Electromagnetic fluctuation-induced interactions with metallic gratings

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Collaborators:

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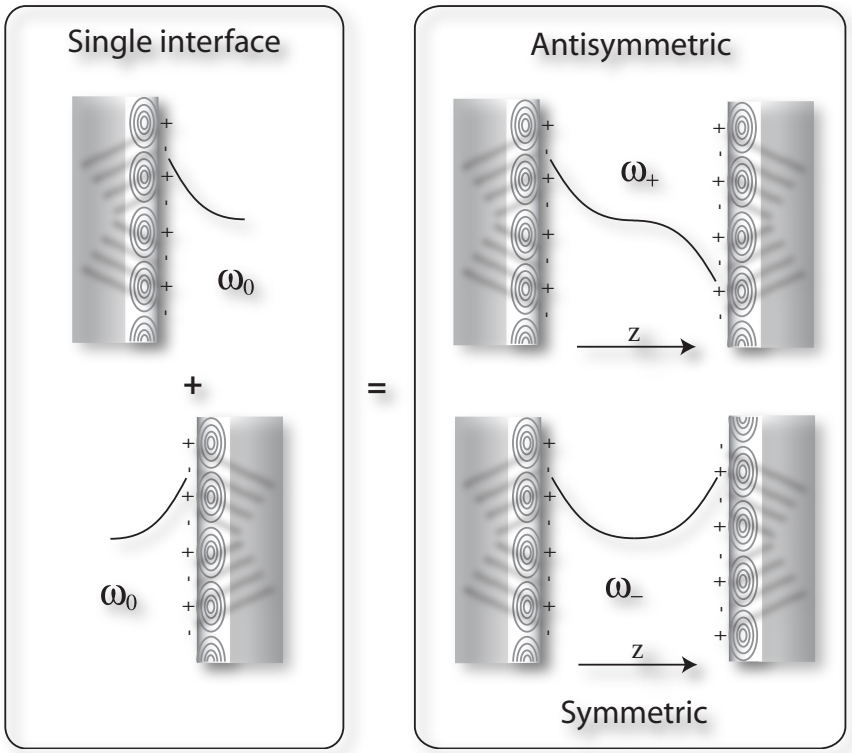
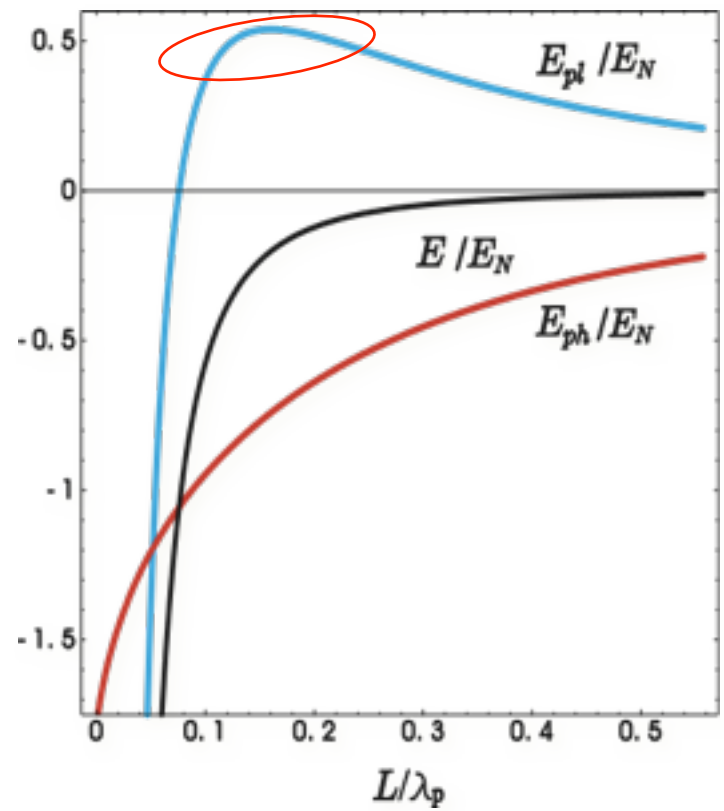
Casimir Plasmonics

