Resonances at RHIC: What is next?

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- Accomplishments
- What is next…
  - Motivations
- What is needed…
  - Simulations
- Summary

Accomplishments

- Observed resonances
- Resonance Yields ⇒ Interactions between chemical and kinetic freeze-outs ⇒ time estimation
- Resonance Nuclear Modification Factor ⇒ Discriminating between baryon/meson or mass effect
- Resonance Elliptic Flow v_2 ⇒ Information resonance production mechanism in the hadronic phase
- Resonance mass shifts ⇒ Possible medium modification

Observed resonances

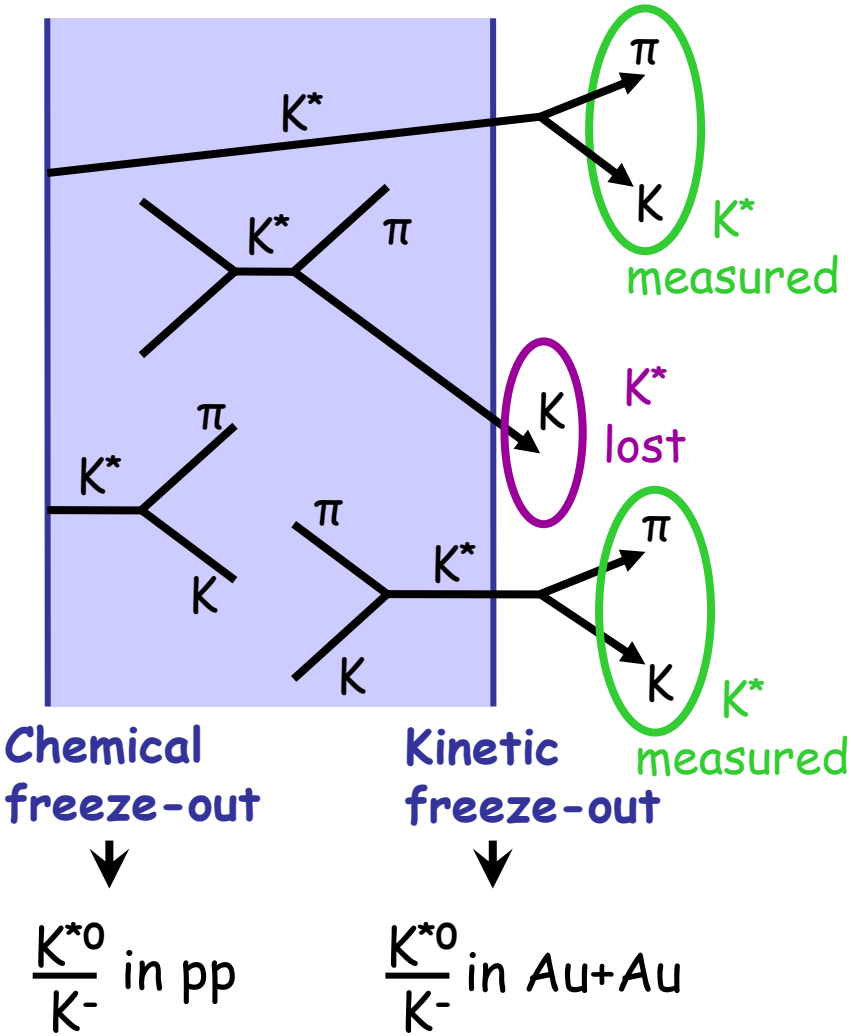
Observed Resonances ⇒ pp, dAu, Au+Au

$f_2(1270) \rightarrow \pi^+ \pi^-$	B.R. 0.85	$c\tau$ = 1.1 fm
$\rho^0(770) \rightarrow \pi^+ \pi^-$	B.R. ~1	$c\tau$ = 1.3 fm
$\Delta^{++}(1232) \rightarrow p\ \pi^+$	B.R. ~1	$c\tau$ = 1.6 fm
$f_0(980) \rightarrow \pi^+ \pi^-$	B.R. 2/3	$c\tau$ = 2.6 fm
$K^{*0\pm}(892) \rightarrow \pi\ K$	B.R. 2/3	$c\tau$ = 4 fm
$\Sigma(1385) \rightarrow \Lambda\ \pi$	B.R. 0.88	$c\tau$ = 5.5 fm
$\Lambda(1520) \rightarrow p\ K$	B.R. 0.45	$c\tau$ = 12.6 fm
$\Phi(1020) \rightarrow K^+ K^-$	B.R. 0.49	$c\tau$ = 44 fm

Life Time ↓

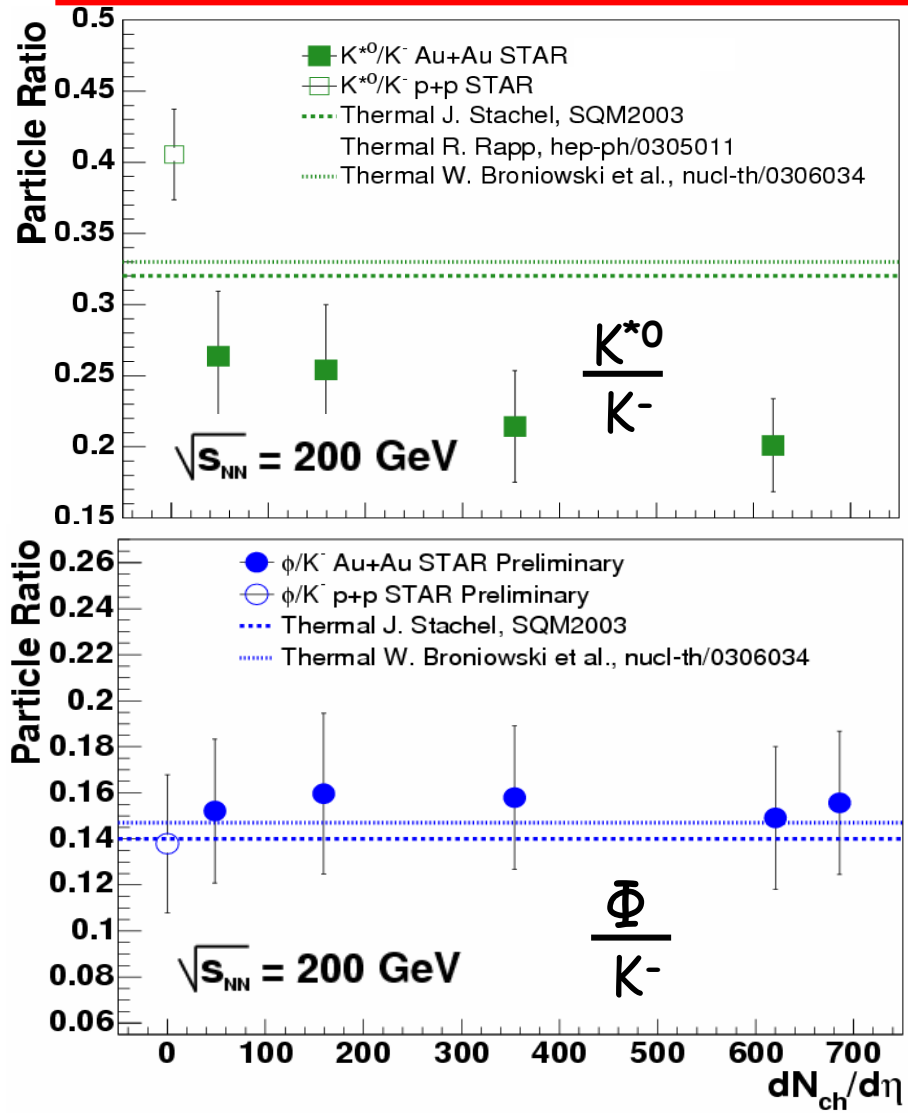
Resonance Yields

Resonance Yields - I



- If resonance decays before kinetic freeze-out ⇒ not reconstructed due to rescattering of daughters
- K^{*0} ($c\tau$ = 4 fm) survival probability ⇒ time between chemical and kinetic freeze-out, source size and p_T of K^{*0}
- Chemical freeze-out ⇒ elastic interactions $\pi K \rightarrow K^{*0} \rightarrow \pi K$ regenerate $K^{*0}(892)$ until kinetic freeze-out
- K^{*0}/K estimate time between chemical and kinetic freeze-out

