3Dπ scanner, an application in medical physics of the DarkSide collaboration

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On behalf of the 3Dπ TB-TOF-PET Collaboration

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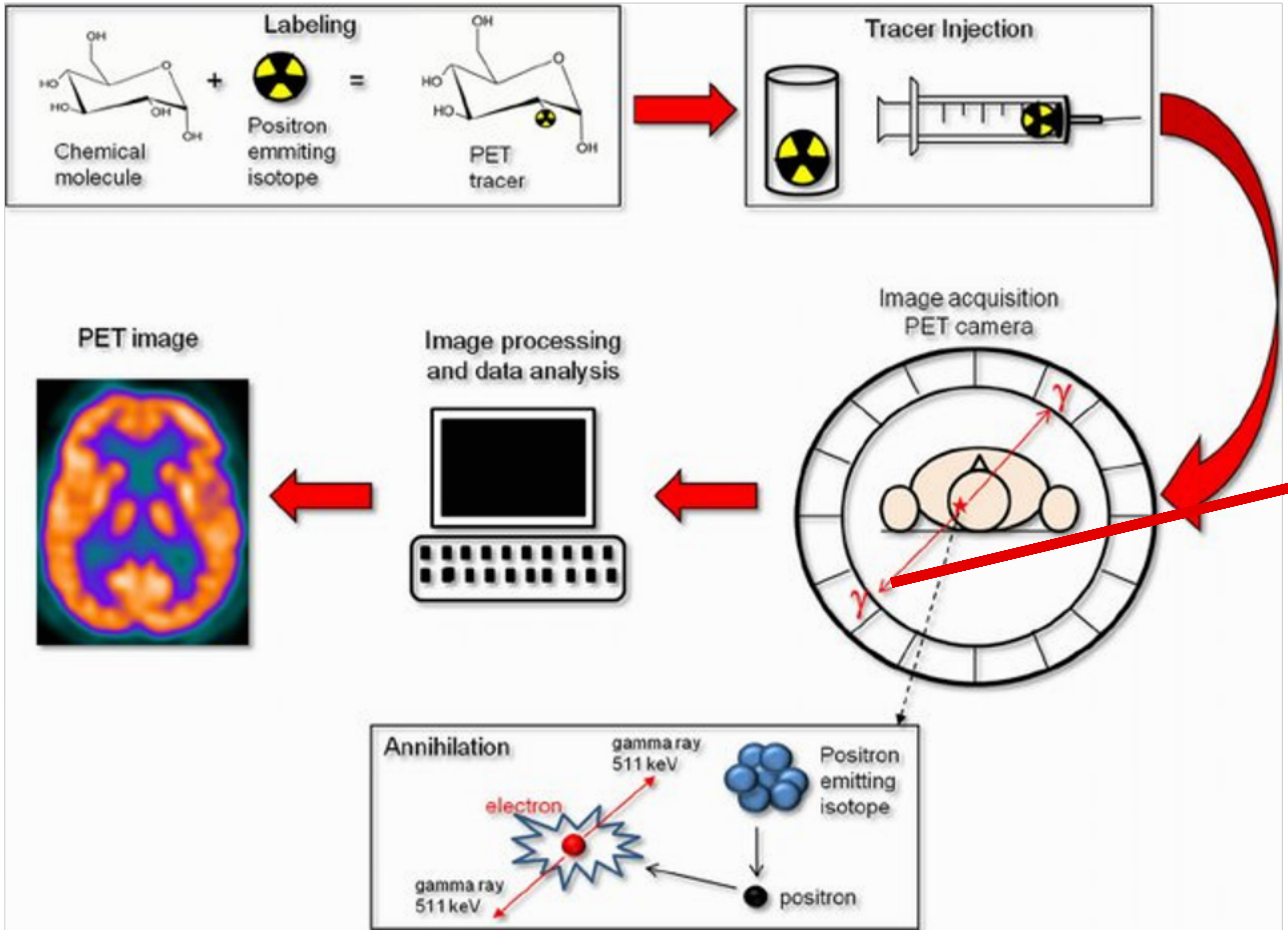
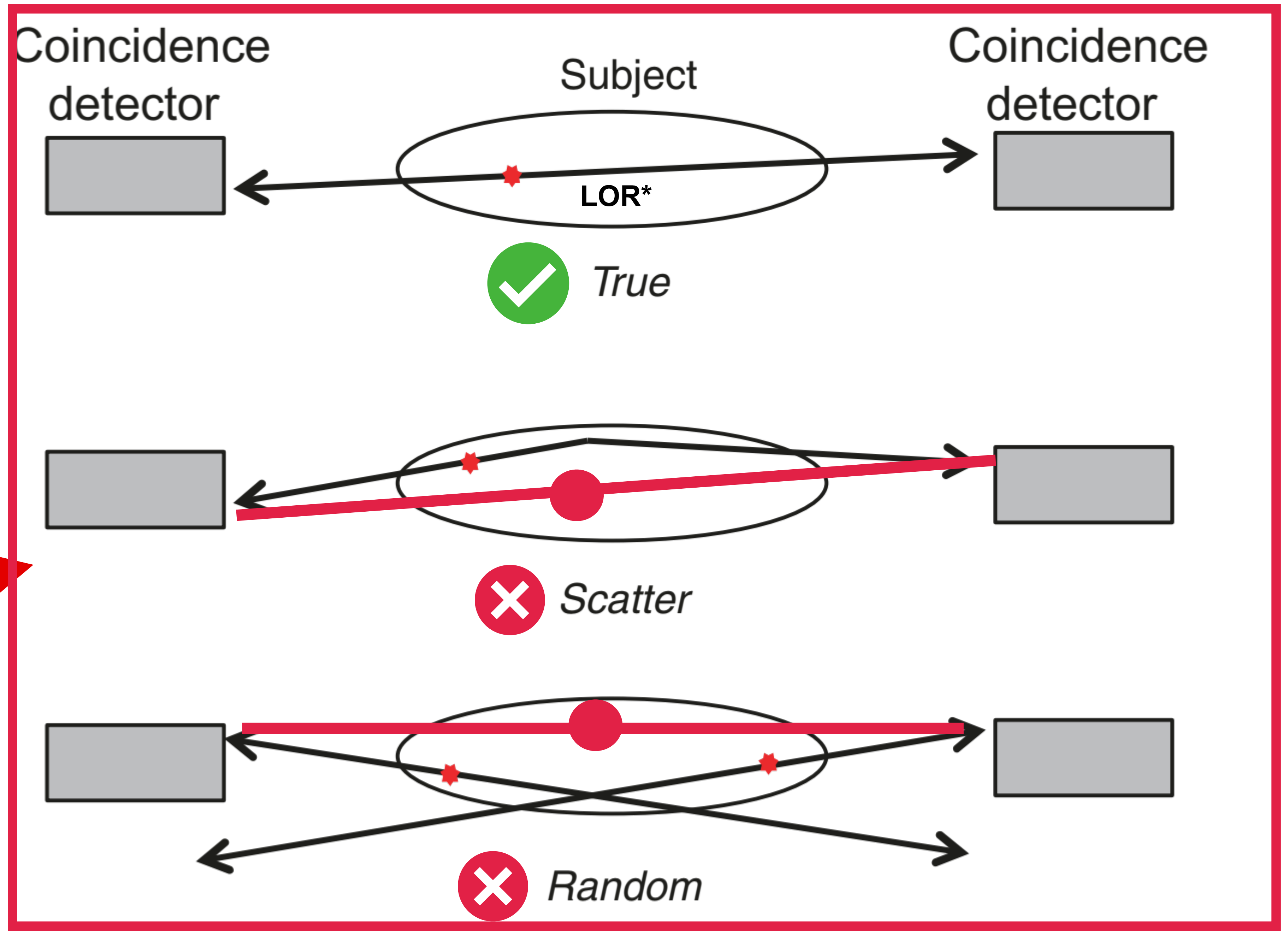
Dark Wave



