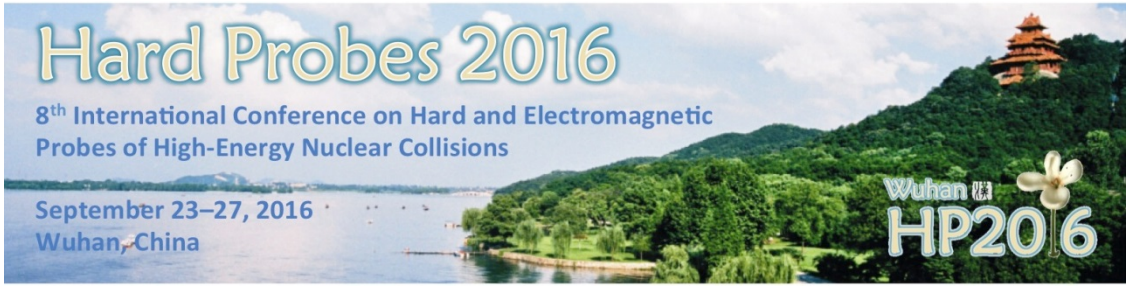
Jet and Leading Hadron Production in d+Au Collisions in the PHENIX Experiment

Takao Sakaguchi
Brookhaven National Laboratory
for the PHENIX collaboration



Leading Hadron Production in d+Au and ^{3}He+Au Collisions in the PHENIX Experiment

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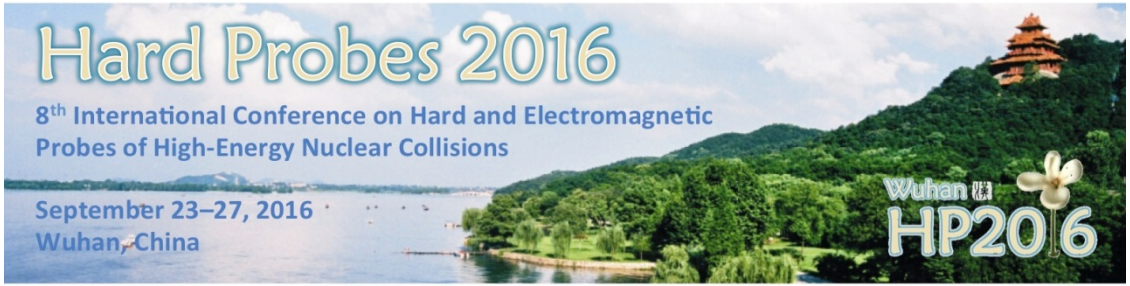
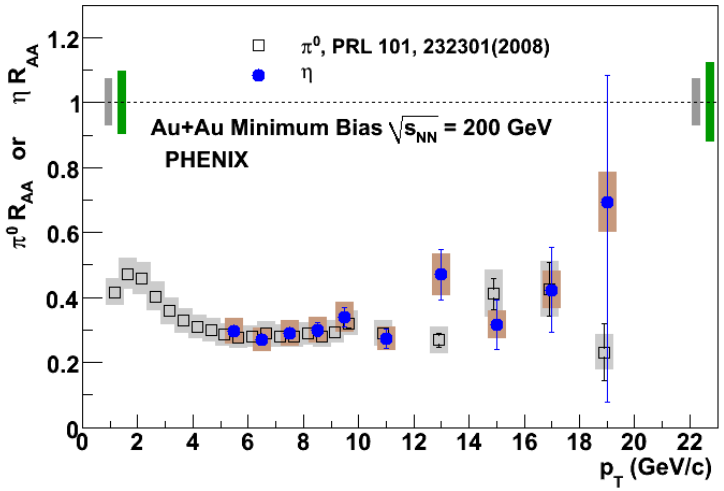
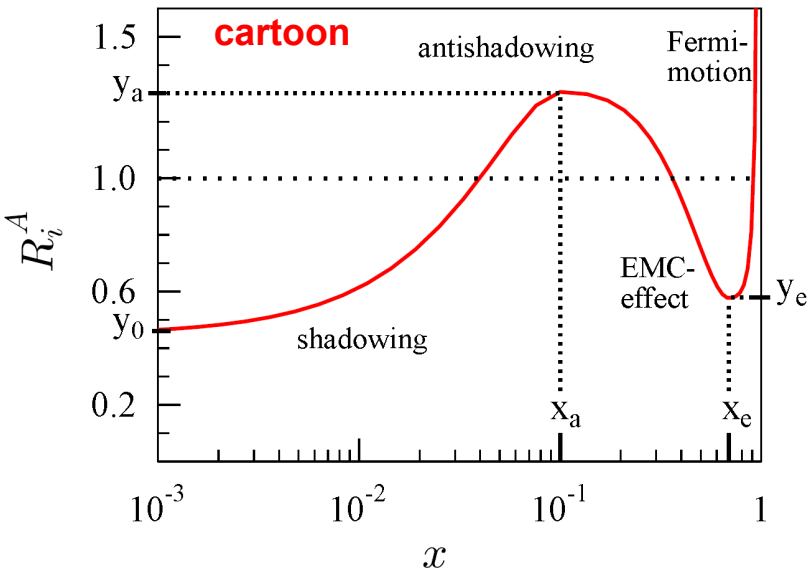


Why *were* we interested in *d*+Au collisions?

- To confirm the high p_T hadron suppression is due to final state effects, and not cold nuclear matter (CNM) effects
  - Needed system without additional effects from a hot medium.
- CNM effects include:
  - k_T-broadening
  - Shadowing of parton distributions
  - Cold nuclear matter energy loss
  - And possibly more…
- *d*+Au was more favorable for RHIC operation because of better rigidity match
  - *p*+Au became feasible later

PHENIX, PRC82, 011902(R) (2010)

