MICHAEL MEWS

AIP CONGRESS DECEMBER 12 2022

Pyrate

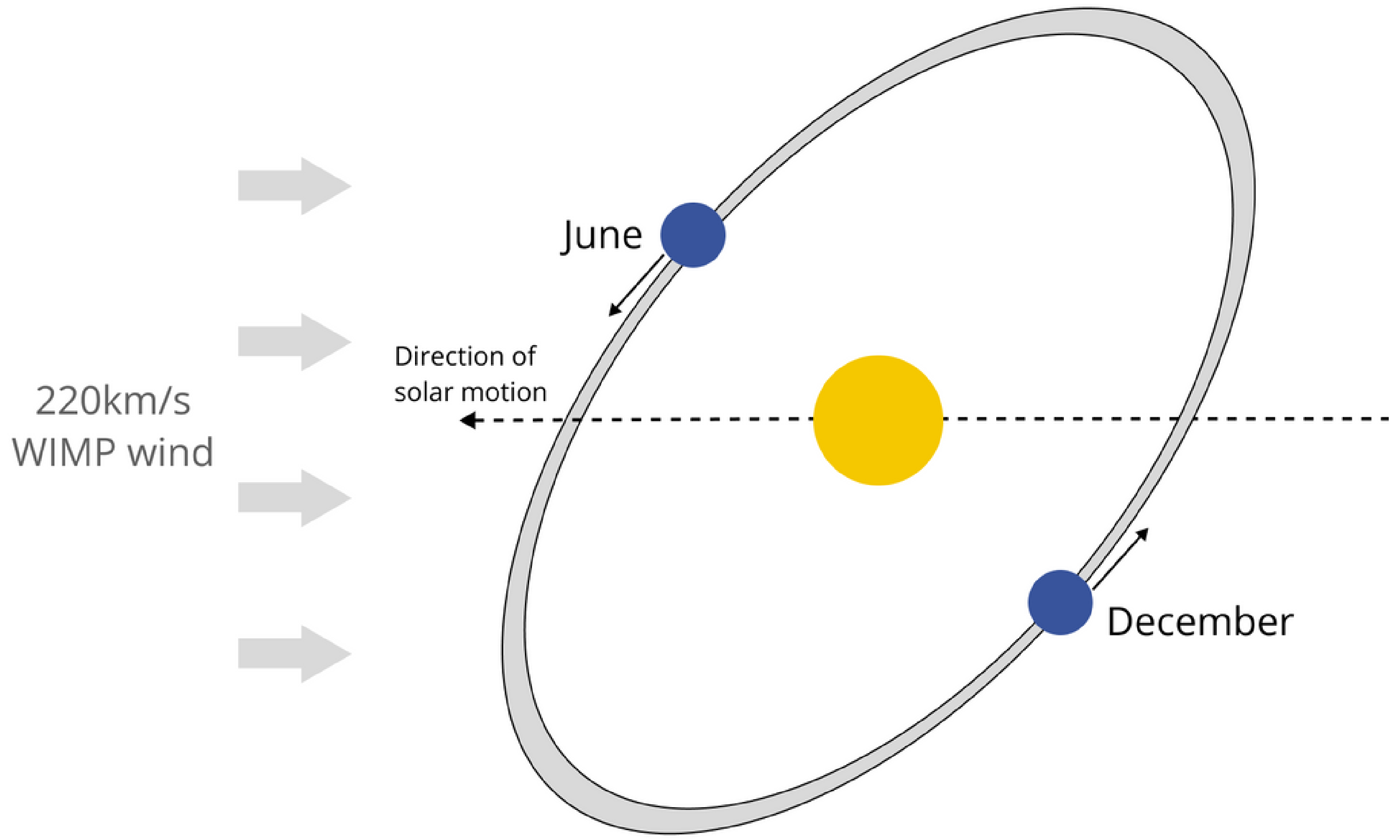
A novel system for data transformation, reconstruction, and analysis for the SABRE experiement

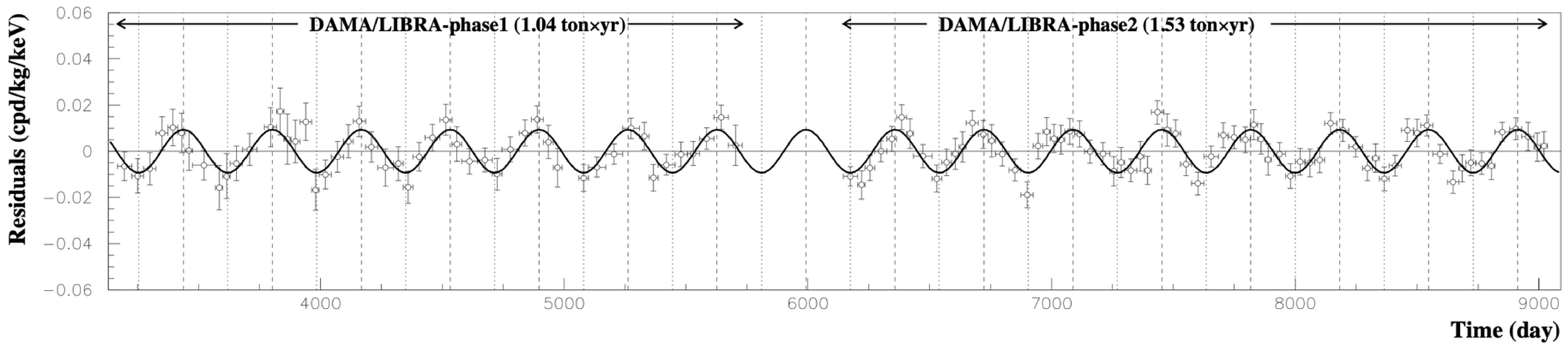
The Univeristy of Melbourne
On behalf of Federico Scutti and the SABRE South Collaboration

Dark matter direct detection

Annual modulation

- Period of 1 year
- DAMA observes signal at 13σ
- In low energy region 1-6keV
- Amplitude R = **0.01058±0.00090 cpd/kg/keV**



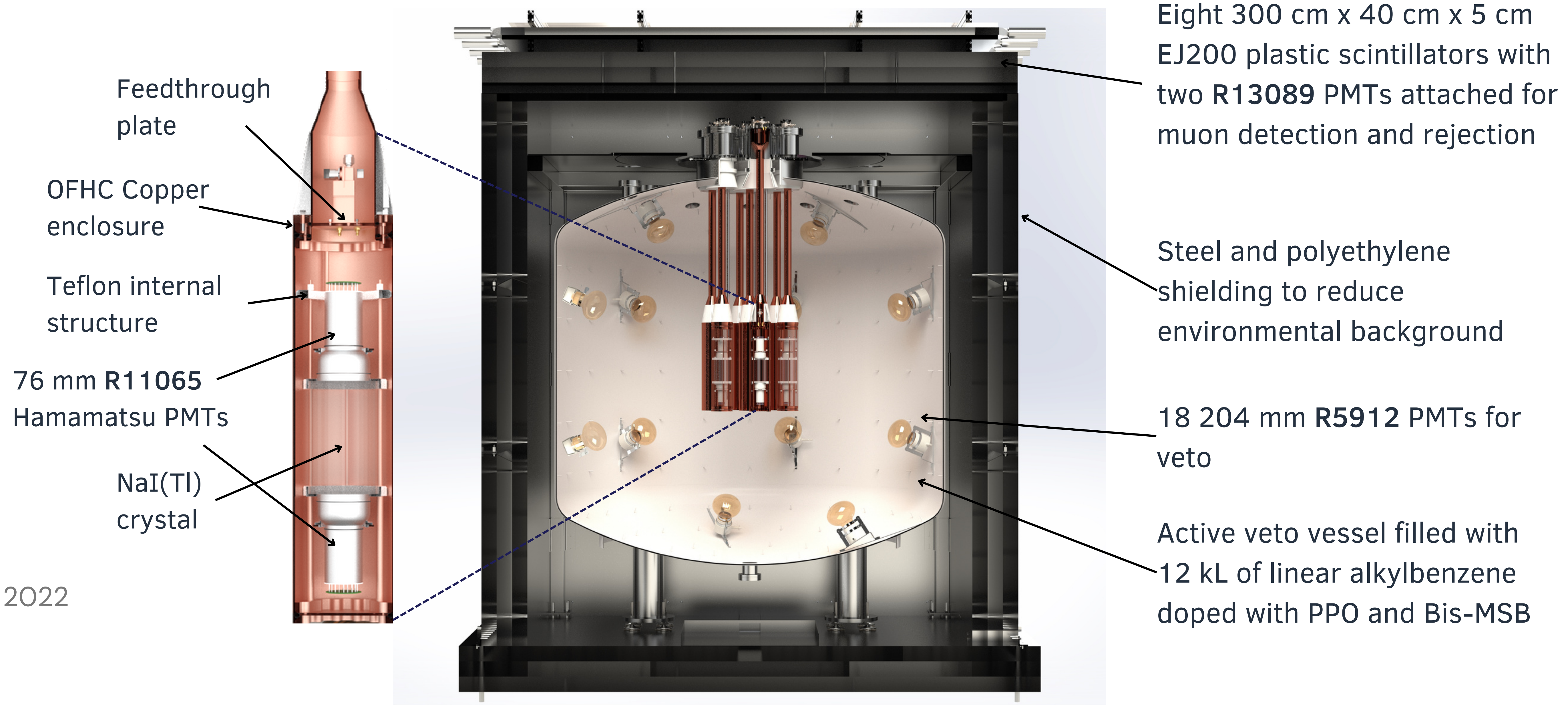


Bernabei, R., et al. "First results from DAMA/LIBRA–phase2." Nuclear and Particle Physics Proceedings 303 (2018): 74–79

SABRE

Sodium **I**odide with **A**ctive **B**ackground **RE**jection aims to test the DAMA annual modulation signal

See Irene Bolognino's SABRE South talk, 4pm Wednesday



Eight 300 cm x 40 cm x 5 cm EJ200 plastic scintillators with two **R13089** PMTs attached for muon detection and rejection

Steel and polyethylene shielding to reduce environmental background

18 204 mm **R5912** PMTs for veto

Active veto vessel filled with 12 kL of linear alkylbenzene doped with PPO and Bis-MSB