Credit: https://www.researchgate.net/publication/262189675_PET_imaging_in_multiple_sclerosis

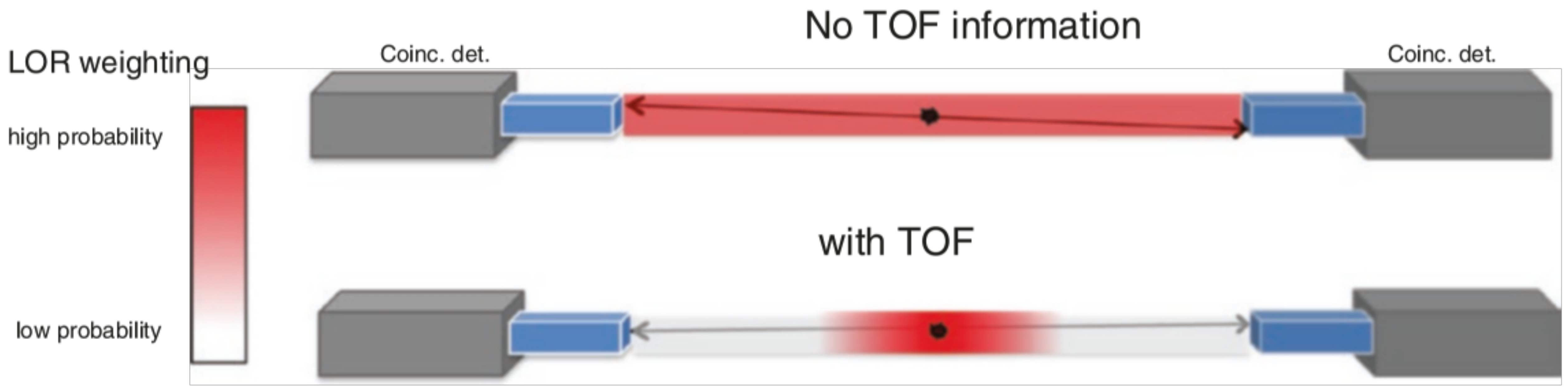


* Line Of Response

Three types of coincident events

Conventional PET vs. Time of Flight (TOF) PET

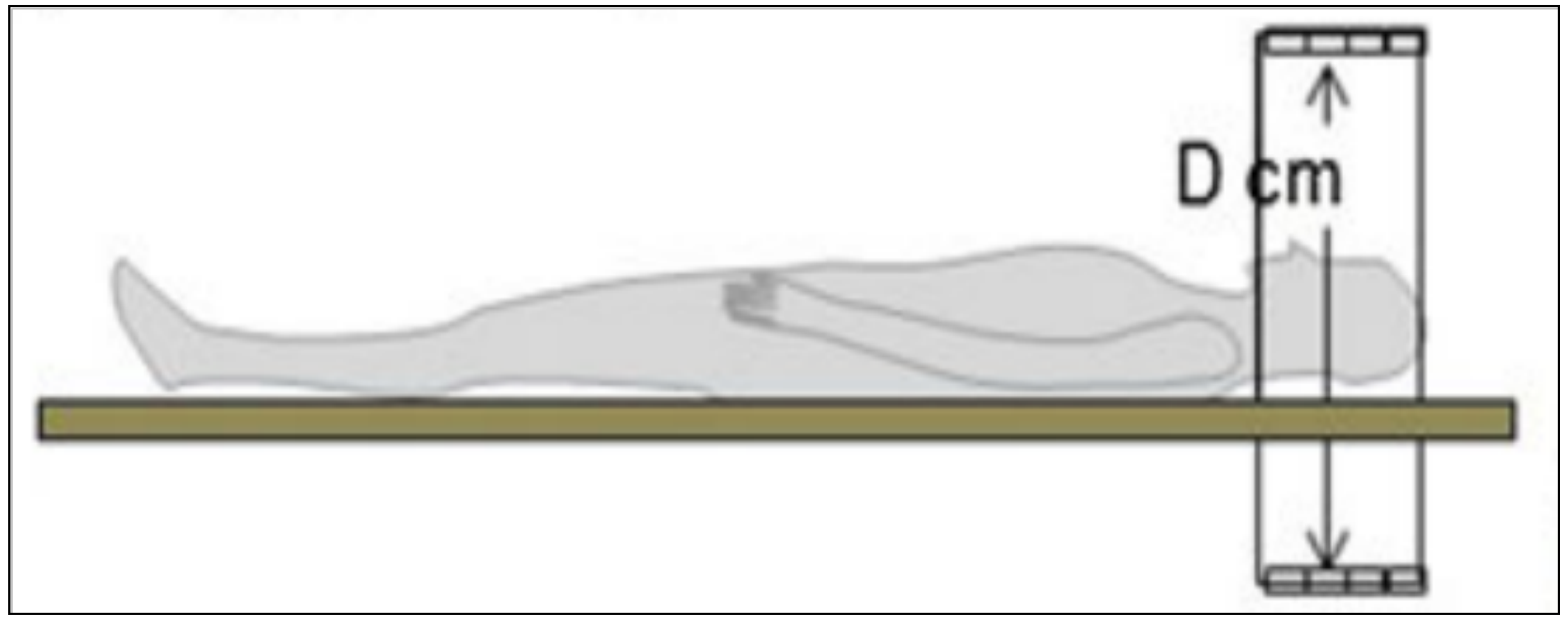
Routine PET vs. Total-Body PET (TB-PET)

