

Widefield Interferometric Detection and Size Determination of Dielectric Particles

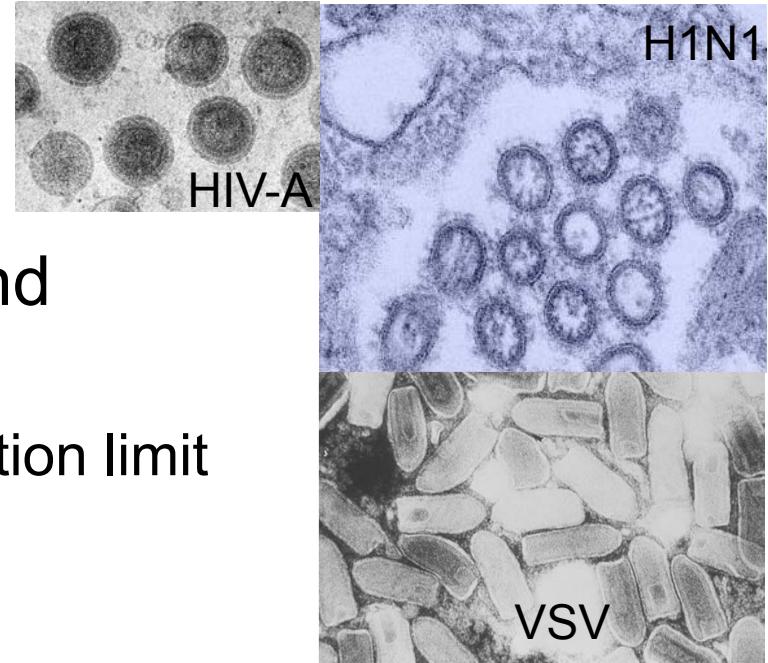
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MITRE *

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Motivation



- Label-free optical detection and identification of single viruses.
 - Mostly much smaller than diffraction limit
 - Low-index ($n = 1.4 - 1.5$)

- A sensor:
 - Sensitive to small size and concentration
 - Determine size and shape
 - High-throughput
 - Cost-effective and robust

Outline

- Introduction
- Our sensor: IRIS
- Forward Model for sizing nanoparticles
- Experimental Results
- Discussion of design parameters
- Defocus : disadvantage or advantage?

Introduction

- Elastic light scattering
 - Size, shape, material constituents
 - For small spherical particles ($R \ll \lambda_{dr}$):

$$\mathbf{E}_{\text{sca}} \propto \frac{1}{\lambda_{dr}^3} \alpha \mathbf{E}_{\text{dr}} \quad \alpha = 4\pi\epsilon_0 R^3 \frac{\epsilon_{\text{par}}(\lambda_{dr}) - \epsilon_0}{\epsilon_{\text{par}}(\lambda_{dr}) + 2\epsilon_0}$$

$$I_d \propto |\mathbf{E}_{\text{sca}}|^2 \propto \left(\frac{R}{\lambda_{dr}} \right)^6 \longrightarrow \text{Conventional}$$

$$I_d \propto |\mathbf{E}_{\text{sca}} + \mathbf{E}_{\text{ref}}|^2 = |\mathbf{E}_{\text{sca}}|^2 + |\mathbf{E}_{\text{ref}}|^2 + 2|\mathbf{E}_{\text{sca}}||\mathbf{E}_{\text{ref}}| \cos(\beta)$$