Direct detection challenges

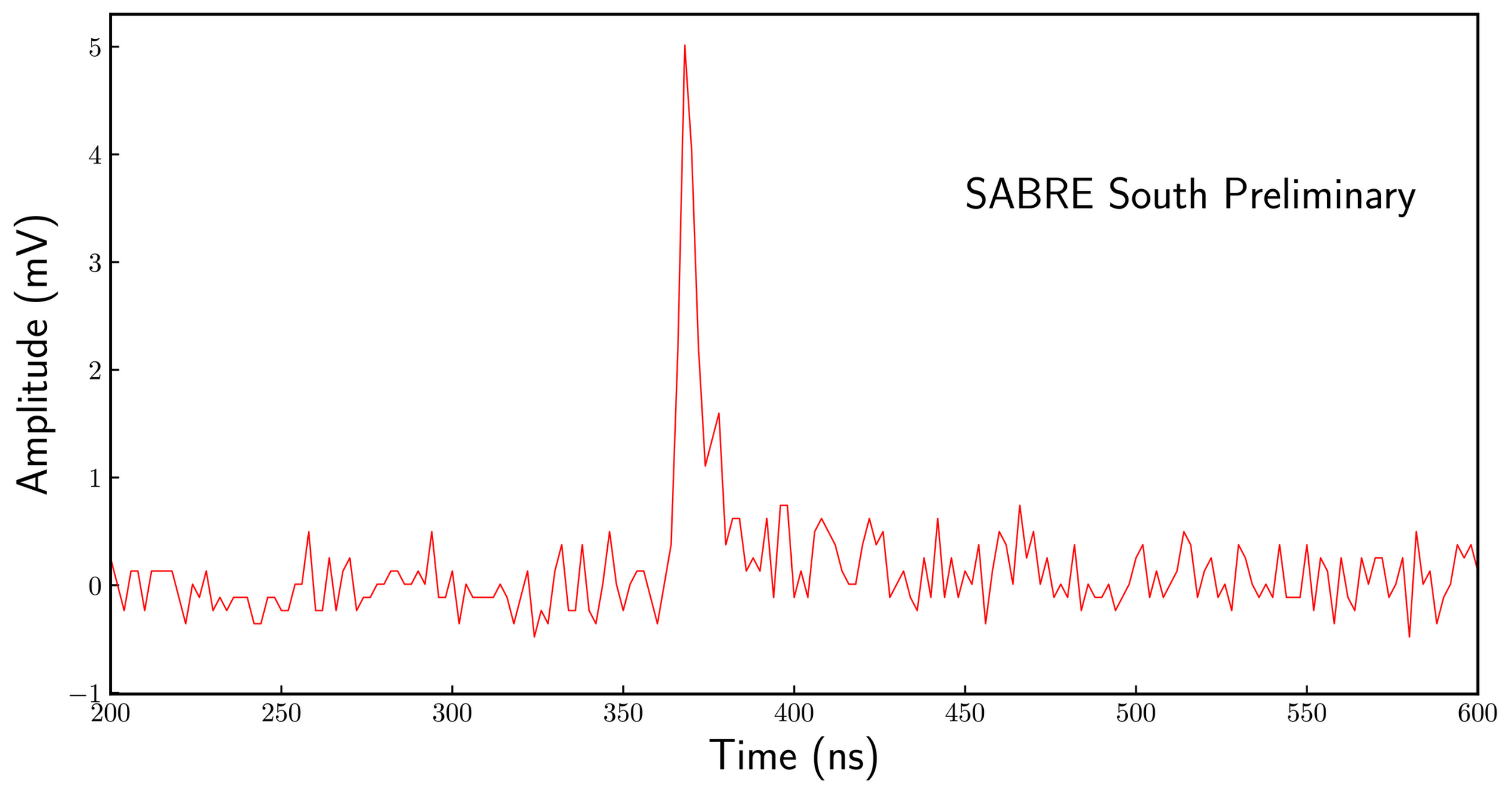
Rare signal events

- Expect ~1–2 signal events per day
- Signal in the 1–6keV energy region

High PMT dark rates

- 1–2kHz per PMT with 48 channels
- High-background rate induced deadtime

Example veto PMT dark photon pulse

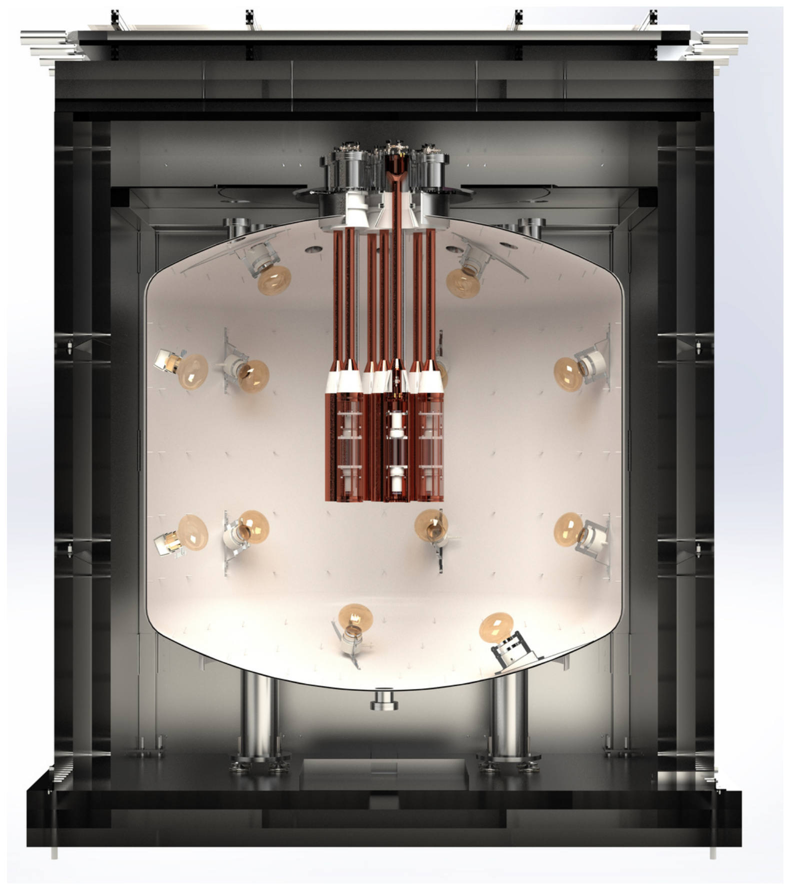


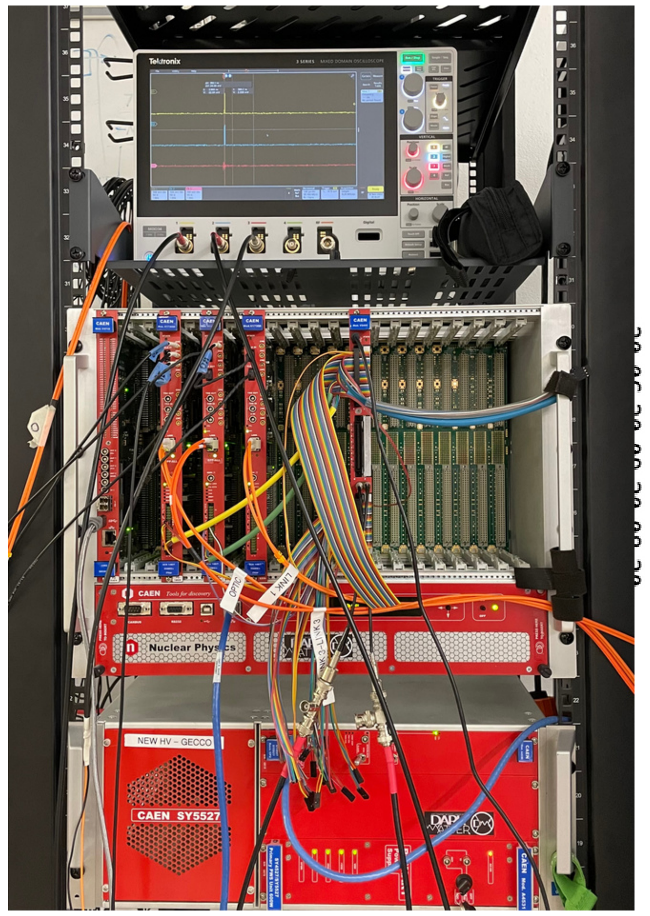
Required data processing

- Sub-detector calibration with database integration
- Machine learning classifiers used in crystal processing
- Position tracking in the veto vessel
- Particle idenfitication

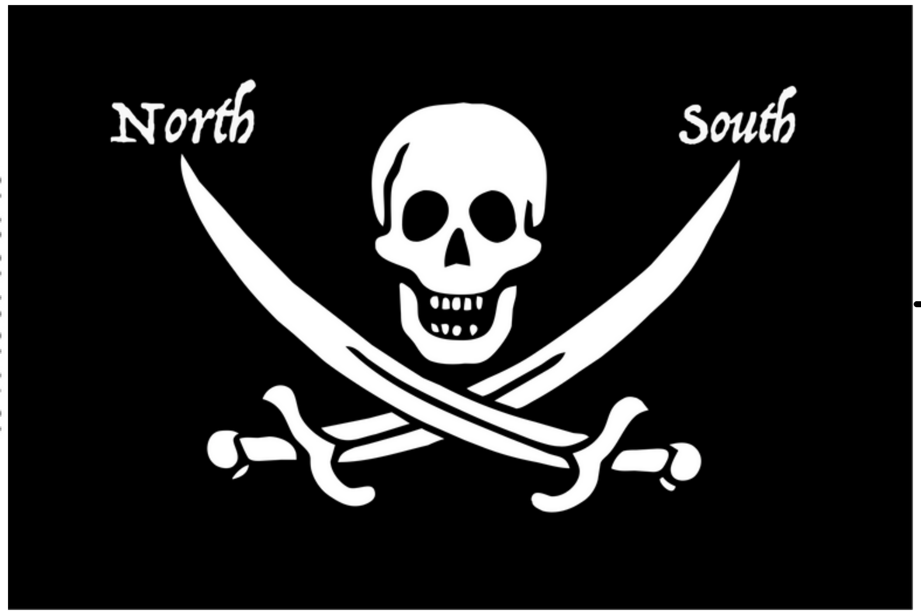
SABRE's dataflow

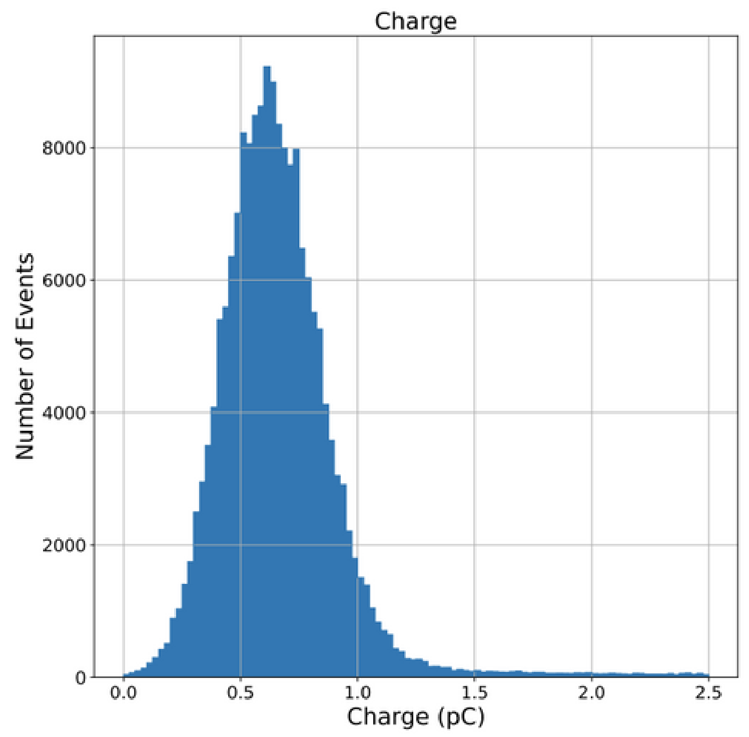
1 Detector modules → 2 Data Acquisition & digitisation → 3 Process raw digitiser output – Pyrate – → 4 Produce analysis





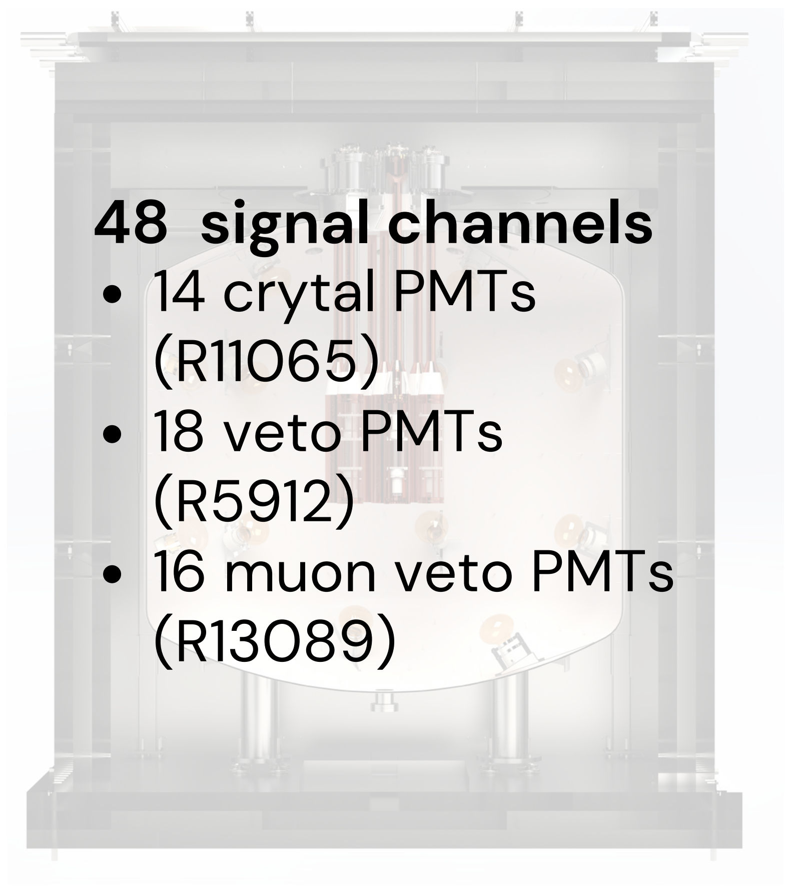
```
20 08 20 0C 20 01 20
20 0C 20 0D 20 07 20
20 0E 20 0B 20 08 20
20 08 20 09 20 09 20
20 0F 20 0B 20 05 20
```



