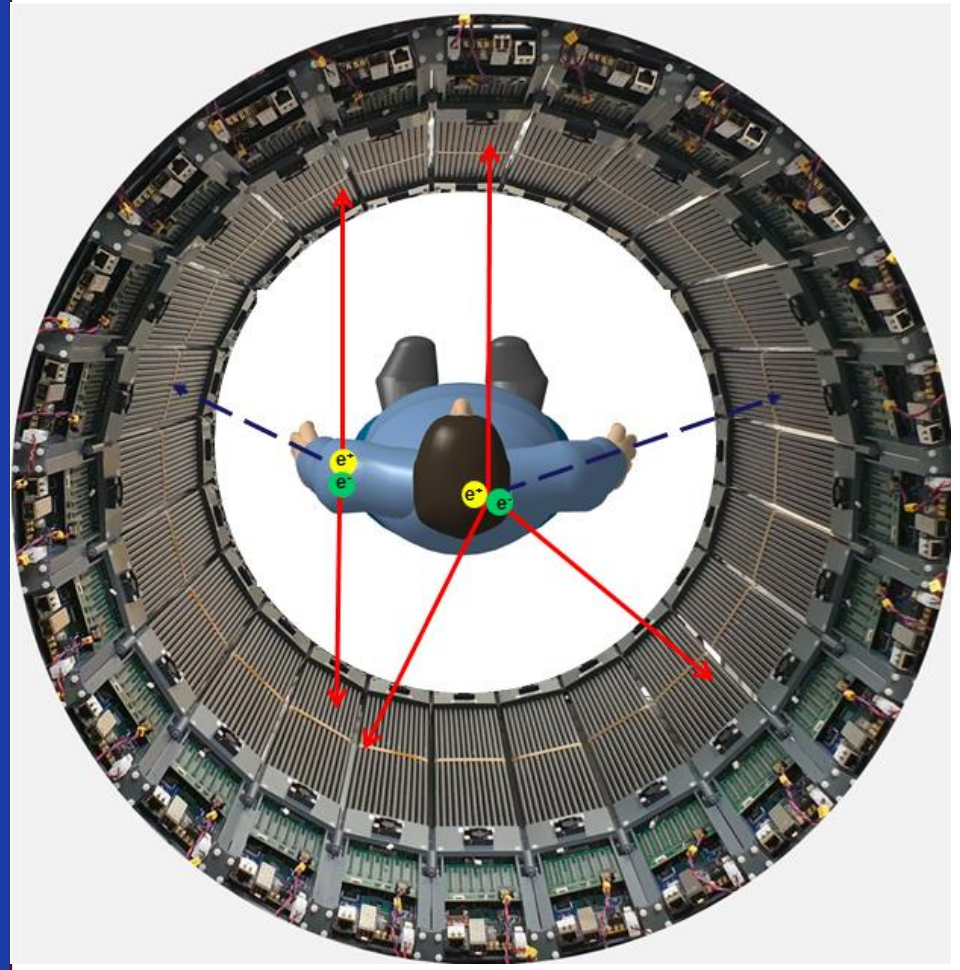
Novel applications of β^++γ emitters in medical diagnostics

Manish Das, PhD

[1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Kraków, Poland

[2]Center for Theranostics, Jagiellonian University, Krakow, Poland



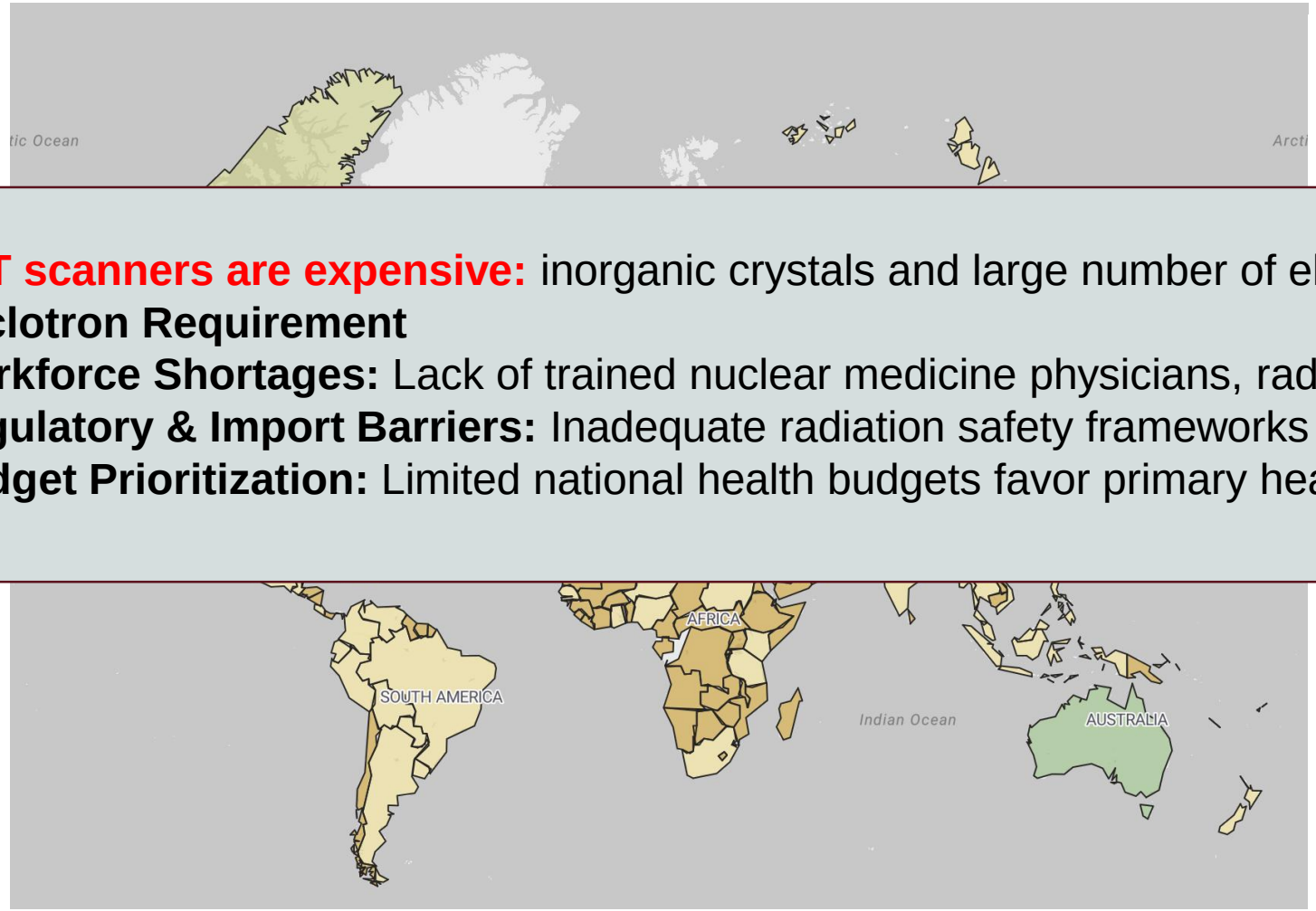
JAGIELLONIAN UNIVERSITY IN KRAKÓW

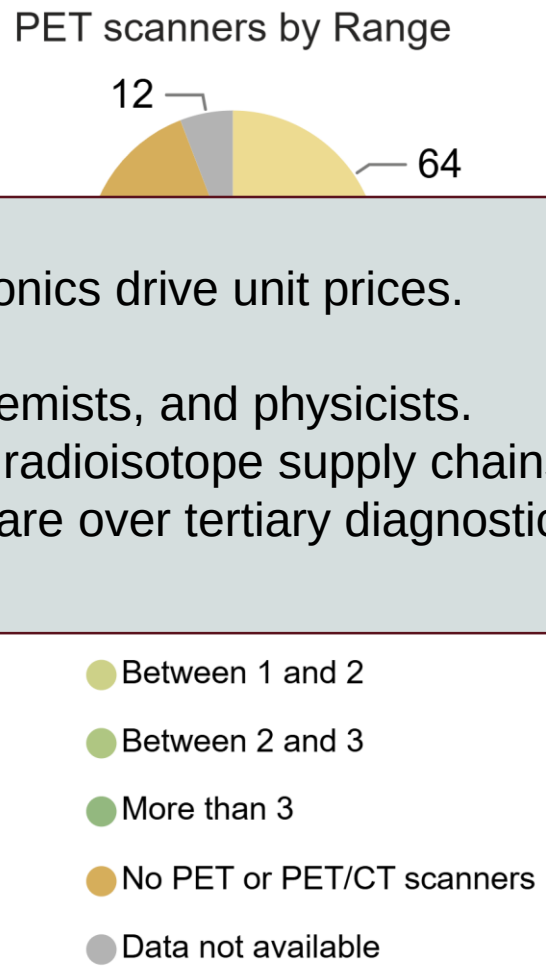
3rd Workshop on Research & Innovation in Poland: Research Programme for Linear Accelerator - Radioisotopes and Applications

22-23 September 2026

J-PET

Number of PET Scanner worldwide (per million)





- **PET scanners are expensive:** inorganic crystals and large number of electronics drive unit prices.
- **Cyclotron Requirement**
- **Workforce Shortages:** Lack of trained nuclear medicine physicians, radiochemists, and physicists.
- **Regulatory & Import Barriers:** Inadequate radiation safety frameworks and radioisotope supply chains.
- **Budget Prioritization:** Limited national health budgets favor primary healthcare over tertiary diagnostics.

https://www.iaea.org/resources/hhc/nuclear-medicine/databases/imagine/pet-scanners

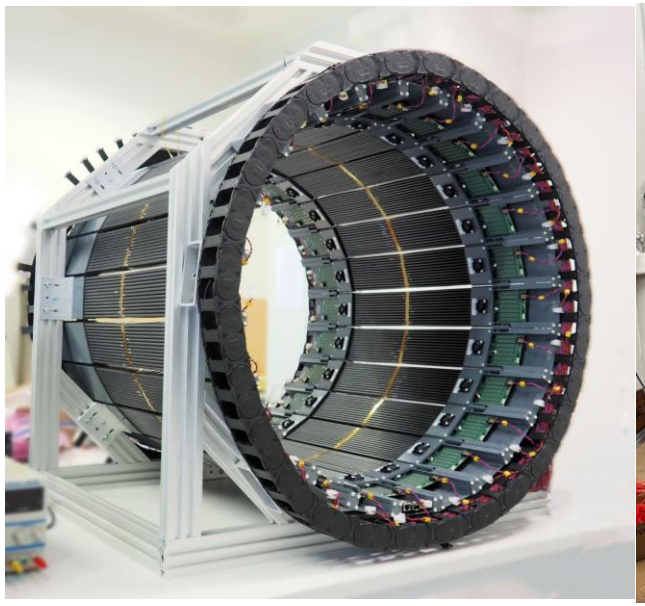
J-PET (Solution to the expensive Crystal based PET)

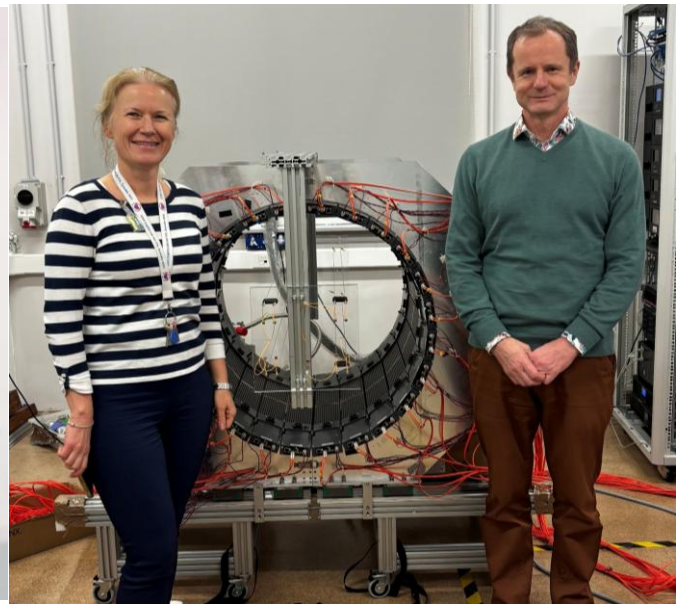
Why plastic?