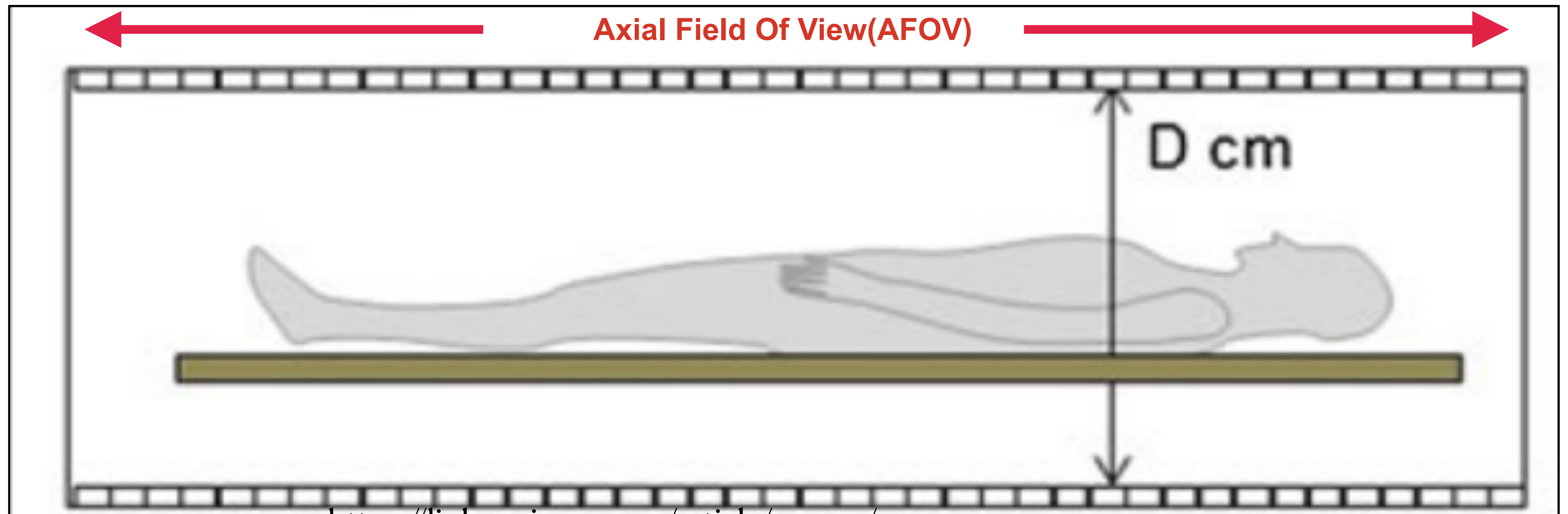


https://link.springer.com/book/10.1007/978-3-319-40070-9

TOF-PET

✦Limiting the event localization probability along the line of response (LOR)
✦**Better locate the annihilation position** of the emitted positron





https://link.springer.com/article/10.1007/s12194-013-0253-y

Total body

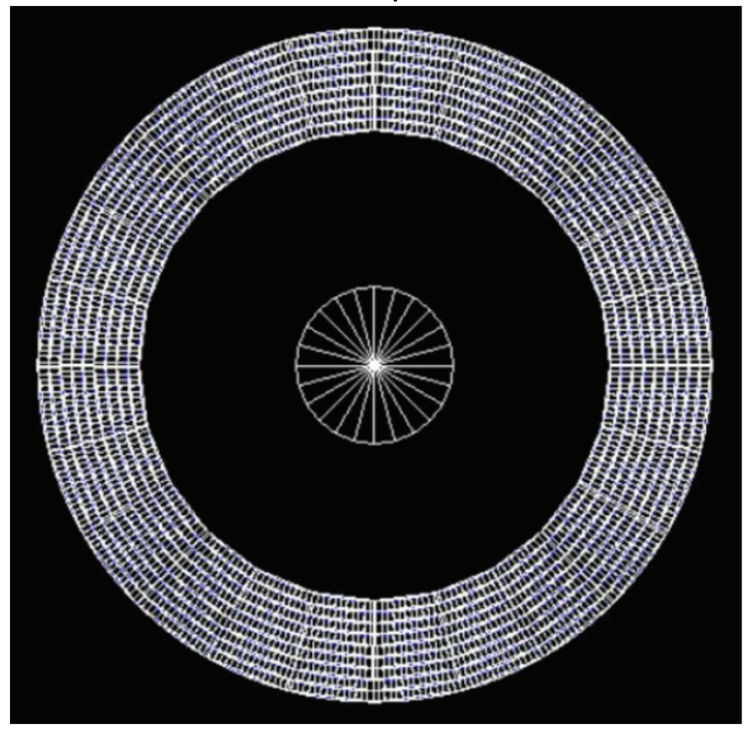
✦Trace whole-body uptake images at the same time
✦**Improve the sensitivity** dynamically
✦**Reduce the scan time** dramatically