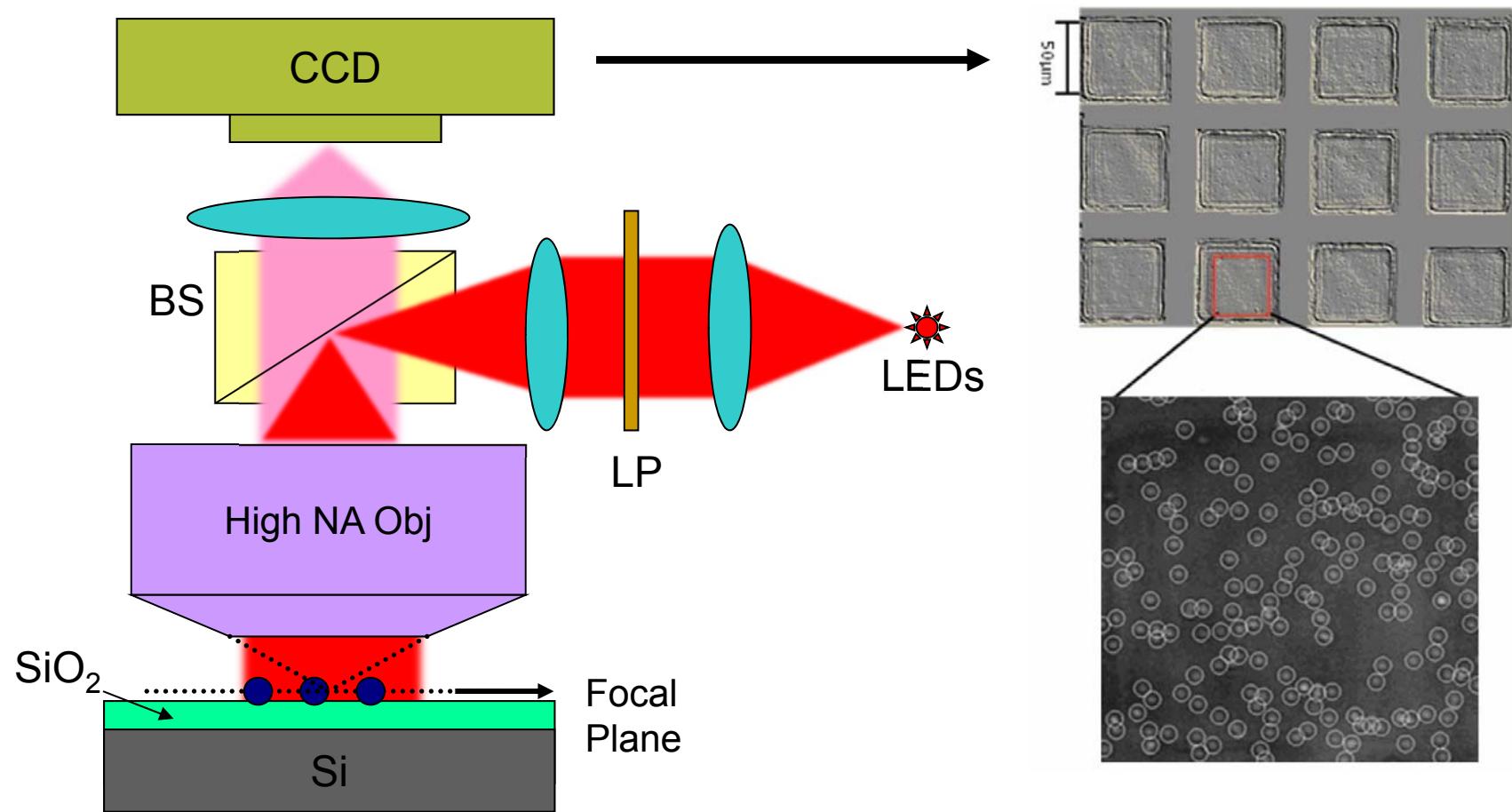
negligible background

Higher sensitivity

Interferometric

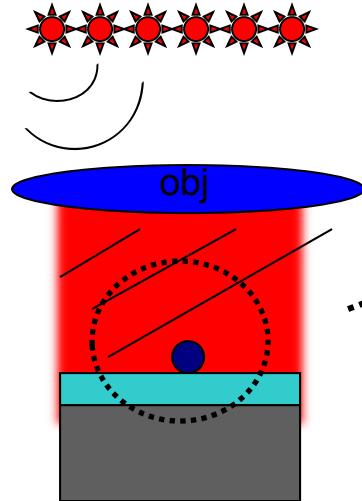
$$\propto |\alpha| \propto \left(\frac{R}{\lambda_{dr}} \right)^3$$

IRIS

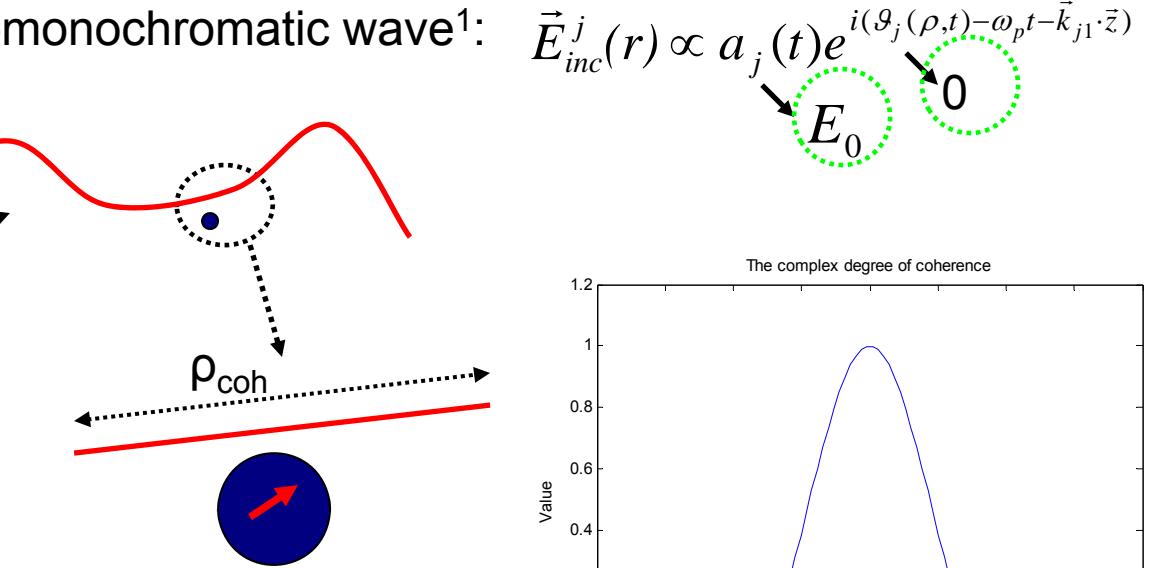


Fields in object space

Incoh. point sources



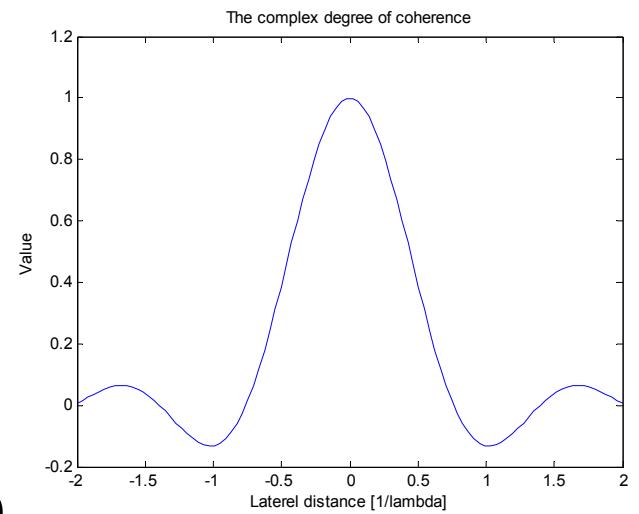
Quasi-monochromatic wave¹:



Induced dipole moment: $\vec{p}^j \propto \vec{\alpha} \cdot \vec{E}_{dr}^j(r_0, R_{slab})$

The scattered dipole field: $\vec{E}_{sca,1}^j(r) \propto \frac{e^{ikr}}{r} f(R_{slab}, \vec{p}^j)$

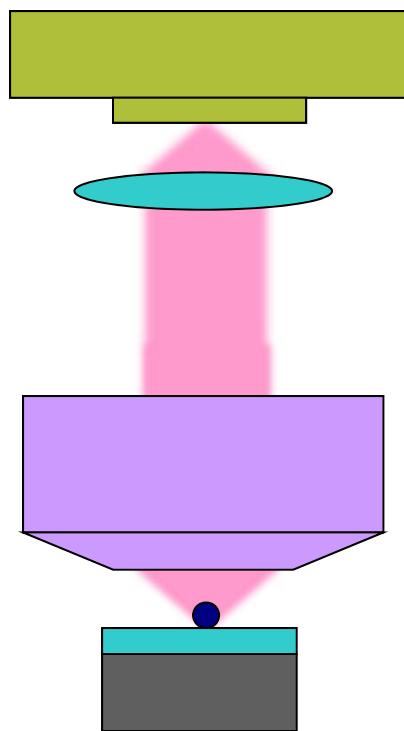
The reference field: $\vec{E}_{ref,1}^j(r) = R_{slab} \vec{E}_{inc}^j(r)$



¹ Born, M., Wolf, E. *Principles of Optics*; Cambridge University Press: Cambridge, 1999.

Fields on image plane

Theory of Angular Spectrum Representation of Fields¹

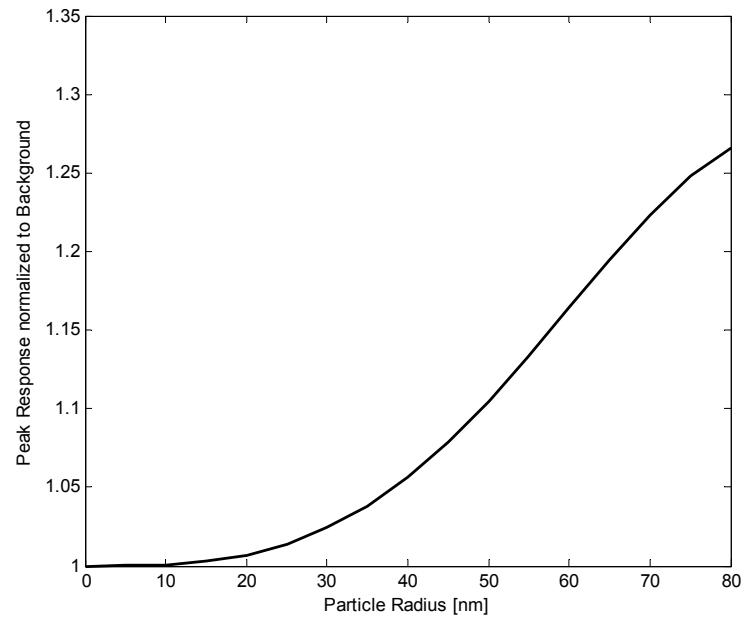
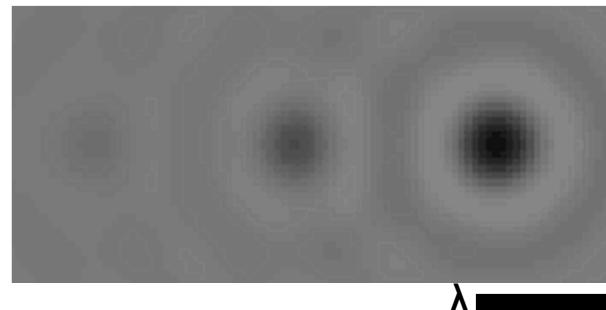


Total field on CCD:

$$\vec{E}_{\text{int}}^j(\rho_3, \varphi_3) = \vec{E}_{\text{sca},3}^j(\rho_3, \varphi_3) + \vec{E}_{\text{ref},3}^j(\rho_3, \varphi_3)$$

Sum of intensities:

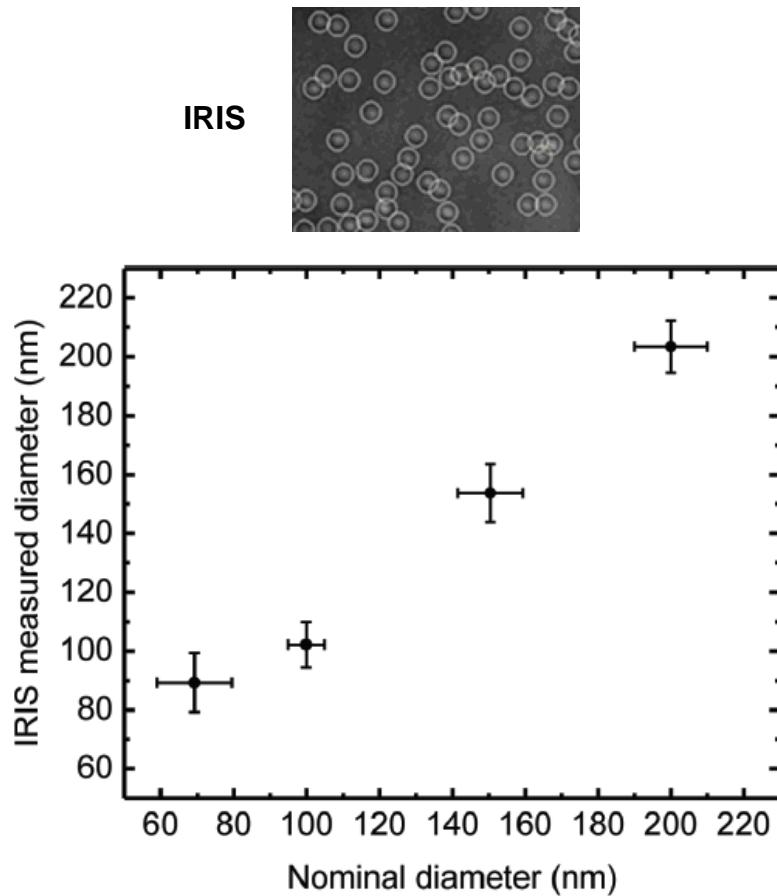
$$I_{\text{int}}^j(\rho_3, \varphi_3) \propto \sum_j \left| \vec{E}_{\text{int}}^j(\rho_3, \varphi_3) \right|^2$$



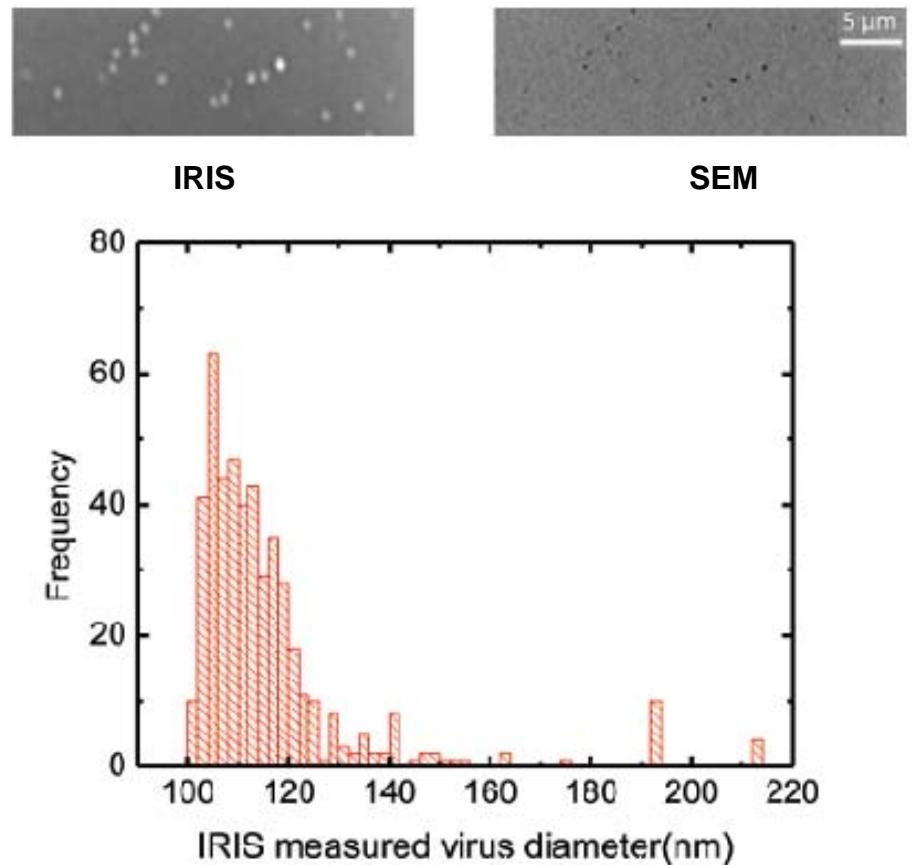
¹ Novotny, L., Hecht, B. *Principles of Nano-Optics*; Cambridge University Press: Cambridge, 2006.

