# Smart Fast-Digitizer system for astro-particle detectors

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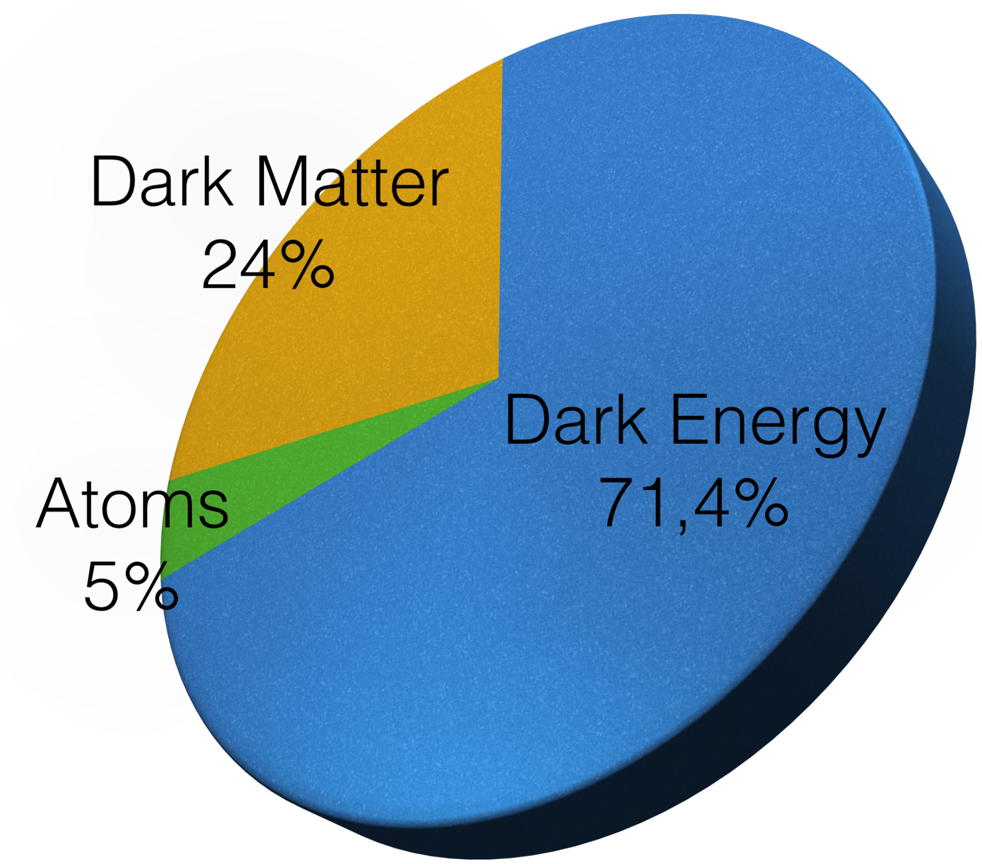
# Outline

- The Universe and dark matter
- The DarkSide project
- The Fast-Digitizer system for astro-particle detectors
- Conclusions

