Cone-Beam Flat Detector CT

incl. Rotational Angiography and Interventional CT

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DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Terminology

- Confusing terminology
  - Wikipedia, the free encyclopedia, says ”Rotational angiography is a medical imaging technique based on x-ray, that allows to acquire CT-like 3D volumes during hybrid surgery or during a catheter intervention using a fixed C-arm.”
  - In this sense, “rotational angiography” refers to the device used, i.e. a C-arm device, and not to angiography itself
  - “Angio” = 2D = projection imaging, “Rotational Angio” = 3D = tomographic imaging, both types of angio are more or less associated with the application of contrast agent
  - “DynaCT” is a Siemens implementation, but often the term is used as a synonym
  - Cone-beam CT is often associated with C-arm CT without contrast agent
- Cone-beam CT = CT with many detector rows
- Flat detector CT = CT with a flat detector of low aspect ratio
- C-arm CT = image intensifier- or flat detector-based cone-beam CT mounted on a C-arm

Interventional C-Arm CT

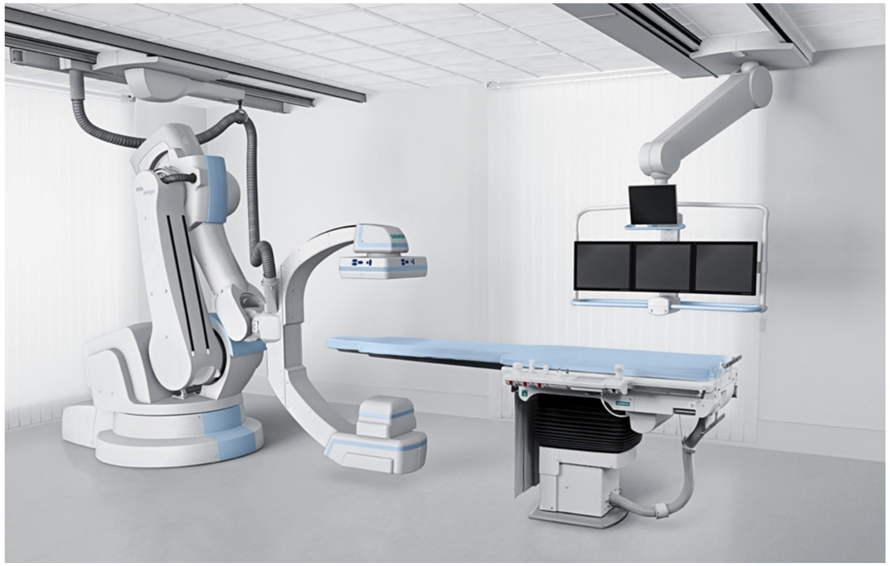
- There are fixed and mobile fluoroscopic (2D) and rotational (3D) systems available
- Cone-beam C-arm CT systems
  - Used for rotational angiography
  - Used for surgery
  - Used for neuro imaging
  - Therapeutic studies (line placements i.e. Permacath/Hickman, transjugular biopsies, TIPS stent, embolisations)
  - Cardiac studies (e.g. percutaneous coronary intervention)
  - Orthopedic procedures (ORIF, DHS, MUA, spinal work)
- Rotational angiography
  - Similar to diagnostic CTA, but in the intervention suite/cath lab
  - Angiography studies (peripheral, central and cerebral)
  - Detection and surgery of aneurysms
  - Placing of coils and stents
  - Detection of malformations, and of feeding vessels of malformations
- In general, the orthopetic procedures are carried out with a mobile C-arm because the workflow does not justify to dedicate an operation room to a fixed C-arm.

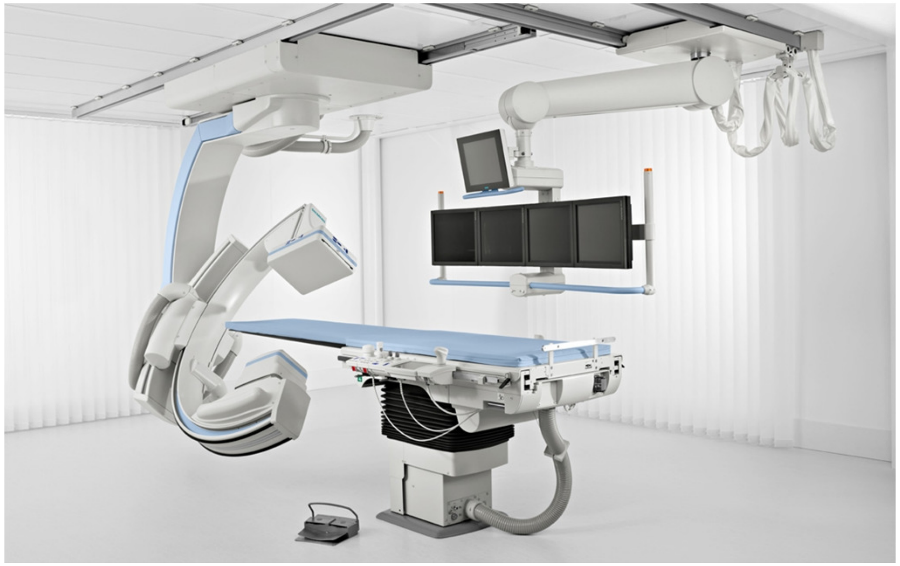
Clinical CT

e.g. Definition Flash dual source spiral cone-beam CT scanner, Siemens Healthcare, Forchheim, Germany.

Clinical CT is used for special types of interventions, such as needle biopsies and drainages, for example. They currently do not allow for 2D fluoroscopy. Compared to C-arm systems their form factor is not suitable to be used in the OR and the patient access is limited.

