Finite Volume & Lifetime Effects on Secondary-Particle Spectra in Relativistic Collision

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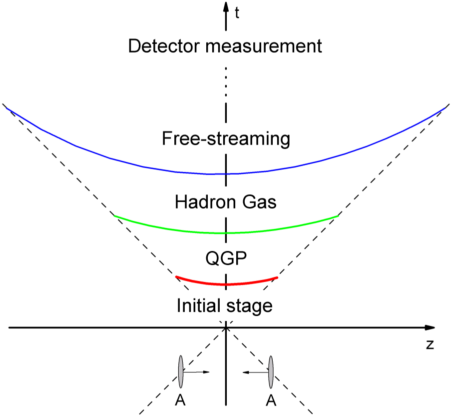
Outline

- Relativistic Heavy Ion Collision consists of several phases.
- We are interested in description of the system created during collision process. Meanwhile, information that we obtain consists just of some observables that need to be treated on the base of our models.



- After chemical freeze-out system of hadrons expands until kinetic freeze-out is reached and then particles propagate freely (mean free path is large).

Motivation

- Investigation of the transverse momentum distribution,
- Study of influence of the finiteness of system volume and life-time on the single-particle spectra,
- Study of influence of interactions on the single-particle spectra.

- Most models use statistics and thermodynamics without any quantum effects, and provide spectra with Cooper-Frye formalism with parametrization of hydrodynamic flow (Blast-Wave Model) or Non-extensive entropy (Tsallis distribution) which lacks physical evidence.
- This approach indirectly considers hydrodynamic flow, purely quantum, can be extended to describe origins of non-extensive entropy.

General formula: the spectrum is determined by the lesser Green's function $G^<(\omega, \mathbf{k})$

$$2E_k \frac{d^3N}{dk^3} = V \int \frac{d\omega}{2\pi} \left(E_k + \omega\right)^2 \, iG^<(\omega, \mathbf{k})$$

Finite life-time: Breit-Wigner(1)

$$\frac{d^3N}{dk^3} = V \int_0^\infty \frac{ds}{\pi} \, \frac{m\gamma}{(s - E_k^2)^2 + (m\gamma)^2} \, f_{\mathrm{BE}}(\sqrt{s})$$

Finite life-time: Breit-Wigner(2)

$$E_k \frac{d^3N}{dk^3} = V \int_0^\infty \frac{dk^0}{\pi} \left(E_k^2 + k_0^2\right) \frac{\gamma k^0}{\left(k_0^2 - E_k^2 - \frac{1}{4}\gamma^2\right)^2 + (k^0\gamma)^2} f_{\mathrm{BE}}(k^0)$$

Finite Volume and Life-time

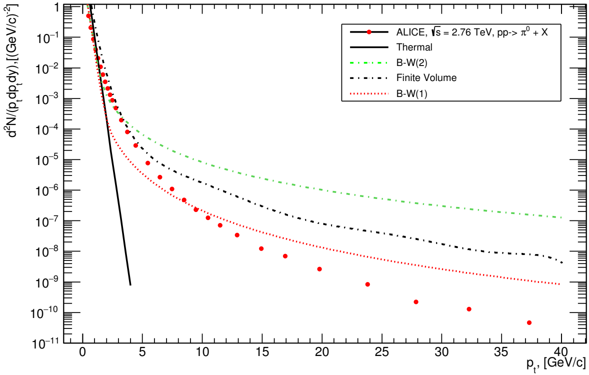


Figure 1: Finite life-time of the system versus finite volume for proton-proton collisions. All curves with $T = 160$ MeV. Breit-Wigner (1) and Breit-Wigner (2) with $\gamma = 63$ MeV. Finite Volume with $R = 1$ fm, $L = 1.5$ fm. Exp. data from [2]

Finite Volume and Life-time

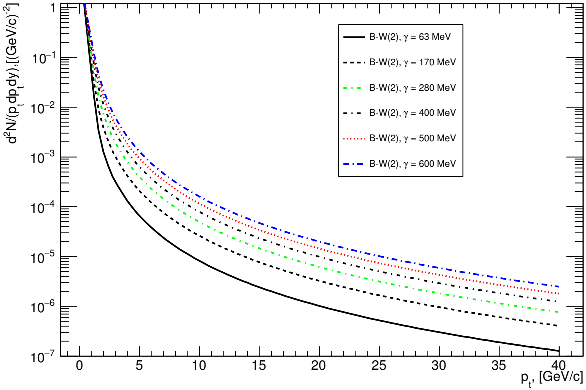


Figure 2: Account for finite life-time of the system. For high p_t the spectra converts to power law and the difference between energy levels decreases with increase of γ.

