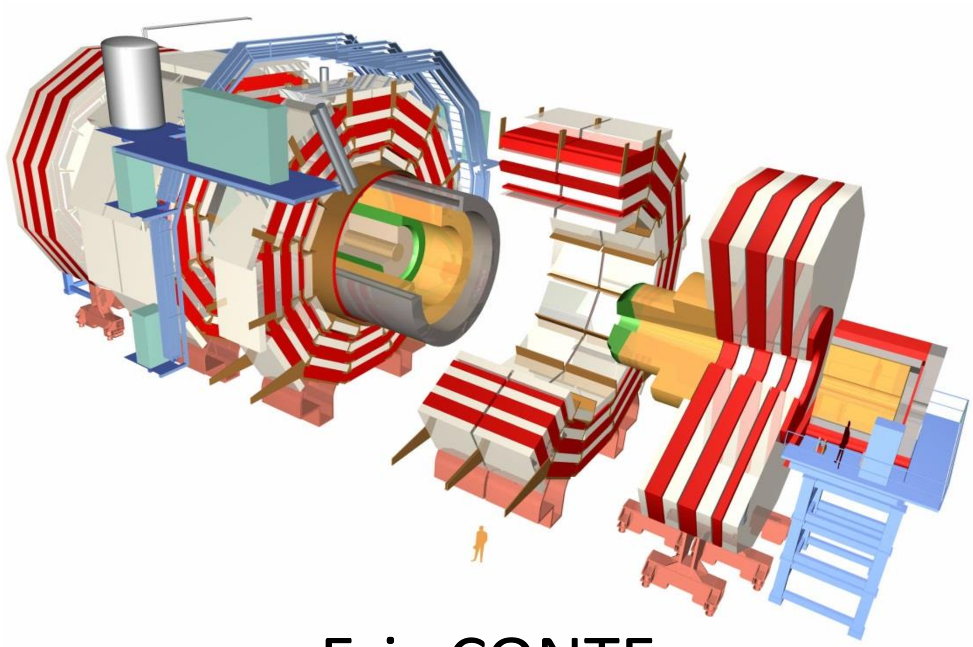
Detector simulation for LHC analyses recasting



Eric CONTE

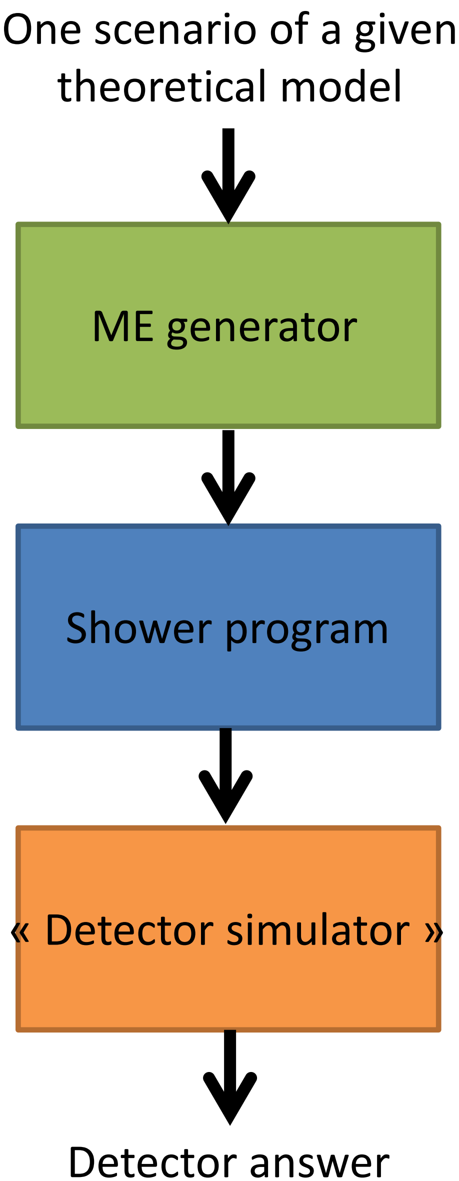
The first MadAnalysis 5 workshop on LHC recasting @ Korea
20-27 August 2017

Outlines

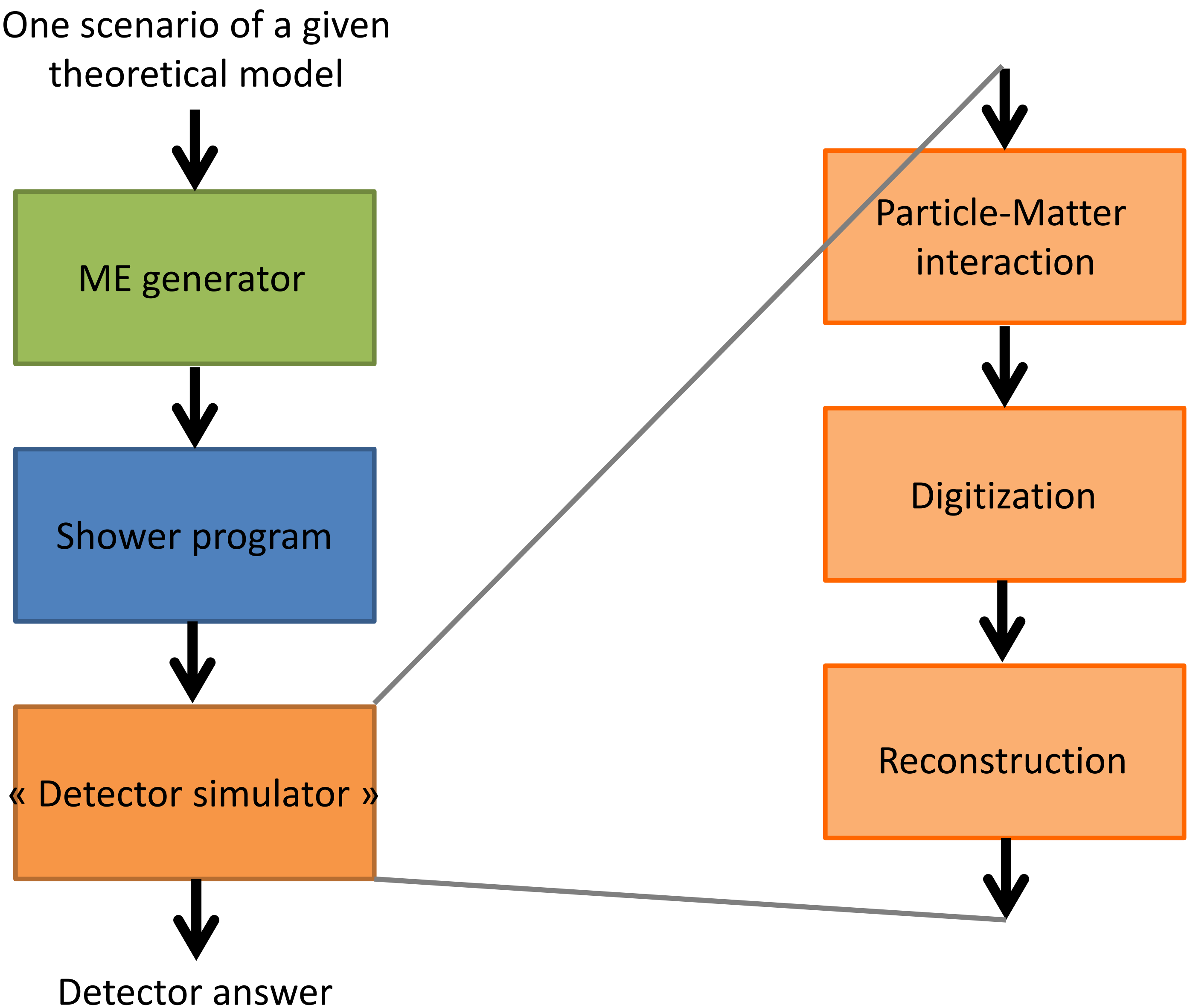
1. Introduction
2. General concepts on Delphes
3. CMS detector simulation with Delphes
4. Including pile-up effects
5. Validation & limitations of Delphes
6. Beyond Delphes: the tunes

1. Introduction

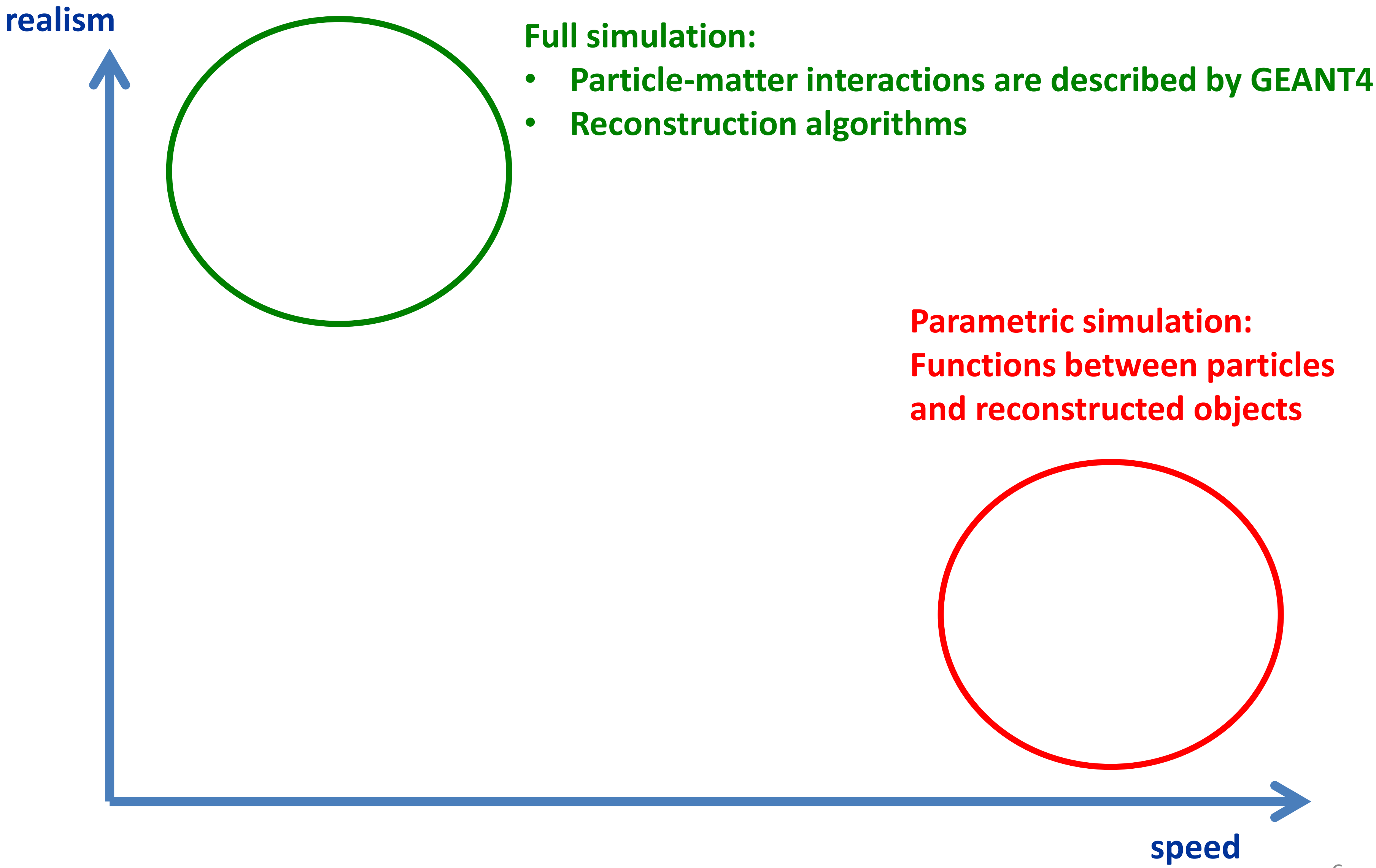
Monte-Carlo chain for recasting



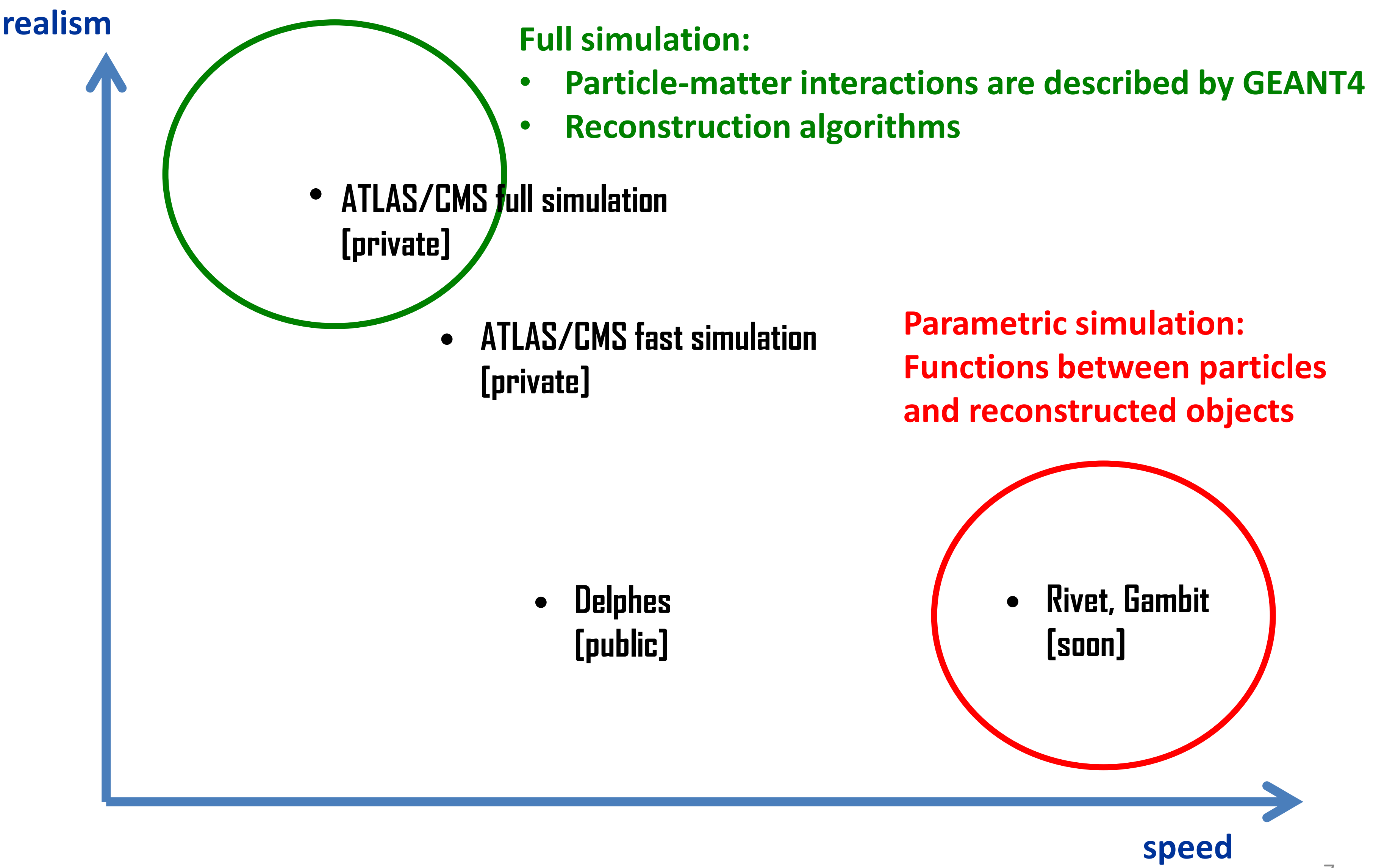
Monte-Carlo chain for recasting



2 big categories of tools



2 big categories



Which tool for recasting?

