Rapid Measurements of Aerosol Size Distributions Using a Fast Integrated Mobility Spectrometer (FIMS)

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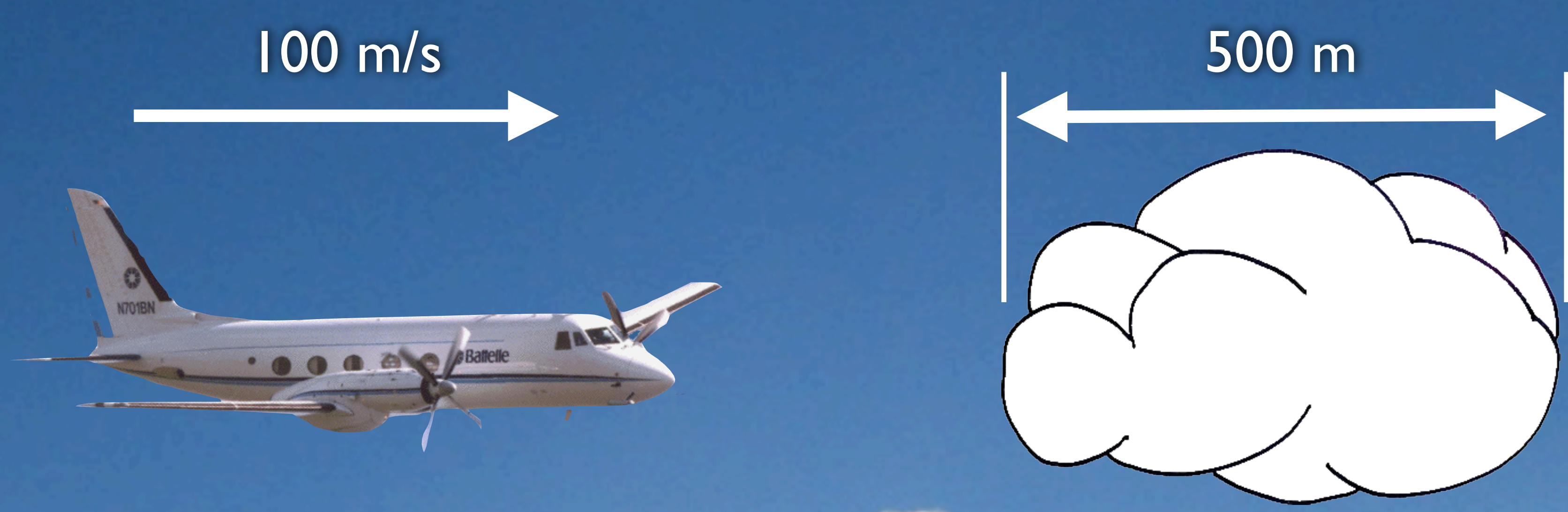
Measurement of Aerosol Size Distributions from Aircraft

- For aircraft-based atmospheric studies an instrument must have:
  - high sensitivity and good counting statistics for low particle concentrations
  - fast response time for good spatial resolution.