- Polymer scintillators replace costly inorganic crystals
- Enable large axial coverage, which reduces the cost of electronics.

Modular J-PET Scanner

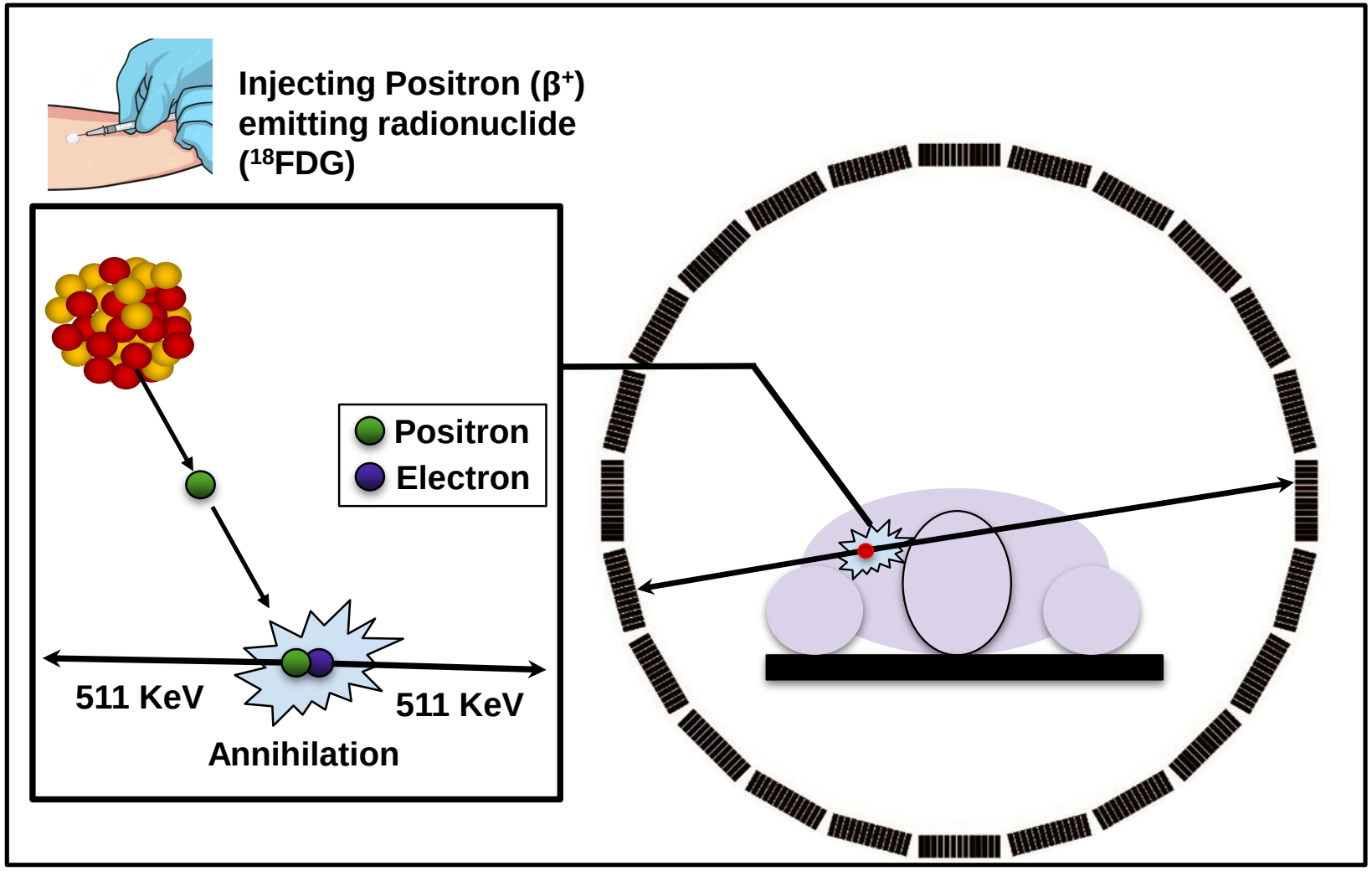
- **24 detection modules, Each contains 13 plastic scintillator strips with 4 SiPM on each side of a scintillator**
- **Triggerless data acquisition system**
- **Modular and Portable**
- **Weighs around 60 kg**

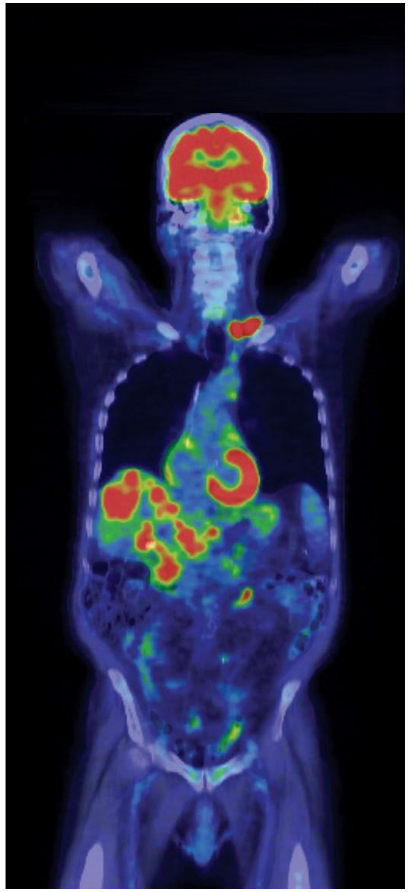




P. Moskal and E. Ł. Stępień, "Prospects and Clinical Perspectives of Total-Body PET Imaging using Plastic Scintillators," *PET Clinics*, vol. 15, no. 4, pp. 439–452, Jul. 2020.

Two-gamma coincidence Imaging

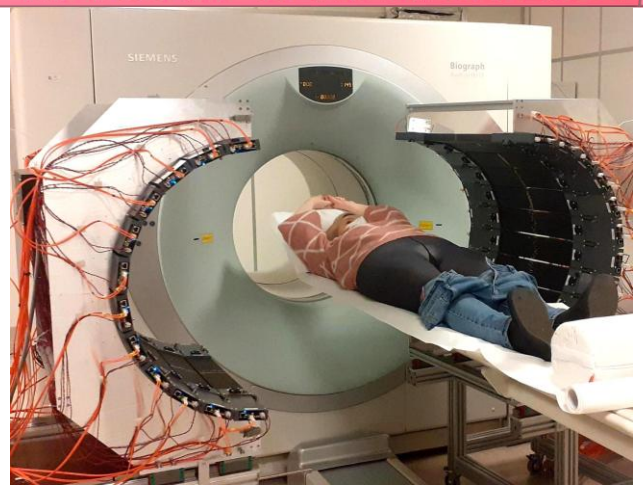




Reconstruction of the Annihilation Point (SUV Image)

J-PET campaign at Warsaw Medical University and University hospital in Krakow

WARSAW CAMPAIGN 2022



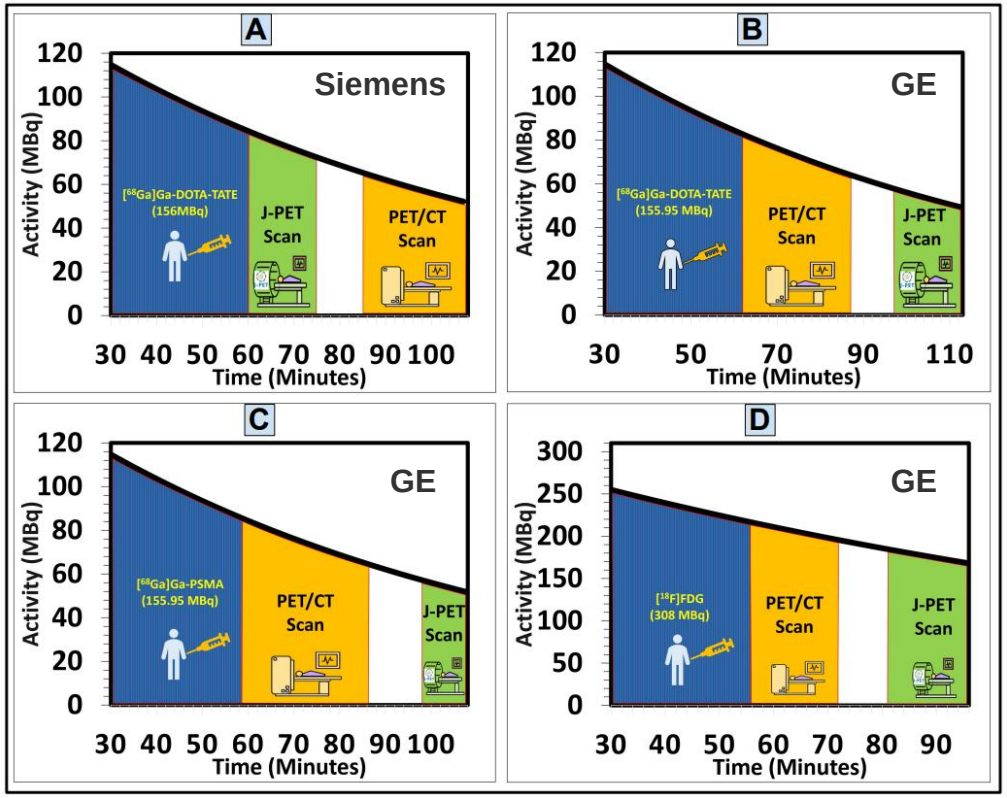
- Siemens Biograph 64 TruePoint @ WMU in Warsaw
- Subject scanned on same bed

KRAKOW CAMPAIGN 2024



- GE Discovery MI Gen 2 @ KMU in Krakow
- Subject scanned on separate bed

Patient No	Age (Sex)	Weight (kg)	Total activity Injected	Measurement time
1 (Warsaw)	56(F)	64	[68Ga]Ga-DOTA-TATE (156 MBq)	15 Min
2 (Krakow)	62(F)	73	[68Ga]Ga-DOTA-TATE (155.95 MBq)	16 Min
3(Krakow)	70(M)	94	[68Ga]Ga-PSMA (155.95 MBq)	10 Min
4 (Krakow)	50(M)	75	[18F]FDG (308 MBq)	15 Min

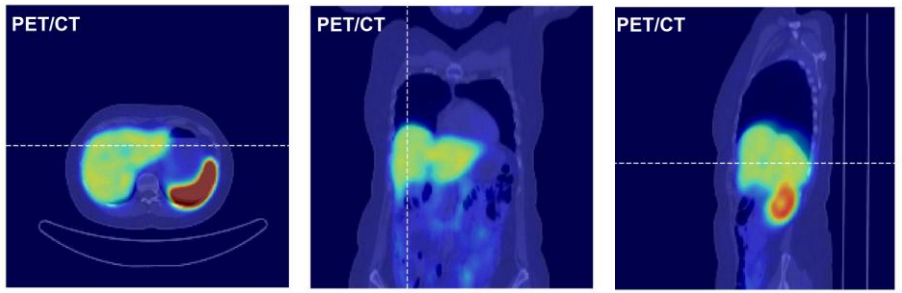


JAGIELLONIAN UNIVERSITY IN KRAKÓW

J-PET

First Human subject image with the J-PET Scanner

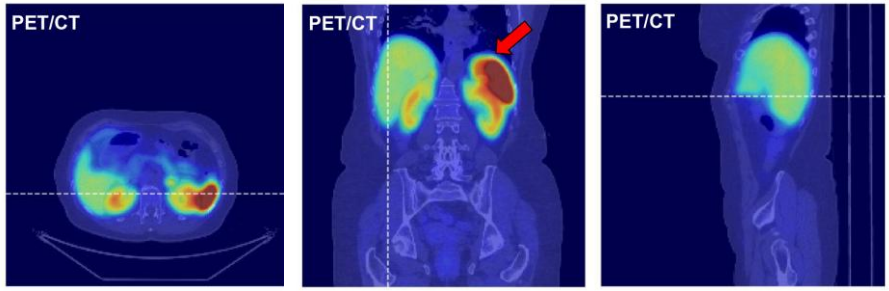
[68Ga]Ga-DOTA-TATE

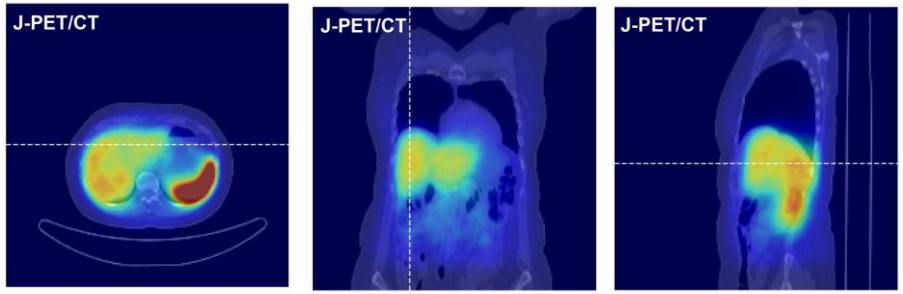


Standard PET image

Siemens PET/CT Biograph 64 TruePoint (Warsaw)

