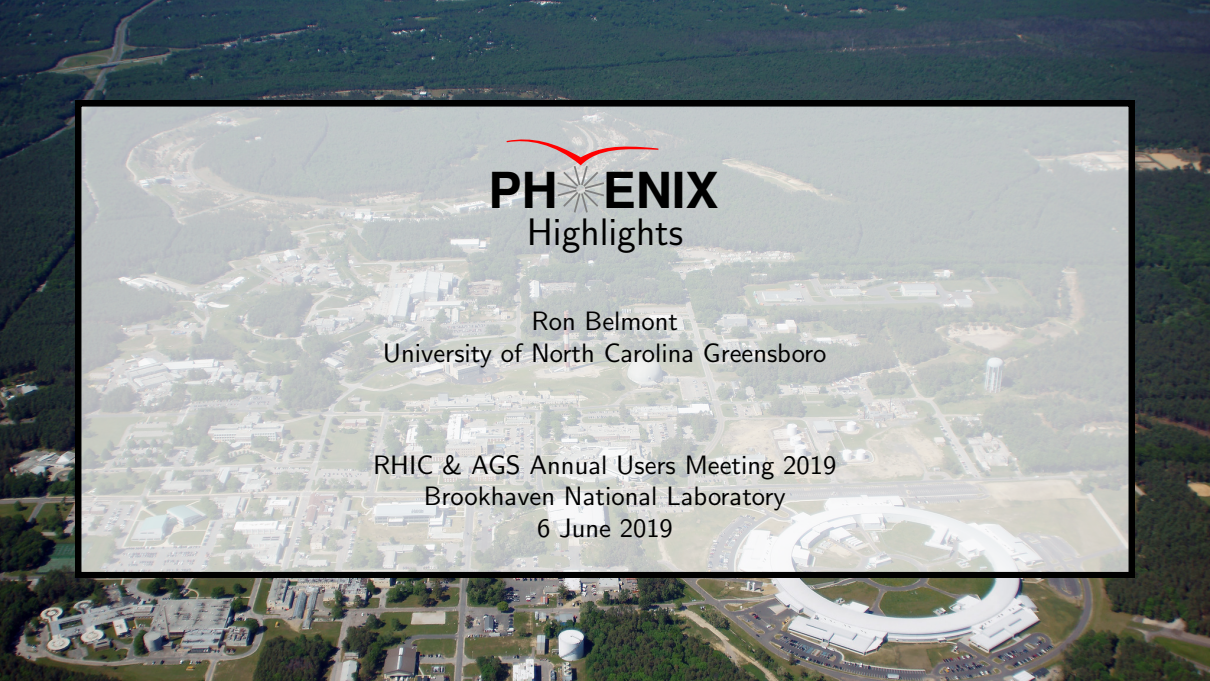
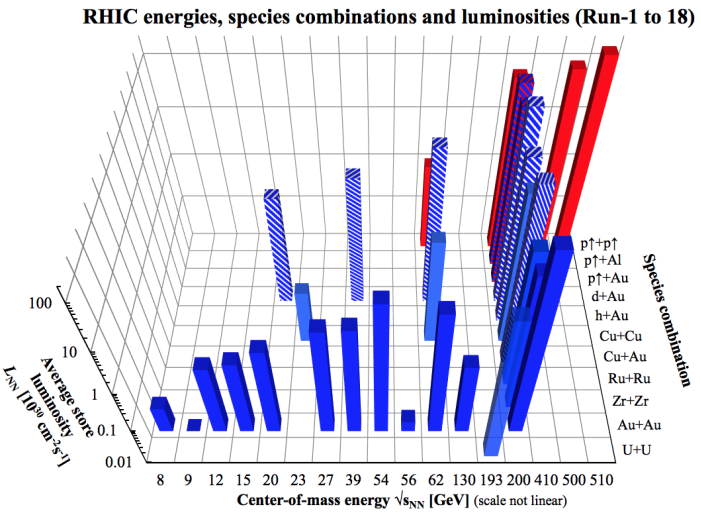


PHENIX Highlights

Ron Belmont
University of North Carolina Greensboro

RHIC & AGS Annual Users Meeting 2019
Brookhaven National Laboratory
6 June 2019

Key ingredient of **nuclear** physics:
Change the **nucleus**



Outline

Spin physics

—W A_L results — **Now published!**
—J/ψ A_N results — **Now published!**
—η A_N results — **New!**
—h^+ A_N results — **Just submitted!**

Large systems

—Single particle R_{AA} results, multiple species and collisions — **New!**
—π^0-h correlations in Au+Au — **New!**
—Spectra of charm and bottom in p+p — **Now published!**
—v_2 of charm and bottom in Au+Au

Small systems

—ϕ meson nuclear modification factors — **New!**
—Drell-Yan measurement in p+Au — **New!**
—Longitudinal dynamics in small systems — **Now published!**
—Small systems geometry scan — **Now published!**
—Direct photon measurements in p+Au

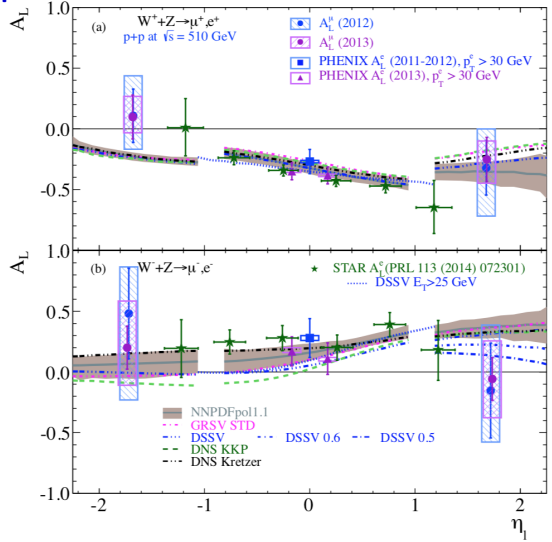
Intermission

Spin physics

W A_L

Now published!

Phys. Rev. D 98, 032007 (2018)



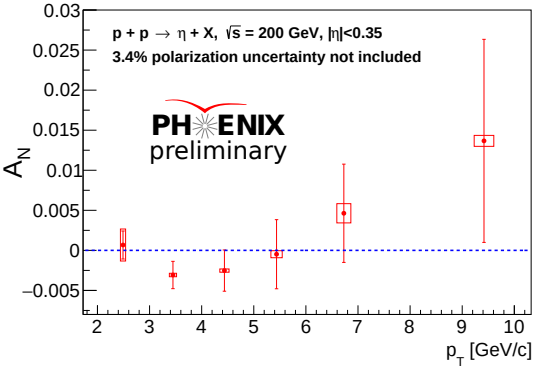
W A_L

Sensitivity to light sea quarks

Consistency between PHENIX, STAR, global fits

η A_N

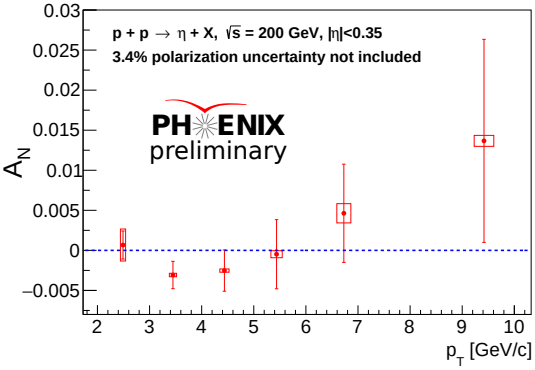
New!

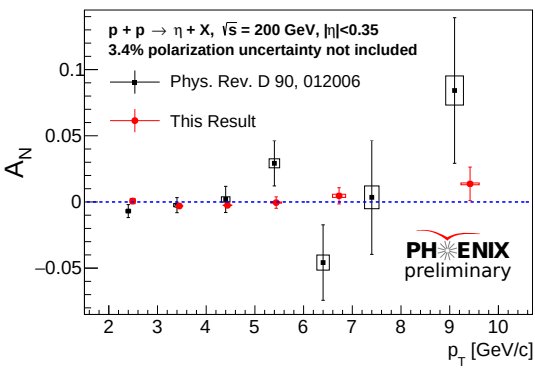


η A_N is consistent with zero (but noticeable structure)

η A_N

New!





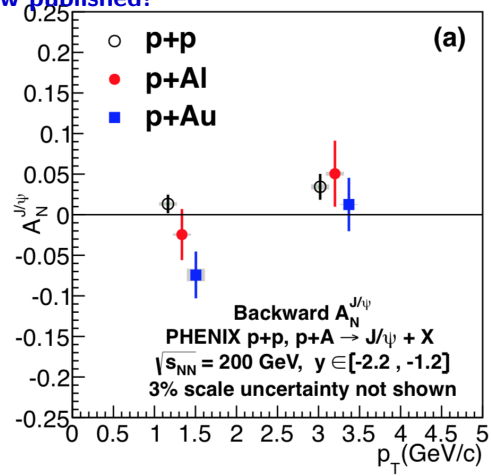
η A_N is consistent with zero (but noticeable structure)

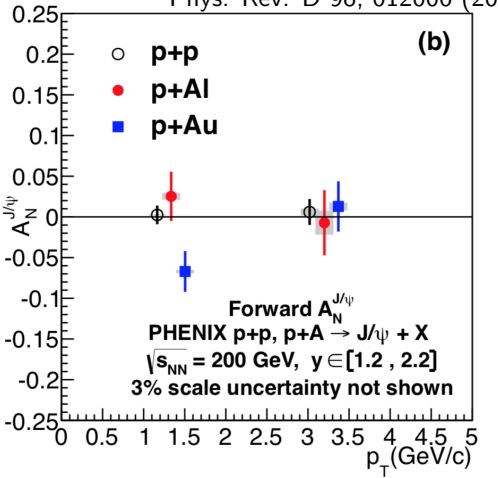
Dramatic improvement in statistical and systematic uncertainties over previous result

J/ψ A_N

Now published!

Phys. Rev. D 98, 012006 (2018)





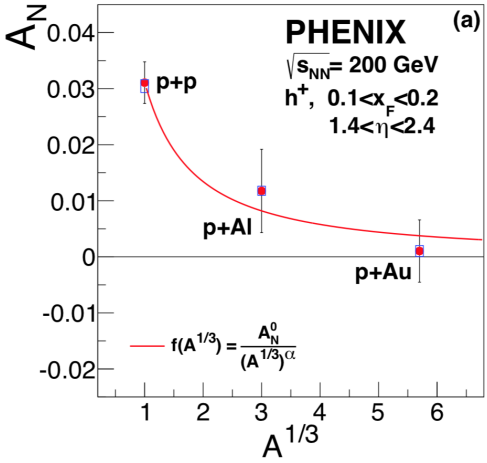
Nuclear target dependence on J/ψ A_N

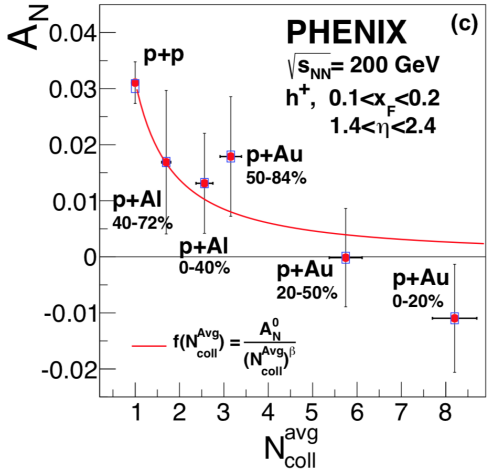
What's the origin of the asymmetry at low p_T in p+Au?

h^+ A_N

Just submitted!

arXiv:1903.07422 (submitted to PRL)





Clear and strong dependence on nuclear target size $A^{1/3}$ $(\alpha = 1.21)$

Very similar depence on $N_{\rm coll}$ $(\beta = 1.19)$

Spin Summary

W A_L now published

New results on η A_N
—Dramatic improvement in statistical and systematic precision over previous results
—Results consistent with zero

J/ψ A_N now published
—Illustrates important of changing nuclear target in spin physics
—Why is J/ψ A_N non-zero in p+Au?

