Biases in the coalescence parameters estimation

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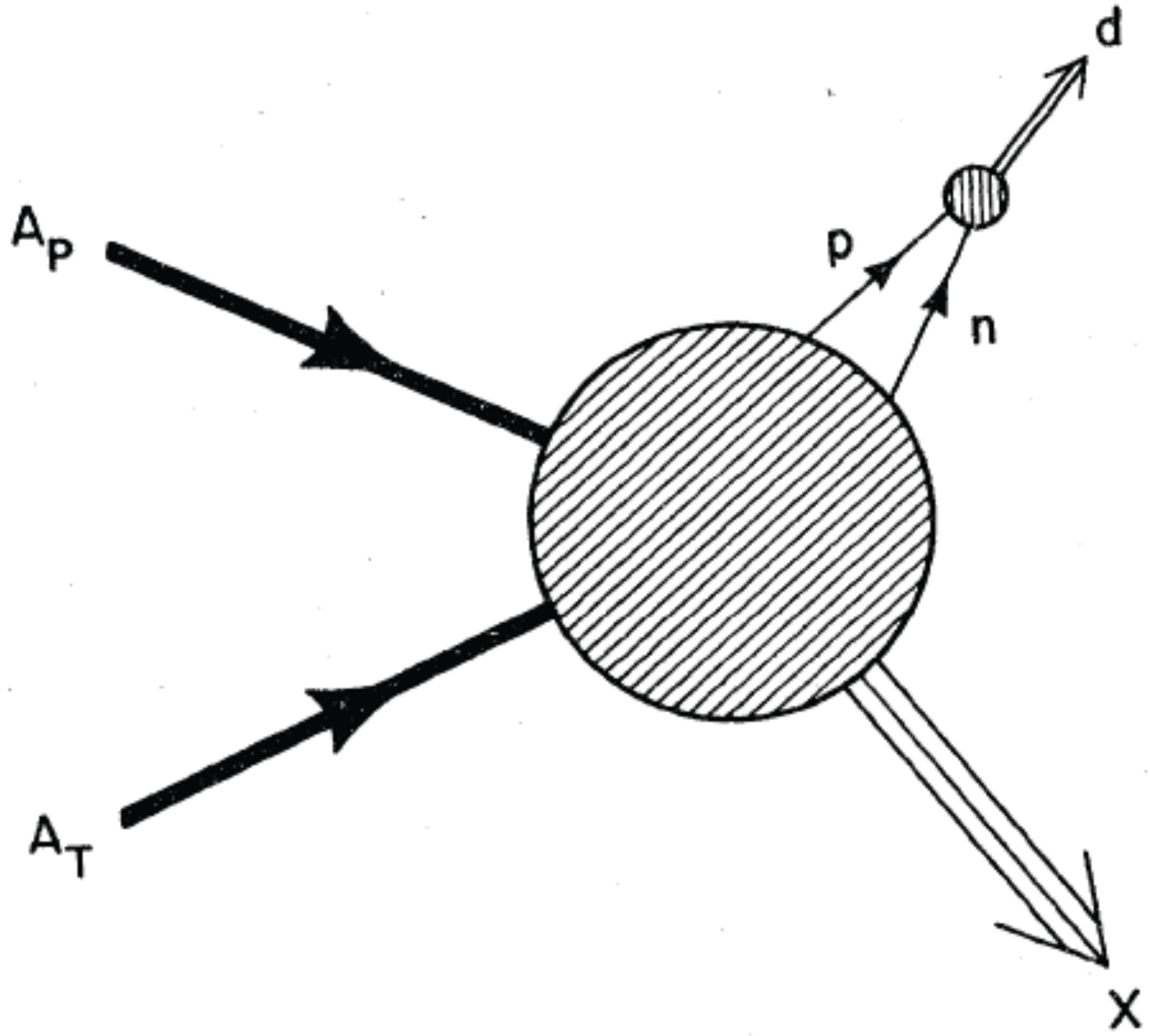
The coalescence model (again)

- If (anti-)baryons are close in phase space after the kinetic freeze-out they can form a (anti-)nucleus
- In heavy ion collisions after the chemical freeze-out (anti-)nuclei produced at the chemical freeze-out during the time span between the chemical freeze-out and the kinetic freeze-out.
  - might break up
  - might re-form with final state coalescence



J. I. Kapusta, Phys.Rev. C21, 1301 (1980)

The coalescence parameter

The coalescence parameter for a nucleus *i* with A nucleons connects nuclei and nucleons spectra:

$$E_i \frac{\mathrm{d}^3 N_i}{\mathrm{d}p_i^3} = B_A \left(E_p \frac{\mathrm{d}^3 N_p}{\mathrm{d}p_p^3} \right)^A \xrightarrow{\text{deuterons}} B_2 = E_d \frac{\mathrm{d}^3 N_d}{\mathrm{d}p_d^3} \left(E_p \frac{\mathrm{d}^3 N_p}{\mathrm{d}p_p^3} \right)^{-2}$$

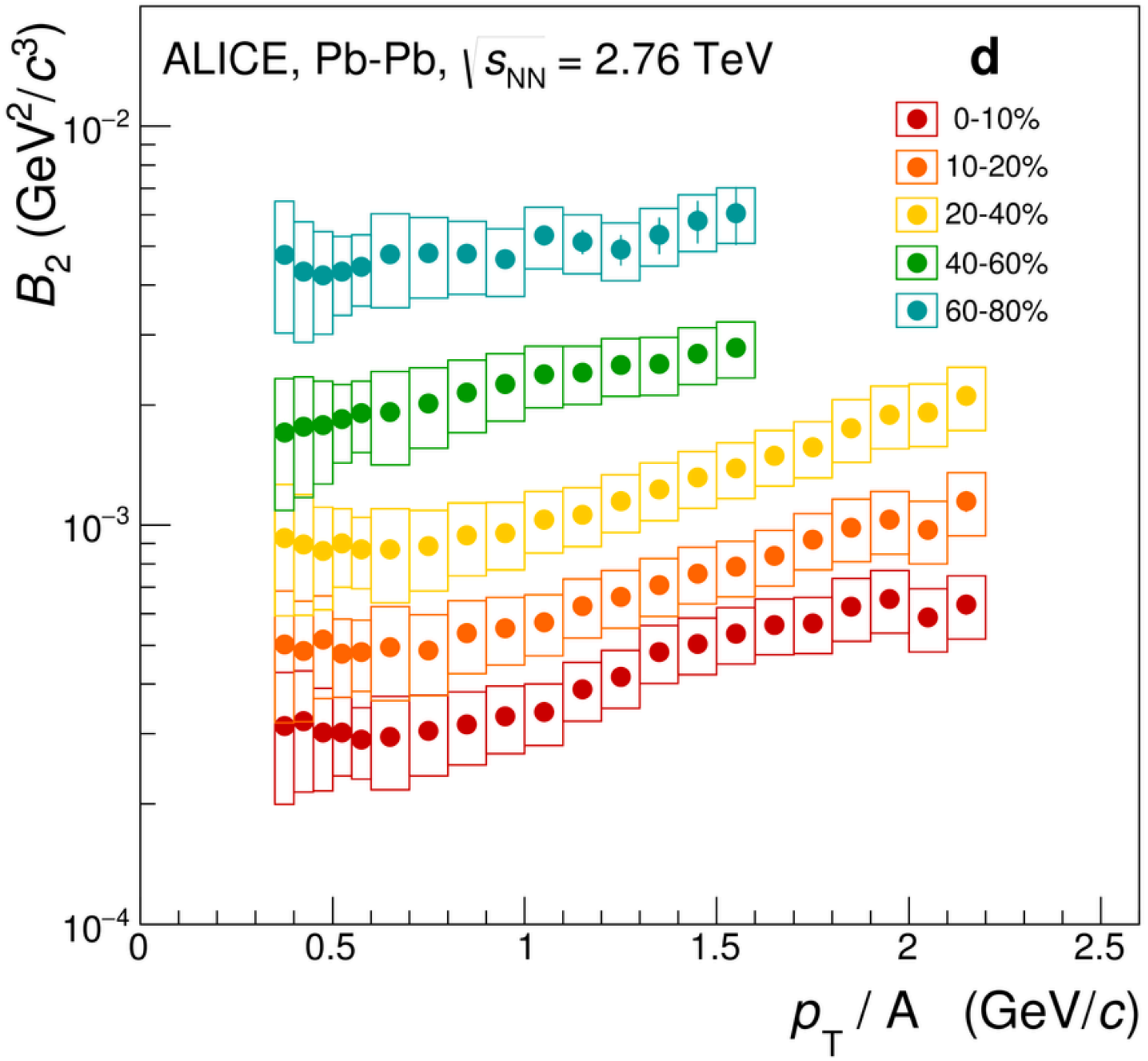
Ratio between the invariant spectrum of the nucleus and the product of the invariant spectra of the constituent baryons.