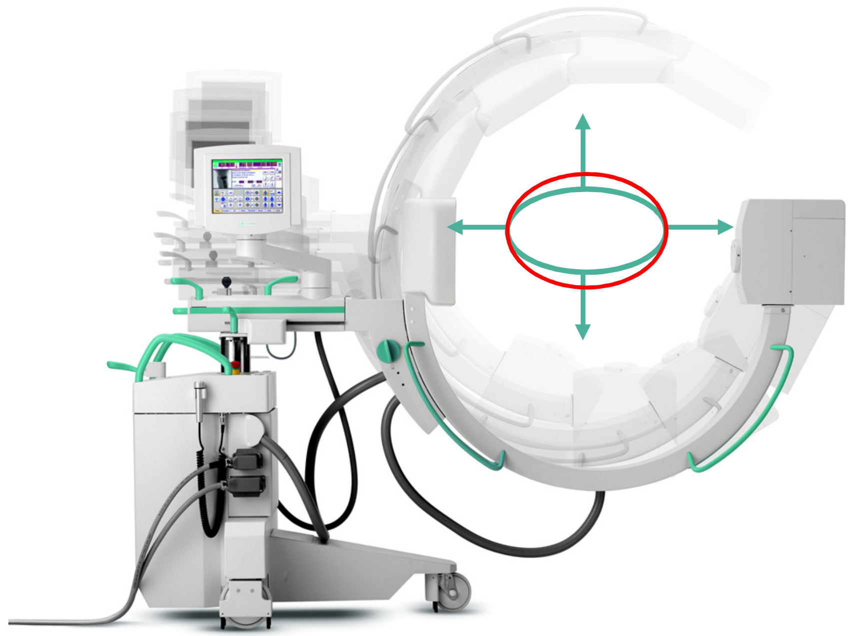
Fixed C-Arm CT



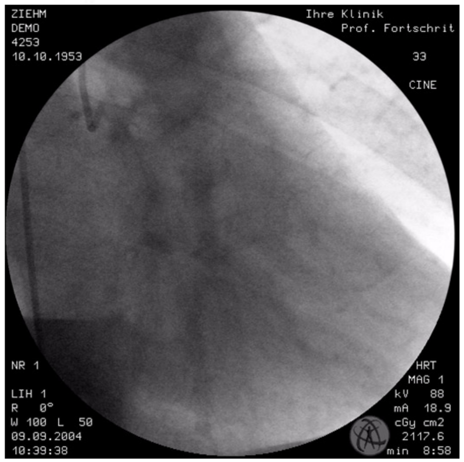


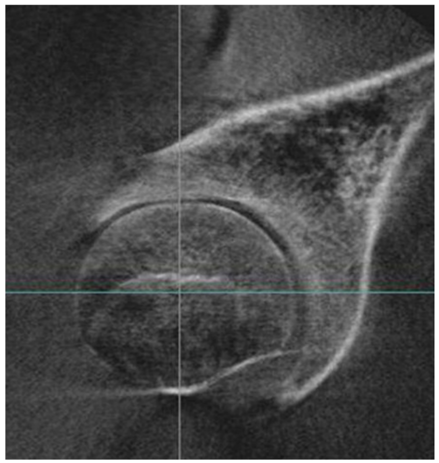
e.g. floor-mounted Artis Zeego or ceiling-mounted Artis Zee, Siemens Healthcare, Forchheim, Germany

Mobile C-Arm CT



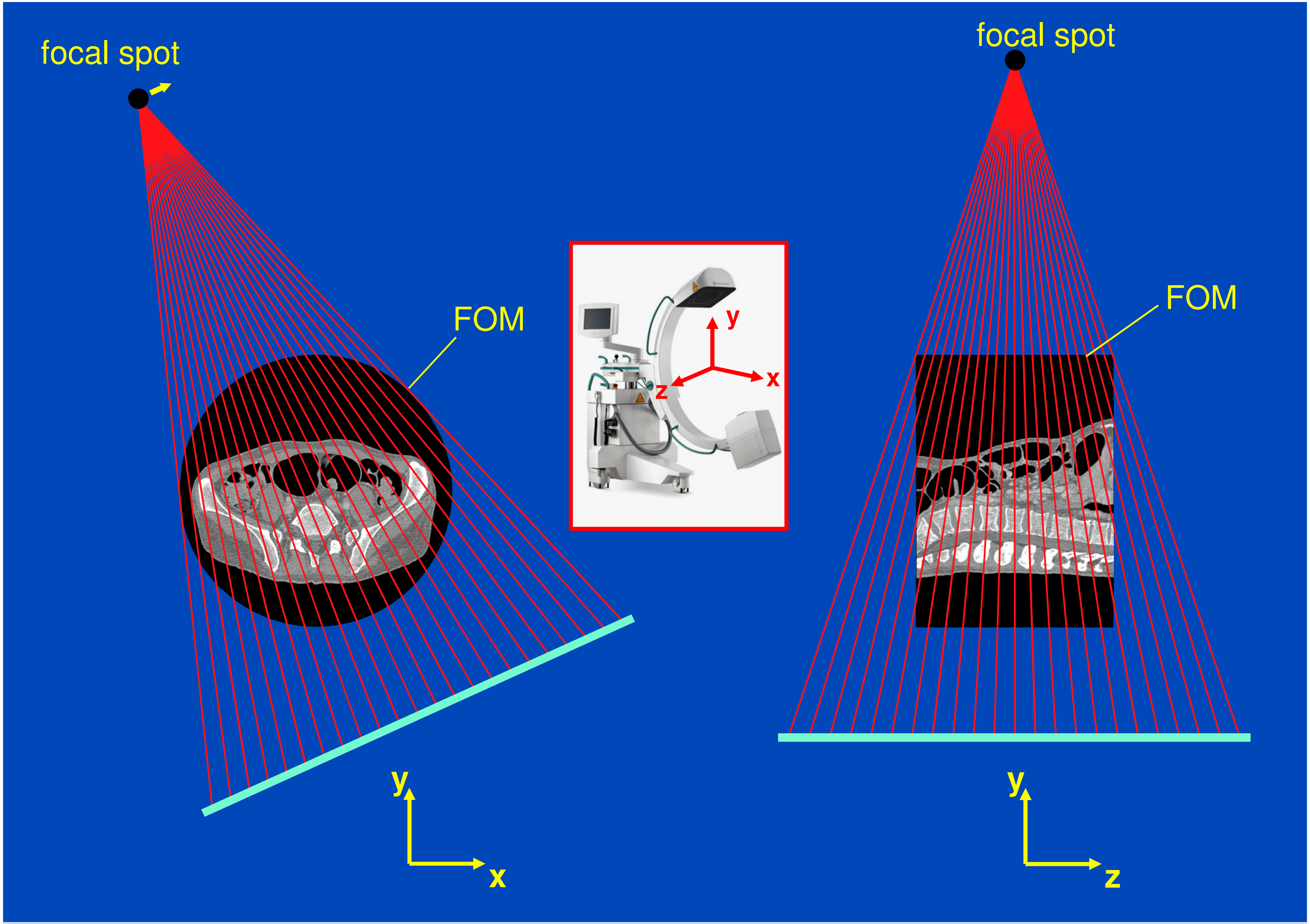
e.g. Vision FD Vario 3D, Ziehm Imaging GmbH, Nürnberg, Germany



