Signal Sensing and Reconstruction Paradigms for a Novel Multi-source Static Computed Tomography System

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Disclosures

- Govt:
  - IARPA, DARPA, DoD, FBI, NIH, CIMIT
- Industry:
  - Idorsia
  - Siemens

Recreation of first surgery October 16, 1846
Ether Dome

Overview

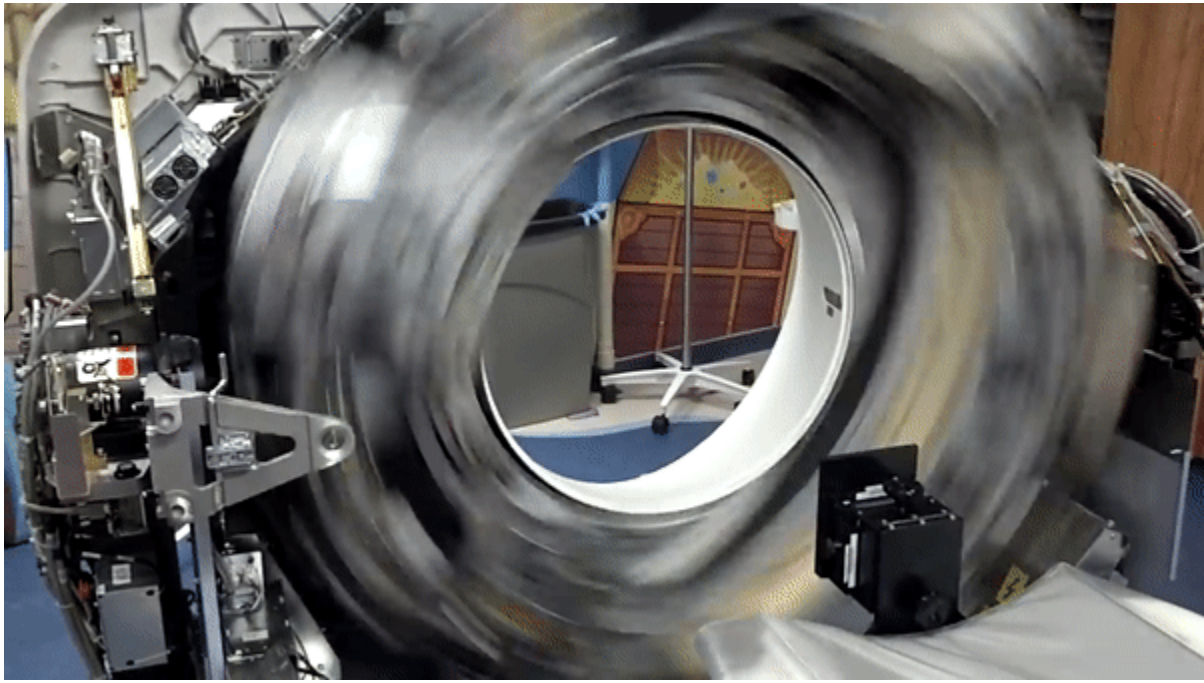
- The current CT paradigm
- A new CT paradigm
- Projection data acquisition paradigms:
  - Multiplexed, coded acquisition
  - Exposure modulation
  - Adaptive projection acquisition

Current Computed Tomography

A single 100 kW x-ray source on a spinning gantry that weighs ~2 tons and rotates at up to 300 rpm.

Challenges:

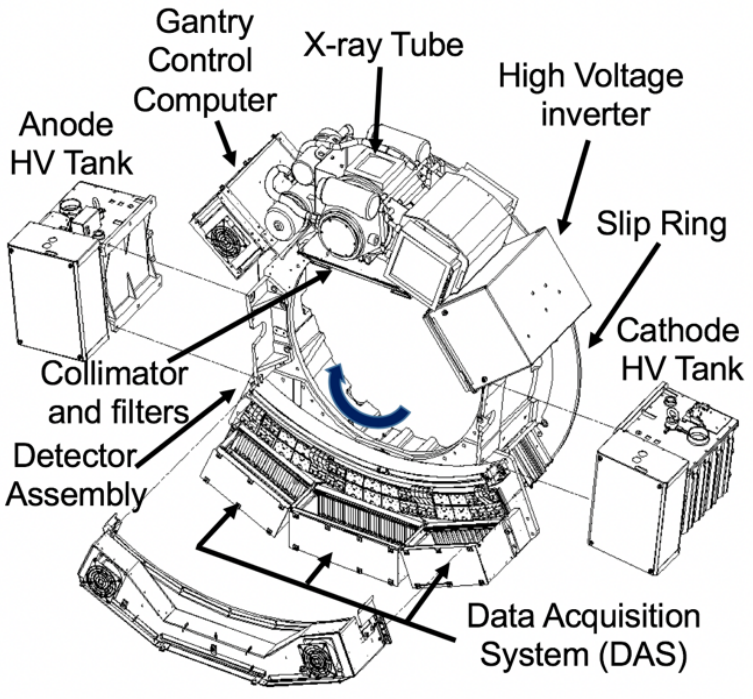
- Power
- Weight
- Inertia



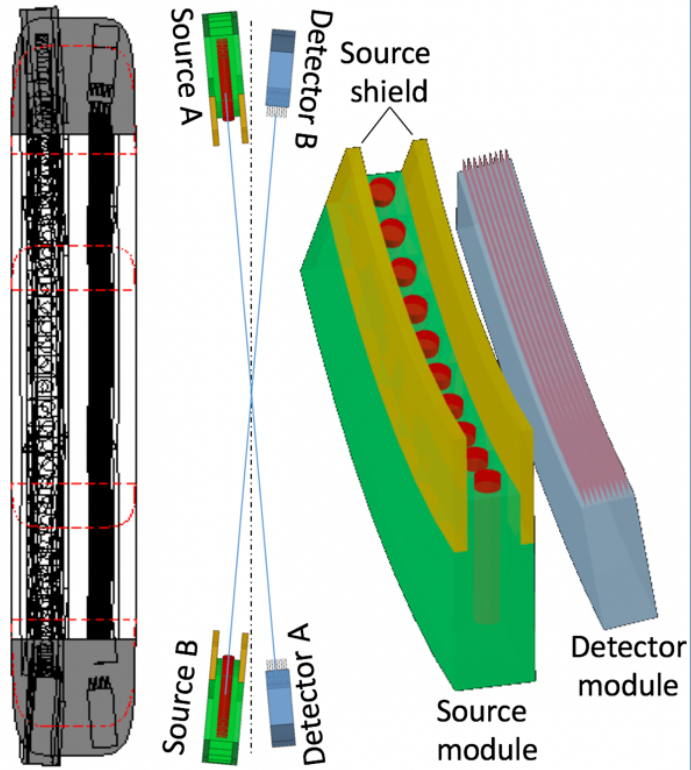
https://www.youtube.com/watch?v=TWU-nB4l5dU

Geva, Schechner, Chernyak, Gupta. X-ray CT Through Scatter, ECCV 2008.

