Xe doping of LAr in ProtoDUNE-SP

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on behalf of ProtoDUNE-SP Xenon Doping working group

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INFN MILANO
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Content

- Motivation of Xe doping in ProtoDUNE-SP
- Xe-doping conditions
- X-ARAPUCA telescope
- Physics Analysis
  - X-ARAPUCA telescope
  - Standard ARAPUCA ProtoDUNE-SP system

Motivation of Xe doping (I)

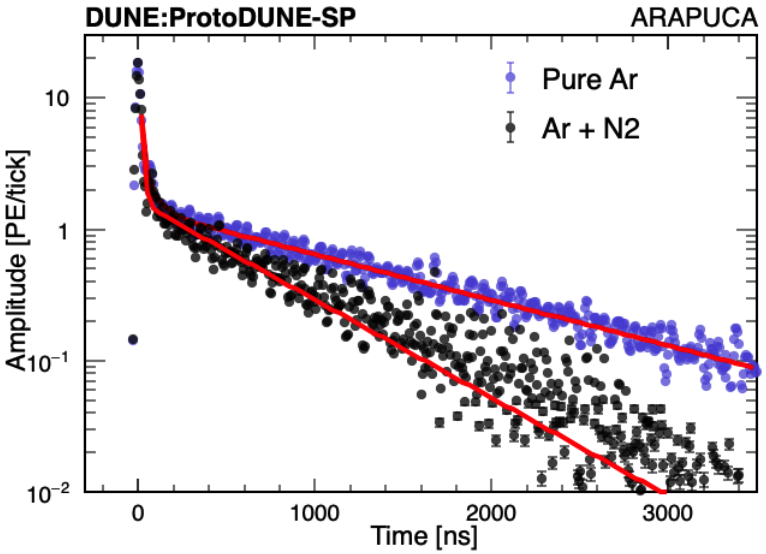
- LAr as a scintillating media and challenges to use it
  - Scintillation efficiency comparable with other liquid noble gases
  - Very efficient Pulse Shape Discrimination (PSD) due to the significant difference in relative intensities of the fast and slow components
  - Disadvantage comes from the wavelength of scintillation that lies in the VUV range (~128 nm). A common and convenient solution is the use of wavelength shifters (WLS) that comes with some issues:
    - Low geometrical efficiency
    - sensitivity to mechanical stress
    - scattering and re-absorption of the re-emitted light inside the WLS layer
    - dependence of the WLS efficiency on the coating method
    - long term stability?

Motivation of Xe doping (II)

- Elegant alternative: volume distributed “WLS” in LAr experiments → Xenon doping
  - Shift 128 nm wavelength to 175 nm
  - Uniform light distribution
  - Larger Rayleigh scattering length @175 nm
  - Increase light yield and detection efficiency
- In literature small scale tests or gas mixture tests so far
  - How about physics, uniformity and stability of doped Xe at large scale setups?

With this in mind, an R&D effort and Xe-doping in ProtoDUNE-SP was performed

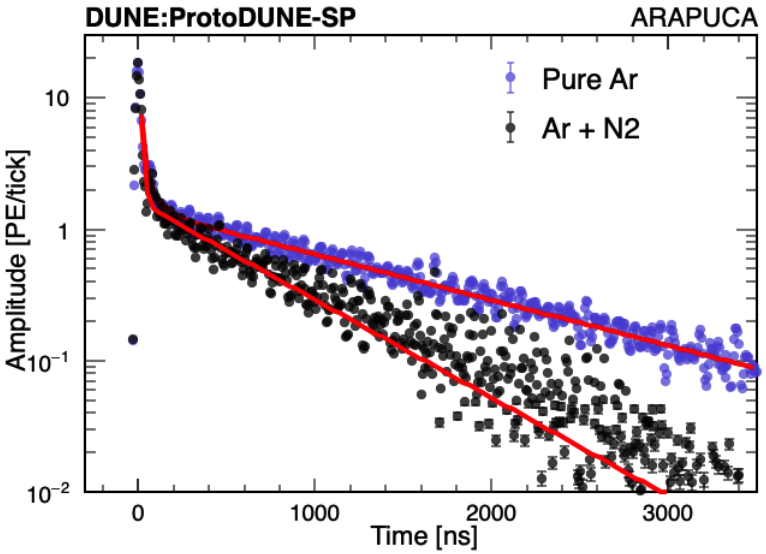
Doping condition



- Summer 2019 → gas recirculation pump failure caused a N_2 contamination in ProtoDUNE-SP
  - $(5.2 \pm 0.1)\ ppm$ of N_2 injected into the detector

Doping	Date	Doped Xe[gr]	Doped Xe[ppm]
1	13-14 February 2020	776	1.1
2	26-28 February 2020	2234	3.1
3	3-8 April 2020	5335	7.4
4	27-30 April 2020	3192	4.5
5	15-16 May 2020	400	0.6
6	18-20 May 2020	1584	2.2

