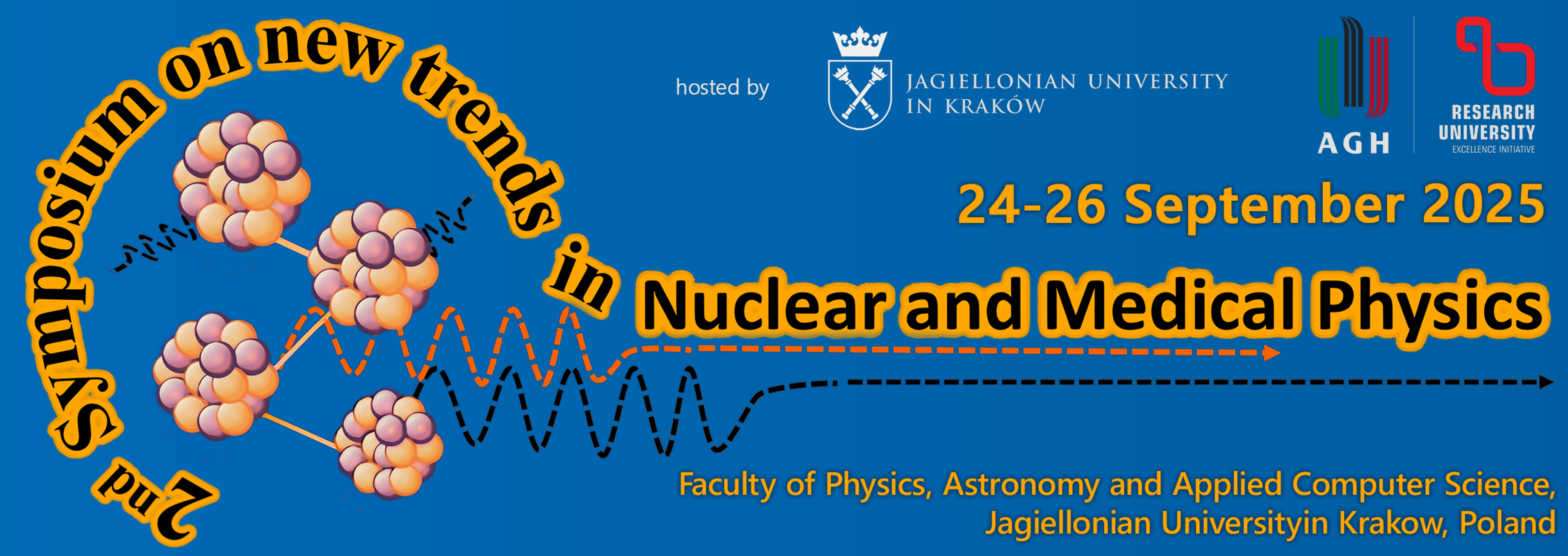

Development of high-Z organic scintillators for modern SPECT imaging and theranostic dosimetry

Flaminia Quattrini – Sapienza University of Rome

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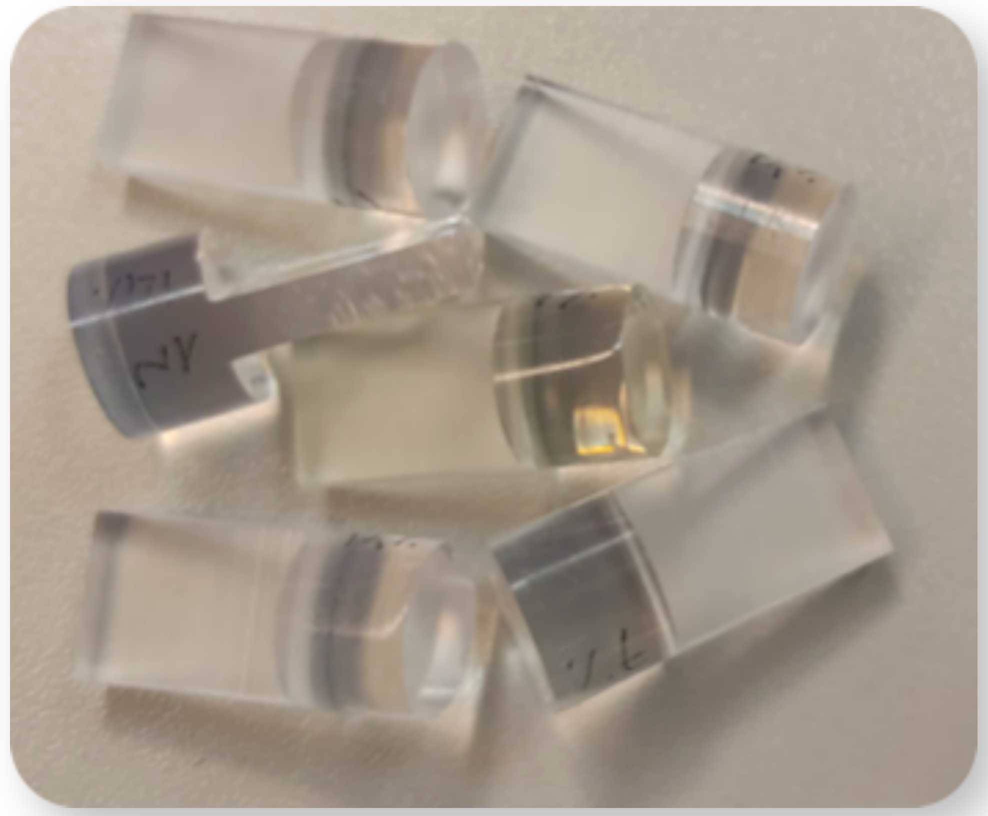
Plastic scintillators

- Easy to process and shape
- Fast response time
- Low cost

- Low Z → poor photoelectric cross-section
- No clear photopeak → not used in medical imaging



Goal

Bringing the benefits of plastic scintillators to the medical field

Idea

Loading plastic scintillators with high-Z elements to boost photoelectric interaction

Challenge

High-Z loading often reduces optical clarity and scintillation efficiency

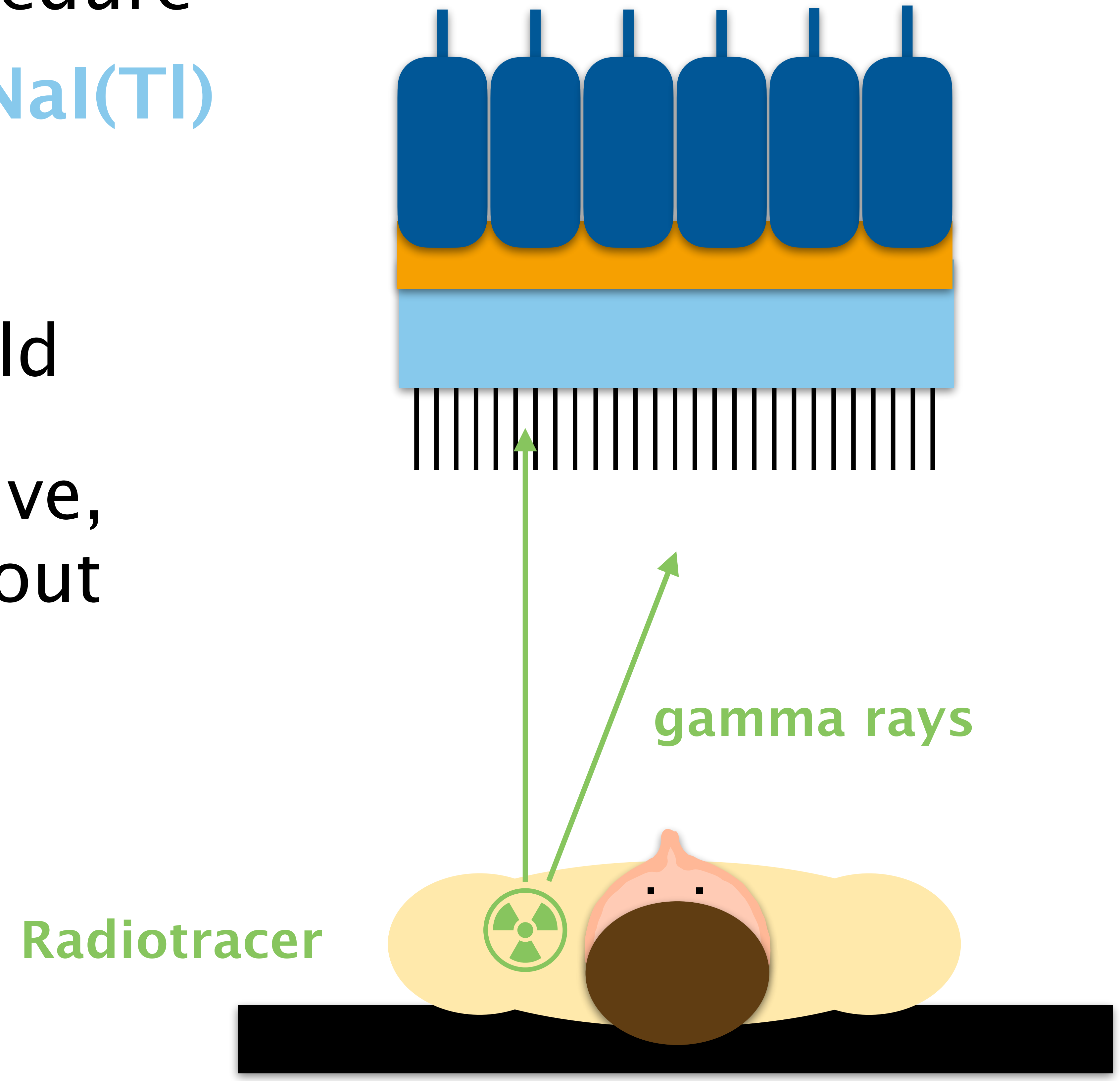
Why plastic scintillators for medical imaging?

