Hadronic Resonances from STAR

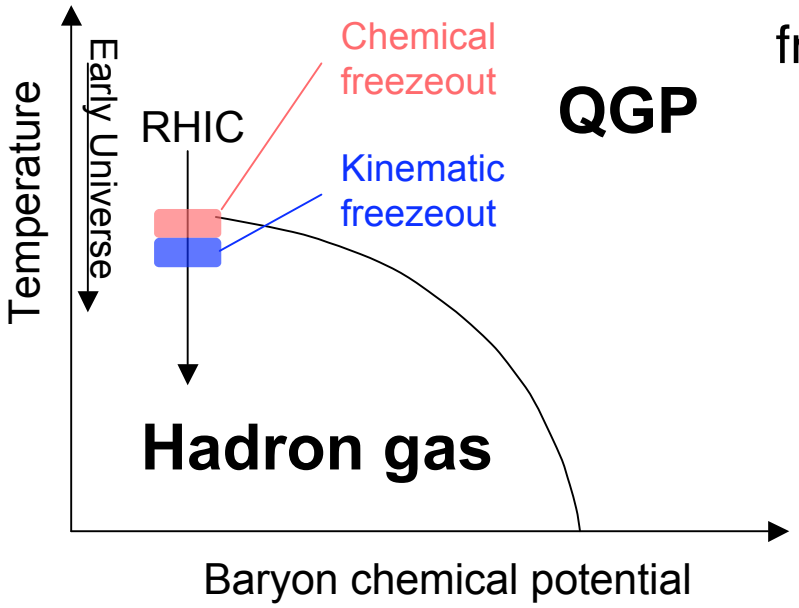
Masayuki Wada

For the STAR Collaboration

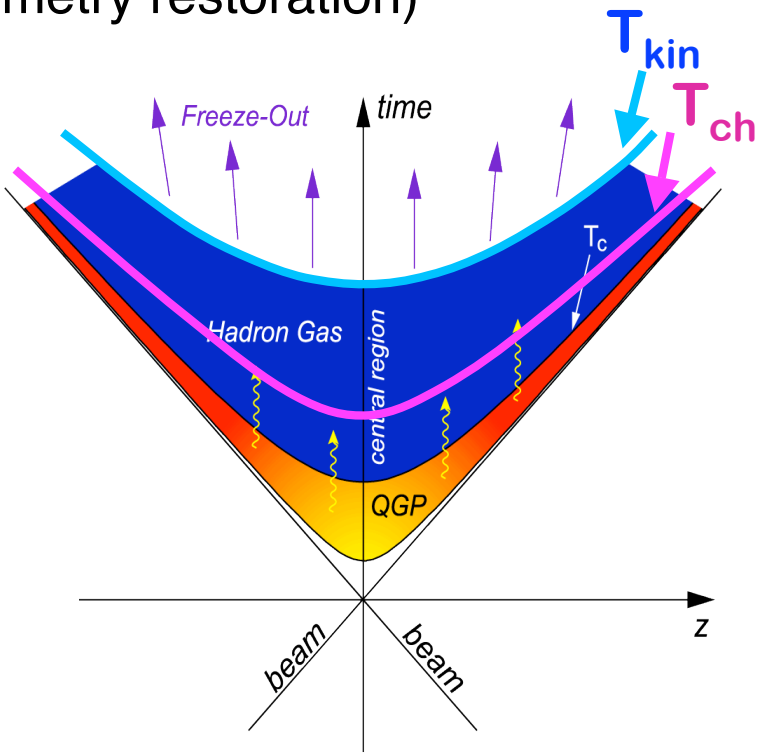
Outline

- **Motivation and Introduction**
- **Hadronic decay channel (Mass & Width, Yield Ratio, $\langle p_T \rangle$)**
- **Leptonic decay channel**
- **Conclusions**

Resonances In Medium

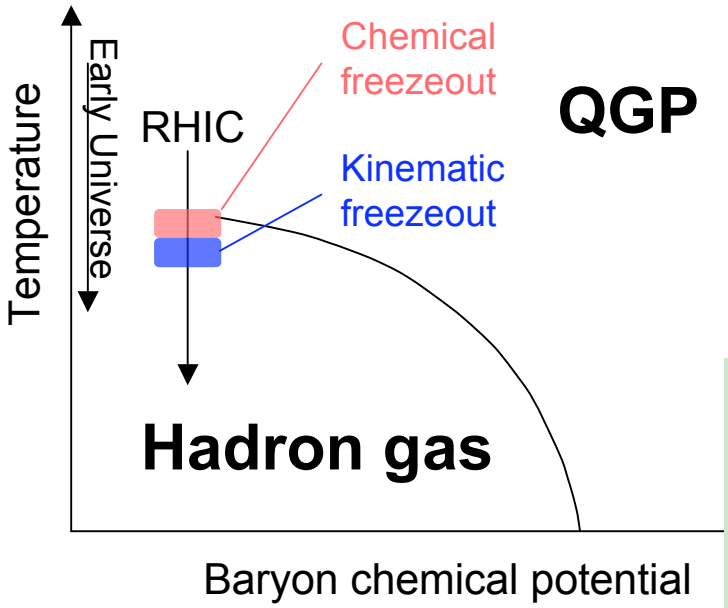


- **Resonance particles** are short lived (few fm/c) particles (strong interaction).
  - decay inside medium
  - sensitive to medium effects (mass shift, width broadening possible link to chiral symmetry restoration)



Resonance	Mass [MeV/c^2]	Lifetime [fm/c]	decays (BR)
ϕ ($s\bar{s}$)	1020	44	K+K , e^++e^-(10^{-4})

Resonances In Medium



- **Resonance particles** are short lived (few fm/c) particles (strong interaction).
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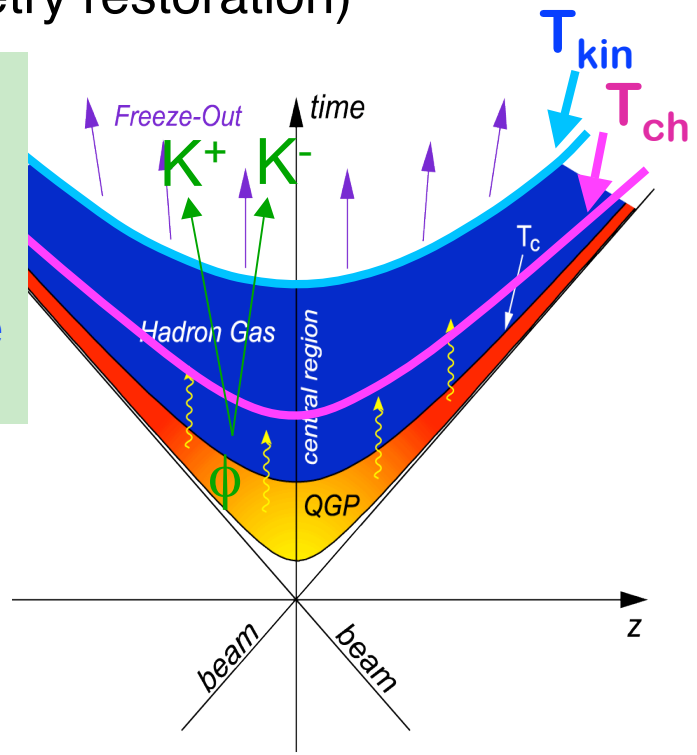
Hadronic Decay

- Interact with hadronic medium
- sensitive to lifetime of hadronic medium



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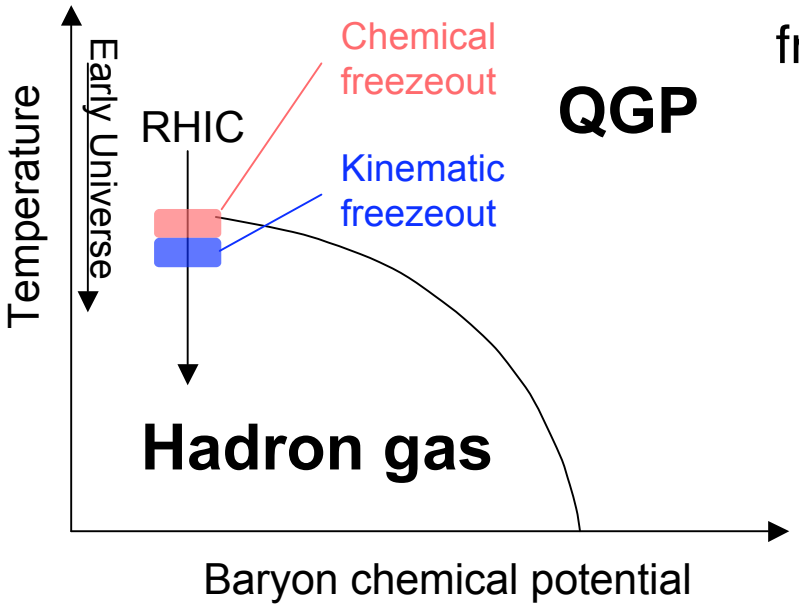
hadronic decay

Resonances In Medium



- **Resonance particles** are short lived (few fm/c) particles (strong interaction).
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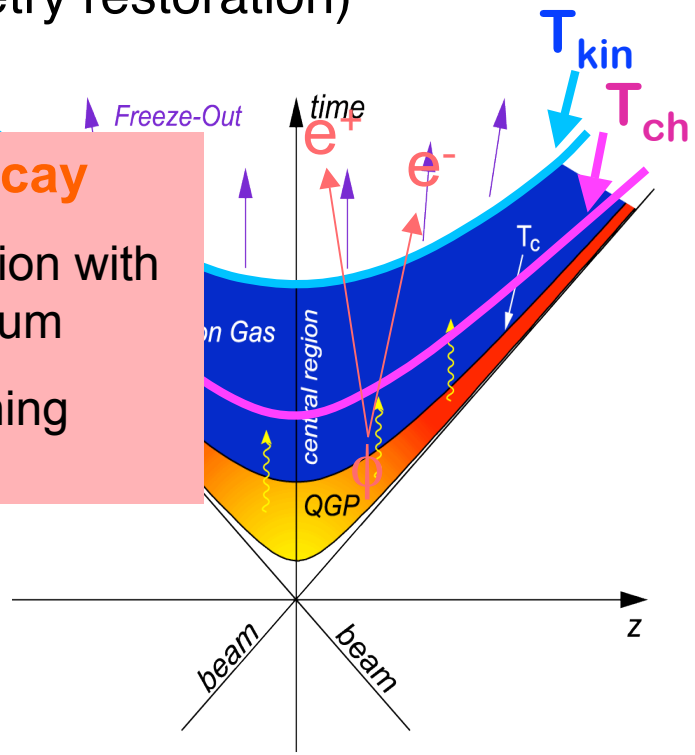
Leptonic Decay

- Less interaction with hadronic medium
- Small branching ratio~10^{-4}



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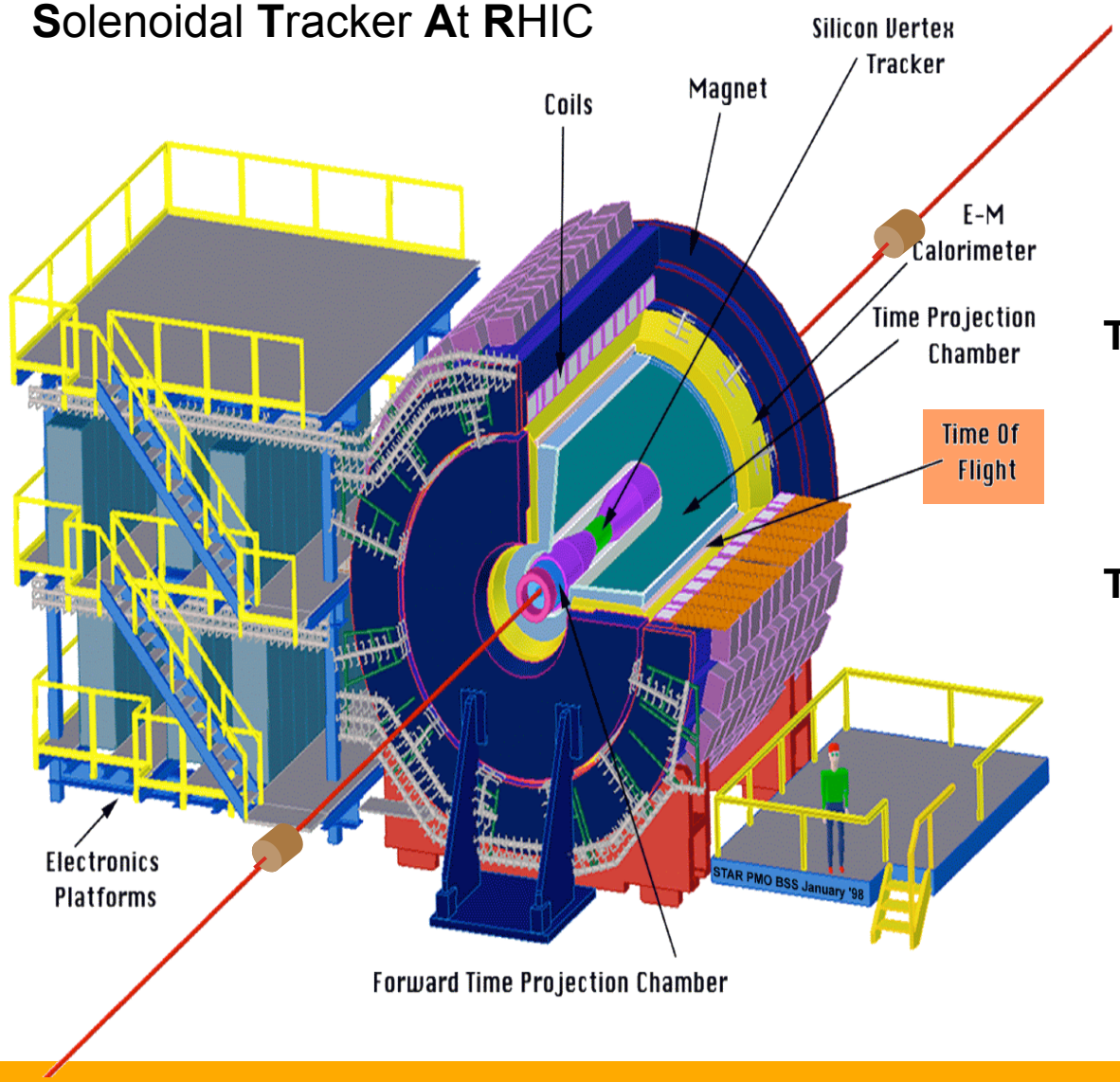
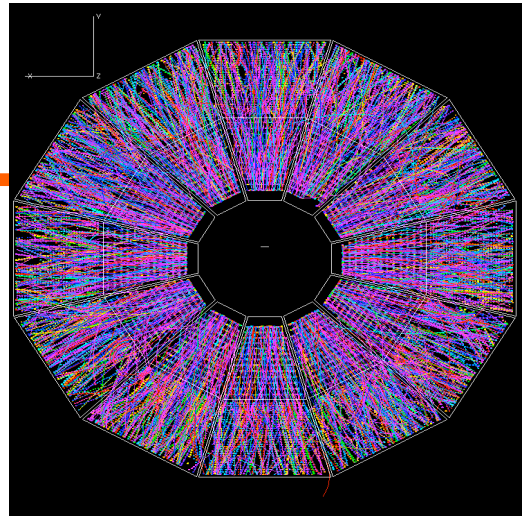
leptonic decay

STAR Detector

Solenoidal **T**racker **A**t **R**HIC





Time Projection Chamber (TPC)

- full azimuth, $|\eta| < 1$
- Momentum & dE/dx

Time of Flight System (TOF)

- full azimuth, $|\eta| < 0.9$
  ~70% (2009)
  ~100% (2010)
- Velocity (particle identification)

