Overview of technical workflow for FCC-hh studies
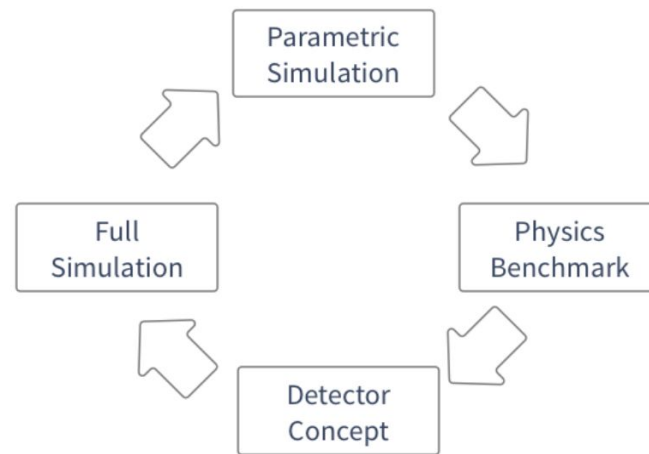
Birgit Stapf, Angela Taliercio, Sarah Williams

Introduction

- As introduced during the <u>kick-off workshop</u>, there are many opportunities to contribute to FCC-hh studies/updates in the ESPP 2025 process
- Do you have an idea, but find yourself wondering how you would go about putting it into practice?
  - This talk aims to give you an overview

Introduction

- As introduced during the <u>kick-off workshop</u>, there are many opportunities to contribute to FCC-hh studies/updates in the ESPP 2025 process
- Do you have an idea, but find yourself wondering how you would go about putting it into practice?
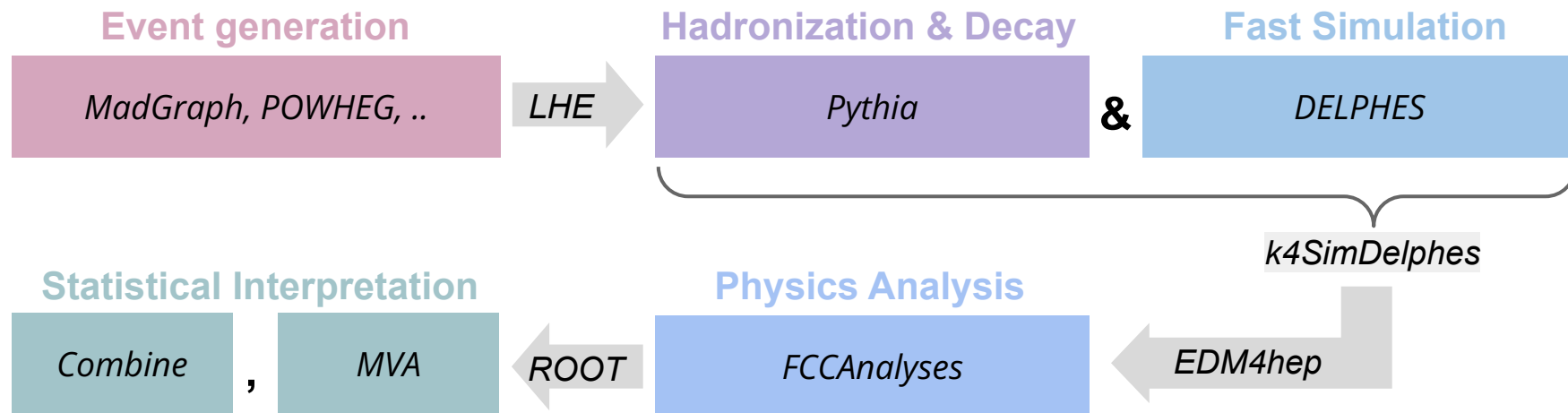 - This talk aims to give you an overview
- Note: All current and planned physics studies for FCC-hh rely on fast simulation with Delphes, there is also ongoing work and lots of opportunity for stand-alone full simulation studies, focussing e.g. on pile-up, tracking with timing information, flavour tagging
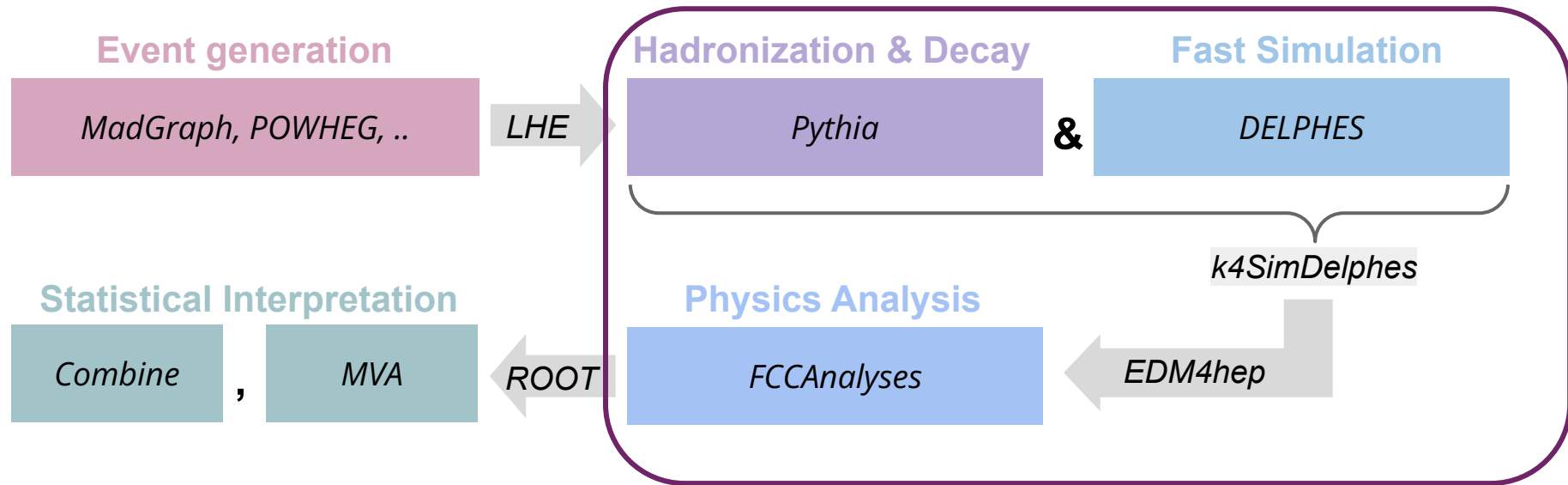

