Photodiode read-out system for the calorimeter of the HERD experiment

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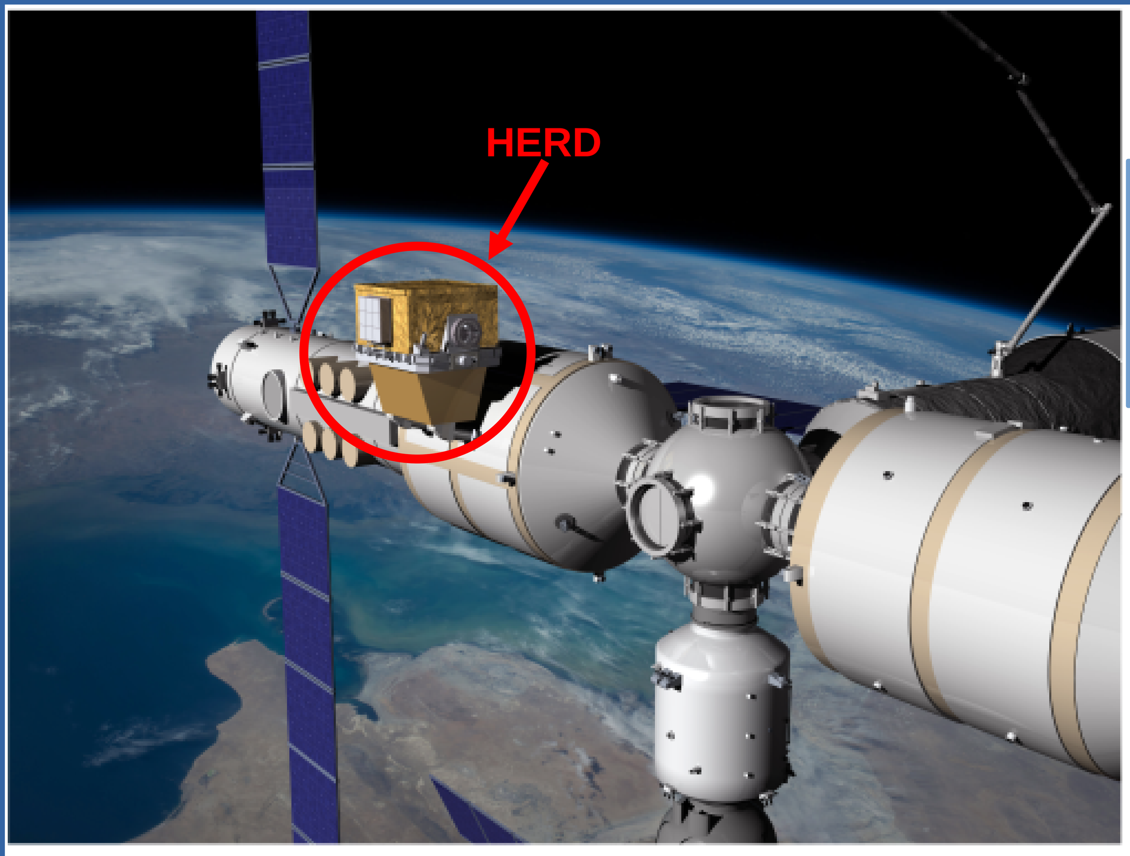
Abstract

The HERD experiment is a future experiment for the direct detection of high energy cosmic rays. The instrument is based on a calorimeter optimized not only for a good energy resolution but also for a large acceptance . Each crystal is equipped with two read-out systems: one based on wavelength shifting fibers and the other based on two photodiodes with different active areas assembled in a monolithic package. In this poster we discuss the photodiode read-out system, focusing on the experimental requirements, the system design and the estimated performances.

