Mass modification of φ mesons through Kaons

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Introduction

- **Mass and width modification of vector mesons → Properties of strongly interacting matter**
  - Mass shifts of heavy charmonium states → gluon condensate at finite densities
  - ρ, and ω meson mass shifts → quark condensates at finite densities
  - φ meson mass modification ←→ change in $\langle \bar{s}s \rangle$ condensate
  - Dilepton spectra is straightforward to observe
    - no final state effects, direct information on the density its created

Phi meson mass modification

Possible channels to observe DM:

- Dilepton: Γ_{ee}= 0.0002 → high statistics needed, but very clean signal
- $\varphi \rightarrow K^+K^-$: Γ_{KK}=0.49 , good, but final state effects could smear out the spectrum

- **Proton+Nucleus reactions at 12, and 30 GeV**
  - Cleaner signal than heavy ion reactions
  - Results from dileptons at 12GeV → Δm~34 MeV, but no clear evidence
  - Higher statistics needed
  - JPARC E16: p+N (C,Cu,Pb) reactions @30 GeV

BUU Transport model

- **To understant the signal → off-shell transport methods (PHSD,AMPT,BUU,…)**
- **Mass modifications with respecting energy conservation → off-shell transport equations:**
  - Propagating the spectral functions (finite width, not Dirac delta particles)
  - EOM consists of the real and imaginary parts of the self energies:

$$\mathcal{R}\Sigma^{ret} = 2m\Delta m_0 \frac{\rho}{\rho_0} \qquad \mathcal{I}\Sigma^{ret} = -m(\Gamma_0 + \Delta\Gamma \frac{\rho}{\rho_0})$$

  - Density and momentum dependent mean fields for nucleons
  - Coulomb force for charged particles
  - Pauli exclusion, … , and many other technical details...

BUU Transport model

- **Important parts for φ mesons:**
  - Creation cross sections
    - NN→φX, πN→ φX inclusive channels are dominant
  - Elastic collisions, and absorption on nucleons
  - Decay probability to Kaons, pions, dileptons,…
  - Elastic KN, $\overline{K}$N scattering
  - Absorption of $\overline{K}$-s through: $\overline{K}N \to \Lambda\pi$, $\overline{K}N \to \Sigma\pi$, $\overline{K}N \to \overline{K}'N'$, $\overline{K}N \to \Sigma\pi\pi$
  - Mean field for Kaons

BUU Transport model

– Mean field for Kaons:

- $$U_K = \rho(\vec{r})\left(a + b \cdot e^{-c \cdot p_K}\right)$$

M1. $U_{K^+} = 0$, and $U_{K^-} = 0$, no mean field.
M2. $U_{K^+} = +0.167 \cdot \rho$, $U_{K^-} = -0.167 \cdot \rho$.
M3. $U_{K^+} = +0.167 \cdot \rho$, $U_{K^-} = -\rho(0.341 + 0.823 \cdot e^{-2.5 p_K})$

- More 'realistic' density and momentum dependent mean field (M4)

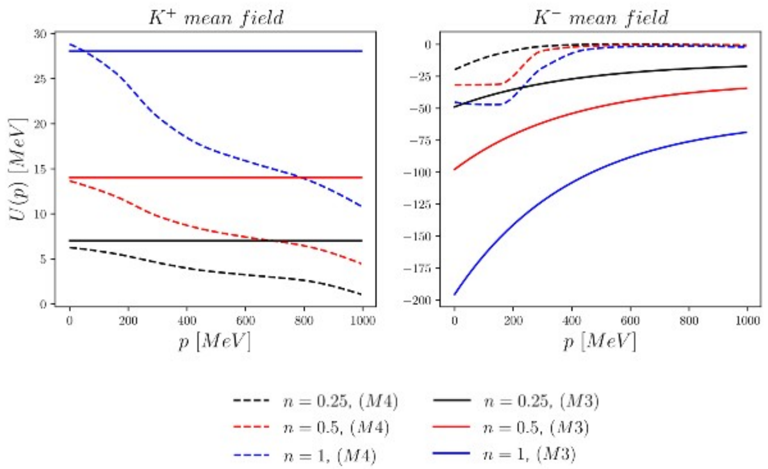


Fig. 1. Comparison of the density and momentum dependence of the (M3) and (M4) mean fields. The dashed lines show the results for (M4), while the solid lines correspond to the (M3) potentials. Here, $n = \rho/\rho_0$ is the normalized density, where $\rho_0 = 0.168$ [fm^{-3}].

