Recent Results from the PHENIX Heavy-Ion Program at RHIC

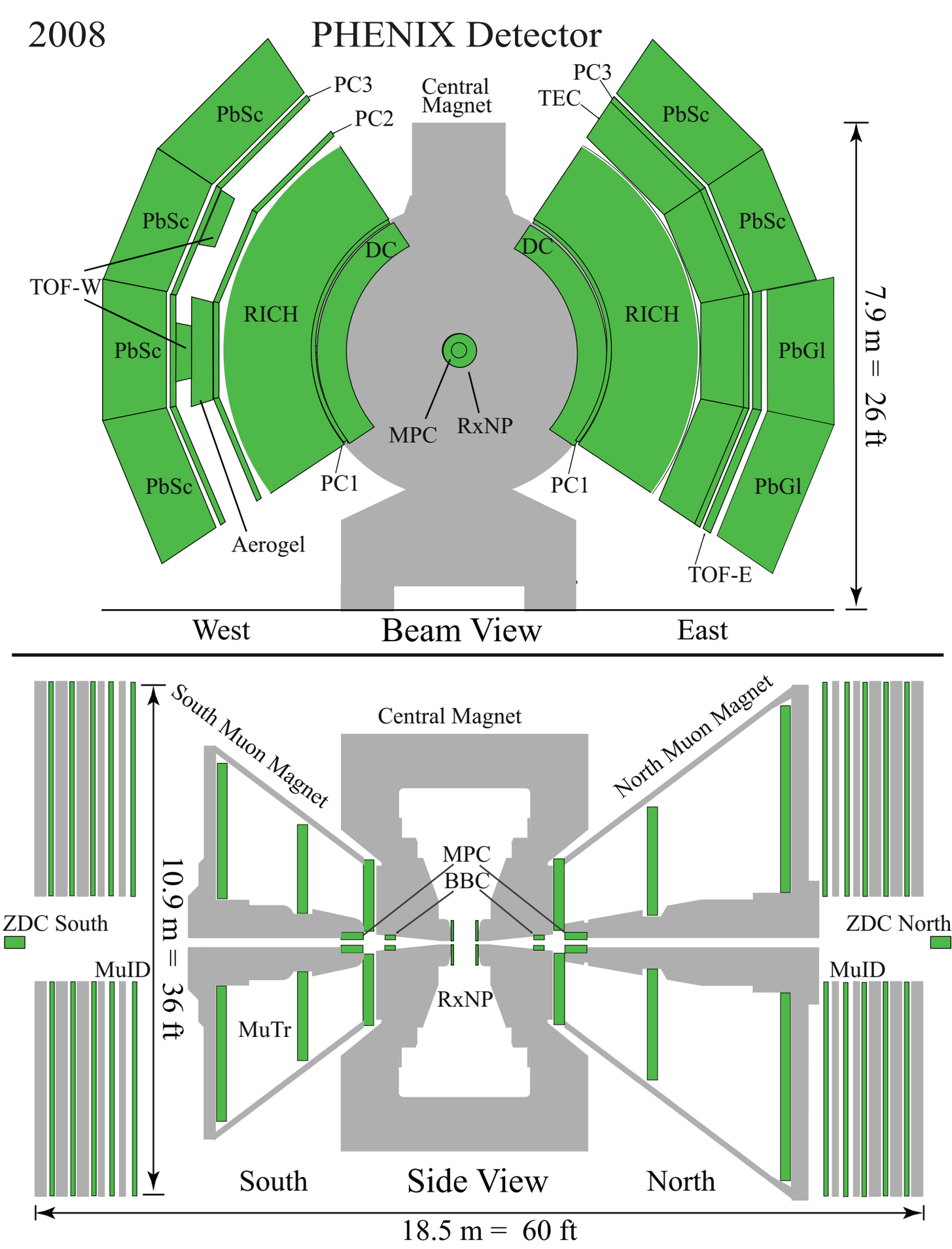
Baldo Sahlmüller - University of Frankfurt

Outline

- This talk cannot highlight all the measurements from the rich PHENIX heavy-ion program
- Will focus on some highlights:
  - Electromagnetic Probes: direct photons, dark photon search
  - Heavy Flavor physics: heavy quarks and quarkonia
  - Event observables: multiplicities and correlations
  - Small systems: initial state or small QGP
- RHIC has a future:
  - Future RHIC runs
  - Building a new detector

PHENIX

- Detector evolves over time
- Adding new subsystems to improve measurement of rare probes
  - HBD for photons and dileptons
  - (F)VTX for heavy flavor and charm-bottom separation



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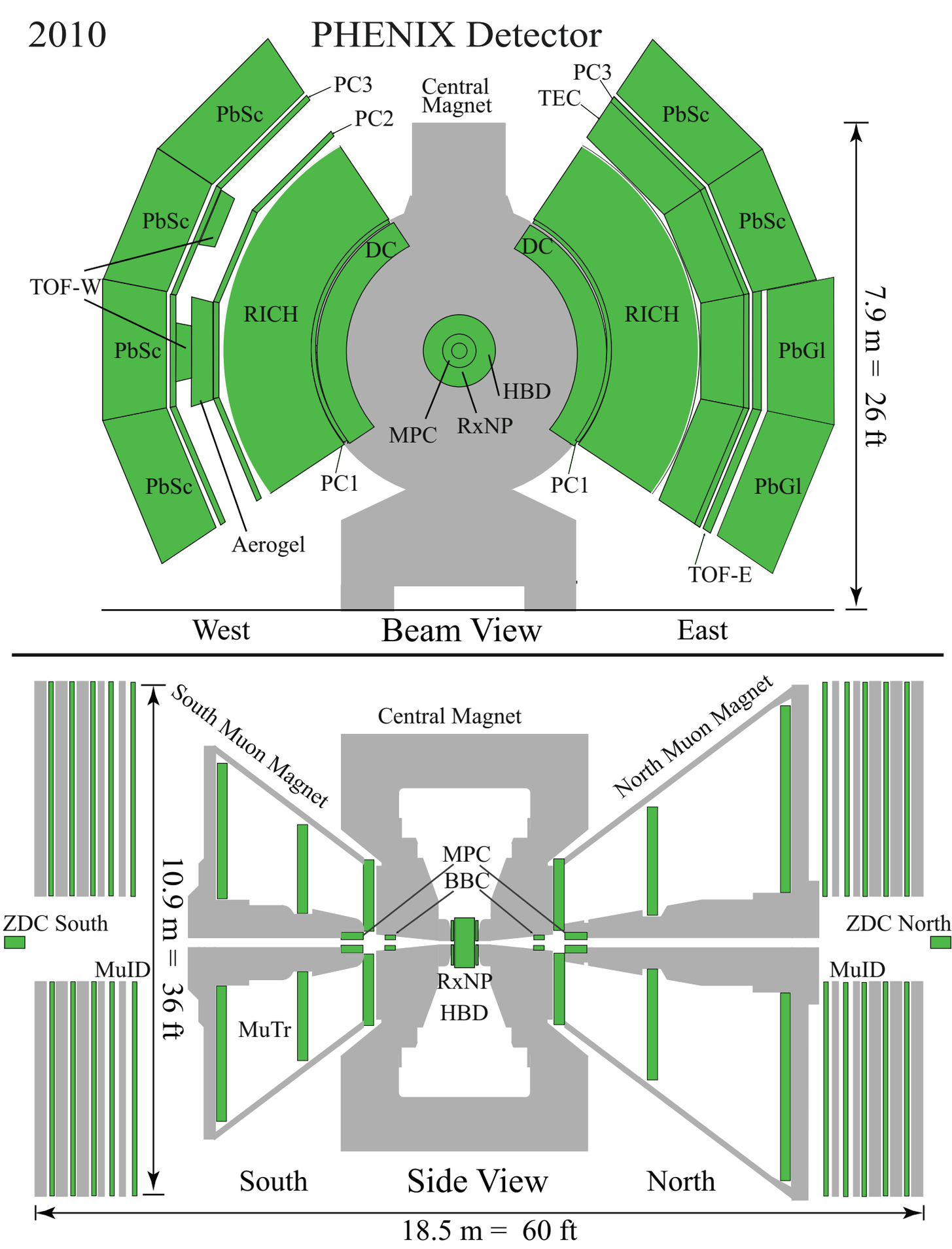

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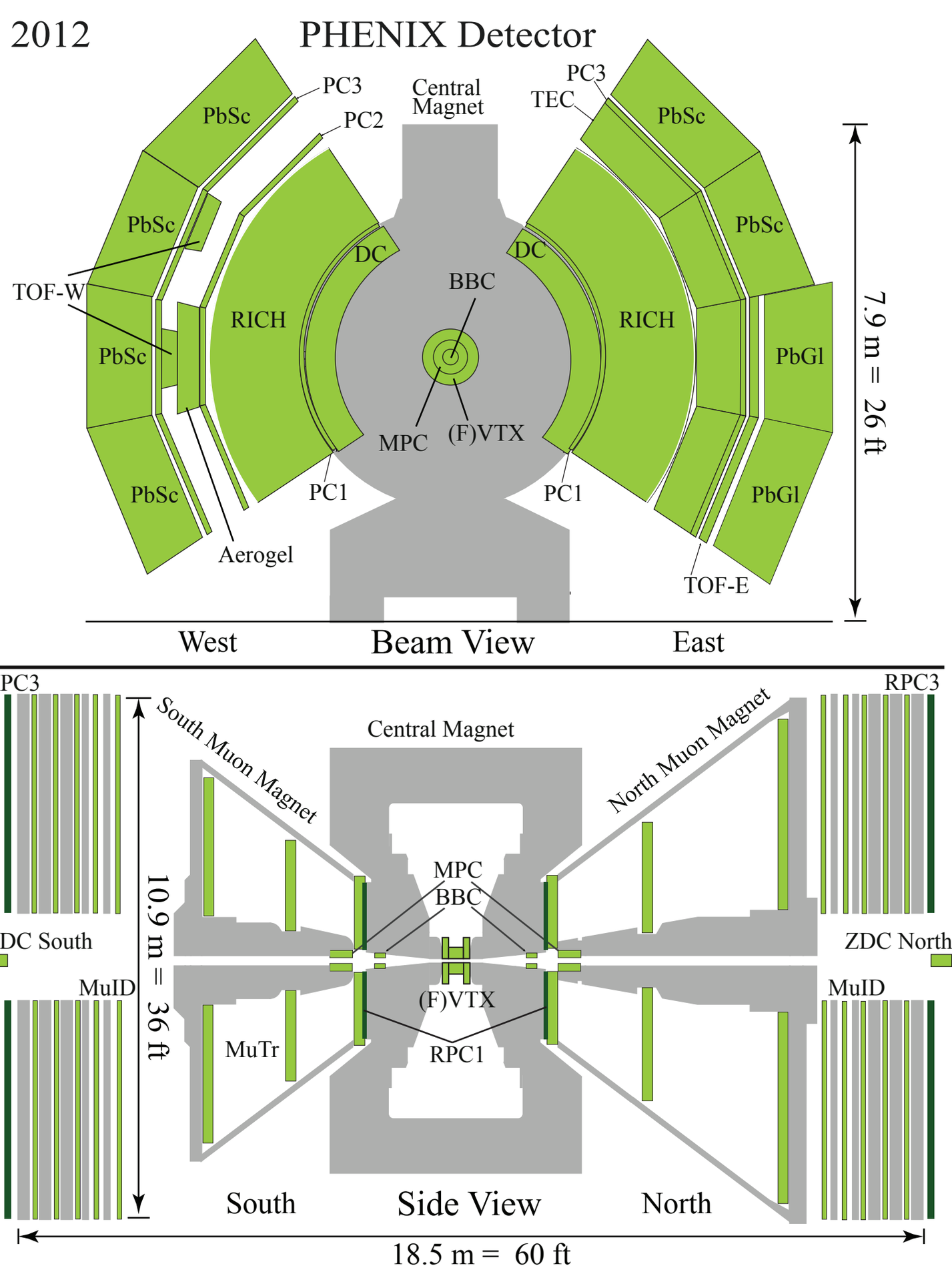


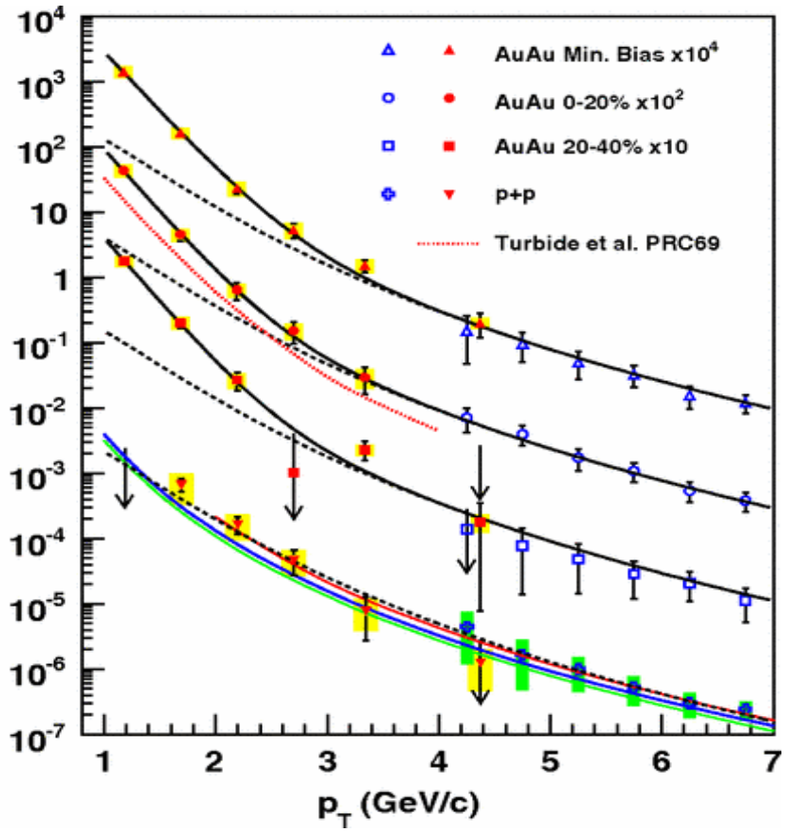
Electromagnetic Probes

Improving our Measurement

- Eugenio Scapparone showed this plot from PHENIX in his overview
- Slope parameter T extracted for excess yield in Au+Au
- Assumption: thermal photons in Au+Au, slope related to the initial temperature

