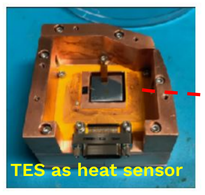
Multi-channel Processing and Simulation (MPS)
a python processing framework for the RICOCHET experiment

Jules Colas on behalf of the **RICOCHET collaboration**

RICOCHET
A Coherent Neutrino Scattering Program

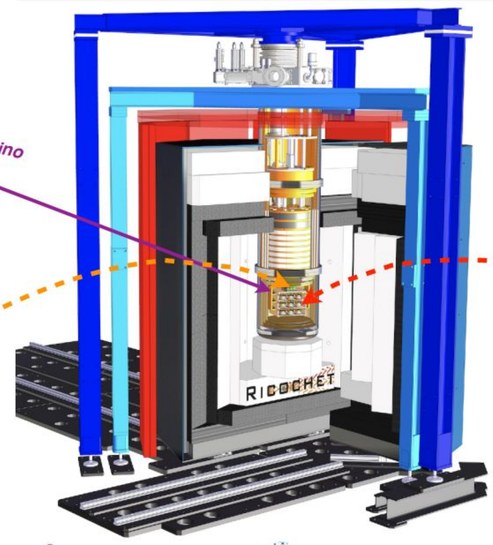
RICOCHET is a **France, USA and Russia** wide collaboration accounting for about 50 physicists, engineers, and technicians, aiming at building the **first low-energy neutrino observatory**

9 superconducting target ~30g
Zn, Al, Tin, ...

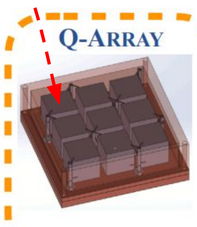


ILL: 58 MW research reactor
~15 m.w.e overburden

Neutrino

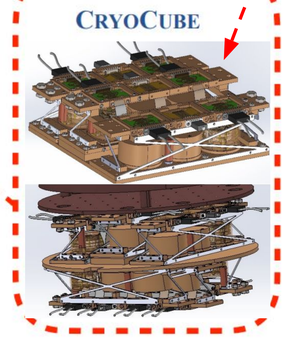


Q-ARRAY

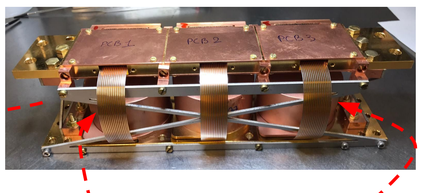


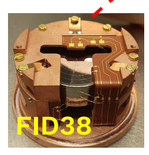
ANR AGENCE NATIONALE DE LA RECHERCHE

CRYOCUBE



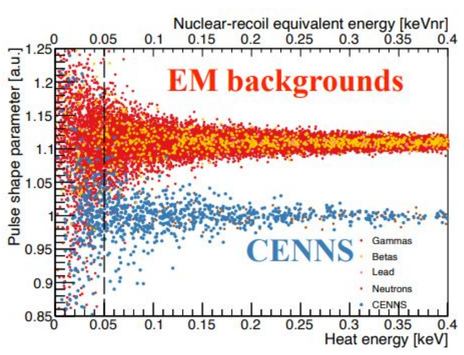
18-27 ultra-pure Ge crystals of 38 g



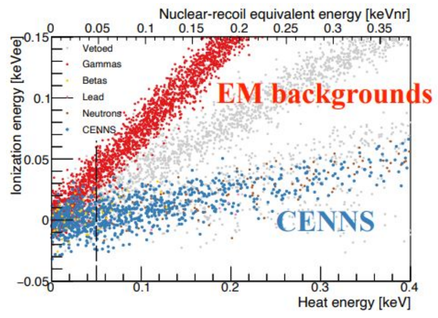


Goal
σ_{heat} ~ 10 eV (RMS)
σ_{ion} ~ 20 eV (RMS)

