Production of Heavy Flavour Decay Muons using Angantyr Model in PYTHIA8 at LHC energies

by

Md Samsul Islam

Saha Institute of Nuclear Physics

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Outline

Motivation

Angantyr Model: Heavy ion collisions using Pythia8 event generators.

Glauber Monte-Carlo: calculate centrality.

Results: **H**eavy-flavour decay muon (HFM) production in pp and Heavy-Ion (Pb-Pb, Xe-Xe, O-O) collisions.

Measurement of R_{AA}.

Summary and **O**utlook

Ref: Int. J. Mod. Phys. E 31 (2022) 2250007 [DOI:10.1142/S0218301322500070]

Motivation

Heavy quarks (i.e, charm and bottom) are produced at the very early stage of high energy nucleon-nucleon and heavy-ion collisions mainly through initial hard parton-parton scattering with large momentum transfer (Q^2).

In relativistic heavy-ion collisions, the heavy quarks are produced much before the formation of deconfined medium consisting of quarks and gluons called quark-gluon plasma (QGP).

Therefore, the heavy quarks experience full evolution while propagating through the produced medium and lose energy by successive elastic and inealstic collisions in the fireball

The study of Heavy Flavour (charm and beauty) production in proton-proton (pp) collisions at LHC energy regime provides an investigation of pQCD calculations.

This measurement of heavy flavour serves as a baseline for the same measurement in heavy-ion collisions also.

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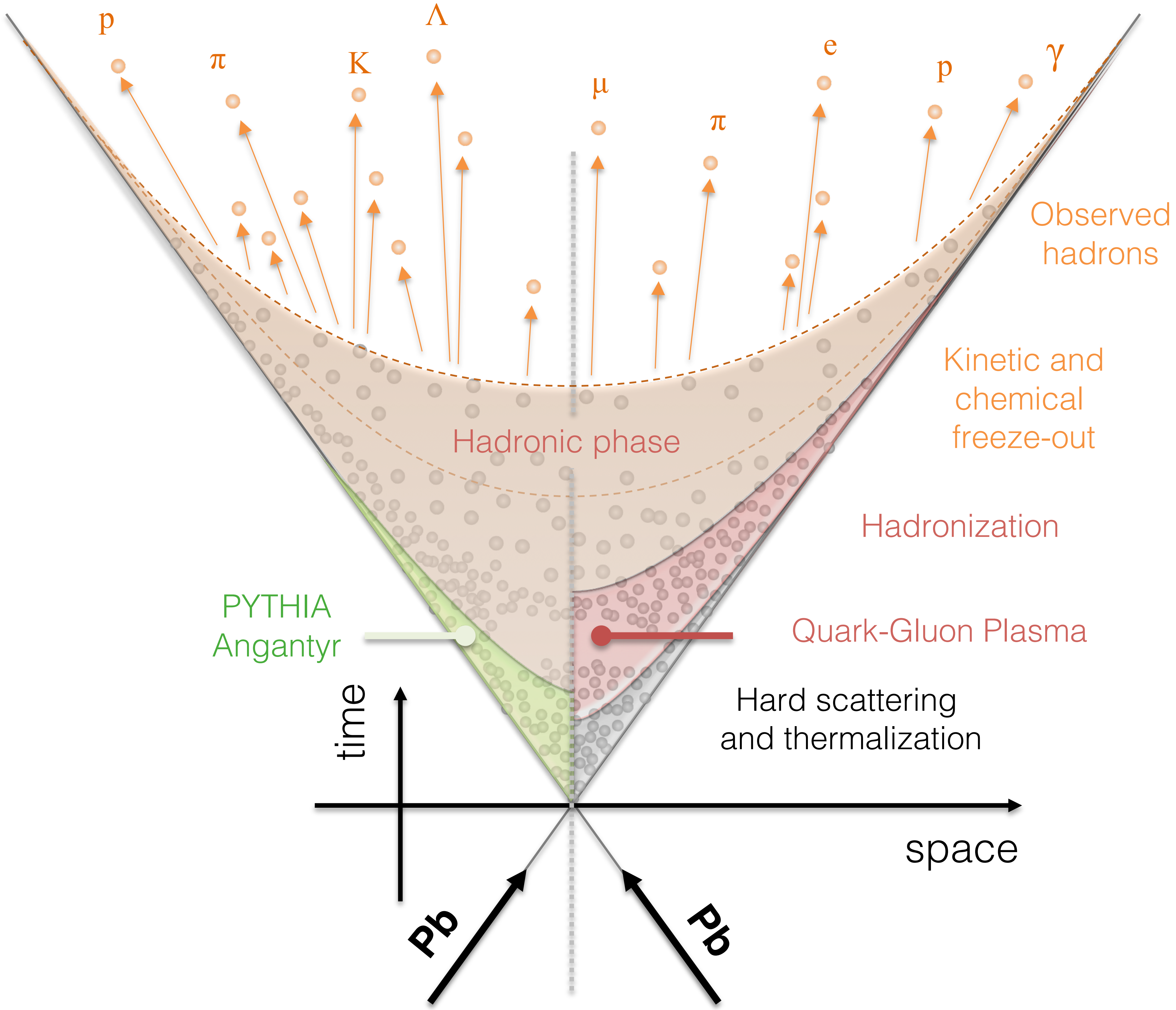
Observations of features similar to Heavy-ion collisions for high multiplicity pp events at LHC=>

a) near side ridge [Phys. Lett. B 765 (2017) 193]

b) strangeness enhancement [Nature Phys. 13 (2017) 535]

=> Understanding the phenomenology of hadronization mechanisms, huge kinetic energy is involved irrespective of collision system sizes => a common phenomenological approach to study both pp and heavy-ion collision in a single framework.

Angantyr model in PYTHIA8



Ref: A. V. da Silva, W. M. Serenone, D. Dobrigkeit Chinellato, J. Takahashi and C. Bierlich, arXiv:2002.10236

Angantyr model extrapolates the pp dynamics into heavy-ion collisions using the PYTHIA8 event generator.

Model doesn't include any mechanism of QGP medium believed to be produced in A-A collision.

In a pp collision, MPIs are generated under the assumption that every partonic interactions are almost independent.

In a heavy-ion collision, each projectile nucleon can interact with several target nucleons and the number of participant nucleons determined by Glauber model.

Angantyr/PYTHIA8 added several algorithms to distinguish different types of nucleon-nucleon interactions such as elastic, diffractive and absorptive.

This model is supposed to well describe the final-state properties such as multiplicity and transverse momentum distributions in both pA and AA collisions.

May serve as a baseline for the understanding of the non-collective background to the collective behaviour.

Heavy-flavor decay muon production in proton–proton and heavy-ion collisions using the Angantyr model at LHC energies

Measurement of heavy flavor hadron decay muon (HFM) production from small to heavy mass systems in a single frame using Angantyr model with PYTHIA8.

Aim is to illustrate how well the extrapolation of pp dynamics into heavy-ions can reproduce the experimental data for the study of HFM in A-A collisions.

Colliding systems: p-p, O-O, Xe-Xe, Pb-Pb

Wide range of energies ($\sqrt{s}$): **p-p**=> 2.76, 5.02, 7 and 13 TeV ; **O-O**=> 6.37 TeV; **Xe-Xe**=>5.44 TeV; **Pb-Pb**=>2.76, 5.02 TeV

HFM p_T -spectra are simulated for all collisional systems. However, the rapidity (y)-distributions are obtained only for pp collisions and compared with the published ALICE data.

For more quantitative model-to-data comparison, Nuclear Modification Factor (R_{AA}) calculated in Pb-Pb at $\sqrt{s}$ = 2.76 and 5.02 TeV.

A prediction is done for HFM production in O-O collisions at $\sqrt{s}$ = 6.37 TeV, to be carried out in ALICE Run 3.

Geometric relation between centrality and the impact parameter using MCG in relativistic heavy-ion collisions.

