

Update on light studies in ProtoDUNE-VD using PMTs

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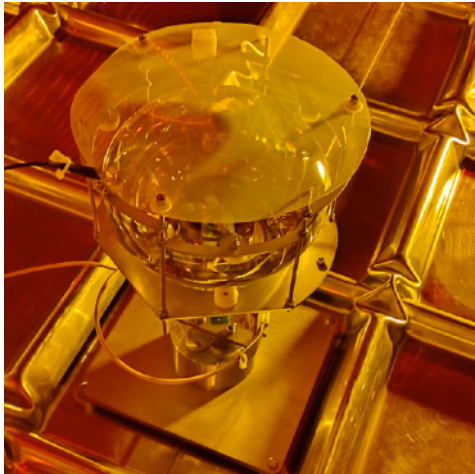


Objectives

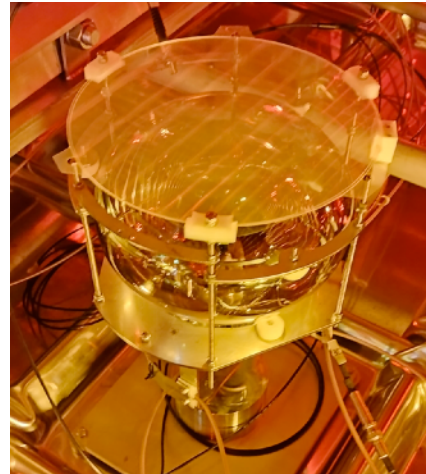
- » Understand the **time profile of the different time components** using various combinations of WLS (PEN, TPB), Quartz windows and Xenon concentrations
- » F

Installation aspects

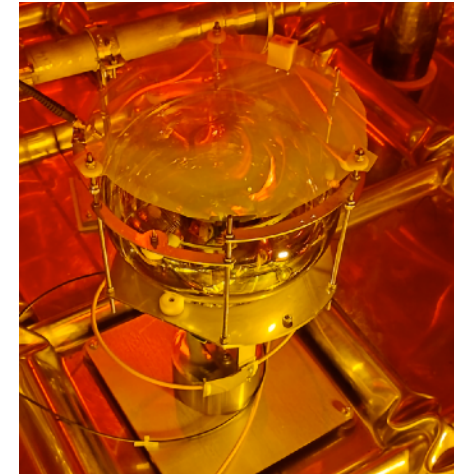
- » IFIC (J. Soto) organized and installed **Quartz windows** on several PMTs and X-ARAPUCAS on ProtoDUNE-VD
- » They are Photon Export UV Grade Fused Silica glasses, already characterized at IFIC



PMT with PEN



PMT with PEN and Quartz window



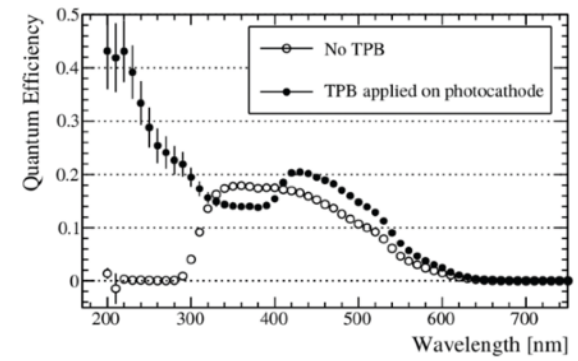
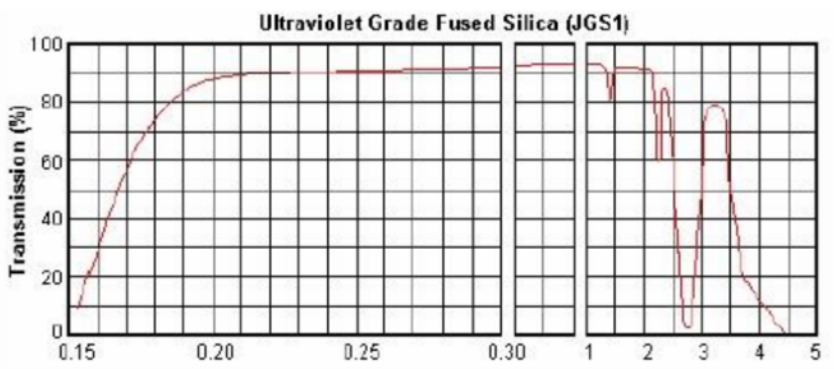
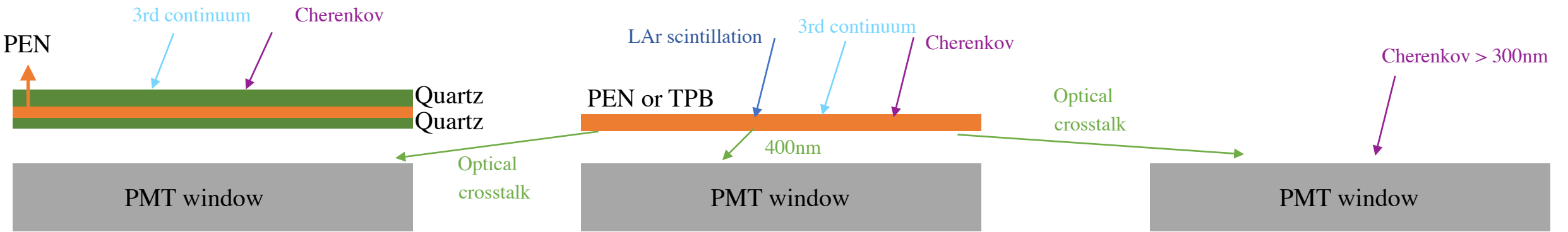
PMT with PEN next to the one with Quartz

1. Introduction - Light contributions in LAr

- ### PMTs with Q
- » Cherenkov from ~170nm
 - » Crosstalk from near PMTs

- ### PMTs with PEN or TPB
- » Scintillation from LAr at 128nm
 - » Cherenkov from ~128nm
 - » Optical crosstalk from near PMTs

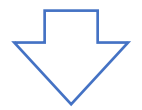
- ### PMTs with NONE
- » Cherenkov from ~300nm
 - » Crosstalk from near PMTs



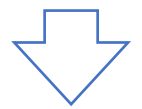
❖ An additional LAr fast component above 160nm has been shown in [Ettore's](#) presentation, that could be detected by the Quartz and PEN/TPB PMTs

