We would like to thank all reviewers for the useful comments and suggestions, which definitely helped us to improve the quality of our manuscript. Hereby we provide a detailed response to the comments and questions raised by Reviewer #2. (The original comments of the reviewer are written using bold fonts, while our responses are with normal fonts.)

Replies to the major comments of the reviewer

The present graupel and snow particles are artificial and limitations of representativeness of the lab data arise. The fact that the snowflakes were created by manually clumping together some dendritic crystals needs to be mentioned in the concluding section and in the abstract.

Following the Reviewer's suggestion, we added in the abstract (line 6):

"The particles were synthetically generated within a cold room through two distinct methods: riming and vapor deposition for graupel with diameters of 2 mm and 4 mm, and by manually sticking vapor grown ice which were generated above a warm bath to form snowflakes with a diameter of 10 mm."

Further, we added in the conclusion (line 479):

"Nevertheless, it is important to note that the present conditions, characterized by high ice supersaturation and large particle size, may not be representative for most ice crystals in clouds. To overcome this limitation, it is necessary to conduct future experiments with technical improvements to explore collisions at lower ice supersaturation levels and with smaller aggregate sizes. We presume that our results are more representative for fragmentation occurring above water saturation, where fragile ice crystals tend to form. To apply our results to a microphysics scheme, it is crucial to consider these factors for precautionary purposes."

And at line 471 we added :

"The snowflake was manually created by sticking dendritic ice crystals monomers together, this method can be improved in the future to have more realistic particles."

Although high numbers of fragments are reported for graupel-graupel and graupel-snow collisions, the morphology of the artificial particles observed are extreme. There is a lack of representativeness. For example, the snow particles studied are 1 cm wide. But most snow particles are smaller than this in any size distribution. Also, the fragility of the snow particle and the number of monomers near the collision path of the incident graupel will increase with the snowflake size.

Of course, laboratory experiments cannot completely represent collisions of particles as occur in clouds. Nevertheless, one important aspect for us was to carry out graupel-graupel and graupel - snowflake collisions in free fall. This limited us to using large particles for the moment for technical reasons. We intend to conduct collision experiments with particles of smaller sizes in the future. The limitations of our current experiments are mentioned in the revised manuscript in line 321: "*The growth of dendrites on the graupel surface that occurs under high supersaturation conditions is faster than at low* *supersaturation, and therefore, may result in a more fragile ice crystal structure. This might lead to more fragments produced by graupel-graupel with dendrites collisions compared to ice crystals growing at lower humidity. Cloud graupel may experience several growth processes that influence their surface properties, making their fragility dependent on their growth history. Consequently, graupel collisions of the same size, with the same collision kinetic energy, can yield different fragment numbers due to their distinct surface properties."*

The fact that the snowflake is large (1 cm) can be at least partly fixed using Phillips et al (2017) theoretical formulation. Nevertheless, we addressed this constraint in the new section "Limitations of the experiments"

In reality, the proposed parameterization (Eq 3) does not necessarily apply to most snow particles, because a crucial quantity is missing: area of contact. These limitations need to be discussed in the concluding section. The proposed parameterization should be adapted to apply to a wider range of particle sizes if possible. Area of contact could be introduced as a multiplying factor into Eq (3).

We decided to remove Eq. 3 and to replace it by Eq. 2 which corresponds to the fit our results on the theory of Phillips et al. (2017) and considers the area of the smallest particle. This allows us to rescale our results in terms of particle size and apply our results to smaller sizes of particles.

I think the title should be changed to convey the fact that the particles being studied are artificial and this should also be highlighted in the abstract. The abstract and conclusions sections need to state clearly the sizes of particles studied.

The fact that the ice particles were generated artificially inside the cold room is now added in the abstract '*The particles were synthetically generated in the cold room through two distinct methods: riming for graupel with diameters of 2 mm and 4 mm, and by manually sticking vapor grown ice which were generated above a warm bath to form snowflakes with a diameter of 10 mm*.'

Furthermore, we added to Conclusion:

"In the second series of experiments the collisions of a 4 mm graupel and a dendritic ice crystal aggregate of 10 mm diameter as proxy for a snowflake were studied. The snowflake was manually created by sticking dendritic ice crystals monomers together, this method can be improved in the future to have more realistic particles"

The size of graupel particle for graupel collisions were already mentioned in the conclusion.

Adding the word 'artificial' or a synonymous term to the title might imply that our crystals are not composed of ice; but instead, they might originate from a different material, e.g., employing 3D printing technique. This could potentially confuse the readers. In contrast, other papers featuring lab-grown ice crystals don't include any terminology related to this characteristic in their titles (e.g., Takahashi et al., 1995). Moreover, lab studies working with natural (i.e. not artificially generated) particles emphasize that including the word "natural" in their title.

Furthermore, in our opinion, the inclusion of the term "artificial" could undermine the credibility of our work and negatively impact the interest for our article. This would be regrettable, particularly considering the scarcity of existing publications on fragmentation during ice-ice collisions. We rather added the quoted elements of the lines to inform the readers of the particle creation process. For the reasons discussed above we decided not to modify the title of our manuscript.

It needs to be specified under what conditions of LWC and temperature the vapour growth can prevail such that the dendritic crystal can grow on the graupel, so that the graupel-graupel results are valid.

