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From projections to small-angle scattering : Artifacts induced by polychromatic cone-beams

Brisard S.¹, Chateau C.^{1*}, Levitz P.²

¹ Laboratoire Navier, École des Ponts ParisTech, Univ Gustave Eiffel, CNRS, Marne-la-Vallée, France

² Sorbonne Université, CNRS UMR 8234, PHENIX Lab, Paris, France

Context and objectives

Small-angle scattering (SAS - X-ray, neutron) is a technique for the investigation of the structure of disordered materials at the 1nm - 100nm scale. It delivers, in Fourier space, the two-point correlations of the electron density within the material.

For isotropic materials, the SAS pattern $I(q)$ depends on the norm q of the wave-vector only, and the covariance function $\gamma(r)$ depends on the norm r of the lag-vector only.

$$I(q) \propto \int_0^{+\infty} 4\pi r^2 \text{sinc}(qr) \gamma(r) dr$$

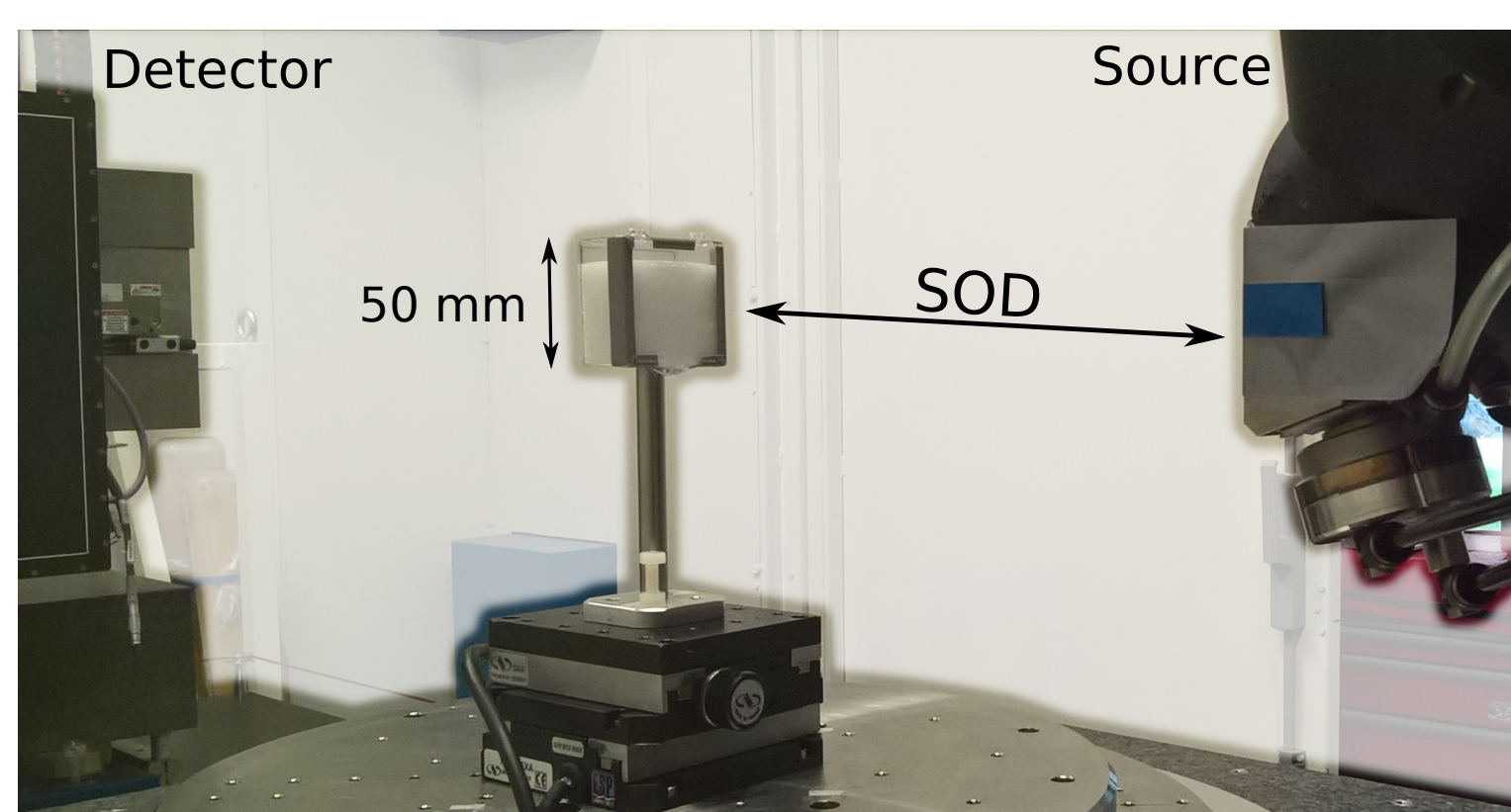
- The sample preparation is kept to a minimum.
- The 3d structural information [$\gamma(r)$] is limited, but quantitative: volume fraction, specific surface area, particle-size distribution...
- Applications from biology [1] to geomaterials [2-3].

