Delphes card for muon collider

Michele Selvaggi

CERN

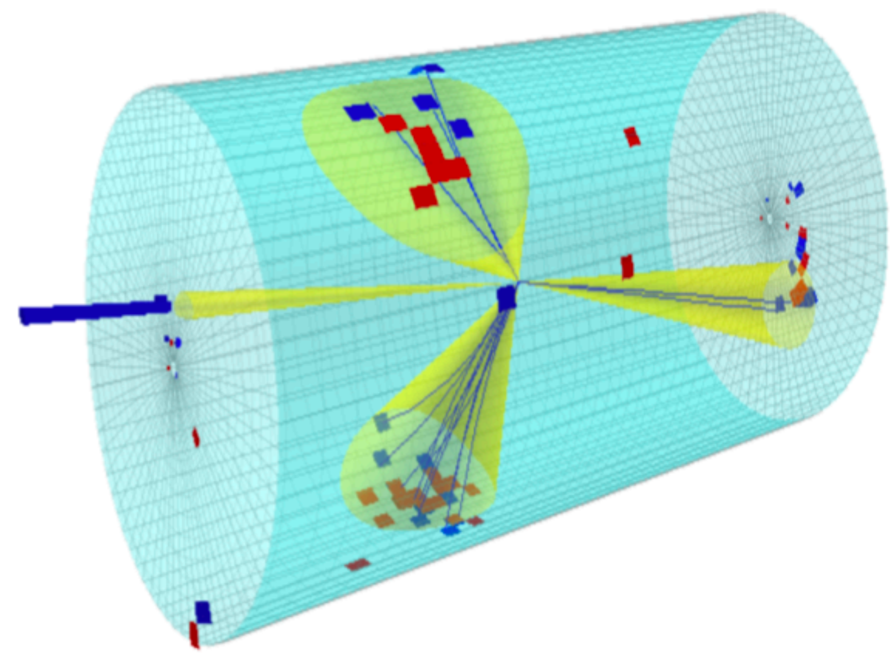
Delphes in a nutshell

DELPHES fast simulation

- **Delphes** is a modular framework that simulates the response of a **multipurpose detector** in a parameterised fashion

- Includes:
  - pile-up
  - charged particle propagation in B field
  - EM/Had calorimeters
  - particle-flow

- Provides:
  - leptons, photons, neutral hadrons
  - jets, missing energy
  - heavy flavour tagging



- designed to deal with hadronic environment
- well-suited also for e+e- studies
- detector cards for: CMS (current/PhaseII) - ATLAS - LHCb - FCC-hh - ILD - CEPC - FCCee (IDEA/CLD) - CLICdet

Detector Simulation

- Full simulation (GEANT):
  - **simulates** all **particle-detector interaction** (e.m/hadron showers, nuclear interaction, brem, conversions)

10^2-10^3 s/ev

- Experiment Fast Simulation (ATLAS, CMS ..)
  - **simplify** geometry, smear at the level of detector hits, frozen showers

10-10^2 s/ev

- Parametric simulation (**Delphes**, PGS):
  - **parameterise detector response** at the particle level(efficiency, resolution on tracks, calorimeter objects)
  - reconstruct **complex objects** and observables(use particle-flow, jets, missing ET, pile-up ..)

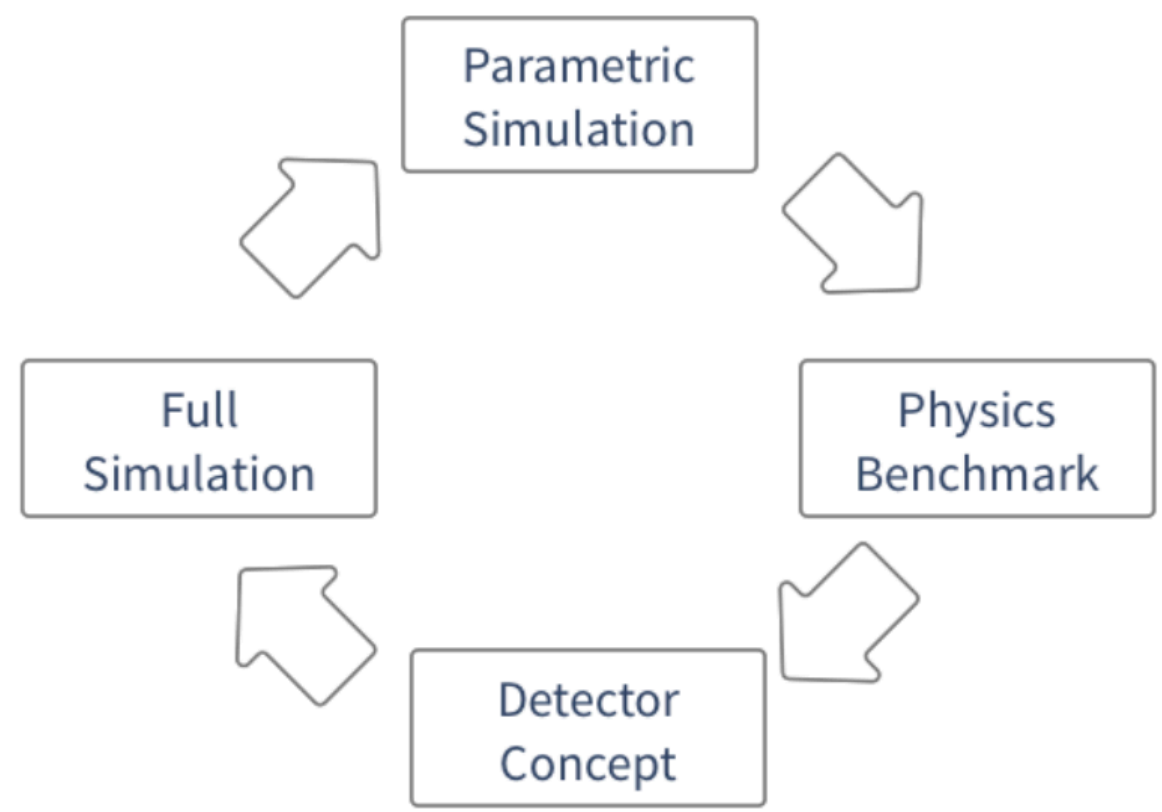
10^{-2} - 10^{-1} s/ev

- Ultra Fast (ATOM, TurboSim):
  - from parton to detector object (smearing/lookup tables)

Parametric simulation paradigm

Why fast parametric detector simulation?