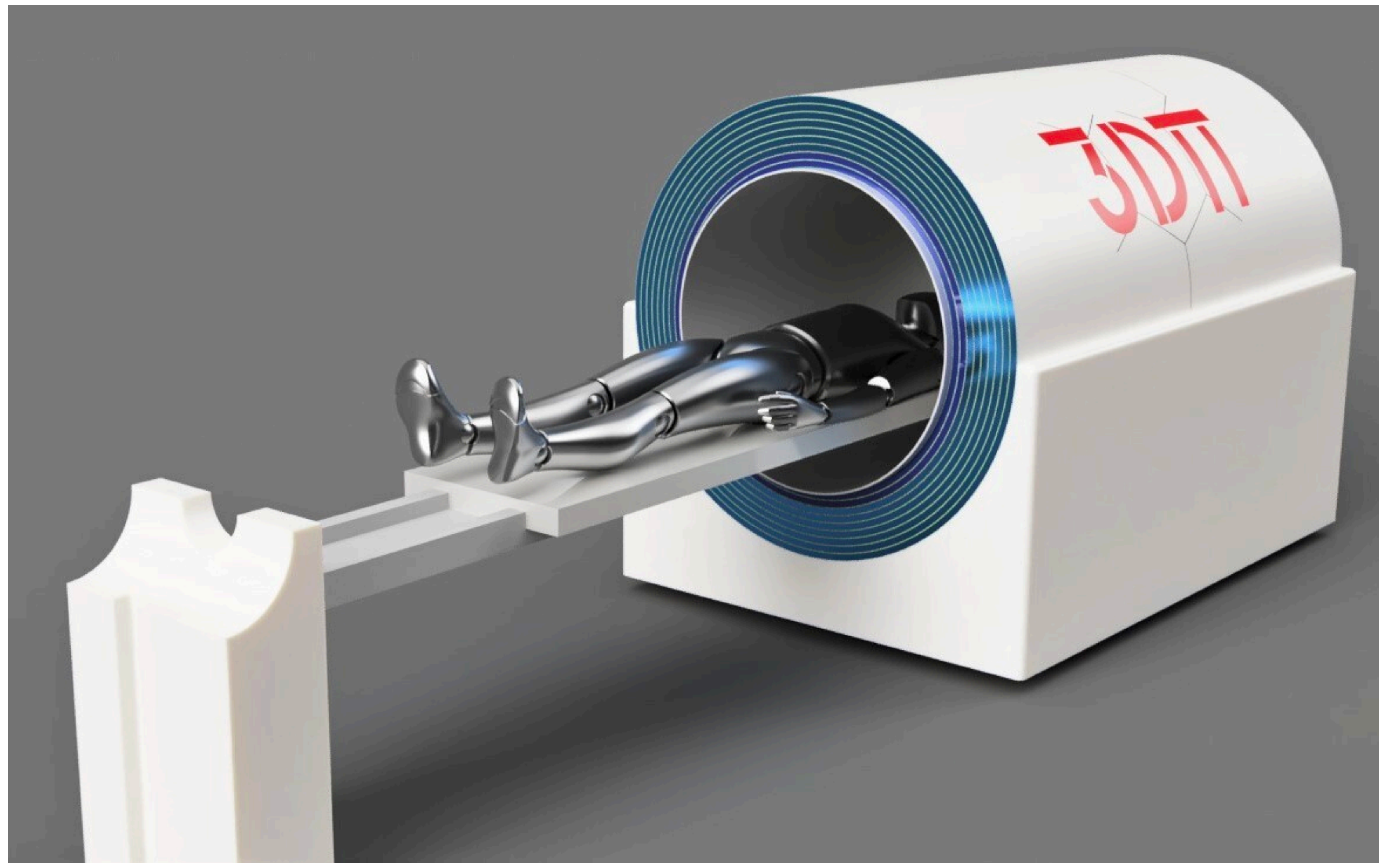
Our 3-Dimensional Positron Emission Tomography scanner (3DPi)
Monte Carlo Simulation

- Length: 2 m (Total Body)
- Inner radius: 45 cm
- Outer radius: 64 cm
- 9 annulus detection rings (Multiple layers)
- Each ring has Liquid Argon sandwiched Between two layers of SiPMs

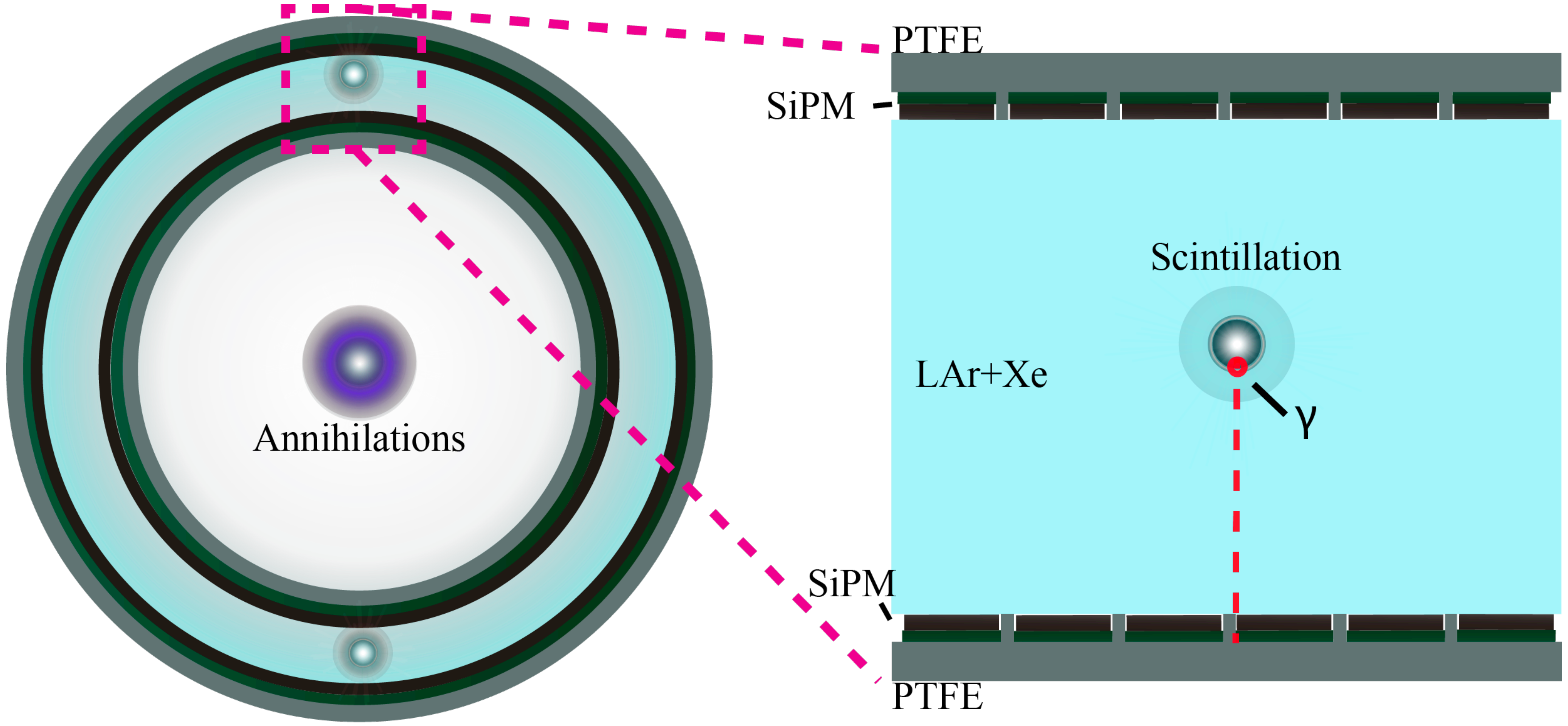
- SiPM size: 10×10 mm^2
- Number of SiPMs ~10^6 channels
- PTFE (Teflon) supporting structure

Geant4 Geometry Cross-section





Fusion 360 CAD model render of the 3Dπ geometry



(A)
Single detection layer of the 3Dπ detector with the LAr+Xe scintillation conguration.

