# DELPHES3 for fast simulation of a generic collider experiment

Chen Cheng

2017.3.24

- Introduction
- CEPC Delphes Card
- MadGraph for ISR
- Pythia8 Generate Events
- Efficiency and Resolution
- Event display

# Introduction

**Delphes is a C++ framework. The simulation includes a tracking system, embedded into a magnetic field, calorimeters and a muon system.**

- **Track**
- **Calorimeter**
- **Particle-flow**

# CEPC Delphes Card

```
##############################
# Electron tracking efficiency
##############################

module Efficiency ElectronTrackingEfficiency {
  set InputArray ParticlePropagator/electrons
  set OutputArray electrons

  # set EfficiencyFormula {efficiency formula as a function of eta and pt}

  # tracking efficiency formula for electrons
  set EfficiencyFormula {                                          (energy <= 2.)   * (0.80) +
                                    (abs(eta) <= 3.0)            * (energy > 2.)    * (1.00) +
                                    (abs(eta) >  3.0)                                * (0.00)}
}
#pt<0.1
############################
```

```
#####################################
# Momentum resolution for electrons
#####################################

module MomentumSmearing ElectronMomentumSmearing {
  set InputArray ElectronTrackingEfficiency/electrons
  set OutputArray electrons

  # set ResolutionFormula {resolution formula as a function of eta and energy}

   # resolution formula for charged hadrons
  set ResolutionFormula {    (abs(eta) <= 1.5)                    * sqrt(0.001^2 + pt^2*1.e-5^2) +
                             (abs(eta) > 1.5 && abs(eta) <= 4.0) * sqrt(0.01^2 + pt^2*1.e-4^2)}
}
```

```
#############
#   ECAL
#############

module SimpleCalorimeter ECal {
  set ParticleInputArray ParticlePropagator/stableParticles
  set TrackInputArray TrackMerger/tracks

  set TowerOutputArray ecalTowers
  set EFlowTrackOutputArray eflowTracks
  set EFlowTowerOutputArray eflowPhotons

  set IsEcal true

  set EnergyMin 0.5
  set EnergySignificanceMin 1.0

  set SmearTowerCenter true

  set pi [expr {acos(-1)}]

  # lists of the edges of each tower in eta and phi
  # each list starts with the lower edge of the first tower
  # the list ends with the higher edged of the last tower

  # 1.0 degree towers (3 cm x 3 cm)
  set PhiBins {}
  for {set i -180} {$i <= 180} {incr i} {
    add PhiBins [expr {$i * $pi/180.0}]
  }
```

```
# 0.02 unit in eta up to eta = 3.0
for {set i -150} {$i <= 150} {incr i} {
  set eta [expr {$i * 0.02}]
  add EtaPhiBins $eta $PhiBins
}

# default energy fractions {abs(PDG code)} {fraction of energy deposited in ECAL}

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}

# set ECalResolutionFormula {resolution formula as a function of eta and energy}

set ResolutionFormula { (abs(eta) <= 3.0)                  * sqrt(energy^2*0.005^2 + energy*0.20^2) }
```

```
##############
#   HCAL
##############

module SimpleCalorimeter HCal {
  set ParticleInputArray ParticlePropagator/stableParticles
  set TrackInputArray ECal/eflowTracks

  set TowerOutputArray hcalTowers
  set EFlowTrackOutputArray eflowTracks
  set EFlowTowerOutputArray eflowNeutralHadrons

  set IsEcal false

  set EnergyMin 1.0
  set EnergySignificanceMin 1.0

  set SmearTowerCenter true

  set pi [expr {acos(-1)}]

  # lists of the edges of each tower in eta and phi
  # each list starts with the lower edge of the first tower
  # the list ends with the higher edged of the last tower


  # 2.0 degree towers (6 cm x 6 cm)
  set PhiBins {}
  for {set i -180} {$i <= 180} {incr i} {
    add PhiBins [expr {$i * $pi/180.0}]
  }

  # 0.04 unit in eta up to eta = 3.0
```

```
# 0.04 unit in eta up to eta = 3.0
for {set i -75} {$i <= 75} {incr i} {
  set eta [expr {$i * 0.04}]
  add EtaPhiBins $eta $PhiBins
}
```

**CEPC：** magnetic field

```
# radius of the magnetic field coverage, in m
 set Radius 1.8
 # half-length of the magnetic field coverage,
in m
 set HalfLength 2.35
 # magnetic field
 set Bz 3.5
```

Calorimeter cell

**CEPC:**

ECAL:

```
# 1.0 degree towers (3 cm x 3 cm)
set PhiBins {} for {set i -180} {$i <= 180} {incr i} {
 add PhiBins [expr {$i * $pi/180.0}]
 }
# 0.02 unit in eta up to eta = 3.0
for {set i -150} {$i <= 150} {incr i} {
set eta [expr {$i * 0.02}]
add EtaPhiBins $eta $PhiBins
 }
```

