Measurement of light vector mesons and π^0 meson from the PHENIX Experiment at RHIC.

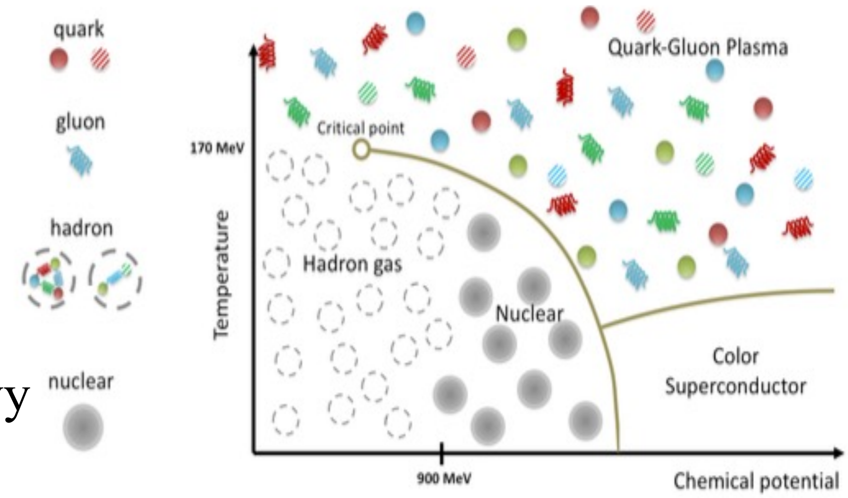
Uttam Acharya

On behalf of PHENIX Collaboration

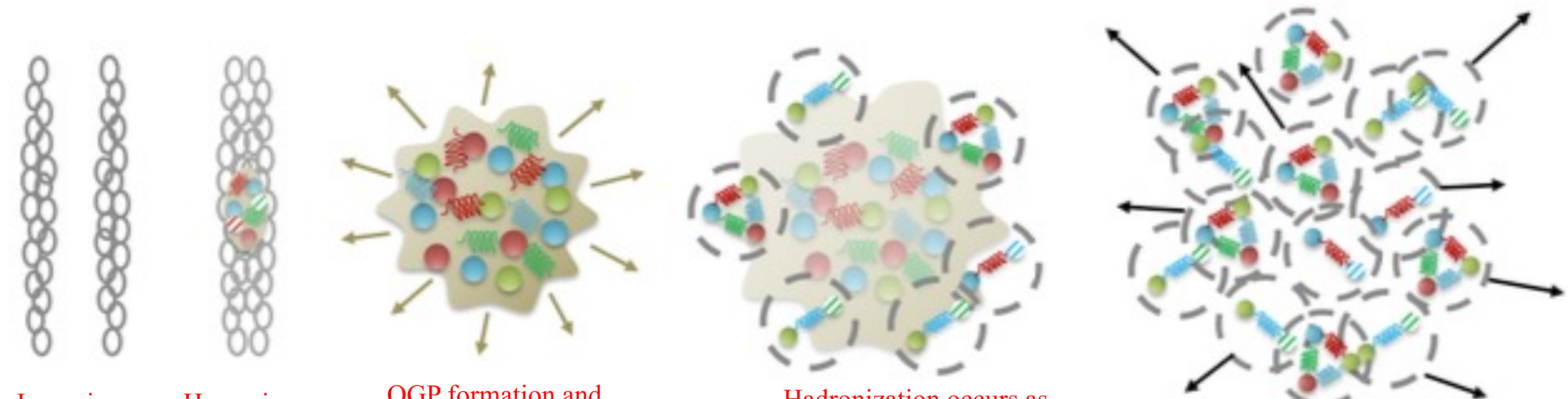
42nd International Symposium in Physics in Collision
Oct 10 – Oct 13
Universidad de Tarapacá, Arica, Chile

Motivation: Quark Gluon Plasma

- At sufficiently high temperature, the bonding between partons weaken → hadrons deconfined and moves freely "Asymptotic freedom".
- Existed few microseconds after Big Bang:- Produced in laboratory from collision of heavy ions at sufficiently high temperature.
- In p + p collision, no QGP formation ⇒ taken as baseline for studying QGP.



QCD Phase Diagram



Incoming nuclei

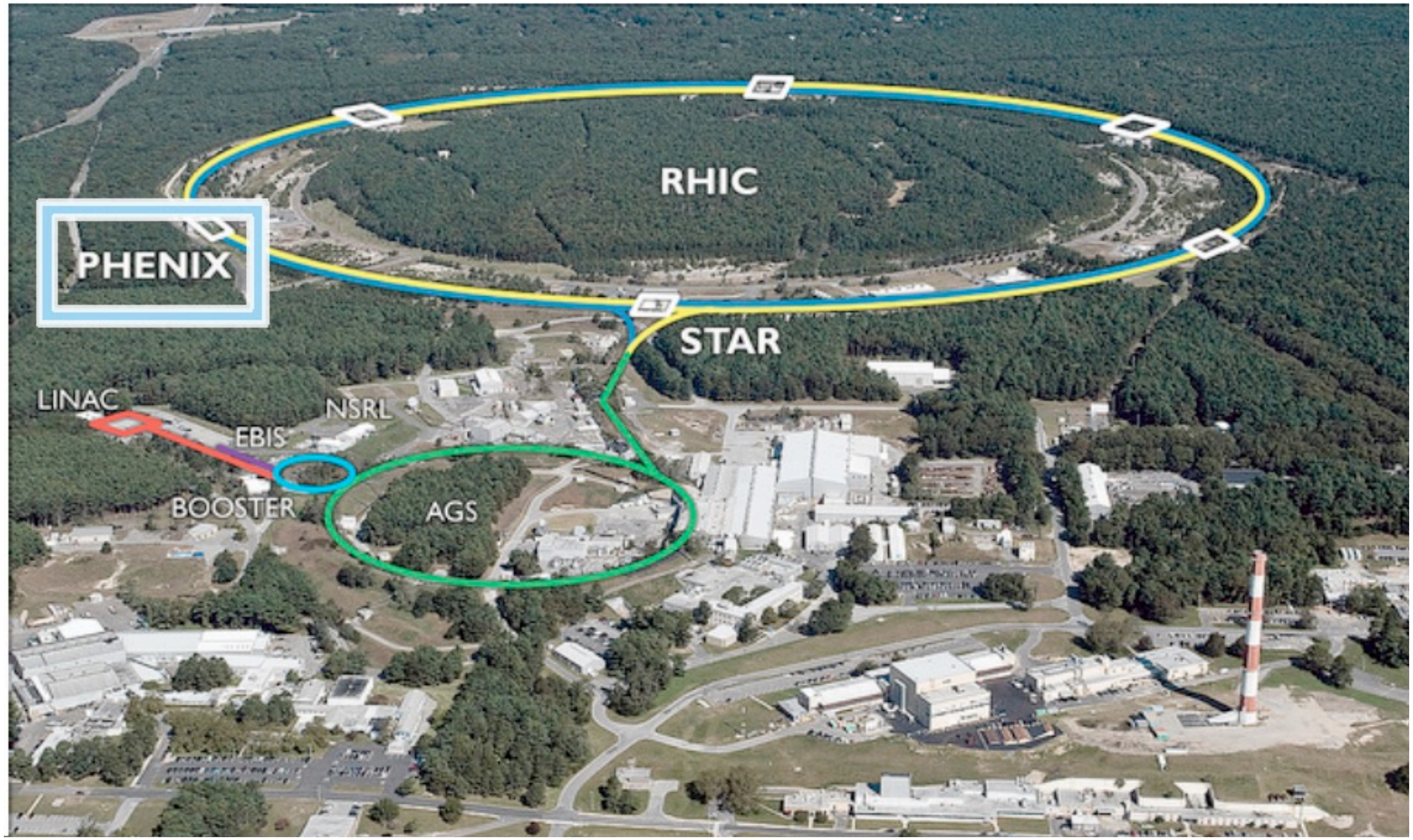
Heavy ions collide

QGP formation and Thermal expansion

Hadronization occurs as temperature decreases.

Hadronic freeze out

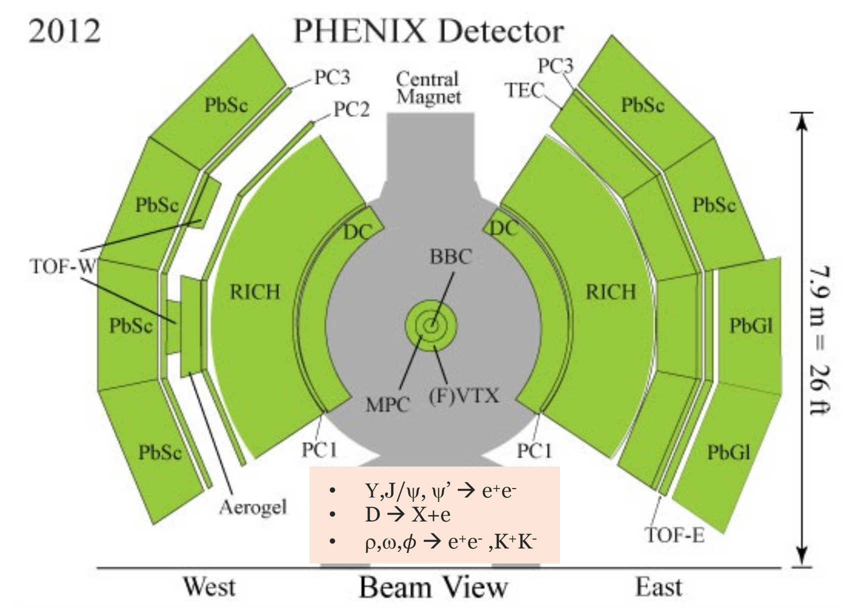
The Relativistic Heavy Ion Collider(RHIC)

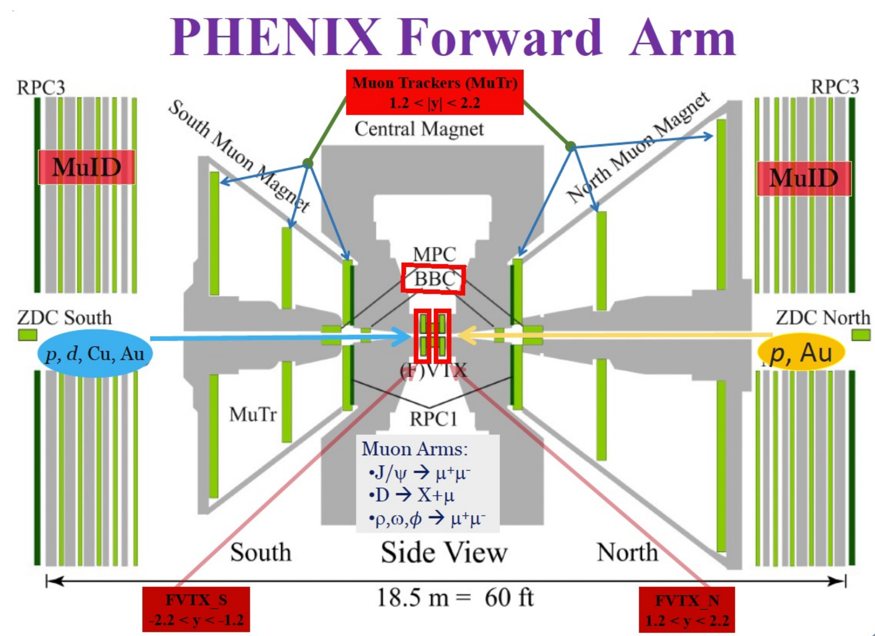


- RHIC is an extremely versatile machine, located at Brookhaven National Lab (BNL), that collides a variety of collision species at various energies.
    - Collision species:- p + p, d + Au, p + Al, p + Au, Cu + Cu, Cu + Au, U + U, Au + Au.
- First machine capable of colliding polarized protons up to 510 GeV.