# The Universe

# What do we know?

- The Universe we can see is a **small fraction** of the total

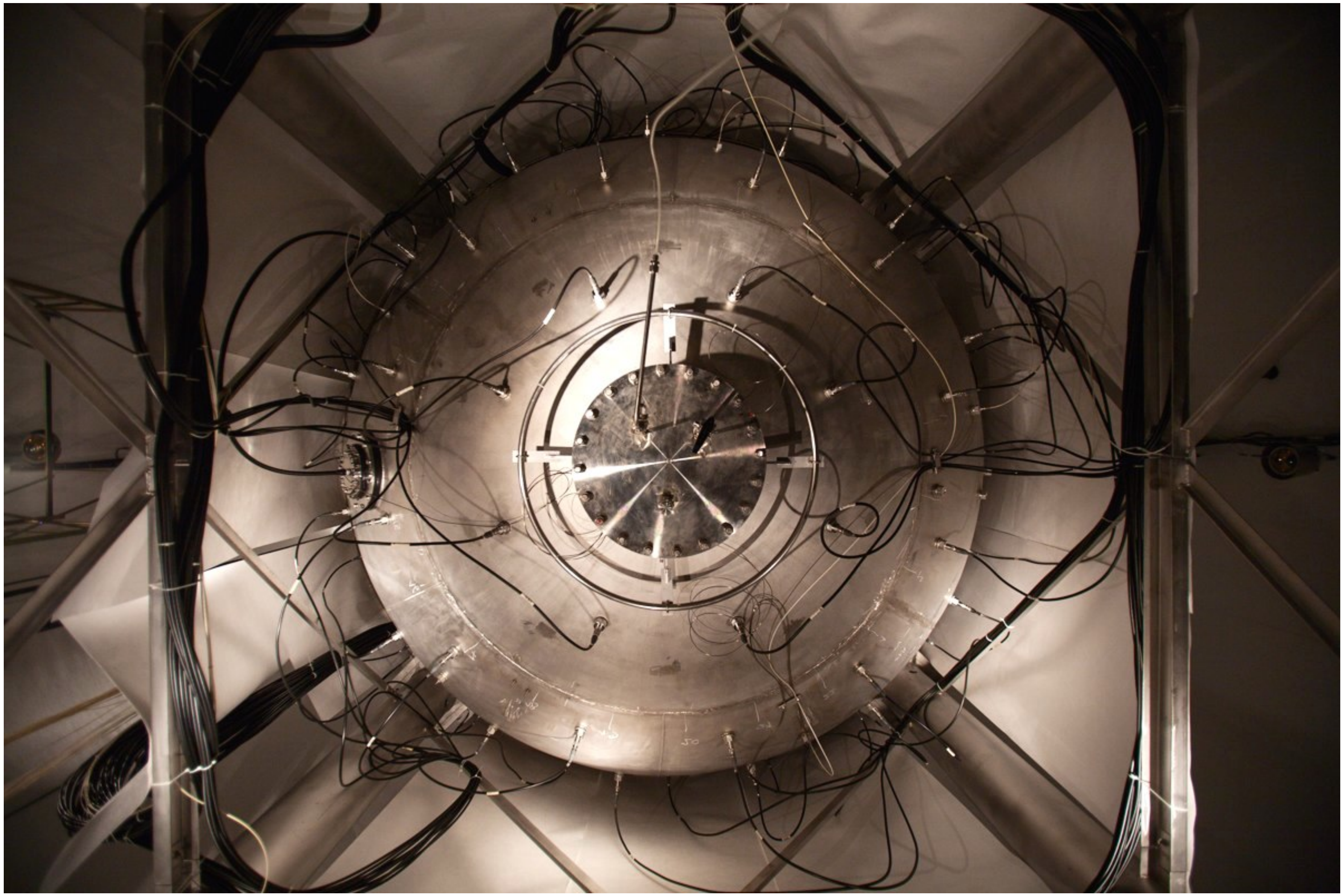



- The rest is made of something which we call **dark**, because we can not see it, and **matter** and **energy** because we do not know what it is

# Dark matter

- There are many compelling pieces of **evidence** for the existence of dark matter at various scale
- **Hypothesis:** could be made of particles called **WIMPs** (*Weakly Interacting Massive Particles*)
    - WIMPs should be **massive** (10-100 times the mass of a proton), **neutral** and **transparent** to ordinary matter
- **Challenge:** are **extremely difficult** to detect
    - WIMPs could be seen by detecting their **direct interaction** via *elastic scattering* with detector atoms
    - **Warning:** because the WIMP signal is **extremely rare** it is needed to **reduce** natural and cosmogenic radioactivity

# DarkSide



- DarkSide searches for WIMPs using a liquid argon detector immerse in a liquid scintillator veto and in a water tank

