Highlights from the PHENIX experiment

Ron Belmont
University of Colorado Boulder

Quark Matter 2018
Lido di Venezia, Veneto, Italia
14 May 2018

PHENIX at Quark Matter 2018

Our third paper (now well over 200 papers) Phys. Rev. Lett. 88, 022301 (2002)

HEP **1** records found Search to

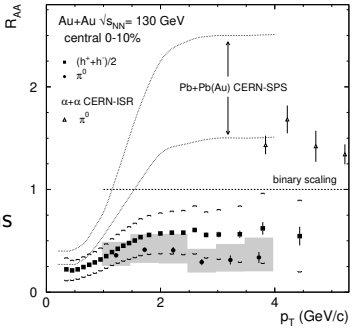
1. **Suppression of hadrons with large transverse momentum in central Au+Au collisions at $\sqrt{s_{NN}}$ = 130-GeV**

PHENIX Collaboration (K. Adcox (Vanderbilt U.) *et al.*). Sep 2001. 6 pp.
Published in **Phys.Rev.Lett. 88 (2002) 022301**
DOI: 10.1103/PhysRevLett.88.022301
e-Print: **nucl-ex/0109003** | **PDF**

References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service

Detailed record - Cited by 1000 records 1000+

First regular paper from RHIC experiment to reach 1000 citations



PHENIX at Quark Matter 2018

15 papers submitted since last Quark Matter (and 10 of those featured here)

10 talks and 19 posters at this Quark Matter

$\sqrt{s}$ [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

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39				✓				✓	
27								✓	
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14.5								✓	
7.7								✓	

Outline

High-p_T hadrons
—Correlation measurements and search for factorization breaking in p+p
—Measurements of light hadron modification in small and large systems

Heavy flavor
—Comprehensive measurements of J/ψ modification in small and large systems
—First measurement of bottom flow in Au+Au

Collectivity
—Observation of geometrical correlations in small systems
—Strongest evidence to date for QGP formation in small systems

Electromagnetic probes
—Observation of photon enhancement at low p_T in p+Au, consistent with QGP formation
—Observation of scaling relation of photon production in large systems

High-p_T hadrons

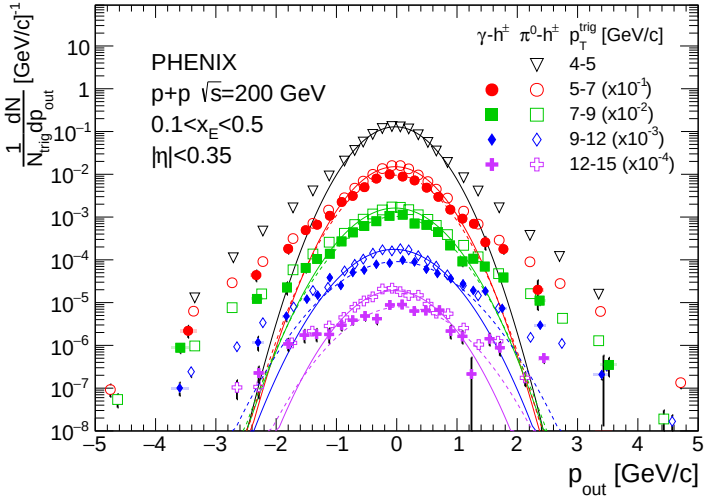
"PHENIX results on jet modification with π^0- and photon-triggered two particle correlations in p+p, $p(d)$+Au, and Au(Cu)+Au collisions"
Joe Osborn, Wednesday 16/05/2018, 9:00

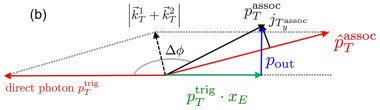
"PHENIX study of the initial state with forward hadron measurements in 200 GeV $p(d)$+A and ^{3}He+Au collisions"
Jason Bryslawskyj, Wednesday 16/05/2018, 16:50

π^0-$h^\pm$ and γ-$h^\pm$ correlations

Joe Osborn, Wednesday 16/05/2018, 9:00

arxiv:1805.02450 (submitted to PRD)





$$p_{\text{out}} = p_T^{\text{assoc}} \sin\Delta\phi$$

$$x_E = \frac{p_T^{\text{assoc}}}{p_T^{\text{trig}}} \cos\Delta\phi$$

p_{out} is Gaussian in non-perturbative regime

π^0-$h^\pm$ and γ-$h^\pm$ correlations

Joe Osborn, Wednesday 16/05/2018, 9:00

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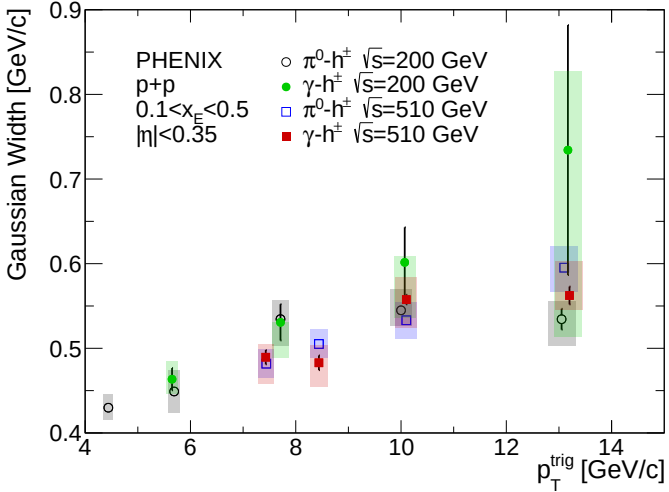
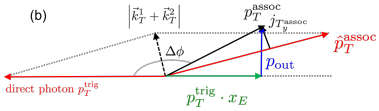


Similar behavior as pair-p_T broadening in Drell-Yan



$$p_{\text{out}} = p_T^{\text{assoc}} \sin \Delta\phi$$

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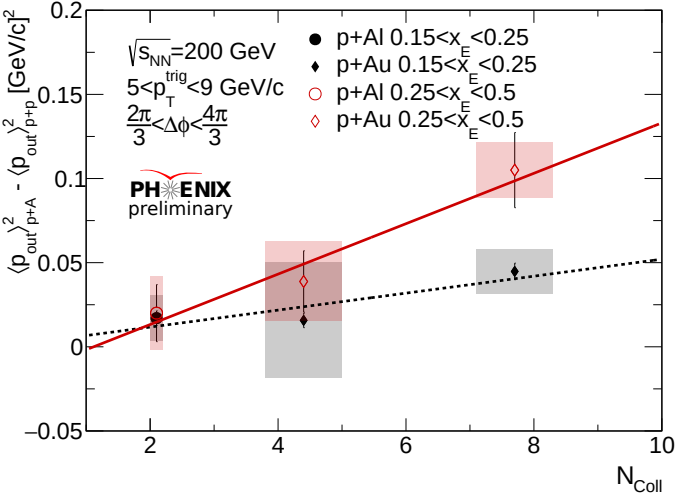
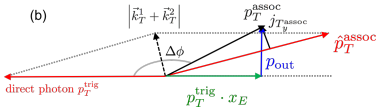
π^0-$h^{\pm}$ and γ-$h^{\pm}$ correlations

Joe Osborn, Wednesday 16/05/2018, 9:00



Observation of broadening in p+A

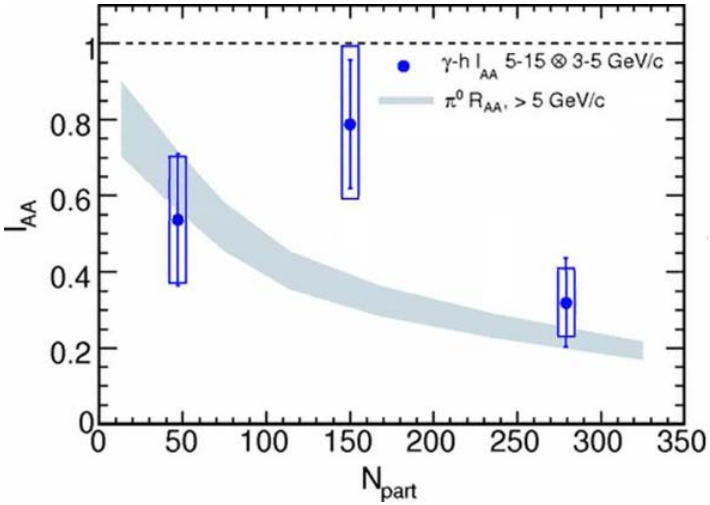


$$p_{\text{out}} = p_T^{\text{assoc}} \sin \Delta\phi$$

$$x_E = \frac{p_T^{\text{assoc}}}{p_T^{\text{trig}}} \cos \Delta\phi$$

γ-$h^{\pm}$ correlations in Au+Au

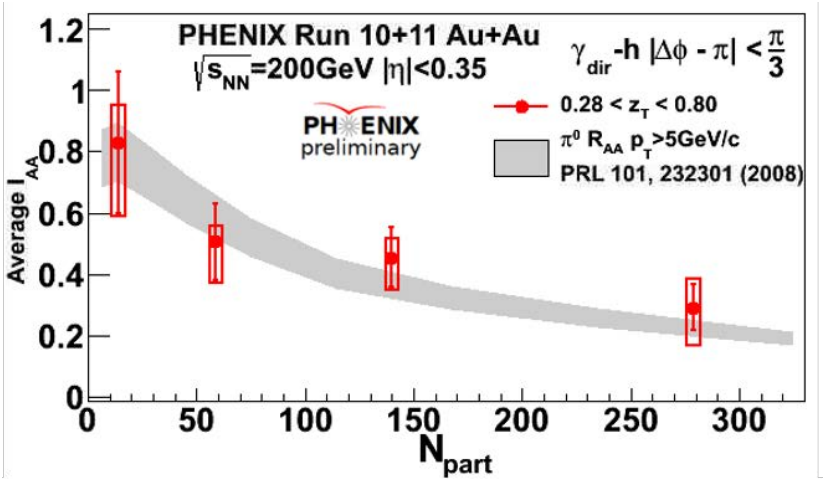
Joe Osborn, Wednesday 16/05/2018, 9:00



I_{AA} of away side hadron (previous)

