A short story on how the $\Delta(1232)$ lost its mass

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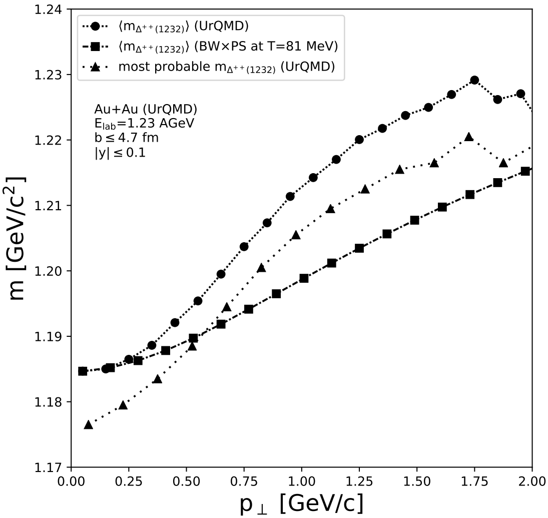
Final result



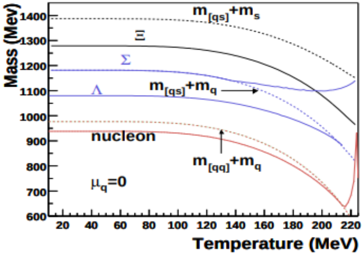
Contents

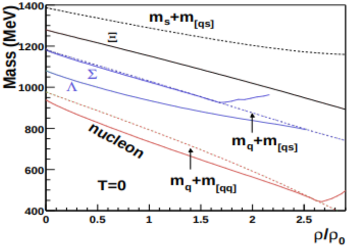
Mass of hadrons constant?

- Mass drops with increasing temperature
- Hadrons become unstable at very high T

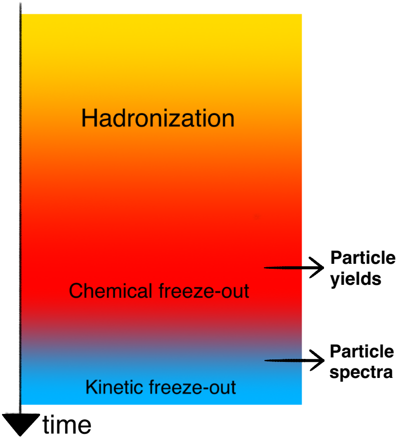
- Mass drops with increasing density

Figure: F. Gastineau, J. Aichelin. arXiv:nucl-th/0201063





Hot and dense medium



- Early: Hot and dense phase, charm, QGP (?)
- Post-early: Hadronization, strangeness
- Intermediate: Chemical freeze-out
  $\rightarrow$ yields
- Late: Kinetic freeze-out
  $\rightarrow$ spectra

UrQMD (Ultra-relativistic Quantum Molecular Dynamics)

- Covariant propagation of hadronic resonances up to 2 GeV
- String dynamics, strangeness exchange reactions
- Decay widths via evolution of momentum distributions
- Established history of describing resonances over a broad range of energies

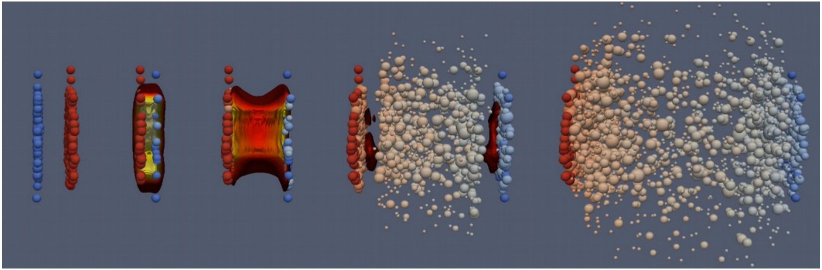
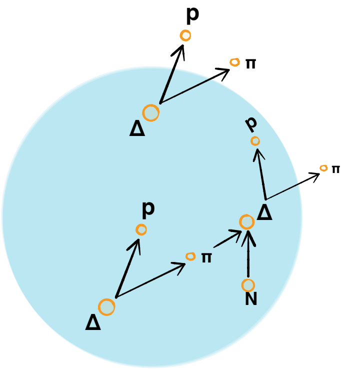