- SPECT is the most widespread nuclear medicine procedure
- The current clinical standard for SPECT detectors is NaI(Tl) monolithic inorganic crystal coupled to a PMT matrix

✔ **Why NaI(Tl)?** Good energy resolution and light yield

✘ **And why not?** Slow, fragile, hygroscopic, expensive, incompatible with MRI due to the PMT-based readout

High-Z enriched plastic scintillators would enable total-body scans, faster acquisitions and hence lower patient dose, MRI-compatibility if coupled to silicon-based readout, theranostic applications…



State-of-the-art SPECT detection system

Roadmap

1. Develop a novel class of organic fluorophores
2. Optimise fabrication and high-Z loading
3. Characterise the samples in terms of optical and timing properties
4. Translate to clinics by developing custom electronics and tailored detector designs

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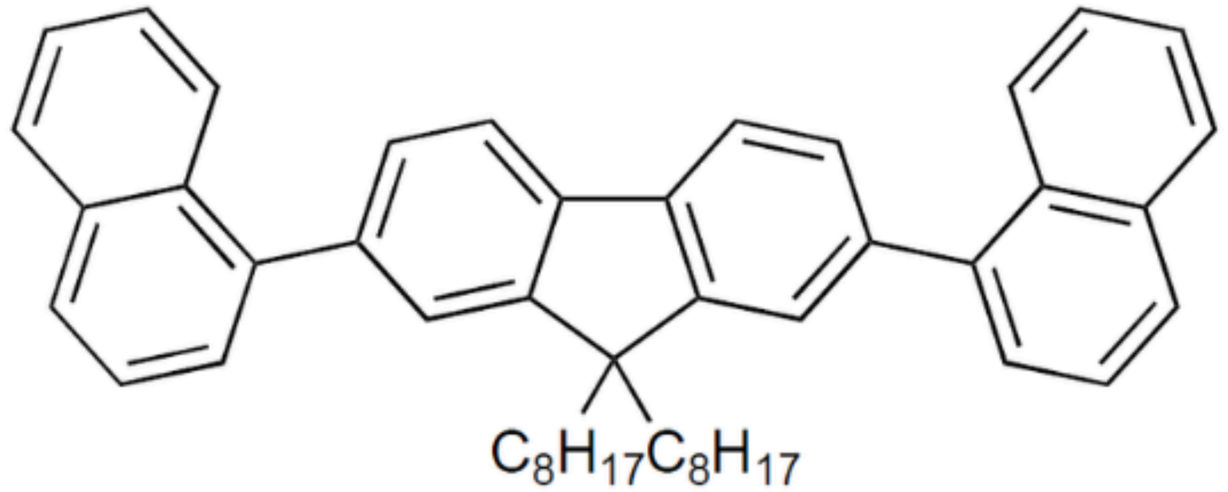
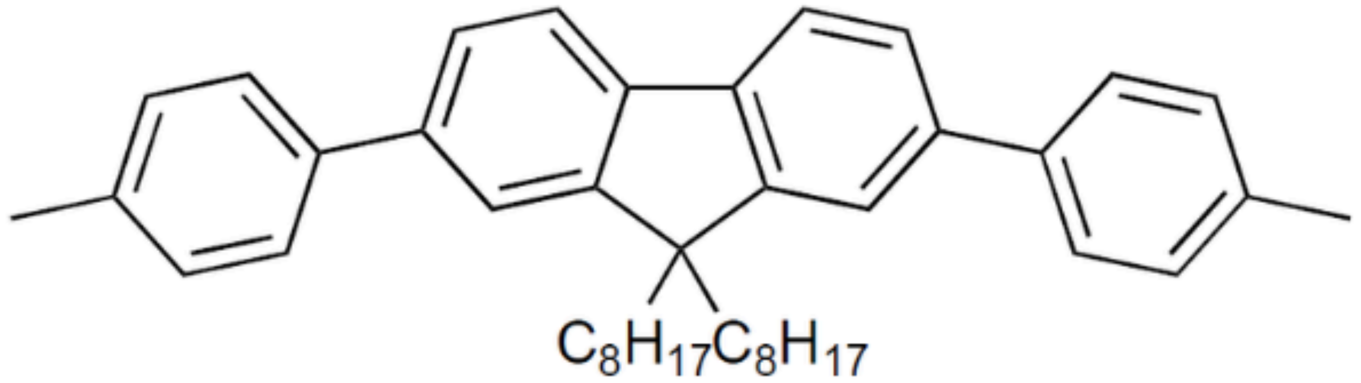
New organic fluorophores

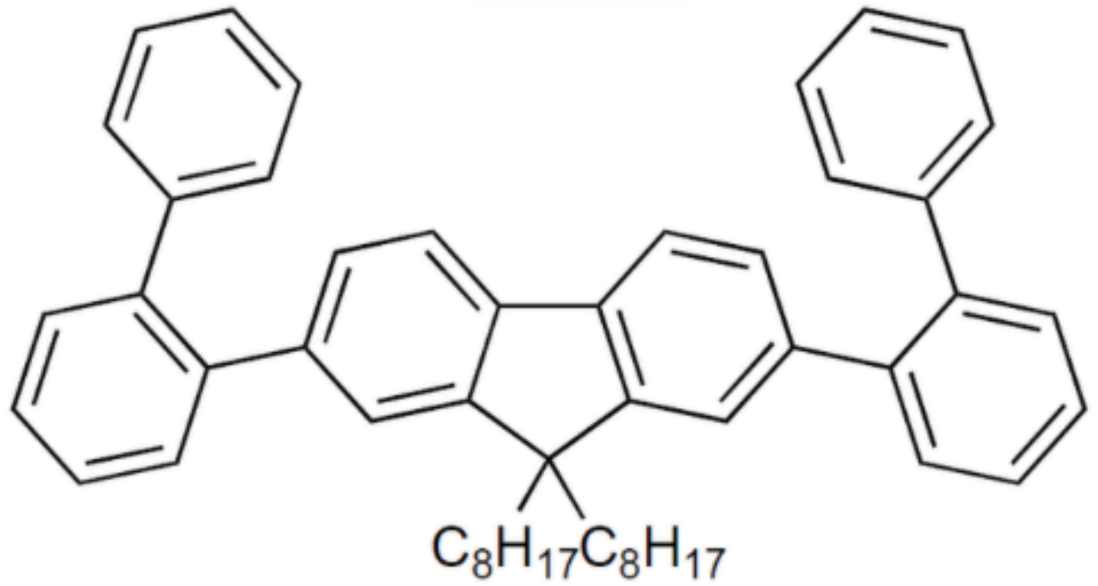
We developed and patented [1] a new class of fluorophores using organometallic chemistry.



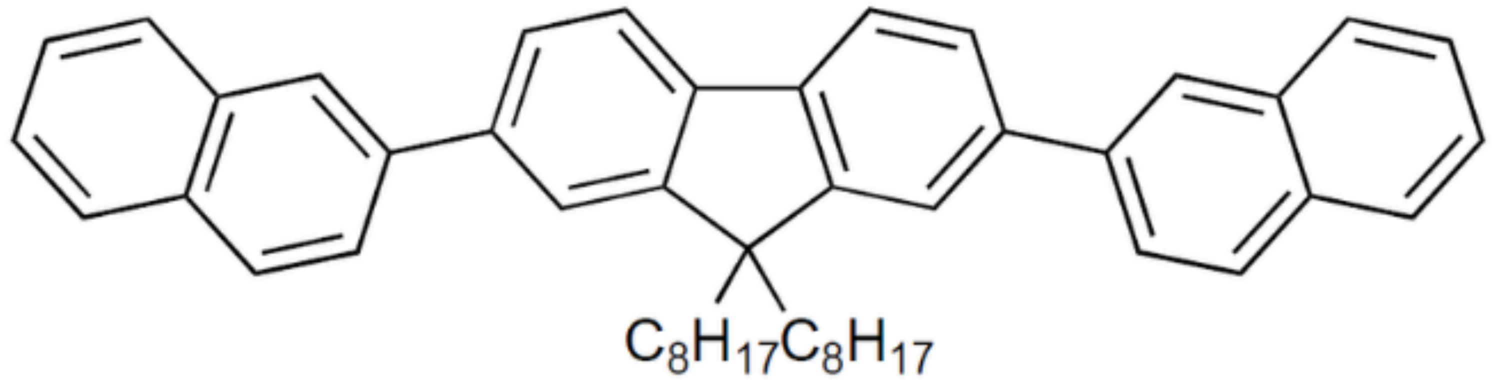
1N



2T



2B



2N

[1] L. Mattiello, V. Patera, A. Belardini, D. Rocco, M. Marafini, Organic Scintillator, Patent US20250154404, 2025

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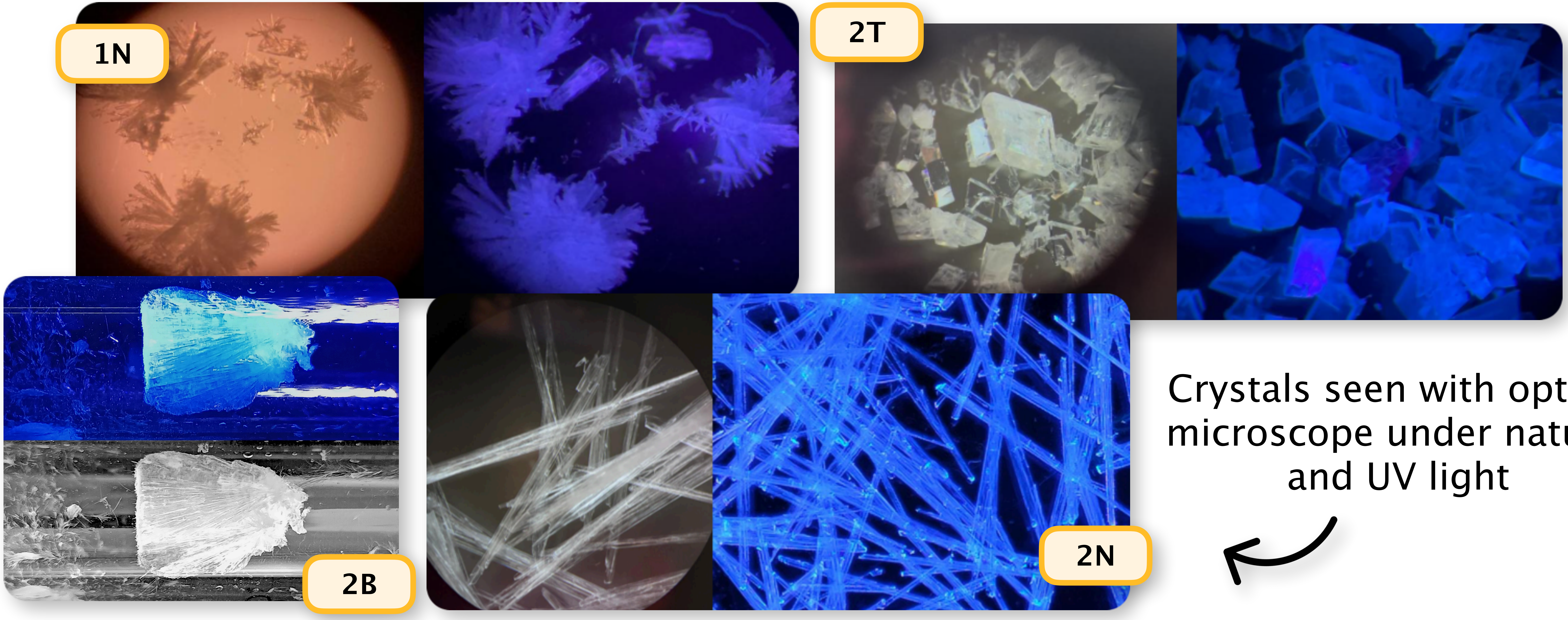

Crystals seen with optical microscope under natural and UV light

[1] L. Mattiello, V. Patera, A. Belardini, D. Rocco, M. Marafini, Organic Scintillator, Patent US20250154404, 2025