From Michele Selvaggi
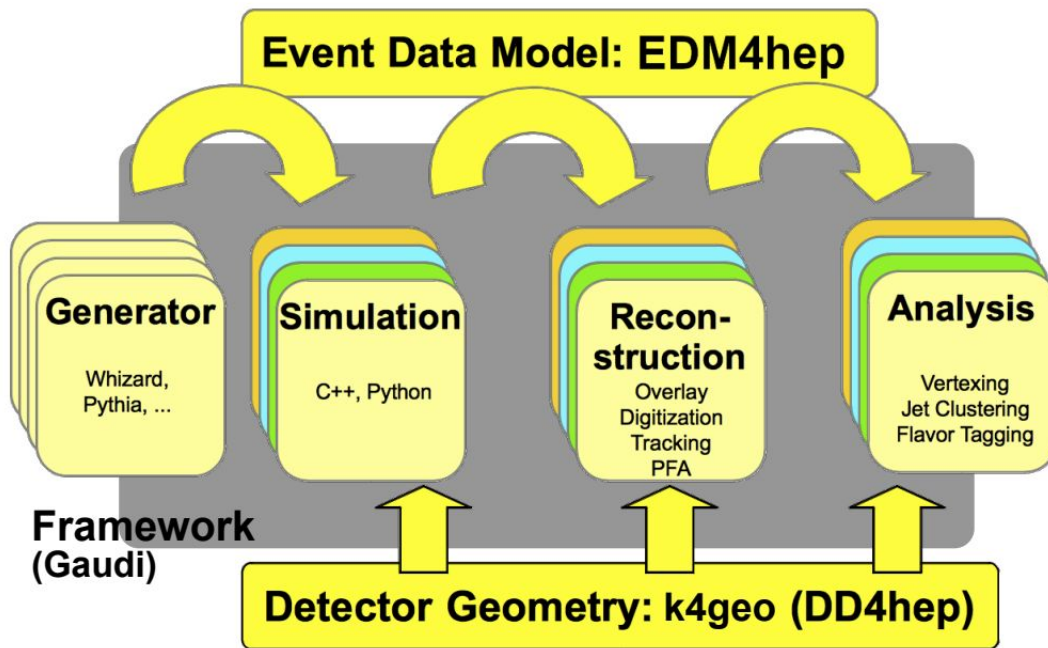
Overview of technical workflow