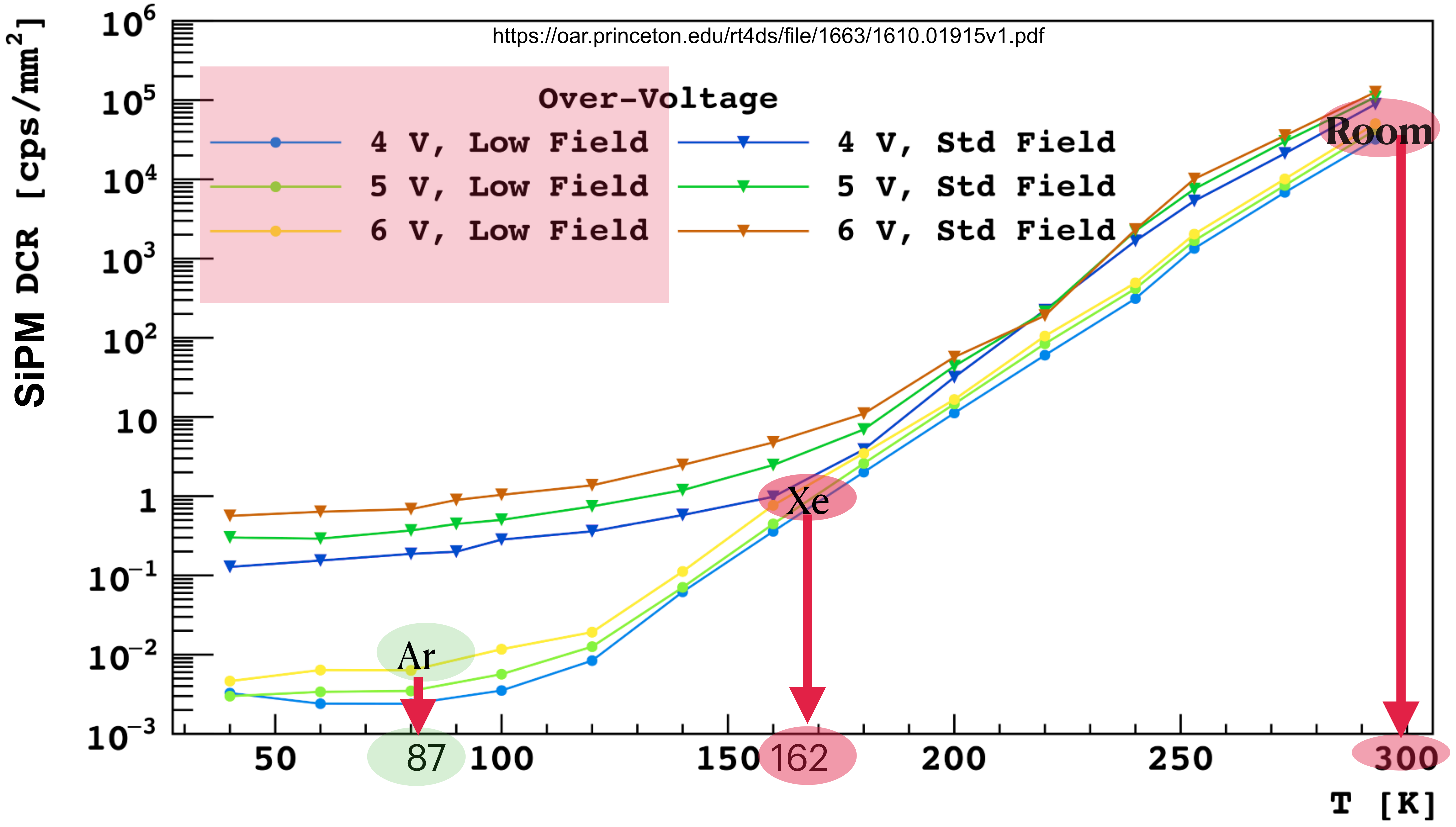
(B)
Each detection layer contains bottom and top layer of PTFE supporting material with an array of SiPMs.

Liquid Xenon vs. Liquid Argon

Credit: arXiv:1403.0525

Property	LAr	LXe	LAr+LX
Fast decay time (ns)	7	4.3	~6
Slow decay time (ns)	1600	22	~100
Light yield (Photons/keV)	40	42	41
Wavelength (nm)	128	175	~175
Density (g/cm3)	1.40	2.94	~1.40
Temperature (K)	87	162	87
Cost (US$/kg)	~2	~2000	~2

SiPM Dark Count Rate (DCR) vs. Temperature



Reduction in the dark count rate improves the timing capability of the devices

Combine the advantages of both ===>Xenon-doped Liquid Argon (Xe concentration ~100 ppm)

- Scintillation light at a wavelength of 175 nm (as a WLS)
- Operation at temperatures close to the argon boiling point, so don't need cooling down and have lower DCR
- Shorter slow decay time than the pure liquid argon

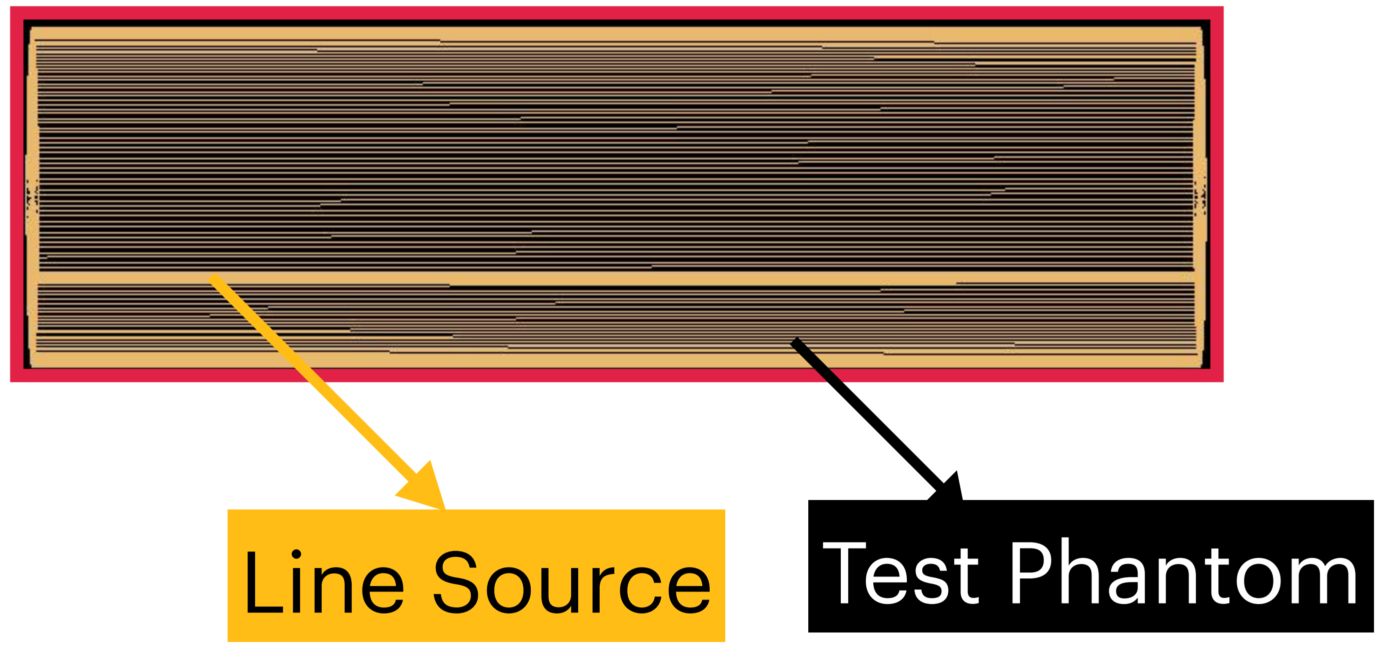
National Electrical Manufacturers Association, NEMA NU 2–2018