Doping condition



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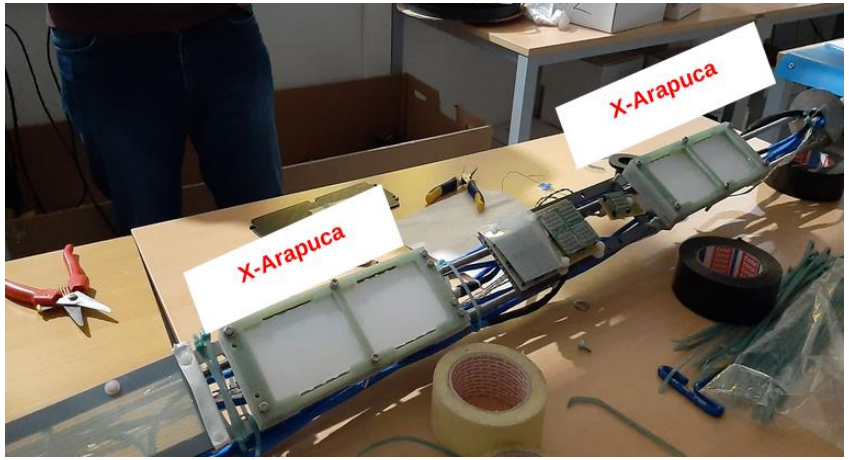
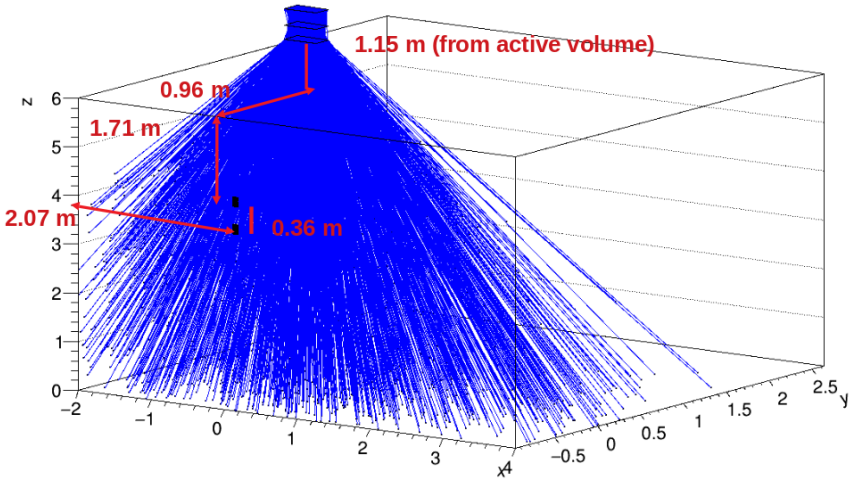
In total
18.9 ppm
of Xe injected

X-ARAPUCA Telescope



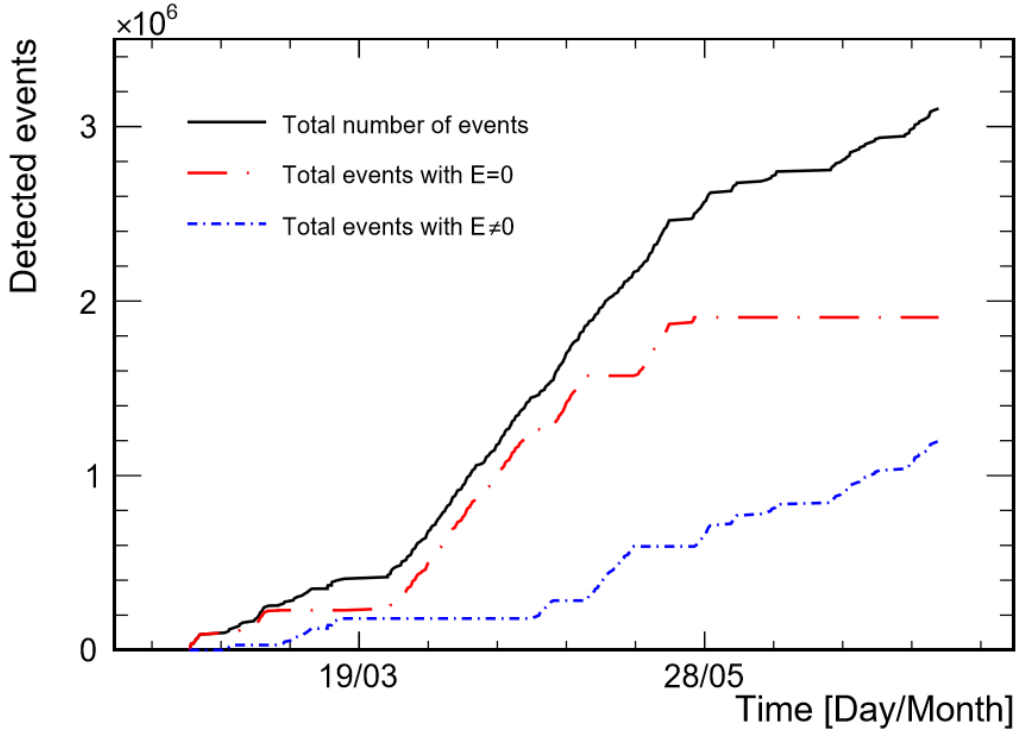
- Two X-ARAPUCA:
  - One is sensitive to both LAr and Xe light
  - One has a Quartz-window in front of it filtering the LAr light



