# Xenon doping of Liquid Argon in ProtoDUNE Single Phase


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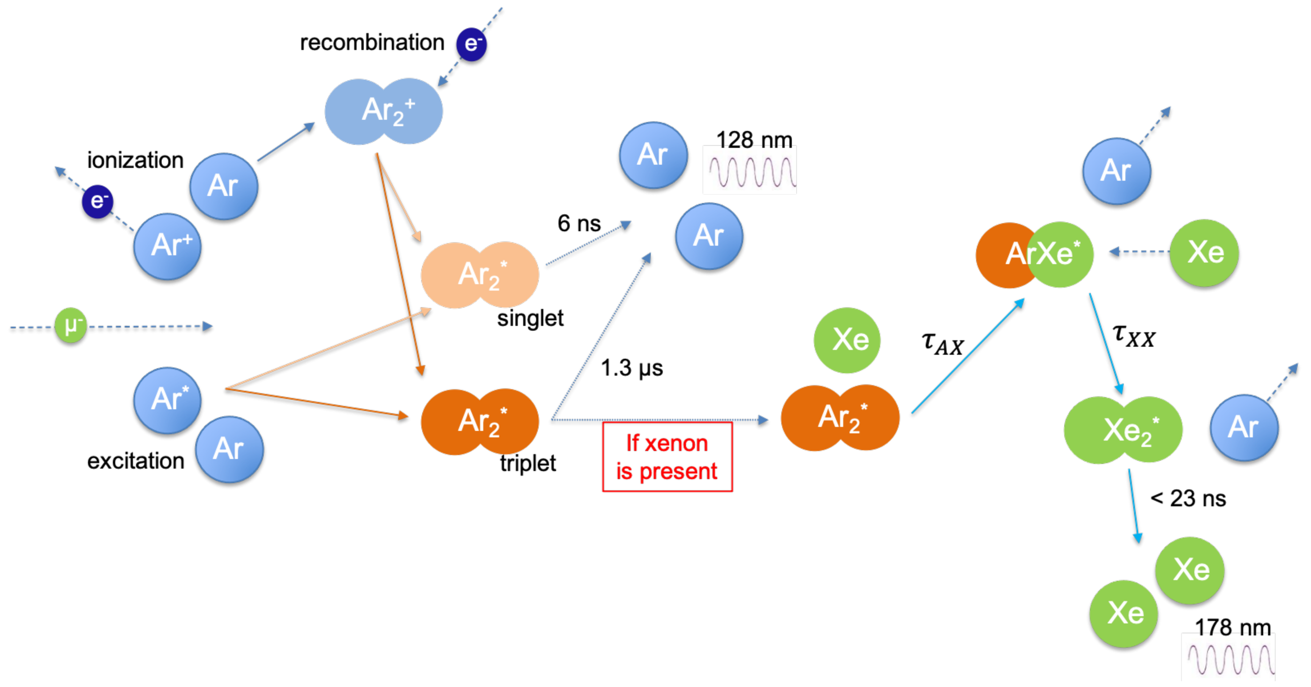
## Introduction

Doping argon with xenon is a known technique[a] to shift the scintillation light of argon (128 nm) to a longer wavelength (175 nm) [1]. This can be used to improve the light detection system of Liquid Argon Time Projection Chambers (LAr TPCs) like DUNE [2] (Deep Underground Neutrino Experiment). Photon detectors are more sensitive to the longer Xe wavelength, the larger Rayleigh scattering length of 178 nm photons increases the light response uniformity across the TPC volume and the overall light emission profile is faster than the pure argon case. The high efficiency of energy transfer between argon and xenon dimers also allows for the light recovery in case of quenching due to pollutants ($N_2$) [3]. The first ever very large scale doping test was carried out in ProtoDUNE Single Phase (ProtoDUNE-SP) at the CERN Neutrino Platform [4].

