Group 4

Ultrapure SiPMs and Associated Readout Electronics

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AstroCeNT, CAMK PAN
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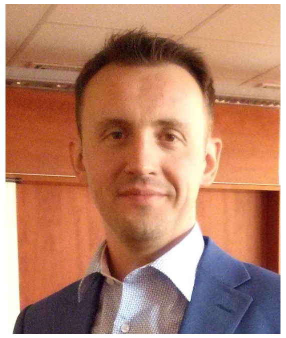
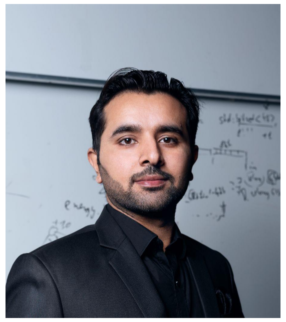
MEMBERS

- Azam Zabihi
  - PostDoc working on Medical applications



- Rafał Wojaczyński
  - PostDoc working on low mass dark matter search and neutrino detection

- Masato Kimura
  - PostDoc working on low mass dark matter search



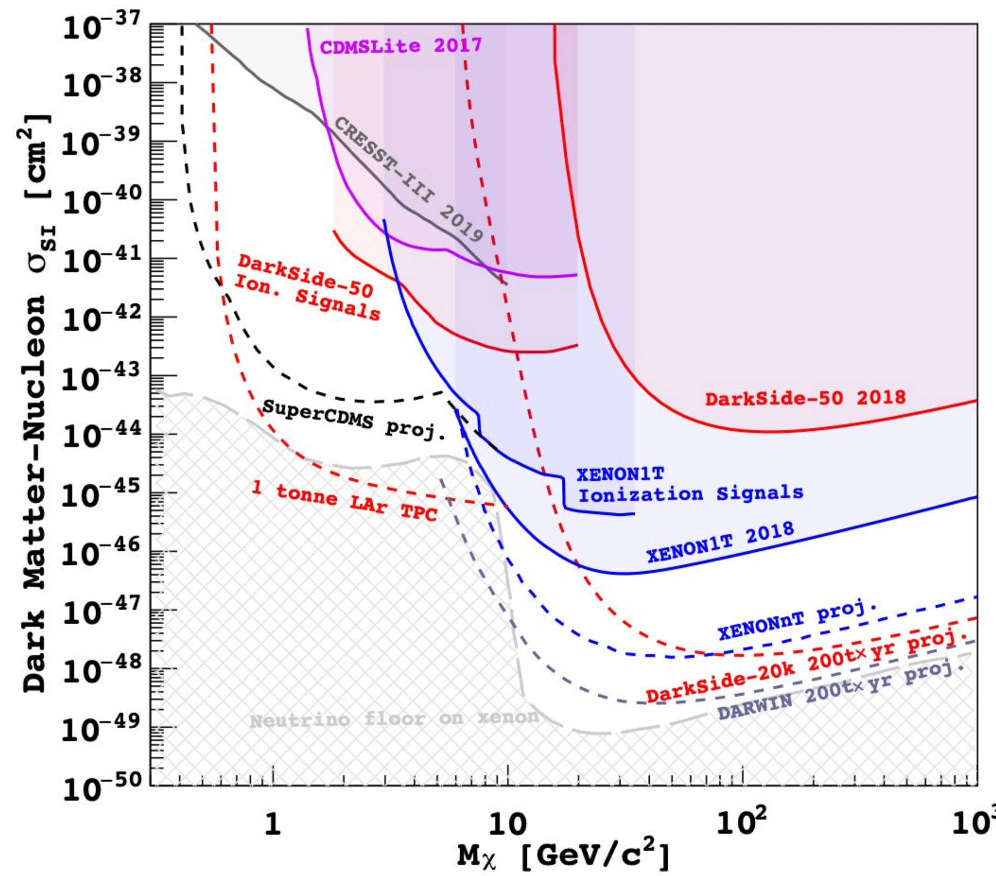
- Iftikhar Ahmad
  - 4th year PhD student working on SiPM development

- Paul Zakhary
  - 4th year PhD student working on low energy calibration

- Clea Sunny
  - 2nd year PhD student

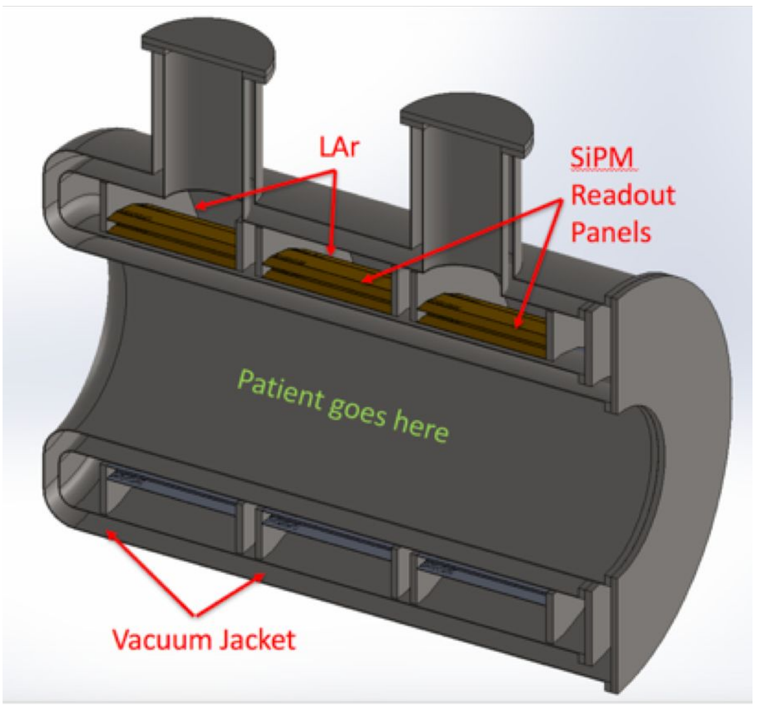
DARK MATTER SEARCH

- DarkSide-20k for high mass search
- Argon is a good target also for low-mass dark matter search.
- Need ultra-pure Photo-detectors.
- Potential to search entire available parameter space in 1-10 GeV/c^2 dark matter mass range.



