Background Monitoring in DarkSide-20k

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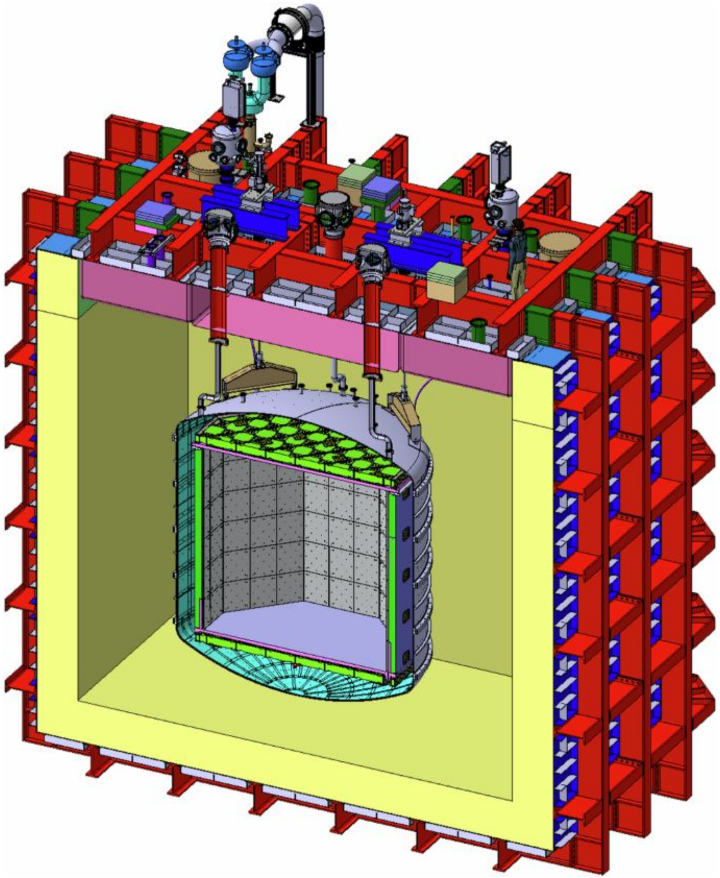
The DarkSide-20k Detector

It is a direct detection dark matter experiment being built in the Gran Sasso National Laboratory in Italy. It consists of three detectors:

1. The dual phase **time projection chamber (TPC)**, which is filled with underground argon (UAr).
2. The **inner neutron veto**, which is filled with UAr.
3. The **outer muon veto**, which is filled with atmospheric argon (AAr).



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Dual Phase Time Projection Chambers

A TPC has large liquid argon-40 volume and a thin layer of gaseous argon with an electric field applied.

When a particle interacts with the liquid argon, scintillation light and ionized electrons are released.

The electric field causes the electrons to move towards the gas layer.

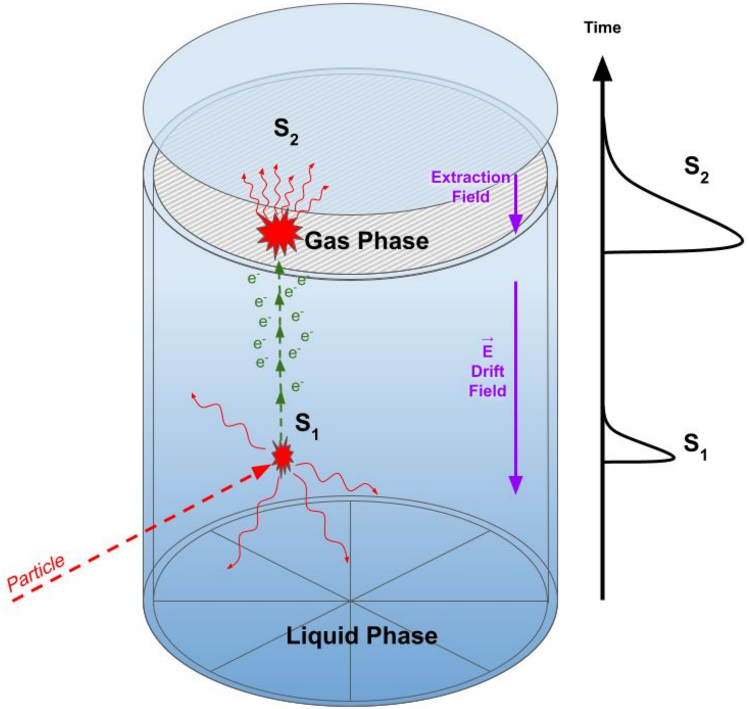


Figure from Nick Swidinsky

Two Types of Pulses

Argon is used as a detection target because it flashes light when particles deposit energy!