New organic fluorophores

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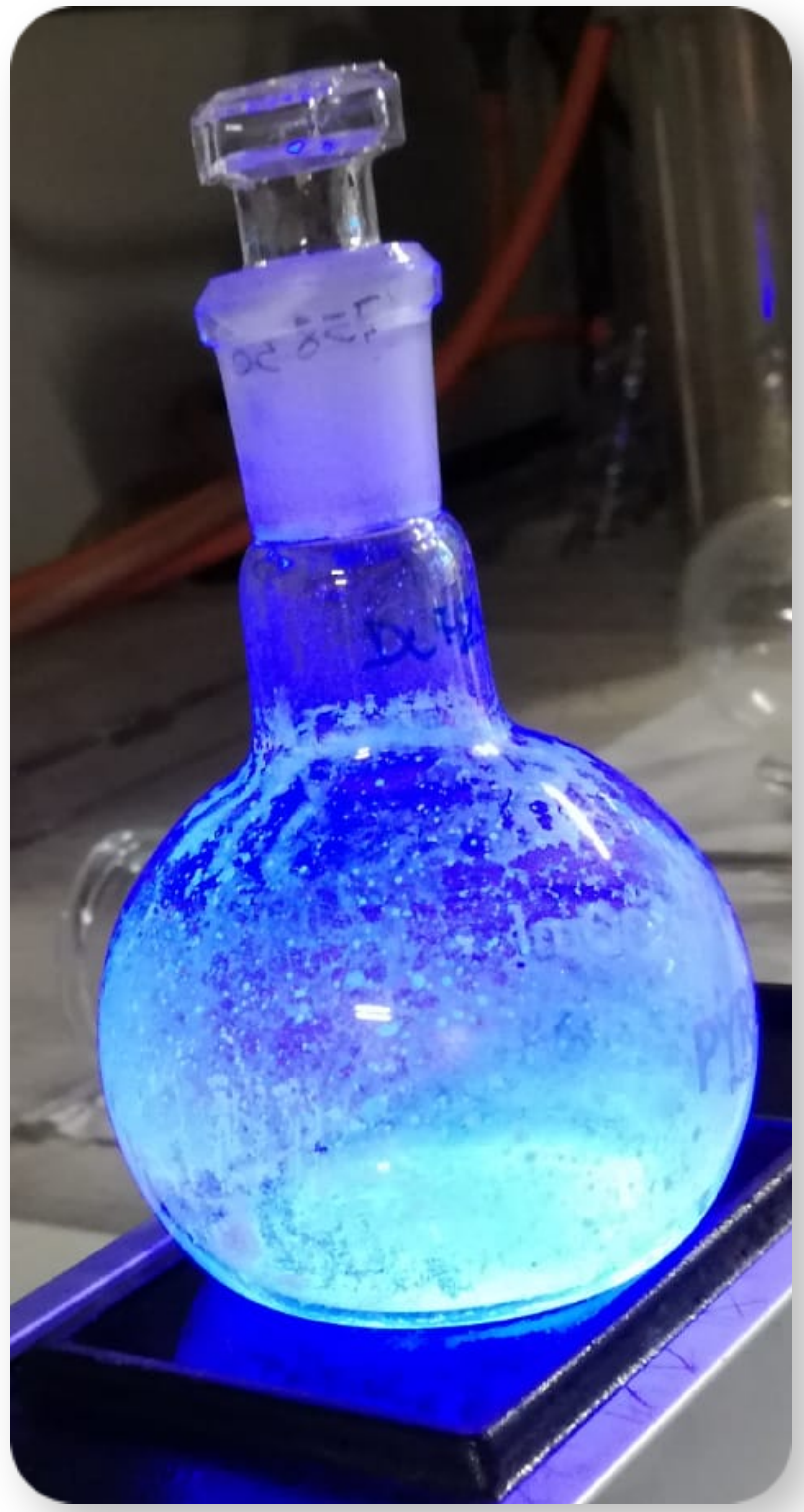
Sample	Primary fluorophore [%]	Decay time [ns]	Wavelength of max emission [nm]	Wavelength shifter
2N	14	1.3 ± 0.1	409	None
2T	14	2.6 ± 0.1	457	MDAC 5%
1N	14	1.0 ± 0.1	454	MDAC 0.3%
2B	14	1.1 ± 0.1	454	MDAC 0.3%
EJ-200	-	2.1	425	-
EJ-232	-	1.4	370	-



Commercial for comparison by Eljen Technology

[1] L. Mattiello, V. Patera, A. Belardini, D. Rocco, M. Marafini, Organic Scintillator, Patent US20250154404, 2025

Roadmap

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Plastic scintillators R&D

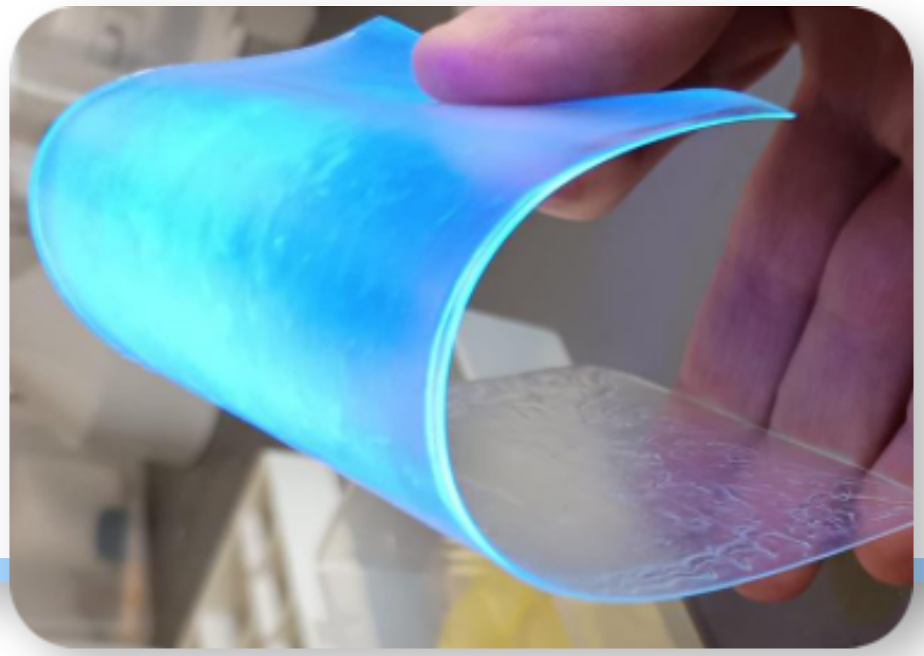
- ✓ Starting monomers: styrene, vinyl toluene, methyl-methacrylate → after polymerisation: **PS, PVT, PMMA**
- ✓ Cross-linking agent (**DVB**) to increase mechanical robustness
- ✓ Wavelength shifter: **MDAC**

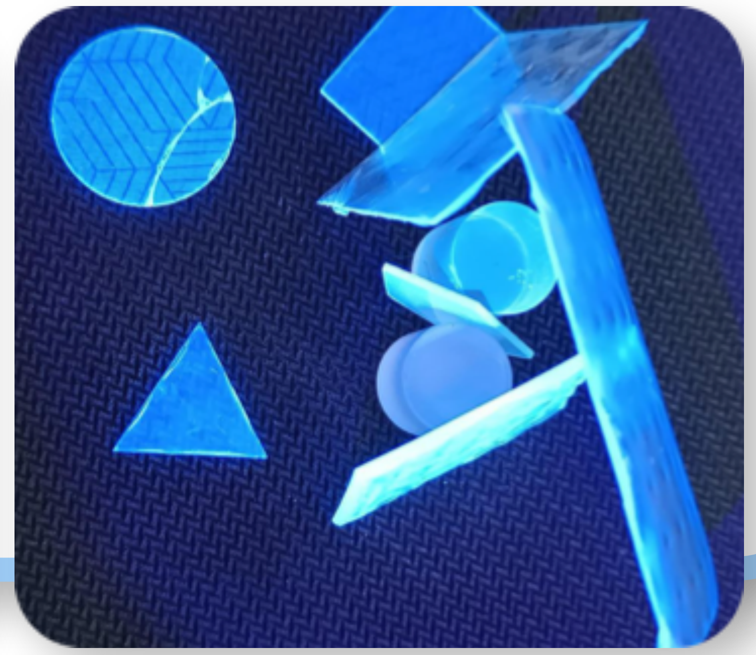
Polymerisation techniques

1. Thermal polymerisation
- good clarity but difficult to reach high loadings
- ~24h
- only simple geometries

2. Photo-initiated polymerisation
- higher loadings can be reached
- ~10h
- only simple geometries

3. 3D printing with commercial resin*
- flexible scintillators
- faster production
- complex geometries





*Aquaclear by Phrozen or ABS Photoresin by Elegoo

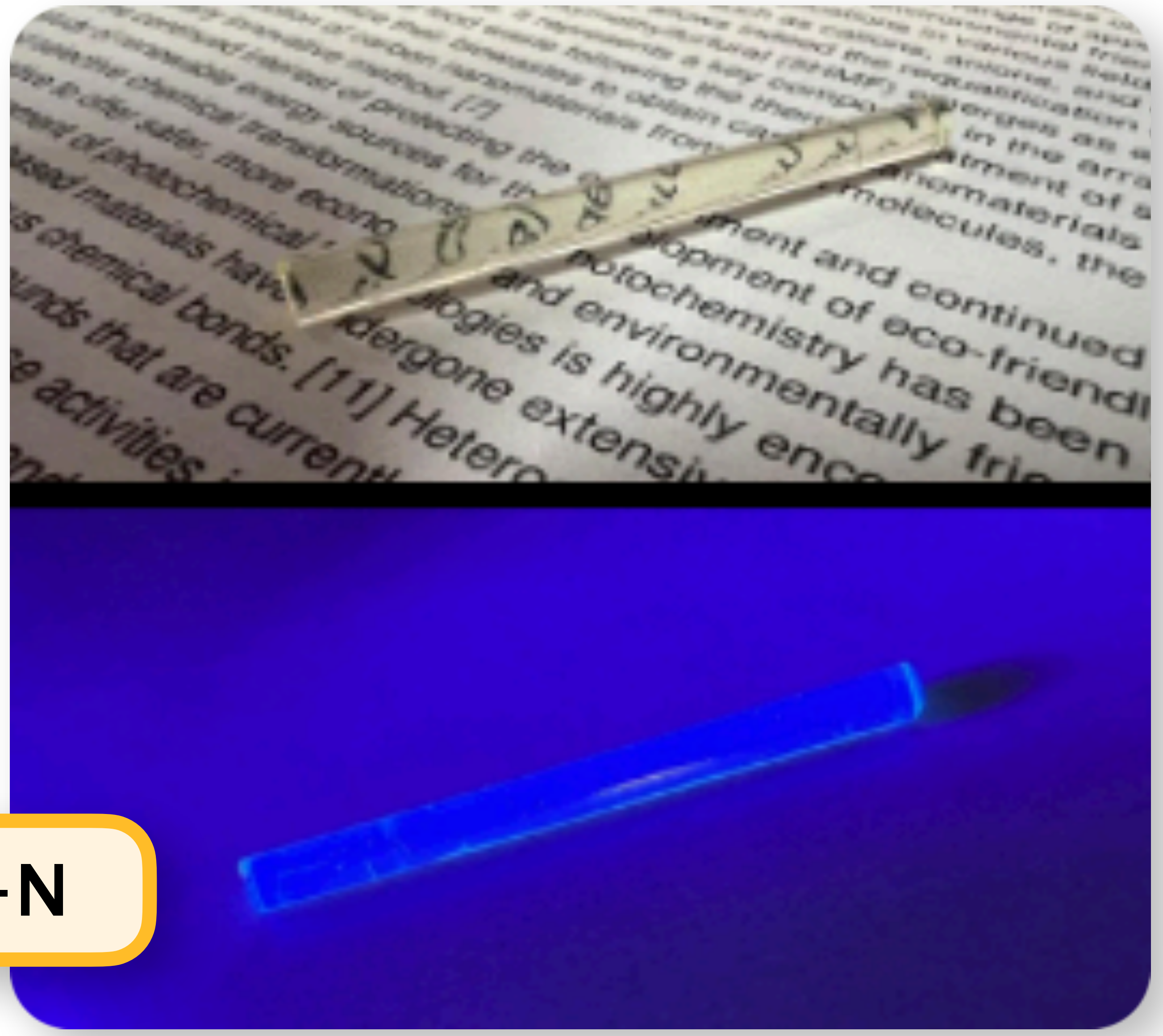
High-Z loading

- We tested different high-Z impurities trying to reach high loadings without compromising clarity, homogeneity and scintillation efficiency.
- Max loading on the market: 5%, but we need at least 10%

