Novel technologies for mitigation of cone-beam artifacts in C-arm CT imaging of the head

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Outline

- Motivation
- Background
- Rebinning process →

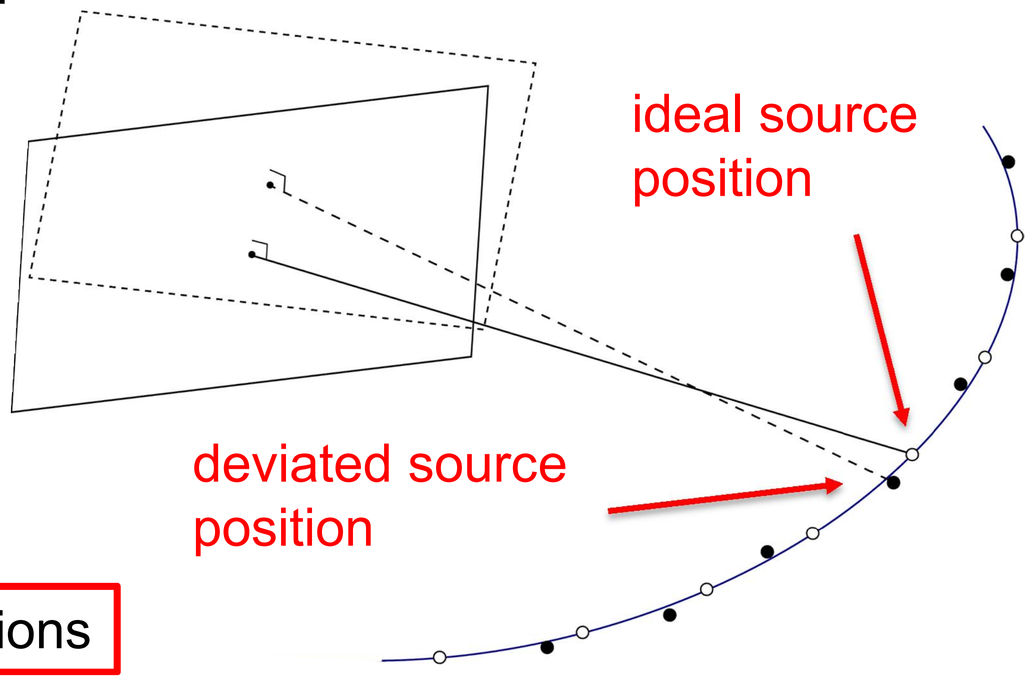
  to transform the real data into CB measurements in an ideal geometry
  - Trajectory registration
  - Data rebinning
- Evaluations
  - Computer-simulation
  - Real-data experiment (without and with gantry-tilt equivalent)
- Conclusion and discussion

Motivation

- C-arm CT is a valuable tool in interventional radiology, with new applications continually demanding for higher image quality.
- Incomplete data acquisitions by circular short-scan (SS) cause cone-beam (CB) artifacts, and improper data redundancy weights of SS-FDK exacerbate the artifacts.
- Can we improve image quality by algorithms with proper data redundancy weights, like the ACE method?
- Can we improve image quality by applying a tilt scanning geometry, to emulate the gantry-tilt geometry used in diagnostic CT?

Background

- Analytical reconstruction methods with proper data weighting (e.g. the ACE method) require ideal data acquisition geometries
- CB projections in C-arm CT present non-negligible geometrical deviations due to various mechanical forces.
- For many clinical C-arm systems, deviations are reproducible, and hence geometrically-accurate reconstruction can be achieved using off-line calibration.



Trajectory deviations

Rebinning process

Rebinning process

We propose a novel rebinning algorithm to transform real data into CB measurements in an ideal geometry, using interpolation.

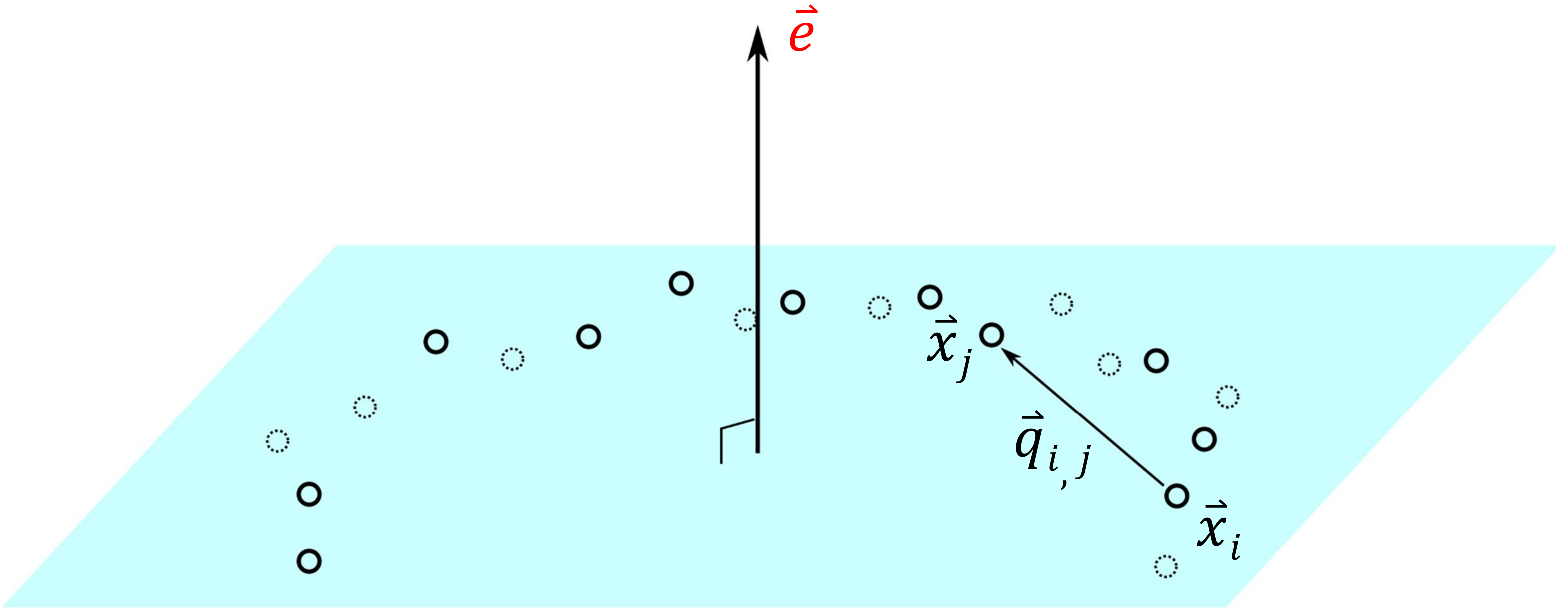
Find trajectory plane → Fit trajectory to a circular arc → Data rebinning