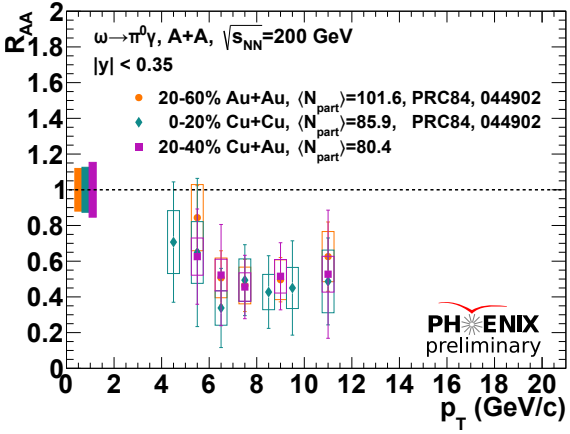
h^+ A_N just submitted to PRL
—Clear dependence of asymmetries on nuclear target, both $A^{1/3}$ and N_{coll}

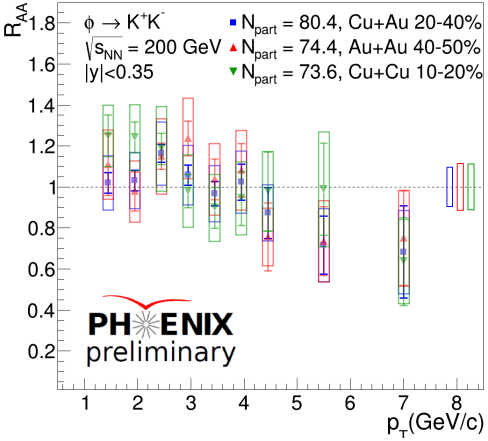
Intermission

Large Systems

Identified particle R_{AA} in large systems

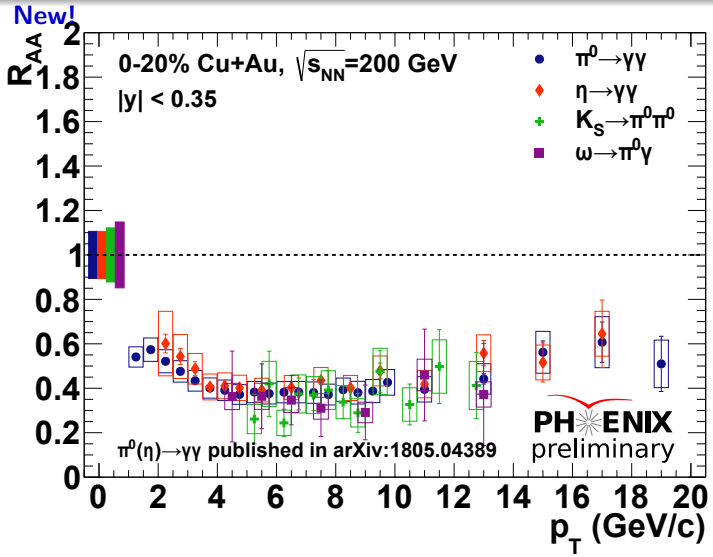
New!





ω and ϕ mesons behave similarly in Cu+Cu, Cu+Au, Au+Au

Identified particle R_{AA} in Cu+Au

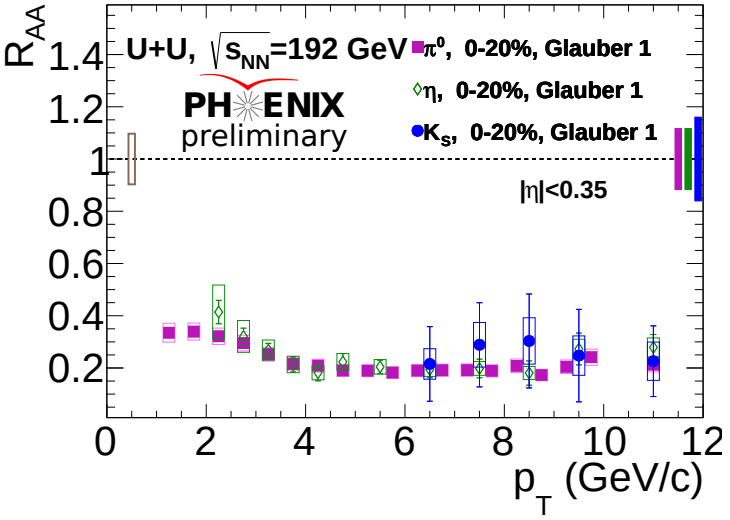


R_{AA} of identified neutral mesons π^0, η, K^0_S, ω

Similar behavior for all species at high p_T

Identified particle R_{AA} in U+U

New!

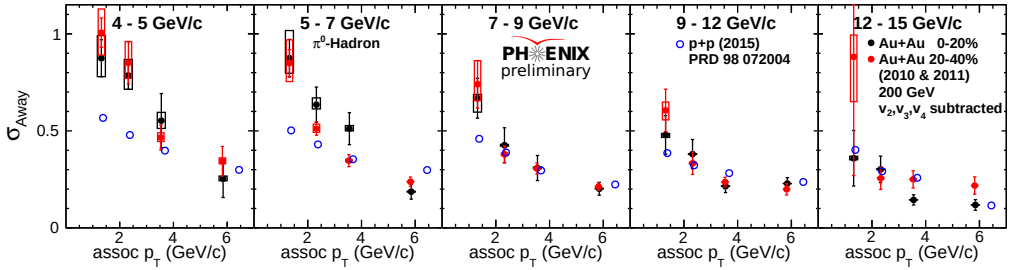


R_{AA} of identified neutral mesons π^0, η, K^0_S

Similar behavior for all species at high p_T

π^0-h in Au+Au

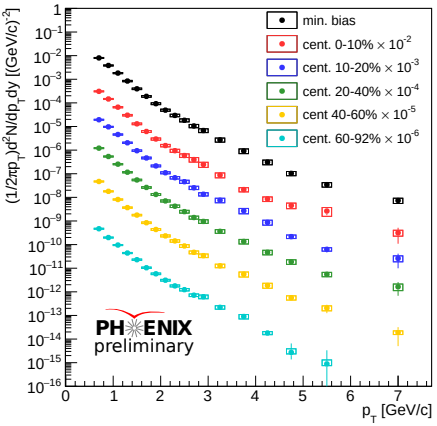
New!



Broadening of the away side for low p_T,
similar width at high p_T

$c \to e$ and $b \to e$ in Au+Au and p+p

Phys. Rev. D 99, 092003 (2019)

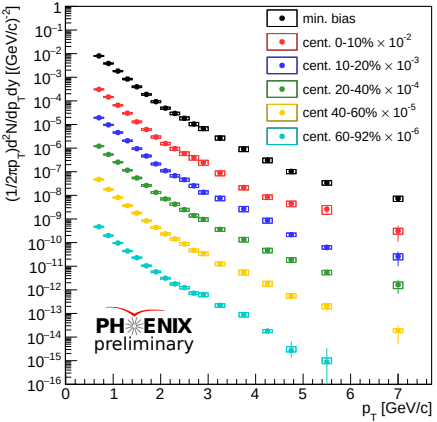


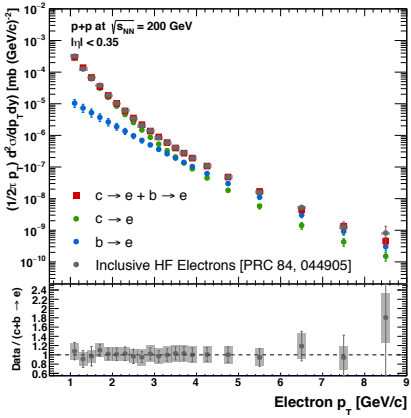
HF electron spectra, all centralities and using all available data

$c \to e$ and $b \to e$ in Au+Au and p+p

Now published!

Phys. Rev. D 99, 092003 (2019)

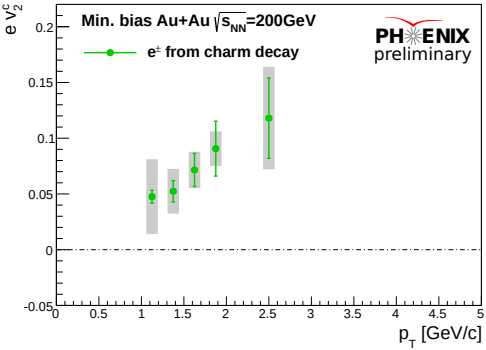


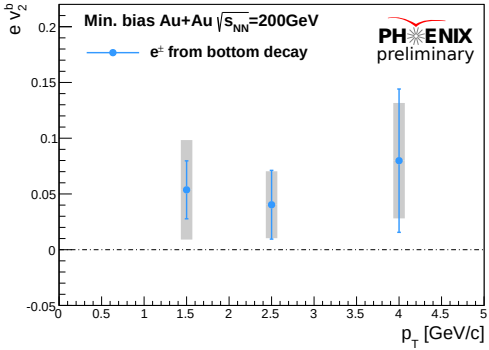


HF electron spectra, all centralities and using all available data

New p+p reference data; new publication with R_{AA} on the way!

$c \to e$ and $b \to e$ in Au+Au

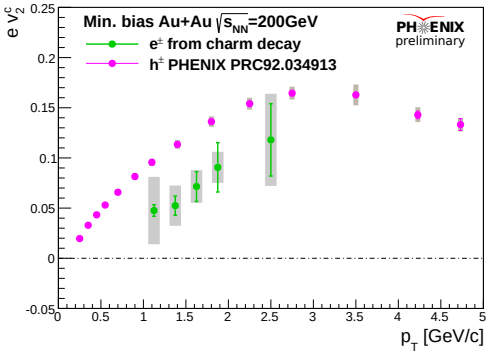


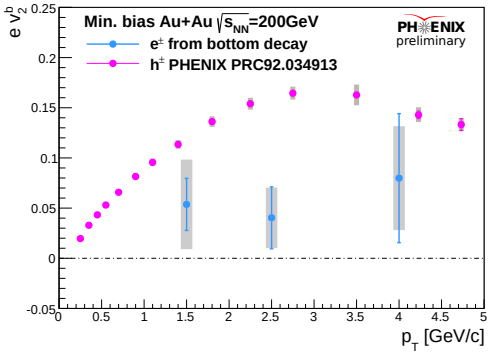


Charm $v_2 > 0$

Bottom $v_2 > 0$

$c \to e$ and $b \to e$ in Au+Au





Charm $v_2 > 0$

Bottom $v_2 > 0$

Both smaller than light flavor

Large Systems Summary

Single particle R_{AA} independent of collision species when selecting for similar N_{part}

Neutral mesons R_{AA} very similar in Au+Au despite different strangeness content
—Strangeness very important at low p_T but not at high p_T

Correlation measurements show away-side broadening
—Indicates large-angle radiation of high-p_T partons

Measurement of $c \to e$ and $b \to e$ spectra in p+p
—Publication with new R_{AA} coming soon

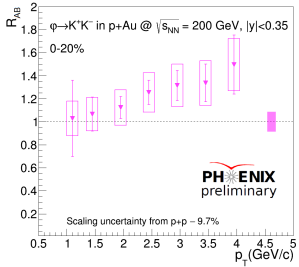
First measurement of bottom flow at RHIC
—Refinements and publication forthcoming

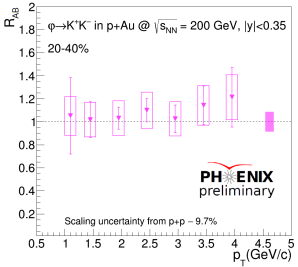
Intermission

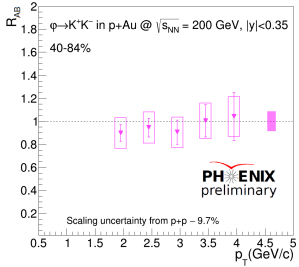
Small Systems

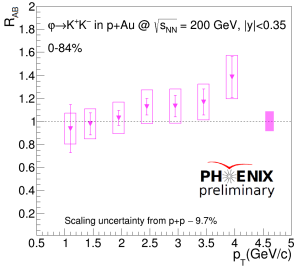
Identified hadron nuclear modification factors in p+Au

New!





