Progress on the design and construction of a high vacuum LII system using an aerodynamic lens.

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22nd September 2009

Nanoparticles

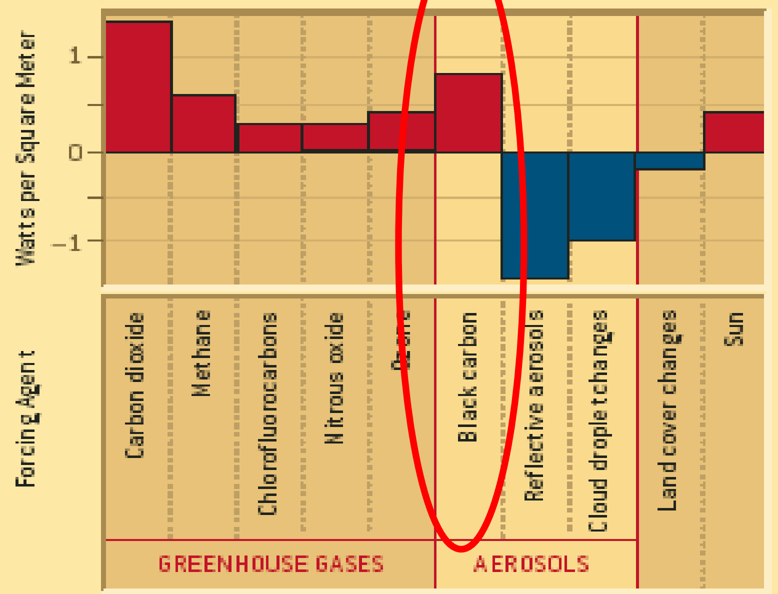
Soot and black carbon present serious health hazards to the respiratory system, in addition they are contributing significantly to climate forcing or the greenhouse effect.

Nanoparticles in the atmosphere, both carbon and non carbon are a cause for concern.

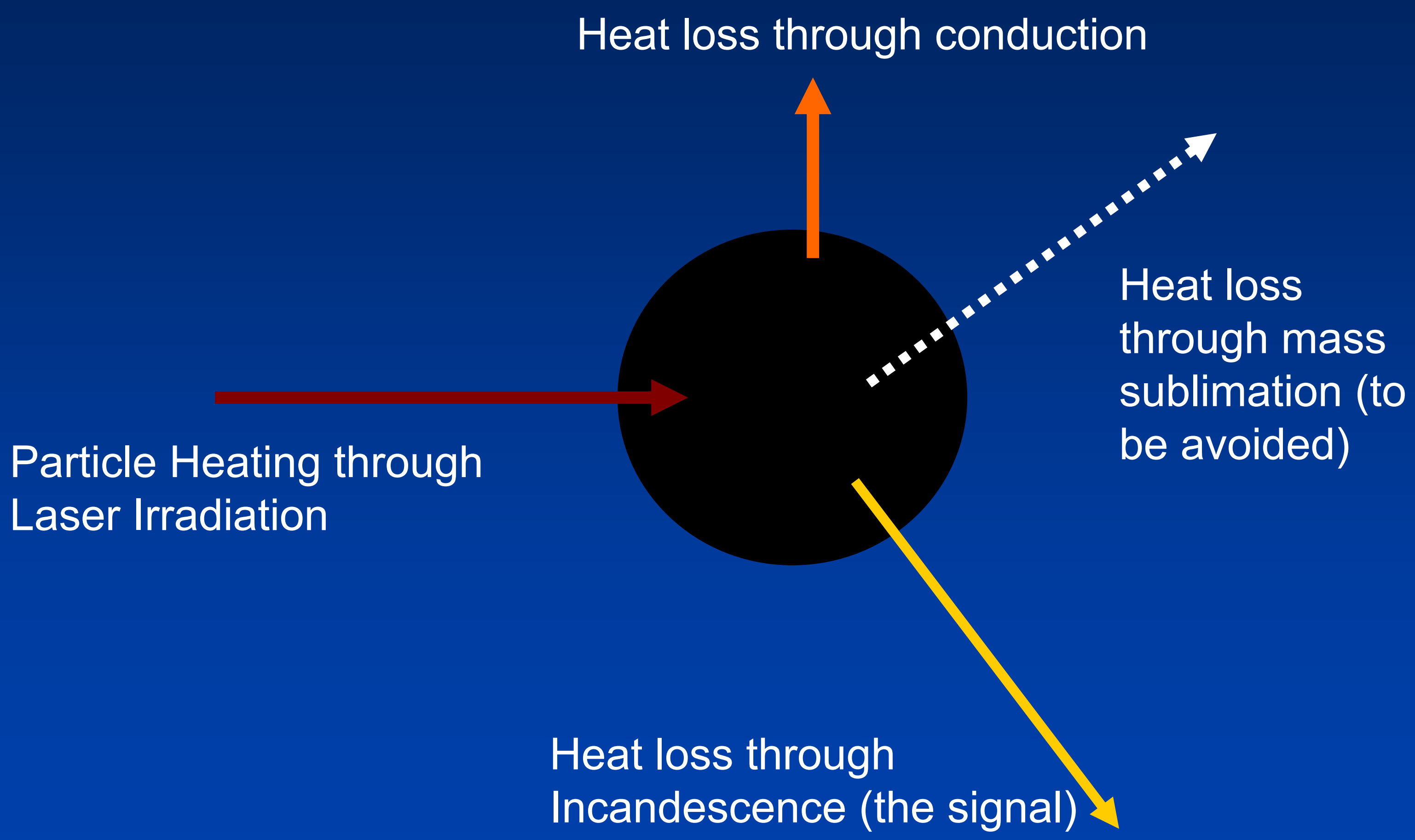
A very sensitive method which can measure nanoparticles (number & density) and estimate morphology is required.

CLIMATE FORCINGS

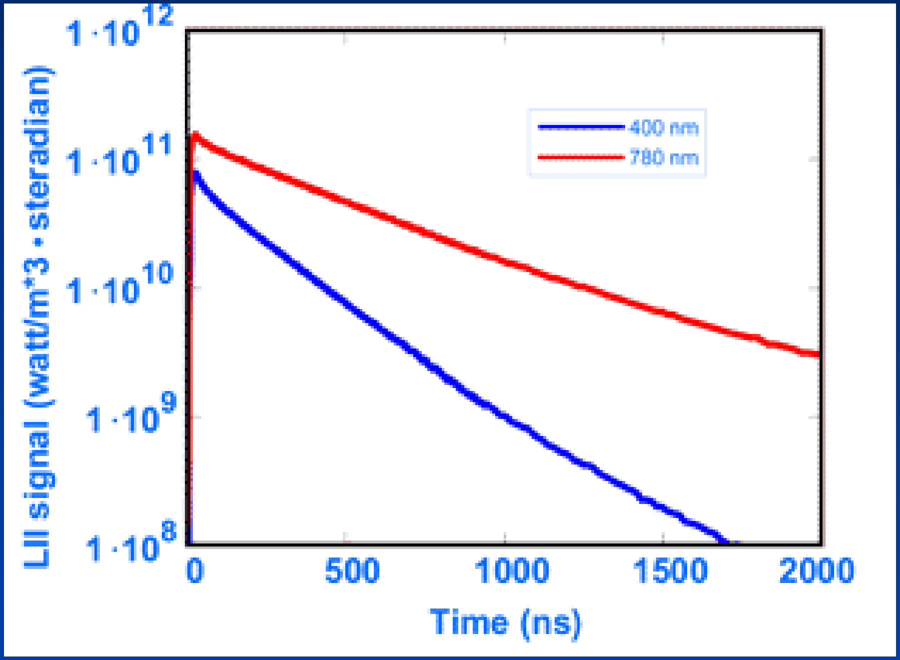
A CLIMATE FORCING is a mechanism that alters the global energy balance. A forcing can be natural—fluctuations in the earth's orbit, for example—or human-made, such as aerosols and greenhouse gases. Human-made climate forcings now dominate natural forcings. Carbon dioxide is the largest forcing, but air pollutants (black carbon, ozone, methane) together are comparable. (Aerosol effects are not known accurately.)

