
Pair production tomography (P2T) imaging

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Disclosure

- This study is supported by:
 - DOE DE-SC0017057
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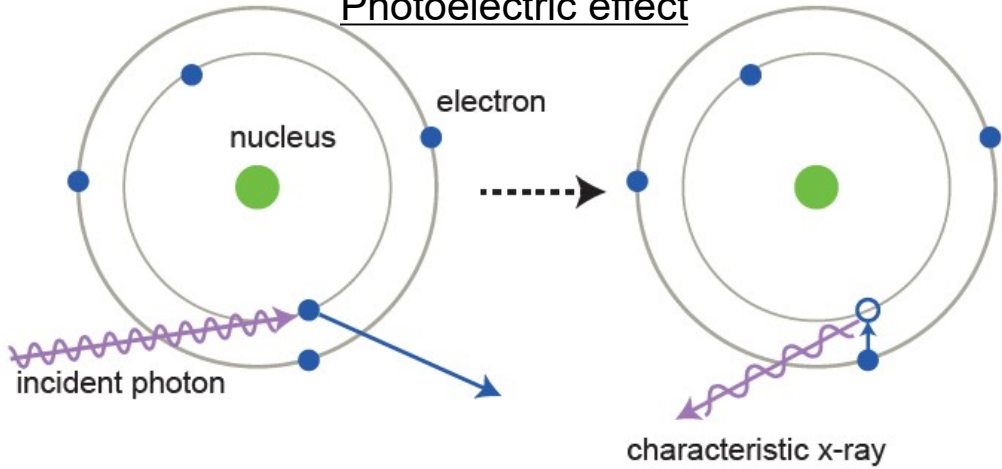
Radiotherapy: an open-loop treatment

- The delivered 3D dose in the patient is not directly verified
- Current research on in-vivo dosimetry is clinically infeasible
 - Implanted dosimeters¹: invasive; only measure point doses.
 - Cerenkov imaging²: limited to superficial locations.
 - X-ray induced acoustic CT (XACT)³: low resolution and signal-to-noise ratio
- Can X-ray treatment beams provide monitoring signals?

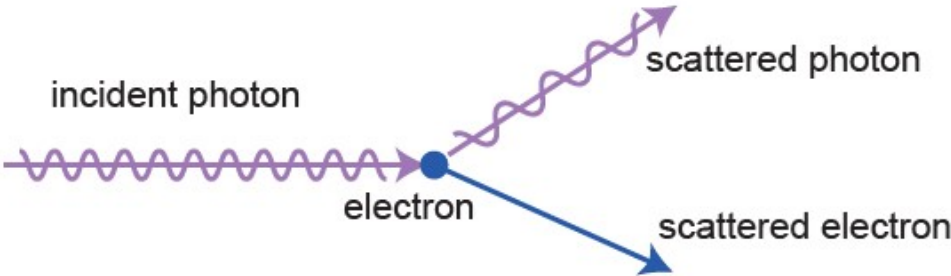


Photon interaction with matter

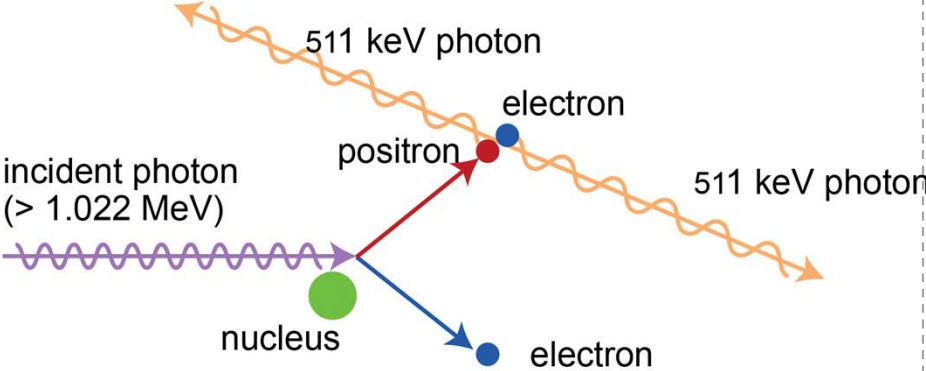
Photoelectric effect



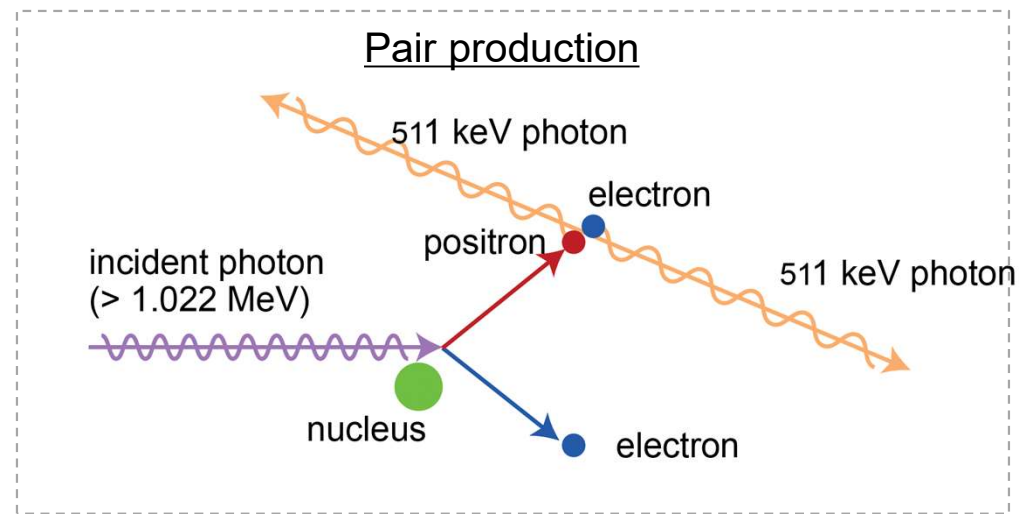
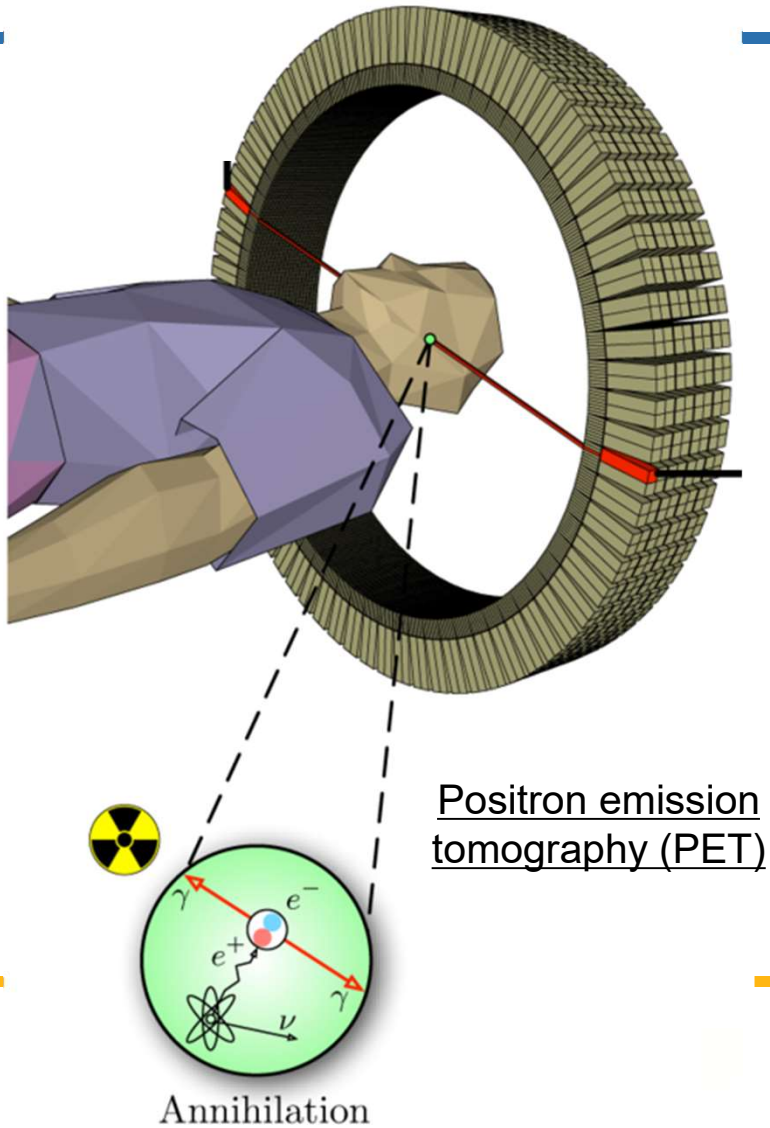
Compton scatter