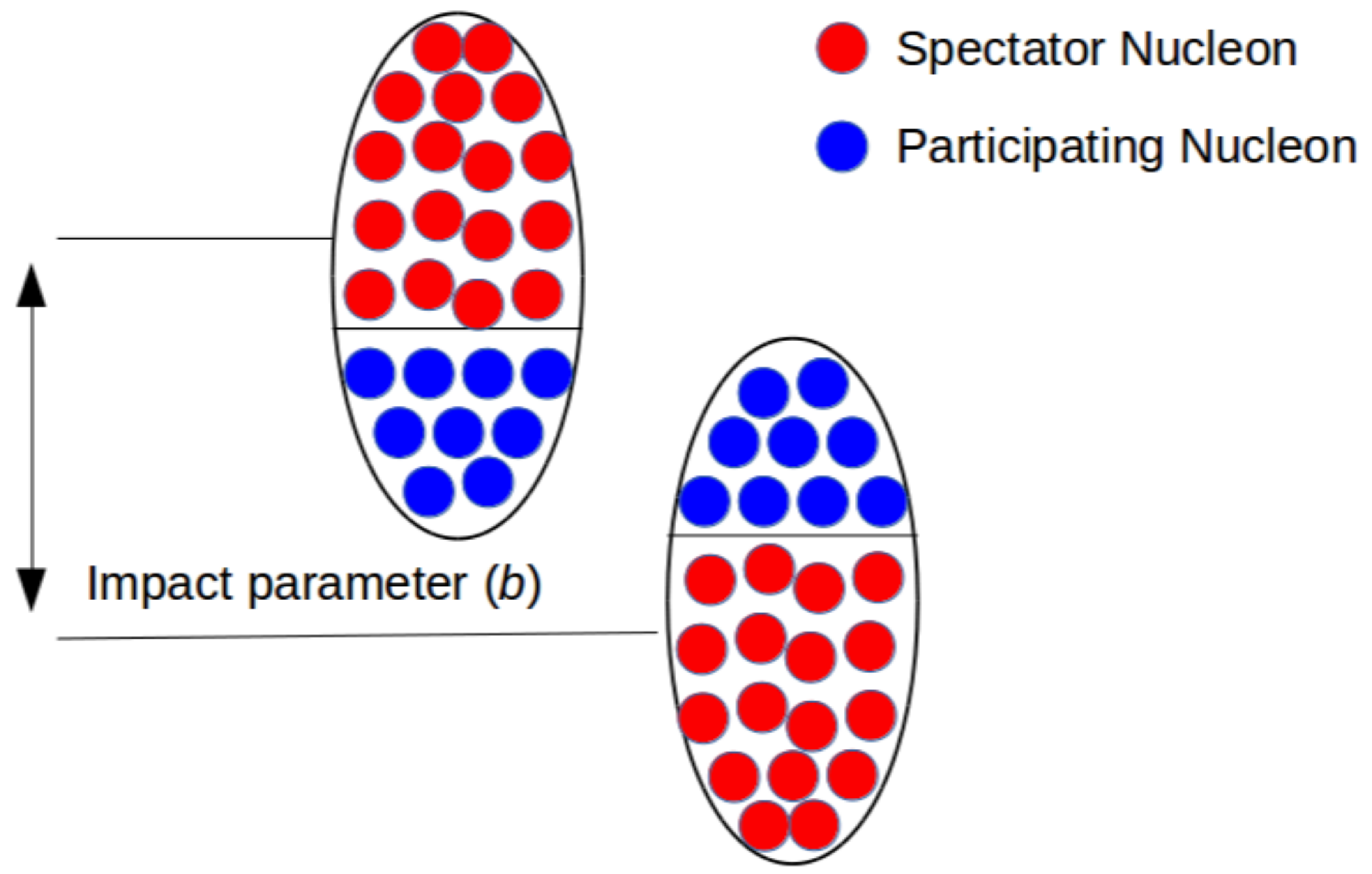
In heavy-ion collisions, quantities like impact parameter (b), number of participating nucleons in the collision (N_{part}), nuclear overlap function (T_{AA}), number of binary nucleon-nucleon collisions (N_{coll}) etc are measured by Glauber Monte Carlo (MC) calculations.

In the Glauber MC based models, individual nucleons are stochastically distributed event by event. Finally, the collisional properties are calculated by averaging over many events.

The centrality of a collision is measured by giving a sharp cut in the impact parameter distribution.

$$c_i \simeq \frac{\pi b_i^2}{\sigma_{AA}} \ , b_i < \bar{R}$$

where σ_{AA} is the total inelastic nucleus-nucleus cross-section and $\bar{R}$ is the sum of the radii of the colliding nuclei.



Comparison of mean of Npart (⟨Npart⟩ ± rms) in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 and 5.02TeV and in Xe–Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV obtained from MCG, Angantyr (this work) and ALICE

In Angantyr simulation, a centrality class is defined by applying a sharp cut on $< N_{part} >$

Centrality	$\langle N_{\rm part}\rangle_{\rm Pb–Pb}$						$\langle N_{\rm part}\rangle_{\rm Xe–Xe}$		
	2.76 TeV			5.02 TeV			5.44 TeV		
	MCG	ALICE	Angantyr	MCG	ALICE	Angantyr	MCG	ALICE	Angantyr
0–5%	381.2 ± 17.1	381.5 ± 18	380.3 ± 14.5	383.9 ± 16.5	383.4 ± 17.8	383.6 ± 14.0	237.3 ± 9.9	235.8 ± 11	236.6 ± 8.3
5–10%	327.8 ± 17.9	327.8 ± 20	327.9 ± 15.6	331.7 ± 17.8	331.2 ± 19.6	331.9 ± 15.6	207.0 ± 11.6	206.7 ± 13	206.2 ± 9.2
10–20%	258.5 ± 26.9	259.3 ± 27	258.0 ± 23.9	262.7 ± 27.0	262 ± 27.2	262.1 ± 23.9	164.8 ± 17.8	164.8 ± 18	163.4 ± 15.0
20–30%	184.3 ± 22.4	186.5 ± 21	183.4 ± 19.3	188.2 ± 22.6	187.9 ± 21.6	186.9 ± 19.6	117.84 ± 15.6	118.4 ± 14	115.5 ± 12.7
30–40%	127.2 ± 18.8	130.1 ± 17	126.4 ± 13.8	130.5 ± 19.1	130.8 ± 17	129.4 ± 13.8	81.4 ± 13.8	82.2 ± 11	78.8 ± 8.7
40–50%	83.8 ± 15.9	86.7 ± 13	82.4 ± 11.5	86.5 ± 16.2	87.1 ± 13.2	84.9 ± 11.8	53.8 ± 12.1	54.6 ± 8.8	50.7 ± 7.5
50–60%	51.8 ± 13.3	54.3 ± 9.6	50.9 ± 6.9	53.8 ± 13.6	54.3 ± 9.9	52.3 ± 7.2	33.5 ± 10.3	34.1 ± 6.5	30.6 ± 4.3
60–70%	29.4 ± 10.8	31 ± 6.9	28.7 ± 5.8	30.8 ± 10.9	31 ± 7	29.7 ± 5.8	19.4 ± 8.3	19.7 ± 4.7	17.0 ± 3.5
70–80%	15.2 ± 7.7	15.8 ± 4.5	15.3 ± 2.3	16.0 ± 7.9	15.7 ± 4.6	16.3 ± 2.3	10.9 ± 6.1	10.5 ± 3.1	10.0 ± 0.8

