Reconstruction of data acquired with SiPMs in liquid argon for DarkSide

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on behalf of

DarkSide Collaboration

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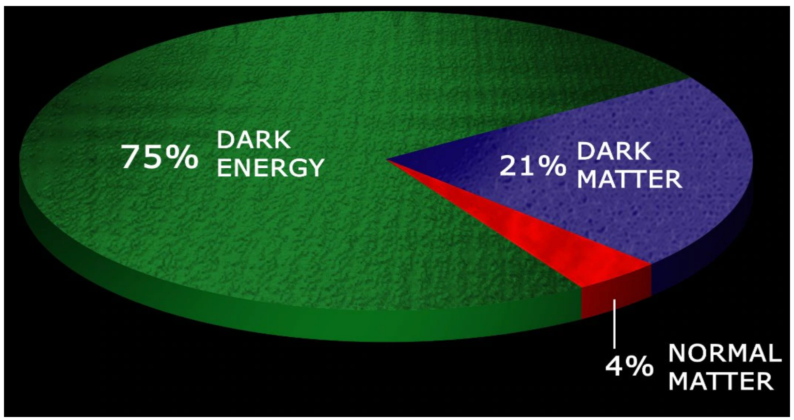
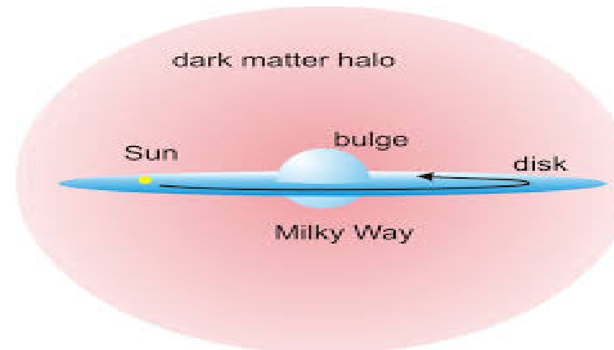
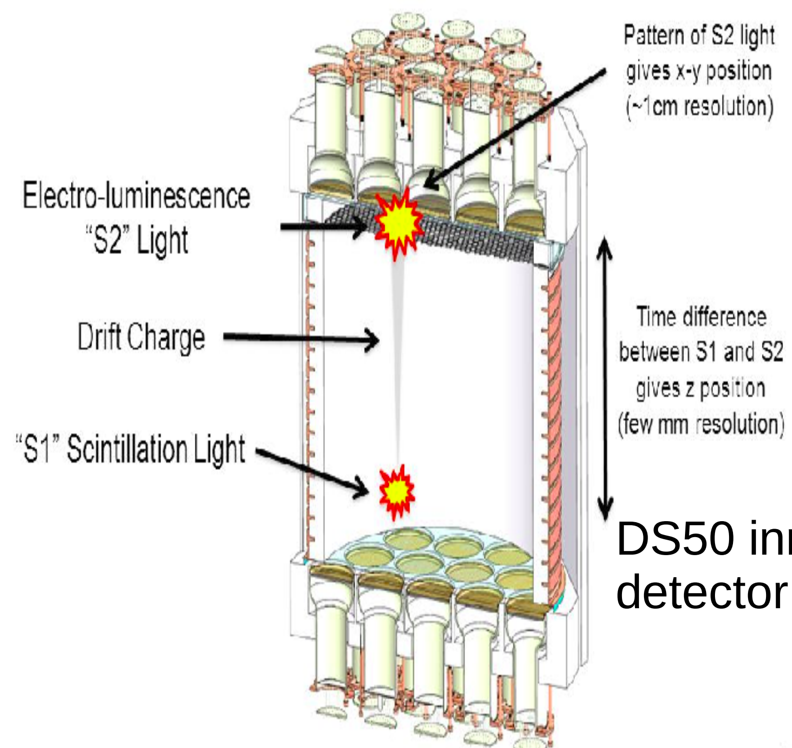
Direct Detection of Dark Matter Particles

Many astrophysical phenomena (bullect clusters, lensing, rotational galactic curves, CMB …) would be explained by “dark matter”, but still a **direct detection**, if possible, is missing





The main aim of the DarkSide collaboration is the direct detection of WIMPs (Weakly Interacting Massive Particles), one of the most promising model for cold dark matter



DS50 inner detector

WIMP detection in a double phase TPC

The Time Projection Chamber (TPC) is filled with a noble liquid, Argon, for DarkSide detectors

-Relatively inexpensive and dense

-High ionization (W_{LAr} = 21.5 eV)

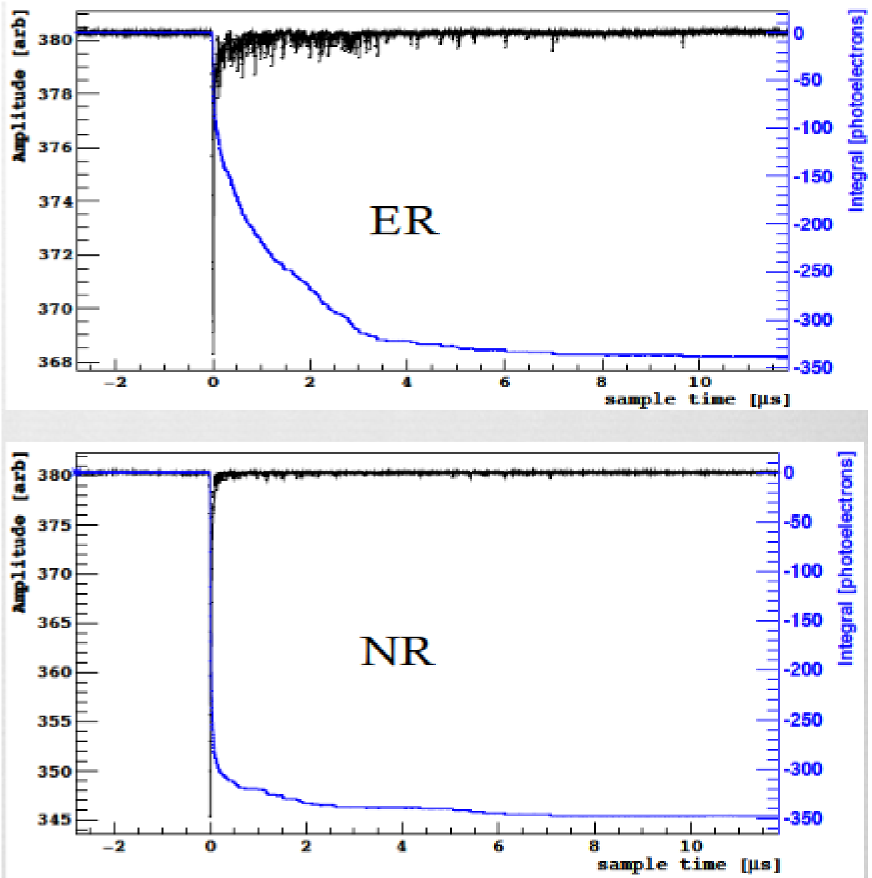
-Very high scintillation yield ~40000 photons/MeV

-Trasparent to their own scintillation light (128 nm)

