Scatter Correction Methods in Dimensional CT

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Scatter Artifacts in CT Images

- Standard reconstruction algorithms for CT imaging rely on the assumption that the (primary) intensity I_p measured behind an object of thickness d is given by

$$I_{\mathrm{p}} = I_0\, e^{-\mu \cdot d}$$

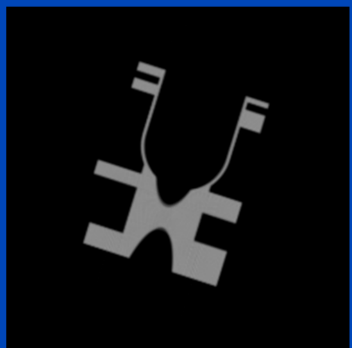
$$I_{\mathrm{p}}\text{: Primary intensity, } \mu\text{: Linear attenuation coefficient,}$$
$$I_0 \text{ unattenuated intensity}$$

- Scattered radiation violates this assumption which leads to artifacts in reconstructed CT images

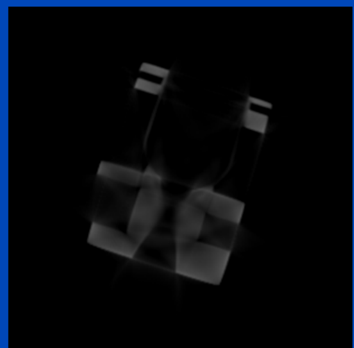
$$I_{\mathrm{ps}} = I_0\, e^{-\mu \cdot d} + I_{\mathrm{s}}$$

$$I_{\mathrm{s}}\text{: Intensity of scattered radiation}$$

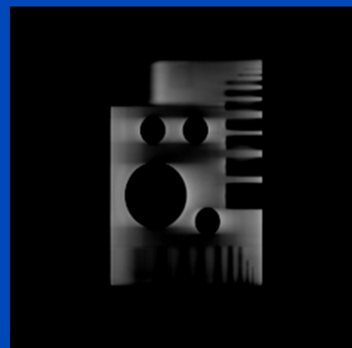
Reconstructed I_p
(Simulation)



Reconstructed I_{ps}
(Simulation)



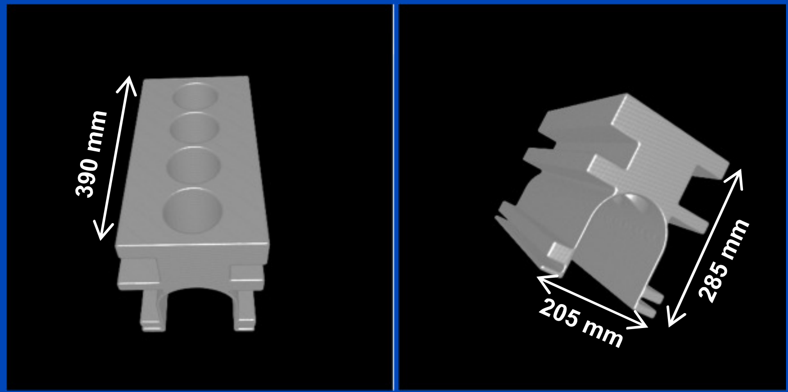
Reconstructed I_{ps}
(Measurement)



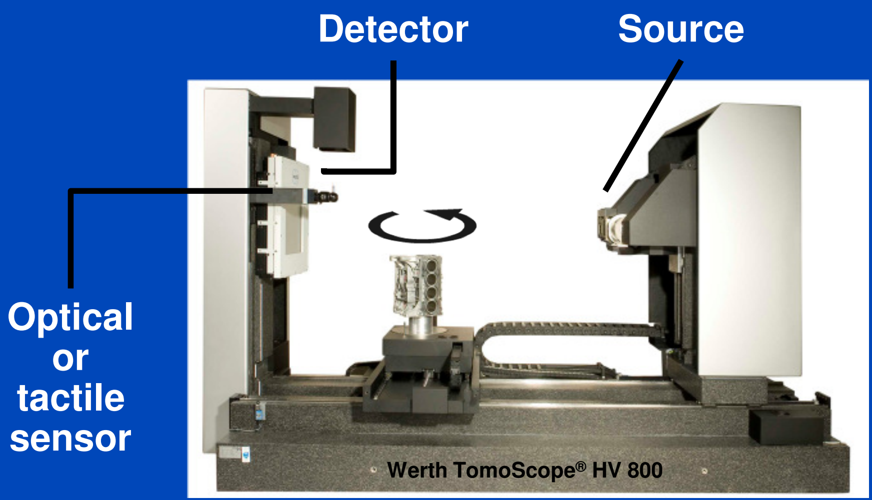
Aim of this Study

- Improve image quality in case of strong scatter artifacts
- Simulation study to evaluate different approaches to reduce scatter artifacts in dimensional computed tomography
- Scatter correction and reduction methods
  - Monte Carlo-based scatter correction
  - Scatter reduction by the usage of an anti-scatter grid
  - Scatter reduction by the using the slit scan technique
- The focus was to increase image quality. A detailed metrological analysis of the correction methods was not within the scope of this study.