γ-$h^{\pm}$ correlations in Au+Au

Joe Osborn, Wednesday 16/05/2018, 9:00

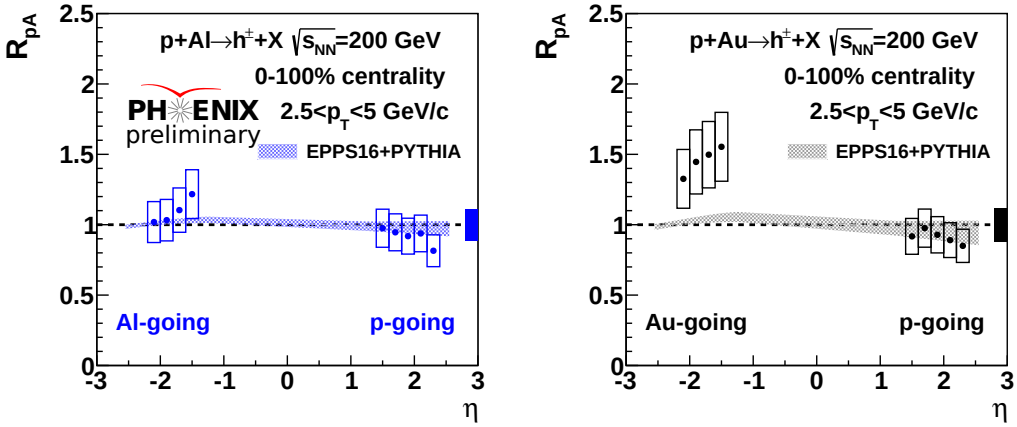


I_{AA} of away side hadron (new)

More statistics and isolation cut significantly improve precision of I_{AA}

Small systems nuclear modification

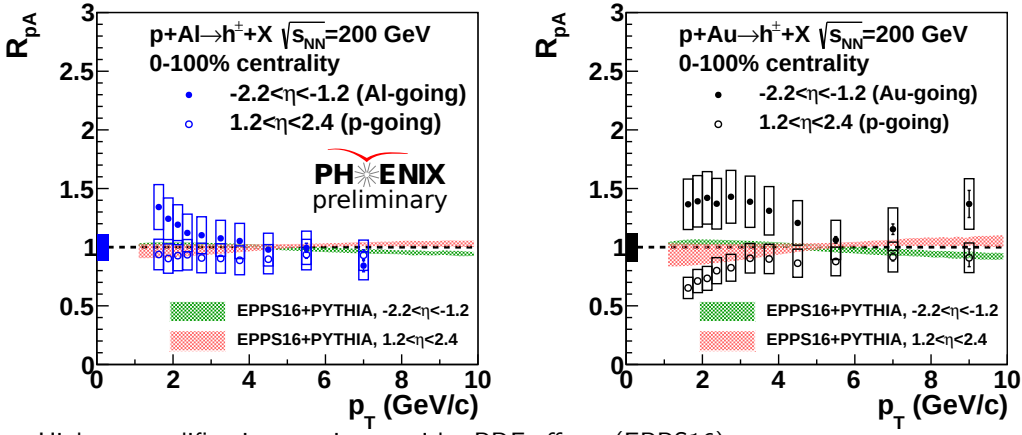
Jason Bryslawskyj, Wednesday 16/05/2018, 16:50



Forward modification consistent with nPDF effects (EPPS16)

Small systems nuclear modification

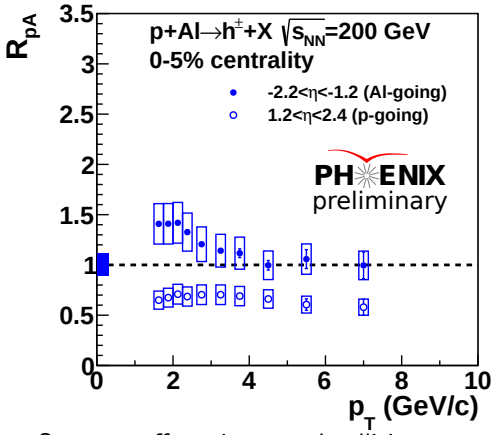
Jason Bryslawskyj, Wednesday 16/05/2018, 16:50

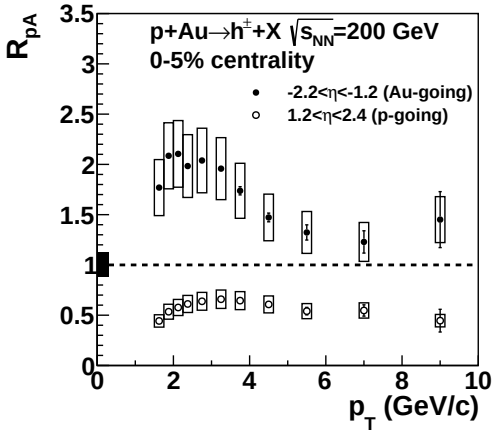


High-p_T modification consistent with nPDF effects (EPPS16)

Small systems nuclear modification

Jason Bryslawskyj, Wednesday 16/05/2018, 16:50

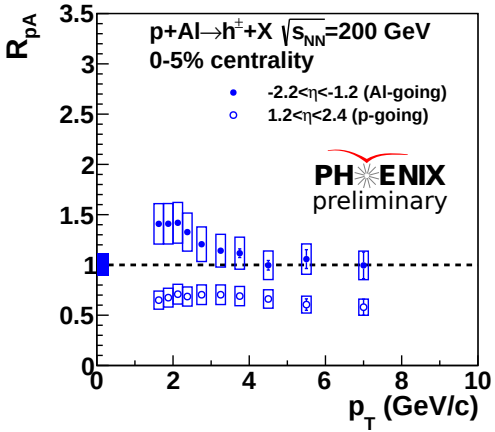


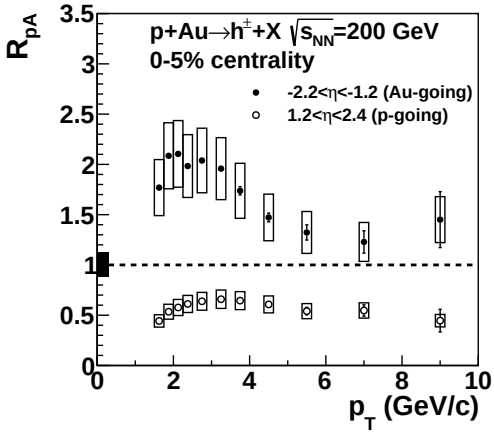


Stronger effects in central collisions

Small systems nuclear modification

Jason Bryslawskyj, Wednesday 16/05/2018, 16:50

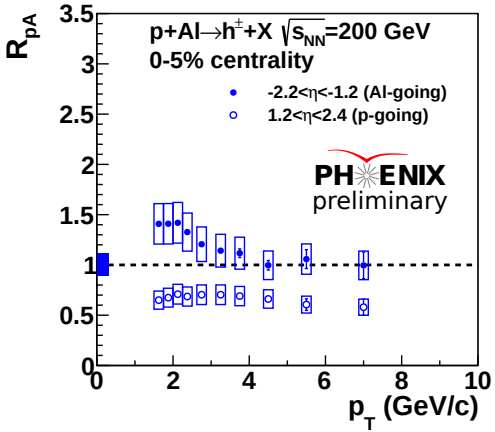


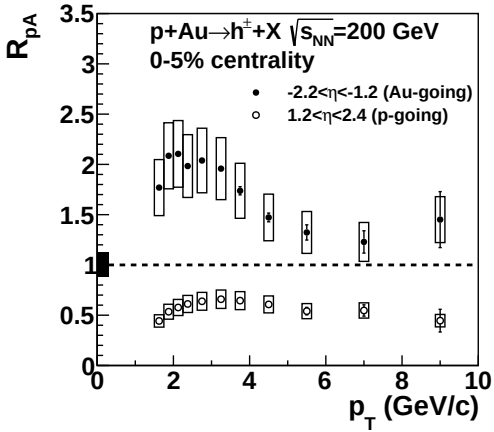


Strong enhancement for backward at intermediate p_T—why?

Small systems nuclear modification

Jason Bryslawskyj, Wednesday 16/05/2018, 16:50





Strong enhancement for backward at intermediate p_T—why?

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

High-p_T hadrons: Summary

p_{out} in p+p collisions similar to Drell-Yan behavior
—Detailed theory comparisons are needed

p_{out} in p+Al and p+Au collisions indicate initial-state broadening in p+A relative to p+p

Forward R_{pA} consistent with nPDF effects

Backward R_{pA} shows strong enhancement at intermediate p_T
—Final state effects are important: radial flow, hadronization, etc...

