Highly efficient radon detectors

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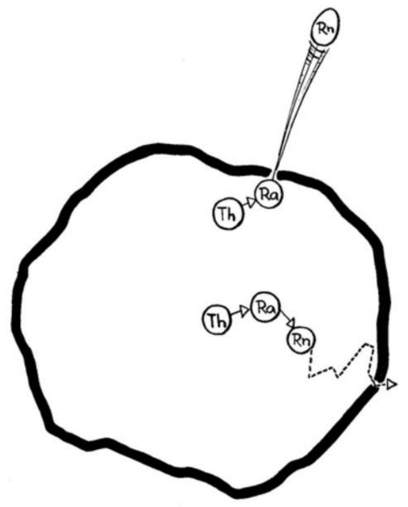
Radon and emanation

- Radon - noble natural radioactive gas with $T_{1/2}$=3.8 days. It does not mix with other gases and does not interact with them under normal conditions.
- It is characterized by high penetration and the ability to be adsorbed on various surfaces and materials.
- Widespread all over the world.
- Emanations - varieties of radon isotopes emitted by the mother isotope from various materials and substances as a result of radioactive decay.
- All natural emanations have a large chain of radioactive isotopes, which are heavy metals with lifetimes from the mks to tens of years with various types of emitted particles **(α,β,γ)** and an energy range from several eV to several MeV.



^{86}Rn $T_{1/2}$~3.8d
(222) Radon

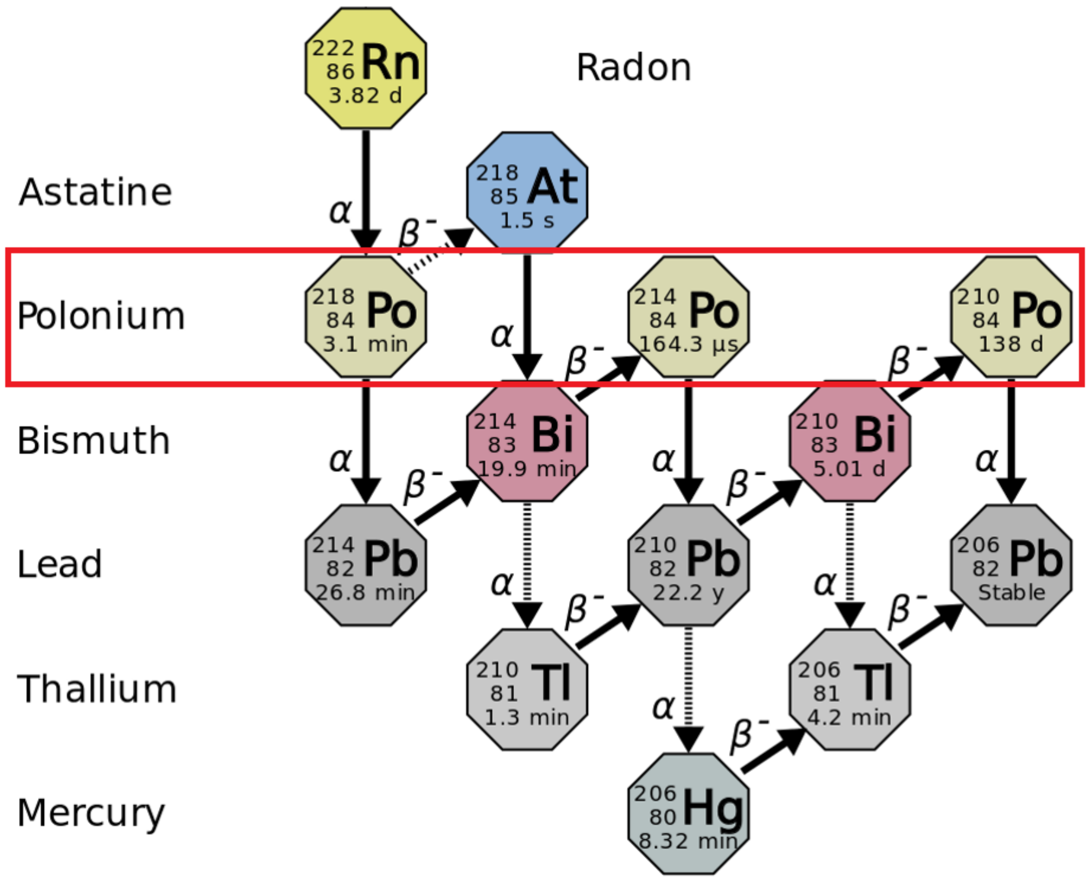
^{86}Rn $T_{1/2}$~55.6 sec
(220) Thoron

^{86}Rn $T_{1/2}$~3.96 sec
(219) Actinon

^{86}Rn $T_{1/2}$~35 ms
(218) Radon

Motivation of radon measurement

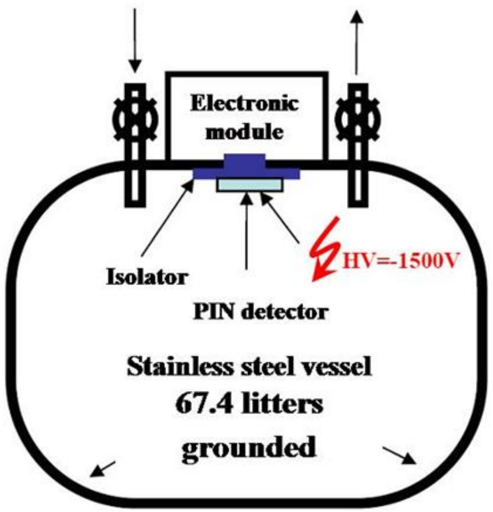
- Radon presents a serious danger for various experiments requiring a low background and the study of rare and ultra-rare effects (dark matter, dark energy, double β decay, CEvNS…) due to its long chain of radioactive decays in a wide energy range. In such experiments, in addition to various noise reduction measures, continuous measurement of radon levels is necessary. Special high-efficiency radon detectors and expensive facilities (cost more $1 million) are used for this purpose.
- Example experiments use precession radon detectors and facilities: XENONnT, Super-Kamiokande, LEGEND, EDELWEISS…
- The generally accepted level of radon content in such experiments is 1 mBq/m^3 and below.
- For example, the concentration of radon in an ordinary room is from 10 to 100 Bq/m^3, for a street about 10 Bq/m^3, in underground laboratories (without air purification) - from 100 to 100000 Bq/m^3.