PHENIX DETECTOR

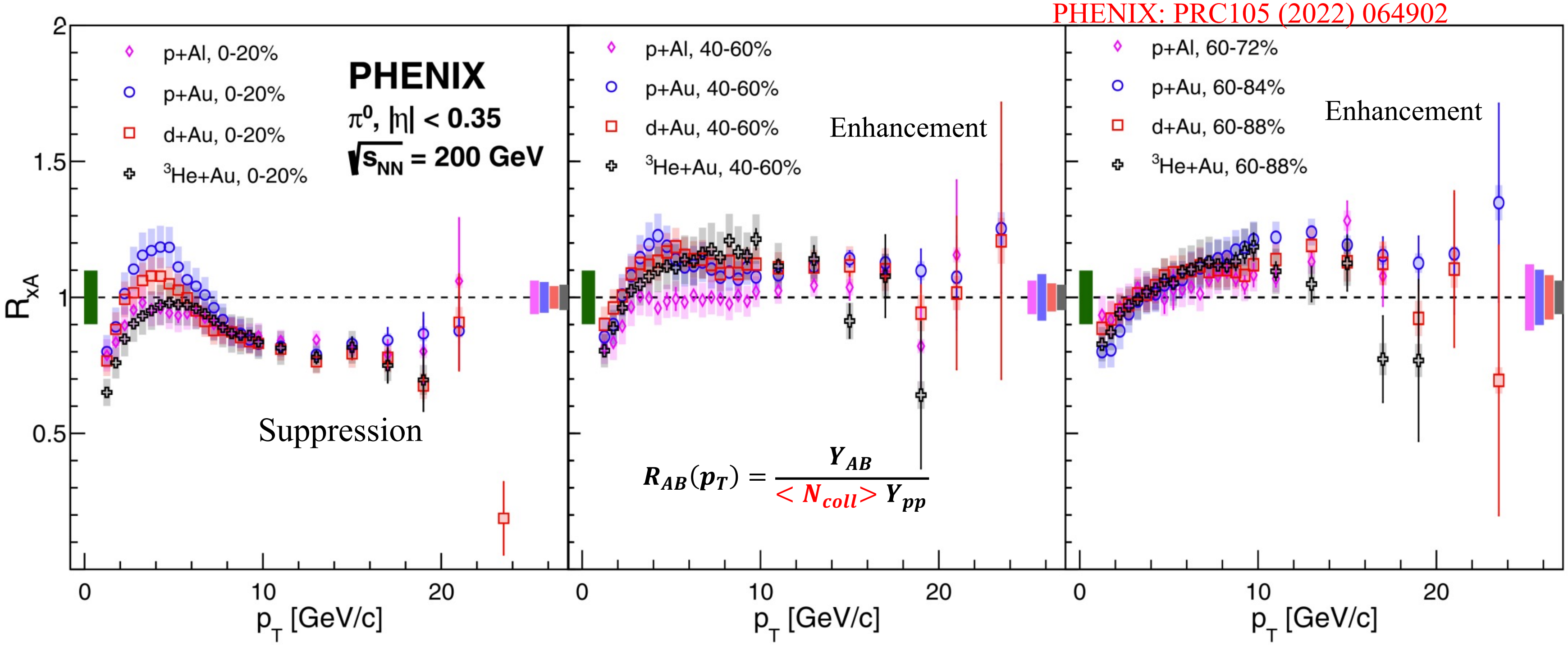
- Comprises of four spectrometers.
- Central Spectrometer:
  - o Rapidity |y|<0.35.
  - o Electromagnetic calorimetry (EMCal), Pad Chamber (PC) Drift Chamber (DC).
- Muon Spectrometers.
  - o Rapidity 1.2<|y|<2.2
  - o FVTX
  - o Muon Trackers (MuTr):
    - o three stations of cathode strip chambers in radial magnetic field.
  - o Muon Identifiers (MuID):
    - o Five alternating steel absorbers and Iarocci tubes.





High p_T π^0 measurement in small system using PHENIX Central Arm

PHENIX: PRC105 (2022) 064902



Central — Peripheral

- Centrality dependence of nuclear modification factor in small system.
- At high p_T, suppression in most central event while enhancement in peripheral collision.
- Suppression at high p_T for most central event can be interpreted through the QGP formation.
- Enhancement at peripheral collision cannot be explained from existing physics.

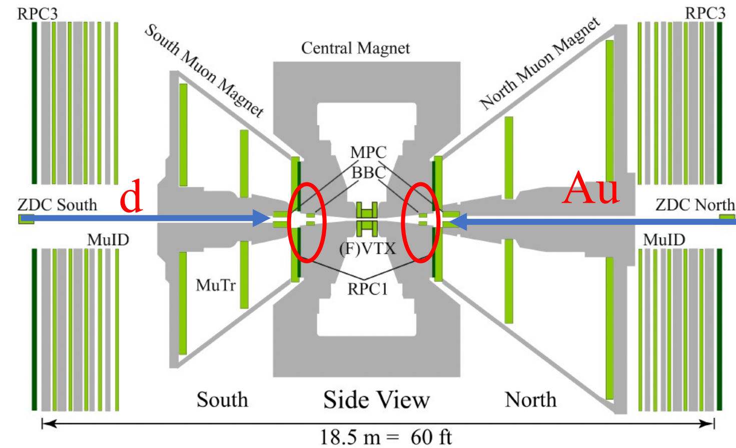
Is this linked to mismatch of centrality selection of events!!!!

Centralization Categorization in PHENIX

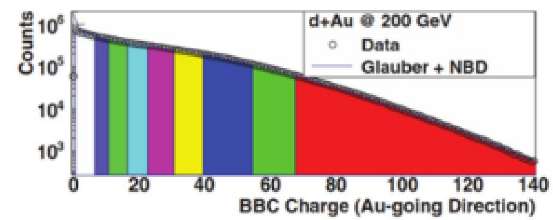
- Centrality is determined by event activity in the BBC, on Au going direction.

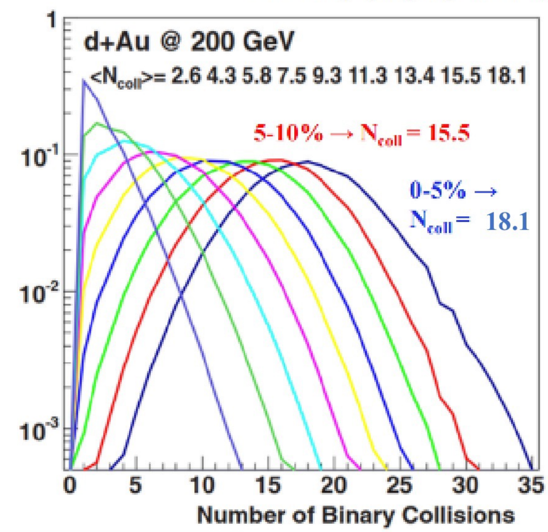
Impact parameter(b) → N_{part} & N_{Coll} → N_{ch}

- $N_{Coll}^{GL} \propto \left(\frac{dN_{ch}}{d\eta}\right)^{a}$; <u>Not directly measurable</u>
    - Obtained through the Glauber Model(GLM)



PHENIX: PRC90 (2014) 034902





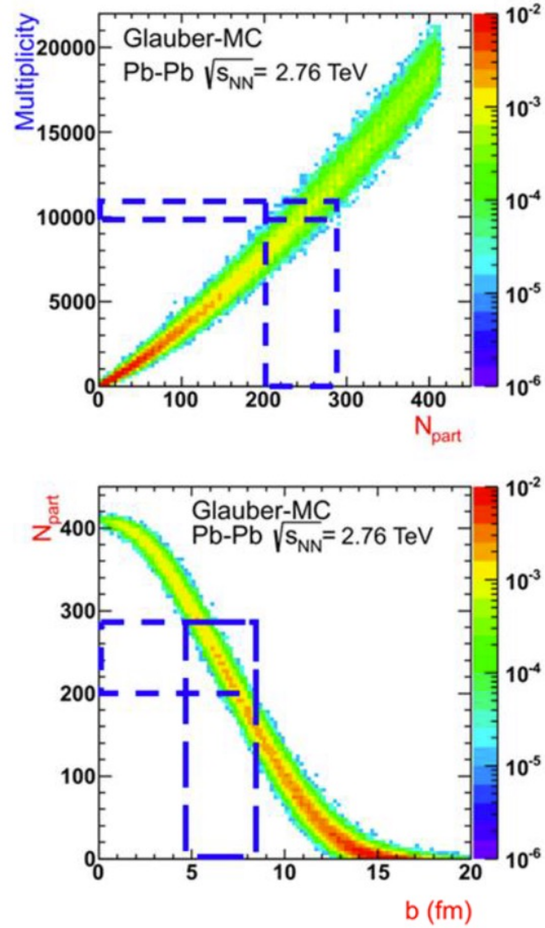
Mapping N_{ch} to N_{coll} with GLM.