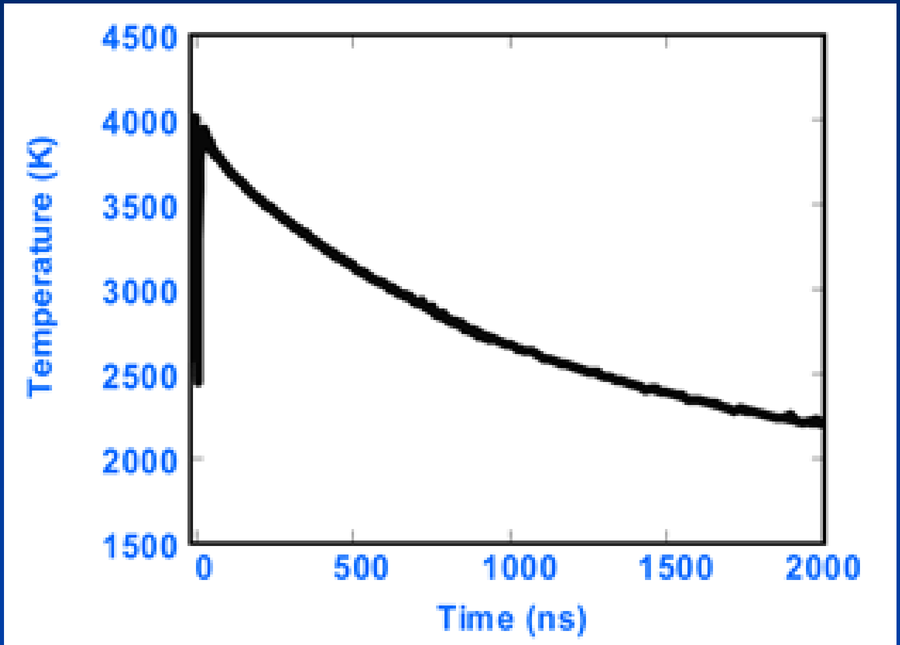


LII – Heat Balance

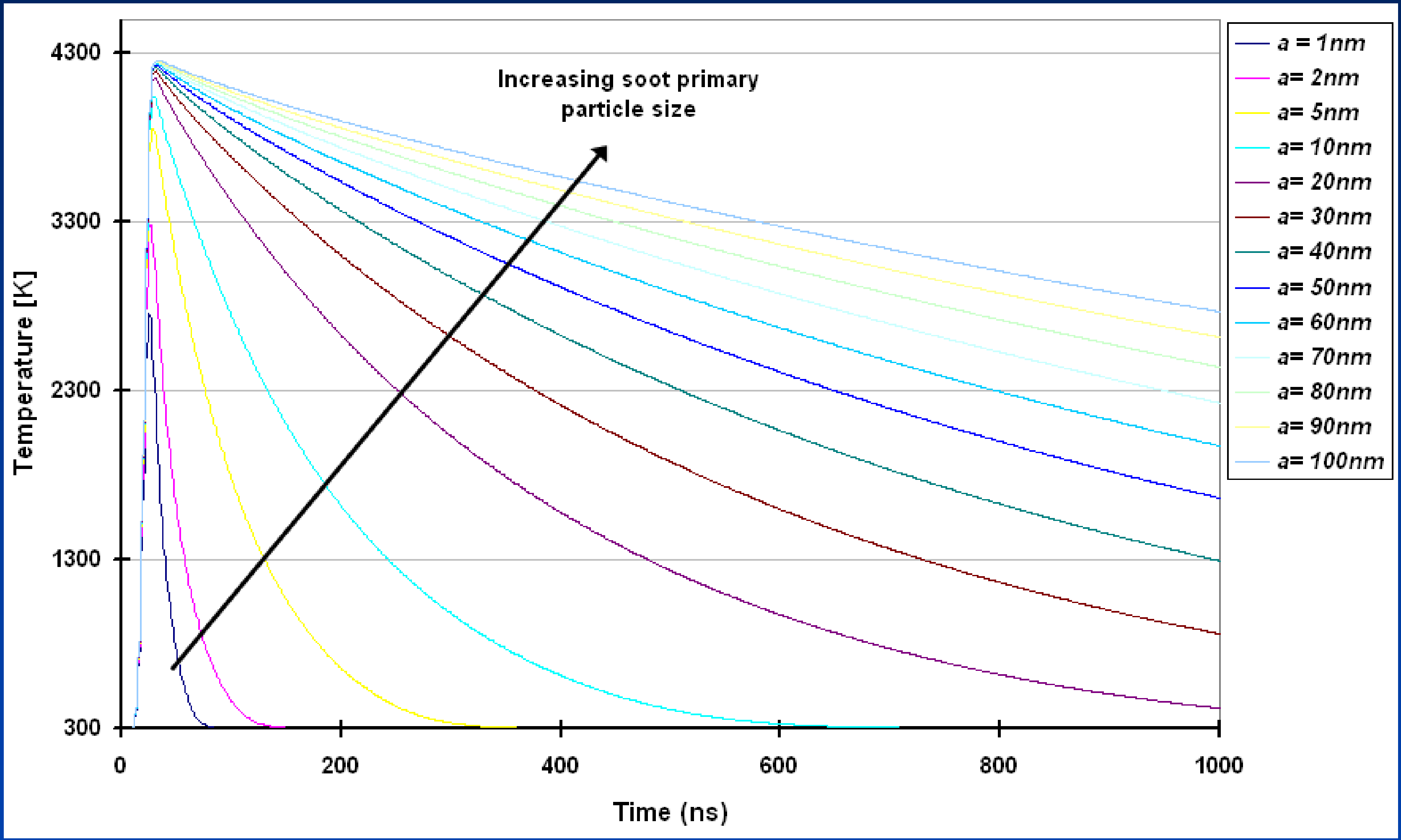


Converting 2-colour signals to T

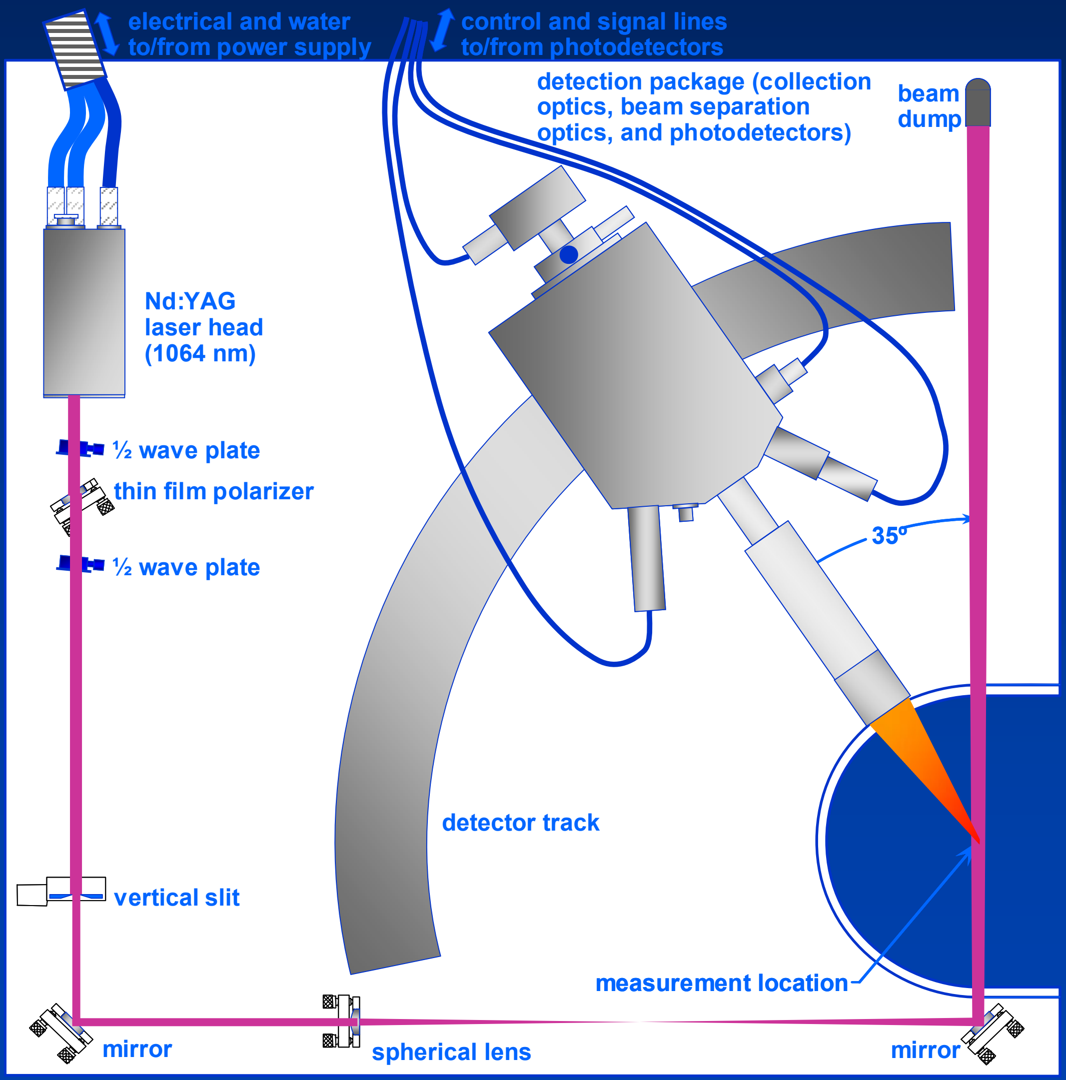




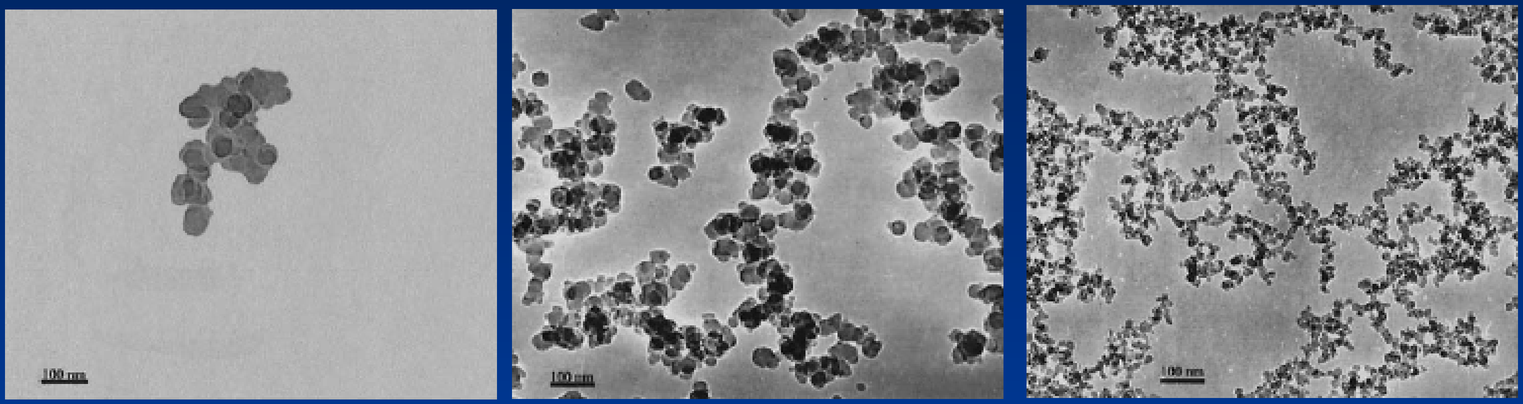
Measuring Primary Particle Size



LII Optical System

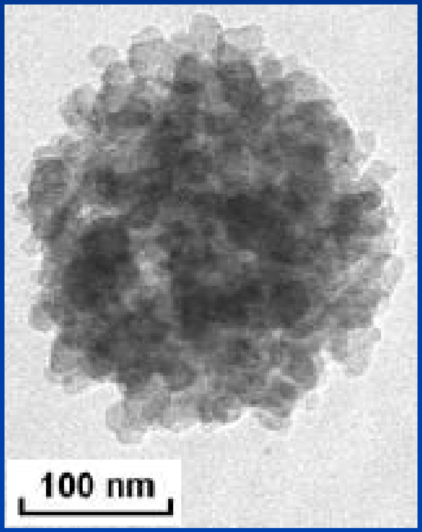


Examples of soot structure



Typical TEM images of ***flame*** soot

Soot after polarisation and exposure to water

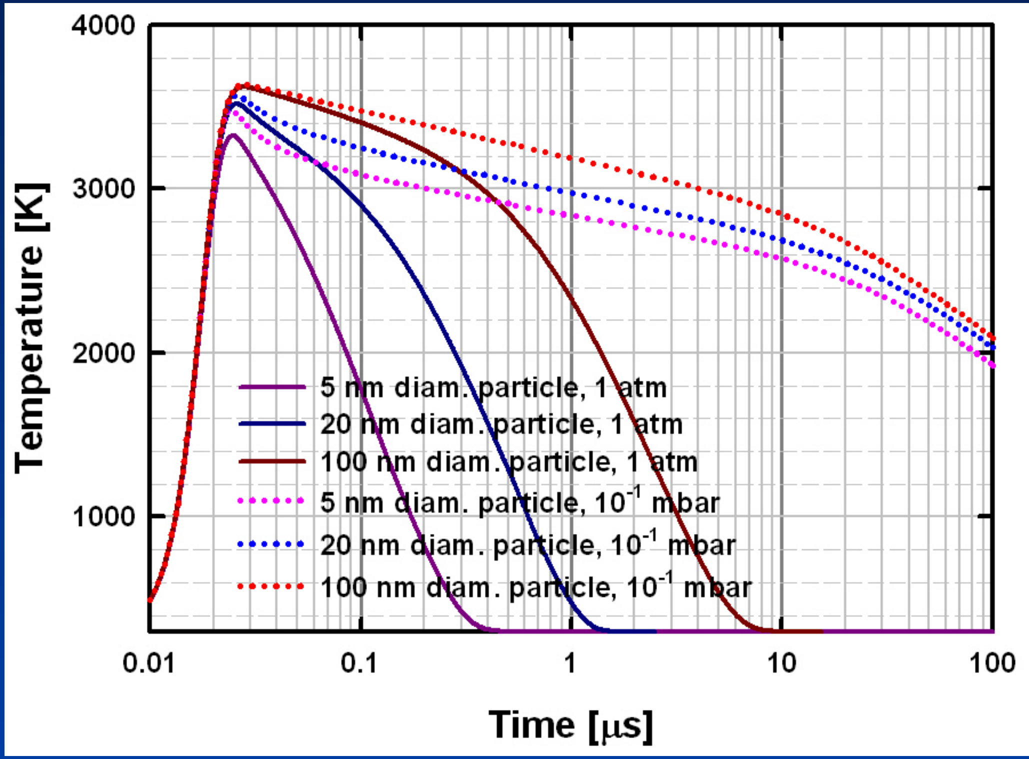


Laser-Induced Incandescence (LII) under high vacuum conditions*

- A high vacuum eliminates any conductive heat transfer.