- Easily scan detector parameters
- Reverse engineer detector that maximises performance
- Preliminary sensitivity studies for key physics benchmarks



→ (usual) paradigm adopted in the context of FCC studies

Philosophy

- The interest in the TH/pheno community is to **assess the physics reach at the highest possible energies** sqrt(s) = 10, 14, 30 TeV

  (at any rate, such a detector would perform great also at 1.5, 3 TeV)

- Need to be able to reconstruct: mu, ele, jets, tops, V up to **p_T = 15 TeV**

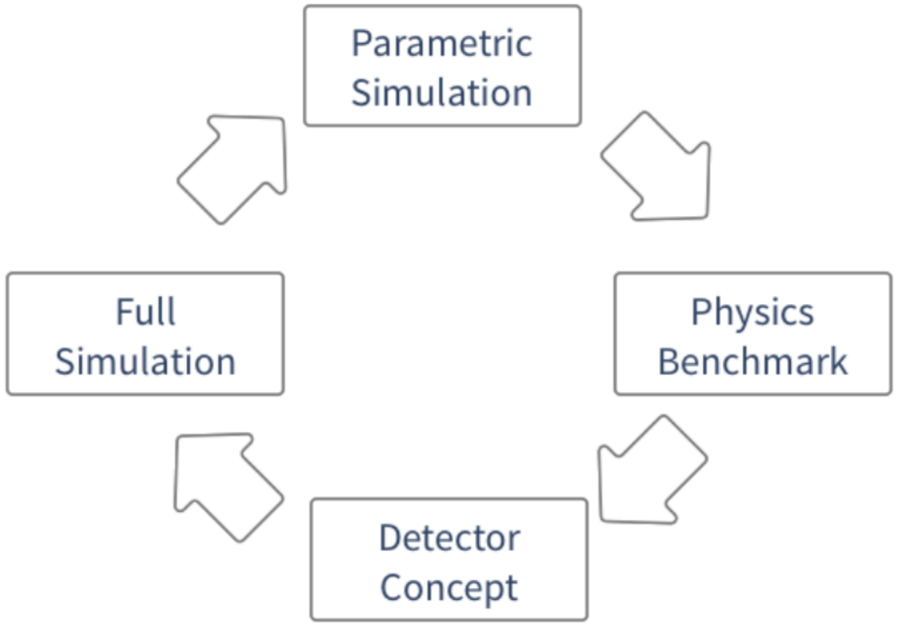
  - $\mu\ \mu \rightarrow \mu\ \mu$, e e , j j, t t~ (hadronic) ,V V (hadronic)
  - $\mu\ \mu \rightarrow$ EW-inos, stops $\rightarrow$ SM

With many respects, the constraints from physics at high p_T are similar:
to the **FCC-hh** and **CLIC** (also easier to start from existing detector concept)

→ delphes card for muon collider is an **hybrid** of the FCC-hh and CLIC cards

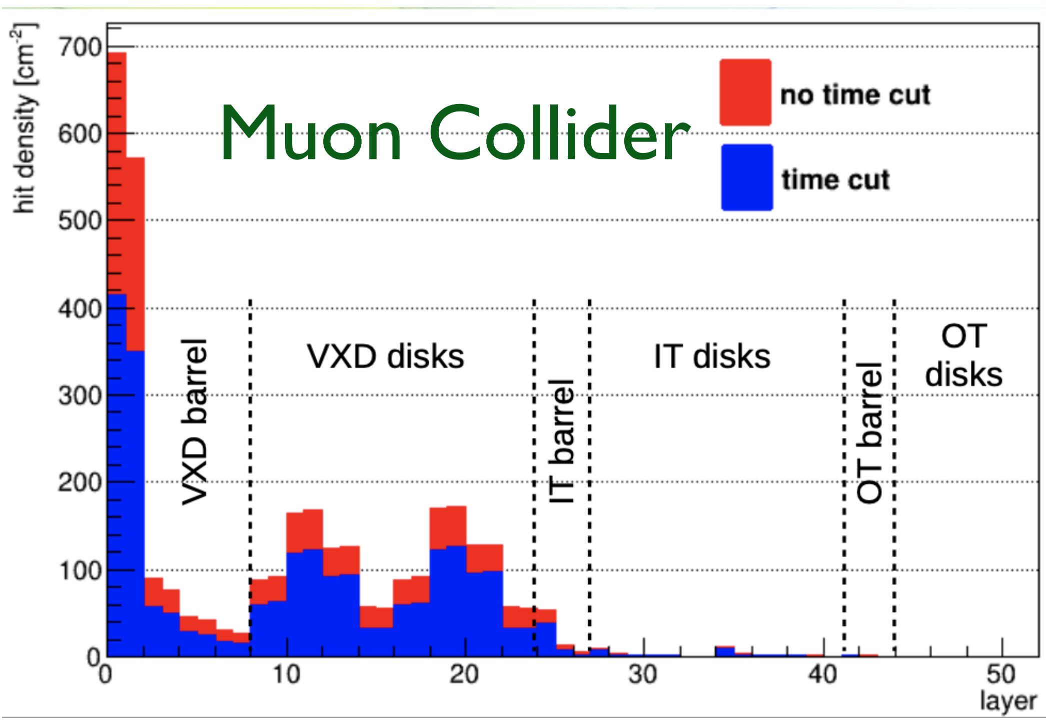
Philosophy

- **Goal** of the Delphes card (and physics studies):
  - **define a target** for the detector performance (free of BIB)
  - **study benchmark physics** channels with **target performance**
  - study impact of **variations of detector performance** around nominal on physics
  - **iterate** on detector design



BIB vs FCC-hh

@first pixel ~ 2 cm from beam-pipe



charged fluence: 400-700 (cm^{-2} / BX)

FCC-hh

Barrel layer:	1	2	3	4	5	6
Average radius [mm]	25	60	100	150	260	380
Maximum fluence [cm^{-2}]	328.1	79.7	35.1	16.9	6.8	3.3
Module occupancy [%]	1.63	0.39	0.18	0.10	0.28	0.15
Data size per bunch crossing [Mb]	56.60	37.66	28.51	23.46	10.95	8.72
Data rate [Tb/s]	2263.1	1506.4	1140.3	938.5	438.0	348.6
Data rate density @ 40 MHz [Gb/s/cm^{-2}]	944.0	229.6	107.0	60.2	14.8	8.0
Data rate density @ 1 MHz [Gb/s/cm^{-2}]	23.6	5.7	2.7	1.5	0.4	0.2
	7	**8**	**9**	**10**	**11**	**12**
	530	742	937	1132	1327	1540
	1.9	0.83	0.46	0.26	0.16	0.13
	0.09	0.04	3.0	1.9	1.3	0.9
	835.5	537.8	331.3	249.0	192.8	109.5
	20.8875	13.445	8.2825	6.225	4.82	2.7375
	5.1	2.4	1.2	0.7	0.5	0.2
	0.1	…				

Table 5: Summary of maximum fluence [cm^{-2}], module occupancy, data size per bunch crossing [Mb/s], data rates [Tb/s] and data rate densities [Gb/s/cm^{-2}], as estimated for the nominal FCC-hh pile-up of 1000 events and tracker in flat layout [28].

charged fluence: 330 (cm^{-2} / BX)

