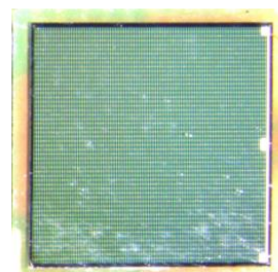
# Characterization of the DUNE photodetectors and study of the event burst phenomenon

Tommaso Giammaria
on behalf of the DUNE collaboration



LIDINE2021:Light Detection In Noble Elements 16/09/2021

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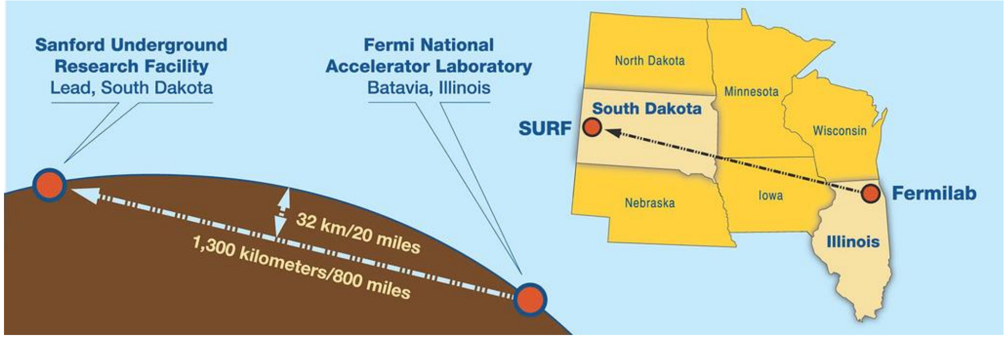
# The DUNE experiment

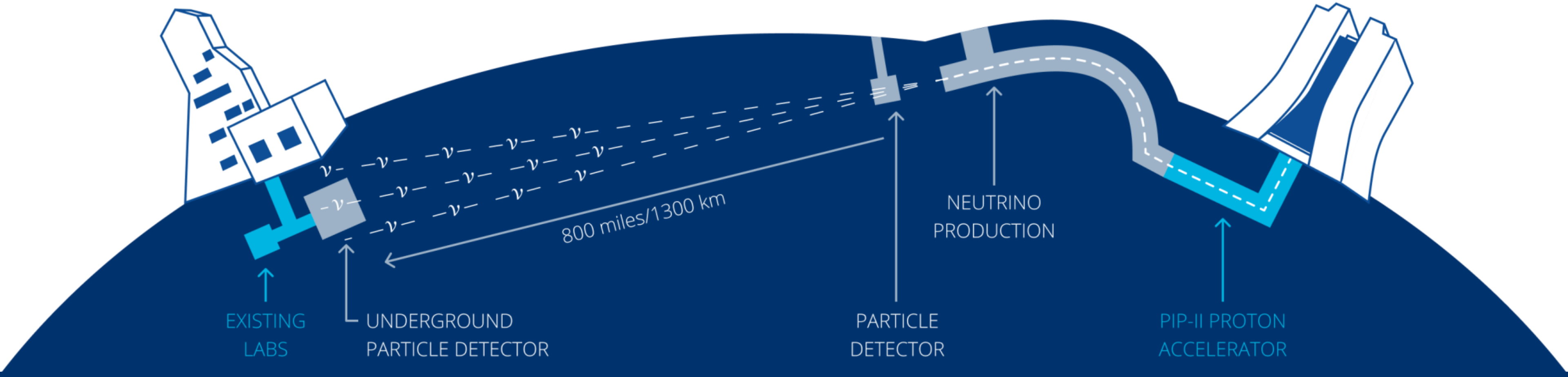
## Deep Underground Neutrino Experiment

- Broad-band neutrino beam (subGeV-10 GeV)
- Longest baseline accelerator experiment (1285 km)
- Both $\nu_\mu(\bar{\nu}_\mu)$ disappearance and $\nu_e(\bar{\nu}_e)$ appearance

**Aims** of DUNE:

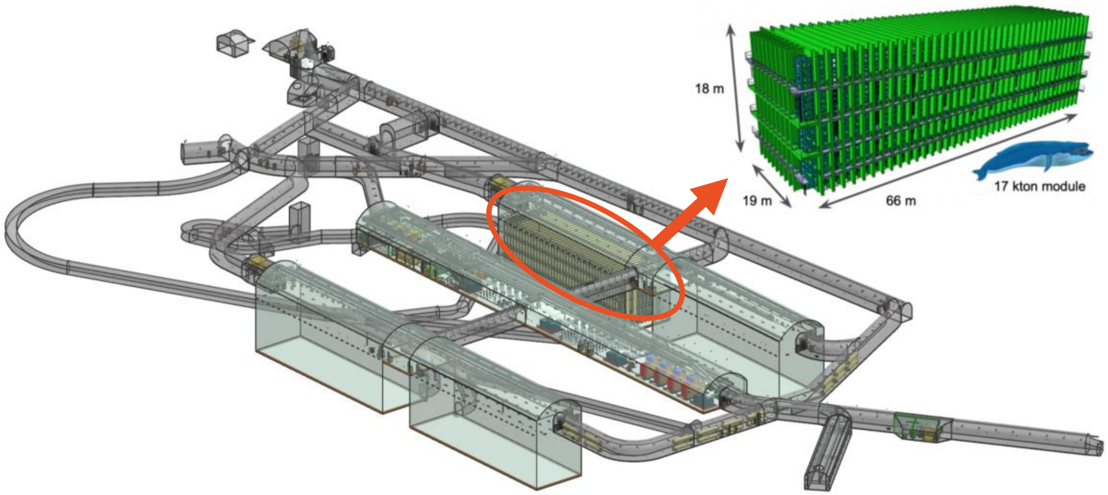
- CP violating phase
- Mixing angles $\theta_{13}$, $\theta_{23}$
- $\Delta m_{1,3}{}^2$ (mass ordering, 5σ)
- Supernova neutrino bursts
- Proton decay