S1 pulses

When a particle hits liquid argon, primary **S1 light** is released along with ionized electrons.

S2 pulses

When ionized electrons reach the gas layer, they excite the gaseous argon and cause secondary **S2 light** through electroluminescence.

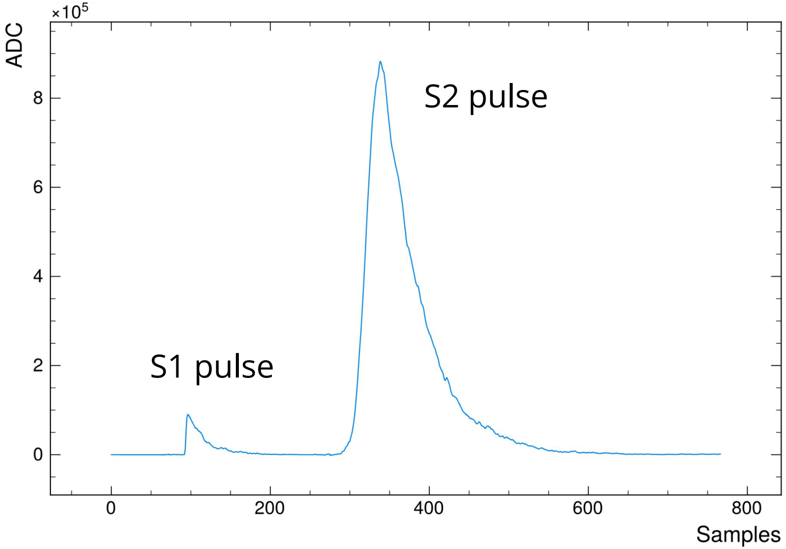
Photosensors at the top and bottom of the detector capture light.

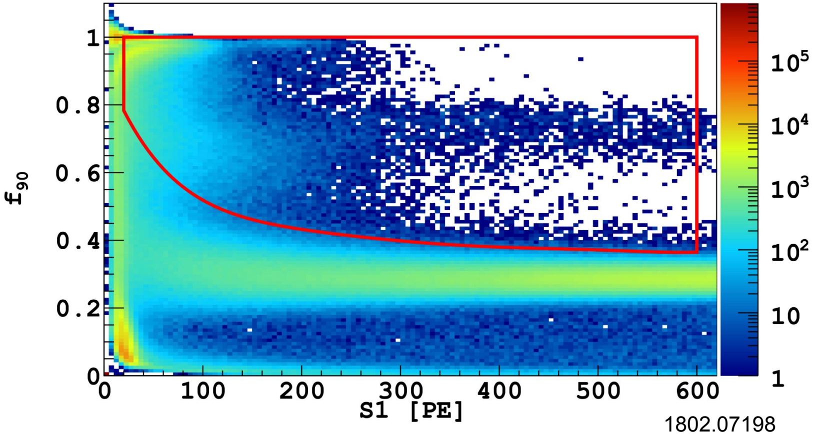
Types of Signal

Electron recoils are caused by interactions with an argon atom's electrons.

Nuclear recoils are caused by interactions with a nucleus. WIMPs would cause nuclear recoils.