PRL 104, 132301

PHENIX T = 221 ± 19(stat) ± 19(sys) MeV



PRL 109, 122302

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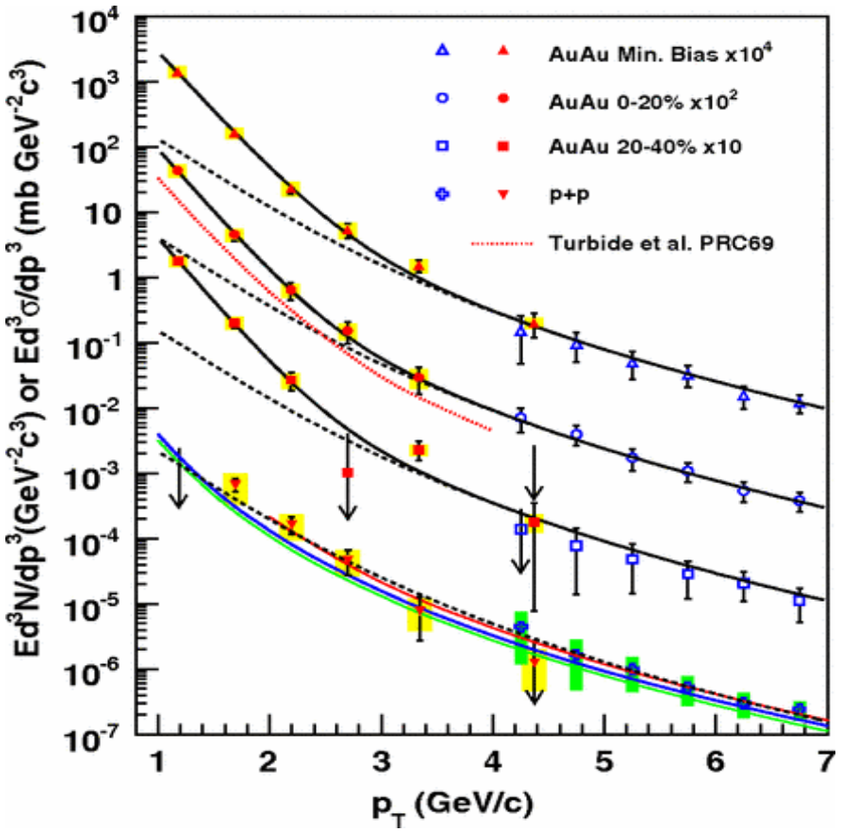
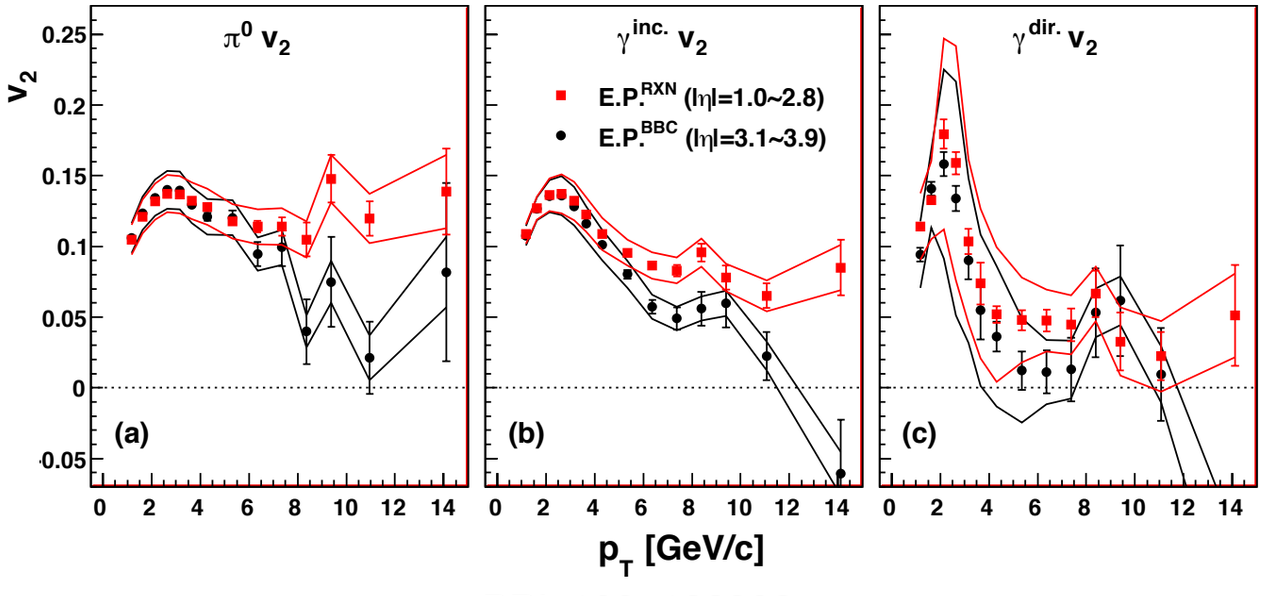
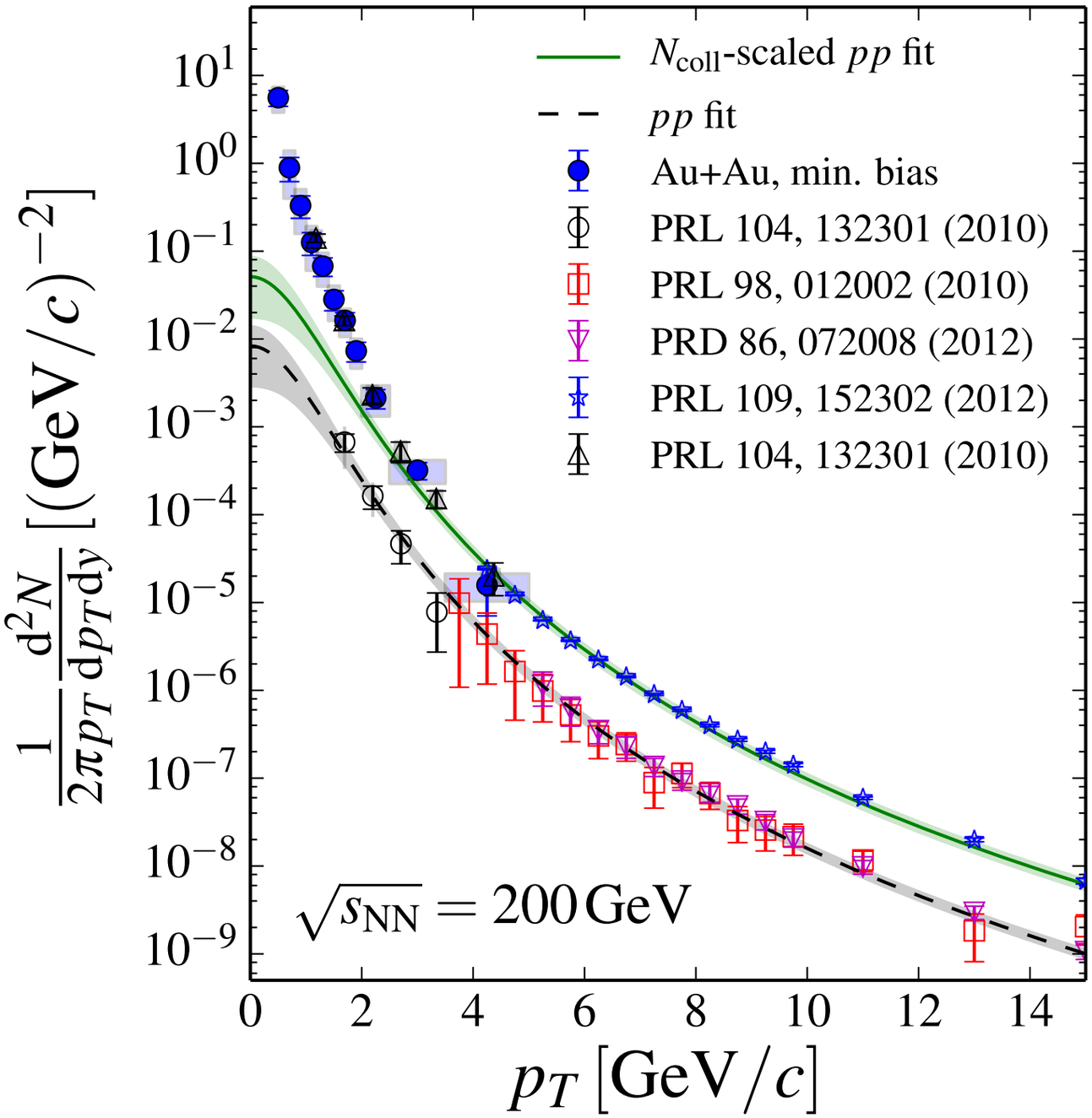




PRL 109, 122302

- Direct photon v2 surprisingly large at RHIC
- "Direct photon puzzle"
- Well, we did not stop there …

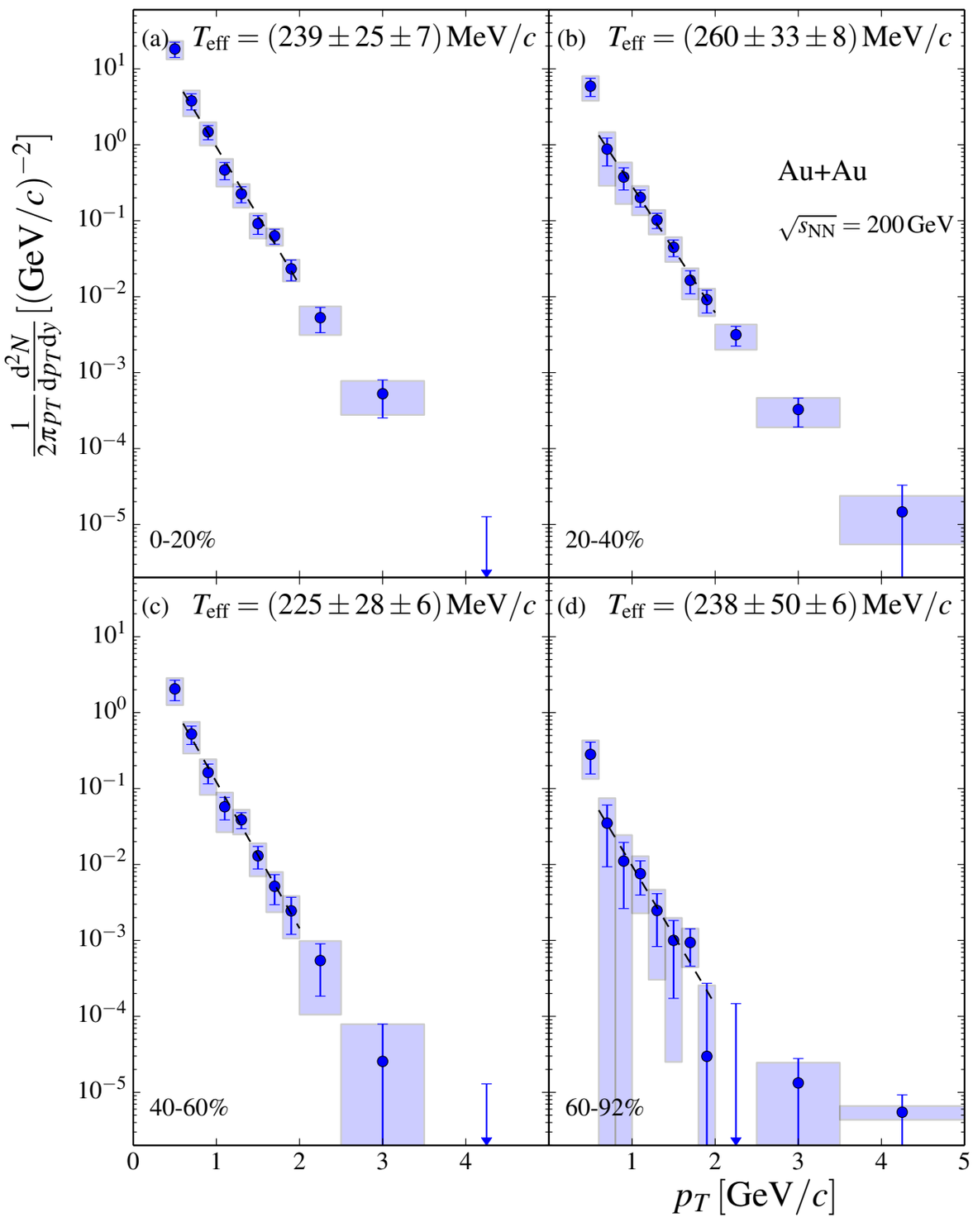
New Measurement (arXiv:1405.3940): Au+Au, 200 GeV: Direct Photon Spectra



- New analysis technique, using conversions of real photons
  - Different systematics, more statistics
- Agrees with earlier virtual photon measurement
- Extends transverse momentum range, higher precision, more centrality selections

Centrality Dependence, p+p Subtracted

arXiv:1405.3940



- Subtract scaled p+p spectrum to get direct photon yield from Au +Au sources alone
- Exponential slope T of remaining spectrum (thermal photons?) independent of centrality within uncertainties

Yield = B exp(-p_T/T)

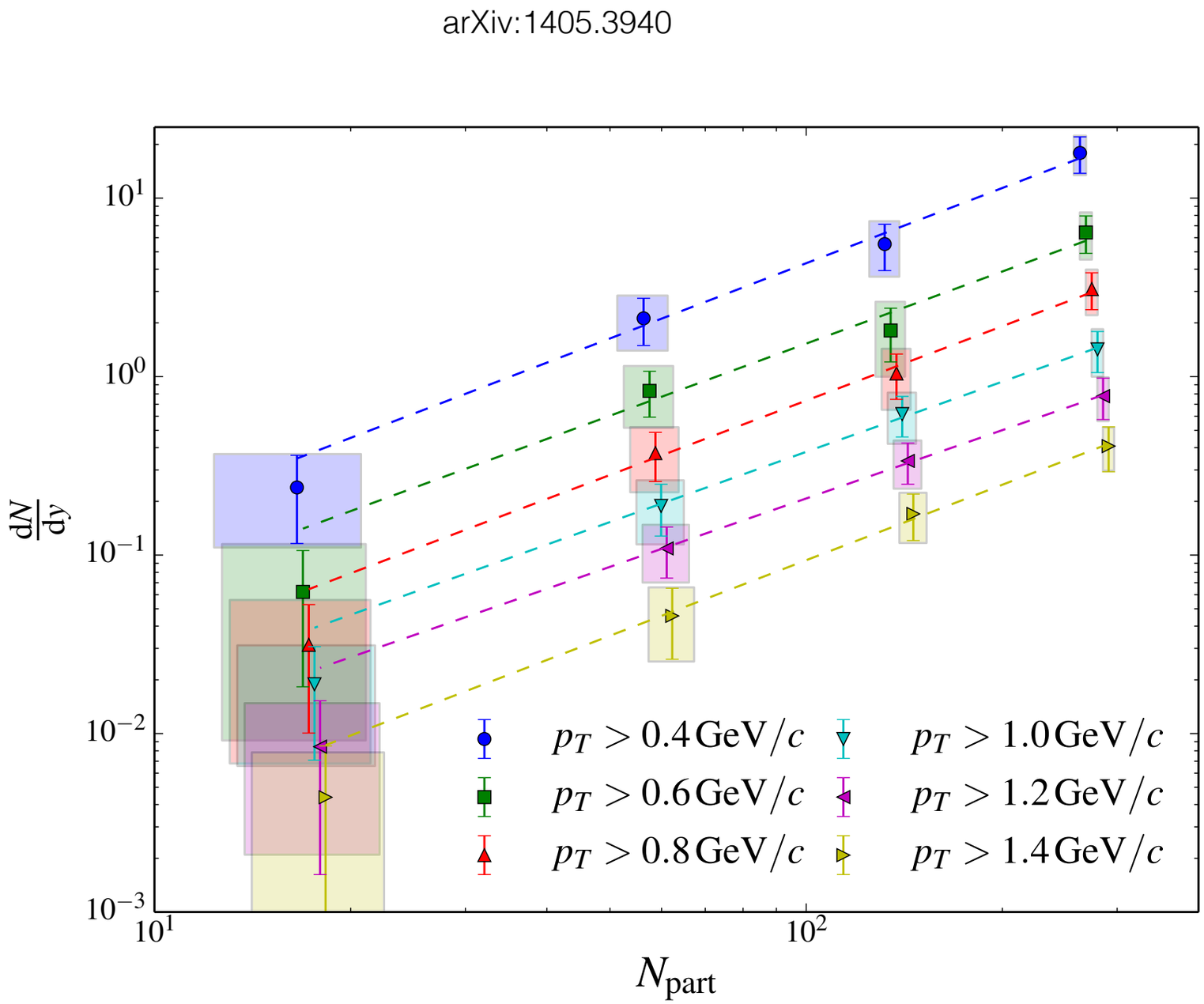
T (0-20%) = 239 ± 25 ± 7 MeV

T (20-40%) = 260 ± 33 ± 8 MeV

T (40-60%) = 225 ± 28 ± 6 MeV

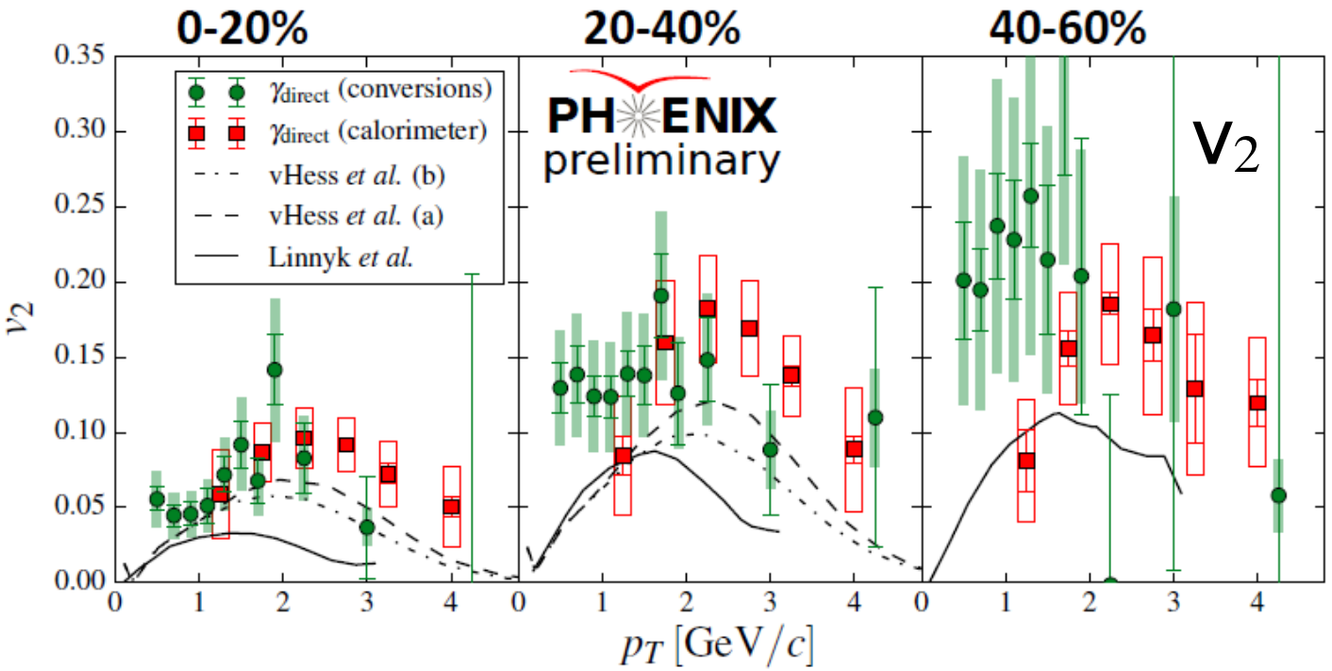
T (60-92%) = 238 ± 50 ± 6 MeV

Direct Photon Excess

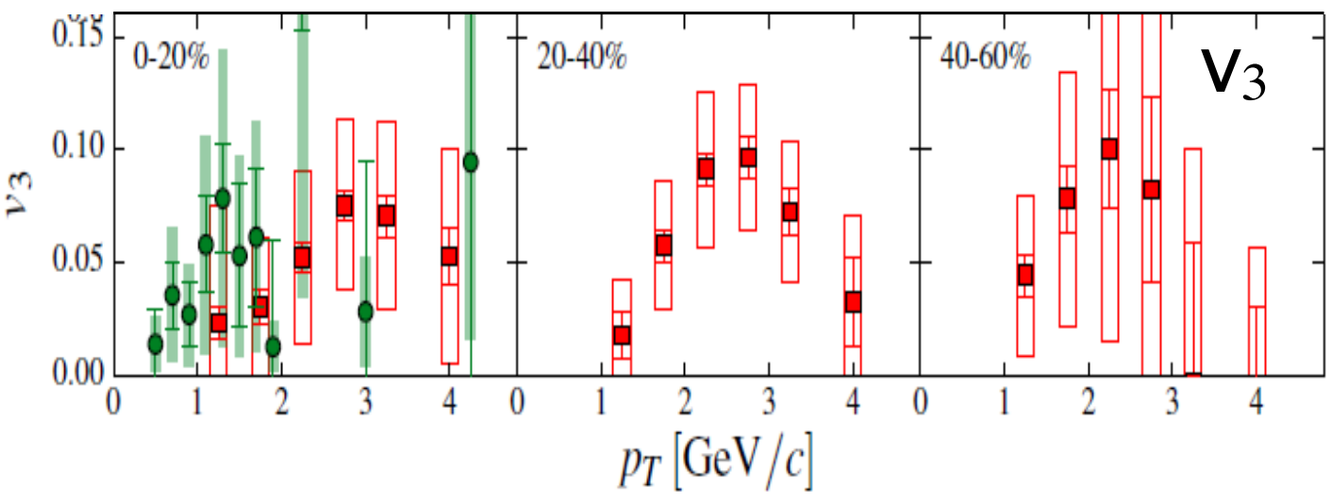


- Integrated excess photon yields Y for different p_T thresholds
- Scale as $Y = A\, N^{\alpha}_{part}$ with $\alpha = 1.48 \pm 0.08\,(stat) \pm 0.04\,(sys)$
- Together with slope parameters: Strong new constraint on hydrodynamic time evolution and modeling of radiation emission

A puzzle: Direct Photon Anisotropy



- New methods to measure direct photon v_2 confirm surprising large v_2 from first PHENIX measurement
- Challenge for dynamical models



- New methods allow measuring v_3
- Also non-zero v_3, adds to the challenge for the models!

