Fast Simulation for Future collider Experiments

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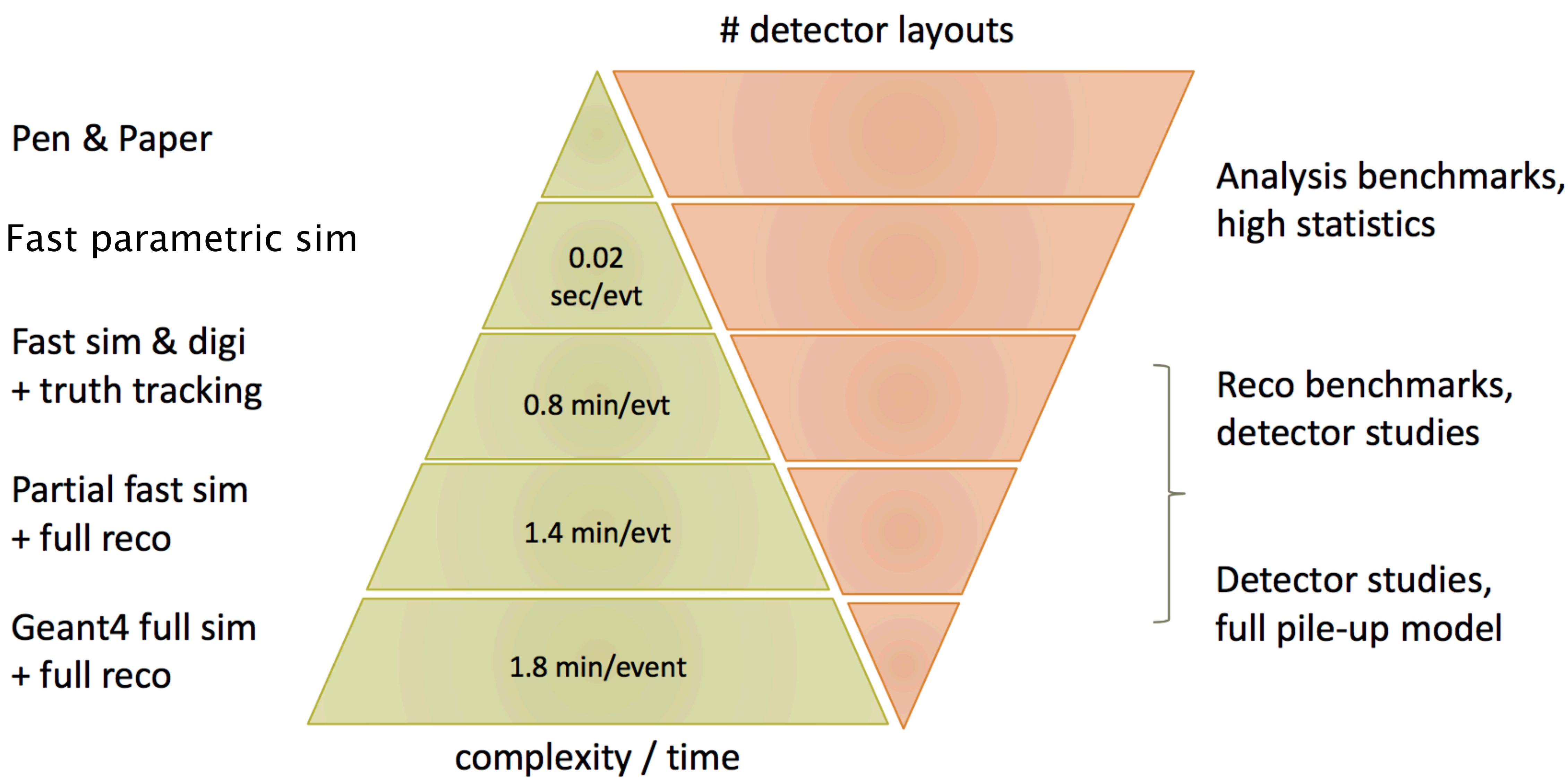
CERN