2. Statistical analysis of events

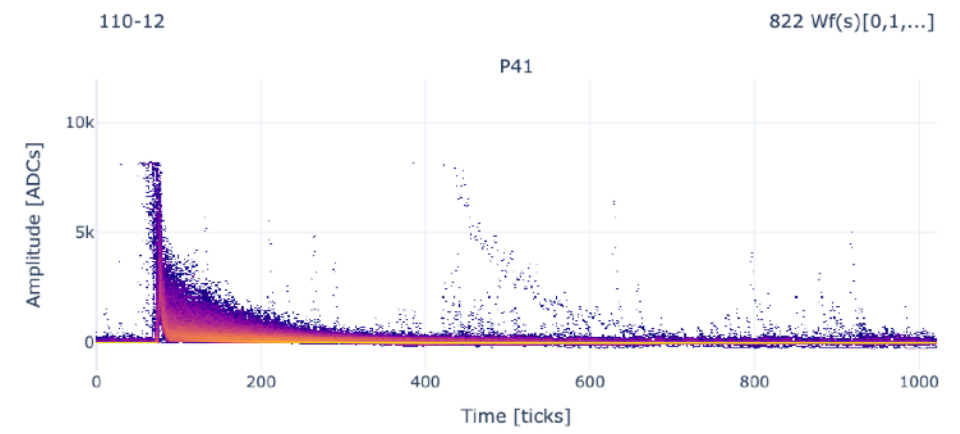
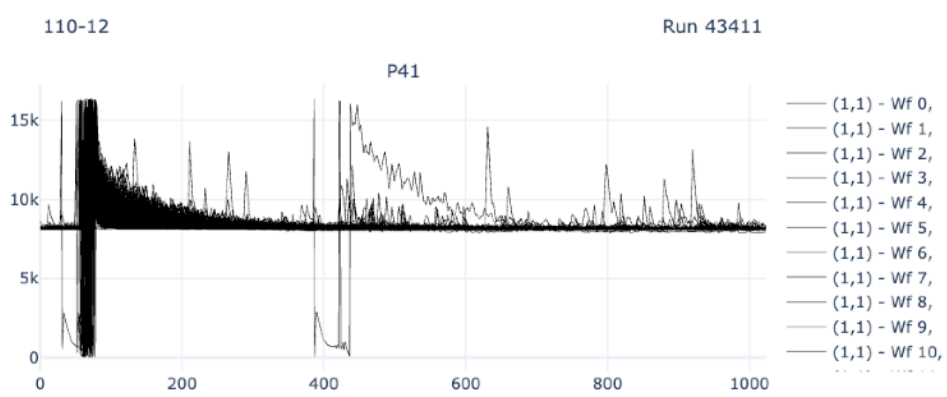
Visualization of raw waveforms



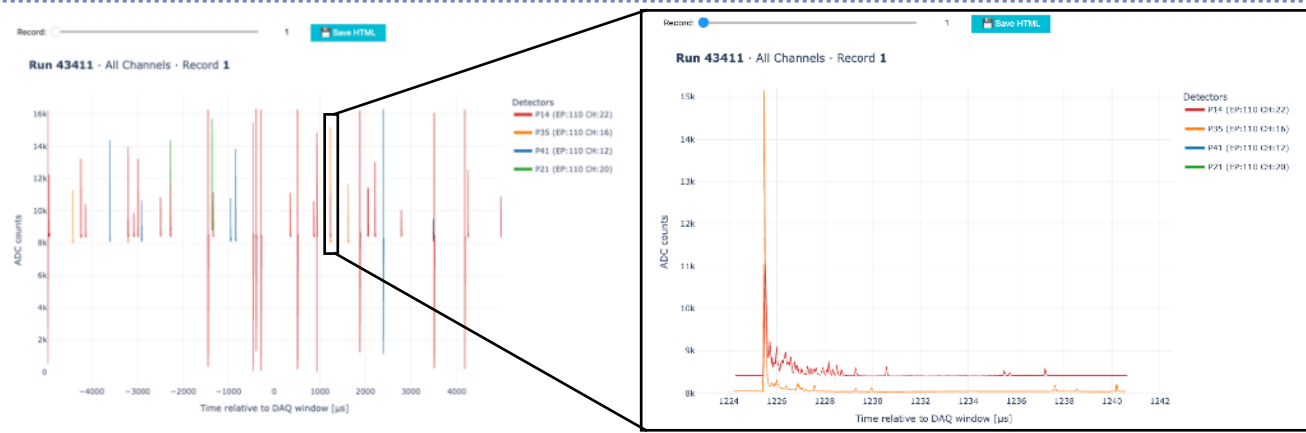
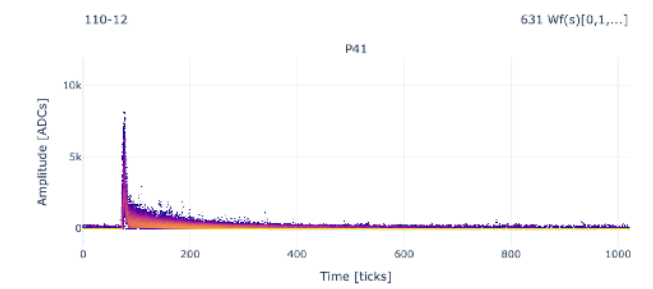
Apply generic cuts for all PMTs



Event selection (time matching) and statistical study



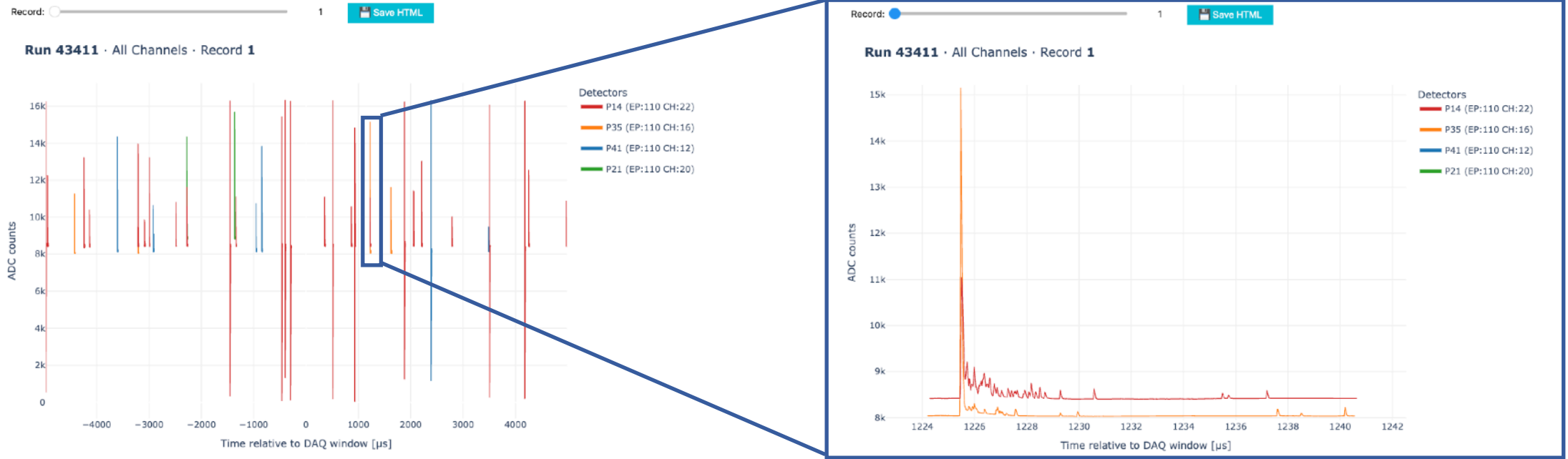
```
.defaultPcut: &defaultPcut
1: { t0: 0, tf: 67, threshold: 300, type: lower, filter: 0, npop: max }
2: { t0: 200, tf: 400, threshold: 1500, type: lower, filter: 0, npop: max }
3: { t0: 400, tf: 1024, threshold: 600, type: lower, filter: 0, npop: max }
4: { t0: 90, tf: 1024, threshold: 5110, type: lower, filter: 0, npop: max }
5: { t0: 0, tf: 1024, threshold: -300, type: higher, filter: 0, npop: min }
```



```
def get_synchronized_events(wfset, reference_endpoint, reference_channel,
                             fast_interval, total_interval,
                             tolerance=10, verbose=True):
    """
    Finds time-coincident events within the same record_number and
    calculates charge ratios (beta), delta t, and spatial radial
    coordinates (r) respect to PMTs.
    """
```