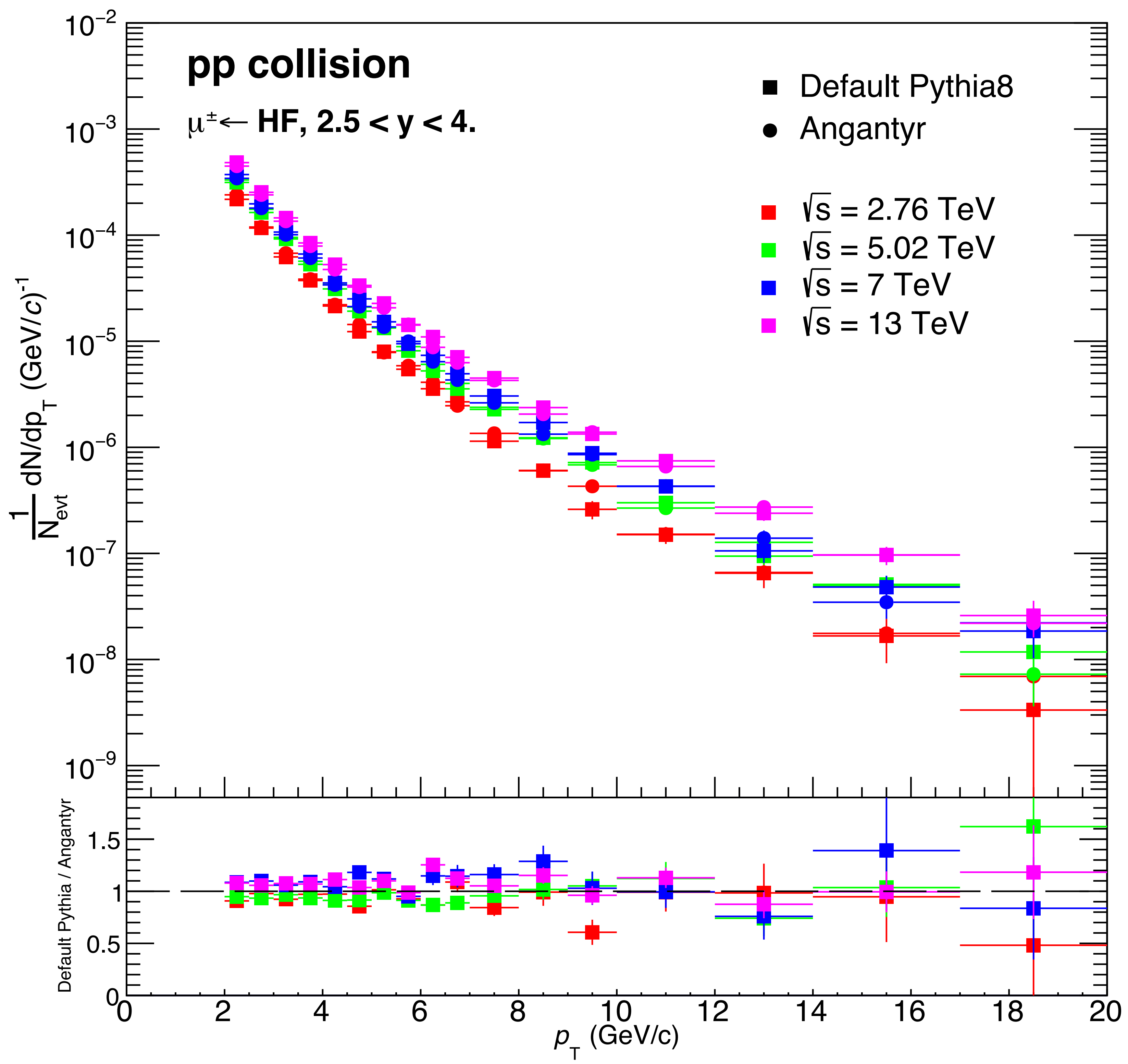
Comparison for pp collisions with results from default Pythia8 and Angantyr model using Pythia8

The p_T-distribution of open Heavy-flavour decay muon (HFM) at forward rapidity are measured.

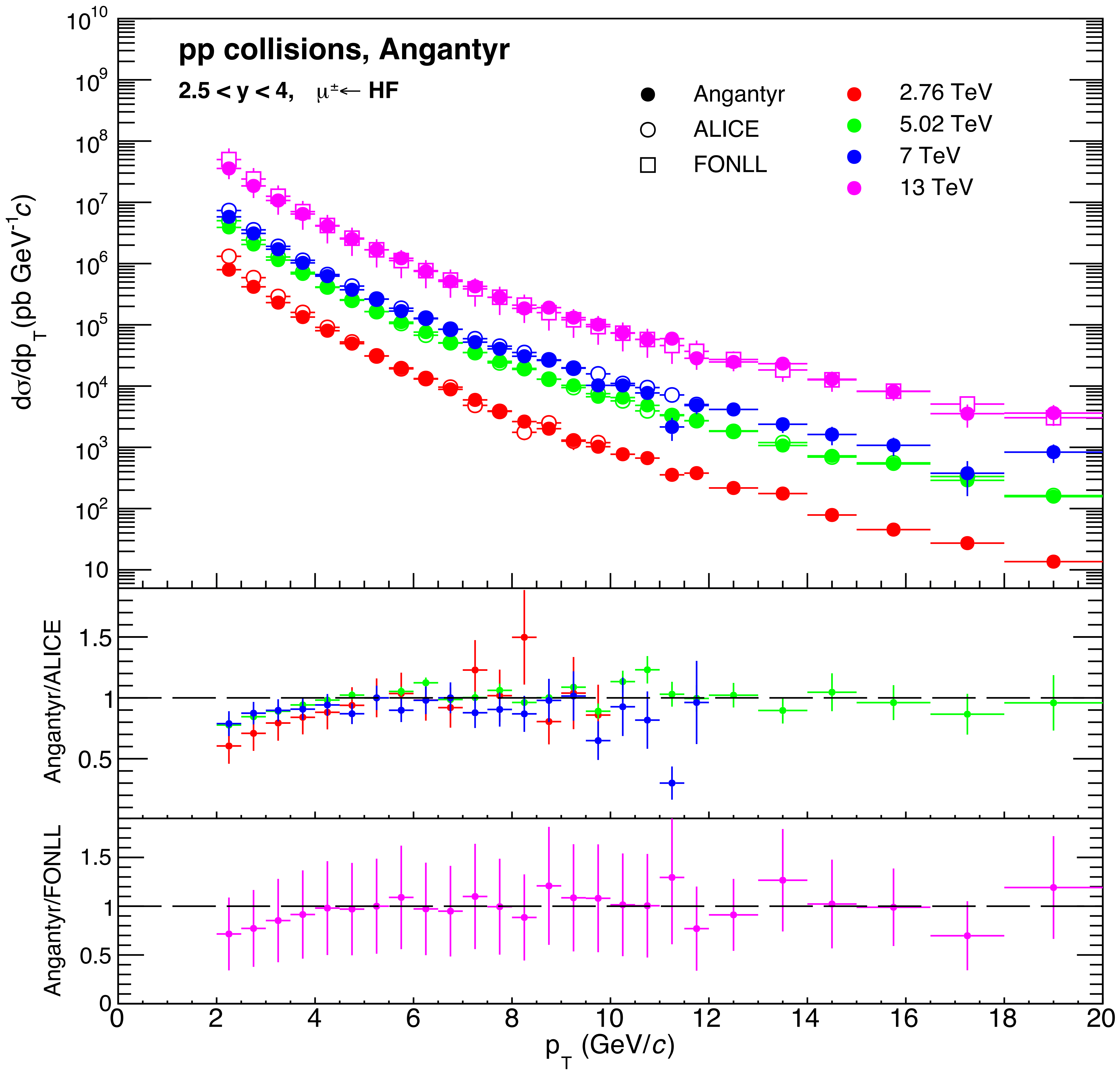
The muons decaying from charm & beauty hadrons within ALICE muon spectrometer acceptance ($-4. < \eta < -2.5$) are measured.

The results are compared for pp collision between Pythia8 default and Pythia8 Heavy-ion based model.