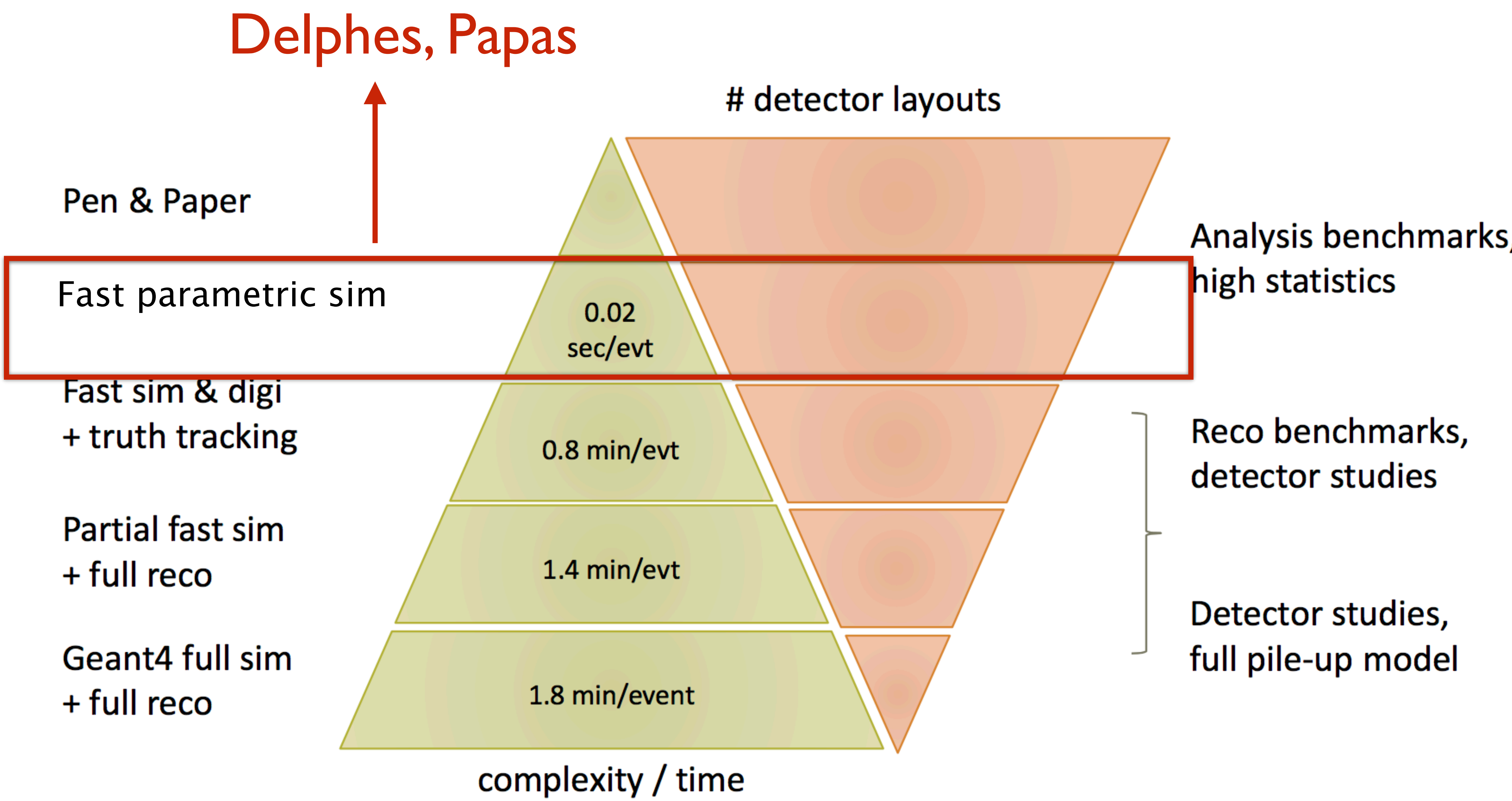
RDFA meeting — 04/07/2017 — Bologna

Introductory remarks



Courtesy of J. Lingemann

Introductory remarks

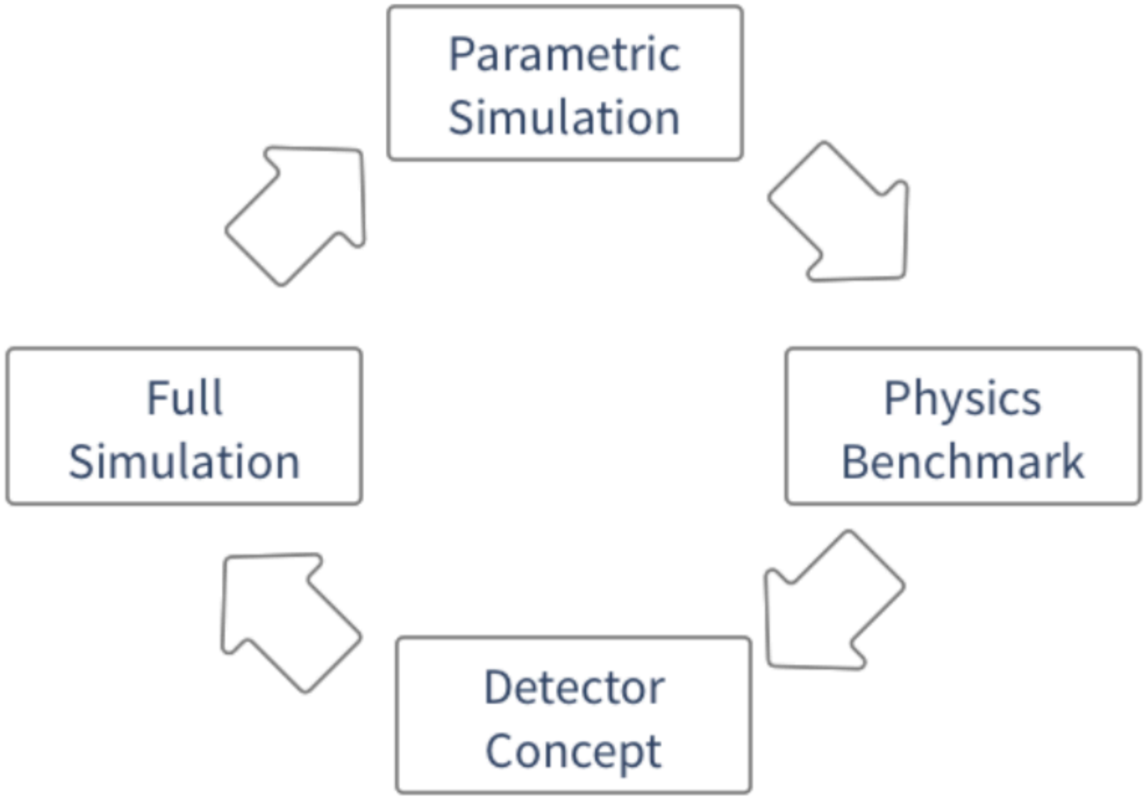


Courtesy of J. Lingemann

Introductory remarks

Why fast **parametric** detector simulation?

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



Courtesy of J. Lingemann

Outline

- Delphes (at FCC-hh)
- PAPAS (at FCC-ee)

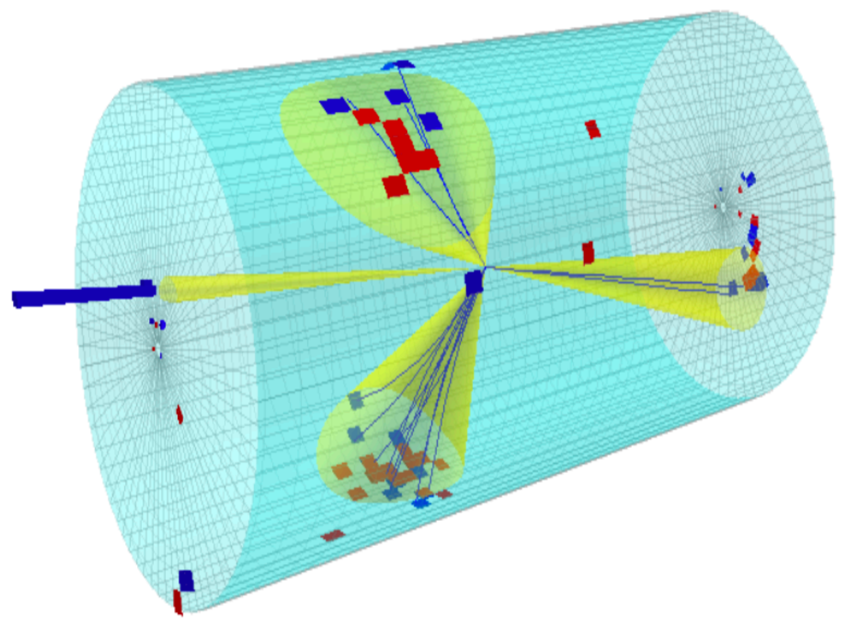
Delphes

github.com/delphes

What is Delphes ?

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

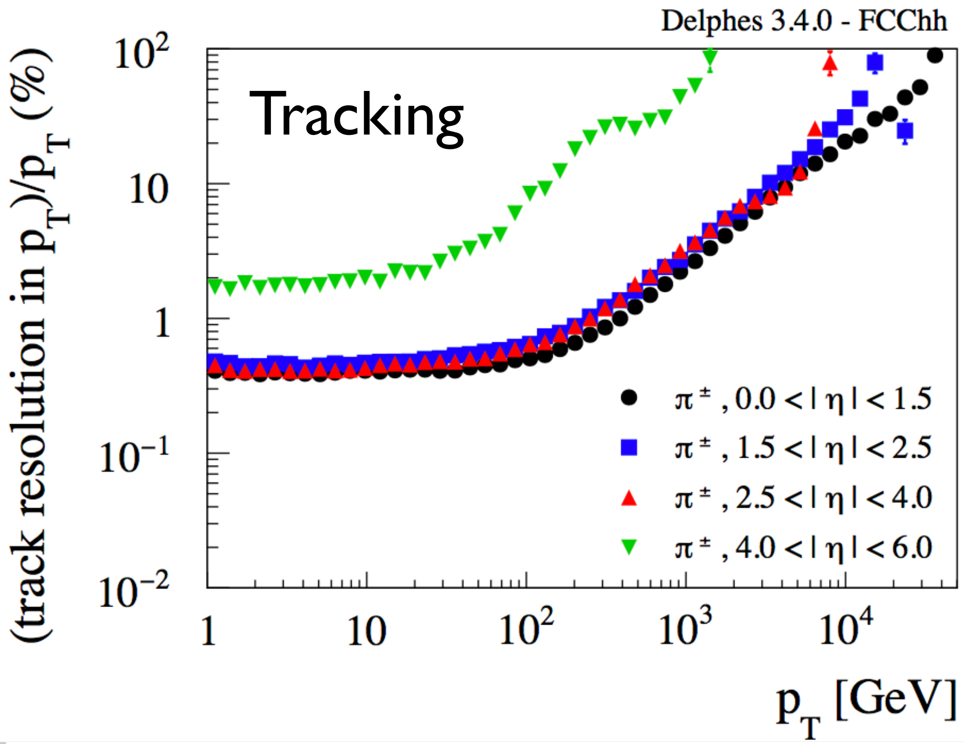
- **Includes:**
  - pile-up
  - charged particle **propagation** in magnetic field
  - electromagnetic and hadronic **calorimeters**
  - **particle flow**