Bi-Piv

Bismuth pivalate

→ solubility issues



Bi-N

Bismuth neodecanoate

→ clear homogeneous samples with up to 7.5%-10% loading have been obtained

TEIQ

Erbium compound

→ high solubility but yellowing of the final plastic

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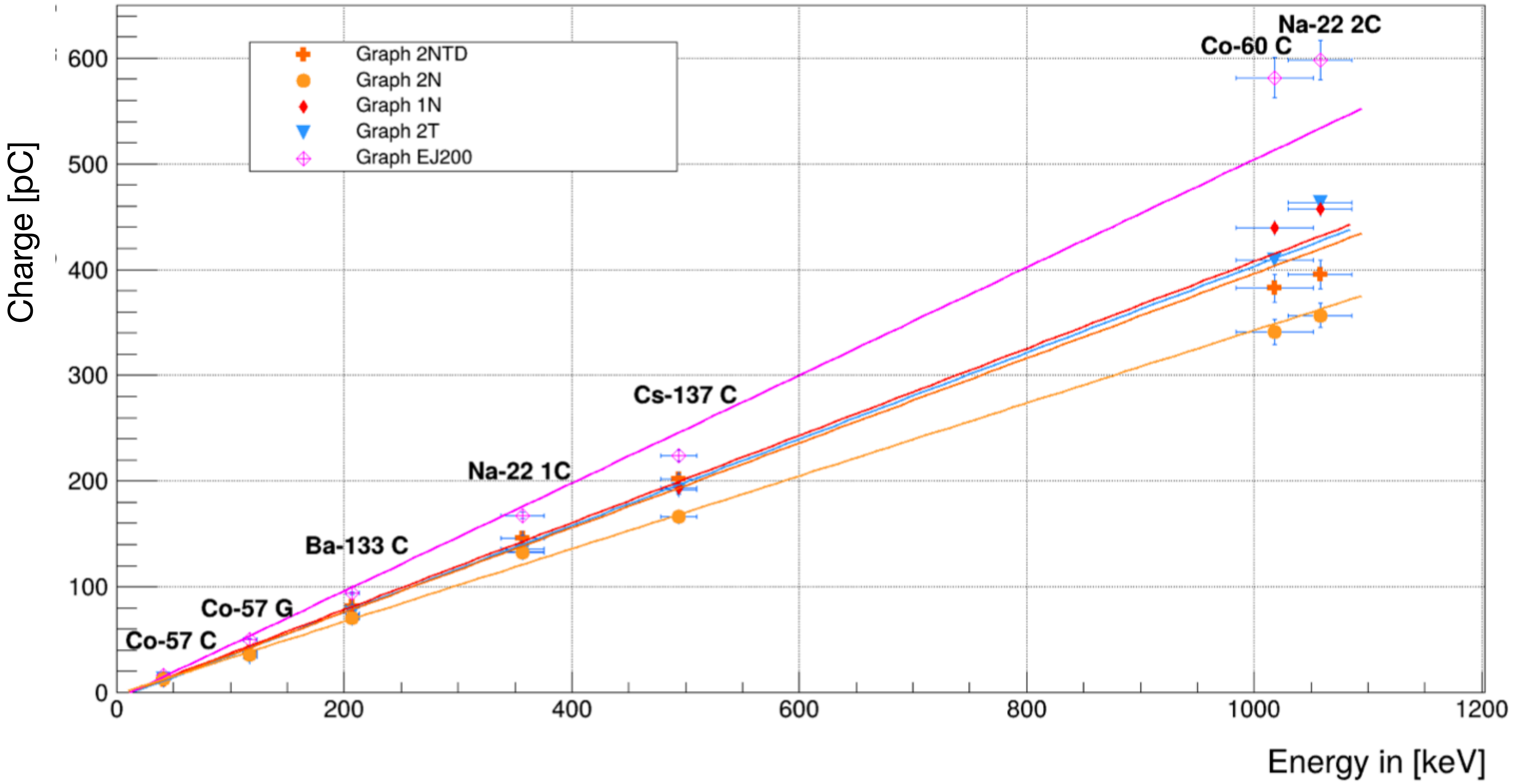
Characterisation of coin-shaped scintillators

1° geometry: coin-shaped scintillators for wearable portable dosimeter

- Unloaded scintillators
- Setup: one-side readout with PMT
- Calibration with radioactive sources (Na-22, Co-57, Co-60, Ba-133, Cs-137)
- Energy resolution and light output



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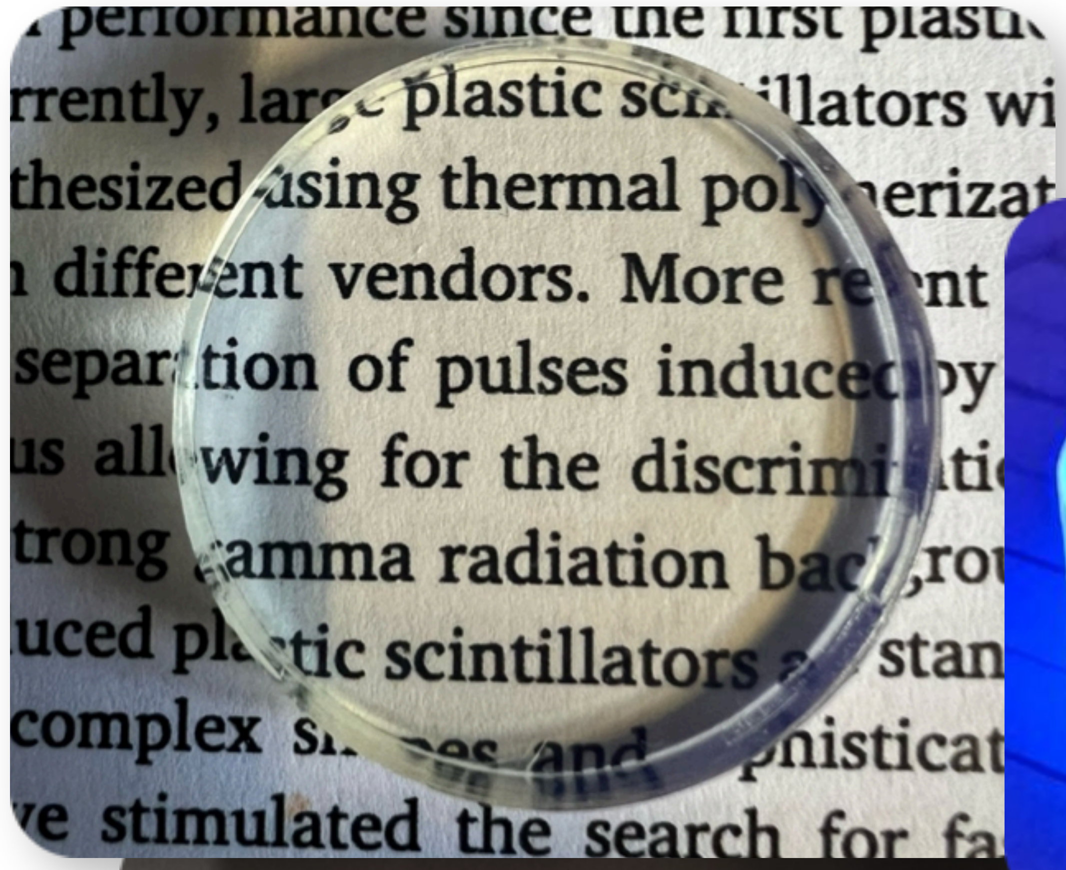
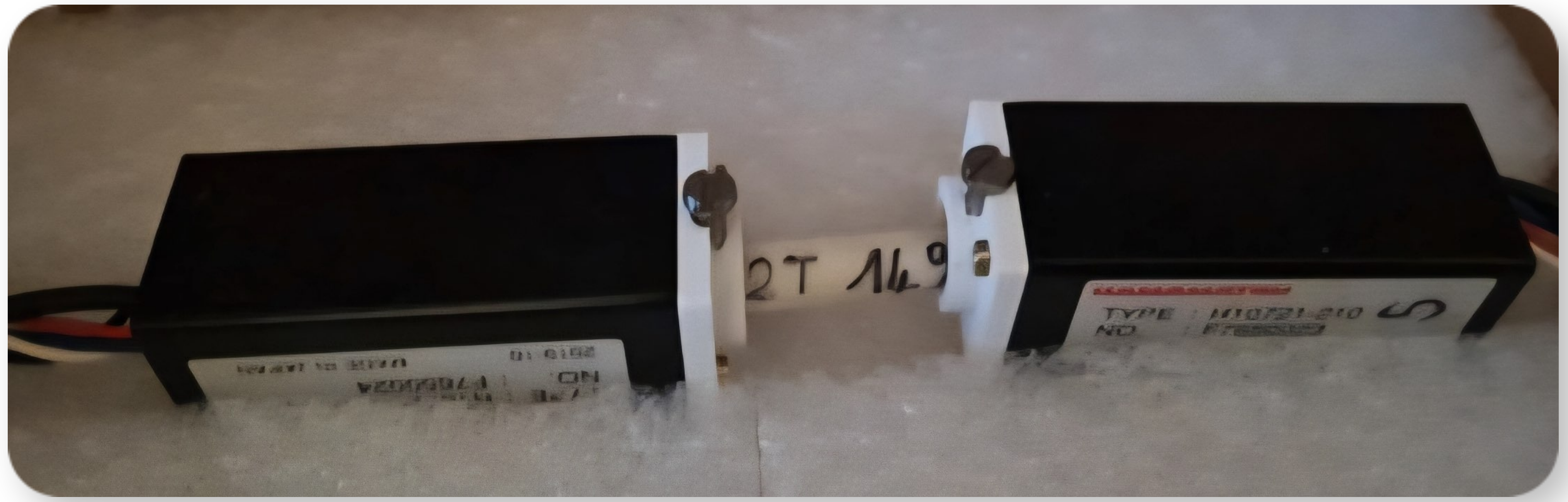


- Unloaded scintillators
- Setup: one-side readout with PMT
- Calibration with radioactive sources (Na-22, Co-57, Co-60, Ba-133, Cs-137)
- Energy resolution and light output