-High electron mobility

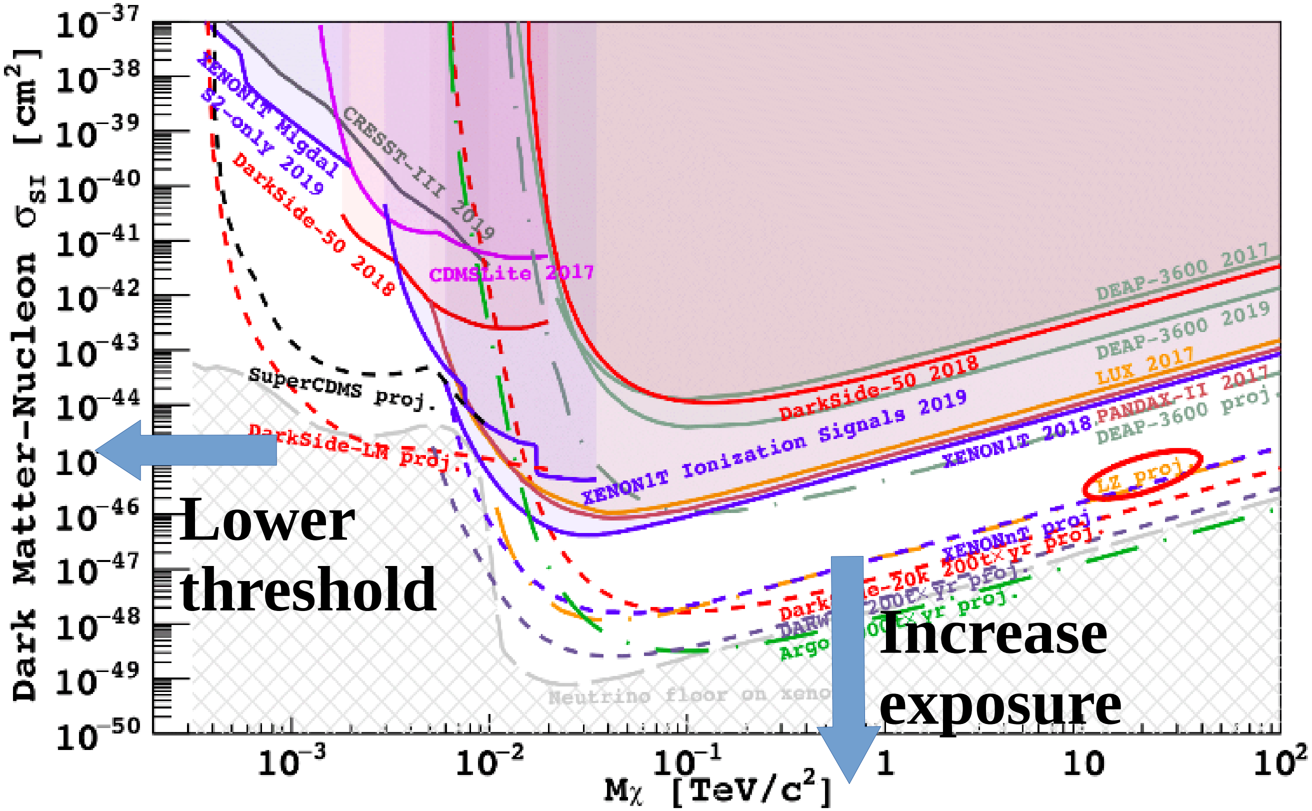
-Low electron diffusion

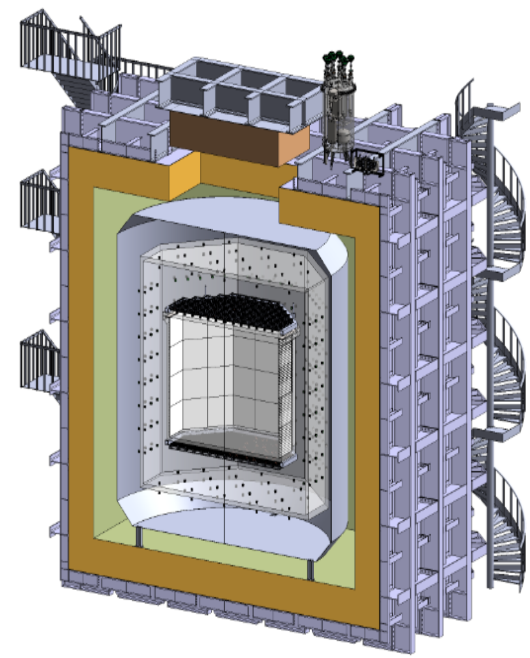
-Two excitation states: singlet (6 ns) and triplet (1600 ns)



Pulse Shape Discrimination power in DS50 > 10^8

How to improve exclusion limits





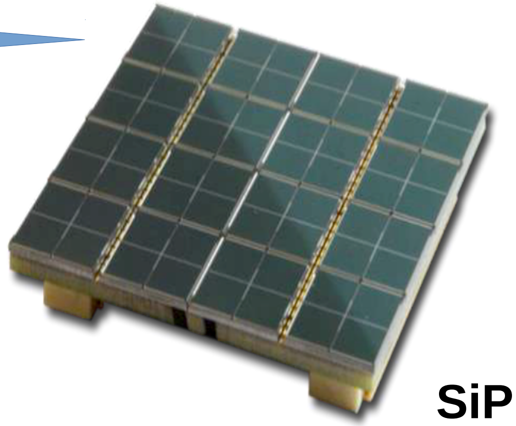
The next step is the build of a multi-tonne detector designed to be background free: DS20K (40 ton) and, finally, ARGO (300 ton)

From PMTs to Silicon Photomultipliers (SiPMs)

The read-out in DS20K will be done by 8260 Silicon Photomultipliers (SiPMs)

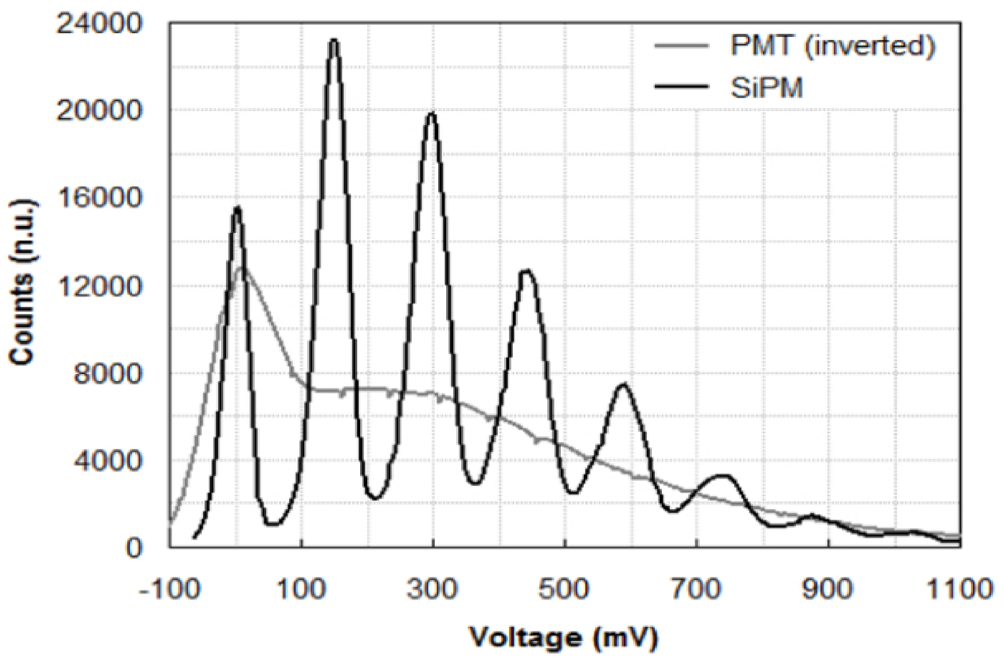
PMT

Higher radiopurity
Insensitive to magnetic field
Lower cost
Higher optical coverage
Higher quantum efficiency



SiPM

The SiPM resolution will allow for **DS20K high sensitivity at low energies**

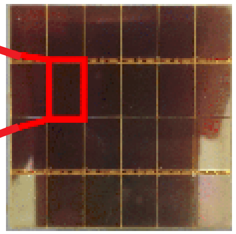


Photoelectronics in DS20k

Strict collaboration with Fondazione Bruno Kessler (FBK): development of **specific SiPMs** for LAr (50 PDM under way).

Individual SPADs
25 x 30 um^2

Single SiPM
1 cm^2



24 SiPMs
5 x 5 cm^2

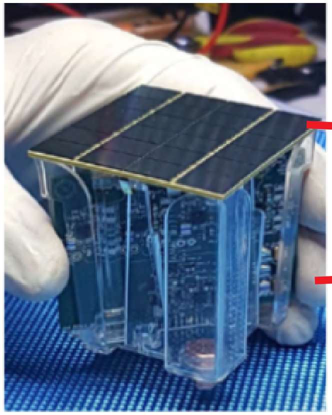
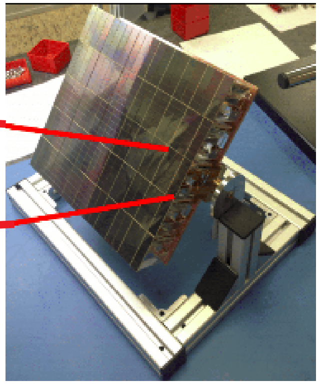
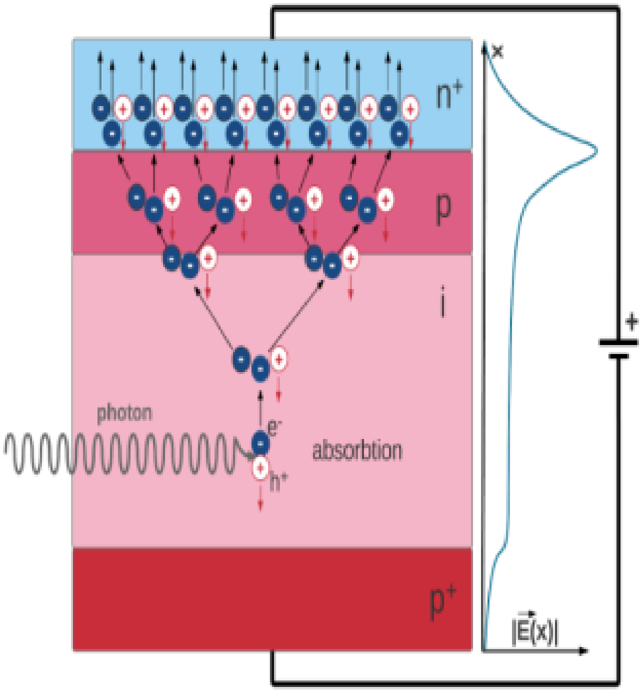


