

General

The paper has improved and I really appreciate that you incorporated our comments in a nice way. I also liked the fact that you added a new subsection where you focus on the similarities and the differences between the NL and the total vn. However, I feel that it is misplaced and can profit from a further expansion of the discussion (some suggestions and further ideas about this are listed below).

Finally, the text needs some still a bit of tweaks here and there so I give some additional suggestions below.

Thanks for your kind words. We have addressed these comments below each comment and wherever necessary we have applied them to the text.

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Physics+analysis related

• maybe state at the end of the abstract how better/worse the models do wrt the total flow instead of the generic statement of lines 18-19?

Answer: ok, thanks. We changed the abstract to describe the model comparison section better. It now reads:

“Hydrodynamical calculations (iEBE-VISHNU) that use different initial conditions and values of shear and bulk viscosity to entropy density ratios are confronted with the data at low transverse momenta. Previous comparisons between the anisotropic flow coefficients,  $v_{\{2\}}$ ,  $v_{\{3\}}$  and  $v_{\{4\}}$ , and these calculations present a better agreement with respect to the comparisons for non-linear flow modes. These observations indicate that non-linear flow modes can provide additional discriminatory power in the study of initial conditions as well as new stringent constraints to hydrodynamical calculations.”

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• L80: I feel you are mixing the name of the  $\chi$ s which you call here “non-linear flow mode coefficients” with how you call the  $v_{nmk}$  (non-linear mode coefficients)”

Answer: You are correct that the names are similar but the naming is taken from the first non-linear flow paper (arXiv:1705.04377v1). Right after equ 5 in page 3:

“ Here  $\chi_{n,mk}$  is a new observable called the non-linear mode coefficient [34] and  $V^{NL}_n$  represents the nonlinear mode which has contributions from modes with lower order anisotropy coefficients.”

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• L83-84: “The approximation...flow coefficients” this needs a reference. How valid is this assumption?

Answer: We added two references. One from the symmetric cumulants paper and the other a hydro paper from Jean-Yves Ollitrault:

SC paper: <https://arxiv.org/abs/1709.01127>

Hydro paper: <https://arxiv.org/abs/1411.5160>

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• L196: ru sure the cut in the z-coordinate of the dca is that loose?

Answer: We used an even larger DCAz cut in the PID vn paper in 2.76 TeV:  $DCAz < 3.2$  cm,  $DCAxy < 2.4$  cm.

Similar cuts were used in the PID vn paper at 5.02 TeV as take from this paper:

"Furthermore, tracks with a distance of closest approach (DCA) to the reconstructed event vertex smaller than 2 cm in the longitudinal direction (z) and  $(0.0105 + 0.0350 \text{ (pT c/GeV)} - 1.1)$  cm in the transverse plane (xy) are selected"

In our paper in line 305-306:

"(iv) varying the selection criteria on both the longitudinal and transverse components of the DCA to estimate the impact of secondary particles from a strict  $p_T$ -dependent cut to 0.15 cm and 2 cm to 0.2 cm, respectively."

Longitudinal and transverse have to be swapped and we correct it in the new version :

"(iv) varying the selection criteria on both the transverse and longitudinal components of the DCA to estimate the impact of secondary particles from a strict  $p_T$ -dependent cut to 0.15 cm and 2 cm to 0.2 cm, respectively."

For DCAz we use a cut of 2 cm as default and 0.2 cm and 0.3 cm as variations. The systematics were very small.

The effect is shown in twiki: [https://twiki.cern.ch/twiki/pub/ALICE/DCAdistribution/DCAz\\_cuts\\_1.pdf](https://twiki.cern.ch/twiki/pub/ALICE/DCAdistribution/DCAz_cuts_1.pdf)

With 0.2 cm cut we only reject 1% of the the total events in <2cm cut.