2. Statistical analysis of events - Time matching

Time matching to get an event



Input of the function

```
def get_synchronized_events(wfset, reference_endpoint, reference_channel,
                             fast_interval, total_interval,
                             tolerance=10, verbose=True):
    """
    Finds time-coincident events within the same record_number and
    calculates charge ratios (beta), delta t, and spatial radial
    coordinates (r) respect to PMTs.
    """
```

Output of the function

```
event_key = f"Event {found_events}"
final_events[event_key] = {
    'event_wfset': WaveformSet(*current_event_wfs),
    'n_pmt': len(current_event_wfs),
    'betas': betas,
    'beta_mean': beta_mean,
    'beta_std': beta_std,
    'dts': dts,
    'rs': rs,
    'r_mean': r_mean,
    'r_sigma': r_sigma,
    'record_number': record_no,
    'integrals': integrals,
    'amplitudes': amplitudes,
    'total_charges': total_charges
}
```

2. Statistical analysis of events - Events respect to PMT41

Example 1

DASHBOARD INTERACTIVO: RUN 43411 — Event 14 (Record 3)
PMTs Coincidentes: 7 | Beta Media Evento = 0.363 | Radio Medio Evento = 473.2 mm



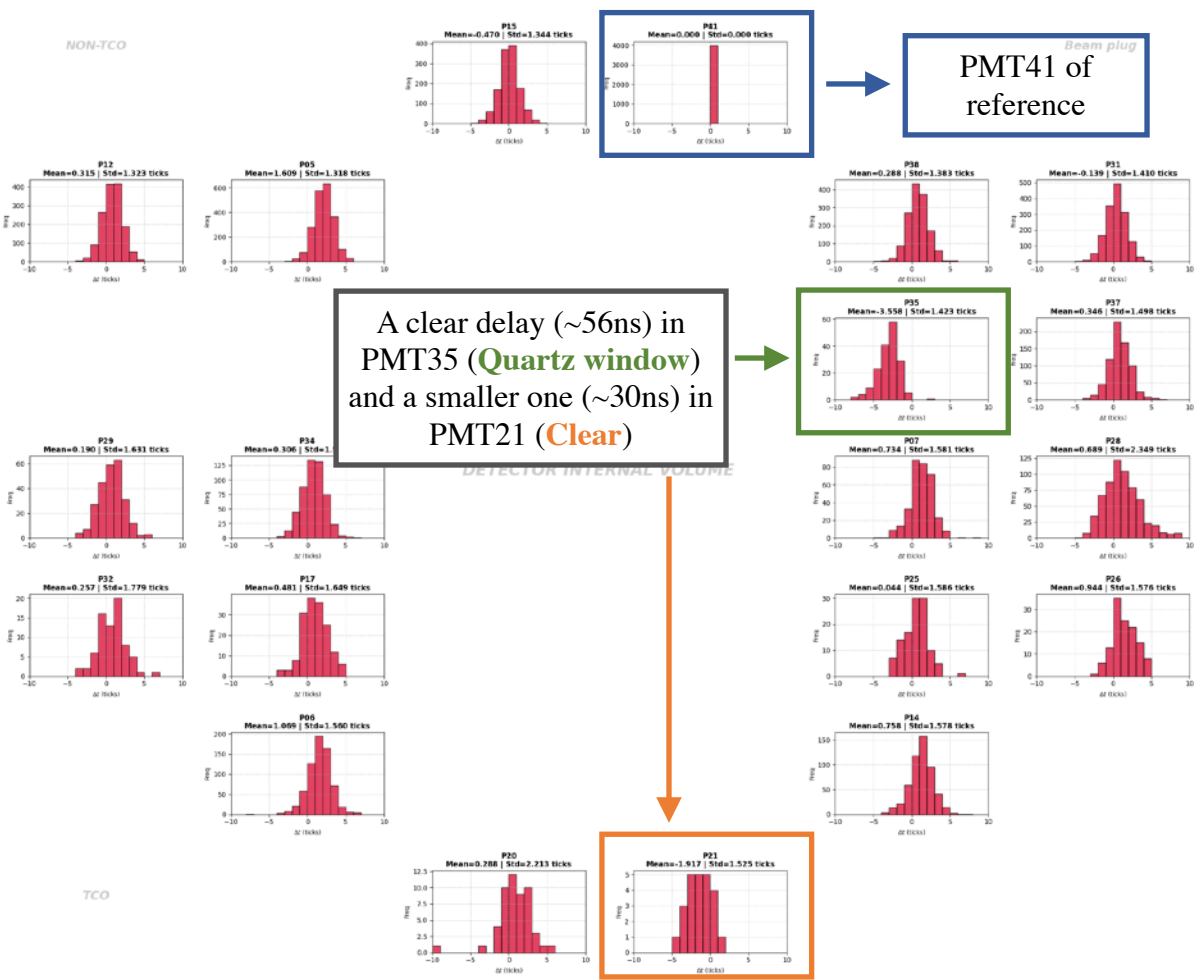
Example 2

DASHBOARD INTERACTIVO: RUN 43411 — Event 47 (Record 9)
PMTs Coincidentes: 4 | Beta Media Evento = 0.249 | Radio Medio Evento = 498.1 mm