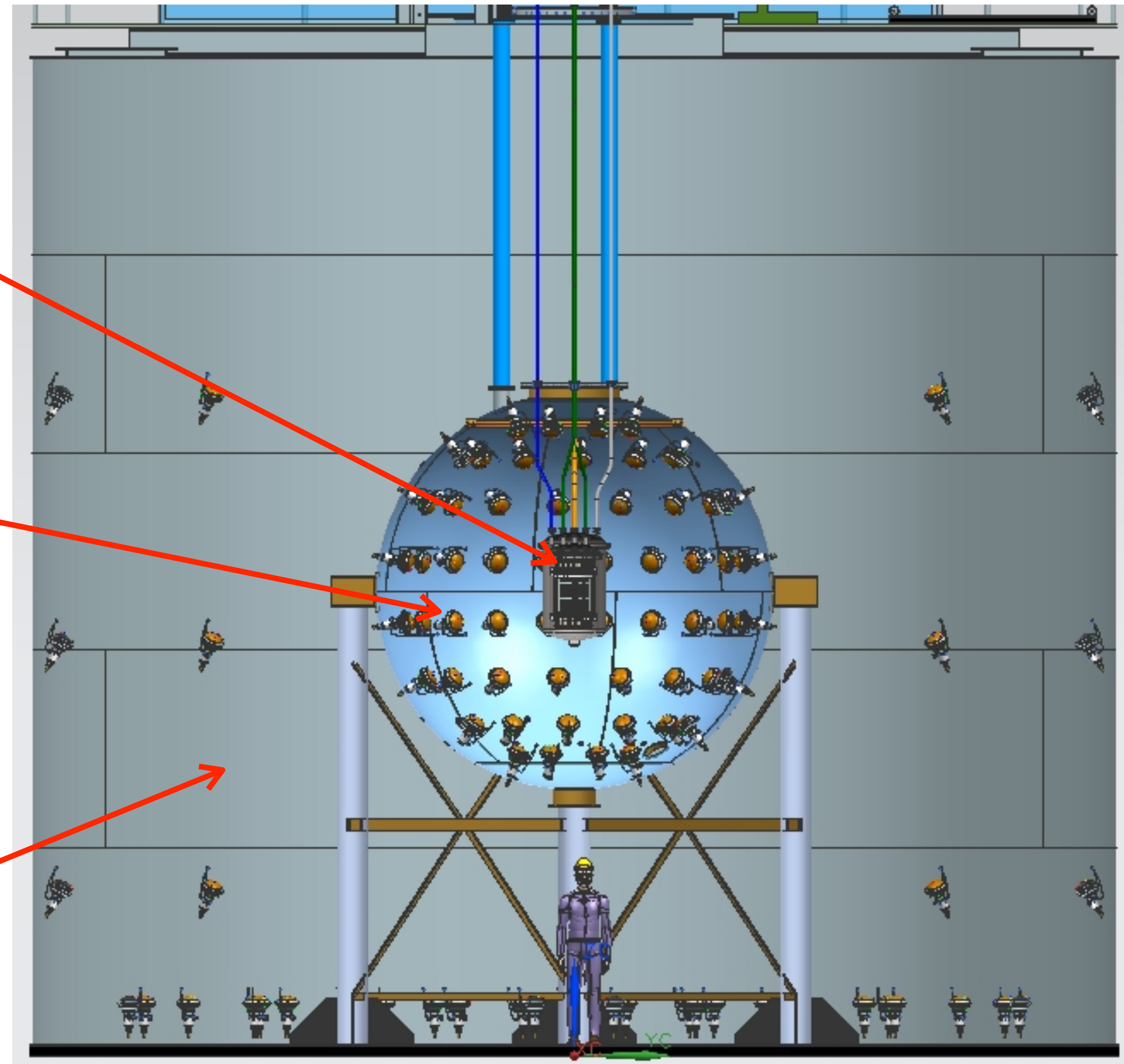
# DarkSide

# DarkSide

Liquid argon TPC
(target for dark matter)
~150 kg

**Neutron veto**
scintillator based
detector
~30 tons
Stainless Steel Sphere
(diameter: 4 m)

**Muon veto**
ultra-pure water
Cherenkov detector
~1000 tons
Cylindrical tank
(high: 10 m, width: 11 m)



# Muon veto

# Neutron veto

# DarkSide veto system

- **Water** and **scintillator** are meant to reject neutrons which can mimic dark matter

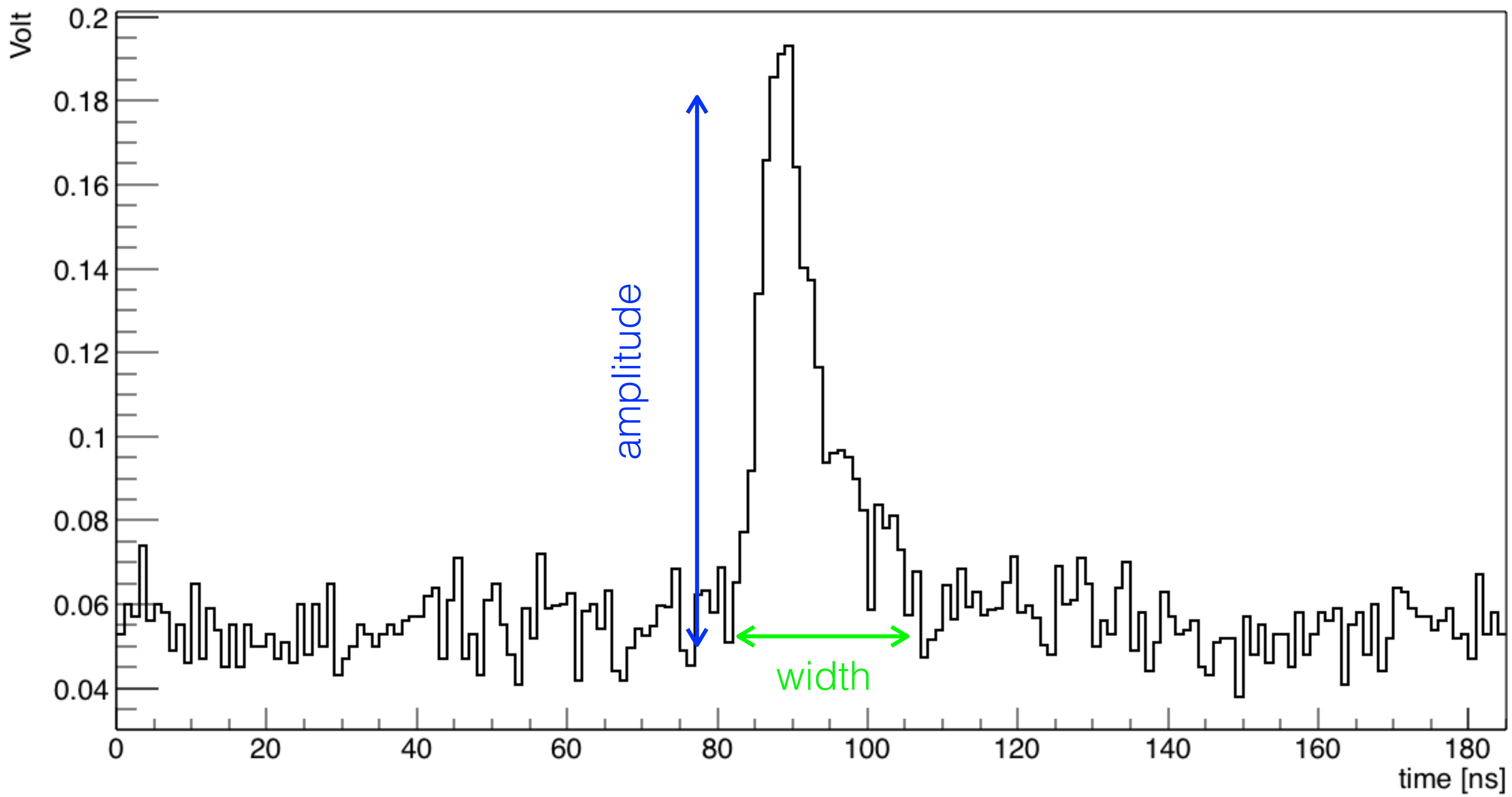
    - detecting the scintillation light produced and by reconstructing their positions making time of flight measurements of the photons through the material