List to Santa Klaus:

I would like a tool which is:

- Generic for handling the CMS & ATLAS detectors, for different kind of analyses
- Public
- Very fast: allowing to scan on huge parameter space (SUSY-like models)
- But realistic enough
- User-friendly
- Validated & has proved itself

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Delphes!!!!!

2. General concepts of Delphes

What is Delphes?

- **Delphes** is a very-fast-simulation for generic detector:
  - ATLAS & CMS detectors
  - Upgrade of ATLAS & CMS
  - LHCb
  - Future detectors: FCC

- **Output in ROOT format**

Delphes fast simulation

- **JHEP 02 (2014) 057**
- **J.Phys.Conf.Ser. 523 (2014) 012033**
- **J.Phys.Conf.Ser. 608 (2015) 1, 012045**

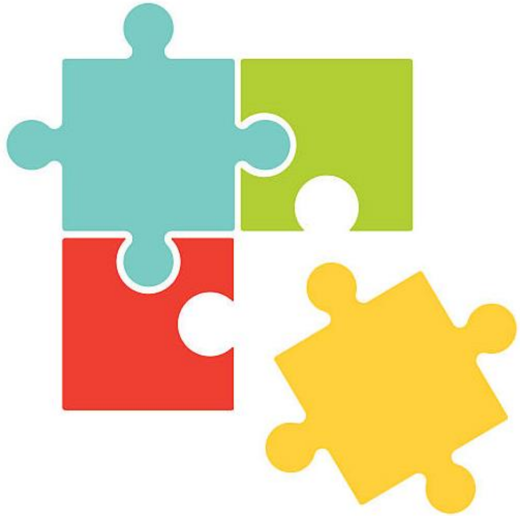
A question of linguistics:

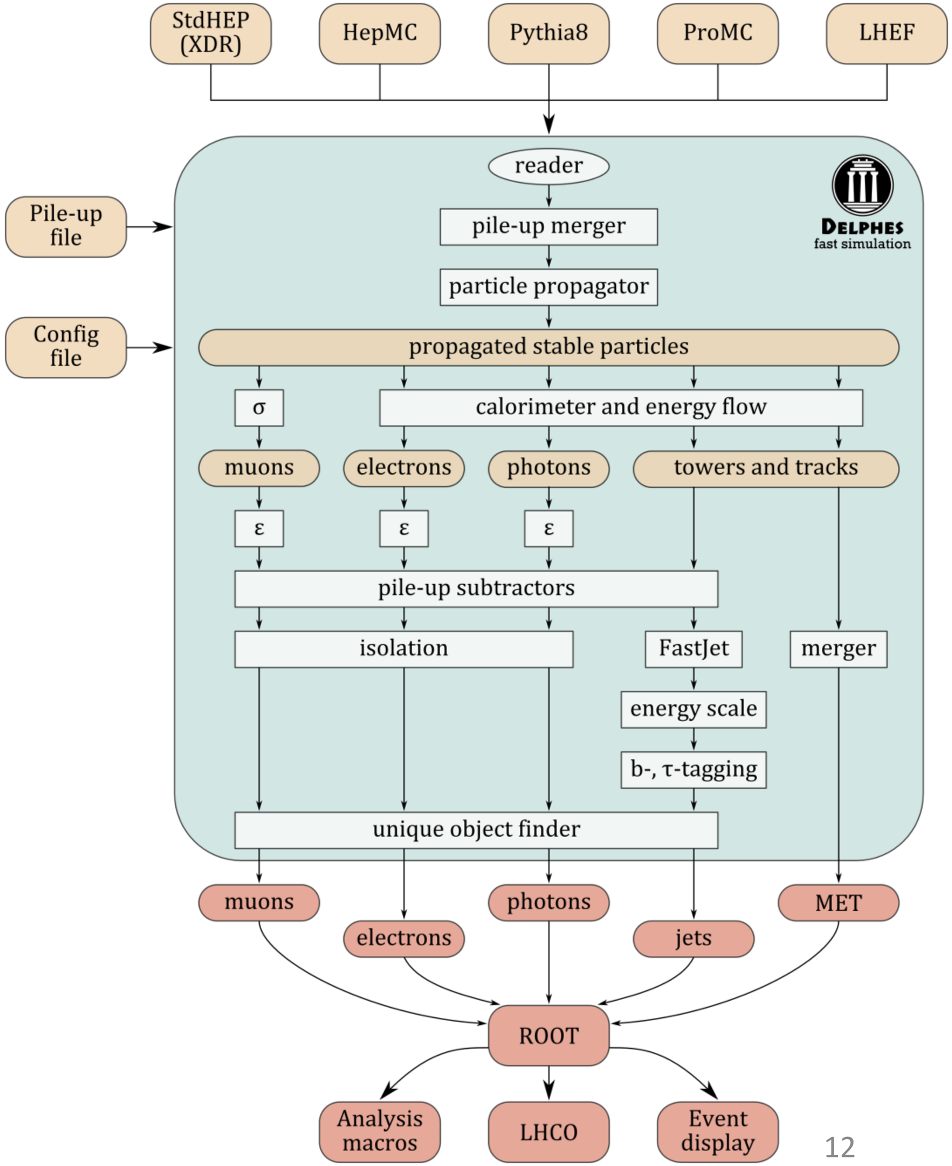
What does "Delphes" mean?

Modular architecture

The detector simulation is split into modules.

→ Each module is devoted to a function.





Modular architecture

List of modules

- AngularSmearing.h
- BeamSpotFilter.h
- BTagging.h
- Calorimeter.h
- Cloner.h
- ConstituentFilter.h
- Delphes.h
- Efficiency.h
- EnergyScale.h
- EnergySmearing.h
- ExampleModule.h
- FastJetFinder.h
- FastJetGridMedianEstimator.h
- FastJetLinkDef.h
- Hector.h
- IdentificationMap.h
- ImpactParameterSmearing.h
- Isolation.h
- JetFakeParticle.h
- JetFlavorAssociation.h
- JetPileUpSubtractor.h
- LeptonDressing.h
- Merger.h
- ModulesLinkDef.h
- MomentumSmearing.h
- OldCalorimeter.h
- ParticlePropagator.h
- PdgCodeFilter.h
- PhotonConversions.h
- PileUpJetID.h
- PileUpMerger.h
- PileUpMergerPythia8.h
- Pythia8LinkDef.h
- RecoPuFilter.h
- RunPUPPI.h
- SimpleCalorimeter.h
- StatusPidFilter.h
- TaggingParticlesSkimmer.h
- TauTagging.h
- TimeSmearing.h
- TrackCountingBTagging.h
- TrackCountingTauTagging.h
- TrackPileUpSubtractor.h
- TrackSmearing.h
- TreeWriter.h
- UniqueObjectFinder.h
- VertexFinder.h
- VertexFinderDA4D.h
- VertexSorter.h
- Weighter.h

Detector description

Detector simulation is totally described by a card (text file in **tcl** language).

This card contains:

- the sequence of the modules that you need
- how they interact between themselves.

```
set ExecutionPath {
  ParticlePropagator
  ChargedHadronTrackingEfficiency
  ElectronTrackingEfficiency
  MuonTrackingEfficiency
  ChargedHadronMomentumSmearing
  ElectronMomentumSmearing
  MuonMomentumSmearing
  TrackMerger
  ECal
  HCal
  Calorimeter
  EFlowMerger
  EFlowFilter
  PhotonEfficiency
  PhotonIsolation
  ElectronFilter
  ElectronEfficiency
  ElectronIsolation
  ChargedHadronFilter
  MuonEfficiency
  MuonIsolation
  MissingET
  NeutrinoFilter
  GenJetFinder
  GenMissingET
  FastJetFinder
```

Order of execution of the modules use in the simulation

Detector description

Detector simulation is totally described by a card (text file in **tcl** language).

This card contains:

- the sequence of the modules that you need
- how they interact between themselves.

Syntax of module declaration

```
module FastJetFinder FastJetFinder
{
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  set JetAlgorithm 6
  set ParameterR 0.5
  set JetPTMin 20.0
}
```

Name & type of module

Input collection

Output collection

Parameters

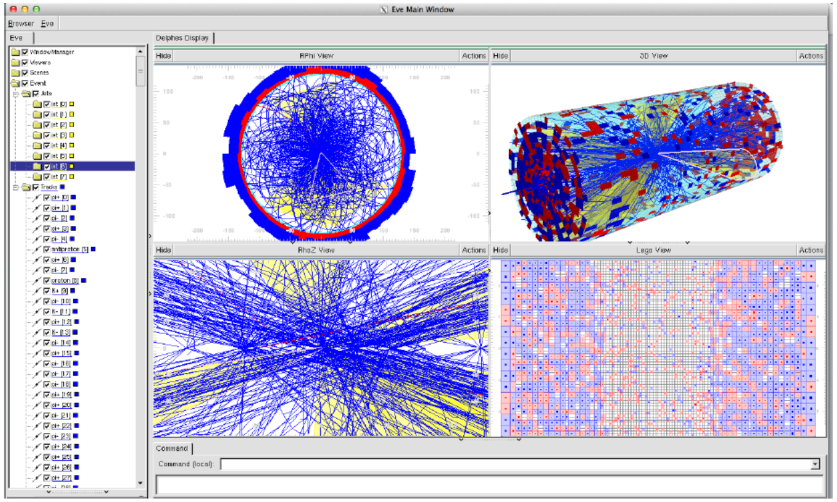
Other informations

Requirements:

Package	Utility	
ROOT 6	Main framework & data format	→ To be installed
TCL	Language of detector card	→ To be installed
FastJet	Jet-clustering algorithm, pile-up	→ Encapsulated in the delphes package

Extra programs:

- **EVE** (former FROG): program of event vizualisation
- **DelphesAnalysis**: reading Delphes ROOT file with Python

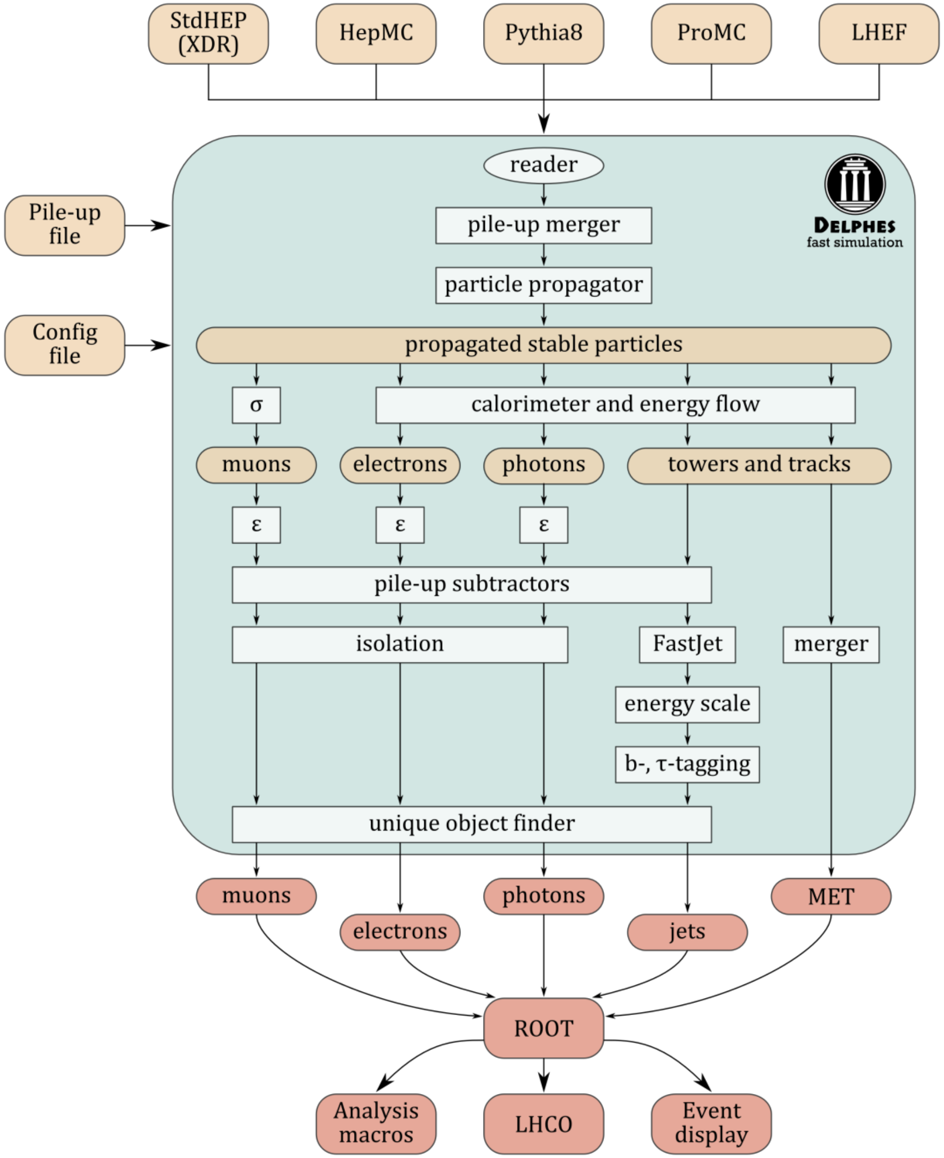


Site web: https://cp3.irmp.ucl.ac.be/projects/delphes

3. CMS detector simulation

with Delphes

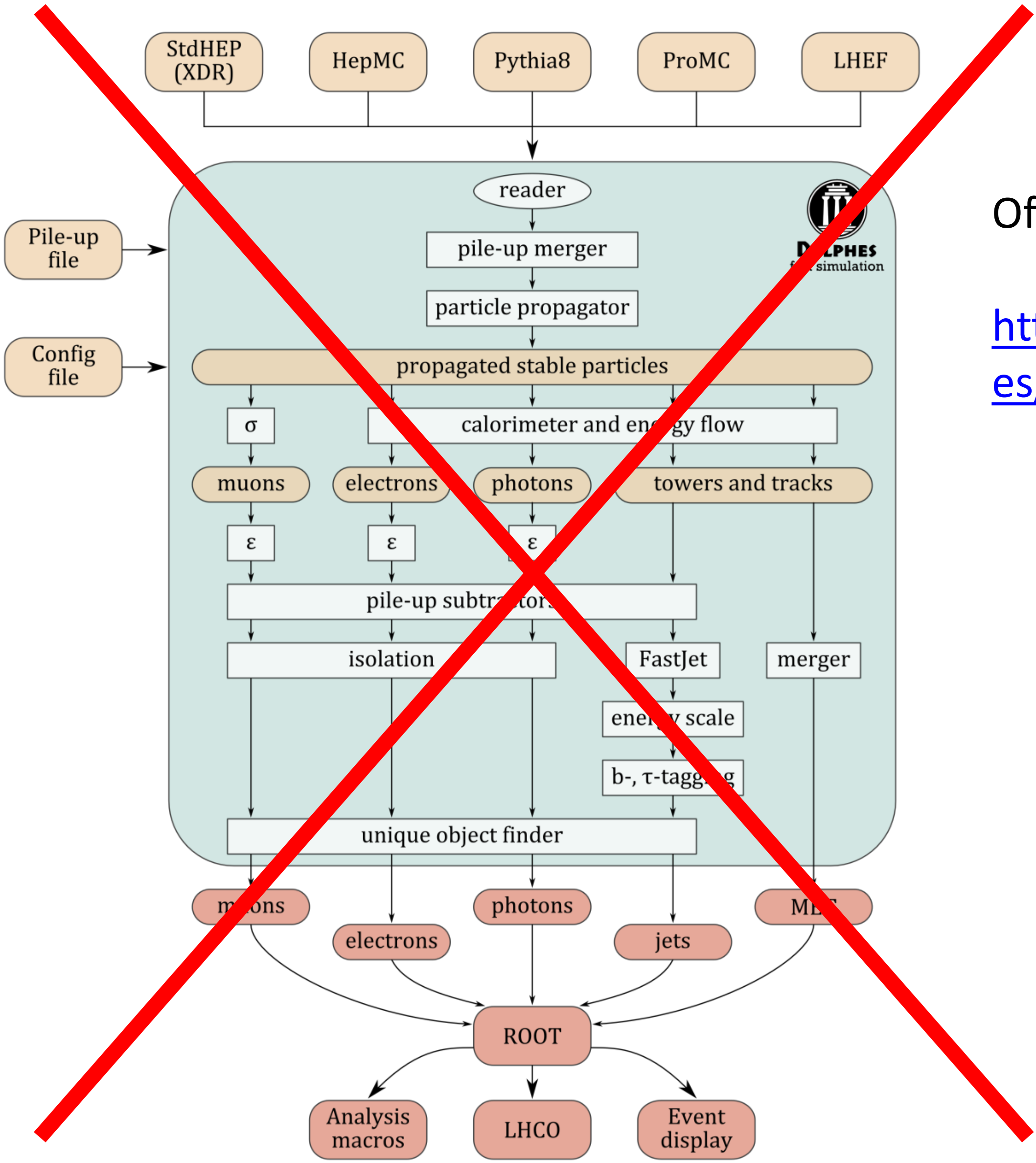
Dataflow diagram



Official dataflow diagram:

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

Dataflow diagram

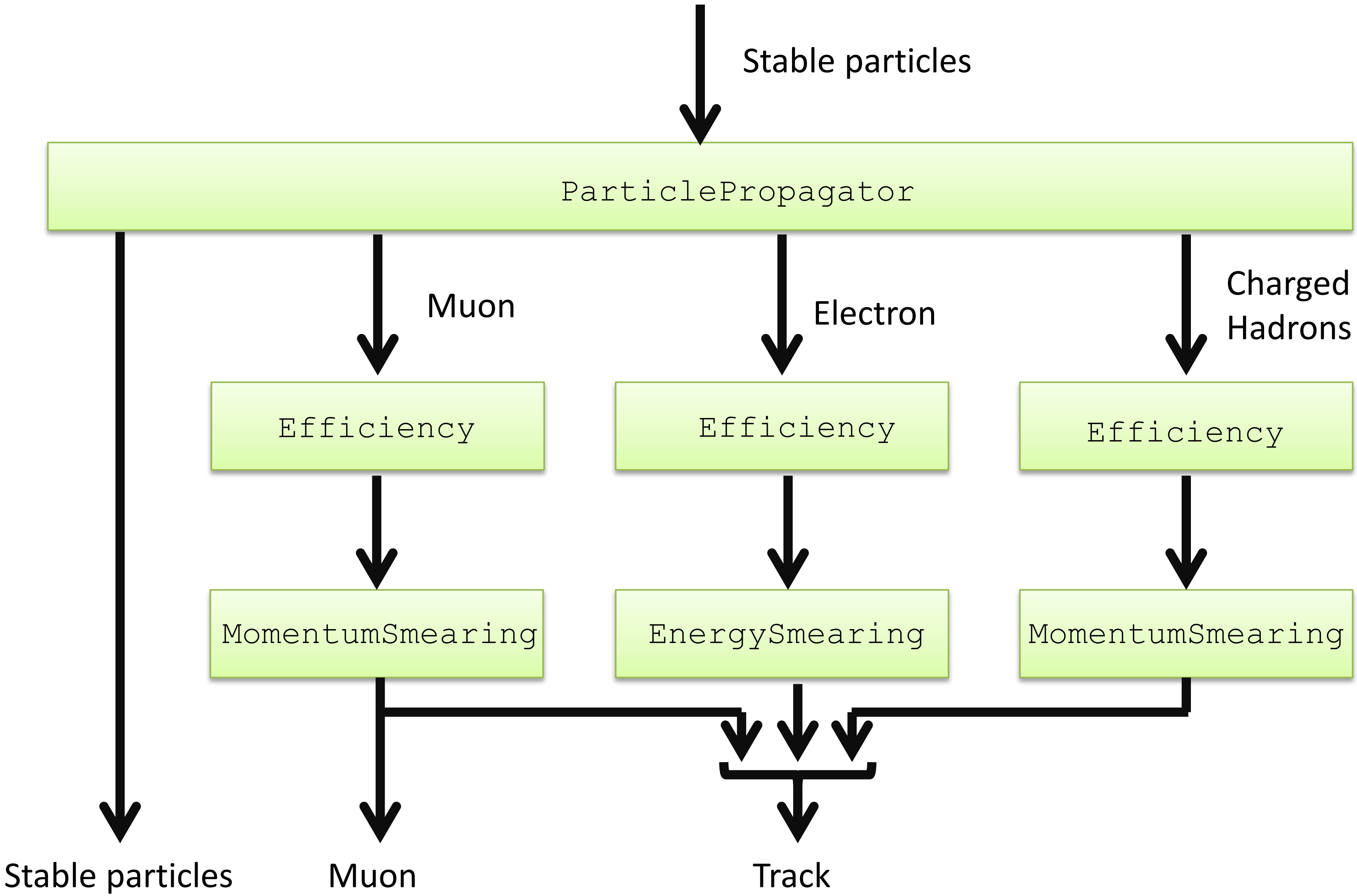


Official dataflow diagram:

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

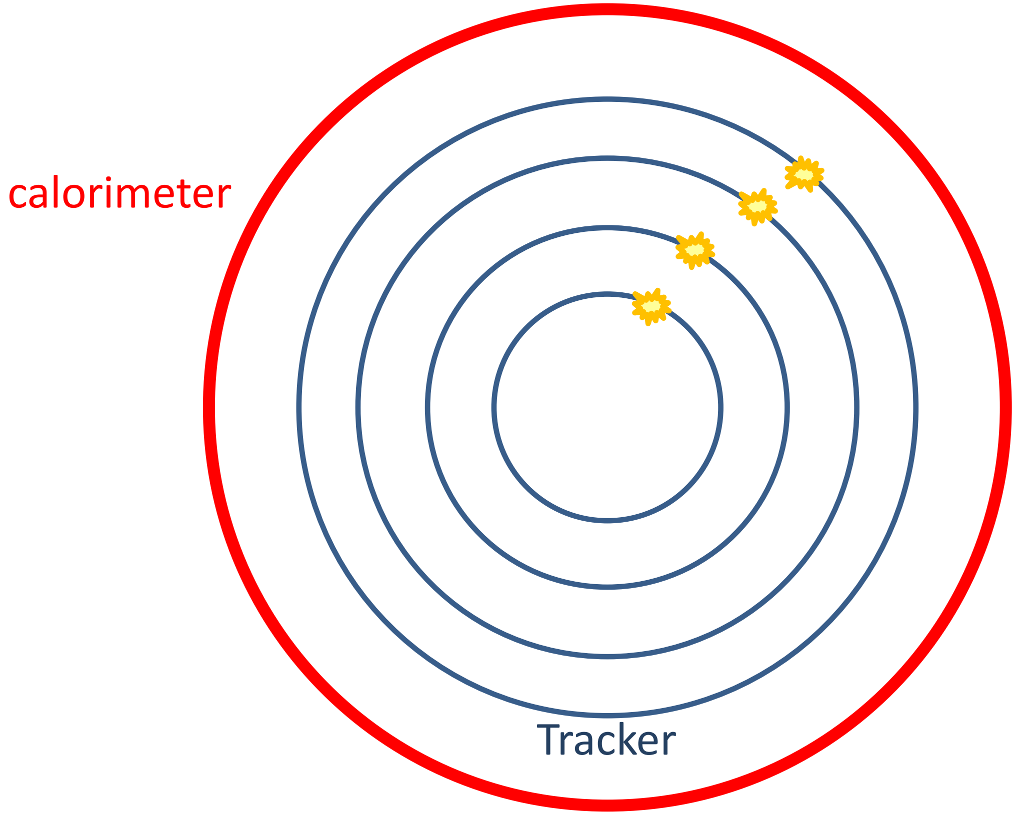
Obsolete with Delphes 3.4.1

Process Part 1: tracking



Process Part 1: tracking

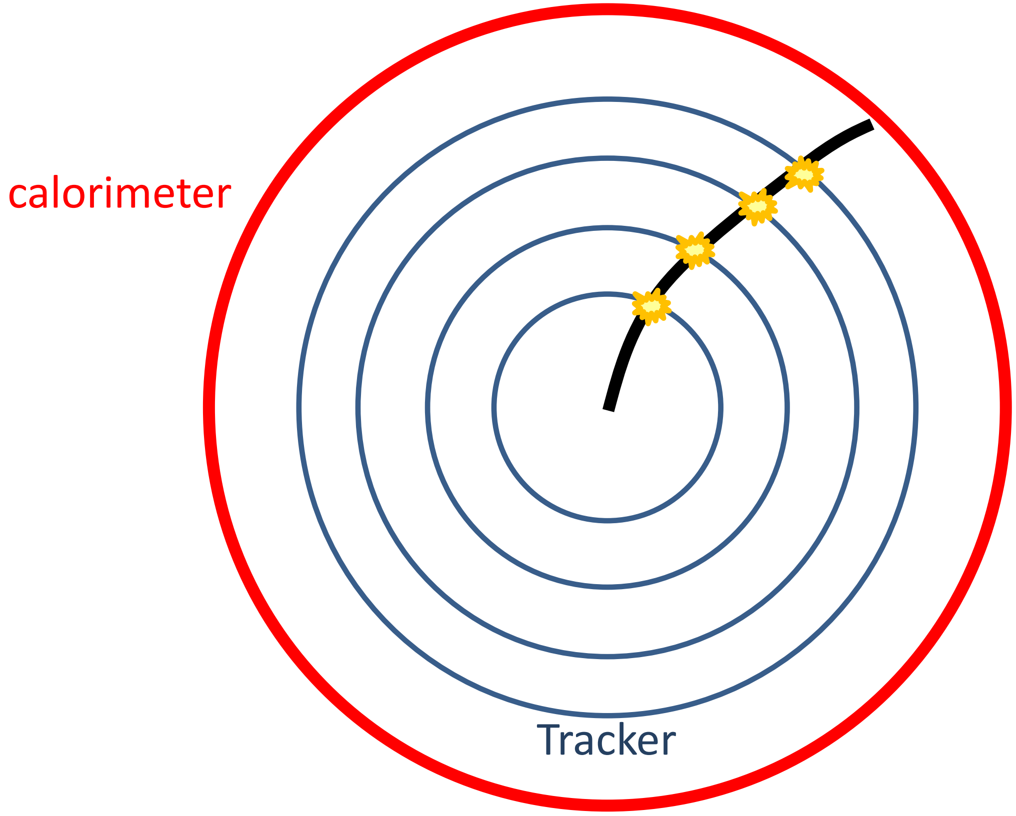
In the real life:



In Delphes, there is no real tracking or vertexing.

Process Part 1: tracking

In the real life:



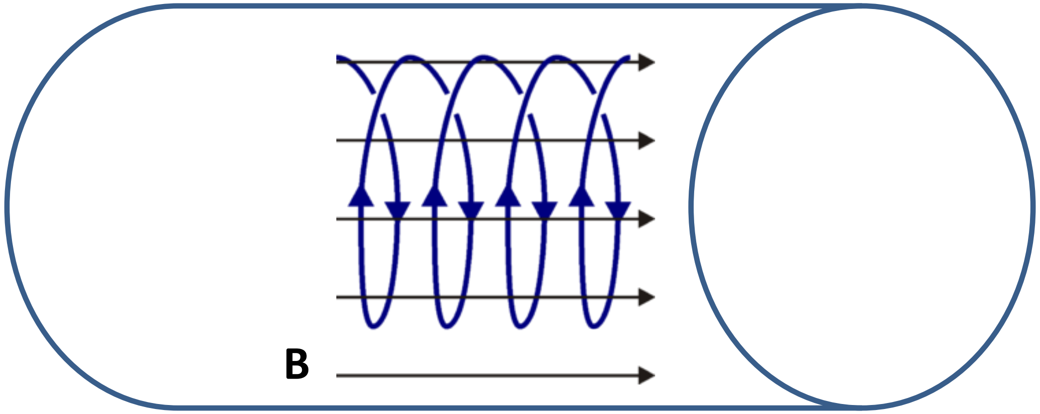
In Delphes, there is no real tracking or vertexing.

Process Part 1: tracking

ParticlePropagator

→ Charged particles are propagated in the magnetic field until they reach calorimeters. We apply the following movment equations in a cylinder:

$$\frac{d\vec{p}}{dt} = q(\vec{v} \times \vec{B})$$



→ The result of this computation is to compute the position @ first calorimeter layer.

Process Part 1: tracking

ParticlePropagator

```
module ParticlePropagator ParticlePropagator
{
  # input
  set InputArray Delphes/stableParticles

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

  # radius of the magnetic field coverage, in m
  set Radius 1.29
  # half-length of the magnetic field coverage, in m
  set HalfLength 3.00

  # magnetic field
  set Bz 3.8
}
```

Definition of the cylindral volume of the tracker.

Magnitude of the magnetic field

PS: for ATLAS

```
set Radius 1.15
set HalfLength 3.51
set Bz 2.0
```

Process Part 1: tracking

Efficiency

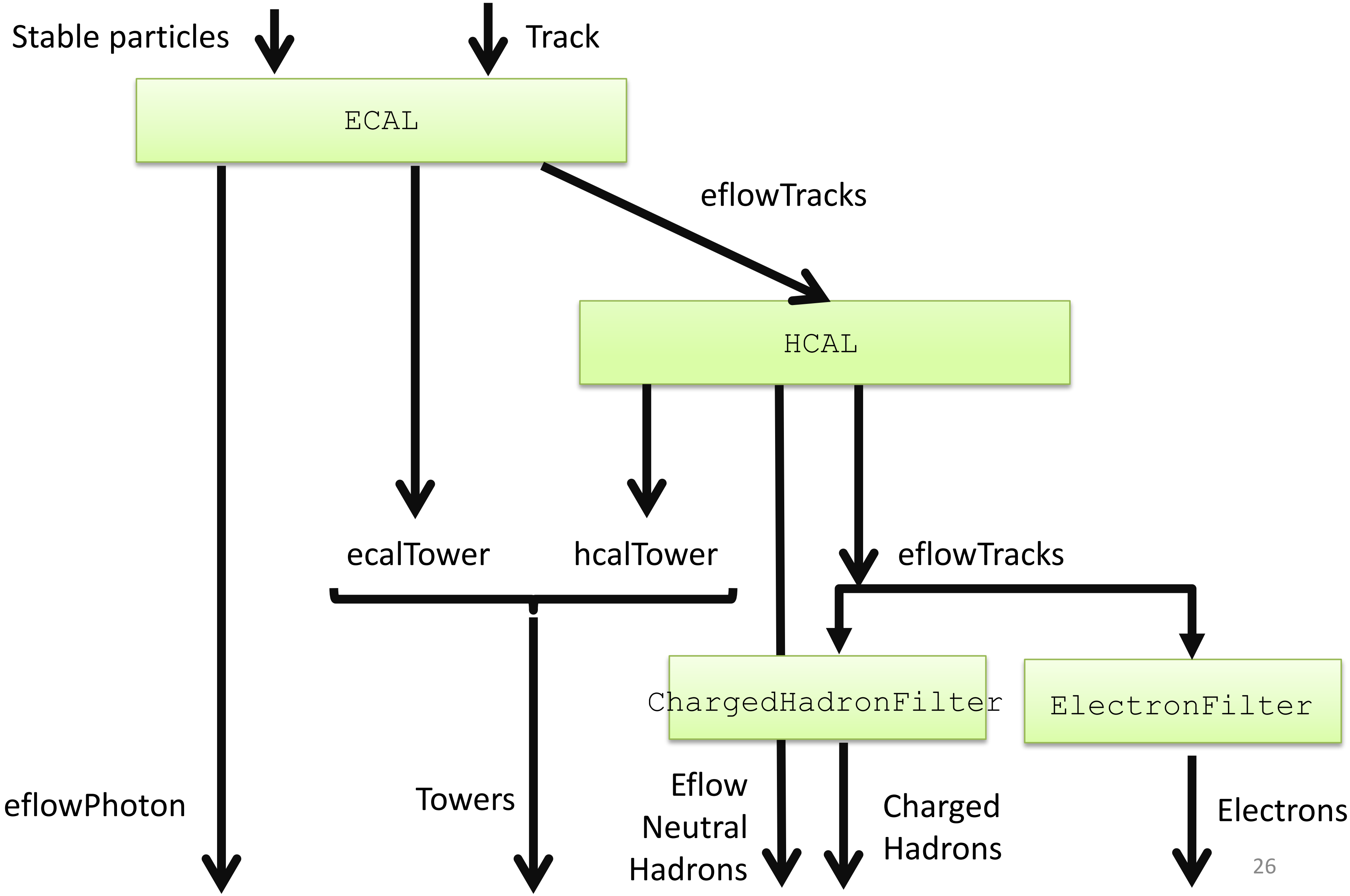
```
module Efficiency MuonTrackingEfficiency {
  set InputArray ParticlePropagator/muons
  set OutputArray muons

  # tracking efficiency formula for muons
  set EfficiencyFormula {                                              (pt <= 0.1)    * (0.00) +
                                      (abs(eta) <= 1.5) * (pt > 0.1   && pt <= 1.0)   * (0.75) +
                                      (abs(eta) <= 1.5) * (pt > 1.0)                  * (0.99) +
                        (abs(eta) > 1.5 && abs(eta) <= 2.5) * (pt > 0.1   && pt <= 1.0)   * (0.70) +
                        (abs(eta) > 1.5 && abs(eta) <= 2.5) * (pt > 1.0)                  * (0.98) +
                        (abs(eta) > 2.5)                                                  * (0.00)}
}
```

