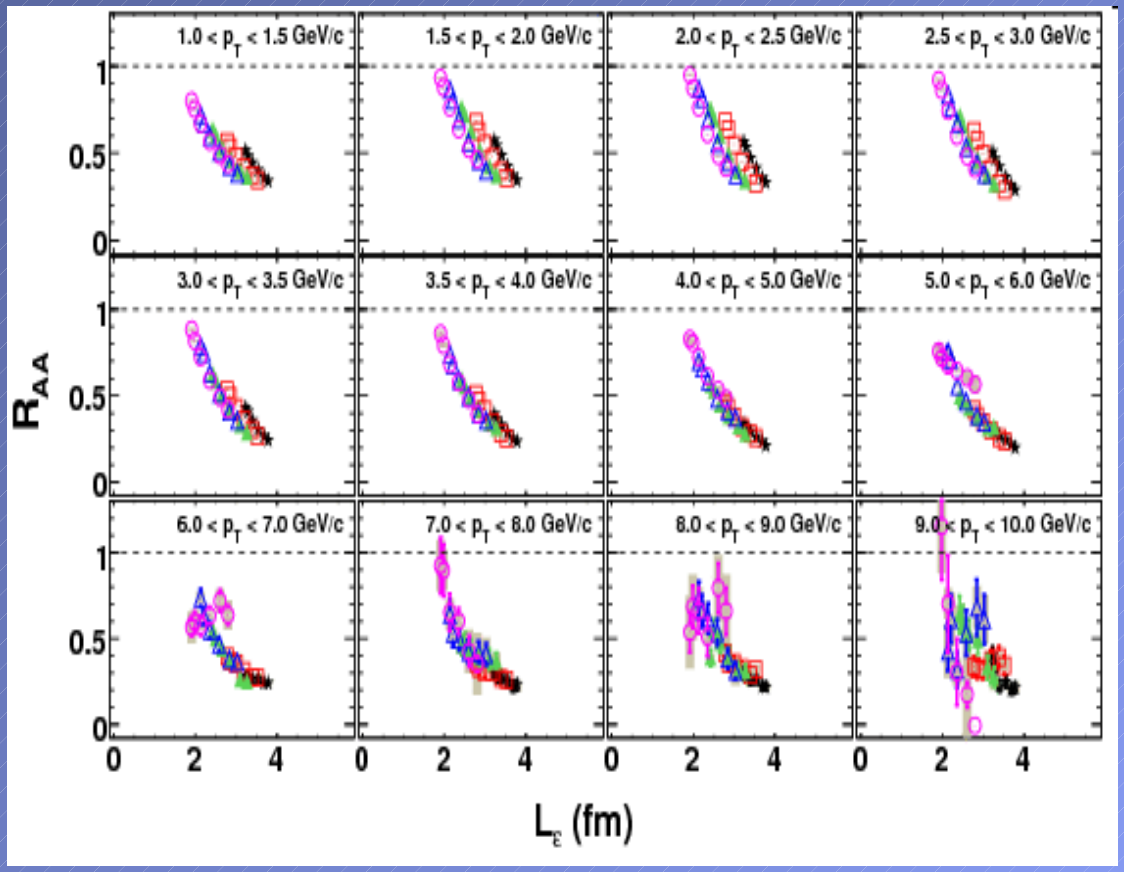
Path Length Dependence

This is R_{AA} as a function of the calculated path length L_{ε}

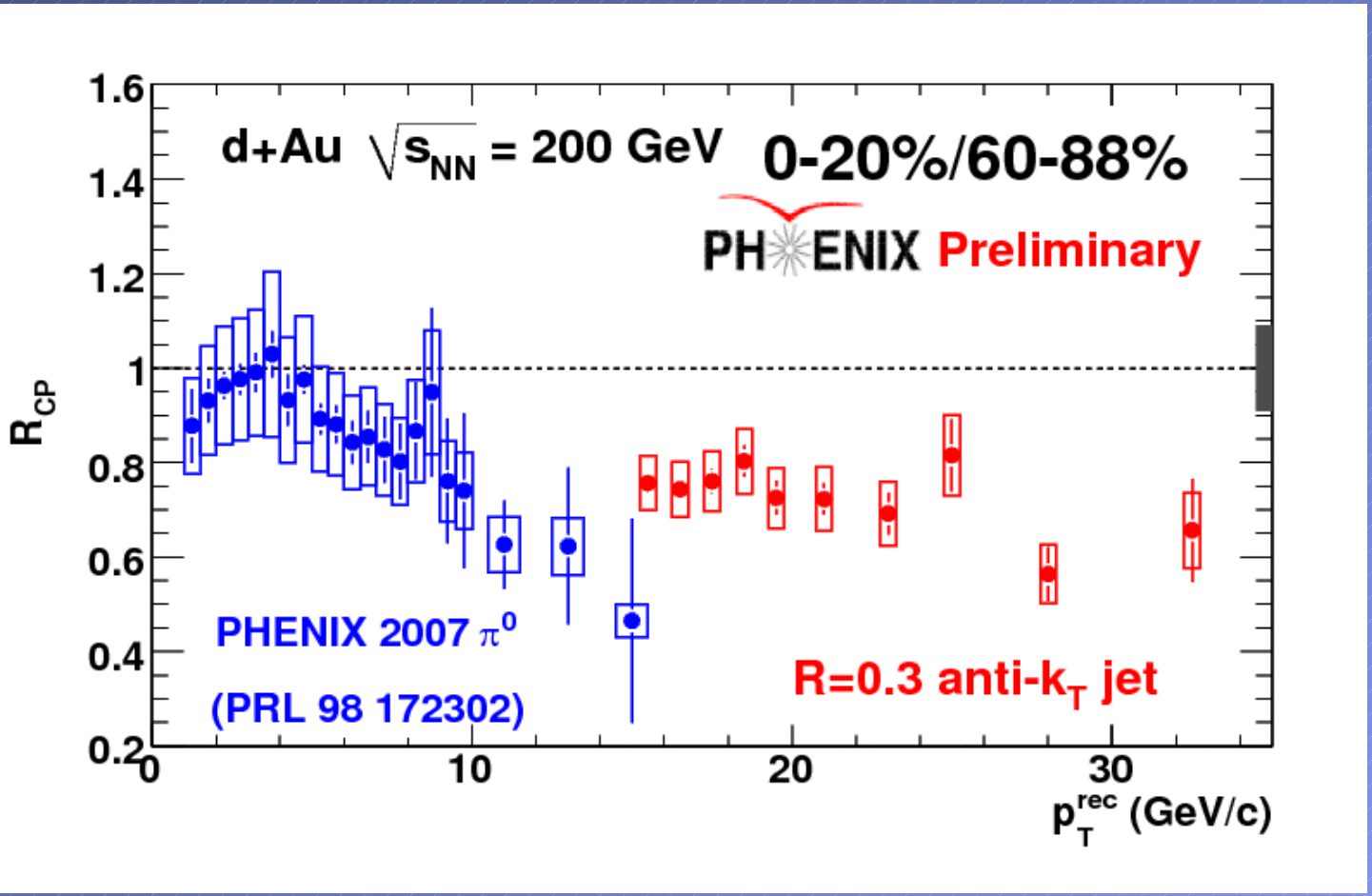