Signal/Background discrimination is done using pulse shape



Signal/Background discrimination is done with heat/ionization



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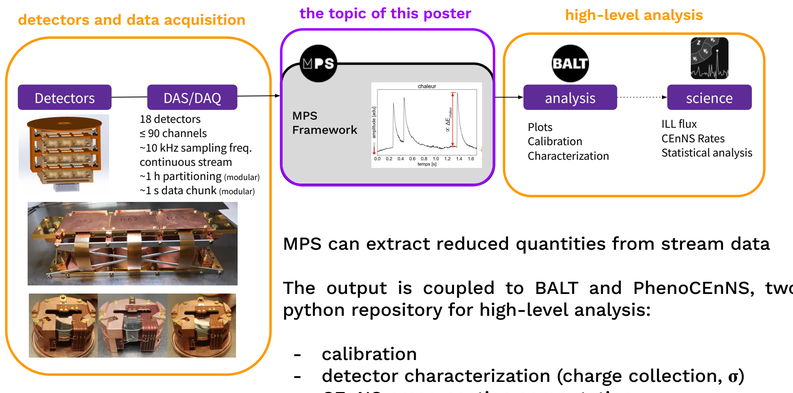
The global overview

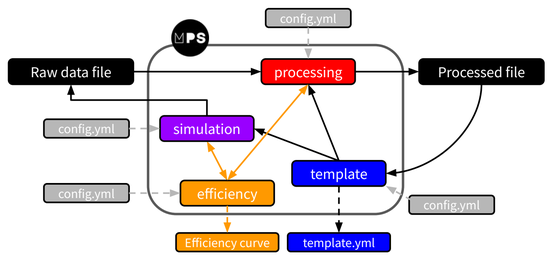


MPS can extract reduced quantities from stream data

The output is coupled to BALT and PhenoCEnNS, two python repository for high-level analysis:

- calibration
- detector characterization (charge collection, σ)
- CEnNS cross-section computation
- Statistical analysis (bayesian estimation, ...)

MPS as a framework



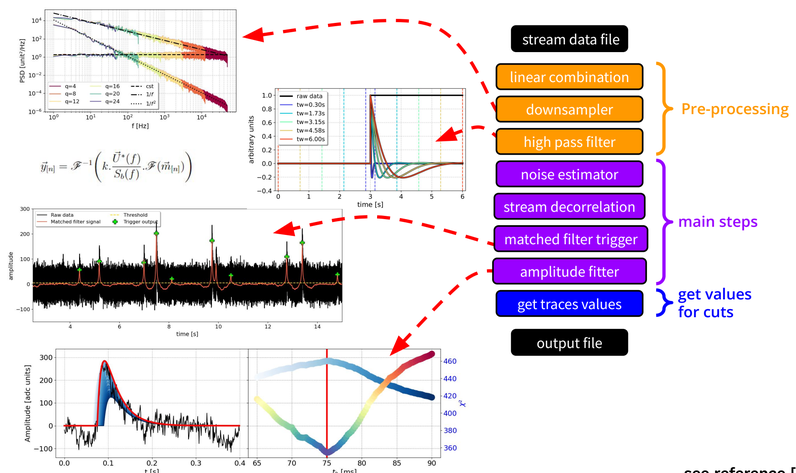
template helps us to extract the parameters for analytical pulses: the signal template

efficiency is a module for pulse injection in stream data to estimate the survival fraction

processing of stream data consists of extracting reduced quantities from them

simulation of raw data stream can be done using custom hypothesis (noise, quenching, ...)

MPS processing steps



see reference [3]

Minimum-correlation noise finding algorithm

Only two (required) input parameters:
- the expected noise fraction ***nf***
- a pulse template ***s***

"The noise is everything except a signal"

The idea

- compute the correlation between the ***stream data*** and ***s*** → ***y***
- set a ***threshold*** to 0 on ***y***
- find all window of size ***nw*** which totally fit in ***[-threshold, threshold]***
- apply some **quality cut** if needed (can be what you want: spike, chi², offset ...)
- iteratively increase the ***threshold*** until ***(nf * stream size)*** windows are found
- **compute the PSD** of the selected traces

Making the PSD computation more robust

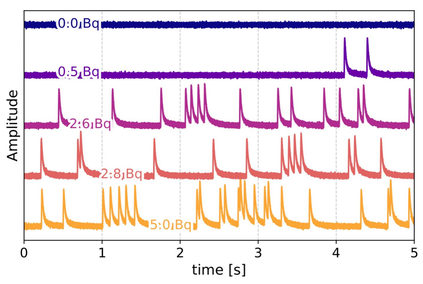
Using **median** instead of **mean** of the FFT of traces leads to a more robust estimate. But it requires to compensate for the induced bias, as explained in [1].

