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1) Brief introduction of IEAP CTU

2) Specialized double beta decay experiments

3) Selected technologies for deep underground laboratories

IEAP CTU was found in 2002 as a scientific and educational institute of the CTU in Prague, focusing on a research in the field of particle and subatomic physics performed in an international experiments, 101 people (32 from abroad)

Special stamp

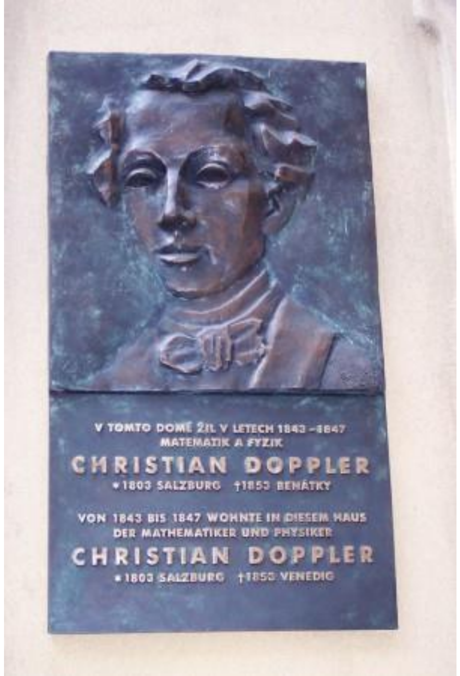
of the Czech Post

18.4.1869: Czech Polytechnical School in Prague, and Deutsche Technische Hochschule in Prag.

Advertisement of Prague:

- high level of Czech science and education
- very good connections of Prague with many airports
- attractive location

PRAGUE is nice, historical city



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Main research subjects in IEAP CTU:

(1) **CERN** – experiments ATLAS (ATLAS TPX – radiation field measurement, luminosity monitoring, theory, data processing), MoEDAL, AFP, ISOLDE (nuclear physics at CERN)

(2) **Neutrino physics** – theory, 2νEC/EC decay of ^{106}Cd (experiment TGV – necessity to upgrade), experiment COBRA (finished), detection of 0ν and 2νββ decay of ^{82}Se (experiment SuperNEMO), experiment LEGEND (USA/Germany – 0νββ decay of ^{76}Ge); detection of atmospheric neutrinos in experiments KM3NeT and Baikal-GVD); detection of reactor antineutrinos

(3) **Detection of dark matter** – experiment PICO in SNOLAB (Canada), neutralino

(4) **Detection of high-energy cosmic rays** – detection of radiation from universe (8 Timepix detectors on ISS, NASA; Timepix detector on Proba-V and RISESAT satellites; small unit VZLUSat), new projects with ESA (HardPix on-board GOMX-5 Cubesat mission, 12U, 20 kg. Launch 2023; 2x HardPix outside Lunar Gateway as part of ESA ERSA. Launch 2024).

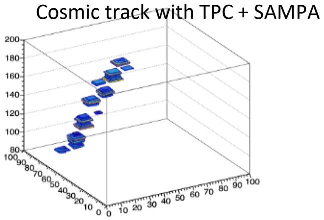
(5) **Applications –** pixel and strip detectors, imaging (X-rays and neutrons), biomedicine, hadron therapy, study of material…..

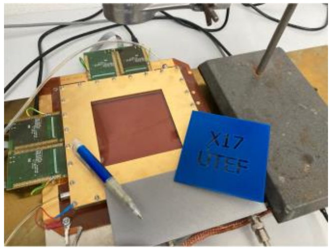
IEAP is not „big“ institute => all our activities are based on international cooperation

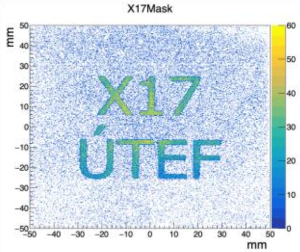
IEAP is financed by projects and results (articles, citations, patents…)

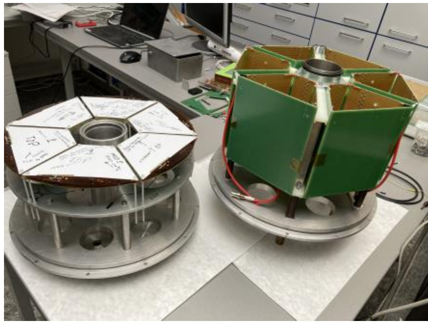
IEAP CTU gaseous detectors

1) Micro Pattern Gaseous Detectors MPGD (for experiments on VdG accelerator)
2) Implementation of SAMPA readout (designed for ALICE) integrated in general purpose electronics for MPGD (collaboration with University of São Paulo, Brazil)
3) GAČR grant GA21-21801S (with FEE UWB Pilsen): combining TPX3 detector, Multiwire proportional chambers, Time projection chambers.
4) Member of CERN/RD51; 5 senior scientists, 1 Bachelor student.





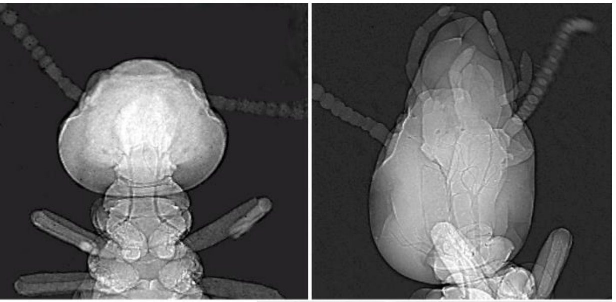


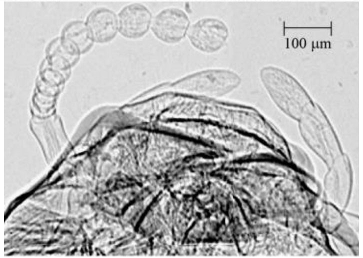


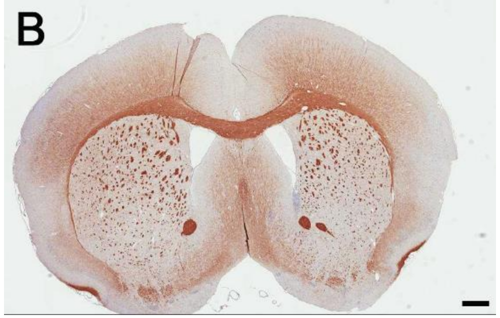
Selected applications of pixel detectors

1) Imaging of biological objects using X-ray (high resolution): living termites (5s exposure, 0.7mGy dose)
2) Micro-CT of mouse brain

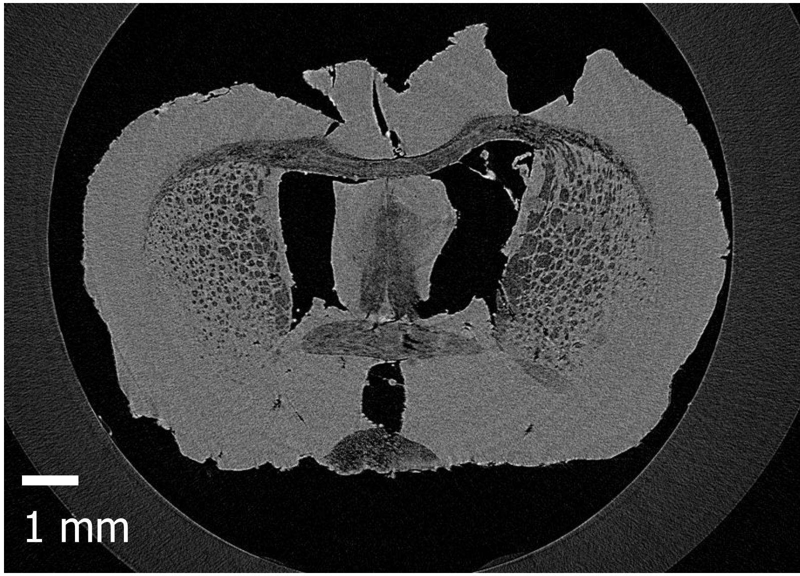
medipix collaboration







*Reference histological section of a mouse brain. Stephenson D.T. et al: in: Molecular Autism **2**(1):7 (2011).*

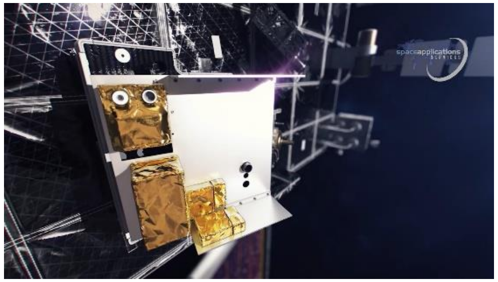


Micro-CT slices can be used for virtual histology with isotropic spatial resolution. Data acquired with large area Timepix PCD at imaging laboratory of IEAP CTU (sample from 3FM CU).

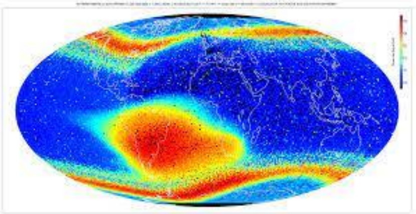
IEAP CTU detectors in space

1) Personal dosimetry and human crew safety (ISS, Gateway)

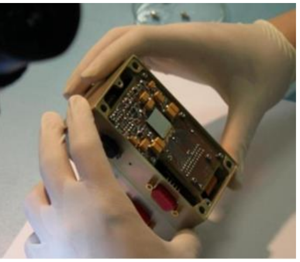
6 miniature Timepix-Lite online dosimeters developed by IEAP CTU placed on ISS in 2012.



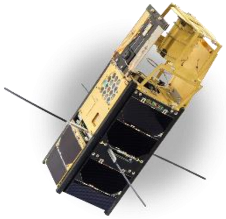
2 HardPix radiation monitors detectors onboard Lunar Gateway station



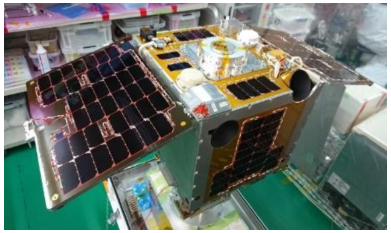
2) Science (Space weather monitoring, Heliophysics)



SATRAM onboard ESA Proba-V since 2013, still functional after 10 years!
High resolution mapping of space radiation at altitude 820 km



Timepix detector onboard Czech VZLUSAT-1 cubesat since 2017.

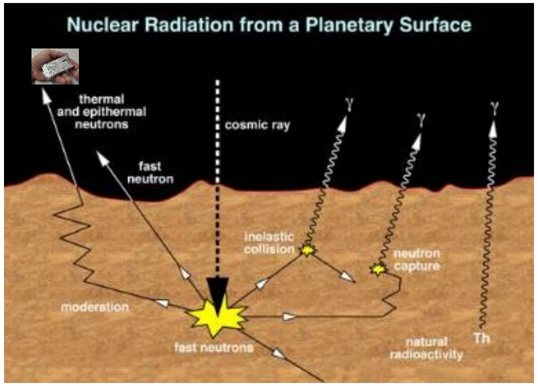


2xTimepix detector onboard Japanese RISESAT since 2019.