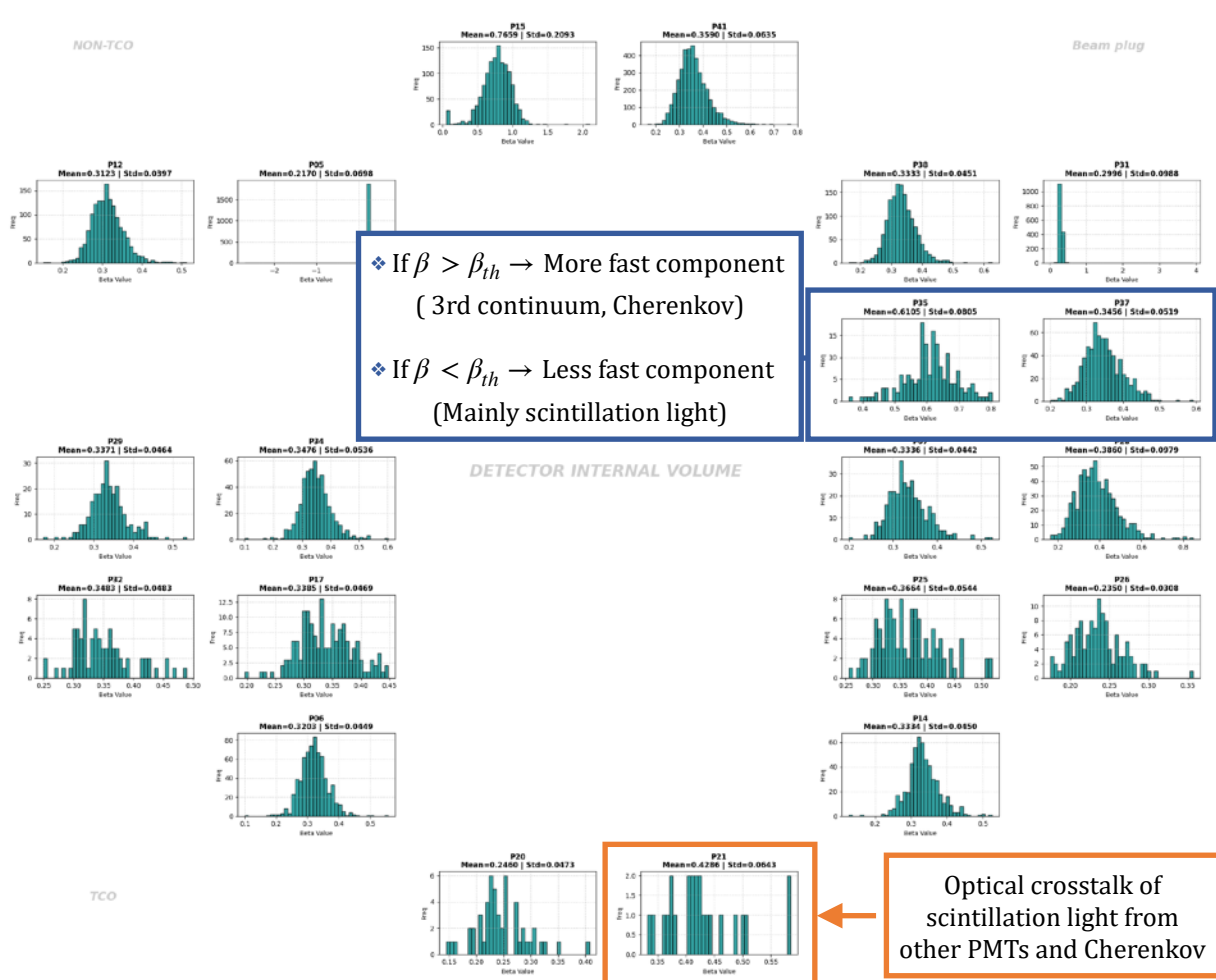


2. Statistical analysis of events - Events respect to PMT41

$$\Delta t = t_{pmt} - t_{ref}$$



$$\beta = Q_{fast} / Q_{total}$$

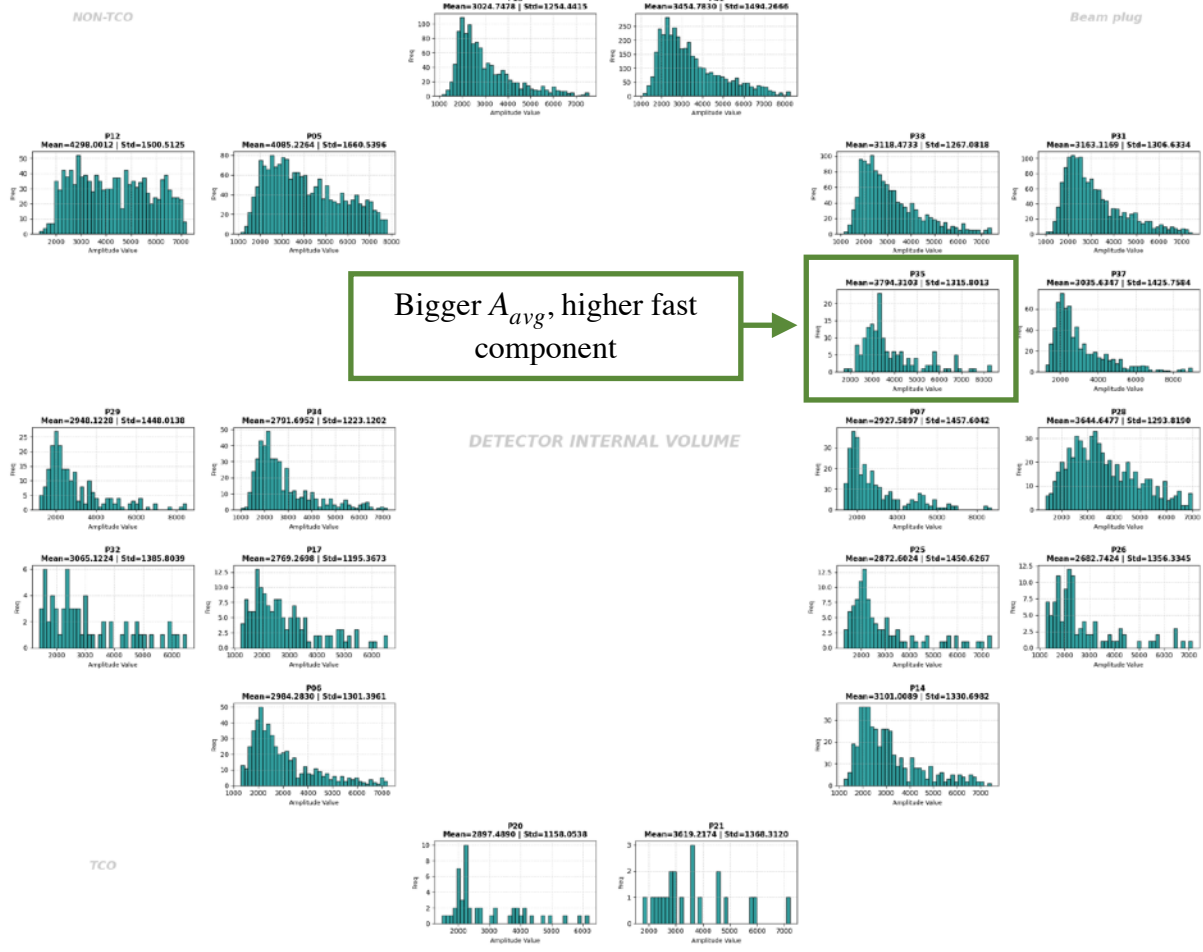


2. Statistical analysis of events - Events respect to PMT41

Q_{total}

Amplitude (A)