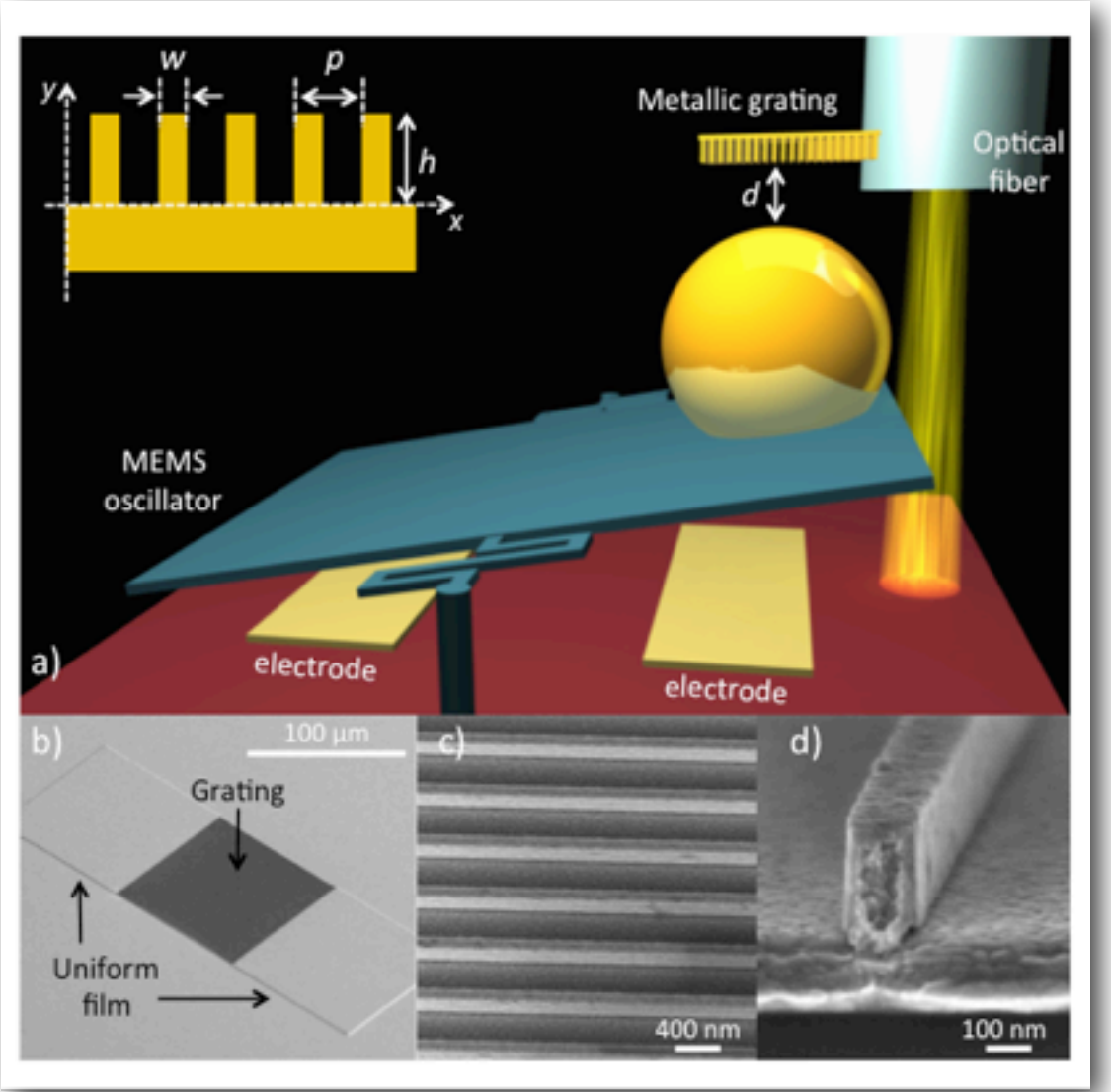




- Plasmonic contribution to the Casimir energy is repulsive at large separations
- Photonic contribution wins, resulting in a net attraction
- Can one engineer the plasmonic contribution?

Intravaia+Lambrecht (2005)

Grating set-up



- Torsional balance set-up
- Metallic sphere

$$R = 150\ \mu\mathrm{m}$$

- Metallic nanostructures

$$w, p, h \approx 100\ \mathrm{nm}$$

- Sputtering and electroplating
- Distances explored

$$150\ \mathrm{nm} < d < 1\ \mu\mathrm{m}$$

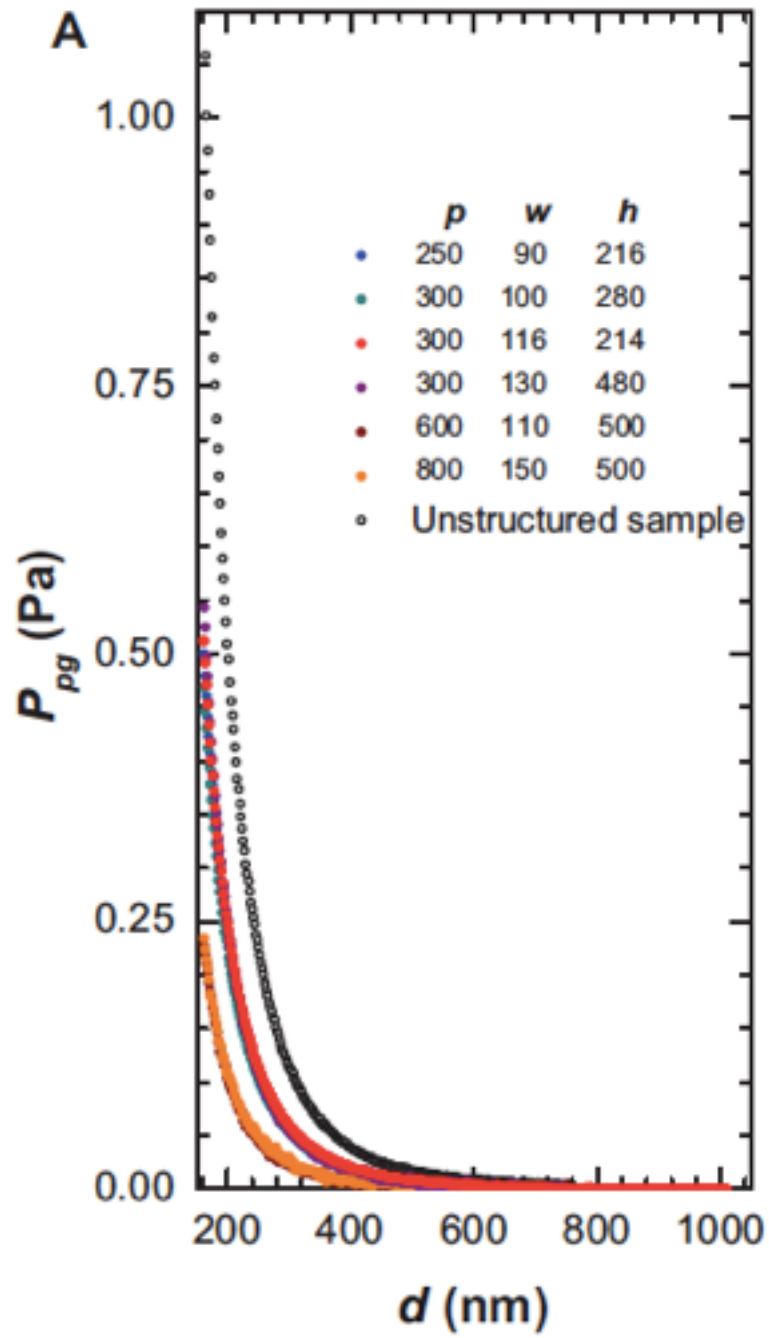
Measurement data

$$P_{pg} = F'_{sg}/2\pi R$$

(effective plane-grating pressure)