Simulation Setup



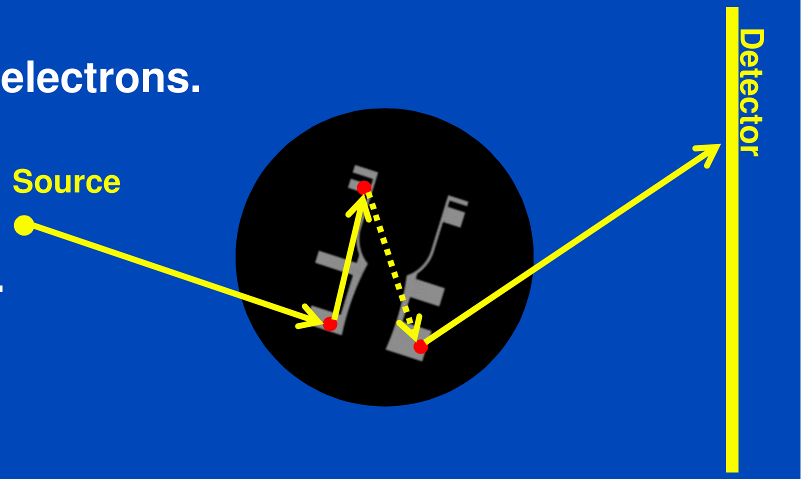
Motor block phantom, material:
Aluminum, ρ_{Al} = 0.002699 g/mm^3.



- Simulations were done for a typical coordinate measurement machine with CT sensor.
- All simulations with a polychromatic source spectrum at 450 kV.
- Scatter simulation was done with the Monte Carlo method.

Monte Carlo Scatter Simulation

- Simulation of physical correct photon paths through the object in order to generate realistic estimates of the scatter intensities measured at the detector.
- Considered physical effects
  - Photo effect:
    Absorption of photons by interaction with electrons.
  - Compton scattering:
    Scattering of photons on electrons,
    photons change their flight direction,
    energy is partially transferred to electrons.
  - Rayleigh scattering:
    Scattering of photons on electrons,
    energy of photons is conserved,
    only flight direction changes.

