Light transport in high refractive index photonic glasses

L. Schertel[1,2] · G. J. Aubry[2,3] · I. Wimmer[4] · P. Besirske[4] · S. Polarz[4] · G. Maret[2] · C. M. Aegerter[1,*]

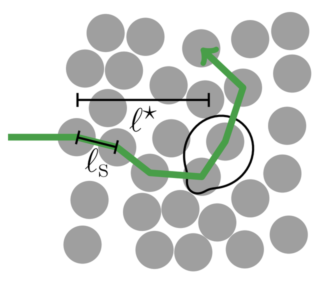
*: aegerter@physik.uzh.ch
1: Physik-Institut, Universität Zürich, Switzerland
2: Fachbereich Physik, Universität Konstanz, Germany
3: Department of Physics, University of Fribourg, Switzerland
4: Chemie-Institut, Universität Konstanz, Germany

Universität Konstanz

Universität Zürich UZH

1. Previous work: Resonant transport model

Quantitative transport description in photonic glass [2]



diffusion

Transport mean free path:

$$\ell^* = \frac{\ell_s}{1-\langle\cos\Theta\rangle} \overset{\text{sphere}}{=} \frac{4\pi}{3}\frac{R^3}{(1-\langle\cos\Theta\rangle)f\sigma_s}$$

scattering cross section:

$$\sigma_s = \frac{\pi}{k^2}\int_0^\pi F(\theta)S(\theta)\sin\theta\,\mathrm{d}\theta$$

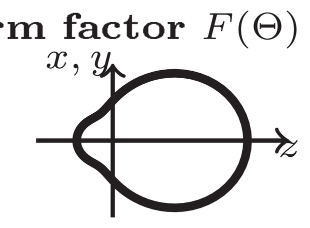
anisotropy factor:

$$\langle\cos\theta\rangle = \frac{\int_0^\pi \cos\theta F(\theta)S(\theta)\sin\theta\,\mathrm{d}\theta}{\int_0^\pi F(\theta)S(\theta)\sin\theta\,\mathrm{d}\theta}$$

Energy coherent potential approximation [1]

Advanced version of the CPA guaranteeing a homogeneous energy density
⇒ replace k by k_{eff}

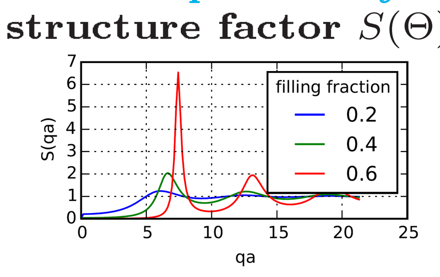
form factor $F(\Theta)$



single scattering

+

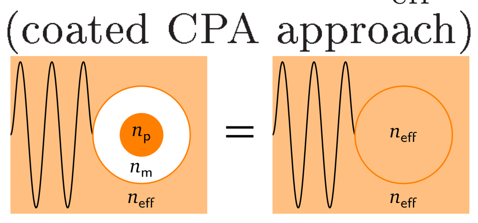
structure factor $S(\Theta)$



structural correlations

+

effective index n_{eff} (coated CPA approach)



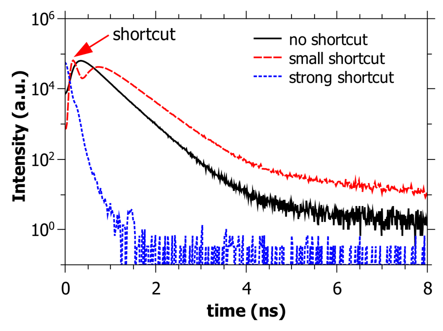
near field coupling

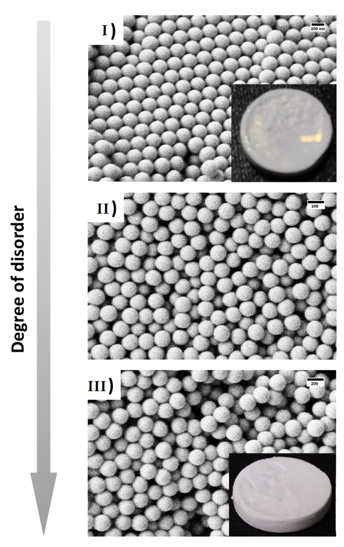
2. Previous work: Polymeric photonic glass

