The XXVII International Scientific Conference of Young Scientists and Specialists (AYSS-2023)

NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

MEPhI National Research Nuclear University

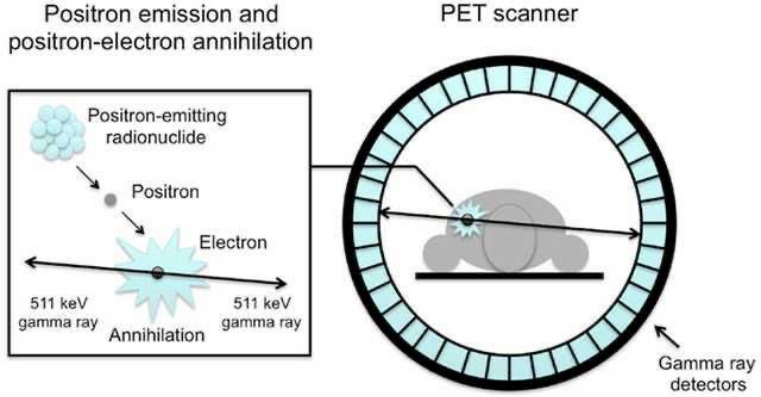
PET prototype based on scintillation detectors GAGG-SiPM couped to 32-channel PETIROC2A chip

Speaker:
Boyko Nadezhda

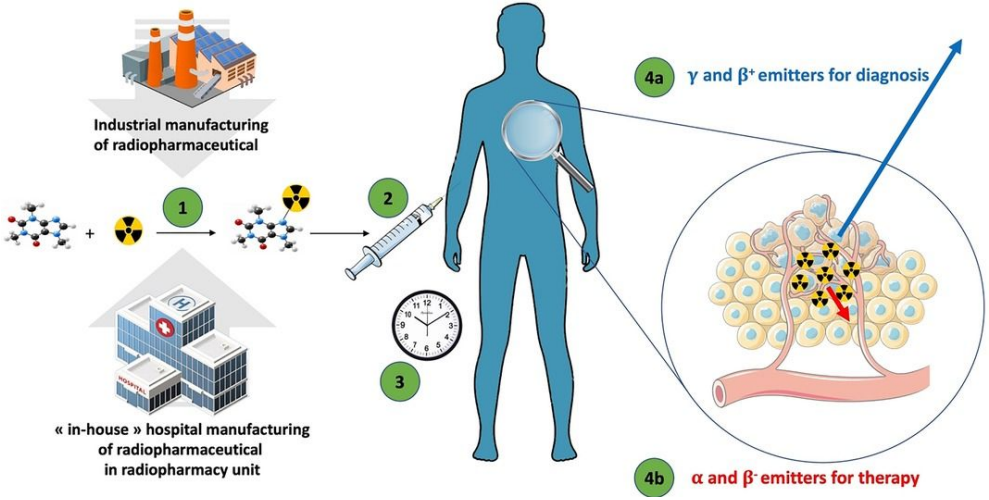
Co-authors:
Filipp Dubinin, Gregory Dolganov,
Alexei Konotop

Principles of PET Scanning

1. Radioactive Decay
2. Positron annihilation, emission of two photons
3. Photons Detection
4. Image Reconstruction



В.Н. Беляев Физика ядерной медицины, 2012

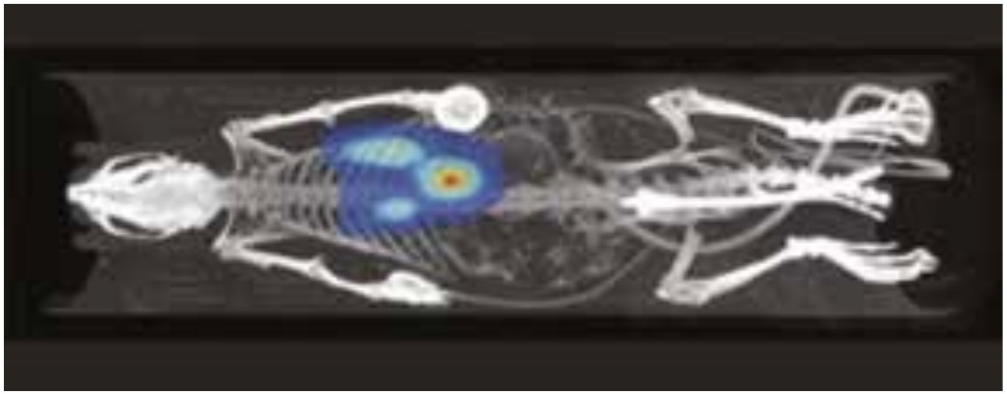


https://www.frontiersin.org/articles/10.3389/fnume.2022.990330/full

Nucleide	Half-life	Type of decay	Emax, MeV	Atten. in water
^{11}C	20,4 min	$\beta^+(100)$	0,970	4,1
^{13}N	10 min	$\beta^+(100)$	1,2	5,1
^{15}O	2 min	$\beta^+(100)$	1,74	7,3
^{18}F	110 min	$\beta^+(97)$	0,64	2,4
^{68}Ga	68 min	$\beta^+(89)$	1,9	8,0
^{82}Rb	72 s	$\beta^+(95)$	3,25	10,0
^{124}I	4,2 days	$\beta^+(23)$	2,14	-

Pharmacokinetic studies on laboratory animals using PET

- Dynamic profile of chemical kinetics
- Drug's rate of absorption, distribution, metabolism, and excretion
- Studying functions of organs and tissues



https://sernia.ru/

Scintillation crystal

- High photoeffect probability
- Low decay time
- High light yield
- No hygroscopicity
- No self-radioactivity