L_{ε} assumes an ellipsoid as an overlap of hard spheres

calculates distance from center as function of angle

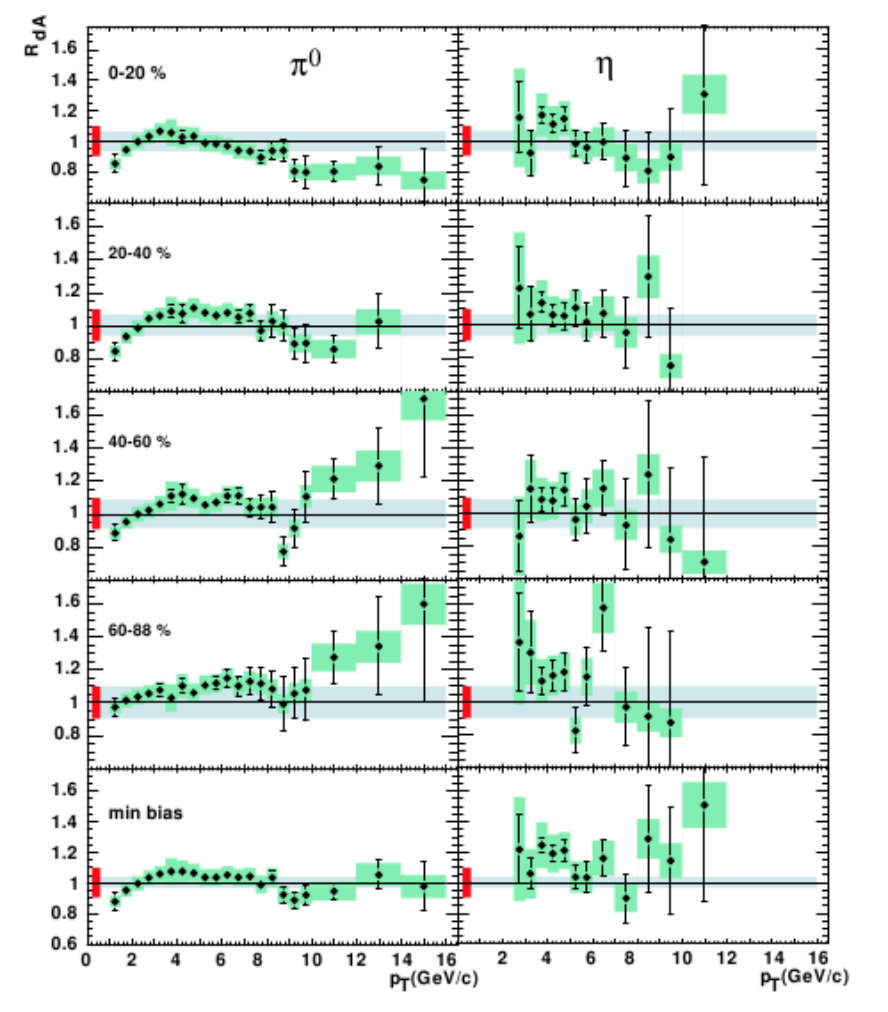
Details in Phys. Rev C 80, 054907 (2009)