Rebinning process—trajectory registration

- Find the plane with normal vector $\vec{e}$ that best fits the trajectory:

$$\vec{e} = argmin\{\vec{e}\}\left\{\sum_{i,j}(\vec{q}_{i,j} \cdot \vec{e})^2 - \beta(\vec{e} \cdot \vec{e} - 1)\right\} \quad (i,j = 1,2,\ldots,N \quad i \neq j)$$

(β: Lagrange multiplier)



Rebinning process—trajectory registration

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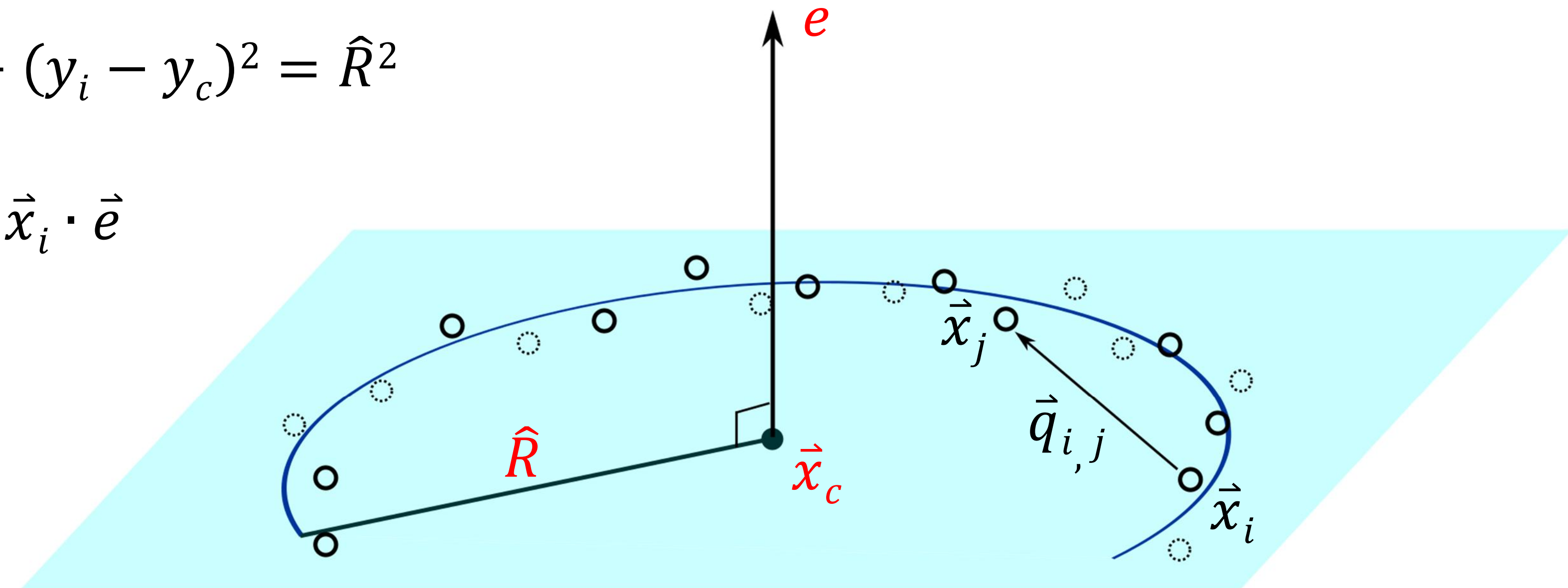
(β: Lagrange multiplier)

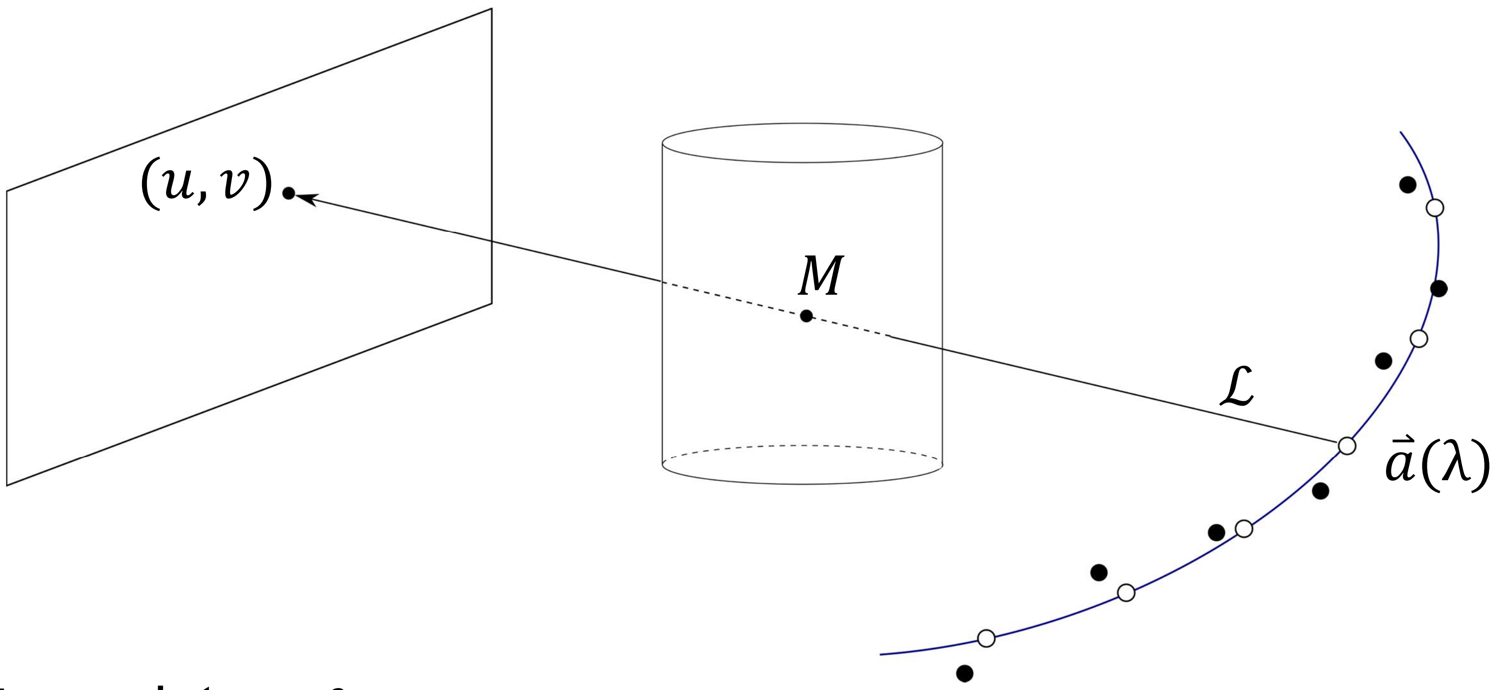
- Find the center $\vec{x}_c = (x_c, y_c, z_c)^{\mathsf{T}}$ and the radius $\hat{R}$ of the circular arc that best fits the source positions in the plane orthogonal to $\vec{e}$:

$$(x_i - x_c)^2 + (y_i - y_c)^2 = \hat{R}^2$$

$$z_c = \frac{1}{N}\sum_i \vec{x}_i \cdot \vec{e}$$

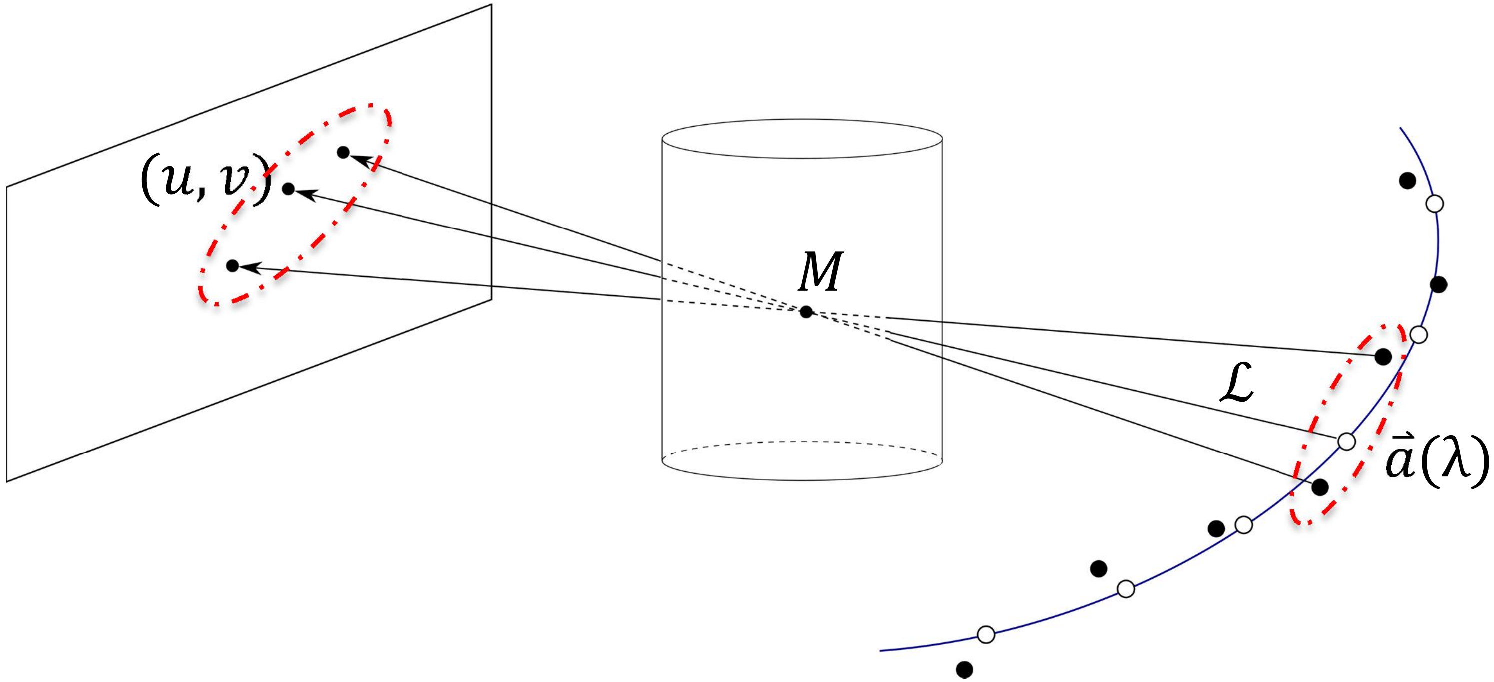


Rebinning process—data rebinning



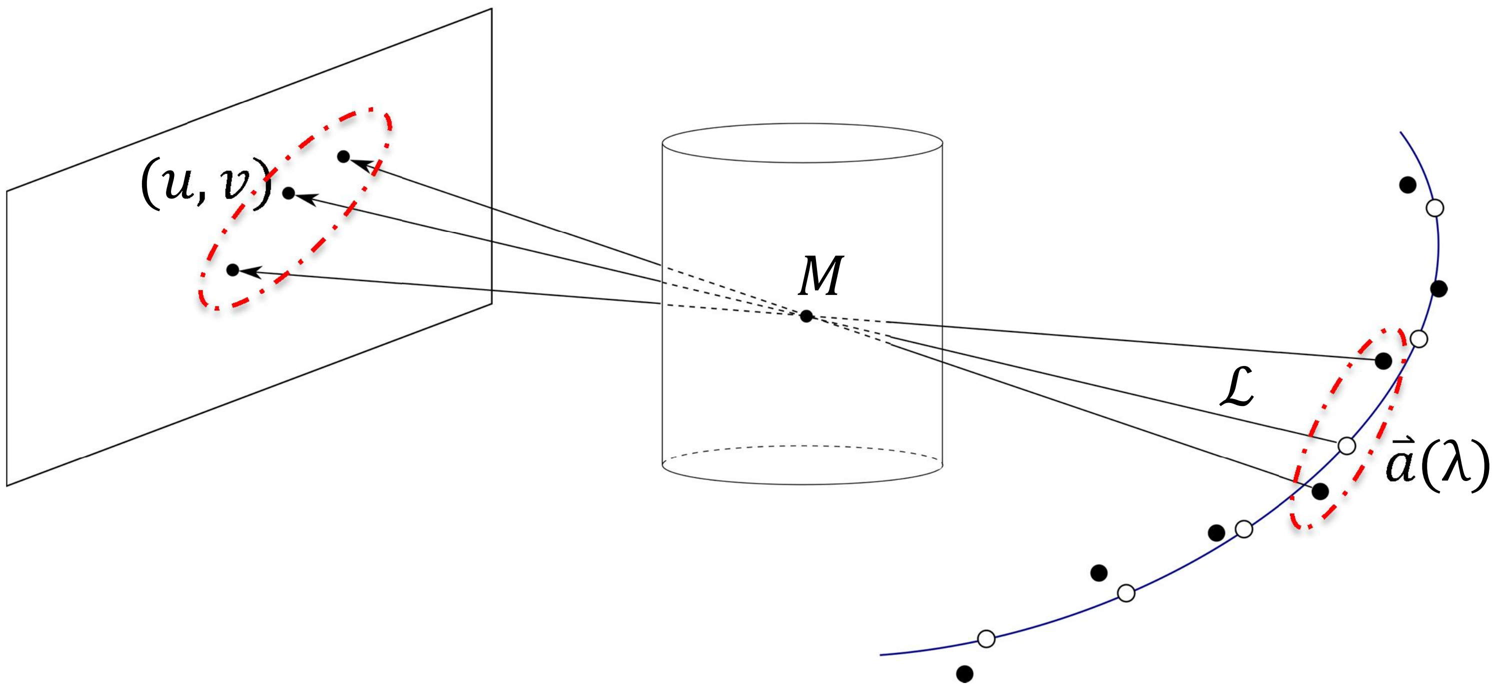
M: a point on $\mathcal{L}$;
chosen to be centered within the ROI