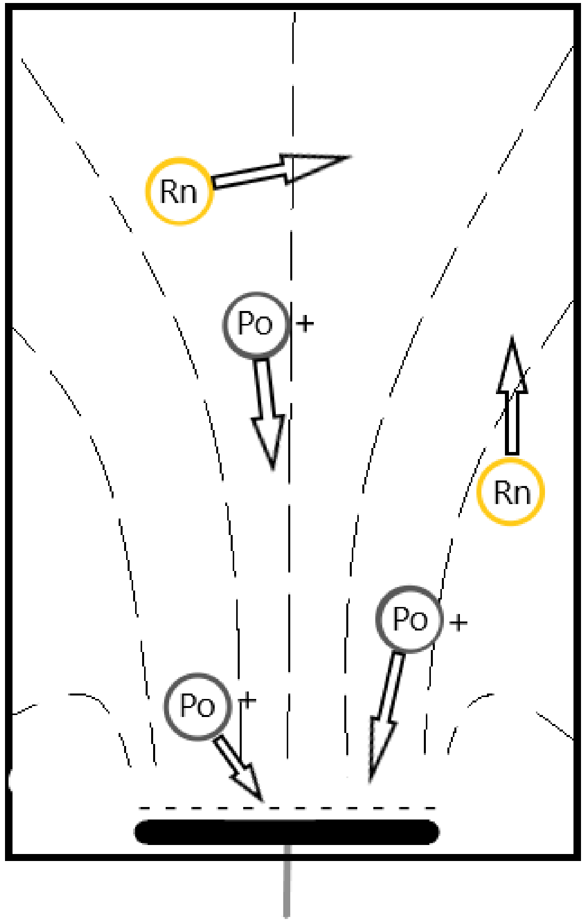
Radon decay chain

Highly efficient radon detectors

- A typical radon detector is a silicon P-i-N detector (undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region) inside a stainless steel vessel.
- Stainless steel vessel is used because of the low content of uranium and thorium in the composition (<1 mBq/kg). It is also corrosion-resistant, non-magnetic and durable.
- The volume of the vessel varies from several liters to cubic meters.
- A high voltage is applied to the detector to create a collecting field. The larger the volume of the camera, the more voltage is needed.
- Such detectors base on method of electrostatic collection of positively charged ions under the action of an electrostatic field created by inverse bias voltage on the negatively charged surface of the detector and registration of their alpha decay.
- This detectors have advantages: high performance, constant monitoring of radon levels, durability, operation in various conditions, relatively low-cost, simple of use and maintenance, measurement stability.

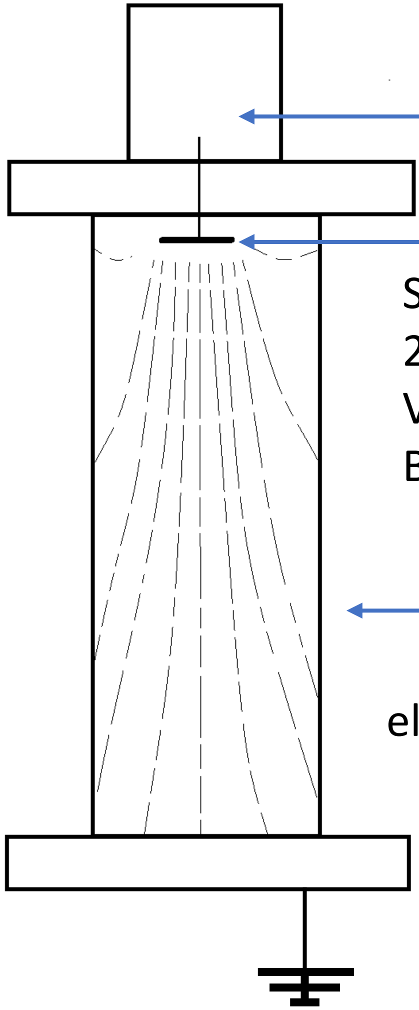


Scheme radon detector use at EDELWEISS experiment (MODANE, LSM)



Schematic description of the principle of electrostatic collection in a radon detector