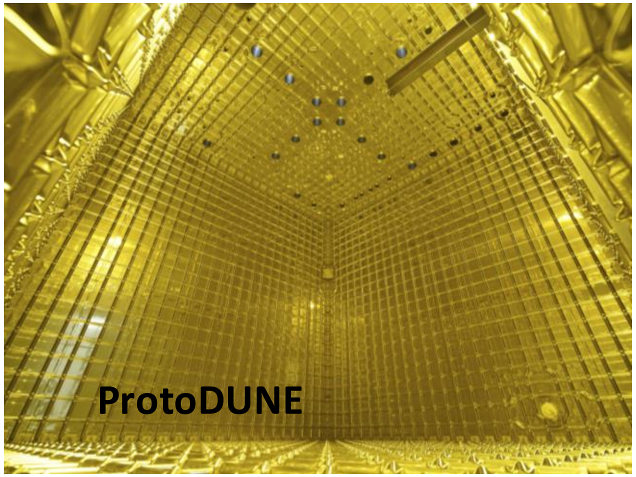


# Photodetection system for ProtoDUNE2-SP

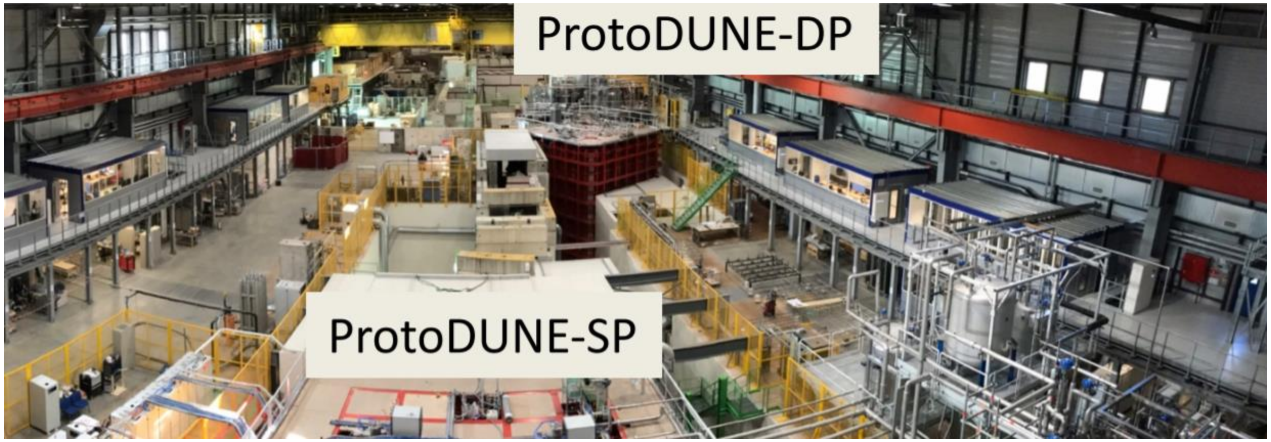
DUNE **Far Detector** (FD): 4x new generation **LArTPCs** (17-kton)




**ProtoDUNE2-SP** will employ modern technologies

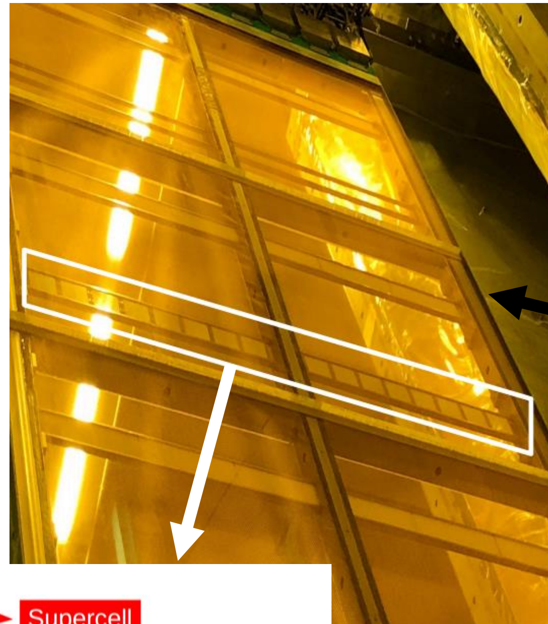
Among these: Silicon Photomultipliers (**SiPMs**) for PD