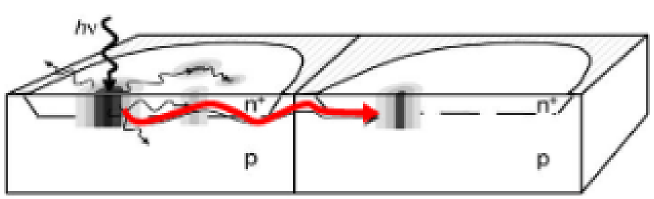
Photo Detection Module (PDM, 5x5x5 cm^3) tile and front end board in acrylic cage, base detection unit, one summed readout channel



Motherboard (MB, 25x5x5 cm2) 25 PDMs with mechanical support structure, base mechanical unit for DS-20k, routing structure for power and signal readout contained

Noises in a SiPM



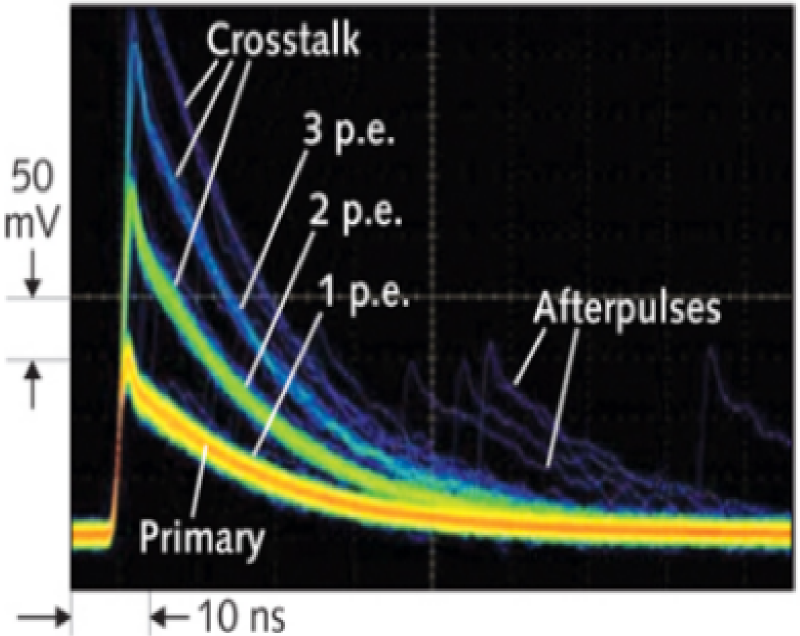


Sketch from Cova et al. NIST 2003
Workshop on single photon detectors

SiPM : Avalanche Photodiode set in Geiger Mode

Optical Crosstalk: noise induced by the isotropic photon emission of the primary avalanche on a surrounding pixel, and so simultaneous to the primary avalanche

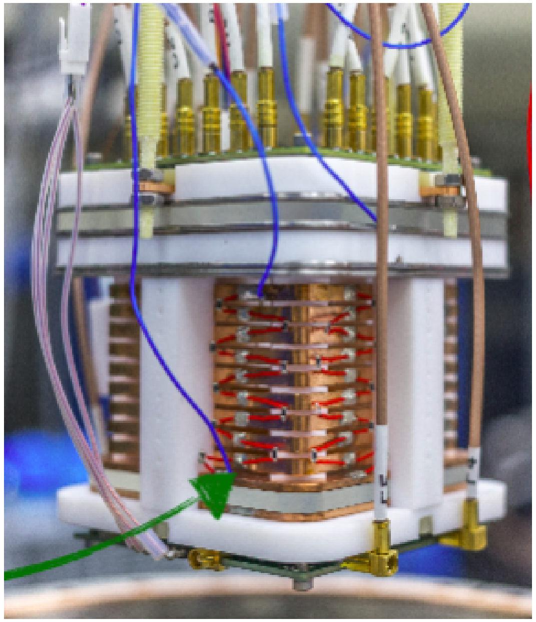
Afterpulse : noise induced by electrons of the avalanche at first trapped in silicon defects and slowly after released.



First analysis with SiPM read-out: ReD experiment

Thanks to the high radiopurity and resolution we will be able to reach the best sensitivity at low energy ever achieved.

Two drawbacks are expected:
-a decrease in the energy resolution, due to AP and CT
-a decrease of the PSD power, due to the slow recharge time



ReD TPC

The photoelectronics was tested for the first time in DarkSide Collaboration in ReD, a small detector located in Naples setup for calibrations.

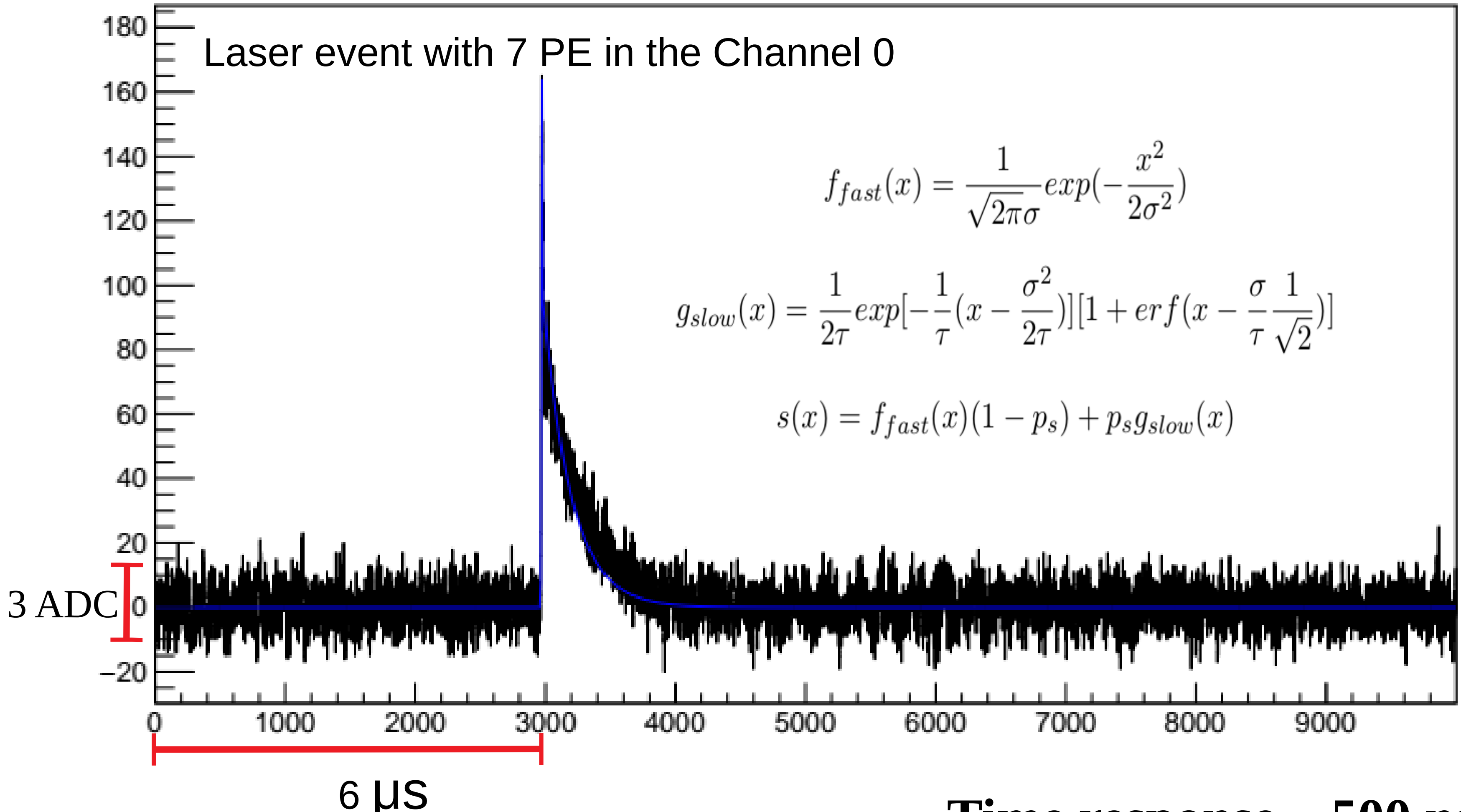
Three main studies ongoing in ReD:
-Determination of the SiPM time response
-Afterpulse and crosstalk characterization
-Reconstruction of the x-y coordinates (now starting with Prof. deFalco)

Bottom Tile: 4 channel, 6 SiPM each

Top Tile : 24 channel, 1 SiPM each

Determination of the SiPM response

Analysis of laser events from ReD, to determine the shape of the SiPM time response and evaluate the noise



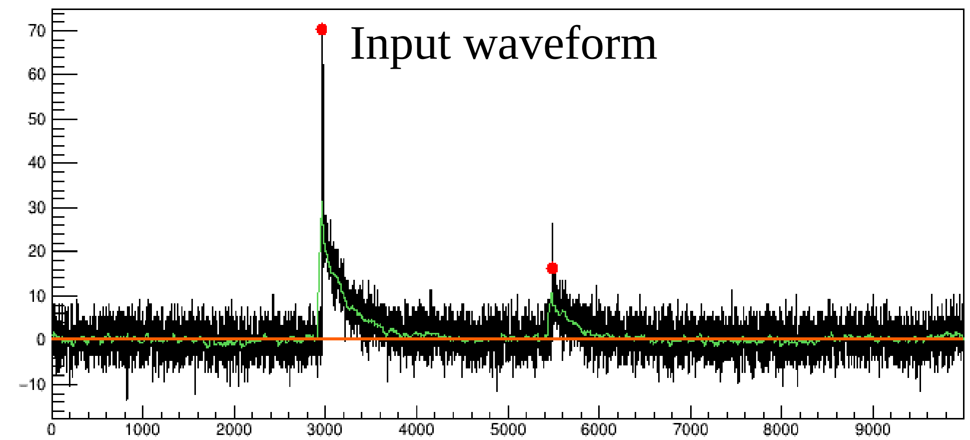
Time response ~ 500 ns !

