FUTURE CIRCULAR COLLIDER

CERN SUMMER SCHOOL 2024

NEW DEVELOPMENTS IN FULL SIMULATION SOFTWARE FOR FCC

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INTRODUCTION
THE GOAL OF THE PROJECT

The main pupose of this project is developing new tools for the validation of the **FCC software**.

What is validation?

Fundamental step in the software development lifecycle

Ensures the final product meets the specified requirements and fulfills its intended purpose

And for physics?

Making sure that the physics results obtained from the simulations are compatible with what we expect

How to achieve it?

GitLab CI/CD pipeline to run daily automated tests
Results comparing the output of new versions of the stack with reference stable ones can be checked on **website**

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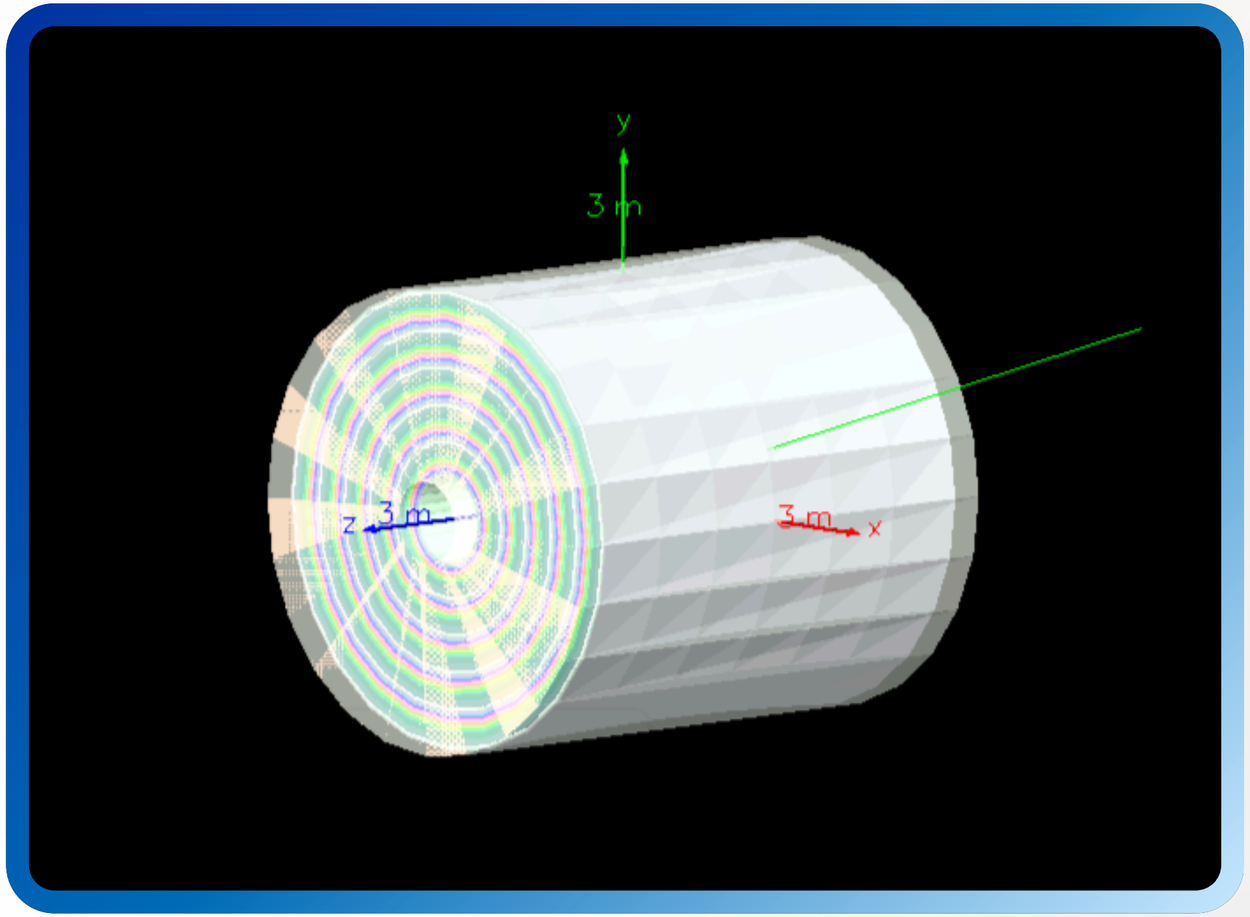
WARNING!

