

# *Multi-particle decays of light mesons measured at RHIC by **PHENIX***

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*for the PHENIX Collaboration*

# Outline

❖ What do we learn from  $\omega$ ,  $\eta$  & K

❖ Analysis:

- ✓ PHENIX detector
- ✓ Acceptance
- ✓ Trigger efficiency
- ✓ Raw data

❖ Results:

- ✓ Spectra
- ✓ Cross-checks
- ✓ Particle Ratios
- ✓ Nuclear modification factors  $R_{AB}$

❖ Summary

# Motivation

## What can we learn from high $p_T$ spectra of $\omega$ , $\eta$ & K

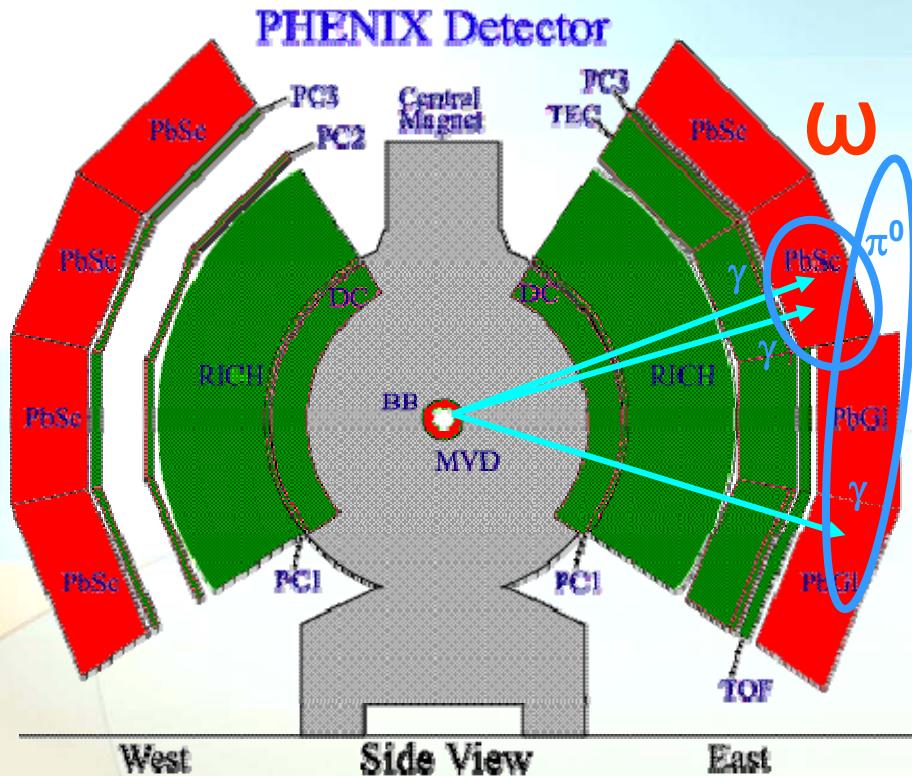
### ❖ In p+p

- ✓ Parton distribution function of the proton.
- ✓ Fragmentation functions
- ✓ Test of pQCD
- ✓ Strangeness content of the event (K)
- ✓ Vector-to-pseudoscalar particle ratio ( $\omega$ )

### ❖ In Heavy Ions collisions:

- ✓ Nuclear modification factors
- ✓ An insight at the Chiral Symmetry Restoration ( $\omega$ )

# PHENIX Experiment

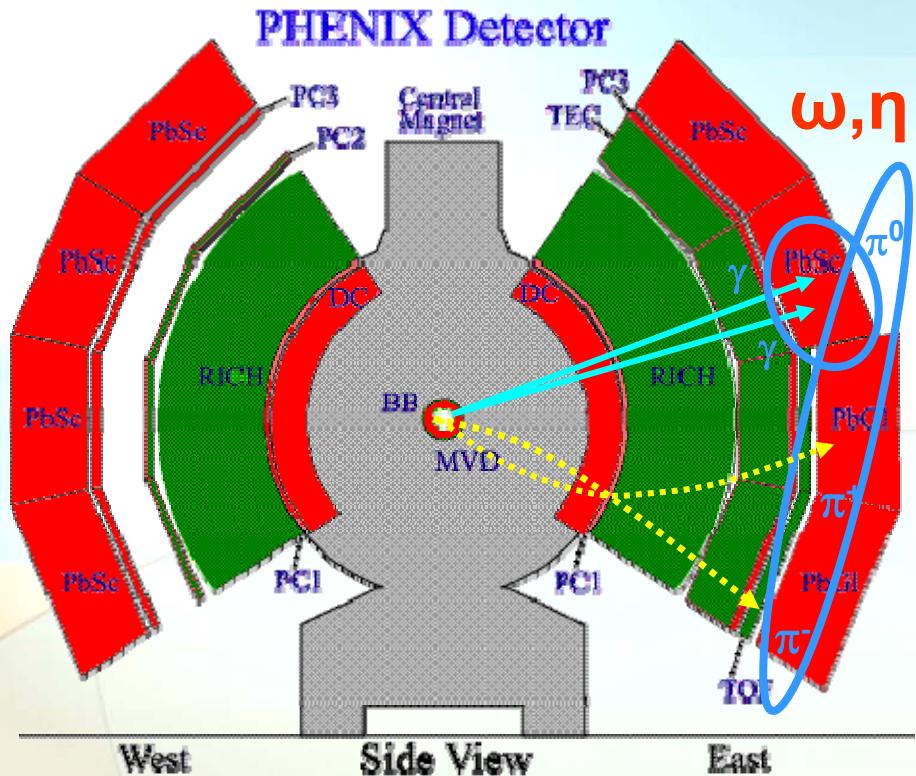


BBC (vertex)	$dz = 0.5\text{cm} \dots 2\text{cm}$
BBC (trigger)	$\epsilon = 50\% \dots 92\%$
DC/PC1 (tracking)	$d\mathbf{p}_T/\mathbf{p}_T \sim 1.0\% \cdot \mathbf{p}_T + 0.7\%$
EMC (calorimetric)	$dE/E \sim 8.1\%/\sqrt{E} + 3.0\%$
EMC (t.o.f.)	$d\tau \sim 500 \text{ ns}$
EMC ( $\gamma$ -trigger)	$0.4\text{GeV} \dots 2.5\text{GeV}$
PC3 (matching)	2-4 mm

PHENIX acceptance :  
 $-0.35 < \eta < 0.35$   
 $2 \times 90^\circ$  for two arms

$\omega \rightarrow \pi^0\gamma$	$BR = 8.90 \pm 0.25\%$
$\omega \rightarrow \pi^0\pi^+\pi^-$	$BR = 89.1 \pm 0.7\%$
$\eta \rightarrow \pi^0\pi^+\pi^-$	$BR = 22.6 \pm 0.4\%$
$K_s^0 \rightarrow \pi^0\pi^0$	$BR = 31.1 \pm 0.2\%$
$\eta \rightarrow \gamma\gamma$	$BR = 39.4 \pm 0.3\%$
$K^\pm$	using ToF
$K_s^0 \rightarrow \pi^+\pi^-$	$BR = 69.0 \pm 0.2\%$