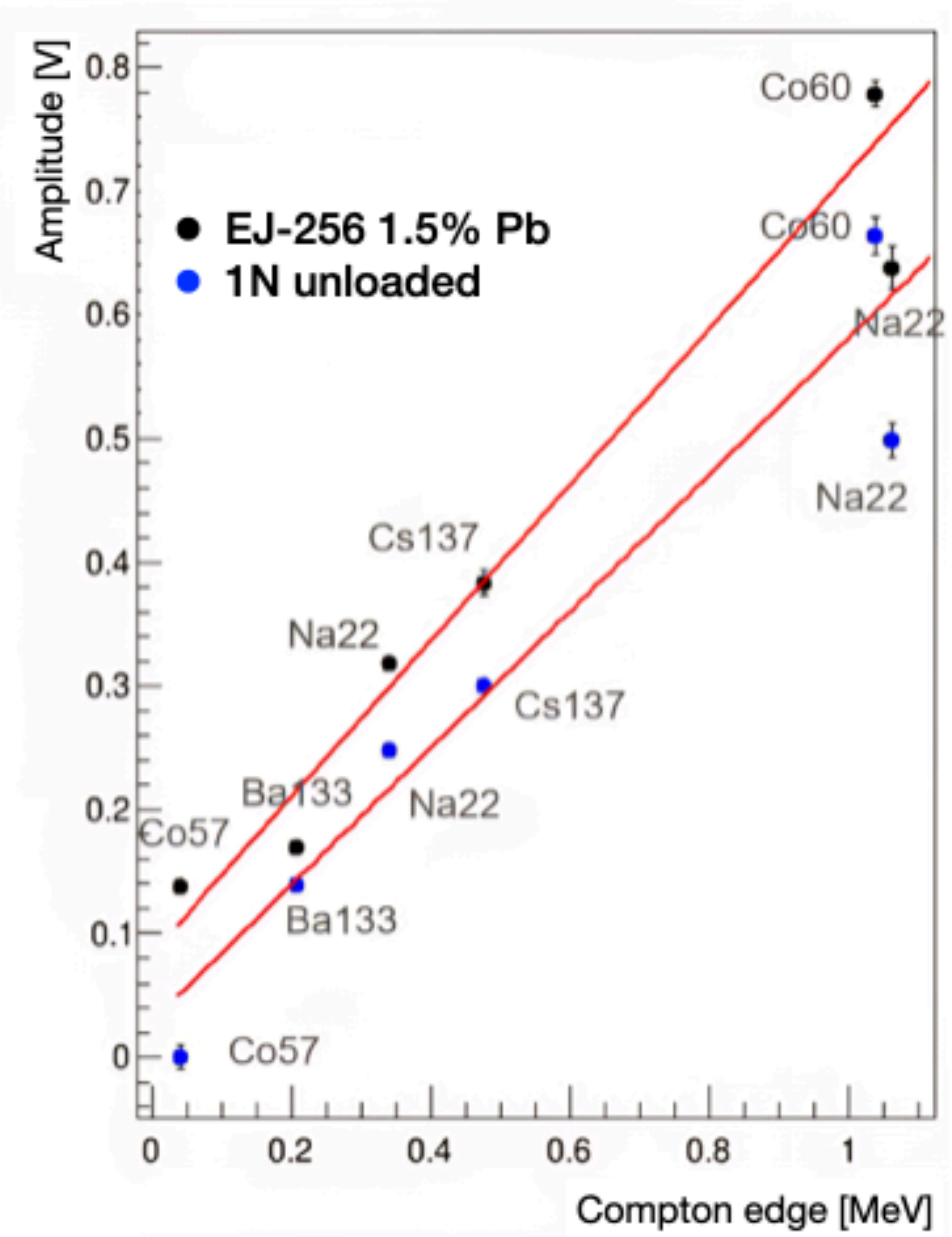
	2N	2T	1N	EJ-200
R_E at the ^{137}Cs Compton edge [%]	12.2±2.8	12.7±3.5	14.2±9.2	14.7±6.5
R_E at the 122-keV ^{57}Co photopeak [%]	17.0±3.7	18.5±5.2	22.7±14.8	13.8±6.1
L.O. wrt EJ-200 [%]	90±2	86±2	87±2	100

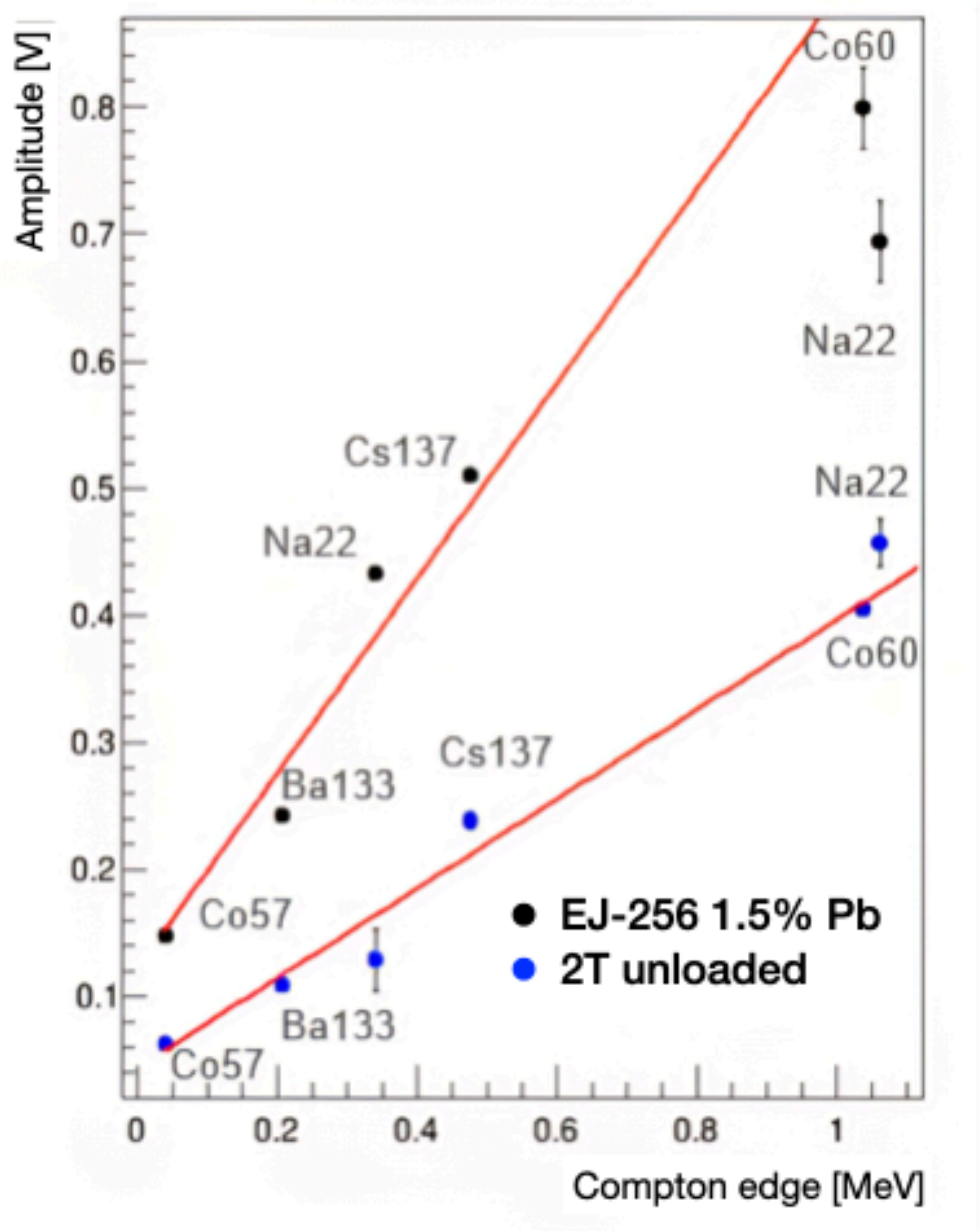
Characterisation of rod-shaped scintillators

2° geometry: rod-shaped scintillators for total-body MRI-compliant SPECT detector



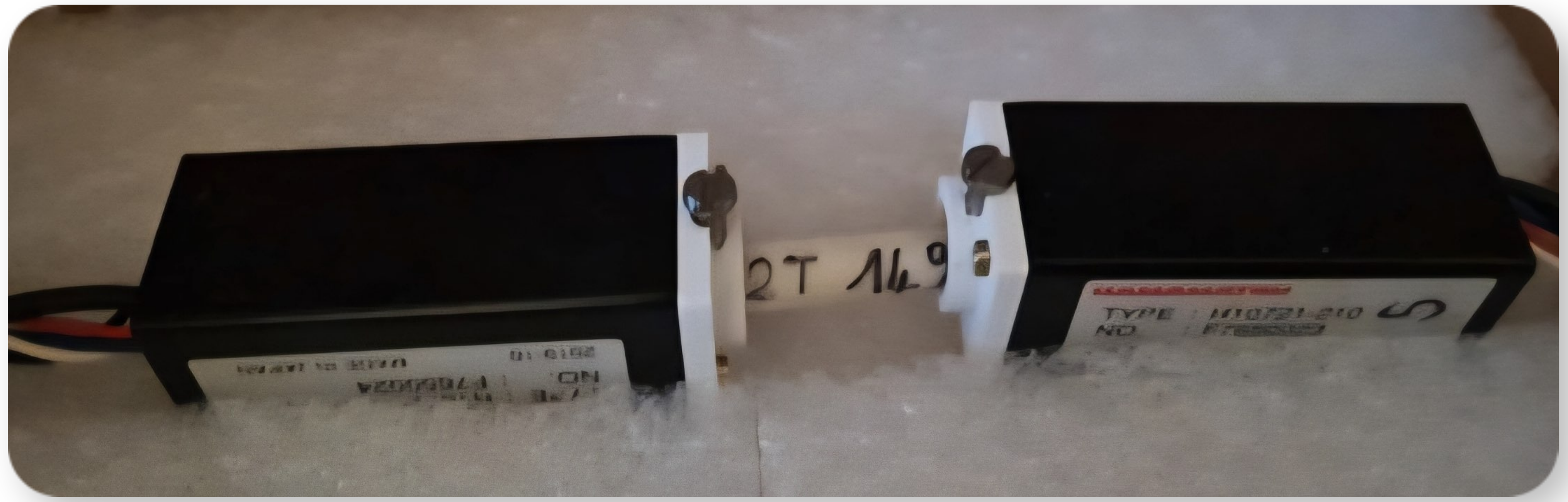
- Unloaded scintillators
- Setup: two-side readout with PMT
- Calibration with radioactive sources (Na-22, Co-57, Co-60, Ba-133, Cs-137)
- Light output and timing
- To study: performance dependence on sample length





Characterisation of rod-shaped scintillators

2° geometry: rod-shaped scintillators for total-body MRI-compliant SPECT detector



- Unloaded scintillators
- Setup: two-side readout with PMT
- Calibration with radioactive sources (Na-22, Co-57, Co-60, Ba-133, Cs-137)
- Light output and timing
- To study: performance dependence on sample length

