3Dπ, A Total-Body Time of Flight Positron Emission Tomography scanner, using Xenon-doped Liquid Argon detector

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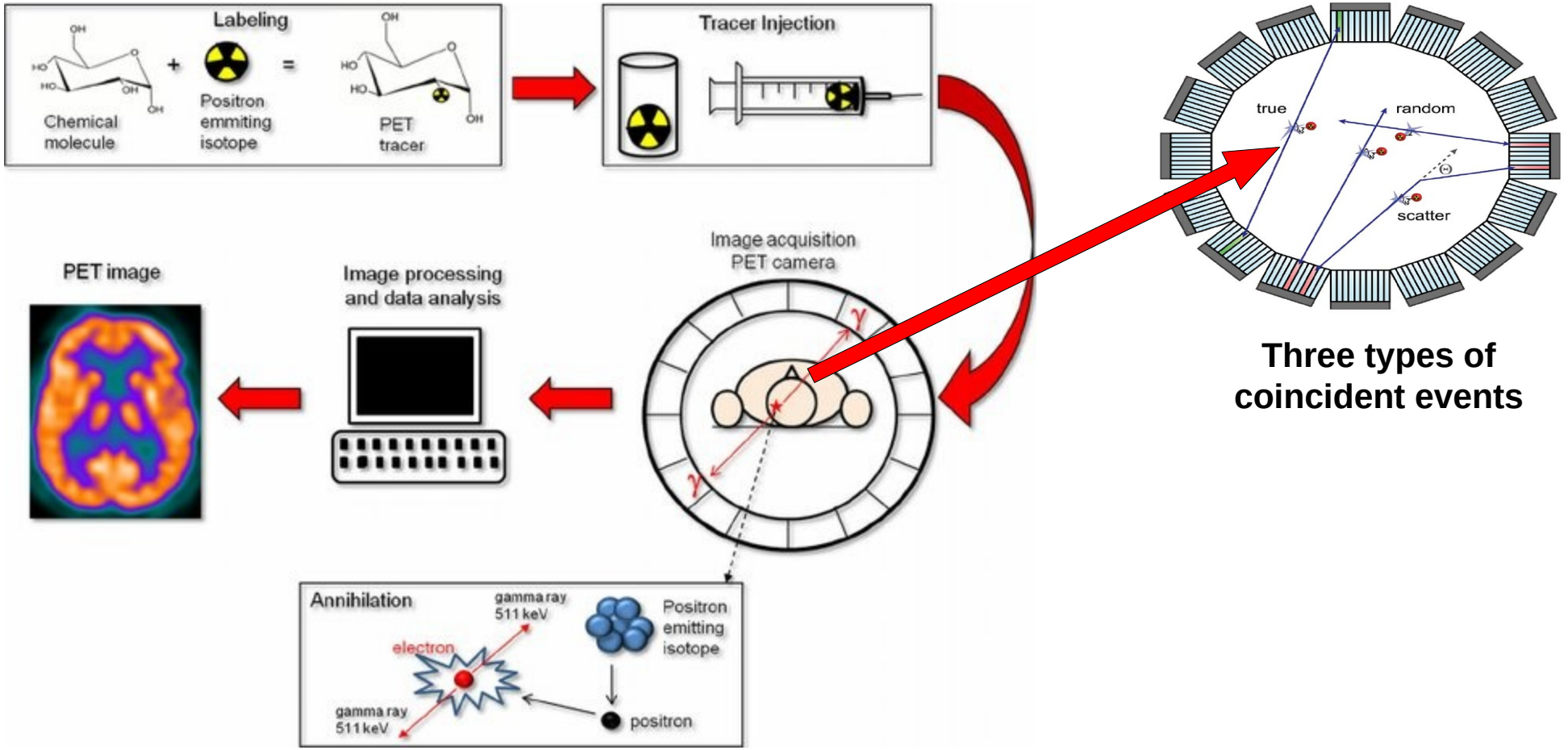
On behalf of the 3Dπ TB-TOF-PET Collaboration