Resonance Yields - II



- K^{*0} ($c\tau$ = 4 fm)
- If rescattering is the dominant process ⇒ $\Delta t \sim 3$ fm
- If regeneration is the dominant process ⇒ $\Delta t \geq 3$ fm

  J. Adams, nucl-ex/0412019 to be published PRC

- Blast-Wave fit to $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$ ⇒ $\Delta t > 6$ fm

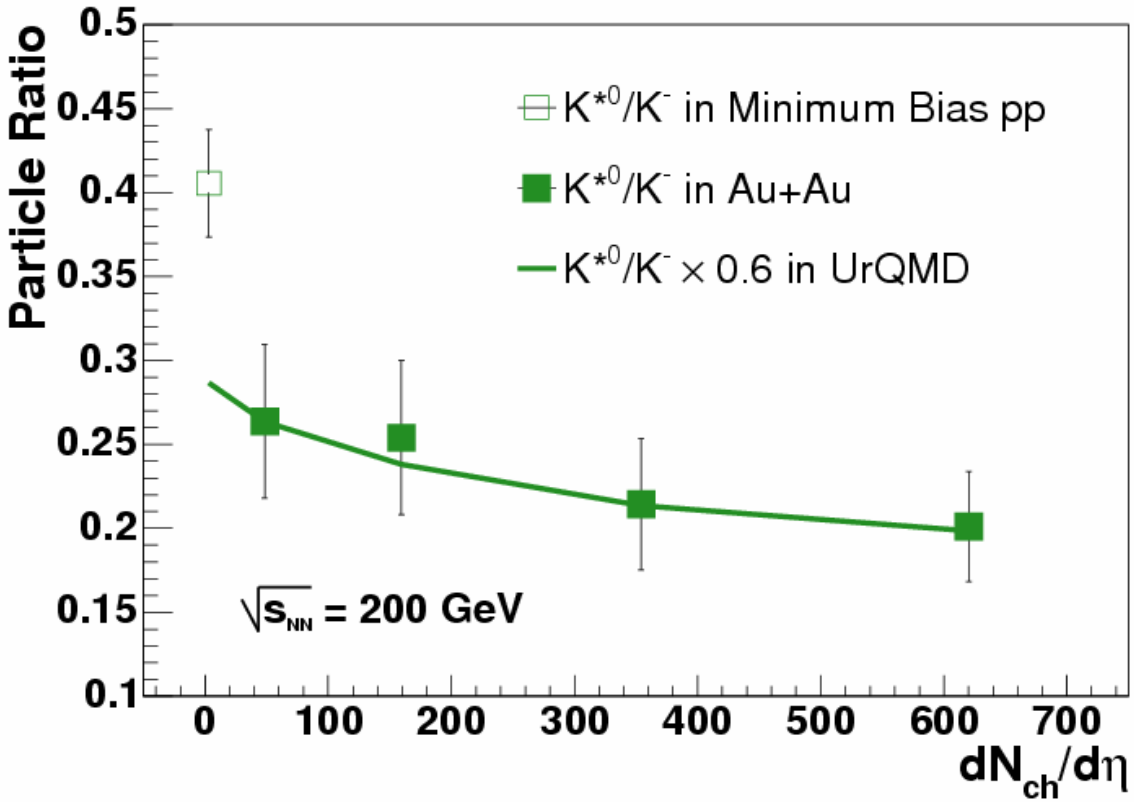
  J. Adams, Phys. Rev. Lett. 92 (2004) 112301

- Φ ($c\tau$ = 44 fm) ⇒ Rescattering and regeneration negligible ⇒ agreement thermal model
- Φ/K^- independent centrality ⇒ Φ not produced via coalescence

  J. Adams, nucl-ex/0406003 to be published PLB

Resonance Yields - III

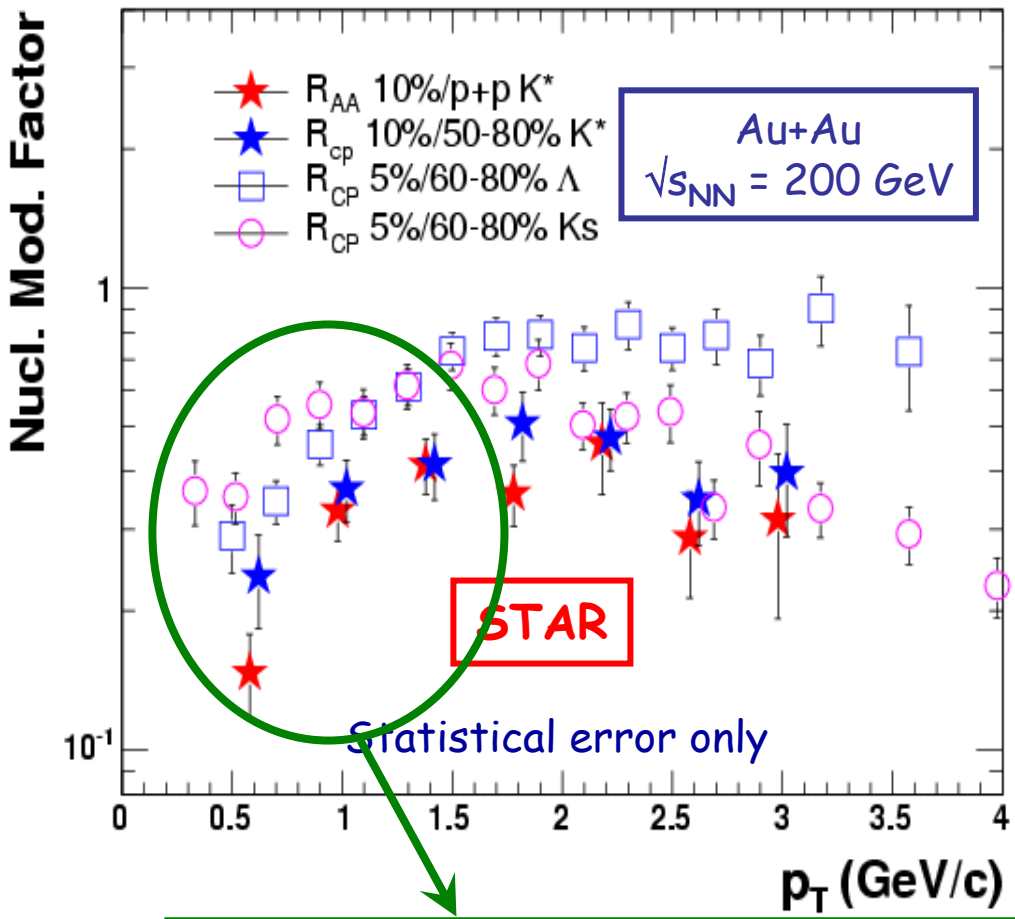
- Transport model calculation ⇒ UrQMD
- Good agreement of the K^{*0}/K^- ratio behavior as a function of N_{ch}