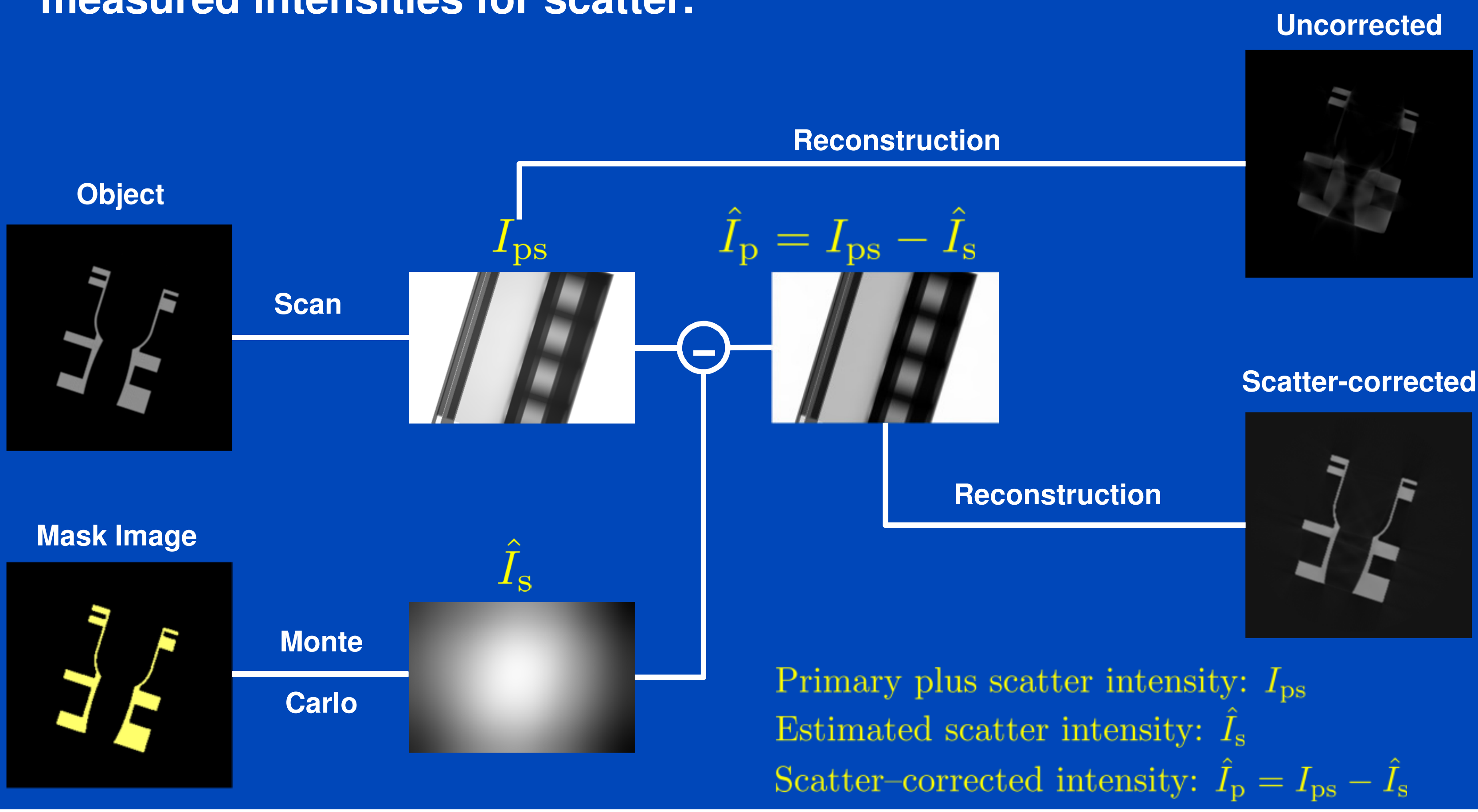


- Complex computations.
- Acceleration can be achieved for example by combination with analytical models*.
- Important: Object model is needed.

*Baer, M. and Kachelrieß, M., Hybrid scatter correction for CT imaging, Phys. Med. Biol. in press.

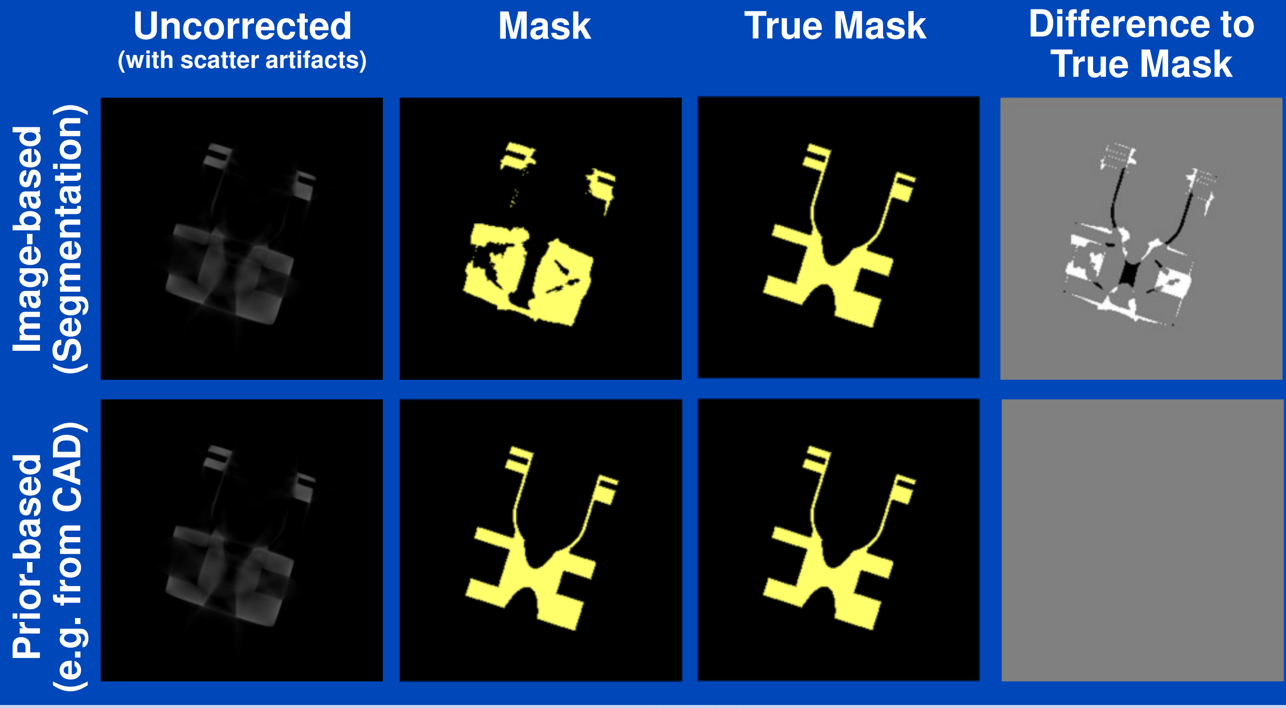
Monte Carlo-based Scatter Correction

- **Based on an initial guess of the material and density distribution within the object, a so-called mask image, an estimate of the scatter fraction in measured intensities is calculated which is then used to correct measured intensities for scatter.**