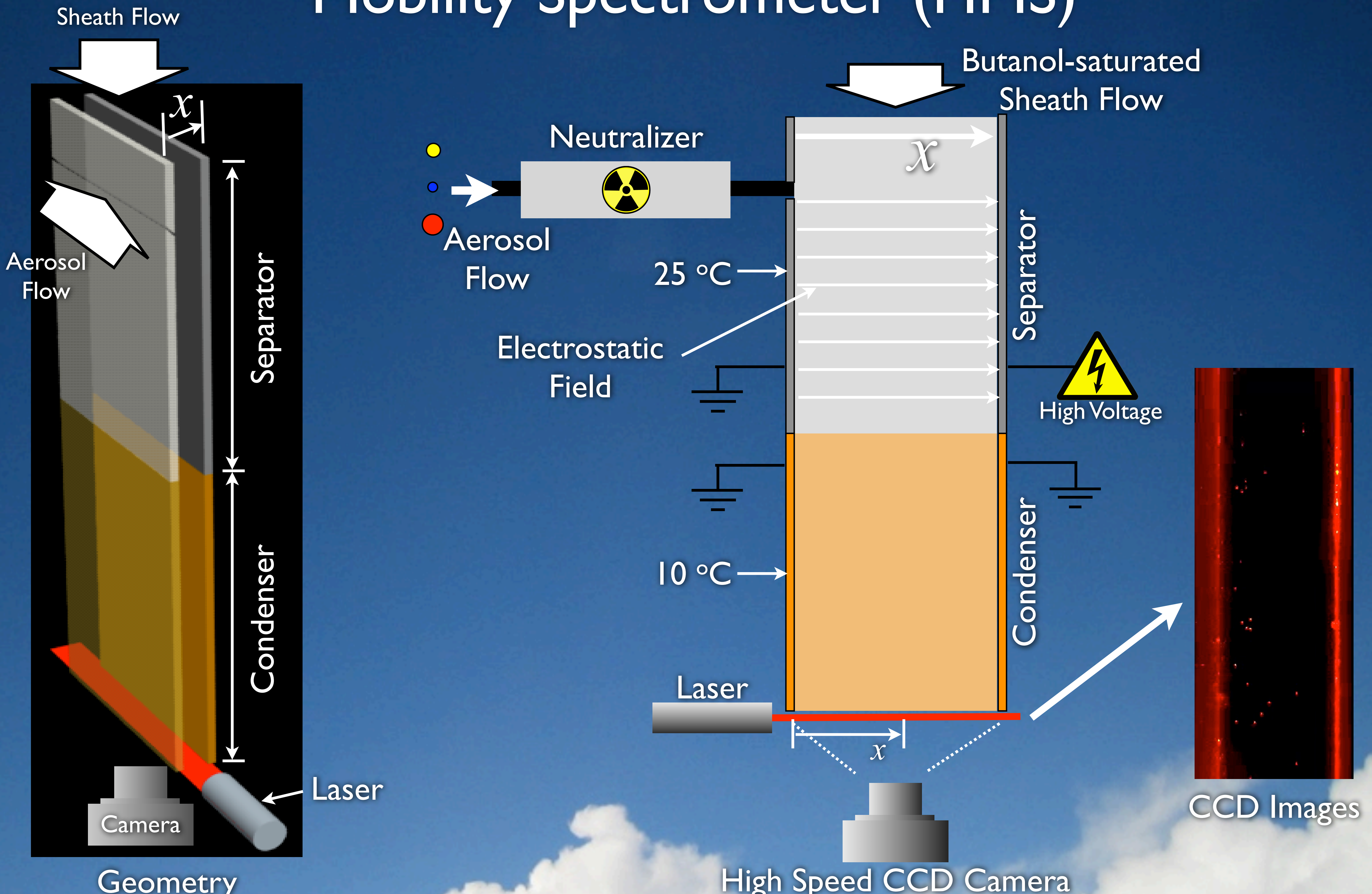


Time in cloud = 5 s

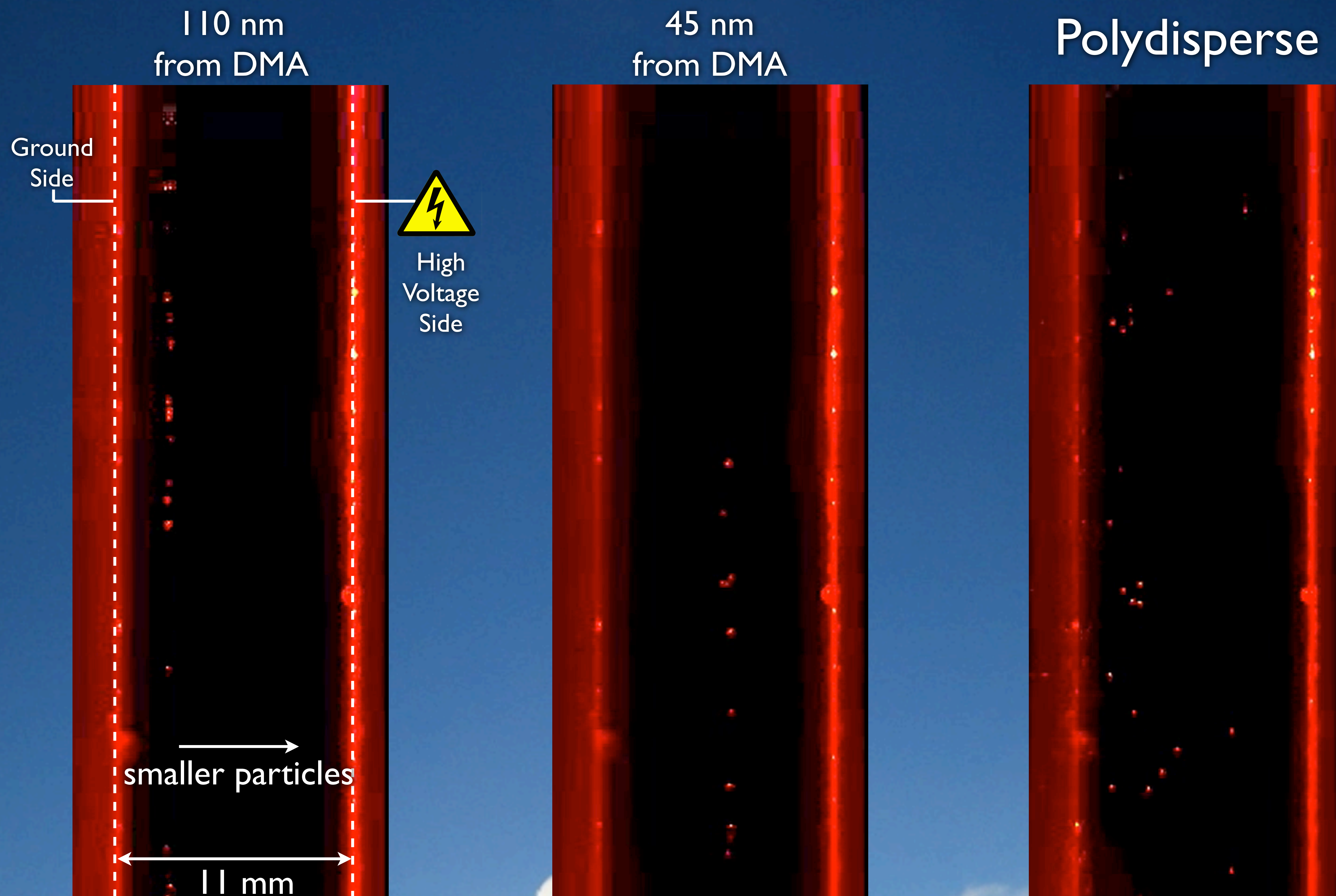
Fast Size Distribution Measurements

- Scanning Mobility Particle Sizer (SMPS) - The 'industry standard', but ~1 min is needed for each scan.
- Electrical Aerosol Spectrometers (Cambustion's DMS & TSI's EEPS) - Response time much less than 1 s, but have low sensitivity.
- Electrical Low Pressure Impactor (ELPI) - Fast inertial-based instrument, but has limited size resolution and low sensitivity.
- Optical Particle Counter (OPC) - Fast measurements but range limited to d_p>100 nm, and uncertainties due to particle shape and refractive index.

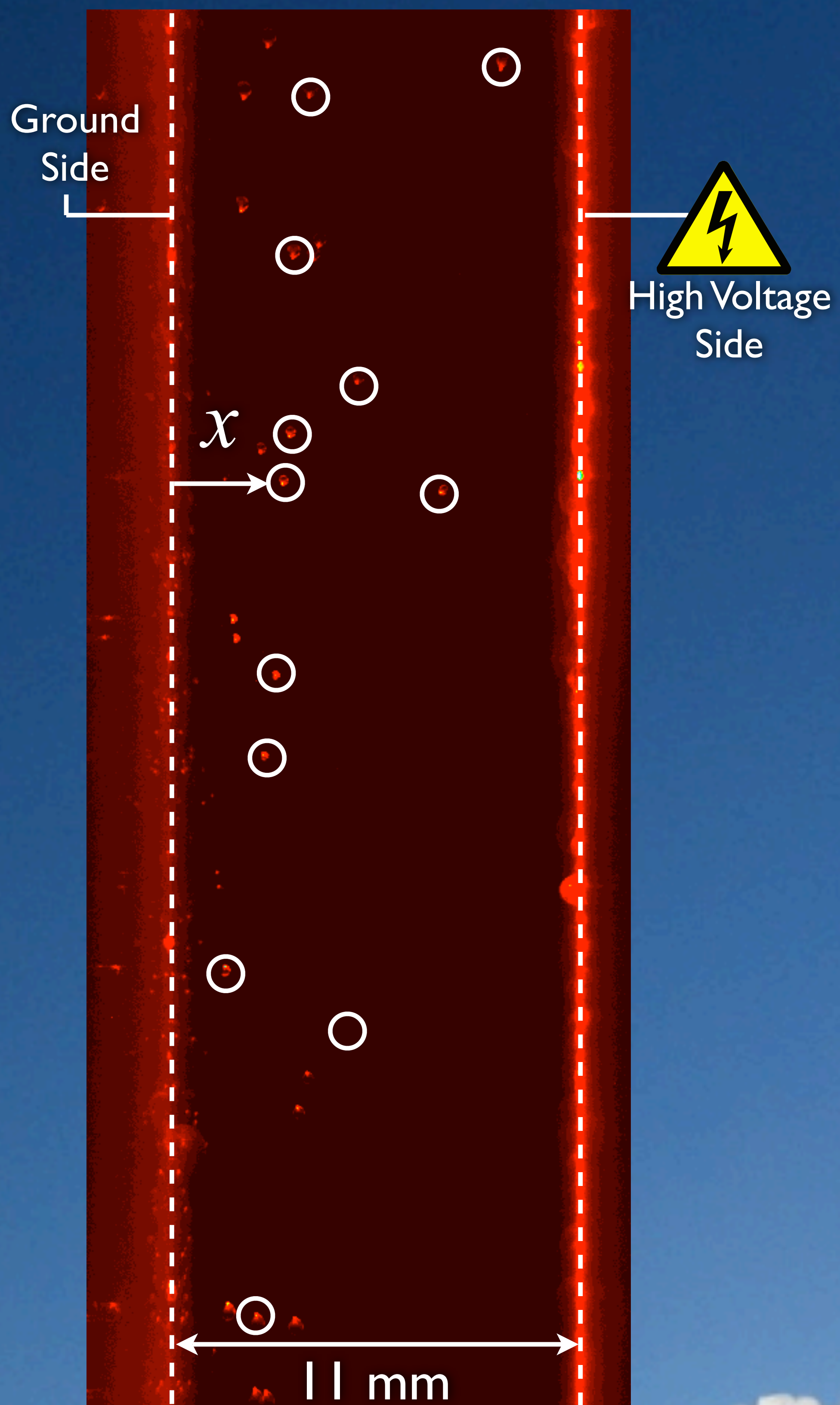
Operating Principle of the Fast Integrated Mobility Spectrometer (FIMS)