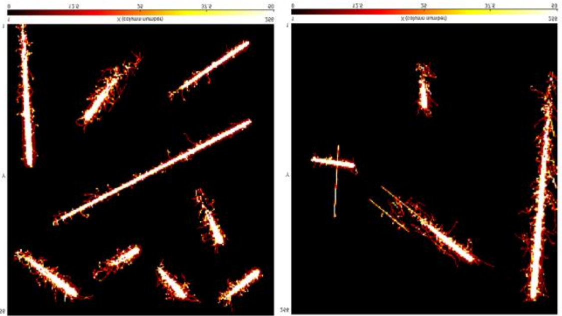
HardPix is part of UK SWIMMR programme. Planned launch 2023

3) Prospecting (neutron and gamma spectrometers)

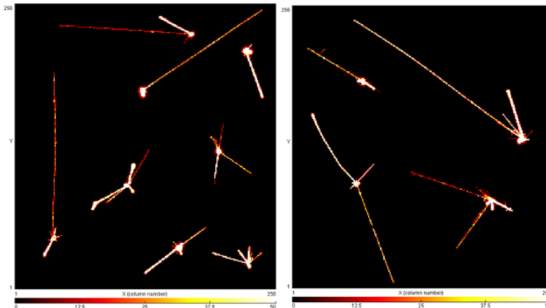
HardPix neutron spectrometer can be placed in lunar rovers (due to its size and mass even in very small ones) and map water presence in lunar subsurface. Neutron detection already tested by network of Timepix detectors in the ATLAS detector at CERN LHC.

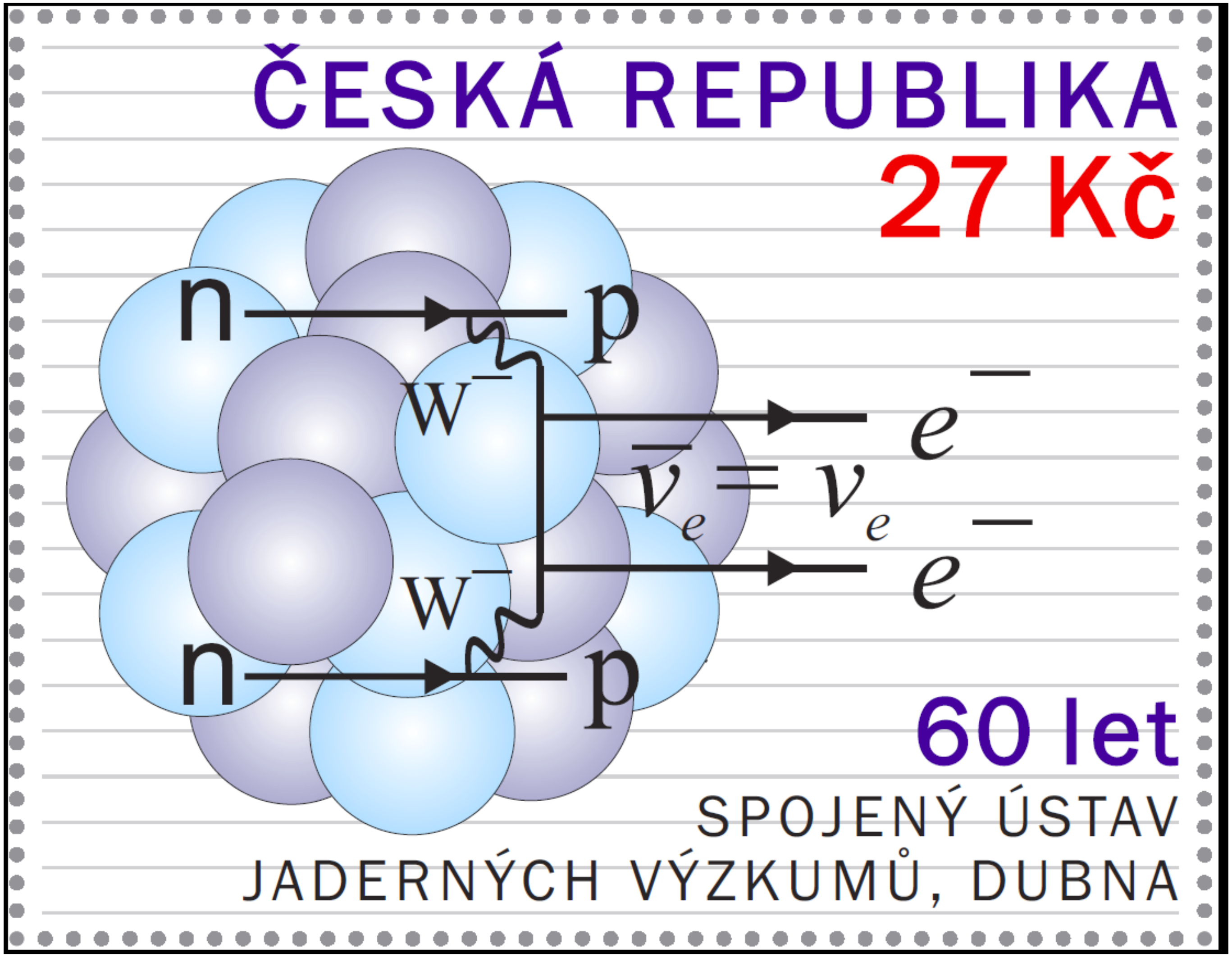


Timepix/ESA Proba-V (LEO, 820 km): highly energetic heavy charged particles (ions)



Timepix/ESA Proba-V: energetic light charged particles





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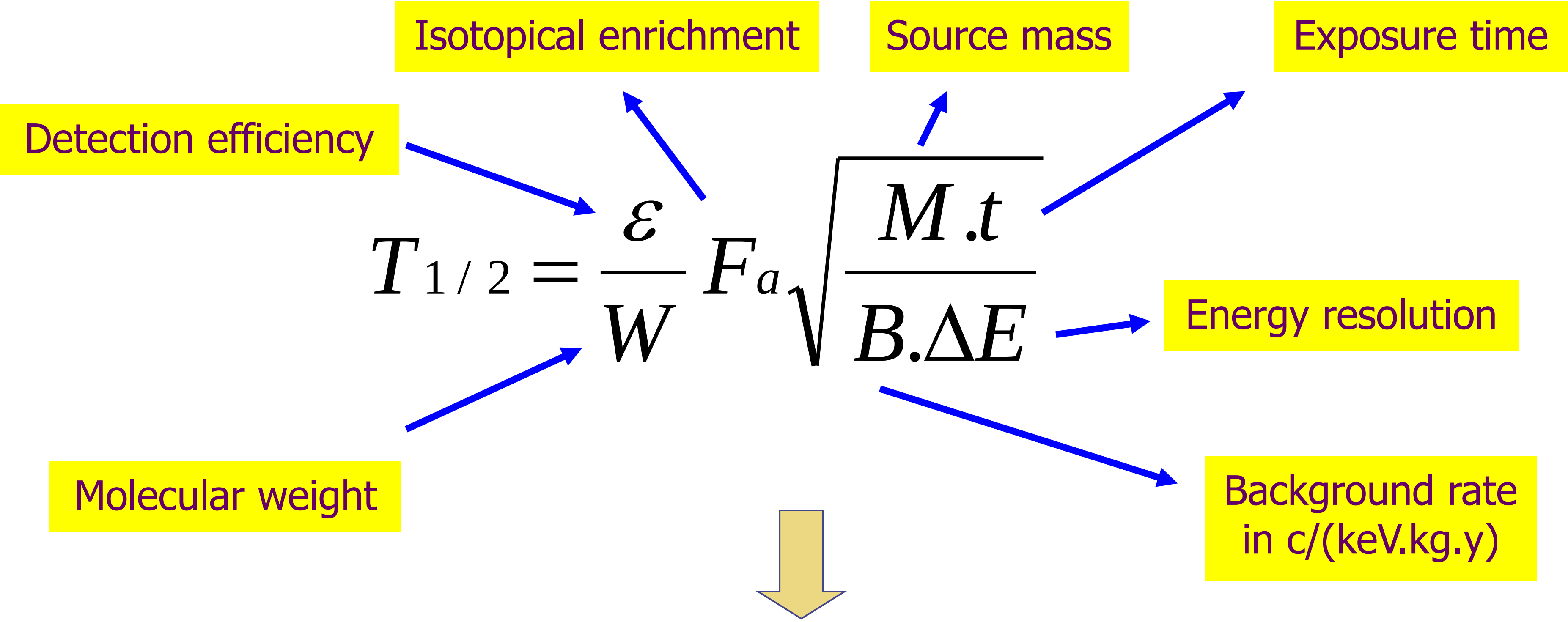
Half-life for 0νββ:



$$T_{1/2} = \frac{\varepsilon}{W} F_a \sqrt{\frac{M.t}{B.\Delta E}}$$

Detection efficiency

Isotopical enrichment

Source mass

Exposure time

Energy resolution

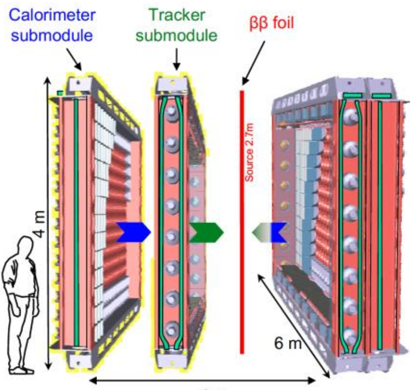
Molecular weight

Background rate in c/(keV.kg.y)

- source = enriched material (F_a)
- big mass of the source (M)
- long time of measurement (t)
- "best" energetical resolution of the detector (ΔE)
- background as low as possible (B)

Example of fruitful cooperation (broad collaboration, our strict responsibility for dedicated tasks)

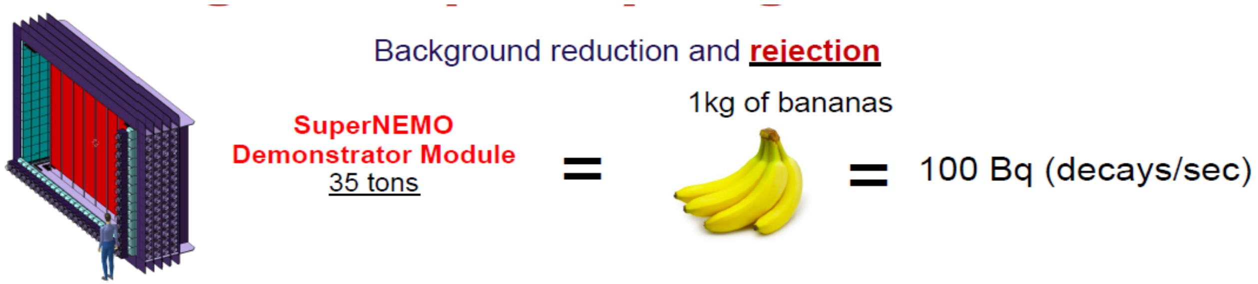
SuperNEMO: measurement of double beta decay in the LSM underground laboratory in Modane, France (4 800 m w.e.) – cooperation of institutions (**France, UK**, Czechia, Slovakia, Russia, Ukraine, JINR); DEMONSTRATOR = 1 module (7 kg of ^{82}Se)



The goal is to reach a zero background level in the region of interest of 0νββ.

Demonstrator sensitivity for 0νββ:

$T_{1/2}$ > 5.9 x10^{24} y (90% C.L.) and ⟨m⟩ < 0.2 - 0.55 eV



Calorimeter (712 Optical Modules, plastic scintillator, PMT) is ready. Tracking detector (2034 cells running in Geiger mode and filled with a gas mixture (95% He, 4% ethanol, 1% Ar) is ready. A magnetic field is installed. Gamma and neutron shielding under installation. Data taking. Start of measurement: 6/2024.