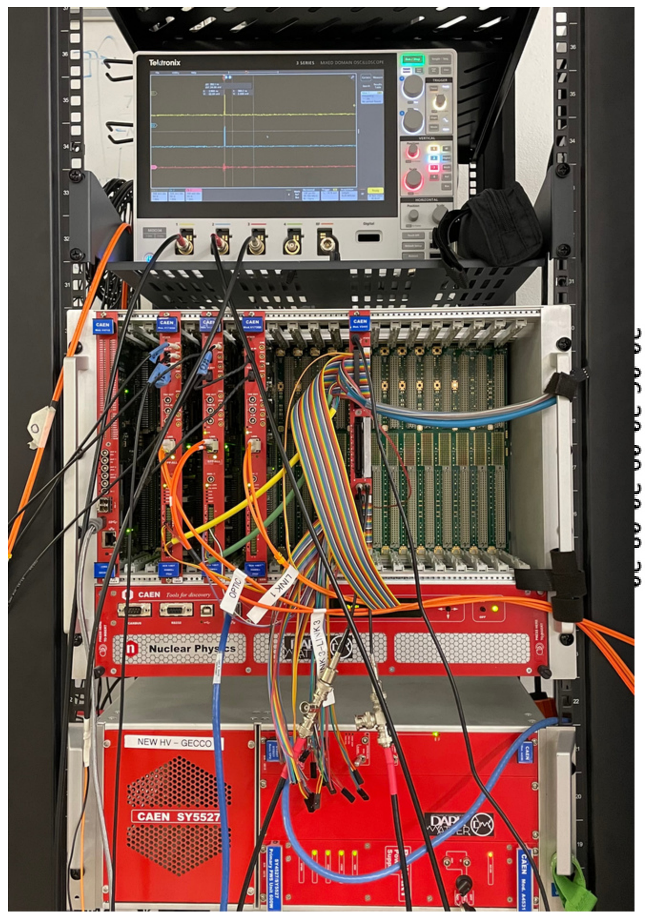


SABRE's dataflow

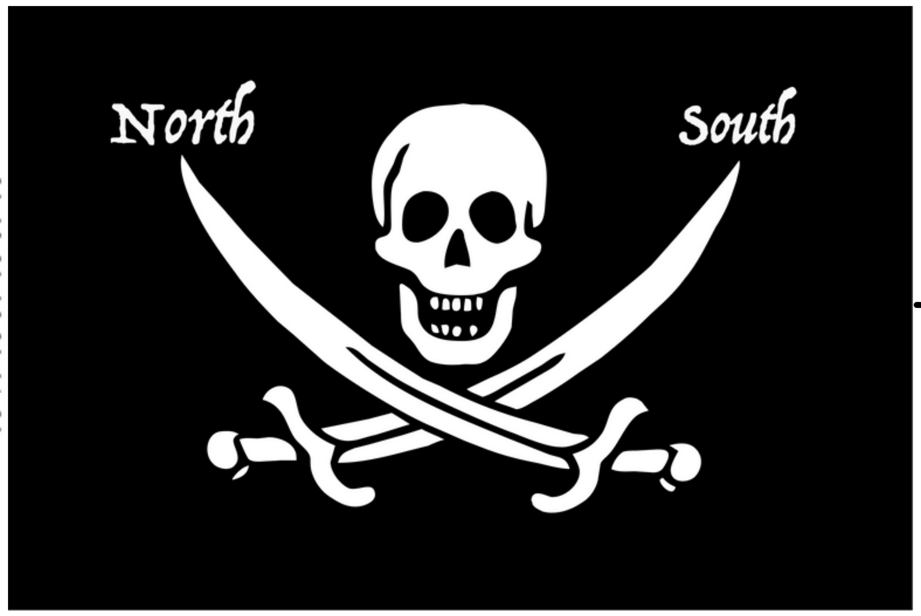
1 Detector modules → 2 Data Acquisition & digitisation → 3 Process raw digitiser output – Pyrate – → 4 Produce analysis

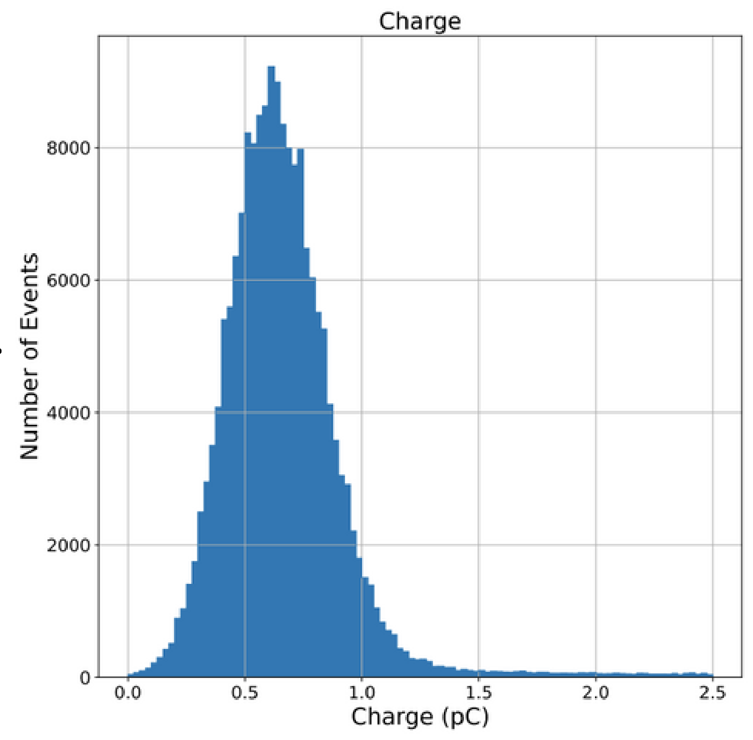


48 signal channels
- 14 crytal PMTs (R11065)
- 18 veto PMTs (R5912)
- 16 muon veto PMTs (R13089)



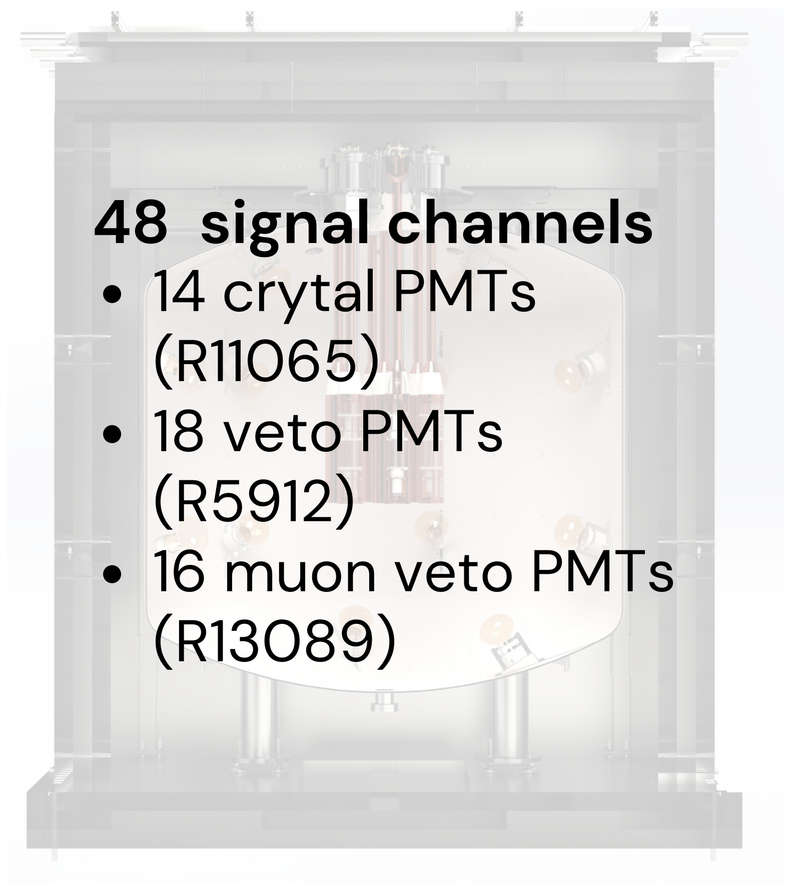
```
20 08 20 0C 20 01 20
20 0C 20 0D 20 07 20
20 0E 20 0B 20 08 20
20 08 20 09 20 09 20
20 0F 20 0B 20 05 20
```



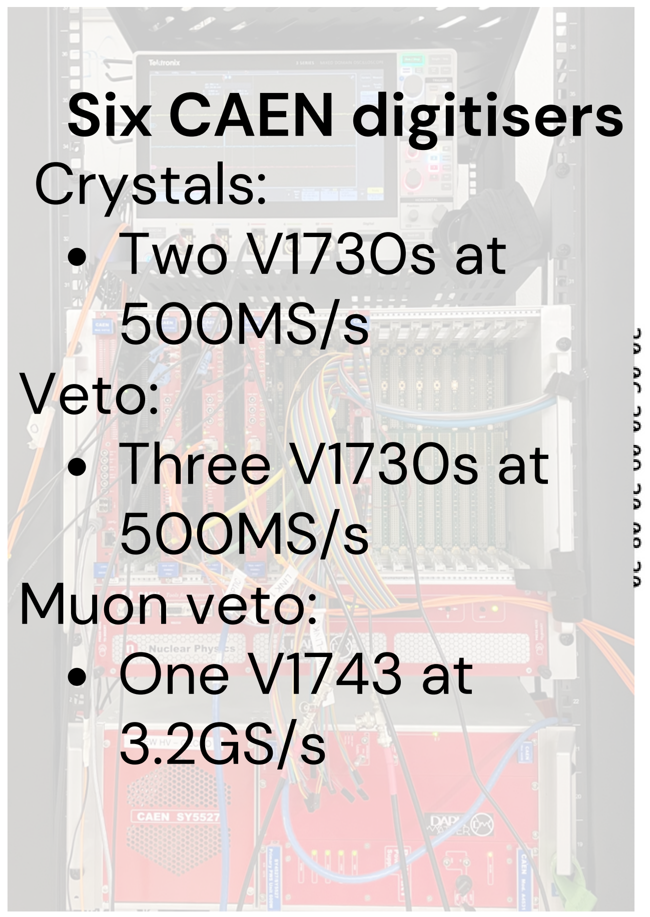


SABRE's dataflow

1 Detector modules → 2 Data Acquisition & digitisation → 3 Process raw digitiser output – Pyrate – → 4 Produce analysis



48 signal channels
- 14 crytal PMTs (R11065)
- 18 veto PMTs (R5912)
- 16 muon veto PMTs (R13089)



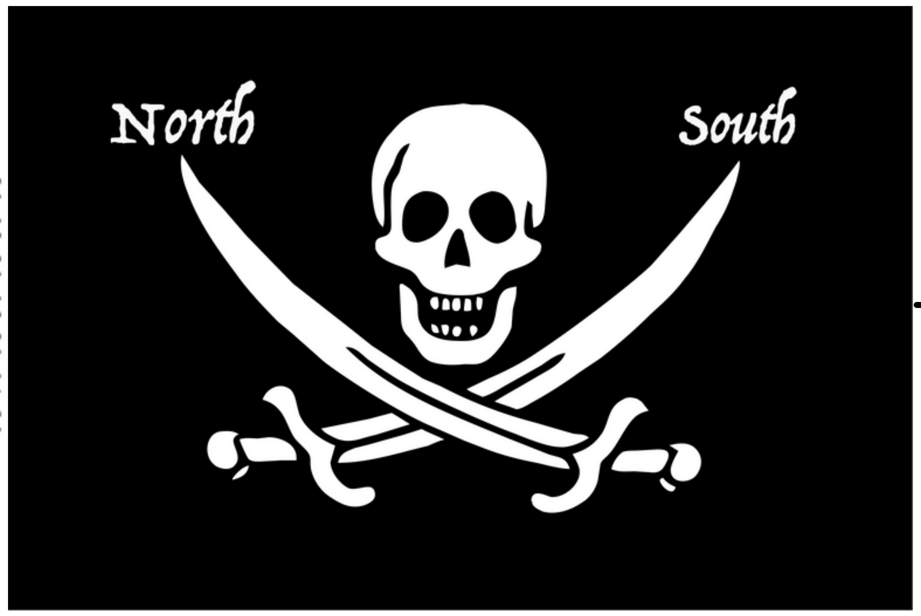
Six CAEN digitisers

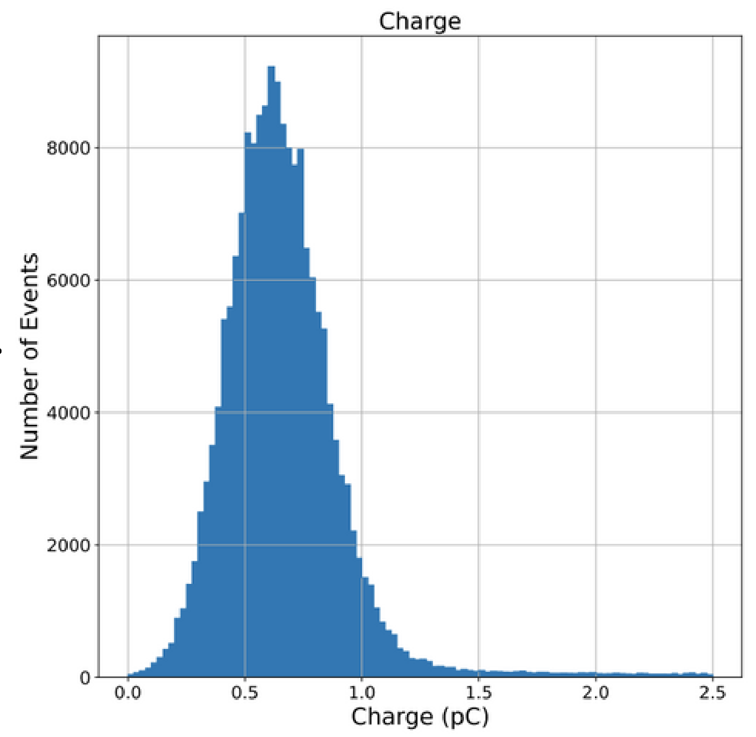
Crystals:
- Two V1730s at 500MS/s

Veto:
- Three V1730s at 500MS/s

Muon veto:
- One V1743 at 3.2GS/s

```
20 08 20 0C 20 01 20
20 0C 20 0D 20 07 20
20 0E 20 0B 20 08 20
20 08 20 09 20 09 20
20 0F 20 0B 20 05 20
```