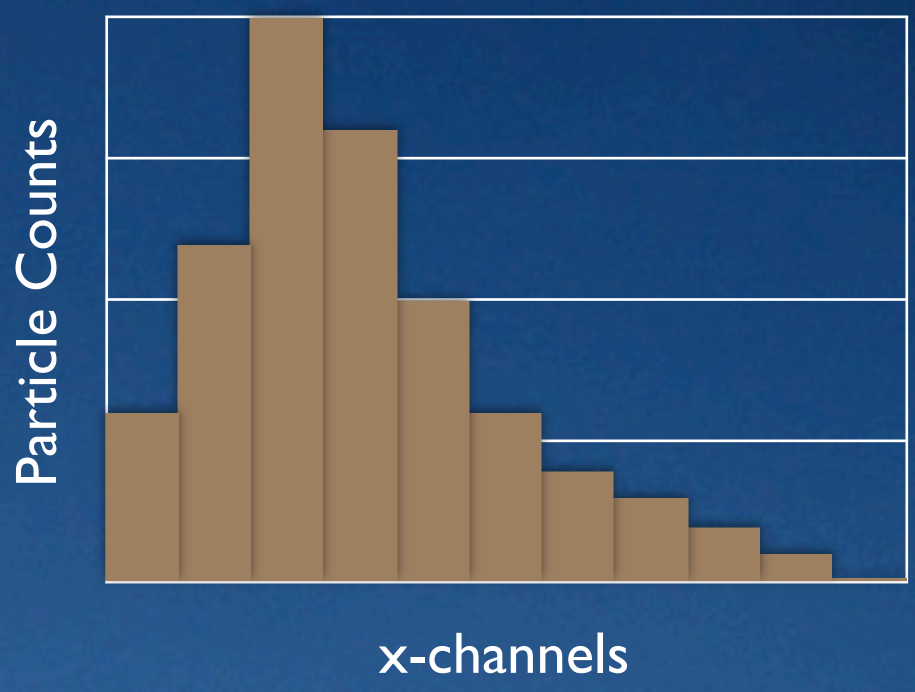
FIMS Classification Examples



From Particle Location to Size Distribution

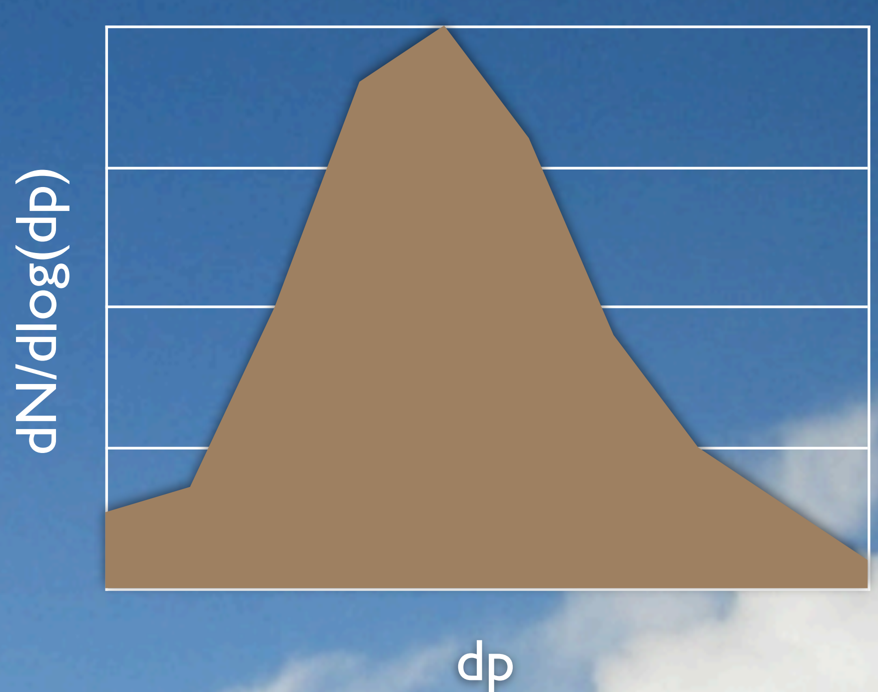


Binning



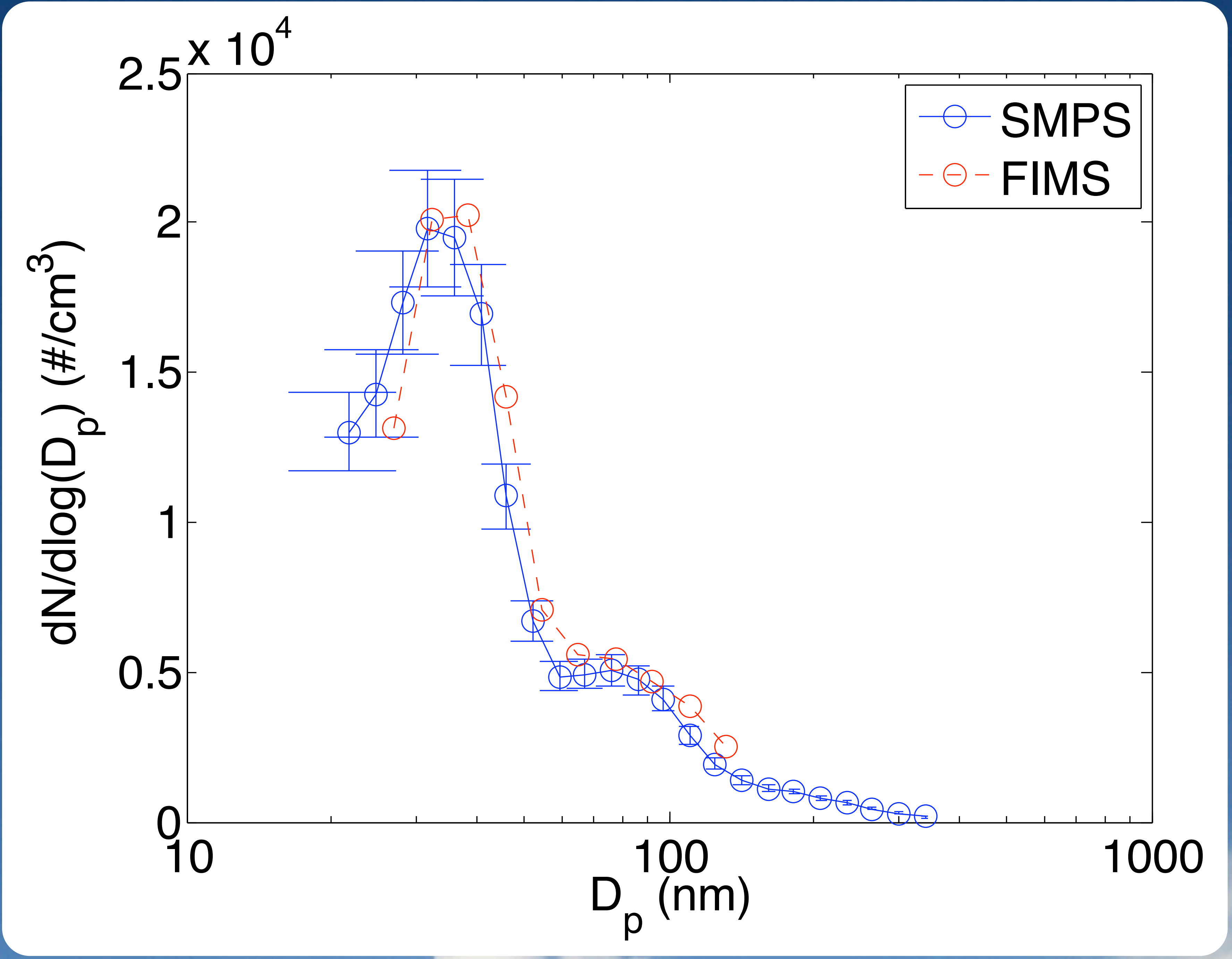
$$x \propto Z_p \propto d_p$$

Inversion



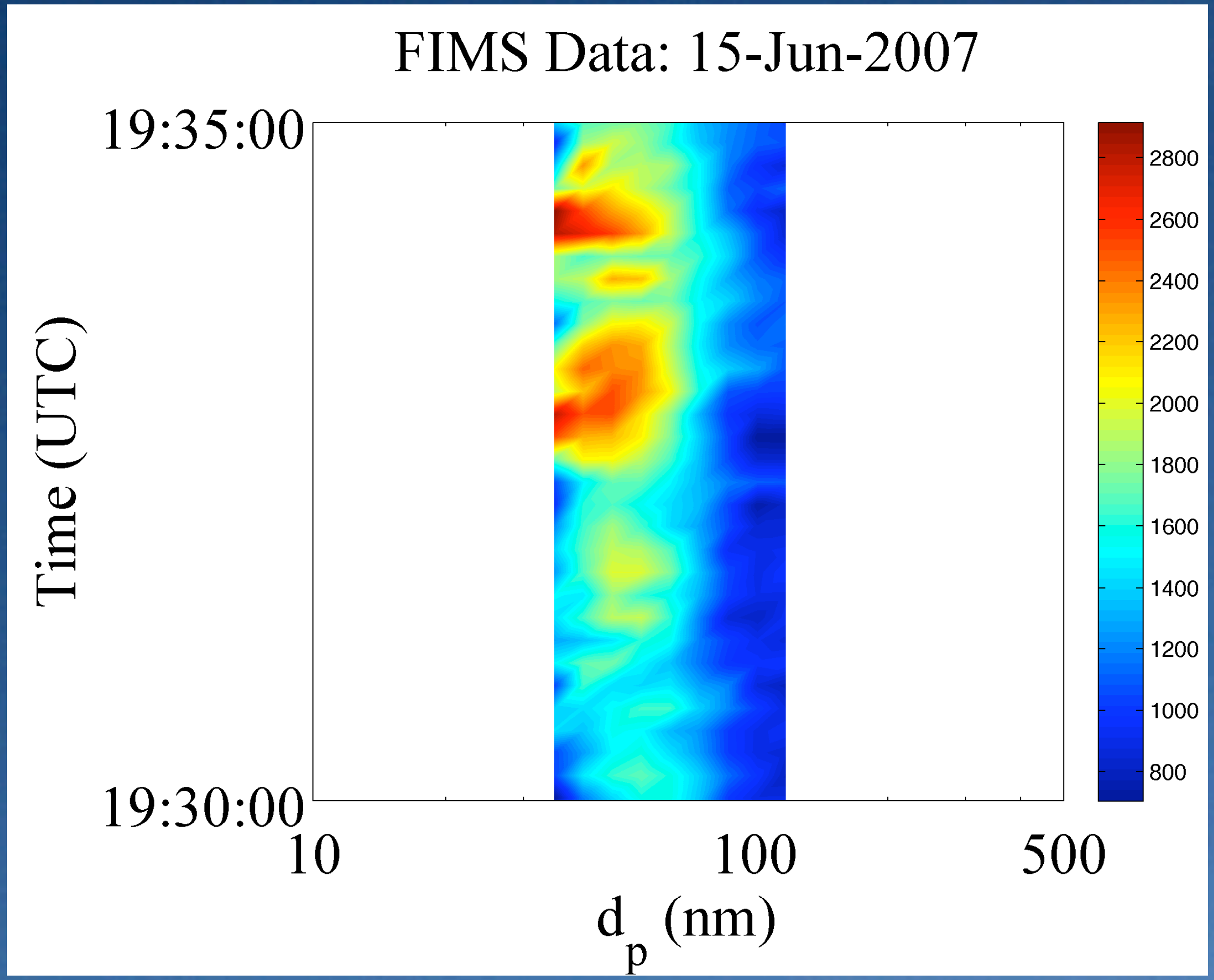
Comparing FIMS to SMPS