A > 1000 adcs in all cases



2. Statistical analysis of events - Events respect to PMT41

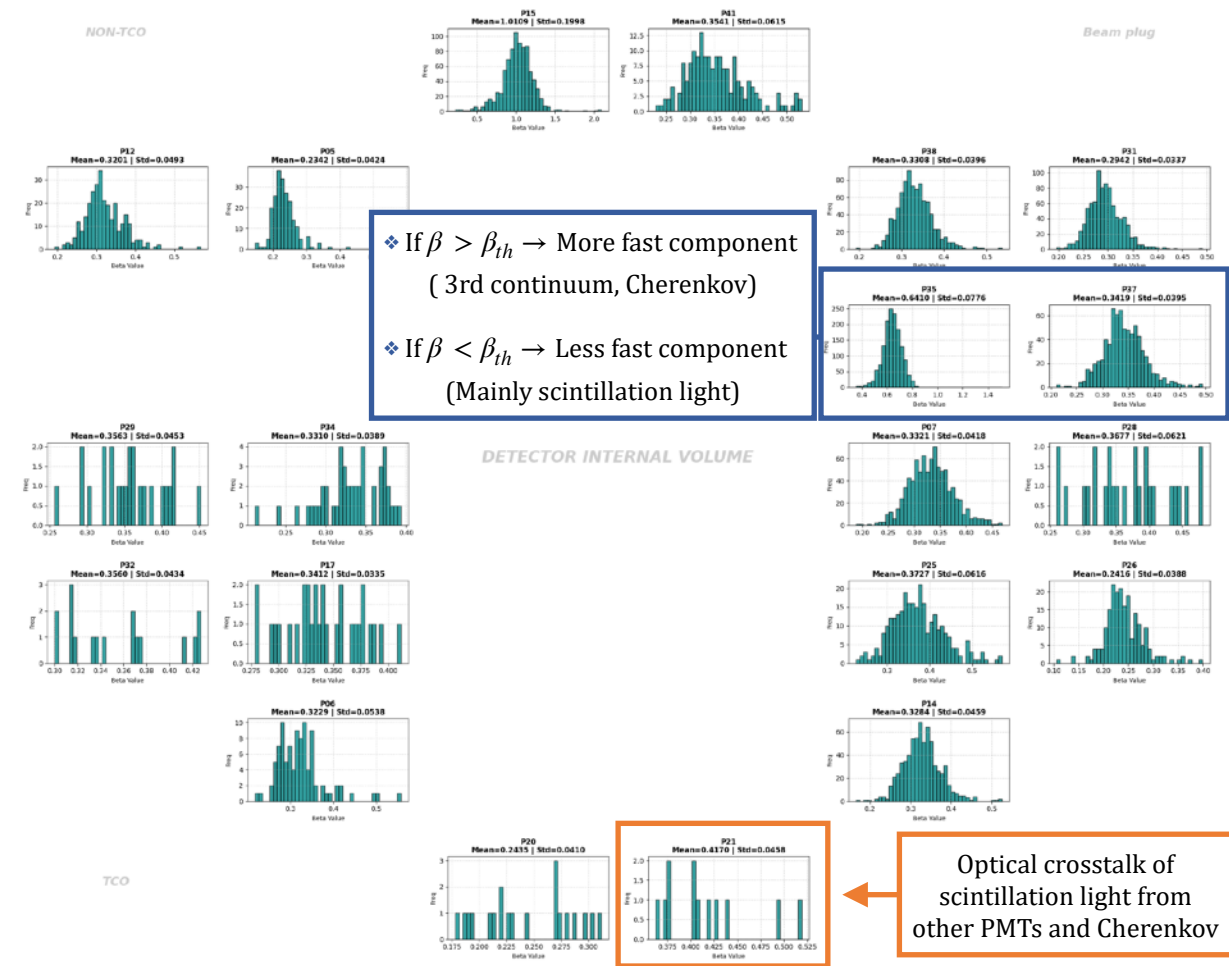
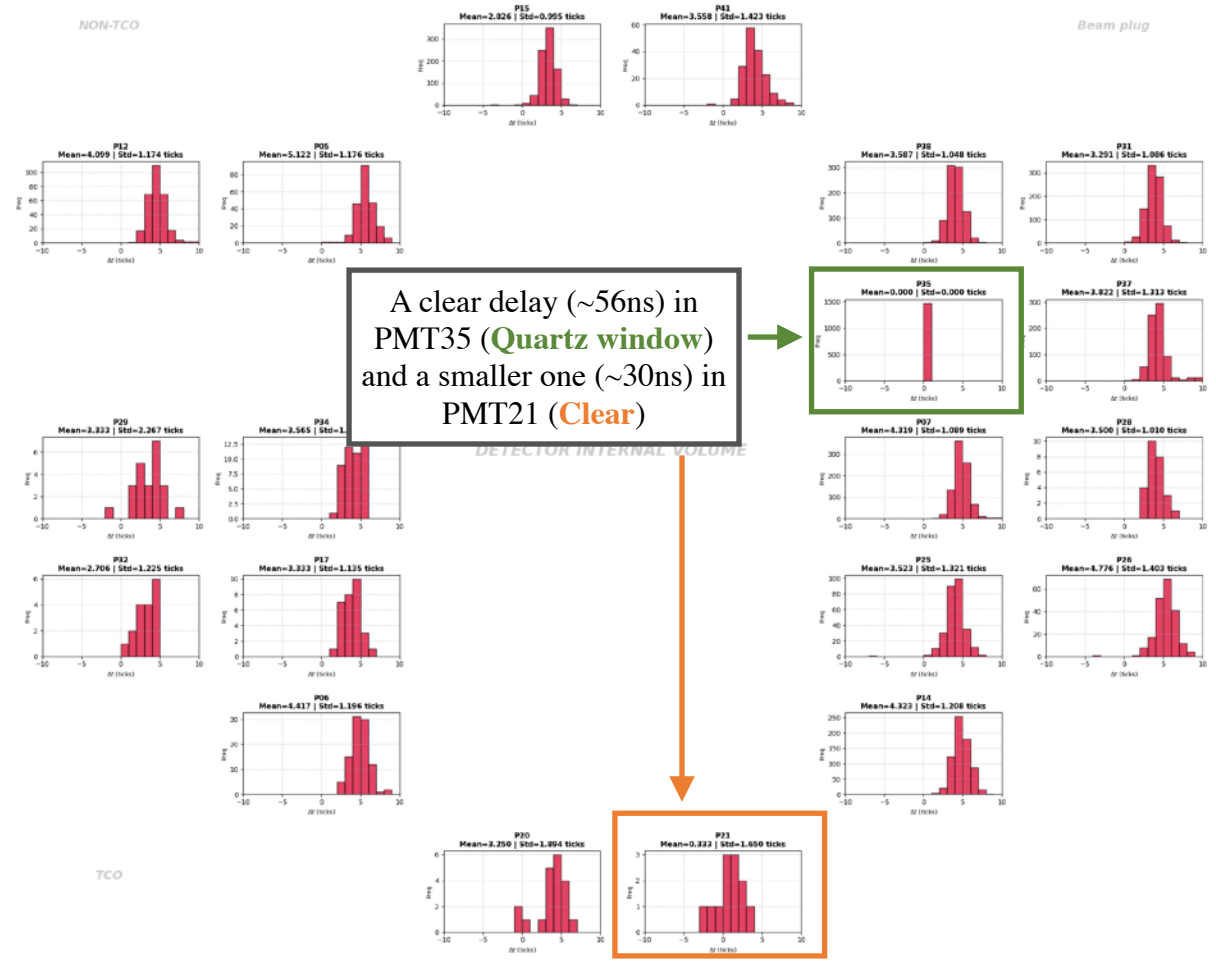
Average waveform



