Photon detection system for ProtoDUNE at CERN

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Introduction and Outline

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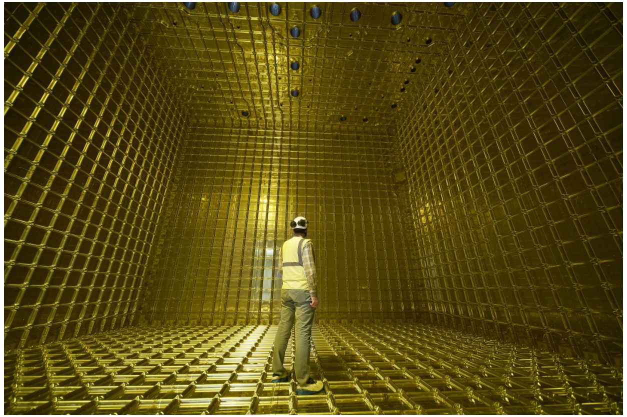
Introduction to ProtoDUNE

- ProtoDUNE is a prototype detector for the Deep Underground Neutrino Experiment (DUNE)
- It is the largest liquid-argon time projection chamber (TPC) ever constructed
- First data taking in 2018

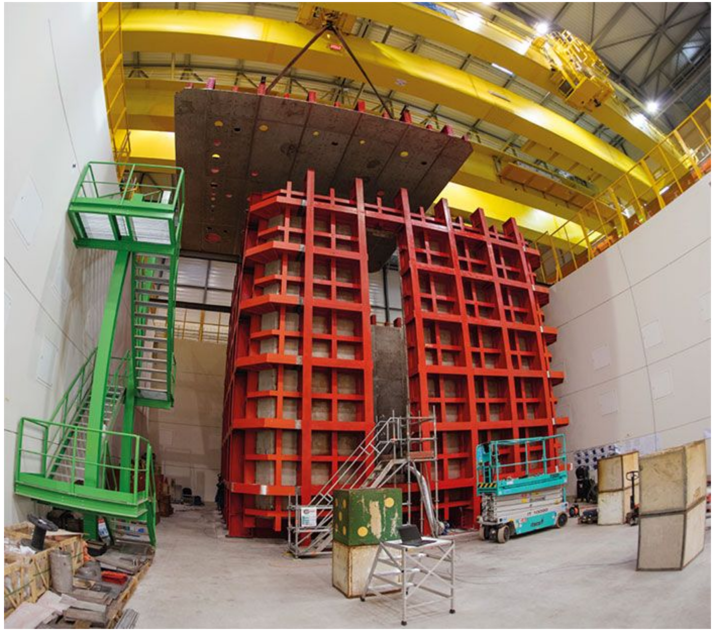


Introduction to ProtoDUNE

- Testing the design, assembly, and installation procedures
- Data acquisition, storage, processing, and analysis
- beam data taking and cosmic ray data
- 2 types of geometries - VD and HD

Design and Technology

- The detector uses liquid argon as the medium to detect neutrino interactions
- Liquid argon works as a scintillator
- Based on the geometry, we can reconstruct the tracks of charged particles
- active volume of 6×6×6 m3
- active mass of mass of 300 t

