Hands-On: Corryvreckan

The Maelstrom for Your Test Beam Data

10th BTTB Workshop

21th June 2022

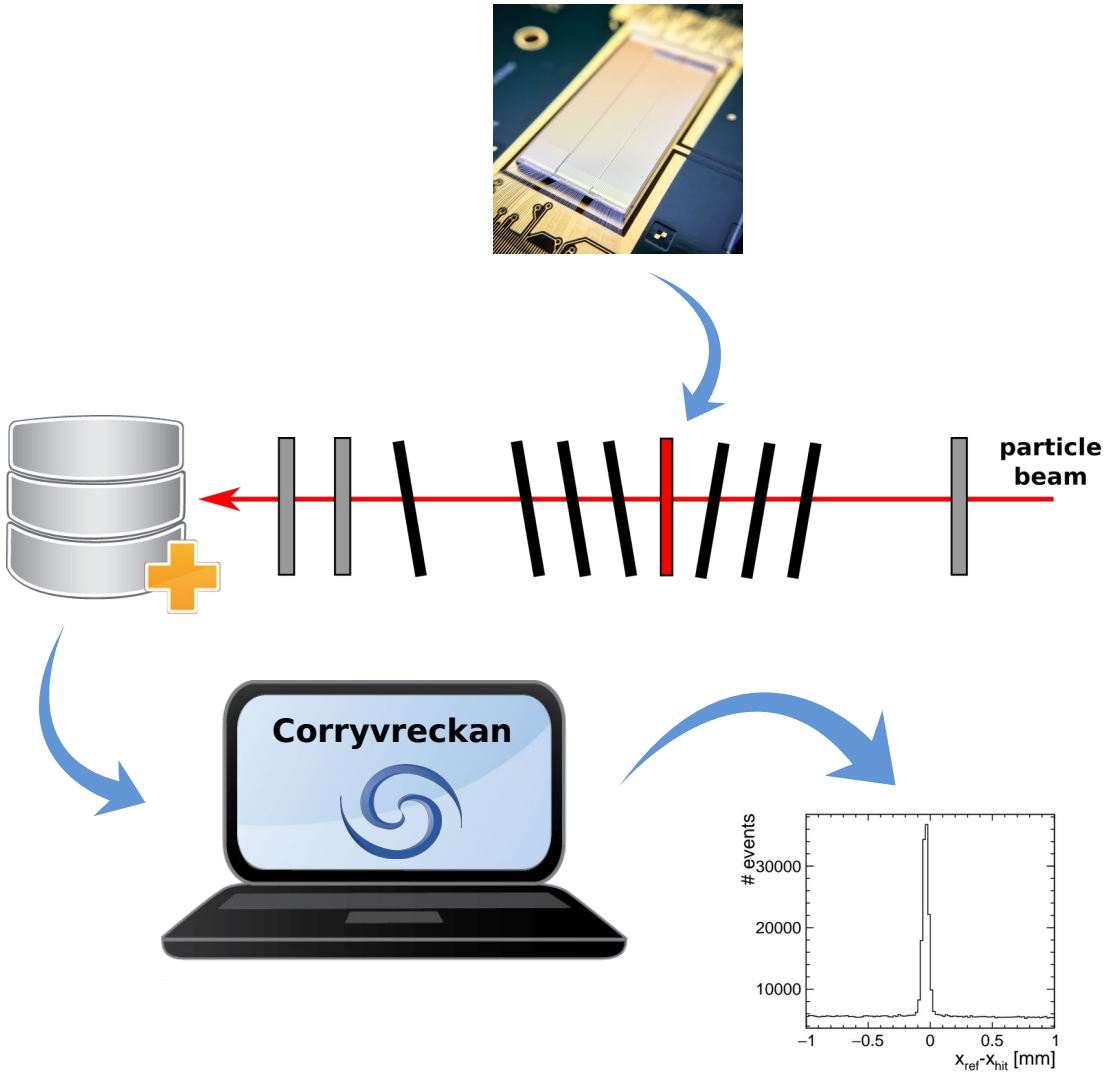
Finn Feindt, DESY

on behalf of the Corryvreckan Developers

Based on the work from: Jens Kröger, formerly Heidelberg University & CERN

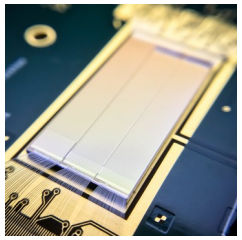
What are we going to learn today?

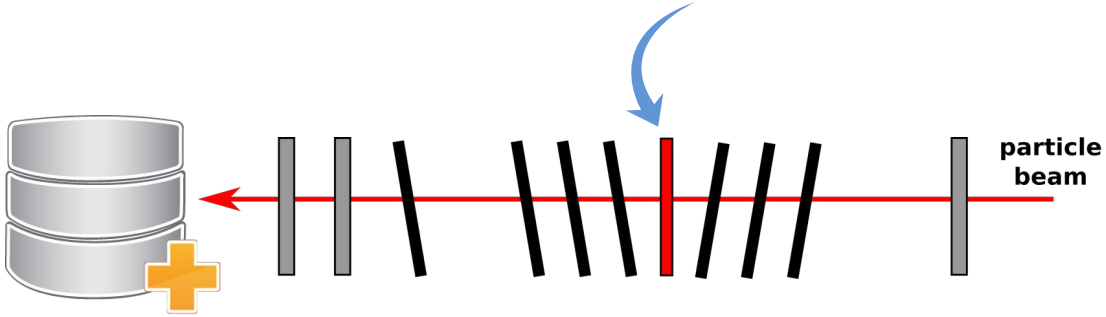
- **Introduction**
  - What is Corryvreckan?
  - What's new since BTTB9?
- **Hands-on:**
  - installation options
  - setting up an analysis step-by-step
- Please ask questions at any time!

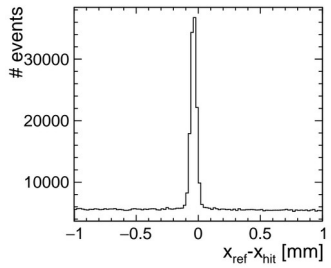


What is Corryvreckan?

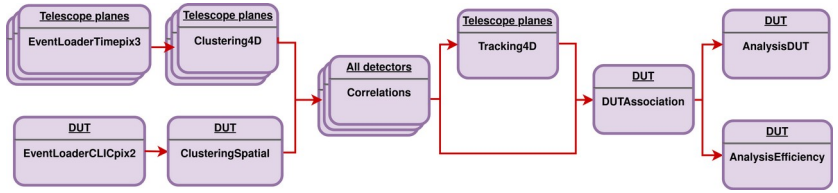
A **reconstruction and analysis** tool for pixel sensor test-beam data







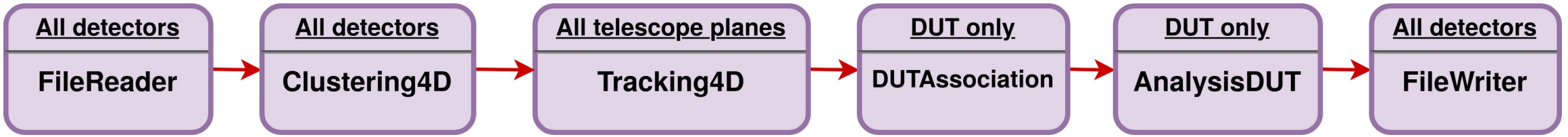
- modular structure
  - framework core
  - modules for specific tasks
- highly flexible and configurable
- easy to understand
  - written in modern C++
  - comprehensive documentation (> 120 pages!)



The Modular Approach

- modular structure:
  - framework core
  - implementation of algorithms → **`[Modules]`**
- modules:
  (user) algorithms for specific tasks
- objects are stored temporarily:
  - events, pixels, clusters, tracks

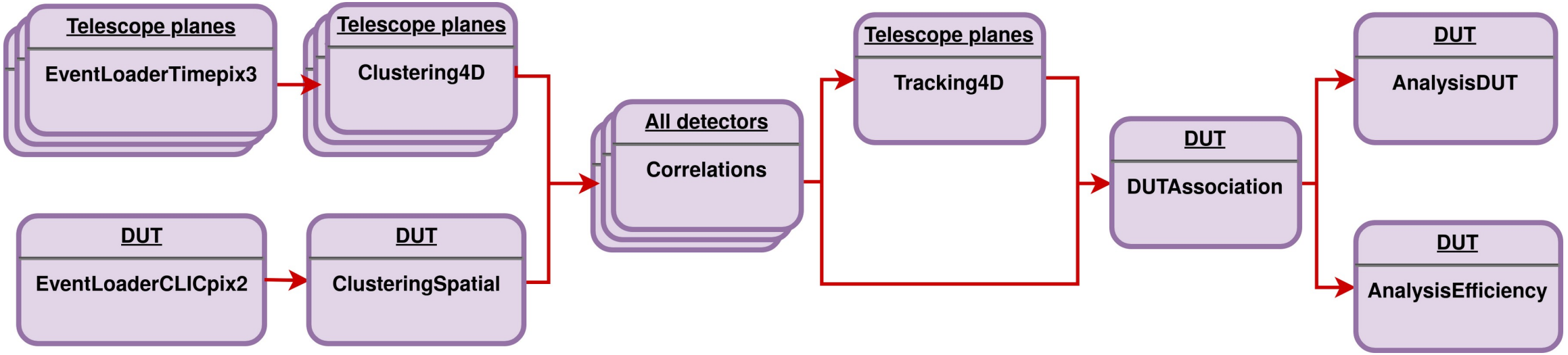
- select suitable modules for
  - event building
  - clustering
  - tracking
  - analysis (also multiple DUTs)
  - ...
- quick to set up and easy to configure



The Modular Approach

- can create more **complex reconstruction chains**
- apply **different modules to different devices** in the same reconstruction

We will build this reco chain in ***Example 2***:

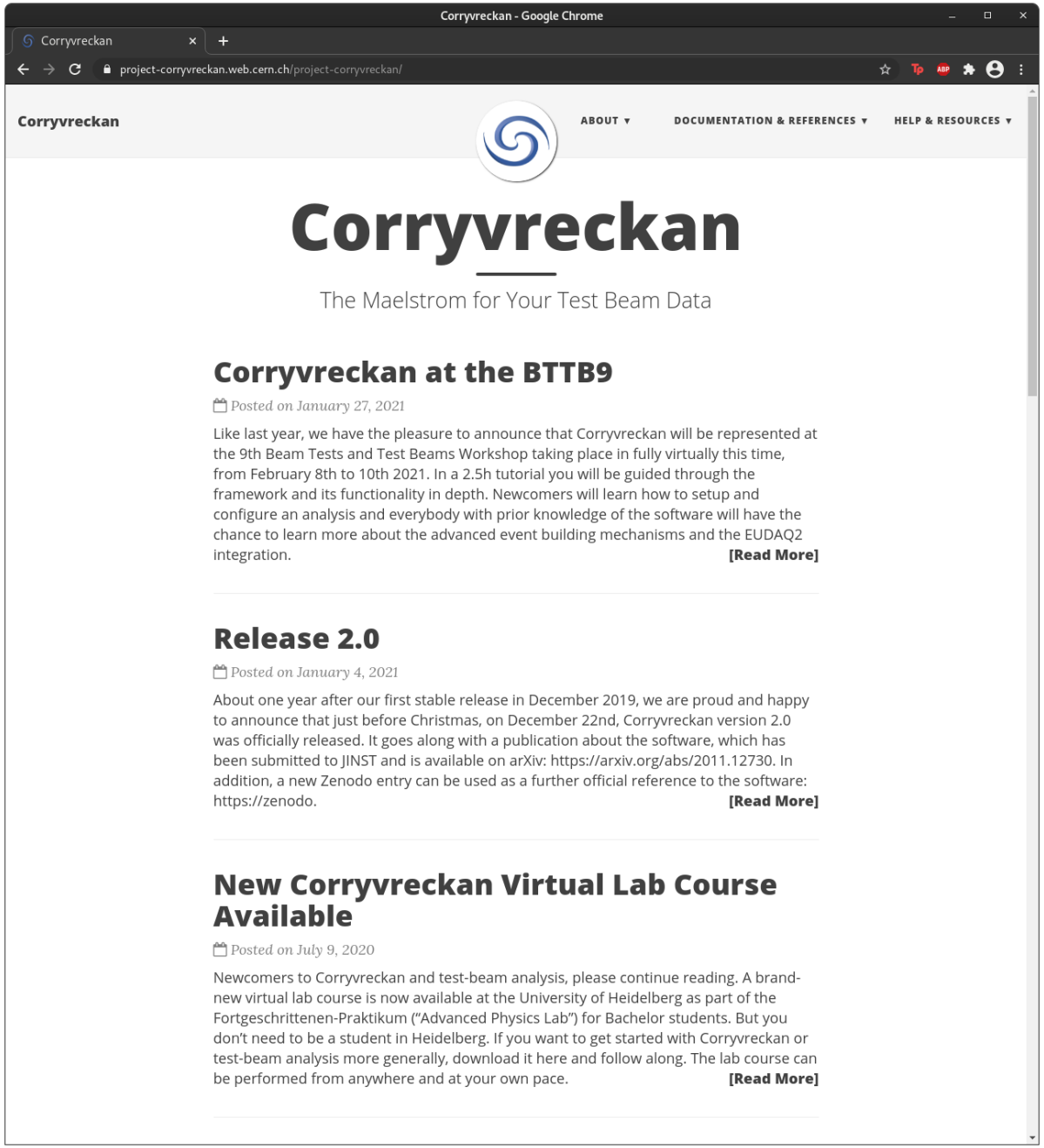


Project Website

First place to go:

https://cern.ch/corryvreckan

- News on releases
- Installation/Getting Started
- **Links:**
  - code repository
  - issue tracker
  - forum
  - ...

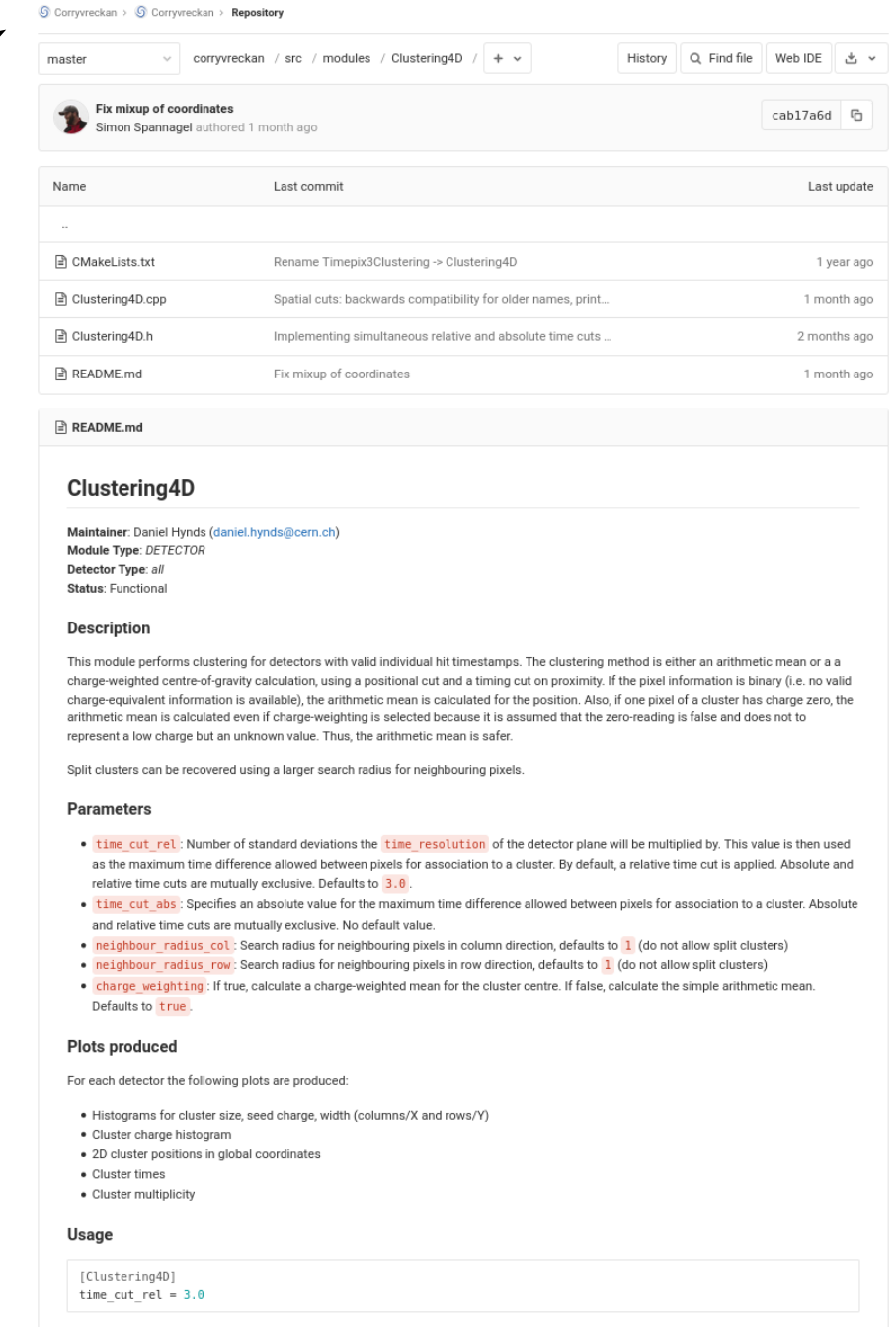


Documentation

- **online documentation** in repo
  https://gitlab.cern.ch/corryvreckan/corryvreckan
  - every modules has a README