2. Statistical analysis of events - Events respect to PMT35

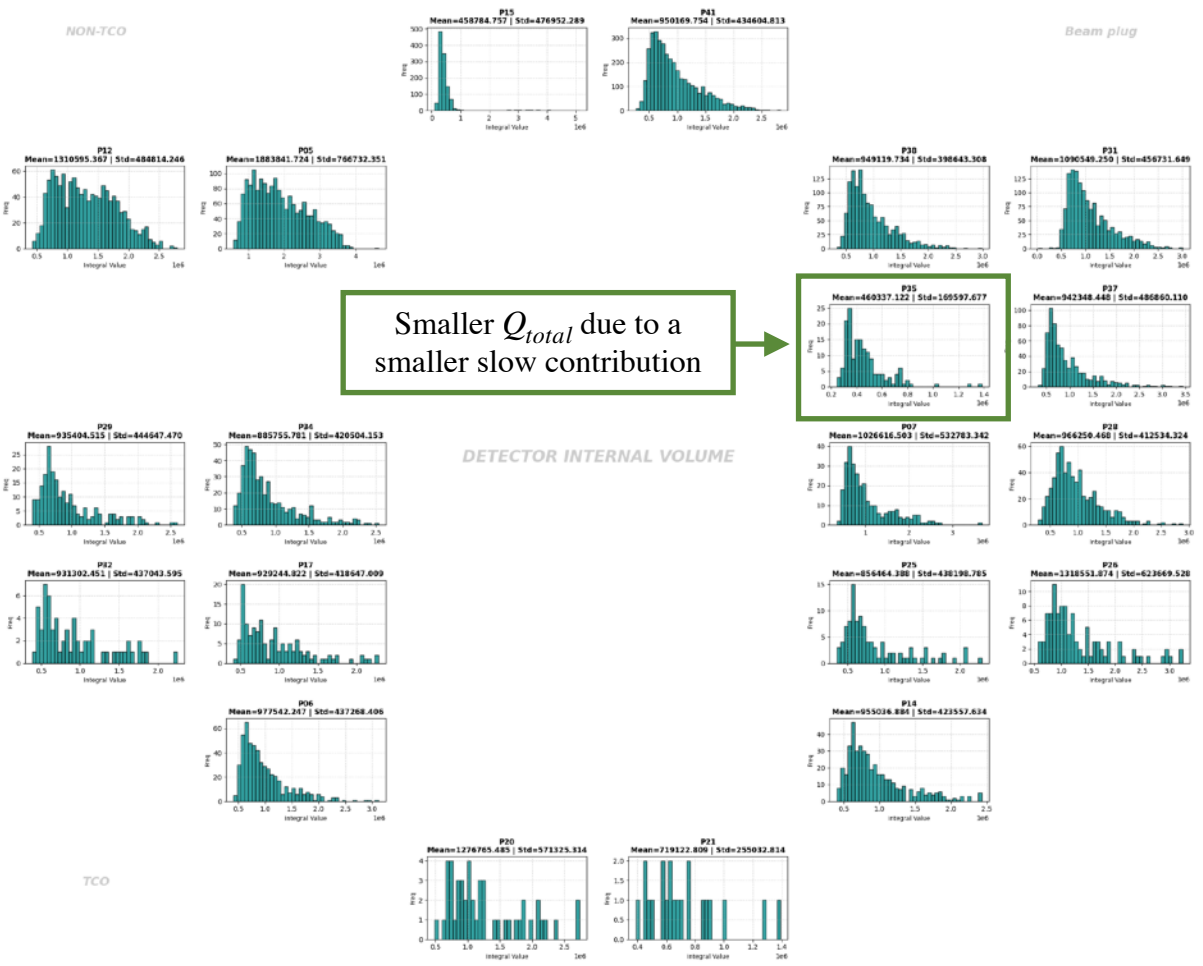
$$\Delta t = t_{pmt} - t_{ref}$$

$$\beta = Q_{fast} / Q_{total}$$



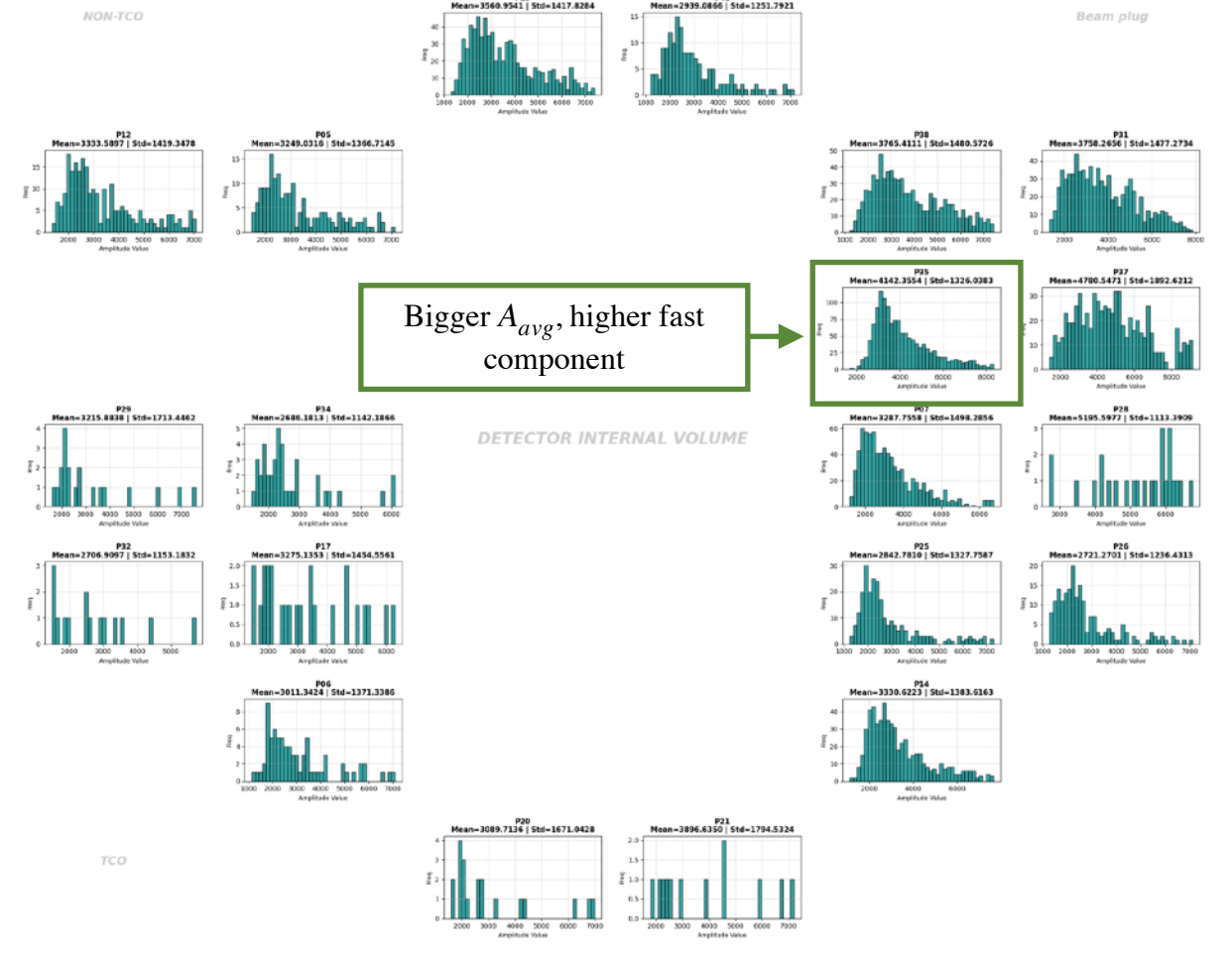
2. Statistical analysis of events - Events respect to PMT35

