Laser Induced Incandescence of Carbon Nanotubes

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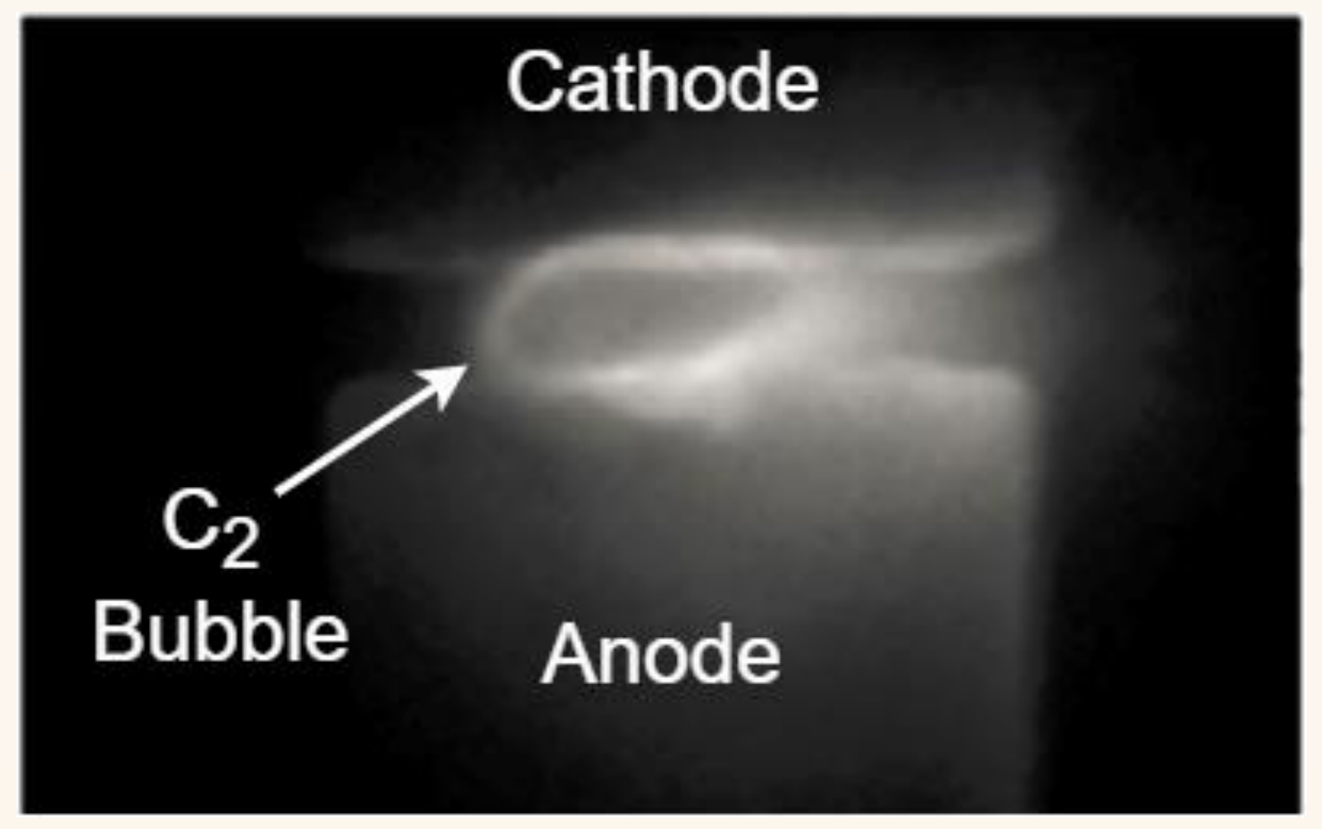
Goals

- Develop a model for the Laser Induced Incandescence (LII) signal of cylindrical single-walled carbon nanotubes (SWCNTs)
- Look at how the LII signal of SWCNTs differs from the LII signal of solid spherical particles
- Examine how a the LII signal of a mixture of SWCNTs and solid spherical particles behaves with different mixture ratios