Radon detector 5.8L

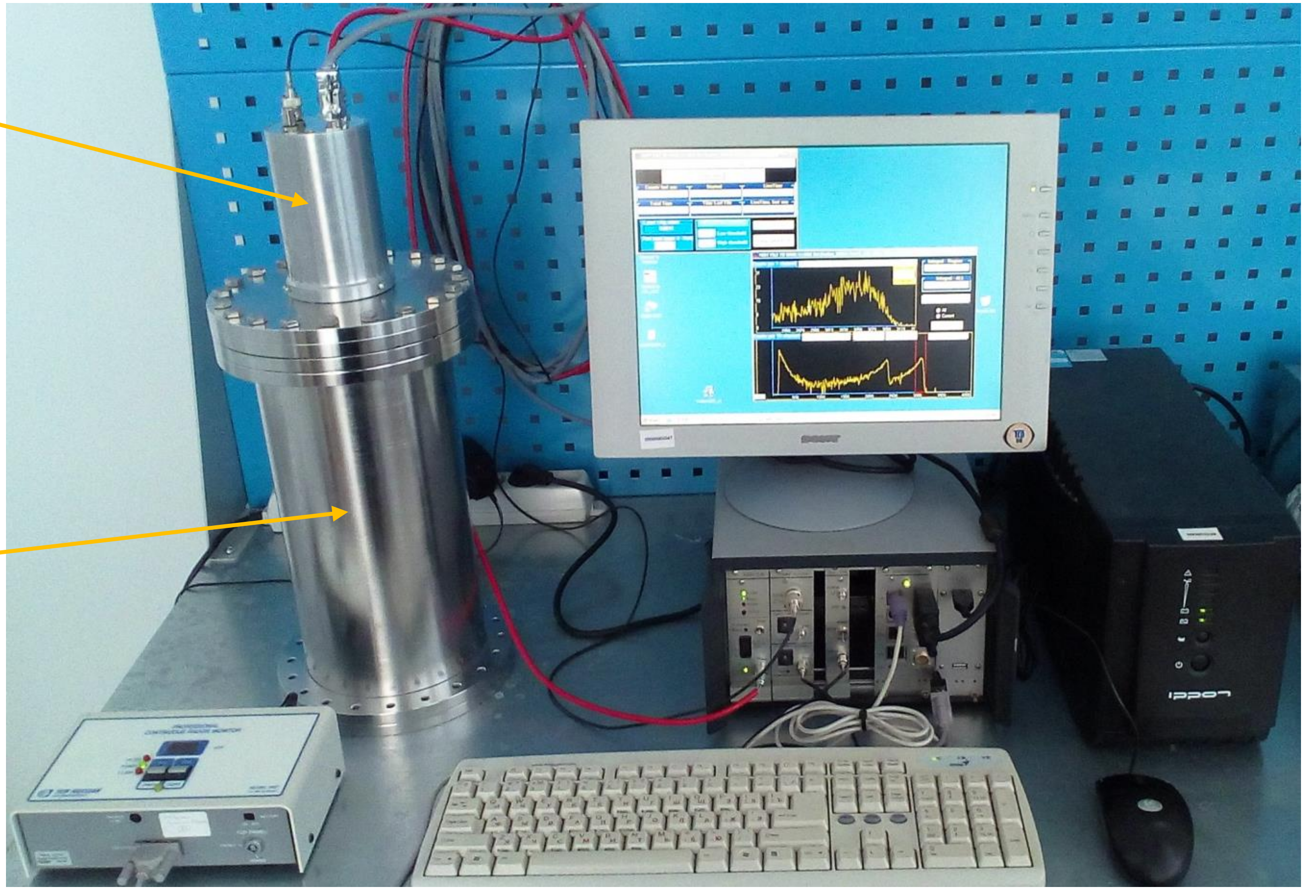


Preamplifier with a power supply circuit for the detector

Silicon P-i-N Detector
20x20 mm
Voltage: -1300V,
Bias voltage: -50V

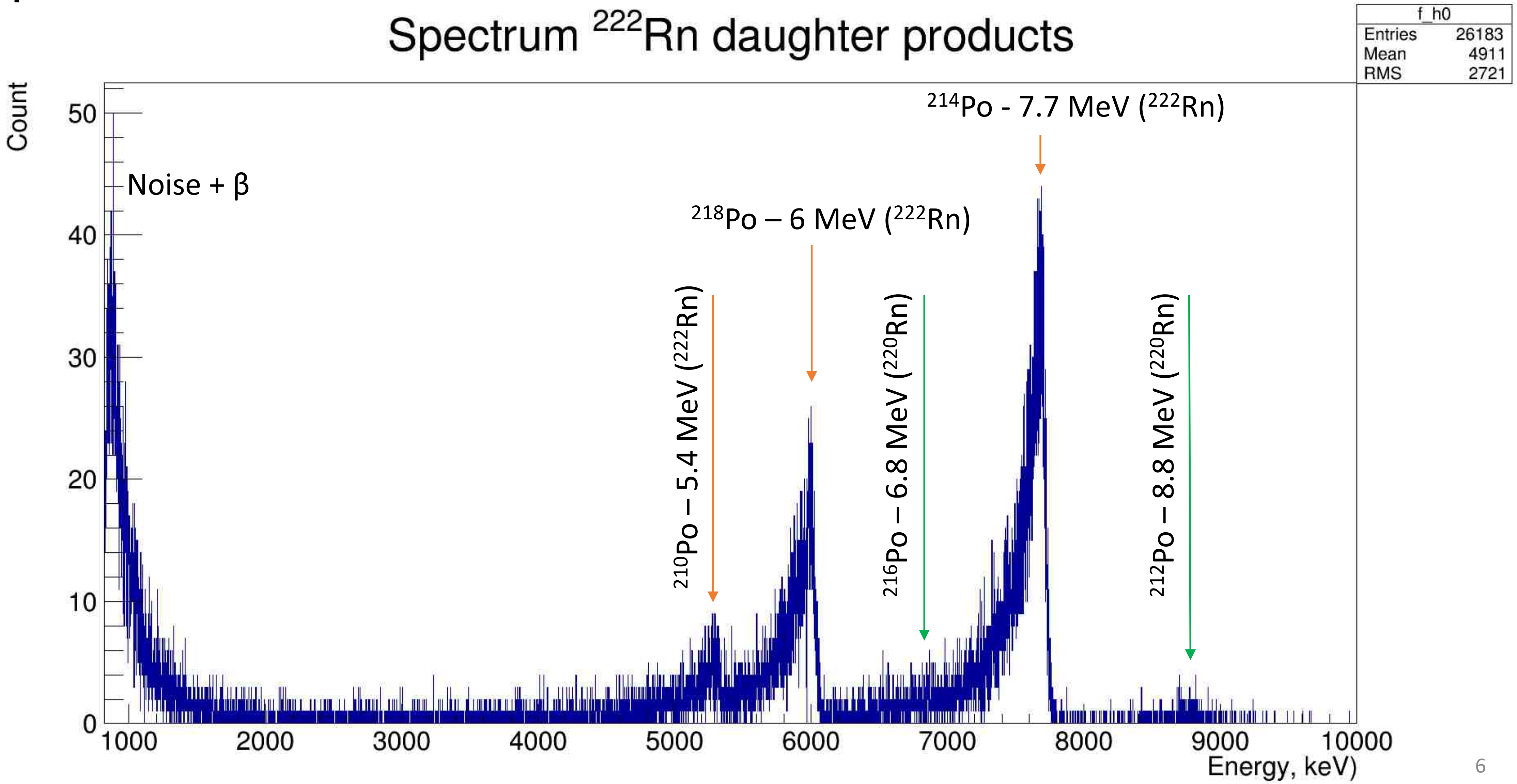
Detector chamber
Material: stainless steel 316L electropolished with the option of vacuuming

Detector case is grounded



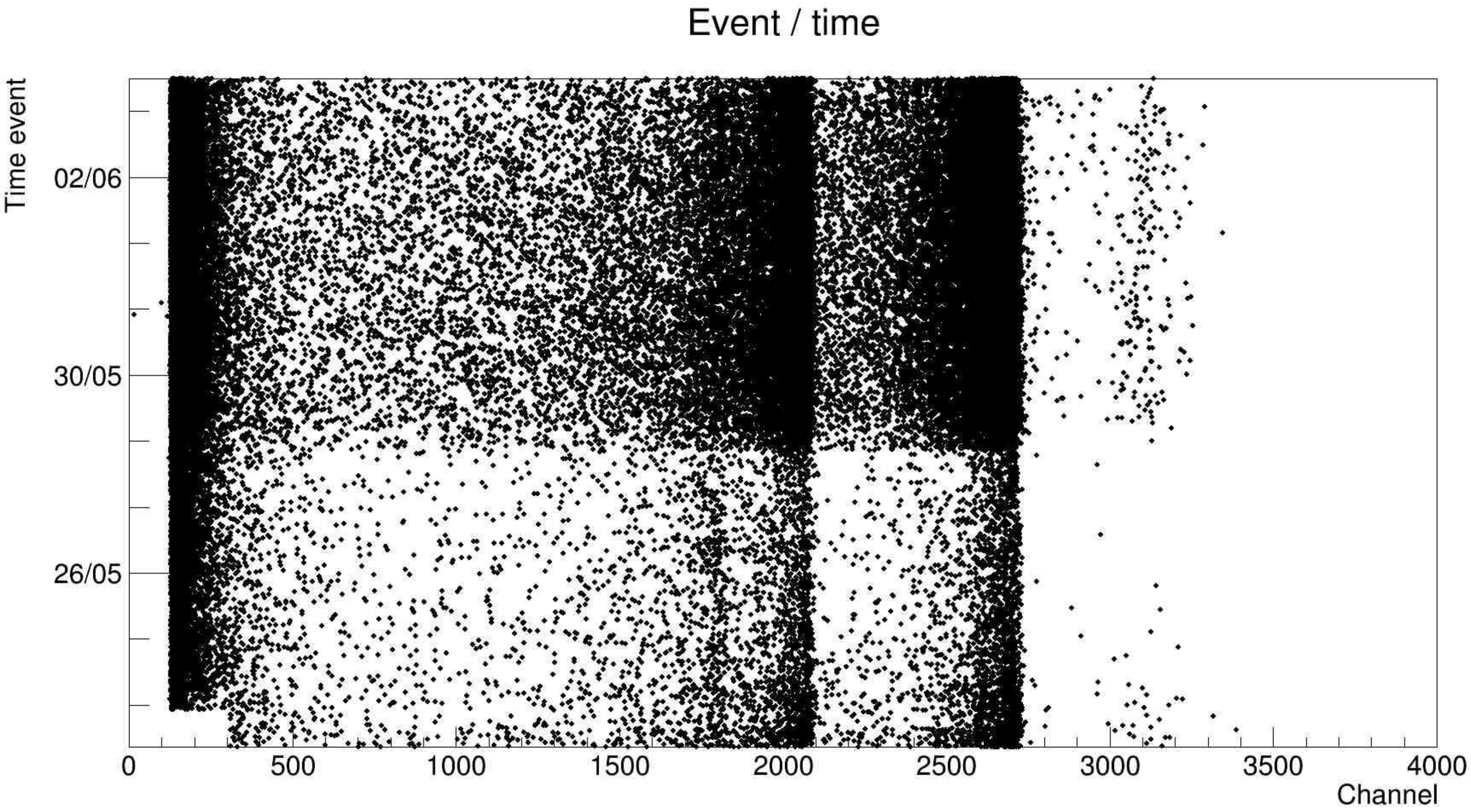
The radon detector 5.8 L.