MomentumSmearing

```
module MomentumSmearing MuonMomentumSmearing {
  set InputArray MuonTrackingEfficiency/muons
  set OutputArray muons

  # set ResolutionFormula {resolution formula as a function of eta and pt}
  # resolution formula for muons
  set ResolutionFormula {                  (abs(eta) <= 0.5) * (pt > 0.1) * sqrt(0.01^2 + pt^2*1.0e-4^2) +
                        (abs(eta) > 0.5 && abs(eta) <= 1.5) * (pt > 0.1) * sqrt(0.015^2 + pt^2*1.5e-4^2) +
                        (abs(eta) > 1.5 && abs(eta) <= 2.5) * (pt > 0.1) * sqrt(0.025^2 + pt^2*3.5e-4^2)}
}
```

Resolution on pT

Process Part 2: calorimetry



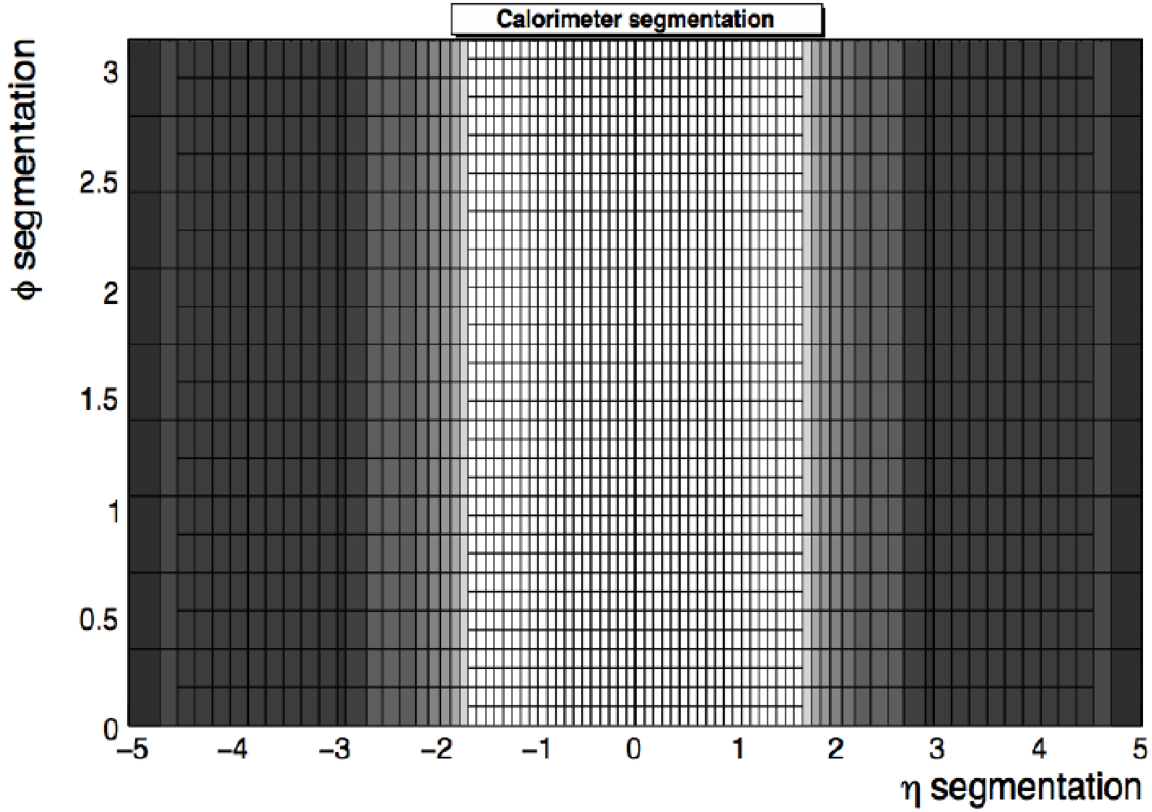
Process Part 2: calorimetry

ECAL

HCAL

= inheritance from the same module : Calorimeter

1) Segmentation of the calorimeter into cells



Process Part 2: calorimetry

ECAL | HCAL = inheritance from the same module : Calorimeter

2) Energy fraction absorbed by the calorimeter

ECAL case

```
add EnergyFraction {0} {0.0}
# energy fractions for e, gamma and pi0
add EnergyFraction {11} {1.0}
add EnergyFraction {22} {1.0}
add EnergyFraction {111} {1.0}
# energy fractions for muon, neutrinos and neutralinos
add EnergyFraction {12} {0.0}
add EnergyFraction {13} {0.0}
add EnergyFraction {14} {0.0}
add EnergyFraction {16} {0.0}
add EnergyFraction {1000022} {0.0}
add EnergyFraction {1000023} {0.0}
add EnergyFraction {1000025} {0.0}
add EnergyFraction {1000035} {0.0}
add EnergyFraction {1000045} {0.0}
# energy fractions for K0short and Lambda
add EnergyFraction {310} {0.3}
add EnergyFraction {3122} {0.3}
```

HCAL case

```
# default energy fractions {abs(PDG code)} {Fecal Fhcal}
add EnergyFraction {0} {1.0}
# energy fractions for e, gamma and pi0
add EnergyFraction {11} {0.0}
add EnergyFraction {22} {0.0}
add EnergyFraction {111} {0.0}
# energy fractions for muon, neutrinos and neutralinos
add EnergyFraction {12} {0.0}
add EnergyFraction {13} {0.0}
add EnergyFraction {14} {0.0}
add EnergyFraction {16} {0.0}
add EnergyFraction {1000022} {0.0}
add EnergyFraction {1000023} {0.0}
add EnergyFraction {1000025} {0.0}
add EnergyFraction {1000035} {0.0}
add EnergyFraction {1000045} {0.0}
# energy fractions for K0short and Lambda
add EnergyFraction {310} {0.7}
add EnergyFraction {3122} {0.7}
```

WARNING: if you had exotic particle in your sample, declare its EnergyFractions.

Process Part 2: calorimetry

ECAL

HCAL

= inheritance from the same module : Calorimeter

3) Smearing of cell energy

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S(\eta)}{\sqrt{E}}\right)^2 + \left(\frac{N(\eta)}{E}\right)^2 + C(\eta)^2$$

ECAL case

```
set ResolutionFormula {                    (abs(eta) <= 1.5) * (1+0.64*eta^2) * sqrt(energy^2*0.008^2 + energy*0.11^2 + 0.40^2) +
                           (abs(eta) > 1.5 && abs(eta) <= 2.5) * (2.16 + 5.6*(abs(eta)-2)^2) * sqrt(energy^2*0.008^2 + energy*0.11^2 + 0.40^2) +
                           (abs(eta) > 2.5 && abs(eta) <= 5.0) * sqrt(energy^2*0.107^2 + energy*2.08^2)}
```

arXiv:1306.2016, Xiv:1502.02701

HCAL case

```
# set HCalResolutionFormula {resolution formula as a function of eta and energy}
set ResolutionFormula {                    (abs(eta) <= 3.0) * sqrt(energy^2*0.050^2 + energy*1.50^2) +
                           (abs(eta) > 3.0 && abs(eta) <= 5.0) * sqrt(energy^2*0.130^2 + energy*2.70^2)}
```

+ Min value on energy cell

Process Part 2: calorimetry

ECAL

HCAL

= inheritance from the same module : Calorimeter

4) Two kinds of output collection

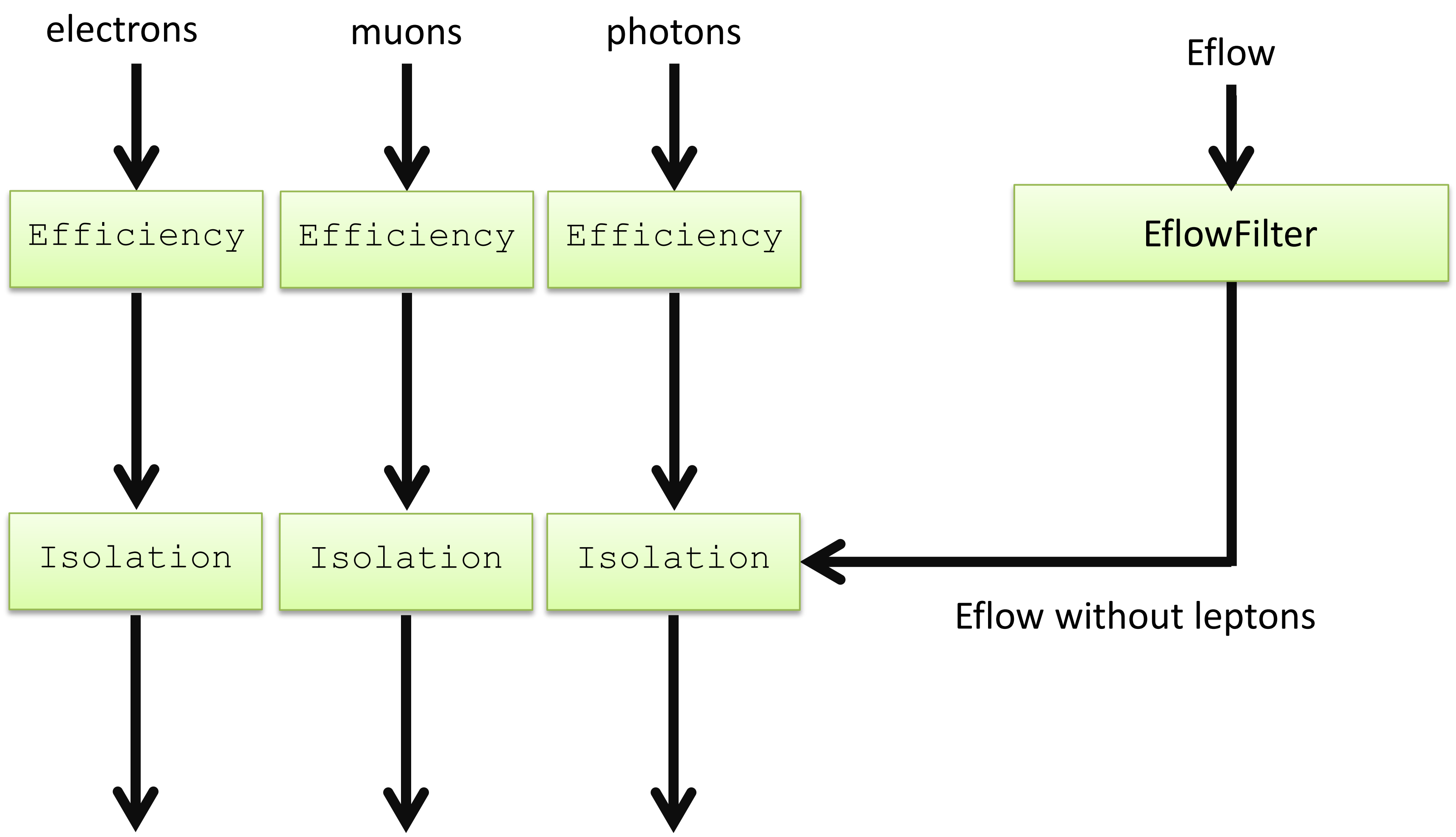
- Calorimeter information: **towers**
  `ecalTower, hcalTower`

- Calorimeter + tracker information: **particle (or energy) flow**

	With track	Without track
ECAL	`eflowElectron`	`eflowPhoton`
HCAL	`eflowChargedHadron`	`eflowNeutralHadron`

Characteristic of objects are corrected:
- tracking provides good measurement of momenta at low energy
- calorimeter provides good measurement of momenta at high energy

Process Part 3: e, μ, γ



Process Part 3: e, μ, γ

Efficiency

Applying efficiency corresponding to identification

```
module Efficiency MuonEfficiency {
  set InputArray MuonMomentumSmearing/muons
  set OutputArray muons

  # efficiency formula for muons
  set EfficiencyFormula {                                    (pt <= 10.0)                  * (0.00) +
                                         (abs(eta) <= 1.5) * (pt > 10.0)                  * (0.95) +
                         (abs(eta) > 1.5 && abs(eta) <= 2.4) * (pt > 10.0)                  * (0.95) +
                         (abs(eta) > 2.4)                                                   * (0.00)}
```

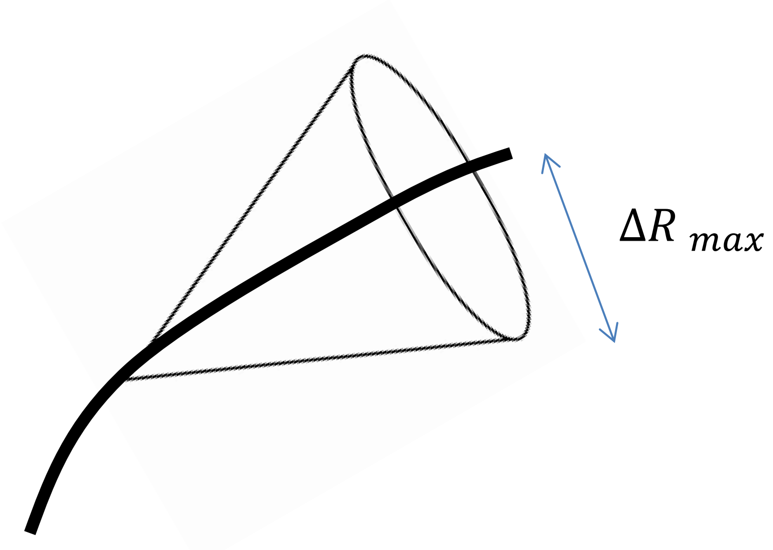
```
module Efficiency ElectronEfficiency {
  set InputArray ElectronFilter/electrons
  set OutputArray electrons

  # efficiency formula for electrons
  set EfficiencyFormula {                                    (pt <= 10.0) * (0.00) +
                                         (abs(eta) <= 1.5) * (pt > 10.0)  * (0.95) +
                         (abs(eta) > 1.5 && abs(eta) <= 2.5) * (pt > 10.0)  * (0.85) +
                         (abs(eta) > 2.5)                                   * (0.00)}
}
```

```
module Efficiency PhotonEfficiency {
  set InputArray ECal/eflowPhotons
  set OutputArray photons

  # efficiency formula for photons
  set EfficiencyFormula {                                    (pt <= 10.0) * (0.00) +
                                         (abs(eta) <= 1.5) * (pt > 10.0)  * (0.95) +
                         (abs(eta) > 1.5 && abs(eta) <= 2.5) * (pt > 10.0)  * (0.85) +
                         (abs(eta) > 2.5)                                   * (0.00)}
}
```