This pipeline only validates the physics!
The software itself is tested by cron jobs in other repositories

DO WE REALLY NEED THIS? **WELL...**

- Recently found bug in Geant4 navigation that was distorting the tracking and interaction of particles.
- Compilation was still successful and no run time error appeared
- Only possible to spot by **looking at physics** quantities
  - Problem was spotted “by chance” when shooting γ-rays at θ = 90° , when it became obvious
- Thanks to the physics validation system, the reaction time will be **~ 1 day!**



Drift Chamber detector containing the shape (not visible) responsible for the bug

HOW DOES THE PIPELINE WORK?
VARIABLES

The pipeline acts as a bash script executed in the *pipeline runner*.

The behaviour of the script is controlled by specific **variables** defined at the start of the file. Here are the most important...

Different *pipeline schedules* can be instantiated using different variable values.

1. **VALIDATION_JOB_TYPE:**
   Which type of validation job to run. In order to use the new version of the pipeline, select *run_script*

2. **VERSIONS:**
   List of detector versions that need to tested, separated by a comma (e.g. "ALLEGRO_o1_v03, IDEA_o1_v03, CLD_o3_v01")

3. **MAKE_REFERENCE_SAMPLE:**
   Whether to store the output of the simulation and reconstruction phase as a reference for future use or new results to be checked

4. **TAG:**
   Which tag to use for the key4hep release, identified by its date

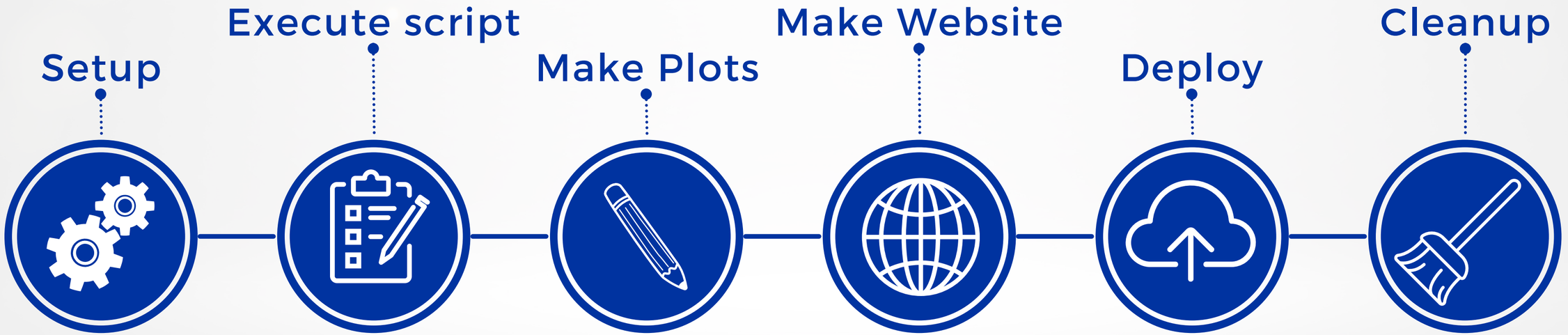
5. **COMPARISON_TEST:**
   Which test to use to compare histograms:
   Exact match, Chi squared or Kolmogorov-Smirnov

HOW DOES THE PIPELINE WORK?
STAGES

The pipeline is divided into stages, logically distinct steps that are run in a specified order.

The execution of the stages can depend on the global pipeline variables set at the start or on the success of the previous stages, providing a way to handle different situations.