Rebinning process—data rebinning



M: a point on $\mathcal{L}$;
chosen to be centered within the ROI

Rebinning process—data rebinning



M: a point on $\mathcal{L}$;
chosen to be centered within the ROI

- Frequency-boosting filter ($sinc^2$ function) is applied to compensate resolution loss due to interpolation within the detector

Evaluations

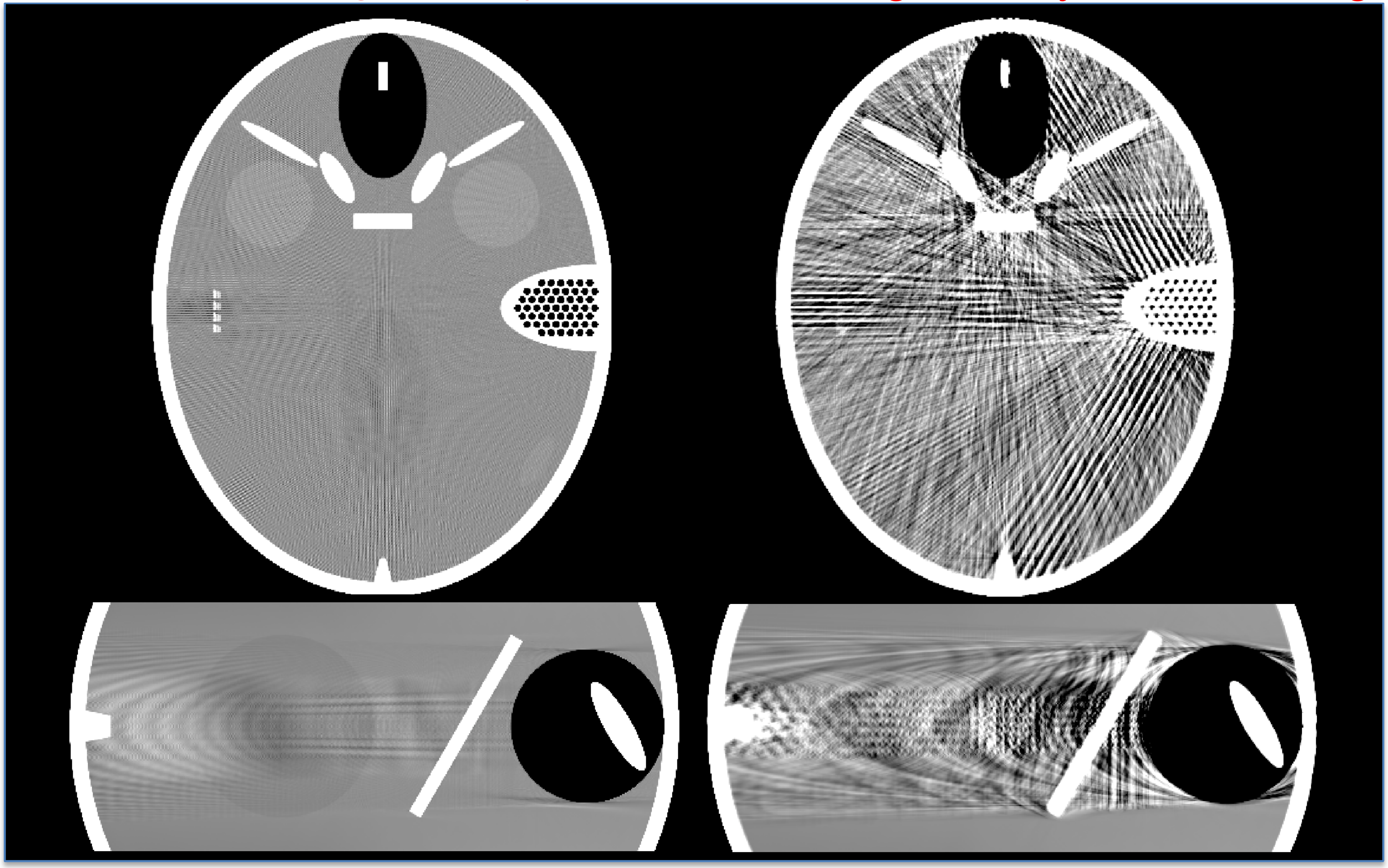
Evaluations

- Evaluations are performed by simulations on the FORBILD head phantom, as well as experiments on an anthropomorphic head phantom.
- Both the simulations and real-data experiments use the same trajectory parameters.
- For the computer simulation, we were using the ACE method for reconstruction; for the real data experiment, both SS-FDK and ACE were implemented.

Distance from source to isocenter (R)	786 mm
Distance from source to detector (D)	1198 mm
Radius of the FOV (r)	125 mm
Scanning range	198^{o}
Number of projections	496
Detector pixel size	0.308 mm
Detector size	1240×960