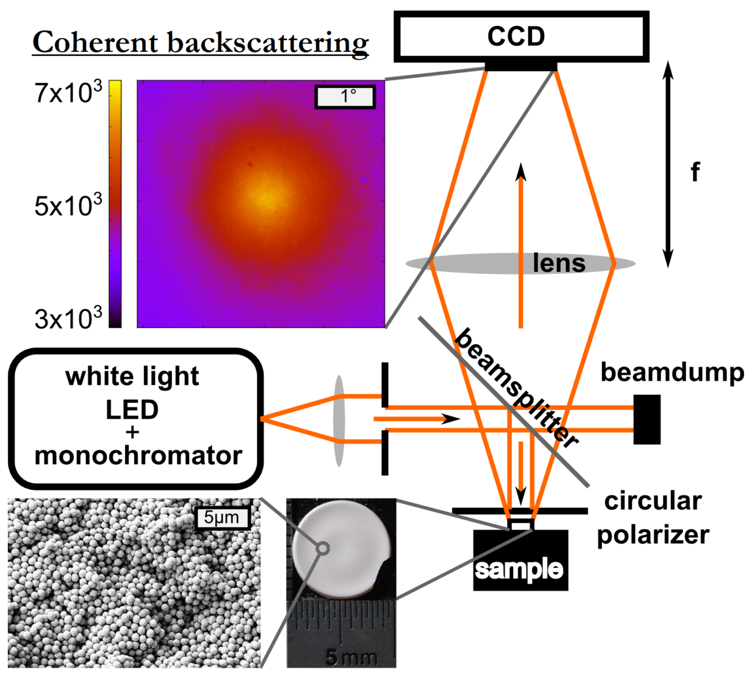
Sample control [3]

polystyrene PG
($n = 1.6$)

prevent crystallization (via salt concentration), avoid optical shortcuts (hydrogel network)







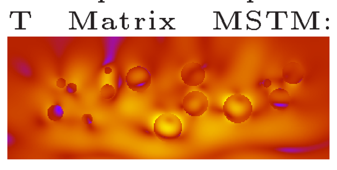
Probing multiple scattering Mie resonances [2]

(a) n_{ECPA}: ECPA effective index model

- $n_0 = 1$: no effective index used
- $n_{\mathrm{vol}} = n_p f + n_m(1-f)$
- n_{MG}: Maxwell Garnett effective index model
- $N = x$ cluster: $F(\Theta)$ calculated for clusters, no n_{eff}

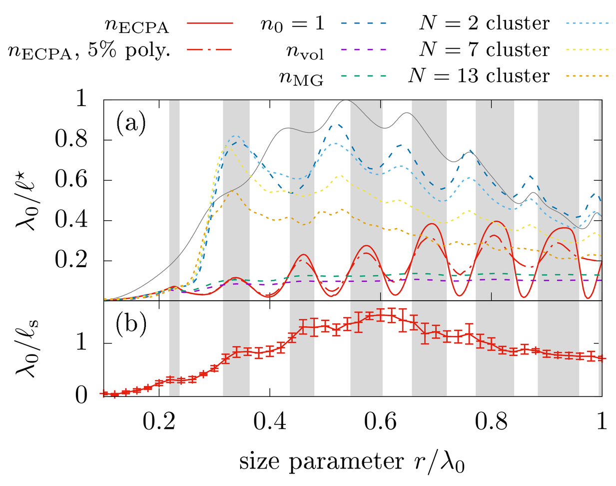
(b) ballistic regime: $I_c = I_0 \exp(-L/\ell_s)$

