Measurement of Light Mesons (ω, ϕ, K^*, K_s) by PHENIX Experiment at RHIC

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Outline

1. **Motivation**
2. **The PHENIX detector**
3. **Transverse momentum spectra of ω, ϕ, K_s , K^***
4. **Nuclear modification factor R_{AA}**
   - R_{AA} at $\sqrt{s_{NN}} = 200$ GeV
   - R_{AA} at $\sqrt{s_{NN}} = 62.4$ GeV

Motivation

Light mesons are among the important probes to understand several aspects of the heavy-ion collisions:

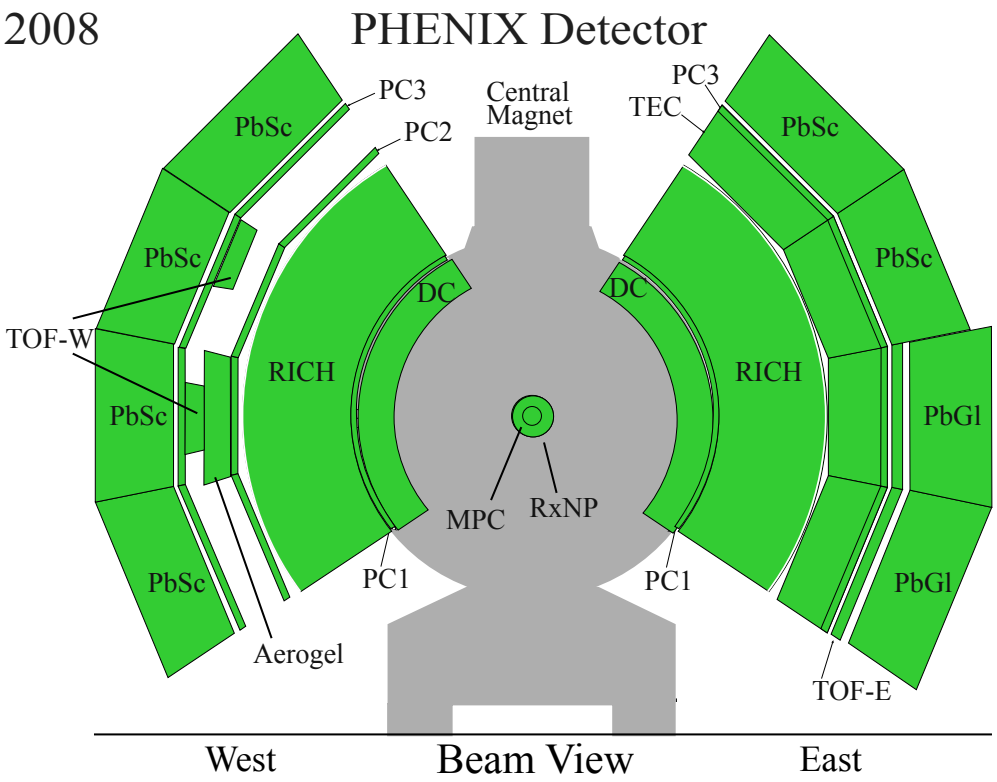
- **Systematic measurements of different particles is needed to understand the medium properties:**
  - **Comparisons of p_T/m_T spectra of mesons using different decay modes.**
  - **Nuclear modification factor defined as:**
    $R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T dy}{\langle n_{coll}\rangle \cdot d^2N^{pp}/dp_T dy}$
    comparison of several mesons allows to disentagle if suppression is mass or quark number or flavor dependent.
- **as probes to chiral symmetry restoration (*not discussed in this talk*):**
  - **a modification of line shape parameters (mass or width) inside the nuclear medium.**
  - **a difference in the yields between the hadronic and leptonic decay channels.**

Topics covered in this talk

Particle	200 GeV	62.4 GeV
$\omega \to \pi^0\gamma$	$p+p, d+Au, Au+Au$	
$\omega \to \pi^+\pi^-\pi^0$	$p+p, d+Au, Au+Au$	
$\omega \to e^+e^-$	$p+p, d+Au$	
$\phi \to K^+K^-$	$p+p, d+Au, Cu+Cu\, Au+Au$	$p+p, Cu+Cu, Au+Au$
$\phi \to e^+e^-$	$p+p, d+Au$	
$K_S \to \pi^0\pi^0$	$p+p, Cu+Cu, Au+Au$	
$K_* \to \pi K$	$p+p, d+Au$	

The PHENIX detector

PHENIX Central arms Acceptance: -0.35< η <0.35, 2×90° in φ



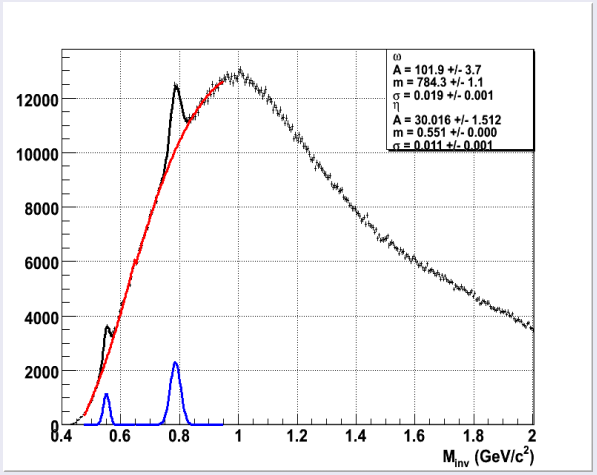
- Vertex: **BBC**
- Tracking: **Drift Chambers/Pad Chambers**
- Trigger:
  - **Min. bias**:**BBC**
  - **e**: **RICH,EmCal**
- **h** ID: Time-of-flight
  - **TOF** $d\tau \sim 100$ ns
  - **EmCal** $d\tau \sim 500$ ns
  - **Aerogel** $d\tau \sim 500$ ns
- **e** ID:
  - **RICH**(e/π rejection >1000)
  - E-p matching **EmCal** (e/π rejection$\sim$ 10)

Mass spectra examples - I

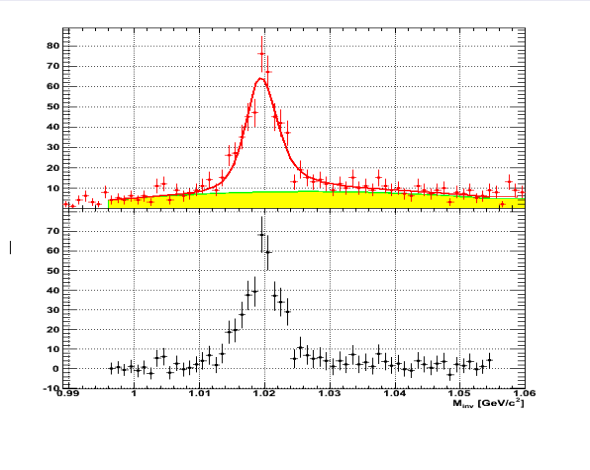
ω and ϕ hadronic decay modes

p+p

$\omega \rightarrow \pi^+\pi^-\pi^0$

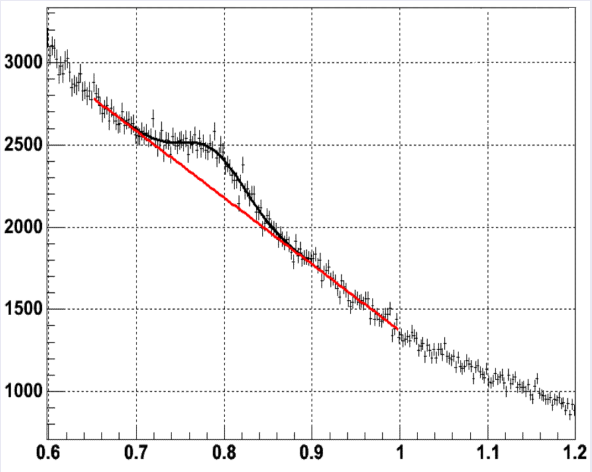


$\phi \rightarrow K^+K^-$

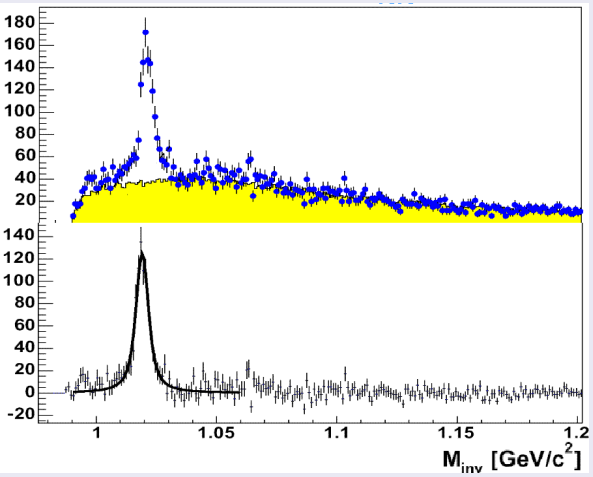


d+Au

$\omega \rightarrow \pi^+\pi^-\pi^0$

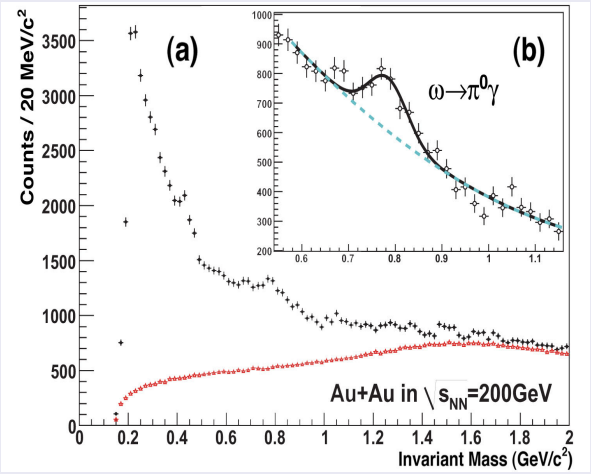


$\phi \rightarrow K^+K^-$

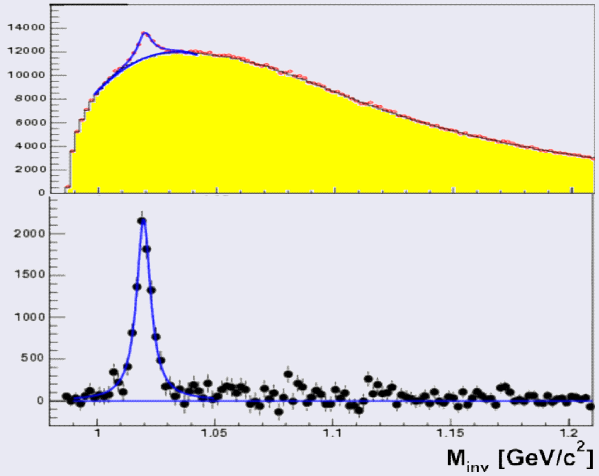


Au+Au

$\omega \rightarrow \pi^0\gamma$



$\phi \rightarrow K^+K^-$

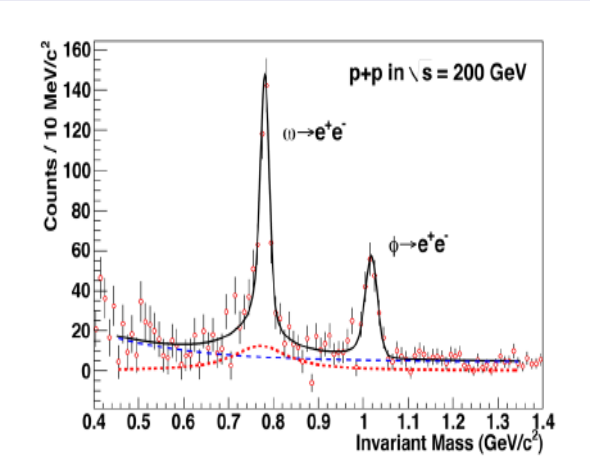


Mass spectra examples -II

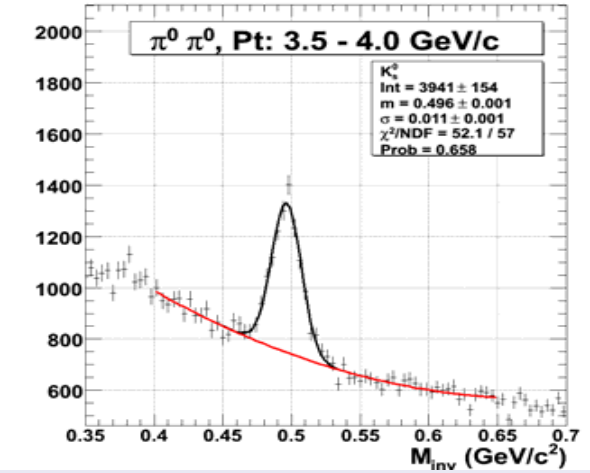
$\omega, \phi \rightarrow e^+e^-, K_s \rightarrow \pi^0\pi^0, K^* \rightarrow \pi K$