Resonance Particles

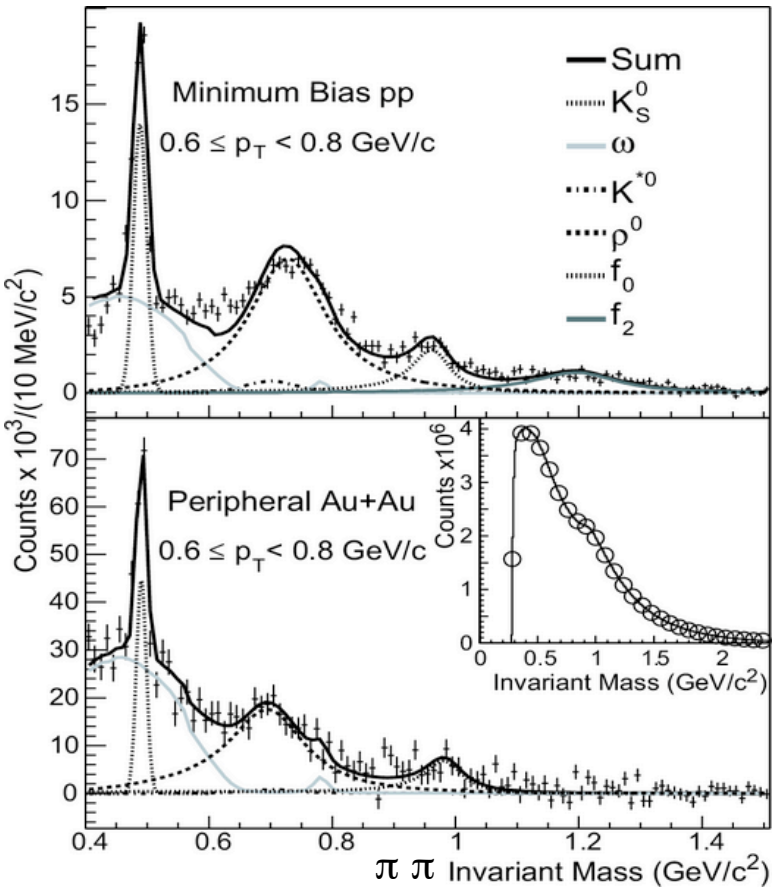
- ρ^0 ($\rightarrow\pi^+\pi^-$), K* ($\rightarrow\pi$K), ϕ ($\rightarrow$K$^+$K$^-$), Σ^* ($\rightarrow\pi\Lambda$), Λ^* ($\rightarrow$Kp)

- Hadronic resonances are measured in STAR from various colliding systems (p+p, d+Au, Cu+Cu, and Au+Au) and colliding energies (62.4, 200 GeV).

Resonance	Lifetime [fm/c]	decays (BR)
ρ^0 (770)	1.3	$\pi+\pi$, $e^+ + e^-$ (10^{-5})
K* (892)	4.0	π+K
ϕ (1020)	44	K+K , $e^+ + e^-$ (10^{-4})
Σ^*(1385)	5.7	$\Lambda+\pi$
Λ^*(1520)	13	$\Lambda+\pi$

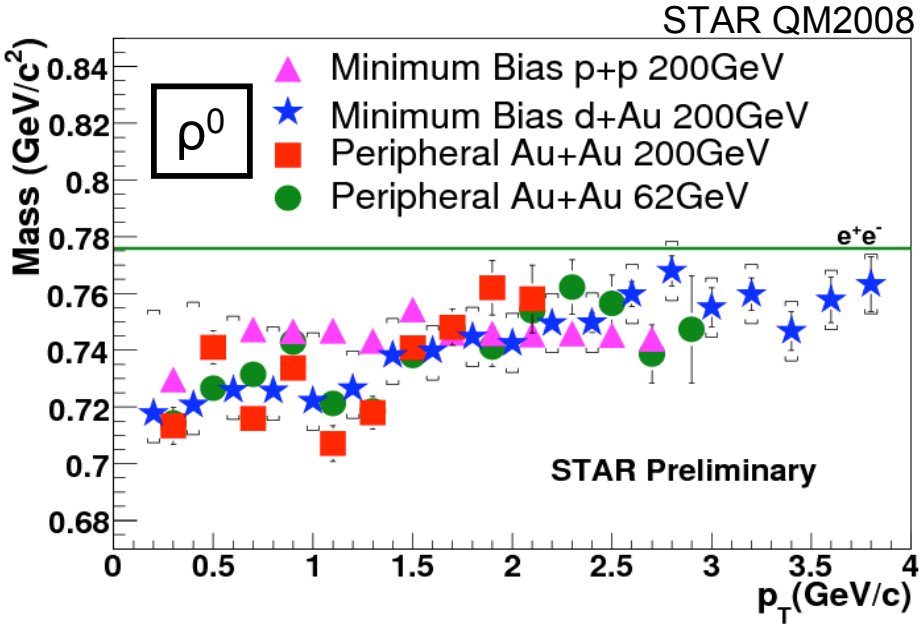
ρ^0 (770) Mass & Width

Phys. Rev. Lett. **92,** 092301(2004)



ρ^0 fit w/ relativistic Breit-Wigner func. times phase space factor

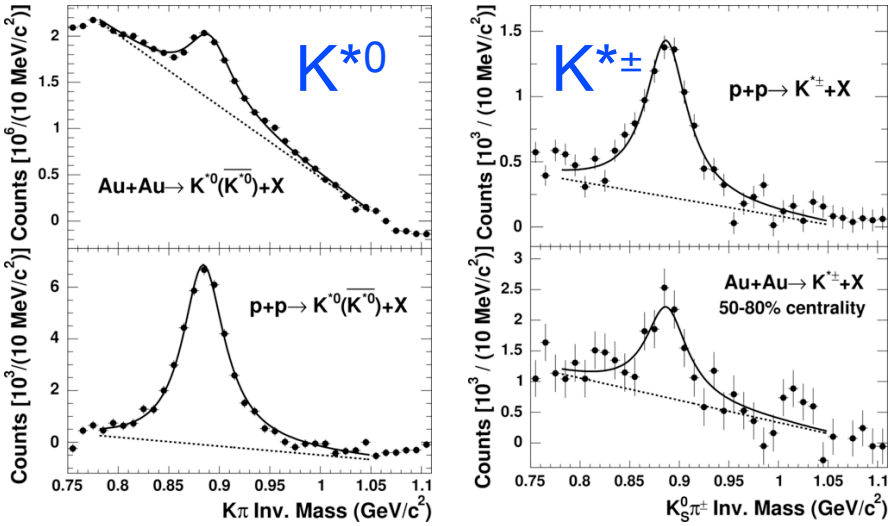
STAR QM2008

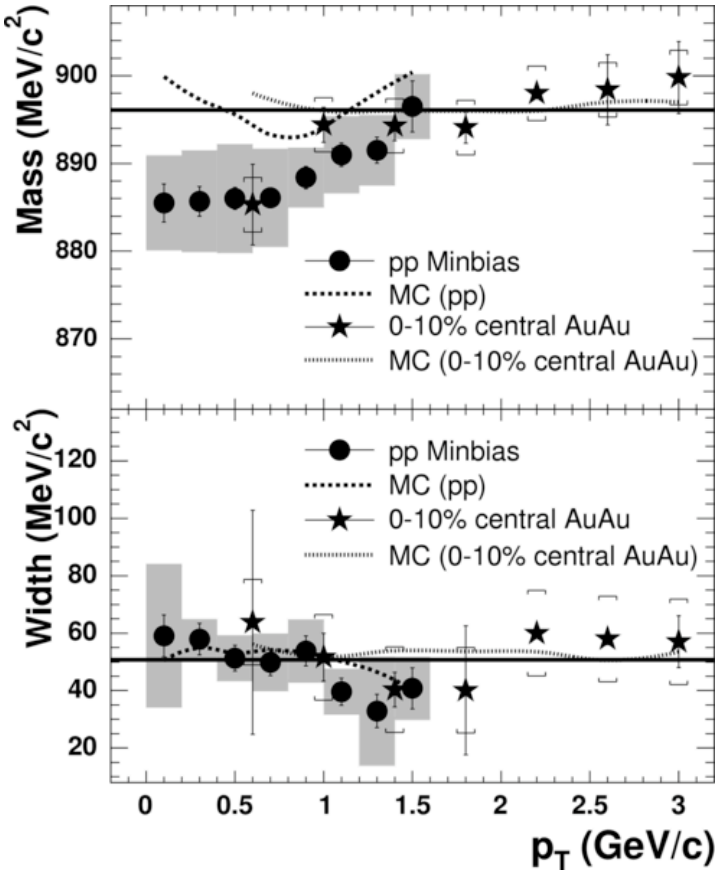


- ρ^0 mass shifted at low p_T by ~30 MeV/c^2.
- Same mass shifts in all collision systems and energies (200 & 62.4 GeV)
- Detector effect may be not fully accounted in the simulation.
- Width is fixed.

K*(892) Mass & Width

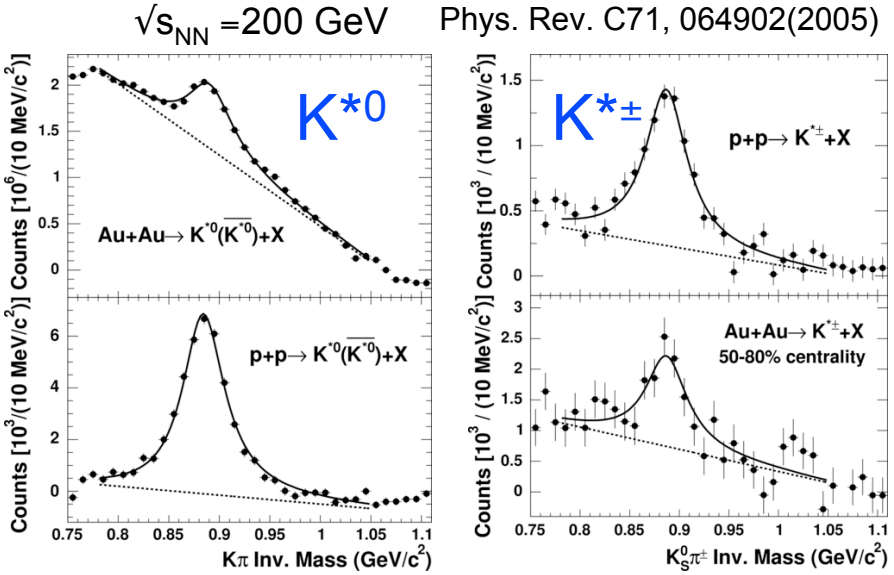
$\sqrt{s_{NN}}$ =200 GeV Phys. Rev. C71, 064902(2005)





- Mass shifts at low p_T by ~6-15 MeV/c^2
  - Consistent within 2 sigma level
- p+p and Au+Au have same trends ➔medium effect?
- No width broadening
- Detector effect may be not fully accounted in the simulation.

K*(892) Mass & Width



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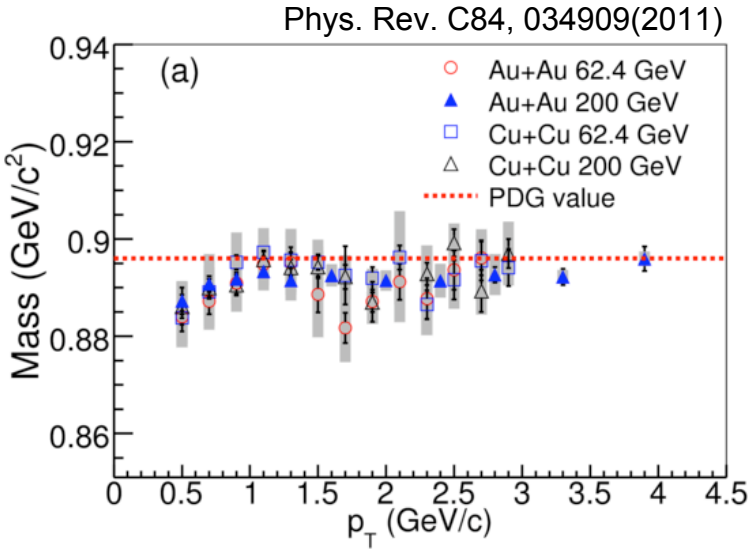
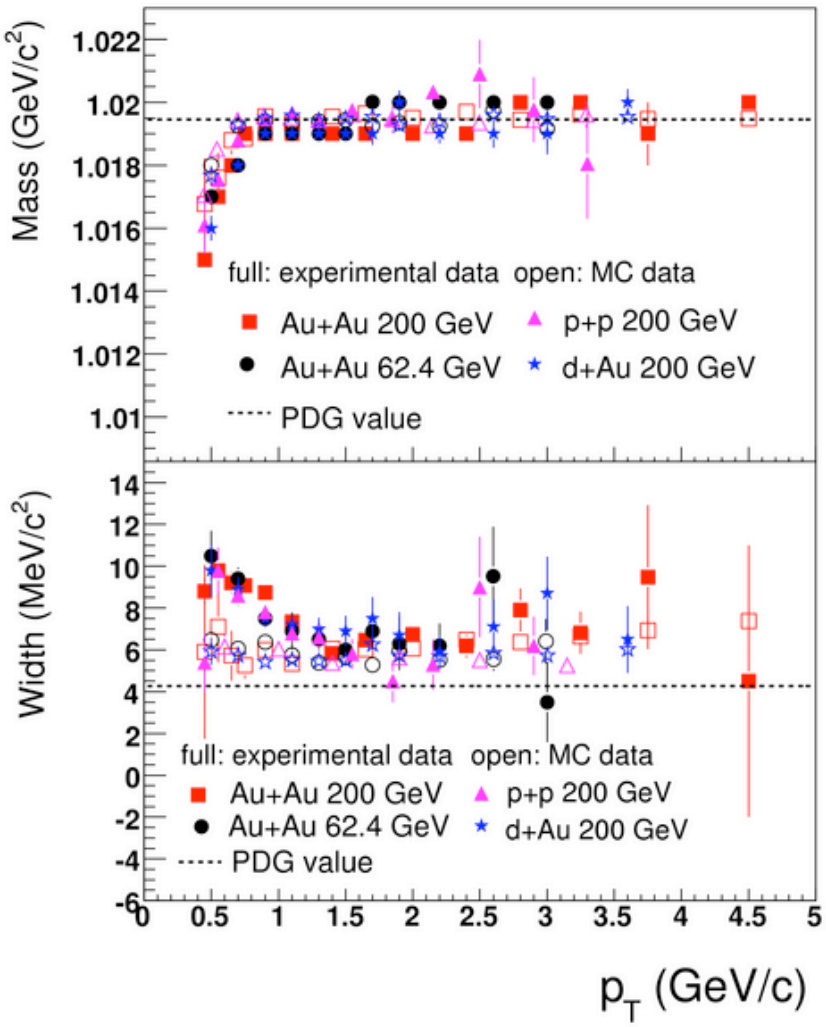
Different Collision systems & energies

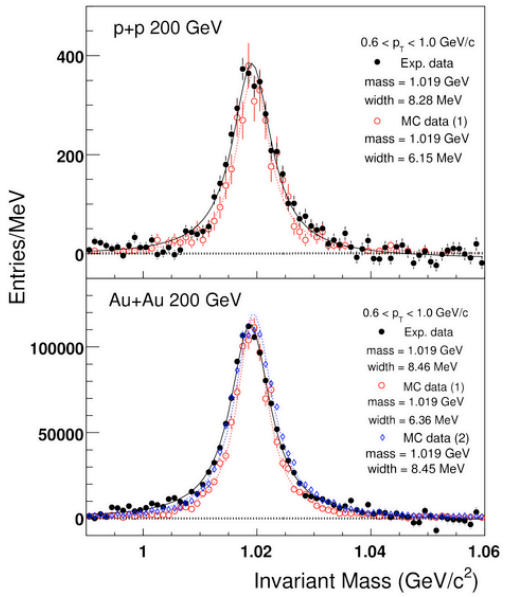


No dependence of mass and width within the errors on beam energy and colliding ion species