LIQUID ARGON PET SCANNER

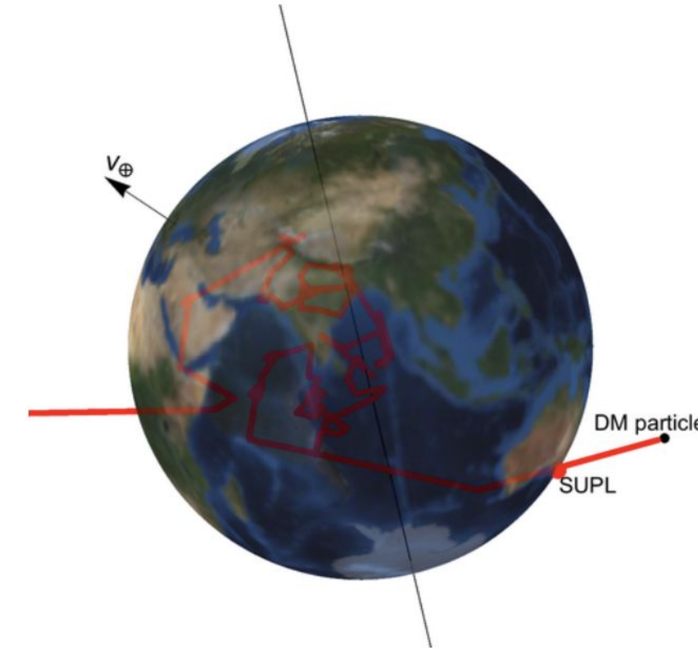
- Positron emission tomography (PET) scanner measures physiological function of human body.
- Cutting edge technologies from Physics to the medical application.

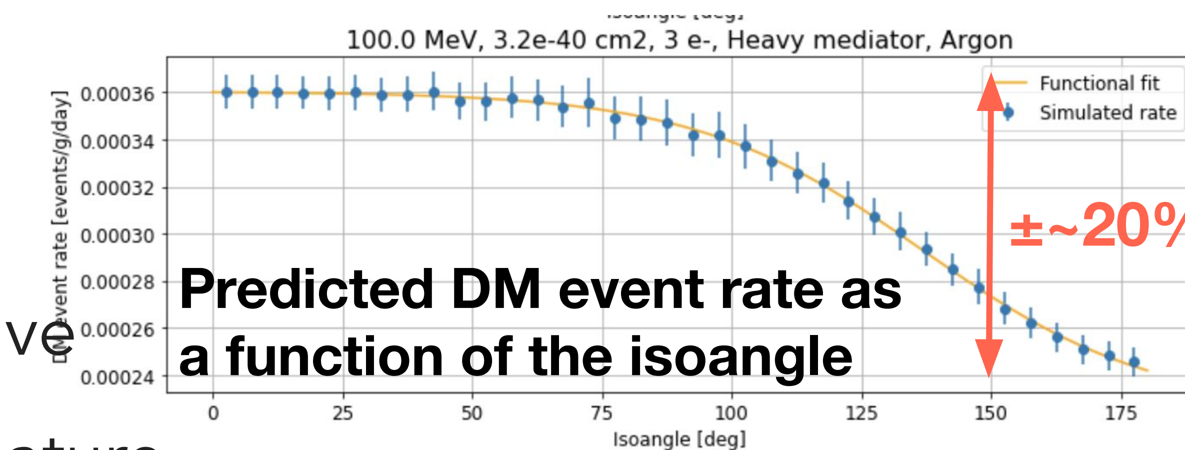


Main Goal: Development of ultra-pure SiPM based photo-detectors for physics and medical application.

Daily Modulation Analysis

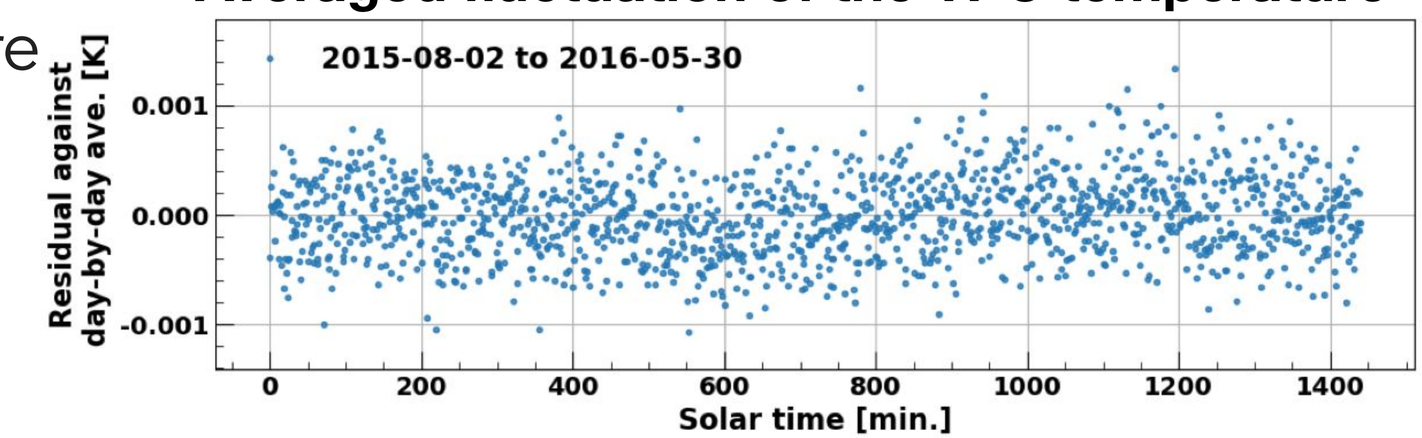
- Dark matter event rate could modulate in a day due to dark matter-Earth scattering
- Searching for such daily modulation benefits from the DarkSide-50 thanks to its low energy threshold as well as the stable and continuous data taking over years
- Collaborate with Argentina's group, we have started the analysis to search for such signature
  - No critical fluctuation is found in the TPC parameters such as pressure and temperature
  - Stability of the observables are under investigation