- Therefore it is in an ideal situation to study radiative temperature decays LII duration is > 50 also μs and this considerably enhances the signal.
- Thus should be able to estimate E(m)

*V. Beyer & D.A. Greenhalgh, Appl. Phys B83, 455-567 (2006)
See also: F. Lui, K.J. Daun, V. Beyer, G.J Smallwood, and D.A Greenhalgh, Appl. Phys B87, 179-191 (2007)

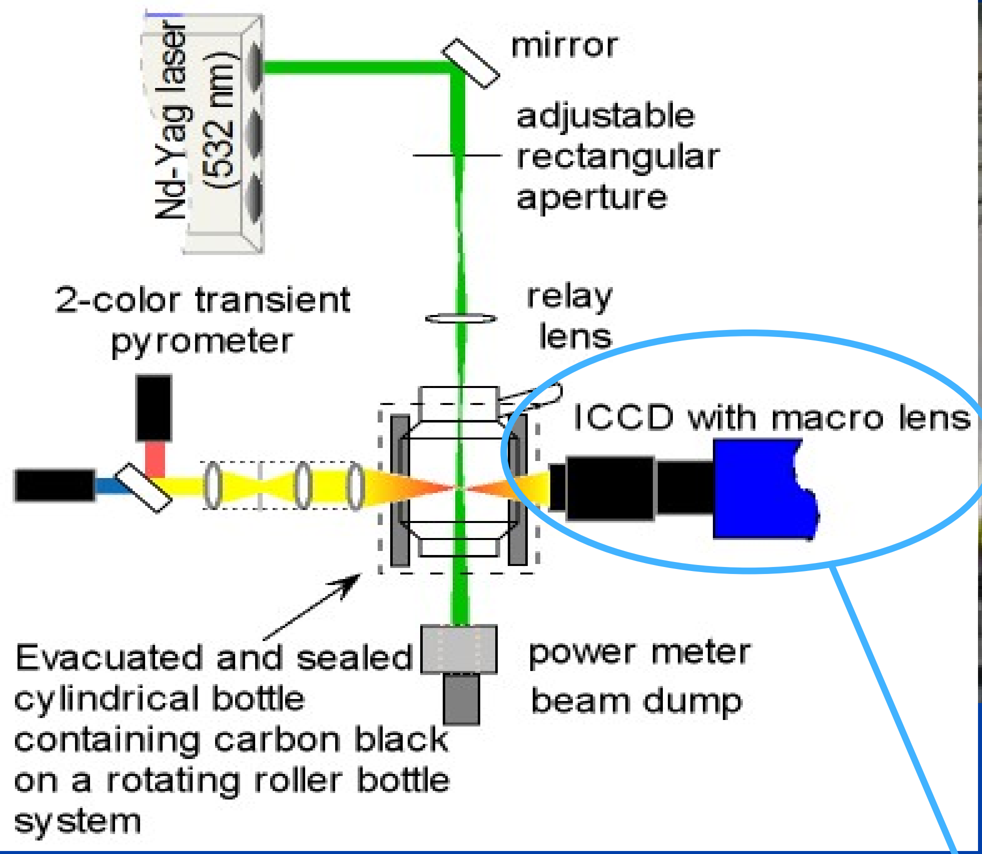
LII under vacuum - Theory

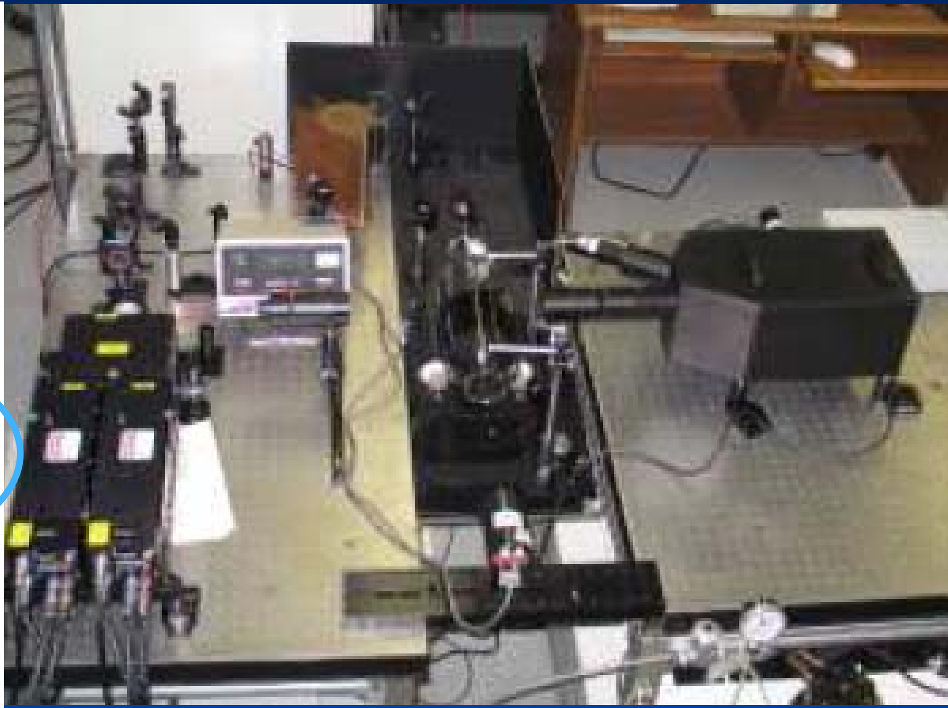


- Soot particle temperature decay lengthened to 100μs
- Time – integrated signal gain of > 300 - very desirable for nanoparticulates