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**• L296: "iv) not rejecting all events with tracks caused by pileup." I commented on this before! I hope you mean that you make the "pile up cut" stricter not that u make it looser; if so the sentence should be modified accordingly**

Answer: In our paper we use strict pileup cuts specially in the most central collisions. What we mean by looser pile-up cuts is using a looser cut in most-central collisions while the other centralities are untouched. The reason is we reject many events in most-central collisions with our strict pile-up cuts and we wanted to investigate the effect of a slightly looser cut in this centrality interval.

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**• L314: you need to describe here what online is! don't use jargon: nobody outside ALICE knows what offline and online V0 finder is! You have to say sth like "combining pairs of track candidates while the track reconstruction is performed..." ==> find the proper description of this mode**

Answer: You're absolutely correct. What do you think about the following replacement?  
"(i) changing the reconstruction method for V0 particles to an alternate technique that uses raw tracking information during the Kalman filtering stage"

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**• L316: why do you loosen the cut for the pointing angle? you increase the background like this! for all other cuts we always tighten the requirement**

Answer: We use 0.998 as default and 0.99 as systematics. We loosen the super tight cut here however it was motivated by Run 2 PID vn paper, where they did the same, but loosen it even more. In page 10:

"(ix) changing the minimum value of the  $\cos\theta_p$  from 0.998 to 0.98"

Which is even looser than what we used in this paper. As to why not tighter, the cut is already tight and by tightening it further, the sample shrinks a lot and the statistical uncertainties cover any variation.

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• **L350-351:** “It is shown in MC studies that both  $\epsilon_2$  and  $\epsilon_3$  increase for peripheral collisions [8]. Although, this increase is less pronounced for  $\epsilon_3$ .” ==> isn't it mainly that  $\epsilon_2$  is the one rising with centrality?  $\epsilon_3$  rises as well but the relative rise is smaller than the one of  $\epsilon_2$ ? See Z. Qiu, U. W. Heinz, Phys.Rev. C84, (2011) 024911 as an example; i see you write it later in the end of the paragraph; but I feel that it's better if stated in one go? think about it

Answer: Thanks, we changed this sentence to:

"It is shown in MC studies that  $\epsilon_2$  and to a lesser extent,  $\epsilon_3$  increase for peripheral collisions [8]."

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• **L354-356:** make sure you spell out why it is "as expected" for 6,222 and why 6,33 is not changing as much with centrality

Answer: We changed this sentence. It now reads:

"As expected, measurements of  $v_{6,222}(\sqrt{s_{NN}})$  which probe the contribution of  $\epsilon_2$ , show an increase in the magnitude of this non-linear flow mode with increasing centrality percentile. On the other hand,  $v_{6,33}(\sqrt{s_{NN}})$  measurements, which probe the contribution of  $\epsilon_3$ , present little to no dependence on centrality"

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• **L364-365:** “between the non-linear response of the system and radial flow.” ==> I don't understand this about the “interplay of the \*nl response with radial flow\*; don't you want to say that it arises from the initial coordinate space anisotropy ( $\epsilon_2+\epsilon_3$ ) + radial flow?

Answer: You're correct. We fixed all the occurrences of this statement.

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• **L382:** you should indicate here the  $p_T/n_q$  range where the scaling is supposed to be relevant!

Answer: You are correct. We changed the text to:

"It is seen that for the non-linear flow modes this scaling holds at an approximate level ( $\pm 20\%$ ) for  $p_T > 1$  GeV/c, where quark coalescence is hypothetically the dominant process."

