

Introduction

The Symmetric 2-harmonic 4-particle Cumulants (SC), which quantify the relationship between event-by-event fluctuations of two different flow harmonics, are defined as:

$$\begin{aligned} \langle\langle \cos(m\varphi_1 + n\varphi_2 - m\varphi_3 - n\varphi_4) \rangle\rangle_c &= \langle\langle \cos(m\varphi_1 + n\varphi_2 - m\varphi_3 - n\varphi_4) \rangle\rangle \\ &\quad - \langle\langle \cos[m(\varphi_1 - \varphi_2)] \rangle\rangle \langle\langle \cos[n(\varphi_1 - \varphi_2)] \rangle\rangle \\ &= \langle v_m^2 v_n^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle, \end{aligned} \quad (1)$$

with the condition $m \neq n$ for two positive integers m and n . $SC(m,n)$ normalized by the product $\langle v_m^2 \rangle \langle v_n^2 \rangle$ [1] is denoted by $NSC(m,n)$:

$$NSC(m,n) \equiv \frac{SC(m,n)}{\langle v_m^2 \rangle \langle v_n^2 \rangle}. \quad (2)$$

$NSC(m,n)$ reflects only the strength of the correlation which is expected to be insensitive to the magnitudes of v_m and v_n , while $SC(m,n)$ has contributions from both the correlations between the two different flow harmonics and the individual v_n harmonics.