Pair production

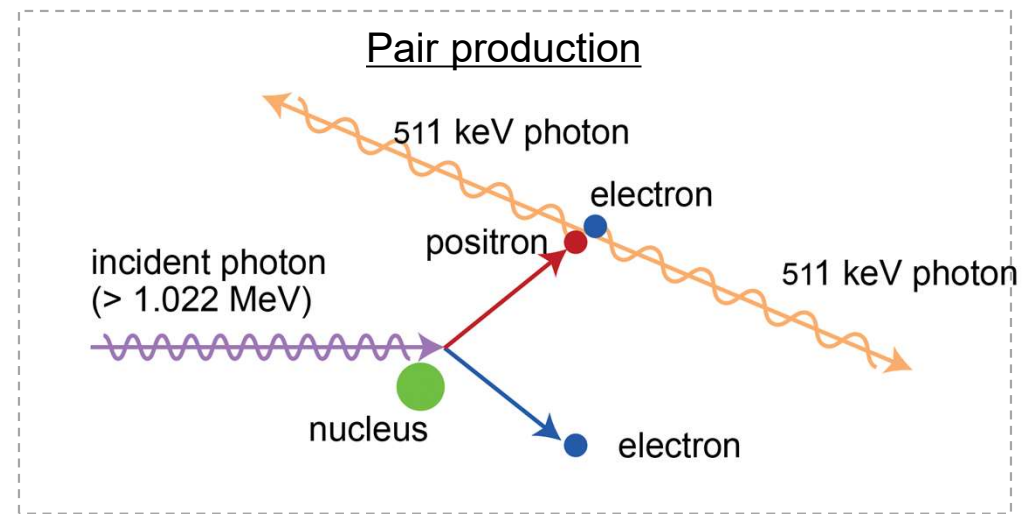
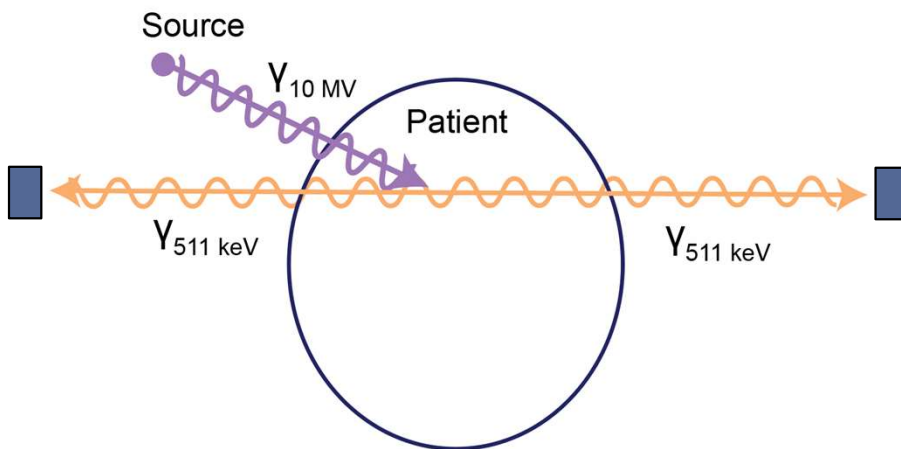


PET vs Pair production

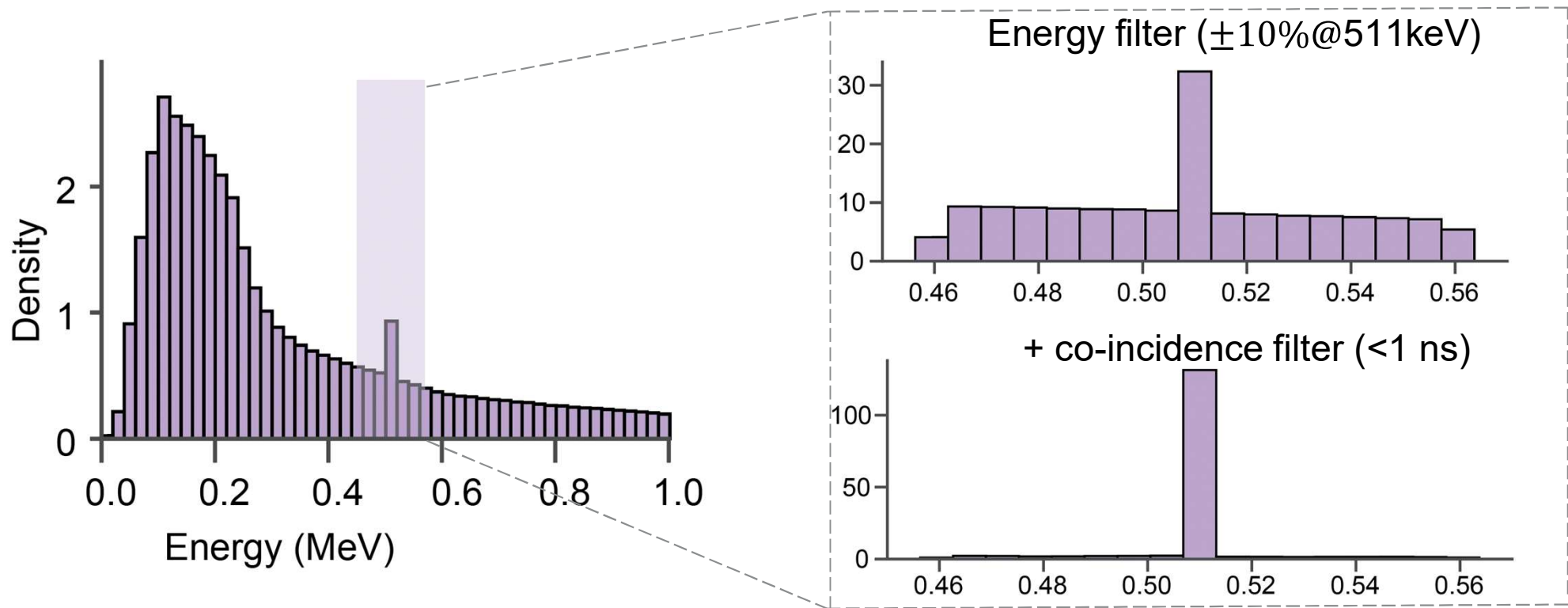


A new imaging mechanism

Pair production events carry information of X-ray fluence

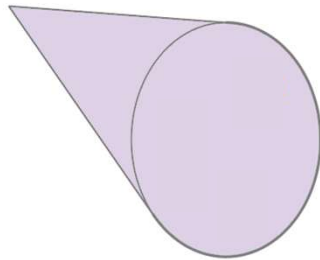


Pair production signals filtered out

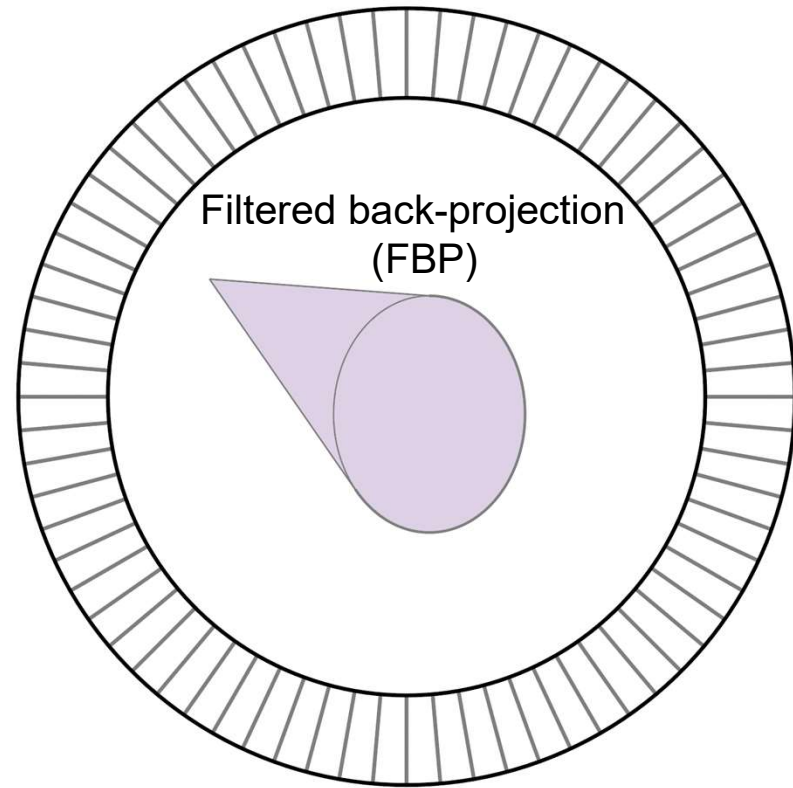


Pair production tomography (P2T)

