COFFEA-FCC

Build schema class for FCC simulation samples in COFFEA and develop some example based on that

Prayag Yadav ➚
HSF-India
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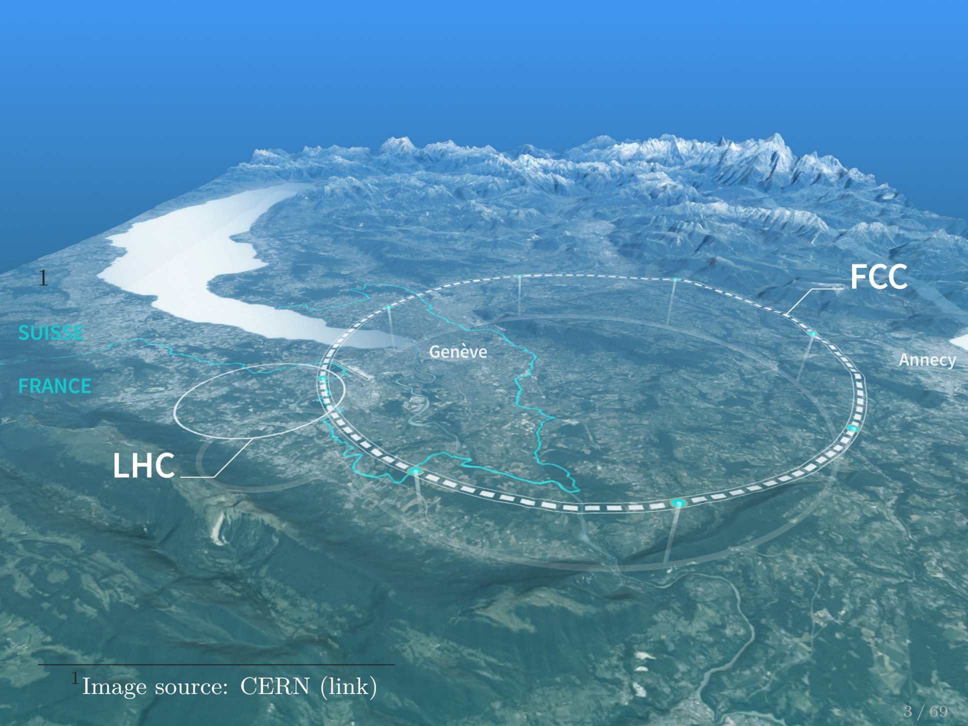
Guided by Dr. David Lange and Dr. Bhawna Gomber

Outline



[1] Image source: CERN (link)

Future Circular Collider

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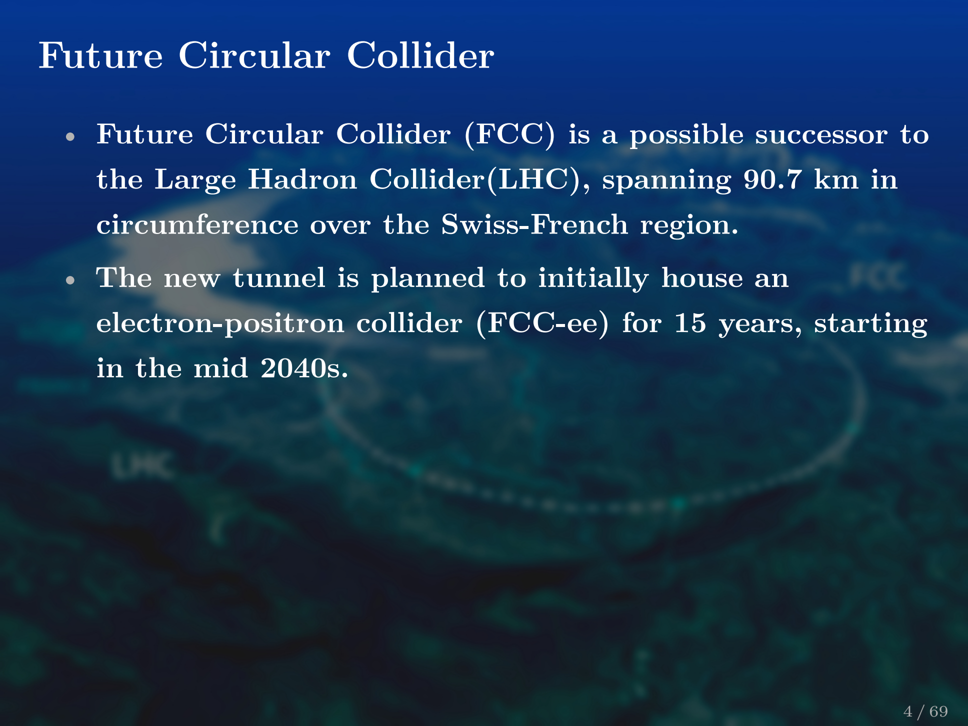

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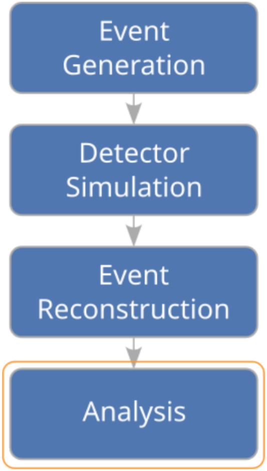
- Expect precision measurements of Higgs properties and BSM Physics

FCCAnalyses

- **FCCAnalyses** [2] is a common framework used for FCC related analyses
- It's an **RDataFrame** framework that utilises input from the user in the form of configuration python scripts.
- It takes in "**EDM4HEP**" root files, creates an RDataFrame, performs calculation on the dataframe as defined by the user and then saves histograms.
- Find an example in upcoming slides

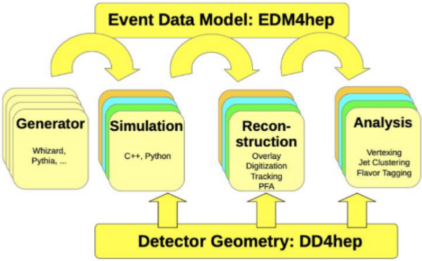


[3]

[2] FCCSW Team
[3] Juraj Smieško for FCC Week 2023

Event Data Model: EDM4HEP

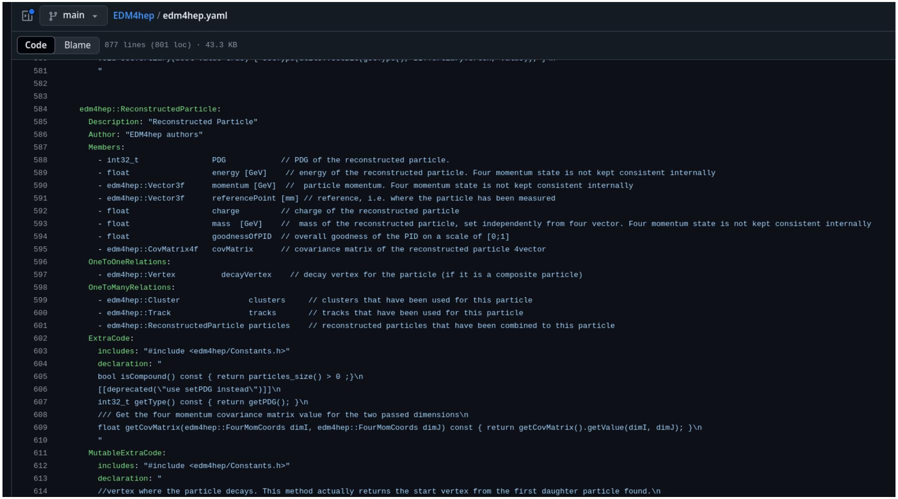
- **EDM4HEP** [4] is a type of event data format that is used for FCC **event data storage** in a root file.
- Event data, generated with **podio**[5], is described by a set of standard objects, defined in a single **yaml file**.
- EDM4HEP, FCCAnalyses, podio and other useful software are shipped in the **KEY4HEP software stack**.



[6]

