15th ETH Conference on Combustion Generated Nanoparticles
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Investigation of Solid Particle Number Measurement Smaller than 23nm

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Particulate emission of vehicles has been regulated by mass so far. And, the particle number regulation has been newly introduced from Euro5b. Recently, particles smaller than 23nm draw people's attention. According to JRC report, if particles smaller than 23nm are included, not only GDI but also PFI would not achieve the limit of Diesel Euro5b (Slide1). Therefore, we investigated sub 23 nm particles emissions.

The objective of this study is firstly to investigate solid particles of vehicle emission including particles smaller than 23nm. And secondly to clarify the concerns about accuracy in measuring particle number smaller than 23nm.

We measured emission of 7 vehicles including 3 PFI, 3 GDI, and a diesel vehicle equipped with after treatment system (Slide3). They were measured on the New European Driving Cycle. For research of particle number emissions, we measured particle emissions larger than 7nm and larger than 23nm simultaneously. From the result of particle emissions measurement, even if particles smaller than 23nm are included, 3 vehicles of PFI are below Diesel Euro5b (Slide5). Also from the result of particle size distribution measured by EEPS that principal of classification was electric mobility, we can see that particles smaller than 23nm of PFI are very low and nearly equal to that of Diesel with DPF (Slide6). In addition, we checked the repeatability of particle number measurement smaller than 23nm. From the result of PFI, we found that the Coefficient of Variation of particle number emissions larger than 7nm was higher than current PMP method (Slide7). This means that the particle measurement method itself for particles smaller than 23nm have some issues in accuracy.

To clarify issues in the measurement method, we paid attention to next 3 points. First one is whether the VPR can entirely remove volatile particles. Second point is whether particles may increase by heat treatment of VPR. Third point is the calibration of the PNC. We are still working on the third one. Then, we introduce upper 2 points.

Firstly, we investigated the Removal performance of VPR. For this examination, we used VPR that complied with the PMP regulation and can remove 99% of Tetracontane. We managed engine control system which enables to emit volatile particles in high concentration for this test. After setting temperature of the evaporation tube to 300 degrees, we investigated removal performance. Result was that particles smaller than 23nm were detected (Slide11). When setting the

temperature to 500 degrees, this was not the case. As a result, particles smaller than 23nm were mostly volatile particles. Therefore if VPR temperature is low, semi-volatile particles will pass VPR and it may cause inaccurate measurement. Secondly, we investigated influence of VPR itself. We confirmed phenomenon that particles smaller than 23nm were increased after passing evaporation tube (Slide12). This means that state of the particle was changed by evaporation tube. Then we considered 2 hypotheses to study that mechanism. One was that vaporous semi-volatile particles coagulated to smaller particles. The other was that larger particles fragmented into smaller particles. Then we investigated the capability of semi-volatile particles to coagulate. In order to let only the vaporous components passing, we put a heated quartz filter in front of evaporation tube and removed only solid particles. If smaller particles were increased in this set up, then they would be vaporous component. So, I could confirm if these particles are generated by coagulation of semi-volatile particles. Then result was that there were few particles smaller than 23nm (Slide13). Therefore the mechanism of increased small particles is caused by fragmentation in the VPR. If that's the case, lowering temperature of the evaporation tube might be effective to control the fragmentation of the particles. However as we describe before, lowering temperature has the downside that volatile particles are not removed entirely. Therefore it's necessary to determine VPR temperature which can balance controlling fragmentation of particles with removing volatile particles.

Summary

As a result of investigation of particle number emissions and measurement method smaller than 23nm, these are found.

If particles smaller than 23nm were included into the PN measurement, certainly particle number emissions increase. But PFIs and Diesel were below the Diesel Euro5b on NEDC.

We found that the increased particles smaller than 23nm may be caused by fragmentation of larger particles. In order to establish the PN measurement method for below 23 nm particles, it's necessary to examine VPR temperature. It should be considered to appropriate calibration method.

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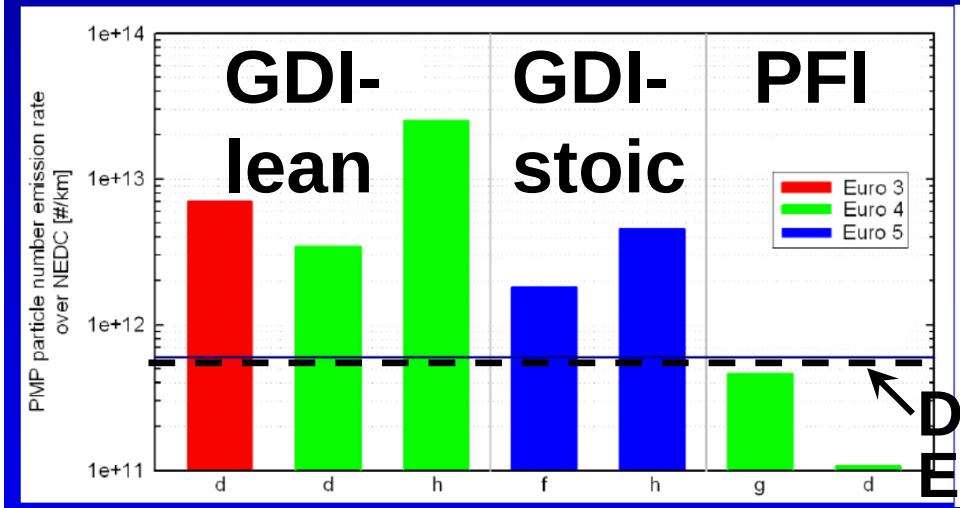
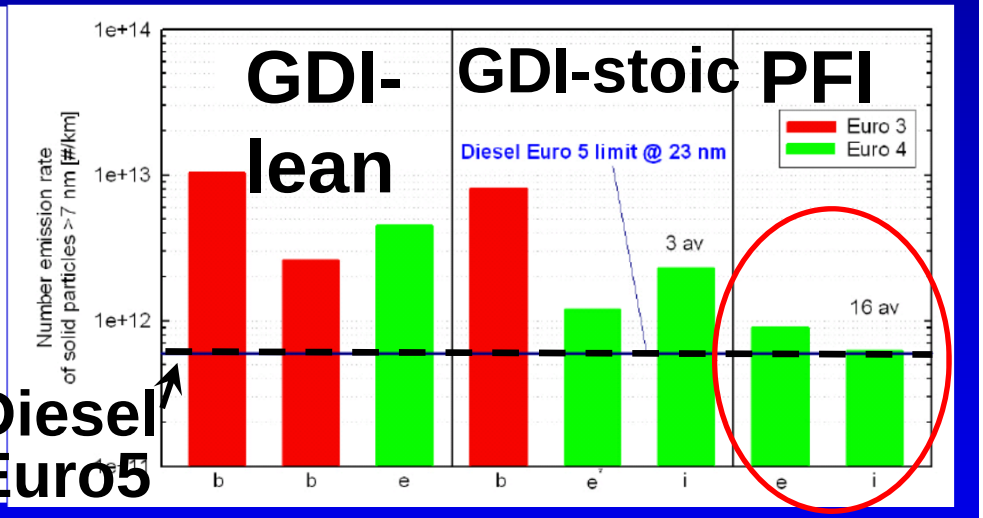
Background

Particles smaller than 23nm are paid attention.

Larger than 23nm



Larger than >7nm



Reference : JRC Assessment of particle number limits for petrol vehicles

Contents

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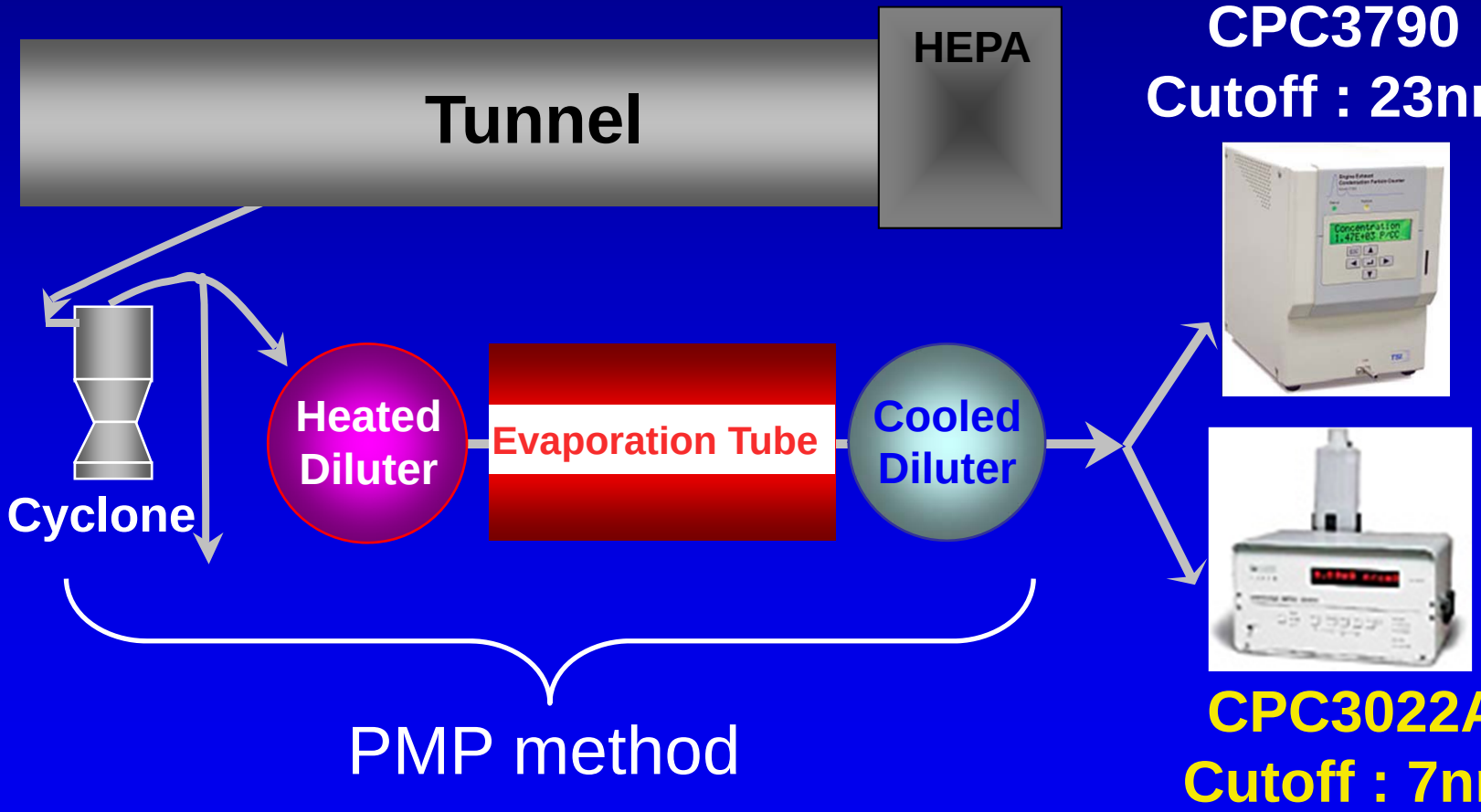
1-1. Test Vehicles