Resonance Nuclear Modification Factor

Resonance Nuclear Modification Factor

J. Adams, nucl-ex/0412019 to be published PRC



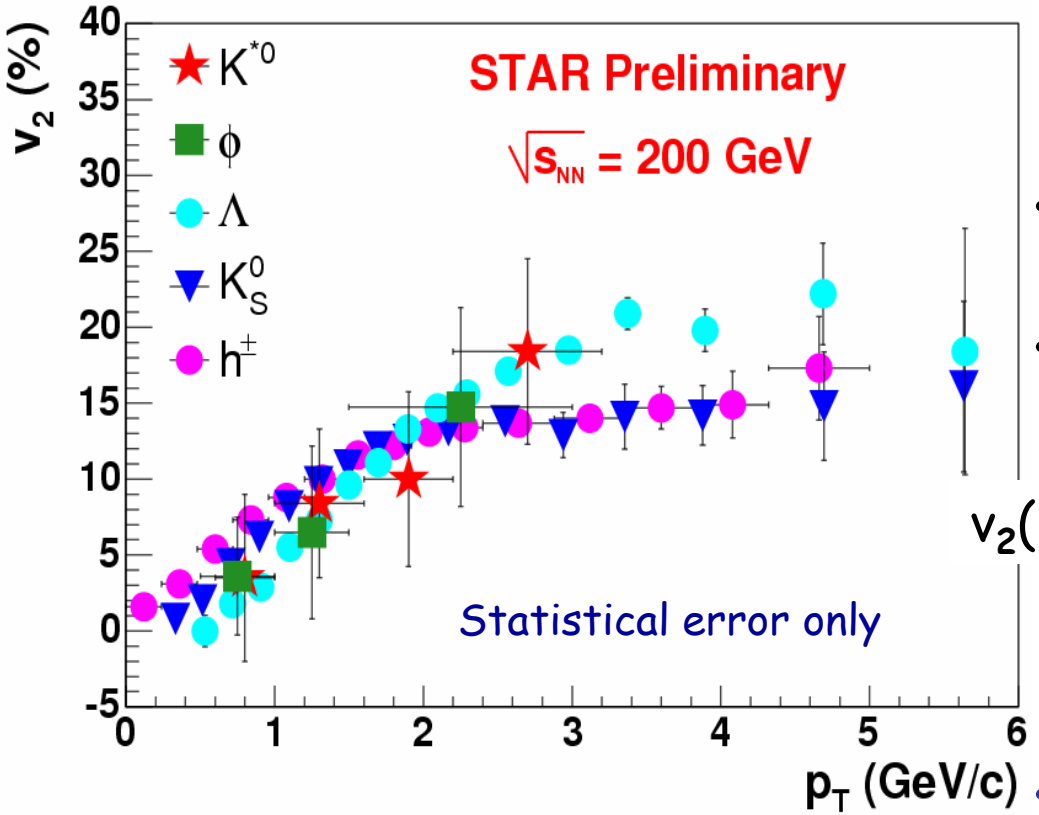
K* daughters rescattering at low p_T

- Nuclear modification factor ⇒ difference K_S^0 and Λ ⇒ baryon/meson or mass effect ?
- K* R_{AA} and R_{CP} ⇒ intermediate p_T ⇒ distinguish the two effects
  - K*(892) ⇒ meson
  - K*(892) ⇒ mass closer to Λ mass
- K* R_{AA} and R_{CP} ⇒ intermediate p_T ⇒ closer to K_S than Λ ⇒ evidence for baryon/meson effect

Resonance Elliptic Flow v_2

Resonance Elliptic Flow v_2

- K_S^0 and Λ $v_2 \Rightarrow$ scale number constituent quarks $\Rightarrow v_2/n$



J. Adams, nucl-ex/0412019 to be published PRC

- Resonance $v_2 \Rightarrow$

  C. Nonaka *et al.*, nucl-th/0312081

  - $\pi K \rightarrow K^* \Rightarrow n = 4$
  - $qq \rightarrow K^* \Rightarrow n = 2$
- Significant K^{*0} and Φ v_2 measured
- Fitting K^{*0} v_2 to

  X. Dong *et al.*, nucl-th/0403030

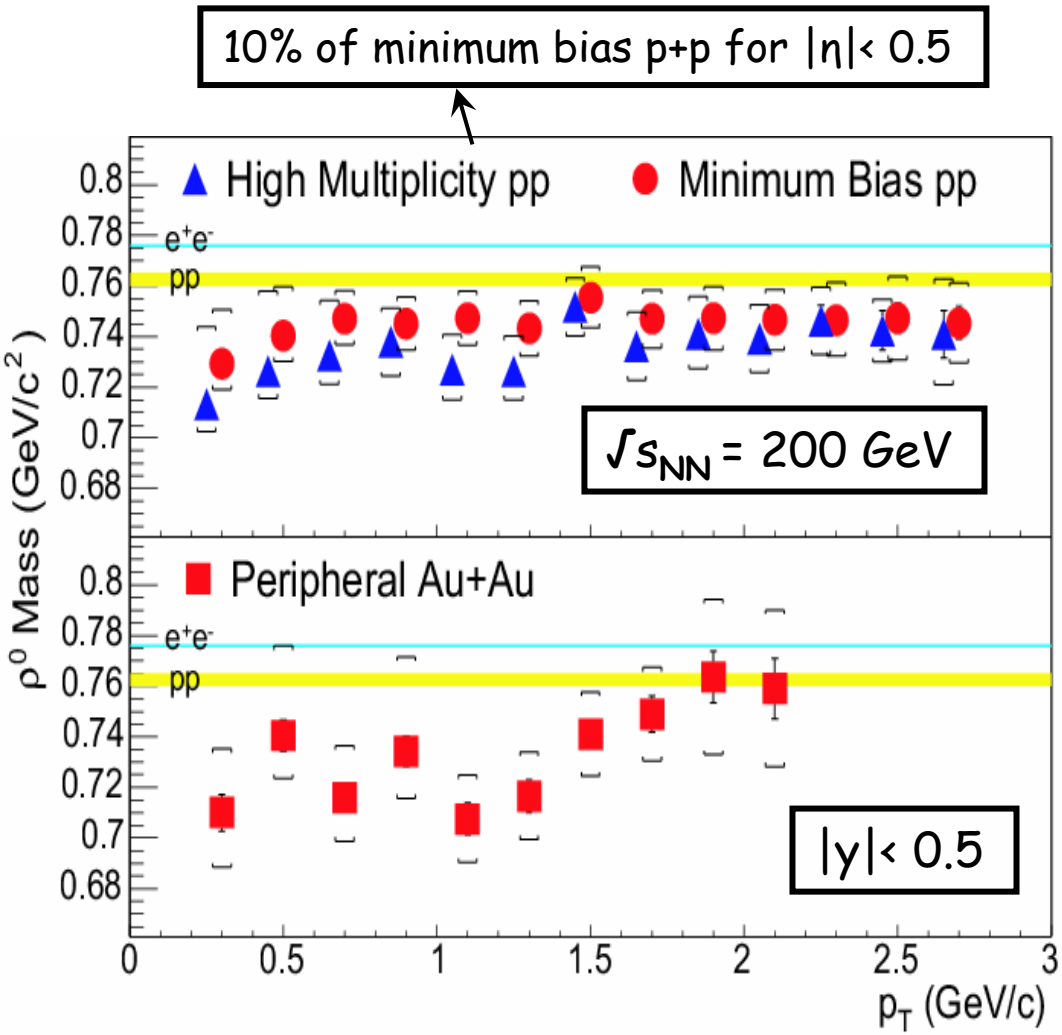
$$v_2(p_T,n) = \frac{an}{1 + \exp[-(p_T/n - b)/c]} - dn$$