Experimental Results

Size measurement of PS particles



Size measurement of H1N1 viruses

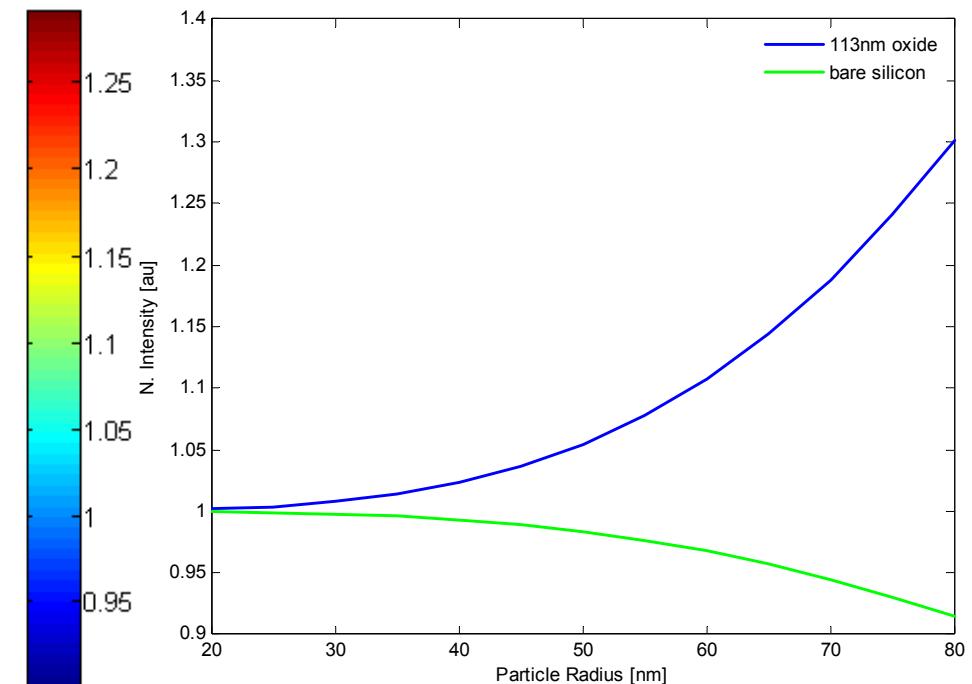
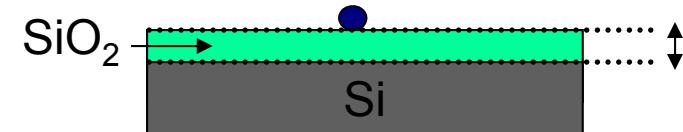
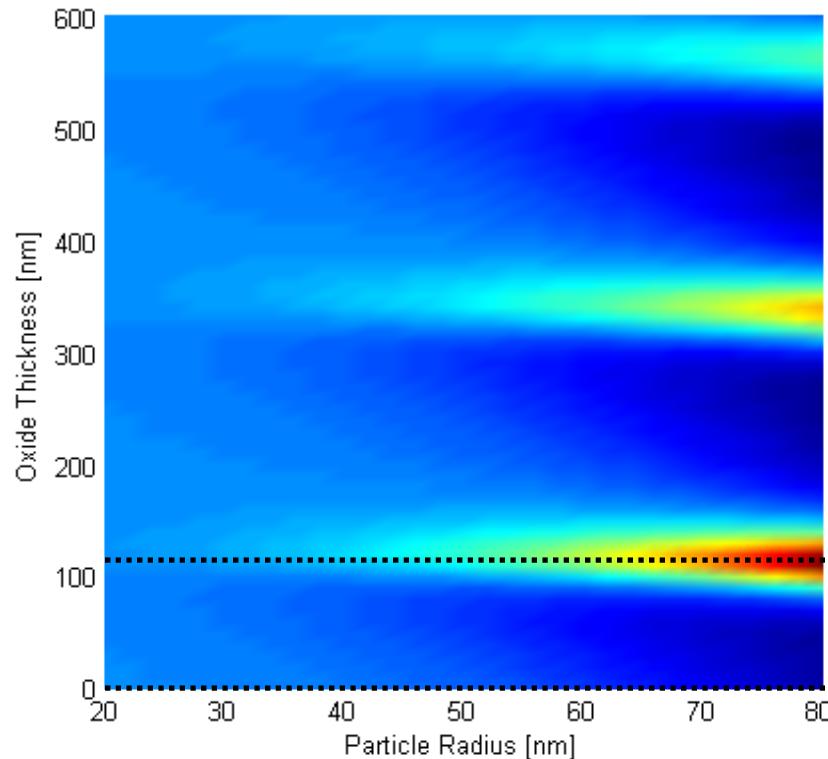


Discussion

- The response of the particles depends on:
 - Thickness of oxide layer
 - Illumination NA
 - Defocus distance

Optimizing the layered substrate

$\lambda = 630\text{nm}$



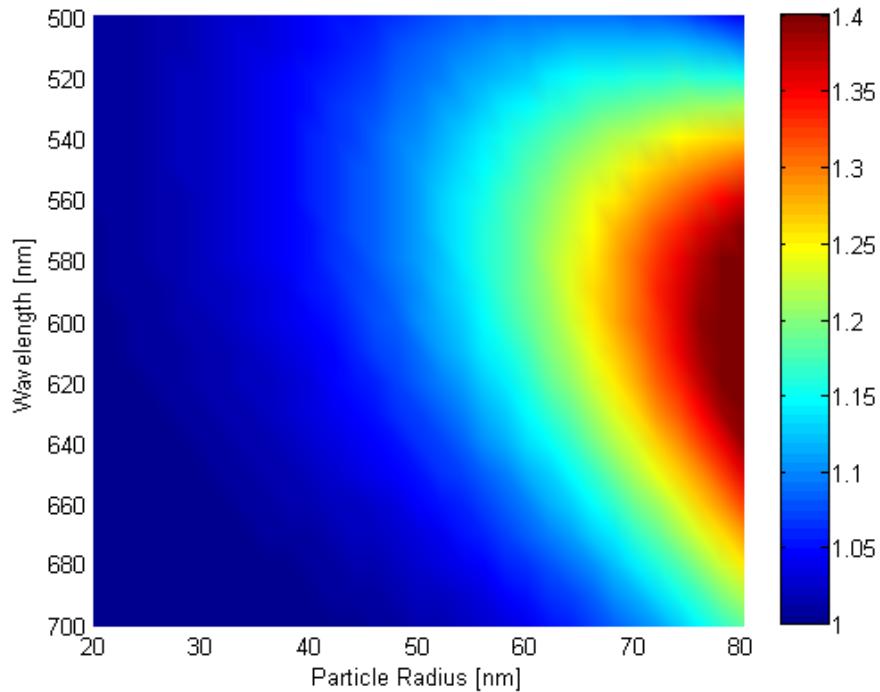
- The contrast is maximized around 100nm oxide thickness for $\lambda = 630\text{nm}$