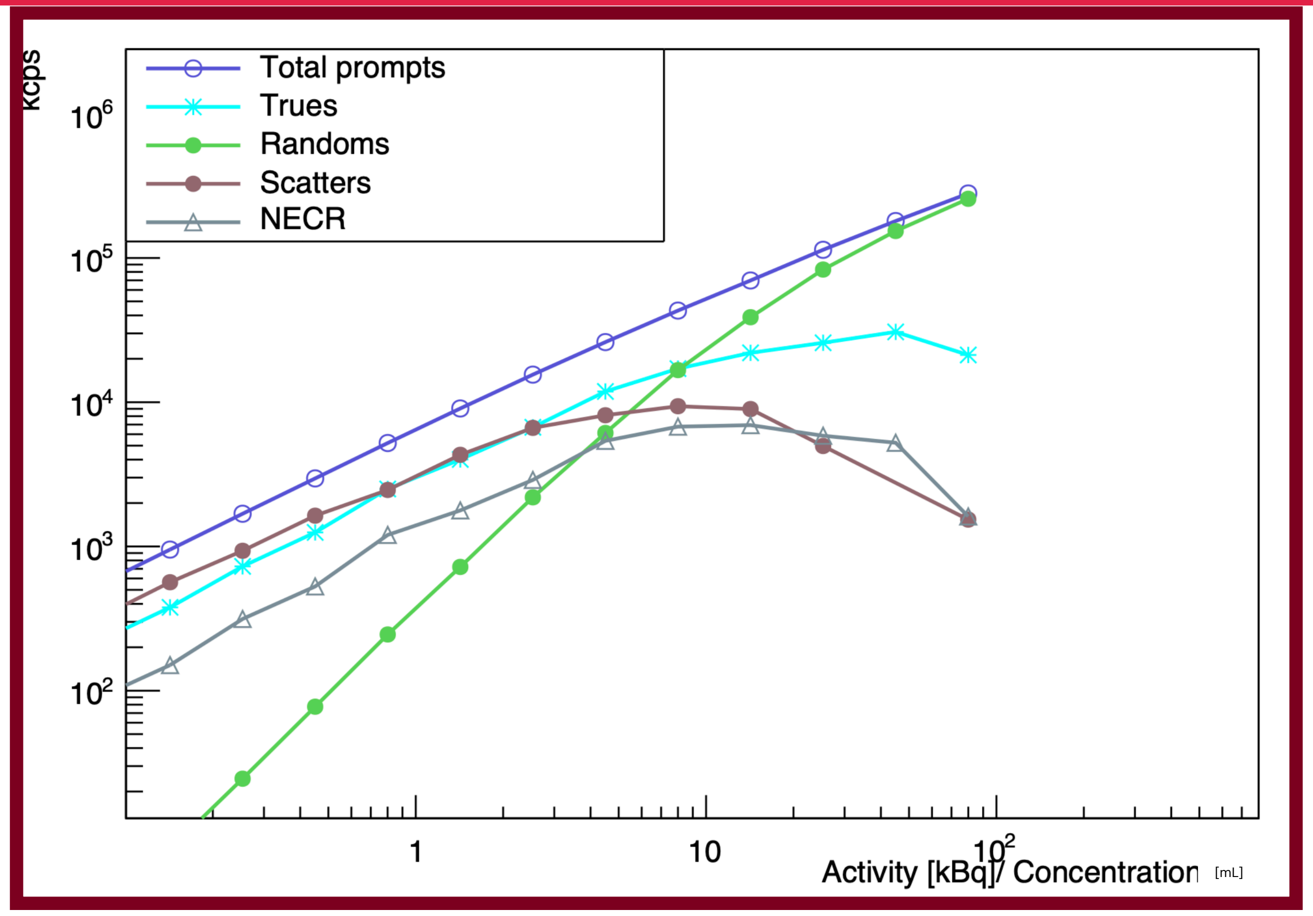
A guide to characterize PET performance

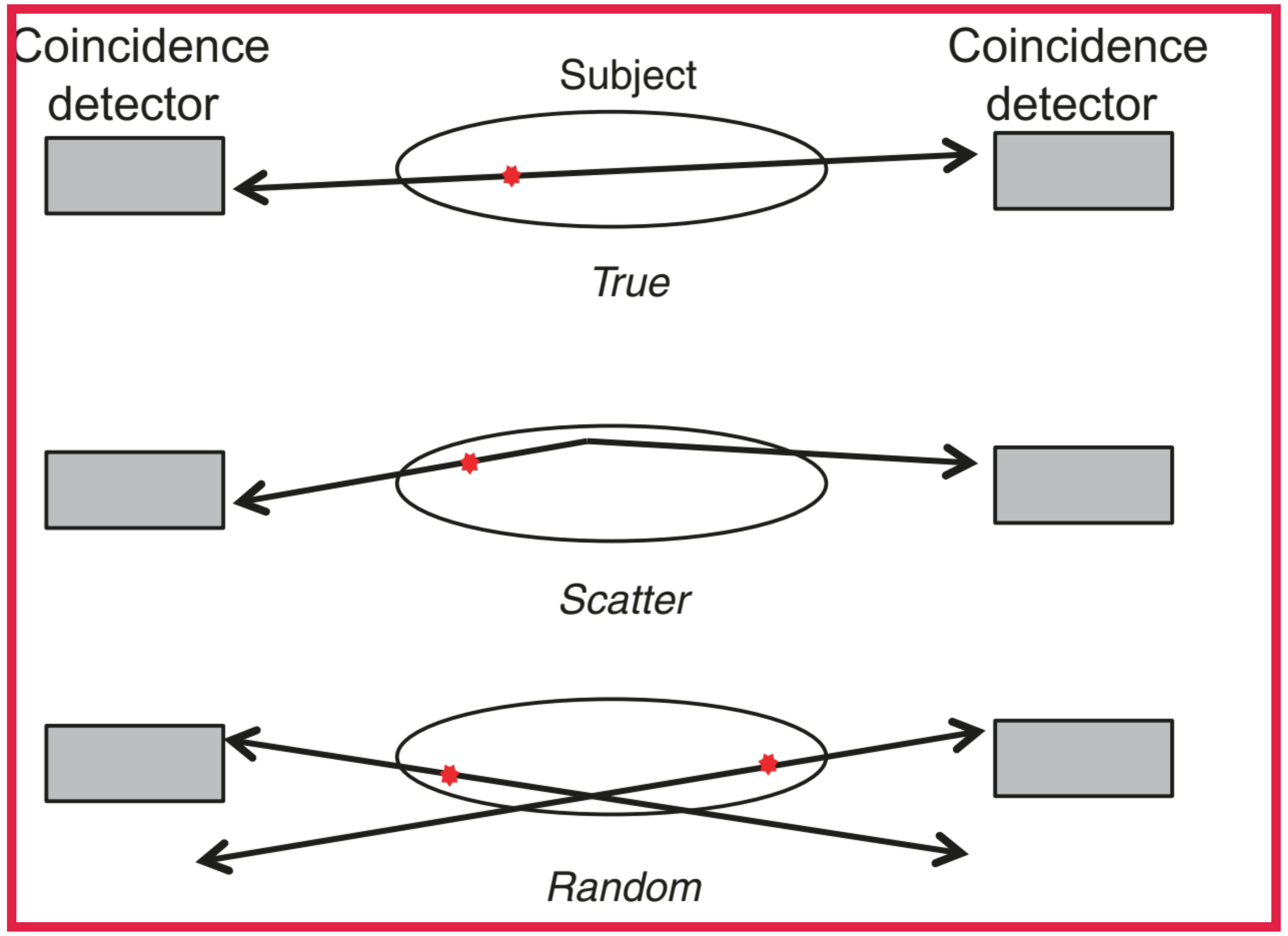
Noise Equivalent Count Rate (NECR)

$$\frac{T^2}{T+S+R}$$

T: True coincidences count rate
S: Scattered coincidences count rate
R: Random (accidental) coincidences count rate







Three types of coincident events