Predicted DM event rate as a function of the isoangle

Averaged fluctuation of the TPC temperature



Developments for DarkSide

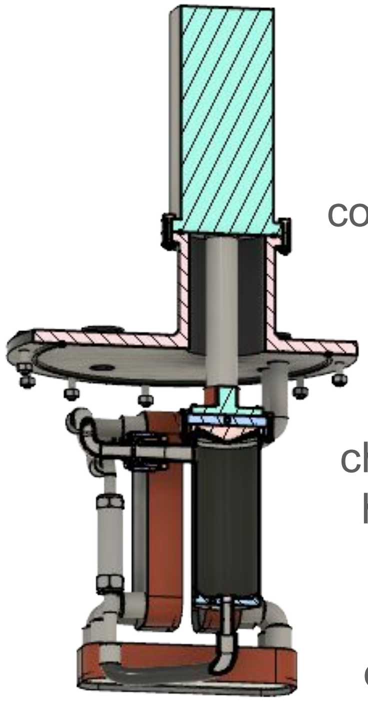
Underground Ar Purification:

- Reduction of ^{39}Ar is important for future experiments.
- High-volume chemical and isotopic purification of Underground Argon
- It is essential technology and AstroCeNT's participation is important for the success of the project.
- A. Zabihi, M, Kimura, and M. Wada participate the test operation for Ar distillation on Oct. 2021.
- A paper based on this run is published.

Data taking for Argon run with Seruci-0 at Cagliari
M. Kimura and A. Zabihi (NCAC)

Chemical Purification

- Remove chemical impurity from detector materials and improve their properties.
- A cold trap is designed and plan to be built at AstroCeNT. Due to the limited budget, we changed to a design without ca cryocooler.



Cross section of Kr cold trap

ReD Experiment

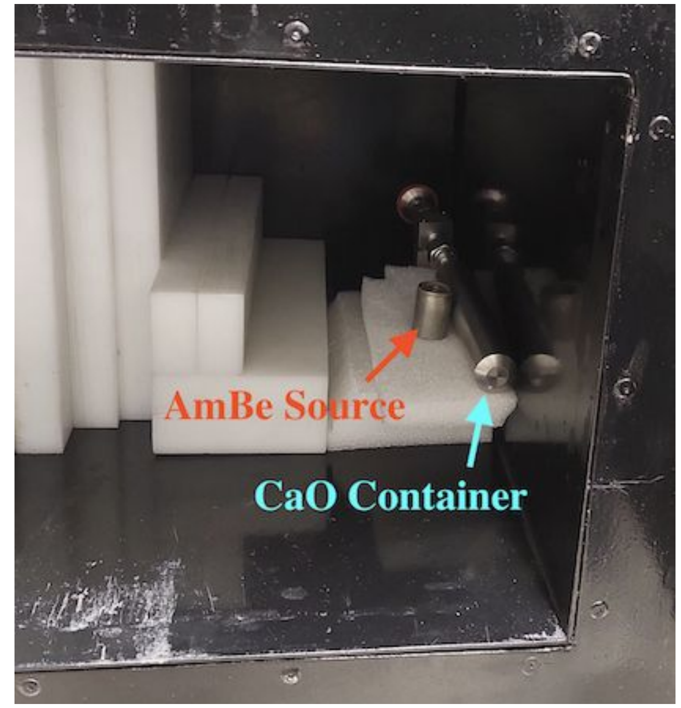
- Low energy Nuclear Recoil calibration is necessary for Low mass dark matter search.
- A small TPC with SiPM readout
- Finished the directionality study and prepare for low energy NR calibration. The results are published.
- PhD student, Paul Zakhary stayed at Catania, Italy for more than a half year.
- AstroCeNT provides ^{37}Ar source for cross calibration from CaO nano-powder.
- Our group members are working heavily on the data analysis.

ReD TPC at Catania, Italy

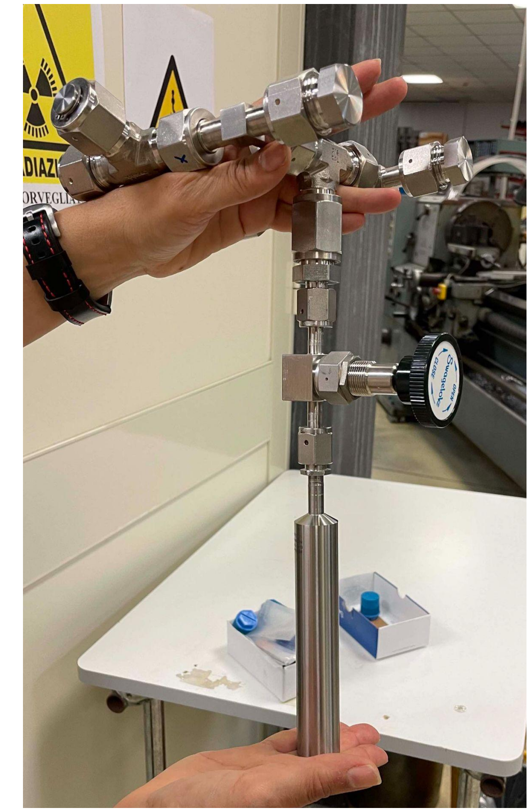
37Ar source holder

^{37}Ar source

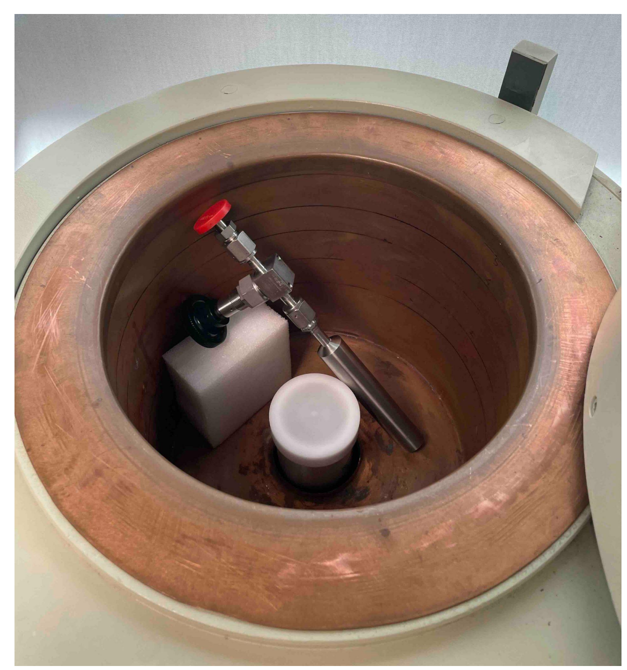
- Low energy calibration points are important to understand the detector response to dark matter.
- ^{37}Ar produce 0.27 and 2.82 keV peaks.
- Use $^{40}Ca(n, \alpha)^{37}Ar$ reaction.
- On-demand production of ^{37}Ar source.
- Check activation by measuring by product γ-decays with HPGe detector.

