



The Multigap Resistive Plate Chambers – a novel approach to the positron emission tomography



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Physical limitations of PET

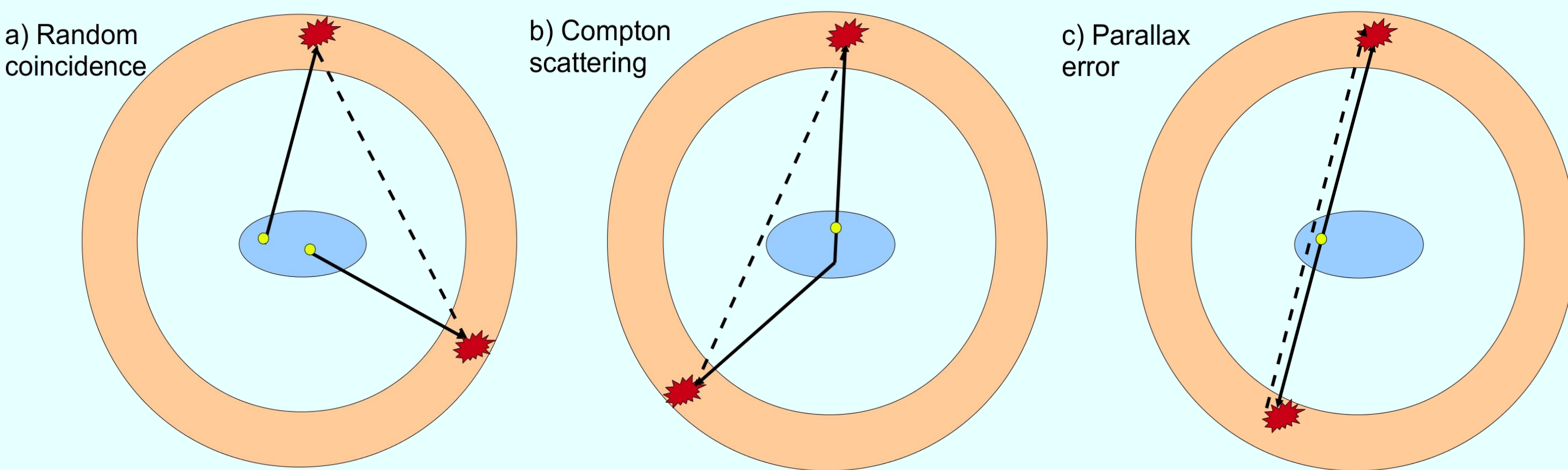
Positron Emission Tomography (PET) is a nuclear-medicine imaging technique for registration of the whole-body distribution of positron-emitting biomarkers.

Several processes are responsible for physical limitations of PET:

• **Random coincidence.** If gammas from two different annihilations are detected by PET, spurious line will be reconstructed. Increasing the detector time resolution will decrease the probability for simultaneous detection of two gammas from different annihilations.

• **Compton scattering.** The gamma may scatter in the medium. That leads to wrong LOR reconstruction. The detector should suppress the Compton scattered gammas. The standard solution is to measure the photon energy and to perform a cut. Thus good detector energy resolution is needed.

• **Parallax error** depends of detector spatial resolution. Detectors with high spatial resolution are needed.



PET/MRI

PET scan gives information about the density distribution and metabolism of the biomarker but does not provide a clear anatomical framing which is envisaged within hybrid imaging modalities, e.g. with computed tomography (PET/CT) or magnetic-resonance imaging (PET/MRI), the latter being considered by many experts as the optimal diagnostic combination to become a real breakthrough in the clinical practice. The main problem in the PET/MRI system is the sensitivity of the traditionally used photomultiplier tubes to magnetic fields. A prospective PET candidate for a hybrid PET/MRI system should be insensitive to strong and fast varying magnetic fields, as are SiPM and dSiPM. Another attractive possibility are the modified Resistive Plate Chambers.