Here are the stages when **VALIDATION_JOB_TYPE** is set to run_script:



HOW DOES THE PIPELINE WORK?
STAGES

SETUP:

- Clean up the working directory from previous iterations and/or create them
- Clone the *key4hep-reco-validation* repository

EXECUTE SCRIPT:

- Execute scripts written by experts on sim/reco. Ideally they contain:
  - Script for simulation + reconstruction
  - Analysis step

- Follow the **proper structure and naming conventions!**
  Scripts are contained in the *key4hep-reco-validation/* directory which mirrors the k4geo repository (containing the detector geometries)
  ⇒ scripts are looked for in *key4hep-reco-validation/scripts/FCCee/GEOMETRY/VERSION/* directory

- Optionally move output ROOT files to specific reference folders if MAKE_REFERENCE_SAMPLE variable is set to "yes"

HOW DOES THE PIPELINE WORK?
STAGES

MAKE PLOTS:

- Compares histograms in output ROOT file to reference ones
- Plots the two distributions with different background color depending on the result of the comparison: matching ⚪, not matching 🔴, missing reference 🟡

MAKE WEBSITE:

- Create the html files for the static website.
- Collect information about the release of key4hep used.

DEPLOY:

- Deploy the website online

CLEANUP:

- Remove key4hep-reco-validation repo and the key4hep release metadata file
- All the other files produced are not deleted until the next setup stage

SCALIBILITY
ADDING A NEW DETECTOR

The pipeline has been designed with flexibility in mind, so that adding new detector concepts to be tested would be as easy and straightforward as possible.

1. **CREATE BASH SCRIPT**
2. **ADD NEW SCRIPT TO KEY4HEP-RECO-VALIDATION**
3. **ADD NEW DETECTOR TO *VERSIONS* VARIABLE**

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1 Create bash script to run in the **EXECUTE SCRIPT** stage
Goal: produce a properly structured ROOT file containing histograms

Two steps:

- **Simulation and reconstruction**
  usually done with script in FCCConfig, e.g. :
  `source $FCCCONFIG/share/FCC-config/FullSim/ALLEGRO/ALLEGRO_o1_v03/ctest_sim_digi_reco.sh`
- **Analysis**
  usually is done with seperate python or ROOT script

Histograms should be saved as TH1 into specific TDirectories corresponding to the subsystems under study for the plot stage to work correctly.

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2 The bash script needs to be saved in the correct subdirectory of **key4hep-reco-validation**

The repository's structure mirrors the one for **k4geo:**

- Go to scripts/FCCee/ and check if there already is a directory for the **geometry** or create one if needed

```
key4hep-reco-validation/
└── scripts/
    └── FCCee/
        ├── ALLEGRO/
        │   └── ALLEGRO_o1_v03/
        │       └── ALLEGRO_o1_v03_script.sh
        ├── IDEA/
        │   └── IDEA_o1_v03/
        │       └── IDEA_o1_v03_script.sh
```

- Create a subdirectory for the specific version

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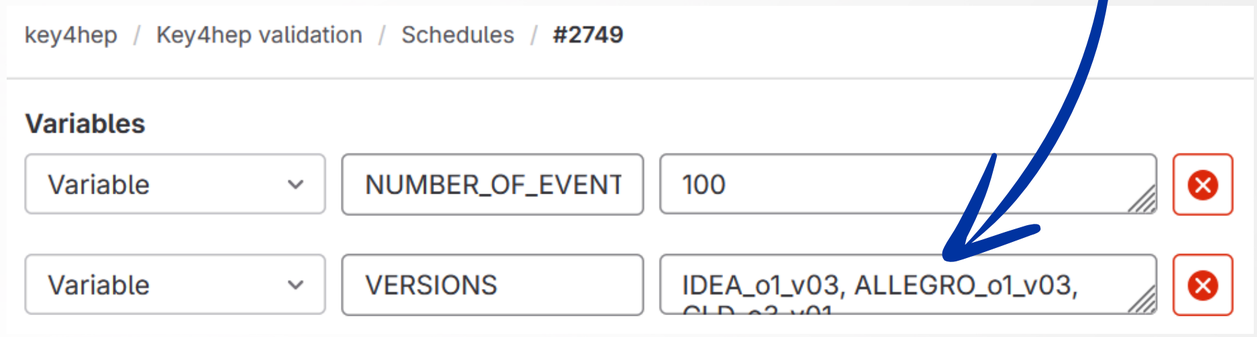
2. **ADD NEW SCRIPT TO KEY4HEP-RECO-VALIDATION**
3. **ADD NEW DETECTOR TO *VERSIONS* VARIABLE**