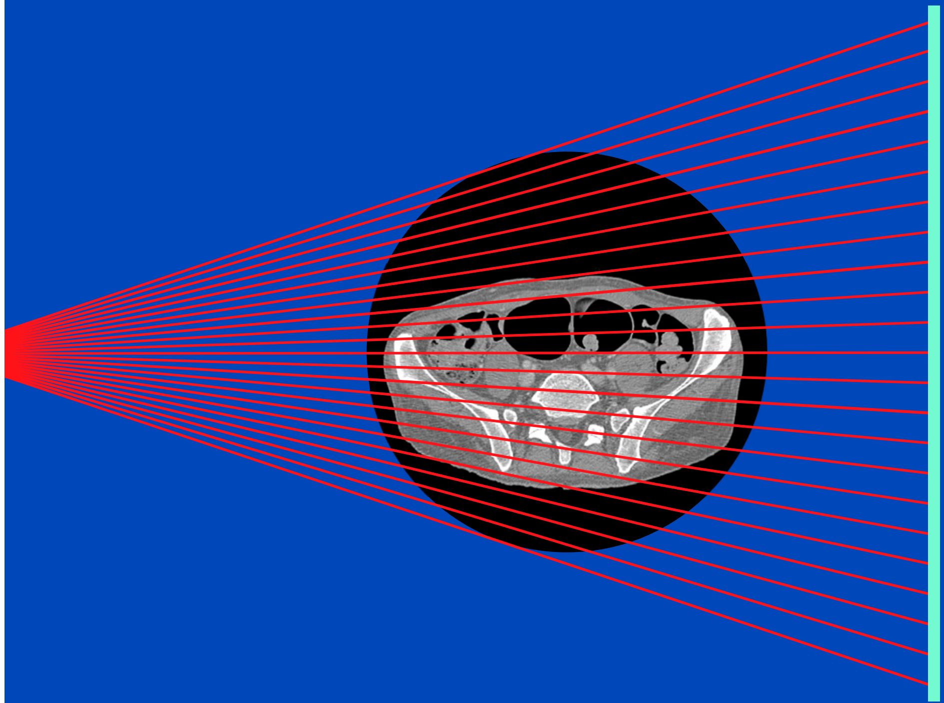
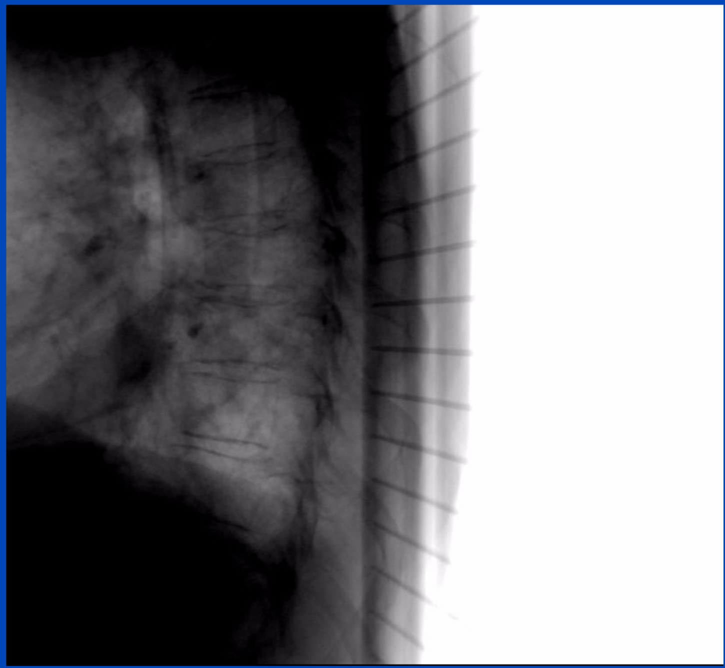


Typical Parameters

- Rotation speed: 30 to 100°/s
- Scan duration: 2 to 20 s
- Tube voltage: 40 to 110 kV
- Tube current: 20 to 80 mA (0.1 to 6 mA for fluoroscopy)
- Tube current time product: 0.1 to 160 mAs
- Typical patient dose values: 0.3 to 5 mSv
- Detector type: image intensifier or flat panel
- Detector size: 1024^2 to 4096^2
- Detector element size at isocenter: about 200 µm
- Volume size: 256^3 to 512^3

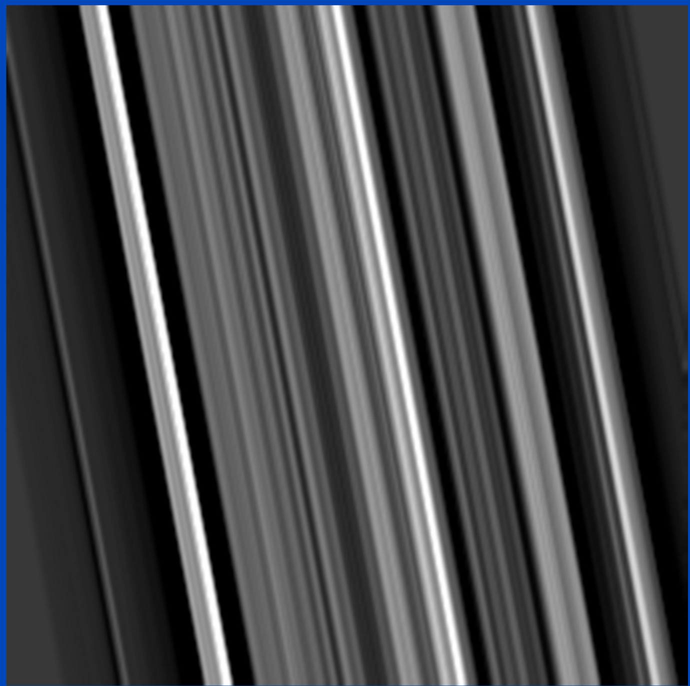


Detector: 1000×1000 to 4000×4000 elements, typically

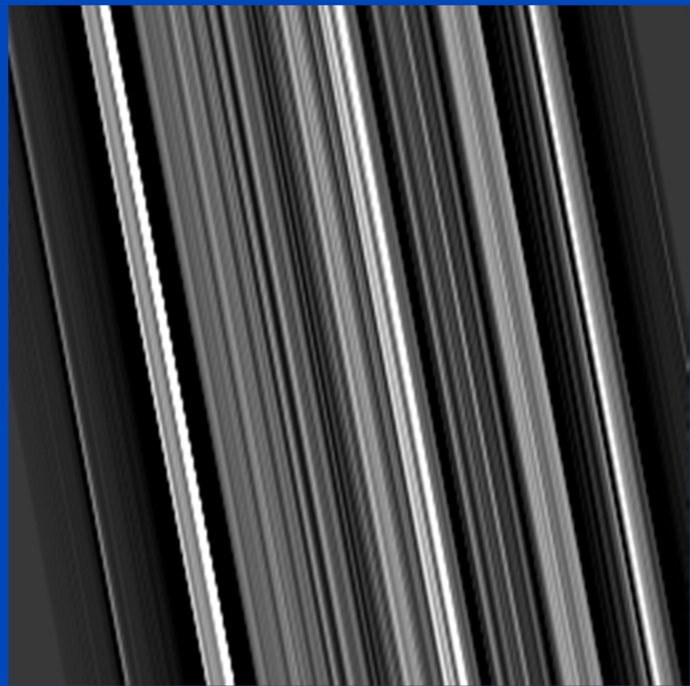



Filtered Backprojection (FBP)