# What the experiment needs

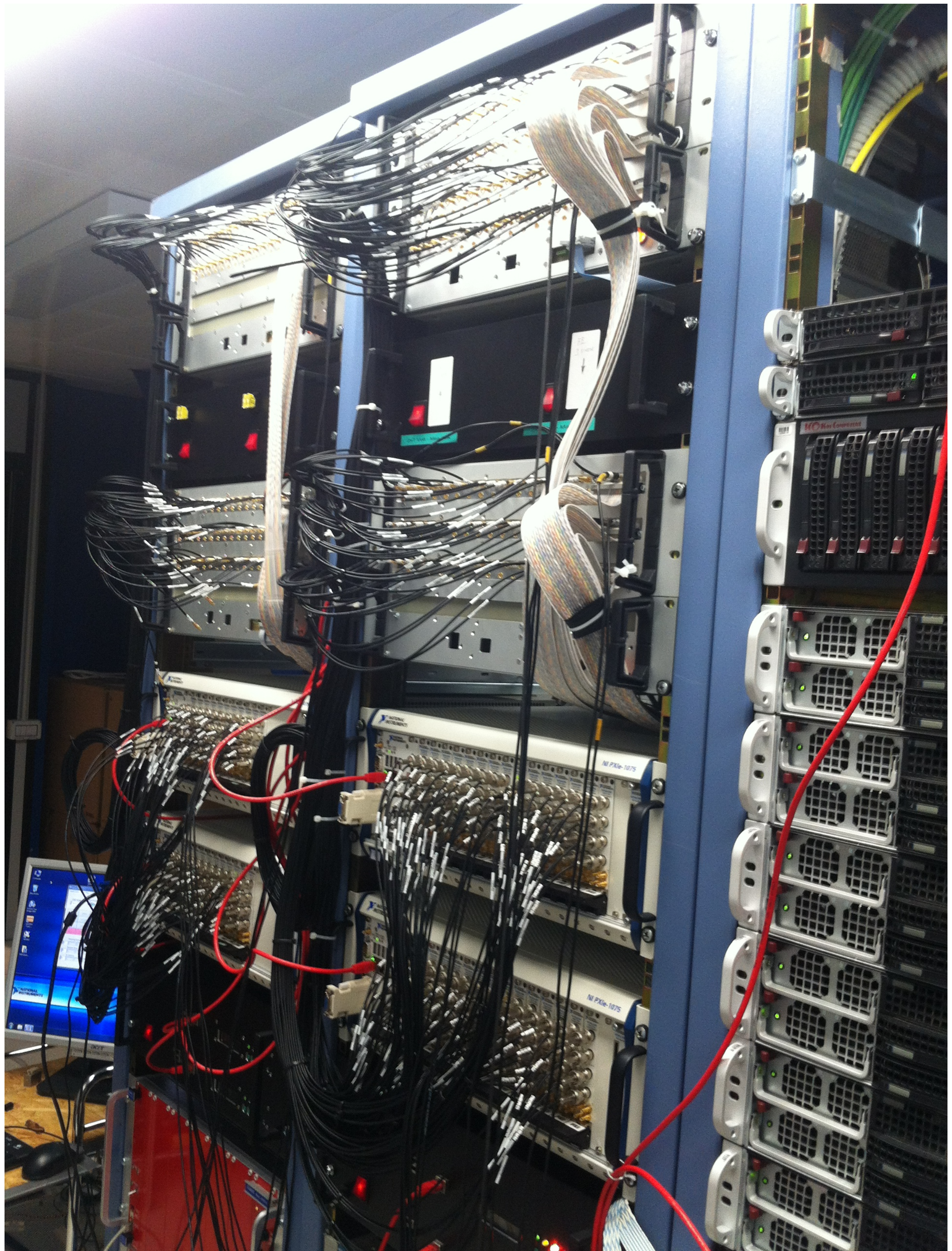
- Signal of interest (SoI) is limited to relatively short pulses (10-100 ns)
    - Detector requires continuous acquisition
    - Only data (sampled data and time of the pulse) associated to SoI is of scientific interest

# Signal example

- SoI is **fast** (~5 ns rise time) with amplitude ranging from ~0.1 to 2 V, width of ~25 ns and rate ~250 Hz



# The hardware




- 4 NI PXIe chassis full of NI PXIe-5162 digitizers
  - 4 channels
  - 10-bit: good resolution
  - 1.25 GSample/s: good timing
- ~200 (110 neutron +80 muon) channels