Heavy flavor

"Recent Quarkonia Studies from the PHENIX Experiment"
Matt Durham, Monday 14/05/2018, 18:10

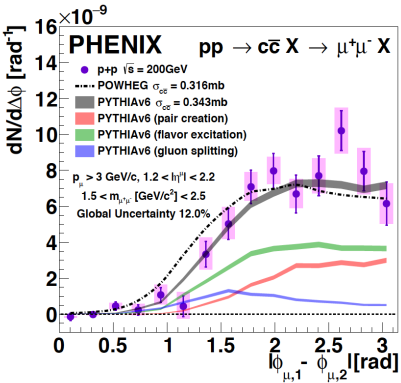
"Nuclear modification factor of charm and bottom quark yields in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX Experiment"
Takashi Hachiya, Tuesday 15/05/2018, 16:00

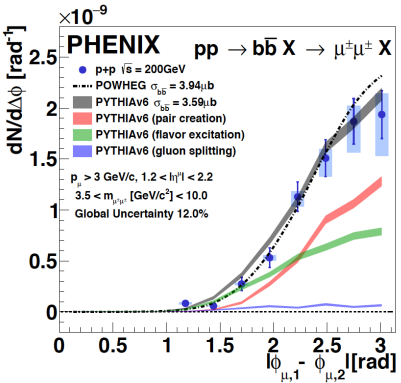
"Measurements of charm, bottom, and Drell-Yan via dimuons in p+p and p+Au collisions $\sqrt{s_{NN}} = 200$ GeV with PHENIX at RHIC"
Yue Hang Leung, Wednesday 16/05/2018, 15:40

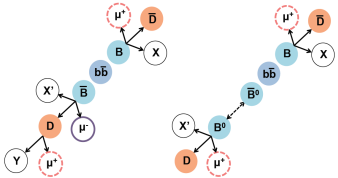
$c\bar{c}$ and $b\bar{b}$ from angular correlations in p+p

Yue Hang Leung, Wednesday 16/05/2018, 15:40

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







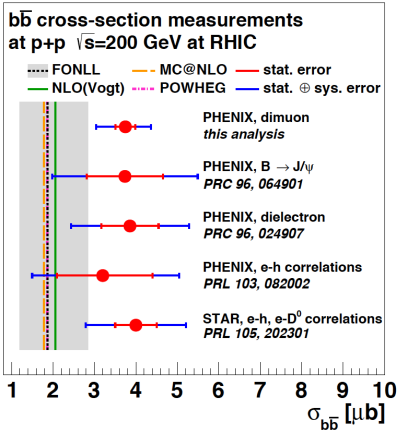
Pair creation at LO, flavor excitation and gluon splitting at NLO

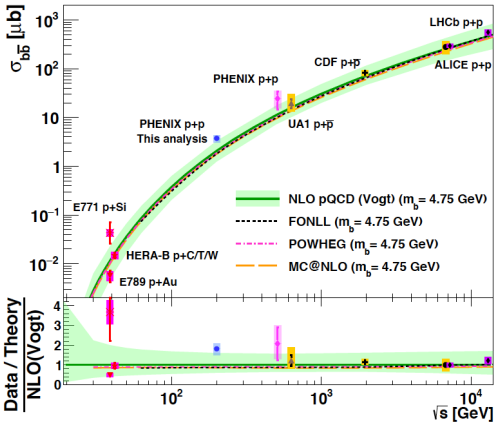
PYTHIA suggests $b\bar{b}$ dominated by pair creation

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

Yue Hang Leung, Wednesday 16/05/2018, 15:40

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

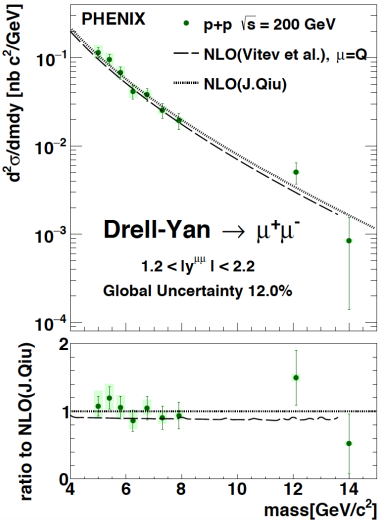


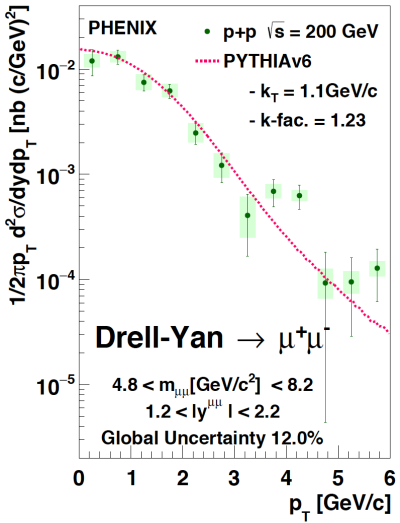


$b\bar{b}$ cross-section consistent with previous measurements, larger than FONLL

Drell-Yan from angular correlations in p+p

Yue Hang Leung, Wednesday 16/05/2018, 15:40



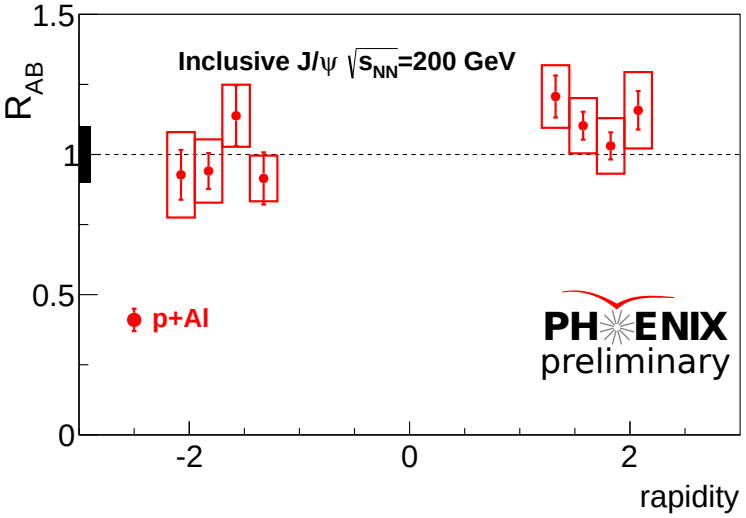


arXiv:1805.04075 (PRL)
arXiv:1805.02448 (PRD)

Drell-Yan well-described by NLO & PYTHIA

J/ψ nuclear modification in small systems

Matt Durham, Monday 14/05/2018, 18:10



J/ψ R_{AB}:

p+Al

J/ψ nuclear modification in small systems

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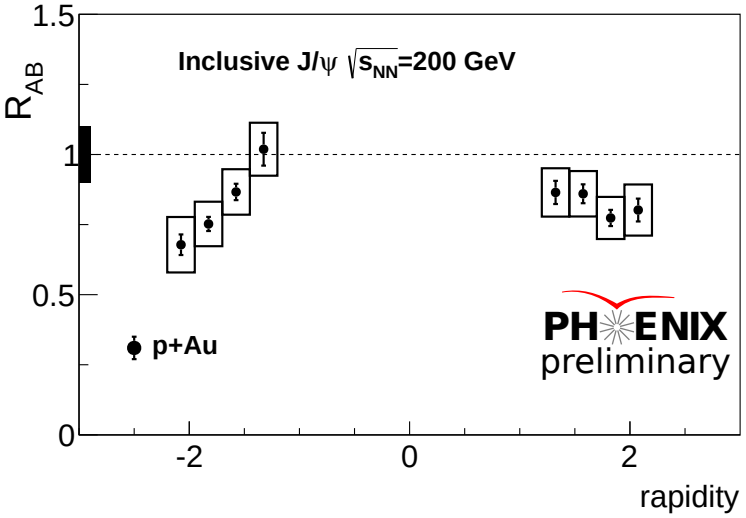

J/ψ R_{AB}:

p+Au

J/ψ nuclear modification in small systems

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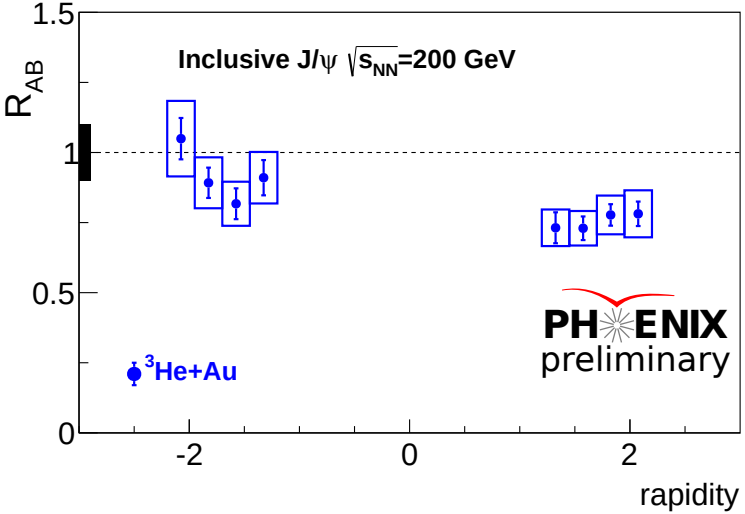
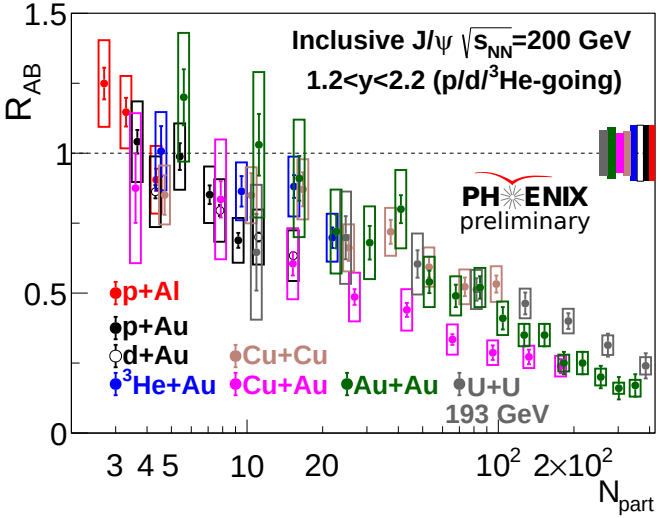