Event generation

| MadGraph, POWHEG, .. |

→ LHE →

Hadronization & Decay

| Pythia |

&

Fast Simulation

| DELPHES |

k4SimDelphes

Statistical Interpretation

| Combine | **,** | MVA |

← ROOT ←

Physics Analysis

| FCCAnalyses |

← EDM4hep ←

Overview of technical workflow

Key4hep project

- Turnkey software for future accelerators, used by different communities, e.g. CEPC, ILC, muon collider, ..

- Provides complete workflow from generator to analysis (although for FCC we are not using every step)

- In practice: A complete software stack to set up in one simple step

```
source /cvmfs/sw.hsf.org/key4hep/setup.sh
```

Event generation

- Typically use MadGraph and Powheg for FCC-hh studies with PDF sets from LHAPDF

  - Produced with common FCC framework: EventProducer

- Database of available LHE events here

Hadronization & fast simulation with k4SimDelphes

- The <u>k4SimDelphes</u> tool allows us to run Pythia8 and Delphes in one step (and converts to EDM4hep format)
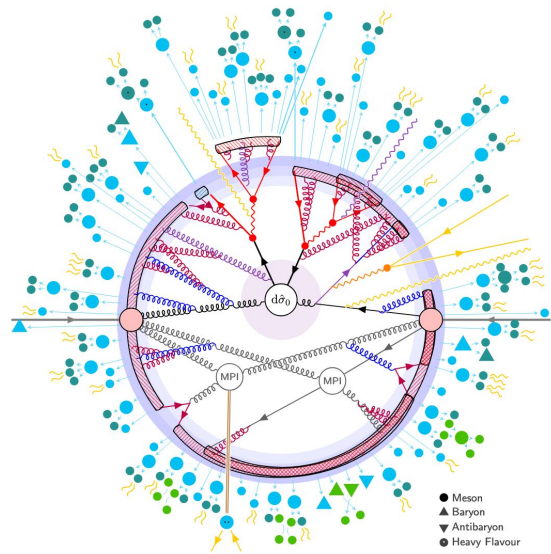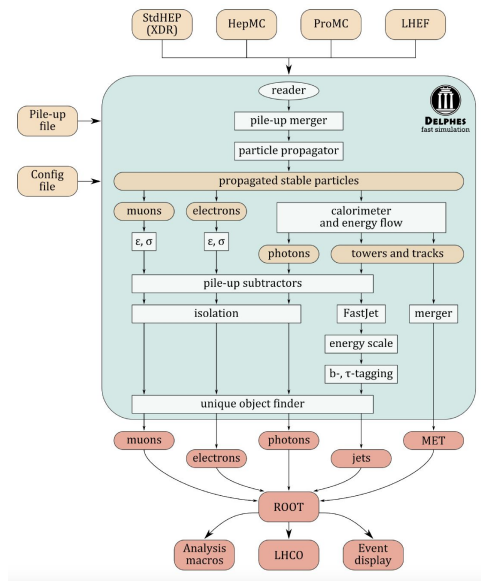
Hadronization & fast simulation with k4SimDelphes