p+p

$\omega, \phi \rightarrow e^+e^-$

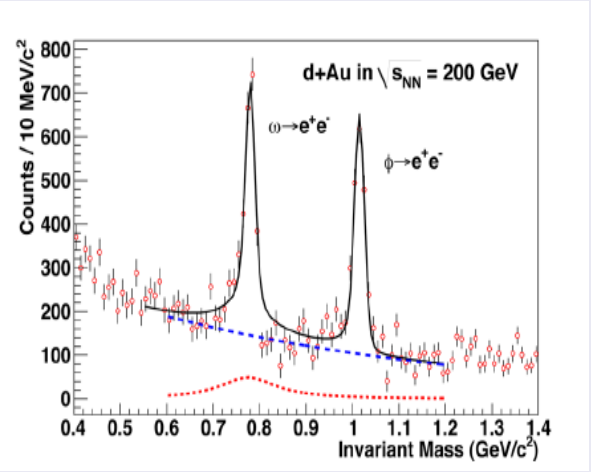


$K_s \rightarrow \pi^0\pi^0$

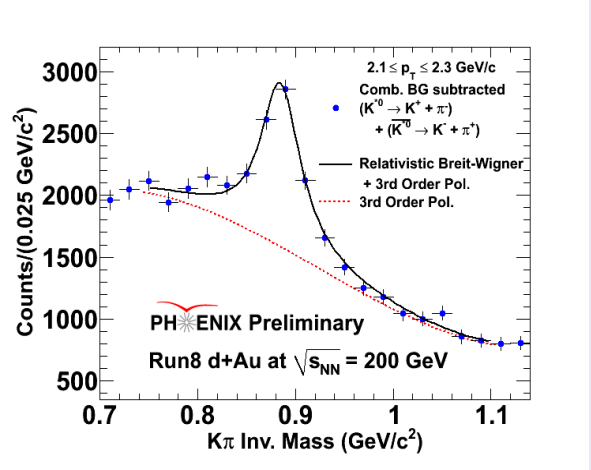


d+Au

$\omega, \phi \rightarrow e^+e^-$

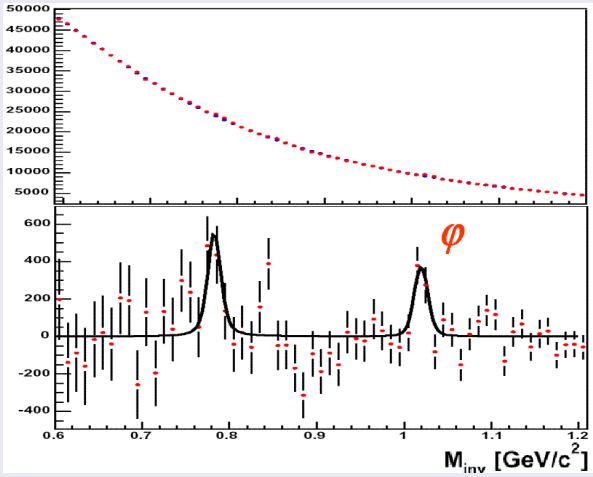


$K^* \rightarrow \pi K$

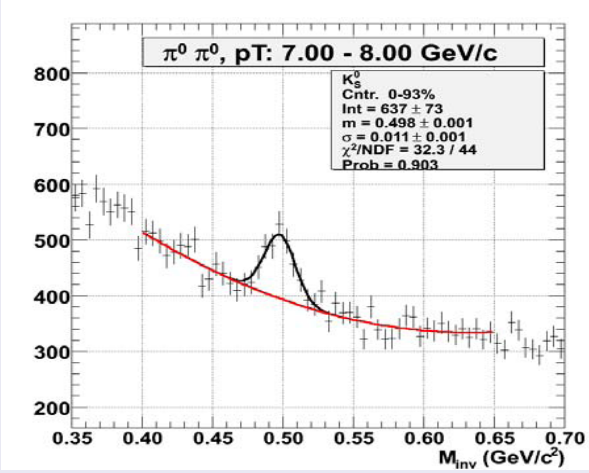


Au+Au

$\omega, \phi \rightarrow e^+e^-$



$K_s \rightarrow \pi^0\pi^0$

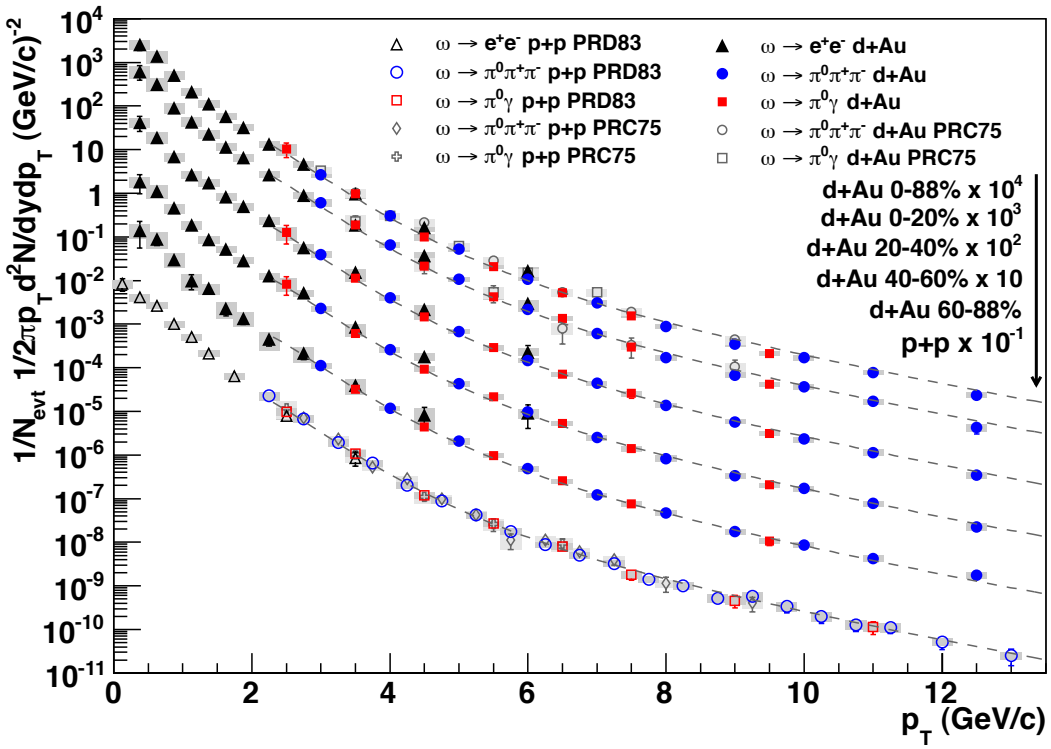


Transverse momentum spectra of ω, ϕ, K_s , K^*

Transverse momentum spectrum - I

$\omega \to \pi^0\gamma, \omega \to \pi^+\pi^-\pi^0, \omega \to e^+e^-$

$p + p$ **(PRD83, 052004) and** $d + Au$ **(arXiv:1105.3467)**



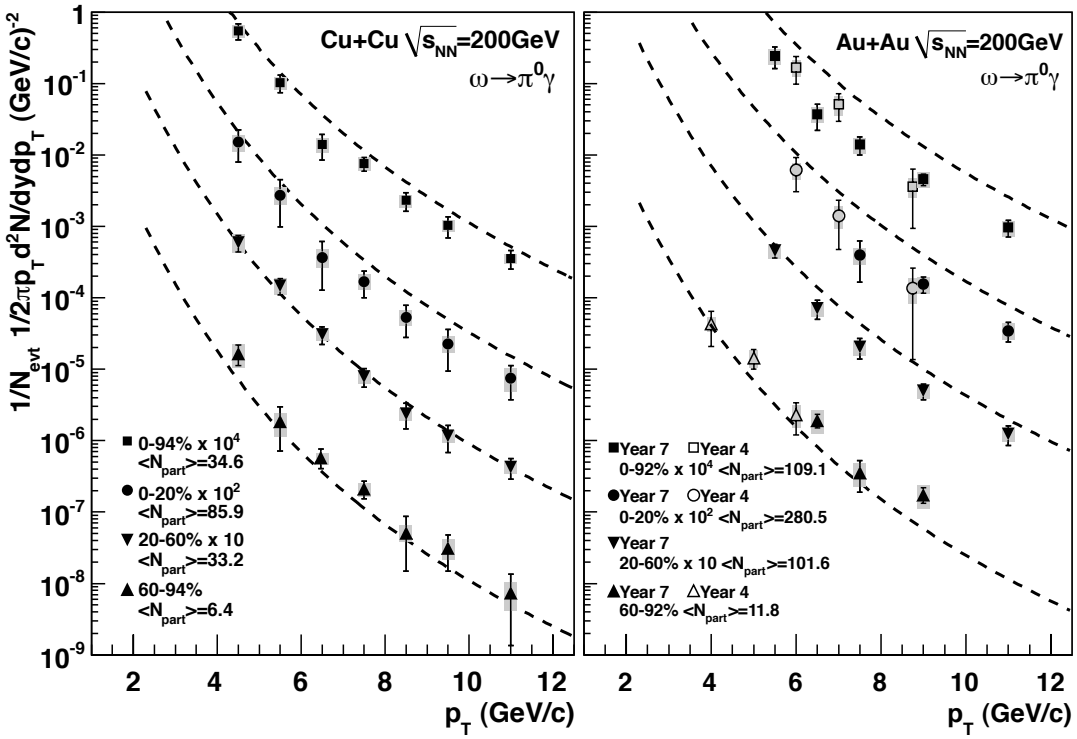
Dashed lines represent the fit to $p + p$ data, scaled by respective binary collisions.

Consistent results using different decay modes.

Transverse momentum spectrum - I

$\omega \to \pi^0\gamma, \omega \to \pi^+\pi^-\pi^0, \omega \to e^+e^-$

$Cu + Cu$ and $Au + Au$, arXiv:1105.3467



Dashed lines represent the fit to $p + p$ data, scaled by respective binary collisions.

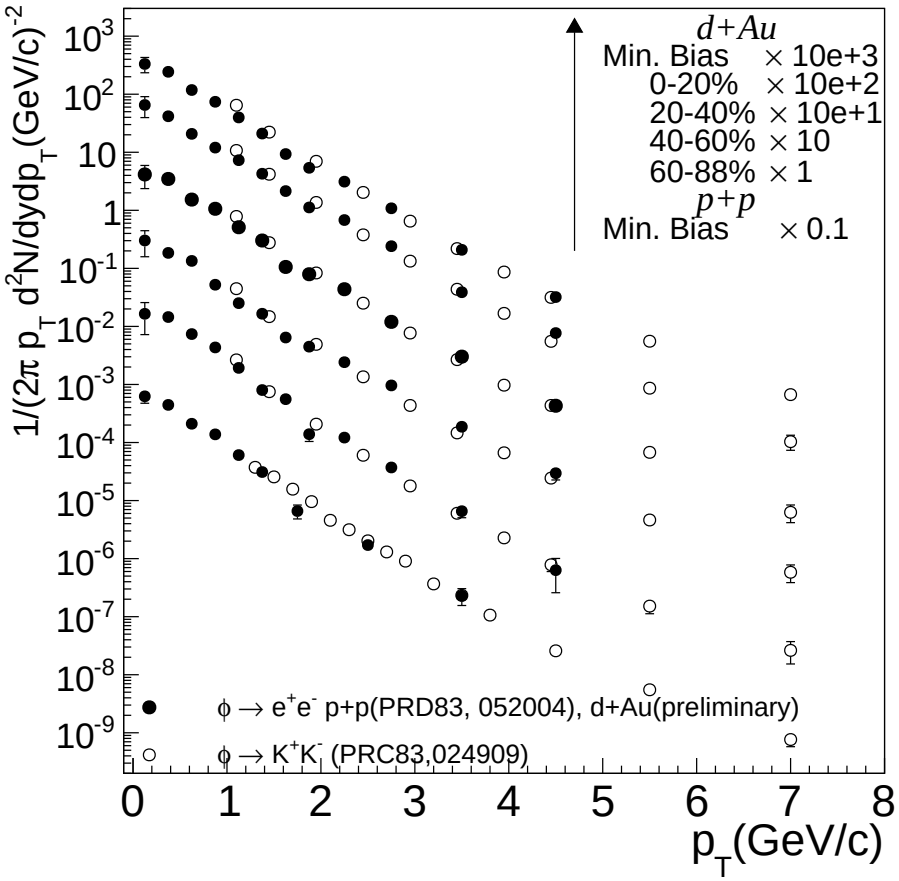
New PHENIX results in $d + Au$, $Cu + Cu$ and $Au + Au$

PHENIX

Transverse momentum spectrum - II

$\phi \rightarrow K^+K^-, \phi \rightarrow e^+e^-$

$p + p$ **and** $d + Au$, PRD83, 052004

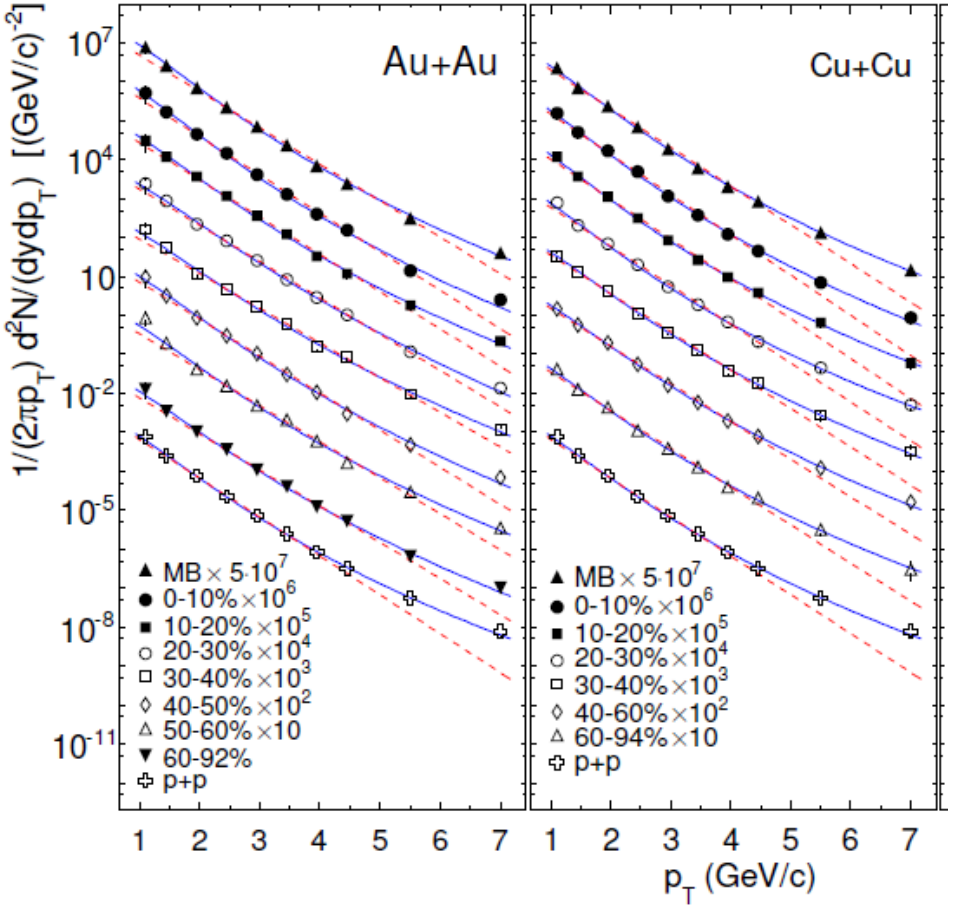


- **Consistent results obtained using the two decay modes.**
- **Two decay channels allow to cover a p_T range from 0 - 7 GeV/c.**

Transverse momentum spectrum - II

$\phi \rightarrow K^+K^-, \phi \rightarrow e^+e^-$

$Cu + Cu$ **and** $Au + Au$**, PRC83, 024909**



Dashed (Solid) lines correspond to exponential (Tsallis) fit to the data.