Q_{total}



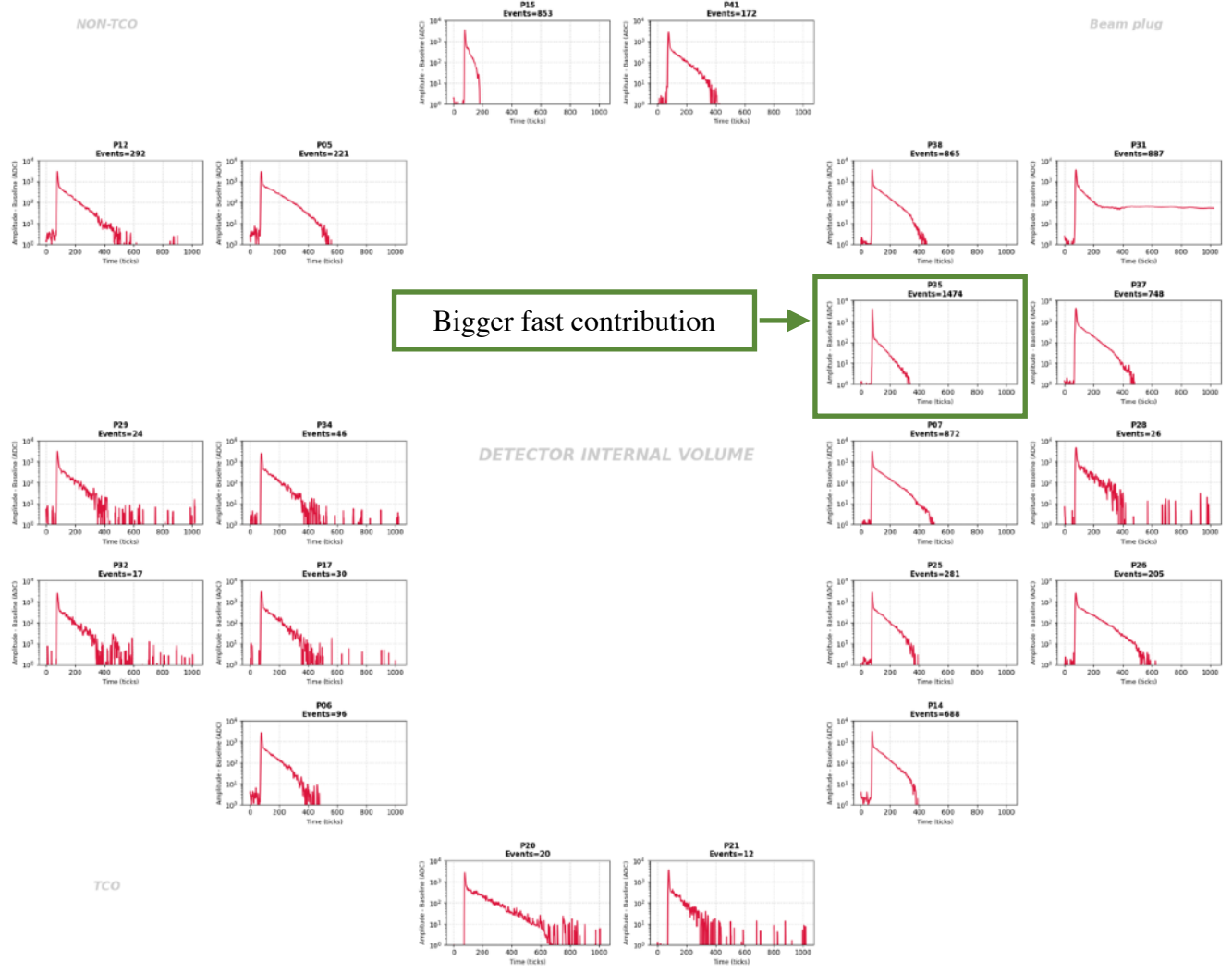
Amplitude (A)

A > 1000 adcs in all cases



2. Statistical analysis of events - Events respect to PMT35

Average waveform



Conclusions

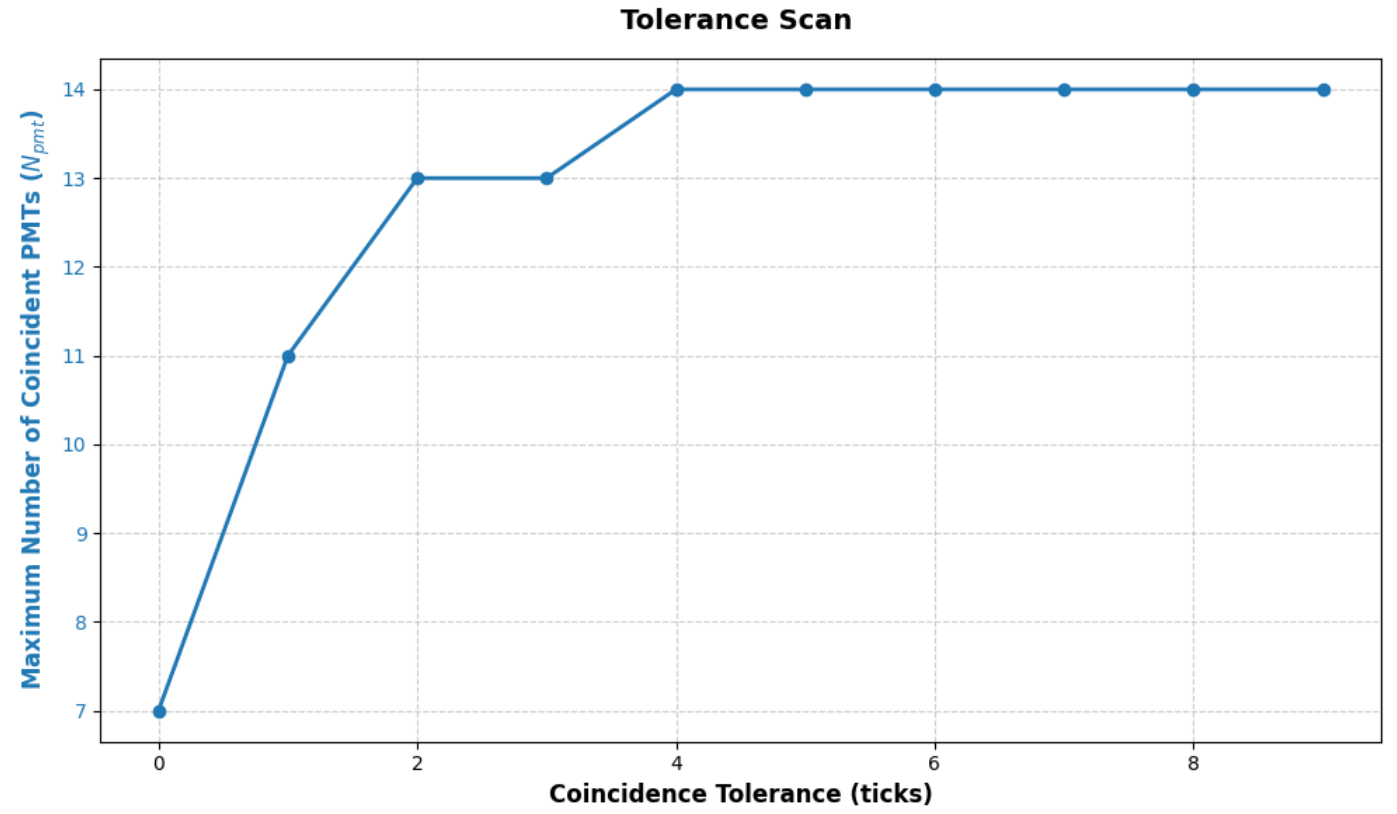
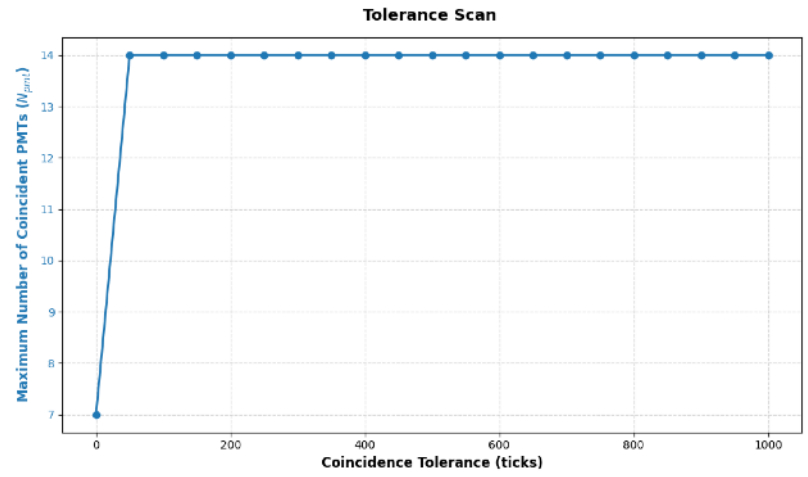
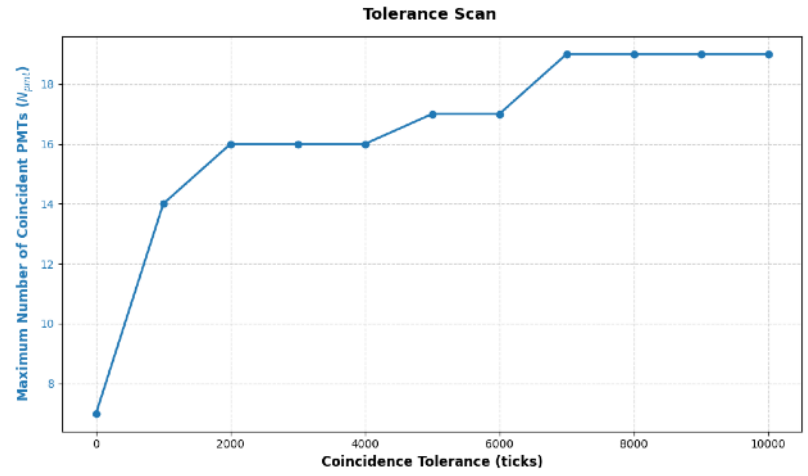
- » There is a time delay in the PMT with Quartz window and clear one, respect to the others PMTs
- » Different evidences of a bigger fast contribution in the PMT with Quartz