# PHENIX Experiment

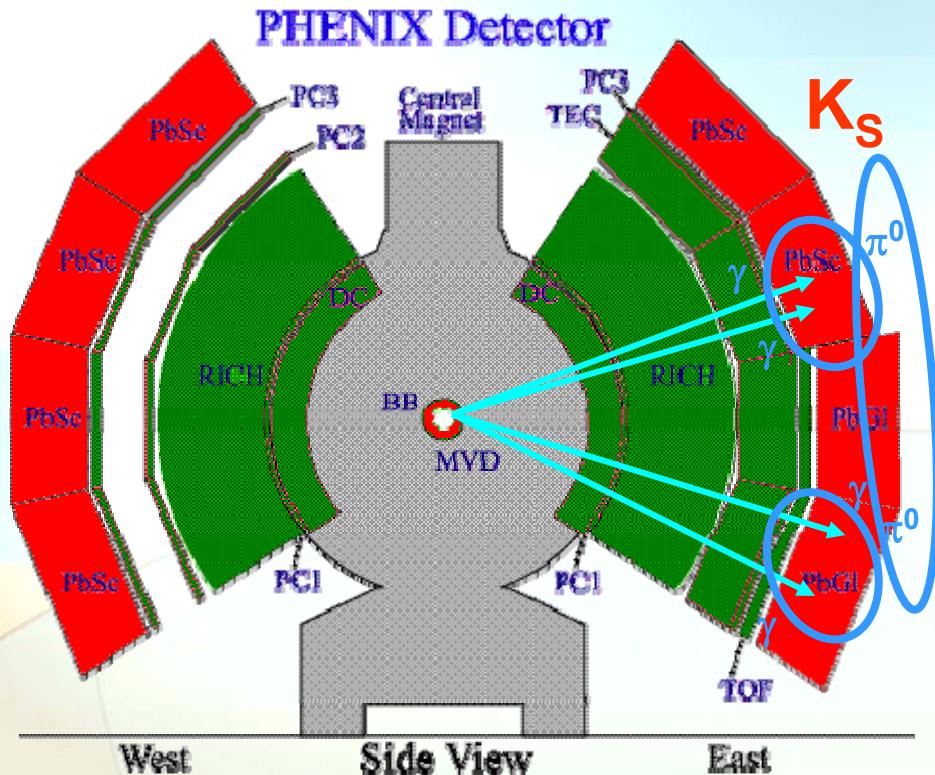


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# Phase space density

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

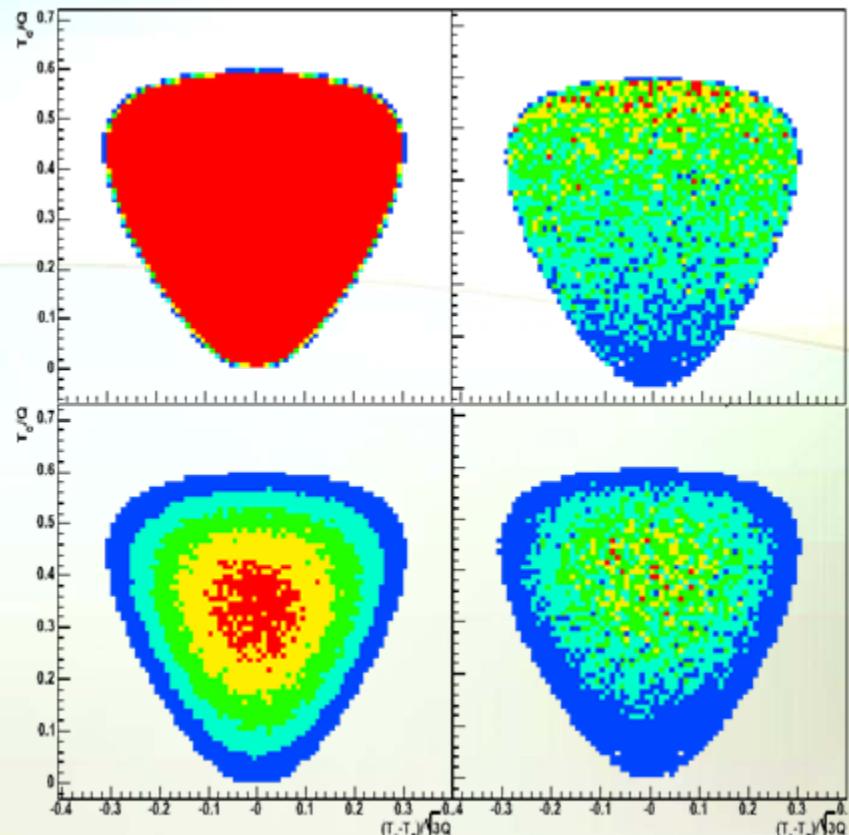
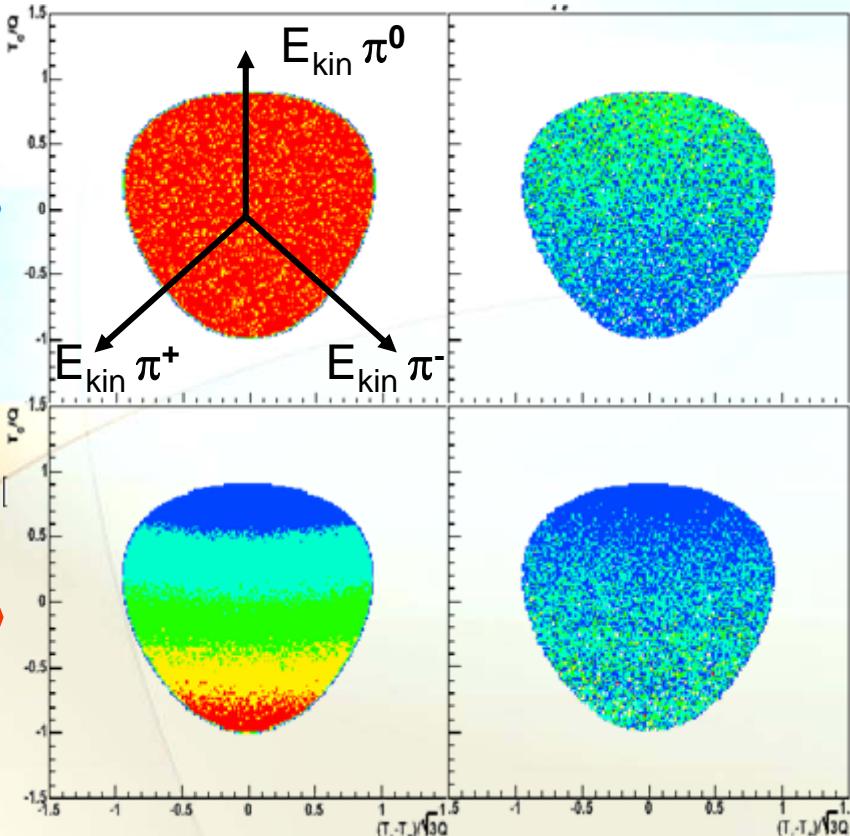
$\omega \rightarrow \pi^0 \pi^+ \pi^-$

All

Accepted

All

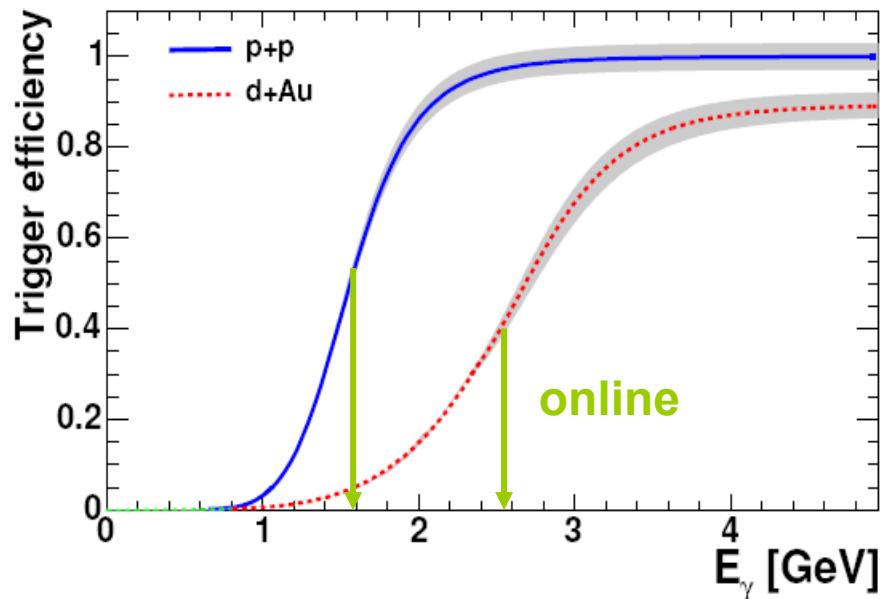
Accepted



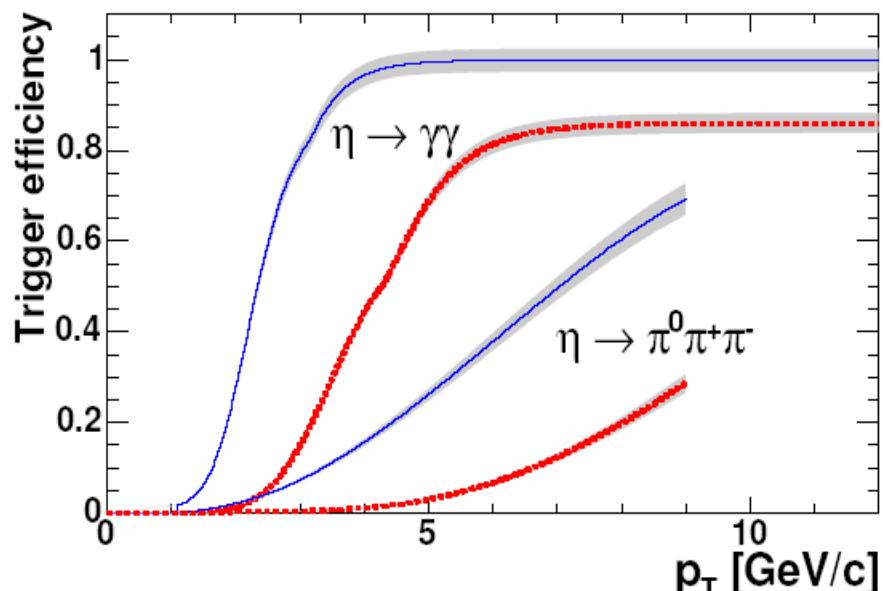
Taking phase space into account is absolutely crucial to get the results right. In PHENIX acceptance difference can reach 40%

# Gamma trigger efficiency

daughters



parents



Gamma-trigger efficiency must be worked out very precisely.

Because of the multi-particle final state even very high  $p_T$  of are affected by the efficiency rising region.

Comparison to Minimum Bias trigger sample is very important.