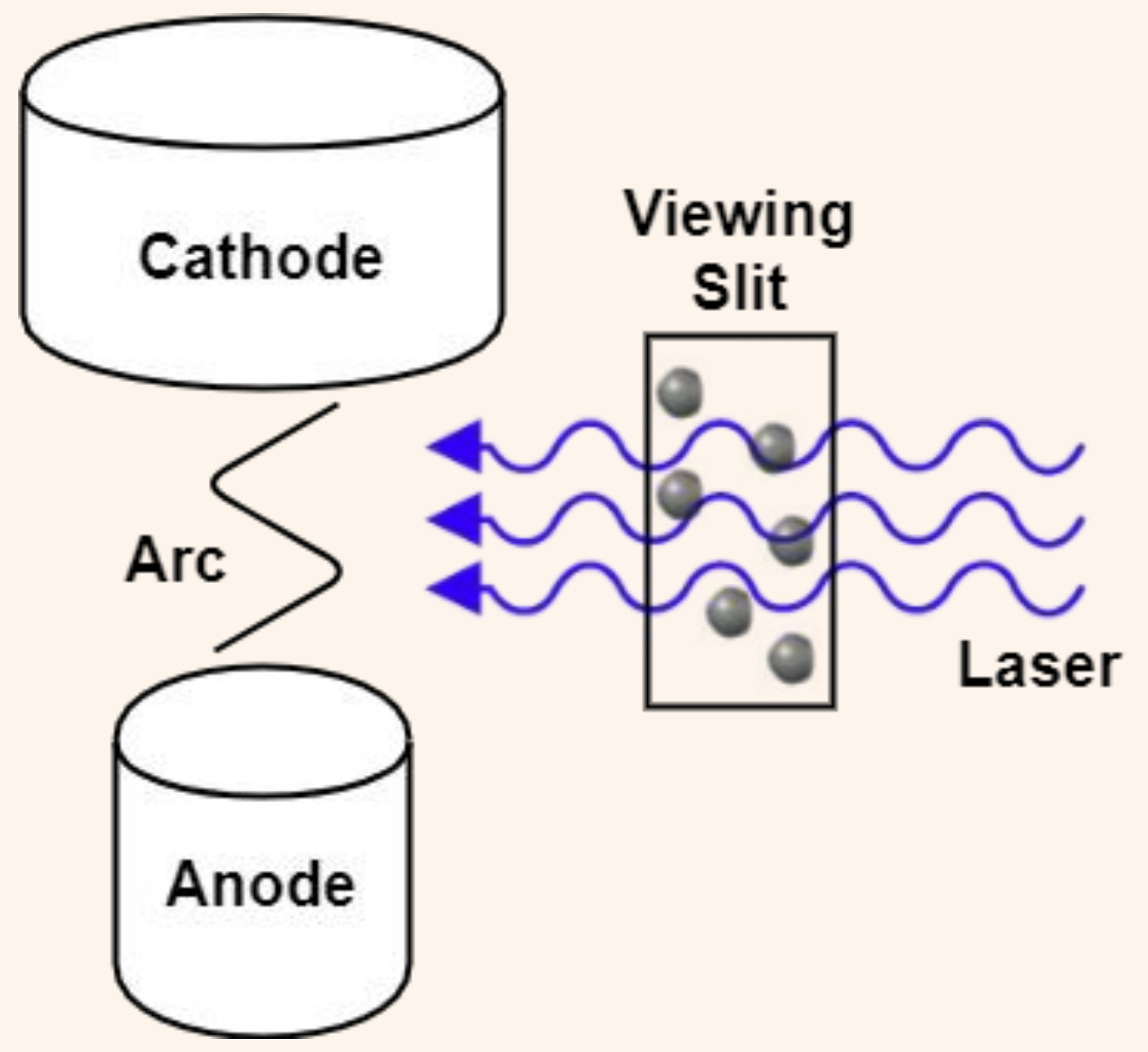
Introduction

Laser Induced Incandescence (LII) is a process which uses lasers to heat up particles, causing them to incandesce. From this signal, we can determine information on the size of the particles [1]. It is currently the only way to measure nanoparticles formed in arcs, insitu.

In the Nano lab at the Princeton Plasma Physics Lab (PPPL), LII is being used to investigate the carbon nanoparticles which are formed in an arc plasma. Arcs are used to produce amorphous carbon, nanohorns, and carbon nanotubes (CNTs). This method is the first way in which CNTs were produced, and remains the cheapest process which produces the highest quantities, with the highest crystallinities [2,3].