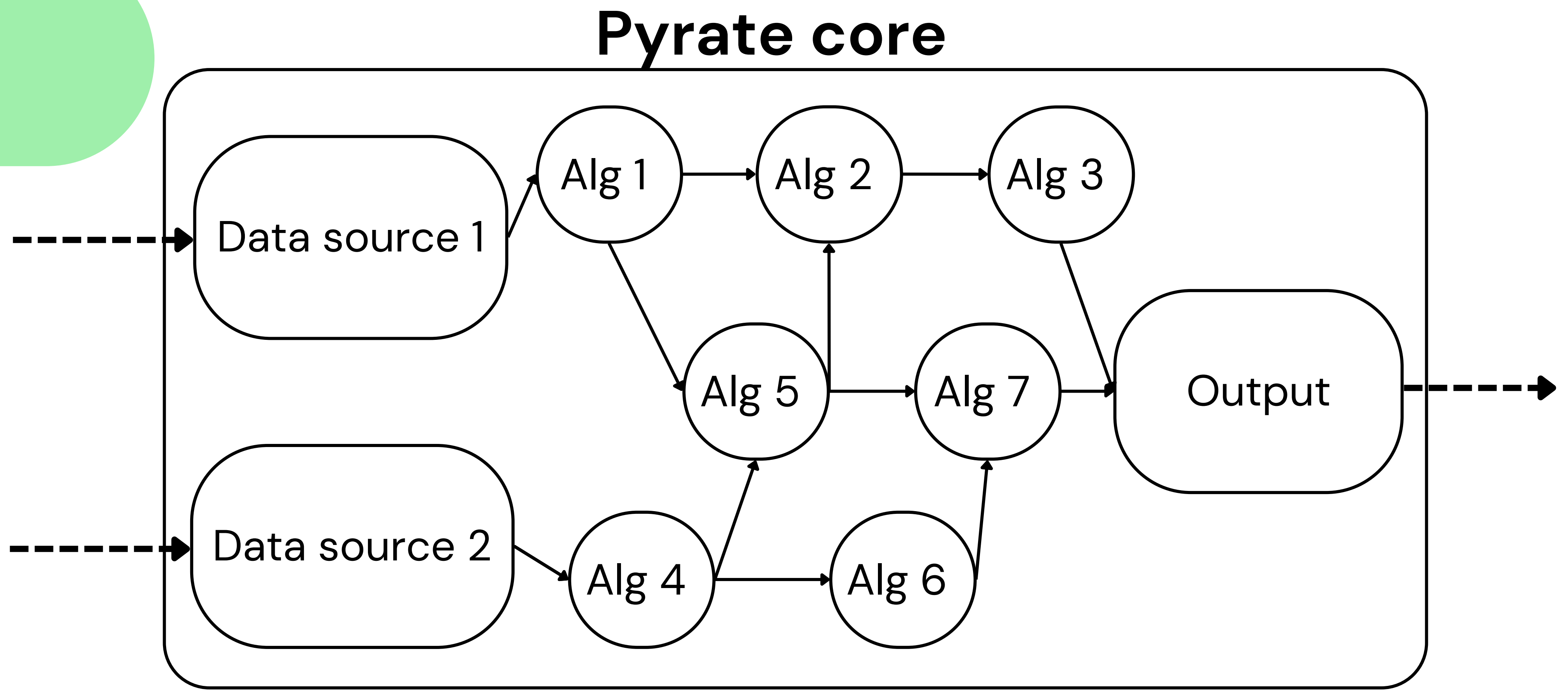
What is pyrate?

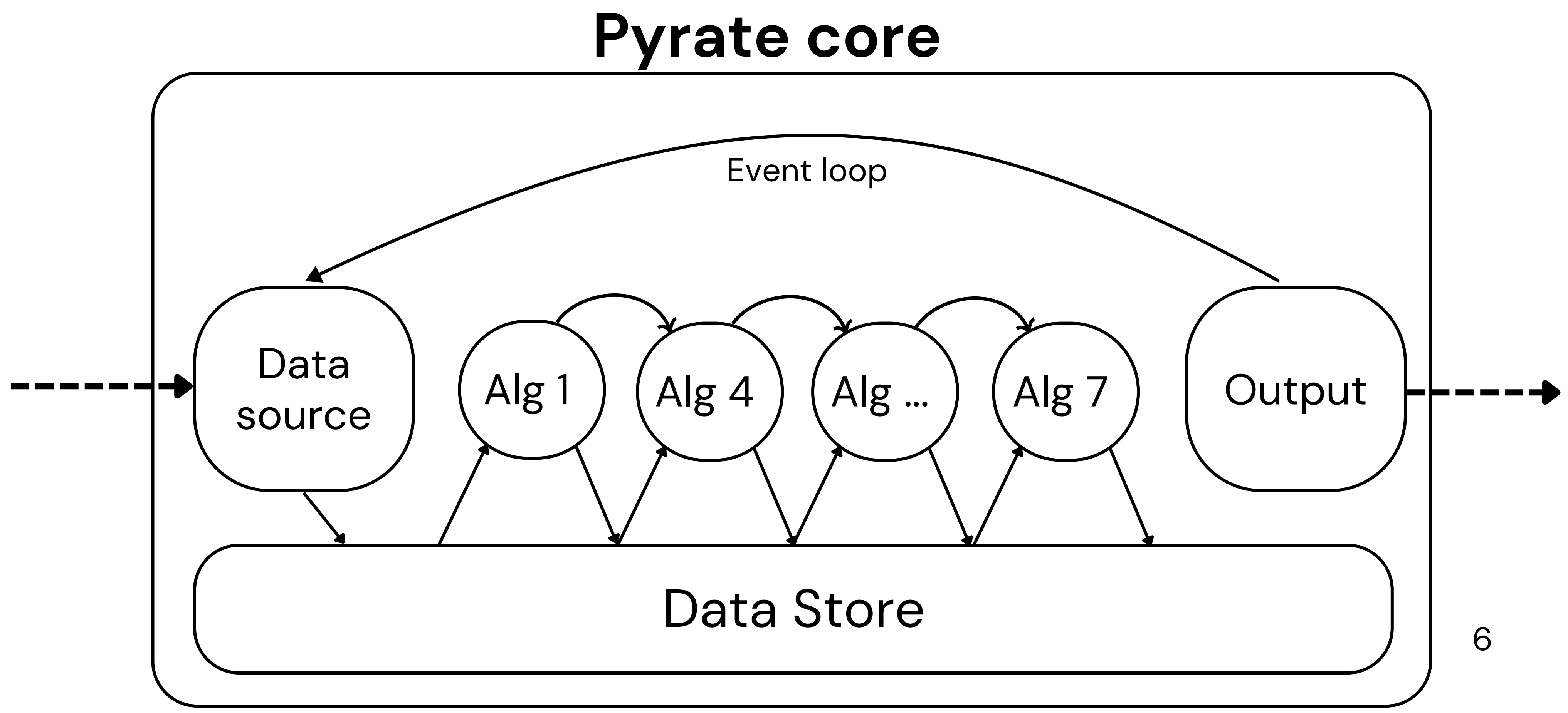
PYthon-based **R**econstruction, **A**nalysis, **T**ransformations, **E**tc.

SABRE's data processing program in python

Flexible, object-oriented. Pyrate can be used at all stages in data taking and analysis:

- Raw data transformation
- Signal processing
- Event building and reconstruction





Main components

1 Inputs

Time ordered datasets

- Unprocessed digitiser binary files
- Event-based ROOT datasets

2 Algorithms

Singular self-contained data transforms

- Used to calculate variables from waveforms
- Runs in three 'phases': *initialise, execute,* and *finalise*

3 Core

Governs the order of execution and loops over all the events

4 Outputs

Writes transformed data to disk

Input

Pyrate processes event-based datasets

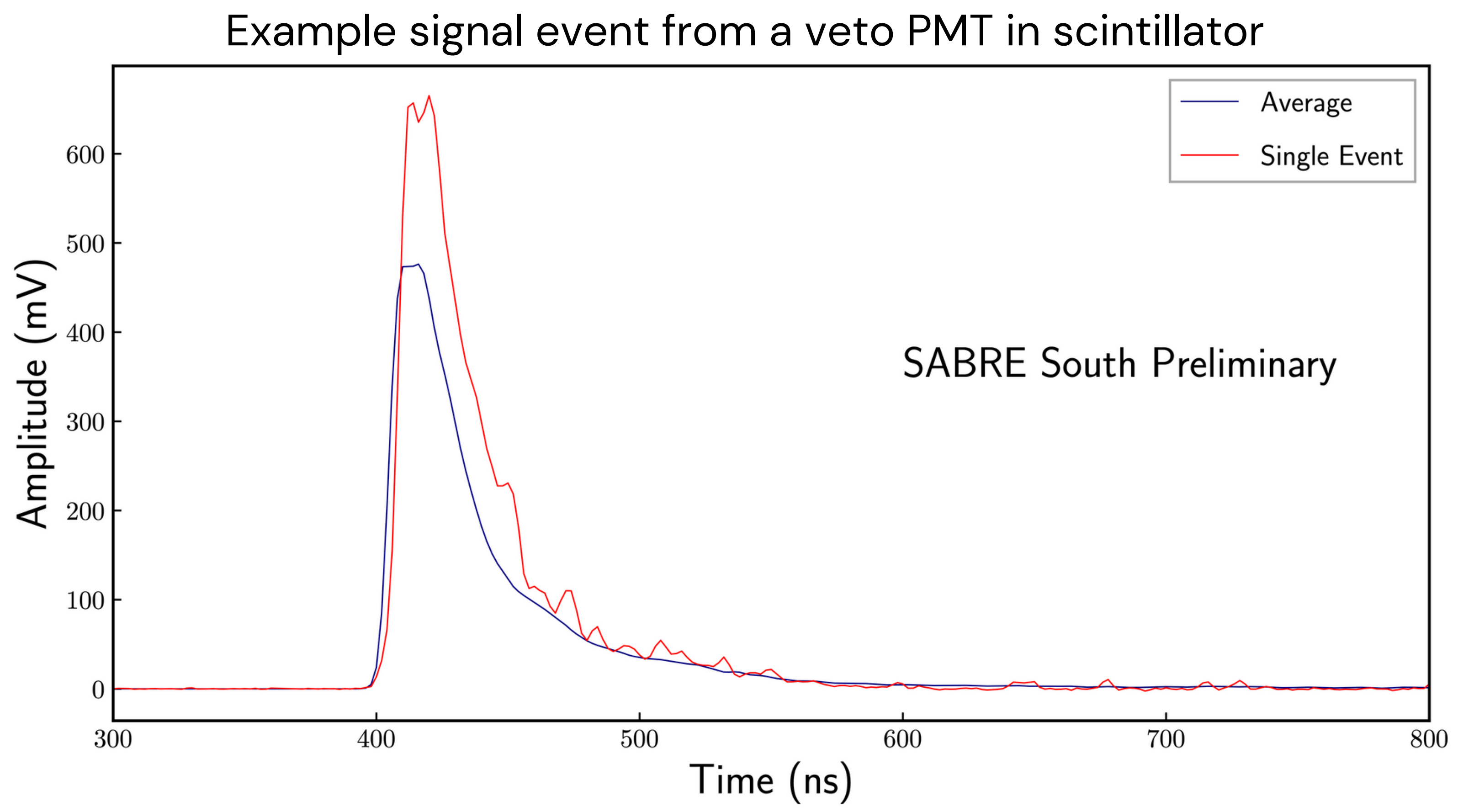
- Collects a single *event's* data from the input and pushes it only the shared memory 'store'
- Calcuates a range of variables for each of these events

