LEARNING PARTICLE PHYSICS USING TIMEPIX-BASED PIXEL DETECTORS AT CERN S'COOL LAB

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Hybrid Pixel Detectors

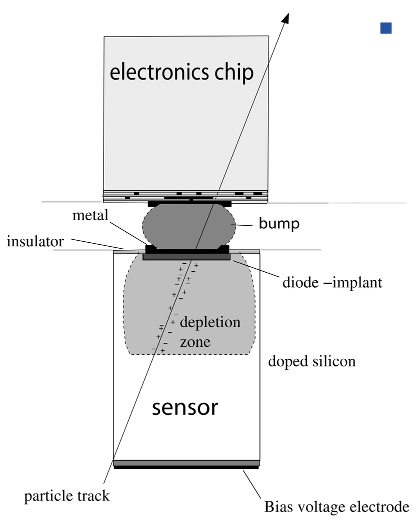
MX-10 particle camera, Timepix-based product from Jablotron

The Timepix electronics chip series

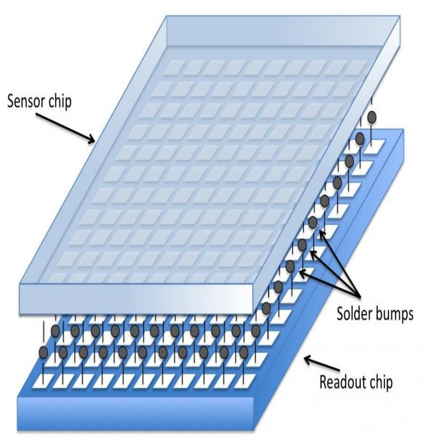
- Technology transfer from particle physics to new fields like medical applications
- Developed within the Medipix2 Collaboration hosted at CERN since 1999 [1]
- Hybrid assembly: segmented silicon sensor bump-bonded to the electronics chip
- 256 x 256 pixels, measuring 55 x 55 µm^2, sensitive area: 1.4 x 1.4 cm^2
- Different measurements modes per pixel: counting, deposited energy, arrival time
- Minimum threshold energy is configurable: robust to noise, large detection range

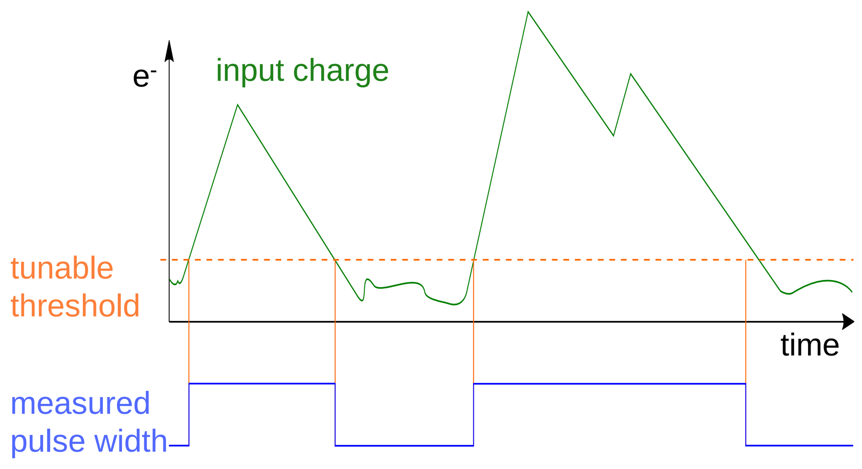
Detection Principle

- Ionising radiation frees electron-hole pairs in the depletion zone of the silicon.
- The charges are collected through an electrical field, converted into voltage pulses and digitalized by Timepix (depending on the sensor either electrons or holes).
- The duration of the pulse is measured per pixel in energy mode.
  Energy range per pixel after calibration with known sources of ionising radiation: ~4 keV up to several MeV



Cross section through one pixel with particle track [2]





S'Cool LAB Concept and Aims

Hands-on particle physics learning laboratory

- Out-of-school learning place with target group: students age group 16-19
- International audience from more than 20 countries
- Independent experimentation in small groups

200 m^2 modular laboratory space at CERN

- state-of-the-art IT equipment incl. videoconferencing
- high-tech equipment in the framework of 14 experiments linked to particle physics and CERN's scientific programme and technologies [3]

Test bed for physics education research

- iterative re-design of workshops, experiments, and student worksheets
- accompanying research on students' conceptions
- accompanying research on preparation of students