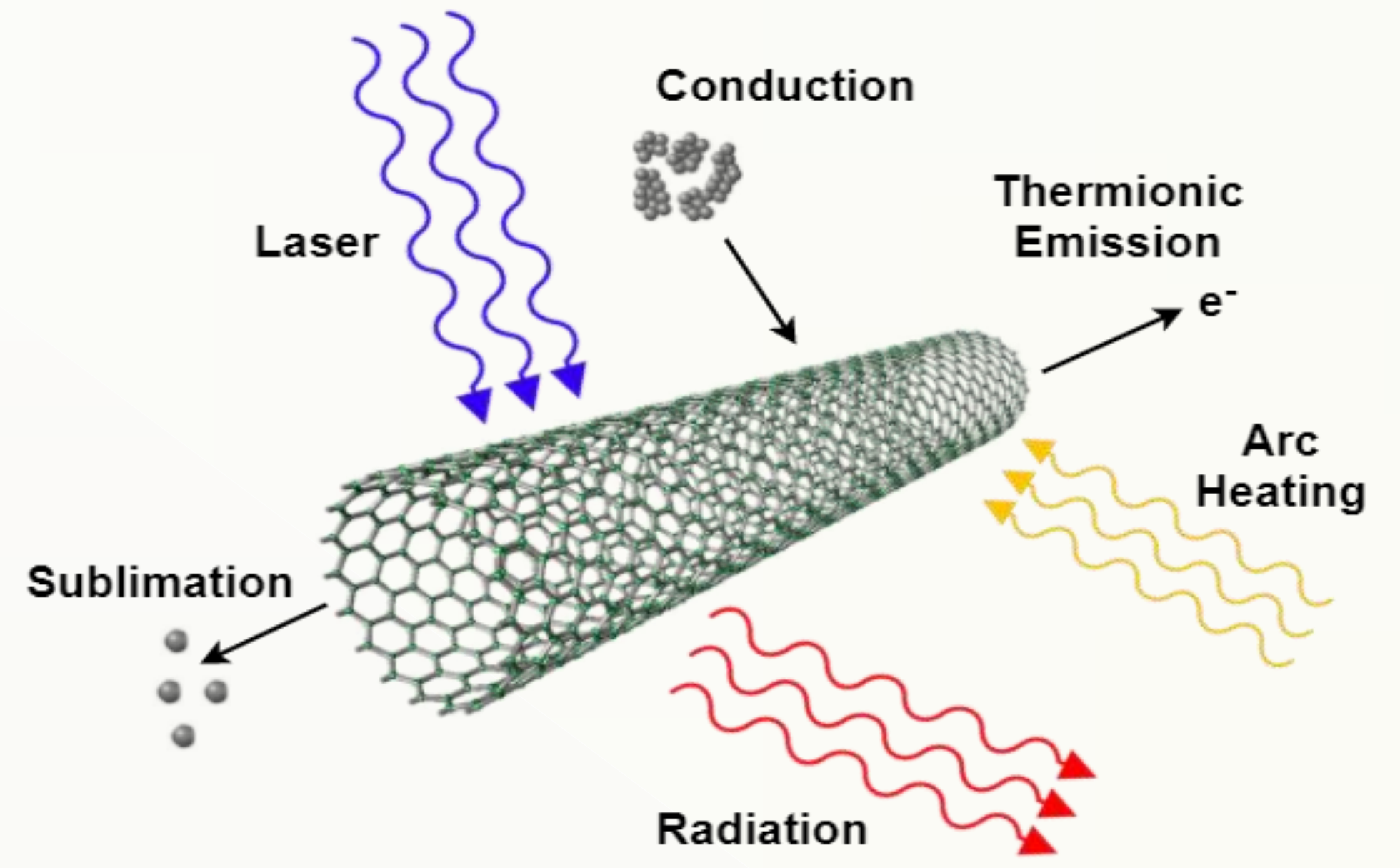


Models to simulate LII signals already exist, but are only designed for spherical particles. Such a model is not the complete picture in an environment where it is possible to find (CNTs) such as in the plasma arcs [1,2].



Model

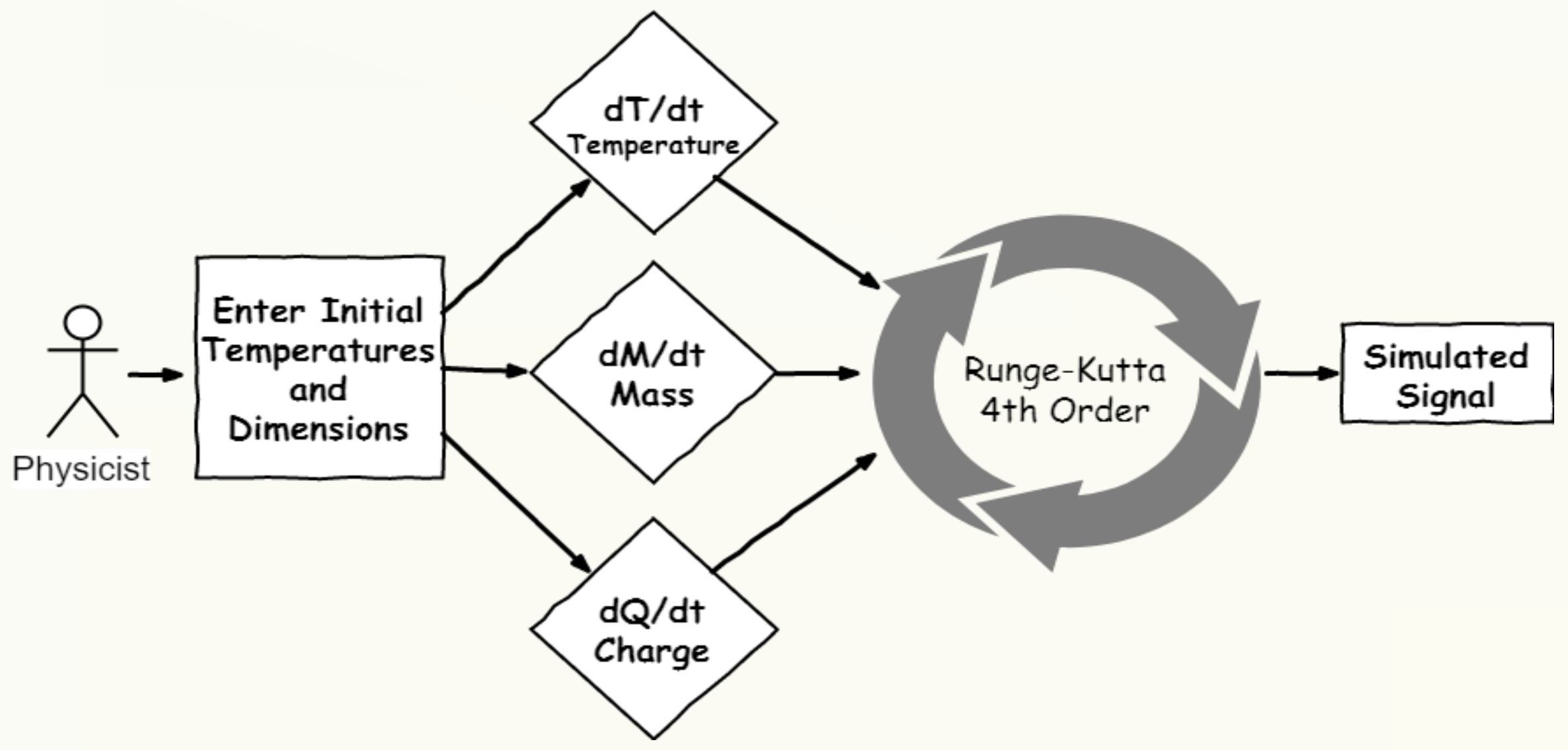
There are six effects which are accounted for in the LII model. These six terms are used to solve the energy balance equation, to determine the temperature of the particle [1,2,4].