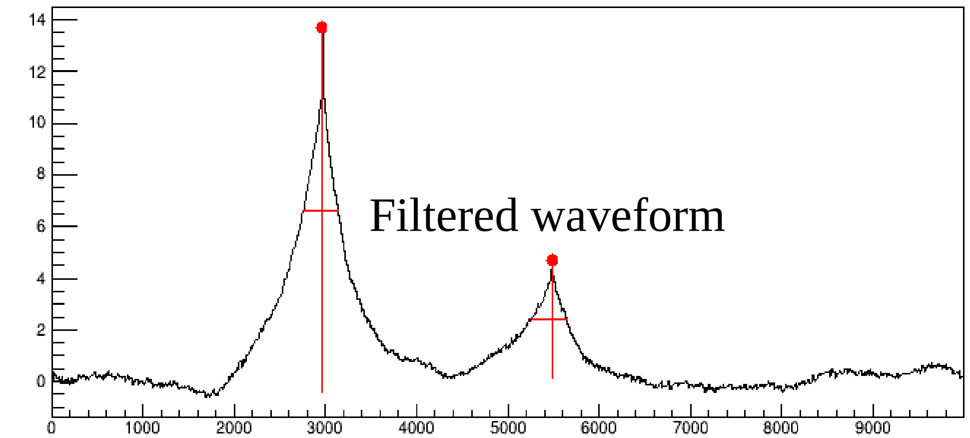
The “prominence” charge

A matched filter is applied on the input waveform, determining a high **increase of the signal to noise ratio**

For each acquired waveform the peak-finder scans the filtered signal and stores the peak time and “prominence”.

The “prominence” is the height of the peaks on the filtered waveform, after subtraction of the baseline and dominant close peaks.

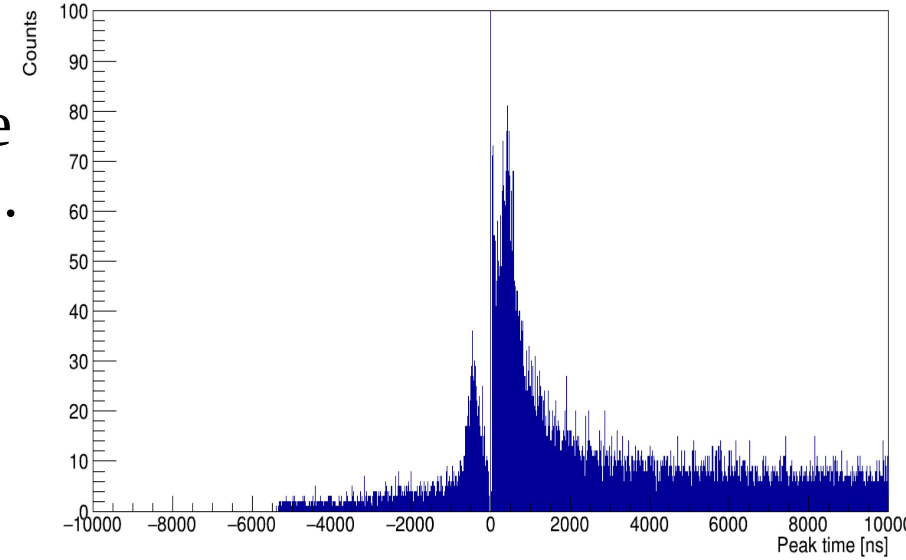




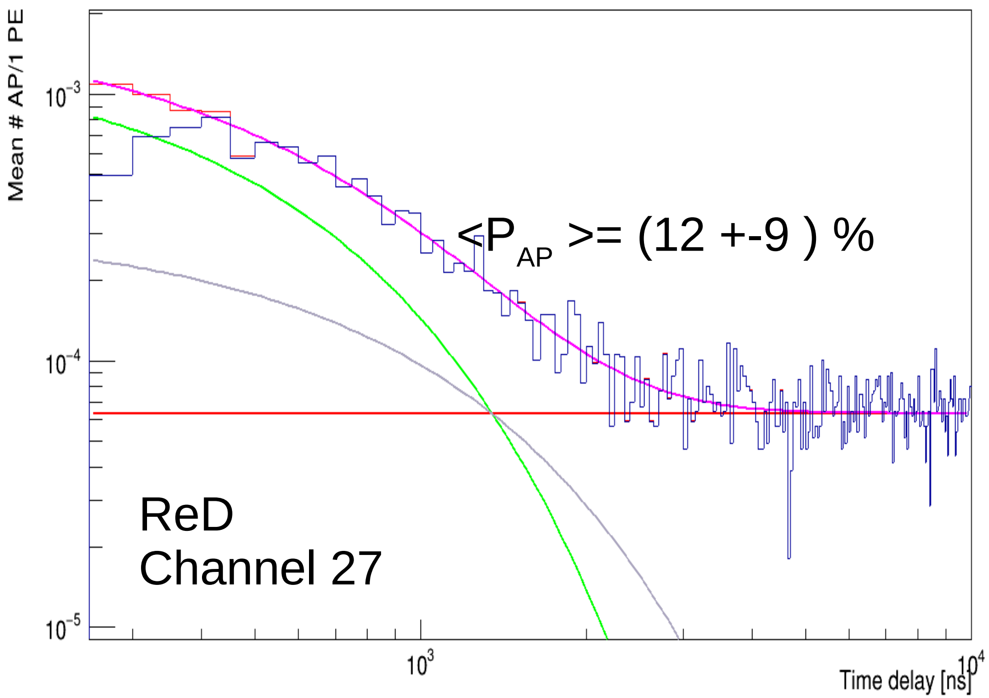
Example of laser events in the Channel 1 in ReD (above) and then its processing with the filtering and the peak finder (below)

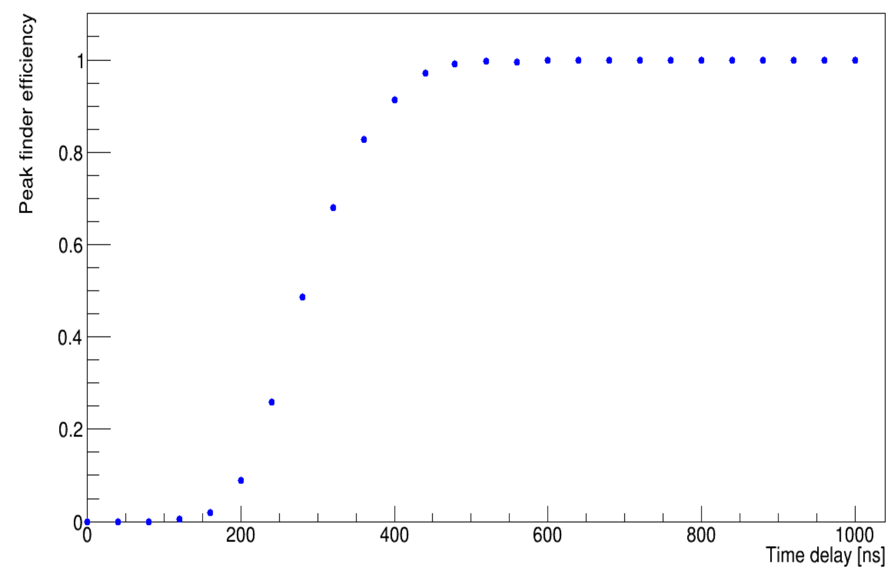
Afterpulses characterization in ReD

Thanks to this signal processing, the distribution of afterpulses on ReD data was determined for each channel



A scan of the peaks before and after the primary peak, chosen to be due to 1 PE. The subtraction of the two populations returns the afterpulses (blue).