PFI 3, GDI 3, Diesel 1

Vehicle	Fuel	Engine Type	Engine Displacement (L)	After treatment	Emission level
1	Gasoline	PFI	1.3	3way	11MY
2		PFI	1.8	3way	11MY
3		PFI	2.5	3way	10MY
4		DI	2.4	3way	11MY
5		DI	2.5	3way	11MY
6		DI	3.0	3way	J-SULEV
7	Diesel	DI	3.0	DPF	Euro5

1-2. PN Measurement Method

PN larger than 7nm and larger than 23nm were measured simultaneously



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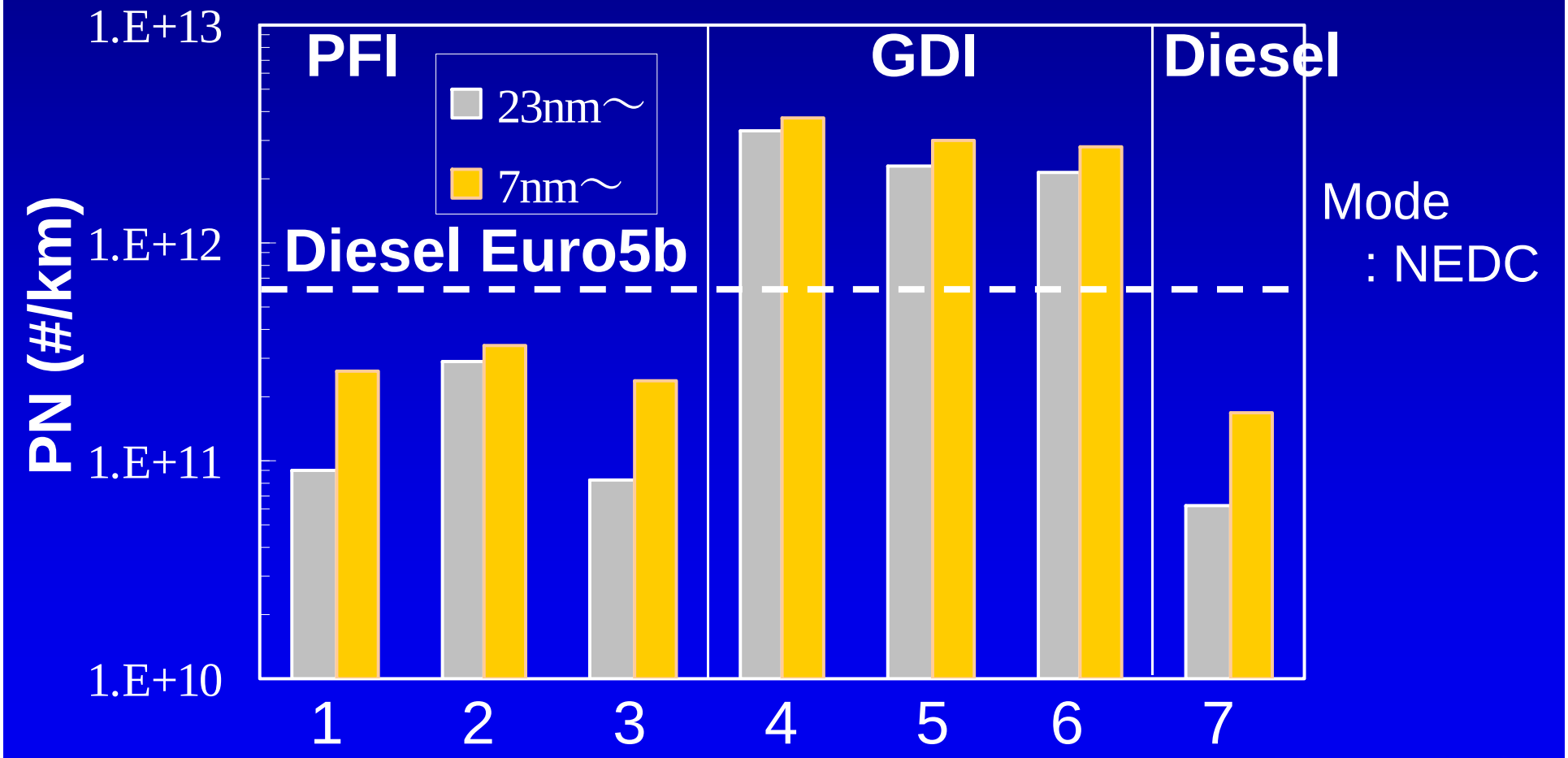
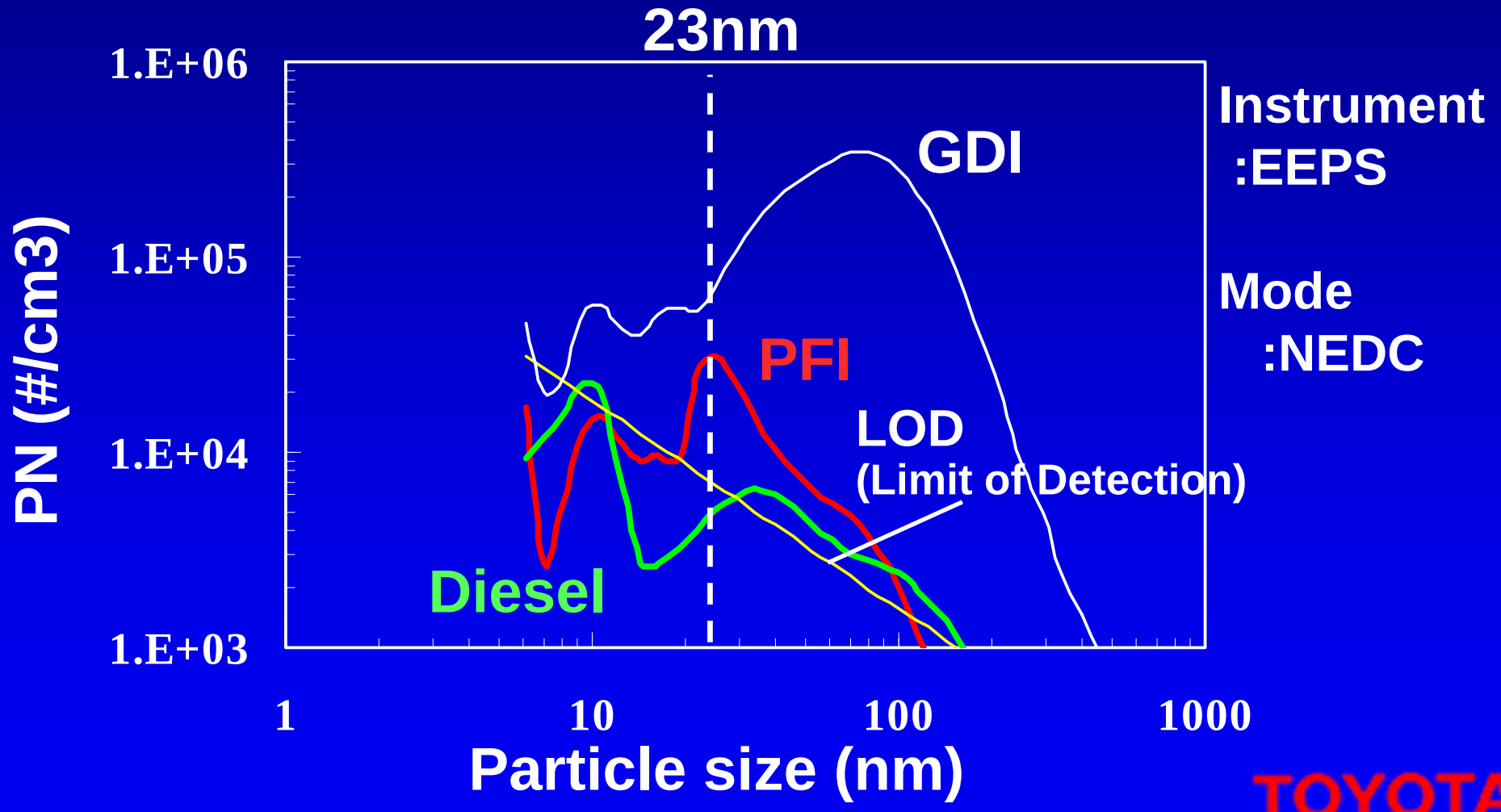
1-3. Particle Number Emissions

PFIs are below 6×10^{11}#/km, even if PN smaller than 23nm are included.