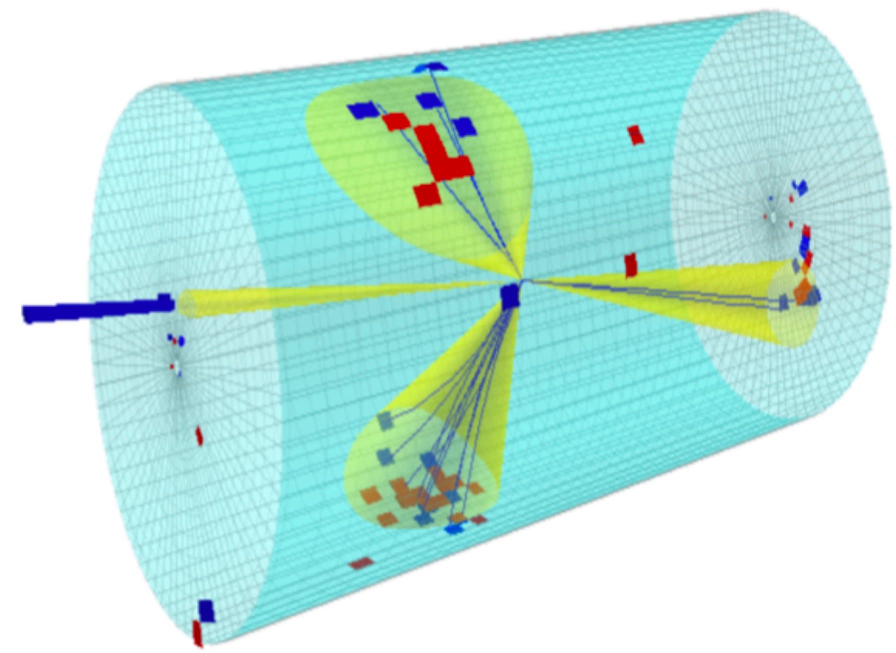
At MuonCollider can afford **low power pixel** sensors thanks to **low BX rate** (70 kHz) e. g MAPs (30 μm x 30 μm):

→ occupancy: 0.6% (700 / (1cm^2 / 30 μm^2)) ~ **2x HL-LHC** or **0.5x FCC-hh**

But … non pointing background!

Particle Propagator/DTF

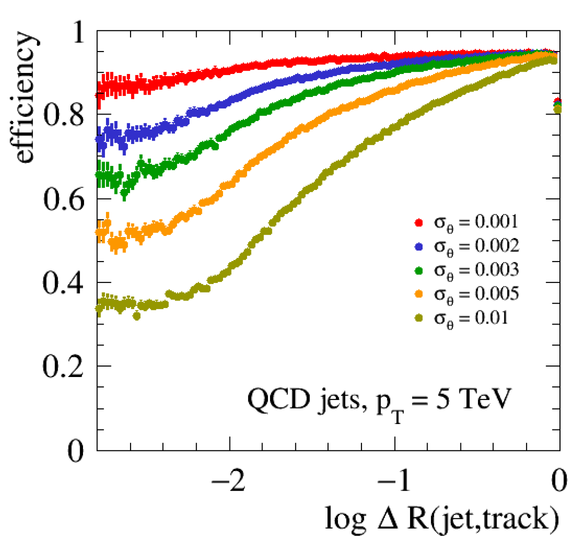
```
##################################
# Propagate particles in cylinder
##################################

module ParticlePropagator ParticlePropagator {
    set InputArray Delphes/stableParticles

    set OutputArray stableParticles
    set ChargedHadronOutputArray chargedHadrons
    set ElectronOutputArray electrons
    set MuonOutputArray muons

    # radius of the magnetic field coverage in the calorimeter, in m
    set Radius 1.5
    # half-length of the magnetic field coverage in the calorimeter, in m
    set HalfLength 2.31

    # magnetic field, in T
    set Bz 4.0
}
```



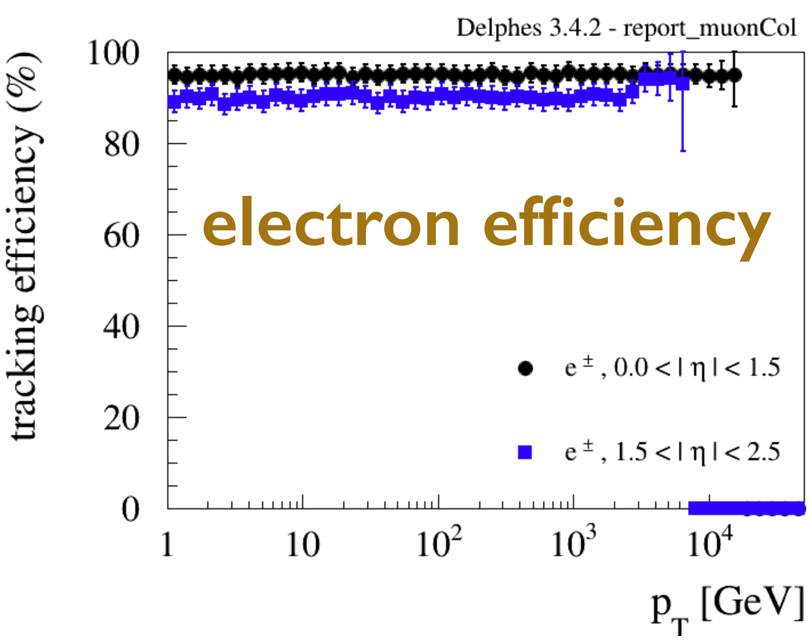
from CLIC

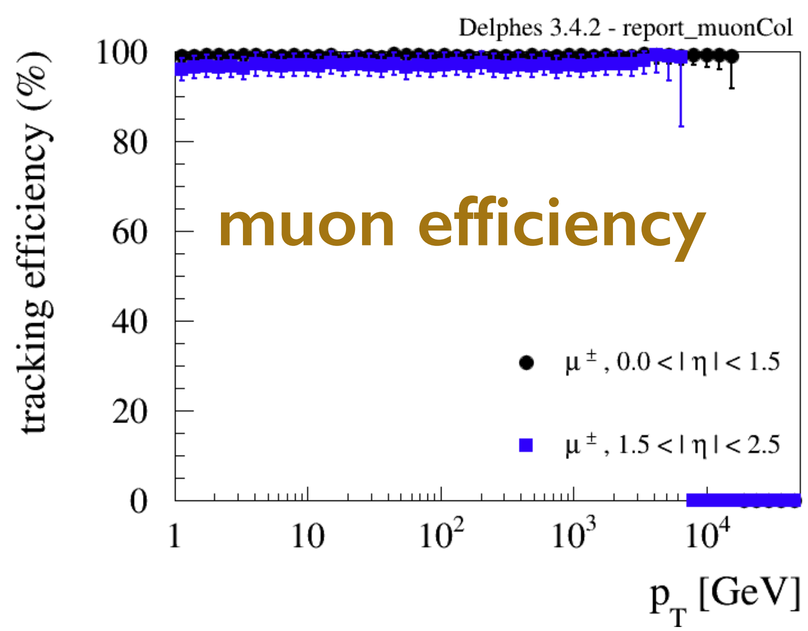
```
######################
#   Dense Track Filter
######################

module DenseTrackFilter DenseTrackFilter {

  set TrackInputArray DenseMergeTracks/tracks

  set TrackOutputArray tracks
  set ChargedHadronOutputArray chargedHadrons
  set ElectronOutputArray electrons
  set MuonOutputArray muons

  set EtaPhiRes 0.003
  set EtaMax 2.5
```