A technique was proposed to simulate the SAS pattern of a material from a **single X-ray radiography** [4], which:

- bridges the length scales explored by SAS and by microtomography,
- opens the door to time-resolved, quantitative experiments,
- was successfully used in various applications [3, 5, 6].

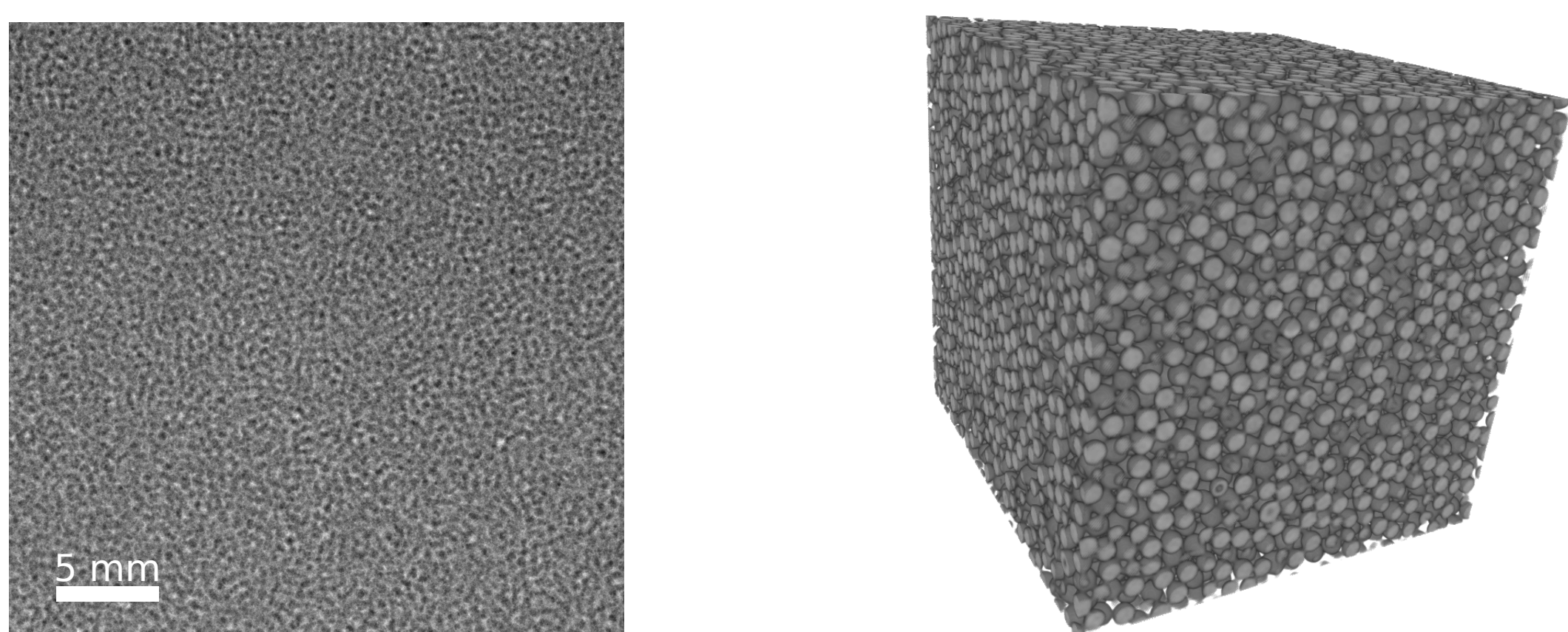
However, it is mathematically correct (and fully validated) for parallel beams only. In order to **extend this technique to cone-beam geometries**, our goal in this project is to quantify the distortions induced by non paraxial rays.