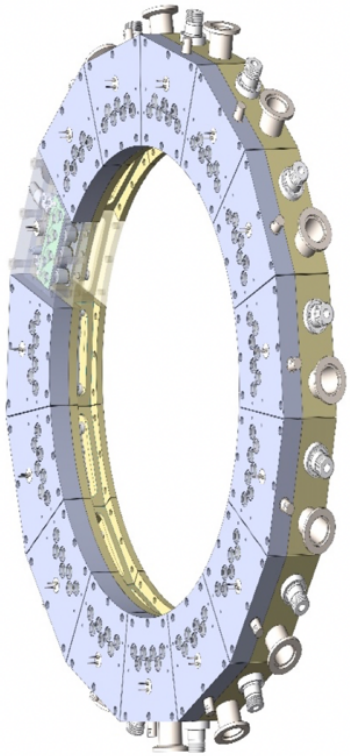
Multi-Source Static CT Concept



(a) A convention 3rd generation rotating gantry CT

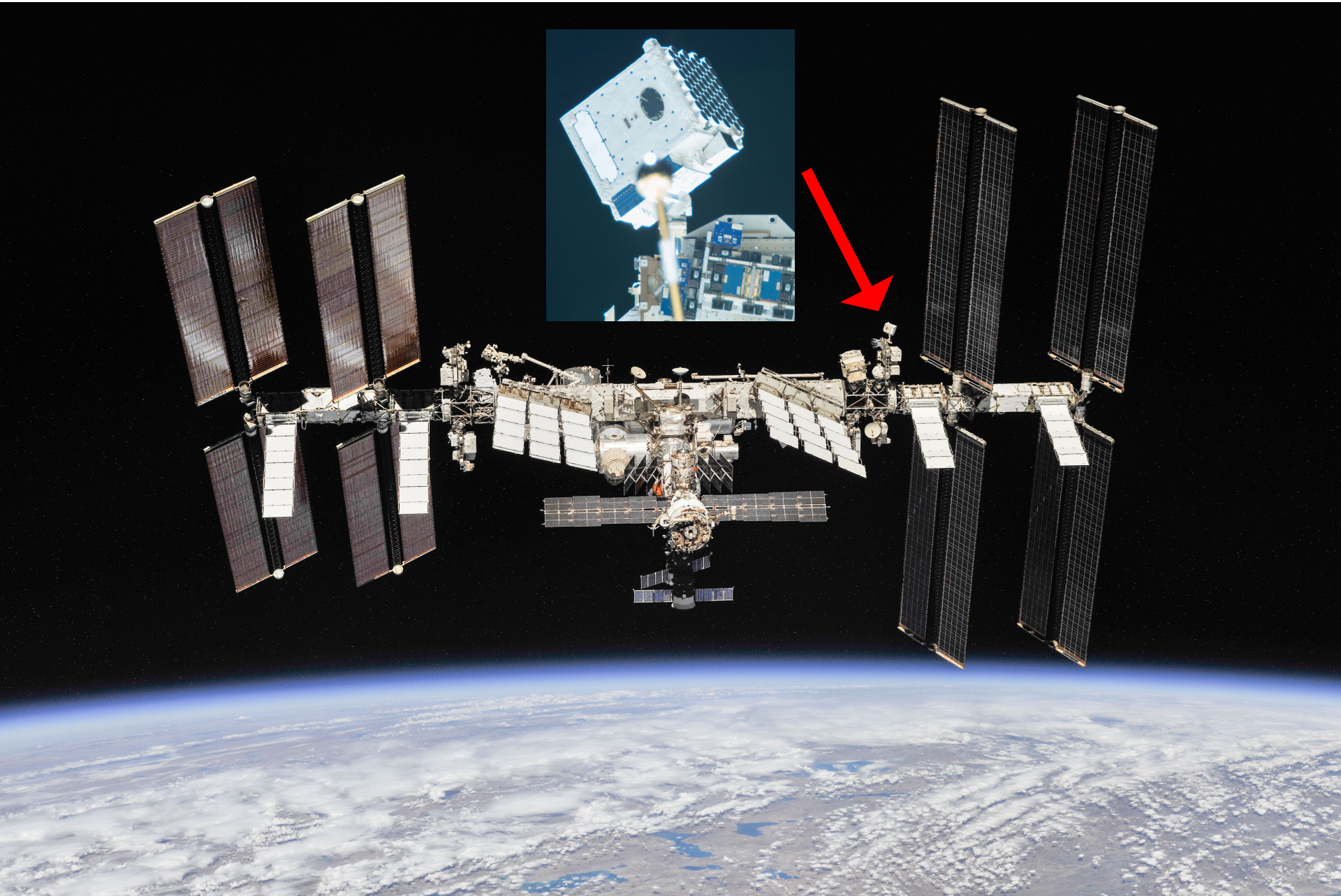


(b) Multi-Source Static CT gantry showing the arrangement of X-ray sources and detectors

