Shifted Detector Short Scan Reconstruction for the Rotate-Plus-Shift Trajectories

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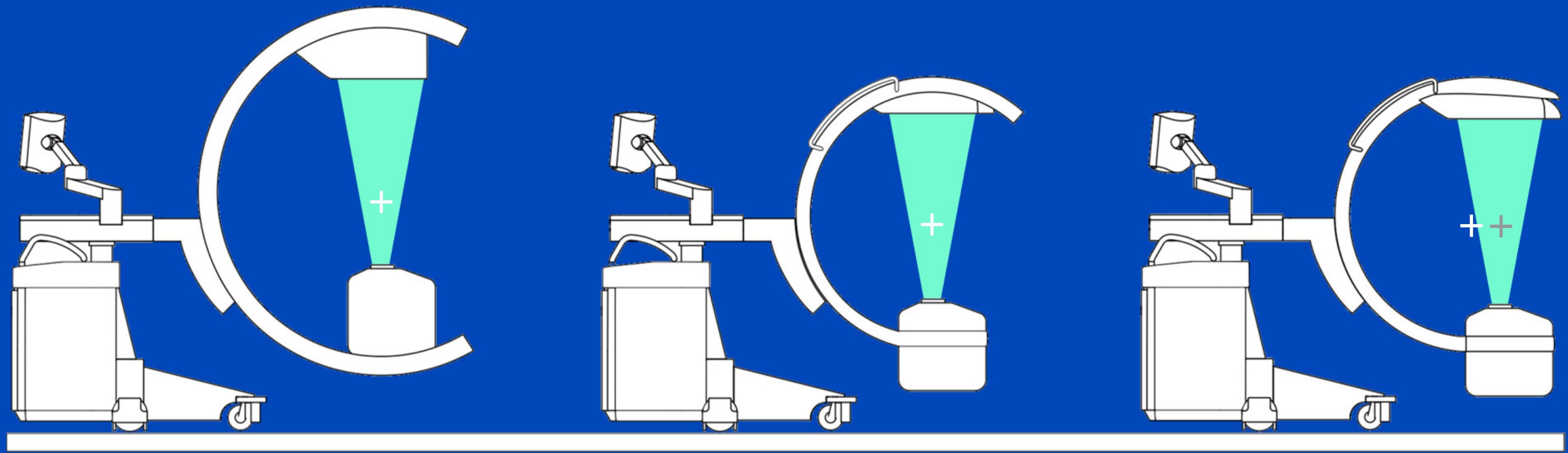
Typical OR Situation

The compactness of C-arm systems is of particular importance when complex interventions are carried out and many other medical devices are in the OR.

C-Arm Designs



Vendor A … Vendor Z

Mobile C-arm systems should be small and compact to ensure flexible use in the operation room. From this point-of-view a non-isocentric design with rotation range of less than 180° is optimal.

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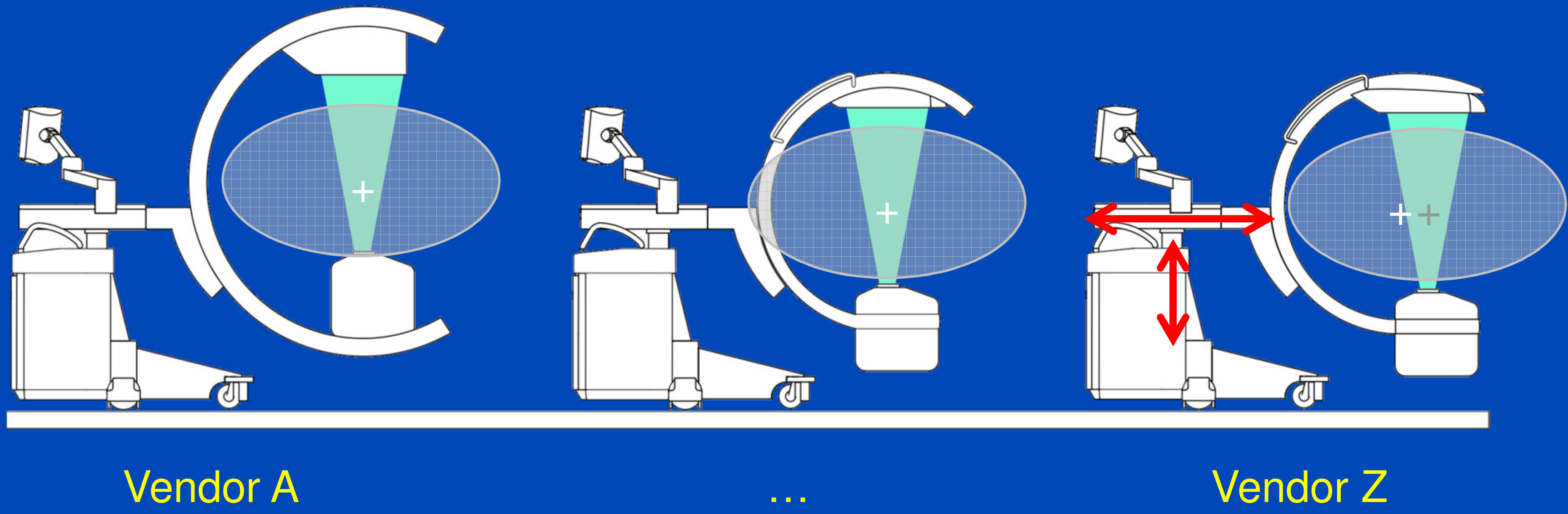