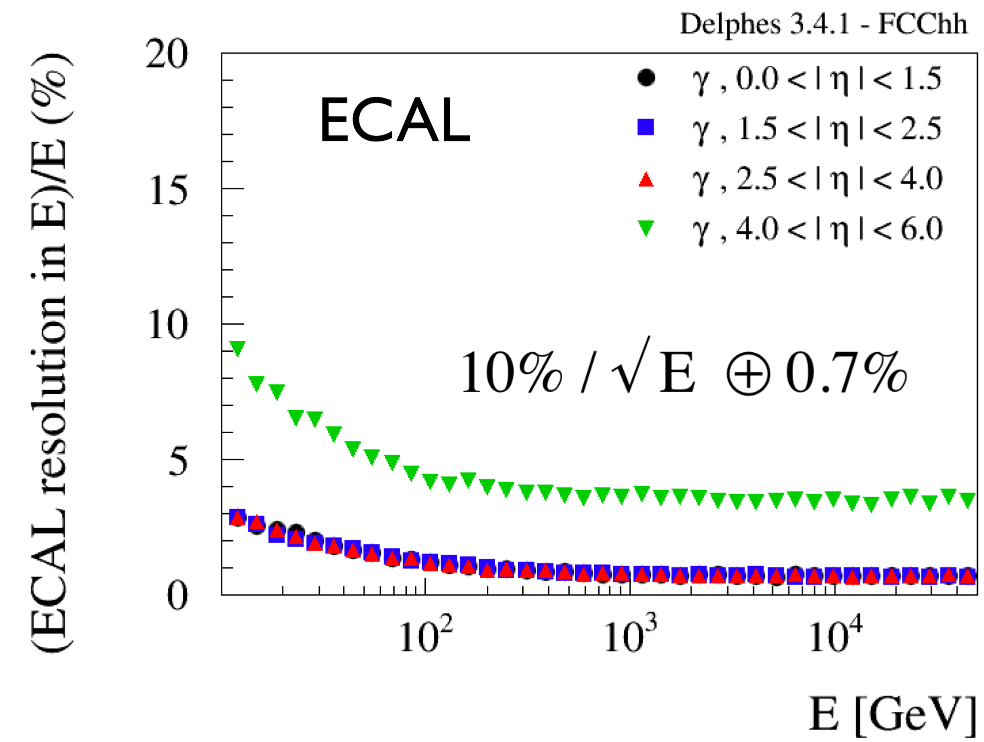


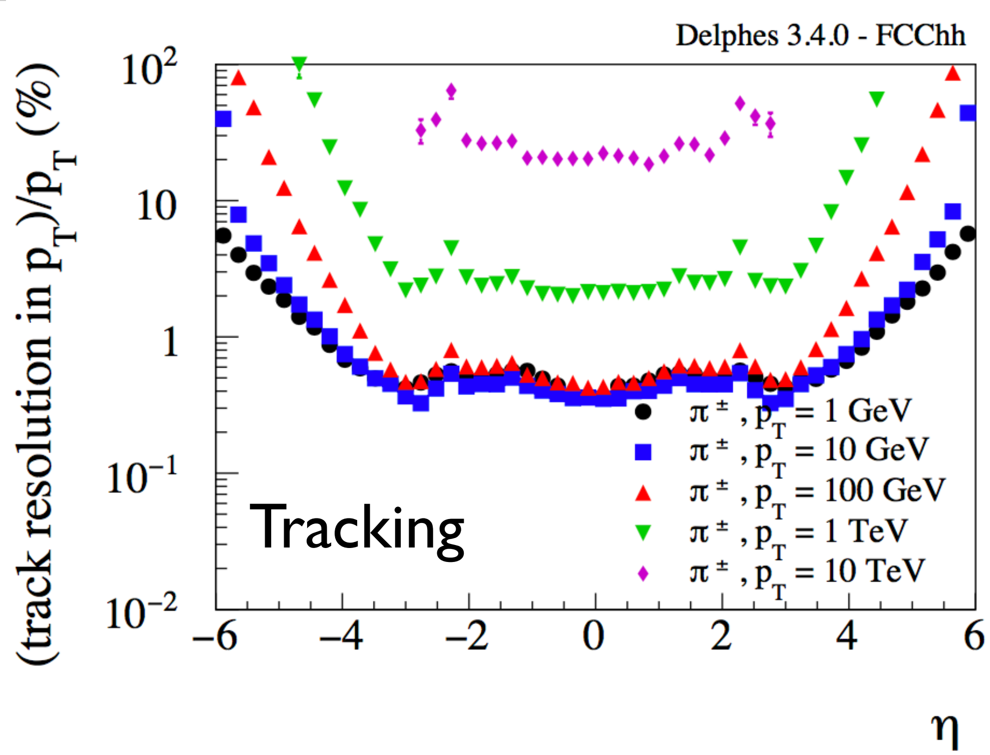
- **Provides:**
  - leptons (electrons and muons)
  - photons
  - jets and missing transverse energy (particle flow)
  - taus and b's

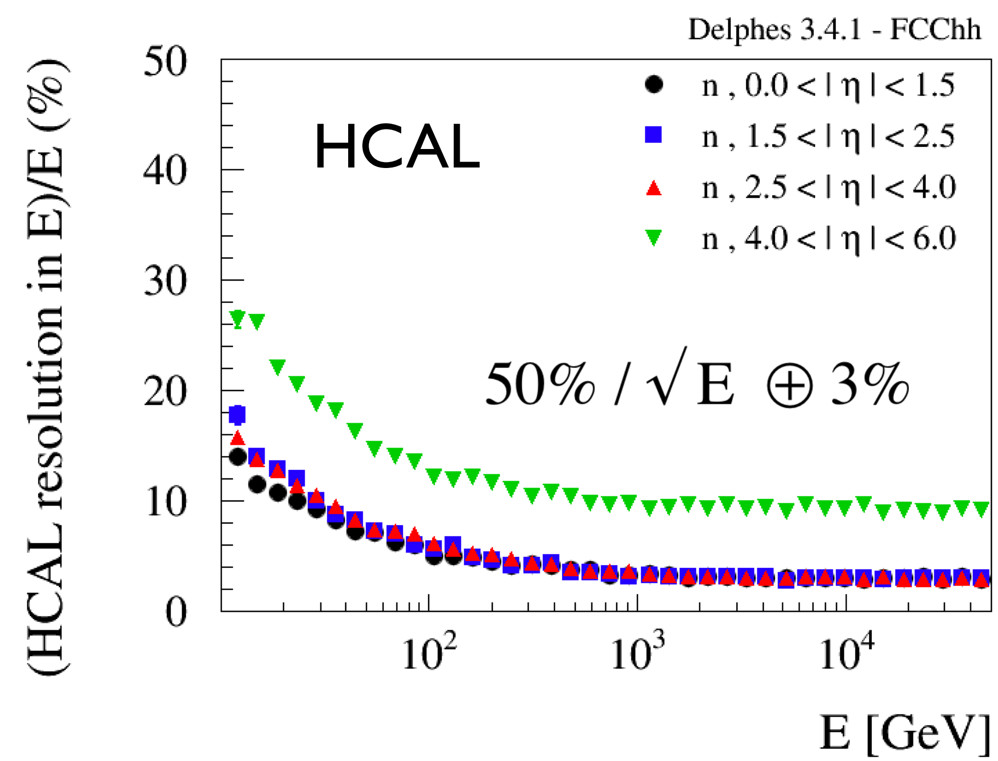
- designed to deal with hadronic environment
- well-suited also for e+e- studies
- detector cards for: CMS - ATLAS - LHCb - FCC-hh - ILD - CEPC
- fully integrated within the FCC software (FCCSW)

FCC-hh









DELPHES fast simulation

Particle-Flow

- Given **charged track** hitting given **calorimeter cell**:

  - are deposits more **compatible** with **charged** or **charged + neutrals** hypotheses?
  - how to assign momenta to all resulting components ?

- We have **two** measurements (E_{trk}, σ_{trk}) and $(E_{calo}, \sigma_{calo})$
- Call $E_{neutral} = E_{calo} - E_{trk}$

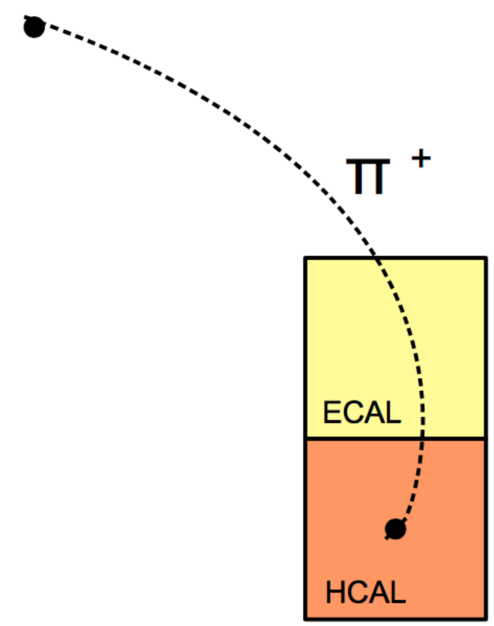
<u>Algorithm:</u>

If $E_{neutral} / \sqrt{(\sigma_{trk}^2 + \sigma_{calo}^2)} > S$:

→ create PF neutral particle + PF track

Otherwise:

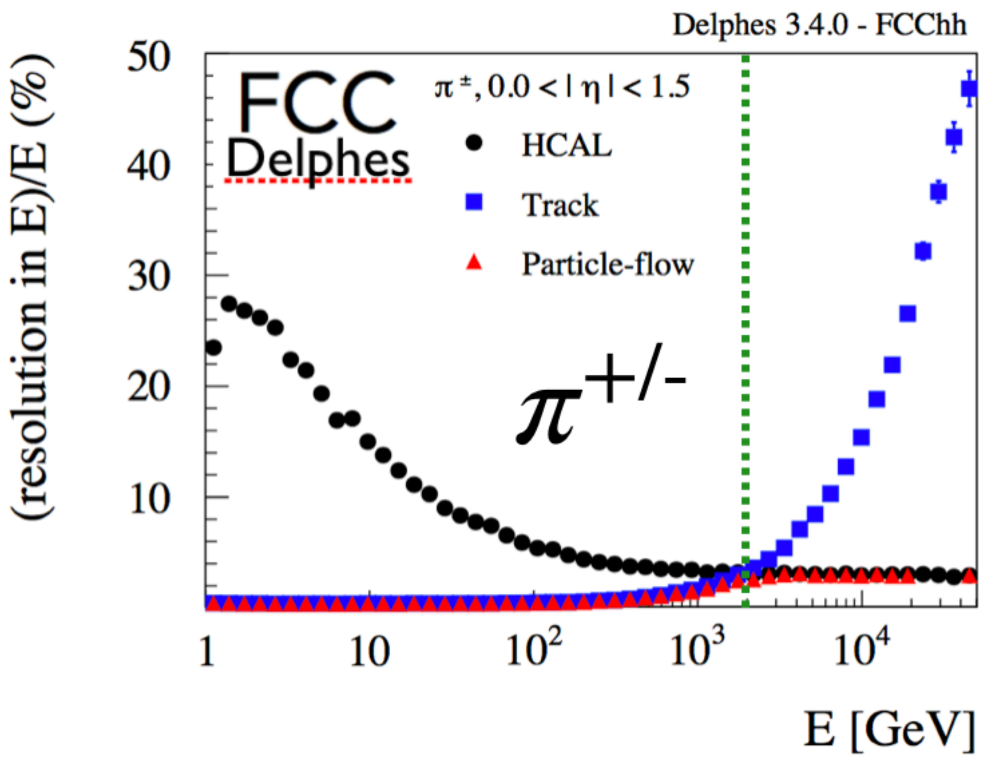
→ create PF track with (weighted) average energy $w_i = 1/\sigma_i^2$