Process Part 3: e, μ, γ

Isolation

Applying an isolation criterion to leptons & photons wrt jets



2 methods

UsePTSum=1 — **Scalar sum of track PT < threshold**

UsePTSum=0 [default] — **Scalar sum of track PT / lepton PT < threshold**

Process Part 3: e, μ, γ

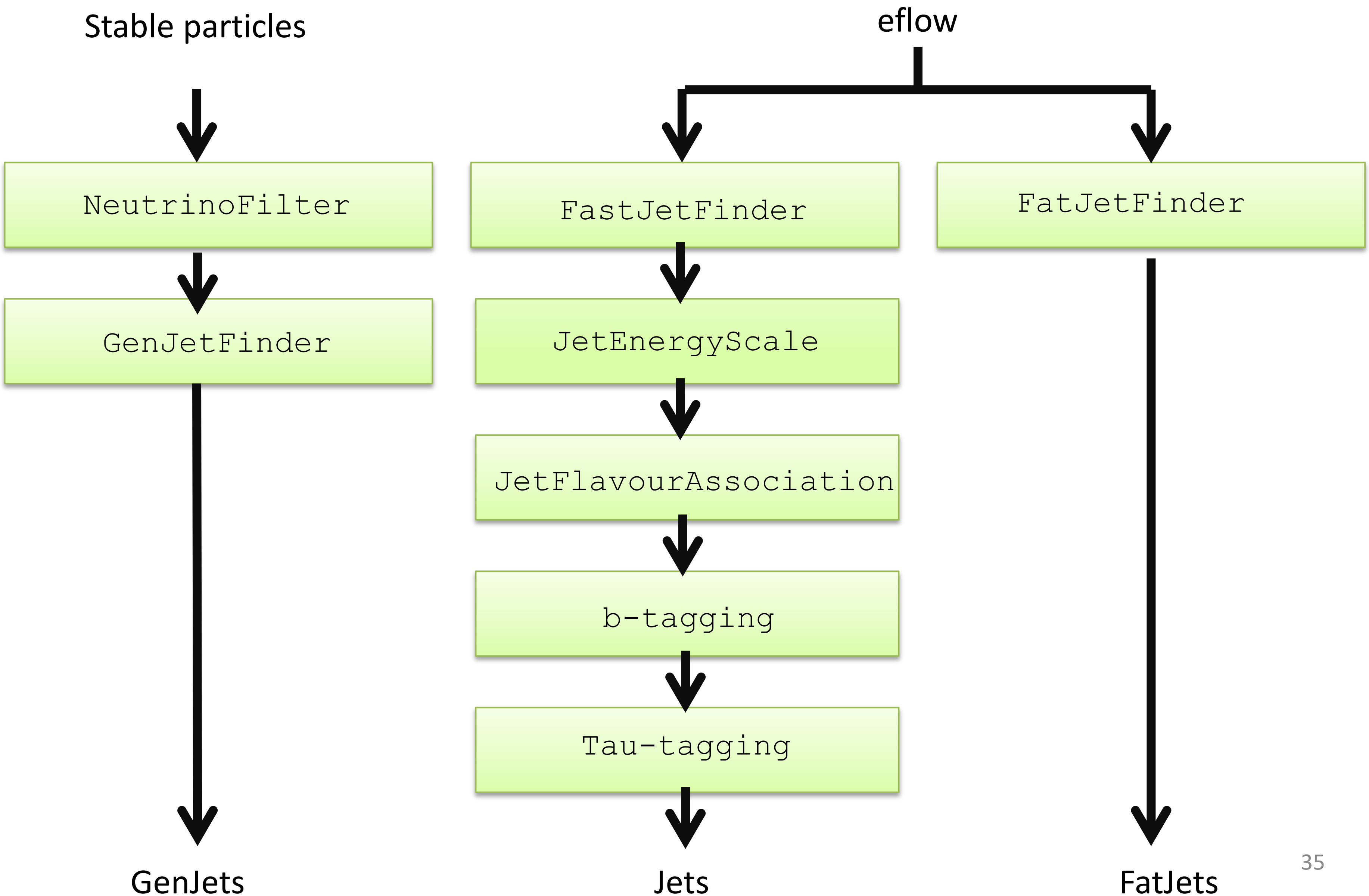
Isolation

Applying an isolation criterion to leptons & photons wrt jets

```
module Isolation MuonIsolation
{
  set CandidateInputArray MuonEfficiency/muons
  set IsolationInputArray EFlowFilter/eflow

  set OutputArray muons

  set DeltaRMax 0.5
  set PTMin 0.5
  set PTRatioMax 0.25
}
```

- DeltaRMax → Size of the isolation cone
- PTMin → Remove muons with low PT
- PTRatioMax → Threshold on the ratio

Process Part 4: jets



Process Part 4: jets

Stable particles

↓

NeutrinoFilter → Remove invisible particle from the stable particles.

↓

GenJetFinder → Apply a jet –clustering algorithm

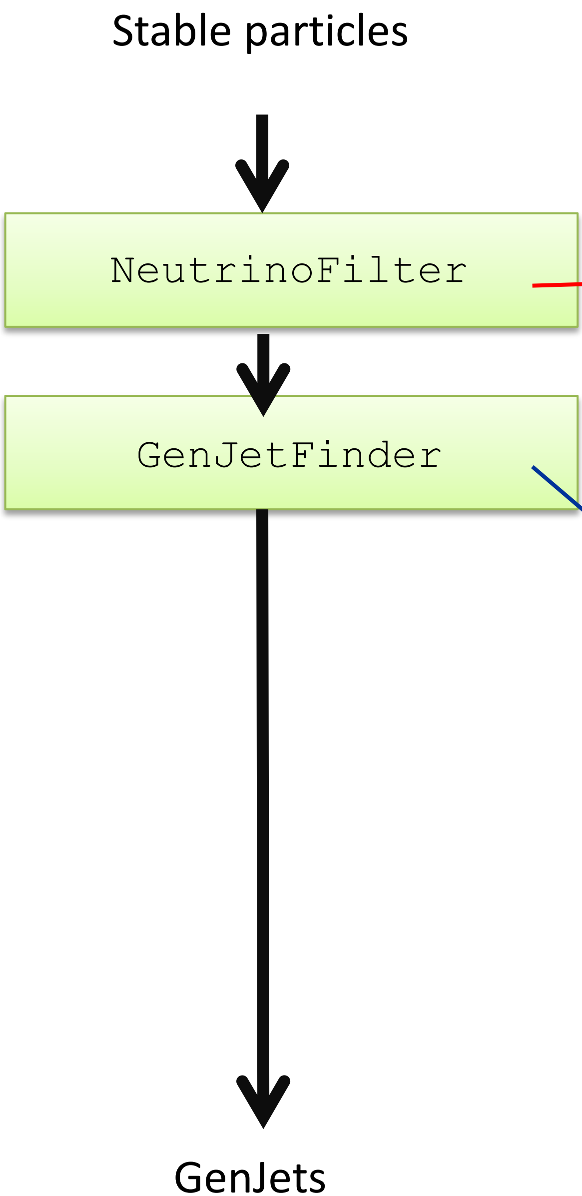
- 1 CDFJetClu
- 2 MidPoint
- 3 SIScone
- 4 kt
- 5 Cambridge/Aachen
- 6 antikt

And remove low-PT jets

↓

GenJets → Reconstructed jets with a perfect calorimeter

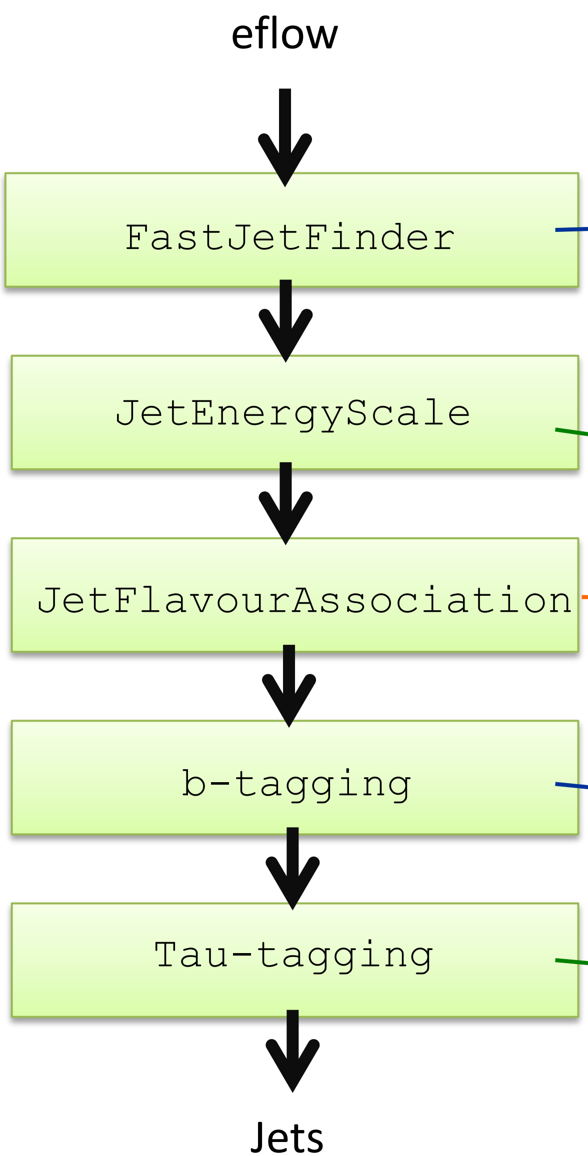
Process Part 4: jets




```
module PdgCodeFilter NeutrinoFilter {
  set InputArray Delphes/stableParticles
  set OutputArray filteredParticles

  add PdgCode {12}
  add PdgCode {14}
  add PdgCode {16}
  add PdgCode {-12}
  add PdgCode {-14}
  add PdgCode {-16}
}
```

```
module FastJetFinder GenJetFinder {
  set InputArray NeutrinoFilter/filteredParticles
  set OutputArray jets

  set JetAlgorithm 6
  set ParameterR 0.5
  set JetPTMin 20.0
}
```

Process Part 4: jets



Apply a jet –clustering algorithm

- 1 CDFJetClu
- 2 MidPoint
- 3 SIScone
- 4 kt
- 5 Cambridge/Aachen
- 6 antikt

And remove low-PT jets

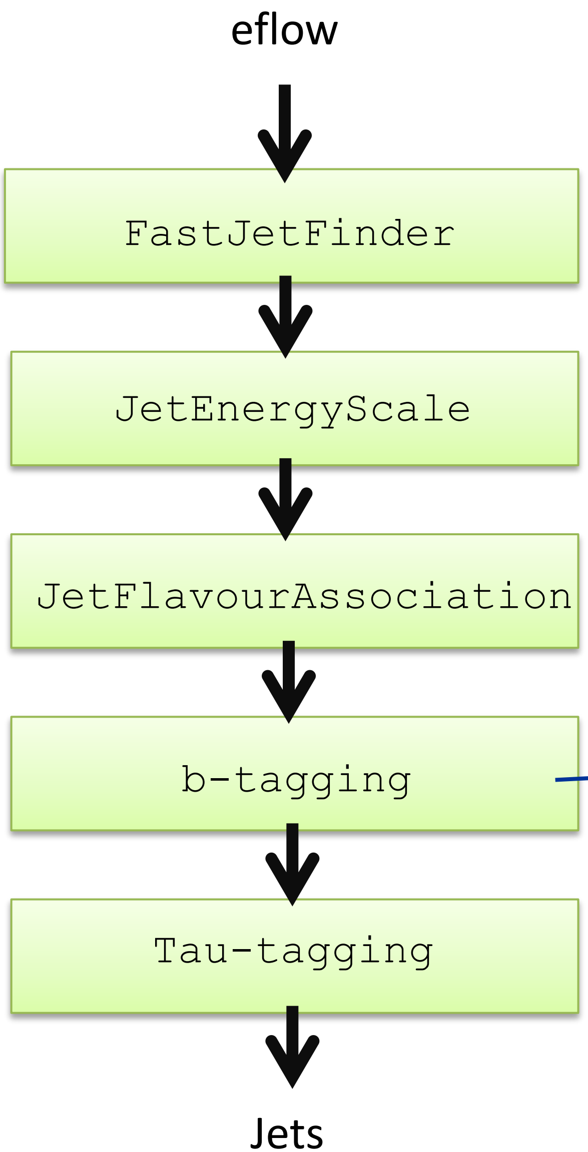
Apply correction to jet energy

Match jets to partons and determine the « true » b-jets and taus

B-tagging id and mis-id

tau-tagging id and mis-id

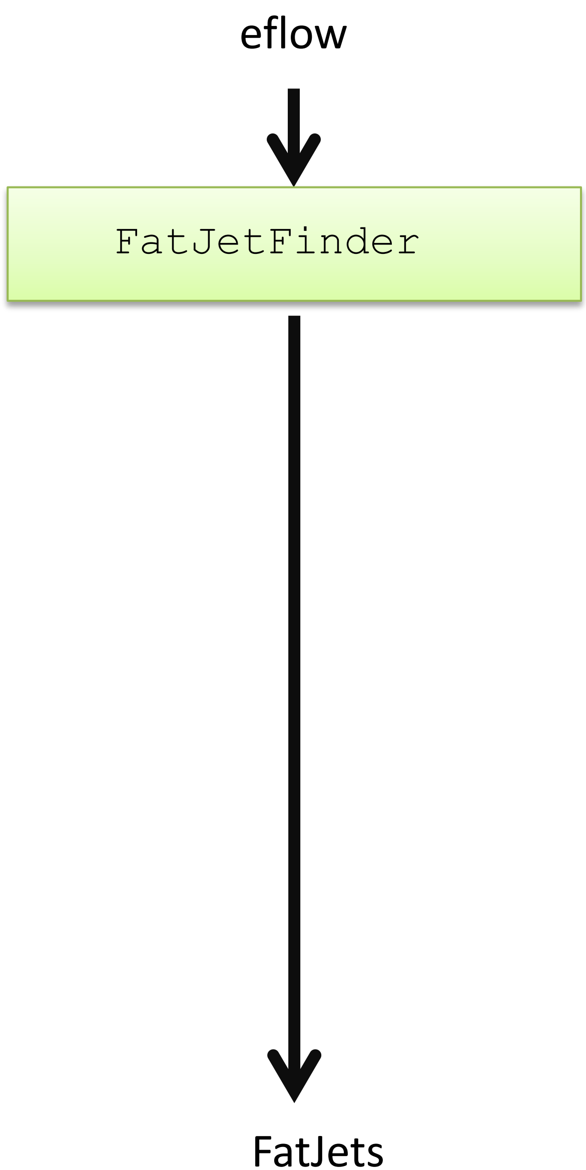
Process Part 4: jets




```
module BTagging BTagging {
  set JetInputArray JetEnergyScale/jets

  set BitNumber 0

  # default efficiency formula (misidentification rate)
  add EfficiencyFormula {0} {0.01+0.000038*pt}

  # efficiency formula for c-jets (misidentification rate)
  add EfficiencyFormula {4} {0.25*tanh(0.018*pt)*(1/(1+ 0.0013*pt))}

  # efficiency formula for b-jets
  add EfficiencyFormula {5} {0.85*tanh(0.0025*pt)*(25.0/(1+0.063*pt))}
}
```

arXiv:1211.4462

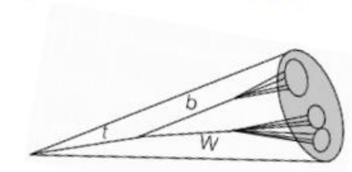
Process Part 4: jets




```
module FastJetFinder FatJetFinder {
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  set JetAlgorithm 6
  set ParameterR 0.8

  set ComputeNsubjettiness 1
  set Beta 1.0
  set AxisMode 4

  set ComputeTrimming 1
  set RTrim 0.2
  set PtFracTrim 0.05

  set ComputePruning 1
  set ZcutPrun 0.1
  set RcutPrun 0.5
  set RPrun 0.8

  set ComputeSoftDrop 1
  set BetaSoftDrop 0.0
  set SymmetryCutSoftDrop 0.1
  set R0SoftDrop 0.8

  set JetPTMin 200.0
}
```