Evaluations—simulations

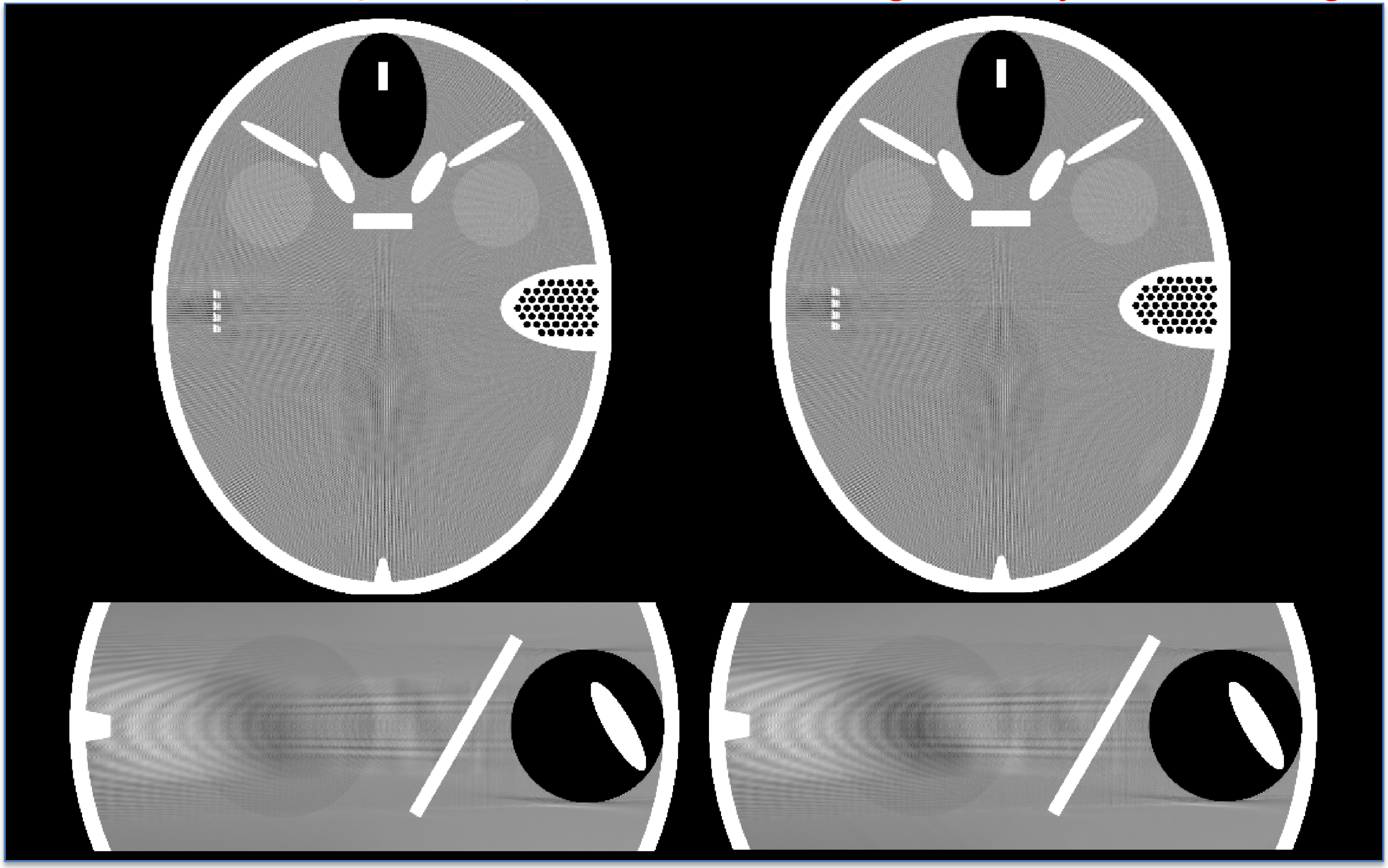
ideal geometry non-ideal geometry w/o rebinning



Results are from the ACE method. Scale window: [-50,150] HU

Evaluations—simulations

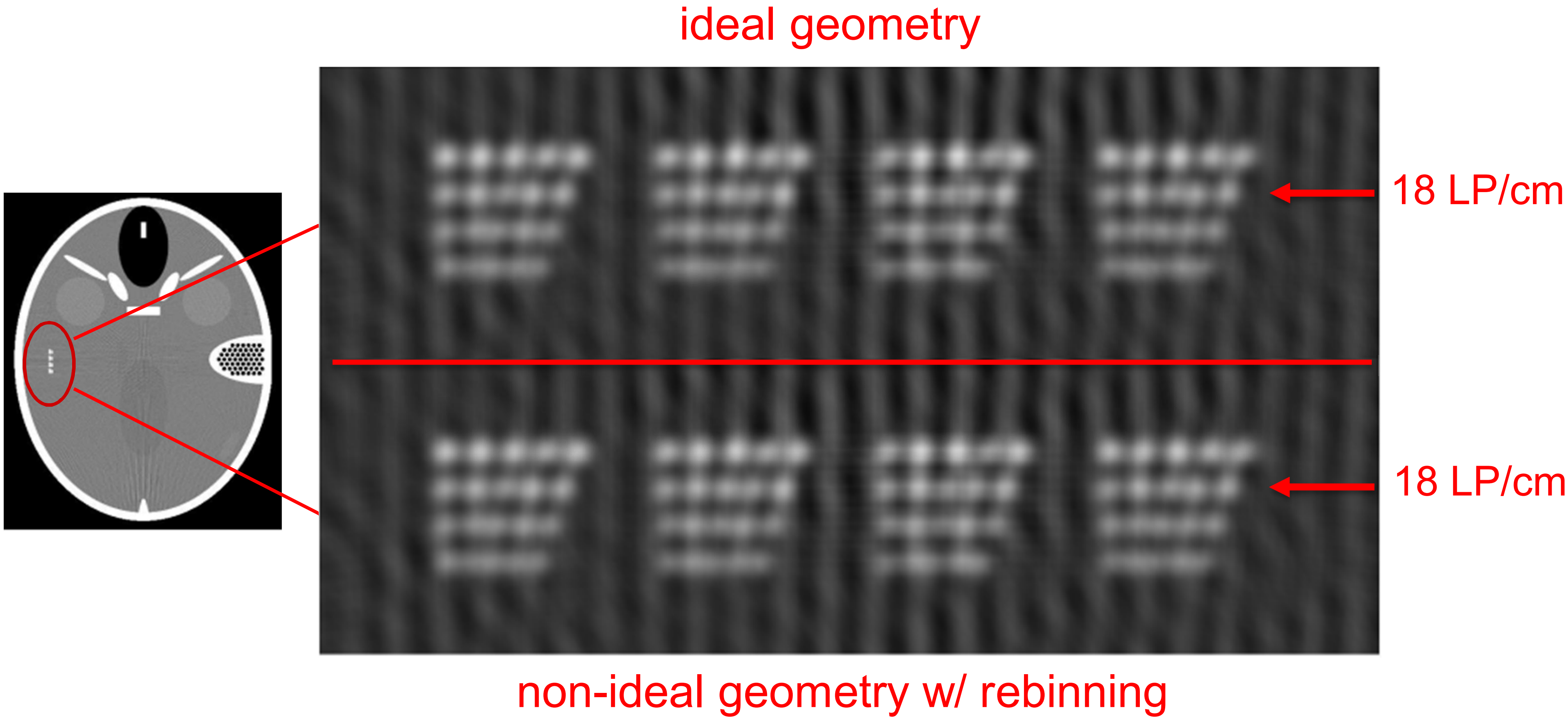
ideal geometry | non-ideal geometry w/ rebinning



Results are from the ACE method. Scale window: [-50,150] HU

Evaluations—simulations (cont.)