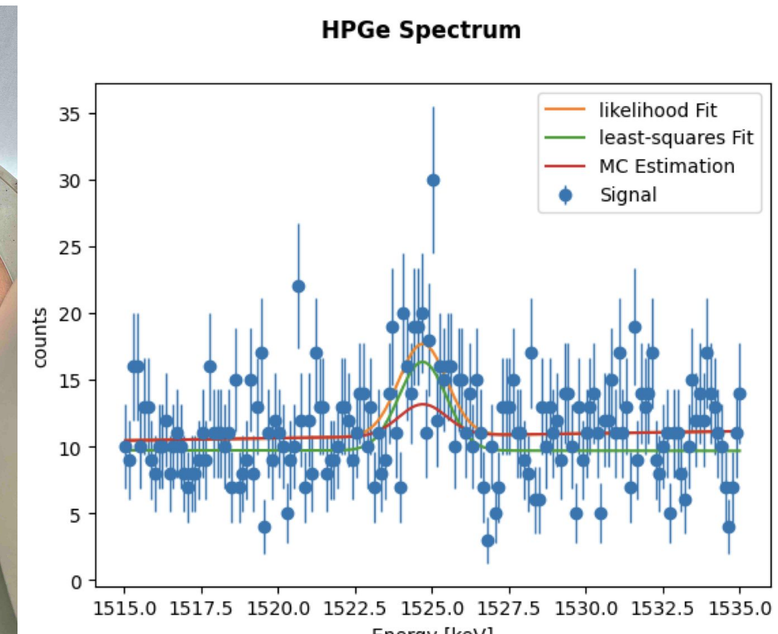


CaO nano-powder activation with AmBe neutron source



Source holder

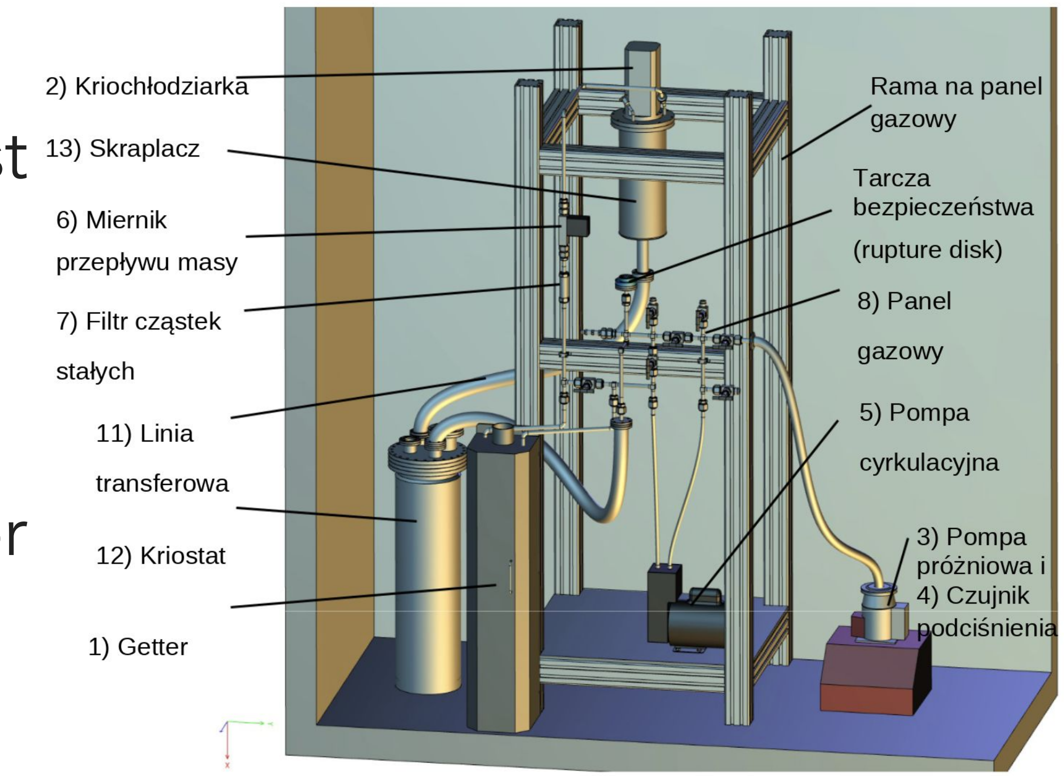


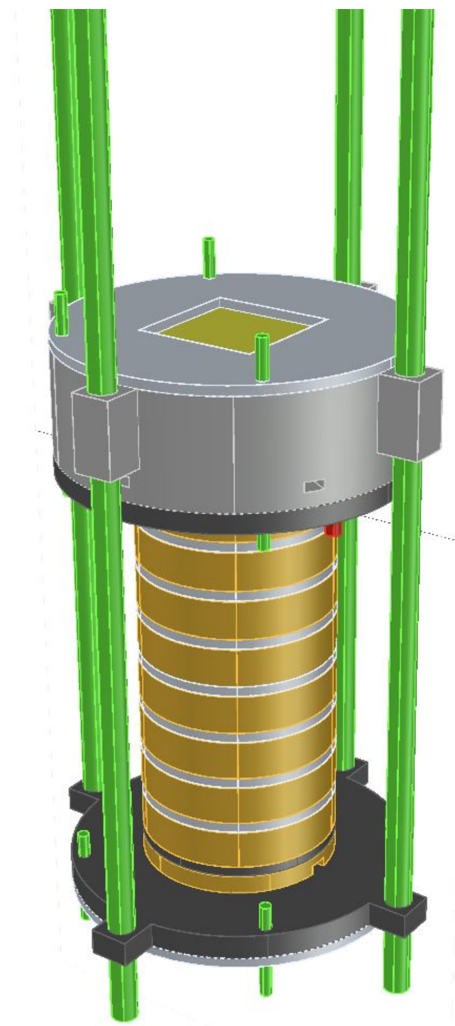


High purity Ge detector to confirm activation

TPC at AstroCeNT

- We are planning to build a liquid argon test bench (cryogenic system + time projection chamber (TPC)) in Warsaw
  - Study of the spurious electron events for future dark matter experiments
  - Low energy liquid argon response calibration
  - Proof-of-principle of new detector concept (in collaboration with Group1)
- The design of the TPC is being compiled by CAD drawing and 3D-printing mockup