Next steps

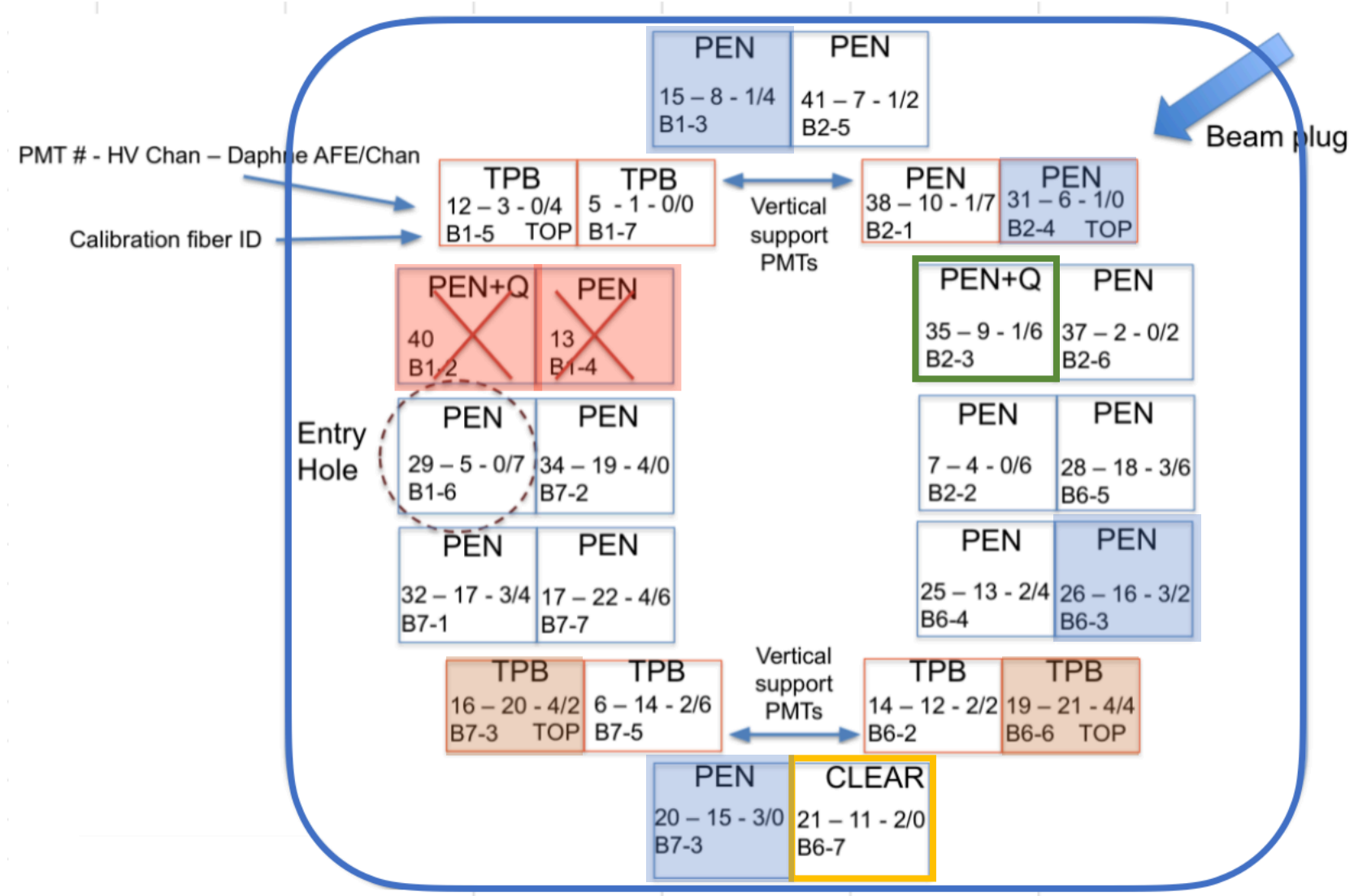
- » Continue the statistical analysis, including beam data
- » Perform an **event per event study** using CRTs data to select cosmic muons with a well defined trajectory
- » **Extend this study to all the different Xe concentrations** in ProtoDUNE-VD
- » **Compare these results** with the membranes and cathodes as well

2. Statistical analysis of events - Suitable tolerance (to)?

» There are in total 20 PMTs connected



2. Results from PMTs in LAr - Mapping



- Not connected
- PEN PMTs with a different tendency
- TPB PMTs with a different tendency
- PMT with a Quartz window
- Clear PMT