AIMS

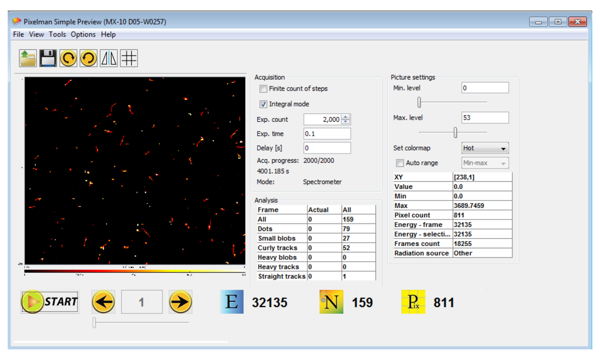
Give an insight into the working methods, technologies, and research of the world's largest particle physics laboratory

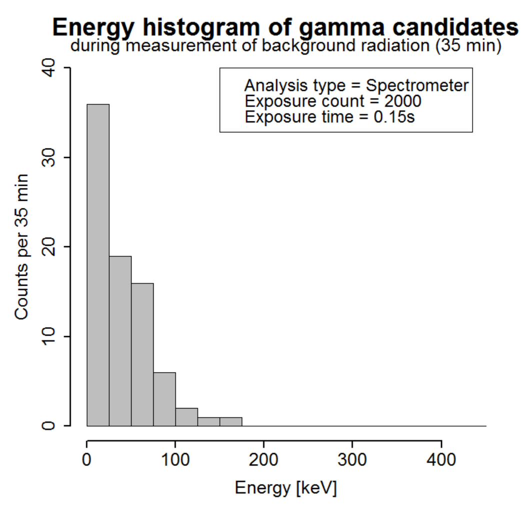
Make CERN's physics and technologies understandable for students through hands-on experimentation

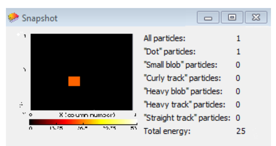
Examples of possible experiments tested with the MX-10 Detector

Background Radiation

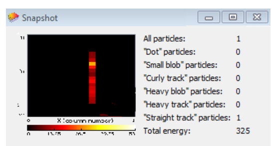
Students can study tracks of particles originating from space or naturally occurring radioactive isotopes in real-time. They distinguish different types of particles by their specific signature in the detector.



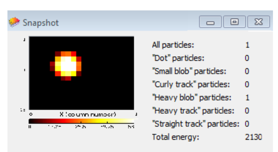




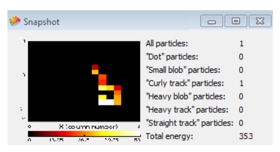
"Dot"
(gamma candidate)



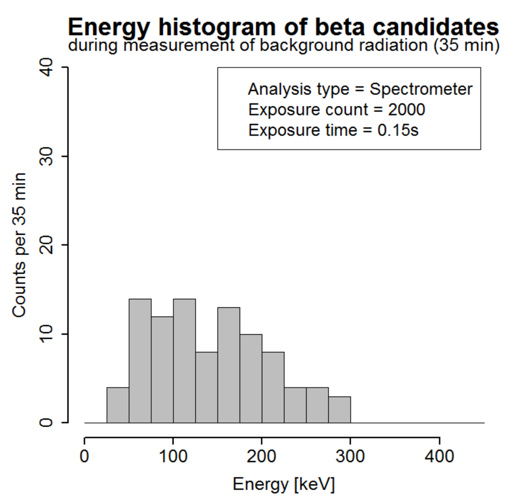
"Straight track"
(muon candidate)



"Heavy blob"
(alpha candidate)

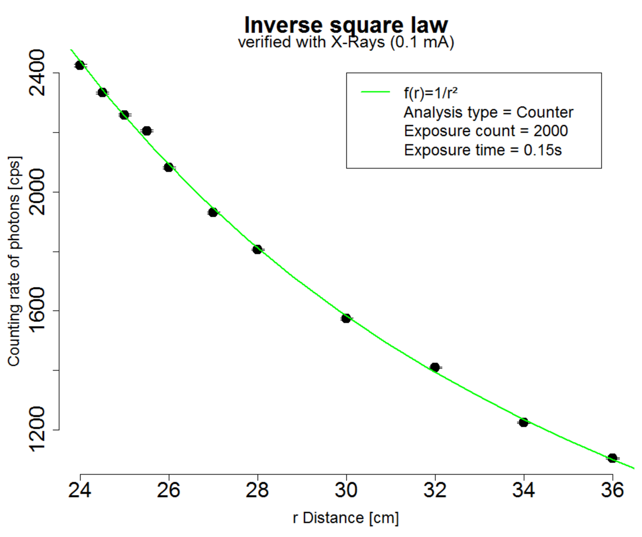


"Curly track"
(beta candidate)