a, b, c, and d $\Rightarrow$ constants extracted using K_S and Λ v_2

- K^{*0} $v_2 \Rightarrow n = 3 \pm 2$
- Need more statistics !

Resonance mass shifts

Resonance mass shifts - II

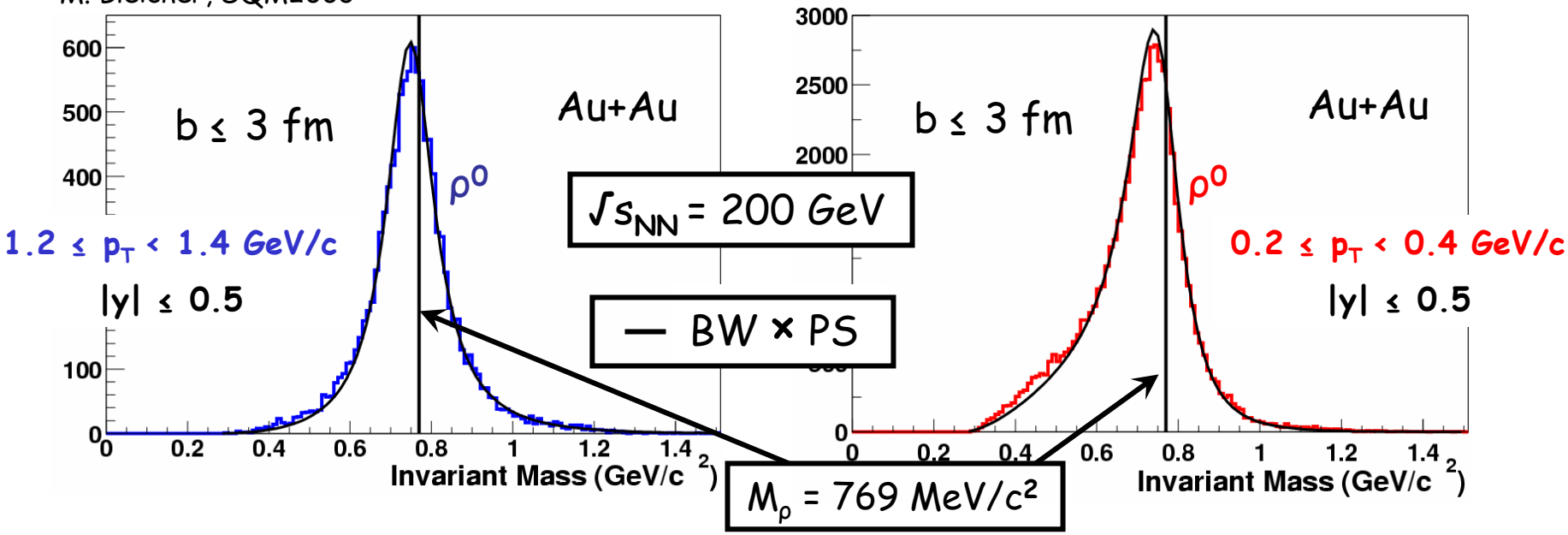


- ρ^0 mass p_t dependent and lower than previous pp measurement in both pp and peripheral Au+Au collisions
- ρ^0 mass high multiplicity pp lower than minimum bias pp ⇒ multiplicity dependent
- peripheral Au+Au collisions at $\sqrt{s_{NN}}$ = 62 GeV and dAu at $\sqrt{s_{NN}}$ = 200 GeV ⇒ similar shift
- Systematic errors ⇒ common and correlated for pp and peripheral Au+Au
- ρ^0 width ⇒ no sensitivity for systematic study

Phase Space

Phase Space ⇒ Transport Model ⇒ UrQMD

M. Bleicher, SQM2003



- UrQMD ⇒ Only imaginary part ⇒ No medium modification
- Central Au+Au ⇒ ρ^0 mass shifted ~30 MeV at low p_T
- ρ^0 shape reproduced by p-wave Breit-Wigner × Phase Space
  - M_ρ= 765.6 ± 0.4 MeV/c^2 for $0.2 \le p_T < 0.4$ GeV/c
  - M_ρ = 761.2 ± 0.9 MeV/c^2 for $1.2 \le p_T < 1.4$ GeV/c
  - M_ρ = 769 MeV/c^2 input

Γ = 150 MeV

Possible Explanations Mass Shift

Resonance mass shifts - III

- **1. Medium modification**
  R. Rapp, Nucl.Phys. A725, 254 (2003), E.V. Shuryak and G.E. Brown, Nucl. Phys. A 717 (2003) 322
- **2. Interference**
  R. Longacre, nucl-exp/0305015
- **3. Bose-Einstein correlations**
  G.D. Lafferty, Z. Phys. C 60, 659 (1993); R. Rapp, hep-ph/0305011; S. Pratt *et al.*, nucl-th/0308087

Interference and **Bose-Einstein correlations** **DO NOT** account for the mass shift in high multiplicity pp, dAu, and peripheral Au+Au ⇒ possible medium modification of ρ^0

What is next for Resonances…

What is next for Resonances…

- Yields
- Nuclear Modification Factor
- Elliptic Flow v_2
- Mass
- Width
- Centrality dependence all the above

$\Rightarrow$ in Au+Au for all observed resonances

- Leptonic channels $\Rightarrow$ Φ, ρ^0, and ω
- Comparison hadronic and leptonic channels in Au+Au
  - $\Phi \rightarrow e^+ e^-$ and $\Phi \rightarrow K^+ K^-$
  - $\rho^0 \rightarrow e^+ e^-$ and $\rho^0 \rightarrow \pi^+ \pi^-$
- Different resonances and channels
  - a_1, $\sigma(500)$, …

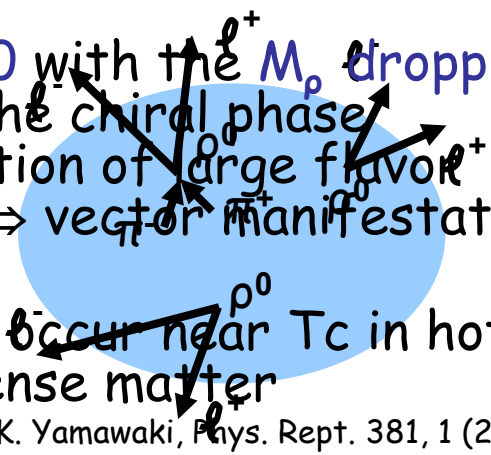
Motivations

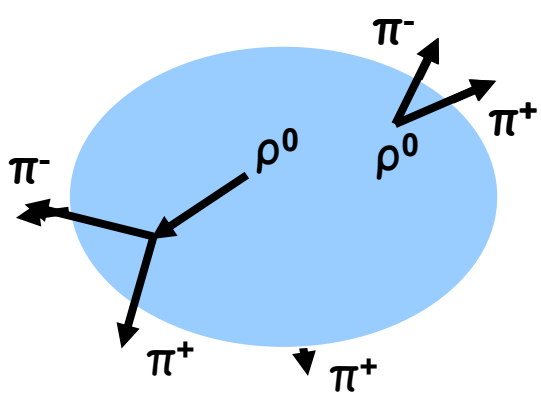
Motivation - I

- Medium modification of mass and/or width ⇒ Chiral Symmetry Restoration, Collision Broadening and/or Phase Space?