Supports auxilliary non-event-based inputs

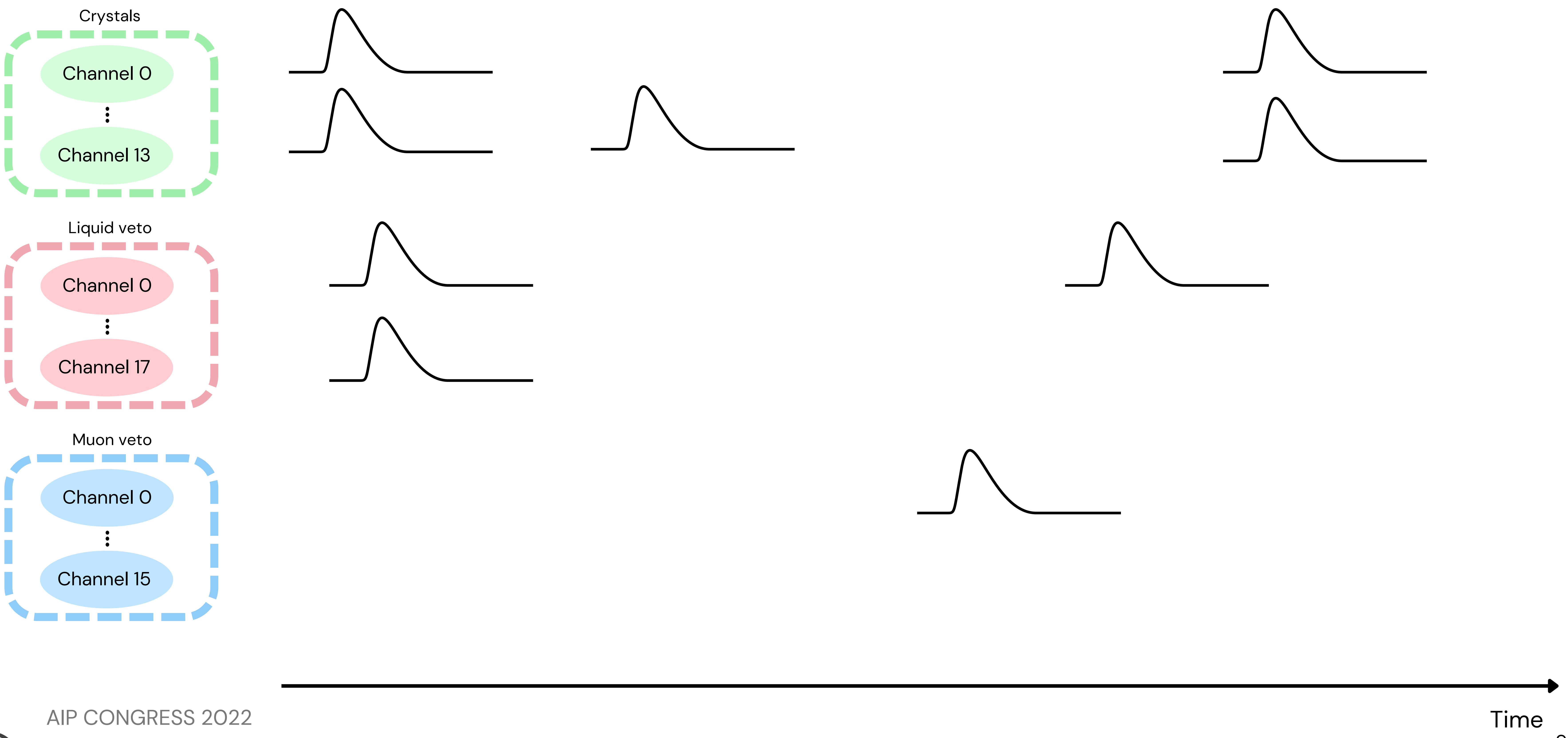
- Calibration data
- Environmental monitoring

Currently supports

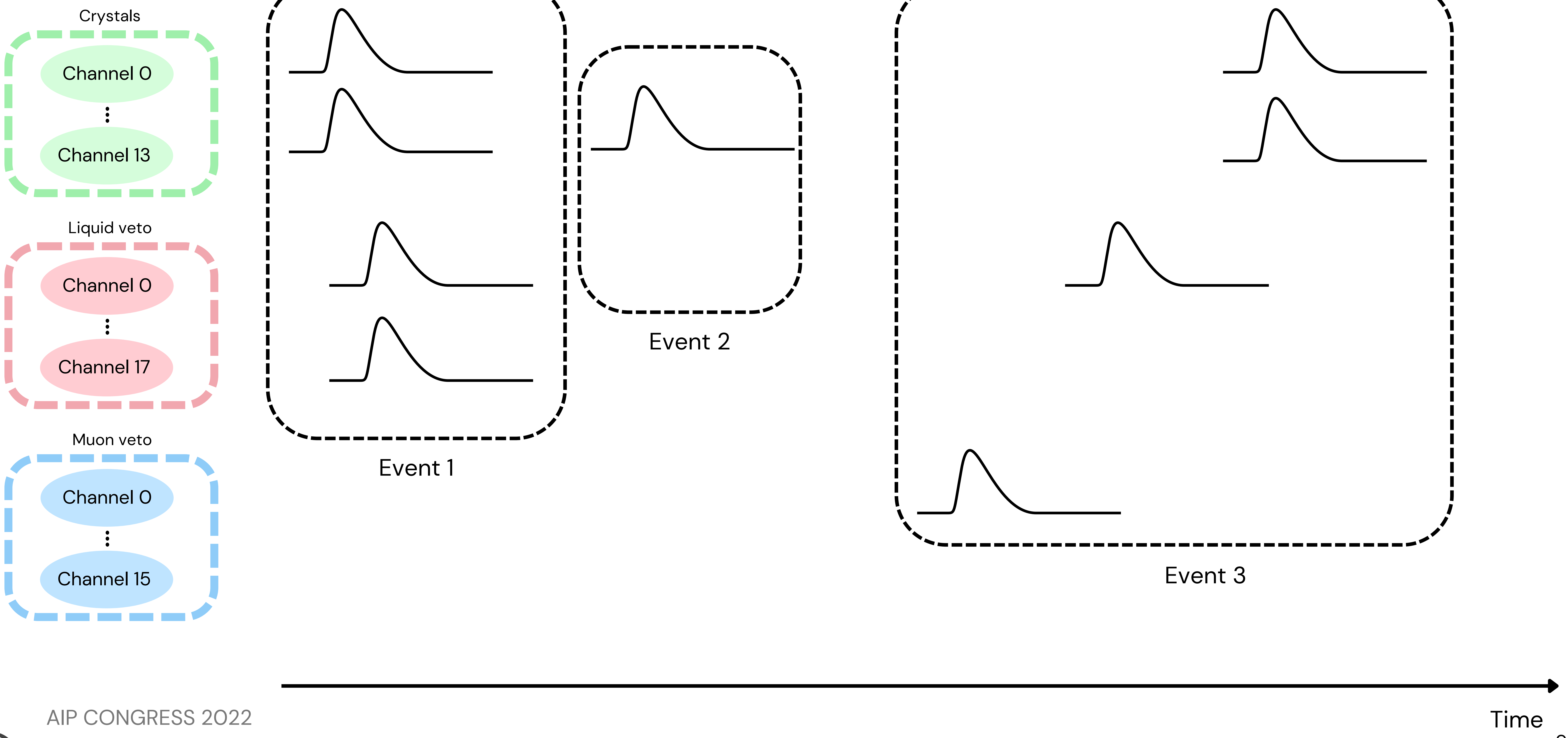
- SABRE DAQ & common CAEN digitiser binary files
- ROOT files from pyrate or Geant4