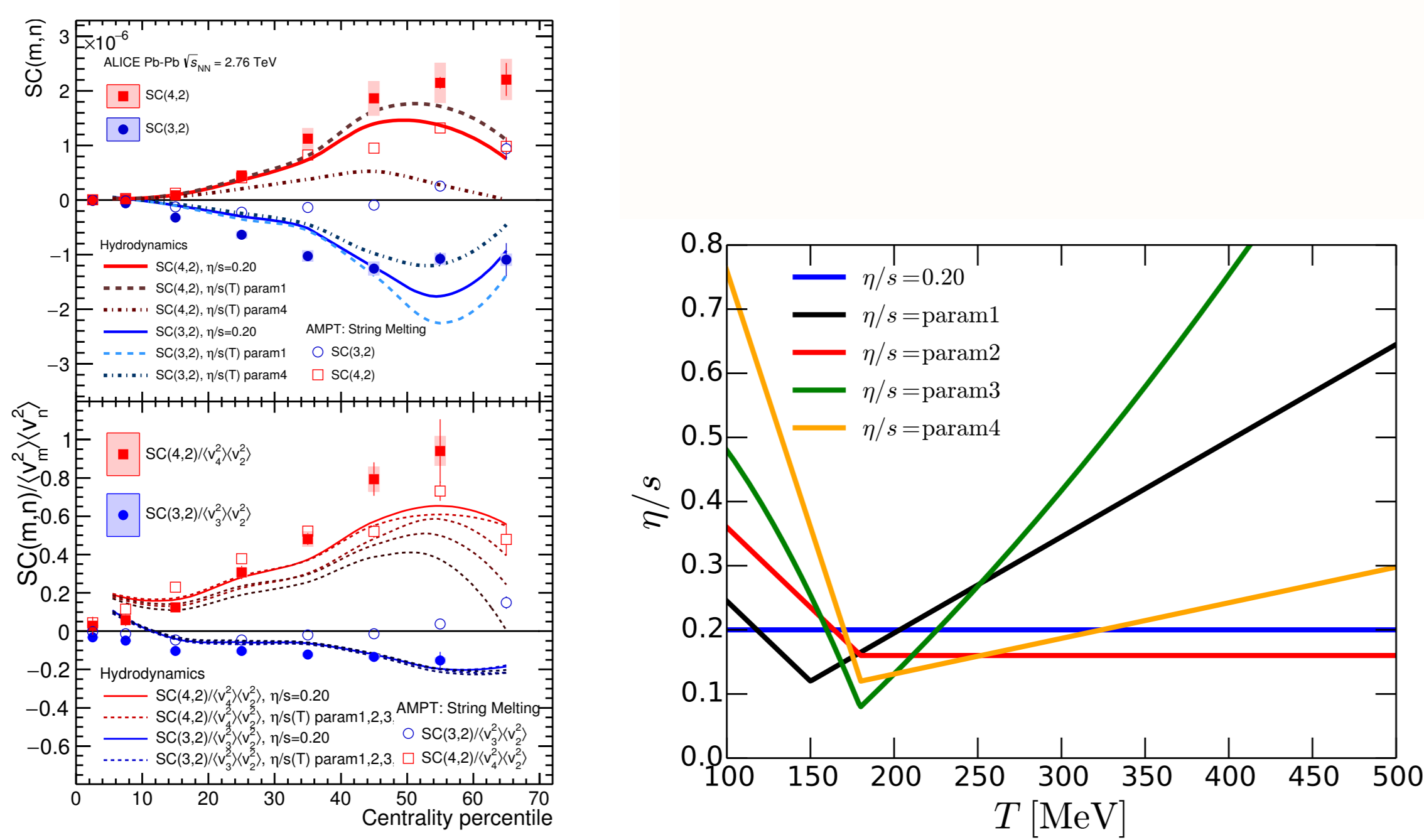


Figure: (Left) Published ALICE SC and NSC results [1] in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. (Right) The $\eta/s(T)$ parameterizations used in theoretical model [2].

The SC observables are particularly robust against few-particle non-flow correlations and they are sensitive to the temperature dependence of η/s of the expanding medium [1]. We extended the analysis of SC observables to higher order harmonics (up to 5th order) as well as to the measurement of the p_T dependence of correlations for the lower order harmonics (v_3 - v_2 and v_4 - v_2) with unidentified charged particles ($|\eta| < 0.8$, $0.2 < p_T < 5.0$ GeV/c).

