A Novel Total-Body PET Scanner Using Xenon-Doped Liquid Argon Scintillator for Outstanding Detection

An application in medical physics of the DarkSide collaboration

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ASTROCENT

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Dark Wave

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3Dπ Overview

A Total-body (TB), Time of Flight (TOF) PET scanner

- Xenon-doped Liquid Argon instead of Crystal scintillators
- Multiple detection layers
- Using Silicon Photomultipliers (SiPM)
- Double sided SiPM on scintillation

Geometry:

- 9 annulus detection layers
- Each layer has the scintillator sandwiched between two layers of SiPMs, Each detection layer has ~18 mm LAr thickness
- PTFE supporting structure
- 2 m in length
- Geant4 simulations

Parameter	Value
Inner radius (cm)	45
Outer radius (cm)	64
Length/AFOV (cm)	200
LAr thickness (cm)	16.2
Number of LAr layers	9
SiPM size (mm x mm)	10 x 10
Number of SiPMs	~1 x 10^6
Cryostat Thickness (mm)	6

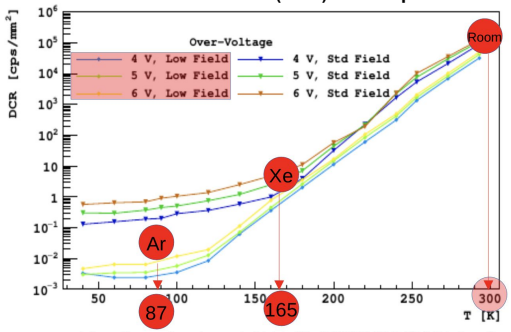
Liquid Xenon vs. Liquid Argon And Benefit of Cryogenic

0.5%

Scintillator:	LAr	LXe	LAr + Xe	LYSO
Decay F/S (ns):	7/1600	4.3/22	~6/100*	41
Wavelength (nm):	128	175	~175 **	420
Density (g/cm^3):	1.40	2.94	~1.40	7.1
Temperature (K):	87	162	87 ***	298
Photons/keV:	40	42	~41	28.5
Cost (US$/kg):	~2	~2000	~2	~4

*Shorter slow decay time than the pure liquid argon.
**Scintillation light at a wavelength of 175 nm; Xe operates as a wavelength shifter (WLS).
***Operating at temperatures near the boiling point of argon eliminates the need for cooling and results in lower Dark Count Rate (DCR).

SiPM Dark Count Rate (DCR) vs. Temperature



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

Reduction in the dark count rate (DCR), improves the timing capability of the devices and Signal-to-Noise Ratio (SNR)

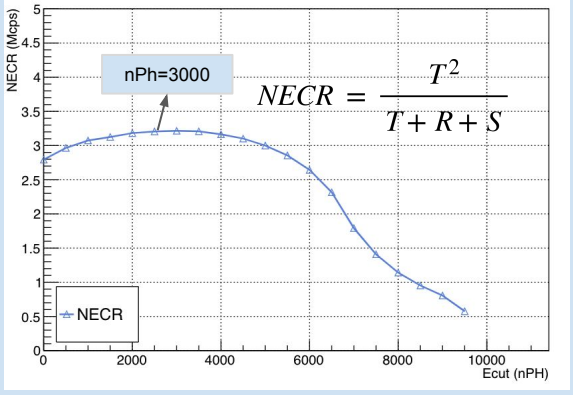
Preliminary Results

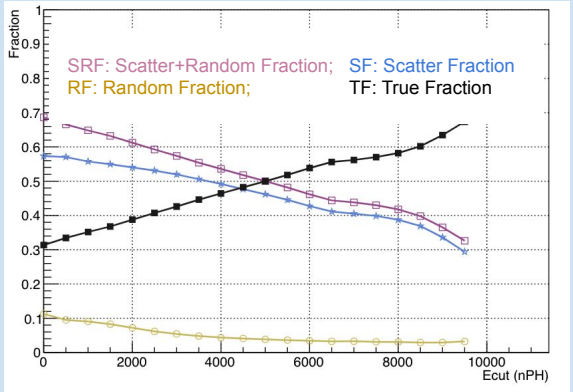
Implementing Energy Cut (Optical Photons)

System sensitivity	3Dπ LAr+Xe (200 cm AFOV*)	GE SIGNA PET/MR (25 cm AFOV)	uExplorer PET/CT (192 cm AFOV)
At Center [kcps/MBq]	**564.0**	21.8	174.0

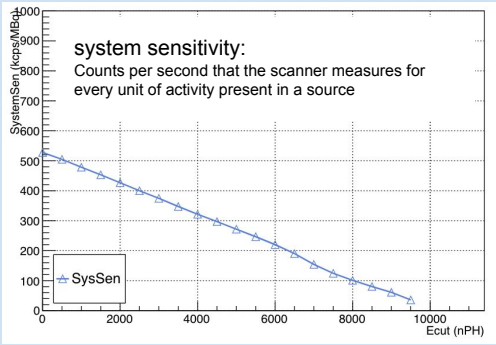
*AFOV: Axial Field of View

Comparing Scatter Fractions and NECR with Various Photon Cuts and Similar Activity Concentrations to uEXPLORER's peak NECR