- extensive user manual
  corryvreckan-manual-v2.0.1.pdf
  - full description of framework
  - installation instructions
  - “Getting started”, FAQs
  - module descriptions (fetched from repo)

- Doxygen code reference
  https://cern.ch/corryvreckan/reference/
  - more details on code



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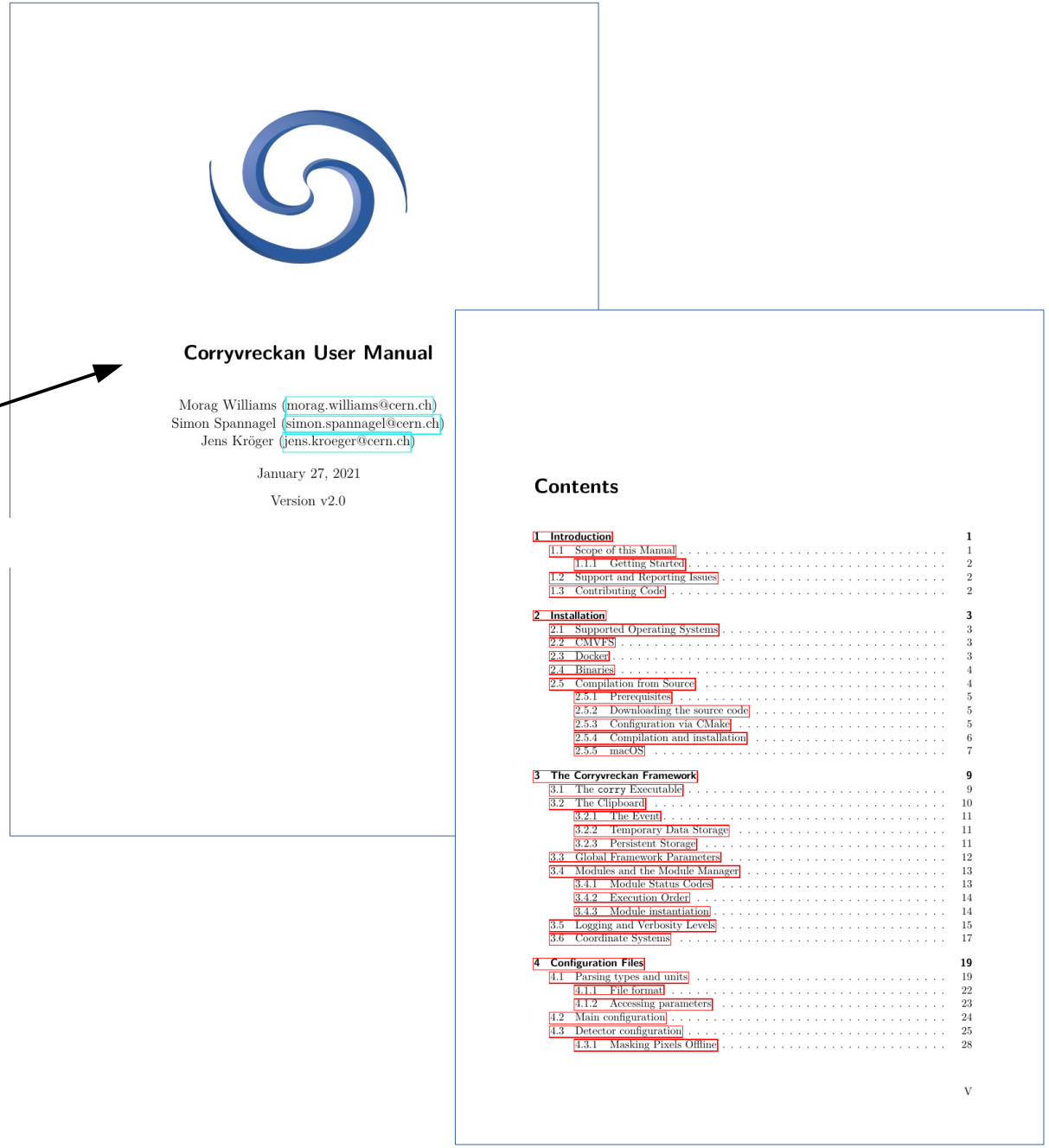

Corryvreckan User Manual

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Version v2.0

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Documentation

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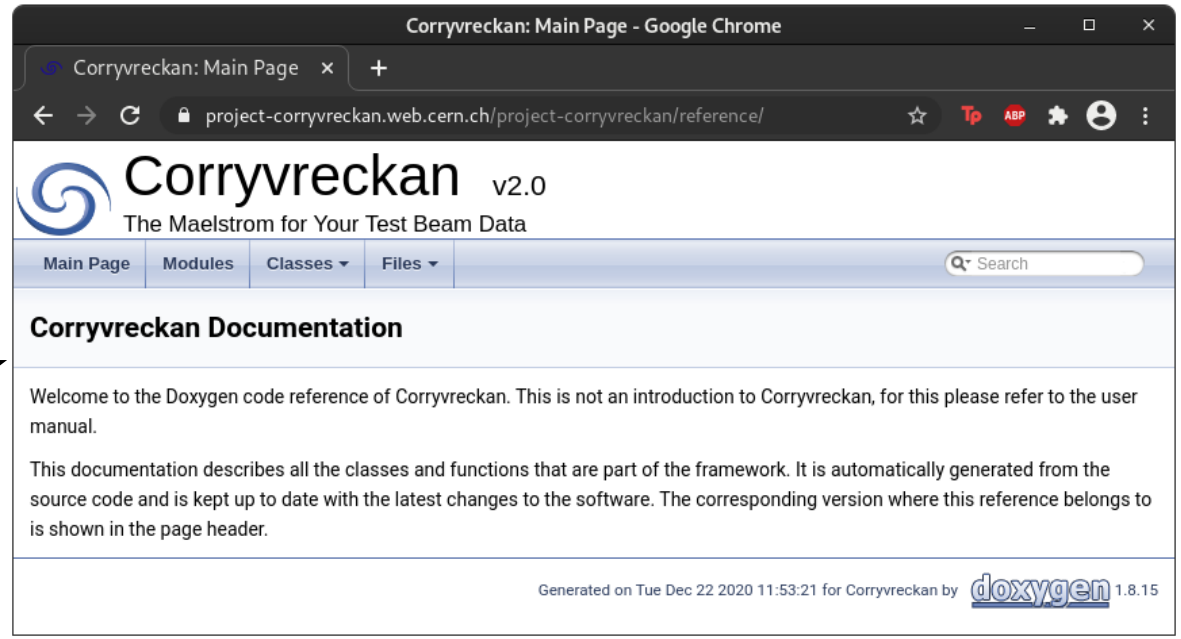
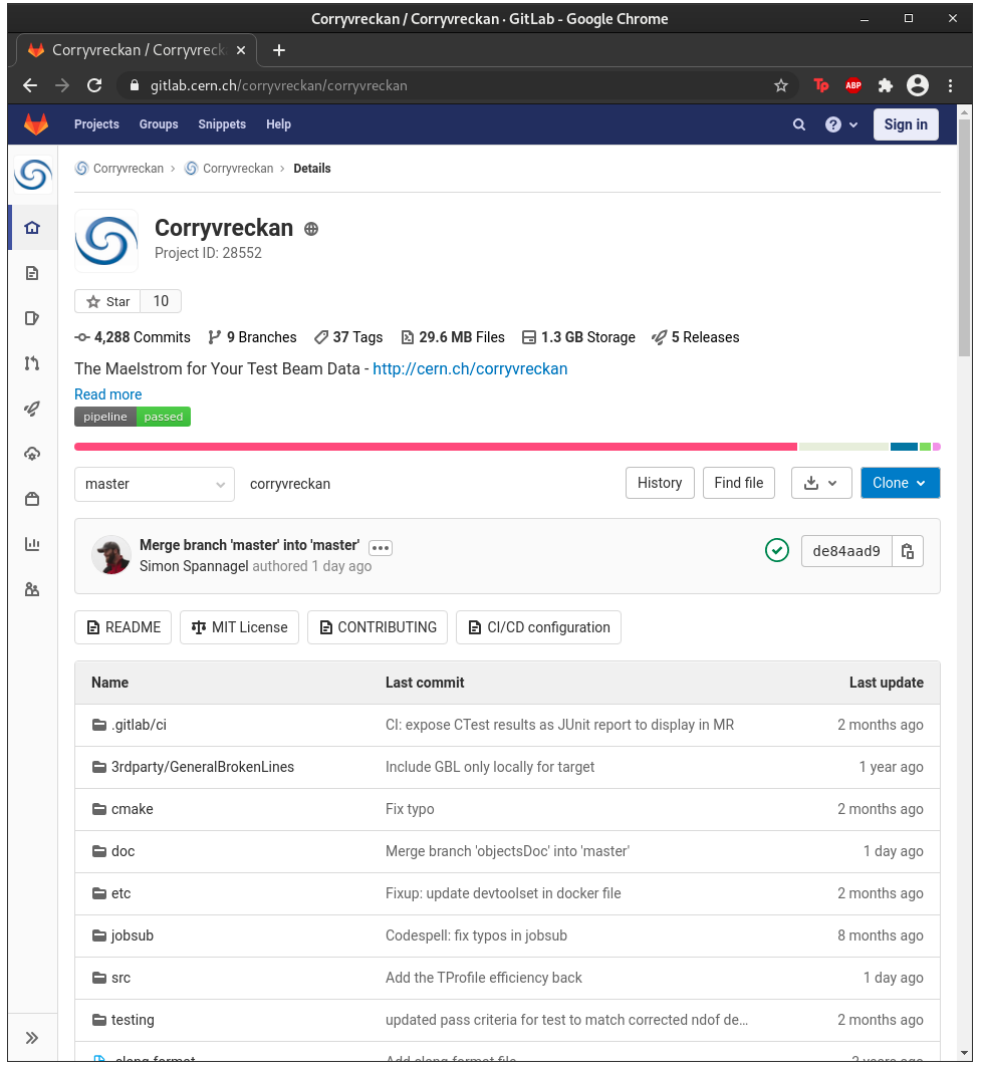


The Corryvreckan Repository

Let's explore the **repository**
https://gitlab.cern.ch/corryvreckan/corryvreckan

- **`doc/`** → documentation/user manual
- **`etc/`** → lxplus setup script, etc.
- **`jobsub/`** → job submission tool + README
- **`src/`** → all the source code
  - → **`modules/`** → code and READMEs of all modules
- **`testing/`** → CI test configs

- **`README.md`** → short introduction/getting started
- **`Contributing.md`** → contribution guidelines

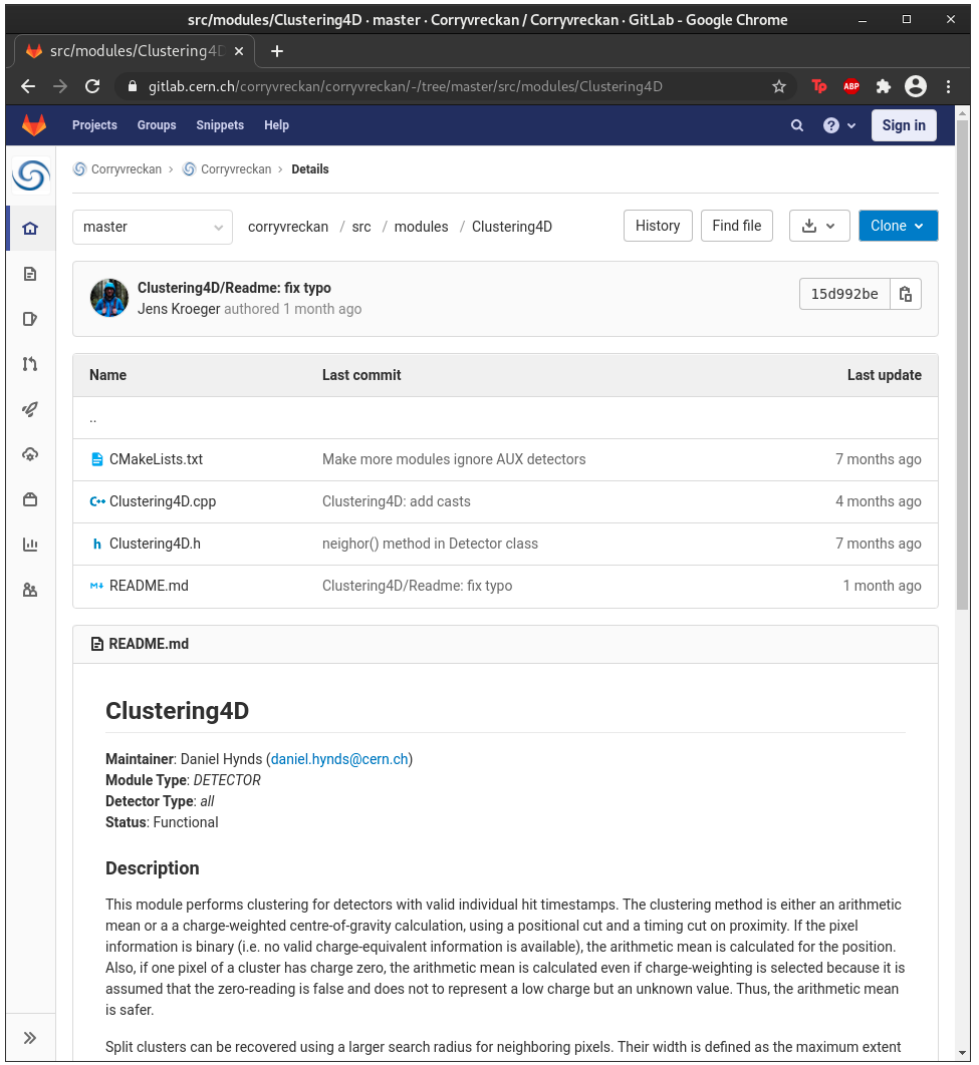


The Corryvreckan Repository

Read the **documentation,**
explore the **source code**:

- **`src/`** → all the source code
  - → **`modules/`** → code and READMEs of all modules

- e.g. Clustering4D (click here)



What's new since BTTB9?

Official **Release v2.0** in December 2020 (and **first patch release v2.0.1** on 4th February)

- **reference paper** accepted by JINST:
  Corryvreckan: A Modular 4D Track Reconstruction and Analysis Software for Test Beam Data
  arXiv:2011.12730
- Zenodo entry: https://zenodo.org/record/4384186
- Many updates since then! Checkout the newest version on git!

New Features:

(for a full description, see Release Notes)

- New module: AnalysisTracks: Module to study e.g. track-to-track distance
- New module: FilterEvents: Skip events, e.g. based on the number of tracks
- New DetectorRole: PASSIVE: For scattering on passive material
- Ongoing developments: Alignment parallelization, hexagonal pixels, waveforms

Let’s get started

Installing Corryvreckan…

1) **Virtual Machine**
2) Download **Binary**
3) Compile from **Source**
4) Use on **LXPLUS**
5) **Docker** Image

Installation – 1) Download the Virtual Machine

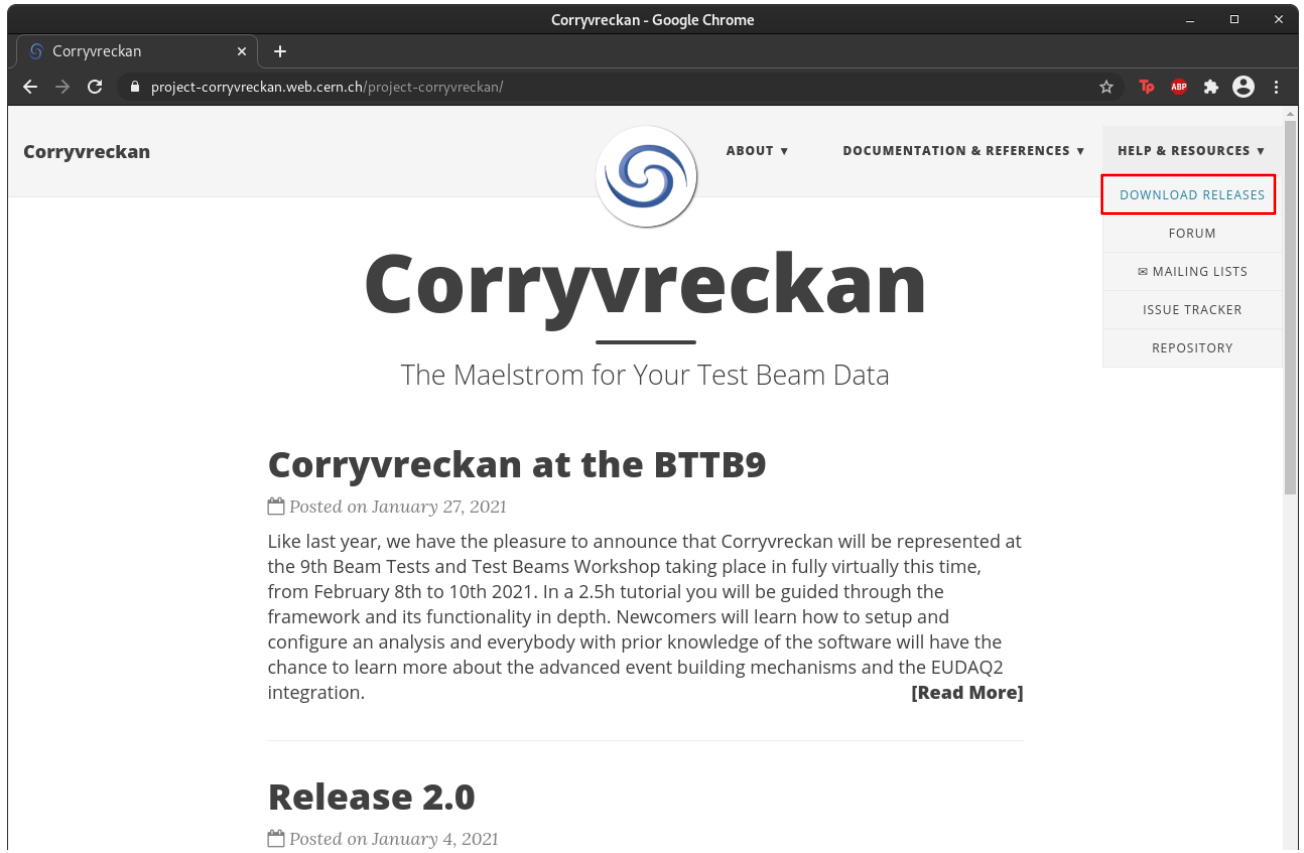
- works on any operating system with **Virtual Box 6.1**
  - https://www.virtualbox.org/
  - setup instructions here