Figure: MADAI collaboration, Hannah Petersen and Jonah Bernhard

$\Delta \leftrightarrow N + \pi$ cycle



Δ travels $\sim$ 1 fm before it decays into N+π

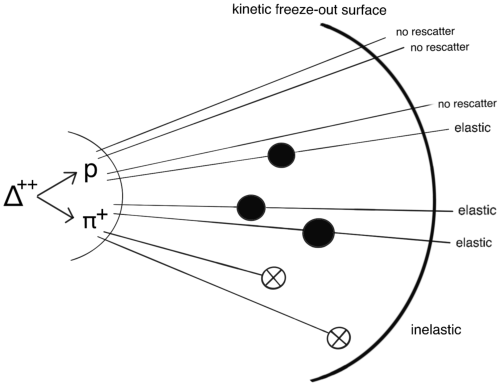
$\downarrow$

N and π scatter, loose energy, thermalize

$\downarrow$

N+π form new Δ

Reconstruction of resonances



- ✓ Both the p and π^+ escape without re-scattering
- ✓ Only one daughter re-scatters elastically
- ✓ Both the p and π^+ re-scatter elastically
- × At least one daughter scatters inelastically

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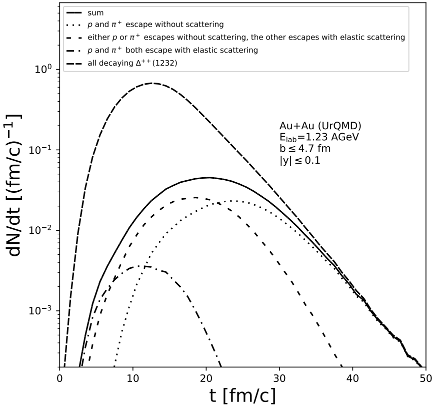
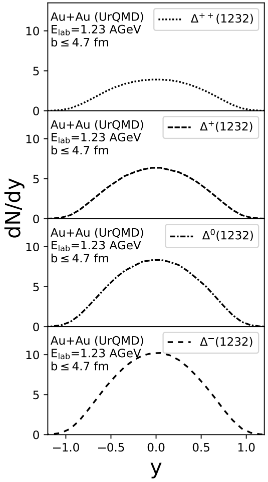
Time distribution



- From 30 fm/c on, nearly every Δ will be reconstructed
- Time shift between contribution 1 and 2
- Integrated yield is roughly the same!

Rapidity distribution



- Isospin dependence of Δ yield

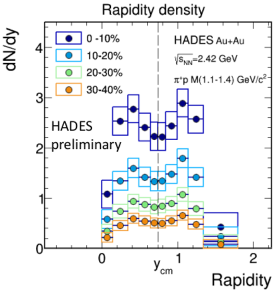
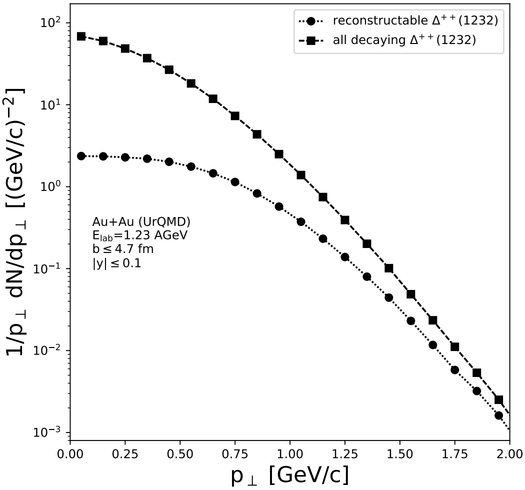


Figure: G. Kornakov, Talk "Experimental results on hadron production" held at EMMI workshop, Feb. 2019

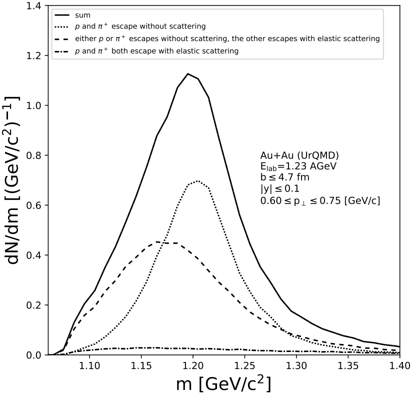
Transverse momentum spectra



- Suppression of low-$p_\perp$ Δ^{++}
- Inverse proportional to T
- Nearly every Δ^{++} will be reconstructed at high $p_\perp$