The heavy-ion model can well reproduce the measurement in Pythia8 pp collision.



p_T spectra of HFM in pp collisions

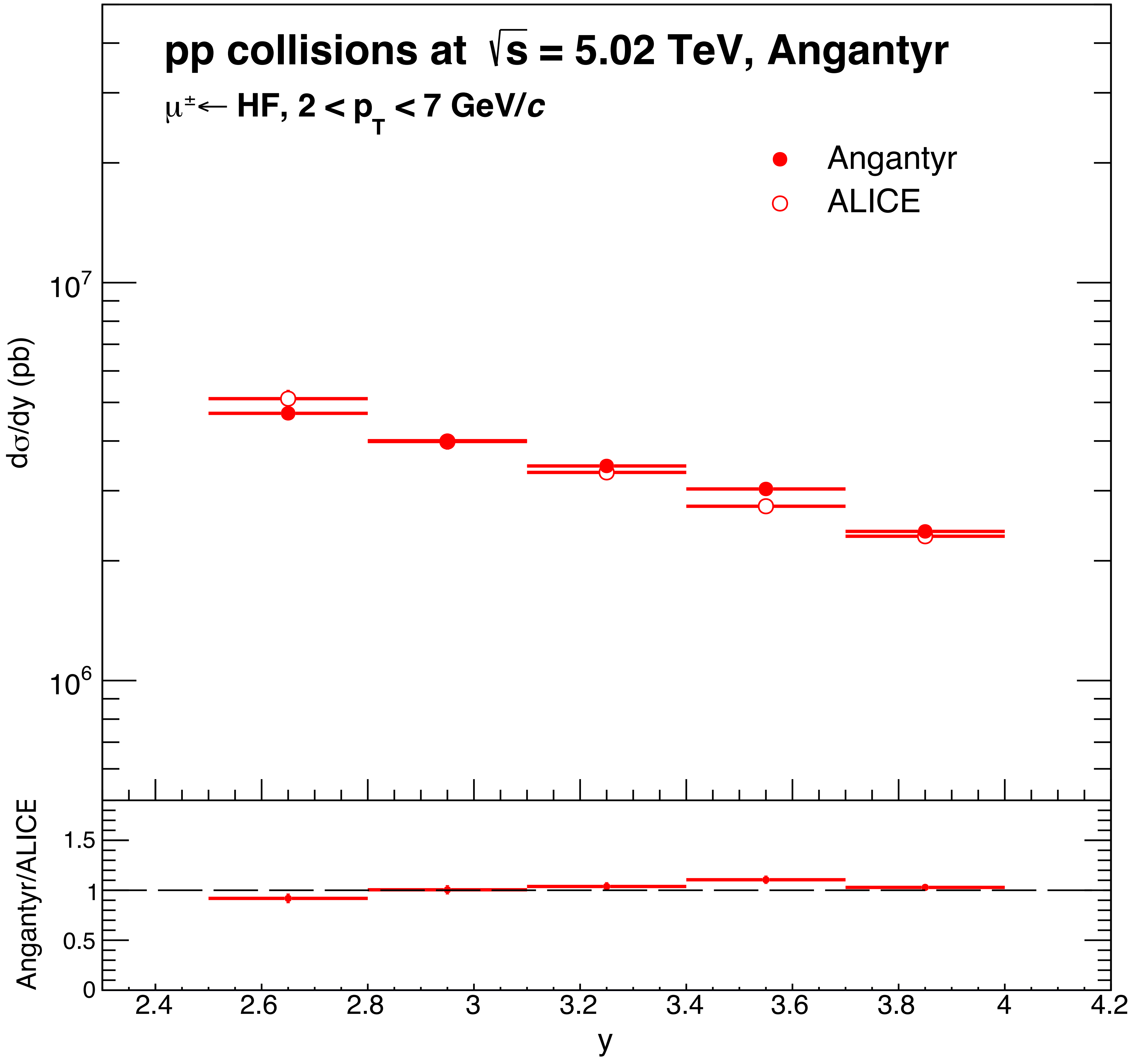


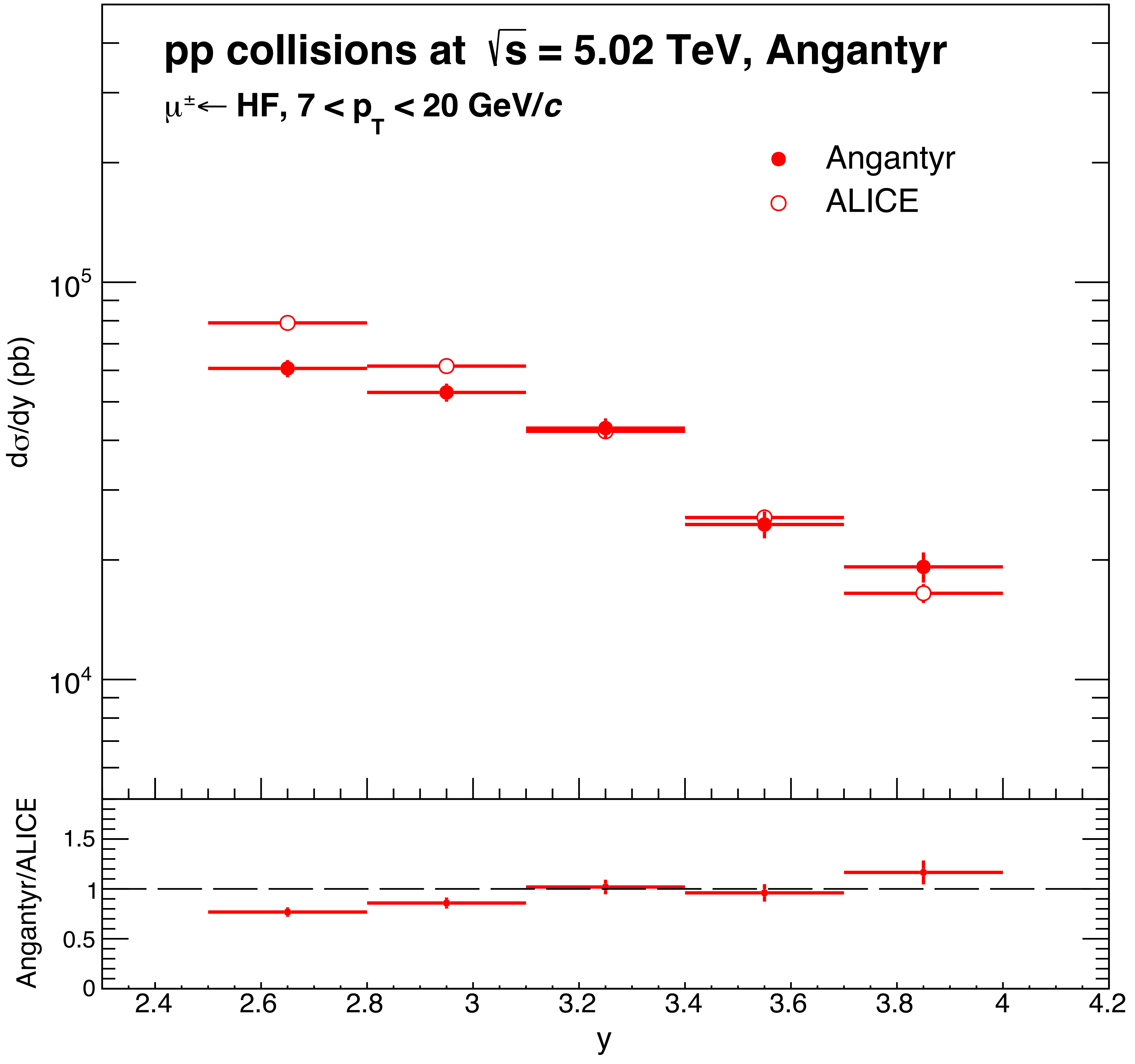
HFM p_T-spectra are simulated with Angantyr model and compared with the available published ALICE data.

At $\sqrt{s}$=13 TeV, the simulation result of HFM is compared with FONLL.