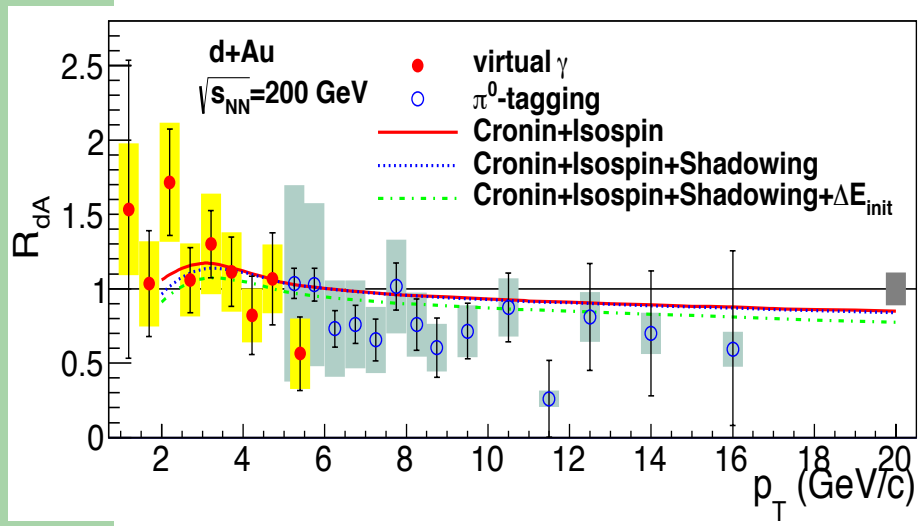




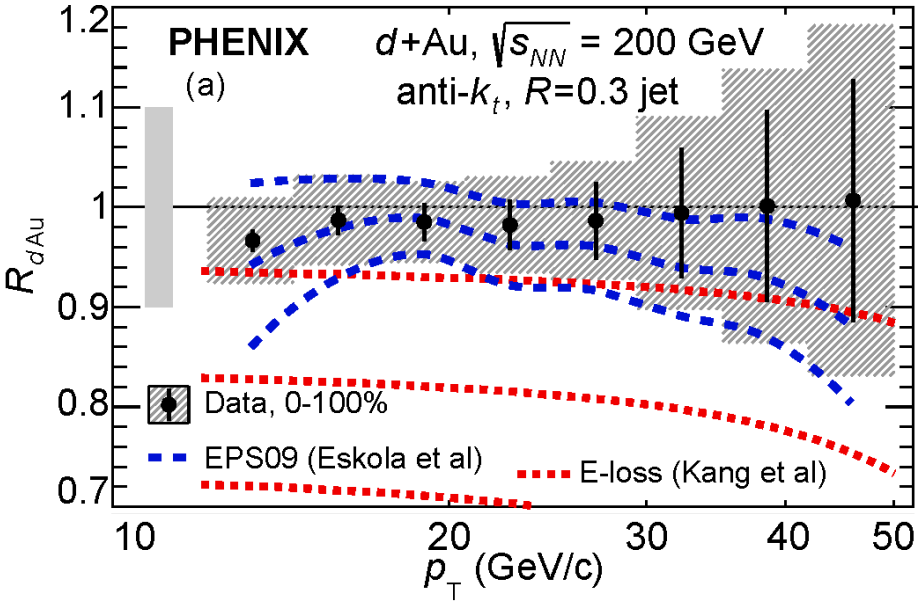
Direct photons / Jets in minbias *d*+Au

- Direct photon R_{dA} is consistent with unity up to 16GeV/c
  - No modification in initial hard scattering
- Jets R_{dA} is consistent with unity up to 50 GeV/c
  - As expected from PDF (EPS09), no final state effect.
- Both are as expected.

PRC87, 054907 (2013)



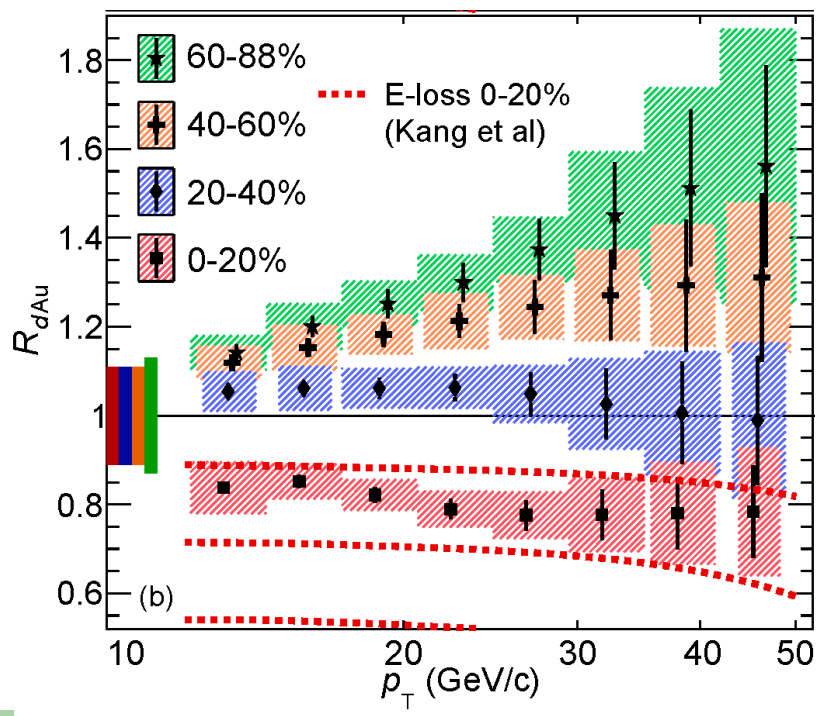
PRL 116, 1223011 (2016)



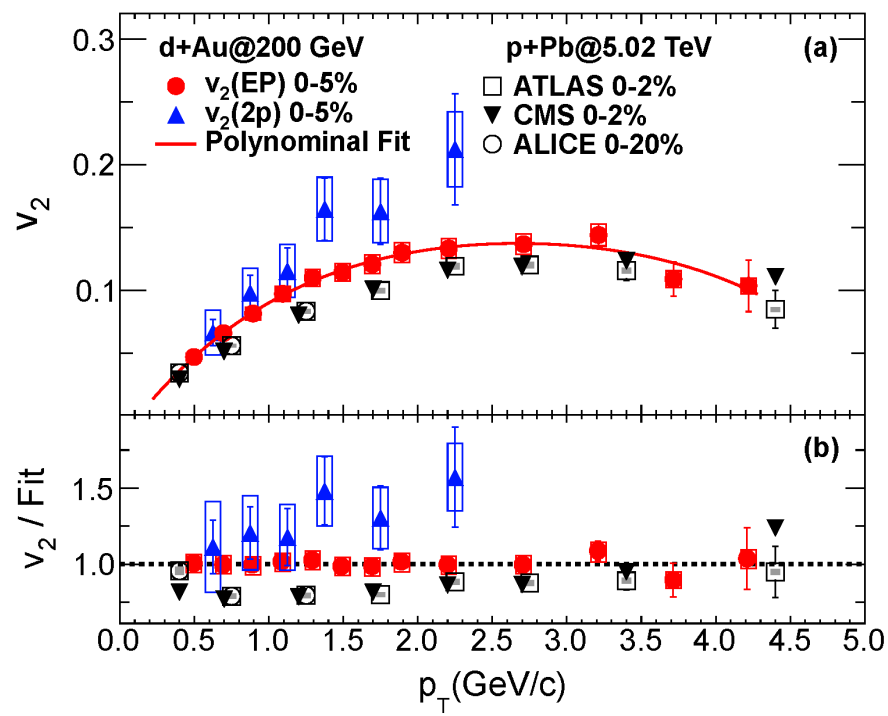
Centrality dependence is unexpected

- Jets R_{dA} shows a sizable centrality dependence
  - Suppression in most central, enhancement in most peripheral
- Strong flow like A+A is seen in most central *d*+Au collisions
  - Similar observation by the LHC experiments
  - We didn't anticipate "flow" in a small system like *p*/*d*+A

PRL 116, 1223011 (2016)