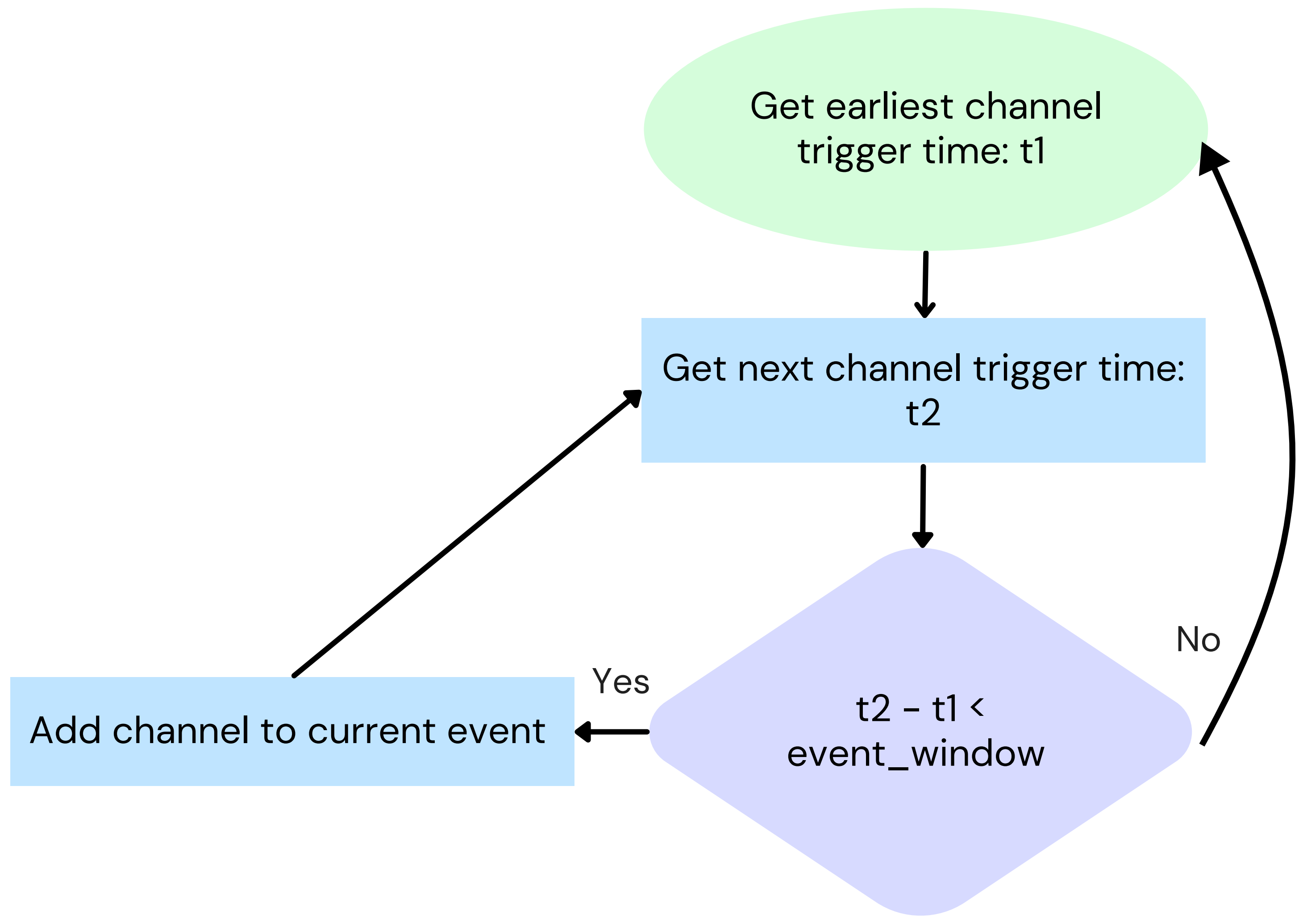
Pyrate Inputs



Pyrate Inputs

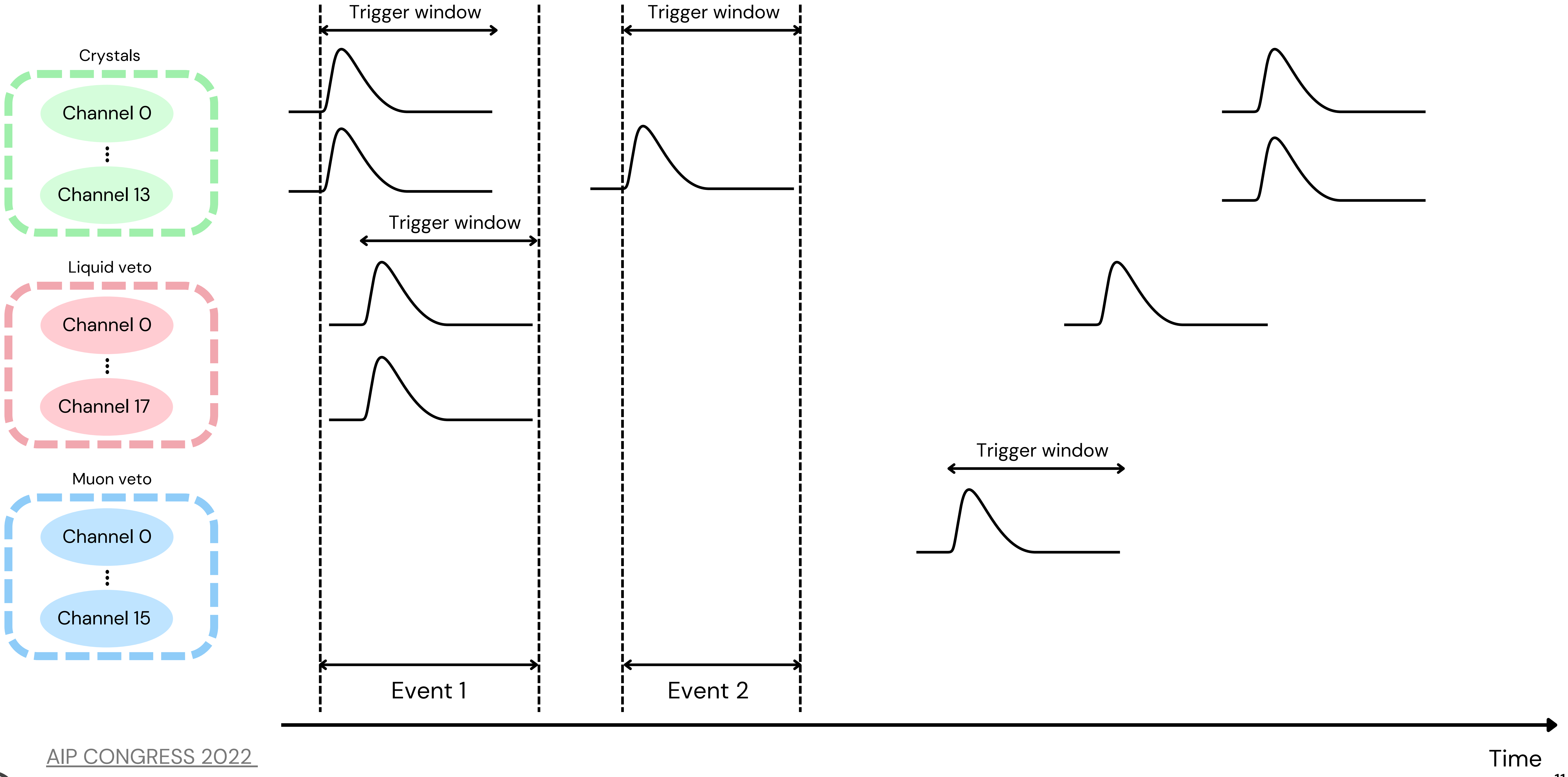


Event Builder

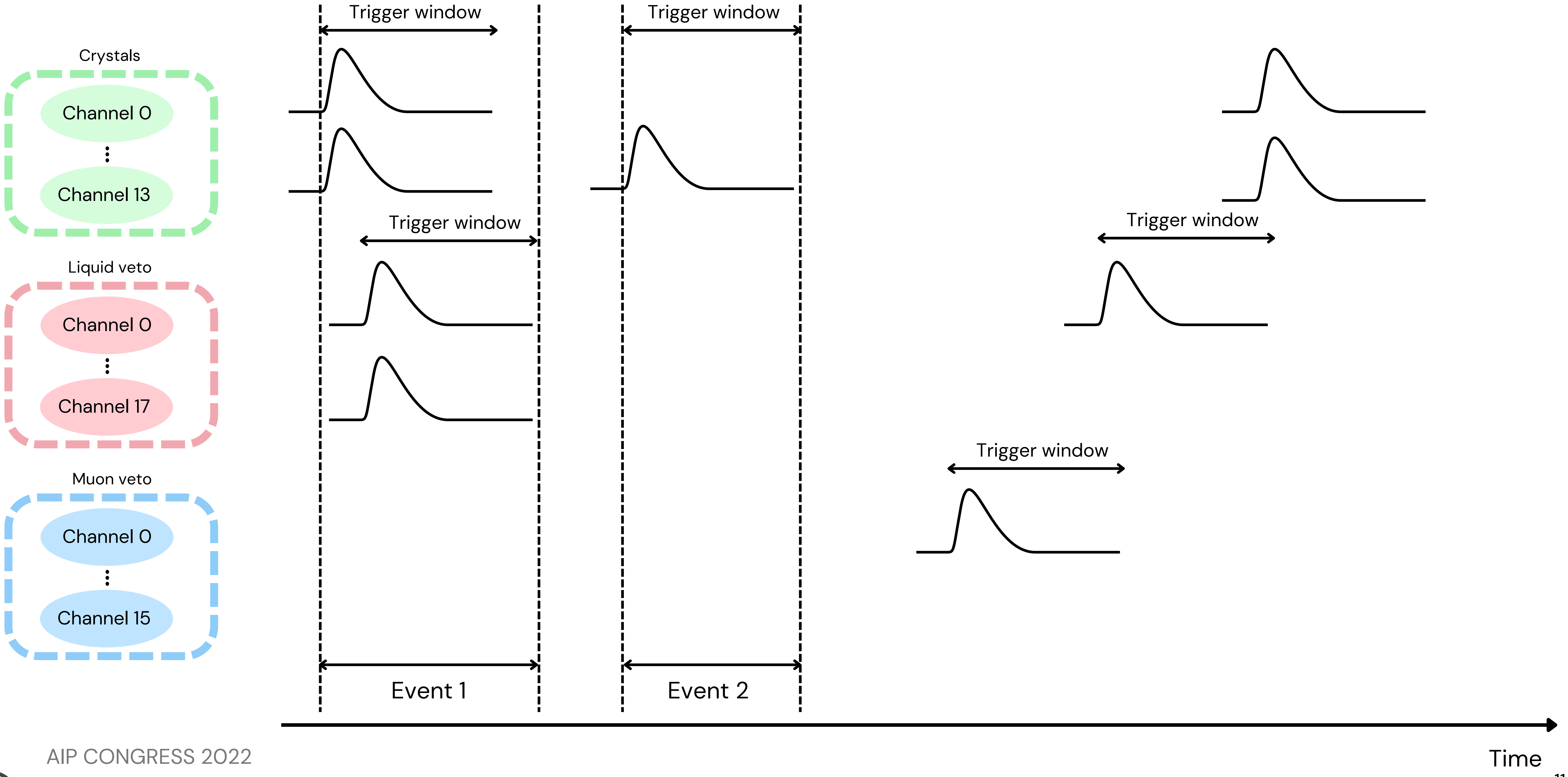

Get earliest channel trigger time: t1
Get next channel trigger time: t2
t2 - t1 < event_window
Yes
No
Add channel to current event

- Run requests latest full *event* from the event builder input
- Event builder collects all the channel triggers based on their trigger times and the *event window*
- All event data pushed onto the store