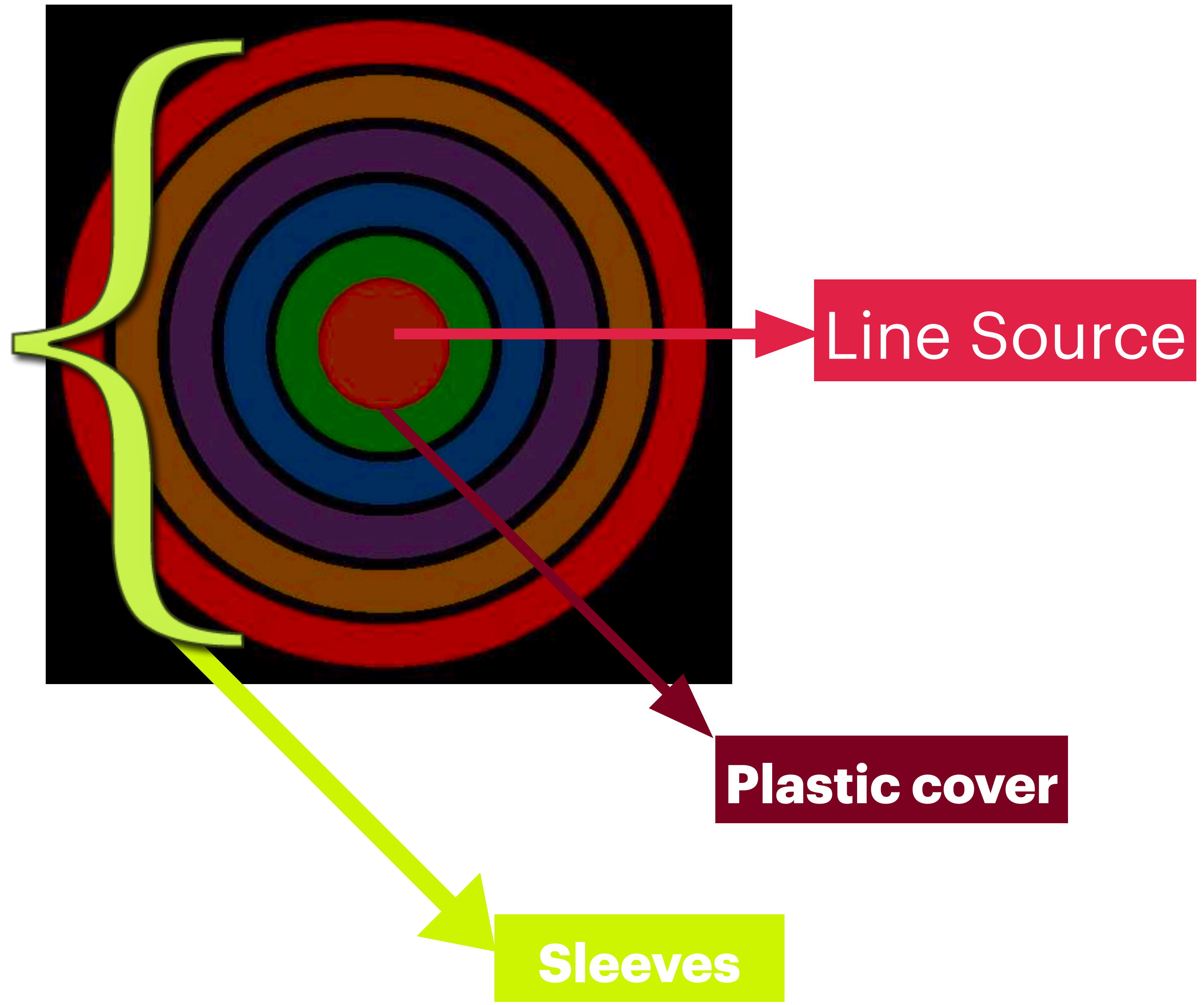
Scanner	Peak NECR	Activity concentration at peak	Scatter Fraction at peak
Our PET (MC) (Preliminary)	~10^4 kcps	7.7 kBq/mL	35.2%
EXPLORER TB-PET/CT (Actual)	~10^3 kcps	17.3 kBq/mL	37.4%
GE SIGNA PET/CT (Actual)	218 kcps	17.8 kB/mL	43.6%
CareMainBrain PET (Actual)	49 kcps	~14 kB/mL	48%