At the LHC?

- PHENIX result is very challenging for models
- Many internal cross checks, but what happens at other enegies?

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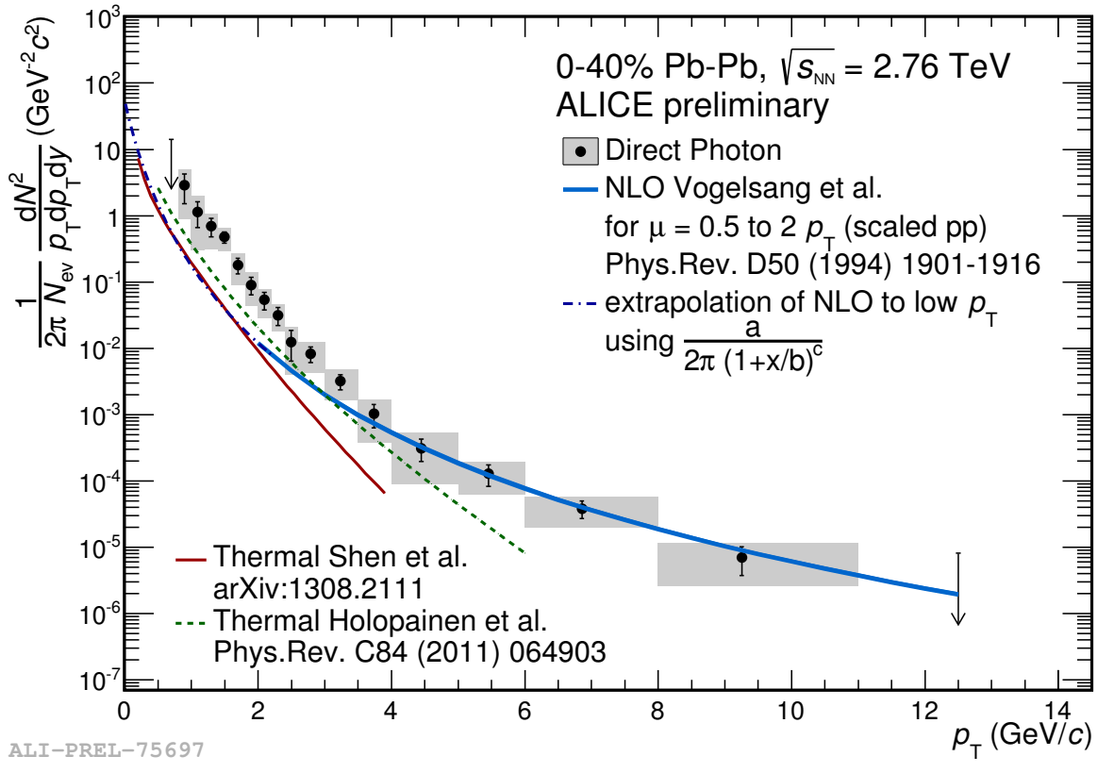
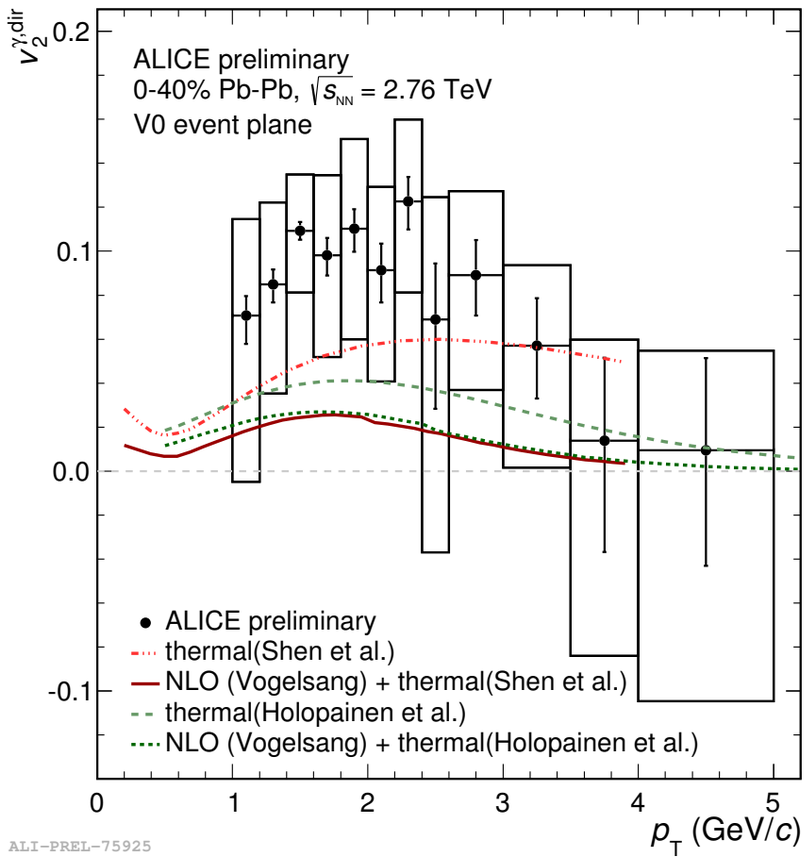
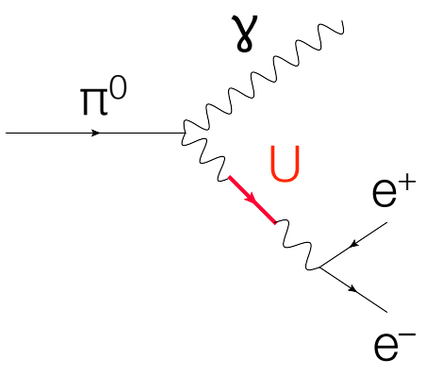
- PHENIX result is very challenging for models
- Many internal cross checks, but what happens at other enegies?
- ALICE measurement of direct photon excess and v_2



- Inverse slope even larger than at RHIC: $T_{ALICE} = 304 \pm 51$ MeV
- Observation of positive v_2 as well
- However: ALICE advises to handle result with care, uncertainties play a crucial role



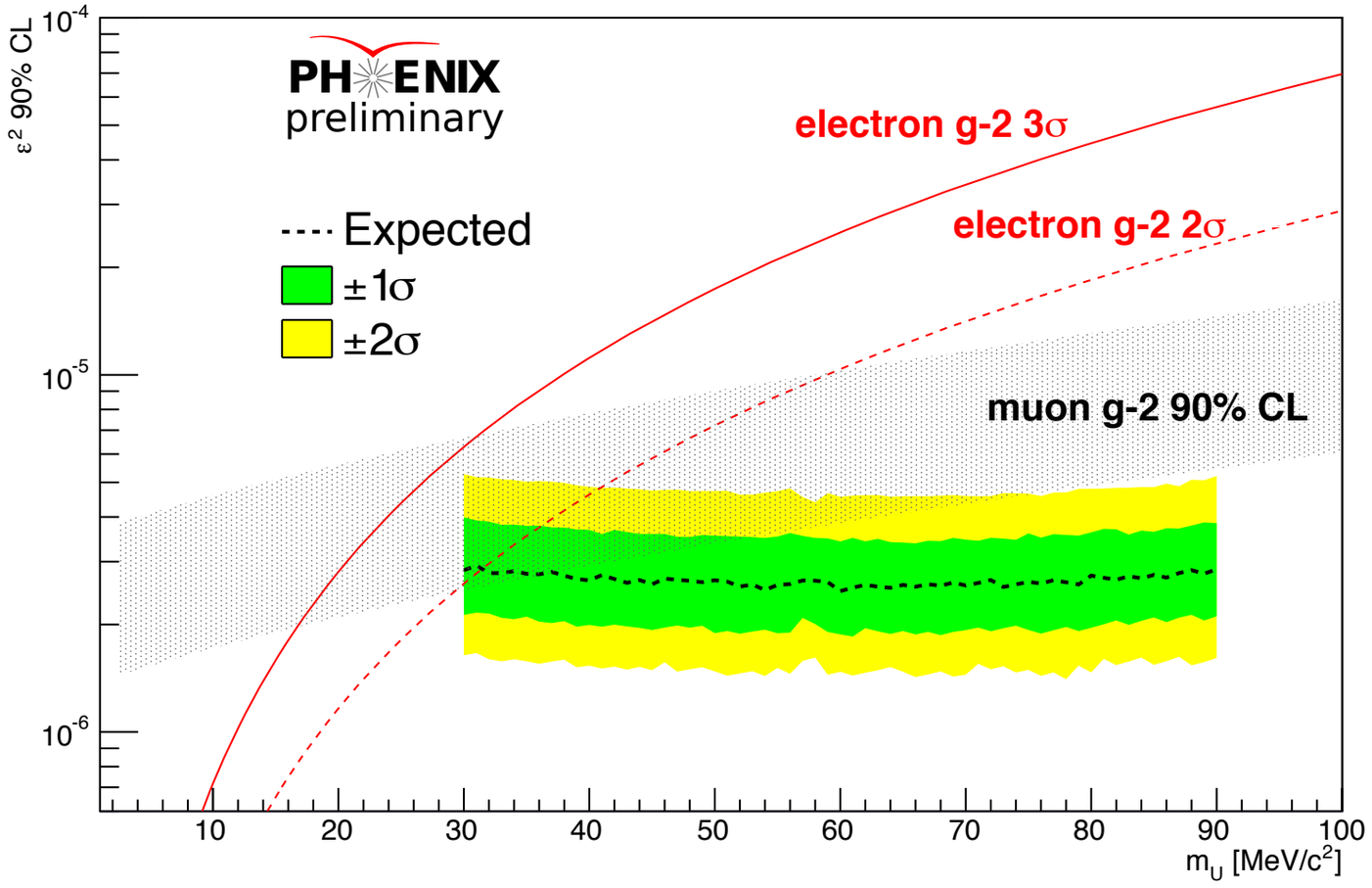
Constraints on Dark Photons



3.6σ result beyond SM from muon g-2 measurement

Possible explanation are dark photons - low mass, very weakly coupled particles

Many searches ongoing, using fluctuations of virtual dark photons



- No dark photon signal seen in PHENIX (using p+p and d+Au collision data)
- Our upper limit, together with other results (HADES, …) almost rules out dark photons

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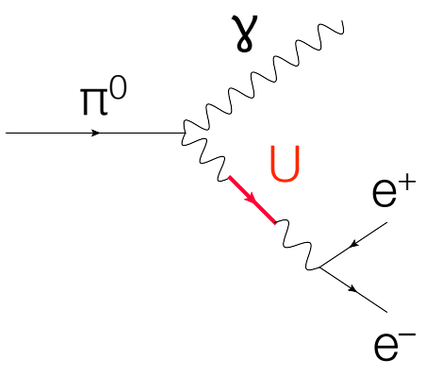

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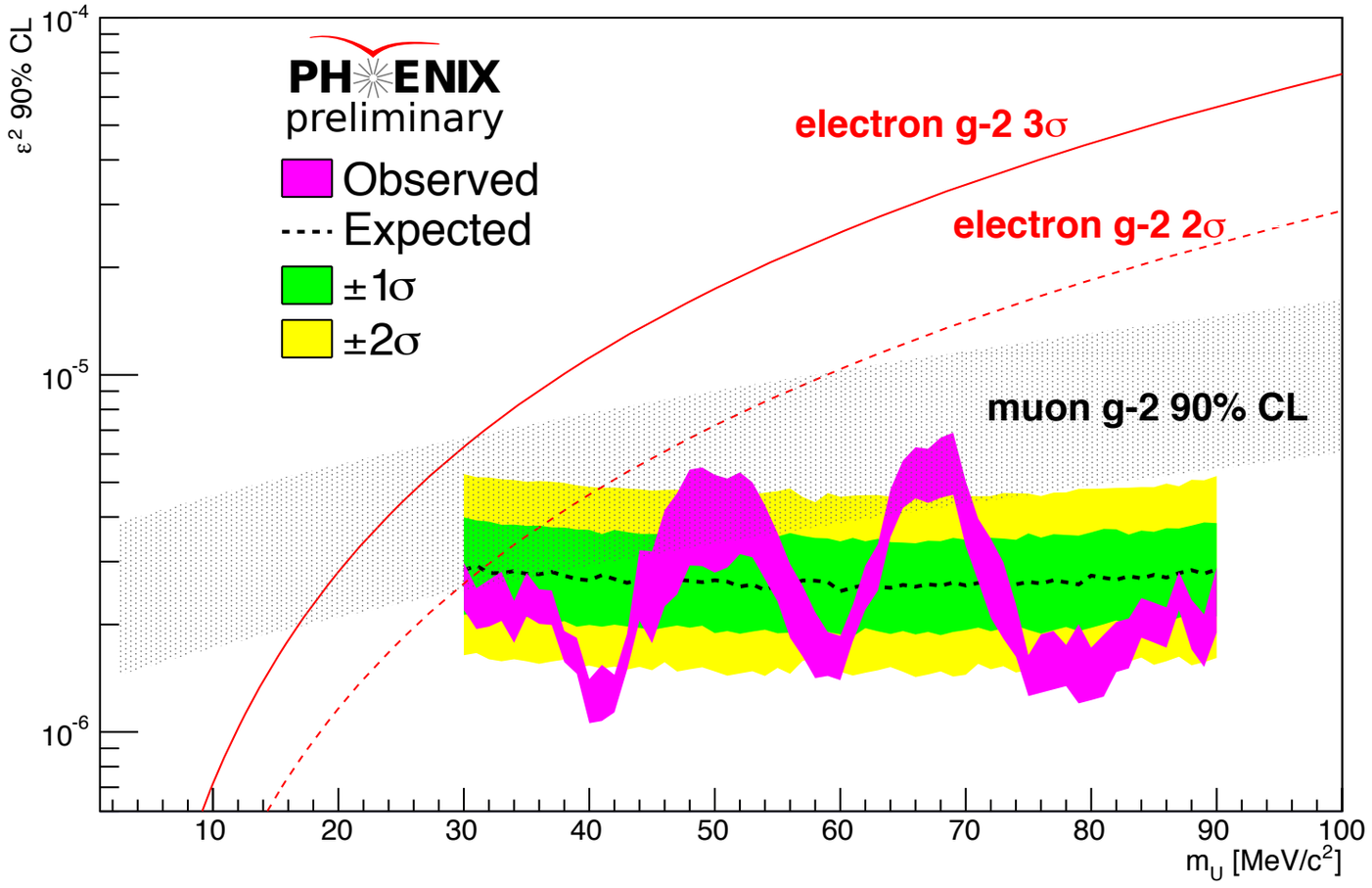

