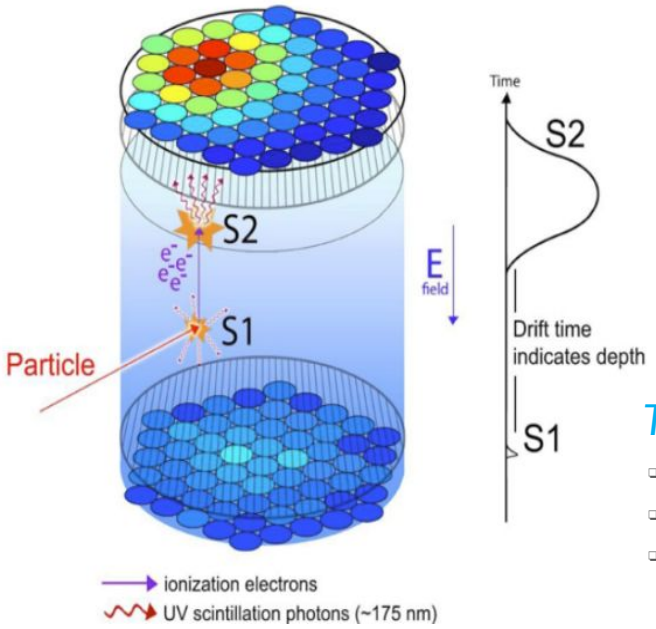
Reconstruction of single-scatter events for dark matter direct search with the DarkSide-20k experiment

Camilla Salerno

Double-phase DarkSide-20k TPC



Inner veto (IV):

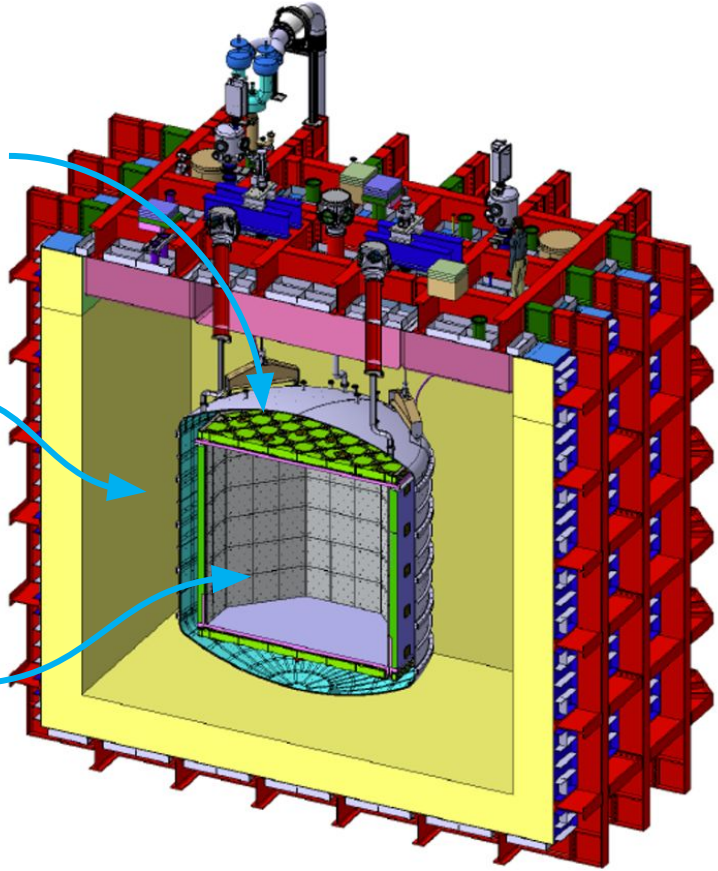
- Active UAr mass: 32 tonnes
- Neutron tagging

Outer Veto (OV):

- 700 t of AAr

TPC:

- Active UAr mass: 49.7 tonnes
- Gas pocket thickness: 7.0 mm
- Conductive polymer: Clevios
- Light yield: 10 PE/keV
- Ionization yield: 20 PE/e^-



3D reconstruction:

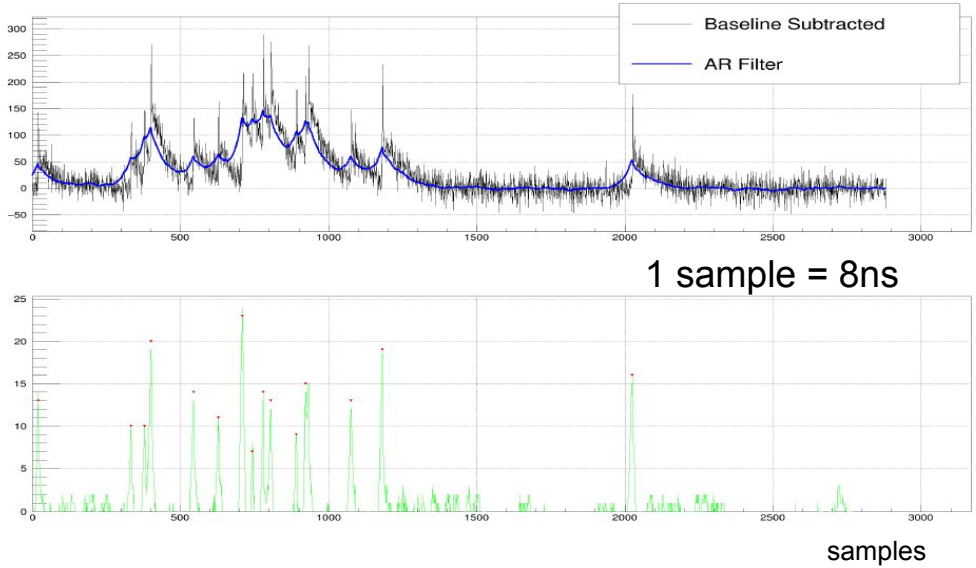
- X,Y from the S2 signal
- Z from the time difference between S1 and S2

Energy measured from the combination of S1 and S2

DS-20k: MC & Reconstruction strategy

Raw data → Pulse Finder → Pulse classification: S1, S2, multiple S2 → XY, PSD reconstruction → Event Building: association between S1 and S2 of the same event

SiPM waveform



SiPM waveform showing in red the *hit prominences* which are proportional to the number of photoelectrons in the hit

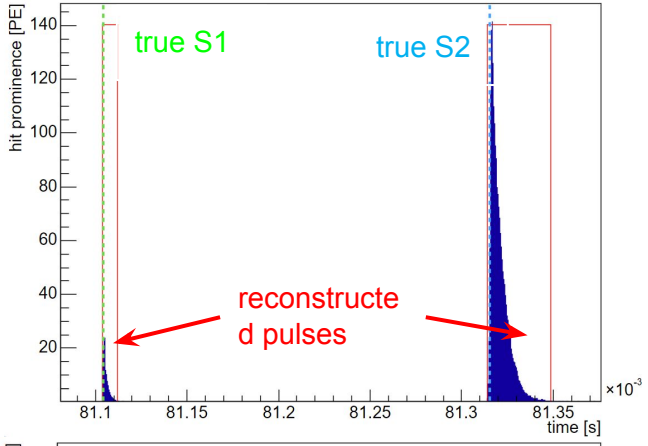
↓

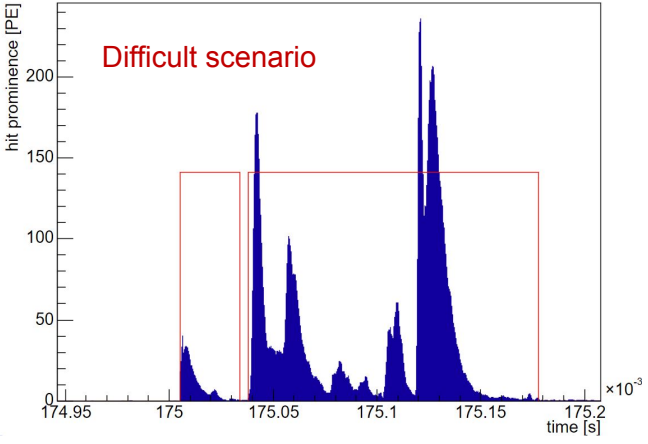
Final raw data: charge and time of the hits