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• **L423-437:** in general I like this attempt; however it needs to become clear that:  
i. for the total  $v_n$  you look at  $v_2$ ,  $v_3$  (which have indeed larger magnitude than the ones you report in your analysis but this is irrelevant) and at  $v_4$  which is the only relevant harmonic where this direct comparison can be made

ii. you report  $v_{52}$  and two modes of  $v_6$ , which indeed have small magnitudes but the total  $v_5$  and  $v_6$  is not reported (not your fault, I'm just stating it)

So in total, I propose the following:

- you first put Table 4 and make it Table 3 i.e. the comparison of the total  $v_n$  to the models comes first and you discuss the ranges, finishing with the total  $v_4$

- you then add the table for  $v_{nmk}$ , and you start with  $v_{422}$  and make the comparison not only with the models but also how better/worse they describe  $v_{422}$  wrt to total  $v_4$

- you then discuss how the models do for  $v_{532}$  and the two  $v_6$  you report

Answer: thanks for your suggestion. We swapped the two tables and made a few changes as requested.

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- **L438: I would move this new subsection just before the model comparison; the argument is that we first discuss in detail all the data points and then we go to the comparison with models**
  - **In the current subsection 6.3 I think I'm missing a couple of plots here that would support the discussion. I would try to do the following:**
    - **split the discussion in two paragraphs, the first about the mass ordering the other about the grouping**
    - **I would add a couple of indicative plots e.g. relative mass ordering, relative grouping**
    - **for each paragraph I would attach the indicative plot and I would discuss in detail the observation**
    - **can we make a story about the expectation of the mass ordering and the grouping for  $v_{4,22}$  and  $v_4$  from  $v_2^2$ ?**
  - **similarly for  $v_{5,32}$  from  $v_2$  and  $v_3$ ?**

Answer: Thanks again for the detailed suggestions. We have changed the text accordingly. It is now discussed before model comparison. Following the conclusion from the video meeting and the comment from Sergei one figure was added. The text was slightly expanded to discuss the details seen in the ratios (By relative ratios we refer to pion, proton difference divided by the integrated flow of charged particles)

The text now reads:

“The features seen in the measurement of non-linear flow modes can be further studied by comparing to that of anisotropic flow coefficients. Such comparisons have been performed for  $v_{4,22}(\sqrt{s})$  (this study) and  $v_4(\sqrt{s})$  measurements [Acharya:2018zuq] by taking the difference between pions and protons at a given  $\sqrt{s}$  in both modes and normalising it by the integrated flow of the corresponding mode for charged particles [Adam:2016izf]. This comparison is shown in Fig. [massOrderingComparison] for 0-5% up to 40-50% centrality interval. In this figure, at low  $\sqrt{s}$  region ( $0 < \sqrt{s} < 2.5-3$  GeV) where mass ordering is prominent, the comparison shows two features. At very low  $\sqrt{s}$  values ( $\sqrt{s} < 0.8$  GeV), the ratio for  $v_4$  shows slightly lower magnitude with respect to that of  $v_{4,22}$  from 0-5% up to 20-30% centrality intervals. At more peripheral collisions, the ratios are compatible. This observation, though based on one datapoint, hints to different mass orderings in this  $\sqrt{s}$  region. If this difference and its centrality dependence persists for lower values of  $\sqrt{s}$ , it could indicate that hydrodynamic evolution is reflected differently in  $v_4$  and  $v_{4,22}$  and could be explained by the contribution of  $\epsilon_2^2$ . By increasing the  $\sqrt{s}$  value ( $0.8 < \sqrt{s} < 2.5-3$  GeV), this difference disappears which points to a similar mass ordering between  $v_4$  and  $v_{4,22}$  at this  $\sqrt{s}$  region. In the intermediate  $\sqrt{s}$  region ( $\sqrt{s} > 2.5$  GeV), the same comparison shows that the results are compatible in all centrality intervals within one standard deviation indicating similar particle type grouping in  $v_4$  and  $v_{4,22}$ . This observation suggests that quark coalescence affects both flow modes similarly.”

If you think we should modify the text or the figure please let us know.

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Cosmetics for plots

**I like what you did with the plots; if there is anything more we can do to make them even nicer we will do it better**

Answer: We will try to beautify the plots even further.