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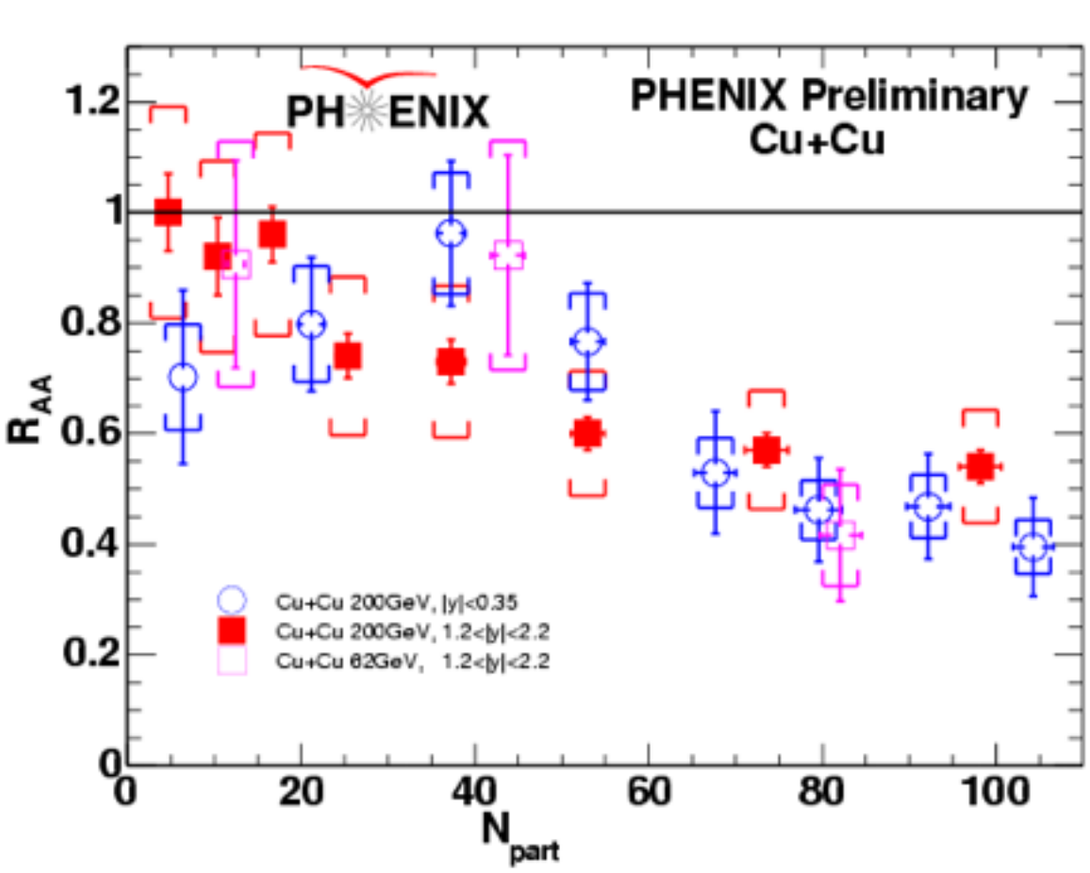
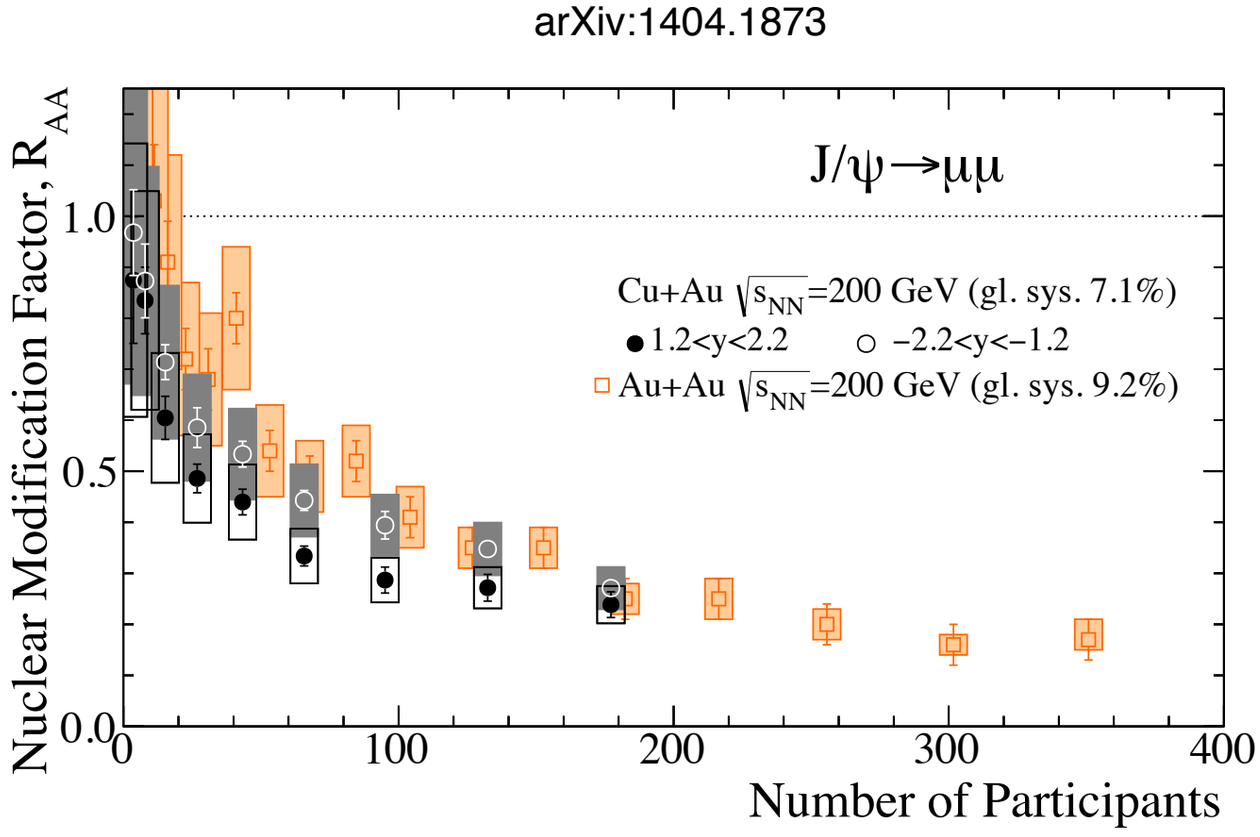
Heavy Quarks, Quarkonia

J/ψ in Cu+Au at 200 GeV

- An asymmetric system: J/ψ nuclear modification factor in forward rapidity in Cu+Au compared to Cu+Cu and Au+Au
  - similar centrality dependence, however, difference in forward and backward for Cu+Au

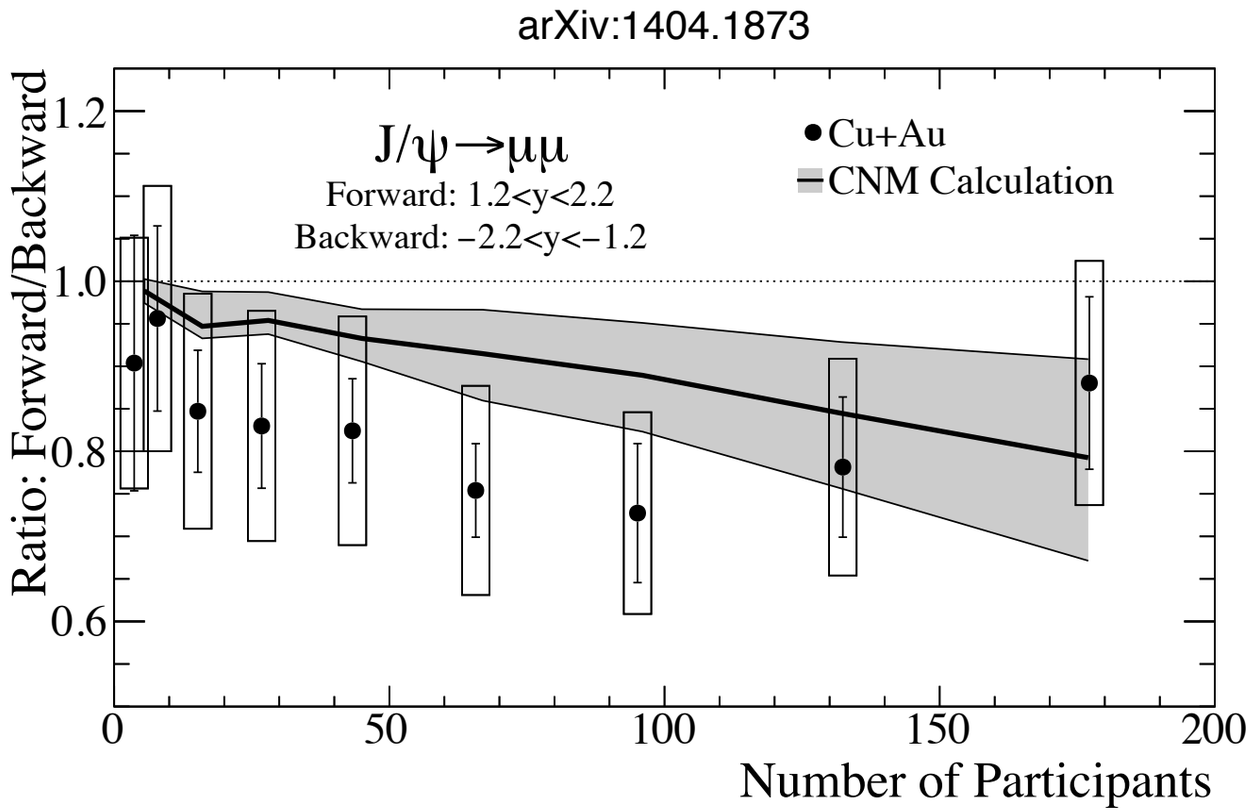


arXiv:1404.1873

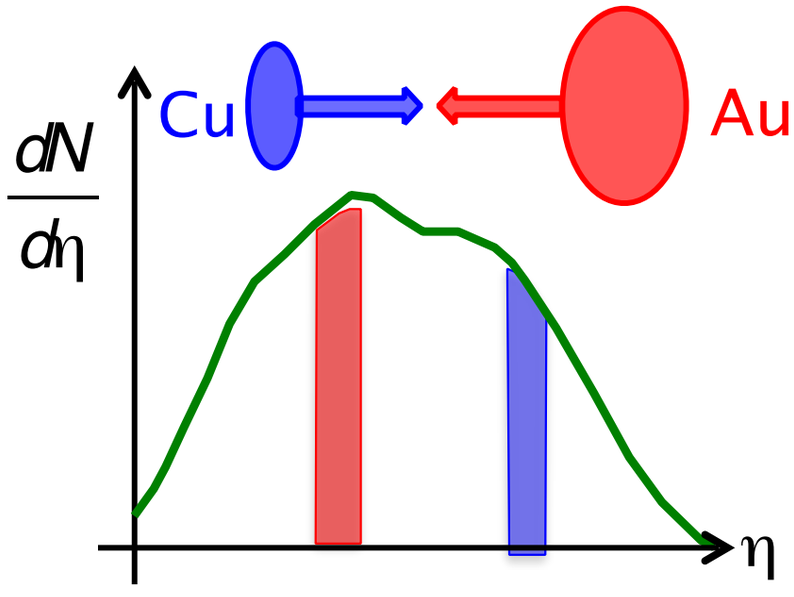


J/ψ in Cu+Au at 200 GeV

- J/ψ more suppressed in Cu going direction
- Trend consistent with CNM calculation (used here: EPS09), more low-x shadowing in Au than in Cu



- Less suppression in direction of lower particle density would produce a rising trend in the ratio!



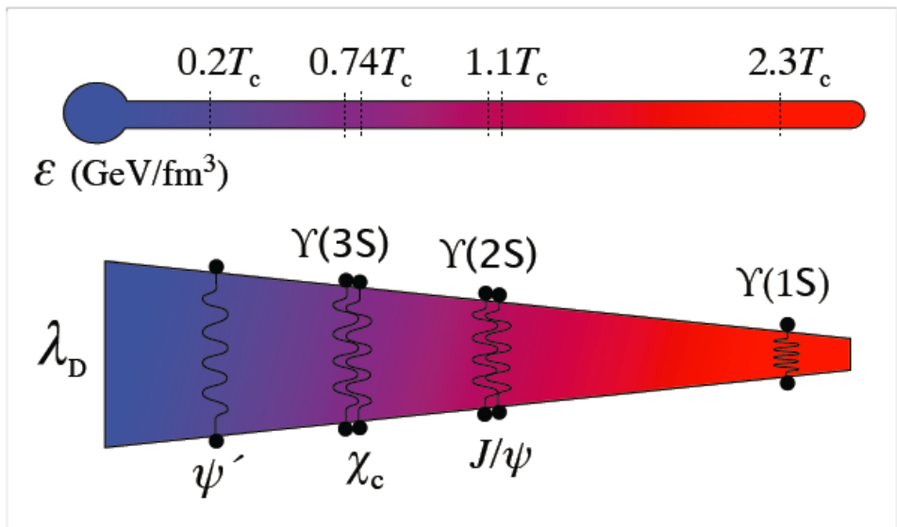
ϒ in Au+Au

- Looking at more states, following the idea of the "quarkonia thermometer"

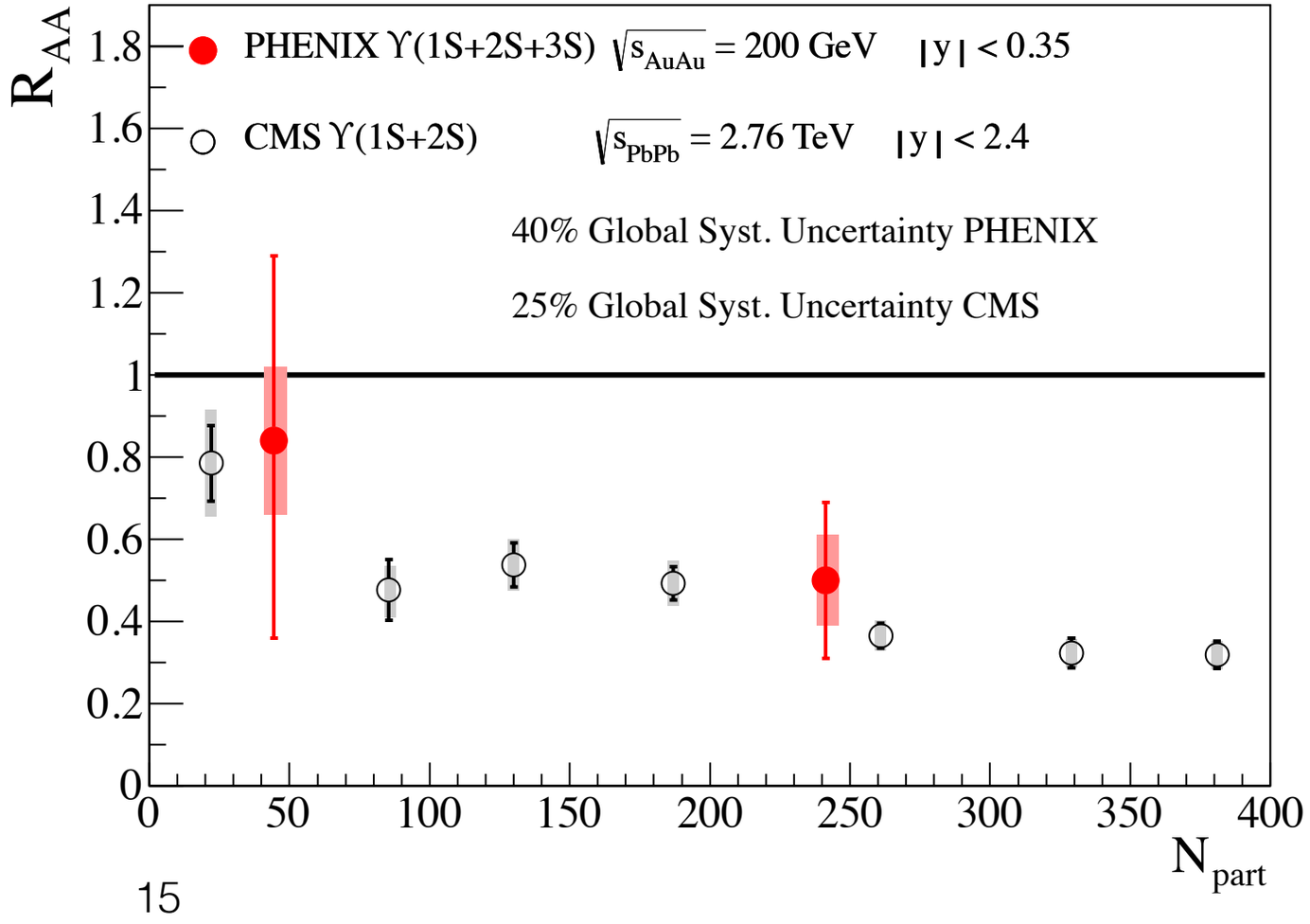
- Suppression of ϒ at RHIC observed

- Suppression consistent with disappearance of **2s** and **3s** contributions

- Similar suppression seen by CMS in Pb+Pb collisions at LHC energies (within uncertainties)