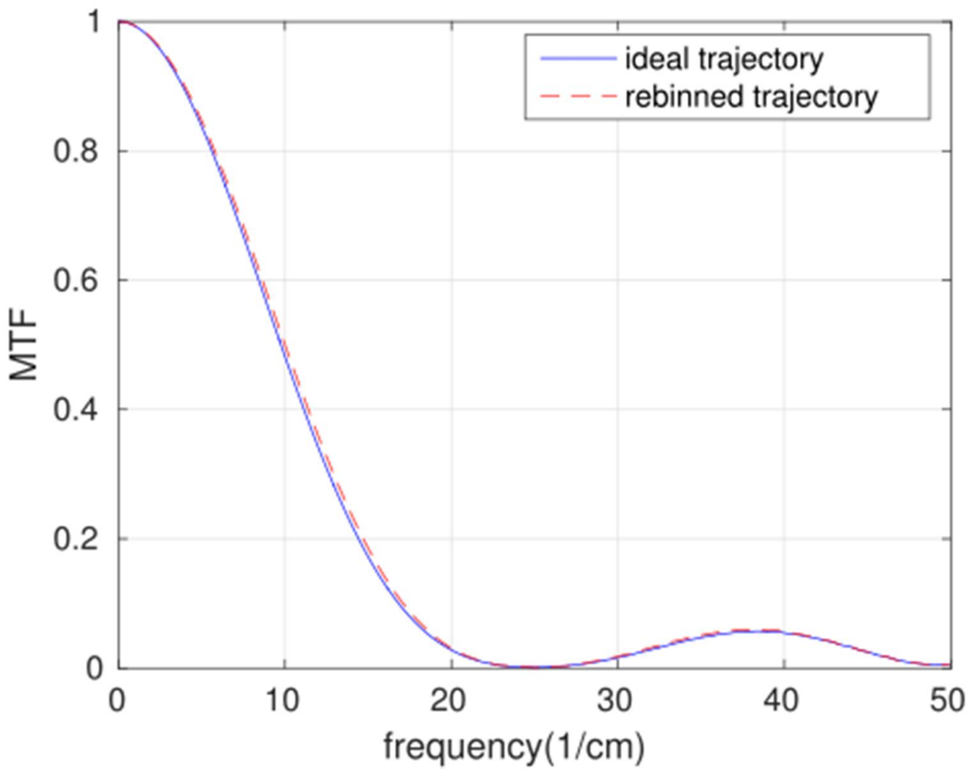
- Zoomed view on the resolution pattern



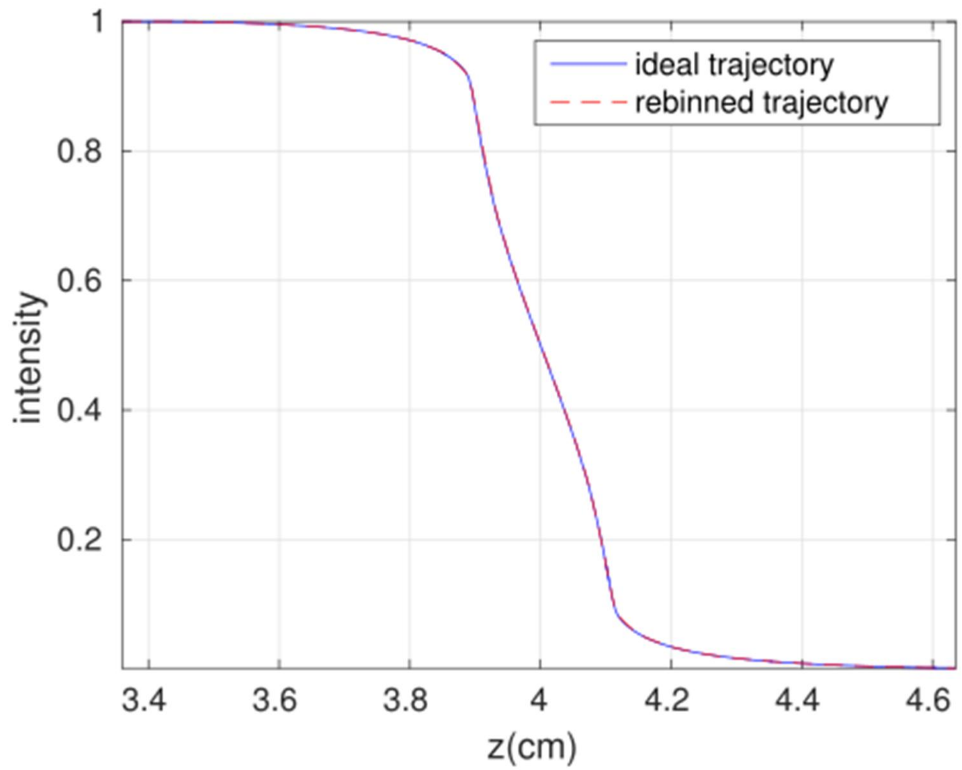
Scale window: [-50,450] HU

Evaluations—MTF and SSP

- MTF in the (x, y) plane and SSP along the z-axis were generated from reconstruction of a cylindrical object centered on the origin and parallel to the z-axis (diameter: $4\ cm$; height: $8\ cm$)



MTF in the (x, y) plane



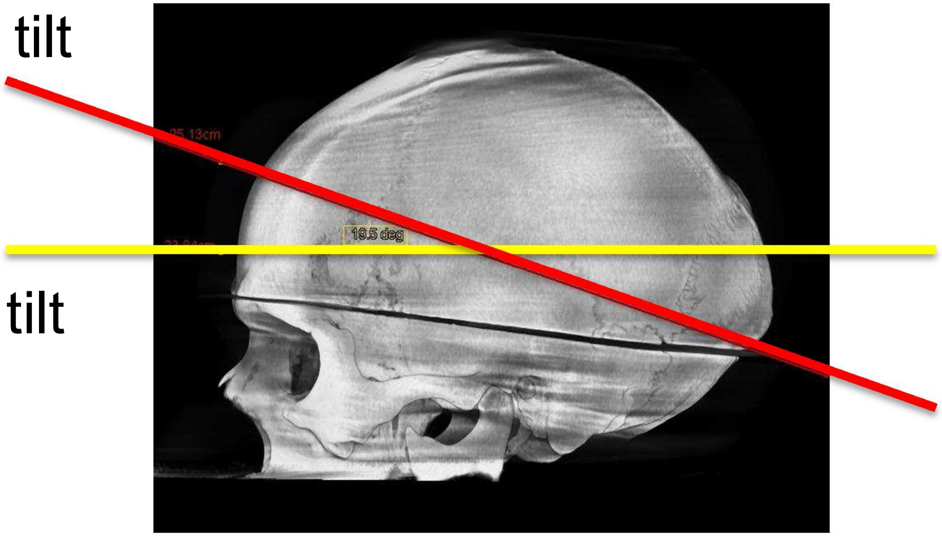
SSP along the z -axis

Evaluations–real data

- Experiments with an anthropomorphic head phantom
- No tilt and $20°$ tilt of the scanning plane are applied