PRC75 (2007) 024909

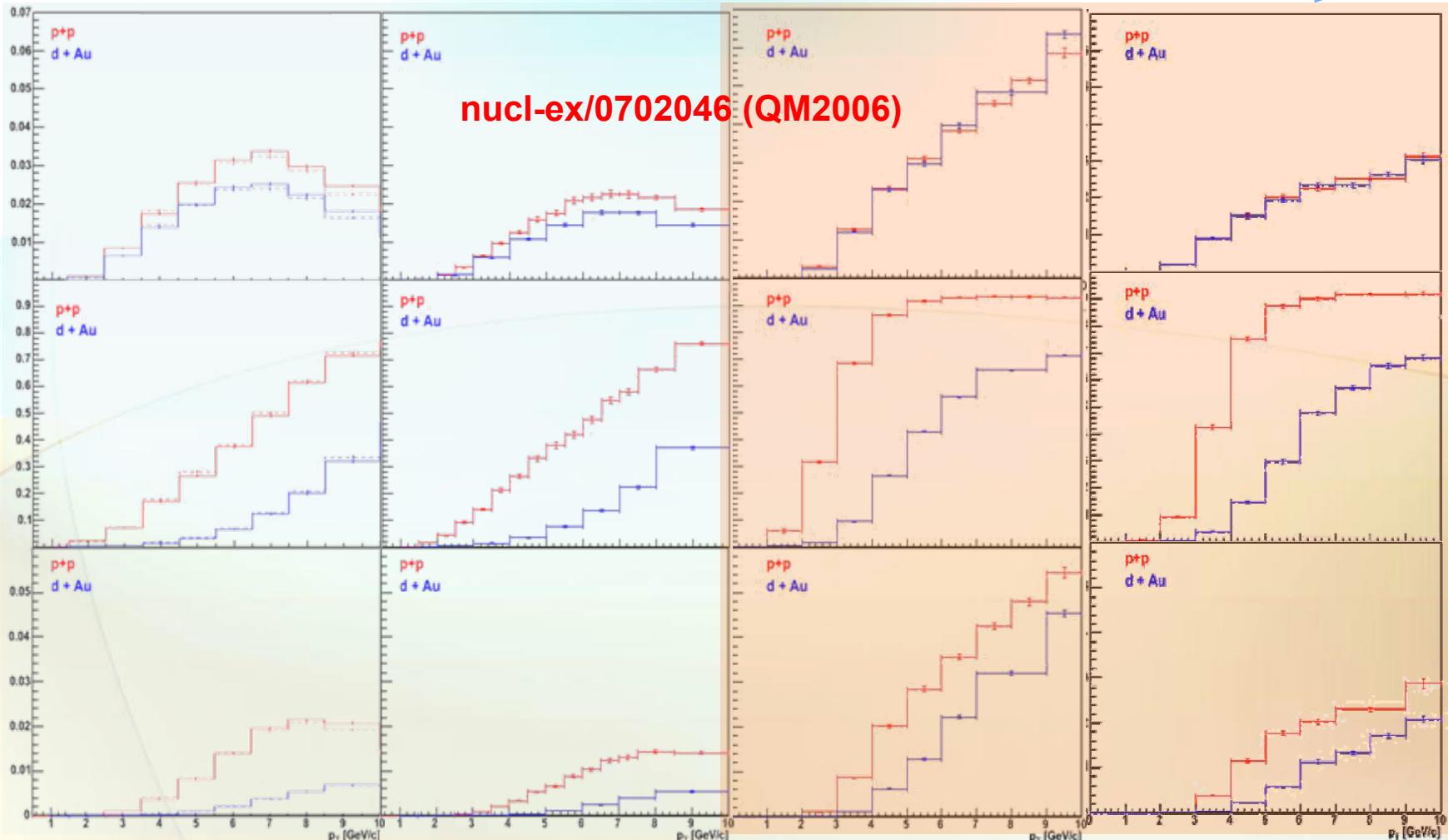
# Acceptances

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

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

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

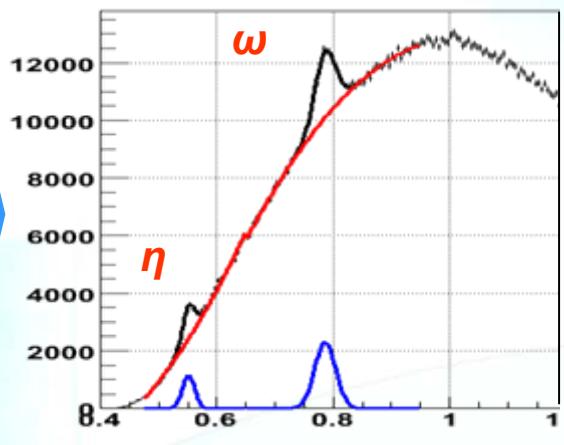
$K^0_S \rightarrow \pi^0 \pi^0$



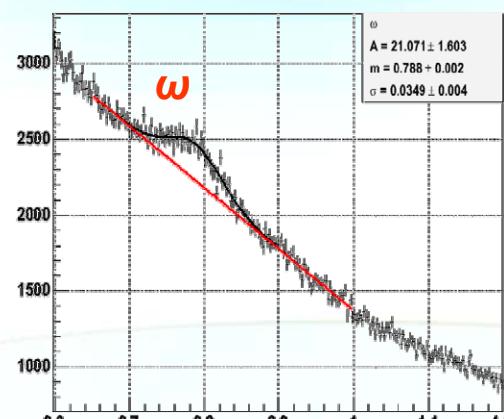
Efficiencies are very different for all decay modes, but certain similarities can be seen.

# Raw yields

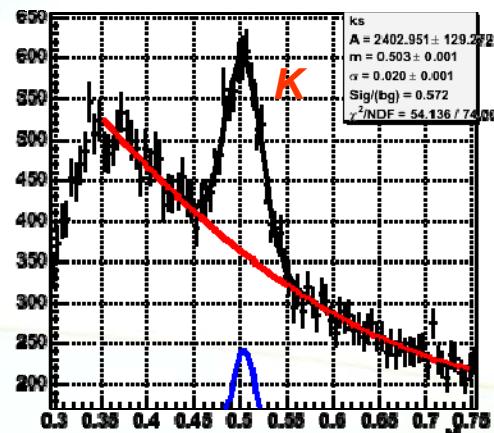
$\eta, \omega \rightarrow \pi^0 \pi^+ \pi^-$



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



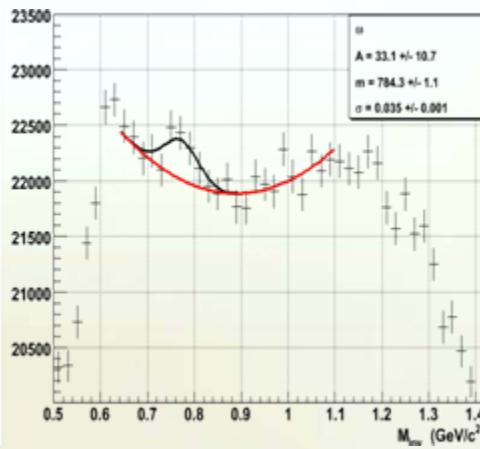
$K_s^0 \rightarrow \pi^0 \pi^0$



$p+p$

$Au+Au$

?

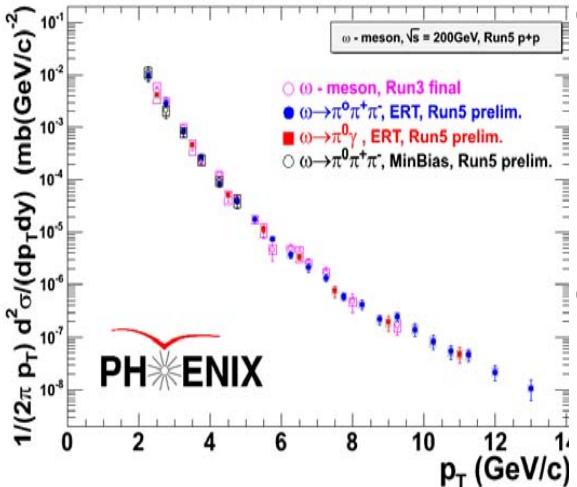


?