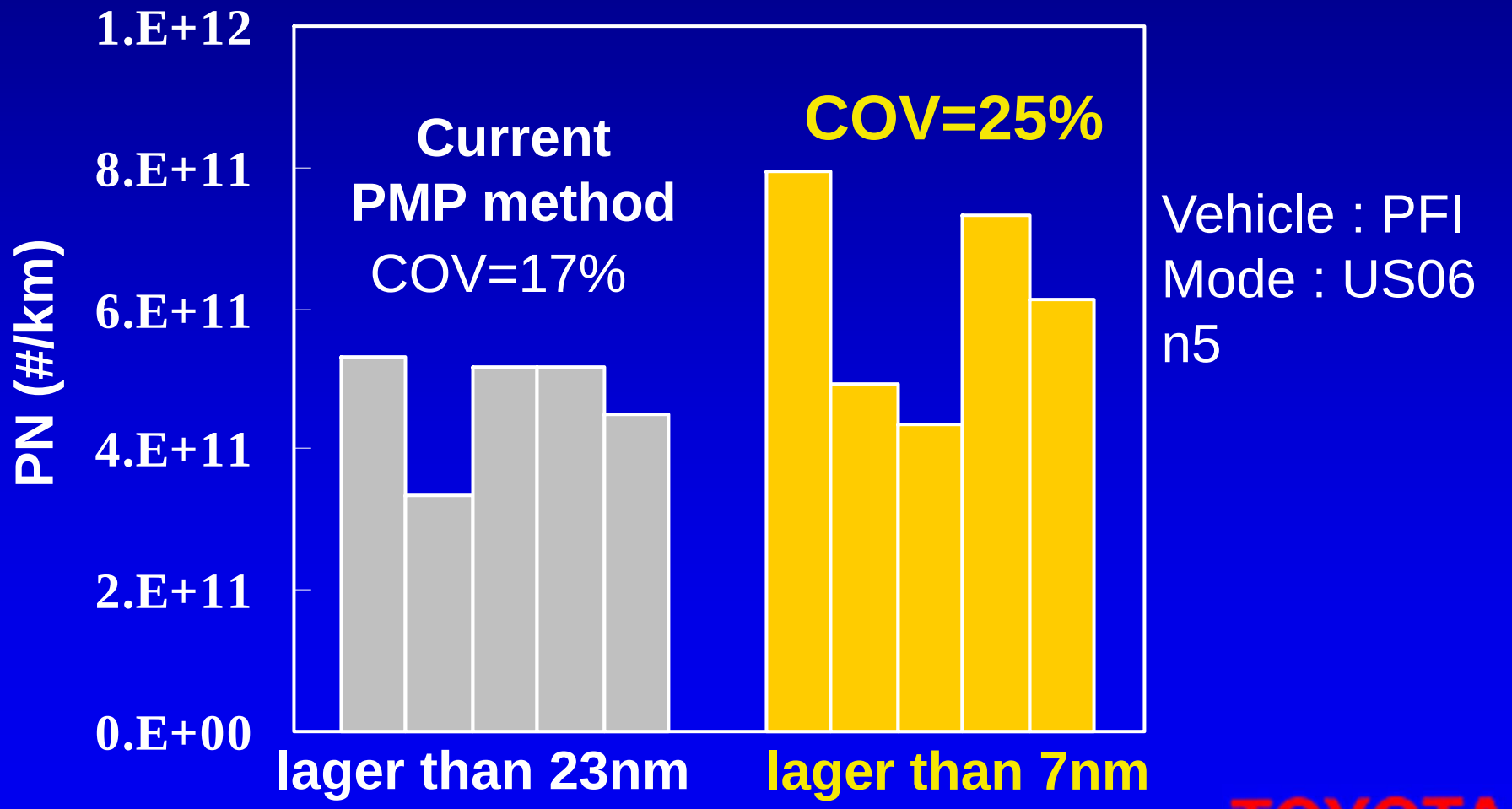
1-4. Particle Size Distribution

PN smaller than 23nm of PFI are low and nearly equal to that of Diesel with DPF.



1-5. Repeatability of PN Measurement

COV of PN larger than 7nm is higher than current PMP method



Vehicle : PFI
Mode : US06
n5

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Contents

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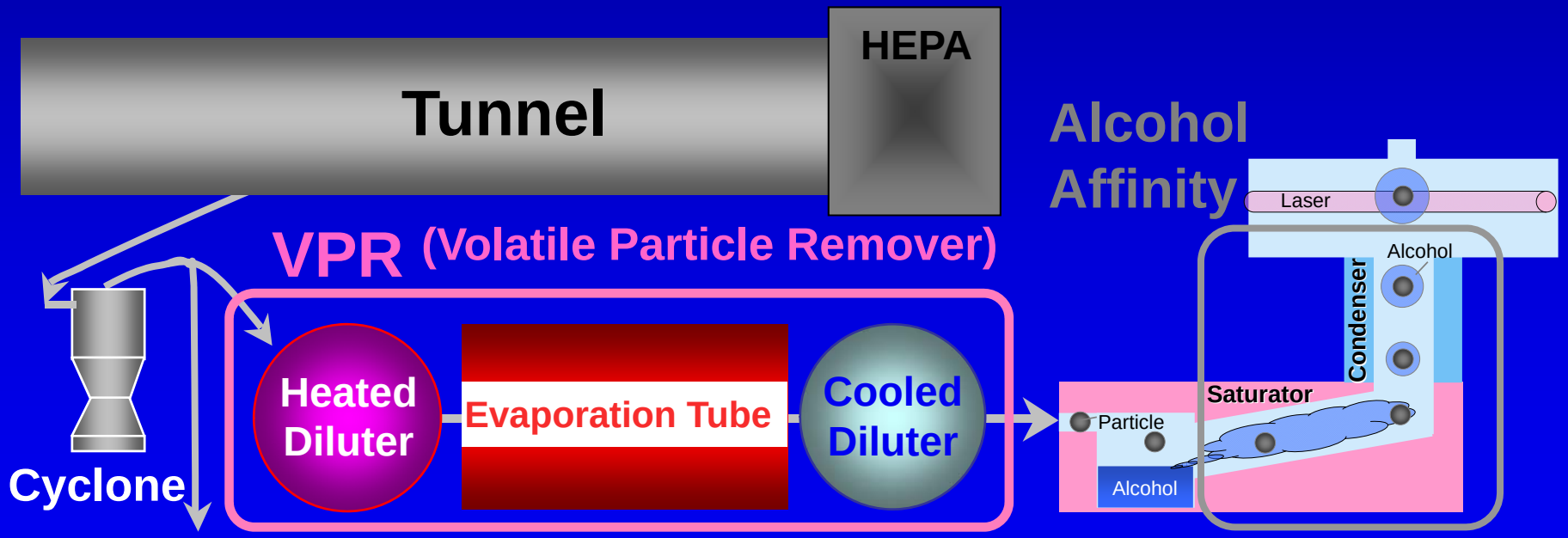
2. Issues

Concerns about measurement accuracy

1) Removal performance of VPR
2) Change of particle properties by VPR
3) Calibration smaller than 23nm of PNC



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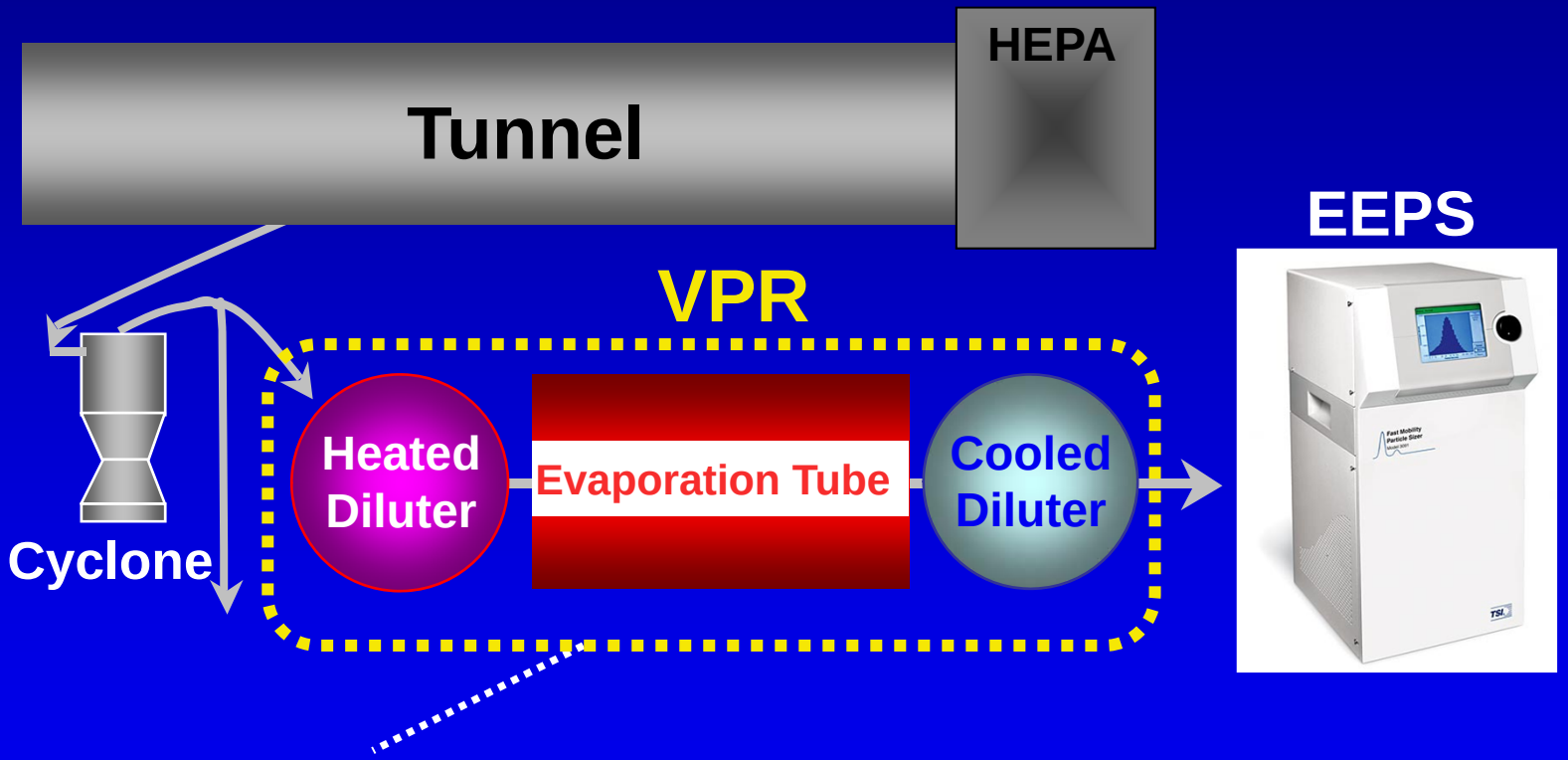
2-1. Removal Performance of VPR

