Effective spectral functions of vector mesons from lifetime analysis [2206.15166]

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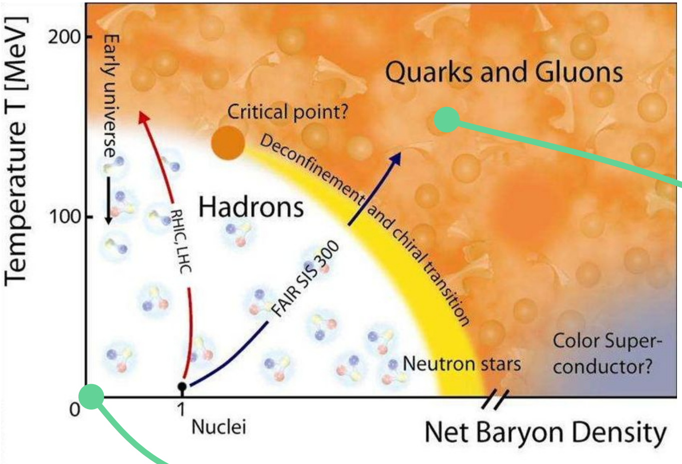
Introduction

Chiral phase transition



[CBM collaboration]

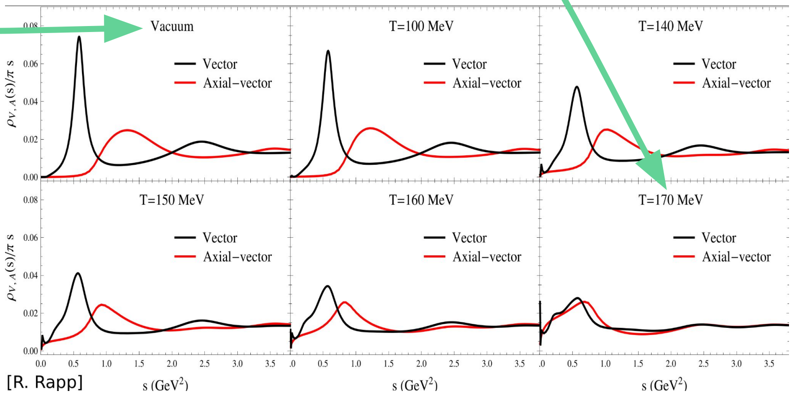
Chiral symmetry restoration at high temperatures/densities

mixing

Degenerate chiral partners

➔ Vector: $\rho(770)$

➔ Axial: $a_1(1260)$

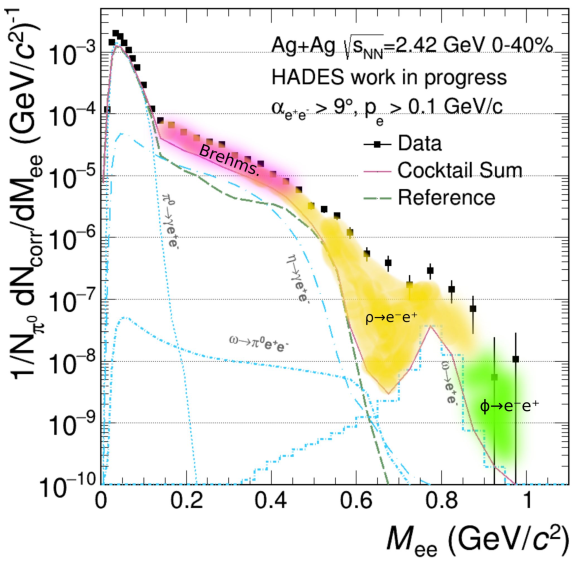


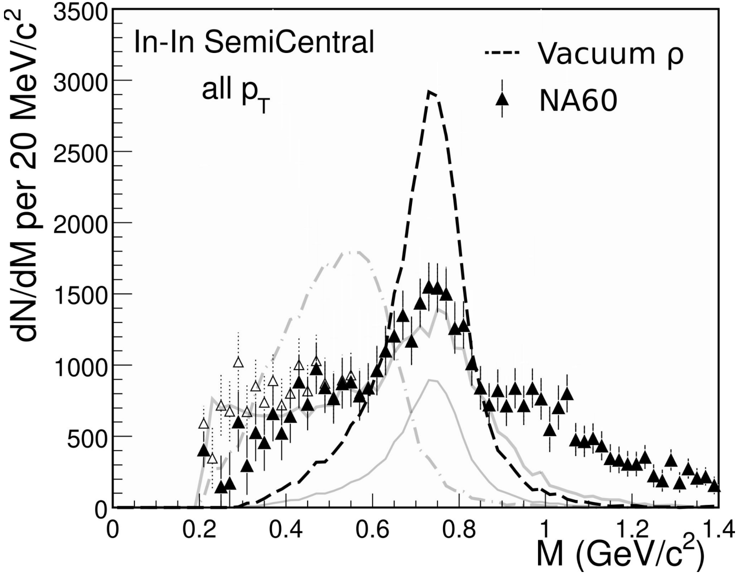
[R. Rapp]