What are Resistive Plate Chambers

Resistive-plate chambers (RPC) are gaseous parallel-plate charged-particle detectors with plate resistivity of about $(10^{10} \pm 10^{11}) \Omega \text{cm}$ that are widely used in large-scale high energy physics experiments. Choosing appropriate materials for one or both of the electrodes transforms them into gamma-to-electron converters, which in turn modifies RPC into a gamma-quanta detector. Transforming the resistive plate chambers from charged-particle into gamma-quanta detectors opens the way towards their application as a basic element of a hybrid imaging system, which combines positron emission tomography (PET) with magnetic resonance imaging (MRI) in a single device and provides non- and minimally- invasive quantitative methods for diagnostics.

Why use Resistive Plate Chambers in PET

The decisive RPC advantages from a PET point of view are:

- excellent time resolution (20 ps time resolution reported for charged particles is reported in the literature);
- sub-millimeter spatial resolution;
- absence of parallax error;
- insensitivity to strong and varying magnetic fields, which ensures compatibility with MRI;
- effective Compton-scattered photons suppression without energy measurement;
- possibility for building detectors with a large field of view (FOV);
- substantially lower price in comparison to the crystals.

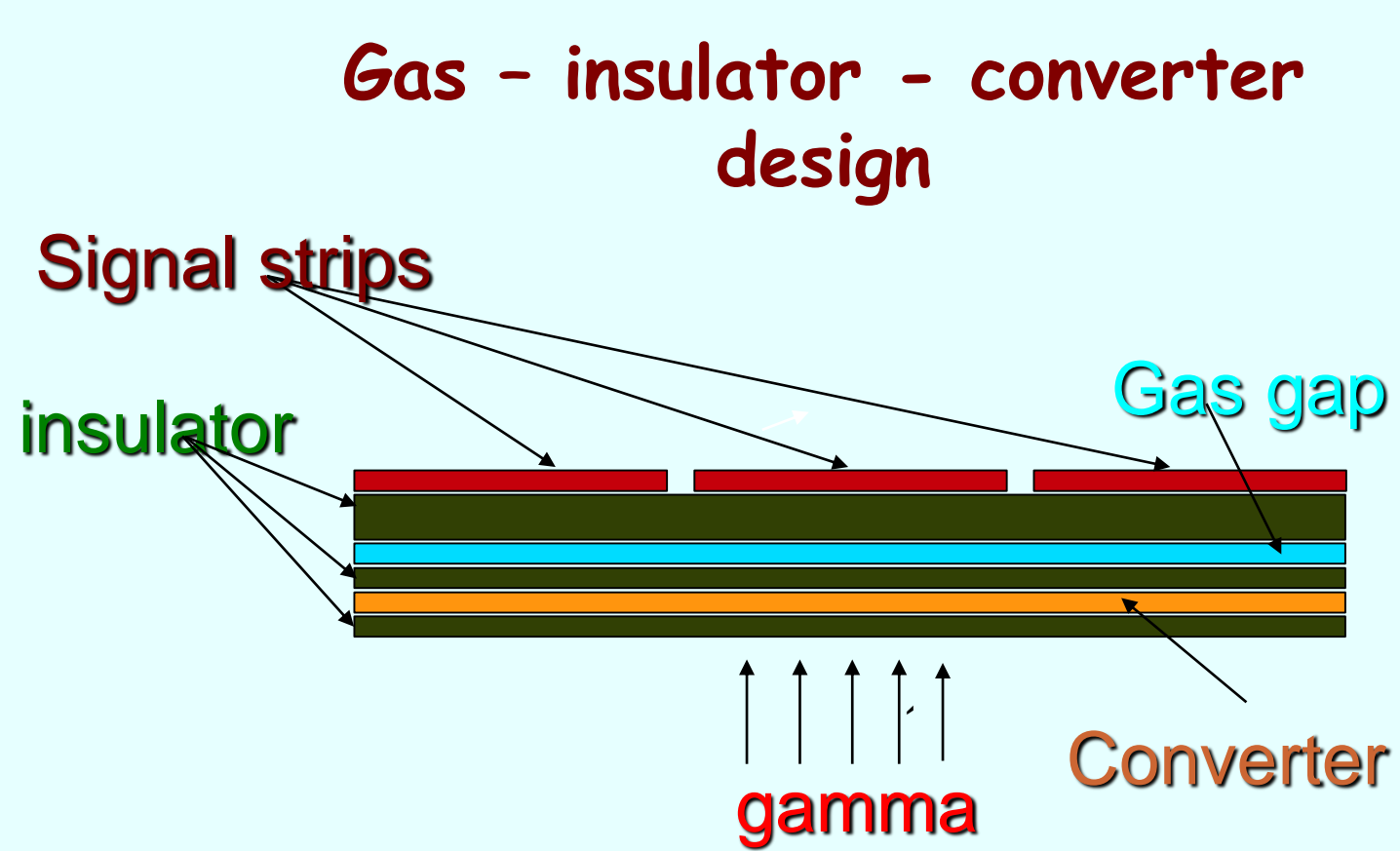
Why time resolution is so important

The excellent RPC timing resolution opens the possibility to measure photons Time of Flight (ToF). The ToF information constrains the positron annihilation position to a few millimeters region on the LOR, thus enhancing the image reconstruction and essentially patient's dose – up to ten times without image quality loss, according to the estimates. The ToF information helps also for Compton suppression. Thus the RPCs with their exceptional time resolution are suitable for ToF PET.

Main R&D goals

- * efficiency increase.
- * suppression of Compton-scattered photons.
- * achievement of an excellent time resolution, suitable for photon ToF measurements.

RPC design and simulations



GEANT4 based simulations of the efficiency of the RPC photon detectors with different converter materials and geometry were conducted for optimization of the detector design. The results justify the selection of a sandwich-type gas-insulator-converter design, with Bi or Pb as converter materials. The design ensures Compton suppression and good efficiency for 511 KeV photons. To increase further the efficiency a multi-gap design is chosen.