J/ψ R_{AB}:

^{3}He+Au

J/ψ nuclear modification in all systems

Matt Durham, Monday 14/05/2018, 18:10

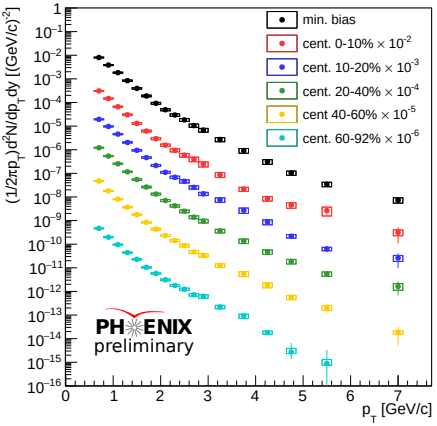


Small systems:
p+Al, p+Au,
d+Au, ^{3}He+Au,

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

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

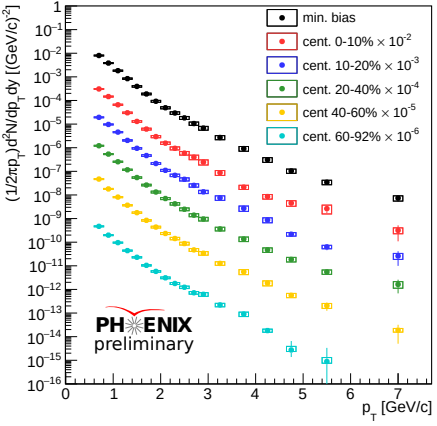
Takashi Hachiya, Tuesday 15/05/2018, 16:00

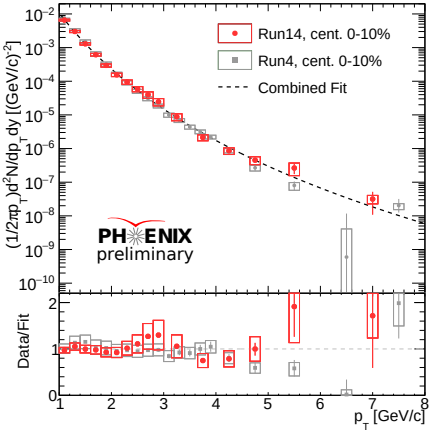


New HF electron spectra, now using all available data

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

Takashi Hachiya, Tuesday 15/05/2018, 16:00



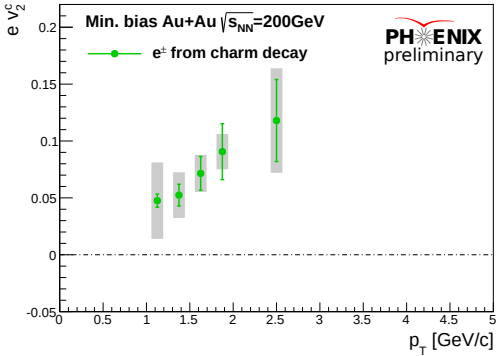


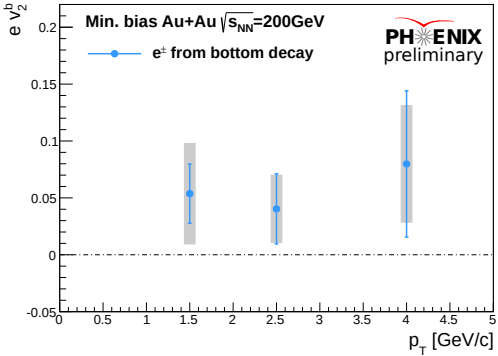
New HF electron spectra, now using all available data

Different method and better precision compared to previous results

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

Takashi Hachiya, Tuesday 15/05/2018, 16:00



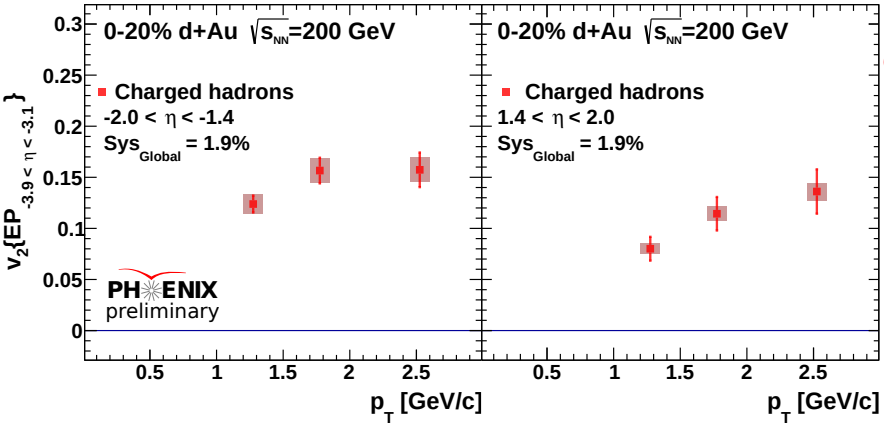


Charm $v_2 > 0$

Bottom $v_2 > 0$

Small systems flow

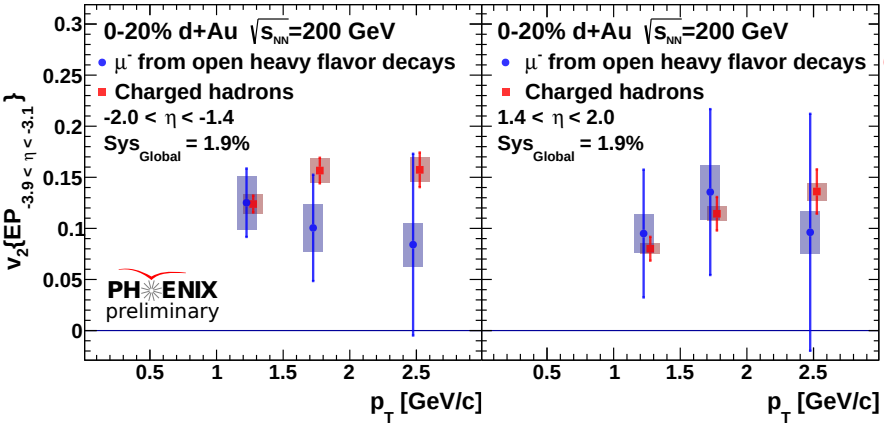
Takashi Hachiya, Tuesday 15/05/2018, 16:00



charged hadrons

Small systems flow—heavy flavor

Takashi Hachiya, Tuesday 15/05/2018, 16:00



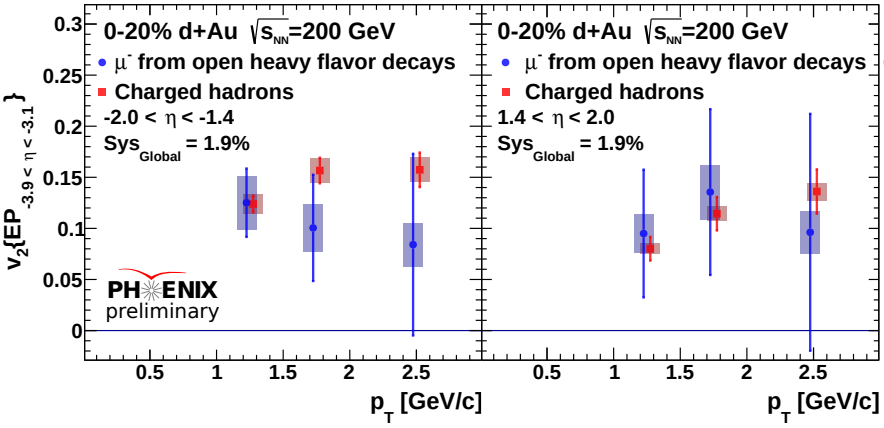
charged hadrons

heavy flavor muons

Nonzero v_2 for heavy flavor in d+Au

Small systems flow—heavy flavor

Takashi Hachiya, Tuesday 15/05/2018, 16:00



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)

Heavy flavor: Summary

New measurements of DY, $c\bar{c}$, $b\bar{b}$ cross-sections
—$b\bar{b}$ production dominated by pair creation

Comprehensive set of measurements of J/ψ modification in small systems

First measurement of charm-to-electron and bottom-to-electron v_2 in Au+Au
—Clear charm flow
—First measurement of bottom flow at RHIC

First measurement of heavy flavor v_2 in small systems (d+Au) at RHIC

Collectivity

"Implications for small-system collectivity from a comprehensive set of soft physics measurements in a wide rapidity range in 200 GeV p+Au collisions by PHENIX"
Qiao Xu, Monday 14/05/2018, 17:10

"PHENIX Results on elliptic and triangular flow from the small-system geometry scan at 200 GeV"
Sylvia Morrow, Tuesday 15/05/2018, 11:10