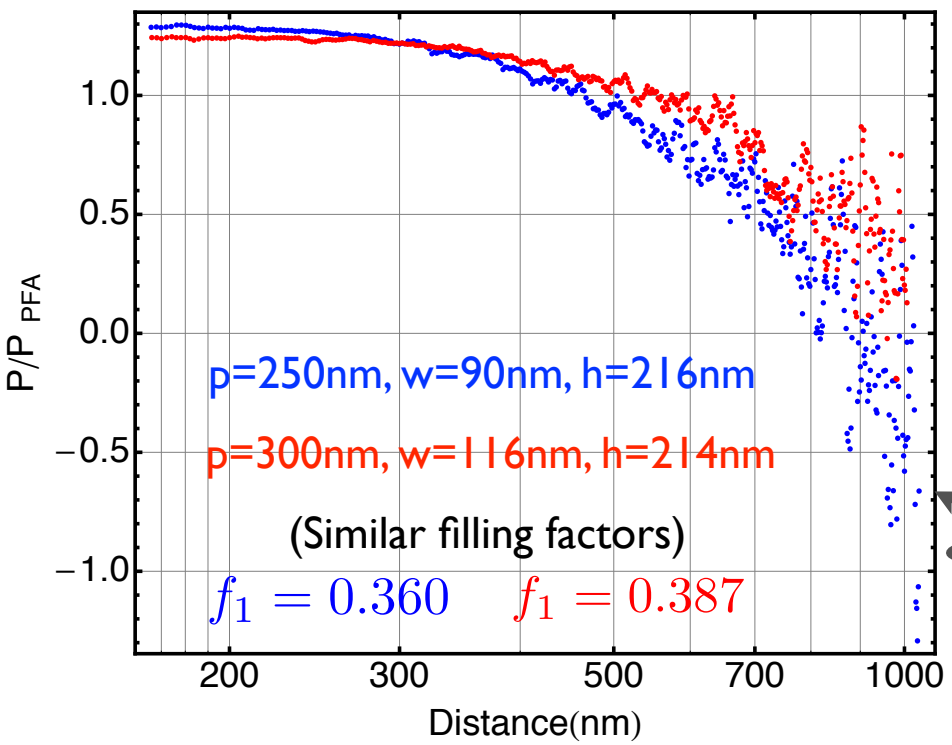
Main effect: reduce the pressure according the decreasing filling factor

$$f = w/p$$



Normalizing to PFA for grating

$$P_{pg}^{\mathrm{PFA}}(d) = f P_{pp}(d) + (1-f) P_{pp}(d+h)$$



Small separations: *PFA underestimates the total pressure.*

Similar to Si gratings: Chan (2008)

Large separations: *PFA overestimates the exact pressure.*

Pressure is going to zero faster than d^{-4}

- Strong suppression of the Casimir force

Modeling and simulation

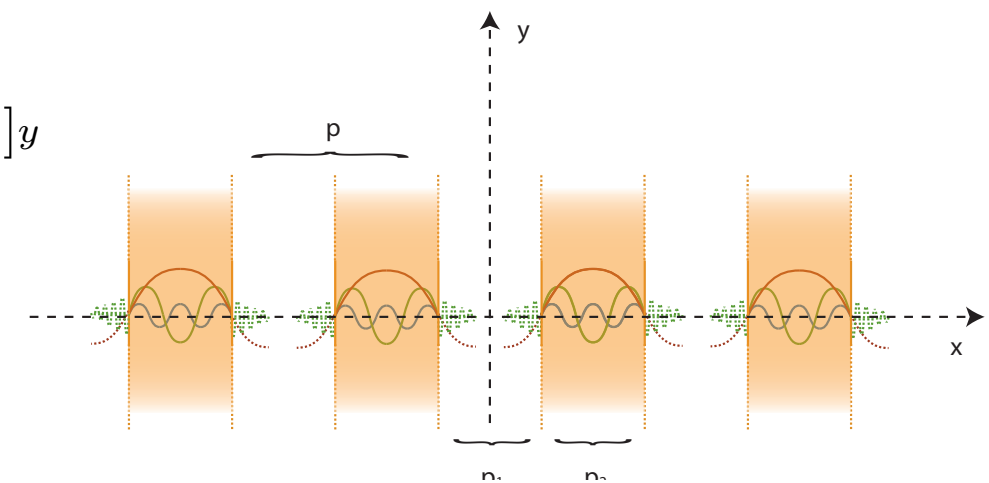
- Use of standard PFA to treat the sphere's curvature $F'_{sg} \approx 2\pi R P_{pg}$

  This PFA is expected to be valid for our set-up: $d/R < 6 \times 10^{-3}$

- Exact computation of the plane-grating pressure P_{pg}

  Scattering approach + modal expansions Li (1993)

$$\begin{pmatrix} E_z(x,y) \\ E_x(x,y) \\ H_z(x,y) \\ H_x(x,y) \end{pmatrix}_i = \sum_{\nu,s} A_\nu^{(s,i)} \mathbf{Y}^{(s,i)}[x, \eta_\nu^{(s,i)}] e^{\imath\lambda[\eta_\nu^{(s,i)}]y}$$