L. Tolos, A. Ramos, and E. Oset, Phys. Rev. C **74**, 015203 (2006)

L. Tolos, D. Cabrera, and A. Ramos, Phys. Rev. C **78**, 045205 (2008)

Mean field effects and final state interactions

- Simulations for p+C/Cu/Pb collisions @30 GeV bombarding energies

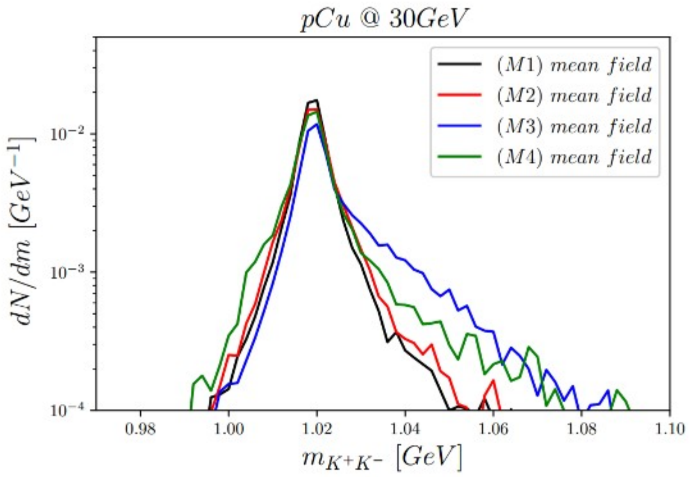


Fig. 2. Comparison of the invariant mass spectra of kaon pairs in p+Cu reactions at 30 GeV bombarding energies with different kaonic mean fields without final-state interactions of kaons.

M1. $U_{K^+} = 0$, and $U_{K^-} = 0$, no mean field.

M2. $U_{K^+} = +0.167 \cdot \rho$, $U_{K^-} = -0.167 \cdot \rho$.

M3. $U_{K^+} = +0.167 \cdot \rho$, $U_{K^-} = -\rho(0.341 + 0.823 \cdot e^{-2.5 p_K})$

-No elastic collisions, No absorptions for Kaons

+ only M1,M2,M3,M4 mean fields

→ asymmetry in the K^+/K^- mean fields causes asymmetry in the invariant mass spectrum

Mean field effects and final state interactions

- **Simulations for p+C/Cu/Pb collisions @30 GeV bombarding energies**

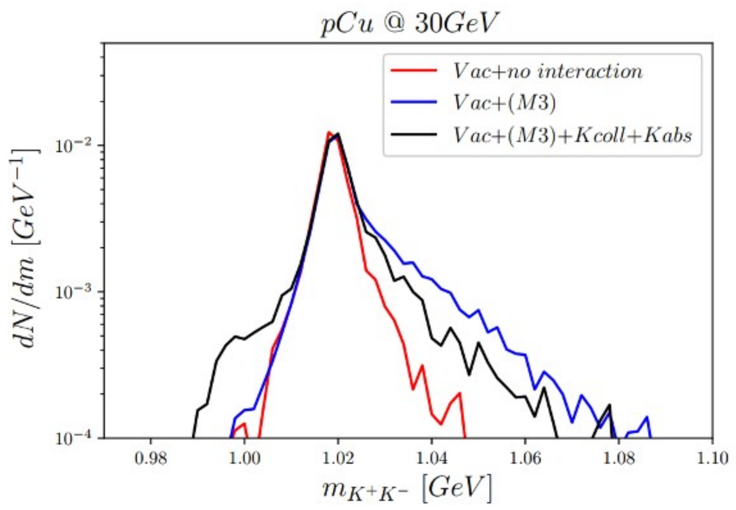


Fig. 3. Effects of the scatterings and absorption of kaons on the invariant mass spectrum when applying the (M3) mean field in p+Cu collisions at 30 GeV.