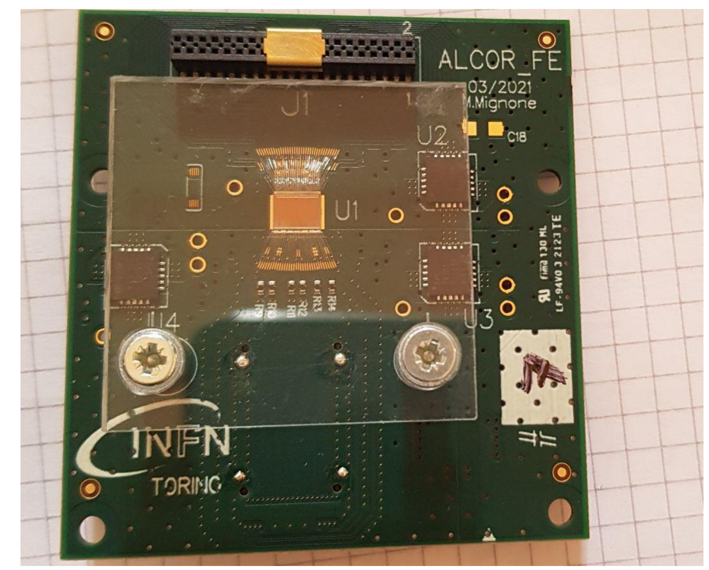
3D printed TPC components

SiPM + ASIC Developments

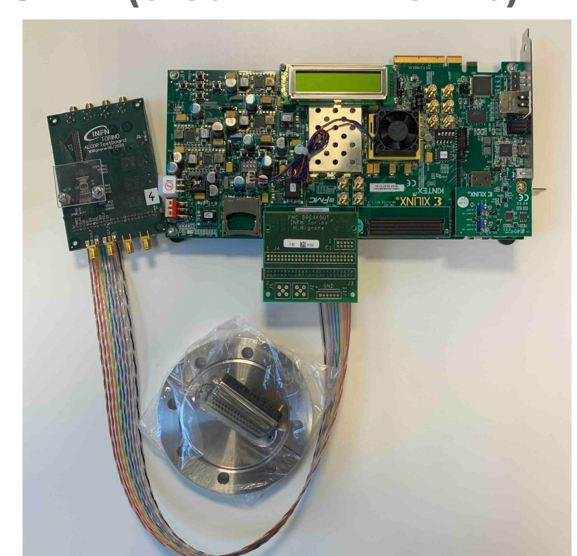
Ultrapure SiPM

- Conventional PMTs are dominant background source for future experiments
- Higher radio-purity & detection efficiency
- Relatively cheaper than PMTs
- SiPM with integrated electronics will reduce radioactive components
- Collaborate with INFN Torino, PhD student, Iftikhar Ahmad stayed there for half a year for development.
- Test ASIC + SiPM in a cryostat at AstroCeNT with liquid N2.

Iftikhar with INFN Torino group at Torino



A test board of integrated electronics for SiPM (credit INFN Torino)

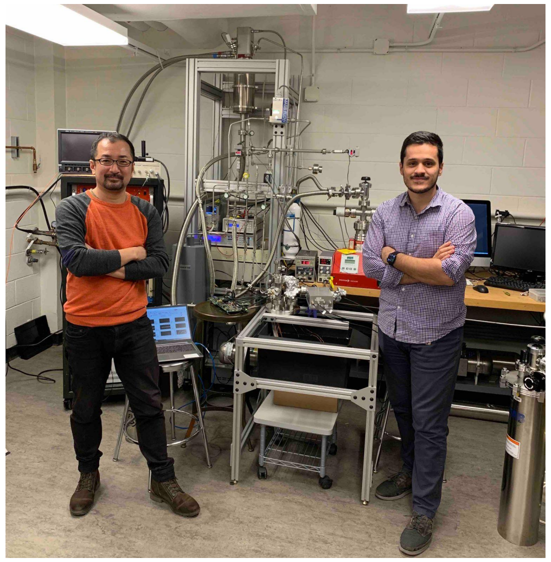


LIQUID ARGON PET SCANNER

- Positron emission tomography (PET) scanner measures physiological function of human body
- Effective against such as Alzheimer and Parkinson diseases

3DPi workshop and meeting at University of Houston
M. Wada and A. Zabihi with collaborators

- SiPM readout with good timing resolution is necessary
- SiPM with integrated electronics is inevitable for large number of channels.
- Azam Zabihi is leading the simulation study.
- Potential for commercialization.



SiPM + ASIC testing at Princeton University
M. Wada and A. Jamil

- Collaboration with Princeton U., U. Houston, and INFN Cagliari and Torino.
- This will be my main activity in the next MAB if it is approved.