[a]Proven so far only in small scale or gas TPCs

## Xenon doping mechanism

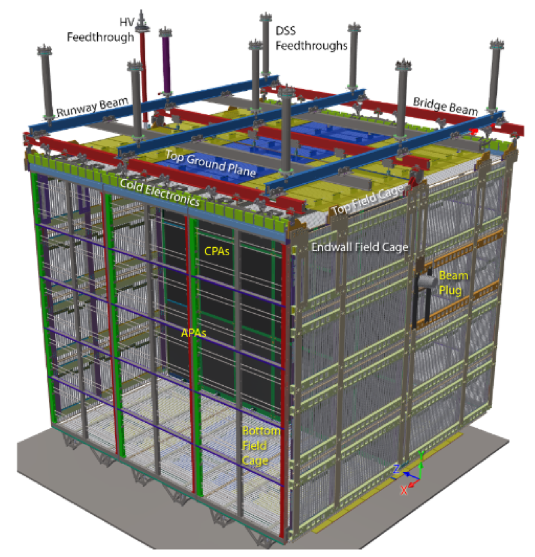


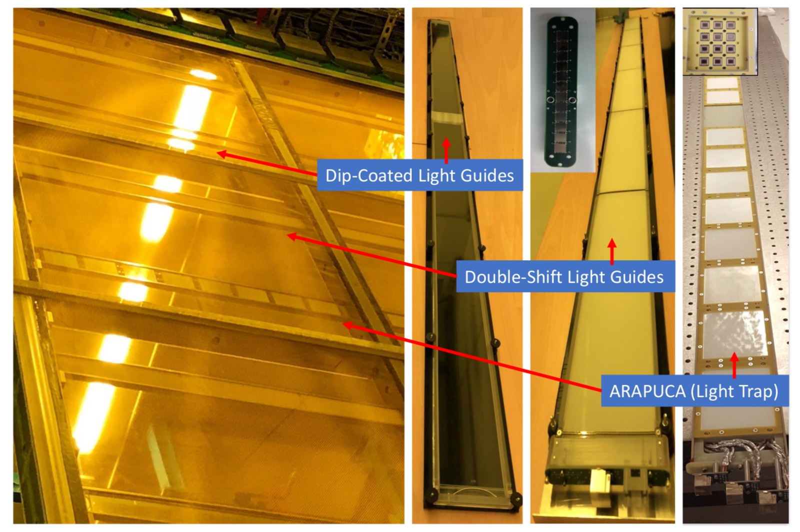

Xenon atoms in suspension in LAr can interact with a $Ar_2^*$ excited dimer, mainly with the long-lived triplet state ($^3\Sigma_u{}^+$). The non-radiative collision with a xenon atom leads to the formation of an hybrid excimer $ArXe^*$, whereas a second collision yields a full-energy transfer to $Xe_2^*$, which decays at 178 nm. The energy transfer mechanism has typical time constants $\tau_{AX}$ and $\tau_{XX}$ that are inversely proportional to xenon concentration.

The overall effect is a decrease of the number of emitted photons by argon triplet component (128 nm), in favour of the light emitted by xenon (178 nm). The light distribution becomes shorter in time because $\tau_{AX}$ and $\tau_{XX}$ decrease as function of the injected xenon.

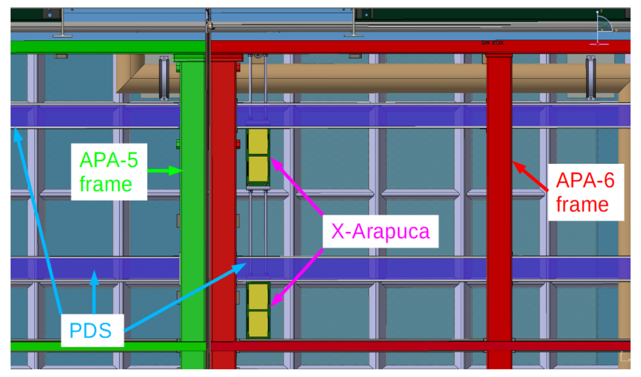
## Experimental setup and data selection