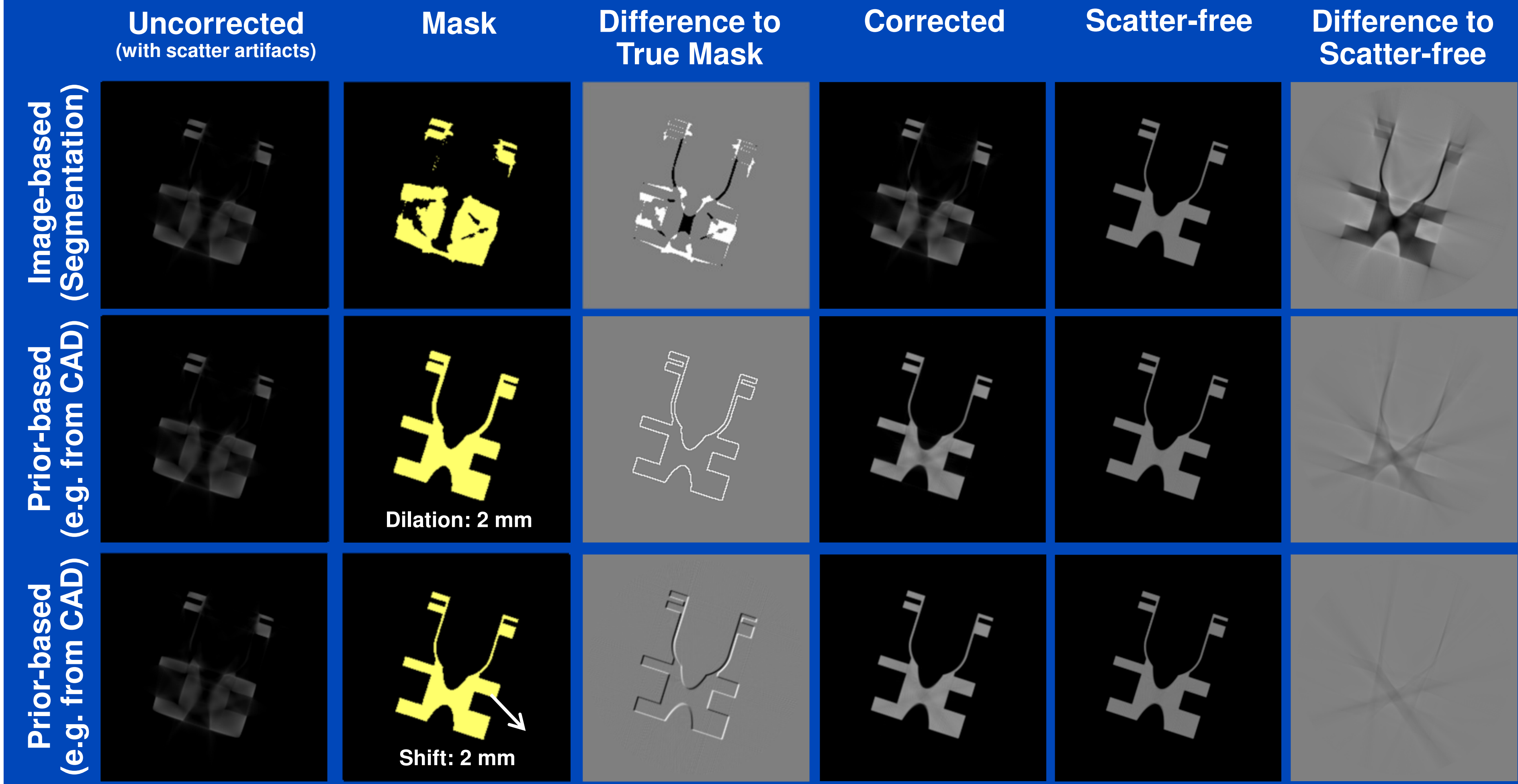


Monte Carlo-based Scatter Correction

- If the mask is created by segmentation of an initial reconstruction from uncorrected intensities the accuracy of the mask image may be degraded by the presence of scatter artifacts.
- We here propose to use prior information about the object that may come for example from a CAD model to generate the mask image.