[Hohler & Rapp, PLB 731 (2014)]

Dilepton excess yields

Measured by (dilepton yield) - (hadronic cocktail)





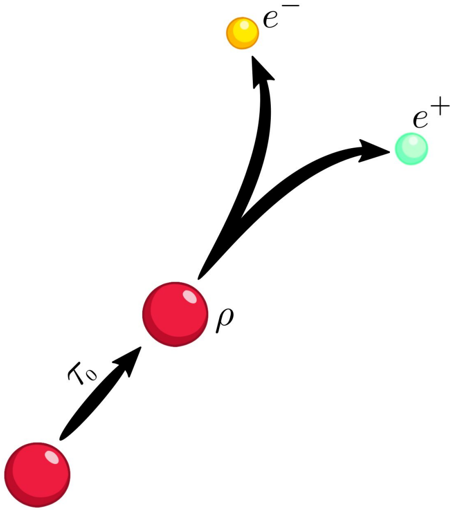
not the same experiment!

How much *actually* comes from chiral PT?

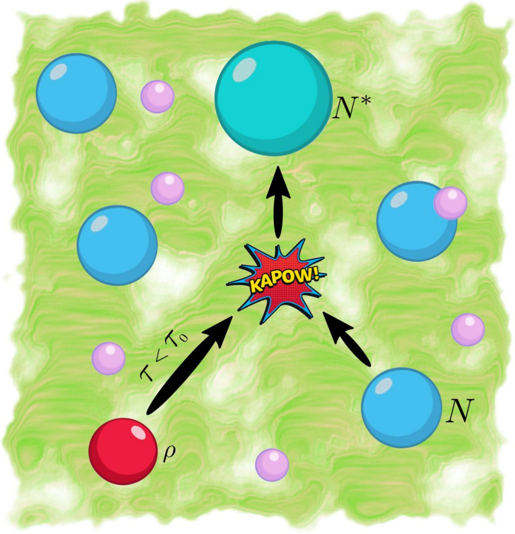
Collisional broadening:

shortening the lifetime of a resonance
due to absorptions by a medium

Vacuum



Medium



Absorbed particles cannot decay! → Mass-dependent suppression of dilepton yield

SMASH!

smash

On-shell hadronic transport

- Evolved with relativistic Boltzmann equation
- Degrees of freedom are hadrons (no chirality)
- Resonances as *particles* with fixed mass, sampled from vacuum

$$\mathcal{A}(m) = \frac{2\mathcal{N}}{\pi} \frac{m^2 \Gamma^{\text{vac}}(m)}{(m^2 - M_0^2)^2 + m^2 \Gamma^{\text{vac}}(m)^2}$$

mass-dependent vacuum decay width (see backup)

$$P(\text{decay in } \Delta t) = \Gamma^{\text{vac}}(m) \Delta t$$

No information of the medium is known a priori!

SMASH!

From the interaction history:

- Effective width

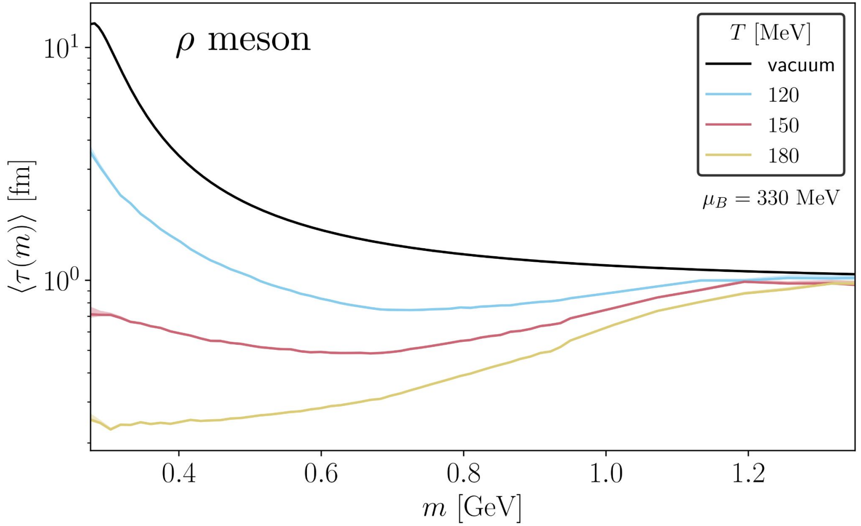
$$\Gamma^{\text{eff}}(x) = \frac{1}{\langle\tau\rangle_x} = \left\langle \frac{t_f - t_i}{\gamma} \right\rangle_x^{-1}$$