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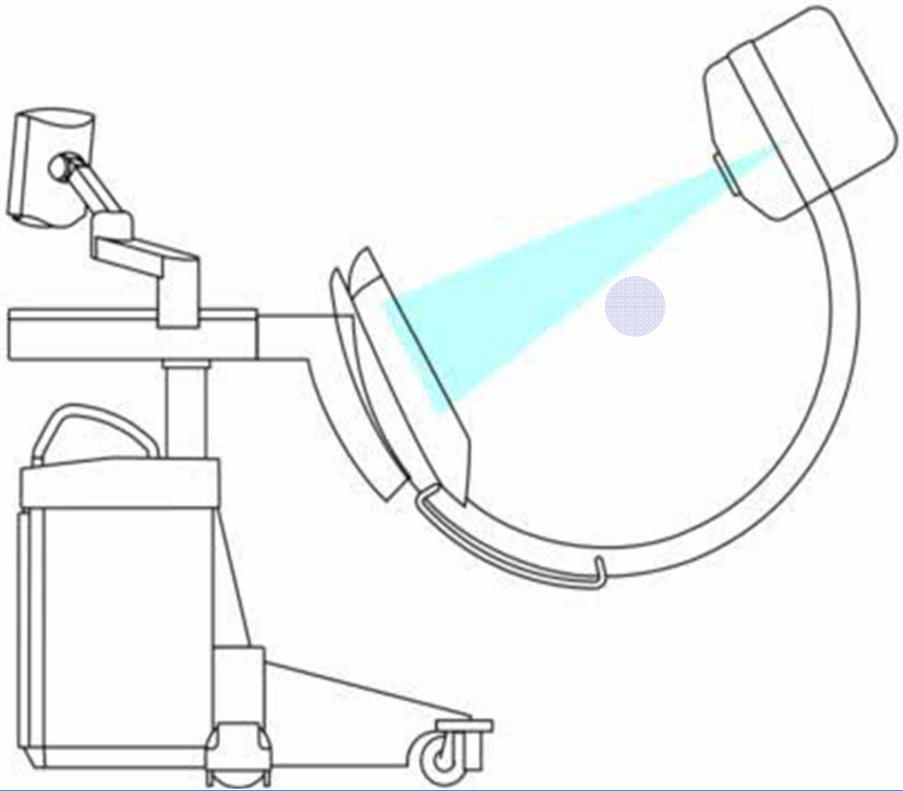
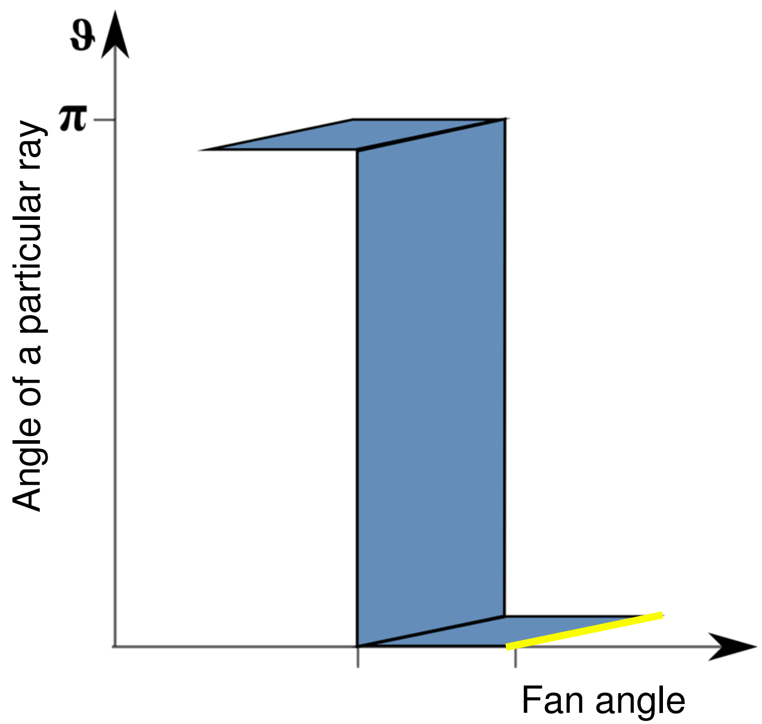
Rotate-Plus-Shift (RPS) Trajectory



180° data completeness in parallel sinogram

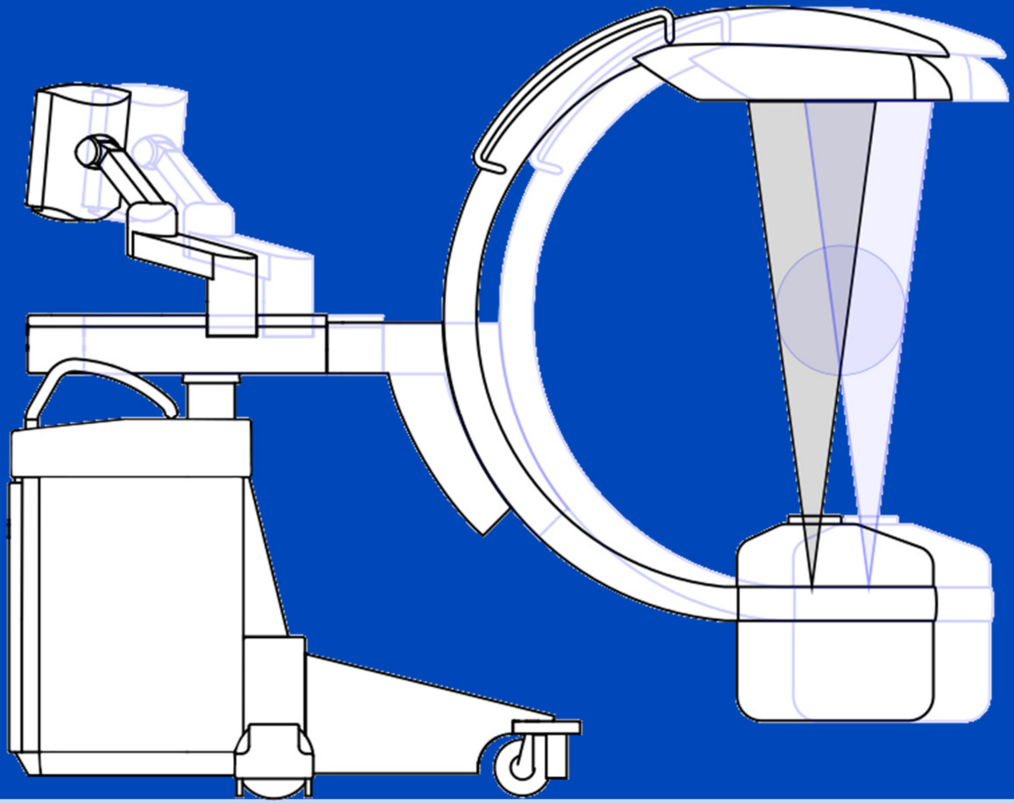


Rotate-Plus-Shift[1] (RPS) Trajectory

[1]J. Kuntz, L. Ritschl, C. Fleischmann, M. Knaup, and M. Kachelrieß. The Rotate-Plus-Shift C-Arm Trajectory (Parts I and II). MedPhys 2016 in press.

Purpose

- To increase the FOM acquired with mobile C-arm CT systems using a shifted detector option.