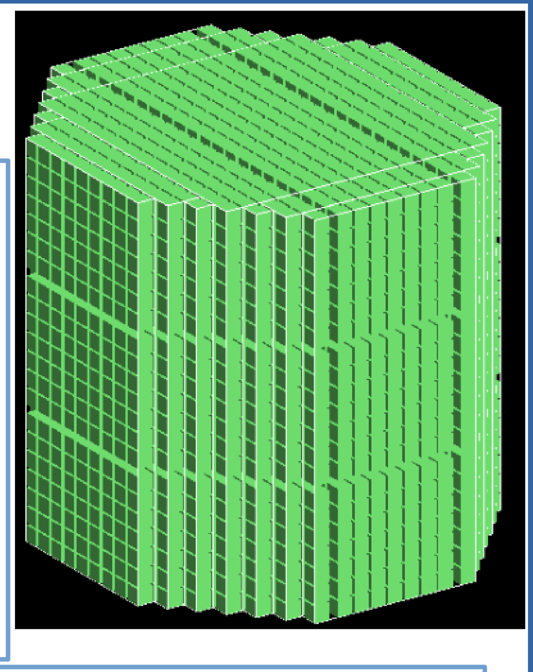
The HERD experiment



Future experiment dedicated to the direct detection of cosmic rays.
Installation on the Chinese Space Station scheduled in 2027.

Scientific objectives:
- proton flux up to PeV
- electron + positron flux up to TeV
- gamma astronomy
- indirect search of dark matter

Calorimeter characteristics:
- 3D
- homogeneous
- isotropic
- deep (55 X_0, 3 λ_I)
- finely segmented
- composed by about 7500 LYSO scintillating crystals
- large acceptance (2 m^2sr for electrons, 1 m^2sr for protons)
- good energy resolution (< 2% for electrons, < 30% for protons)



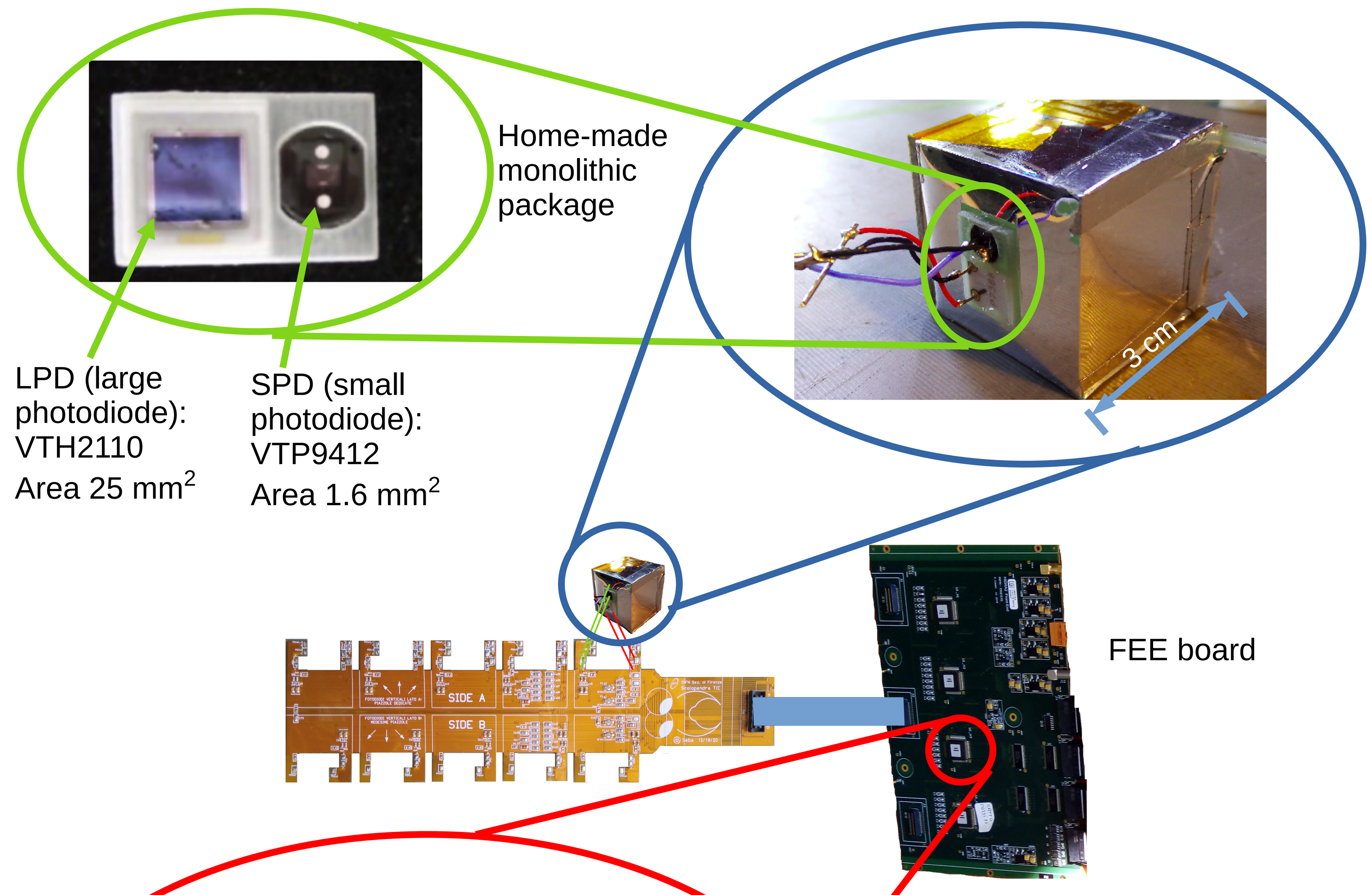
Calorimeter requirements:
- strong control of energy scale
- independent triggers
- redundancy