Steady-state ambient aerosol size distribution

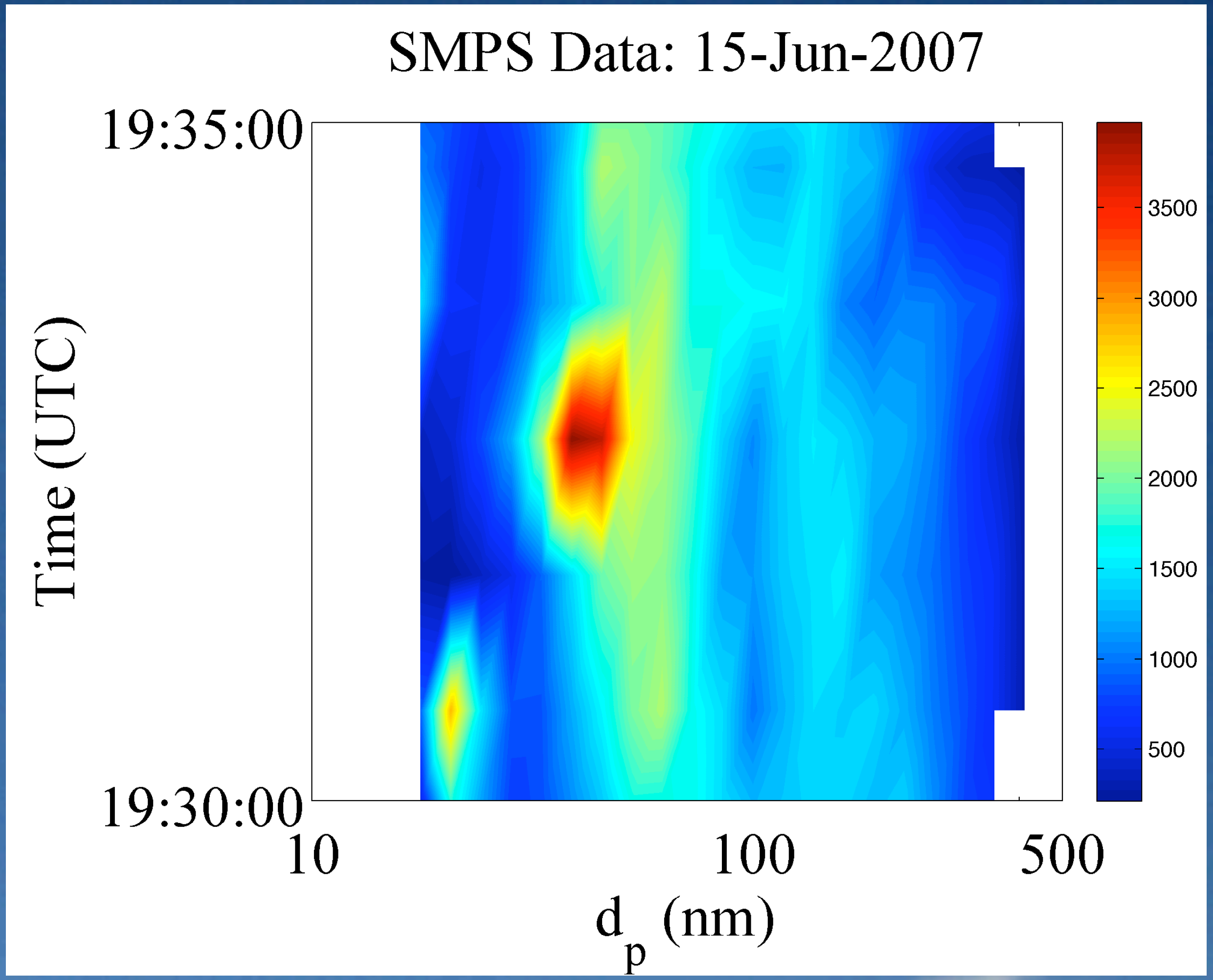


Measurements from a field study

FIMS 1 s data



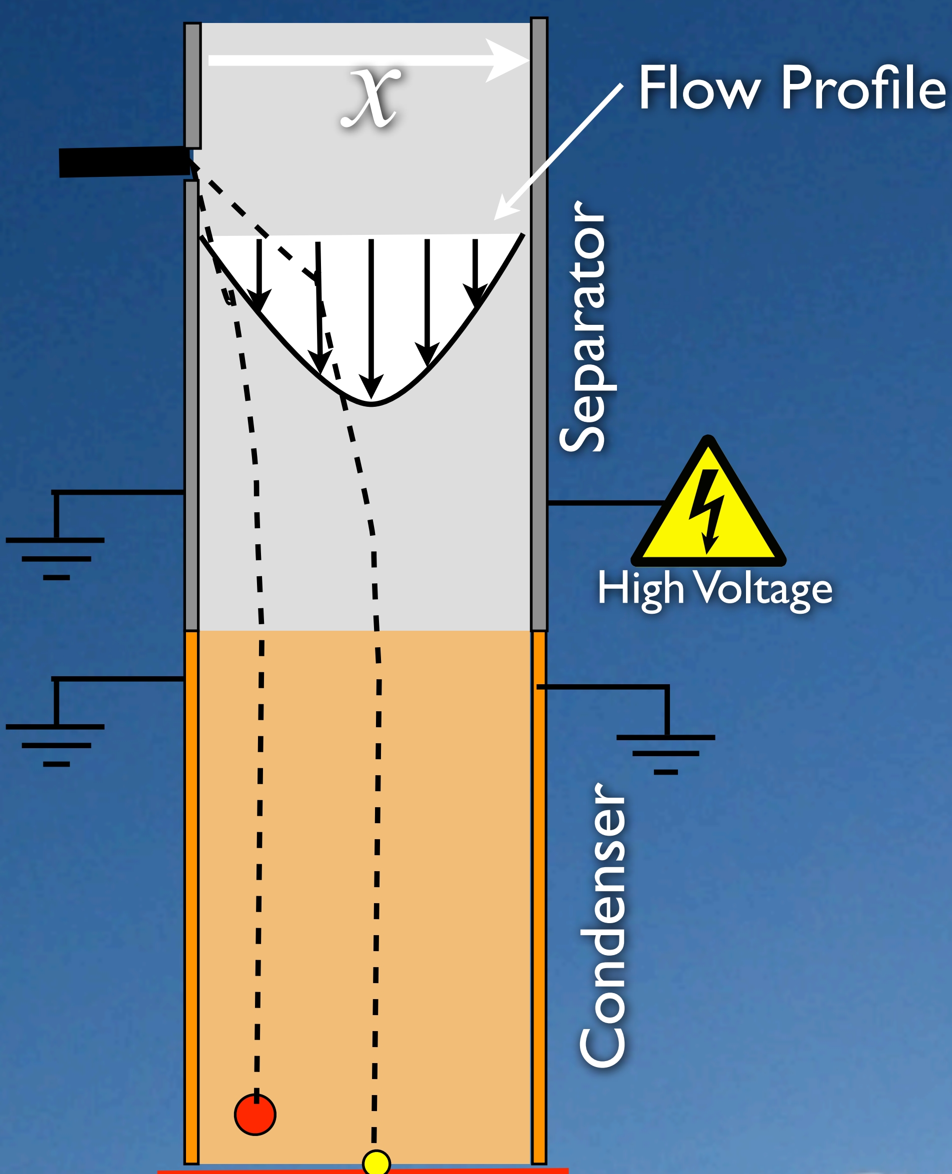
SMPS 60 s data

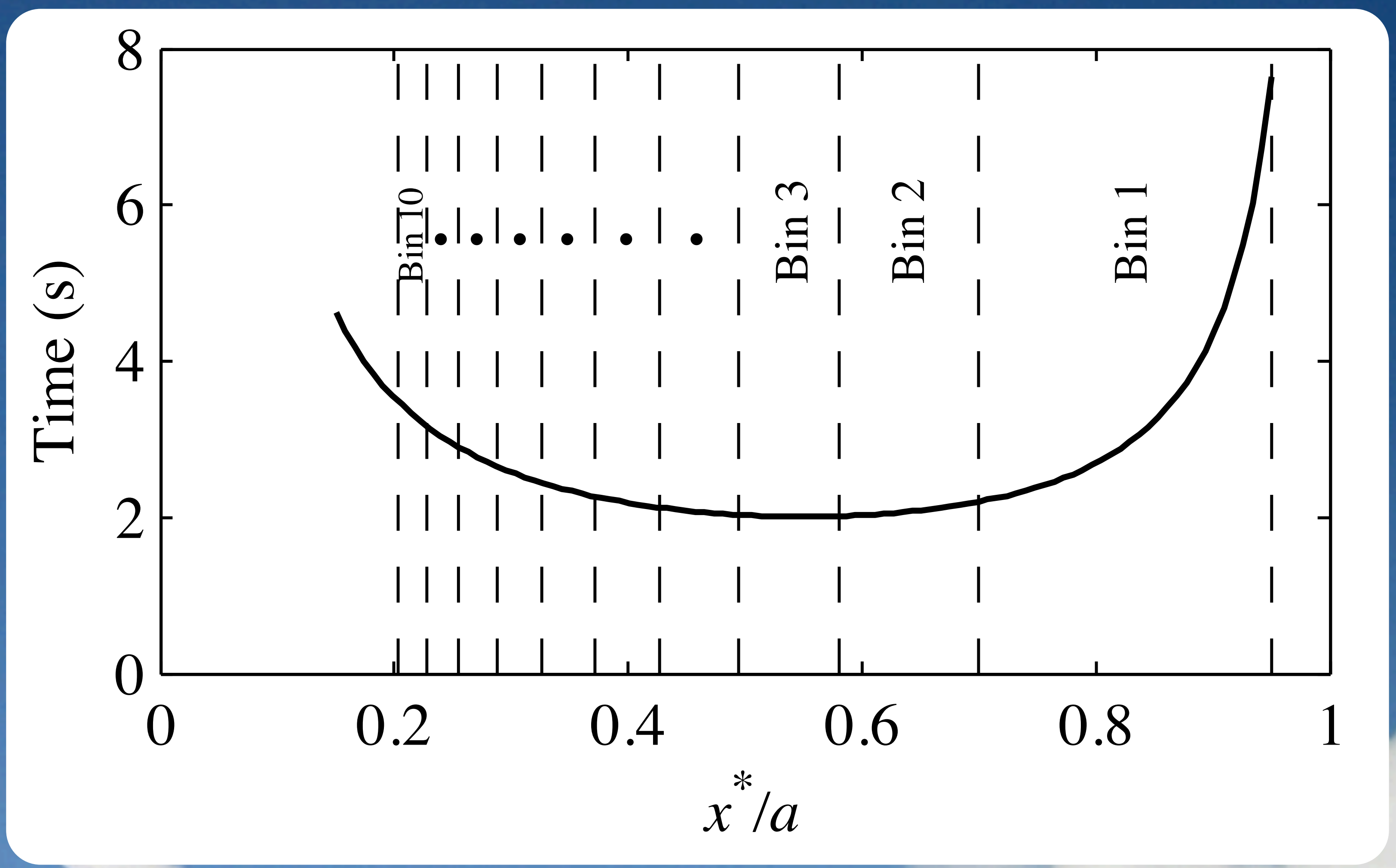


Dynamic Characteristics of the FIMS

Sources of transient error - Residence time in separator and condenser