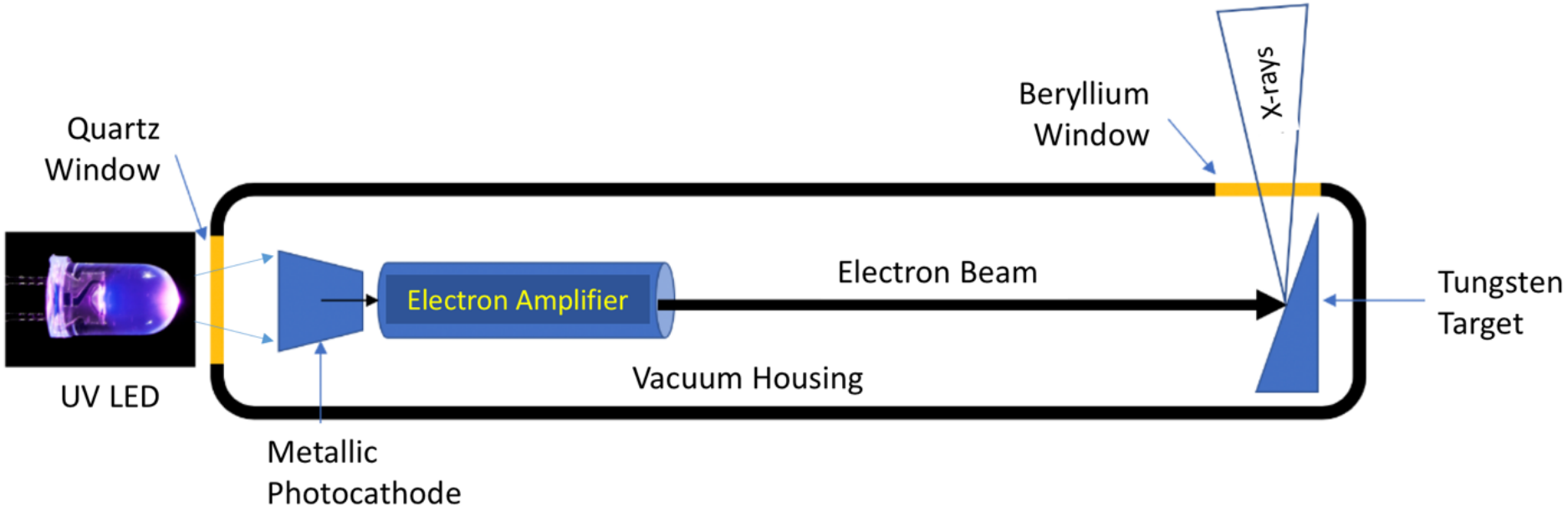


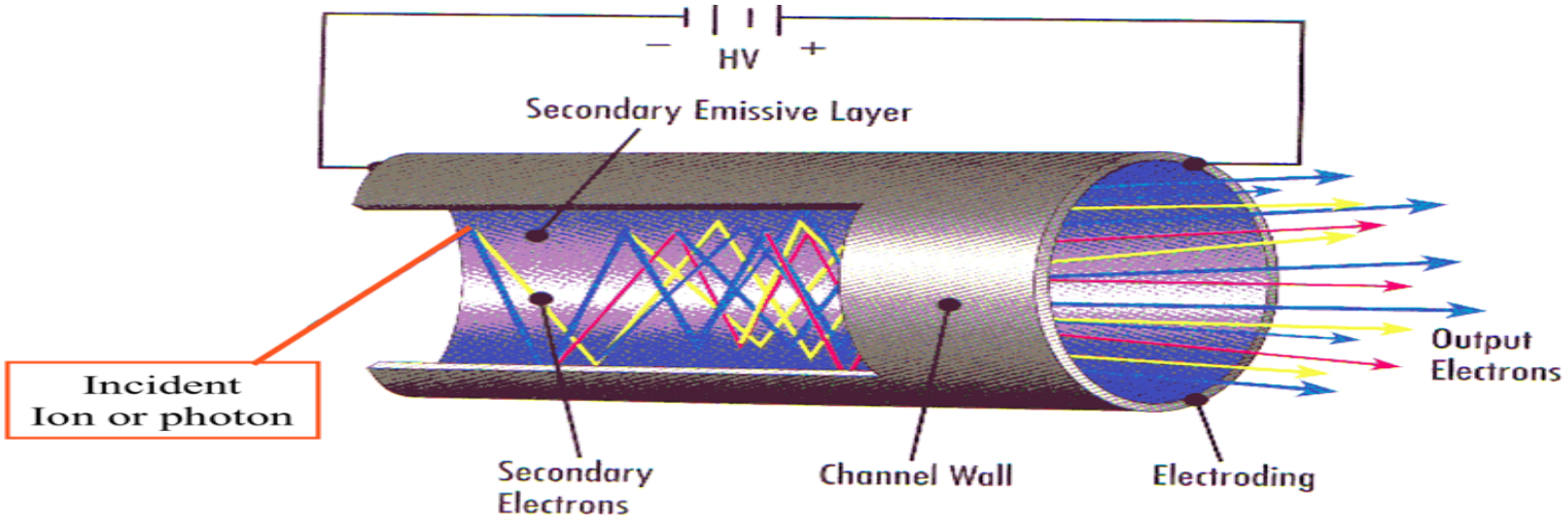
(c) MSCT gantry made of 15 X-ray modules