1. Filter projection data with the reconstruction kernel.
2. Backproject the filtered data into the image:



Smooth

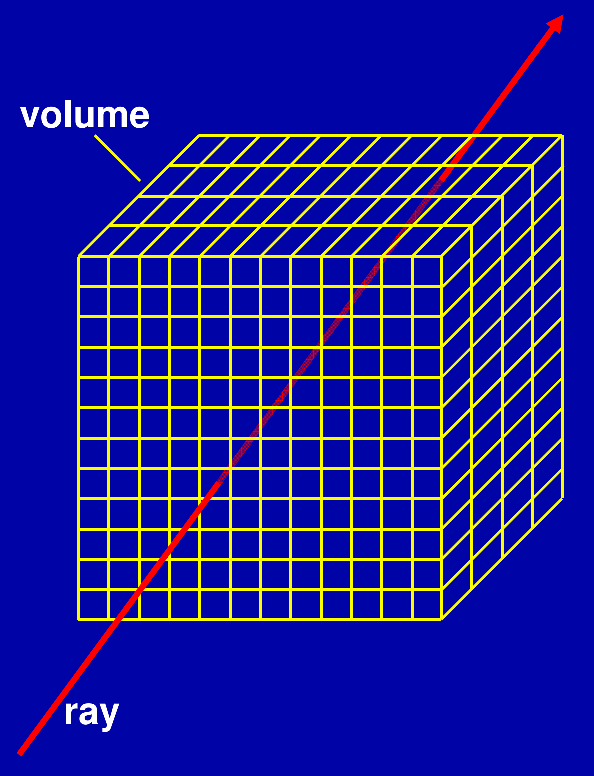


Standard

Reconstruction kernels balance between spatial resolution and image noise.

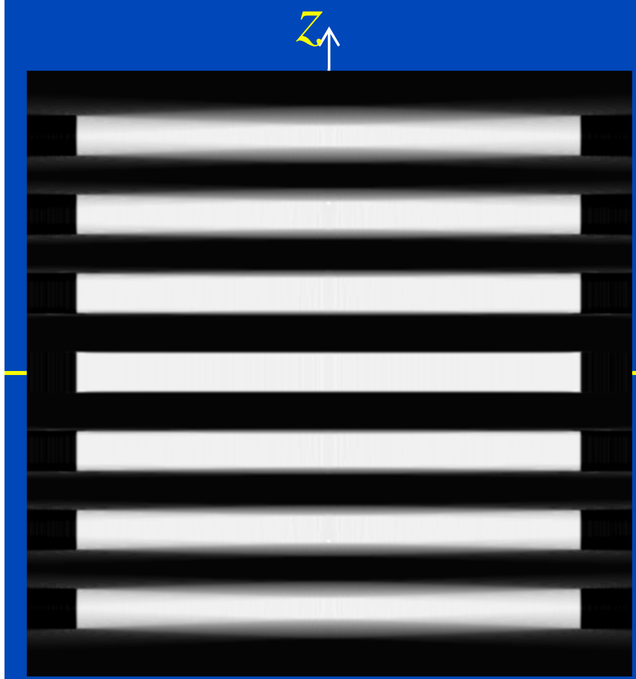
Feldkamp-Type Reconstruction

- **Approximate**
- **Similar to 2D reconstruction:**
  - **row-wise filtering of the rawdata**
  - **followed by backprojection**
- **True 3D volumetric backprojection along the original ray direction**