These energy transfer rates also depend on the mass of the particle, its surface area, and its charge.

Typical SWCNT: $D \approx 1nm$, $l \approx 0.3 - 50\mu m$
>> May use Infinite Cylinder Approximation [5]

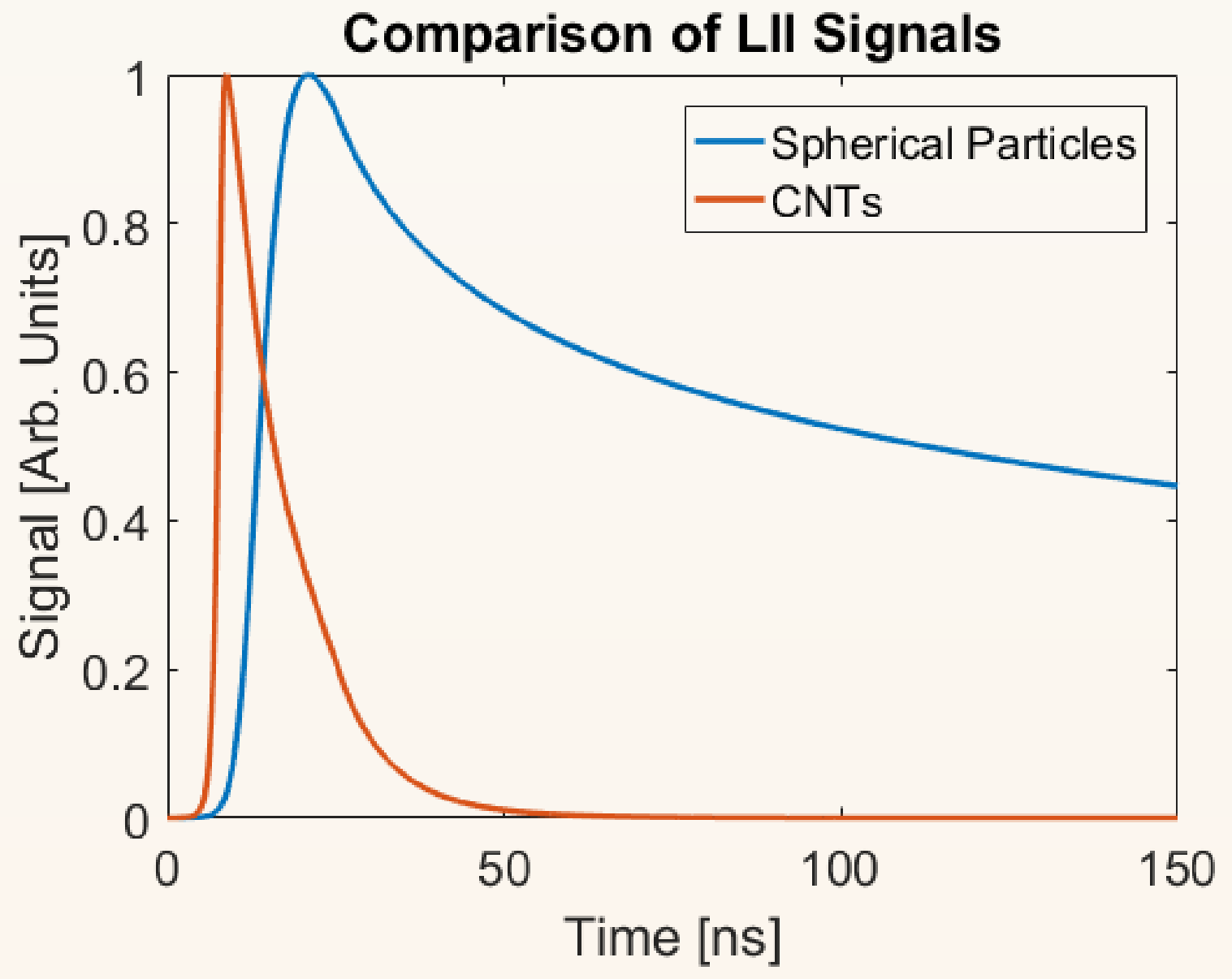
The signal depends on the temperature of the particle, its mass, and its charge. These three coupled differential equations must be solved simultaneously using the Runge-Kutta 4th order method.