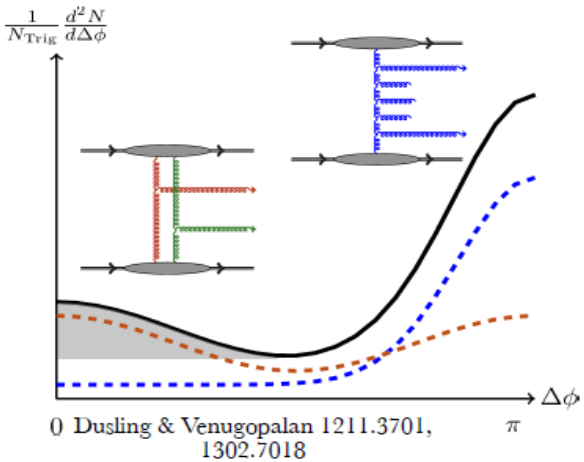


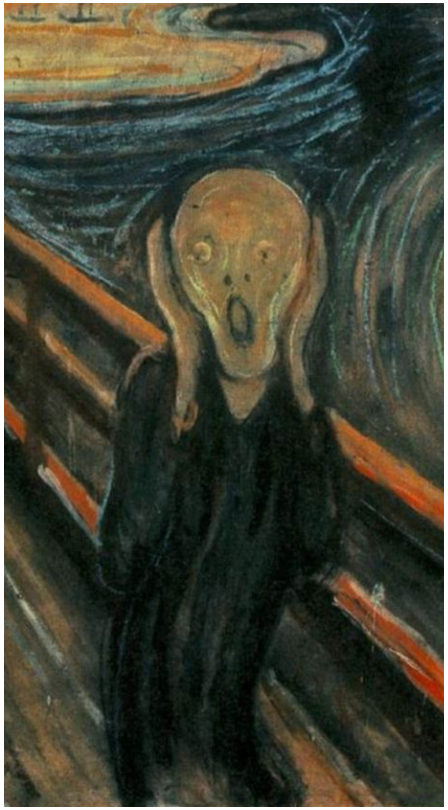
PRL114, 192301 (2015)



p/*d*+Au is no longer a baseline or a simple system…

- Mini-QGP production?
  - Initial state effects, e.g. CGC, will affect to production cross-section of particles
  - Final state effects, e.g. hydrodynamics will produce flow-like structure





p/*d*+Au is no longer a baseline or a simple system…

- Mini-QGP production?
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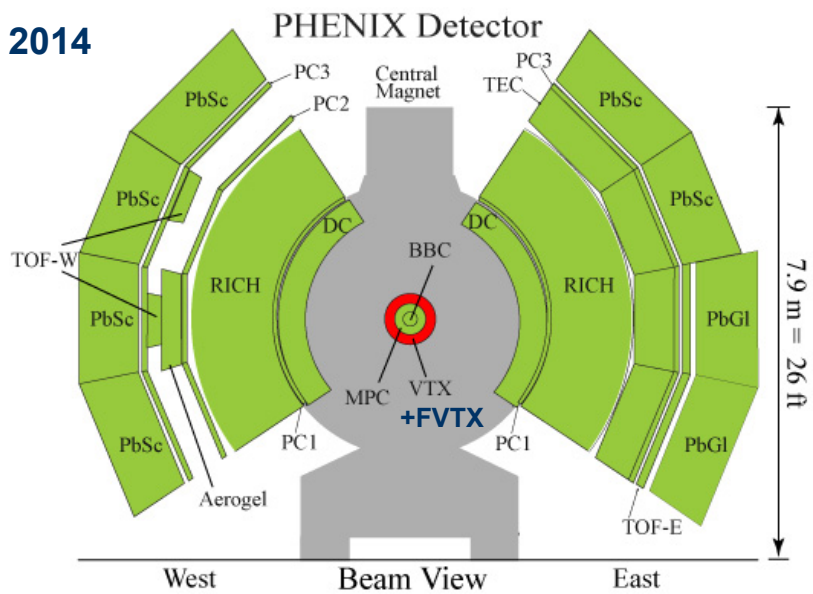
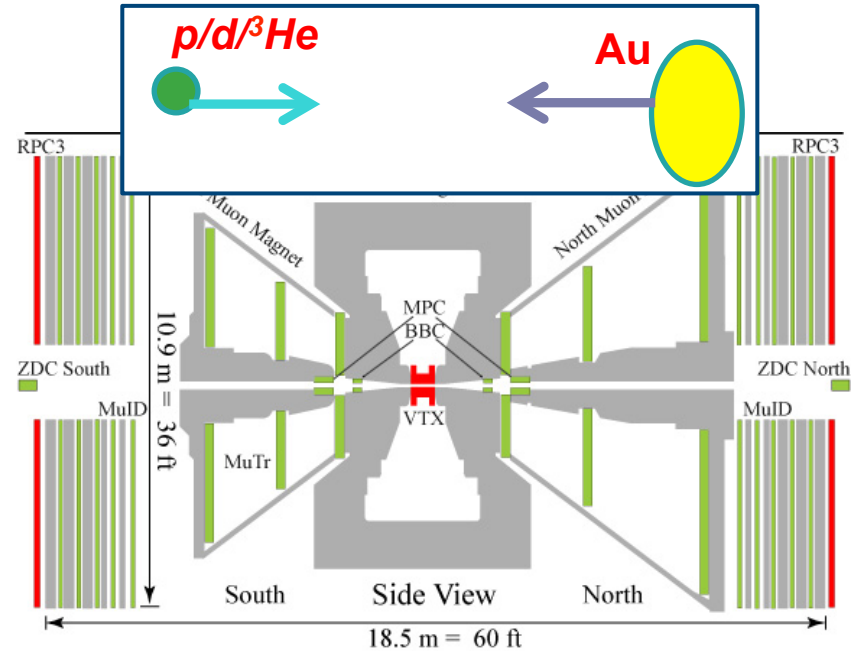
- If there is QGP, detail investigation of the interaction of partons with the medium will give insight on its characteristics

- Systematic study of the leading hadron spectra in p/d/^{3}He+A will help

PHENIX Detector and analysis

- We analyzed ^{3}He+Au events recorded in RHIC Year-14 run.
- π^0 are reconstructed via $\pi^0 \rightarrow 2\gamma$ channel
  - Use of EM Calorimeter (EMCal, PbSc) for photon ID and energy measurement
- Events used this analysis are triggered by:
  - Beam-beam counter (BBC) as minimum bias events: **2.0×10^9 evts**
  - EMCal and BBC coincidence trigger (ERT): **4.5×10^{10} MinBias-equiv. evts**
  - **Total analyzed luminosity: 22 nb^{-1}**