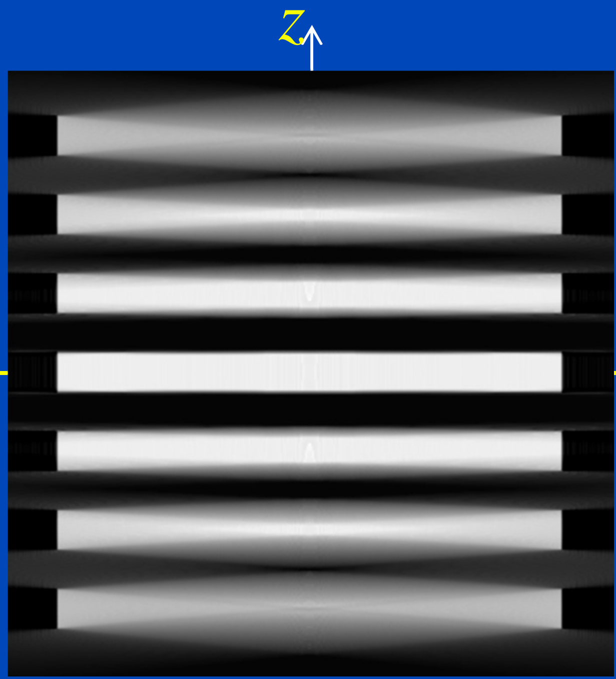


3D backprojection

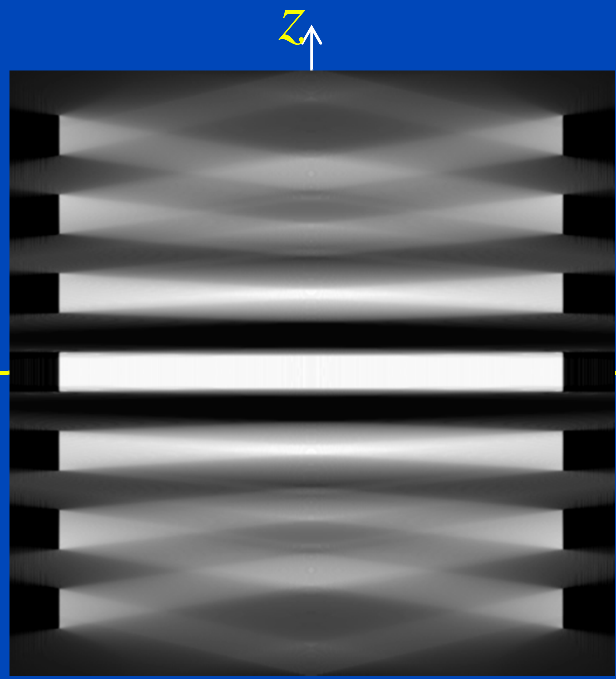
Cone-Beam Artifacts



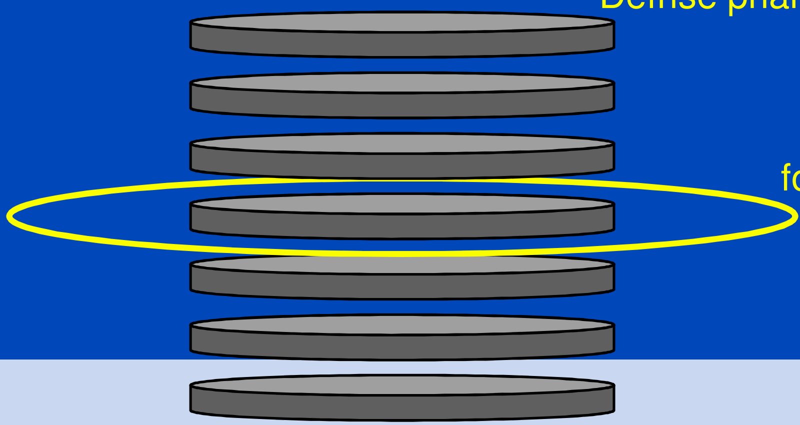
Cone-angle Γ = 6°

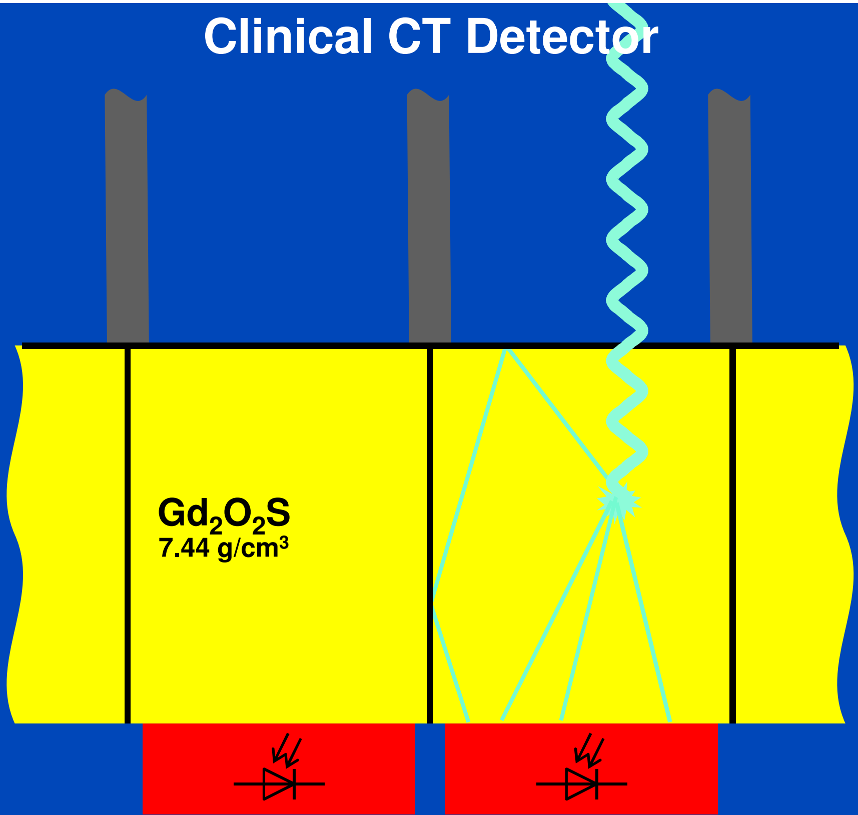


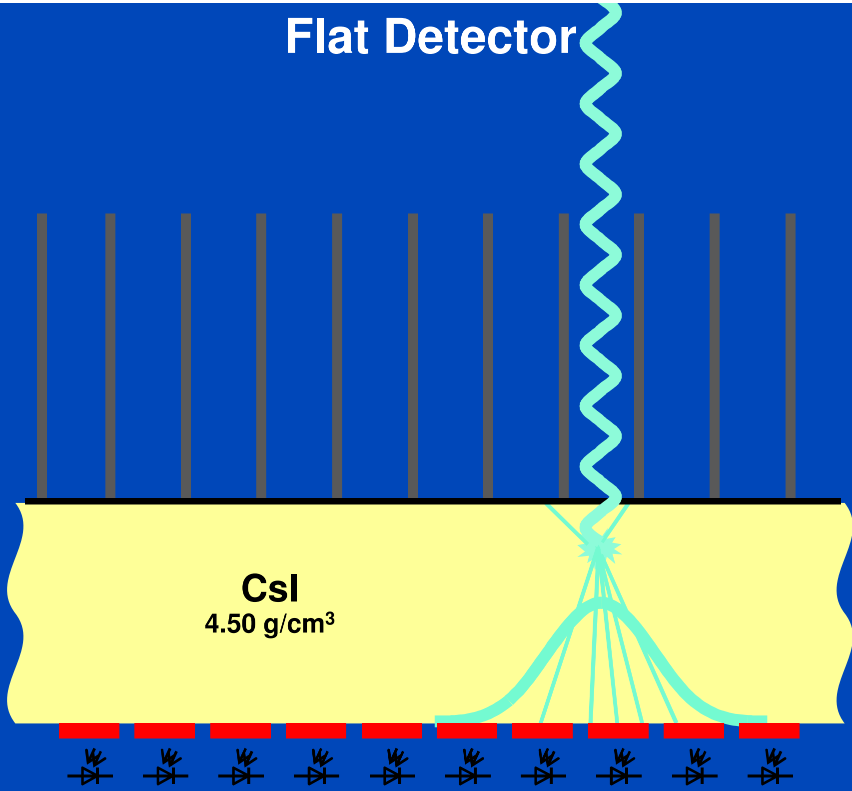
Cone-angle Γ = 14°



Cone-angle Γ = 28°





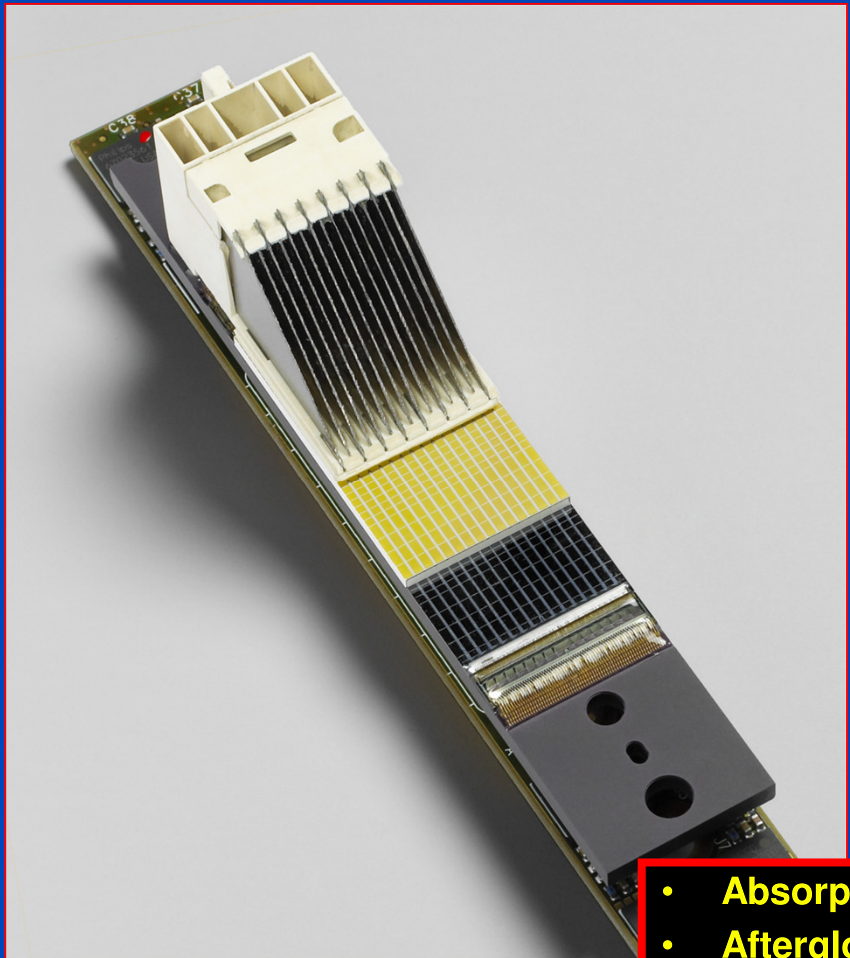


- Anti-scatter grids are aligned to the detector pixels
- Anti-scatter grids reject scattered radiation
- Detector pixels are of about 1.2 mm size
- Detector pixels are structured, reflective coating maximizes light usage
- Thick scintillators improve dose usage
- Gd_2O_2S is a high density scintillator with favourable decay times
- Individual electronics allow for fast read-out
- Very high dynamic range can be realized