Higher NECR at lower activity decay rate means extremely reduction radiopharmaceutical dose

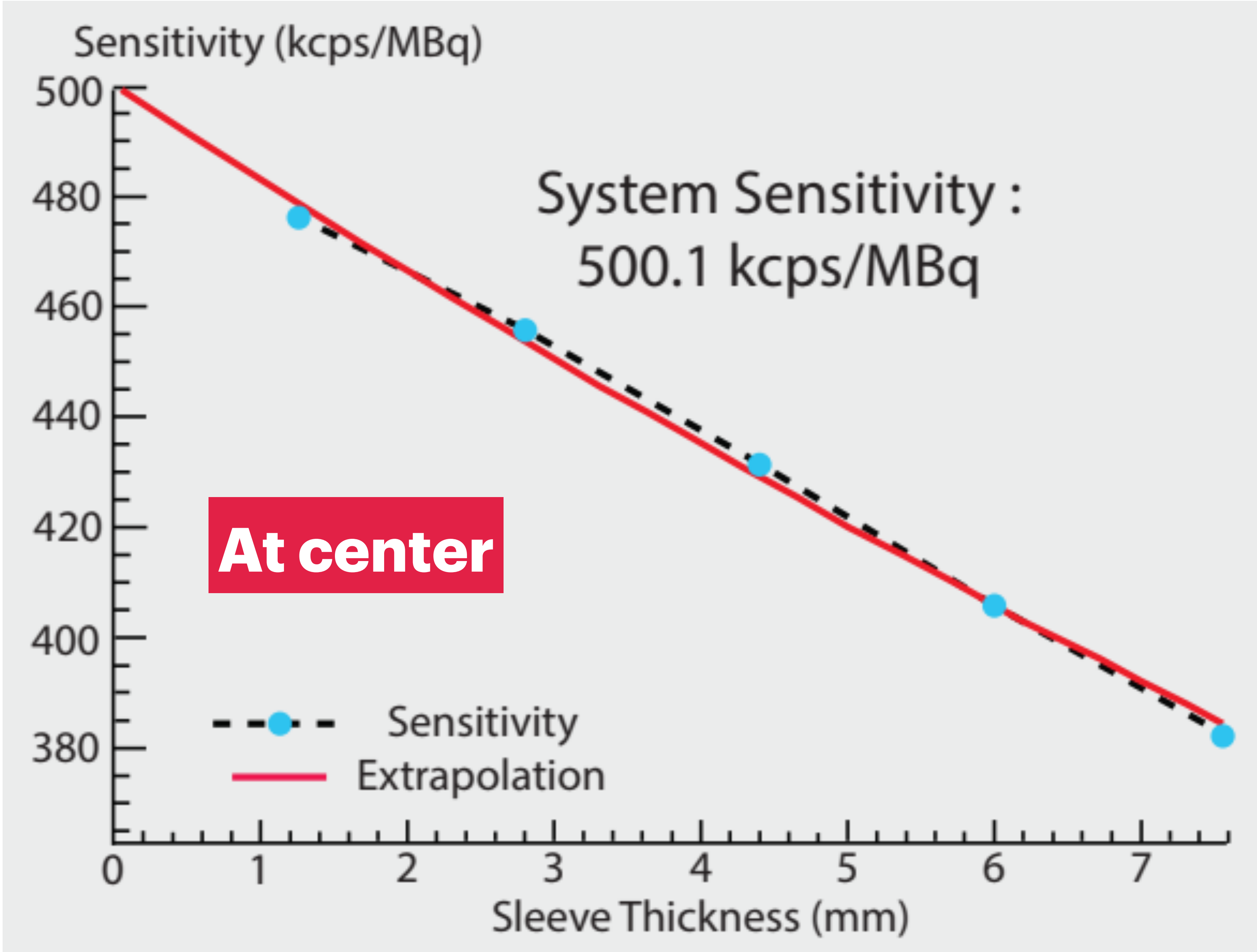
The sensitivity test measures the counts per second that the scanner measures for every unit of activity present in a source.

$$S_{tot} = \frac{R_{CORR,0}}{A_{cal}}$$

S_{tot}: System Sensitivity
$R_{CORR,0}$: The true coincidences count rate with no attenuation
A_{cal}: Line source radioactivity



At low decay activy



System Sensitivity at center

(Preliminary) **Our Total-Body TOF-PET** **500 kcps/MBq**
EXPLORER Total-Body PET/CT **147 kcps/MBq**
CareMainBrain PET **13.82 kcps/MBq**

Summary

3Dπ PET Scanner

- ❖LAr+Xe as scintillation material, operates at temperatures close to the argon boiling point, So it reduces SiPM DCR.
- ❖LAr+Xe as scintillation material, operates as WLS, and shifts optical photon wavelength 128 nm (LAr) to 178 nm (Xe).
- ❖LAr + Xe + SiPMs allows for fast scintillation and better timing and spatial resolution.
- ❖Higher NECR at lower activity decay rate and higher sensitivity means extremely reduction of the whole-body imaging duration or the lessen of the radiopharmaceutical dose

Ongoing activities

- ◆Setup at INFN Cagliari, to test coincidence time resolution in the liquid argon-xenon mixture (Funding:300k€)
- ◆Setup at Princeton to test stability of the Xe-doped LAr
- ◆Agreement with Fondazione Bruno Kessler (FBK) to test their SiPM sensitive to Xe scintillation with ASIC
- ◆Testing of the ALCOR chip (ASIC) from INFN Torino at cryogenic temperature

Future work on MC simulation

- ✷Optimizing SiPM size
- ✷Optimizing layer geometry
- ✷New reconstruction algorithms

Current Collaboration

- ✻Princeton University
- ✻ASTROCENT
- ✻University of Houston
- ✻Lawrence Berkeley National Laboratory
- ✻University of Cagliari
- ✻INFN
- ✻APC, University of Paris, CNRS
- ✻Gran Sasso Science Institute


Thanks for your attention