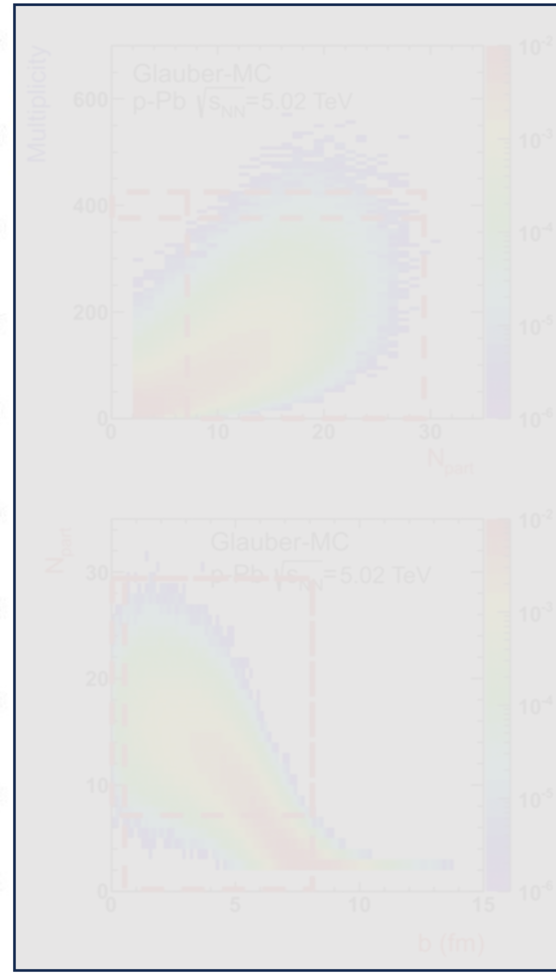
- Measure events activity (**N_{ch}**) in BBC on Au going side.
- Fit event activity to superposition of negative binomial distribution for each nucleon nucleon collision.
- Select events in percentiles of events activity for data and model.
- Assign **N_{coll}** from model to data.

Is Glauber Model Valid in Small System?

- A very small variance can be observed when analyzed 0-20% centrality bin(an equivalent class of event with average impact parameter of 3fm) in Pb+Pb collision.

ALICE: PRC91 (2015) 064905

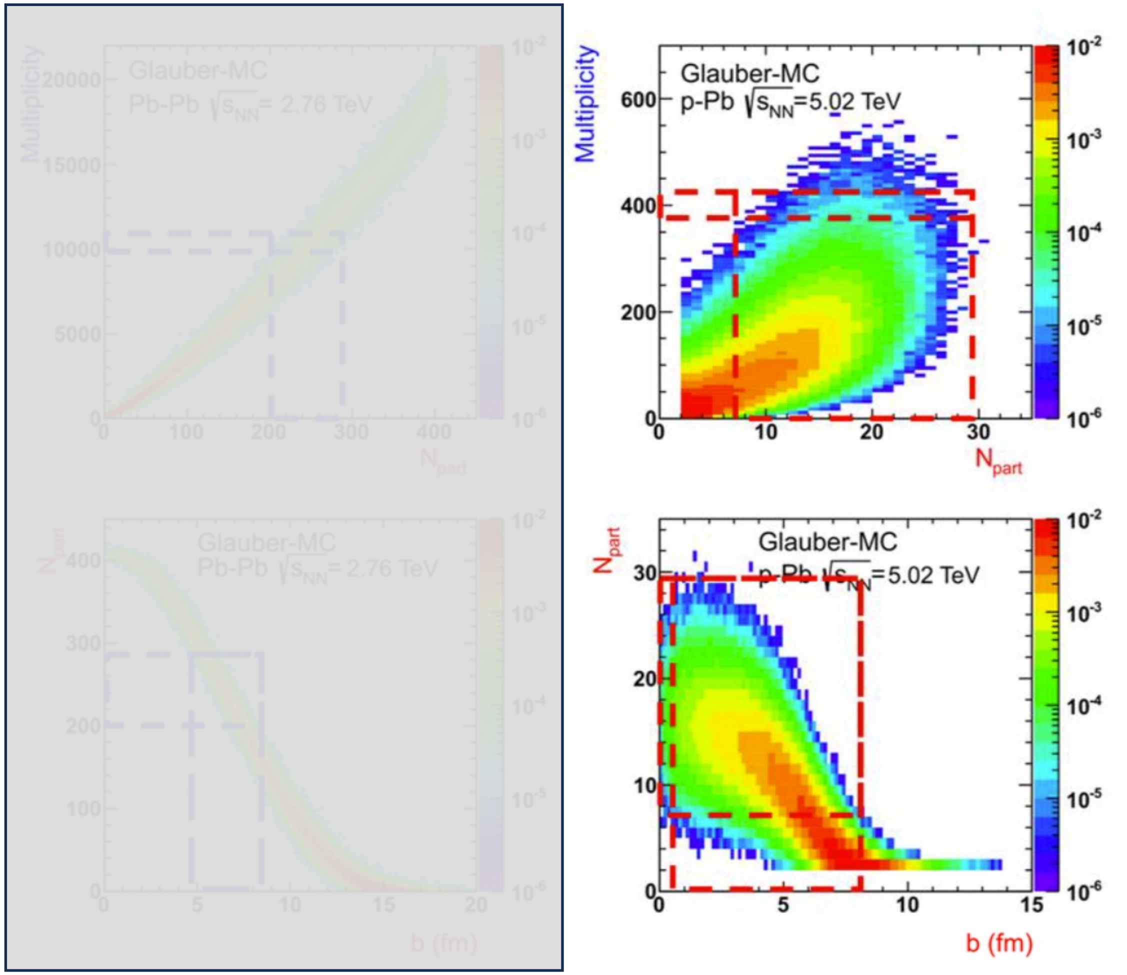




Is Glauber Model Valid in Small System?

- A very small variance can be observed when analyzed 0-20% centrality bin(an equivalent class of event with average impact parameter of 3fm) in Pb+Pb collision.
- Analyzing the 0-20% centrality bin in p+Pb is equivalent to studying the class of events with average impact parameter of 3 fm but with large variance.

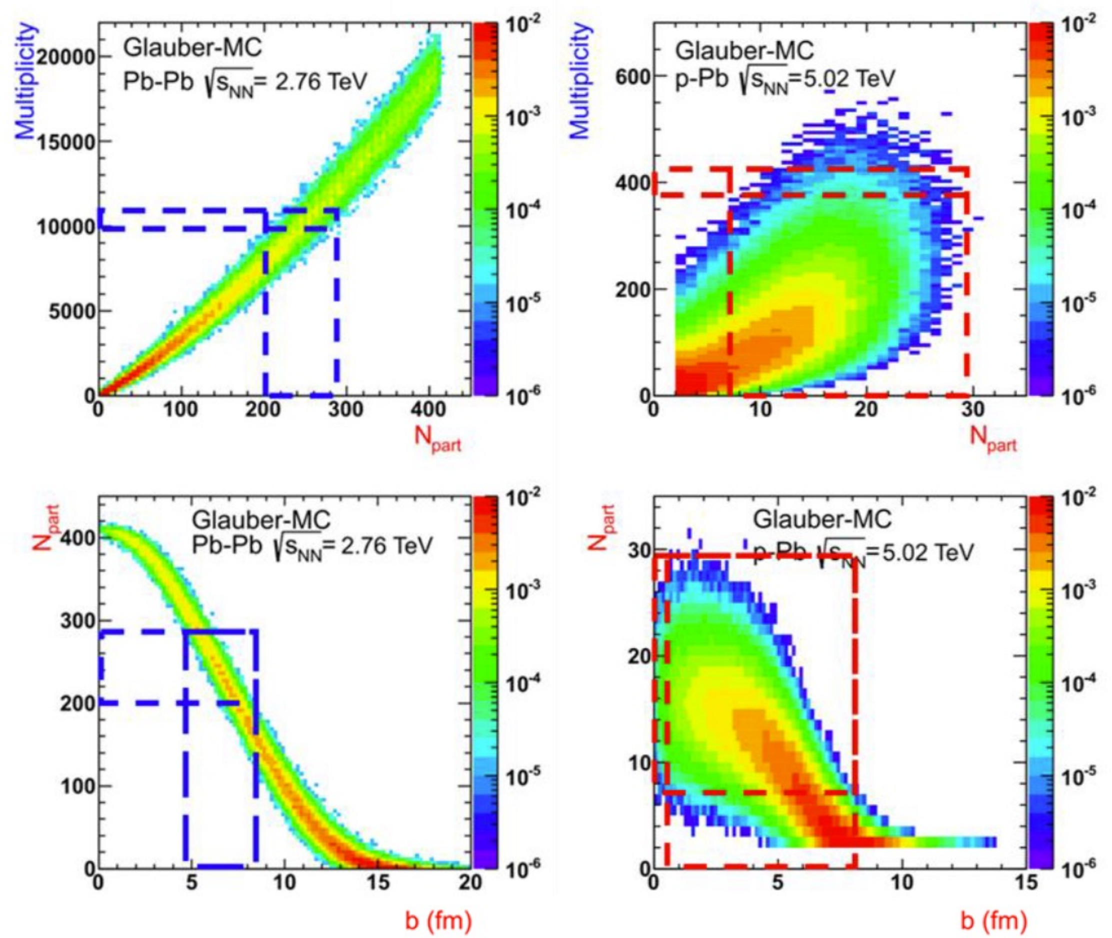
ALICE: PRC91 (2015) 064905



Is Glauber Model Valid in Small System?

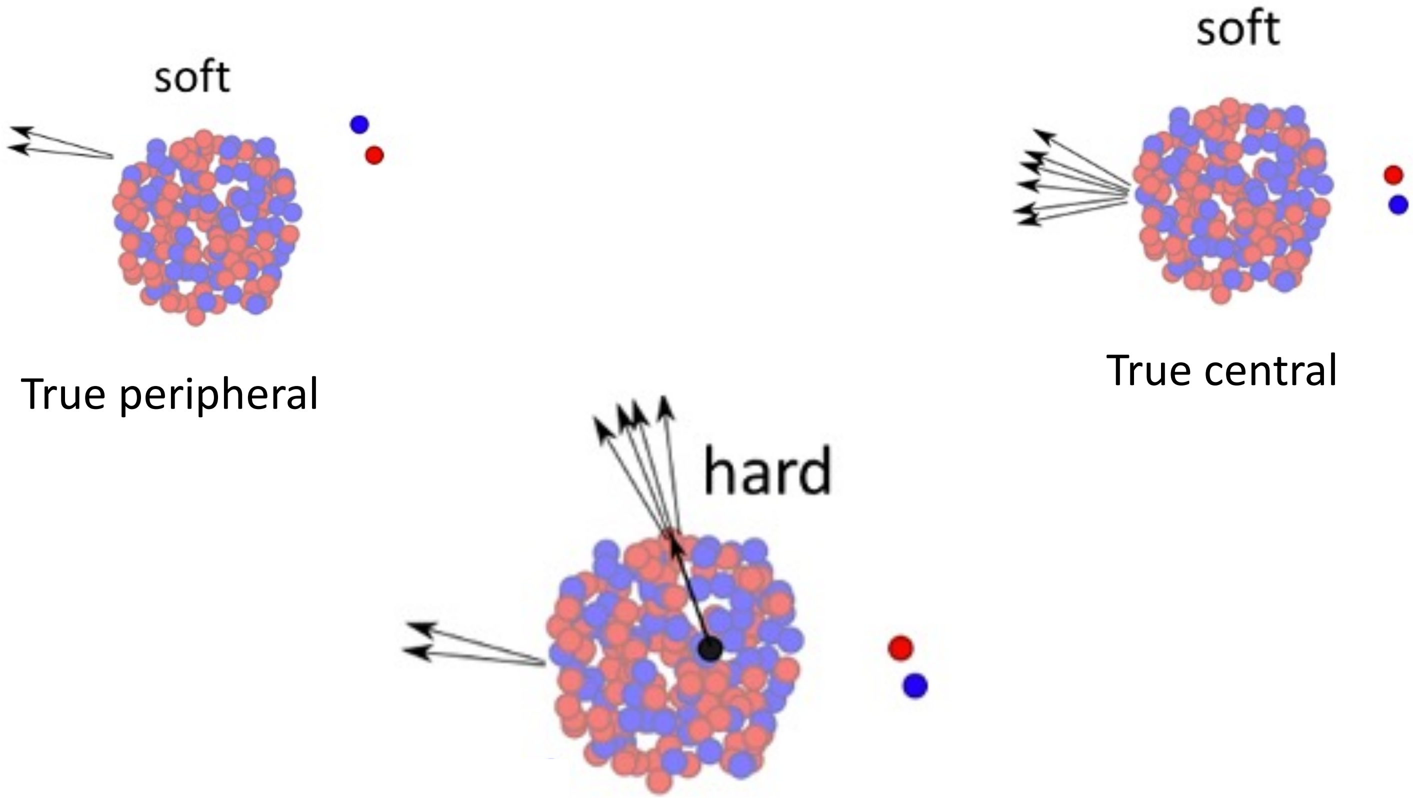
- A very small variance can be observed when analyzed 0-20% centrality bin(an equivalent class of event with average impact parameter of 3fm) in Pb+Pb collision.
- Analyzing the 0-20% centrality bin in p+Pb is equivalent to studying the class of events with average impact parameter of 3 fm but with large variance.
- This difference in particle multiplicity implies that we cannot draw equivalent physics conclusion about central p+Pb and Pb+Pb event.
- Centrality categorization in small system using Glauber Model have biasness in classifying event activity.