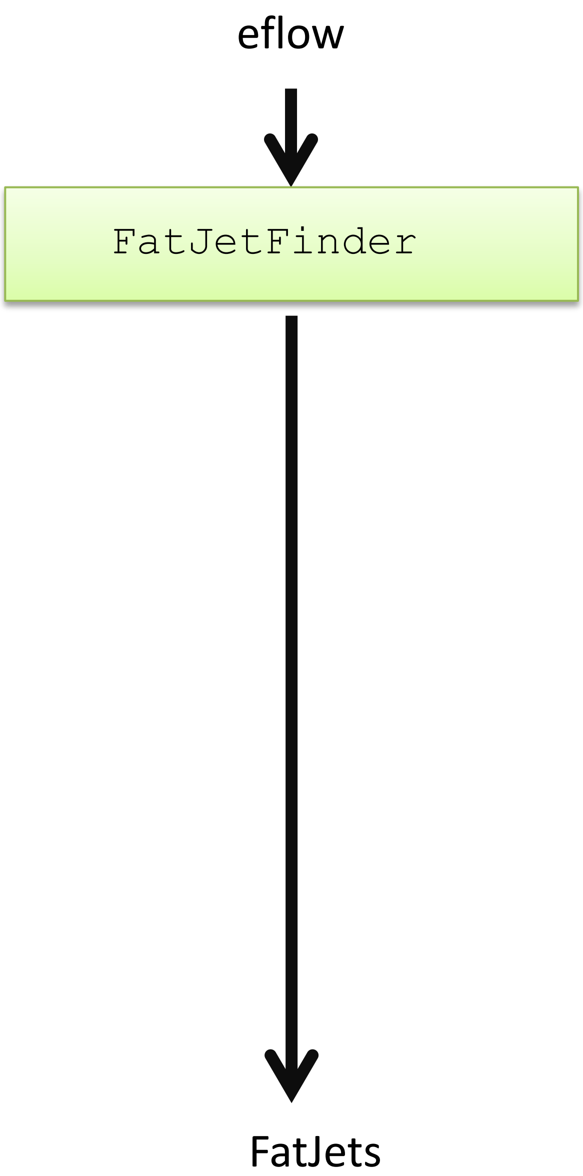
Collection devoted to boosted objects

tops in a single jet



ParameterR is bigger than the normal one. Therefore these « fat » jets has a substructure.

Process Part 4: jets




```
module FastJetFinder FatJetFinder {
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  set JetAlgorithm 6
  set ParameterR 0.8

  set ComputeNsubjettiness 1
  set Beta 1.0
  set AxisMode 4

  set ComputeTrimming 1
  set RTrim 0.2
  set PtFracTrim 0.05

  set ComputePruning 1
  set ZcutPrun 0.1
  set RcutPrun 0.5
  set RPrun 0.8

  set ComputeSoftDrop 1
  set BetaSoftDrop 0.0
  set SymmetryCutSoftDrop 0.1
  set R0SoftDrop 0.8

  set JetPTMin 200.0
}
```

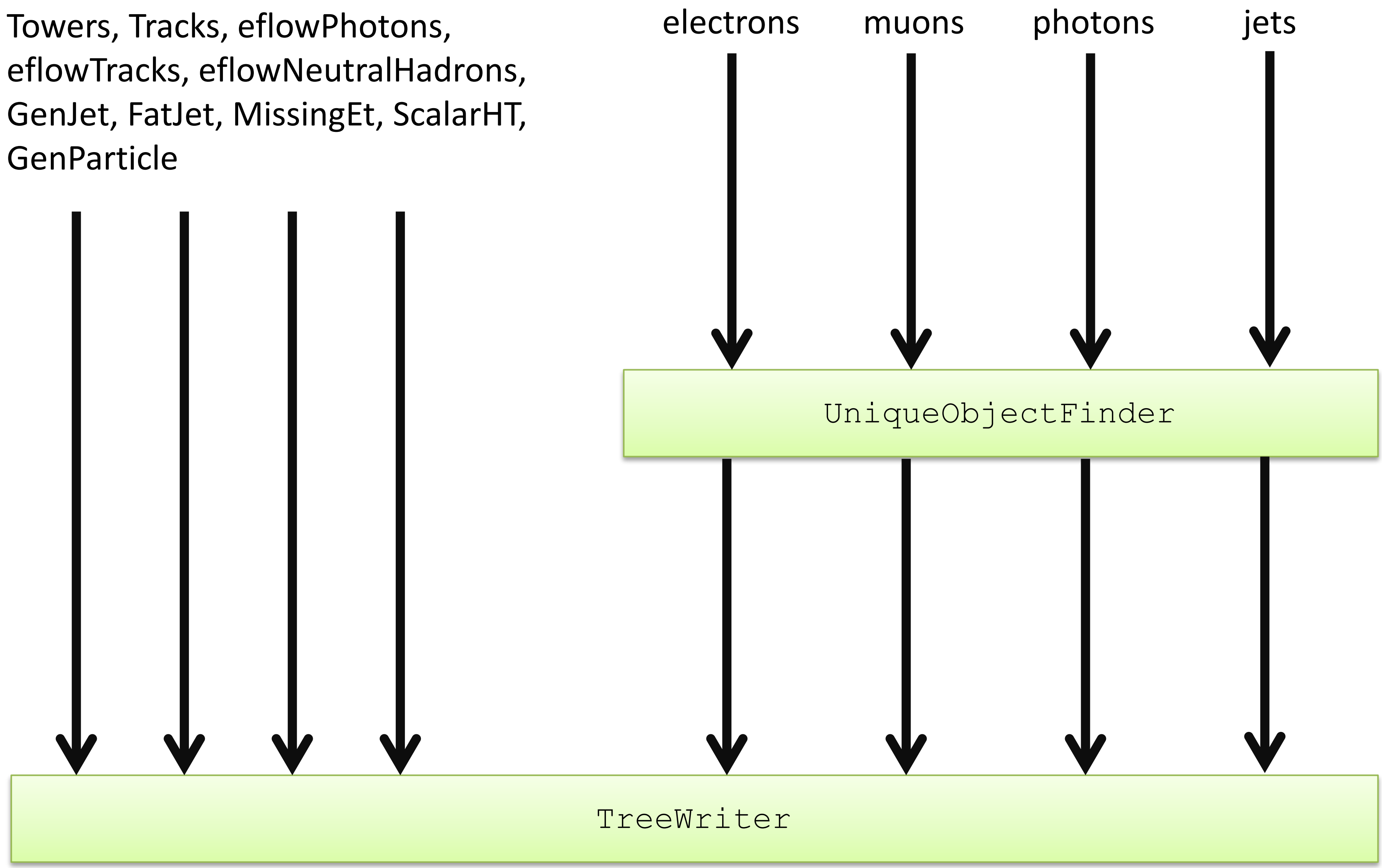
Probing jet substructure with N-subjettiness algo with N=1,2,3,4,5

Trimming algo

Pruning algo

SoftDrop algo

Process Part 5: output



Process Part 5: output

UniqueObjectFinder

```
module UniqueObjectFinder UniqueObjectFinder
{
  add InputArray PhotonIsolation/photons photons
  add InputArray ElectronIsolation/electrons electrons
  add InputArray MuonIsolation/muons muons
  add InputArray JetEnergyScale/jets jets
}
```

Jet collection can contain photons, electrons & muons.

→ Cleaning collections by removing redundancies.

Process Part 5: output

TreeWriter

```
module TreeWriter TreeWriter
{
  add Branch Delphes/allParticles Particle GenParticle
  add Branch TrackMerger/tracks Track Track
  add Branch Calorimeter/towers Tower Tower
  add Branch HCal/eflowTracks EFlowTrack Track
  add Branch ECal/eflowPhotons EFlowPhoton Tower
  add Branch HCal/eflowNeutralHadrons EFlowNeutralHadron Tower
  add Branch GenJetFinder/jets GenJet Jet
  add Branch GenMissingET/momentum GenMissingET MissingET
  add Branch UniqueObjectFinder/jets Jet Jet
  add Branch UniqueObjectFinder/electrons Electron Electron
  add Branch UniqueObjectFinder/photons Photon Photon
  add Branch UniqueObjectFinder/muons Muon Muon
  add Branch FatJetFinder/jets FatJet Jet
  add Branch MissingET/momentum MissingET MissingET
  add Branch ScalarHT/energy ScalarHT ScalarHT
}
```

List of all

(temporary or final)

collection of objects

saved in the ROOT files

Process Part 5: output

List of Arrays

Array name	Description
Delphes/allParticles	All generated particles
Delphes/stableParticles	Final state particles (Status==1)
Delphes/partons	Decayed particles or partons produced in shower (Status==2)
ParticlePropagator/stableParticles	All propagated particles
ParticlePropagator/chargedHadrons	Propagated charged hadrons
ParticlePropagator/electrons	Propagated electrons
ParticlePropagator/muons	Propagated muons
ChargedHadronTrackingEfficiency/chargedHadrons	Propagated charged hadrons that pass the efficiency selection
ChargedHadronMomentumSmearing/chargedHadrons	Tracks with momentum smeared according to the charged hadrons momentum resolution
ElectronTrackingEfficiency/electrons	Propagated electrons that pass the efficiency selection
ElectronEnergySmearing/electrons	Tracks with energy smeared according to the electron energy resolution
MuonTrackingEfficiency/muons	Propagated muons that pass the efficiency selection
MuonMomentumSmearing/muons	Tracks with momentum smeared according to the muon momentum resolution
TrackMerger/tracks	Combination of charged hadrons and electrons
Calorimeter/towers	All calorimeter towers
Calorimeter/photons	Calorimeter towers associated with the photons
Calorimeter/eflowTracks	Tracks output from the energy flow algorithm
Calorimeter/eflowPhotons	Photon output from the energy flow algorithm
Calorimeter/eflowNeutralHadrons	Neutral hadron output from the energy flow algorithm
EFlowMerger/eflow	Combination of tracks, calorimeter towers and muons required for jet finding
ElectronEfficiency/electrons	Electrons that pass the efficiency selection
ElectronIsolation/electrons	Isolated electrons
PhotonEfficiency/photons	Photons that pass the efficiency selection
PhotonIsolation/photons	Isolated photons
MuonEfficiency/muons	Muons that pass the efficiency selection
MuonIsolation/muons	Isolated muons
FastJetFinder/jets	Reconstructed jets
MissingET/momentum	Missing transverse energy
ScalarHT/energy	Scalar sum of transverse momenta and energy of all reconstructed objects
UniqueObjectFinder/photons	Uniquely identified photons
UniqueObjectFinder/electrons	Uniquely identified electrons
UniqueObjectFinder/jets	Uniquely identified jets

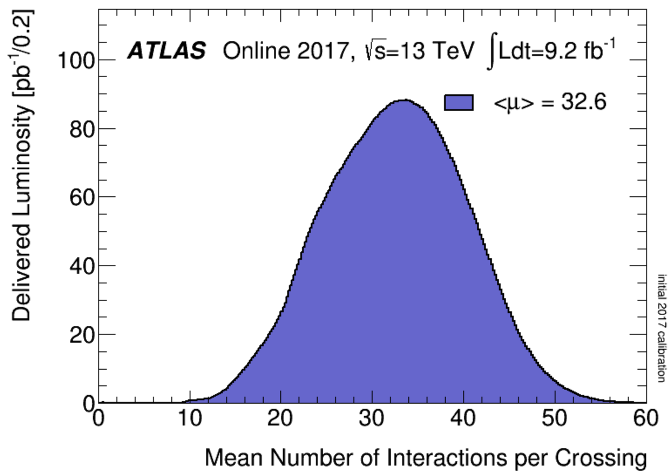
https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/Arrays

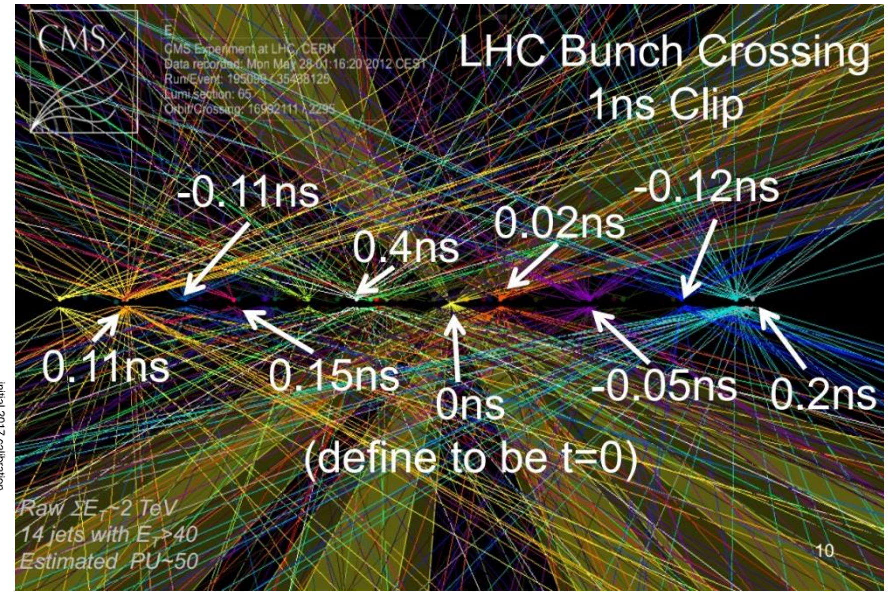
4. Including pile-up effects

What is pile-up?