Sample	Length [cm]	L.O. [%]	Rise time [ns]	Time resol. [ns]
EJ-256 +Pb 1.5%	3.0	100	1.3 ± 0.1	300 ± 10
EJ-256 +Pb 1.5%	5.6	92	1.8 ± 0.1	330 ± 10
1N	4.0	85	1.4 ± 0.1	290 ± 10
2T	3.6	71	1.2 ± 0.1	350 ± 10

Roadmap

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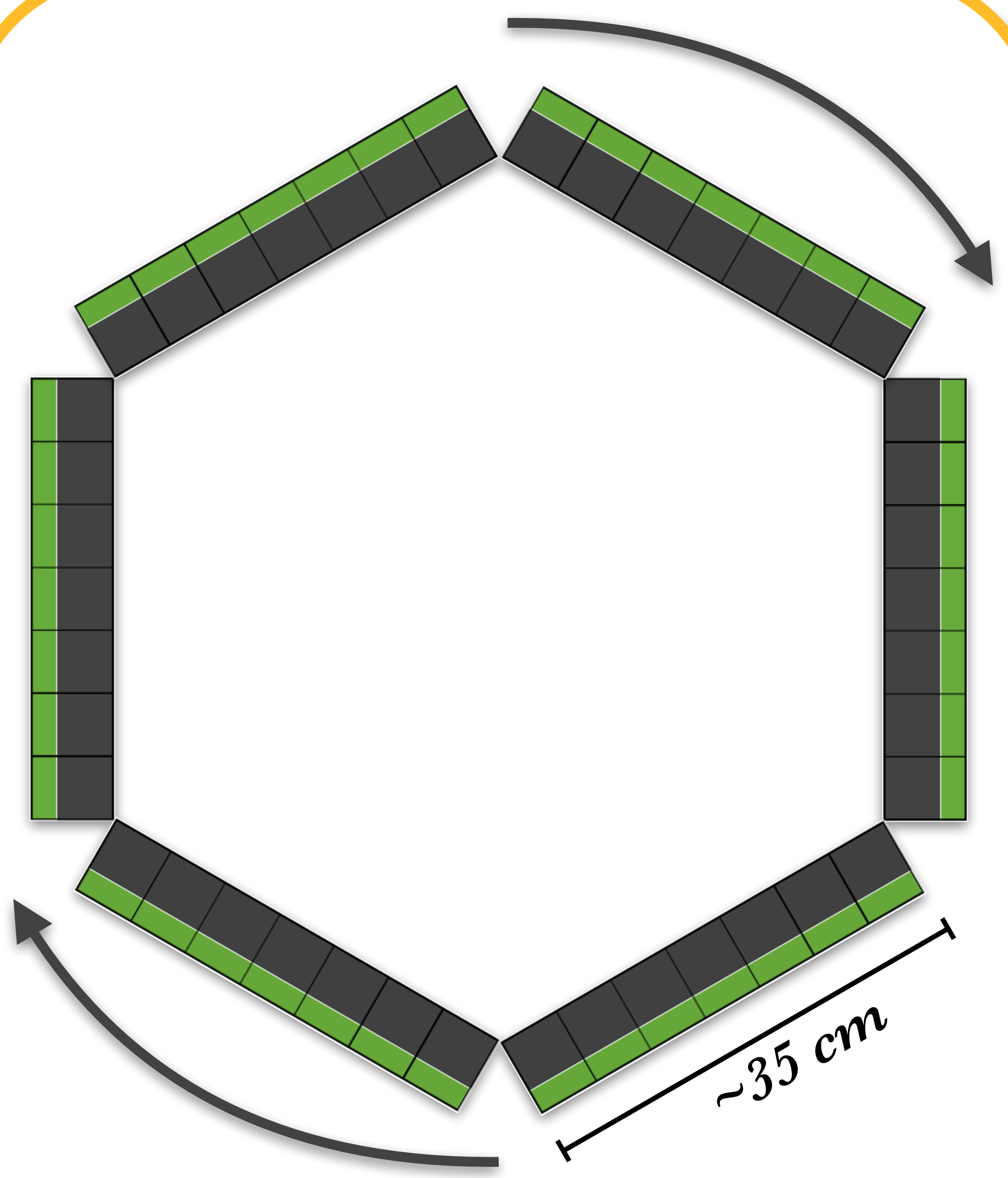
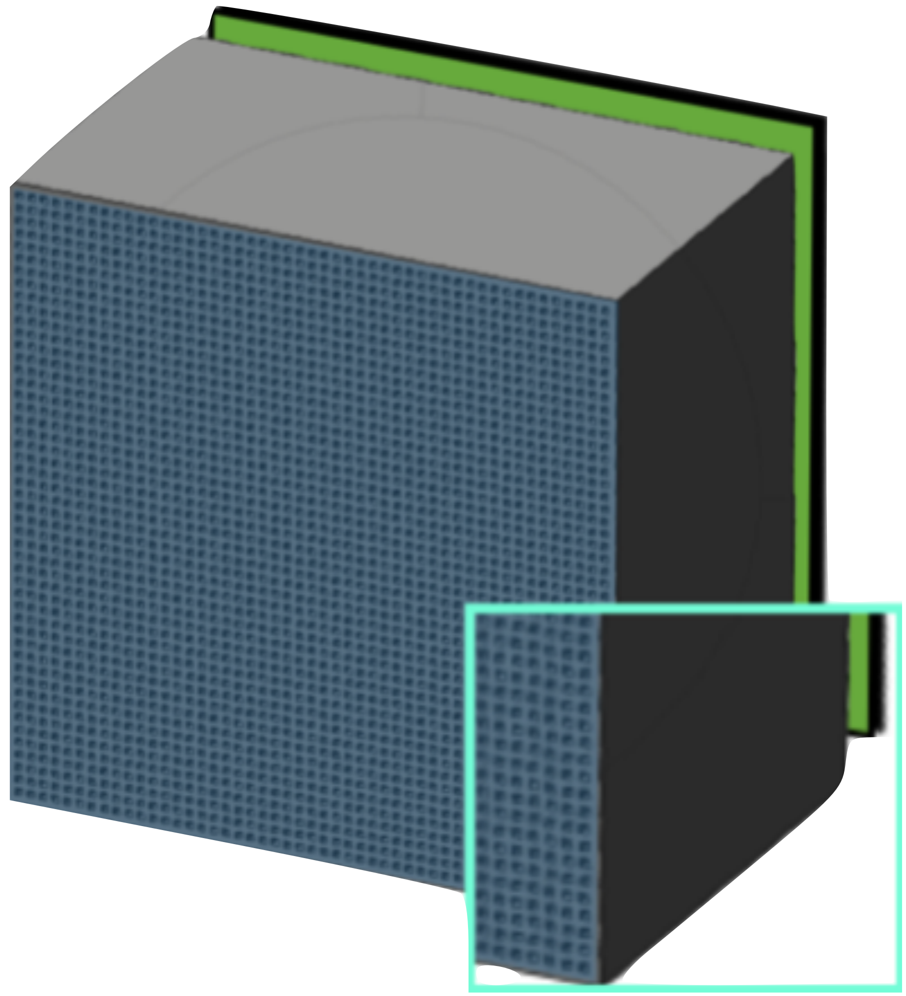
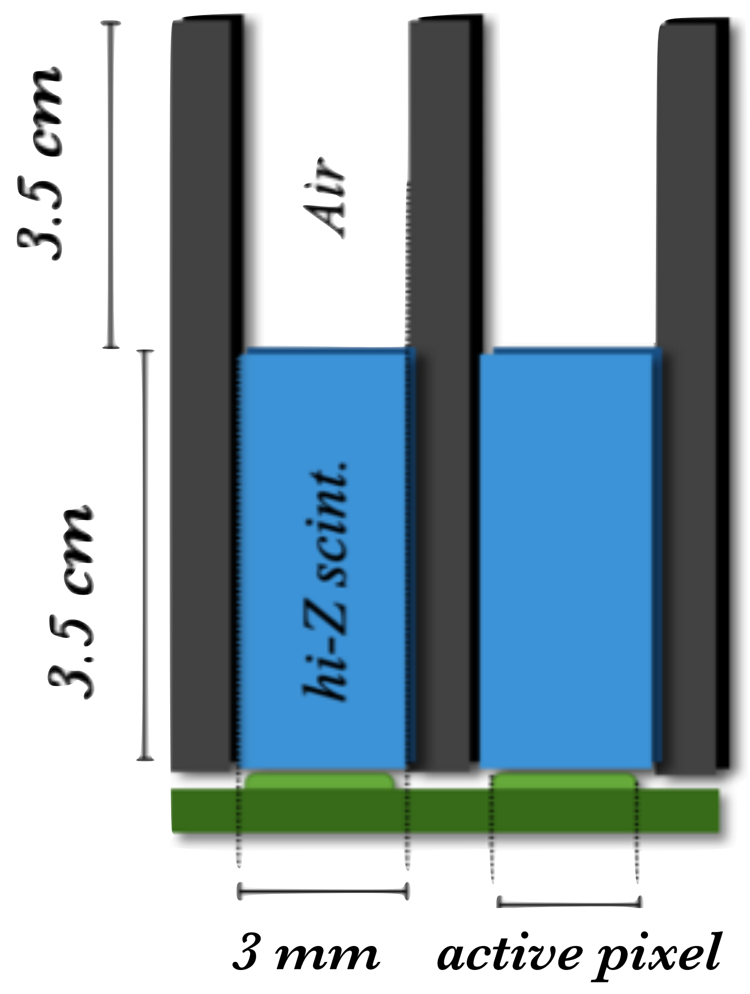
Medical application: modern SPECT detector



Modular structure revolving around the patient.

3D-printed **tungsten collimator, scintillator segments** polymerised inside the holes.

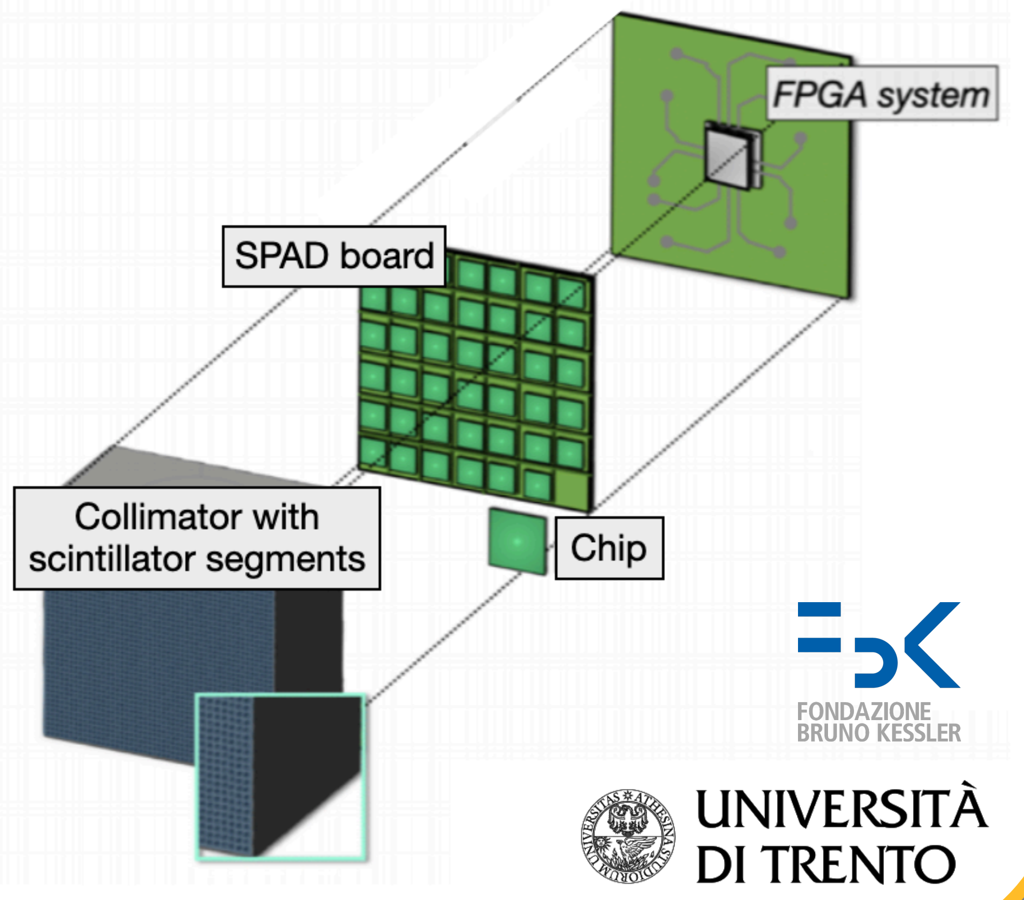




CMOS arranged in small-size pixels, individually coupled to the scintillator segments.