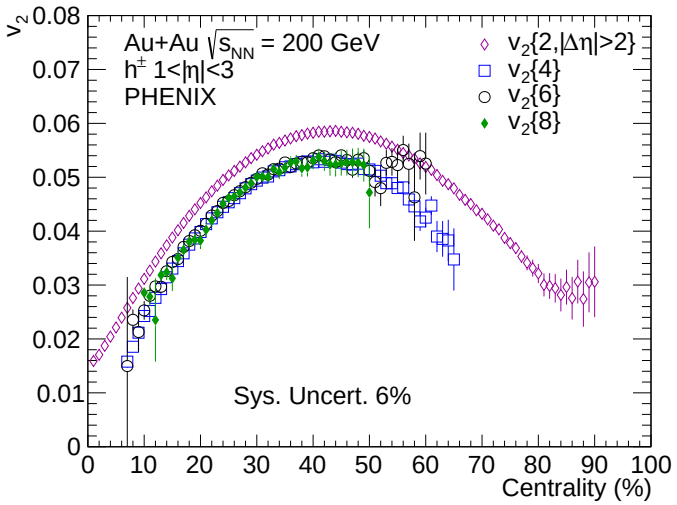
"PHENIX Measurements of collectivity in Au+Au collisions from higher order cumulants and flow unfolding"
Kurt Hill, Tuesday 15/05/2018, 15:40

"PHENIX Measurements of $dN_{\mathrm{ch}}/d\eta$ in small systems (p+A, d+Au, and ^{3}He+Au)"
Darren McGlinchey, Wednesday 16/05/2018, 10:20

Collectivity in large systems

Kurt Hill, Tuesday 15/05/2018, 15:40

arXiv:1804.10024 (submitted to Phys Rev C)



$1 < |\eta| < 3$

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

$v_2\{8\}$

Collectivity in large systems

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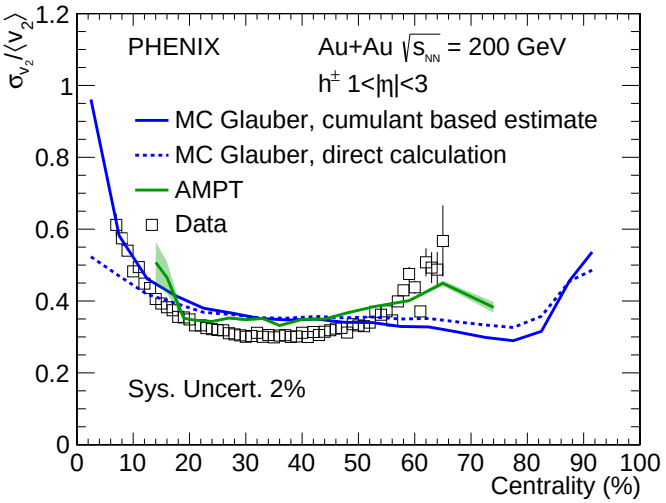


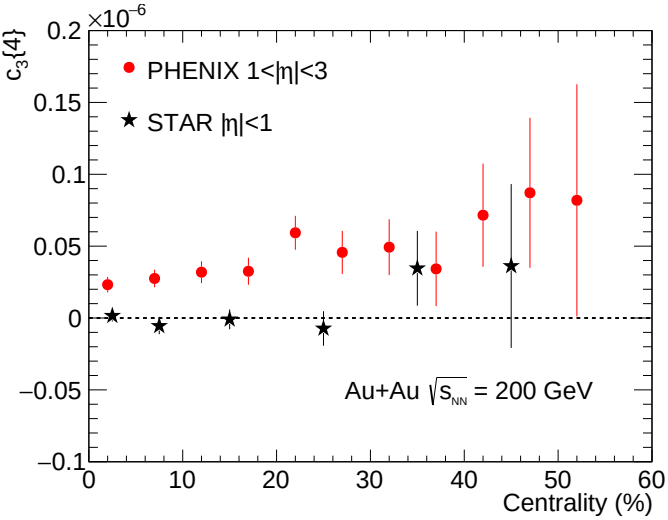
$$1 < |\eta| < 3$$

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

Collectivity in large systems

Kurt Hill, Tuesday 15/05/2018, 15:40

arXiv:1804.10024 (submitted to Phys Rev C)



$1 < |\eta| < 3$

Cannot extract

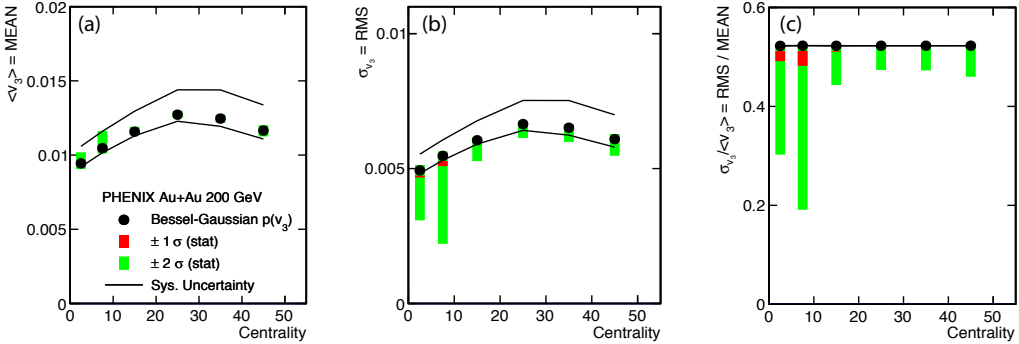
$\sigma_{v_3} / \langle v_3 \rangle$

Collectivity in large systems

Kurt Hill, Tuesday 15/05/2018, 15:40

arXiv:1804.10024 (submitted to Phys Rev C)

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



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

Testing hydro by controlling system geometry

Sylvia Morrow, Tuesday 15/05/2018, 11:10

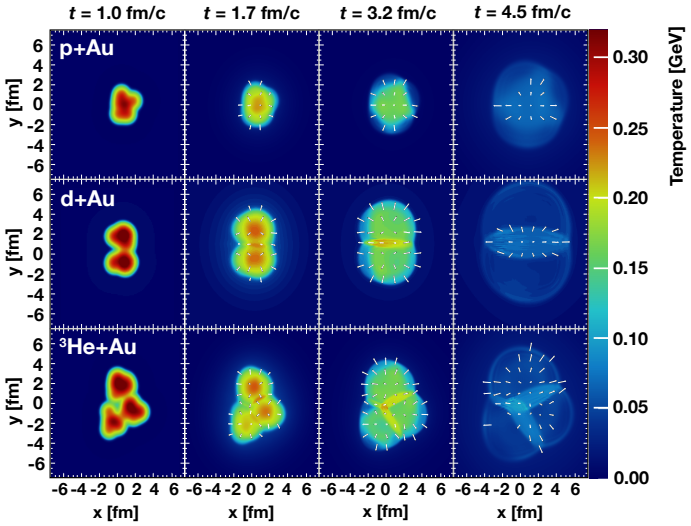
arXiv:1805.02973, submitted to Nature Physics

Hydrodynamics translates initial geometry into final state

Test hydro hypothesis by varying initial state

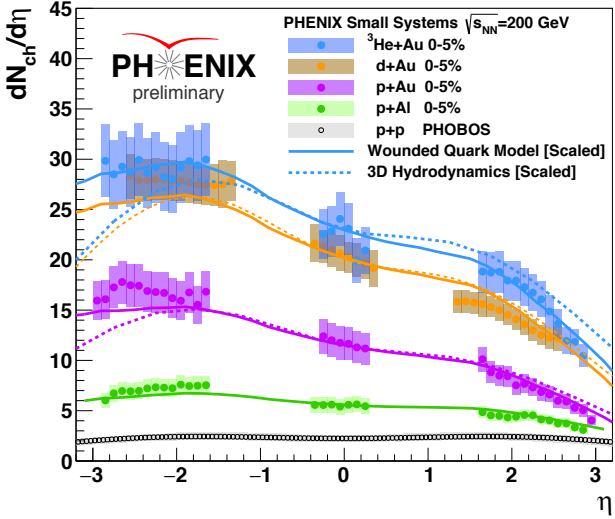
	ε_2	ε_3
p+Au	0.24	0.16
d+Au	0.57	0.17
^{3}He+Au	0.48	0.23

$$\varepsilon_2^{\mathrm{p+Au}} < \varepsilon_2^{\mathrm{d+Au}} \approx \varepsilon_2^{\mathrm{3He+Au}}$$
$$\varepsilon_3^{\mathrm{p+Au}} \approx \varepsilon_3^{\mathrm{d+Au}} < \varepsilon_3^{\mathrm{3He+Au}}$$