[4] key4hep/edm4hep
[5] key4hep/podio
[6] Juraj Smieško for FCC Week 2023

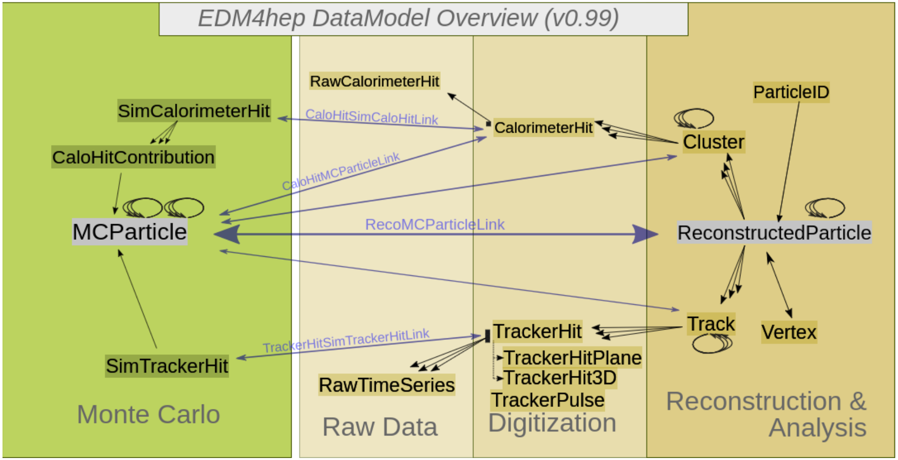
EDM4HEP yaml description


main
EDM4hep / edm4hep.yaml
Code Blame 877 lines (801 loc) · 43.3 KB

```yaml
      "


  edm4hep::ReconstructedParticle:
    Description: "Reconstructed Particle"
    Author: "EDM4hep authors"
    Members:
      - int32_t                PDG            // PDG of the reconstructed particle.
      - float                  energy [GeV]    // energy of the reconstructed particle. Four momentum state is not kept consistent internally
      - edm4hep::Vector3f      momentum [GeV]  //  particle momentum. Four momentum state is not kept consistent internally
      - edm4hep::Vector3f      referencePoint [mm] // reference, i.e. where the particle has been measured
      - float                  charge         // charge of the reconstructed particle
      - float                  mass  [GeV]    //  mass of the reconstructed particle, set independently from four vector. Four momentum state is not kept consistent internally
      - float                  goodnessOfPID  // overall goodness of the PID on a scale of [0;1]
      - edm4hep::CovMatrix4f   covMatrix      // covariance matrix of the reconstructed particle 4vector
    OneToOneRelations:
      - edm4hep::Vertex          decayVertex    // decay vertex for the particle (if it is a composite particle)
    OneToManyRelations:
      - edm4hep::Cluster               clusters     // clusters that have been used for this particle
      - edm4hep::Track                 tracks       // tracks that have been used for this particle
      - edm4hep::ReconstructedParticle particles    // reconstructed particles that have been combined to this particle
    ExtraCode:
      includes: "#include <edm4hep/Constants.h>"
      declaration: "
      bool isCompound() const { return particles_size() > 0 ;}\n
      [[deprecated(\"use setPDG instead\")]]\n
      int32_t getType() const { return getPDG(); }\n
      /// Get the four momentum covariance matrix value for the two passed dimensions\n
      float getCovMatrix(edm4hep::FourMomCoords dimI, edm4hep::FourMomCoords dimJ) const { return getCovMatrix().getValue(dimI, dimJ); }\n
      "
    MutableExtraCode:
      includes: "#include <edm4hep/Constants.h>"
      declaration: "
      //vertex where the particle decays. This method actually returns the start vertex from the first daughter particle found.\n
```

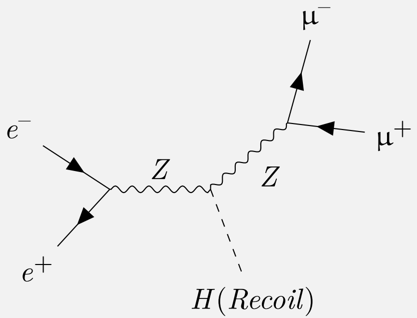
EDM4HEP relation graph



An example analysis: ZH recoil (or mHrecoil)

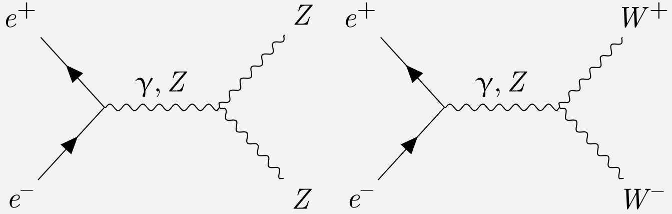
The Signal

$$e^+e^- \to ZH \to \mu^+\mu^- + X$$



An example analysis: ZH recoil (or mHrecoil)

Major Backgrounds



How is this analysis done in fccanalysis?

Setup various path variables

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

ZH-$\mu^+\mu^-$ recoil example

```
fccanalysis run examples/FCCee/higgs/mH-recoil/mumu/analysis_stage1.py
fccanalysis run examples/FCCee/higgs/mH-recoil/mumu/analysis_stage2.py
fccanalysis final examples/FCCee/higgs/mH-recoil/mumu/analysis_final.py
fccanalysis plots examples/FCCee/higgs/mH-recoil/mumu/analysis_plots.py
```

- analysis_stage1.py is for first preselection stage
- analysis_stage2.py is for the second preselection stage
- analysis_final.py is for the final selections
- analysis_plots.py is to generate plots

Selections

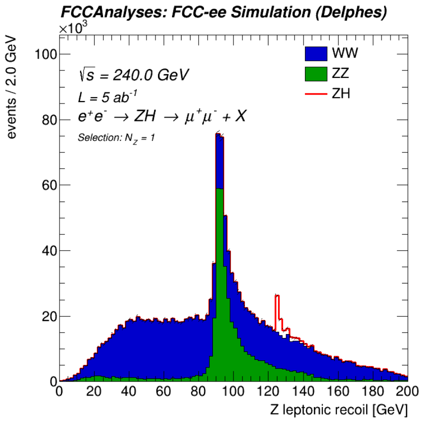
analysis_stage1.py

- Gather Muons: Match muon index with reconstructed particles
- Compute arrays (columns for RDF) to get Muon pt, eta, energy(p)
- Compute arrays of Z objects(Dimuon)(Require mass near 91 GeV)
- Compute Z p_T , η, recoil

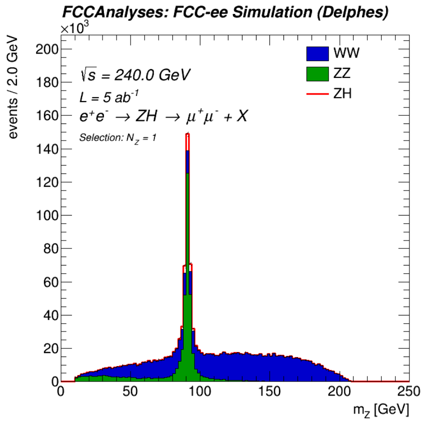
analysis_stage2.py

- Select events with exactly one Z candidate
- Get Z p_T , η, recoil mass, charge
- Compute a filtered column with $80 GeV < Z_{mass} < 100 GeV$

Plots



Recoil mass



Z candidate mass

COFFEA

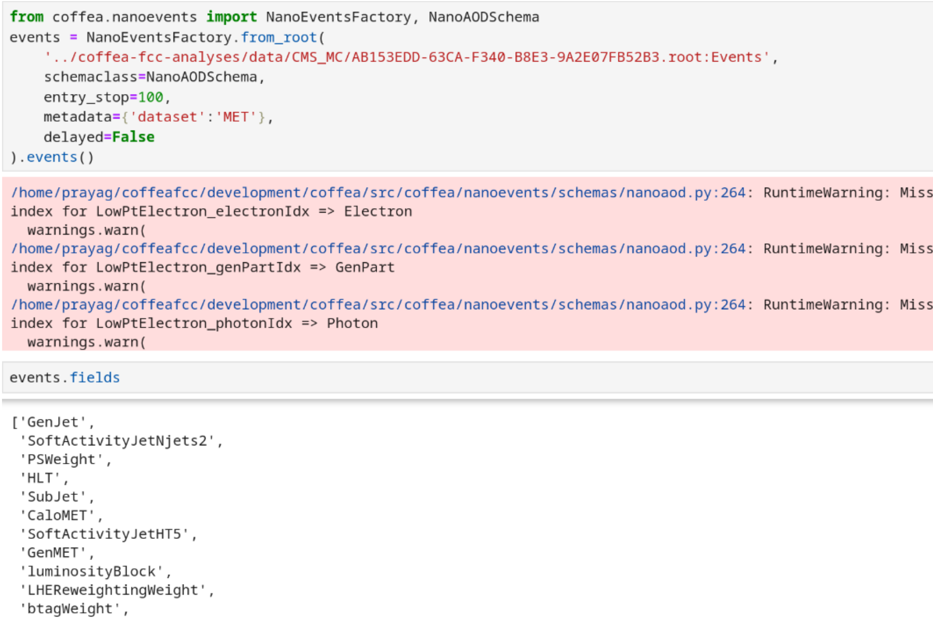
- **Columnar Object Framework For Effective Analysis (COFFEA)**[7] is a python package that unifies all the necessary HEP scientific python packages for a HEP analysis.

[7] COFFEA Docs

COFFEA and the Python ecosystem

- **Uproot** to read and write root files.
- **Awkward Array** to manipulate HEP data in a numpythonic way.
- **Dask** to for scaling-out
- **Hist** for histogramming
- **MPLHEP** for plotting
- **Numba** for just-in-time compilation
- and other useful packages ...

COFFEA: In the field [1]



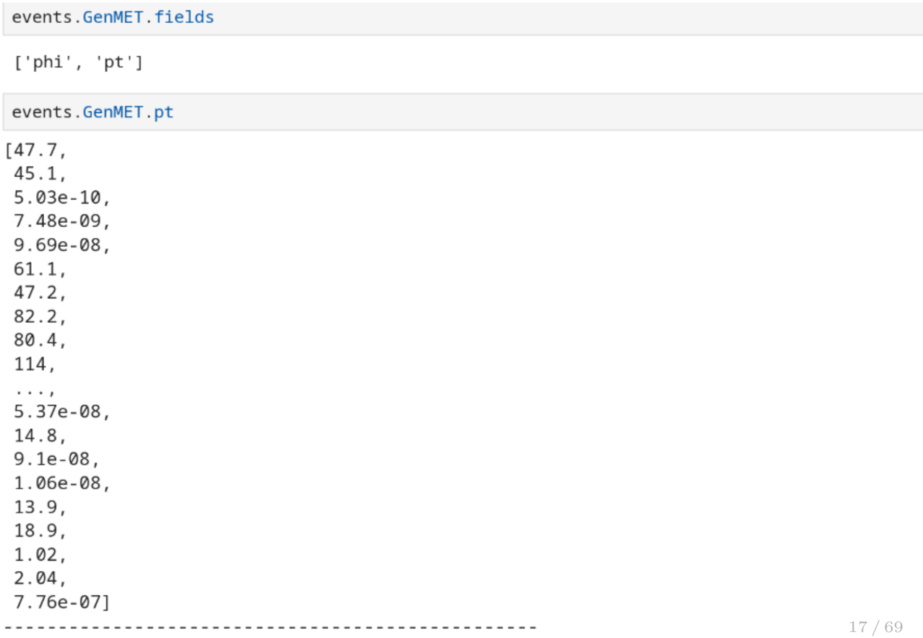
```
from coffea.nanoevents import NanoEventsFactory, NanoAODSchema
events = NanoEventsFactory.from_root(
    '../coffea-fcc-analyses/data/CMS_MC/AB153EDD-63CA-F340-B8E3-9A2E07FB52B3.root:Events',
    schemaclass=NanoAODSchema,
    entry_stop=100,
    metadata={'dataset':'MET'},
    delayed=False
).events()
```

```
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/schemas/nanoaod.py:264: RuntimeWarning: Miss
index for LowPtElectron_electronIdx => Electron
  warnings.warn(
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/schemas/nanoaod.py:264: RuntimeWarning: Miss
index for LowPtElectron_genPartIdx => GenPart
  warnings.warn(
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/schemas/nanoaod.py:264: RuntimeWarning: Miss
index for LowPtElectron_photonIdx => Photon
  warnings.warn(
```

```
events.fields
```

```
['GenJet',
 'SoftActivityJetNjets2',
 'PSWeight',
 'HLT',
 'SubJet',
 'CaloMET',
 'SoftActivityJetHT5',
 'GenMET',
 'luminosityBlock',
 'LHEReweightingWeight',
 'btagWeight',
```