Spectrum of Radon and Thoron daughter products



Monitoring stability of the detector

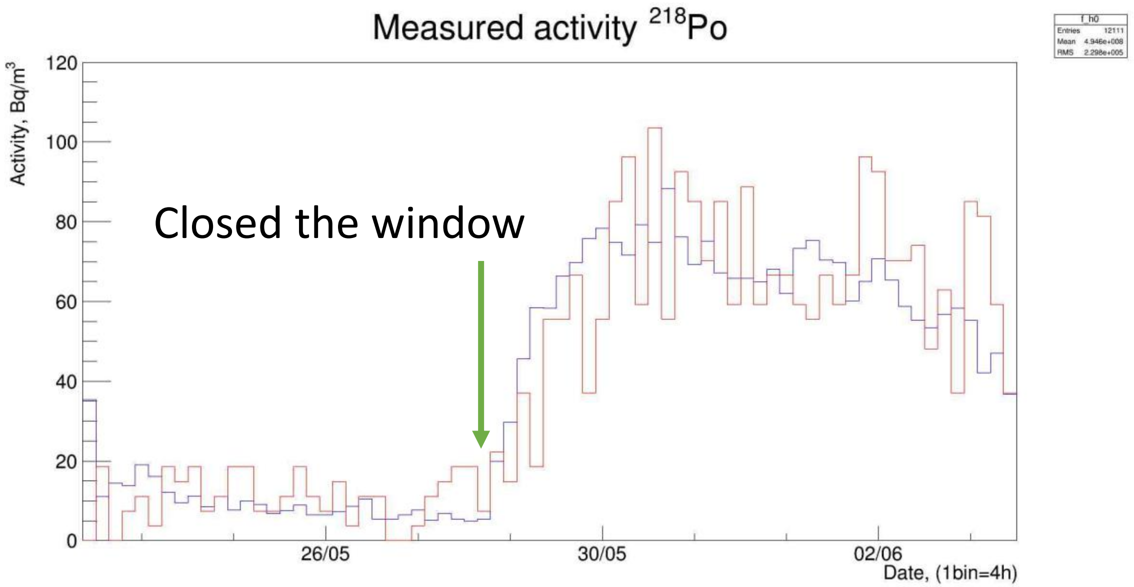
- Control the stability of the detector
- Promptly notice anomalies and shifts

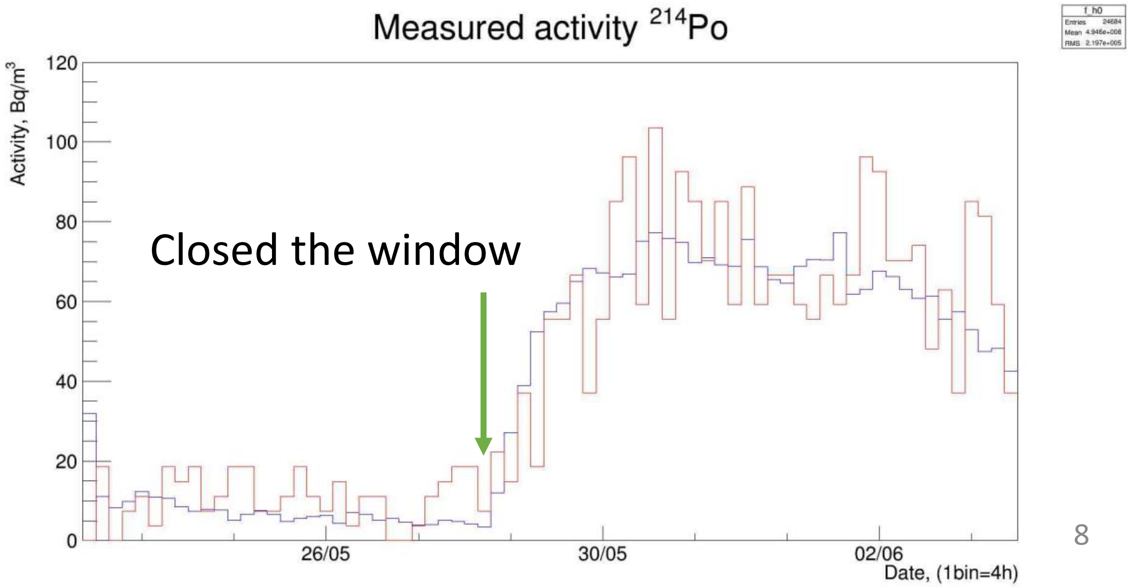


Monitoring Radon level in the room

- Monitoring the radon level in the room through registration of $^{218,214}Po$ and using a professional Radon monitor Sun Nuclear 1027
- Pre-calculated sensitivity level radon detector – **310 mBq/m³** (measure time 601700 sec)
- Sensitivity level SN1027 (passport data) – **3.7 Bq/m³**
- Detector has a higher sensitivity to radon than the professional radon monitor SN1027