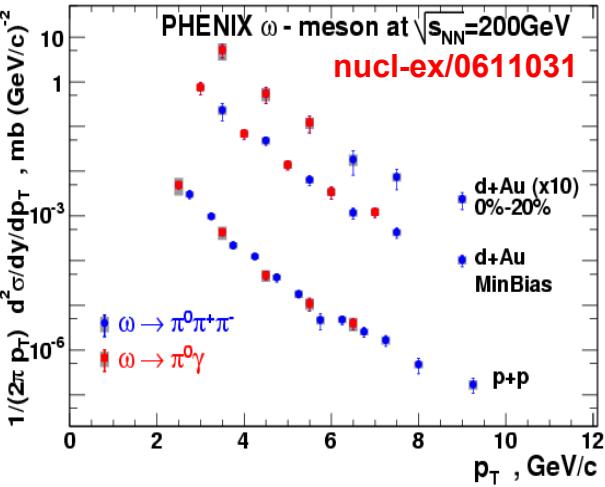
PHENIX has first measurement of  $\omega$  in  $p+p$ ,  $d+Au$  &  $Au+Au$  and measurement of  $K_s^0$  at high  $p_T$  in  $p+p$  and  $d+Au$

# $\omega$ - meson spectra

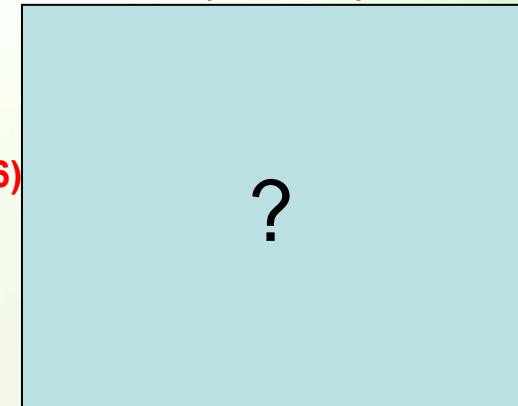
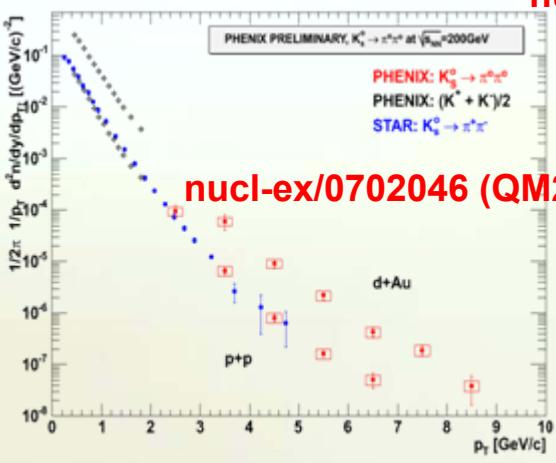
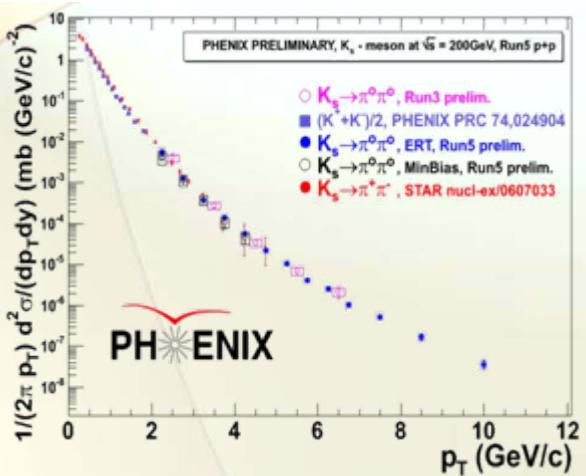
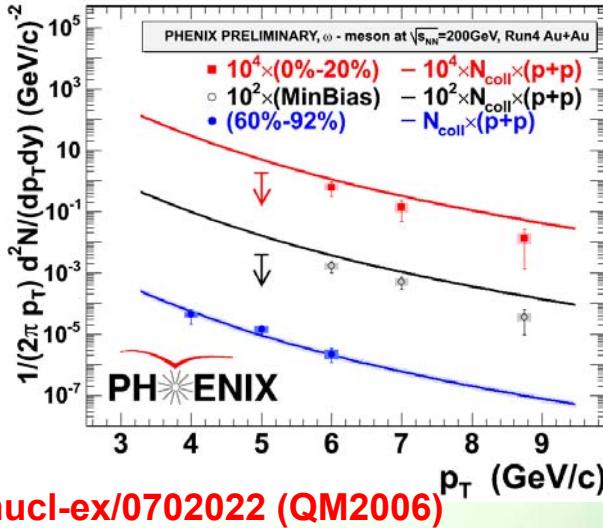
$p+p$



$d+Au$

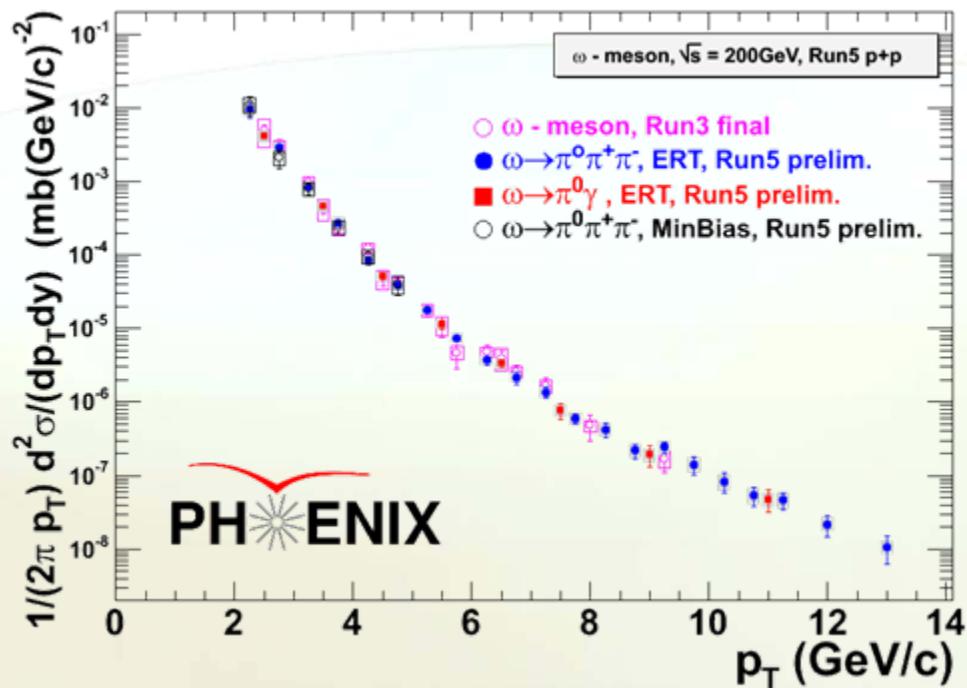


$Au+Au$



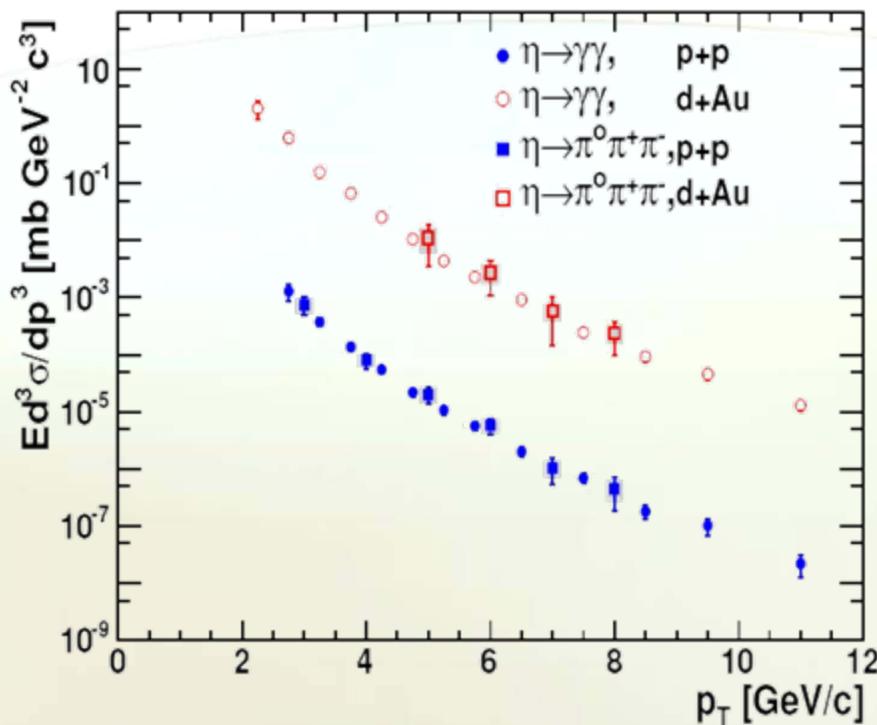
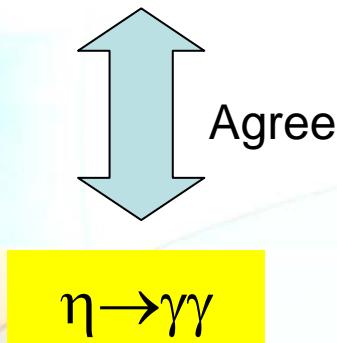
PHENIX mapped out high  $p_T$   $\omega$  in  $p+p$ ,  $d+Au$  & produced a first result in  $Au+Au$   
 $K_s^0$  is measured in  $p+p$  and  $d+Au$