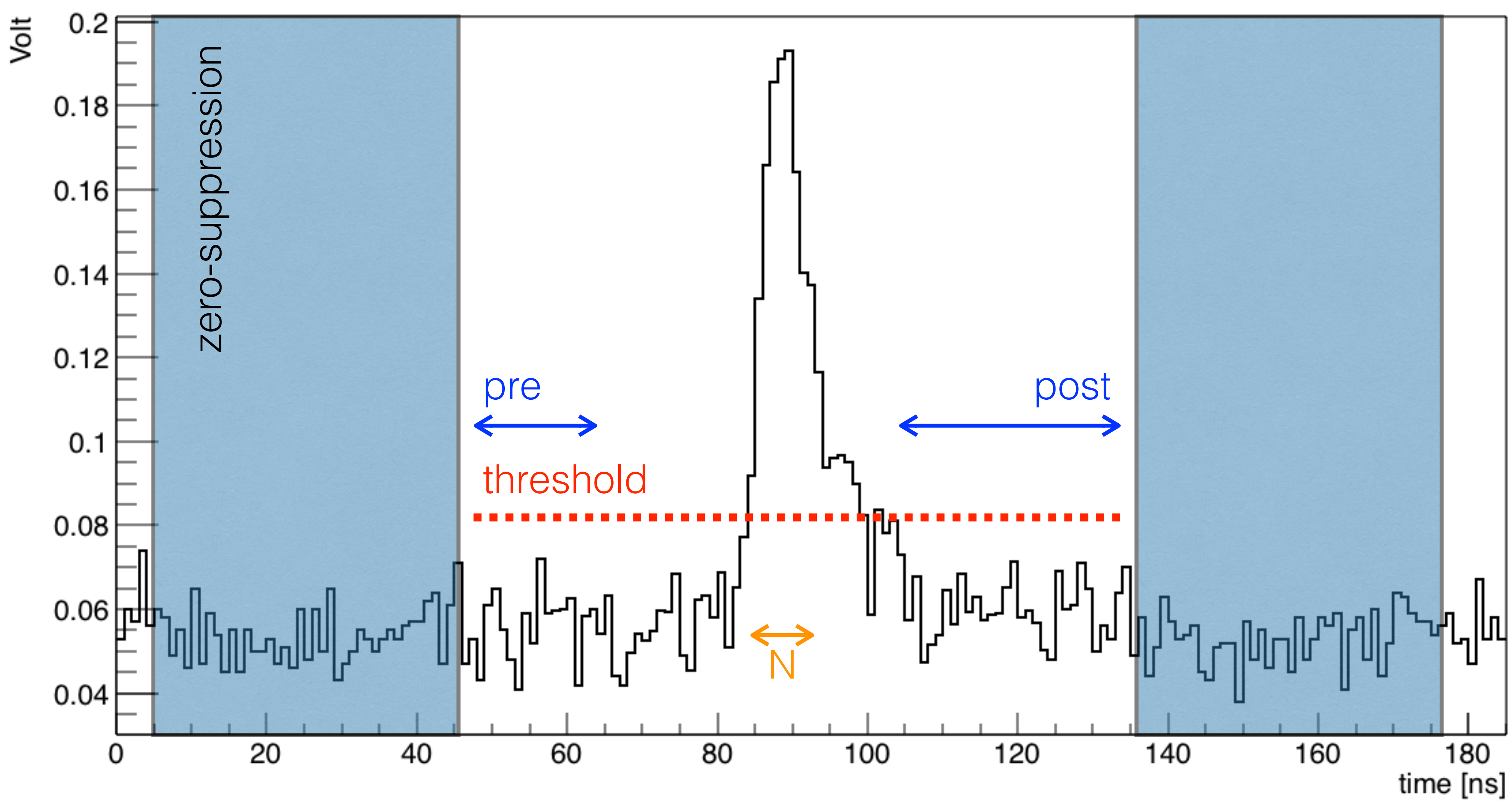
# The application

- Implemented a novel system for
  - **data reduction**
  - **software group trigger**
- Done using LabVIEW and new custom API made for the NI PXIe-5162 digitizer

# Data reduction

- Each channel on board is able to identify pulses and perform **zero-suppression**
    - A pulse is detected when **N** (programmable) consecutive samples exceed a **threshold** (programmable in value and slope)
- Once a pulse is detected on any channel of the board, data from all the channels are stored on the on-board memory together with a **pre-** and **post-samples** (programmable)