Ground truth (GT)

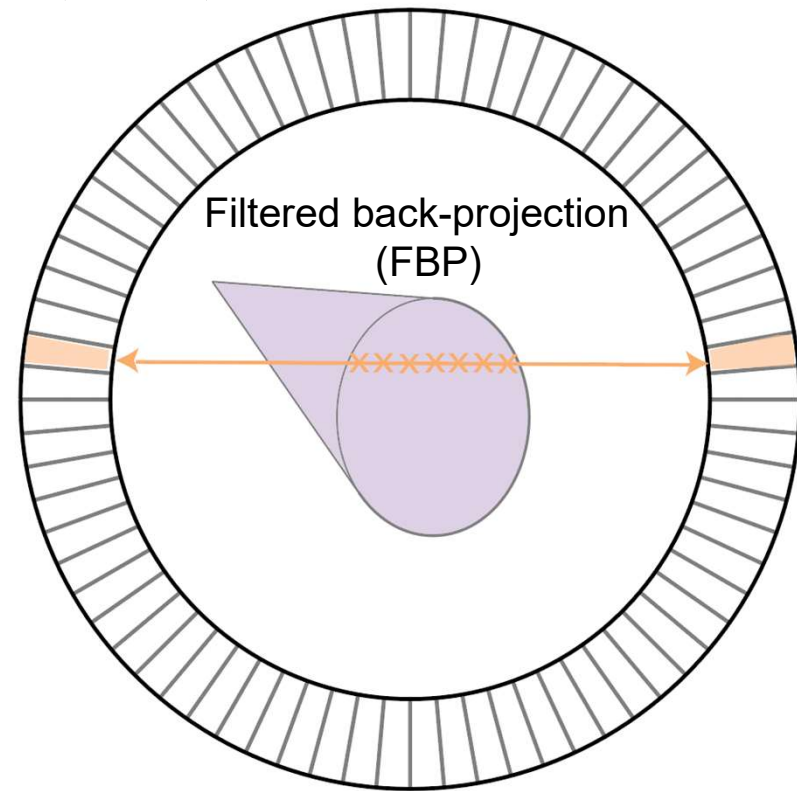
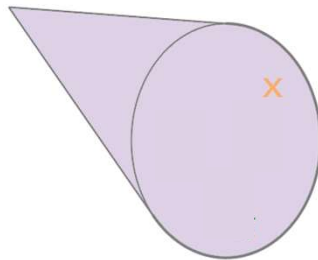


Filtered back-projection (FBP)



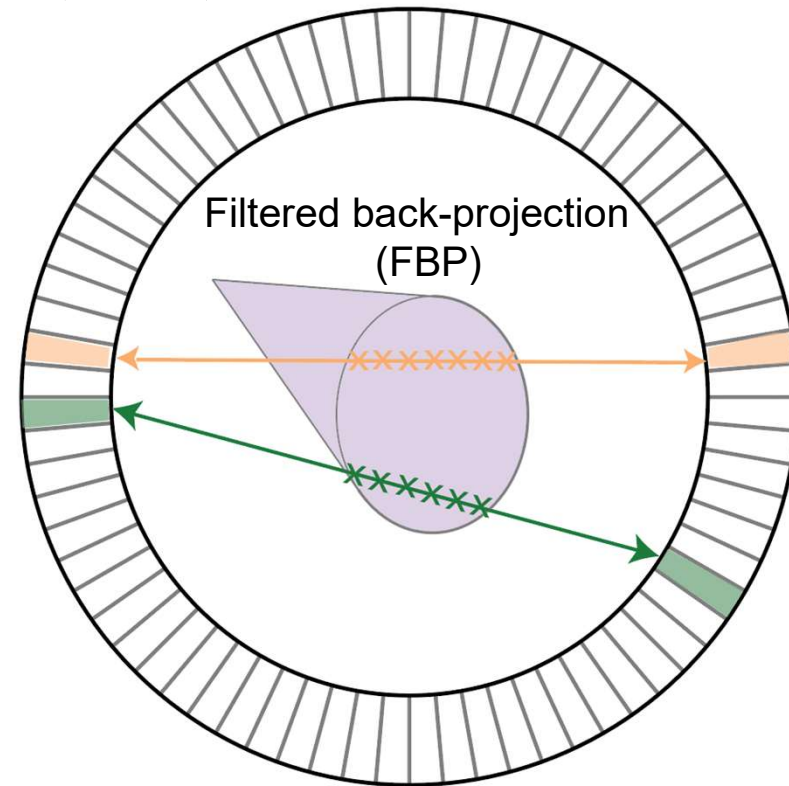
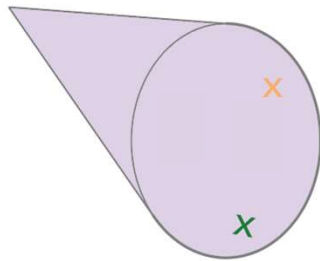
Pair production tomography (P2T)

Ground truth (GT)

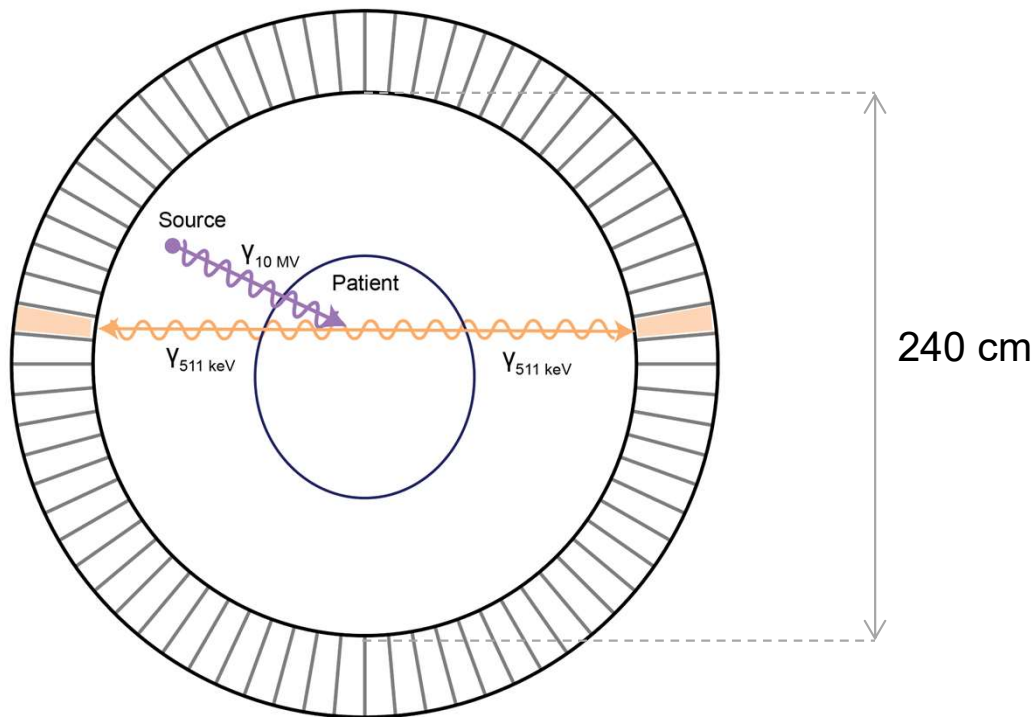


Pair production tomography (P2T)

Ground truth (GT)



