Light detection for neutrino physics

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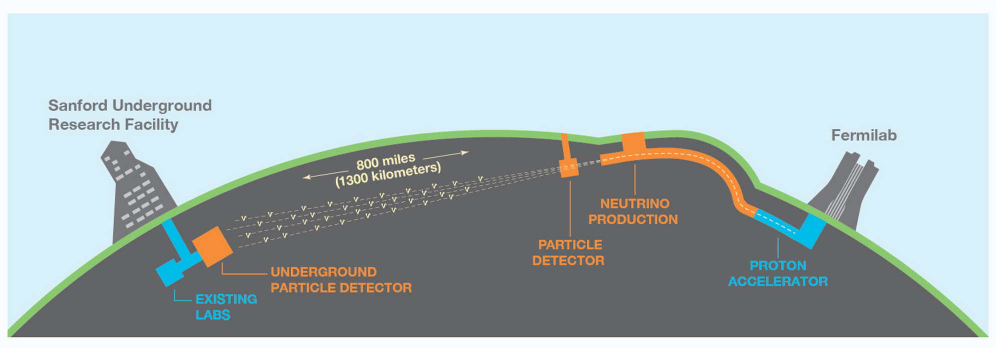
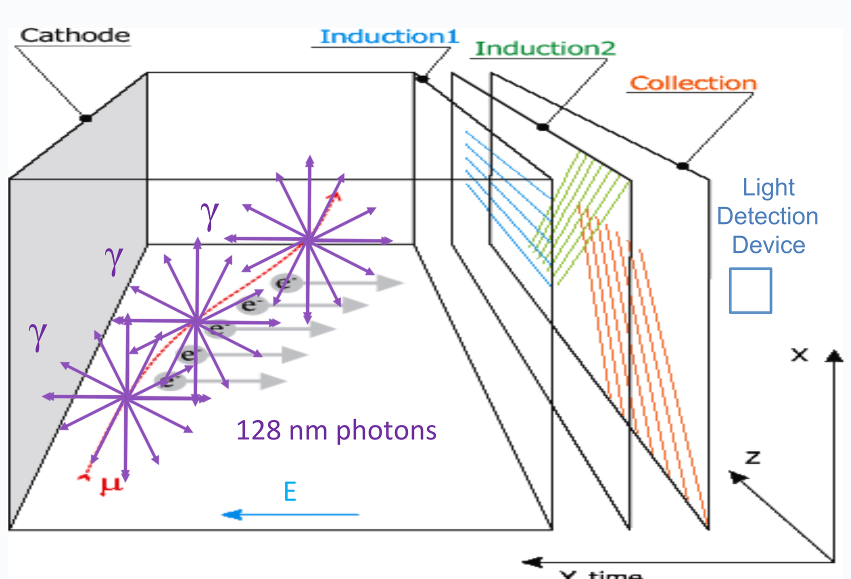
In order to reach SiPM effective surfaces ~10 cm^2, tens of ~ mm^2 SiPMs must be read out in parallel. This kind of connection implies a deterioration of the signal to noise due to the increase of the detector capacitance and a deterioration of the time response, too. This drawback can be overtaken reading groups of SiPM with trans-impedance amplifiers and processing the summed signal with an additional amplifying stage. This technique is often named as "active ganging". **My project focuses on developing and testing an active ganging system:**

- **with cryogenic amplifiers optimized for the needs of DUNE, reaching a time resolution of <20 ns.**
- **with low noise at warm and high time resolution of <100 ps, for the needs of ENUBET.**