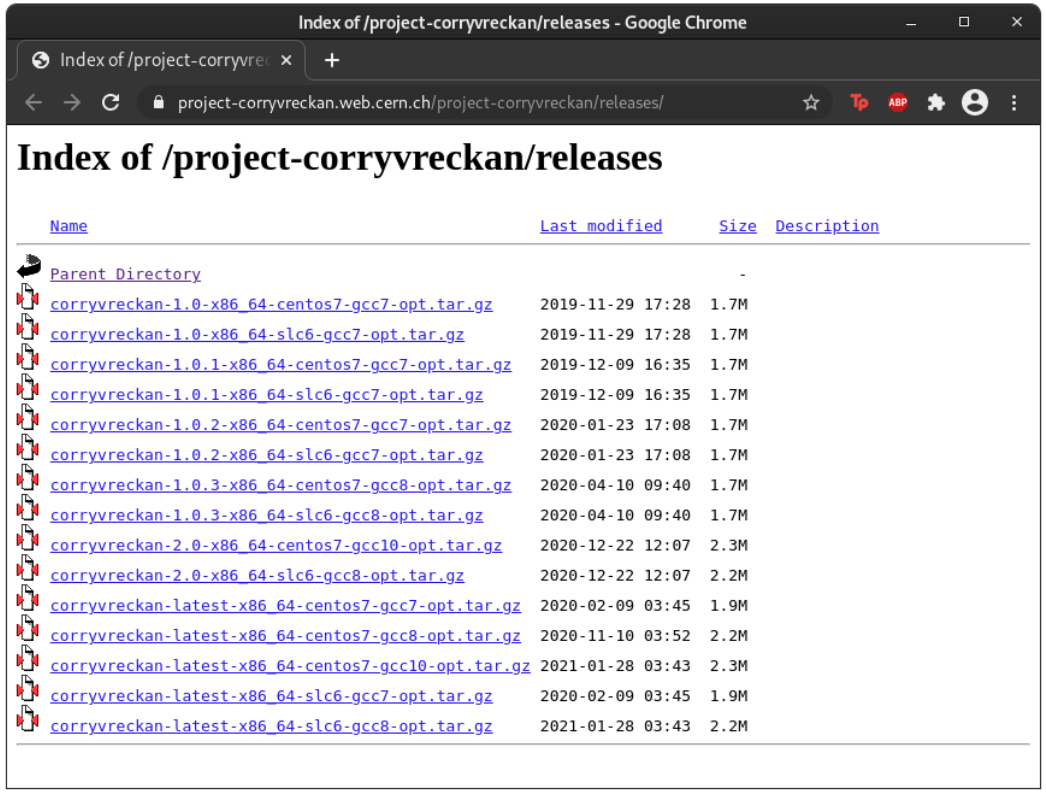
- virtual machine image contains everything needed for this tutorial:
  - Corryvreckan v2.0.1
  - all dependencies
  - data

→ ideal to get started

Installation – 2) Download the binary

- for **Centos7** and **SLC6**: download binary release tarballs
  - https://cern.ch/corryvreckan → Help & Resources → Download Releases





Installation – 3) Compile from source code

- requires local **ROOT 6** installation
- recommended if you want to **develop your own code**

```
$ git clone https://gitlab.cern.ch/corryvreckan/corryvreckan.git
$ cd corryvreckan
$ mkdir build && cd build/
$ cmake ..                              # change CMake flags as needed
$ make install -j<number_of_cores>
```

- **corry executable** available in installation directory:

```
$ path/to/corryvreckan/bin/corry
```

Installation – 4) Use Corryvreckan on LXPLUS

- requires a **CERN LXPLUS** account

- 2 options:
  - **source CVMFS version**

```
$ source /cvmfs/clicdp.cern.ch/software/
         corryvreckan/<version>/x86_64-
         <slc6/centos7>-gcc7-opt/setup.sh
```

Note:

- only default modules available
- e.g. not **`[EventLoaderEUDAQ2]`**
  (needed for Example 3)

  - **install on LXPLUS**

```
$ git clone https://gitlab.cern.ch/
            corryvreckan/corryvreckan.git
$
$ cd corryvreckan
$ source etc/setup_lxplus.sh
$
$ # continue as for local installation
```

→ rest as for local installation

Installation – 5) Use docker image

- run software in container including all dependencies
  → like “light-weight virtual machine”

- needs “docker” executable
  - install via `$ sudo snap install docker`

- start docker container:
  `$ sudo ./start_docker_container.sh`

- then use like usual terminal

Note:

- only **default** modules active are available (like CVMFS version)
  - e.g. not **`[EventLoaderEUDAQ2]`** (needed for Example 3)
- docker does **not** support **graphics**
  - for **TBrowser** to inspect output: external ROOT installation

Installation – 5) Use docker image

- run software in container including all dependencies
  → like “light-weight virtual machine”

- needs “docker” executable
  - install via `$ sudo snap install docker`

- start docker container:
  `$ sudo ./start_docker_container.sh`

If you run docker the **first time**:

```
$ sudo groupadd docker

$ sudo usermod -aG docker $USER
```

Then log out and back in and try:

```
$ docker run hello-world
```

Small docker **cheat sheet:**

1. Start corry in docker container:
   `$ ./start_docker_container.sh`

2. Exit by typing
   `$ exit`

3. List all containers using
   `$ docker container ls -a`

4. Re-start exited container
   `$ docker start <container_name>`

5. Re-attach to interactive container:
   `$ docker attach <container_name>`

6. Removed (stopped) container:
   `$ docker rm <container_name>`

Let’s get started

Setting up an analysis...

Download the example data and configs

→ Skip this if using the virtual machine!

- example **configs** and **scripts**:

```
$ git clone https://gitlab.cern.ch/ffeindt/bttb10_tutorial_corryvreckan.git
```

- In this repo we've got **3 examples** we'll go through:

```
01_atlaspix/          ← simple
02_clicpix2/          ← simple
03_desy/              ← advanced
```

- Go to **`data/`** and download the example data files:

```
$ cd data/
$ ./download_example_data_01.sh     ← only this if connection is slow
$ ./download_example_data_02.sh
$ ./download_example_data_03.sh
```

Reminder: Configuring Corryvreckan

- TOML style = easy to read
- support of physical units (e.g. 25um)
- **configuration** file:
  - global parameters
  - specifies modules and parameters
  - sets input/output paths
  - defines log level
- **geometry** file:
  - number, types and positions/rotations of sensors
  - role of sensors (DUT, reference, auxiliary)

example ***configuration***

```
[Corryvreckan]
log_level = "WARNING"
detectors_file = "geometry.conf"
number_of_tracks = 900000

[EventLoaderEUDAQ2]
file_name = "data/run0000456.raw"
inclusive = false
buffer_depth = 1000
shift_triggers = -1
```

example ***geometry***

```
[W0013_D04]
number_of_pixels = 256, 256
orientation = 10.9deg, 17.2deg, -1.3deg
orientation_mode = "xyz"
pixel_pitch = 55um, 55um
position = 886.5um, 270um, 0
spatial_resolution = 4.8um,4.8um
time_resolution = 1.56ns
type = "Timepix3"
role = "reference"
```

Example 1 – Data and configuration files

- All **configuration** and **geometry** files in

  `01_atlaspix/`

  - `geometries/`
  - `01_analysis_telescope.conf`
  - `02_analysis_withDUT.conf`
  - `03_online_monitor.conf`
  - `04_filewriter.conf`
  - `05_filereader.conf`

- The **data** is in

  `data/`

  - `01_data_atlaspix/`
  - `01_data_telescope/`

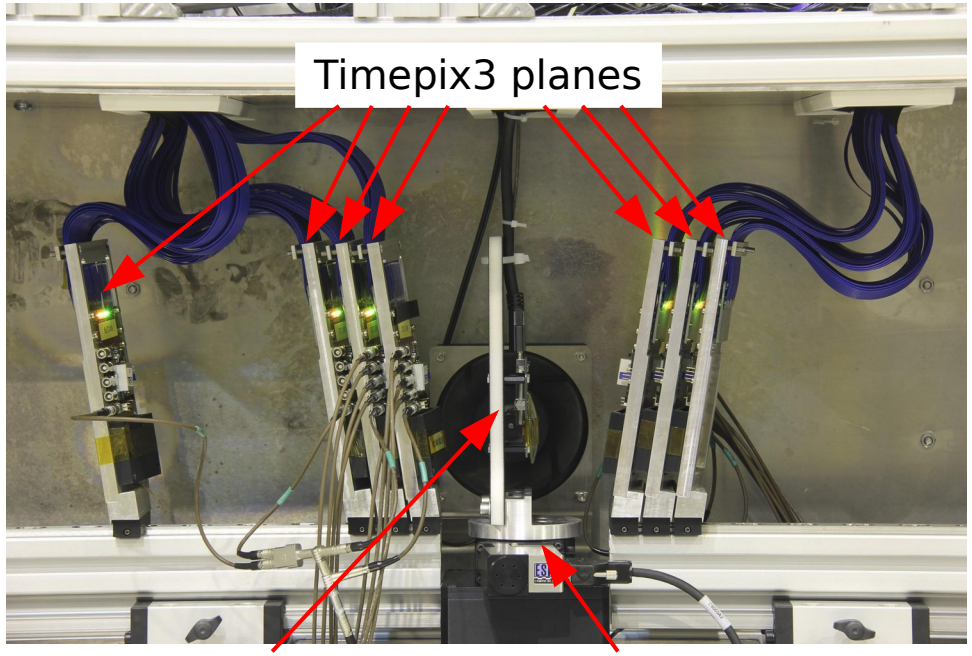
Disclaimer:
The shown analyses are chosen to be instructive and illustrate the framework functionality.

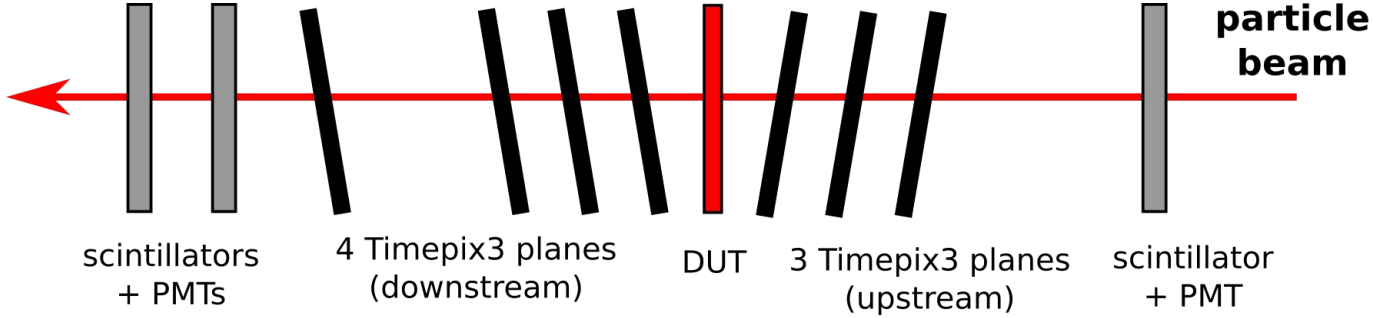
Please don’t infer any sensor performance estimates.

Example 1 – Let's have a look at the setup

- Timepix3 **telescope**:
  - data-driven readout
  - pixel-by-pixel timestamp

- ATLASpix as **device-under-test**:
  - data-driven readout
  - pixel-by-pixel timestamp





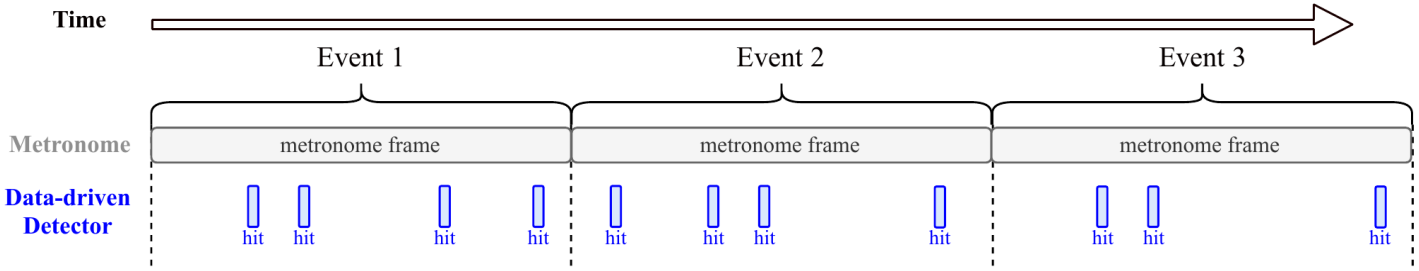
Example 1.1 – Let's start with the **telescope only**

- **configuration** file:
  - global parameters
  - specifies **[Modules]** and **parameters**
  - sets input/output paths
  - defines log level

- all detectors are data-driven
  → need **[Metronome]** to define event

01_analysis_telescope.conf

```
[Corryvreckan]
output_directory = "output"
detectors_file =
      "geometries/01_alignment_telescope.geo"
histograms_file =
      "01_histograms_analysis_telescope.root"

[Metronome]
event_length = 20us

[EventLoaderTimepix3]
input_directory = "../data/01_data_telescope"

[Clustering4D]
time_cut_abs = 200ns

[Correlations]

[Tracking4D]
min_hits_on_track = 6
spatial_cut_abs = 200um, 200um
time_cut_abs = 50ns
```



Example 1.1 – Let's check the geometry

- **geometry** file:
  - number/size of pixels
  - detector type
  - position/rotation
  - role of particular sensors:
    - DUT
    - reference
    - auxiliary

geometries/01_alignment_telescope.geo

```
[Timepix3_0]
number_of_pixels = 256,256
orientation = 9.94299deg,187.403deg,-1.36501deg
orientation_mode = "xyz"
pixel_pitch = 55um,55um
position = 939.743um,285.05um,0
spatial_resolution = 4um,4um
time_resolution = 1.5ns
type = "Timepix3"

[Timepix3_1]
...

[Timepix3_2]
...
role = "reference"
```

Example 1.1 – Let's run the analysis

- run analysis:

```
$ corry -c 01_analysis_telescope.conf
```

- event loop is updated continuously:

```
|16:24:49.775|  (STATUS) ========================| Event loop |========================
|16:25:12.339|  (STATUS) Ev: 564.9k Px: 310.4k Tr: 17.6k (0.0312/ev) t = 11.298s
```

- You can interrupt gently by hitting **Ctrl+C**
- alternatively use

```
$ corry -c 01_analysis_telescope.conf -o number_of_events=25000
$ corry -c 01_analysis_telescope.conf -o number_of_tracks=250000
```

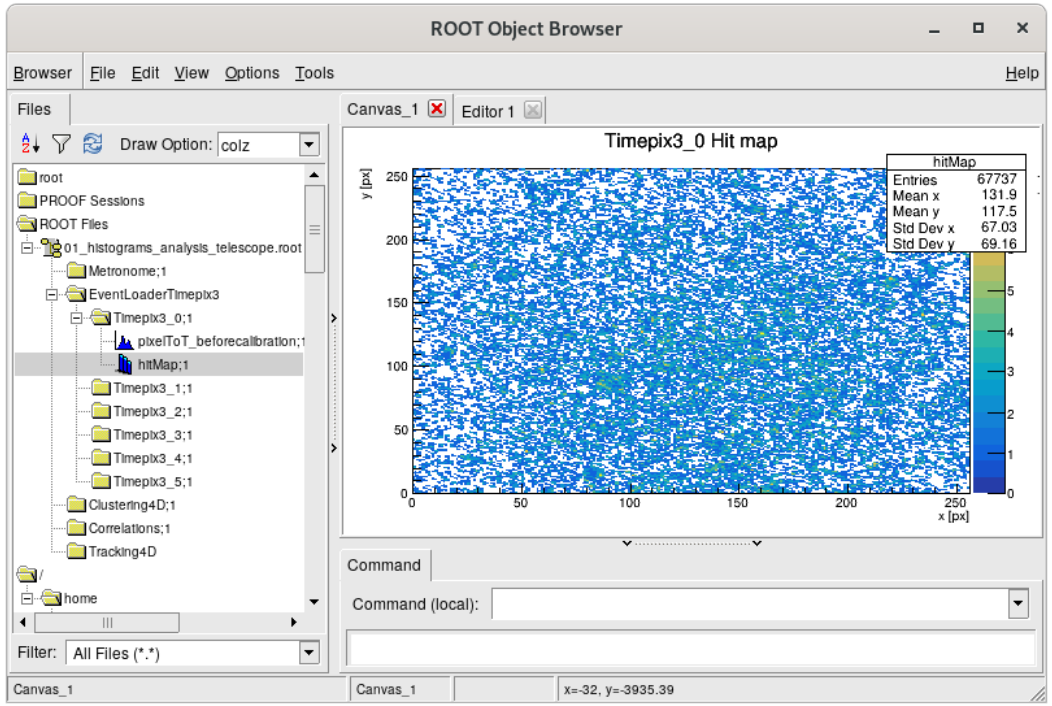
We'll look at this in more detail in a minute!