European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union European Regional Development Fund
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952480
Dark Wave

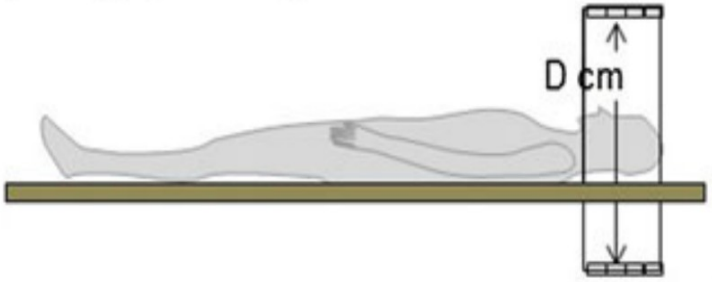
What is Positron Emission Tomography (PET)?
How does it Work?

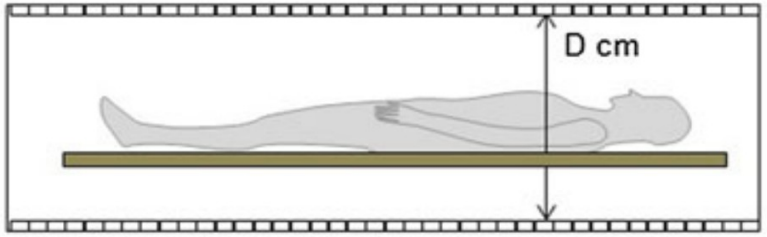


Three types of coincident events

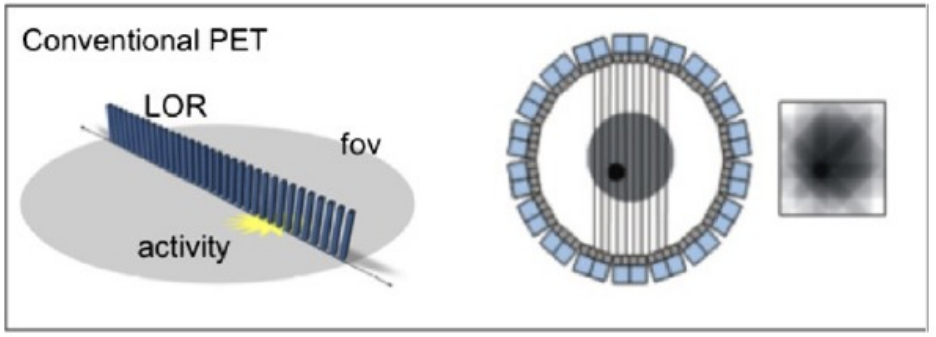
Credit: https://www.researchgate.net/publication/262189675_PET_imaging_in_multiple_sclerosis

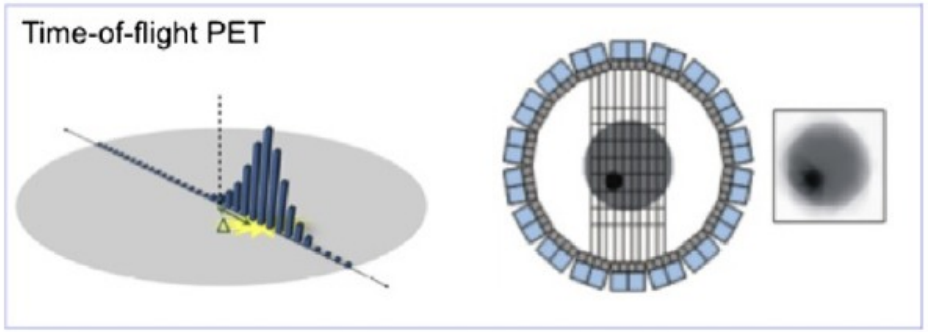
Routine PET vs. Total-Body PET (TB-PET)