# Result consistency checks



# Result consistency checks

Similar analysis



# Result consistency checks

Similar analysis

$\eta \rightarrow \pi\pi\pi$

$\omega \rightarrow \pi\pi\pi$

Agree

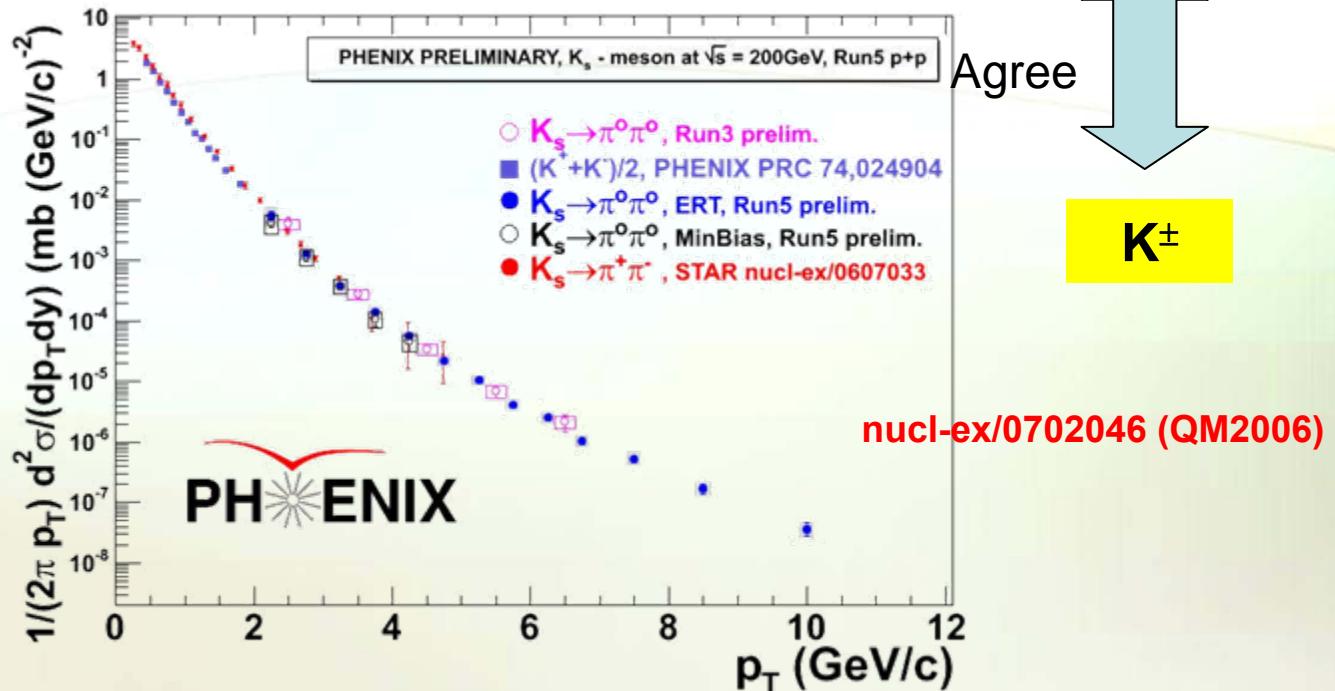
Similar analysis

$\omega \rightarrow \gamma\gamma\gamma$

$K \rightarrow \gamma\gamma\gamma$

Agree

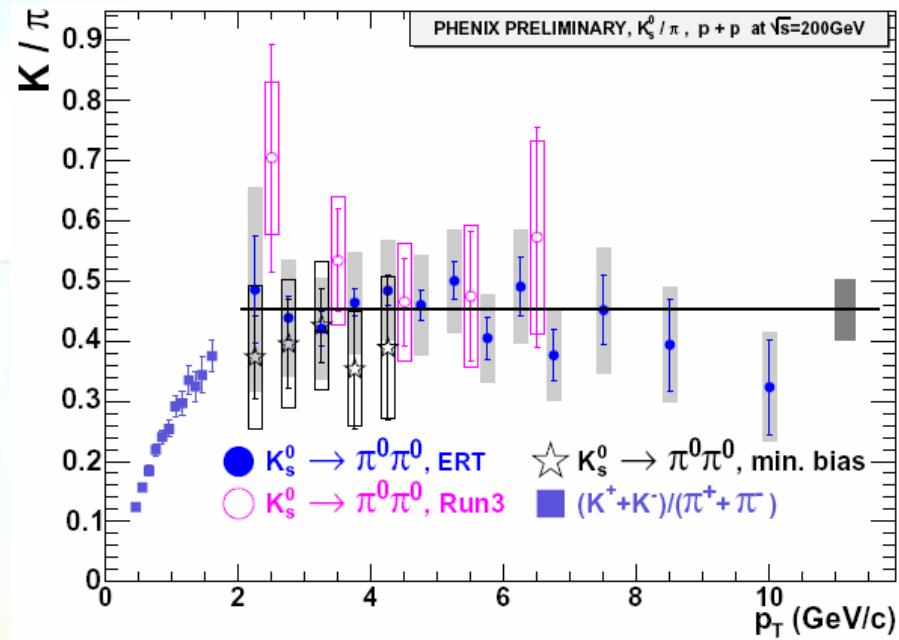
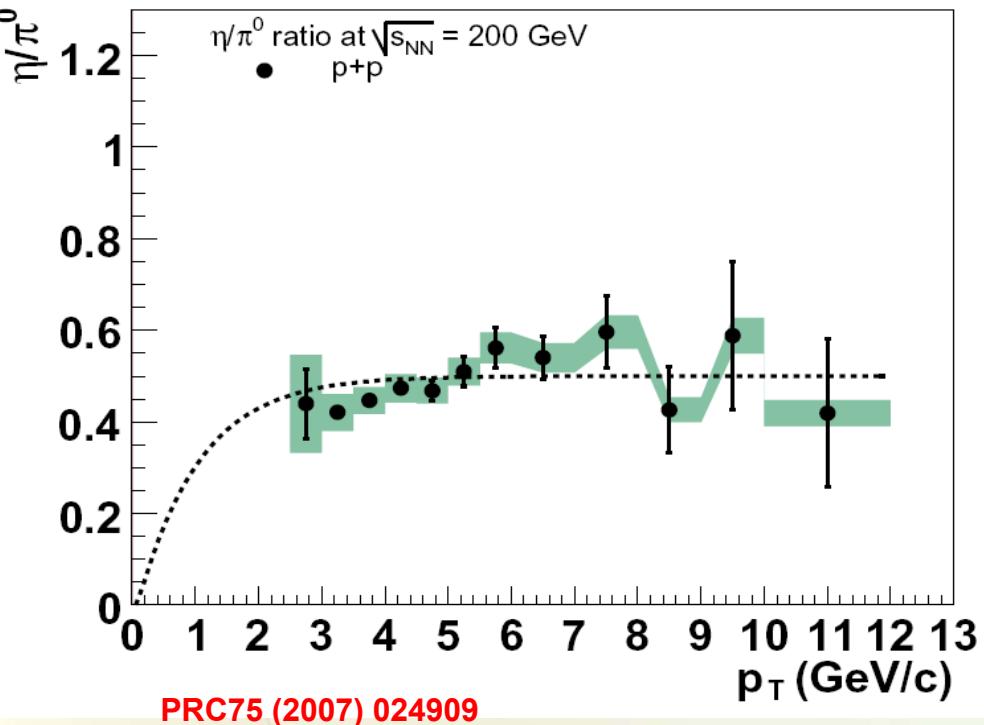
$\eta \rightarrow \gamma\gamma$