They can be distinguished using **pulse shape discrimination.**





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Data Acquisition System

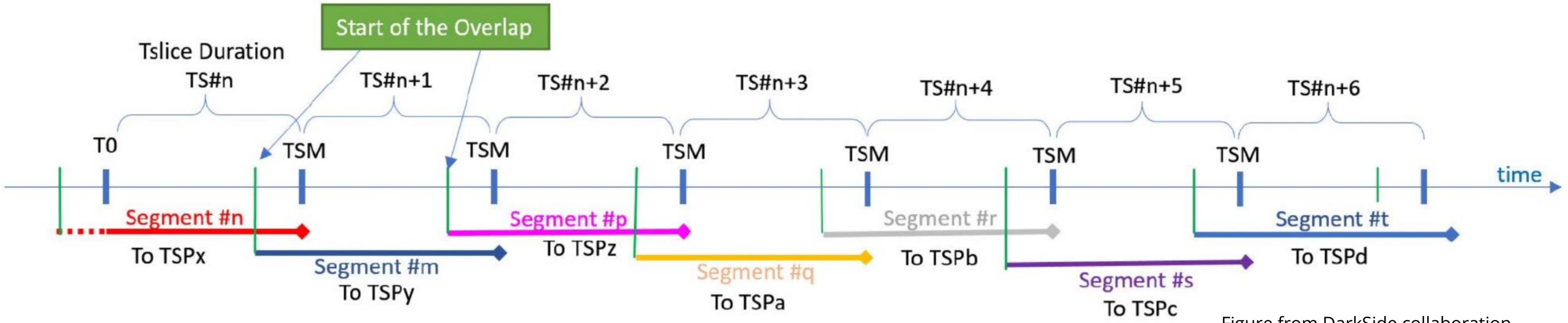


Figure from DarkSide collaboration

The data acquisition system (DAQ) is **triggerless**. Instead of an event triggering the detector to record information, data is continuously acquired, then filtered and processed using time slices. One **time slice** is all of the data from the detector that occurred in a fixed time interval.

Data Acquisition System

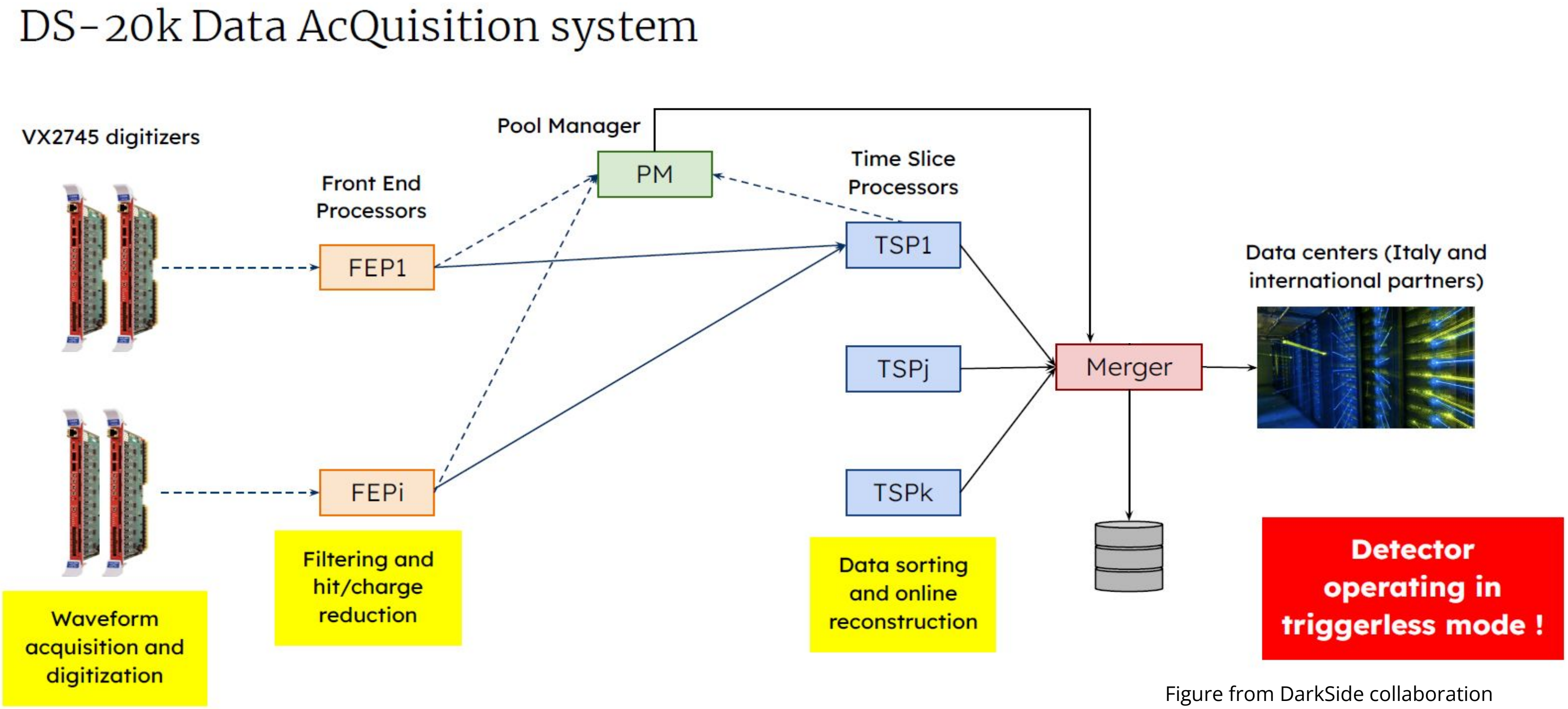


Figure from DarkSide collaboration

Background Monitoring

Monitoring backgrounds in the detector can be used to ensure that everything is working correctly. There are two levels of monitoring:

Channel level monitoring

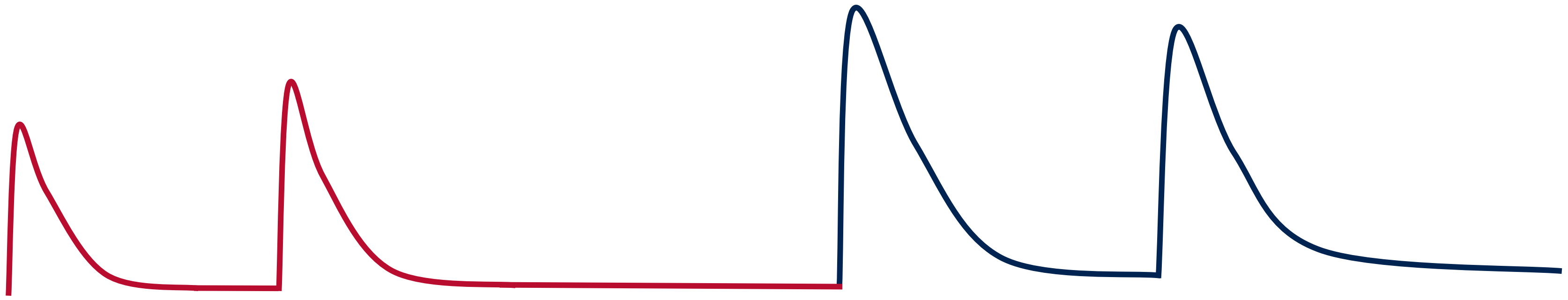
Monitors the gain and electronic noise of channels at the FEP level.

Event level monitoring

Monitors the S1/S2 ratio and the drift time at the TSP level.

S1-S2 Pairing

Pairing S1 and S2 pulses allows for the **position of the event** to be reconstructed and for the **energy of the event** to be determined. However, this can be difficult due to the rate of events in the detector.



First S1 occurs.

Next S1 occurs later, but at a higher z position.

This means their S2s are recorded at a similar time.