- The <u>k4SimDelphes</u> tool allows us to run Pythia8 and Delphes in one step
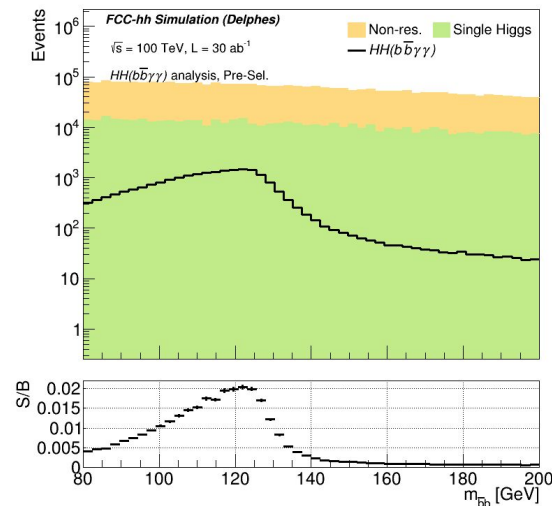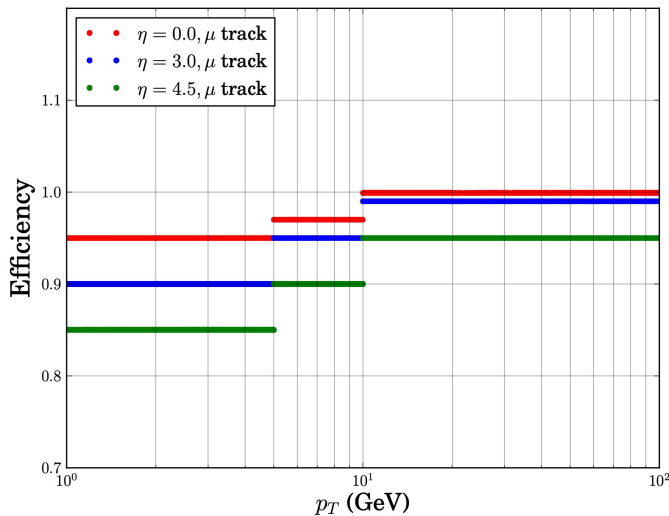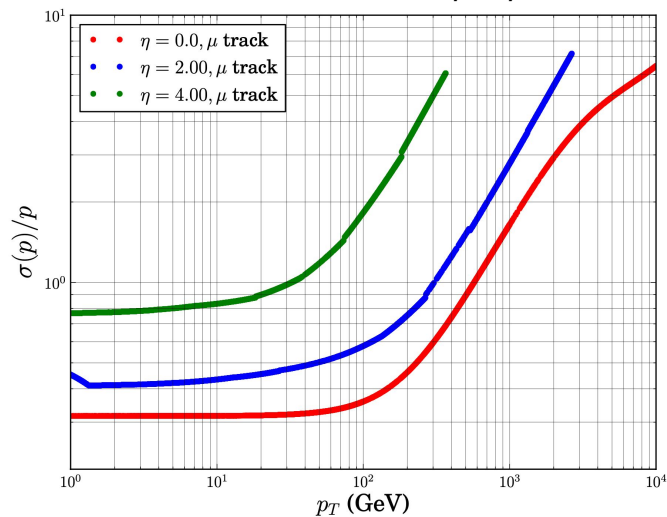
- Two current Delphes scenarios for FCC-hh:

Example parametrization for muons

Hadronization & fast simulation with k4SimDelphes

From Michele Selvaggi

Barrel ECAL: LAr/Pb
$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
$30\ X_0$
lat. segm: $\Delta\eta\Delta\phi \approx 0.01$
long. segm: 8 layers

Tracker: $\sigma_{p_T}/p_T \sim 20\%$
at 10 TeV (1.5m radius)

Central Magnet + Fwd solenoids

9 m

23 m

Fwd ECAL: LAr/Cu
$\sigma_E/E \sim 30\%/\sqrt{E} \oplus 1\%$
lat. segm: $\Delta\eta\Delta\phi \approx 0.01$
long. segm: 6 layers

Fwd HCAL: LAr/Cu
$\sigma_E/E \sim 100\%/\sqrt{E} \oplus 10\%$
lat. segm: $\Delta\eta\Delta\phi \approx 0.05$
long. segm: 6 layers