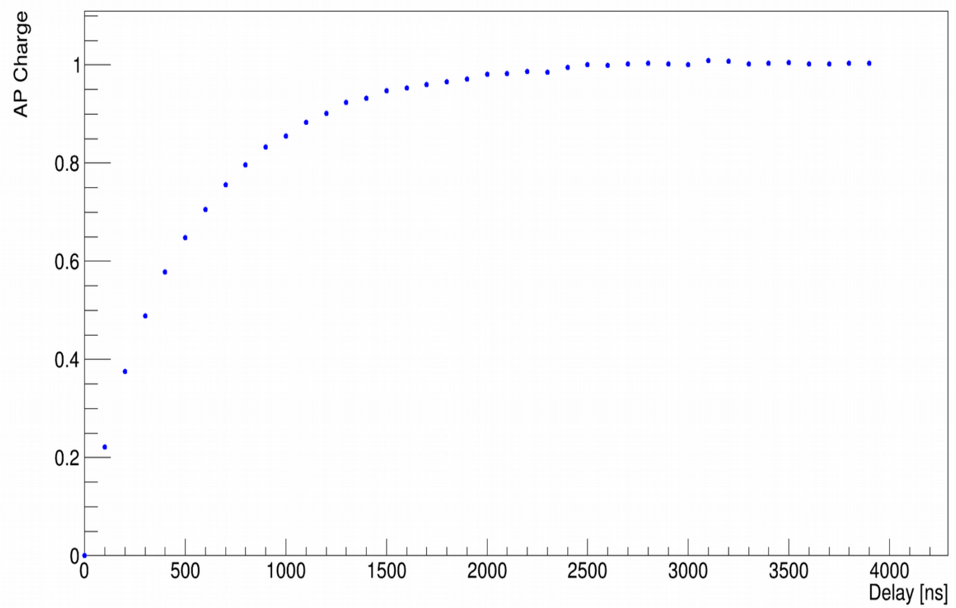




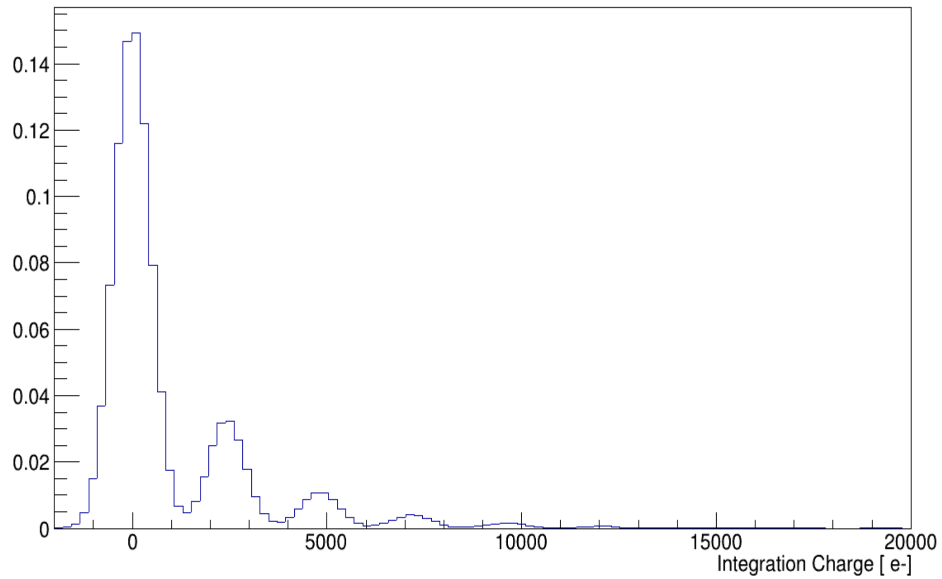
The afterpulse distribution was then corrected for the peak-finder efficiency (red line)

Afterpulses characterization in ReD

The cumulative on the modeled waveform is the charge available for an afterpulse.



The integration charge from laser run returns the channel single photoelectron (SPE) response.



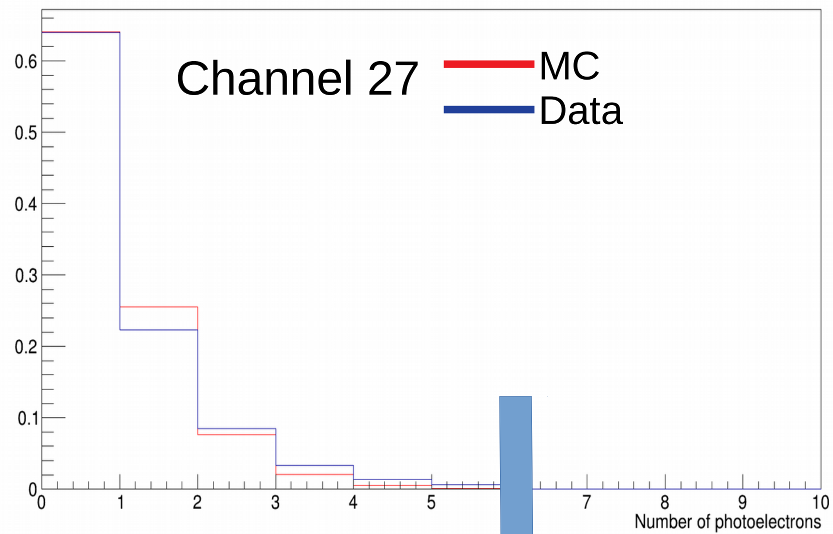
Without afterpulses and cross talks the distribution would be poissonian on the average value given by :

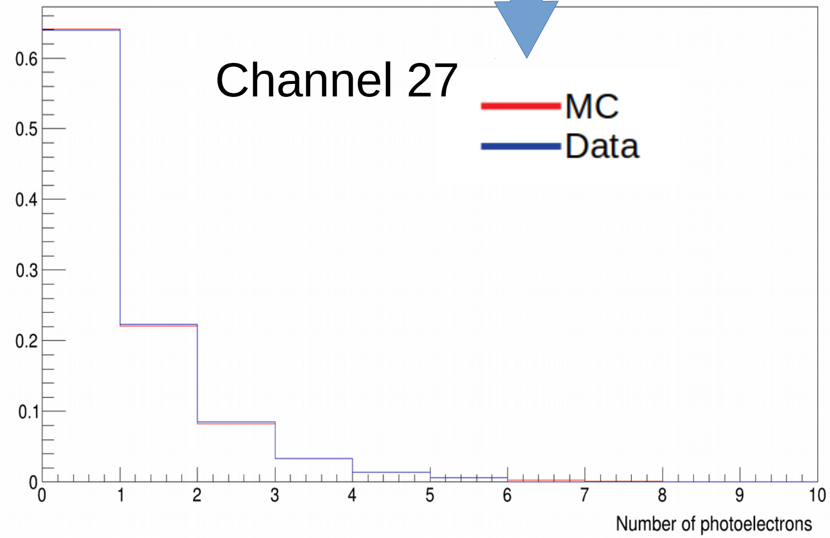
$$\mu = \log(-N_0)$$

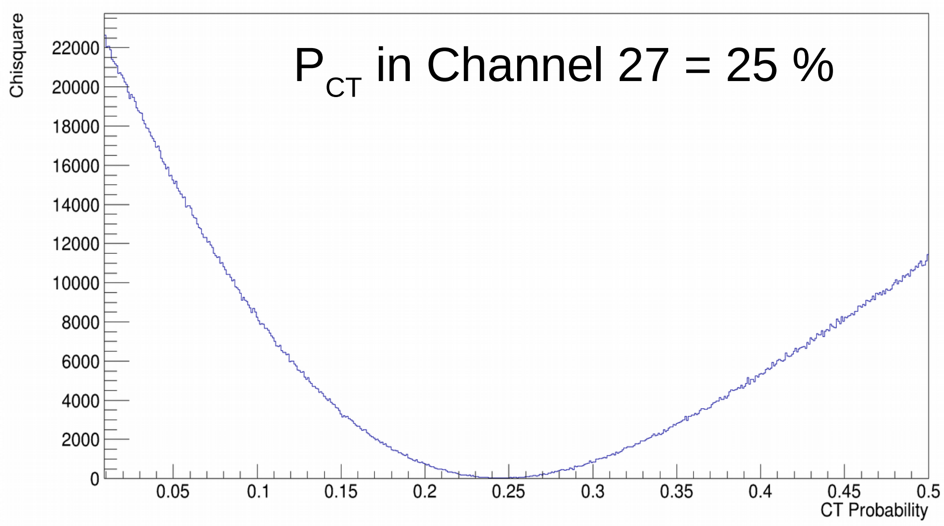
Where N_0 is the height of the gaussian fitting the 0 PE peak

Crosstalk probability in ReD

Given the “true” Single Photoelectron response and the afterpulse distribution, the only parameter to be constrained is the crosstalk probability







Hundreds of toyMC simulations were runned, scanning different values for the crosstalk probability. A chi-square test returned the crosstalk probability fitting the data, for each channel. On average