COFFEA: In the field [2]



```
events.GenMET.fields
```

```
['phi', 'pt']
```

```
events.GenMET.pt
```

```
[47.7,
 45.1,
 5.03e-10,
 7.48e-09,
 9.69e-08,
 61.1,
 47.2,
 82.2,
 80.4,
 114,
 ...,
 5.37e-08,
 14.8,
 9.1e-08,
 1.06e-08,
 13.9,
 18.9,
 1.02,
 2.04,
 7.76e-07]
-------------------------------------------------
```

Schema

- COFFEA supports **schemas** for reading data efficiently. A schema **builds collection of branches, adds helper functions and describe relations between different branches**.
- A **base schema** is provided that reads any columnar dataformat. However a format specific schema can be used to make it easier for users to read data and use it in their analysis.

Available schema
BaseSchema
DelphesSchema
FCCSchema
TreeMakerSchema
PHYSLITESchema
PFNanoAODSchema
NanoAODSchema
ScoutingNanoAODSchema
PDUNESchema

Structure of a Schema class

What is a collection?

A **Collection** is a group of essentially a group branches. Eg. `ReconstructedParticle.energy`, `ReconstructedParticle.charge`, etc can be **'zipped'** together to form the `ReconstructedParticle` collection.

A Schema has three important methods:

- $\rightarrow$ `__init__`, where `_build_collections(args...)` is called to update `_form`.
- $\rightarrow$ `_build_collections`, that collects branches, creates LorentzVectors and collections of branches
- $\rightarrow$ `behavior` (classmethod) , that imports behavior (special functionality) from methods directory

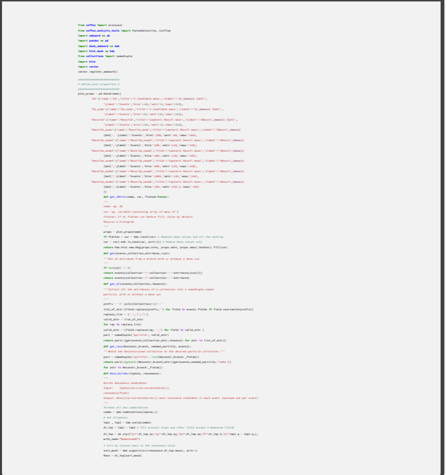
ZH Recoil example with BaseSchema

- It is possible to perform an FCC analysis using the base schema, but it requires a lot of code for putting together collections by hand.
- BaseSchema is the default schema in COFFEA, that provides each branch as a field, without building collections.
- The ZH-Recoil example can be written purely in python with COFFEA and BaseSchema.

BaseSchema Processor

[8]

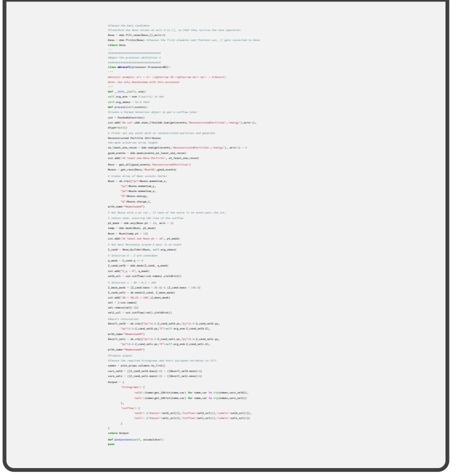
python code (1)



```python
from coffea import processor
from coffea.analysis_tools import PackedSelection, Cutflow
import awkward as ak
import pandas as pd
import dask_awkward as dak
import hist.dask as hda
from collections import namedtuple
import hist
import vector
vector.register_awkward()

##########################
# Define plot properties #
##########################
plot_props = pd.DataFrame({
        'Zm':{'name':'Zm','title':'Z Candidate mass','xlabel':'$Z_{mass}$ [GeV]',
                'ylabel':'Events','bins':100,'xmin':0,'xmax':250},
        'Zm_zoom':{'name':'Zm_zoom','title':'Z Candidate mass','xlabel':'$Z_{mass}$ [GeV]',
                'ylabel':'Events','bins':40,'xmin':80,'xmax':100},
        'Recoilm':{'name':'Recoilm','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$ [GeV]',
                'ylabel':'Events','bins':100,'xmin':0,'xmax':200},
        'Recoilm_zoom':{'name':'Recoilm_zoom','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]', 'ylabel':'Events','bins':200,'xmin':80,'xmax':160},
        'Recoilm_zoom2':{'name':'Recoilm_zoom2','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]','ylabel':'Events','bins':200,'xmin':120,'xmax':140},
        'Recoilm_zoom3':{'name':'Recoilm_zoom3','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]','ylabel':'Events','bins':400,'xmin':120,'xmax':140},
        'Recoilm_zoom4':{'name':'Recoilm_zoom4','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]','ylabel':'Events','bins':800,'xmin':120,'xmax':140},
        'Recoilm_zoom5':{'name':'Recoilm_zoom5','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]','ylabel':'Events','bins':2000,'xmin':120,'xmax':140},
        'Recoilm_zoom6':{'name':'Recoilm_zoom6','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]','ylabel':'Events','bins':100,'xmin':130.3,'xmax':140}
                })
                def get_1Dhist(name, var, flatten=False):
                '''
                name: eg. Zm
                var: eg. variable containing array of mass of Z
                flatten: If to flatten var before fill; False by default
                Returns a histogram
                '''
                props = plot_props[name]
                if flatten : var = dak.ravel(var) # Removes None values and all the nesting
                var = var[~dak.is_none(var, axis=0)] # Remove None values only
                return hda.Hist.new.Reg(props.bins, props.xmin, props.xmax).Double().fill(var)
                def get(events,collection,attribute,*cut):
                '''Get an attribute from a branch with or without a base cut.
                '''
                if len(cut) != 0:
                return events[collection+'/'+collection+'.'+attribute][cut[0]]
                return events[collection+'/'+collection+'.'+attribute]
                def get_all(events,Collection,*basecut):
                '''Collect all the attributes of a collection into a namedtuple named
                particle, with or without a base cut
                '''
                prefix = '/'.join([Collection]*2)+'.'
                list_of_attr=[field.replace(prefix,'') for field in events.fields if field.startswith(prefix)]
                replace_list = ['.','[',']']
                valid_attr = list_of_attr
                for rep in replace_list:
                valid_attr = [field.replace(rep, '_') for field in valid_attr ]
                part = namedtuple('particle', valid_attr)
                return part(*[get(events,Collection,attr,*basecut) for attr in list_of_attr])
                def get_reco(Reconstr_branch, needed_particle, events):
                '''Match the Reconstructed collection to the desired particle collection.'''
                part = namedtuple('particle', list(Reconstr_branch._fields))
                return part(*[getattr(Reconstr_branch,attr)[get(events,needed_particle,'index')]
                for attr in Reconstr_branch._fields])
                def Reso_builder(lepton, resonance):
                '''
                Builds Resonance candidates
                Input:    lepton(var*[var*LorentzVector]),
                resonance(float)
                Output: Reso([var*LorentzVecctor]) best resonance candidate in each event (maximum one per event)
                '''
                #Create all the combinations
                combs = dak.combinations(lepton,2)
                # Get dileptons
                lep1 , lep2 = dak.unzip(combs)
                di_lep = lep1 + lep2 # This process drops any other field except 4 momentum fields
                di_lep = ak.zip({"px":di_lep.px,"py":di_lep.py,"pz":di_lep.pz,"E":di_lep.E,"q":lep1.q + lep2.q,},
                with_name="Momentum4D")
                # Sort by closest mass to the resonance value
                sort_mask = dak.argsort(abs(resonance-di_lep.mass), axis=1)
                Reso = di_lep[sort_mask]
```

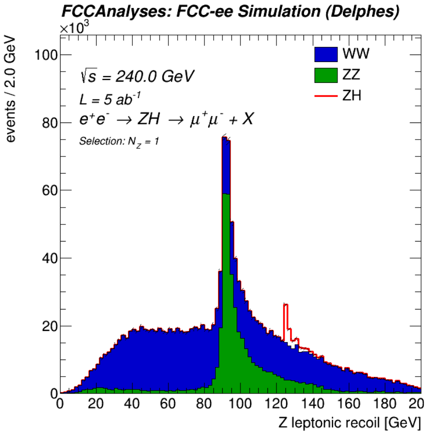
python code (2)