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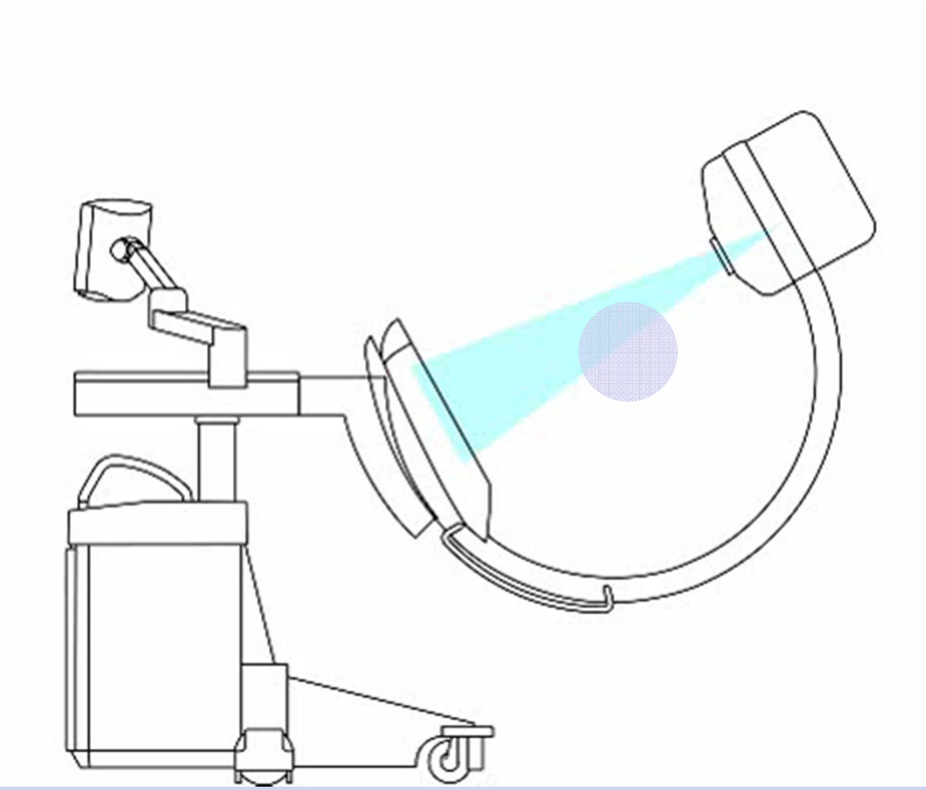
SDRPS Trajectory

Combining the shifted detector (SD) technology with the RPS trajectory yields the new shifted detector rotate-plus-shift (SDRPS) trajectory.



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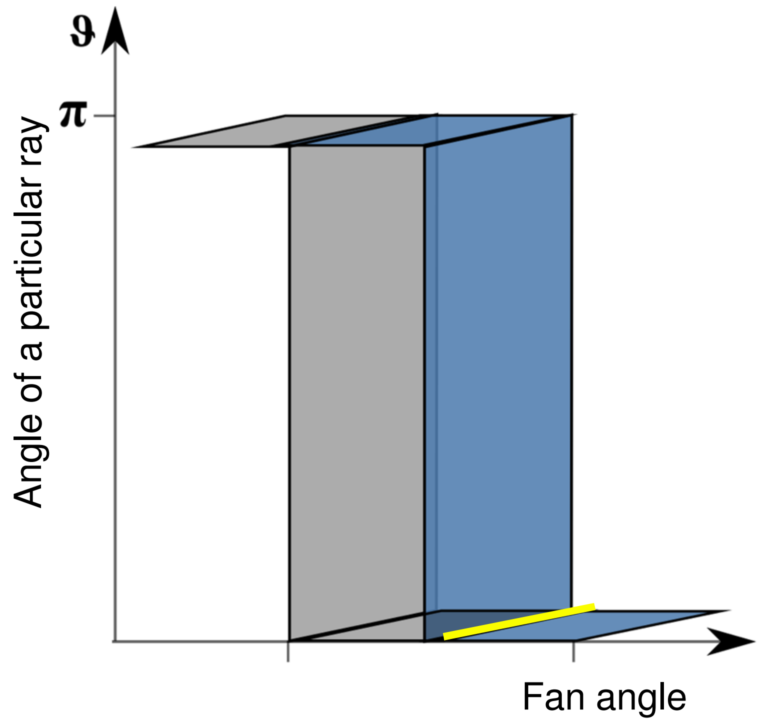
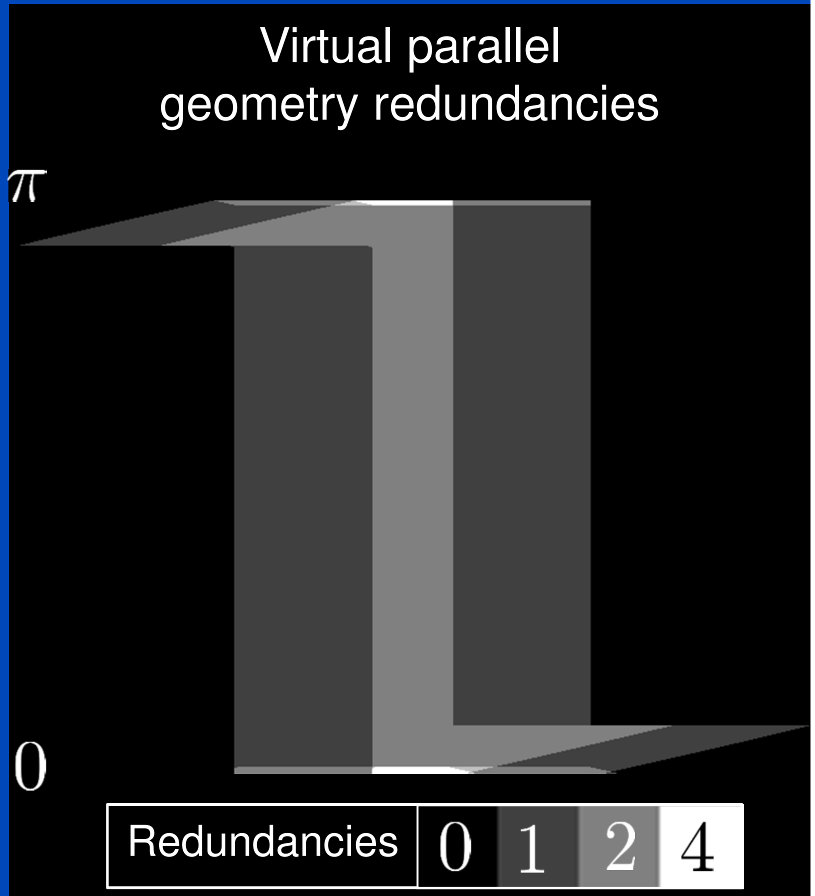