Analytical expressions for eigenvectors

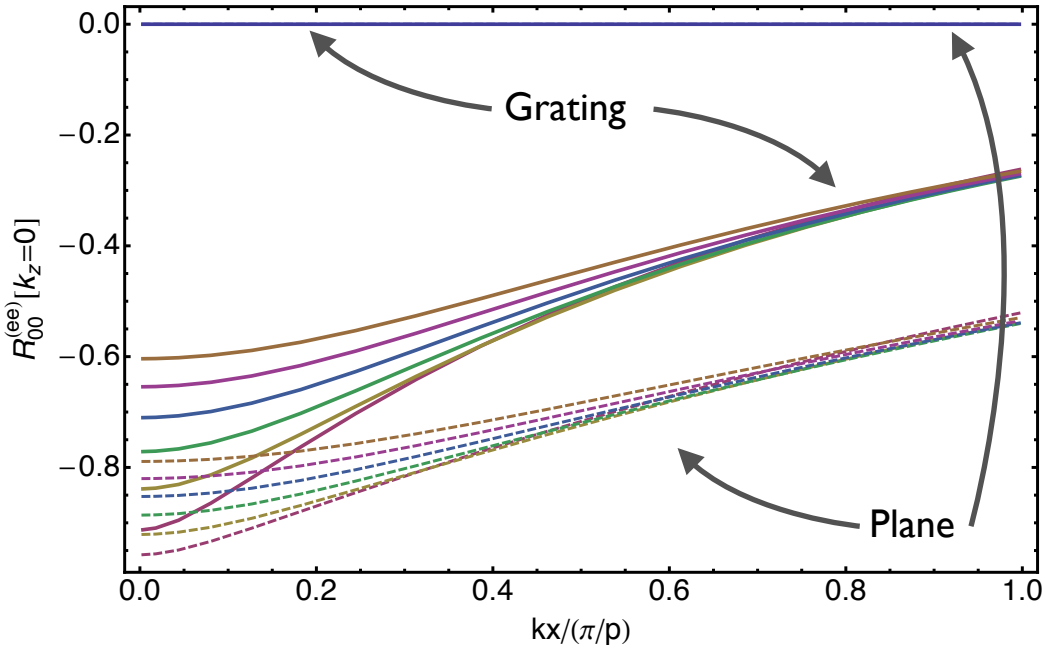
Transcendental equation for eigenvalues

$$0 = \tilde{D}^{(s)}(\eta) = -\cos(\alpha_0 p) + \cos(p_1\sqrt{\eta})\cos(p_2\sqrt{\eta - [\epsilon(i\xi)-1]\xi^2})$$
$$-\frac{1}{2}\left(\frac{\sqrt{\eta - [\epsilon(i\xi)-1]\xi^2}}{\sigma_2^{(s)}(i\xi)\sqrt{\eta}} + \frac{\sigma_2^{(s)}(i\xi)\sqrt{\eta}}{\sqrt{\eta - [\epsilon(i\xi)-1]\xi^2}}\right)\sin(p_1\sqrt{\eta})\sin(p_2\sqrt{\eta - [\epsilon(i\xi)-1]\xi^2}),$$

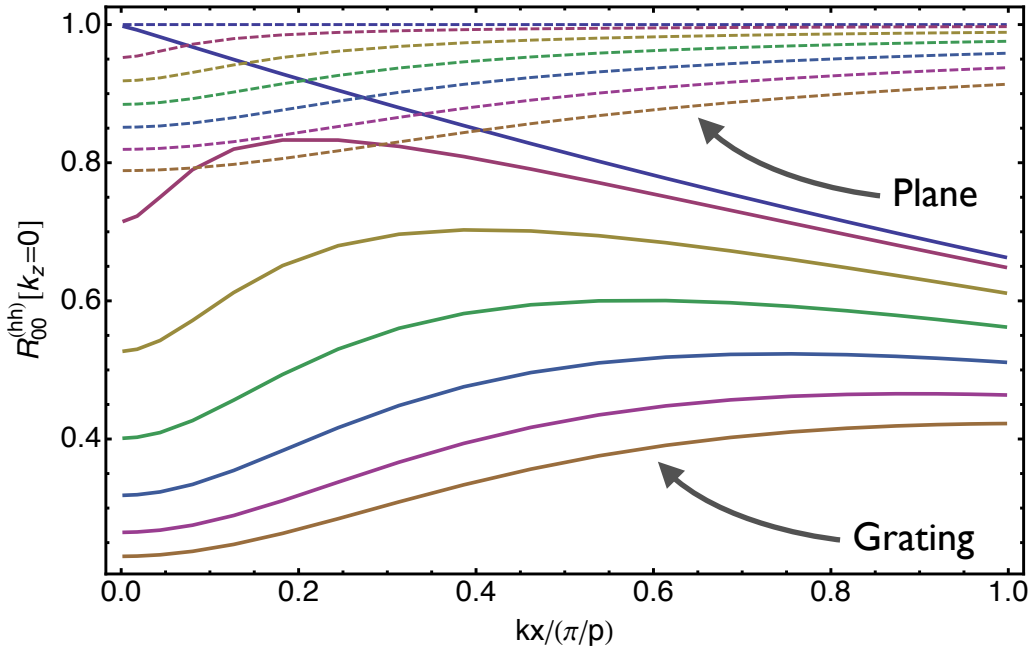
Intravaia et al (2012)