R_{CP} for π^0 and Jet R_{CP}

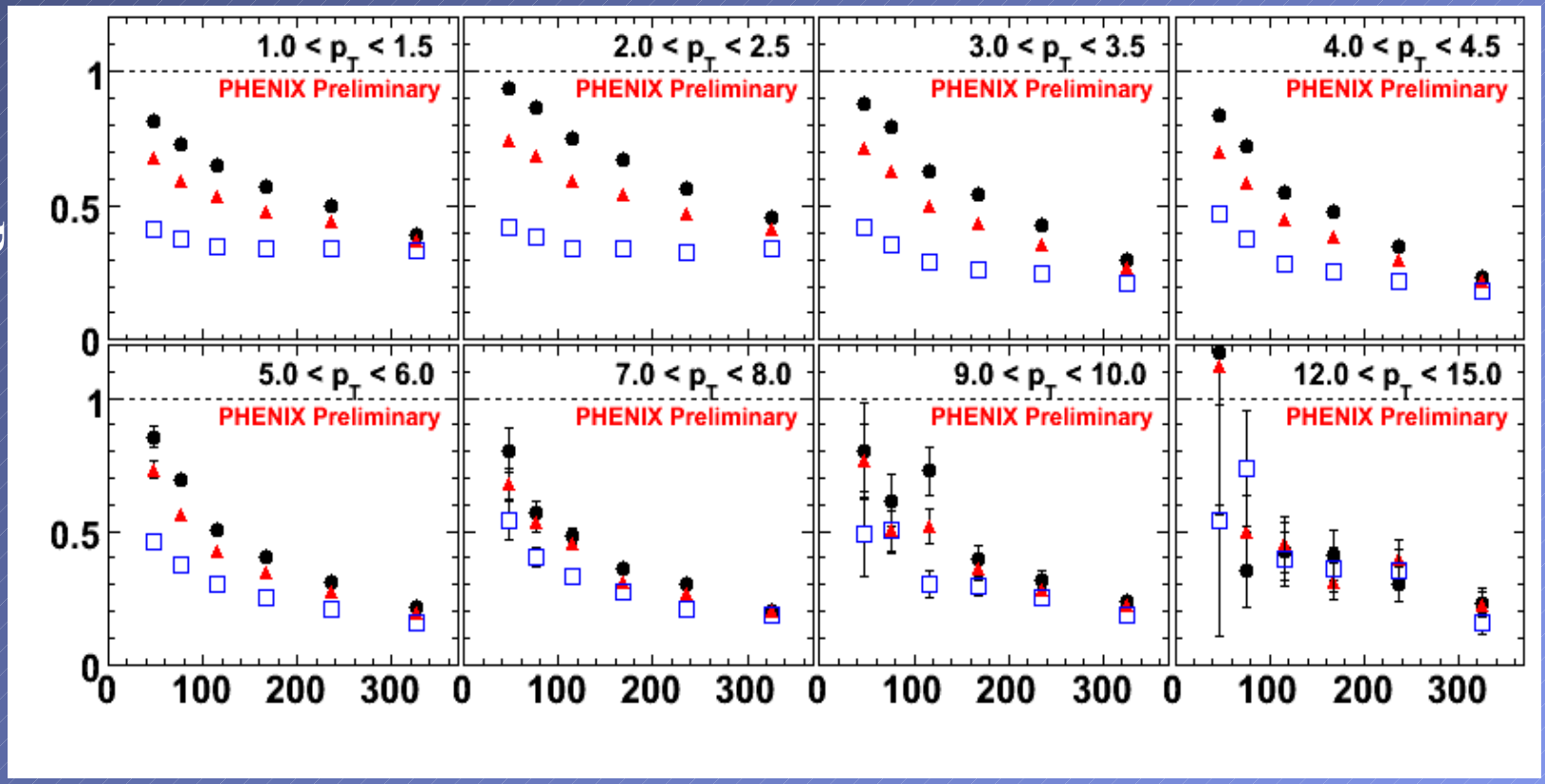


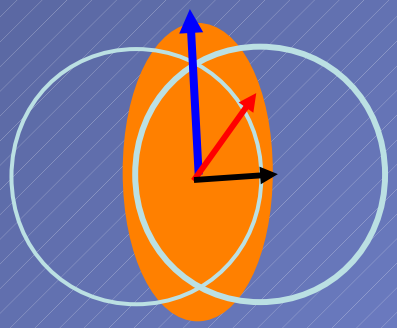
R_{dA} for π^0 and η



Phys. Rev. Lett. 98, 172302 (2007)