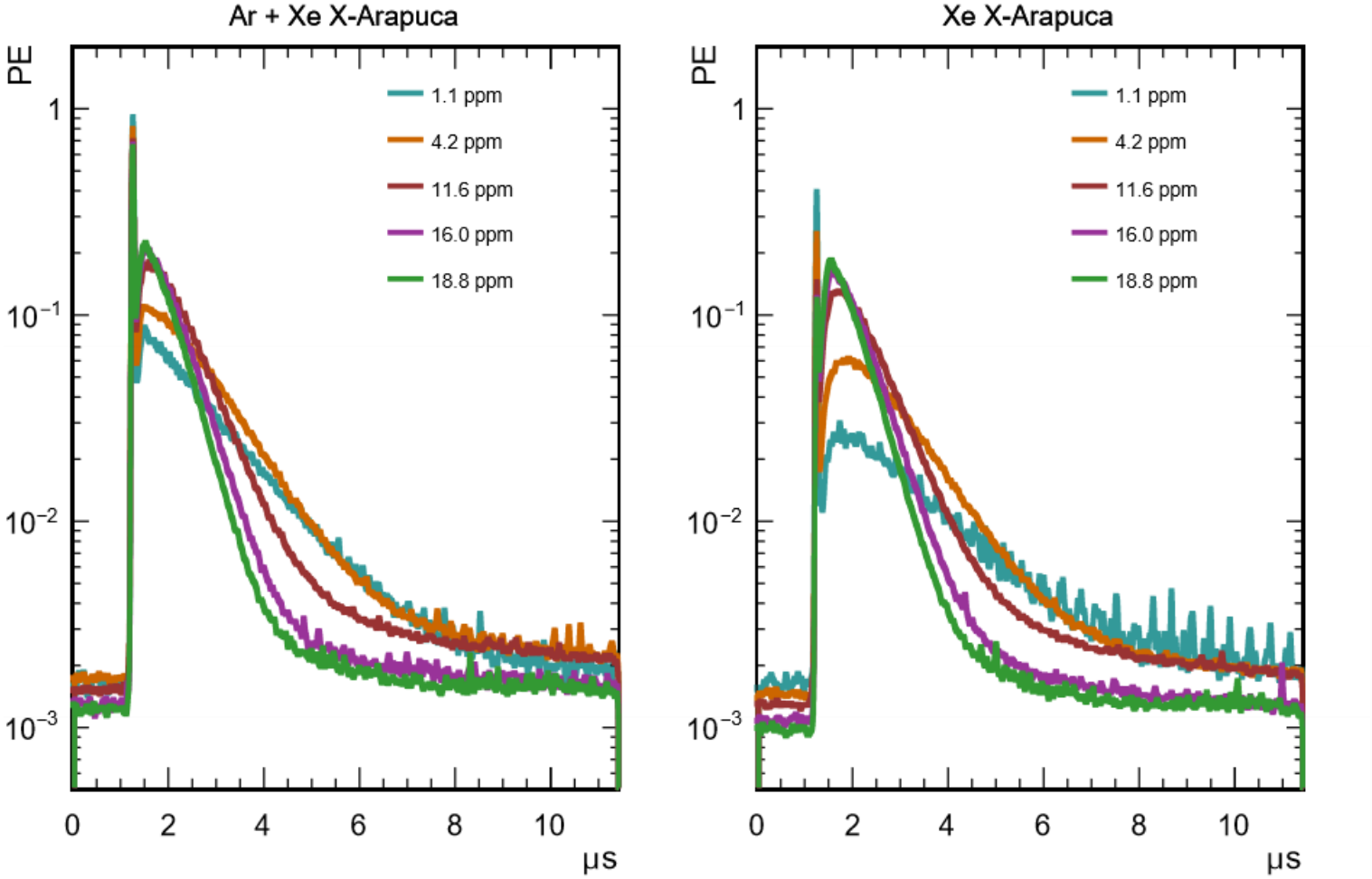
- The system is triggered by the coincidence of three paddles that select vertical cosmic rays

Data Sample

- Data consists of vertical cosmic rays
- The electrical field was set at different values during data-taking
- More than 3×10^6 events analyzed