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Editorial

**L10: “...identified hadrons with reference particles from...” ==> “...identified hadrons with reference charged particles from...”**

Answer: done.

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**L11: “..contribution from second and...” ==> “...contribution from the second and...”**

Answer: done.

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**L12: “...anisotropy coefficients in higher flow harmonics.” ==> “...anisotropy coefficients to higher flow harmonics.”**

Answer: done.

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**L13: remove "(e.g. v2 and v3)"**

Answer: done.

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**L14: remove “measurement of the”**

Answer: done.

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**L15: “...the centrality percentile...” ==> “...centrality percentile...”**

Answer: done.

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**L40: “...of matter is called quark-gluon plasma...” ==> “...of matter is called the quark-gluon plasma”**

Answer: done.

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**L43: “...sensitive to the properties of the QGP is the azimuthal...” ==> “...sensitive to these properties is the azimuthal...”**

Answer: done.

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**L47: “....in the transverse plane. Through interactions...” ==> “...in the transverse plane which fluctuates from event to event. Through interactions...”**

Answer: done.

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**L58: “...(sQGP) but they have also constrained the value...” ==> “...(sQGP) but have also contributed in constraining the value...”**

Answer: done.

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**L59: “...( $\eta/s$ ) very close to the lower...” ==> “...( $\eta/s$ ) which is very close to the lower**

Answer: done.

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**L60: “...calculations [46] show that higher...” ==> “...calculations [46] showed that higher...”**

Answer: done.

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**L65: “...in a collisions according to...” ==> “...in a collision according to...”**

Answer: done.

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**L67-68: “Model calculations show that for non peripheral collisions,  $v_2$  and to a large extent,  $v_3$  are...” ==> “Model calculations show that  $v_2$  and to a large extent,  $v_3$  are...”**

Answer: done.

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**L68: “...linearly proportional to their corresponding...” ==> “...linearly proportional for a wide range of impact parameters to their corresponding...”**

Answer: done.

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**L70: “...initial anisotropic coefficient suggests...” ==> “...initial anisotropic coefficients suggests...”**

Answer: done.

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**L73-74: “...coefficient [48,49]. This dependence on lower order initial anisotropies gives rise to additional terms in the higher order flow coefficients.” ==> “...coefficient [48,49], where the second term reveals a non-linear dependence of  $e_4$  on the lower order  $e_2$ ”**

Answer: done.

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**L81: “...modes in higher order...” ==> “...modes for higher order...”**

Answer: done.

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**L87: “...showed that  $p_T$ ...” ==> “...showed that the  $p_T$ ...”**

Answer: done.

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**L89: “...of state and hadronic rescattering phase [53, 54] as well as particle...” ==> “...of state, the highly dissipative hadronic rescattering phase [53, 54] as well as probing particle...”**

Answer: done.

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**L90-91: Reverse “species at the LHC [37, 38, 40, 44] and RHIC [13–16].” i.e. first RHIC and the LHC**

Answer: done.

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**L91-92: “...between radial flow and anisotropic flow...” ==> “...between radial and anisotropic flow...”**

Answer: done.

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**L92: “...transverse momentum (pT)...” ==> “...transverse momentum...”**

Answer: done.

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**L98: “...coefficients exhibit number of...” ==> “...coefficients exhibit what is usually referred to as number of...”**

Answer: done.

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**L101: “...centralities challenge hydrodynamic...” ==> “...centralities could pose a challenge to hydrodynamic...”**

Answer: done.

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**L107: “...of the mass ordering and particle...” ==> “...of the particle...”**

Answer: we added respectively to associate the hadronic stage with the increased radial flow and in turn development of mass ordering...

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**L120: “The reported measurements are therefore...” ==> “The measurements reported in Section 6 are therefore...”**

Answer: done.

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**L140: “...for the hadron...” ==> “...for different hadron...”**

Answer: done.