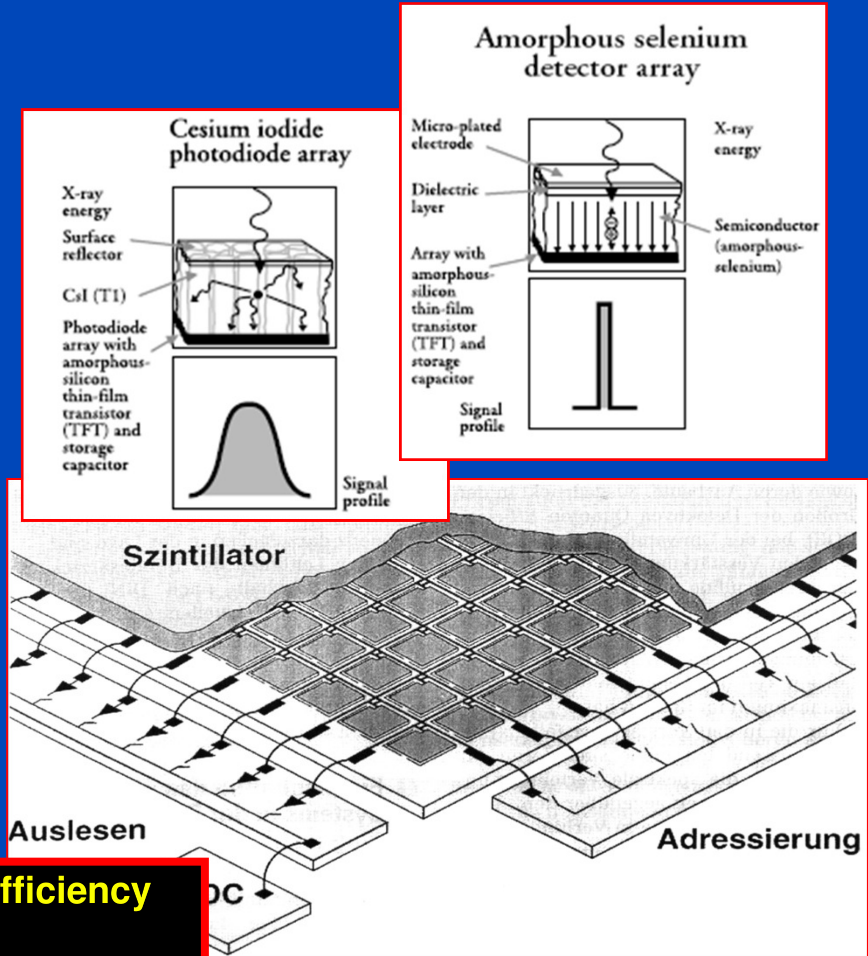
- Anti-scatter grids are not aligned to the detector pixels
- The benefit of anti-scatter grids is unclear
- Detector pixels are of about 0.2 mm size
- Detector pixels are unstructured, light scatters to neighboring pixels
- Thick scintillators decrease spatial resolution
- CsI grows columnar and suppresses light scatter to some extent
- Row-wise readout is rather slow
- Long read-out paths decrease the dynamic range

Detector Technology

Clinical CT Detector



Flat Detector



- Absorption efficiency
- Afterglow
- Dynamic range
- Cross-talk
- Framerate
- Scatter grid

Dose Efficiency of Flat Detectors

	Clinical CT (120 kV)			Flat Detector CT (120 kV)			Micro CT (60 kV)		
Material	Gd_2O_2S			CsI			CsI		
Density	7.44 g/cm^3			4.5 g/cm^3			4.5 g/cm^3		
Thickness	1.4 mm			0.6 mm			0.3 mm		
Manufacturer	Siemens			Varian			Hamamatsu		
Water Layer	0 cm	20 cm	40 cm	0 cm	20 cm	40 cm	0 cm	4 cm	8 cm
Photons absorbed	98.6%	97.7%	96.7%	80.0%	69.8%	62.2%	85.3%	85.6%	85.8%
Energy absorbed	94.5%	91.4%	88.7%	66.6%	55.4%	48.3%	67.1%	65.2%	64.2%

Absorption values are relative to a detector of infinite thickness.