Removal performance of high concentration of semi-volatile particles by VPR



Regulation : removal efficiency of C40 is lager than 99%

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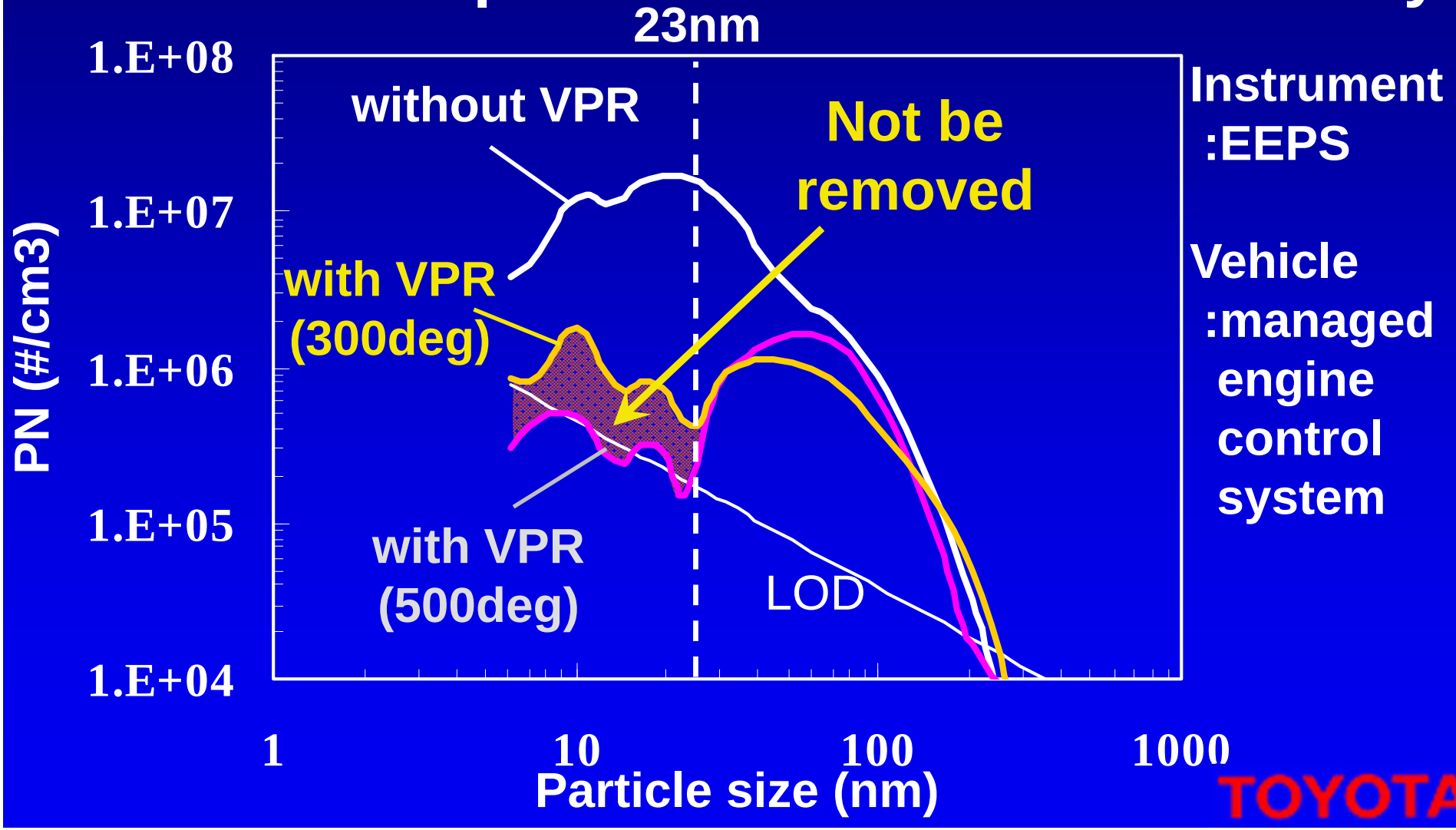
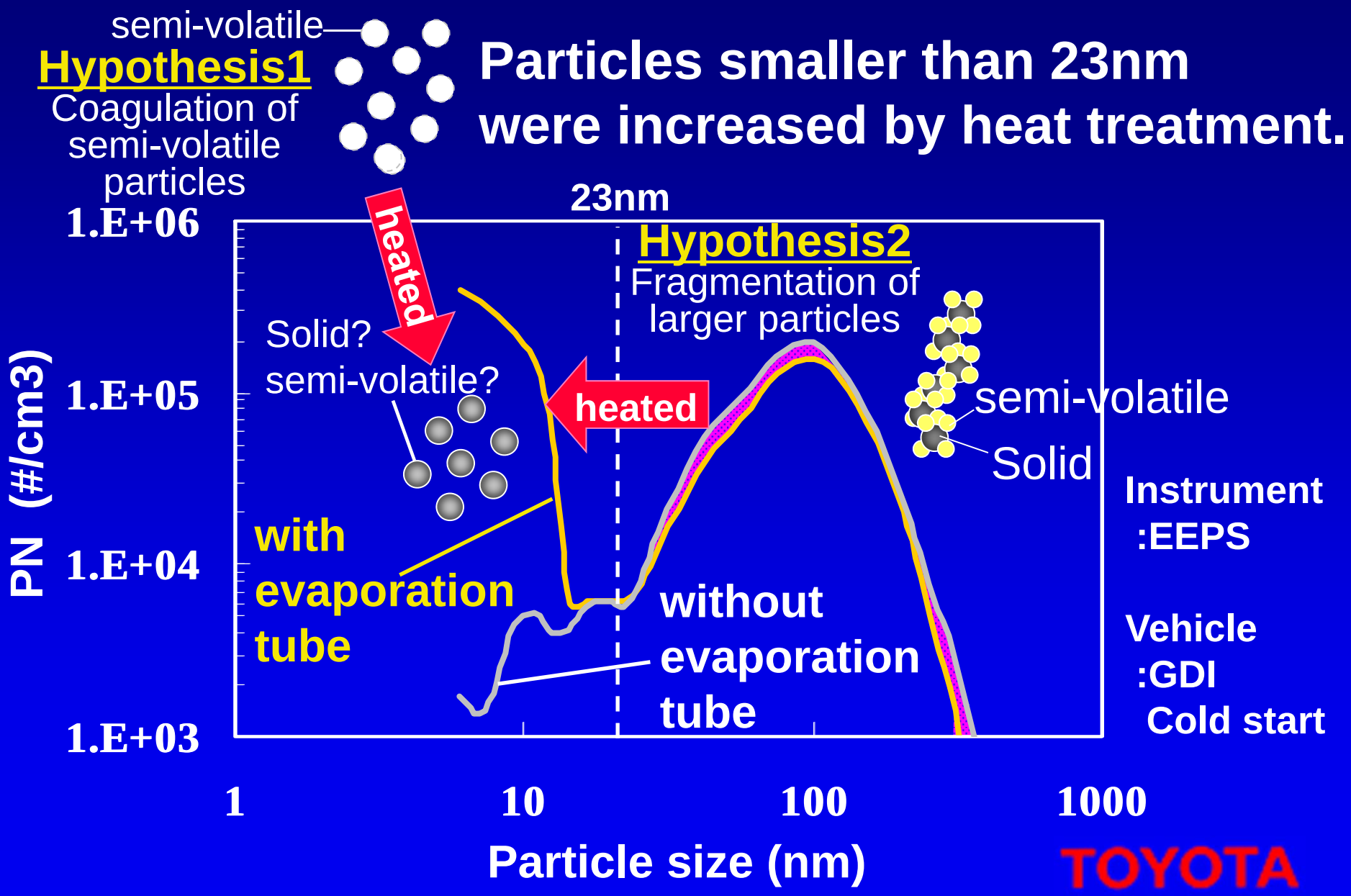
2-1. Removal Performance of VPR

If VPR temperature is low, VPR passed semi-volatile particles and cause inaccuracy



2-2. Change of Particle Properties by VPR

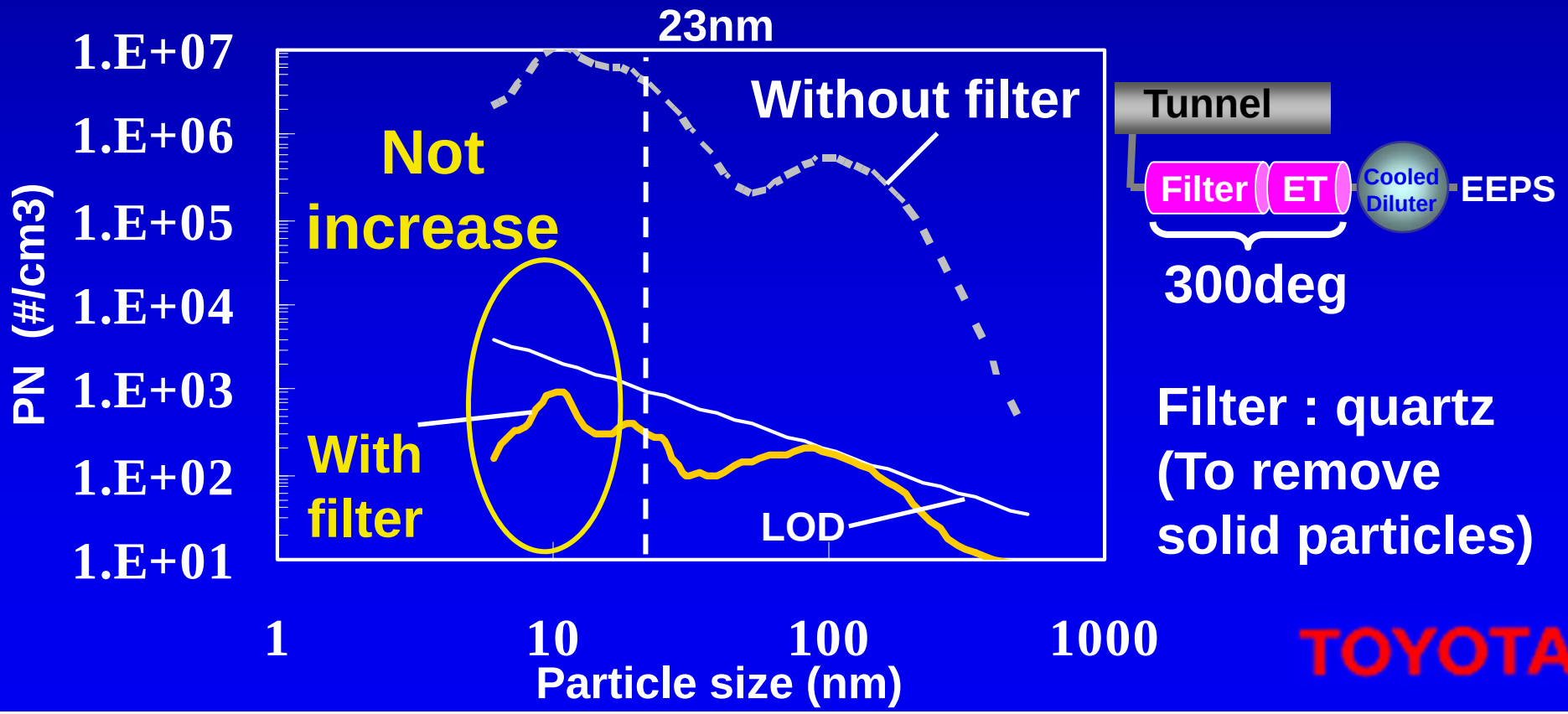
Particles smaller than 23nm were increased by heat treatment.