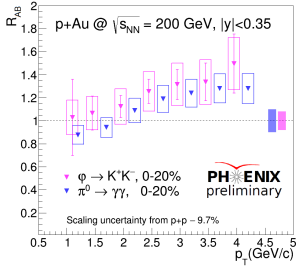


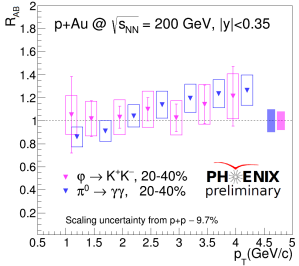


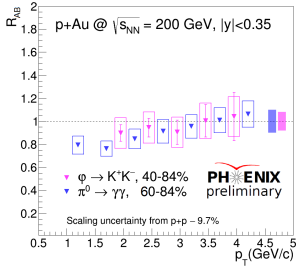
ϕ meson in p+Au

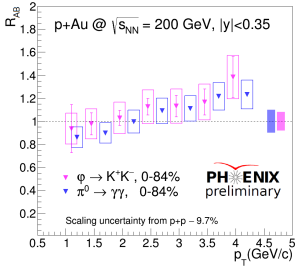
Identified hadron nuclear modification factors in p+Au

New!









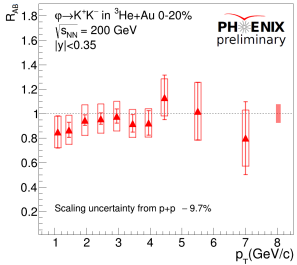
ϕ meson in p+Au

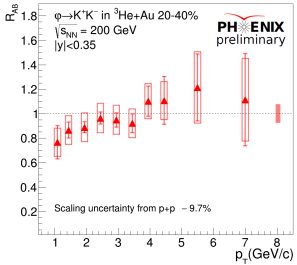
ϕ shows similar modification to π^0 in p+Au despite different mass and strangeness content

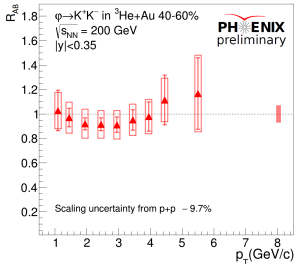
Identified hadron nuclear modification factors in ^{3}He+Au

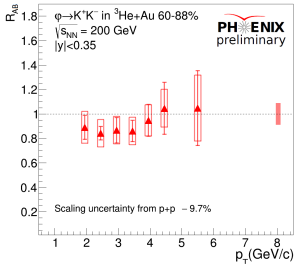
New!

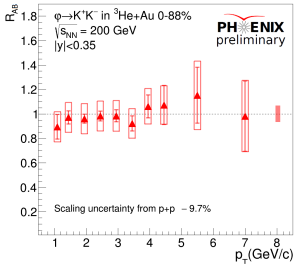
ϕ meson in ^{3}He+Au







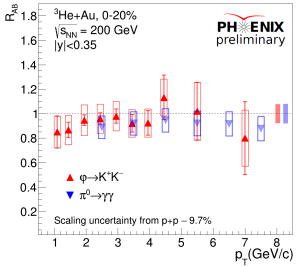


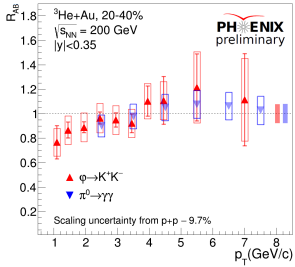


Identified hadron nuclear modification factors in ^{3}He+Au

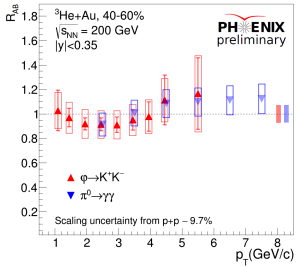
New!

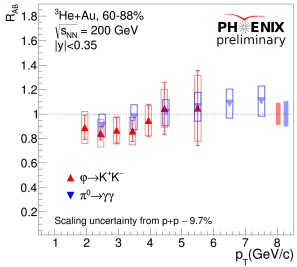
ϕ meson in ^{3}He+Au

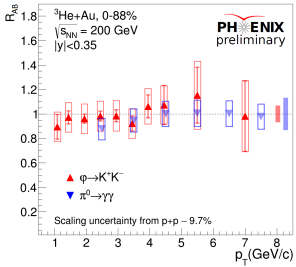




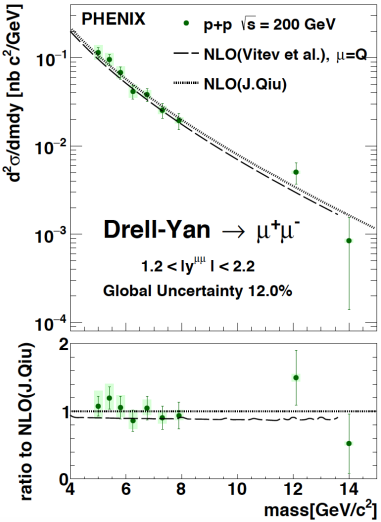
ϕ shows similar modification to π^0 in ^{3}He+Au despite different mass and strangeness content

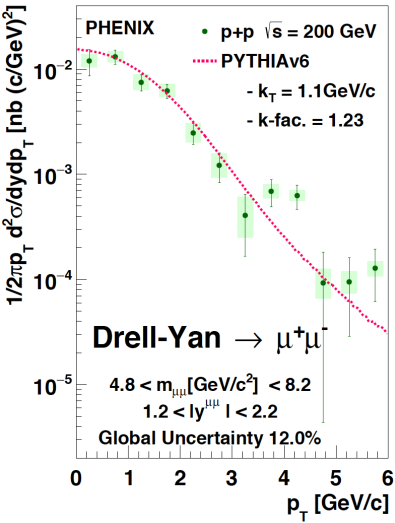






Drell-Yan from angular correlations in p+p



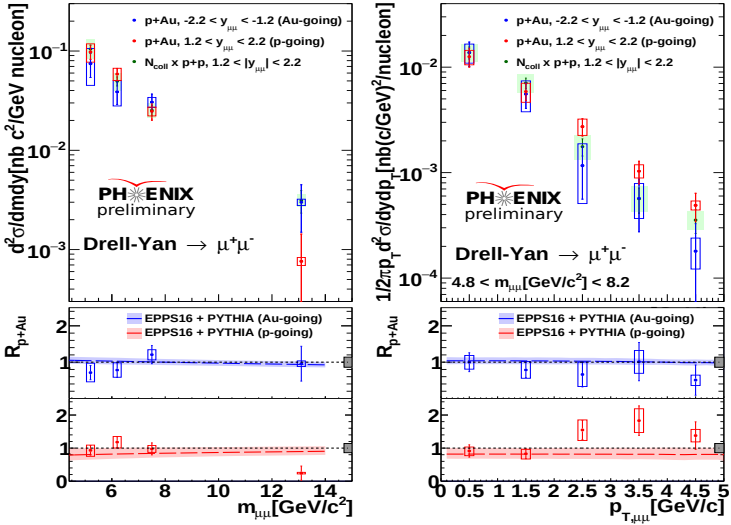


arXiv:1805.04075 (PRD)
arXiv:1805.02448 (PRD)

Drell-Yan well-described by NLO pQCD & PYTHIA

Drell-Yan from angular correlations in p+Au

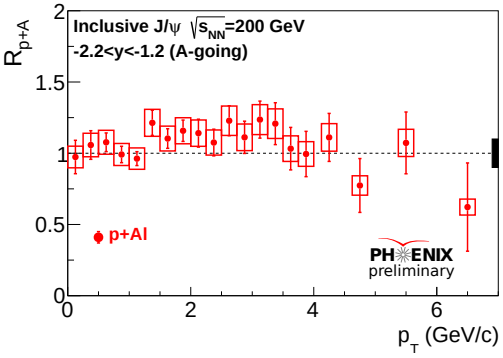
New!

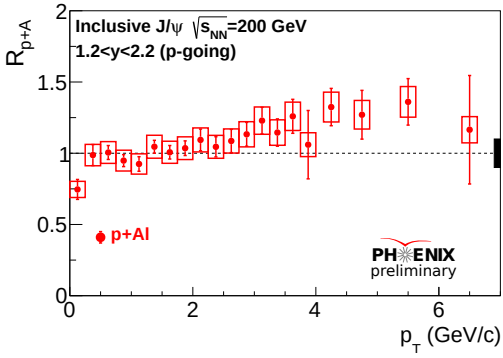


Hints of modification to Drell-Yan in p+Au, though large uncertainties prevent a firm conclusion

J/ψ nuclear modification in small systems

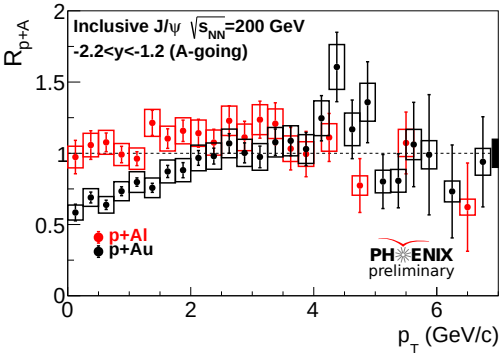
New!

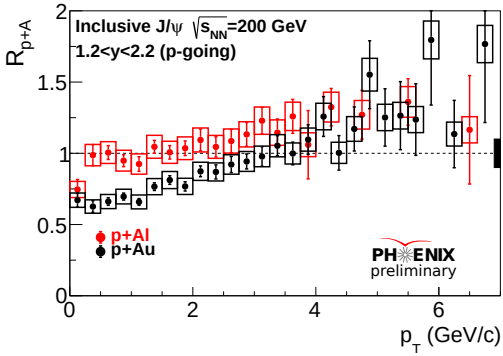




J/ψ nuclear modification in small systems

New!

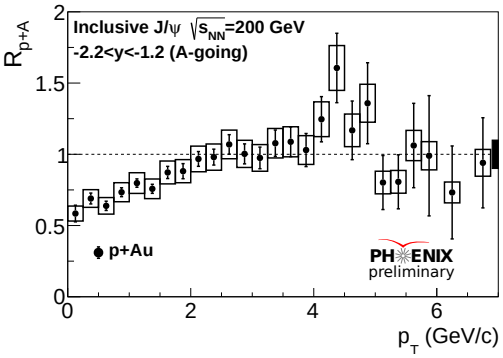


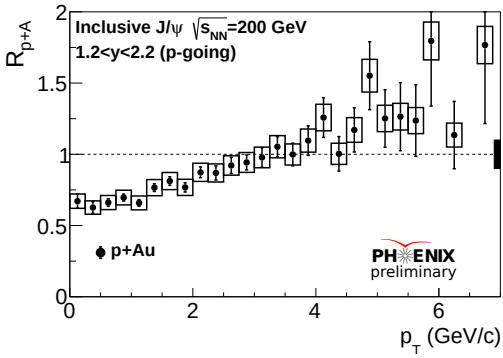


p+Al $\rightarrow$ p+Au—big change when increasing nuclear target size

J/ψ nuclear modification in small systems

New!