ϕ(1020) Mass & Width

Phys. Rev. C79, 064903(2009)

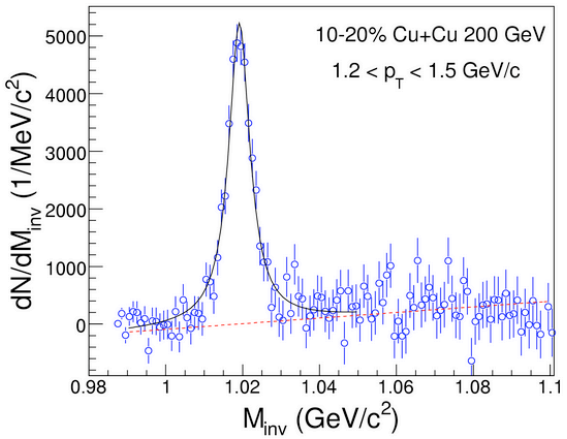


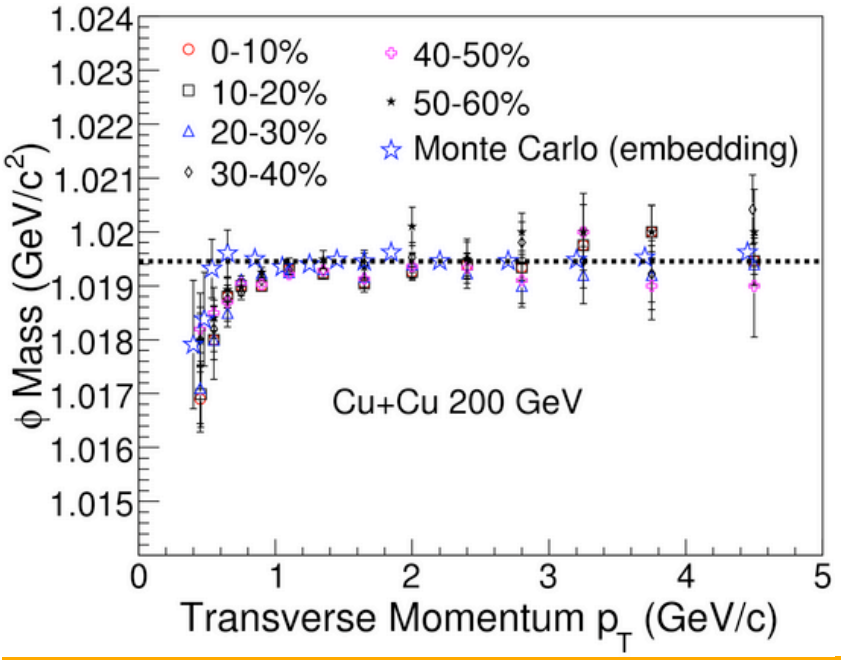


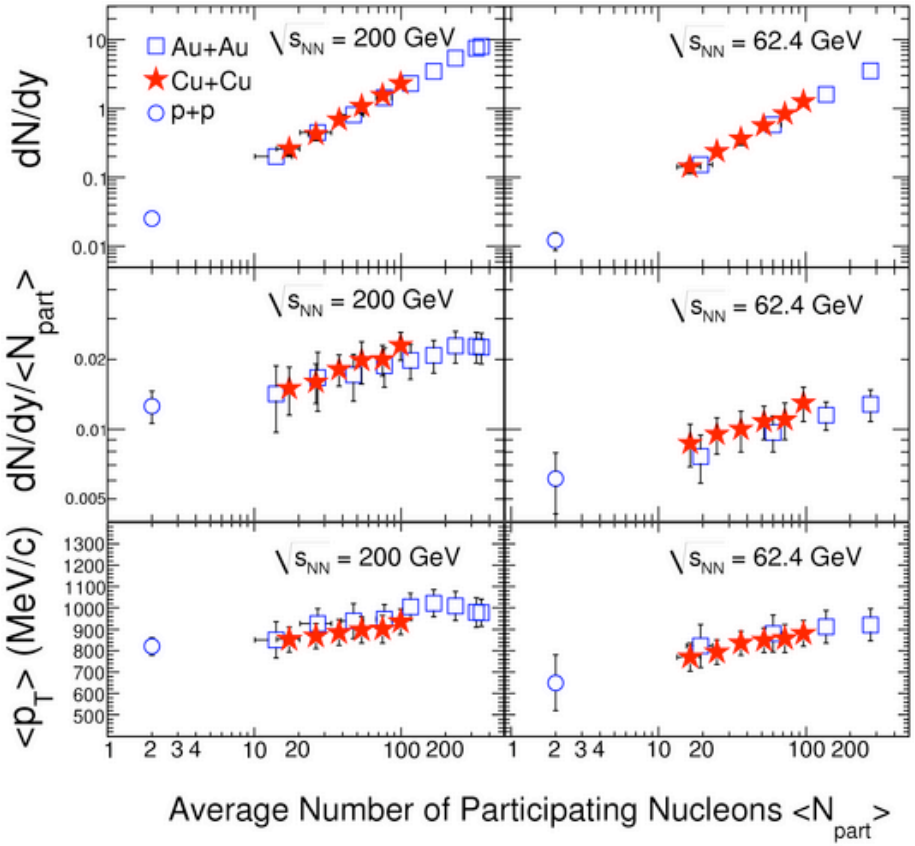
- At low p_T, ϕ mass is lower and width is larger than from simulation.
- No significant dependence of mass and width on beam energy and colliding ion species
- Detector effect may be not fully accounted in the simulation.

ϕ(1020) in Cu+Cu

Phys. Lett. B 673, 183(2009)

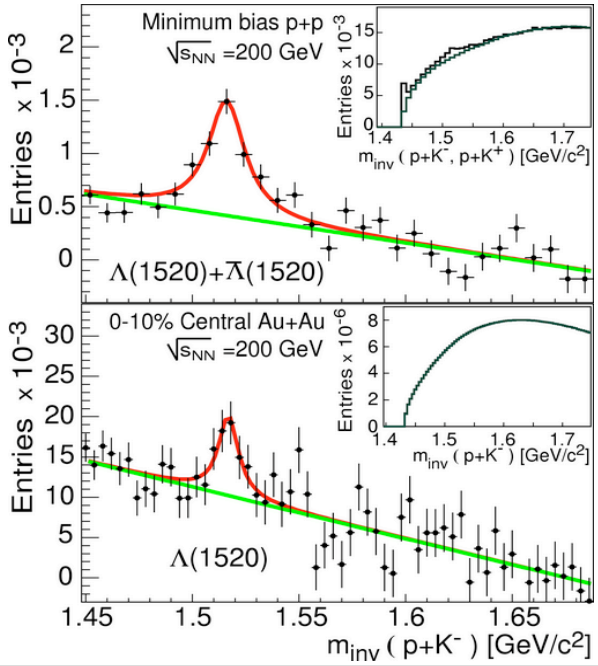


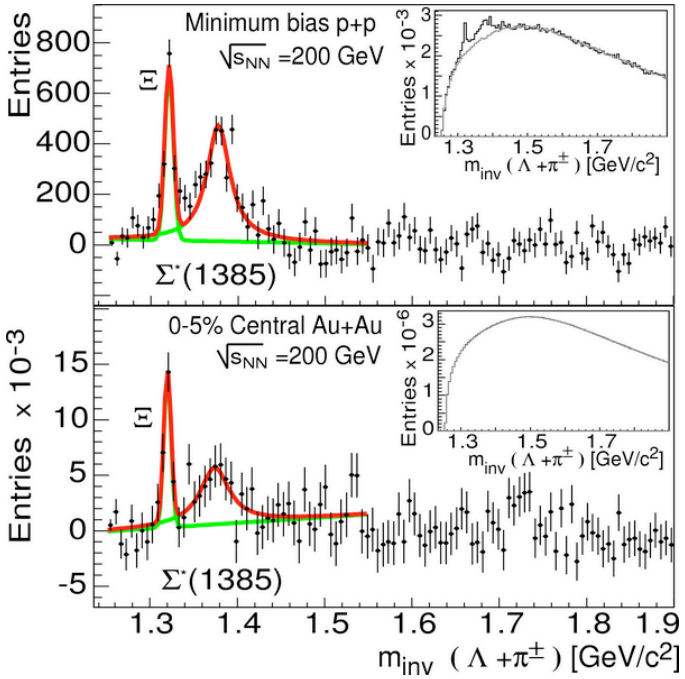




- Same system size dependence in dN/dy and $\langle p_T \rangle$

Λ*(1520) & Σ*(1385) Mass & Width



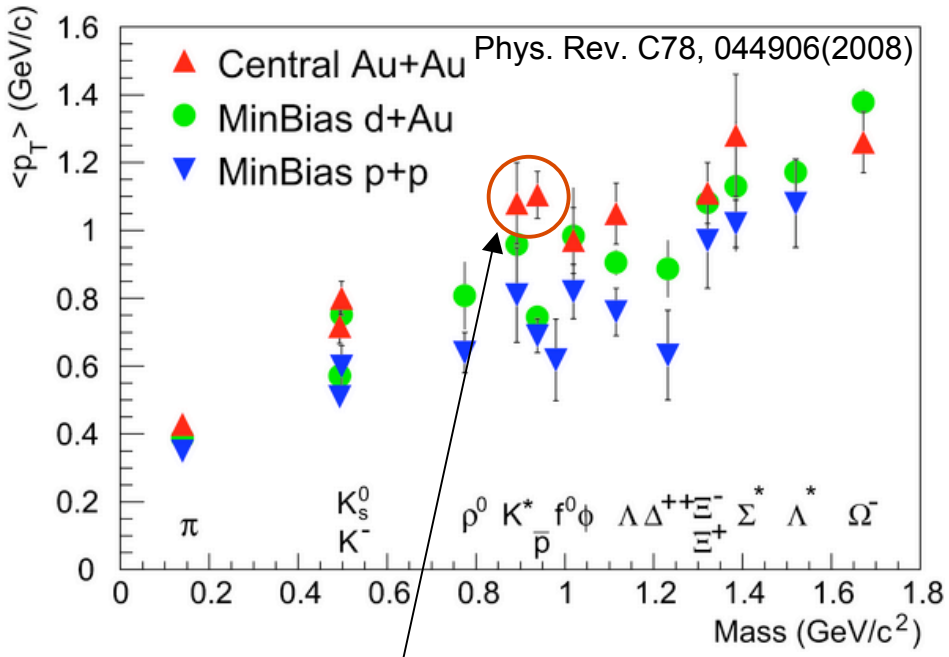


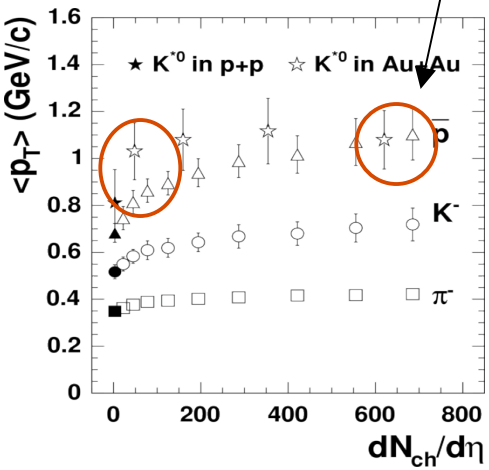
Particle	M [MeV/c²]	Γ [MeV/c²]
Σ*(p+p)	1376±3±3	44±8±8
Σ*(Au+Au)	1375±5±3	43±5±6
Λ*(p+p)	1516±2±2	20±4±2
Λ*(Au+Au)	1516±2±2	12±6±3
Σ⁰*(PDG)	1383.7 ± 1	36 ± 5
Λ*(PDG)	1519.5 ± 1	15.6 ± 1

- Mass & width of Λ* and Σ* are in agreement with the PDG values within errors.

Phys. Rev. Lett. **97,** 132301 (2006)

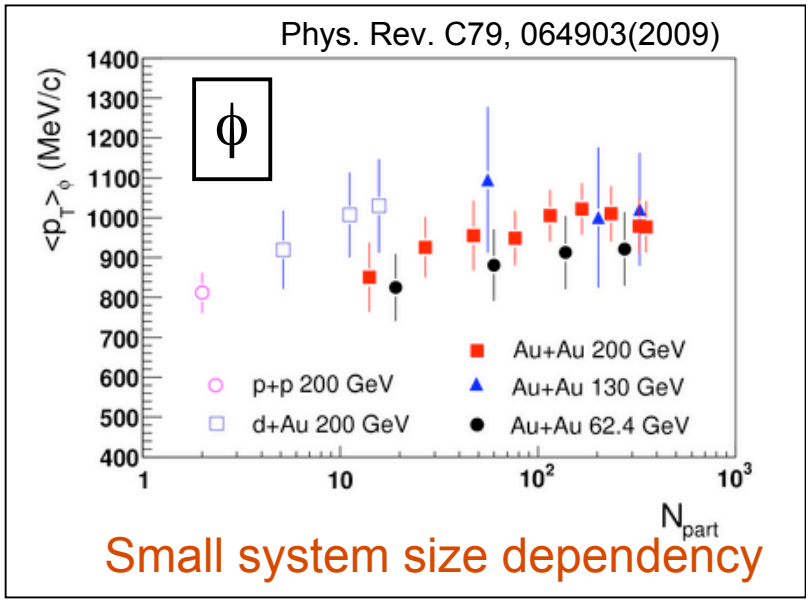
$\langle p_T \rangle$





Phys. Rev. C71, 064902(2005)

- In most central, K* & non-reso. (anti-p) agree.
- In peripheral, K* $\langle p_T \rangle$ is enhanced.