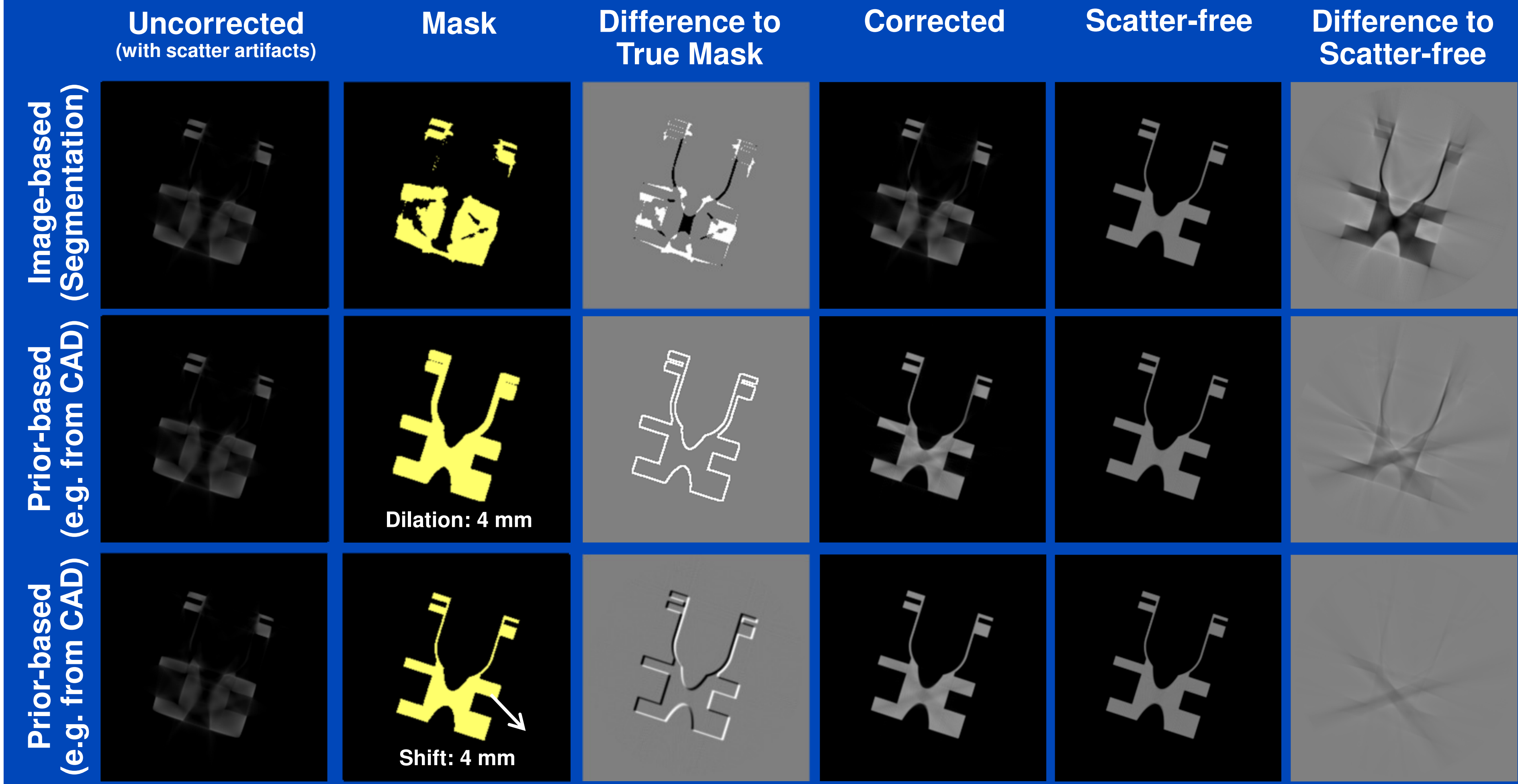


Results



Constant center / window setting for all reconstructions.

Results



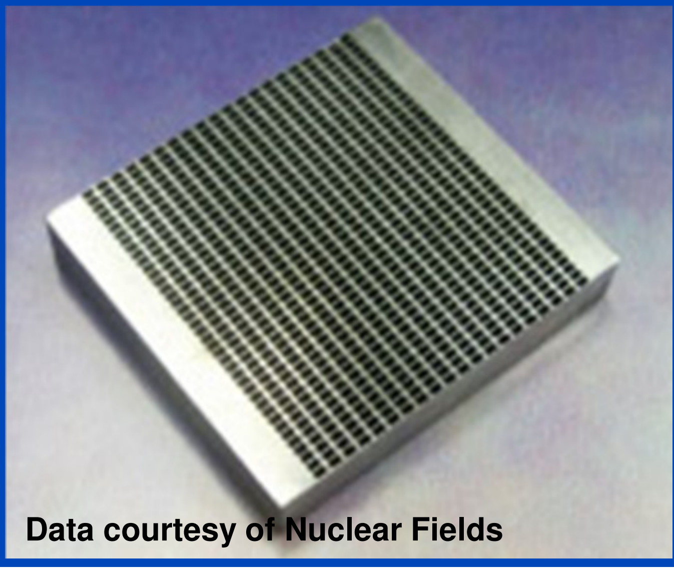
For measurements errors in the prior-based mask may be by far lower. Multisensor coordinate measuring machines can be used to enhance the registration between the prior-based mask and the CT reconstruction.

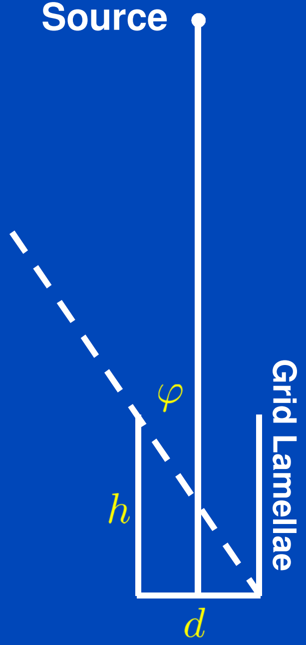
Anti-Scatter Grid

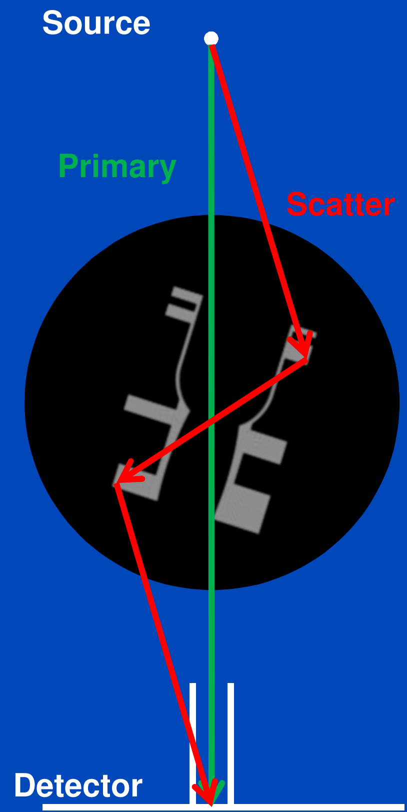
Basic concept of anti-scatter grids is that the acceptance angle φ for a detector pixels is restricted.