Our contribution: delivery of plastic scintillators (NUVIA company), delivery of steel construction, delivery of part of neutron shielding, cooperation in develoment of SW for calibration and tracking (3 students are involved), development of circulation system of inner gas (headed by J. Busto, removing Rn from He, Ar).

“Specialized” double beta decay experiments

a) Excited states of $2\nu\beta\beta$ decay
b) $2\nu EC/EC$ decay

Detector “Obelix” (JINR/IEAP CTU/LSM)

P type coaxial HPGe detector (U-type ultra low background cryostat located at LSM (4800 m w.e.)

Sensitive volume 600 cm^3 Efficiency 162%

Energy resolution ~1.2 keV at 122 keV (^{57}Co), ~2 keV at 1332 keV (^{60}Co)

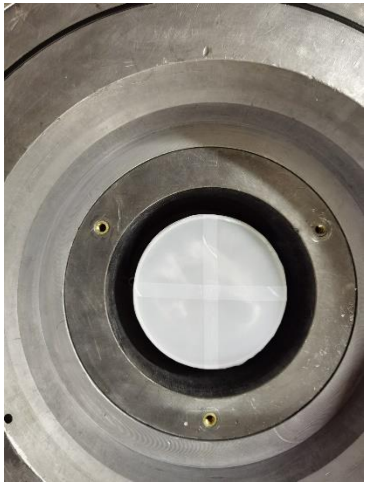
12 cm of arch. Pb, 20 cm of low active Pb, Radon free air

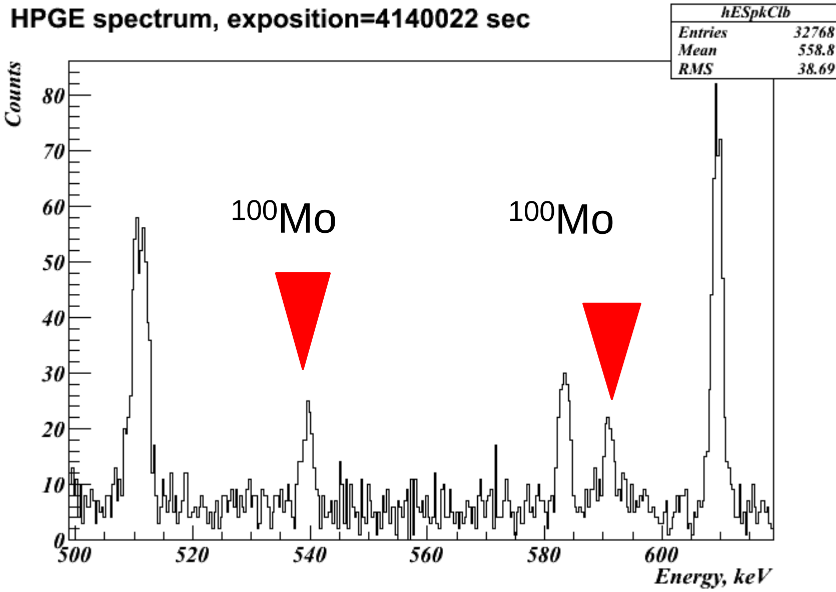
The price of such detector was 250 kEUROs => we needed international cooperation

Excited states of $2\nu\beta\beta$ decay of ^{100}Mo:

- **Mass of ^{100}Mo – 2517,15 g**
- **Total measurement time – 2288 h**

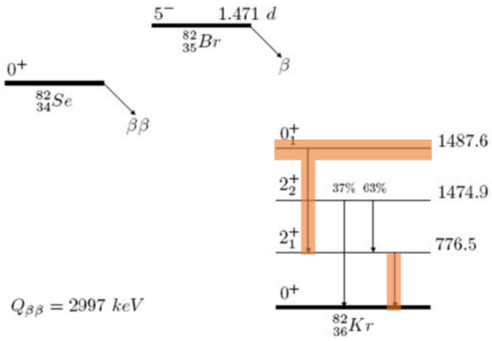
Process	T1/2 [years]
$2\nu2\beta^-$ decay to 0^+_1 [1130 keV]	7.5×10^{20}
$2\nu2\beta^-$ decay to 2^+_1 [540 keV]	$> 2.5 \times 10^{21}$





Excited states of 2νββ decay ^{82}Se by OBELIX (international cooperation – JINR, ITEP, IEAP CTU, …)

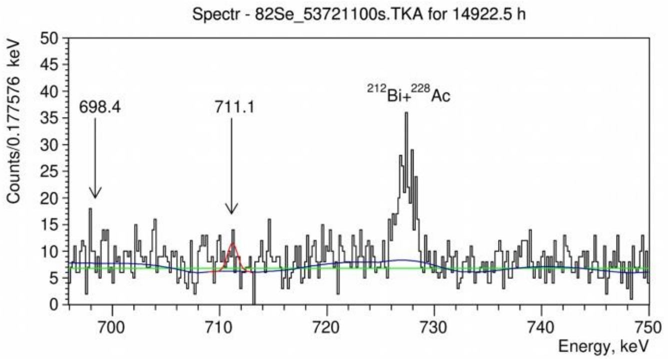
6,501 kg of ^{82}Se was installed on OBELIX (October of 2021), search for ββ decay into excited states of the daughter nucleus ^{82}Kr, which have not yet been observed by anyone.

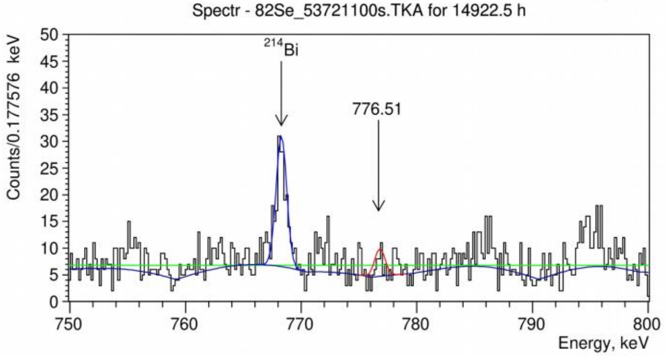


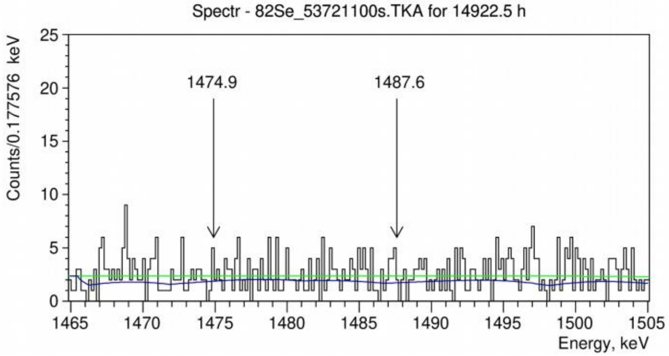
Theoretical expectations of transition to 0^+_1 exited state are at the level of $T_{1/2}$ ~ 5-7.5 x 10^{22} y (A. Barabash, F. Šimkovic).

- No clear effect was observed in 15000 hours of measurement (**10.12.2021-5.10.2023**)
- Some „indication“ on the effect – 0^+_1 state
- We reached sensitivity level $T_{1/2}$ ~ 5-9 x 10^{22} y
- Measurements are in progress to reach $T_{1/2}$ ~ 10^{23} y…

Level	Gammas with efficiencies	Limit $T_{1/2}$(90% CL)10^{22} y		
		present	MPI	[1]
2^+_1 (776.5 keV)	776.5 (2.416%)	**8.93**	1.19	1.3
2^+_2 (1474.9 keV)	776.5 (1.341%)+1474.9 (0.756%)	**6.37**	1.02	1.0
0^+_1 (1487.6 keV)	711.1 (2.129%)	**2.82**	0.95	
	776.5 (2.076%)	**7.67**	1.10	
	711.1 (2.129%) + 776.5 (2.076%)	**5.51**	1.38	3.4



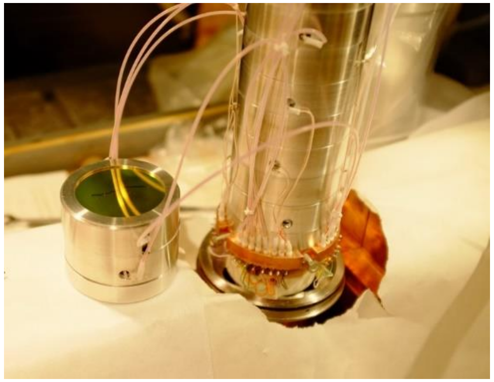


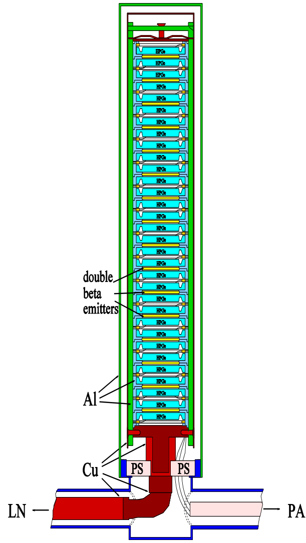


[1] J. W. Beeman et al., Eur. Phys. J. 75 (2015) 591

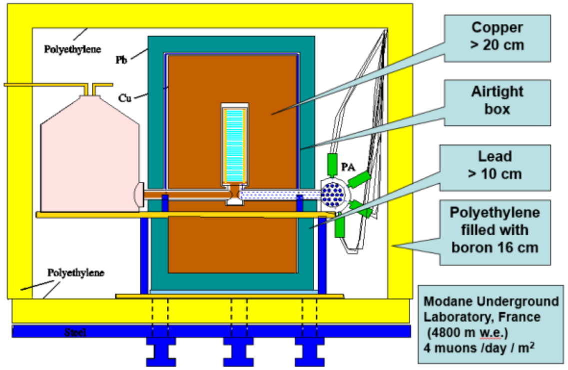
2νEC/EC decay **TGV-2** **Double beta decay of ^{106}Cd** (international cooperation – JINR, IEAP CTU)

32 HPGe planar detectors ∅60 mm x 6 mm, with sensitive volume: 20.4 cm^2 x 6 mm
Total sensitive volume and mass of detectors: ~400 cm^3, ~3 kg
Total area of sources : 330 cm^2



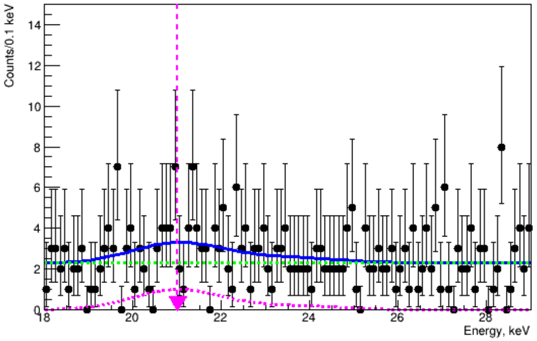


E-resolution : 3 ÷ 4 keV @ ^{60}Co
LE-threshold : 5 ÷ 6 keV
Double beta emitters:
16 sources (~70μm) of ^{106}Cd (enrichment 99.57%)
~23.2 g (~ 1.3 x 10^{23} atoms) of ^{106}Cd



$T_{1/2}$theor. (2νEC/EC) ~ $10^{20} – 10^{22}$

Decay mode	Final level of ^{106}Pd	$T_{1/2}$, y Phase II* (2012)	$T_{1/2}$, y Phase III (2021)*	$T_{1/2}$, y Phase III (2022)*
2νEC/EC	0^+g.s.	4.2×10^{20}	7.2×10^{20}	1.7×10^{21}
	2^+,511.9 keV	1.2×10^{20}	8.9×10^{20}	1.2×10^{21}
	$0^+{}_1$,1134 keV	1.0×10^{20}	7.2×10^{20}	9.6×10^{20}
2νβ$^+$/EC	0^+g.s.	1.1×10^{20}	6.6×10^{20}	8.4×10^{20}
	2^+,511.9 keV	1.1×10^{20}	7.9×10^{20}	1.0×10^{21}
	$0^+{}_1$,1134 keV	1.6×10^{20}	9.0×10^{20}	1.2×10^{21}
2νβ$^+$β$^+$	0^+g.s.	1.4×10^{20}	3.9×10^{20}	4.9×10^{20}
	2^+,511.9 keV	1.7×10^{20}	4.7×10^{20}	6.0×10^{20}



Fit of experimental data (45160 h)

Experiment is stopped, we plan: new detector part (32 HPGe detectors with better energy resolution, new electronics).