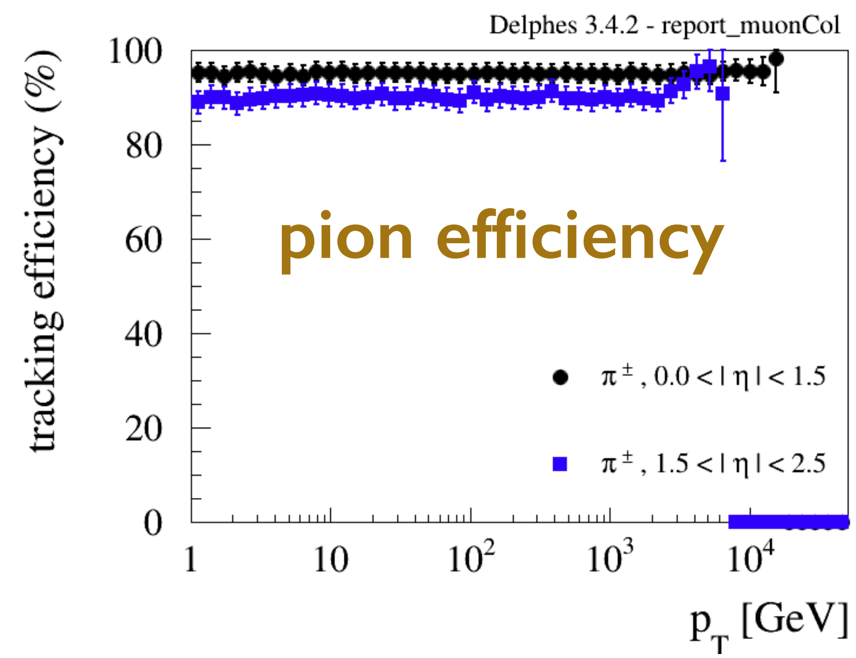
from FCC-hh



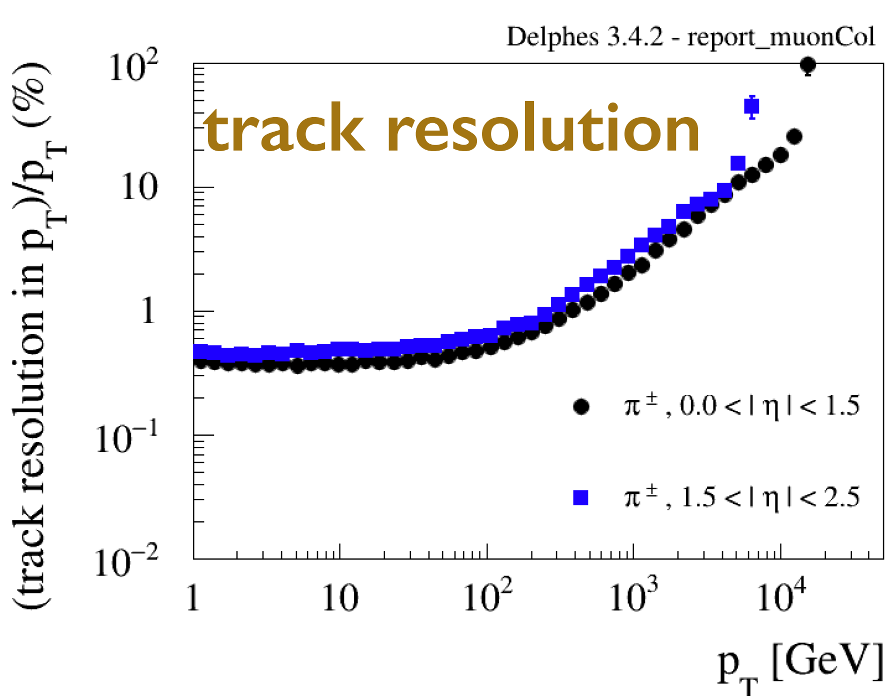
Tracking efficiency/resolution

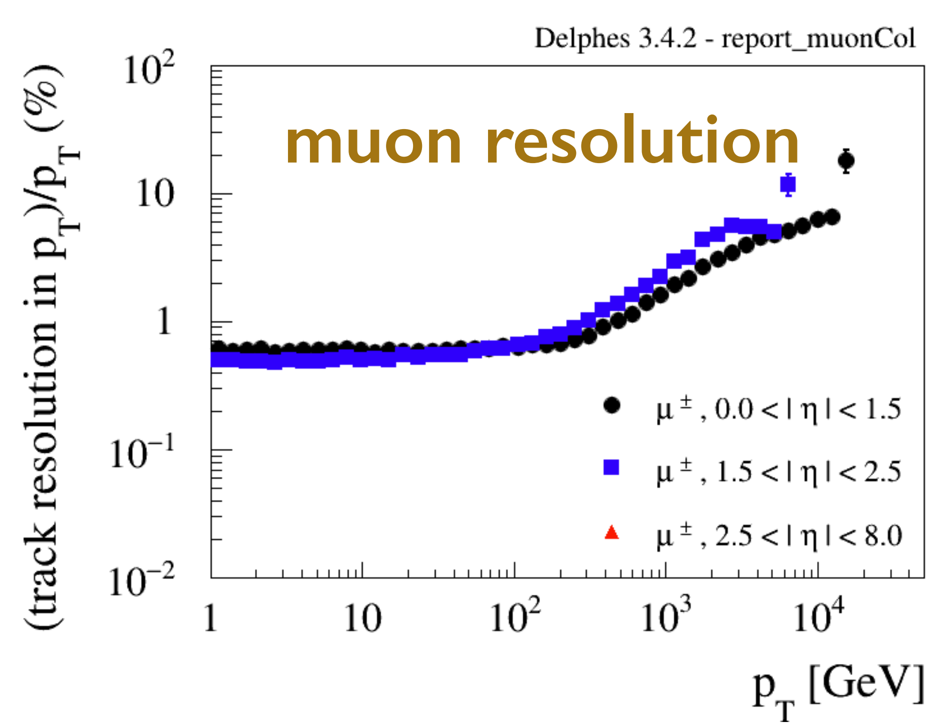




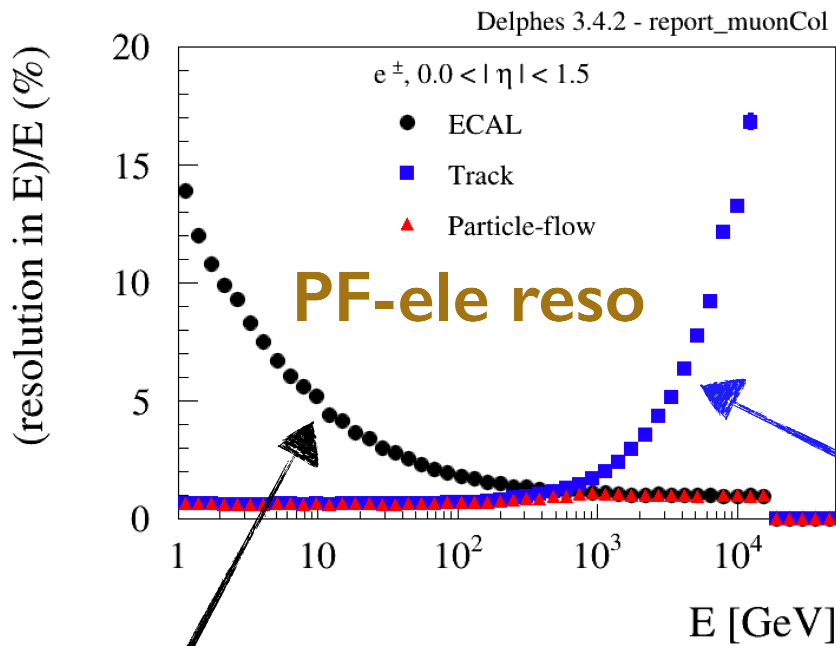


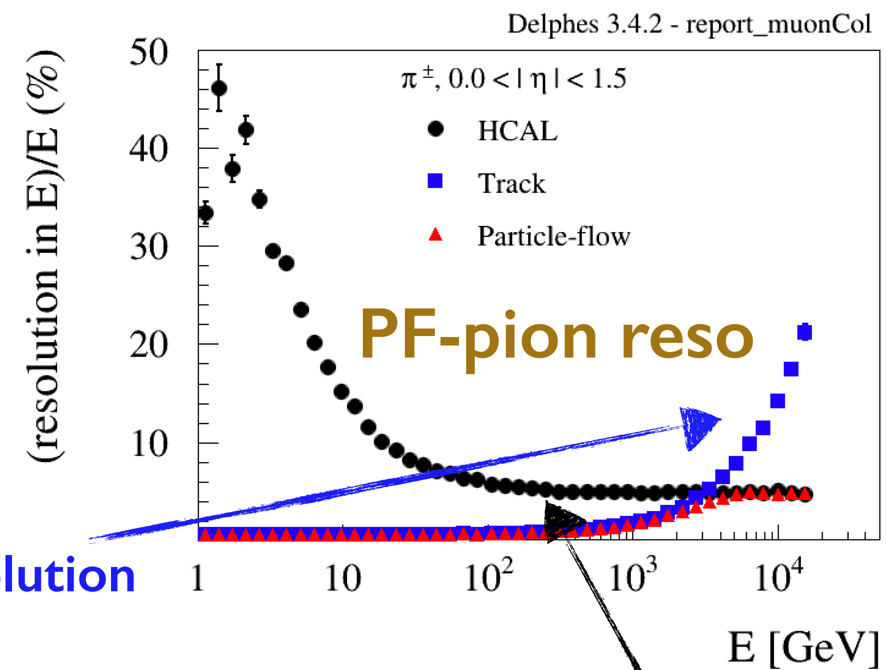
inspired from FCC-hh





