Mass reduction of the η' meson in hot QCD matter

Work in progress

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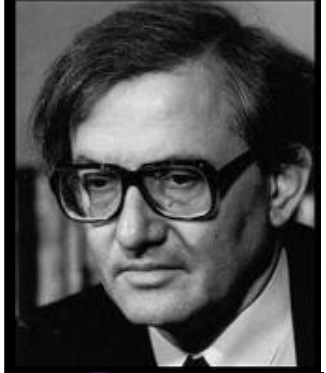
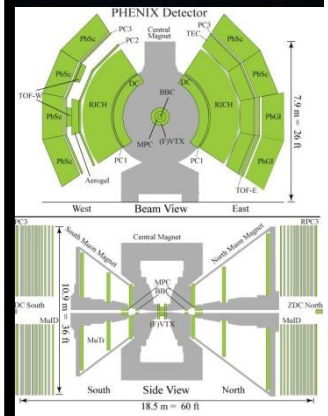
ELTE



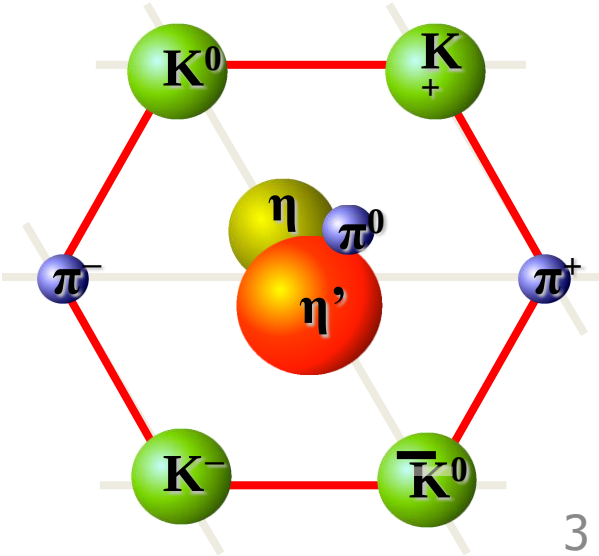


Outline

- Introduction
- Channels of observation
- Simulation results
- Summary

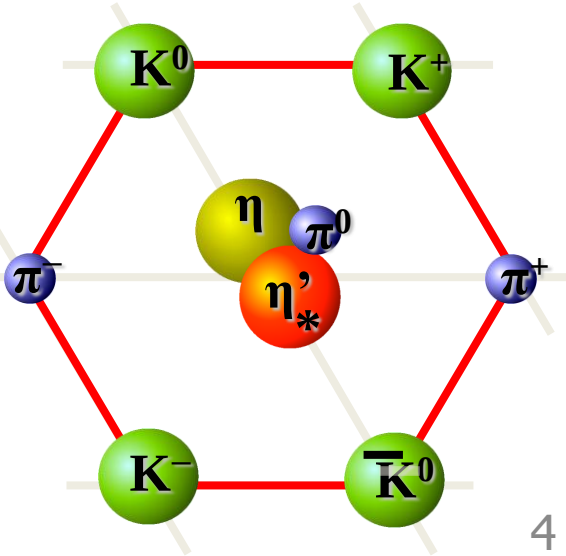
Symmetries in the 3 quark model

- Chiral symmetry: **$U(3)=SU(3)_L \; SU(3)_R \; U(1) \; U_A(1)$**
- $SU(3)_L \;\; SU(3)_R$ flavour spontan. broken
- U(3)
  - 9 Goldstone bosons = pseudoscalar mesons
  - 9. Goldstone boson = η'
  - $m_{\eta'} = 958$ MeV ~ 2 m_η
- $U_A(1)$ explicitly broken
  - Nontrivial vacuum
  - η' gains extra mass



Symmetry restoration

- In a hot, dense medium
  - "asymptotic freedom": α_s decreases
  - $U_A(1)$ restored
  - Nontrivial vacuum vanishes
- Mass drop!
  - $m_{\eta'} = m^*_{\eta'} + \Delta m$ (broken symm.)
  - $m^*_{\eta'} \approx$ 400-700 MeV
  - Kapusta *et al.*:
    has to be near to the η mass
    arXiv:hep-ph/9507343v2



Consequences of a mass drop

- Light mesons: Hagedorn formula

$$N \sim e^{-m/T}$$

  - $T \approx 170$ MeV (Hagedorn-temperature)
  - Initially few η' : $N_{\eta'}/N_{\pi^0} \sim 2 \cdot 10^{-2}$
  - With mass drop: $N_{\eta'}/N_{\pi^0} \sim 1$

Max. 50-times enhancement

- Consequence: **more η'** in the spectra
  - Annihilation cross section is small
  - Free path is long, width does not increase significantly
  - So η' decays in the vacuum with the "original" mass (958 MeV)

Channels of observation

1. **Low-p_T pions** $\eta' \to \eta\pi\pi$ (BR=43%)

   $\eta' \to \pi^+\pi^-(\pi^+\pi^-\pi^0)$: $\langle m_T \rangle \sim 250$ MeV → characteristic p_T range

   Non-correlated pions → **BEC**

2. **Photonic decay?** $\eta' \to \gamma\gamma$
   - Would be convincing; however, miserable S/B ratio ($\pi^0 \to \gamma\gamma$)

3. **Leptonic decay** $\eta' \to \ell^+\ell^-\gamma$

   - Higher η'/π ratio at low p_T-values
   - Enhancement in the $\ell^+\ell^-$ spectrum at low invariant masses

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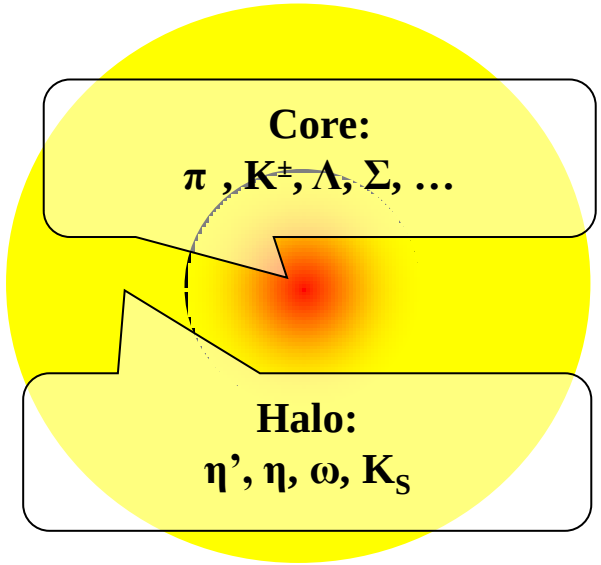
Channels of observation 1