Path Length Dependence



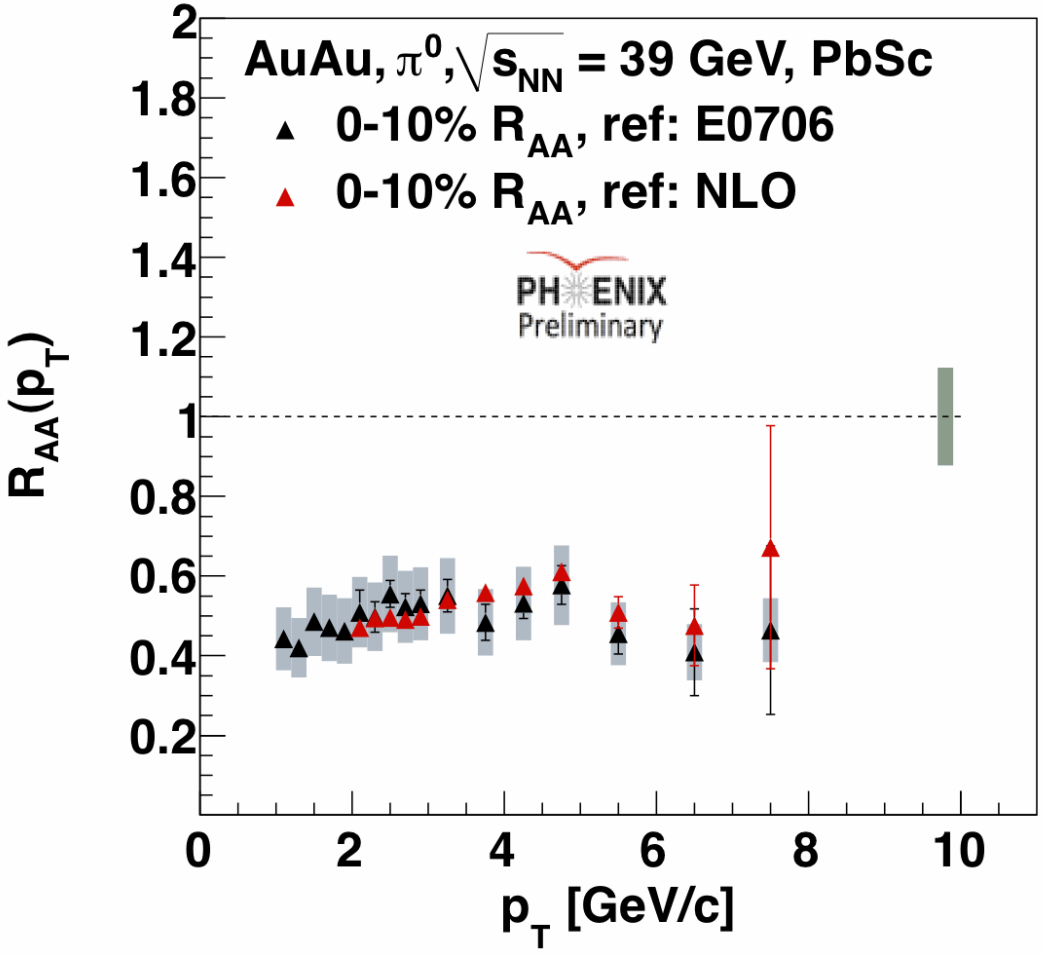


RAA in-plane, out-of-plane, and in between, Au+ Au 200

RAA flatter out of plane (longest path) with centrality

Curves converge at highest centralities (diminishing asymmetries)

The new AuAu 39AGeV data points



No in-house p-p reference data yet at 39GeV.

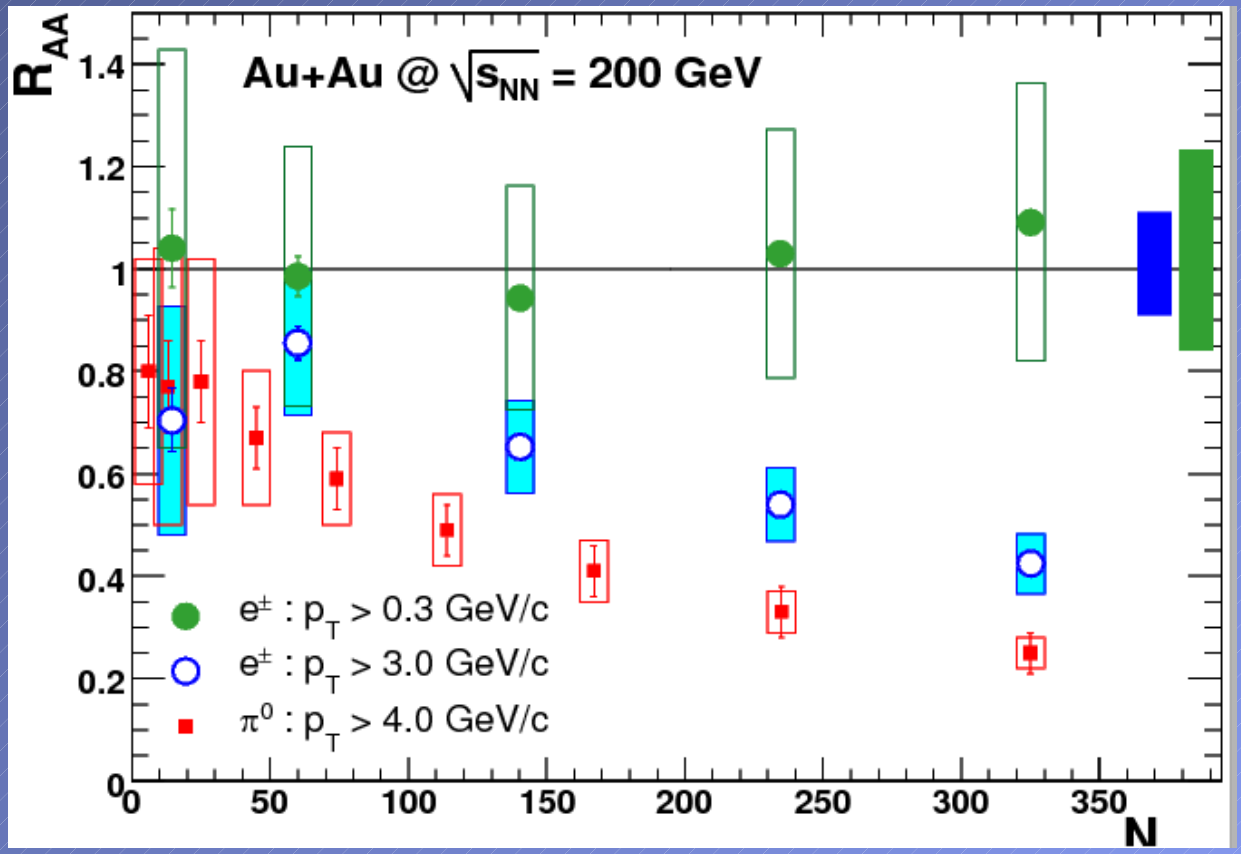
Interpolation of 62.4, 200GeV data with the help of the Tevatron E706 data, and theoretical predictions