- Dynamic spectral function

$$\mathcal{A}^{\text{dyn}}(m) = \frac{2\mathcal{N}'}{\pi} \frac{m^2\Gamma^{\text{eff}}(m)}{(m^2 - M_0^2)^2 + m^2\Gamma^{\text{eff}}(m)^2}$$

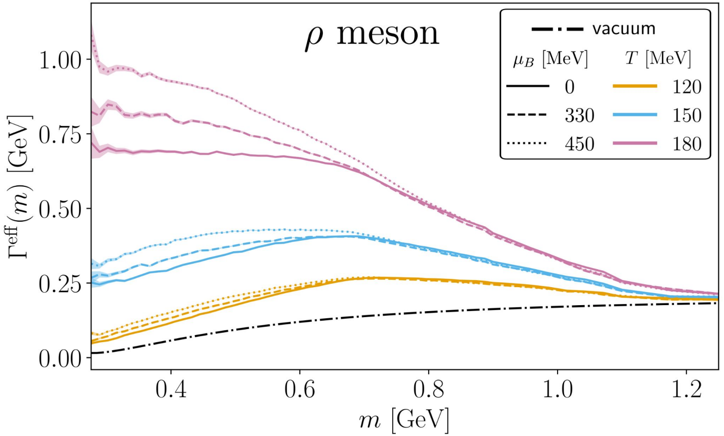
- *Collisional* width (only mass-dependence)

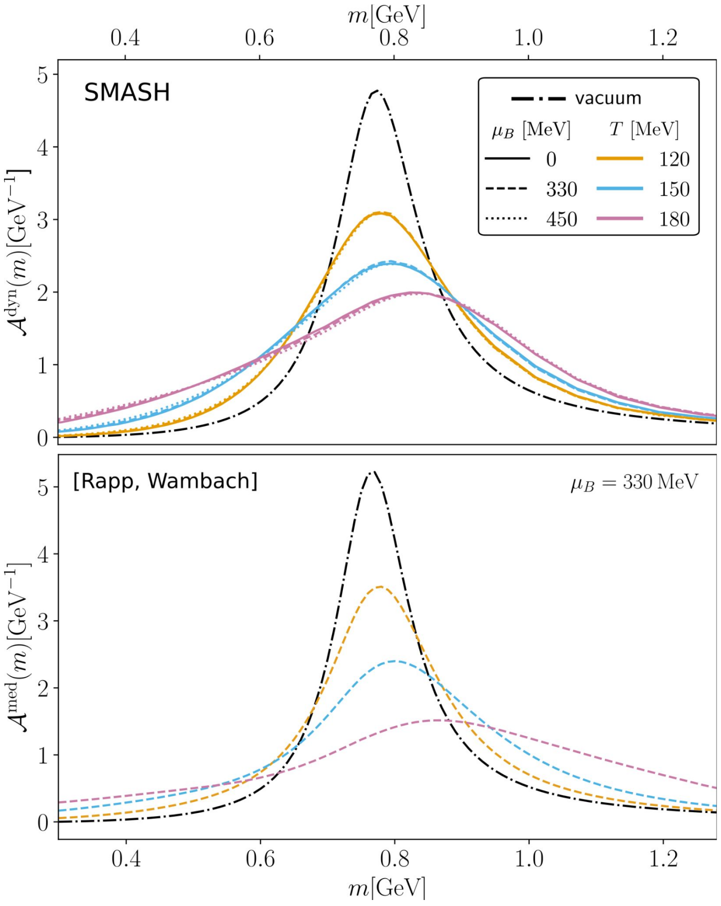
$$\Gamma^{\text{col}}(m) = \Gamma^{\text{eff}}(m) - \Gamma^{\text{vac}}(m)$$