- **A mass drop was observed in π BEC**

η’ has long lifetime, decays into pions
Core-halo picture: more η’ mesons enhance halo

Measurable through
the intercept parameter

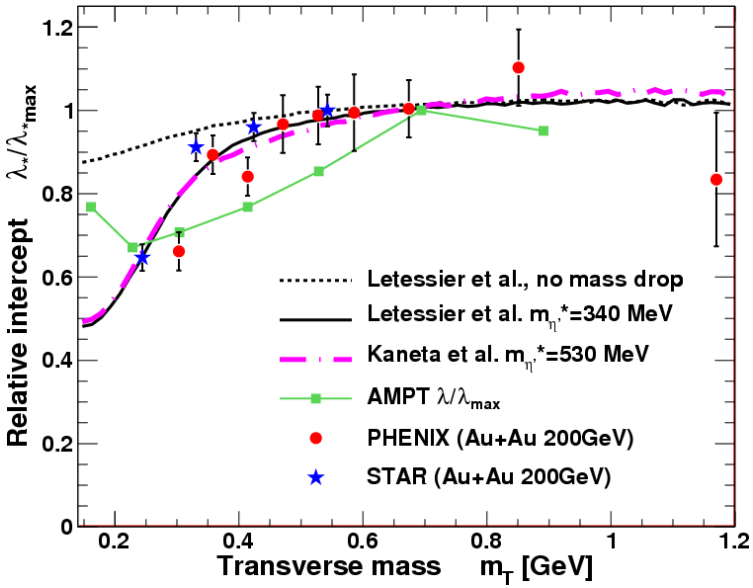
$$\lambda^* = \left(\frac{N^{\pi^+}_{\text{core}}}{N^{\pi^+}_{\text{halo}} + N^{\pi^+}_{\text{core}}} \right)^2$$



Csörgő, Vértesi, Sziklai: arXiv:0912.5526 [nucl-ex]

Channels of observation 1

- RHIC data: Clear signs of low-p_T halo enhancement
- $\pi^+\pi^+$ correlation
- Central Au+Au (200 GeV) (at Mid-rapidity $|\eta|<0.1$)



- Best fit (model dependent)

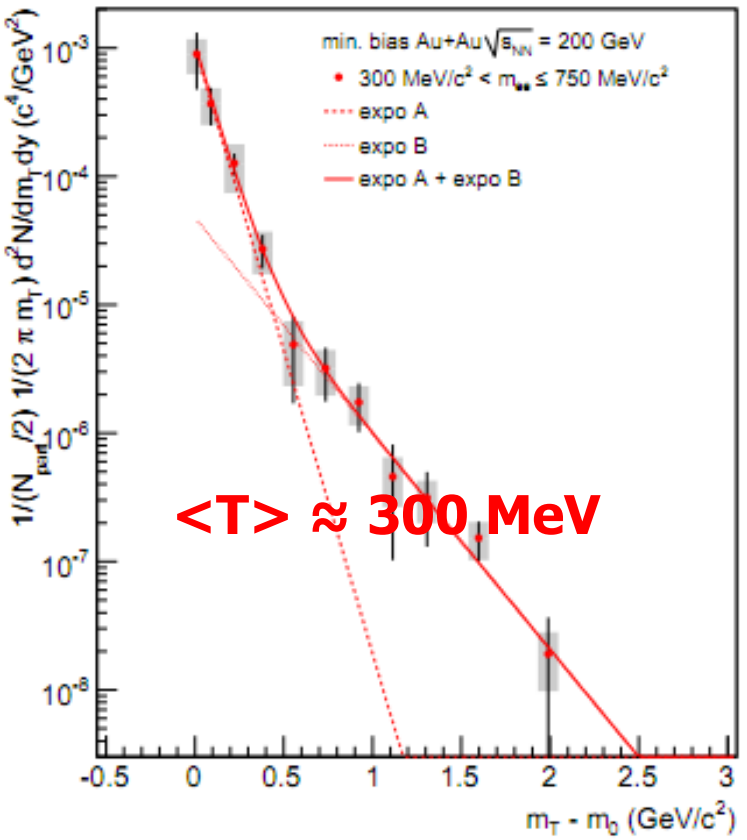
- $m_{\eta'}^* = 340\,^{+50}_{-60}\,^{+280}_{-140} \pm 45$ MeV

Phys. Rev. C 83, 054903 (2011)

Channels of observation 2

- Direct photons (arXiv:0912.0244 [nucl-ex])