Small system size dependency

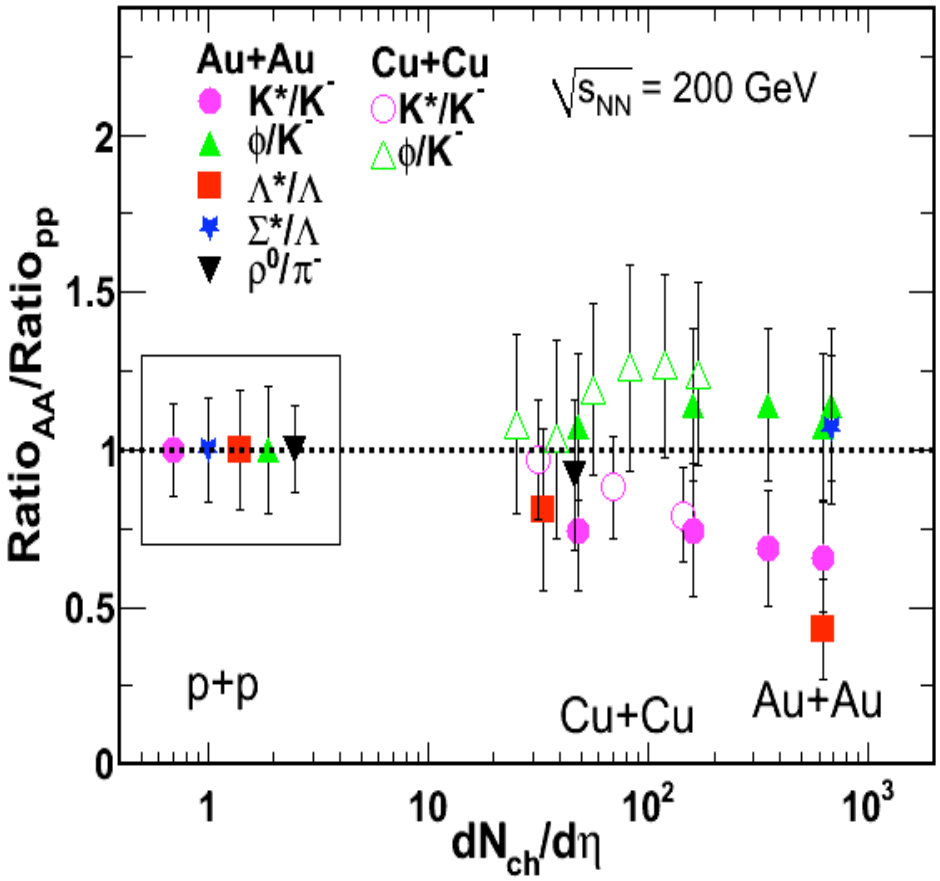
- Flat K* $\langle p_T \rangle$

➔low p_T daughters are re-scattered in medium

➔ p_T distribution shifts to higher p_T

Yield Ratio

$\rho^0 \rightarrow \pi^+\pi^-$, $K^* \rightarrow \pi K$, $\phi \rightarrow K^+K^-$, $\Sigma^* \rightarrow \pi\Lambda$, $\Lambda^* \rightarrow Kp$



- K^*/K^- suppressed with centrality

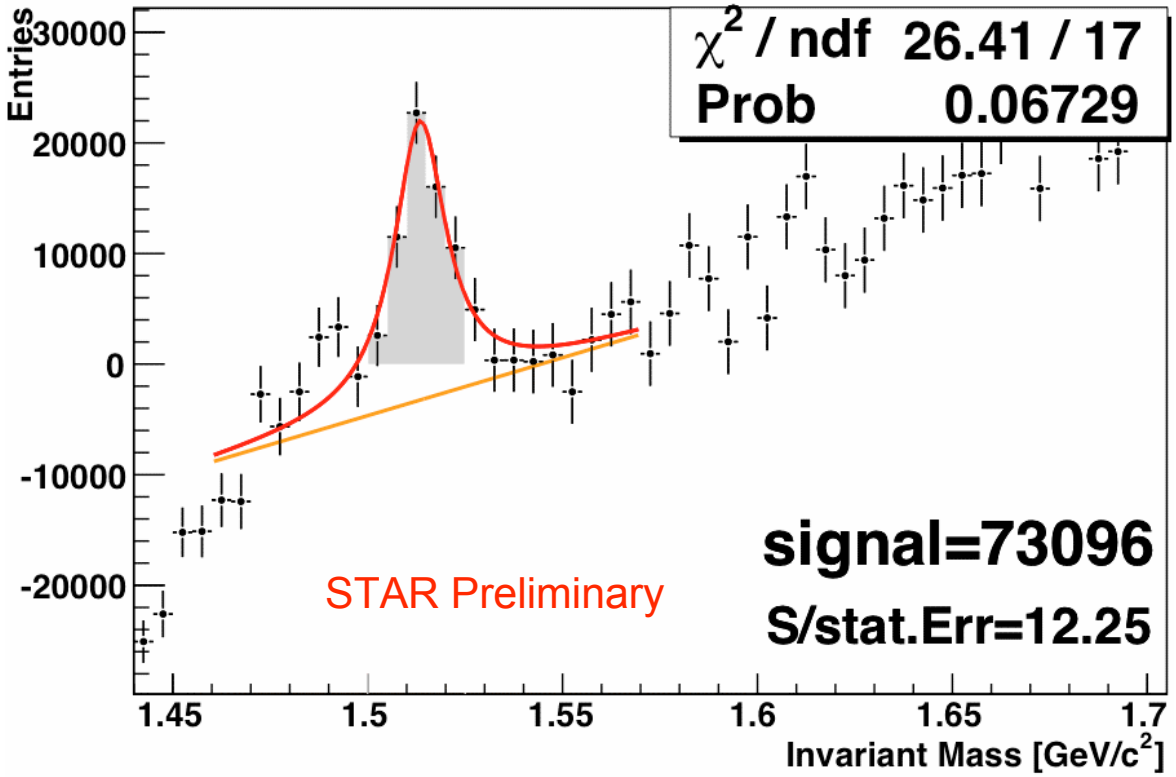
  ➔re-scatt.($\sigma_{\pi\pi}$) > re-gen. ($\sigma_{\pi K}$)
- ρ^0 & ϕ no suppression

  ➔re-scatt. = re-gen.
- Λ^* suppressed most

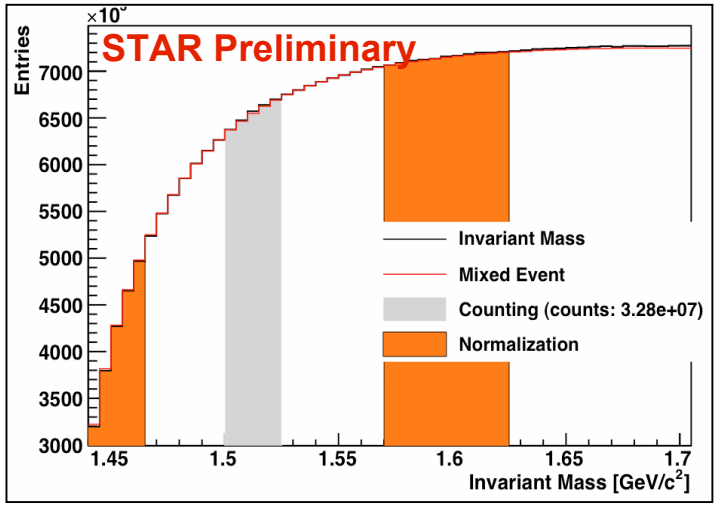
Phys. Rev. Lett. 97, 132301 (2006)
Phys. Lett. B 673, 183 (2009)
Phys. Rev. C 84, 034909 (2011)

$\Lambda(1520) + \bar{\Lambda}(1520)$ in Cu+Cu 200GeV

$\Lambda(1520) + \bar{\Lambda}(1520)$ p_T : 0.4-3.2 [GeV/c]



~20M Min. Bias events
(after event selection)



Fit with the Breit-Wigner func. + background.

Error is statistical only. Systematic is under study.

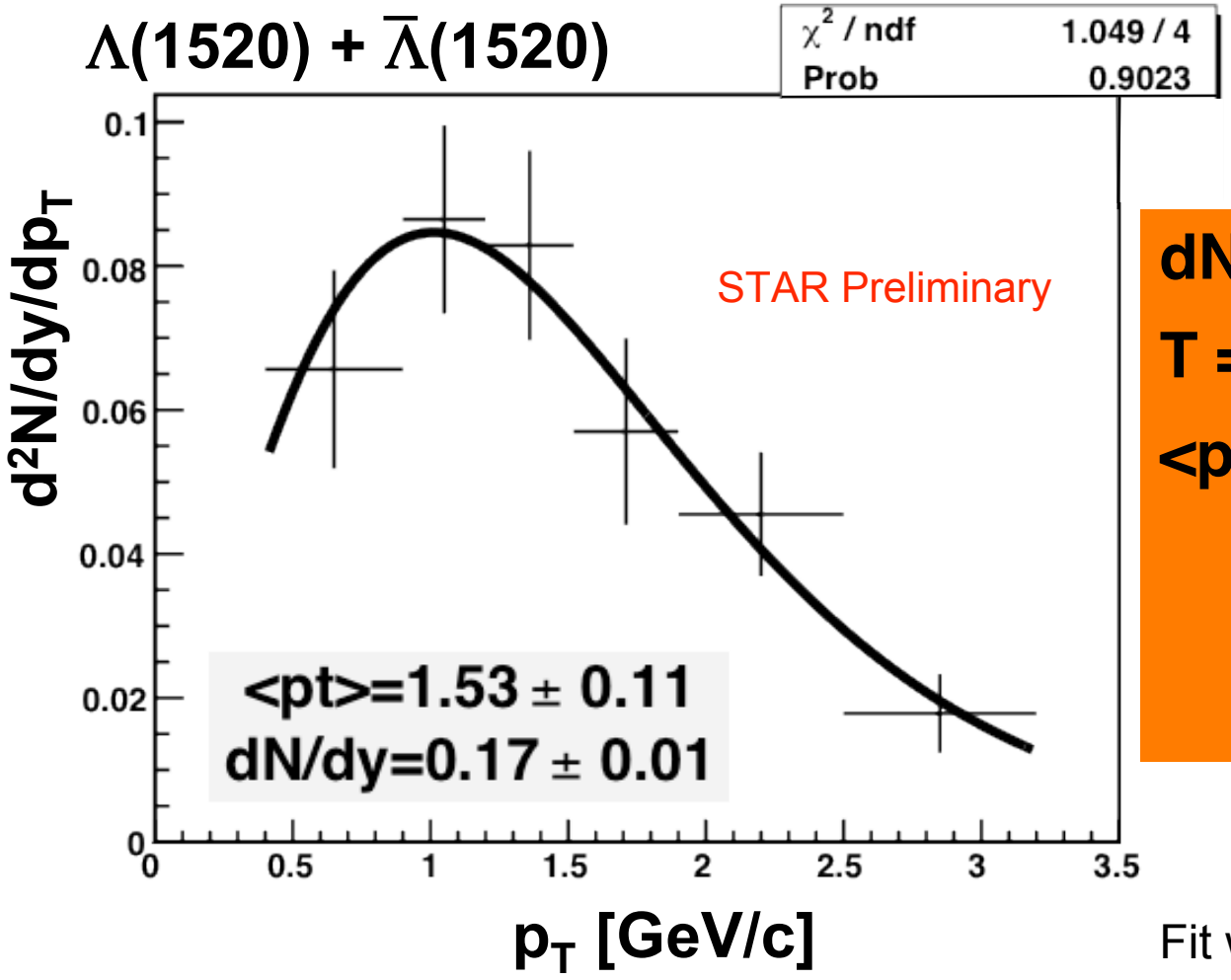
STAR APS2011

Fit: mass = 1513 ± 1 ± sys. MeV/c^2
width = 16 ± 3 ± sys. MeV/c^2
Simulation:
mass = 1518 ± 0.1 MeV/c^2
width = 16.3 ± 0.1 MeV/c^2
Particle Data Group:
mass = 1519.5 ± 1.0 MeV/c^2
width = 15.6 ± 1.0 MeV/c^2

$\Lambda(1520) + \bar{\Lambda}(1520)$ in Cu+Cu

Corrected

$\Lambda(1520) + \bar{\Lambda}(1520)$



dN/dy = 0.17 ± 0.01

T = 0.56 ± 0.055 [GeV]

$\langle p_T \rangle$ = 1.53 ± 0.11 [GeV/c]

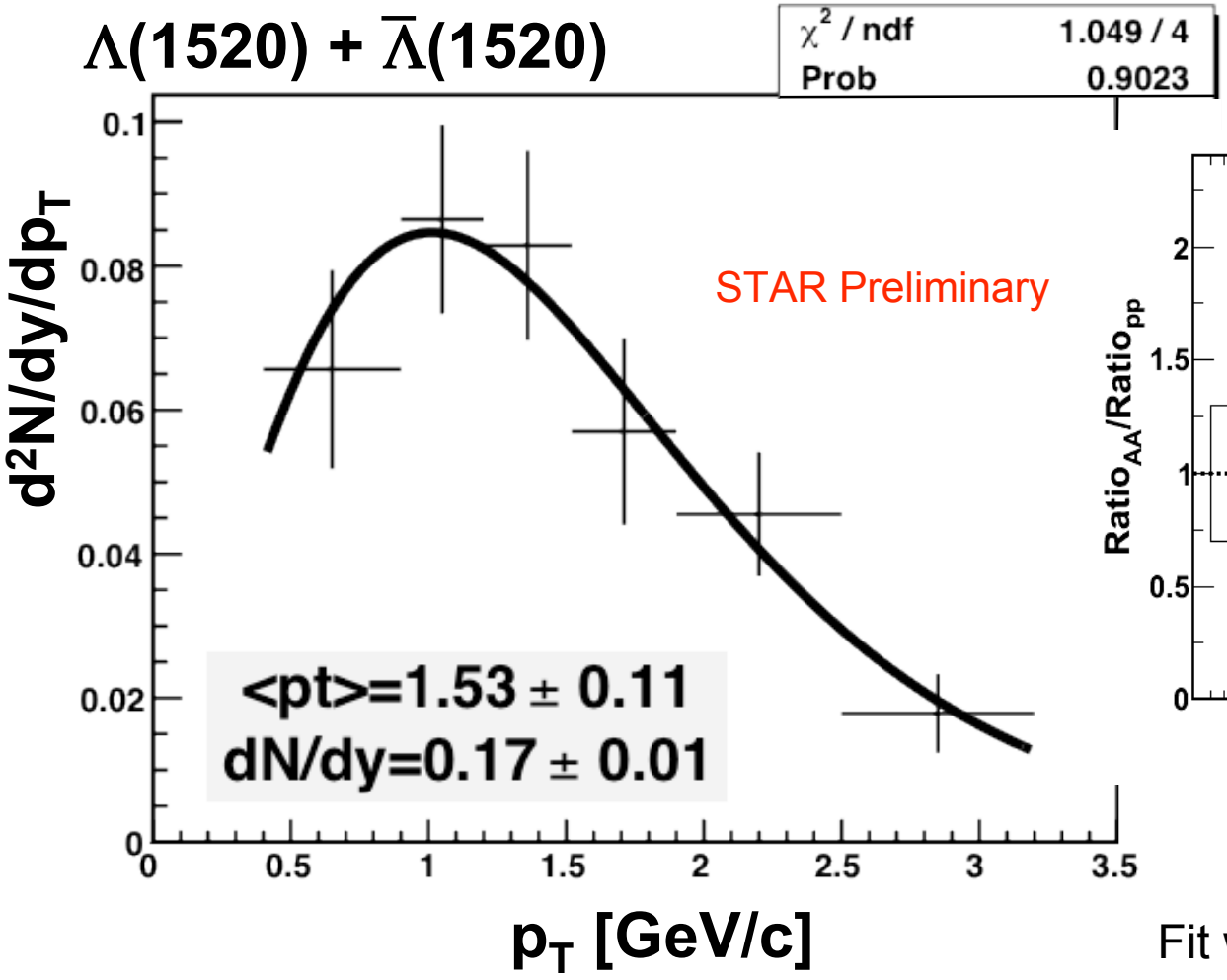
Fit with Maxwell-Boltzmann dist.
Error is statistical only.

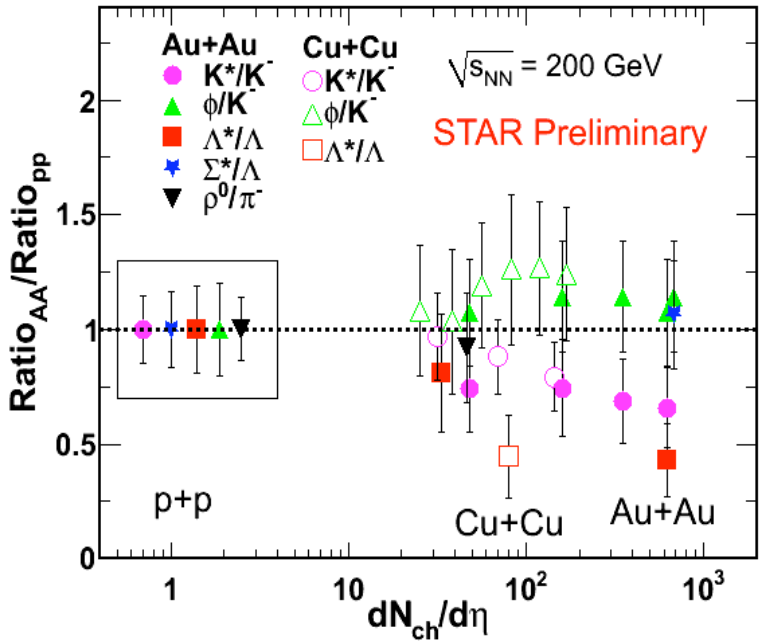
STAR APS2011

$\Lambda(1520) + \bar{\Lambda}(1520)$ in Cu+Cu

Corrected

$\Lambda(1520) + \bar{\Lambda}(1520)$





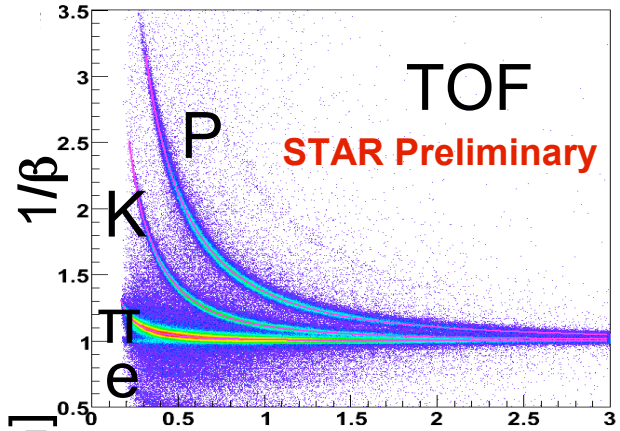
Fit with Maxwell-Boltzmann dist.
Error is statistical only.