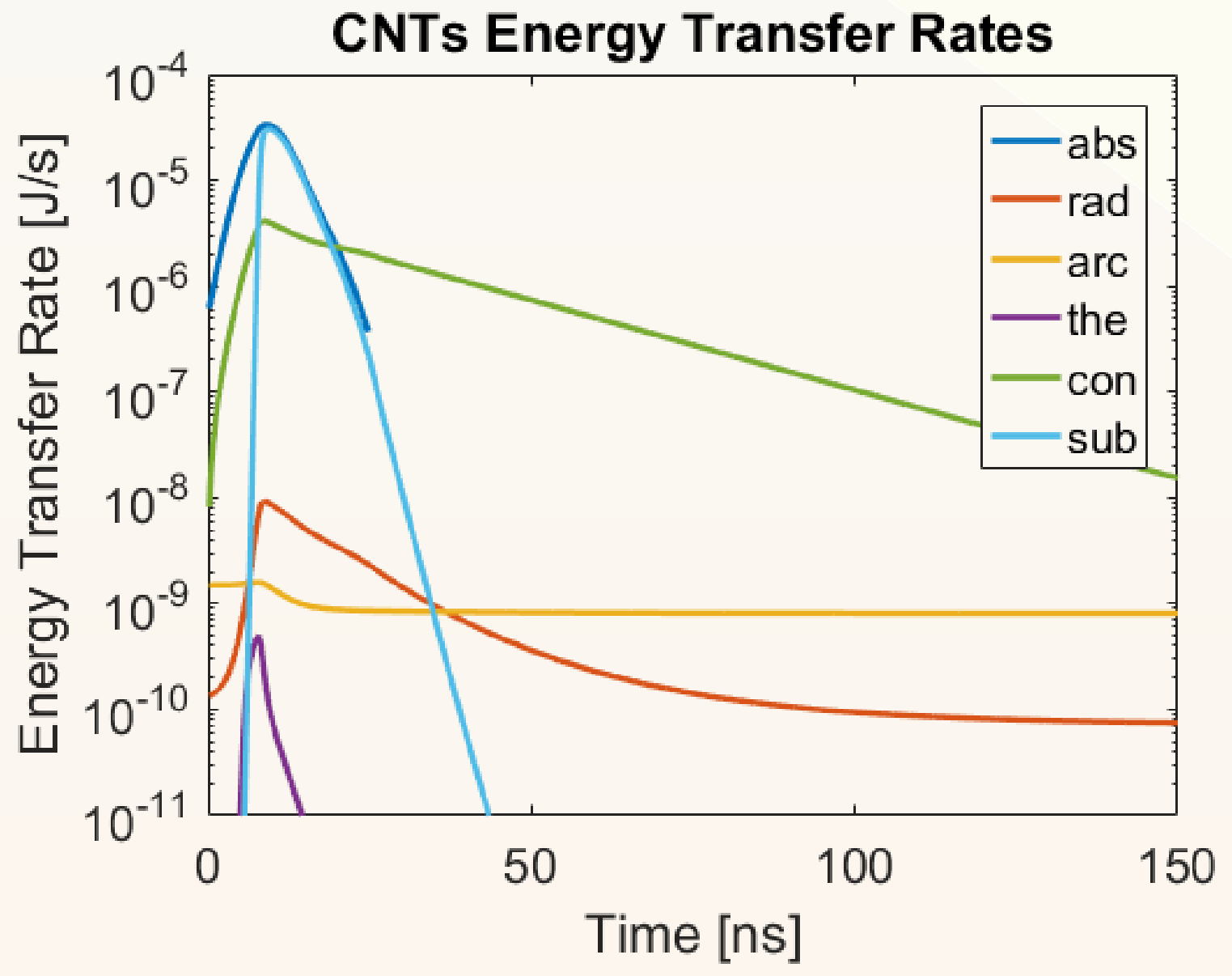
We then calculate the signal using the black body formula using the following equation:

$$S = \varepsilon_{\lambda_s} \frac{4\pi^2 r l h c^2}{{\lambda_s}^5\left[\exp\left(\frac{hc}{\lambda_s k_B T}\right) - 1\right]}$$