3 Add the name of the version to be tested in the **VERSIONS** list variable



This step can only be done by the owner or maintainer of the project, so please get in contact with them

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ADDING NEW VARIABLES

Adding a new variable or even subsytem to analyze is even easier, as you only need to change one file.

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1 Open the analysis script (e.g. IDEA_make_TH1.py)

2 Add the correct TDirectory and histograms initialization at the beginning

```
dir_DCH = outputFile.mkdir("DriftChamber")

hist_dch_hits = ROOT.TH1F("h_DriftChamber_hits",
                          "Number of hits;Hits;Counts / 5 hits",
                          40, 0, 200)

dir_list.append(dir_DCH)
histo_list.append([hist_dch_hits])
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3 Add the analysis inside the event loop

```
# Loop over dataset
for event in podio_reader.get("events"):

  ##############################################################################
  ##                                                                          ##
  ##                BEGIN: Drift Chamber Event Loop                           ##
  ##                                                                          ##
  ##############################################################################

  n_hits = 0
  for dch_hit in event.get("DCHCollection"):
    n_hits += 1
  hist_dch_hits.Fill(n_hits)
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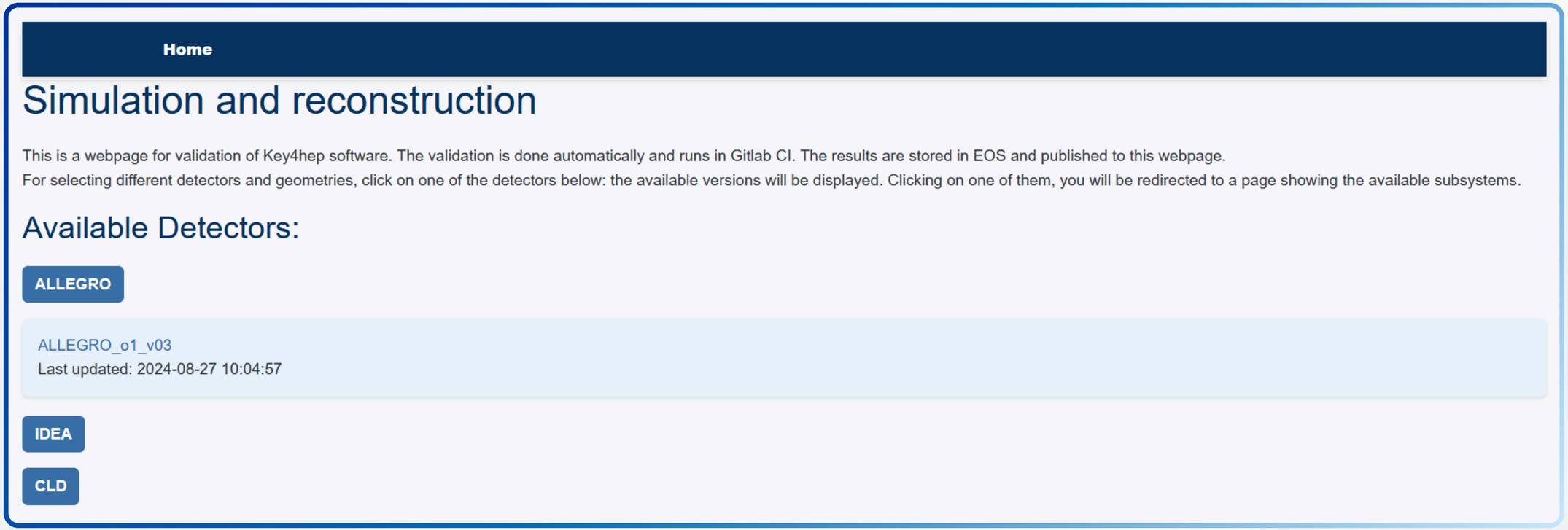
```

And that's it! Only add the new sections in the correct file without modifying anything else.

RESULTS
THE VALIDATION WEBSITE

The website provides an accessible and easy-to-navigate way to check the results of the pipeline.



Home page, containing the list of available detectors

RESULTS
THE VALIDATION WEBSITE

The website provides an accessible and easy-to-navigate way to check the results of the pipeline.

Detector version page, containing metadata information and list of available subsystems

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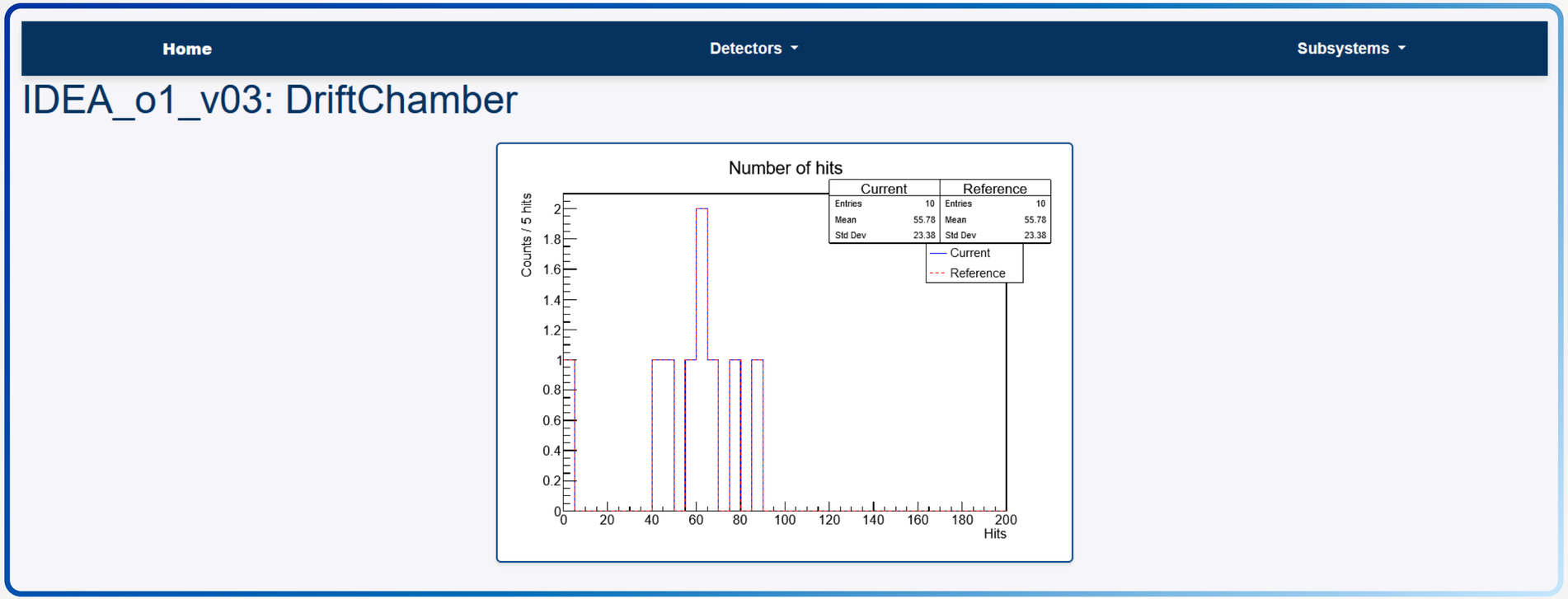

Subsystems page, containing the histogram plots.
In this example, the new and reference histograms match.

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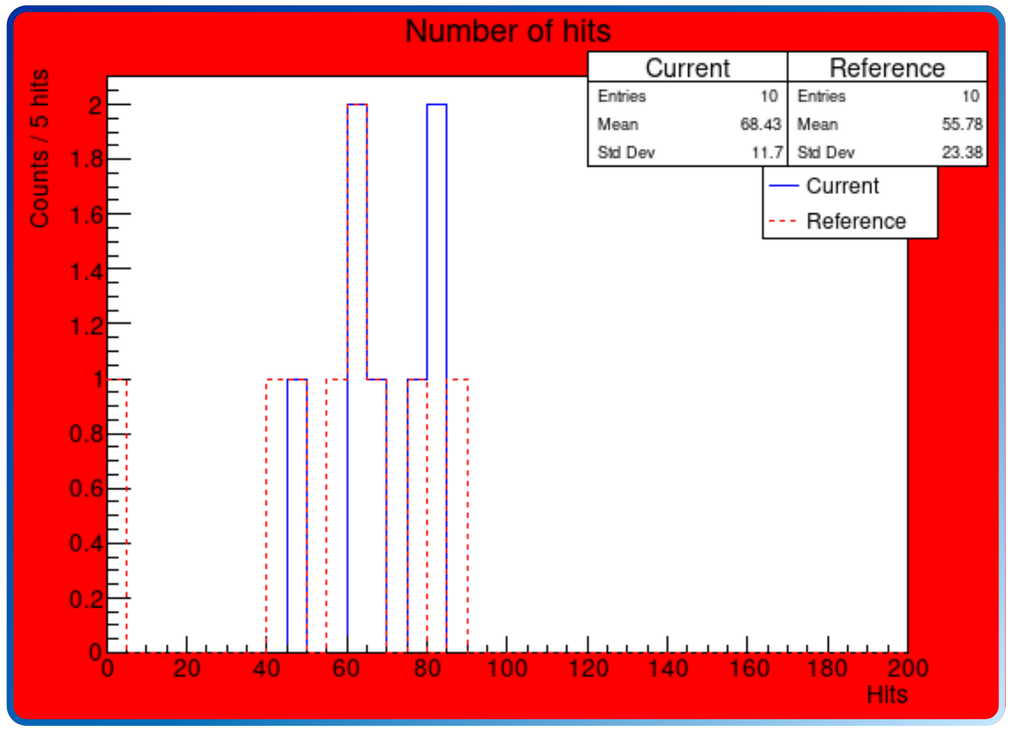

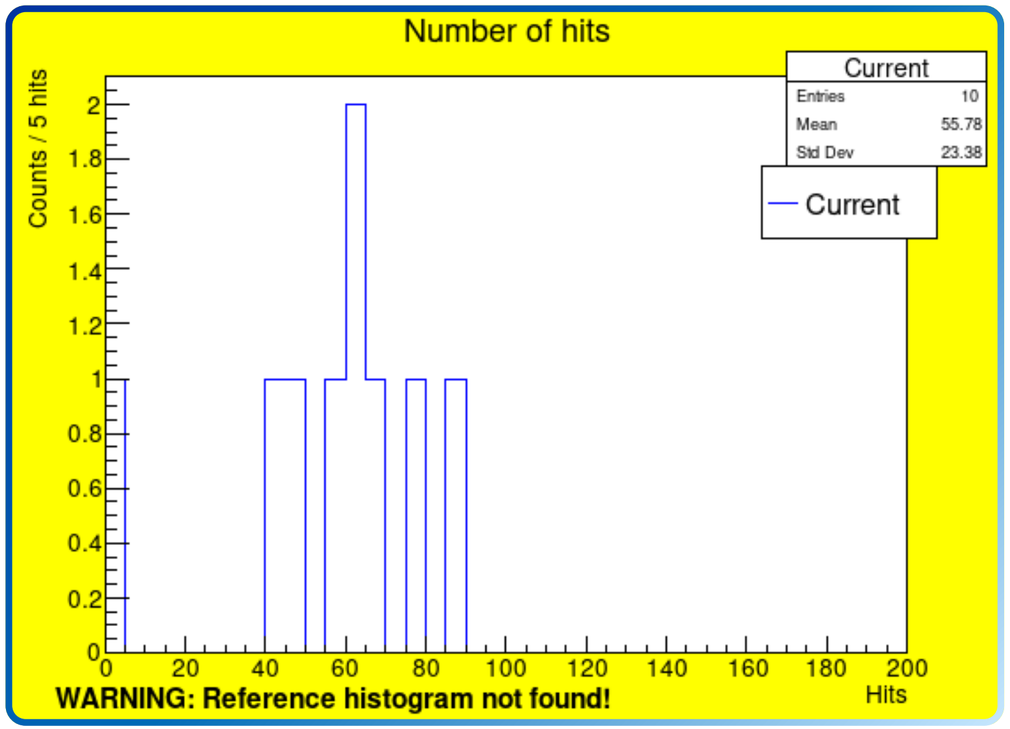

Examples of plot appearance when histograms do not match (left)