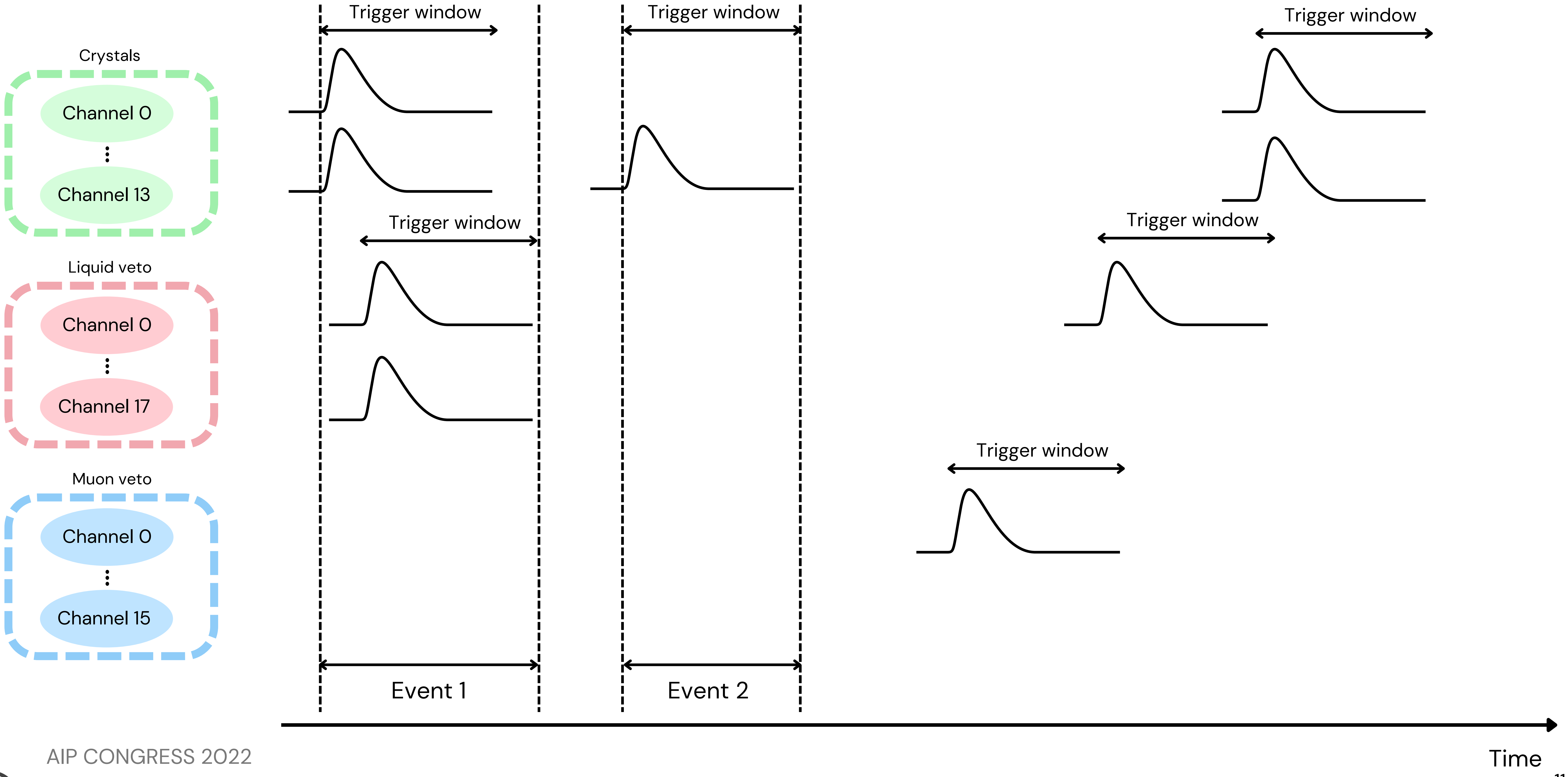
Pyrate Inputs



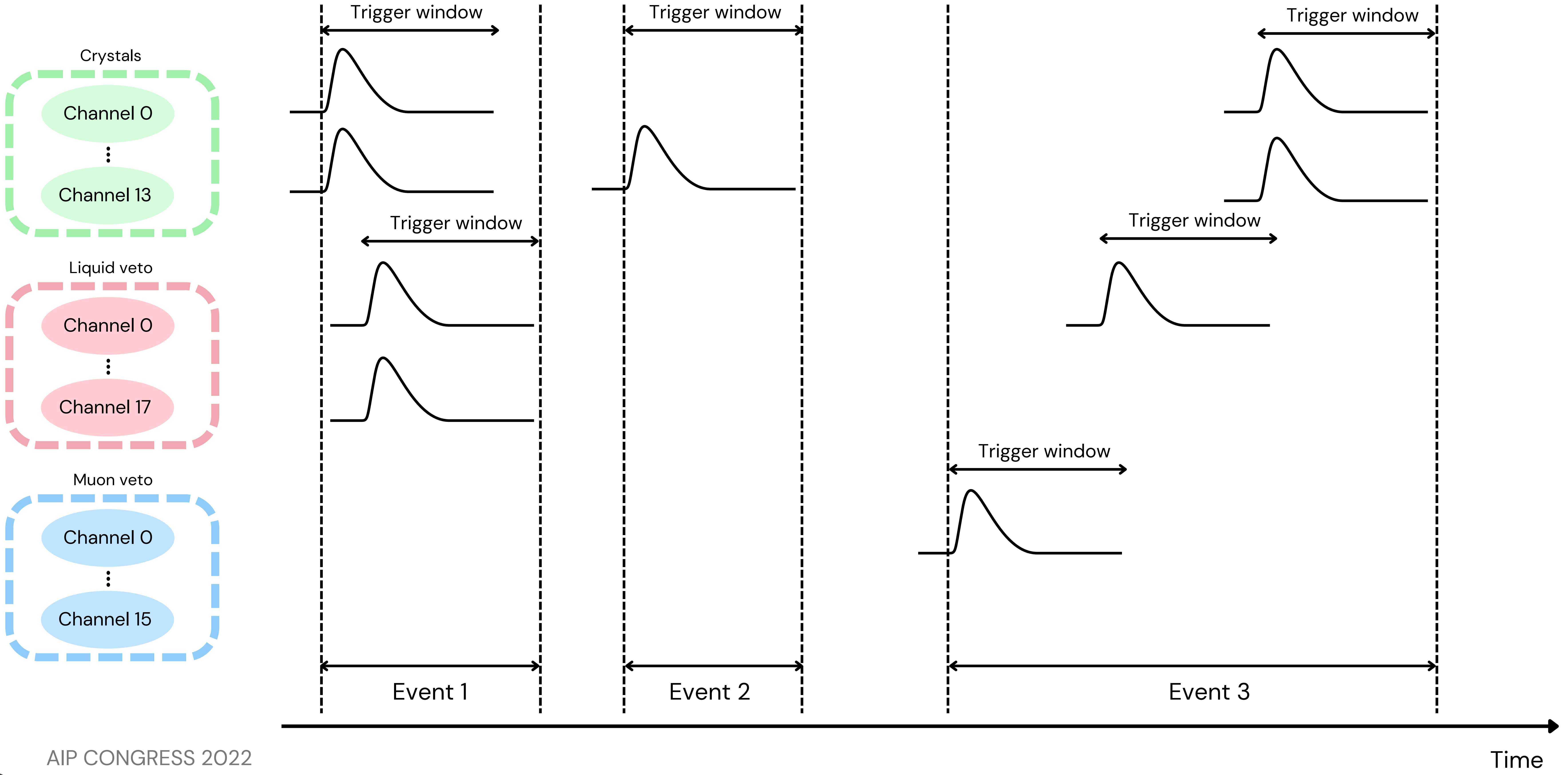
Pyrate Inputs



Pyrate Inputs

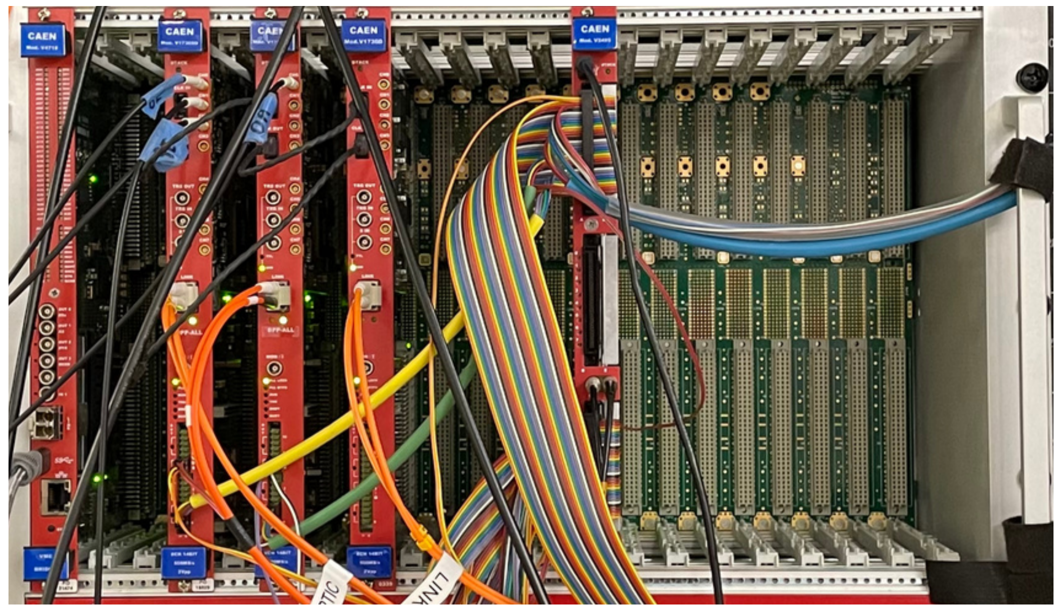


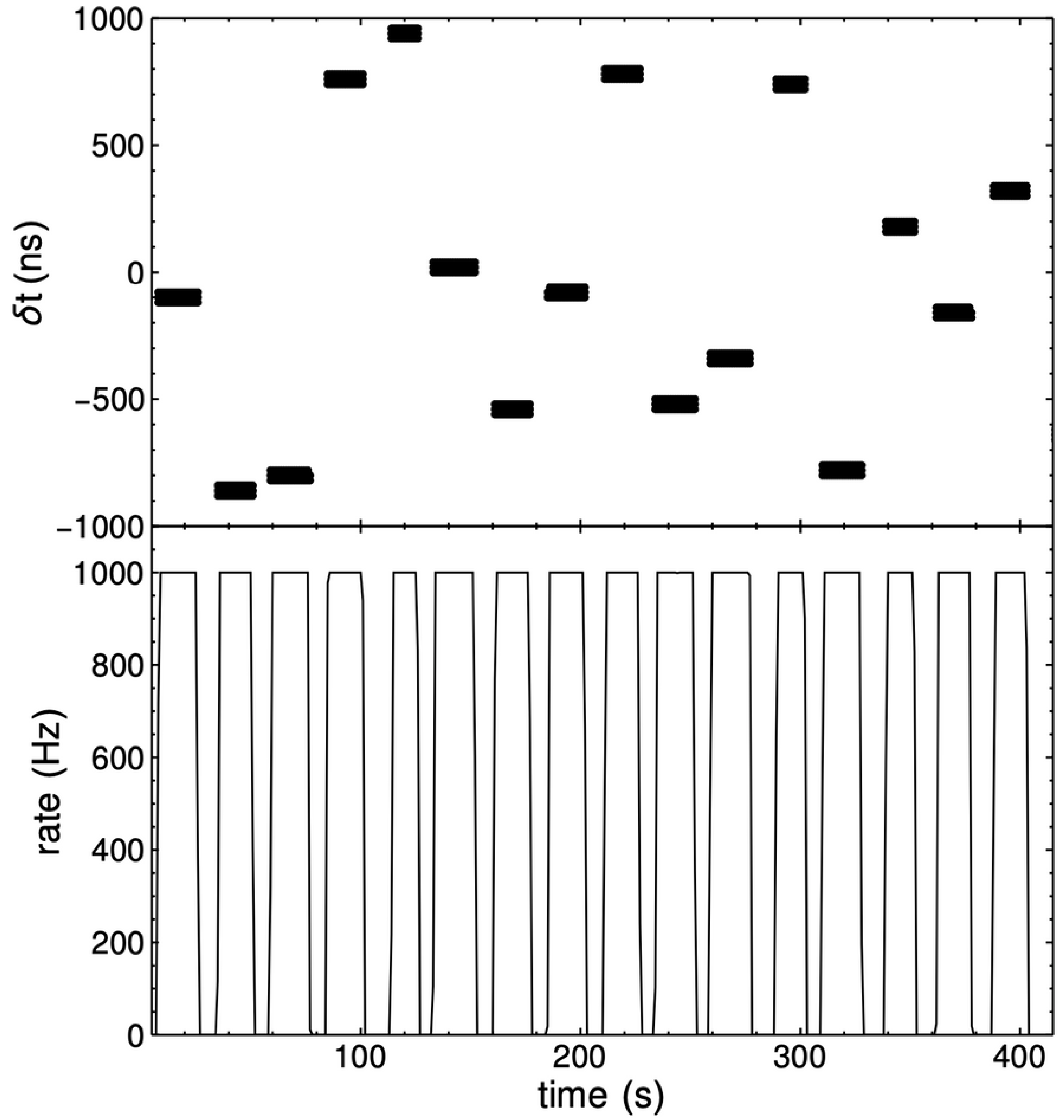
Pyrate Inputs



Event Builder Validation

1. Generated a 1kHz test signal
2. Split the signal into multiple channels, each with a different time delay (δt)
3. Reconstruct the event in pyrate using appropriate trigger window

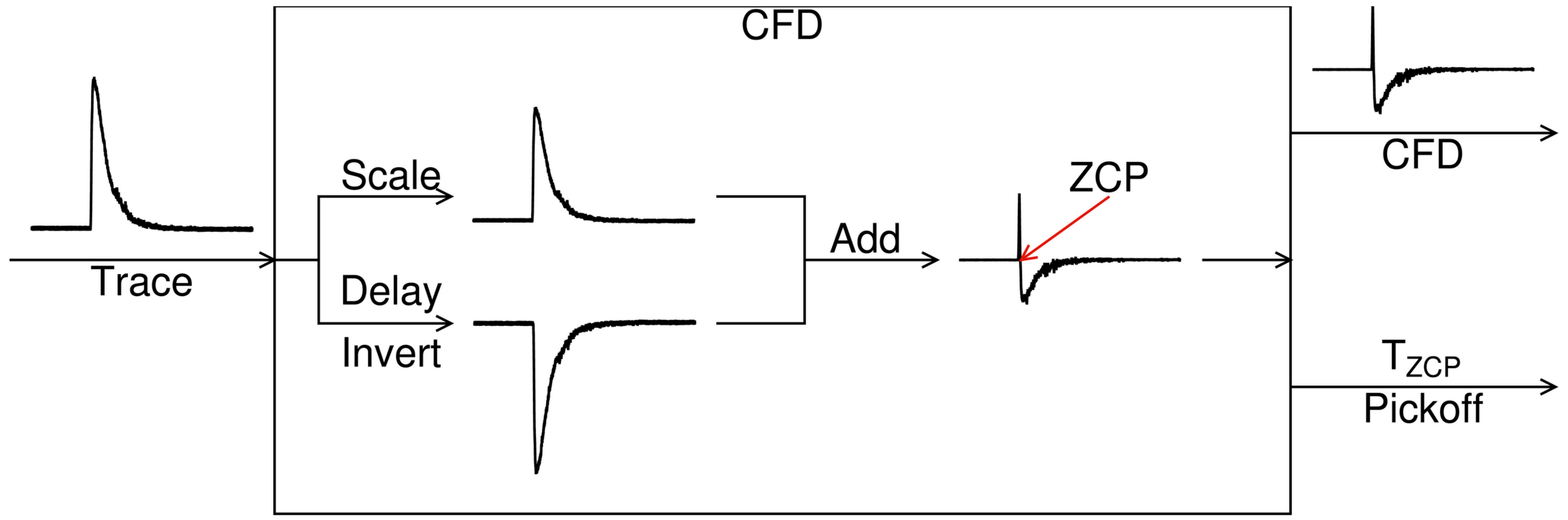




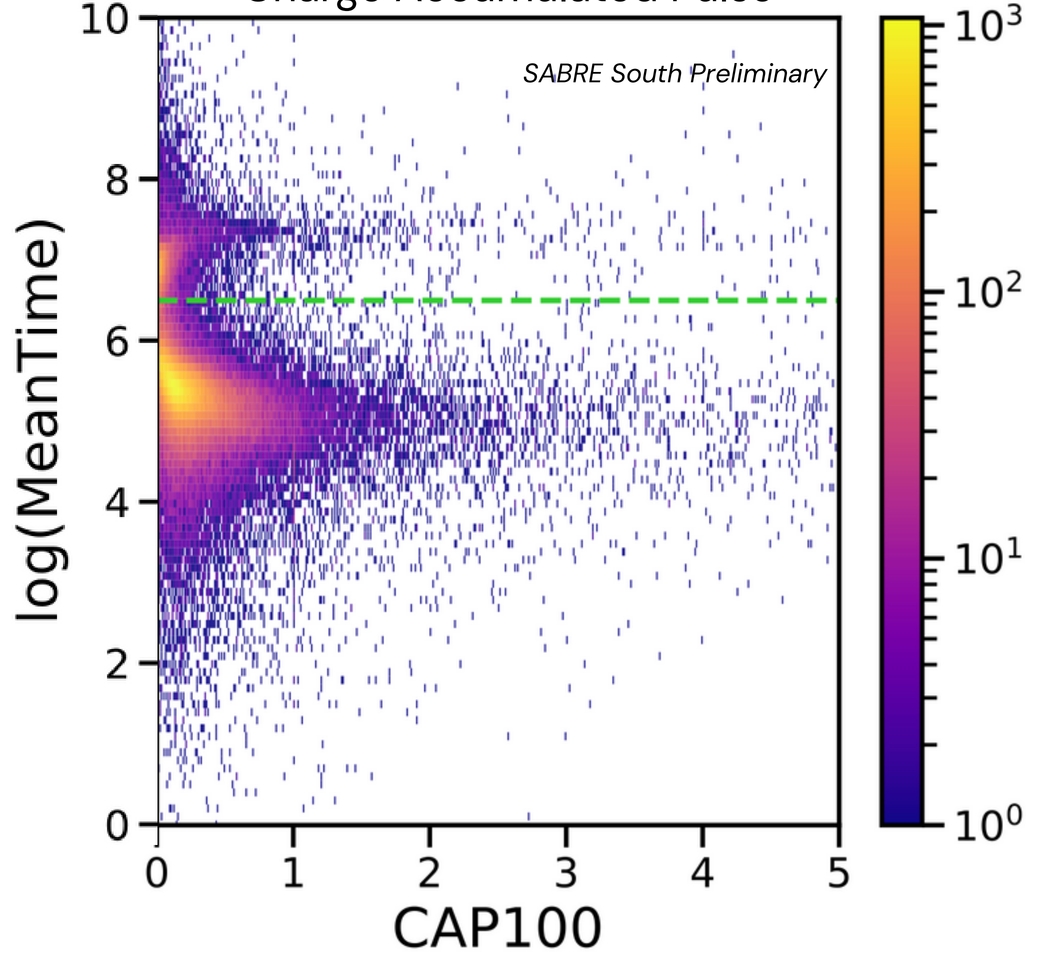
Algorithms

- Algorithms process and transform data
- Pyrate is algorithm agnostic
  - Only cares about the algorithms inputs and outputs
  - Inputs and outputs pulled from and pushed to the 'store'