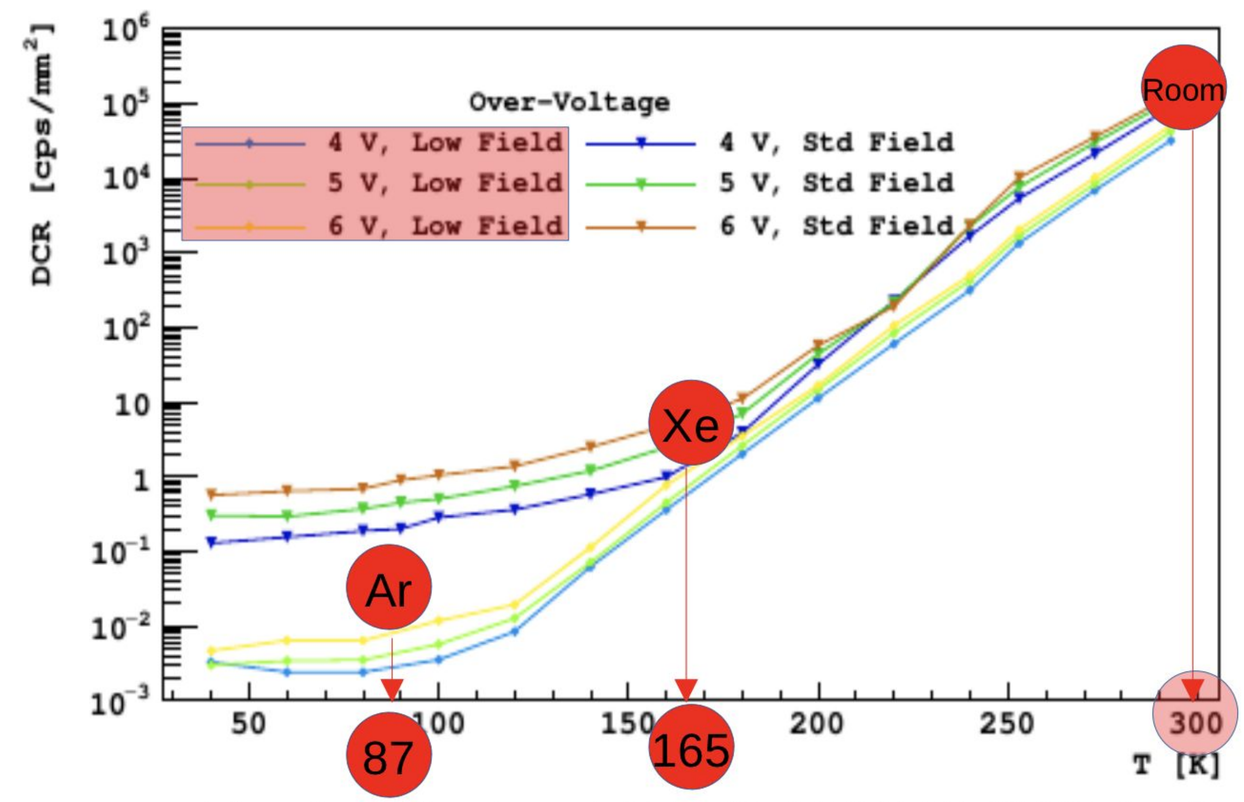
Liquid Xenon vs. Liquid Argon

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/cm³):	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

SiPM Dark Count Rate (DCR) vs. Temperature



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

*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).

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

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

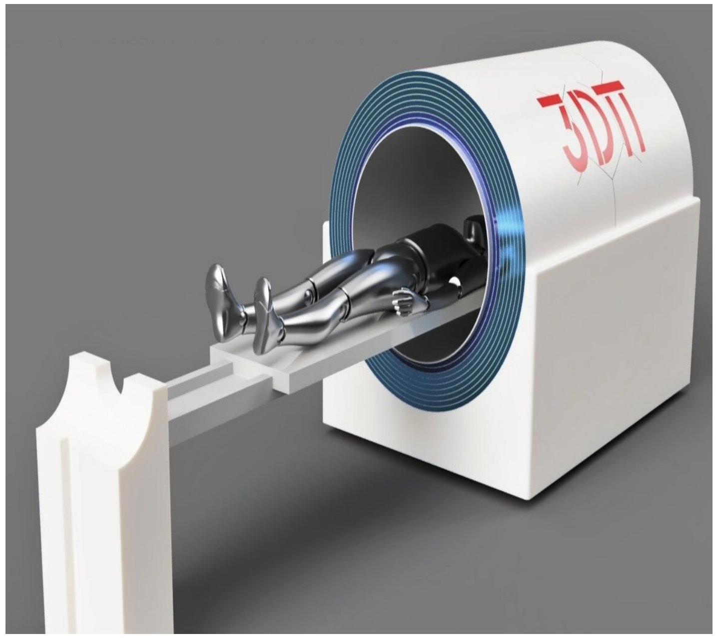
Two configurations:

❖ **LAr+Xe, as the main focus**

❖ LAr+TPB (TetraPhenylButadiene: an organic WLS), for comparison

Geant4 Geometry Parameters

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



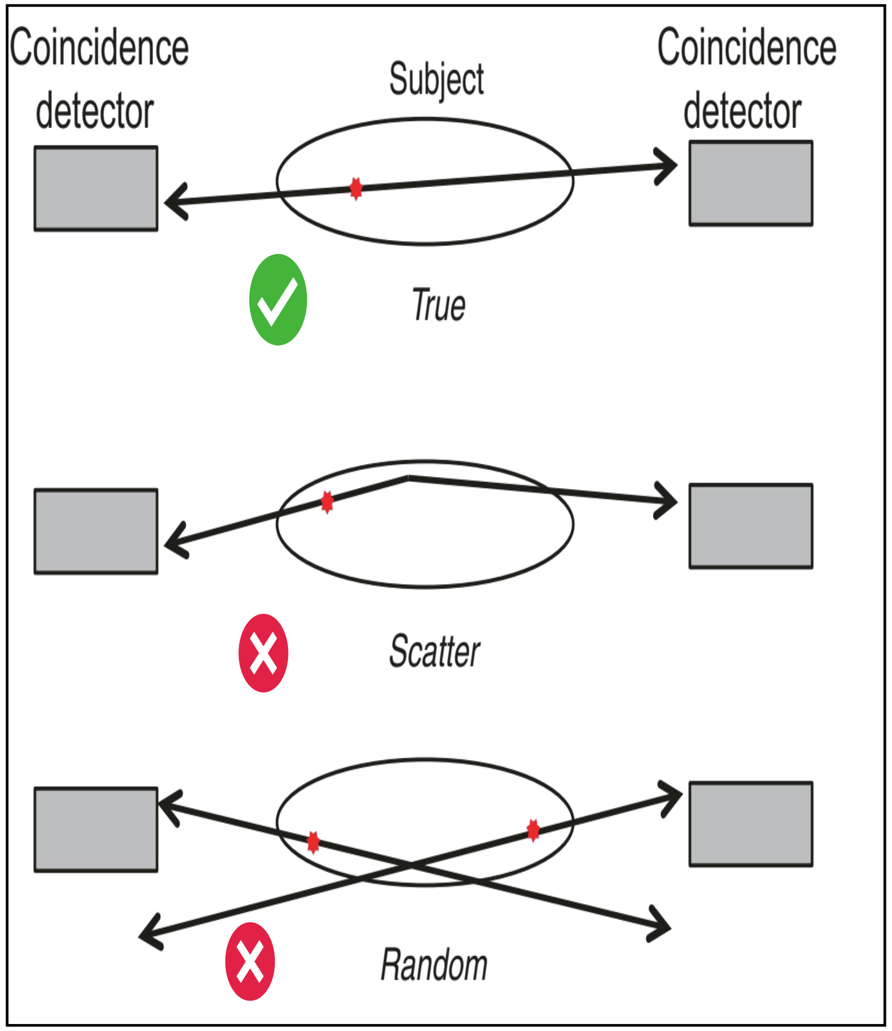
3DΠ Geometry rendered in Fusion 360

Noise Equivalent Count Rate (NECR)

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

Noise Equivalent Count Rate: ability to detect and accurately quantify true coincident counts while minimizing the impact of noise, (random, and scatter events.)