Experimentally we have to make two approximations:

- Instead of the neutron spectra (that we cannot measure) we use the proton ones
- We use the measured invariant spectra as we cannot access directly the nucleon spectra as they were before the nucleus formation
  - Negligible effect since nuclei are *less than* 1/300 of produced protons

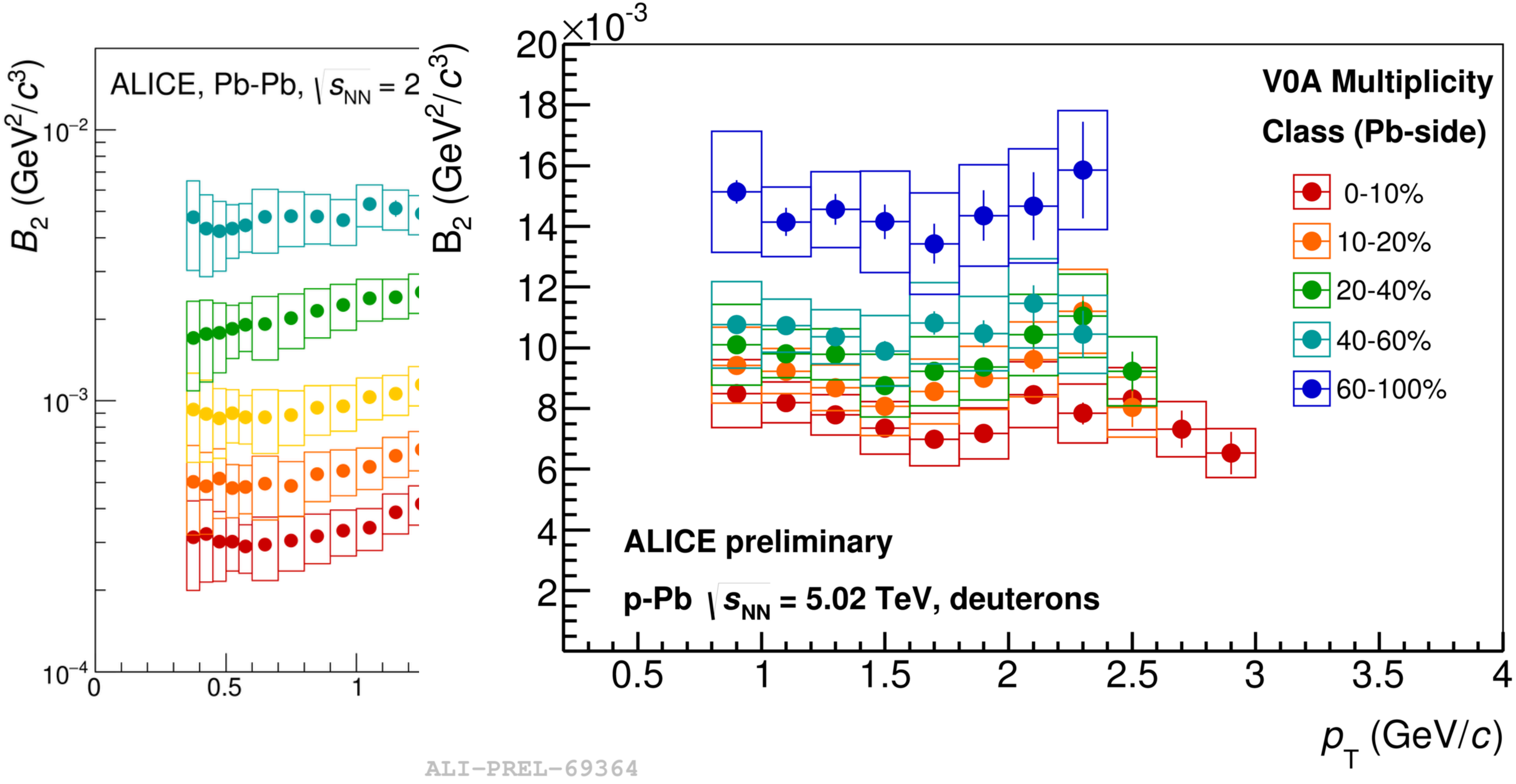
In the most simple coalescence formulations the B_A value is momentum independent

B_2 measurements at the LHC



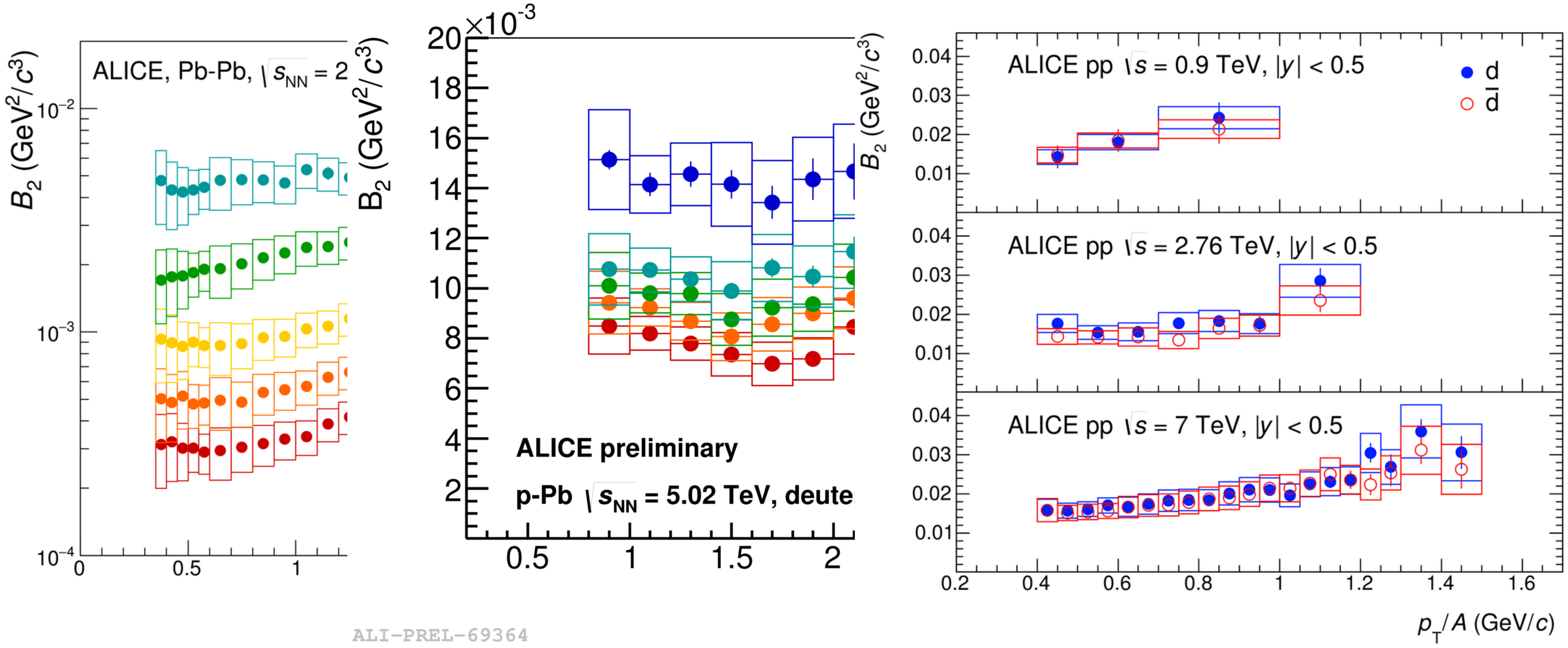
Pb-Pb: clear evolution with centrality (system size) and p_T! Simple coalescence picture does not hold here, however the B_2 seems to get flatter in peripheral collision.

B_2 measurements at the LHC



p-Pb: clear evolution with multiplicity (system size) but p_T dependence. Simple coalescence picture seems to hold here.