Results

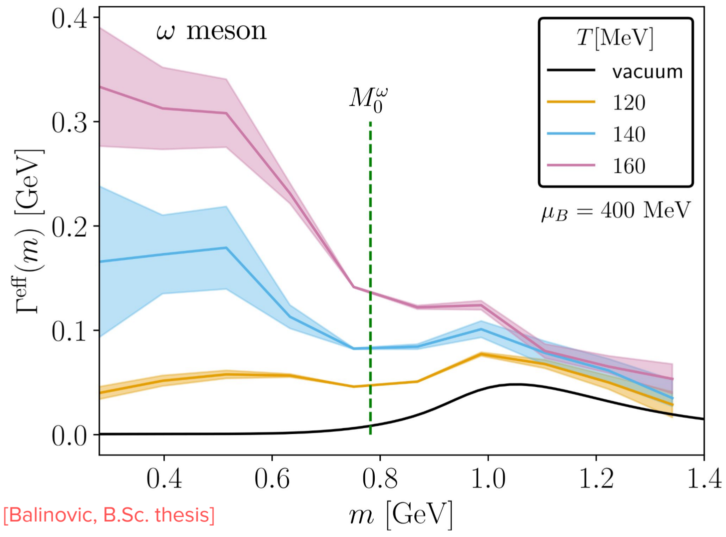
Thermodynamic behavior



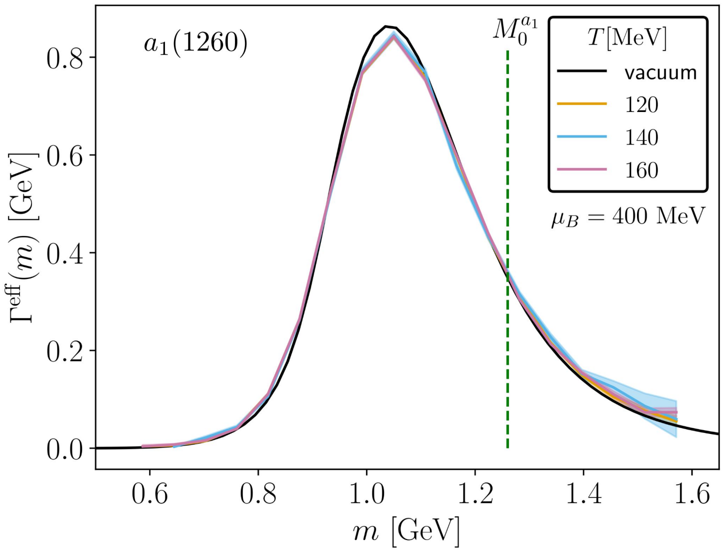


- Heavier resonances are less broadened ($\sigma_{2\to1} \sim 1/M^4$)
- Temperature modifies whole spectrum, baryochemical potential matters for $m \leq M_0$
- Similar to full in-medium model ✅
  - Melting of pole mass
  - Positive shift of peak
- Differences: SMASH is “tree-level” ❌

Thermodynamic behavior



[Balinovic, B.Sc. thesis]



- Thermal medium affects other vector channels, always similar to Rapp-Wambach model
- Broadening independent of pole mass

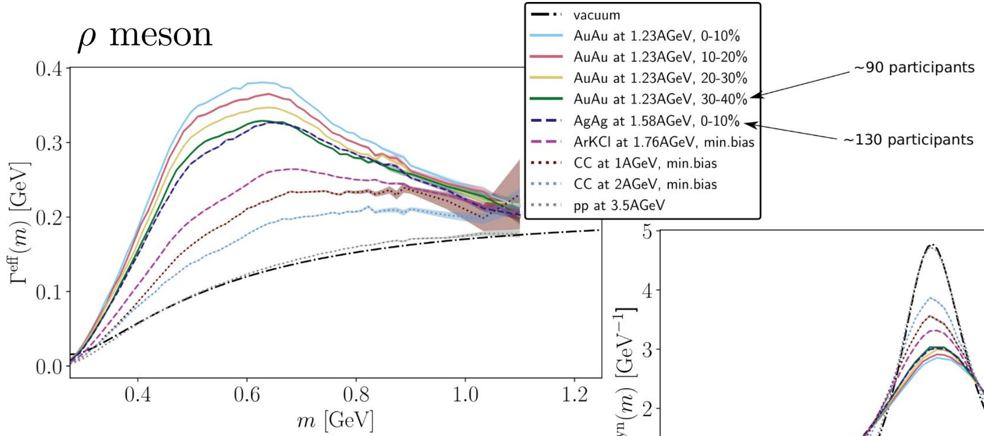
- (little to) **no broadening** in chiral partner of ρ
  - If $a_1(1260)$ melts, it's not collisional broadening!
    - Chiral symmetry restoration?