M1. $U_{K^+} = 0$, and $U_{K^-} = 0$, no mean field.

M2. $U_{K^+} = +0.167 \cdot \rho$, $U_{K^-} = -0.167 \cdot \rho$.

M3. $U_{K^+} = +0.167 \cdot \rho$, $U_{K^-} = -\rho(0.341 + 0.823 \cdot e^{-2.5 p_K})$

+ M3 mean field

+ Effects of elastic scatterings, and absorptions

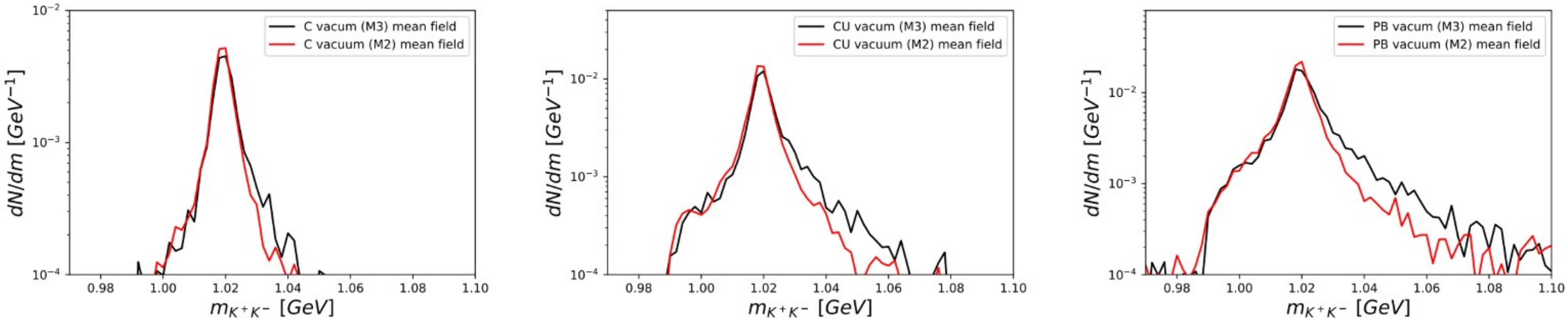
→ The asymmetry is 'tamed' by the final state interactions.

→ elastic scatterings → broadening

→ absorption → symmetrizes the spectrum

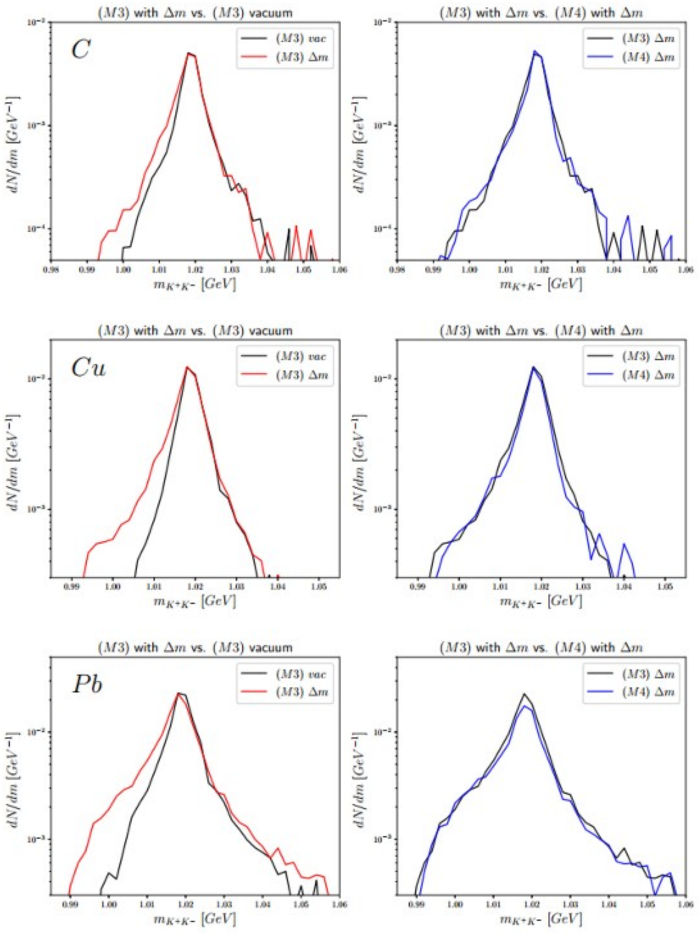
Mean field effects and final state interactions