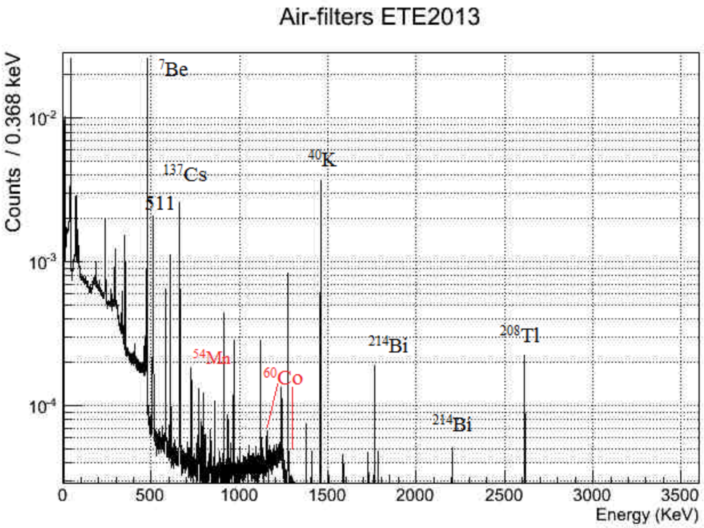
Selected technologies for deep underground laboratories (cooperation with industrial partners)

1) Sensitive background detection (using HPGe detectors – tens of μBq/kg) – e.g. selection of radiopure materials for construction of underground facilities
2) Suppression of radon – final source of radioactive background after removing gammas, neutrons, muons….

Example of sensitivity: Air-filters close to nuclear power station (measured in LSM, responsible institution NRPI)

^{54}Mn and ^{60}Co were first time seen in the spectrum

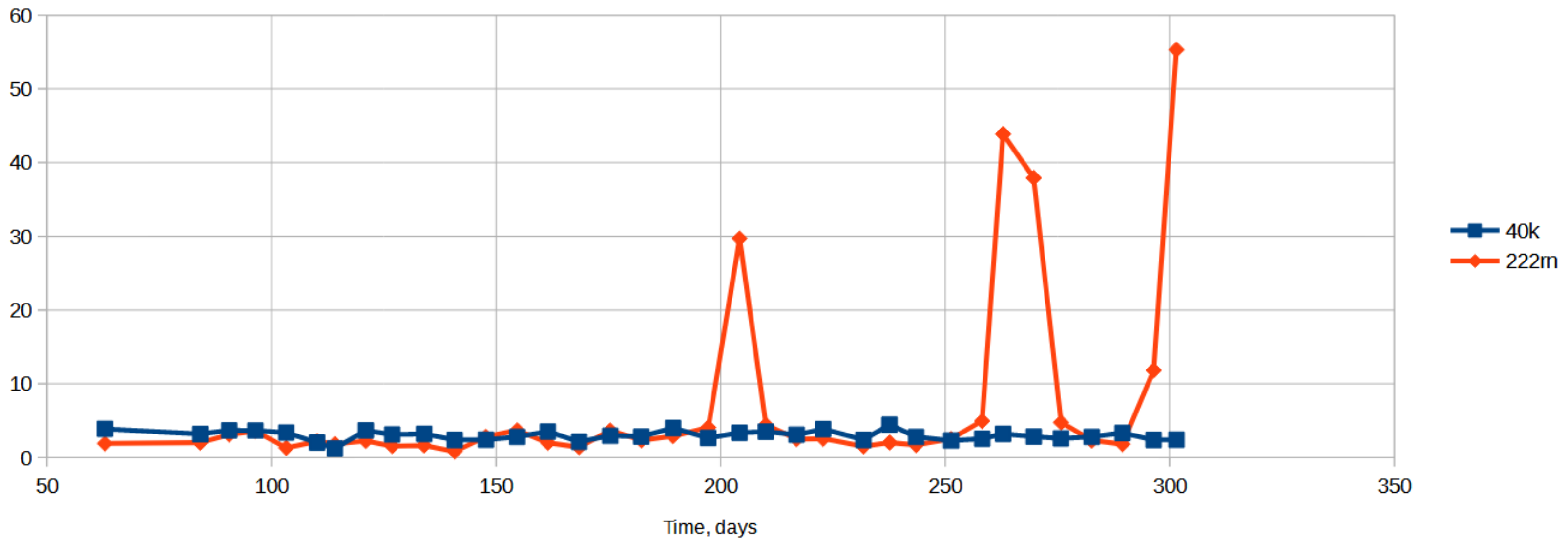
Sample	II measurement	I measurement
Time of measurement	33,3 days	22.3 days
Nuclide (KeV)	**MDA (Bq/m3)**	**MDA (Bq/m3)**
Mn-54 (834)	3.39E-009	8.79E-009
Co-60 (1173)	3.85E-009	1.5E-008
Co-60 (1332)	2.94E-009	9.9E-009
Ag-110M (884)	7.61E-009	2.01E-008



Why we need to suppress Rn caused background?

Search for ββ decay on excited levels of ^{82}Se with the OBELIX spectrometer and the influence of radon background:

- Look at radon peaks (the sum of the 351 keV, ^{214}Pb, and 609 keV, ^{214}Bi, lines from the ^{222}Rn) we observe anomalous spikes.
- **The reason is unknown (open shielding, stop clean air flushing???), but it cost us a month of exposure, which we had to reject.**



Suppression of Rn from air

Radon trapping on charcoal => Radon decays during trapping

reduction factor 100 => „retention time“ T = 606 hours (~ 25 days)

T (hours) = K (m^3/kg) * m (kg) / f (m^3/hour)

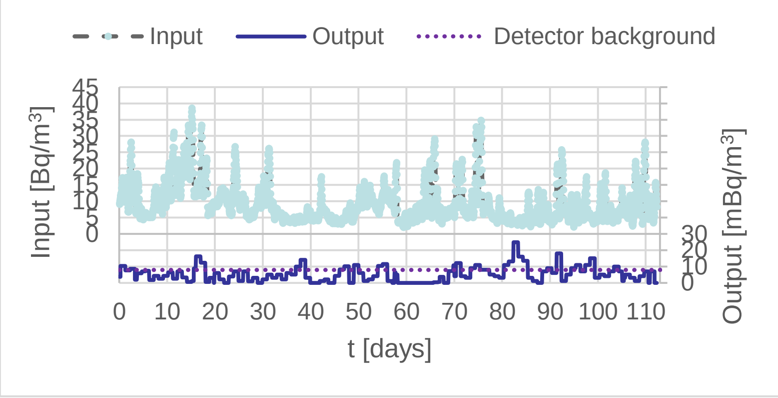
T – retention time of Radon in charcoal; m – mass of charcoal, f – flux of gas

K – depends on charcoal type, temperature, pressure (J. Busto, CPPM):

t (°C)	20	0	-30	-40	-50	-60
K(m^3/kg)	4	12	53	78	152	272

A(222Rn) in LSM ~ 10-20 Bq/m^3, Antiradon setup: 500 kg charcoal @ -50°C, 7 bars

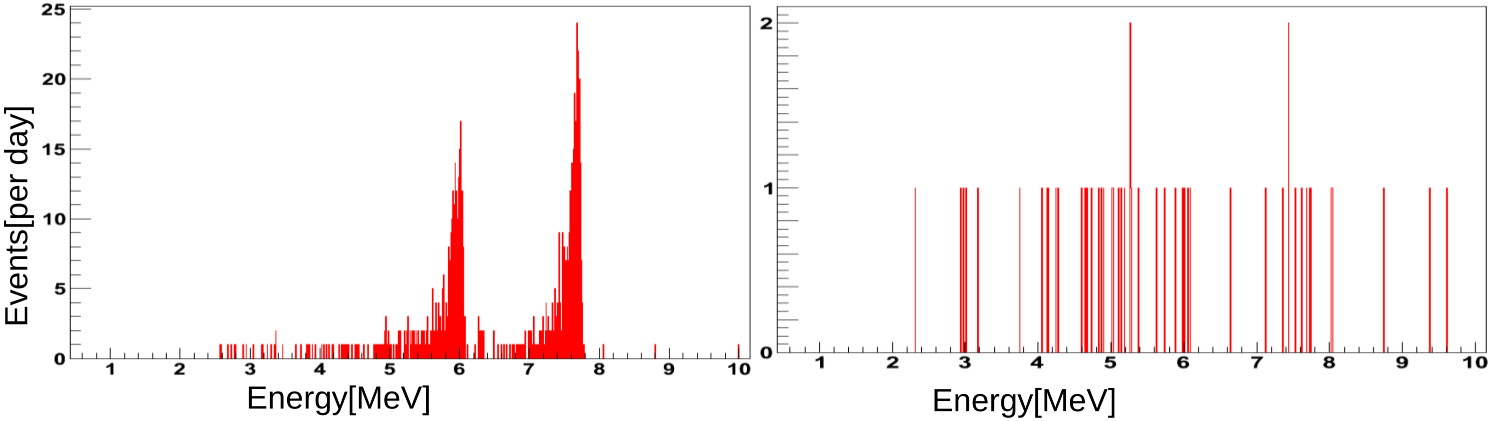
Activity: A(^{222}Rn) < 10 mBq/m^3 !!! Flux: 150-250 m^3/h (ATEKO company, Czech Republic), delivered to USA, Korea, Italy, China…



Sensitive detection of Rn: stainless steel (50 l); electrostatic collection (HV 12 kV), PIN diode.