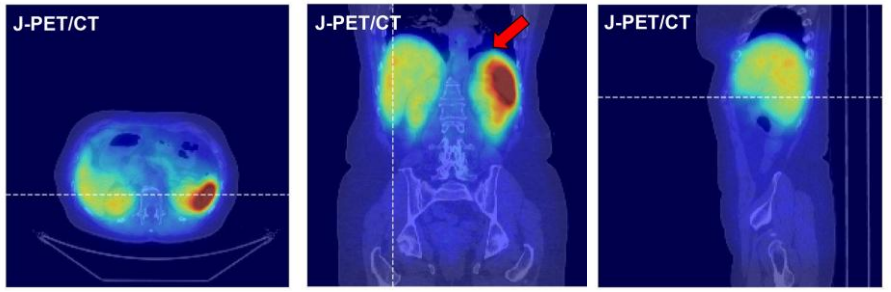
GE Discovery Mi Gen 2 PET-CT (Krakow)

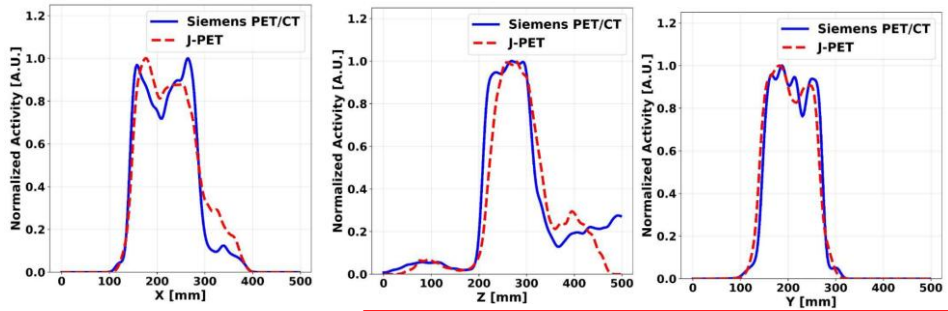


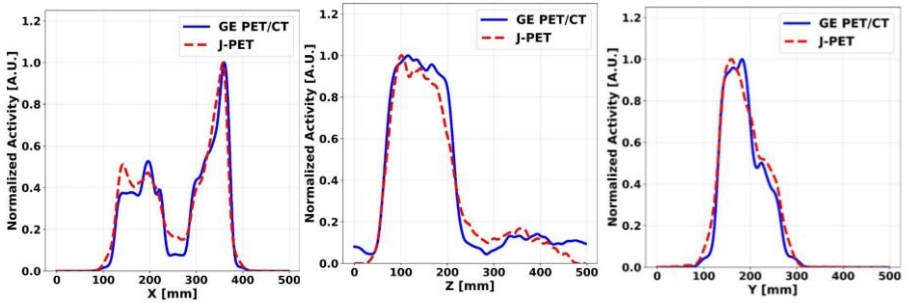


Standard J-PET image

J-PET





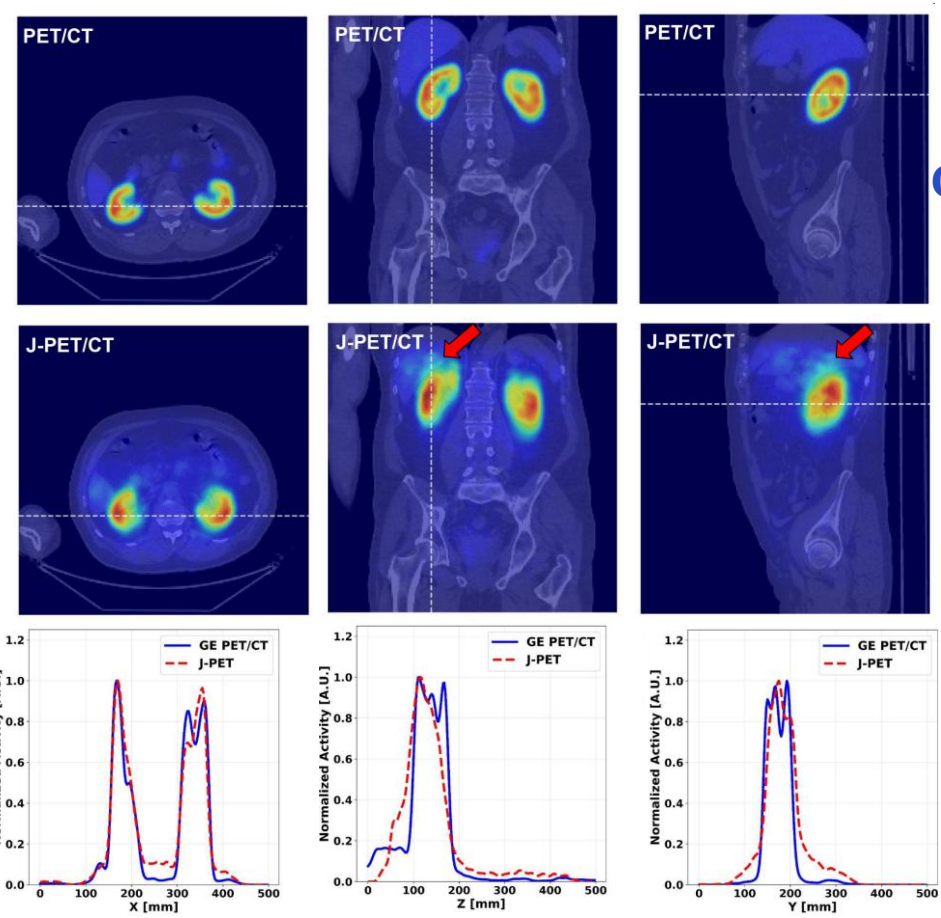


Moskal P. ,Das M. *et al.*, "Economical portable PET scanner from plastic scintillators - the first clinical images," *(Under Preparation)*

First Human subject image with the J-PET Scanner

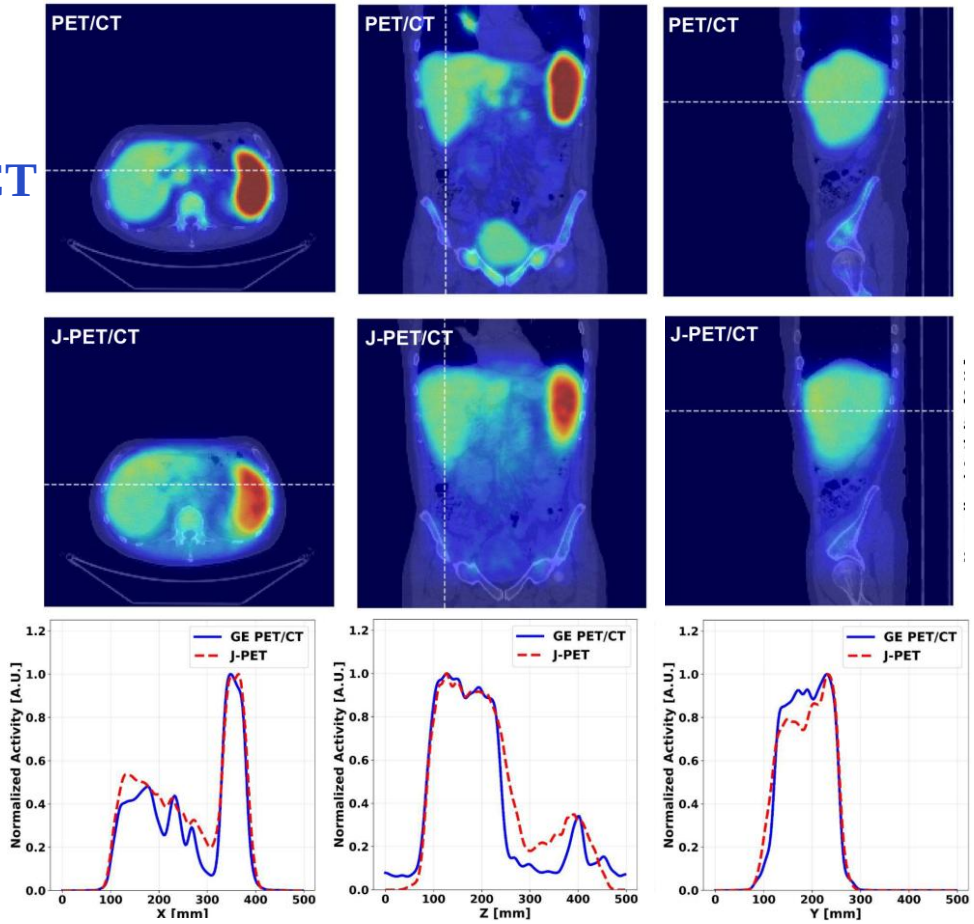
[68Ga]Ga-PSMA

[18F]FDG



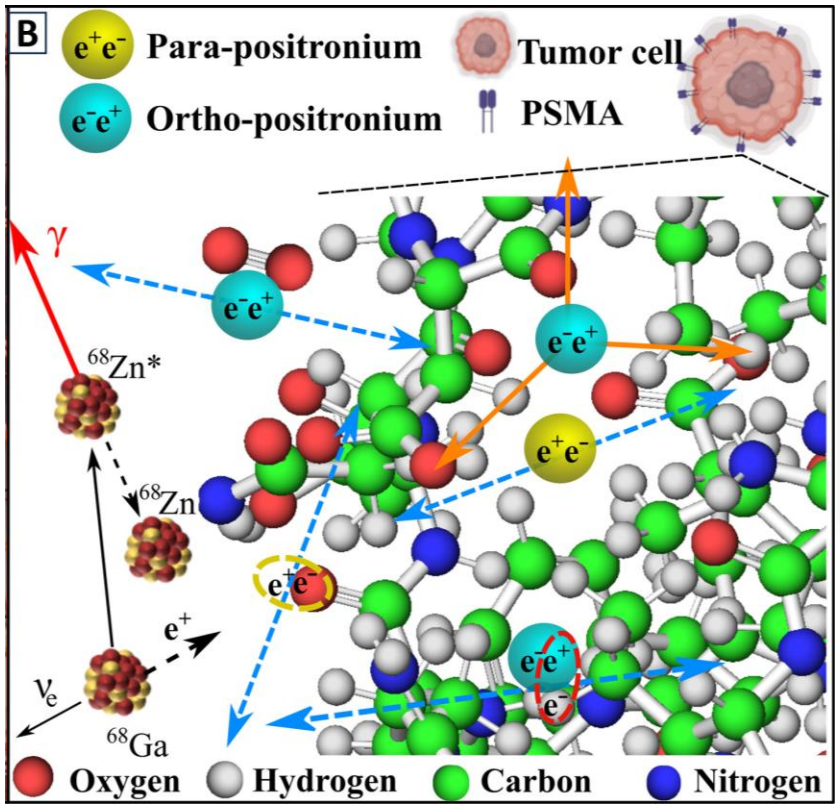
Standard PET image
GE Discovery Mi Gen 2 PET-CT

