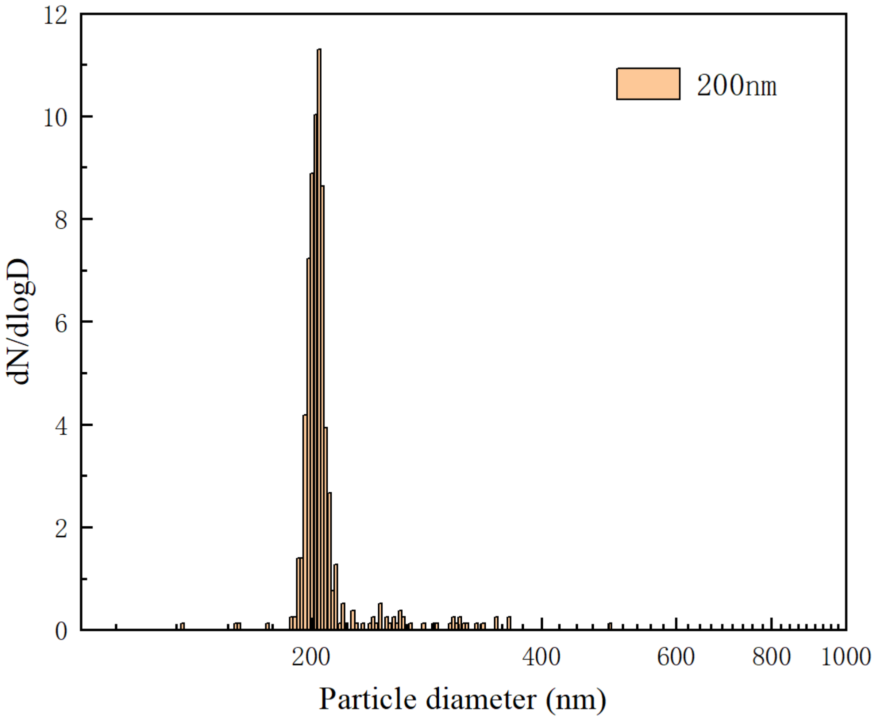
Answer for Major comments:

Q1: There are multiple lines of evidence that put the experimental TE results of Fig 7, and the uncanny agreement with simulation, into question. A) Most of the values are exactly 100%, which is highly suspect, and include no error bars showing variability. B) As written, the reference system for submicron sizes (a CPC without a DMA) is incapable of accurately counting PSL generated by nebulization, assuming that many (typically very many) non-PSL (surfactant) particles are also generated. C) The simulated particle trajectories in Fig 6 show that particle beam widths at the detection laser(s) are much larger than a typical SPAMS laser beam width (Du et al., 2024). Therefore a large fraction of the simulated particles would not be detected by SPAMS, and experimental TEs cannot be at or near 100%. Furthermore, it is very likely that these simulated beam widths provide a lower limit, and the actual particle beam widths are probably much larger.

A1: We thank the reviewer for the careful examination of the paper. For issues (a) and (b), the authors performed experimental tests on the transmission efficiency of PSL spheres using SMPS. The figure below shows the particle size distribution when generating 200 nm particle, indicating that the produced particles are primarily 200 nm, with no smaller particles generated. The calculation of transmission efficiency has been defined in Section 2.3, and specific test results are shown in Fig. 6, with error bars added based on the experimental results. Regarding issue (c), the authors would like to clarify that the Bio-SPAMS used in this study is not the same as Du et al.'s HP-SPAMS, and a different laser is employed. This study utilized the Sony SLD3234VF laser, which has a beam width of 3 mm, larger than the beam width shown in Fig. 6, thus it will not affect particle counting.