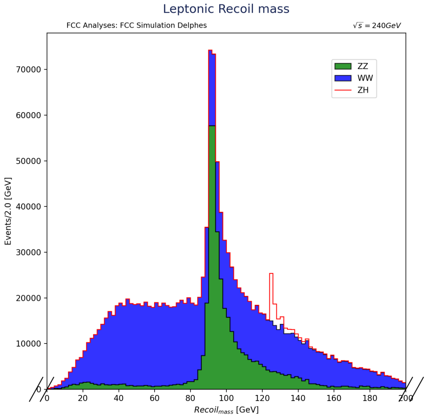
```python
#Choose the best candidate
#Transform the None values at axis 0 to [], so that they survive the next operation
Reso = dak.fill_none(Reso,[],axis=0)
Reso = dak.firsts(Reso) #Chooses the first elements and flattens out, [] gets converted to None
return Reso
'''
#################################
#Begin the processor definition #
#################################
class mHrecoil(processor.ProcessorABC):
'''
mHrecoil example: e^+ + e^- rightarrow ZH rightarrow mu^+ mu^- + X(Recoil)
Note: Use only BaseSchema with this processor
'''
def __init__(self, ecm):
self.arg_ecm = ecm #\sqrt(s) in GeV
self.arg_zmass = 91.0 #GeV
def process(self,events):
#Create a Packed Selection object to get a cutflow later
cut = PackedSelection()
cut.add('No cut',dak.ones_like(dak.num(get(events,'ReconstructedParticles','energy'),axis=1),
dtype=bool))
# Filter out any event with no reconstructed particles and generate
Reconstructed Particle Attributes
#ak.mask preserves array length
at_least_one_recon = dak.num(get(events,'ReconstructedParticles','energy'), axis=1) > 0
good_events = dak.mask(events,at_least_one_recon)
cut.add('At least one Reco Particle', at_least_one_recon)
Reco = get_all(good_events,'ReconstructedParticles')
Muons = get_reco(Reco,'Muon#0',good_events)
# Create Array of Muon Lorentz Vector
Muon = ak.zip({"px":Muons.momentum_x,
        "py":Muons.momentum_y,
        "pz":Muons.momentum_z,
        "E":Muons.energy,
        "q":Muons.charge,},
with_name="Momentum4D")
# Get Muons with a pt cut , if none of the muons in an event pass the cut,
# return none, ensuring the size of the cutflow
pt_mask = dak.any(Muon.pt > 10, axis = 1)
temp = dak.mask(Muon, pt_mask)
Muon = Muon[temp.pt > 10]
cut.add('At least one Muon pt > 10', pt_mask)
# Get best Resonance around Z mass in an event
Z_cand = Reso_builder(Muon, self.arg_zmass)
# Selection 0 : Z q=0 candidate
q_mask = Z_cand.q == 0
Z_cand_sel0 = dak.mask(Z_cand, q_mask)
cut.add("Z_q = 0", q_mask)
sel0_ocl = cut.cutflow(*cut.names).yieldhist()
# Selection 1 : 80 < M_Z < 100
Z_mass_mask = (Z_cand.mass > 80.0) & (Z_cand.mass < 100.0)
Z_cand_sel1 = ak.mask(Z_cand, Z_mass_mask)
cut.add('80 < $M_Z$ < 100',Z_mass_mask)
sel = [*cut.names]
sel.remove(sel[-2])
sel1_ocl = cut.cutflow(*sel).yieldhist()
#Recoil Calculation
Recoil_sel0 = ak.zip({"px":0.0-Z_cand_sel0.px,"py":0.0-Z_cand_sel0.py,
        "pz":0.0-Z_cand_sel0.pz,"E":self.arg_ecm-Z_cand_sel0.E},
with_name="Momentum4D")
Recoil_sel1 = ak.zip({"px":0.0-Z_cand_sel1.px,"py":0.0-Z_cand_sel1.py,
        "pz":0.0-Z_cand_sel1.pz,"E":self.arg_ecm-Z_cand_sel1.E},
with_name="Momentum4D")
#Prepare output
#Choose the required histograms and their assigned variables to fill
names = plot_props.columns.to_list()
vars_sel0 = ([Z_cand_sel0.mass]*2) + ([Recoil_sel0.mass]*8)
vars_sel1 = ([Z_cand_sel1.mass]*2) + ([Recoil_sel1.mass]*8)
Output = {
        'histograms': {
                'sel0':{name:get_1Dhist(name,var) for name,var in zip(names,vars_sel0)},
                'sel1':{name:get_1Dhist(name,var) for name,var in zip(names,vars_sel1)}
        },
        'cutflow': {
                'sel0': {'Onecut':sel0_ocl[0],'Cutflow':sel0_ocl[1],'Labels':sel0_ocl[2]},
                'sel1': {'Onecut':sel1_ocl[0],'Cutflow':sel1_ocl[1],'Labels':sel1_ocl[2]}
        }
}
return Output
def postprocess(self, accumulator):
pass
```

[8] Full, visible code in backup slides

Plots: Selection 0 : Recoil mass

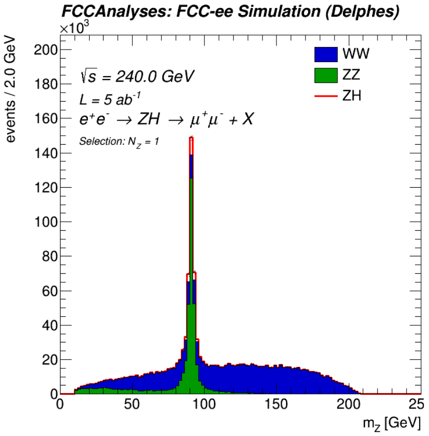


FCCAnalyses

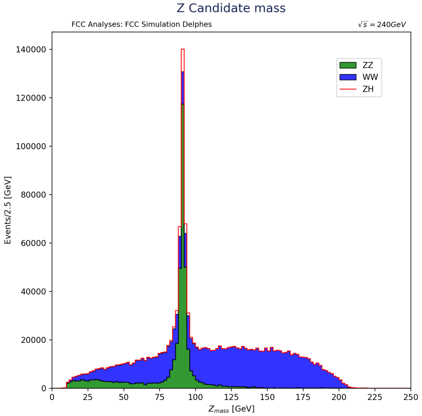


COFFEA

Plots: Selection 0 : Z candidate mass



FCCAnalyses



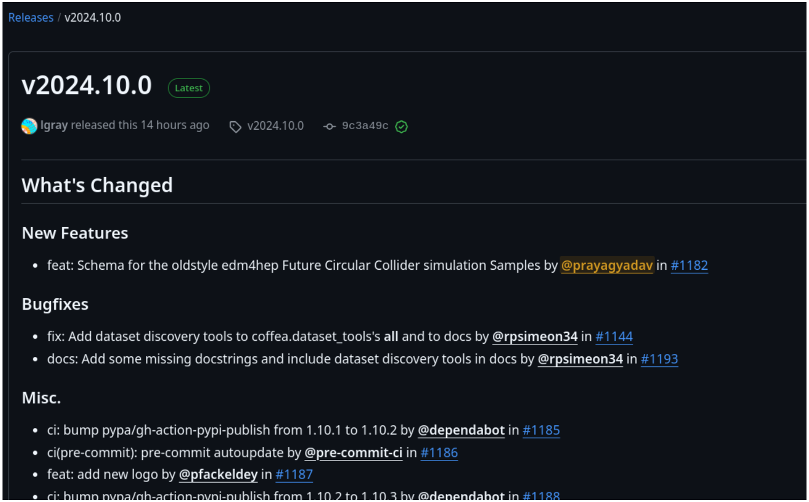
COFFEA

FCCSchema

- The schema used for edm4hep root files has recently undergone a substantial backwards incompatible change (edm4hep v1.0). Both "old" and "new" samples are in use.
- Pregenerated samples from datasets: **Spring2021** and **Winter2023** have the oldstyle edm4hep root structure.
- A schema to interpret those files, has been developed by me, building all the necessary collections and relations

FCCSchema merged

- Oldstyle EDM4HEP FCCSchema available from coffea version 2024.10.0



Releases / v2024.10.0

v2024.10.0 Latest

lgray released this 14 hours ago v2024.10.0 9c3a49c

What's Changed

New Features

- feat: Schema for the oldstyle edm4hep Future Circular Collider simulation Samples by @prayagyadav in #1182

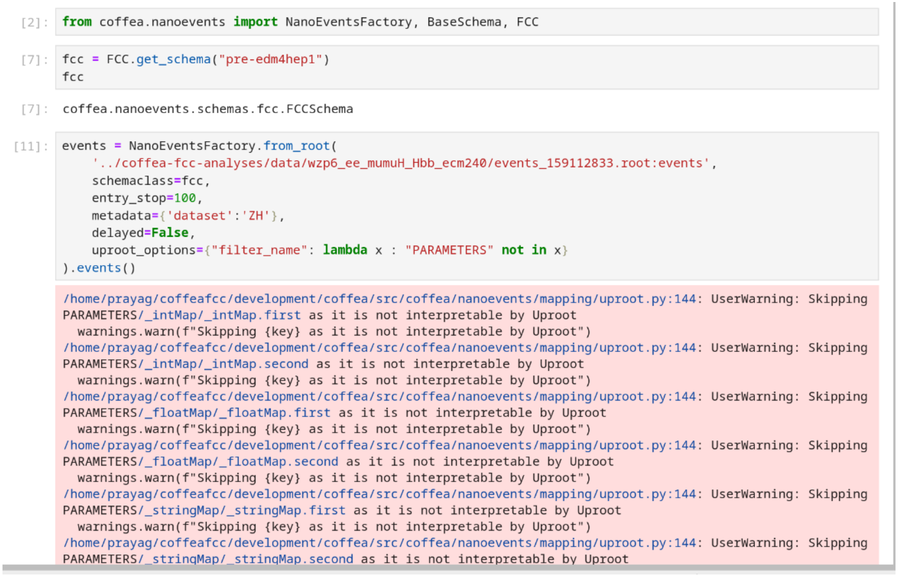
Bugfixes

- fix: Add dataset discovery tools to coffea.dataset_tools's **all** and to docs by @rpsimeon34 in #1144
- docs: Add some missing docstrings and include dataset discovery tools in docs by @rpsimeon34 in #1193

Misc.