- Particle detection time must be corrected for differences in detection time.





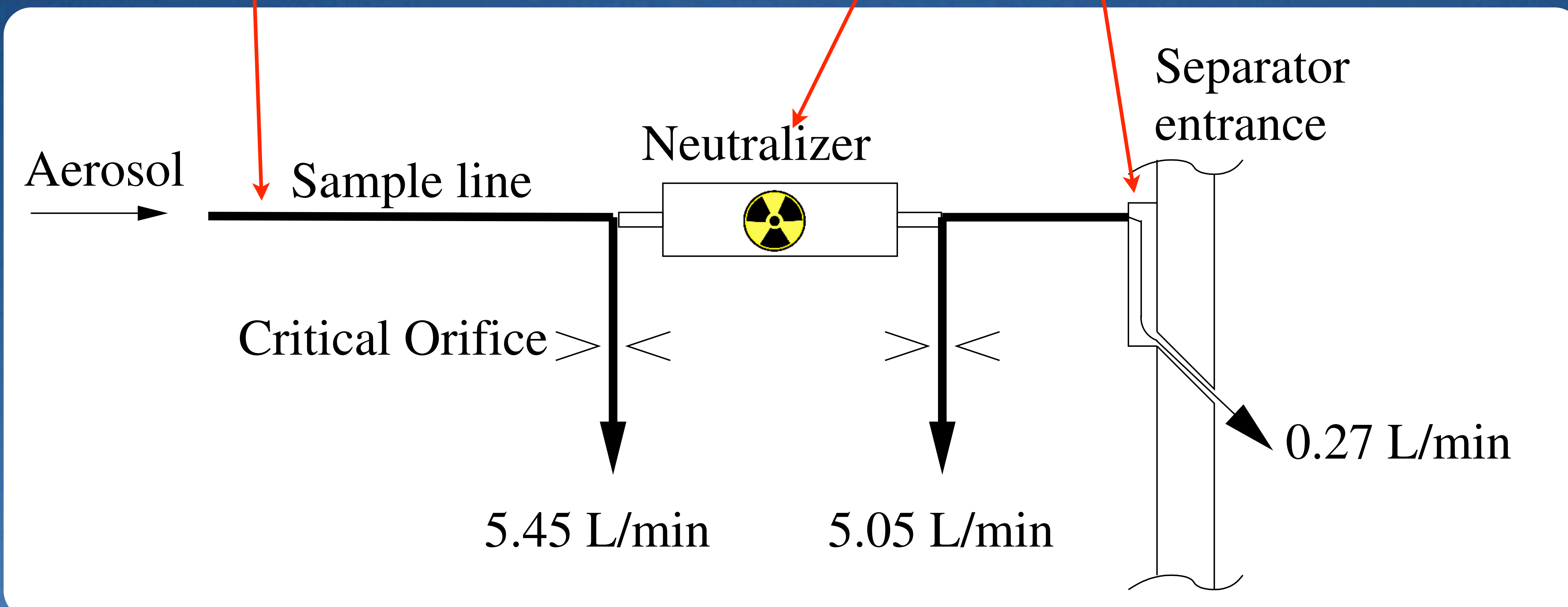
Sources of transient error - 'Smearing' in the FIMS inlet

- Mixing of the aerosol in the inlet causes particles sampled at one instant to enter the separator at different times.