Q2: There is much confusion surrounding the presentation of results for "new" and "old" systems. The new design for the current study is presented in Fig 1, the "PFW-Alens". The old system is that of Du et al., 2023. However, the simulations in Fig 5 present what is apparently a mix of the Du 2023 design (large buffer region, skimmer style VI) and the current design (5 focusing stages) for all five panels, despite that these are described in the text as the PFW-Alens. "New" and "old" designs are compared in Fig 5a & 5b, but these are again just the Du design with and without a pre-focuser. Confusingly, the final Du 2023 design contains a pre-focuser, so it's unclear what Fig 5b ("old") refers to. Consequently, the simulated transmission efficiency (TE) results of Fig 3 are also in question. Which design was simulated for the "Present Study" lines?

A2: Thank you for the valuable comments. The systems have been renamed in the article. As introduced in Section 3.1, "this study first removed the virtual impactor and pre-focus structure from Fig. 1 and simulated the transmission efficiency of the model (represented by the blue left triangle line). Subsequently, the virtual impactor (orange diamond line, original design) and the pre-focus structure (black square line, present design) were sequentially reintroduced to observe the enhancements in transmission efficiency." Additionally, the model in Fig. 1 has been updated to include details such as the virtual impactor to avoid any misunderstanding for the readers. Fig. 5 has also been modified accordingly, where Fig. 5(a) and (b) respectively show the transmission trajectories of 5 μm particles in both the design of this study and the original design, highlighting the advantages of the pre-focus structure in this study. Meanwhile, (c) and (d) display the transmission trajectories of 8 μm and 10 μm particles under the design of this study, demonstrating the advantages of this structure in transmitting larger particles. The line used in Fig. 3 (black square line) corresponds to the design shown in Fig. 1.

Answer for Minor comments

Q1: General. The text needs another editing pass with a focus on sentence structure and verb tense. Examples of grammatical problems and repetition are lines 29-31, 89-92, 196-199, 232-233, 241-245, 303-305, although the problems occur throughout. Also, it is strange that simulated transmission efficiency is discussed in two separate places: section 3.1/Fig 3 and section 3.3/Fig 6. Consider combining those two Figures, e.g., as a single figure with two panels, along with their associated text. Also use consistent terminology throughout, e.g., choose either “inlet” or “injection system”.

A1: Thank you for identifying and correcting several spelling and grammatical errors in my article, which has improved its overall quality. The author has modified the sentence structures, verb tenses, and some complex sentences throughout the text, as well as standardized the term “injection system” for better readability. Regarding the transmission efficiency curves in the original Figures 3 and 6, the revised manuscript has combined these into a new Fig. 3.

Q2: Line 18, 271, 309. Clearly this newly designed aerodynamic lens is not a “PM2.5” lens – it transmits much larger particles! Omit this terminology or explain.

A2: We thank the reviewer for the careful examination of the paper. The revised manuscript has removed the description of PM2.5 lenses.

Q3: Line 28. Define APS.

A3: We thank the reviewer for the careful examination of the paper. The revised manuscript has rewritten the description of APS as follows: "In the testing of standard dust, the wide-range particle size distribution obtained by the new injection system is highly consistent with Aerodynamic Particle Sizer (APS)".

Q4: Line 52-60. The brief summary of previous aerosol inlets gives helpful context. However, the size ranges given seem arbitrarily chosen. For instance, while the Zelenyuk inlet transmits the given size range of 125-600nm at near 100% transmission efficiency (TE), their inlet transmits a much wider size range out to ~1.5um or larger at lower but still useful efficiency for SPMS studies. Modify the text to clarify the given range, for instance, if they denote the peak of the TE for each inlet, or the range where TE approaches 100%.

A4: Thank you for your feedback. The transmission range mentioned in your comments is defined as the particle diameter range where the transmission efficiency exceeds 50%. The revised expression in the article is as follows: "We typically assess the particle transmission capacity of injection systems by considering the range where the transmission efficiency exceeds 50%.".

Q5: Line 104. It would be much clearer to the reader if the authors stated clearly that the purpose of the study is to design a miniaturized version of the Du et al., 2023 inlet that gives similar performance.

A5: Thank you for your feedback. In fact, although the injection system designed in this paper is similar in performance to that of Du et al., it outperforms their design in terms of the composition of the pre-focus structure and the performance of the particle beam width. Additionally, it employs a smaller buffer chamber and fewer stages of aerodynamic lenses. Therefore, it cannot be simply regarded as a miniaturized version of Du et al.'s design.