# $\eta, K / \pi^0$ ratio

$\eta \rightarrow 2\gamma$

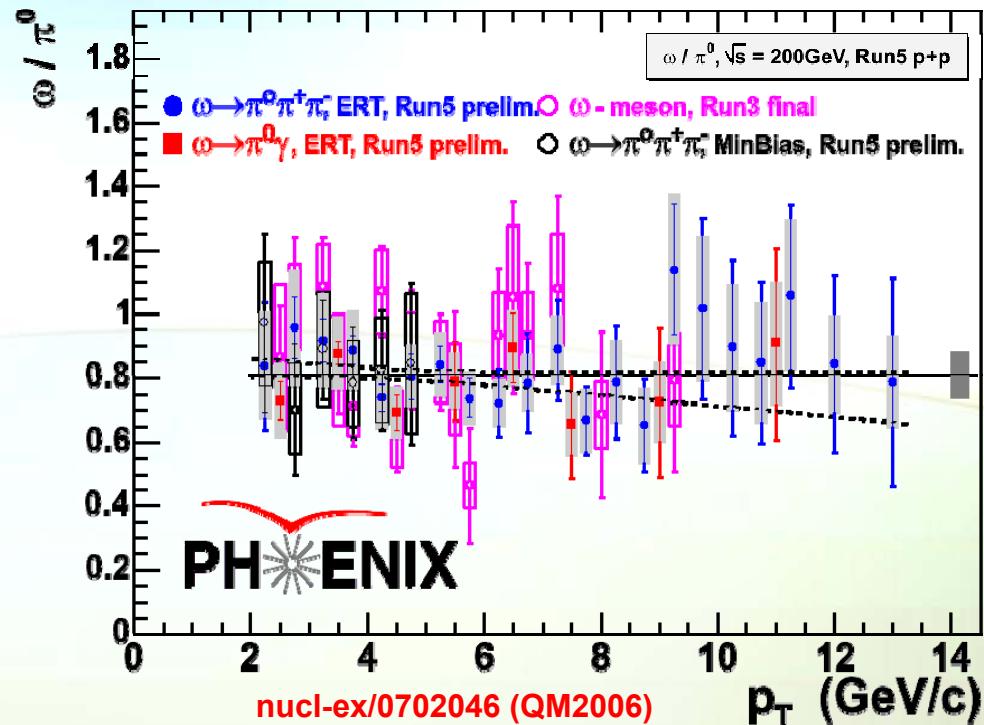
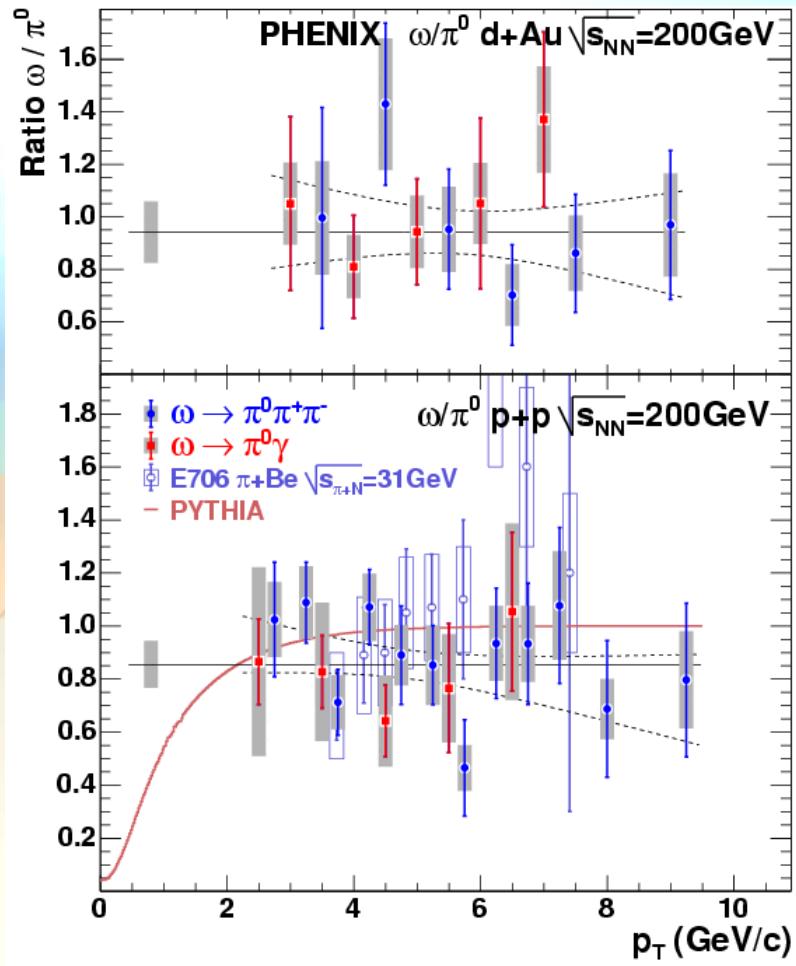
$K^0_S \rightarrow \pi^0\pi^0$



nucl-ex/0702046 (QM2006)

# $\omega/\pi^0$ ratio

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

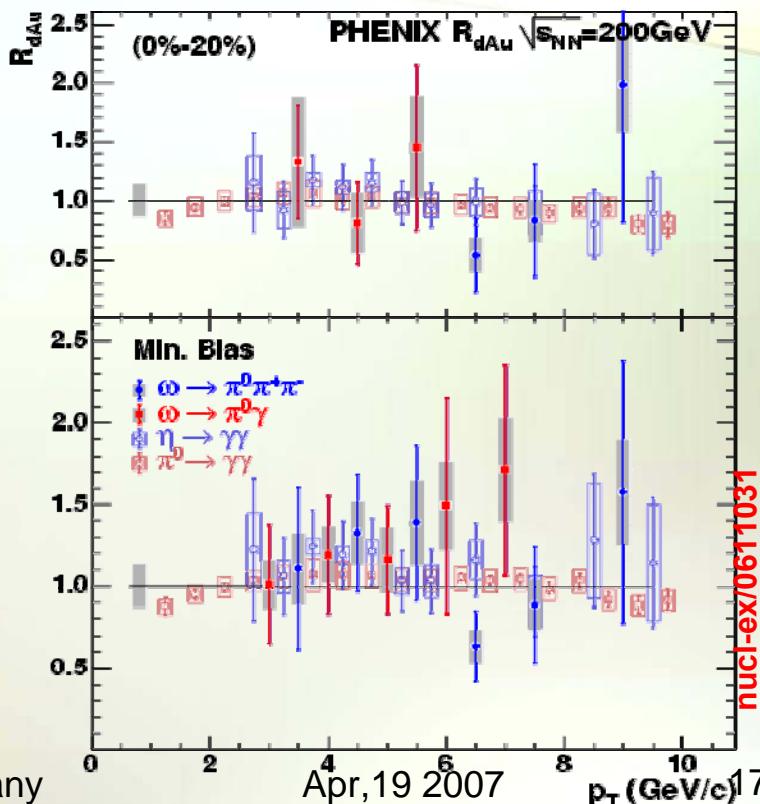
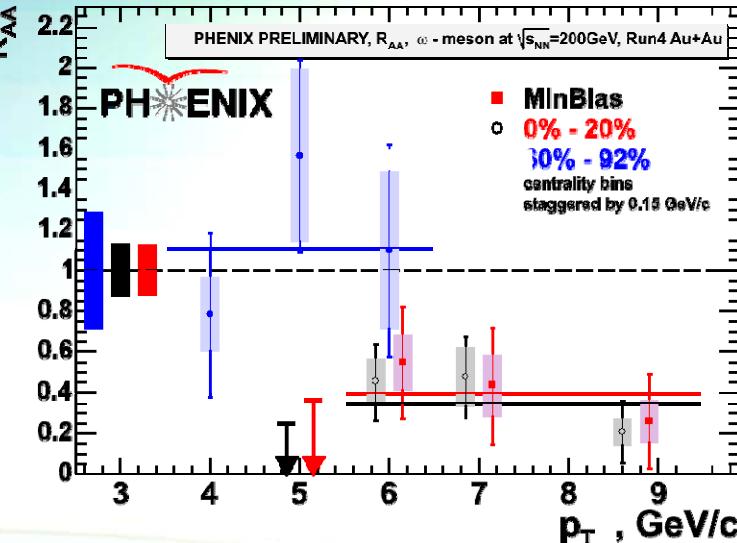
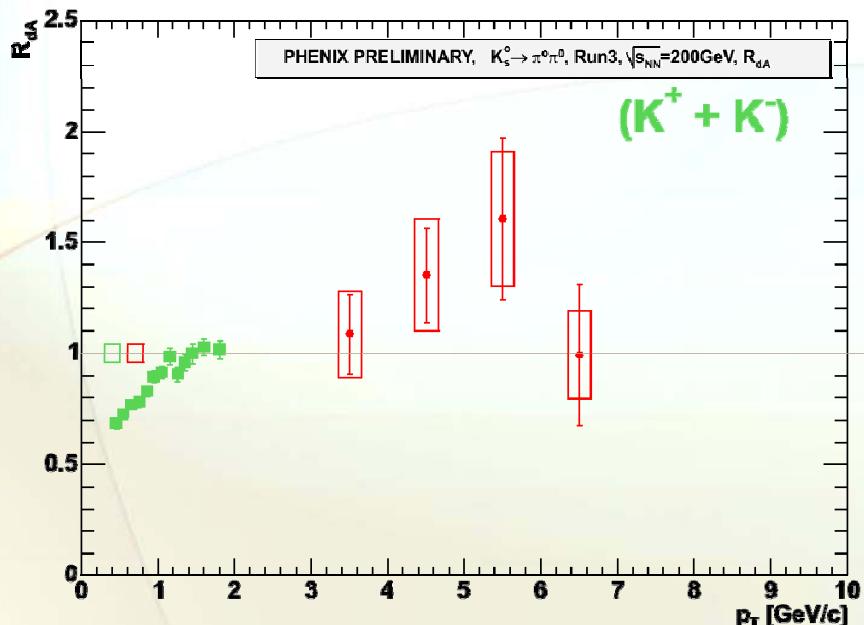


nucl-ex/0611031 acc. to PRC

$\omega/\pi^0$  in  $p+p$  Run3 @  $\sqrt{s} = 200$  GeV =  $0.85 \pm 0.05(\text{stat}) \pm 0.09(\text{syst}) \leftarrow \text{nucl-ex/0611031 (PRC)}$   
 $\omega/\pi^0$  in  $p+p$  Run5 @  $\sqrt{s} = 200$  GeV =  $0.81 \pm 0.02(\text{stat}) \pm 0.07(\text{syst}) \leftarrow \text{nucl-ex/0702046 (QM)}$   
 $\omega/\pi^0$  in  $d+Au$  Run3 @  $\sqrt{s_{NN}} = 200$  GeV =  $0.94 \pm 0.08(\text{stat}) \pm 0.12(\text{syst}) \leftarrow \text{nucl-ex/0611031 (PRC)}$

# Nuclear Modification Factor

$$R_{A+A} = \frac{dN^{A+A}/dp_T}{\langle N_{coll} \rangle dN^{p+p}/dp_T}$$



$R_{dA}$  for all light mesons are around 1  
 $R_{AA}$  for  $\omega$  at high  $p_T$  is <1, same as other mesons

# Summary

- ❖ PHENIX measured  $\omega, \eta$  &  $K_0$  production in hadronic channels, providing pioneering and robust measurement for  $\omega$  and  $K$ .
- ❖ All mesons behave consistently with other mesons in different collision systems at different energies.
- ❖ The baseline measurements ( $p+p \sqrt{s}=200\text{GeV}$ ) exist in hadronic channels and are being analyzed in leptonic channel using accumulated data.
- ❖ Current analysis is in progress and needs improvement on the background conditions and more data.
- ❖ In future we plan to finalize  $\omega$  data, reduce  $K_S$  systematic errors to address  $\pi/K/p$  separation. The multi-particle approach can reveal more information than is currently analyzed.