Full Width at Half Maximum

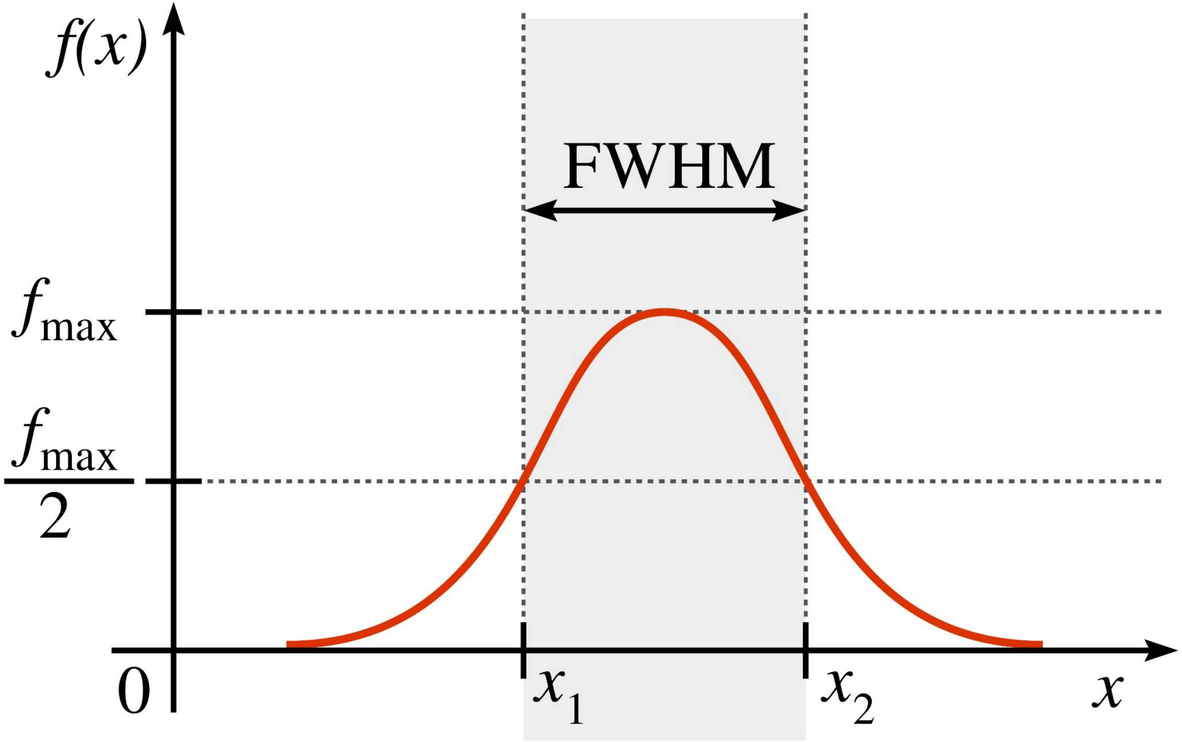


Figure from Wikipedia

The FWHM is width of the peak at half of its maximum value.

S1-S2 Pairing Algorithm

The current pairing algorithm uses the **full width at half maximum (FWHM) of the S2 pulse** to determine a time range that the corresponding S1 should have occurred in.

1. Determine an energy range.
2. For each S2 pulse in that energy range, calculate the FWHM of the S2 pulse and plot it against the time difference (ΔT) between the S1 and S2 pulse.
3. Calculate the 95% and 5% quantiles for the upper and lower errors and fit with the function:

$$FWHM_{fit} = a\sqrt{\Delta T} + b$$

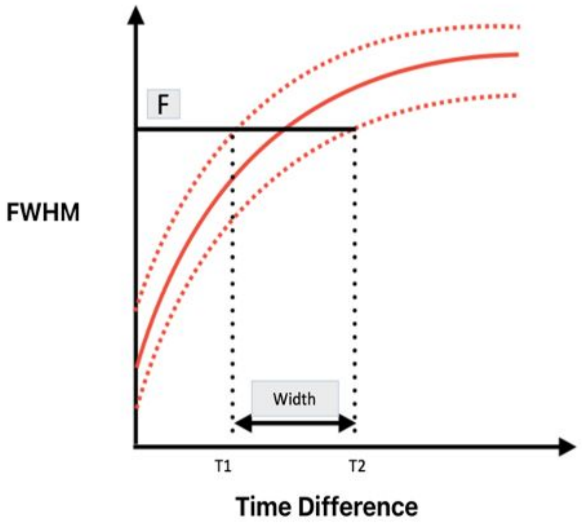


Figure from Anantha Padmanabhan

S1-S2 Pairing Algorithm

Pairing an S2 to an S1 using the current algorithm:

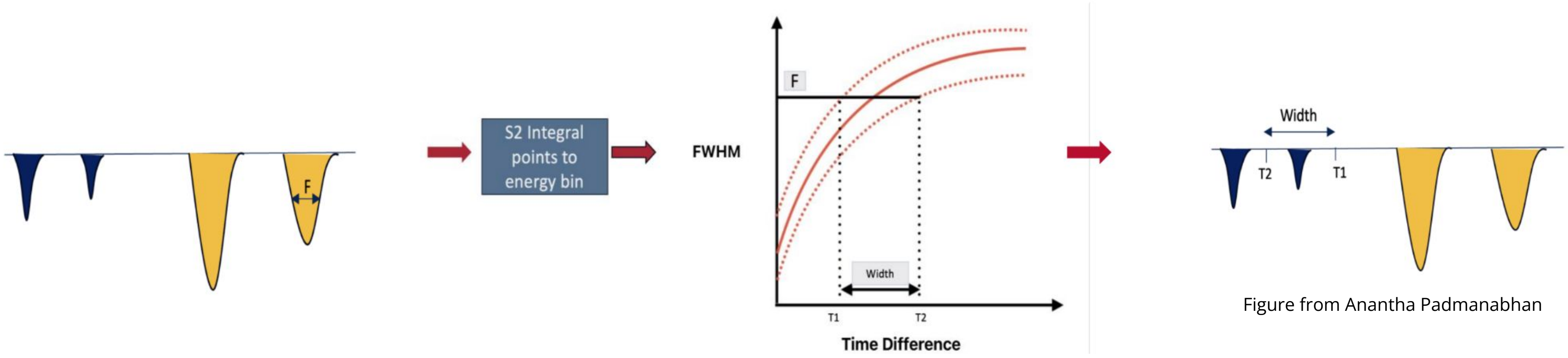


Figure from Anantha Padmanabhan

1. The FWHM of an S2 pulse is calculated.

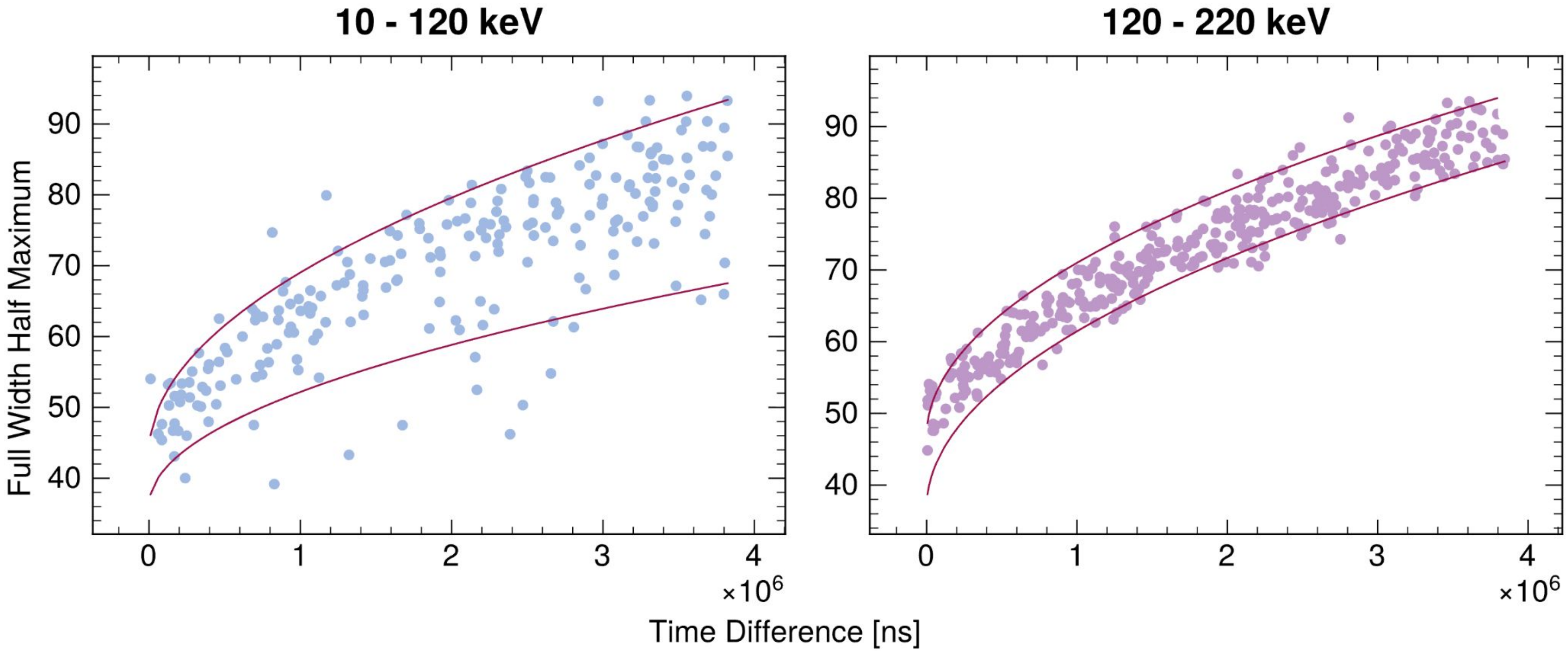
2. The pulse’s integral is used to determine its energy.