2-2. Coagulation of Semi-volatile Particle

Coagulation is not be seen

Larger particles fragment into particles smaller than 23nm



Filter : quartz (To remove solid particles)

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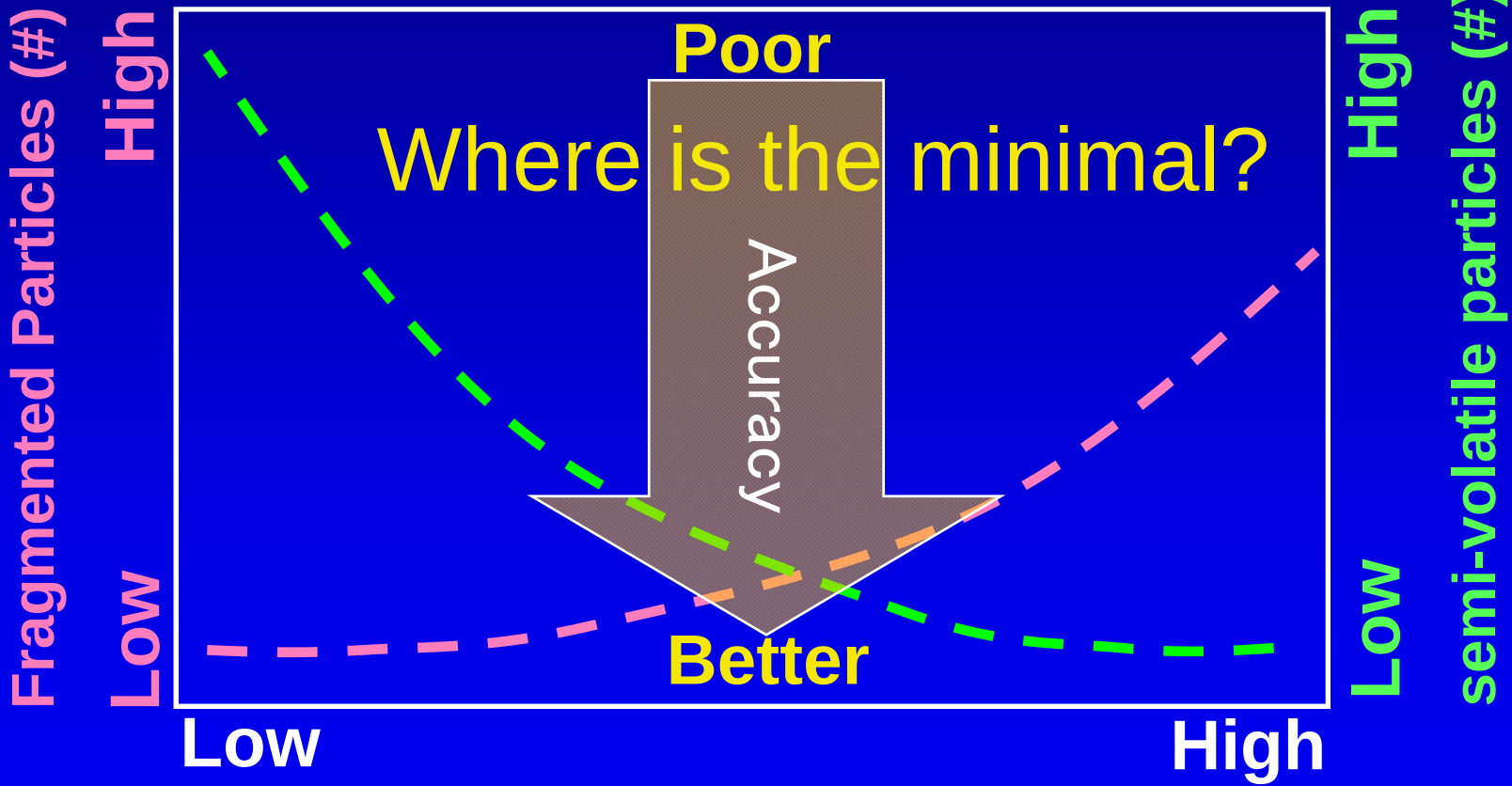
2-2. Temperature Condition of VPR

It's necessary to determine VPR temperature which can balance controlling fragmentation with removing semi-volatile particles.



3. Conclusion

1. PFIs and Diesel were below 6×10^{11}#/km on NEDC, even if particles smaller than 23nm were included.
2. Increased particles smaller than 23nm may be caused by fragmented particles.
3. There are issues on the measurement method smaller than 23nm. It's necessary to establish VPR temperature.
4. It should be considered to appropriate calibration method of PNC.

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Thank you for your attention

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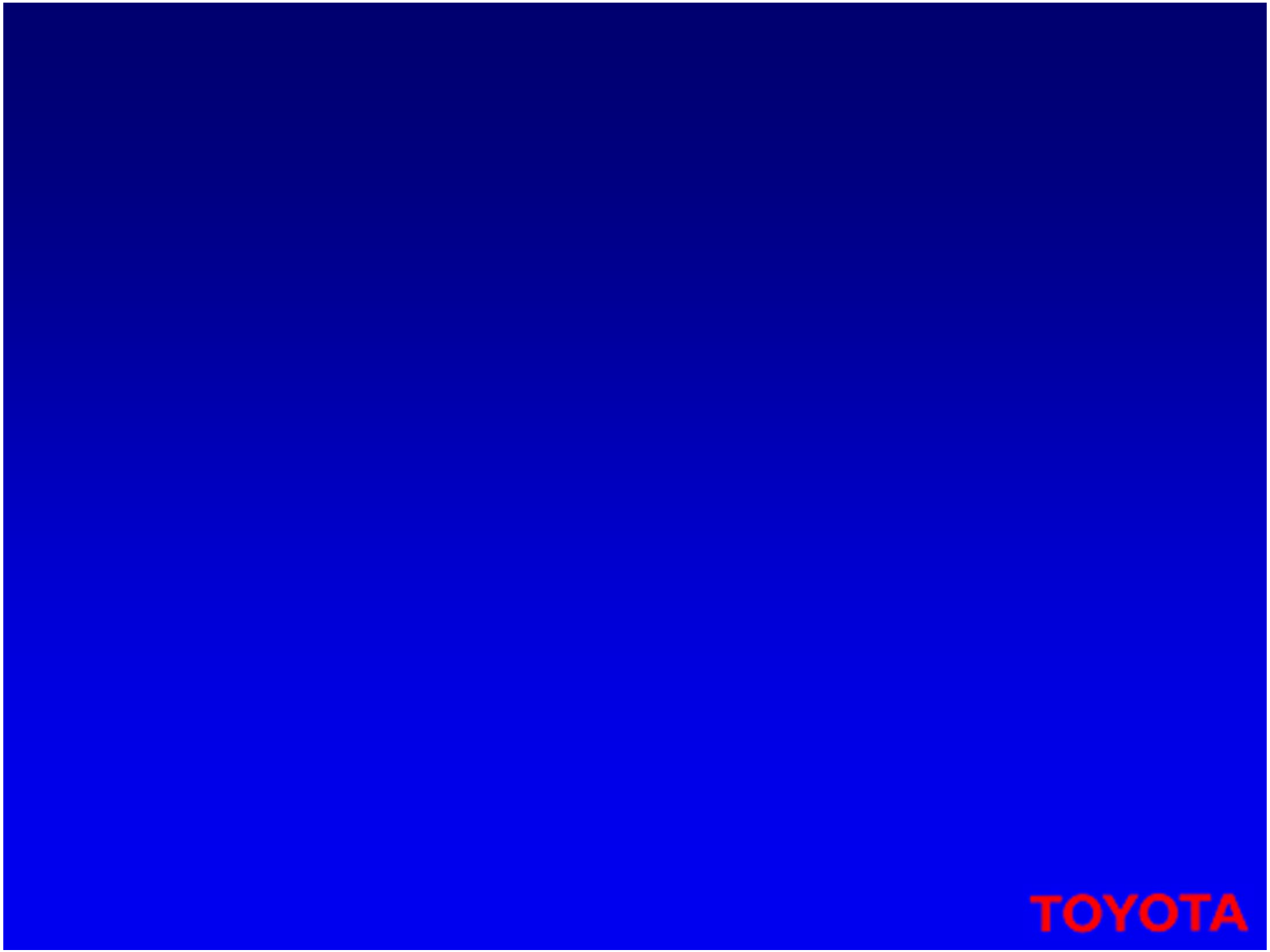
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Supplement