- ci: bump pypa/gh-action-pypi-publish from 1.10.1 to 1.10.2 by @dependabot in #1185
- ci(pre-commit): pre-commit autoupdate by @pre-commit-ci in #1186
- feat: add new logo by @pfackeldey in #1187
- ci: bump pypa/gh-action-pypi-publish from 1.10.2 to 1.10.3 by @dependabot in #1188

FCCSchema in action



```
[2]: from coffea.nanoevents import NanoEventsFactory, BaseSchema, FCC
```

```
[7]: fcc = FCC.get_schema("pre-edm4hep1")
     fcc
```

```
[7]: coffea.nanoevents.schemas.fcc.FCCSchema
```

```
[11]: events = NanoEventsFactory.from_root(
          '../coffea-fcc-analyses/data/wzp6_ee_mumuH_Hbb_ecm240/events_159112833.root:events',
          schemaclass=fcc,
          entry_stop=100,
          metadata={'dataset':'ZH'},
          delayed=False,
          uproot_options={"filter_name": lambda x : "PARAMETERS" not in x}
      ).events()
```

```
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/mapping/uproot.py:144: UserWarning: Skipping
PARAMETERS/_intMap/_intMap.first as it is not interpretable by Uproot
  warnings.warn(f"Skipping {key} as it is not interpretable by Uproot")
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/mapping/uproot.py:144: UserWarning: Skipping
PARAMETERS/_intMap/_intMap.second as it is not interpretable by Uproot
  warnings.warn(f"Skipping {key} as it is not interpretable by Uproot")
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/mapping/uproot.py:144: UserWarning: Skipping
PARAMETERS/_floatMap/_floatMap.first as it is not interpretable by Uproot
  warnings.warn(f"Skipping {key} as it is not interpretable by Uproot")
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/mapping/uproot.py:144: UserWarning: Skipping
PARAMETERS/_floatMap/_floatMap.second as it is not interpretable by Uproot
  warnings.warn(f"Skipping {key} as it is not interpretable by Uproot")
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/mapping/uproot.py:144: UserWarning: Skipping
PARAMETERS/_stringMap/_stringMap.first as it is not interpretable by Uproot
  warnings.warn(f"Skipping {key} as it is not interpretable by Uproot")
/home/prayag/coffeafcc/development/coffea/src/coffea/nanoevents/mapping/uproot.py:144: UserWarning: Skipping
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```
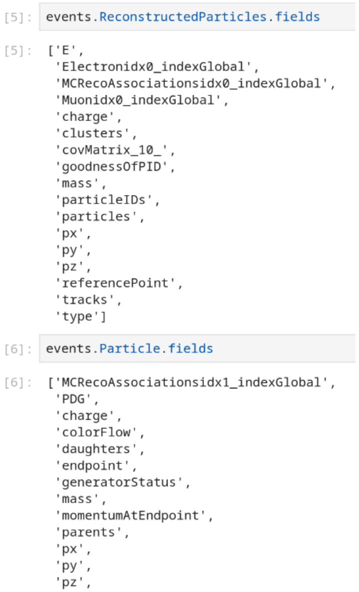
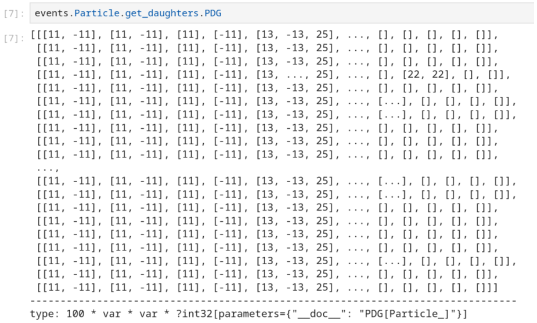

FCCSchema in action



```
[5]:  events.ReconstructedParticles.fields

[5]:  ['E',
       'Electronidx0_indexGlobal',
       'MCRecoAssociationsidx0_indexGlobal',
       'Muonidx0_indexGlobal',
       'charge',
       'clusters',
       'covMatrix_10_',
       'goodnessOfPID',
       'mass',
       'particleIDs',
       'particles',
       'px',
       'py',
       'pz',
       'referencePoint',
       'tracks',
       'type']

[6]:  events.Particle.fields

[6]:  ['MCRecoAssociationsidx1_indexGlobal',
       'PDG',
       'charge',
       'colorFlow',
       'daughters',
       'endpoint',
       'generatorStatus',
       'mass',
       'momentumAtEndpoint',
       'parents',
       'px',
       'py',
       'pz',
```