P2T image formed in a radiotherapy treatment

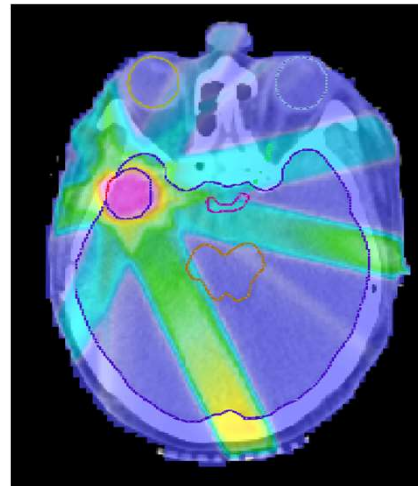
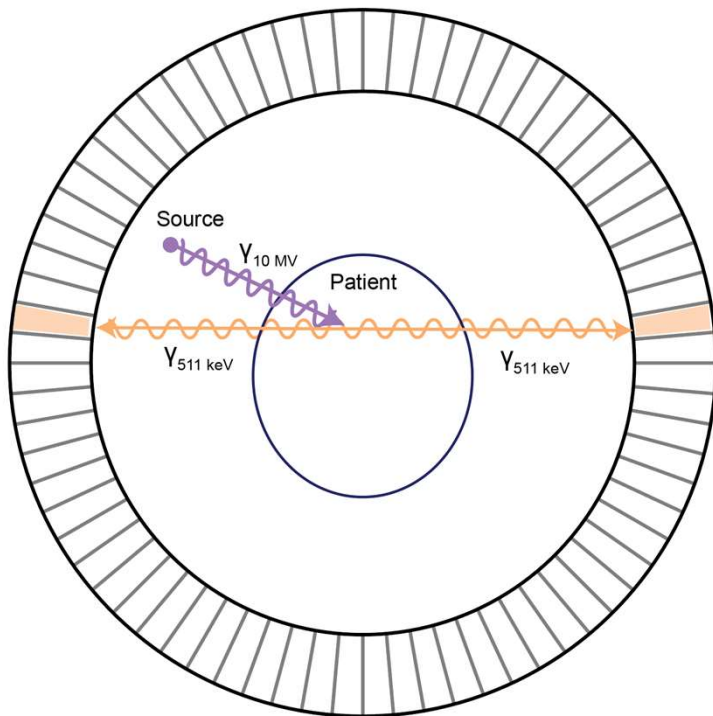


Geometry parameters:

- Detector Radius: 120 cm
- Detector length (Z direction): 10 cm
- Source to Isocenter distance: 100 cm
- Coincident photon time window: 1 ns
- Detector energy window: $\pm 10\%$



P2T image formed in a radiotherapy treatment



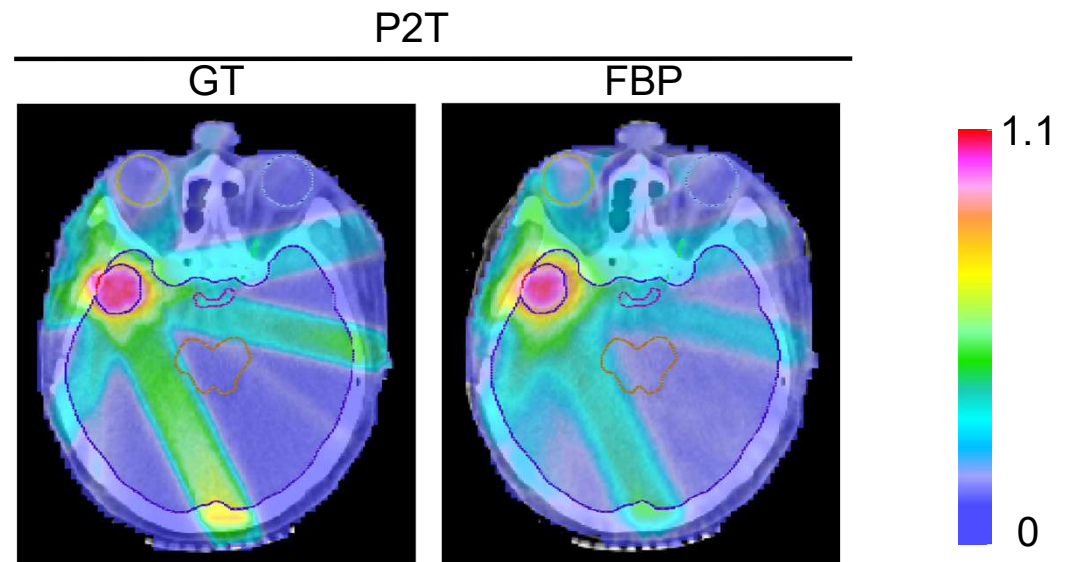
- 7-beam coplanar IMRT plan
- 10MV X-ray
- 2Gy fraction treatment, GBM
- 221.2 billion primary particles simulated



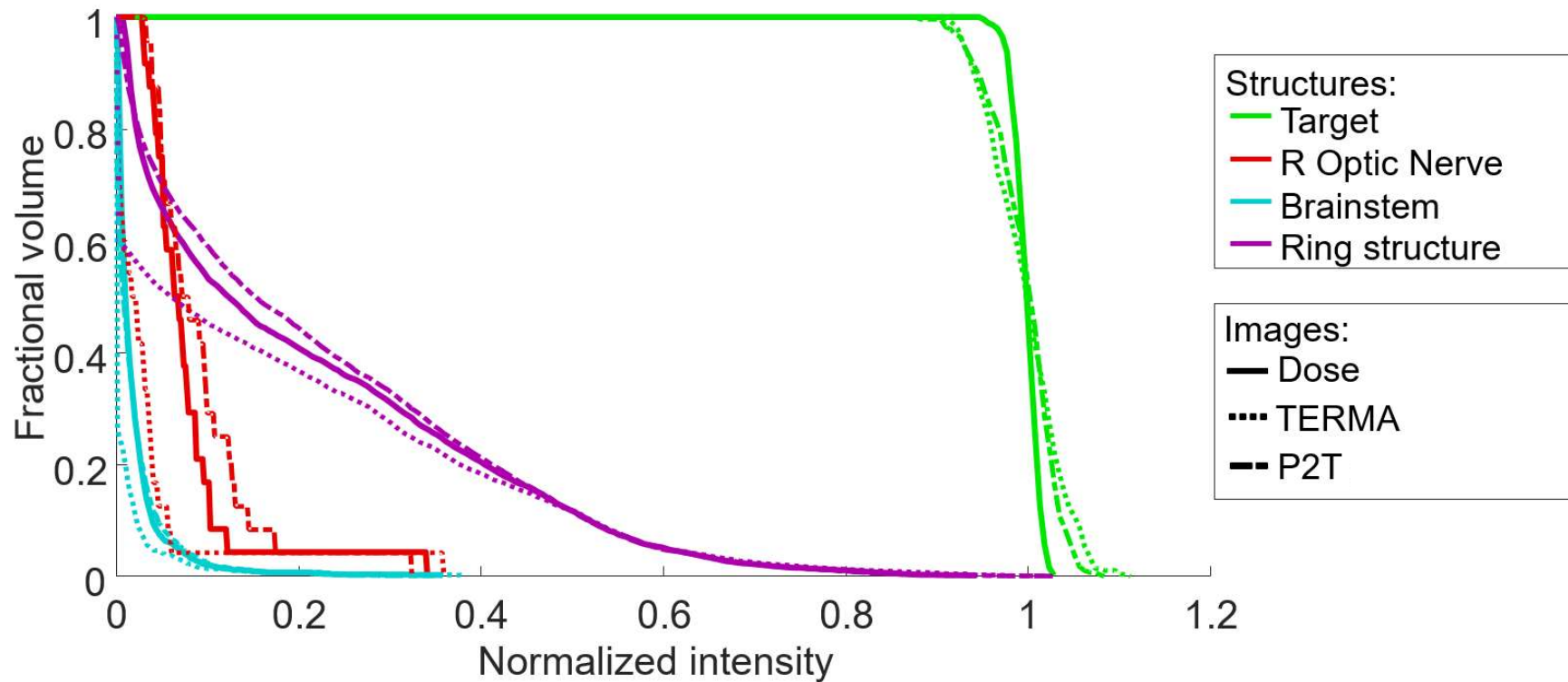
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P2T image formed in a radiotherapy treatment