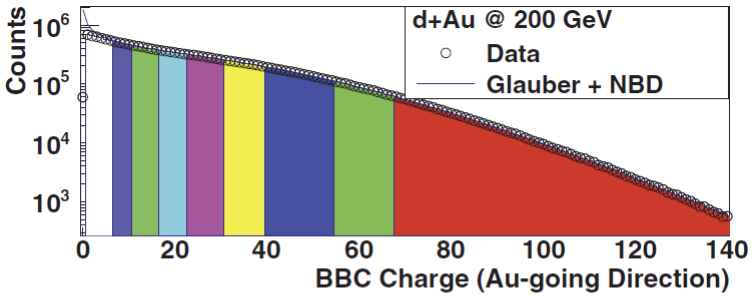


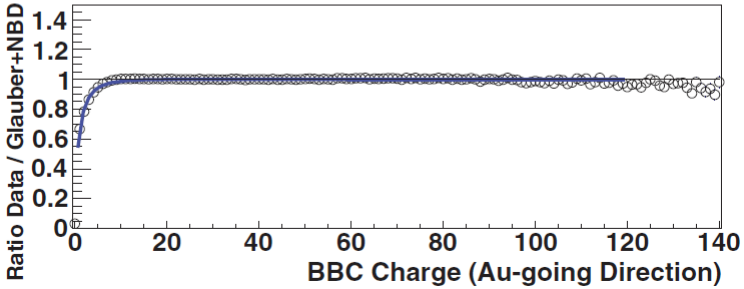
Event trigger and bias

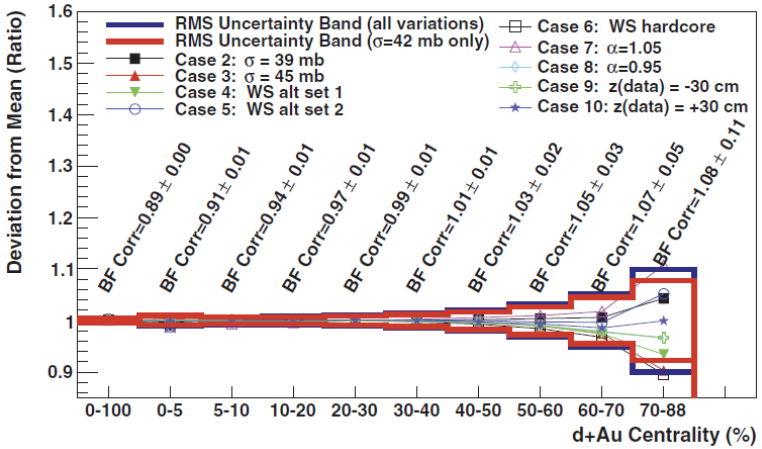
- Min. Bias trigger has inefficiency
  - Inefficiency is already studied in *d*+Au collisions in detail.
  - BBC charge distribution was compared with a Glauber Monte Carlo simulation folded with a negative binomial distribution (NBD)
- Efficiencies for d+Au and ^{3}He+Au are both determined as **88%**.
- Bias factors (BF) for centrality selection are calculated
  - Bias is from auto-correlation between particles in mid- and backward rapidity
  - Same method as *d*+Au case is applied and calculated as in the following table

Cent (%)	0-20	20-40	40-60	60-88	0-100
d+Au BF	0.94	1.00	1.03	1.03	0.89
^{3}He+Au BF	0.95	1.02	1.02	1.03	0.89

PRC 90, 034902 (2014)

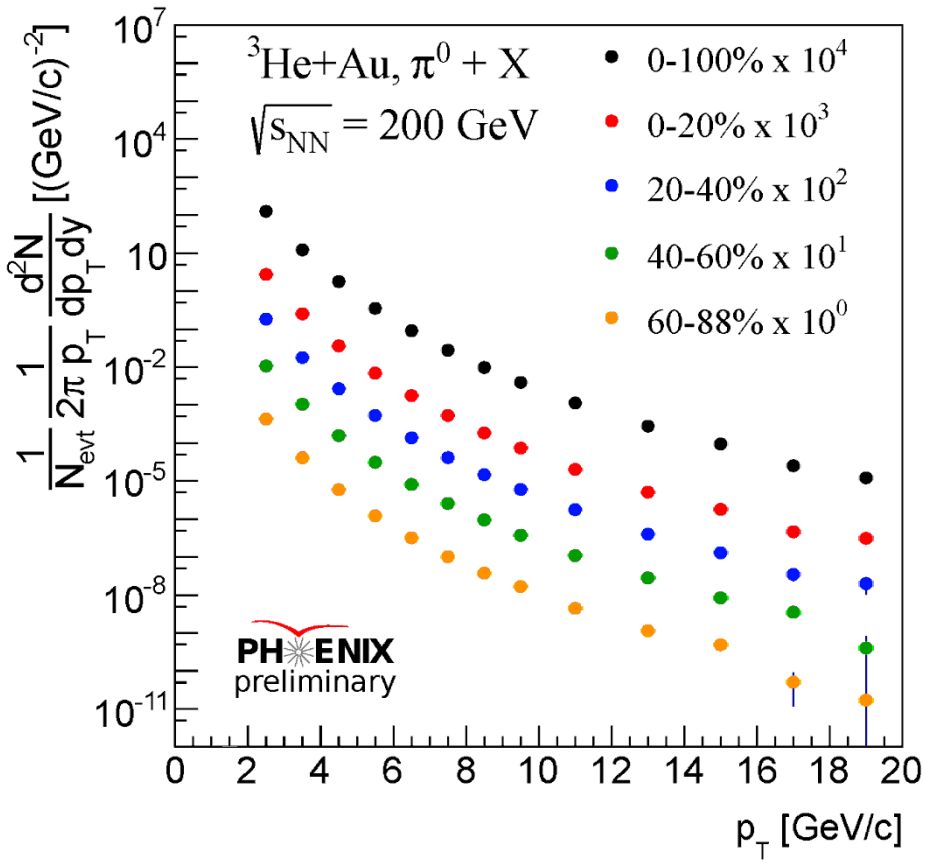






π^0 p_T spectra in ^{3}He+Au collisions

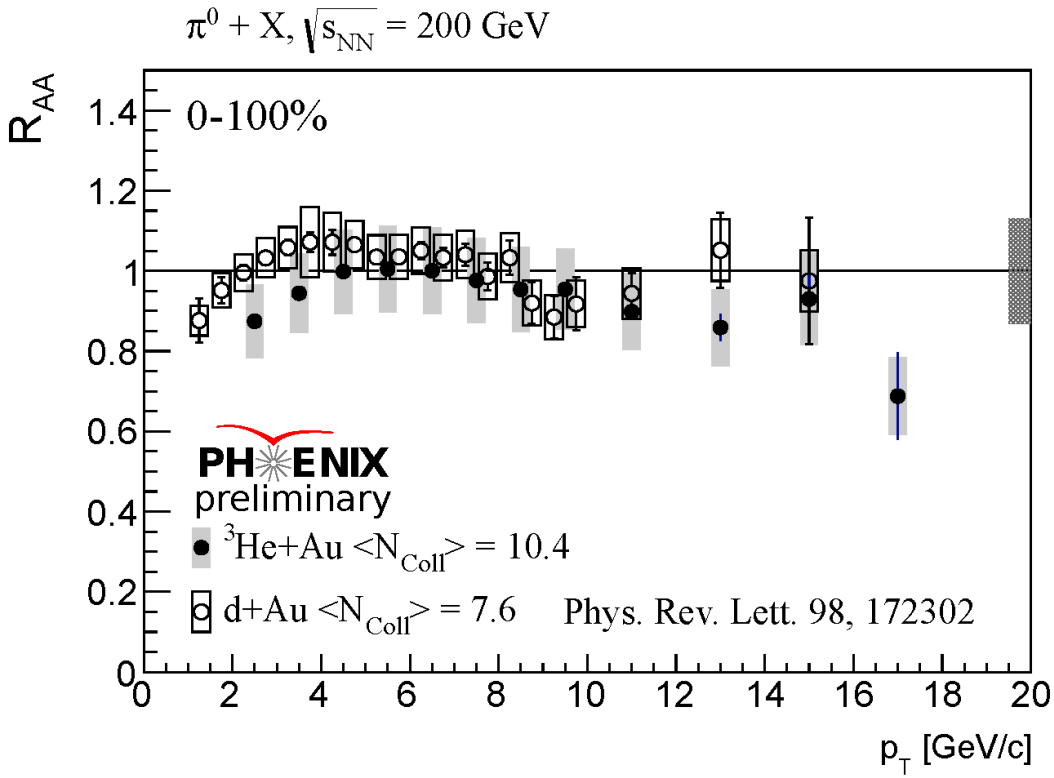
- p_T spectra have been measured up to p_T=20GeV for minimum bias events as well as for four centrality classes