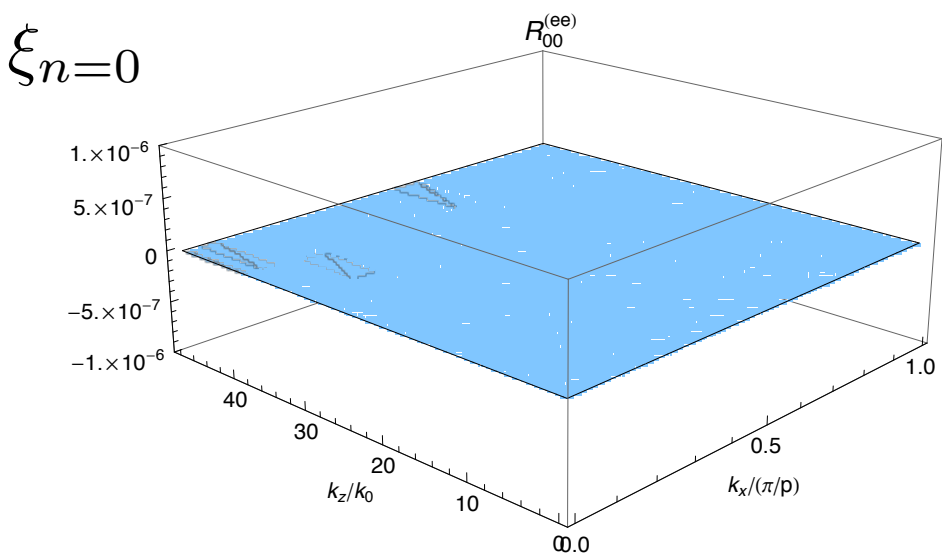
Reflection Matrices

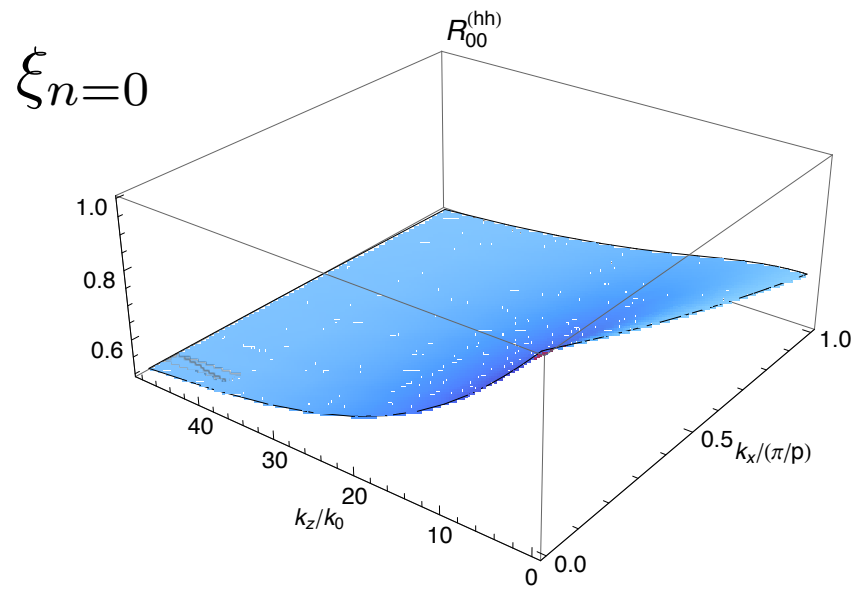
e-polarization (first 7 ξ_n's)



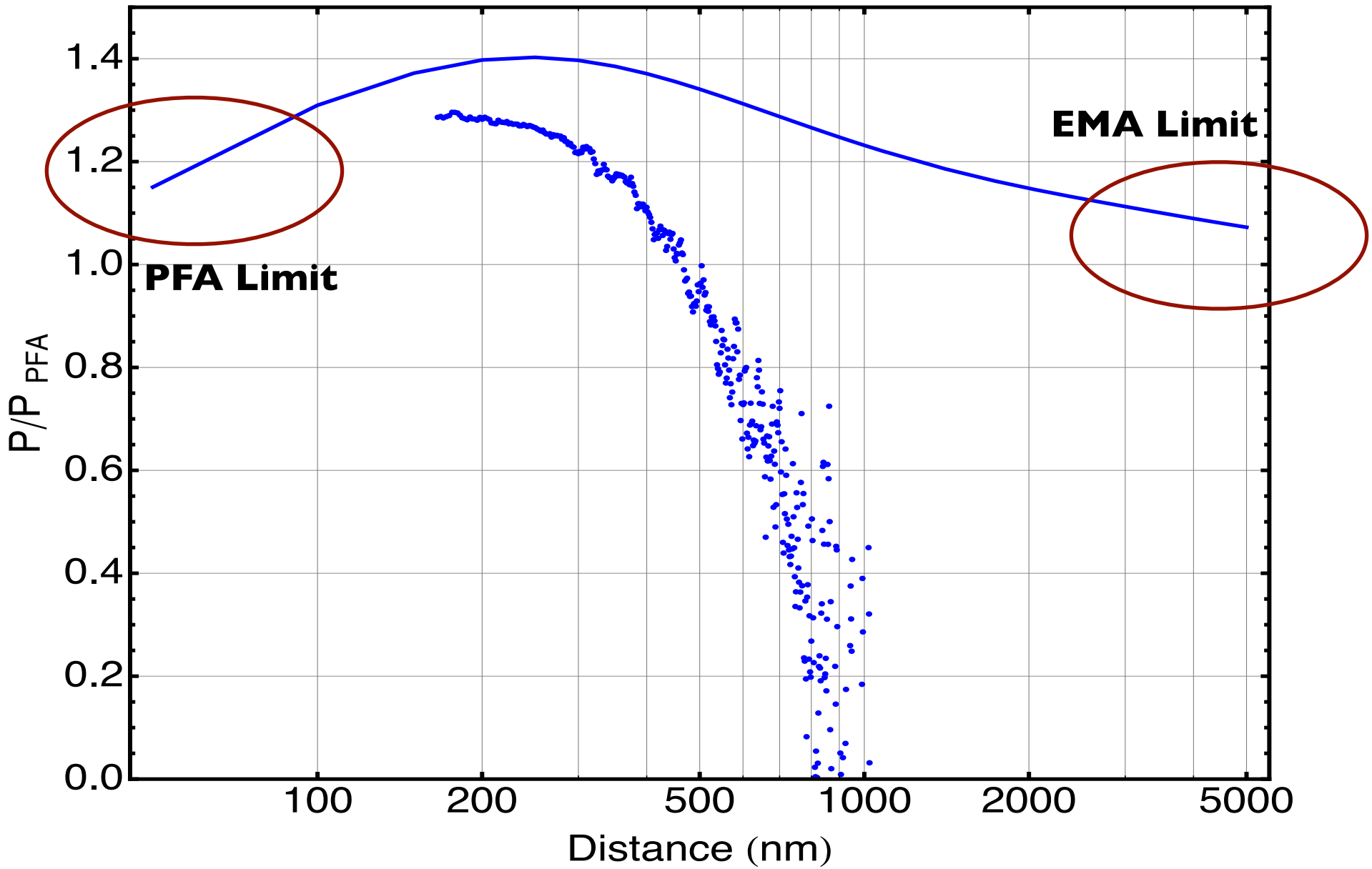
h-polarization (first 7 ξ_n's)