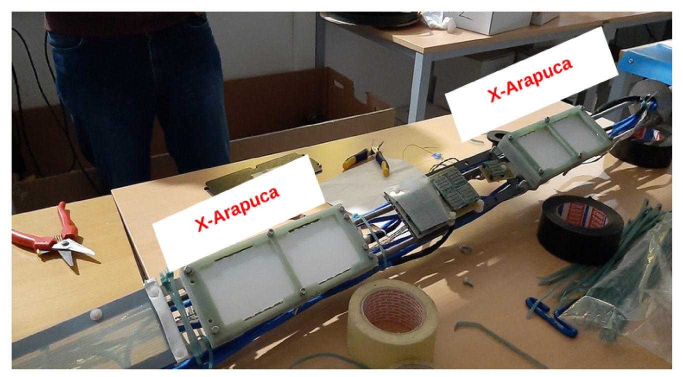
ProtoDUNE-SP (left) is a full scale LAr-TPC prototype for the first module of DUNE far detector with a total LAr mass of 770 t: it consists of two drift volumes separated by a CPA (Cathode Plane Assembly) biased to produce a 500 V cm$^{-1}$ electric field to drift ionization electrons towards APAs (Anode Plane Assemblies), where they are collected.






10 **Photon Detection System (PDS)** modules (right), regularly spaced along the vertical direction, are inserted into each APA module to detect LAr scintillation photons. Three different designs [4] were installed in ProtoDUNE-SP: "double-shift light guides", "dip-coated light guides", and ARAPUCA light traps. In the xenon doping run this system exploited a sample of horizontal crossing muons, selected through a Cosmic Ray Tagger (CRT). The CRT is made of scintillator counters (strips) that enable the reconstruction of muons tracks and therefore the estimation of the radial distance between muons and light detectors.

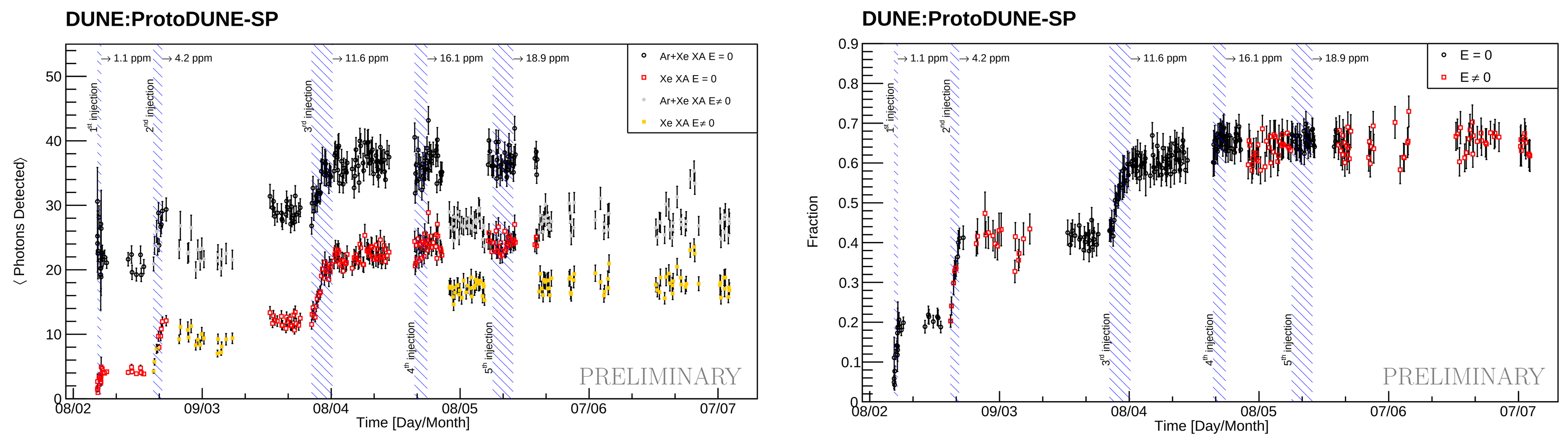



A **dedicated setup** was installed in ProtoDUNE-SP before the doping. It consists of two **X-ARAPUCA** [5] detectors (20×7.5 cm$^2$) installed behind one APA module. The first detector ("Ar+Xe XA") can collect both 128 nm (Ar) light and 178 nm (Xe) light, while the second one ("Xe XA") is equipped with a fused silica window that is opaque to the 128 nm (Ar) component. The system selects a sample of vertical cosmic muons, triggered through a standard triple coincidence of 15.5×44 cm$^2$ plastic scintillators, located on the cryostat roof.

