Novel analysis techniques for neutrino and dark-matter experiments with the DIANA framework

Matteo Cappelli

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The DIANA analysis framework

- **DIANA** is an analysis software written in **C++** (with **ROOT** classes) for a **fast and robust analysis** of low energy particle physics experiments (neutrinos, dark matter…)
- **Maintained for +10 years** (baltig.infn.it/diana/dianasw), **portable** (runs on Linux distros and MacOS), and with an **easy interface** (configuration files for running the analysis, no coding required)
- **Advanced algorithms** in C++ for waveform analysis and **python interface with jupyter notebooks** for data visualization, fitting and high-level analysis

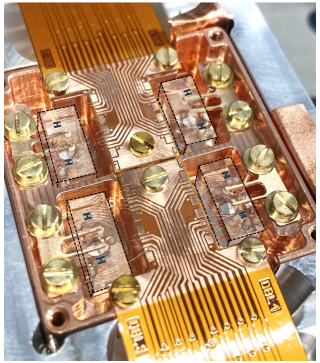
Diana Software

ROOT Data Analysis Framework

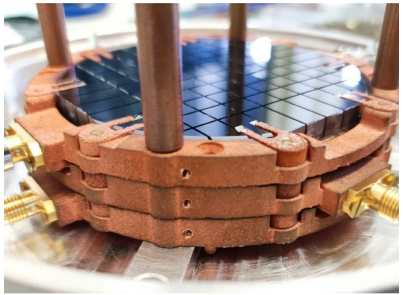
GitHub

- Possibility to integrate the main installation with an **external software for a specific experiment**. Currently used for **NUCLEUS** and **BULLKID**