A cluster of hits is defined as a *pulse*

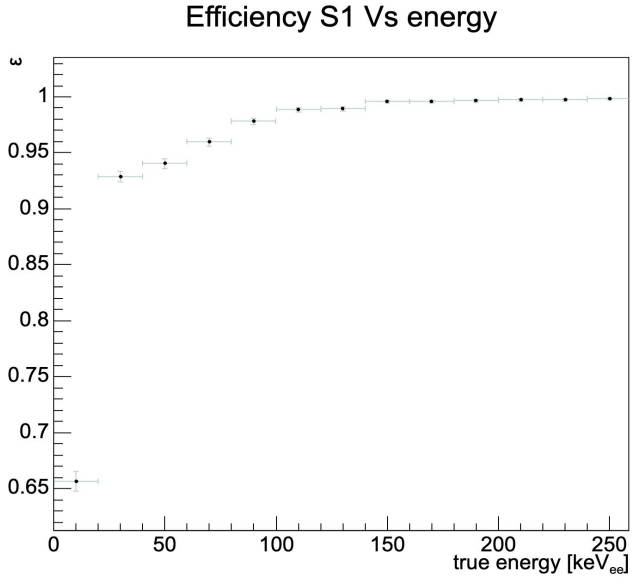
2112 readout channel only for the TPC!!! expected 200 evts/s in the TPC + IV

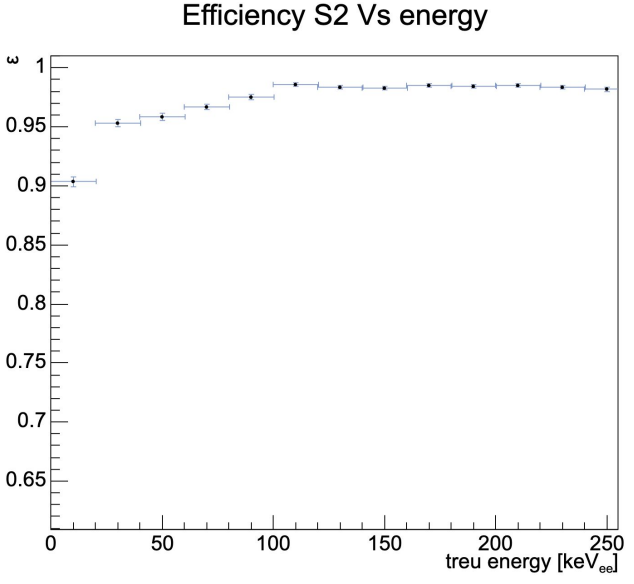
Pulse Finder: Efficiency





Reconstruction efficiency as a function of the energy of the event: for each bin of energy how many S1 and S2 have been recognised





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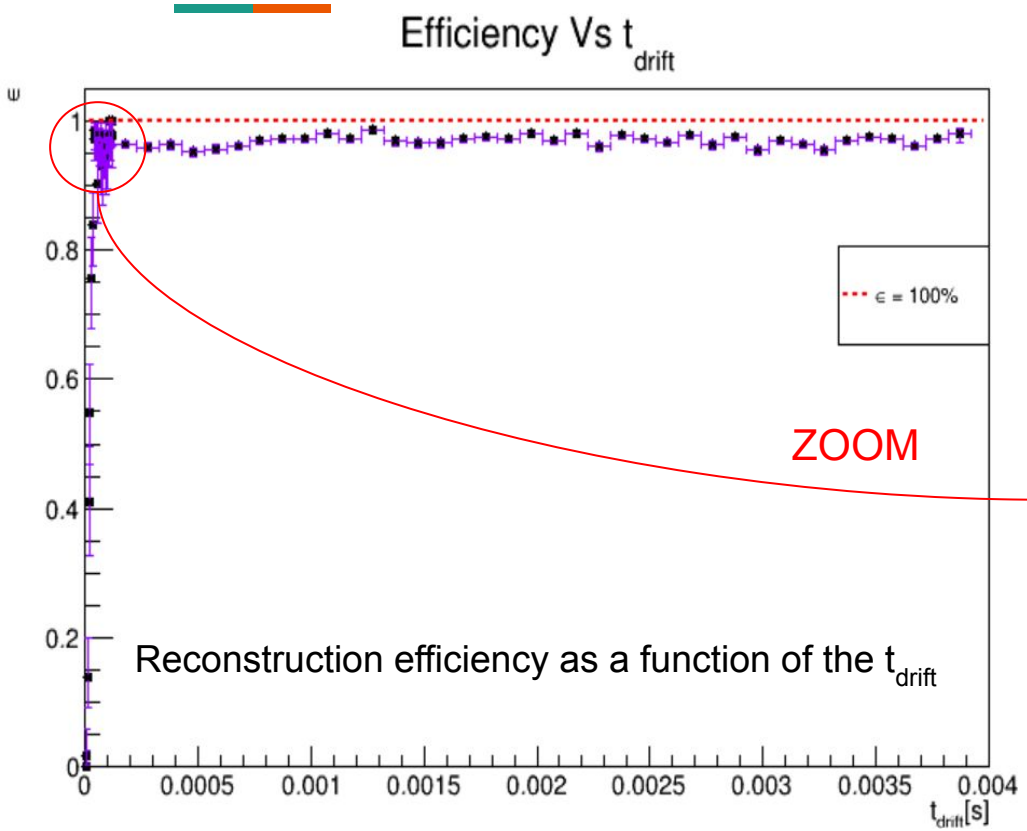
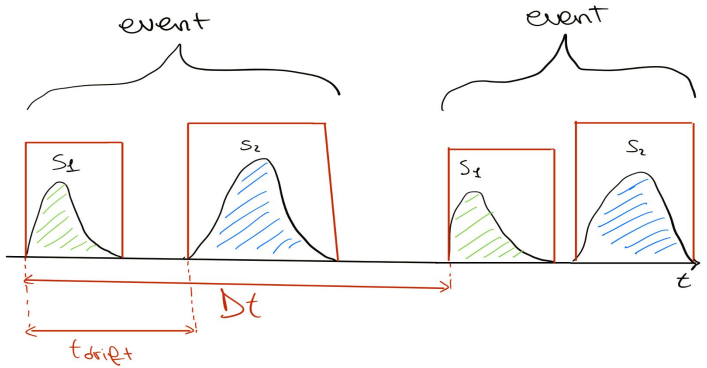
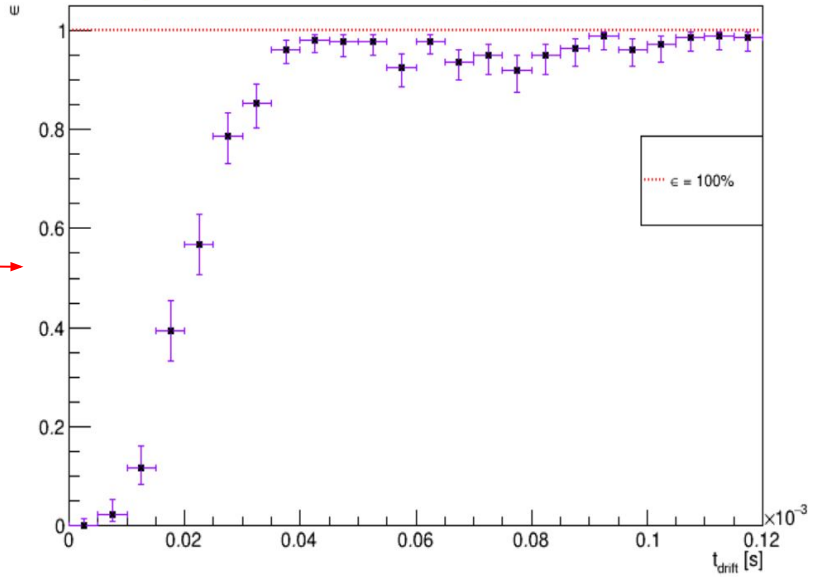