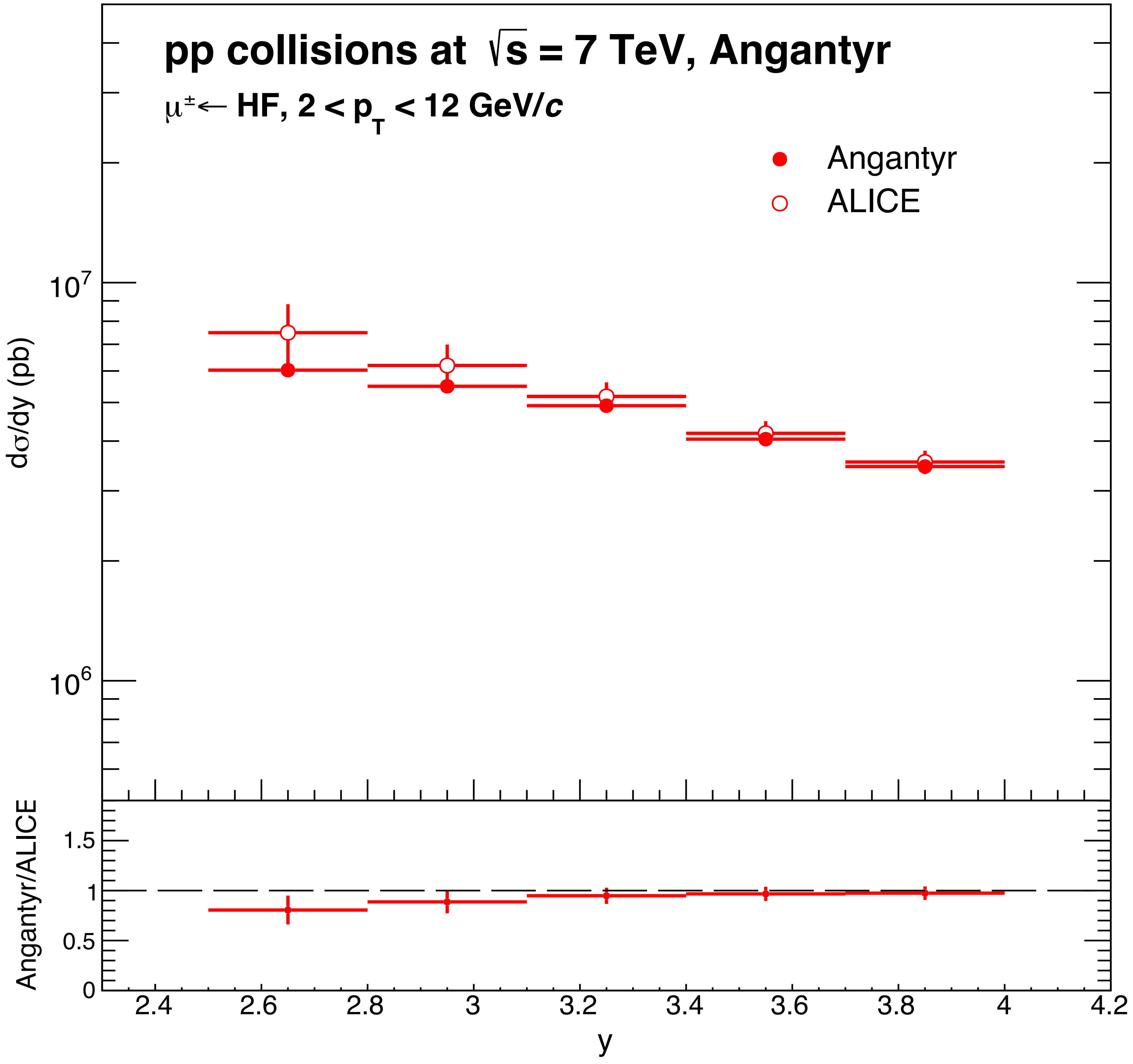
Simulation results are shown upto p_T = 20 GeV/c for all the four energies.

HFM production cross-section as a function of rapidity in pp collisions at $\sqrt{s}$ = 5.02 TeV

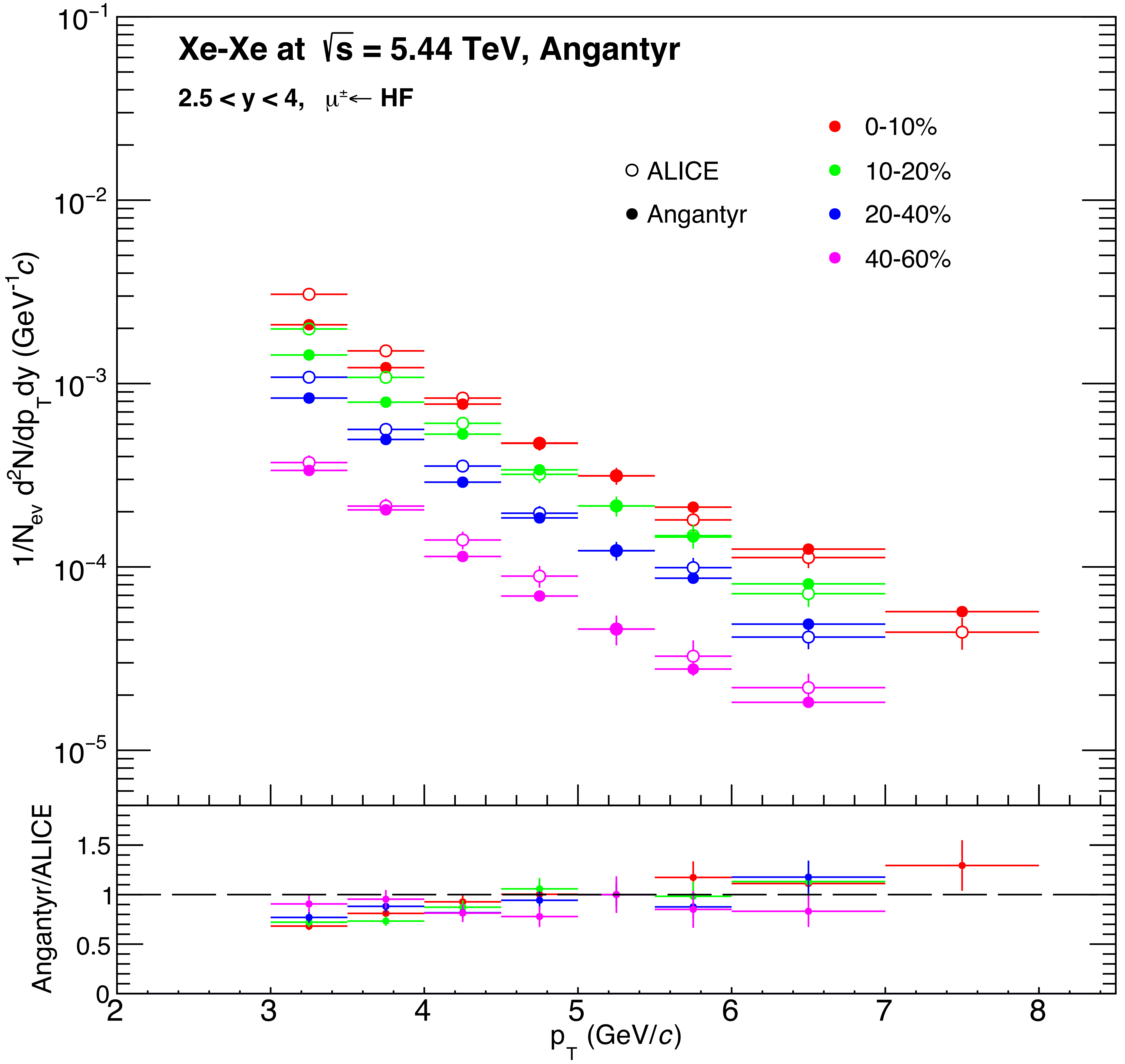




HFM production cross-section as a function of rapidity in pp collisions at $\sqrt{s}$ = 7 TeV