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**My research is supported by the Goldhaber Fellowship at BNL with funds provided by Brookhaven Science Associates.**

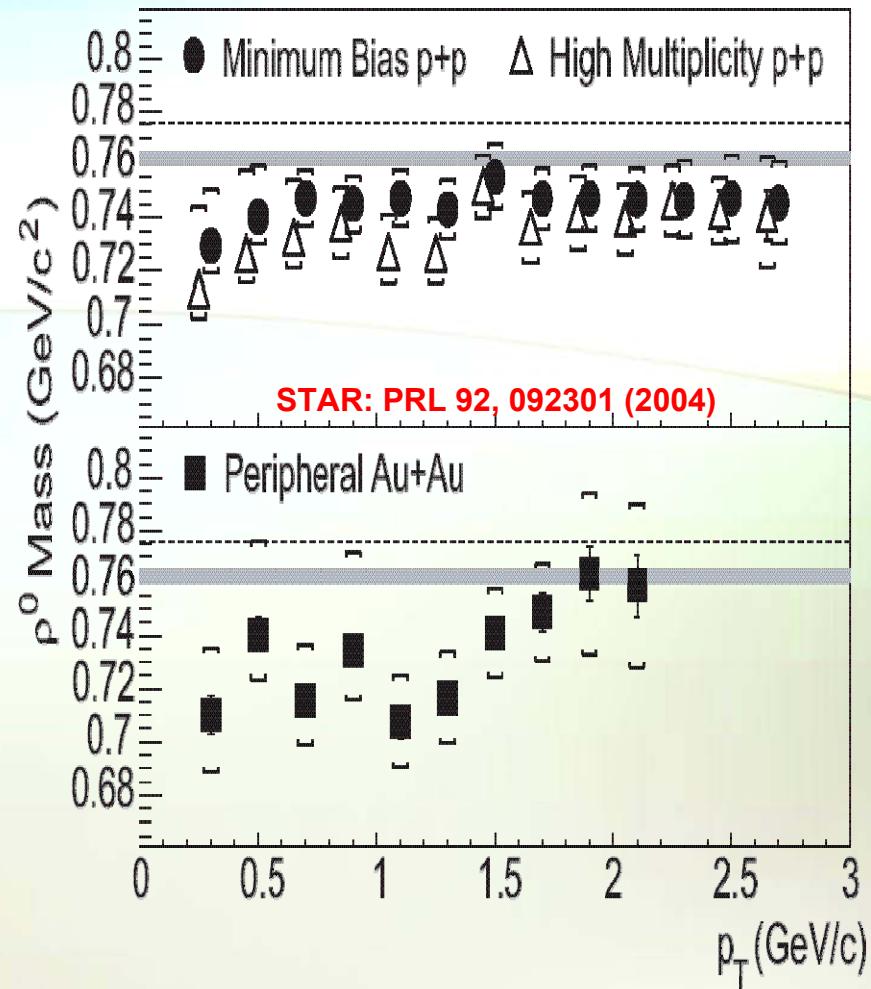
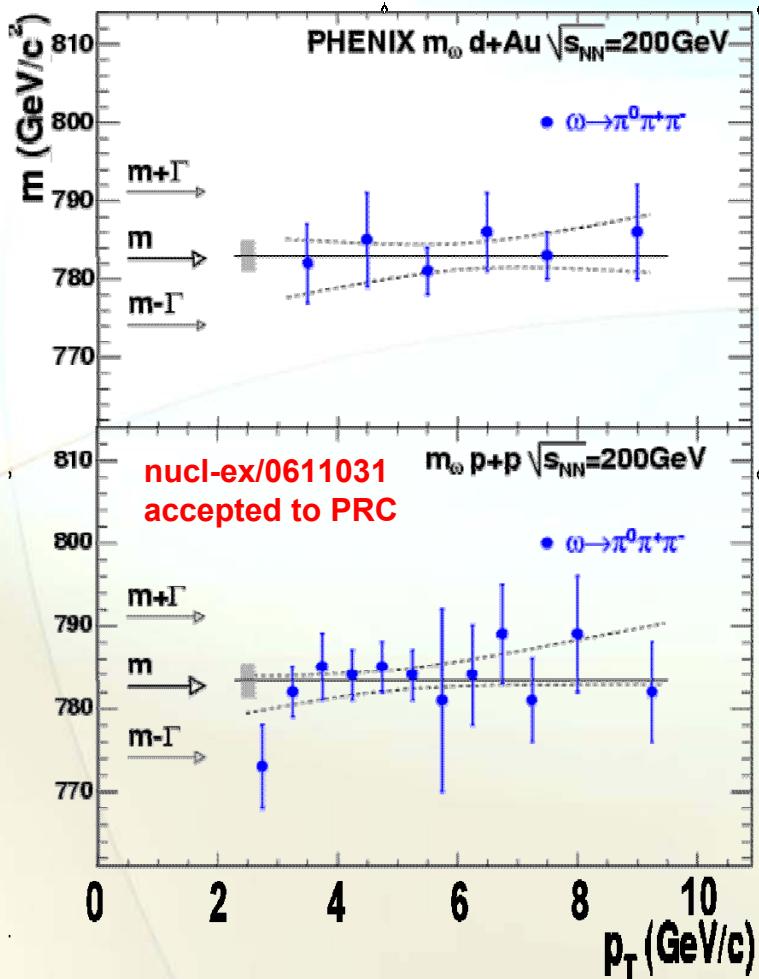
# Backgrounds

# Mass peak shape

$p+p$

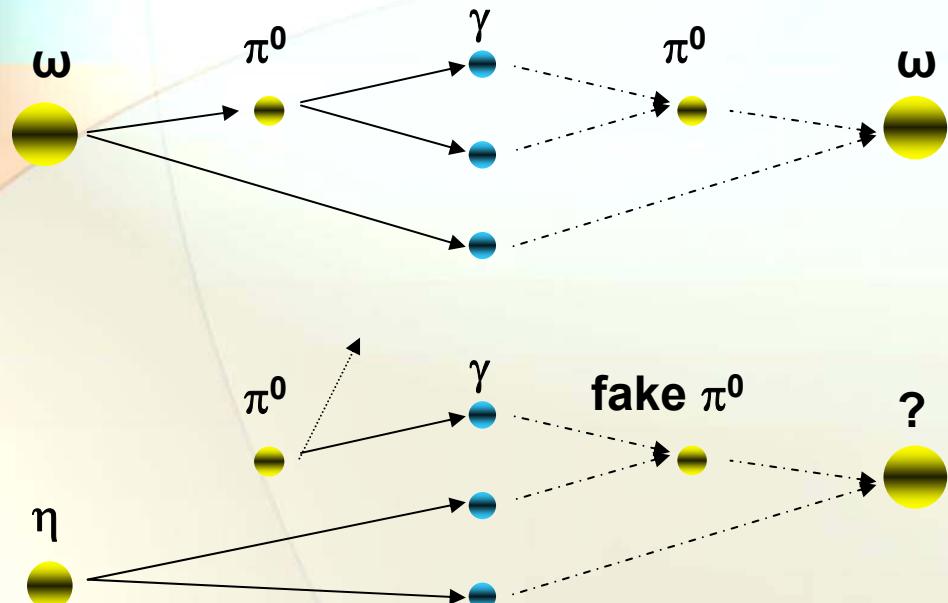
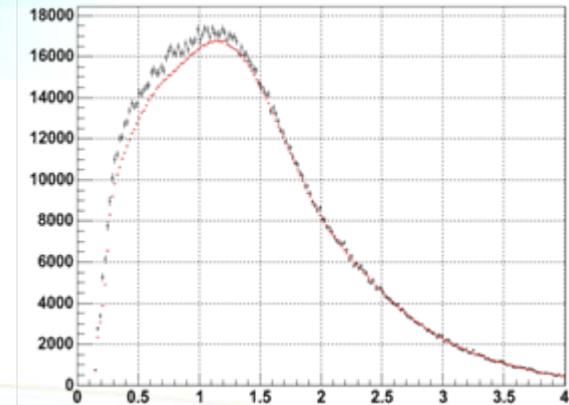
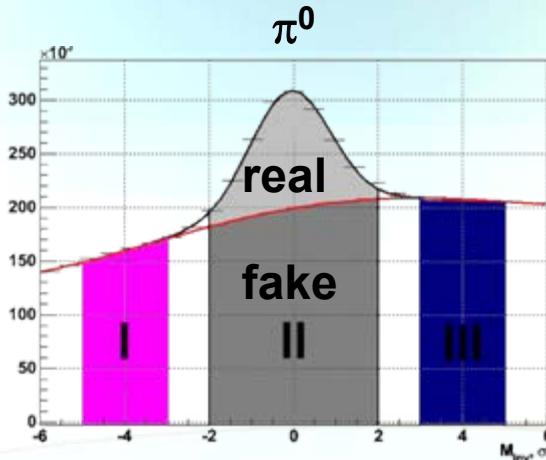
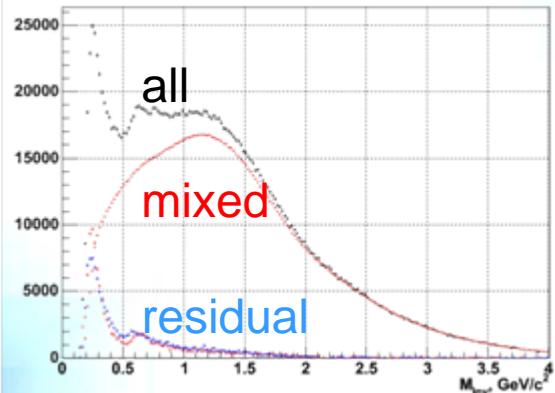
$d+Au$