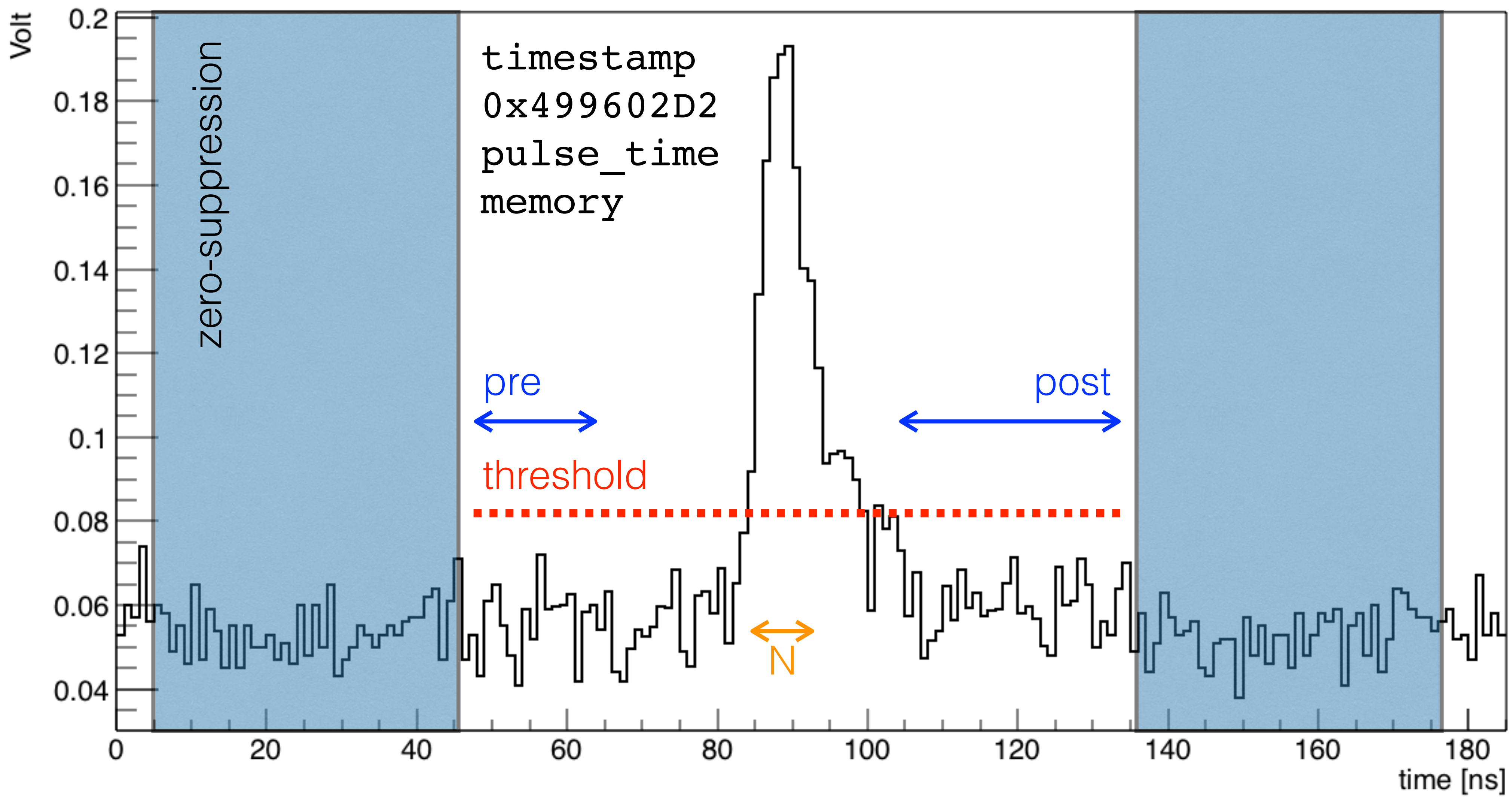
# Zero-suppression example



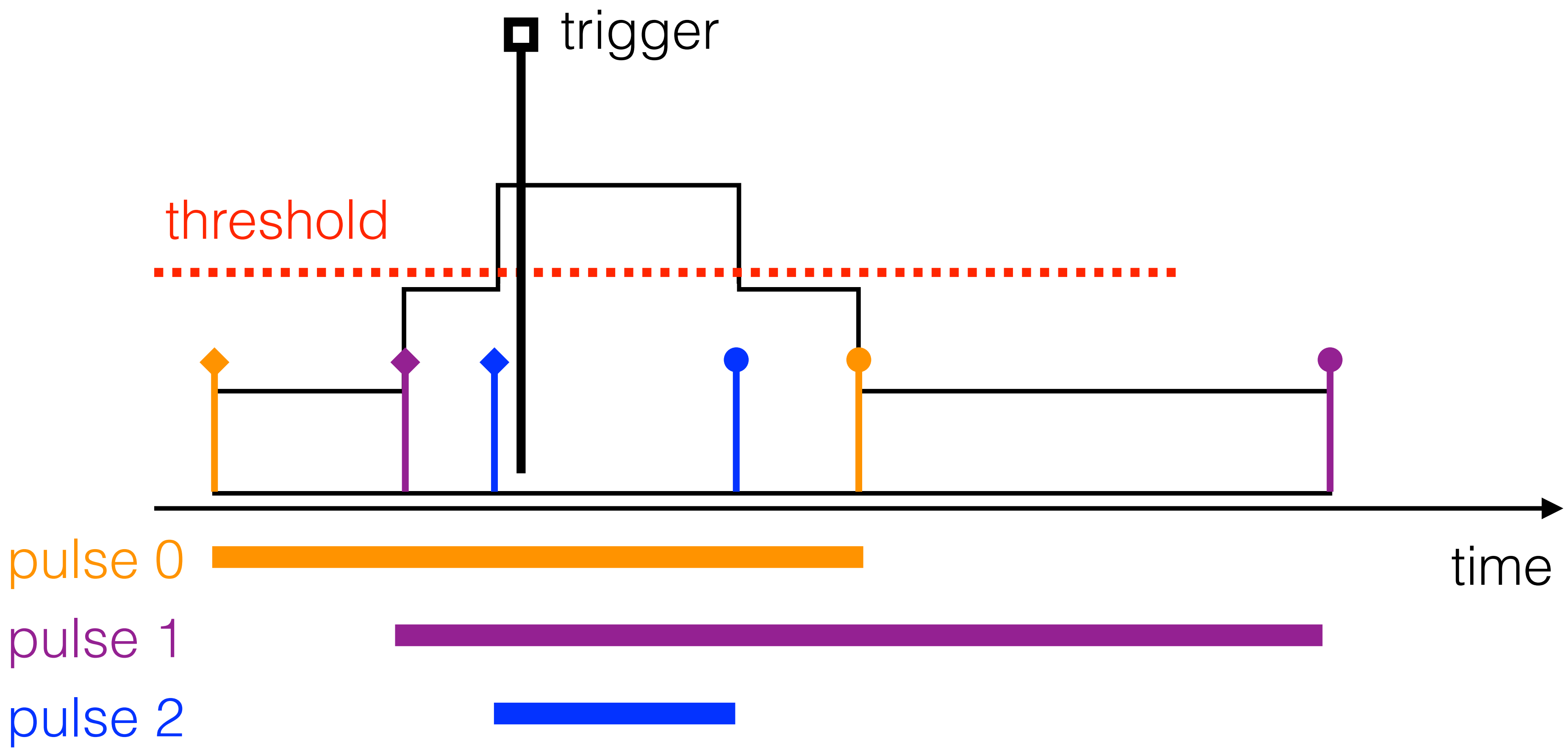
# Timestamping

- For each detected pulse a high resolution 128-bit timestamp is generated (time of a pulse + ids) including
  - timing information (64-bit) about the pulse essential to define the trigger logic
  - the memory address (32-bit) at which data are stored