```
[7]:  events.Particle.get_daughters.PDG

[7]:  [[[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, ..., 25], ..., [], [22, 22], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [...], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [...], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       ...,
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [...], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [...], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [...], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []],
       [[11, -11], [11, -11], [11], [-11], [13, -13, 25], ..., [], [], [], [], []]]
      -----------------------------------------------------------------------------
      type: 100 * var * var * ?int32[parameters={"__doc__": "PDG[Particle_]"}]
```

A simple speed test

- With a simple example, lets compare the speed of FCCAnalyses and coffea-fcc-analyses
- The simple analysis will plot Z boson mass and Recoil from it, in the ZH sample. The Z boson is assumed to decay to two muons.
- FCCAnalyses works after sourcing the key4hep stack.
- COFFEA works after calling the container for the same.
- For a fair evaluation, lets time both of them, after the stack or container is loaded (as it needs to be done only once per session)

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Speed Test

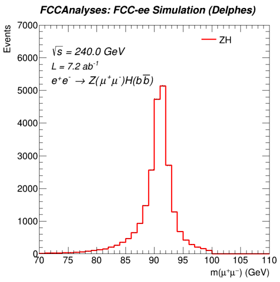
FCCAnalyses

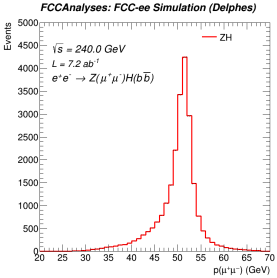
```
time fccanalyses run histmaker.py
time fccanalyses plots plots.py
```

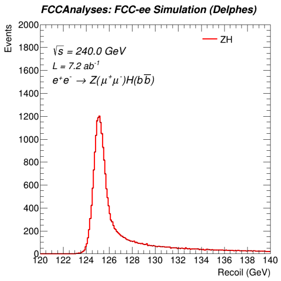
coffea-fcc-analyses

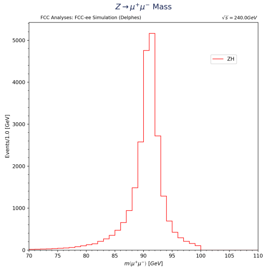
```
time python runner.py -e dask
time python plotter.py
```

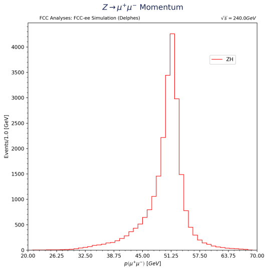
Results

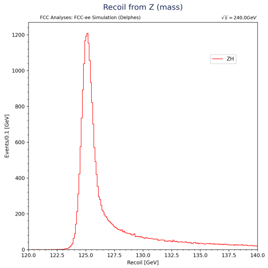












Z_{mass} Z_p $Recoil$

Results

Attempt	FCCAnalyses (sec.)		coffea-fcc-analyses (sec.)	
	run	**plots**	**runner.py**	**plotter.py**
1	22.5	10.1	14.4	5.3
2	21.9	12.6	12.7	5.3
3	19.1	10.2	12.6	5.3
4	20.2	10.5	13.0	5.3
5	19.7	10.3	13.1	5.3
Mean	20.7 ± 1.3	10.2 ± 0.2	13.1 ± 0.7	5.3 ± 0.1

- **Total time taken by FCCAnalyses:** 30.9 ± 1.5 s
- **Total time taken by coffea-fcc-analyses:** 18.4 ± 0.8 s
- Coffea with FCCSchema is around 40 % faster on this simple example. Can conclude that there is no performance problem with our Coffea implementation

A more involved example: JetClustering

- **Main Objective:** Cluster jets from their constituent reconstructed particles
- Utilizes the **FastJet** [9] library to cluster jets.
- In case of coffea, we use the python bindings[10] for FastJet.

➚ Link to the example in FCCAnalyses

➚ Link to the example in coffea-fcc-analyses

[9] https://fastjet.fr/

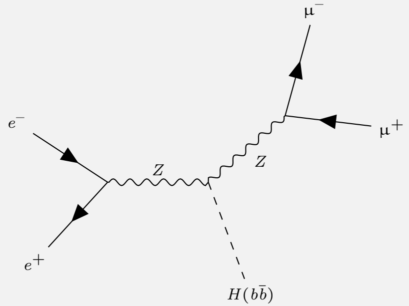
[10] https://fastjet.readthedocs.io/en/latest/

JetClustering example

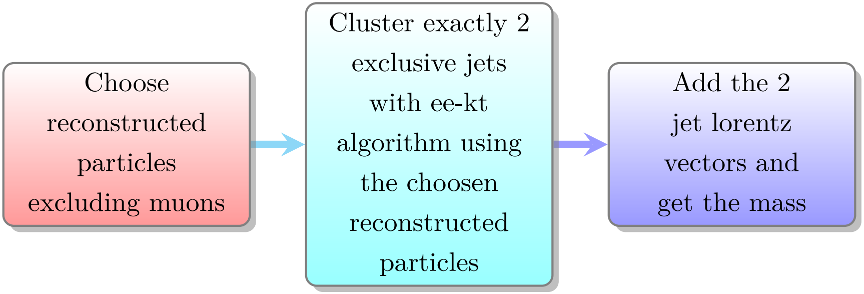
Process

Sample used : wzp6_ee_mumuH_Hbb_ecm240
Campaign : winter2023

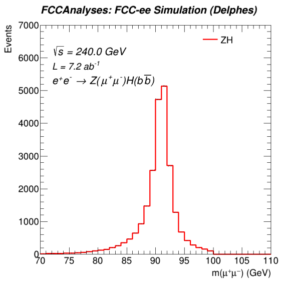
$$e^+e^- \to Z(\mu^+\mu^-)\ H(b\bar{b})$$

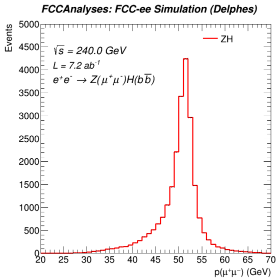


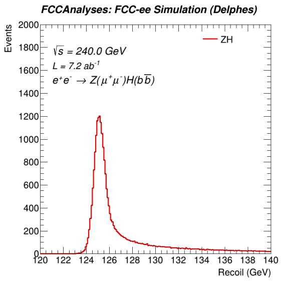
Main stages of the analysis

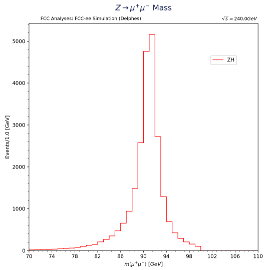

Choose reconstructed particles excluding muons
Cluster exactly 2 exclusive jets with ee-kt algorithm using the choosen reconstructed particles
Add the 2 jet lorentz vectors and get the mass

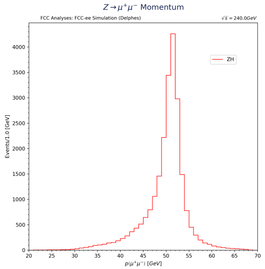
JetClustering: Z kinematics

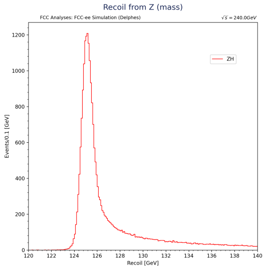






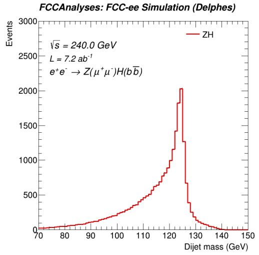


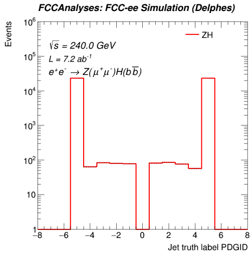


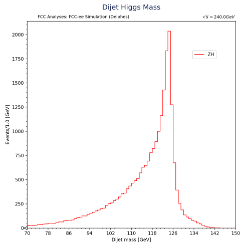


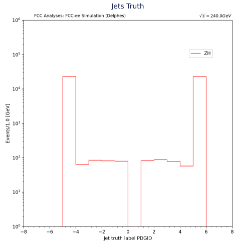
Z_{mass} $\quad$ Z_p $\quad$ $Recoil$

JetClustering: Dijet mass and Jet PDGID









$$Dijet_{mass}$$

$$Jet\ PDGID$$

Conclusion

- Developed and released the COFFEA schema for old-style EDM4HEP
- Developed examples based on the schema: ZH-Recoil example, JetClustering example and the speed tests.
- Contributed directly to the COFFEA project and learned a lot in the process.
- The repository (in development) for examples and relevant coffea tools for an analysis is also developed : coffea-fcc-analysis

Work In Progress: EDM4HEPSchema

- EDM4HEP has two main versions: Oldstyle (version < 1) and Newstyle (version $>= 1$). Currently working on creating a schema for the Newstyle EDM4HEP format.
- FCCSchema generated with the new EDM4HEP can then be easily built.

11

[11] Image from freepik

Backup Slides

About the project

HSF-India Trainee Project

Building examples for Future Circular Collider (FCC) analyses using the Columnar Framework For Effective Analysis (COFFEA) framework and developing the schema class implementation of FCC simulation samples in COFFEA [12]
July 2024 - Present

Guided by :
Dr. David Lange (Princeton University)
Dr. Bhawna Gomber (University of Hyderabad)

[12] https://research-software-collaborations.org/trainees/PrayagYadav.html

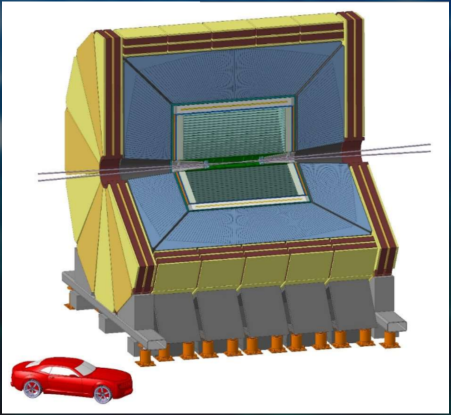
Future Circular Collider

- **Estimated cost:** Upwards of 17 Billion CHF
- **Feature:** upto 4 experiments (example: IDEA and ALLEGRO)
- **Physics outcome:** Precision measurement of Higgs and BSM physics
- **FCC Feasibility Study final results by end of 2025** [13]

[13] F. Gianotti

Future Circular Collider

- **Features:** upto 4 experiments (example: IDEA and ALLEGRO)
- **FCC Feasibility Study final results by end of 2025** [14]



IDEA concept (F. Bedeschi)

[14] F. Gianotti

FCC Analyses setup

Setup various path variables

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

Call fccanalysis python binary and use on your analysis file

```
fccanalysis run analysis_script.py
```

- Samples located at `/eos/experiment/fcc/*`
- fccanalysis binary located at repo FCCAnalyses/bin/
- analysis_script.py is a user defined script

The RDataFrame format

analysis_stage1.py

```
.
.
.
#Mandatory: RDFanalysis class where the use defines the
#operations on the TTree
class RDFanalysis():

#Mandatory: analyzer funtion to define the
#analyzer to process,
#please make sure you return the last dataframe,
# in this example it is df2
def analysers(df):
df2 = (
df
# define an alias for muon index collection
.Alias("Muon0", "Muon#0.index")
.
.
.
```

A look into the Schemas

Layout

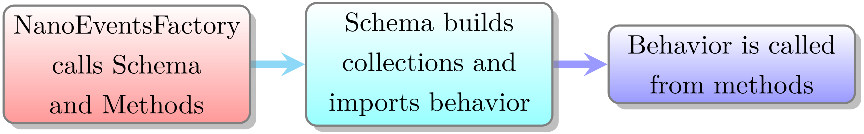
```
coffea.nanoevents/
├── factory.py     --> coffea.nanoevents.NanoEventsFactory defined here
├── __init__.py    --> imports for coffea.nanoevents
├── mapping/       --> Info on how to load samples(from_root, from_parquet etc)
├── methods/       --> Definition of mixins for various Schemas
├── schemas/       --> coffea.nanoevents.<SchemaName> defined here
├── transforms.py  --> Helper functions
└── util.py        --> Helper functions
```

What's a mixin?

A mixin class is a helper class that has no `__init__` and is merely present to add functionality to other classes. For example, Electron, Photon etc are mixin classes defined to add special functionalities to the Electron and Photon collections defined in the NanoAODSchema.

More info: `https://awkward-array.org/doc/main/reference/ak.behavior.html#mixin-decorators`

Flow of data


NanoEventsFactory calls Schema and Methods
Schema builds collections and imports behavior
Behavior is called from methods

What's a behavior?

A behavior is a dictionary of names and mixin classes and mixin methods. Instead of defining methods to each and every class.

More info: `https://awkward-array.org/doc/main/reference/ak.behavior.html`

Structure of a Schema class

- Any Schema class inherits from the `BaseSchema` class.
- `BaseSchema` provides fields and their corresponding contents, through a dictionary named `_form`
- A Schema has three important methods:
  - → `__init__`, where `_build_collections(args...)` is passed and `_form` is updated
  - → `_build_collections`, that collects branches, creates LorentzVectors and collections
  - → `behavior` (classmethod) , that imports behavior from methods

Example: NanoAODSchema

/src/coffea/nanoevents/schemas/nanoaod.py

```
class NanoAODSchema(BaseSchema):
....
def __init__(self, base_form, version="latest"):
super().__init__(base_form)
...
self._form["fields"], self._form["contents"] =
self._build_collections(
self._form["fields"], self._form["contents"]
)
...
def _build_collections(self, field_names, input_contents):
branch_forms = {k: v for k, v in zip(field_names, input_contents)}
...
@classmethod
def behavior(cls):
"""Behaviors necessary to implement this schema"""
from coffea.nanoevents.methods import nanoaod
return nanoaod.behavior
```

BaseSchema Processor

python code (1)

```
from coffea import processor
from coffea.analysis_tools import PackedSelection, Cutflow
import awkward as ak
import pandas as pd
import dask_awkward as dak
import hist.dask as hda
from collections import namedtuple
import hist
import vector
vector.register_awkward()


##########################
# Define plot properties #
##########################
plot_props = pd.DataFrame({
        'Zm':{'name':'Zm','title':'Z Candidate mass','xlabel':'$Z_{mass}$ [GeV]',
                'ylabel':'Events','bins':100,'xmin':0,'xmax':250},
        'Zm_zoom':{'name':'Zm_zoom','title':'Z Candidate mass','xlabel':'$Z_{mass}$ [GeV]',
                'ylabel':'Events','bins':40,'xmin':80,'xmax':100},
        'Recoilm':{'name':'Recoilm','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$ [GeV]',
                'ylabel':'Events','bins':100,'xmin':0,'xmax':200},
        'Recoilm_zoom':{'name':'Recoilm_zoom','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                [GeV]', 'ylabel':'Events','bins':200,'xmin':80,'xmax':160},
        ...
```

BaseSchema Processor

python code (2)