Conventional PET vs. Time of Flight (TOF) PET





Credit: https://iopscience.iop.org/article/10.1088/1748-0221/13/01/C01044

PET Detectors: Scintillation Material & Photo Detectors

Scintillator	Light Output (photons/MeV)	Decay time (ns)	Total Body Cost
LYSO	33,200	36	~$ 10 million or more
BGO	8,000-10,000	300	~$ 5 million or more
BC-480;EJ-200	10,000	2.1	~5 times less than the crystal-based

	Photomultiplier Tubes (PMTs)	Silicon Photomultipliers (SiPMs)
Range (nm)	300-800	400-1000+
Noise	Relatively low until the ~800nm mark, increases with voltage and higher emission wavelengths	Noisier than PMT except at ~800nm+, but comparable over whole range

Liquid Xenon vs. Liquid Argon

Liquid Scintillator is easier to scale up than a Crystals Scintillator

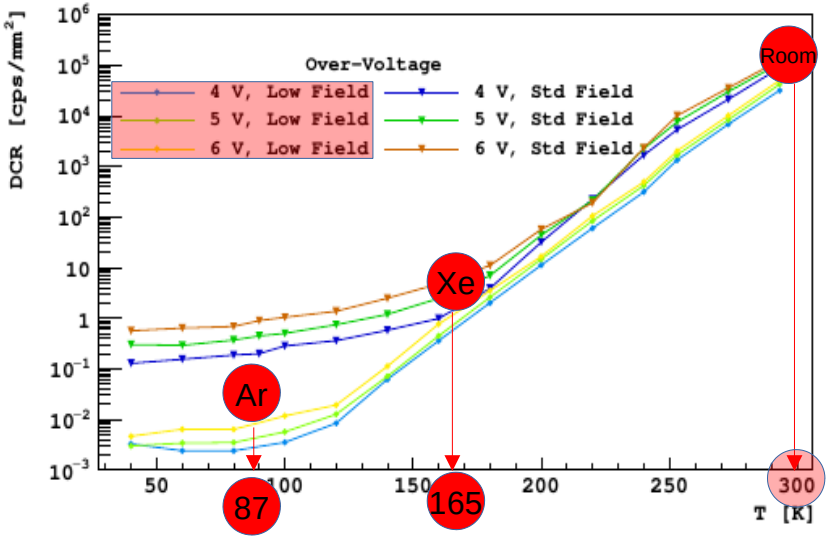
Property	Argon	Xenon
Fast decay time (ns)	7	4.3
Slow decay time (ns)	1600	22
Light yield (photons/keV)	40	42
Wavelength (nm)	128	175
Density at boiling temperature at 1 atm (g/cm^3)	1.40	2.94
Cost (US$/kg)	~2	~2000
Boiling point	87 K	165 K

Credit: arXiv:1403.0525

Combine the advantages of both: Xenon-doped Liquid Argon

- ✓ The mixture emits **scintillation light** at a wavelength of **178 nm.**
- ✓ It operates at **temperatures** close to the **argon boiling point.**
- ✓ Its triplet state **decay time** is **shorter** than the one of pure liquid argon.
- ✓ The de-excitation process in the mixture can be accomplished with direct energy transfer from argon excimers to xenon and direct emission of xenon light, it will be **faster than** the fluorescence processes of **WLS.**
- ✓ It has the potential to achieve **sub-nanosecond timing resolution.**

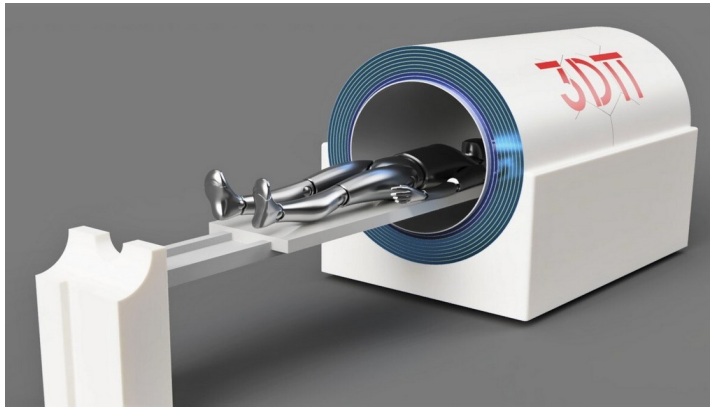
SiPM Dark Count Rate (DCR) vs. Temperature