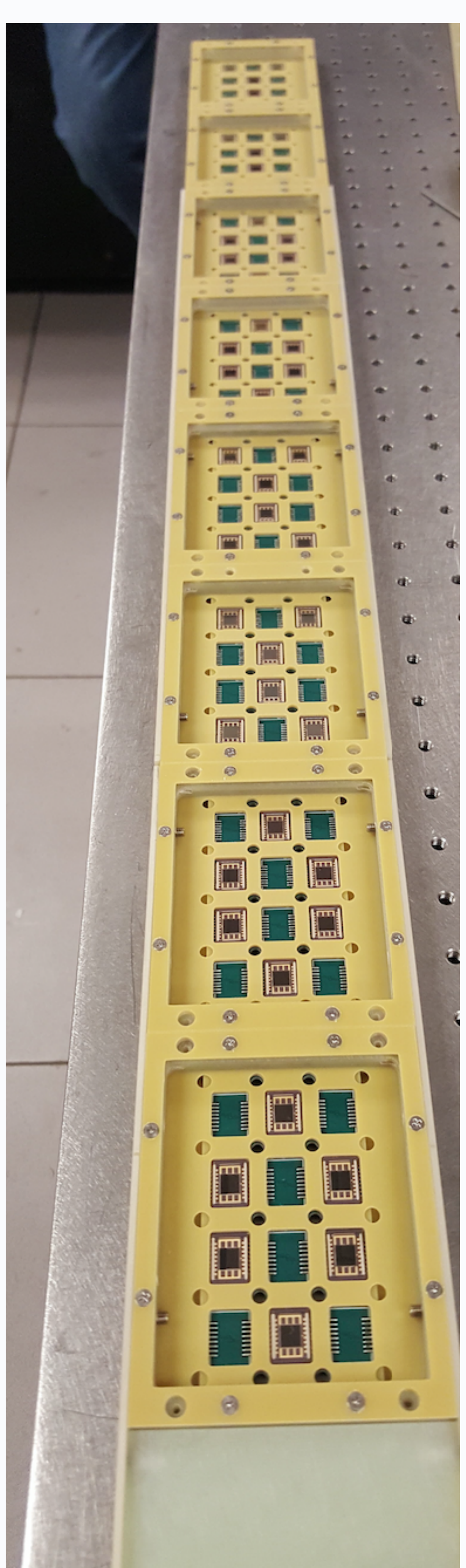
COLD

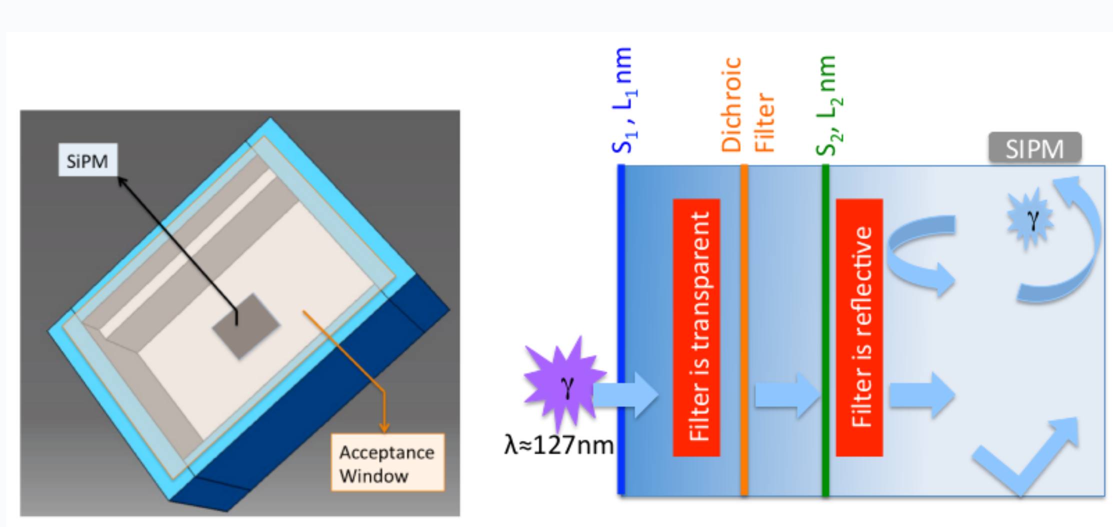




The DUNE LArTPC will be the largest liquid argon detector ever built. Noble liquid particle detectors normally use both the prompt scintillation light and the charge ionisation signals to perform event reconstruction.

The prompt emitted light in liquid argon is in the far UV region and the emission is strongly peaked around 128 nm, with a fast decay component of 7 ns and a much slower component of about 1.5 μs. The detection of scintillation light is important in DUNE because it provides a fast signal (in a few ns scale compared to several tens of μs or more for the collection of the charge signal), which is crucial for self-triggering applications and for off-beam background rejection.