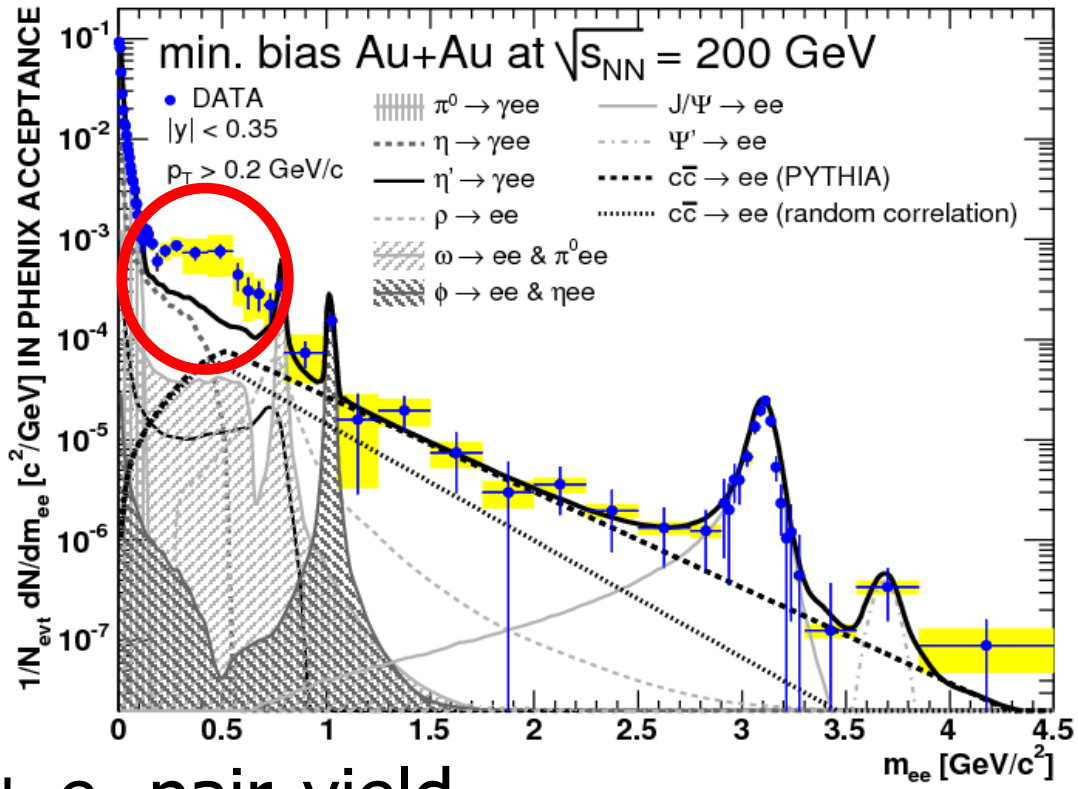
<T> ≈ 100 MeV



- Double exp. spectra
- First part:
  similar to the η' slope

Channels of observation 3

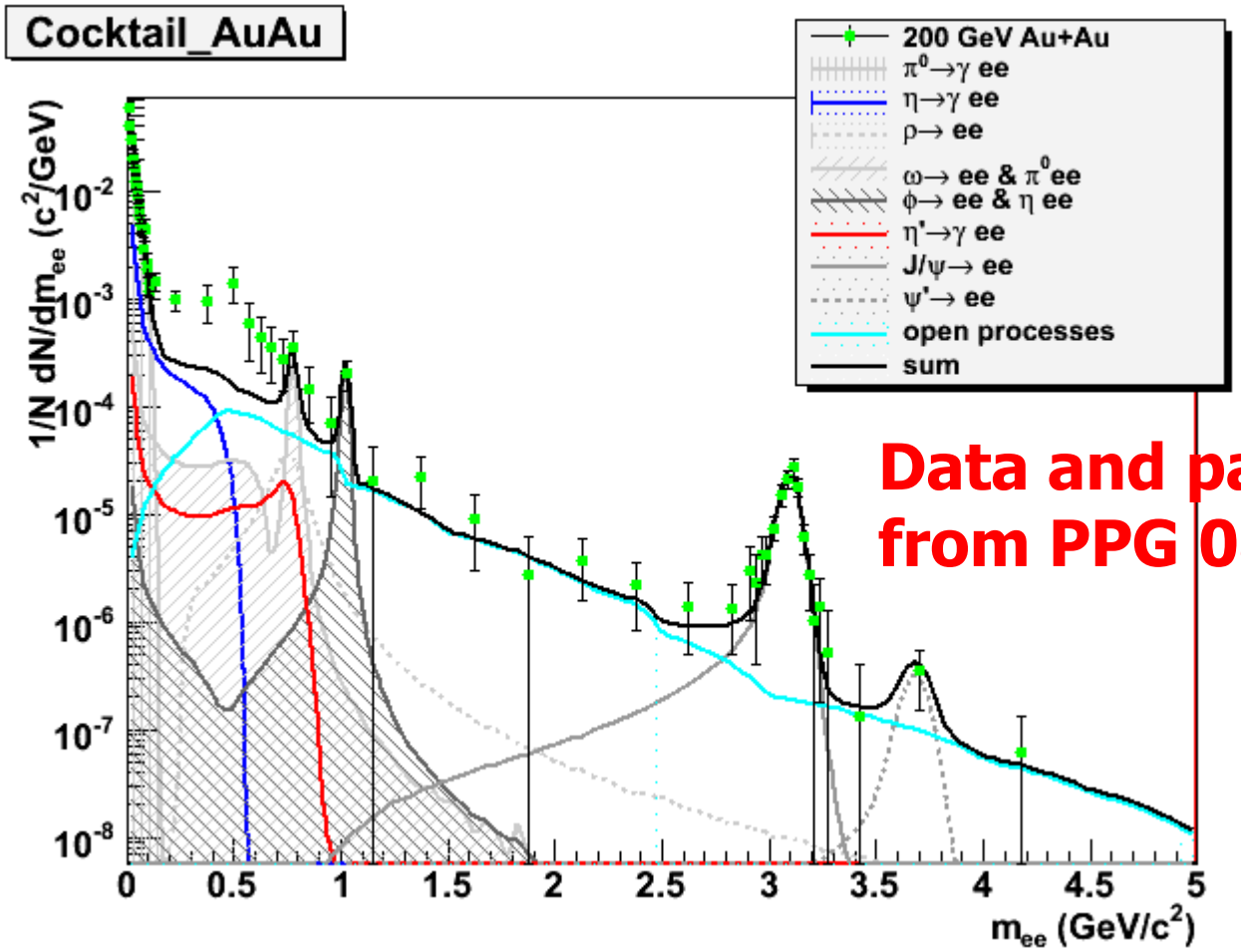
- Dileptonic channel



Au+Au invariant e+ e- pair yield

- Significant excess in PHENIX 200 GeV Au+Au
- Not present in p+p data
- Excess must be an effect of the hot, dense medium

Simulation



Data and parameters from PPG 088

Original dilepton cocktail reproduced (from PPG088)
$9*10^8$ events, χ^2**/NDF** ($0.15 < m_{ee} < 0.7$) = 4.6, **CL** = 0.011 %

Simulation

- The η' enhancement:

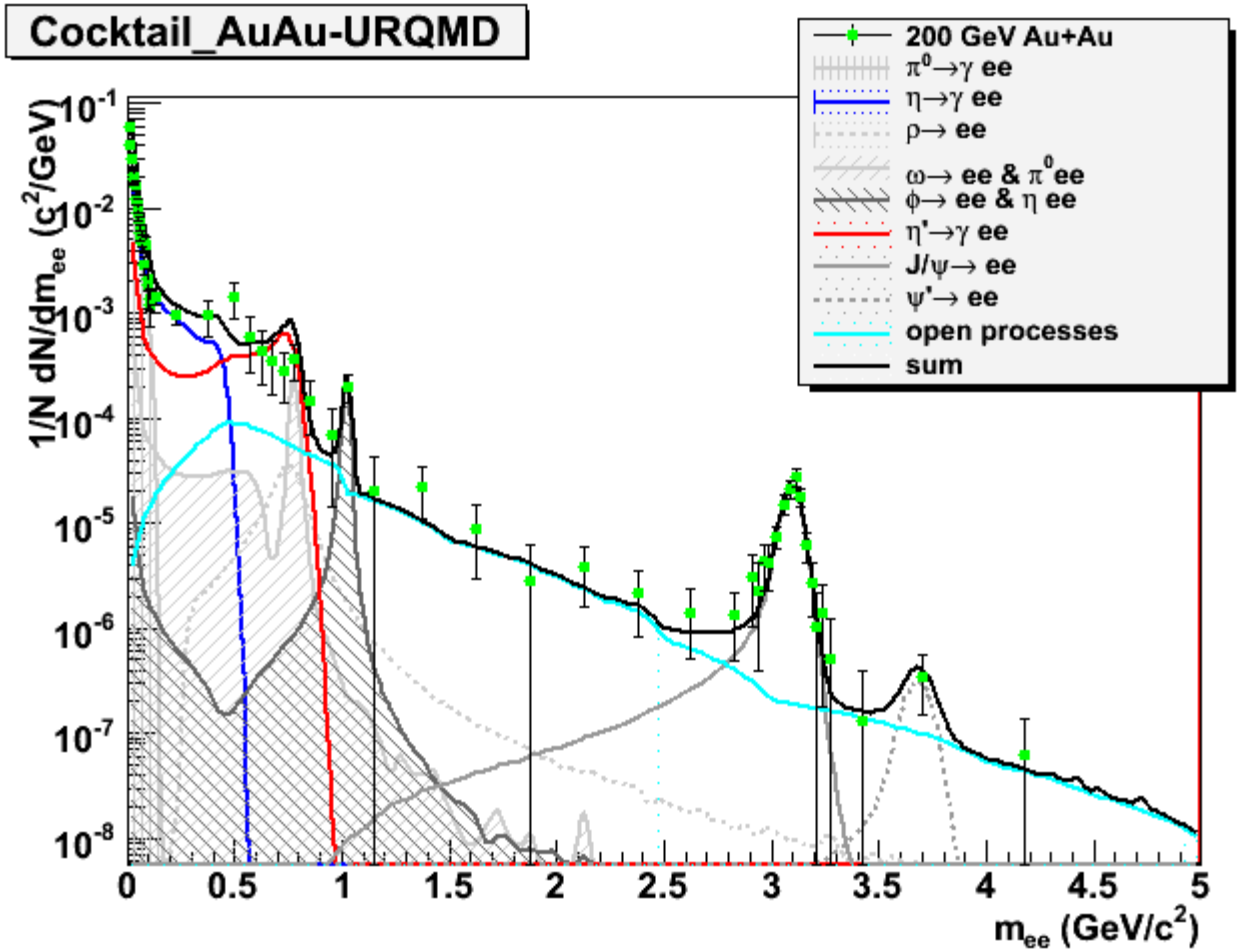
  $f_{\eta'} = \exp(-(m^*-m)/T)$

  where m=958 MeV, T=177 MeV

- Channel η'->$\eta(\pi\pi)$ taken into account via

$$f_\eta \equiv \frac{N_\eta^*}{N_\eta} = 1 + \left(\frac{N_{\eta'}^*}{N_{\eta'}} - 1 \right) \frac{N_{\eta'}}{N_\eta} BR(\eta' \to \eta + \pi\pi)$$

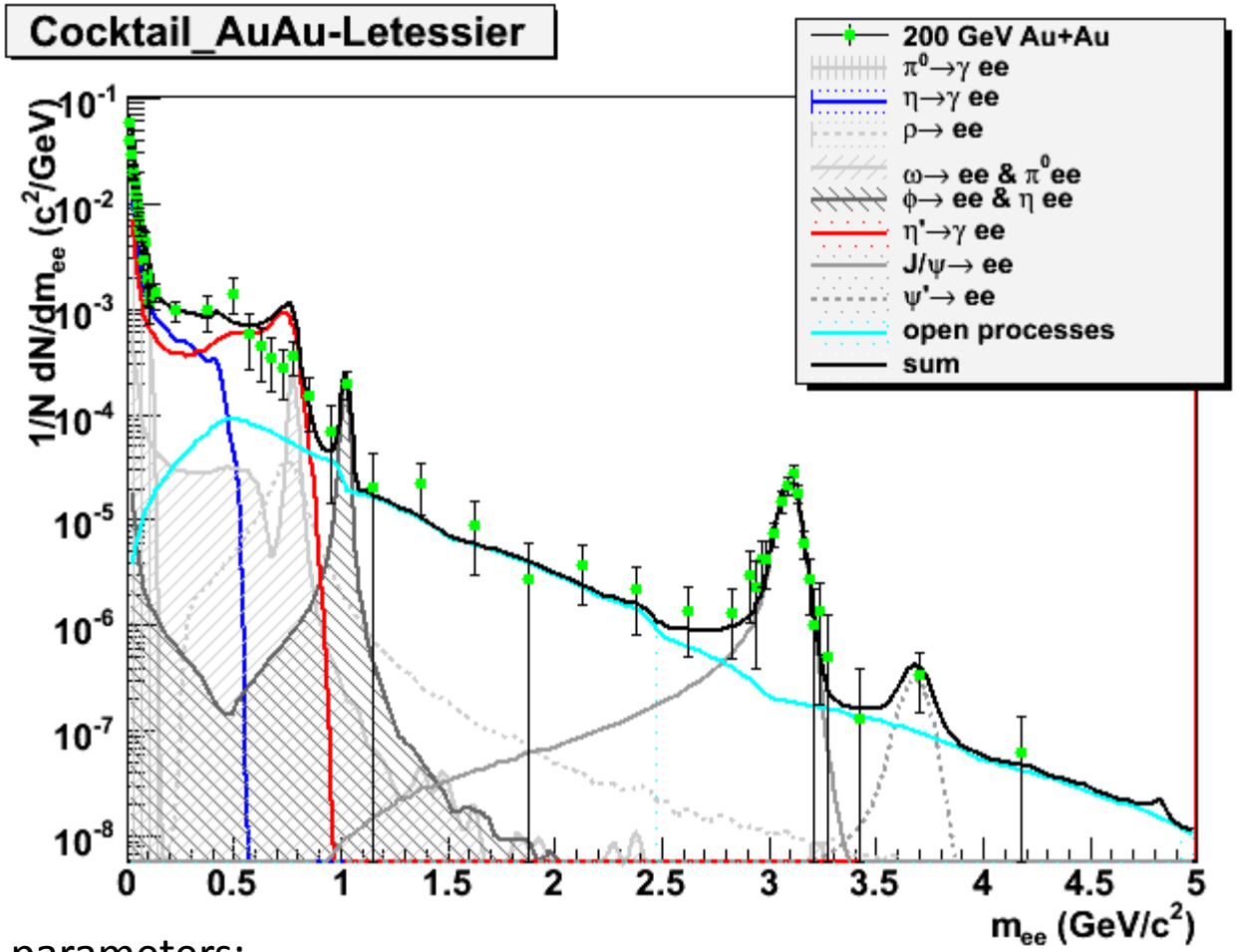
Simulation results



Simulation parameters:

f_η = 7.49, $f_{\eta'}$ = 45.0, $m^*_{\eta'}$ = 400 MeV

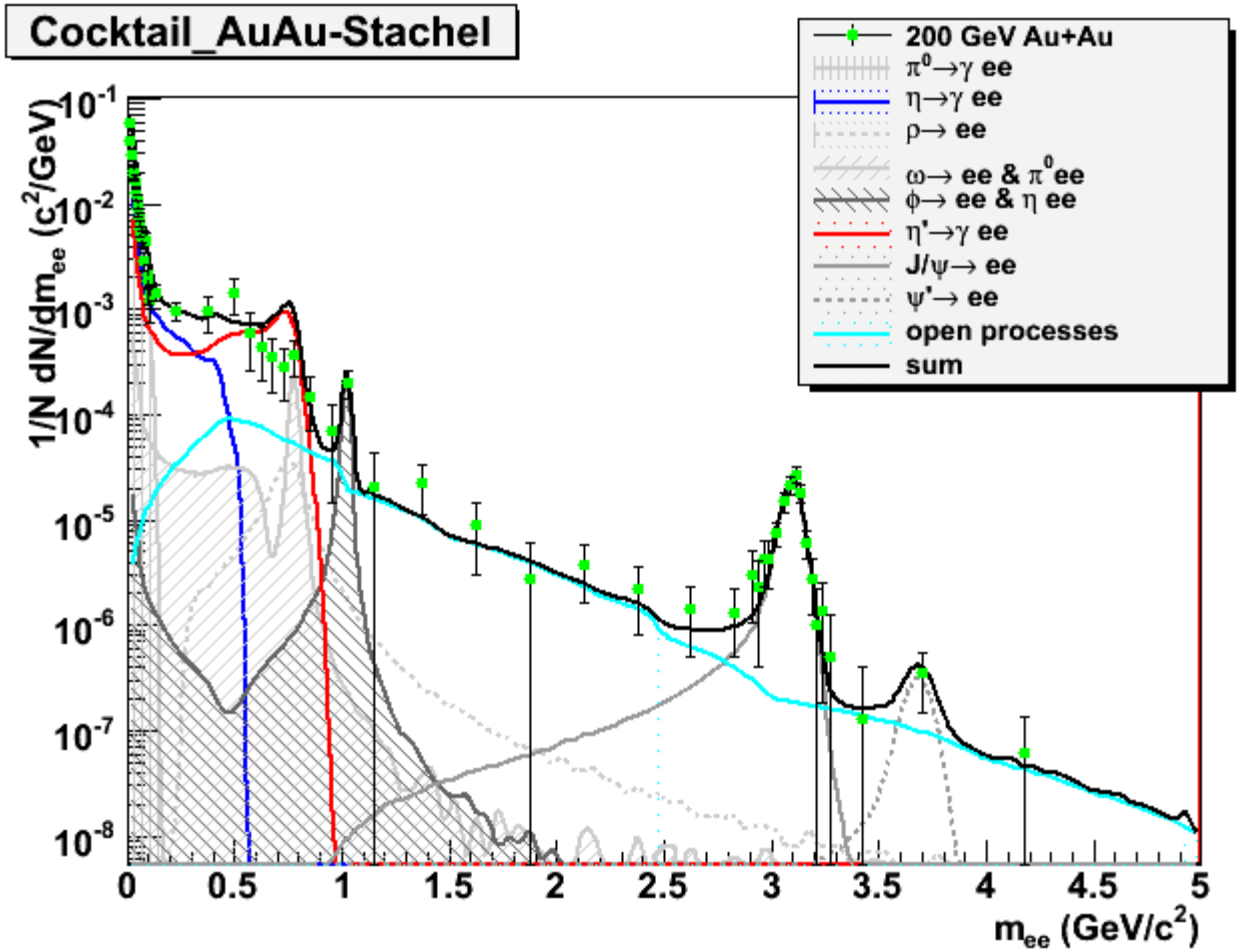
Simulation results



Simulation parameters:

$f_\eta = 4.75$, $f_{\eta'} = 67.6$, $m^*_{\eta'} = 340$ MeV

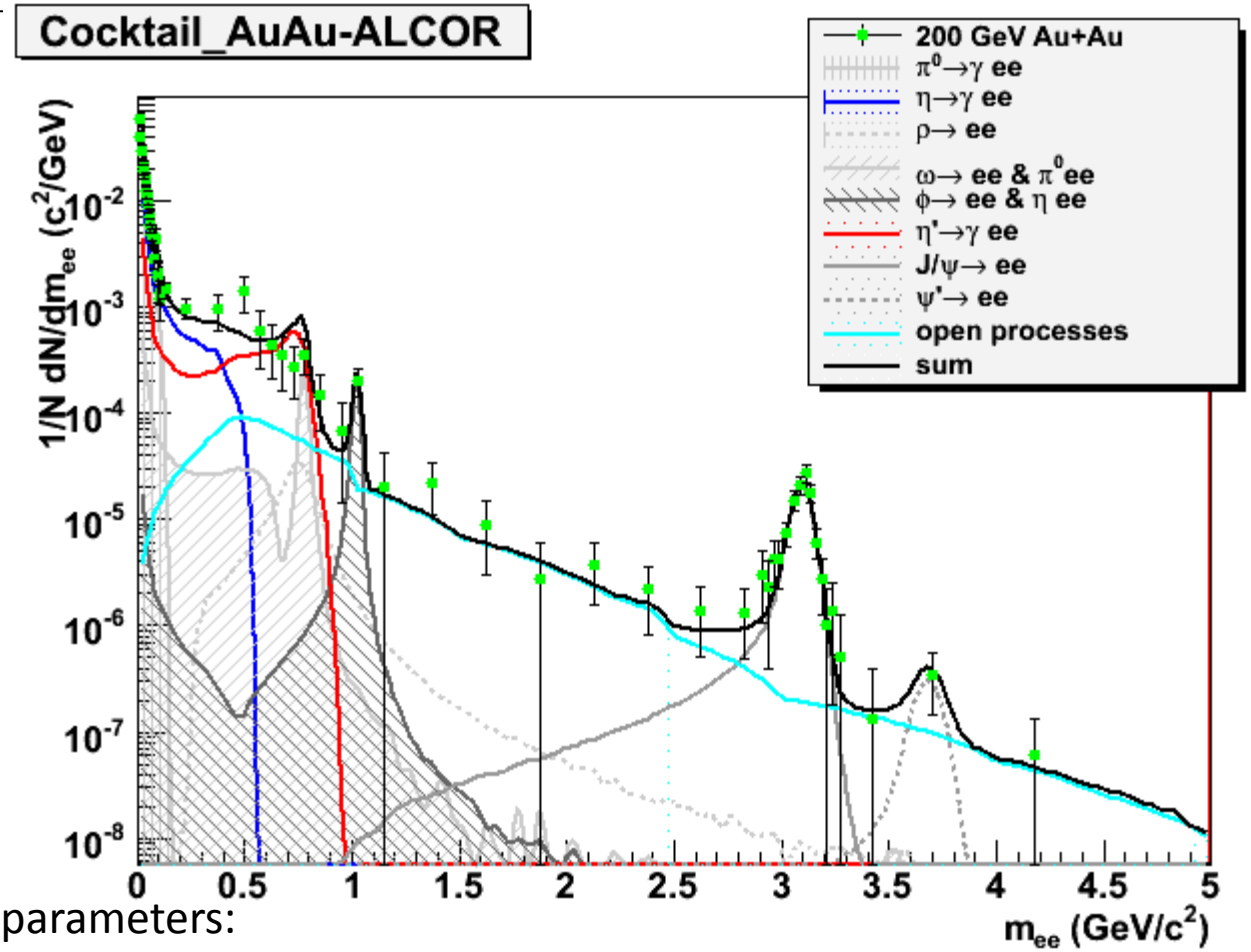
Simulation results



Simulation parameters:

f_η = 4.97, $f_{\eta'}$ = 67.6, $m^*_{\eta'}$ = 340 MeV

Simulation results

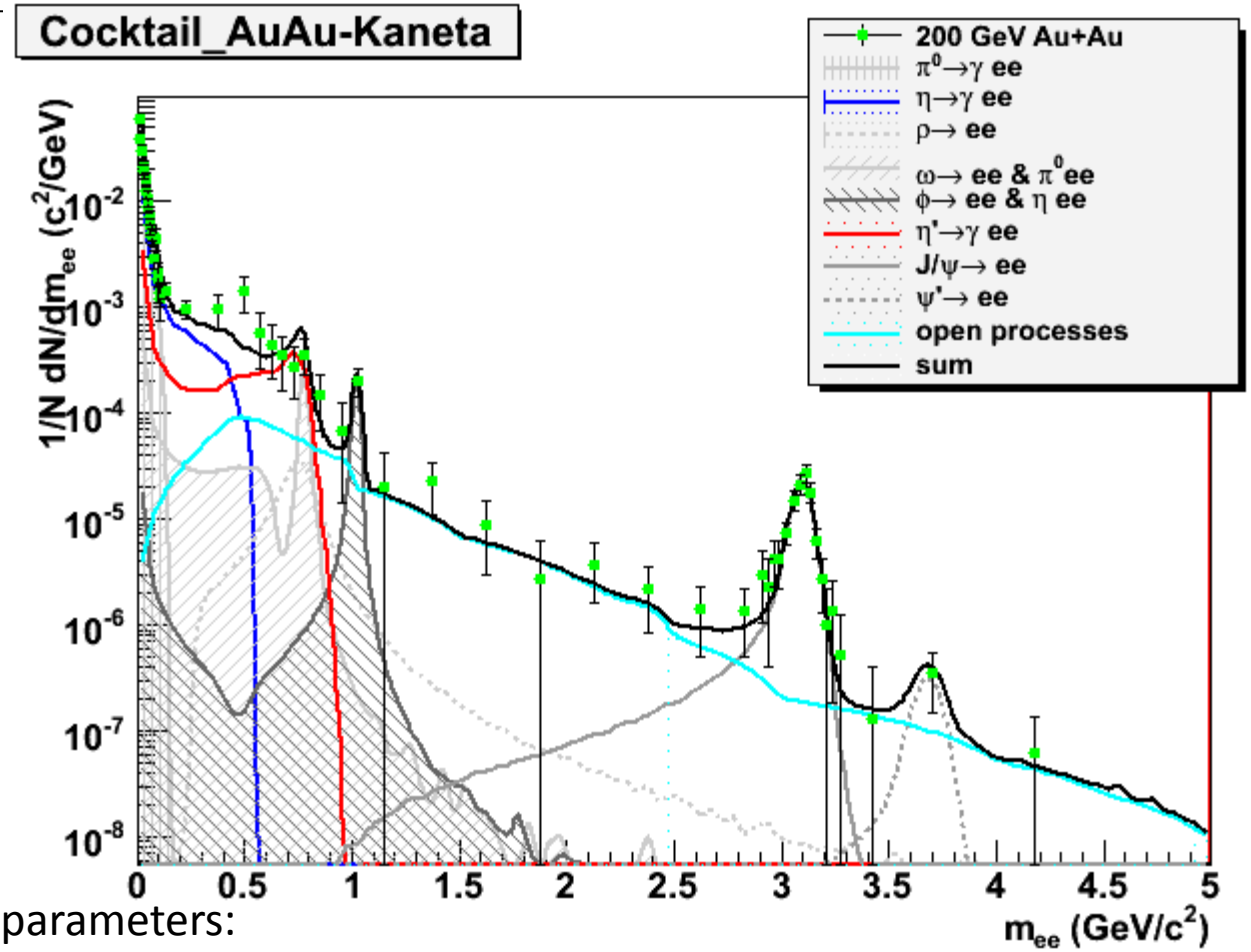


Simulation parameters:

f_η = 5.25, $f_{\eta'}$ = 43.4, $m^*_{\eta'}$ = 490 MeV

χ^2**/NDF** ($0.15 < m_{ee} < 0.7$) = 2.25, **CL** = 1.8 %

Simulation results



Simulation parameters:

f_η = 3.48, $f_{\eta'}$ = 25.6, $m^*_{\eta'}$ = 530 MeV

χ^2**/NDF** ($0.15 < m_{ee} < 0.7$) = 1.35, **CL** = 23.16 %

Summary

- Better agreement in the LMR

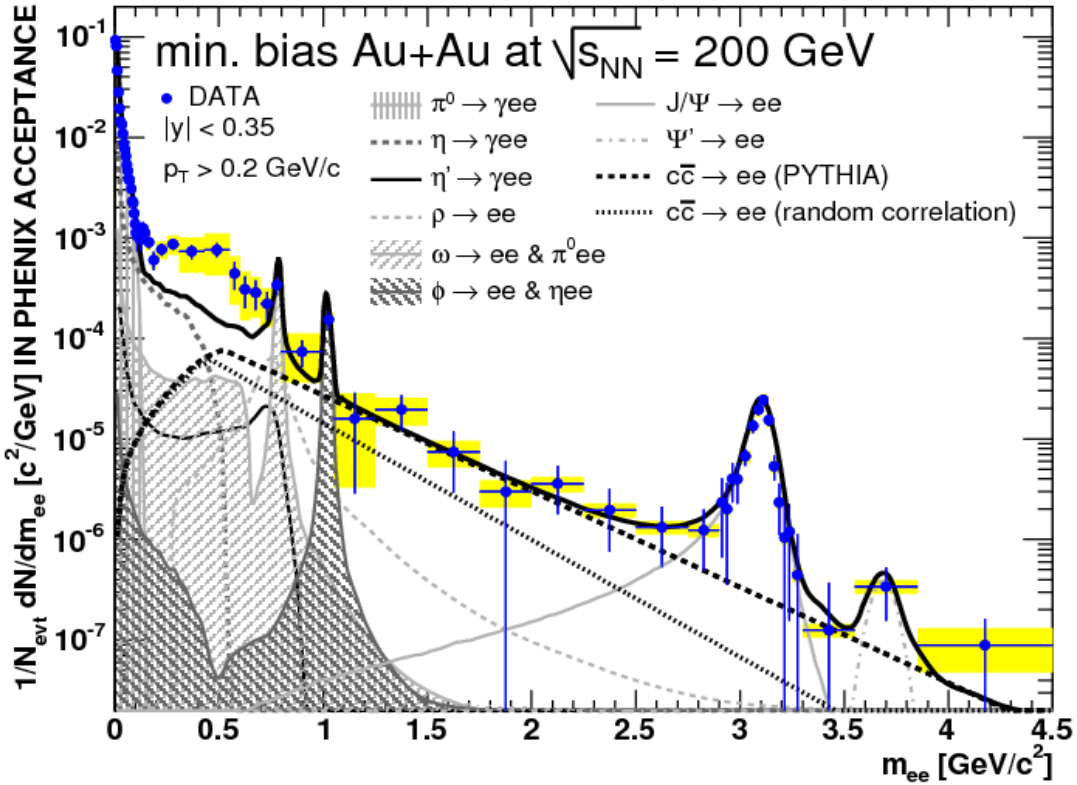
- Detailed simulation
- p_T dependence
- Other in-medium effects

} in progress

Thank you for your attention!

Context

- PHENIX Au-Au collision:
- LMR dilepton enhancement not explained



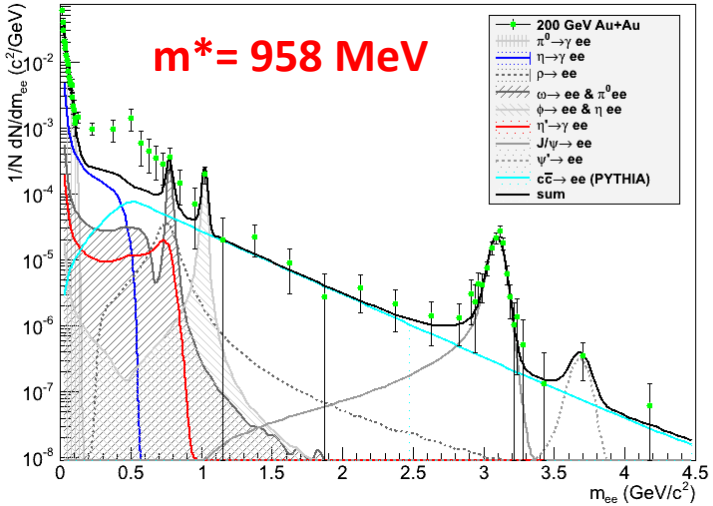
- In case of a significant in-medium η' mass modification
- Enhanced number of η' particles (Hagedorn)

$$N \sim e^{-m/T}$$

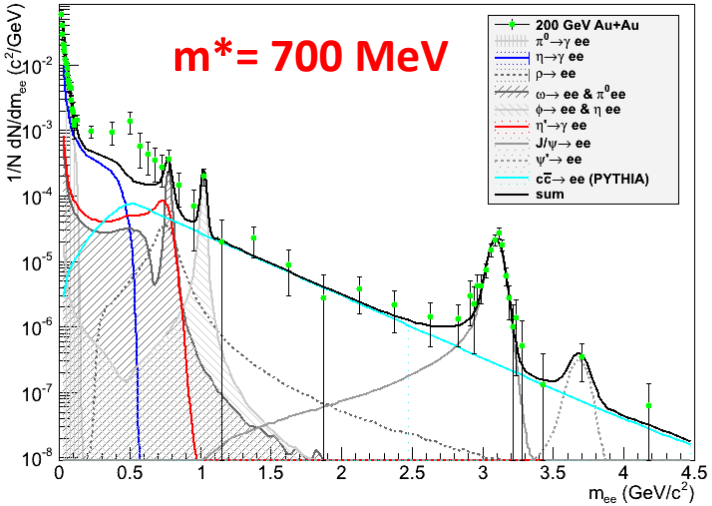
- May be a significant contributor of the excess on the whole region (0.12-1 GeV)

Simulation results

Original dilepton spectra



Original dilepton spectra



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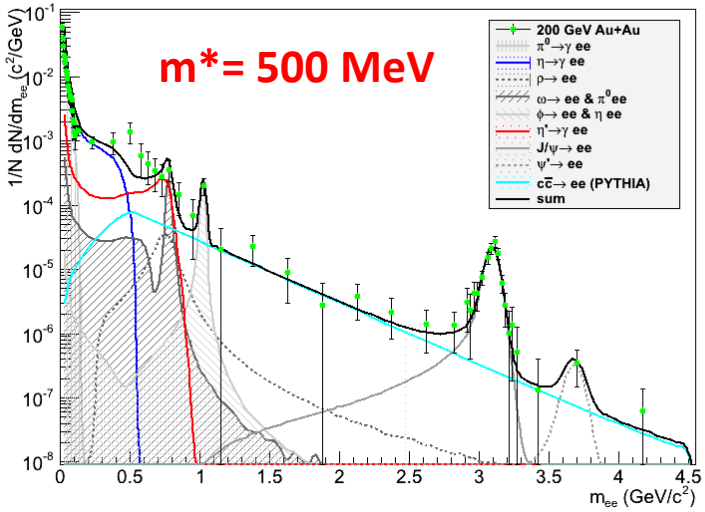
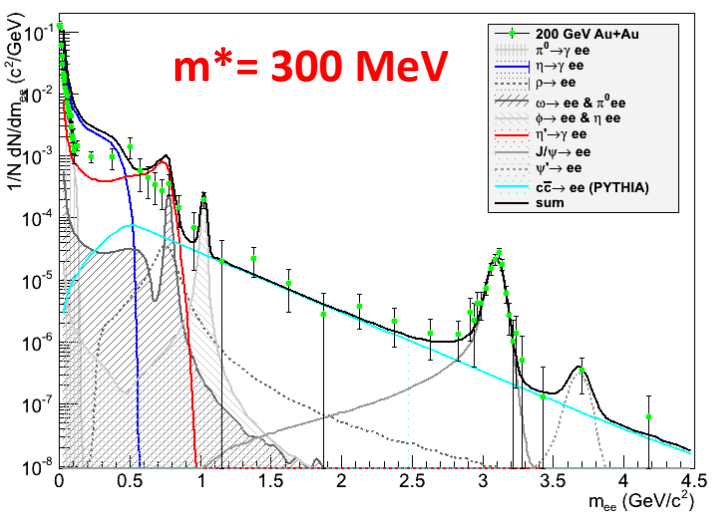