ZOOM

Reconstruction efficiency as a function of the t_{drift}





Conclusion & Perspectives

Summary of what I have worked on:

- I developed an algorithm able to identify S1 and S2 pulses
- I studied and evaluated the classification of these pulses in S1 or S2

Future perspectives:

- Improve the algorithms to obtain better efficiencies
- Implementation of next reconstruction steps including the event building: the challenge is to reconstruct pile-up events
  R=100 Hz ; maximum t_{drift} = 4 ms ⇒ Pile-up probability≅ 30%
- Evaluation of these algorithms using real data coming from the DarkSide demonstrator Proto-0, first dual phase prototype TPC using DarkSide-20k SiPMs using 6 kg of Argon

Backup slides

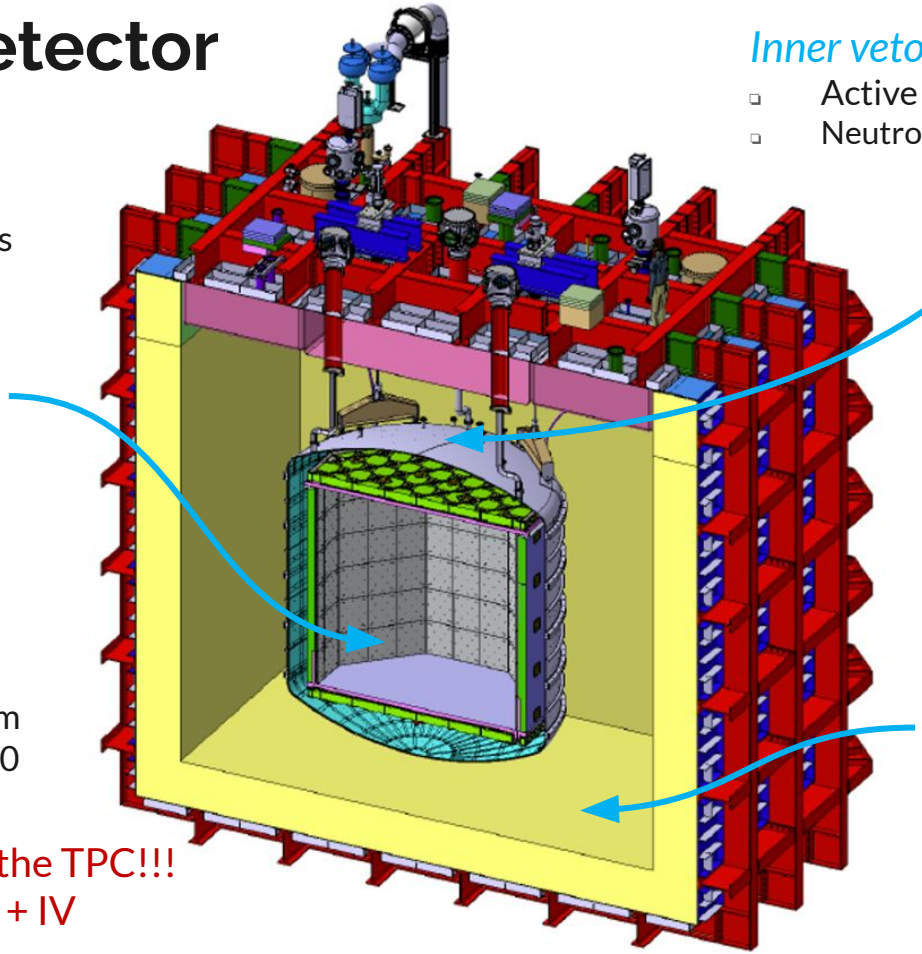
DS-20k: Inner Detector

TPC:

- Active UAr mass: 49.7 tonnes
- Fiducial UAr mass: 20.2 tonnes
- Height: 365 cm
- Gas pocket thickness: 7.0 mm
- Conductive polymer: Clevios
- ESR as reflector and TPB as wavelength shifter
- Light yield: 10 PE/keV
- Ionization yield: 20 PE/e^-

Readout

- SiPM as photosensors: 21 m^2
- Single pixel 30 μm^2
- Readout channel 10 cm X 10 cm (Dark count rate per channel 40 Hz)



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Outer Veto (OV):

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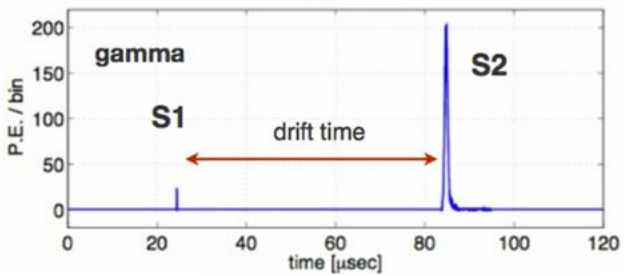
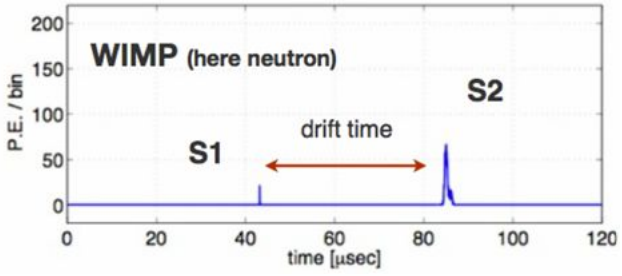
2112 readout channel only for the TPC!!!
expected 200 evts/s in the TPC + IV

Argon target

S2/S1 ratio greater for ER than NR due to a higher recombination (a factor 2-3) probability for NR





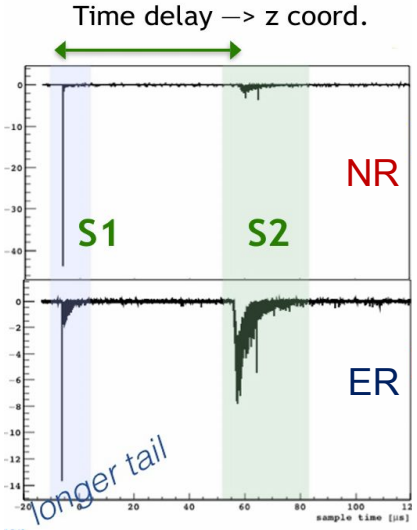
Only for Argon PSD

Argon excited decay into two different spin states: a singlet and a triplet, having very different decay times