  - other infos (32-bit)
- Timestamps can be read **independently** from the waveform allowing TDC functionalities and detector triggering capabilities

# Timestamping example



# TDC capability example



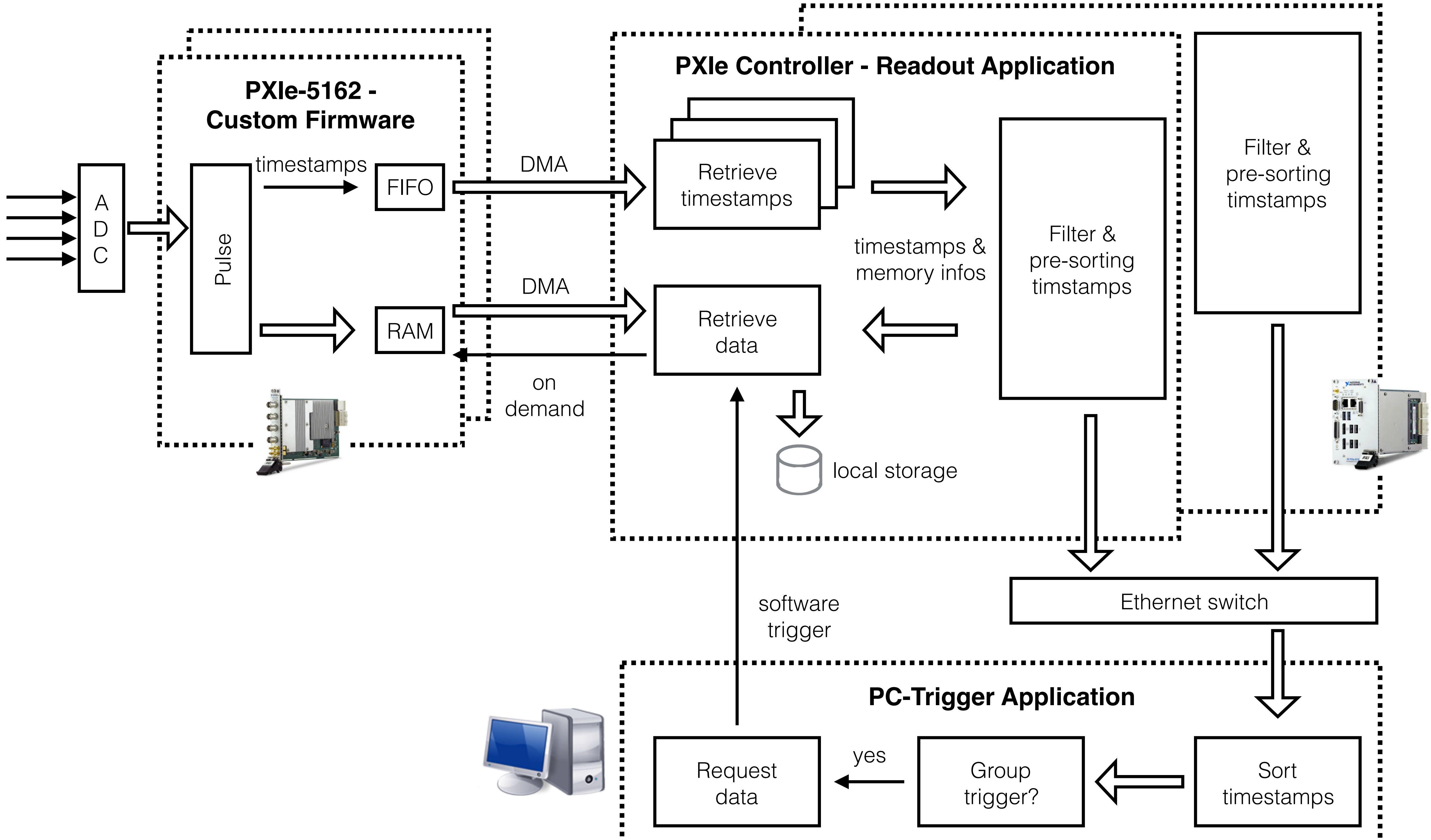

- Reading timestamps independently allows you to have the building blocks for the generation of software trigger