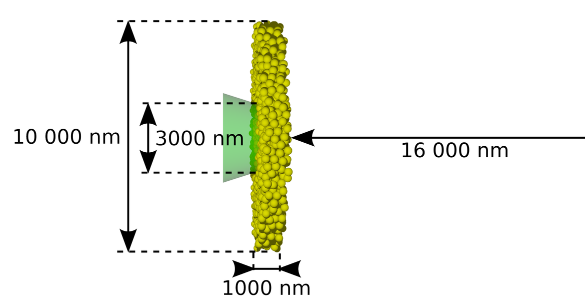
- Multiple Sphere T Matrix MSTM:



http://eng.auburn.edu/users/dmckwski/scatcodes/

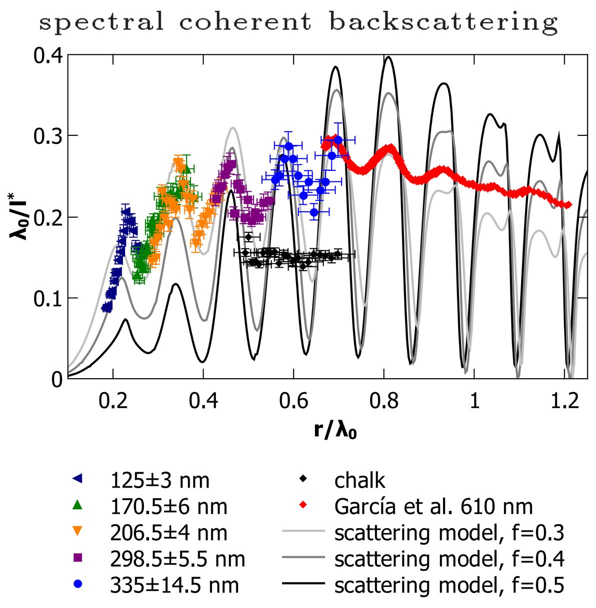
Simulations





Experiments

spectral coherent backscattering

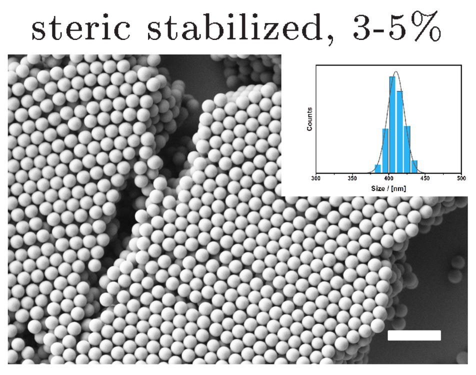


⇒ **Position** of the resonances are very **well predicted by ECPA model.**

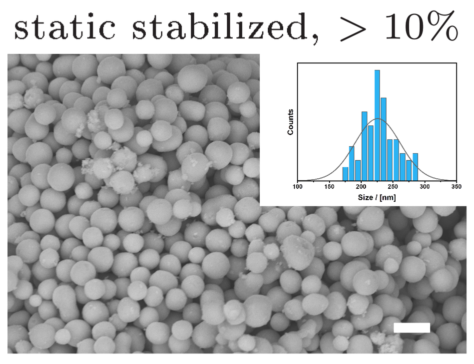