```
                ...
                'Recoilm_zoom2':{'name':'Recoilm_zoom2','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                        [GeV]','ylabel':'Events','bins':200,'xmin':120,'xmax':140},
                'Recoilm_zoom3':{'name':'Recoilm_zoom3','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                        [GeV]','ylabel':'Events','bins':400,'xmin':120,'xmax':140},
                'Recoilm_zoom4':{'name':'Recoilm_zoom4','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                        [GeV]','ylabel':'Events','bins':800,'xmin':120,'xmax':140},
                'Recoilm_zoom5':{'name':'Recoilm_zoom5','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                        [GeV]','ylabel':'Events','bins':2000,'xmin':120,'xmax':140},
                'Recoilm_zoom6':{'name':'Recoilm_zoom6','title':'Leptonic Recoil mass','xlabel':'$Recoil_{mass}$
                        [GeV]','ylabel':'Events','bins':100,'xmin':130.3,'xmax':140}
        })
        def get_1Dhist(name, var, flatten=False):
        '''
        name: eg. Zm
        var: eg. variable containing array of mass of Z
        flatten: If to flatten var before fill; False by default
        Returns a histogram
        '''
        props = plot_props[name]
        if flatten : var = dak.ravel(var) # Removes None values and all the nesting
        var = var[~dak.is_none(var, axis=0)] # Remove None values only
        return hda.Hist.new.Reg(props.bins, props.xmin, props.xmax).Double().fill(var)
        ...
```

BaseSchema Processor

python code (3)

```
...
def get(events,collection,attribute,*cut):
'''Get an attribute from a branch with or without a base cut.
'''
if len(cut) != 0:
return events[collection+'/'+collection+'.'+attribute][cut[0]]
return events[collection+'/'+collection+'.'+attribute]

def get_all(events,Collection,*basecut):
'''Collect all the attributes of a collection into a namedtuple named
particle, with or without a base cut
'''
prefix = '/'.join([Collection]*2)+'.'
list_of_attr=[field.replace(prefix,'') for field in events.fields if field.startswith(prefix)]
replace_list = ['.','[',']']
valid_attr = list_of_attr
for rep in replace_list:
valid_attr = [field.replace(rep, '_') for field in valid_attr ]
part = namedtuple('particle', valid_attr)
return part(*[get(events,Collection,attr,*basecut) for attr in list_of_attr])

def get_reco(Reconstr_branch, needed_particle, events):
'''Match the Reconstructed collection to the desired particle collection.'''
part = namedtuple('particle', list(Reconstr_branch._fields))
return part(*[getattr(Reconstr_branch,attr)[get(events,needed_particle,'index')]
for attr in Reconstr_branch._fields])
```

BaseSchema Processor

python code (4)

```python
...
def Reso_builder(lepton, resonance):
'''
Builds Resonance candidates
Input:    lepton(var*[var*LorentzVector]),
resonance(float)
Output: Reso([var*LorentzVecctor]) best resonance candidate in each event (maximum one per event)
'''
#Create all the combinations
combs = dak.combinations(lepton,2)
# Get dileptons
lep1 , lep2 = dak.unzip(combs)
di_lep = lep1 + lep2 # This process drops any other field except 4 momentum fields

di_lep = ak.zip({"px":di_lep.px,"py":di_lep.py,"pz":di_lep.pz,"E":di_lep.E,"q":lep1.q + lep2.q,},
with_name="Momentum4D")

# Sort by closest mass to the resonance value
sort_mask = dak.argsort(abs(resonance-di_lep.mass), axis=1)
Reso = di_lep[sort_mask]

#Choose the best candidate
#Transform the None values at axis 0 to [], so that they survive the next operation
Reso = dak.fill_none(Reso,[],axis=0)
Reso = dak.firsts(Reso) #Chooses the first elements and flattens out, [] gets converted to None
return Reso
```

BaseSchema Processor

python code (5)

```
...
#################################
#Begin the processor definition #
#################################
class mHrecoil(processor.ProcessorABC):
'''
mHrecoil example: e^+ + e^- rightarrow ZH rightarrow mu^+ mu^- + X(Recoil)
Note: Use only BaseSchema with this processor
'''
def __init__(self, ecm):
self.arg_ecm = ecm #\sqrt(s) in GeV
self.arg_zmass = 91.0 #GeV
def process(self,events):
#Create a Packed Selection object to get a cutflow later
cut = PackedSelection()
cut.add('No cut',dak.ones_like(dak.num(get(events,'ReconstructedParticles','energy'),axis=1),
dtype=bool))
# Filter out any event with no reconstructed particles and generate
Reconstructed Particle Attributes
#ak.mask preserves array length
at_least_one_recon = dak.num(get(events,'ReconstructedParticles','energy'), axis=1) > 0
good_events = dak.mask(events,at_least_one_recon)
cut.add('At least one Reco Particle', at_least_one_recon)

Reco = get_all(good_events,'ReconstructedParticles')
Muons = get_reco(Reco,'Muon#0',good_events)
```

BaseSchema Processor

python code (6)

```python
...
# Create Array of Muon Lorentz Vector
Muon = ak.zip({"px":Muons.momentum_x,
        "py":Muons.momentum_y,
        "pz":Muons.momentum_z,
        "E":Muons.energy,
        "q":Muons.charge,},
with_name="Momentum4D")

# Get Muons with a pt cut , if none of the muons in an event pass the cut,
# return none, ensuring the size of the cutflow
pt_mask = dak.any(Muon.pt > 10, axis = 1)
temp = dak.mask(Muon, pt_mask)
Muon = Muon[temp.pt > 10]
cut.add('At least one Muon pt > 10', pt_mask)

# Get best Resonance around Z mass in an event
Z_cand = Reso_builder(Muon, self.arg_zmass)

# Selection 0 : Z q=0 candidate
q_mask = Z_cand.q == 0
Z_cand_sel0 = dak.mask(Z_cand, q_mask)
cut.add("Z_q = 0", q_mask)
sel0_ocl = cut.cutflow(*cut.names).yieldhist()
```

BaseSchema Processor

python code (7)

```python
...
# Selection 1 : 80 < M_Z < 100
Z_mass_mask = (Z_cand.mass > 80.0) & (Z_cand.mass < 100.0)
Z_cand_sel1 = ak.mask(Z_cand, Z_mass_mask)
cut.add('80 < $M_Z$ < 100',Z_mass_mask)
sel = [*cut.names]
sel.remove(sel[-2])
sel1_ocl = cut.cutflow(*sel).yieldhist()

#Recoil Calculation
Recoil_sel0 = ak.zip({"px":0.0-Z_cand_sel0.px,"py":0.0-Z_cand_sel0.py,
        "pz":0.0-Z_cand_sel0.pz,"E":self.arg_ecm-Z_cand_sel0.E},
with_name="Momentum4D")
Recoil_sel1 = ak.zip({"px":0.0-Z_cand_sel1.px,"py":0.0-Z_cand_sel1.py,
        "pz":0.0-Z_cand_sel1.pz,"E":self.arg_ecm-Z_cand_sel1.E},
with_name="Momentum4D")

#Prepare output
#Choose the required histograms and their assigned variables to fill
names = plot_props.columns.to_list()
vars_sel0 = ([Z_cand_sel0.mass]*2) + ([Recoil_sel0.mass]*8)
vars_sel1 = ([Z_cand_sel1.mass]*2) + ([Recoil_sel1.mass]*8)
```

BaseSchema Processor

python code (8)

```
        ...
        Output = {
                'histograms': {
                        'sel0':{name:get_1Dhist(name,var) for name,var in zip(names,vars_sel0)},
                        'sel1':{name:get_1Dhist(name,var) for name,var in zip(names,vars_sel1)}
                },
                'cutflow': {
                        'sel0': {'Onecut':sel0_ocl[0],'Cutflow':sel0_ocl[1],'Labels':sel0_ocl[2]},
                        'sel1': {'Onecut':sel1_ocl[0],'Cutflow':sel1_ocl[1],'Labels':sel1_ocl[2]}
                }
        }
        return Output

        def postprocess(self, accumulator):
        pass
```

FCCAnalyses

- Link to the test

Graph builder part of the histmaker code(1)

```python
def build_graph(df, dataset):
results = []
df = df.Define("weight", "1.0")
weightsum = df.Sum("weight")

# select muons from Z decay and form Z/recoil mass
df = df.Alias("Muon0", "Muon#0.index")
df = df.Define("muons_all", "FCCAnalyses::ReconstructedParticle::get(Muon0, ReconstructedParticles)")
df = df.Define("muons", "FCCAnalyses::ReconstructedParticle::sel_p(25)(muons_all)")
df = df.Define("muons_p", "FCCAnalyses::ReconstructedParticle::get_p(muons)")
df = df.Define("muons_no", "FCCAnalyses::ReconstructedParticle::get_n(muons)")
df = df.Filter("muons_no >= 2")
...
```

FCCAnalyses

Graph builder part of the histmaker code(2)

```
...
df = df.Define("zmumu", "ReconstructedParticle::resonanceBuilder(91)(muons)")
df = df.Define("zmumu_m", "ReconstructedParticle::get_mass(zmumu)[0]")
df = df.Define("zmumu_p", "ReconstructedParticle::get_p(zmumu)[0]")
df = df.Define("zmumu_recoil", "ReconstructedParticle::recoilBuilder(240)(zmumu)")
df = df.Define("zmumu_recoil_m", "ReconstructedParticle::get_mass(zmumu_recoil)[0]")

# basic selection
df = df.Filter("zmumu_m > 70 && zmumu_m < 100")
df = df.Filter("zmumu_p > 20 && zmumu_p < 70")
df = df.Filter("zmumu_recoil_m < 140 && zmumu_recoil_m > 120")