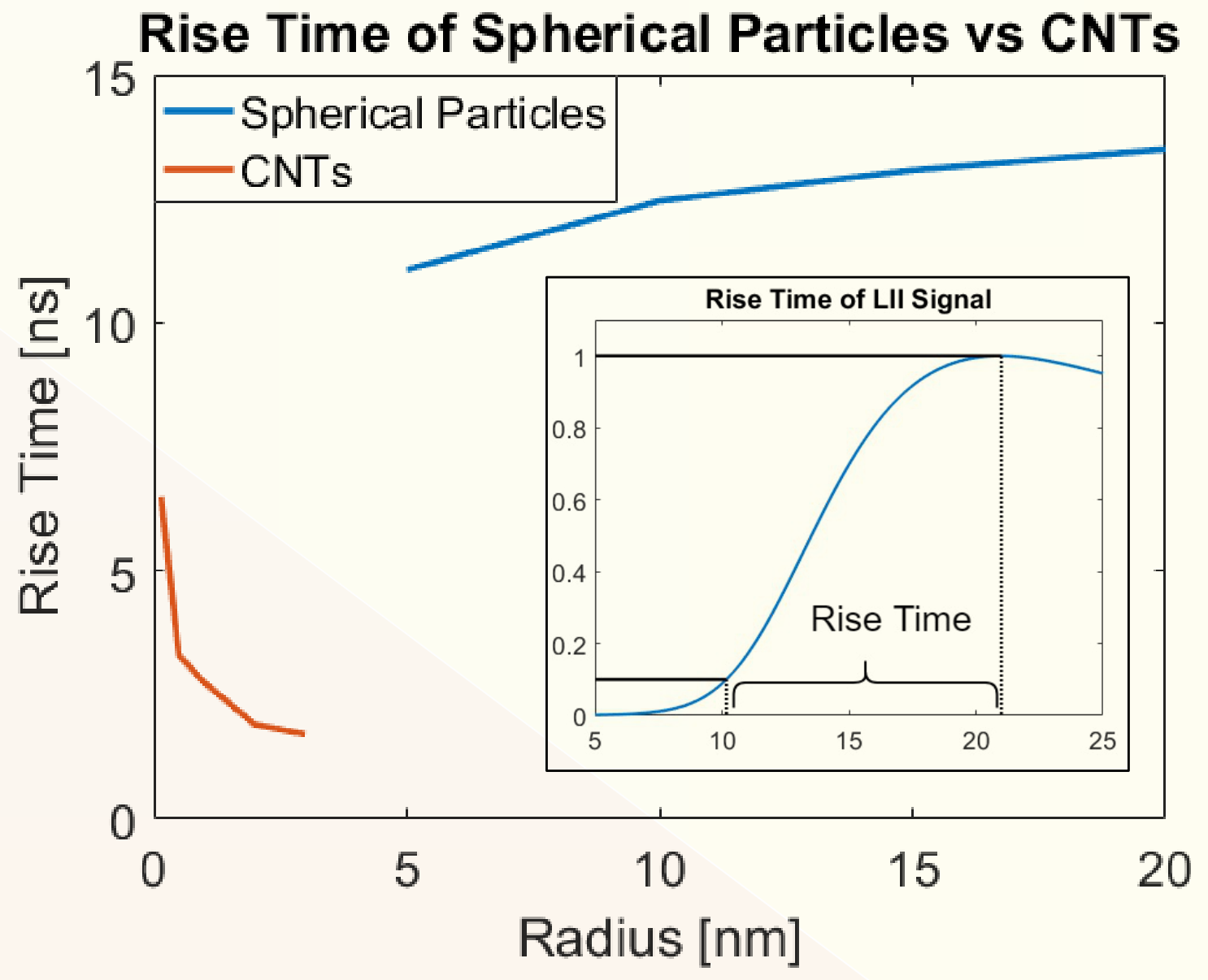
Results



Both the spherical particles and CNTs have the same initial mass. CNTs: $r = 1nm$, $l = 10\mu m$; Spheres: $r = 25nm$