1 mBq/m^3 means 86 decays of Rn in m^3 per day

Energy spectra measured at the beginning (5 Bq/m^3) and the end of background measurement (2 months, 11±1 events/day in the ROI (6.2-7.8 MeV, ^{214}Po)



Time of measurement [day]	Sensitivity [mBq/m^3]
1	11
7	3.5
30	1.6
75	1

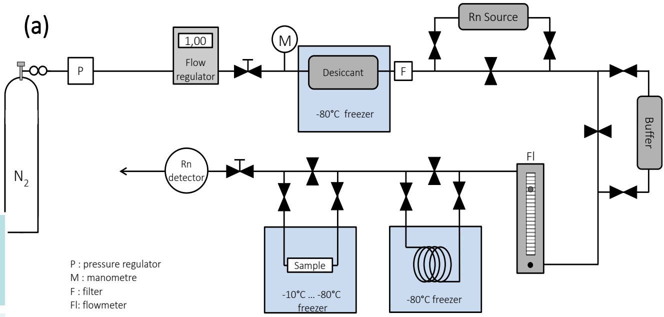
R&D for antiradon system:

- Radon infrastructure in CPPM, Marseille (prof. J. Busto):

Testing equipment (in broad range of temperature) for new absorption materials in air, He+Ar atmosphere, influence of alcohol …

Sensitive Rn detectors

New sorption material Ag-ETS-10:



T_{mes}, °C	Ag-ZSM-5	Ag-13X	Ag-ETS-10	13X	ETS-10
18	7±2	15±2	1400±279		
-12	26±4	114±15	9952±2405		
-30	80±11	247±30	19940±5981		
-50	172±22	632±85		3±1	11±2
-80	2221±329	4519±788		15±2	26±4

https://academic.oup.com/ptep/advance-article/doi/10.1093/ptep/ptad160/7504754

Based on the obtained results, together with ATEKO we received grant support (Technological Agency of CR) – application of new absorbent, smaller equipment, lower energy consumption…

Clean room in LSM (ISO 5, zero-dose environment for multipurpose research)

- Anti-radon system and clean room (ISO 5) was installed in NRPI and in LSM

- Suppression of all types of radioactivity (including Radon) for biological studies, preparation of detectors, enriched foils…..

Low Rn clean room ("ZERO DOSE“ radiation condition)–company CRAC
(our article - https://www.frontiersin.org/articles/10.3389/fpubh.2020.589891/full)

Long-term storage HDF (human dermal fibroblast) cells in LN_2 at reduced radiation background conditions

○ Reference cells stored in Czech Republic on the surface (no shielding),

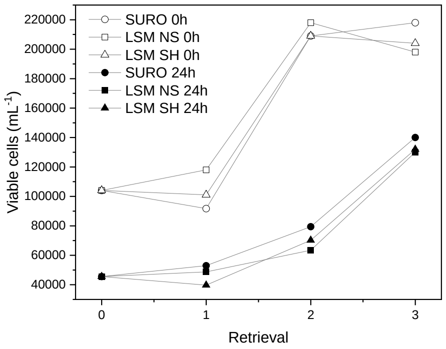
□ Reference cells stored in LSM, France on the surface (no shielding),

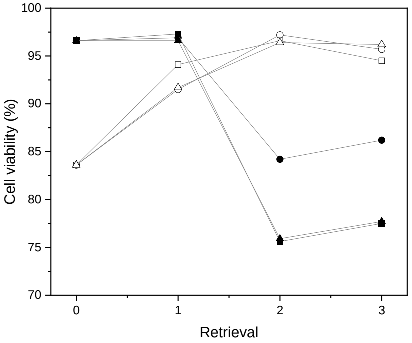
Δ Cells stored in LSM, France under the ground (with shielding).

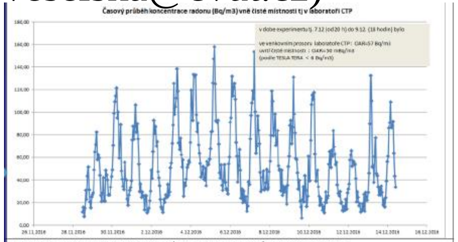
Start of experiment = March 2022; 3 cells retrievals; analysis = cell viability, cell cycle, apoptosis and proliferation study;

gH2AX analysis and gene expression studies by qPCR upon cells thawing (0 h) and incubation (24 h)

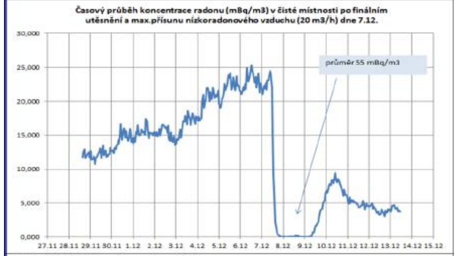
Responsible persons: M. Davídkova (NRPI), O. Veselska (IEAP CTU, oleksandra.veselska@cvut.cz)







Měření v prostoru laboratoře CTP (vně čisté místnosti) – prosinec 2016



Měření v čisté místnosti– prosinec 2016

Cytometric analysis shows that all three cells’ groups undergo similar changes.

gH2AX and qPCR results are upcoming, Re-installation of clean room with suppressed Rn: ideal location for cells experiments (no α)

Home infrastructure for testing of technologies for LSM-CZ: everything must be prepared at home, „only“ application in LSM (financial effective), based on reciprocity

1) Radon infrastructure:

Testing antiradon facility (providing 20 m^3/h of air with Rn activity < 10 mBq/m^3)

Testing and research low Rn clean room at NRPI Prague

Sensitive Rn detectors (e.g. volume of 50 litres) and radon concentration line (100 mBq/m^3)

Radon testing and research chamber at NRPI (range 10 mBq/m^3 till 1 GBq/m^3)

2) Low background detection infrastructure:

Sensitive HPGe detectors in low background environment (gamma and alpha spectrometry, whole body counter for internal contamination) at NRPI

Ultra sensitive detection technology with pixel detectors for LSM - determination of ^{137}Cs and ^{90}Sr in water samples (<1 mBq/l) to study vulnerability of hydrogeological districts in radiation accident

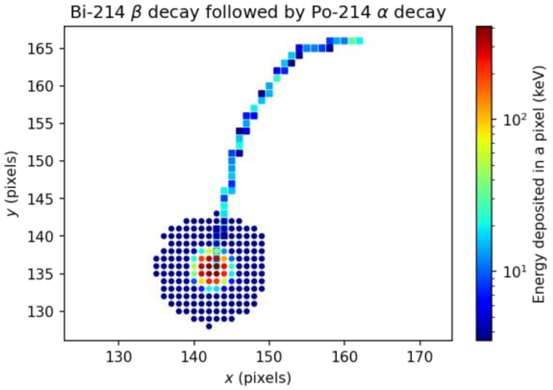
3) Radiobiology and radioecology infrastructure:

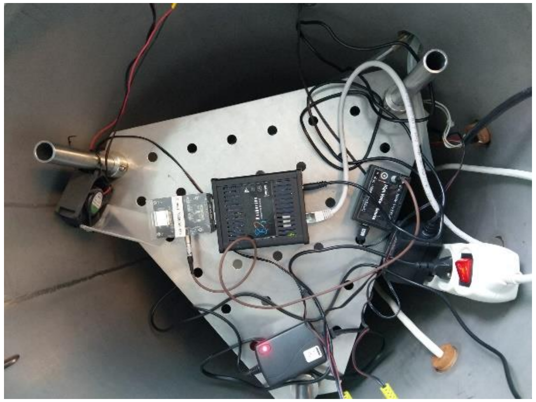
Radiobiological NRPI and NRI research laboratories equipped with automated analysis of DNA damage METAFER, incubators, irradiation facility for cells experiments. On-site experimental facilities for radionuclide migration (soil, plants)

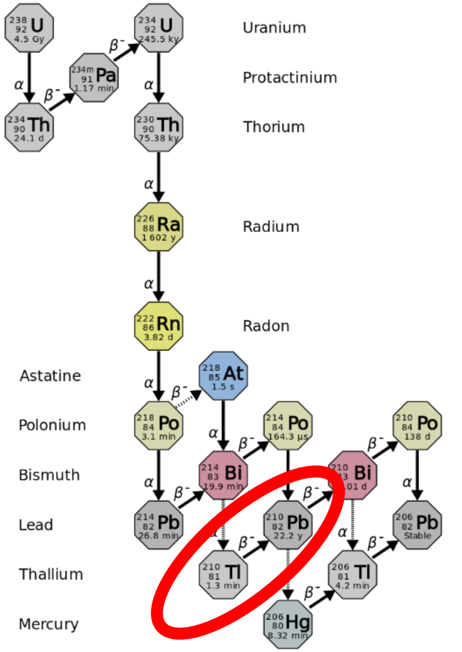
Automatic system for changing of samples for HPGe detectors (NUVIA company)

Student activities: measurement of half-life time of Po-214 (also Po-212) with high precision using TPX3 detector (J. Jelínek)

- Measurement was done in NRPI, Timepix3 into barrel with high activity of Rn-222 (units to tens of MBq m^{-3}) for 140 hours
- Daughter nuclei attach to Timepix3 surface and subsequent decays were observed.







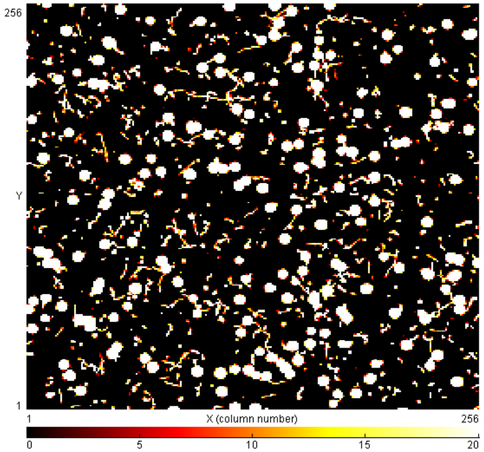
The overal result of measurements is: $T_{1/2} = 163{,}565 \pm 0{,}034(\mathrm{stat}) \pm 0{,}022(\mathrm{syst})\ \mu\mathrm{s}$

Other recent experimental values:

$T_{1/2} = 163{,}58 \pm 0{,}29(\mathrm{stat}) \pm 0{,}10(\mathrm{syst})\ \mu\mathrm{s}$ (Bellini et al., 2013)

$T_{1/2} = 163{,}47 \pm 0{,}03\ \mu\mathrm{s}$ (Alexeyev et al., 2020, no proper error discussion)

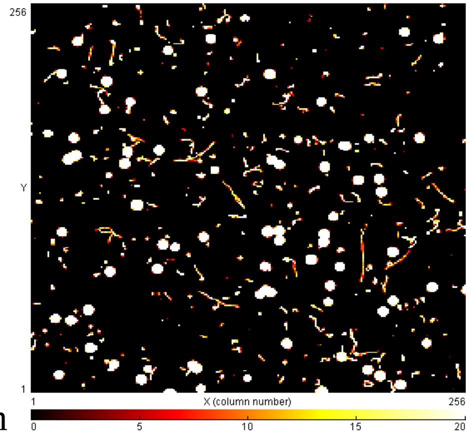
Spatial resolution of Timepix3 allowed to collect large data set (order of 10^7 events) in short time (approx. 6 days) while maintaining reasonable signal to noise ratio.