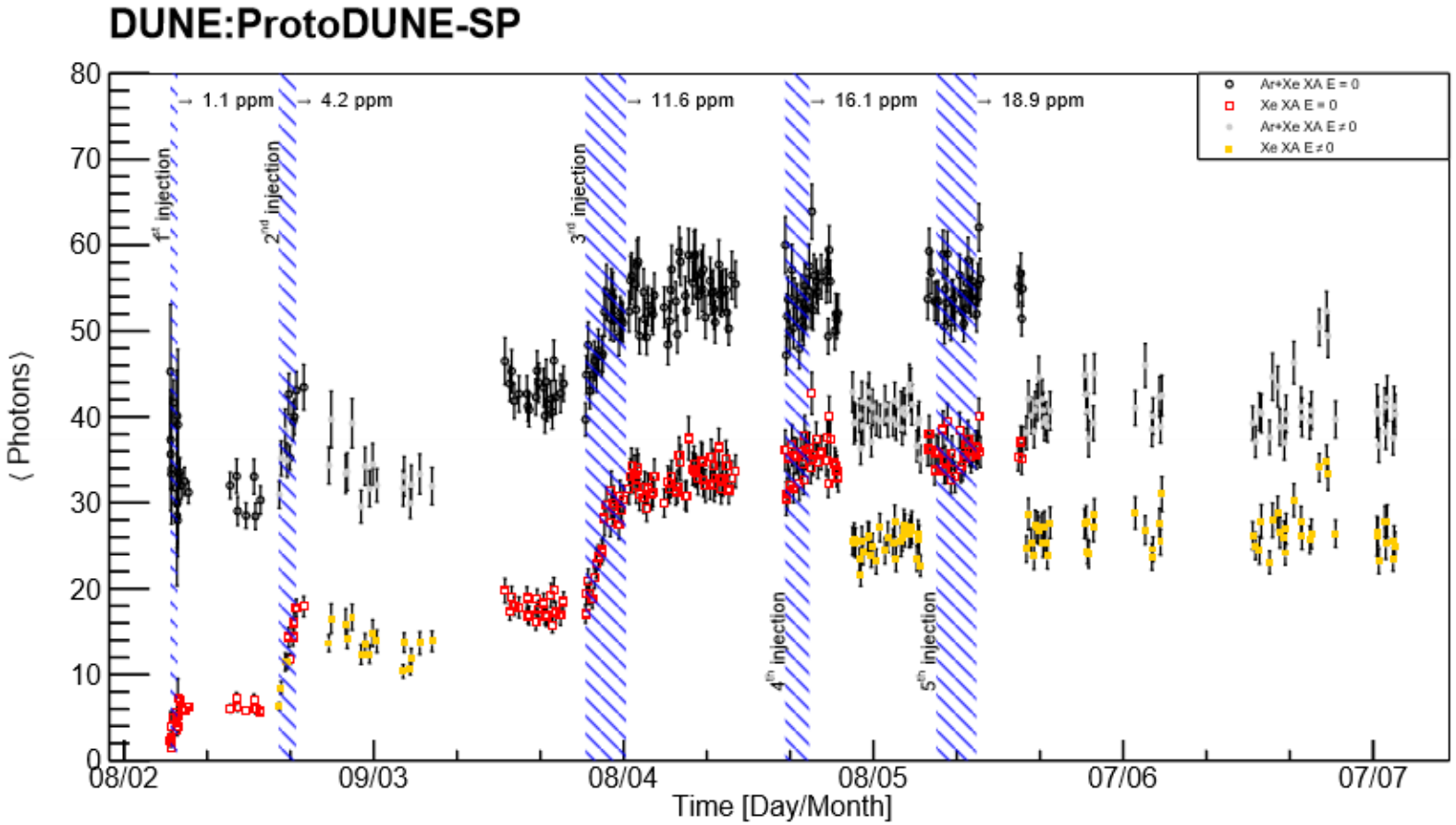


Light distribution



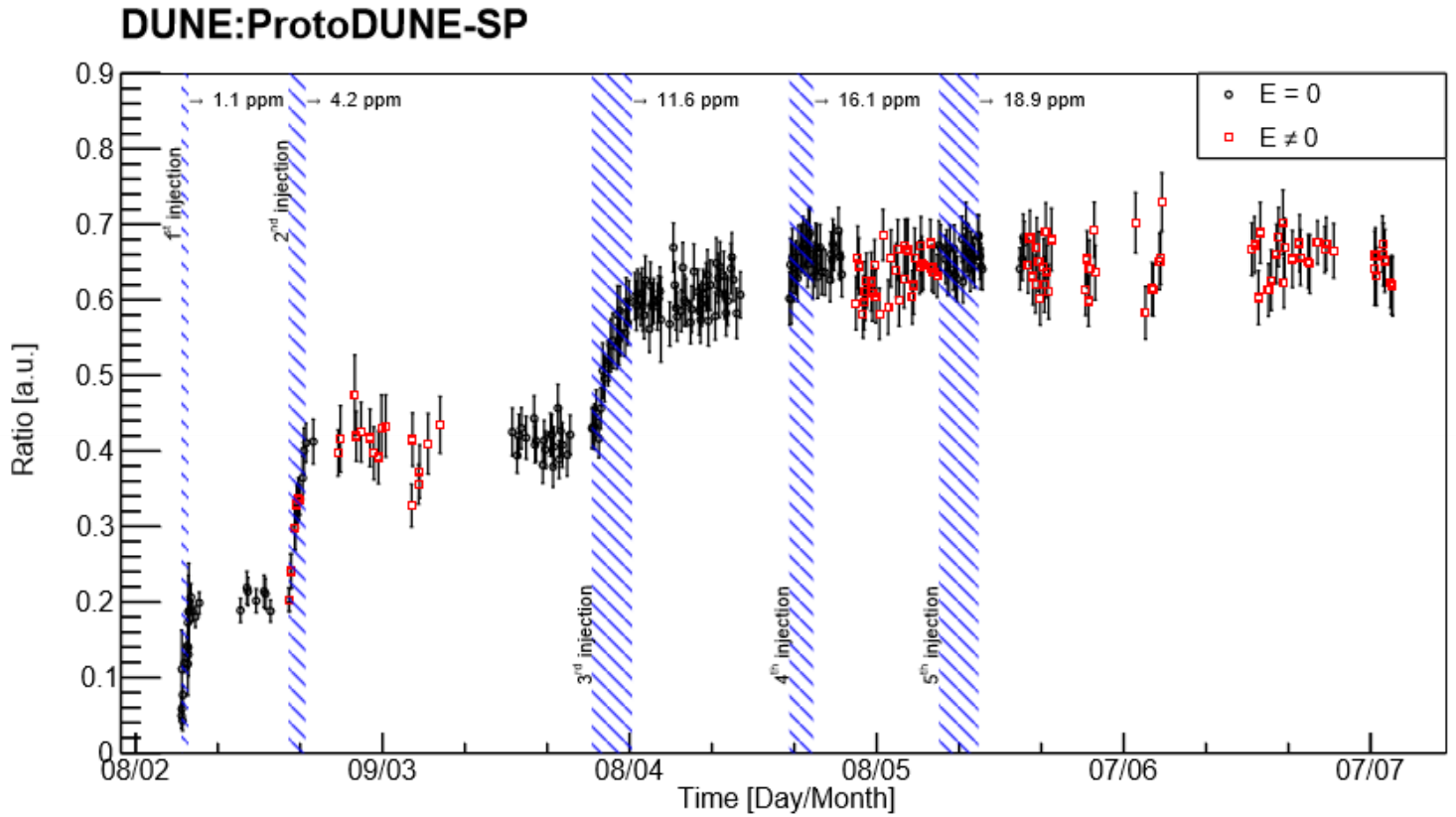
Light detected

- Total light detected by X-ARAPUCA telescope during the data acquisition

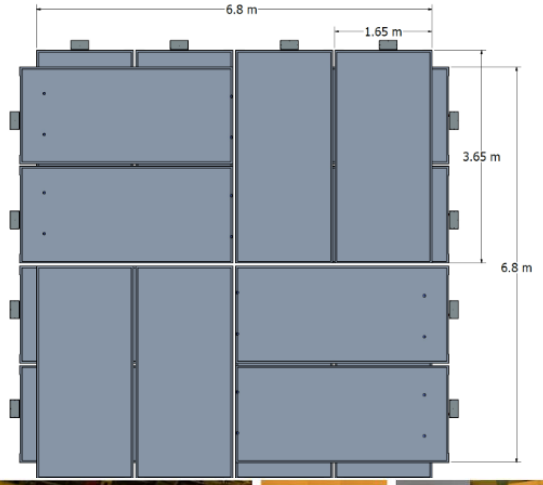