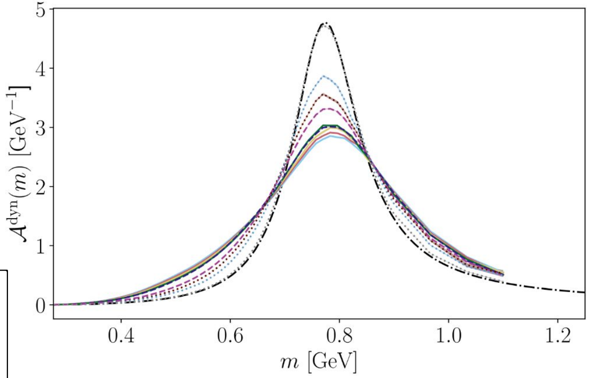
Nuclear collisions

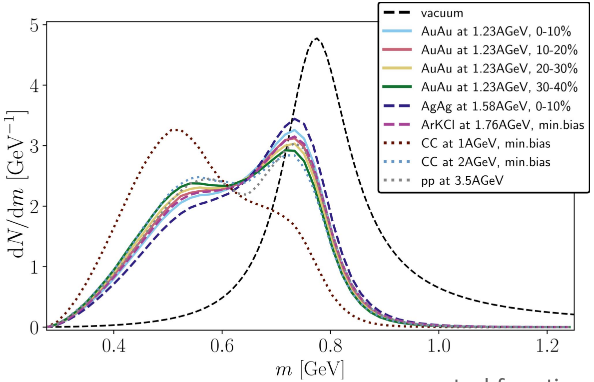
- Width decreases near $2m_\pi$
- System size dependence:
  - p+p ≈ vacuum ✅
  - Nucleus size & centrality increase medium effect
- Higher beam energy leads to less broadening

↓

- Different systems with same overall collisional broadening

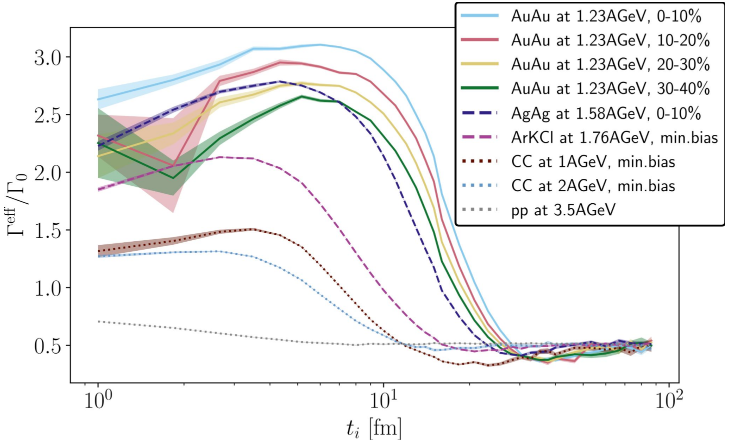




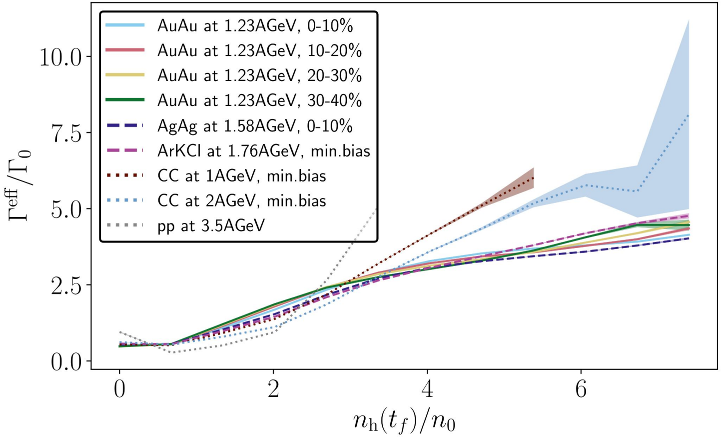


spectral function ≠ mass distribution!