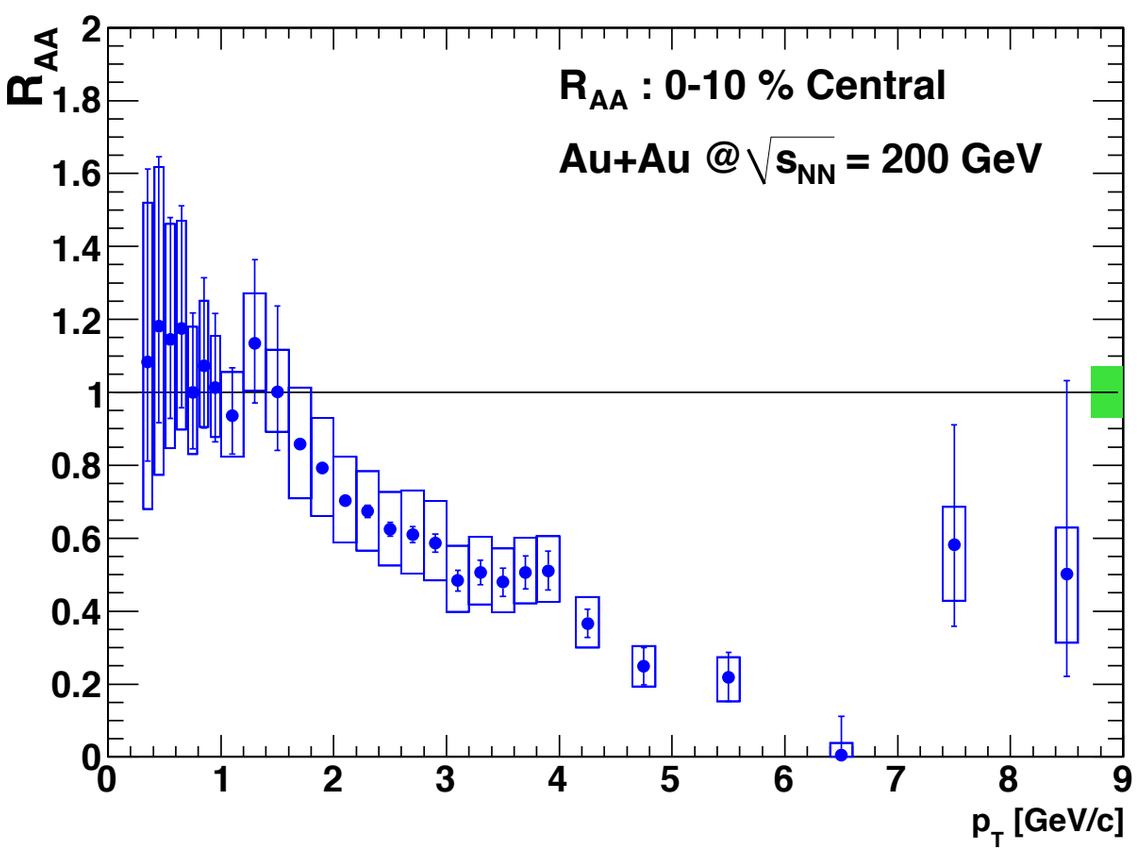


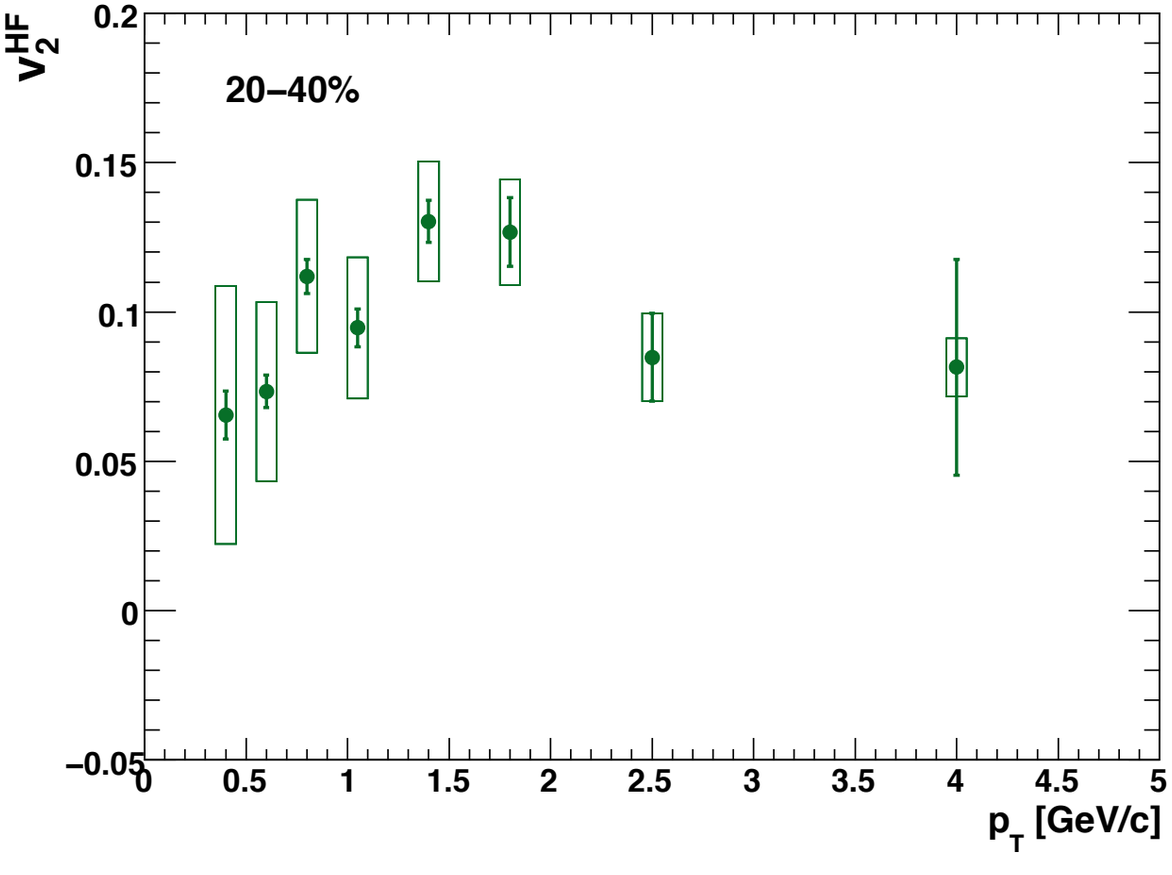
arXiv:1404.2246



Heavy Flavor, Au+Au at 200 GeV

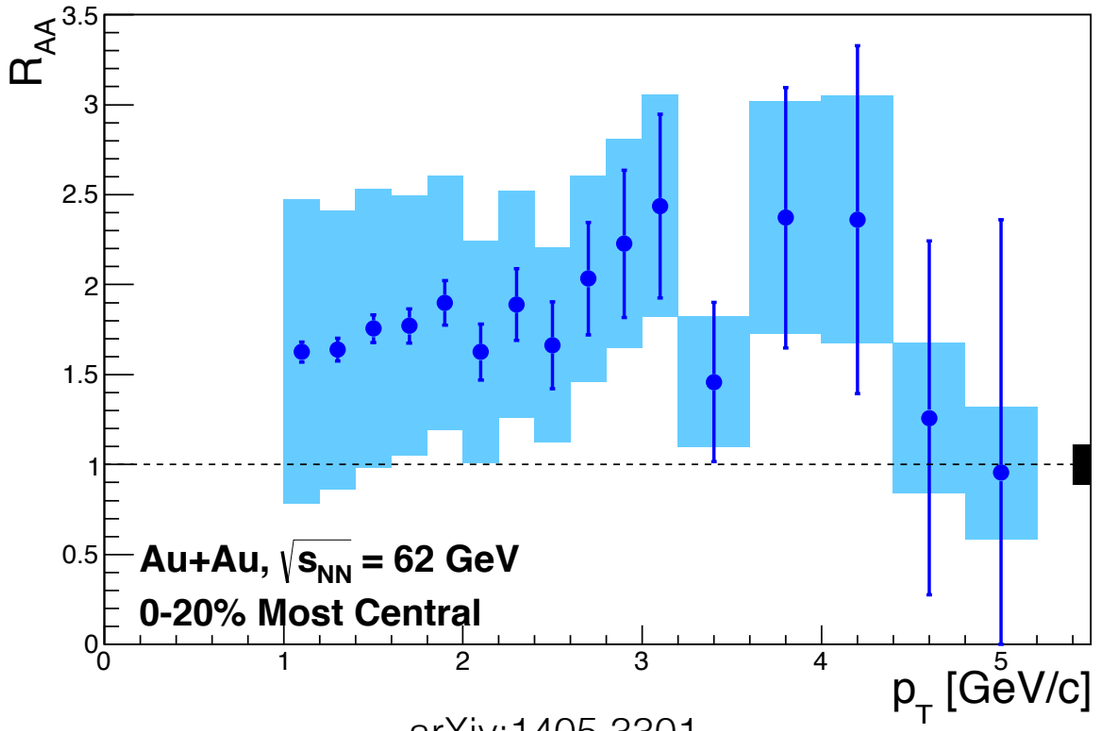
- 200 GeV measurement from 2010 shows strong HF suppression, large v_2





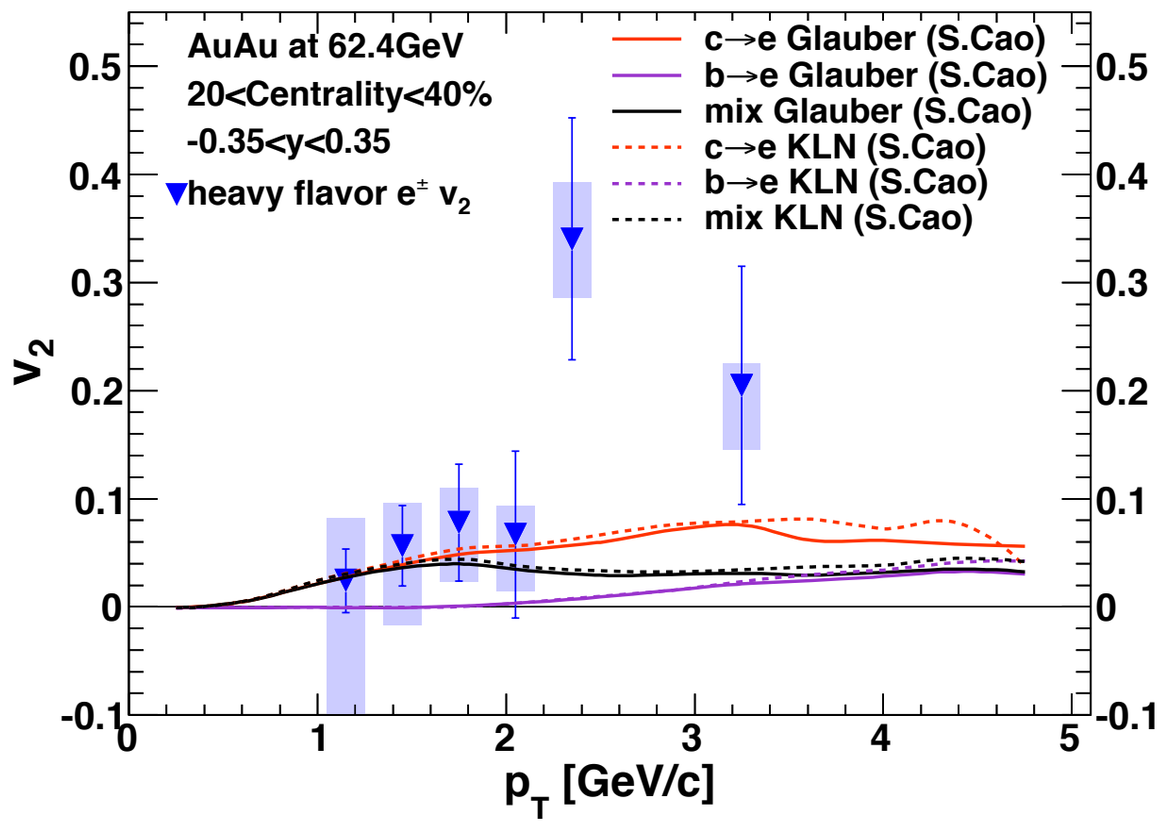
PRC 84, 044905

Heavy Flavor, Au+Au at 62.4 GeV



arXiv:1405.3301

- At lower energy, HF electrons enhanced in central Au+Au!
- Opposite to Au+Au at 200 GeV
- Opposite to energy loss models
- Different dynamics at work?

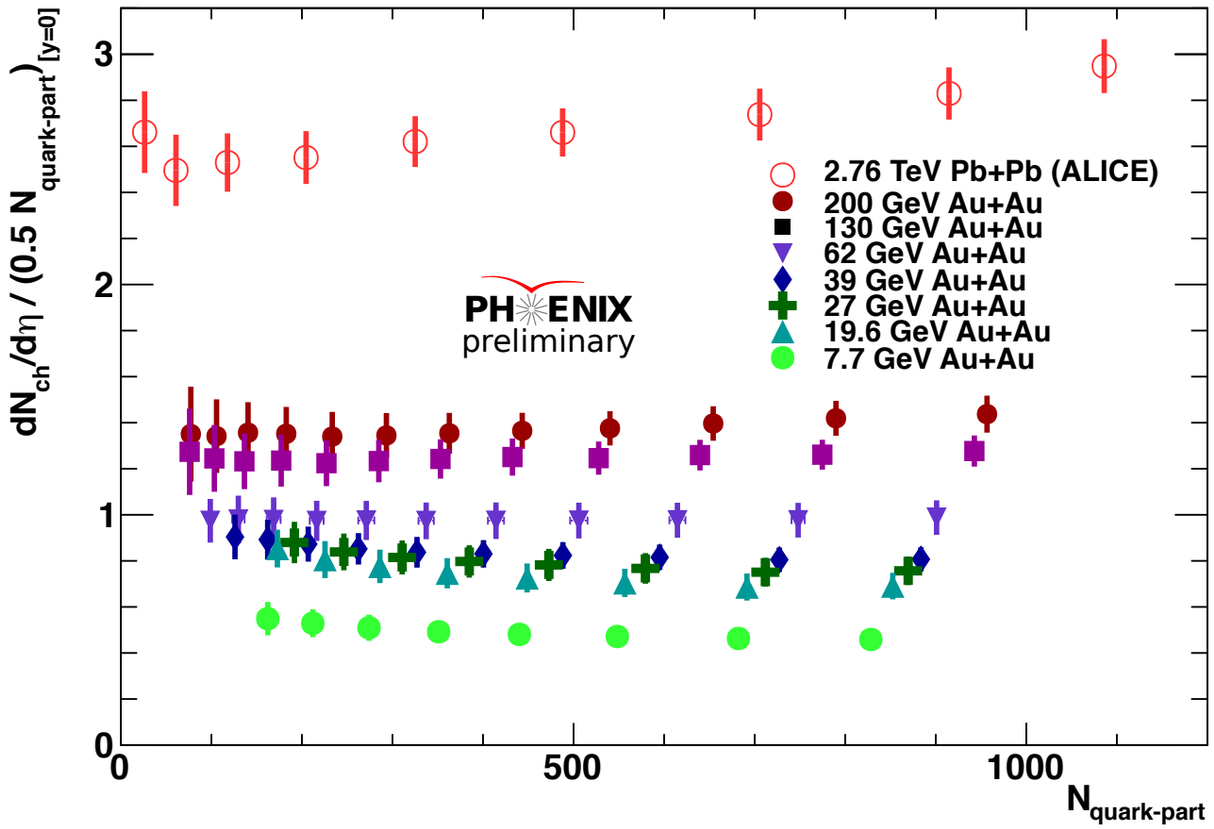


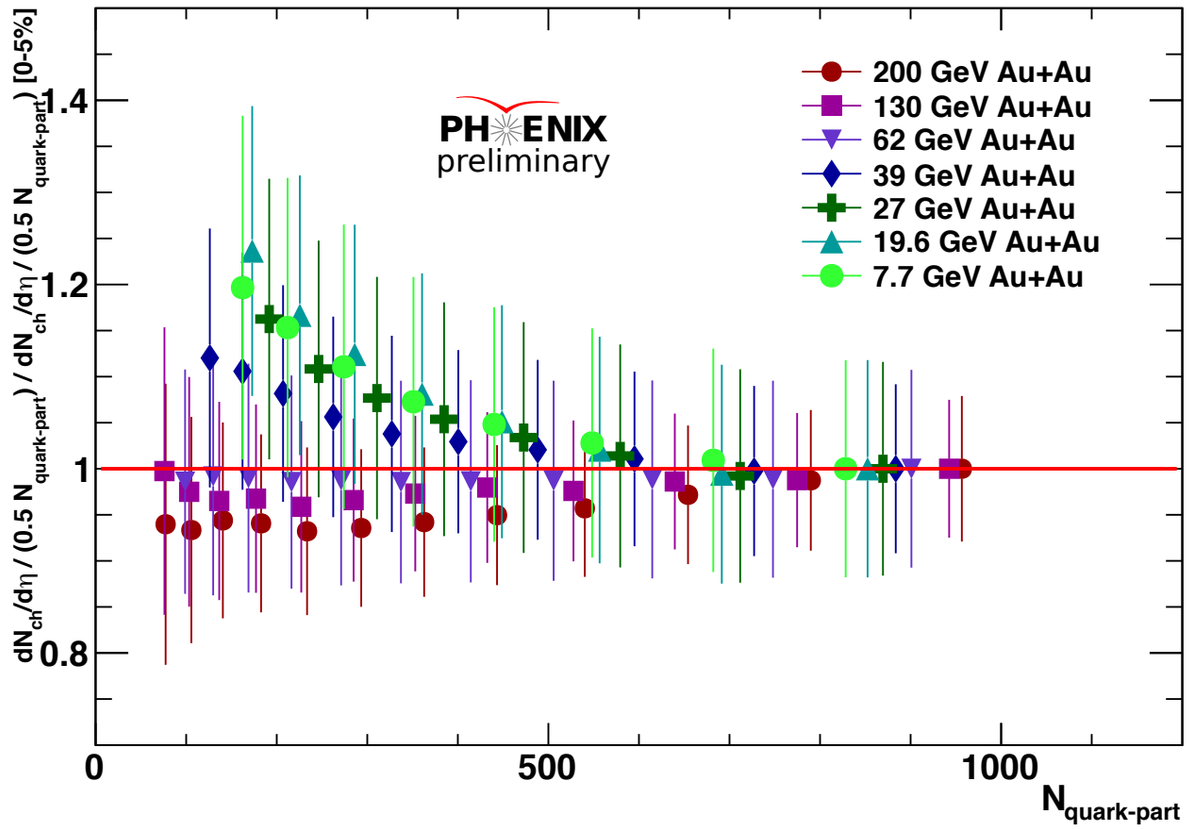
- HF v_2 measurement hints to small positive v_2
- Impacting spectra and R_{AA}?
- Need more statistics for conclusive measurement!