- **First 10μs: sublimative T decay**
- **Remaining ~ 90μs: radiative T decay**
- **Signals independent of particle size during radiative T decay**

Experiment setup

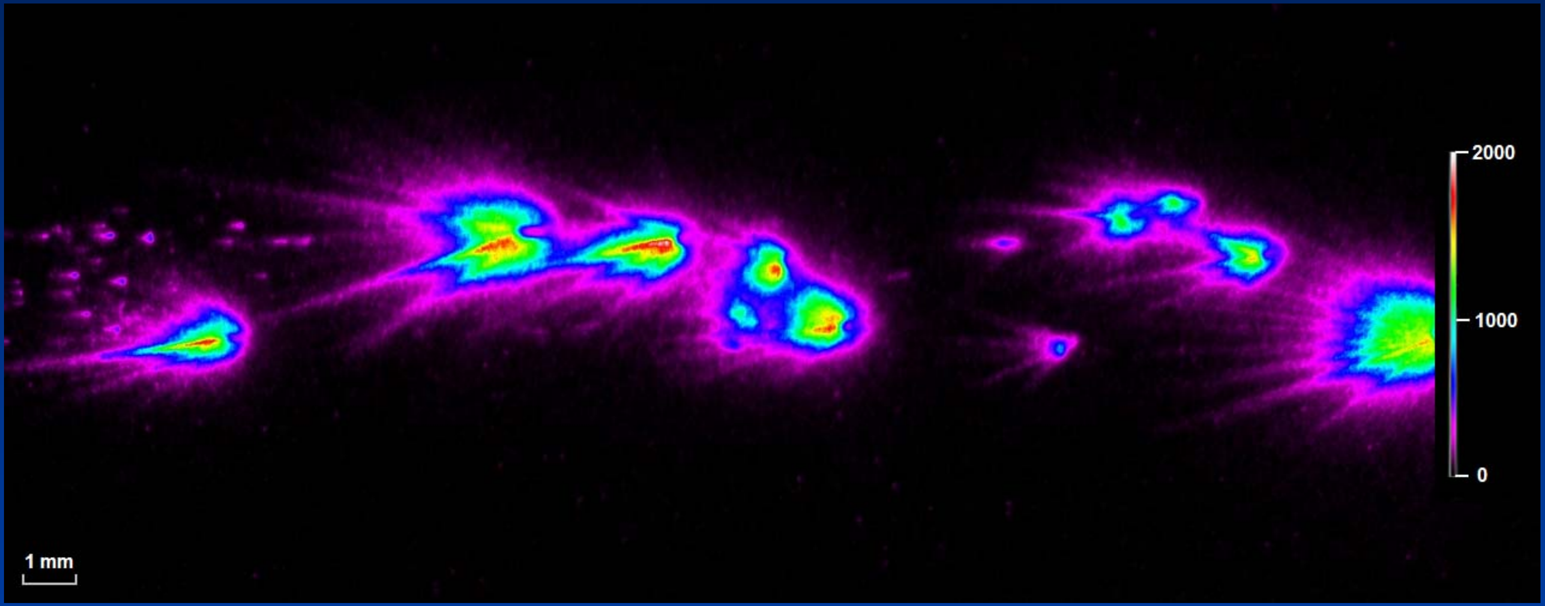




Vac. Bottle with NRC LII System

(Only in the earlier Cranfield Experiments)

Long exposure LII pictures



0.24 J/cm², ICCD gate 0-50 us

- The aggregates explode….