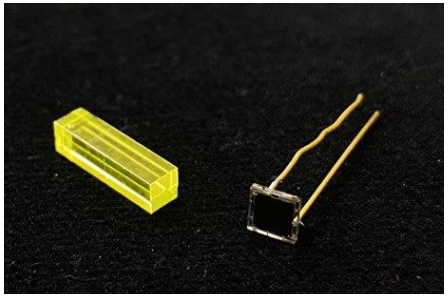
GAGG(Ce) 3x3x20 mm3

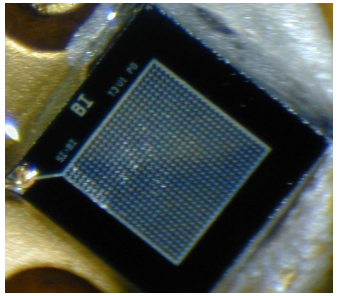
Crystal	CsI(Tl)	LYSO(Ce)	LaCl3(Ce)	NaI(Tl)	GAGG(Ce)
Density, g/cm^2	4.51	7.2	3.85	3.67	6.63
Zeff	54	65	59.5	50	54.4
λmax, нм	550	420	350	415	520
t, нс	1000	40	30	230	100
Light yield, photon/keV	54	32	49	38	50
Hygroscopic	YES	NO	YES	YES	NO
Self radioactiv.	NO	YES	NO	NO	NO

Silicon photomultiplier

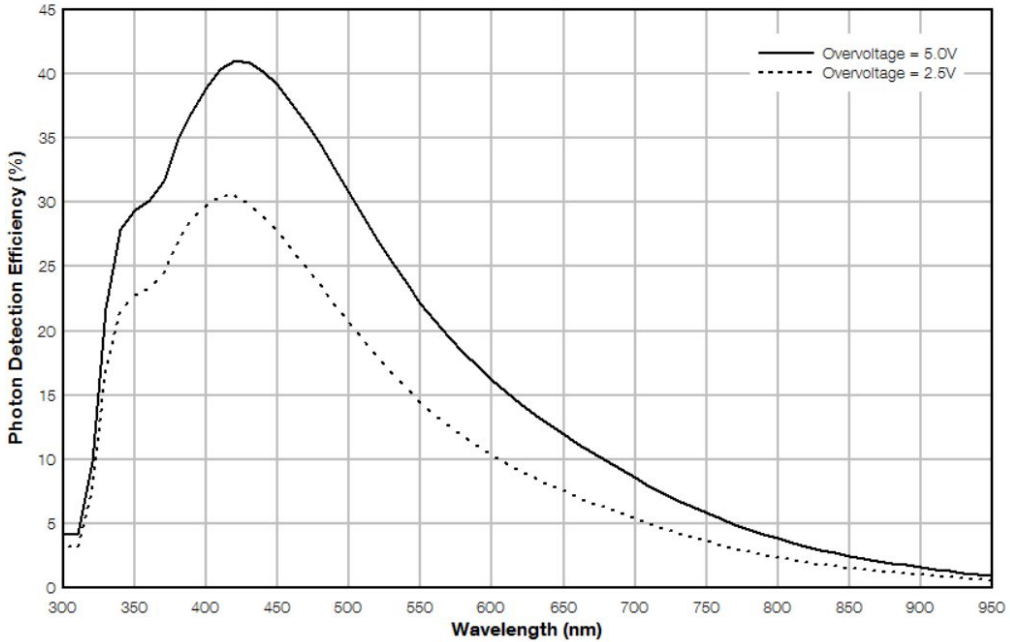
Inorganic scintillators GAGG(Ce) 3x3x20 mm
SiPM Onsemi FC30035:

- Active area 3mm
- Cell size 35μm





Parameter	Typ.
Breakdown Voltage(Vbr), V	24.2 - 24.7
Peak Wavelength (lp), nm	420
PDE, %	31 (Vbr+2.5V)
Gain	$3 * 10^6$
Dark Count Rate, kHz	300



https://www.onsemi.com/

Line of Weeroc chips

	Citiroc	Petiroc	Triroc
Prod. Version	1A	2A	1A
TRL	9	6	8
Package*	PQFP160 TFBGA353	TQFP208 TFBGA353	TFBGA353
Detector Compatibility	- SiPM - SiPM array	- SiPM - SiPM array	- SiPM - SiPM array
Optimized readout	SiPM	SiPM	SiPM
Channel	32	32	64
Measurements and operations	- Free running trigger - Ext trigger - Charge (shaper) - Time (trigger)	- Free running trigger - Charge (shaper) - Time (trigger) - Time (TDC)	- Free running trigger - Charge (shaper) - Time (TDC)
Outputs	- 32 triggers - Trigger OR - 1 analog multiplexer (charge)	- 32 triggers - Trigger OR - 1 analog multiplexer (charge) - 1 digital multiplexer (trigger) - ADC (10b) - TDC (10b)	- Trigger OR - analog multiplexer (charge) - 1 digital multiplexer (trigger) - ADC (10b) - TDC (10b)
Input Polarity	Positive	Negative (optimized) Positive	Negative (optimized) Positive
Applications Main features	Energy meas. Time of flight Photon counting Calibration input SPE spectrum Input DAC SiPM HV adjust.	Energy meas. Time of flight Time stamping Photon counting Input DAC SiPM HV adjust.	Energy meas. Time of flight Time stamping Zero suppress data Input DAC SiPM HV adjust.

Requirements:

- Optimized for SiPMs
- Compatible with long edge signals
- Time and amplitude measurements
- Low and high thresholds
- Coincidence trigger

Multichannel Analyzer Petiroc2A

Universal 32-channel system for working with SiPMs

- ➢ Single board solution
- ➢ Input DAC
- ➢ Flat cable readout, 200 Ohm input
- ➢ Wide dynamic range

- Optimized for a pair of 4x4 SiPM matrices
- Other types of detectors can also be read out
- Ready-made software