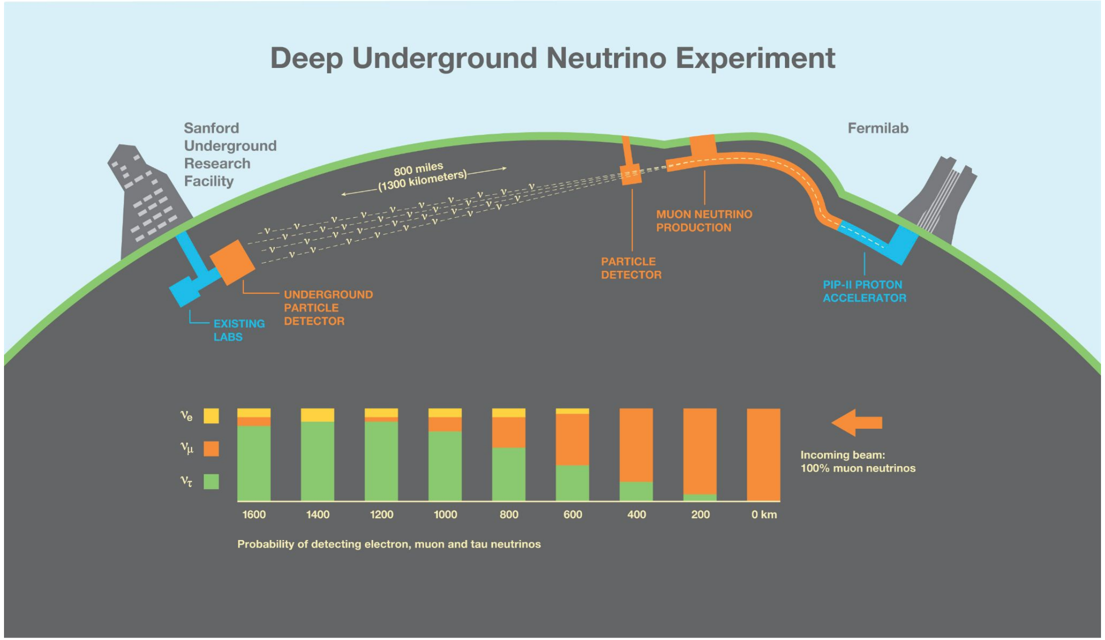


Photon detection at ProtoDUNE

- 36 8-inch cryogenic photomultipliers
- Tetraphenyl butadiene (TPB) is coated directly on the PMTs
- Modification of the PMTs - 14 dynodes are used instead of 10
- External DAQ system records the light signal

ProtoDUNE in the context of DUNE

- The final aim is to build underground detector in South Dakota
- Near detector at Fermilab and a far detector at SURF
- Sending muon neutrino beam through the ground
- The ratio of the neutrino types is changing
- The final ratio should help us to understand the neutrino oscillations



ProtoDUNE in the context of DUNE

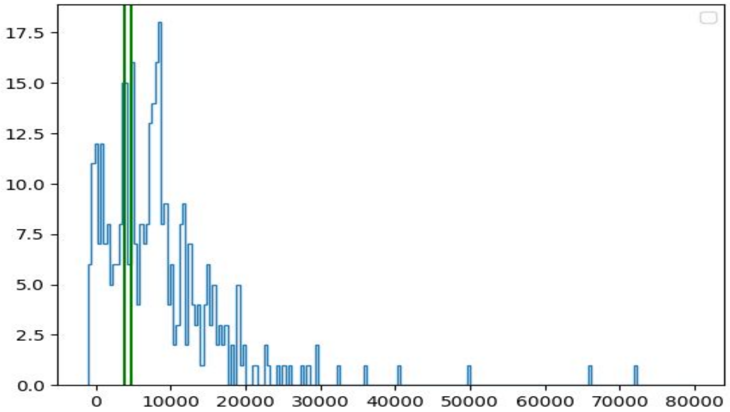
- 20-year period of data collection
- The primary science objectives:
  - Investigation of neutrino oscillations to test CP violation in the lepton sector
  - Determination of the ordering of the neutrino masses
  - Studies of supernovae and the formation of a neutron star or black hole
  - Search for proton decay
- Main competition with Hyper-Kamiokande
- DUNE data taking in the early 2030's - delays

SPE Calibration

- Calibration runs with LED source
- Calculation of the gain and SNR out of the charge histogram
- We use these runs for creating the SPE template