3. From the corresponding FWHM vs. time difference plot, a possible time range for the S1 is determined.

4. The S1 pulse that occurred in that time range is found.

Improving the Pairing Algorithm

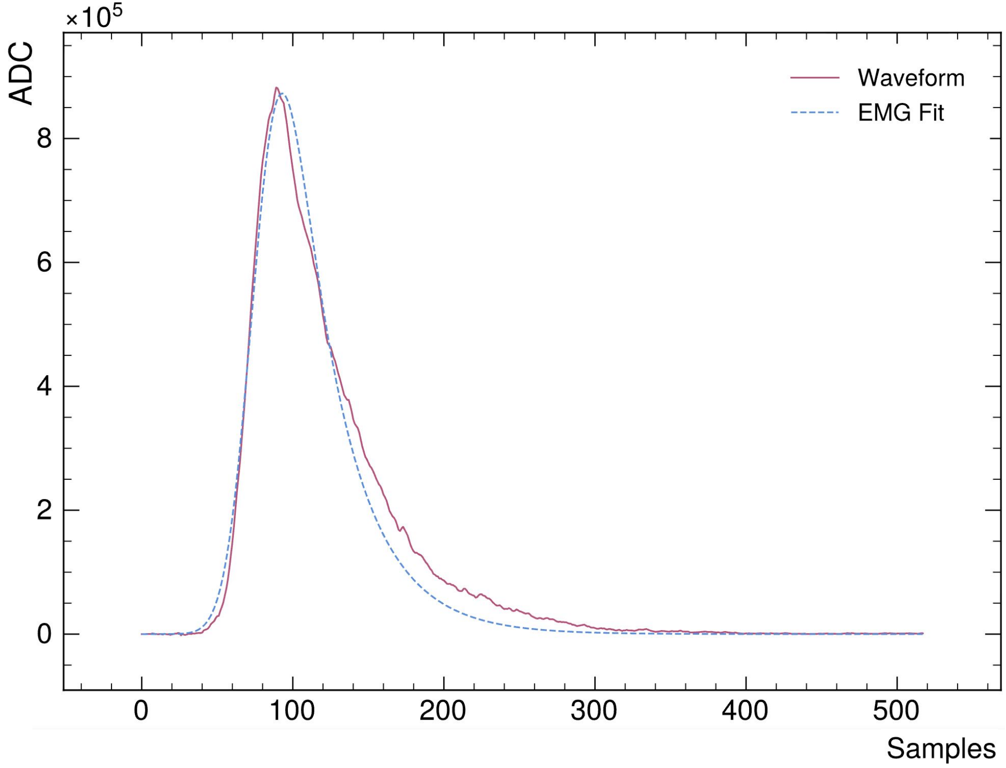
I am working on pairing S1 and S2 pulses from argon-39 events. Currently, I am trying to improve the resolution at lower energies.