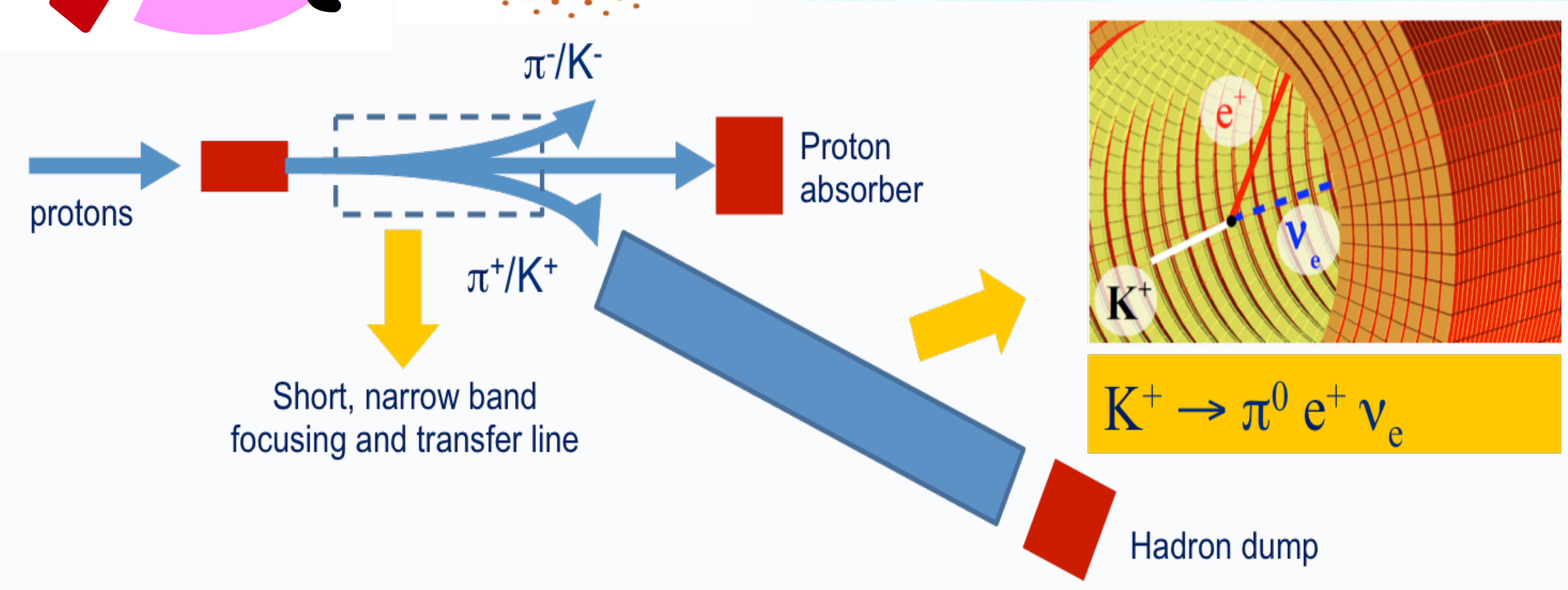




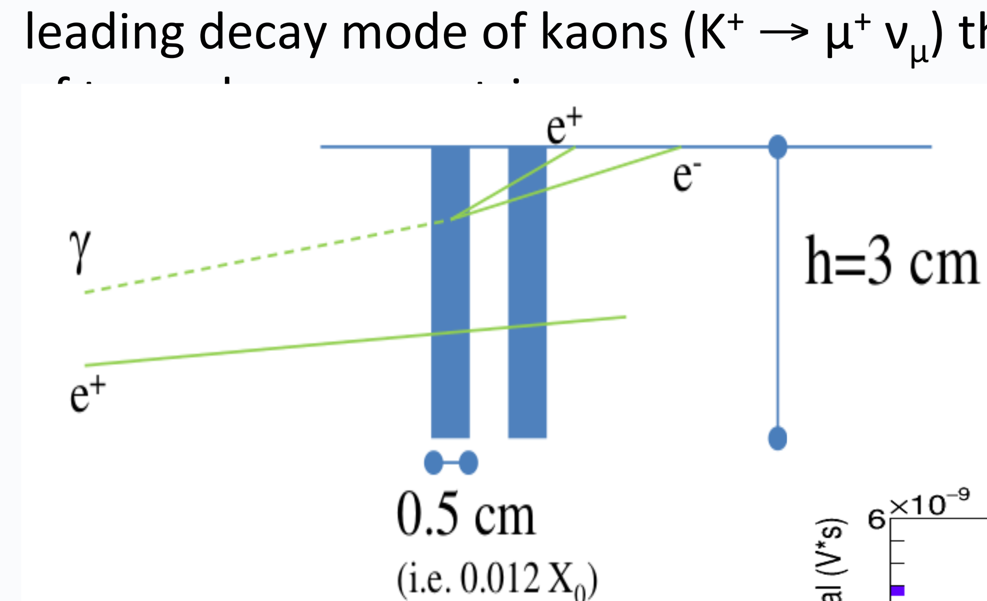
The main challenge in DUNE is photon detection over an extremely large surface: this can be achieved with a typical efficiency of a few per-cent using light traps (ARAPUCA) equipped with SiPMs. The ARAPUCA is made by a light collector coupled to silicon photo-sensors, used to read-out the collected photons. The collector consists of a box cavity with highly reflective internal surfaces from which photons can reflect back and forth until being detected by the SiPM array (or absorbed). The acceptance window of the box is made by a short-pass dichroic filter, which has the properties of being highly transparent to photons with wavelength below a given cut-off, while being highly reflective to photons with wavelength above the same cut-off. VUV scintillation light is shifted one time outside the box, by a wavelength shifting film deposited on the external side of the dichroic filter to a wavelength below the cut-off to allow the photons to enter inside the collector box and a second time inside the box, to a wavelength above the cut-off to prevent photons from leaving the box.

The use of the SiPM matrix in active ganging will permit to increase the light collection without increasing the number of read-out channels.