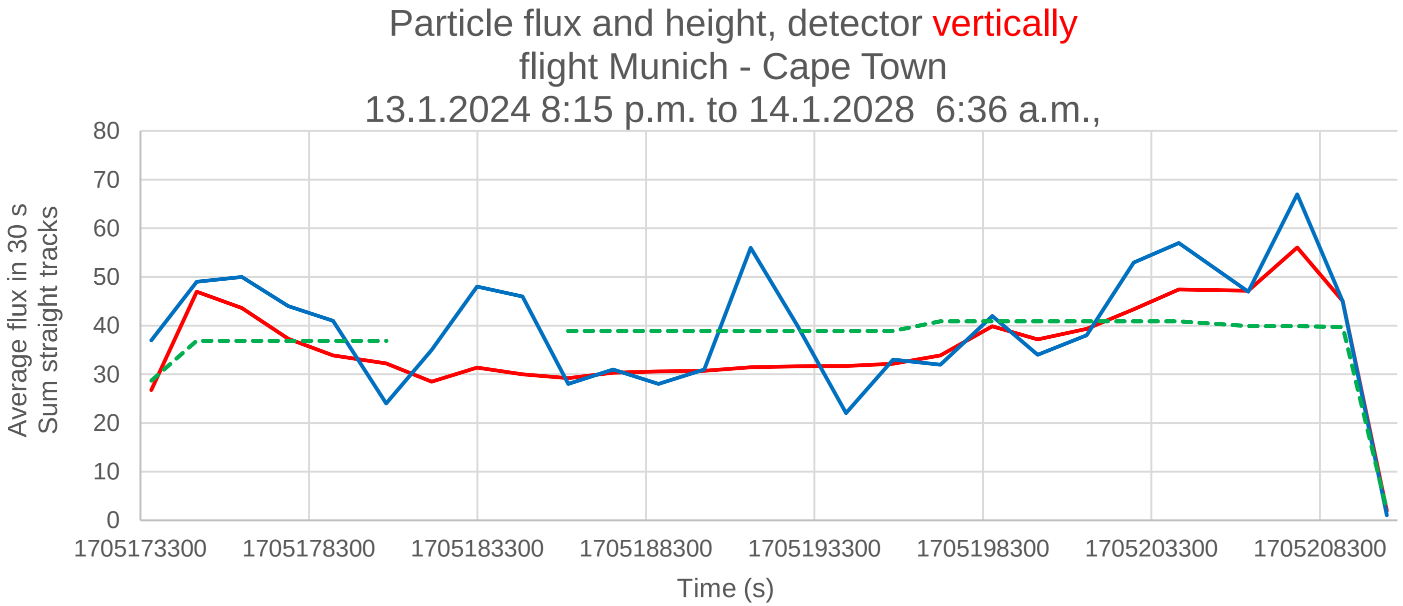
Visualizations of the Rn caused radioactivity of the paper tissue used as an air filter at home. The filtering took 5 minutes and exposure time was 10 minutes in both cases.

Not-ventilated room

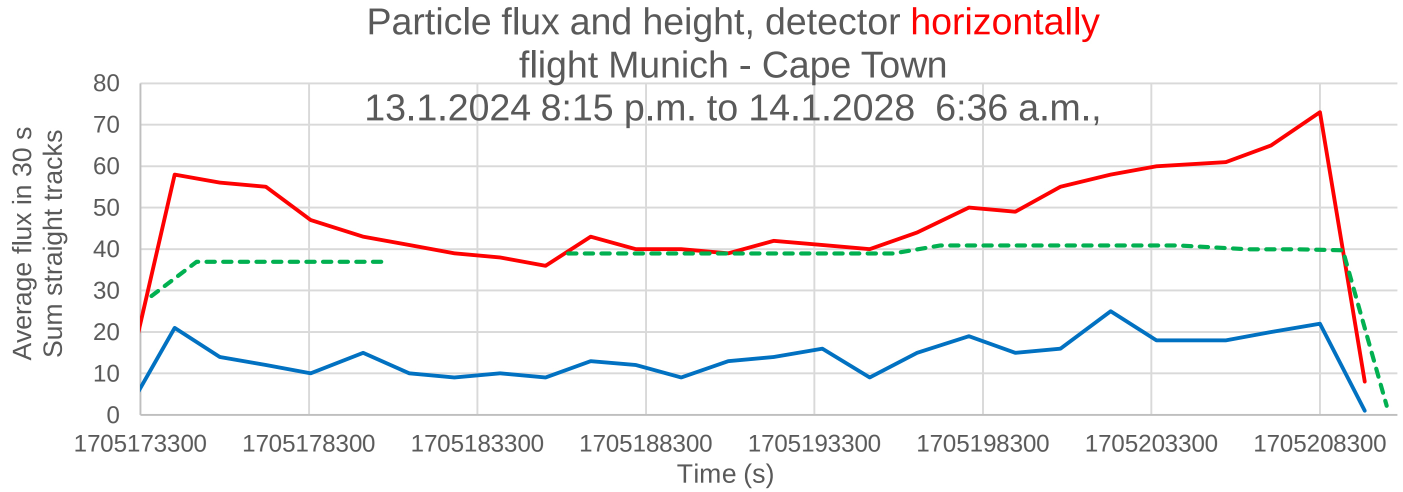
Ventilated room



Measurement of particles in a plane with the pixel detector

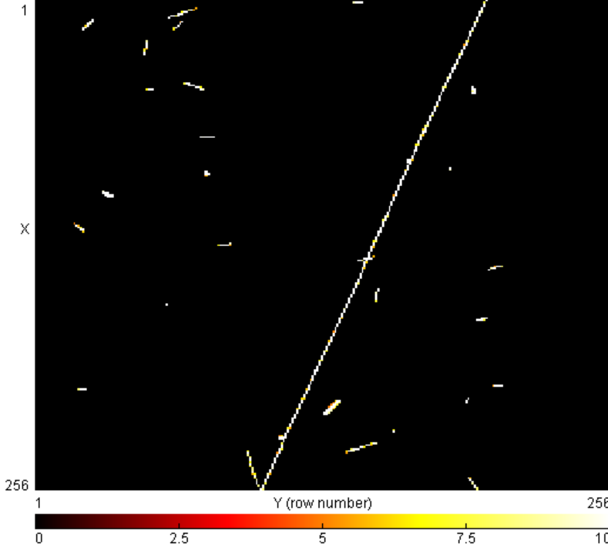


Particle flux and height, detector vertically
flight Munich - Cape Town
13.1.2024 8:15 p.m. to 14.1.2028 6:36 a.m.,

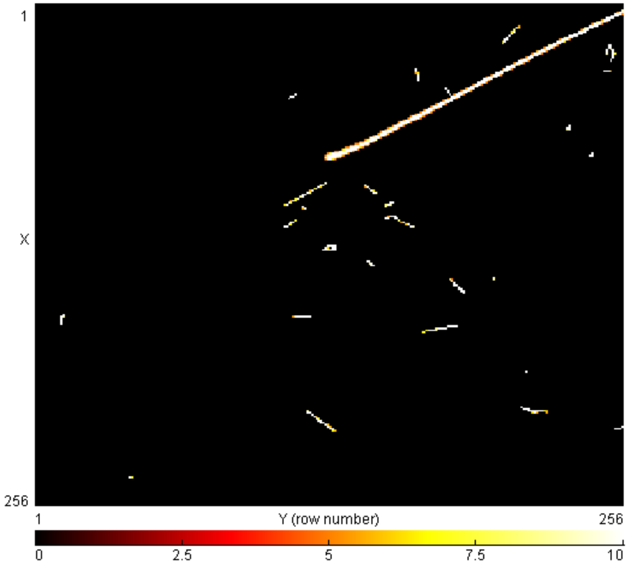


Particle flux and height, detector horizontally
flight Munich - Cape Town
13.1.2024 8:15 p.m. to 14.1.2028 6:36 a.m.,

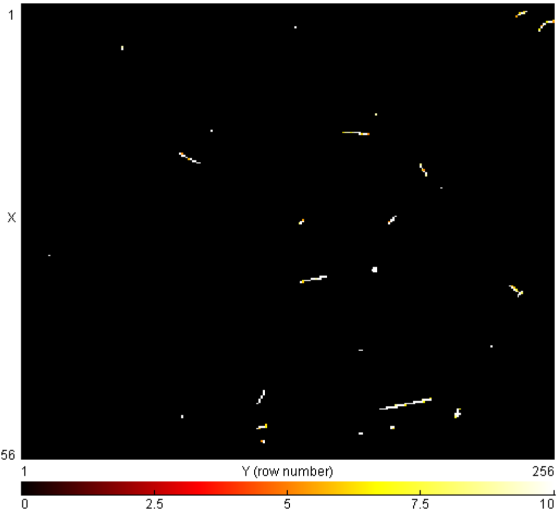
Measurement during flight (30 s exposition): muon track



Example of proton track:

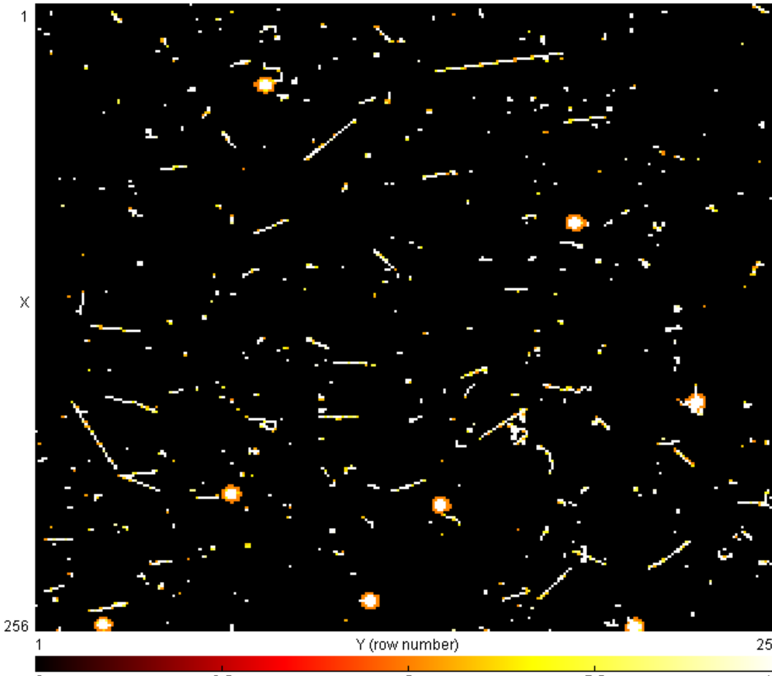


Time before landing =
15 minutes



Time before landing =
3 minutes

Measurement in conference room (30 minutes exposition)



Conclusions:

1) **Big vs Small experiments:** The most important are “flagship” experiments. Important position for small experiments (e.g. data for special modes of ββ decay, R&D of emerging technologies, education..)

2) **Theory:** support for experimentalists (e.g. nuclear structure theory in neutrino physics, F. Simkovic)

3) **Cooperation with EuCAPT** (European Consortium of Astroparticle Theory): IEAP CTU (A. Smetana) organizes a second Czech EuCAPT unit (3 institutions, 21 people), e.g EuCAPT workshop of Astroparticle theory

4) **Industrial companies:** for our activities in LSM we have close cooperation with technological companies (common projects). NUVIA, CRYTUR, ADVACAM, ATEKO.

5) **Infrastructures outside DUL:** efficient way to attract new staff and support interest of different institutions, reduction of costs.

6) **Organization of collaborations:** example Medipix/Timepix collaboration (headed by M. Campbell), ~20 institutions, „fee“ for common R&I (new readout chips), applications are responsibility of teams.