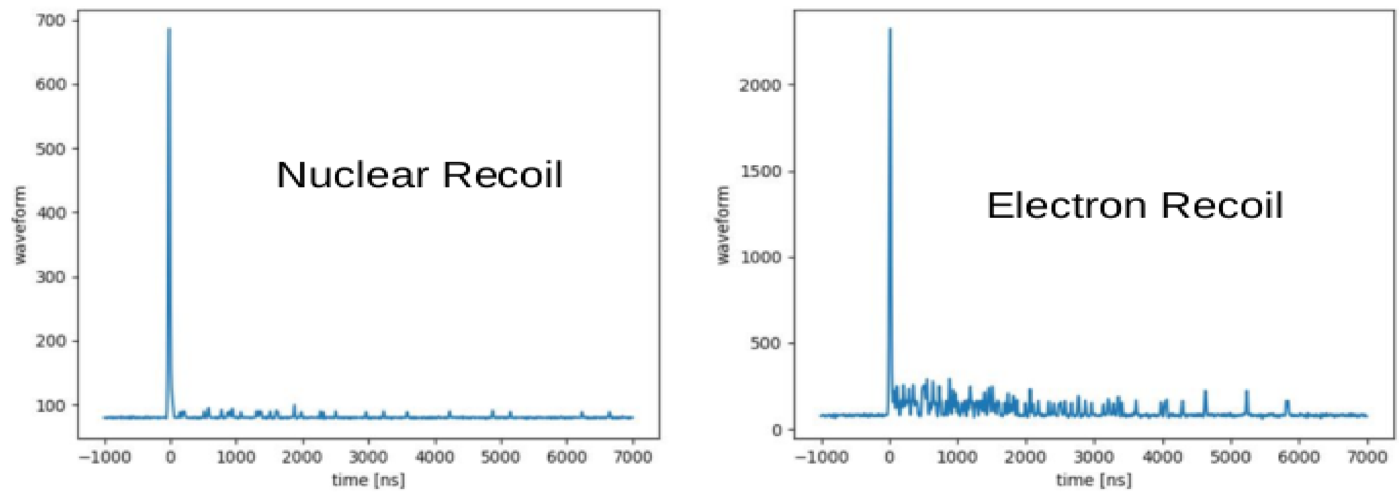
$$\langle P_{CT} \rangle = (18 \pm 7)\ \%$$

Pulse Shape Discrimination with SiPMs

The pulse shape discrimination is strongly affected by the long recharge time of the avalanche if the #PE/channel ("occupancy") is high, giving photoelectrons pile-up on the waveform.

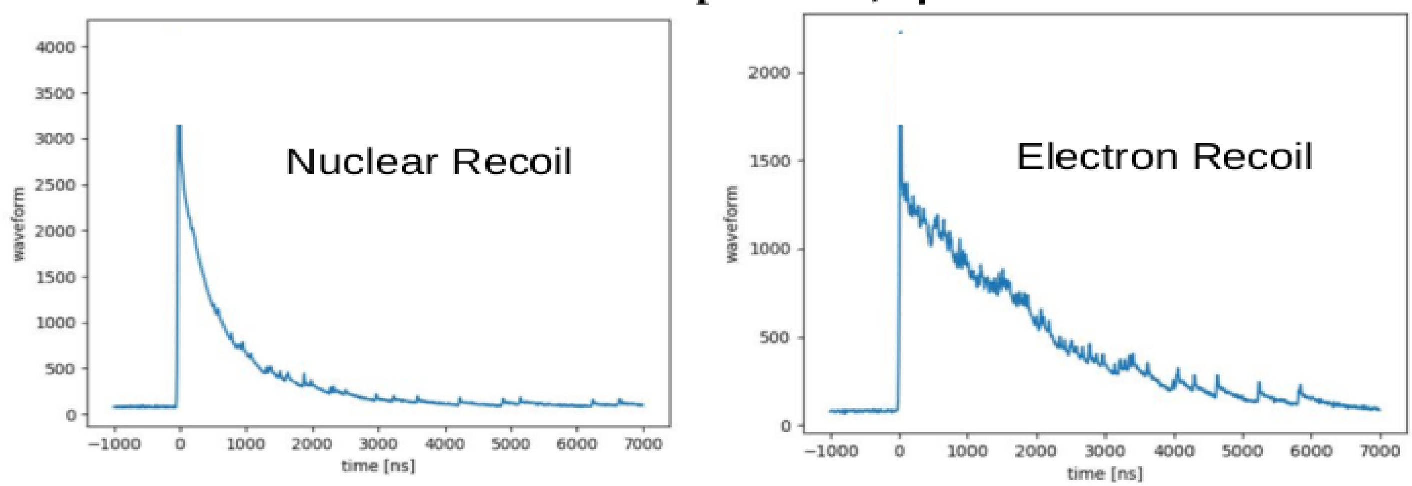
E = 500 keV

Before SiPM



SiPM time response ~ 0,5 µs

After SiPM

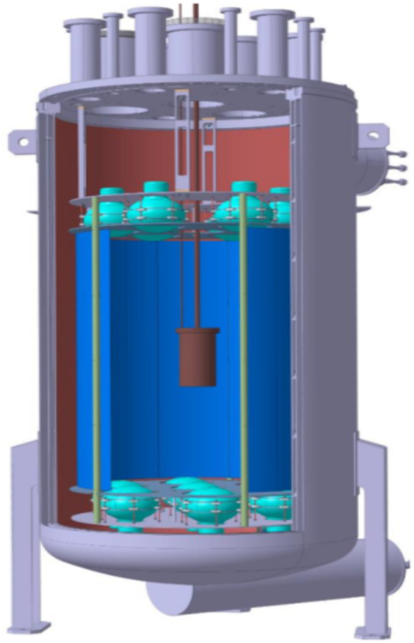


Reconstruction in DarT detector

In DS20K the photoelectron pile-up will be unlikely, thanks to the huge number of photodetectors.

On the other hand a strong decrease of the PSD is expected in DArT (Depletion Argon Test, lead by INFN Cagliari), a small single phase TPC filled with 1.4 kg of Argon seen by 2 SiPMs (11.9×7.8 mm^2 each) and surrounded by ArDM detector (double phase in Atmospheric Argon, here working as single phase)

The aim of DArT, whose data taking will start next winter, is measuring the depletion level of the extracted and purified liquid argon from Urania and Aria (see Alberto talk).



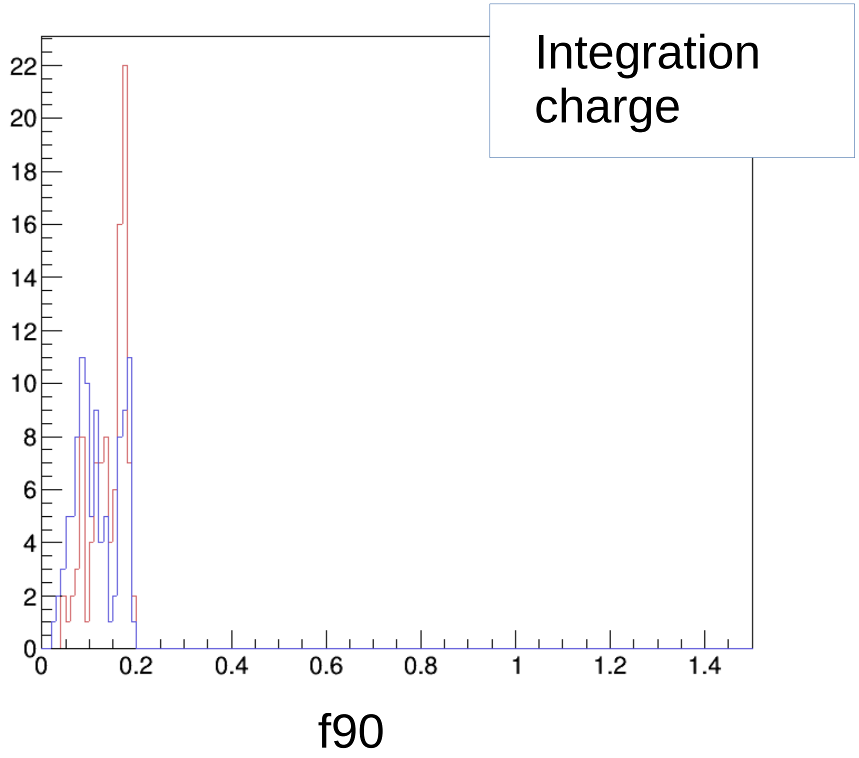
Light Yield = 11 PE/keV assuming Photon detection Efficiency = 40 %