WARM

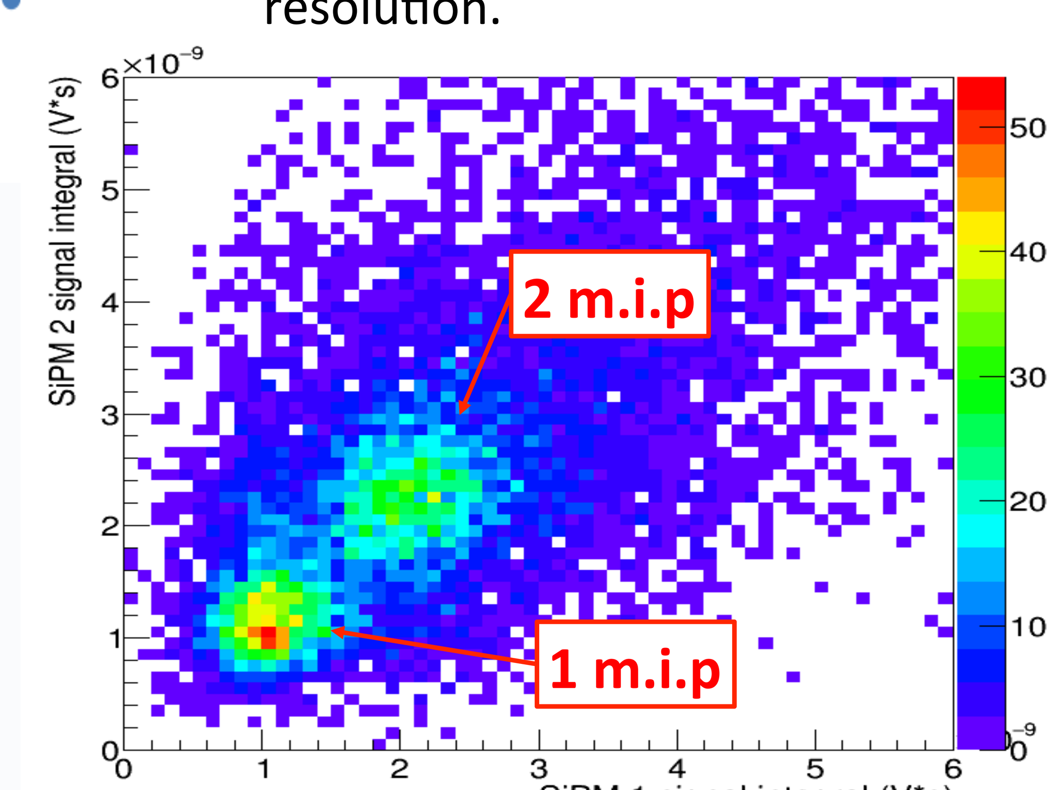


In a tagged neutrino beam based on the ENUBET design, the particles are focused by a purely static system: the extraction time of the protons onto the target is extremely long (>2 s), to reduce the number of particles per unit time and to perform a good particle identification. The walls of the tunnel are instrumented with devices that reconstruct the charged particles created in the tunnel impinging on the walls. These particles are mostly decay products of kaons and the golden channel of ENUBET is the three body semi-leptonic decay of the charged kaon ($K^+ \rightarrow \pi^0 e^+ \nu_e$), which contributes to 99.5% of the electron neutrino in the standard ν_μ beam. This e^+ identification provides a drastic reduction on the neutrino flux uncertainties. ENUBET also reconstructs the leading decay mode of kaons ($K^+ \rightarrow \mu^+ \nu_\mu$) thus providing a high statistics sample



π^0 rejection and t_0 reconstruction are now obtained by means of two scintillation layers. Good discrimination but only ~ 2 ns of resolution.

A LYSO crystal



Under study is a system that has the time resolution to associate one-to-one a neutrino originating from a kaon decay and observed at the detector to the positrons that stop in the decay tunnel. To achieve this goal, particles belonging to the same kaon decay must be associated unambiguously, i.e. the time resolution of the system must reduce contributions from accidental coincidences at the per-cent level. In turn, the particles created in the tunnel have to be time tagged with a precision of <100 ps. The timing layer in development is made of 3x3x0.3 cm^3 Lutetium Oxyorthosilicate (LYSO) scintillator crystals, whose light is readout by SiPMs. This system has been developed at small scale (1 cm^2) for the upgrade of the CMS experiment at the Large Hadron Collider. In tagged neutrino beams, the timing performance will have to be preserved on a surface 9x larger than the size envisaged for CMS, employing a matrix of SiPMs read out by the trans-impedance amplifiers. Simulations indicate that a time resolution of 100 ps can be achieved by 3x3 cm^2 LYSO crystals read out by nine 4x4 mm^2 ganged SiPMs.