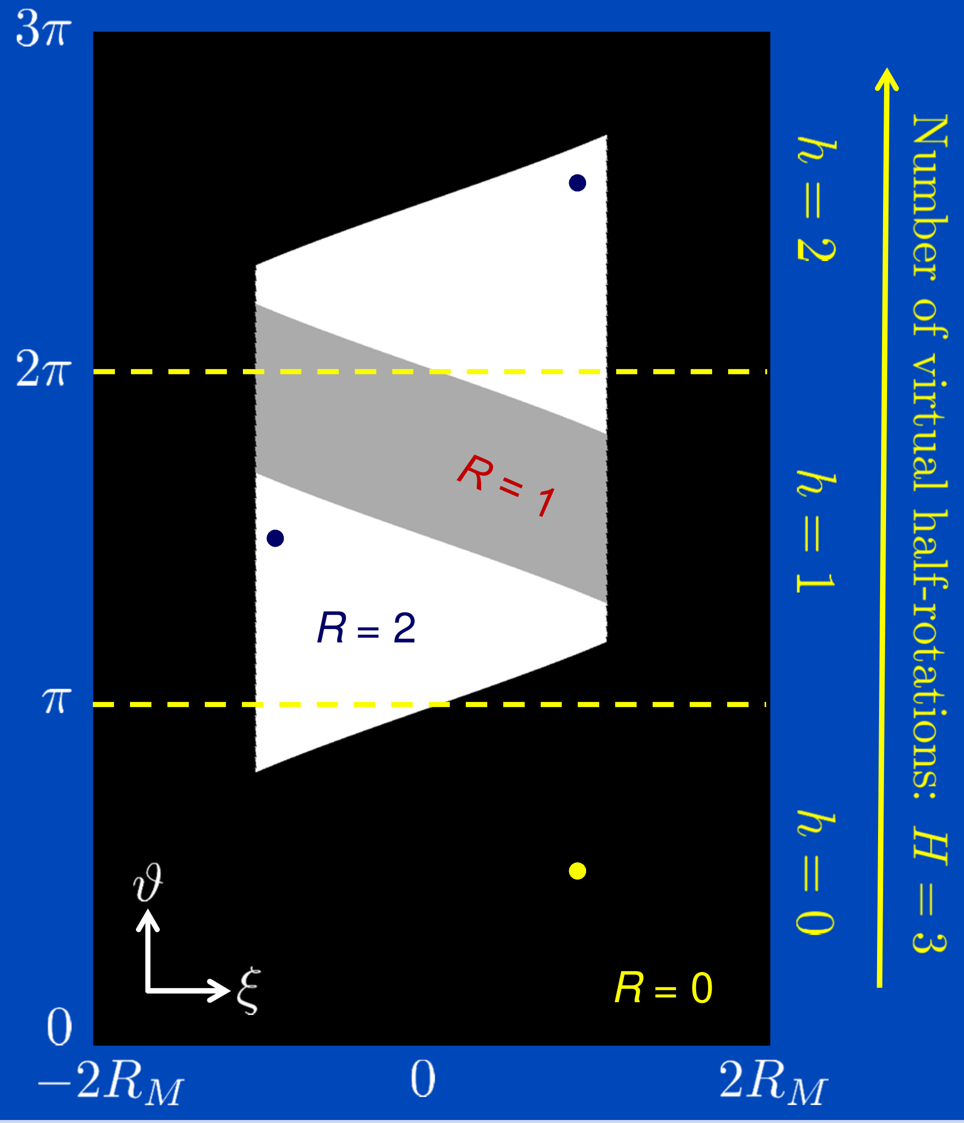
Redundancies in SDRPS Scans

- The practical implementation of the SDRPS scan leads to up to fourfold redundancies in small part of the sinogram
- Conventional redundancy weights like the Parker weight or the overscan weight are not applicable to these rawdata
- Therefore a generalized approach was developed[1]



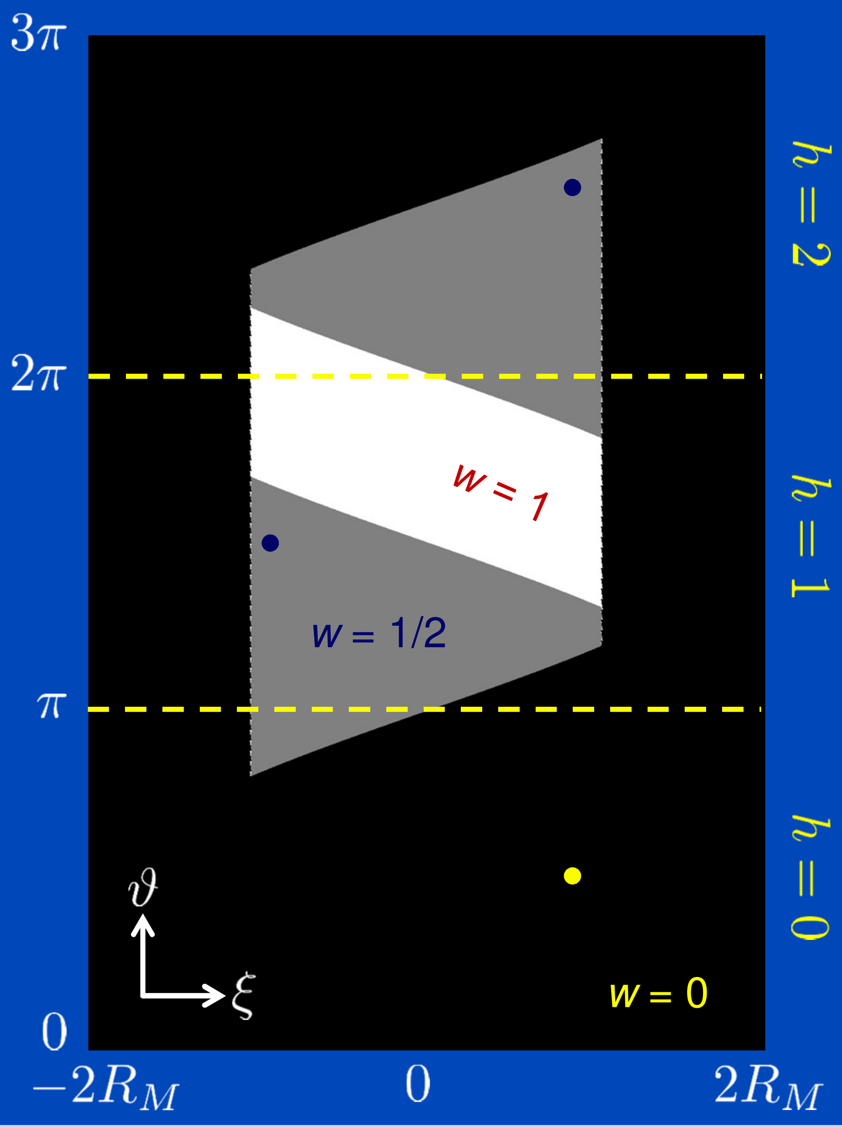
[1]M. Knaup, J. Kuntz, S. Sawall, and M. Kachelrieß. A General Projection Weight for Feldkamp-Type Cone-Beam Image Reconstruction from Arbitrary CT Scan Trajectories. Proceedings of the Fully 3D 2015

Step 1: Counting Redundancies



- For each ray (ϑ, ξ) we count the number of fan projections covering this ray.
- This number of fan projections is called the redundancy $R(\vartheta, \xi)$ of this ray.
- The list of fan projections is mapped to a list of virtual half rotations *h* such that adjacent rays in the extended parallel sinogram are covered by adjacent fan projections.