Particles at center of tube will travel faster than particles near tube wall

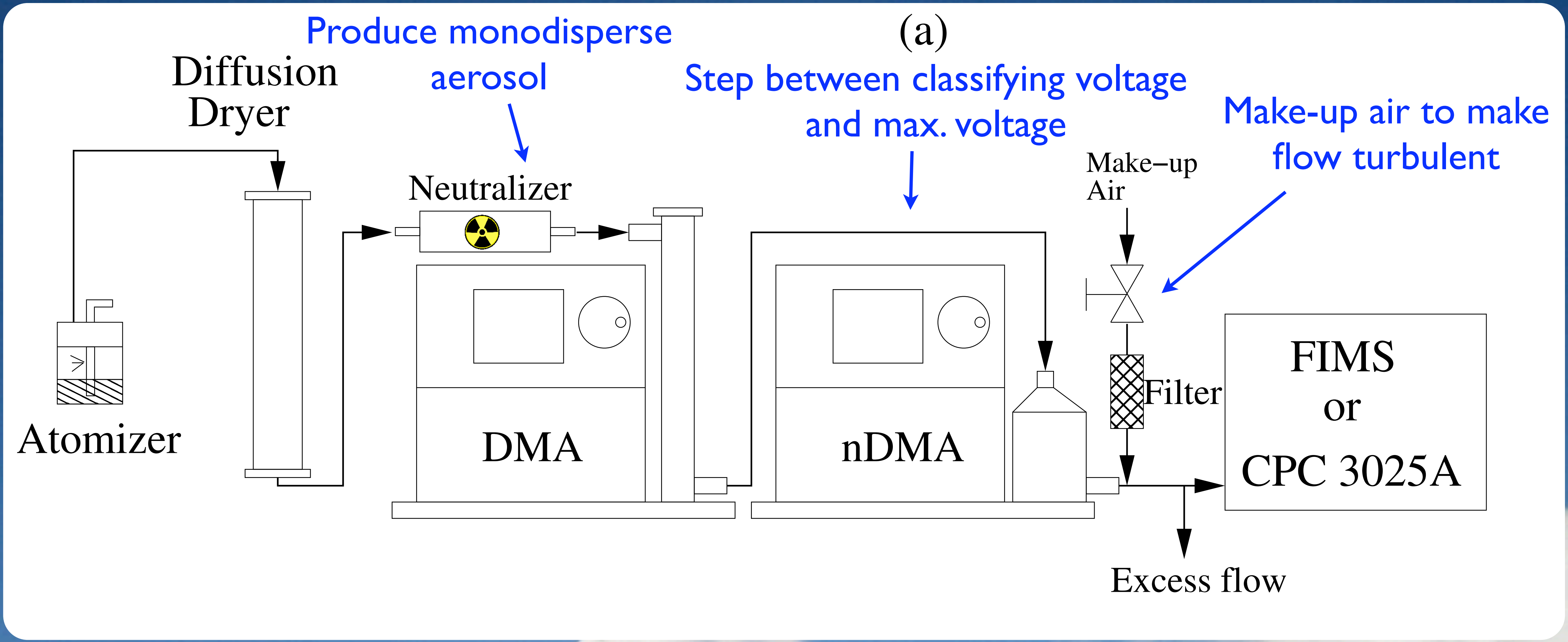
Flow mixing in neutralizer

Distributing the flow causes time delays

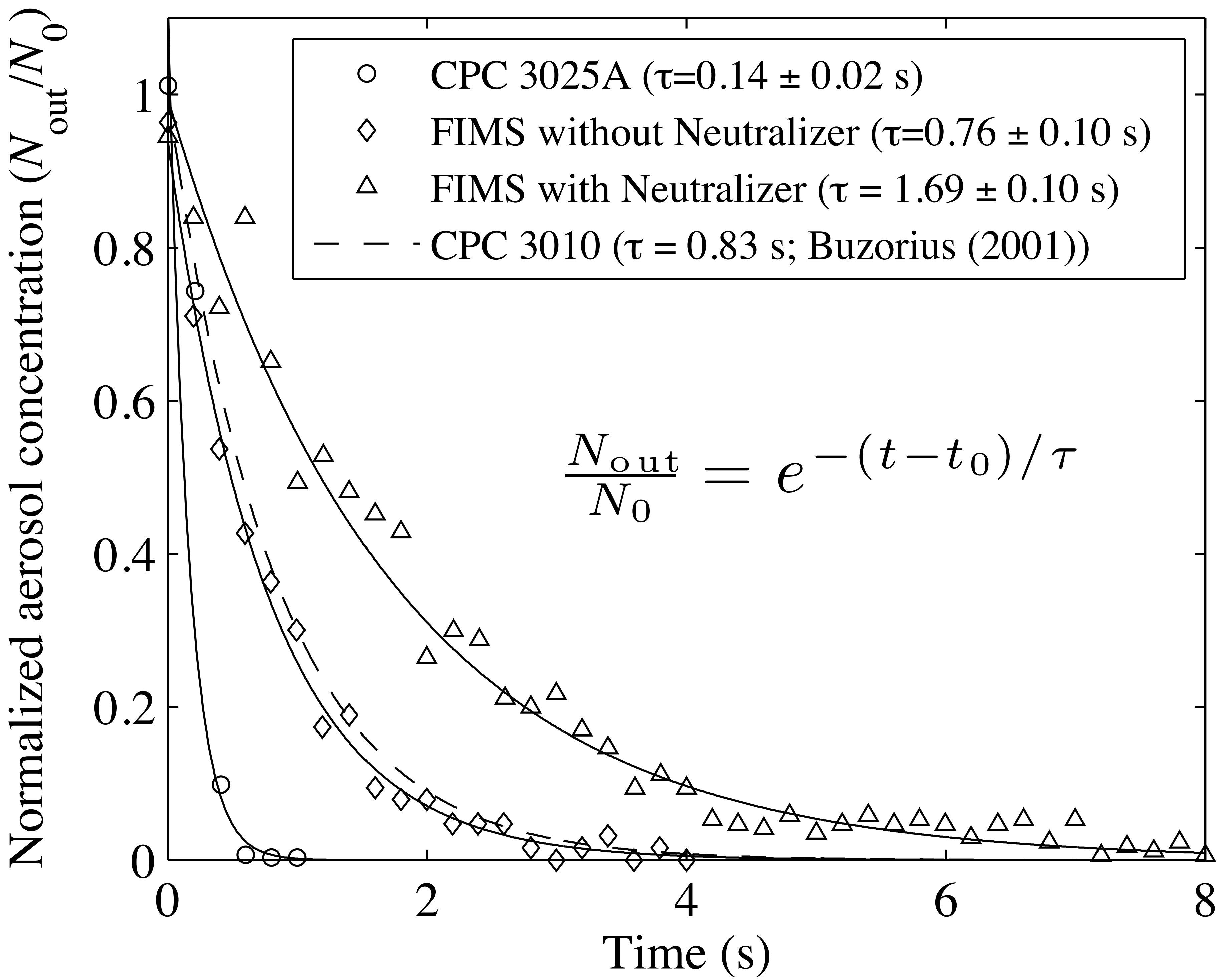


Determining the time constant – Step-response of the instrument

- Time constant can be found by measuring the response to a step-change in the input.