Longitudinal dynamics in small systems

Darren McGlinchey, Wednesday 16/05/2018, 10:20



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

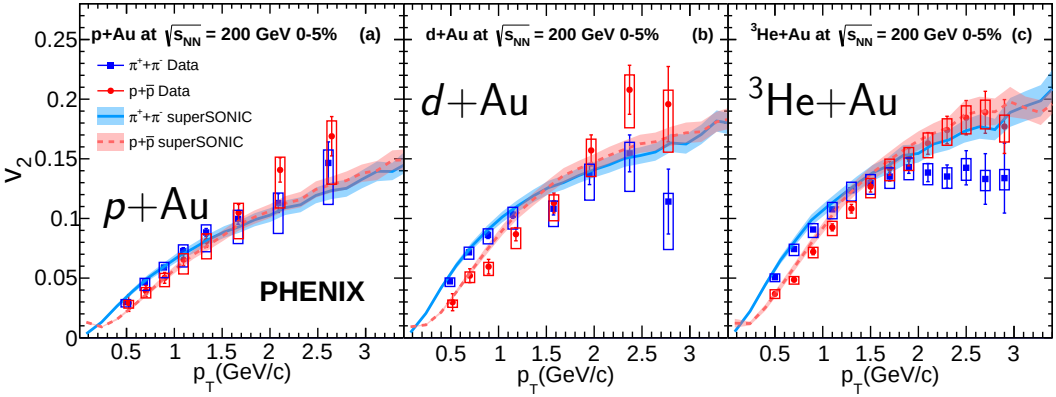
Good agreement with wounded quark model

Good agreement with 3D hydro

Small systems geometry scan

Sylvia Morrow, Tuesday 15/05/2018, 11:10

arXiv:1710.09736, accepted by Phys. Rev. C

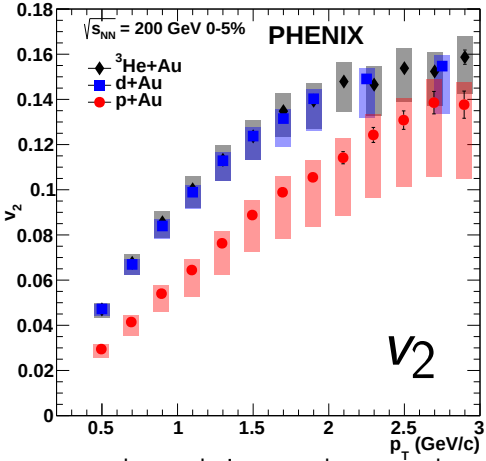


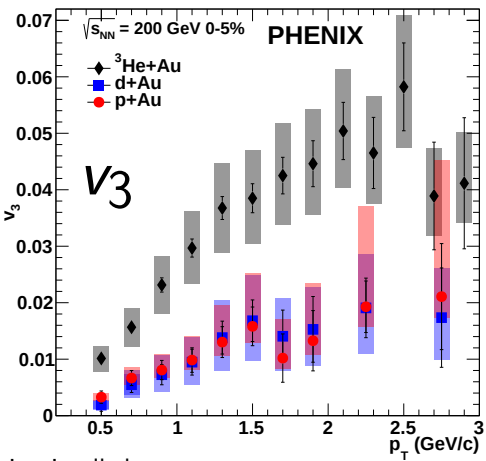
Identified particle v_2 vs p_T in p+Au, d+Au, and ^{3}He+Au
—Mass ordering well-described by hydro

Testing hydro by controlling system geometry

Sylvia Morrow, Tuesday 15/05/2018, 11:10

arXiv:1805.02973, submitted to Nature Physics





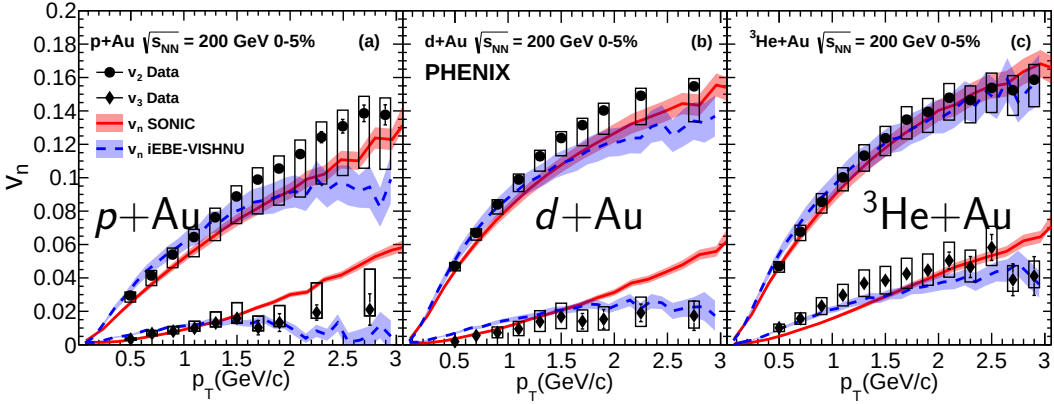
v_2 and v_3 ordering matches ε_2 and ε_3 ordering in all three systems

—Regardless of mechanism, the correlation is geometrical

Testing hydro by controlling system geometry

Sylvia Morrow, Tuesday 15/05/2018, 11:10

arXiv:1805.02973, submitted to Nature Physics



v_2 and v_3 vs p_T described very well by hydro in all three systems
—Strongly suggests QGP droplets in hydro evolution

Collectivity: Summary

First measurement of relative fluctuations $\sigma_{v_3}/\langle v_3 \rangle$ in Au+Au at RHIC

Comprehensive set of measurements for longitudinal dynamics

v_2 and v_3 match ε_2 and ε_3 ordering in p+Au, d+Au, ^{3}He+Au
—Correlation is definitively geometrical in origin

v_2 and v_3 in p+Au, d+Au, ^{3}He+Au are well-described by hydro theory
—Strongest evidence to date for QGP formation in small systems

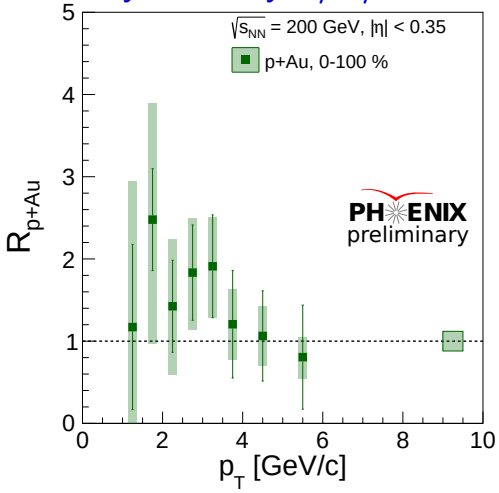
Electromagnetic probes

"PHENIX measurement of low momentum direct photon radiation from p+p and p+A collisions"

Vlad Khachatryan, Monday 14/05/2018, 16:50

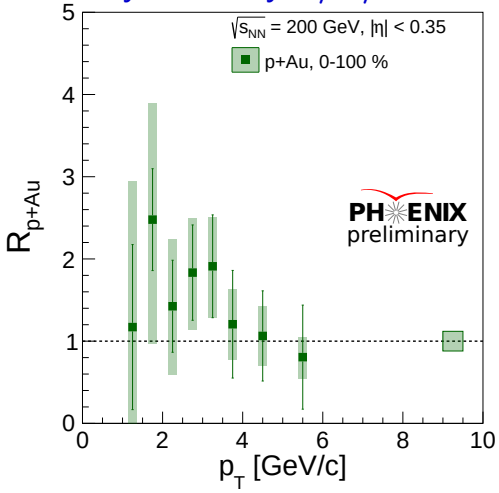
Photons in small systems

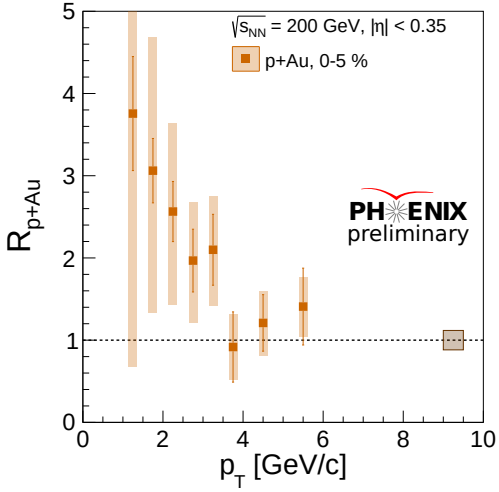
Vlad Khachatryan, Monday 14/05/2018, 16:50



Photons in small systems

Vlad Khachatryan, Monday 14/05/2018, 16:50

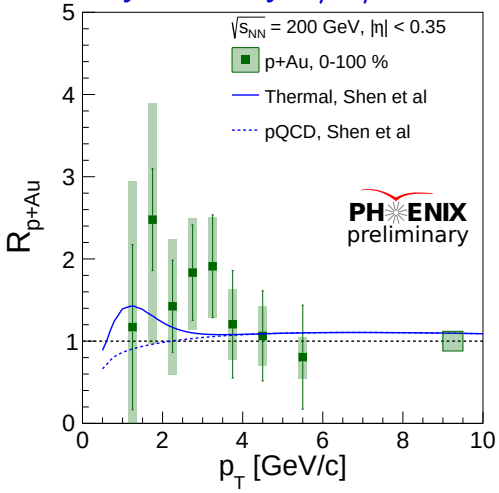


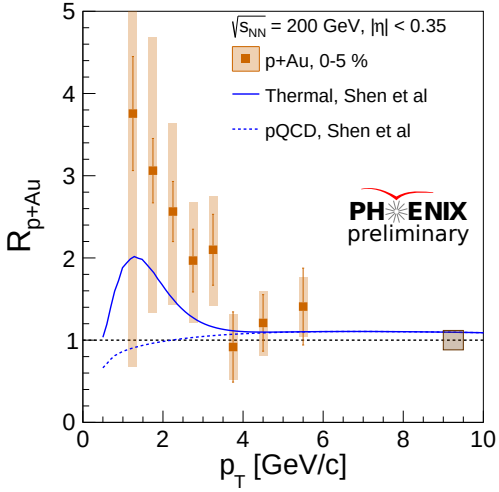


Thermal photons in p+Au?