ALICE: PRC91 (2015) 064905



Biasness in Small System

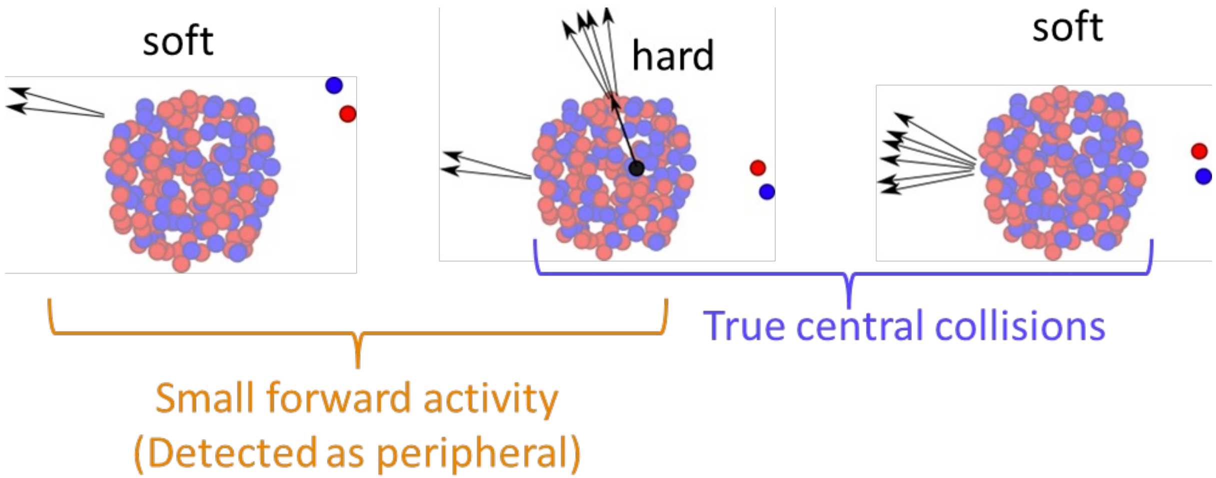
- Number of the charged particles in forward region is dictated by the soft particle production: determine centrality class of events.



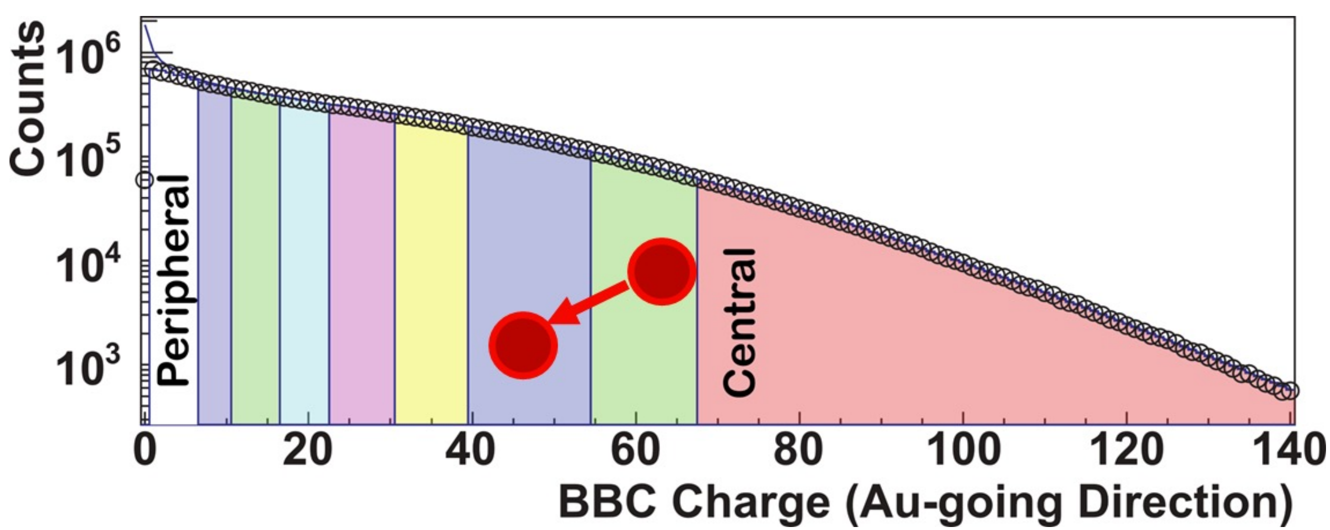
- Events with high p_T particles coming from the interaction of the high-x partons within the nucleons of interacting nucleons deplete energy available for soft particle production.

Biasness in Small System

- Any modification to this soft particle production mechanism affect the centrality binning.

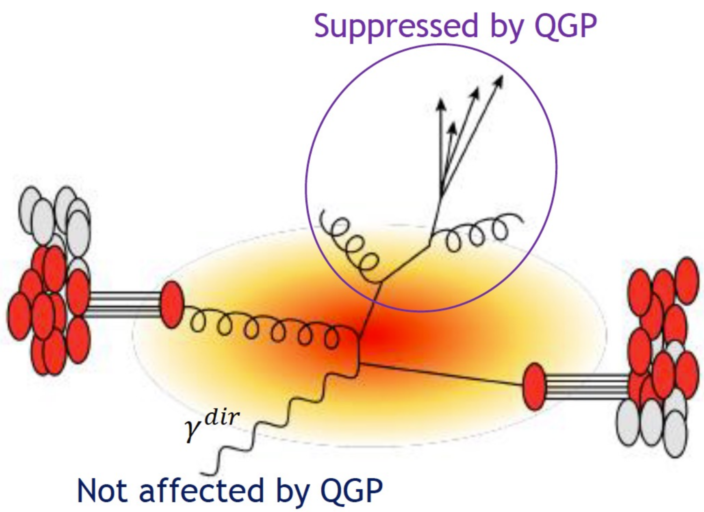


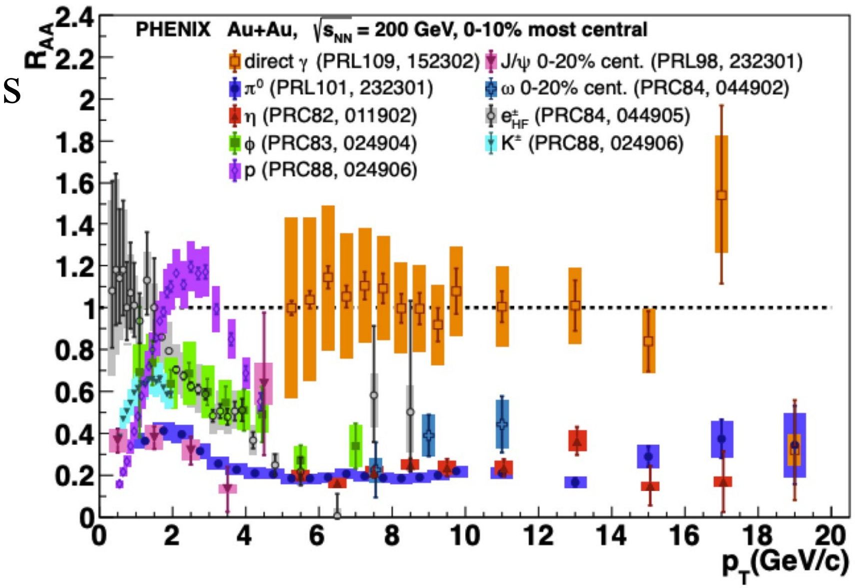
- For hard scattering process, events with small impact parameter(b) , ie, **true central** events, are now categorized as peripheral events.

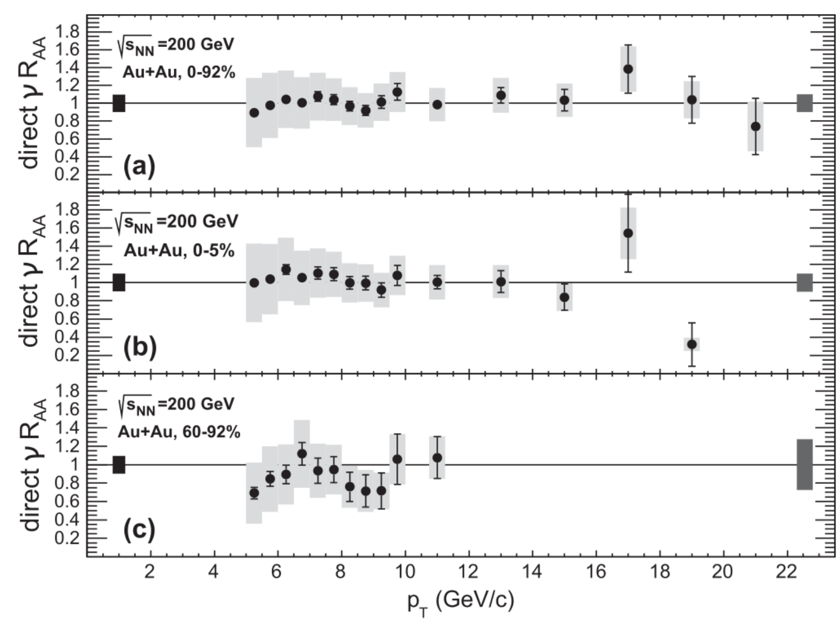


Minimizing Event selection bias

- Direct photon , unlike color charged particles are unaffected by QGP.
- Experimentally, N_{coll} for small system is redefined using $\boldsymbol{\gamma}^{dir}$ yield.