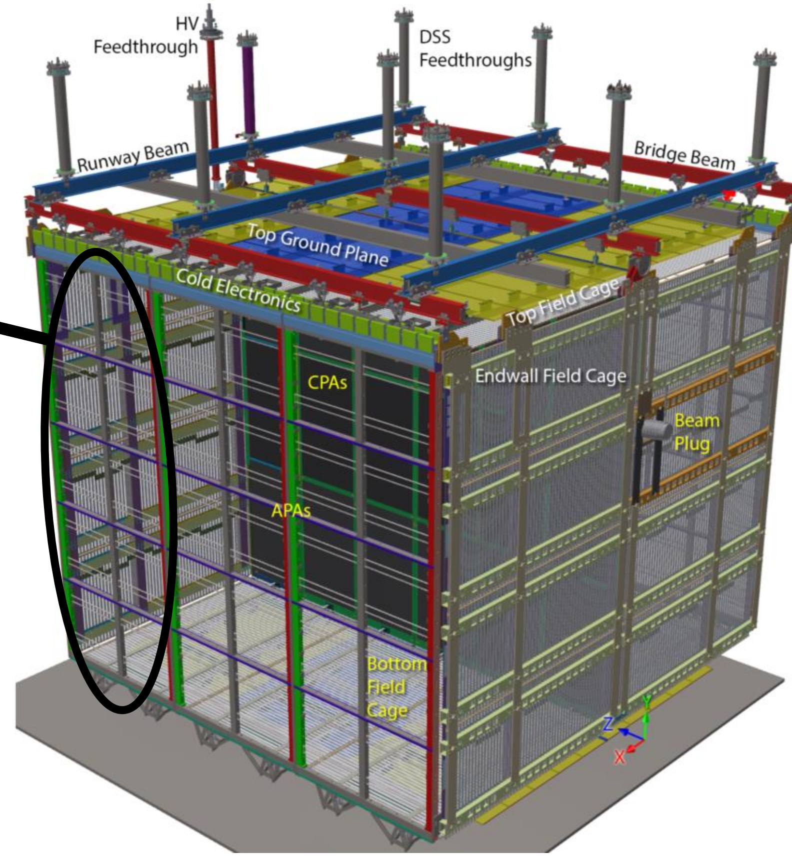


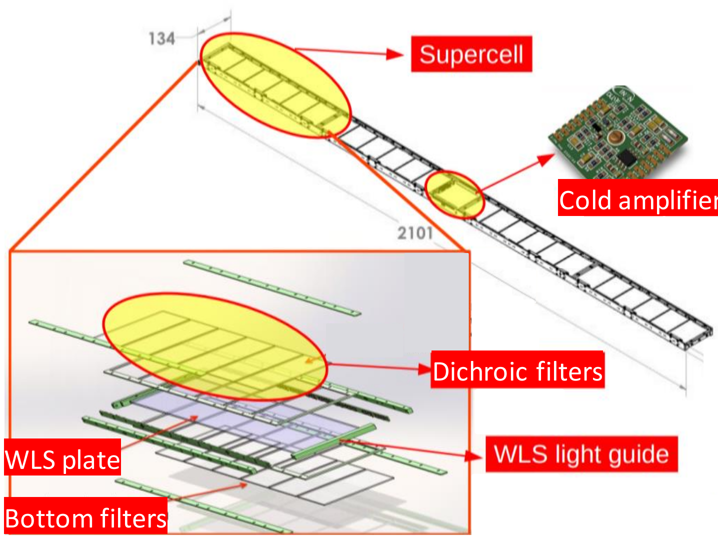
# Photodetection system for ProtoDUNE2-SP

ProtoDUNE2-SP PD system design:

- massive usage of SiPM photosensors
- install 6000 SiPM in 30 X-ARAPUCA modules (3 APA)





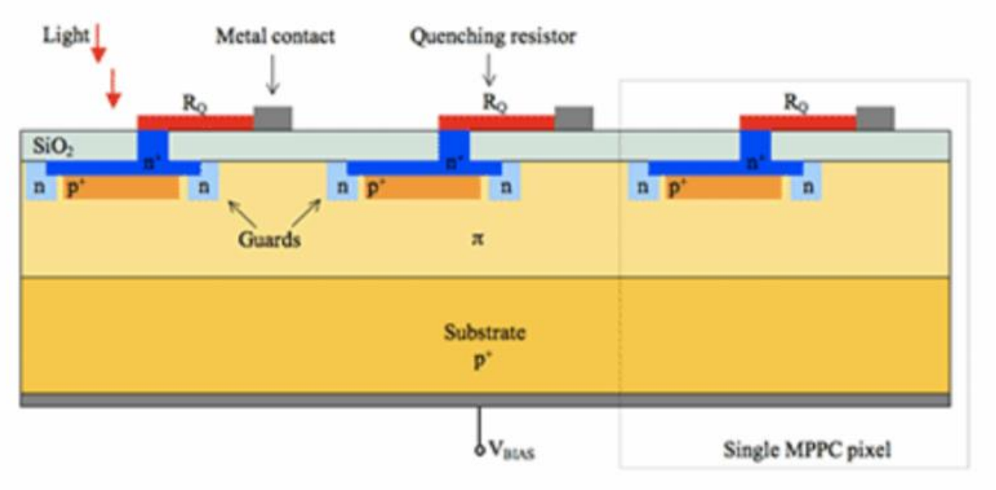

- SiPMs encapsulated in arrays of 6 units
- Modules divided in supercells along the APA
- Cold amplifier to handle signals from the neighboring supercells

# SiPMs for low photon count applications

SiPM = matrix of single photon avalanche photodiodes (SPADs)

**Properties:**

- mechanical robustness
- reduced cost and size
- magnetic field immunity
- high sensitivity
- high dynamic range




**Dark Count Rate (DCR):**

- background signal happening also in absolute darkness
- main drawback for low photon count applications
- high at room T (~100 kHz/mm$^2$)
- drops to few tens of mHz/mm$^2$ at cryogeinc T