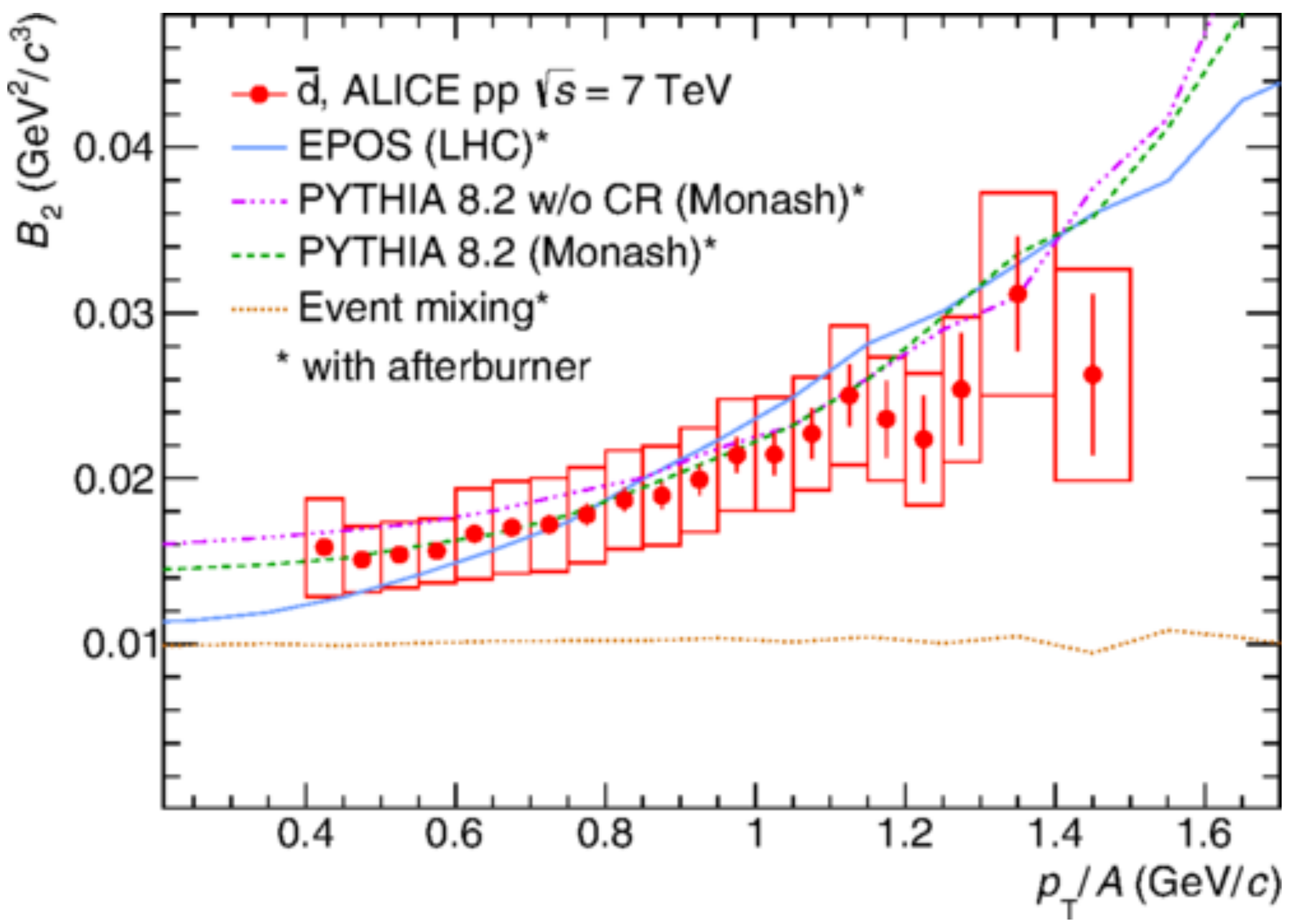
B_2 measurements at the LHC

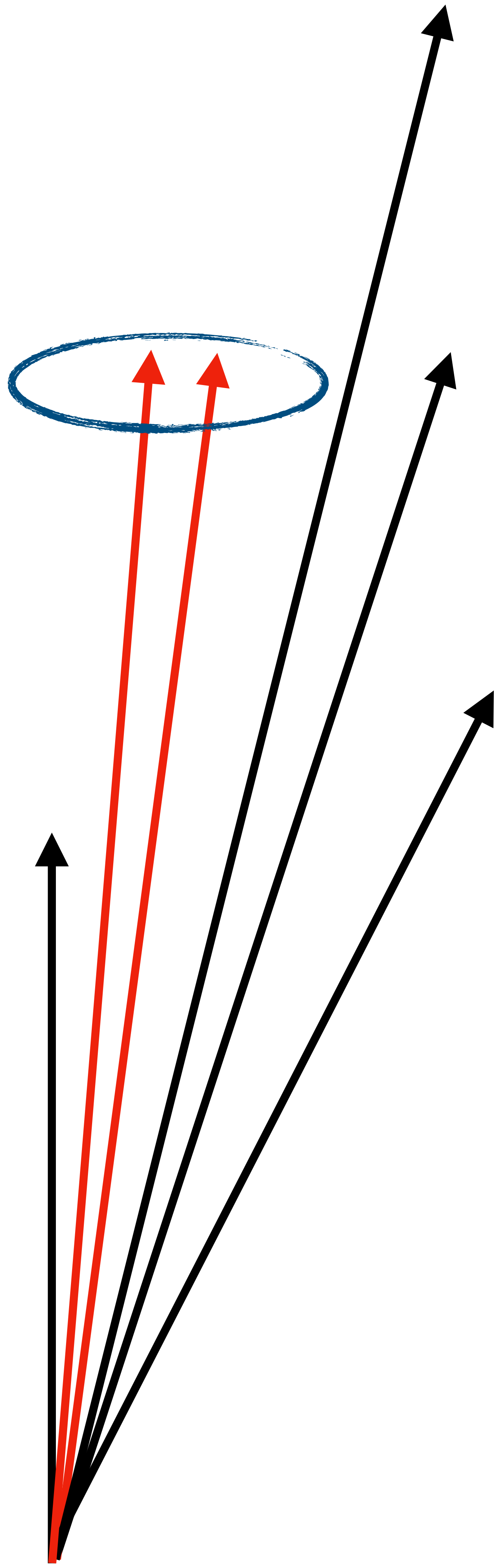


pp: clear p_T dependence. Who turned off coalescence?

Jets: a possible explanation

- Particles in the jet cone are close in phase space!
- If inside a jet it is easier to form a nucleus then this might explain why the B_2 is higher at high transverse momentum





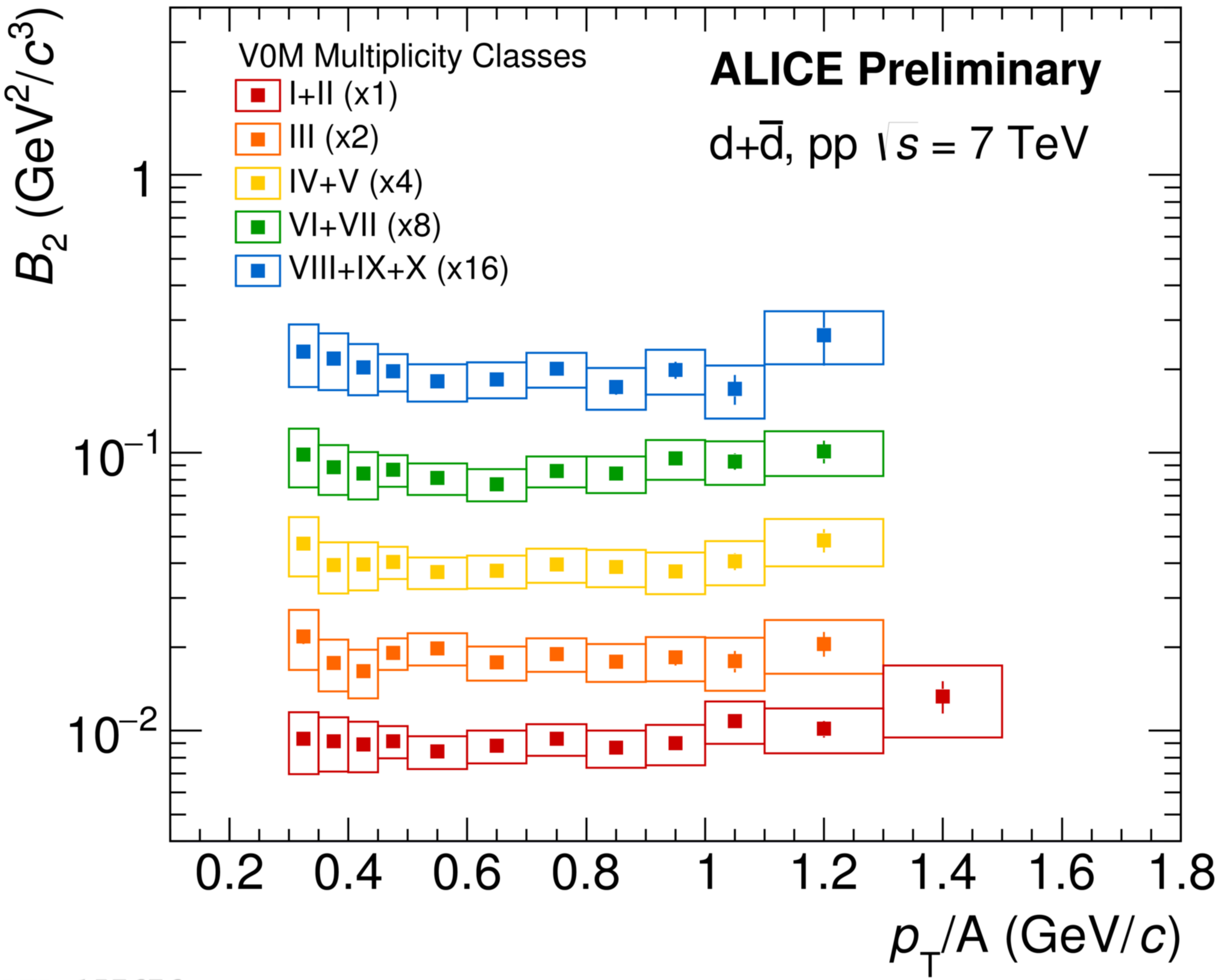
A simple coalescence afterburner on top of PYTHIA and EPOS reproduce qualitatively well the feature of the measured B_2

- But why we don't see the effect of jets in p-Pb collisions?