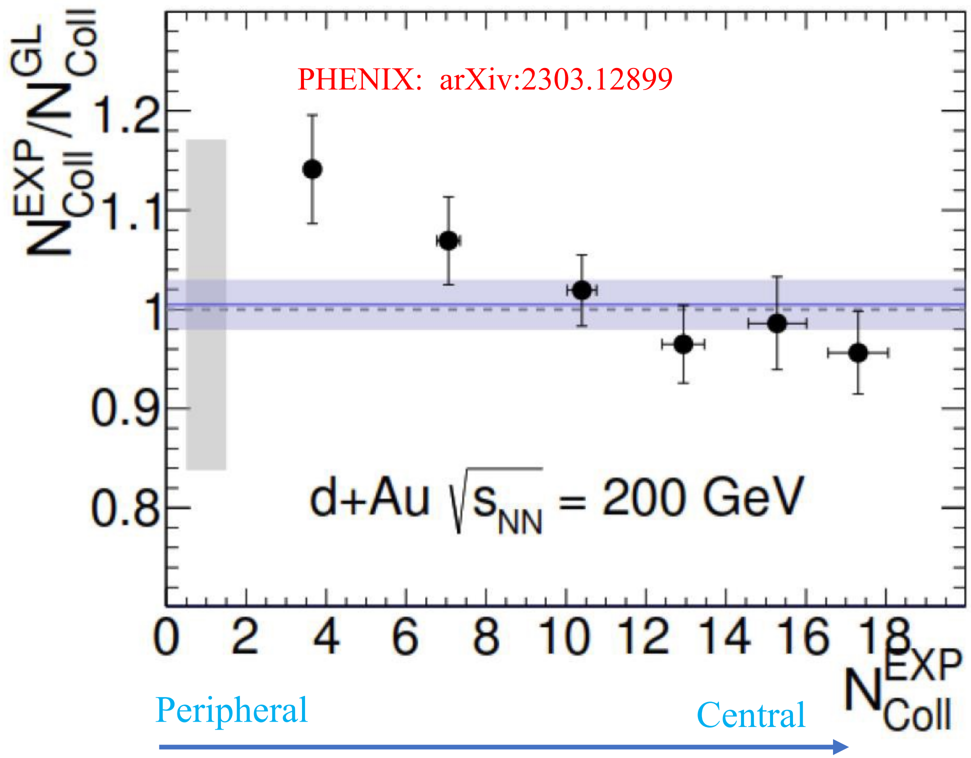
$$R_{AB}^{\gamma^{dir}}(p_T) = \frac{Y_{AB}^{\gamma^{dir}}(p_T)}{N_{coll}\, Y_{pp}^{\gamma^{dir}}(p_T)} \approx 1$$

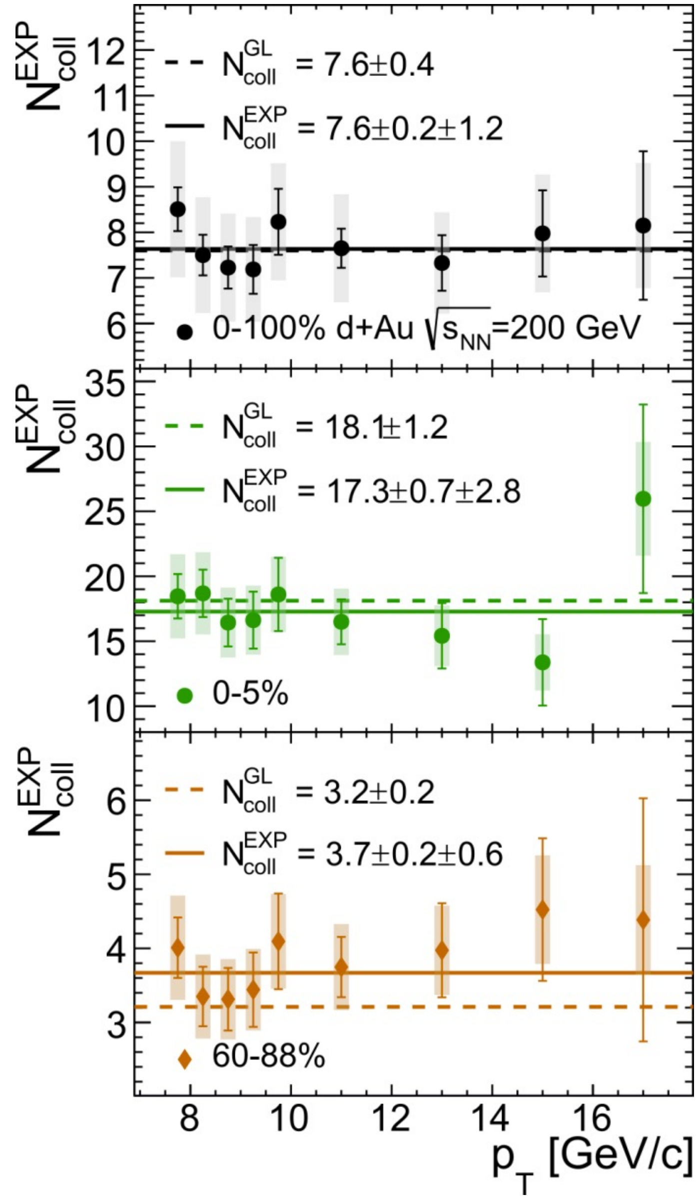
$$N_{coll} = N_{Coll}^{Exp}(p_T) = \frac{Y_{AB}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{dir}}(p_T)}$$

Minimizing Event selection bias

$$N_{Coll}^{Exp}(p_T) = \frac{Y_{dAu}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{dir}}(p_T)}$$

- While, for event with central activity, N_{Coll}^{Exp} and N_{Coll}^{GL} shows good agreements, 15% deviation is seen in peripheral collision.

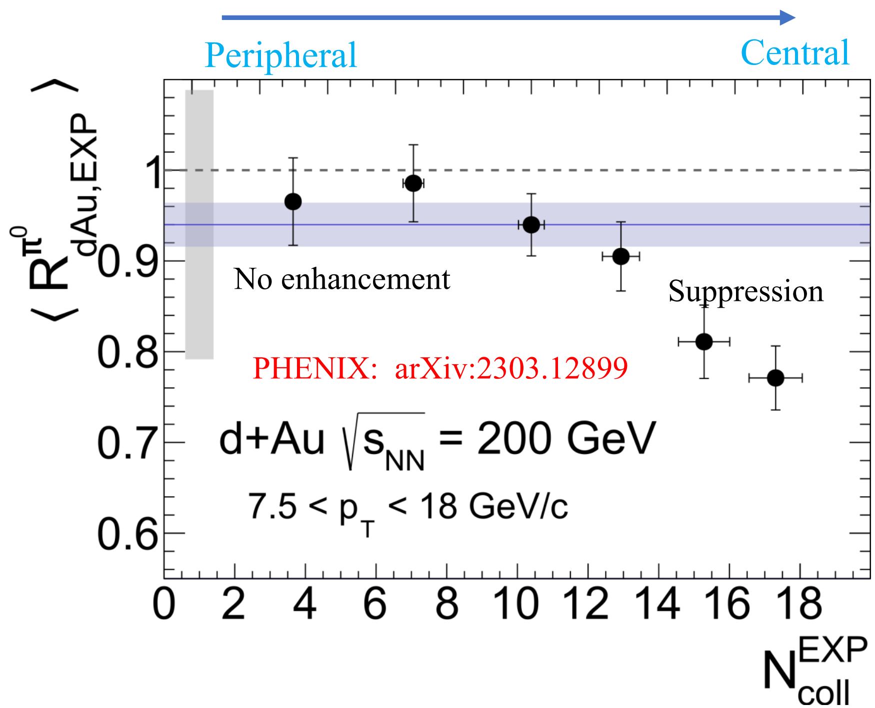


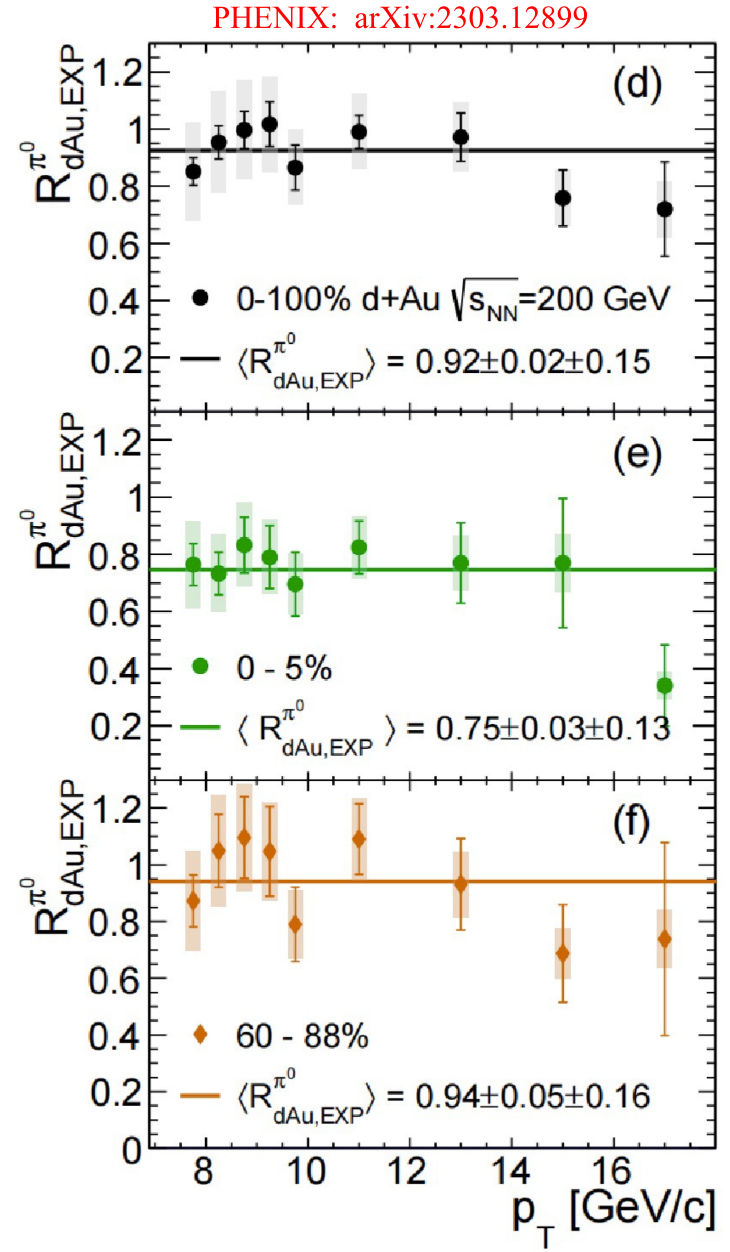


Redefined Nuclear modification factor for π^0

$$R^{\pi^0}_{dAu,Exp}(p_T) = \frac{Y^{\pi^0}_{dAu}(p_T)}{N^{Exp}_{coll}\ Y^{\pi^0}_{pp}(p_T)}$$