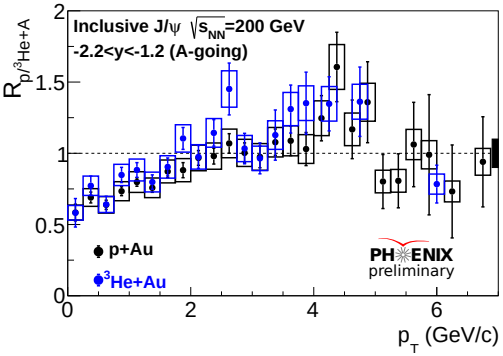


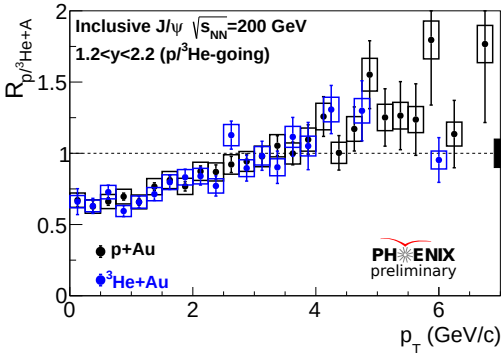


p+Al $\rightarrow$ p+Au—big change when increasing nuclear target size

J/ψ nuclear modification in small systems

New!





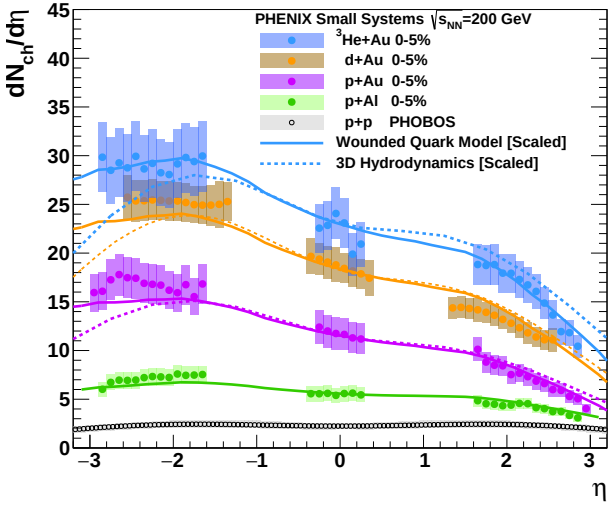
p+Al $\rightarrow$ p+Au—big change when increasing nuclear target size

p+Au $\rightarrow$ ^{3}He+Au—small change when increasing projectile size

Longitudinal dynamics in small systems

Now published!

Phys. Rev. Lett. 121, 222301 (2018)



p+Al, p+Au, d+Au, ^{3}He+Au

Good agreement with wounded quark model

Good agreement with 3D hydro

Longitudinal dynamics in small systems

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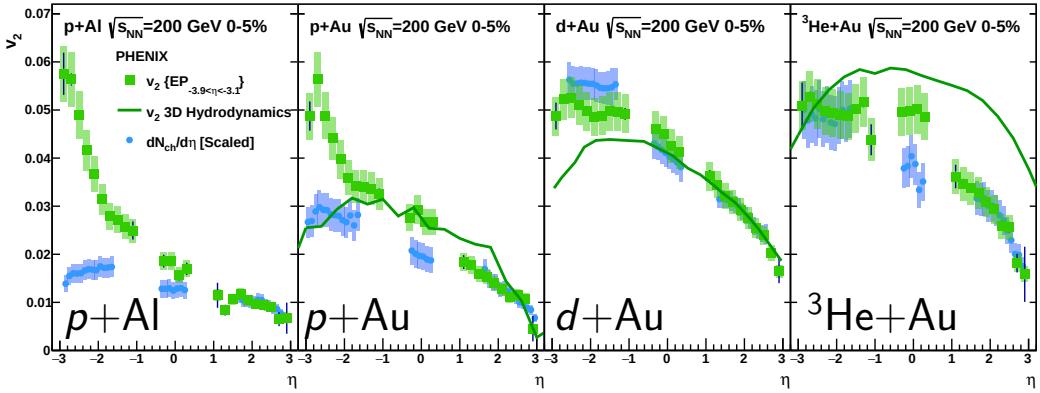
Phys. Rev. Lett. 121, 222301 (2018)



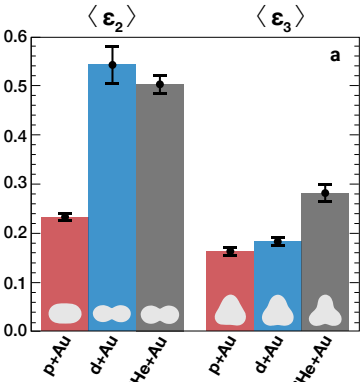
v_2 vs η in p+Al, p+Au, d+Au, and ^{3}He+Au

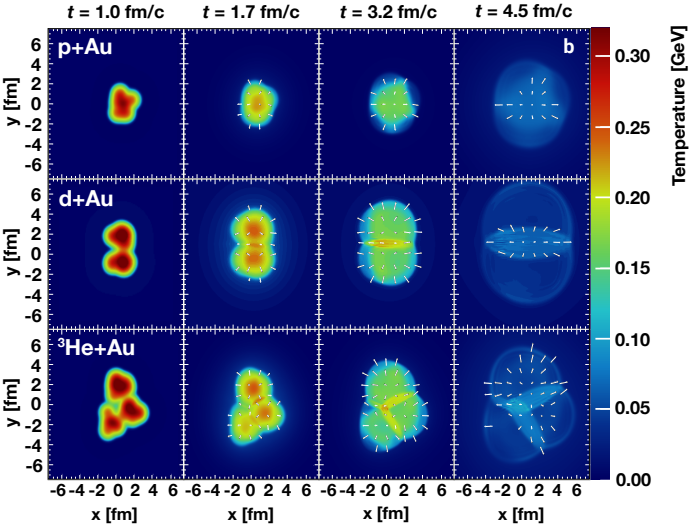
Good agreement with 3D hydro for p+Au and d+Au

Testing hydro by controlling system geometry

Now published!

Nature Physics 15, 214–220 (2019)





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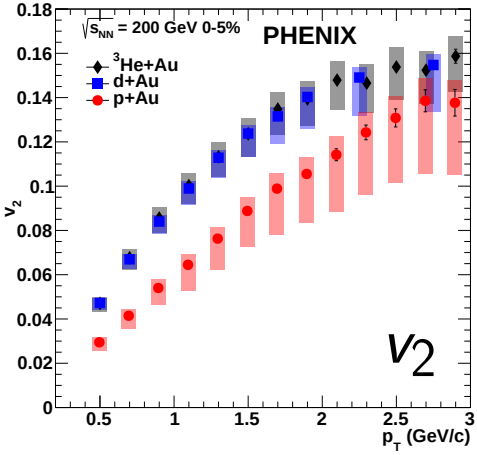
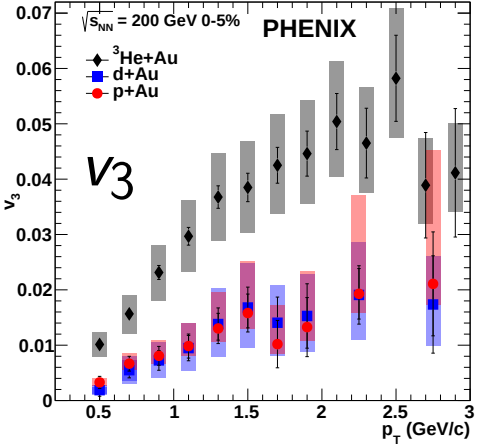


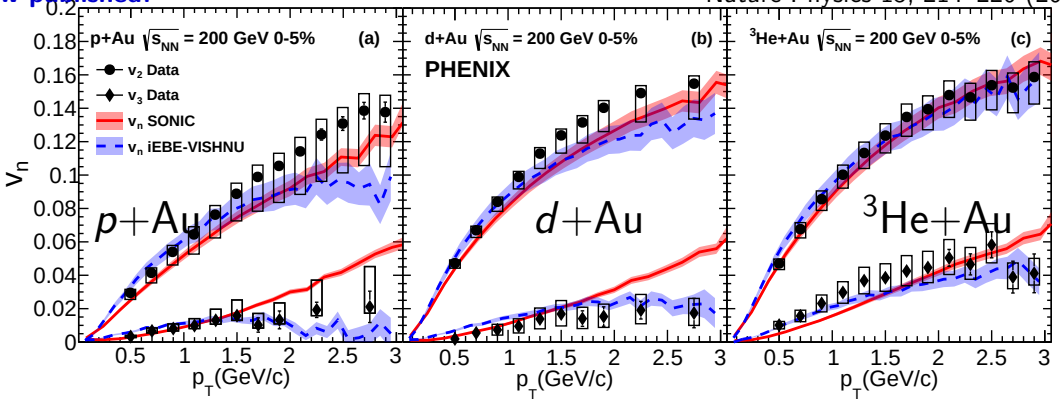


v_2 and v_3 ordering matches ε_2 and ε_3 ordering in all three systems

Testing hydro by controlling system geometry

Now published!

Nature Physics 15, 214–220 (2019)



v_2 and v_3 vs p_T described very well by hydro in all three systems

Testing hydro by controlling system geometry

Now published!

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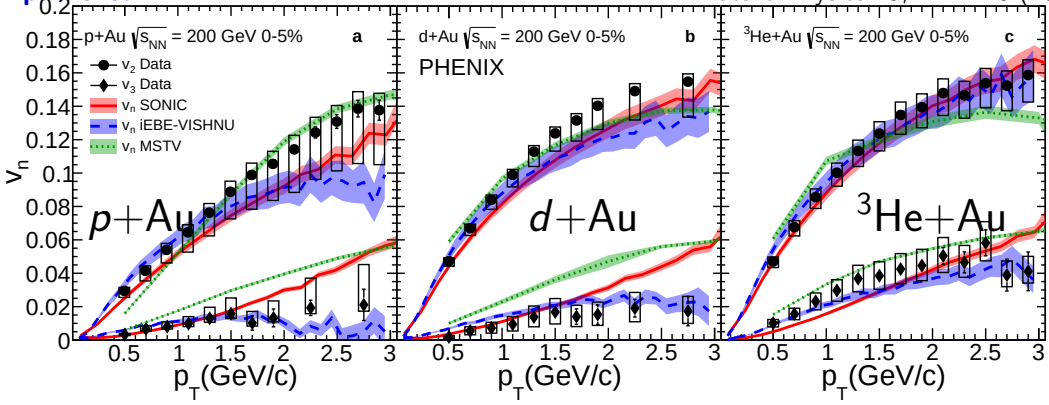

v_2 and v_3 vs p_T described very well by hydro in all three systems

Initial state model qualitatively agreed with data...

Testing hydro by controlling system geometry

Now published!