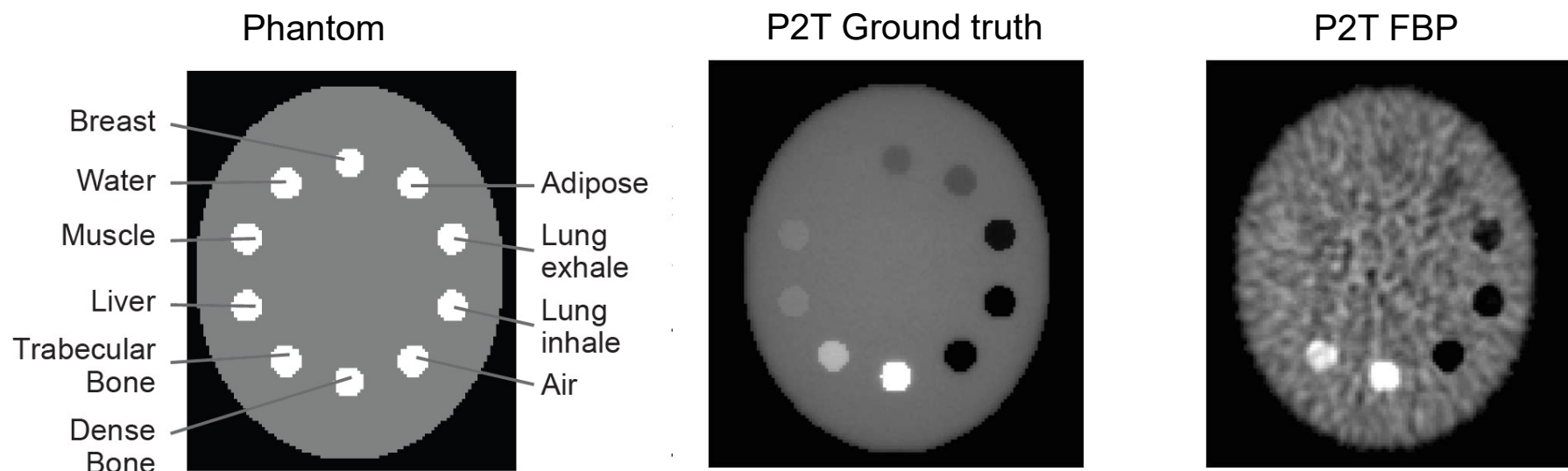
P2T provides real-time radiotherapy dose monitoring



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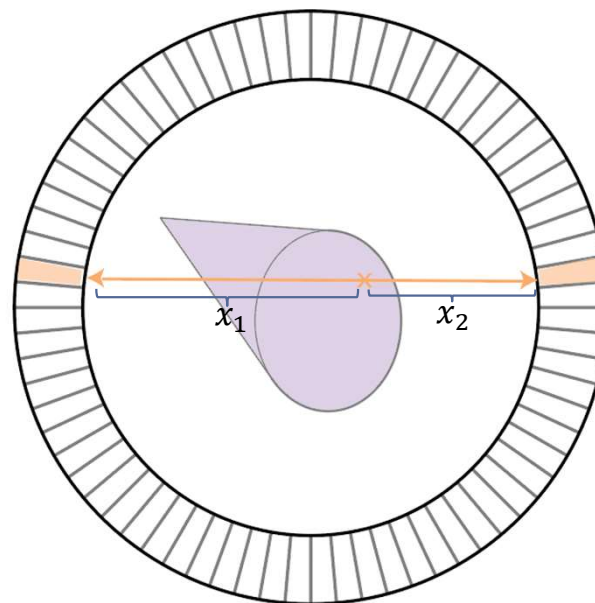
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P2T as an image modality



A higher detector time resolution

Time-of-flight (TOF) method assuming $\Delta T = 20$ ps

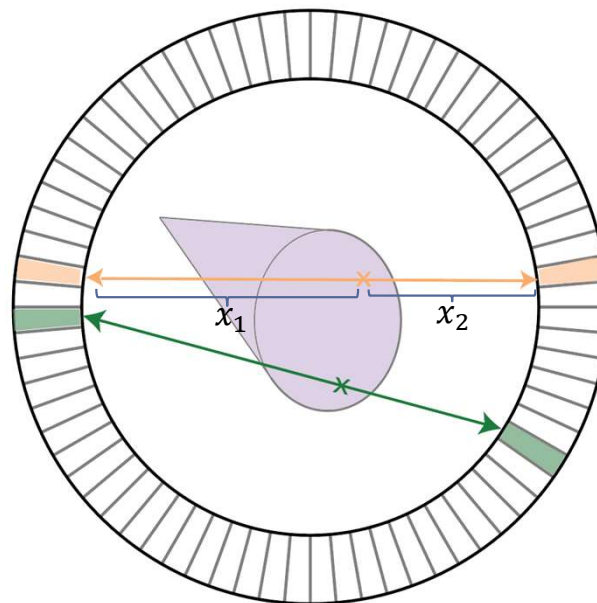


$$x_1 - x_2 = c \delta t$$



A higher detector time resolution

Time-of-flight (TOF) method assuming $\Delta T = 20$ ps

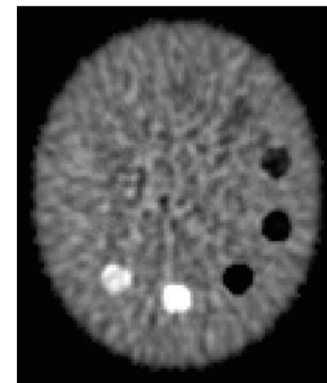
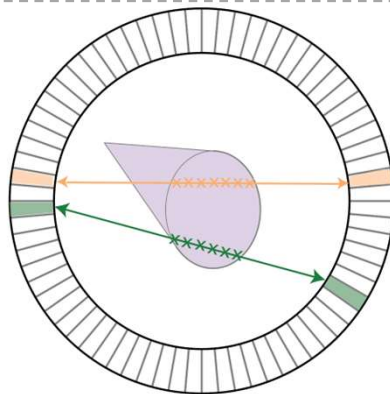


$$x_1 - x_2 = c \delta t$$

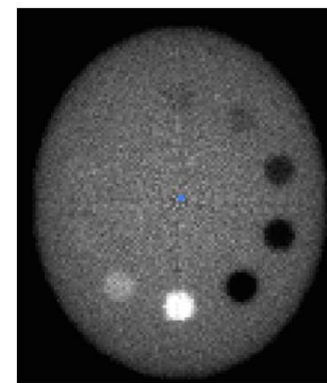
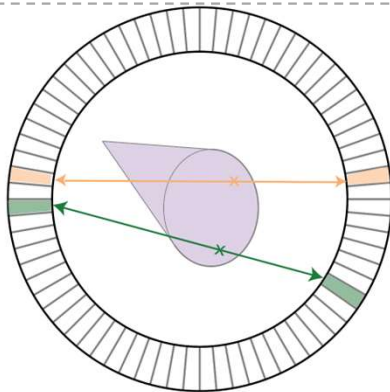


Improved image signal to noise ratio

Filtered back-projection (FBP)
 $\Delta T = 300$ ps



Time-of-flight (TOF)
 $\Delta T = 20$ ps

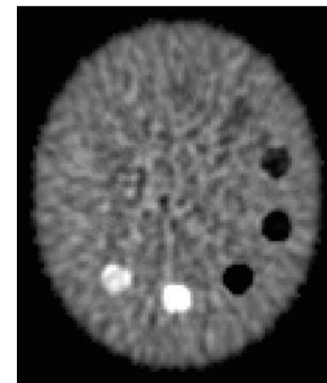
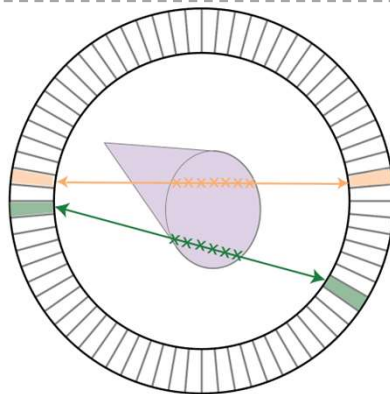