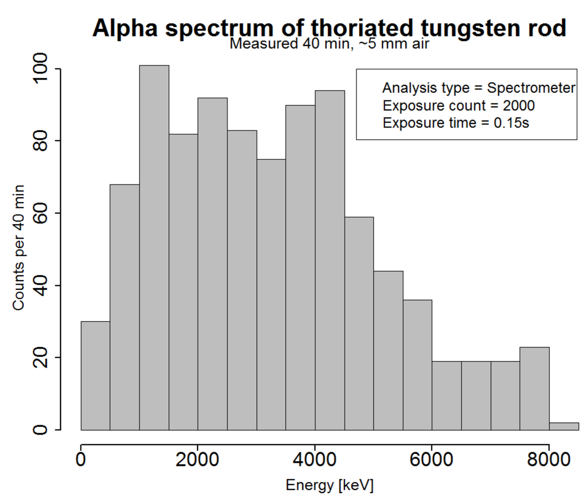
Properties of ionising Radiation

Students can use the detector to verify the inverse square law, determine emission spectra of radioactive sources and examine unknown radioactive materials.



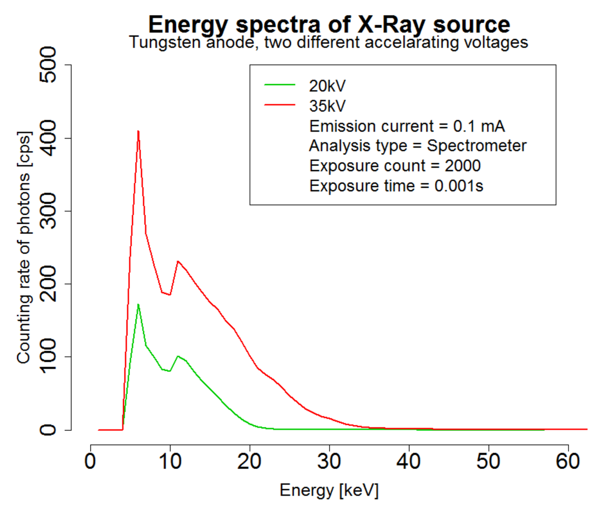
In the analysis type "counter" the MX-10 detector measures the number of particles. This can be used, for example, to verify the inverse square law.

In the analysis type "spectrometer" the MX-10 detector measures the energy of particles. This can be used, for example, to record the energy spectrum of α-particles of a thoriated tungsten rod.



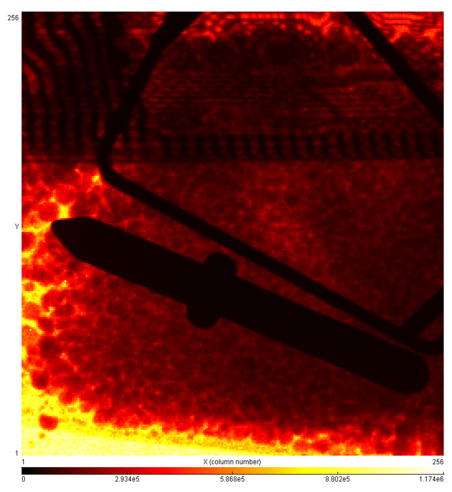
X-Ray Imaging

Combining the MX-10 detector with an X-Ray source, students can measure the energy spectrum of the X-Ray source or record radiographs of objects like memory cards.



The energy spectrum of X-Ray machines with different acceleration voltages can be measured.