20^o tilt

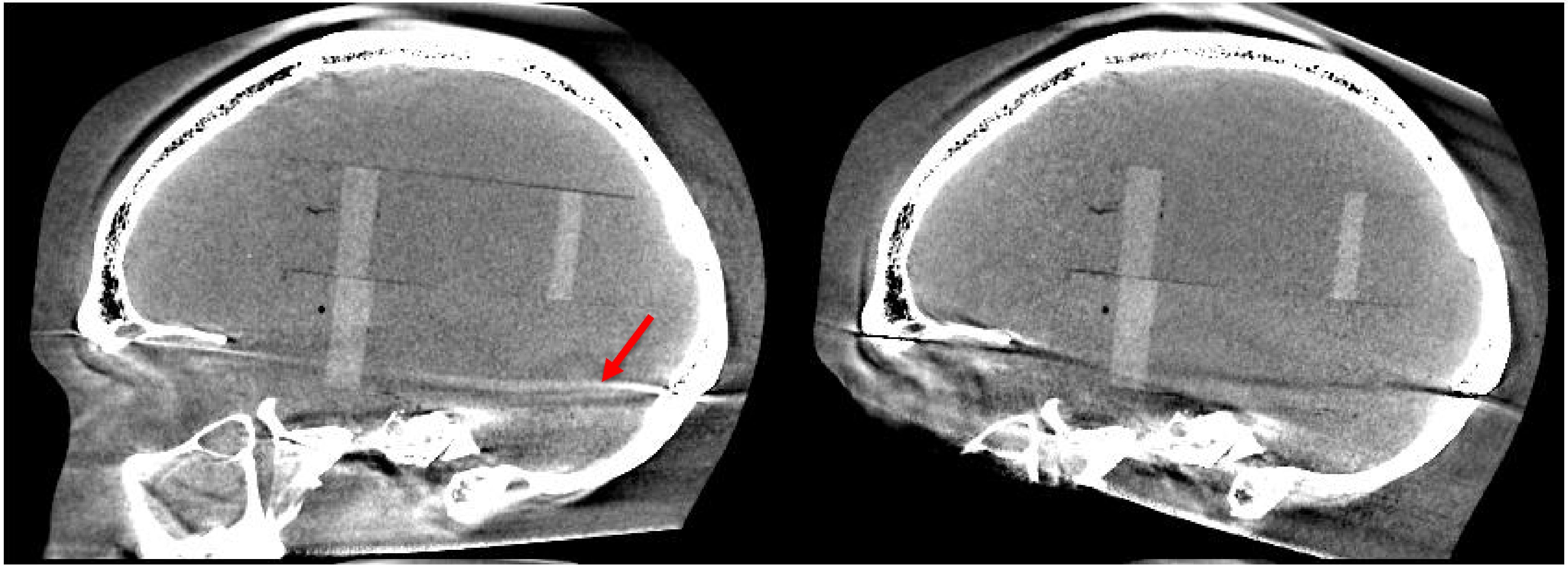
no tilt



Evaluations–real data (cont.)

- SS-FDK

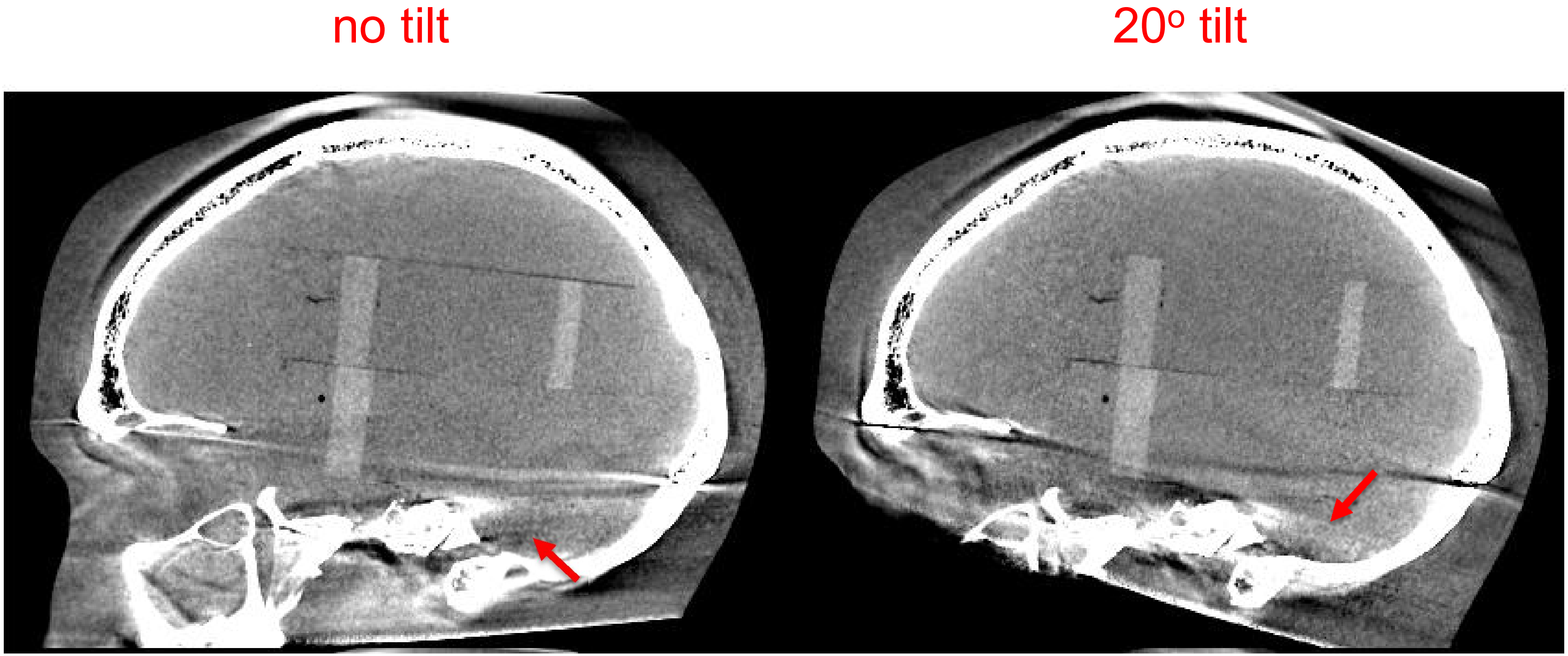
no tilt 20^o tilt



Scale window: [-200,200] HU

Evaluations–real data (cont.)