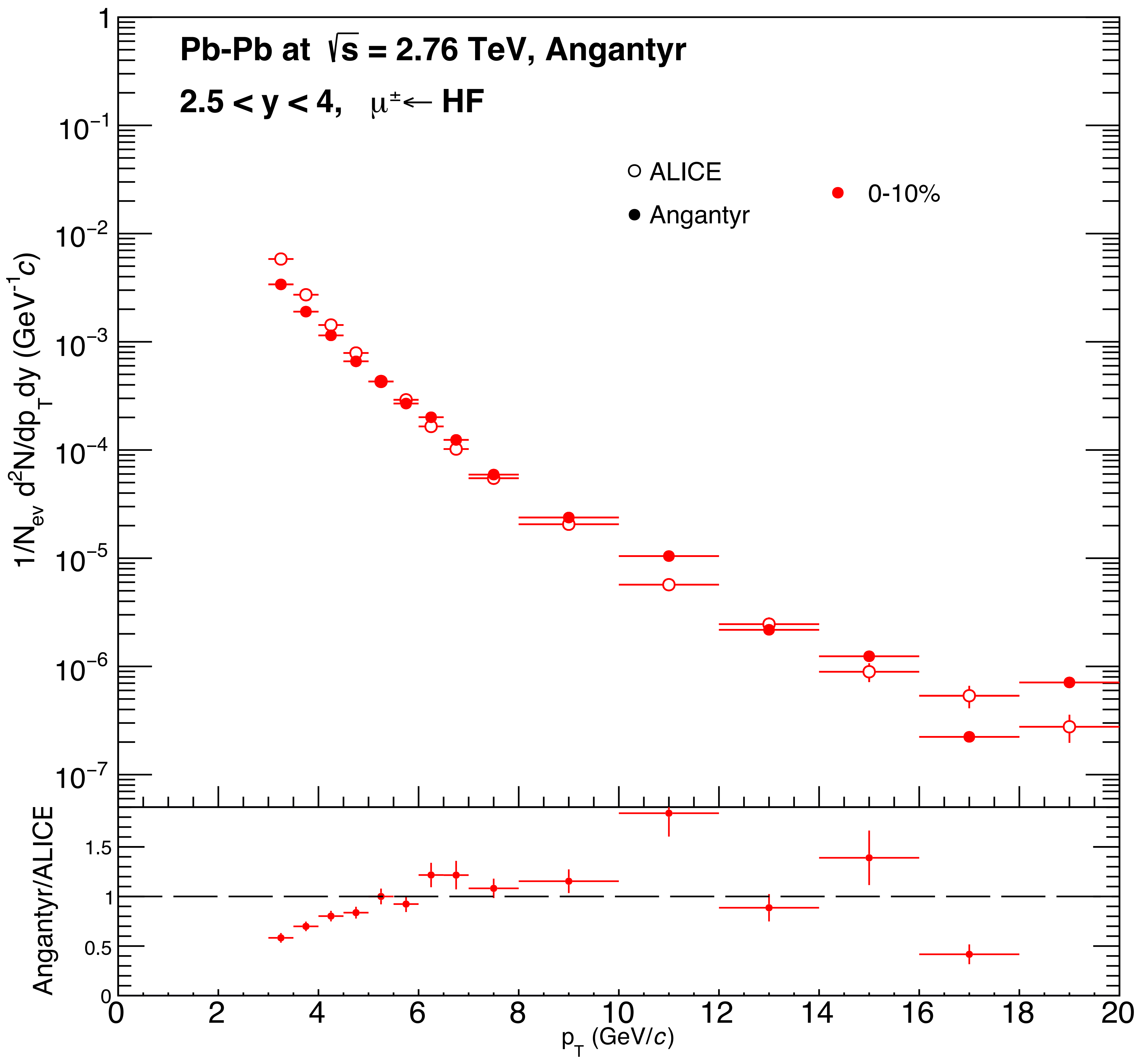
HFM production in Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV

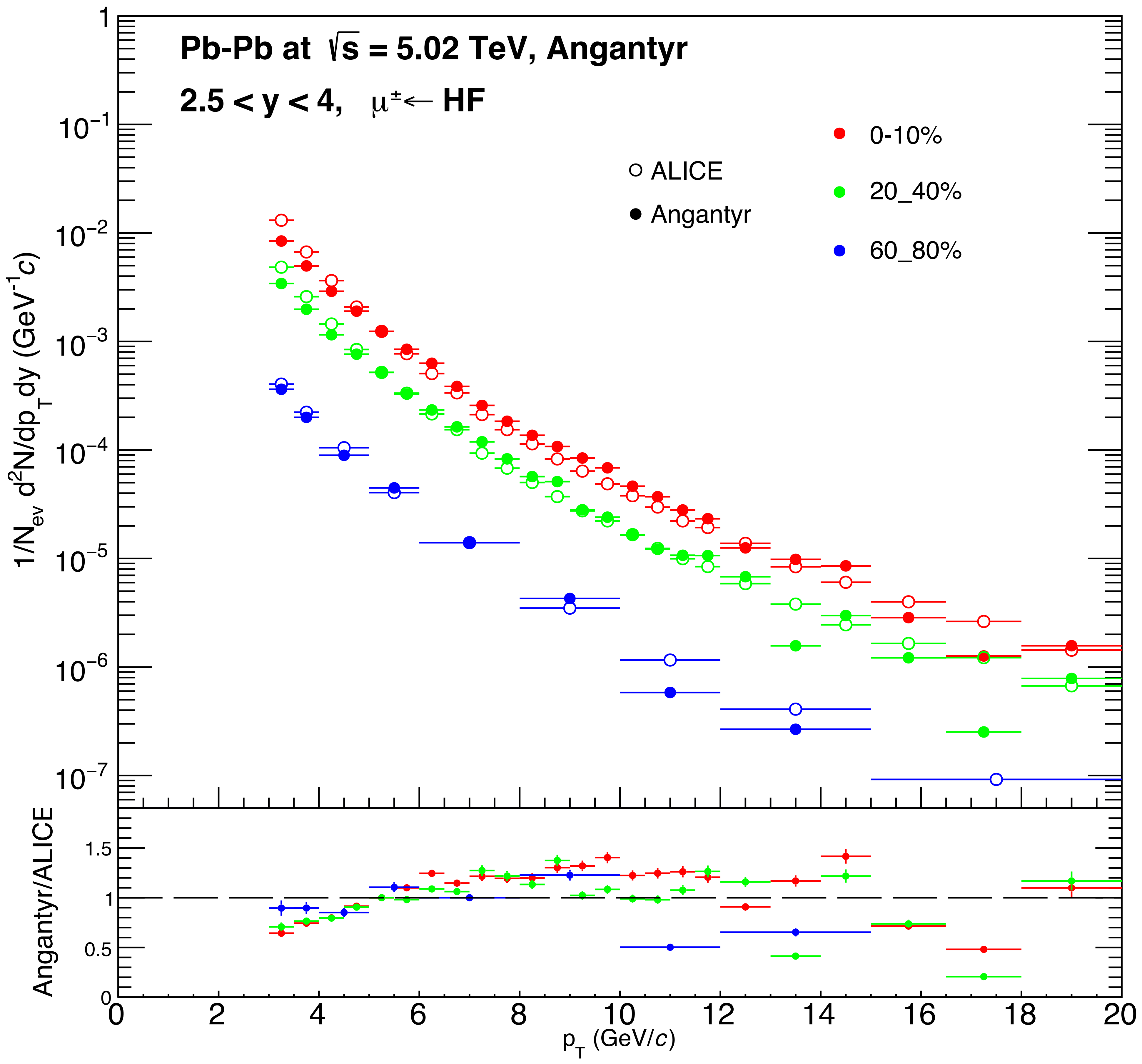


HFM production in Pb-Pb collisions

Differential p_T spectra of HFM in Pb-Pb Collisions at $\sqrt{s}$ = 2.76 TeV and 5.02 TeV.