Produced by N. Apadula

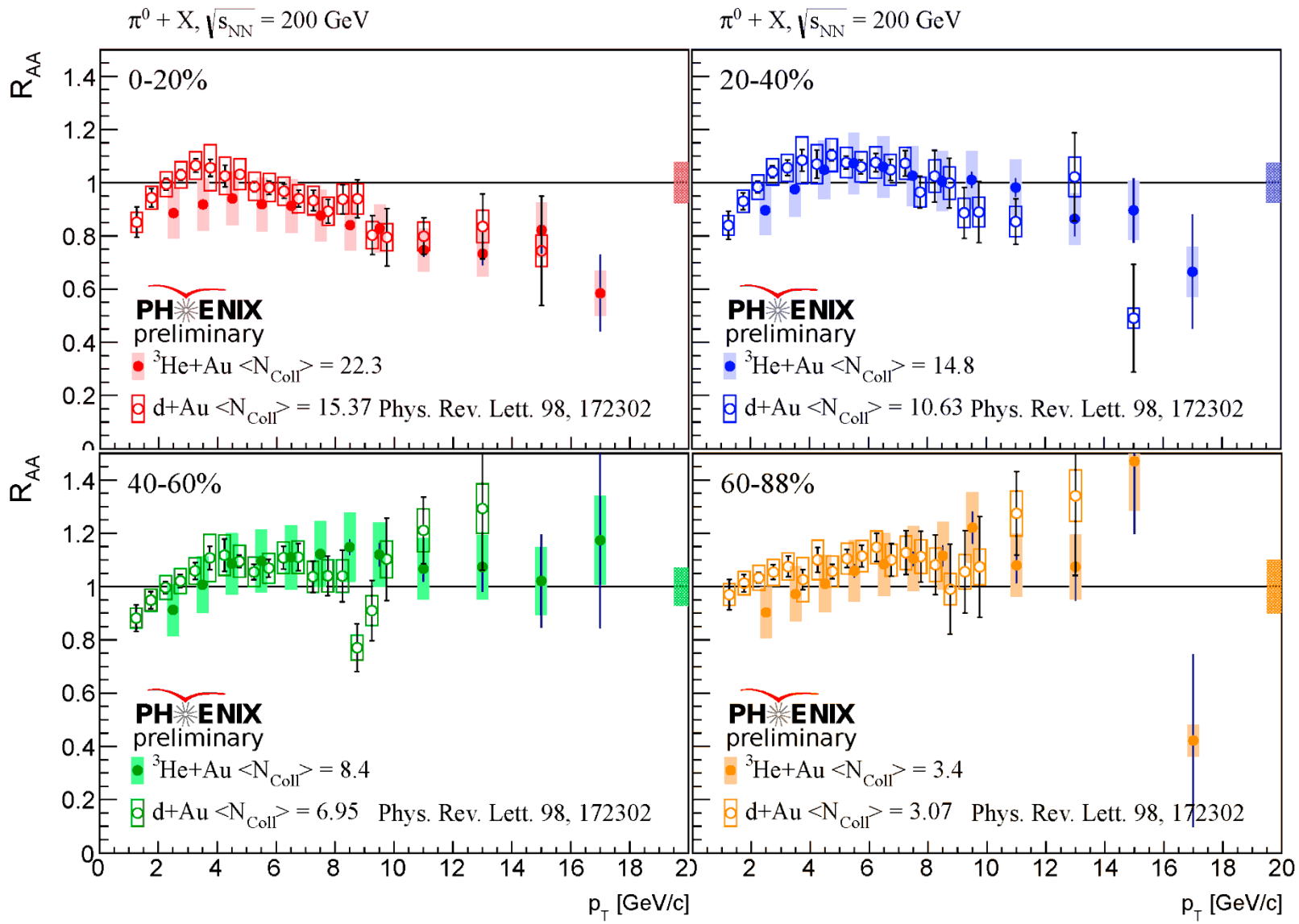
π^0 R_{AA} in ^{3}He+Au collisions

- R_{AA} has been measured and compared with d+Au collision data
- Both absolute magnitudes and p_T dependence are consistent within quoted uncertainties