R. Rapp and J. Wambach, Adv. Nucl. Phys. 25, 1 (2000); G. E. Brown and M. Rho, Phys. Rev. Let. 66 2720 (1991); P. Braun-Munzinger, GSI Internal Report

- $\Gamma_\rho \rightarrow 0$ with the M_ρ dropping near the chiral phase transition of large flavor QCD ⇒ vector manifestation (VM)
- VM ⇒ occur near Tc in hot and dense matter





M. Harada and K. Yamawaki, Phys. Rept. 381, 1 (2003)

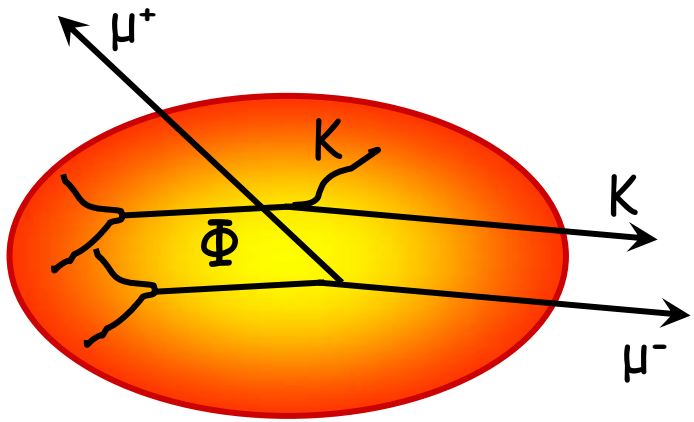
$\rho^0 \rho^0 \tau = 1.3$ fm

- Leptonic decay channel ⇒ probes all stages of the collision
- Hadronic decay channel ⇒ probes only late **stages of the collision**

Motivation - II

- $\Phi \Rightarrow$ information from early time $\Rightarrow$ sensitivity to changes in Kaon mass
- $\Phi \Rightarrow$ medium modification $\Rightarrow$ change in the yield $\Phi \rightarrow e^+e^-$ and $\Phi \rightarrow K^+ K^-$

Φ $c\tau$ = 44 fm



- Chiral Symmetry Restoration
  - medium modification a_1 spectral shape $\Rightarrow$ compare $\rho^0 \rightarrow e^+e^-$ and $a_1 \rightarrow \gamma\, \pi^\pm \rightarrow e^+e^-\, \pi^\pm$
  - medium modification $\sigma(500)$ spectral shape $\Rightarrow$ $\sigma(500) \rightarrow \gamma\, \gamma$