Q6: Line 125 Fig 1 shows a disc at the downstream end of the separation cone that provides an inner diameter reduction. What is the effect of that diameter reduction (presumably to 1.6mm – please add a label)? Does it provide a pressure drop so that separation cone acts as a better virtual impactor? Or is it a skimmer? Later in the manuscript (section 3.1) and also in the abstract, the authors refer to a virtual impactor, but it is not shown in Fig 1. Add a description of how the cone acts as a virtual impactor, and perhaps how it compares in design to Du 2023, which is quite different, and update your terminology in Section 2.1 accordingly.

A6: Thank you for the valuable comments from the reviewer. The revised manuscript has adjusted Fig. 1, which now includes additional details such as the virtual impactor and the differential vacuum after the nozzle. The design of the virtual impactor is largely consistent with that of Du et al.

Q7: Line 129. It seems important to mention that the accelerating/downstream nozzle has a tapered cone just upstream. Presumably, this reduces impaction, and it will also affect the trajectories of particles entering the particle sizing region. State any known effects of this converging nozzle design.

A7: Thank you for the valuable comments from the reviewer. The revised manuscript has added a description of the conical nozzle and highlighted its advantages. The revised description is as follows: "In addition, this study utilized a smooth nozzle at the end of the aerodynamic lens. As mentioned by Zhang et al. (2004) in their study, this nozzle provides better collimation for small particles and improves the transport efficiency of large particles compared to stepped nozzles."

Q8: Section 2.1. It appears that Du et al., 2023 used a differentially pumped region between the aerodynamic lenses and the downstream nozzle, whereas the current study does not. State any ramifications of this design difference (is it just simpler?).

A8: Thank you for your feedback. In fact, this study also employs a differential pumping design between the nozzle and the vacuum chamber. To avoid any misunderstanding, the revised manuscript has added this detail in Fig. 1

Q9: Line 139. I don't quite follow the pressure descriptions. Please clarify. Are the two pump-out lines on the “separation cone” fixed at 600 Pa? Is 300 Pa a fixed pressure, or is that the approximate pressure aerodynamic lens pressure that results from the calculation? Other parameters of interest to include would be the volume flow rate through the upstream critical orifice, the lens pressure, and the pressure drop down the lens stack.

A9: Thank you to the reviewer for your meticulous review; your suggestions have encouraged us to present our findings more effectively. In this study's simulation setup, the boundary pressure at the inlet is set to 101325 Pa, the boundary pressure at the pump outlet of the virtual impactor is set to 600 Pa, the boundary pressure at the nozzle outlet is set to 1 Pa, and the boundary pressure at the vacuum chamber outlet is set to 0.01 Pa. The mentioned pressure of below 300 Pa in the buffer chamber and lenses refers to the internal pressure under the constraints of the above boundary conditions. This explanation clarifies that the pressure conditions are intended to align with the study by Zhang et al. to ensure the accuracy of the model setup.

Q10: Line 143. Presumably the critical orifice region contains non-laminar and supersonic flow. Does the viscous model treat this region appropriately? Also state whether any symmetry was enforced for the simulations.

A10: Thank you to the reviewer for your meticulous review. In fact, the simulation conditions used in this study are consistent with those employed by Zhang et al. and Du et al. in their numerical simulations, both utilizing a laminar flow model for calculations. Additionally, to reduce computation time, the model used in this study is a two-dimensional axisymmetric model.

Q11: Lines 143-147. Several sentences are poorly written. Please re-write to clarify. What is DPM? What are cloud images? What is the UDF that you refer to?

A11: We are grateful for the reviewer's recommendations; your input has clarified several key points in our research. DPM refers to the Discrete Phase Model, which is used to simulate the motion of discrete phases (such as particles) in a fluid. The term “cloud images” was incorrectly translated and has been changed to “contours.” UDF stands for User-Defined Functions, which add volume forces such as Brownian and drag forces to Fluent through a compiled program, allowing for more accurate particle motion.