Optimizing the illumination

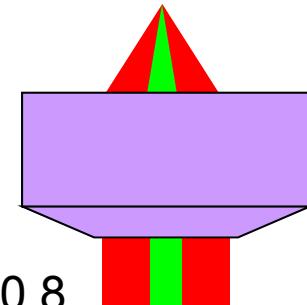
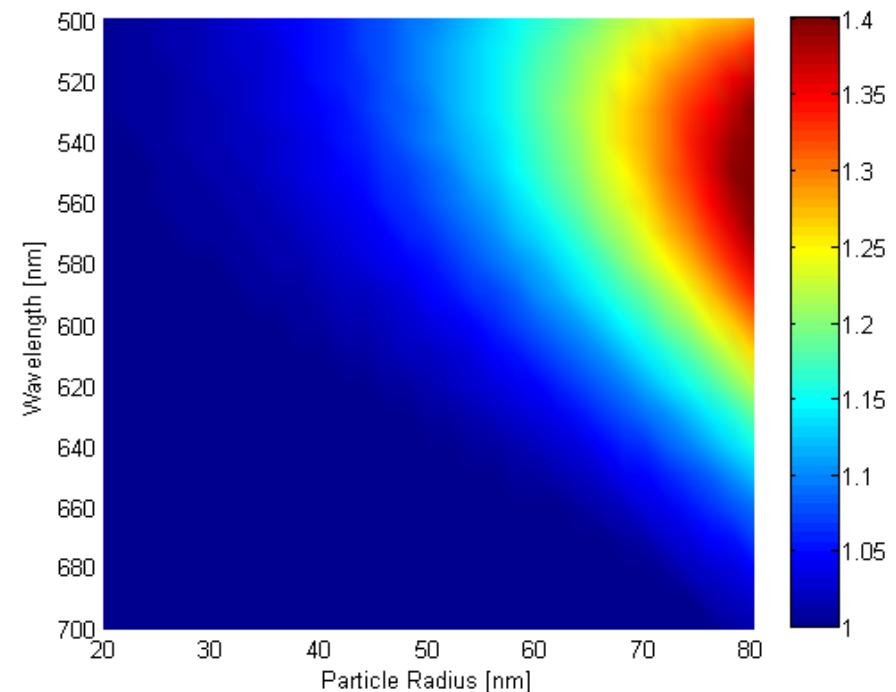
$z_{\text{oxide}} = 100\text{nm}$

Illumination NA = 0.05

Collection NA = 0.8

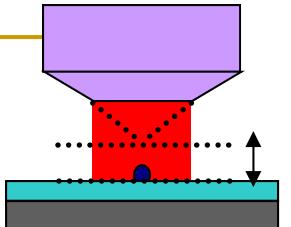


Illumination NA = 0.8
Collection NA = 0.8



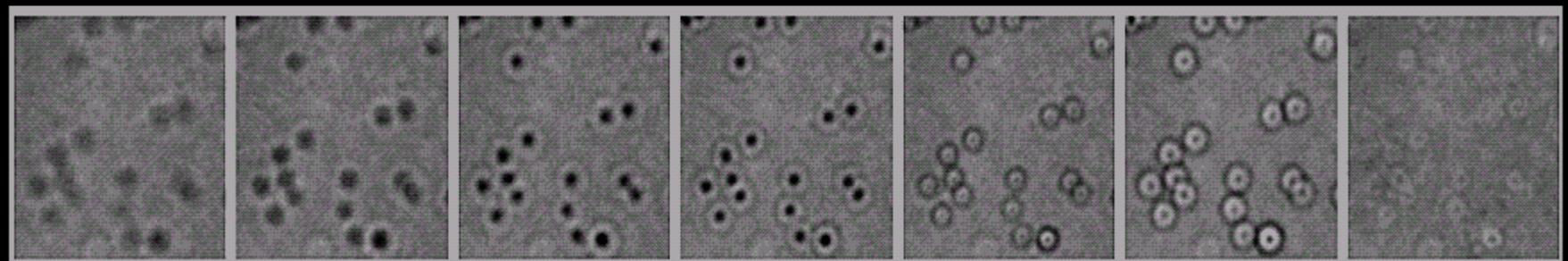
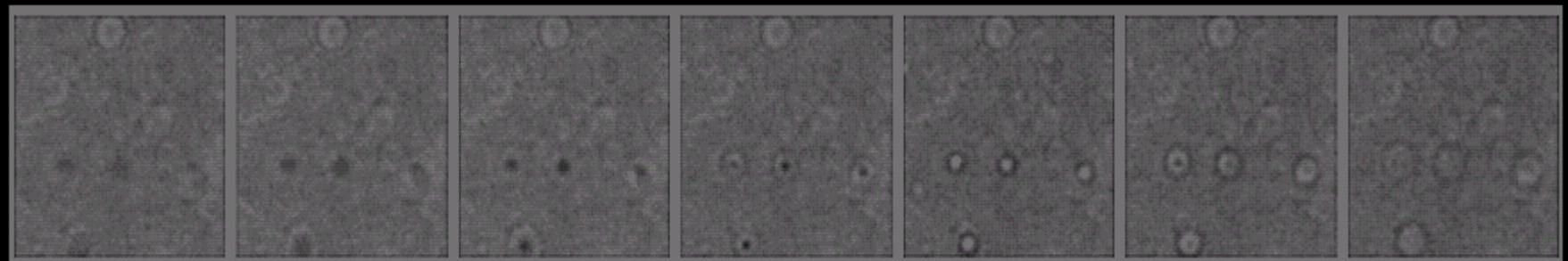
- Similar response for low&high NA illumination (slightly shifted)