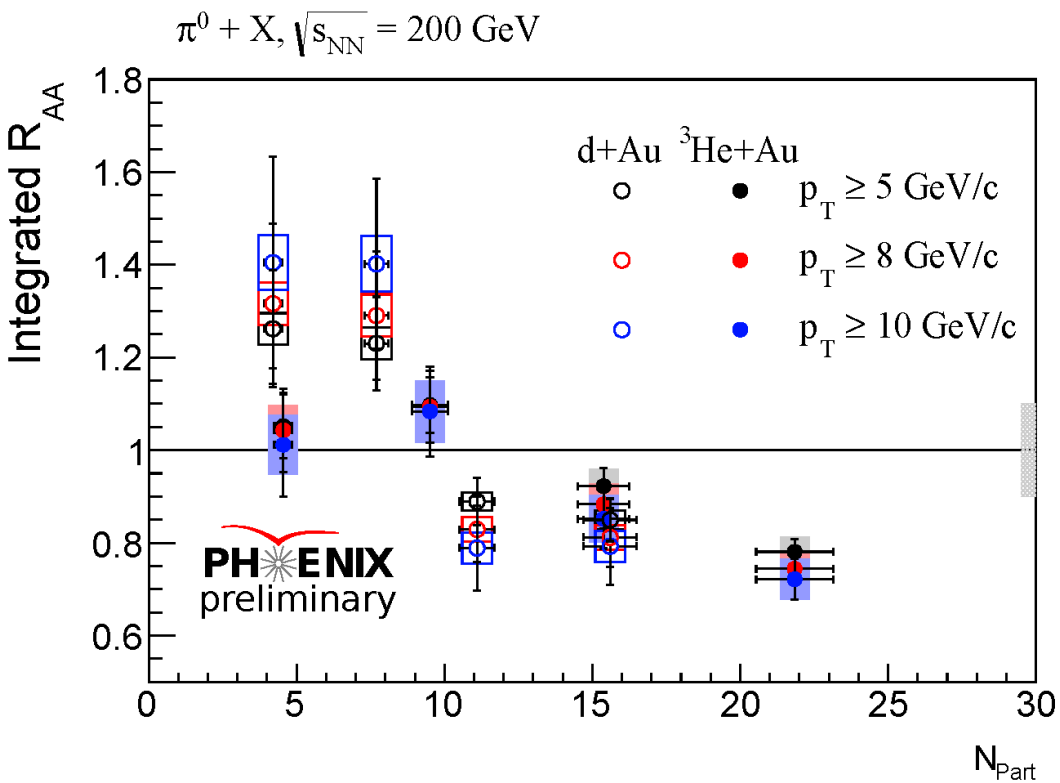
Produced by N. Apadula

π^0 R_{AA} for various centralities



π^0 integrated R_{AA} in ^{3}He+Au collisions

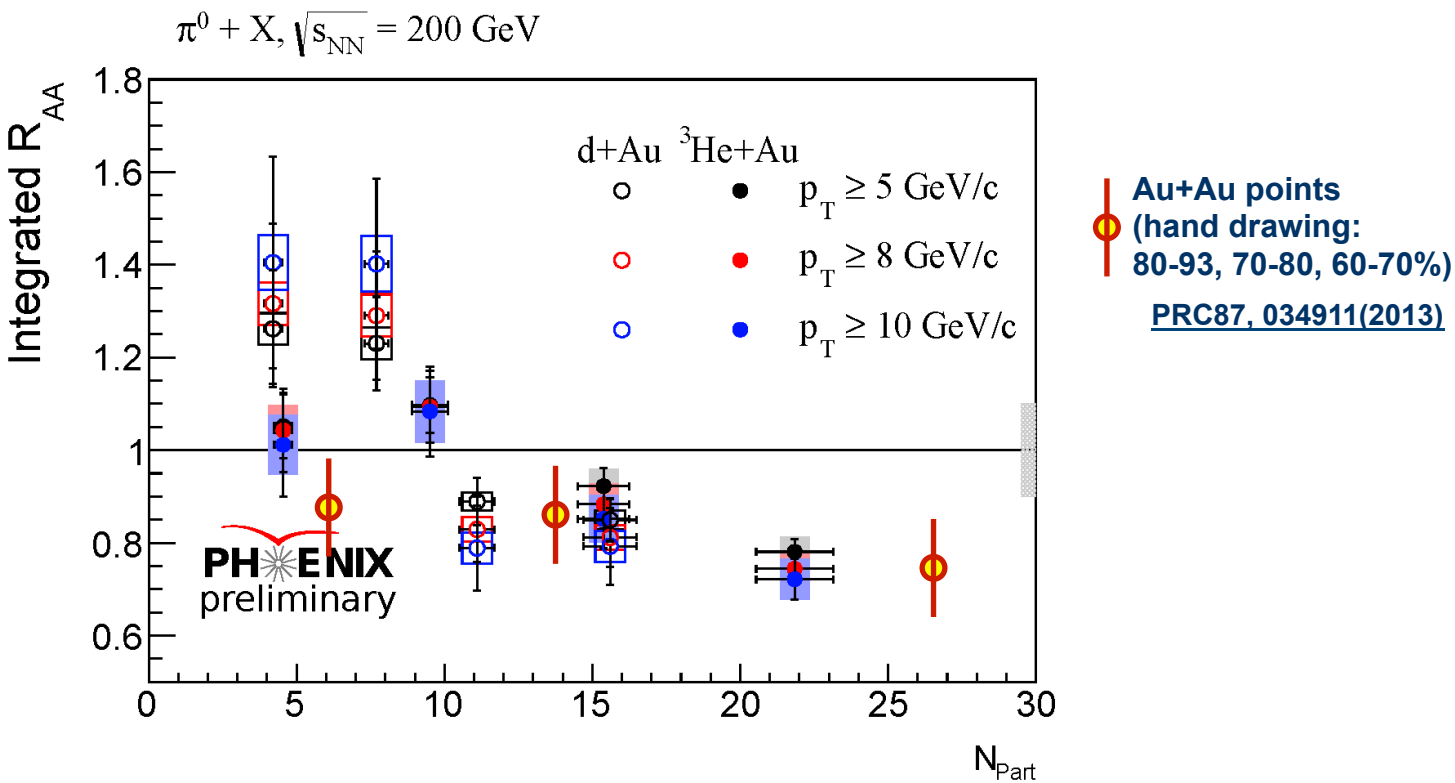
- Integrated R_{AA} has been plotted with ones in *d*+Au
- At higher N_{part}, *d*+Au and ^{3}He+Au show very similar N_{part} dependence
- At lower N_{part}, *d*+Au collisions show more enhancement
  - More Cronin effect, or less suppression (energy loss)



Produced by Nicole Apadula

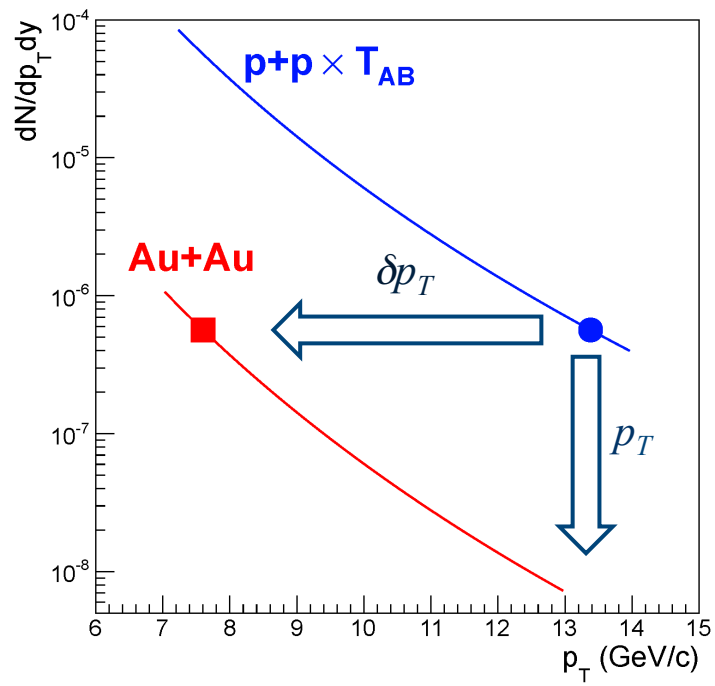
π^0 integrated R_{AA} in ^{3}He+Au collisions

- Integrated R_{AA} has been plotted with ones in *d*+Au and ***Au+Au***
- R_{AA} from all three systems converge for N_{part}>~12
  - Similar degree of suppression suggesting similar **hot** matter is produced?
- System ordering of R_{AA} is seen for N_{part}<12
  - $R_{dAu}>R_{HeAu}>R_{AuAu}$. Of course, better precision is desired



Fractional momentum loss in ^{3}He+Au

- Let's convert R_{AA} to fractional momentum loss ($\delta p_T/p_T$).
  - One can directly measure the spectra shift (δp_T)
- 0-20% ^{3}He+Au collisions shows similar R_{AA} as 60-70% Au+Au
  - At the same cms energy, the same R_{AA} implies the same $\delta p_T/p_T$
- $\delta p_T/p_T$ **= ~0.03** in most central ^{3}He+Au collisions



$$p_T : p_T(p+p) \qquad \delta p_T = p_T(p+p) - p_T(A+A)$$

PHENIX, PRC93, 024911 (2016)

TABLE IV. Centrality dependence of $\delta p_T / p_T^{pp}$ in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV from 2007 data from the PHENIX experiment at RHIC.