Example 1.1 – Let's check the results

- **terminal output**:

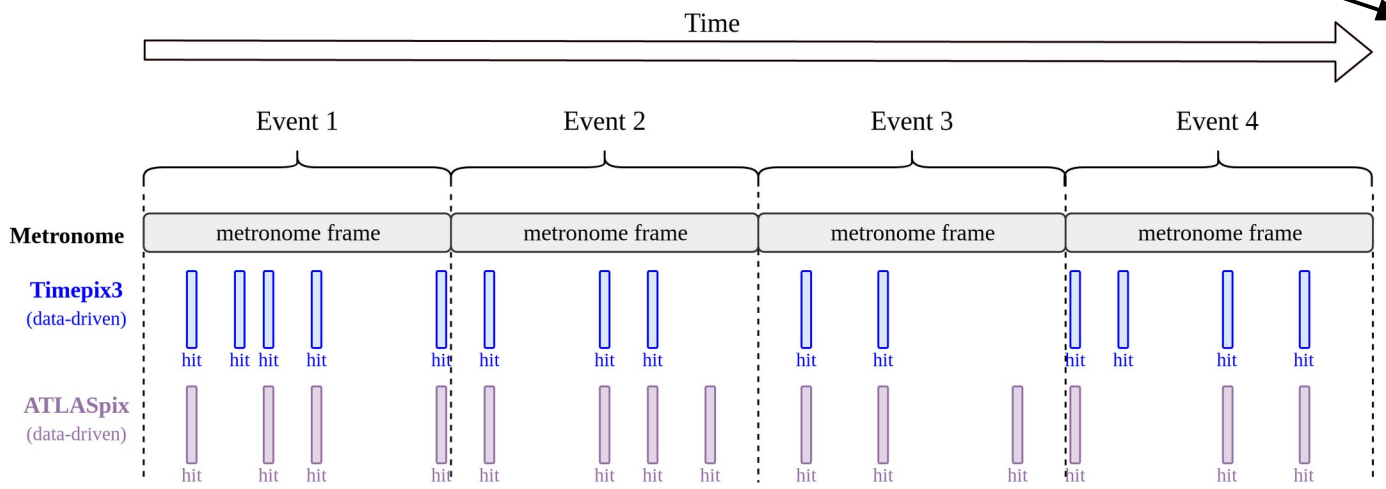
```
|16:37:52.337|  (STATUS) ==================| Finalising modules |==================
|16:37:53.317|  (STATUS) Wrote histogram output file to /home/jens/Documents/bttb8_tutorial_corryvreckan/01_atlaspix/output/01_histograms_analysis_telescope.root
```

- **ROOT file:**
  histograms of all modules



Example 1.2 – Now let's add a device-under-test

- still all detectors are data-driven
  → keep **[Metronome]** to define event
- in **configuration** file:
  - add **[EventLoaderATLASpix]**
  - add **[DUTAssociation]** to associate tracks to hits on the device-under-test
  - add analysis module(s)



02_analysis_telescope_withDUT.conf

```
[EventLoaderTimepix3]
input_directory = "../data/01_data_telescope"

[EventLoaderATLASpix]
input_directory = "../data/01_data_atlaspix"

[Clustering4D]

[Correlations]
time_cut_abs = 200ns

[Tracking4D]
min_hits_on_track = 6
spatial_cut_abs = 200um, 200um
time_cut_abs = 50ns

[DUTAssociation]
time_cut_abs = 200ns
spatial_cut_abs = 300um,150um

[AnalysisDUT]

[AnalysisEfficiency]
```

Example 1.2 – Now let's add a device-under-test

- in **geometry** file:
  - add **[ATLASpix_0]**
  - mark as device-under-test (**"dut"**)
  - optionally define region-of-interest (**"roi"**) for analysis modules

geometries/02_alignment_telescope_withDUT.geo

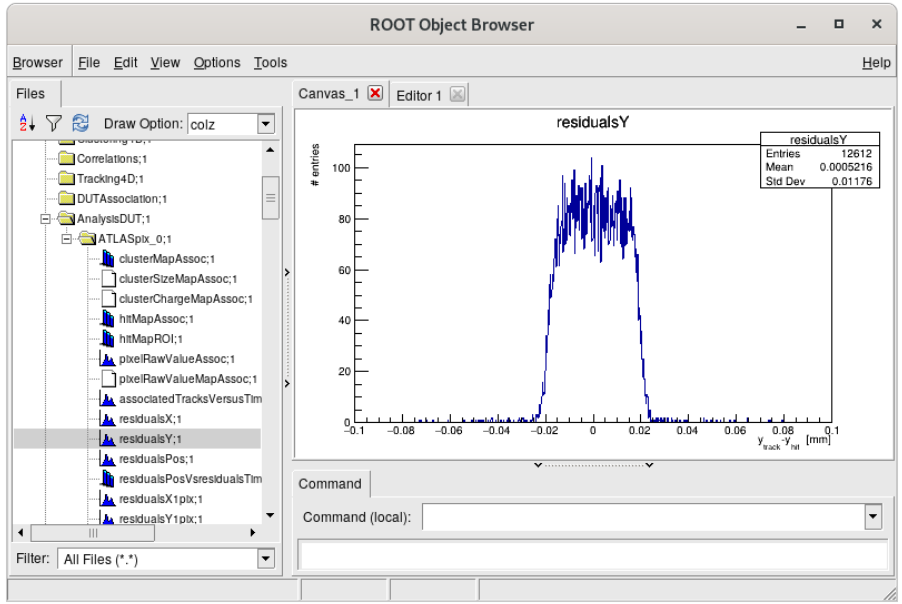
```
[Timepix3_2]
...

[ATLASpix_0]
number_of_pixels = 25,400
orientation = -0.0124905deg,0.0684685deg,-0.52609deg
orientation_mode = "xyz"
pixel_pitch = 130um,40um
position = 335.278um,-1.55396mm,105mm
spatial_resolution = 40um,10um
time_resolution = 200ns
role = "dut"
type = "ATLASpix"
roi = [1,1], [1, 398], [23, 398], [23, 1]

[Timepix3_3]
...
```

Example 1.2 – Let's check the result again

- now the **terminal** has some more information:

```
|17:21:35.912|  (STATUS) ==================| Finalising modules |==================
|17:21:38.781|  (STATUS) [F:DUTAssociation:ATLASpix_0] In total, 28385 clusters are associated to 28323 tracks.
|17:21:38.781|    (INFO) [F:DUTAssociation:ATLASpix_0] Number of tracks with at least one associated cluster: 28323
|17:21:40.187|  (STATUS) [F:AnalysisEfficiency:ATLASpix_0] Track selection flow:       86598
                                                          * rejected by chi2          -45801
                                                          * track outside ROI         -529
                                                          * track outside DUT         -28712
                                                          * track close to masked px  -0
                                                          Accepted tracks:            12073
|17:21:40.187|  (STATUS) [F:AnalysisEfficiency:ATLASpix_0] Total efficiency of detector ATLASpix_0: 99.9255%, measured with 12064/12073 matched/total tracks
|17:21:40.329|  (STATUS) Wrote histogram output file to /home/jens/Documents/bttb8_tutorial_corryvreckan/01_atlaspix/output/02_histograms_analysis_telescope_withDUT.root
```

- **ROOT file:**
  histograms of all modules



Example 1.2 – Ways to quit the framework

- **Ctrl+C** (SIGINT):
  - **gently** quit corry
  - finish processing current event and finalize properly
  - recommended option

```
|11:12:18.931|  (STATUS) ========================| Event loop |========================
|11:12:21.607|  (STATUS) Ev: 122.1k Px: 0.3k Tr: 0.0k (0/ev) t = 2.442s^C
|11:12:21.610|  (STATUS) Interrupted! Finishing up current event...
|11:12:21.610|  (STATUS) Ev: 122.2k Px: 0.3k Tr: 0.0k (0/ev) t = 2.444s
|11:12:21.610|  (STATUS) ===================| Finalising modules |===================
|11:12:22.077|  (STATUS) Wrote histogram output file to /home/jens/Documents/bttb8_tutoria
nalysis_telescope.root
|11:12:22.077|  (STATUS) ===============| Wall-clock timing (seconds) |================
|11:12:22.077|  (STATUS)            Metronome                --  0.04757s = 0.000389ms/evt
|11:12:22.077|  (STATUS)  EventLoaderTimepix3 : Timepix3_0  --  0.28141s = 0.002303ms/evt
|11:12:22.077|  (STATUS)  EventLoaderTimepix3 : Timepix3_1  --  0.27699s = 0.002267ms/evt
|11:12:22.077|  (STATUS)  EventLoaderTimepix3 : Timepix3_2  --  0.30479s = 0.002494ms/evt
|11:12:22.077|  (STATUS)  EventLoaderTimepix3 : Timepix3_3  --  0.27372s = 0.002240ms/evt
|11:12:22.078|  (STATUS)  EventLoaderTimepix3 : Timepix3_4  --  0.27328s = 0.002236ms/evt
|11:12:22.078|  (STATUS)  EventLoaderTimepix3 : Timepix3_5  --  0.27130s = 0.002220ms/evt
|11:12:22.078|  (STATUS)         Clustering4D : Timepix3_0  --  0.06246s = 0.000511ms/evt
|11:12:22.078|  (STATUS)         Clustering4D : Timepix3_1  --  0.05449s = 0.000446ms/evt
|11:12:22.078|  (STATUS)         Clustering4D : Timepix3_2  --  0.05425s = 0.000444ms/evt
|11:12:22.078|  (STATUS)         Clustering4D : Timepix3_3  --  0.05352s = 0.000438ms/evt
|11:12:22.078|  (STATUS)         Clustering4D : Timepix3_4  --  0.05330s = 0.000436ms/evt
|11:12:22.078|  (STATUS)         Clustering4D : Timepix3_5  --  0.06170s = 0.000505ms/evt
|11:12:22.078|  (STATUS)         Correlations : Timepix3_0  --  0.05661s = 0.000463ms/evt
|11:12:22.078|  (STATUS)         Correlations : Timepix3_1  --  0.05492s = 0.000449ms/evt
|11:12:22.078|  (STATUS)         Correlations : Timepix3_2  --  0.05488s = 0.000449ms/evt
|11:12:22.078|  (STATUS)         Correlations : Timepix3_3  --  0.05459s = 0.000447ms/evt
|11:12:22.078|  (STATUS)         Correlations : Timepix3_4  --  0.05364s = 0.000439ms/evt
|11:12:22.078|  (STATUS)         Correlations : Timepix3_5  --  0.05346s = 0.000437ms/evt
|11:12:22.078|  (STATUS)           Tracking4D               --  0.10156s = 0.000831ms/evt
|11:12:22.078|  (STATUS) ============================================================
```

- **Ctrl+** (SIGQUIT):
  - **forcefully** terminate corry
  - leads to loss of all generated data
  - generally not recommended

```
|11:12:46.911|  (STATUS) [I:Tracking4D] Initialising "Tracking4D"
|11:12:46.911|  (STATUS) ========================| Event loop |========================
|11:12:49.362|  (STATUS) Ev: 113.4k Px: 0.3k Tr: 0.0k (0/ev) t = 2.268s ^\
|11:12:49.362|   (FATAL) Aborting!
Aborted (core dumped)
```

Example 1.2 – Let's play with the command line

- parameters from config file can be **overwritten** in the command line:

```
corry  -c config.cfg                                  → path to configuration file
       -l log.txt                                     → write terminal output to file

       -v "FATAL","STATUS","ERROR",                   → logging verbosity level
          "WARNING","INFO","DEBUG"                      also per module: -o MyModule.log_level="DEBUG"

       -o histogram_file="hists.root"                 → global framework parameter
       -o AnalysisDUT.chi2ndof_cut=3                  → module configuration
                                                        specified by dot (.) between module and key

       -g mydut.orientation=0deg,5deg,0deg            → detector geometry parameter
```

→ Play around for a few minutes!

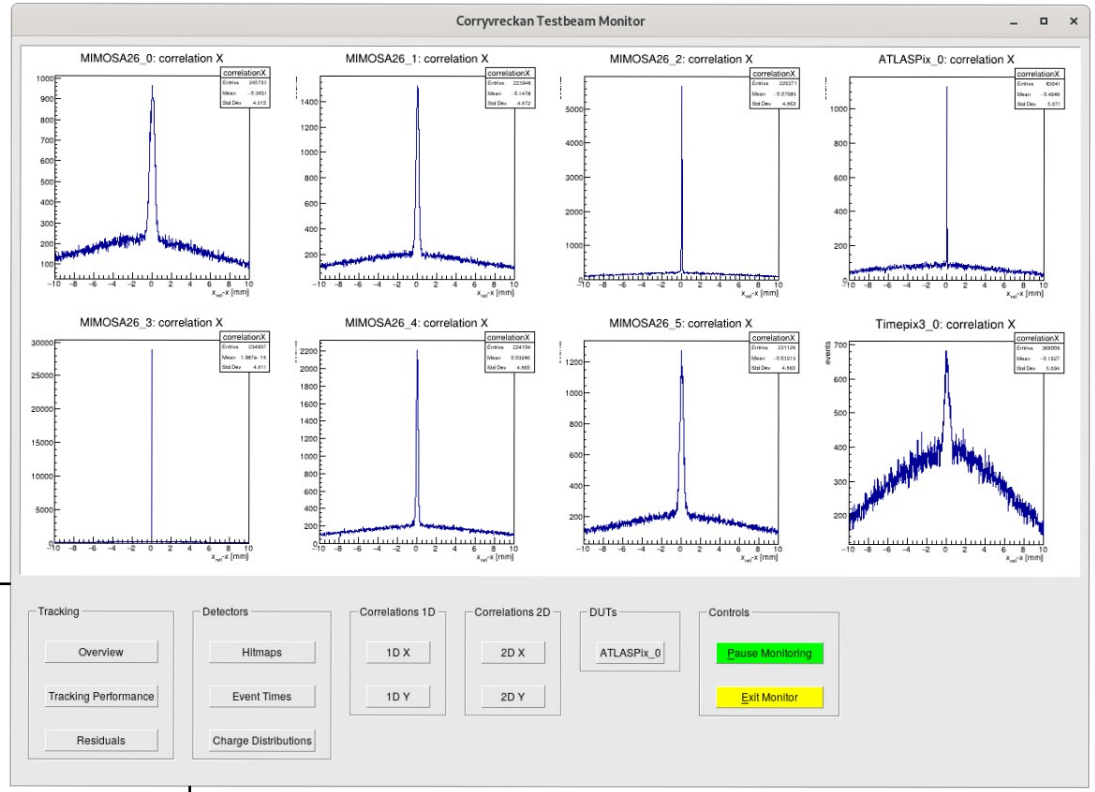
Example 1.3 – the Online Monitor

- we can also see the results **while** the analysis is running
- **configuration** file:
  - add `[OnlineMonitor]`
  - specify which plots you want to see
  - supported keywords: `%DETECTOR%, %DUT%, %REFERENCE%`

03_online_monitor.conf

```
[OnlineMonitor]
update = 200
dut_plots =
    [["EventLoaderATLASpix/%DUT%/hitMap", "colz"],
     ["EventLoaderATLASpix/%DUT%/pixelToT"],
     ["EventLoaderATLASpix/%DUT%/pixelMultiplicity","log"],
     ["EventLoaderATLASpix/%DUT%/hPixelTimes_long"]]
```

- opens interactive window
  (**Note:** does not work in docker container!)