## Doping procedure and results

Xenon was inserted in ProtoDUNE-SP argon purification system through different injections of (1.1, 3.1, 7.4, 4.5 , 2.8) ppm, respectively. All data collected during the xenon doping run are characterized by a $N_2$ pollution in LAr estimated at $(5.2 \pm 0.1)$ ppm due to a previous Ar-gas recirculation pump failure.




(a) (b)

Figure 1: Panel (a): number of photons detected by the two X-ARAPUCAs increases steadily at each doping. Samples with lower photon yield correspond to periods when TPC electric field was on. Panel (b): Fraction of the argon light (128 nm) that is converted to xenon light (178 nm): $\frac{Xe}{Ar+Xe}$. This fraction increases with each doping and it reaches a plateau around 0.65 for xenon concentration greater than 16.1 ppm. Shaded areas in both panels show xenon injection periods.

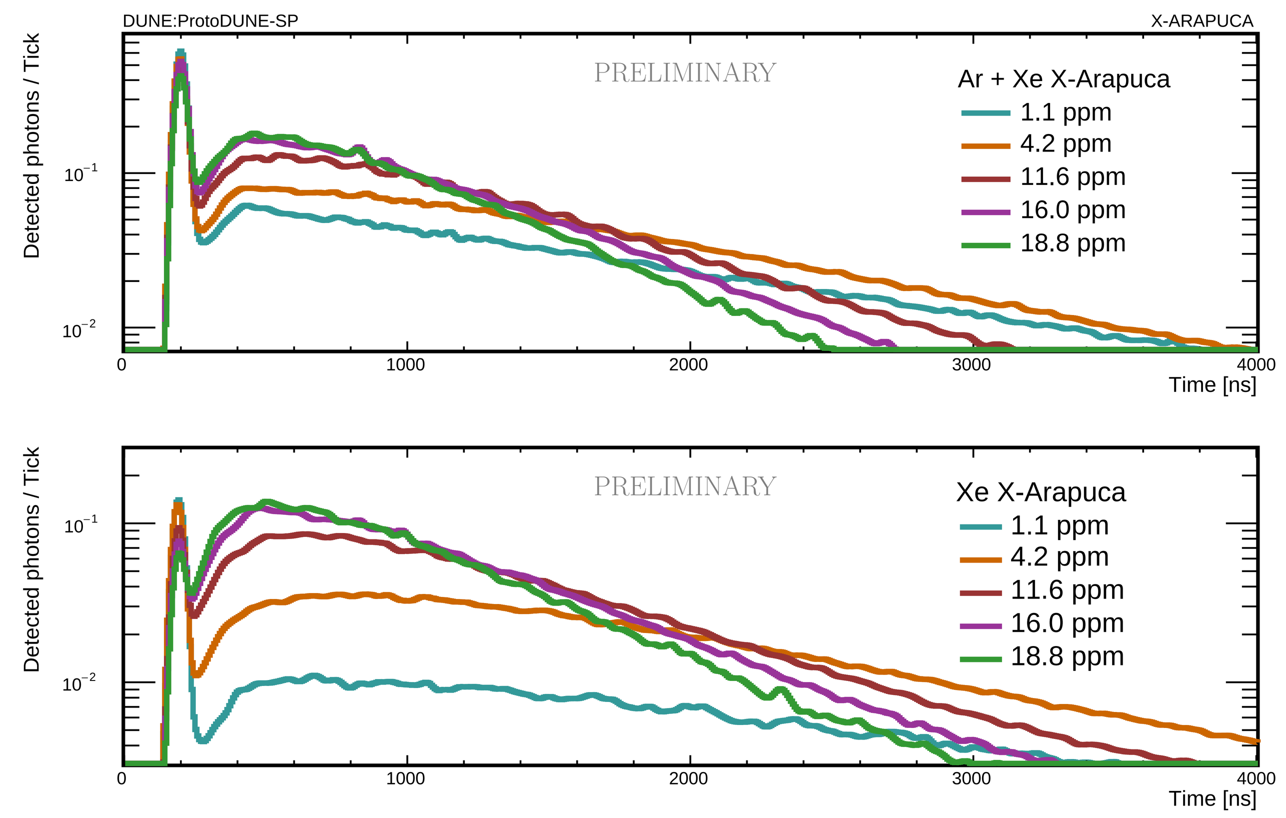
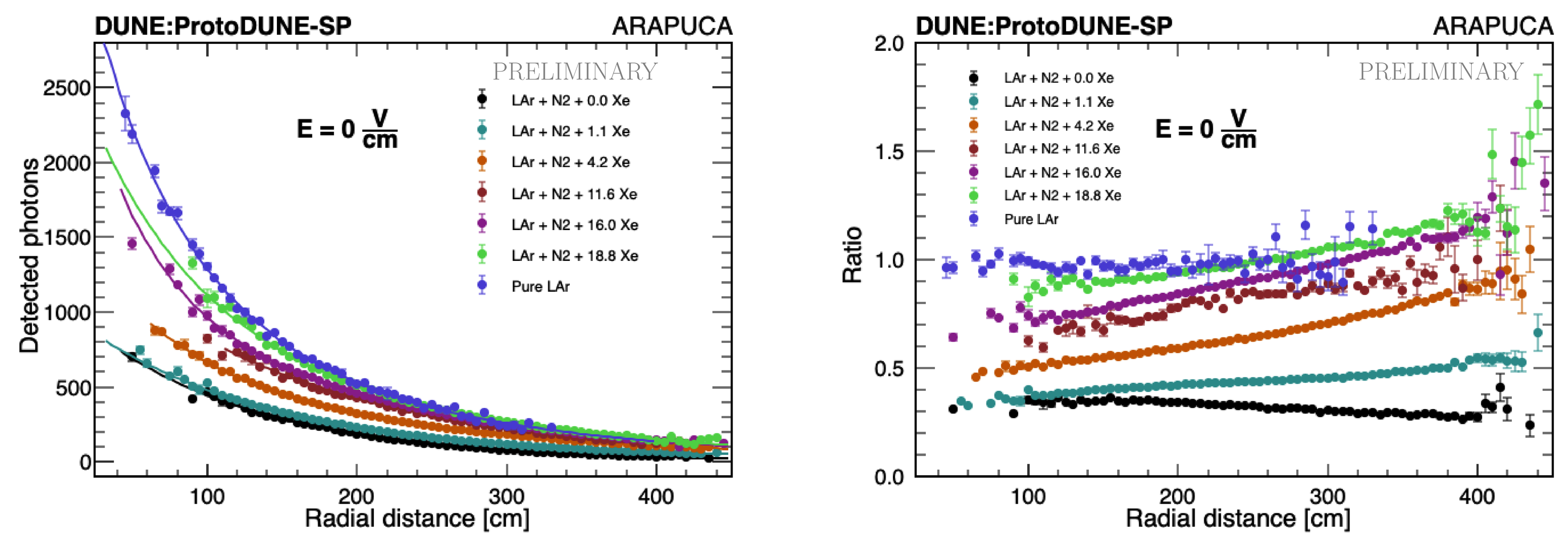



Figure 2: Deconvolved waveforms of X-ARAPUCA for different xenon concentrations: Ar+Xe light (top) and Xe light only (bottom). Light increases as a function of Xe concentration, and the distribution becomes shorter in time.




(a) (b)

Figure 3: Panel (a) shows the collected light versus radial distance: injecting xenon helps recovering the light loss due to $N_2$ contamination. Panel (b) shows the ratio of collected light relative to the pure LAr (no $N_2$ contamination), the light collection uniformity improves as the light collection efficiency far from the APA increases. The trends shown are unaffected by the presence of the TPC electric field.

## References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