Nuclear collisions



- Chronometer for medium lifetime
- Highlight difference between central AgAg and 30-40% AuAu:
  - The former has more participants ➡ larger initial width
  - Higher beam energy spreads out particles ➡ width decreases faster
  - The two effects cancel over the whole evolution
- Faster beam creates a *less dense medium*

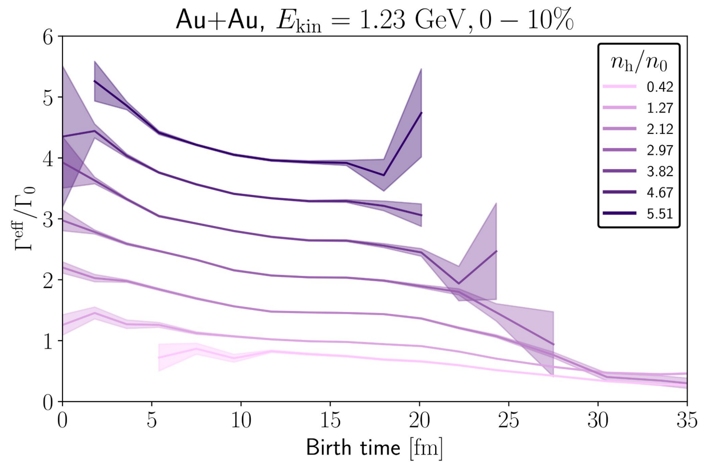


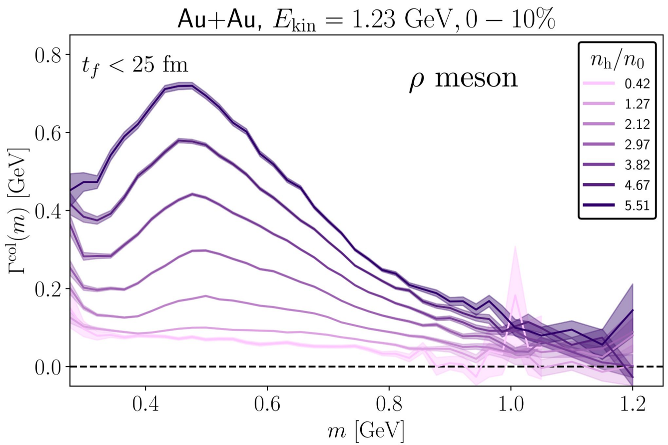
- “Universal” dependence on density
- Consistent with *off-shell* models (GiBUU, PHSD)

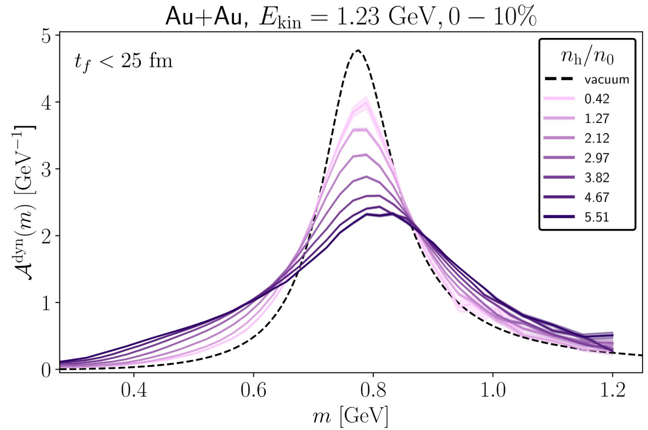
$$\Gamma^{\text{coll}} = \gamma n_N \left\langle v\sigma_{VN}^{\text{tot}} \right\rangle$$

- Deviations for very dense regions in small systems

Universality in density?

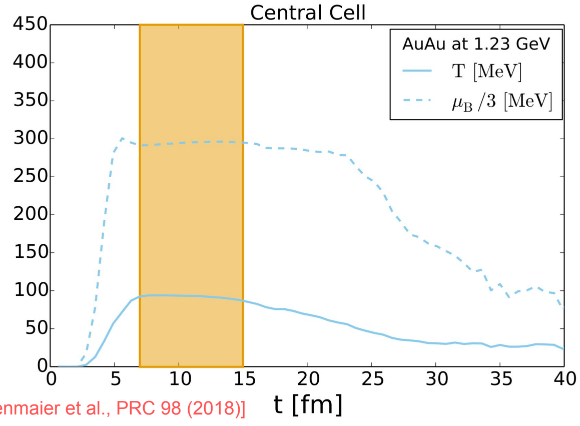




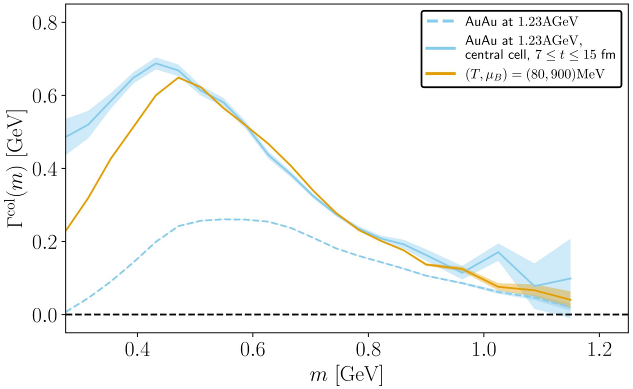


- Nearly constant
- No dense regions after **t ≈ 25 fm**
- Before that, width at hadronic threshold is not 0.
  (only small masses are produced in late stage)
- Spectral function resembles thermal behavior