Example 1.4 – The FileWriter

- we can **write out reconstructed data** at **any stage** during the reconstruction

- in **configuration** file:
  - add **[FileWriter]**
  - objects of **all previous modules** will be written to file

04_filewriter.conf

```
[Tracking4D]
min_hits_on_track = 6
spatial_cut_abs = 200um, 200um
time_cut_abs = 50ns

[FileWriter]
file_name = "04_output_tuples.root"

[DUTAssociation]
time_cut_abs = 200ns
spatial_cut_abs = 300um,150um

[AnalysisDUT]

[AnalysisEfficiency]
```

- explore output file with ROOT TBrowser
- read in for further analysis via the **[FileReader]** (next slide)

Example 1.5 – The FileReader

- we can **read in** reconstructed data and **continue** the reconstruction

- in **configuration** file:
  - add **[FileReader]**
  - all objects from modules above will be written to file

05_filereader.conf

```
# [Tracking4D] ← not needed anymore!
# min_hits_on_track = 6
# spatial_cut_abs = 200um, 200um
# time_cut_abs = 50ns

[FileReader]
file_name = "output/04_output_tuples.root"

[DUTAssociation]
time_cut_abs = 200ns
spatial_cut_abs = 300um,150um

[AnalysisDUT]

[AnalysisEfficiency]
```

- we can also read in **simulated** data from **Allpix Squared**
  - Talk: What's new on Allpix Squared?
  - Hands-On: Silicon Detector Monte-Carlo Simulations with Allpix Squared - Beginners
  - Hands-On: Everything you would like to know about Allpix Squared - Advanced

Example 2 – Data and configuration files

- All **configuration** and **geometry** files in

  `02_clicpix2/`

  - `geometries/`
  - `01_analysis_telescope.conf`
  - `02_analysis_withDUT.conf`

- The **data** is in

  `data/`

  - `02_data_clicpix2/`
  - `02_data_telescope/`

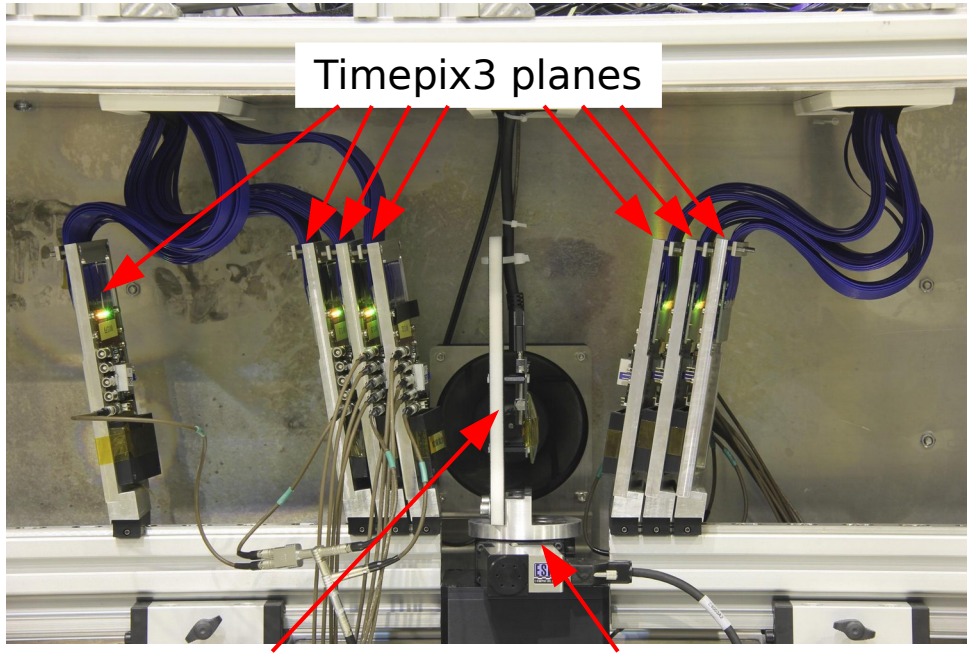
Disclaimer:
The shown analyses are chosen to be instructive and illustrate the framework functionality.

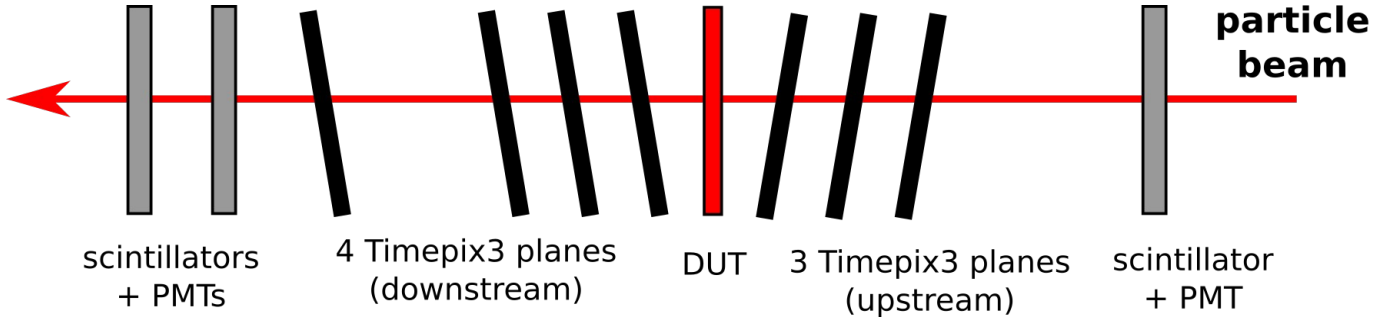
Please don’t infer any sensor performance estimates.

Example 2 – Let's have a look at the setup

- Timepix3 telescope: same as in Example 1
  - data-driven readout
  - pixel-by-pixel timestamp

- CLICpix2 as device-under-test:
  - **frame-based readout:**
    → shutter open/close
  - no pixel-by-pixel timestamp
    (in this operation mode)

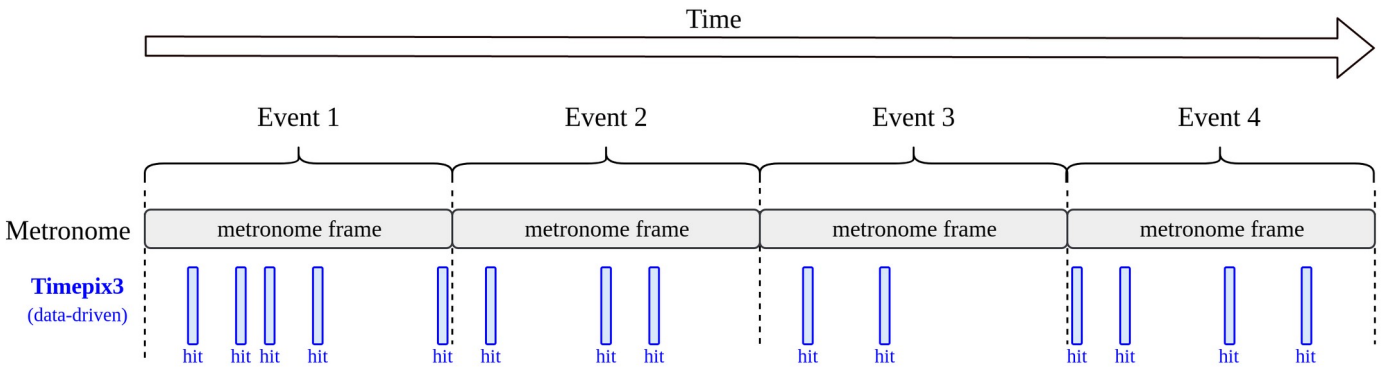




Example 2.1 – Again let's start with the **telescope only**

- telescope detectors are data-driven
  → need **[Metronome]** to define event

- **configuration** file as before
  (only path/to/data is updated)



01_analysis_telescope.conf

```
[Corryvreckan]
detectors_file =
      "geometries/01_alignment_telescope.geo"
histograms_file =
      "01_histograms_telescope.root"

[Metronome]
event_length = 100us

[EventLoaderTimepix3]
input_directory = "../data/02_data_telescope"

[Clustering4D]

[Correlations]

[Tracking4D]
min_hits_on_track = 6
spatial_cut_abs = 200um, 200um
time_cut_abs = 60ns
```

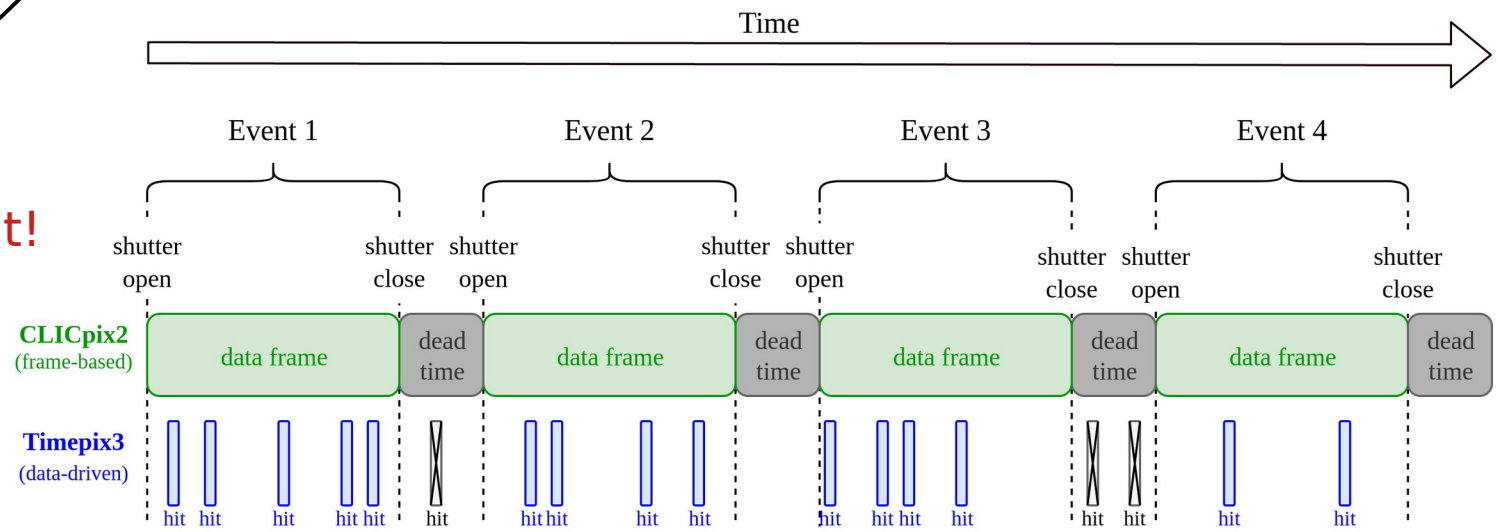
Example 2.2 – Now let's add the device-under-test

- CLICpix2 is frame-based
  - this detector needs to define the events
  - data from Timepix3 are filled in

- **configuration** file:
  - remove **[Metronome]**
  - place **[EventLoaderCLICpix2]** above Timepix3
  - **Remember:**
    The 1st module defines the event!

02_analysis_telescope_withDUT.conf

```
# Remove this module:
# [Metronome]
# event_length = 20us

# Now the CLICpix2 defines the frames:
[EventLoaderCLICpix2]
input_directory = "../data/01_data_clicpix2"

[EventLoaderTimepix3]
input_directory = "../data/01_data_telescope"
```



Example 2.2 – Now let's add the device-under-test

- CLICpix2 does **not** have **pixel timestamps** (in this operation mode)

- **configuration** file:
  - add **[ClusteringSpatial]**
  - now need to specify which clustering for which detector:

    hierarchy: name > type > nothing

  - also add DUT association + analysis module

02_analysis_telescope_withDUT.conf

```
[Clustering4D]
type = "Timepix3"

[ClusteringSpatial]
name = "CLICpix2_0"

[Correlations]

[Tracking4D]

[DUTAssociation]

[AnalysisDUT]
```

Example 3 – Data and configuration files

- All **configuration** and **geometry** files in

  `03_desy/`

  - `geometries/`
  - `01_tlu_mimosa26_timepix3.conf`
  - `02_tlu_mimosa26_timepix3_atlaspix.conf`
  - `03_EventDefinitionM26.conf`
  - `04_clictd_tlu_mimosa26_timepix3.conf`

- The **data** is in

  `data/`

  - `03_data_desy/`

Note:
This example uses the modules
- `[EventLoaderEUDAQ2]`
- `[EventDefinitionM26]`

which require EUDAQ2:
https://github.com/eudaq/eudaq

Use:
→ VirtualBox (already prepared)
→ Compilation from source

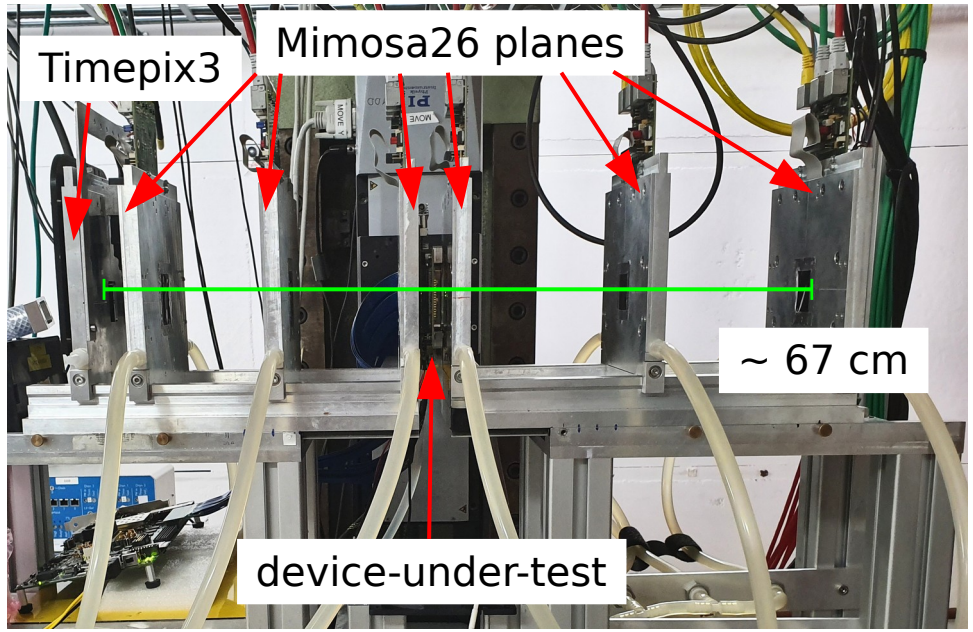
Disclaimer:
The shown analyses are chosen to be instructive and illustrate the framework functionality.

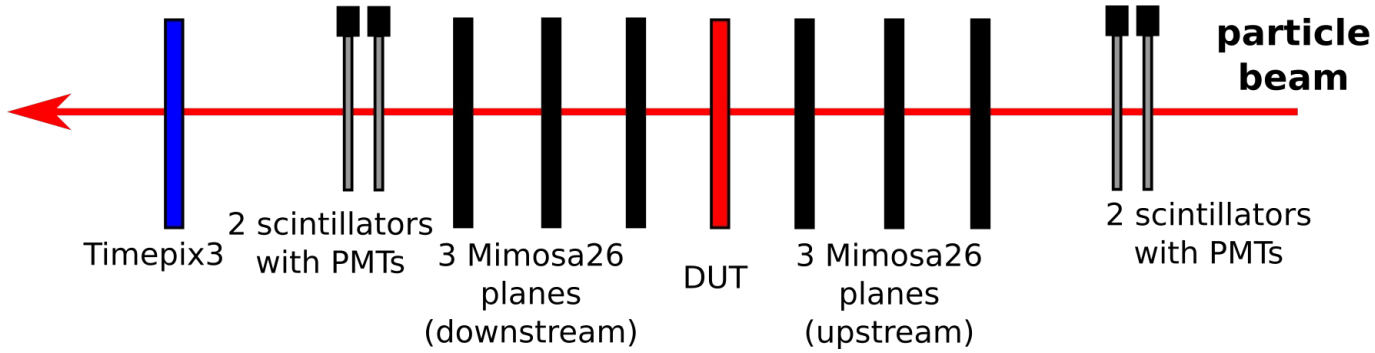
Please don’t infer any sensor performance estimates.