NICER: **N**eutron star **I**nterior **C**omposition **E**xplore**R**



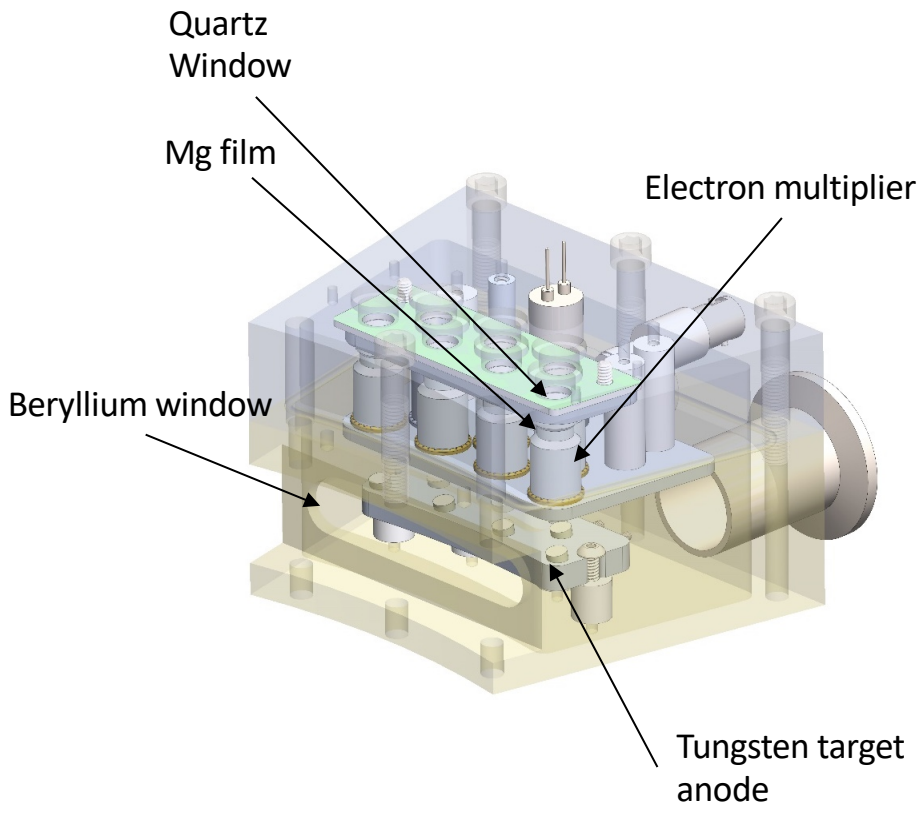
X-ray Source Element Design

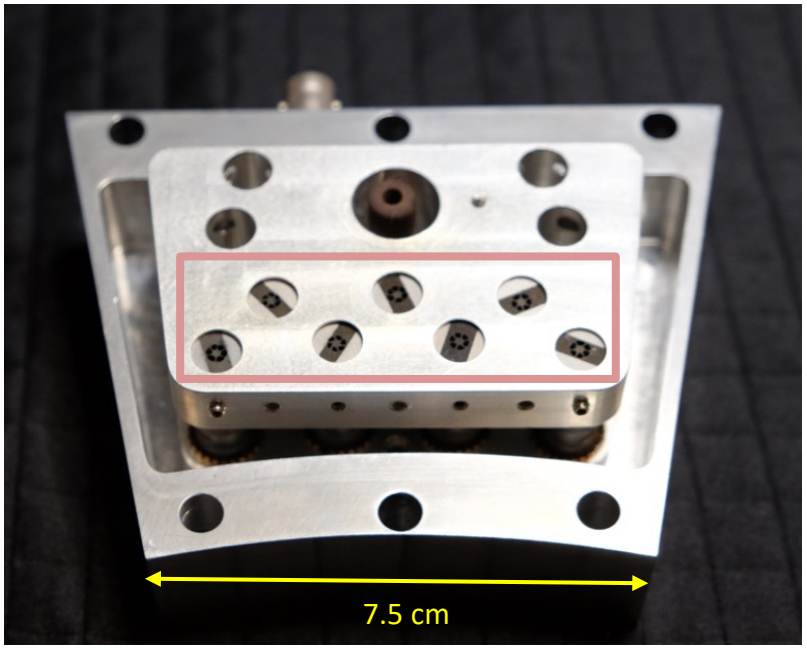




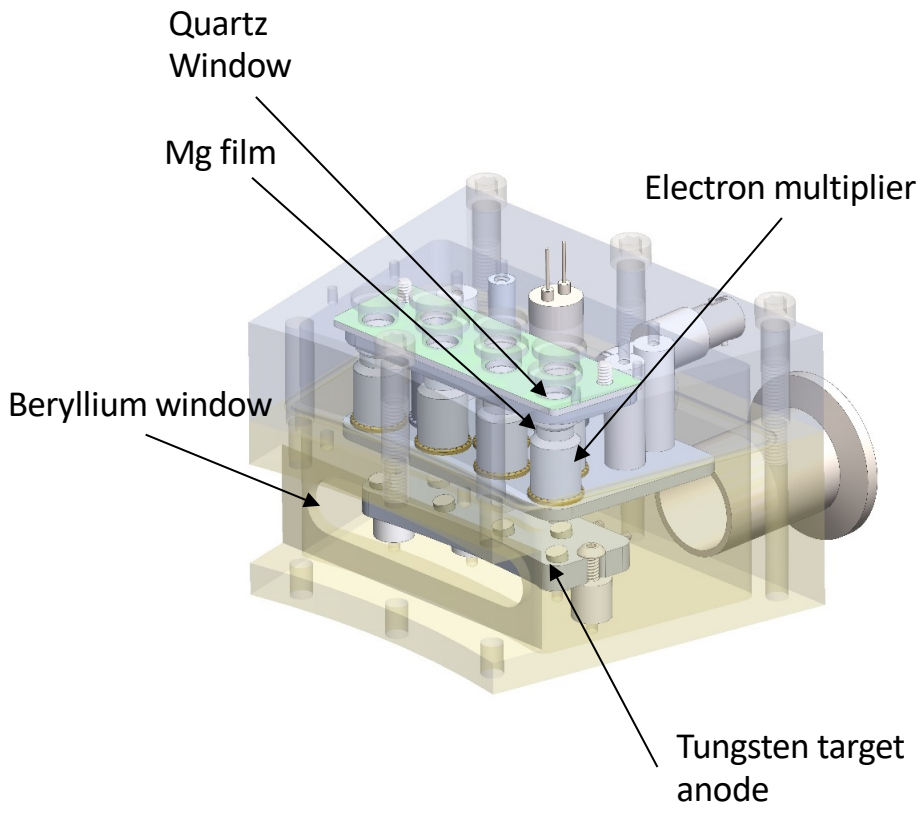
Electron Amplification: Channeltron® Operation