Results and Model comparisons

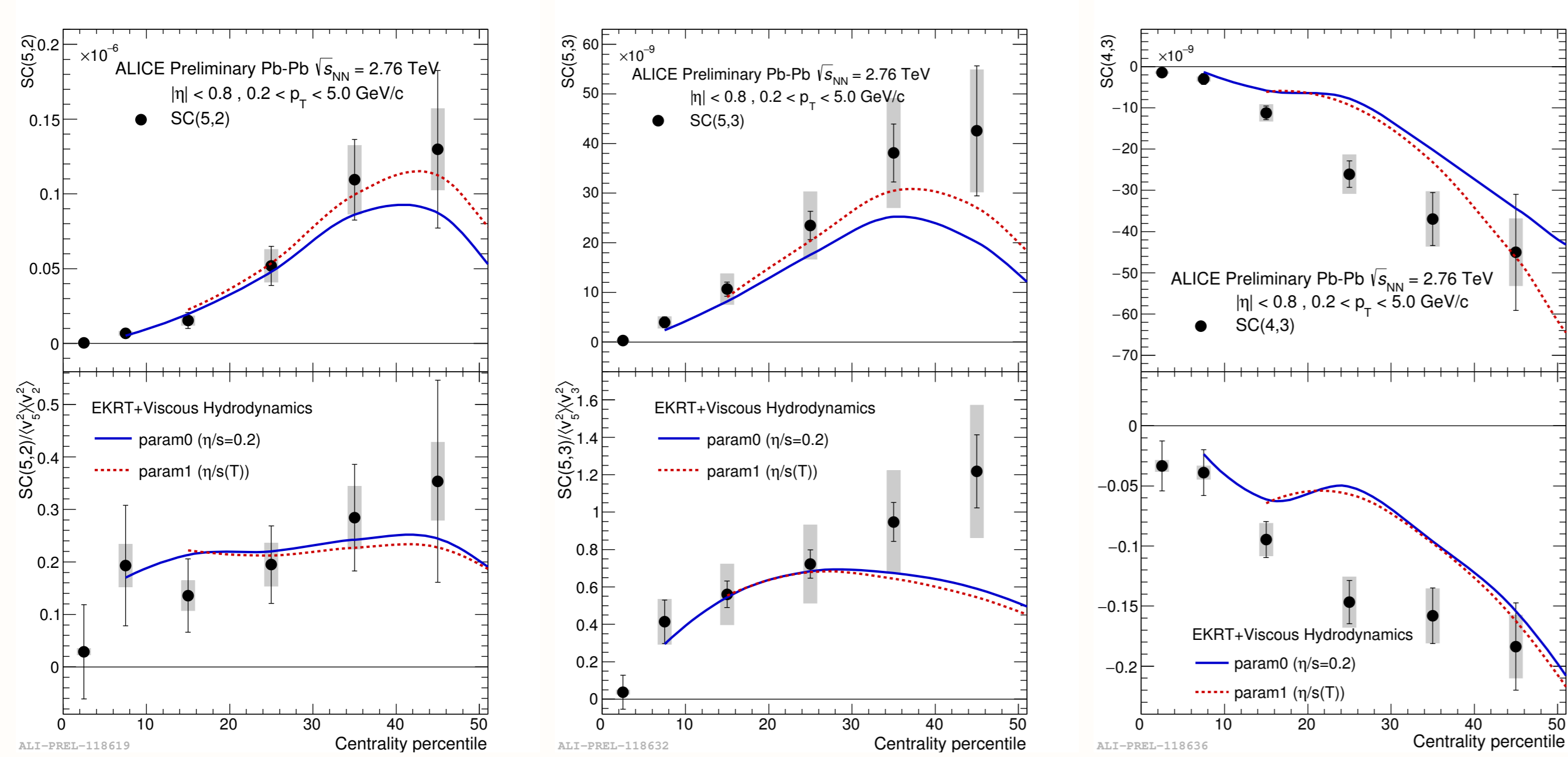


Figure: SC(5,2) (a), SC(5,3) (b) and SC(4,3) (c) are compared to the event-by-event EKRT+viscous hydrodynamic calculations [2].

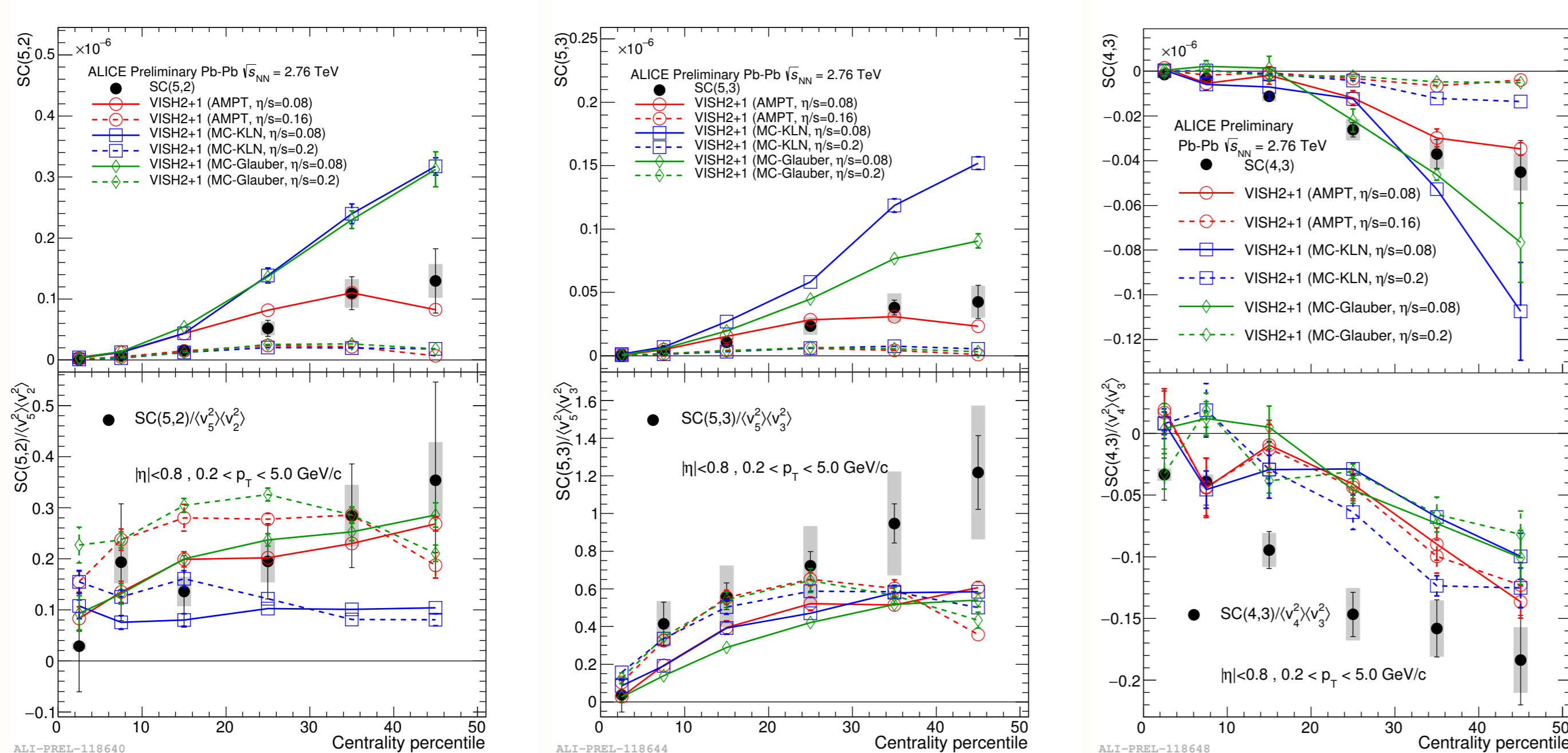


Figure: SC(5,2), SC(5,3) and SC(4,3) are compared to various VISH2+1 calculations [3].