3. High index photonic glass

White paint materials: titanium dioxide

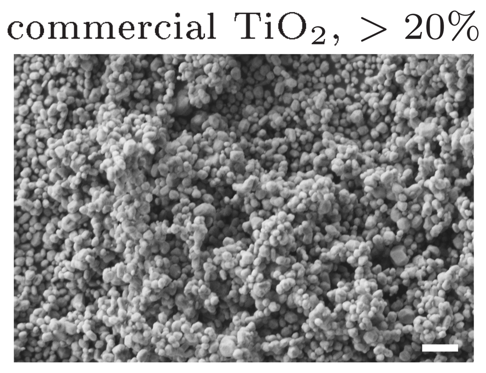
steric stabilized, 3-5%



static stabilized, > 10%

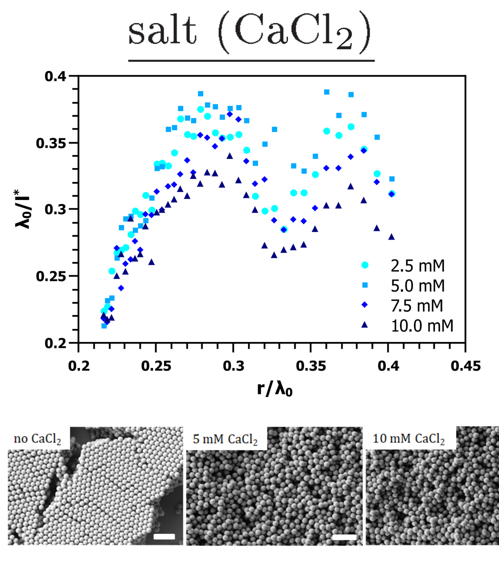


commercial TiO_2, > 20%

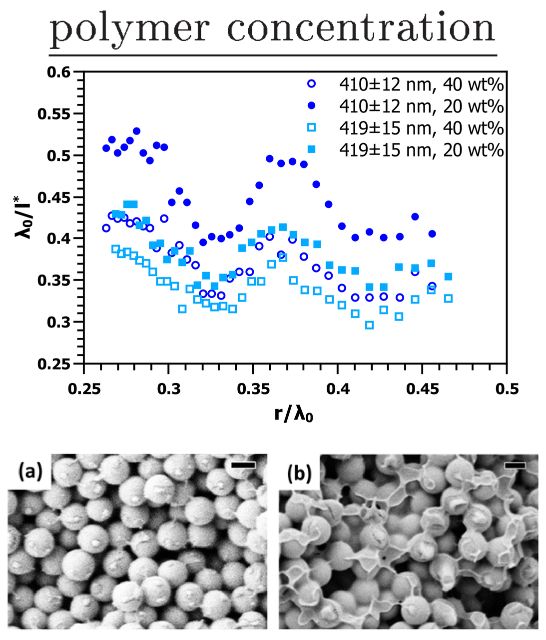


→ polydispersity

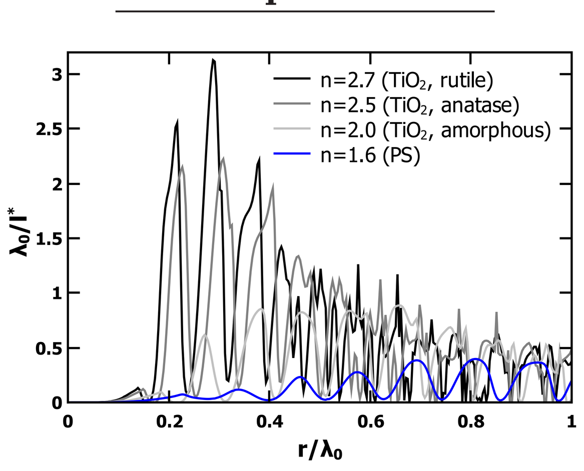
salt ($CaCl_2$)