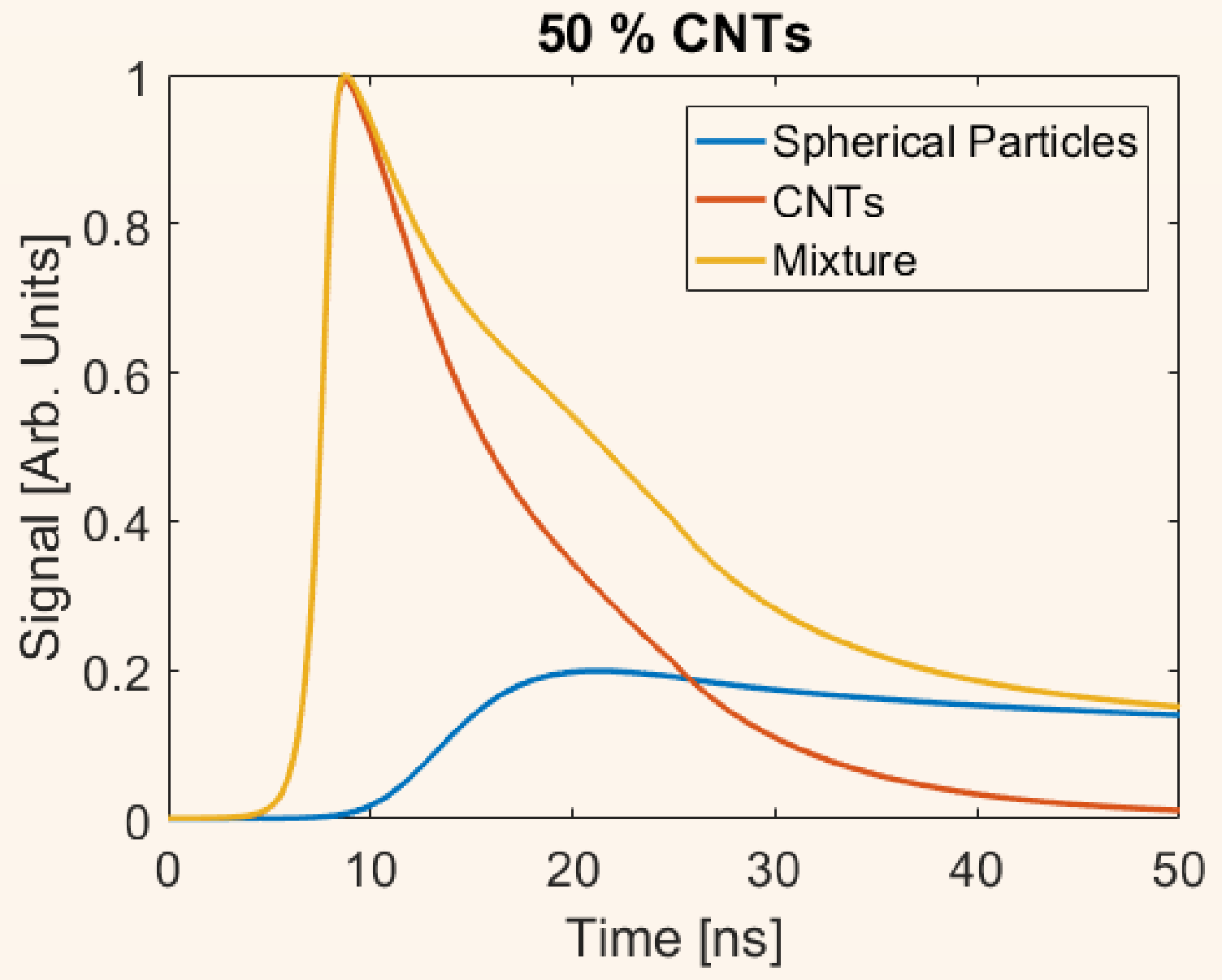


After the laser has turned off, conduction becomes the dominant term in the decay rate of the CNT signal.

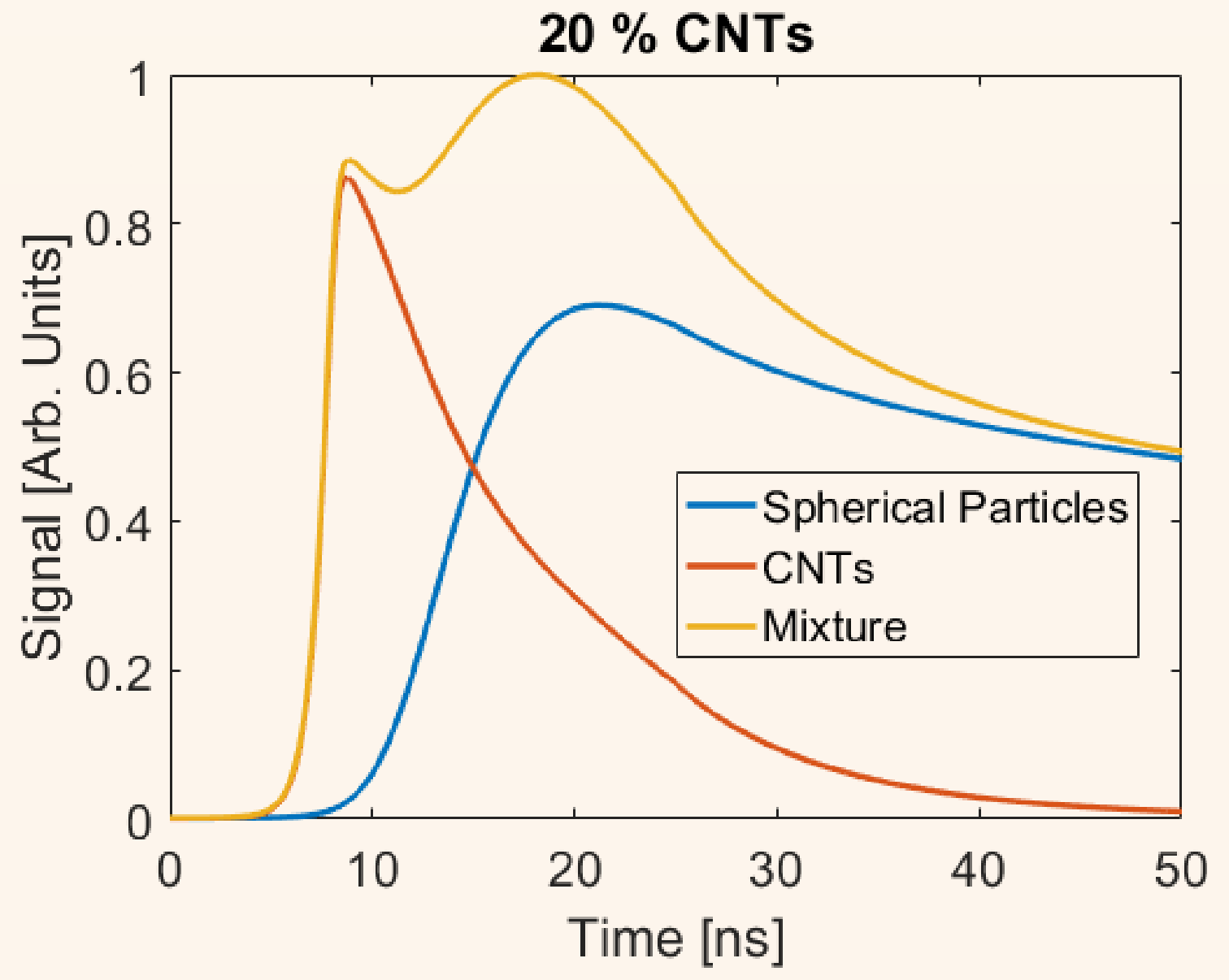


Rise Time of signal as function of radius. Length of CNTs has little effect on rise time.