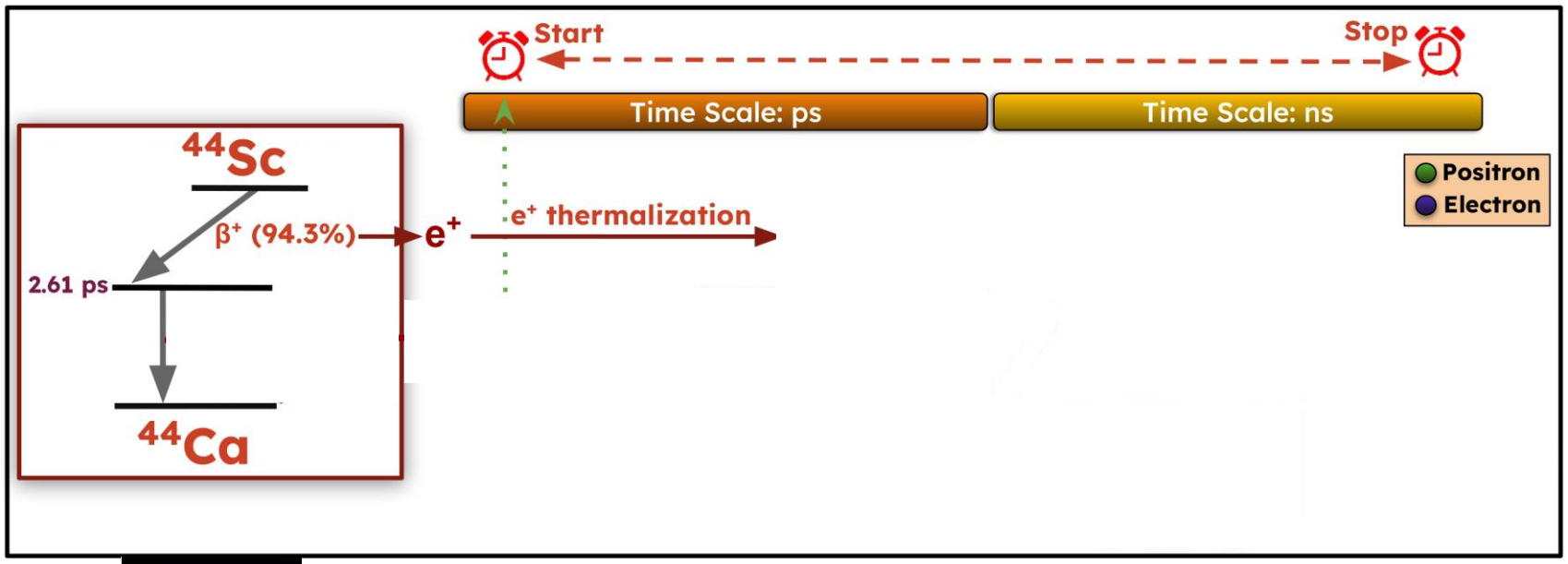
Standard J-PET image
J-PET

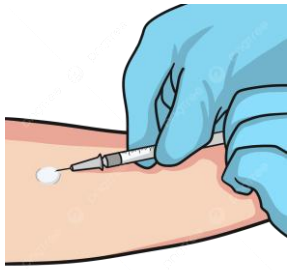


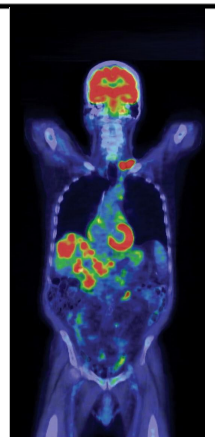
Moskal P. ,Das M. *et al.*, "Economical portable PET scanner from plastic scintillators - the first clinical images," *(Under Preparation)*

Positronium Lifetime Imaging

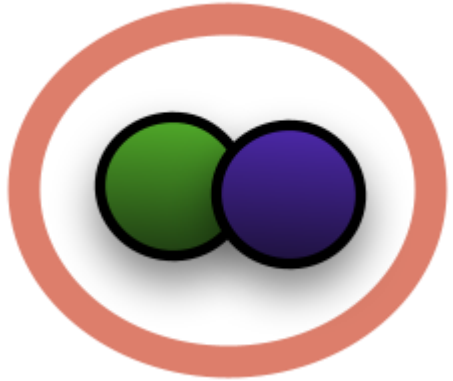






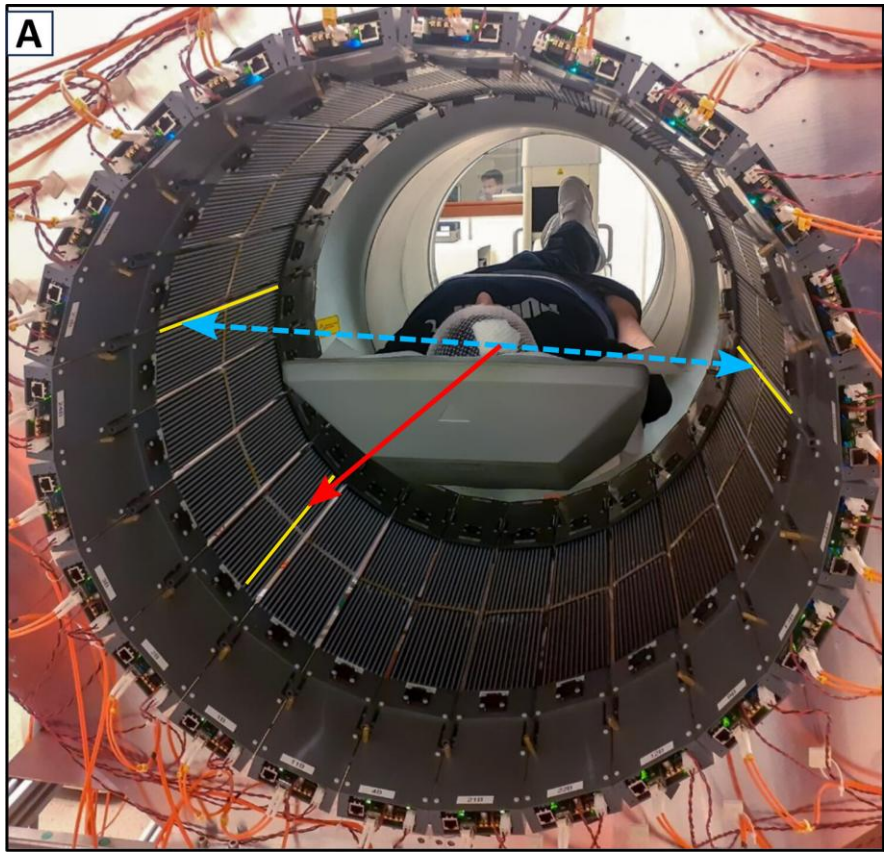


Reconstruction of the Annihilation Point (SUV Image)



Positronium formation

Positronium lifetime Imaging



$\beta^+ + \gamma$ Emitter

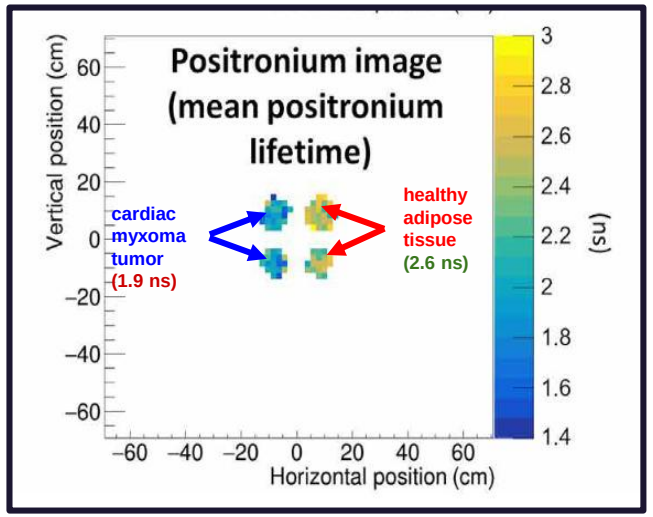
[1]Das M, et al. "First positronium imaging using 44Sc with the J-PET scanner: a case study on the NEMA-Image Quality phantom" *IEEE Transactions on Radiation and Plasma Medical Sciences,* vol. 10, no. 4, pp. 593-602, 2026

[2]Das M, et al. "First Positronium Lifetime Imaging using ^{52}Mn and ^{55}Co with a plastic-based PET scanner" *Scientific Reports, vol.* 16, no. 16230*, 2026*

A recap to the history

^{22}Na (*ex-vivo*)

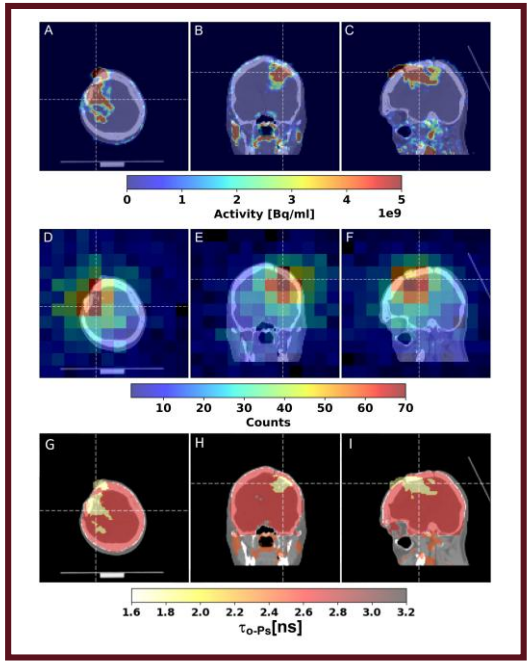
1



J-PET

^{68}Ga (*in-vivo*)