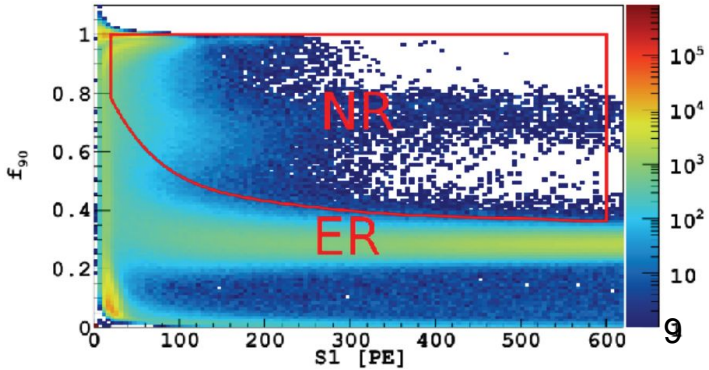
- Singlet ~ 7ns (Xe 3 ns)
- Triplet ~ 1.5μs (Xe 27 ns)

NR and ER have different singlet to triplet ratios due to the different dE/dx

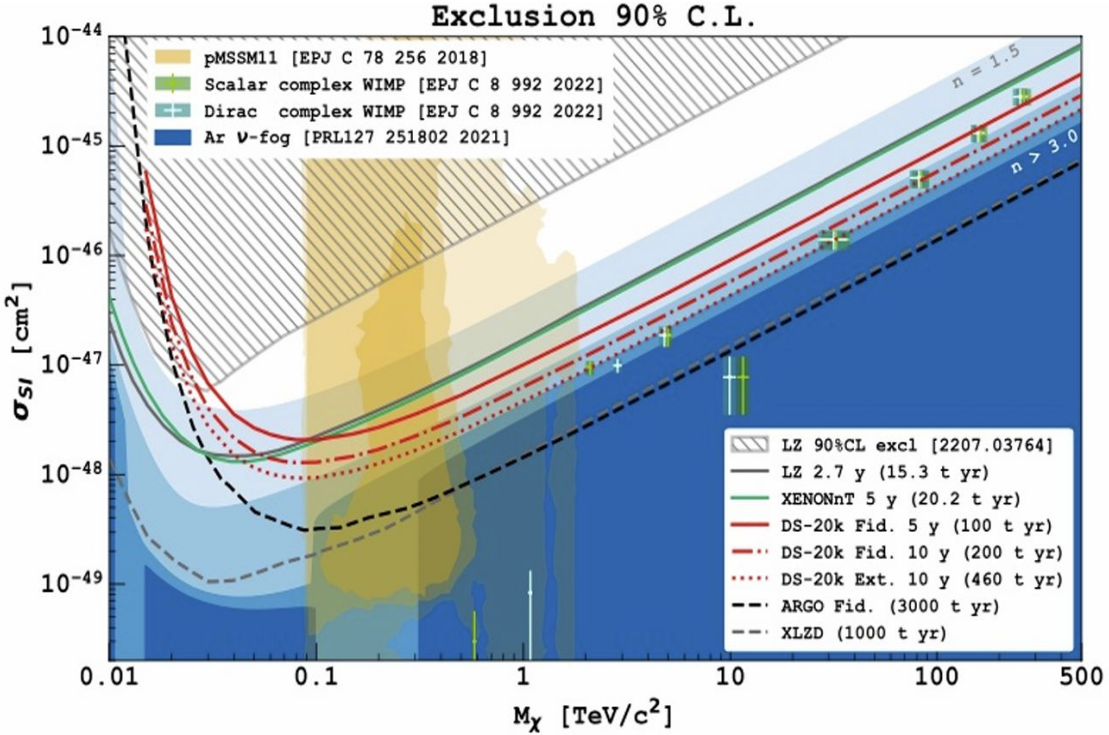
- NR~70% singlet
- ER ~70% triplet

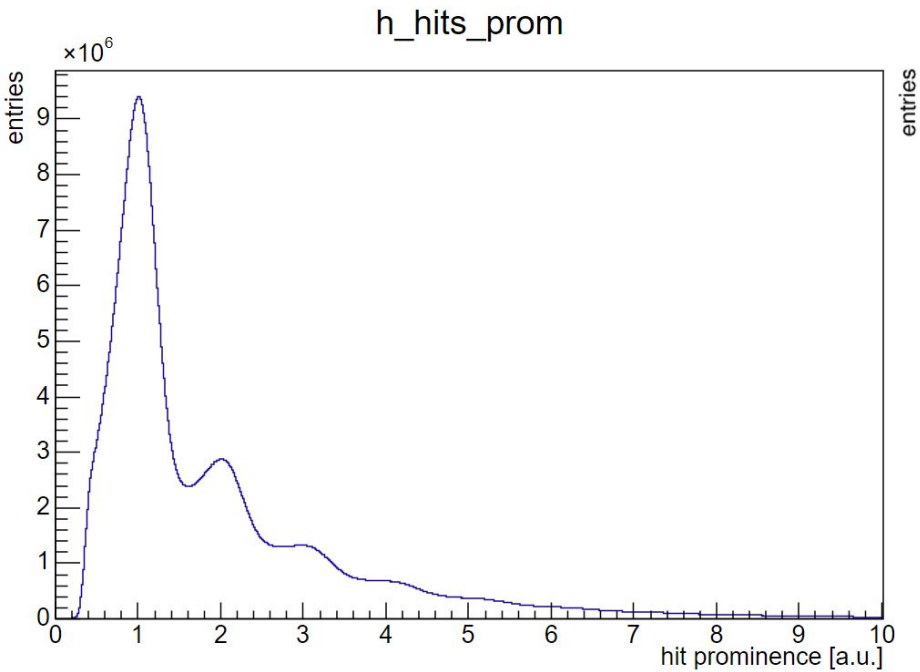


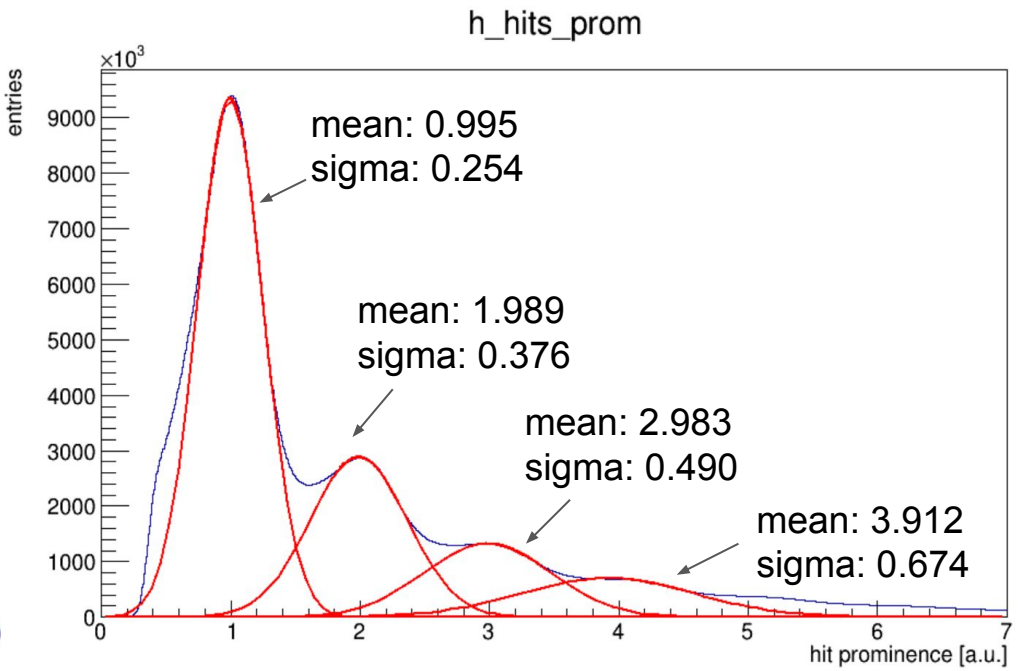
$$f_p = \frac{\int_{T_i}^{\xi} S_1(t)dt}{\int_{T_i}^{T_f} S_1(t)dt}$$