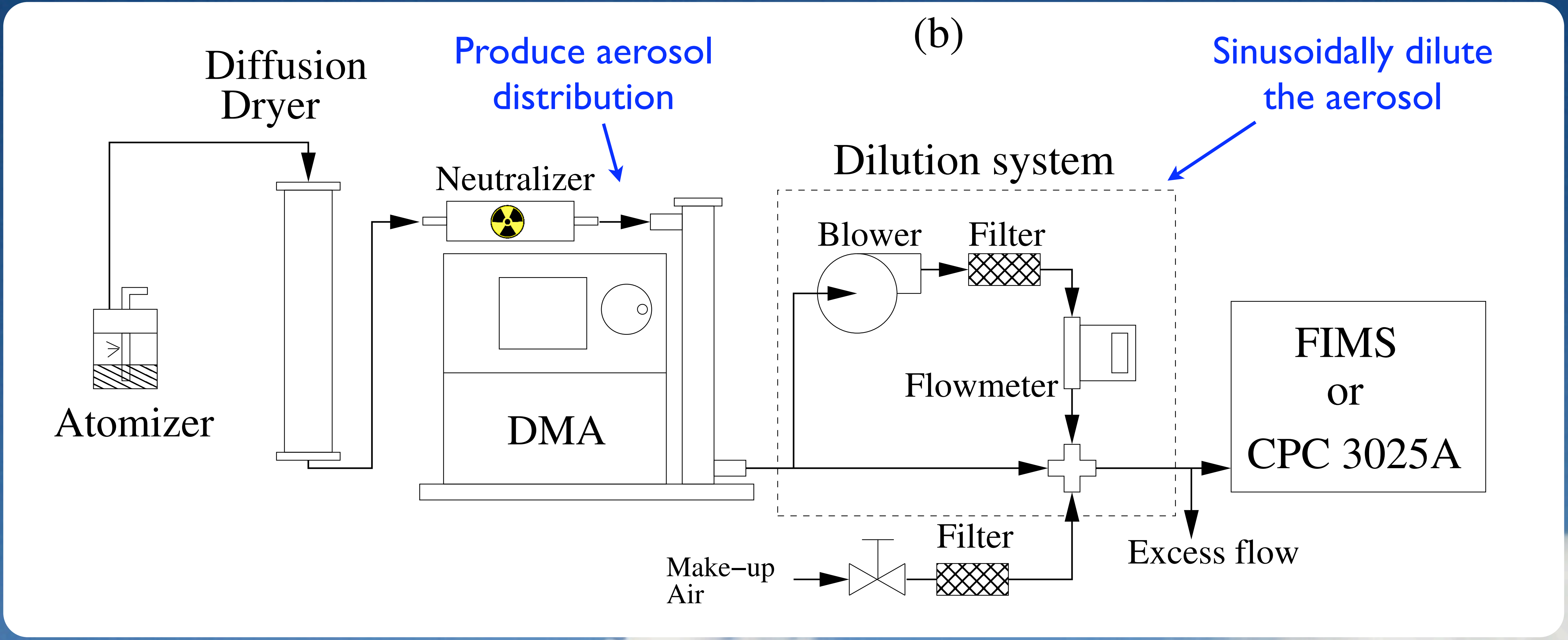


Step-response of FIMS and CPC

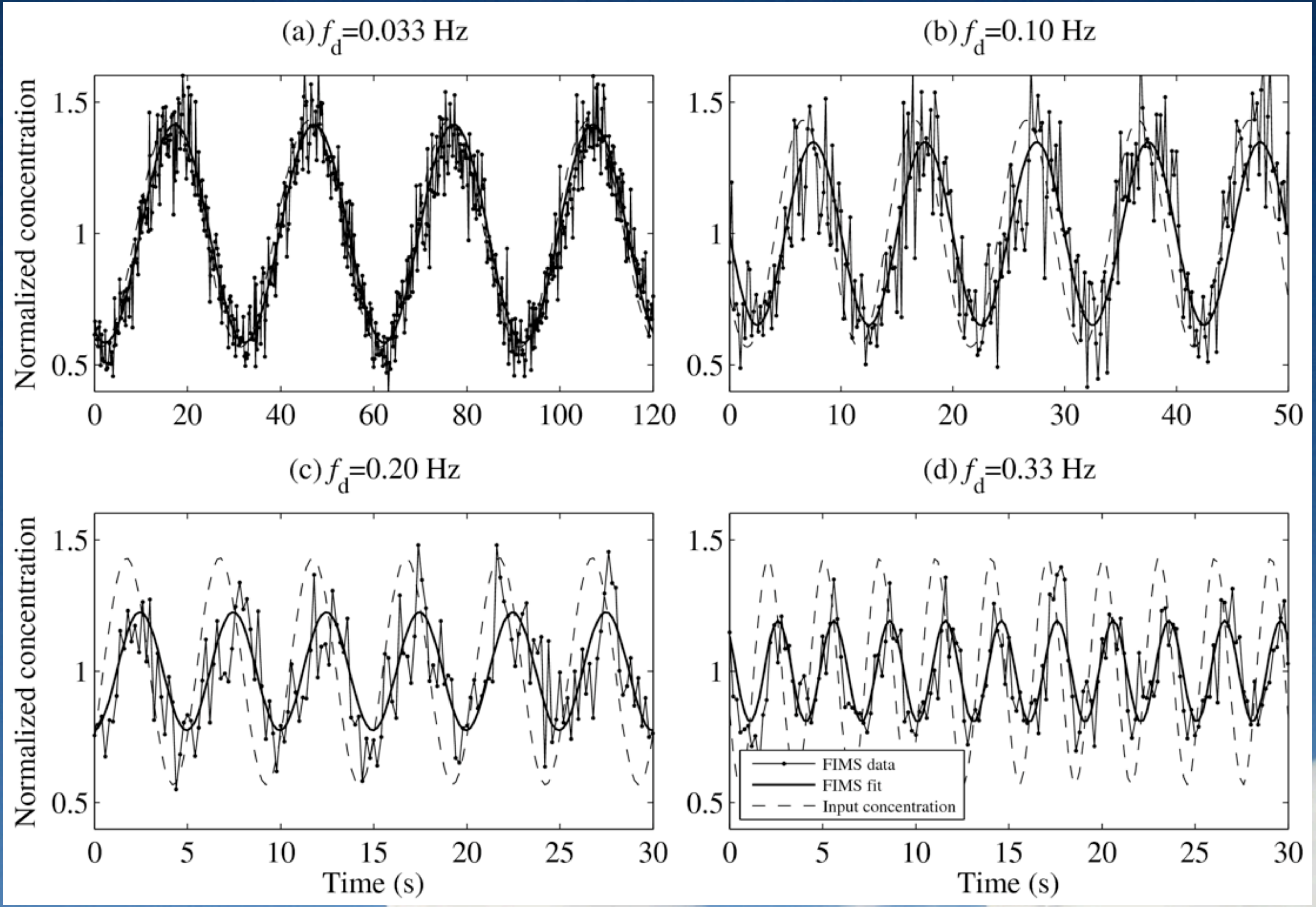


Determining the time constant – Frequency-response of the instrument

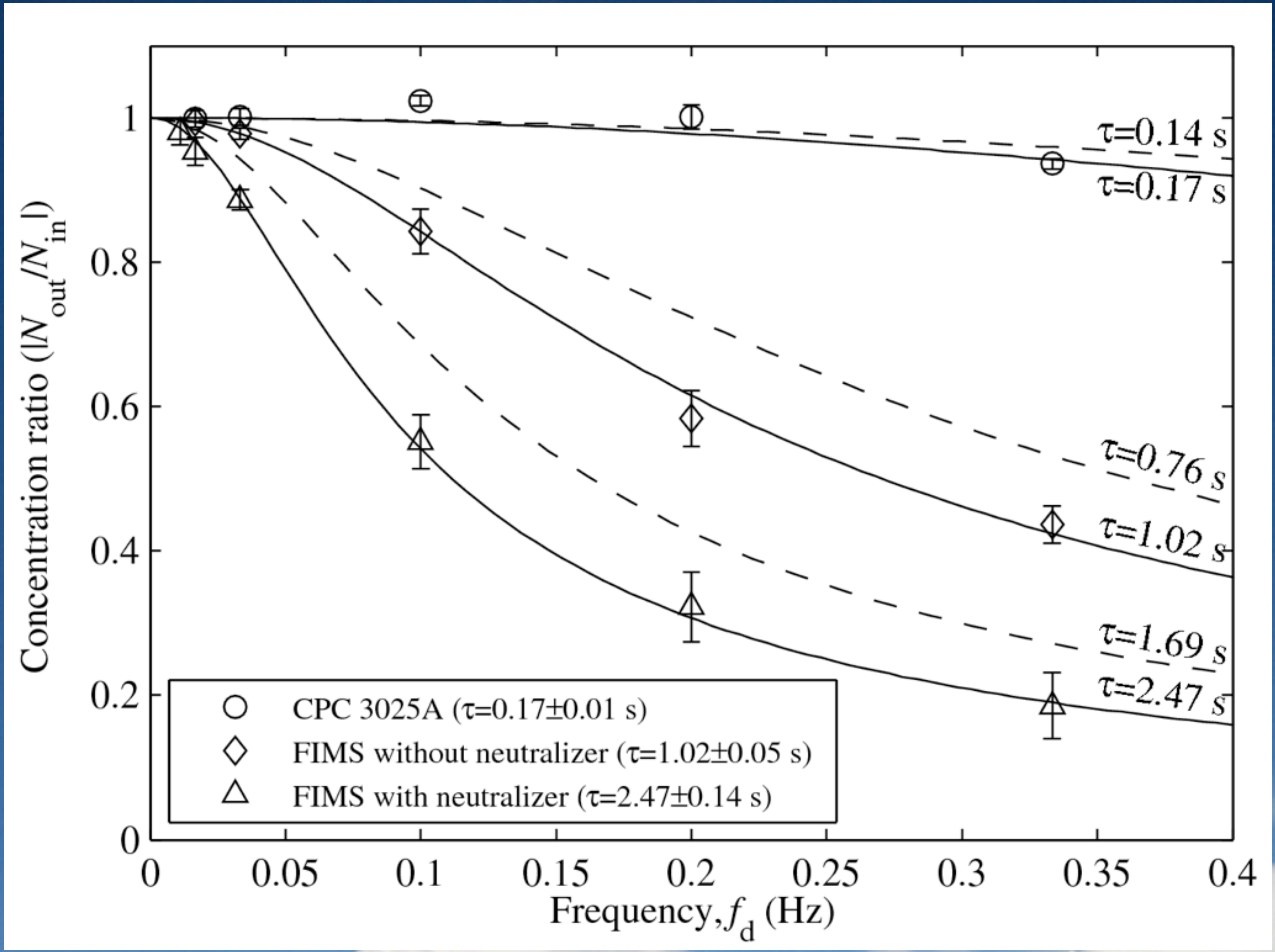
- Time constant can also be determined by measuring the response to sinusoidal input



Attenuation of the FIMS measurement



Frequency-response curve of the FIMS



'De-smearing' the data

- de-convolve the time series of particle counts in each size bin before inverting the data.

$$C^i(t) = \frac{1}{t}\int_0^t R^i(t')\Theta(t-t')\mathrm{d}t'$$

Concentration measured in each size bin, i, at time, t (known)