$Au+Au$



$\omega$  measurements show no evidence of mass modification at high  $p_T$

# Backgrounds: e.g. $\omega \rightarrow \pi^0 \gamma$

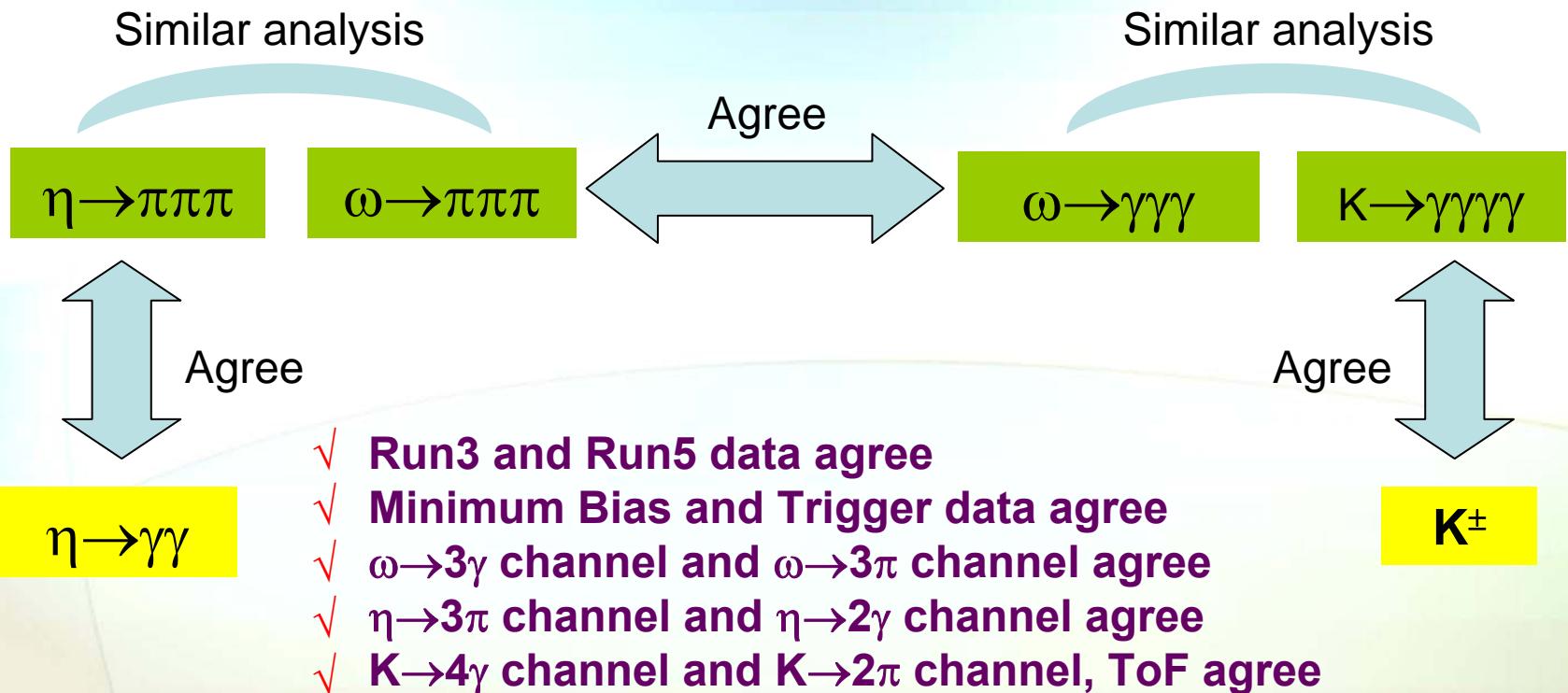


Mixed event technique takes care only of uncorrelated combinatorial background.

Correlated background can be explained, but cannot be efficiently eliminated.

We rely on fitting to get the results.

# Result consistency checks

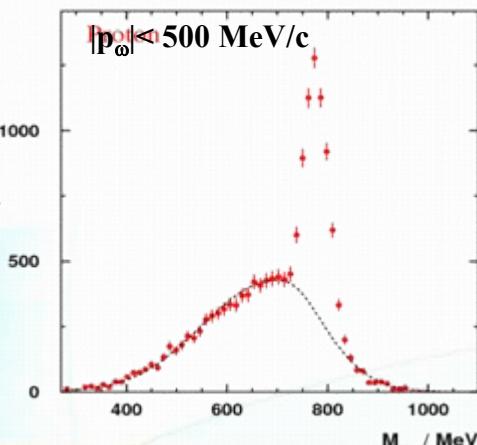


In spite of difficulties of the new approach the method is robust and the results are consistent.

# $\omega \rightarrow \pi^0 \gamma$ invariant mass spectra

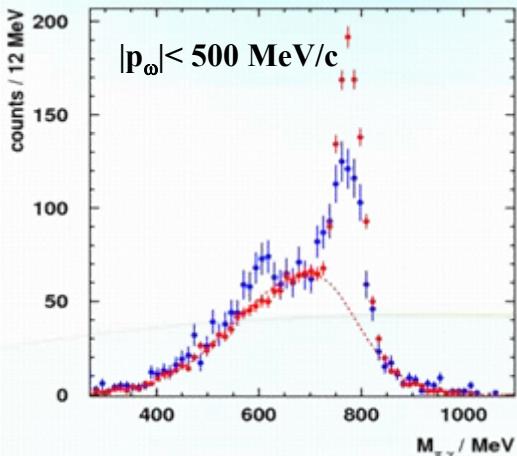
e+p

$\omega \rightarrow \pi^0 \gamma$  e+p  $E_e = 2.8$  GeV

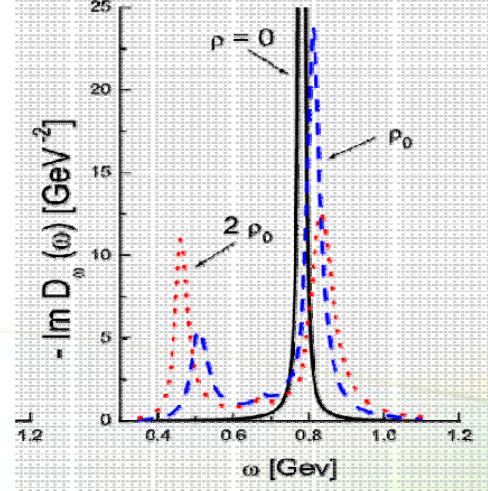


e+C

e+C  $E_e = 2.8$  GeV



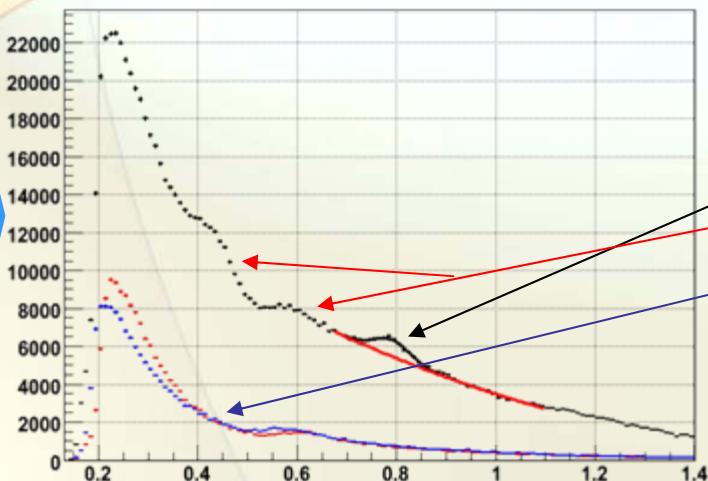
M.Lutz Nucl. Phys. A706 431 (2002)



CBELSA/TAPS

PHENIX

$\omega \rightarrow \pi^0 \gamma$  p+p  $\sqrt{s} = 200$  GeV



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

Other peaks seen in p+p... Au+Au

Correlated background reproduced  
from the data

Part, not all of it!!!

Peaks at low masses in the channel may  
be in part , explained by correlated  
background from eta, pi0 Ks ...