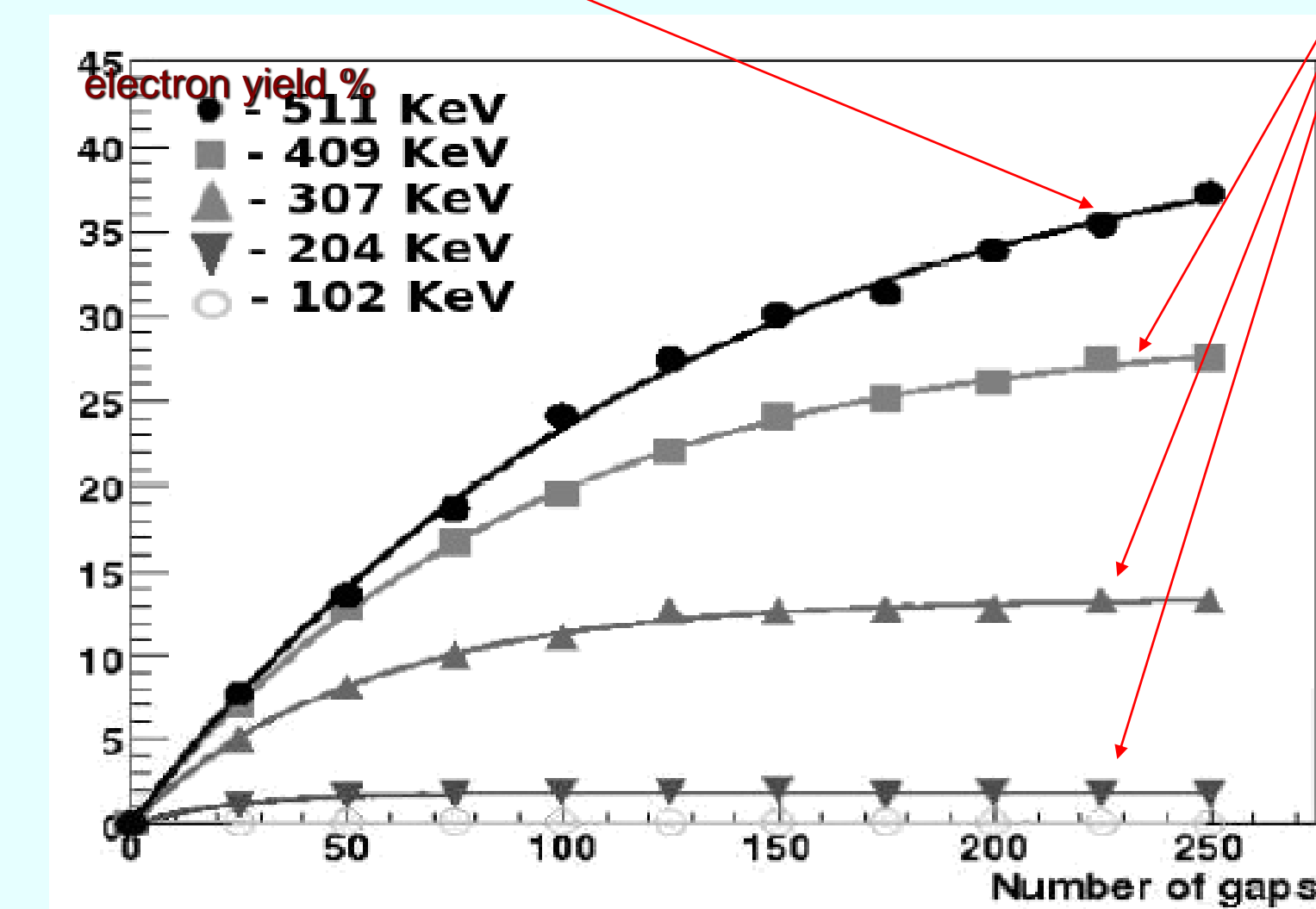
Multi-gap GIC design



MC simulation results