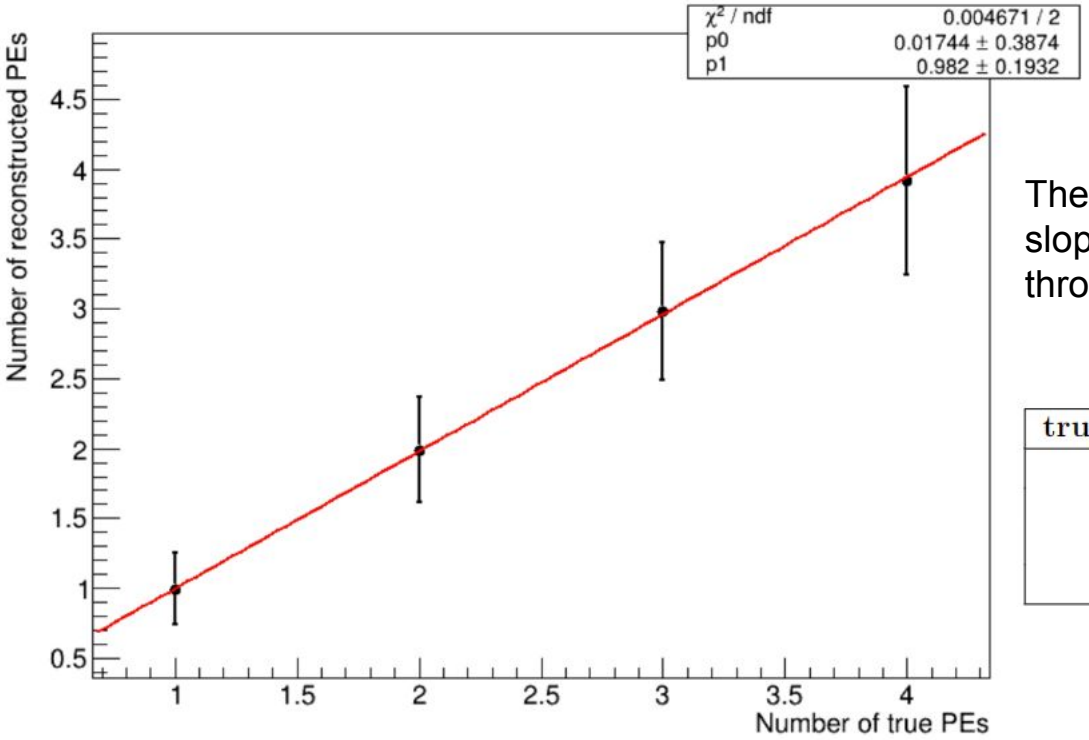
DarkSide-20k: Sensitivity




h_hits_prom
×10^6
entries
hit prominence [a.u.]


h_hits_prom
×10^3
entries
mean: 0.995
sigma: 0.254
mean: 1.989
sigma: 0.376
mean: 2.983
sigma: 0.490
mean: 3.912
sigma: 0.674
hit prominence [a.u.]

Single PE calibration



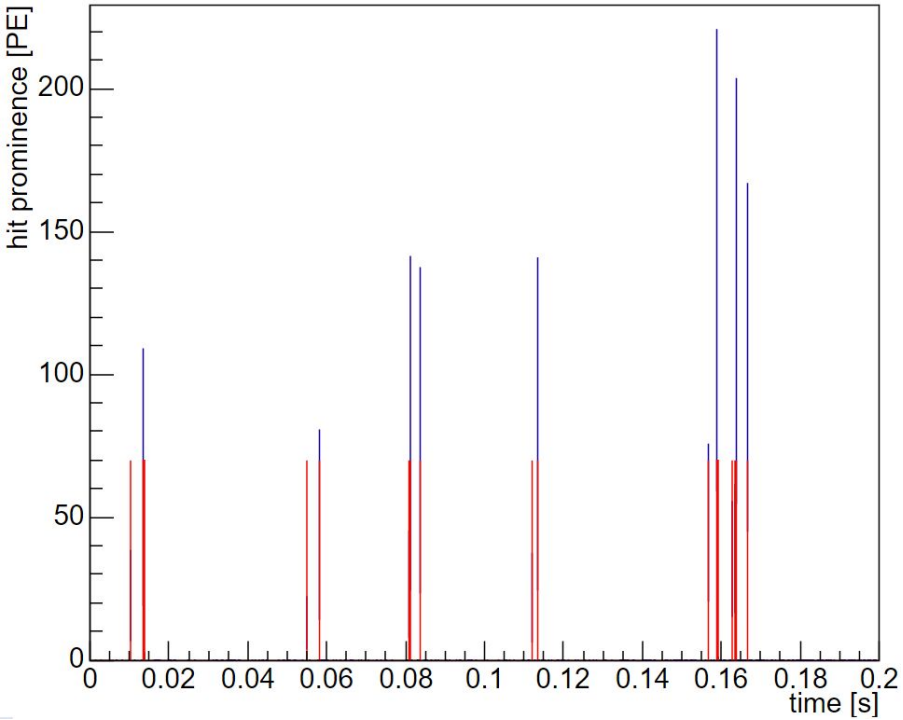
The linear fit with p0 being the intercept and p1 the slope of the fit, is compatible with a line passing through 0

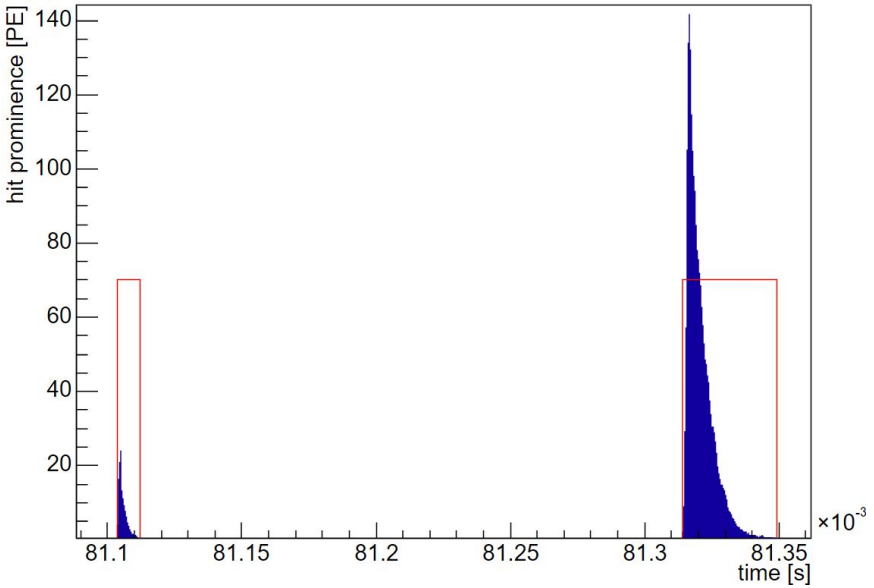
true number of PEs	Mean	Std Deviation
1 PE	0.9955 ± 0.0001	0.2538 ± 0.0003
2 PE	1.9890 ± 0.0009	0.3763 ± 0.0019
3 PE	2.9834 ± 0.0116	0.4906 ± 0.0120
4 PE	3.9126 ± 0.0925	0.6746 ± 0.0643