or when the reference is missing (right).

RESULTS
THE VALIDATION WEBSITE

Here are the plots already available...

Detector Version	Subsystem	Histograms

ALLEGRO_o1_v03	• Electromagnetic Calorimeter - Barrel	• CaloCluster Energy
		• CaloTopoCluster Energy
		• ECalBarrelModuleThetaMergedPosition:
		  ◦ total Energy per evt
		  ◦ X, Y and Z position

IDEA_o1_v03	• Drift Chamber • Vertex Detector • Vertex Inner Barrel • Vertex Outer Barrel	Number of Hits
CLD_o3_v01	• Standalone ARC Detector	• Photon counts per event • Photon counts vs. θ • Photon counts vs. θ of incoming particle

...and many more to come!

OUTLOOK
CURRENT LIMITATIONS

NUMBER_OF_EVENTS pipeline variable exists, but sim digi reco scripts actually are fixed to **only 10 events**

- Could lead to **large fluctuations** that trigger notifications even though the physics is still valid
- Could make the system **blind to small** but relevant **changes** in the physics

Might be worth it to modify the scripts and let the number of events be an input

Pipeline relies on the software working as intended, and only checks the physics

No policy is implemented to handle **software failure**: the pipeline will just keep working until an exit code 1 and then break

Pipeline **variables are global**: same event number, statistical test, significance level... for all detectors and subsystems

OUTLOOK
WHAT DO WE NEED NOW?

EMAIL WARNING SYSTEM:

- Automatic email system that alerts users if histograms do not match
- Can be easily added as an extra stage after the **MAKE_PLOTS** stage
- Care needed due to privacy issues...

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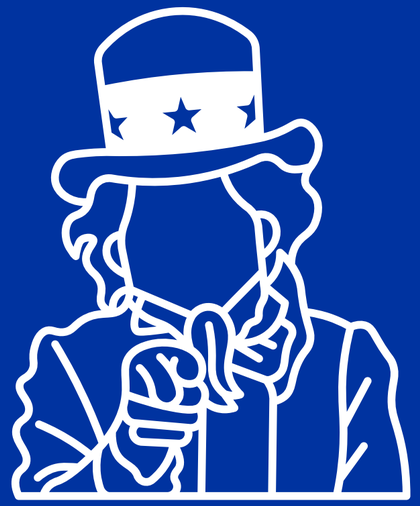

WE WANT YOU
FOR THE FCC VALIDATION

YOUR HELP!

- The pipeline is ready, but there is still a lot of work to do...
- Are you an expert on sim/reco for FCC FullSim?
  Now it is your turn to provide us scripts to populate the validation website! (Maybe after finishing the FCC FSR...)
- Are you an expert on validation in the SFT group?
  We are eager to accept any suggestions on how you would improve this project!

THANK YOU!

Special Thanks to:
My supervisors, Alvaro and Brieuc, for their guidance and patience
Juan Miguel Carceller, for starting this project and providing constant support

Contacts:
Enrico Lupi: enrico.lupi@cern.ch, enricolupi00@gmail.com

Links:
Valiation website: https://key4hep-validation.web.cern.ch/index.html
Key4hep-validation-reco repository: https://github.com/key4hep/key4hep-reco-validation