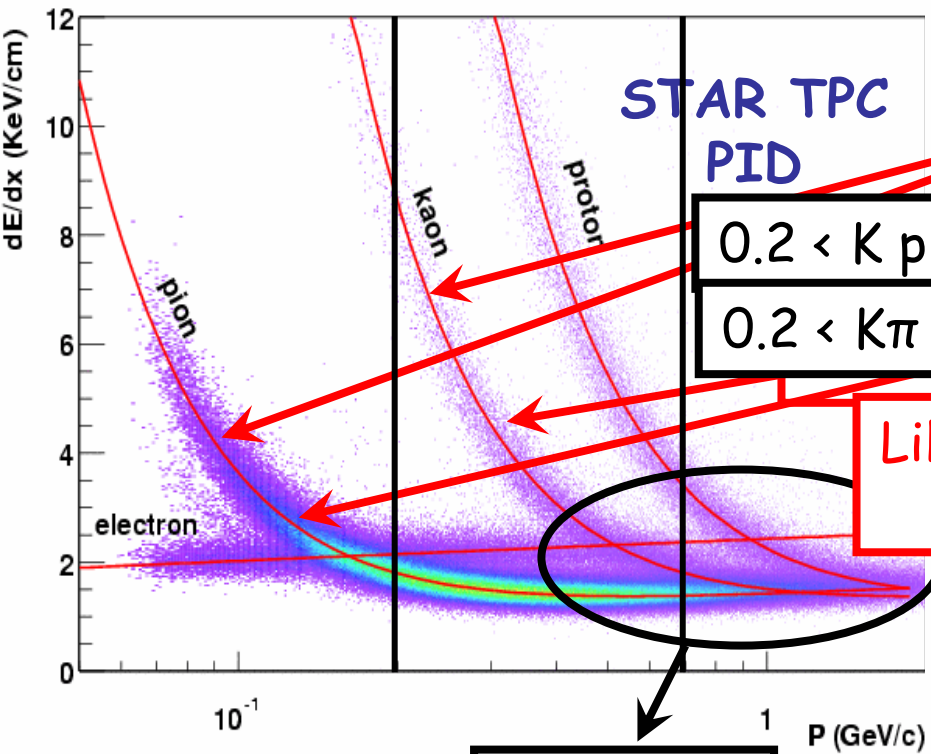
R. Rapp

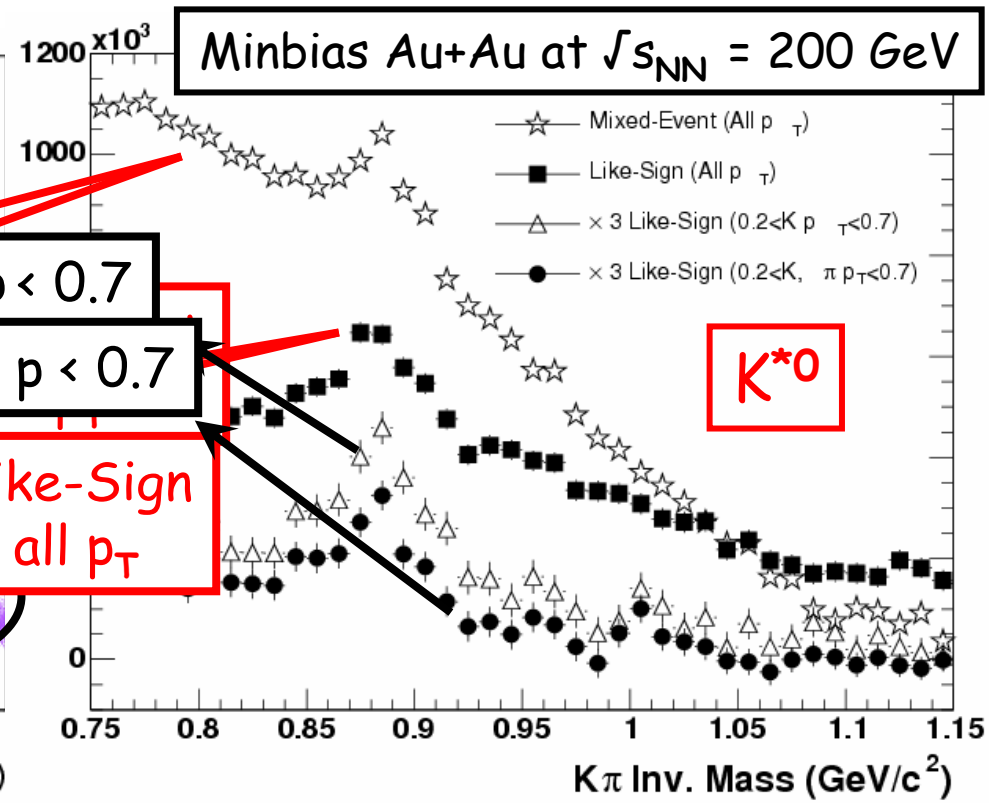
What is needed…

What is needed… - I

J. Adams, nucl-ex/0412019 to be published PRC

- More Statistics ⇒ obvious ⇒ but not enough!
- Cleaner particle identification ⇒ improve particle misidentification





0.2 < K p < 0.7

0.2 < Kπ p < 0.7

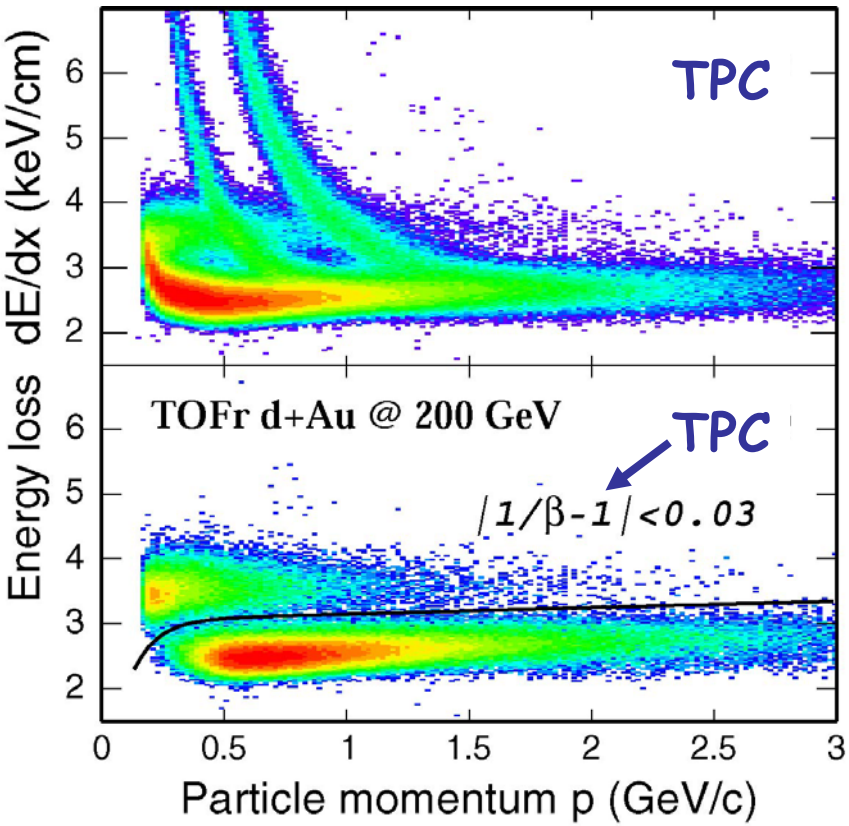
Like-Sign all p_T

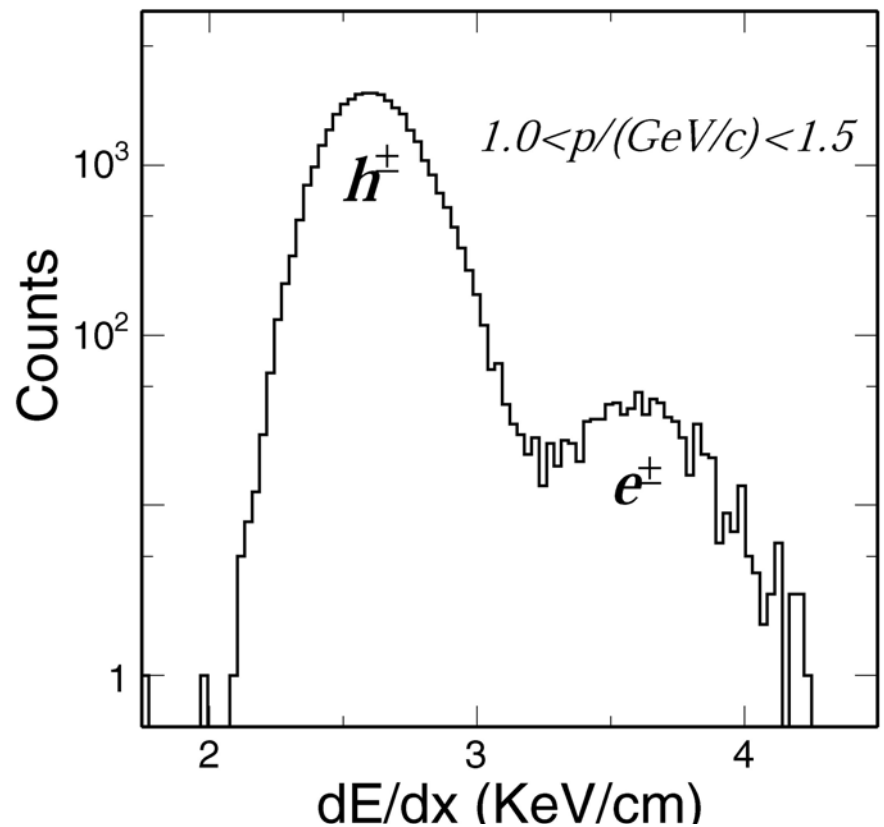
Problem!

⇒ Need Time of Flight (TOF) full coverage in STAR

What is needed… - II

J. Adams et. Al., Phys. Rev. Lett. 94, 062301 (2005)





- **TOF** ⇒ Clean PID ⇒ π, K, and p
- **TOF** ⇒ Clean PID ⇒ **low momentum electrons** !!!