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**L176: “...the energy deposition measured in the V0 detectors.” ==> “the signal magnitude measured in the V0 detectors which is related to the number of particles crossing their sensitive areas.”**

Answer: done.

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**L198: “...at  $p_T < 0.6$  GeV...” ==> “...at  $p_T \approx 0.6$  GeV...”**

Answer: done.

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**L209: “...purity was required to be 80%.” ==> “...purity was varied to more strict values” (maybe give an indicative number in parenthesis?)**

Answer: done. Removed the number.

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**L217: “...topology among reconstructed tracks.” ==> “...topology among pairs of reconstructed tracks.”**

Answer: done.

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**L231: “...first layer of the ITS.” ==> “...first layer of the ITS, where the occupancy is the largest.”**

Answer: done.

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**L239: “...utilising Bayesian PID...” ==> “...utilising the Bayesian PID...”**

Answer: done.

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**L240: “...of 85% using TPC and TOF detectors.” ==> “...of 85% using the TPC and TOF detectors.”**

Answer: done.

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**L241: remove “of phi candidates”**

Answer: done.

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**L251: “...multi-particle correlators” ==> “...multi-particle correlators given by”**

Answer: done.

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**L252: “...sub-event method which was originally...” ==> “...sub-event method originally...”**

Answer: done.

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**Eq.12-15 should be moved before Eq. 10-11**

Answer: Not sure if this is the best way. We think that it is best to first introduce these correlators and then  $v_n, m_k$ .

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**L259: "...technique by nature removes majority of non-flow..." ==> "...technique by construction removes a significant part of non-flow..."**

Answer: done.

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**L259-260: "In order to reduce residual..." ==> "In order to further reduce residual..."**

Answer: done.

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**L260-261: "...a larger pseudorapidity gap was applied between the two pseudorapidity regions." ==> "...a pseudorapidity gap was applied between the two pseudorapidity regions." mention here in the end the gaps applied**

Answer: done.

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**L263: "For inclusive charged hadrons,..." ==> "For charged hadrons,..."**

Answer: done.

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**L264-265: "...reconstructed on statistical basis from..." ==> "...reconstructed on a statistical basis from..."**

Answer: done.

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**L266: "Therefore, for the aforementioned particle species, the..." ==> "Therefore, the..."**

Answer: done.

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**L267: "...and pT per centrality percentile." ==> "...and pT for each centrality percentile."**

Answer: done.

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**L285: "...as topological reconstruction..." ==> "...as the topological reconstruction..."**

Answer: done.

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**L301: "...are used to hybrid mode..." ==> "...are used to what is referred to as hybrid mode..."**

Answer: done.

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**L312-313: remove “The default V0 finding method is described in Sec. 3.3.”**

Answer: done.

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**L315: “...to the primary...” ==> “...from the primary...”**

Answer: done.

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**L325: Add a last paragraph that connects the previous text with the tables and explain also in the text what these tables contain!**

Answer: done.

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**L327: “...the results for the pT-dependent...” ==> “...the results of the pT-dependent...”**

Answer: done.

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**L331: “...are compared with vn measurements in Sec....” ==> “...are compared with the total vn measurements for the same particle species in Sec....”**

Answer: done. Although, not sure if we should use the word total or not.

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**L331-333: “Note that the same...highlight the physics implications of the measurements in each section.” ==> “Note that in some of the following sections the same...highlight the various physics implications of the measurements in each section.”**

Answer: done.

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**L337: “For  $\phi$ -meson,...” ==> “For the  $\phi$ -meson,...”**

Answer: done.

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**L339: “...expected as v4;22 measures...” ==> “...expected as v4;22 reflects...”**

Answer: done.

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**L340: “...which increases for peripheral collisions...” ==> “...which increases from central to peripheral collisions...”**

Answer: done.

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**L342: “...observed also in vn measurements...” ==> “...observed also in the total vn measurements...”**

Answer: The same answer as above. Not sure if we can call it total vn...