- **Simulations for p+C/Cu/Pb collisions @30 GeV bombarding energies**
- **Comparison of (M2) and (M3) mean fields including final state interactions.**



- **Conclusions: Important to know a qualitatively good mean field!**
  - Mean fields play an important role in the shape of the spectrum.
  - Final state interactions broadens and symmetrizes the spectrum.

Mass shift of phi mesons @ 30 GeV p+C/Cu/Pb

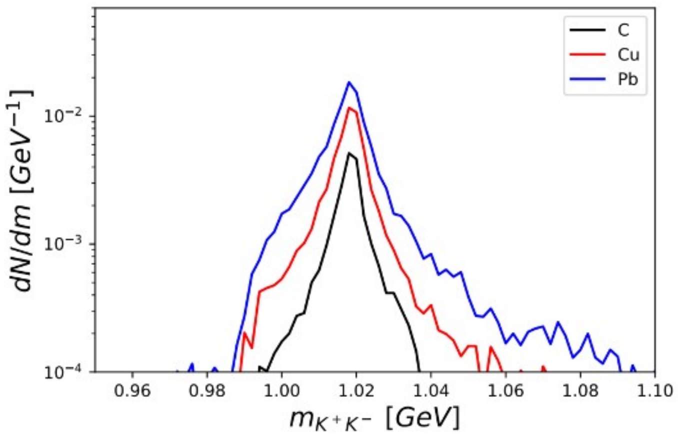


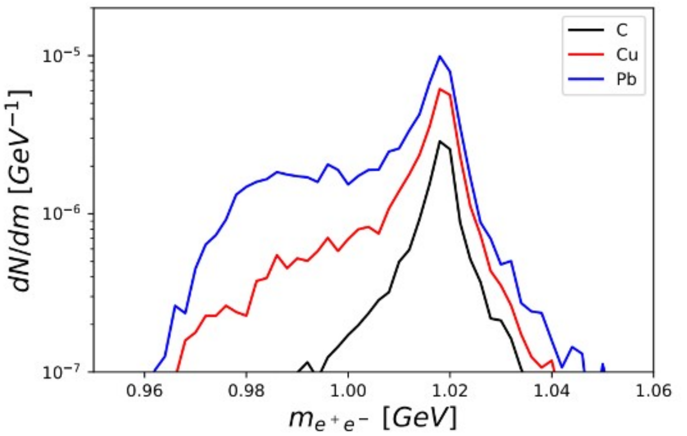
- Clear vacuum peak + a small broadening at lower masses
- The broadening is more dominant for larger targets, but still hard to interpret
- Careful analysis is needed if we want to quantify the mass shifts.

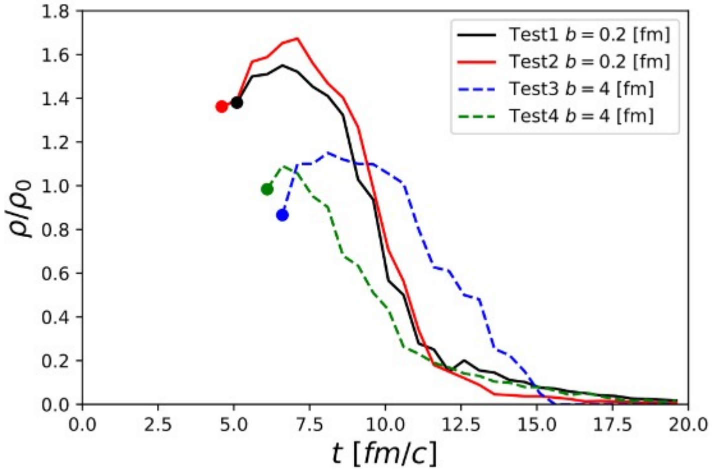
Fig. 6. Invariant mass spectra of the K meson pairs when the $\Delta m(\rho_0) = -34$ MeV mass shift is applied to the ϕ mesons using the (M3) and (M4) mean fields. On the left side, the vacuum (without mean fields or final-state interactions for reference) and the mass shift cases are compared using only the (M3) mean field, while on the right side, the (M3) and (M4) mean field cases are compared using $\Delta m(\rho_0) = -34$ MeV.