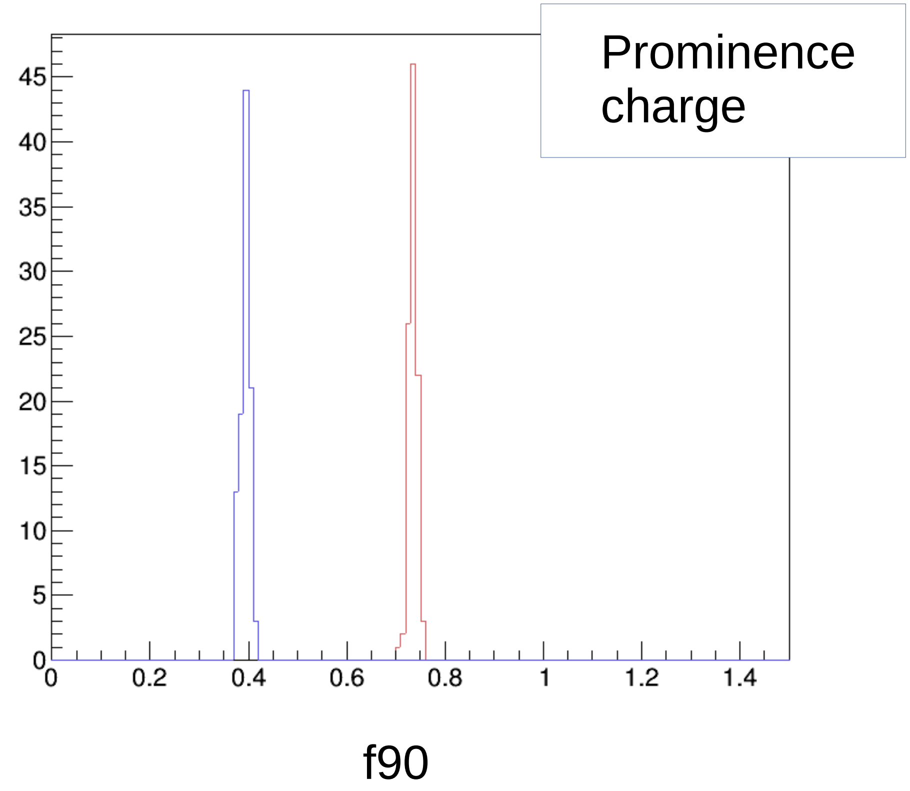
Main background: gammas from cryostat

Rejection: Double coincidence DArT - ArDM

Pulse shape discrimination in DART

A Toy-MonteCarlo simulation of 500 keV events, an α for Nuclear recoils (red) and a β for Electron recoils (blue), in DArT TPC was performed.





Strong improvement of the Pulse shape discrimination

Conclusion

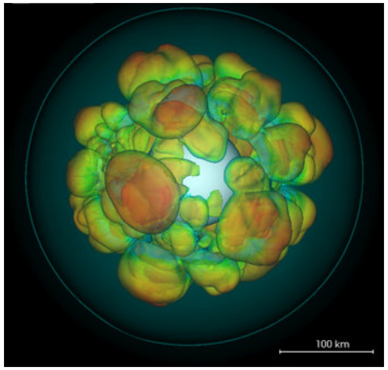
- The new read-out in DarkSide detectors will be fundamental to reach a background-free condition
- On the other hand, drawbacks as the slow recharge time and the AP/CT noises can affect our PSD power and energy resolution
- Looking also at the peaks of the filtered waveform could:

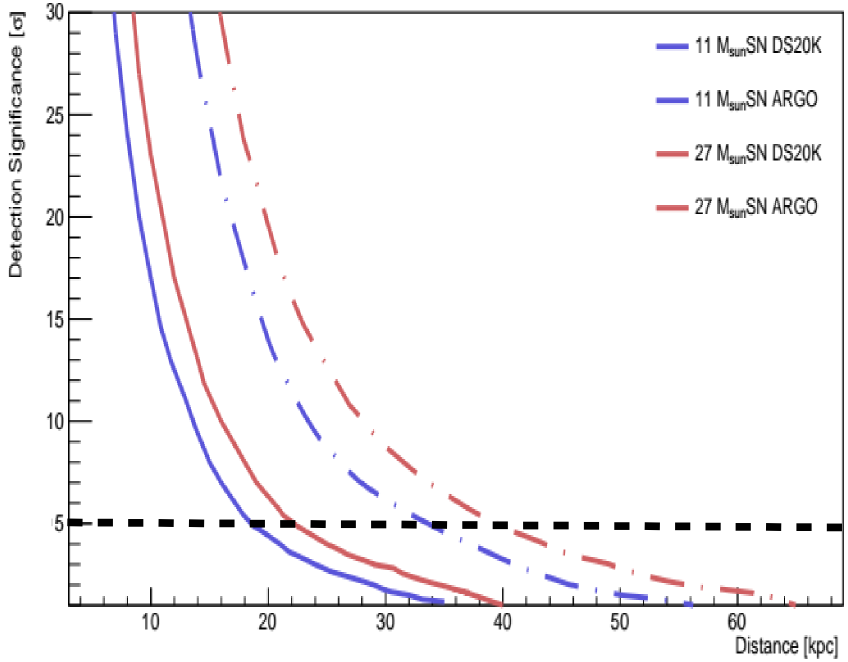
  -Preserve our PSD power

  -Recognize instrumental noises and improve light yield resolution

Other project: Supernova neutrinos detection in DS20K and ARGO

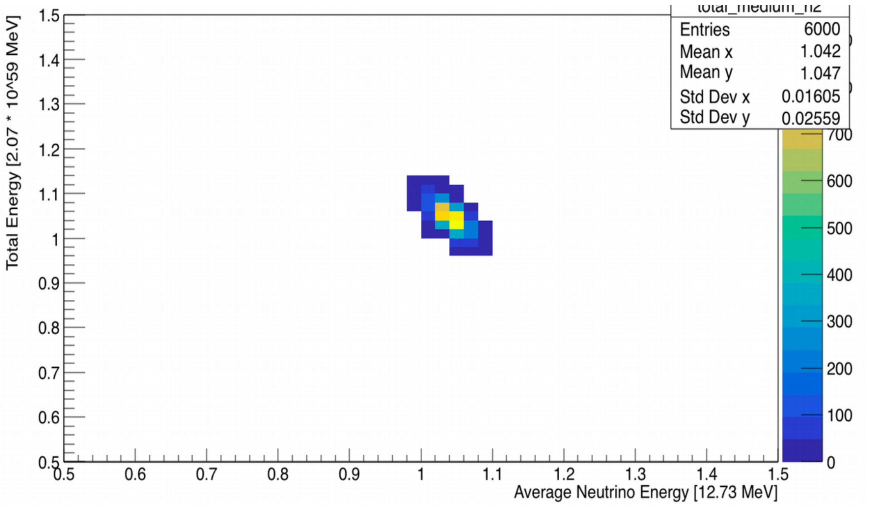
Tipe II supernovae are very rare events (2/3 per century on average), in which 3 x10^{46} J are released in ~ 10 s, mainly via neutrinos of any flavour





5 detection of any galactic supernova

As we are going to be sensitive to all flavours (CevNS scattering), we can reconstruct the main parameters of the global emission



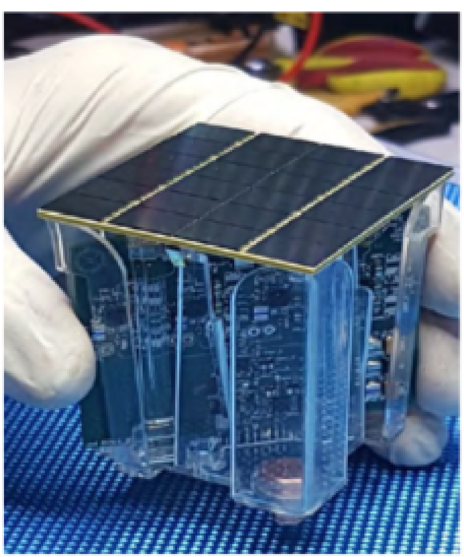
Back up

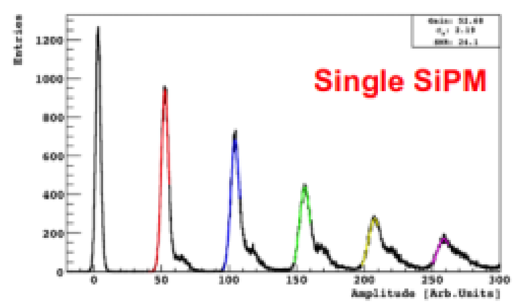
FBK NUV-HD SiPM specifics

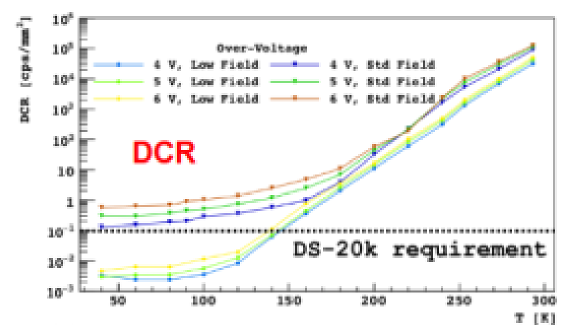
Strict collaboration with Fondazione Bruno Kessler (FBK): development of **specific SiPM** for LAr (50 PDM under way)