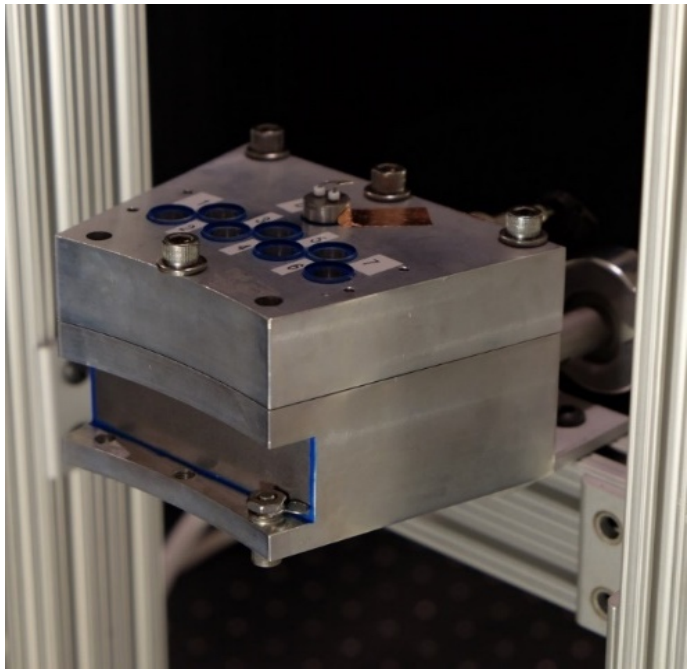
Prototype X-ray Source Module



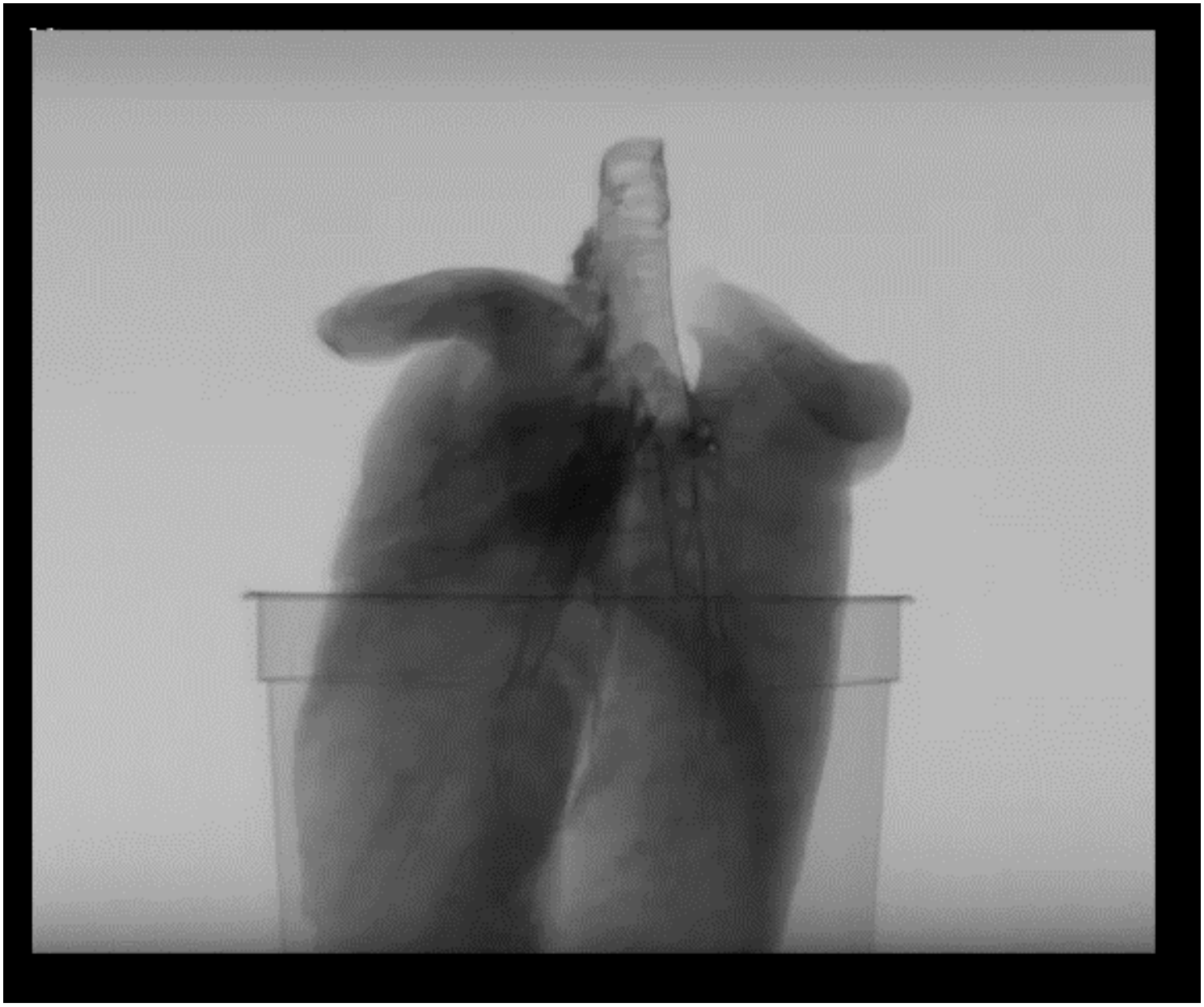


Prototype X-ray Source Module

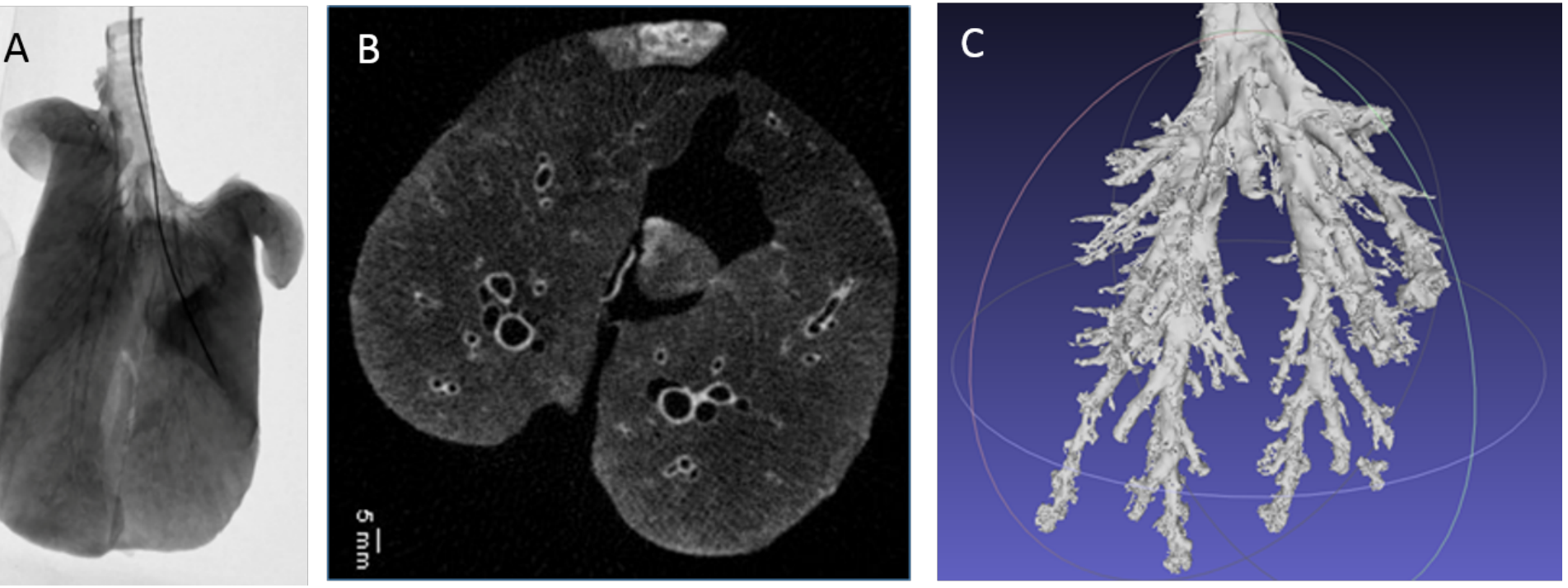




Prototype Module- raw data



Prototype Module- results

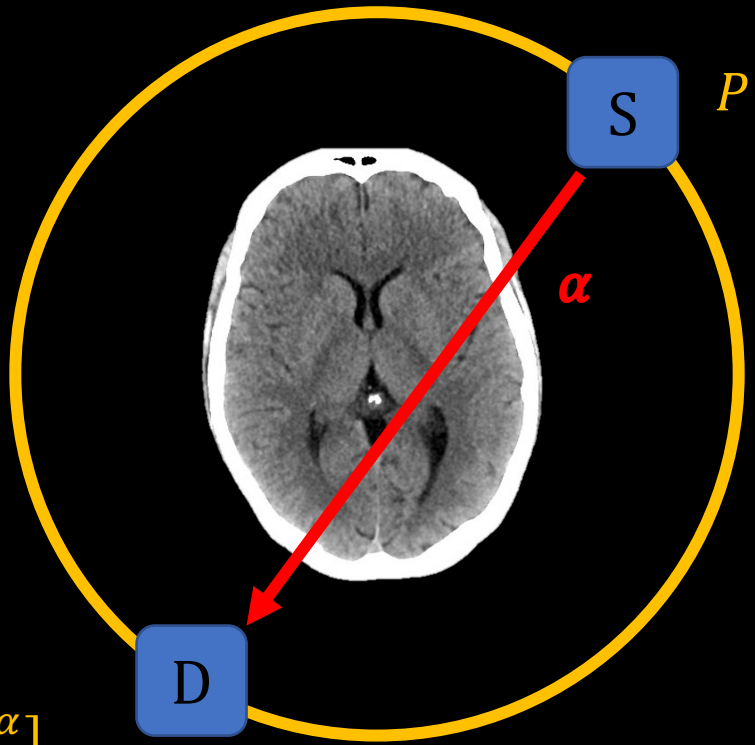


A: X-ray projection image of pig lung with an inserted catheter. B: axial slice from pig lung reconstruction. C: segmented bronchial tree from pig lung.