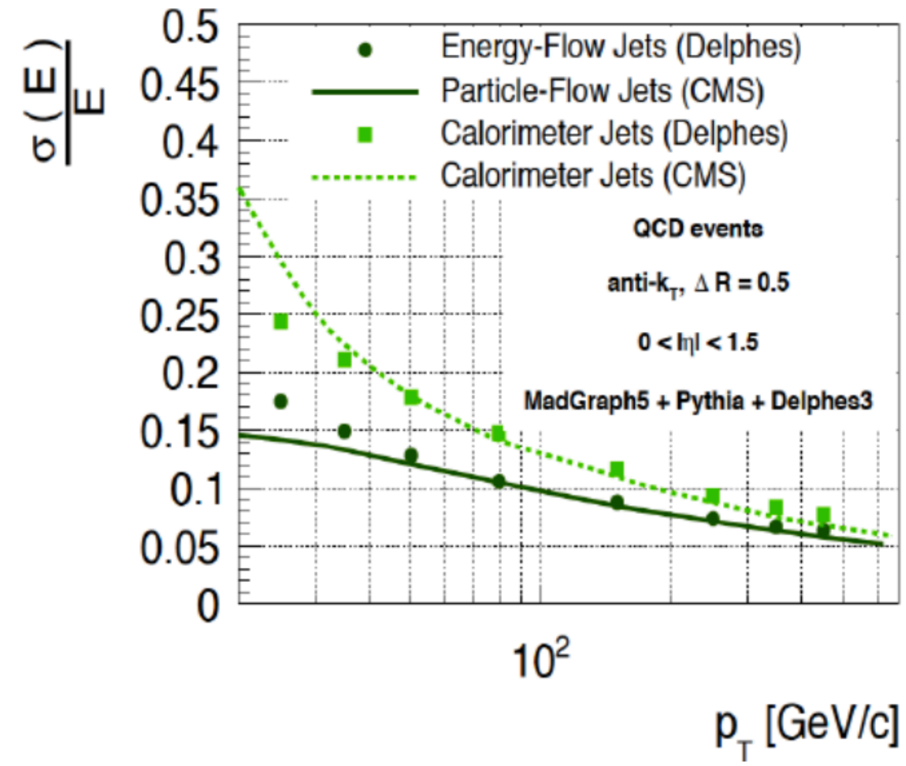


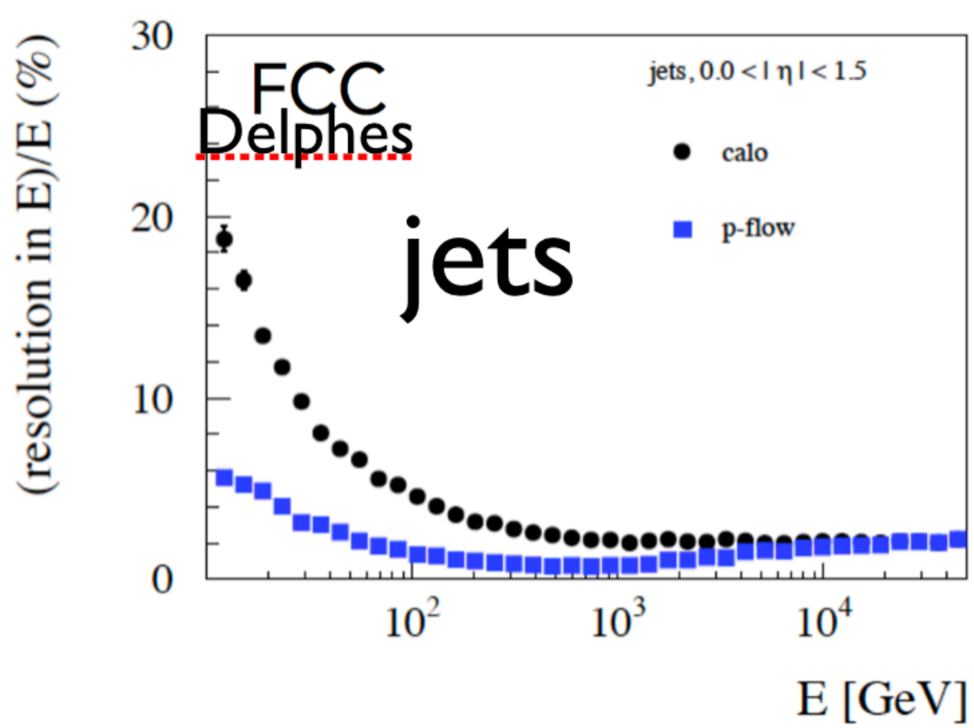
9

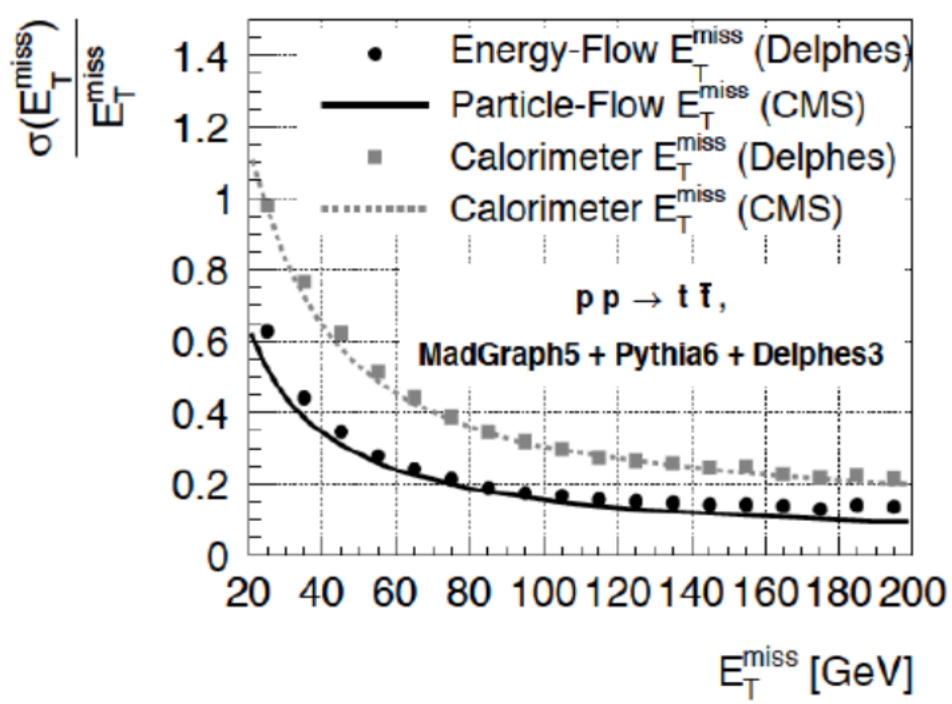
- EM (had) deposit 100% in ECAL (HCAL)
- No propagation in calorimeters
- No clustering (topological) clustering, exploiting pre-defined grid