$$\text{Gain} = \mu_1 - \mu_0$$

$$SN_C = \frac{\text{Gain}}{\sqrt{\sigma_0^2 + \sigma_{1st}^2}}$$

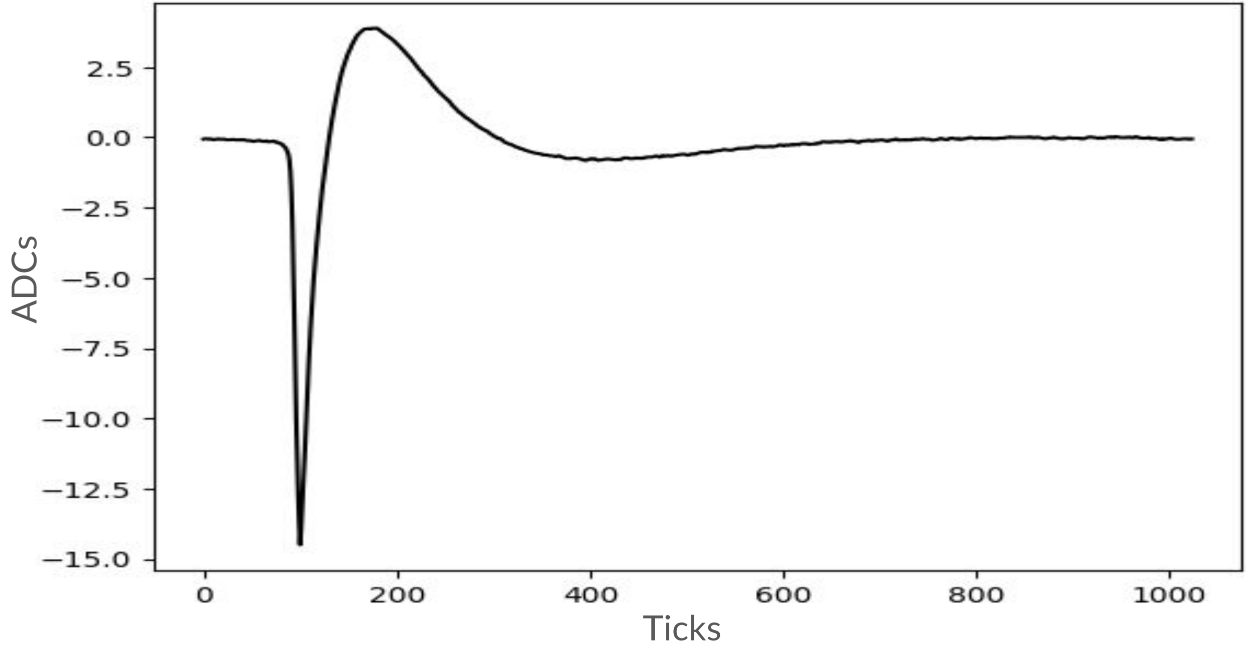


Charge histogram

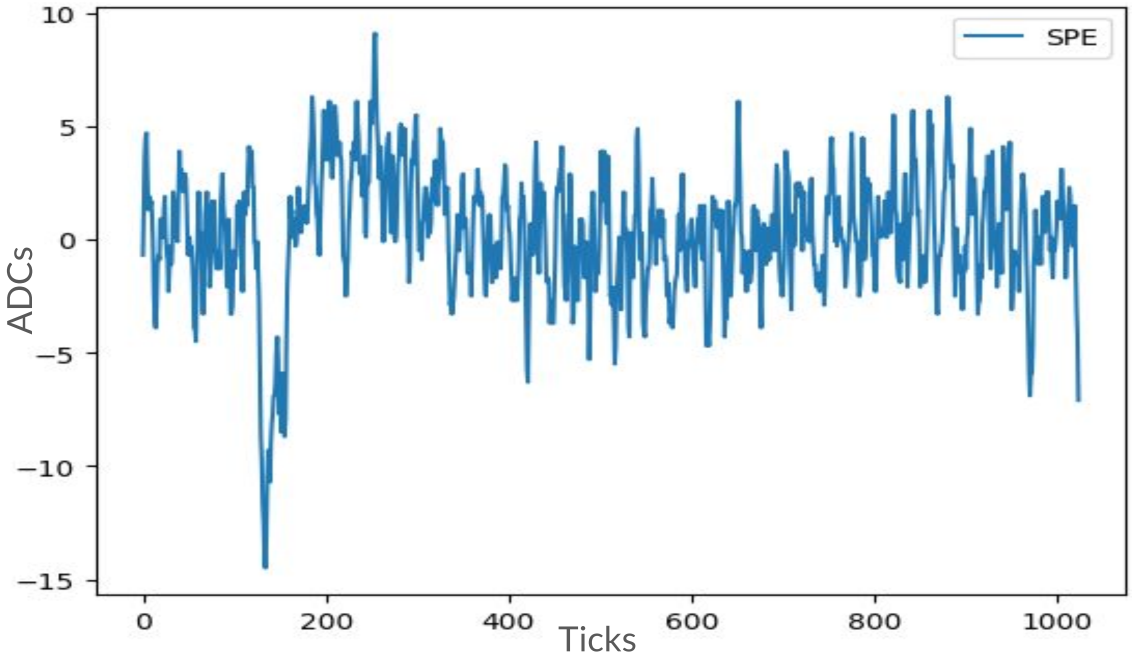
Templates for the deconvolution

- Signal from the detector is convoluted, we need to deconvolute
- One template of single photoelectron signal for each channel
- In total 160 templates
- We are using calibration runs (LED)
- SPE as well as MPE events (rescaled) -> large statistics

This is what we want the signal to look like



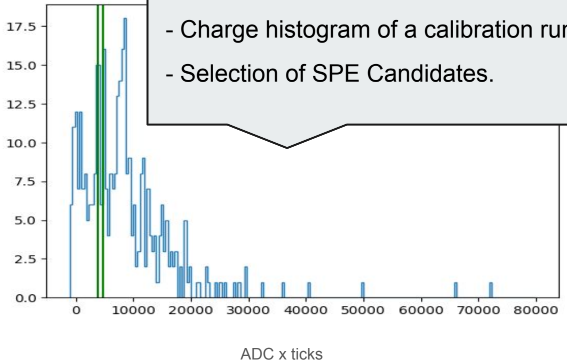
And this is how it looks like

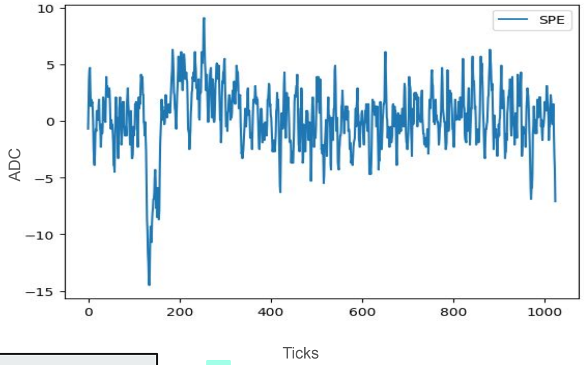


SPE templates

1st step:

- Charge histogram of a calibration run ;
- Selection of SPE Candidates.