Projection Paradigms

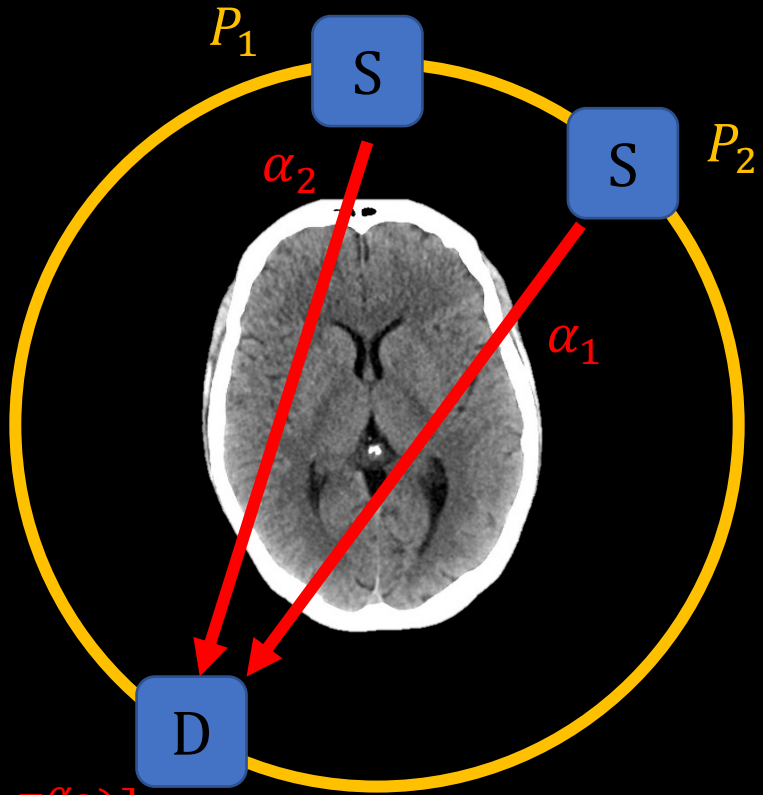
- X-ray on, one at a time, sequentially
- Multiplexed, coded X-ray exposures
- X-ray on, one at a time, sequentially, with modulation
- X-ray on, one at a time, adaptively

Forward Projection Model



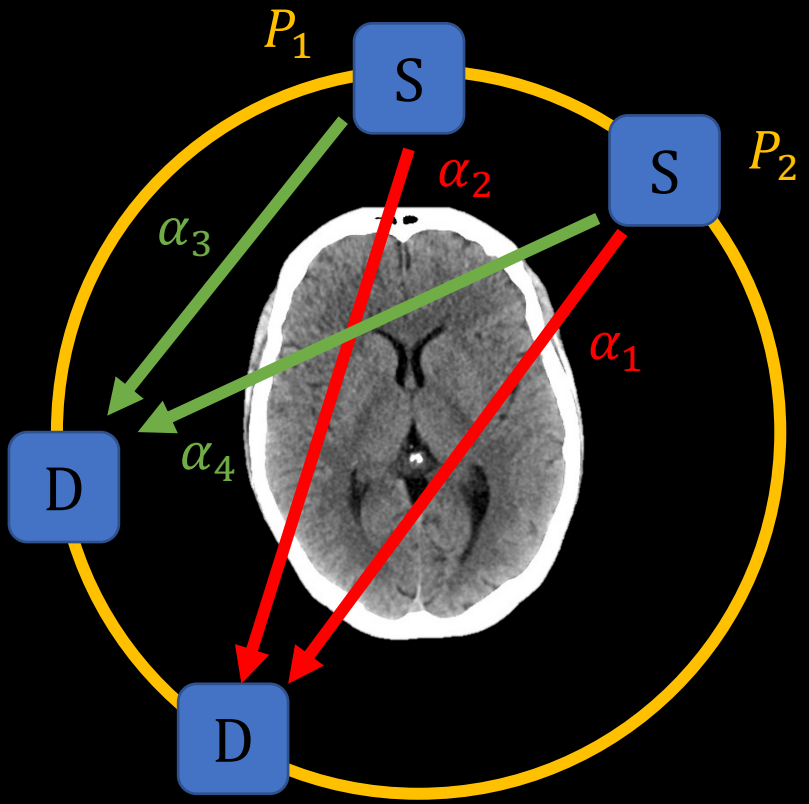
$$y = \mathbb{P}[tPe^{-\alpha}]$$

Multiplexed Forward Projection Model



$$y = \mathbb{P}[t(P_1 e^{-\alpha_1} + P_2 e^{-\alpha_2})]$$

Inverse Problem: Multiplexed Forward Projection Model

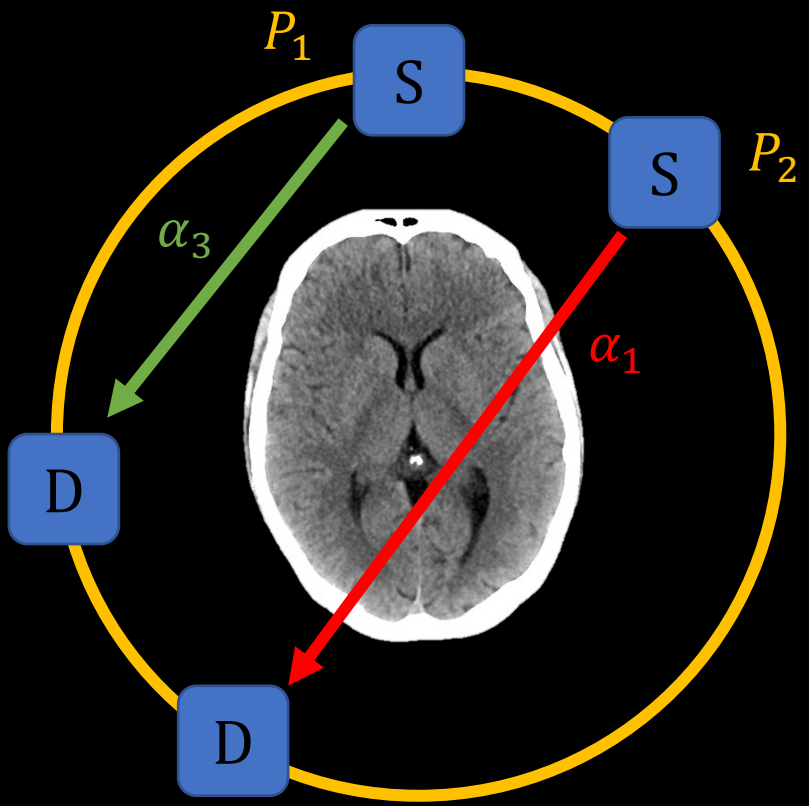


$$y_1 = \mathbb{P}[t(P_1 e^{-\alpha_1} + P_2 e^{-\alpha_2})]$$

$$y_2 = \mathbb{P}[t(P_1 e^{-\alpha_3} + P_2 e^{-\alpha_4})]$$

...