7) **Financial support for running of DUL**: to support the sustainability (10 years), to cover running costs.

e.g. Timepix3 (256x256 pixels): Each pixel can be configured to operate in different mode independently to other pixels

Measuring Energy and Time-stamping (1.56 ns, new generation 200 ps) simultaneously

Readout modes: a) Frame-based mode (max~1300 fps); b) Data-driven mode (~40Mhits/s), dead time per pixel min. 475ns

Max. data rate= 5.12 Gbps

Successful story in technology transfer: spin-off company ADVACAM (https://advacam.com/)

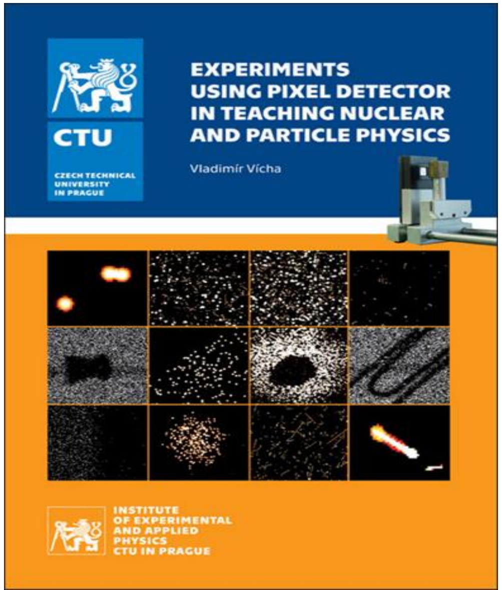
EY Entrepreneur Of The Year™

2021 Czech Republic Technology Category

Baie dankie vir u aandag en uitnodiging

SESTRA - **S**chool **E**ducation **S**et with **T**imepix for **R**adiation **A**nalysis

- Particle Camera MiniPixEDU
  (Timepix detector, calibrated)
- Control Software
  Pixelman Simple preview & Pixet basic
  (acquisition, online visualisation, etc.,)
- Alfa source
  (241Am, α and γ source, 9.5 kBq)
- Gamma source
  (241Am, γ source, 300 kBq, optional)
- Potassium Salt
  (β and γ source)
- Thoriated Tungsten Electrode
  (α, β and γ source)
- Uranium Glass *(α, β and γ source)*
- Mounting Rails
- Source Holder
- Camera Holder
- Aluminium, Stainless, Copper, Brass
  and Lead Shielding Plates
- Radiography Adapter Head
  +Samples with Hidden Patterns
- Vacuum Cleaner Grate Adapter
- USB Cable
- Book of detailed guidelines
  "Experiments Using Pixel Detector in
  Teaching Nuclear and Particle Physics"



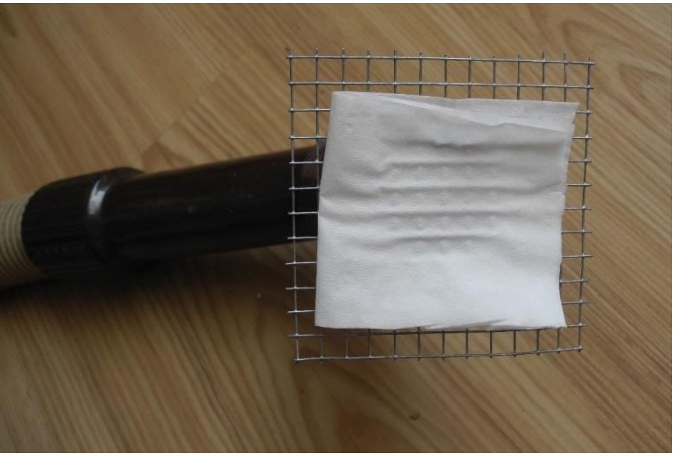
CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

EXPERIMENTS USING PIXEL DETECTOR IN TEACHING NUCLEAR AND PARTICLE PHYSICS

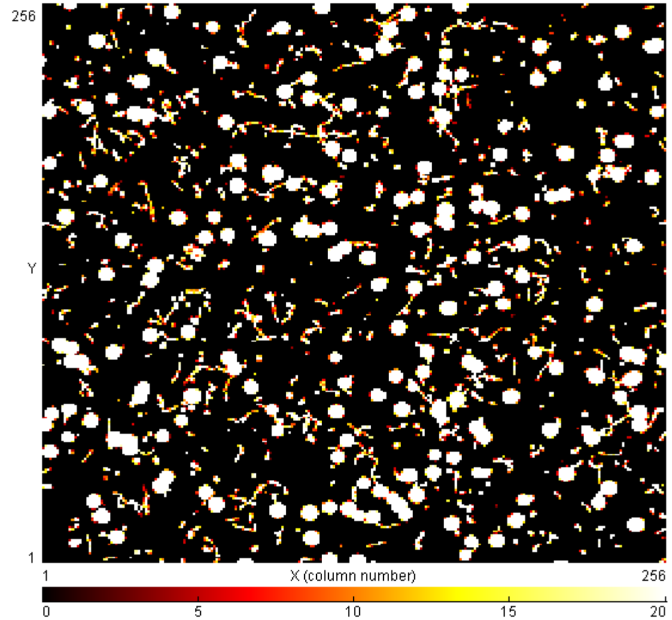
Vladimír Vícha

INSTITUTE OF EXPERIMENTAL AND APPLIED PHYSICS CTU IN PRAGUE

DEMONSTRATION OF BACKGROUND RADIOACTIVITY CAUSED BY RADON

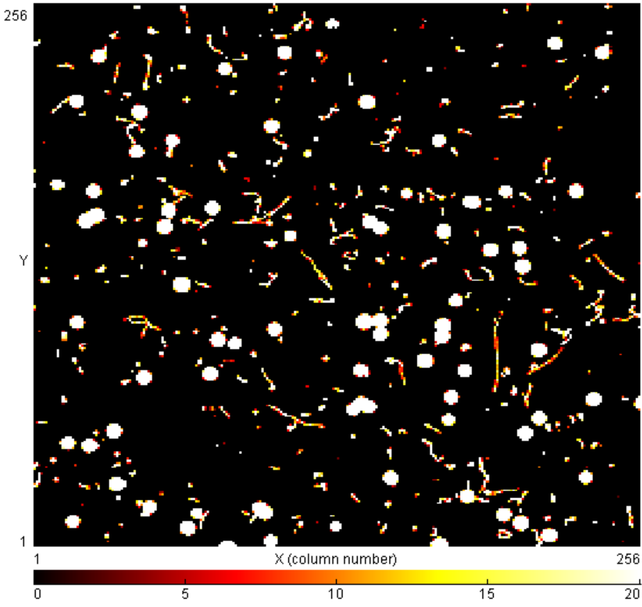


Visualizations of the Rn caused radioactivity of the paper tissue used as an air filter at home. The filtering took 5 minutes and exposure time was 10 minutes in both cases.

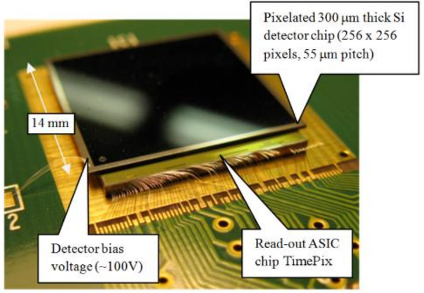


Not-ventilated (left) room

Ventilated (right) room

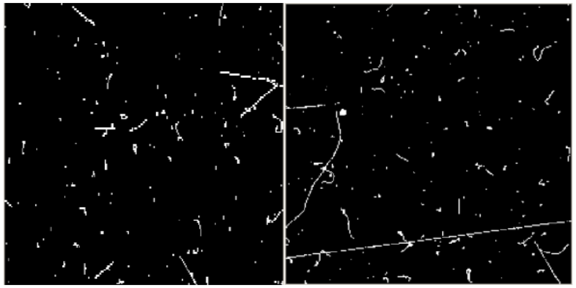


IEAP CTU pixel detectors: Medipix/Timepix collaboration (headed by M. Campbell, CERN):




Timepix3 CERN chip board

Typical response of Timepix device to natural background radiation:



Recognizable tracks and traces of
- X-rays
- electrons
- alpha particles
- muon
- electron-positron pair, … .

e.g. Timepix3

Each pixel can be configured to operate in different mode independently to other pixels

Measuring Energy (TOT, dead time per pixel 475 ns) and Time-stamping (TOA, 1.56 ns) simultaneously

Readout modes: a) Frame-based mode (max~1300 fps); b) Data-driven mode (~40Mhits/s), dead time per pixel min. 475ns

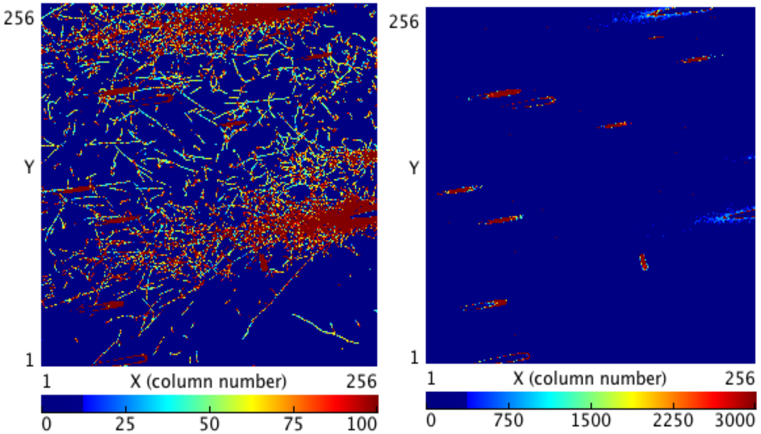
Output data: up to 8 serial lines, 640MHz => max. data rate= 5.12 Gbps

Successful story in technology transfer: spin-off company ADVACAM (https://advacam.com/)

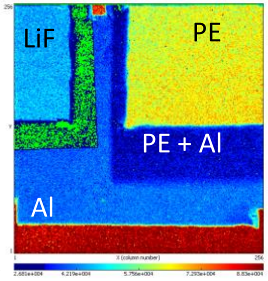
EY Entrepreneur Of The Year™

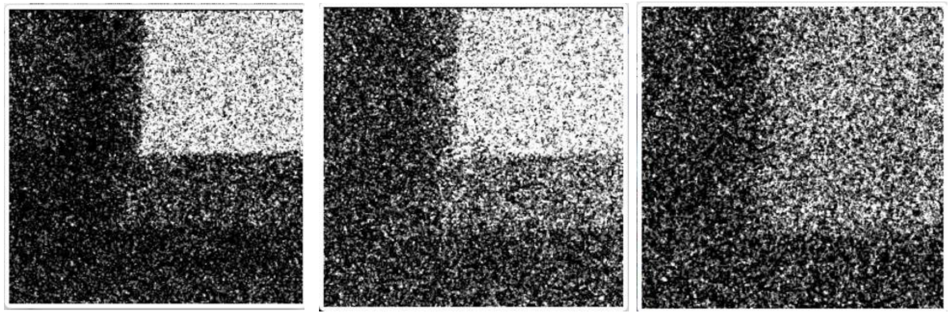
2021 Czech Republic Technology Category

Tracks of Pb ions as measured on SPS beam at CERN (rear-side glancing angular incidence about 4.1 degree) (left – low threshold; right – high threshold)