Q12: Section 2.3. Mention why the additional airflow in the upper right of Fig 2 is needed and how it is used your TE calculation.

A12: Thank you to the reviewer for your valuable insights; we have incorporated your suggestions to enhance the overall quality of our paper. In Fig. 2, the airflow in the upper right corner is primarily intended to match the flow rate differences among the experimental devices. As mentioned in the text: "It is important to note that during the experiment, we utilized additional airflow. For experiments involving particles smaller than 1 μm, this additional airflow was implemented to..." By balancing the flow rates of the various devices, this study calculated the transmission efficiency using the ratio of the number of particles.

Q13: Line 154. Give a model number or describe the ICPMS atomizer.

A13: Thank you for your feedback. The model of the atomizer has been added, and the revised manuscript describes it as follows: "Initially, the PSL solution is diluted with pure water, after which nitrogen serves as the carrier gas to atomize the PSL solution using an ICPMS atomizer (Ge, C21-1-UFT02)."

Q14: Line 167. Define APS 3321. Describe how aerodynamic diameter is measured.

A14: Thank you to the reviewer for your expert feedback; your recommendations have been beneficial in refining our conclusions. The revised manuscript has been changed to APS3321. Additionally, the diameter measurement method used by Bio-SPAMS is similar to that of APS, so the principles of laser diameter measurement for both have also been included in the text. Specifically, it states: "The first diameter measuring laser is designed with a beam-splitting optical structure similar to that of the APS 3321. The method involves using a beam splitter to divide the diameter measuring laser (Sony SLD3234VF) into two nearly parallel beams and calculating the aerodynamic diameter of the particles by the time they pass through these beams."

Q15: Line 169-170. The PMT detections for which laser, the first or second? State what % of particles detected by the first PMT are also detected by the second PMT.

A15: Thank you for your feedback. PMT1-1 is used to detect the number of particles. Therefore, the calculation of transmission efficiency in this study is based on the counts from PMT1-1. During the research process, we found that there was essentially no loss in transmission between the two PMTs, and this result can also be validated by the transmission trajectory shown in Fig. 5.

Q16: Line 172-173. Presumably, you are also accounting for the flow rates into the instruments (and any dilution flow)? State all the flow rates.

A16: Thank you for your feedback. The revised manuscript has labeled the flow rate into the instrument in Fig. 2.

Q17. Line 175. Nebulized PSL solutions typically produce polydisperse particles containing surfactant, which can greatly outnumber the PSL particles. How are these non-PSL particles accounted for in the TE calculation, both for the supermicron and sub-micron setups, particularly since the CPC cannot distinguish between PSL and surfactant particles? Can you show a size distribution of the generated particles?

A17: Thank you to the reviewer for your meticulous review. This study utilized SMPS to test the transmission efficiency of small particles. The response to question 1 also confirmed that no other particles were produced to affect the count when measuring the 200 nm particle. Other experimental test results are shown in Fig. 6, where the lower transmission efficiency for the 100 nm particles is due to the Bio-SPAMS used in this study having fluorescence detection capability. As a result, the energy of the two beams of the first laser was adjusted to a ratio of 70:30, which led to a weaker bimodal signal for the 100 nm particles, ultimately resulting in a lower efficiency.

Q18: Line 185. It is not clear what the authors refer to as a "virtual impactor", particularly an inlet design that does not contain one. For the "without VI" case, what part was removed in Fig 1? Note that in general, any type of transverse pumpout design like the separation cone presented here will act as a VI to some extent for large particles. Please clarify VI and without VI throughout this section.

A18: Thank you to the reviewer for your meticulous review. The revised manuscript has added a schematic diagram of the virtual impactor structure in Fig. 1.

Q19: Section 3.1. Since virtual impactor is mentioned frequently, state the approximate particle size above which the VI becomes effective, ie, where nearly all particles are transmitted downstream and very few are being pumped out. From Fig 3, it appears that ~90% of 100 nm particles are transmitted downstream and are not pumped out, correct?