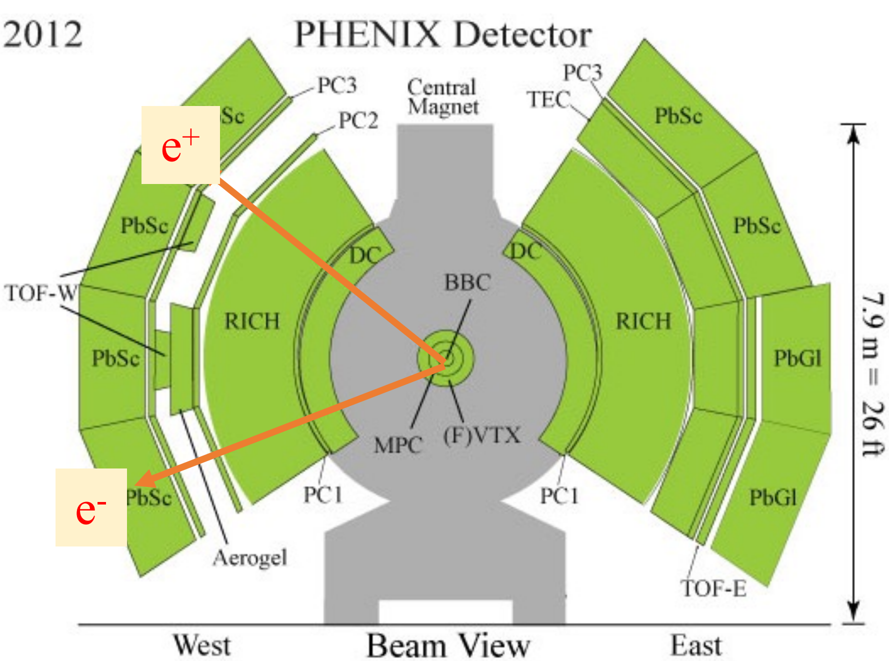
- Peripheral collisions are consistent with the Min bias event.
- Central collisions are consistent with >20 % suppression.

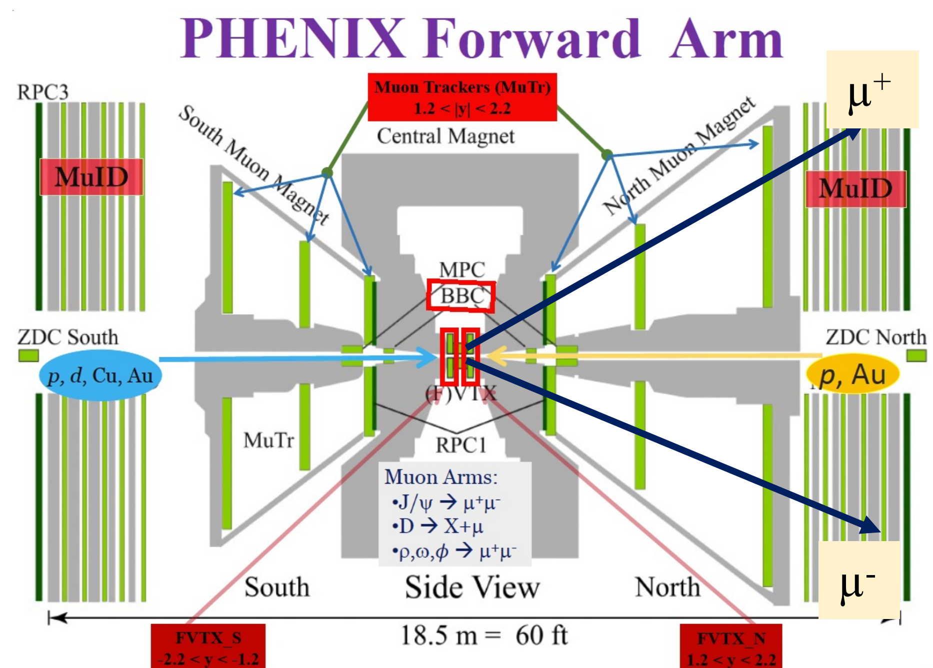




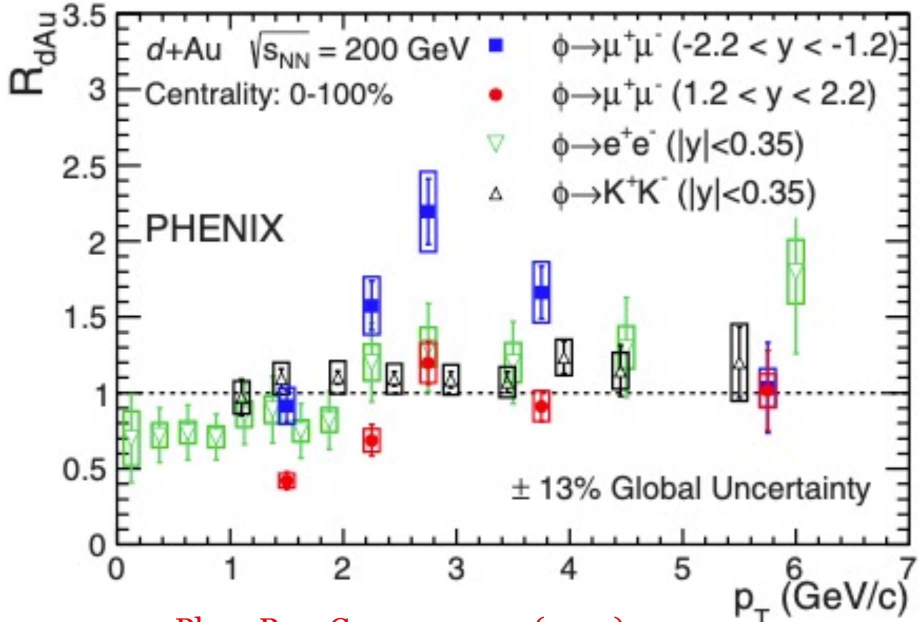
Low mass vector meson production in PHENIX

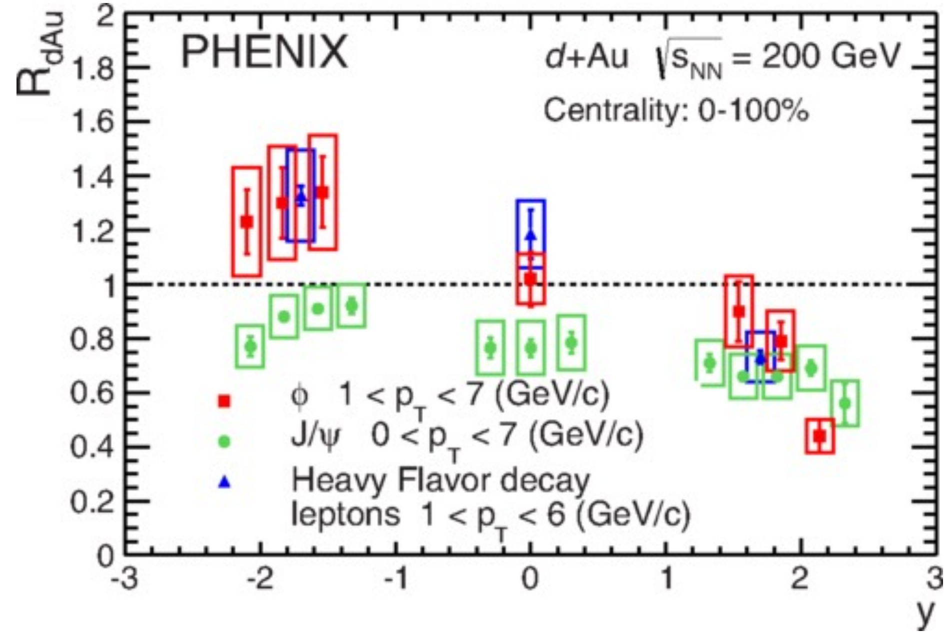
- PHENIX has measured the low mass vector meson in both central rapidity and in forward rapidity region.
- Decay channel ($\phi \rightarrow e^+e^-$)and ($\phi \rightarrow K^+K^-$) in central arm and ($\phi \rightarrow \mu^+\mu^-$) in forward region.



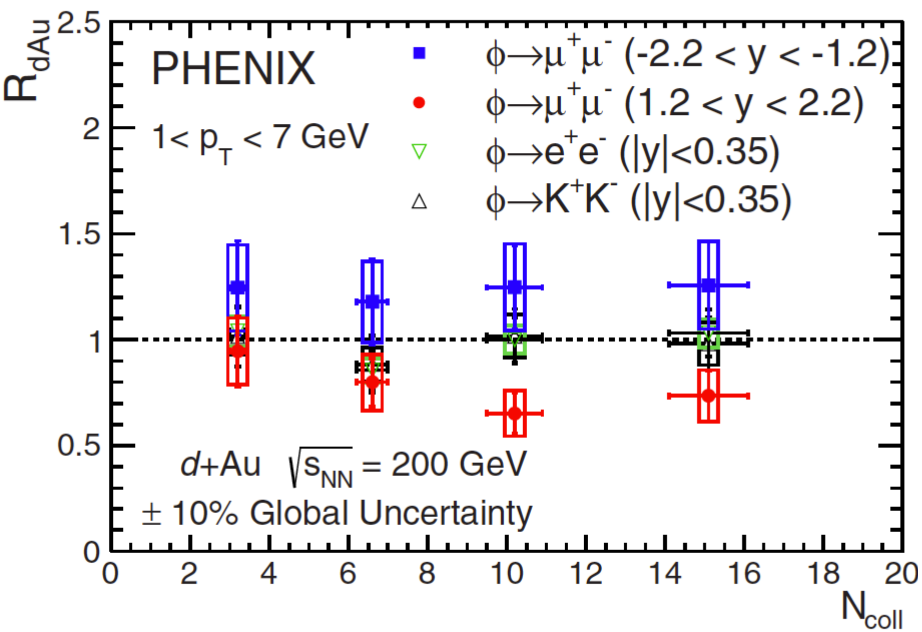


ϕ - Meson production at Forward Rapidity





Phys. Rev. C **92**, 044909 (2015)



- An enhancement (suppression) observed at backward (forward) rapidity region in d + Au collision.
- The observed enhancement in intermediate p_T region in Au going direction (backward) is a typical behavior of Cronin effect.
- The rapidity dependent R_{dAu} is similar to the open heavy flavor modification.
    - indicates cold nuclear matter effects.