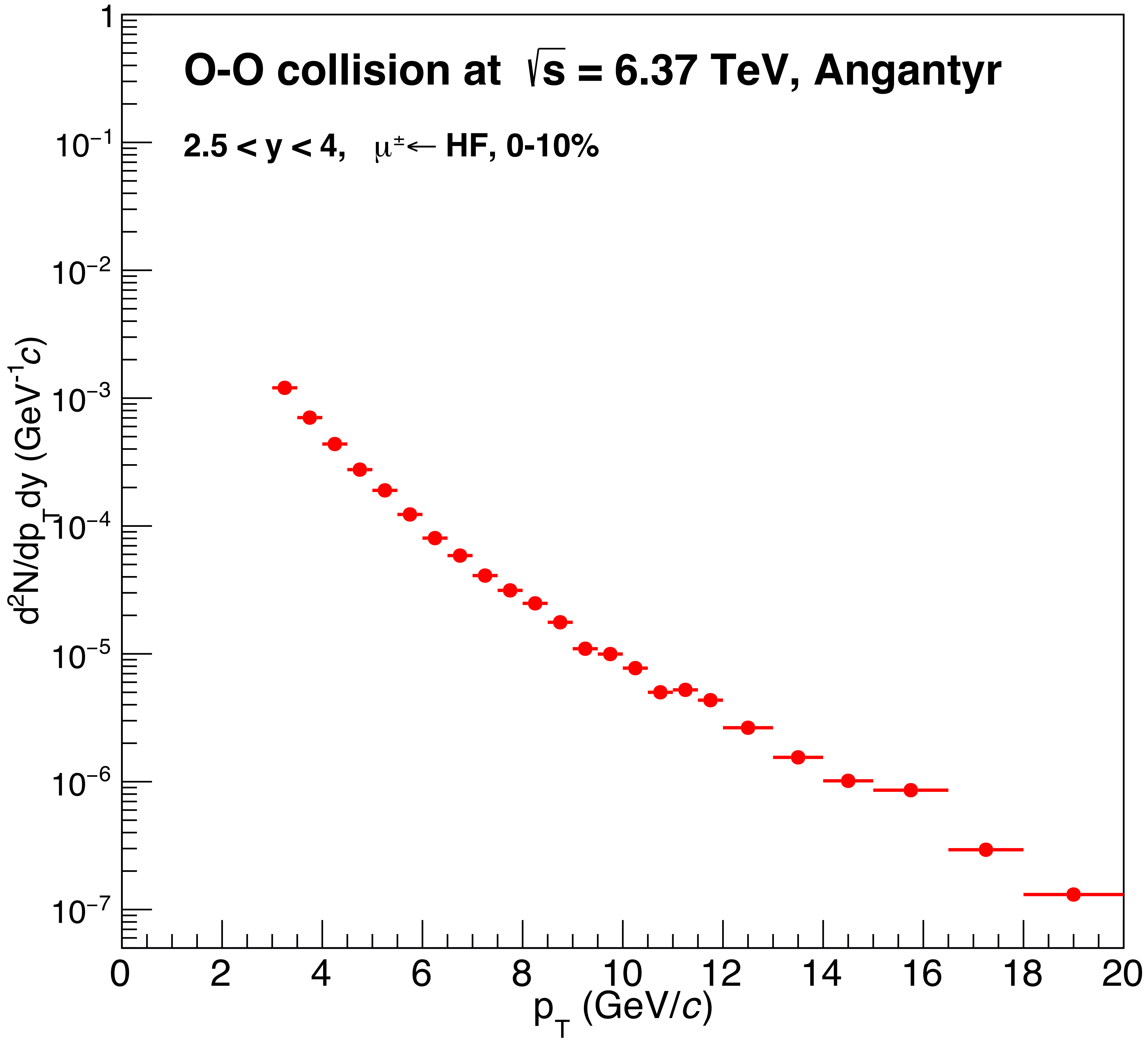
Compared with the respective ALICE measurements.

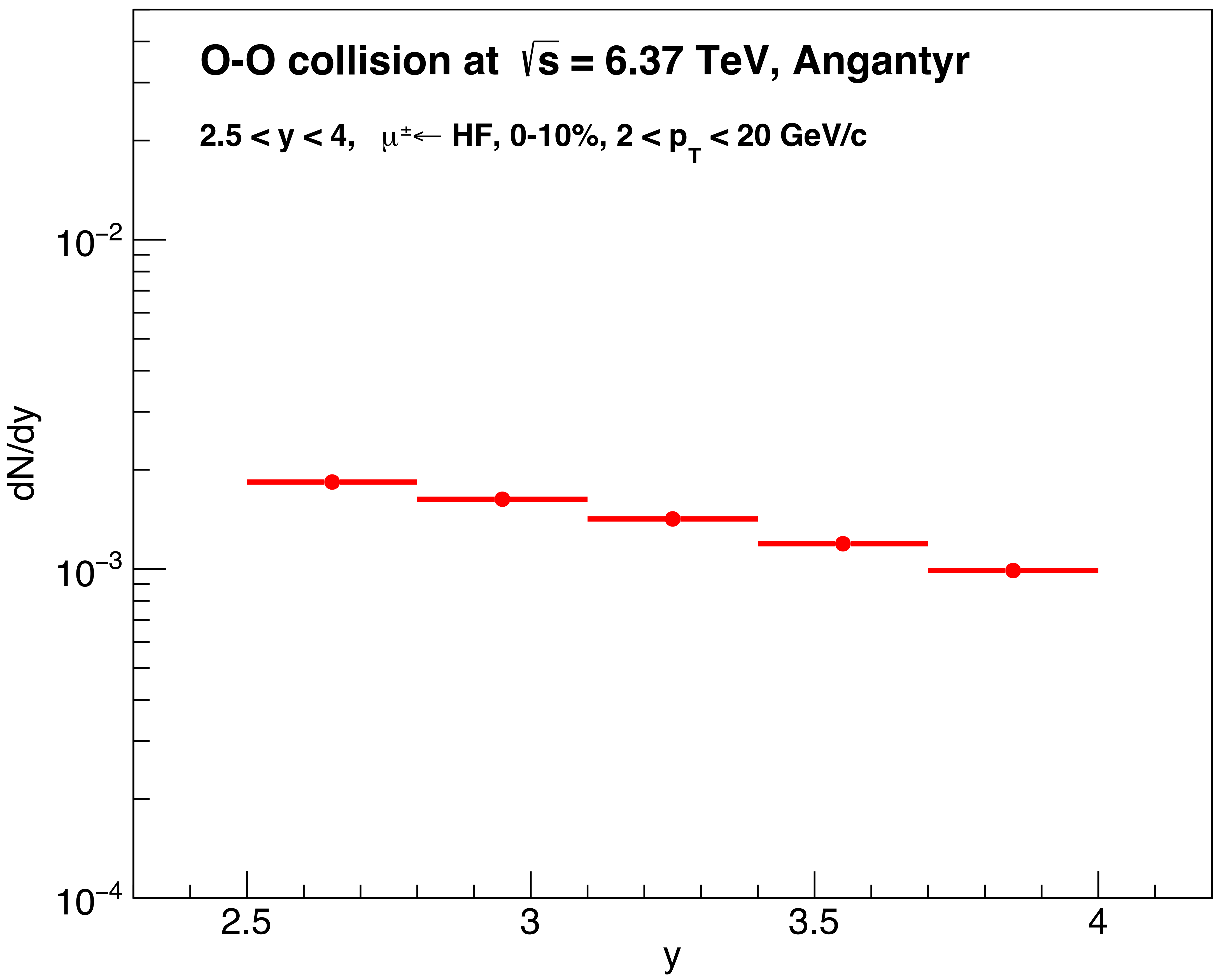




HFM production in O-O collisions at $\sqrt{s_{NN}}$ = 6.37 TeV

ALICE has plan to have short run for O-O collisions at $\sqrt{s_{NN}}$ = 6.37 TeV during Run 3





Nuclear Modification Factor (R_{AA}) HFM production in Pb-Pb collisions

p_T dependence of R_{AA} for HFM measured at both the energies in Pb-Pb for most central (0-10%) collisions.