HBT and Beam Energy Scan

Quark Scaling

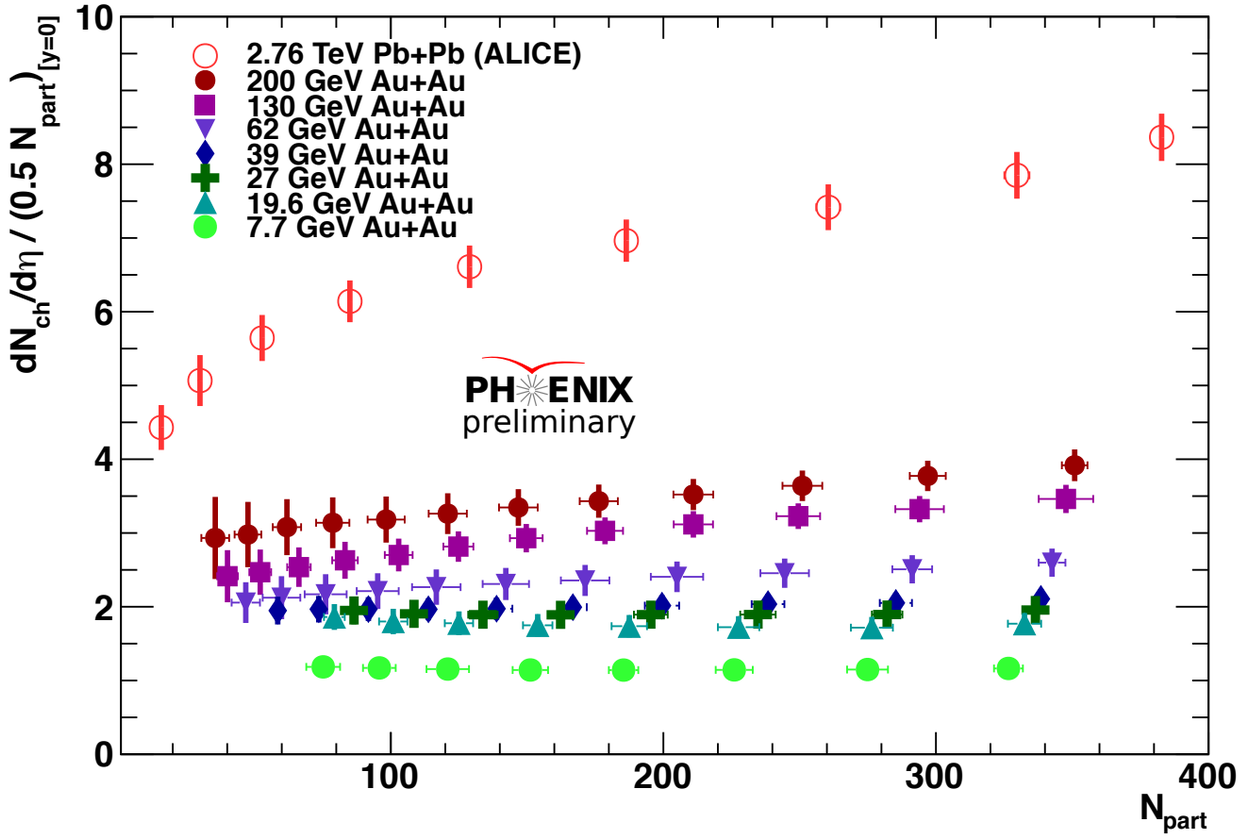
- Looking at charged particle multiplicity at mid-rapidity
- Participant quark scaling works well for $\sqrt{s_{NN}}$ = 62 - 200 GeV

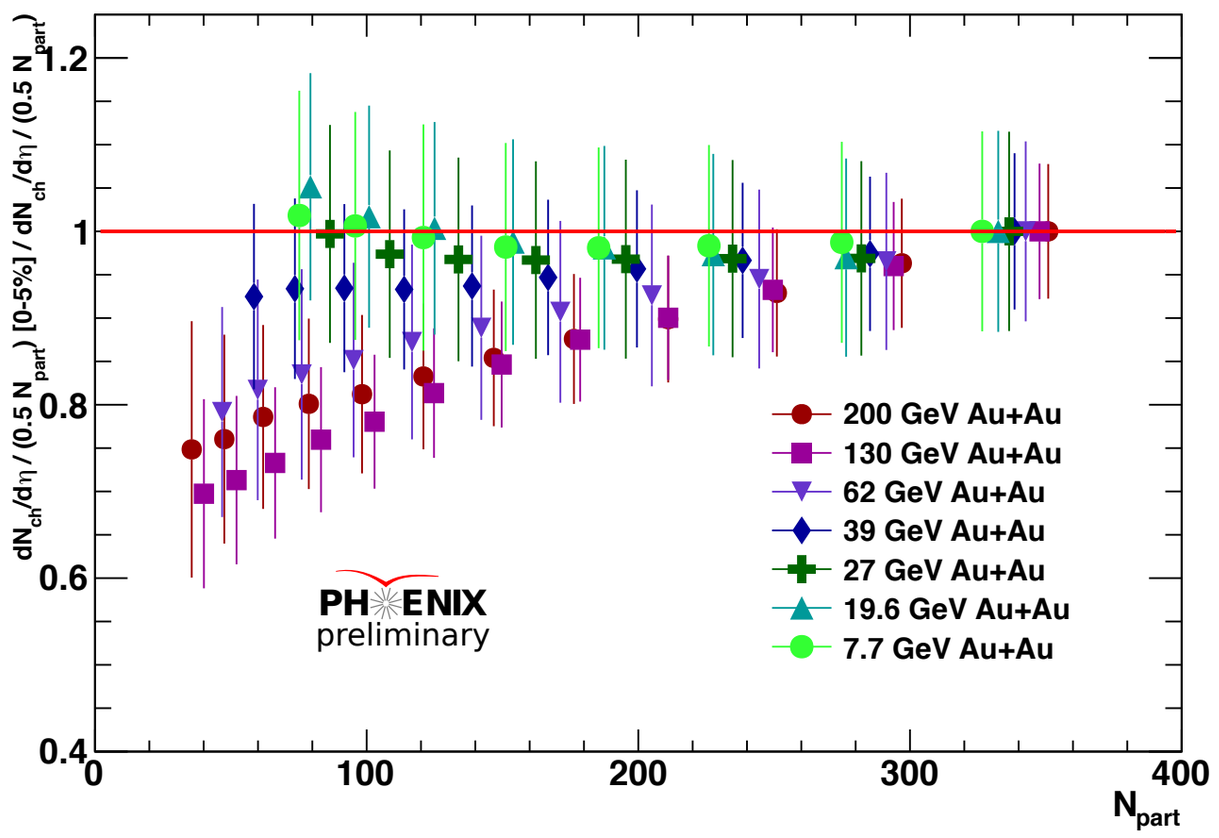




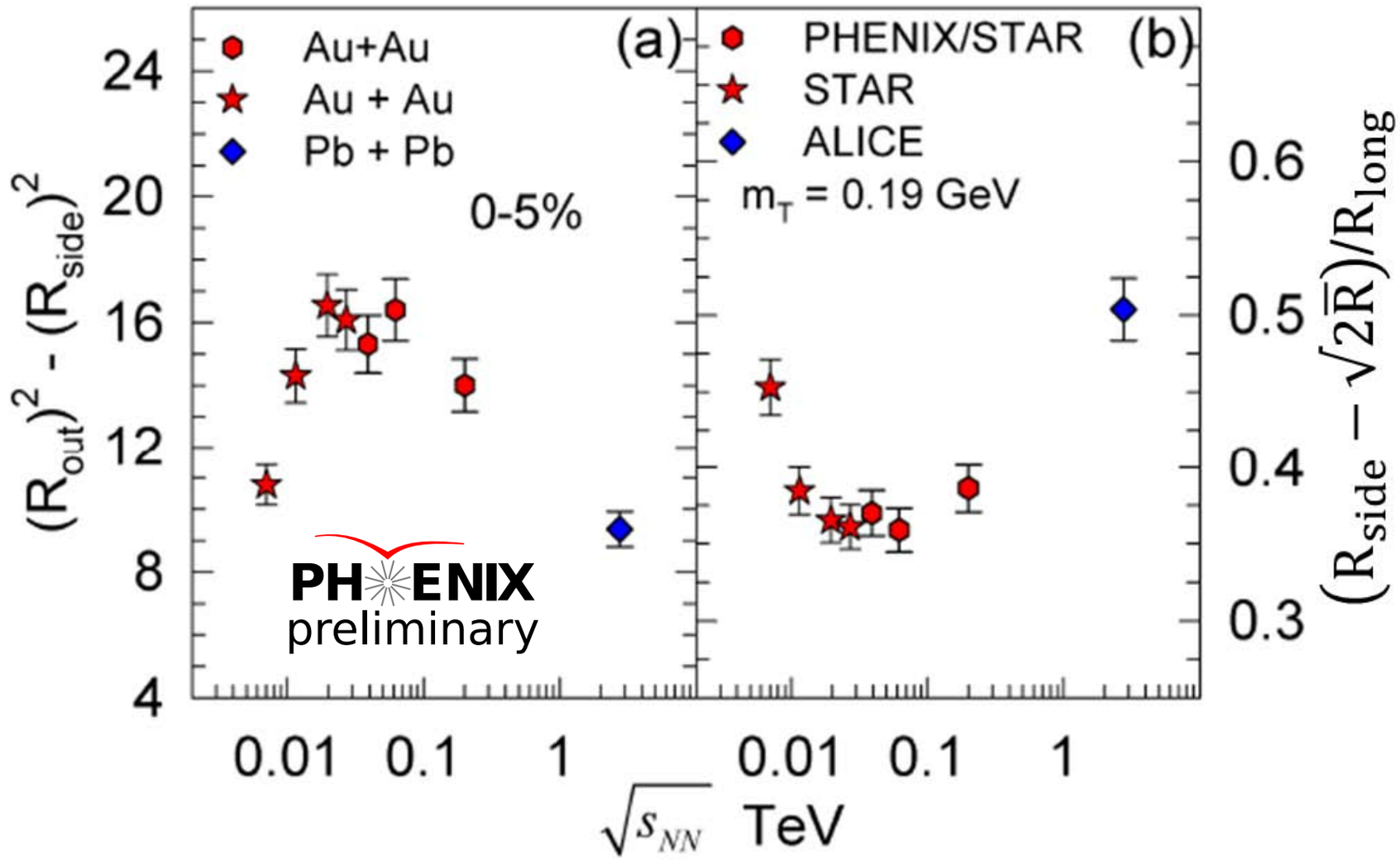
Nucleon Scaling

- But: for $\sqrt{s_{NN}} < 27$ GeV, participant quark scaling does now work, instead: participant nucleon scaling!





HBT Radii versus Beam Energy



- HBT radii measured over large range of √s by PHENIX, STAR, ALICE
- RHIC BES allows tests of the changing equation of state and possible effects of critical end point
- Interesting excitation function observed in 3D HBT result

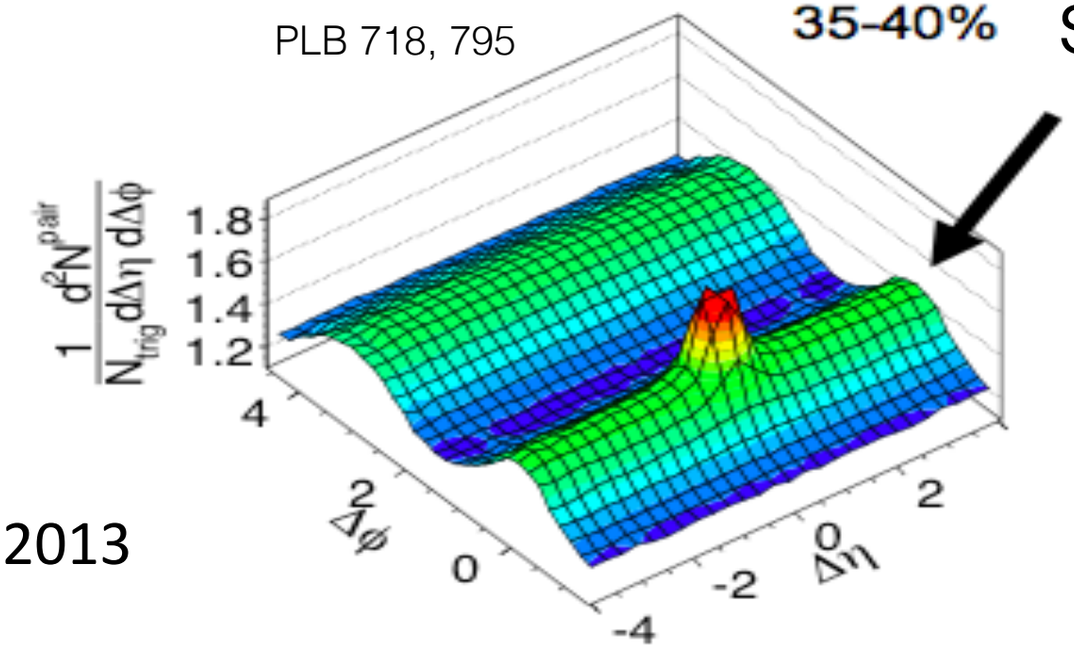
d+Au Collisions: more than a simple Initial State?

d+Au: A New Old Story

- Since ~2012, d+Au became much more interesting! Unexpected results started to show up at RHIC and LHC, for example the “CMS ridge”

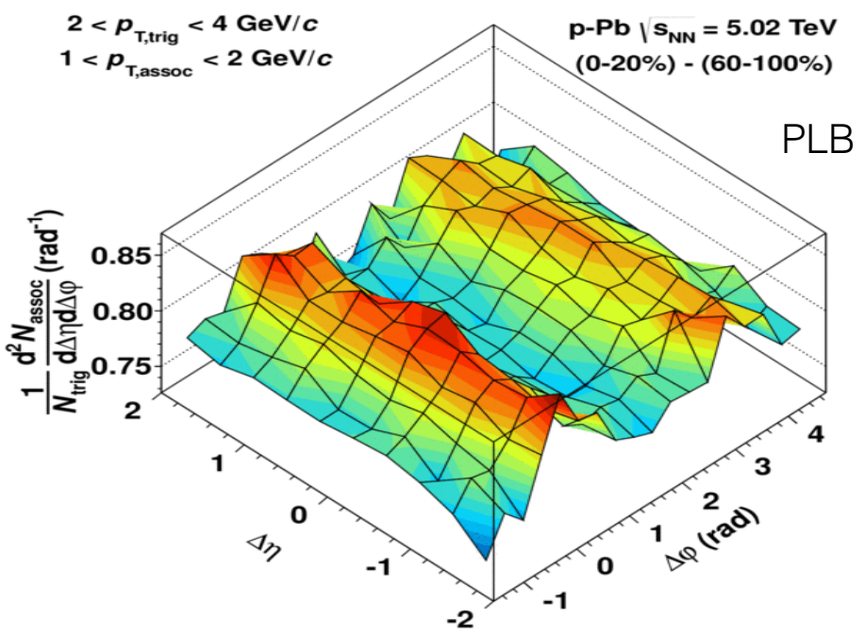
CMS: ridge-like structure at $\Delta\phi = 0$

PLB 718, 795



2013

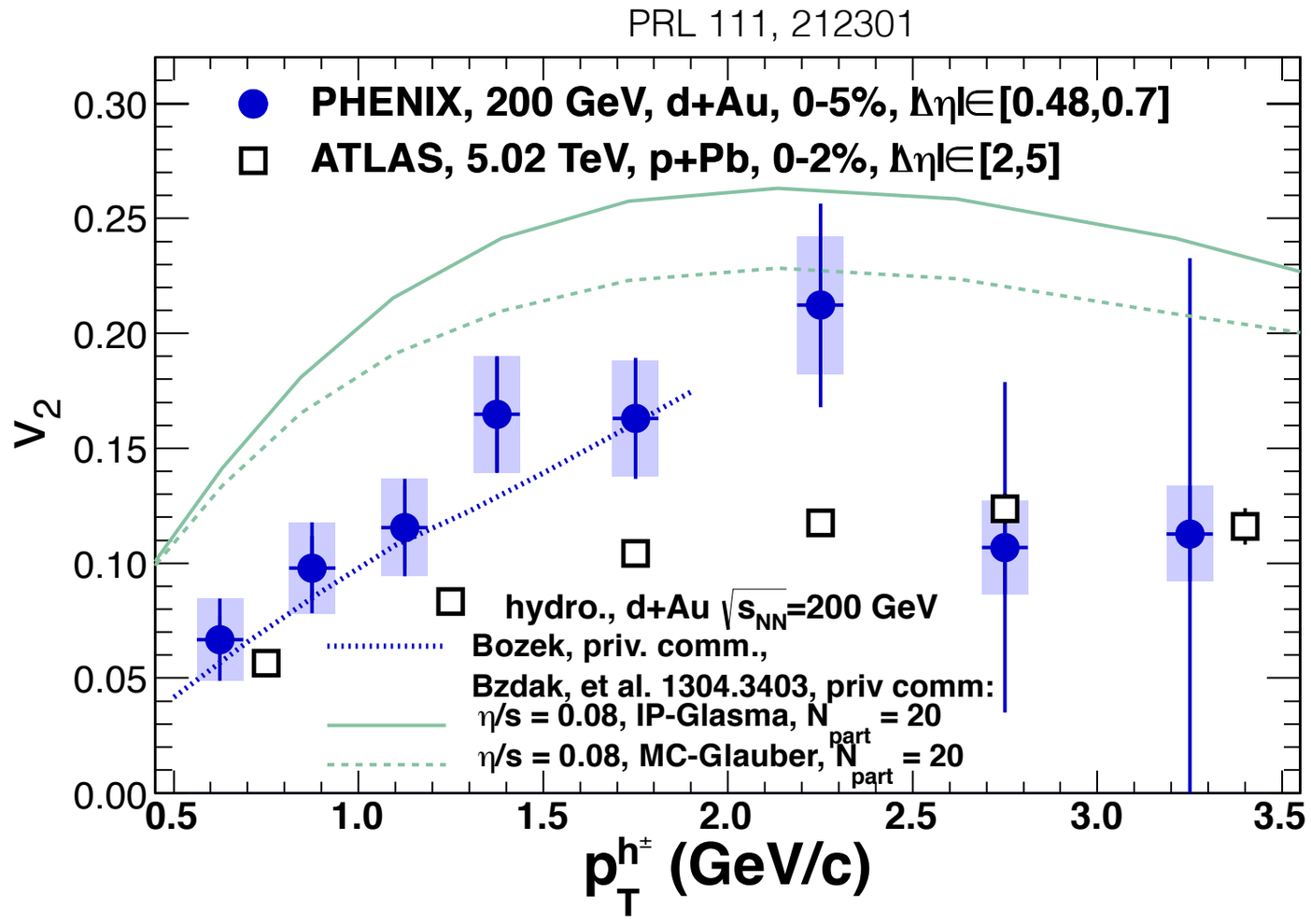
ALICE: double ridge structure



PLB 719, 29

Long Range Correlations in d+Au

- Large v2 measured in central d+Au
- This first result analyzed with small $\Delta\eta$ gap = 0.47 - 0.7