Particle-Flow



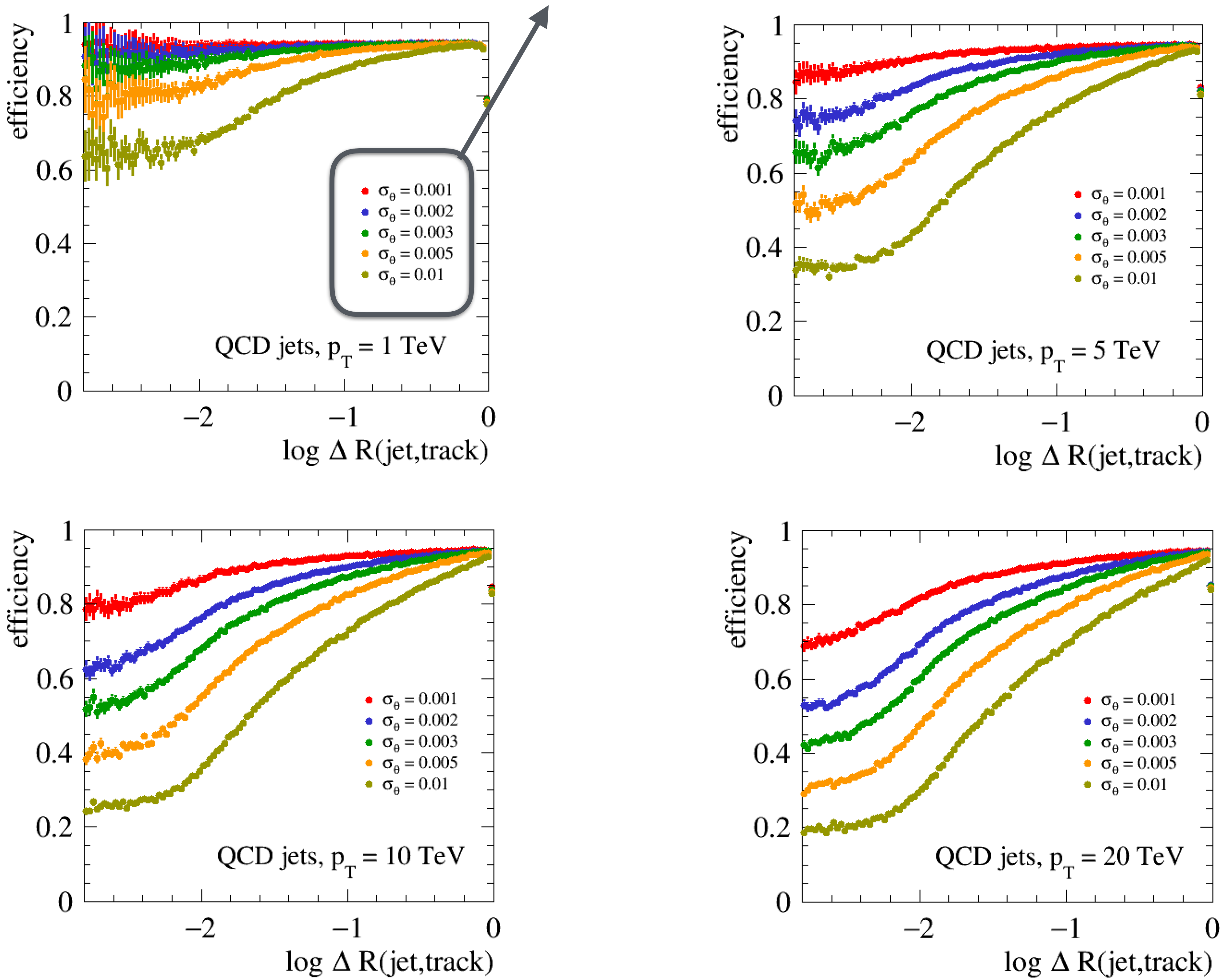






Tracking in Dense environment (NEW!)

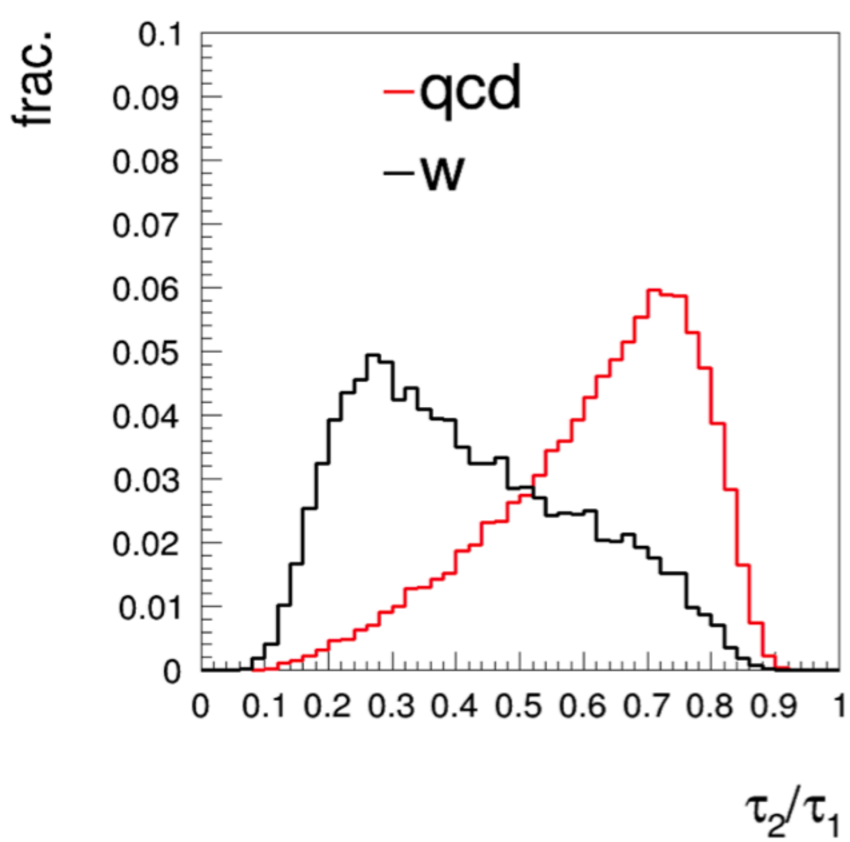
Instrinsic tracking angular resolution



Jet substructure

DELPHES
fast simulation

- Embedded in FastJetFinder module
- $\tau_1, \tau_2, .. , \tau_5$ saved as jet members (N-subjettiness)
- Trimming, Pruning, SoftDrop ...

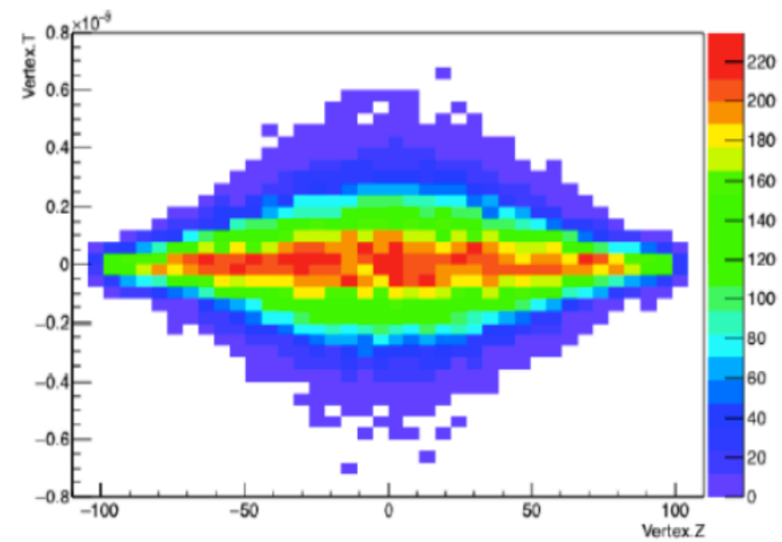



```
############
# Jet finder
############

module FastJetFinder FastJetFinder {
#  set InputArray Calorimeter/towers
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  # algorithm: 1 CDFJetClu, 2 MidPoint, 3 SIScone, 4 kt, 5 Cambridge/Aachen, 6 antikt
  set JetAlgorithm 5
  set ParameterR 1.0

  set JetPTMin 200.0

  set ComputeTrimming true
  set ComputePruning true
  set ComputeSoftDrop true
  set ComputeNsubjettiness true

}
```

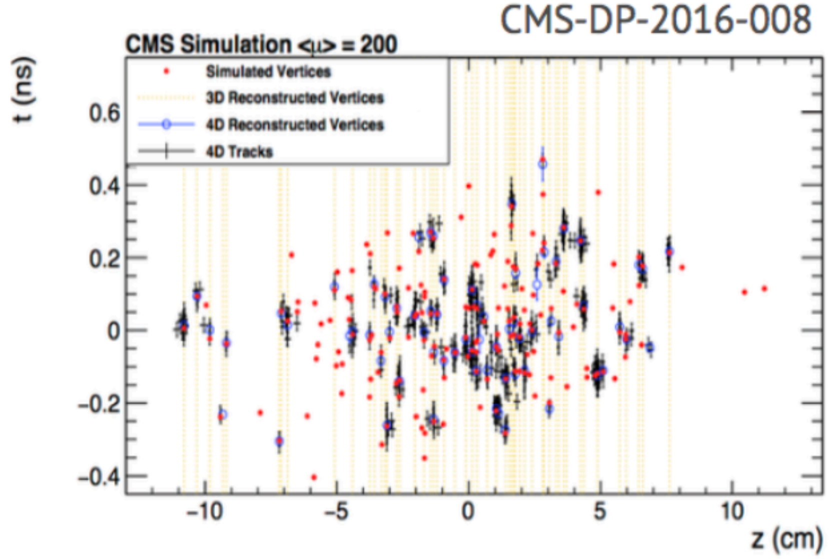
18

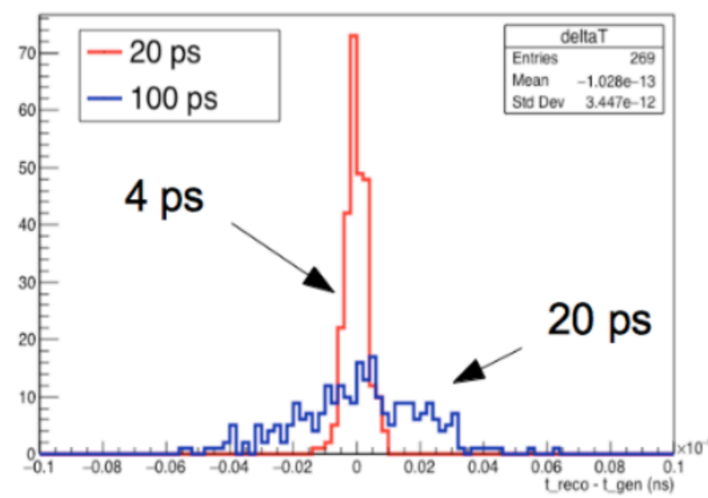
Pile-up and Timing

- Beamspot description with f(z,t) customizable profile has been included
- Time information is propagated up calorimeters, and then smeared
- Vertexing in 3D/4D has been included