Time Sequenced LII images

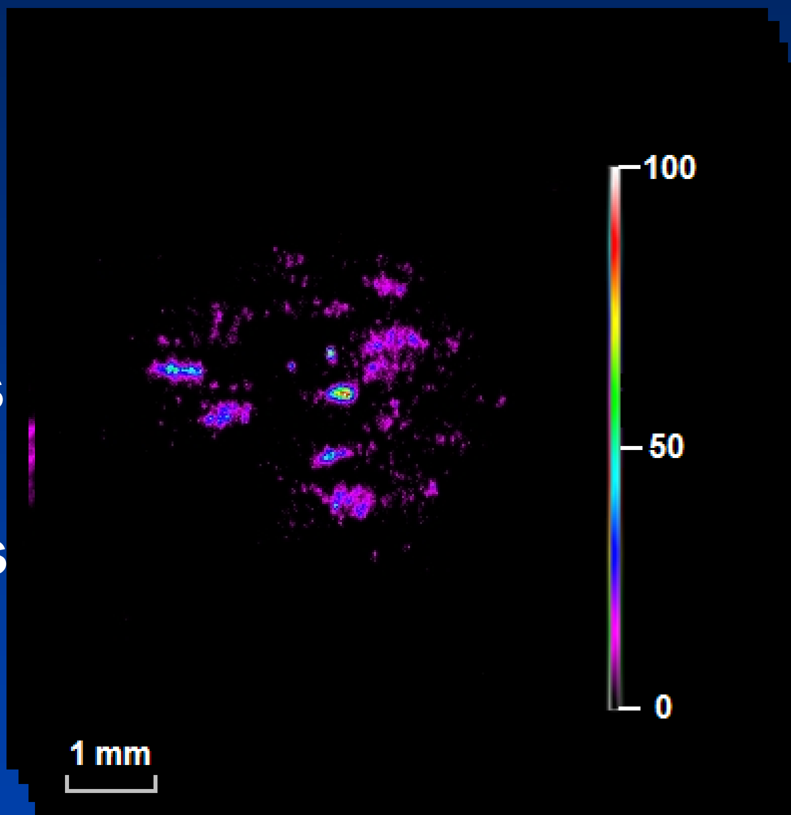
0.18 J/cm^2 | 0.24 J/cm^2

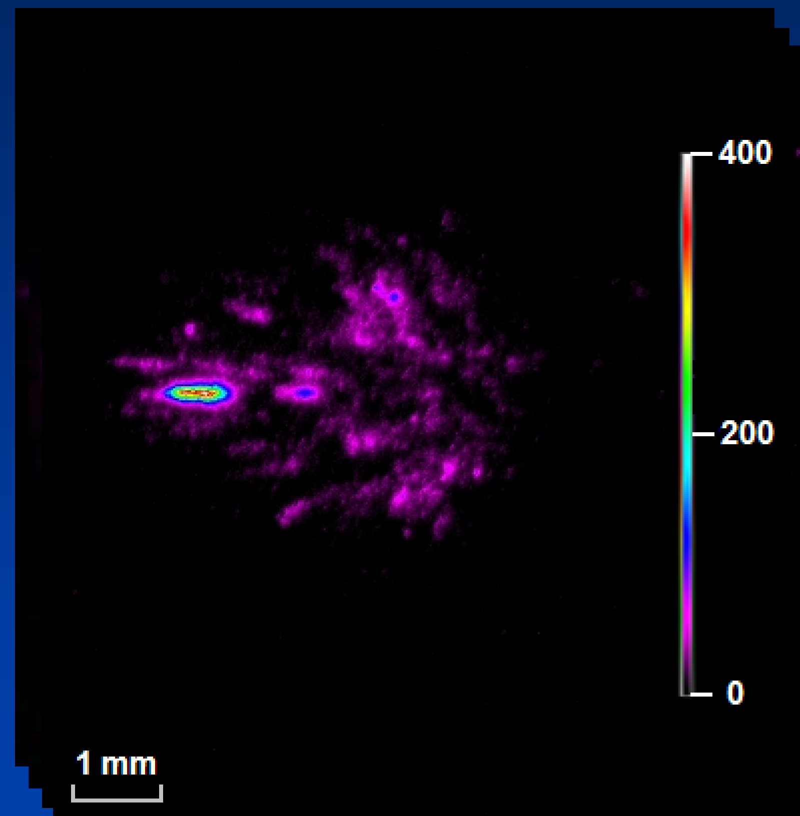
0-5 μs

5-10 μs

20-25 μs

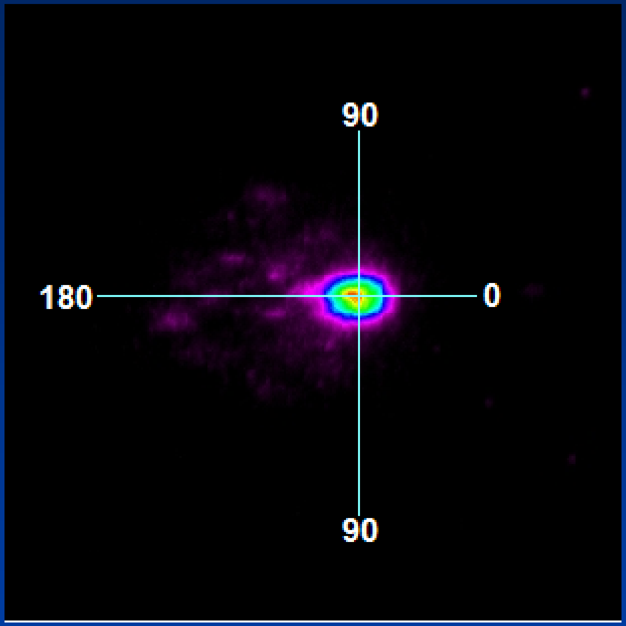
25-30 μs





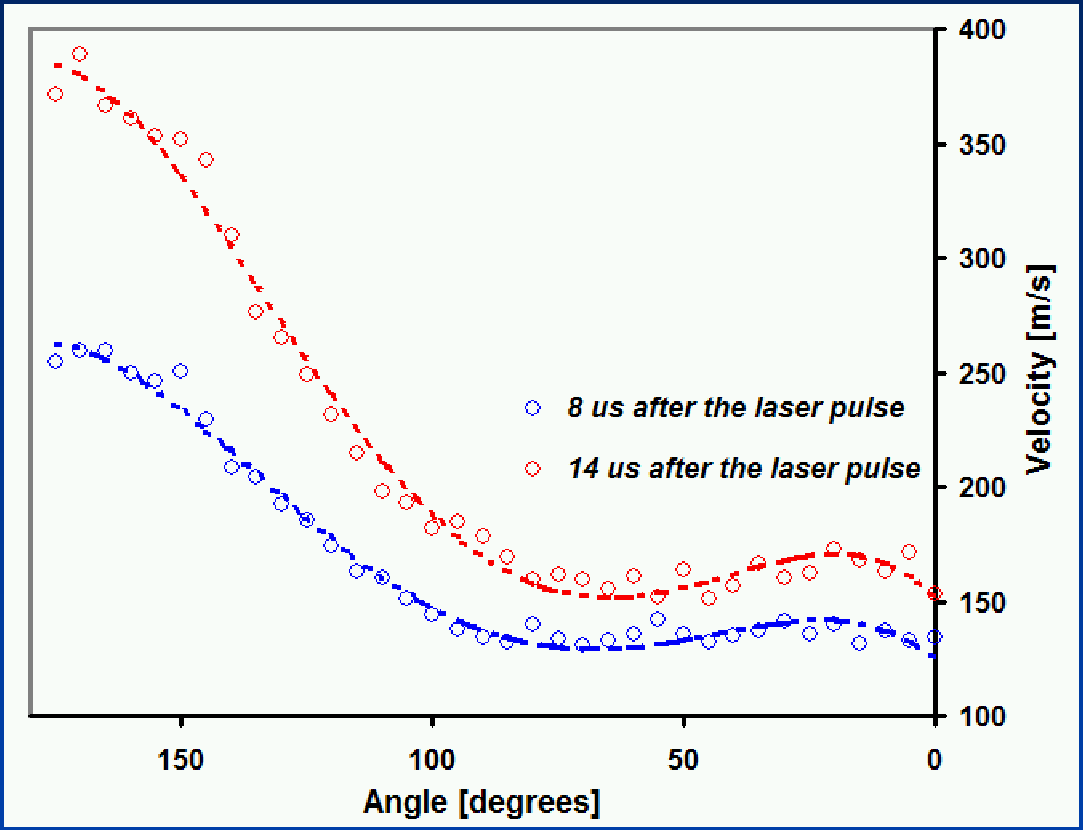
Propagation of the Laser beam

Explosions velocities from dual sequenced images - Particulate Image Velocimetry (PIV)

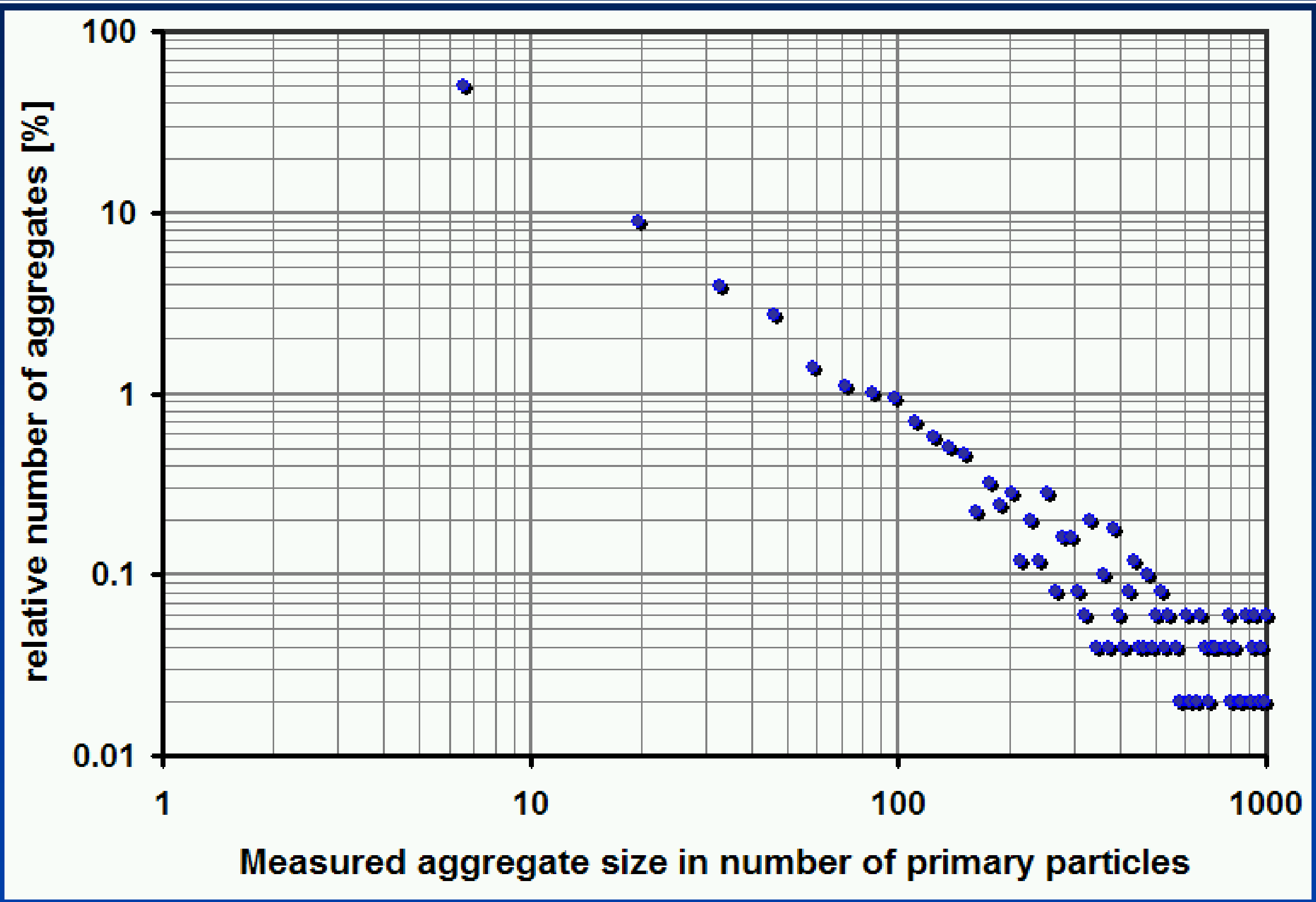


angles

Propagation of the Laser beam



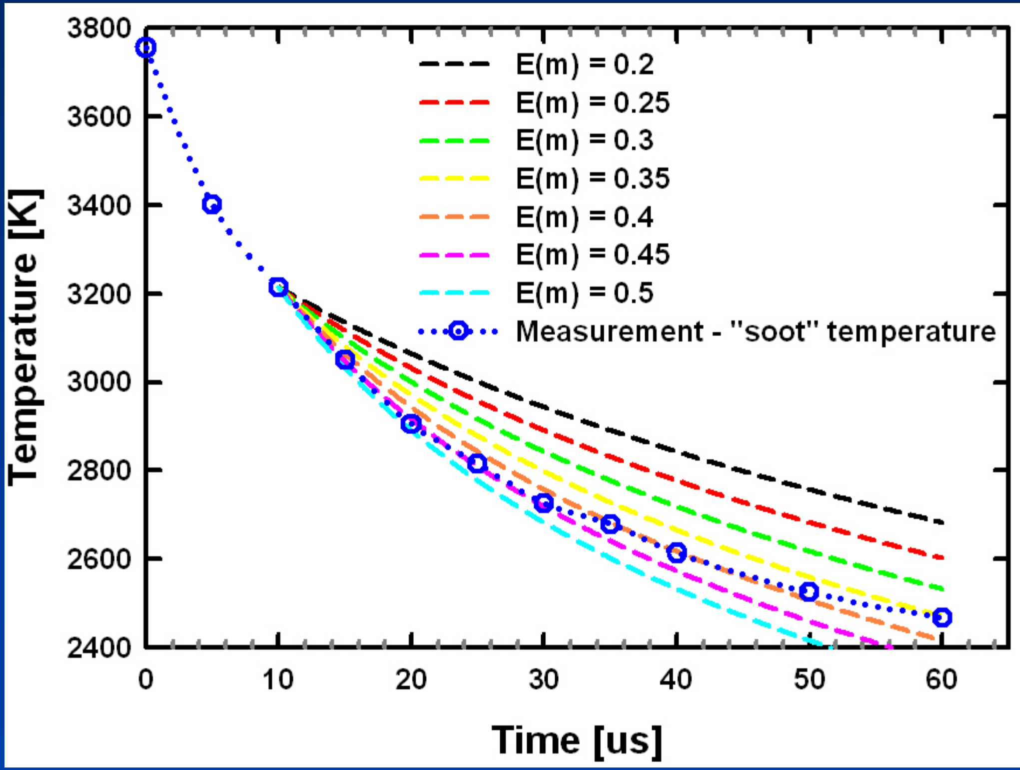
Dynamic range of the experiment



- After 30 μs, aggregates are spatially separated and measurable at high fluence.
- So we can size them (results obtained at 2550K).