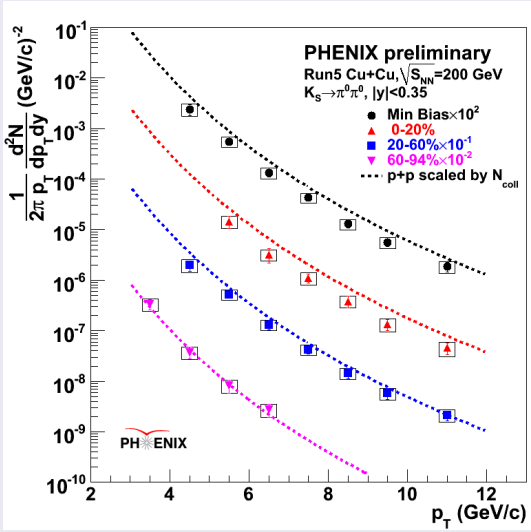
- **Wide p_T coverage from 1- 7 GeV/c.**

Transverse momentum spectrum - III

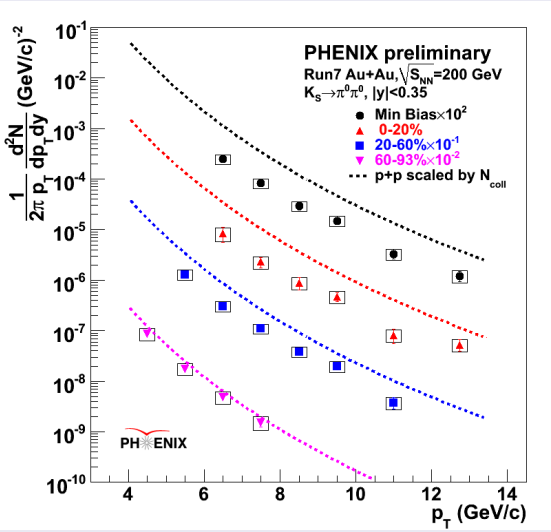
$K^* \rightarrow \pi K$, $K_s \rightarrow \pi^0\pi^0$

$K_s \rightarrow \pi^0\pi^0$

Cu+Cu

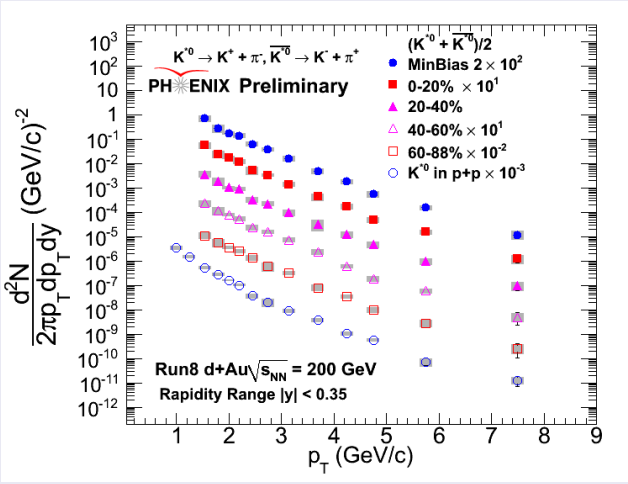


Au+Au



$K^* \rightarrow \pi K$

p+p & d+Au

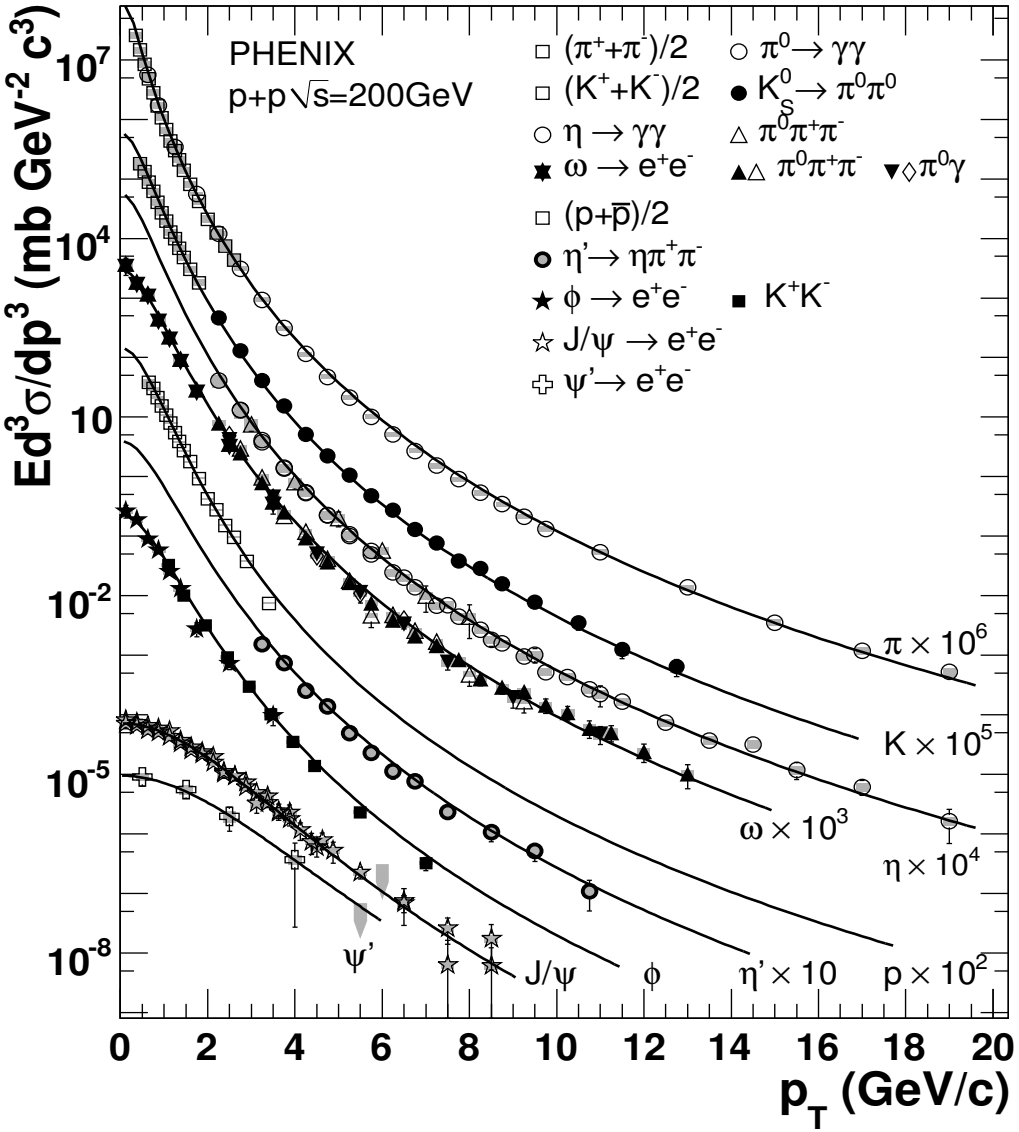


- K_s is measured in $Cu + Cu$ and $Au + Au$ collisions over a p_T range of 3-12 GeV/c.
- K^* measured in $p + p$ and $d + Au$ collisions from 1 to 8 GeV/c.

Meson production in $p + p$ collisions

Compilation of published PHENIX results on meson production in $p+p$ collisions at $\sqrt{s_{NN}}$ = 200 GeV

PRD83, 052004



Impressive set of meson measurements: wide p_T range, multiple decay modes, solid baseline for A+A collisions.

At mid-rapidity, spectra are very well described by Tsallis functional form over the entire momentum range.

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{2\pi}\frac{d\sigma}{dy}\frac{(n-1)(n-2)}{(nT+m_0(n-1))(nT+m_0)} \times \left(\frac{nT+m_T}{nT+m0}\right)^{-n}$$

Only two global parameters n and T, and one particle dependent normalization are sufficient.

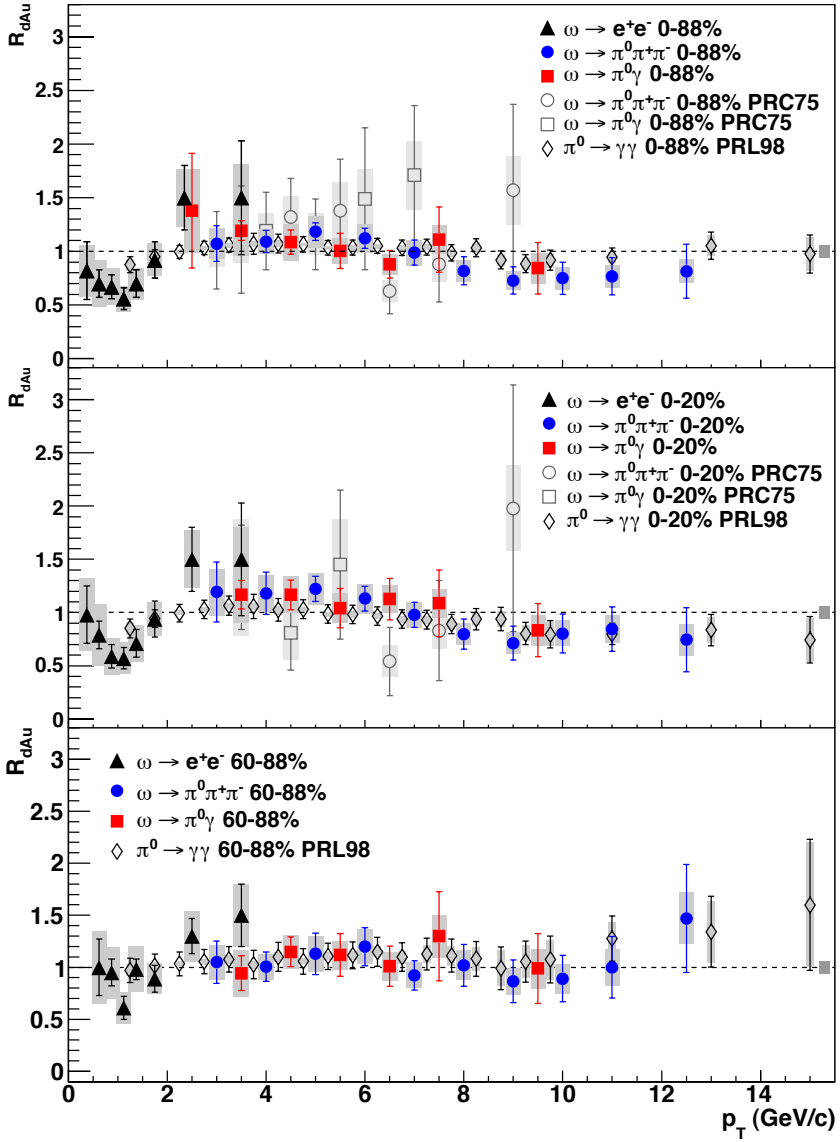
Consequently, one can extract the integrated yield (dN/dy) of a given particle, even if the spectra are measured over a limited p_T range.