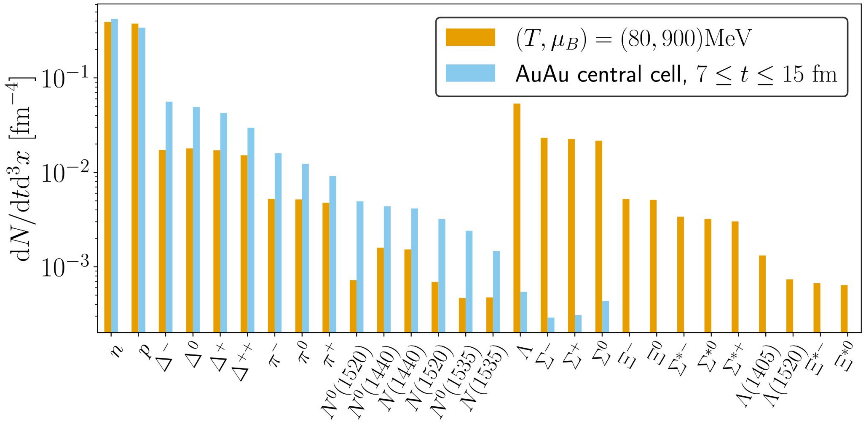
Thermal equilibrium?



[Staudenmaier et al., PRC 98 (2018)]



- "Golden window" of constant (T, μ_B) in the middle of nuclear collisions
  - Is this thermal equilibrium?
- Equal widths for **m ≳ 0.5 GeV**, while low-mass resonances broaden less in thermal gas



- Different chemical composition:
  - Equilibrium also populated by strange particles $(N \propto e^{-m/T})$
  - Collision system has more particles that absorb a ρ meson

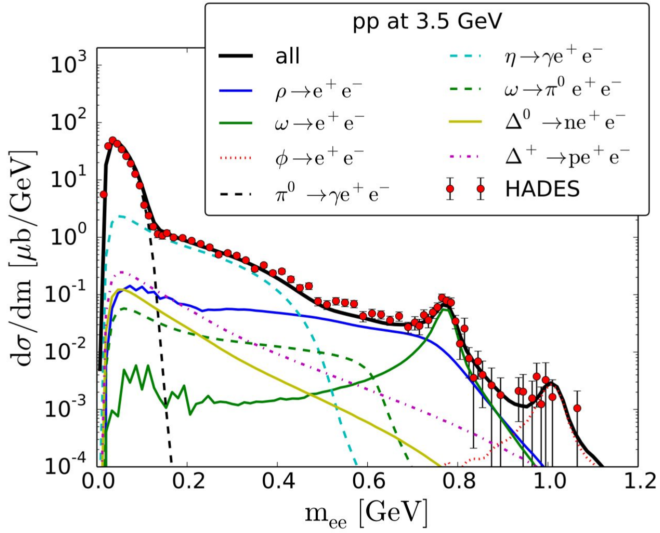
Summary

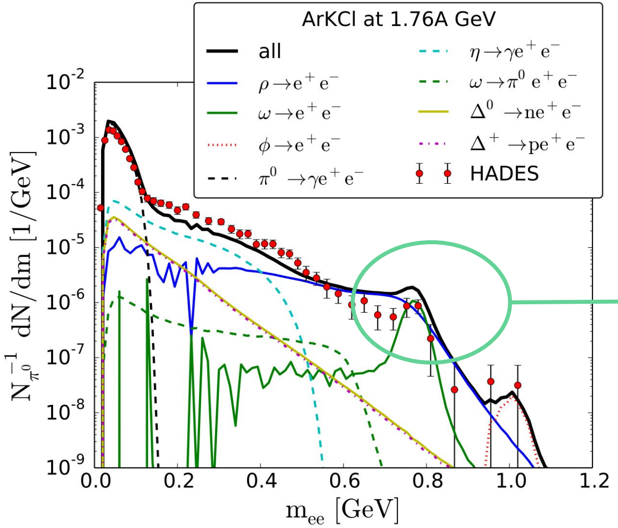
- Medium effects in dilepton yields have large contribution of collisional broadening
- Chiral symmetry may play a role if $a_1(1260)$ indeed melts
- Collisional broadening quantified in low-energy nuclear collisions, "universal" dependence on local density
- Non-equilibrium in real systems may increase effective width ⇦ relevant for e.g. coarse-graining