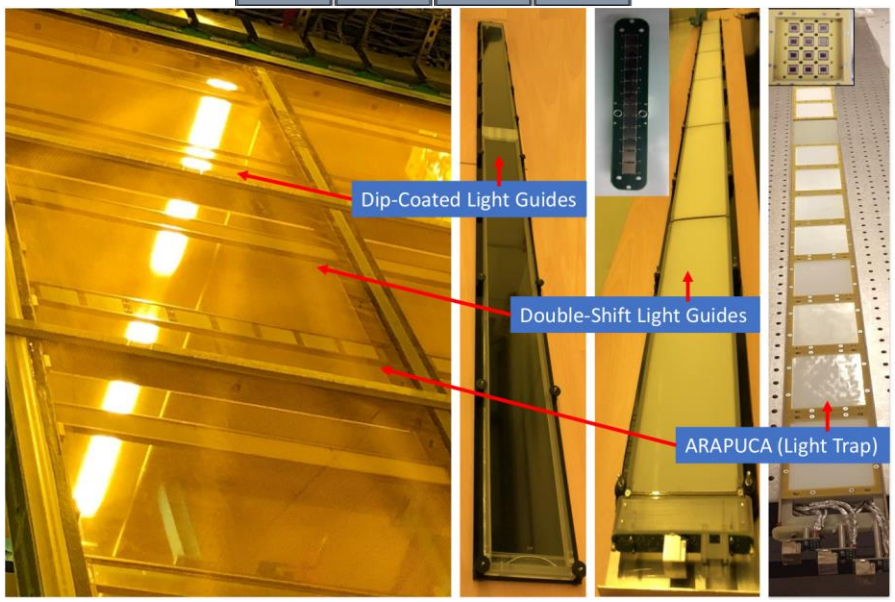
Ratio

- The ratio measures the amount of Argon light that is shifted to Xenon light
- It is measured as the ratio of the light detected by the Xe X-ARAPUCA and the light detected by the Ar+Xe X-ARAPUCA