- *e.g.* construct a time histogram on which determine the trigger condition whatever it is

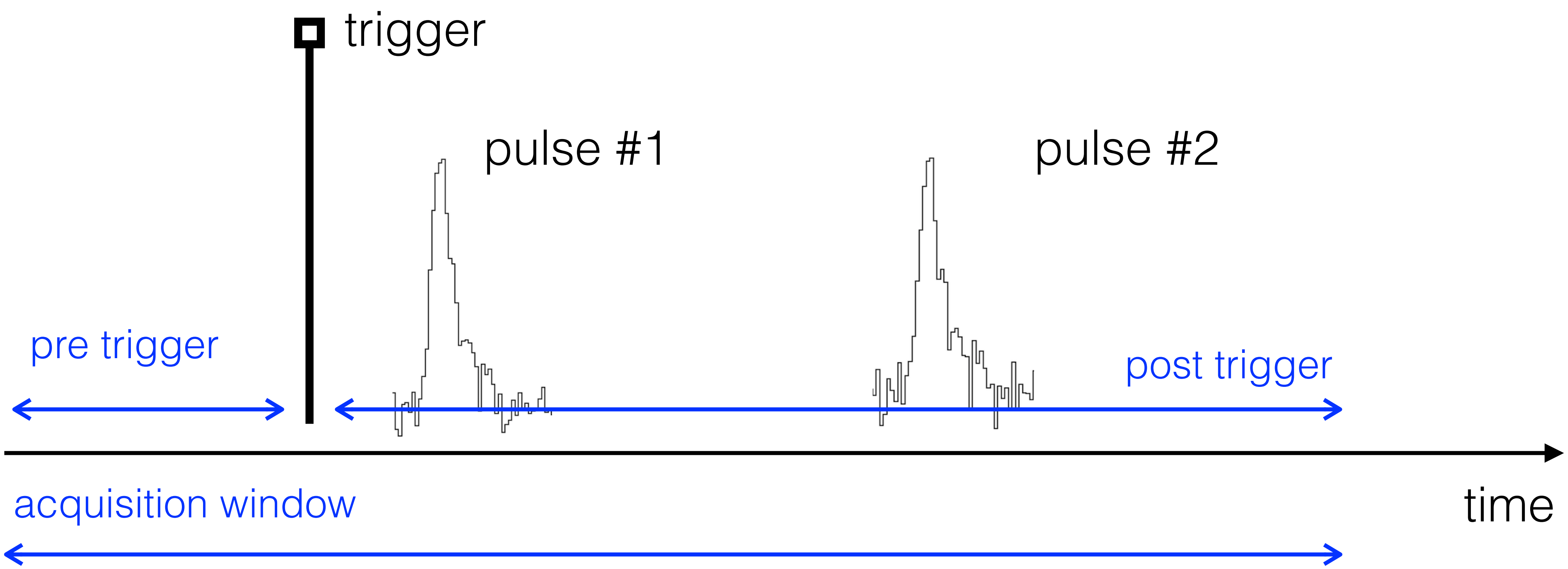
# Software trigger

- The trigger of the system is entirely generated by software
- Timestamps and ADC sampled data can be fetched independently
- In actual implementation timestamps are read continuously and trigger condition is computed on the fly
- If it is met, sampled data of the interesting pulses are fetched in the defined ROI (acquisition window)
- The waveform data of the relevant pulses are only read on demand by the DAQ when the software group trigger is issued

# Software trigger architecture



# Software trigger architecture




- After the trigger condition is met, sampled data of interest can be fetch in a specific ROI with a programmable acquisition windows
- Zero-suppression reduces the amount of data to be transferred

# Results

- **Successfully** tested the system in the DarkSide veto system
- Maximum sustainable single-channel pulse rate is ~80 kHz
- Compared to the old DAQ application now the system can sustain a trigger rate up to ~1 kHz (see next table)
- We simulate also the activity of a larger number of channels to study the scalability of the system reaching up to 1000 channels: using distribution of the computing (natural for a big detector), the system can be scalable up to many thousands of channels

# Results

| Gate [μs] | DAQ max trigger rate [Hz] | DAQ CF max trigger rate [Hz] | gain |
|---|---|---|---|
| 2.5 | 850 | 1400 | 1.6 |
| 5 | 510 | 1370 | 2.7 |
| 10 | 290 | 1350 | 4.7 |
| 50 | 65 | 1250 | 19 |
| 100 | 32 | 1000 | 31 |
| 250 | 14 | 650 | 46 |
| 500 | 7 | 410 | 59 |
| 1000 | 3.5 | 250 | 71 |

# Conclusions

- Successfully tested the system in the DarkSide veto system
- Application build and running
- DAQ system can be used by next generation dark matter or neutrino experiments which use big number of photo-detectors like PMTs or SiPMs