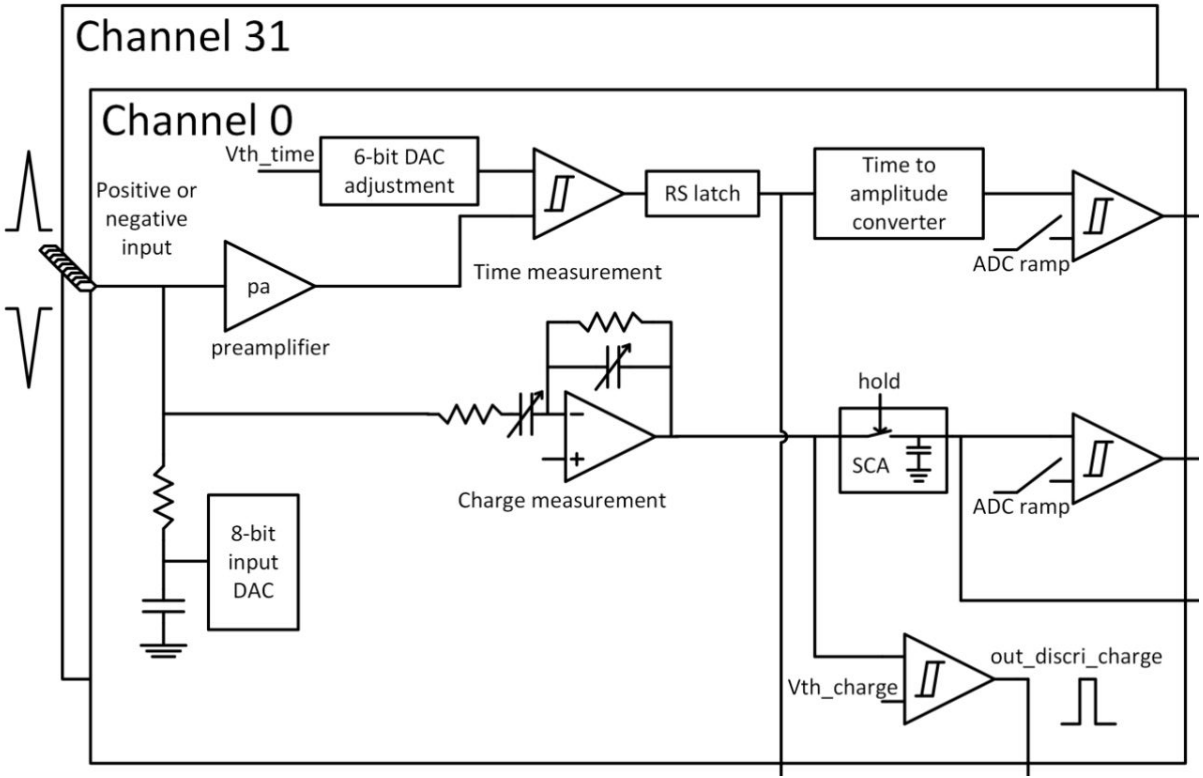
Multichannel Analyzer Petiroc2A

Time channel:

- ➢ Fast preamplifier
- ➢ Discriminator (with latch)
  - ➢ general threshold
  - ➢ individual thresholds
- ➢ 10-bit TDC → 36 ps/channel
- ➢ **General trigger & time stamp**

Charge channel:

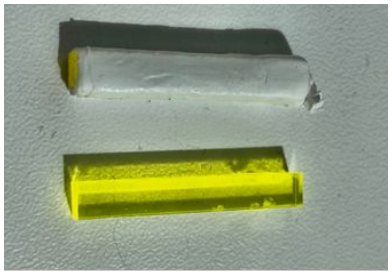
- ○ Charge sensitive amplifier
  - ○ shaping
  - ○ gain adjustment
- ○ Discriminator
  - ○ general threshold
  - ○ individual thresholds
- ○ 10-bit ADC → 2 mV/channel
- ○ **High-level trigger & amplitude**

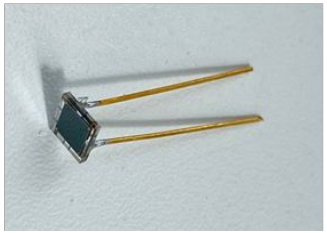


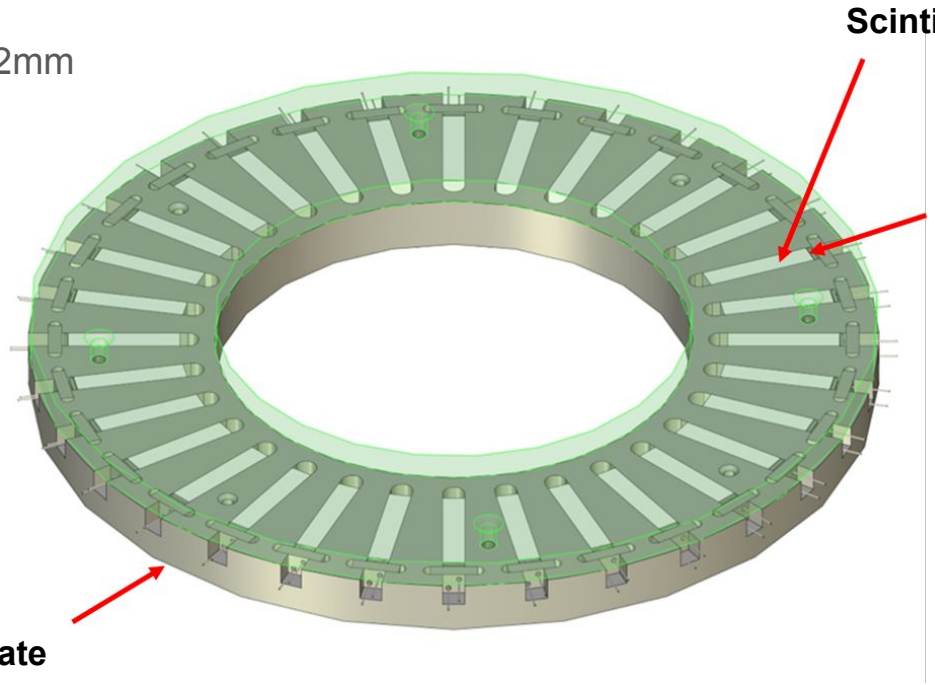
Mechanics

Problem: precise detectors positioning

- Relative crystal position accuracy < 0.2mm
- Centering a SiPM w.r.t. a crystal
- Fixing the SiPM to crystal connection