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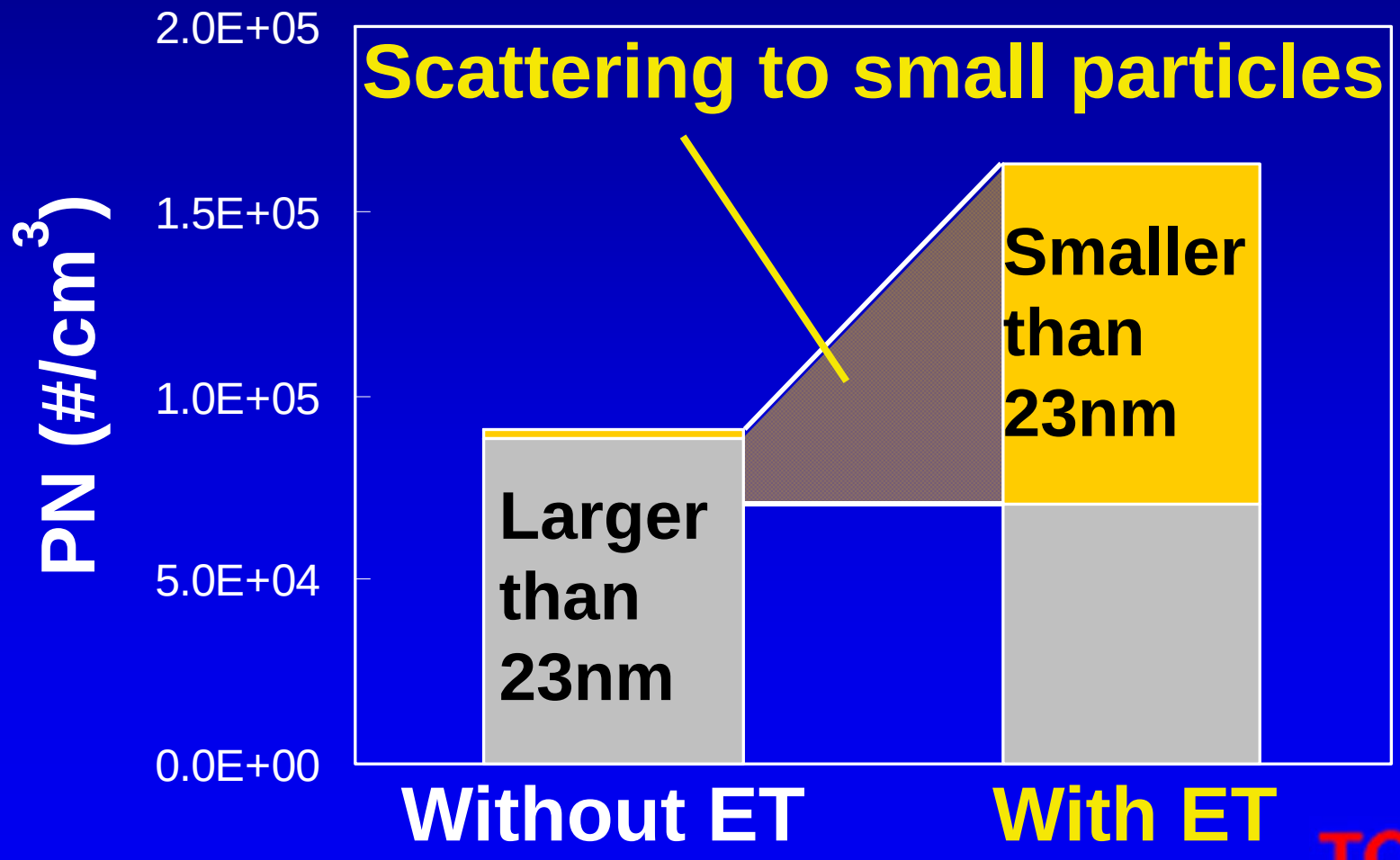
Change of particle properties by VPR

PN scattering to small particles is no more than 15% of particles larger than 23nm



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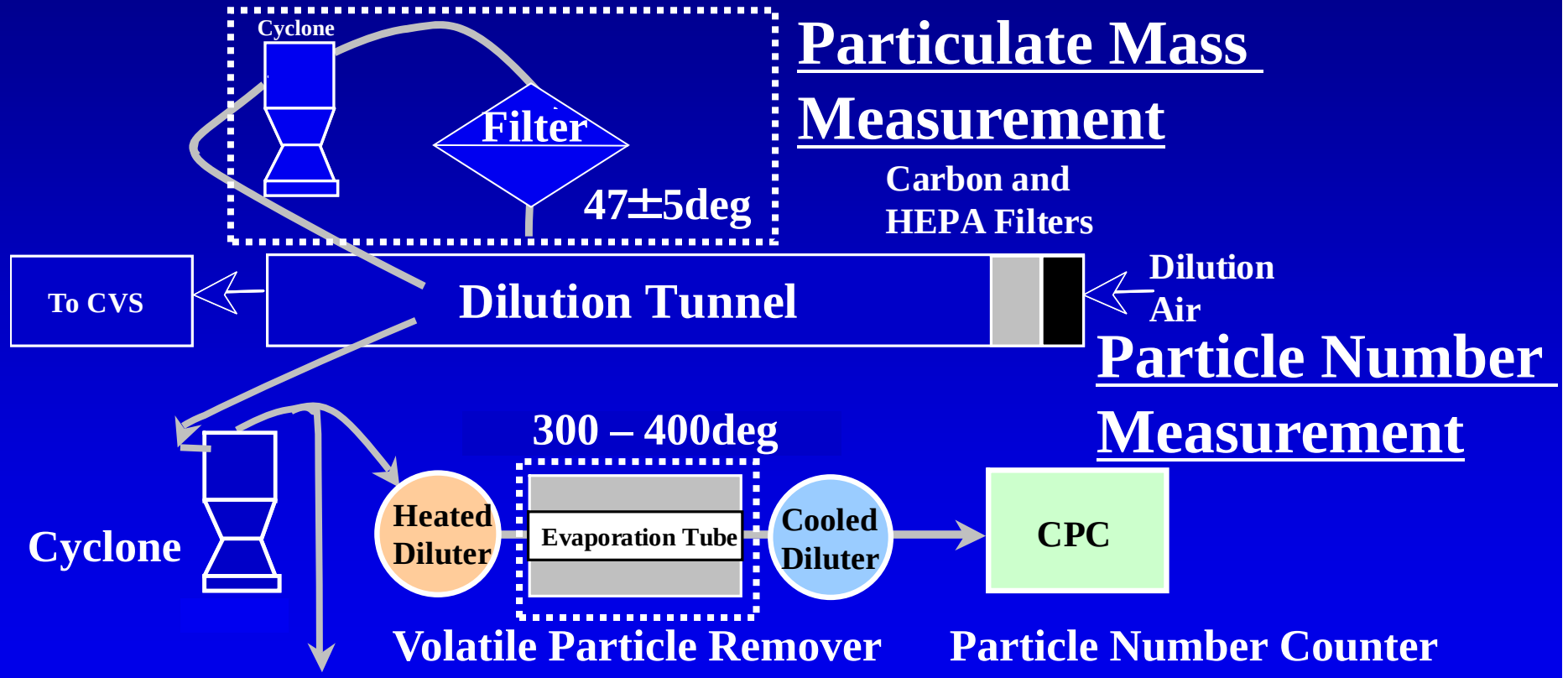
1-2. Measurement of Particulate Matter

The particle number regulation will be newly introduced to Euro5

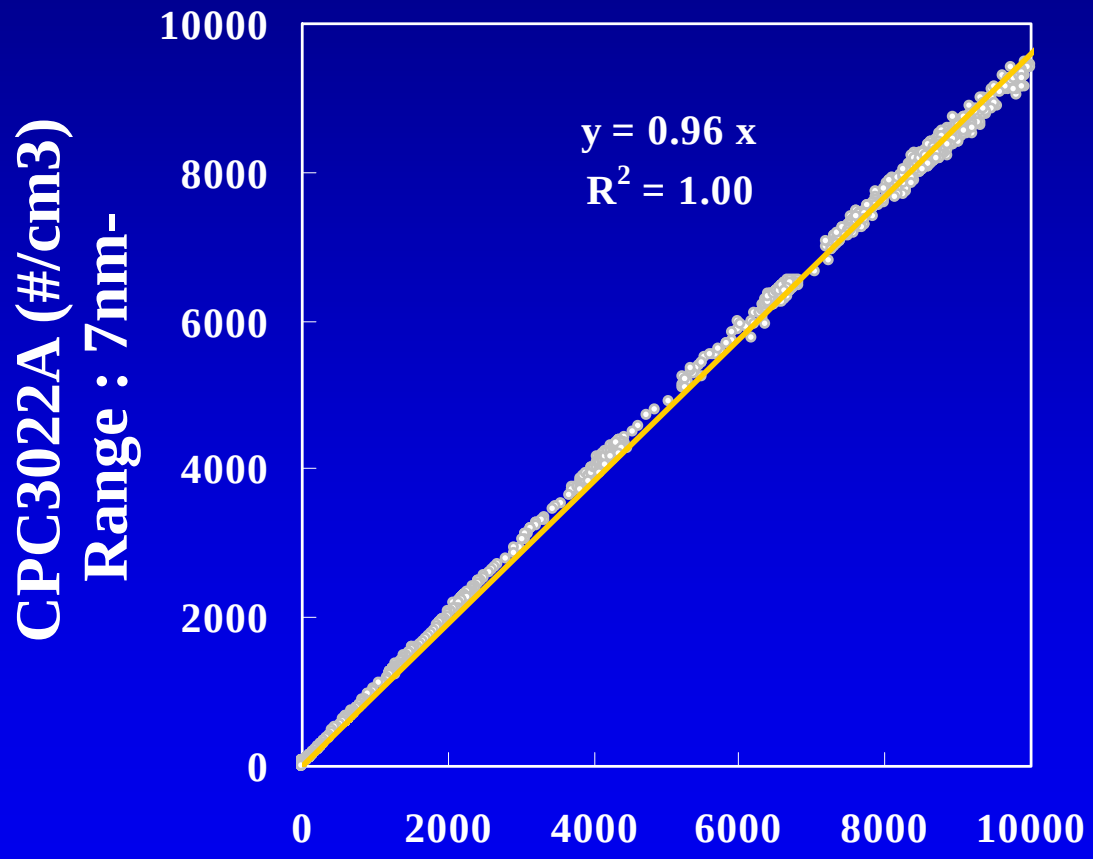


1-3. Regulations

		EURO5		EURO6
		2009～	2011～	2014～
Particulate Mass (mg/km)	Diesel	5.0	4.5	4.5
	Gasoline	5.0	4.5	4.5
Particle Number (#/km)	Diesel	–	6.0×10^{11}	6.0×10^{11}
	Gasoline	–	–	To be defined