Finite Volume Model for proton-proton collisions

$$2E_k \frac{d^3N}{dk^3} = 4LR^2 \sum_{n,l,m} (E_k + E_{nlm})^2 f_{\mathrm{BE}}(E_{nlm}) \left| \frac{[1-(-1)^n \exp(-ik_z L)]}{\pi n \left[\left(\frac{k_z L}{\pi n} \right)^2 - 1 \right]} \frac{J_m(kR)}{\mu_m^{(l)} \left[\left(\frac{kR}{\mu_m^{(l)}} \right)^2 - 1 \right]} \right|^2$$

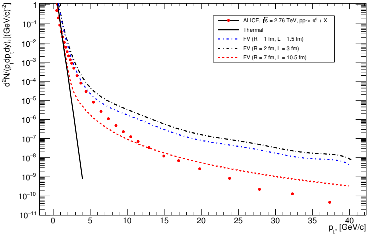


Figure 3: Account for finite volume of the system for proton-proton collisions. Exp. data from [2]

Finite Volume and Life-time

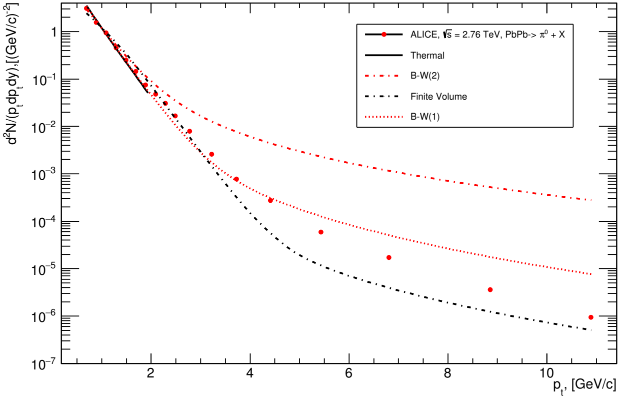


Figure 4: Finite volume of the system versus finite life-time for Pb+Pb collisions. All curves with $T = 300$ MeV. Breit-Wigner(1) and Breit-Wigner(2) with $\gamma = 170$ MeV. Finite Volume with $R = 9$ fm, $L = 13.5$ fm. Exp. data from [1]

Finite Volume and Life-time

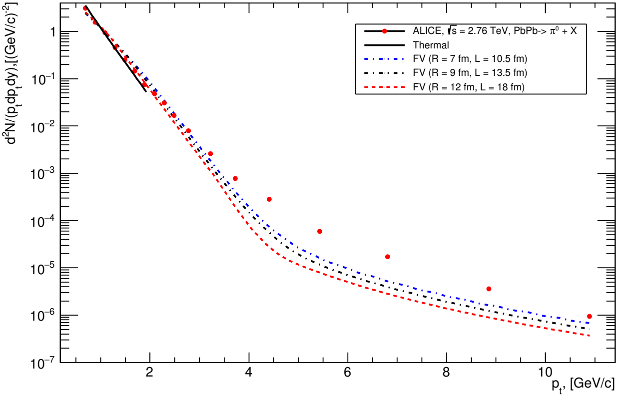


Figure 5: Finite Volume Model for PbPb data. Exp. data from [1]

Combined: finite volume of the system plus finite life time

$$2E_k \frac{d^3N}{dk^3} = 4LR^2 \sum_{n,l,m} \left(E_k^2 + E_{nlm}^2\right) \frac{\gamma E_{nlm}}{(E_{nlm}^2 - E_k^2 - \frac{1}{4}\gamma^2)^2 + (E_{nlm}\gamma)^2} f_{\mathrm{BE}}(E_{nlm}) \times$$

$$\times \left| \frac{[1-(-1)^n \exp(-ik_z L)]}{\pi n \left[\left(\frac{k_z L}{\pi n}\right)^2 - 1\right]} \frac{J_m(kR)}{\mu_m^{(l)} \left[\left(\frac{kR}{\mu_m^{(l)}}\right)^2 - 1\right]} \right|^2$$