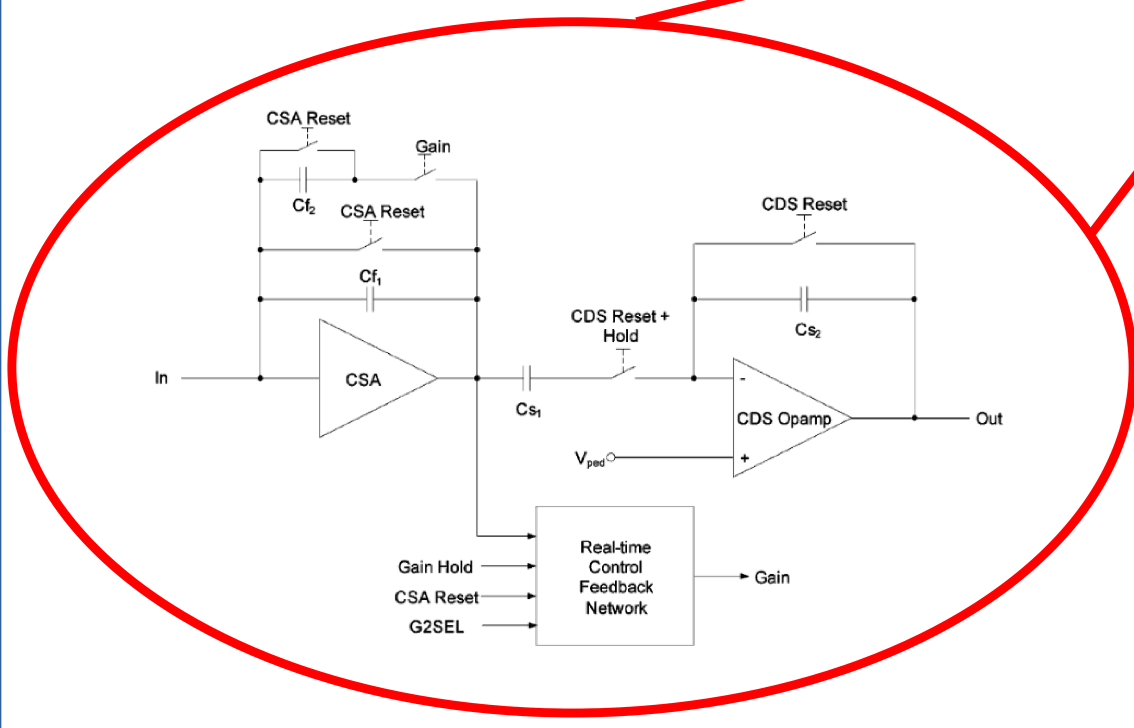
Two different read-out systems:
- wavelength shifting fibers (WLSF) coupled to Intensified scientific CMOS (IsCMOS)
- pairs of photodiodes with different active areas assembled in a monolithic package