Radiograph of a "mysterious suitcase" showing salt grains, memory card, solder pin, and staples



Accompanying Research on Students' Conceptions about Radiation

Students' Conceptions about Radiation

Concepts associated with ionising radiation [R1] and documented students' conceptions [R1-11]

Contamination

Radioactivity | Irradiation

Source | **Ionising radiation** | **Receiver**

Radioactive Material
- Activity depends on external conditions e.g. temperature [R4]
- Half-live is the dangerous timespan, after that no danger is left [R4]

Properties of Radiation
- Without source, radiation lingers a while [R4]
- Properties of ionising radiation are similar to those of light e.g. reflected by screen [R6], transparency of material is the same [R11]
- Radiating particles [R7]

Types of Radiation
- Lack of distinction between α, β, γ, X radiation [R3], [R4]
- Natural background radiation unknown (e.g. cosmic radiation, Radon) [R9], [R10]
- Gamma rays are more dangerous than X-Rays [R8]

Absorption / Interaction
- Radiation can be stopped not at all or 100% [R6]
- Receiver accumulates / contains radiation after irradiation [R4], [R5]
- Receiver becomes radioactive after irradiation [R3], [R4], [R8]

(In blue: students' conceptions which can be addressed in S'Cool LAB workshops)

- lack of distinction between concepts associated with radioactivity and ionising radiation [R1-6]
- context sensitivity of harmfulness, e.g.
  - radiation is safe in hospitals [R3], [R5], [R7]
  - radiation is always dangerous, especially if artificial [R4]

Students' Conceptions in S'Cool LAB Workshops

Prediction-Observation-Explanation (POE) tasks [4] are used to assess students' conceptions.

Example experimental task:
Place a sheet of black paper and a sheet of aluminium of the same thickness next to each other between the X-Ray source and the pixel detector. Compared to the black paper, which number of photons will your detector measure behind the aluminium foil: higher, lower, the same, or zero? Explain!

	Prediction		Observation
higher	„In aluminium, new particles are produced."	7	3
lower	„Aluminium has a higher density."	35	**61**
the same	„Aluminium is not the same as lead."	7	4
zero	"Aluminium reflects X-Rays." „Aluminium is not transparent for radiation."	26	0

- By using POE tasks during a test phase, known students' conceptions have been reproduced when working with pixel detectors in S'Cool LAB.
- A concept test based on the findings from POE tasks is under development and will be used to measure concept learning in S'Cool LAB.

[1] Llopart, X et al. (2007): Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements. *Nucl. Instr. and Meth. A* 581, 485–494 [2] Rossi, L. (2006): Pixel Detectors. *Springer Verlag*
[3] S'Cool LAB Website http://cern.ch/s-cool-lab/experiments [4] White, R. T., Gunstone, R. F. (1992) : Probing Understanding. *Great Britain: Falmer Press*.

Radiation misconceptions literature: [R1] Millar, R., Klaassen, C., Eijkelhof, H. (1990): Teaching about radioactivity and ionising radiation: an alternative approach. Phys Educ, 25, 338-342 [R2] Kaszmarek, R., Bednarek, D. R., Wong, R. (1987): Misconceptions of medical students about radiobiological physics. Health Physics, 52, 106-107 [R3] Eijkelhof, H. (1990): Radiation and risk in Physics Education. Dissertation, Utrecht: Center for Science and Mathematics [R4] Eijkelhof, H., Klaassen, C., Lijnse, P., Scholte, R. (1990): Perceived Incidence and Importance of Lay-Ideas on Ionizing Radiation: Results of a Delphi-Study Among Radiation-Experts. Science Education 74(2), 183–195 [R5] Millar R. (1994): School students' understanding of key ideas about radioactivity and ionizing radiation. Public Understand Sci, 3, 53-70 [R6] Riesch, W., Westphal, W. (1975): Modellhafte Schülervorstellungen zur Ausbreitung radioaktiver Strahlung. Der Physikunterricht, 9(4), 75-85 [R7] Neumann, Hopf (2012): Students' Conception About 'Radiation': Results from an Explorative Interview Study of 9th Grade Students. J Sci Educ Technol 21, 826-834 [R8] Mubeen, S. M., Abbas, Q., Nisar, N. (2008): Knowledge about ionising and non-ionising radiation among medical students. J Ayub Med Coll Abbottabad, 20(1) [R9] Boyes, E., Stanisstreet, M. (1994). Children's Ideas about Radioactivity and Radiation: sources, modes of travel, uses and dangers. Research in Science and Technological Education, 12(2), 145–160 [R10] Rego, F., Peralta, L. (2006): Portugese students' knowledge of radiation physics. Physics Education, 41(3), 259-262 [R11] Clément, P., Fisseux, C. (1999): Opacity of Radiography, Perplexity of Teachers and Pupils in Primary School. Research in science education in Europe, 15-21

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