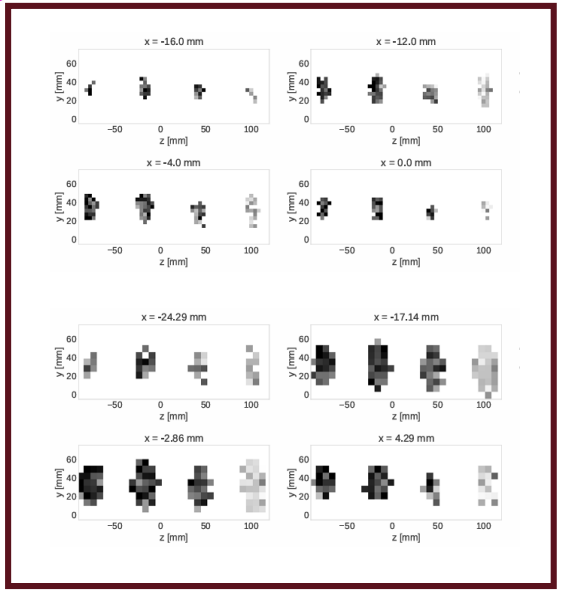
2



J-PET

^{124}I

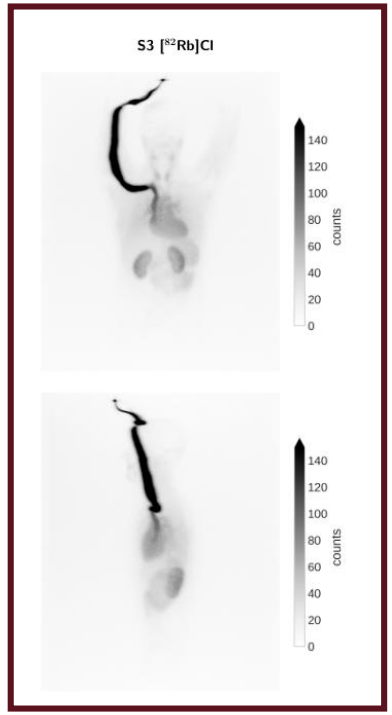
3



Biograph Vision Quadra

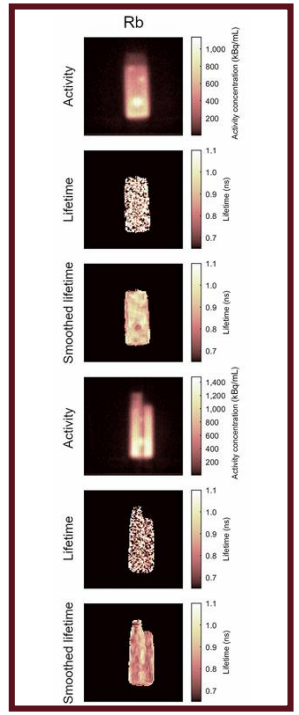
^{82}Rb

4



Biograph Vision Quadra

5



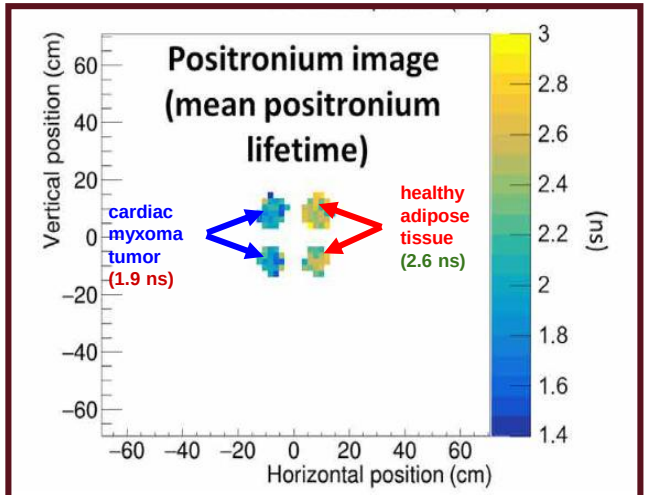
PennPET Explorer

[1]**Moskal, P. et. al** (2021). Positronium imaging with the novel multiphoton PET scanner. ***Science Advances***, *7*(42).
[2]**Moskal, P. et. al** (2024). Positronium image of the human brain in vivo. ***Science Advances***, *10(37).*
[3]**Mercolli, L. et al** (2025). Phantom imaging demonstration of positronium lifetime with a long axial field-of-view PET/CT and124I. **EJNMMI Physic**s 12
[4]**Mercolli, L. et al.** (2026). In Vivo Positronium Lifetime Measurements with Intravenous Tracer Administration and a Long Axial Field-of-View PET/CT, in ***IEEE TRPMS***, *Early access*
[5]**Huang, B. et al.** (2025). High-resolution positronium lifetime tomography at clinical activity levels on the PennPET Explorer. ***Journal of Nuclear Medicine*** *66*(9), 1464–1470.

A recap to the history

1

^{22}Na (*ex-vivo*)



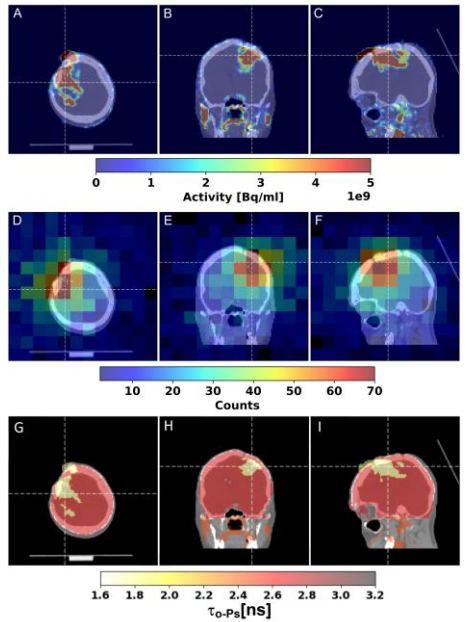
Limitations:

i. long half-life of **2.60 years**

ii. Uptake in **bones**

2

^{68}Ga (*in-vivo*)

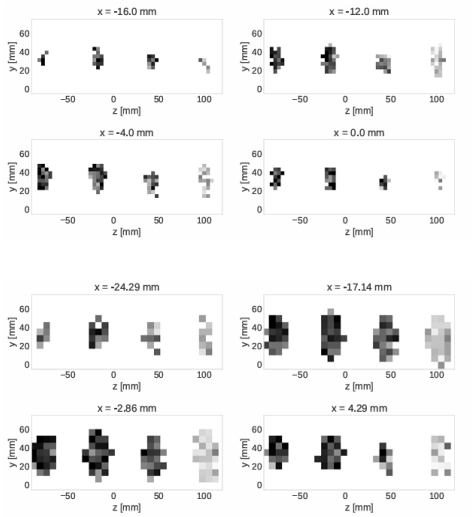


Limitations:

low probability—only 1.34 %—of prompt gamma rays being emitted along with the positron emission

3

^{124}I

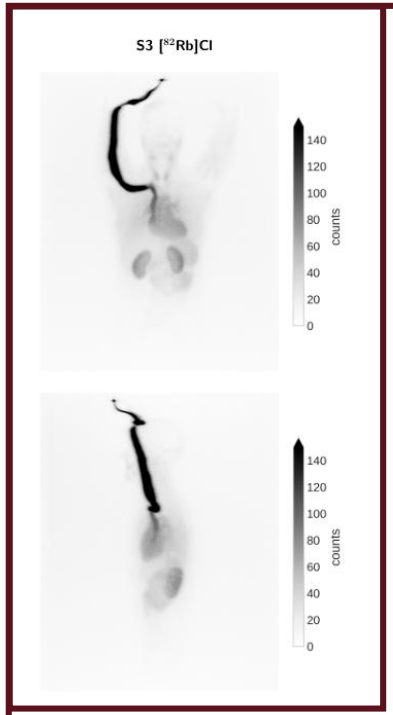


Limitations:

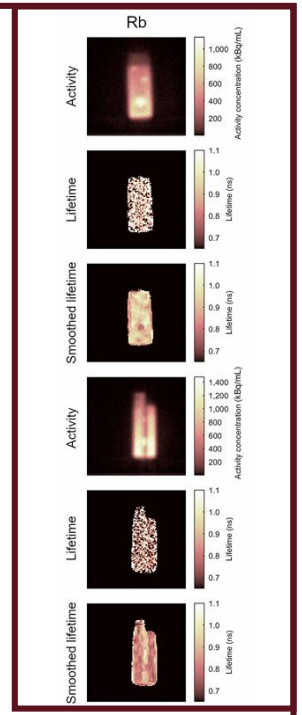
12% prompt gamma yield along with the positron emission

4

^{82}Rb



5

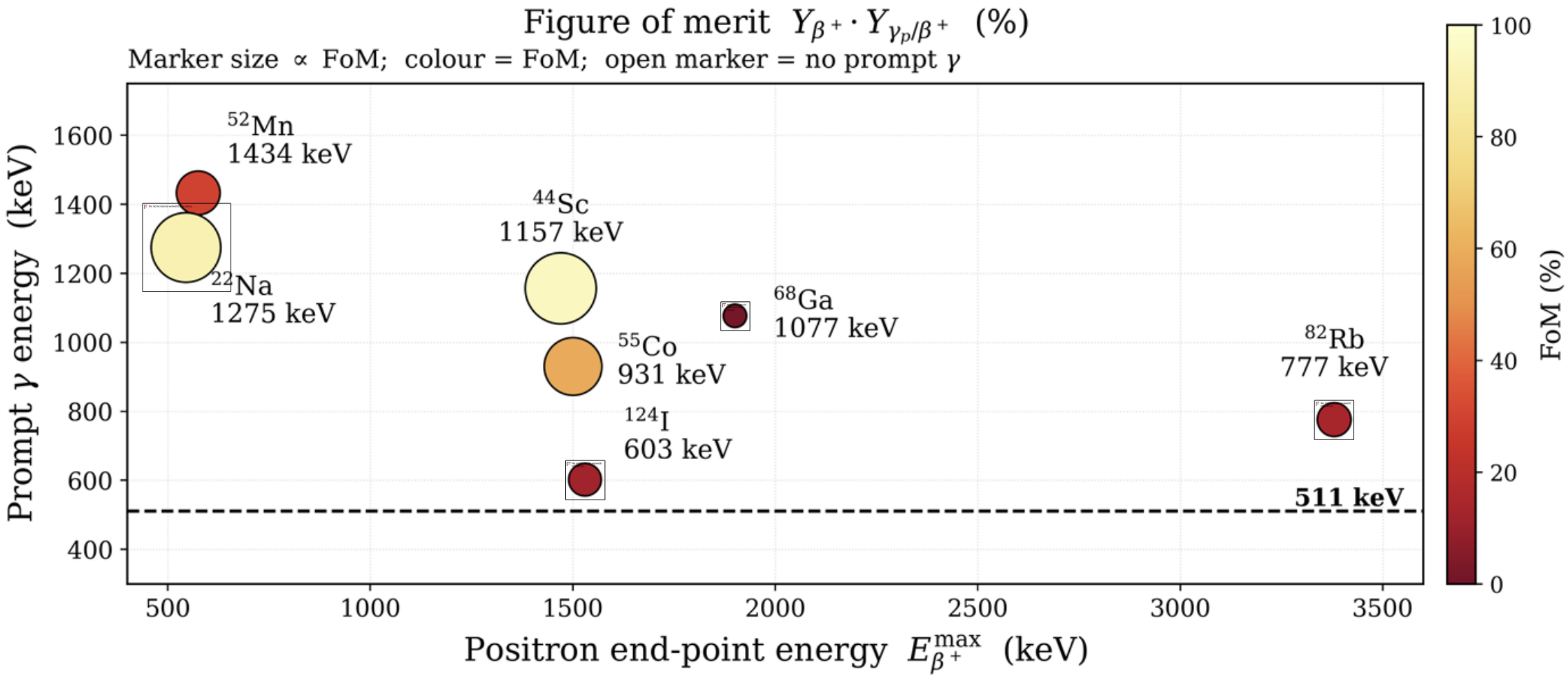


Limitations:

i. **13% prompt gamma yield** along with the positron emission

ii. Short half-life of 1.26 minutes

β⁺+γ Emitters for Positronium Imaging



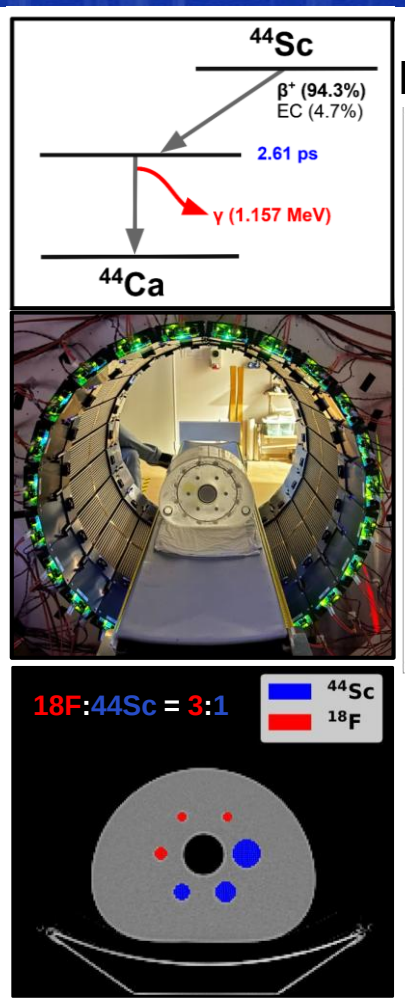
Courtesy of Dr. Sushil Sharma

First Positronium Lifetime Imaging with ^{44}Sc

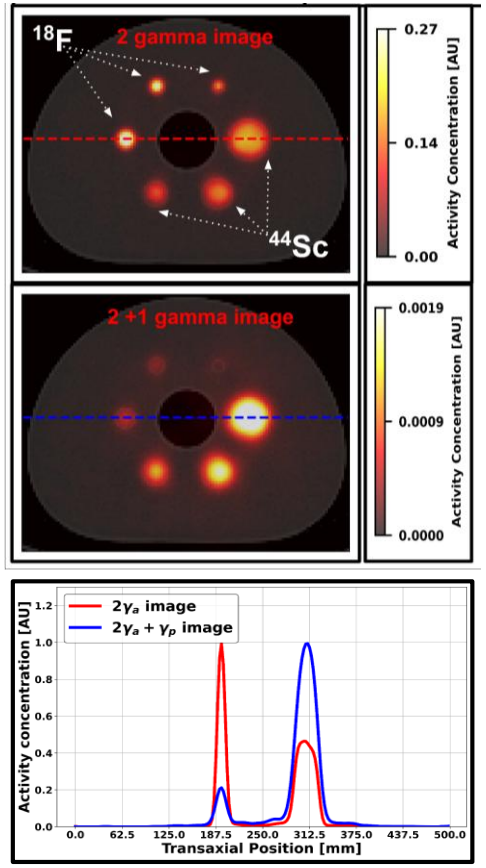
i. Produced at the **Heavy ion Laboratory, Warsaw** and Separated at **ICHTJ Warsaw.**