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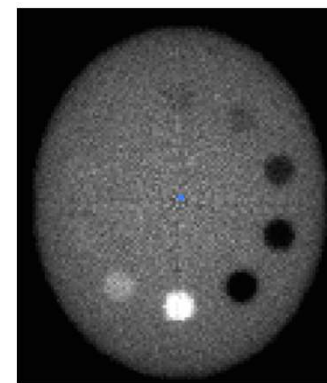
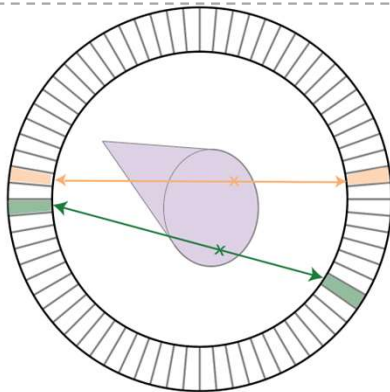
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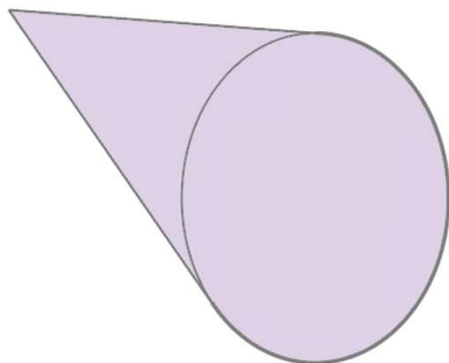


Time-of-flight (TOF)
 $\Delta T = 20$ ps
↑
Technically challenging

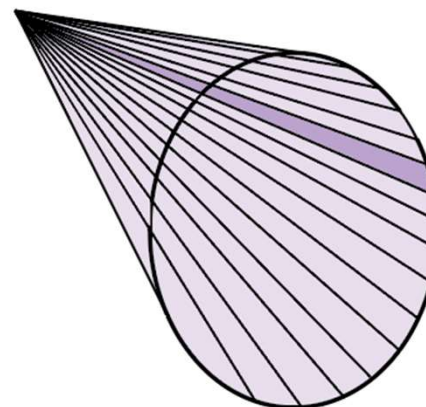


A different excitation method

Volume excitation

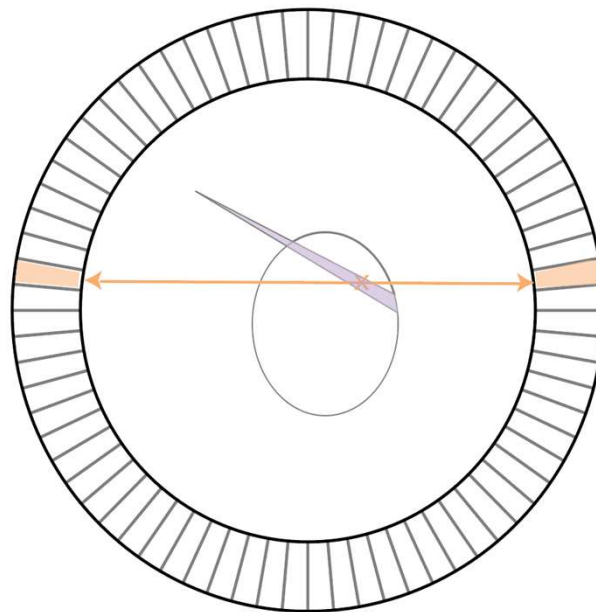


Scanning Pencil Beam excitation



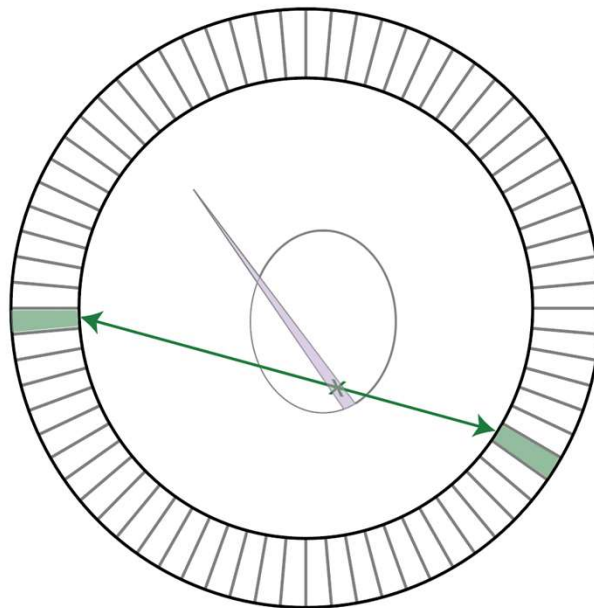
Scanning Pencil Beam excitation

Technically achievable, detector time resolution $\Delta T = 300$ ps



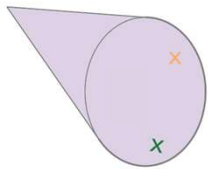
Scanning Pencil Beam excitation

Technically achievable, detector time resolution $\Delta T = 300$ ps

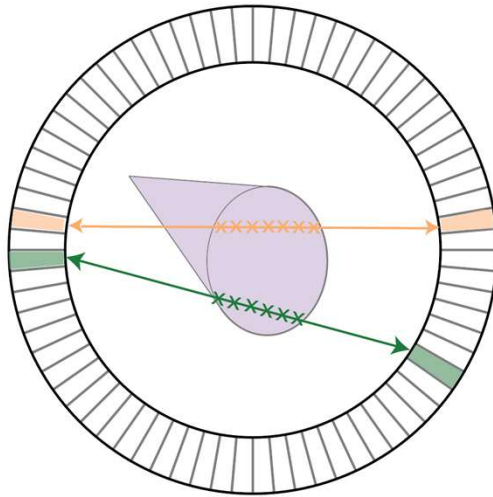


P2T image acquisition methods

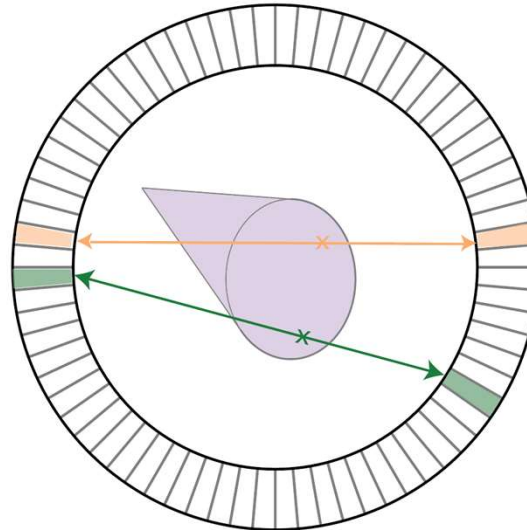
Ground truth (GT)



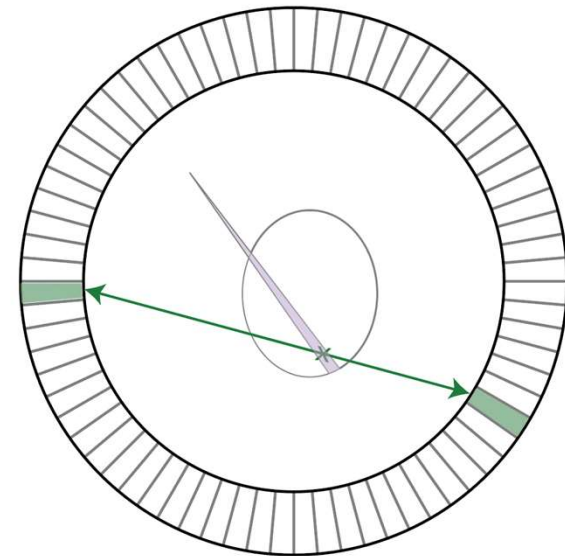
Filtered back-projection (FBP)
 $\Delta T = 300$ ps