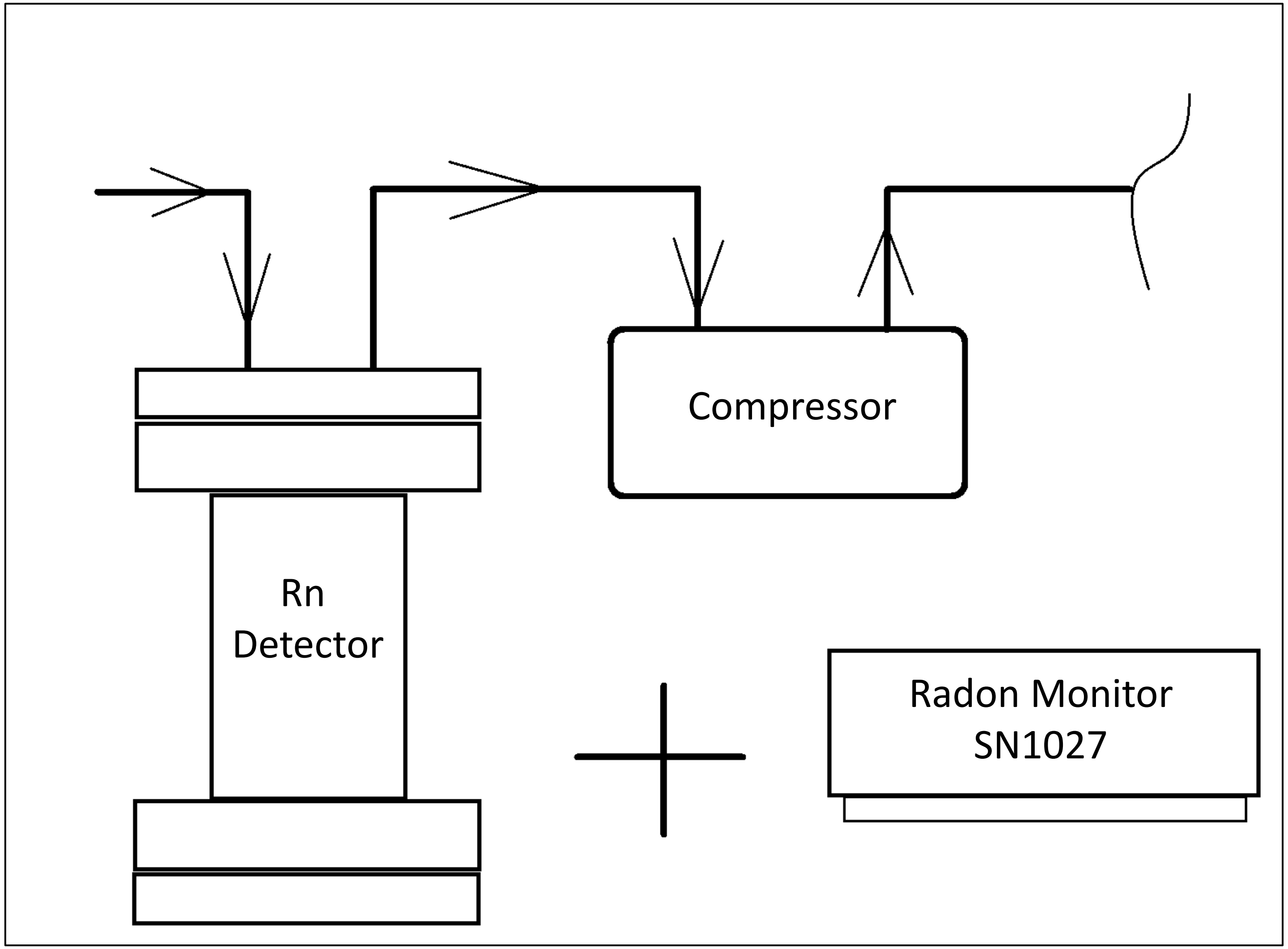
Blue line - 5.8 L Radon detector
Red Line - Radon Monitor SN1027





Measurement and calibration scheme

- The source for calibration detector is air
- The compressor located after the detector to eliminate the influence of the membrane on the radon concentration in the detector chamber
- The pumping speed is selected experimentally and equal to 0.65 L/min.
- For calibrated detector use professional radon monitor



Radon detector 0.9L

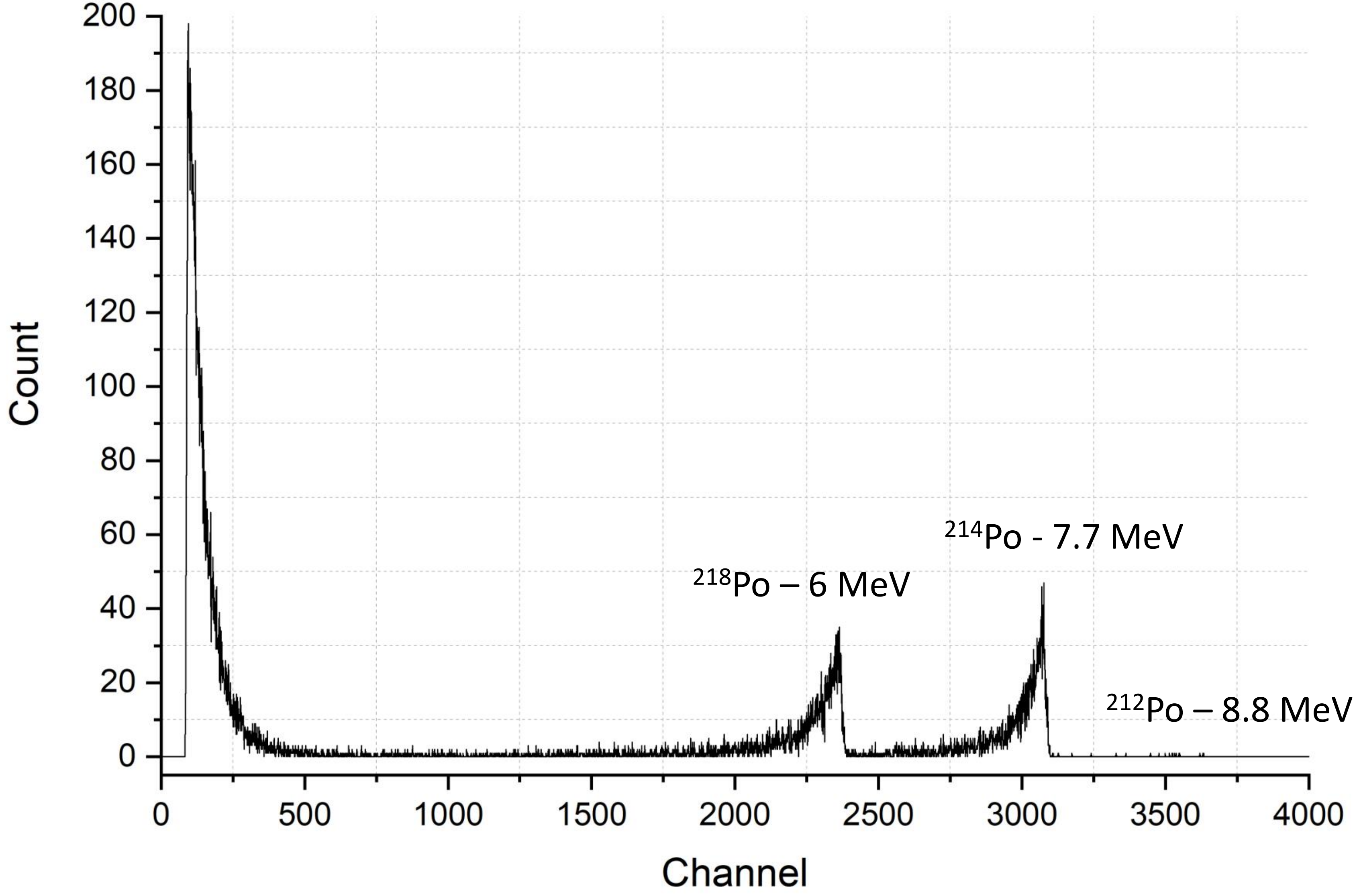
- The detector was developed based on the method of electrostatic collection of Radon daughter products.
- The main advantage of the detector is its compactness and mobility (important for underground low-background laboratories)