Nuclear modification factors

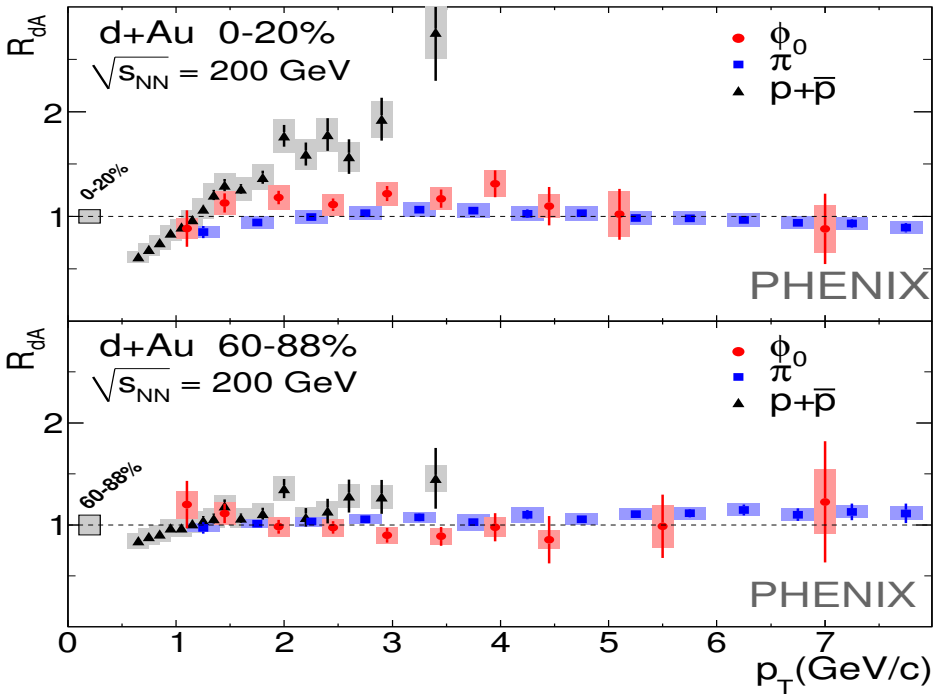
at $\sqrt{s_{NN}} = 200$ GeV

Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
In $d + Au$ collisions

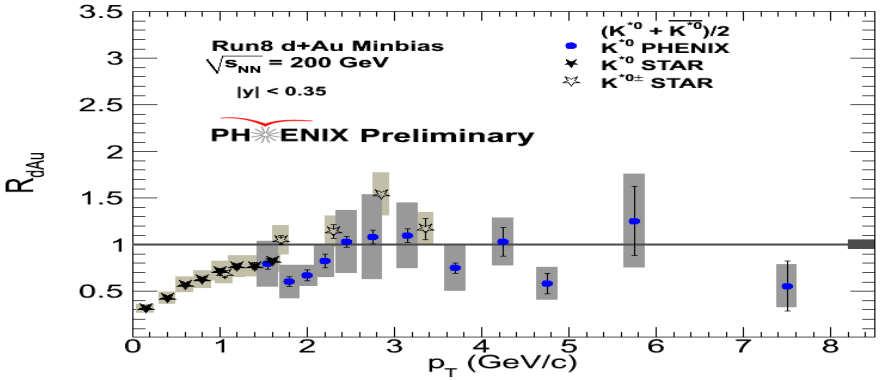
$\omega \to e^+e^-, \pi^0\gamma$



$\phi \to K^+K^-$

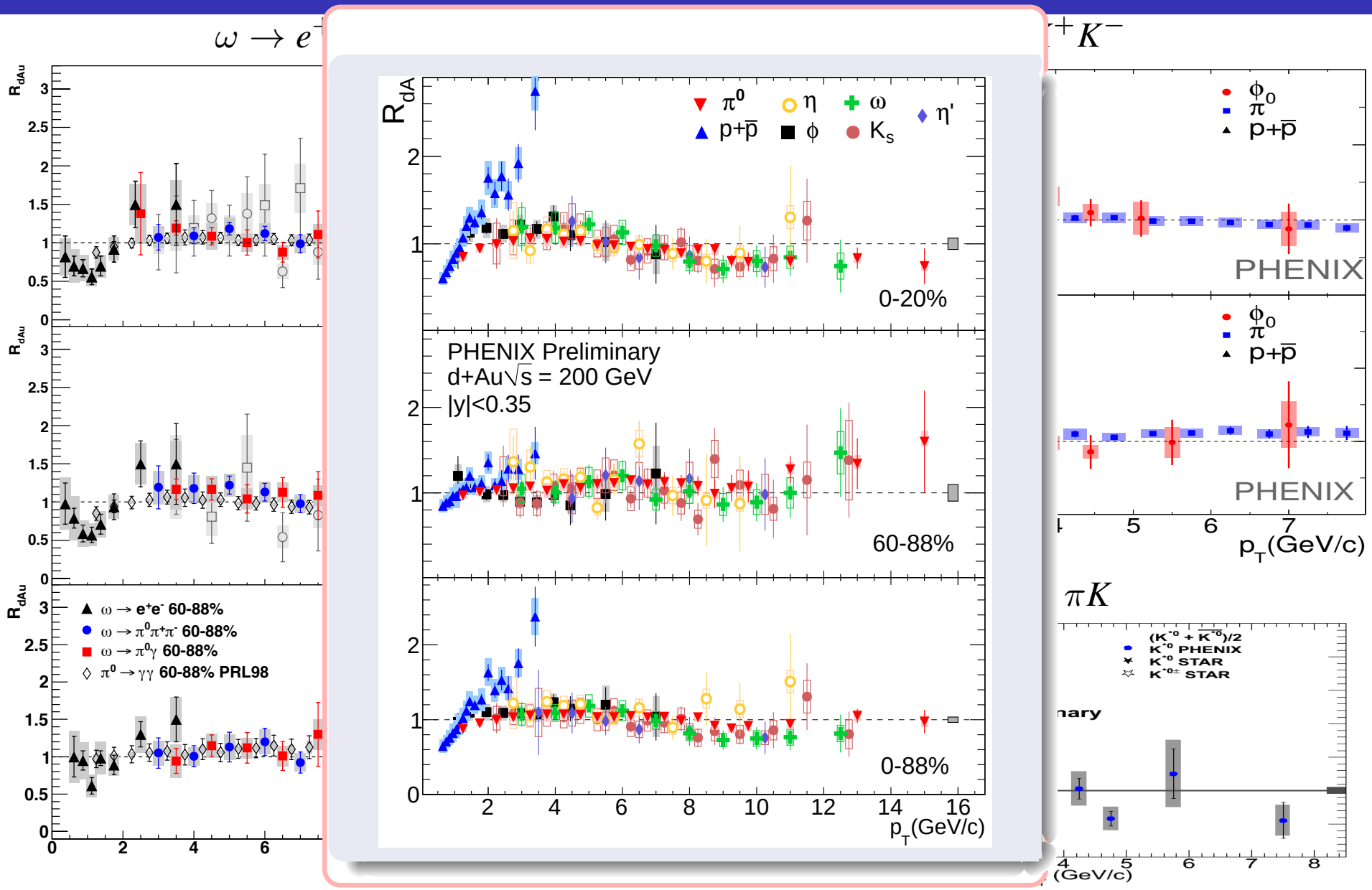


$K^* \to \pi K$



More details in poster by D. Kotov

Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
In $d + Au$ collisions



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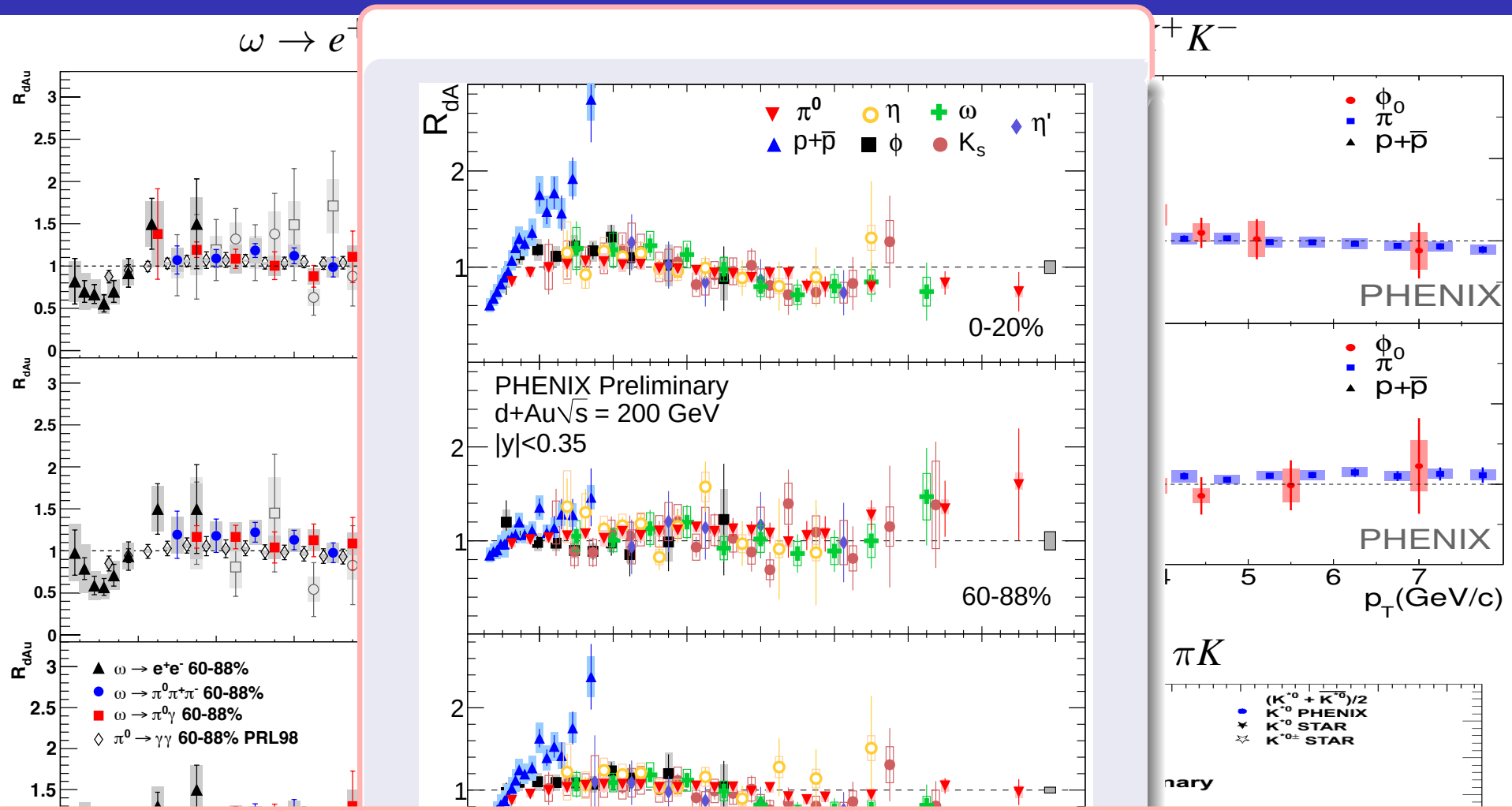
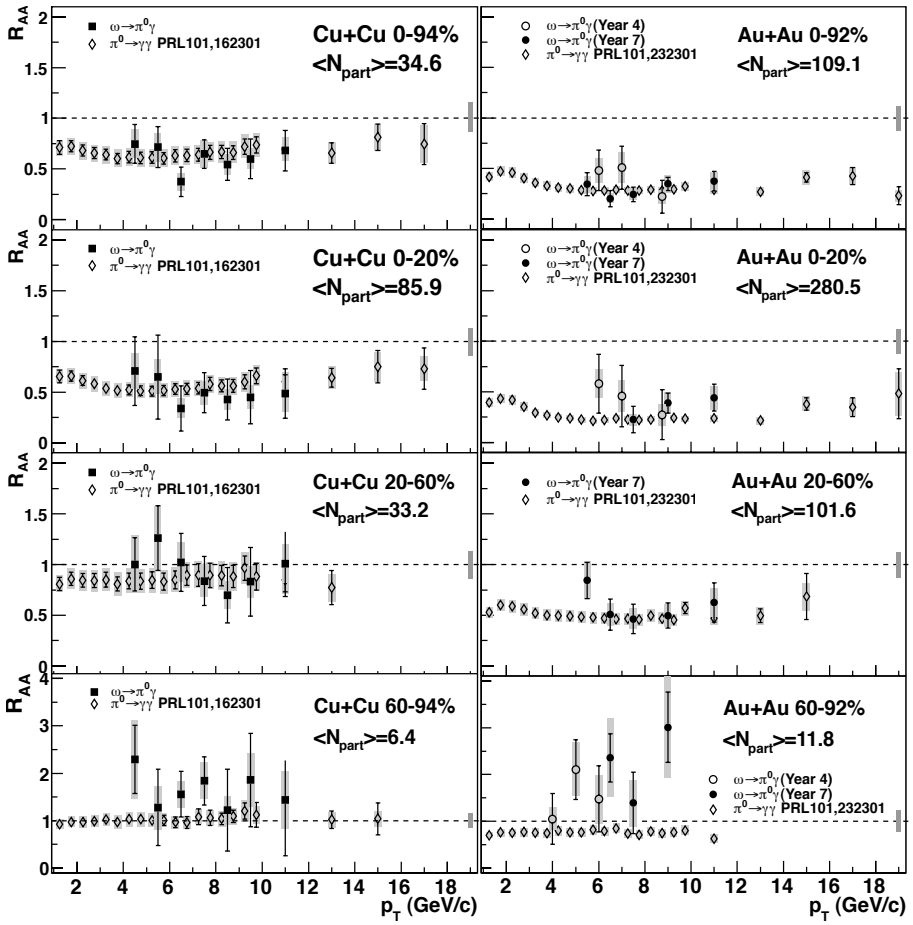


- **In $d + Au$ collisions, the nuclear modification factor (R_{dAu}) of ω, ϕ and K^* are similar to that of π^0.**
- **hint of modest Cronin enhancement in central $d + Au$ collisions at intermediate p_T.**

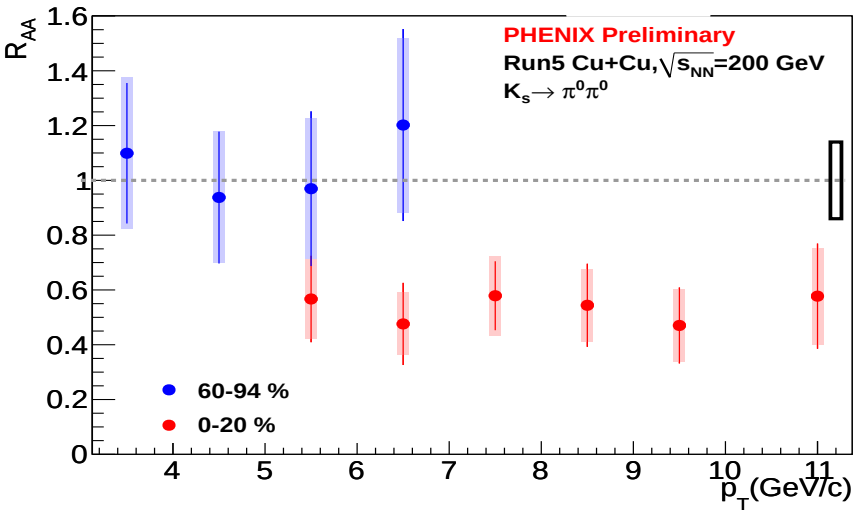
More details in poster by D. Kotov

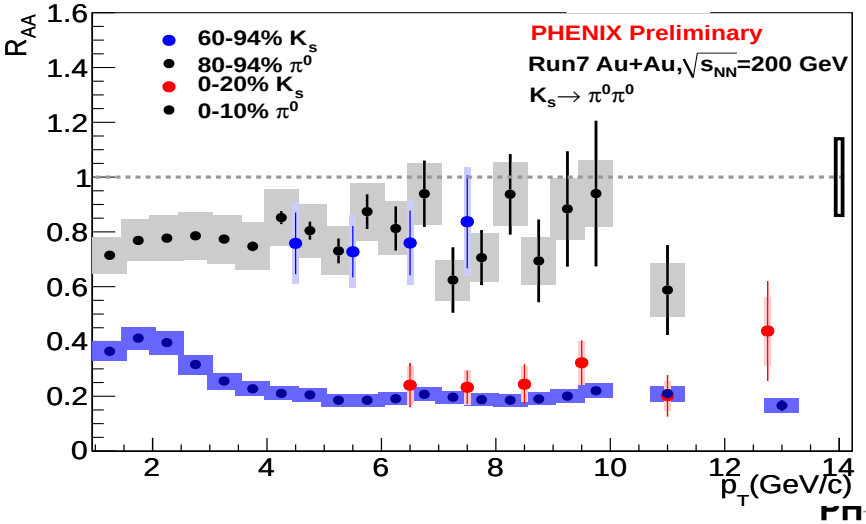
Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
ω and K_s in $Cu + Cu$ and $Au + Au$ collisions

$\omega \rightarrow \pi^0\gamma$ (arXiv:1105.3467)



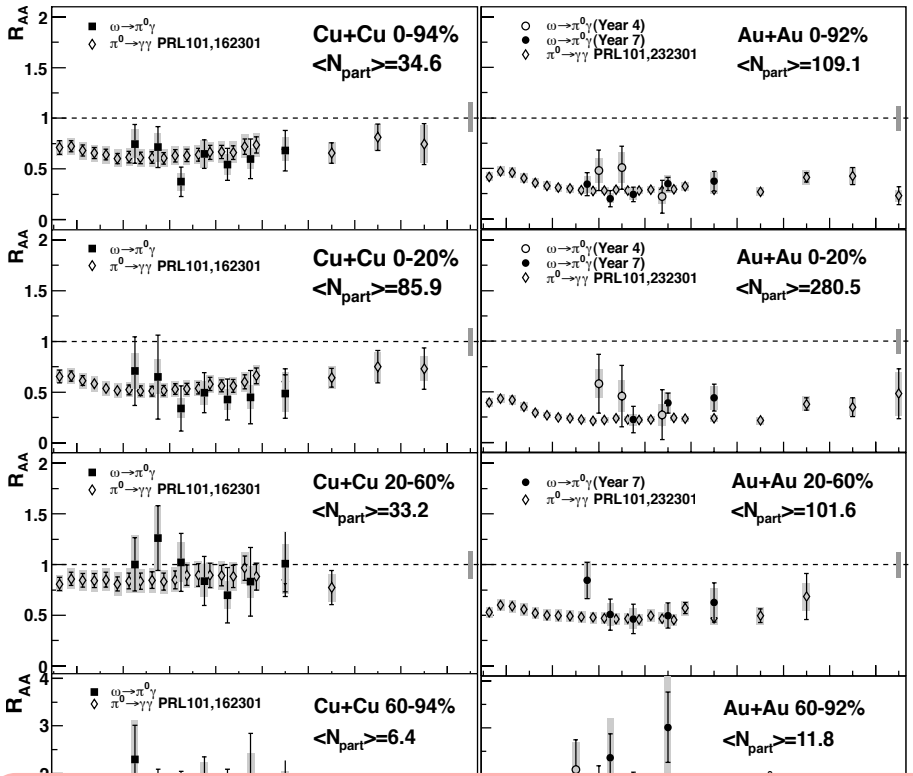
$K_s \rightarrow \pi^0\pi^0$



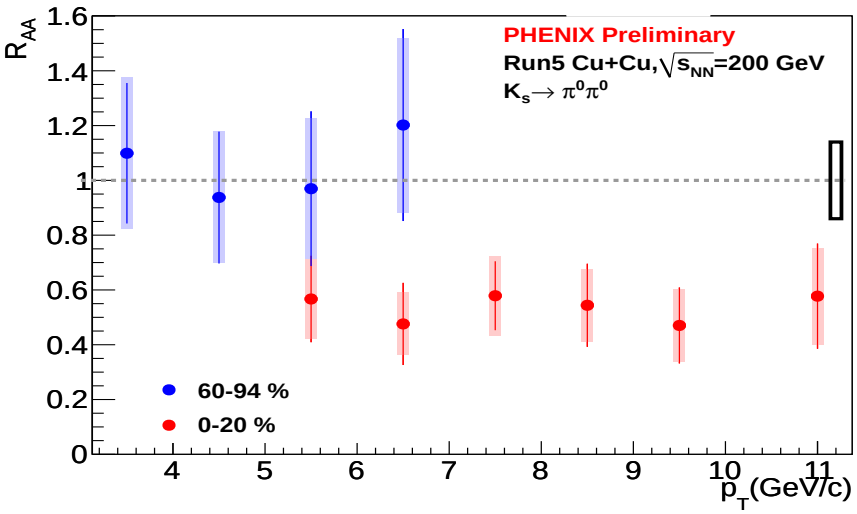


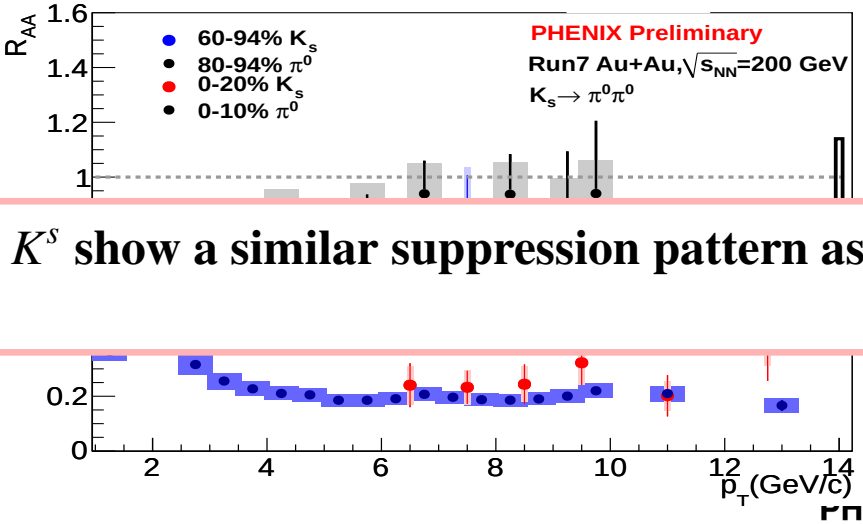
Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
ω and K_s in $Cu + Cu$ and $Au + Au$ collisions