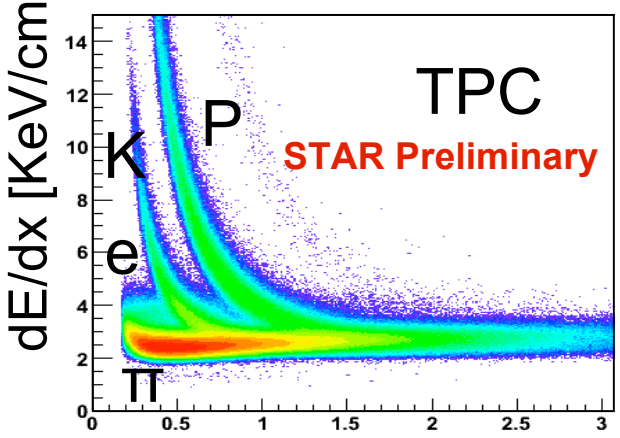
STAR APS2011

ϕ & ω
in Leptonic Decay Channel

Electron Identification

With New TOF Detector



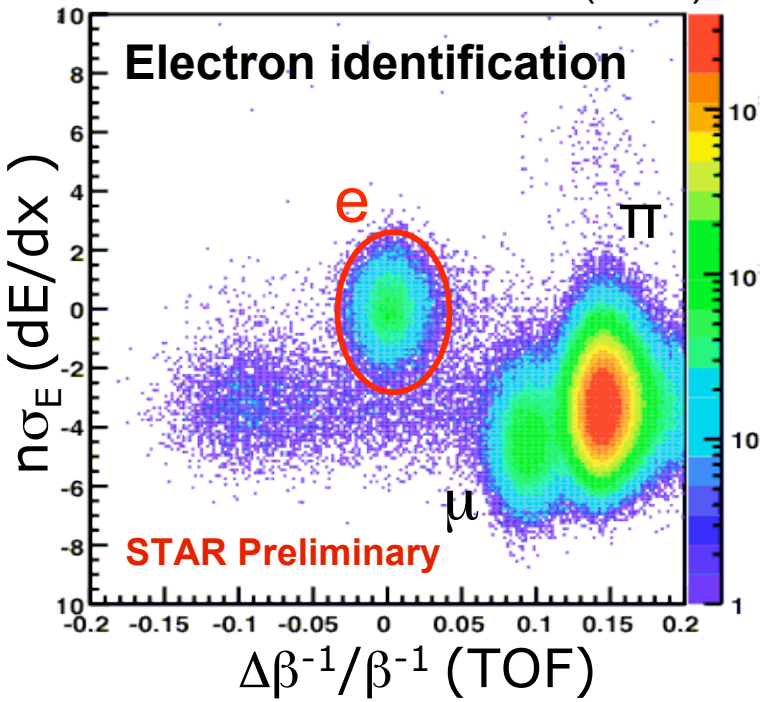


Momentum [GeV/c]

p+p (2009)

Combine

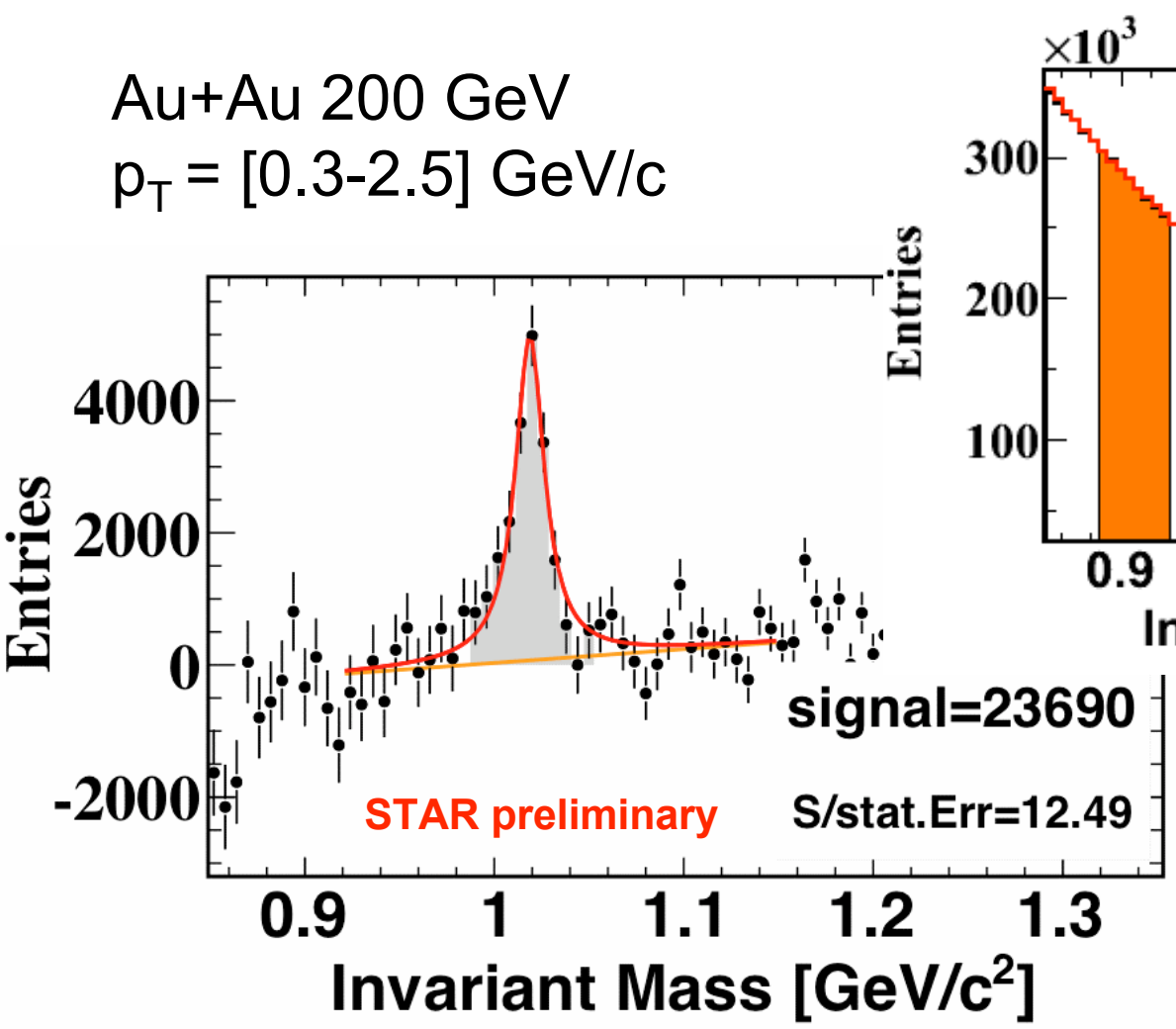
Au+Au (2010)

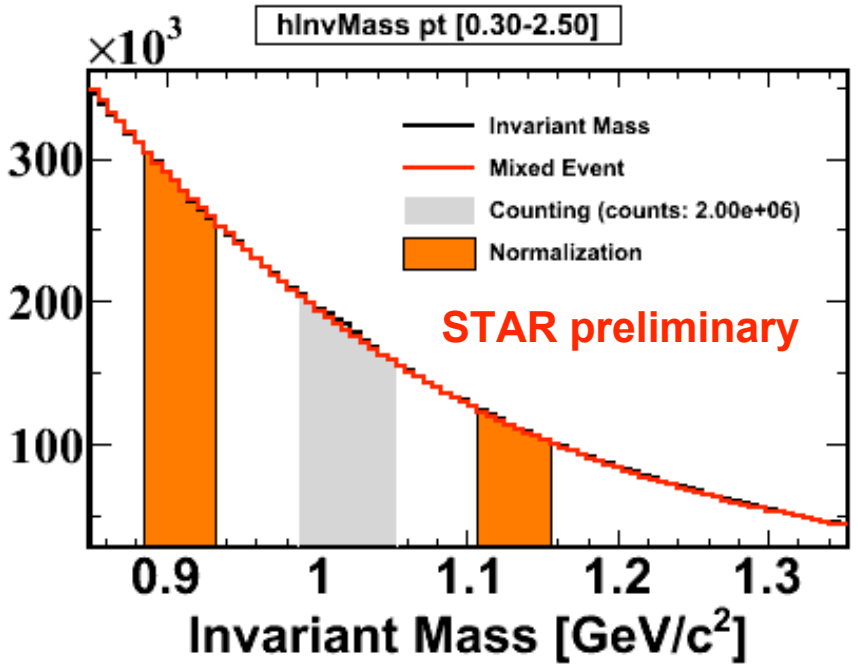


We use electrons up to p=1.5GeV/c due to large contaminations from pions.

ϕ(1020) Signal

Au+Au 200 GeV
p_T = [0.3-2.5] GeV/c





	Mass [MeV/c^2]	width [MeV/c^2]
PDG	1019± 0.02	4.26± 0.04
Fit	1019± 1.0	19.71± 2.93

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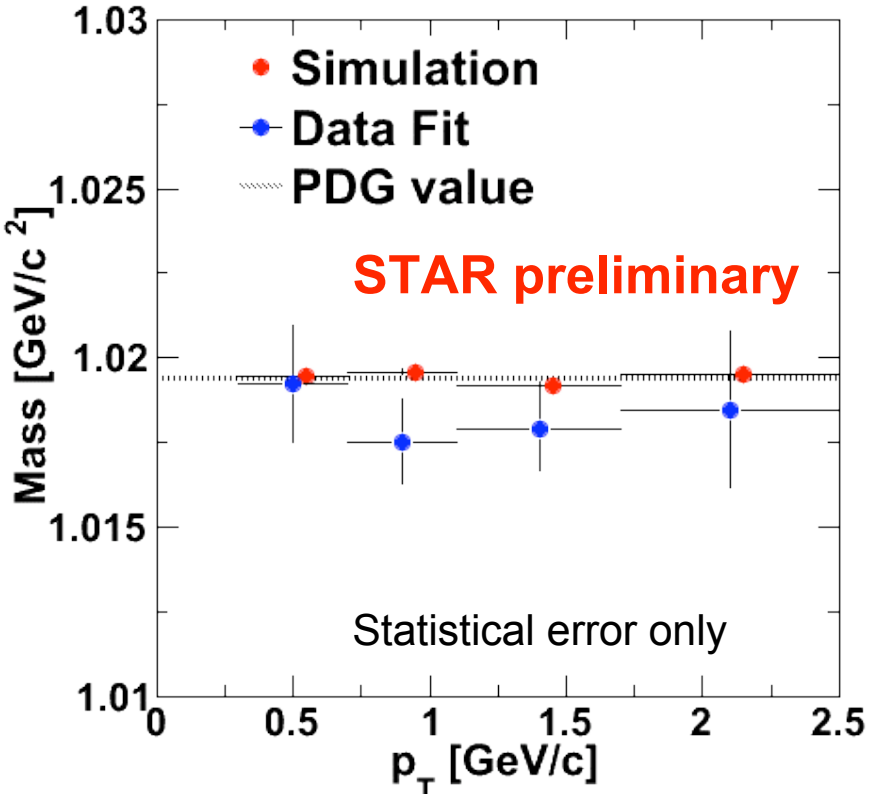
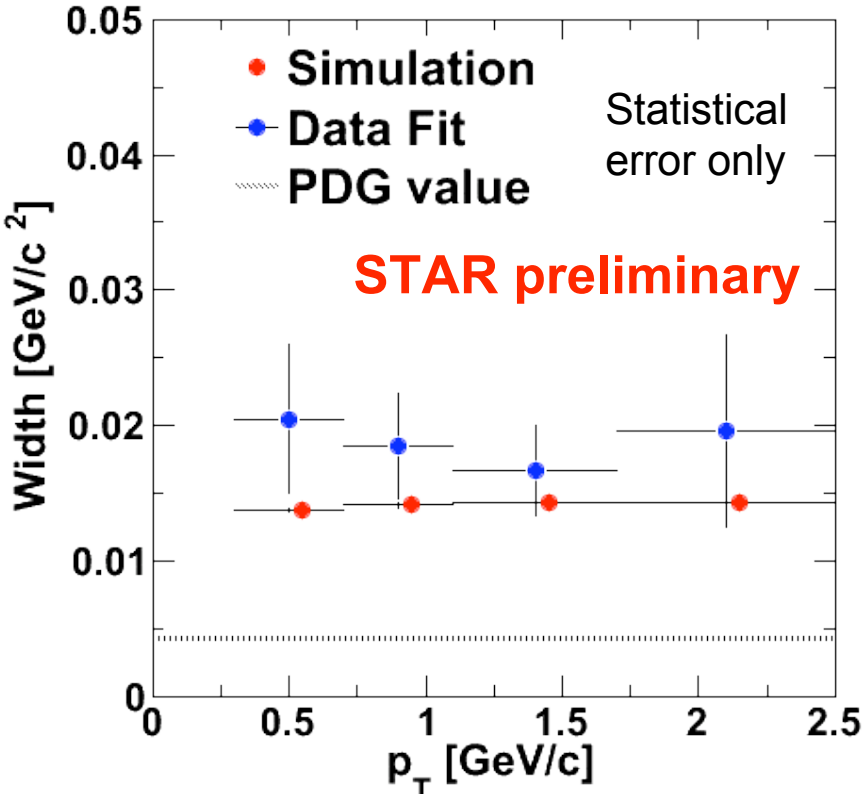
Mass & Width in p_T Bins

Au+Au 200 GeV





Mass and width are in agreement with the simulation.