Materials and Methods



Polystyrene beads were placed in a plastic container. Projections were acquired on a laboratory tomograph (RX Solutions) under various source-to-object distance (SOD) and a long source-to-detector distance.

For reference, a full tomography scan was also acquired (voxel-size 30 μ m).

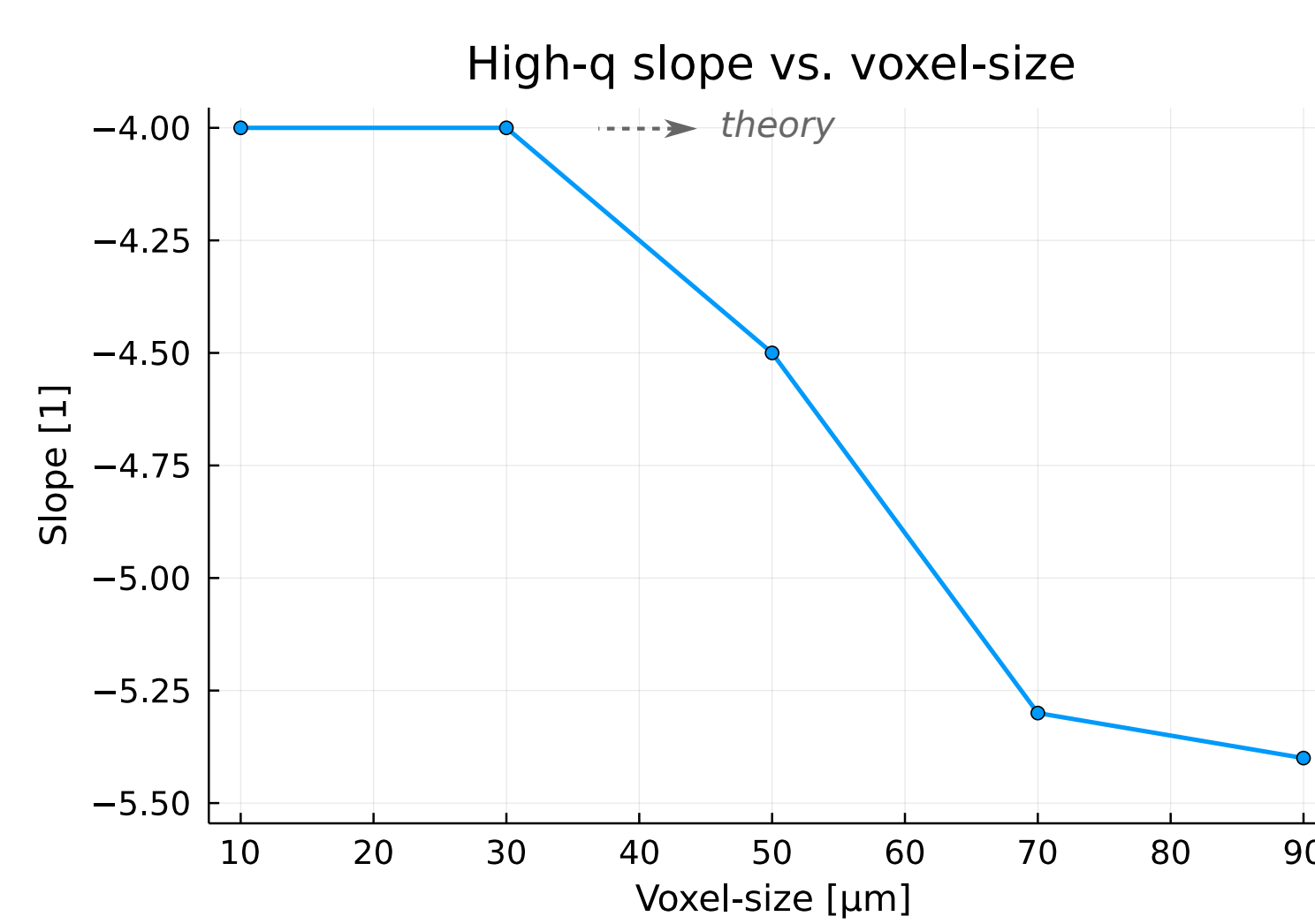
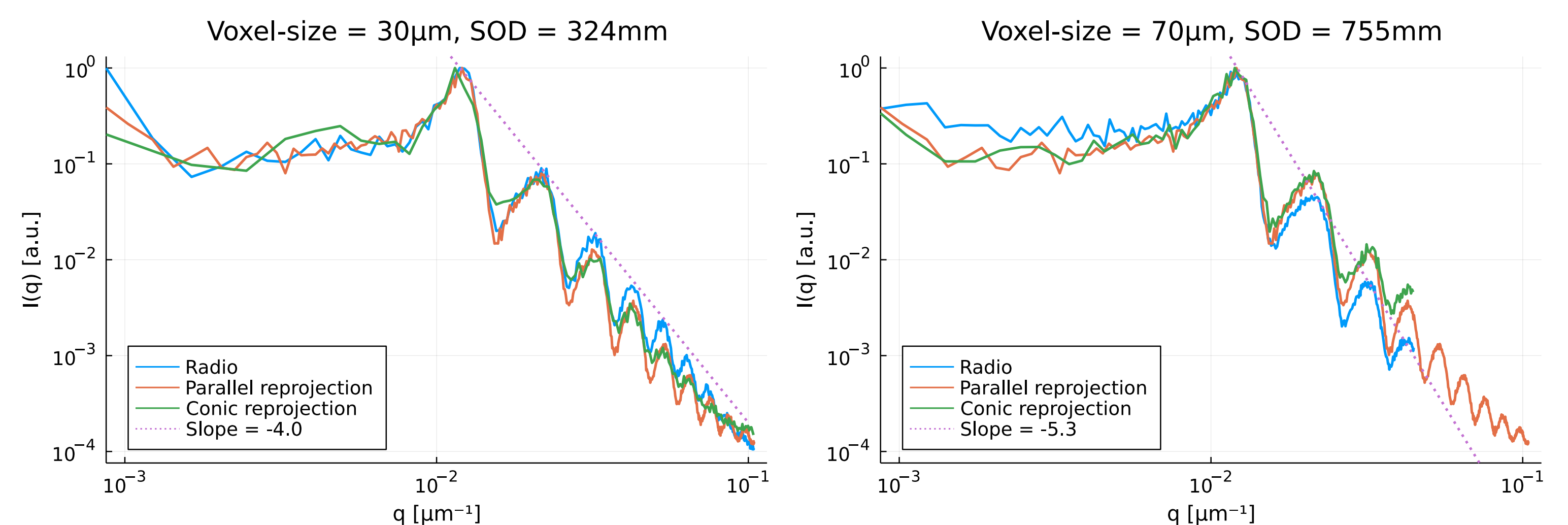