A19: We deeply appreciate the reviewer's constructive criticism; your insights have helped us address potential oversights in our work. Simulation results indicate that the VI achieves a transmission efficiency of nearly 90 % for particles larger than 100 nm. Additionally, the comparison without VI and the pre-focusing sampling system is shown in Fig. 3, depicted by the blue left triangle curve. The definition of transmission efficiency has been added to the text as follows: "The transmission efficiency presented in this study is the ratio of the number of particles at a distance of 110 mm from the lens outlet to the number of particles at the inlet of the sampling system."

Q20: It is difficult to see the data points that are on top of one another.

A20: Thank you to the reviewer for your meticulous review; your suggestions have encouraged us to present our findings more effectively. To increase the visibility of overlapping data points, the symbols of some curves are changed to hollow.

Q21: Line 237-239. The argument about how particle acceleration in the pre-focus stages affects downstream divergence angle is not convincing, and I believe it is incorrect. In both the Du and present designs, the particles achieve the same maximum velocities when passing through the critical hole, regardless of whether the pre-focus stages accelerate them or not. Consider instead the difference in radial distributions between the Du pre-focus design and the current one (Fig 5a). The strong downstream divergence in the Du design is due to the wider radial distribution and higher incident angle as particles approaches the critical hole. Reconsider these arguments and update text accordingly, in this section and the abstract.

A21: Appreciation is extended for the reviewer’s valuable comments. Regarding the distribution of axial velocity, it is indeed true that, regardless of the structure of the injection system, particles achieve the same maximum velocity when passing through the critical orifice. To facilitate a better comparison of the performance of different systems, the comments have been taken into account, and the velocity distribution plot has been changed to a comparison of the beam widths of different particles at various positions within the sampling system, along with an analysis, as shown in Fig. 4.

Q22: Line 239. Clarify “degree of change”

A22: Thank you to the reviewer for your meticulous review. The revised manuscript has removed the description of the impact of the pre-focusing structure on particle velocity. In the previous version, this section aimed to demonstrate that the addition of a pre-focus structure could improve the transmission range of the lens from 5 μm to 10 μm.

Q23: Fig 4. Axial velocity varies considerably across the diameter. Are these average velocities, centerline velocities, … ? Also, add labels for the different parts of the inlet system at the appropriate axial ranges.

A23: We appreciate the reviewer's thorough evaluation; your constructive remarks have guided our revisions significantly. The velocity distribution map has been deleted, and the revised manuscript has added a comparison of beam widths for different particles at different positions in the injection system, as shown in Fig. 4.

Q24: Fig 5. Can you comment on particle divergence in the vacuum region (downstream of the last nozzle), and how it changes with size? Presumably the converging nozzle design is advantageous here.

A24: We greatly appreciate the reviewer's comments; your guidance has been invaluable in shaping the final version of our manuscript. The injection system in this study, under the influence of the newly designed pre-focusing structure, significantly reduces the particle beam width. After focusing through five stages of lenses, the particles exhibit minimal noticeable divergence upon exiting the converging nozzle, as demonstrated by the full movement trajectories at 8 μm (Fig. 5(e)) and 10 μm (Fig. 5(f)). In fact, recent simulation studies have found that reducing the number of lens stages to three can still achieve the transmission range presented in this study.

Q25: Also, add a velocity color scale, with consistent scaling for all panels.

A25: Thank you to the reviewer for your expert feedback. A colormap has been added; however, Fig. 5 primarily aims to illustrate the loss of particle transmission, for which the particle ID colormap has been selected. The color scale allows for understanding where the losses occur for the particles. As for the differing scale ratios in (e) and (f), this is intended to showcase the global flow trajectories of larger particles.

Q26: Line 260. Why 110mm?

A26: Thank you to the reviewer for your meticulous review; your suggestions have encouraged us to present our findings more effectively. In fact, all lasers are located at a position less than 110 mm from the nozzle outlet, so the author chose 110 mm to demonstrate that good beam width and transmission efficiency can still be maintained at a distance from the laser.