ii. Clinically relevant half-life of **4.04 hours**

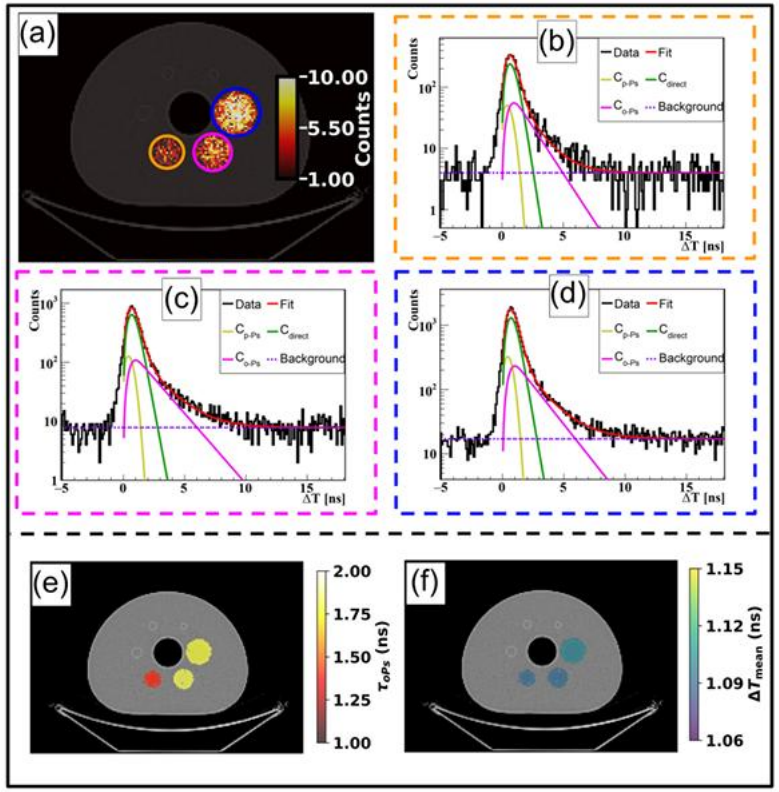
iii. High yield of **94.3% of decays** resulting in positron emission followed by a high-energy prompt gamma of 1157 keV with a **100% yield.**



Reconstructed Image



Positronium Lifetime Image



Reference lifetime in water = 1.83 ns

Das, M. et al. (2026). First positronium imaging using 44Sc with the J-PET scanner: a case study on the NEMA-Image Quality phantom. ***IEEE TRPMS,*** 10(4), 593-602.

Experimental Setup (^{52}Mn and ^{55}Co)

For the ^{52}Mn measurement:

- Cardiac myxoma:1.278 MBq
- Human adipose tissue: 1.298 MBq
- Polycarbonate: 1.346 MBq
- Fused silica 1.354 MBq

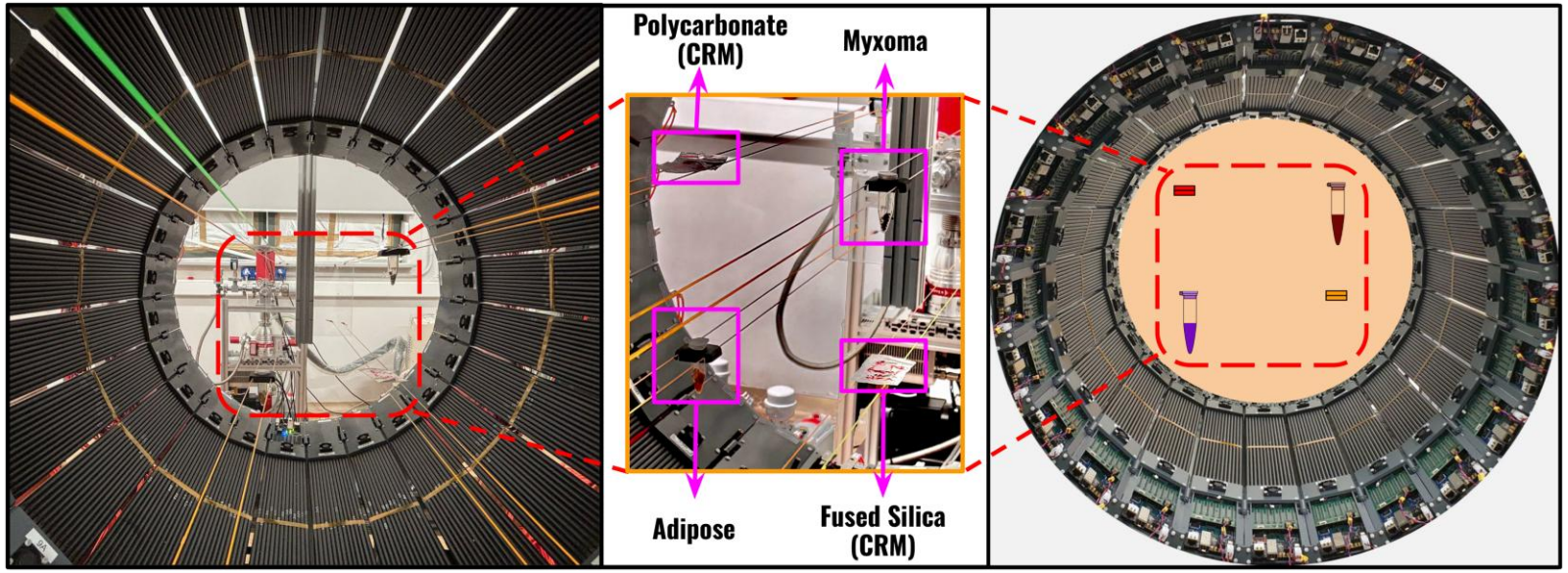
This measurement lasted 19 hours and 44 minutes.

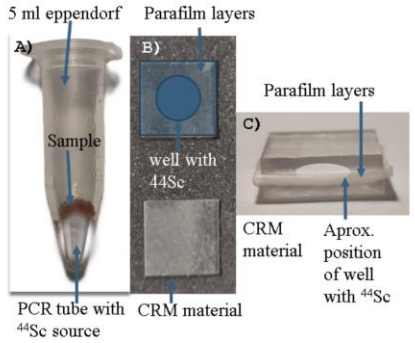
For the ^{55}Co measurement:

- Cardiac myxoma: 1.032 MBq
- Human adipose tissue 1.020 MBq
- Polycarbonate: 1.092 MBq and
- Fused silica: 1.071 MBq

This measurement lasted 15 hours and 5 minutes.

National Institute of Advanced Industrial Science and Technology (AIST) in Tokyo, Japan
Certified material **Polycarbonate: 2.10 ± 0.05 ns**
Certified material **Fused silica: 1.62±0.05 ns**



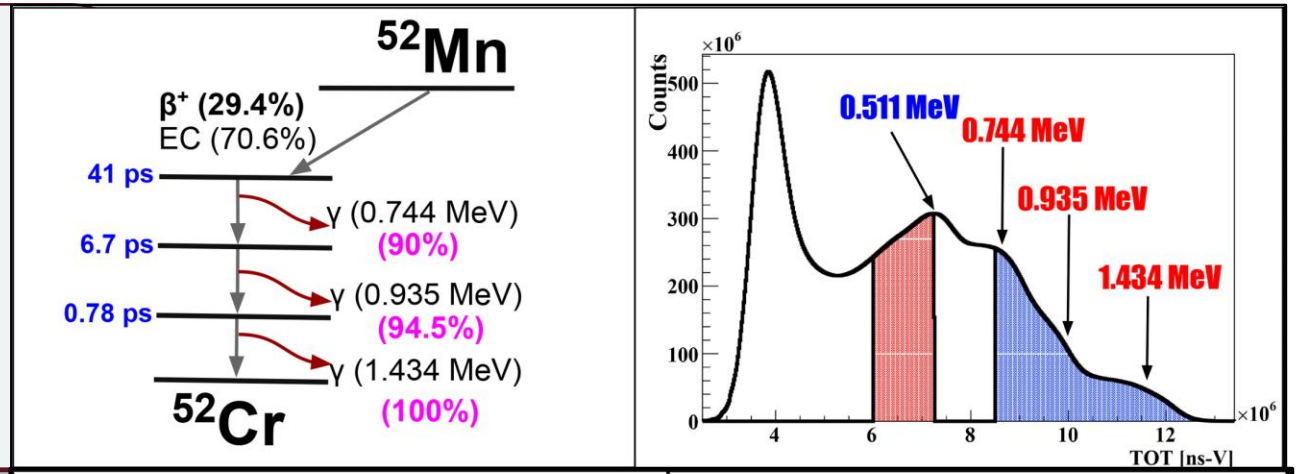


First Positronium imaging with ^{52}Mn and ^{55}Co

^{52}Mn (Produced at the Hevesy Laboratory in the Department of Health Technology at the Technical University of Denmark)

i. Half-life of **5.59 days**

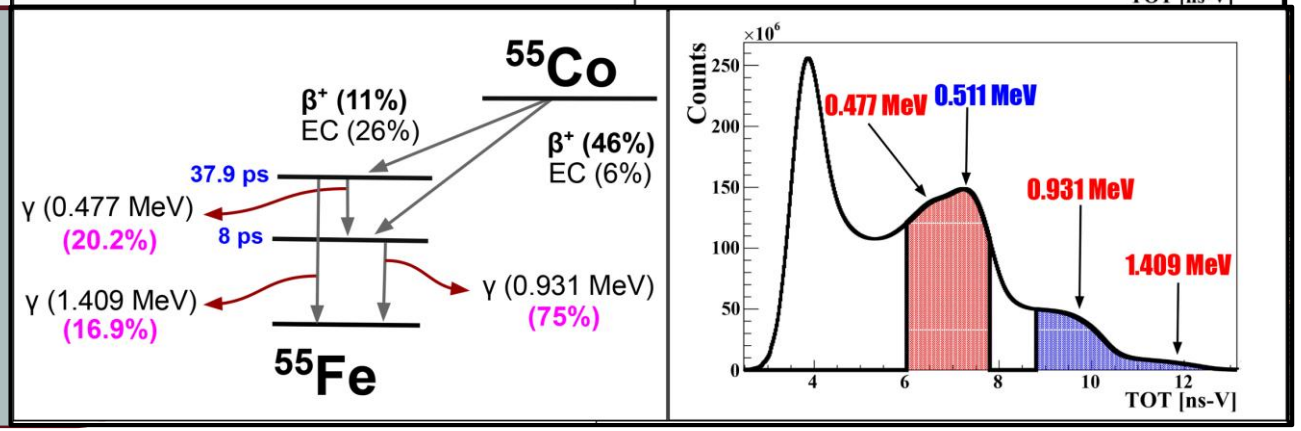
ii. Emits positrons in **29.4%** of its decays, followed by a cascade of three prompt photons 744 keV, 935 keV , and 1434 keV with a almost **100% yield.**



^{55}Co (Produced at the heavy ion Laboratory, Warsaw)

i. Half-life of **17.53 hours**

ii. Produces positrons in 76% of its decays, leading to excited ^{55}Fe states that emit prompt gamma rays at 477 keV, 931 keV, and 1409 keV with 20.2%, 75% and 16.9% intensity, respectively.