Example 3 – Let's have a look at the setup

Setup at **DESY** using **EUDAQ2:**
https://github.com/eudaq/eudaq

- **AIDA TLU** ("trigger logic unit")
  - generates trigger signal from scintillator coincidence
- Mimosa26 **telescope**:
  - triggered by TLU
  - rolling-shutter readout
  - no pixel-by-pixel timestamp
- **additional** Timepix3 plane:
  - data-driven
  - pixel-by-pixel timestamp

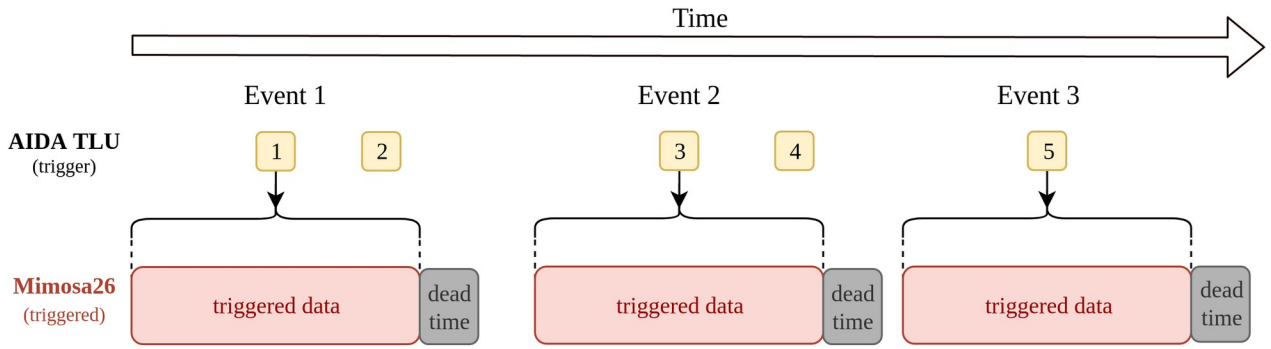


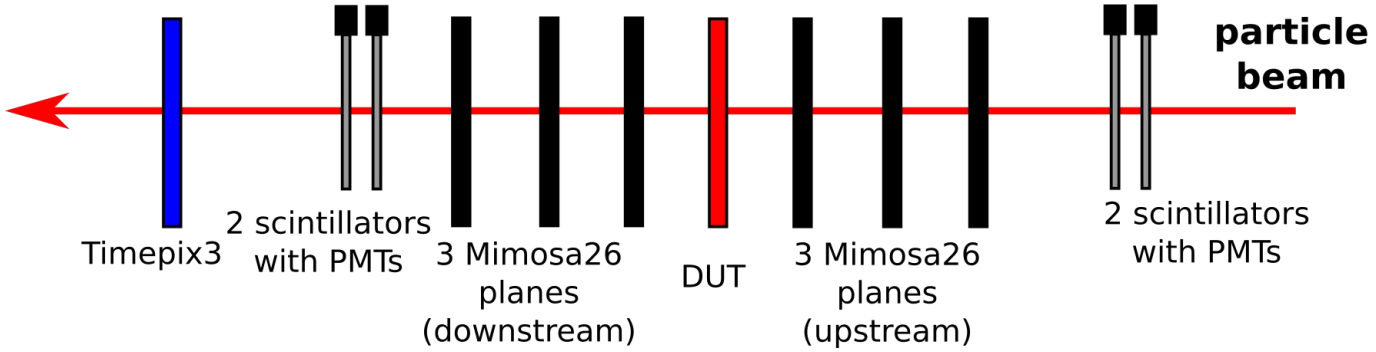


Example 3 – Let's have a look at the event building

Setup at **DESY** using **EUDAQ2:**
https://github.com/eudaq/eudaq

- **AIDA TLU** ("trigger logic unit")
  - generates trigger signal from scintillator coincidence
- Mimosa26 **telescope**:
  - triggered by TLU
  - rolling-shutter readout
  - no pixel-by-pixel timestamp
- **additional** Timepix3 plane:
  - data-driven
  - pixel-by-pixel timestamp

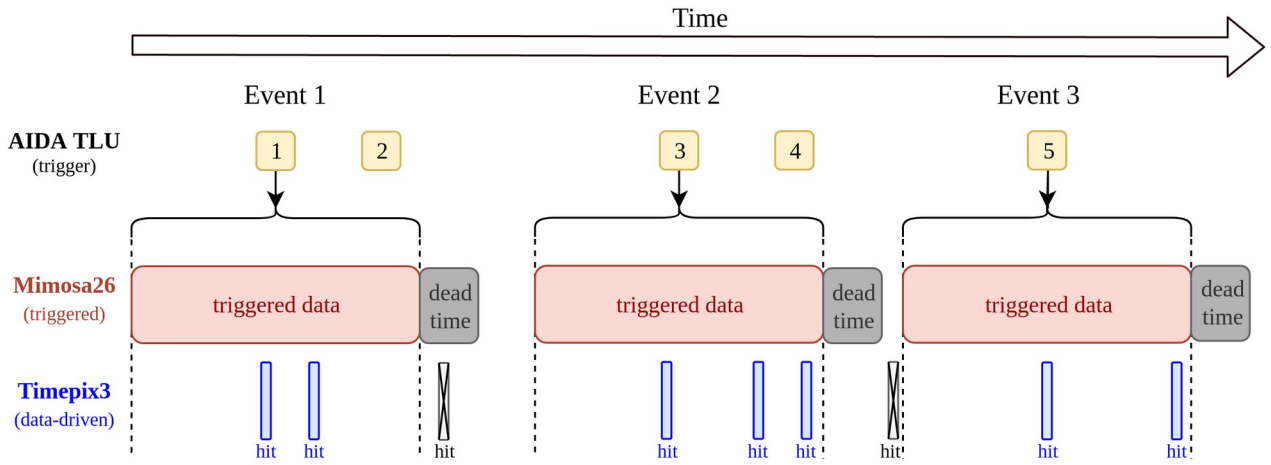


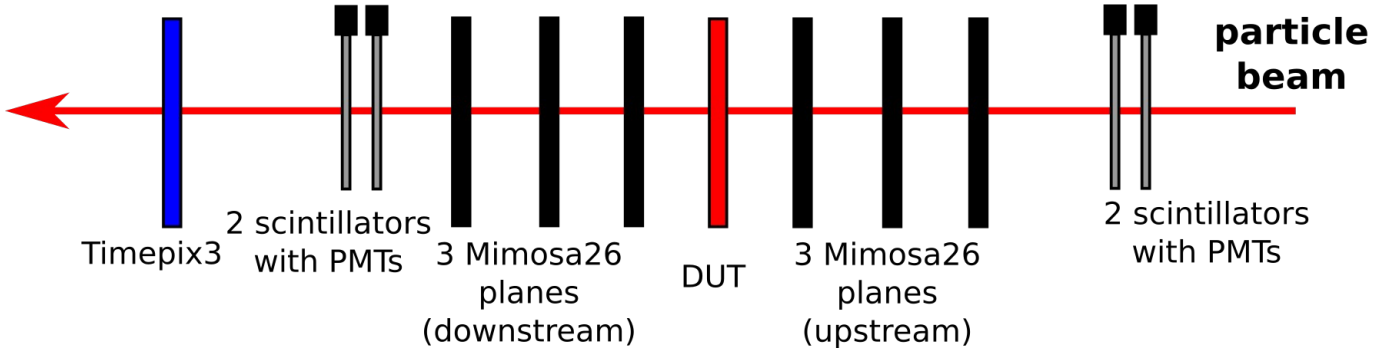


Example 3 – Let's have a look at the event building

Setup at **DESY** using **EUDAQ2:**
https://github.com/eudaq/eudaq

- **AIDA TLU** ("trigger logic unit")
  - generates trigger signal from scintillator coincidence
- Mimosa26 **telescope**:
  - triggered by TLU
  - rolling-shutter readout
  - no pixel-by-pixel timestamp
- **additional** Timepix3 plane:
  - data-driven
  - pixel-by-pixel timestamp





Example 3.1 – Let’s have a look at the geometry

- new situation:
  - **AIDA TLU** is **not a pixel detector**
  - use as “auxiliary” detector
- **geometry** file:
  - **no** pixels/spatial resolution
  - but can have position, time resolution
  - define its role as **“auxiliary”** or **“aux”**

alignment_tlu_mimosa26_timepix3_atlaspix.geo

```
[TLU_0]
...
type = “TLU”
role = “aux”

[Mimosa26_0]
...
```

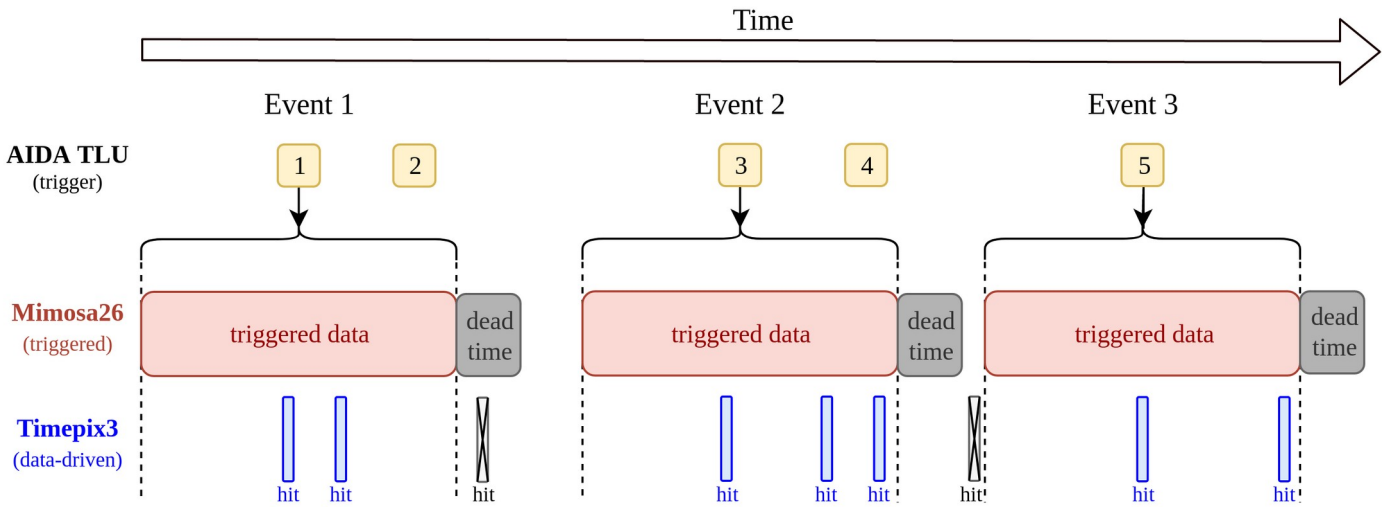
Example 3.1 – Now let's check the config

- **configuration** file:
  - start with the TLU and "expand" the event to match time slice of triggered data
  - add data from Mimosa26 based on **trigger ID**
  - add hits from Timepix3 based on **pixel timestamp**

The 1st module defines the event!

01_tlu_mimosa26_timepix3.conf

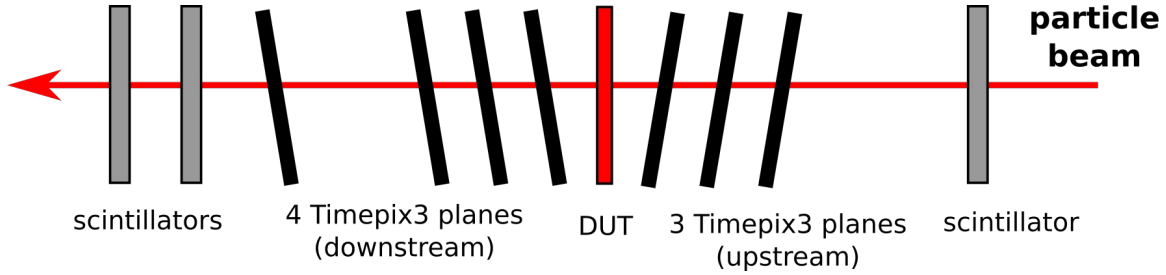
```
[EventLoaderEUDAQ2]
name = "TLU_0"
adjust_event_times =
          [["TluRawDataEvent",-115us,+230us]]

[EventLoaderEUDAQ2]
type = "Mimosa26"

[EventLoaderEUDAQ2]
type = "Timepix3"
```



Example 3 – Differences in Tracking

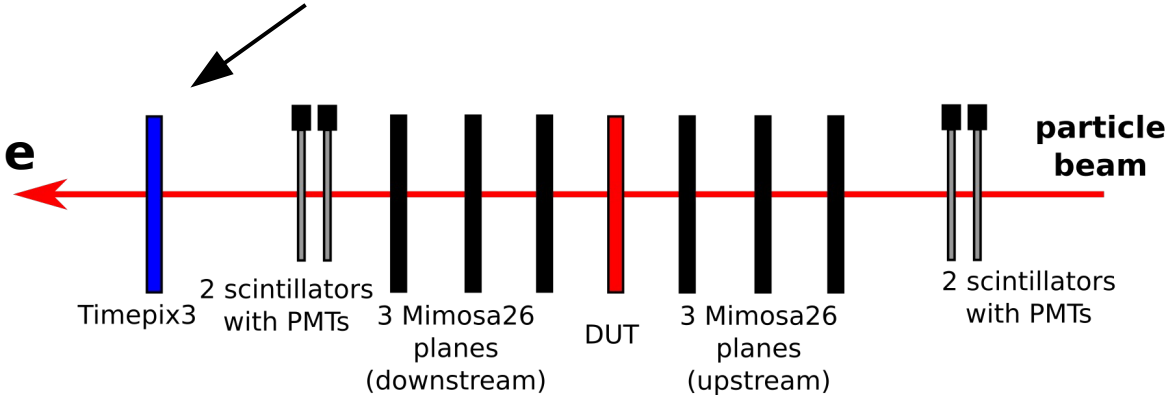
- Examples 1-2: **SPS**
  - 7 Timepix3 hits with precise timestamp
  - track timestamp = **average** TPX3 timestamp

SPS:
all sensors provide hit timestamps for tracking



- Example 3: **DESY**
  - Mimosa26 hits (3x 115µs) with multiple trigger timestamps
  - require Timepix3 for **unambiguous track time**
  - track timestamp = TPX3 timestamp

DESY:
unambiguous track timestamp only with TPX3



Example 3 – Differences in Tracking

- **DESY**
  - **Mimosa26** hits (3x 115µs) with multiple trigger timestamps
  - require **Timepix3** for unambiguous track time

→ track timestamp = TPX3 timestamp

01_tlu_mimosa26_timepix3.conf

```
[ClusteringSpatial]
type = "Mimosa26"
use_trigger_timestamp = true

[Clustering4D]
type = "Timepix3"

[Tracking4D]
require_detector = "Timepix3_0"
timestamp_from = "Timepix3_0"
```

Example 3 – Differences in Tracking

- one more major difference:
  - SPS beam: 120 GeV pions
  - DESY beam: 5.4 GeV electrons

→ much lower momentum
→ use **general-broken-line** tracking instead of straight tracks

- in **configuration**:
  - add momentum and track model
- in **geometry**:
  - add material budget in (X/X_0)

01_tlu_mimosa26_timepix3.conf

```
[Tracking4D]
require_detector = "Timepix3_0"
timestamp_from = "Timepix3_0"
momentum = 5.4GeV
track_model = "gbl"
```

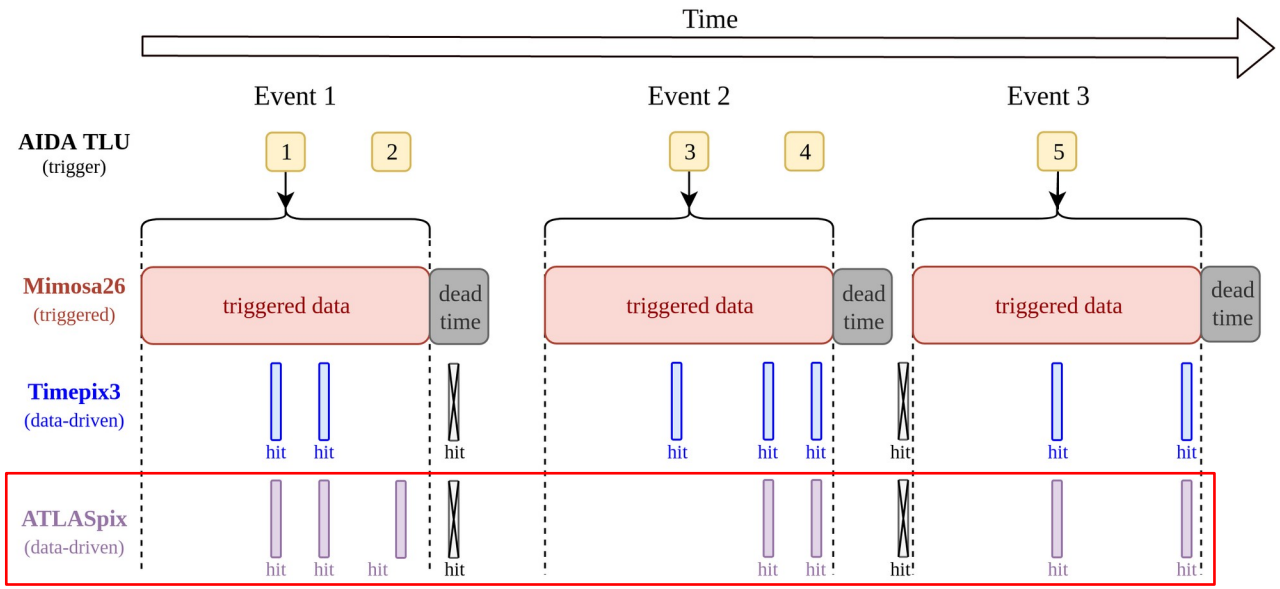
alignment_tlu_mimosa26_timepix3_atlaspix.geo

```
[Mimosa26_0]
material_budget = 0.00075
...

[Timepix3_0]
material_budget = 0.01068
...
```

Example 3.2 – Adding a device-under-test

- ATLASpix as **device-under-test**:
  - data-driven
  - pixel-by-pixel timestamp

→ simply add another event loader



01_tlu_mimosa26_timepix3_atlaspix.conf

```
[EventLoaderEUDAQ2]     # the 1st event loader
name = "TLU_0"          # defines the event!
adjust_event_times =
          [["TluRawDataEvent",-115us,+230us]]

[EventLoaderEUDAQ2]
type = "Mimosa26"

[EventLoaderATLASpix]
type = "ATLASpix"

[EventLoaderEUDAQ2]
type = "Timepix3"
```