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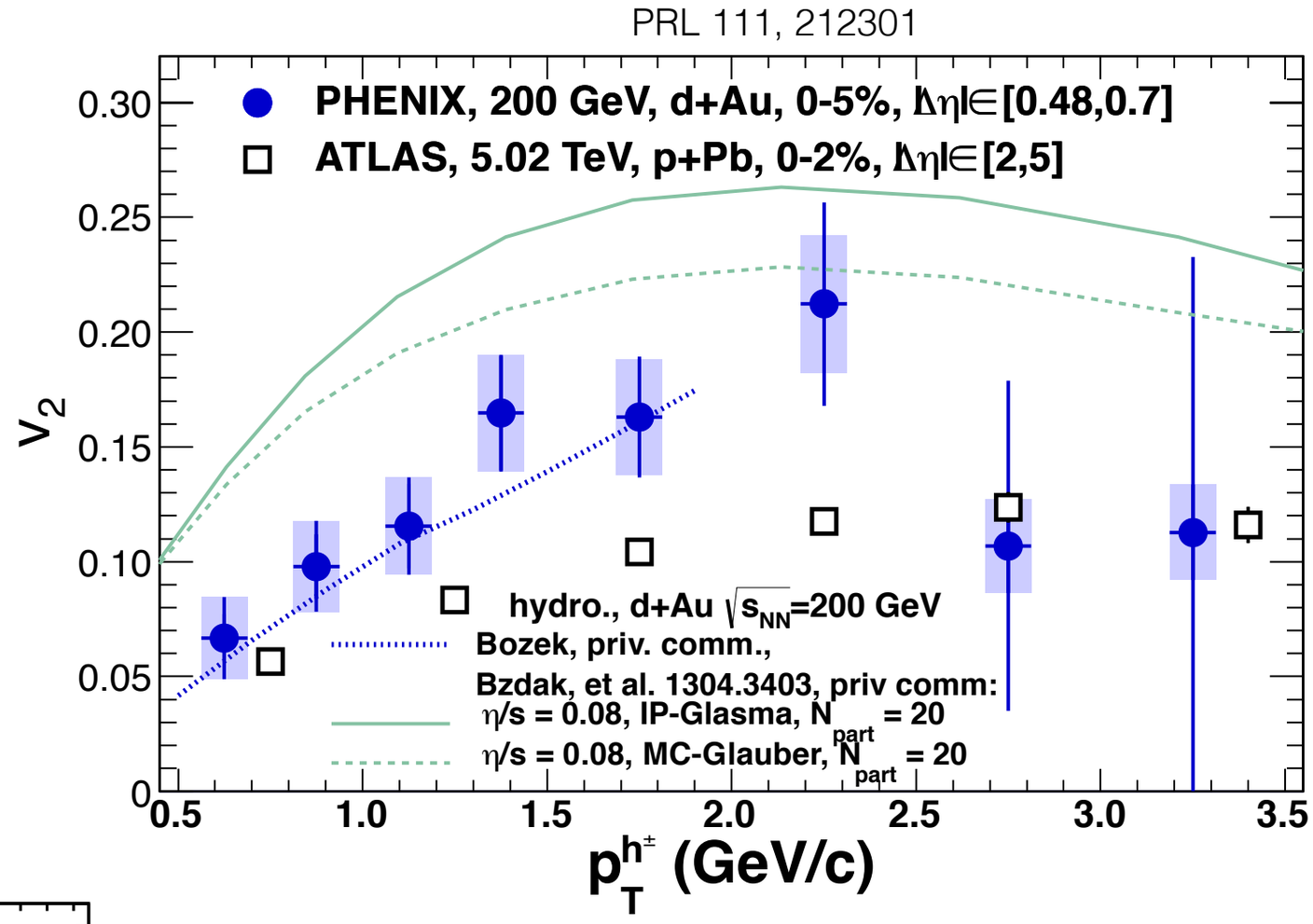
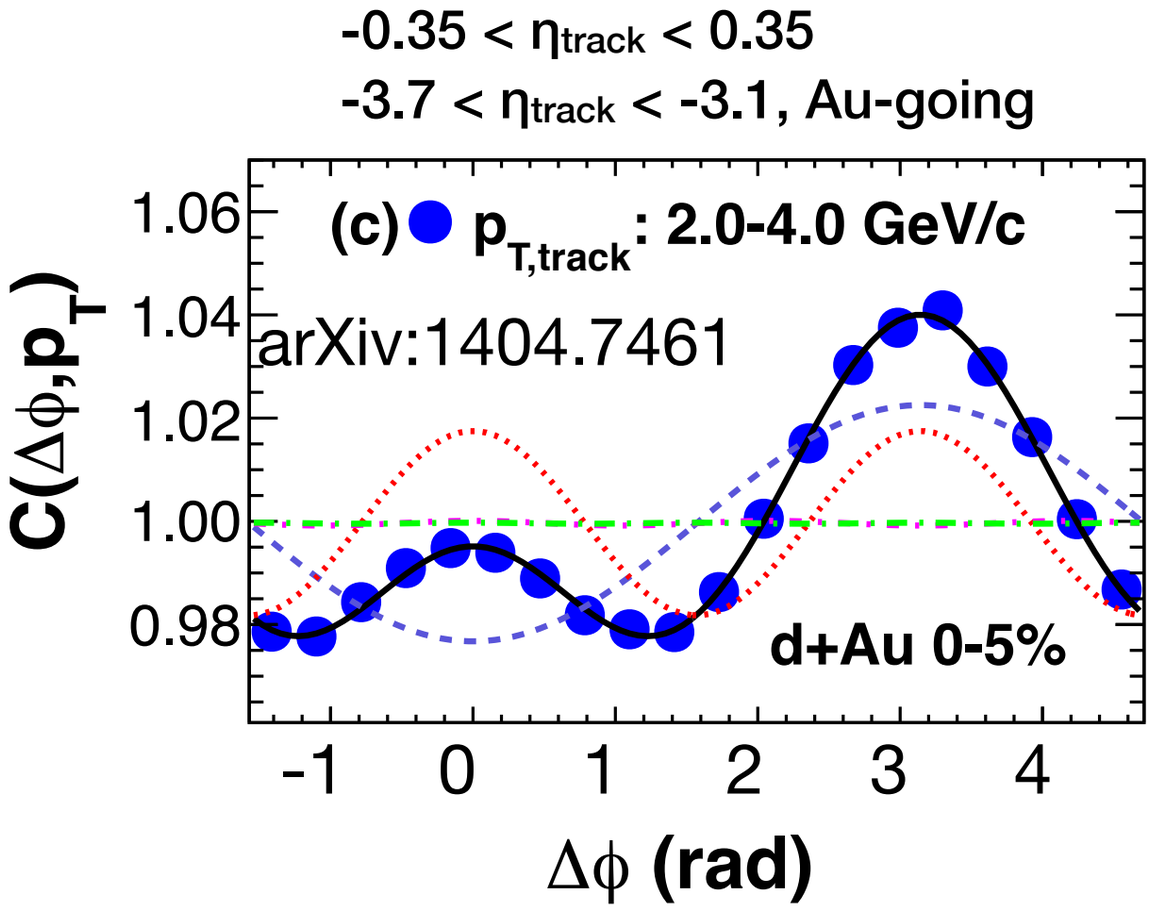
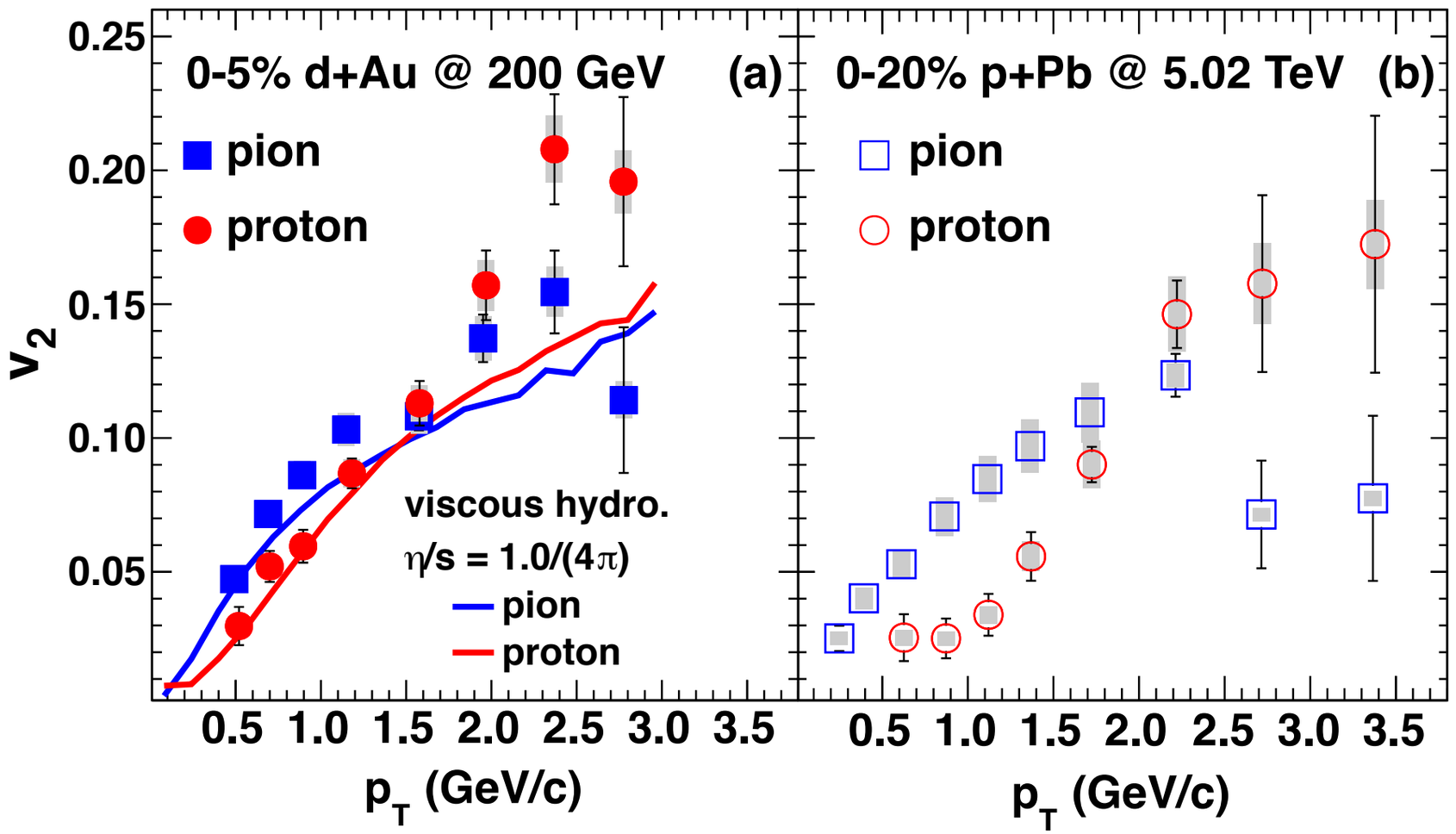




- New result analyzed with large$\Delta\eta$ gap > 2.75, confirms older result
- Long range ridge clearly seen in d+Au collisions at RHIC

Flow in Small Systems?

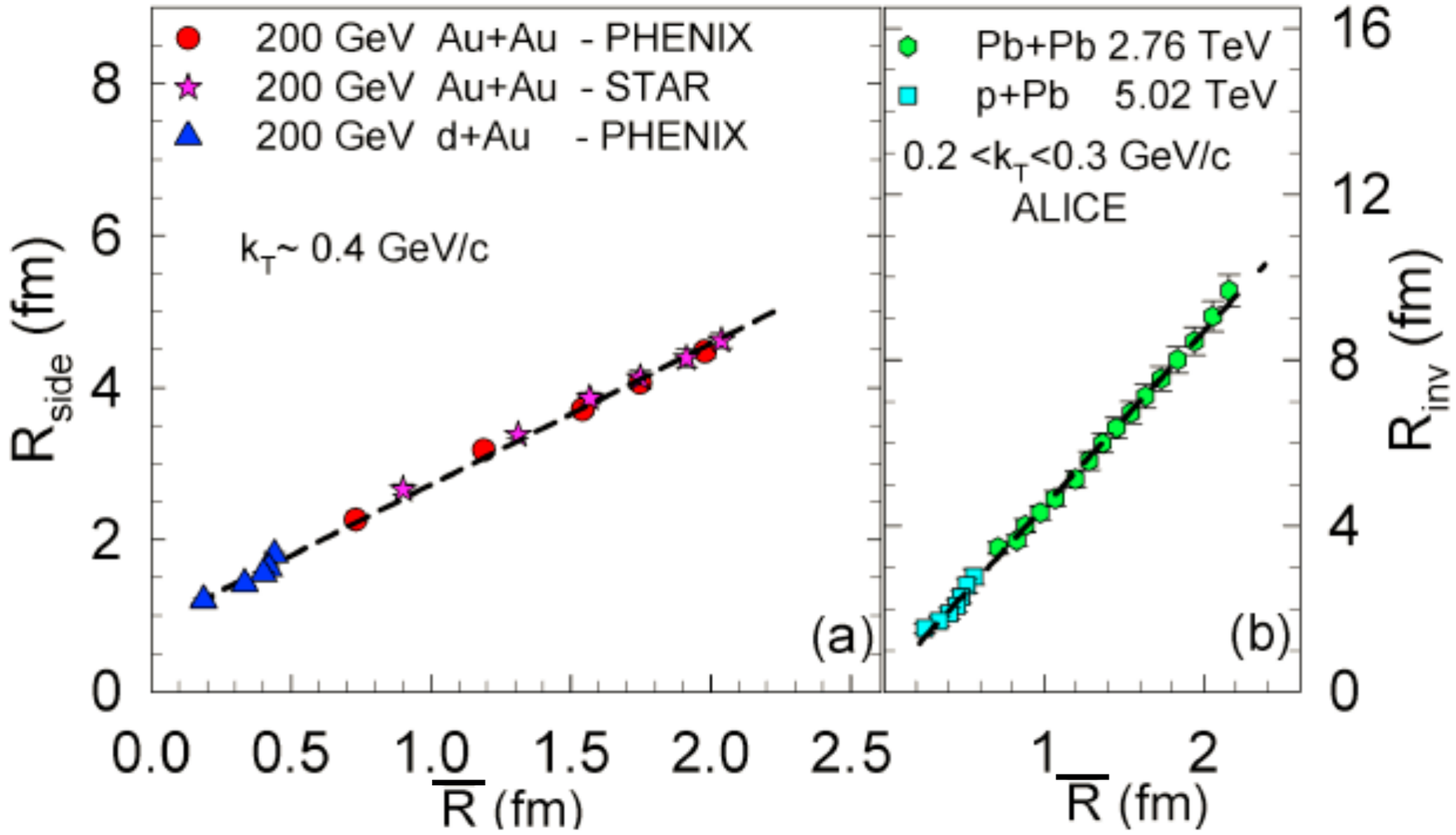
arXiv:1404.7461



- v_2 measured with large rapidity gap between event plane and particle
- Mass ordering observed, as in heavy-ion collisions, also at LHC
- Viscous Hydrodynamics + Hadron cascade qualitatively describes observation

HBT Radii in d+Au

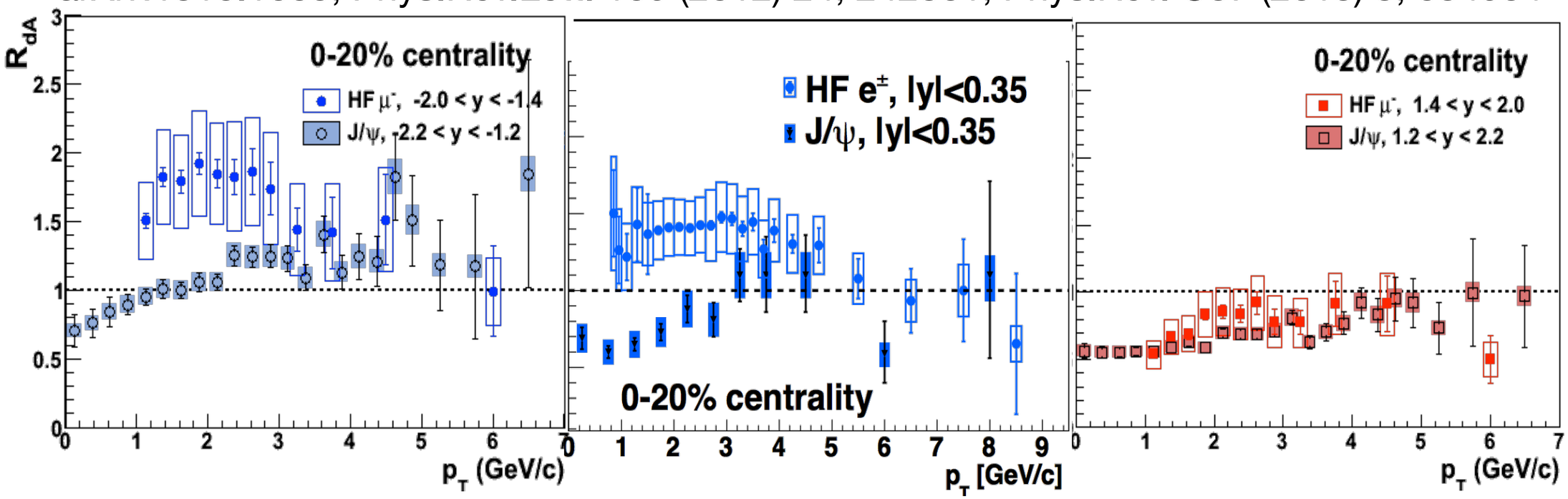
arXiv:1404.5291



- HBT analysis in d+Au
- Radii scale over small (d+Au) and large (Au+Au) systems as function of the characteristic initial length scale (from Glaube MC)
- Same observation at LHC!