Original dilepton spectra



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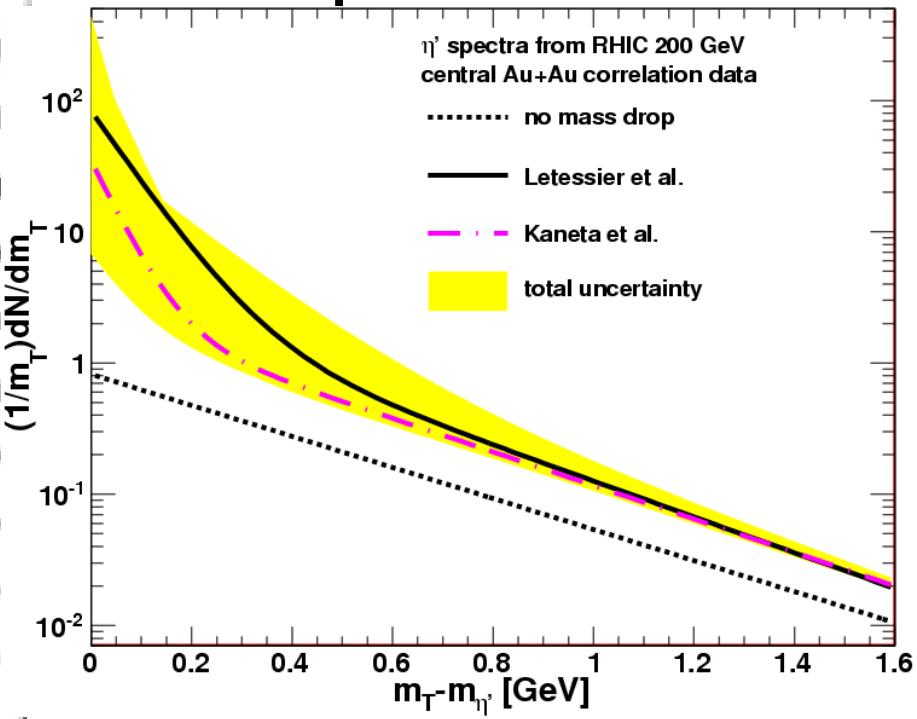
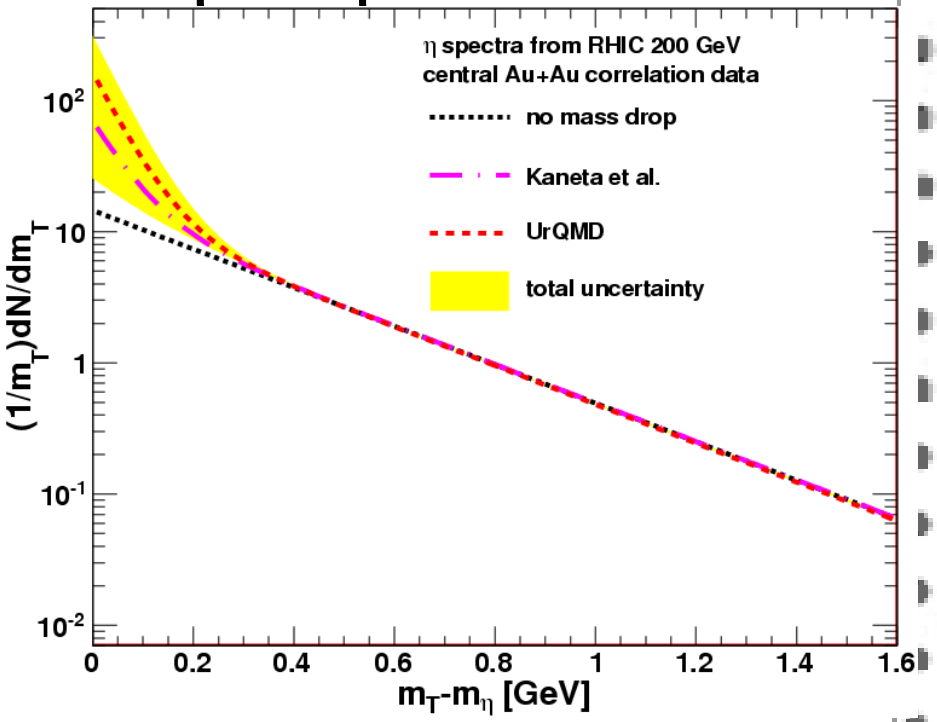
Output/Input spectrum

- Low pT enhancement in η & η'



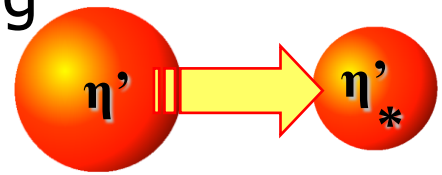


- **An enhancement factor of 25 to 68** depending on model
- Enhancement **breaks m_T** –scaling at low-p_T

- **An enhancement factor of 5.2 to 7.5** depending on model
- Enhancement at low-p_T ←→ Fits measured data at high-p_T

Context

- **Approximate SU(3) symmetry**
  - Spontaneous symmetry breaking
    → 9 Goldstone bosons
  - $U_A(1)$-breaking terms
    → η′ extra mass **(arXiv: hep-ph/9507343v2)**



In hot medium, η′ mass reduced to quark model mass

- **Signal: Enhanced η′production@low p_T**
  - **$N \sim e^{-m/T}$**