polymer concentration

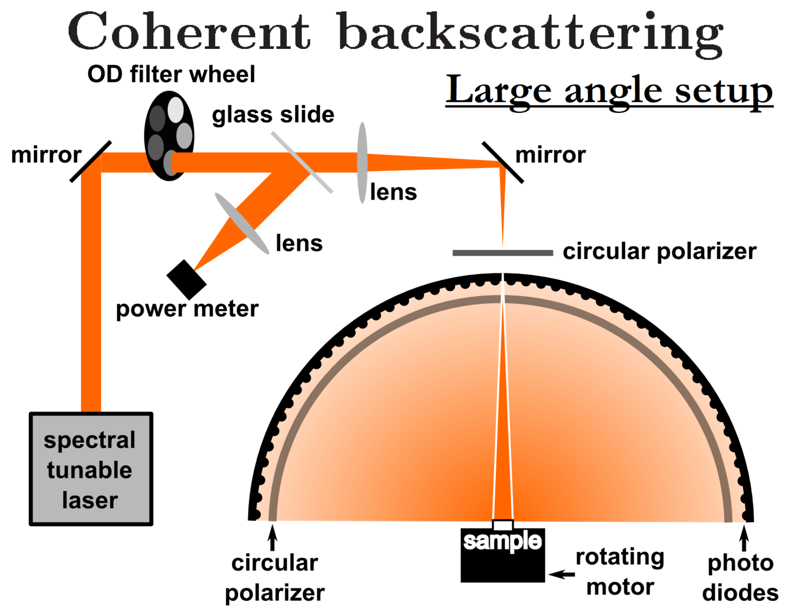


ECPA prediction:

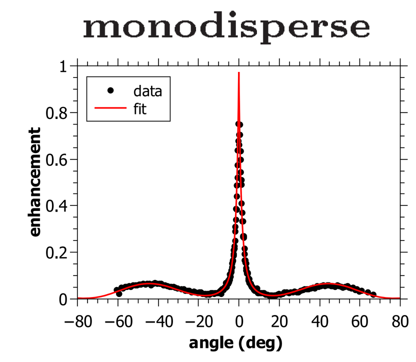


4. TiO_2 photonic glass

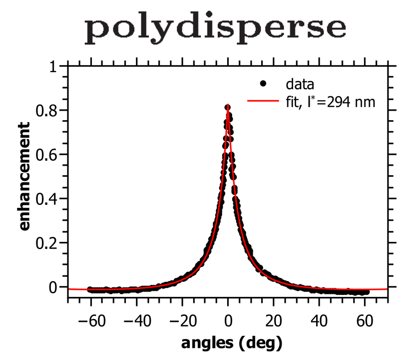
Coherent backscattering



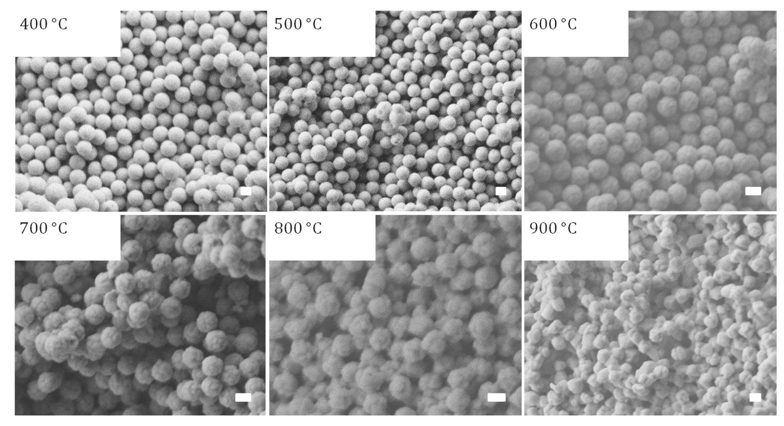
monodisperse



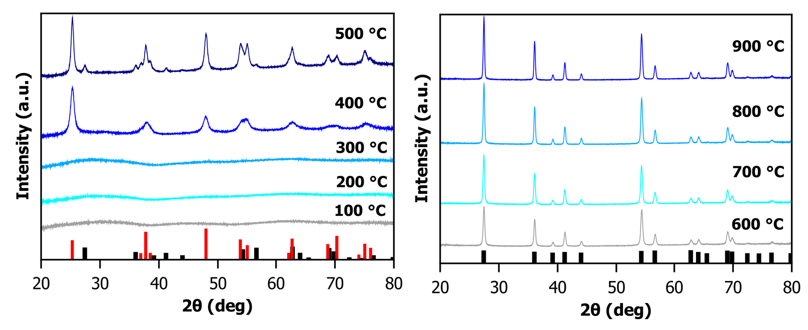
polydisperse



Sintering anatase and rutile phase



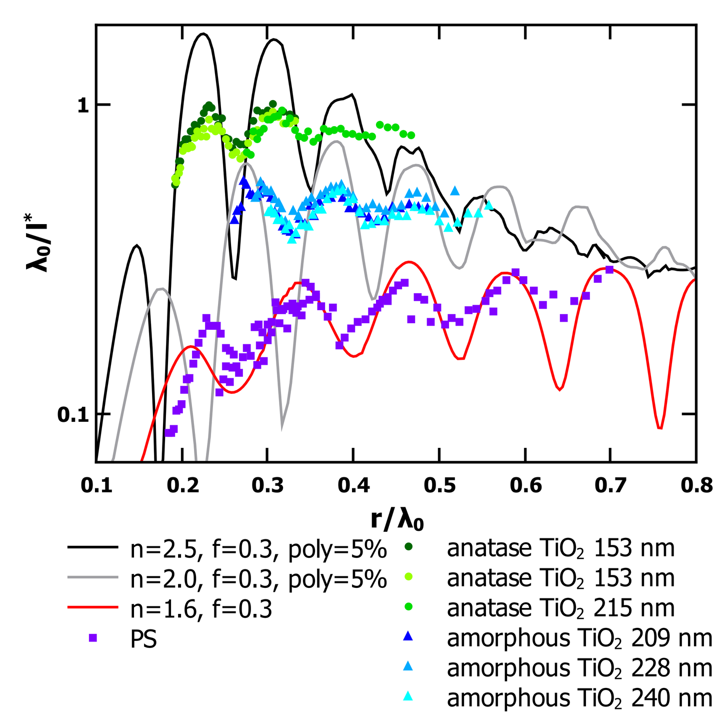
PXRD quantification:



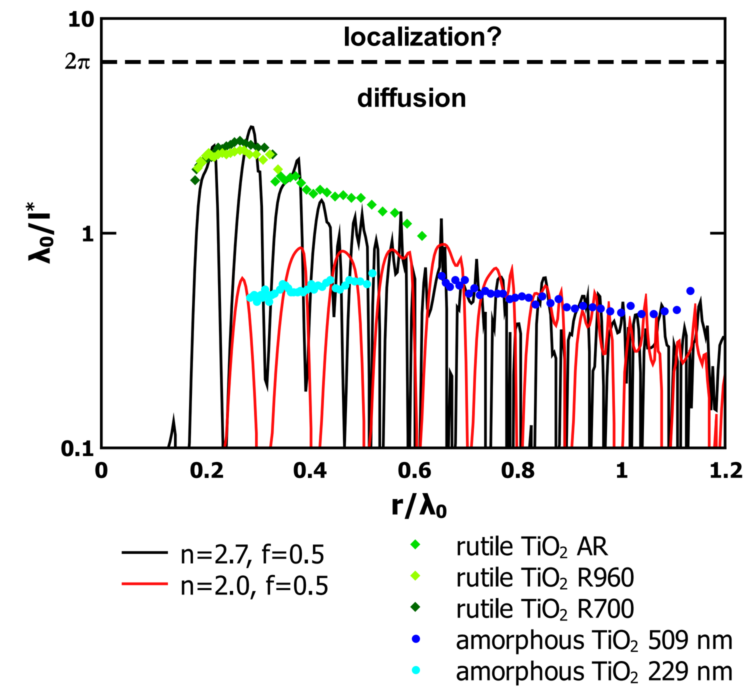
5. Light transport in white paints

Testing the ECPA scattering strength λ_0/ℓ^*

monodisperse photonic glass



polydisperse photonic glass

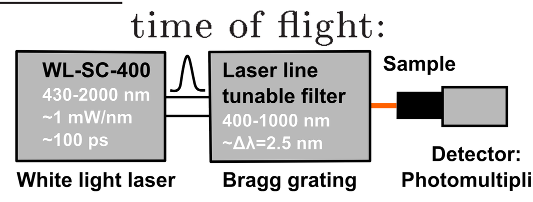


Energy transport velocity

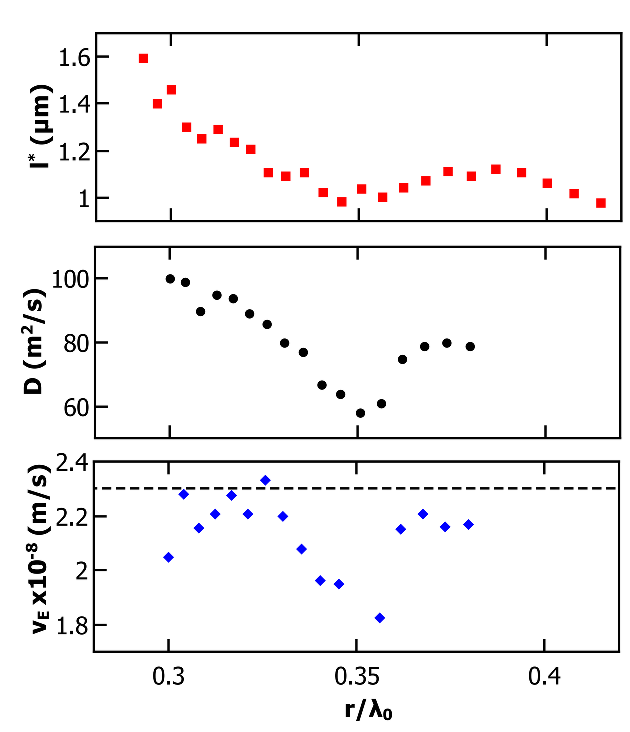
ℓ^*: static scattering
D: dynamic scattering

$$D = \frac{v_E \ell^*}{3}$$

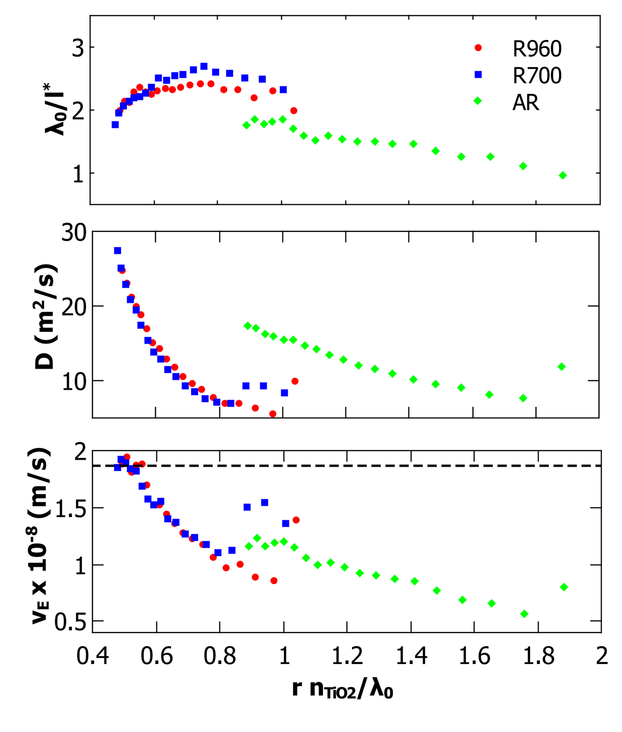
time of flight:



monodisperse amorphous TiO_2



polydisperse commercial TiO_2



⇒ resonant transport

Conclusion

ECPA model:

- predicts **position of multiple scattering Mie resonances** very well
- **four materials/indices** are recovered
- order of magnitude of the scattering strength is also recovered
- polydisperse TiO_2 data **follows envelope of the theory curve**

Perspective:

- improve sample (monodispere, structural correlation, higher index)
- Can sharp **resonances** reach localized regime?

References

[1] Busch K and Soukoulis C M 1996 *Phys. Rev. B* **54**(2) 893–899
[2] Aubry G J, Schertel L, Chen M, Weyer H, Aegerter C M, Polarz S, Cölfen H and Maret G 2017 *Phys. Rev. A* **96**(4) 043871
[3] Chen M, Fischli D, Schertel L, Aubry G J, Häusele B, Polarz S, Maret G and Cölfen H 2017 *Small* **13** 1701392 ISSN 1613-6829