The SAS spectra were computed from the projections P (log of radii) at each SOD.

$$I(q_x, q_y, q_z = 0) = \left| \hat{P}(q_x, q_y) \right|^2$$

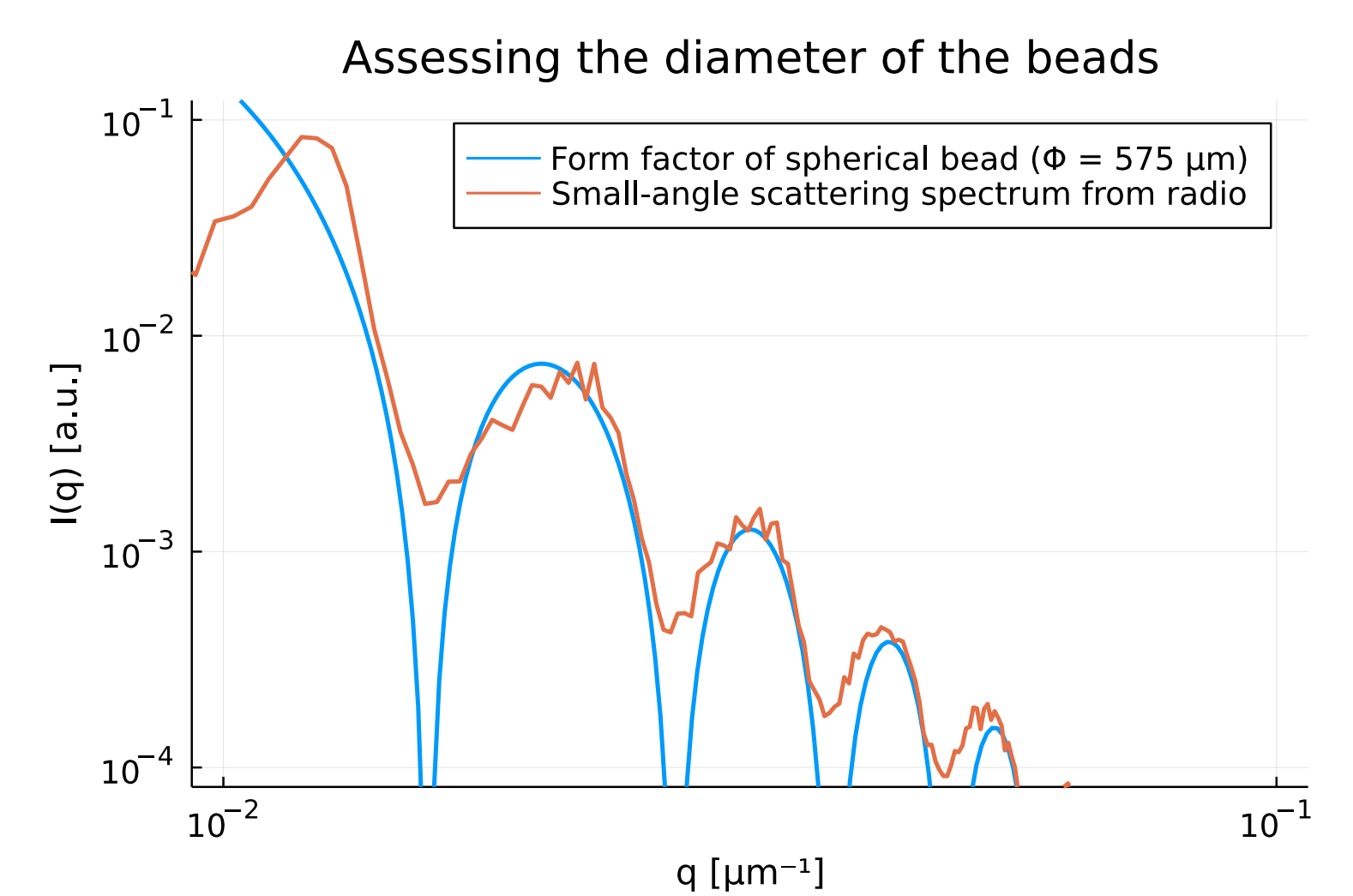
The SAS spectra were also computed from the **parallel reprojection** and **conic reprojection** of the 3D reconstructed + thresholded volume. Both reprojections are monochromatic.