Detector parameter:

- Detector chamber is stainless steel 316L electropolished with the option of vacuuming with Internal efficient volume 0.9 L
- Registration element - Silicon P-i-N detector with a size of 20x20 mm
- Pre-calculated sensitivity level– **635 mBq/m³** (measure time – 24100 sec)

Radon detector 0.9L with SN1027

Radon spectrum from 0.9 L detector



Conclusion and future plans

Conclusion:

- Compact radon detectors with a volume of 5.8 and 0.9 liters based on the electrostatic collection method Radon daughter product have been developed and tested
- At this time radon measurements in the laboratory and detector tests are being carried out
- The sensitivity levels of the developed detectors are pre–calculated: for 5.8 L - 310 mBq/m^3, for 0.9 L – 635 mBq/m^3

Future plans:

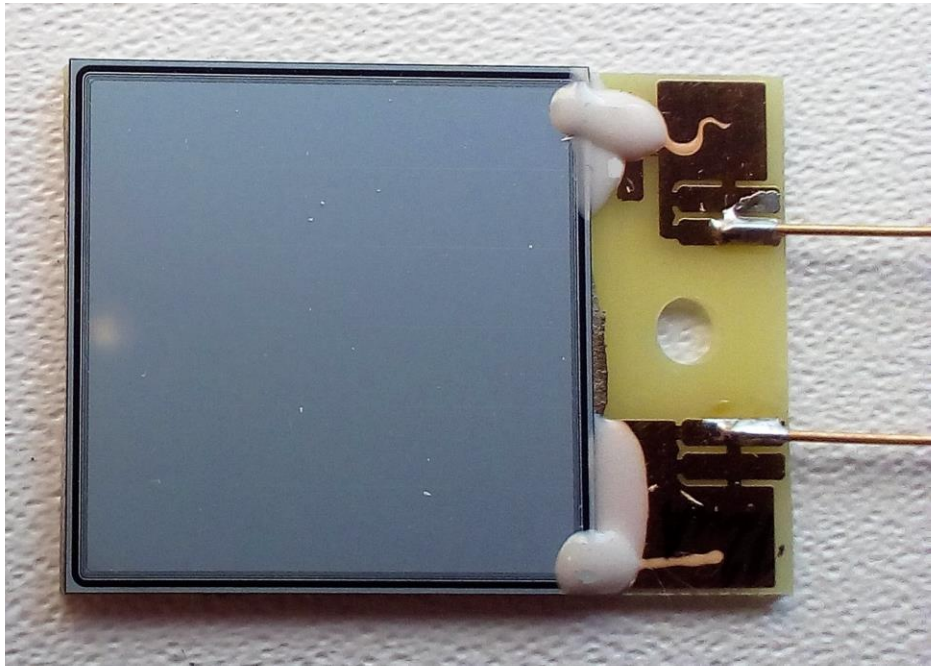
- Increase the sensitivity of the detectors less than 1 mBq/m^3
- The Application of the detector for monitoring radon level in the νGeN experiment aimed to search coherent elastic neutrino scattering and magnetic moment of neutrinos at Kalinin NPP .
- Measurement of radon emanations for various materials

Thanks for your attention!

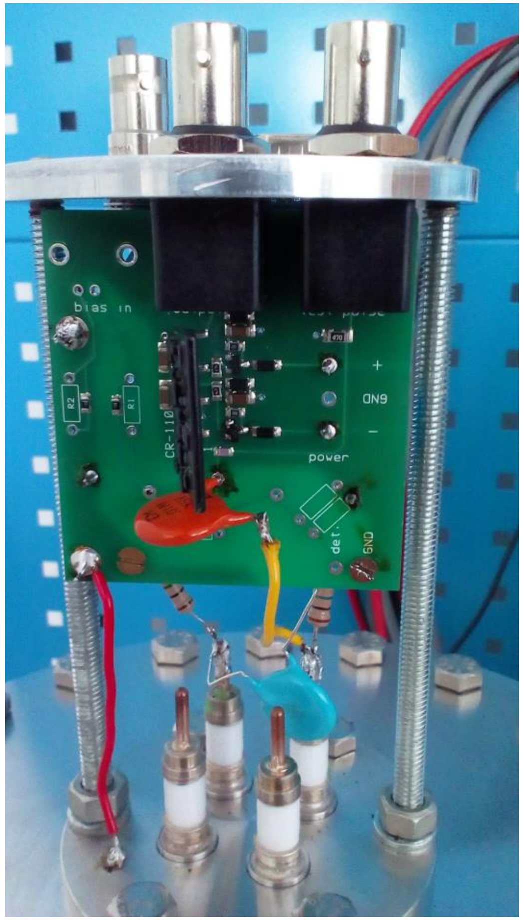
Have a nice evening to all present!