Strong th-exp disagreement



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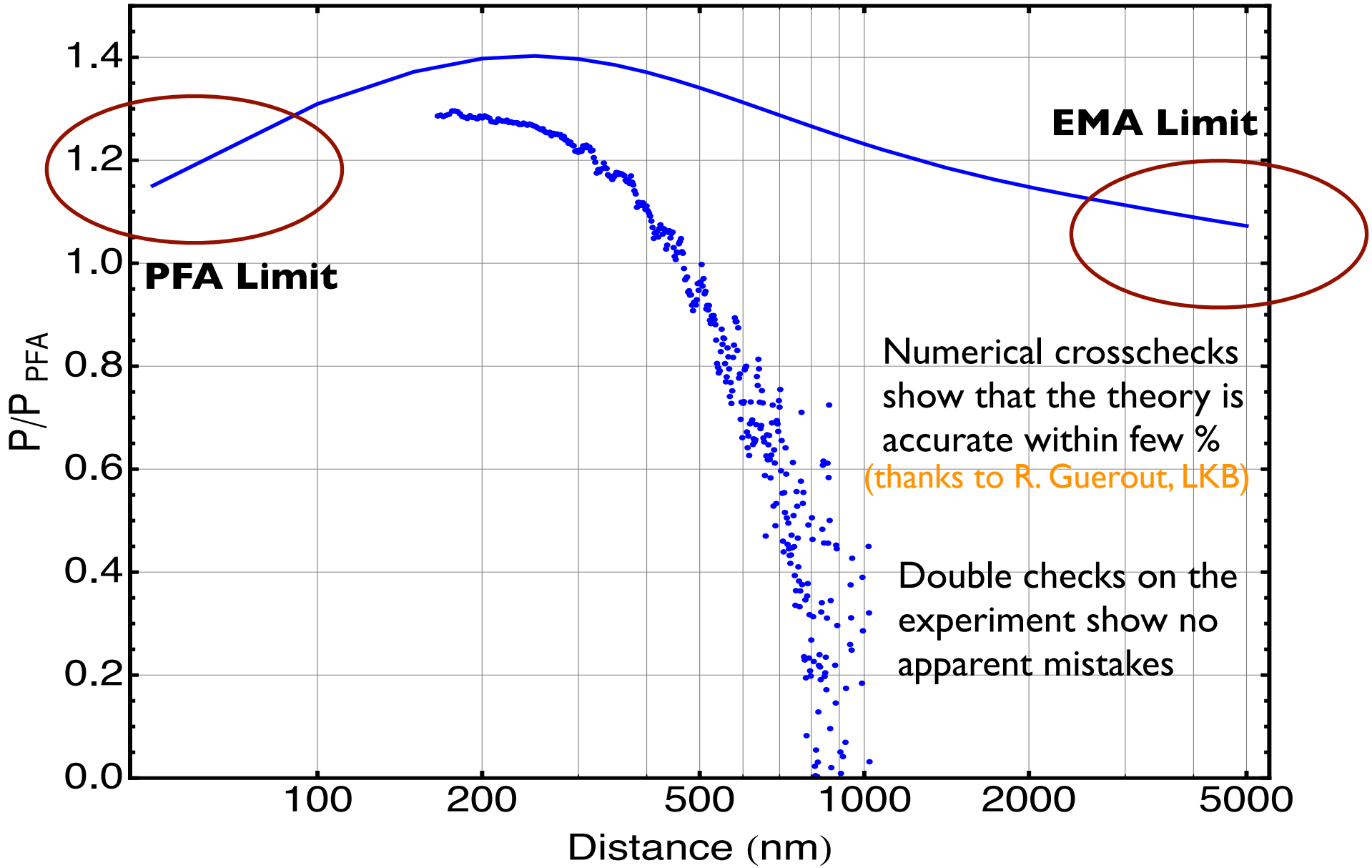