Read-out challenges:
- high dynamic range (> 10^7)
- low power consumption

PD read-out system design

The PD read-out system is based on a **monolithic package composed by two photodiodes with different active areas.**



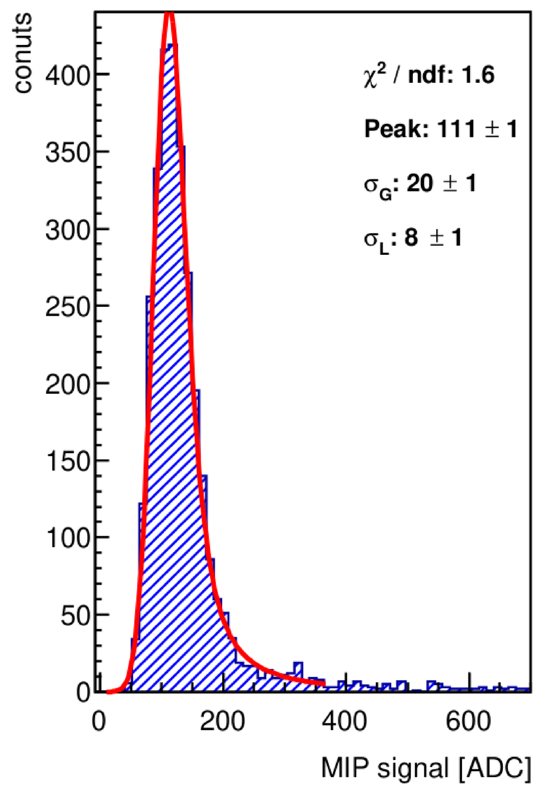


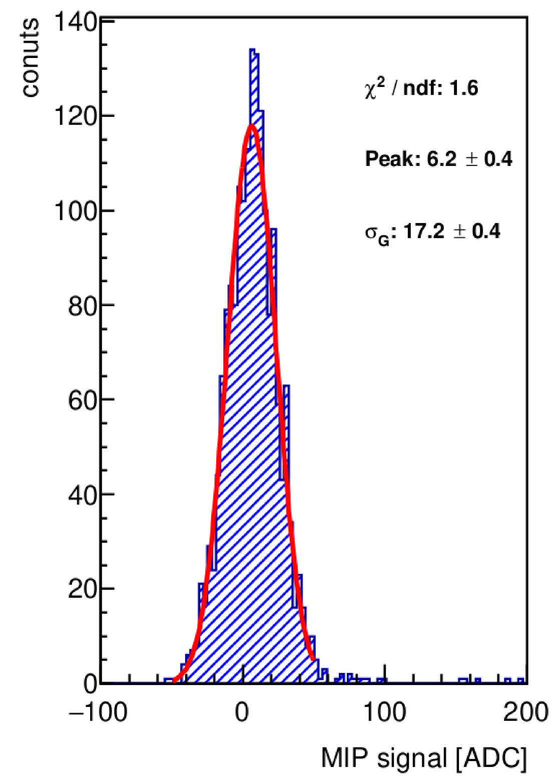
HiDRA-2 chip:
- Charge Sensitive Amplifier (CSA)
- Correlated Double Sampling (CDS)

Specifically designed for this application:
- automatic gain selector
- high dynamic range (10^5)
- low power consumption (about 3.75 mW per channel)
- low noise (ENC about 2500 equivalent electrons)