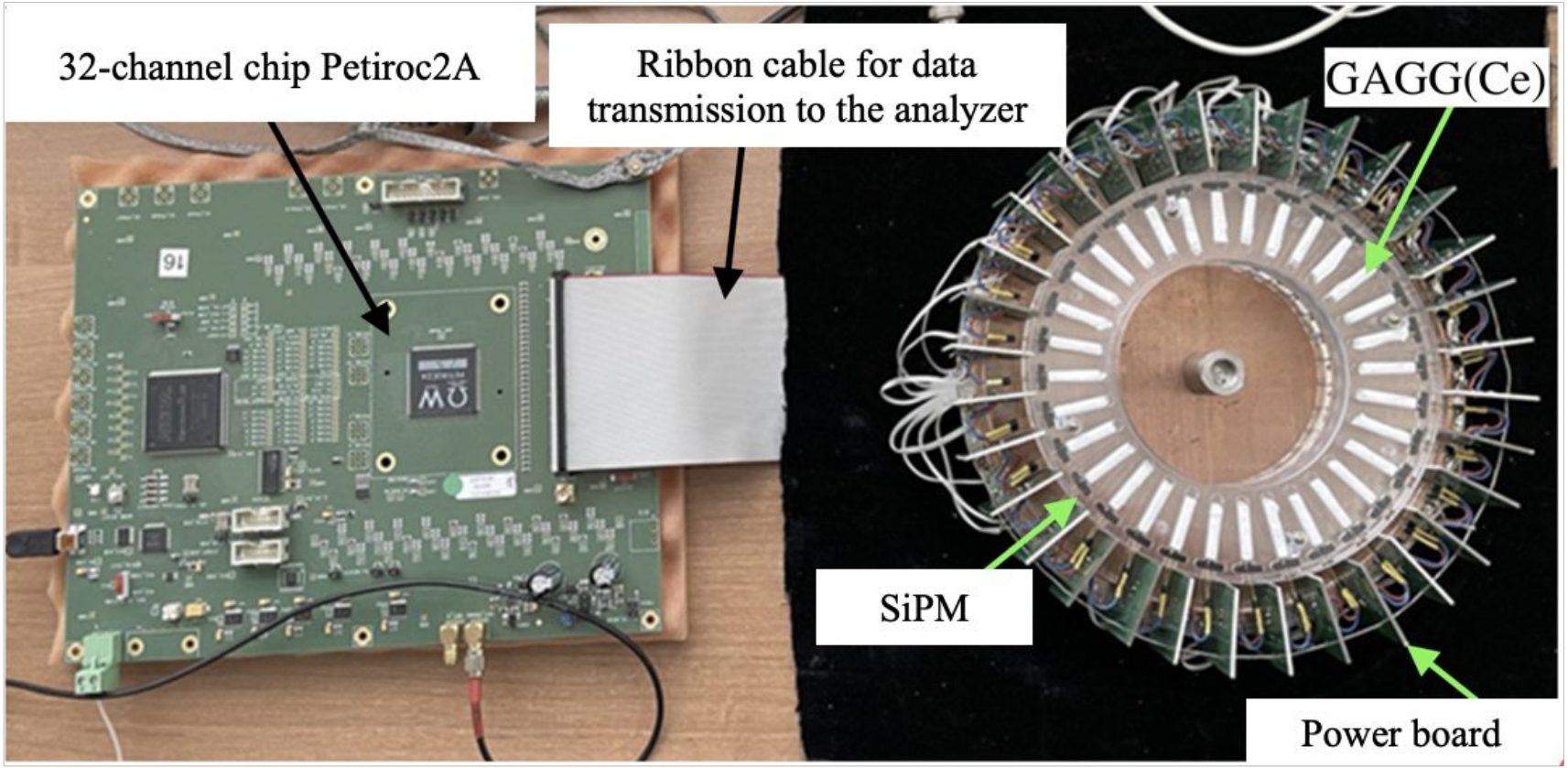






- **Inner diameter: 90 mm**
- **Outer diameter: 220 mm**

PET prototype



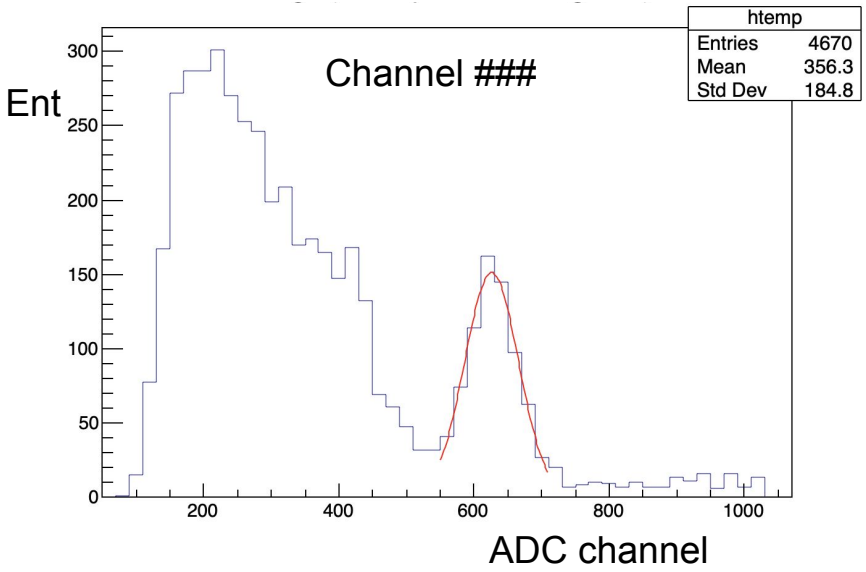
PET prototype's characteristics

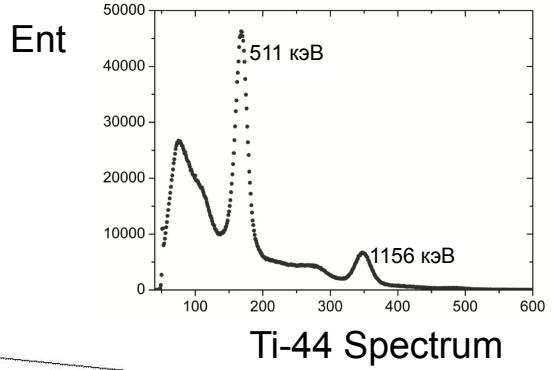
Measurements with Ti-44:

Best ER of the prototype: **14% @ 511 keV**

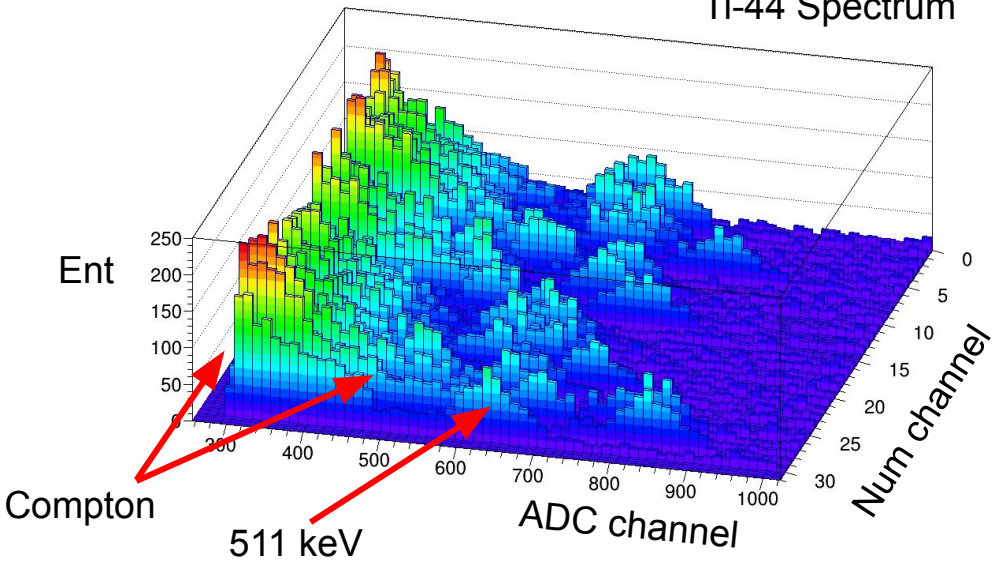
Time resolution: **1.80 ± 0.07 ns** (single detector)