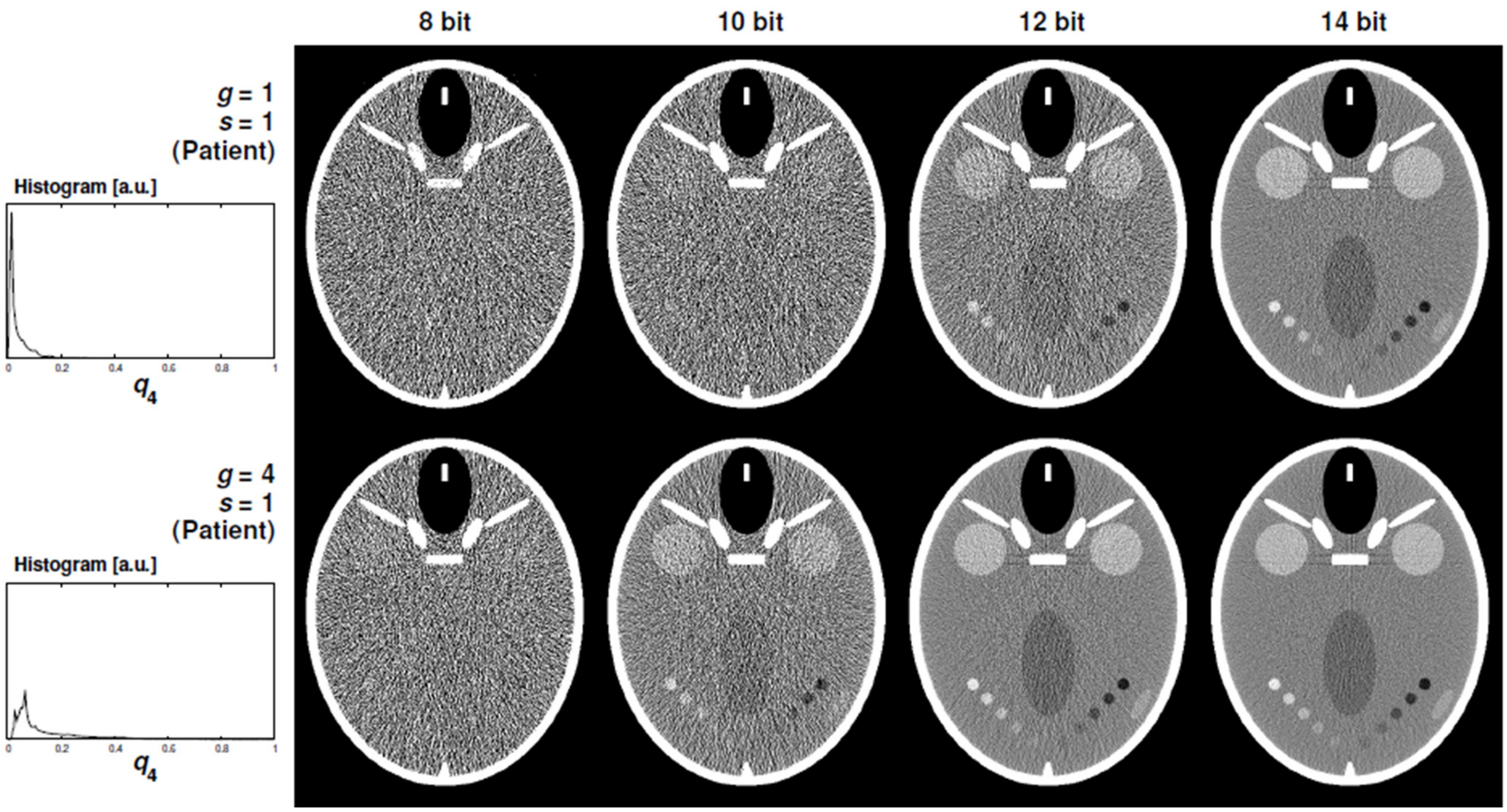
Dynamic Range in Flat Detectors

	Saturation-to-noise range			X-ray exposure range				Digital range	
	Electronic noise (ADU)	Saturation signal (ADU)	Dynamic range	Quantum limited exposure (µR)	Saturation exposure (µR)	Dynamic range	Eff. bit depth (bits)	Quantization range	Eff. bit depth (bits)
No binning, gain 2	**A1**	**B1**	**B1/A1**	**A2**	**B2**	**C2=B2/A2**	**D2=lb(C2)**	**B1:1**	**lb(B1)**
Dynamic gain switching	5.32	80500	15100	2.75	3550	**1291**	**10.3**	80500:1	16.3
0.5 pF fixed	5.32	14500	2700	2.75	595	**216**	**7.8**	14500:1	13.8
4 pF fixed	3.57	14800	4150	35.7	4200	**118**	**6.9**	14800:1	13.8
2x2 binning, gain 1									
Dual gain readout	4.33	80100	18500	1.00	1800	**1800**	**10.8**	80100:1	16.3
Dynamic gain switching	4.37	84200	19300	1.03	2062	**2002**	**11.0**	84200:1	16.4
0.5 pF fixed	4.37	14300	3300	1.03	311	**302**	**8.2**	14300:1	13.8
4 pF fixed	3.14	14800	4700	15.6	2104	**135**	**7.1**	14800:1	13.8
0.5 pF fixed, gain 2 (fluoroscopy mode)	7.25	12900	1700	0.71	125	**176**	**7.5**	12900:1	13.6

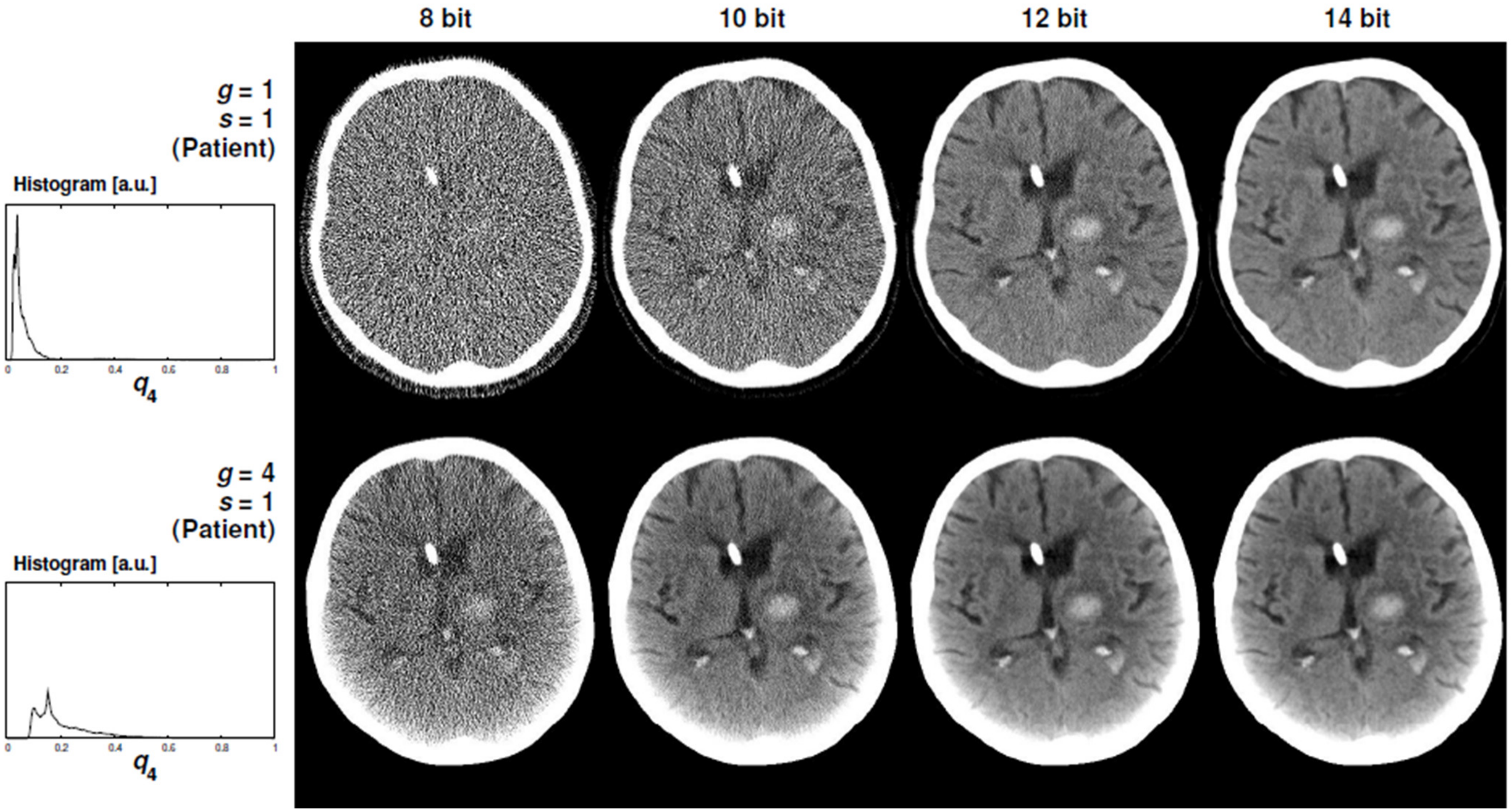
Table 2 4030CB dynamic range in available imaging modes

A2 is defined as the exposure where QuantumNoise=ElectronicNoise.