Performance of the PD read-out system

Typical noise of the system:
- 27.5 ADC
- 22.5 ADC after common noise correction



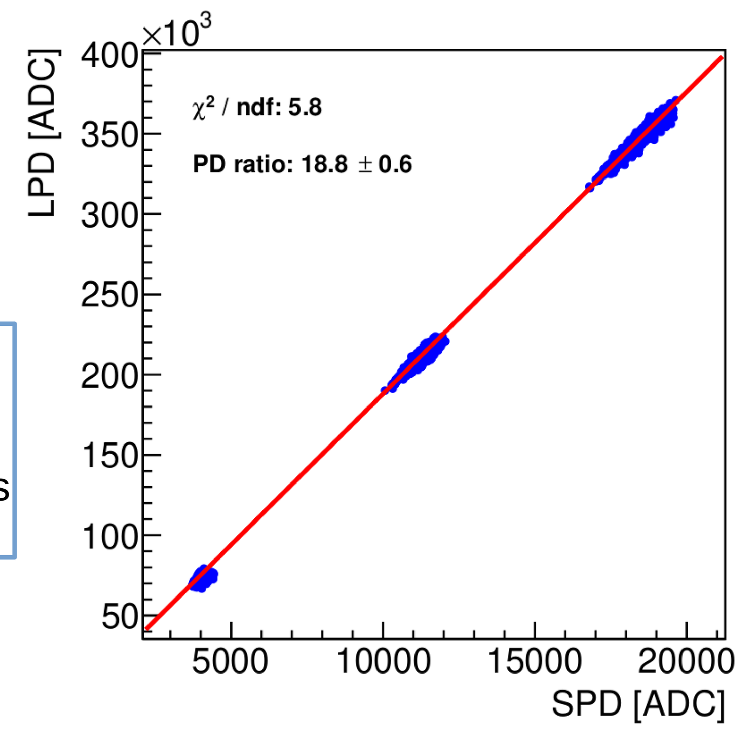


In orbit, the **calibration of the LPD** signal will be done using not interacting protons and nuclei with a deposit similar to that of a minimum ionizing particle (MIP).

Laboratory measurement of the MPV of the energy distribution of cosmic muons detected with a few crystal samples:
- (110 ± 10) ADC for LPD
- (6 ± 2) ADC for SPD

In orbit, the **calibration of the SPD** will be done using its signal correlation with the LPD in high energy shower release.

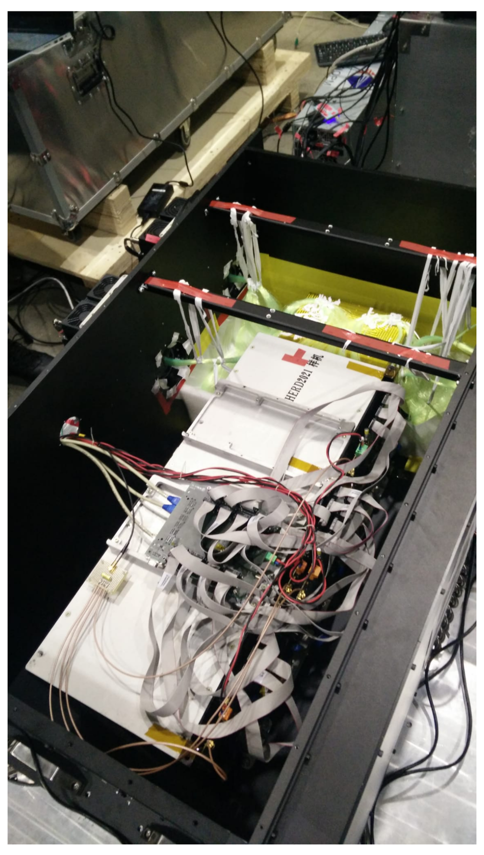
LPD/SPD ratio measured using multiparticle beam at two test beam facilities:
- at the LABEC facility in Florence with 2 MeV protons
- at a linear accelerator ELEKTA VERSA HD with photons
- measured ratio LPD/SPD: 19.5 ± 1.5