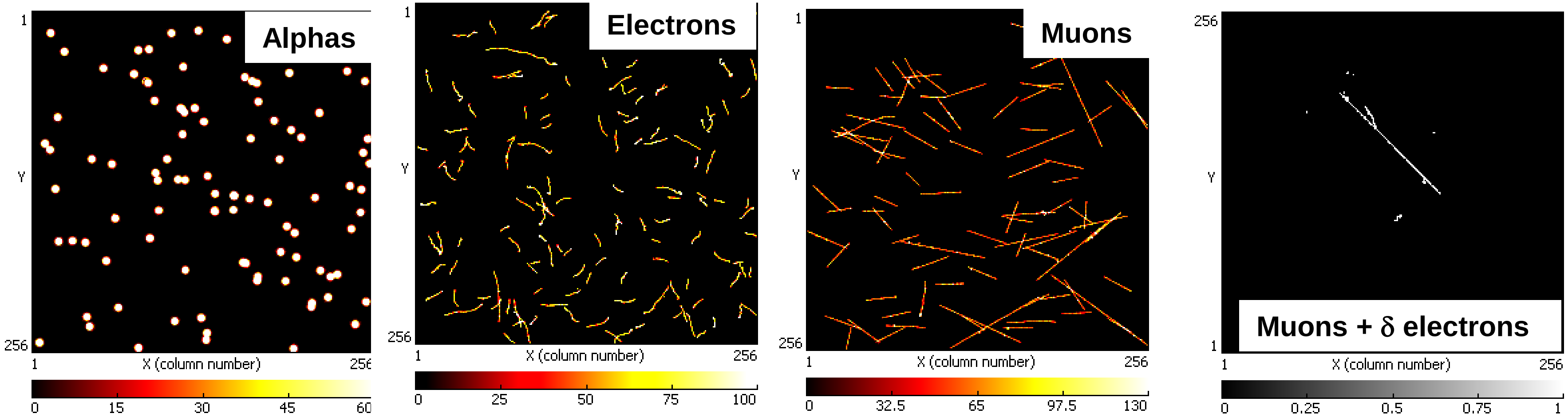


Responses to fast neutrons of different energies (in high threshold in counting mode)
In thermal neutron imaging spatial resolution ~ 400 nm

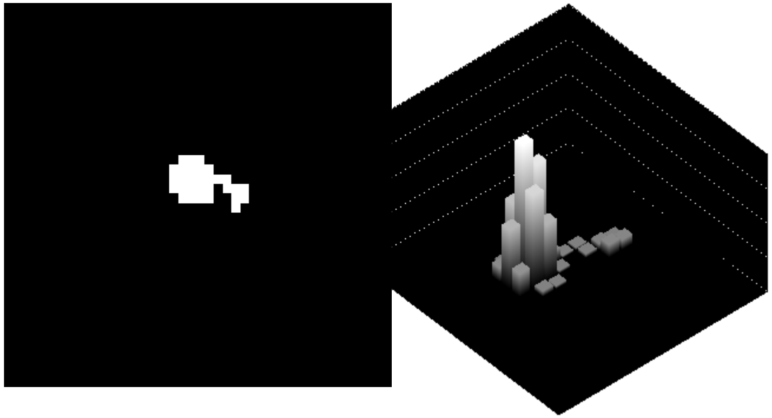




- Particle type identification (size, roundness, linearity,...)



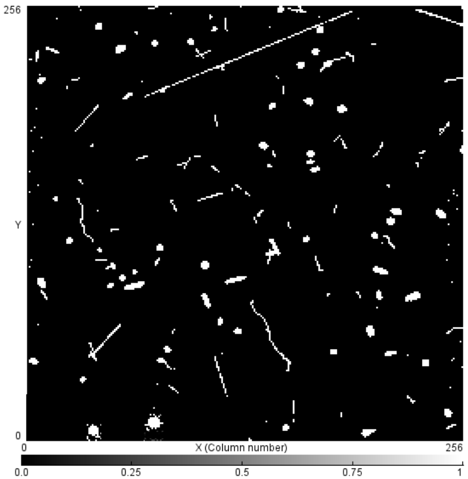
$$^{214}\text{Bi} \xrightarrow{\beta} {}^{214}\text{Po} \xrightarrow{\alpha} {}^{210}\text{Pb}$$



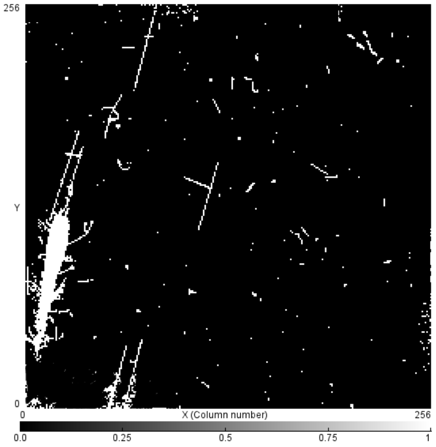
Timepix SATRAM/ESA Proba-V in Open Space
Quantum imaging detection/monitoring of space radiation

Low Earth Orbit (LEO), 820 km altitude

11.11.2013 12:39:17



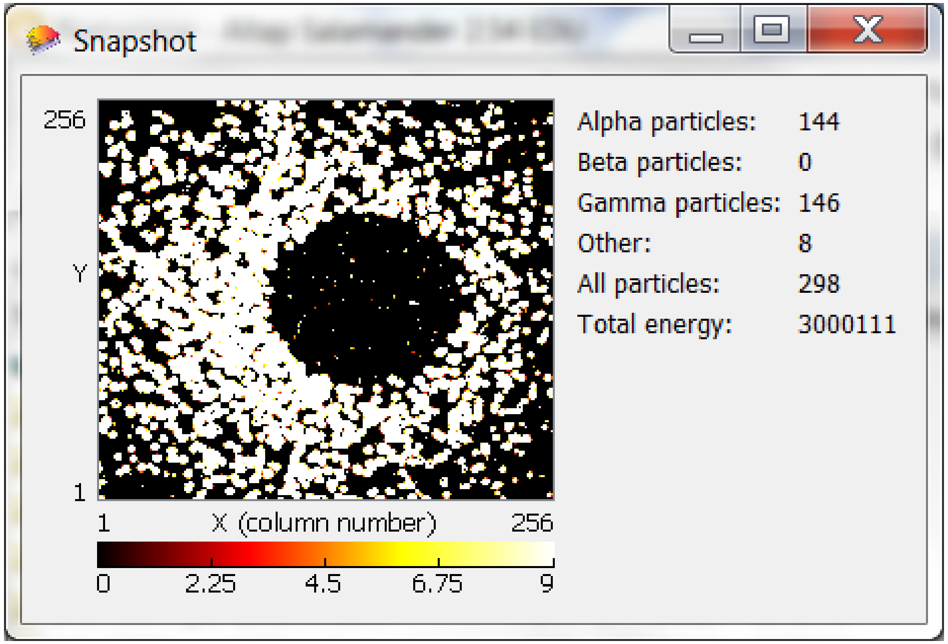
11.11.2013 11:16:59



2. ABSORPTION OF ALPHA PARTICLES IN WATER:

food-wraping foil

Droplet of water

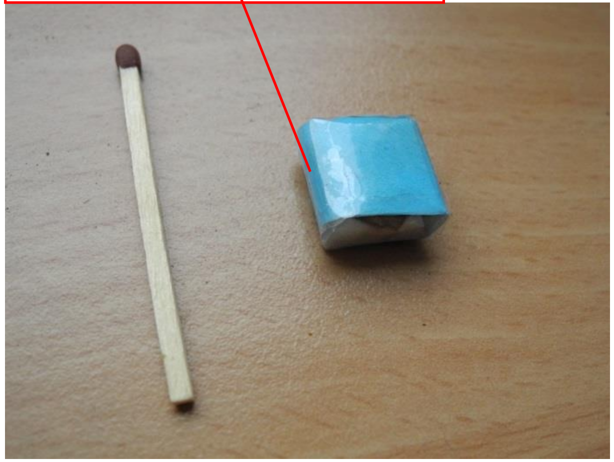


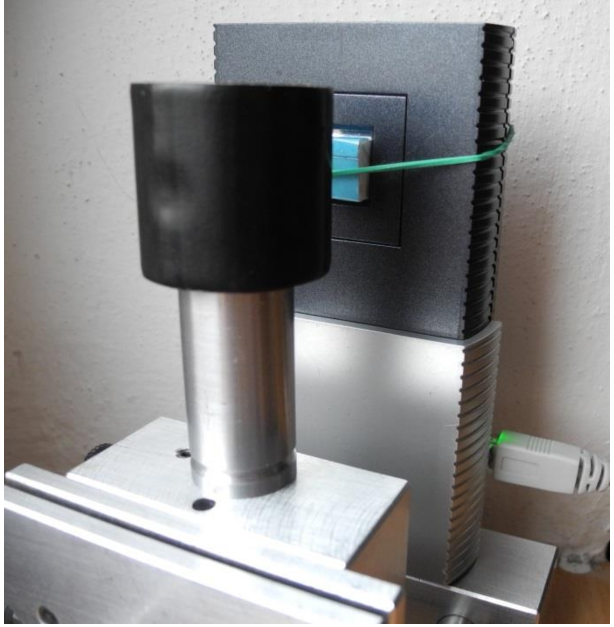
Alpha particles: 144
Beta particles: 0
Gamma particles: 146
Other: 8
All particles: 298
Total energy: 3000111

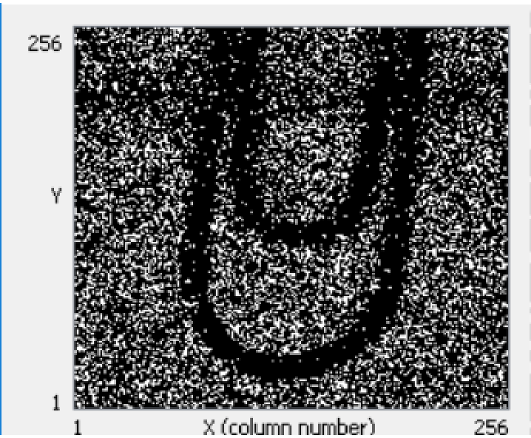
3. X-RAY RADIOGRAPHY:

What is hidden inside?

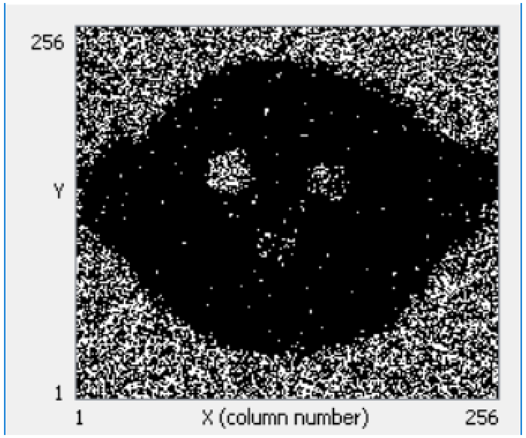
Block of expanded polystyrene foam



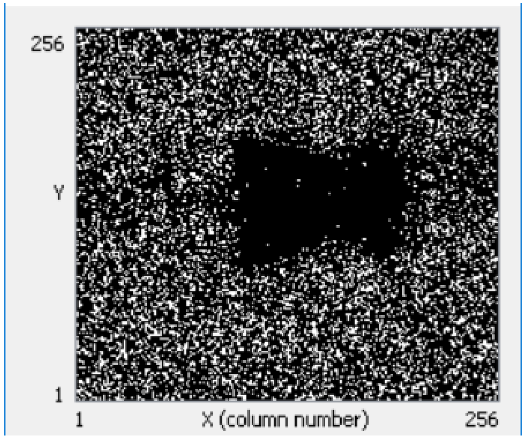




paperclip



smiley



airgun pellet