Time-of-flight (TOF)
 $\Delta T = 20$ ps



Scanning pencil beam (SPB)
 $\Delta T = 300$ ps



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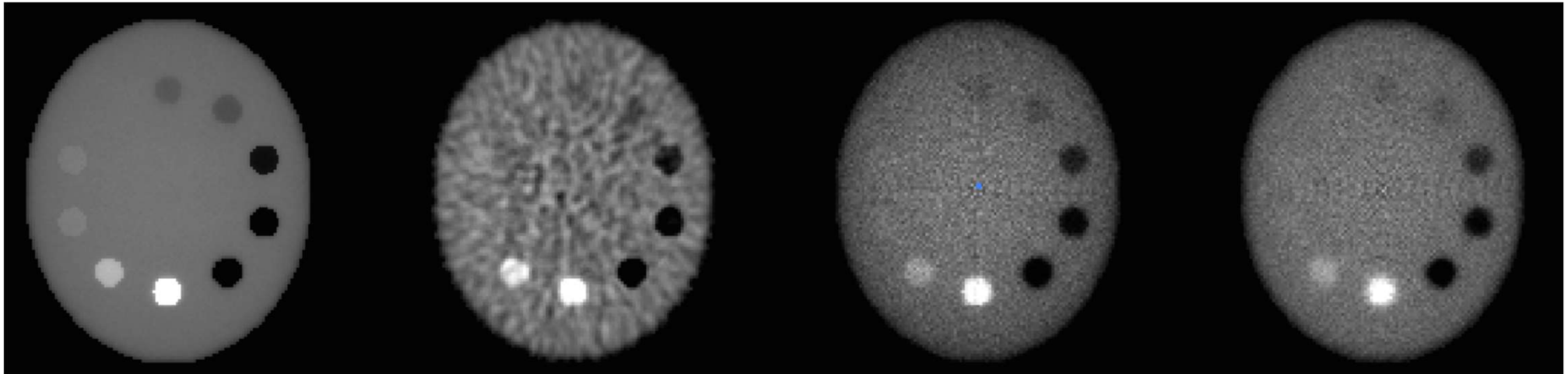
P2T image acquisition methods

Ground truth (GT)

Filtered back-projection (FBP)
 $\Delta T = 300$ ps

Time-of-flight (TOF)
 $\Delta T = 20$ ps

Scanning pencil beam (SPB)
 $\Delta T = 300$ ps

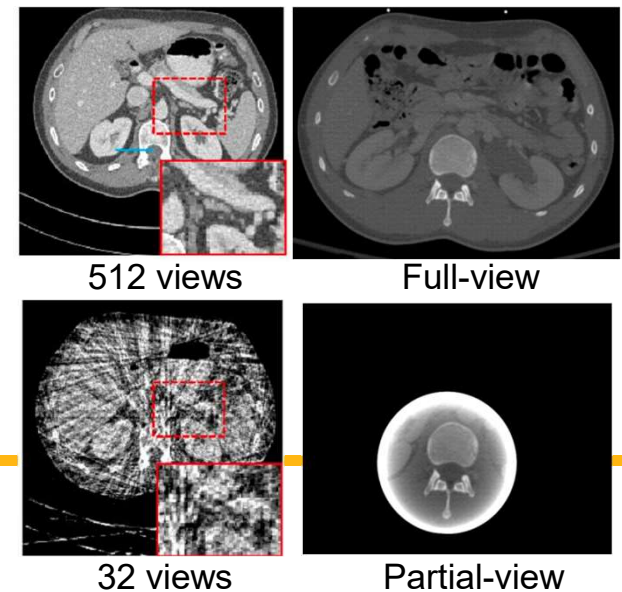


Computed Tomography: an X-ray attenuation map

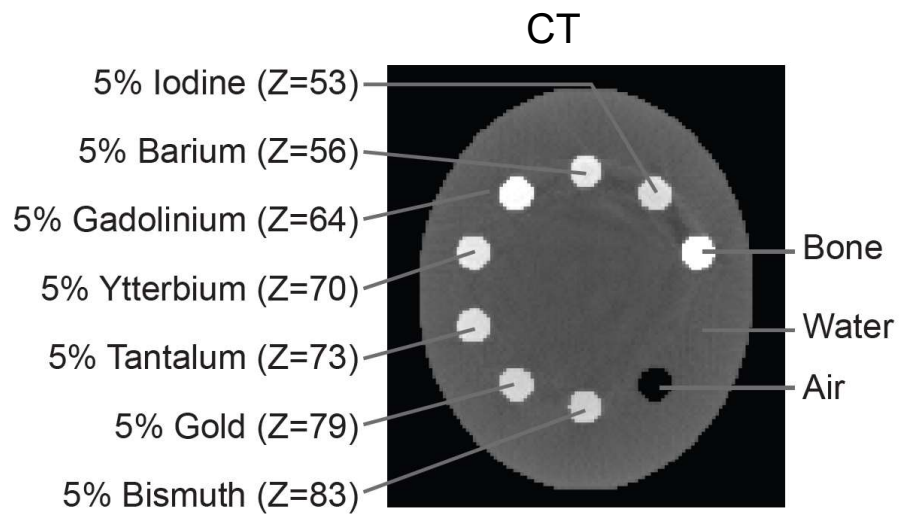
- Disadvantages:

- Material differentiation is difficult ← Mixture of interactions
- Poor soft tissue contrast ← Compton scatter
- Requires many beam angles and full X-ray coverage ← Radon transform

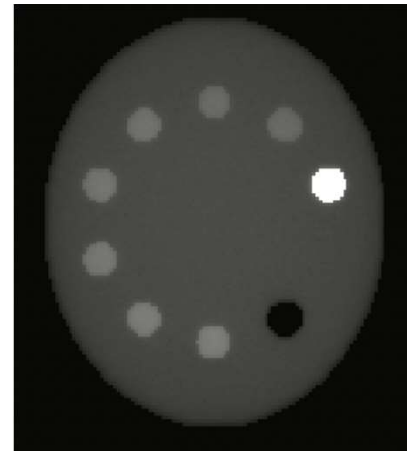
P2T addresses these limitations as it only depends on pair production