Best ER at spectrometry setup: **8% @ 662 keV**

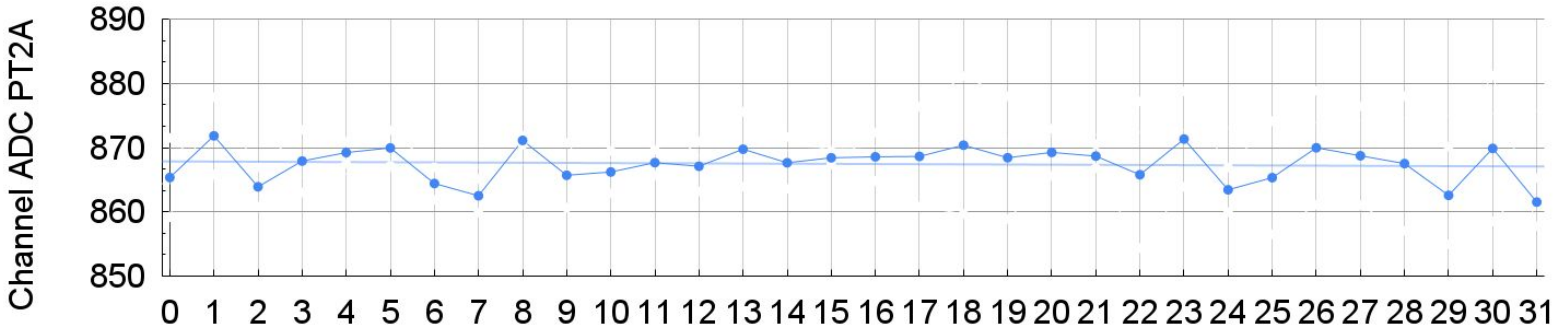




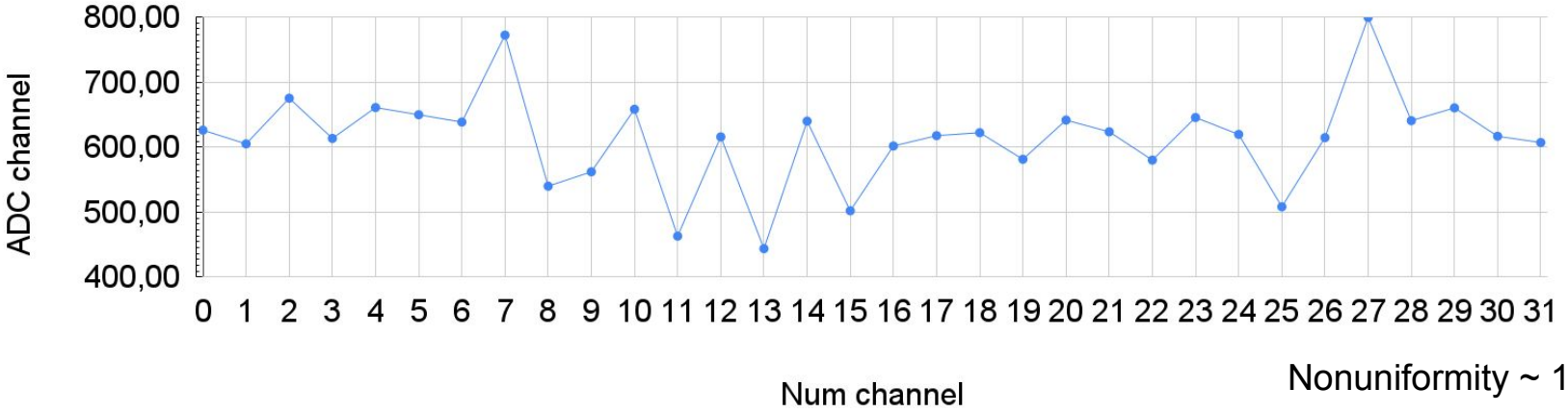
Ti-44 Spectrum



Nonuniformity of channels



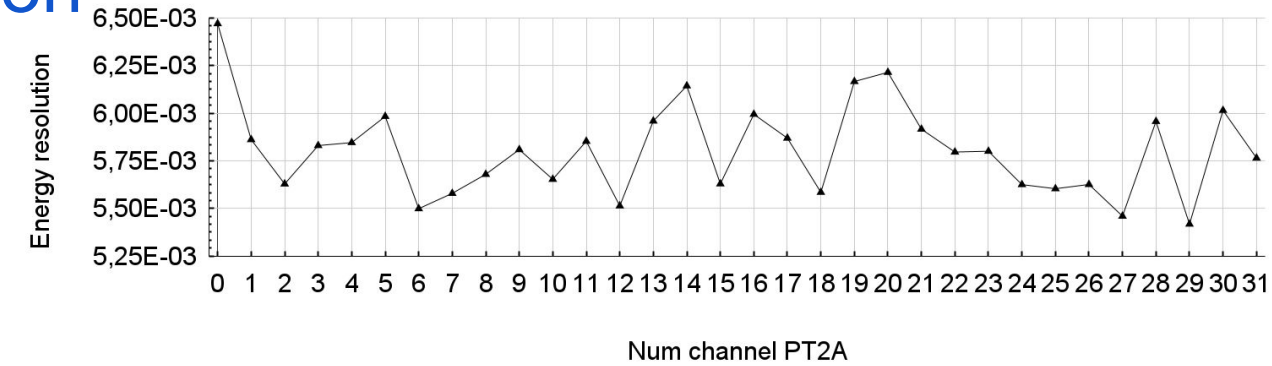
Nonuniformity ~ 1%



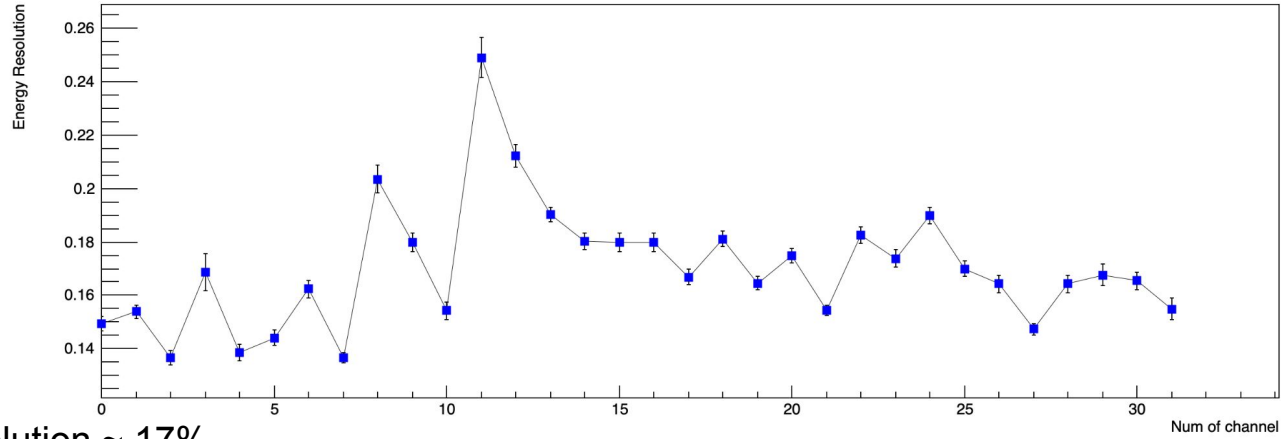
Nonuniformity ~ 12%

Energy resolution

For channels

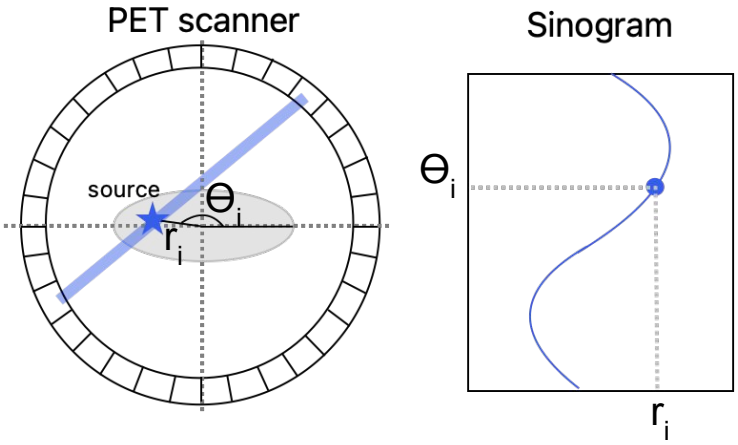


For detectors



Nonuniformity ~ 2%
Average value of energy resolution ~ 17%

Reconstructed sinograms

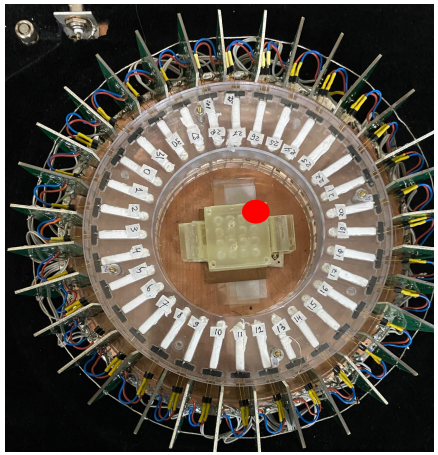