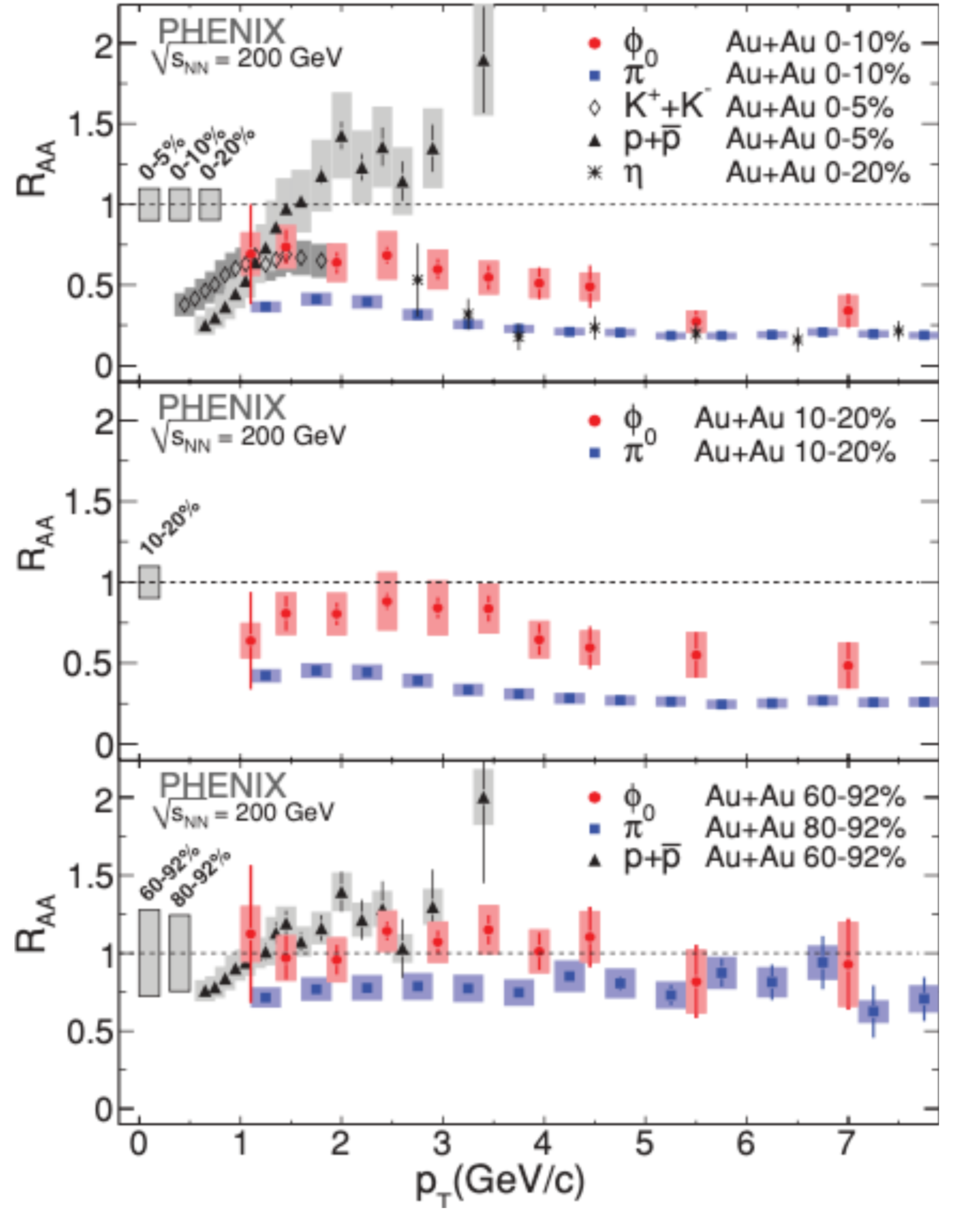
ϕ - Meson production at Mid Rapidity

PHENIX, PRC **83**, 024909 (2011)

- For all centralities , ϕ-meson is less suppressed than π^0 in the intermediate p_T range in Au + Au collision, whereas similar suppression in higher p_T range.

- ϕ-meson production in dense medium has centrality and energy dependence.

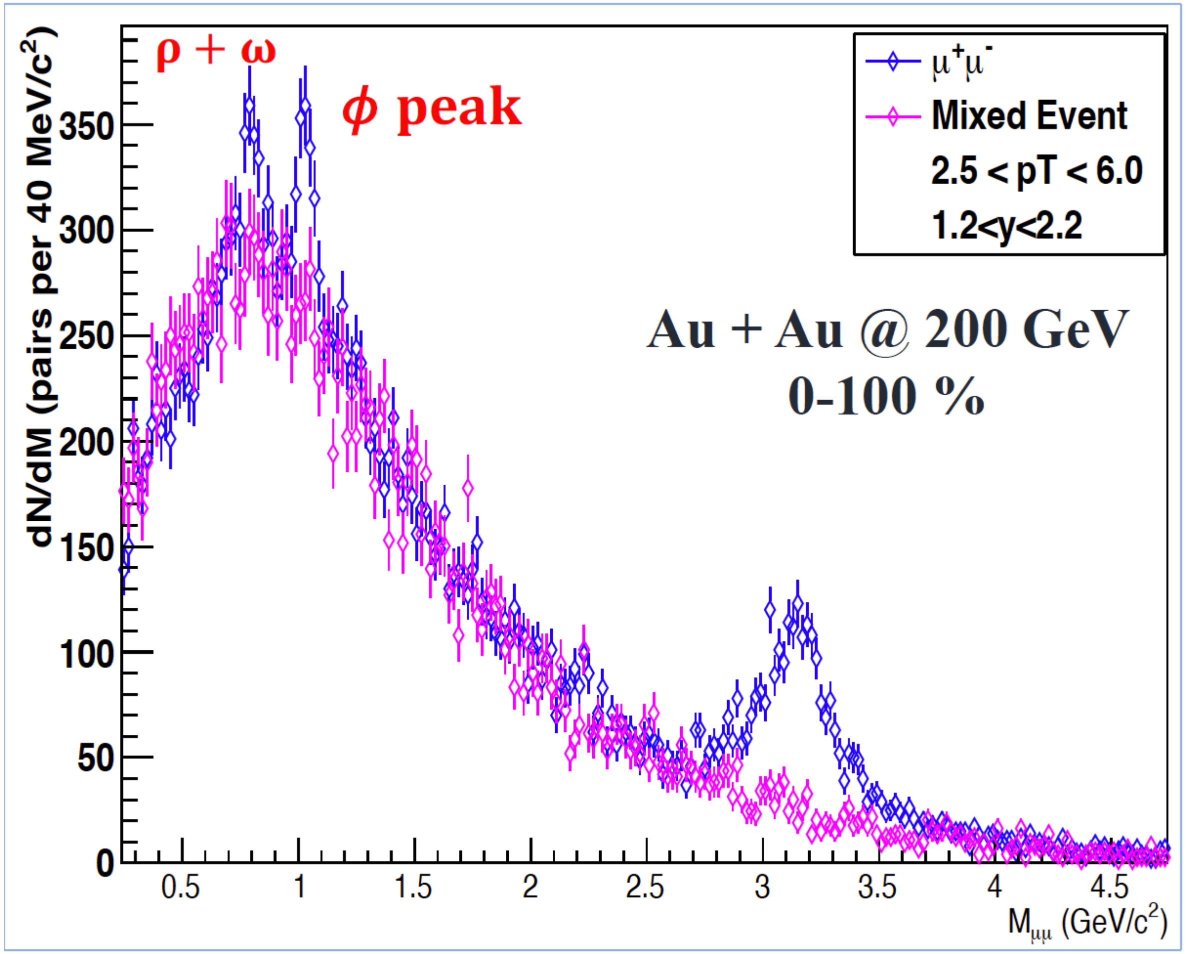
- Suppression patterns of different mesons at high p_T favors the production of mesons via jet fragmentation outside the hot and dense medium created in the collision.



ϕ - Meson production in Au+Au collision at Forward rapidity

❖ The study of ϕ-mesons production at forward rapidity may provide more insight into the QGP formation and possible hot nuclear matter (HNM) effect.

❖ FVTX is used at forward rapidity for the first time: precise tracking and improving signal to background ratio.



Summary & Outlook

- First evidence of significant 20% final state suppression of high p_T π^0 in central d+Au collision.
- Previously observed enhancement of the high p_T π^0 particles in peripheral events was due to biasness in binning of event activity.
- Direct Photon used to redefine N_{Coll} and resolved ambiguity between final state and CNM effects.
- PHENIX observed Φ - meson suppression at forward rapidity and enhancement at backward rapidity in small d+Au system while suppression is observed at mid rapidity in A+A collision.
- Studying Φ - meson at forward rapidity in Au+Au collision may provide more insight into the QGP formation and hot nuclear matter effect (HNM) effect.


THANK YOU

Low mass vector meson Production in PHENIX.

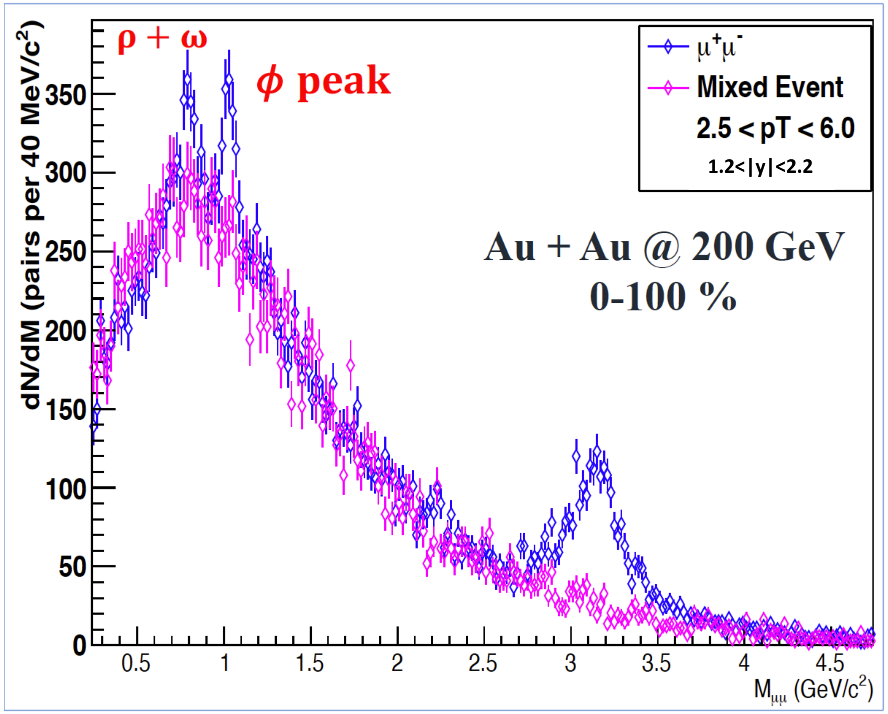
- $\phi(s\bar{s})$: Excellent probe for studying QGP.
- Small cross-section for scattering with non strange hadrons: act as penetrating probe as it retain information on initial state evolution of the system.
- Compose of $s\bar{s}$ quarks: provide insight on strangeness enhancement in-medium.
- $\phi \rightarrow \mu^+\mu^-$, experience no final state effect and carry important information about QGP itself.