Table taken from [Roos et al. “Multiple gain ranging readout method to extend the dynamic range of amorphous silicon flat panel imagers,” *SPIE Medical Imaging Proc.*, vol. 5368, pp. 139-149, 2004]. Additional values were added, for convenience.



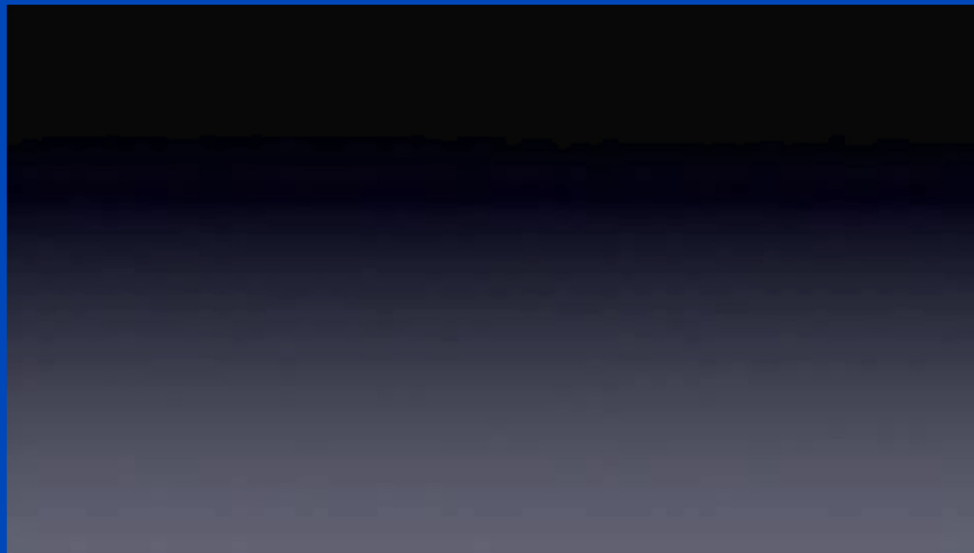
8 bit
10 bit
12 bit
14 bit
g = 1
s = 1
(Patient)
Histogram [a.u.]
0
0.2
0.4
0.6
0.8
1
q4
g = 4
s = 1
(Patient)
Histogram [a.u.]
0
0.2
0.4
0.6
0.8
1
q4


8 bit
10 bit
12 bit
14 bit
g = 1
s = 1
(Patient)
Histogram [a.u.]
q4
g = 4
s = 1
(Patient)
Histogram [a.u.]
q4

Summary

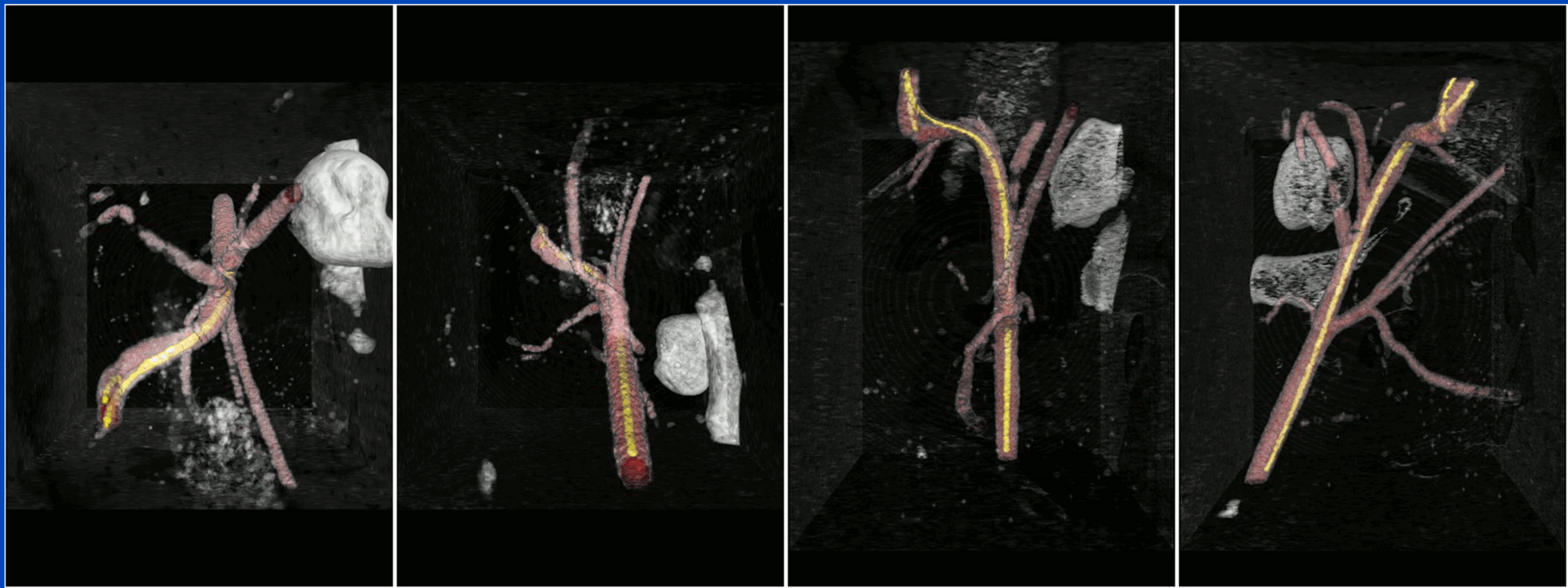
- C-arm-based flat detectors are widely used for interventional CT imaging
- Due to today's flat detector technology, neither dose efficiency nor image quality can compete with clinical CT
- Cone-beam artifacts will remain in C-arm CT, unless scan trajectories different from the half or full circle are implemented
- Patient access and system form factors are more favourable in C-arm systems compared to diagnostic CT systems

The Future of Interventional Imaging: 3D+T Imaging at 2D+T Dose



Courtesy of Dr. Sönke Bartling, Heidelberg, Germany.

The Future of Interventional Imaging: 3D+T Imaging at 2D+T Dose



Kuntz, Brehm, Kachelrieß, Bartling. Towards 4D Intervention Guidance using Compressed Sensing. Proc. Fully3D, July 2011.

Kuntz, Sawall, Socher, Semmler, Kachelrieß, Bartling. 4D Guidance in Interventional Radiology. Insights into Imaging 3 Suppl. 1: B-351, March 2012, ECR 2012.

dkfz.


Thank You!
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