2-2. Method of PN measurement

今回使用した2種検出器は良好な相関であることを確認



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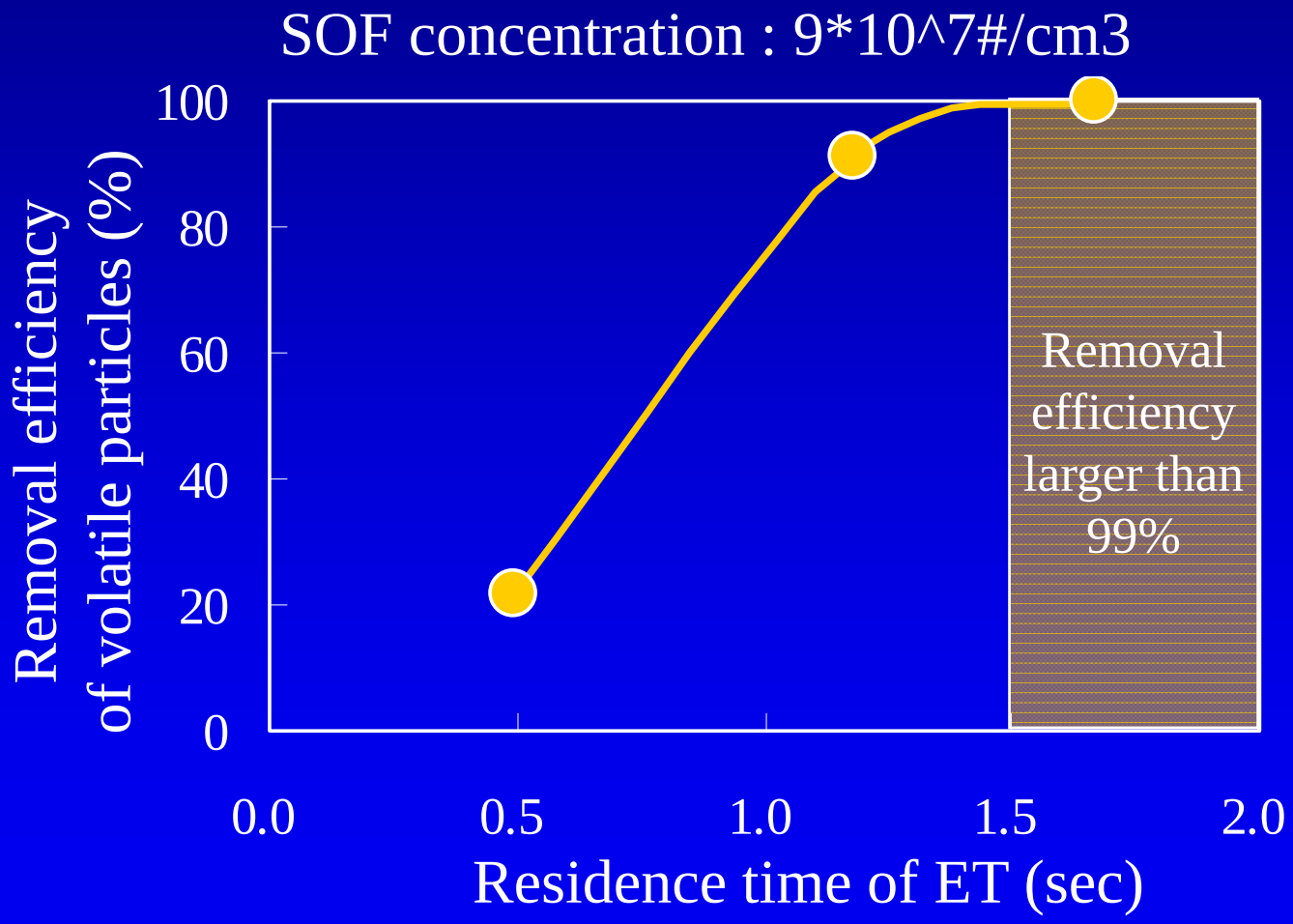
3-1. Influence of residence time for Removal efficiency

Need to determine ET residence time to remove volatile particles entirely



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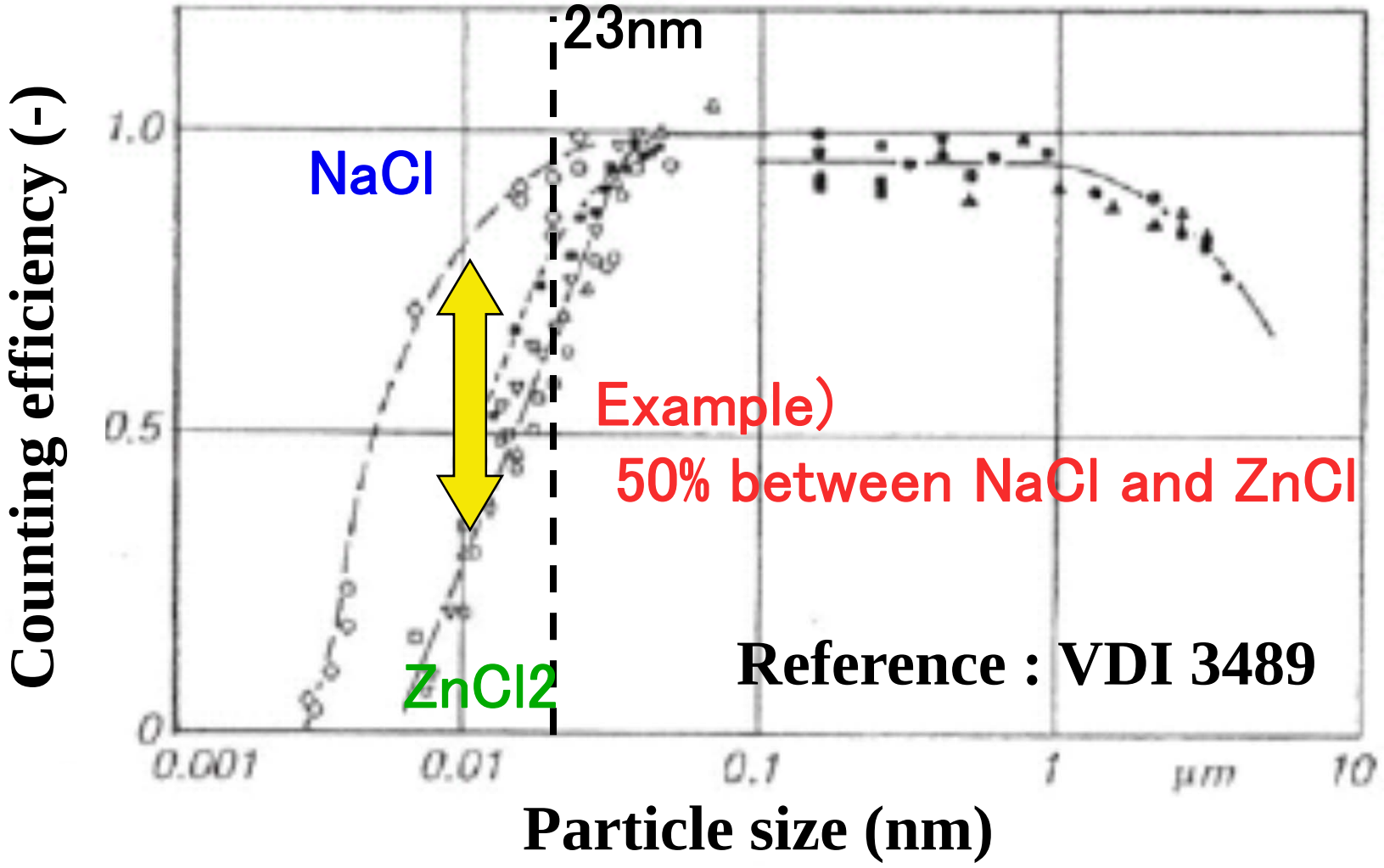
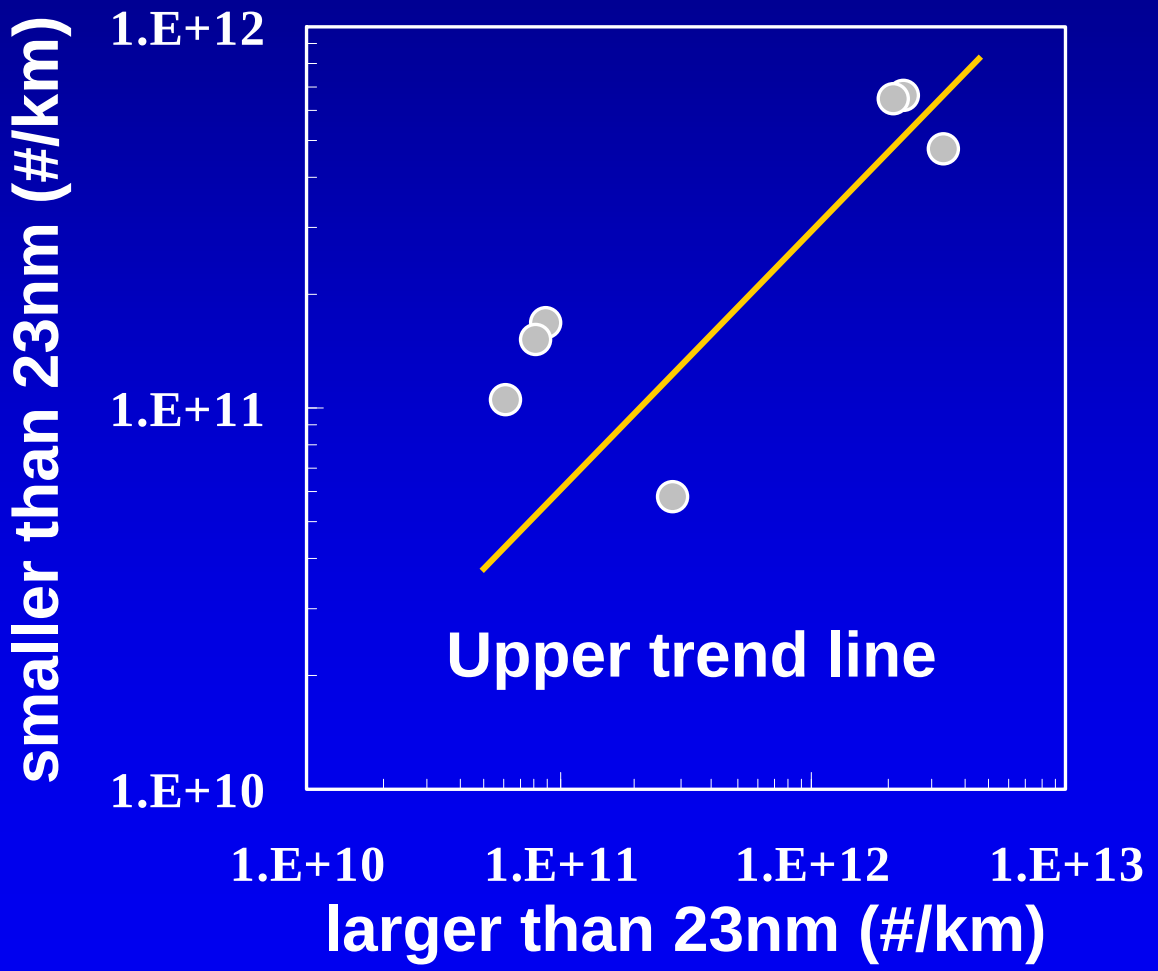
3-3. Calibration CPC under 23nm