Concentration entering FIMS in each size bin, i, at previous time, t' (unknown)

'Response function', Θ

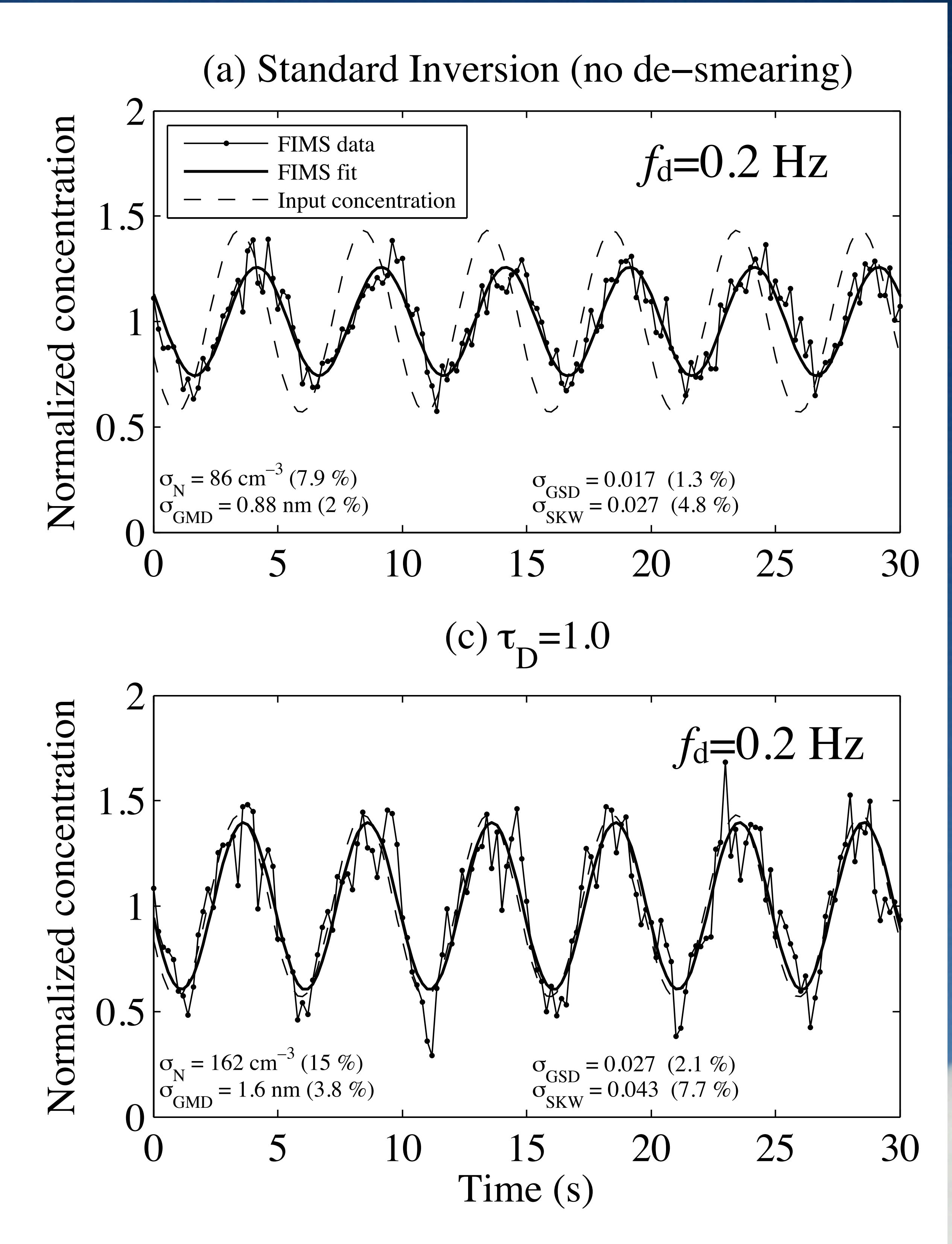
Fraction of particles that enter at previous time, t', that are detected at time t. (known from model)

$$\frac{N_{\mathrm{out}}}{N_{\mathrm{in}}} = e^{-(t-t_0)/\tau}$$

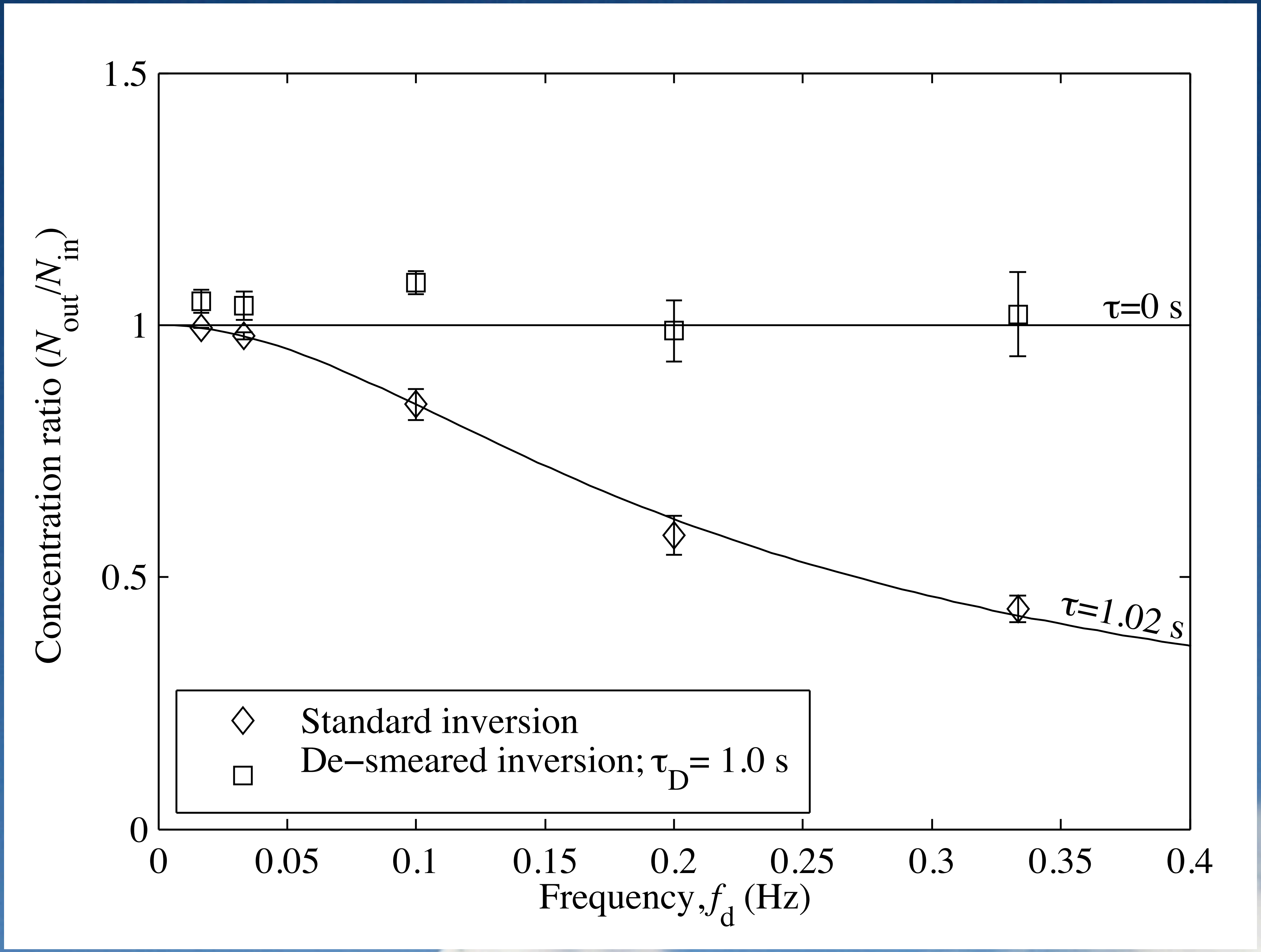
First-order system

De-smearing the FIMS data

- With de-smearing the attenuation and delay is eliminated....
- ... but the random error almost doubles:
  - σ_N went from 7.9% to 15%
  - σ_{GMD} went from 2% to 3.8%



De-smeared frequency-response curve



Conclusions

- The FIMS is a highly sensitive aerosol sizing instrument that is useful in many applications, esp. aircraft-based studies.
- Steady-state measurements agree well with SMPS.
- Error in transient measurements can occur due to 'smearing' in the aerosol inlet.
- Data can be de-smeared to correct for inlet mixing, but random error will increase.

Acknowledgments

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Any Questions?