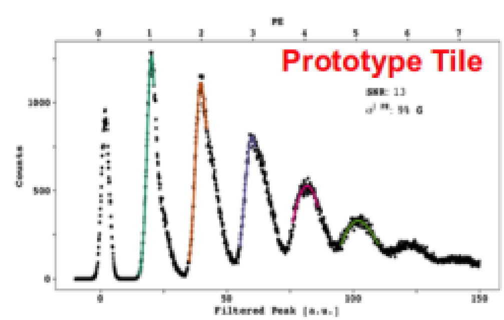
The new SiPM fullfill all the requirements needed by DS-20K

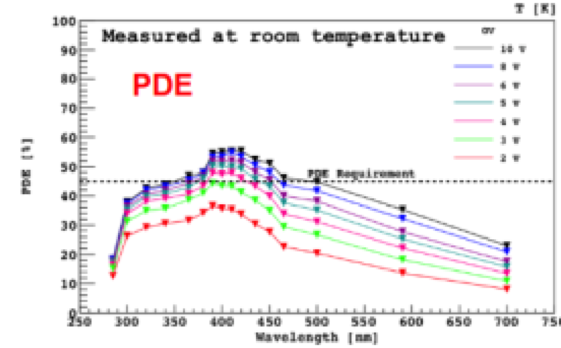
	DS-20k requirement	SiPM tile (PDM)	
Surface	5x5cm^2	24cm^2 prototype 25cm^2 final PDM	✓
Power dissipation	<250mW	~170mW	✓
PDE	>40%	$50\% \cdot \varepsilon_{geom} = 45\%$	✓
Noise Rate	<0.1cps/mm^2	0.004cps/mm^2	✓
Time Resolution	O(10ns)	16ns	✓
Dynamic Range	>50	~100	✓





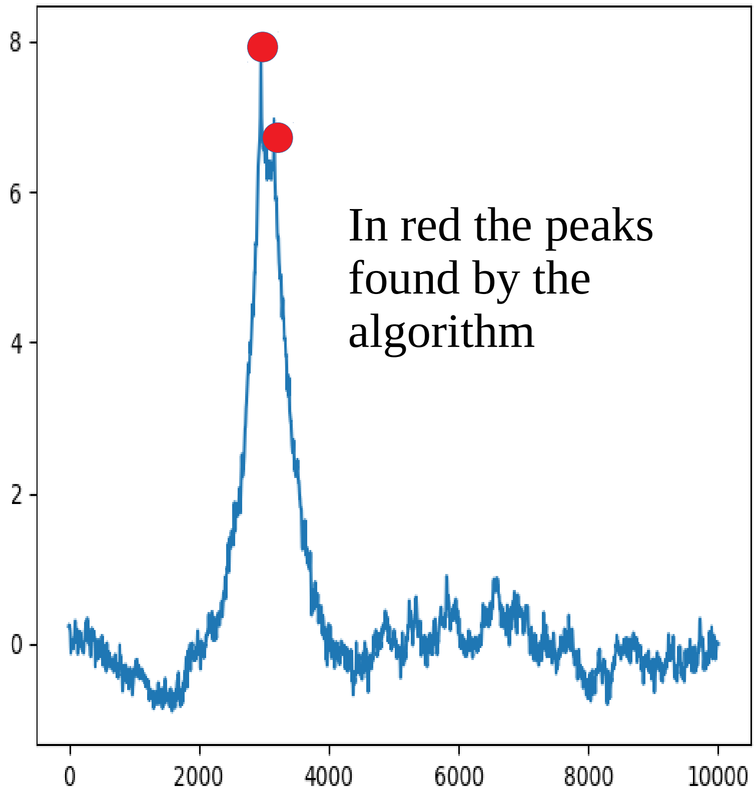




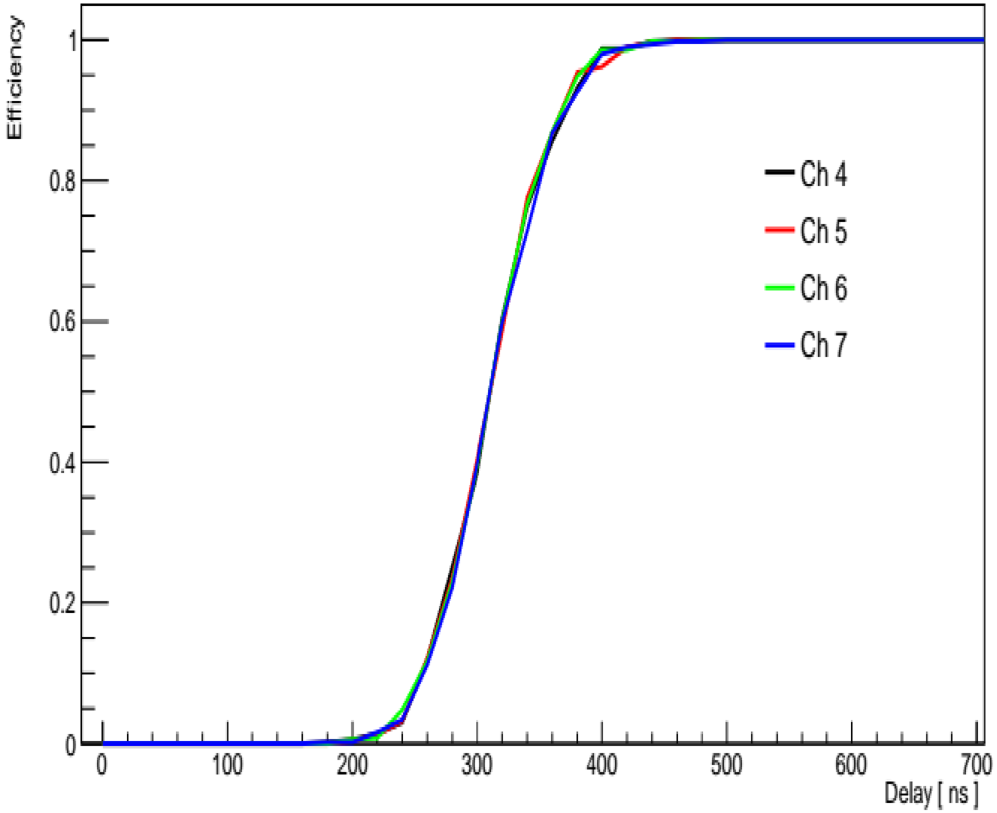


Peak-finder efficiency

The filtering and peak finder has been applied on the ReD laser data, in order to characterize the afterpulses (AP) in a FBK-NUV HD SiPM

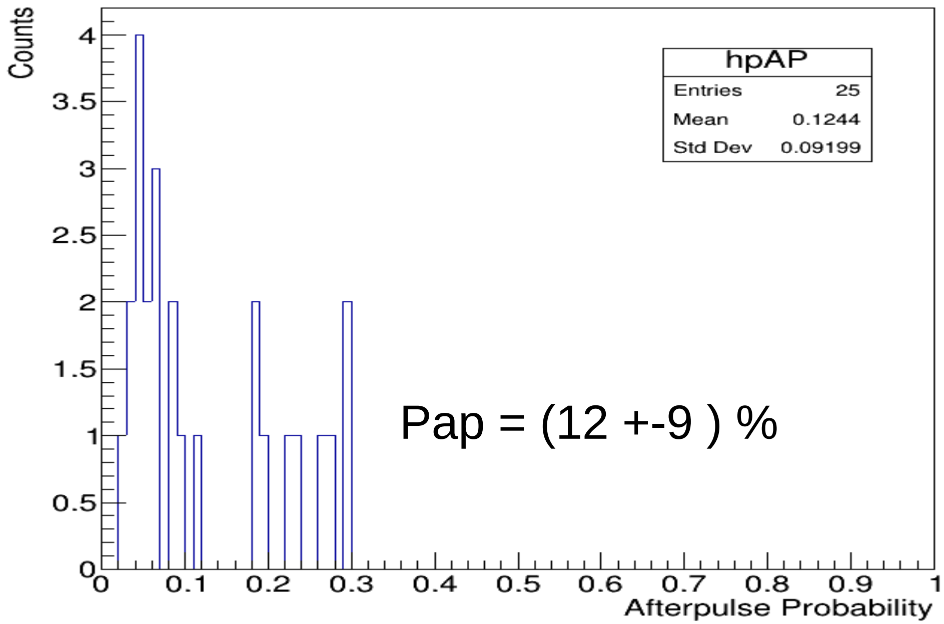


Toy-MC simulation of an afterpulse, based on ReD laser run data



The more the delay of the AP avalanche after primary one, the higher gets the peak finder efficiency

Afterpulse and Crosstalk probability in ReD



The integration on the acquisition gate gave the afterpulse probability for each channel.

Thanks to the comparison between data and a toy-MonteCarlo simulation, the probability to observe a optical crosstalk was also determined for each ReD channel