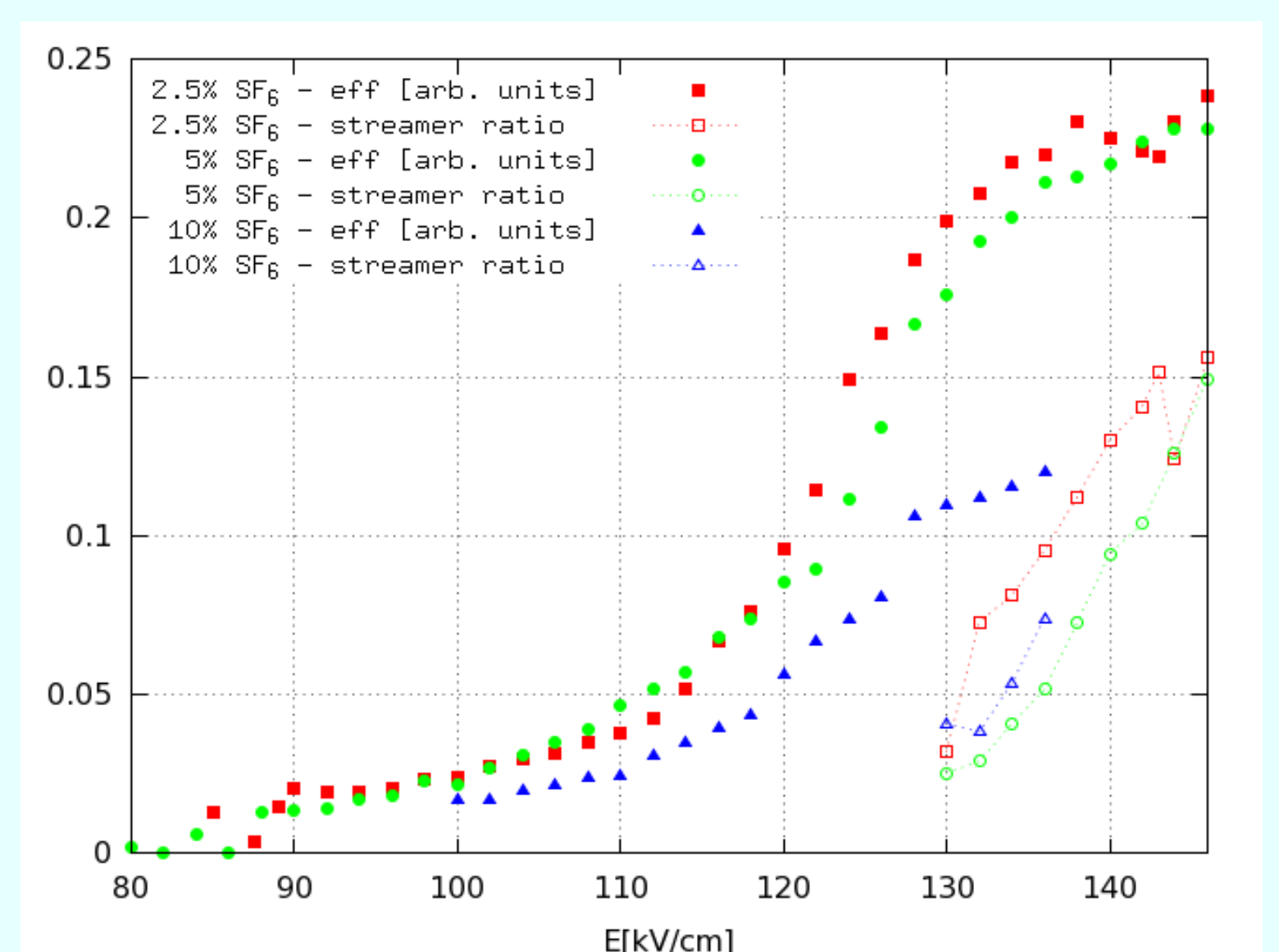
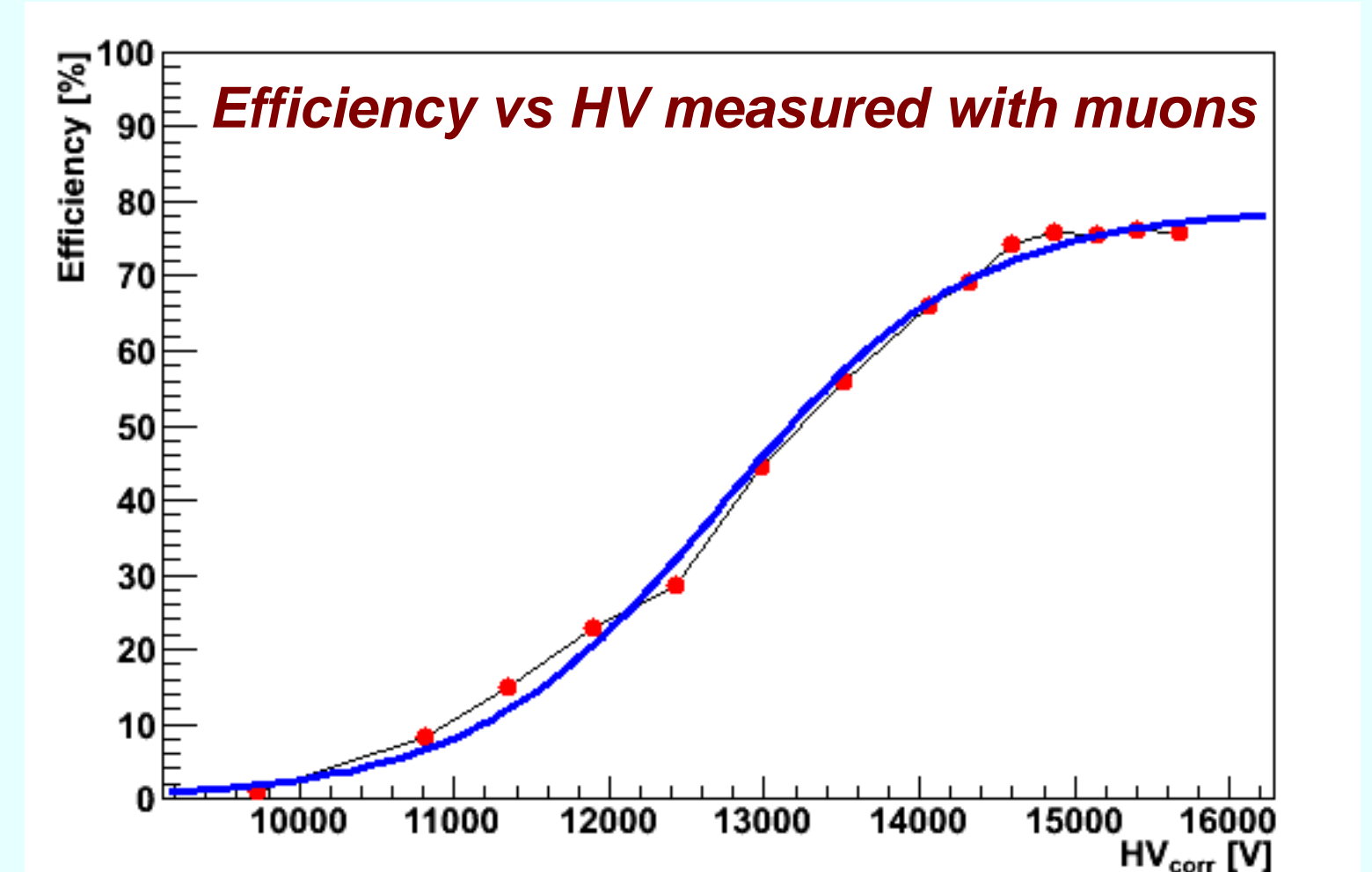
The Compton suppression is evident from the plot. The electron yield depends from the number of the gaps in the multigap design.