$\omega \rightarrow \pi^0\gamma$ (arXiv:1105.3467)



$K_s \rightarrow \pi^0\pi^0$

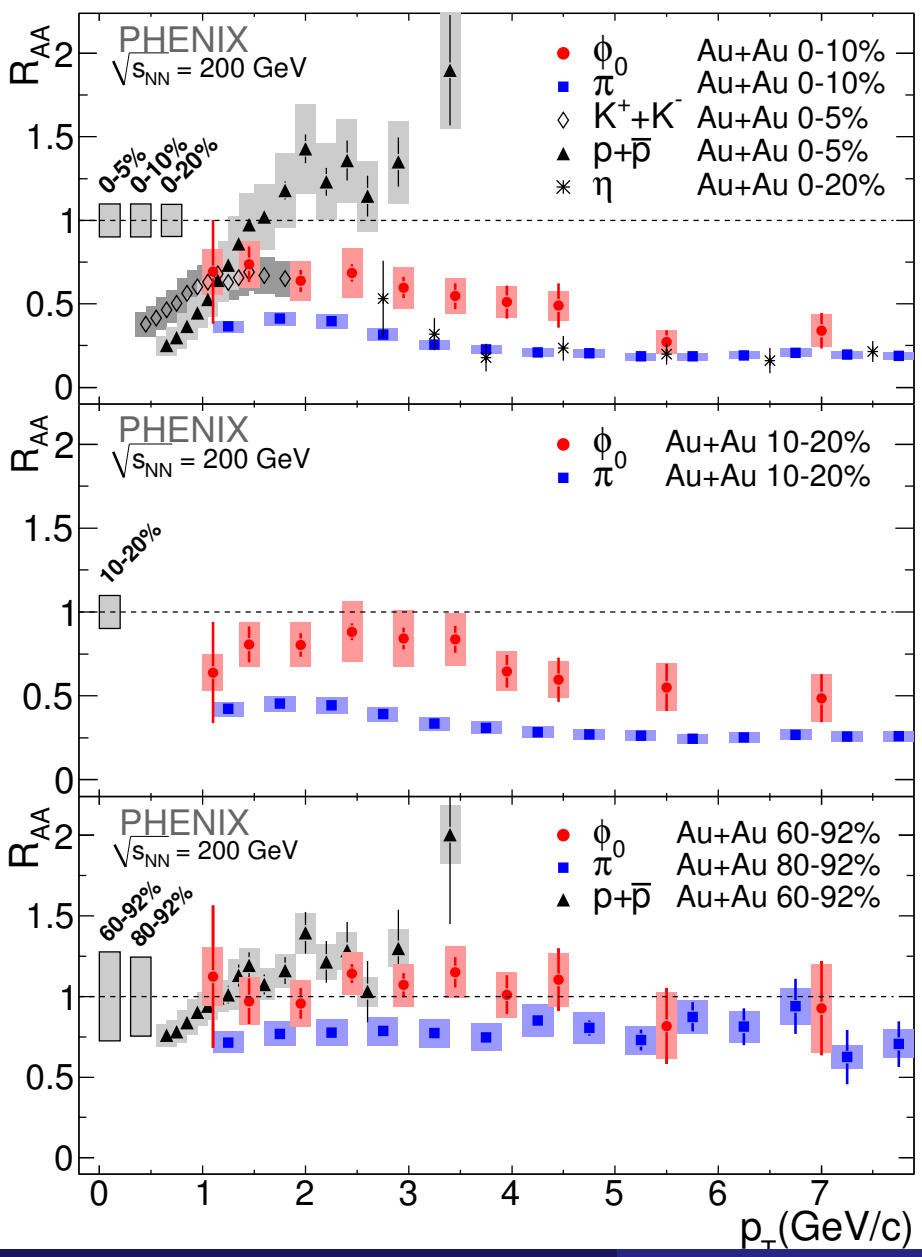


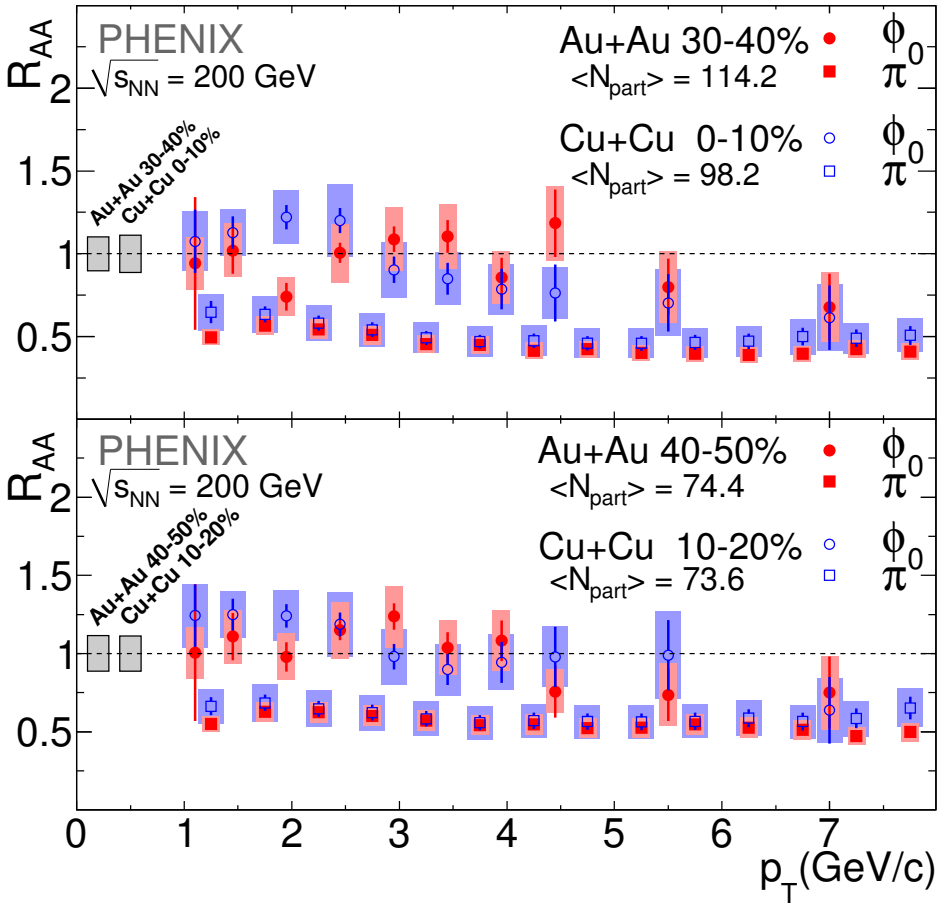


- **In $Cu + Cu$ and $Au + Au$ collisions, ω and K^s show a similar suppression pattern as that of π^0.**

Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV

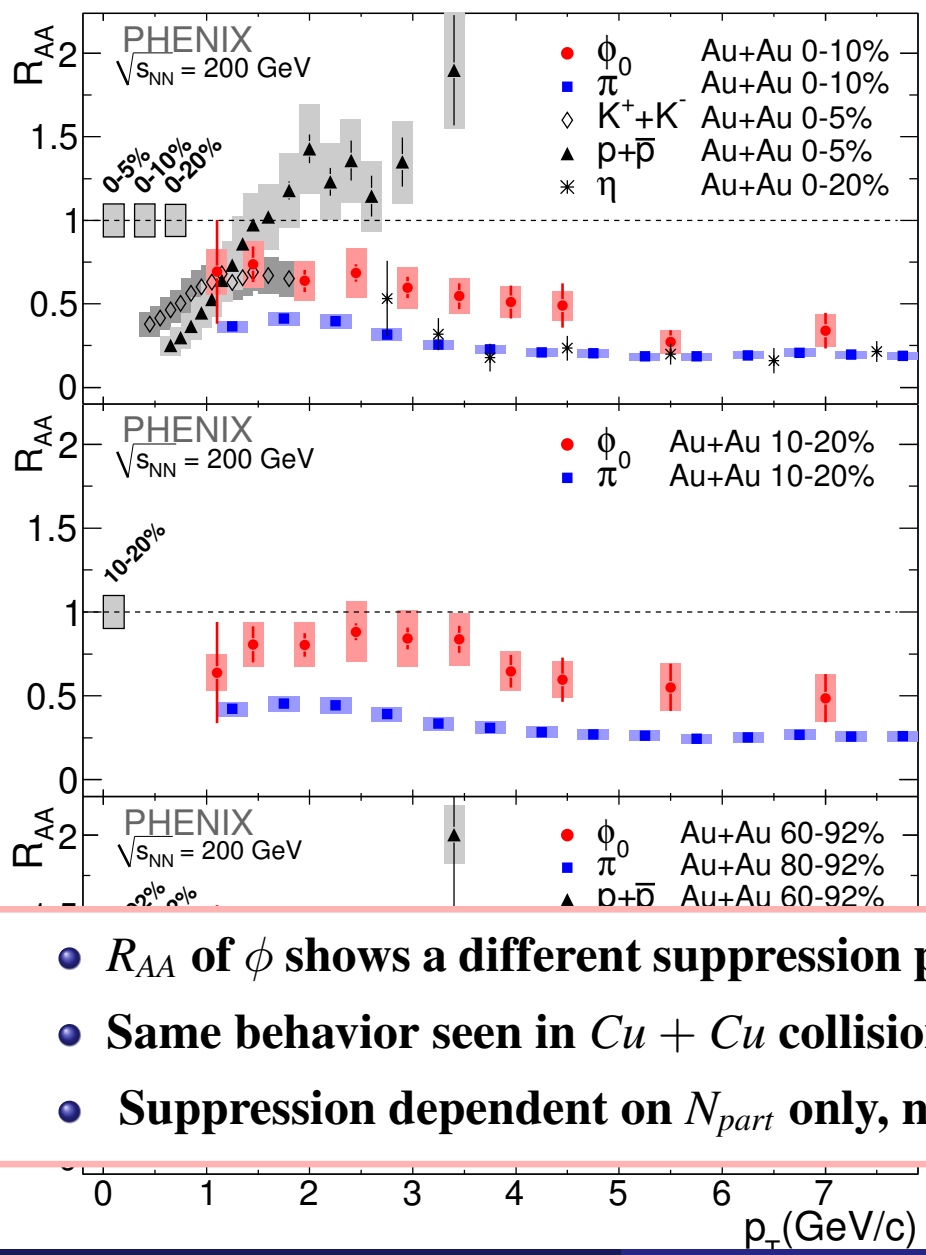
$\phi \rightarrow K^+K^-$ in $Cu + Cu$ and $Au + Au$ collisions (PRC83, 024909)

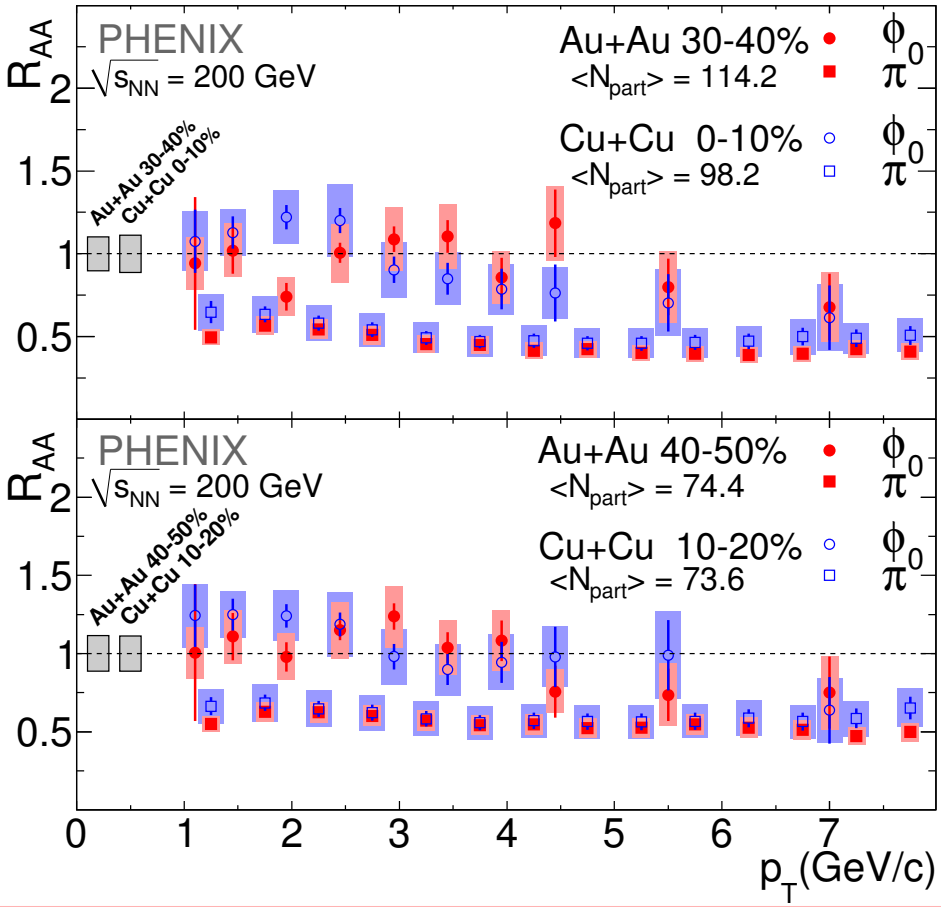




Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV

$\phi \rightarrow K^+K^-$ in $Cu + Cu$ and $Au + Au$ collisions (PRC83, 024909)