Barrel HCAL: Sci/Pb/Fe
$\sigma_E/E \sim 50\text{-}60\%/\sqrt{E} \oplus 3\%$
11 λ (ECAL+HCAL)
lat. segm: $\Delta\eta\Delta\phi \approx 0.025$
long. segm: 10 layers

Note: Both scenarios implement fixes w.r.t the original, e.g. bremsstrahlung for electrons, multiple scattering, resolutions in forward region

- The k4SimDelphes tool allows us to run Pythia8 and Delphes in one step

- Two current Delphes scenarios for FCC-hh:

  - Scenario I: Idealistic scenario for ultimate precision

  - Scenario II: Baseline scenario based on FCC-hh detector concept from CDR

	Relative p resolution		Efficiency	
	Scenario I	Scenario II	Scenario I	Scenario II
Electrons	0.4-1%	0.8-3%	76-95%	72-90%
Muons	0.5-3%	1-6%	90-99%	88-97%
Medium b-tagging			80-90%	76-86%

Hadronization & fast simulation with k4SimDelphes

▼ FCC-hh production tags

Production Tag	Description
Delphes v0.2	Production for CDR studies, not using EDM4hep yet. Using original baseline DELPHES card (now outdated).
Delphes v0.3	Production for CDR studies, not using EDM4hep yet. Using original baseline DELPHES card (now outdated).
Delphes v0.4	First intermediate production switching to EDM4hep. Using original baseline DELPHES card (now outdated).
Delphes v0.5	Intermediate production using the updated DELPHES scenarios I and II, and pre-release EDM4hep in v0.
Delphes v0.6	Production for the strategy update 2025 studies - using DELPHES scenarios I and II, and EDM4hep in v1.

○ FCC   FCC-hh   Gen   Delphes   Full Sim

FCC-hh Samples

Gen | Les Houches
Delphes | v0.2
Delphes | v0.3
Delphes | v0.4

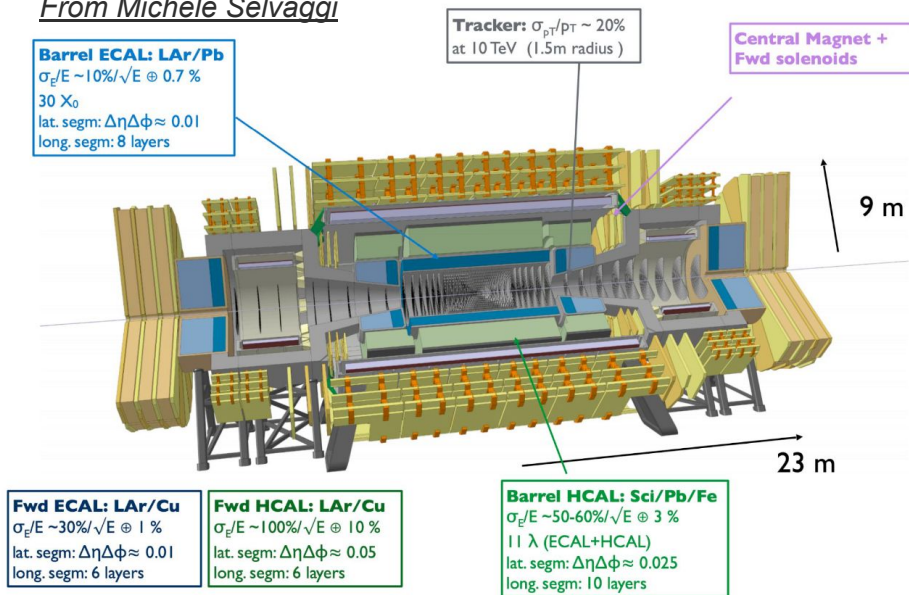- The k4SimDelphes tool allows us to run Pythia8 and Delphes in one step
- Two current Delphes scenarios for FCC-hh:
  - Scenario I: Idealistic scenario for ultimate precision
  - Scenario II: Baseline scenario based on FCC-hh detector concept from CDR
- Large scale productions run with the EventProducer framework and will be available in official database