Efficiency for 511 keV & Compton suppression

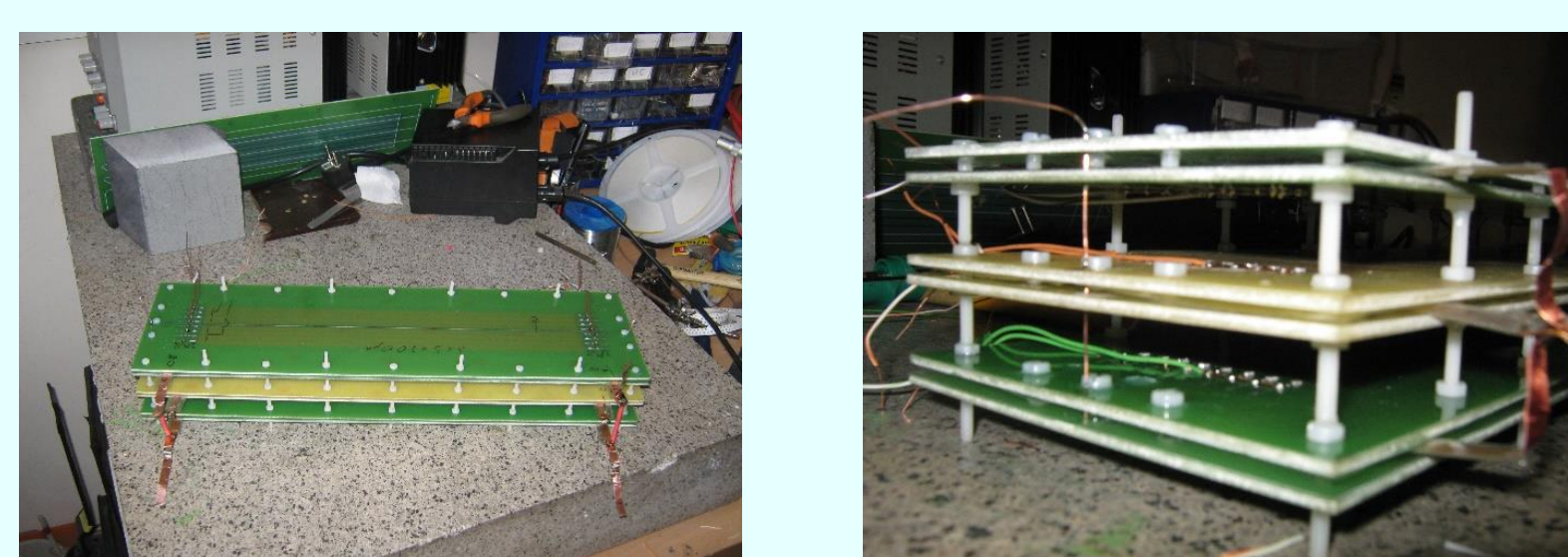


Results

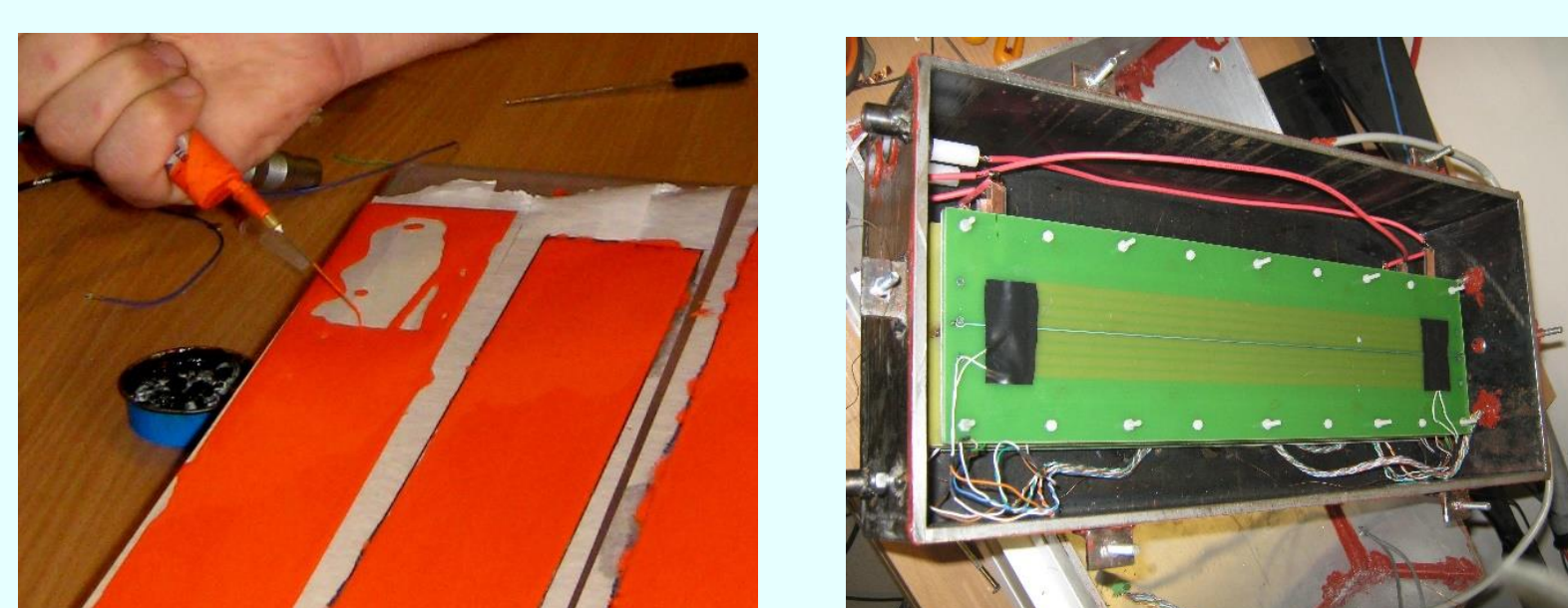
Several prototypes have been build and tested with ²²Na source. The efficiency of six gap GIC RPC prototype for 511 KeV photons is $(0.9 \pm 0.1)\%$ and the value is in a good agreement with the simulation results.