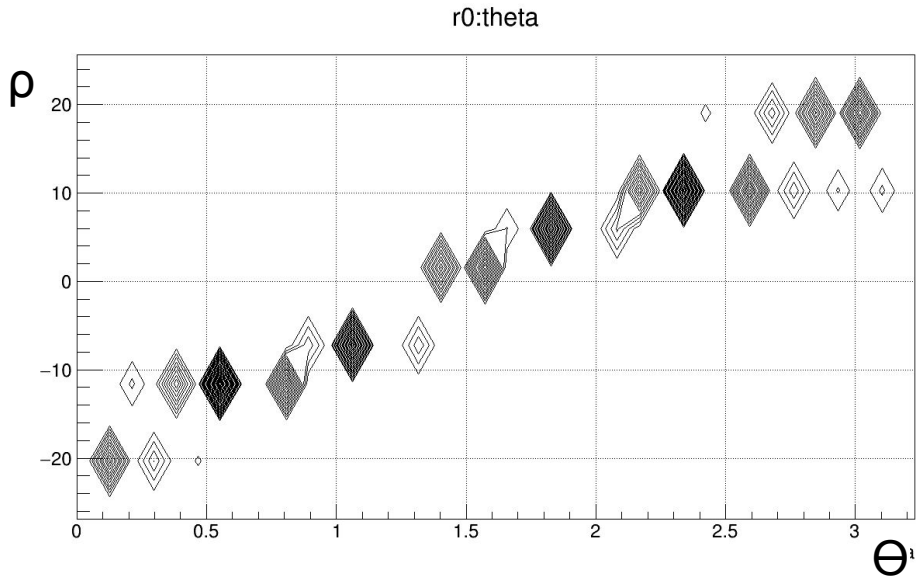
Event selection

Ampl > 250 ADCch
ΔT < 2 ns

FOV 120°

Non Central position

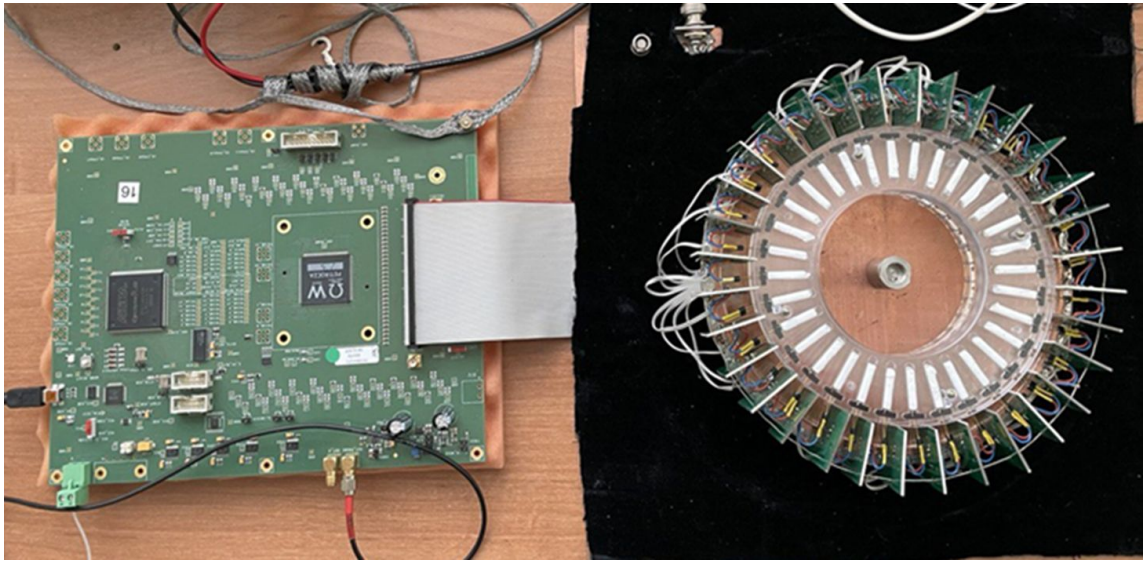




Conclusion

Prototype of PET for small animals:

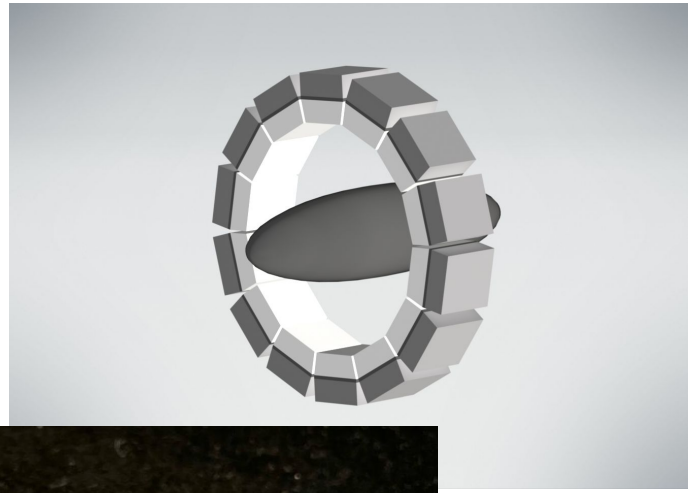
- 32 channels
- 120 mm diameter
- GAGG+SiPM detectors
- Petiroc2A readout chip

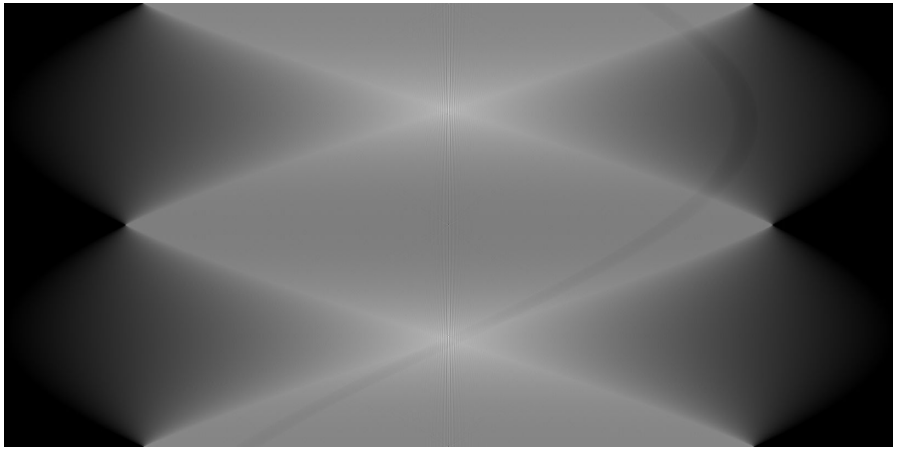


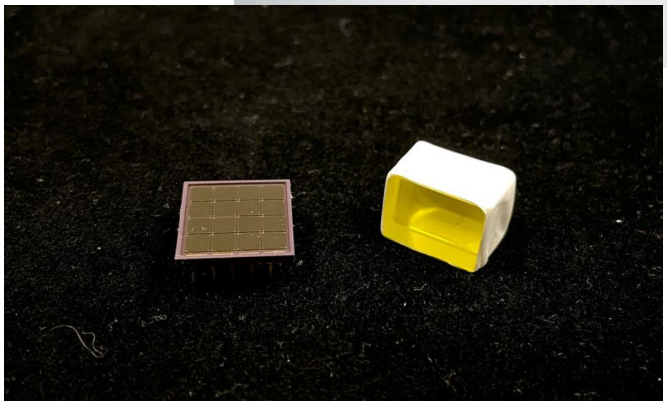
➢ Average TR = 1.8 ns (single detector)
➢ Average ER = 17% @ 511 keV
➢ ER non-homogeneity 2%
➢ Sinogram produced