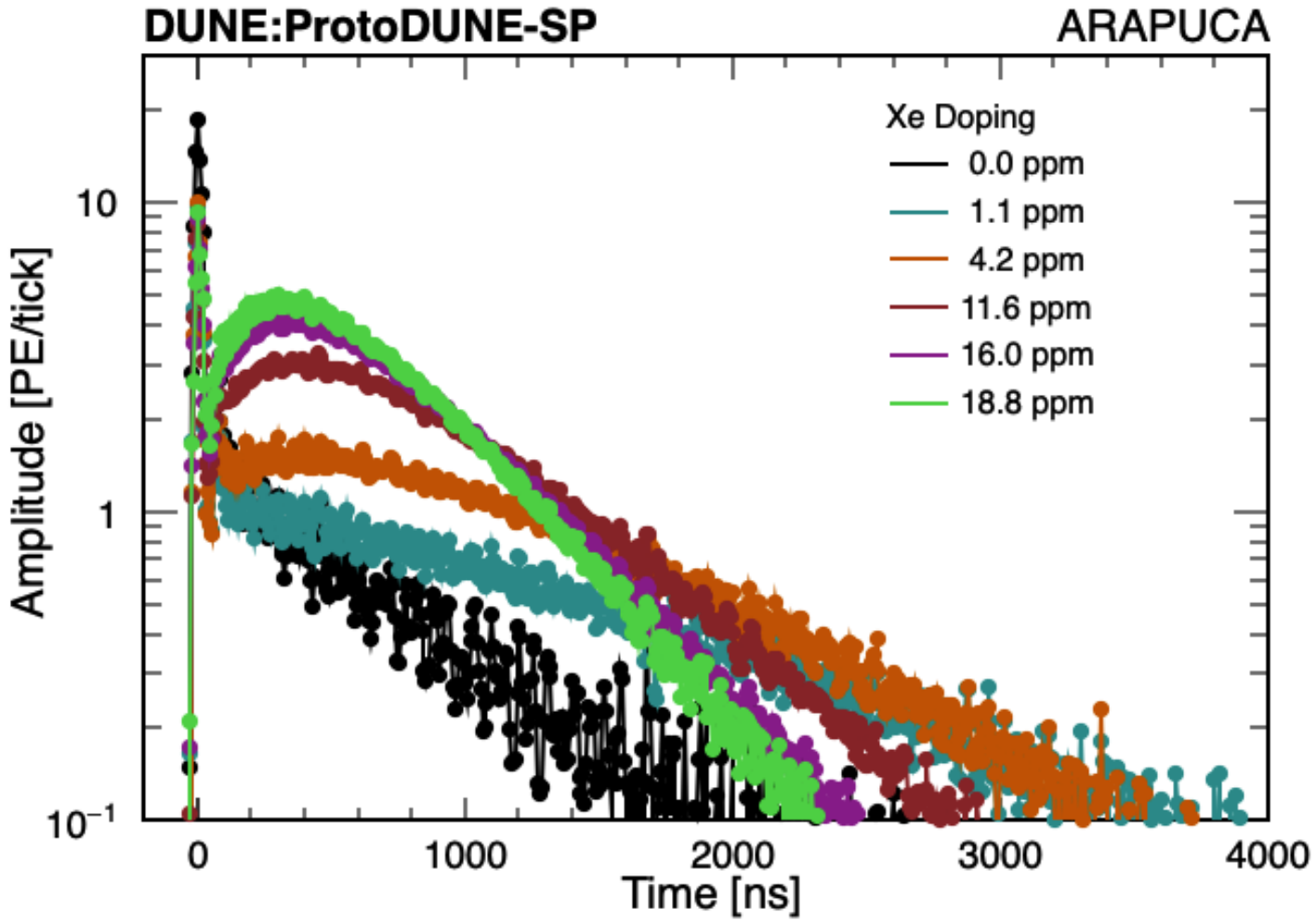
ProtoDUNE-SP PDS



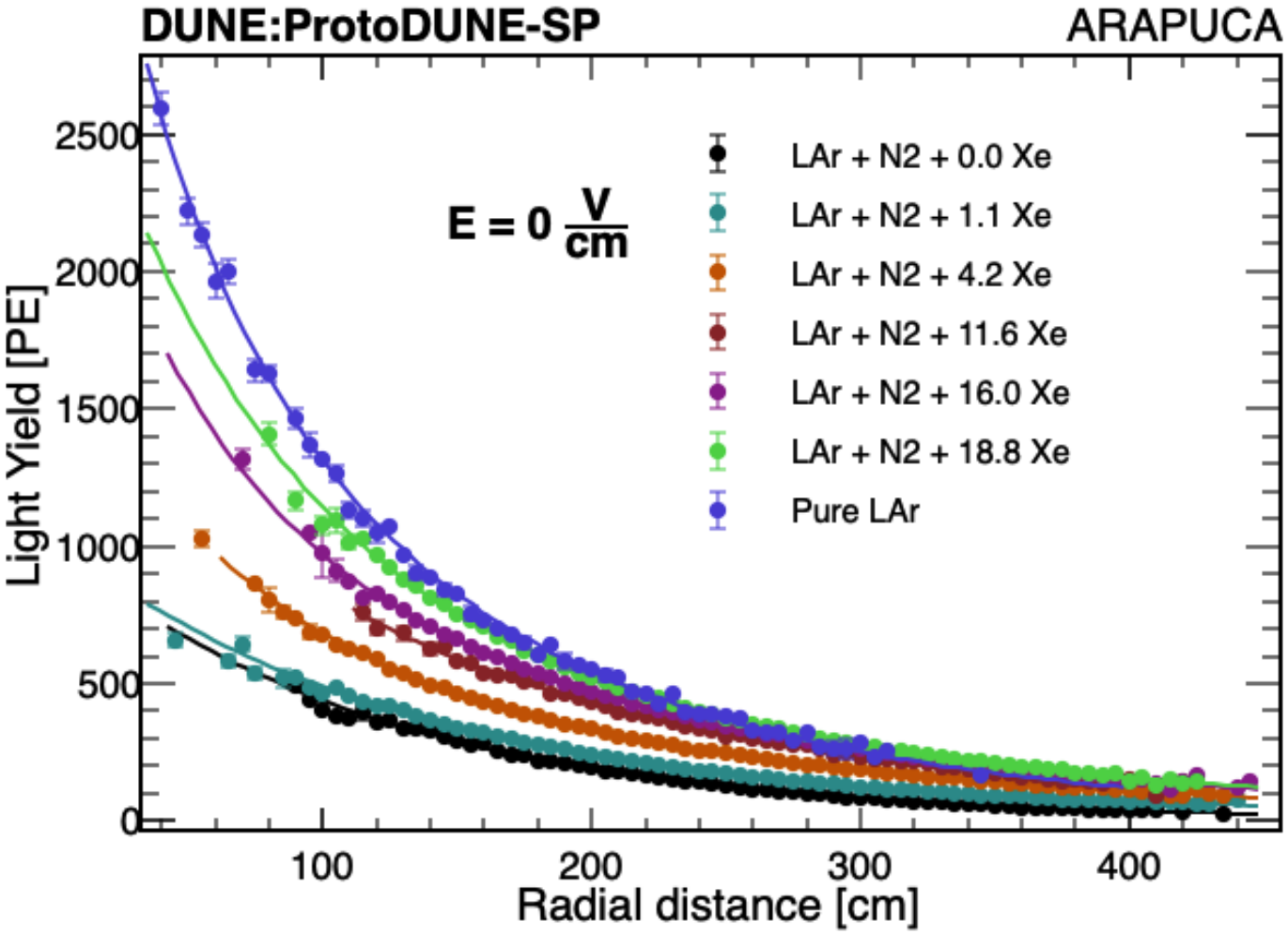


- Trigger on coincidence of Upstream and Downstream CRT
- If electric field is off, two consecutive APA PDS must be triggered by the track
- If electric field is at nominal value, also the track reconstructed angle is compared with CRT
- With this method it is possible to know the geometry of the track