The phenomenon

Several interactions per bunch crossing





The consequences on the reconstruction:

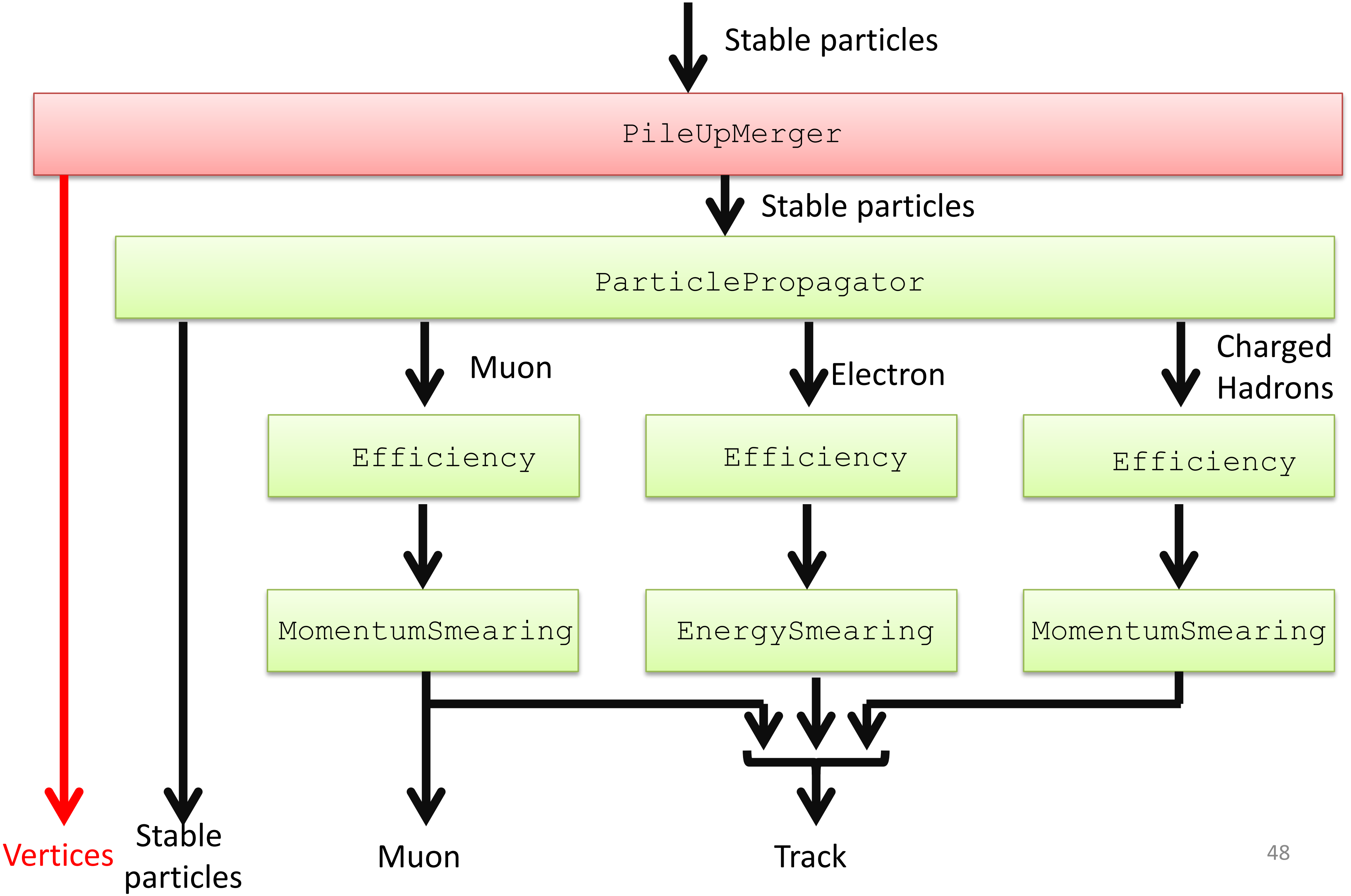
- reduced efficiency
- worsened resolution (jets, MET)
- degraded isolation
- fake tracks, jets

2 ways to simulate this effect:

- Full simulation:
  - Injecting several interactions
  - Pileup subtraction @ reco
- Smearing & efficiency functions
  → no fake & to be tuned @ hand

DELPHES fast simulation

Process Part 1: tracking



Process Part 1: tracking

PileUpMerger

Superimposing to your signal event several MinBias events

```
module PileUpMerger PileUpMerger
{
  set InputArray Delphes/stableParticles

  set ParticleOutputArray stableParticles
  set VertexOutputArray vertices

  # pre-generated minbias input file
  set PileUpFile MinBias.pileup

  # average expected pile up
  set MeanPileUp 50

   # maximum spread in the beam direction in m
  set ZVertexSpread 0.25

  # maximum spread in time in s
  set TVertexSpread 800E-12

  # vertex smearing formula f(z,t) (z,t need to be respectively given in m,s)
  set VertexDistributionFormula {exp(-(t^2/160e-12^2/2))*exp(-(z^2/0.053^2/2))}
}
```

MinBias samples. Events are chosen randomly by Delphes.

A file « MinBias.pileup » with 1,000 events is provided by Delphes.

Average number of interactions (superimposing N interactions according to a Poisson law).

Piece of advice:

Nminbias > average

Process Part 1: tracking

PileUpMerger

Superimposing to your signal event several MinBias events

```
module PileUpMerger PileUpMerger
{
  set InputArray Delphes/stableParticles

  set ParticleOutputArray stableParticles
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  # pre-generated minbias input file
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  # maximum spread in time in s
  set TVertexSpread 800E-12

  # vertex smearing formula f(z,t) (z,t need to be respectively given in m,s)
  set VertexDistributionFormula {exp(-(t^2/160e-12^2/2))*exp(-(z^2/0.053^2/2))}
}
```

Boundaries

Position in time and space (z-axis only) of the vertex interactions

Process Part 1: tracking

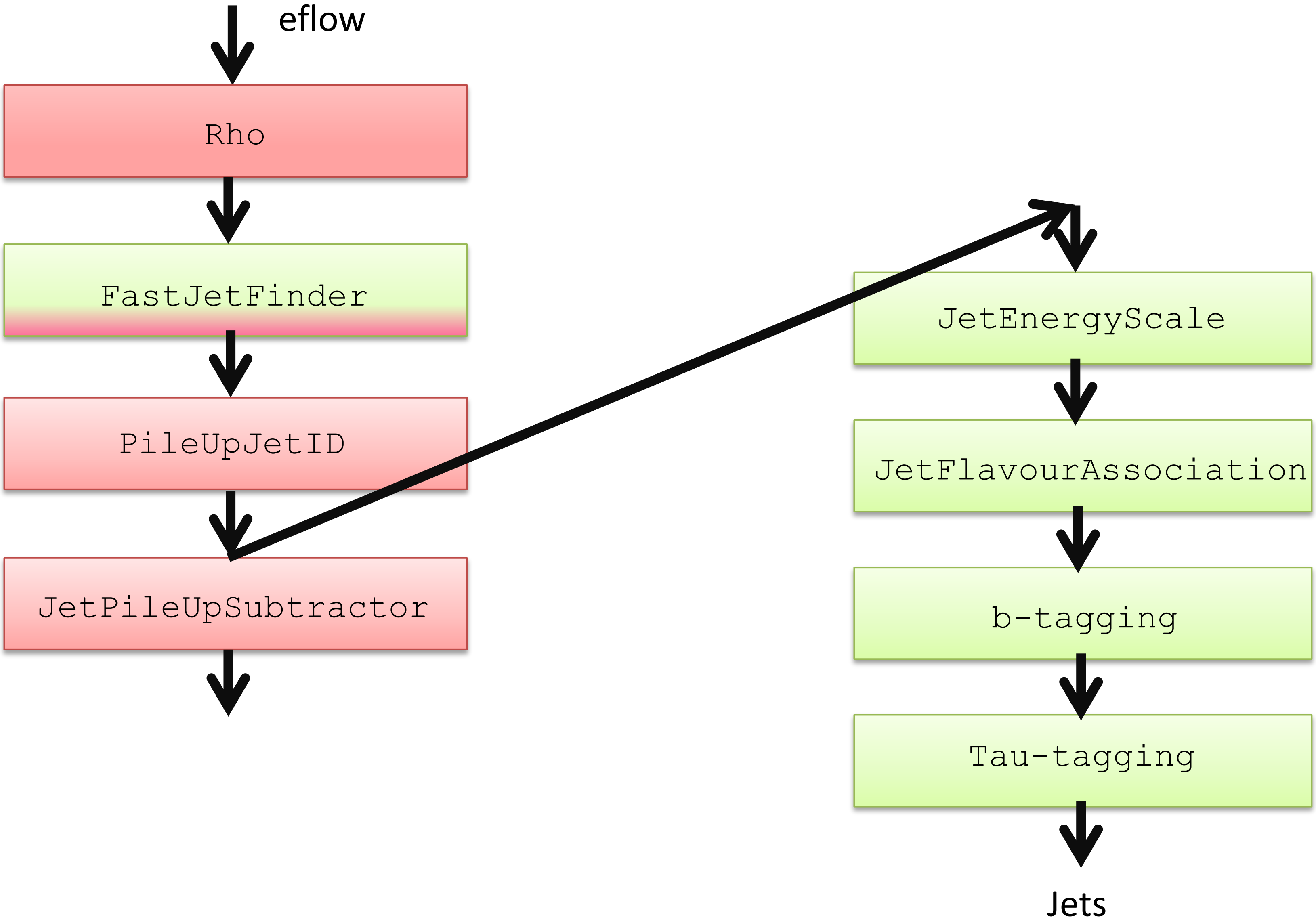
PileUpMerger

Superimposing to your signal event several MinBias events

```
module PileUpMerger PileUpMerger
{
  set InputArray Delphes/stableParticles

  set ParticleOutputArray stableParticles
  set VertexOutputArray vertices

  # pre-generated minbias input file
  set PileUpFile MinBias.pileup

  # average expected pile up
  set MeanPileUp 50

   # maximum spread in the beam direction in m
  set ZVertexSpread 0.25

  # maximum spread in time in s
  set TVertexSpread 800E-12

  # vertex smearing formula f(z,t) (z,t need to be respectively given in m,s)
  set VertexDistributionFormula {exp(-(t^2/160e-12^2/2))*exp(-(z^2/0.053^2/2))}
}
```

→ Add new particles to the collection of stable particles

Process Part 3: jets



Process Part 3: jets

Rho

Computation of rho

```
module FastJetGridMedianEstimator Rho
{
  set InputArray EFlowMerger/eflow
  set RhoOutputArray rho

  # add GridRange rapmin rapmax drap dphi
  # rapmin - the minimum rapidity extent of the grid
  # rapmax - the maximum rapidity extent of the grid
  # drap - the grid spacing in rapidity
  # dphi - the grid spacing in azimuth

  add GridRange -5.0 -2.5 1.0 1.0
  add GridRange -2.5 2.5 1.0 1.0
  add GridRange 2.5 5.0 1.0 1.0
}
```

Use the **GridMedianBackgroundEstimator** approach [FastJet package] for computing:

- ρ = median density of pile-up contamination (for each eta and phi region)

Process Part 3: jets

FastJetFinder

Jet-clustering

Without pile-up

```
module FastJetFinder FastJetFinder
{
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  set JetAlgorithm 6
  set ParameterR 0.5
  set JetPTMin 20.0
}
```

With pile-up

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

  set OutputArray jets

  # area algorithm: 0 Do not compute area, 1 Activ
  set AreaAlgorithm 5

  # jet algorithm: 1 CDFJetClu, 2 MidPoint, 3 SISc
  set JetAlgorithm 6
  set ParameterR 0.5

  set JetPTMin 20.0
}
```

Change: compute **area** for each jet during the jet-clustering algorithm
[arXiv:0707.1378], [arXiv:0802.1188]

Process Part 3: jets

PileUpJetID

Compute jet id variables

```
module PileUpJetID PileUpJetID {
  set JetInputArray FastJetFinder/jets
  set TrackInputArray HCal/eflowTracks
  set NeutralInputArray NeutralTowerMerger/towers

  set VertexInputArray PileUpMerger/vertices
  # assume perfect pile-up subtraction for tracks with |z| > fZVertexResolution
  # Z vertex resolution in m
  set ZVertexResolution 0.0001

  set OutputArray jets

  set UseConstituents 0
  set ParameterR 0.5

  set JetPTMin 20.0
}
```

NCharged
: number of charged constituents

NNeutrals
: number of neutral constituents

Beta
: (sum pt of charged pile-up constituents)/(sum pt of charged constituents)

BetaStar
: (sum pt of charged constituents coming from hard interaction)/(sum pt of charged constituents)

MeanSqDeltaR
: average distance (squared) between constituent and jet weighted by pt (squared) of constituent.

PTD
: average pt between constituent and jet weighted by pt of constituent.

FracPt[i]
: (sum pt of constituent within a ring 0.1*i<DeltaR<0.1*(i+1))/(sum pt)

Process Part 3: jets

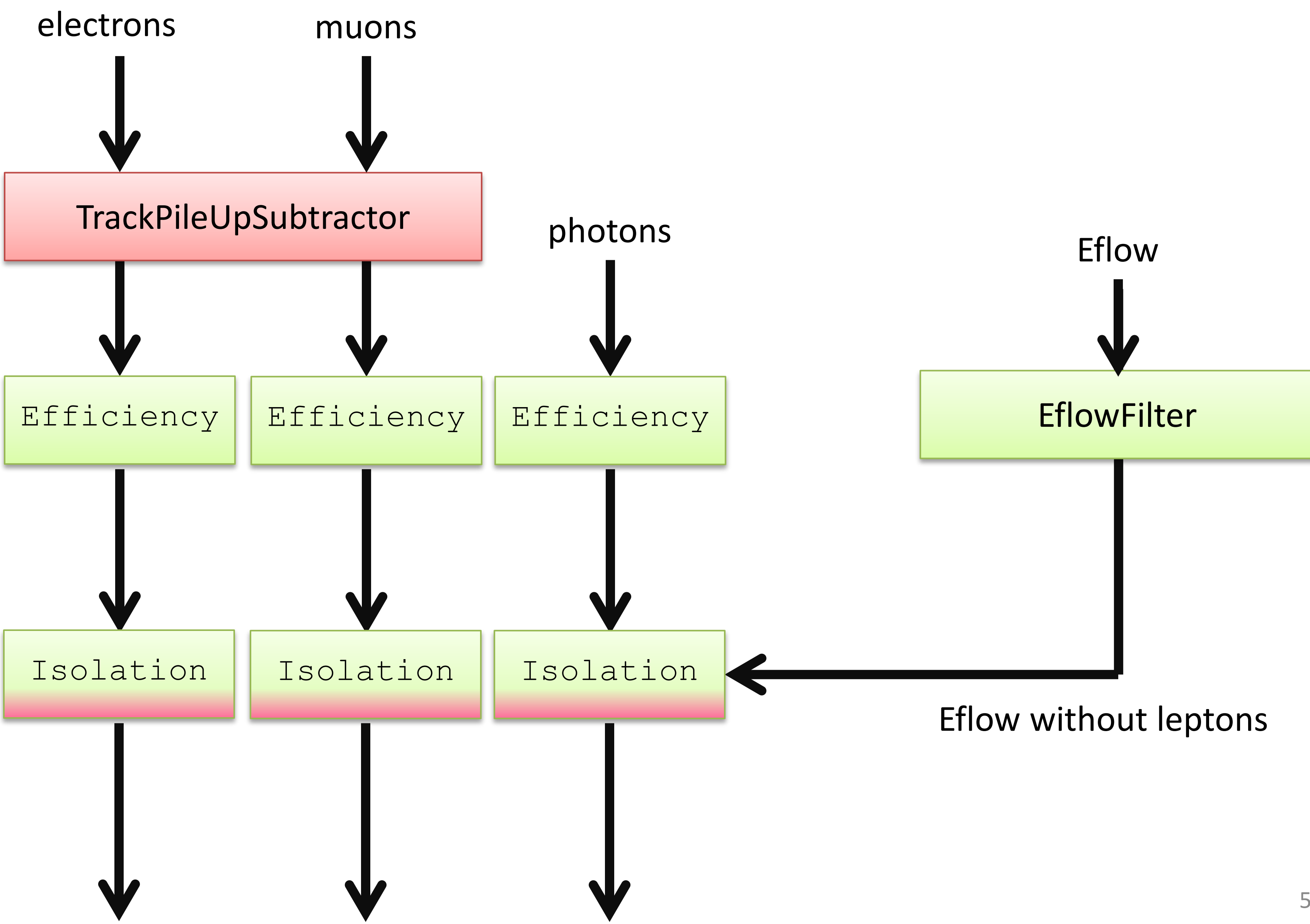
JetPileUpSubtractor

Neutral subtraction of pile-up

```
module JetPileUpSubtractor JetPileUpSubtractor
{
  set JetInputArray PileUpJetID/jets
  set RhoInputArray Rho/rho

  set OutputArray jets

  set JetPTMin 20.0
}
```

- Jet correction : pT → pT – ρ x area.pT
- Remove jets with pT < JetPTMin

Process Part 4: e, μ, γ



Process Part 3: jets

`TrackPileUpSubtractor` Charged subtraction of pile-up