Photons in small systems

Vlad Khachatryan, Monday 14/05/2018, 16:50

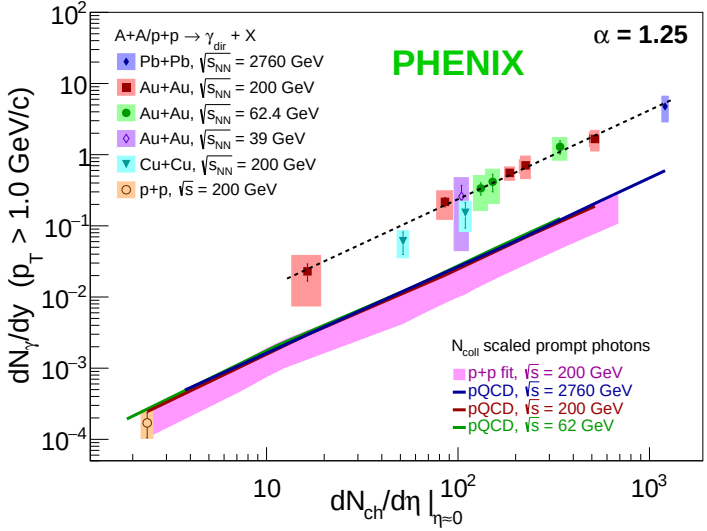




Thermal photons in p+Au? Theory from Phys. Rev. C 95, 014906 (2017)

Photon yields

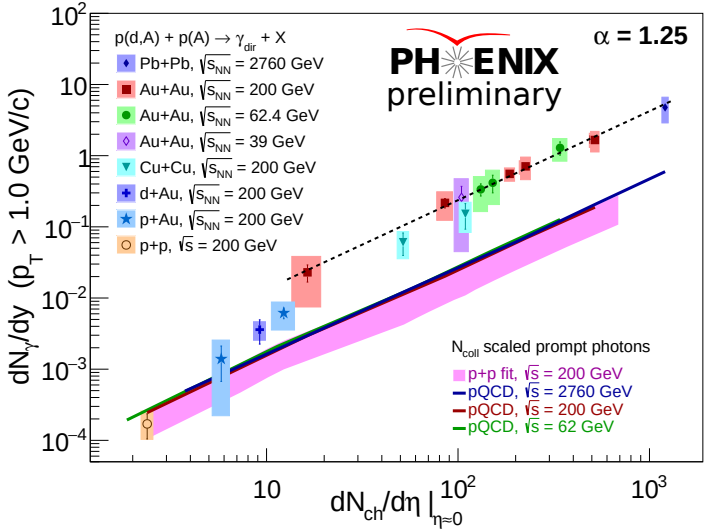
Vlad Khachatryan, Monday 14/05/2018, 16:50 arXiv:1805.04084, submitted to Phys. Rev. Lett.



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

Photon yields

Vlad Khachatryan, Monday 14/05/2018, 16:50



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

p+Au in between

Electromagnetic probes: Summary

Observation of universal scaling for photon yields

Observation of low-p_T photon enhancement in p+Au

Possibly thermal photons, consistent with theory prediction
—Would strongly support QGP droplets in hydro evolution

PHENIX at Quark Matter 2018

New papers highlighted here:

Phys. Rev. C 96, 064905 (2017)—Qiao Xu, Monday 14/05/2018, 17:10
Phys. Rev. Lett. 120, 062302 (2018)—Qiao Xu, Monday 14/05/2018, 17:10
arXiv:1710.09736, accepted by Phys. Rev. C—Sylvia Morrow, Tuesday 15/05/2018, 11:10
arXiv:1804.10024, submitted to Phys. Rev. C—Kurt Hill, Tuesday 15/05/2018, 15:40
arXiv:1805.02450, submitted to Phys. Rev. D—Joe Osborn, Wednesday 16/05/2018, 9:00
arXiv:1805.02973, submitted to Nature Physics—Sylvia Morrow, Tuesday 15/05/2018, 11:10
arXiv:1805.02448, submitted to Phys. Rev. D—Yue Hang Leung, Wednesday 16/05/2018, 15:40
arXiv:1805.04066, submitted to Phys. Rev. C—Vlad Khachatryan, Monday 14/05/2018, 16:50
arXiv:1805.04075, submitted to Phys. Rev. Lett.—Yue Hang Leung, Wednesday 16/05/2018, 15:40
arXiv:1805.04084, submitted to Phys. Rev. Lett.—Vlad Khachatryan, Monday 14/05/2018, 16:50

PHENIX at Quark Matter 2018

"PHENIX measurement of low momentum direct photon radiation from p+p and p+A collisions"
Vlad Khachatryan, Monday 14/05/2018, 16:50
"Implications for small-system collectivity from a comprehensive set of soft physics measurements in a wide rapidity range in 200 GeV p+Au collisions by PHENIX"
Qiao Xu, Monday 14/05/2018, 17:10
"Recent Quarkonia Studies from the PHENIX Experiment"
Matt Durham, Monday 14/05/2018, 18:10
"PHENIX Results on elliptic and triangular flow from the small-system geometry scan at 200 GeV"
Sylvia Morrow, Tuesday 15/05/2018, 11:10
"PHENIX Measurements of collectivity in Au+Au collisions from higher order cumulants and flow unfolding"
Kurt Hill, Tuesday 15/05/2018, 15:40
"Nuclear modification factor of charm and bottom quark yields in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX Experiment"
Takashi Hachiya, Tuesday 15/05/2018, 16:00
"PHENIX results on jet modification with π^0- and photon-triggered two particle correlations in p+p, $p(d)$+Au, and Au(Cu)+Au collisions"
Joe Osborn, Wednesday 16/05/2018, 9:00
"PHENIX Measurements of $dN_{ch}/d\eta$ in small systems (p+A, d+Au, and ^{3}He+Au)"
Darren McGlinchey, Wednesday 16/05/2018, 10:20
"Measurements of charm, bottom, and Drell-Yan via dimuons in p+p and p+Au collisions $\sqrt{s_{NN}} = 200$ GeV with PHENIX at RHIC"
Yue Hang Leung, Wednesday 16/05/2018, 15:40
"PHENIX study of the initial state with forward hadron measurements in 200 GeV $p(d)$+A and ^{3}He+Au collisions"
Jason Bryslawskyj, Wednesday 16/05/2018, 16:50

PHENIX at Quark Matter 2018

357—Forward rapidity open heavy flavor measurements at PHENIX in p+p and Au+Au collisions—Cesar da Silva

383—Azimuthal anisotropy of $b \rightarrow e$ and $c \rightarrow e$ in 200 GeV Au+Au collisions at RHIC-PHENIX—Takashi Hachiya

447—PHENIX results on centrality dependent Lévy analysis of two particle Bose-Einstein correlations in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions—Dániel Kincses

458—PHENIX Measurements of Bottom and Charm Quark Production at Mid Rapidity in p+p Collisions at $\sqrt{s} = 200$ GeV—Marzia Rosati

548—PHENIX beam energy and centrality dependence of direct photon emission in heavy ion collisions—Axel Drees

557—PHENIX results on Bose-Einstein correlation functions using a Levy analysis in Au+Au collisions at RHIC—Sándor Lökös

560—Comprehensive study of hadron production from small to large systems by PHENIX—Rich Seto

562—PHENIX results on collectivity in d+Au collisions from 200 to 19.6 GeV—Kenta Shigaki

567—Azimuthal anisotropy of high p_T hadrons via long-range two particle correlations in d+Au and p+p collisions by PHENIX—Brett Fadem

571—Low p_T direct photon production from small to large systems—Wenqing Fan

596—Centrality and momentum dependent energy loss of electrons from charm and bottom hadron decays in Au+Au collisions at $\sqrt{s_{NN}}$ 200 GeV at mid-rapidity by the PHENIX experiment—Kazuya Nagashima

690—The Study of Muon Production in Ultra-Peripheral Collisions in Au+Au and U+U in the PHENIX Experiment at RHIC—Xiaochun He

719—PHENIX results on three-dimensional Bose-Einstein correlations in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions—Bálint Kurgyis

720—Photon-Hadron Correlations in Heavy Ion Collisions from PHENIX—Tyler Danley

730—Upsilon Production in p+p, p+Au and Au+Au Collisions at large rapidity in the PHENIX Experiment at RHIC—Ming Liu

740—PHENIX measurements of charged hadron and heavy flavor v2 at forward/backward rapidity in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV—Darren McGlinchey

746—PHENIX measurement of J/ψ polarization via decay di-electron pairs produced in p+p collisions at $\sqrt{s} = 510$ GeV at mid-rapidity—Sookhyun Lee

796—PHENIX measurements of elliptic and triangular flow in d+Au collisions—Vicki Greene

853—PHENIX measurements of J/ψ and $\psi(2S)$ production at forward and backward rapidity in $p/d/^3$He+Au and p+Al collisions at 200 GeV—Matt Durham