Effect of defocus



Experimental Result for high_NA illumination at $\lambda_{\text{peak}} = 630\text{nm}$ and $z_{\text{slab}} = 100\text{nm}$

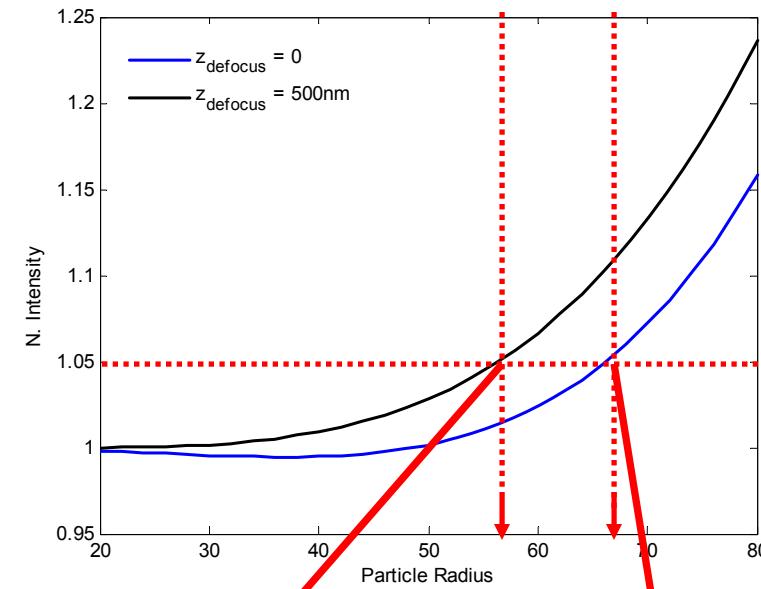
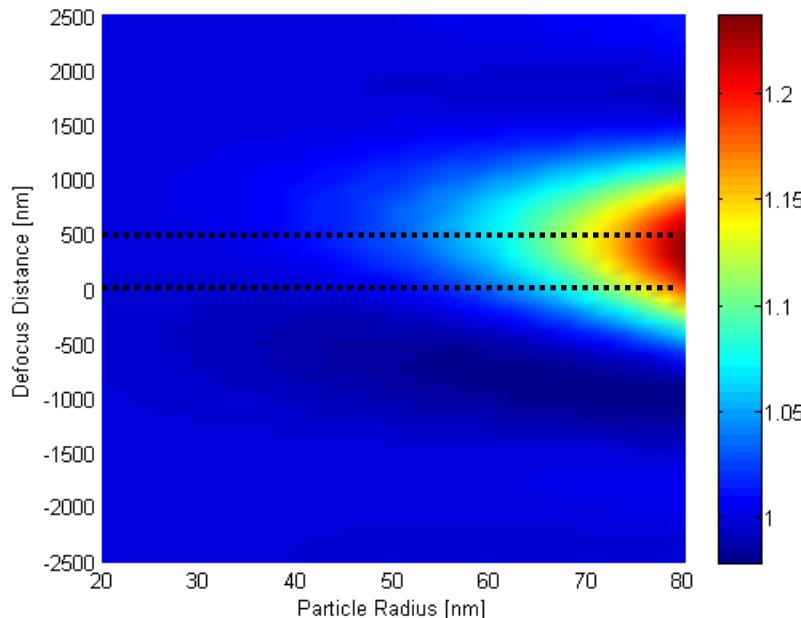
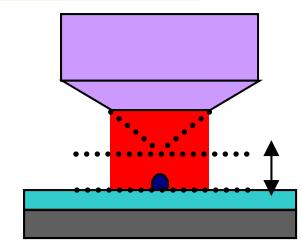
$R = 75\text{ nm}$ particle