Q27: Line 265. State how the particle beam width compares with the beam waist (at focus) for both detection lasers.

A27: Thank you to the reviewer for your expert feedback. By analyzing Fig. 5 and Q26, it can be determined that there is no noticeable divergence or expansion of the particle beam after exiting the nozzle.

Q28: Fig 6 & 7. Are the black lines the same as Fig 3 black line? Why are the simulated TE values different between Fig 6 and 7? The data are plotted versus “aerodynamic diameter”, which is probably determined under the vacuum conditions of the SPAMS instrument, rather than continuum aerodynamic diameter as is typically defined. Clarify.

A28: We appreciate the reviewer's thorough evaluation; your constructive remarks have guided our revisions significantly. The differences in TE between the simulations may be attributed to the author not selecting the same number of particle beams while processing data on different computers. The author has standardized the displayed number of particles and modified the values in the three figures. As for the X-axis in the figures, the revised manuscript has also adjusted it to represent particle diameter. However, it should be noted that the Bio-SPAMS used in this study also employed particle size calibration in the particle size measurement section, determining the aerodynamic diameter of the particles based on their flight time.

Q29: Line 291. Remove all-caps. List vendor. Also, mention something about the experimental sampling setup – is it identical to Fig 1 green lines.

A29: Thank you to the reviewer for the suggestion; the supplier of the standard dust sample has been added. The revised text is as follows: “To characterize the analytical capabilities of the PFW-ALens for large particles, standard ultrafine dust (ISO 12103, PTI) was selected as the test sample.” The experimental sampling setup is consistent with the green line in Fig. 2.

Q30: Fig 8. Are the lines calculated as the average over seconds/minutes/hours? State in the caption. The APS line appears smoothed – is it? Clarify the y-axis – is it normalized dN/dlogD or normalized counts? Clarify “aerodynamic diameter”, which I suspect is continuum for the APS and vacuum for SPAMS. If a conversion was done, what density and shape factor were applied? In general, it is reasonable to plot normalized size distributions as the authors have done here. However, it would be even more informative to plot absolute concentration, say as dN/dlogD, which then provides another demonstration of TE but now for non-spherical particles. Optional, at the authors’ discretion.

A30: Thank you to the reviewer for your expert feedback; your recommendations have been beneficial in refining our conclusions. These lines are calculated based on a 3-minute average and have been added to the title, which now reads: “3-Minutes Average Particle Size Distribution of Standard Dust Across Different Injection Systems.” Additionally, the Y-axis represents dN/dlogD, while the X-axis is selected as particle diameter, which has been calibrated based on flight time.

Q31: Line 307. Add Du 2023 reference, just to be clear what is meant by “traditional”
A31: We greatly appreciate the reviewer's comments. The mention of the design by Du et al. has been added in the conclusion to improve readability. The revised text is as follows: “This injection system incorporates a new pre-focus structure, which effectively minimizes the dimensions of the buffer chamber and the number of lenses compared to traditional pre-focus injection systems, such as the work by Du et al.”. Regarding the two references mentioned by the reviewer, namely Du, X.; Zhuo, Z.; Li, X.; Li, X.; Li, M.; Yang, J.; Zhou, Z.; Gao, W.; Huang, Z.; Li, L.'s “Design and Simulation of Aerosol Inlet System for Particulate Matter with a Wide Size Range. Atmosphere 2023, 14, 664. https://doi.org/10.3390/atmos14040664” and Du, X., Xie, Q., Huang, Q., Li, X., Yang, J., Hou, Z., Wang, J., Li, X., Zhou, Z., Huang, Z., Gao, W., and Li, L.'s “Development and characterization of a high-performance single-particle aerosol mass spectrometer (HP SPAMS), Atmos. Meas. Tech., 17, 1037–1050, https://doi.org/10.5194/amt-17-1037-2024, 2024,” they have been referenced in the previous version of the manuscript.