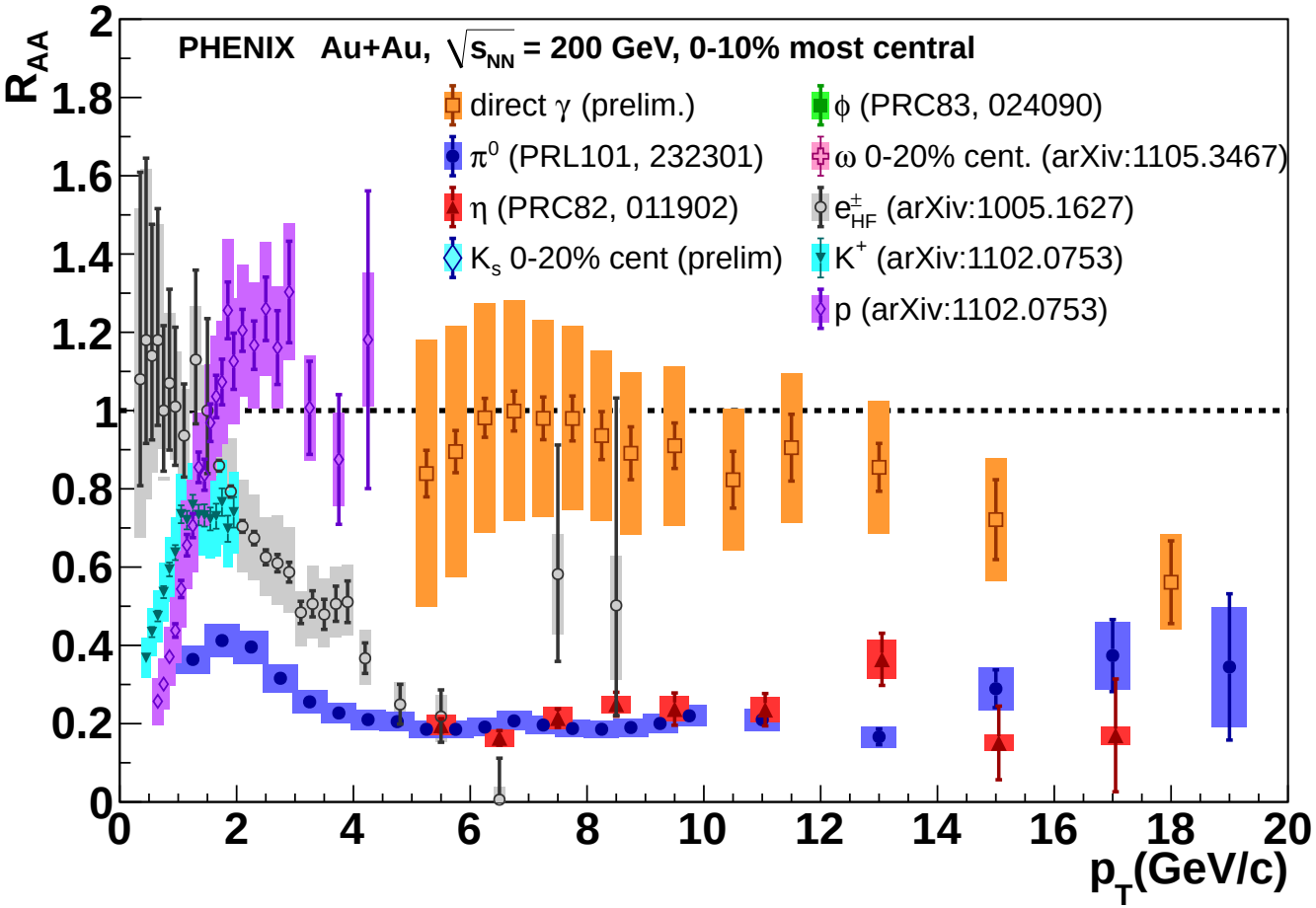




- R_{AA} of ϕ shows a different suppression pattern at intermediate p_T in $Au + Au$ collisions.
- Same behavior seen in $Cu + Cu$ collisions.
- Suppression dependent on N_{part} only, no dependence on collision systems.

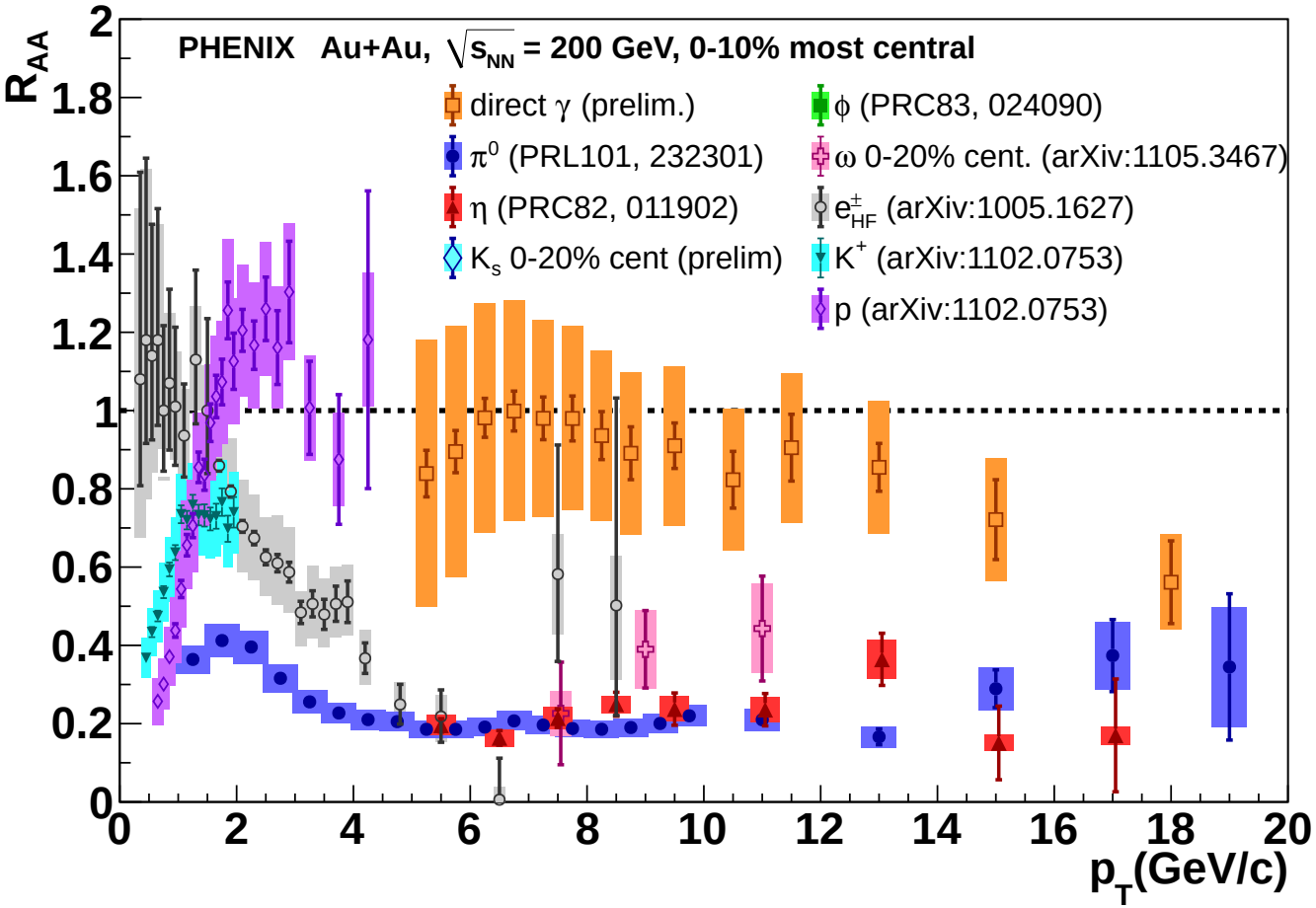
Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
Comparison to other particles

R_{AA} of direct γ, π^0, η, K, ϕ, $e^{\pm}_{HF}$, p, ω, K_s (Plenary talk by M. Purscke (3-1 Jets) 25th May)



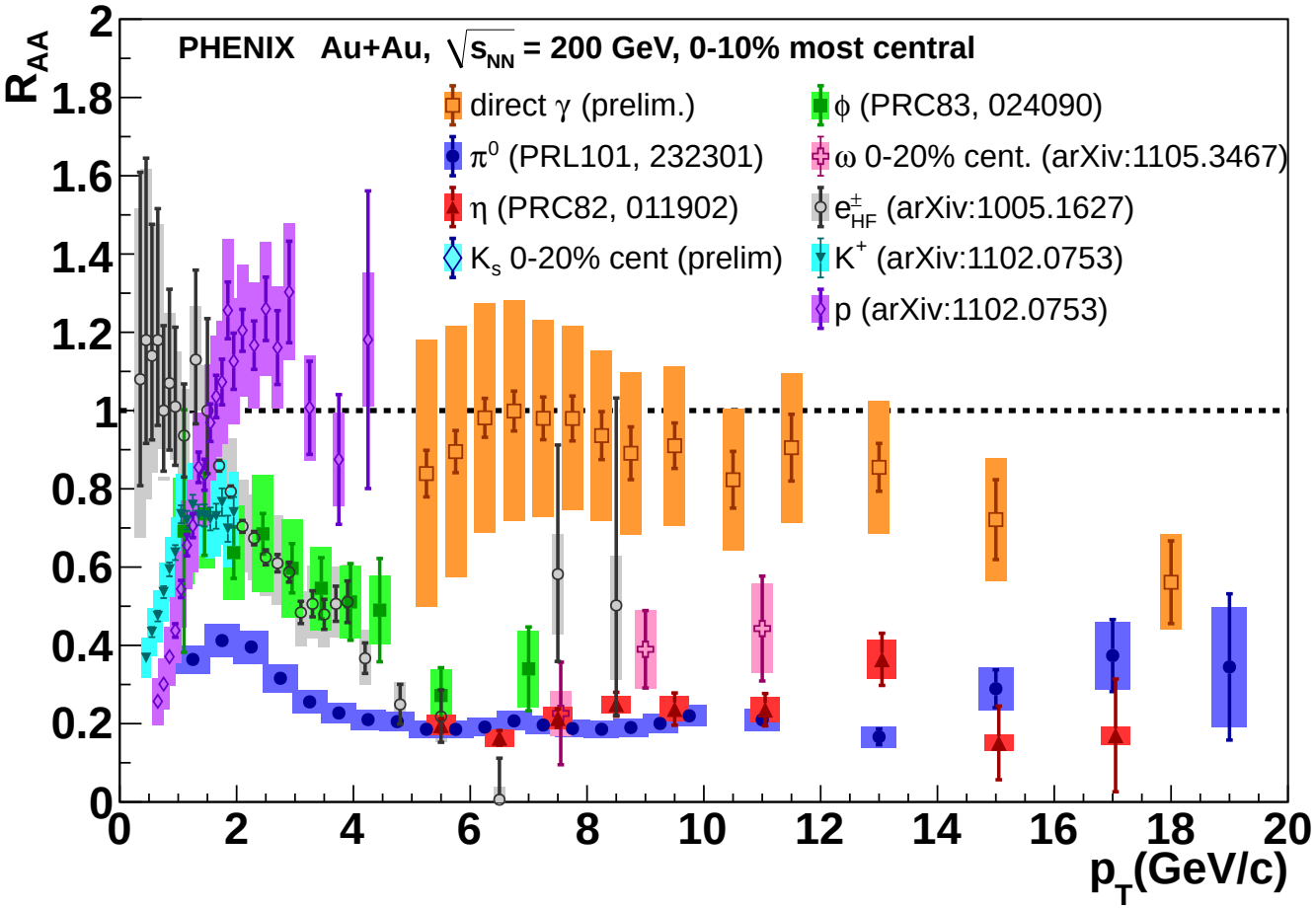
Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
Comparison to other particles

R_{AA} of direct γ, π^0, η, K, ϕ, $e^{\pm}_{HF}$, p, ω, K_s



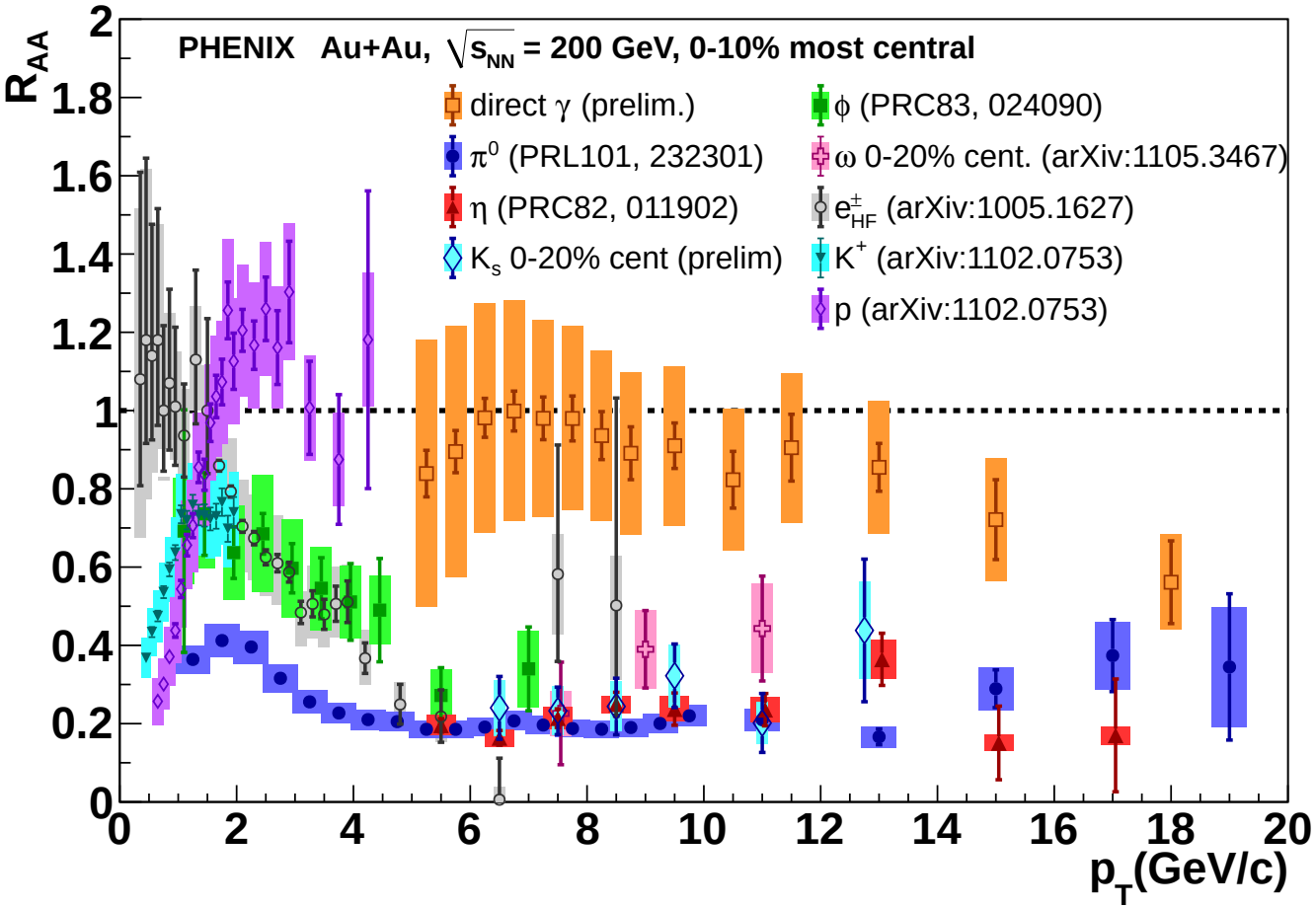
Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
Comparison to other particles