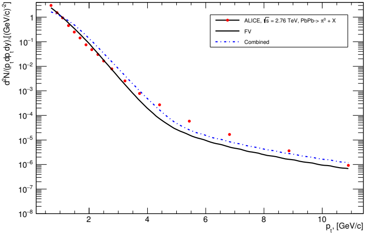


Figure 6: Combined Model with $R = 7$ fm, $L = 10.5$ fm, $\gamma = 170$ MeV. Exp. data from [1]

Finite Volume and Life-time

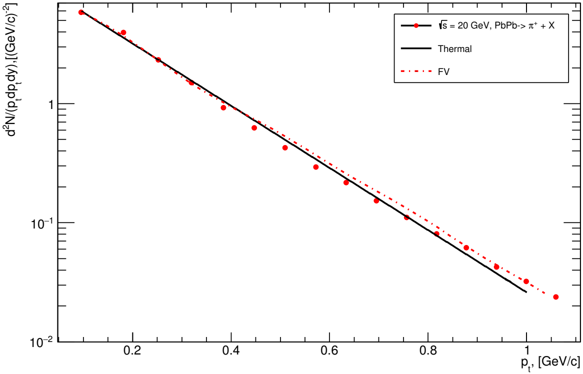


Figure 7: Thermal Model versus Finite Volume Model for PbPb data (small p_t).
Thermal Model with $T = 166$ MeV.
Finite Volume Model with $T = 132$ MeV, $R = 2.5$ fm, $L = 3.75$ fm. Exp. data from [3]

Finite Volume and Life-time

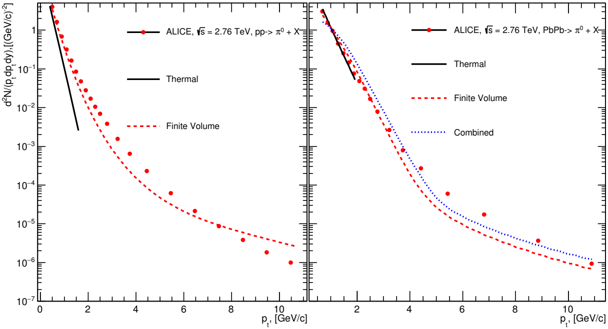


Figure 8: Comparison of two cases of colliding systems at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, p-p (left panel) and Pb-Pb (right panel). For p-p: All curves with $T = 160$ MeV, finite volume $R = 1$ fm, $L = 1.5$ fm. For Pb-Pb: All curves at $T = 300$ MeV, finite volume and combined models with $R = 7$ fm, $L = 10.5$ fm, $\gamma = 170$ MeV. Exp. data from [1, 2]

Next steps

- Influence of interactions.
- Account for the non-equilibrium effects and expansion.
- Account for the resonance decays and presence of many-component systems.

So at the end we have

- Single particle pionic spectrum derived from different models, physical explanation of the shape changes by different phenomena.
- Acquired spectrum provides better explanation in comparison with Bose-Einstein distribution function, but fails to recreate right power law in high momentum part of the spectrum.
- We also conclude that spectral function should decay with the power of 7 at least.
- Some experimental data provided for comparison of different models with it and between.
- Spectrum of Heavy Ion and proton collision compared to see what differences can be calculated from models at hand.

- Betty Bezverkhny Abelev et al. "Neutral pion production at midrapidity in pp and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$". In: *Eur. Phys. J.* C74.10 (2014), p. 3108. DOI: `10.1140/epjc/s10052-014-3108-8`. arXiv: `1405.3794 [nucl-ex]`.
- Shreyasi Acharya et al. "Production of π^0 and η mesons up to high transverse momentum in pp collisions at 2.76 TeV". In: *Eur. Phys. J.* C77.5 (2017). [Eur. Phys. J.C77,no.9,586(2017)], p. 339. DOI: `10.1140/epjc/s10052-017-5144-7,10.1140/epjc/s10052-017-4890-x`. arXiv: `1702.00917 [hep-ex]`.
- C. Alt et al. "Pion and kaon production in central Pb + Pb collisions at 20-A and 30-A-GeV: Evidence for the onset of deconfinement". In: *Phys. Rev.* C77 (2008), p. 024903. DOI: `10.1103/PhysRevC.77.024903`. arXiv: `0710.0118 [nucl-ex]`.

Thank you for attention!

Acknowledgements

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