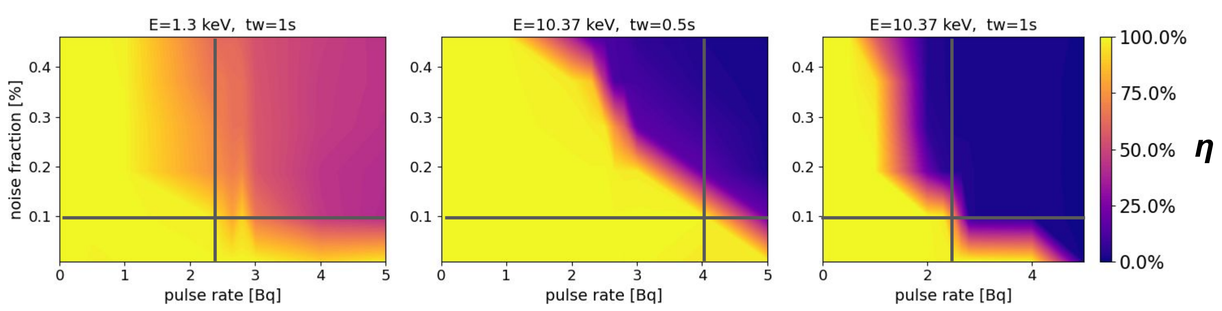
The noise fraction

Define a quantity η equal to the integral of the inverse of the **SNR.**

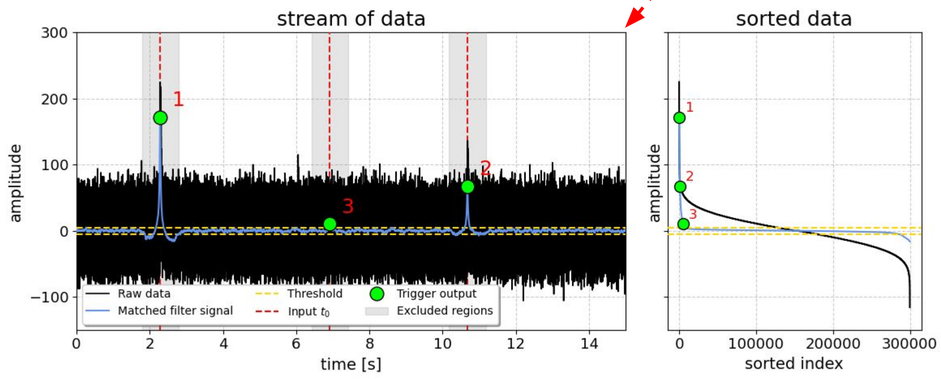
Simulate data with white noise and heat signal pulses at multiple rates.

Evaluate the performances:
vary ***nf*** and ***tw*** and the ***pulse rate***



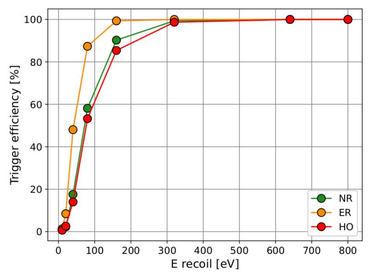


Matched filter based trigger algorithm



Matched filter **[4][5]** based trigger algorithm and it's peak detection algorithm illustrated.

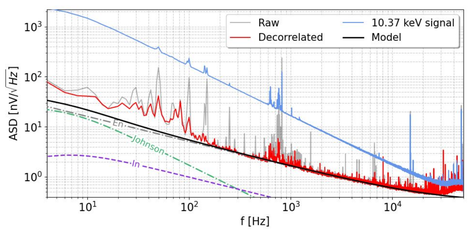
Trigger efficiency estimated with realistic noise and for different type of event **[3]**.