R_{AA} of direct γ, π^0, η, K, ϕ, $e^{\pm}_{HF}$, p, ω, K_s



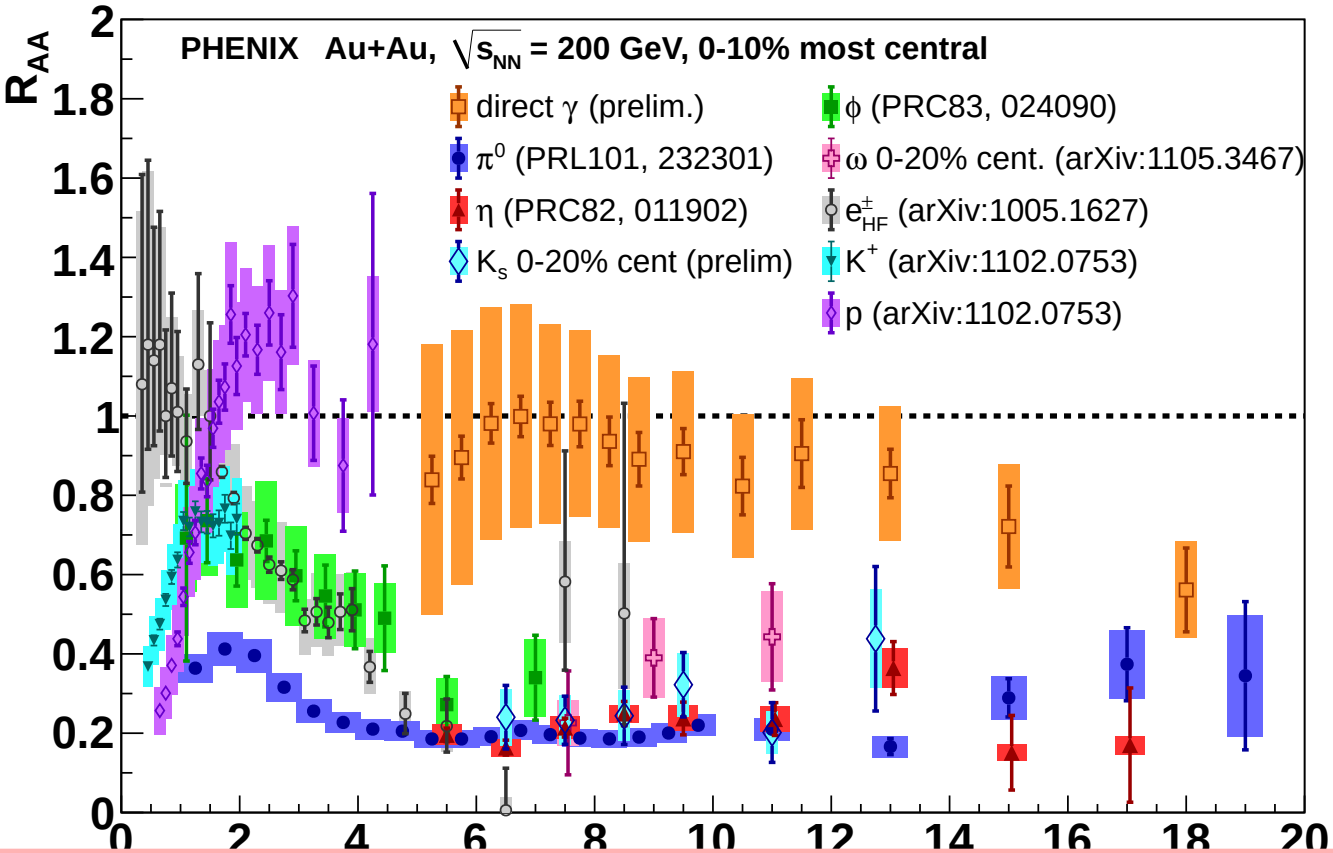
Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
Comparison to other particles

R_{AA} of direct γ, π^0, η, K, ϕ, $e^{\pm}_{HF}$, p, ω, K_s



Nuclear modification factor at $\sqrt{s_{NN}} = 200$ GeV
Comparison to other particles

R_{AA} of direct γ, π^0, η, K, ϕ, $e^{\pm}_{HF}$, p, ω, K_s



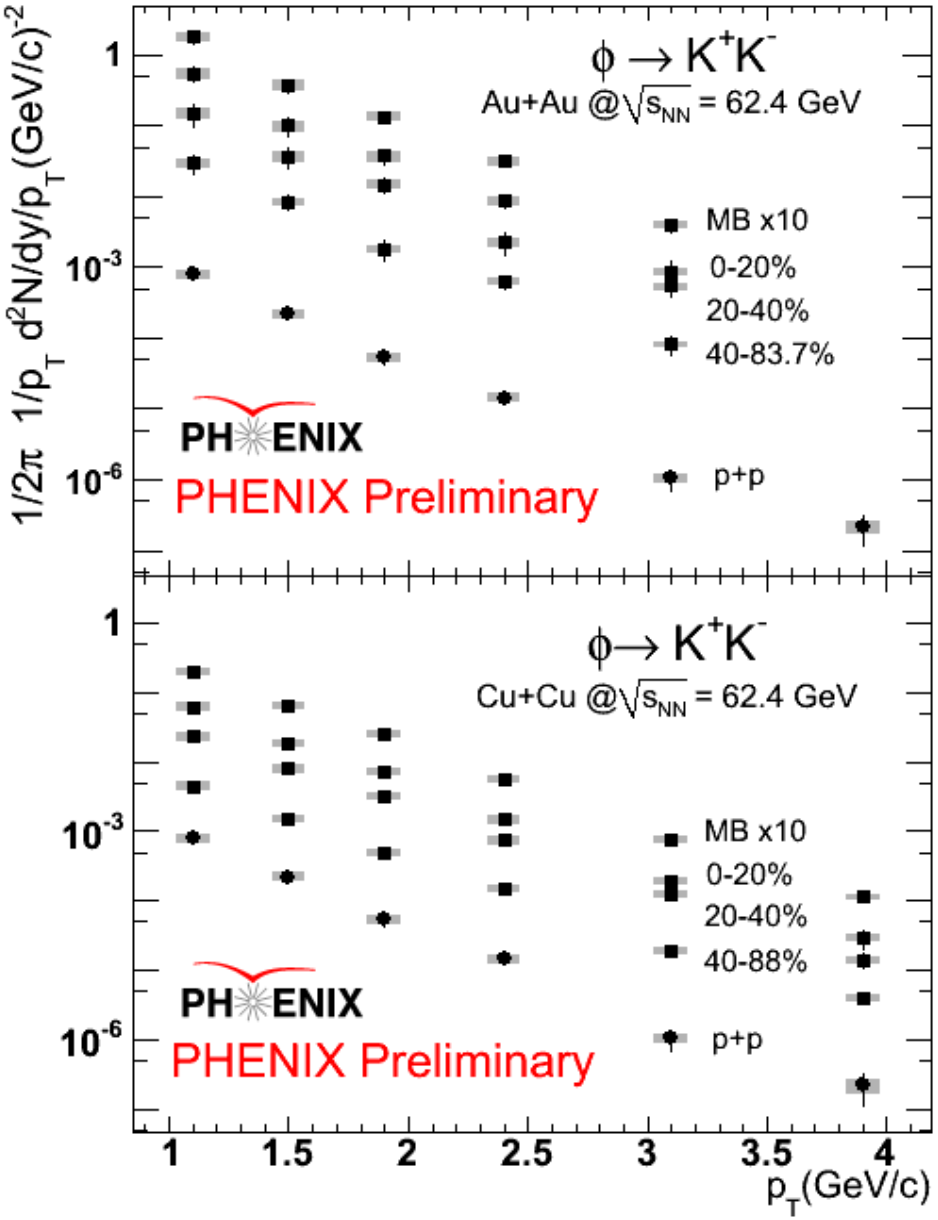
- **The suppression is same (hard scattering/ jet fragmentation) for all mesons at high p_T (> 7 Gev/c) and differences are at intermediate p_T(2-7 GeV/c), essentially for the mesons composed of "s" and "c" quarks.**
- **"s" and "c" seem to follow the same pattern.**

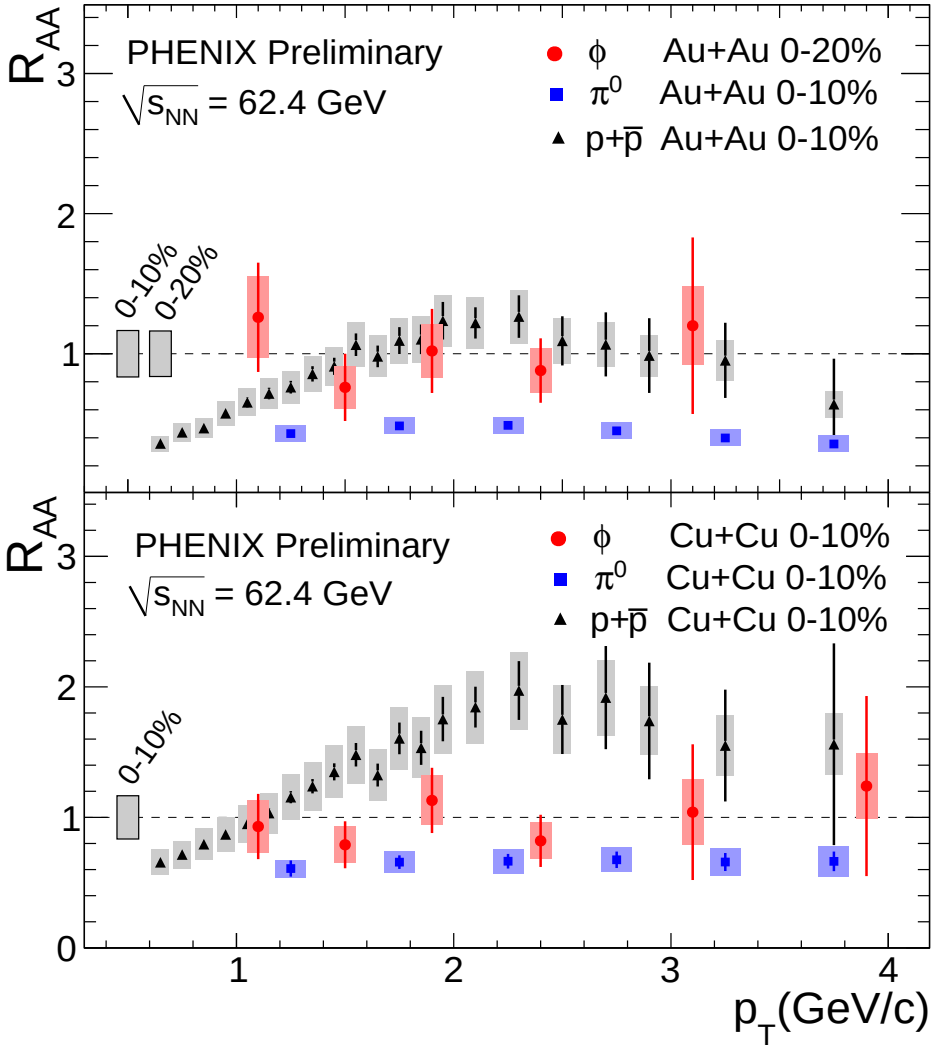
Nuclear modification factors

at $\sqrt{s_{NN}} = 62.4$ GeV

Nuclear modification factor at $\sqrt{s_{NN}} = 62.4$ GeV

$\phi \rightarrow K^+K^-$ in $Cu + Cu$ and $Au + Au$ collisions





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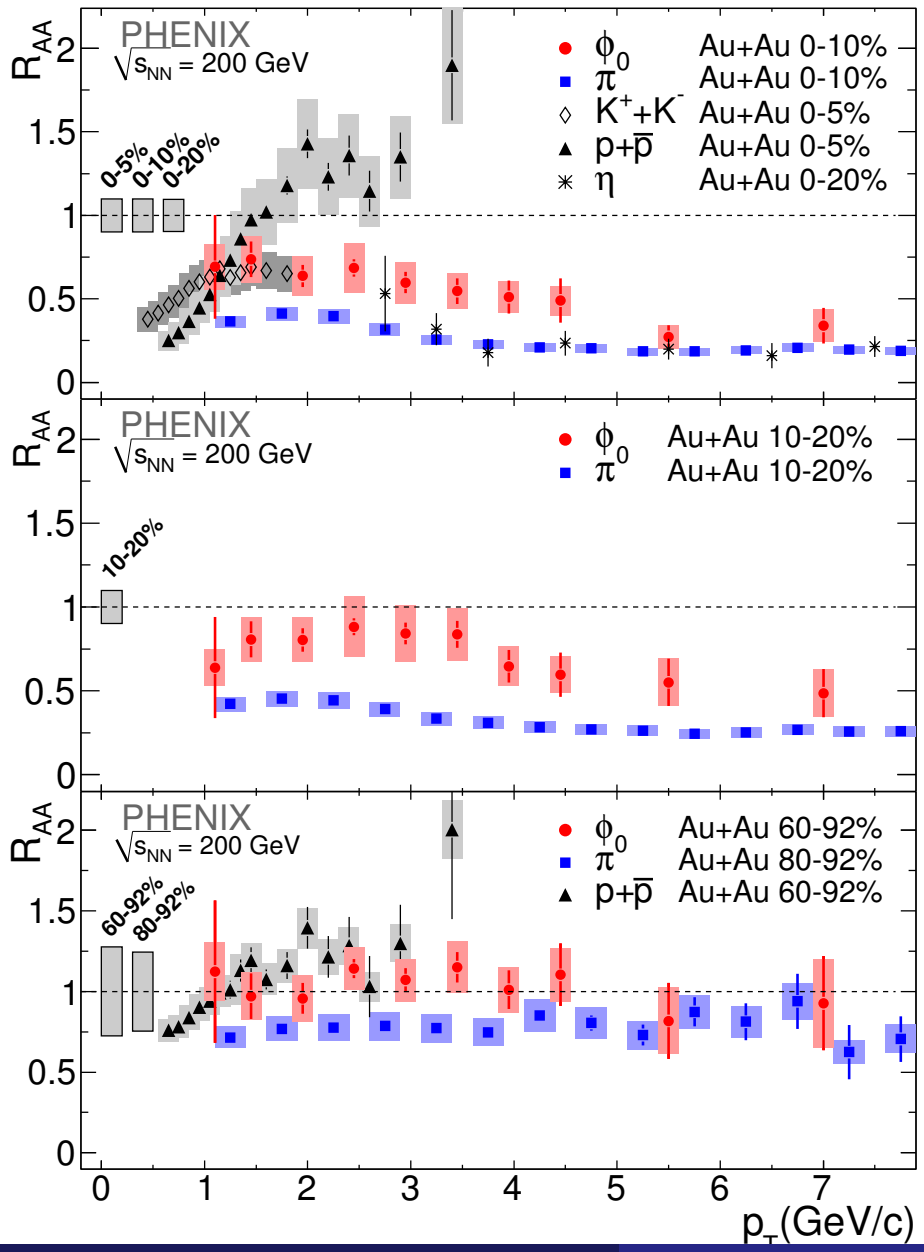