Need to carefully select particle material to calibrate



2-6. Correlation of Larger and Smaller than 23nm

If PN emissions larger than 23nm are reduced, smaller than 23nm can be reduced too.



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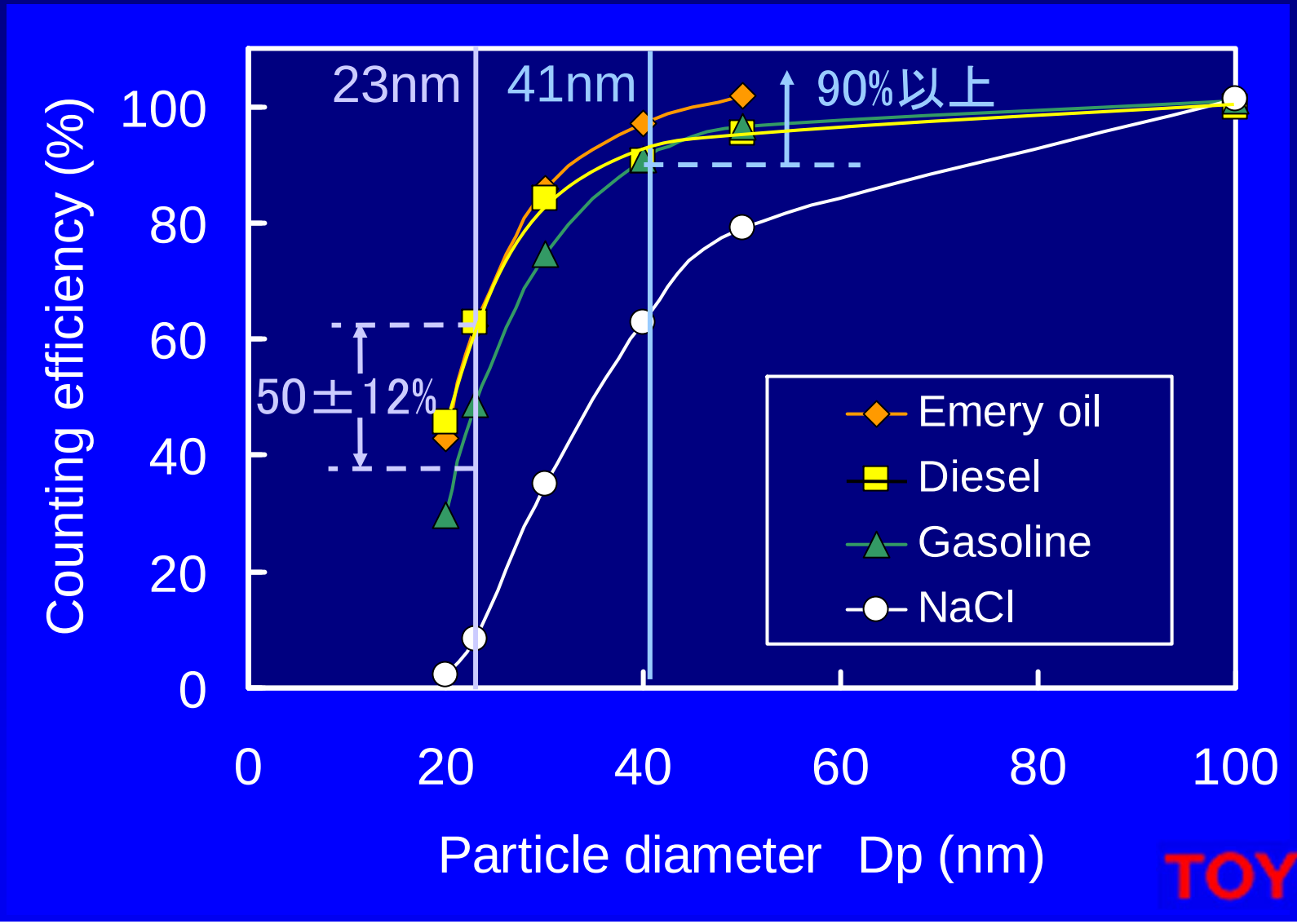
Counting efficiency of CPC3790

23nmカットオフ付近で粒子種影響大



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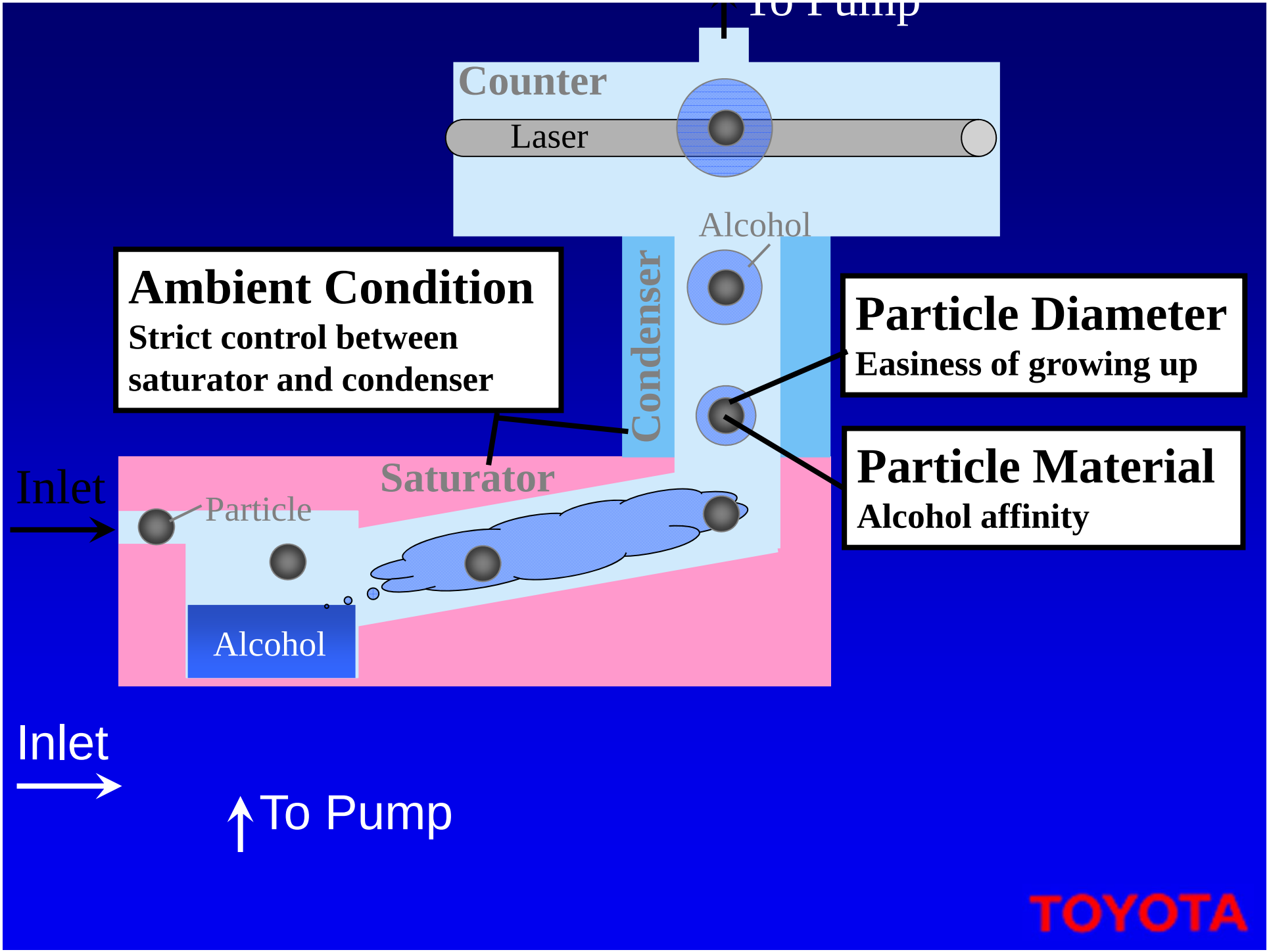
To Pump
Counter
Laser
Alcohol
Condenser
Ambient Condition
Strict control between saturator and condenser
Particle Diameter
Easiness of growing up
Particle Material
Alcohol affinity
Saturator
Inlet
Particle
Alcohol
Inlet
To Pump
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