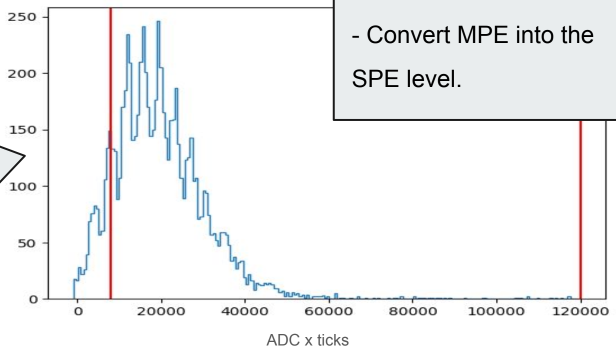


2nd step:

- Computing the average waveform of a SPE.

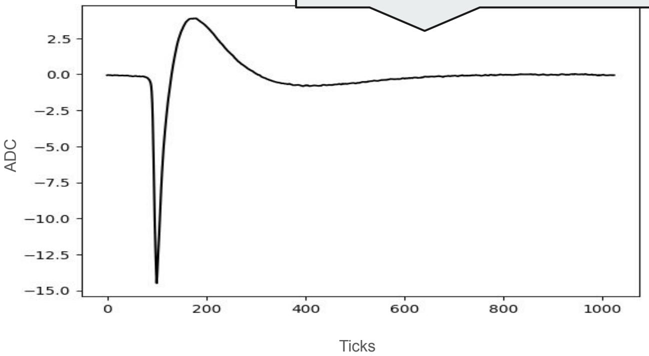
3rd step:

- Charge histogram of a calibration run ;
- Selection of MPE



4th step:

- Convert MPE into the SPE level.



Final step:

- Calculate the SPE template by the average of the waveforms.

Deconvolution

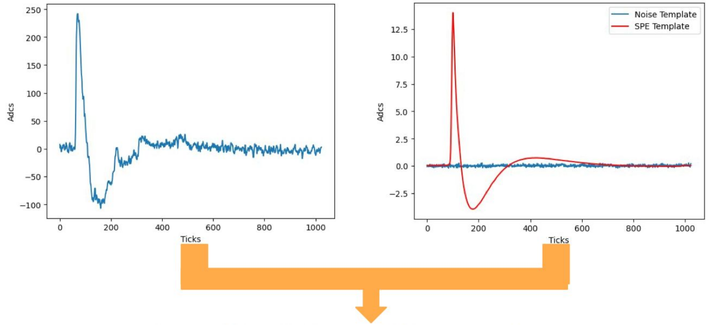
- Based on the SPE and noise templates
- We want to subtract the real scintillation signal
- Noise, overshoots (electronics)
- The method
  - Input: Real signal + noise template + SPE template
  - Filter application (Wiener or Gauss)
  - Computation of the inverse fourier transformation
  - Optional: second filter application on the deconvolved signal
  - Fit

-> try:

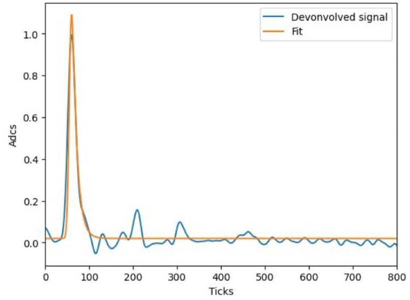
$$fit = \frac{A_S}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_S}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_S}\right) e^{\frac{t-t_0}{\tau_S}} + \frac{A_F}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_F}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_F}\right) e^{\frac{t-t_0}{\tau_F}}$$

-> except:

$$fit = \frac{A_S}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_S}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_S}\right) e^{\frac{t-t_0}{\tau_S}} + \frac{A_I}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_I}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_I}\right) e^{\frac{t-t_0}{\tau_I}} + \frac{A_F}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_F}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_F}\right) e^{\frac{t-t_0}{\tau_F}}$$



Tau_Slow (ns) = 1437.9662761898703 +- 1.2916885792227093e-12
Tau_Fast (ns) = 9.024910321608596 +- 3.2664985155885656e-15
Tau_Intermediary (ns) = 167.6622543045856 +- 9.189659883283042



Outlook

- ProtoDUNE - during summer there was a beam data taking at the HD detector
- Refilling liquid argon from HD to VD cryostat
- Data taking at VD in spring 2025
- Aquisition and analysis of data -> valuable information for the construction of the DUNE far detector

Thank you for your attention!