Detector prototypes



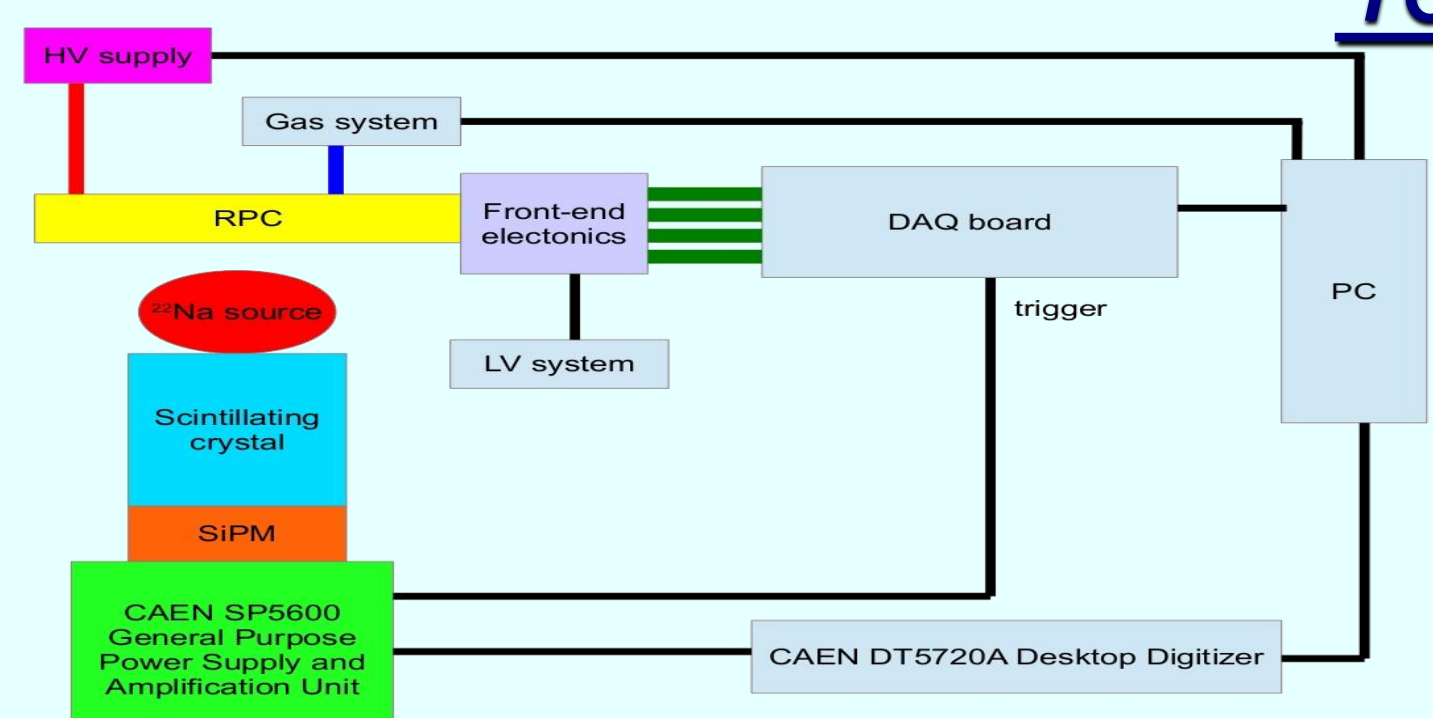
3 multigap prototypes in a stack



Converter „painting“

Prototypes ready for the test

Test Setup



References

- 1.N. Ilieva et al., AIP, 2009; 978-0-7354-0740-4/09, pp 820-825
- 2.G. Georgiev et al., JINST 8 (2013) P01011; doi:10.1088/1748-0221/8/01/P01011