Step 2: Calculating the Weights



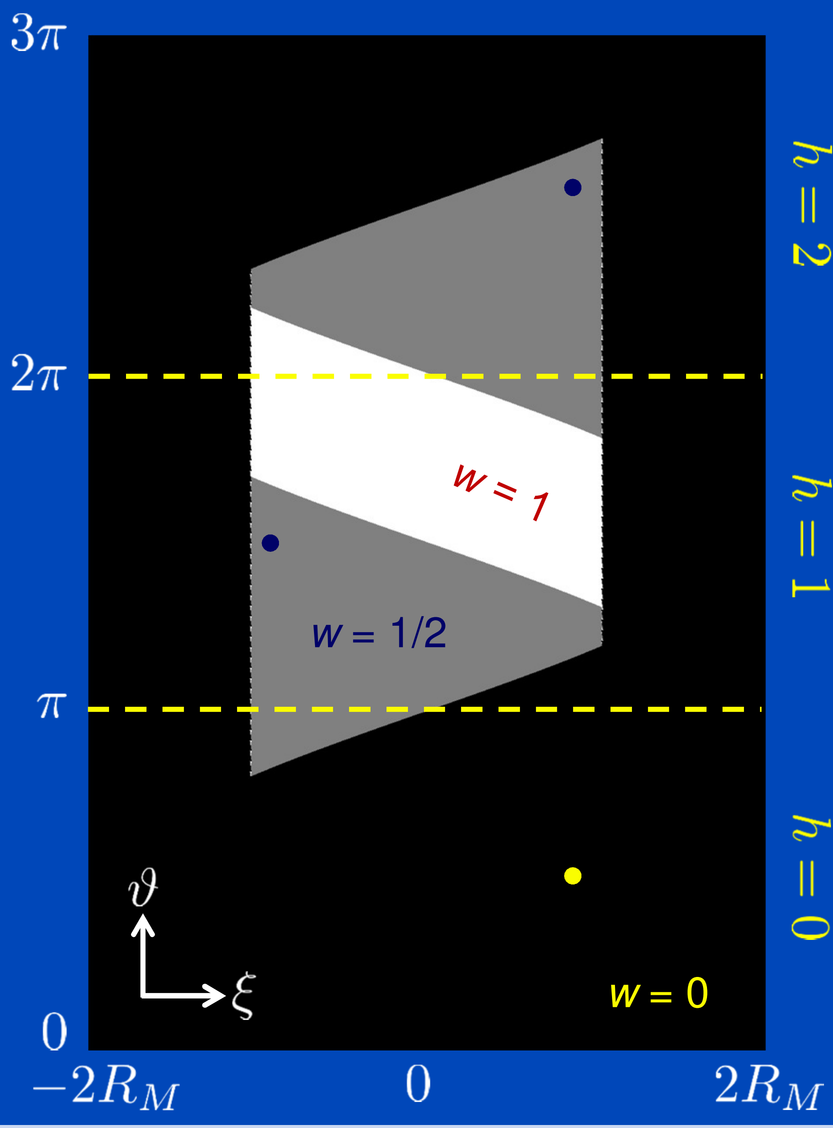
- To account correctly for the redundancies, the weights must fulfill the constraint

$$\sum_{h=0}^{H-1} w\left(\vartheta + h\pi, (-1)^h \xi\right) = 1 \quad \forall \vartheta, \xi$$

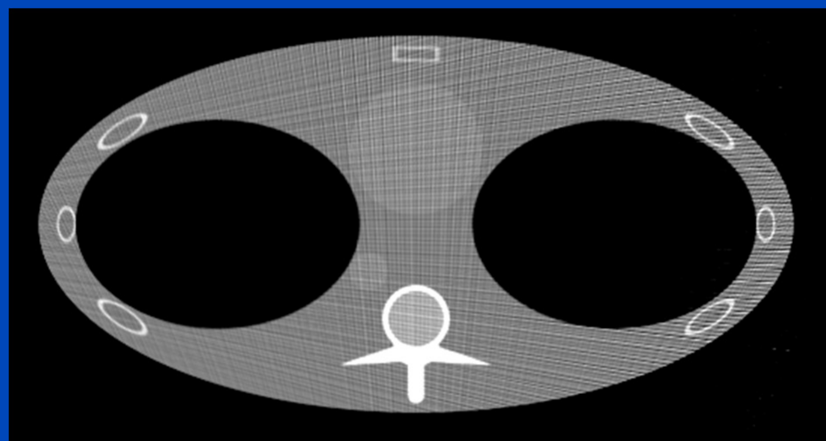
- An obvious choice would be

$$w\left(\vartheta + h\pi, (-1)^h \xi\right) = \\ = \begin{cases} R(\vartheta,\xi)^{-1} & \text{if ray is measured.} \\ 0 & \text{if ray is not measured.} \end{cases}$$

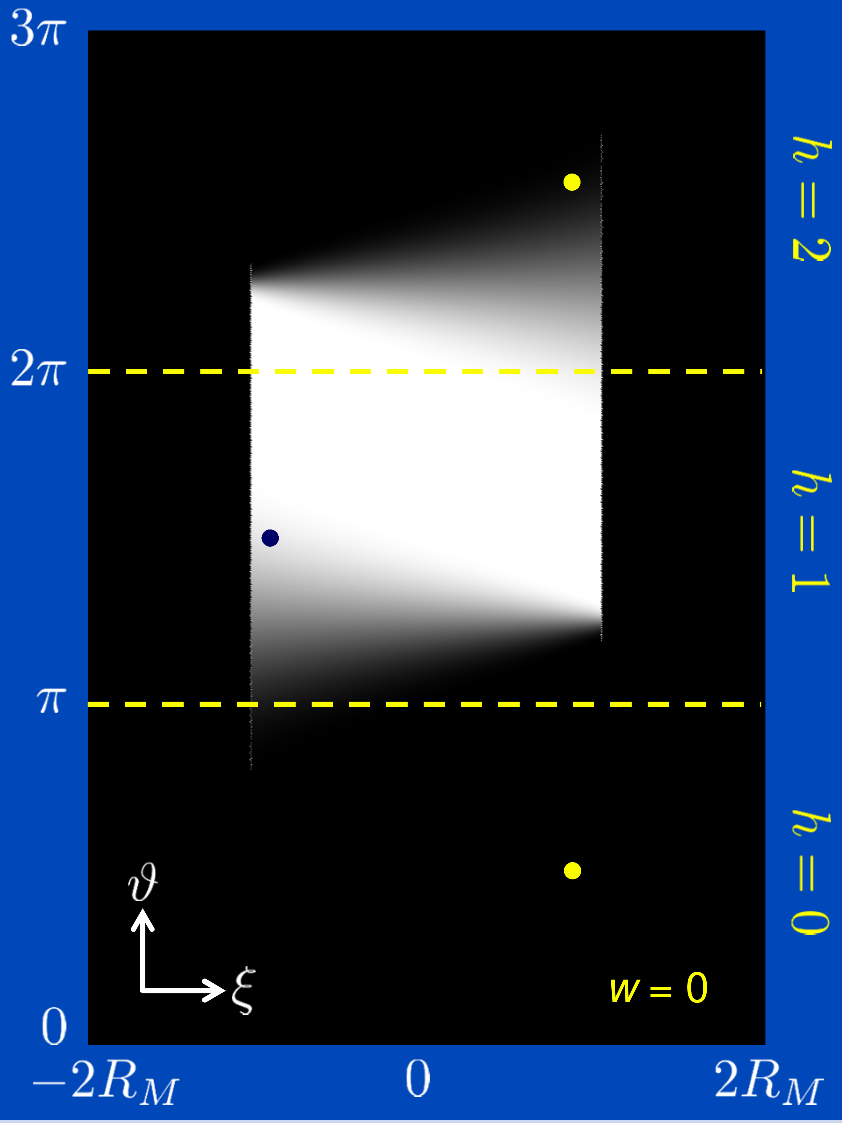
Step 2: Calculating the Weights



- However, this would result in non-continuous weights which produce unwanted streak artifacts in the final image due to the discreteness of the sampling.