What is needed… - III

- TOF full coverage
  - π, K, and p up to ~5GeV/c
    - Resonance at high-p_T
    - Signal/Background ratio increases
  - low momentum electrons
    - Low-mass dileptons at low p_T
    - Calorimeter $\Rightarrow$ only electrons $p_T > 2$ GeV/c
- Better understanding $\pi^+ \pi^-$ combinatorial background $\Rightarrow$ important for $\rho^0 \rightarrow \pi^+ \pi^-$ in central Au+Au
  - TOF $\Rightarrow$ little improvement on the $\rho^0 \rightarrow \pi^+ \pi^-$ measurement

What is needed… - IV

- Background Rejection
  - Time Projection Chamber – TPC
  - Time of Flight - TOF
  - Silicon Vertex Tracker - SVT
  - Heavy Flavor Tracker - HFT

  $\Rightarrow$ Combination

$\Rightarrow$ see Kai Schweda talk on Saturday

  - Examples
    - $\Phi \rightarrow e^+e^-$, $\rho^0 \rightarrow e^+e^-$, and $\omega \rightarrow e^+e^-$ $\Rightarrow$ background $\gamma \rightarrow e^+e^-$
    - $a_1 \rightarrow \gamma\, \pi^\pm \rightarrow e^+e^-\, \pi^\pm$ $\Rightarrow$ background $\Phi \rightarrow e^+e^-$, $\rho^0 \rightarrow e^+e^-$, and $\omega \rightarrow e^+e^-$
- Simulations

Simulations

Simulation - I

- Estimation for number of events to measure $\Phi \rightarrow e^+e^-$ and $\omega \rightarrow e^+e^-$ with 3σ signal in central Au+Au collisions

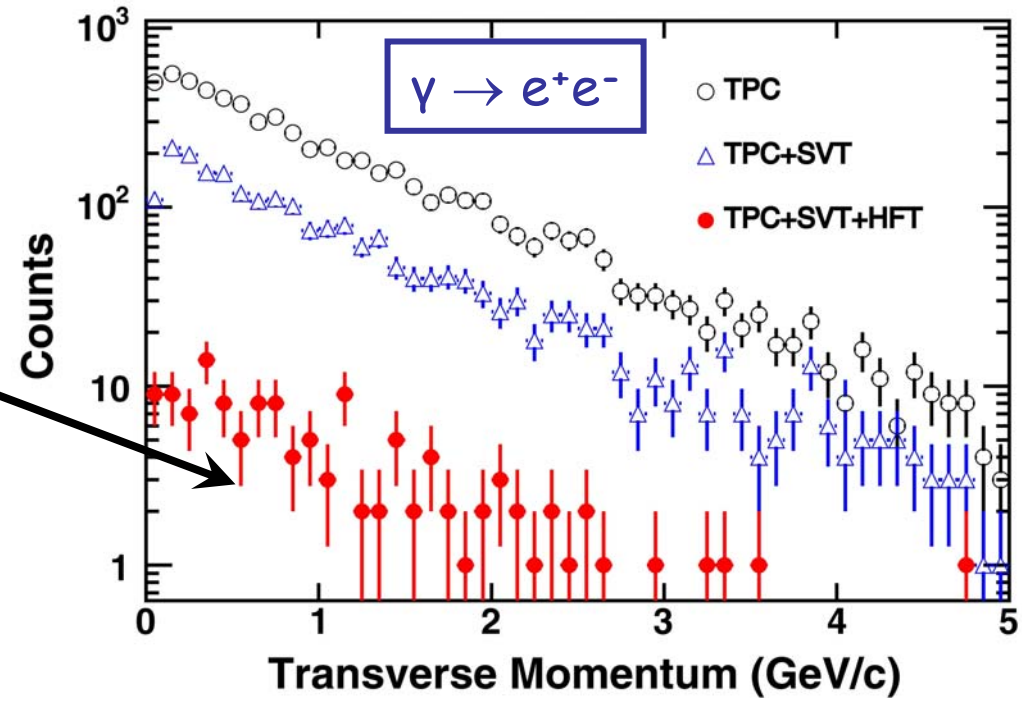
Detectors	ω	Φ
TPC+TOF	8 M	2 M
TPC+TOF+SVT+HFT	200K	100K

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

⇒ background $\gamma \rightarrow e^+e^-$

γ conversion rejection

⇒ see Kai Schweda talk on Saturday



Simulation - II

- Transport Model Calculations ⇒ UrQMD

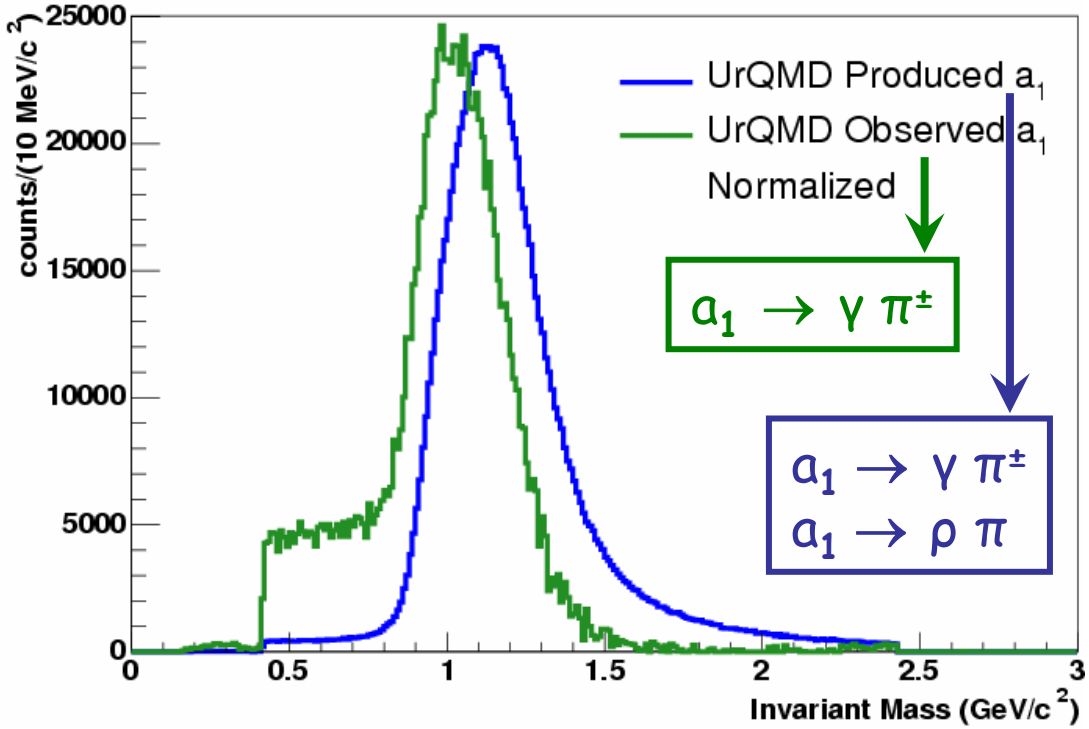
$a_1 \rightarrow \gamma\, \pi^{\pm}$ B.R. = 0.1