PRIN 2022 U40: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE
Prot. 2022Z72Y3K – ReSPECT

FPGA matrices to pre-process the acquired data.



- ✓ Lightness, low cost, modularity → possible total-body SPECT → more scans per day
- ✓ Organic scintillation signal → high-counting rate capability → lower dose to patient
- ✓ Silicon-based readout → MRI-compatibility

Medical application: portable dosimeter for theranostic

^{177}Lu-PSMA-617 radio metabolic therapy for metastatic Castration Resistant Prostate Cancer (mCRPC)

Current approach

Same dose for each patient

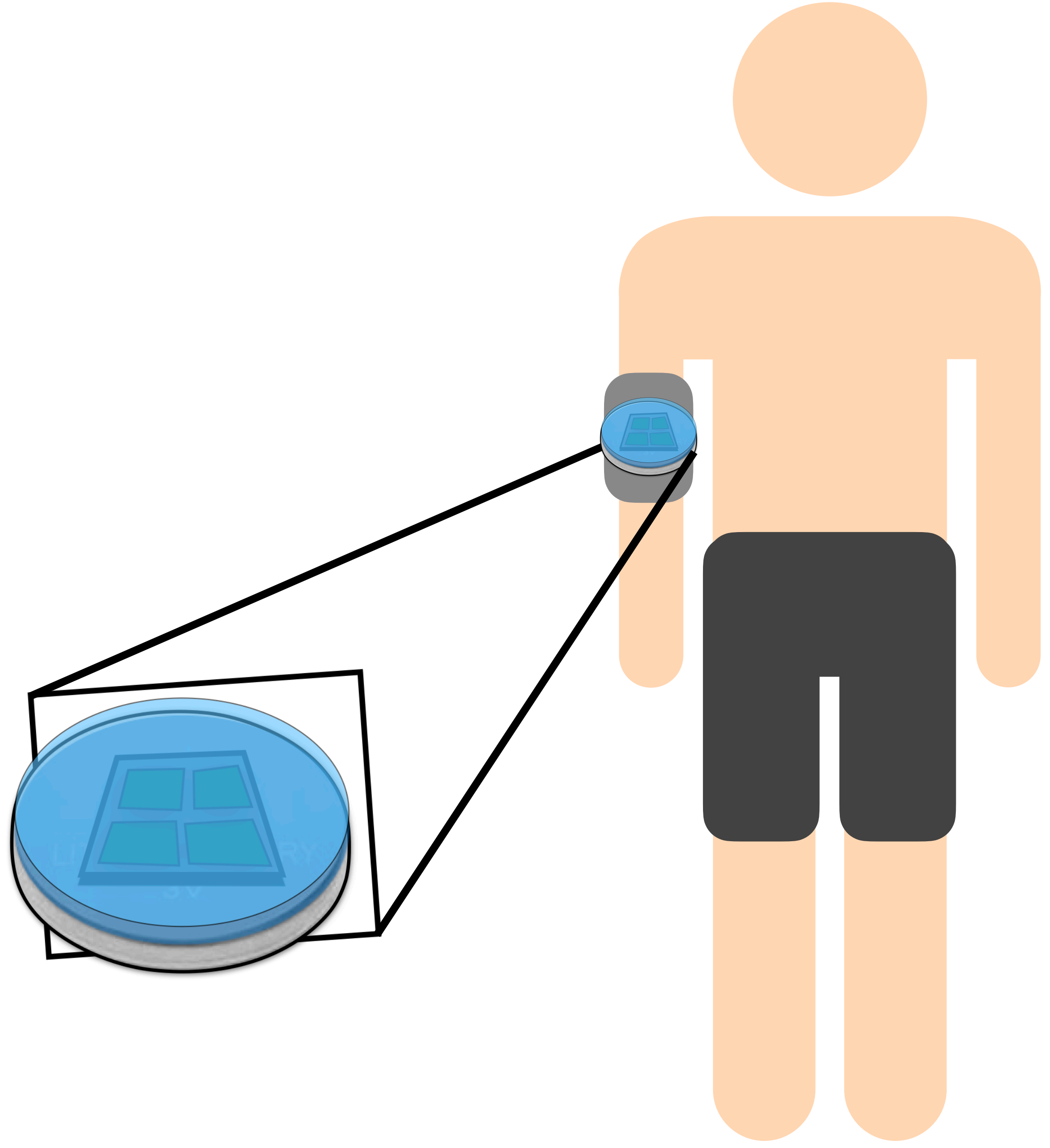
Systematic under treatment

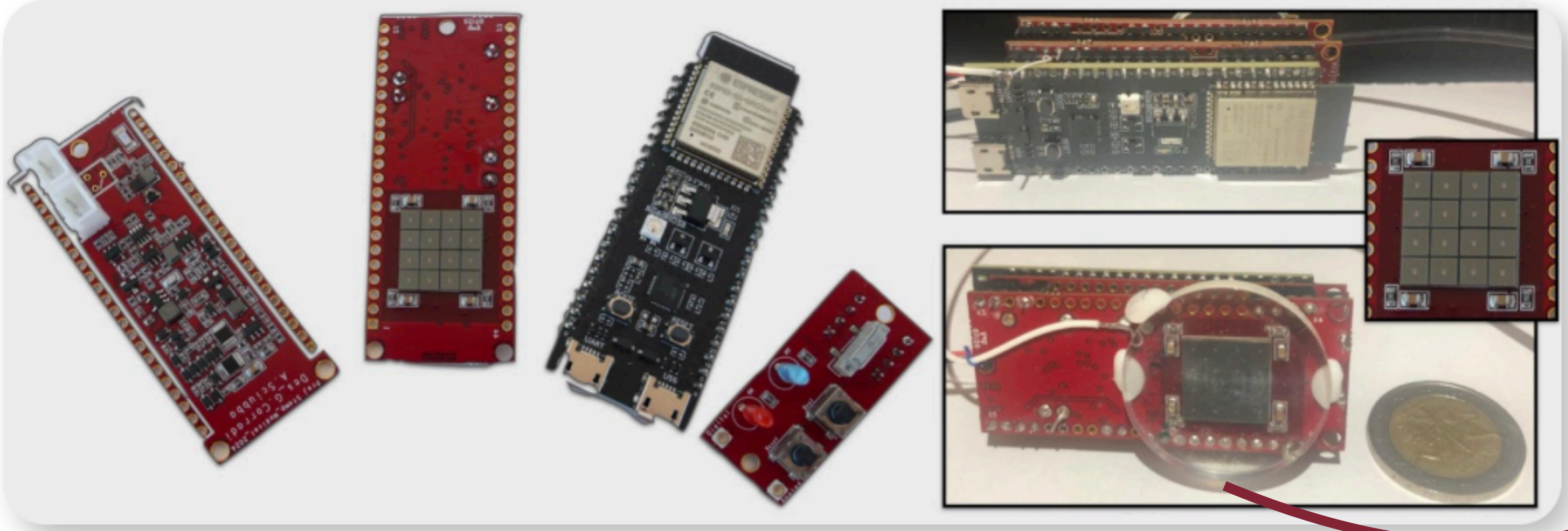
mCRPC patients have mobility limitations → they cannot undergo multiple SPECT scans

Clinical goal

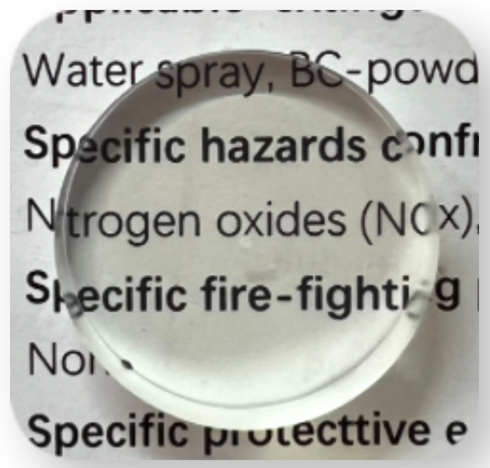
Wearable dosimeter to retrieve the washout curve of the radiopharmaceutical

Personalised treatment





Custom electronics with SiPM arrays



Coin-shaped scintillator

Next steps

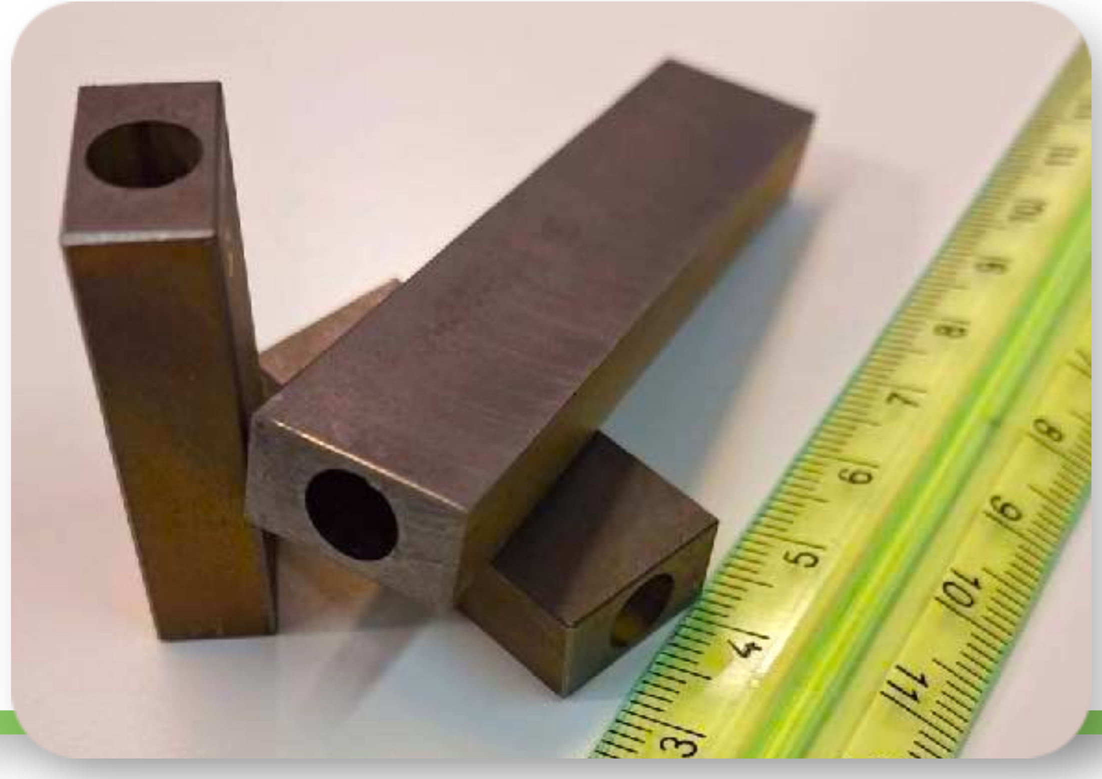
Portable dosimeter for theranostic

- ✓ Testing the custom electronics
- ✓ Characterising the new 3D-printed loaded samples
- ✓ MC studies to optimise device positioning