Thank you for this comment. We added a sentence about that in line 467: "The dendritic crystals grown on the surface of graupel enables the production of many fragments during collisions, differing from a completely rimed surface. Future studies are required to investigate how this transition (observed in Korolev et al, 2004) can affect collision fragmentation under different humidity and temperature conditions. "From Korolev et al, 2004 it seems that the drops remain spherical if the supersaturation is less than half of that of water. Hence, we can suppose that fragmentation by collision is less effective for ice crystals staying at low humidities and more efficient for ice crystals at higher humidities where the vapor growth prevails.

Replies to the detailed comments of the reviewer

Line 36: Other modeling studies can also be cited that use this breakup scheme: Waman et al. (2022,JAS), Sotiropolou et al. (2021, 2022), Zhao et al..

We extended the list of publication using this breakup parameterization scheme, like Sotiropoulou et al., 2020, 2021; Zhao et al., 2021; Huang et al., 2022; Karalis et al., 2022; Waman et al., 2022; Patade et al., 2022.

Line 49: It is not true that Phillips et al. wrote that use of a fixed target could falsify results. In fact, they argued the opposite: "On the one hand, for head-on collisions the fixing of the target boosted the initial CKE without appreciably altering the energy-based coefficient of restitution q governing fragmentation. In the present paper, the laboratory observations were used only by relating fragment numbers to the initial CKE, so there is no problem in this respect.". It is important to read the papers that are cited.

Sorry for the false citation and the misunderstanding statement in the original manuscript. We wanted to express that the use of a fixed target could affect the results due to the non-rotation of the particles after the collision. However, it is apparent that this aspect created a debate. We therefore modified our sentence in line 52 to " *Furthermore, Korolev and Leisner (2020) pointed out that rotational energy should be considered for collisions. This is not the case in Vardiman (1978) where a fixed target was used, which may overestimate the number of generated fragments. Nevertheless Phillips et al. (2021) argue that this final rotational energy is just a small fraction of the initial CKE and that this issue can be solved applying Phillips et al. (2017) theory.* " We hope that this will allow the reader to be informed clearly about this aspect with reference to two points of view.

Line 76-77: It is not true that both colliding spheres were fixed during and after collision. Phillips et al. never wrote that. Only one of the colliding spheres was fixed. Of course, this artificially boosted the CKE. But as noted above, that is not really a problem, if the analysis is done in terms of CKE, relating it to the number of fragments.

We apologize for the unprecise formulation. We removed this part from the revised manuscript and changed the paragraph (line 80) to "Since the mass of the ice spheres of 1.8 cm and their contact area in Takahashi et al. (1995) experiment exceeded by far that of a natural graupel, the CKE resulted in an unnaturally large number of ice crystal fragments as highlighted by Korolev and Leisner (2020). However, Phillips et al. (2017) argue that this issue can be fixed using their theoretical scheme for fragmentation during collisions."

Line 282: This Equation (3) is simplistic because it neglects the role of the area of contact during impact, which depends on the particle sizes.

We agree that this equation is too simplistic and should be replaced by a more appropriate expression. This is why we introduced the Phillips et al. (2017) (line 96) equation relating the number of ice crystals to the CKE (Eq. 2 in the revised manuscript). We fit our results in terms of fragility asperity coefficient and number of asperities per surface area.

Line 283-284: The maximum emission of fragments beyond a certain CKE was not merely "expected", but rather was observed in Takahashi's published data when analysed by Phillips et al. (2017) in terms of CKE.

Yes, thank you for the comment. We modified the sentence (line 300) which now reads "It is expected that a maximum of ice fragments is reached at a certain CKE regarding Takahashi et al (1995) experiments and Phillips et al. (2017) theory."

Line 304: What is really needed for use of the graupel-graupel results is the critical LWC and temperature range, for which the dendritic growth prevails at the surface. Outside of these conditions, there will be no fragmentation because the surface will be rimed and any depositionally grown ice will be continually buried by fresh rime.

The LWC and temperature for riming process is given in table 1: -15°C and 2.2/2.3 $g.m^{-3}$

For vapor deposition: 23% ice supersaturation and -13/-15°C.

Line 386: There was no intention to "rime" (accretion of supercooled droplets) the ice spheres in the Takahashi et al. lab experiment. The purpose of their controlled supply of supercooled cloud-liquid was to control the time of exposure to high humidities and vapour growth of ice.

We deleted "and riming in still air" from this sentence to avoid misleading formulation.

Line 375-400: The concluding section needs to discuss the limitations arising from the fact that all particles studied in the present paper are artificial. What conditions of LWC and duration of exposure are needed for graupel in a simulation to be representative of the artificial graupel observed here ? The artificial manner of creation of these particles must be discussed.

Thank you also for this suggestion. We rewrote the conclusion section and added in line 479: " *Nevertheless, it is important to note that the present conditions, characterized by high ice supersaturation and large particle size, may not be representative for most ice crystals in clouds. To overcome this limitation, it is necessary to conduct future experiments with technical improvements to explore collisions at lower ice supersaturation levels and with smaller aggregate sizes. We presume that our results are more representative for fragmentation occurring above water saturation, where fragile ice crystals tend to form. To apply our results to a microphysics scheme, it is crucial to consider these factors for precautionary purposes. .*"

Furthermore, we added a new section to the manuscript that is dedicated to discuss the constraints of our experiments results.