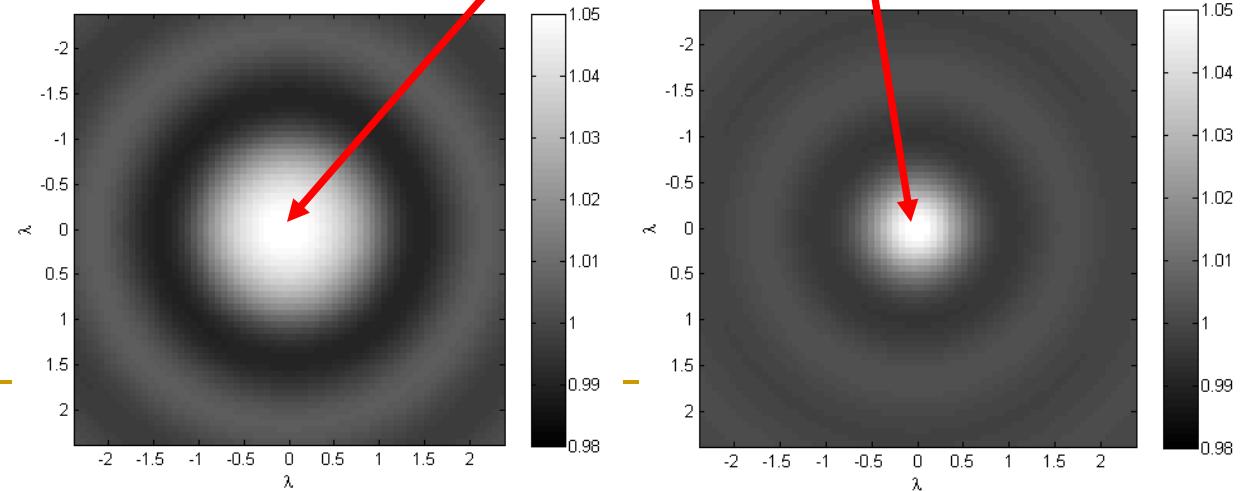
$R = 100\text{ nm}$ particle

inverse color

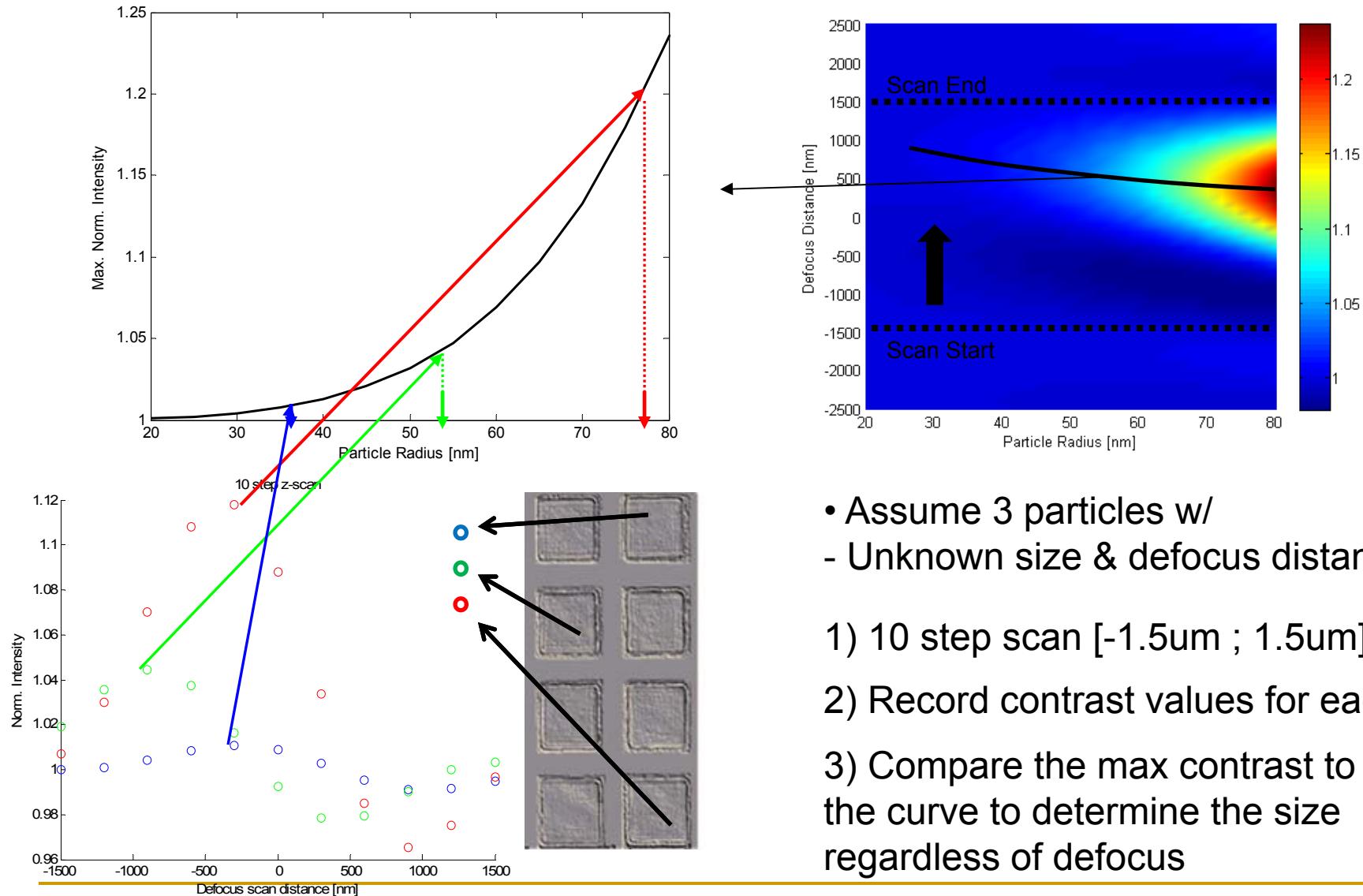
Effect of defocus



Equal Norm.
peak Intensity
for different size
particles!!



Defocus Discussion: z-scan



- Assume 3 particles w/
 - Unknown size & defocus distance
- 1) 10 step scan [-1.5um ; 1.5um]
- 2) Record contrast values for each
- 3) Compare the max contrast to the curve to determine the size regardless of defocus

Conclusion

- High throughput detection and sizing of individual PS and H1N1 viruses.
- Z-scan provides accurate sizing regardless of the defocus.
- Adapted Mie Theory for larger particles

Acknowledgement

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