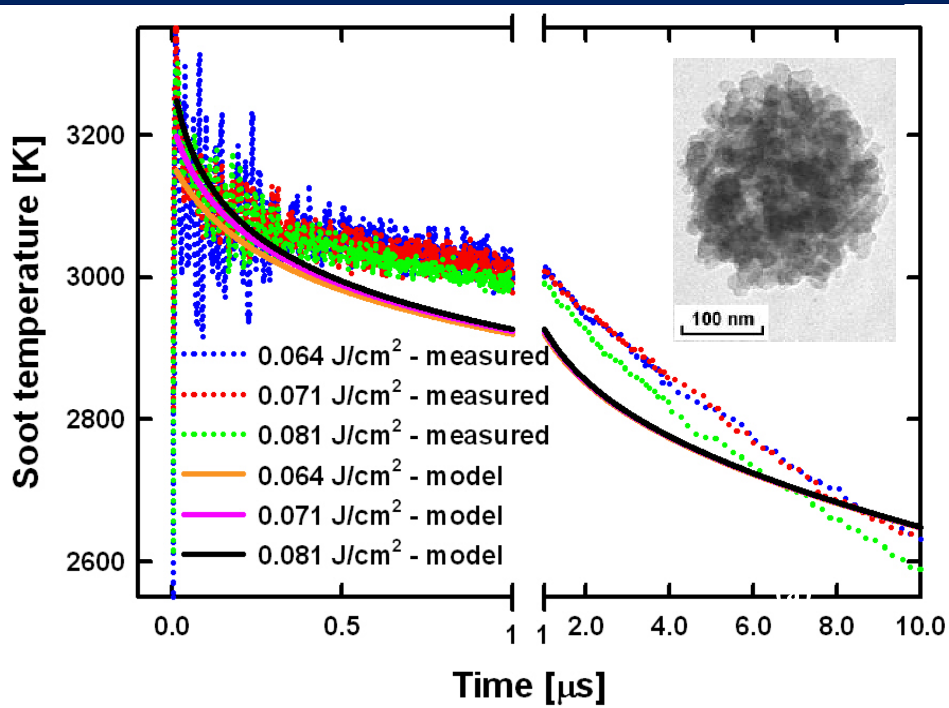
Previous LII T decay measurements at high fluence ~ .24 J/cm^{-2}

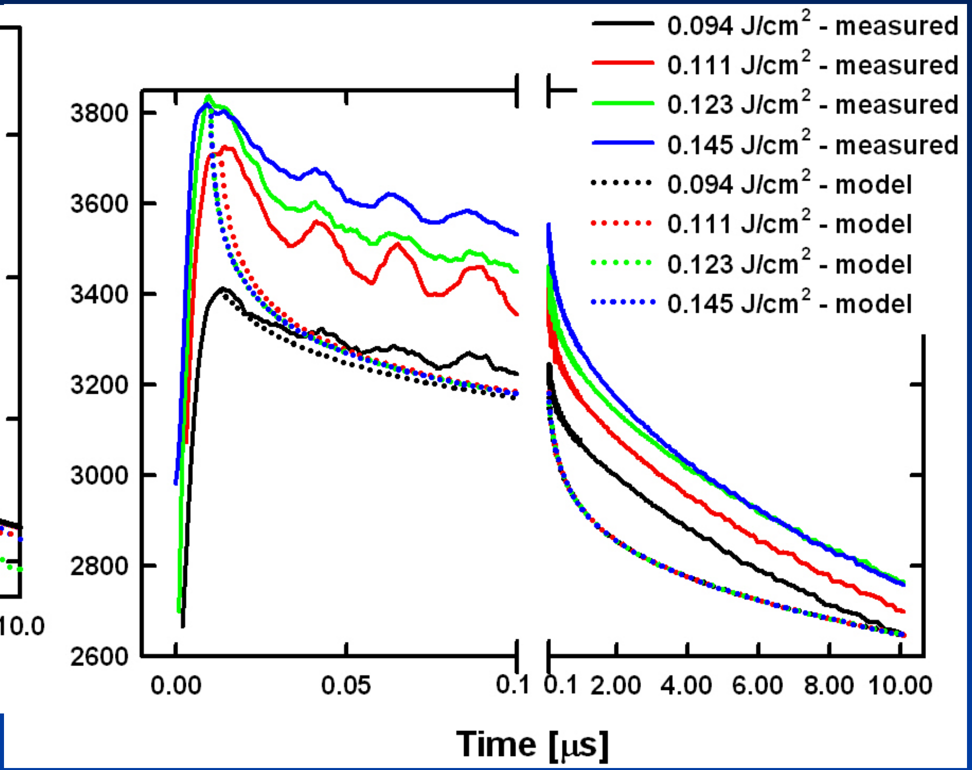
- Could not take into account the “superheated” phase of LII this may add a C_2 emission?
- Measurement accuracy: ± 100 K because of noise level and unexpected signal behaviours.
- Large agglomerates (bulk) absorb and emit light as primary soot particles (unexpected)?
- It works? 0.4 < E(m) < 0.6, consistent with the latest value of 0.41 taken from various measurements.



Note “soot” T implies use of a λ dependant emissivity estimated from E(m).

Sublimation effects

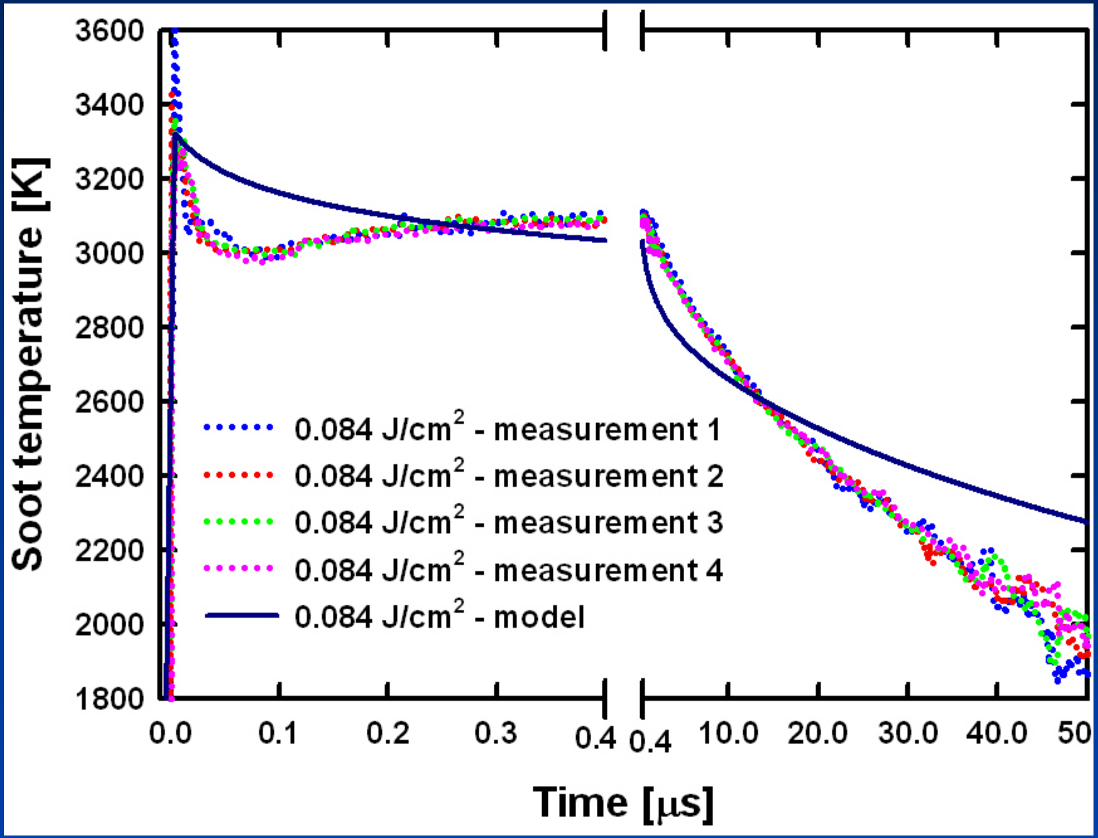




Sublimation heat loss rates overestimated by the model for up to 9 µs. after the laser pulse. At low fluences, the modelled temperature becomes equal and then superior (around 7µs.) to the measured temperature. Therefore radiation dominated decay only occurs from 10 µs. onwards.