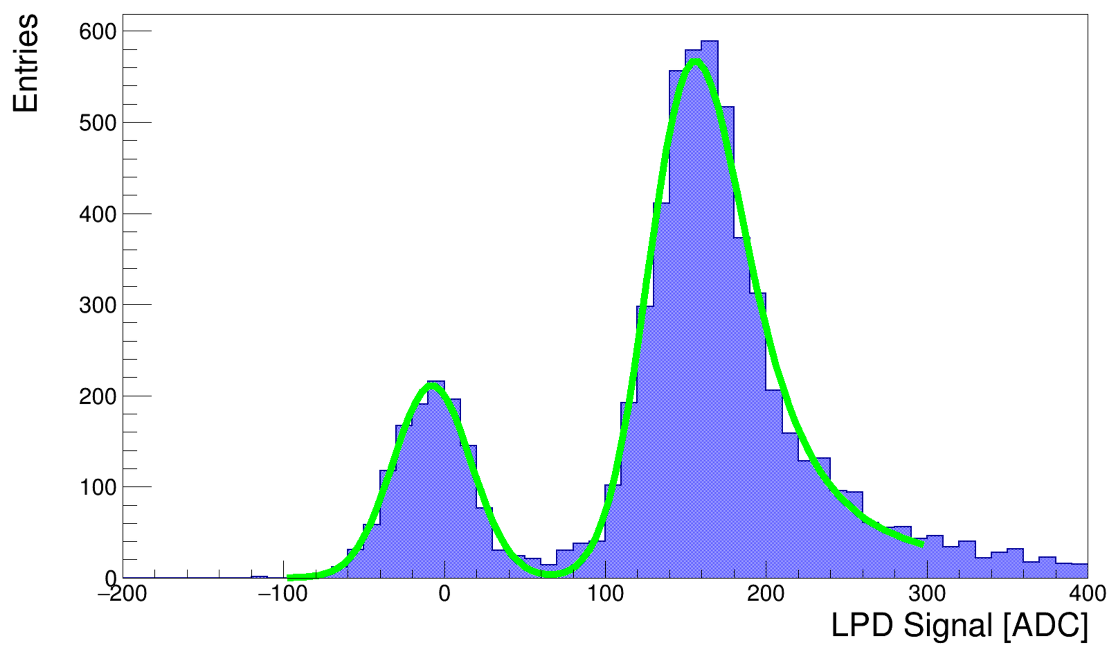
The prototype tested at SPS

Prototype with **63 crystals** equipped with WLSF and monolithic packages tested in 2021 at the CERN Super Proton Synchrotron (SPS).

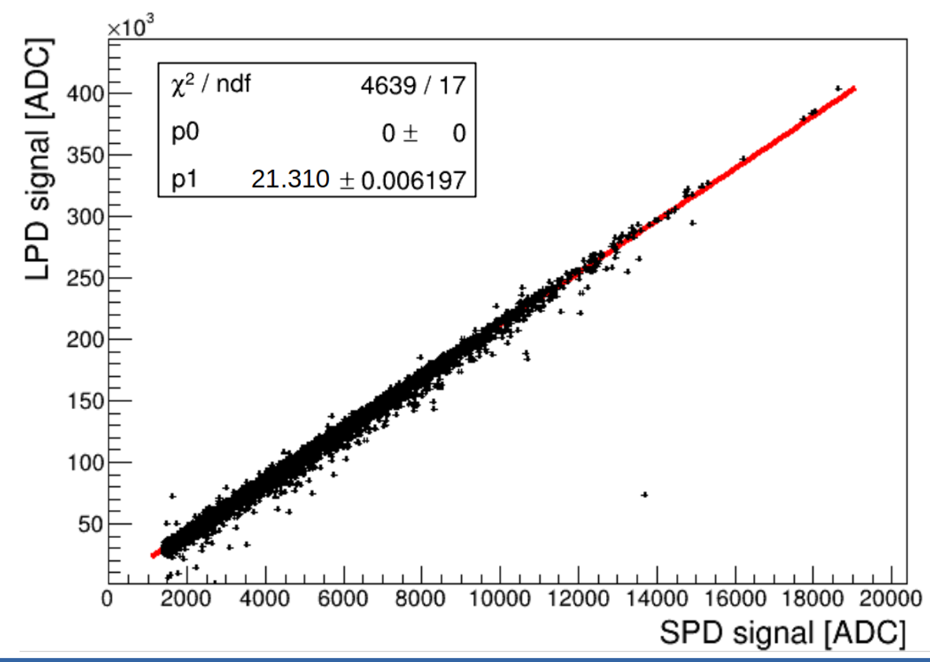
Three types of particles:
- muons
- protons
- electrons