- Example algorithms currently in use in pyrate:
  - Charge summation, noise suppression, baseline correction, charge accumulated pulse, leading edge time pick-off, CFD time pick off, trapezoid filter, FFT, moments, TTree builders, TGraph generators, EPICSReader



Background and signal separation using mean time and Charge Accumulated Pulse



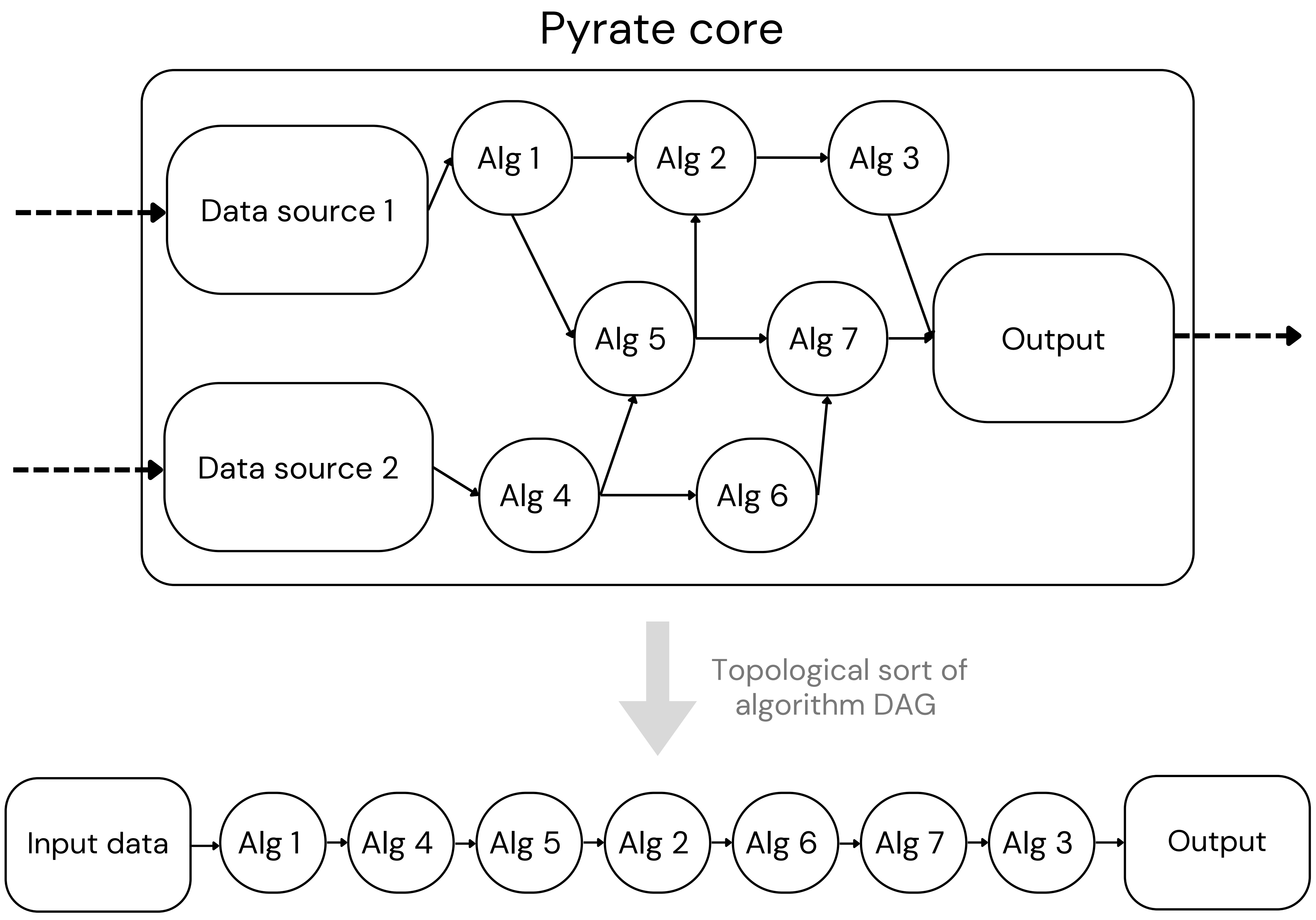
Pyrate core

Pyrate core governs:

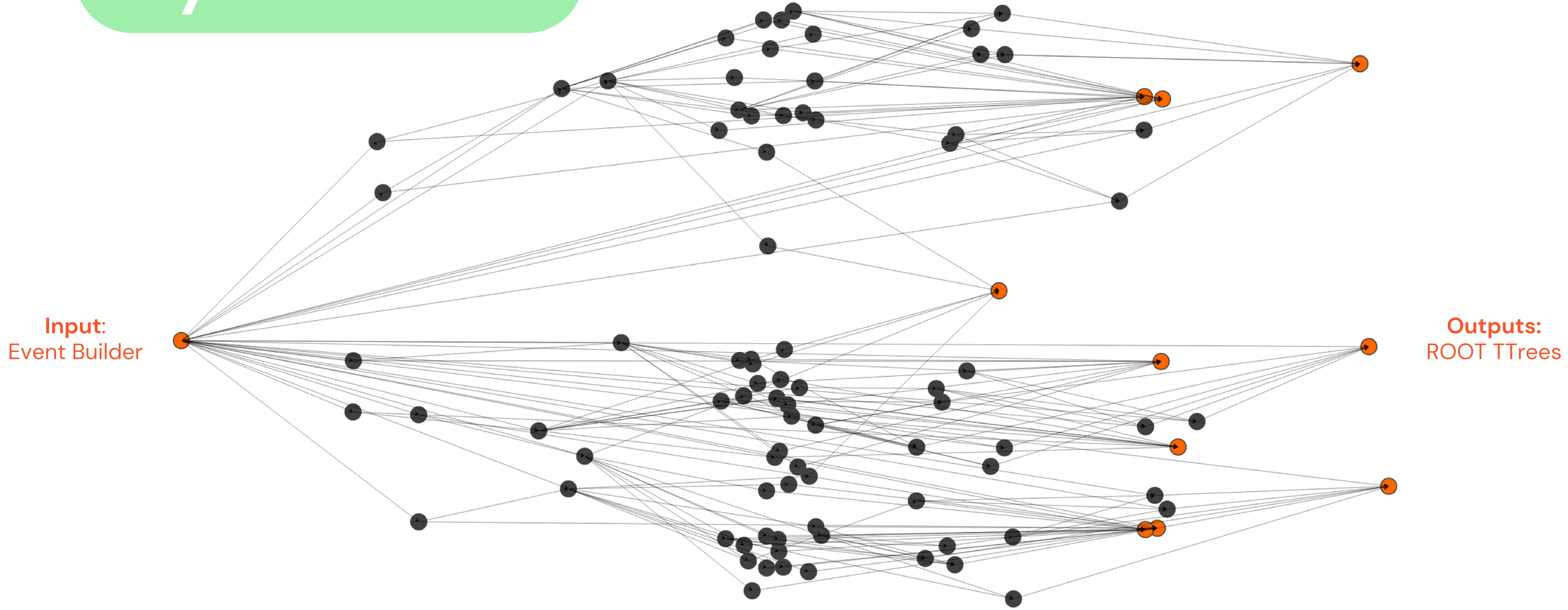
- Retrieval of inputs
- Ensures all required algorithm inputs are available
- Determines algorithm ordering and execution

Each algorithm declares its inputs and outputs

Generates a directional acyclic graph (DAG) of dependencies



Pyrate core

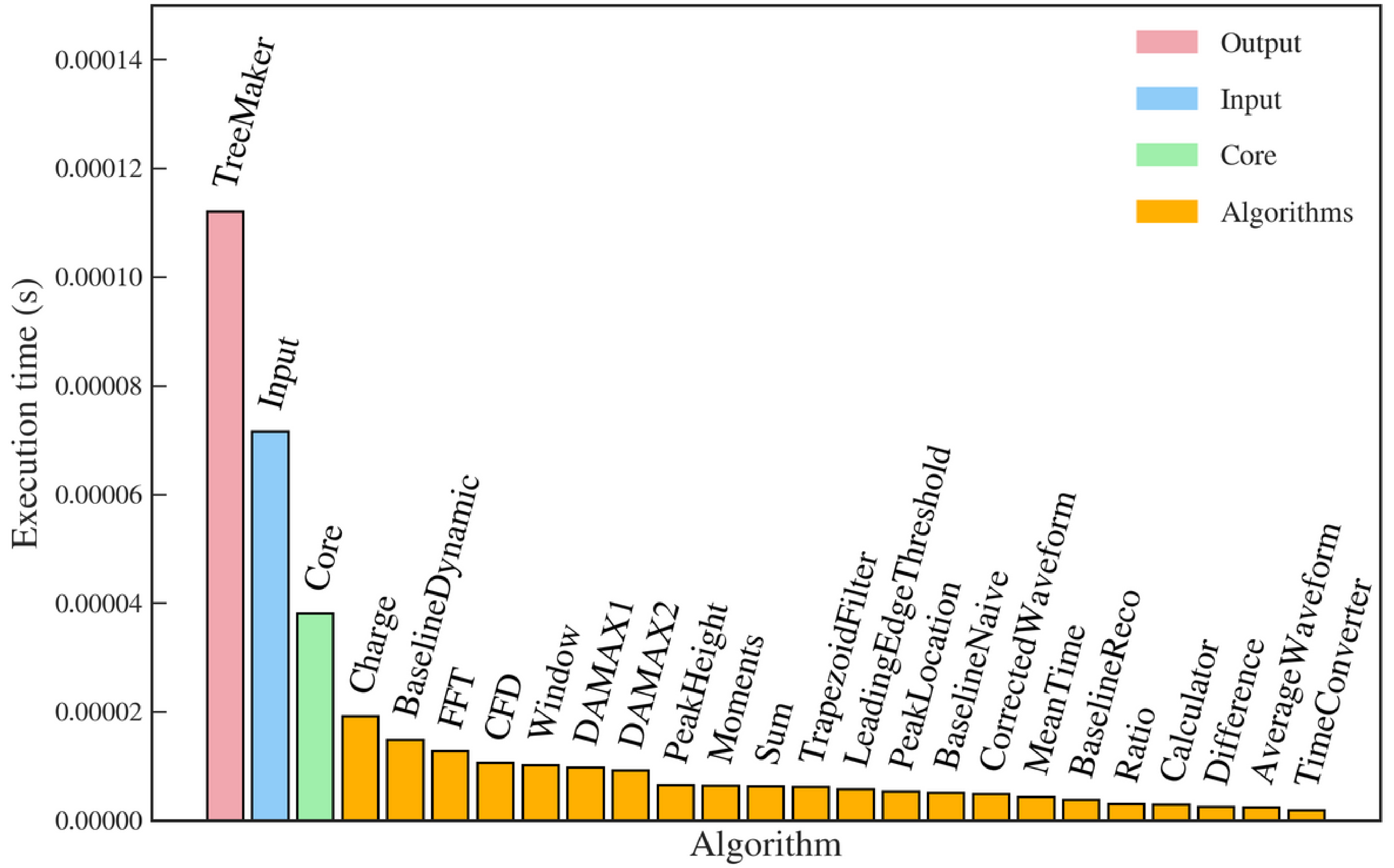


Six-channel network of pyrate algorithms

Performance

Benchmark	Rate
Waveforms only	4600 wavefoms/s
Minimal calculation	4000 waveforms/s
All current algorithms	1500 waveform/s

✳ Waveforms of length 1780
Test performed on single core of SABRE DAQ computer



SABRE will need multiple pyrate instances for live processing

- Depends on the chosen thresholds and trigger rates

Summary

Current usage

- Used to calibrate SABRE's sub-detector modules

Ongoing development

- Core improvements and live monitoring
- New algorithms: database integration, machine learning, full event reconstruction

Future usage

- Deploying pyrate with the first live data taking in SUPL early 2023
- Large scale live operation with the completion of SABRE late 2023