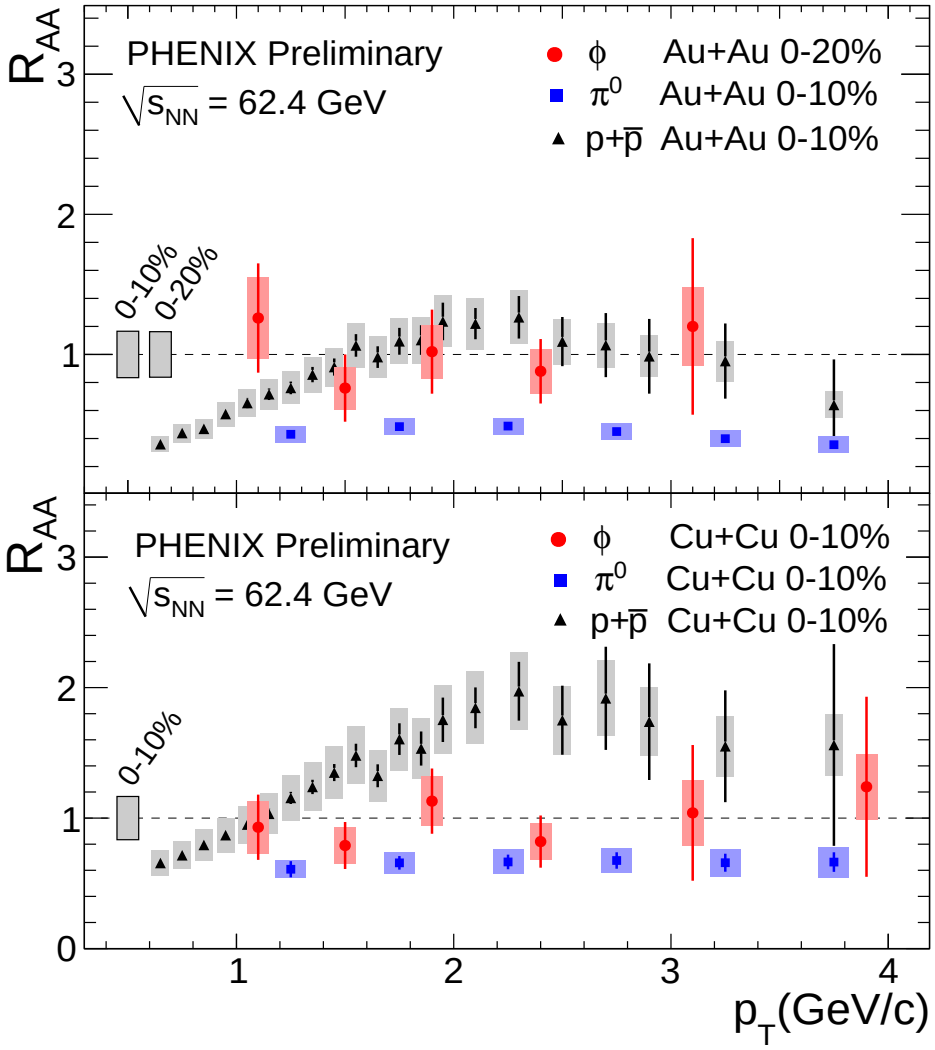

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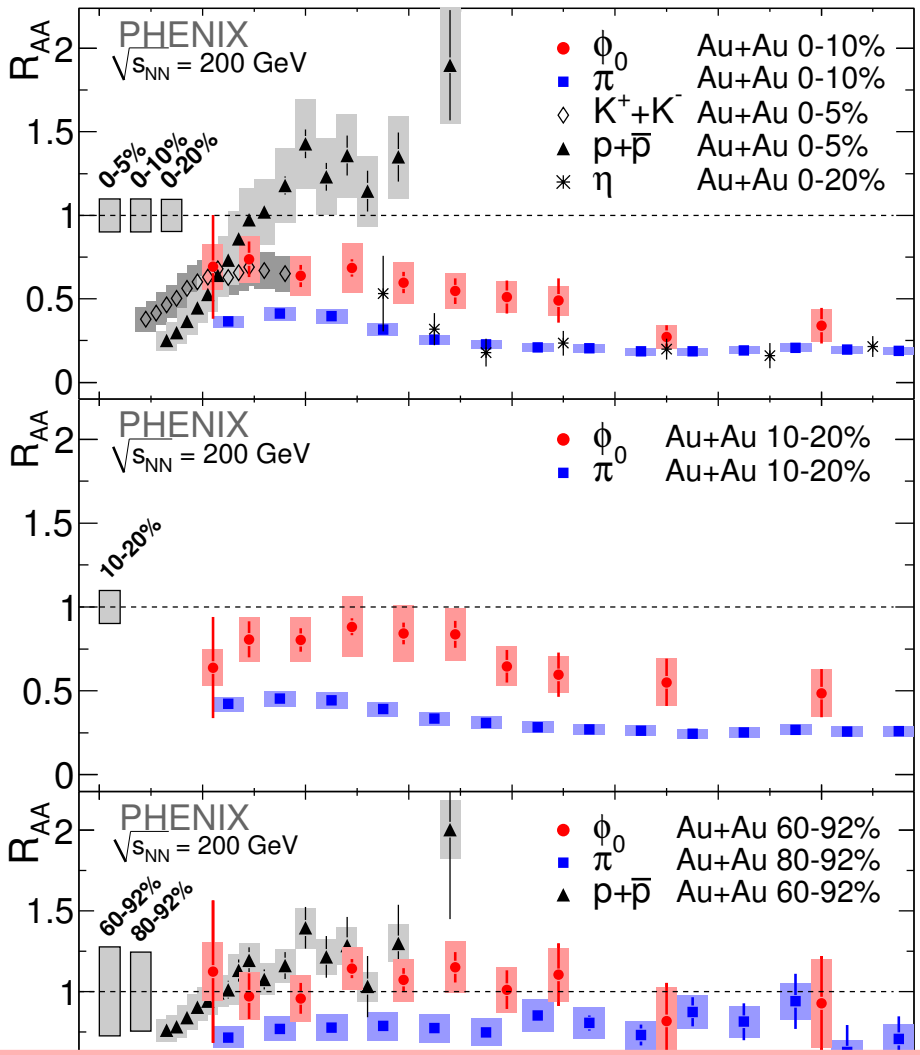
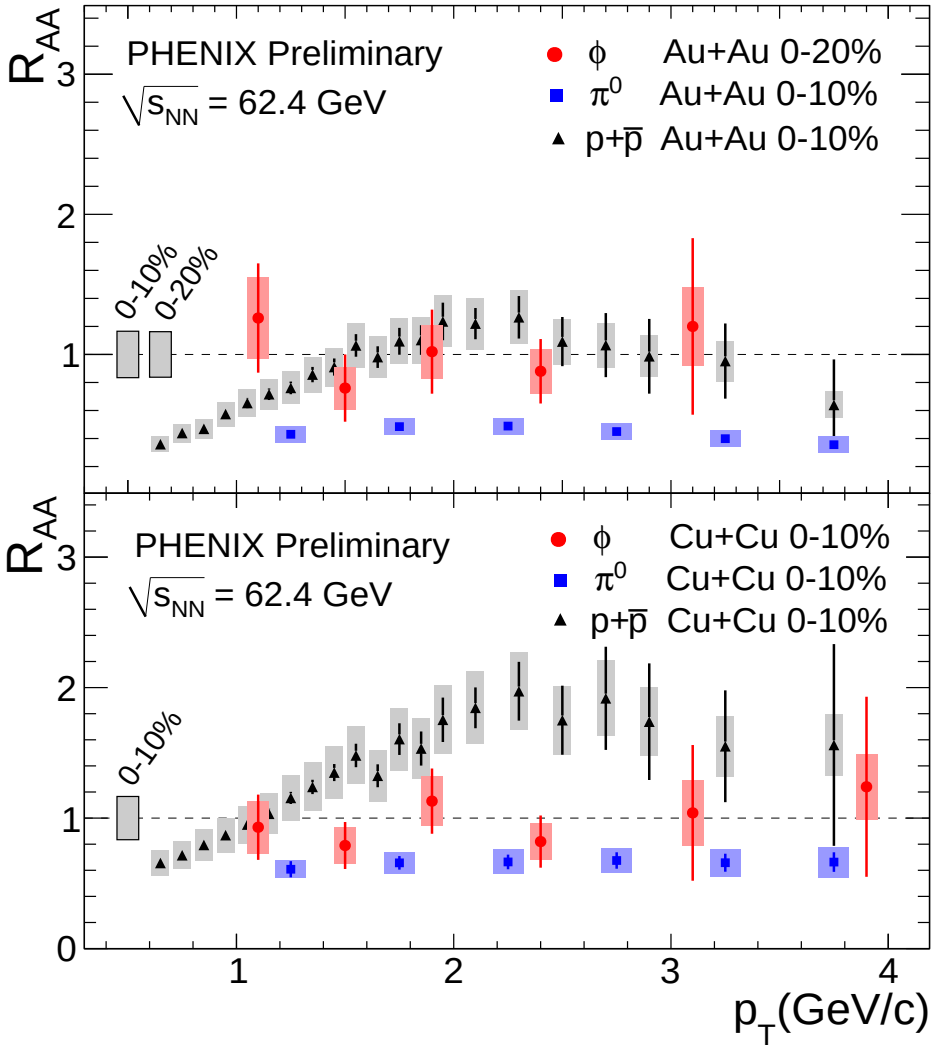




- **Within the current precision, ϕ shows no suppression at 62.4 GeV.**
- **However, similar to 200 GeV results, the R_{AA} of ϕ lies between that of p and π^0.**

Summary

62.4 GeV

The R_{AA} of ϕ at 62.4 GeV shows no suppression, but lies between p and π^0 as seen in 200 GeV collisions.

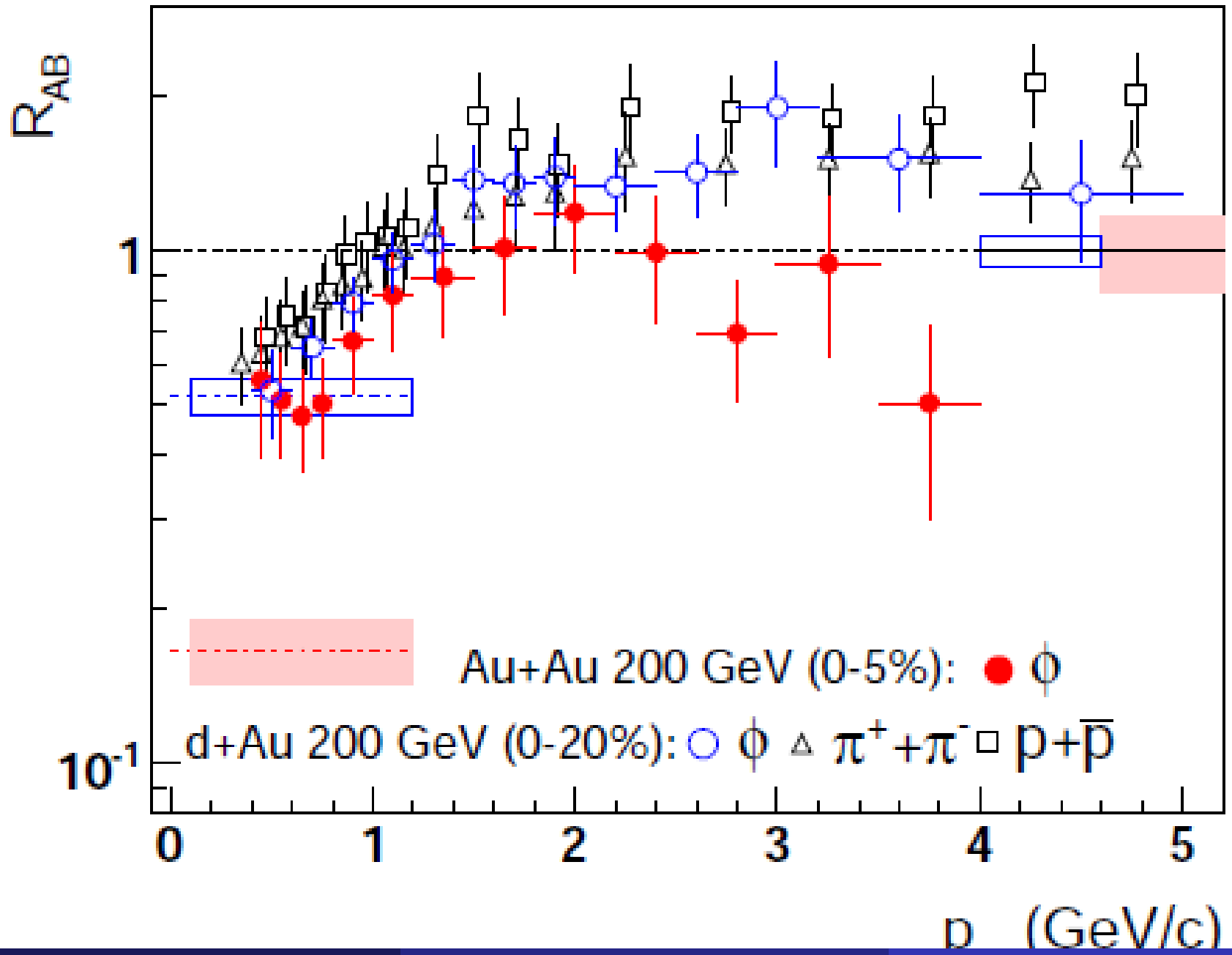
200 GeV

- Consistent results are obtained using the different decay modes for a given meson.
- In $p + p$ collisions, PHENIX measured a wide variety of mesons and the spectra are very well described by the Tsallis functional form over the entire measured p_T.
- In $d + Au$ collisions, the nuclear modification factor of ω, ϕ and K^* is similar to that of π^0
- In $Au + Au$ collisions, similar suppression level is seen for mesons at high p_T, while at intermediate p_T, the suppression is different for ϕ, K and $e^{\pm}_{HF}$.

PHENIX

Back-ups

STAR R_{AA}


R_{AB}
1
10^{-1}
0
1
2
3
4
5
Au+Au 200 GeV (0-5%): ● ϕ
d+Au 200 GeV (0-20%): ○ ϕ △ $\pi^+ + \pi^-$ □ $p+\bar{p}$
p_T (GeV/c)