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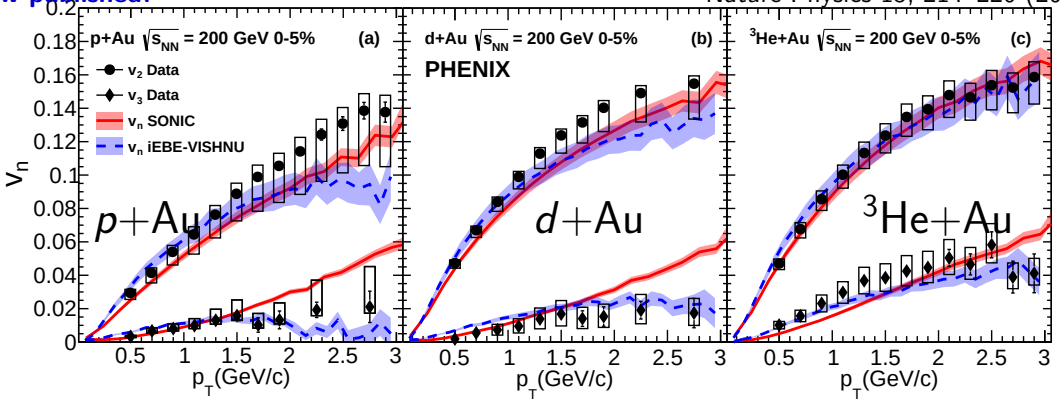

v_2 and v_3 vs p_T described very well by hydro in all three systems

Initial state model qualitatively agreed with data...

But recently discovered issue with calculation reduces p_T scale by factor of 5

—http://www.int.washington.edu/talks/WorkShops/int_19_1b/People/Mace_M/Mace.pdf

Testing hydro by controlling system geometry

Now published!

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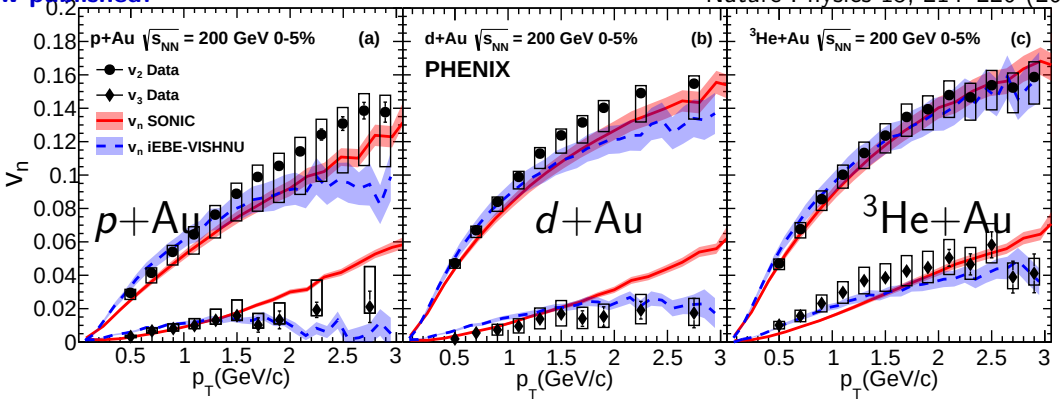
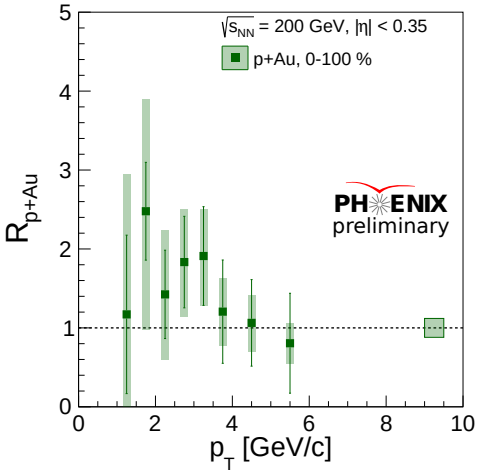
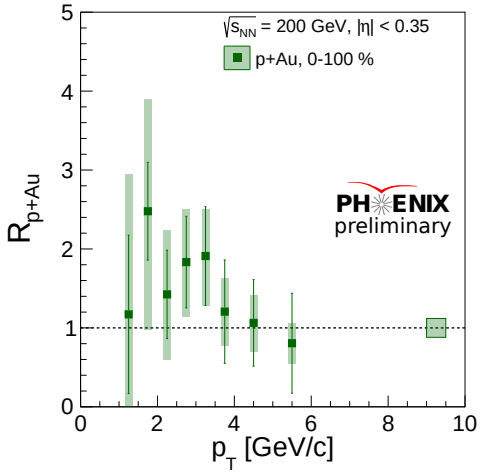


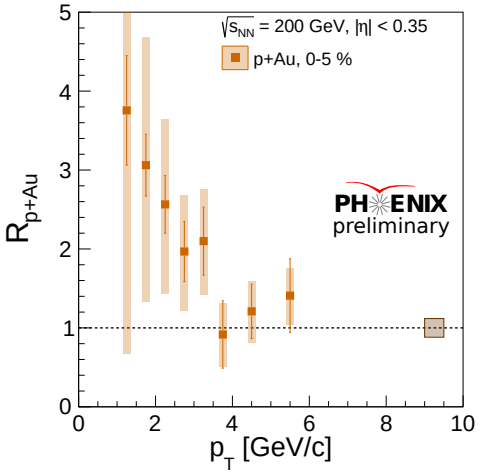
v_2 and v_3 vs p_T described very well by hydro in all three systems

Photons in small systems



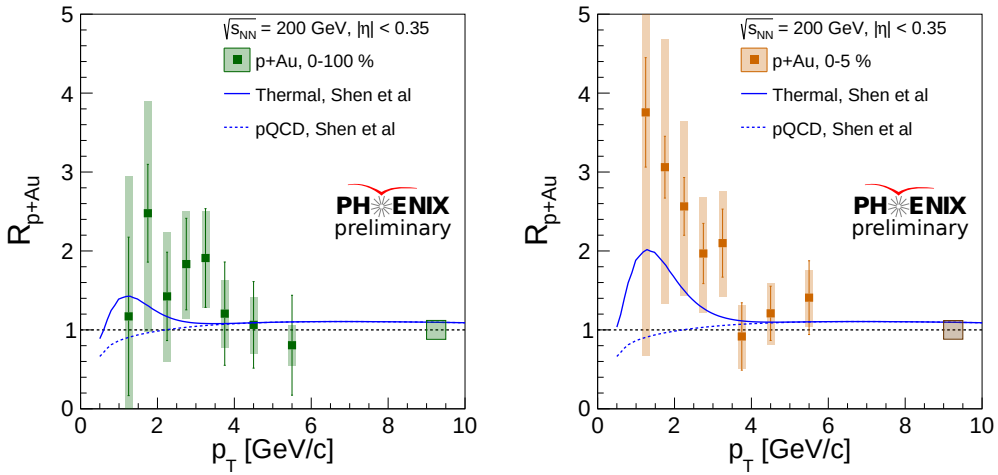
Photons in small systems





Thermal photons in p+Au?

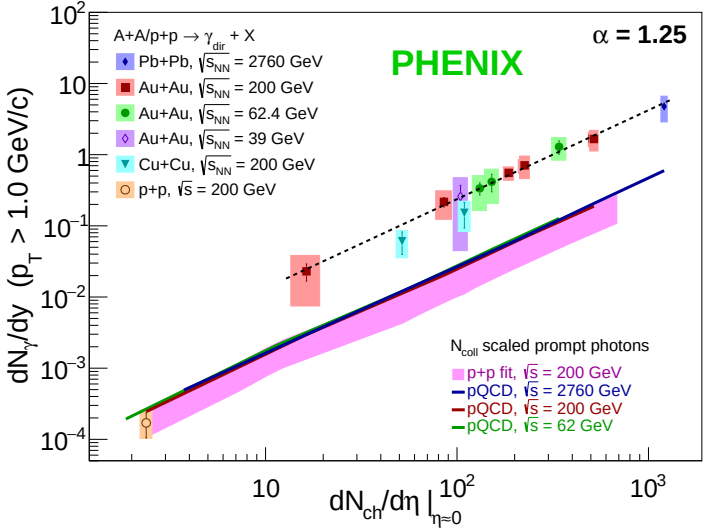
Photons in small systems



Thermal photons in p+Au? Theory from Phys. Rev. C 95, 014906 (2017)

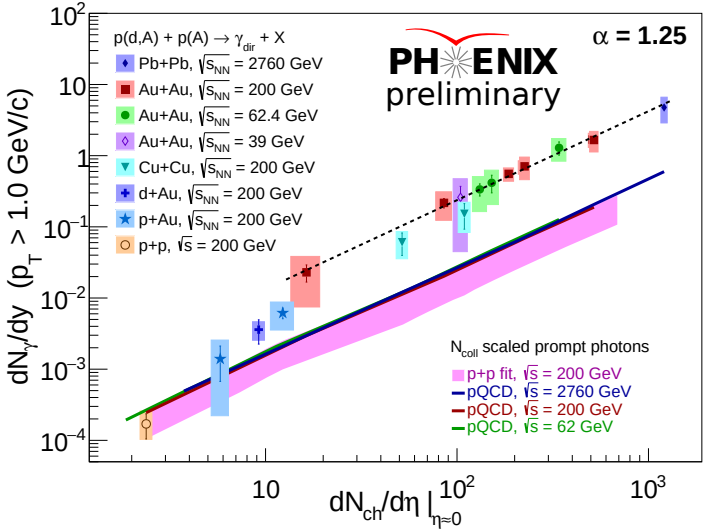
Photon yields

arXiv:1805.04084, accepted by Phys. Rev. Lett.



Common scaling for Au+Au and Pb+Pb at different energies; very different from N_{coll}-scaled p+p

Photon yields



Common scaling for Au+Au and Pb+Pb at different energies; very different from N_{coll}-scaled p+p

p+Au and d+Au in between

Small Systems Summary

Modification of ϕ very similar to that of π^0 despite differences in mass and strangeness content

First measurement of Drell-Yan in small systems at RHIC
—Hint of enhancement but no firm conclusions

Comprehensive set of measurements of longitudinal dynamics
—Good support for wounded quark model and 3D hydro

Geometry scan results published in Nature Physics
—Only hydro can describe all the data

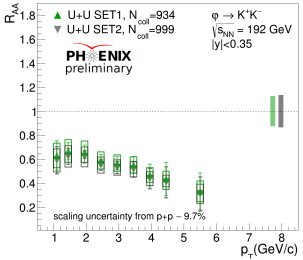
Photon enhancement in small systems
—Important additional evidence in support of QGP droplet formation in small systems

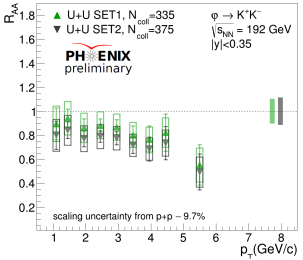
Additional Material

Additional Material

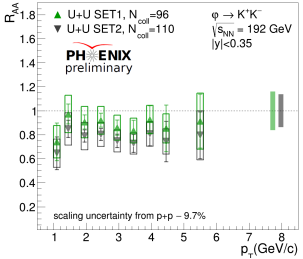
Identified hadron nuclear modification factors

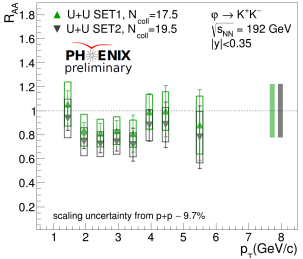
New!