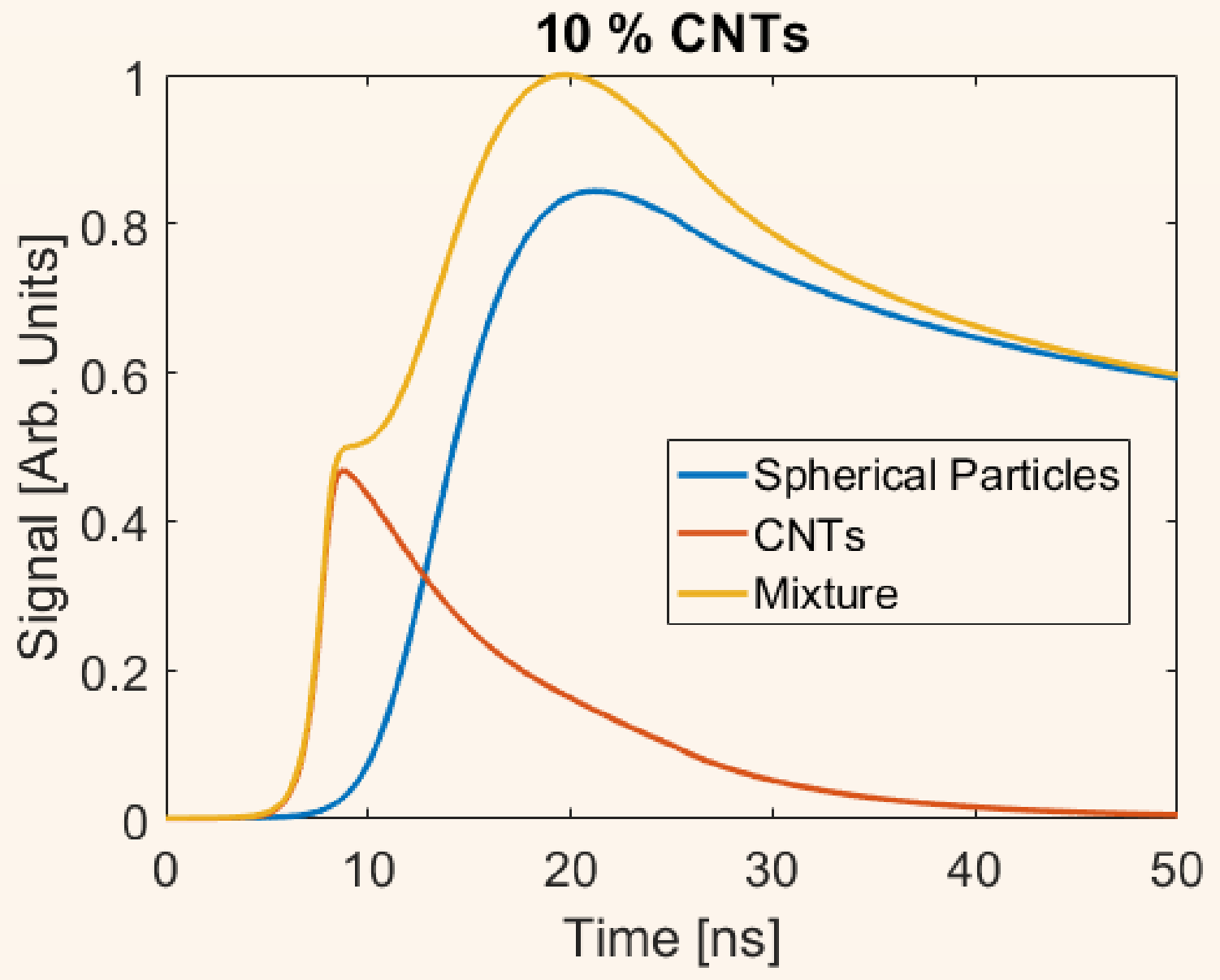
Mixtures of $r = 25nm$ spherical particles and $r = 1nm$, $l = 10\mu m$ CNTs



Despite being a 50 / 50 mixture, the combined signal is dominated by the CNT signal, due to its stronger intensity.



With a mixture made of 20% CNTs, a clear double hump is visible, with a decay which eventually follows the spherical signal.



At only 10% CNTs, the signal starts to follow a profile closer to that of the spherical signal, but is still elevated.

Conclusions

To complete this project, a model was developed to simulate the Laser Induced Incandescence (LII) signal which might be produced by carbon nanotubes (CNTs) produced in plasma arcs. The main results gathered from this project are:

- CNTs should have a shorter LII signal rise time (between 1.7 ns and 6.5 ns) than spherical particles (rise time between 10.5 ns and 14 ns)
- Given a mixture which contains at least 30% CNTs, the rise time of the signal should follow that of CNTs and not spherical particles
- This model may be easily adapted to explore the LII of carbon nanofibers as well

Acknowledgments

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