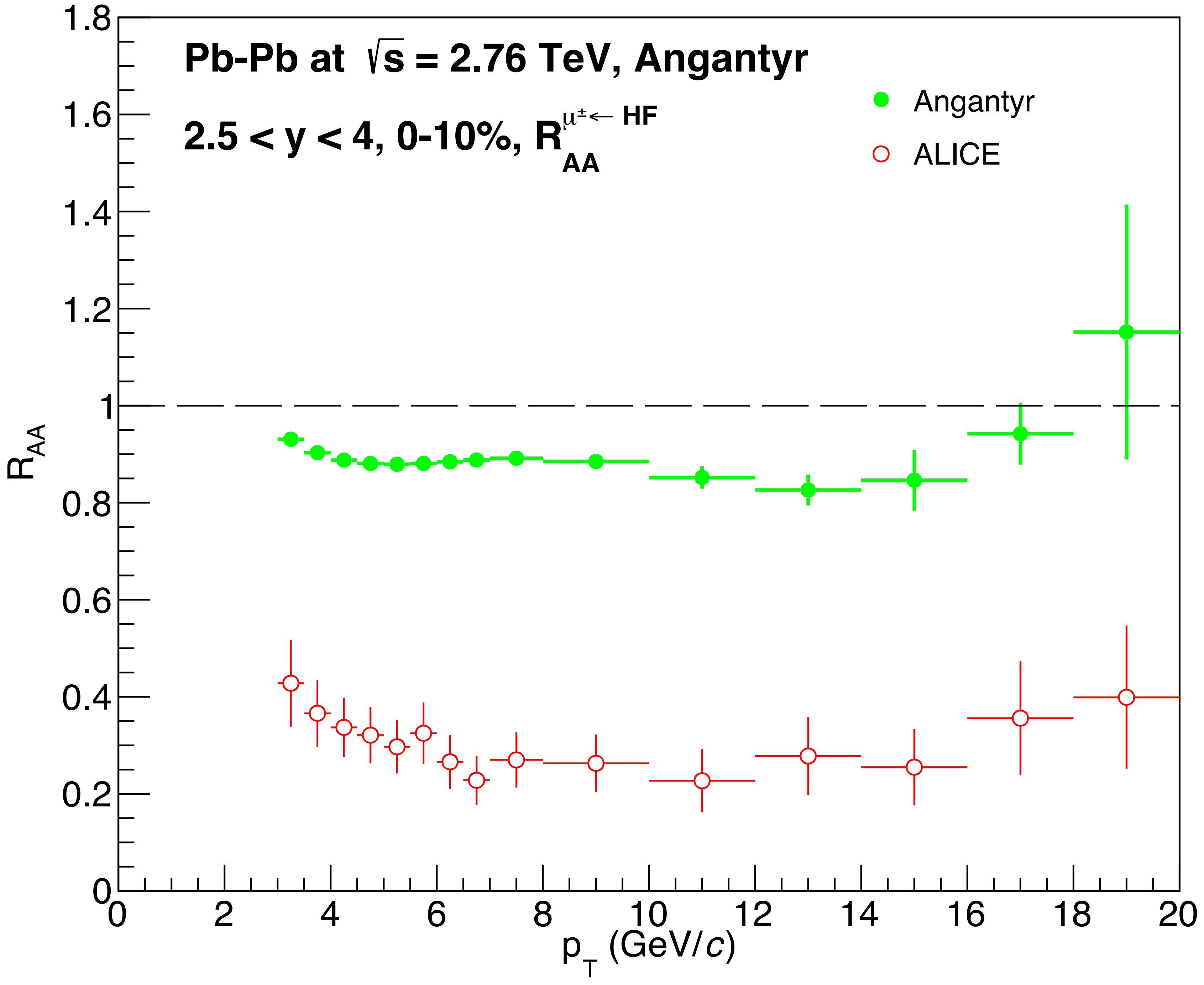
This p_T dependence of R_{AA} demonstrates for the case of QGP free heavy-ion collisions.

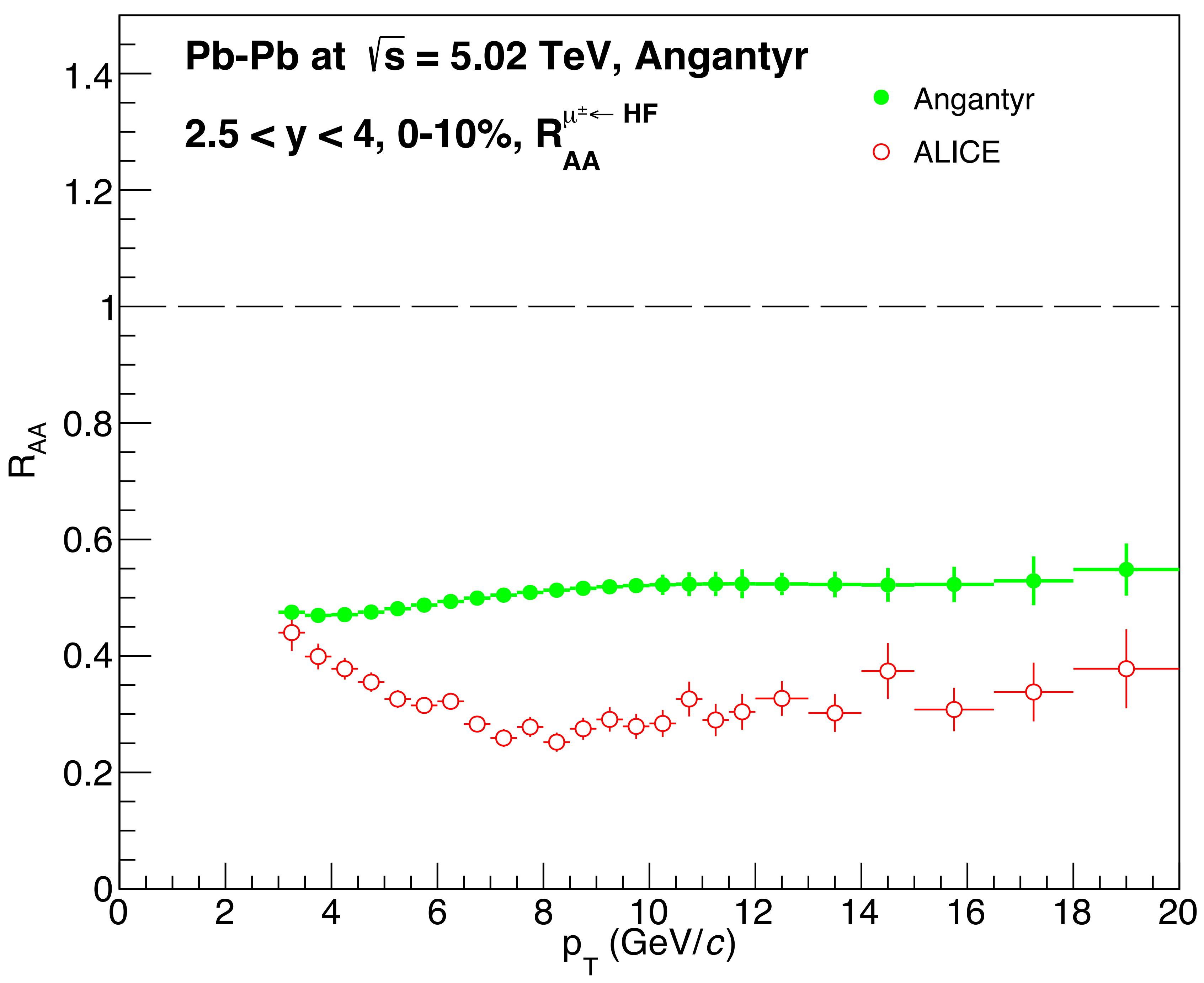
$$R_{AA} = \frac{\frac{d^2N_{AA}}{dp_T dy}}{< N_{coll} > \frac{d^2N_{pp}}{dp_T dy}}$$

deviation of R_{AA} from unity =>

i) Model does not have concept of binary N_{coll} scaling.

ii) Various types of nucleon–nucleon interactions would contribute differently to the high pT particle yields.





Summary

1. The production of HFM is studied in a QGP free Heavy-ion model using PYTHIA8 machinery called Angantyr model.

2. The investigation is done to see how well this model describes the Experimental data with ALICE for both the collision systems (pp and A-A) in a single framework.

3. Various heavy-ion collision systems such as Pb-Pb, Xe-Xe and O-O collision are taken into account.

4. The model results fairly agrees the trend of p_T- and y spectra of HFM with ALICE data.

5. The nuclear modification factor (R_{AA}) is found to be lower than unity but almost independent as a function of p_T.

Outlook of the works

1. To understand the description of the final hadronic state of the underlying events :

a) Multiple parton-parton interactions (MPI): average multiplicity distribution increases with the average number of MPI.

b) Colour reconnection (CR): rearrangement of partons at the perturbative level just before hadronization => hadronization gets modified => could explain the flow like effect in pp collisions.

2. The CR mechanism rearrange the colour flow within the same sub-collisions before hadronisation => can not generate long-range collectivity among the produced hadrons => could be modified the mechanism such that colour flow occurs among all the patrons within same nucleus-nucleus collision event using Angantyr => development of Angantyr needed.

3. The “ridge like effects” and “strangeness enhancement” in high multiplicity pp events observed => To explain these, PYTHIA8 introduced “string shoving” and “rope hadronisation” => modelling based on the modification of effective string tension with string density described by Lund string model => searches for new kinds of hadronization mechanisms when huge kinetic energy is involved in a collision irrespective of the colliding system sizes => concept may applicable to Angantyr HI model.

4. Definition of centrality, trigger selection, primary particle definition etc. play major roles to improve the precision of comparison by phenomenological model => key features of RIVET analyses.

Collaborators:

Prof. Tinku Sinha Sarkar, SINP
Prof. Pradip K Roy, SINP
Dr. Partha Pratim Bhaduri, VECC

Thank you