Calorimeters/PF



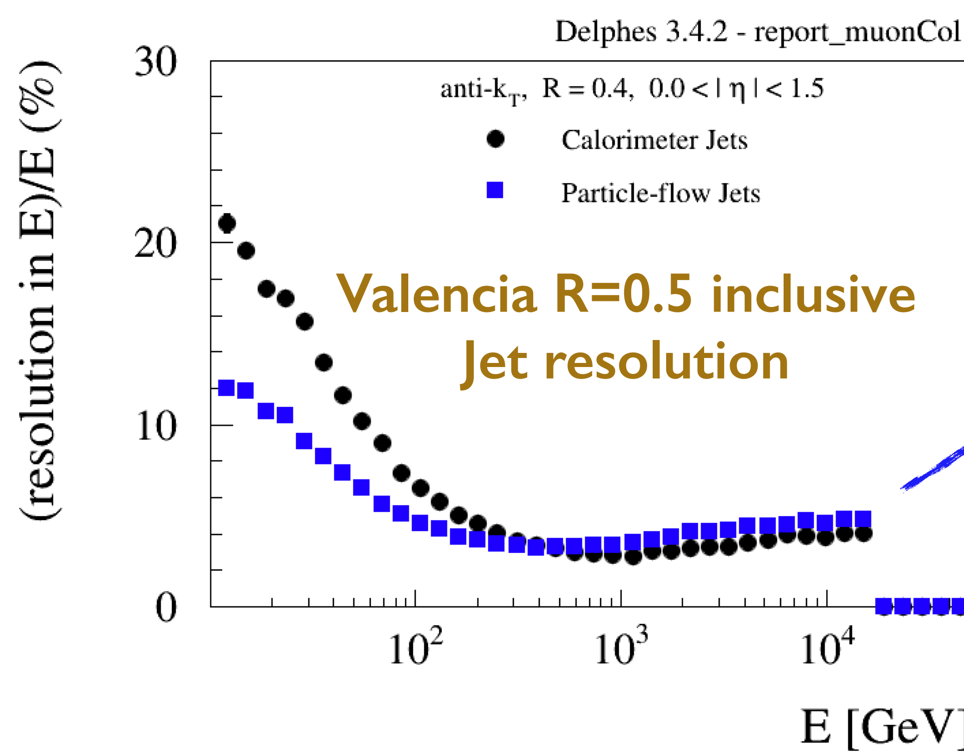


Tracking resolution from FCC-hh

Calorimeters inspired from CLIC

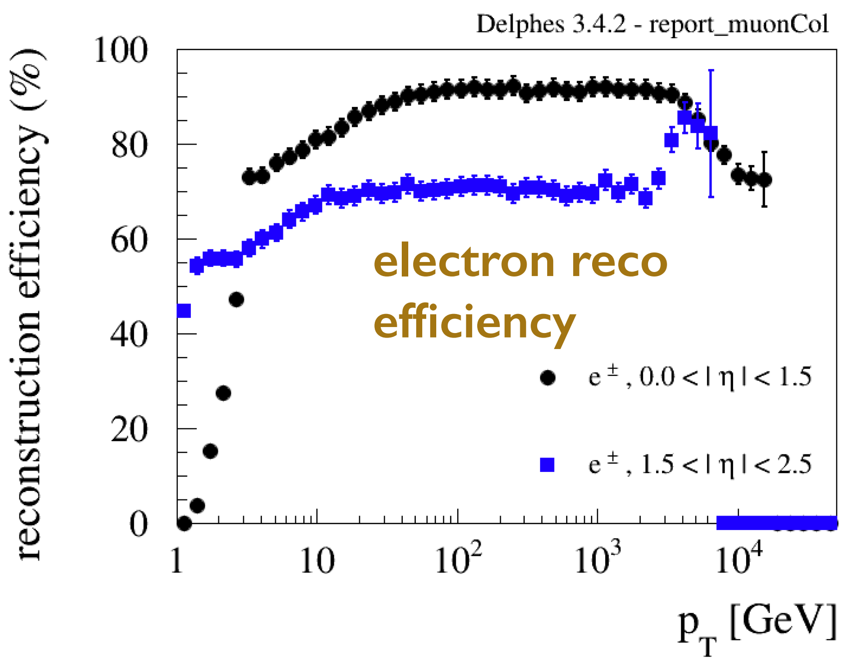
EM resolution from CLICdet

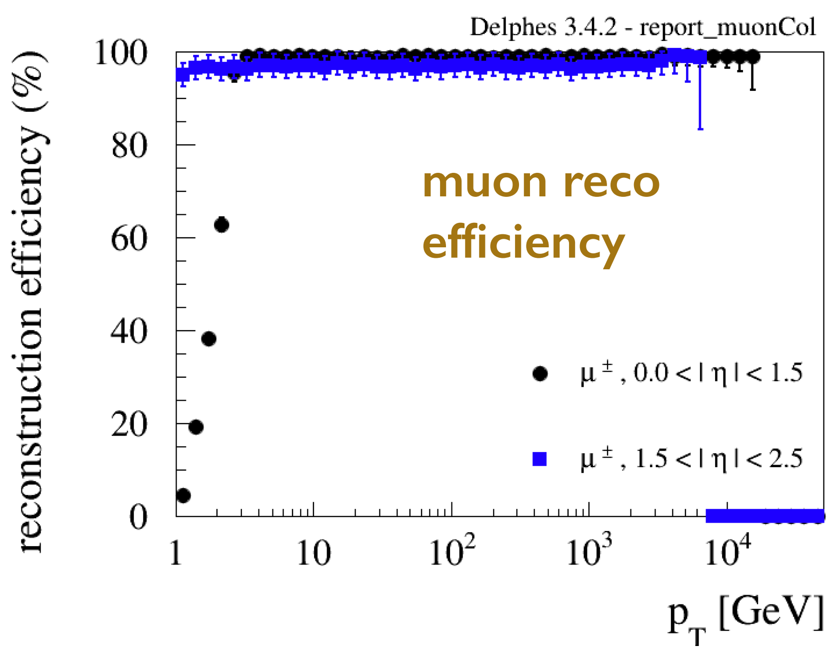
Hadronic resolution from CLICdet