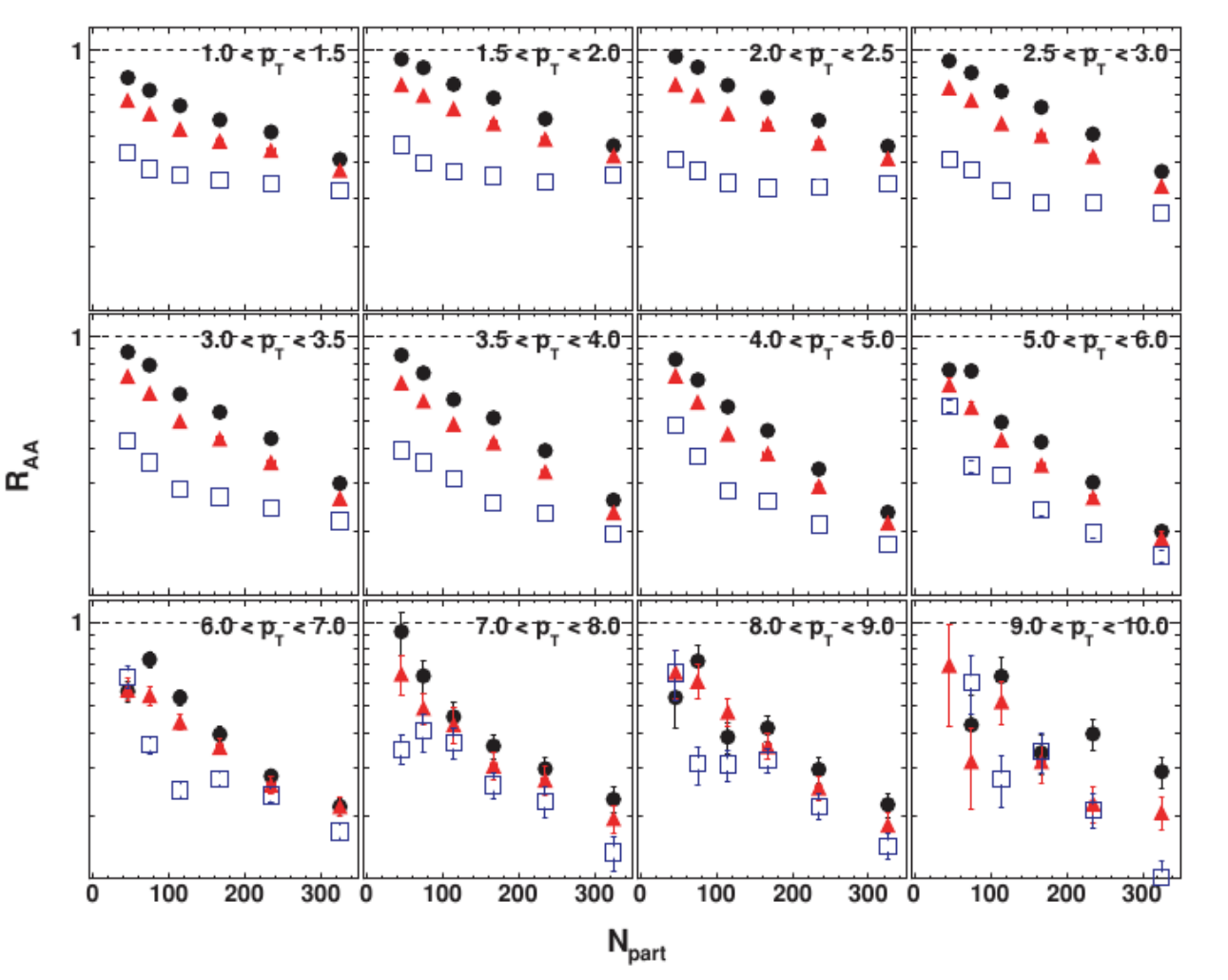
Very "RHIC-like" behavior for Au-Au at 39GeV... no transition yet

Just finished taking 17 Million Au-Au events at 19.6 GeV... stay tuned for more at the next QM.