Invariant mass spectra of dileptons and Kaons

- **Comparison of the integrated e^+e^-, and K^+K^- invariant mass spectra**







Density and centrality dependence of test particles

- **b=0.2 fm, and b=4 fm impact parameters**
- **Central collisions→ sharper transition region+more time in dense region→ more dominant '*two peak structure*'**
- **Pheripheral collisions→ more variation in its shape+longer transition region→ *only broadened shoulder***

Invariant mass spectra of dileptons and Kaons

- **Effects of momentum cuts**
  - Cuts applied at the time of the decay
  - The effects of the cuts are dominant near the vacuum mass

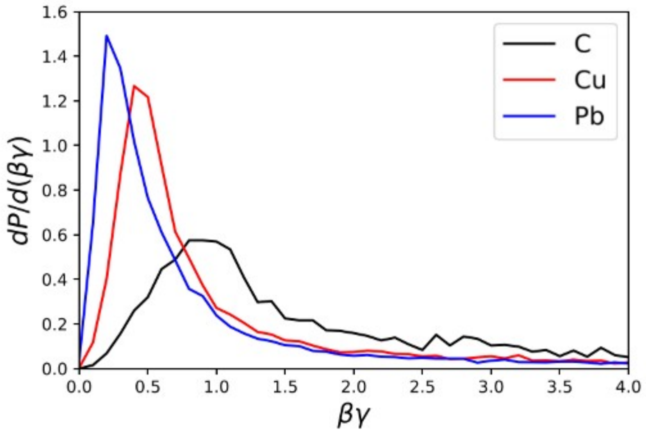


Fig. 9. The $\beta\gamma$ distributions of ϕ mesons in 30 GeV proton+C/Cu/Pb reactions at the time of their decay into K^+/K^- pairs.