Das M, et al. "First Positronium Lifetime Imaging using ^{52}Mn and ^{55}Co with a plastic-based PET scanner" *Scientific Reports, vol.* 16, no. 16230, *2026*

Results: Certified Reference Materials

Certified Lifetime

Polycarbonate: 2.10 ± 0.05 ns
Fused silica: 1.62±0.05 ns

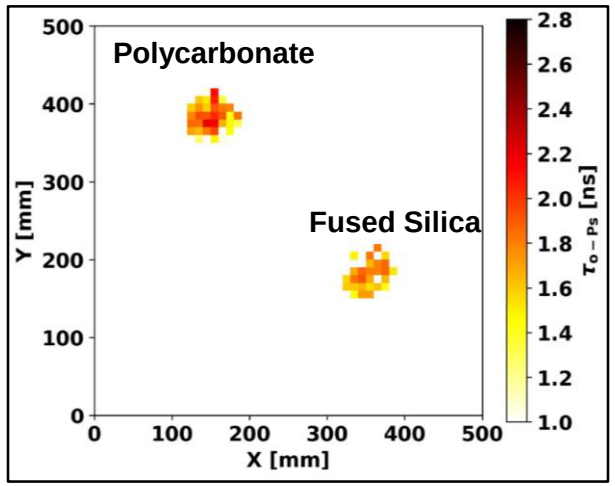
^{52}Mn

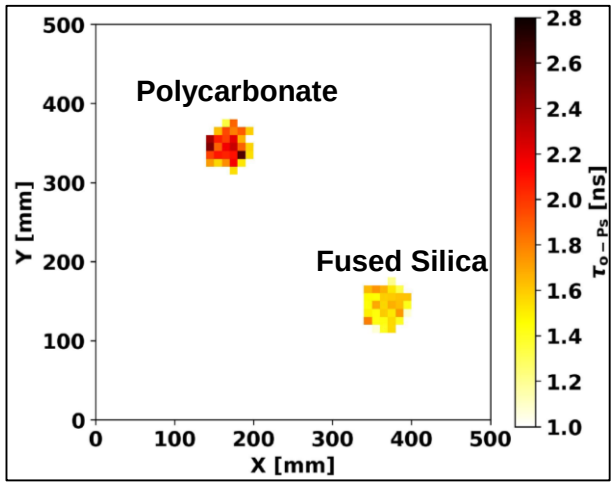
Sample Name	τ_{oPs} [ns]	ΔT_{mean} [ns]
Polycarbonate	2.069 ± 0.020	1.120 ± 0.002
Fused Silica	1.836 ± 0.013	1.223 ± 0.003

^{55}Co

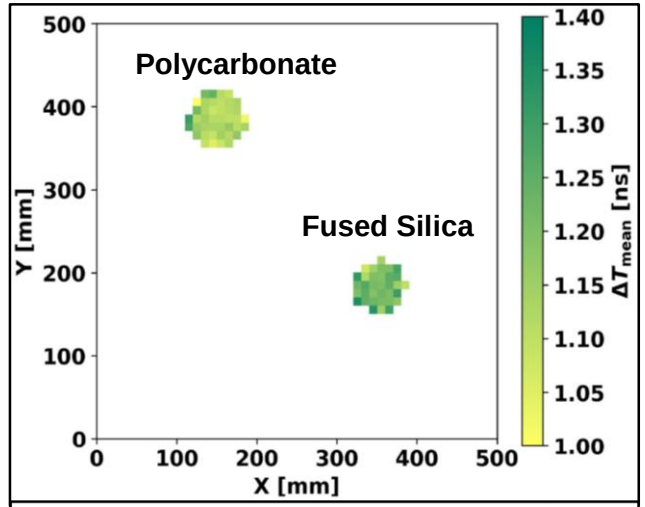
Sample Name	τ_{oPs} [ns]	ΔT_{mean} [ns]
Polycarbonate	2.174 ± 0.024	1.136 ± 0.002
Fused Silica	1.607 ± 0.012	1.240 ± 0.002

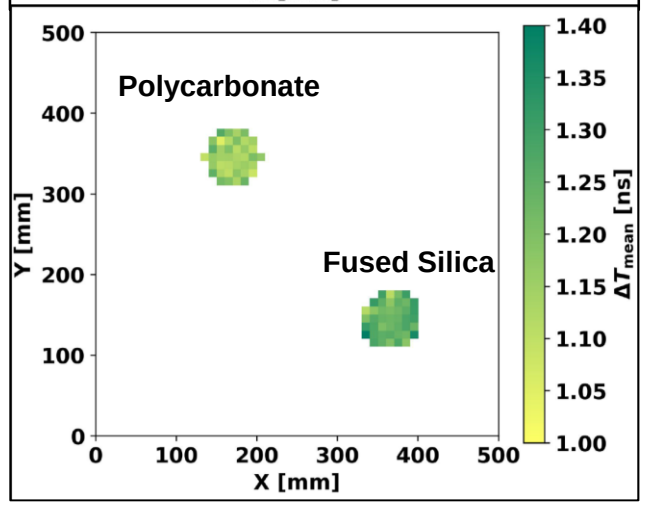
Voxel wise mean o-Ps lifetime ($\tau_{o\text{-}Ps}$)





Voxel wise mean positron lifetime (ΔT_{mean})





Result: Tissues

5 years before

Myxoma – 1.96 ns
Adipose – 2.6 ns

Possible degradation of the tissue samples

^{52}Mn (3 months after removing from formaldehyde)

Sample Name	τ_{oPs} [ns]	I_{oPs} [%]	ΔT_{mean} [ns]
Polycarbonate	2.069 ± 0.020	21.44 ± 0.17	1.120 ± 0.002
Fused Silica	1.836 ± 0.013	32.45 ± 0.20	1.223 ± 0.003
Myxoma (see caption)	2.111 ± 0.018	24.15 ± 0.17	1.043 ± 0.002
Adipose (see caption)	2.081 ± 0.018	23.68 ± 0.17	1.044 ± 0.002

^{55}Co (5 months after removing from formaldehyde)

Sample Name	τ_{oPs} [ns]	I_{oPs} [%]	ΔT_{mean} [ns]
Polycarbonate	2.174 ± 0.024	20.34 ± 0.21	1.136 ± 0.002
Fused Silica	1.607 ± 0.012	36.30 ± 0.22	1.240 ± 0.002
Myxoma (see caption)	2.070 ± 0.029	13.46 ± 0.49	0.983 ± 0.002
Adipose (see caption)	1.996 ± 0.030	11.98 ± 0.92	0.972 ± 0.002

Das M, et al. "First Positronium Lifetime Imaging using ^{52}Mn and ^{55}Co with a plastic-based PET scanner" *Scientific Reports, vol.* 16, no. 16230, *2026*

Result CRM – interlaboratory comparison

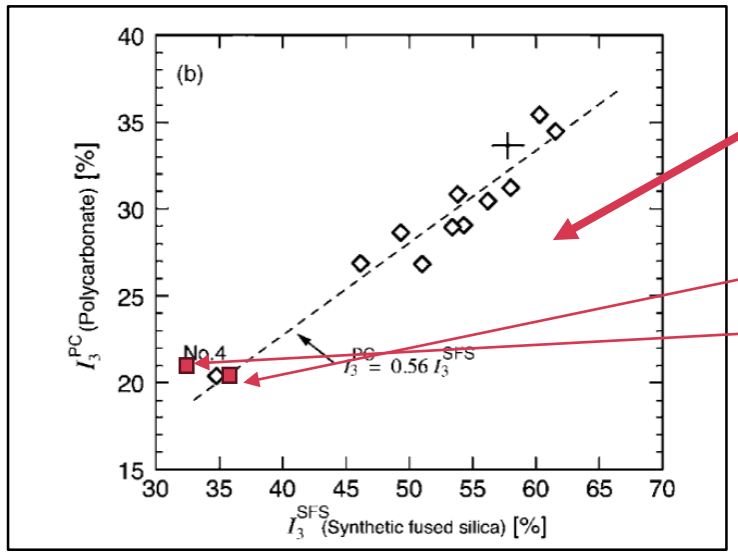
Comparison of the Intensity ratio of the Certified Reference Materials across 12 different laboratories

^{52}Mn

Sample Name	τ_{oPs} [ns]	I_{oPs} [%]	ΔT_{mean} [ns]
Polycarbonate	2.069 ± 0.020	21.44 ± 0.17	1.120 ± 0.002
Fused Silica	1.836 ± 0.013	32.45 ± 0.20	1.223 ± 0.003
Myxoma (see caption)	2.111 ± 0.018	24.15 ± 0.17	1.043 ± 0.002
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^{55}Co

Sample Name	τ_{oPs} [ns]	I_{oPs} [%]	ΔT_{mean} [ns]
Polycarbonate	2.174 ± 0.024	20.34 ± 0.21	1.136 ± 0.002
Fused Silica	1.607 ± 0.012	36.30 ± 0.22	1.240 ± 0.002
Myxoma (see caption)	2.070 ± 0.029	13.46 ± 0.49	0.983 ± 0.002
Adipose (see caption)	1.996 ± 0.030	11.98 ± 0.92	0.972 ± 0.002



$I_{poly} = (0.56)\, I_{silica}$

^{55}Co:
$I_{poly} = (0.560 \pm 0.006)\, I_{silica}$

^{52}Mn:
$I_{poly} = (0.661 \pm 0.007)\, I_{silica}$

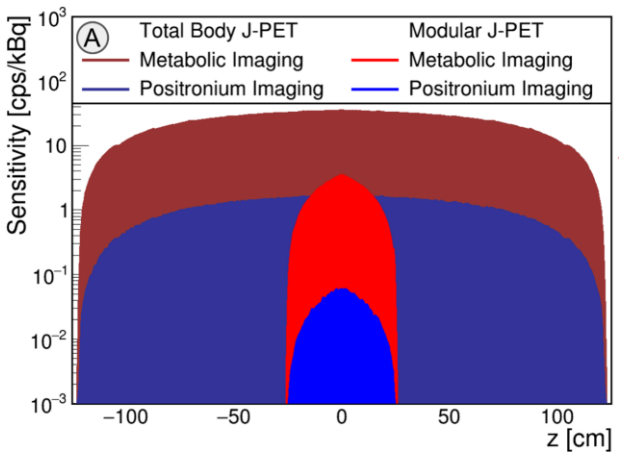
Ito, K., et al (2008). Interlaboratory comparison of positron annihilation lifetime measurements for synthetic fused silica and polycarbonate. Journal of Applied Physics, 104(2). https://doi.org/10.1063/1.2957074

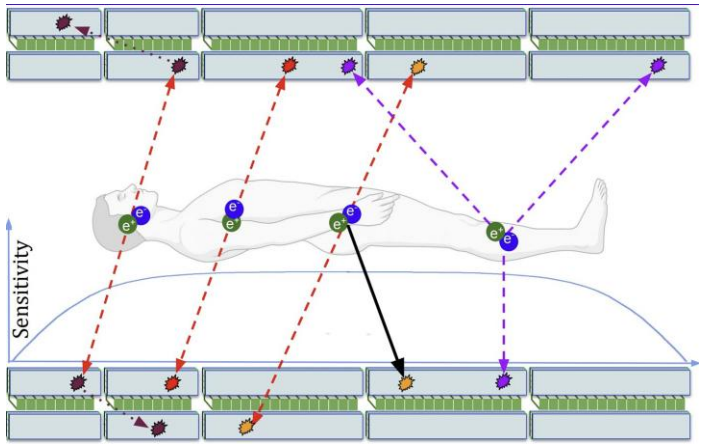
TB-J-PET in action

- **2.5-meter** axial field of view
- ~35 times higher sensitivity for Molecular Imaging/two-gamma
- **~25 higher sensitivity** for Positronium Lifetime Imaging

First Ring of the TB-JPET







Conclusion

• This study presents the first experimental demonstration of positronium lifetime imaging (PLI) using three novel isotopes, **Scandium-44, Manganese-52 and Cobalt-55** with the J-PET scanner.