ϕ meson in U+U





Identified hadron nuclear modification factors

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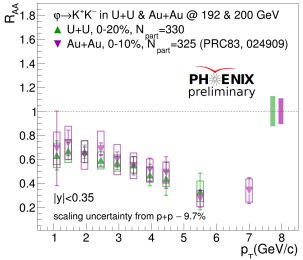

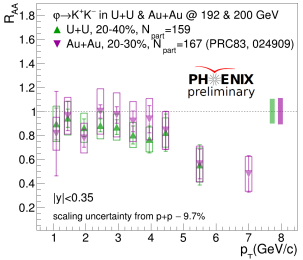

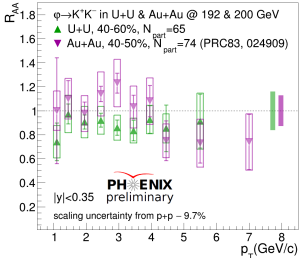

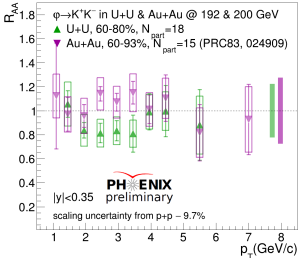

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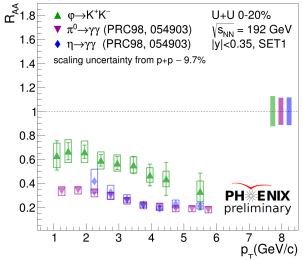
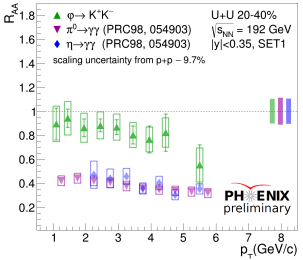
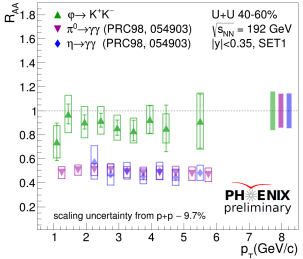
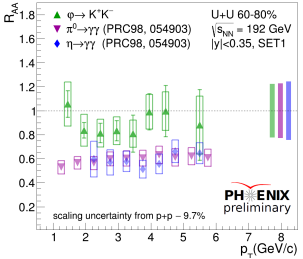


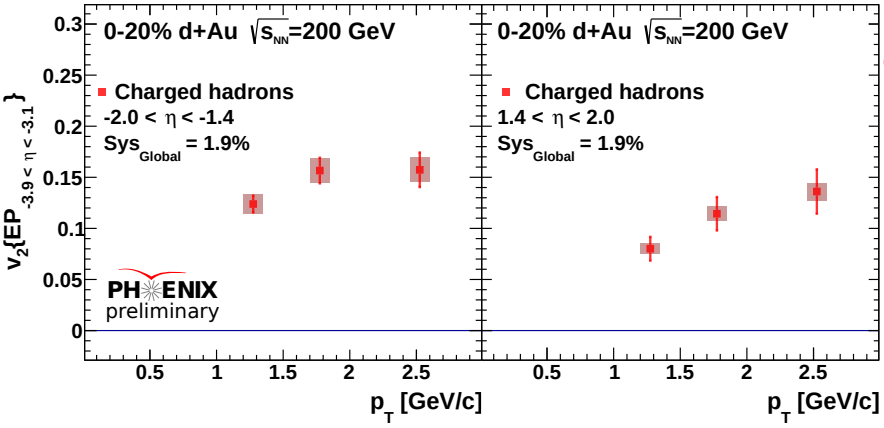






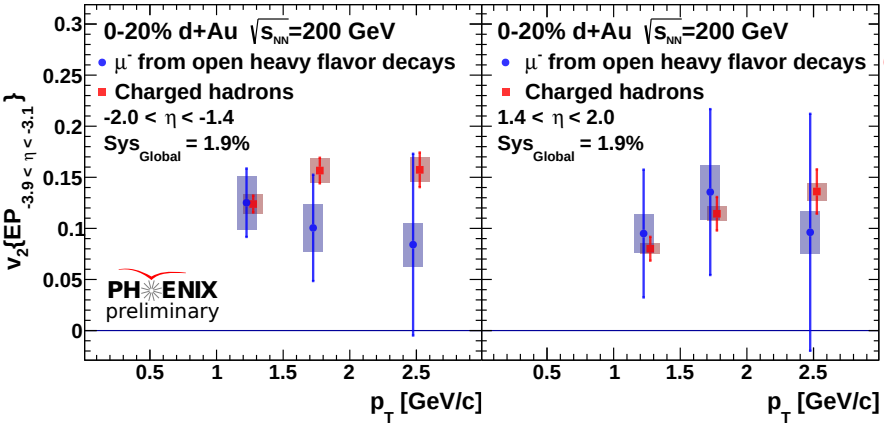
ϕ meson in U+U

Small systems flow



charged hadrons

Small systems flow—heavy flavor

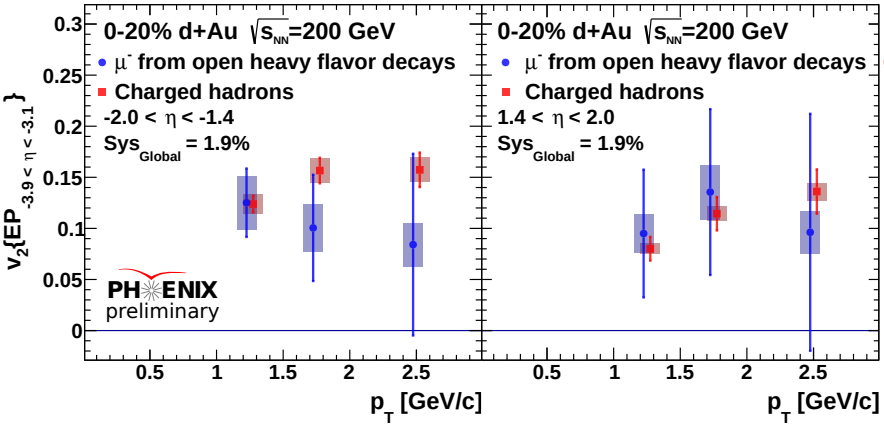


charged hadrons

heavy flavor muons

Nonzero v_2 for heavy flavor in d+Au

Small systems flow—heavy flavor



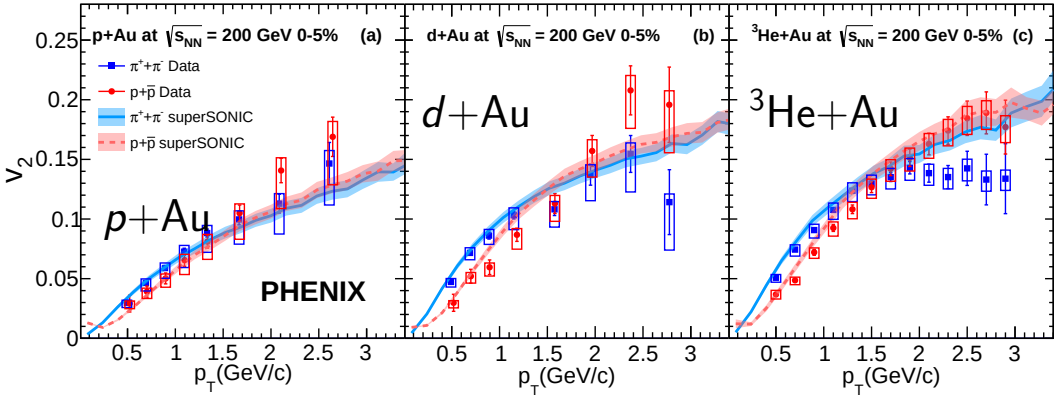
charged hadrons

heavy flavor muons

Nonzero v_2 for heavy flavor in d+Au
3.22σ, 2.16σ for $v_2 > 0$ at backward, forward (99.9%, 98.5% one-sided)

Small systems geometry scan

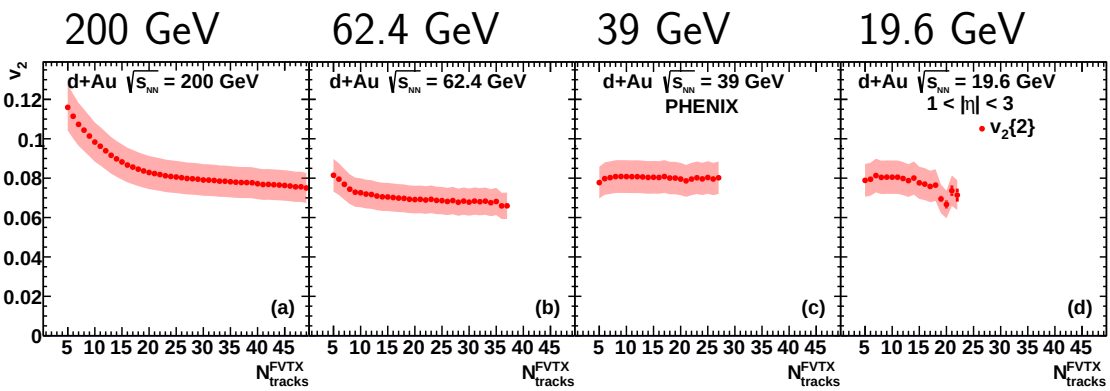
Phys. Rev. C 97, 064904 (2018)



Identified particle v_2 vs p_T in p+Au, d+Au, and ^{3}He+Au
—Mass ordering well-described by hydro

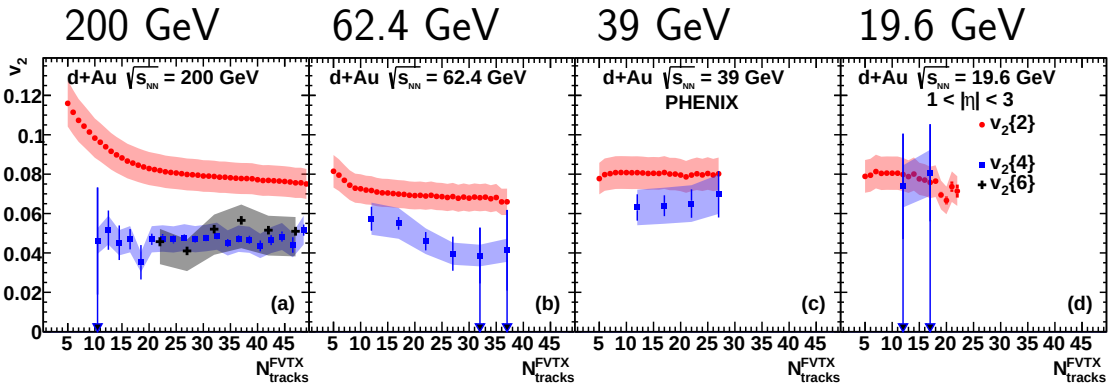
d+Au beam energy scan

Phys. Rev. Lett. 120, 062302 (2018)



d+Au beam energy scan

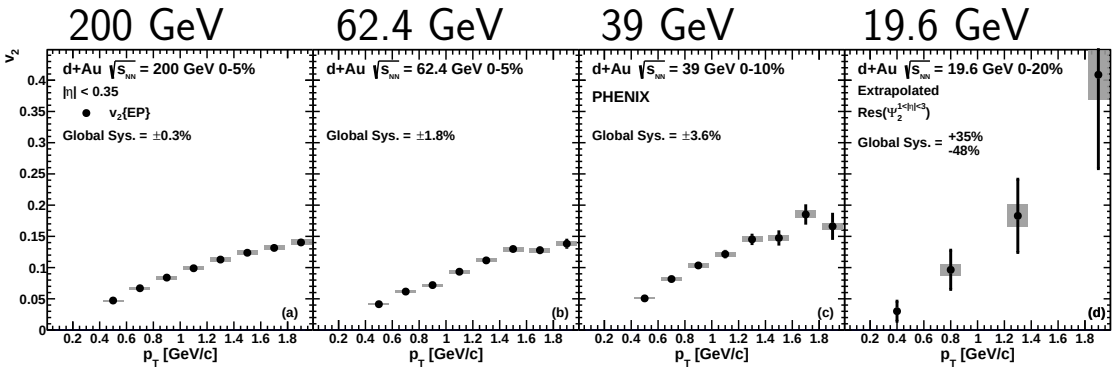
Phys. Rev. Lett. 120, 062302 (2018)