The anti-scatter gird was modeled as an ideal grid. Photons with an incidence angle larger than φ are absorbed completely by the grid.

Scatter artifact reduction in dependency on the grid ratio r was investigated for typical grid ratios (r=5 and r=25).

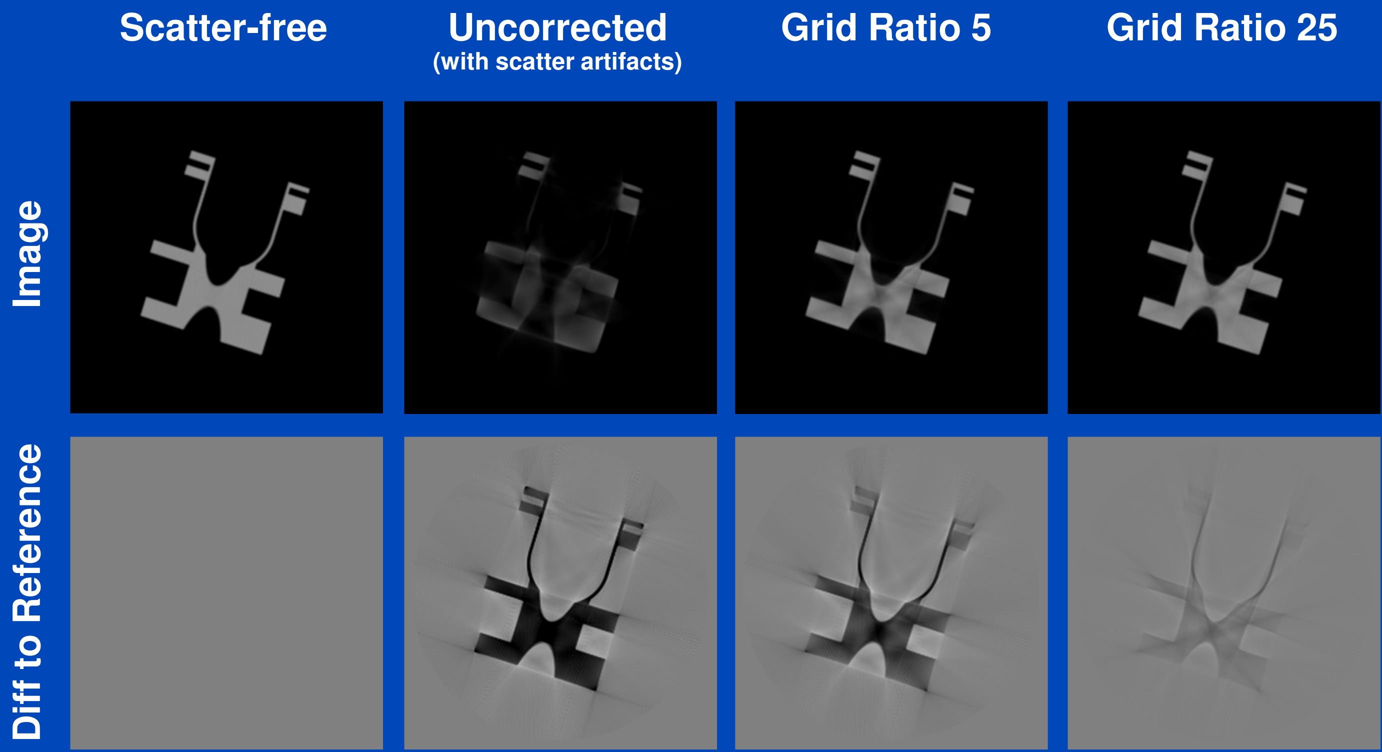

Data courtesy of Nuclear Fields





Height of grid lamellae h
Distance between grid lamellae d
Grid ratio $r = \frac{h}{d}$
Acceptance angle $\varphi = 0.5\,\pi - \arctan r$