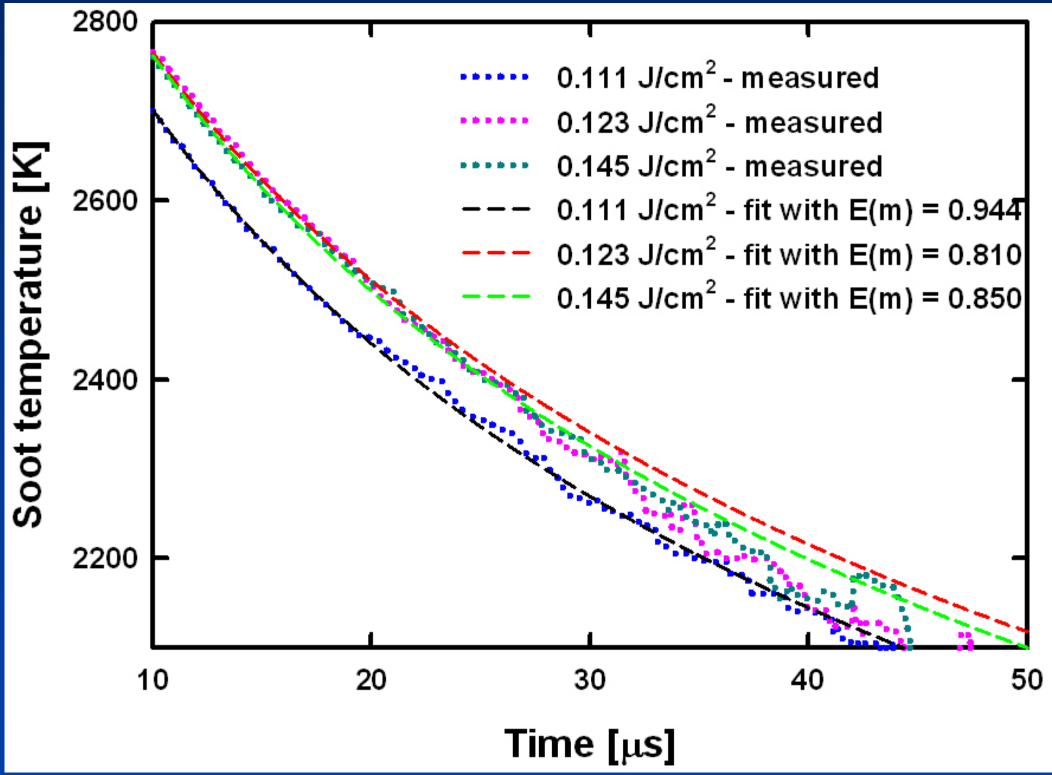
Note that C sublimation modelled for <u>individual</u> primary particles, this may be much lower for aggregates or agglomerates because of steric effects.

NRC experiments - annealing?



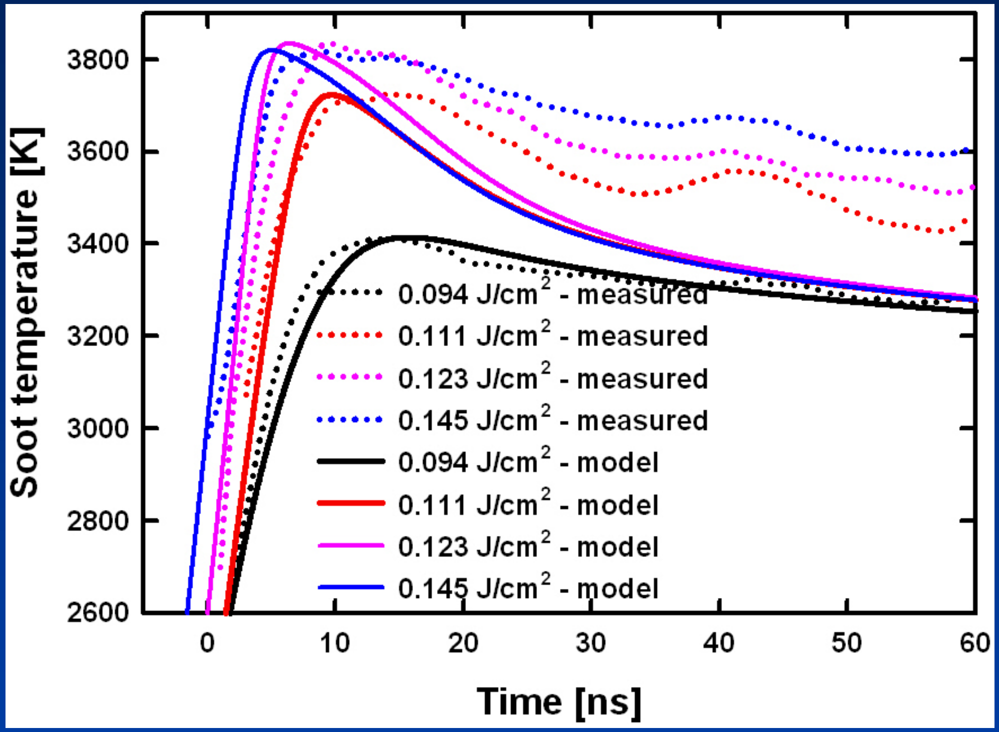
Some data indicated a "reheating phase" consistent with "Wigner energy" release suggesting re-ordering of the crystalline form, i.e. annealing.

NRC Experiments indicate large E(m) values for cooling?



E(m) estimated between 0.81 and 0.94

NRC Experiments – estimating E(m) from laser heating



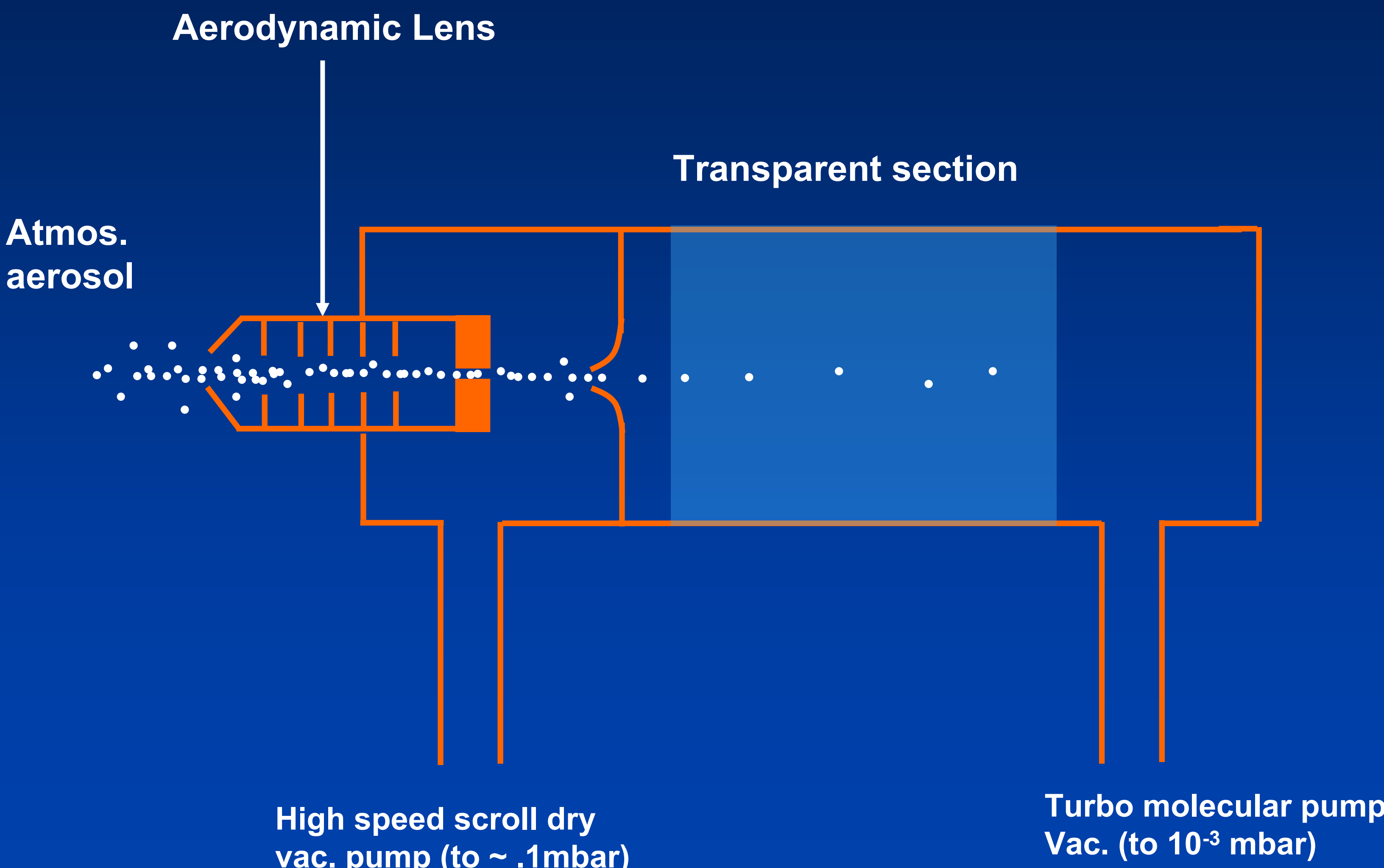
Laser Fluence [J/cm^2]	Measured T [K]	Estimated E(m) value
0.064	~ 3150	0.52
0.071	~ 3200	0.48
0.081	~ 3250	0.43
0.094	3410	0.40
0.111	3726	0.45
0.123	3833	0.54
0.145	3819	0.44

Modelled absorption and measured LII T rise time. Note that model & measurements agree within 2 ns for the rise time, which is near the PM tube response times (1-1.5ns).