$a_1 \rightarrow \rho\, \pi$ B.R. = 0.9

Mass = 1.230 GeV/c²

Γ = 400 MeV/c²

UrQMD
minimum bias Au+Au
at $\sqrt{s_{NN}}$ = 200 GeV

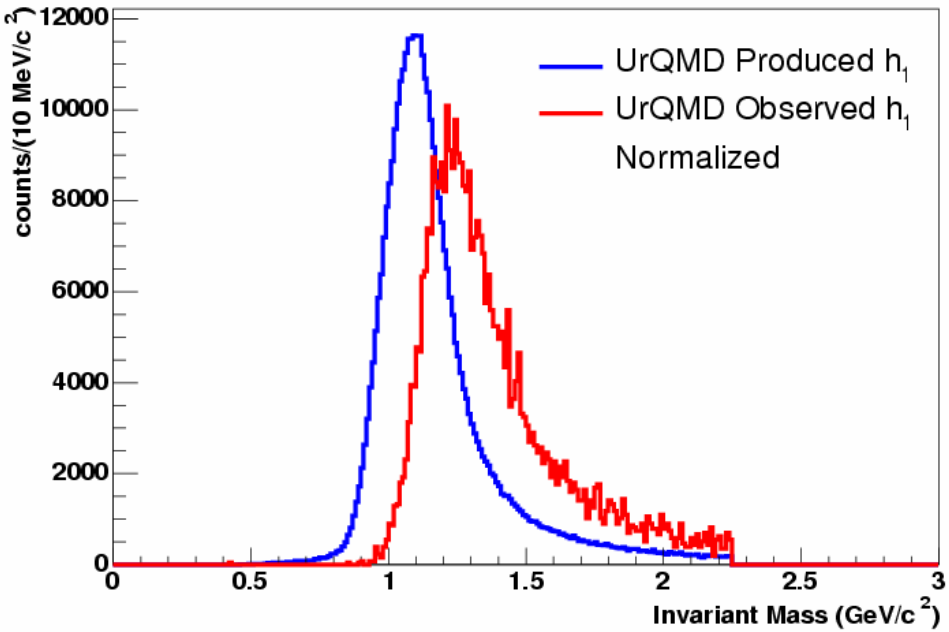


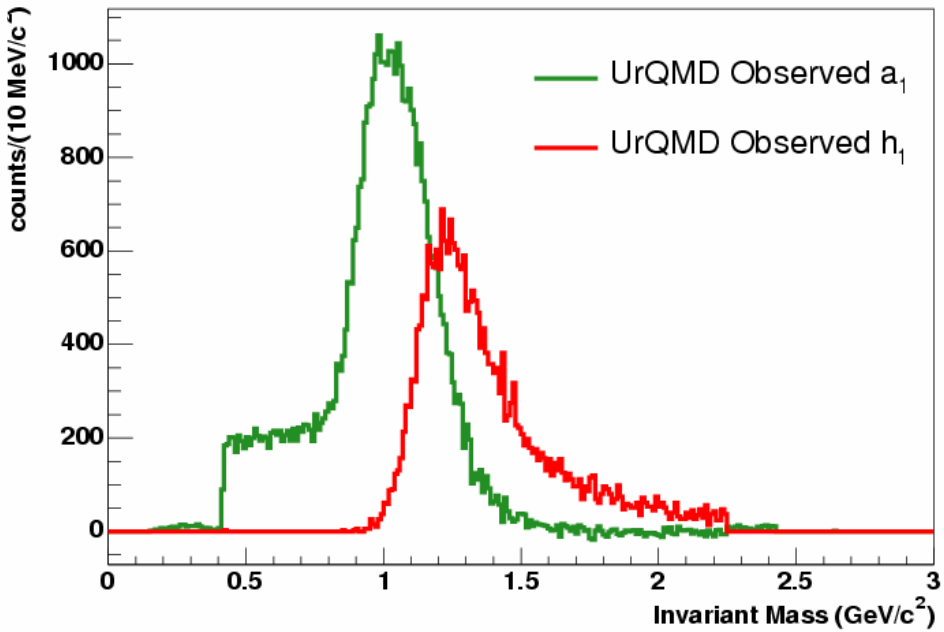
⇒ a_1 not absorbed ⇒ ~5% a_1 produced

⇒ a_1 not absorbed ⇒ 80% $a_1 \rightarrow \gamma\, \pi^{\pm}$ and 20% $a_1 \rightarrow \rho\, \pi$

⇒ significant change in the spectral shape

Simulation - III





$h_1 \rightarrow 3\,\pi$ B.R. = 0.1
$h_1 \rightarrow \rho\,\pi$ B.R. = 0.9
Mass = 1.170 GeV/c²
Γ = 360 MeV/c²

UrQMD
minimum bias Au+Au
at $\sqrt{s_{NN}}$ = 200 GeV

$\Rightarrow$ h_1 not absorbed $\Rightarrow$ ~3% h_1 produced
$\Rightarrow$ significant change in the spectral shape

Simulation - IV

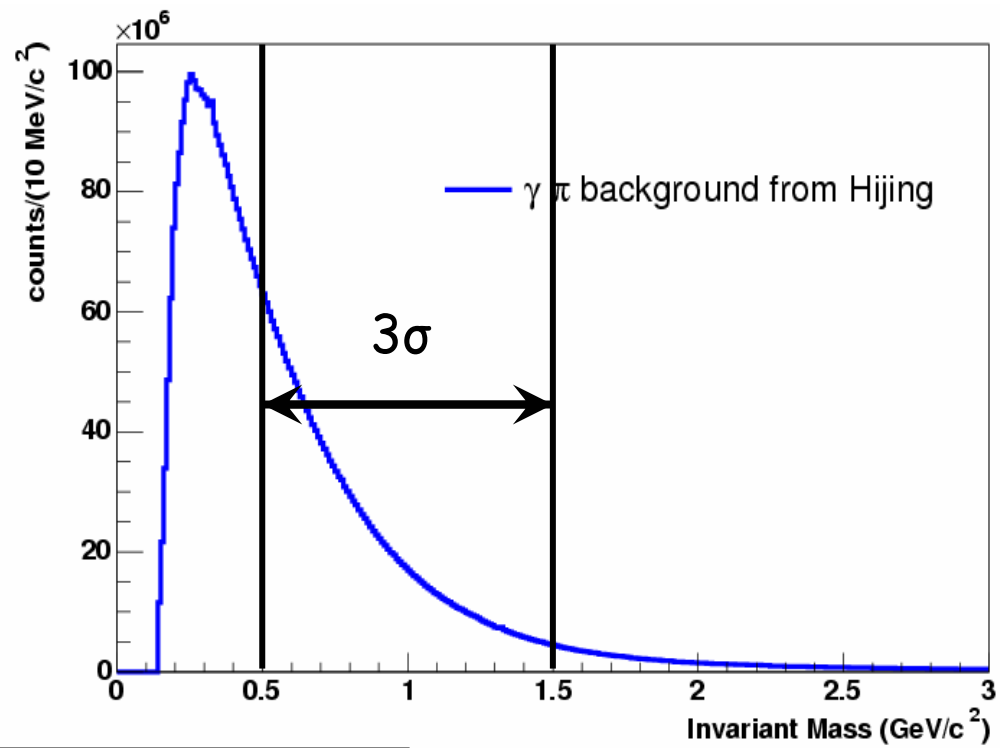
- Number of events for 3σ signal $a_1 \rightarrow \gamma\, \pi^{\pm}$ in minimum bias Au+Au
- Background ⇒ $\gamma\, \pi$ from Hijing

Hijing ⇒ no a_1 but $\pi^0 \rightarrow 2\gamma$

Hijing minimum bias Au+Au at $\sqrt{s_{NN}}$ = 200 GeV plus detector simulation

⇒ $\gamma \rightarrow e^+e^-$ conversion

Efficiency of measuring photon via conversion ⇒ $e^+e^- \rightarrow \gamma$ ⇒ ~5%



⇒ 3σ signal $a_1 \rightarrow \gamma\, \pi^{\pm}$ ⇒ 54M events !

Summary

- Accomplishments from resonance measurements ⇒ Resonances can provide information collision dynamics
- Future…
  - Improve measurements
  - Leptonic channels
  - Comparison hadronic and leptonic channels
  - Different resonances and channels
- Need…
  - TOF full coverage and HFT
  - Better understanding combinatorial background
- Number of events for Φ, ω, and a_1 ⇒ 3σ signal
- More detailed simulations needed