Results



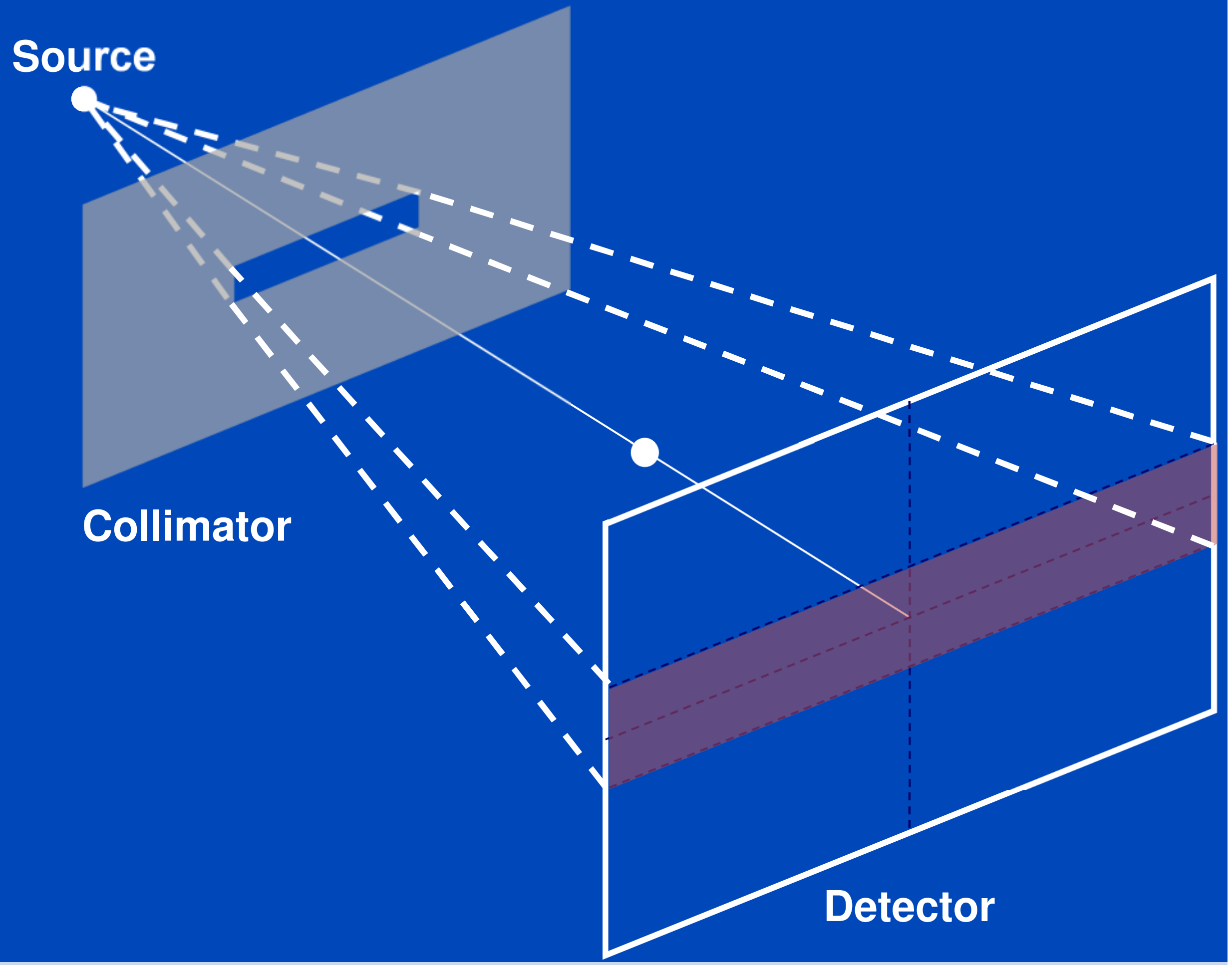
Using an anti-scatter grid yields a strong increase in image quality. For a grid ratio of 25, almost perfect images are obtained.

Constant center / window setting for all reconstructions.