```
module TrackPileUpSubtractor TrackPileUpSubtractor {
  add InputArray HCal/eflowTracks          eflowTracks
  add InputArray ElectronFilter/electrons   electrons
  add InputArray MuonMomentumSmearing/muons muons

  set VertexInputArray PileUpMerger/vertices
  set ZVertexResolution {0.0001}
}
```

Filtering the tracks:

- For |z| < ZVertexResolution → The hard interaction vertex cannot be distinguished from pile-up vertices.
- For |z| > ZVertexResolution → The hard interaction vertex can be distinguished from pile-up vertices → **REMOVE**

Process Part 4: e, μ, γ

Isolation

Isolation of leptons or photons

Without pileup

```
module Isolation MuonIsolation {
  set CandidateInputArray MuonEfficiency/muons
  set IsolationInputArray EFlowFilter/eflow

  set OutputArray muons

  set DeltaRMax 0.5

  set PTMin 0.5

  set PTRatioMax 0.25
}
```

With pileup

```
module Isolation MuonIsolation {
  set CandidateInputArray MuonEfficiency/muons
  set IsolationInputArray EFlowFilter/eflow
  set RhoInputArray Rho/rho

  set OutputArray muons

  set DeltaRMax 0.5

  set PTMin 0.5

  set PTRatioMax 0.25
}
```

Isolation with pile-up

If UseRhoCorrection is set to true the rho-corrected variable is used for isolation:

```
IsolationVarRhoCorr = sumChargedNoPU + max(sumNeutral - max(rho, 0.0)*pi*R^2, 0.0)
```

Otherwise the beta variable is used:

```
IsolationVar = sumChargedNoPU + max(sumNeutral - 0.5*sumChargedPU, 0.0)
```

Warning to recasters

- Pile-up simulation **increases intensively the time processing**.

- **Pile-up simulation requires an extra MC sample**: a MinBias sample. Delphes provides a 1k sample but usually not enough for large production. To generate carefully! More details here: https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/PileUp#RunningDelpheswithPile-Up1

Suggestion to recasters:

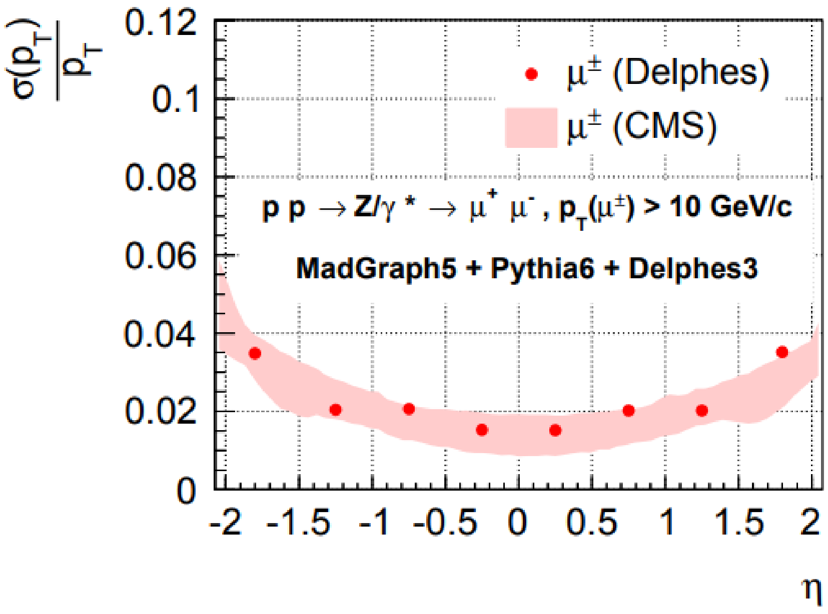
implementing & debugging your analysis

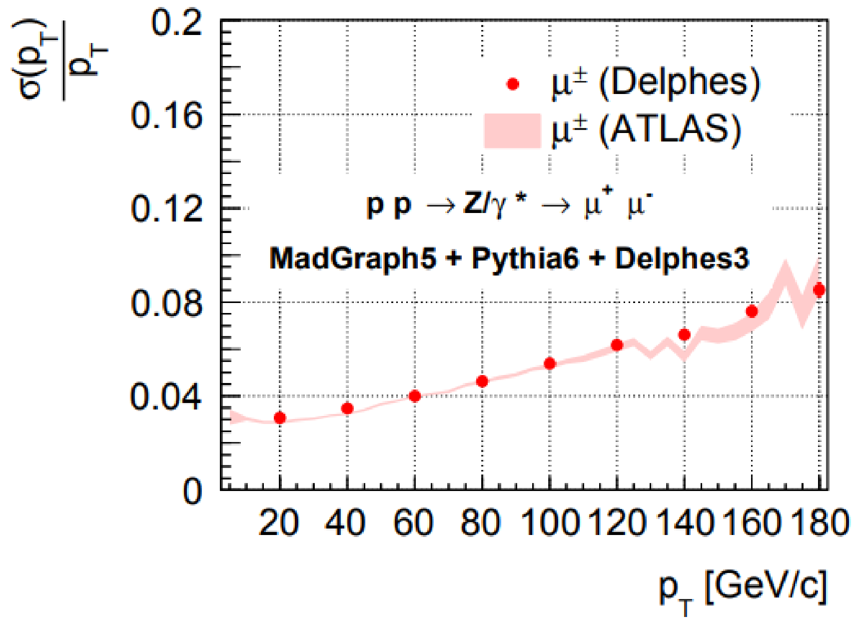
FIRST without pile-up

5. Validation & limitations of Delphes

Validation

PT resolution of reconstructed muons

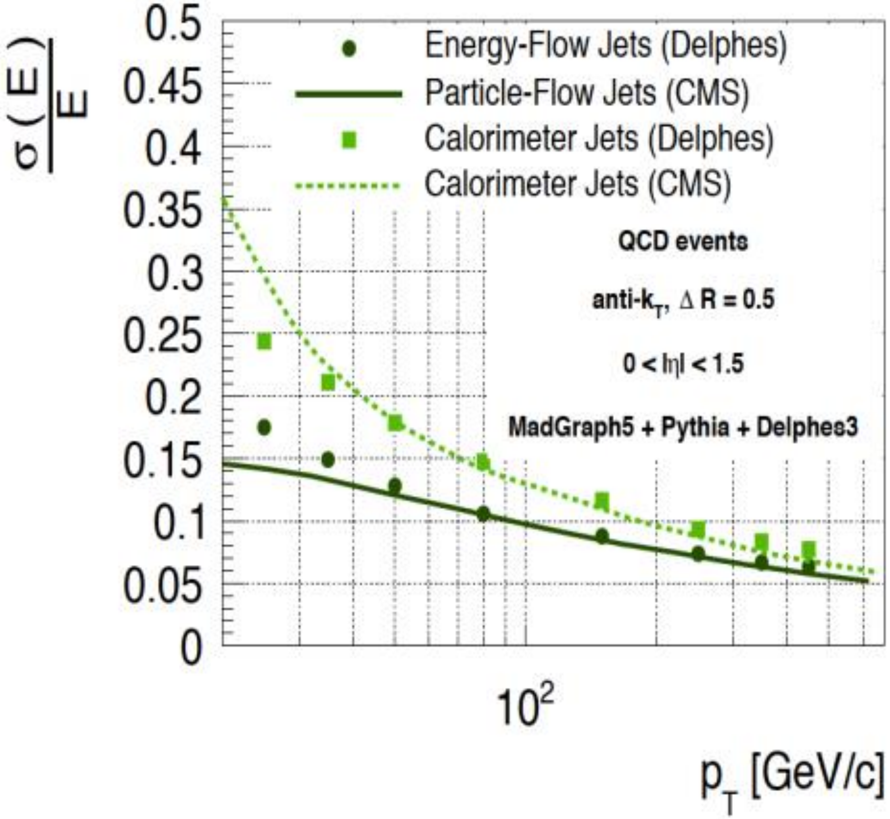




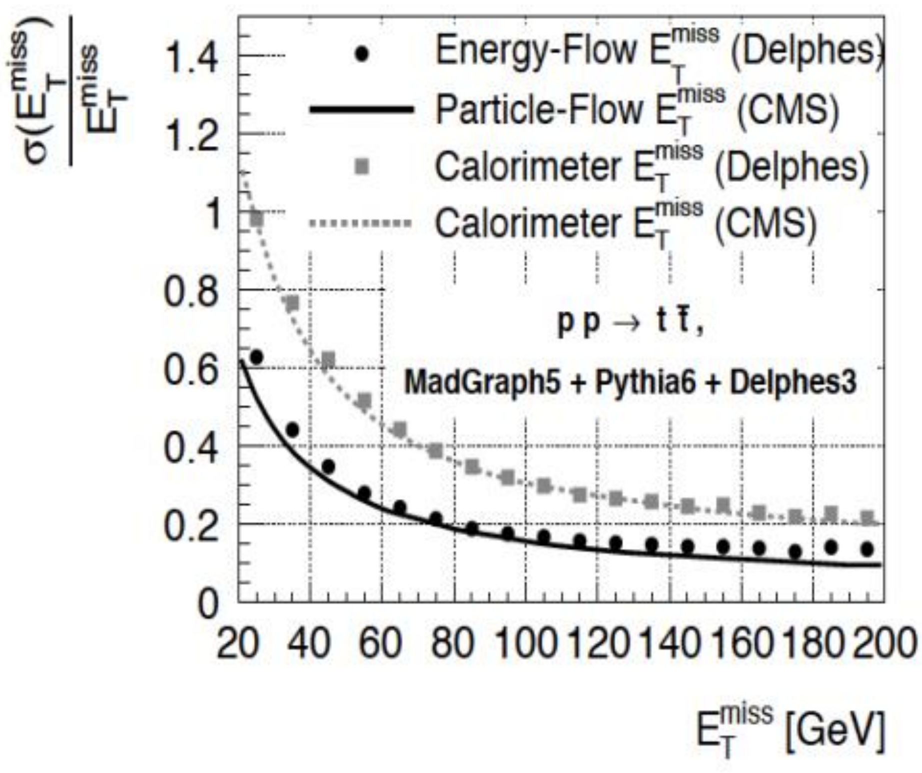
Validation

ParticleFlow validation

Jet energy resolution

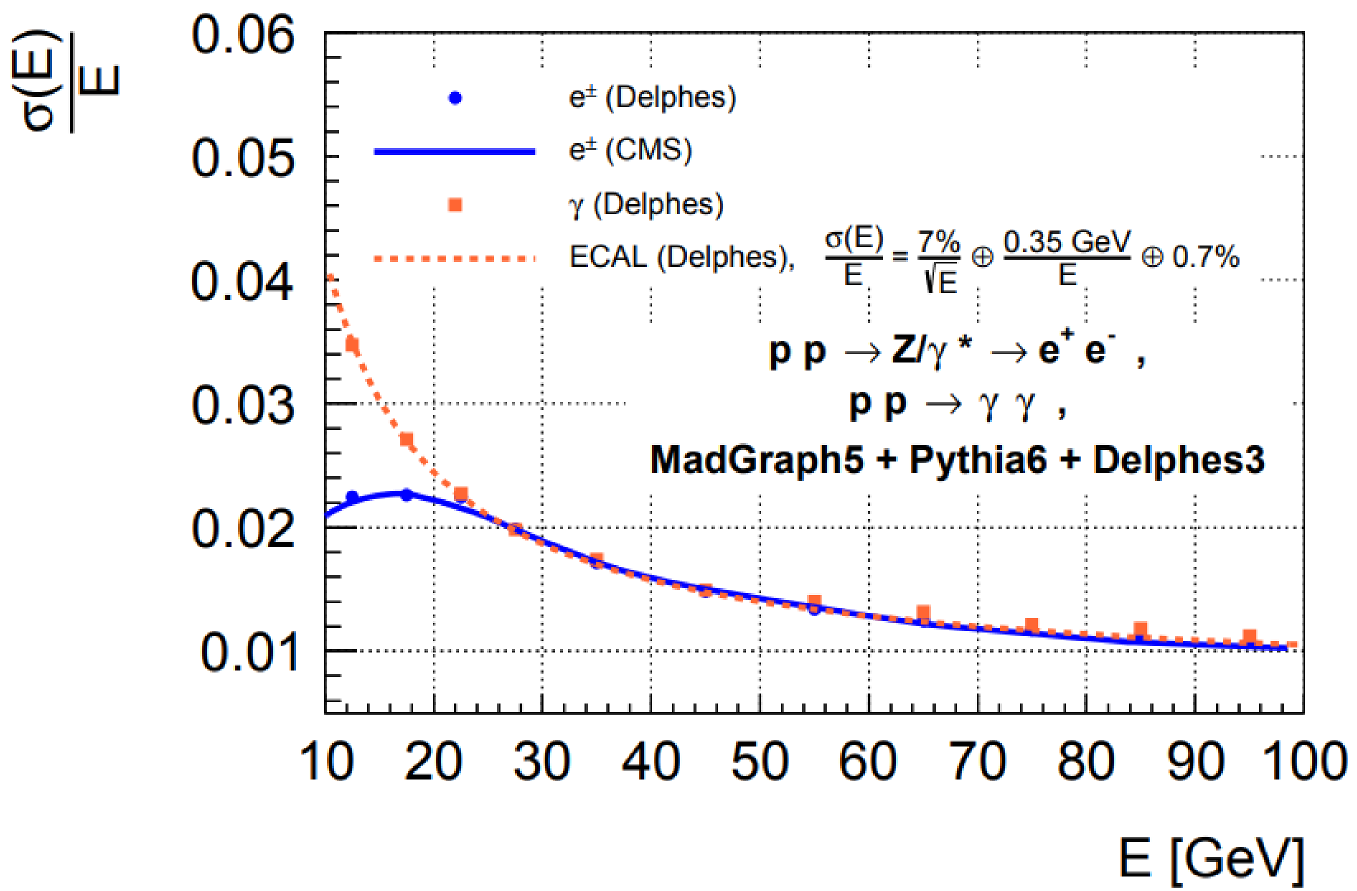


MET resolution



Validation

Energy resolution of reconstructed electrons & photons



Disagreement below 20 GeV for electrons

The limitations of Delphes

- The **simulation of the trigger** (online selection) is missing.
  BUT usually the offline selection includes the effects of the trigger.

- There is no tracker simulation:
  - **No reconstructed vertices**
  - **No fake tracks**
  - **No track quality**

- **No noise in the calorimeters**

- **No photon conversion** (but included for LHCb simulation)

- **No fake muons, electrons or photons**

- **Does not convient for exotics topology.**
  Example of long-lived particles:
  - No displaced vertices
  - No displaced tracks
  - No tracks dispearing

6. Beyond Delphes: the tunes

Different tunes of Delphes

- **The Delphes development model is community-based.**

  People are encouraged to:
  - Tune their detector cards according to their usage
  - Develop their own modules
  - Modify the code if necessary

- **Proliferation of tunes of Delphes. Some example:**

  - **CMS or ATLAS tunes of Delphes** [private]

  - **Rivet tune of Delphes:**
    - Improving ATLAS simulation realism
    - Adding a lot of tags in the data format

  - **MadAnalysis 5 tune(s) of the Delphes cards**
    - Reducing the size of Delphes ROOT file
    - Isolation @ analysis level
    - Displaced tracks **[new]**

Summary

In order to recast LHC analyses, we need a **very-fast & realistic detector simulation**.

Delphes (current release: 3.4.1) suits very well:

- Generic simulation, in particular ATLAS & CMS can handled.
- Modular architecture & initially community- based
- Simulation of pile-up effects & subtraction based on the Jet Area method

It is important in this workshop that people:

- check (and potentially tune) the content of the Delphes card according to their analysis.
- know that Delphes has its limitations

Mssing points in this talk:

- How to install Delphes?
- How to run Delphes?
- How to analyze Delphes output?

→ MadAnalysis 5 will facilitate your life **[see you before the lunch]**