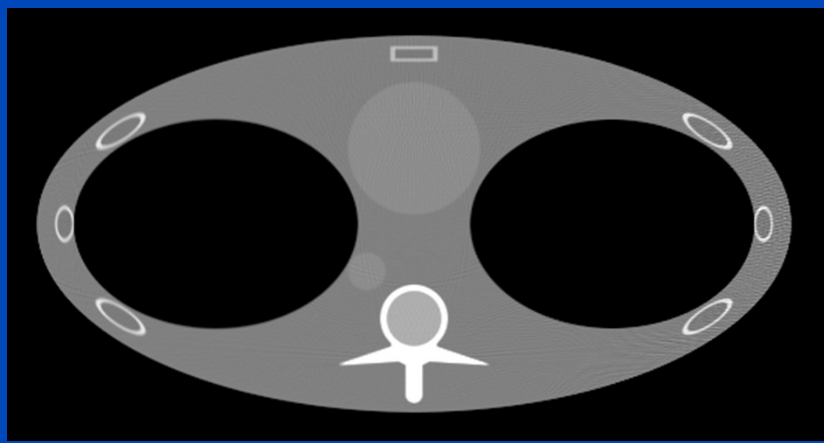


Step 2: Smoothing the Weights



- Therefore, we must smooth the weights under the constraint

$$\sum_{h=0}^{H-1} w\left(\vartheta + h\pi, (-1)^h \xi\right) = 1 \quad \forall \vartheta, \xi$$



Step 3: Smoothing the Weights

We smooth the weights by minimizing the following cost function:

$$C = \sum_{\vartheta,\xi} \left[A_{\vartheta,\xi} + \beta B_{\vartheta,\xi} + \lambda_{\vartheta,\xi} \left(1 - \sum_{h=0}^{H-1} w\big(\vartheta + h\pi, (-1)^h \xi\big) \right) \right]$$

with

$$A_{\vartheta,\xi} = \sum_{h=0}^{H-1} \left[\left(\frac{\partial}{\partial\vartheta} w\big(\vartheta + h\pi, (-1)^h \xi\big) \right)^2 + \left(\frac{\partial}{\partial\xi} w\big(\vartheta + h\pi, (-1)^h \xi\big) \right)^2 \right]$$

(minimizes 1st derivatives)

$$B_{\vartheta,\xi} = \sum_{h=0}^{H-1} \left[\left(\frac{\partial^2}{\partial\vartheta^2} w\big(\vartheta + h\pi, (-1)^h \xi\big) \right)^2 + \left(\frac{\partial^2}{\partial\xi^2} w\big(\vartheta + h\pi, (-1)^h \xi\big) \right)^2 \right]$$

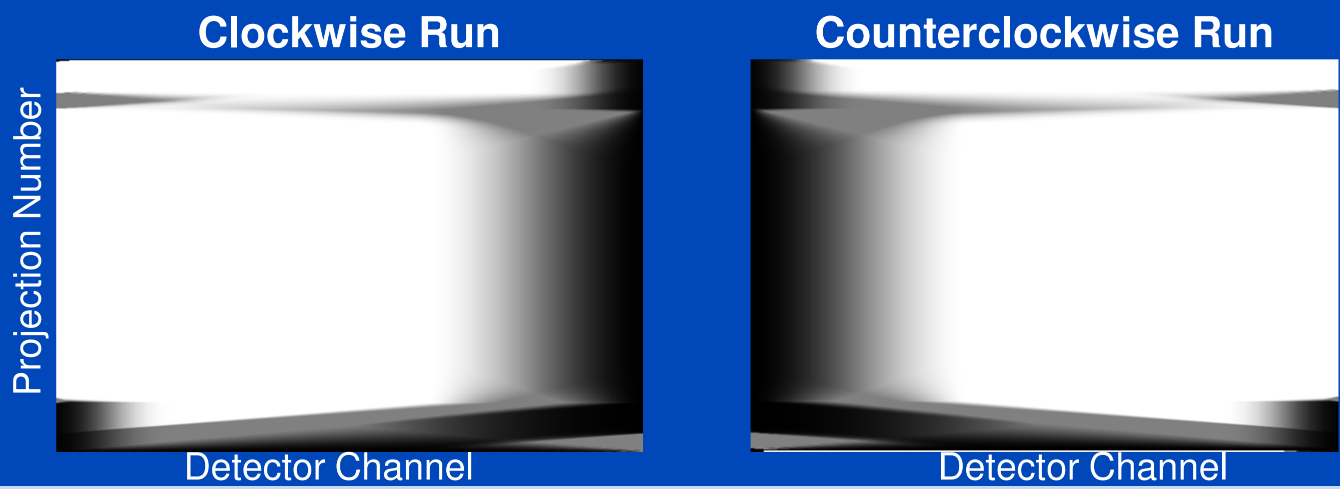
(minimizes 2nd derivatives)

The cost function will be minimized by a gradient descent approach with respect to the following variables:

- All weights $w(\vartheta, \xi)$ with redundancy $R(\vartheta, \xi) > 1$.
- The Lagrange multipliers $\lambda_{\vartheta,\xi}$ which enforce the constraint.

Rawdata Weighting for the SDRPS Trajectory

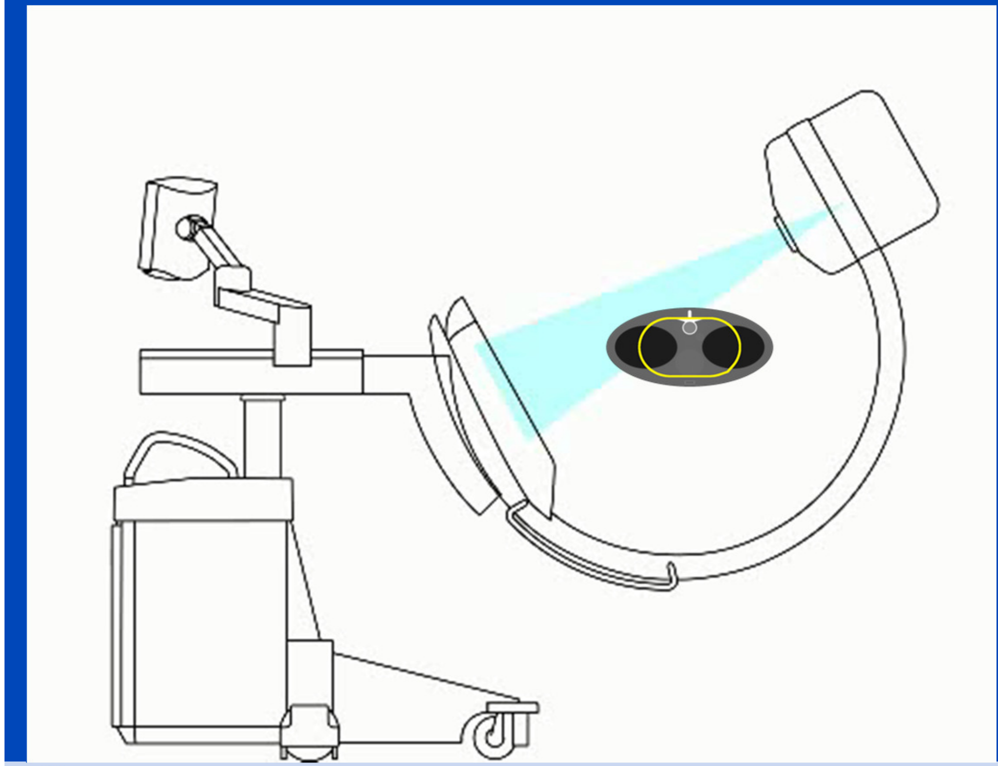
1. **Calculation of coverage in virtual parallel geometry**
2. **Calculation of redundancies in virtual parallel geometry**
3. **Calculation of redundancy weight that ensures that**
   - **the all redundant rays sum up to 1**
   - **all transitions zones in the weight sinogram are smooth**