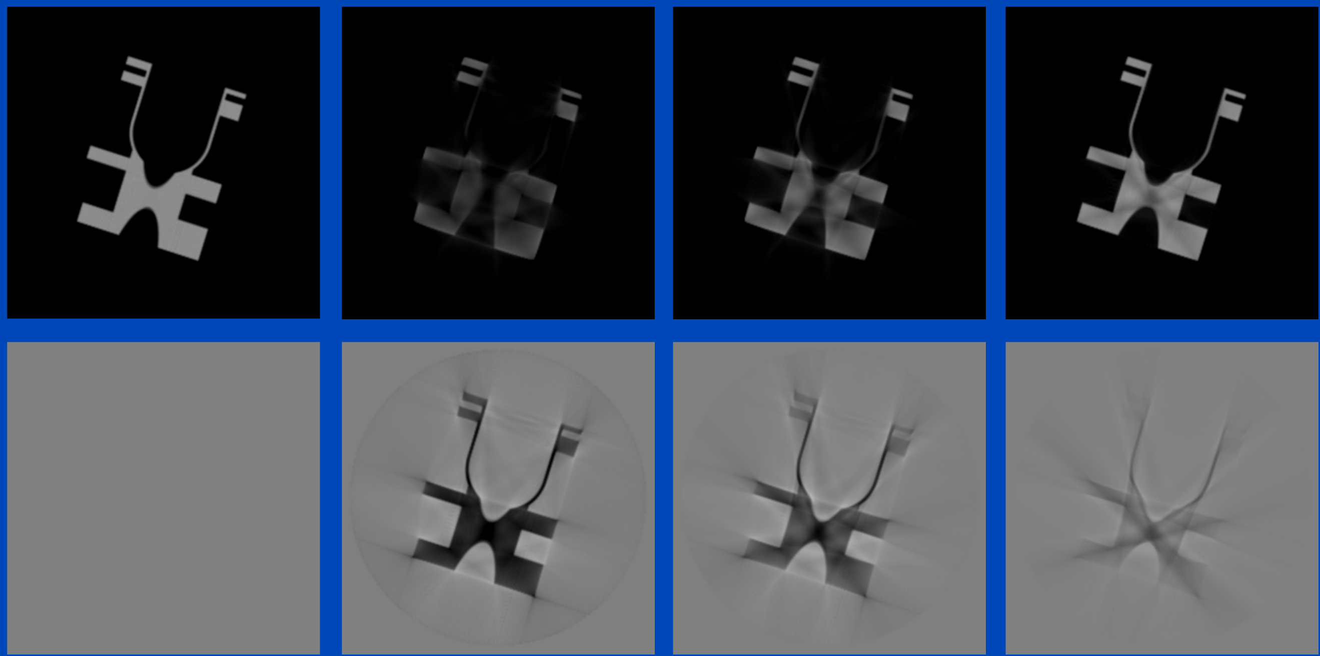
Slit Scan

The size of the irradiated volume has a strong influence on the magnitude of scatter intensities at the detector: The larger the irradiated volume the higher the scatter content in measured intensities.

The slit scan method was evaluated for two collimations: 10% respectively 1% of all detector rows.



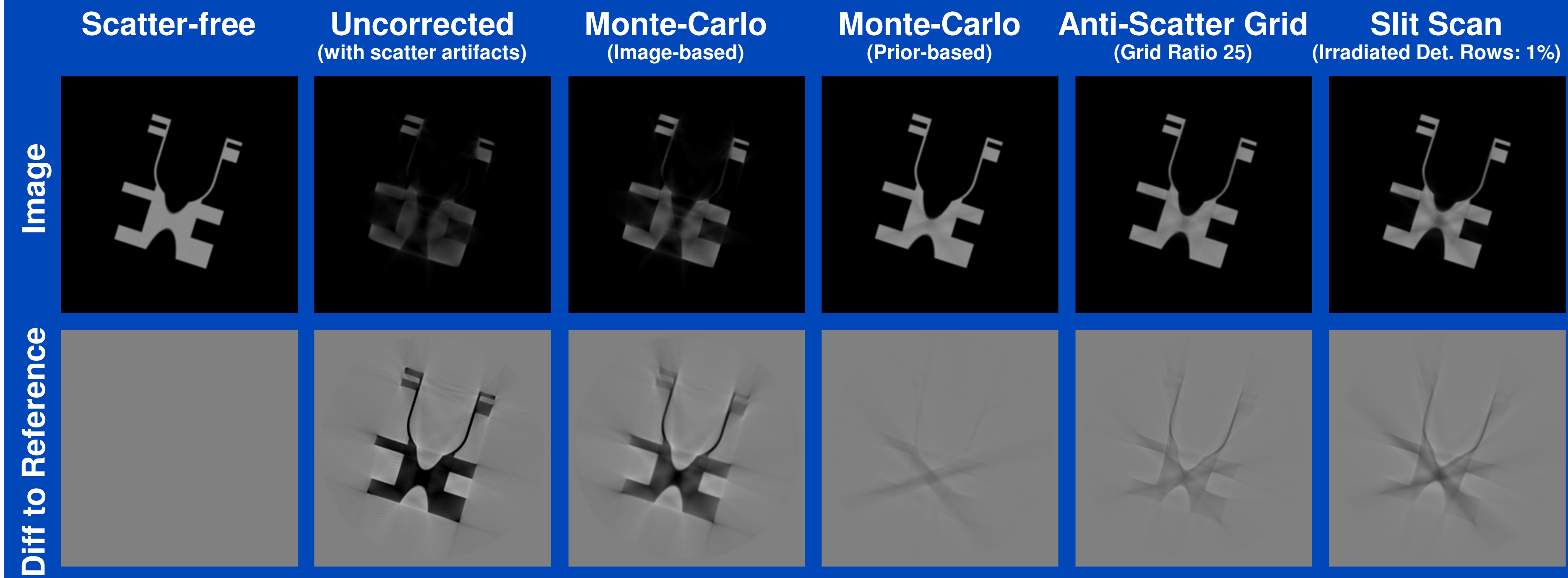
Results



Scatter artifacts decrease with decreasing detector illumination.

Constant center / window setting for all reconstructions.

Comparison



Constant center / window setting for all reconstructions.

Summary and Conclusion

	Pro	Con
Monte Carlo	•Good scatter artifact reduction •No additional hardware •Full 3D volume can be measured and corrected with a single scan	•Complex computation •Scan parameters and physical object properties are needed (e.g. source spectrum and object geometry) •Registration of prior model and CT reconstruction (can be enhanced when using a multi sensor coordinate measuring machine)
Anti-Scatter Grid	•Good scatter artifact reduction •Full 3D volume can be measured and corrected with a single scan	•Additional hardware needed •Special grids for each scan geometry •Scatter reduction potential might be decreased by physical grid properties
Slit Scan	•Good scatter artifact reduction	•Long scan times for full 3D volumes might prohibit routine use, several scans must be done to achieve full volume coverage

To our belief the anti-scatter grid and the Monte Carlo-based method offer the best potential both in terms of scatter reduction and practical applicability. A combination of both methods might be the best choice.

Thank You!

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