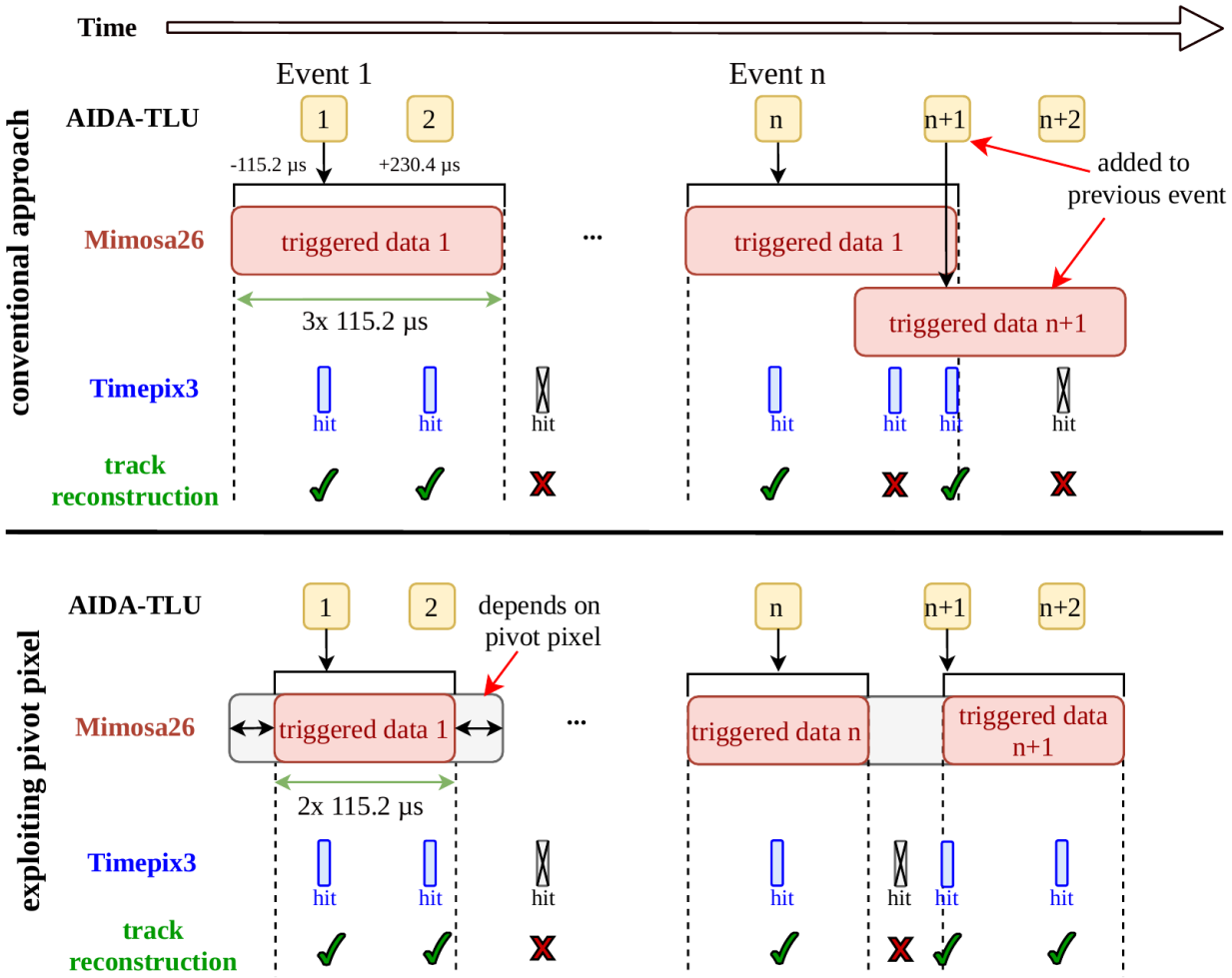
```
# Here the order
# doesn't matter!
```

Example 3.3 – Using the EventDefinitionM26

- new module **EventDefinitionM26**
  - use **pivot pixel** information for more precise event definition
- add before all event loaders
  - **Remember:** The 1st module defines the event!

```
[EventDefinitionM26]                # the 1st module
detector_event_time = "TLU"     # defines the event!
file_timestamp = "path/to/TLUdata"
file_duration = "path/to/M26data"

[EventLoaderEUDAQ2]
name = "TLU_0"
# Remove this parameter! Only add triggers now!
# adjust_event_times =
        [["TluRawDataEvent",-115us,+230us]]

[EventLoaderEUDAQ2]
type = "Mimosa26"

[EventLoaderATLASpix]
type = "ATLASpix"

[EventLoaderEUDAQ2]
type = "Timepix3"
```

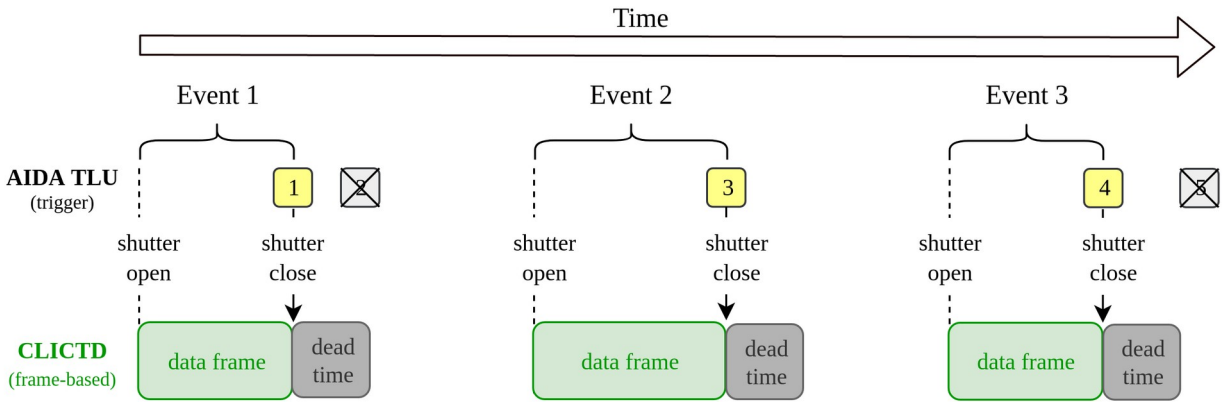
03_EventDefinitionM26.conf



For more details see arXiv:2011.09205

Example 3.4 – Let's have a look at the event building

- CLICTD as **device-under-test**:
  - no pixel-by-pixel timestamp
  - frame-based
    → shutter opened randomly
    → shutter closed by trigger
- CLICTD should define events:



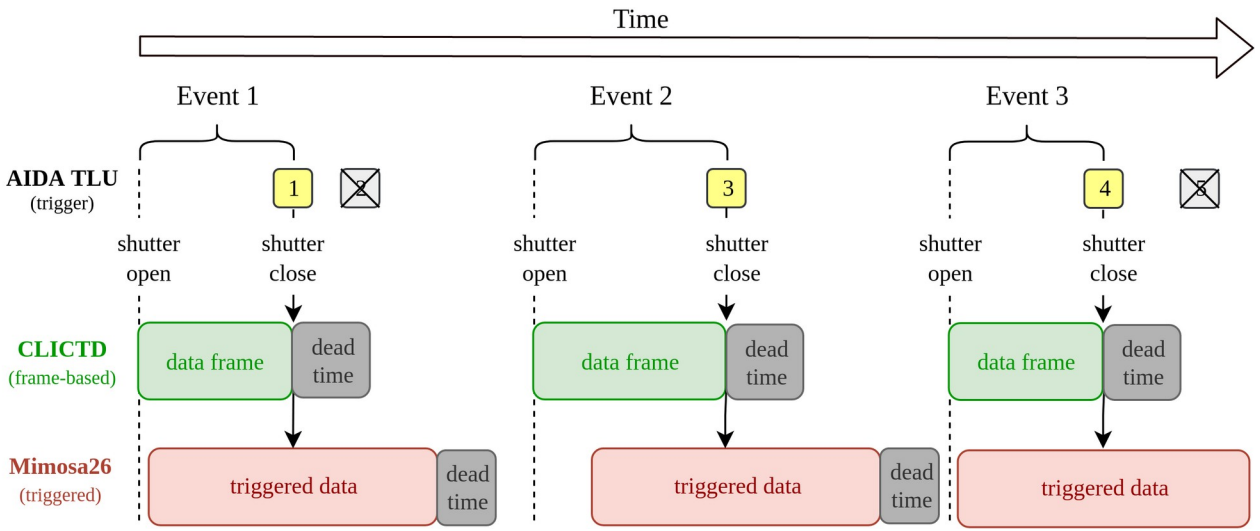
The 1st module defines the event!

04_clicpix2_tlu_mimosa26_timepix3.conf

```
[EventLoaderEUDAQ2]
name = "CLICTD_0"

[EventLoaderEUDAQ2]
name = "TLU_0"
```

Example 3.4 – Let's have a look at the event building

- CLICTD as **device-under-test**:
  - no pixel-by-pixel timestamp
  - frame-based
    → shutter opened randomly
    → shutter closed by trigger
- CLICTD should define events:



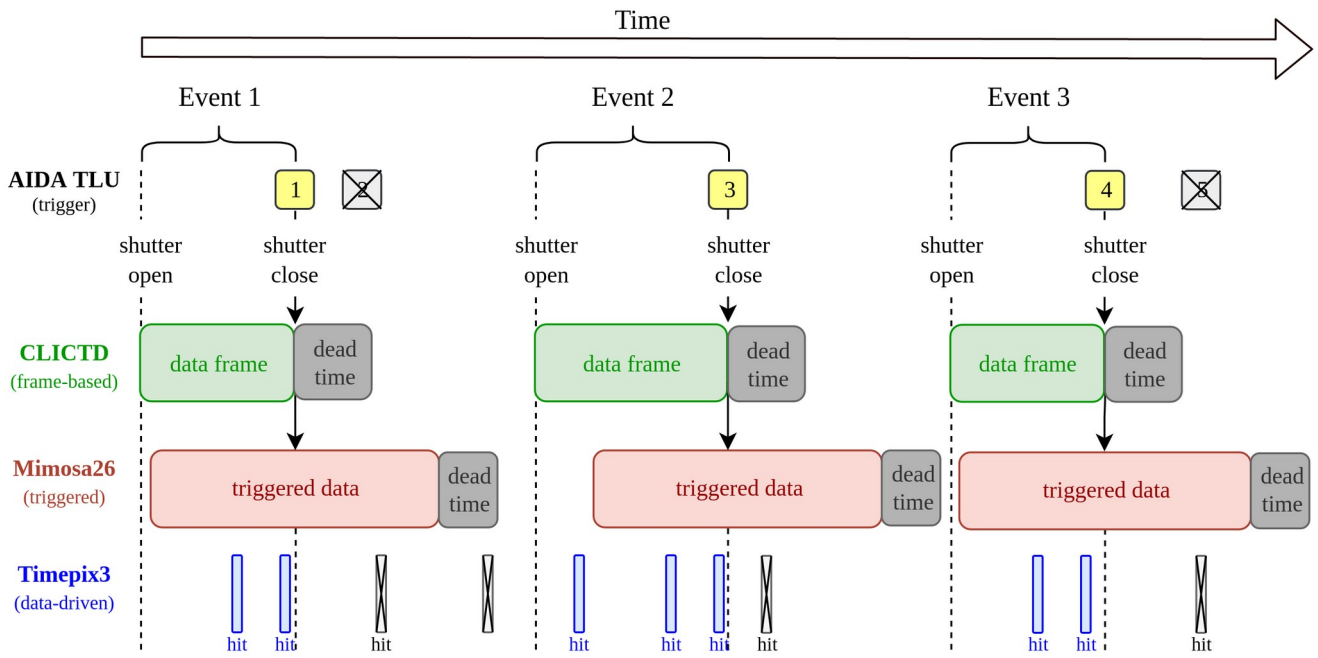
The 1st module defines the event!

04_clicpix2_tlu_mimosa26_timepix3.conf

```
[EventLoaderEUDAQ2]
name = "CLICTD_0"

[EventLoaderEUDAQ2]
name = "TLU_0"

[EventLoaderEUDAQ2]
type = "Mimosa26"
```

Example 3.4 – Let's have a look at the event building

- CLICTD as **device-under-test**:
  - no pixel-by-pixel timestamp
  - frame-based
    → shutter opened randomly
    → shutter closed by trigger
- CLICTD should define events:



The 1st module defines the event!

04_clicpix2_tlu_mimosa26_timepix3.conf

```
[EventLoaderEUDAQ2]
name = "CLICTD_0"

[EventLoaderEUDAQ2]
name = "TLU_0"

[EventLoaderEUDAQ2]
type = "Mimosa26"

[EventLoaderEUDAQ2]
type = "Timepix3"
```

Corryvreckan in short

reconstruction and analysis tool
for pixel sensor test beam data

- highly flexible/configurable
  - separate modules for each reconstructions/analysis step
  - many different event building options
- comprehensive documentation
  + beginner-friendly tutorials
- growing number of users/contributors
  → Thanks to all of you!

Learn more:


Visit our website:
https://cern.ch/corryvreckan


Browse through our manual:
→ Get the lastest version here


Try our other tutorial:
→ Get Started (no prior experience required)


Check out the repository:
https://gitlab.cern.ch/corryvreckan/corryvreckan


Discuss in the forum:
https://corryvreckan-forum.web.cern.ch/


Contact us:
corryvreckan.info@cern.ch
https://mattermost.web.cern.ch/corryvreckan

Backup

In case there are some questions...

Example Publications

for which Corryvreckan has been used

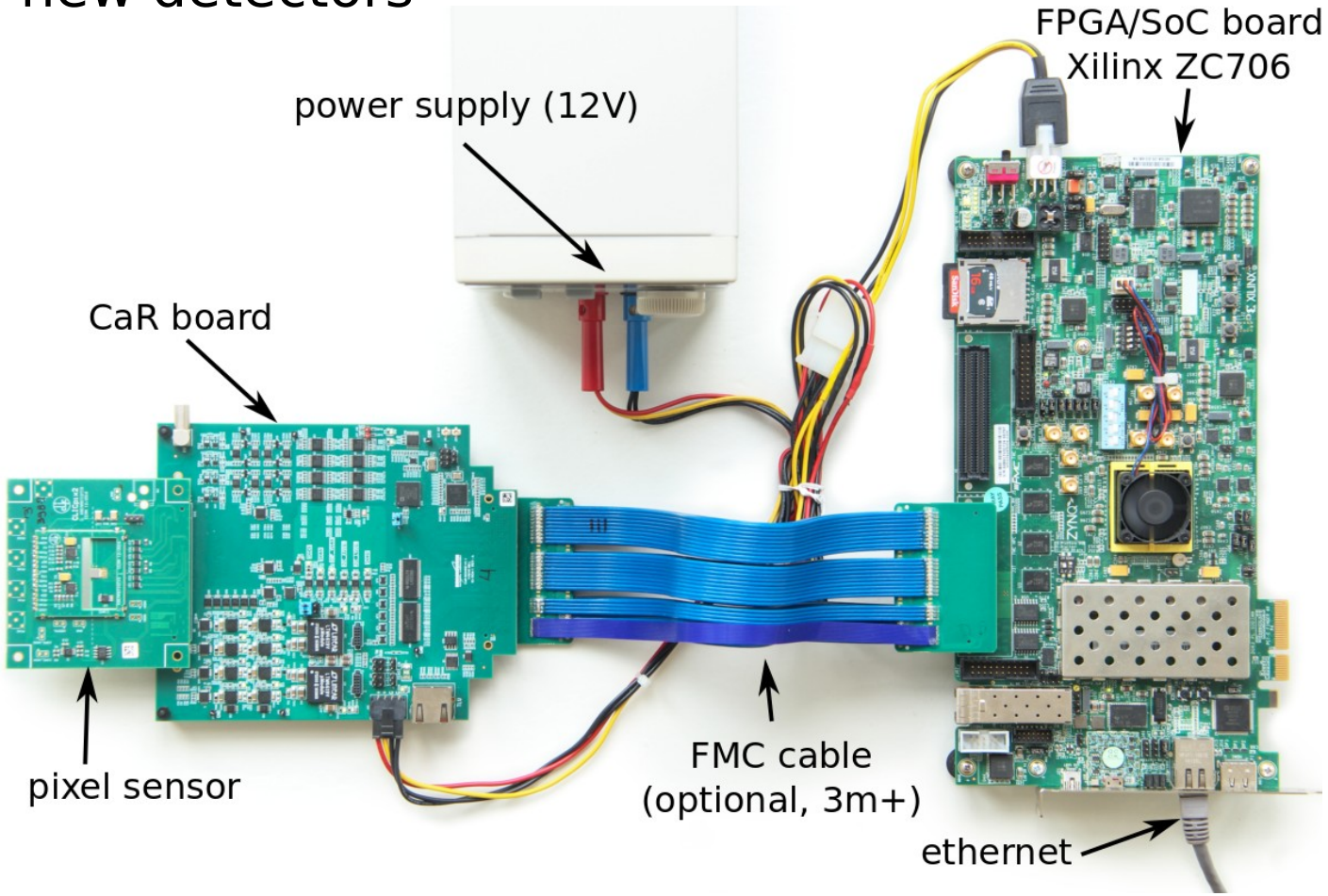
- Florian Pitters:
  Time Resolution Studies with Timepix3 Assemblies with Thin Silicon Pixel Sensors
  JINST 14 (2019) 05, P05022
  DOI: 10.1088/1748-0221/14/05/P05022
- Mathieu Benoit:
  Pixel detector R&D for the Compact Linear Collider
  JINST 14 (2019) 06, C06003
  DOI: 10.1088/1748-0221/14/06/C06003
- Magdalena Munker:
  Vertex and tracking detector R&D for CLIC
  Nucl.Instrum.Meth.A 980 (2020) 164475
  DOI: 10.1016/j.nima.2020.164475
- Morag Williams:
  R&D for the CLIC Vertex and Tracking detectors
  JINST 15 (2020) 03, C03045
  DOI: 10.1088/1748-0221/15/03/C03045
- Jens Kröger:
  Silicon Pixel R&D for the CLIC Tracking Detector
  JINST 15 (2020) 08, C08005
  DOI: JINST 15 (2020) 03, C03045