Results



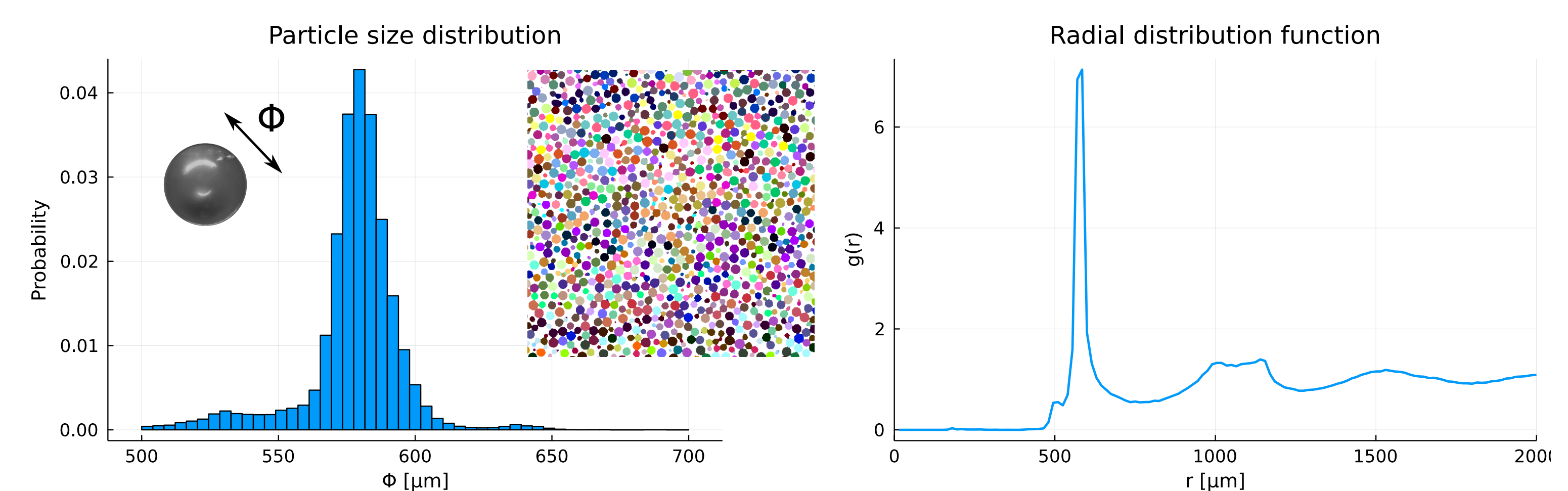
Maximizing the source-to-object distance minimizes the distortions induced by the conic geometry. Our results therefore suggest that there is at least one more source of distortions.

Comparison of **radio** and **conic reprojection** shows that beam-hardening cannot be neglected.



Despite these distortions, the proposed method is **quantitative**. We were able to measure the average radius of the spherical beads from one single radio.

The resulting value was confirmed by a more costly analysis of the 3D reconstructed volume (PSD + RDF [8]).



Perspectives

- New experimental setup, with a more controlled sample (dimensions, ...)
- Quantification of other descriptors: volume fraction, specific surface area ...
- Analytical model of geometric, noise-induced and beam-hardening distortions → deconvolution
- Extension to $N > 2$ phases: vary source kV and/or use photon-counting, dual energy, XC-Thor sensor from DirectConversion
- "Sub-pixel" accuracy?

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* camille.chateau@enpc.fr