CMS-DP-2016-008





11

Lindsey Gray, Andrew Hart

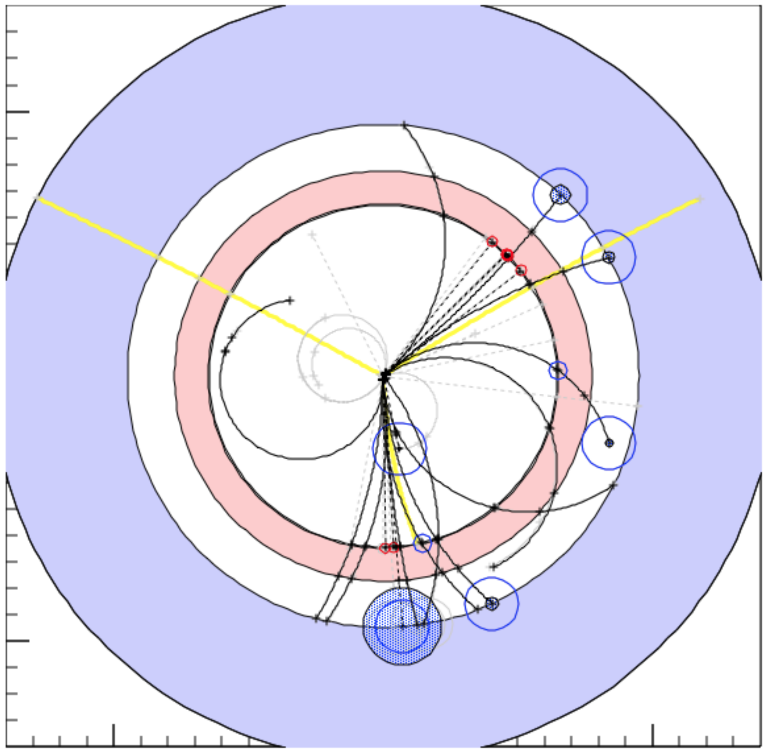
https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/PileUp

PAPAS

github.com/HEP-FCC/papas

What is PAPAS?

Papas: Parameterized Particle Simulation



Approach:

- parameterise detector
- fast simulation/particle flow reconstruction
- Python and C++ versions of Papas

Main authors: Colin Bernet Alice Robson

Detector Parameterisation

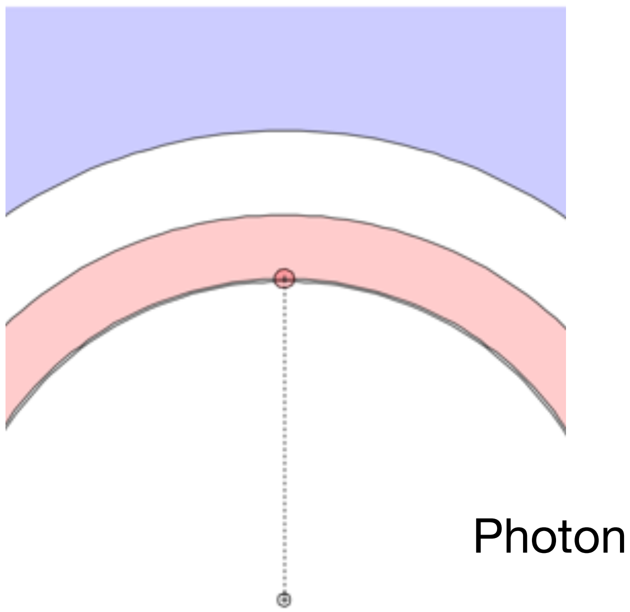
```python
class Tracker(DetectorElement):

    def __init__(self):
        volume = VolumeCylinder('tracker', 1.29, 1.99)
        mat = material.void
        super(Tracker, self).__init__('tracker', volume,  mat)

    def acceptance(self, track):
        pt = track.p3() .Pt()
        eta = abs(track.p3() .Eta())
        if eta < 1.35 and pt>0.5:
            return random.uniform(0,1)<0.95
        elif eta < 2.5 and pt>0.5:
            return random.uniform(0,1)<0.9
        else:
            return False

    def resolution(self, track):
        return 1.1e-2
```

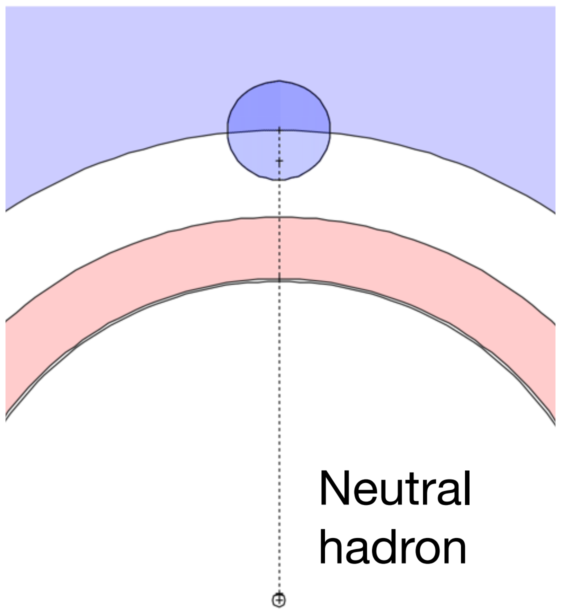
Parameters used to define:

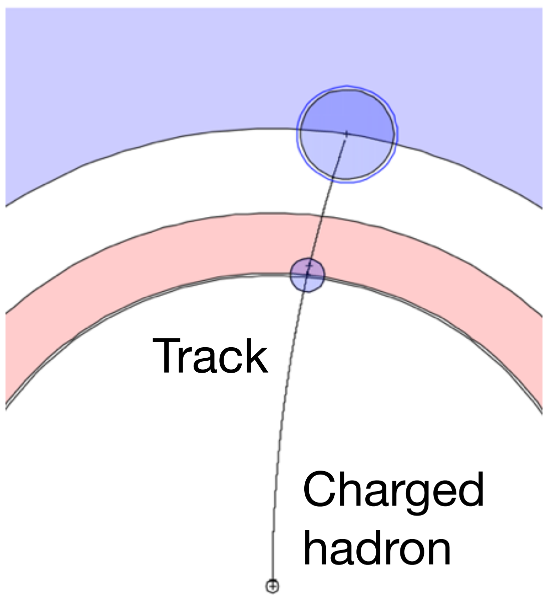
- simple geometry (cylinder)
- acceptance model
- resolution model
- (+ B field)

Particle Flow

- Papas uses a very similar particle flow algorithm as in CMS
- Builds calo-clusters out of realistic stochastic energy deposit
- Finds "connected" sets of clusters/tracks
- Build particles from "connected" clusters/tracks
- Neutral excesses are created using the full ECAL+HCAL information