Light distribution

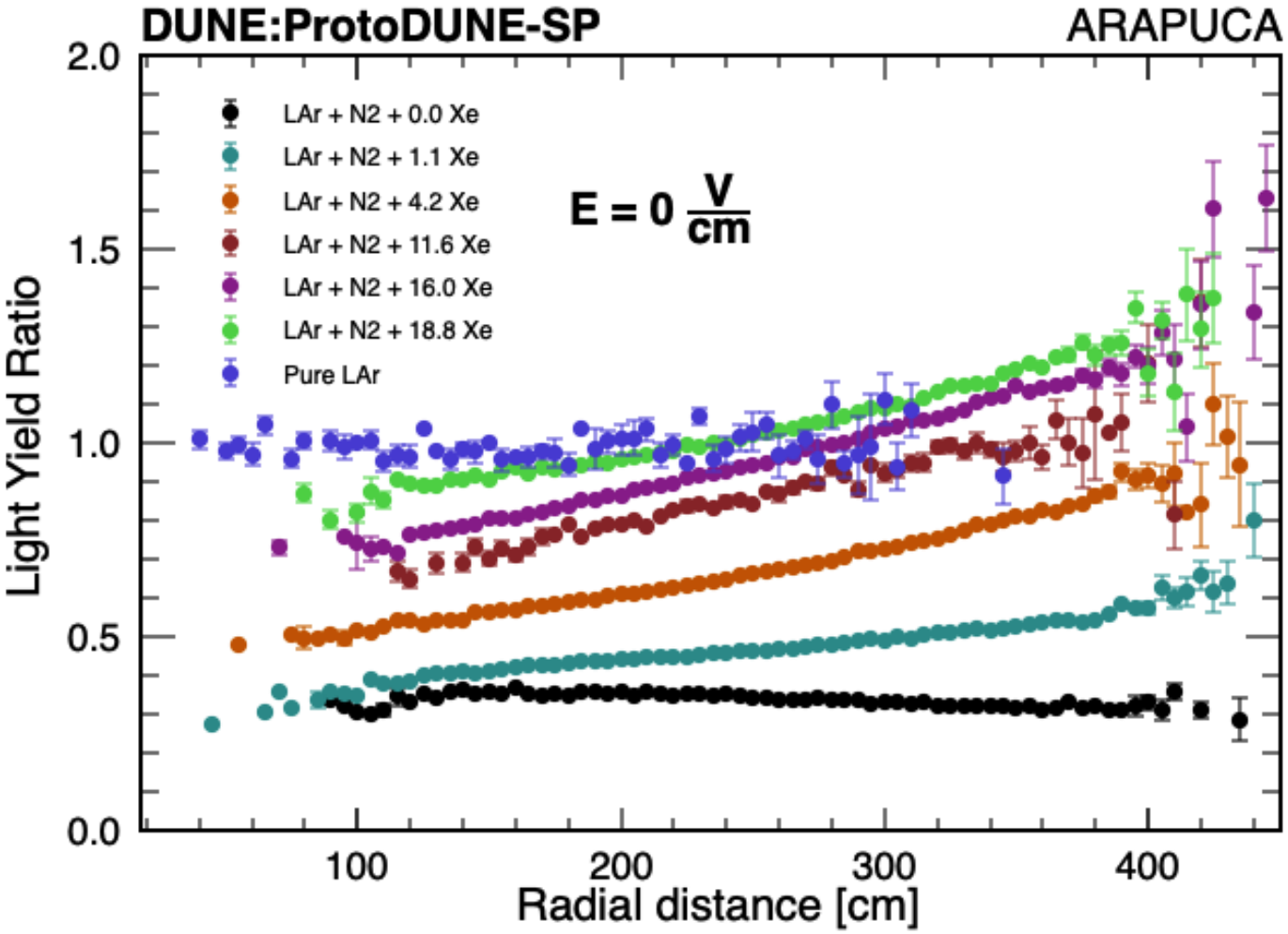


Light vs Doping (I)