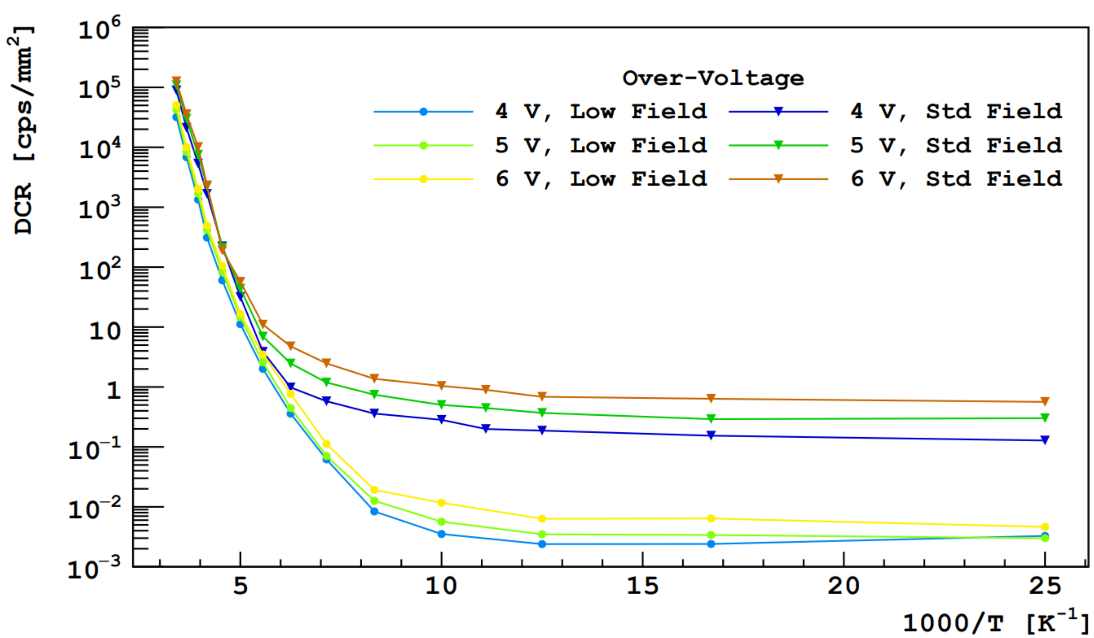
# SiPMs for low photon count applications

ProtoDUNE and DUNE SiPM models produced by **two** vendors**:**

- **Fondazione Bruno Kessler** (FBK)
- **Hamamatsu Photonics K.K.** (HPK)

HAMAMATSU
PHOTON IS OUR BUSINESS

FONDAZIONE BRUNO KESSLER




From *Cryogenic Characterization of FBK HD Near-UV Sensitive SiPMs*, by Fabio Acerbi Et Al. DOI: 10.1109/TED.2016.2641586



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# SiPM characterization

Tested SiPMs

| Vendor | Pitch | $N_{cells}$ | Package | Design |
|---|---|---|---|---|
| HPK | 50 µm | 14331 | Surface mount type | Hole wire bond |
| **HPK** | **75 µm** | **6364** | **Surface mount type** | **Hole wire bond** |
| FBK | 30 µm | 37300 | Chip on board | standard lateral bond, single trench |
| **FBK** | **50 µm** | **11188** | **Chip on board** | **standard lateral bond, triple trench** |

All sensors have the same form factor (6 x 6 $mm^2$ )

1. **Full-characterization** of single devices (following slides)
2. Characterization of **6-SiPM boards** (ganging test)
3. Mass test, test of a **high number** of SiPMs (need of custom experimental setups to speed-up the tests)

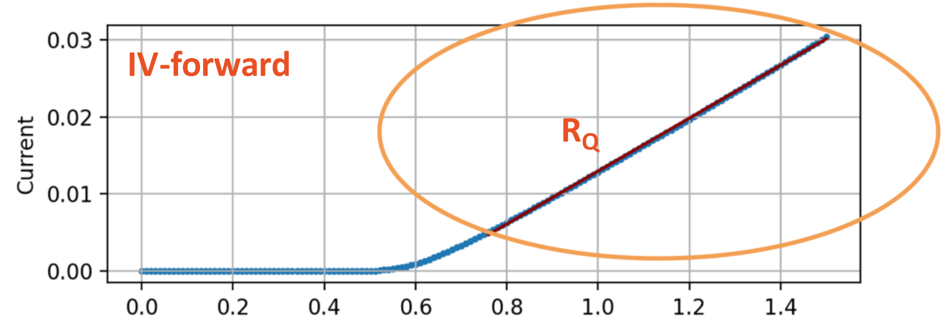
# SiPM characterization

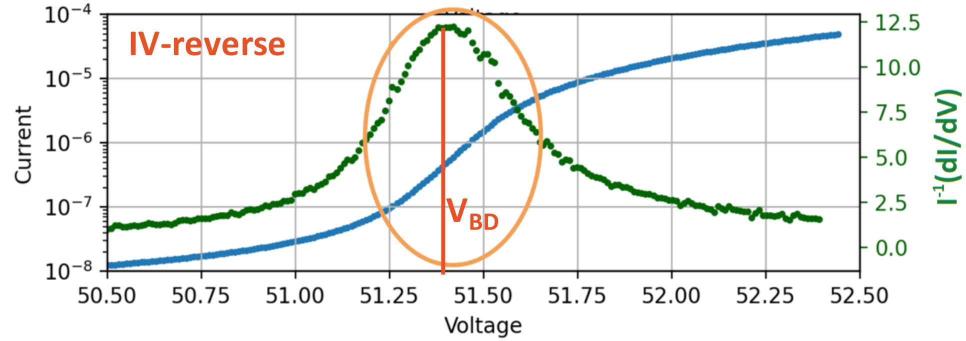
Important physical quantities:

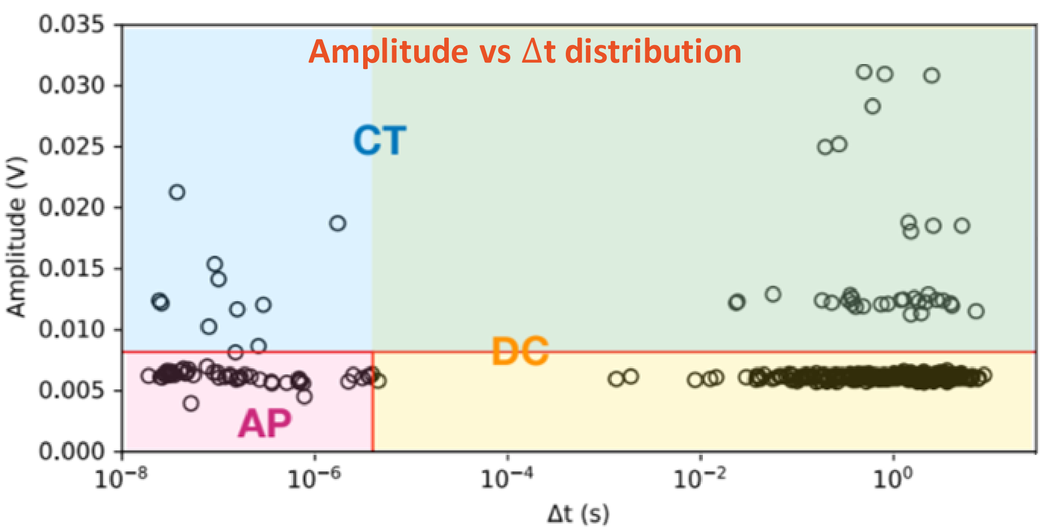
- $V_{BD}$ and $R_Q$
- DCR, AP and CT
- Gain and SNR

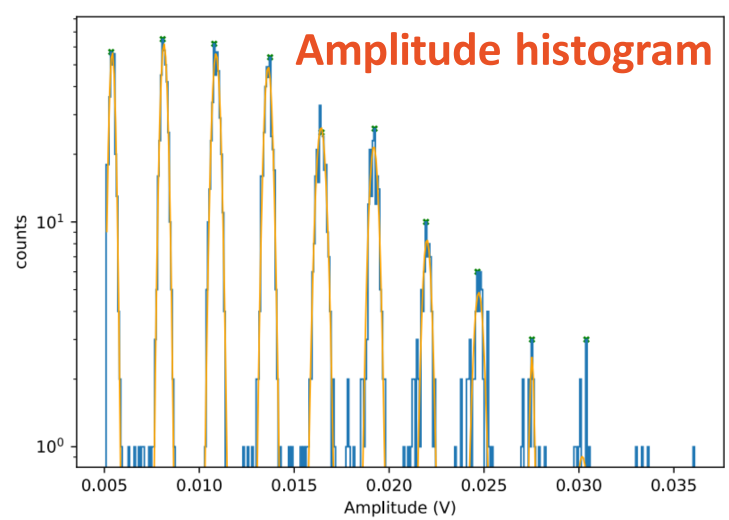
To measure these quantities:

- IV curve
- Dark noise measurement
- LED acquisition



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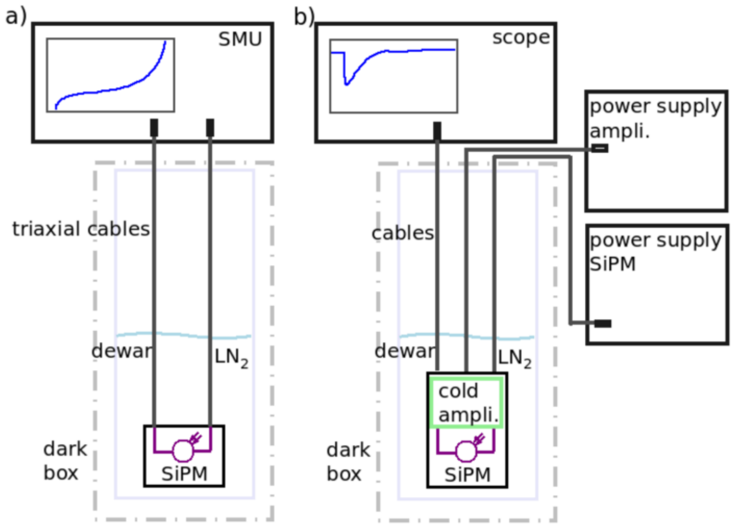
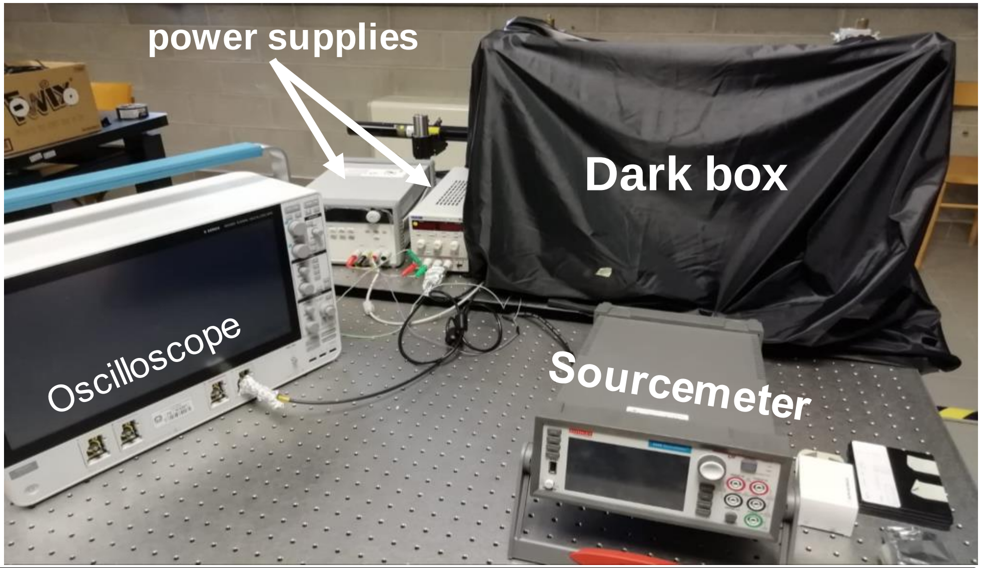
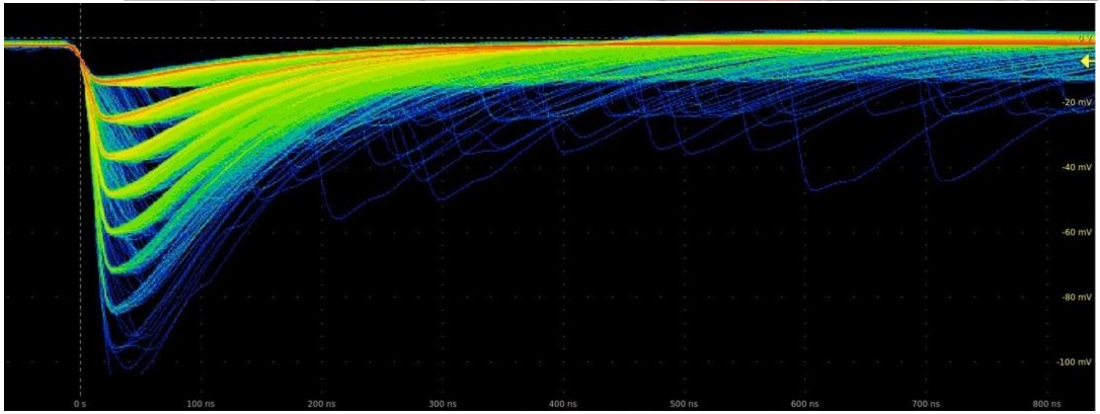
# SiPM characterization