Measurement of $v_2\{6\}$ in d+Au at 200 GeV and $v_2\{4\}$ in d+Au at all energies

d+Au beam energy scan

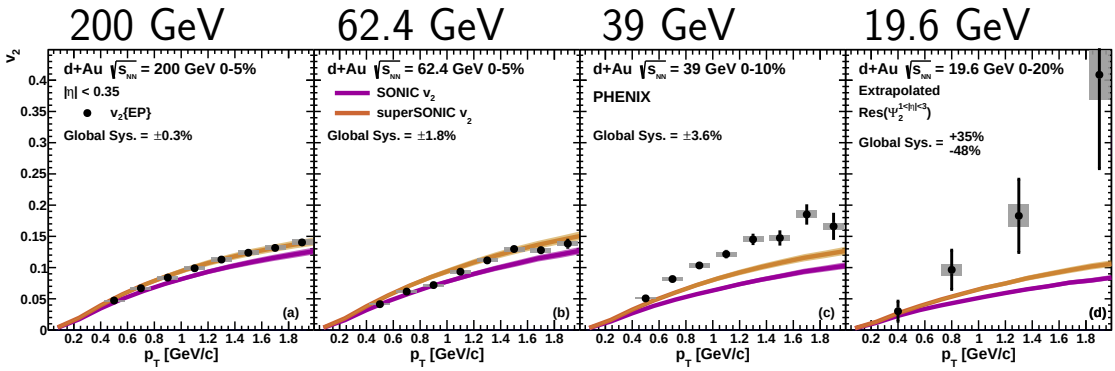
Phys. Rev. C 96, 064905 (2017)



Event plane v_2 vs p_T measured for all energies

d+Au beam energy scan

Phys. Rev. C 96, 064905 (2017)



Event plane v_2 vs p_T measured for all energies

Hydro theory agrees with higher energies very well, underpredicts lower energies—nonflow?

d+Au beam energy scan

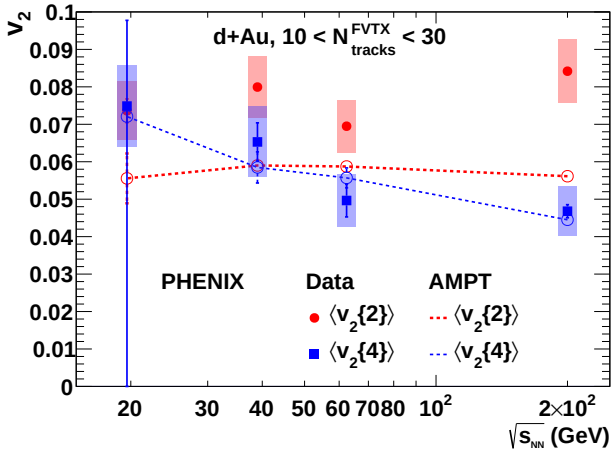
Phys. Rev. Lett. 120, 062302 (2018)

Select $10 < N_{\text{tracks}}^{\text{FVTX}} < 30$, integrate

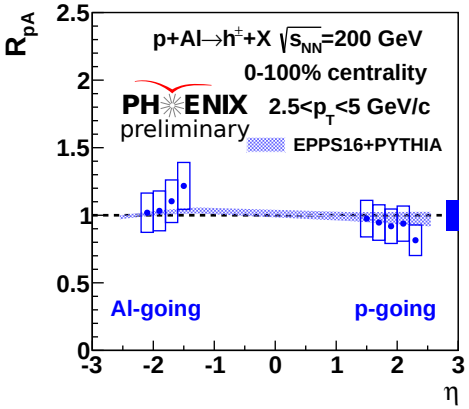
AMPT sees similar trend

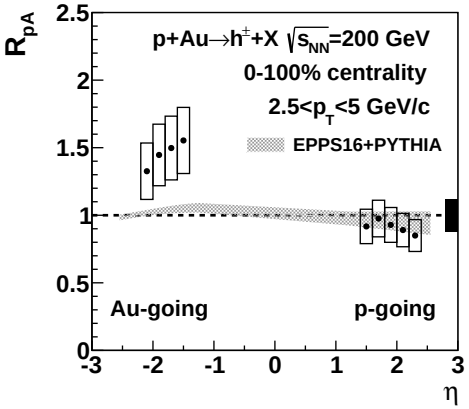
Fluctuations?

- Not Bessel-Gaussian
- Not small-variance limit
- Need to understand fluctuations better



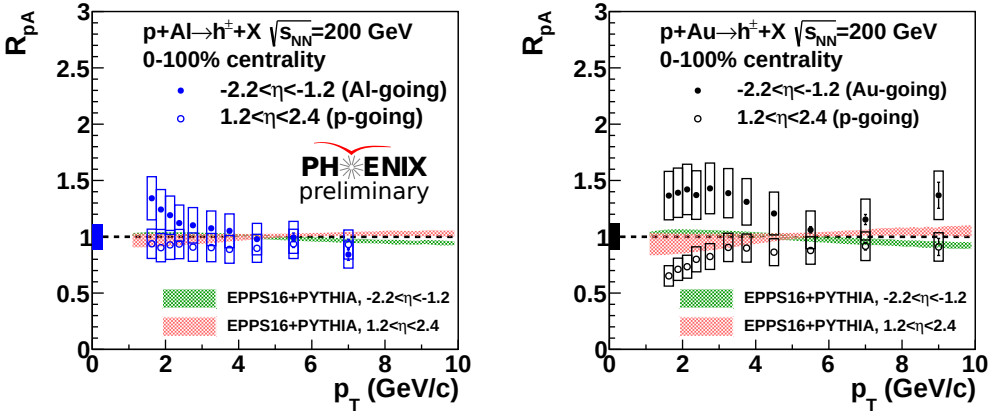
Small systems nuclear modification





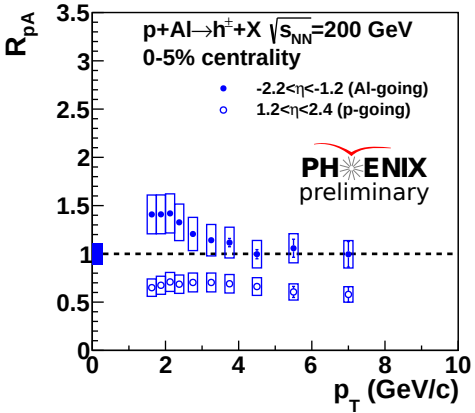
Forward modification consistent with nPDF effects (EPPS16)

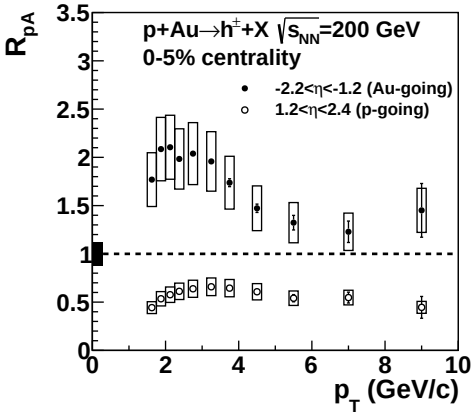
Small systems nuclear modification



High-p_T modification consistent with nPDF effects (EPPS16)

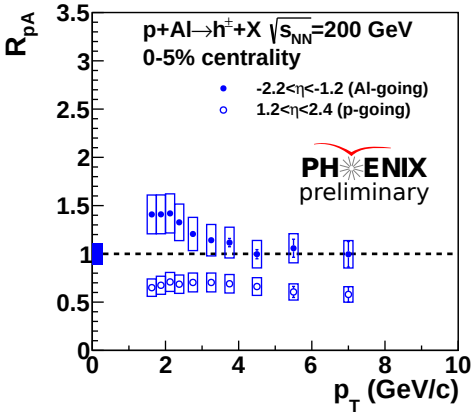
Small systems nuclear modification

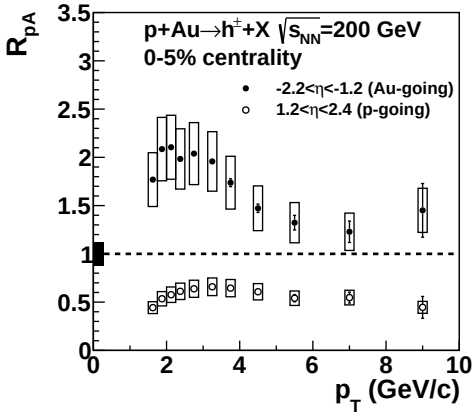




Stronger effects in central collisions

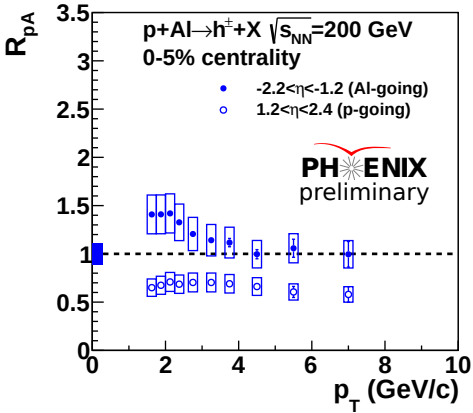
Small systems nuclear modification

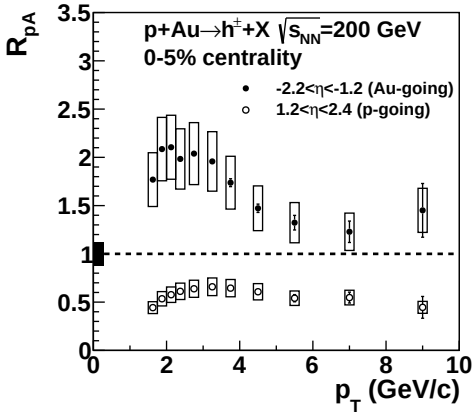




Strong enhancement for backward at intermediate p_T—why?

Small systems nuclear modification



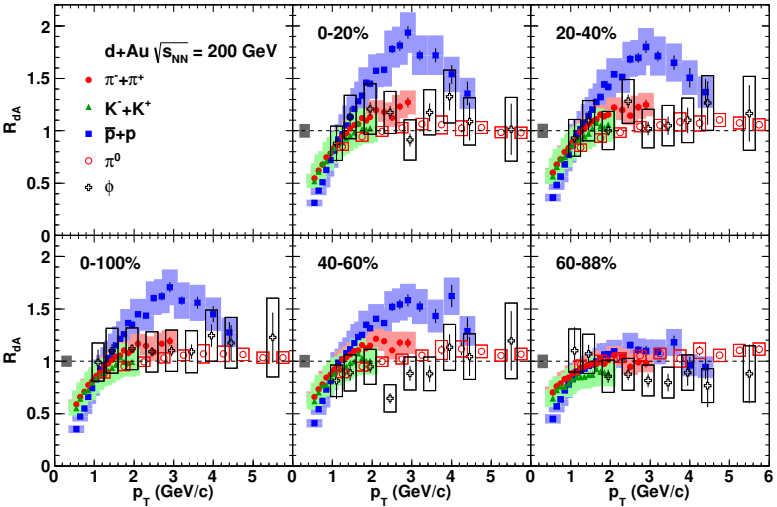


Strong enhancement for backward at intermediate p_T—why?