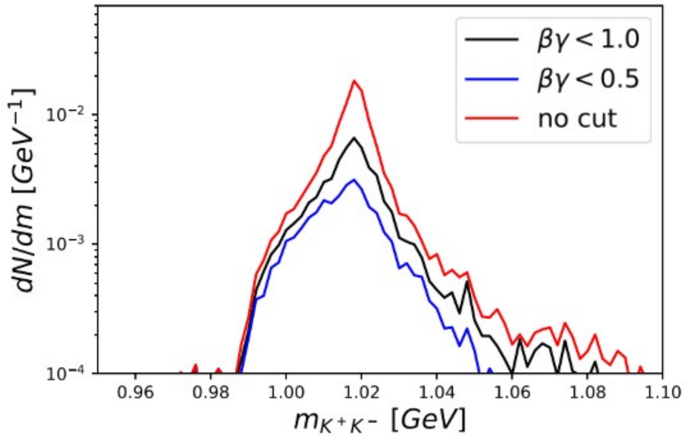
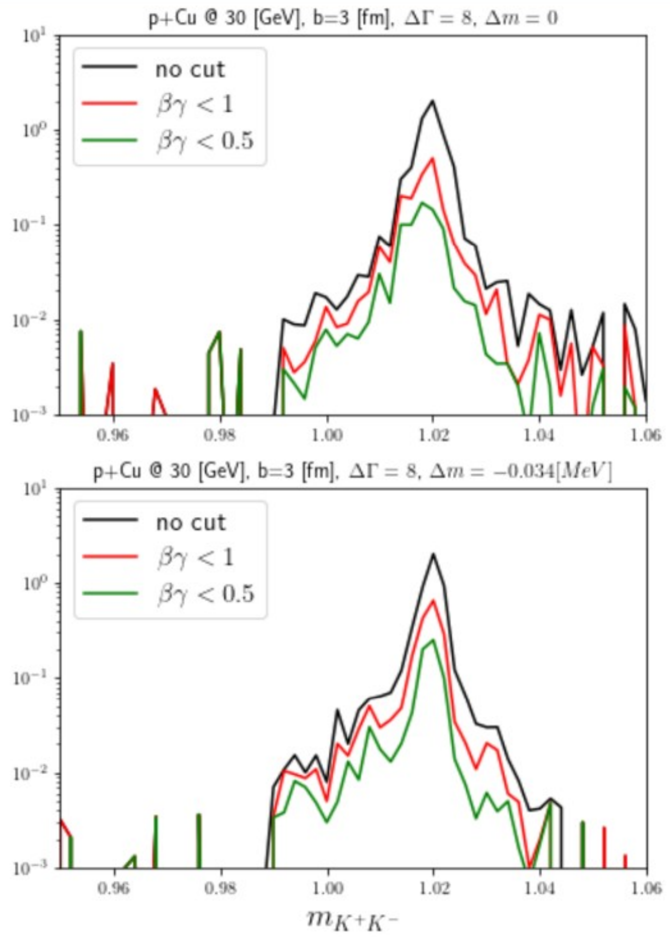
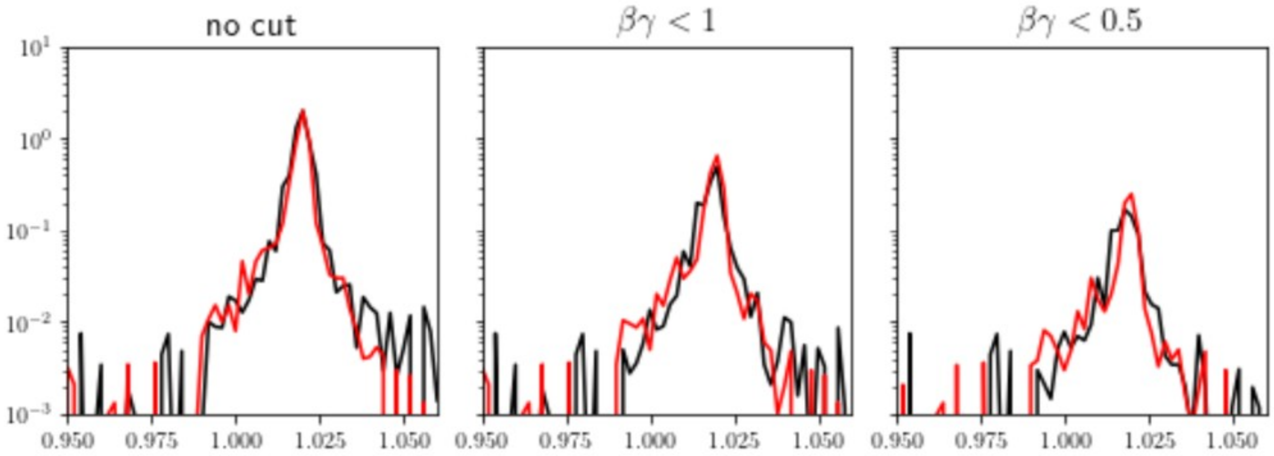


Fig. 10. The effects of different cuts on the ϕ velocity in p+Pb collisions at 30 GeV bombarding energies using the (M3) mean fields. The red curves show the case in which no cuts were applied, for reference.