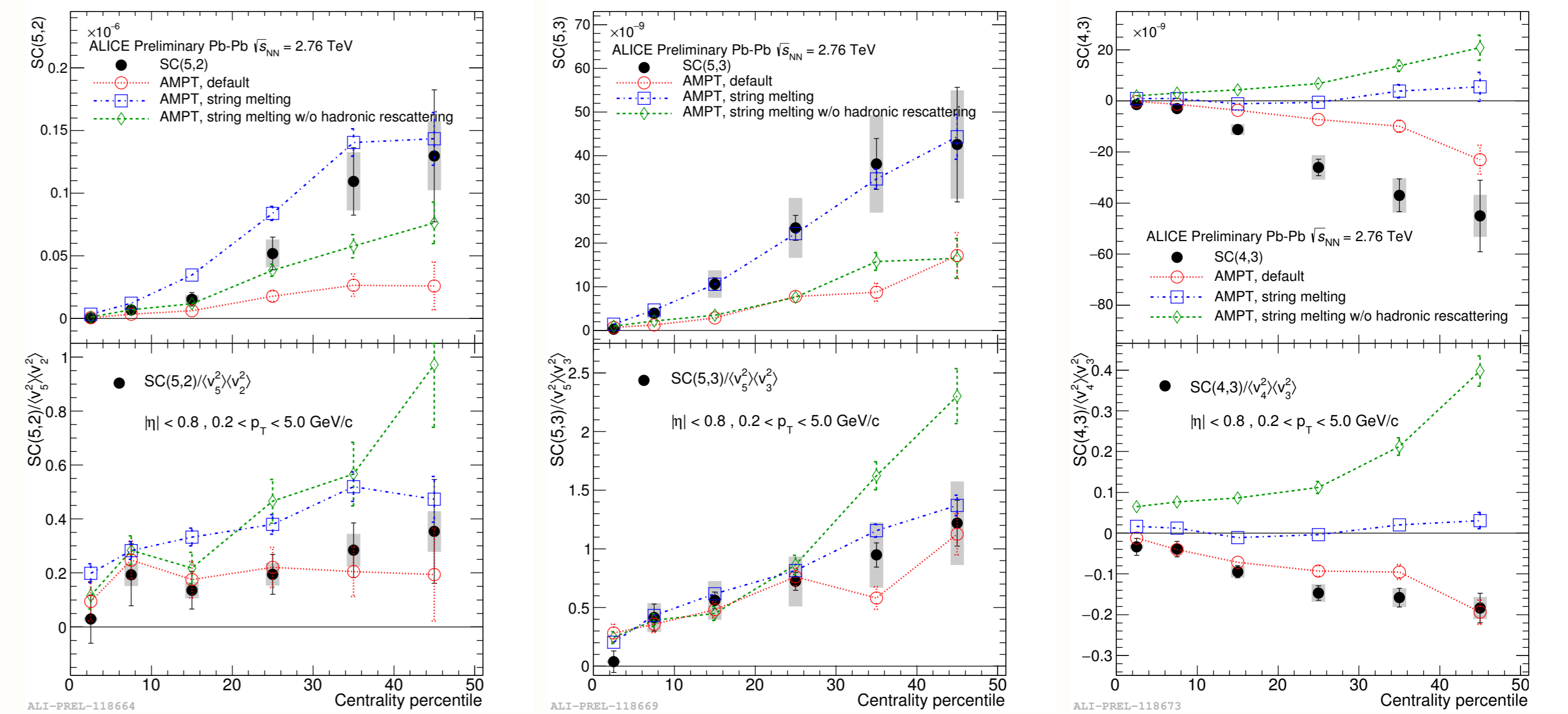


Figure: SC(5,2), SC(5,3) and SC(4,3) are compared to various AMPT models.