NUCLEUS detector

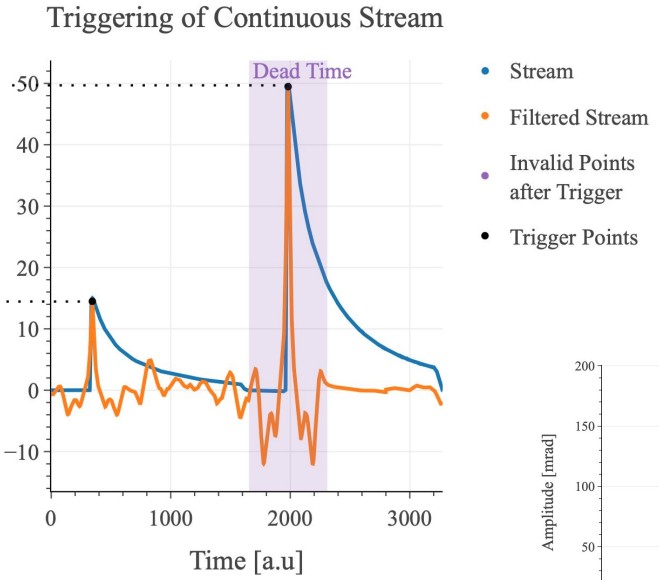


BULLKID detector

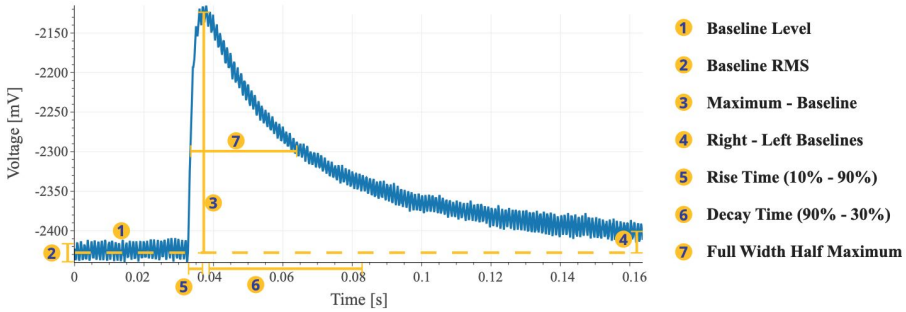


From raw to high level analysis

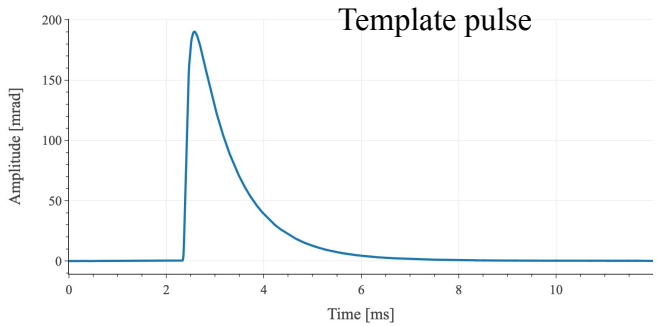
- **Triggering** on continuous stream with **threshold trigger** or **matched filter trigger**

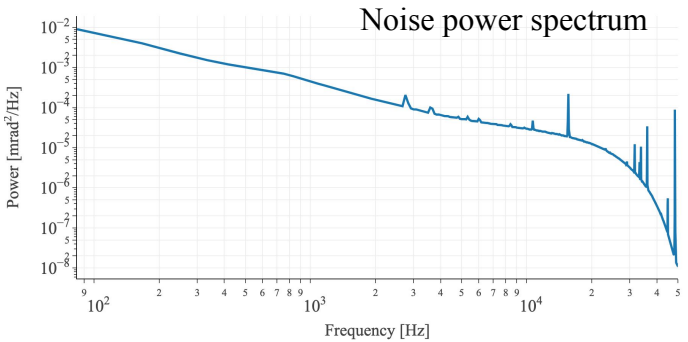


- Many algorithms to evaluate **pulse shape parameters**.



- Average to build **template pulse** and **noise power spectrum**





From raw to high level analysis

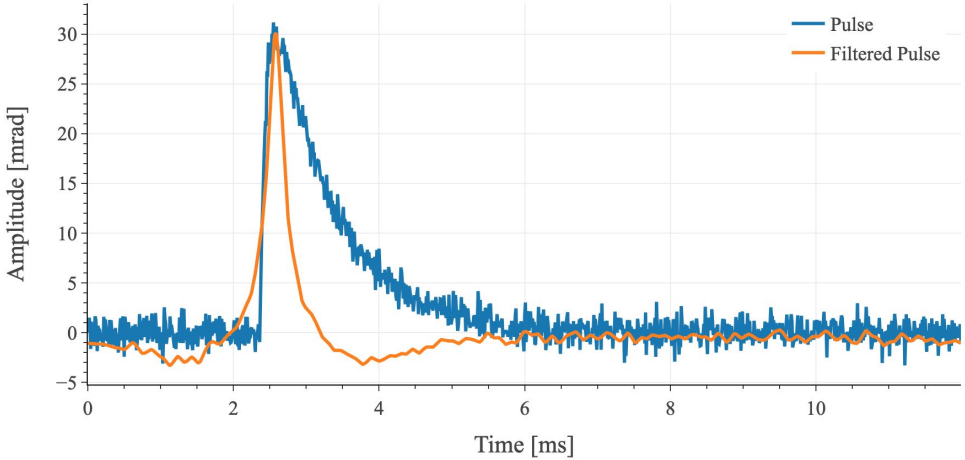
- **Matched filter** used for amplitude reconstruction of pulses. **Template pulse s(t)** and **noise power spectrum σ(f)** as inputs

filter (frequency domain)