T. Hanks!

Backup slides

Dilepton spectra in SMASH

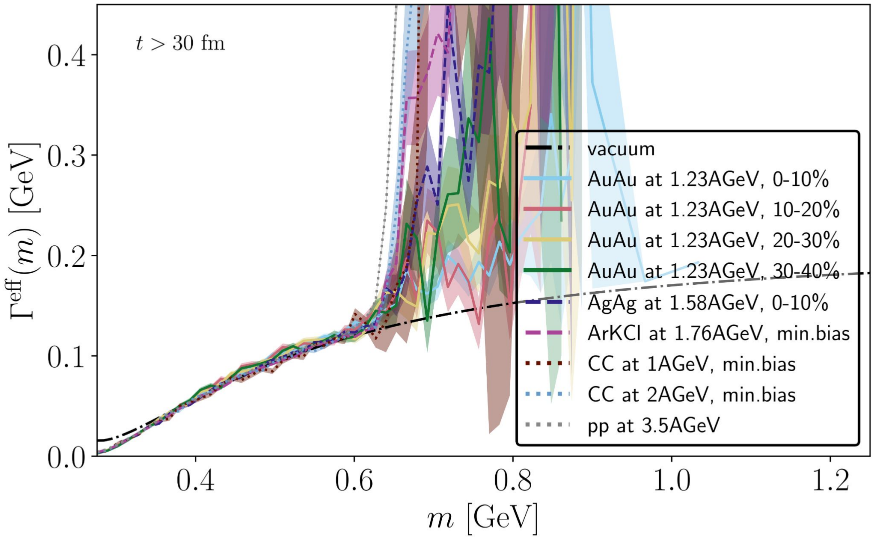


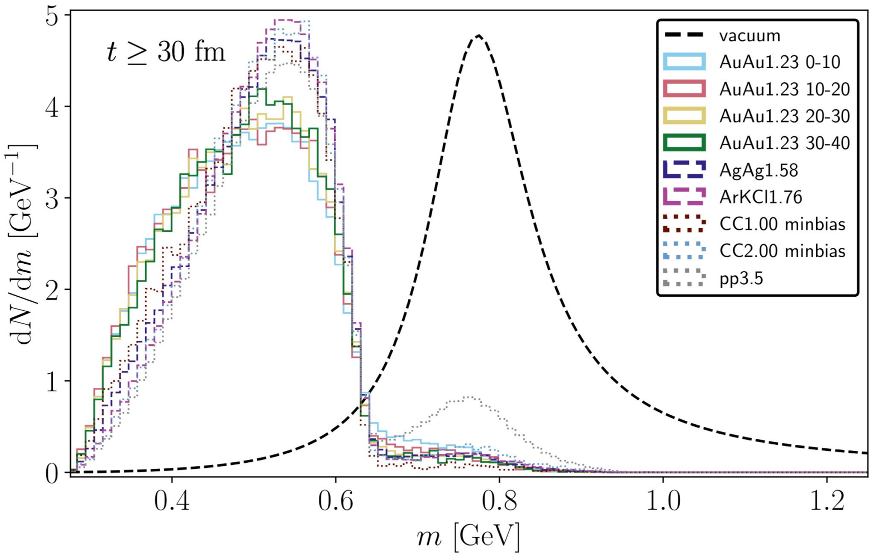


collisional broadening is not sufficient!

Solution: coarse-graining

Late stages of a collision





Particles travel effectively in vacuum!

Vacuum decay widths

$$\Gamma^{\text{vac}}_{\rho\to\pi\pi}(m) = \Gamma^0 \frac{M_0}{m} \left(\frac{\frac{1}{4}m^2 - m_\pi^2}{\frac{1}{4}M_0^2 - m_\pi^2} \right)^{3/2} \left(\frac{\frac{1}{4}M_0^2 - m_\pi^2 + \Lambda^2}{\frac{1}{4}M_0^2 - m_\pi^2 + \Lambda^2} \right)$$

[Manley & Saleski, PRD 45, 4002 (1992)]

$$\Gamma^{\text{vac}}_{\rho\to ll}(m) = \Gamma^0_{\rho\to ll} \left(\frac{M_0}{m} \right)^3 \left(1 + \frac{2m_l^2}{m^2} \right) \sqrt{1 - \frac{4m_l^2}{m^2}}$$

[McLerran & Toimela, PRD 31, 545 (1985)]

ρ cross sections in SMASH