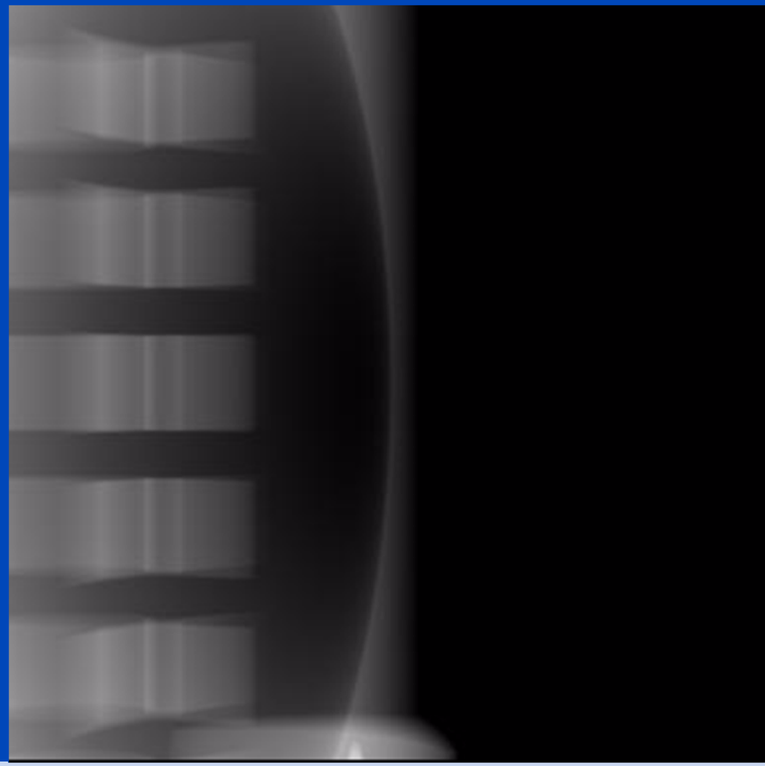


SDRPS Trajectories for Mobile C-Arm CT systems

- In intraoperative C-arm CT the regions of interest are often oval or elliptical
- Prevention of collisions with patient bed or OR equipment
- Trajectory has to be within the technical limitations of the C-arm system

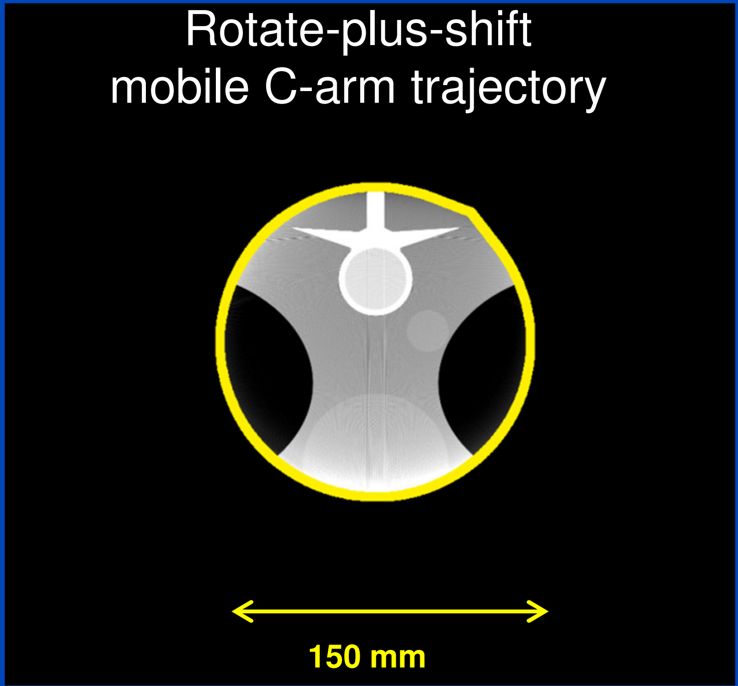
SDRPS Trajectories for Mobile C-Arm CT systems



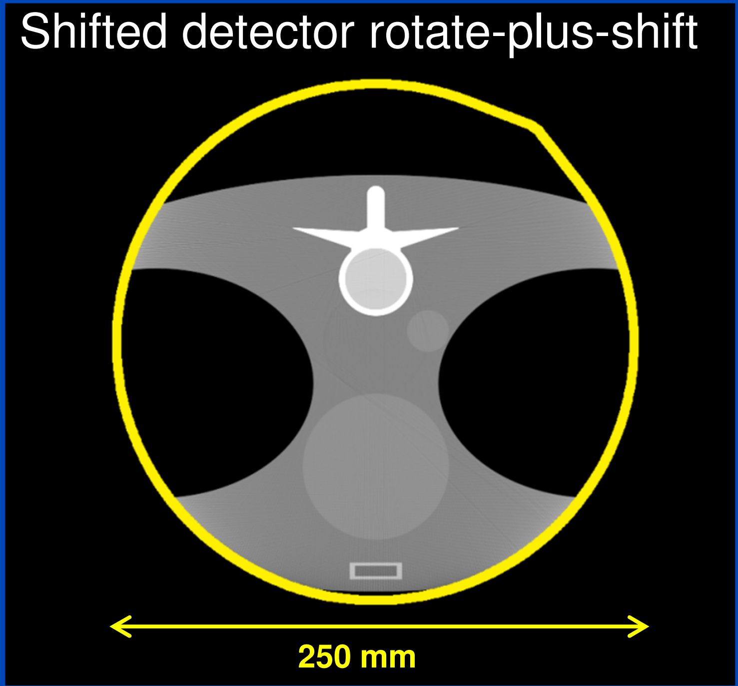


Reconstructions of RPS and SDRPS Simulations

- **The proposed SDRPS trajectory increases the FOM significantly, which is advantageous for spinal and thoracic surgery and many other applications.**