PhD Theses

- Florian Pitters:
  Silicon Detector Technologies for Future Particle Collider Experiments
  https://cds.cern.ch/record/2714709?ln=en
- Thorben Quast:
  Qualification, Performance Validation and Fast Generative Modelling of Beam Test Calorimeter Prototypes for the CMS Calorimeter Endcap Upgrade
  https://cds.cern.ch/record/2725040?ln=en
- Morag Williams:
  Evaluation of Fine-Pitch Hybrid Silicon Pixel Detector Prototypes for the CLIC Vertex Detector in Laboratory and Test-Beam Measurements
  (work-in-progress)

Caribou – the readout system

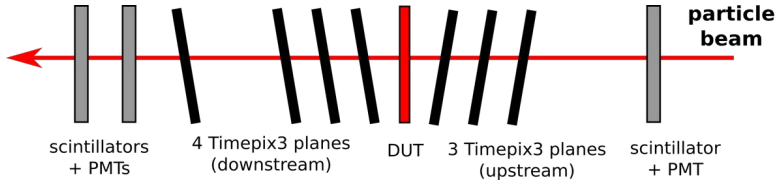
- versatile, open-source, linux-based
- fast & simple implementation of new detectors
  → “fast prototyping”
- **universal:**
  - FPGA board
  - Control & Readout (CaR) board
  - “most of the” firmware/software
- **chip-specific:**
  - chip board
  - “some” firmware/software blocks

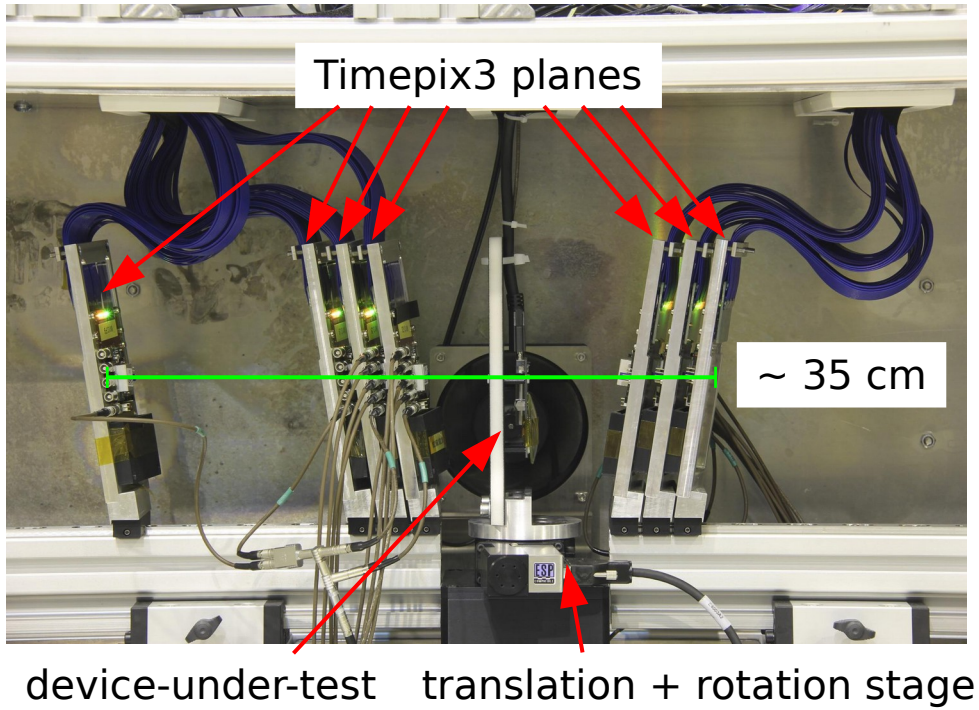


SPS vs. DESY II

SPS:

- typical beam condition:
  120 GeV pions @ few MHz
- telescope in operation
  2014-2018

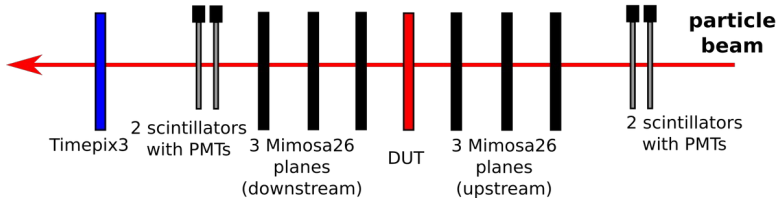


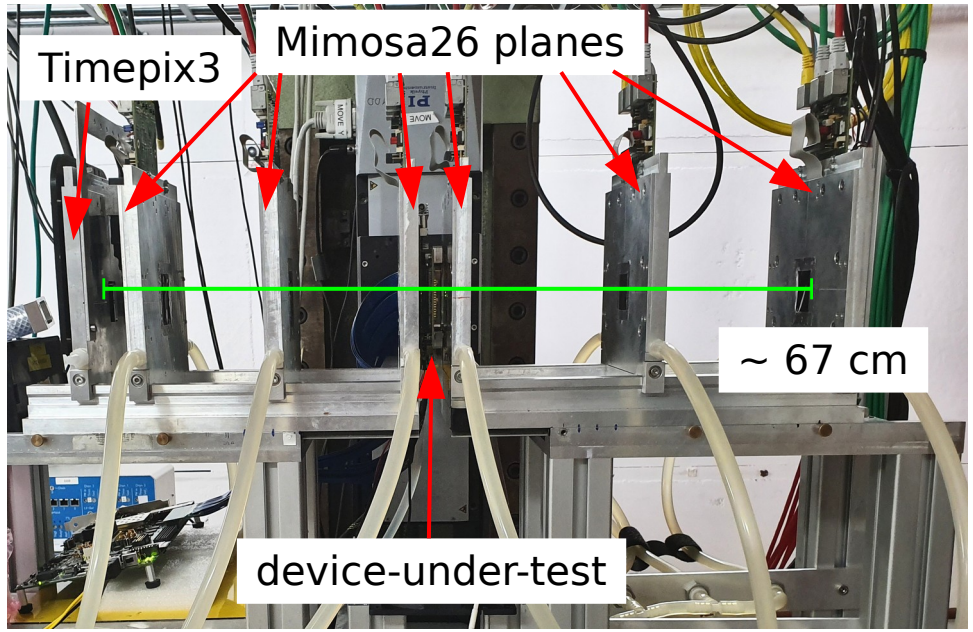


DESY:

- typical beam condition:
  5.4 GeV electrons @ few kHz
- use for CLICdp testbeam campaigns during
  LHC LS2 2019-2020

→ much lower rate & energy



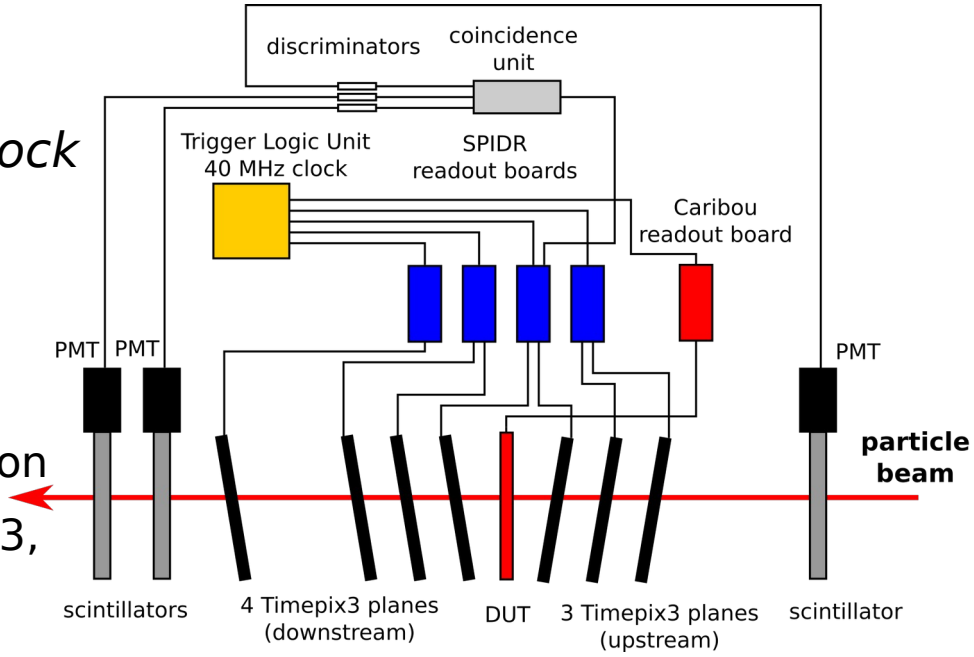


SPS vs. DESY II – Readout

continuous readout, timestamps synchronous with global clock

SPS:

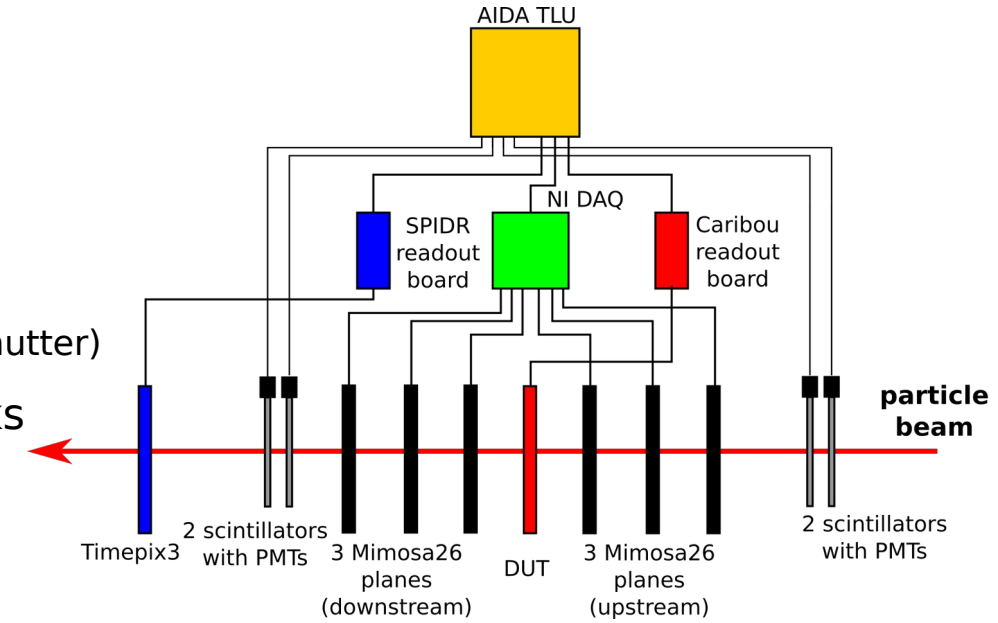
- Trigger Logic Unit (TLU) → provides global clock (time sync.)
- 3 scintillators + PMTs → trigger timestamps
- 7 Timepix3 planes → excellent spatial + timing resolution
- DUT → Investigator, Cracow SOI, Timepix3, CLICpix, CLICpix2, ATLASpix



DESY:

- AIDA TLU → provides global clock (time sync.) + triggers Mimosa Readout
- 4 scintillators + PMTs → input to TLU
- 6 Mimosa26 planes → good spatial res. (2x 115µs bins rolling shutter)
- Timepix3 → used to assign ns timestamp to tracks
- DUT → CLICpix2, ATLASpix, CLICTD

→ additional subsystem

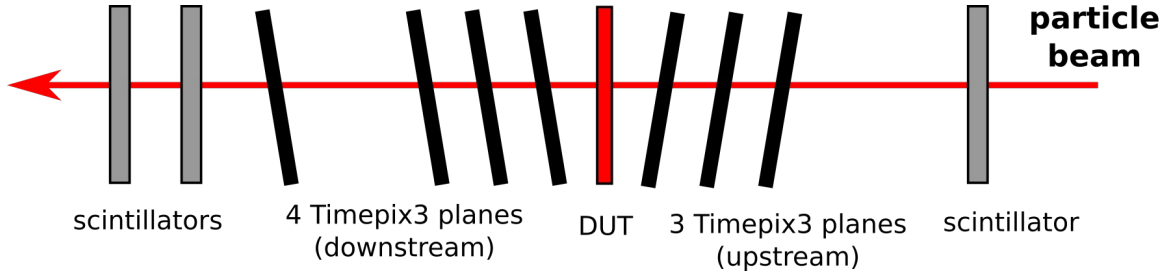


SPS vs. DESY II – Differences in the Analysis

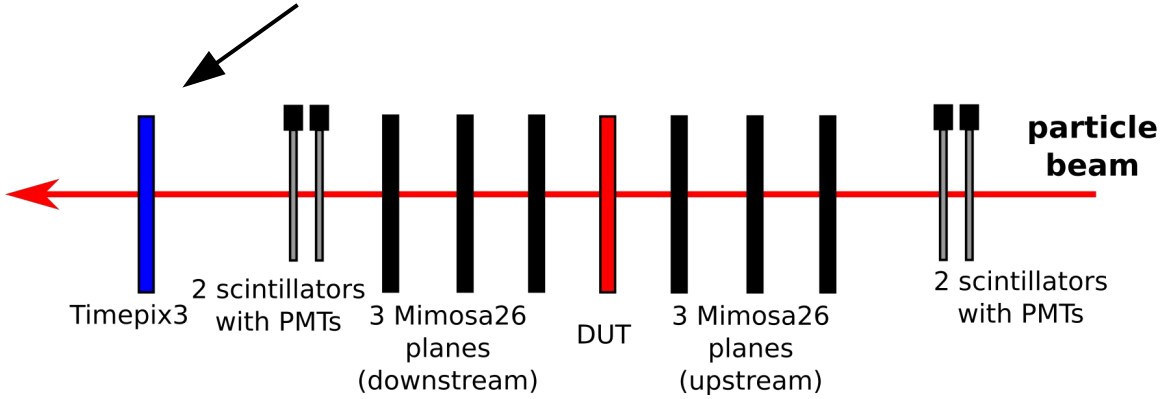
Tracking:

- **SPS**:
  - ➔ 7 Timepix3 hits with precise timestamp
  - ➔ track timestamp = average TPX3 timestamp
- **DESY**:
  - ➔ Mimosa26 hits (3x 115µs) with multiple trigger timestamps
  - ➔ require Timepix3 for unambiguous track time
  - ➔ track timestamp = TPX3 timestamp

SPS:
all sensors provide hit timestamps for tracking

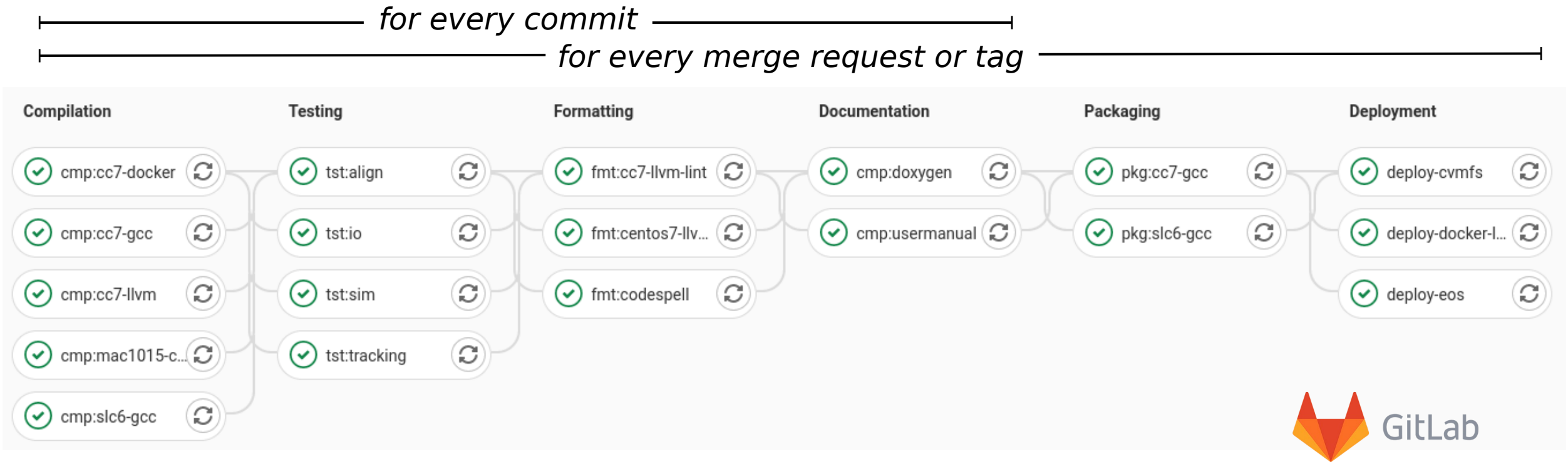


DESY:
unambiguous track timestamp only with TPX3



GitLab Continuous Integration

- ensures compilation, formatting, functionality (all stages explained in backup)
- pipeline runs through for every commit



GitLab Continuous Integration – all stages

- **Compilation**
  - compile source code on Scientific Linux 6, CentOS7, and Mac OS X with GCC, Clang, and AppleClang
- **Testing**
  - analyse test data sets and compare output to pass conditions
- **Formatting**
  - check format against defined syntax rules (e.g. tabs ↔ whitespaces) to avoid changes caused e.g. by different indentation, and apply linting
- **Documentation**
  - compile user manual from LaTeX sources and generate Doxygen code reference
- **Packaging**
  - generate release tarballs
- **Deployment**
  - publish new version of CVMFS, new docker image in registry, new user manual and code reference on the website and release tarballs