3D printed 2N + 10% Bismuth

new SPECT detection system

- ✓ Further research on polymerisation and loading techniques
- ✓ Continue the work on electronics development
- ✓ Implement the tungsten collimator in the measurement setup



Authors

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SBAI Department, Sapienza University of Rome

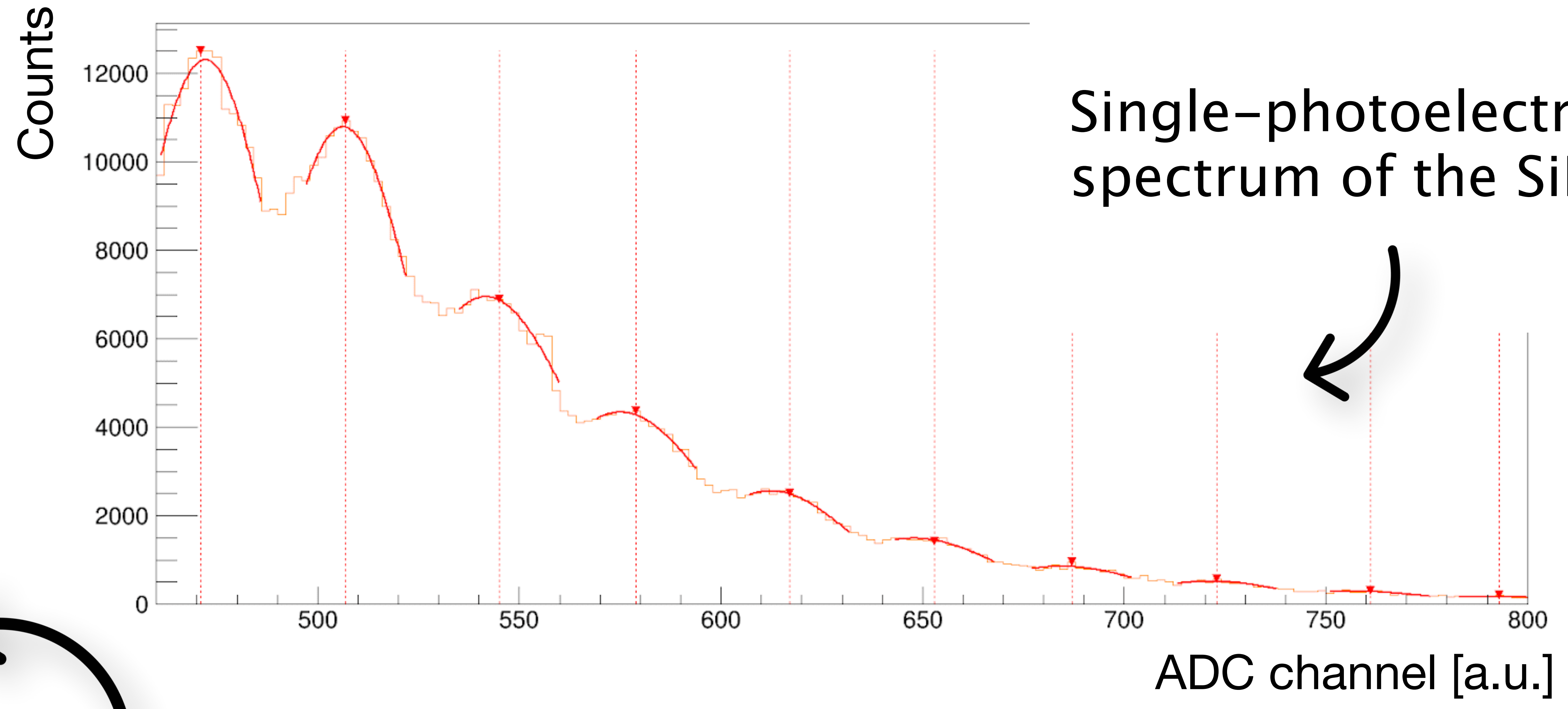
Thank you!

Sapienza Università di Roma | Umberto I Policlinico di Roma | Centro Ricerche Enrico Fermi | INFN | Ministero dell'Università e della Ricerca | Italiadomani Piano Nazionale di Ripresa e Resilienza | Finanziato dall'Unione europea NextGenerationEU

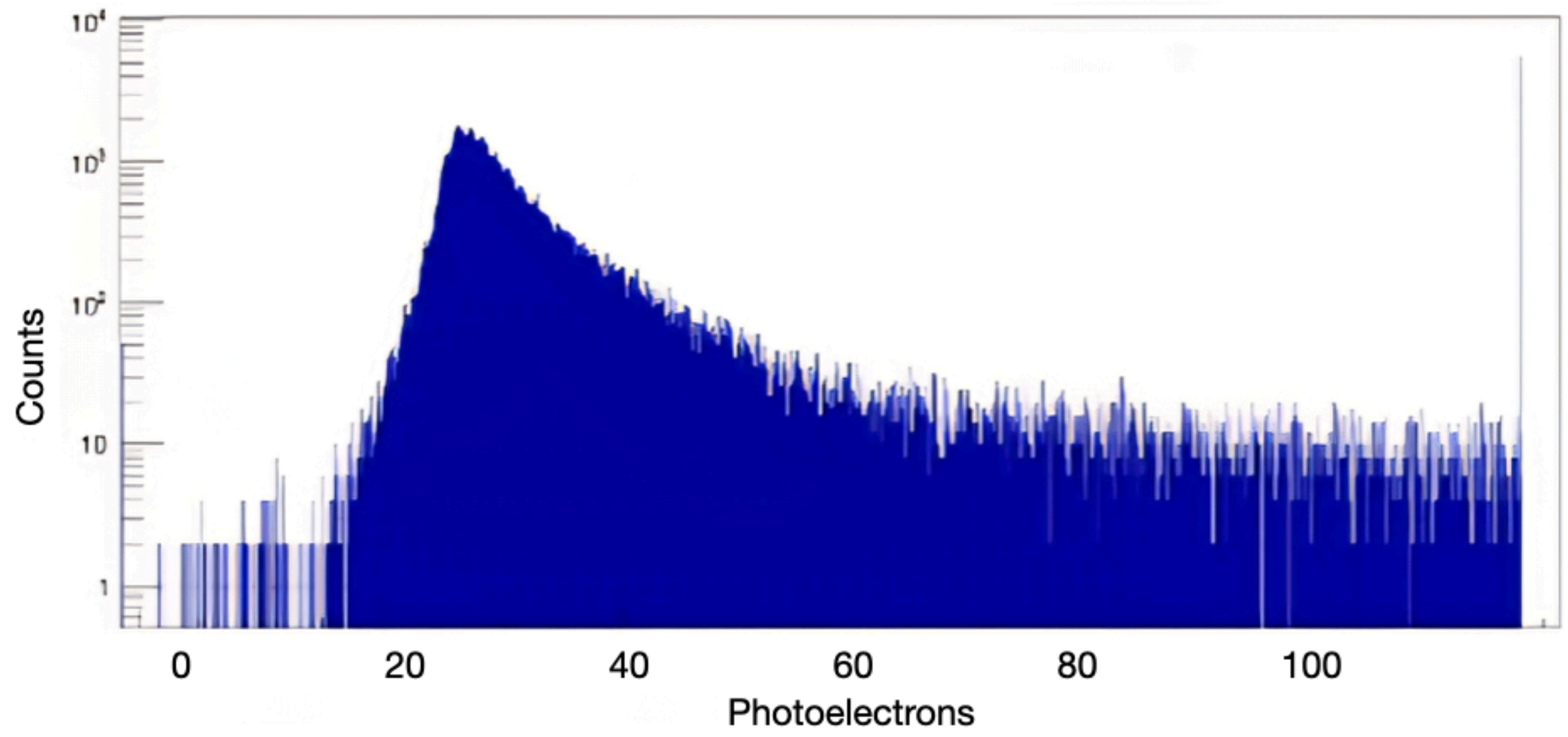
Spare slides

Characterisation of a new setup for loaded samples

- Goal: characterise a new setup for future measurements on loaded samples
- Setup: one-side readout with SiPM
- Estimation of the photoelectron gain



Single-photoelectron spectrum of the SiPM



✓ We estimated that noise produces 11±1 photoelectrons

✓ Photoelectron spectrum obtained by irradiating a EJ-256 +Pb 5% sample with ^{57}Co → signal can be discriminated wrt noise in this setup

Medical application: modern SPECT detector

SPECT DETECTION SYSTEM	SENSITIVITY PER MODULE @140 keV [cpm/μCi]	SYSTEM SPATIAL RESOLUTION [FWHM] @10 cm [mm]	DECAY TIME [ns]	RATE CAPABILITY [cps/cm^2]	TOTAL COST –	MRI COMPLIANCE –
Anger Camera with NaI(Tl) FoV: 53 x 39 cm^2	170	7.4	250	$(0.25 – 3) \cdot 10^3$	\$\$	✗
CZT FoV: 39 x 51 cm^2	190	7.6	350	$(30 – 700) \cdot 10^3$	\$\$\$	✗
reSPECT 6 rotating blocks FoV: 35 x 35 cm^2	184 (Energy cut @80 keV)	8.9 (For pixel size 2 mm)	2	$(50 – 200) \cdot 10^6$	\$	✓

The performances of the reSPECT detection system have been obtained through MonteCarlo simulations assuming a 10% loading

Medical application: portable dosimeter for theranostic

- To date, the most effective treatment for metastatic Castration Resistant Prostate Cancer (mCRPC) is ^{177}Lu-PSMA -617 radiometabolic therapy.
- Thanks to the presence of the PSMA protein, the radiopharmaceutical molecules mainly link to the tumor cells, that are damaged by the electrons emitted by ^{177}Lu via β^- decay (maximum tissue penetration = 2 mm).
- ^{177}Lu also emits 208 keV gamma rays, allowing for dosimetric studies by means of a SPECT detector.
- ^{177}Lu half-life = 6.7 days