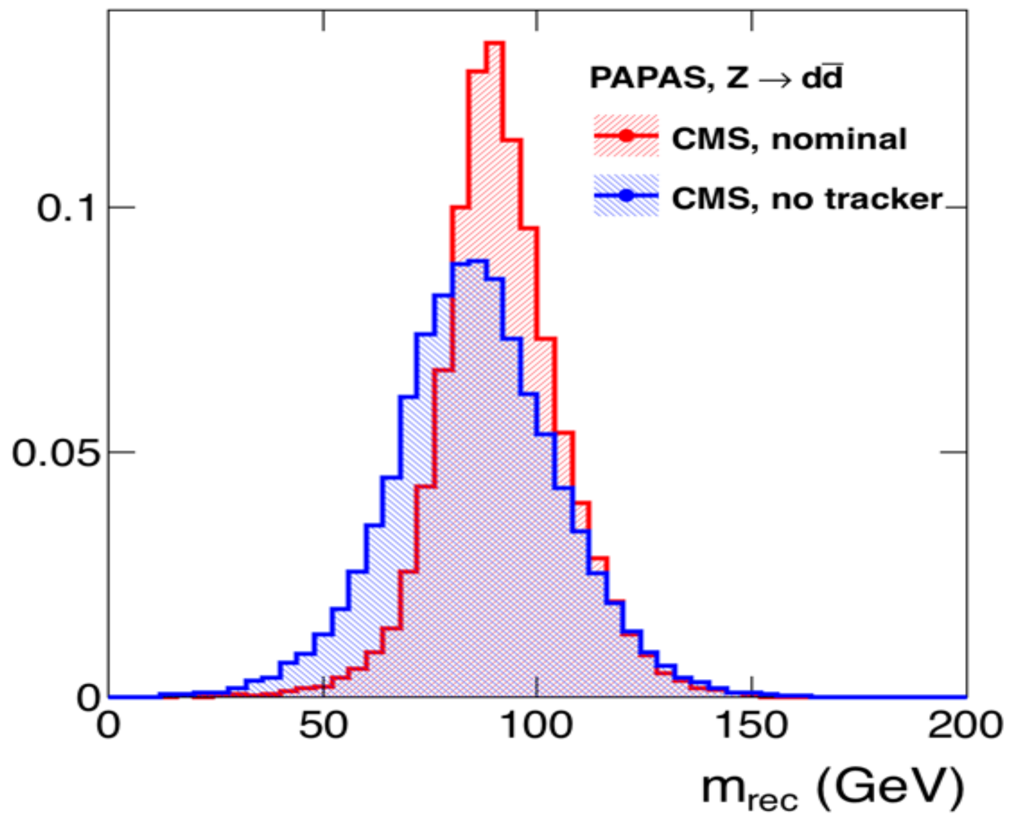




Particle Flow

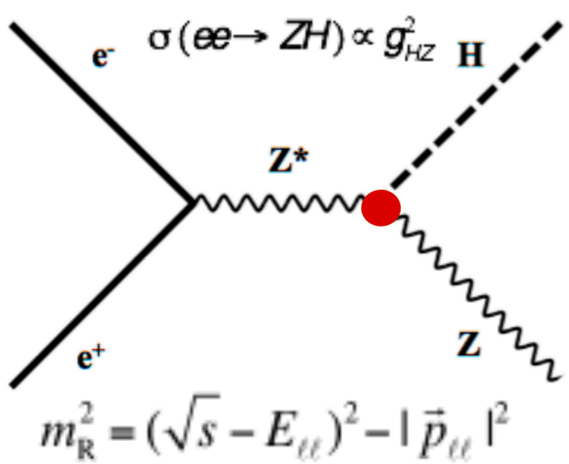
Effect of tracker on Z-mass reconstruction

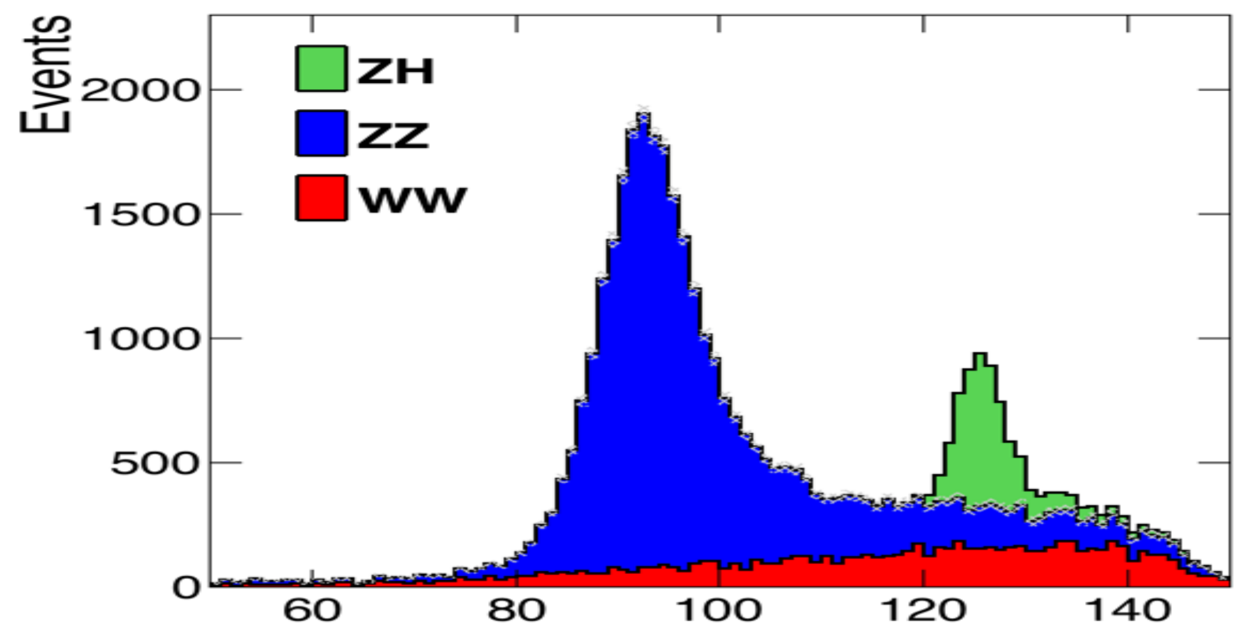
No tracker: calorimetric reconstruction of all particles



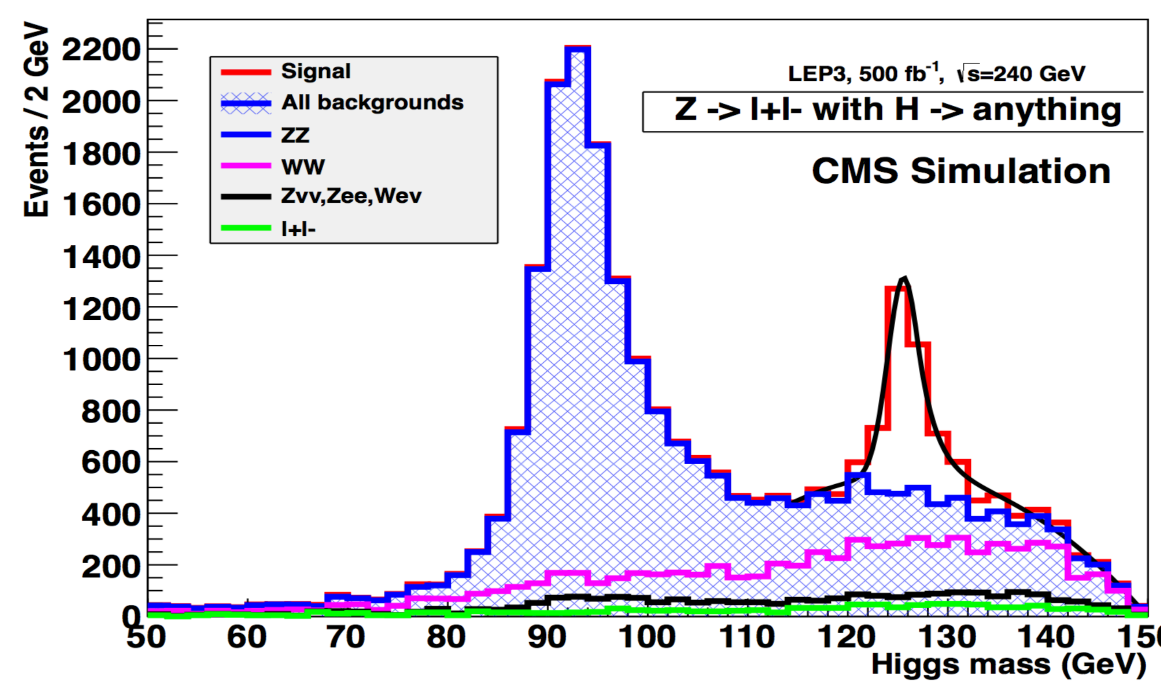
Example

Aim: measure ZH inclusive cross-section at 240GeV, 500 fb^{-1}





- Generate: ZH, ZZ, WW samples
  - two lepton channel
  - determine recoil
  - cuts and normalisation as in LEP3



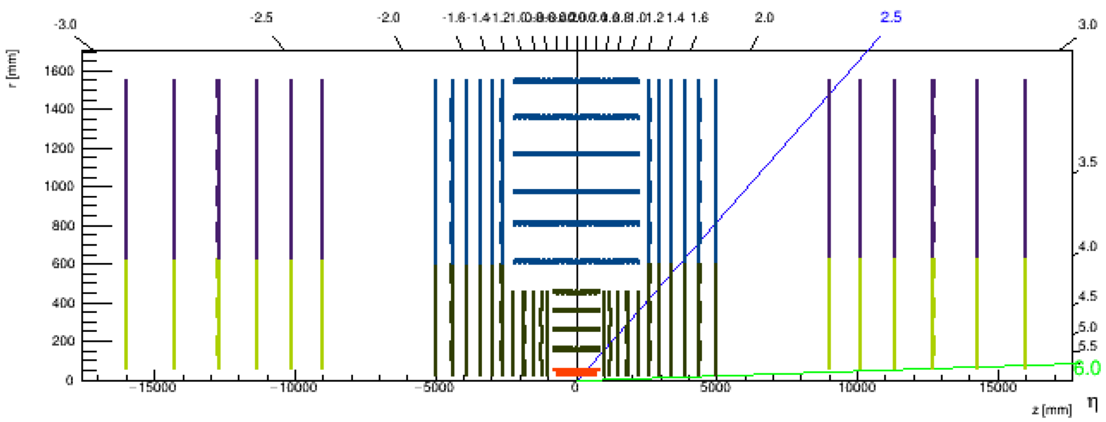
- 600k events in total
- more tuning needed for e and mu resolution
  (a bit too coarse)