Pulse Finder

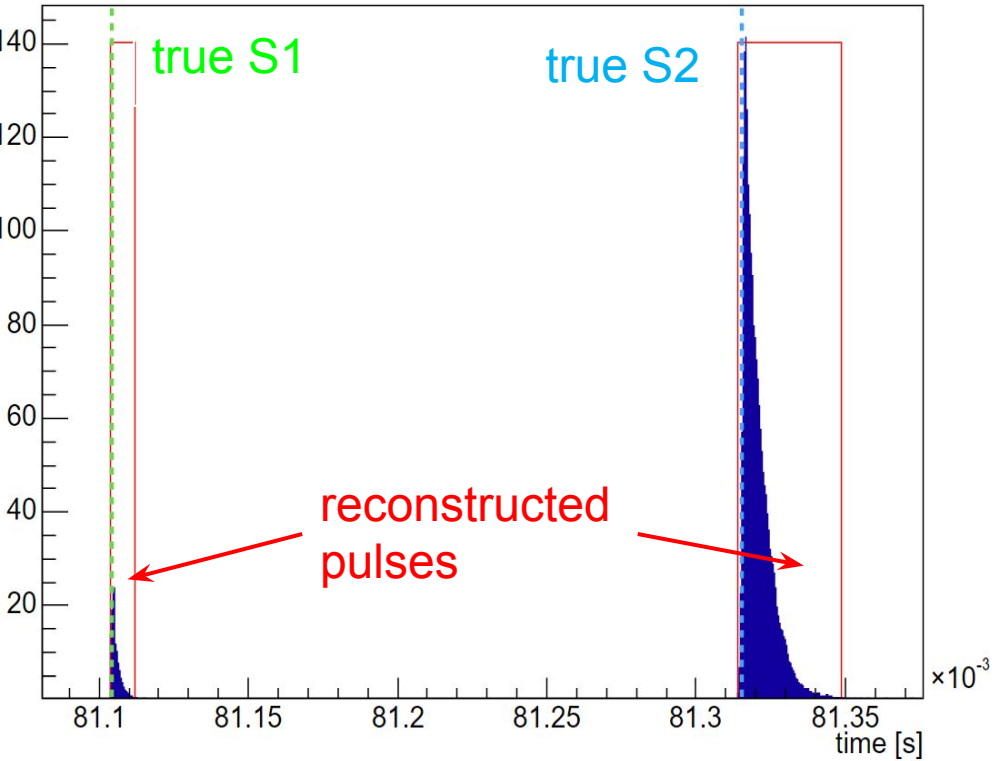
- **Step 1: sum the signal from all channels**
- **Step 2: filter (noise reduction)**
- **Step 3: clustering of hits**

The red rectangles represent the reconstructed pulses, while in blue we have the hit waveform





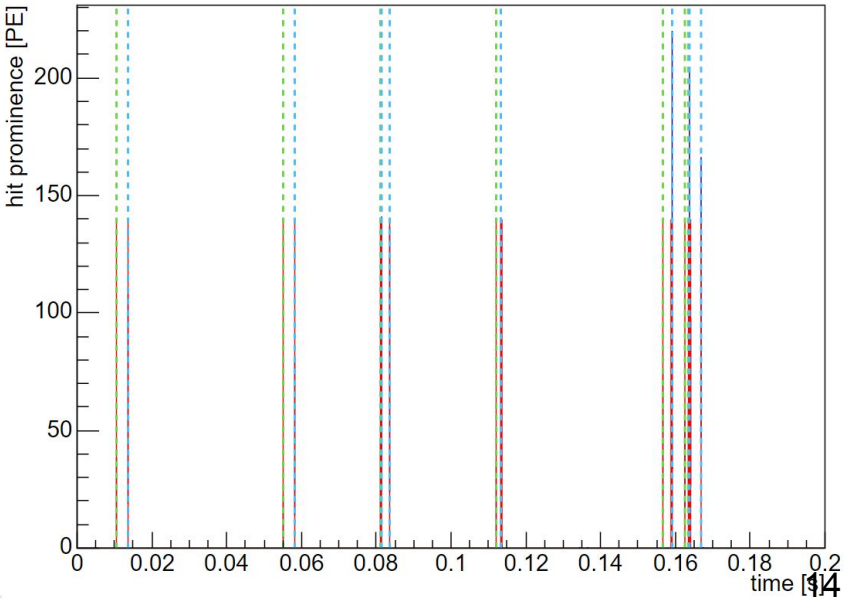
Pulse Finder: truth association



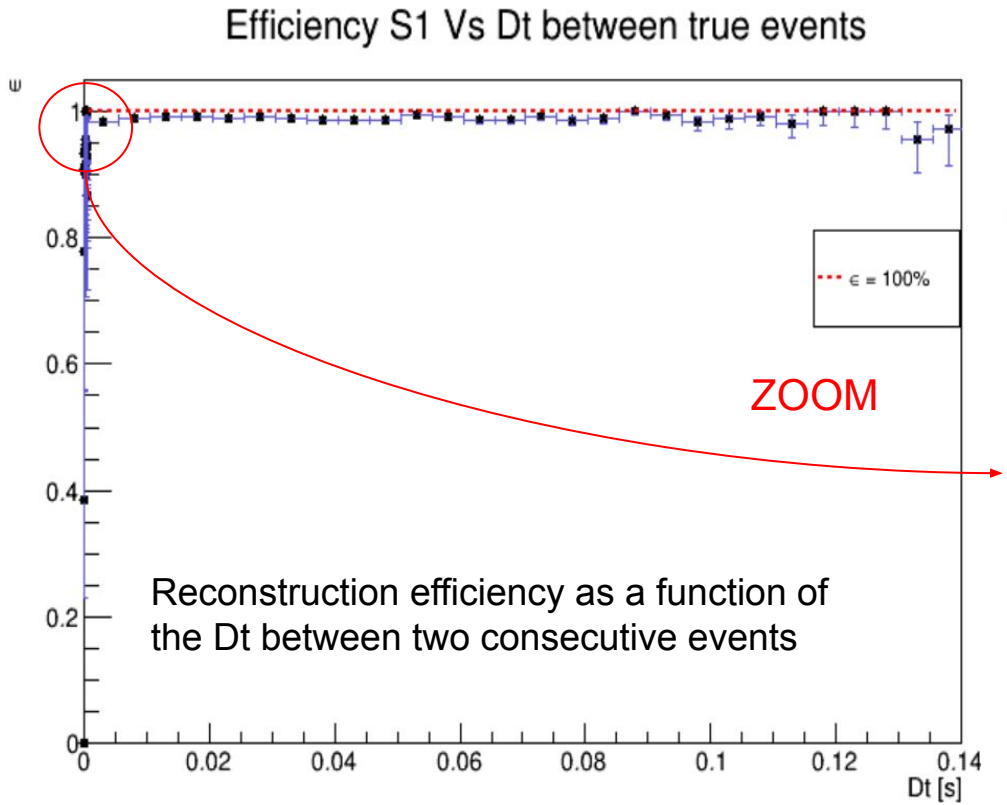
From MC:

- time of the event
- energy of the event
- position of the event

Each true pulse is associated with the closest reconstructed pulse in time.