Coalescence strikes back

- B_2 computed in pp collisions as a function of multiplicity is momentum independent!
- The value of the B_2 does not show any significant variation with multiplicity
- No significant energy dependence

This is the portrait of coalescence in its simplest formulation



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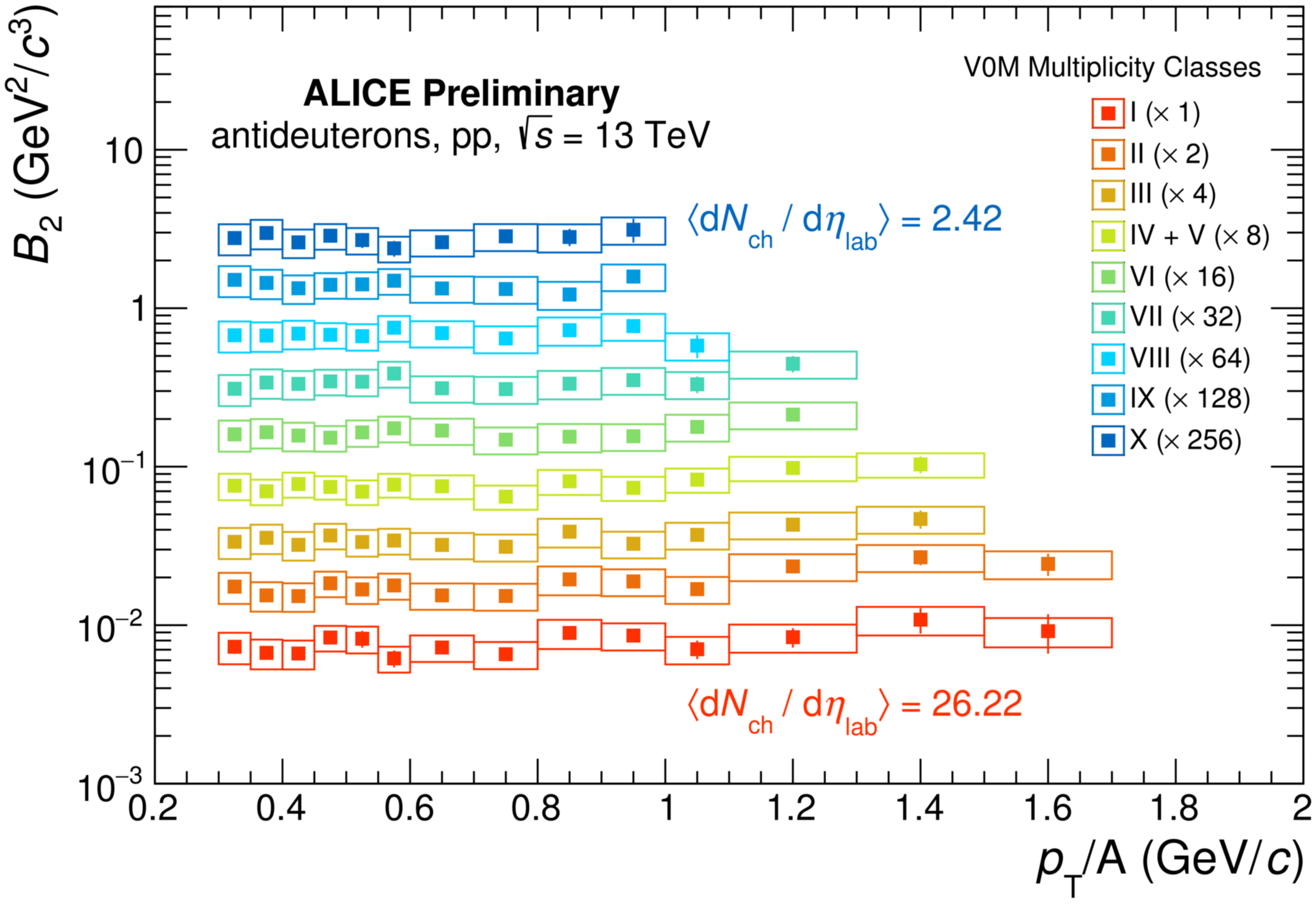

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Reconcile pp MB to pp vs multiplicity

In pp vs multiplicity the coalescence picture works nicely, thus for each multiplicity bin *i* the following formula holds for every momentum bin we measure:

$$\left(E_d \frac{\mathrm{d}^3 N_d}{\mathrm{d}p_d^3}\right)_i = B_2^* \left(E_p \frac{\mathrm{d}^3 N_p}{\mathrm{d}p_p^3}\right)_i^2 \xrightarrow[\textbf{notation}]{\textbf{change of}} S_{d(i)} = B_2^* S_{p(i)}^2$$

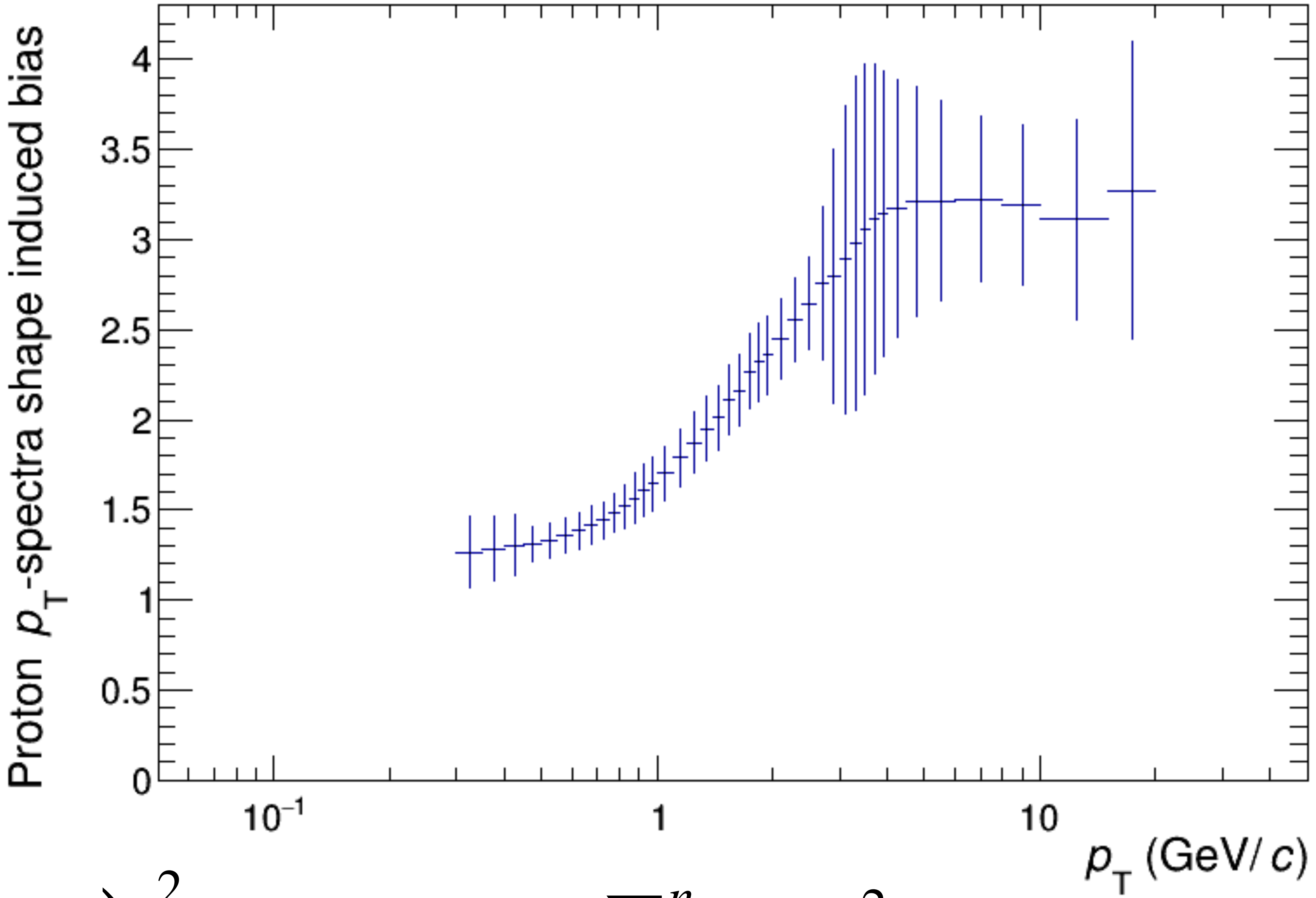
where B^*_2 is the coalescence parameter measured in mult. bins (~0.01 GeV^2/c^3)
The deuteron spectrum in MB collision is the weighted average of the spectra measured in multiplicity intervals:

$$S_d = \frac{1}{N} \sum_{i=0}^{n} N_i S_{d(i)} = \frac{1}{N} \sum_{i=0}^{n} B_2^* N_i S_{p(i)}^2 = \frac{B_2^*}{N} \sum_{i=0}^{n} N_i S_{p(i)}^2$$

Reconcile pp MB to pp vs multiplicity

When we compute the coalescence parameter in pp MB we use the B_2 definition:

$$S_d = B_2 S_p^2 = B_2 \left(\frac{1}{N} \sum_{i=0}^{n} N_i S_{p(i)} \right)^2$$