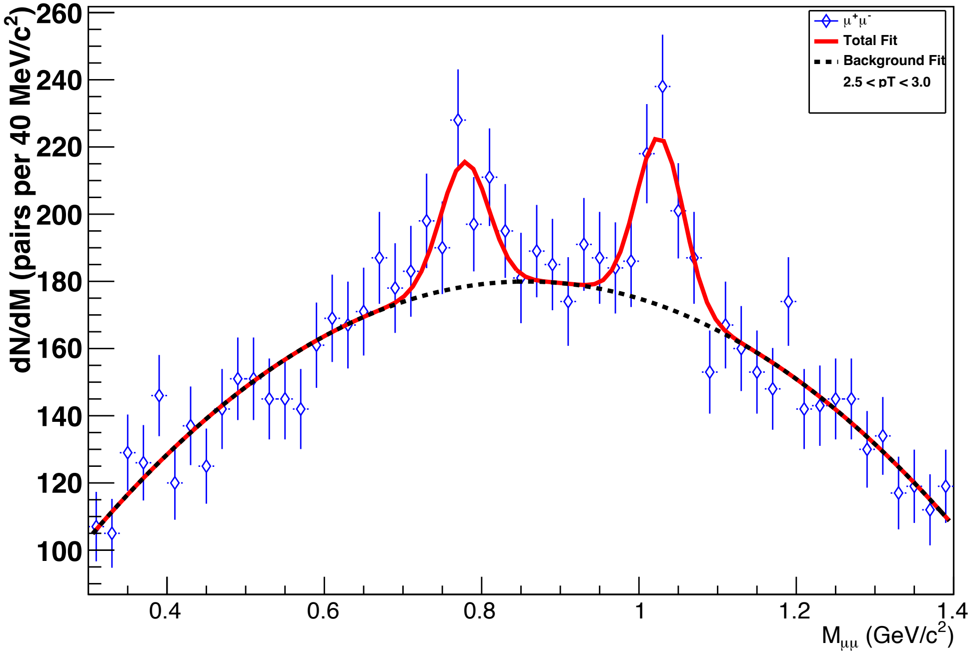
Past Measurements

Collision System	Energy ($\sqrt{s_{NN}}$)	Rapidity	Decay mode	Detector	Publications
p + p	200 GeV	$1.2<\|y\|<2.2$	$\phi \rightarrow \mu^+ \mu^-$	RHIC(PHENIX)	PRD 90, (2014)
	2.76 TeV	$2.5 < y < 4$	$\phi \rightarrow \mu^+ \mu^-$	LHC(ALICE)	PLB, 768, 203 (2017)
d + Au	200 GeV	$1.2<\|y\|<2.2$	$\phi \rightarrow \mu^+ \mu^-$	RHIC(PHENIX)	PRC, 92 (2015) / PRC, 83 (2011)
		$\|y\|<0.35$	$\phi \rightarrow e^+ e^-$ / $\phi \rightarrow K^+ K^-$		
Cu + Cu	200 GeV	$\|y\|<0.35$	$\phi \rightarrow K^+ K^-$	RHIC(PHENIX)	PRC, 83 (2011)
Cu + Au		$1.2<\|y\|<2.2$	$\phi \rightarrow \mu^+ \mu^-$		PRC, 93 (2016)
p + Pb	5.02 TeV	$2.03 < y < 3.53$ $-4.46 < y < -2.96$	$\phi \rightarrow \mu^+ \mu^-$	LHC(ALICE)	PLB, 768, 203 (2017)
Pb + Pb	2.76 TeV	$2.5<y<4$	$\phi \rightarrow \mu^+ \mu^-$	LHC(ALICE)	Eur. Phys. J. C 78(2018)
Au + Au	200 GeV	$1.2<\|y\|<2.2$	-	RHIC(PHENIX)	-

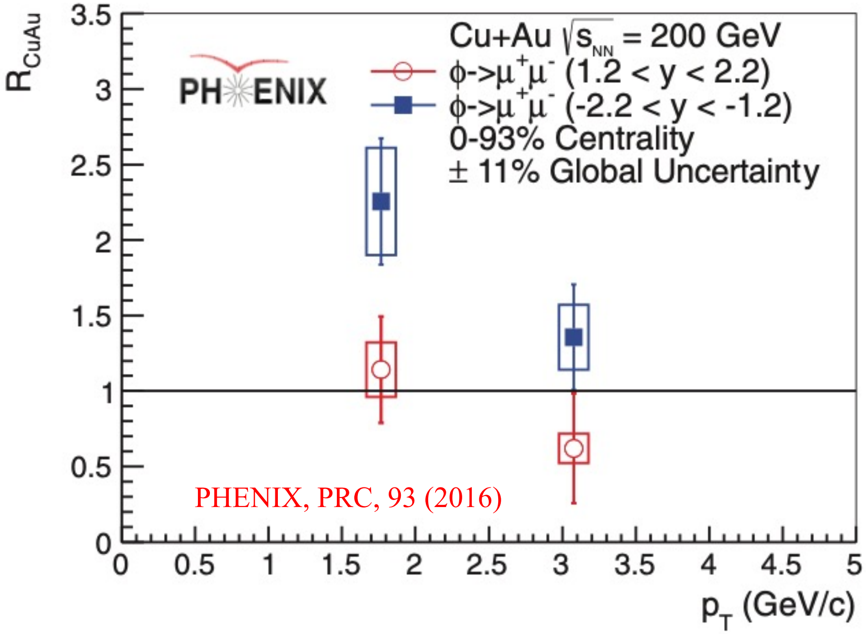
ϕ - Meson production in Au+Au collision at Forward rapidity

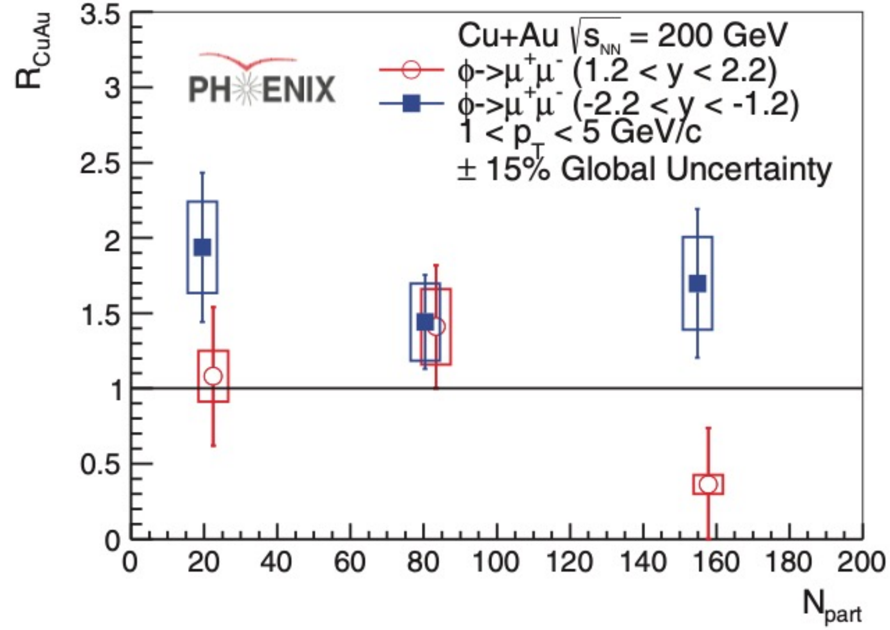
- Φ - mesons production has been observed in small d + A collision system at forward and mid rapidities in A+A collision by PHENIX.
- The study of ϕ-mesons production at forward rapidity may provide more insight into the QGP formation and possible hot nuclear matter (HNM) effect.
- FVTX is used at forward rapidity for the first time: precise tracking and improving signal to background ratio.

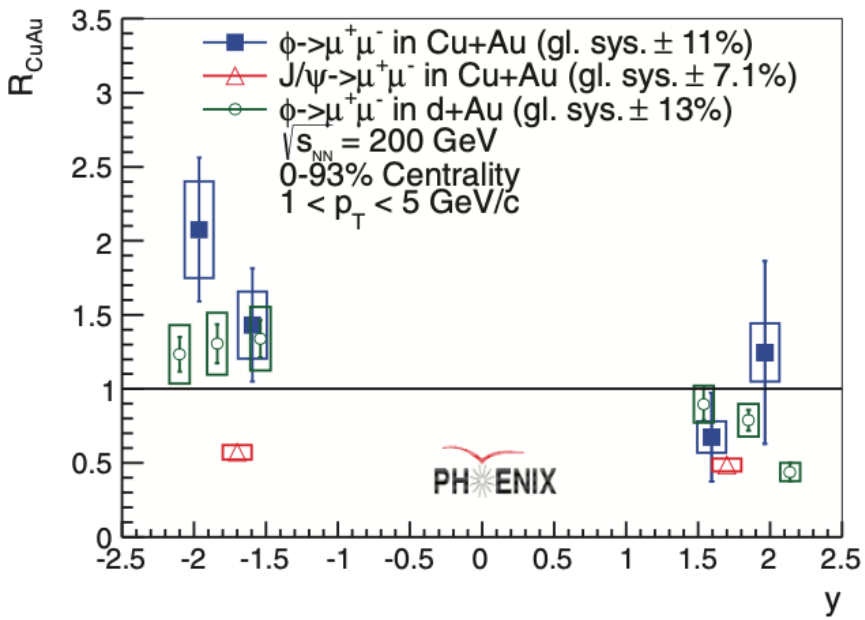




ϕ - Meson production at Forward Rapidity







- ϕ enhancement in Au going direction and most pronounced at low momentum.
  - Similar trend to PHENIX in d +Au collision at same energy and rapidity as well as ALICE measurement in p +Pb collision (CNM effect).

- Expected substantial contribution from HNM effect too.

BACK UP