H.F. Electrons

- [Whatever we add, something has to go]

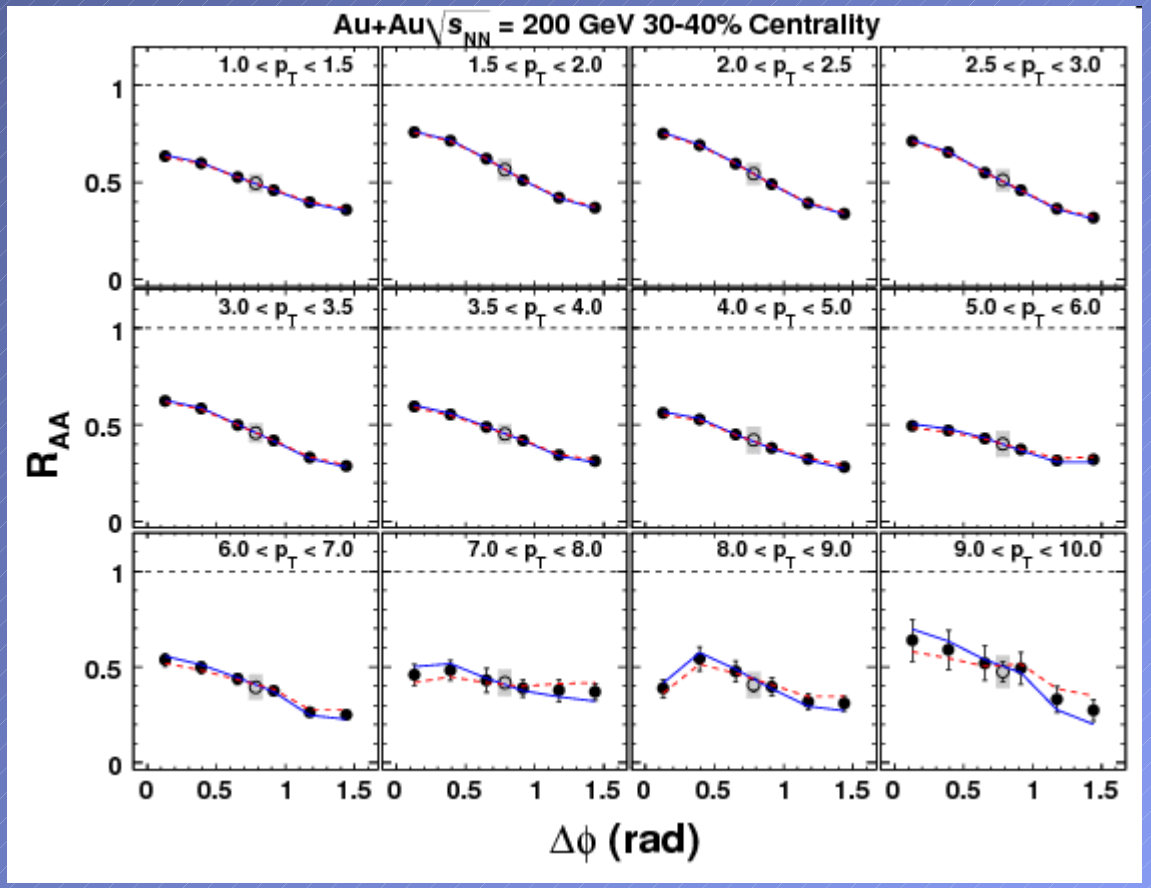



1.0 < p_T < 1.5
1.5 < p_T < 2.0
2.0 < p_T < 2.5
2.5 < p_T < 3.0
3.0 < p_T < 3.5
3.5 < p_T < 4.0
4.0 < p_T < 5.0
5.0 < p_T < 6.0
6.0 < p_T < 7.0
7.0 < p_T < 8.0
8.0 < p_T < 9.0
9.0 < p_T < 10.0
R_AA
N_part
0
100
200
300
1