Numerical crosschecks show that the theory is accurate within few %
(thanks to R. Guerout, LKB)

Double checks on the experiment show no apparent mistakes

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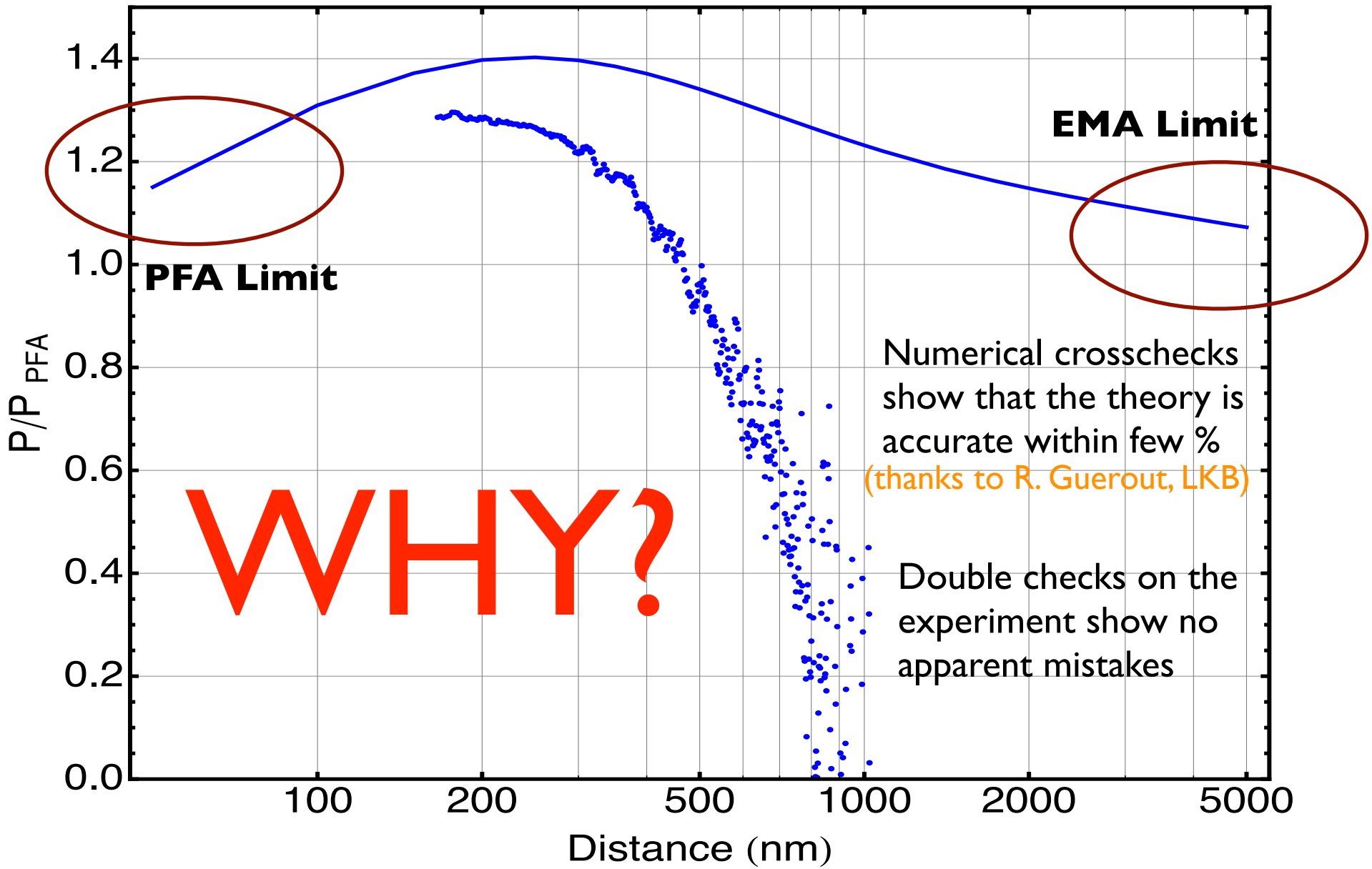

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Modified PFA

- We argue that the standard PFA for the sphere's curvature *might not* be OK

- Only localized modes within the effective area of interaction $A_{\rm eff} \approx 2\pi R d$ i.e, those with $k > k_c \propto A_{\rm eff}^{-1/2}$ should be treated within PFA, and dominate the Casimir interaction

(MIT - LKB)