Poisson linear combinations are bad!

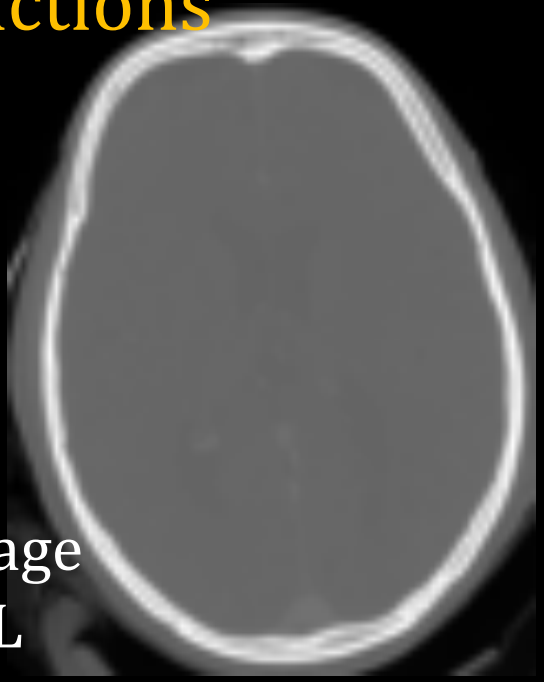


$$y_1 = \mathbb{P}[tP_1e^{-\alpha_1}]$$

$$y_2 = \mathbb{P}[tP_1e^{-\alpha_3}]$$

...