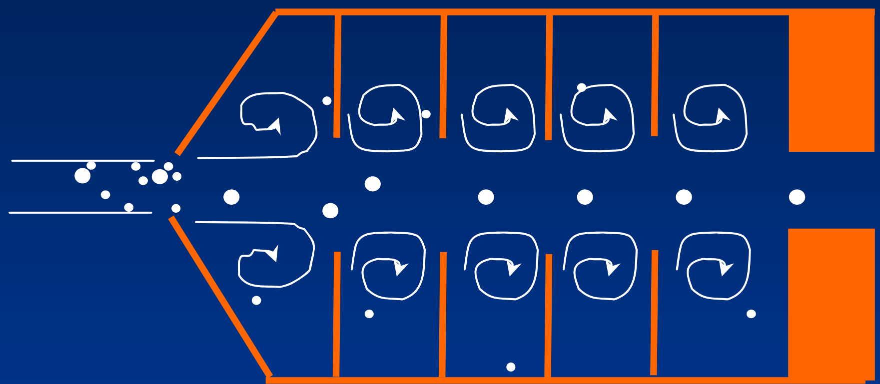
Table: E(m) values estimated from comparing modelled and measured peak temperatures.

The ~ indicates estimates of T limited to 50K due to noise.

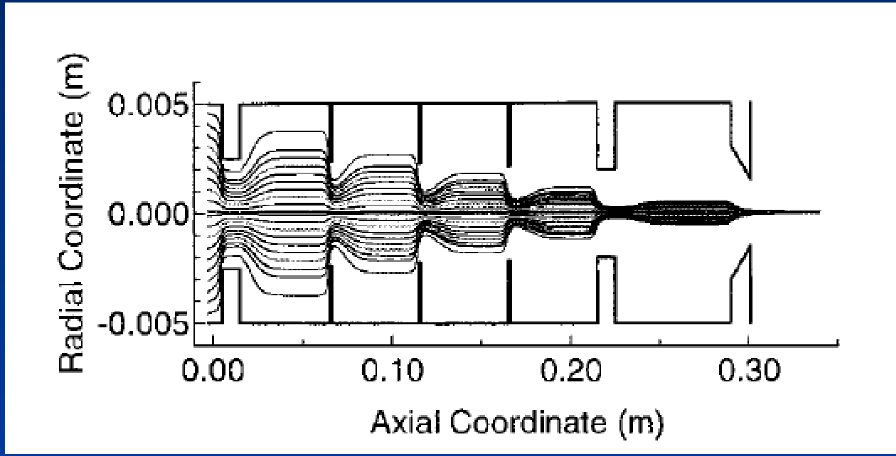
Apparatus for continuous sampling of aerosol particles into a vacuum



The aerodynamic lens after Lui*



CFD simulation for d_p = 100nm



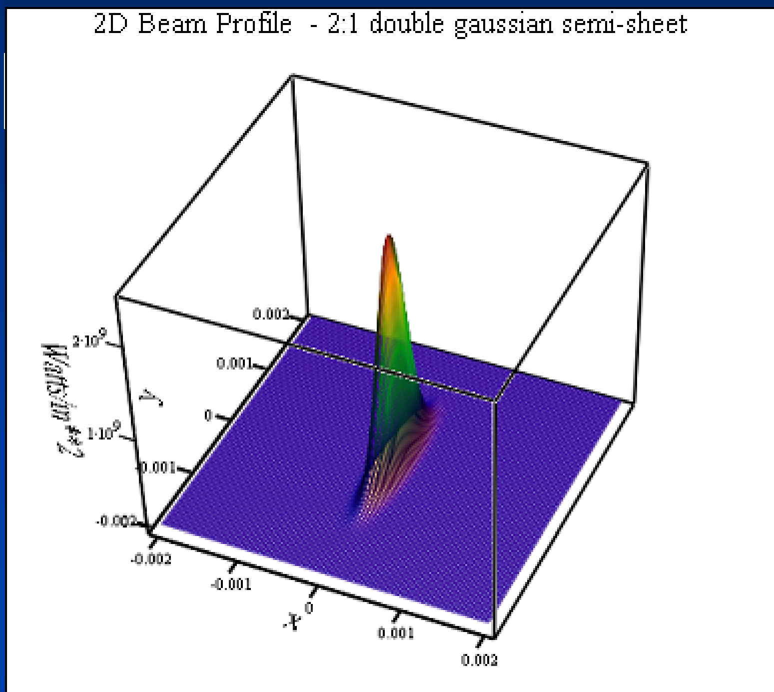
*Liu, P., Ziemann, P. J., Kittelson, D. B., and McMurry, P. H. (1995a). Generating Particle Beams of Controlled Dimensions and Divergence: I. Theory of Particle Motion in Aerodynamic Lenses and Nozzle Expansions, Aerosol Sci. Technol. 22:293-313.

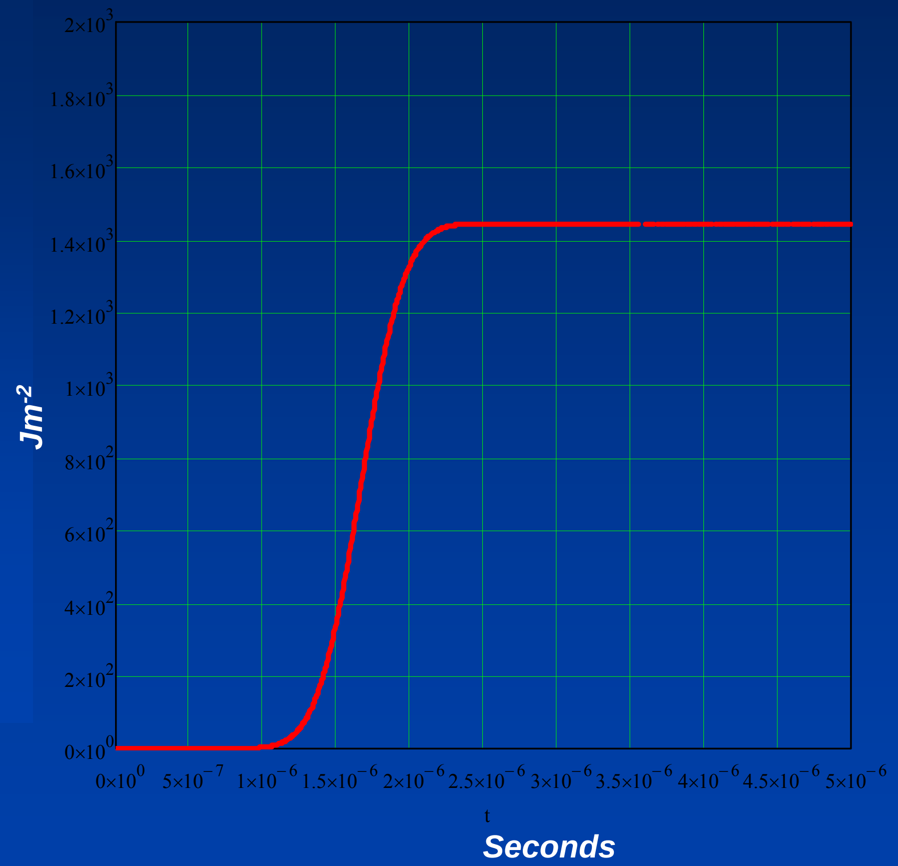
*Liu, P., Ziemann, P. J., Kittelson, D. B., and McMurry, P. H. (1995b). Generating Particle Beams of Controlled Dimensions and Divergence: II. Experimental Evaluation of Particle Motion in Aerodynamic Lenses and Nozzle Expansions, Aerosol Sci. Technol. 22:314-324.

Laser Heating by CW -LII

- CW-LII required because particle arrival is asynchronous and may be infrequent.
- heating time < 1μsec (previous experiments suggest changes occur after > 1.5 μsec.
- particles effectively emanate in a cone, therefore energy fluence should be insensitive to angle.
- fluence should be up to 0.2Jcm-2 = 2000Jm-2

400W in a 100μm by 500μm sheet for a particle velocity of $300ms^{-1}$





Only 7% increase in fluence for particles passing at 20º from axis along the laser direction but only 1% for 20º vertical to sheet because the extra path is reduced by the Gaussian laser intensity fall-off.

Conclusions

- An aerosol beam CW LII system has been designed and constructed.
- We are about to start our experimental phase.
- We are particularly keen to examine LII results as a function of particle size which we will initially classify from aerodynamic size..