# define histograms
results.append(df.Histo1D(("zmumu_m", "", *bins_m_ll), "zmumu_m"))
results.append(df.Histo1D(("zmumu_p", "", *bins_p_ll), "zmumu_p"))
results.append(df.Histo1D(("zmumu_recoil_m", "", *bins_recoil), "zmumu_recoil_m"))

return results, weightsum
```

coffea-fcc-analyses

↗ Link to the test

processor part of the code(1)

```
class speed_test(processor.ProcessorABC):
'''
Processor: Define actual calculations here
'''
def __init__(self, *args, **kwargs):
pass

def process(self,events):

# Object Selections
Muons = events.ReconstructedParticles.match_collection(events.Muonidx0)
sel_muon_p_gt_25 = Muons.p > 25.0
Muons = Muons[sel_muon_p_gt_25]
Z = ReconstructedParticleUtil.resonanceBuilder(Muons, 91.0)
Recoil = ReconstructedParticleUtil.recoilBuilder(Z, 240.0)
...
```

coffea-fcc-analyses

processor part of the code(2)

```
#Event Selections
cuts = PackedSelection()
cuts.add("n_gte_2_Muons", ak.num(Muons, axis=1) >= 2 )
cuts.add("m_gt_70_Z", Z.m > 70.0 )
cuts.add("m_lt_100_Z", Z.m < 100.0 )
cuts.add("p_gt_20_Z", Z.p > 20.0 )
cuts.add("p_lt_70_Z", Z.p < 70.0 )
cuts.add("m_gt_120_Recoil", Recoil.m > 120.0 )
cuts.add("m_lt_140_Recoil", Recoil.m < 140.0 )

# Apply the event selections
Good_Z = Z[cuts.all()]
Good_Recoil = Recoil[cuts.all()]

#Prepare output
#Choose the required histograms and their assigned variables to fill
names = plot_props.columns.to_list()
vars_sel = [
Good_Recoil.m,
Good_Z.p,
Good_Z.m,
]
sel_ocl = cuts.cutflow(*cuts.names).yieldhist()
...
```

coffea-fcc-analyses

processor part of the code(3)

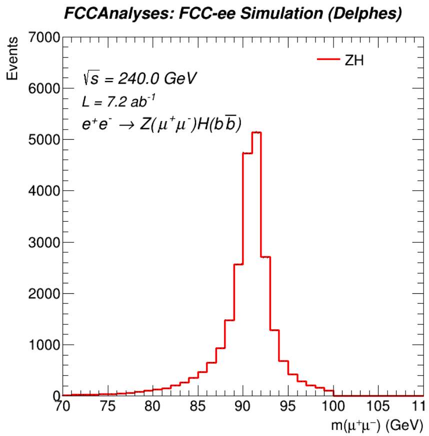
```
...
Output = {
        'histograms': {
                'sel':{
                        name:get_1Dhist(name,var,flatten=False)
                        for name,var in zip(names,vars_sel)},
        },
        'cutflow': {
                'sel': {'Onecut':sel_ocl[0],'Cutflow':sel_ocl[1],'Labels':sel_ocl[2]},
        }
}

return Output

def postprocess(self, accumulator):
pass
```

Results

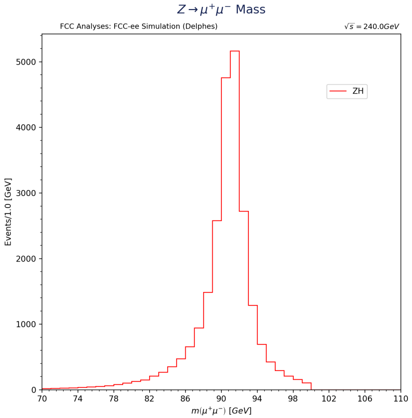
Attempt	FCCAnalyses (sec.)		coffea-fcc-analyses (sec.)	
	run	**plots**	**runner.py**	**plotter.py**
1	22.499	10.097	14.444	5.324
2	21.922	12.574	12.666	5.256
3	19.108	10.225	12.574	5.259
4	20.250	10.477	13.027	5.320
5	19.696	10.324	13.073	5.284
Mean	20.695 ± 1.30	10.238 ± 0.15	13.073 ± 0.70	5.323 ± 0.08

- **Total time taken by FCCAnalyses:** 30.933 ± 1.45 s
- **Total time taken by coffea-fcc-analyses:** 18.396 ± 0.78 s
- COFFEA is around 40 % faster (Unexpected!)

jetclustering: Z mass

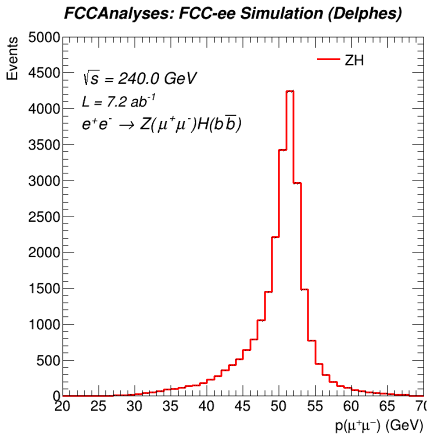


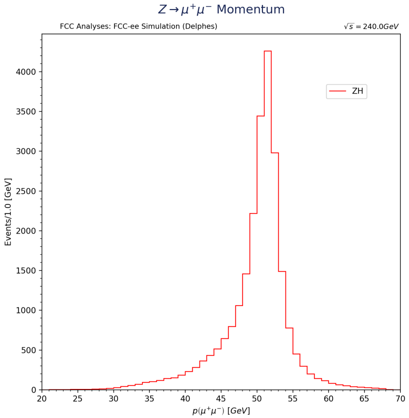
FCCAnalyses



COFFEA-FCC-ANALYSES

jetclustering: Z momentum

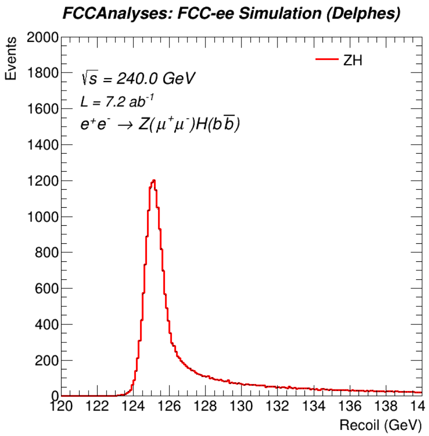




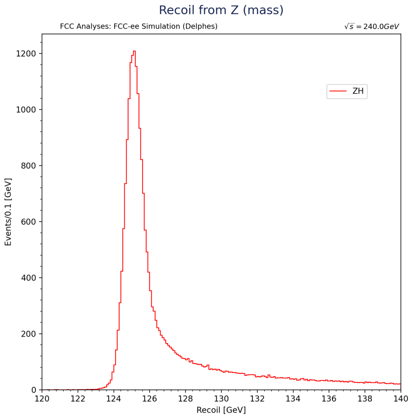
FCCAnalyses

COFFEA-FCC-ANALYSES

jetclustering: Recoil from Z

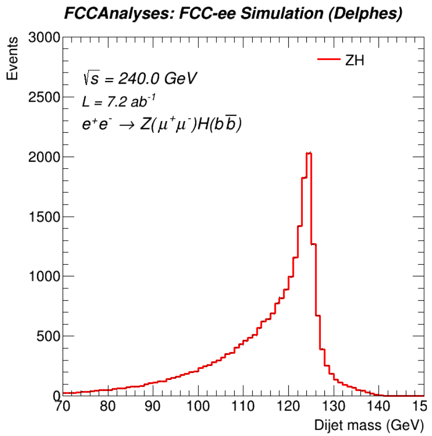


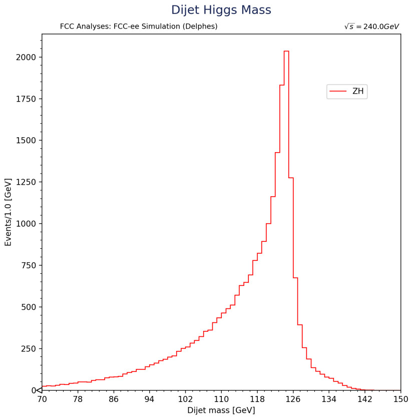
FCCAnalyses



COFFEA-FCC-ANALYSES

jetclustering: Dijet Mass

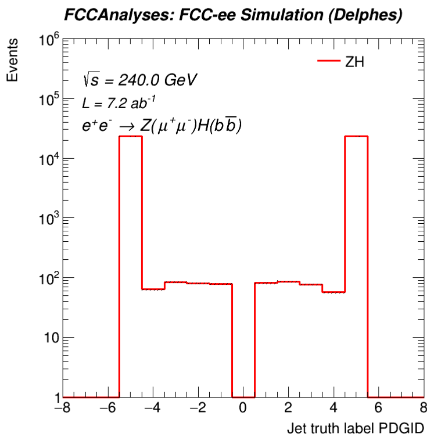




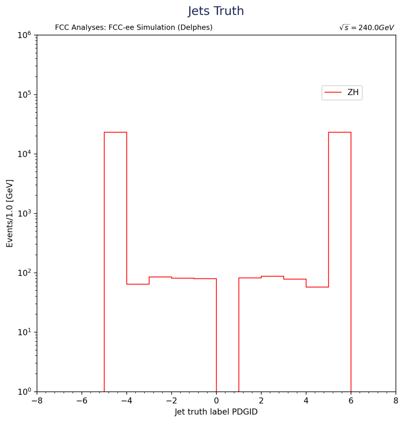
FCCAnalyses

COFFEA-FCC-ANALYSES

jetclustering: Truth Plot (PDGID of the best matched quark)



FCCAnalyses



COFFEA-FCC-ANALYSES

End of the presentation