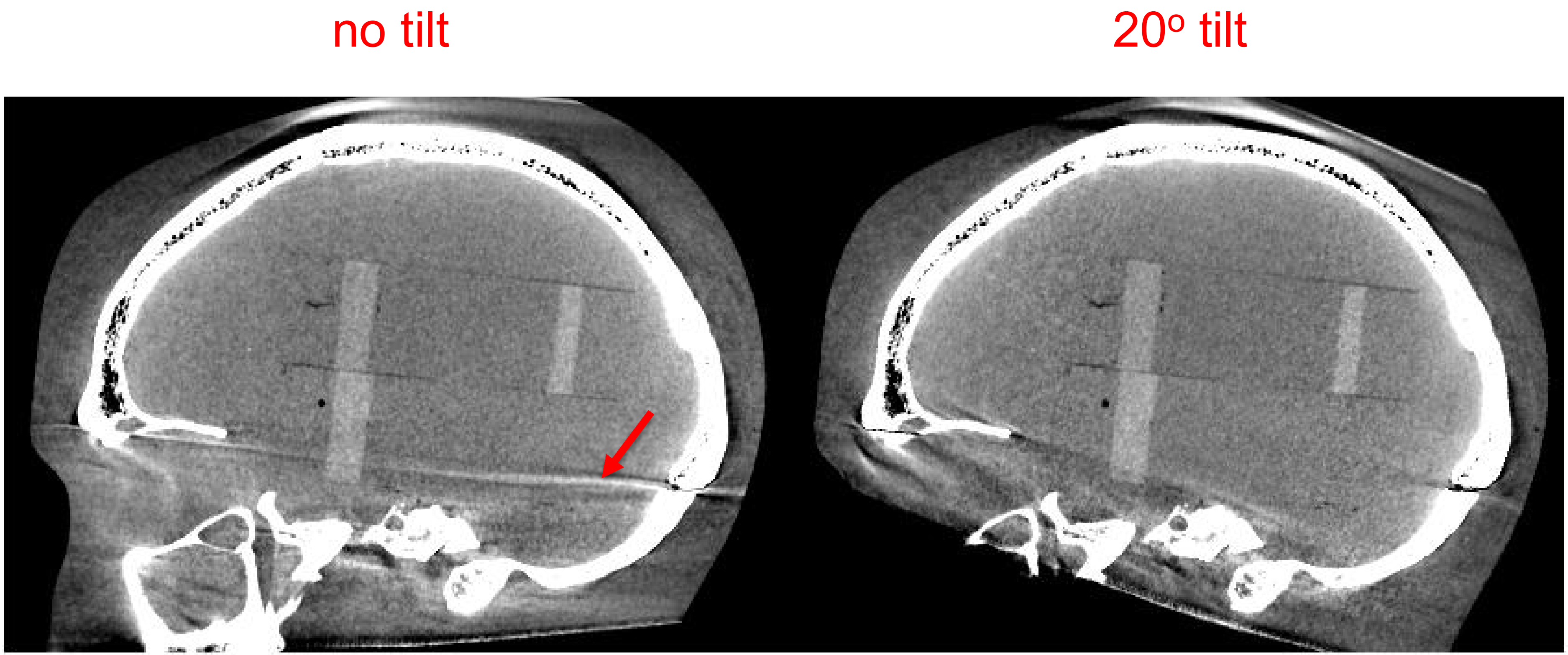
- SS-FDK



Scale window: [-200,200] HU

Evaluations–real data (cont.)

- ACE

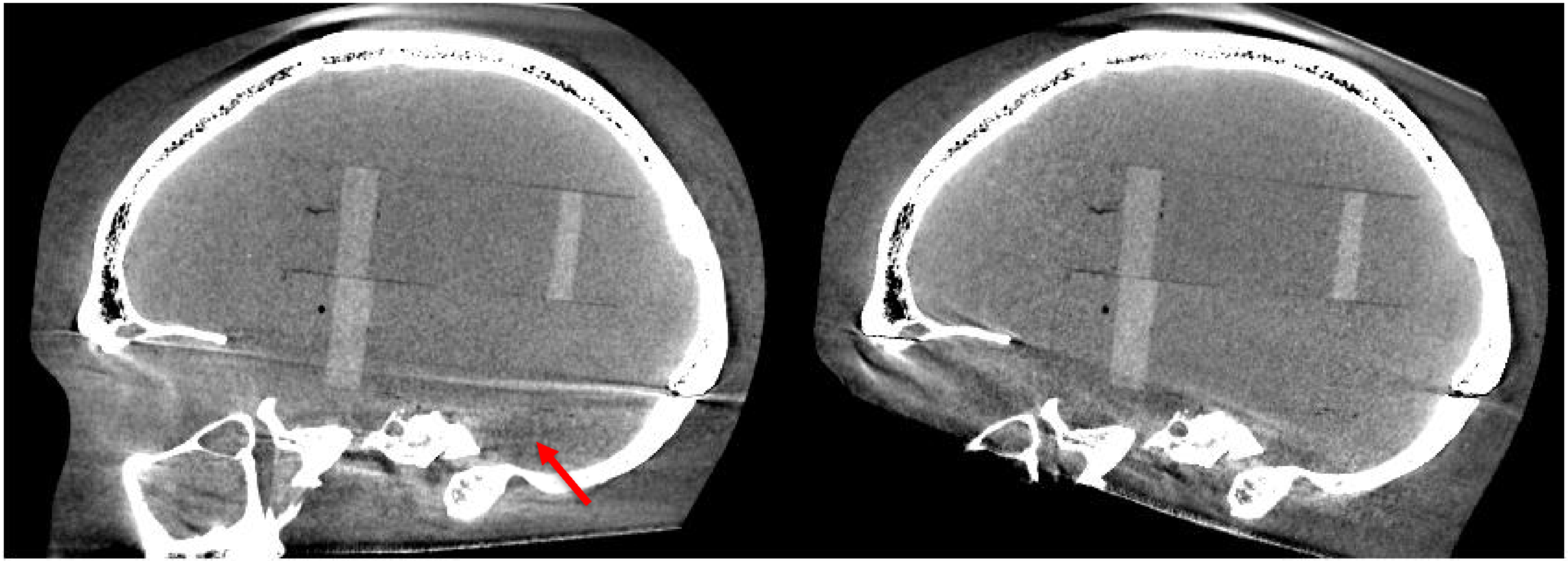


Scale window: [-200,200] HU

Evaluations–real data (cont.)

- ACE

no tilt 20^o tilt



Scale window: [-200,200] HU

Conclusion and discussion

- The proposed rebinning scheme can correct errors caused by trajectory deviations.
- The rebinning scheme enables the utilization of advanced reconstruction methods to mitigate CB artifact.
- The rebinning scheme shows good performance both from computer-simulated and real data. There is a strong hope that the observed improvements can be beneficial in clinical practice.
- Application of a tilt scanning plane may provide additional improvement of image quality in terms of artifacts.
- Future work will vary the amount of geometrical deviations probing the limits of the rebinning process.
- Further test on tilted scanning planes are also needed.

Thank you!

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