Further plans

- Optical glue for better crystal to SiPM coupling
- Creating an image reconstructing program
- Transition to 4x4 SiPM matrices







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Thanks for your attention!

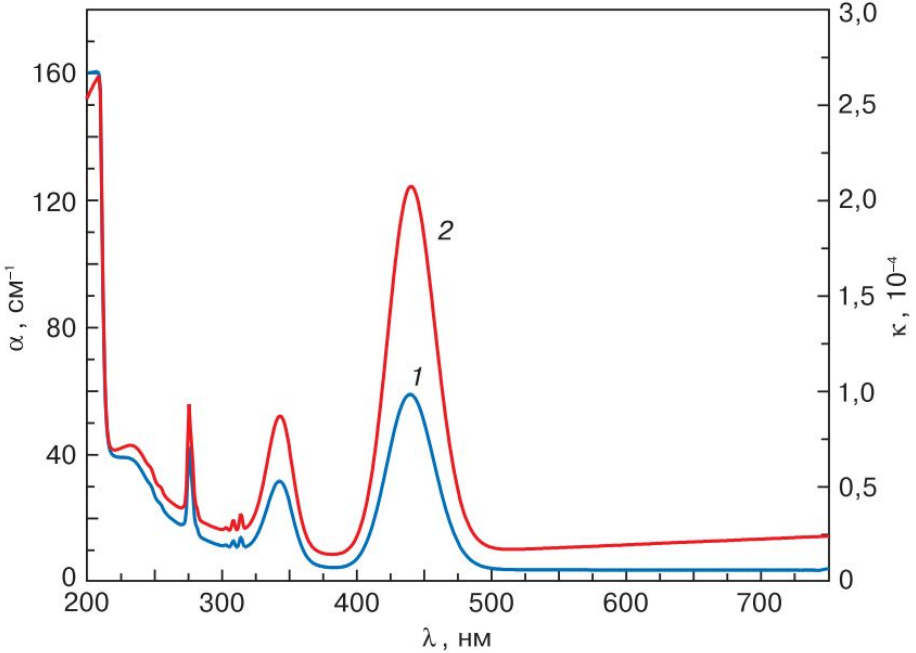
Boyko Nadezhda

junior researcher, NRC “Kurchatov Institute”, Moscow

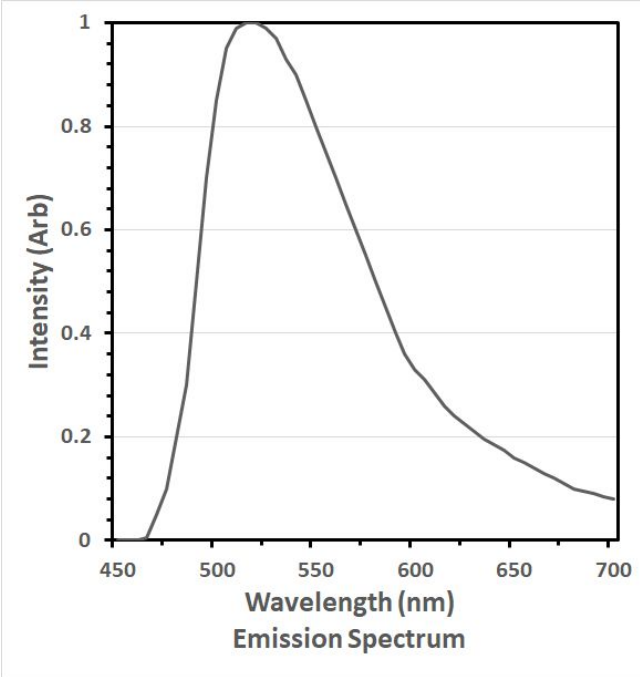
e-mail: bojkonada81@gmail.com

Parameter	Value
Detector Read-Out	SiPM
Number of Channels	32
Signal Polarity	positive or negative
Sensitivity	Voltage input amplifier, 200 Ohm matching
Timing Resolution	~ 18 ps RMS on trigger output (4 photoelectrons injected)
Dynamic Range	160 fC up to 400pC
Packaging & Dimension	LQFP 208 (28x28x1.4 mm) TFBGA 353 (12x12x1.2mm)
Power Consumption	6 mW/channel
Inputs	32 analogue inputs for SiPM connection, no external component required Inputs DC are adjustable to correct SIPM breakdown voltage non uniformity.
Outputs	32-channel trigger outputs ASIC level general trigger (OR of all channel) ASIC level second level general trigger (OR of all channel for energy cut) Charge measurement (10 bits Time measurement (10 bits TDC interpolating 40MHz coarse time) One multiplexed analogue charge output One multiplexed digital trigger output
Internal Programmable Features	Common trigger threshold adjustment and 6bit-DAC/channel for individual adjustment Shaping time & gain of the charge shaper 32 8bit-input DAC for SiPM HV adjustment over 1V span

GAGG(Ce)



Козлова Н.С., Бузанов О.А., Касимова В.М., Козлова А.П., Забелина Е.В. Оптические характеристики монокристаллического материала Gd3Al2Ga3O12 : Ce. *Известия высших учебных заведений. Материалы электронной техники*. 2018;21(1):18-25. https://doi.org/10.17073/1609-3577-2018-1-18-25



https://www.advatech-uk.co.uk/gagg_ce.html