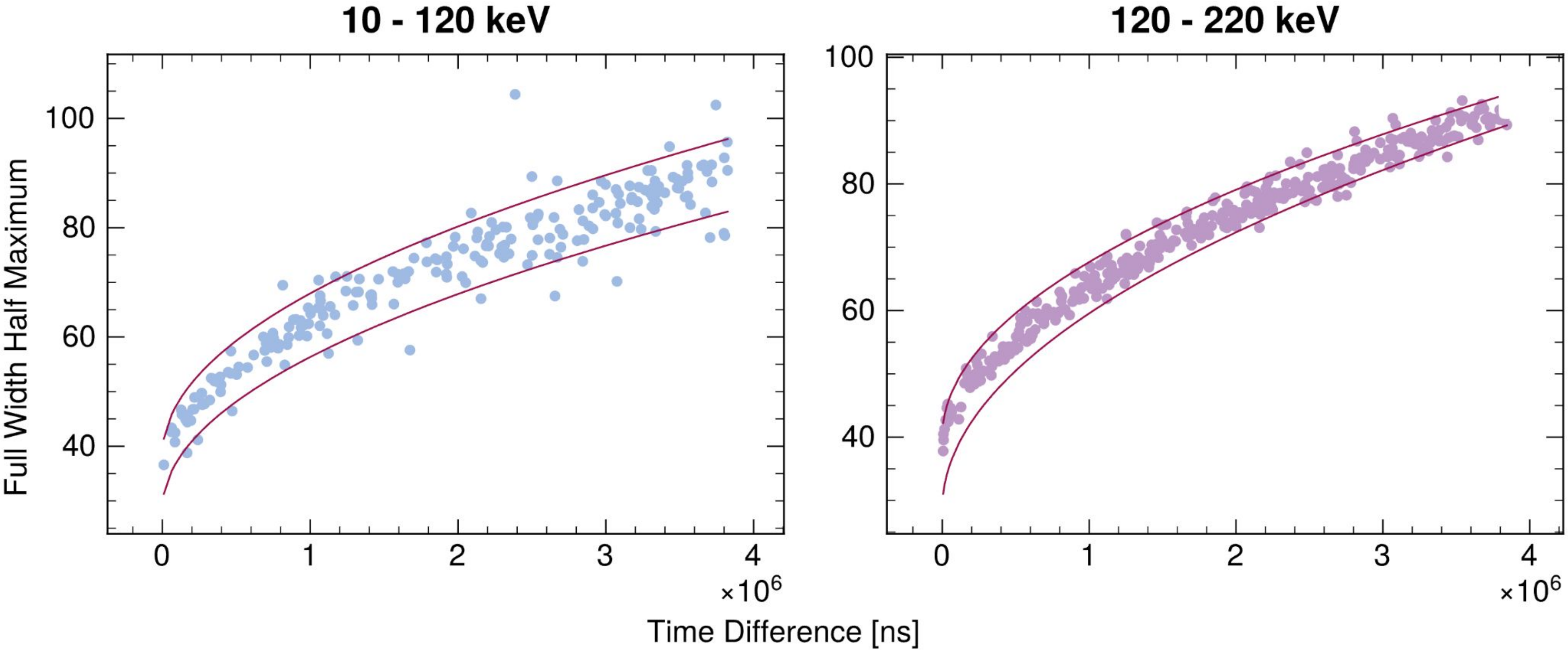
Method 1: Fitting the Waveforms

Fitting the waveform with an **exponentially modified Gaussian (EMG)** fit to reduce the effects of noise on the FWHM.

$$f(x) = \frac{\lambda}{2} \exp\left(\frac{\lambda}{2}(2\mu + \lambda\sigma^2 - 2x)\right) \operatorname{erfc}\left(\frac{\mu + \lambda\sigma^2 - x}{\sigma\sqrt{2}}\right)$$

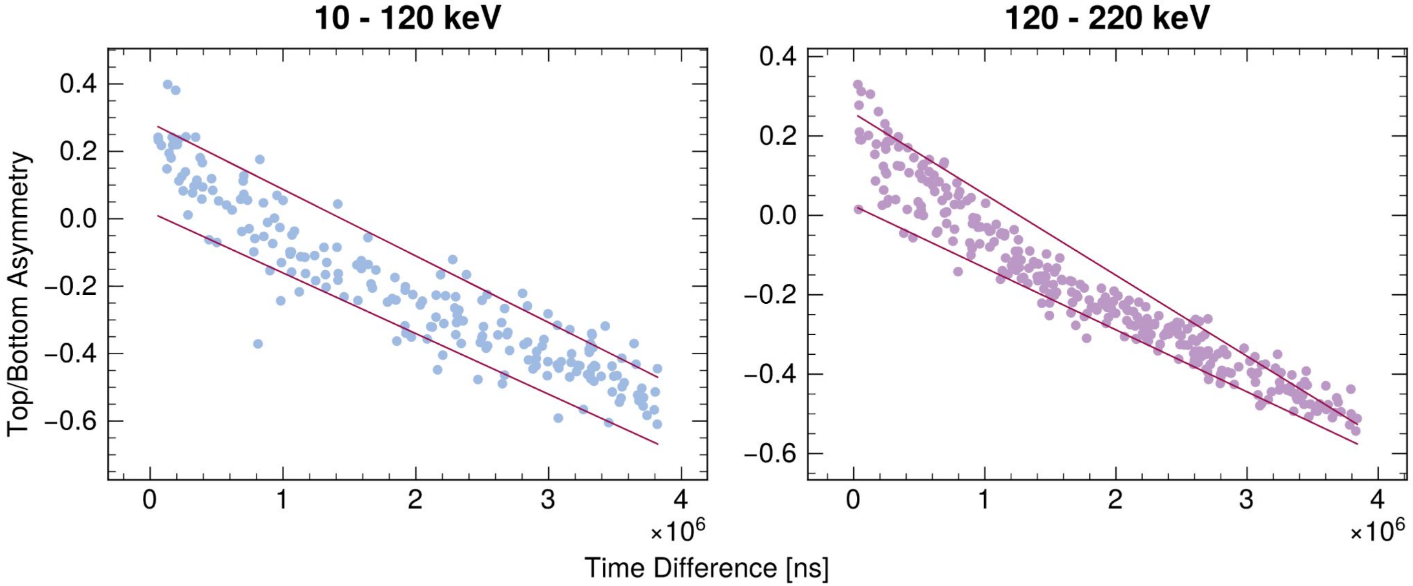


Results After Applying Fit



Method 2: Using other parameters

The time range can also be decreased by using other parameters that depend on the drift time. For example, the **top/bottom asymmetry of the S1 pulse**, which compares the amount of light that reaches the top of the detector to the amount of light that reaches the bottom.



Next Steps

1. Trying other parameters such as the rise time of the pulses.

2. Comparing the resolution of all the parameters.

3. Combining both methods and checking the accuracy.

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