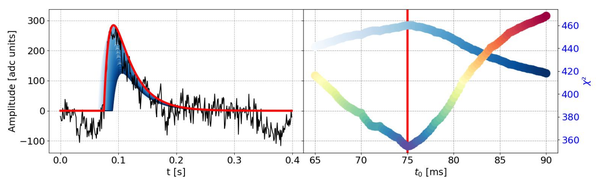


Noise trigger rate (NTR) study is ongoing to reduce the analysis threshold **[6]**

Obtaining the energy spectrum

Estimate the noise PSD and the position of pulses

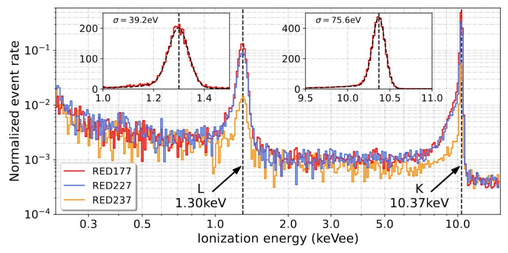




For each pulse, the best amplitude is estimated using χ² minimization

$$\chi^2(\vec{a};t_0) = \sum_f \left[\vec{Y} - \vec{aP}(\vec{\theta};t_0)\right]^\dagger J^{-1} \left[\vec{Y} - \vec{aP}(\vec{\theta};t_0)\right]$$

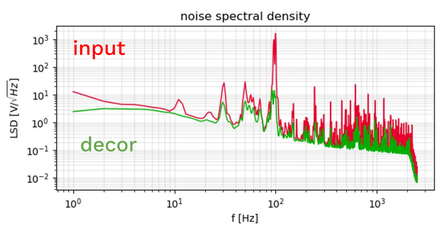
Apply quality cuts using high-level analysis tools and calibrate data



Automatic cross-talk removal

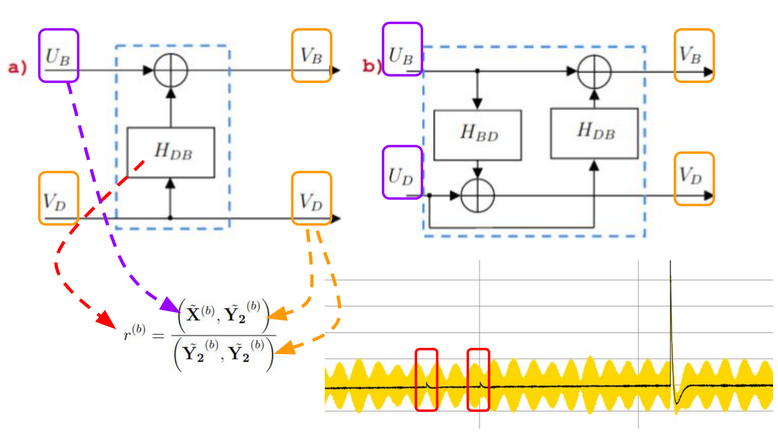
Ionization signal **is strongly coupled** in a low-capacitance design such as the Cryocube.

Using method in **[2]** and differential mode processing improves our resolution **from 70 to 30 eVee** (RMS).



utility signal
"what we are looking for"

measurement
"What we measure"



Conclusion

A pulse rate of ~2 Hz is fully manageable, compatible with light shielded above ground experiment and for RICOCHET at ILL (expected rate 0.2-0.5 Hz).

Assuming the theoretical heat/ion noise PSD, the trigger algorithm detect pulses with an efficiency around **40% for 50 eV of recoil energy**.

Linear combination of channels allows to process ionization data in differential mode giving the best results so far (see N. Martini poster).

Decorrelation (or cross-talk removal) **reduce the effect of correlated noise structure** such as pick-up noise.

The t_0 scan for amplitude fitting gives a **sub-sample timing resolution** resolution compatible to the muon veto trigger rate of RICOCHET.

More to know

MPS framework can be executed on **Slurm farm** and is **highly parallelizable** since each chunk of data stream can be processed independently.

MPS Simulation can be linked with Geant4 output to **reproduce the expected background at ILL**.

MPS Template is a tool to fit experimental pulses with analytical model using algorithms such as **iMinuit minimizer** and **MCMC sampler**.

MPS Efficiency will soon allows to estimate the survival fraction of injected pulses in detector data to **quantify processing and analysis efficiency** and **correct for potential bias**.

Bibliography

[1] Allen & al. (10.1103/PhysRevD.85.122006)

[2] Allen & al. (10.48550/arXiv.gr-qc/9909083)

[3] Colas & al. (10.1007/s10909-022-02907-5)

[4] Di Domizio & al. (10.1088/1748-0221/6/02/P02007)

[5] Gattti & al. (10.1007/BF02822156)

[6] Mancuzo & al. (10.1016/j.nima.2019.06.030)

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