Additional Material

Additional Material

Testing hydro by controlling system geometry

Hydrodynamics translates initial geometry into final state

Test hydro hypothesis by varying initial state

	ε_2	ε_3
p+Au	0.24	0.16
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$$\varepsilon_2^{\mathrm{p+Au}} < \varepsilon_2^{\mathrm{d+Au}} \approx \varepsilon_2^{\mathrm{3He+Au}}$$
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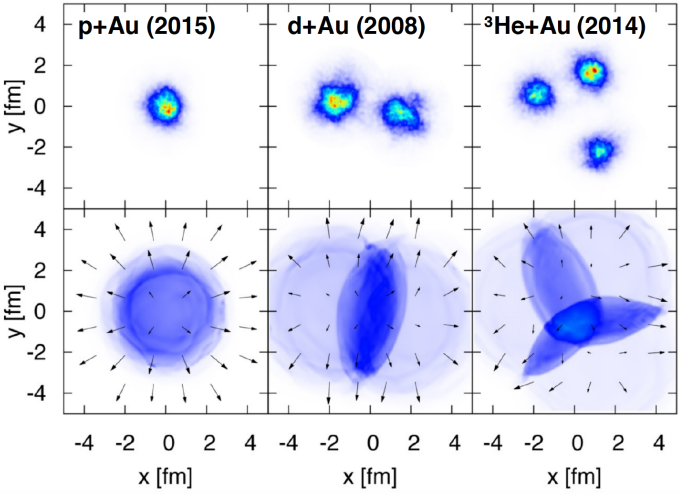
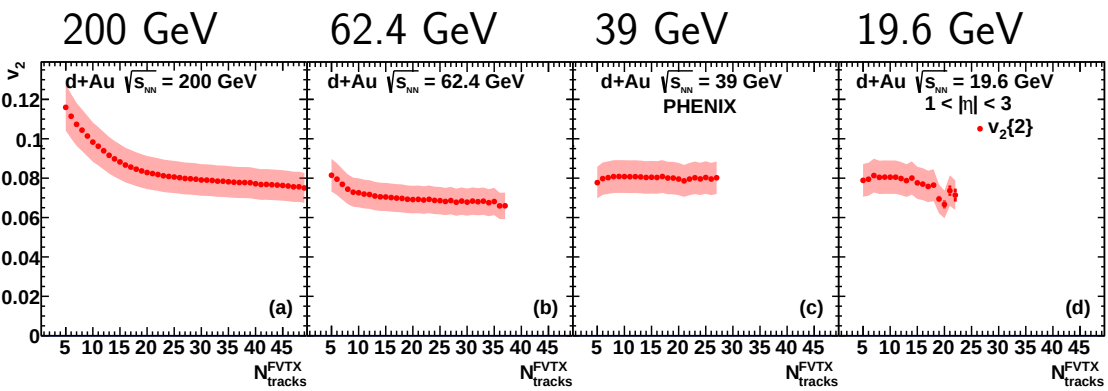


d+Au beam energy scan

Qiao Xu, Monday 14/05/2018, 17:10

Phys. Rev. Lett. 120, 062302 (2018)
and Phys. Rev. C 96, 064905 (2017)



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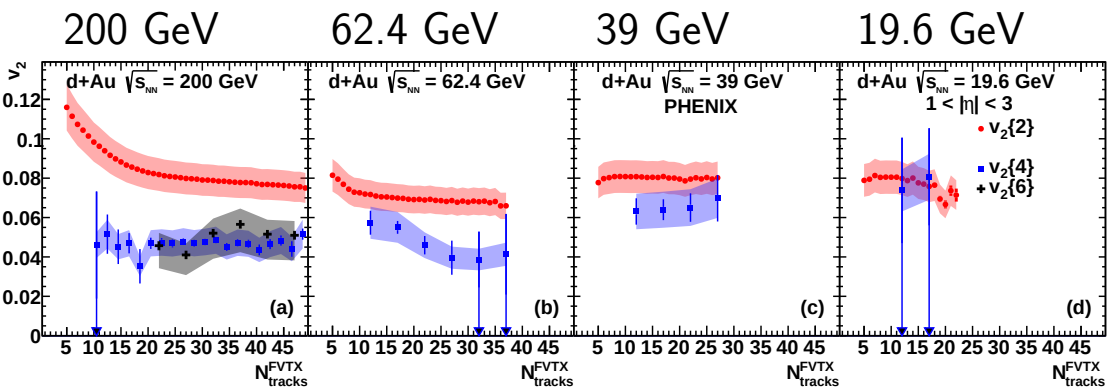
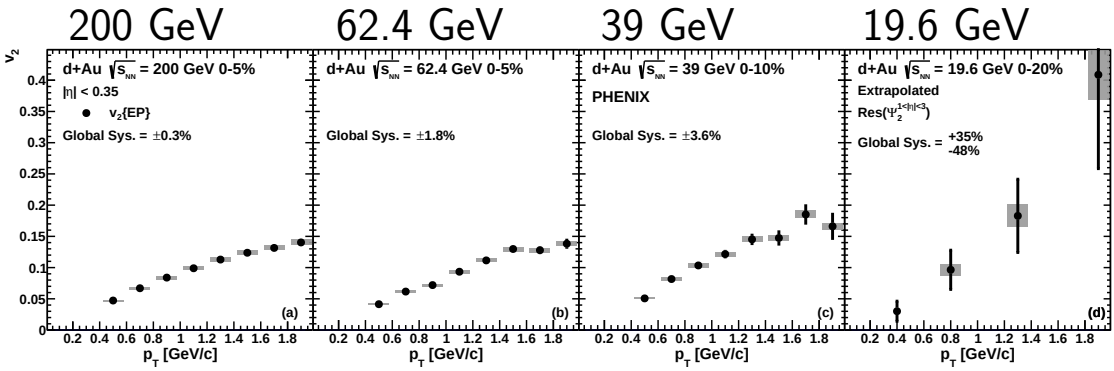


Measurement of $v_2\{6\}$ in d+Au at 200 GeV and $v_2\{4\}$ in d+Au at all energies

d+Au beam energy scan

Published since last QM

Phys. Rev. C 96, 064905 (2017)

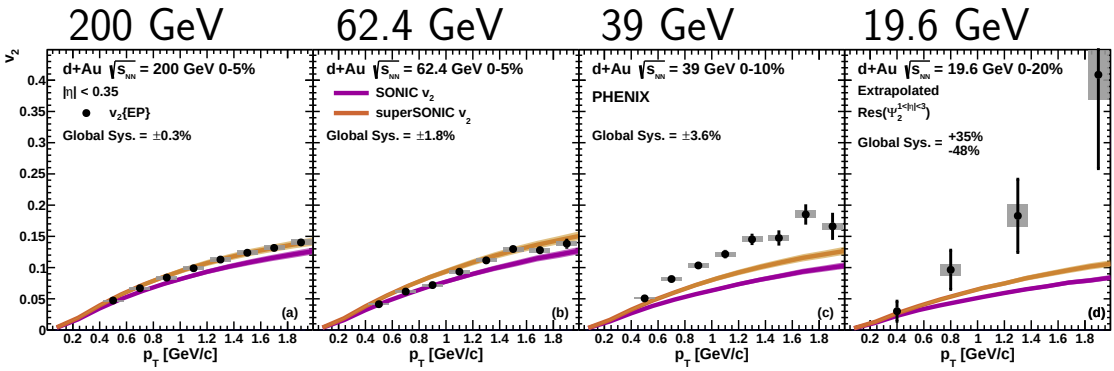


Event plane v_2 vs p_T measured for all energies

d+Au beam energy scan

Published since last QM

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

Published since last QM

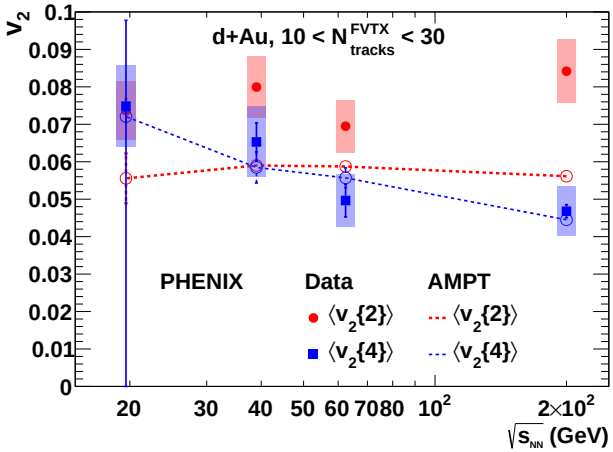
Phys. Rev. Lett. 120, 062302 (2018)

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

AMPT sees similar trend

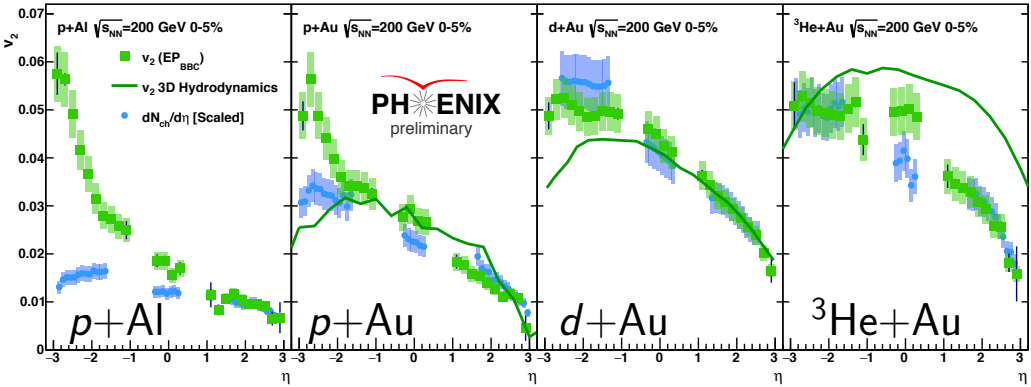
Fluctuations?

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



Longitudinal dynamics in small systems

Darren McGlinchey, Wednesday 16/05/2018, 10:20



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

Particle species dependence of "Cronin enhancement"

PHENIX, Phys. Rev. C 88, 024906 (2013)