Conclusions

- Delphes and PAPAS fast-simulation tools have been presented
- Delphes originally designed for hadronic environment (pile-up, simple particle-flow, optimised for high pT objects)
- PAPAS originally designed for e+e- (more advanced particle-flow)
- Both tools can nevertheless be used in e+e- and hh environments
- Thorough comparative study will be performed soon …
- Try them out at: github.com/HEP-FCC/fcc-tutorials

Thank you

FCC-hh detector

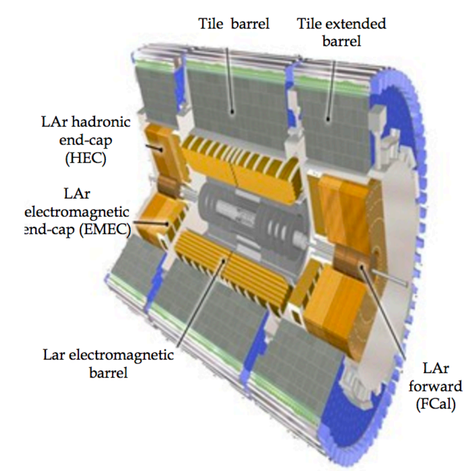


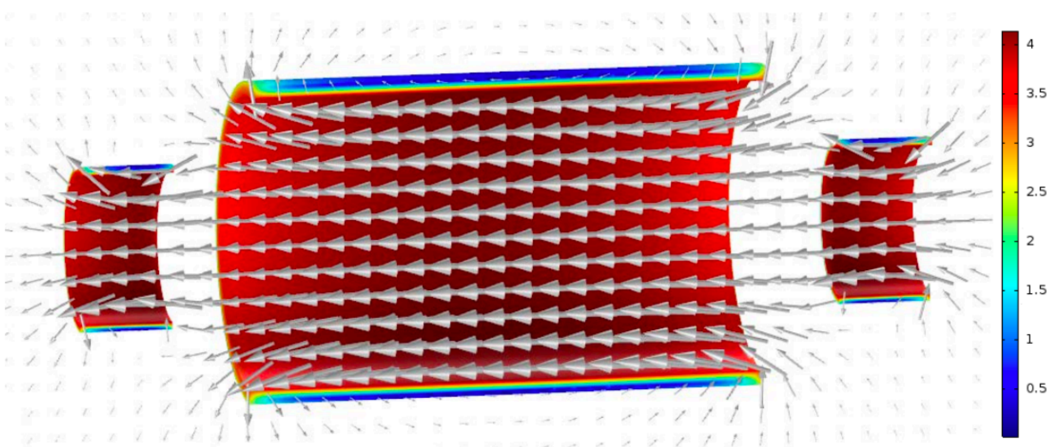
Tracker

- $-6 < \eta < 6$ coverage
- pixel : $\sigma_{r\phi} \sim 10\mu m$, $\sigma_Z \sim 15\text{-}30\mu m$, $X/X_0(\text{layer}) \sim 0.5\text{-}1.5\%$
- outer : $\sigma_{r\phi} \sim 10\mu m$, $\sigma_Z \sim 30\text{-}100\mu m$, $X/X_0(\text{layer}) \sim 1.5\text{-}3\%$

Calorimeters

- ECAL: LArg , $30X_0$, 1.6 λ, r = 1.7-2.7 m (barrel)
- HCAL: Fe/Sci , 9 λ, r = 2.8 - 4.8 m (barrel)
- endcaps and fwd to be defined (investigating HGCAL …)



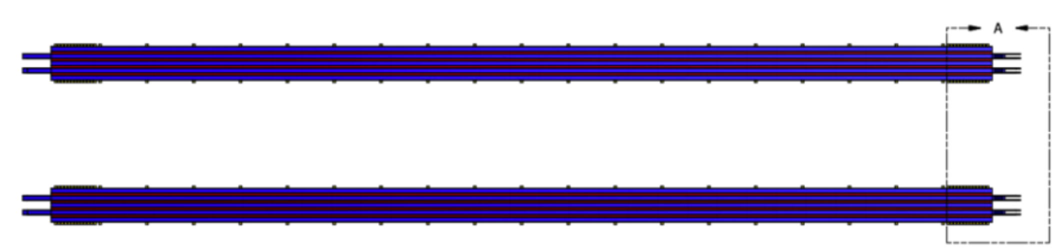


Magnet

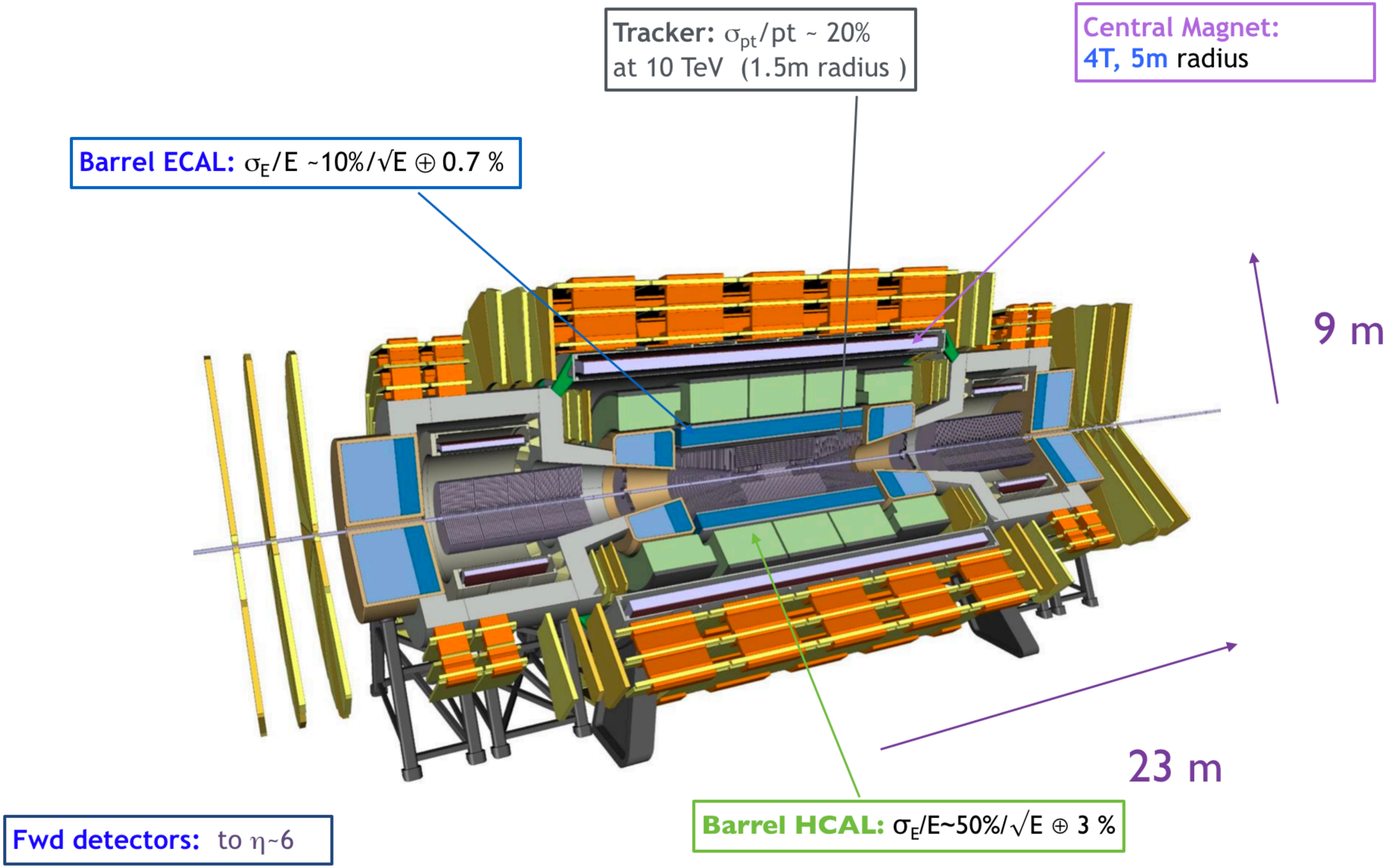
- central R = 5, L = 10 m, B = 4T
- forward R = 3m , L = 3m , B = 4T

Muon spectrometer

- Two stations separated by 1-2 m
- 50 µm pos., 70µrad angular



FCC-hh detector



FCC-ee detector - IDEA

Courtesy of M. Dams

IDEA detector concept based on present state-of-the-art technologies:

- Vertex detector, MAPS
- Ultra-light drift chamber with PID
- Pre-shower counter
- Double read-out calorimetry
- 2 T solenoidal magnetic field
- Possibly instrumented return yoke

- Or possibly surrounded by large tracking volume (R ≃ 8m) for very weakly coupled (long-lived) particles

Two Options: Coil inside or outside calorimetry