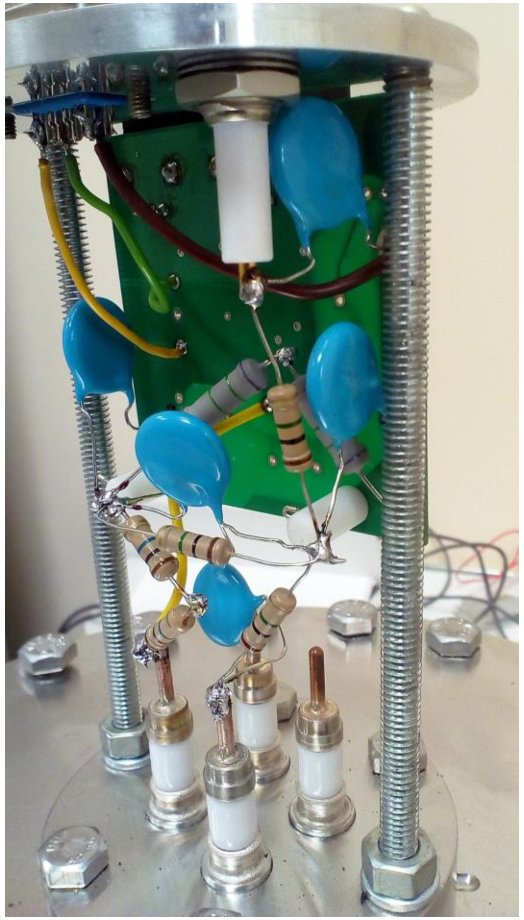
Backup

Setup 5.8 L Radon Detector



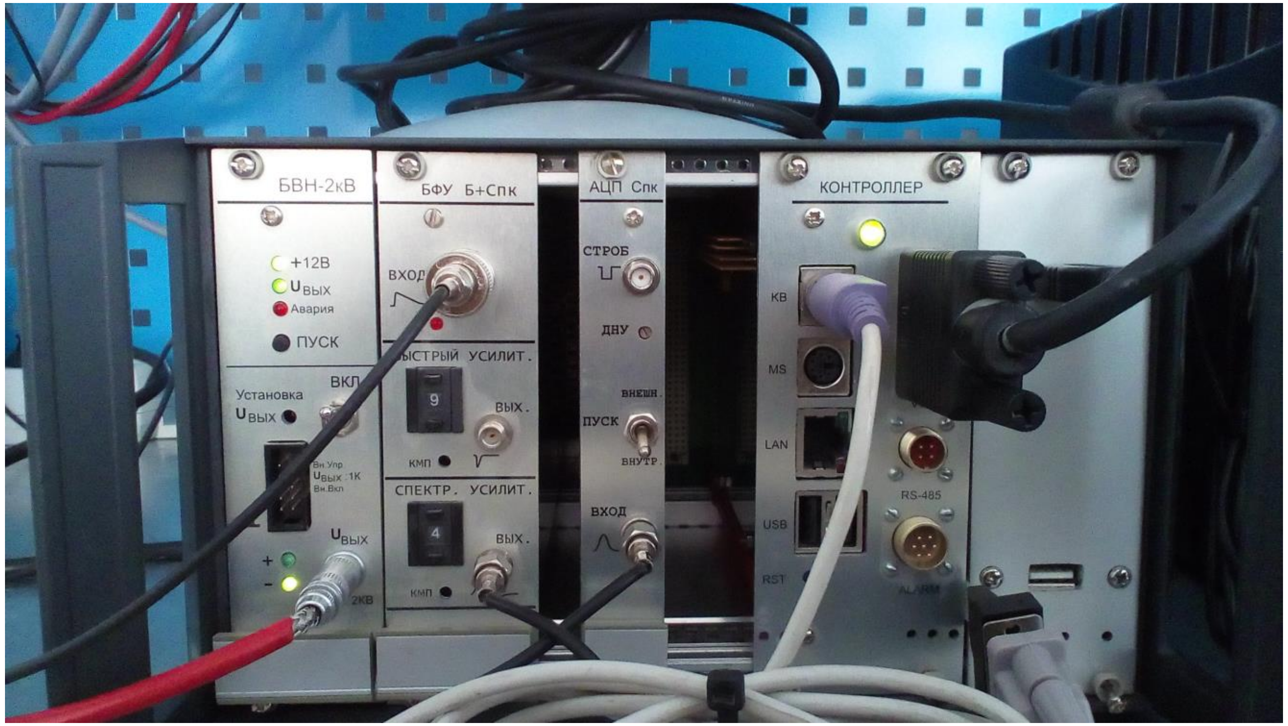
Silicon 20x20 mm PIN - detector





Preamplifier based on Cremat 110 (Charge Sensitive preamplifier Module) and power supply circuit