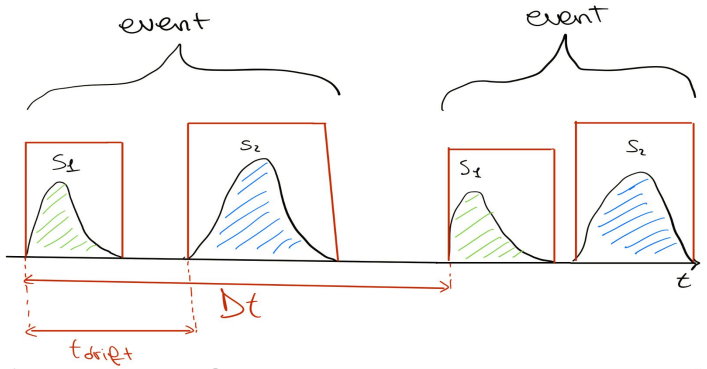


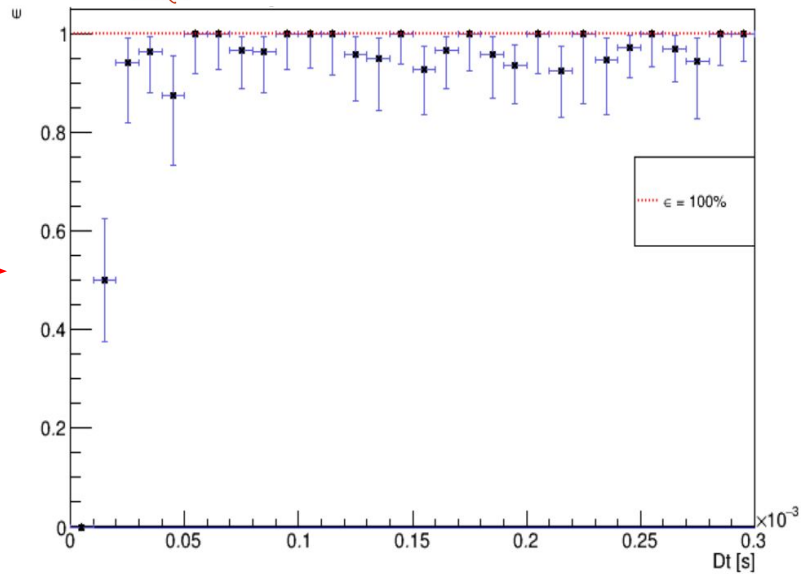
Pulse Finder: Efficiency



ZOOM

Reconstruction efficiency as a function of the Dt between two consecutive events



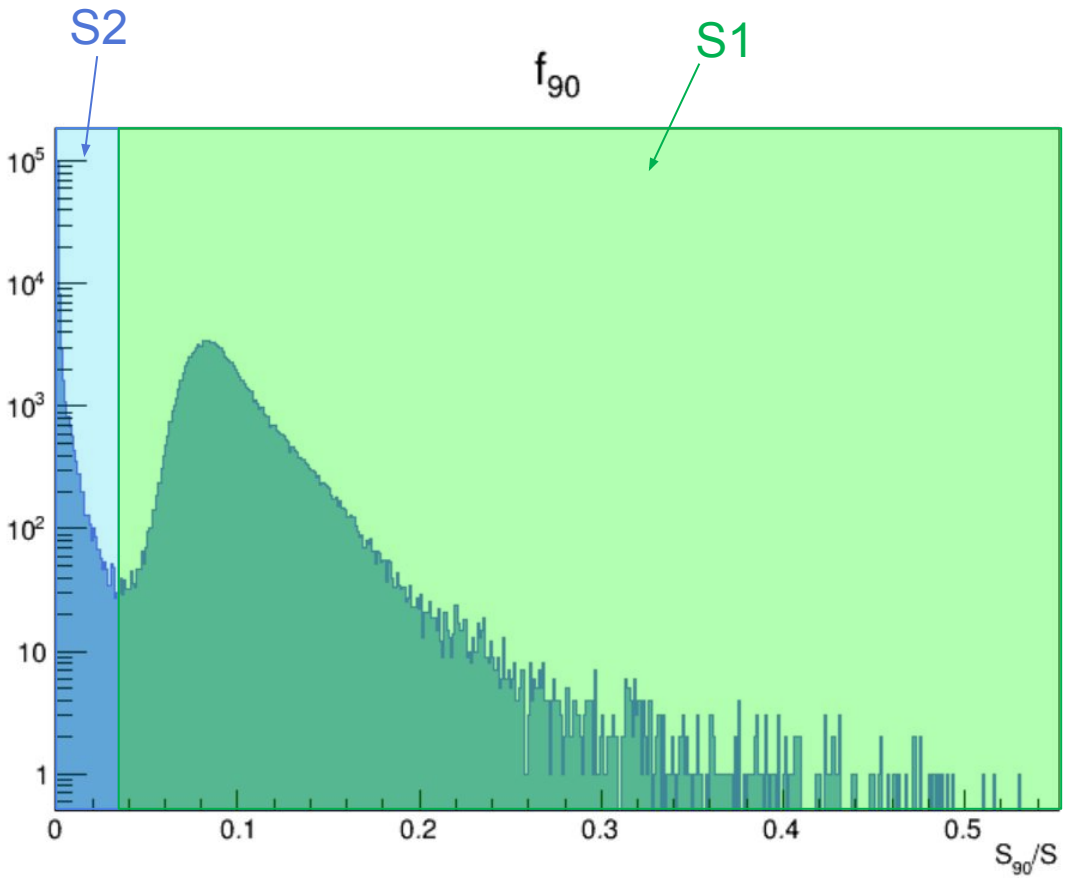


Pulse Classification

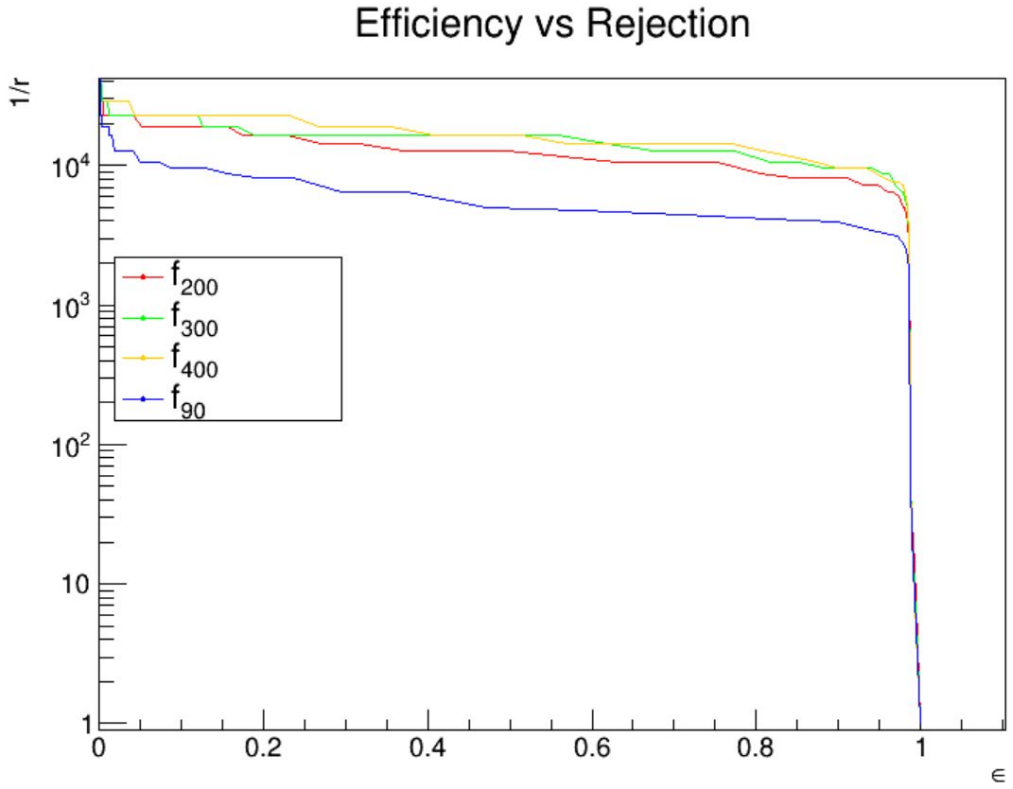
Reconstructed pulse must be classified in scintillation and ionization signals.
S1 is a prompter signal, which is more concentrated in the first ns of the pulse, in contrast with S2 which is much more spread over time due to diffusion, electron transit time in gas and longer decay time of Ar dimer in gaseous phase (11 ns and 3.2 μs).