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**L359: “...at all collision centralities.” ==> “...for all collision centralities.”**

Answer: done.

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**L360: “...between the anisotropic flow and radial flow. Radial flow...” ==> “...between radial flow and the coordinate space anisotropy, created from both the geometry and the fluctuating initial energy density profile. In particular, radial flow...”**

Answer: done.

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**L361: “...which leads to lower  $v_4\{2\}$  for heavier...” ==> “...which becomes larger in- than out-of plane due to the velocity profile. This naturally leads to lower  $v_4\{2\}$  at a given value of  $p_T$  for heavier...”**

Answer: done.

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**L367-370: "In particular,  $v_n\{m\}$  of mesons (p, K, K<sup>0</sup>S and f) and baryons (p+p. and L+L. ) group based on their type, with  $v_n\{m\}$  of baryons having a larger magnitude. This particle type grouping was previously observed in the anisotropic flow measurements of various particle species [13–16, 37, 38, 40]. This suggests that flow...” ==> “In particular, the data points form two groups, one for mesons and one for baryons with the values of  $v_n\{m\}$  of the latter being larger. This particle type grouping was previously observed in the total  $v_n$  measurements of various particle species [13–16, 37, 38, 40]. This could suggest that flow...”**

Answer: done.

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**L372: “As a next step it was suggested...” add reference**

Answer: done.

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**L374: “This scaling, worked...” ==> “This worked...”**

Answer: done.

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**L380-381: “...scaled by the inverse of number of constituent quarks...” ==> “...scaled by the number of constituent quarks...”**

Answer: done.

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**L384: “Similarly, for non-linear flow modes this scaling...” ==> “It is seen that for the non-linear flow modes this scaling...”**

Answer: done.

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**L386: “The comparisons of the anisotropic...” ==> “The comparison of various anisotropic...”**

Answer: done.

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**L387-388: “measurements at ALICE [40]...” ==> “measurements reported by ALICE [40]...”**

Answer: done.

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**L395: “TRENTo [81] initial conditions...” ==> “The version of the model that uses TRENTo [81] initial conditions...”**

Answer: done.

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**L396: “...between vn measurements...” ==> “...between the total vn measurements...”**

Answer: same as before, not sure if we can call it total vn.

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**L399: “...than TRENTo model...” ==> “...than the TRENTo model...”**

Answer: done.

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**L400-401: remove “Recently, it was shown that the pT-integrated non-linear flow modes are good observables to constrain the initial conditions and transport properties of the system [52].”**

Answer: done.

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**L404: “...with two hydrodynamical calculations from [76].” ==> “...with the same two hydrodynamical calculations reported in [76].”**

Answer: done.

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**L410: “...ordering feature in pT...” ==> “...ordering feature at pT...”**

Answer: done.

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**L413: “...reproduce the measurements for 40-50% and 50-60%. AMPT overestimates...” ==> “...reproduce the measurements for the remaining two more peripheral centrality intervals. On the other hand, AMPT overestimates...”**

Answer: done.

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**L415: “...underestimates the pi measurements.” ==> “...underestimates the results for pi”**

Answer: done.

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**L417: “...data better; it slightly...” ==> “...data better, it slightly...”**

Answer: done.

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**L421: “...comparisons...” ==> “...comparison...”**

Answer: done.

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**L424: “...In order to compare the performance of these two models in  $v_n$  and  $v_{n;m}...$ ” ==> “...In order to compare their performance in describing the total  $v_n$  and  $v_{n;m}...$ ”**

Answer: done.

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**L426: “The ranges in these tables present the minimum and maximum value of a constant fit to the relative ratios obtained from most-central to mid-peripheral collisions.” ==> “The values represent the ranges across all centralities that each model is able to describe the measurements of each particle species and  $v_{nmk}$  (Table 3) or total  $v_n$  (Table 4)”**

Answer: done.

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**L434: “wrt” :P**

Answer: Done