Influence of the reconstruction contributions

- Δ^{++} yield originates to 50% from contribution 1 & 2
- Re-scattered particles shift more towards lower masses
- Distribution if both particles re-scatter becomes flat



Qualitative description

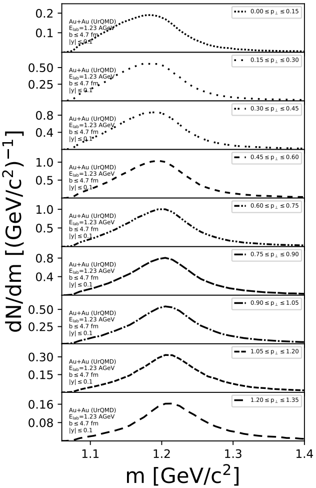
- Invariant mass distribution $\sim$
  Breit-Wigner spectral function $\times$ thermal weight of each resonance
- $\frac{\mathrm{dN}}{\mathrm{dm}} \sim \mathrm{BW}(\mathrm{m}_\Delta, \mathrm{m}^0_\Delta, \Gamma^0_\Delta) \times \mathrm{PS}(\mathrm{m}_\Delta, \mathrm{p}_\mathrm{T}, \mathrm{T})$ with

$$\rightarrow \mathrm{BW}(m_\Delta, m^0_\Delta, \Gamma^0_\Delta) \propto \frac{\Gamma^0_\Delta m_\Delta}{\left(m^2_\Delta - m^0_\Delta\right)^2 + (\Gamma^0_\Delta m_\Delta)^2}$$

$$\rightarrow \mathrm{PS}(m_\Delta, p_\mathrm{T}, T) \propto \frac{m_\Delta}{\sqrt{m^2_\Delta + p^2_\mathrm{T}}} \exp\left(-\frac{\sqrt{m^2_\Delta + p^2_\mathrm{T}}}{T}\right)$$

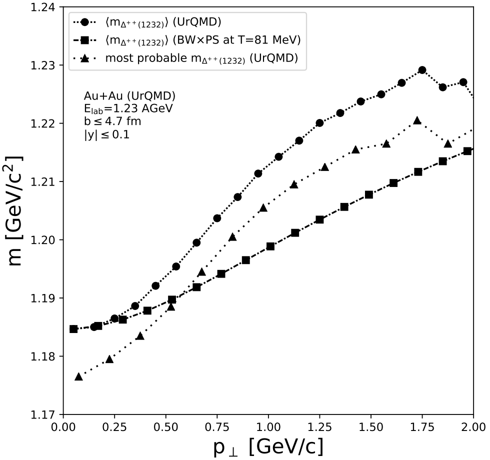
- As long as notion of temperature is useful

Invariant mass distribution



- Peak and mean value shift towards lower masses at low p_T
- Lower boundary due to observation method in $p + \pi^+$ channel
- Possible overshadowing of conventional in-medium effects

Transverse momentum dependence of the mass shift



- Mass shift $\sim$ 50 MeV
- Qualitatively: BS$\times$PS ✓
- Supports late stage Δ formation
- Temperature extraction at low p_T? $\rightarrow$ 81 MeV

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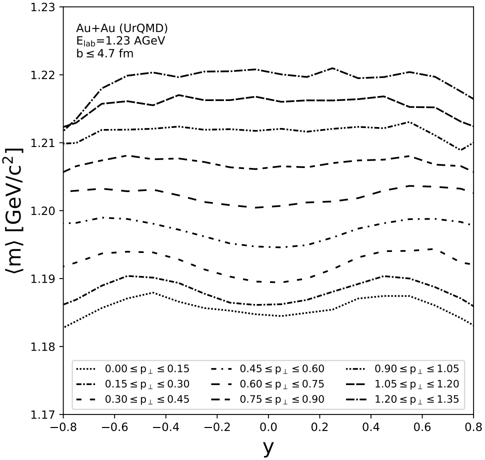
Rapidity dependence of the mass shift



- Flat at high p_T
- Local minimum arises around midrapidity at low p_T
- Supporting idea of $\Delta \leftrightarrow N + \pi$

Conclusion

- Mass shift on the order of $\sim$ 50 MeV should be observed in Au+Au at E_{lab}=1.23 AGeV
- In addition non-trivial rapidity dependence should be observed
- Could be used to extract the decoupling temperature at low p_T