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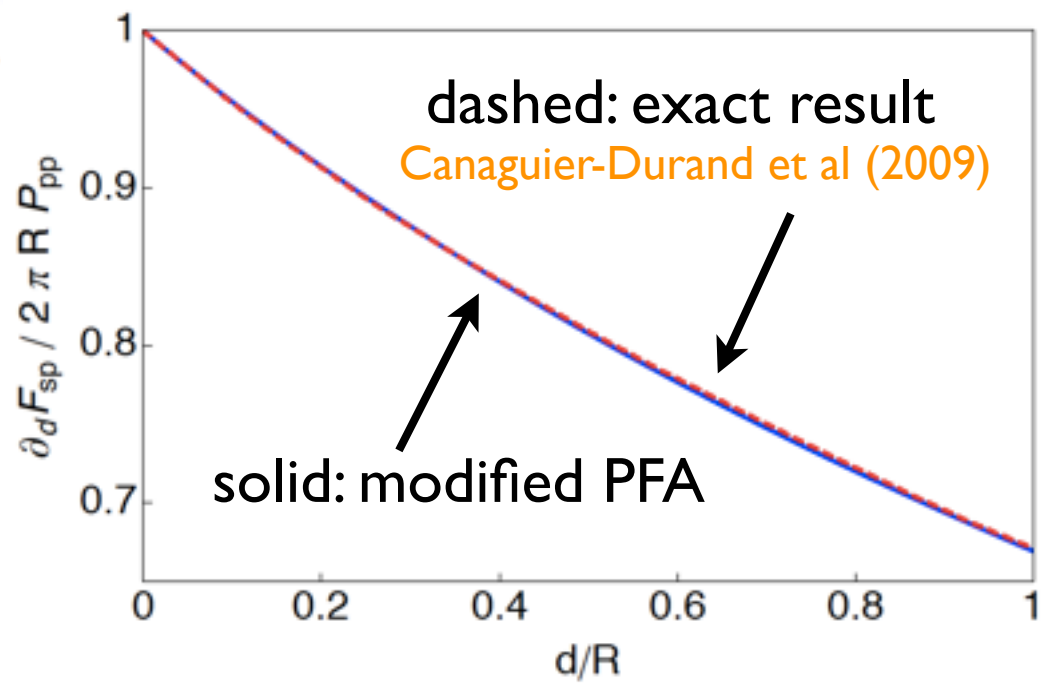
- Test idea in sphere-plane (MIT - LKB)

cut-off obtained by comparing slopes at $d/R \to 0$

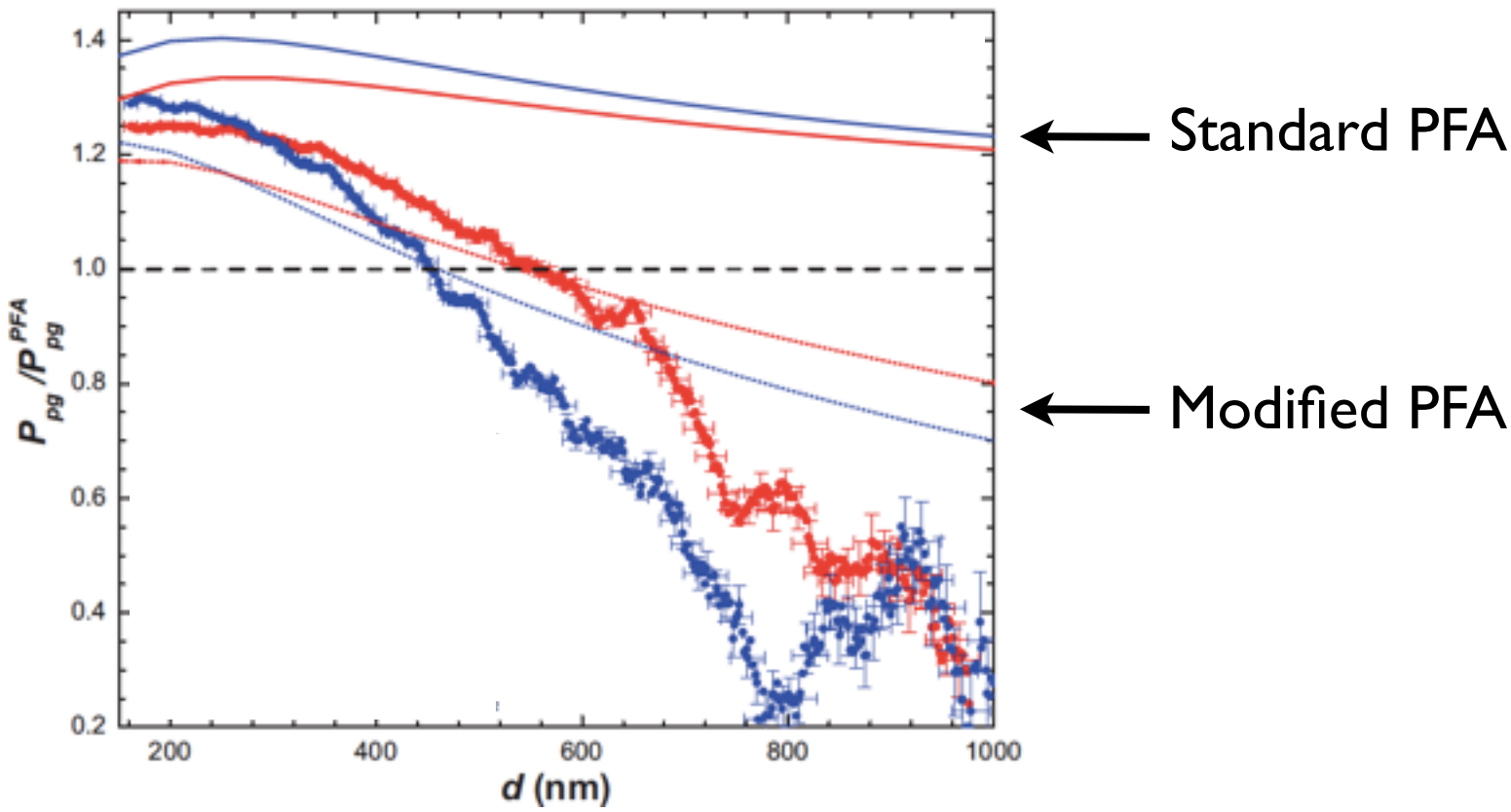
$$k_c = 0.311\pi/\sqrt{Rd}$$

(perfect conductor, zero temperature)

AMAZING AGREEMENT!



Improved th-exp agreement



- Qualitative features of data are reproduced using the modified PFA with the *simplest cut-off possible*.
- Correct cut-off probably depends on optical/geom. parameters of grating.
- To date, exact sphere-grating results are not available.