p_T dependence

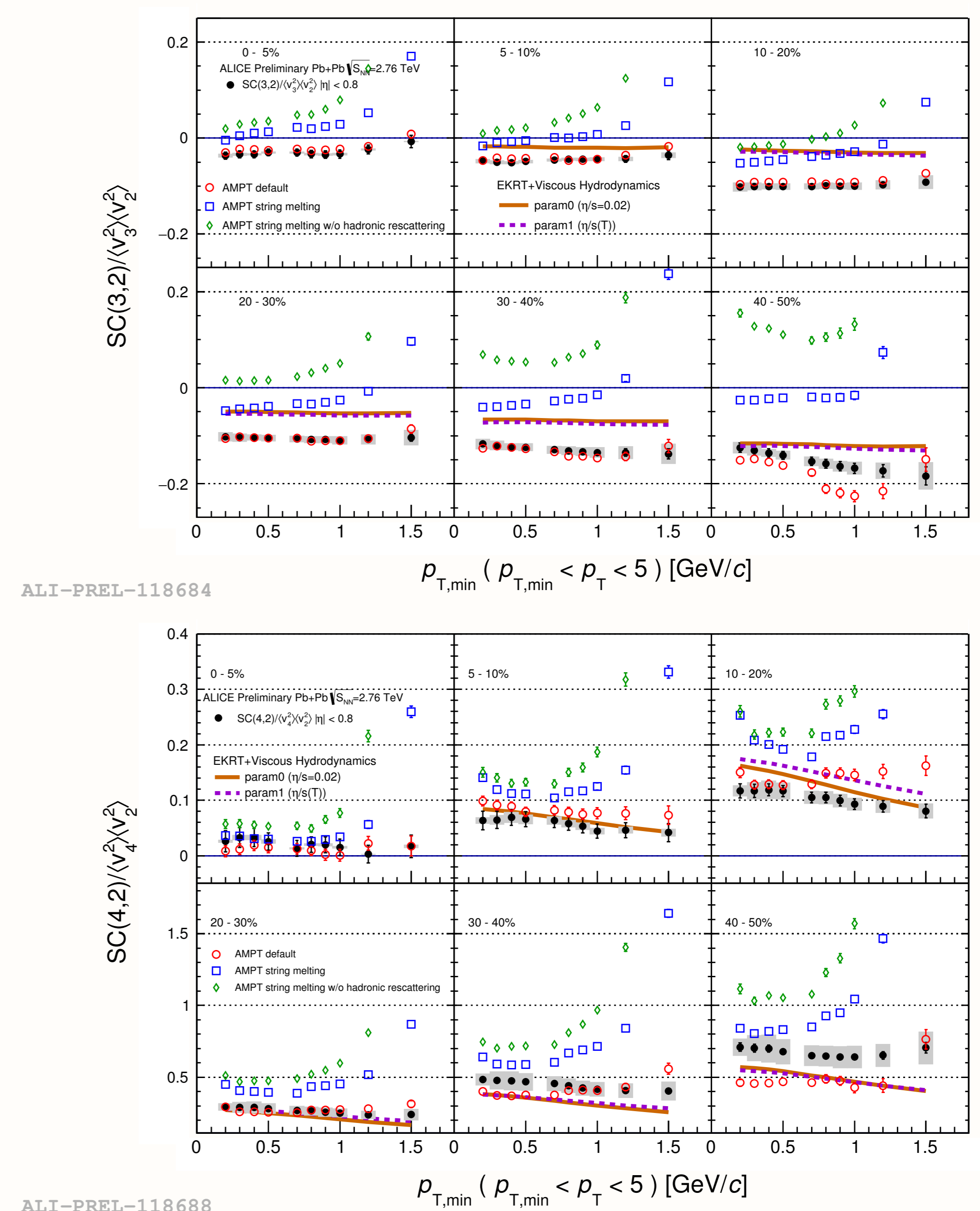


Figure: NSC(3,2) and NSC(4,2) as a function of the minimum p_T cut.

Discussion and Summary

The comparisons to viscous hydrodynamic models show that:

- The different order harmonic correlations respond differently to the initial conditions and the temperature dependence of η/s .
- A small average value of η/s is favored independent of the specific choice of initial conditions in the models. The calculations with the AMPT initial conditions yield results closest to the measurements.
- NSC(3,2) and NSC(4,2) show moderate p_T dependence in mid-central collisions. This might be an indication of possible viscous corrections to the equilibrium distribution at hadronic freeze-out, which might help to understand the possible contribution of bulk viscosity in the hadronic phase of the system.

Together with existing measurements of individual flow harmonics, the presented results provide further constraints on initial conditions and the transport properties of the system produced in heavy-ion collisions.

[1] ALICE Collaboration, J. Adam *et al.*, "Correlated event-by-event fluctuations of flow harmonics in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Rev. Lett.* **117** (2016) 182301.

[2] H. Niemi, K. J. Eskola, and R. Paatelainen, "Event-by-event fluctuations in a perturbative QCD + saturation + hydrodynamics model: Determining QCD matter shear viscosity in ultrarelativistic heavy-ion collisions," *Phys. Rev.* **C93** no. 2, (2016) 024907.

[3] X. Zhu, Y. Zhou, H. Xu, and H. Song, "Correlations of flow harmonics in 2.76A TeV Pb–Pb collisions," arXiv:1608.05305 [nucl-th].