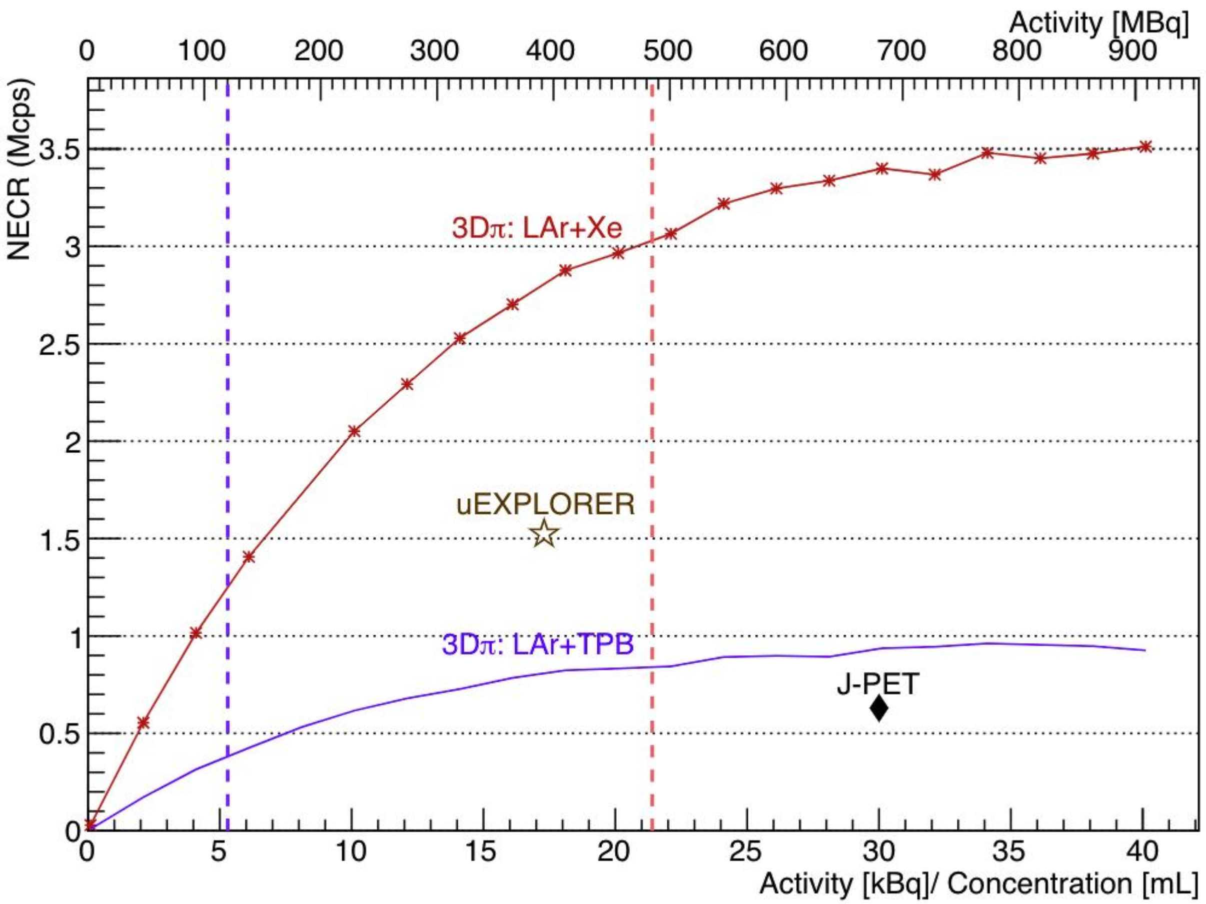
Source Distribution:
A solid right circular high density polyethylene cylinder with a line source.