Reconstructions



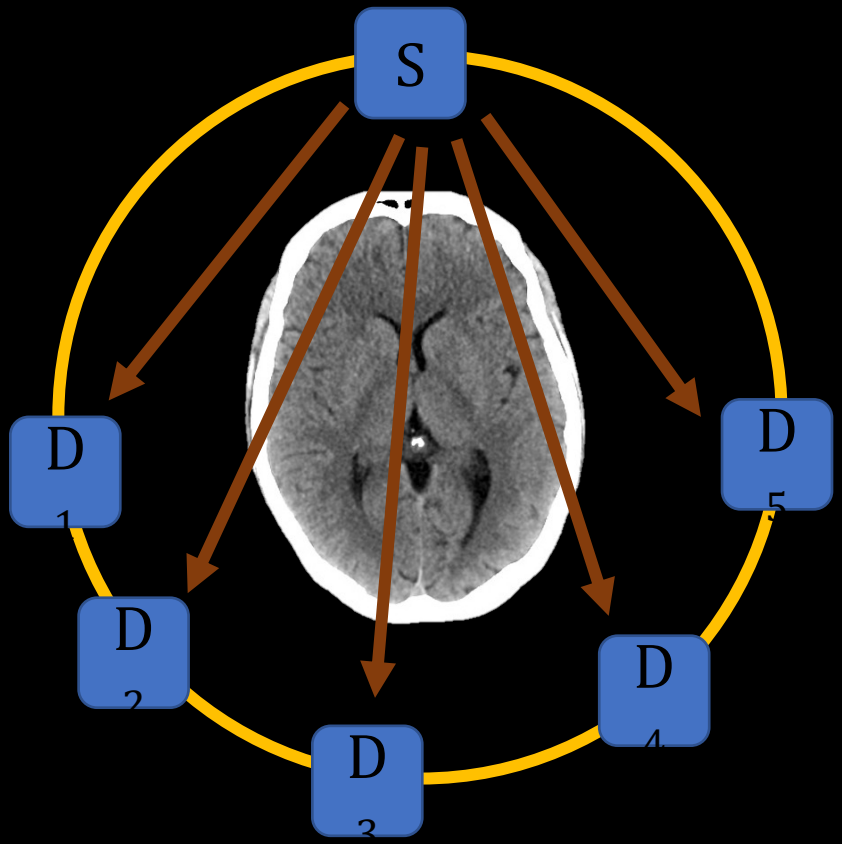
Original image
Bone W/L

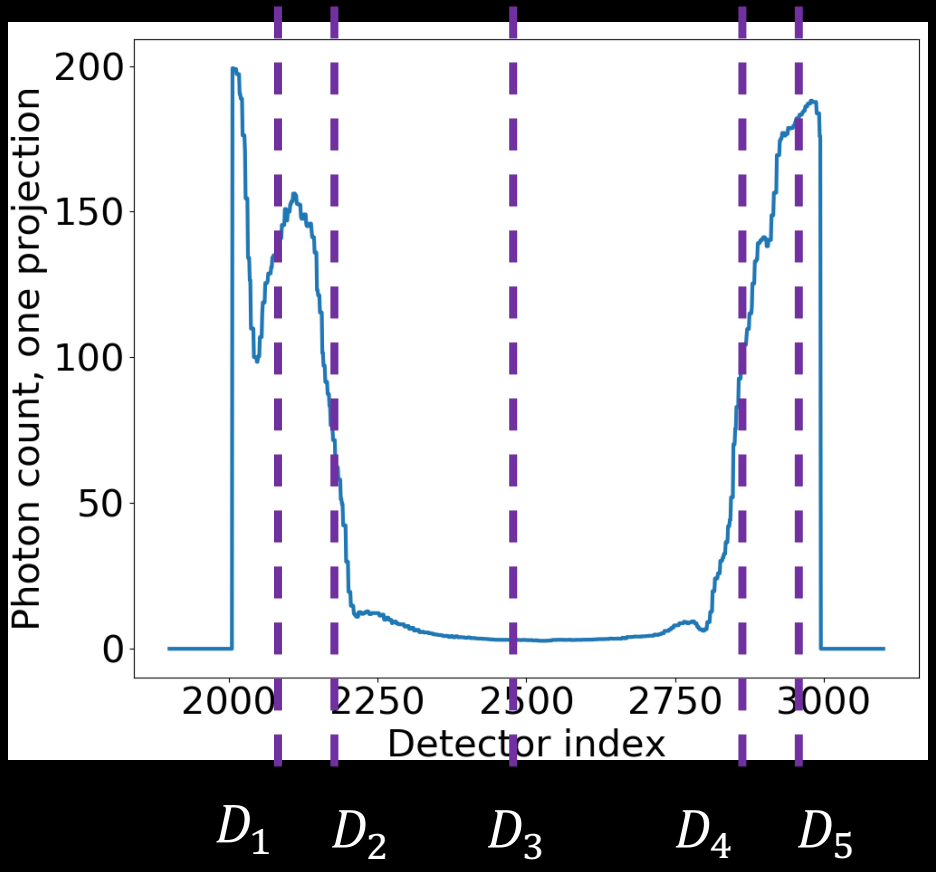
Original image,
brain W/L

Reconstructed
mage, Bone W/L

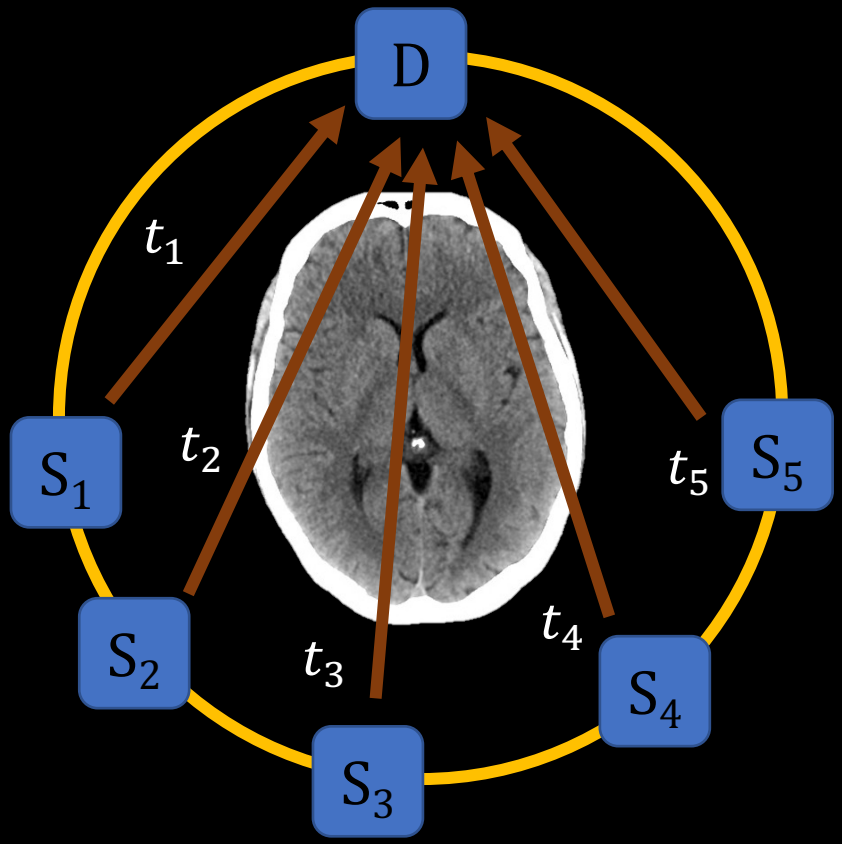
Reconstructed
image, brain
W/L

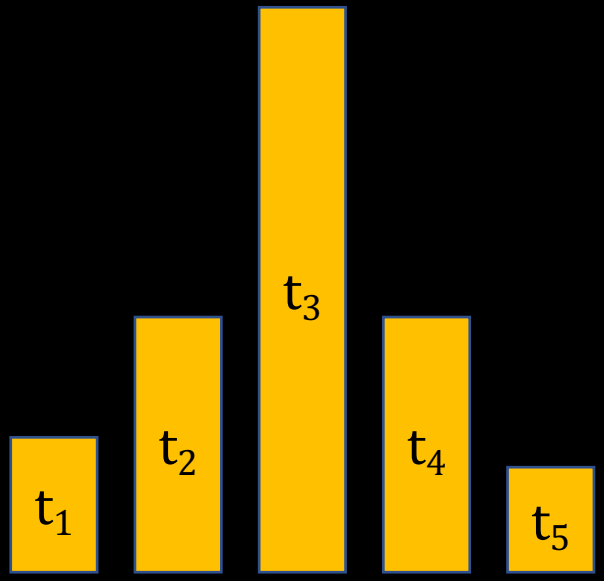
Photon Starvation: Projections by angle



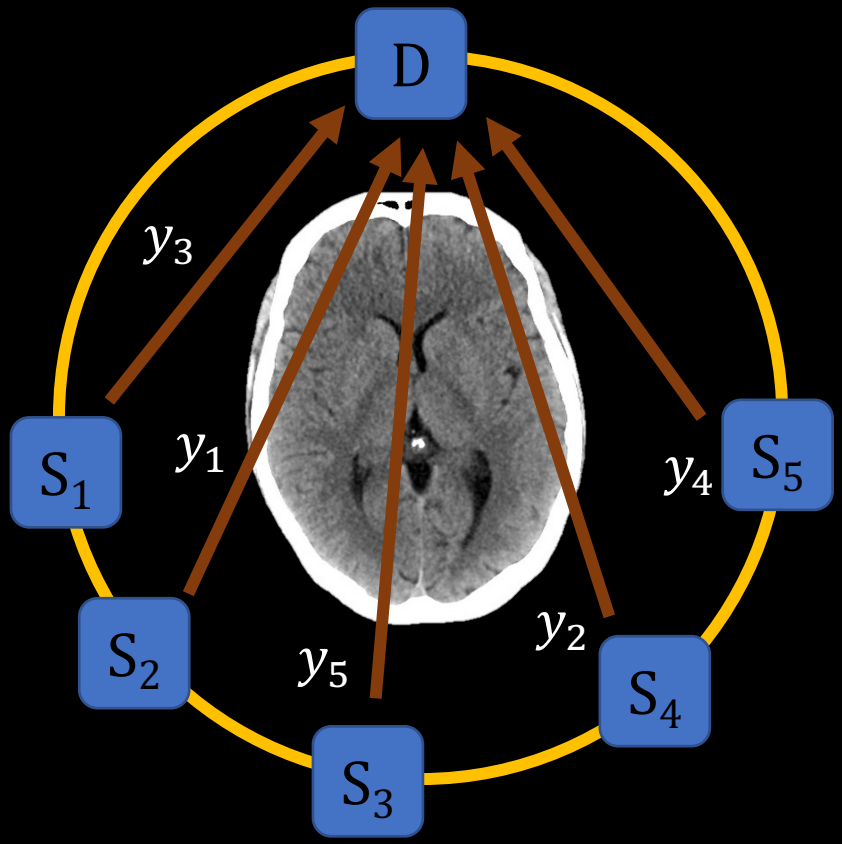


Potential solution: exposure time modulation?





Potential solution: adaptive measurements?



$y_1 \Rightarrow y_2 \Rightarrow y_3$

$\Downarrow$

$? \Leftarrow y_5 \Leftarrow y_4$

Projection Paradigms

- X-ray on, one at a time, sequentially
  - Conventional CT
- Multiplexed, coded X-ray exposures
  - Bad idea; Poisson noise explosion
- X-ray on, one at a time, sequentially, with modulation
  - Good idea
- X-ray on, one at a time, adaptively
  - Good idea


Thank you