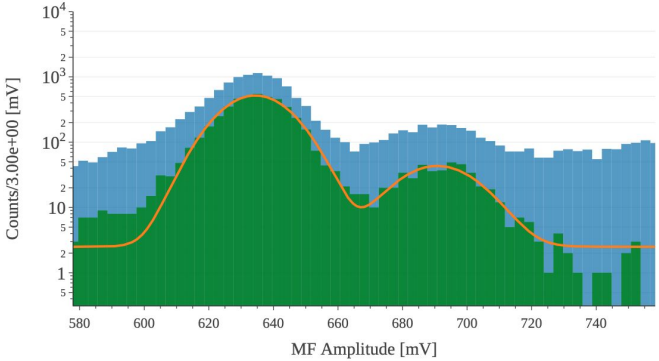
$$H(f) = \frac{\tilde{s}^*(f)\,\hat{\sigma}^{-1}(f)}{\int_{-\infty}^{\infty} df\,|\tilde{s}(f)|^2\,\hat{\sigma}^{-1}(f)}$$

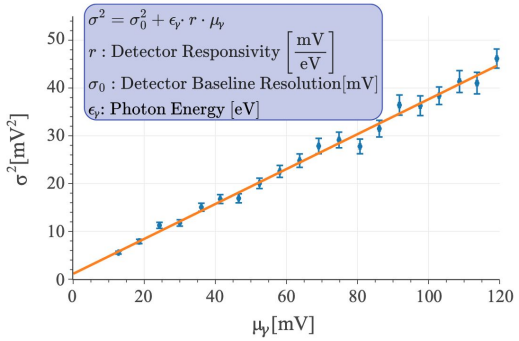
filtered signal (frequency domain)

$$\tilde{v}_{\text{filt}}(f) = H(f)\,\tilde{v}(f)$$



- **Python interface** (Pandas and ROOT dataframes) for **histograms**, **scatter plots**, **heatmaps**, **fitting** (ROOT) and **calibration**





Novel technique: multidimensional matched filter

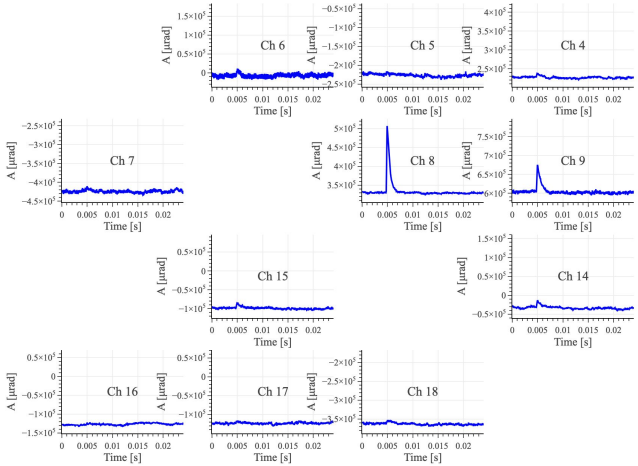
- Exploit the information of **many detectors** to **improve resolution**. Filter **simultaneously N waveforms**, gives one filtered amplitude.
  Best performance with **correlated signals** and **uncorrelated noise**

N filters (frequency domain)

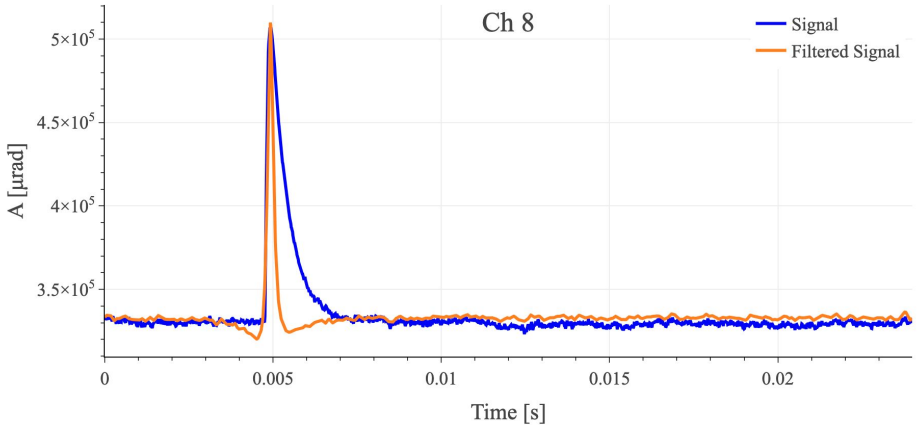
$$H_b(f) = \frac{\sum_{a=1}^{N} \tilde{s}_a^*(f)\, \hat{\sigma}_{ab}^{-1}(f)}{\sum_{a=1}^{N} \int_{-\infty}^{\infty} df\, |\tilde{s}_a(f)|^2\, \hat{\sigma}_{aa}^{-1}(f)}$$