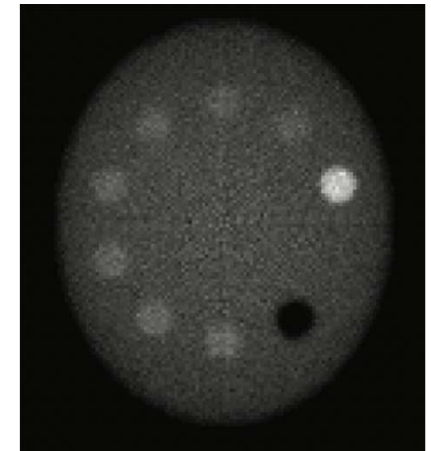
CT vs P2T



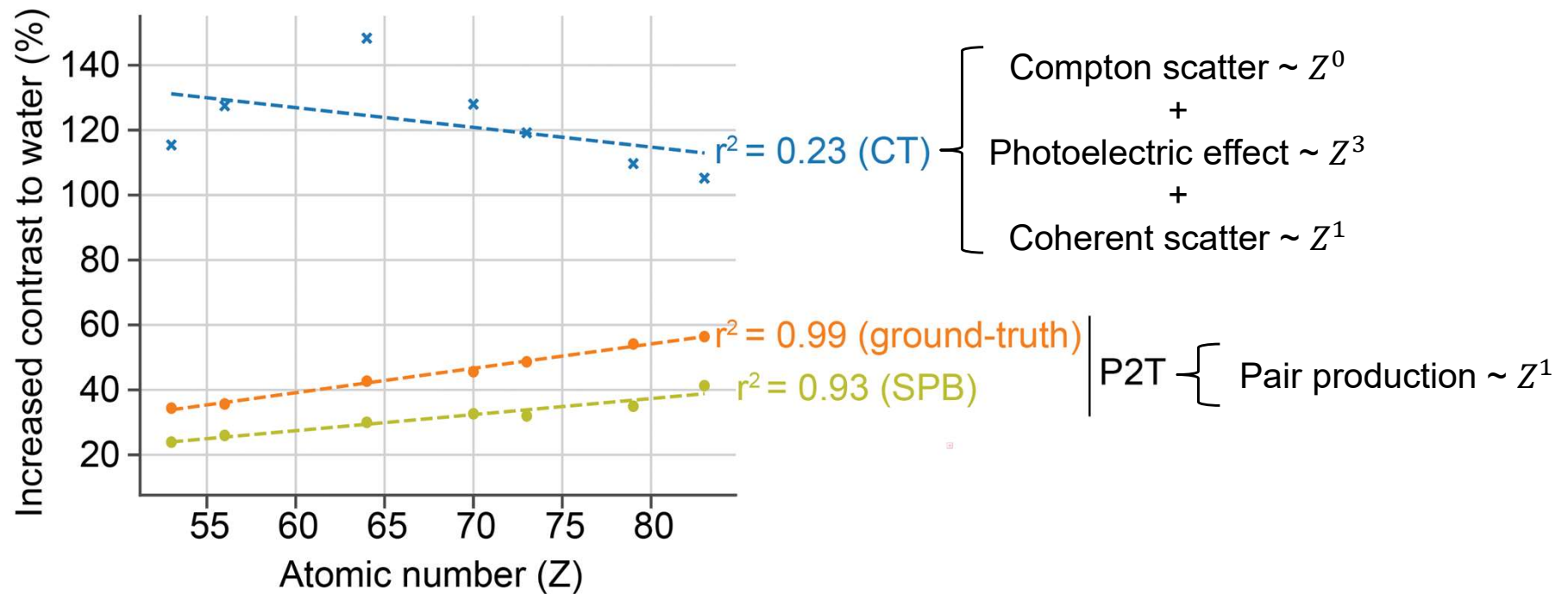
P2T Ground truth



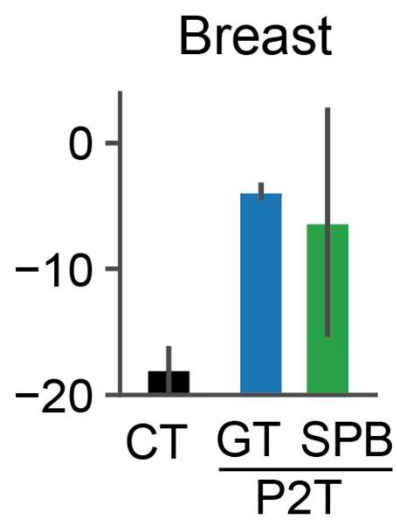
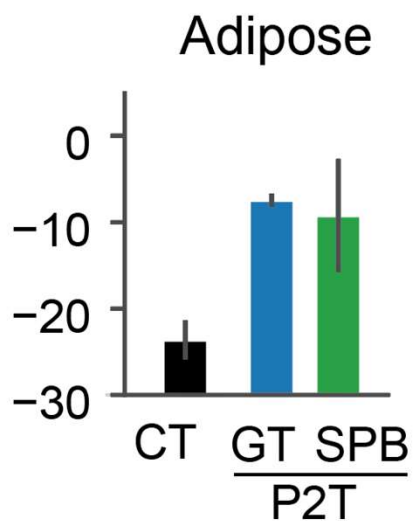
P2T SPB



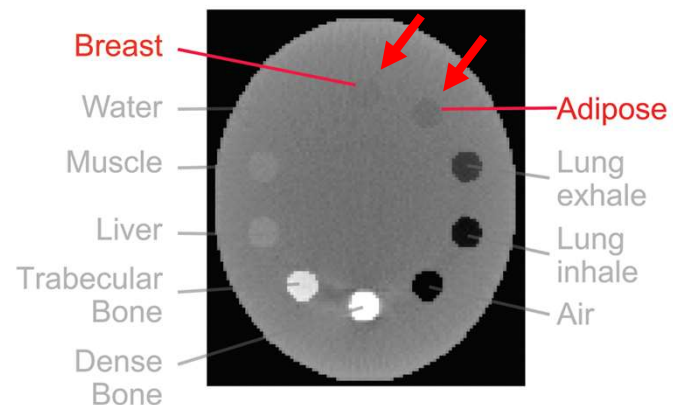
P2T signal is linear to atomic number Z



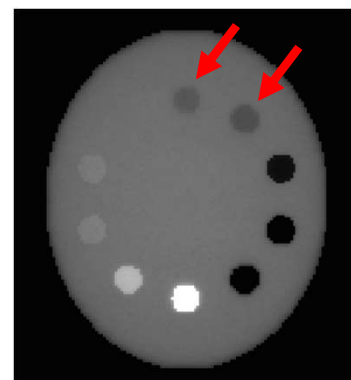
P2T improves low-Z contrast



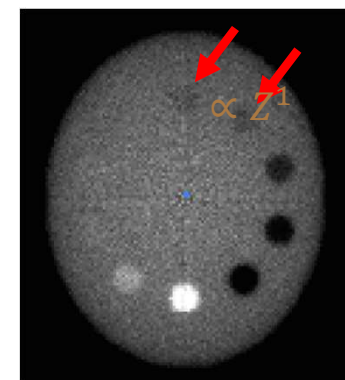
CT $\propto Z^0$ (Compton dominant)



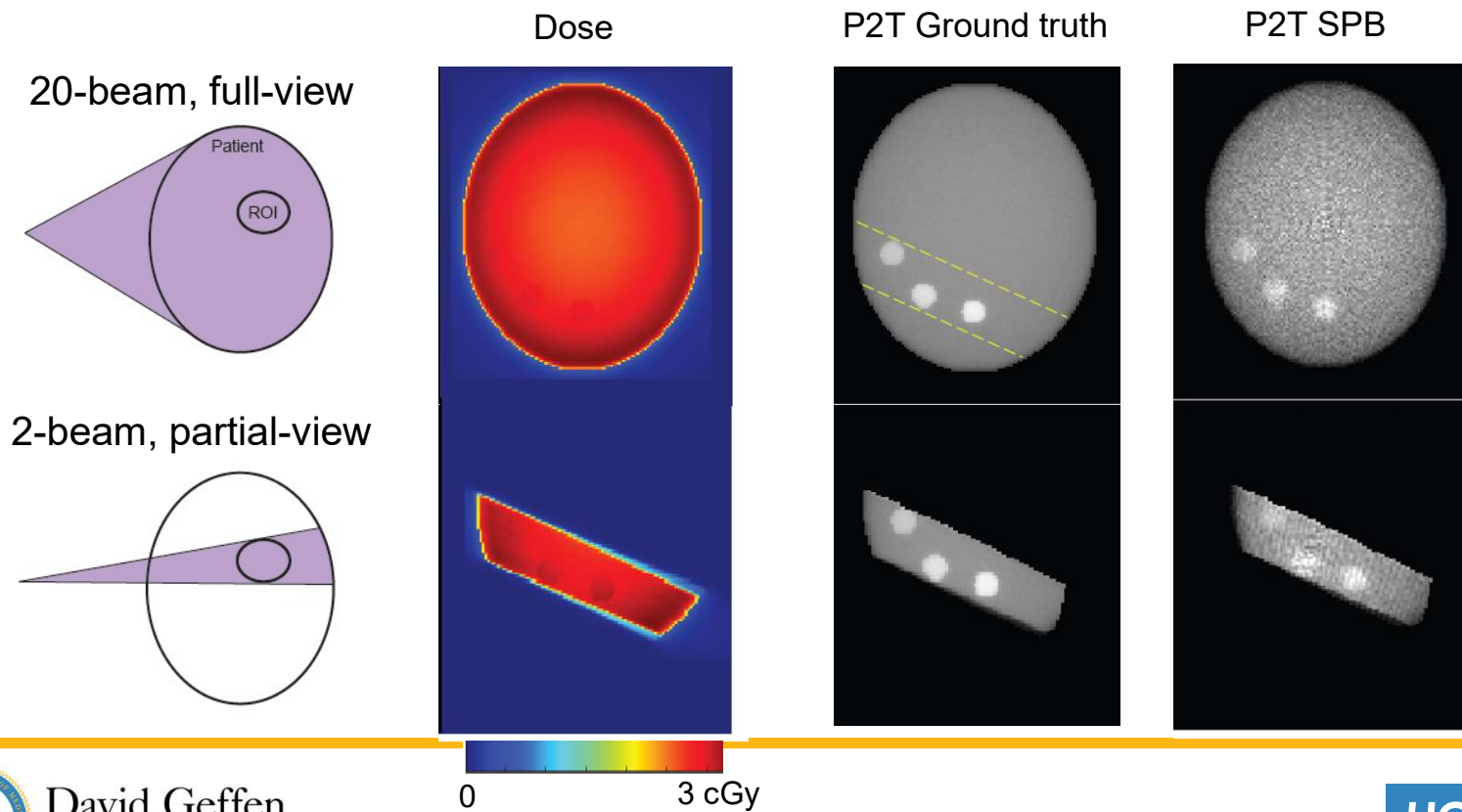
P2T Ground truth $\propto Z^1$



P2T SPB



P2T natively allows partial-view and sparse-angle imaging



Conclusion

- We proposed P2T, a novel image formation method using pair production to form tomography image
- P2T provides real-time radiation dose monitoring
- P2T imaging provides different image properties than CT
 - Linear relationship to atomic number Z
 - Improved image contrast for low Z materials
 - Allow partial-view and limited-view imaging



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Sheng Lab



David Geffen
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