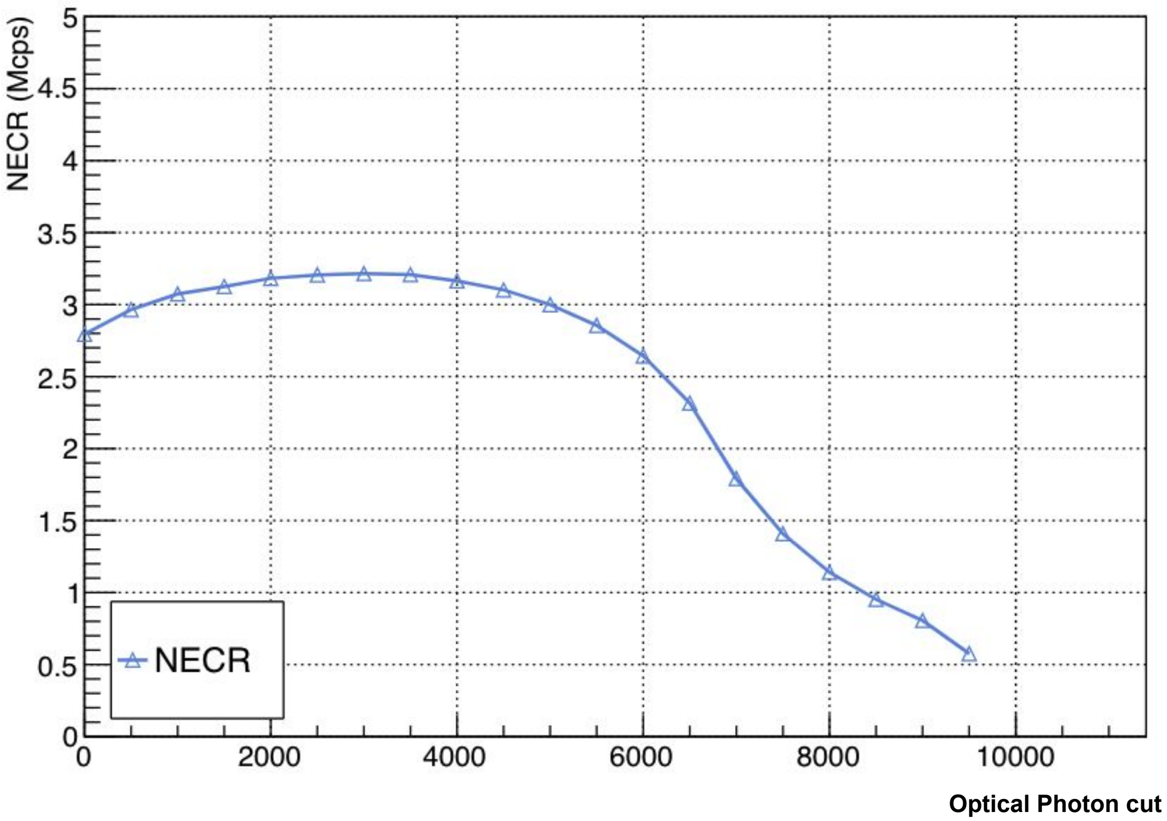
Three types of coincident events

Noise Equivalent Count Rate (NECR)

Preliminary Results



---Background: Activity concentration used as the background in the Image Quality test
---Signal: Activity concentration used as the signal in the Image Quality test



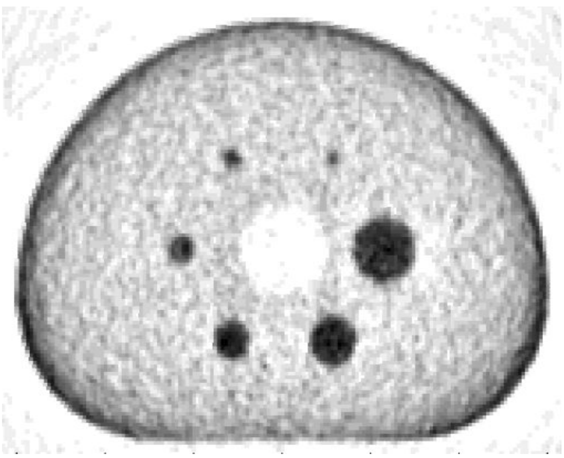
Similar Activity Concentrations to uEXPLORER's peak NECR

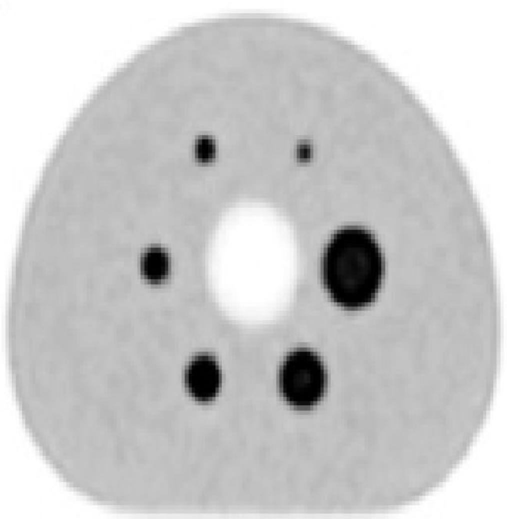
Higher NECR with low activity indicates the possibility to reduce radioactive dose significantly

Image Quality

3Dπ scanned for 60 s.

uEXPLORER scanned for 30 min.

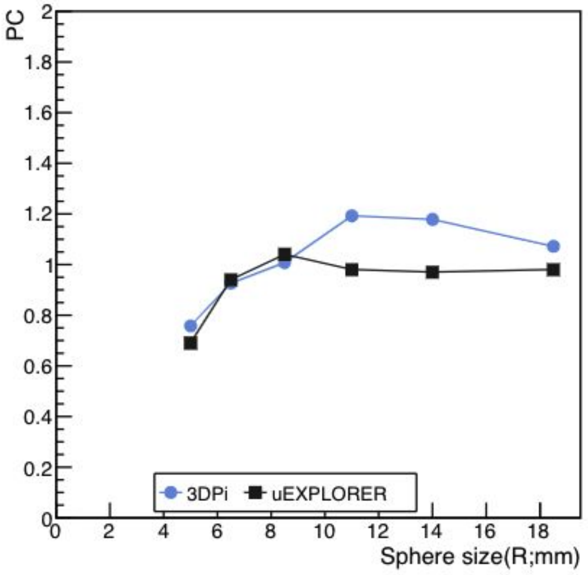


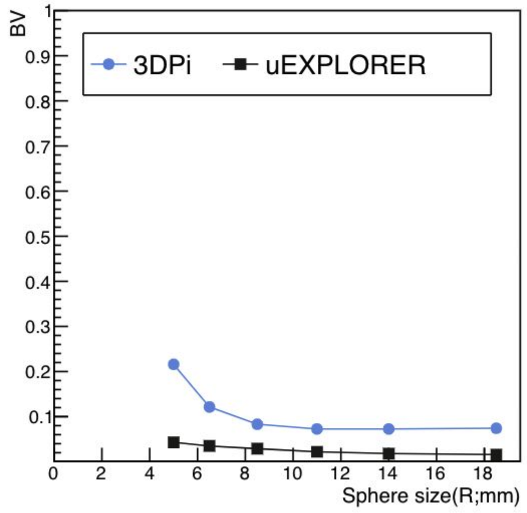


Percent contrast (PC)=

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

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

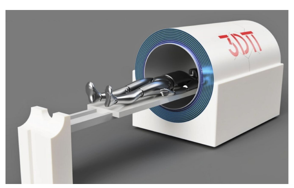




$$\mathrm{SD}_j = \sqrt{\sum_{k=1}^{K} \frac{\left(C_{\mathrm{B},k} - C_{\mathrm{B}}\right)^2}{(K-1)}}, \quad K = 60$$

$$\mathrm{BV}_j = \frac{\mathrm{SD}_j}{C_{\mathrm{B}}} \times 100\%$$

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