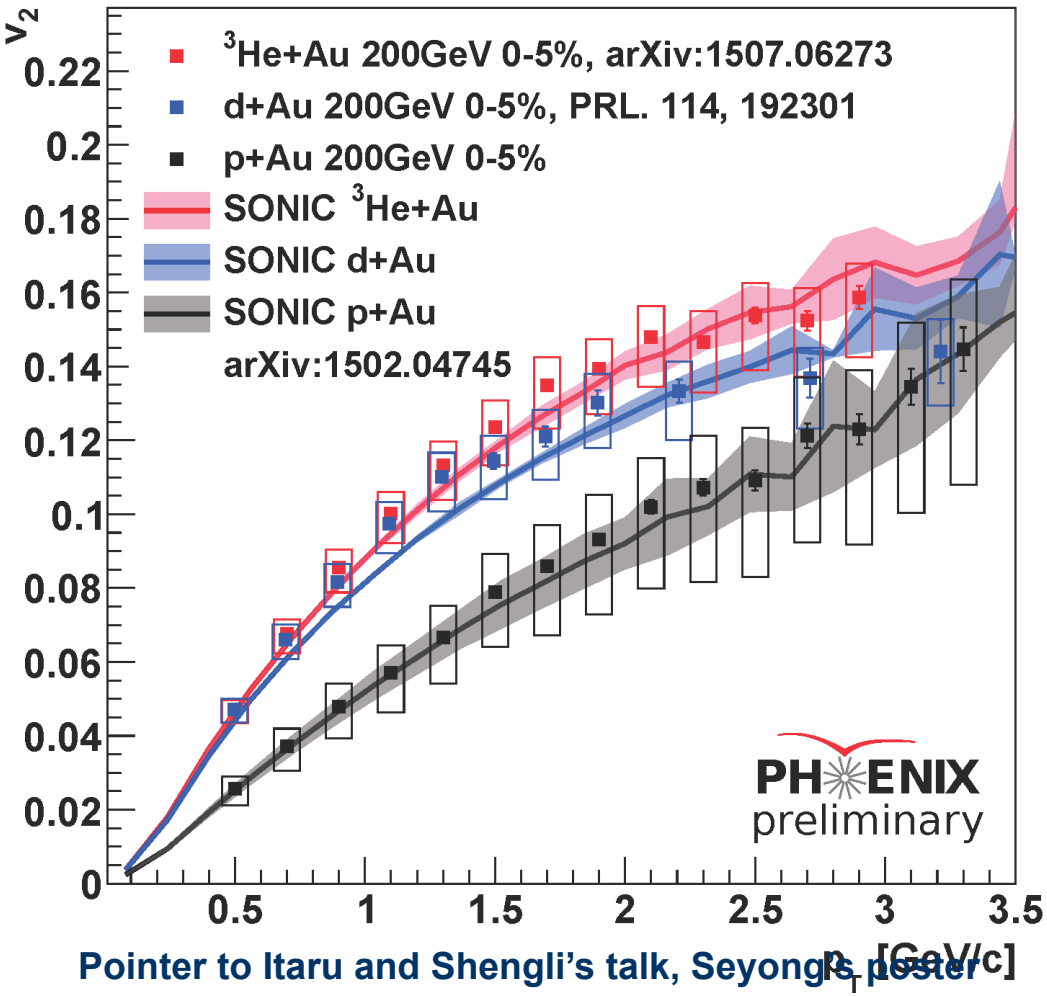
	2007 data			
Centrality	p_T^{pp} [GeV/c]	$\delta p_T / p_T^{pp}$	Stat error	Syst error
60–70%	7.0	0.028	$^{+0.004}_{-0.004}$	$^{+0.019}_{-0.017}$
	10.0	0.011	$^{+0.021}_{-0.019}$	$^{+0.028}_{-0.024}$
	12.0	0.037	$^{+0.025}_{-0.022}$	$^{+0.046}_{-0.037}$

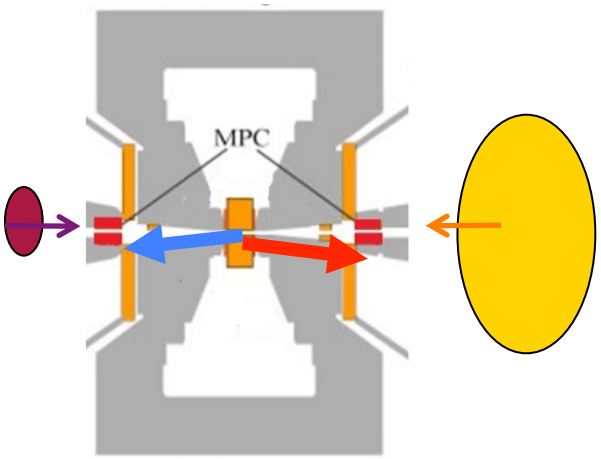
Summary

- *p*/*d*+Au system is no longer a baseline or a simple system.
  - Sizable particle flow (v_2) has been seen in the most central *d*+Au collisions
  - Jet R_{AA} shows anomalous centrality dependence (suppression/enhancement)
- It is important to measure the spectra/R_{AA} systematically in small systems, i.e., *p*+A, *d*+A and ^{3}He+A
- π^0 have been measured in 200GeV ^{3}He+Au collisions for the first time.
  - R_{AA} looks very similar to the ones in *d*+Au.
- Integrated R_{AA} from *d*+Au, ^{3}He+Au and Au+Au merge at N_{part}>~12.
  - Similar degree of suppression suggesting similar **hot** matter is produced?
  - System ordering of R_{AA} is seen for N_{part}<12, i.e., $R_{dAu}>R_{HeAu}>R_{AuAu}$.
- Fractional momentum loss ($\delta p_T/p_T$) is ~0.03 for 0-20% ^{3}He+Au collisions
  - From the $\delta p_T/p_T$ in 60-70% Au+Au collisions at the same cms energy