Comparing this expression of the deuteron spectra with the one we obtained starting from the multiplicity dependent analysis we obtain:

$$\frac{B_2^*}{N} \sum_{i=0}^{n} N_i S_{p(i)}^2 = B_2 \left(\frac{1}{N} \sum_{i=0}^{n} N_i S_{p(i)} \right)^2 \rightarrow B_2 = \frac{B_2^* N \sum_{i=0}^{n} N_i S_{p(i)}^2}{\left(\sum_{i=0}^{n} N_i S_{p(i)} \right)^2}$$

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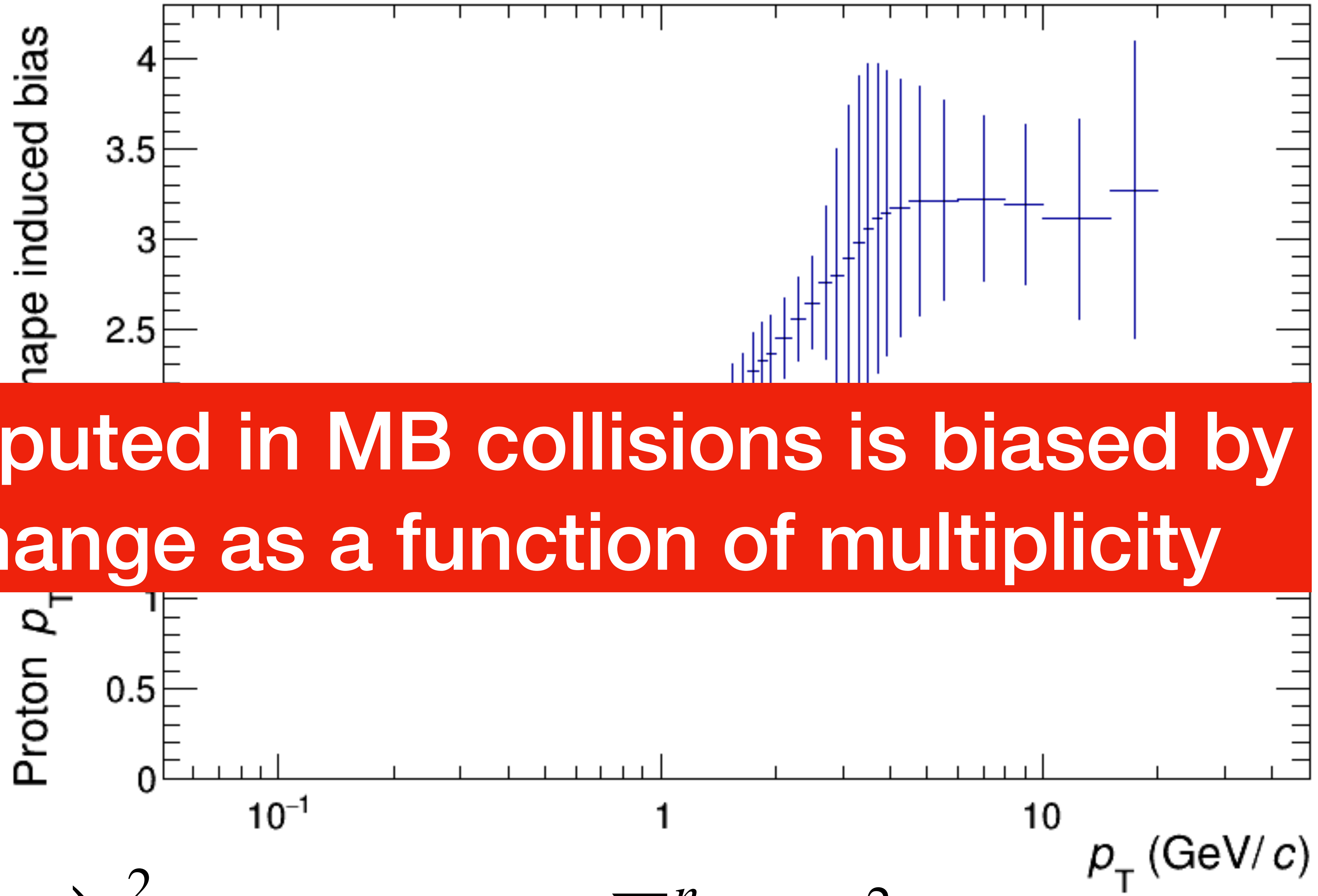

The coalescence parameter computed in MB collisions is biased by the proton-p_T spectra shape change as a function of multiplicity

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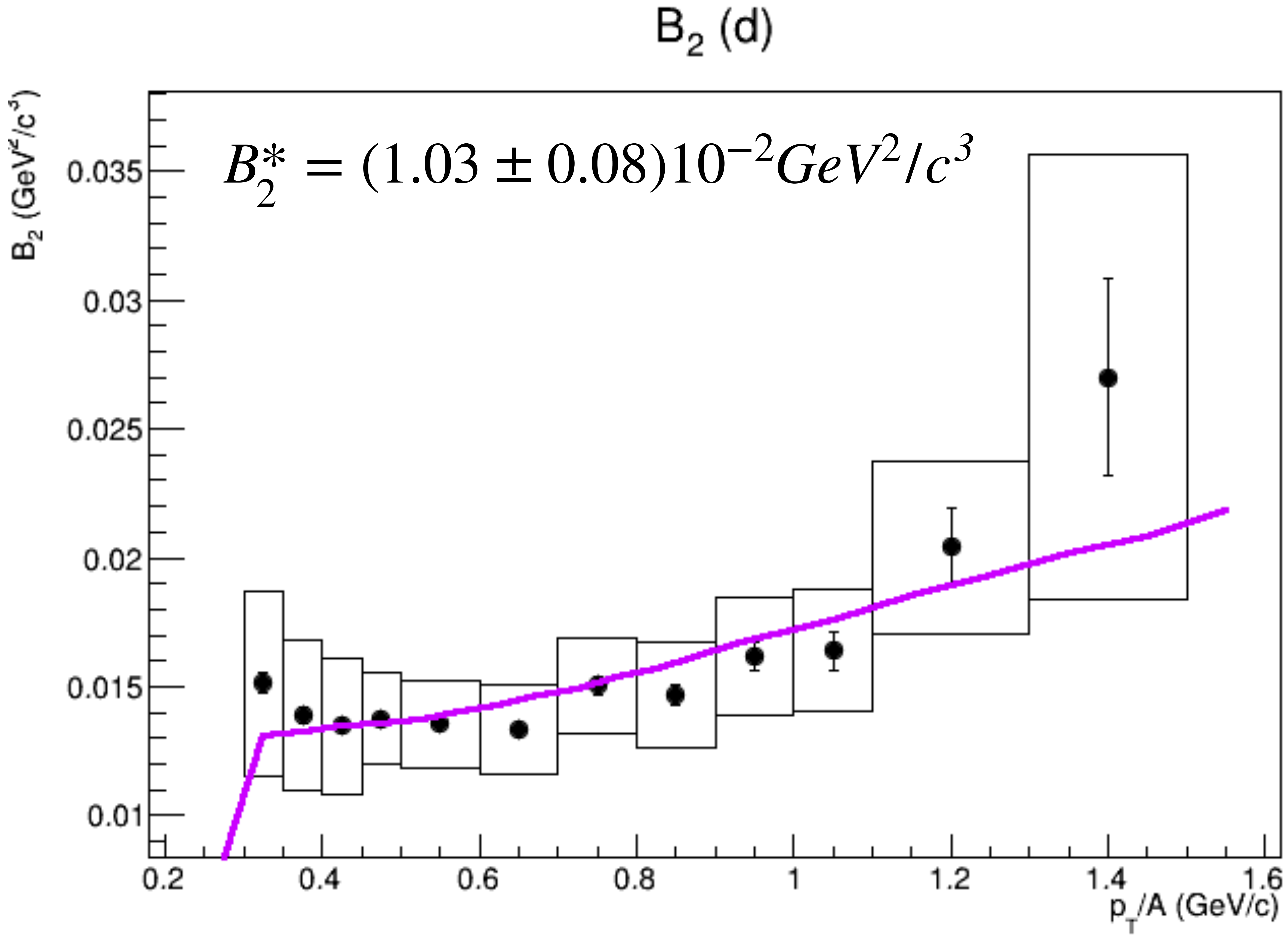
Reconcile pp MB to pp vs multiplicity

We can then compute the expected B^*_2 by fitting the MB B_2 with the formula

$$S_d = B_2 S_p^2 = B_2 \left(\frac{1}{N} \sum_{i=0}^{n} N_i S_{p(i)} \right)^2$$

and you get a B^*_2 value compatible with the measured one.