EDM4hep data model

EDM4hep DataModel Overview (v0.99)
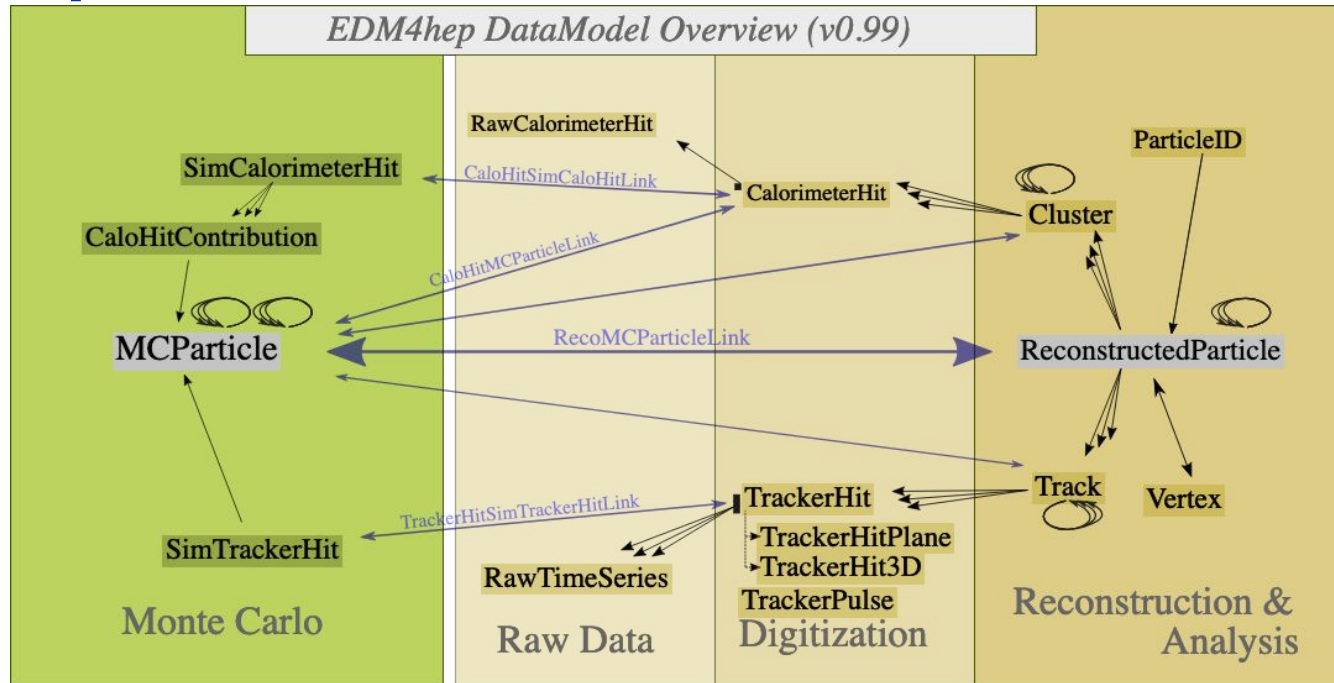
"A generic event data model for future HEP collider experiments"

But how do we analyse it? Could read directly, but existing FW FCCAnalyses handles it for us