➔No mass shifts or width broadenings

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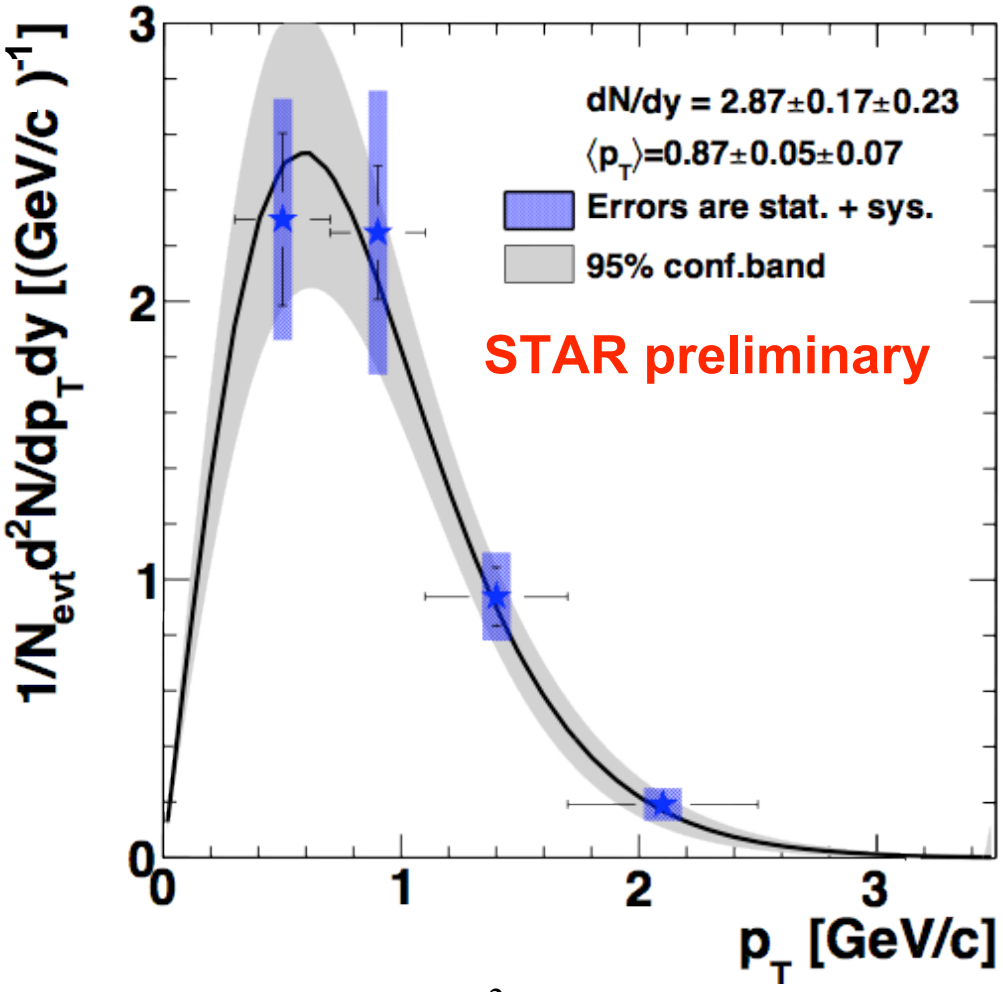
Corrected ϕ(1020) Spectrum



Au+Au 200 GeV
$\phi \rightarrow e^+e^-$ (0-80%)

$\langle p_T \rangle$=0.87±0.05±0.07 [GeV/c]
dN/dy=2.87±0.17±0.23

Run4 $\phi \rightarrow K^+K^-$ (0-80%)

$\langle p_T \rangle$=0.962±0.014 [GeV/c]
dN/dy=2.68±0.15
(Statistical error only)

Fit func. = $\frac{d^2N}{dydp_T} = p_T \frac{dN/dy}{T(m_\phi + T)} \exp\left[-\frac{m_T - m_\phi}{T}\right]$

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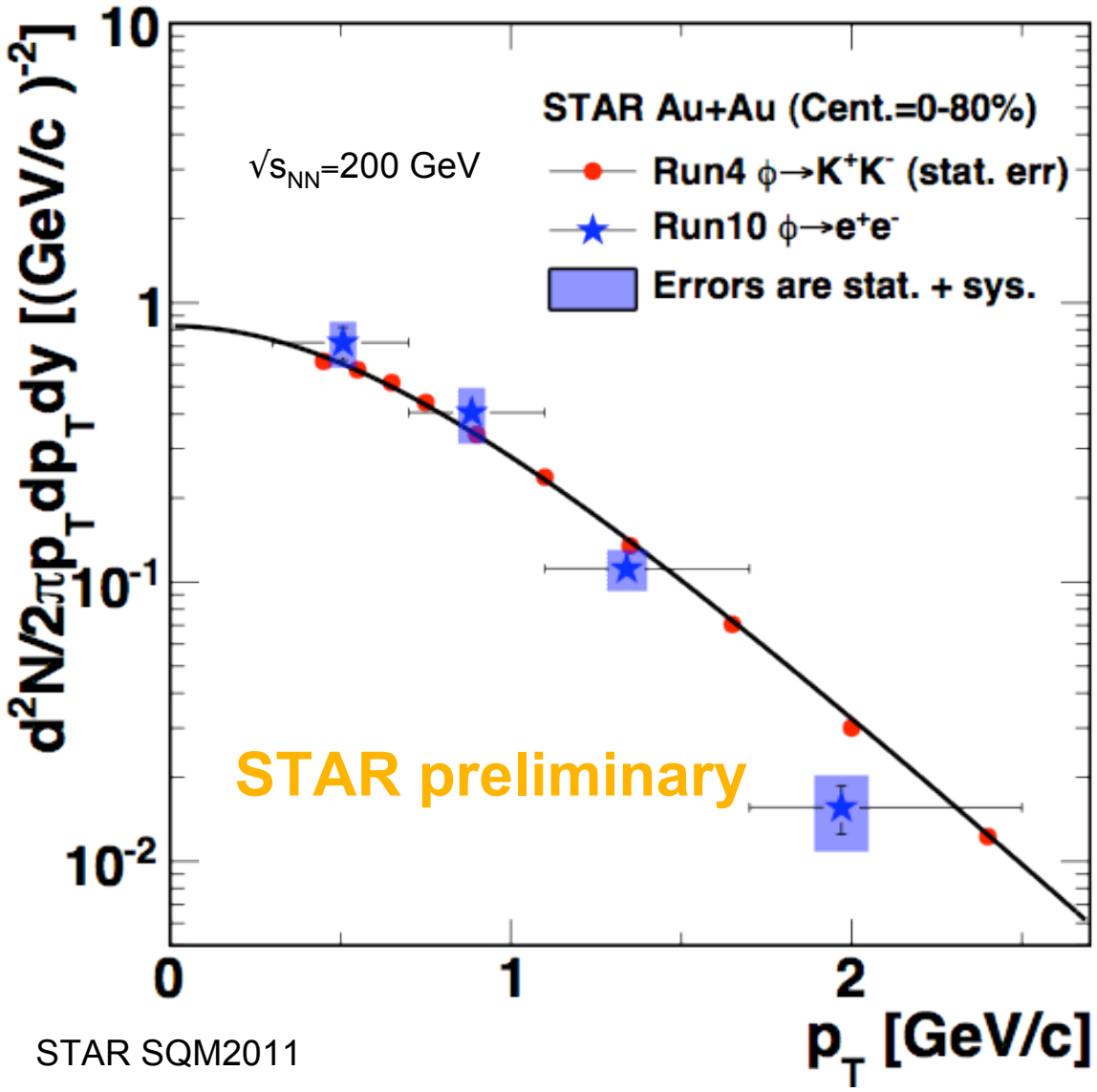
Comparison to Hadronic Decay



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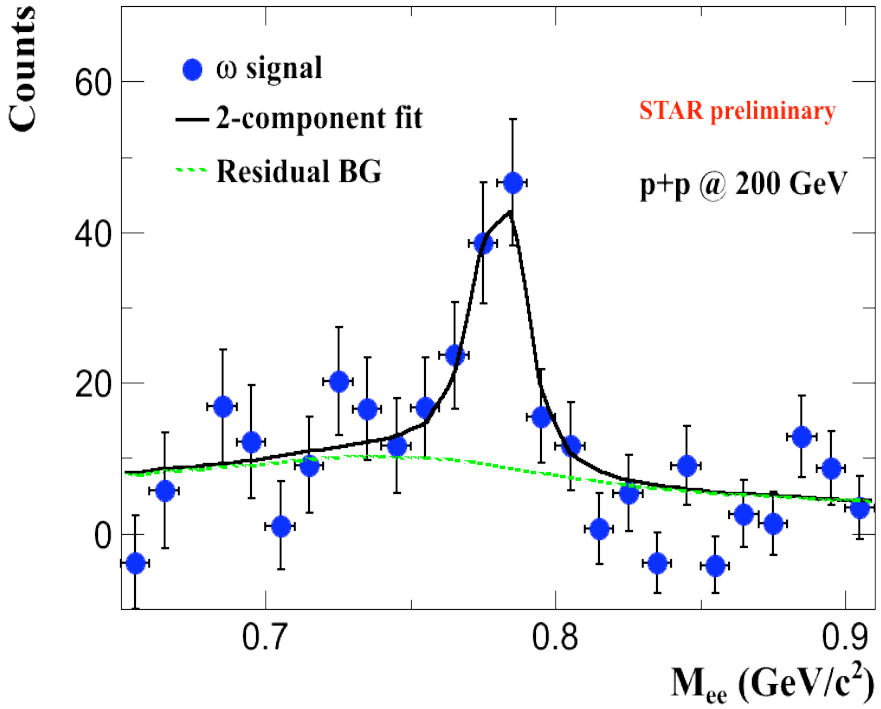
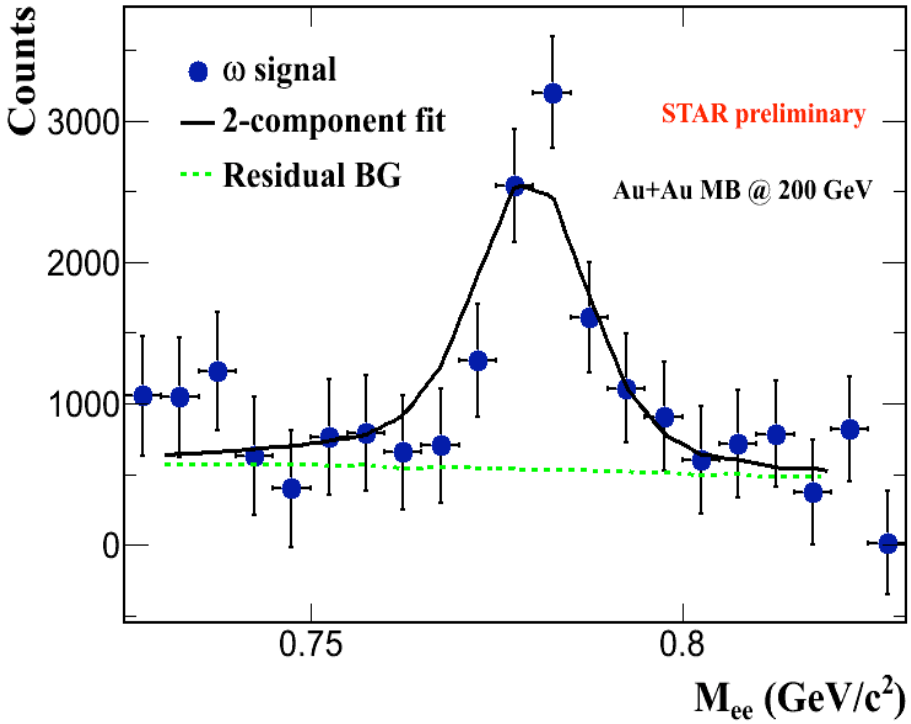
No significant difference between hadronic and leptonic decay channel within the errors.

Phys. Rev. C **79,** 064903 (2009)

ω Signal

STAR QM11



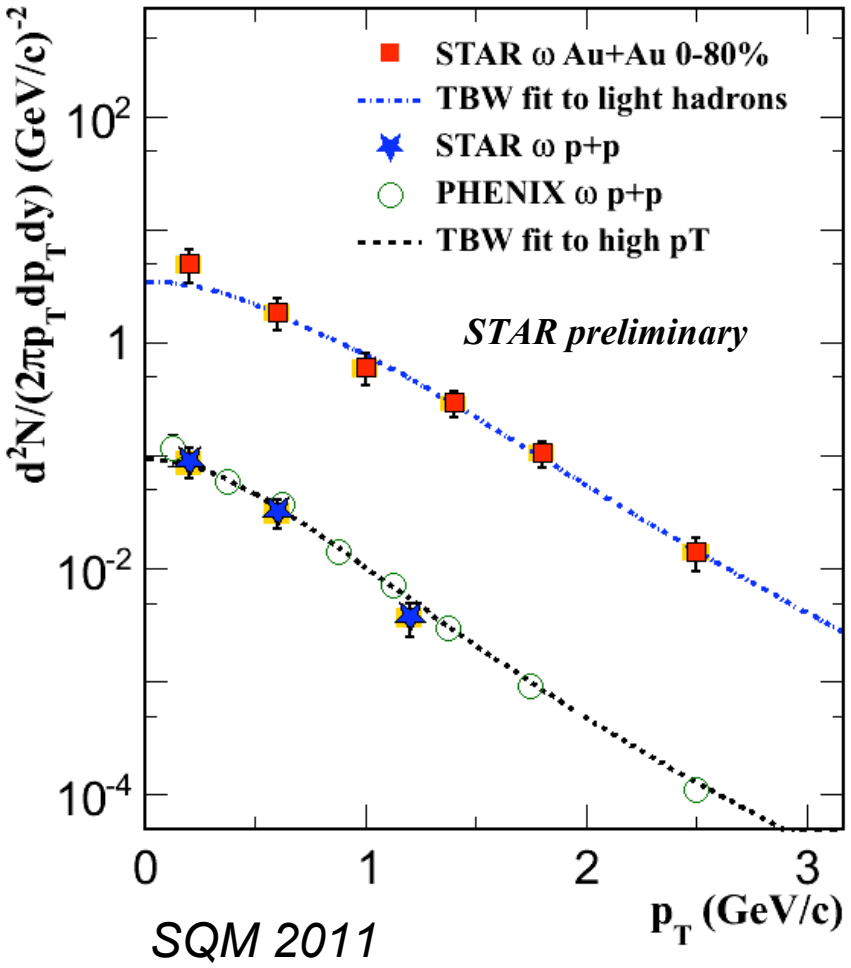


Fit ω by two components

ω Invariant shape from the cocktail simulation

Green line: the cocktail without ω

$\omega \rightarrow e^+e^-$ Spectra



- **$\omega \rightarrow e^+e^-$ spectra measured in p+p and Au+Au 200 GeV**
  - Yield consistent with Tsallis fit expectations
  - Applies to p+p
- dN/dy of ω consistent with previous measurements

Tsallis Blast-wave(TBW) fit:

T=96.4 MeV, q = 1.0926 for mesons <β>=0 in p+p,
T=117 MeV, q = 1.0416 <β>=0.47 in 0-80% AuAu.

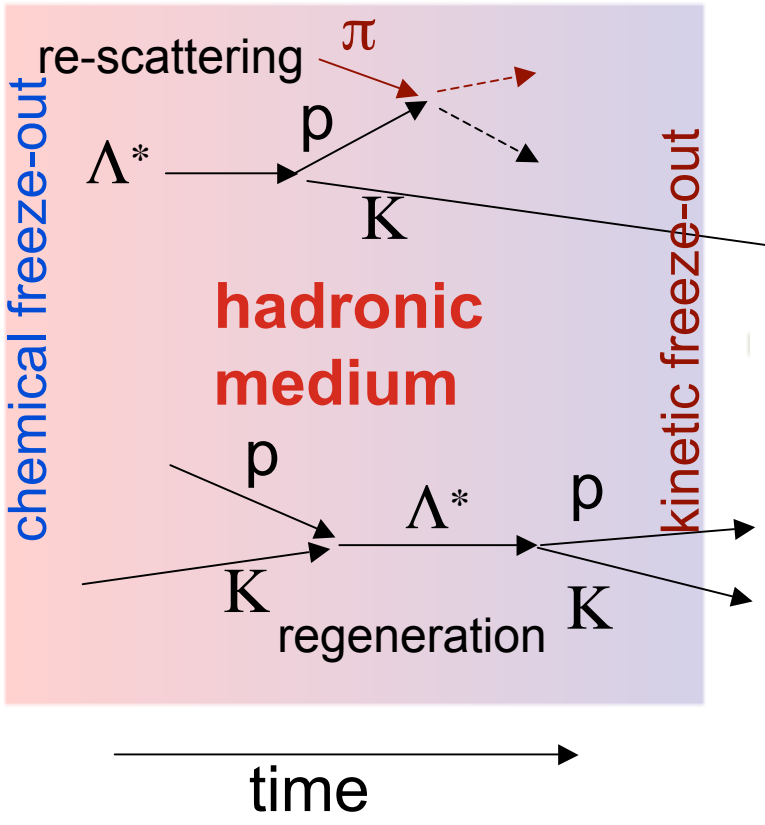
(q is a parameter characterizing the degree of non-equilibrium)
Z.Tang et al., arXiv:1101.1912

Summary

- In STAR, ρ_0, K*, ϕ, Σ^*, Λ^* are measured in various colliding species and colliding energies.
- Masses and widths of those resonances are presented. No significant mass shifts or width broadening are observed.
- $\langle p_T \rangle$ and yields ratios are presented.
  - In most central, the K* $\langle p_T \rangle$ agree to the $\langle p_T \rangle$ of non-resonance particle. However, in peripheral bin, the K^{*0} $\langle p_T \rangle$ shows enhancement.
  - Double ratio of K*/K & Λ^*/Λ ylleds show suppression with centrality possibly due to re-scattering of daughters in hadronic medium.
- New measurements of ϕ and ω from leptonic decay channels are presented. We couldn't see any difference between results from leptonic decay channel and from hadronic decay channel.
- No signature of the Chiral symmetry restoration is observed.