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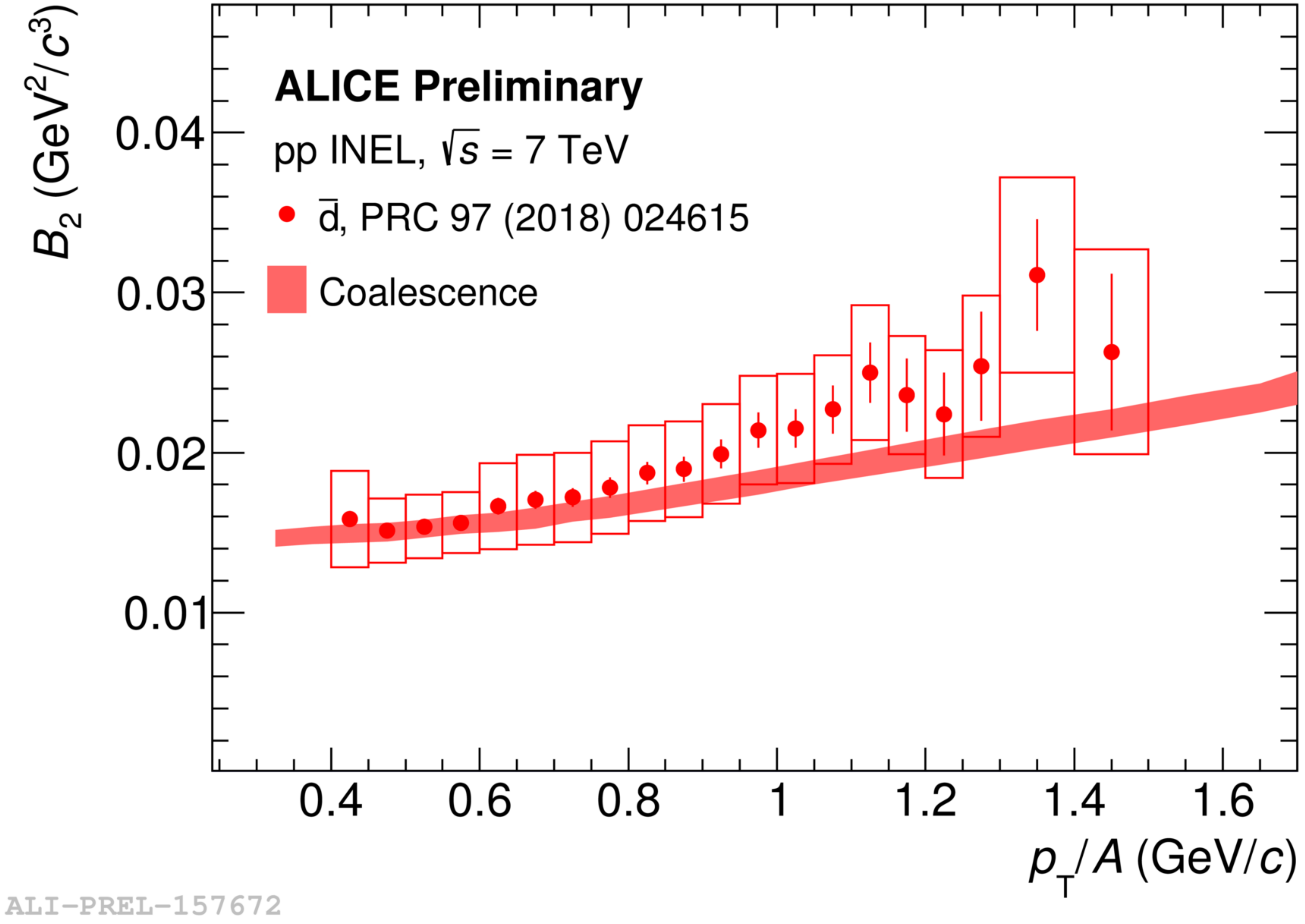
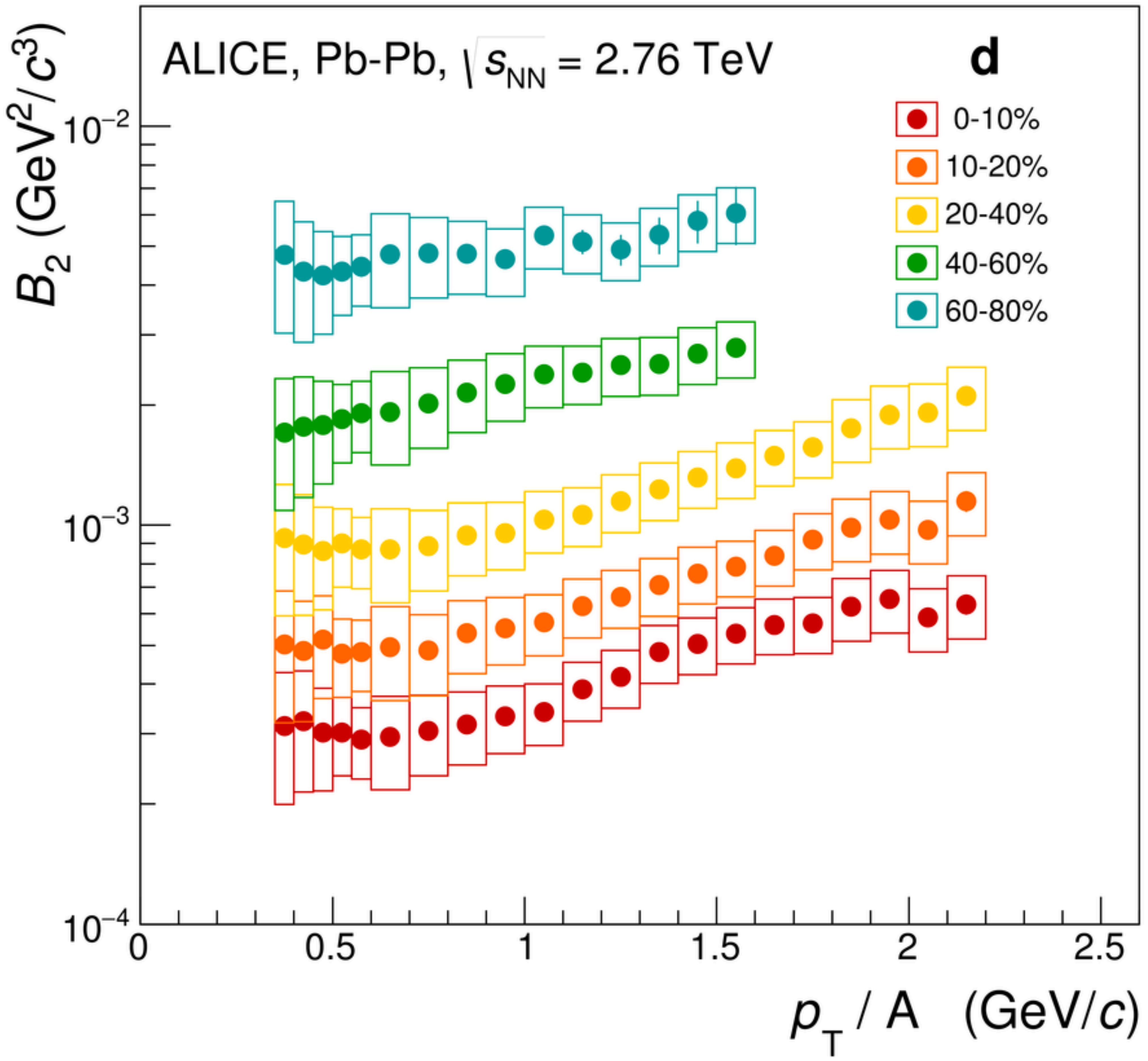
If one does the inverse operation starting from the measured B^*_2 to compute the MB B_2 you also reproduce it correctly.



What about Pb-Pb?