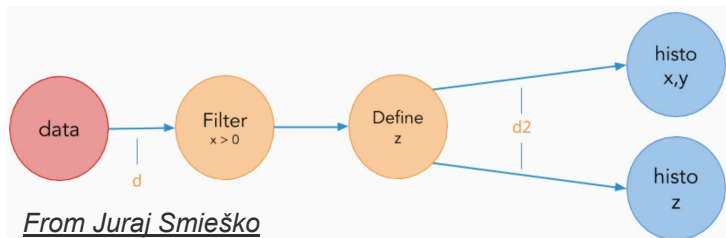# FCCAnalyses framework

From Juraj Smieško

```
# Mandatory: analyzers function to define the analysis graph, please make
# sure you return the dataframe, in this example it is dframe2
def analyzers(self, dframe):
    '''
    Analysis graph.
    '''

    dframe2 = (
        dframe

        .Define("weight",  "EventHeader.weight")

        ################################# PHOTONS #################################

        .Define("gamma",  "FCCAnalyses::ReconstructedParticle::get(Photon_objIdx.index, ReconstructedParticles)")
        .Define("selpt_gamma", "FCCAnalyses::ReconstructedParticle::sel_pt(30.)(gamma)")
        .Define("sel_gamma_unsort", "FCCAnalyses::ReconstructedParticle::sel_eta(4)(selpt_gamma)")
        .Define("sel_gamma", "AnalysisFCChh::SortParticleCollection(sel_gamma_unsort)") #sort by pT

        .Define("ngamma",  "FCCAnalyses::ReconstructedParticle::get_n(sel_gamma)")
        .Define("g1_e",   "FCCAnalyses::ReconstructedParticle::get_e(sel_gamma)[0]")
        .Define("g1_pt",  "FCCAnalyses::ReconstructedParticle::get_pt(sel_gamma)[0]")
        .Define("g1_eta", "FCCAnalyses::ReconstructedParticle::get_eta(sel_gamma)[0]")
        .Define("g1_phi", "FCCAnalyses::ReconstructedParticle::get_phi(sel_gamma)[0]")
        .Define("g2_e",   "FCCAnalyses::ReconstructedParticle::get_e(sel_gamma)[1]")
        .Define("g2_pt",  "FCCAnalyses::ReconstructedParticle::get_pt(sel_gamma)[1]")
        .Define("g2_eta", "FCCAnalyses::ReconstructedParticle::get_eta(sel_gamma)[1]")
        .Define("g2_phi", "FCCAnalyses::ReconstructedParticle::get_phi(sel_gamma)[1]")
```

- FCCAnalyses is a common software framework to analyse EDM4hep events using ROOT's RDataframe

  - Build an "analysis graph" with very simple syntax in python code

  - C++ libraries for the complex computations

  - Examples and tutorials available here

- Additions for FCC-hh analyses to come:

  - Using generator event weights, reading heavy flavour tagging from Delphes

Resources and current documentation status

- Key4hep is a software project under constant development - rely on fixed releases of the software stack, with major updates happening in between
  - Currently the transition to EDM4hep v1 is ongoing, introducing some breaking changes w.r.t. previous versions e.g. name changes, reversing of object links
- For new FCC-hh studies we would like to switch to this new release, working on updating the code & documentation to provide a working example
  - Unfortunately physics was not invariant under release update :(
- Also investigating how to run the event generation step within the key4hep ecosystem

Summary

- Standard FCC-hh fast simulation study workflow relies on the key4hep software stack, as well as common FCC software tools
  - Main players: k4SimDelphes, EventProducer, FCCAnalyses
- All information for FCC-hh physics & performance studies summarized on this page
  - Still under development, please reach out with any feedback!
  - Up-to-date quick start example to come a.s.a. release update issues resolved
  - Planning a large scale EDM4hep event production fcc_v06, if you have any requests for samples you need for your studies please get in touch
- Physics & performance FCC-hh working meetings planned on Thursdays, 4PM
  - Planned to start on 10.10, but due to ECFA workshop exceptionally 17.10 instead?
  - Mailing list: fcc-ped-hh-physicsperformance-espp25@cern.ch

Thank you!

What did we use for the HH studies?

Event generation

Generators: MG5_aMC, v 2.5.X (bkgs), POWHEG-BOX-V2 (sig)
PDF sets: NN23LO1, NNPDF30_nlo_as_0118 from LHAPDF v6.1.6
Production framework: EventProducer from my fork, using custom key4hep release "2023-06-05-fcchh"

Detector simulation

Delphes cards: Scenario I & II
Framework: Same EventProducer setup as above
Production Tags: fcc_v05_scenarioI, fcc_v05_scenarioII

Samples (EDM4HEP)

Edm4hep status: Pre- official v1 release, v00-08

Physics analysis & statistical interpretation

Analysis framework: FCCAnalyses from my fork, with many custom fixes and additions, branched off in July 2023