RPS



SDRPS

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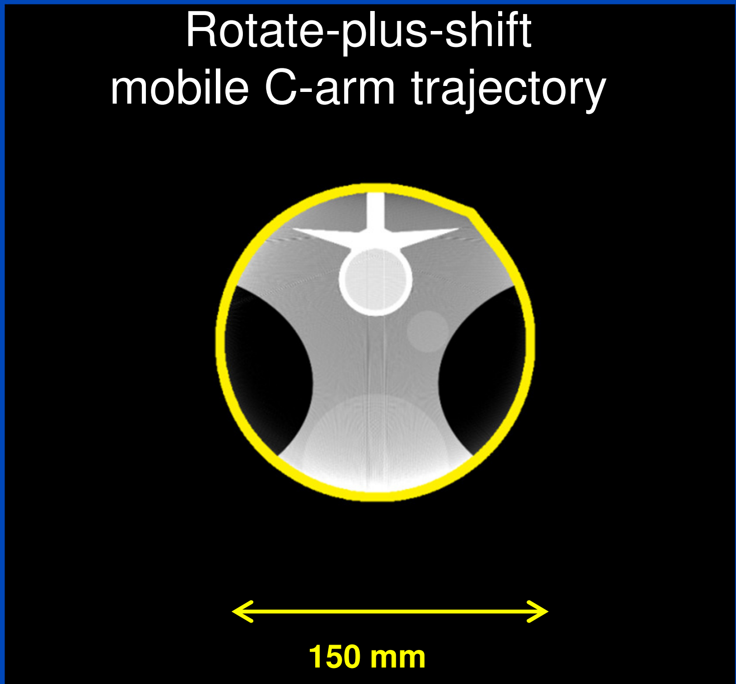
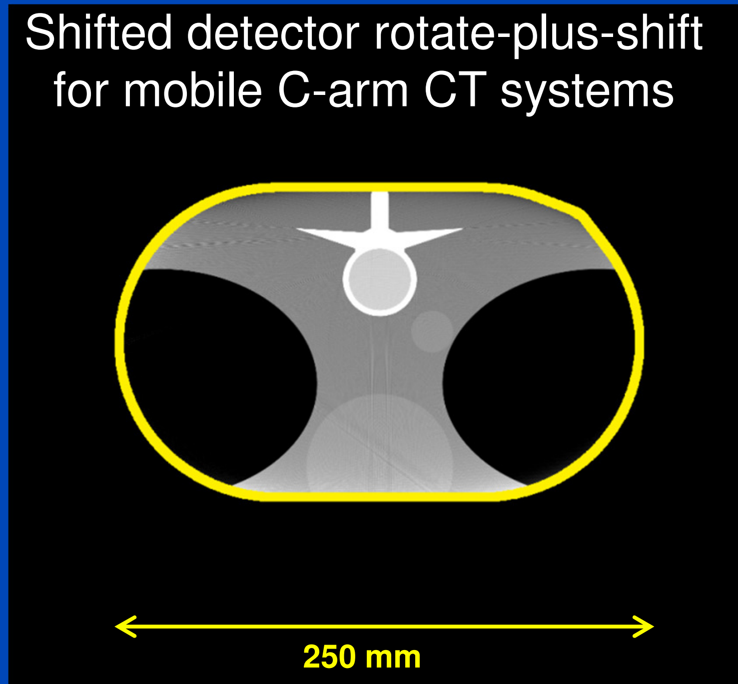


RPS

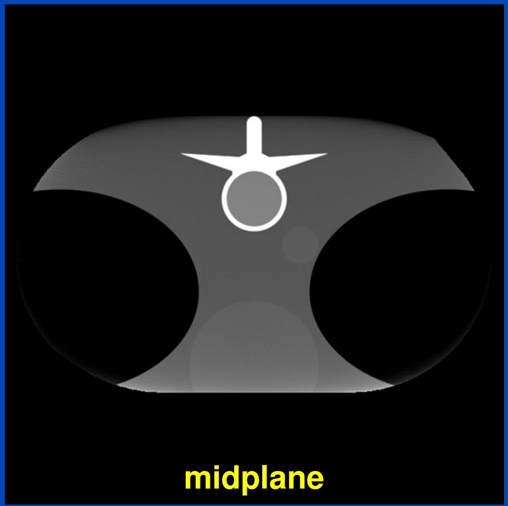


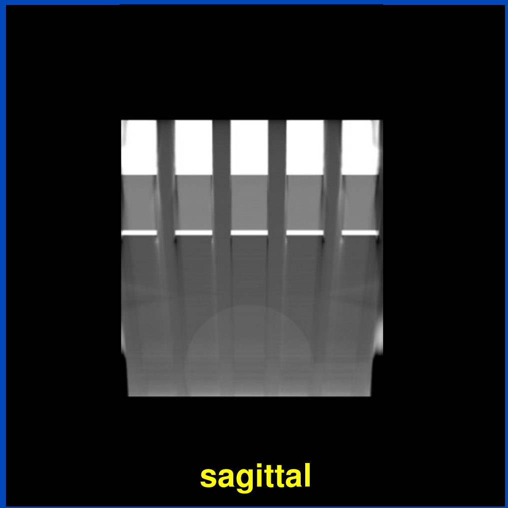
SDRPS

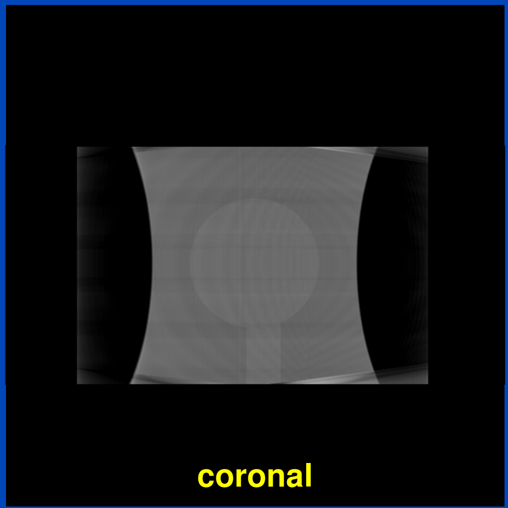
C = 500 HU, *W* = 2000 HU

Reconstructions of SDRPS Simulations

- Axial slices do not suffer from limited angle artifacts
- Cone-beam artifacts are similar to those of conventional short scans.







Conclusions

- The SDRPS trajectory can extend the FOM and provide intraoperative 3D images of a larger anatomical area.
- Image reconstruction is exact in the midplane.
- The trajectory can be readily implemented in fully motorized C-arm CT systems.

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Thank You!

The 4th International Conference on

Image Formation in X-Ray Computed Tomography

Conference Chair

Marc Kachelrieß, German Cancer Research Center (DKFZ), Heidelberg, Germany

This presentation will soon be available at www.dkfz.de/ct.

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