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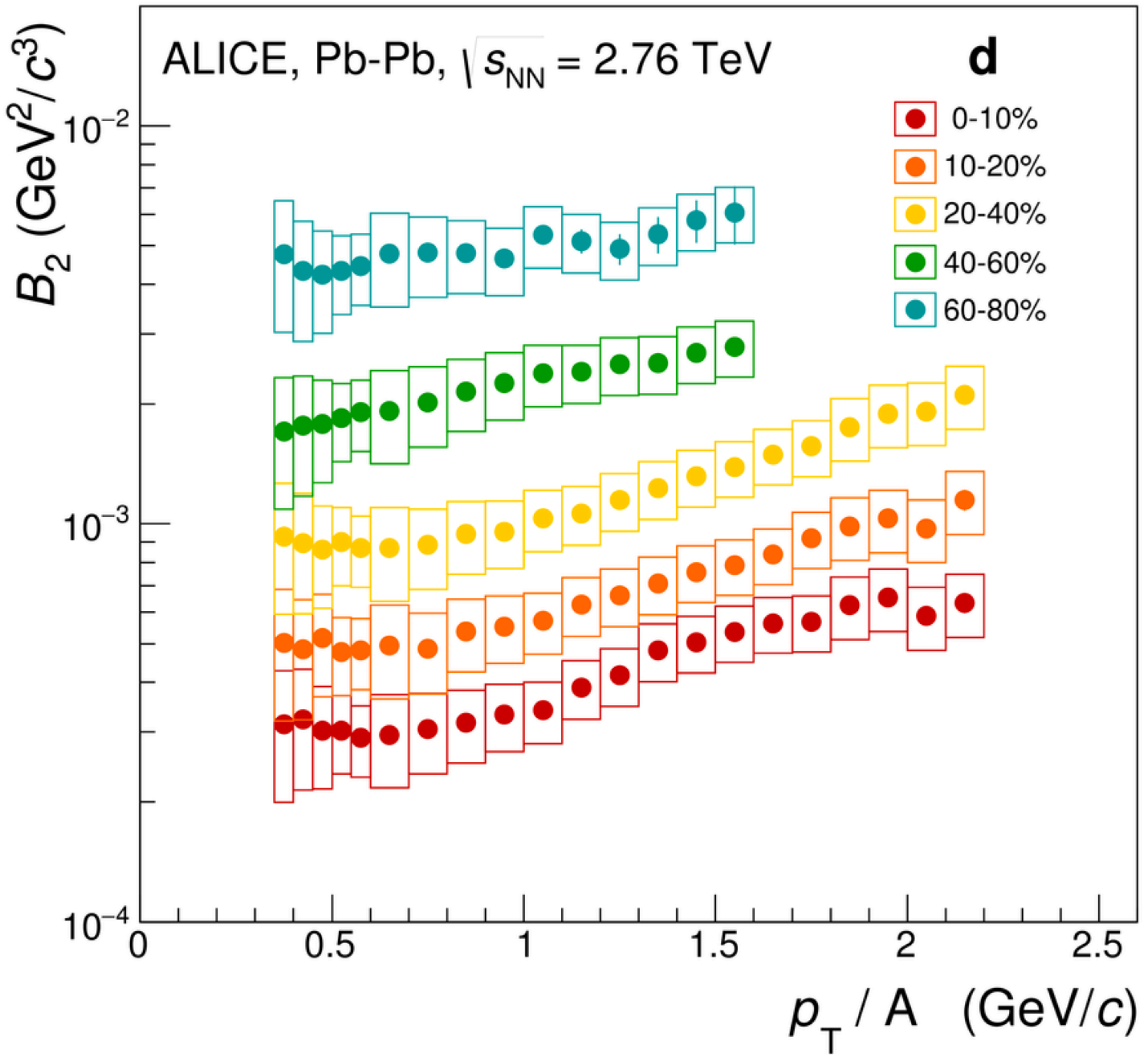

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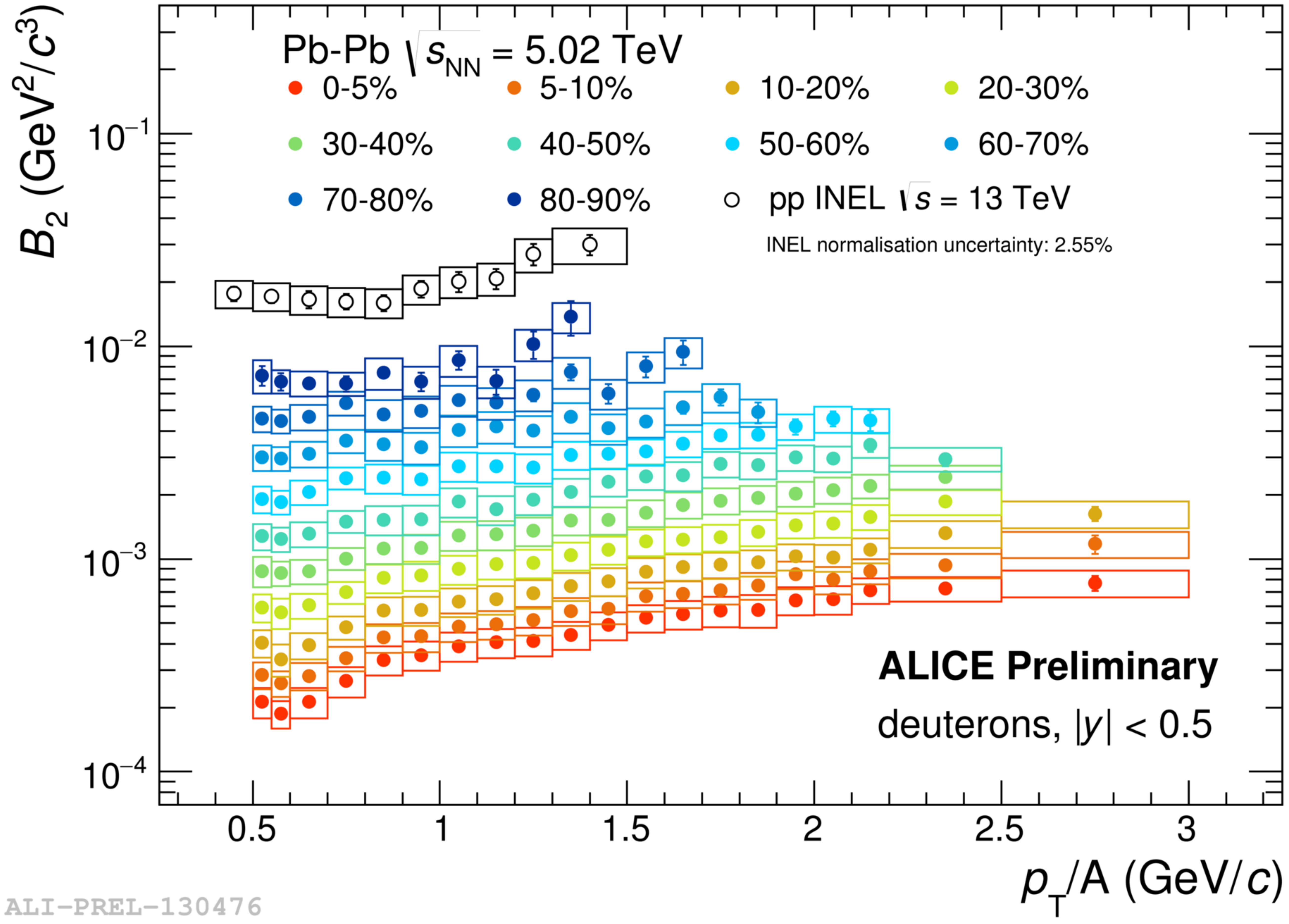
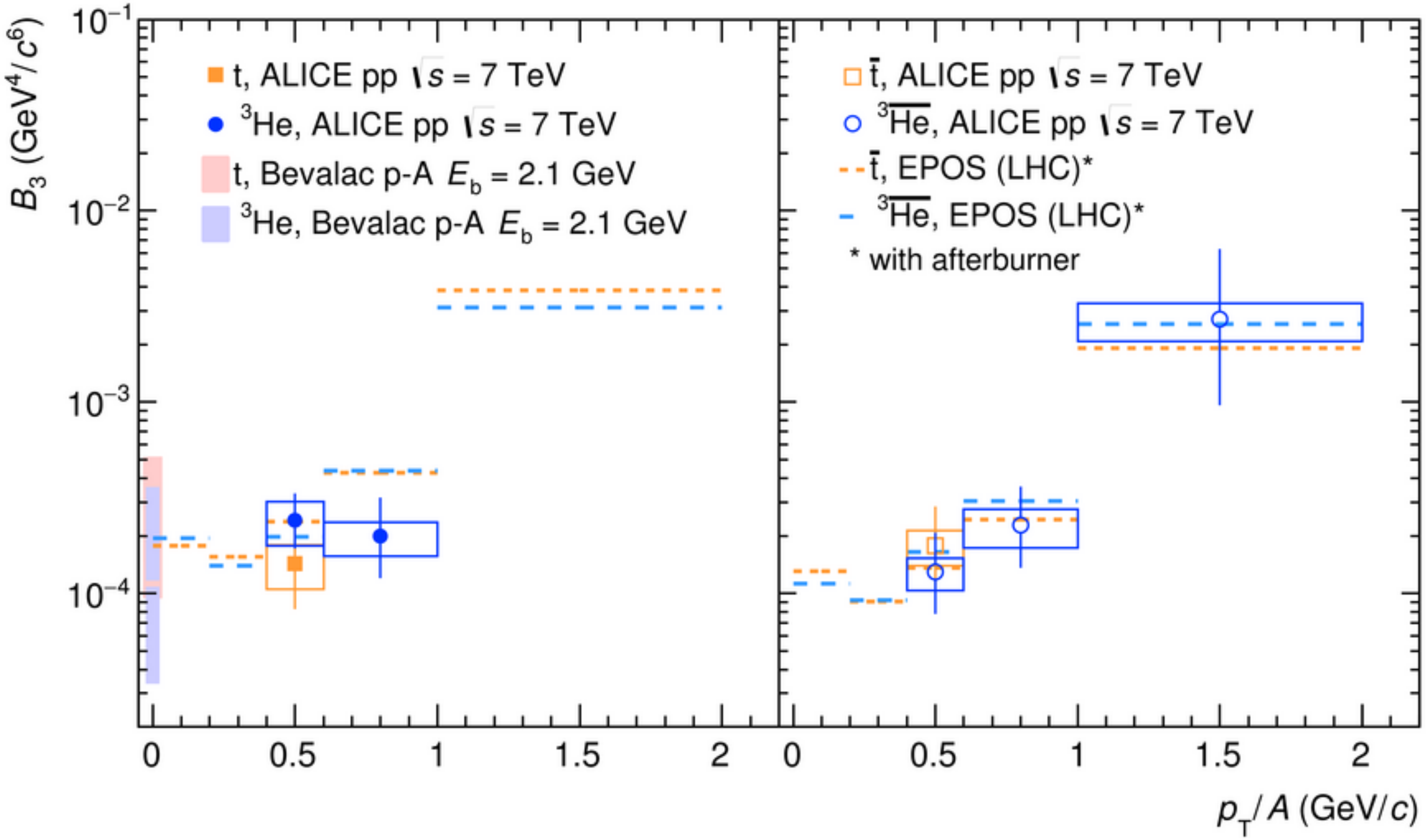


➡ Even in finer centrality bins the p_T dependence stays the same

What about heavier nuclei?