Backup

Comparing with new collision systems



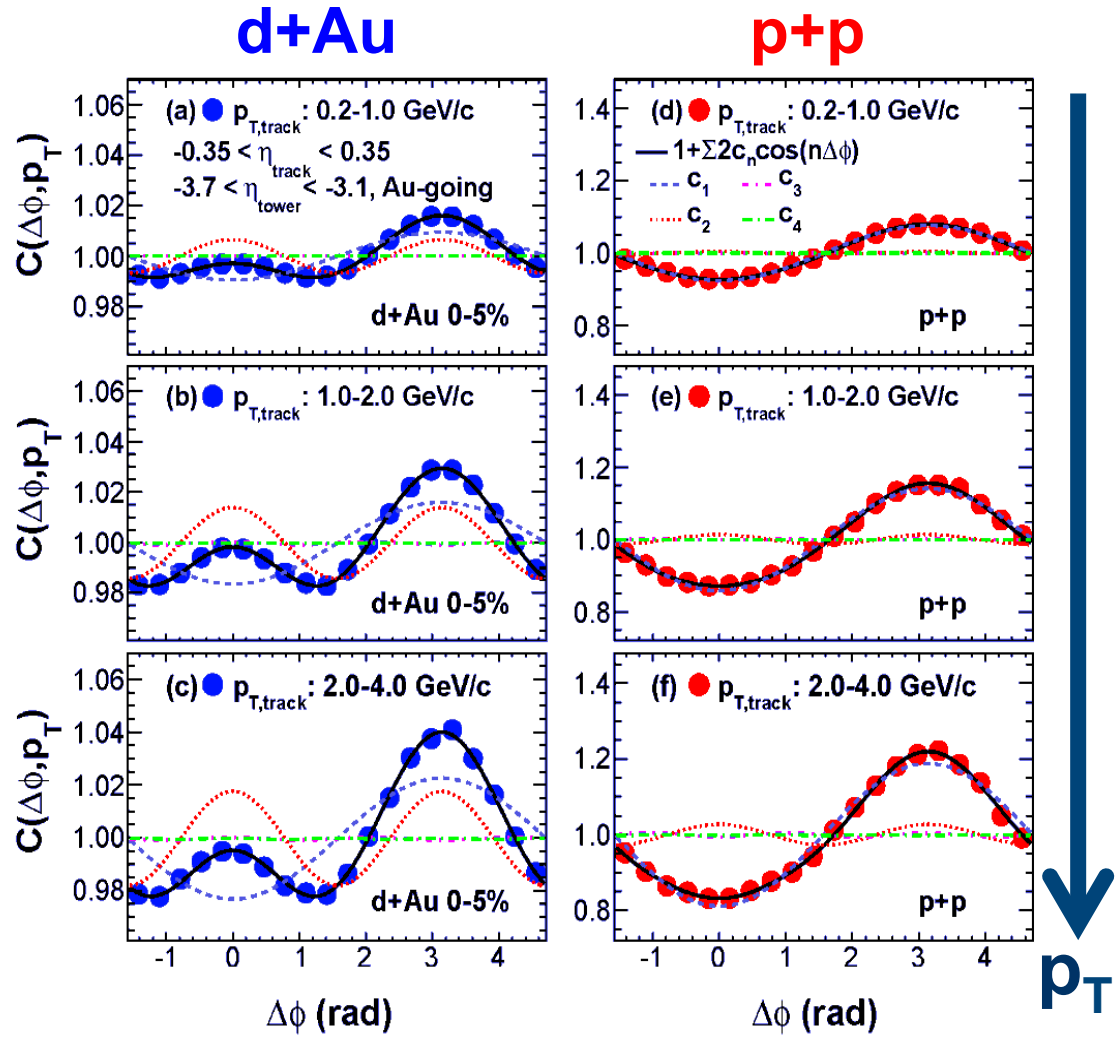


Pointer to Itaru and Shengli's talk, Seyongs poster

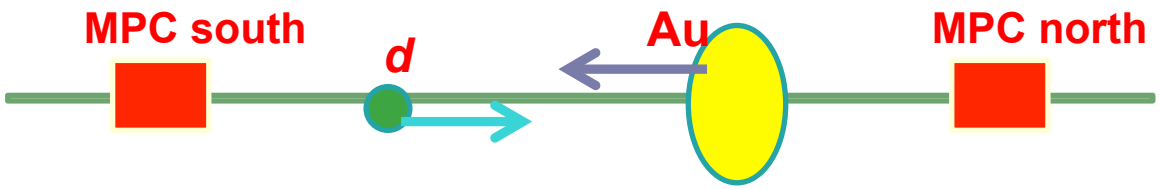
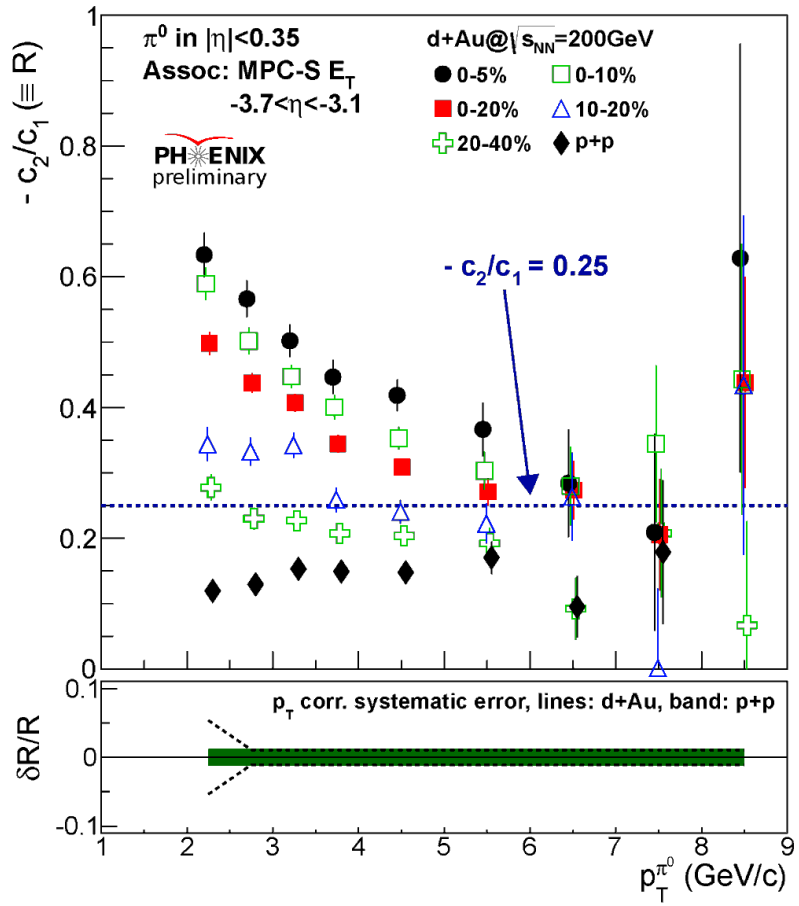
Ridge-like structure is observed in d+Au

PHENIX, PRL114, 192301 (2015)

- $h^{+/-}$ - MPC south correlation functions in central d+Au and minbias p+p collisions
  - Au-going direction
- Near-side peak clearly seen in d+Au but not in p+p
- Analyze correlation functions with Fourier fits
- 2nd order component (c_2) increases as p_T becomes larger
- Similar correlation but the smaller strength is seen in $h^{+/-}$ - MPC north correlation



Ridge evolution in π^0-MPC south / Au-going…



- $-c_2/c_1$ from π^0 - MPC south correlations
  - Au-going direction
  - Assuming c_1 is a proxy of jets or global momentum conservation
- Measure shape evolution by relative magnitude of 2nd order component
- $-c_2/c_1 > 0.25$ corresponds to near-side local maximum (if $c_3 = c_4 = 0$)