All measurements performed at **LN2T**, except IV characterization




For Gain (and SNR):
- DCR setup
- Device is illuminated by a LED
- Acquisition triggered on LED pulse



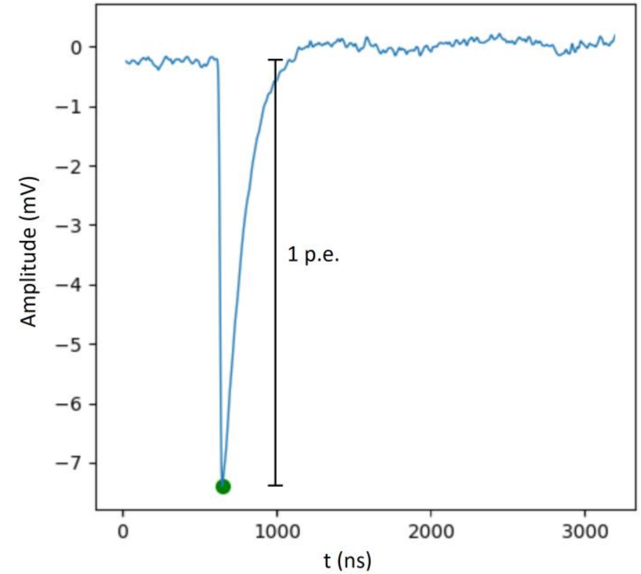
Samples undergo 20 thermal cycles, then we restart the tests (to check long time operation at cryogenic temperatures)

# Results: burst discovery

Custom **offline analysis** to extrapolate DCR, CT and AP values in two steps:

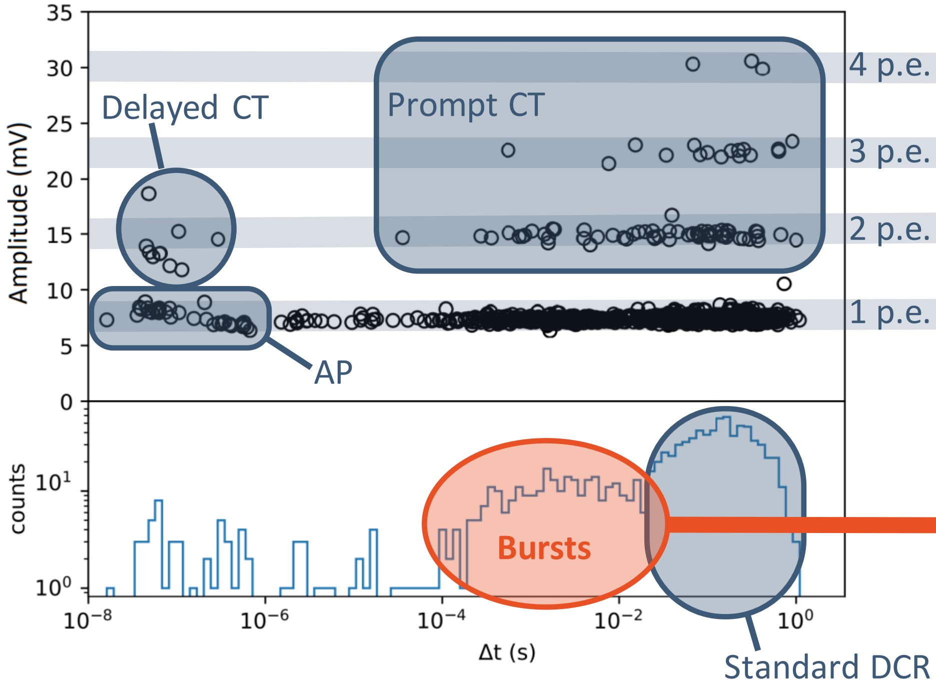
***Event isolation***

- Peak signals identification
- Extract amplitudes and relative times




***DCR analysis***

- Calculates DCR, AP and CT by counting events

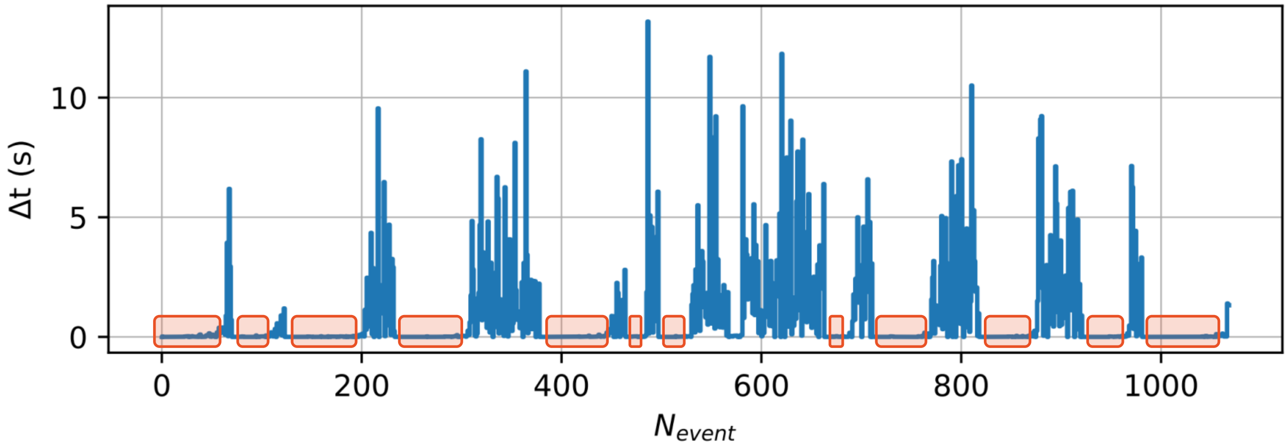



**Quick trains of correlated events**

Currently under investigations...

# Results: burst analysis

Bursts are also distinguishable as valleys in the time trend distribution




- Burst observed in many tested SiPM models
- their randomness brings the DCR to unpredictable values
- **Burts-independent parameter** needed to compare different SiPMs

**This quantity is the standard DCR, without the burst contribution**

Two algorithms to distinguish burst contribution from standard DCR:

- ***tag* method**
- ***fit* method**

# Results: burst analysis

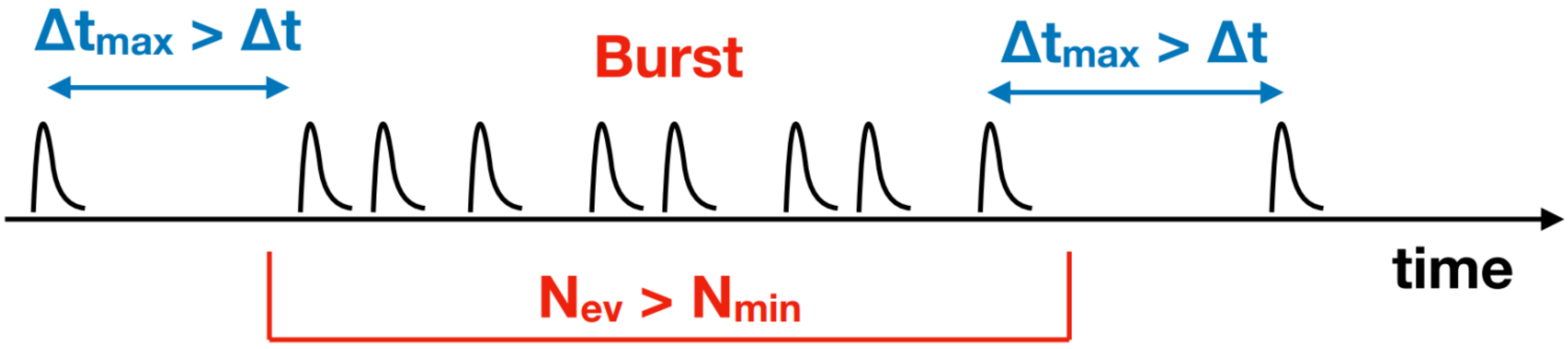
***Tag method***

Isolates the burst's events one by one, finding fast consecutive events:

- Time-interval $\Delta t$ higher than typical AP time
- $\Delta t$ lower than $t_{max}$ (typically 6 μs)
- Number of consecutive events $N_{ev}$ larger than $N_{min}$, (typically 5)

Best values for found by:

- tuning these parameters
- cross-checking the data

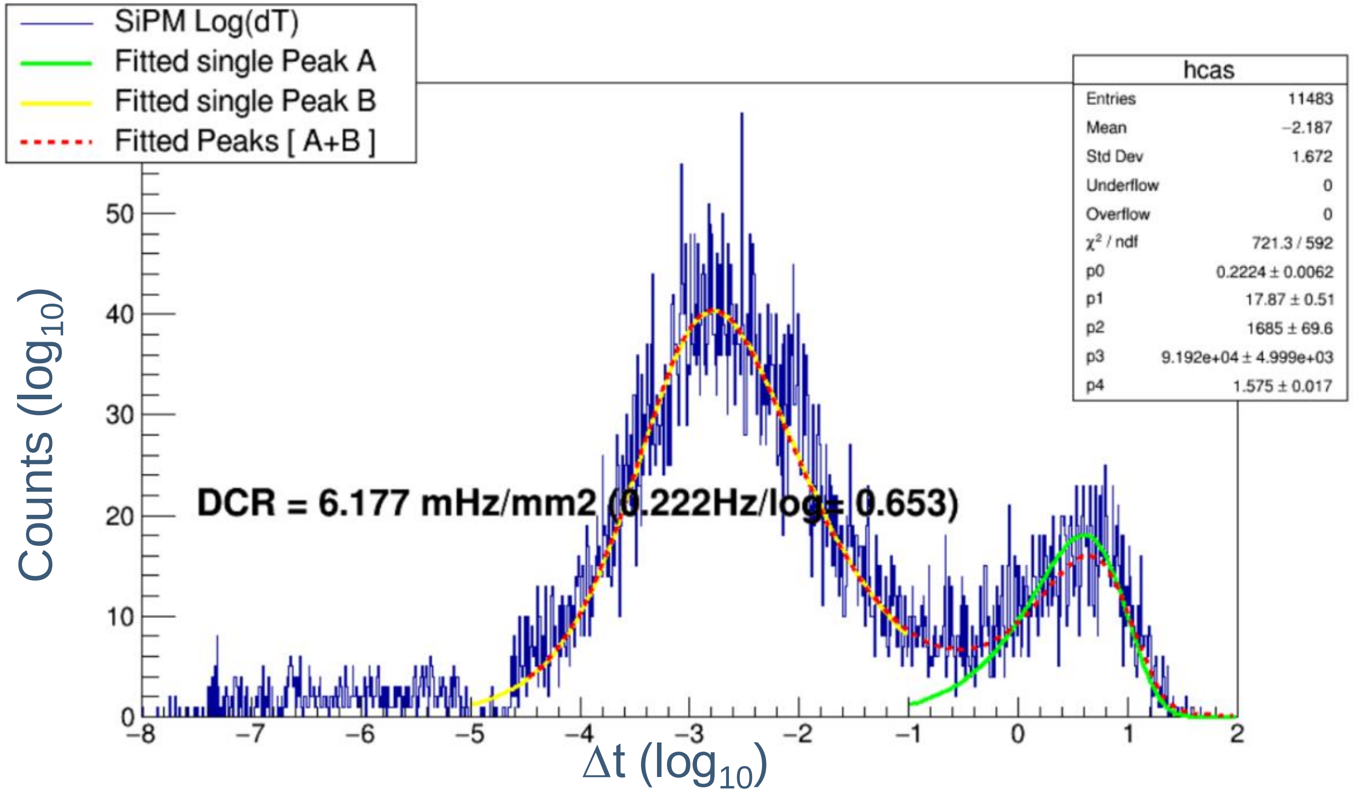


# Results: burst analysis

***Fit method***

Both conceptually and practically different.

It is a fit of the time-trend histogram of the events, as shown in figure.




Functions:

- Poissonian distribution for uncorrelated DCR, $\Delta t = [0.1 - 100]$ s,
- Over-dispersed Poissonian, $\Delta t = [10^{-5} - 10^{-1}]$ s for burst contribution

# Results: burst analysis

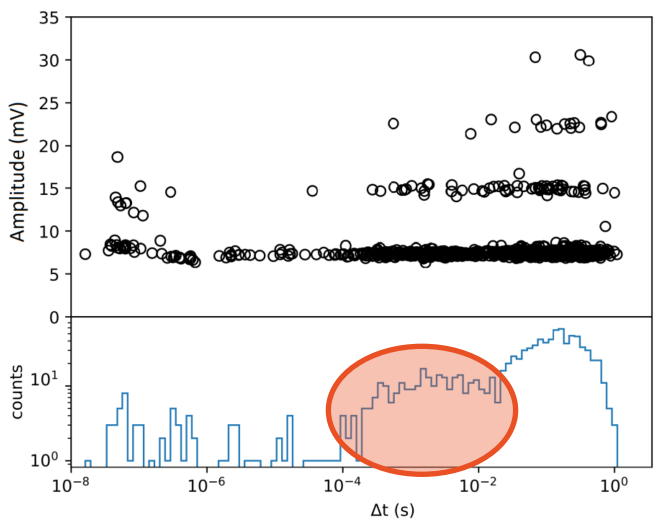
**DCR** extracted with the two methods **in agreement** with each other

Different features of the methods

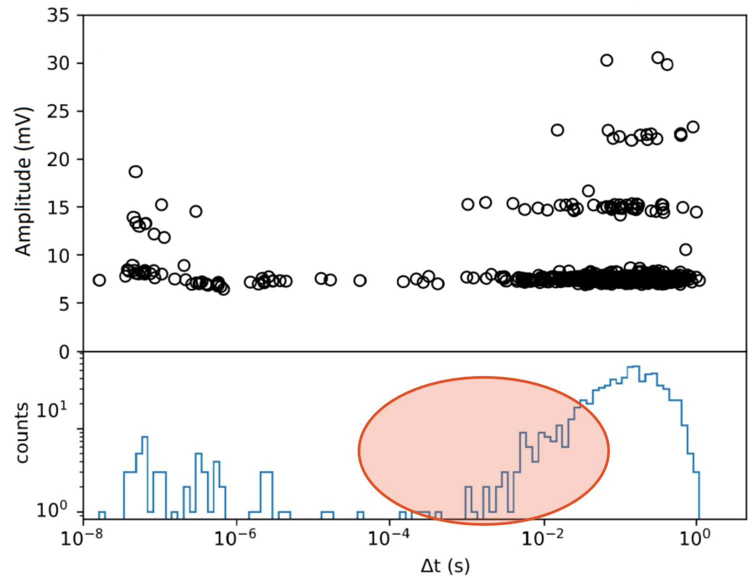
- Fit method faster due to direct fit on the histogram
- Tag method, deep analysis of single events within the bursts

Common features emerged studying the burst events more in details:

- Last for a few tenths of a second
- Events separated by a [0.1-10] ms time delay
- Often triggered by a high-amplitude event
- Almost a hundred of events per burst







# Conclusions and perspectives

- ProtoDUNE2-SP PD system based on SiPMs, as these devices are ideal for low photon count applications
- Thanks to custom experimental setup, full characterization of all SiPMs at cryogenic T accomplished. Results well within the DUNE specs but DCR higher due to unexpected burst phenomenon. Mass-test is ongoing…
- Custom algorithms to eliminate burst contribution from DCR and study burst behavior in more detail, further investigations are ongoing…