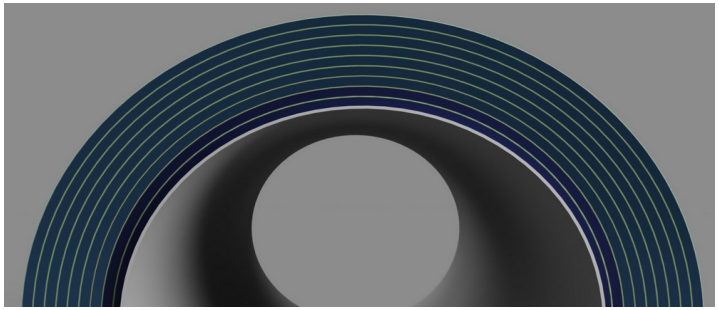
https://oar.princeton.edu/rt4ds/file/1663/1610.01915v1.pdf

Our 3-Dimensional Positron Emission Tomography scanner (3DPi)

- **A Total Body, Time of Flight PET scanner**
  - **More compact** and **more fine-grain** photodetection
  - **Xenon Doped LAr** scintillation
  - **Multiple layers**



- **Geometry**
  - 9 annulus detection rings
  - Each ring has Liquid Argon sandwiched Between two layers of SiPMs
  - 2 m in length



National Electrical Manufacturers Association, NEMA NU 2–2018

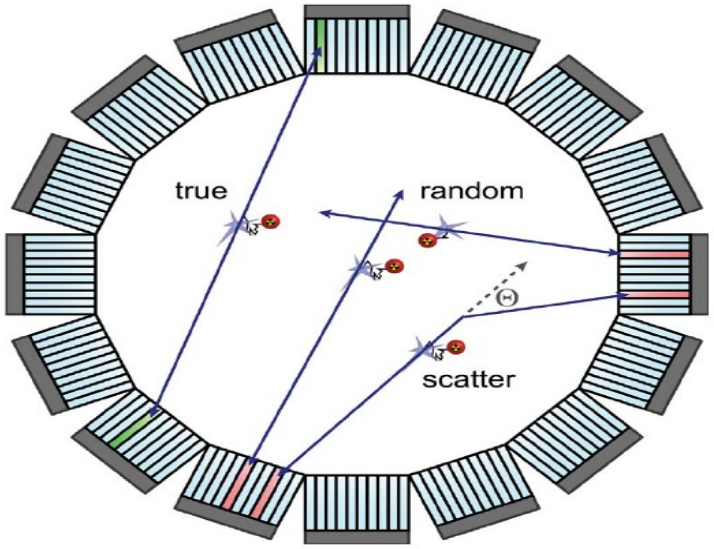
A guide to characterize PET performance

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

https://www.nema.org/standards/view/Performance-Measurements-of-Positron-Emission-Tomographs



Three types of coincident events

System Sensitivity

$$S_{tot} = \frac{R_0}{A_{cal}}$$

S_{tot}=System Sensitivity
R_0=True coincidences count rate with no attenuation
A_{cal}=Line source radioactivity

Current Results

Peak NECR

	Peak NECR
Our TB-PET (preliminary)	~10^4 kcps
EXPLORER TB-PET/CT	~10^3 kcps
GE SIGNA PET/CT	~200 kcps
CareMainBrain PET	~20 kcps

System Sensitivity

(preliminary)
Our Total-Body TOF-PET:
500 kcps/MBq

EXPLORER Total-Body PET/CT:
147 kcps/MBq

The preliminary results demonstrate that our scanner system performance is comparable to commercial scanners.

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

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