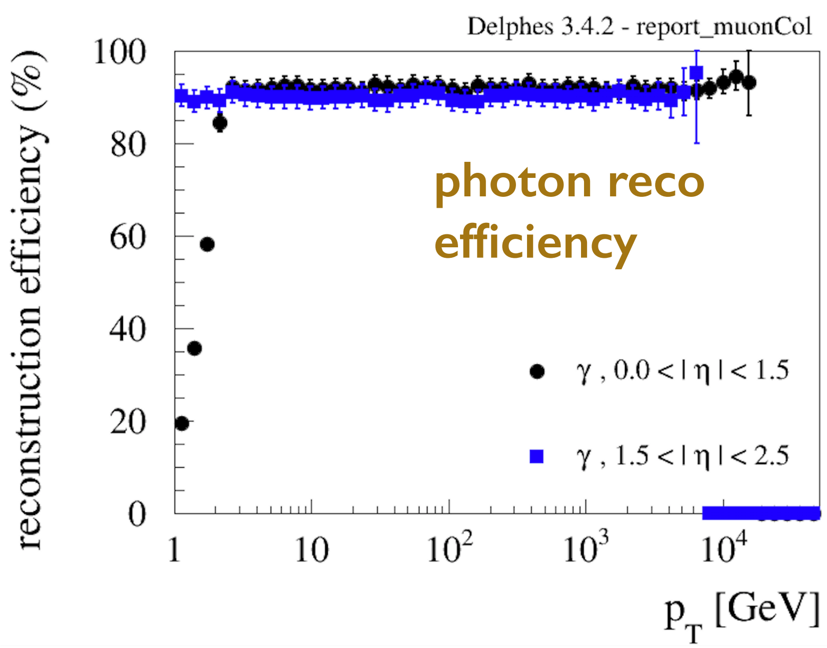


PF jet
include BIB smearing
from CLIC stage 3

E/mu/gamma efficiency

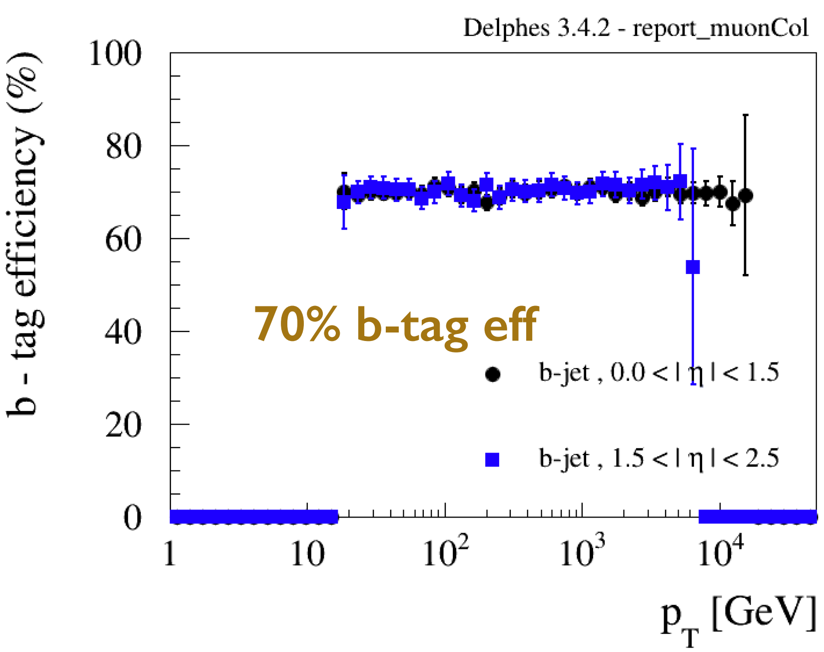


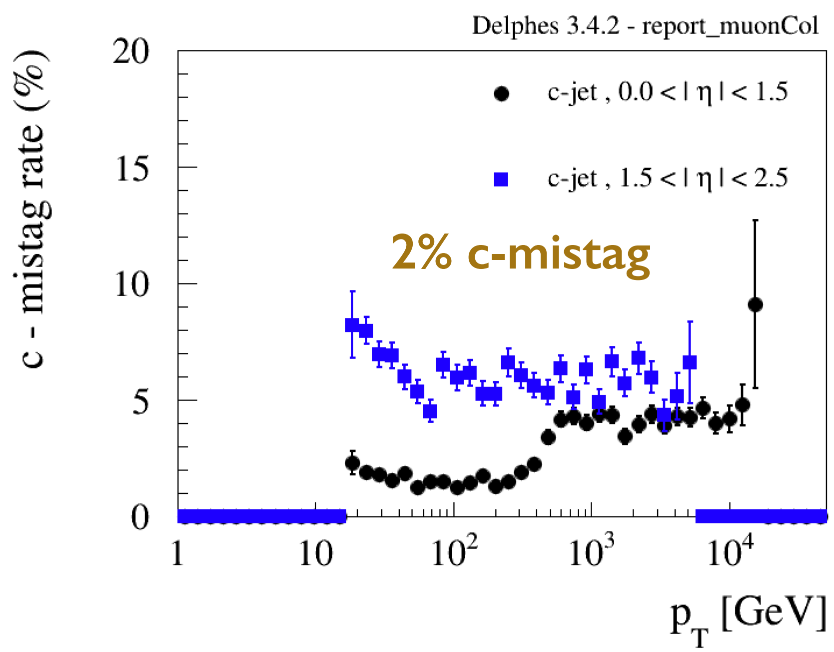


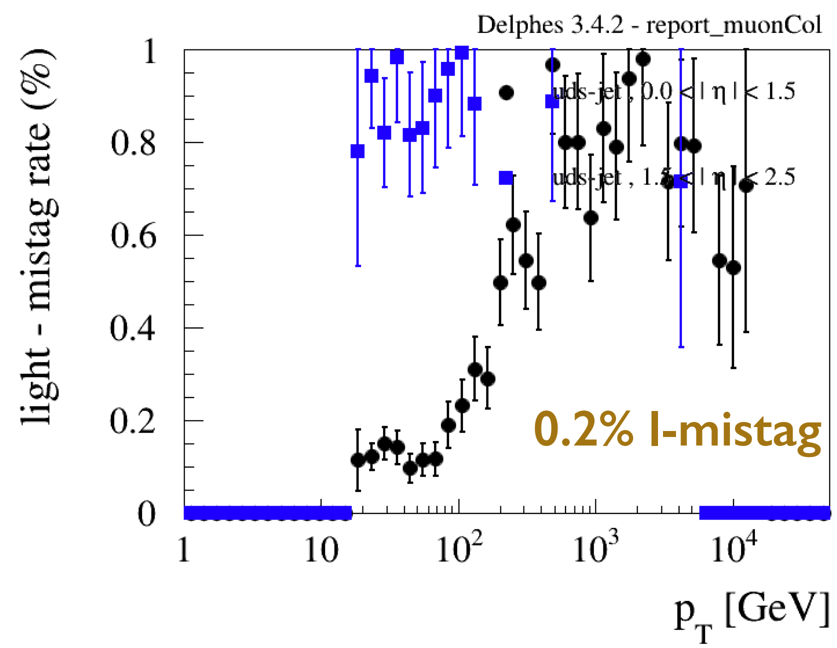


inspired from CLIC det

BTagging (Medium Working point)