• **Scandium–44** remains the **best candidate** for PLI imaging due to its favorable properties.

• **Cobalt-55** also shows strong **potential as a secondary candidate**, offering a high **β+ branching ratio (~76%)** and a relatively simple decay scheme, resulting in a higher peak-to-background ratio (~133) compared to 52Mn (~87).

• **Manganese-52** benefits from a multi-photon decay cascade that **may increase the effective tagging yield**, its **large electron-capture fraction (~71%)** contributes to **increased background**.

Positronium Imaging Attracted Worldwide Attention



Prof. dr hab. Paweł Moskal
Positronium Imaging (2018)

University of Bern, Switzerland (Siemens Biograph Quadra)

University of Pennsylvania, USA (Penn Medicine / PennPET Explorer)

University of California, Davis USA

United Imaging Healthcare America, Houston, Texas, USA (NeuroEXPLORER (NX) brain PET)

Weill Cornell Medicine, Cornell University, NY, USA (PrismPET Scanner)

National Institutes for Quantum Science and Technology (QST), Chiba, Japan (VRAIN PET scanner)

University of Chicago, Chicago, USA

University of Central Florida, Orlando, USA

And many more to come .....

Jagiellonian University, Krakow, Poland

1. Prof. Pawel Moskal
2. Prof. Ewa Stepien
3. Prof. Tomasz Kozik
4. Dr. Sushil Sharma
5. Dr. Eryk Czerwiński
6. Dr. hab. Magdalena Skurzok
7. Dr. Szymon Niedźwiecki
8. Dr. Grzegorz Korcyl
9. Dr. Łukasz Kapłon
10. Dr. Alessio Porcelli
11. Dr. Aleksander Khreptak
12. Dr. Anand Pandey
13. Dr. Martin Rädler
14. Dr. Sumit Kumar Kundu
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16. Dr. Neha Chug
17. Mgr. Maciej Słotwiński
18. Mgr. Ermias Yitayew Beyene
19. Mgr. Kavya Valsan Eliyan
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21. Mgr. Krzysztof Kacprzak
22. Mgr. Tevfik Kaplanoglu
23. Mgr. Kamila Kasperska
24. Mgr. Anoop Kunimmal Venadan
25. Mgr. Deepak Kumar
26. Mgr. Justyna Mędrala-Sowa
27. Mgr. inz. Simbarashe Moyo
28. Mgr. Wiktor Mryka
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30. Mgr. Szymon Parzych
31. Mgr. Satyam Tiwari
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1. Prof. Anna Sowa-Staszczak
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3. Dr. hab. Martą Opalińską
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1. Prof. Jolanta Kunikowska
2. Dr. Małgorzata Kobylecka
3. Dr. Joanna Mączewska
4. Dr. Leszek Królicki
5. Dr. Katarzyna Fronczewska

Inselspital, Bern University Hospital, University of Bern, Switzerland

1. Prof. Axel Rominger
2. Prof. Kuangyu Shi
3. Dr. Narendra Rathod

INFN, Laboratori Nazionali di Frascati, Frascati, Italy

1. Prof. Catalina Curceanu


Thank You


Thank You

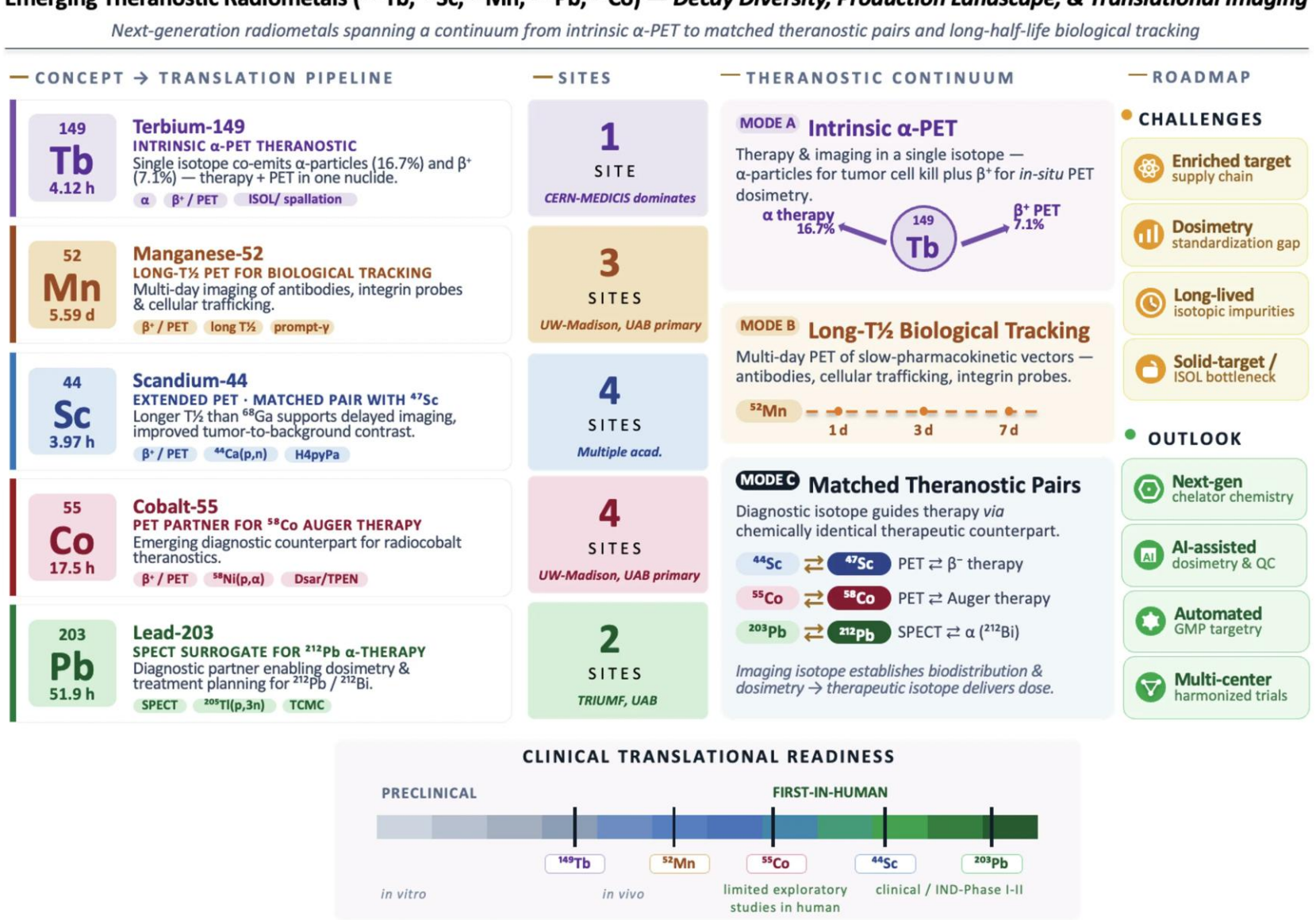
Production

^{44}Sc:
A natural calcium carbonate target (CaCO3 tablets) was irradiated for 2 h and 20 min using a 16.5 MeV proton beam with a current of 15 μA.

^{55}Co:
Co was produced at the Heavy Ion Laboratory of the University of Warsaw via the Fe(d,n)Co reaction. A metal 54Fe target was irradiated for 2 h with an 8.4 MeV deuteron beam at a current of 14.1 muA

52Mn:

The 52Cr(p,n)52Mn production route by irradiating a natural chromium (Cr) target for 8 hours at 40 μ A current with a proton beam energy of 16.5 MeV on a GE PETtrace cyclotron.


Emerging Theranostic Radiometals (149Tb, 44Sc, 52Mn, 203Pb, 55Co) — Decay Diversity, Production Landscape, & Translational Imaging
Next-generation radiometals spanning a continuum from intrinsic α-PET to matched theranostic pairs and long-half-life biological tracking
CONCEPT → TRANSLATION PIPELINE
SITES
THERANOSTIC CONTINUUM
ROADMAP
149 Tb 4.12 h
Terbium-149
INTRINSIC α-PET THERANOSTIC
Single isotope co-emits α-particles (16.7%) and β+ (7.1%) — therapy + PET in one nuclide.
α β+ / PET ISOL/ spallation
1 SITE
CERN-MEDICIS dominates
52 Mn 5.59 d
Manganese-52
LONG-T½ PET FOR BIOLOGICAL TRACKING
Multi-day imaging of antibodies, integrin probes & cellular trafficking.
β+ / PET long T½ prompt-γ
3 SITES
UW-Madison, UAB primary
44 Sc 3.97 h
Scandium-44
EXTENDED PET · MATCHED PAIR WITH 47Sc
Longer T½ than 68Ga supports delayed imaging, improved tumor-to-background contrast.
β+ / PET 44Ca(p,n) H4pyPa
4 SITES
Multiple acad.
55 Co 17.5 h
Cobalt-55
PET PARTNER FOR 58Co AUGER THERAPY
Emerging diagnostic counterpart for radiocobalt theranostics.
β+ / PET 58Ni(p,α) Dsar/TPEN
4 SITES
UW-Madison, UAB primary
203 Pb 51.9 h
Lead-203
SPECT SURROGATE FOR 212Pb α-THERAPY
Diagnostic partner enabling dosimetry & treatment planning for 212Pb / 212Bi.
SPECT 205Tl(p,3n) TCMC
2 SITES
TRIUMF, UAB
MODE A Intrinsic α-PET
Therapy & imaging in a single isotope — α-particles for tumor cell kill plus β+ for in-situ PET dosimetry.
α therapy 16.7%
149 Tb
β+ PET 7.1%
MODE B Long-T½ Biological Tracking
Multi-day PET of slow-pharmacokinetic vectors — antibodies, cellular trafficking, integrin probes.
52Mn
1 d
3 d
7 d
MODE C Matched Theranostic Pairs
Diagnostic isotope guides therapy via chemically identical therapeutic counterpart.
44Sc ⇄ 47Sc PET ⇄ β− therapy
55Co ⇄ 58Co PET ⇄ Auger therapy
203Pb ⇄ 212Pb SPECT ⇄ α (212Bi)
Imaging isotope establishes biodistribution & dosimetry → therapeutic isotope delivers dose.
CHALLENGES
Enriched target supply chain
Dosimetry standardization gap
Long-lived isotopic impurities
Solid-target / ISOL bottleneck
OUTLOOK
Next-gen chelator chemistry
AI-assisted dosimetry & QC
Automated GMP targetry
Multi-center harmonized trials
CLINICAL TRANSLATIONAL READINESS
PRECLINICAL
FIRST-IN-HUMAN
149Tb
52Mn
55Co
44Sc
203Pb
in vitro
in vivo
limited exploratory studies in human
clinical / IND-Phase I-II

J-PET (Solution to the expensive Crystal based PET)

Why plastic?

- Polymer scintillators replace costly inorganic crystals
- Enable large axial coverage, which reduces the cost of electronics.

Production cost reduced by a factor of ≈ 80

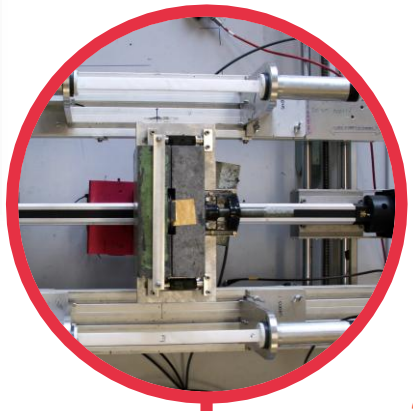
Reduces scanner price per cm axial length

Plastic is cast not grown

No high-temperature furnace
No managing of growth defects
Less limited in size/volume

Easier handling, longer durability

Not hygroscopic
No intrinsic radioactivity
Higher shaping flexibility







2009 2012 2014 2016 2021 2028

FIRST PATENT