Back Up

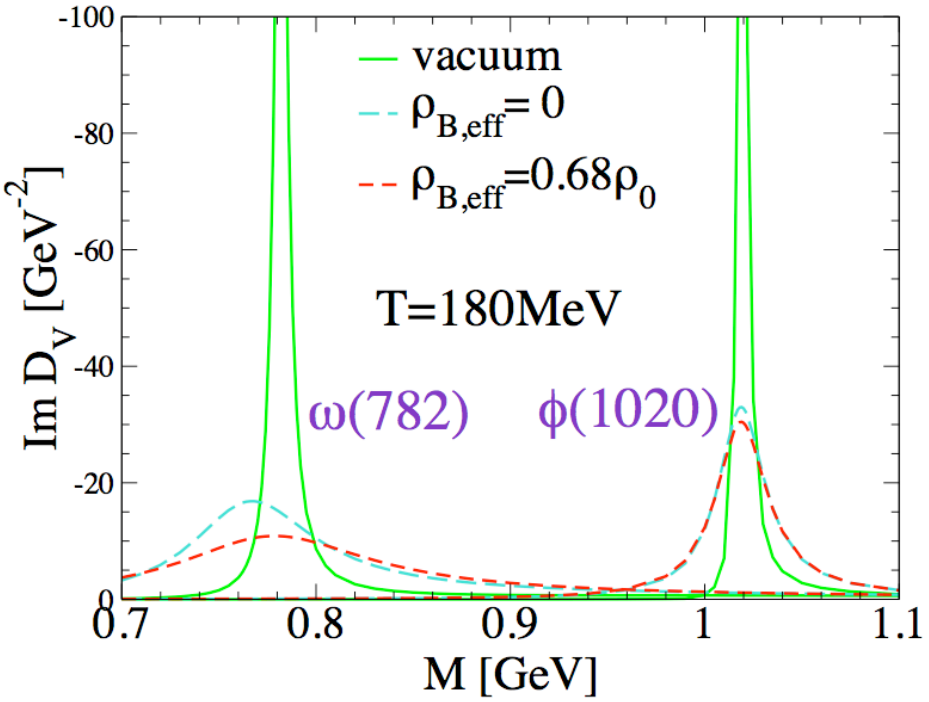
Medium Effects



- **Re-scattering**: loss of signal $\propto \sigma_{\text{daughter-medium}}$
- **Re-generation**: increase resonance yields $\propto \sigma_{\text{daughter-daughter}}$

Estimate time span between chemical and kinetic freeze out.

The Chiral Symmetry Restoration

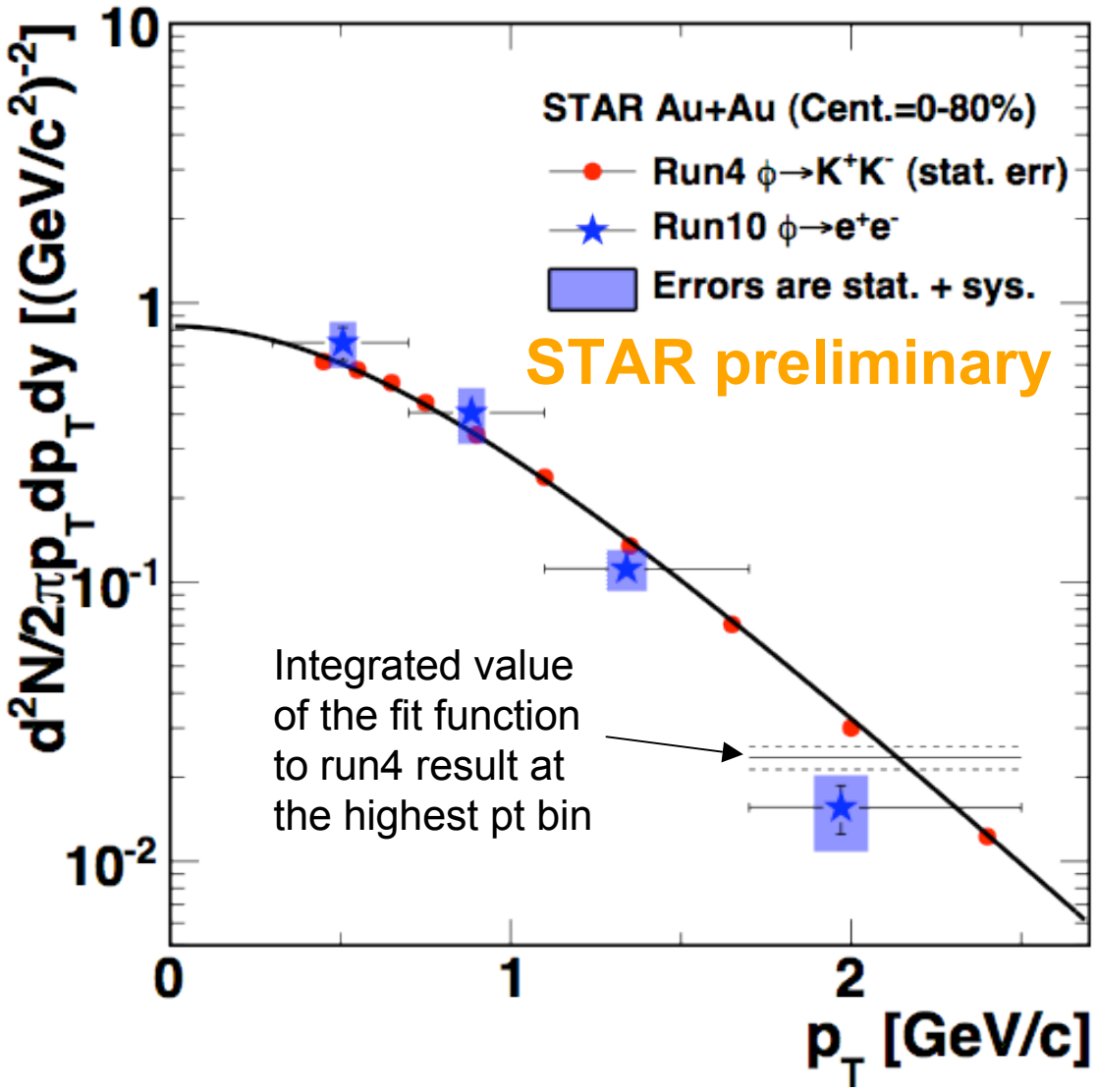


The Chiral Restoration Transition of QCD and Low Mass Dileptons. Stock, R. (ed.). SpringerMaterials

Search for evidence of chiral symmetry restoration

- Masses of ρ→e+e- and ϕ→e+e- may broaden/shift
- Relative production rates of ϕ→e+e- and ϕ→K+K- may change…

Back Up

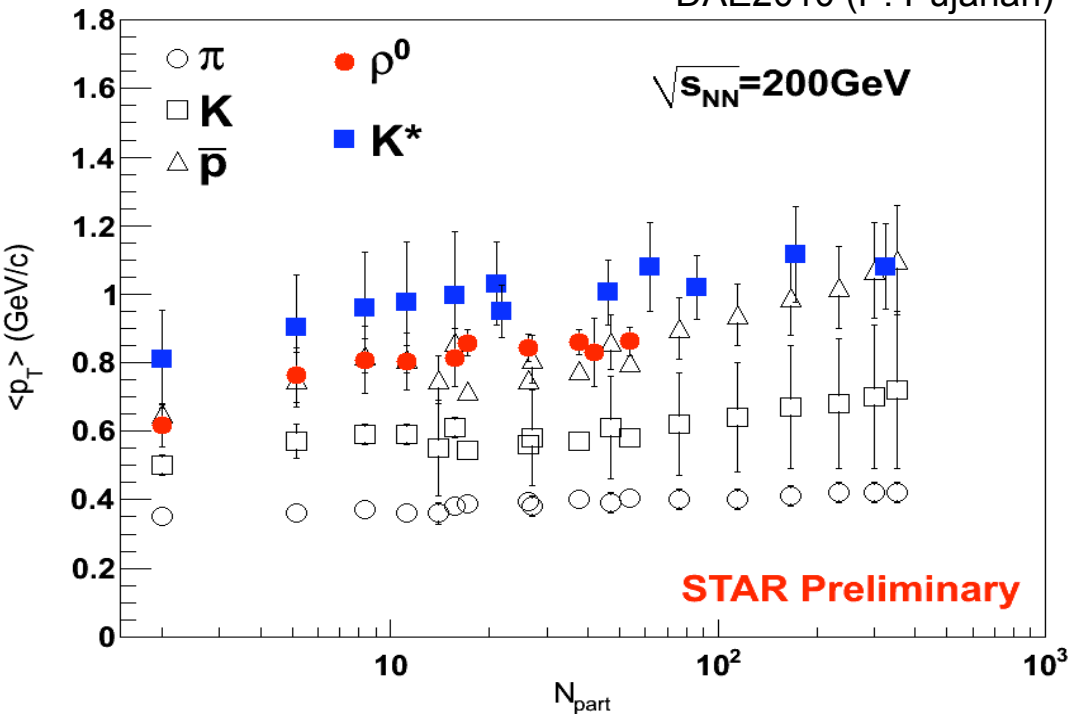


- The difference between Run4 and Run10 is 1.18σ

Phys. Rev. C **79,** 064903 (2009)

Mean p_T Distributions

DAE2010 (P. Pujahari)



The $\langle p_T \rangle$ of π, K, $\bar{p}$ and K* is taken from STAR published results.

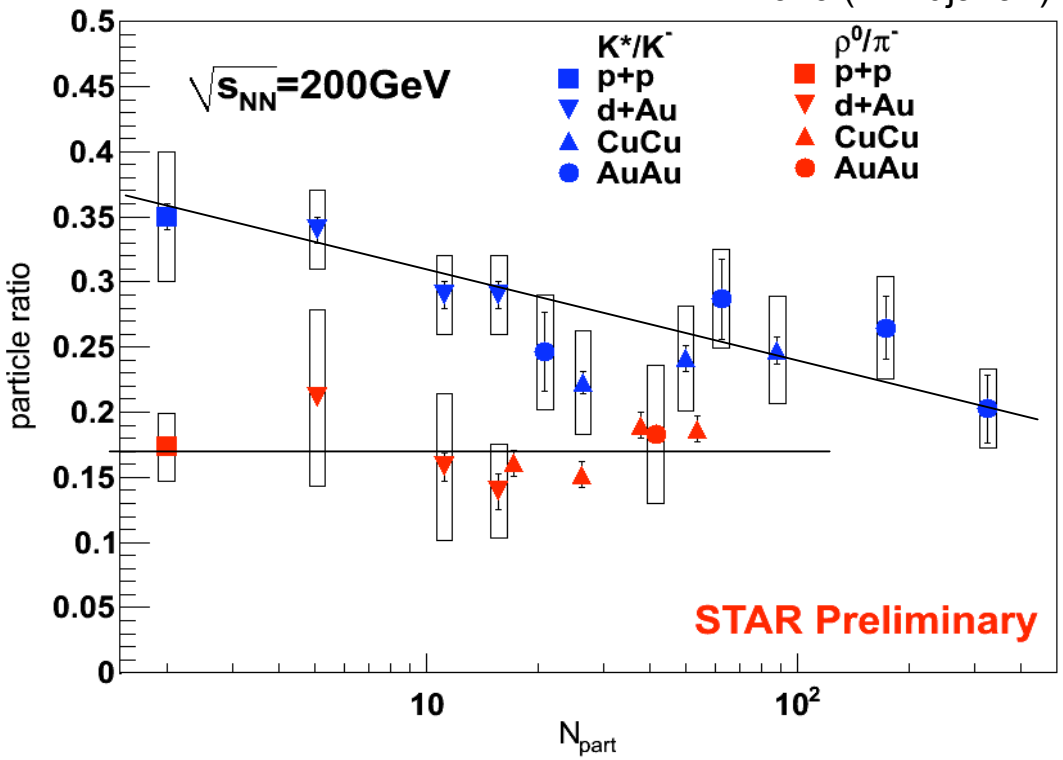
ρ⁰ in p+p, Au+Au 200 GeV: Phys. Rev. Lett. 92 (2004) 92301

ρ⁰ in d+Au 200 GeV: Phys. Rev. C 78 (2008) 44906

- For ρ^0 in Cu+Cu only statistical error.
- ρ^0 mean p_T slightly increases with N_{part}.
- ρ^0 mean p_T comparable with proton mean p_T.

Particle Ratios

DAE2010 (P. Pujahari)

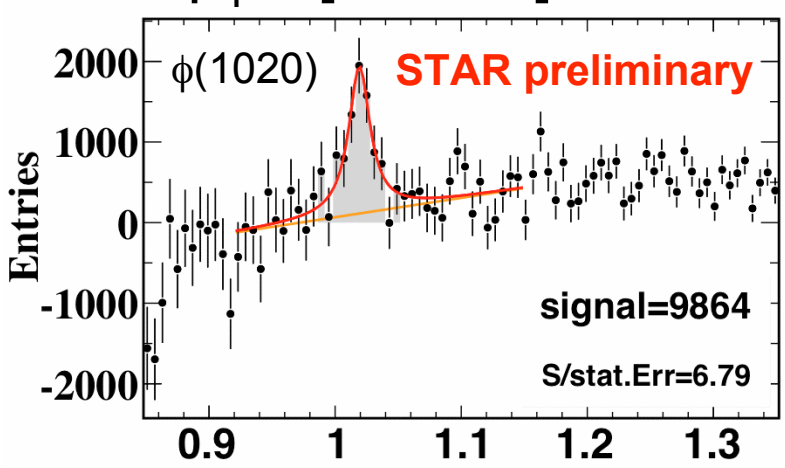


K*/K⁻ ratio is obtained
From STAR published results.