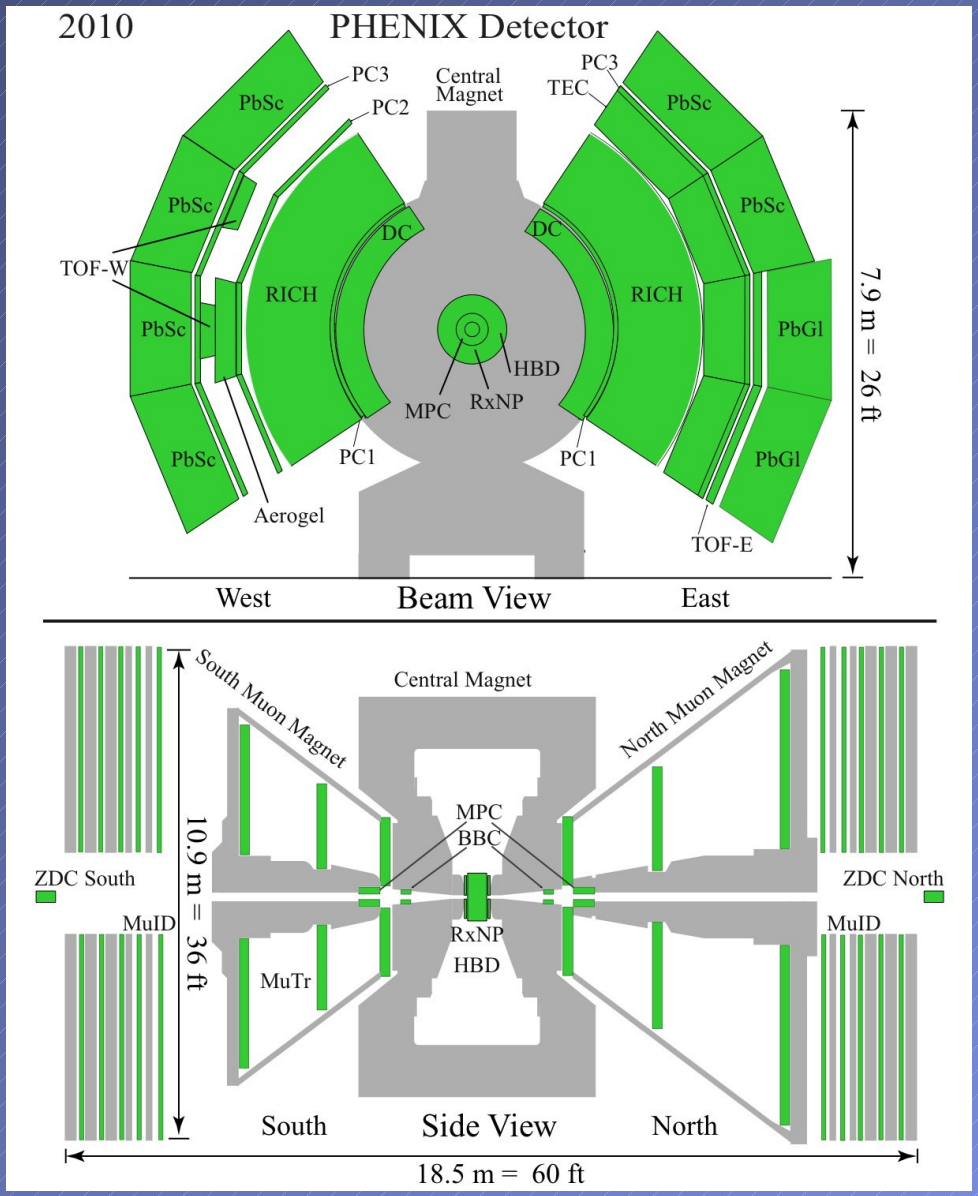
Path Length Dependence

More peripheral collisions mean a more asymmetric overlap region

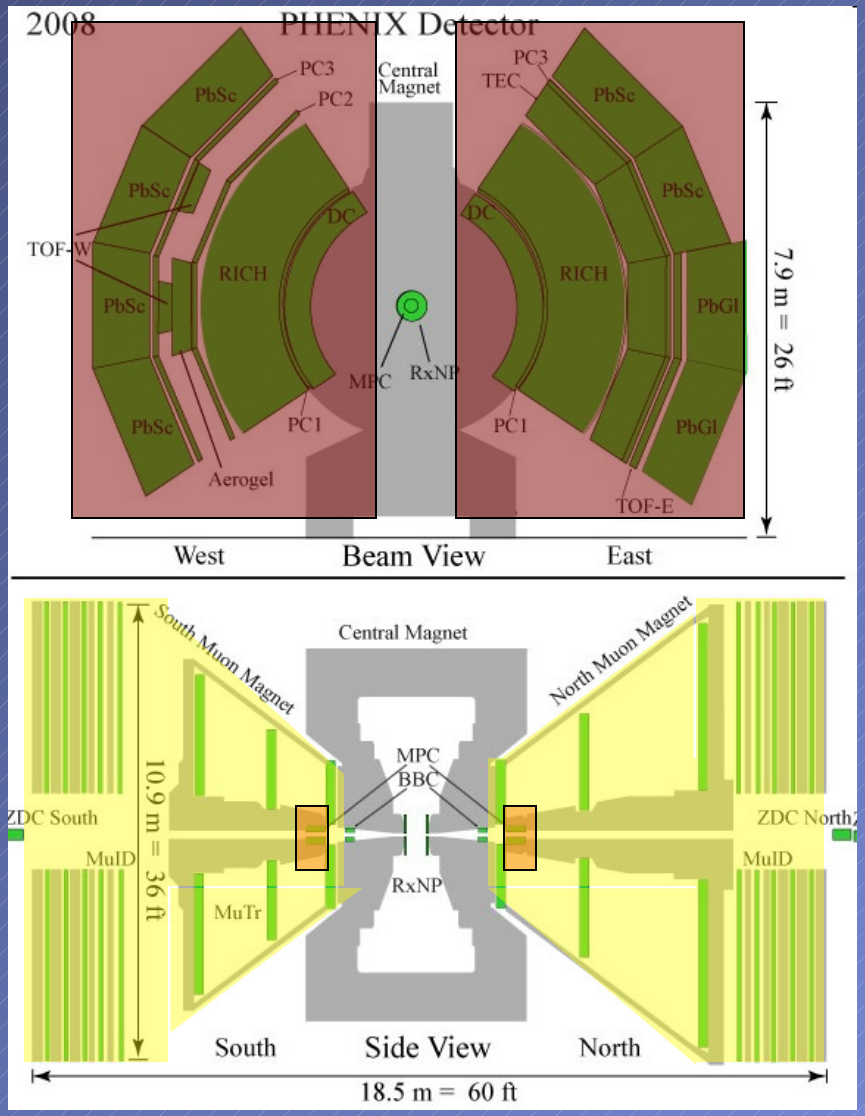
Maximum variation in path length



Reserve Slides



The PHENIX Detector at RHIC

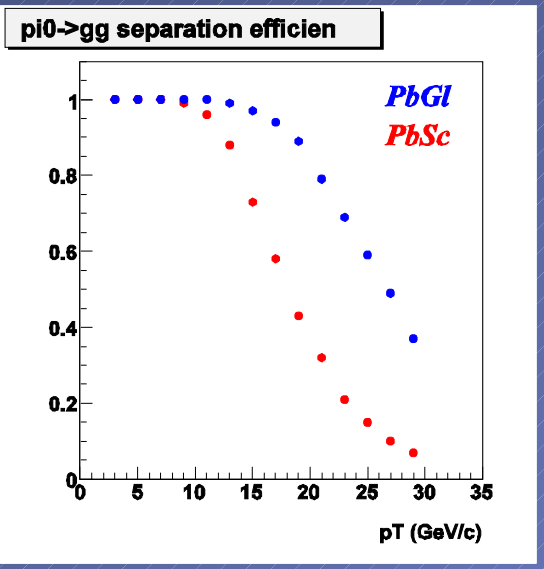


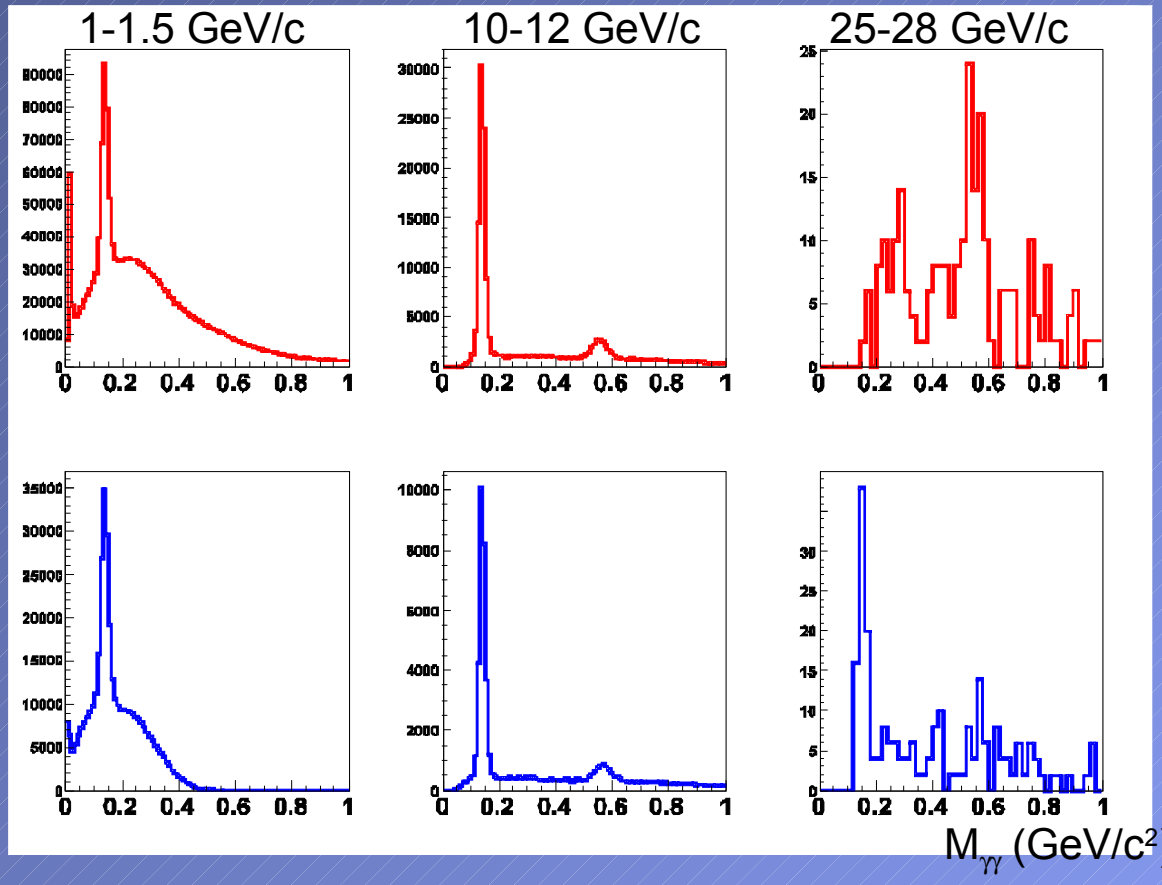
Central Arms $|\eta| < 0.35$
- Identified charged hadrons
- π^0, η
- Direct Photon
- J/Ψ
- Heavy Flavor

Muon Arms $1.2 < |\eta| < 2.4$
- J/Ψ
- Unidentified charged hadrons
- Heavy Flavor

MPC $3.1 < |\eta| < 3.9$
- π^0, η

π^0 reconstruction from inv. mass





$\pi^0 \rightarrow \gamma\gamma$ at pT~25 GeV/c:

~90% are merged in PbSc

~50% are merged in PbGl