Channel-by-channel calibration of LPD using muon signal:
- 250 GeV muons MPV = (126 ± 4) ADC



Channel-by-channel calibration of SPD using proton showers:
- ratio LPD/SPD = 18.7 ± 0.9



Developing the new sensor

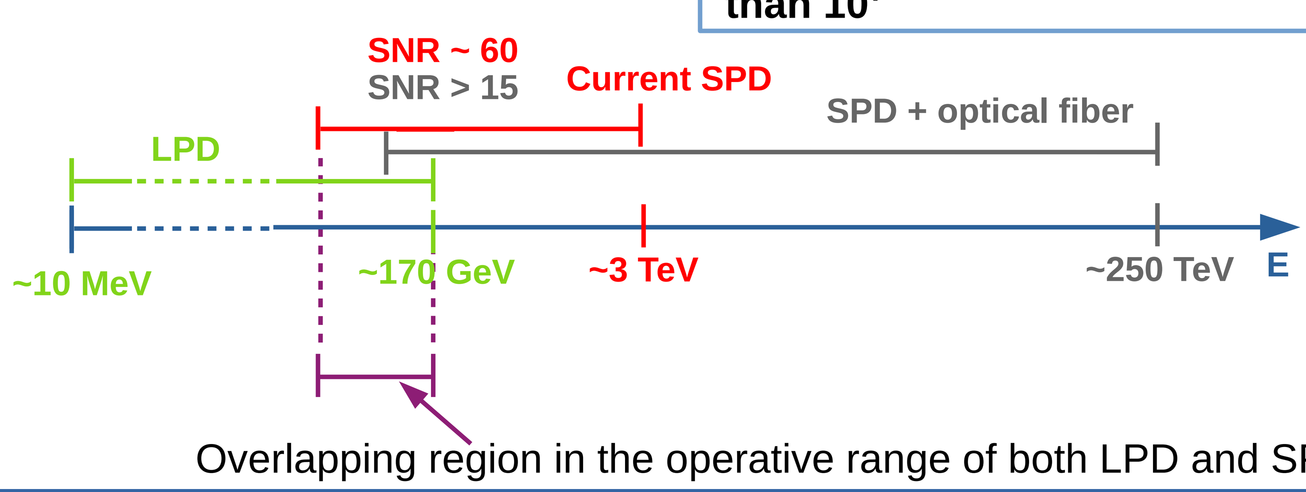
Estimation of the dynamic range:
- maximum detectable energy
- Signal to Noise Ratio (SNR) of SPD near the saturation of LPD

Current system:
- maximum detectable energy before saturation of a **few TeV**

From simulations:
- up to **250 TeV** in a single crystal (for showers induced by PeV protons)

Extension of the actual dynamic range:
- optical filter with a transmittance of about 1.5% on the surface of the SPD to reach a **dynamic range larger than 10^7**

Development of the new monolithic package:
- collaboration with Excelitas
- first new 1000 monolithic packages installation on a prototype that will be tested in 2023 at CERN SPS



Overlapping region in the operative range of both LPD and SPD.