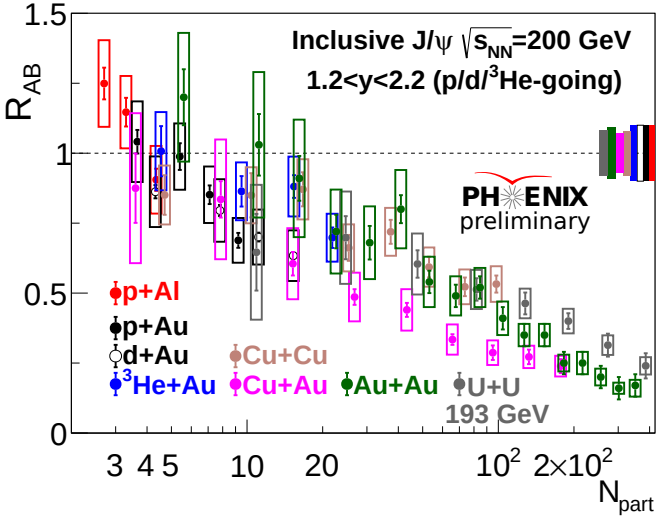
Don't forget: particle species dependence of Cronin! There must be final state effect(s)...

Particle species dependence of "Cronin enhancement"

Phys. Rev. C 88, 024906 (2013)



J/ψ nuclear modification in all systems

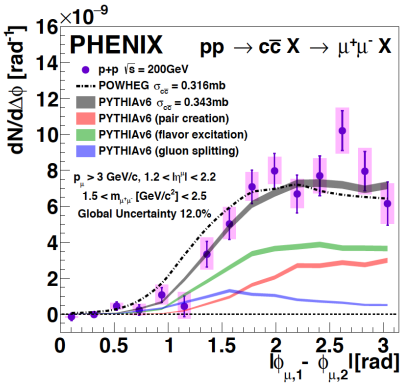


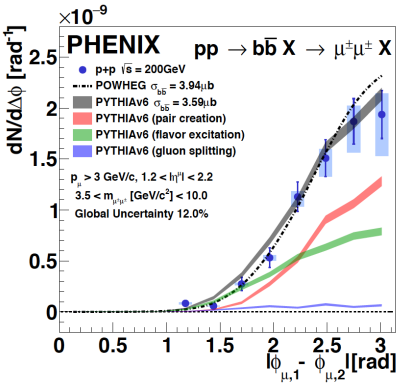
Small systems:
p+Al, p+Au,
d+Au, ^{3}He+Au,

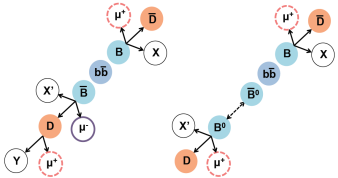
Large systems:
Cu+Cu, Cu+Au,
Au+Au, U+U,

$c\bar{c}$ and $b\bar{b}$ from angular correlations in p+p

arXiv:1805.04075 (submitted to PRL)
arXiv:1805.02448 (submitted to PRD)





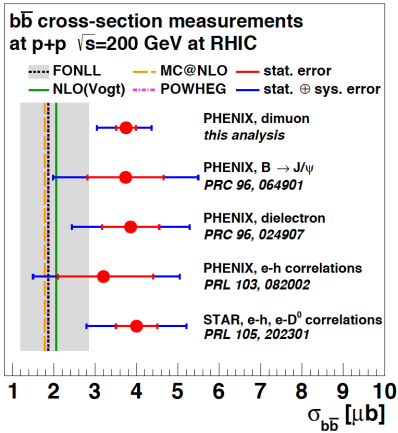


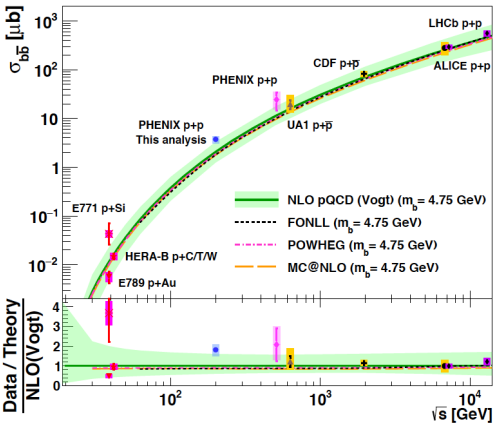
Pair creation at LO, flavor excitation and gluon splitting at NLO

PYTHIA suggests $b\bar{b}$ dominated by pair creation

$b\bar{b}$ from angular correlations in p+p

arXiv:1805.04075 (submitted to PRL)
arXiv:1805.02448 (submitted to PRD)

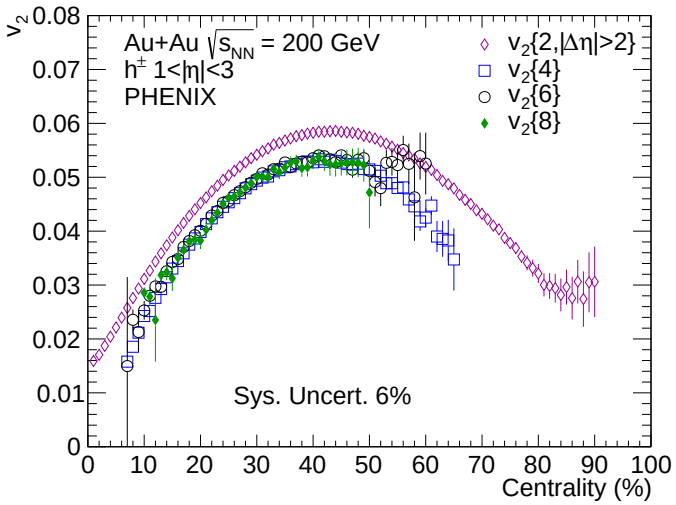




$b\bar{b}$ cross-section consistent with previous measurements, larger than FONLL

Collectivity in large systems

Phys. Rev. C 99, 024903 (2019)



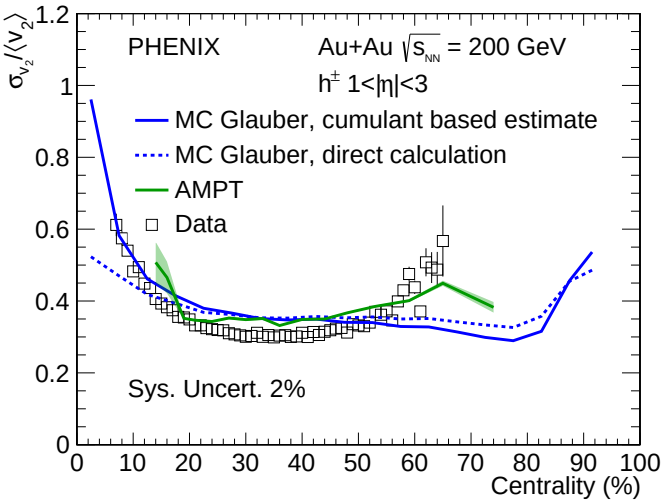
$1 < |\eta| < 3$

$v_2\{2\}$, $v_2\{4\}$, $v_2\{6\}$,

$v_2\{8\}$

Collectivity in large systems

Phys. Rev. C 99, 024903 (2019)

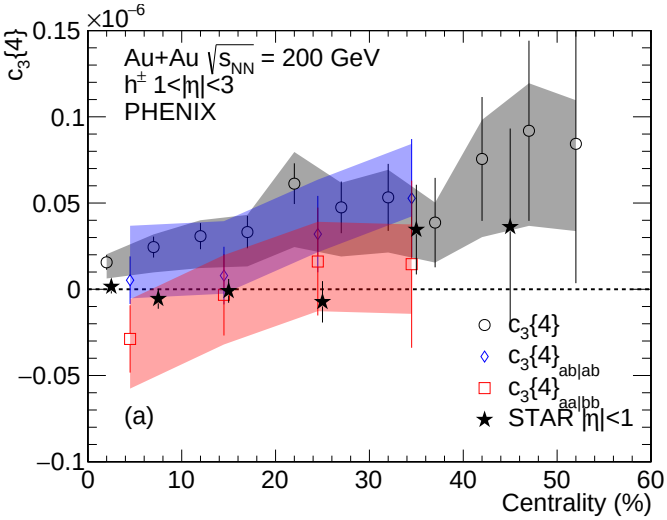


$$1 < |\eta| < 3$$

$$\sigma_{v_2}/\langle v_2 \rangle$$

Collectivity in large systems

Phys. Rev. C 99, 024903 (2019)



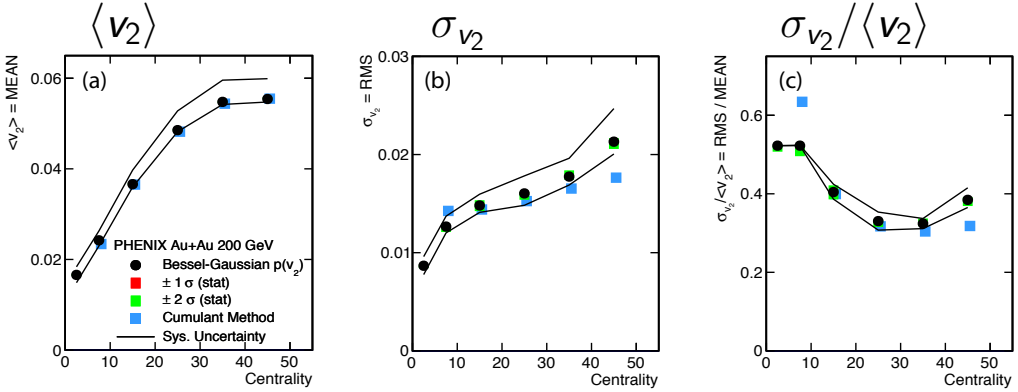
$1 < |\eta| < 3$

Cannot extract

$\sigma_{v_3} / \langle v_3 \rangle$

Collectivity in large systems

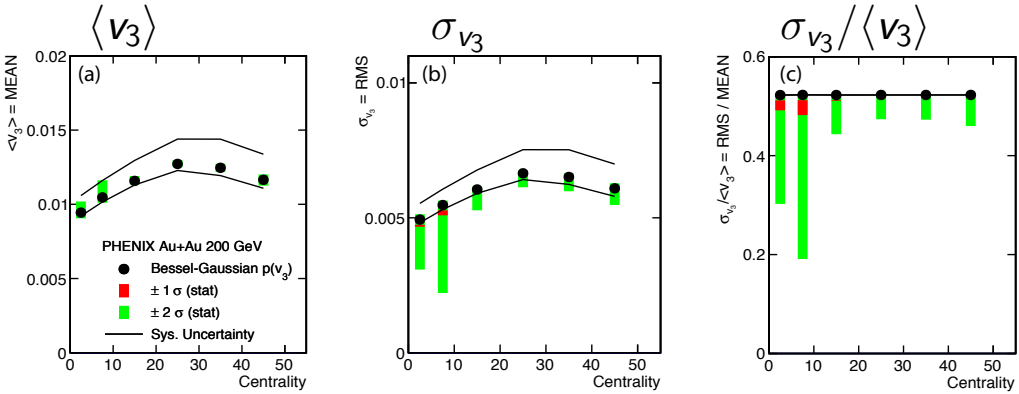
Phys. Rev. C 99, 024903 (2019)



Can extract $\langle v_2 \rangle$ and σ_{v_2} separately using forward-fold

Collectivity in large systems

Phys. Rev. C 99, 024903 (2019)



Can extract $\langle v_3 \rangle$ and σ_{v_3} separately using forward-fold