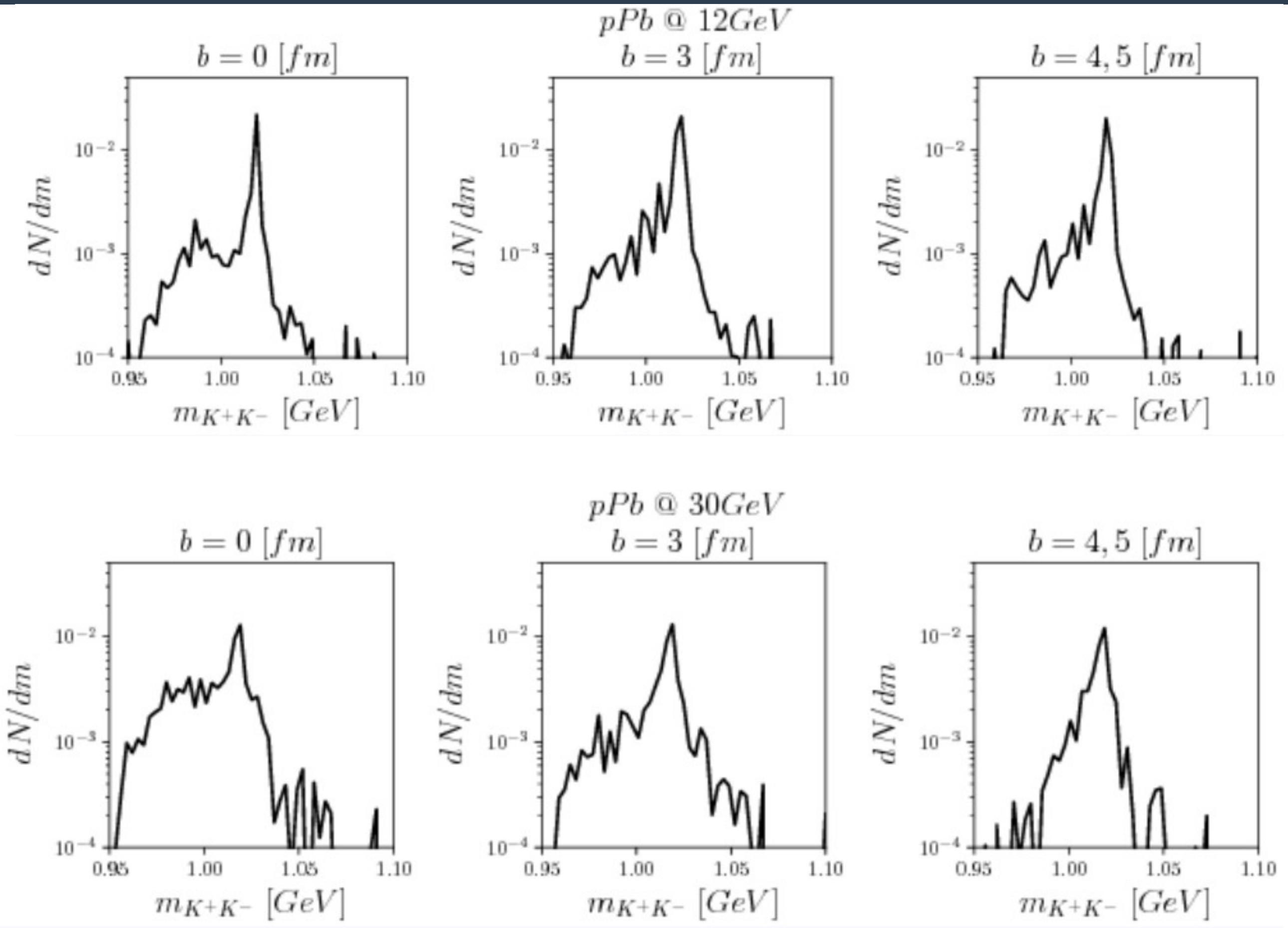
Width modification at fixed impact parameter



- **Parametrization of width broadening:**
  - $\Gamma = \Gamma_0 + \Gamma_0\,(\rho/\rho_0)\Delta\Gamma$



Impact parameter dependence



- **Lower energies and central collisions:**
  - More time in the dense region
  - ’Two peak’ structure (but only at very small impact parameters)
  - In practice b is integrated → ’two peak’ is smeared out

Conclusions

- The mass shift can be seen from the KK channels as well, but carefull analysis is needed.
- No ’two-peak’ structure observed, only a broadened shoulder.
- Good kaon mean fields and final state interactions are crucial to model the system
- Larger targets and more central collisions seems to be better to observe the mass shifts.