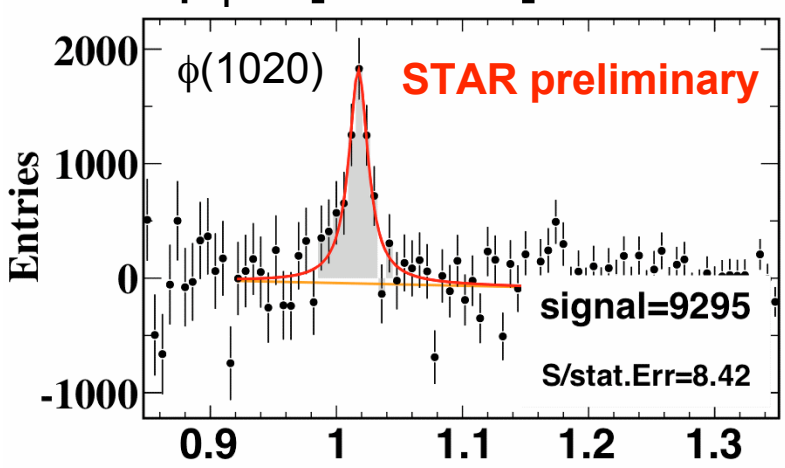
- Cross-section ⇒ regeneration or re-scattering.
- K*/K⁻ ⇒ re-scattering of the daughters.
- ρ^0/π^- ⇒ regeneration compensating re-scattering of the daughters.

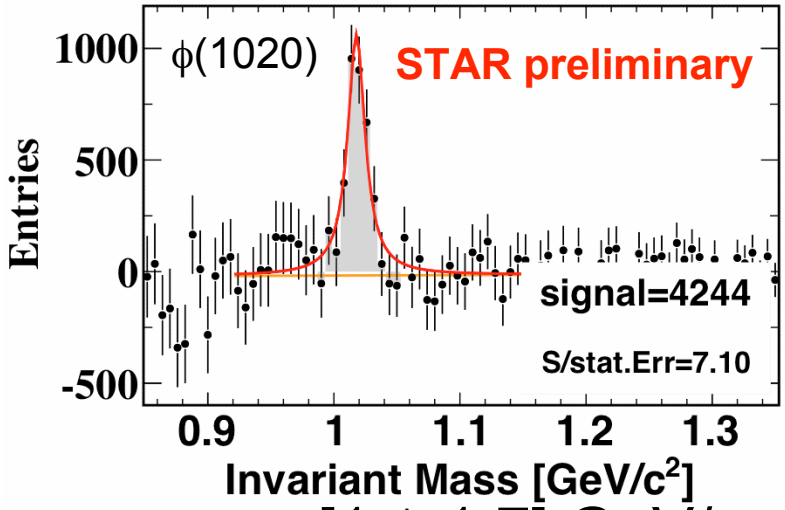
Transverse Momentum Bins

p_T = [0.3-0.7] GeV/c

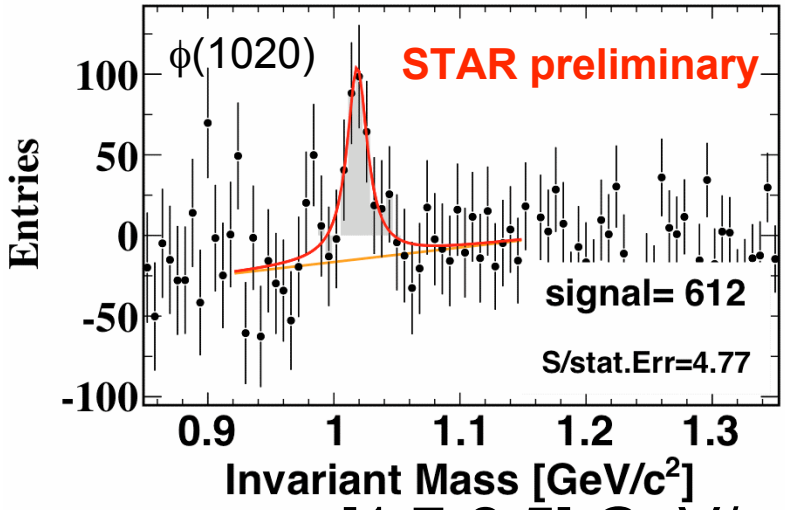


p_T = [0.7-1.1] GeV/c



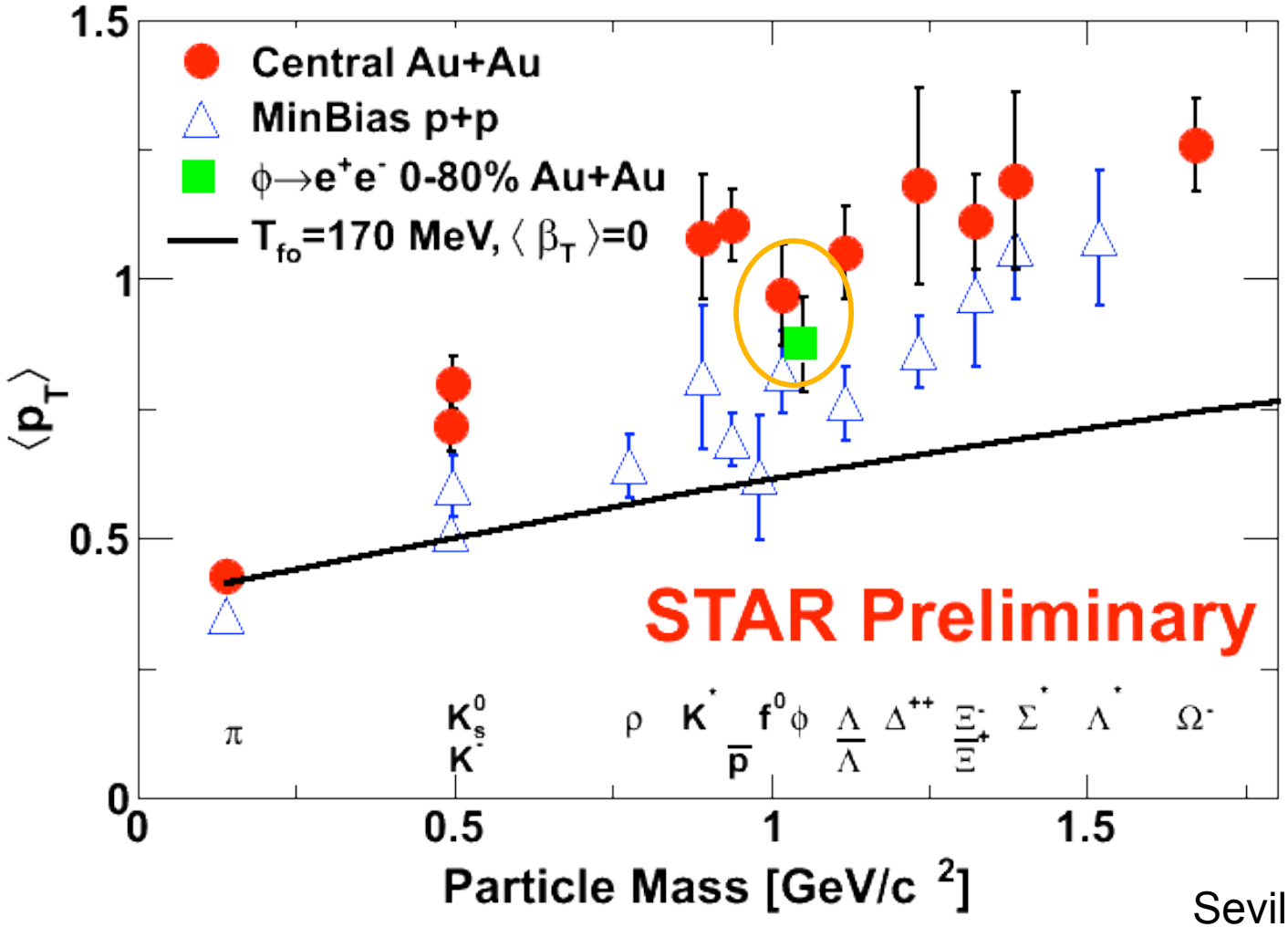


p_T = [1.1-1.7] GeV/c



p_T = [1.7-2.5] GeV/c

Mean Transverse Momentum



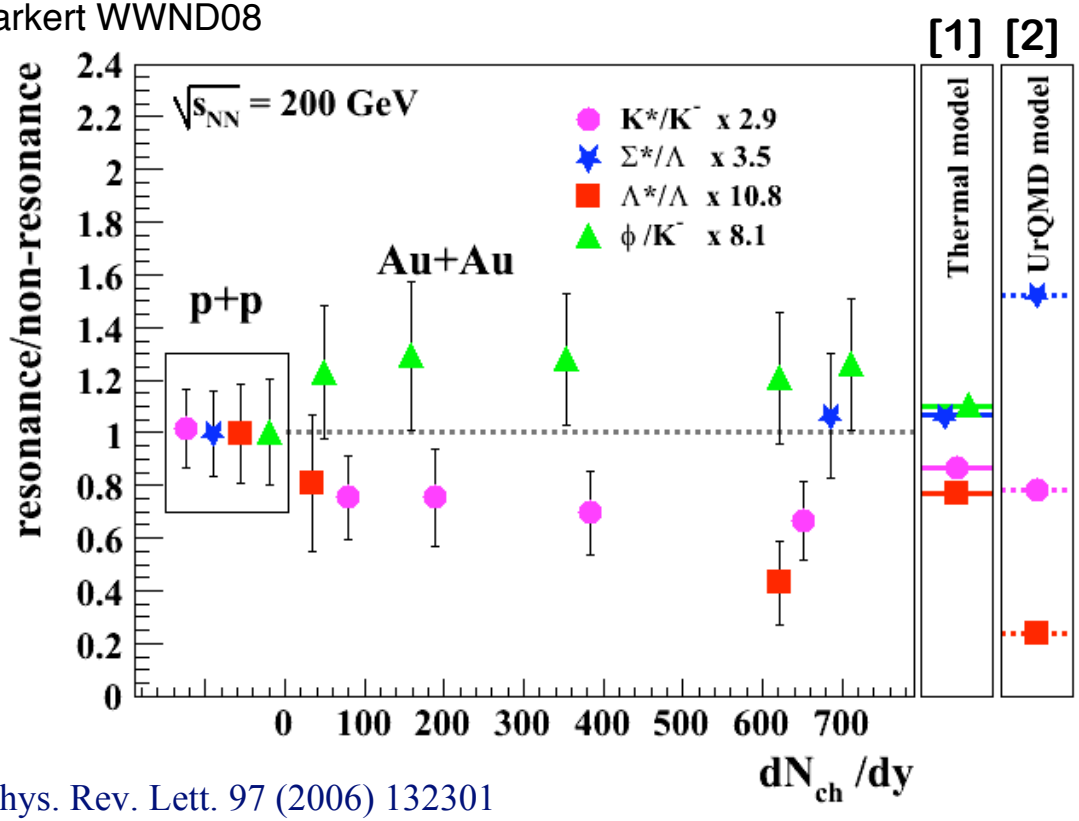
Agreement between hadronic and leptonic decay channel within the errors

Sevil Salur @SQM2006

Error is stat. + sys.

Interactions of resonances in hadronic medium

C. Markert WWND08



Phys. Rev. Lett. 97 (2006) 132301

[1] P. Braun-Munzinger et.al.,PLB 518 (2001) 41,priv. communication
[2] Marcus Bleicher and Jörg Aichelin Phys. Lett. B530 (2002) 81.
M. Bleicher and Horst Stöcker J. Phys.G30 (2004) 111.

Life-time [fm/c] :

K(892)	~ 4.0
Σ(1385)	~ 5.7
Λ(1520)	~ 13
ϕ (1020)	~ 44

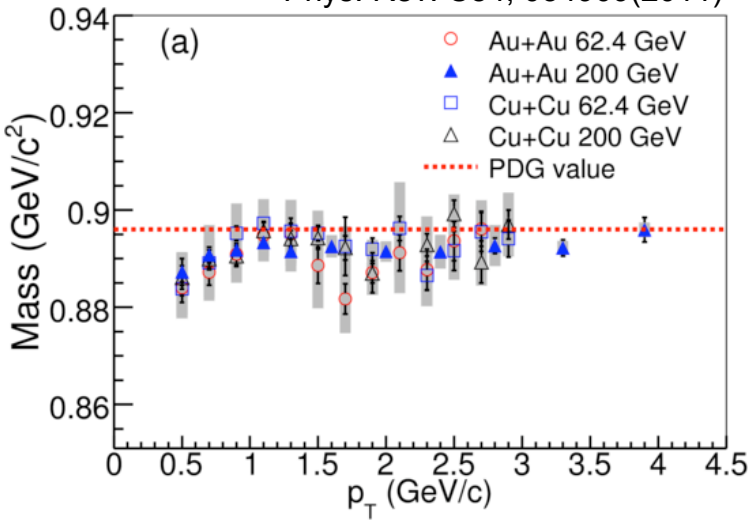
Lifetime of hadronic medium:
C. Markert, G. Torrieri and J. Rafelski, hep-ph/0206260
T= 160 MeV → Δτ > 4 fm/c (lower limit)
UrQMD: Δτ = 13 ± 3 fm/c

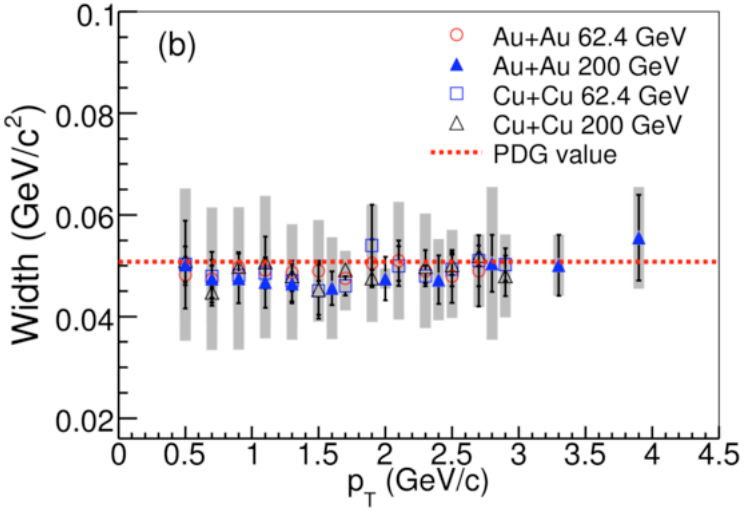
Regeneration/Rescattering cross section:
$\sigma(K+p) < \sigma(K+\pi) < \sigma(\Lambda+\pi)$
Λ^* K^* Σ^*

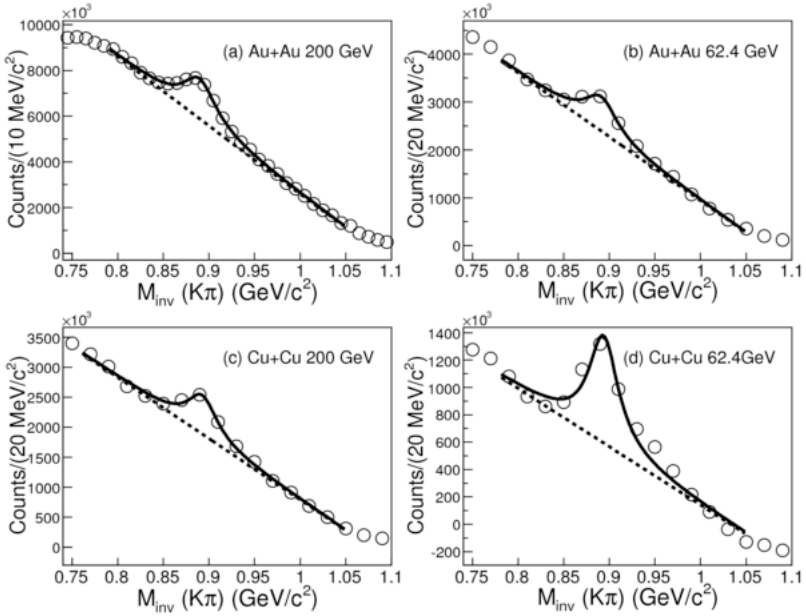
In agreement with UrQMD calculations

K*(892) (cont'd)

Phys. Rev. C84, 034909(2011)







- At low p_T , masses are lower than PDG value
- No significant dependence of mass and width on beam energy and colliding ion species