Heavy Flavor vs Rapidity

arXiv:1310.1005, Phys.Rev.Lett. 109 (2012) 24, 242301, Phys.Rev. C87 (2013) 3, 034904



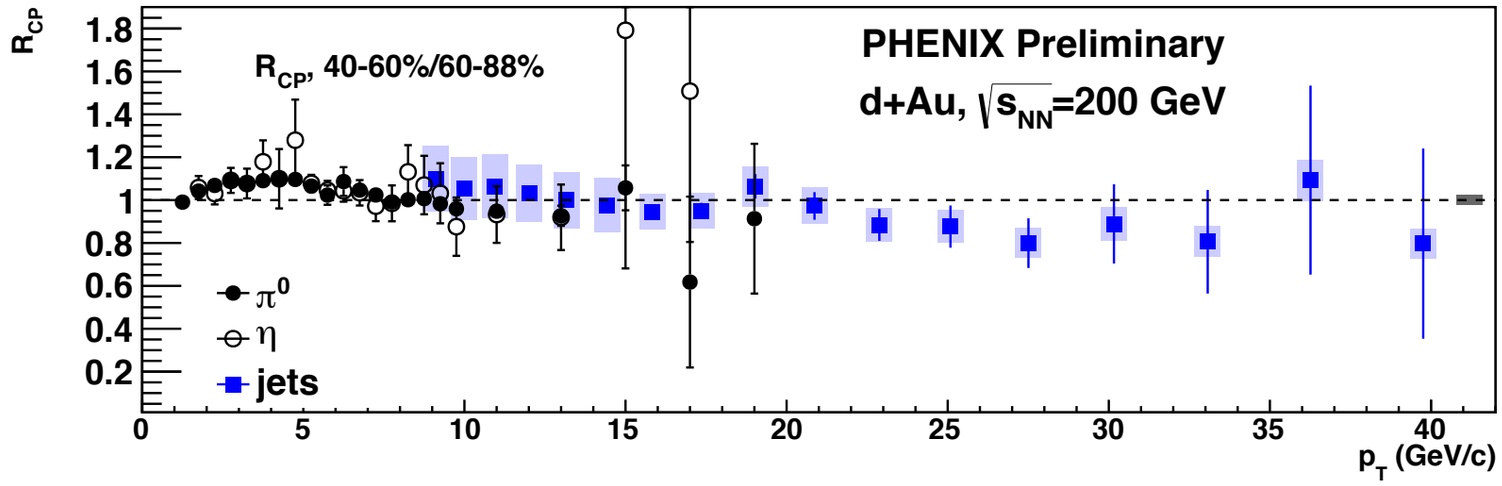
Higher densities

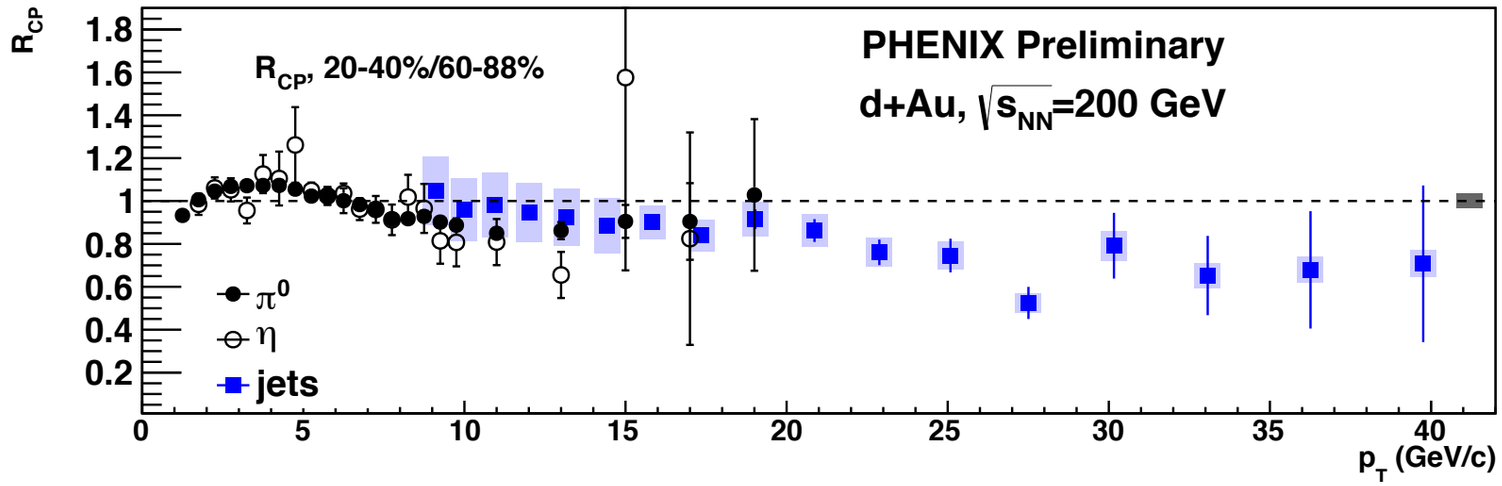
Lower-x gluons in d+Au

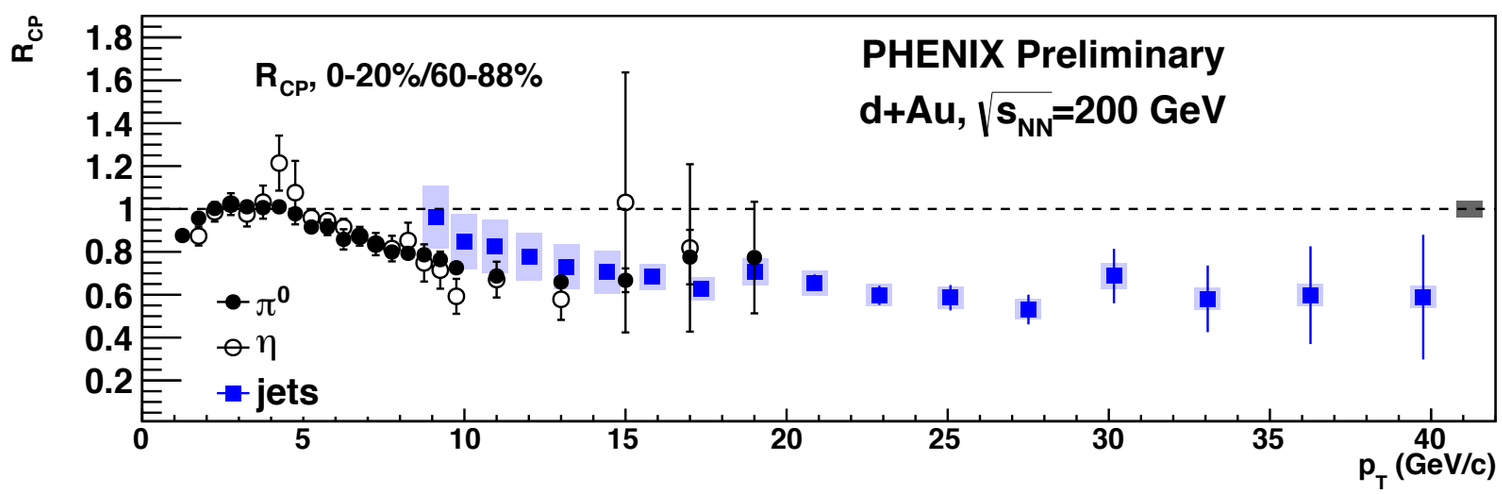
- Open charm enhanced at mid and backward rapidity
- Both open charm and J/ψ suppressed at forward rapidity
- Enhancement larger than anti-shadowing expectations
- Are charm quarks pushed radially even in d+Au?

High p_T Centrality Dependence

- R_{CP} suppressed at high p_T for π^0, η, jets
- Same trend observed in p+Pb at ATLAS as shown by Martin Spousta earlier today
- Still not understood, nuclear PDFs don't predict this at all (but can they anyway, or is this some bias?)



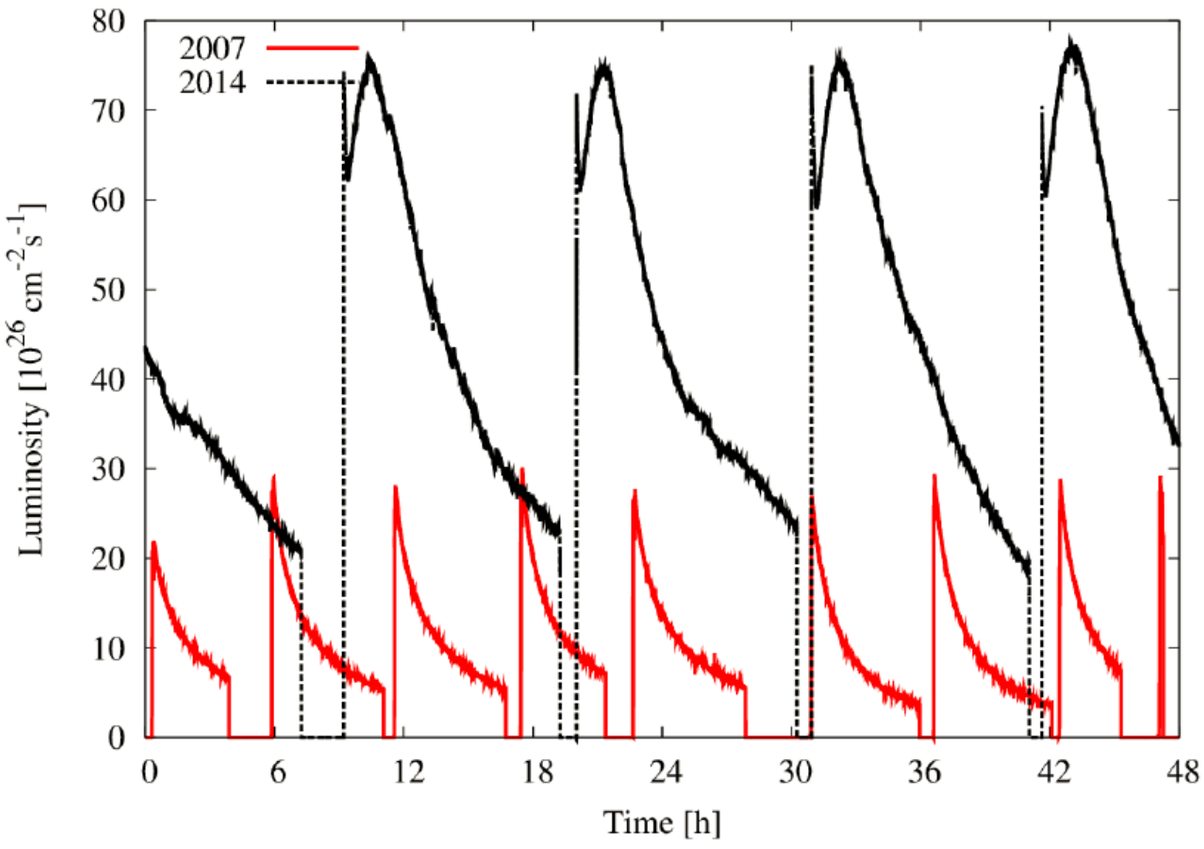




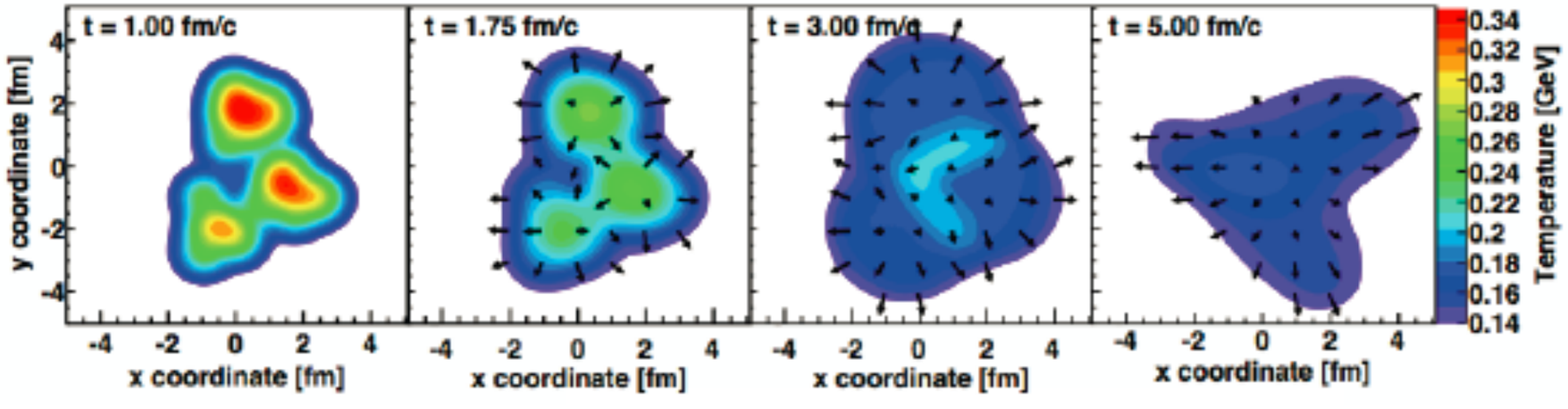
A Bright Future

A new “golden” Au+Au data set: Run 14

- 2014 run was very successful
- 15B Au+Au events recorded
- Analyses starting now
- Silicon detectors operating very well
- RHIC accelerator delivered beyond projections

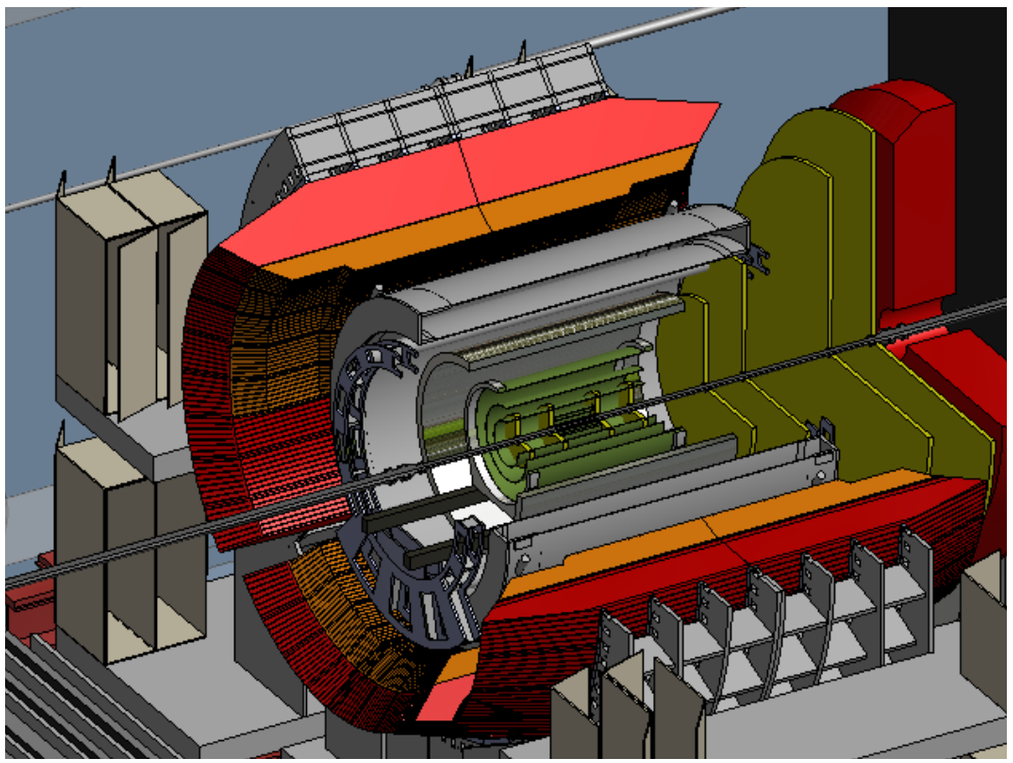


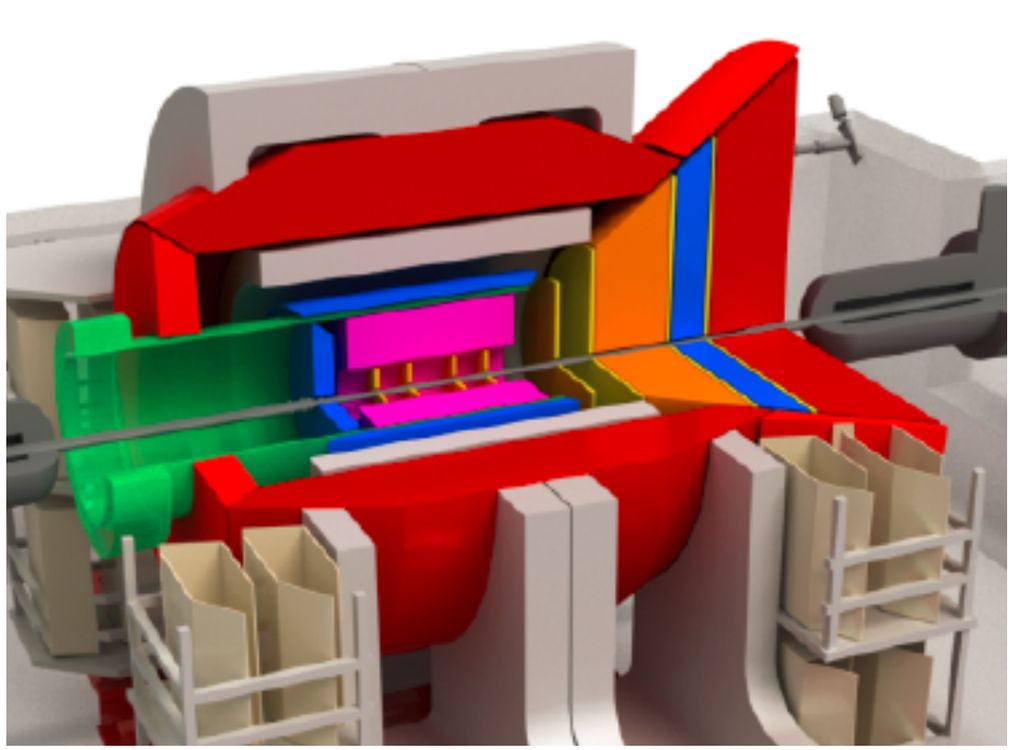
- Later: 2.2B He+Au collisions recorded, allows for geometry test



The Future: a New Detector

- "sPHENIX" is moving forward
  - BaBar magnet acquired, DOE science review this summer
- Excellent jet, dijet, γ-jet, h-jet, quarkonia capabilities
  - Access to new observables
- Electron-Ion-Collider
  - BaBar magnet and sPHENIX calorimetry are excellent foundation for a future EIC detetor





Summary

- Very active physics program at PHENIX, many new publications this year
- New photon and heavy-flavor measurements challenge full dynamical models
- Is d+Au a small QGP, or how can these measurements be understood?
  - No “simple CNM”?
- Excellent collider and detector performance in 2014, after 14 years of running
- Bright future with sPHENIX and future electron-ion collider