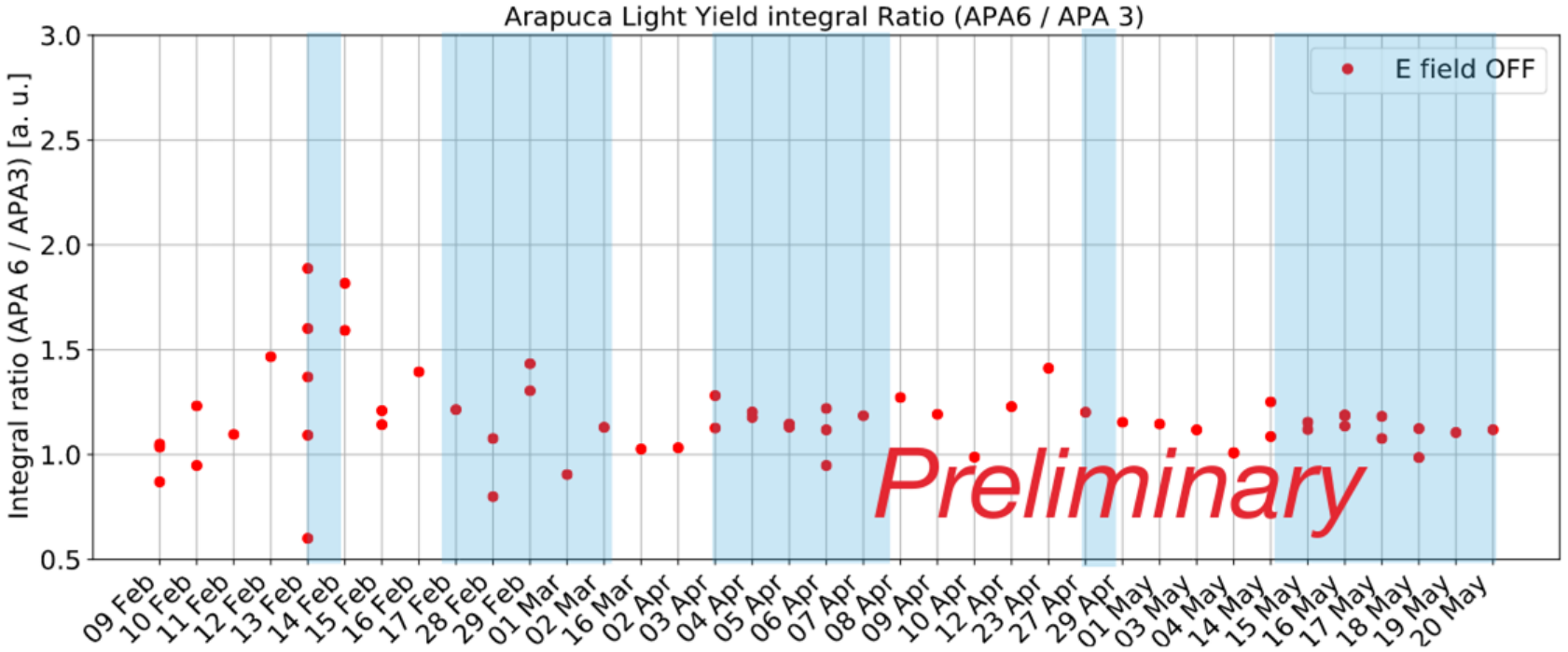
- Light detected as a function of track distance from PDS
- 95% of light recovered

Light vs Doping (II)



- Attenuation of light with respect to LAr measurements

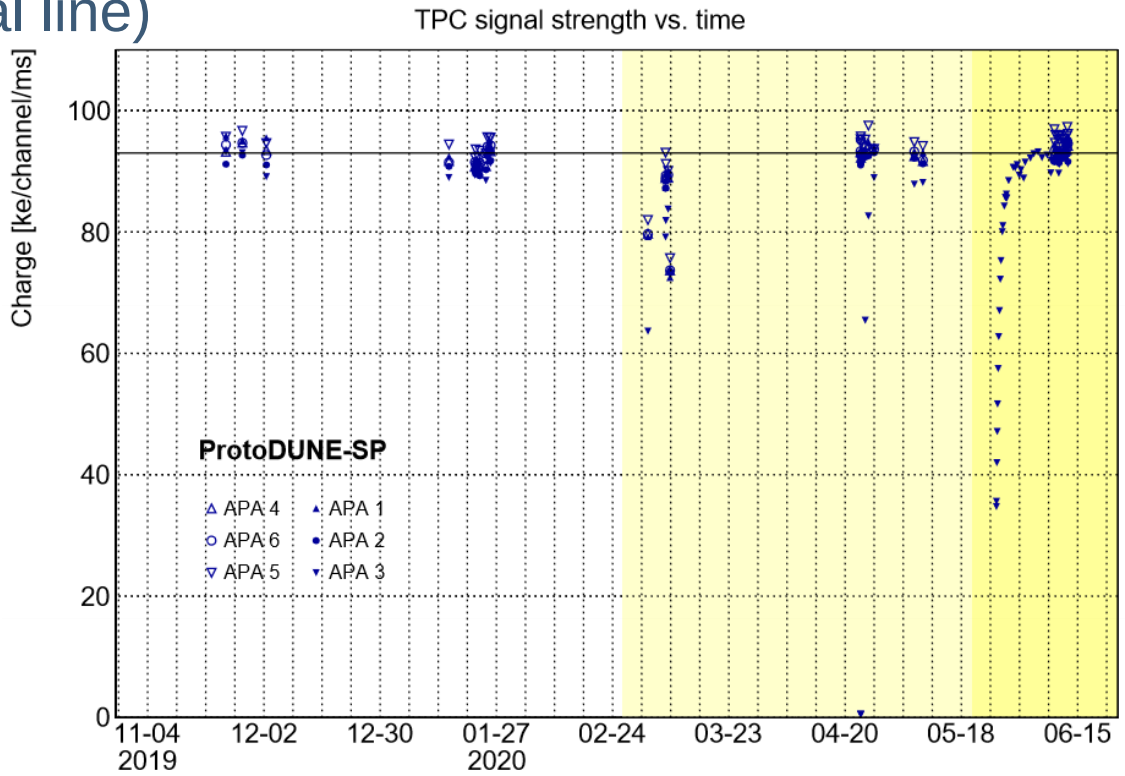
Light vs Time



- Ratio of light detected by ARAPUCA in APA6 with respect to the on of APA3

Charge analysis

- The signal strength is stable during the doping period and after the doping.
- It reaches the pure LAr reference value of $93\ ke^{-}/ch/ms$ (horizontal line)



Conclusions

- First large-scale Xenon Doping in LAr
- In total 13.5 kg of Xe, 18.9 ppm in mass injected into the cryostat
- Uniform distribution of Xenon inside the active volume
- Already at ~10 ppm level LAr slow component has been almost converted into Xe light
- Additional Xe introduced into the cryostat did not had significant effect
- Total light detected has increased, the 95% of the light was recovered
- More uniform light response along the drift direction
- The charge collection is not affected by the Xenon doping

THANK YOU