$$f_p = \frac{\int_{T_i}^{\xi} S(t)dt}{\int_{T_i}^{T_f} S(t)dt}$$

ξ=90, 200, 300 and 400 ns



Pulse Classification: ROC curve



Changing the tagging threshold the efficiency and the rejection power have been evaluated as

$$\epsilon = \frac{\#\text{recognised } S_1}{\#\text{true } S_1}$$

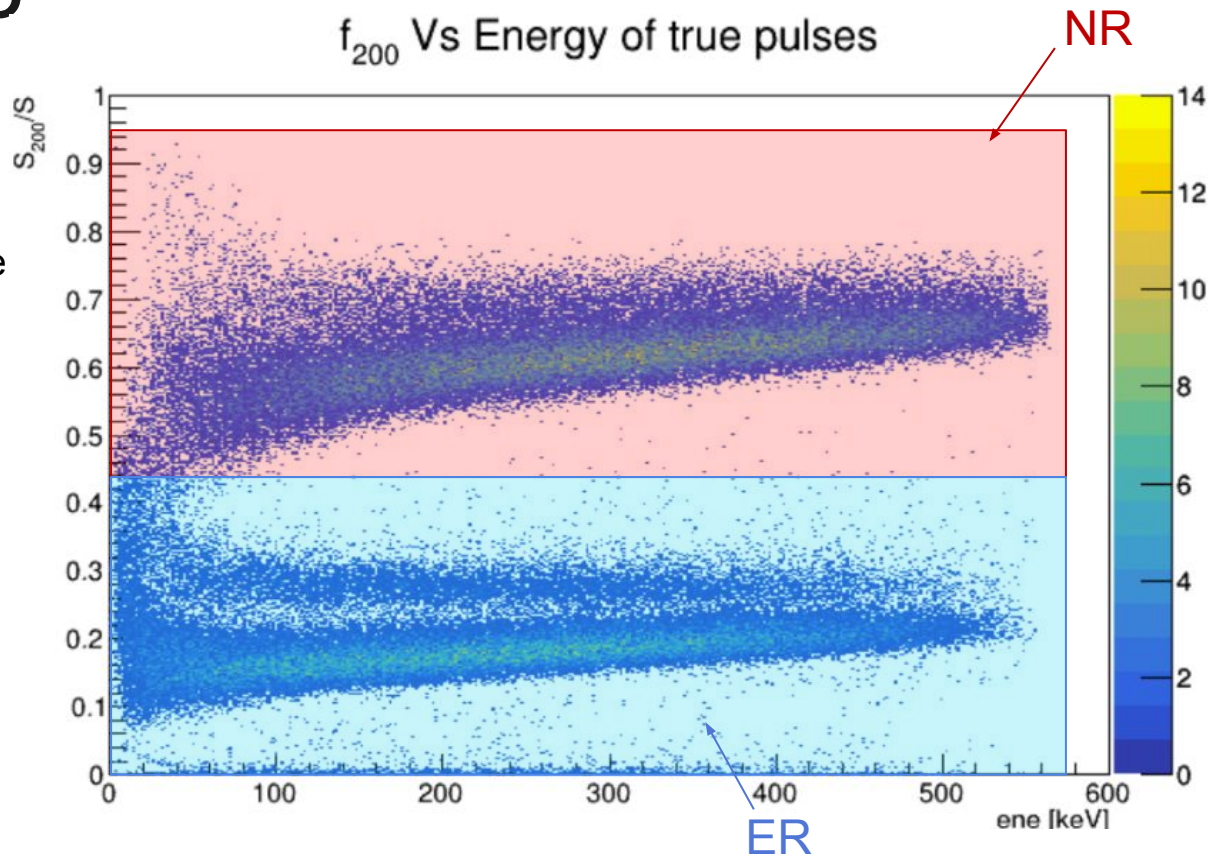
$$\frac{1}{r} = \frac{\#\text{true } S_2}{\#S_2 \text{ recognised as } S_1}$$

The closest function to the ideal behavior corresponds to f_{400}

First look at the PSD

A sample of nuclear recoils, in the same energy range of the , has been simulated to evaluate the PSD

Two bands in the 2D plot of Vs energy, corresponding to ER for the lower band and to NR for the upper band



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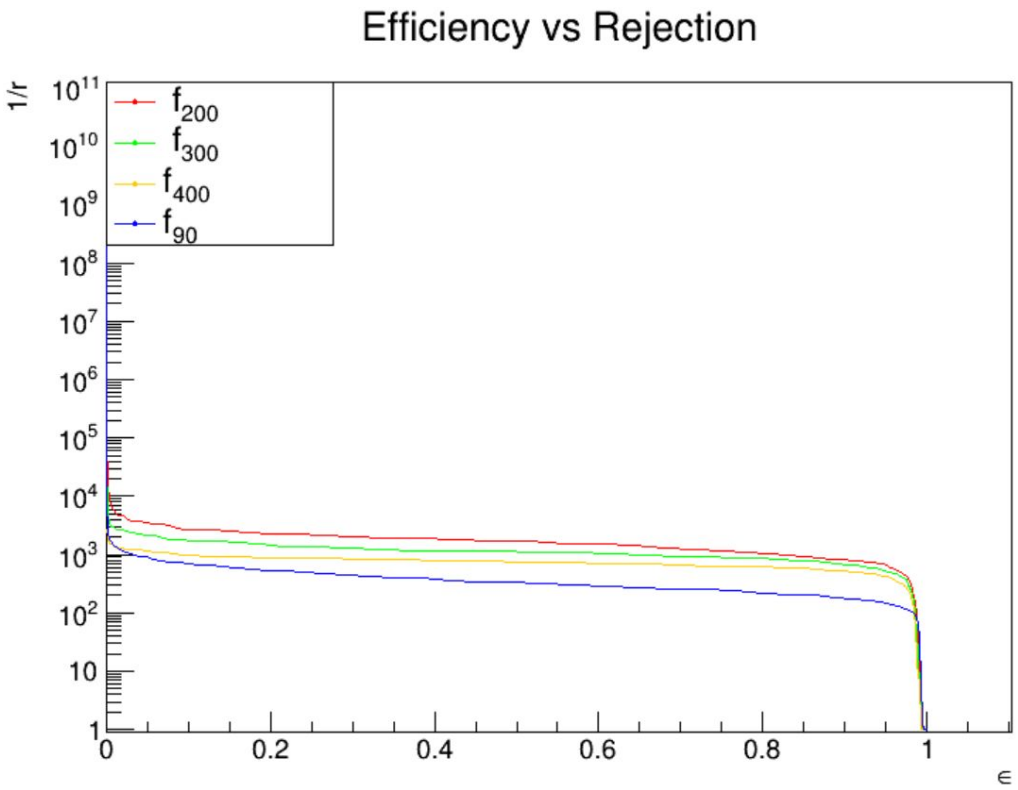

Changing the PSD tagging the efficiency and the rejection power have been evaluated for selectin NR

The closest function to the ideal behavior corresponds to f_{200}