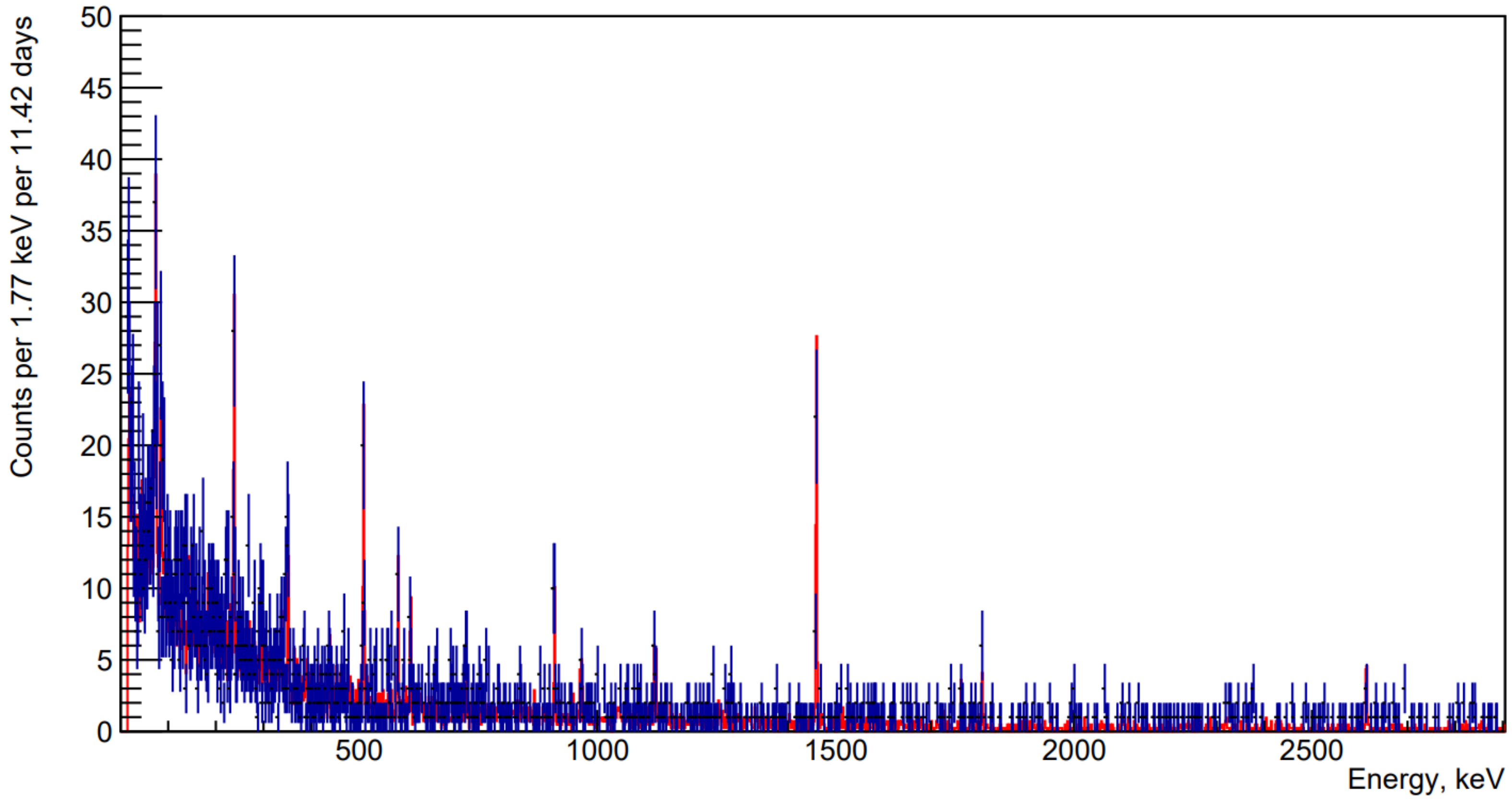
Radon data collected setup for 5.8 L



Mini PC based on Vortex86DX core with HV source and ADC

Radiation Purity of Ultimaker Nylon for 3D Printing

Measurements by gamma spectroscopy on the Obelix HPGe detector (Modan)



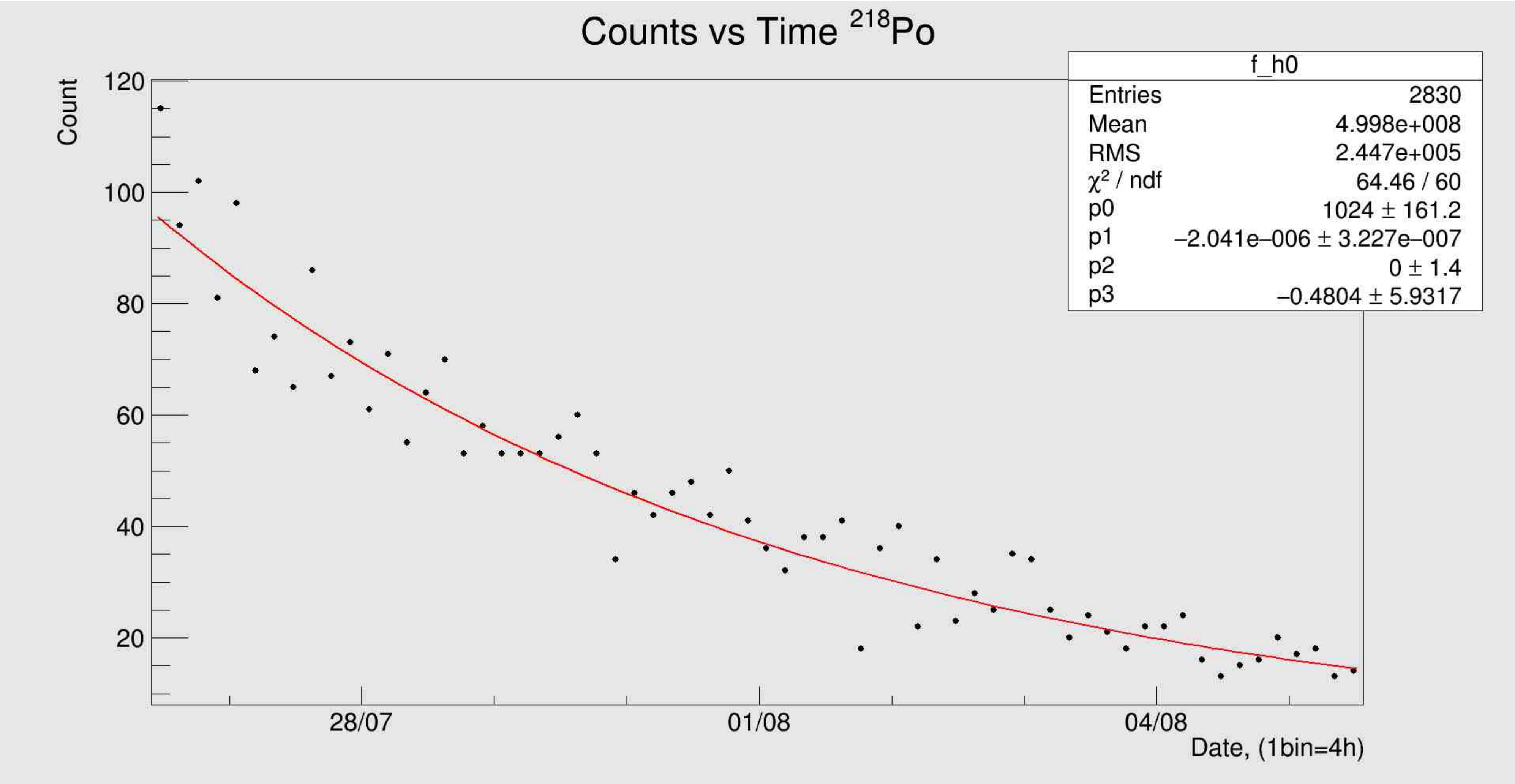
Measurement time– 986600 sec
For Line 583 keV (^{208}Tl):

Isotope	BGR, cpd	Nylon, cpd	Different, cpd
^{208}Tl	0.59±0.11	0.88±0.28	0.29±0.30

The specific activity of ^{208}Tl is less 0.15 mBq/g.

The difference between the other lines and the background is minimal.

Radon decay curve



Experimental decay curve ^{222}Rn. Fit exp + pol0

Calculate sensitivity Radon detector

Calibration factor

C_F[(counts/day)/(mBq/m^3)] = (measured ^{214}Po signal rate) / (^{222}Rn concentration) (1)

Level limit registration

L_c[mBq/m^3]= 1,64 δ_{BG}[counts/day] /C_F[(counts/day)/(mBq/m^3)] (2)

δ_{BG} – Background count to 24 h.

Calculated radon emanation

Activity emanation Rn

Emanation rate E (Bq/s) $E = \frac{N \ ln2}{86400 \times \varepsilon \times T_{½}(Rn)}$ = Bq/s

Activity emanation to mass

Mass emanation rate E_m(Bq/kg/s) with m in kg

$$E_m = \frac{N \ ln2}{86400 \times \varepsilon \times T_{½}(Rn) \times m} = \text{Bq/kg/s}$$

Activity emanation Rn on surface material

Surface emanation rate E_s (Bq/m^2/s) with S in m^2

$$E_s = \frac{N \ ln2}{86400 \times \varepsilon \times T_{½}(Rn) \times S} = \text{Bq/m}^2\text{/s}$$

Mass of materials	kg
Surface of materials	m^2
N the counting rate Measurement of counts Rn detector	(counts/day)
half-life of $T_{½}$ (Rn)	s (330 019 200)
ε the efficiency of Rn detector	30%
Temperature	+21… +25°C