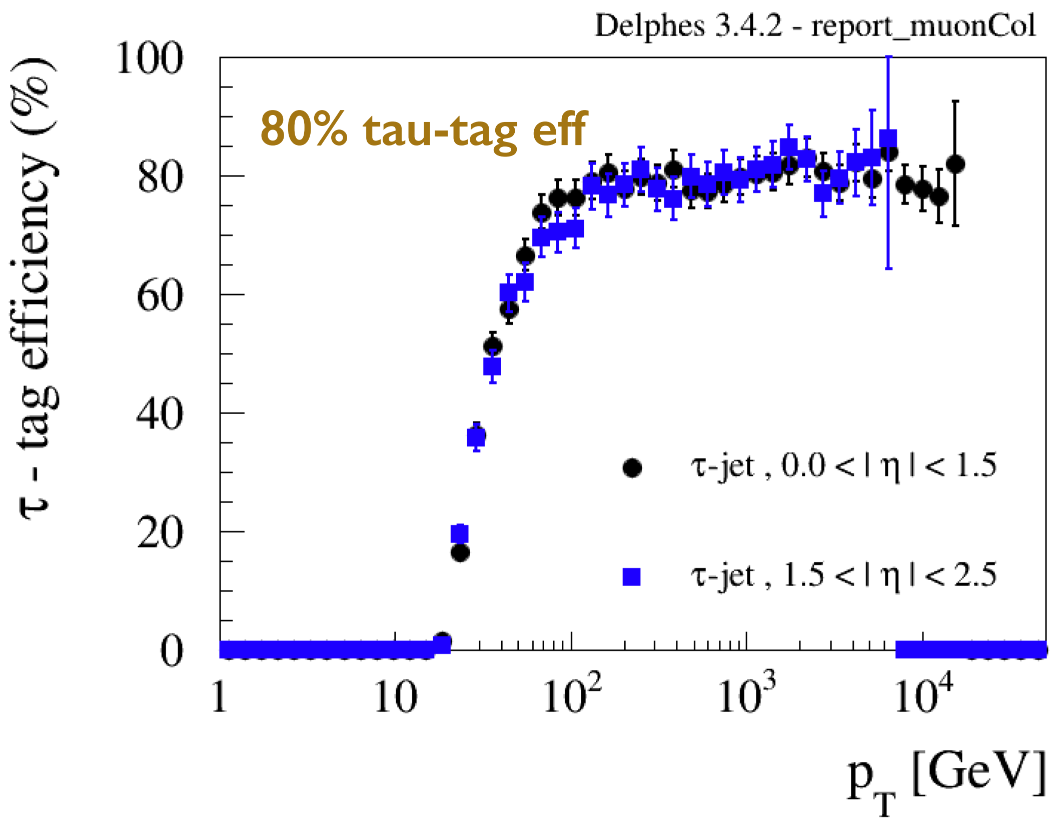


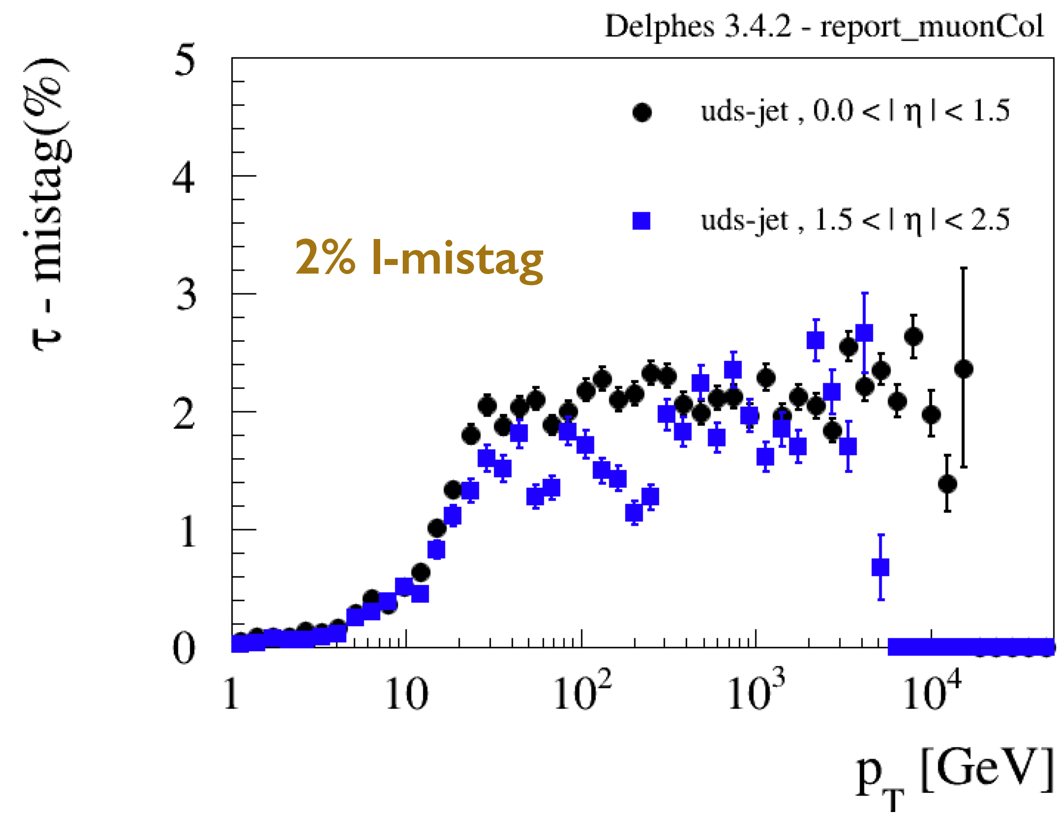




inspired from CLIC det

Tau-tagging

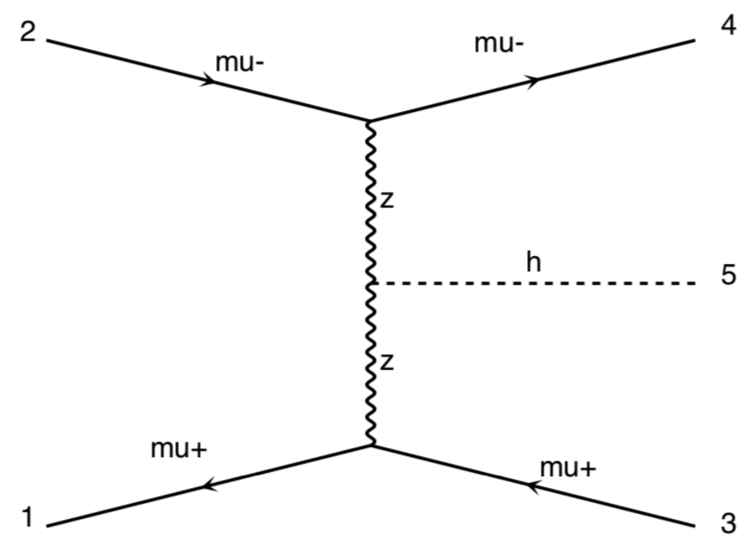


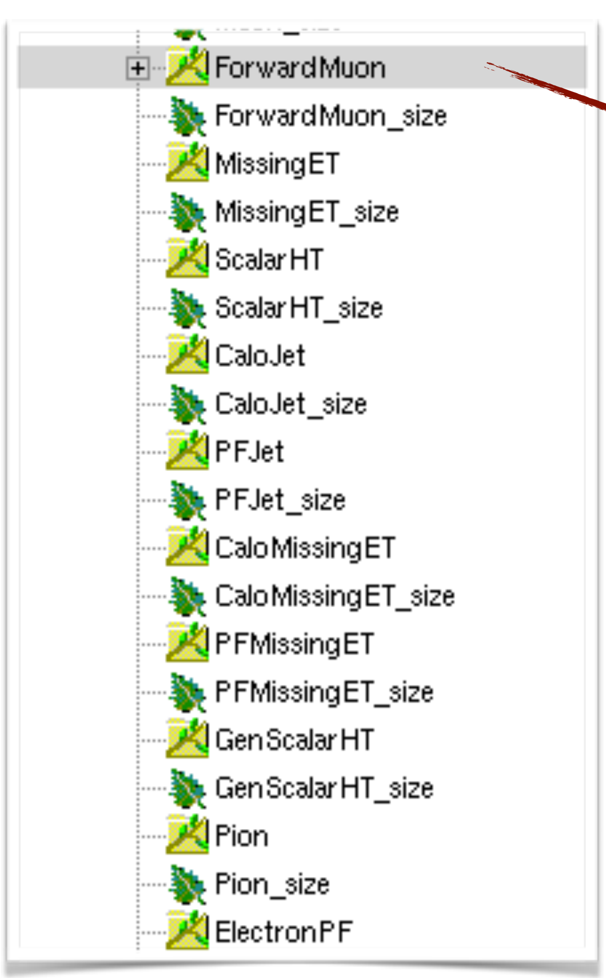


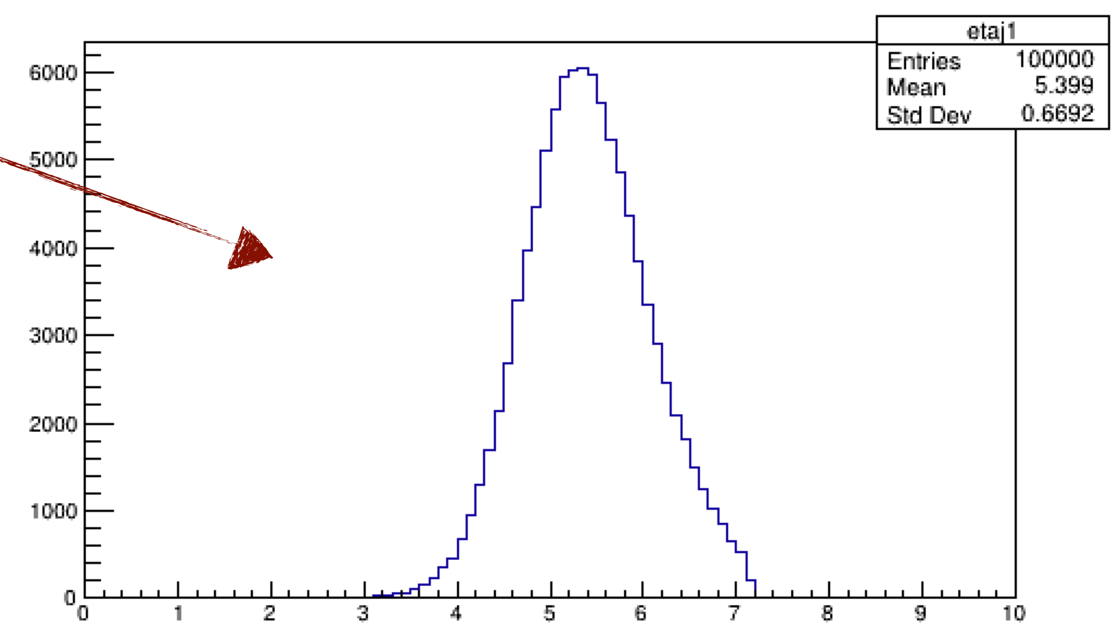
inspired from CMS/FCChh

Forward muon collection

- Forward **Muon collection:**
  - $2.5 < |\eta| < 8.0$
  - energy resolution: 10%







most forward muon $|\eta|$

Muon Collider card

```
########################################
# Order of execution of various modules
########################################

set ExecutionPath {
    ParticlePropagator
    TrackMergerProp

    DenseProp
    DenseMergeTracks
    DenseTrackFilter

    ChargedHadronTrackingEfficiency
    ElectronTrackingEfficiency
    MuonTrackingEfficiency

    ChargedHadronMomentumSmearing
    ElectronMomentumSmearing
    MuonMomentumSmearing
```

```
########################################
# Muon Collider Detector TARGET model
#
# Michele Selvaggi michele.selvaggi@cern.ch
# Ulrike Schnoor ulrike.schnoor@cern.ch
#
#
# !!! DISCLAIMER !!!
#
# The parameterisation of the Muon Collider
# has to be intended as a target performance.
# This has not been validated by full simulation.
# Hybrid between FCC-hh and CLIC performance.
#
#
########################################
```

- "Final" v0 can be found here:
  - https://github.com/delphes/delphes/blob/master/cards/delphes_card_MuonColliderDet.tcl
  - https://github.com/delphes/delphes/tree/master/cards/MuonCollider
- Added:
  - Forward muon collection
  - Jet Substructure
  - Validation

Comments

- The performance that has been encoded in the Delphes muon collider card is to be intended as a **“target” performance** for the highest possible energy

However (disclaimer):

- Nothing will be written in stone, should be intended as a **moving target**
- Users should **explore variations around target performance** to assess sensitivity of physics reach as a function of particular detector choices, and impact of beam induced background