- ➡ Finer multiplicity bins are required to rule out any effect due to the proton spectra shape.
- ➡ Already in most central p-Pb and Pb-Pb B_3 looks genuinely rising

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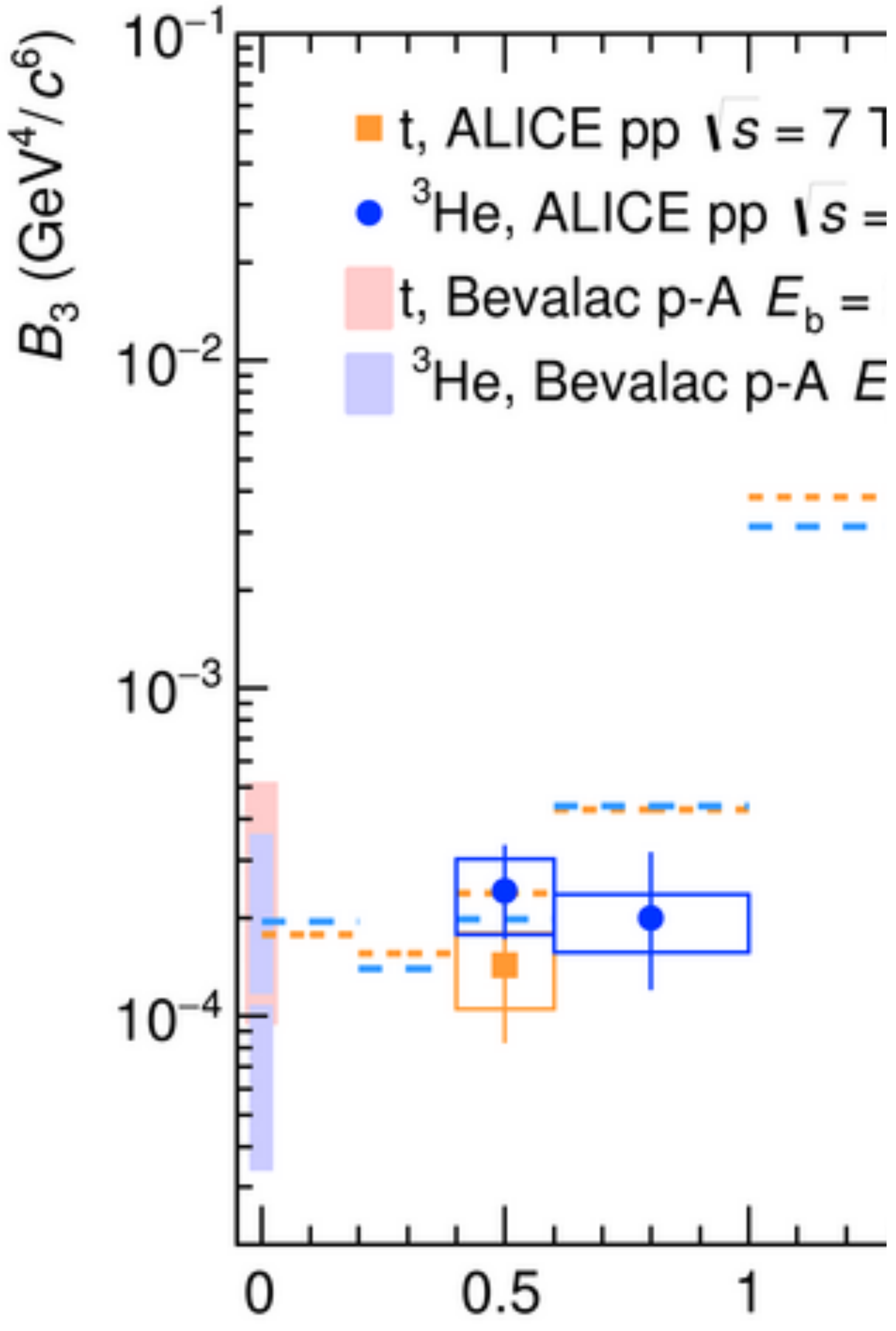

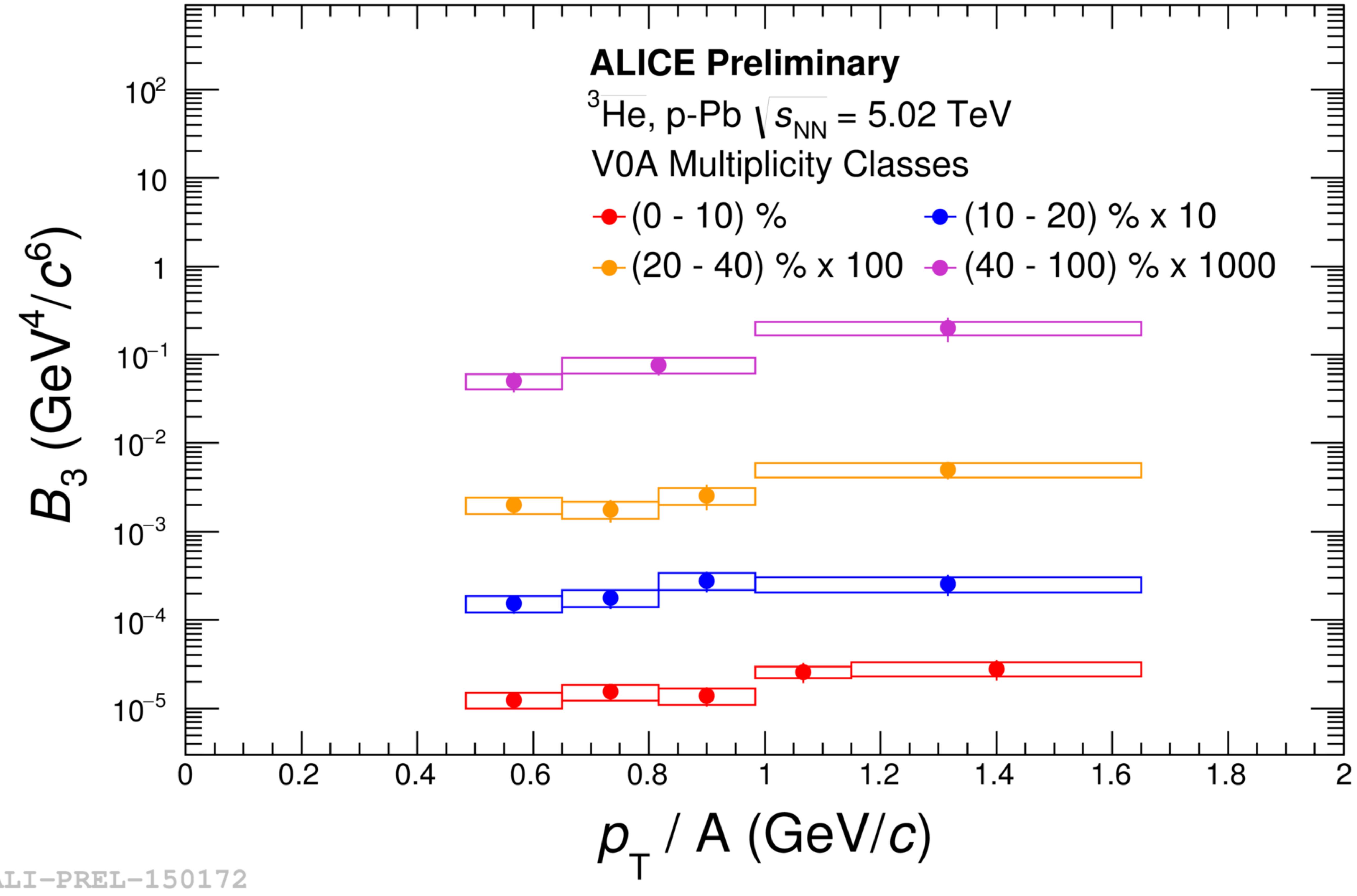

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Conclusions

- The measurement of the B_2 is sensitive to the variation of the proton spectra in the sample you choose for the measurement
- Not only multiplicity affect the measurement: sphericity, number of jets…
  - More differential analyses are required in the future!
- Jet role is still not clear: only direct measurement of nuclei in jets will tell us if their production is enhanced in the jet cone
- The rise of the B_2 (and B_3 in most central collision) seems genuine in Pb-Pb

Thanks a lot to M. Colocci for the fruitful discussion.