Comparing system sensitivity with Various Photon Cuts

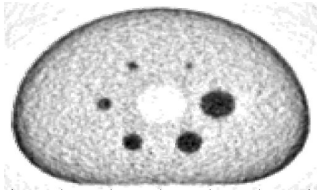


Selected scatters with more than 3000 photons:
The NECR is improving, the system sensitivity still better than uEXPLORER (~twice) and SF is almost the same as uEXPLORER.

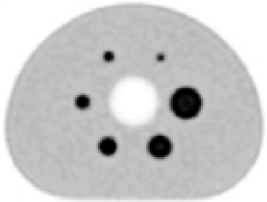
Preliminary Results

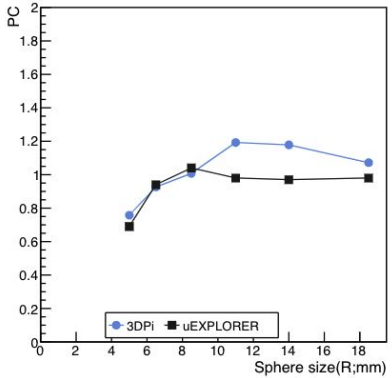
Image Quality

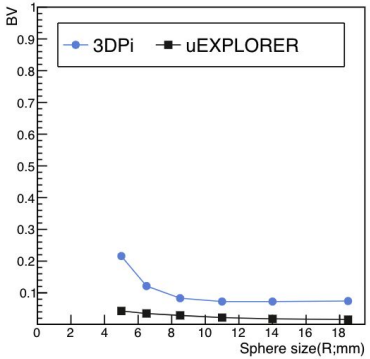
3Dπ scanned for 60 s.



uEXPLORER scanned for 30 min.







Percent contrast (PC)=

$$\frac{\left(C_{H,j}/C_{B,j}\right)-1}{(a_H/a_B)-1}\times 100\%$$

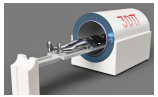
C_H: the counts in the ROI for sphere j
C_B: The average of the background ROI counts for sphere j
a_B: The activity concentration in the background
a_H: The activity concentration in the hot sphere

$$SD_j = \sqrt{\sum_{k=1}^{K}\frac{(C_{B,k}-C_B)^2}{(K-1)}}, \quad K = 60$$

$$BV_j = \frac{SD_j}{C_B}\times 100\%$$

Preliminary Results

Comparison of NEMA Test Results



Scanner	Peak NECR [Mcps]	Activity concentration at peak [kBq/mL]	Sensitivity [kcps/MBq]	TOF resolution [ps]
3Dπ (MC) (Preliminary)	~3	17.3*	560	163
	~3.5	30**		
3Dπ (MC)-CutP*** (Preliminary)	~3.3	17.3*	390	140
uEXPLORER TB-PET/CT	~1.5	17.3	174	412
J-PET-TB (MC)	0.63	30	38	500
GE SIGNA PET/CT	0.22	20.8	21.8	386
VRAIN PET	0.14	9.8	25	229

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

*Activity concentration at peak NECR, uEXPLORER

**Activity concentration at peak NECR, J-PET

*** Optical Photon cut

Overview of 2023 and Plane for 2024

Participation in the UAr Cryogenics Working Group: Since October 2023

Conferences:

- 2023-06: International Workshop on Applications of Noble Gas Xenon to Science and Technology; A Novel Total-Body PET Scanner Using Xenon-Doped Liquid Argon Scintillator for Outstanding Detection Sensitivity,
- 2023-09: Technology & Instrumentation in Particle Physics; (3DΠ: A Novel Total-Body PET Scanner Using Xenon-Doped Liquid Argon Scintillator with SiPM-based Photosensors
- 2023-09: LIght Detection In Noble Elements; Advances in Total-Body PET Imaging: Xenon-Doped Liquid Argon Scintillator and Silicon Photomultiplier Detection

Iranian Scientific Community:

2 Ph.D students, 1 MS.c student.

Submitted Papers:

- **Physics in Medicine and Biology:** Dosimetric evaluation of light ion beams for spatially fractionated radiation therapy: A Geant4 Monte Carlo study
- **Radiation Physics and Chemistry:** Experimental investigation and monte carlo simulation of Selenium nanoparticles' antioxidant properties

Plan for 2024 (DarkSide collaboration)

Development of the Most Sensitive Dark Matter Detector with Liquid Argon

- Measurement of delayed electron emission due to chemical impurities in liquid argon
- Reducing backgrounds from photoelectronics

Thank you

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