one filtered signal (frequency domain)

$$\tilde{v}_{\text{filt}}(f) = \sum_{b=1}^{N} H_b(f)\, \tilde{v}_b(f)$$

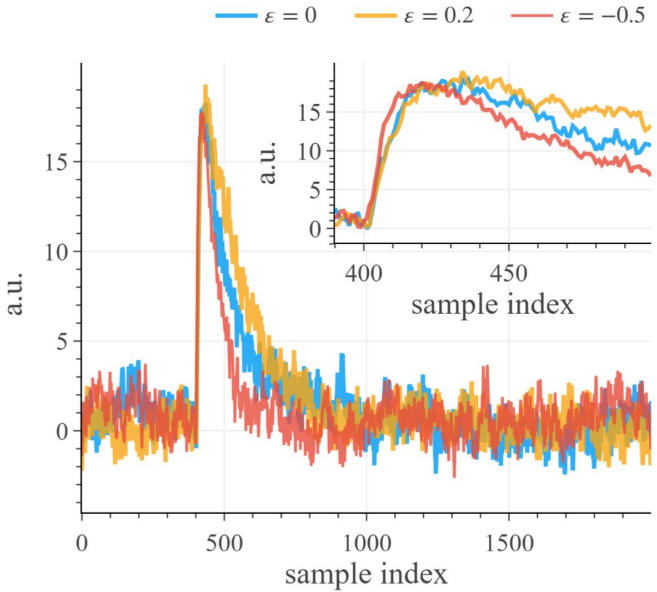


Filter

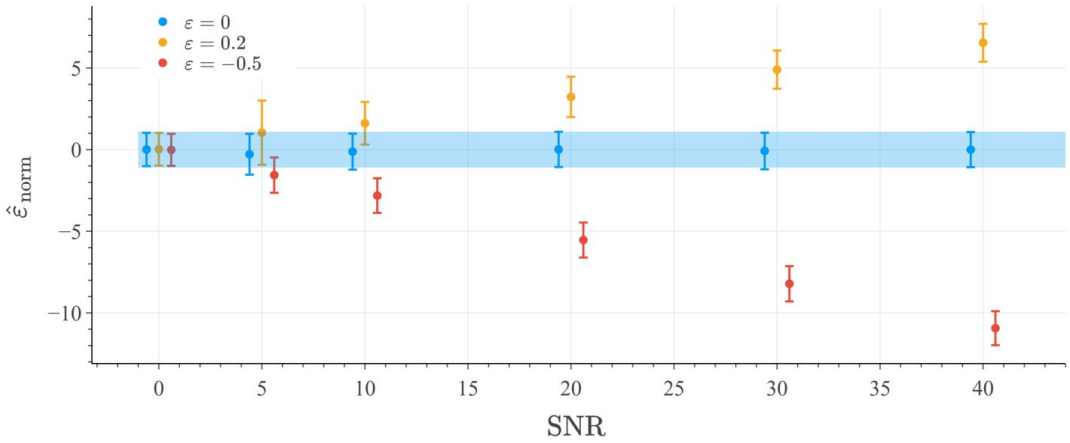


Novel technique: pulse shape deformation

- **Time dilation/contraction** of the waveform w.r.t to the reference template estimated from the matched filter. **Pulse shape variable ε** to **signal/background** discrimination down to low SNR better than other parameters (M. Cappelli et al 2024 JINST 19 P06034).



Signals vs **Background** discrimination (simulation)



Thank you for your attention!