HCAL:

```
# 2.0 degree towers (6 cm x 6 cm)
set PhiBins {} for {set i -180} {$i <= 180} {incr i} {
 add PhiBins [expr {$i * $pi/180.0}]
 }
# 0.04 unit in eta up to eta = 3.0
for {set i -75} {$i <= 75} {incr i} {
set eta [expr {$i * 0.04}]
add EtaPhiBins $eta $PhiBins
 }
```

**FCC:**

ECAL: granularity : 0.0125 x 0.0125 for eta<2.5,

0.025 x 0.025 for eta<4.0,

0.05 x 0.05 for eta<6.0

HCAL: granularity : 0.05 x 0.05 for eta<2.5,

0.1 x 0.1 for eta<4.0,

0.2 x 0.2 for eta<6.0

# MadGraph for ISR

**arXiv: 1505.01270 Beamstruhlung effect at CEPC is small, however, ISR effect is not small**

### 15.6.1 Physics

Whizard Manual

The ISR structure function is in the most crude approximation (LLA without $\alpha$ corrections, i.e. $\epsilon^0$)

$$f_0(x) = \epsilon(1-x)^{-1+\epsilon} \qquad \text{with} \qquad \epsilon = \frac{\alpha}{\pi} q_e^2 \ln\frac{s}{m^2}, \tag{15.27}$$

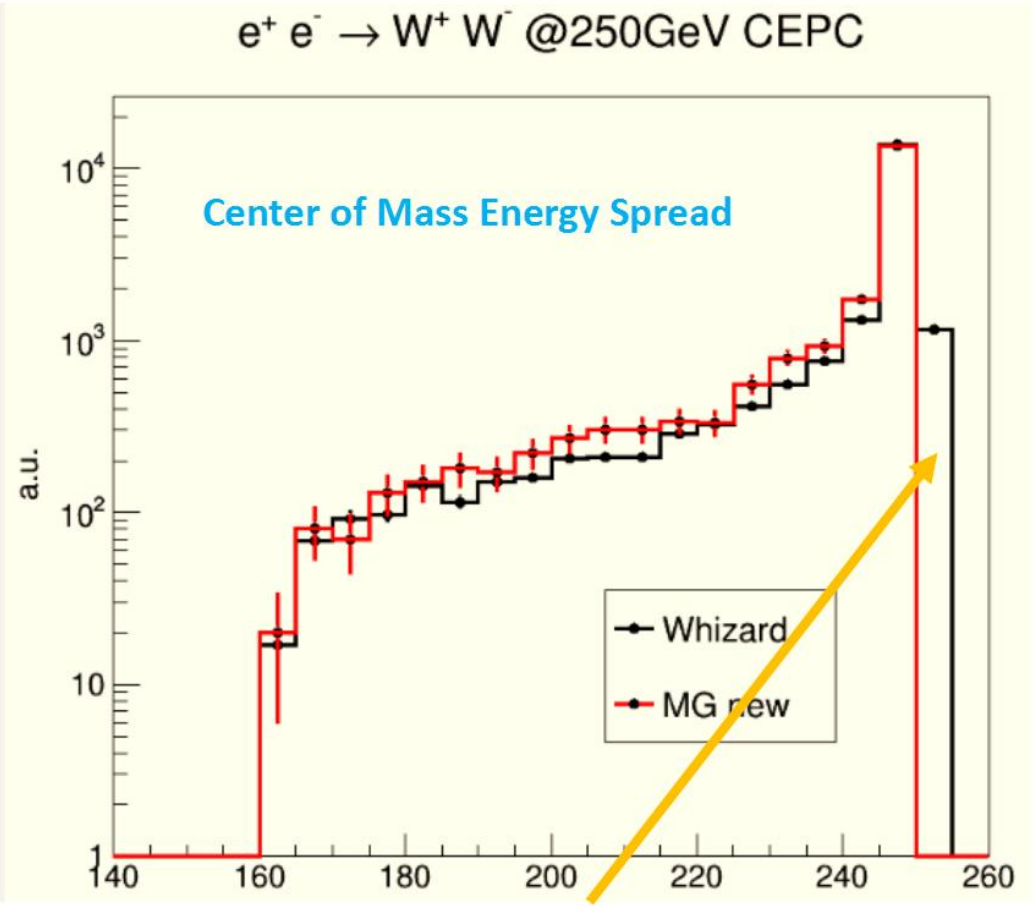
Including $\epsilon$, $\epsilon^2$, and $\epsilon^3$ corrections, the successive approximation of the ISR structure function read

$$f_0(x) = \epsilon(1-x)^{-1+\epsilon} \tag{15.33}$$

$$f_1(x) = g_1(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) \tag{15.34}$$

$$\begin{aligned} f_2(x) &= g_2(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) \\ &\quad - \frac{\epsilon^2}{8}\left(\frac{1+3x^2}{1-x}\ln x + 4(1+x)\ln(1-x) + 5 + x\right) \end{aligned} \tag{15.35}$$

$$\begin{aligned} f_3(x) &= g_3(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) \\ &\quad - \frac{\epsilon^2}{8}\left(\frac{1+3x^2}{1-x}\ln x + 4(1+x)\ln(1-x) + 5 + x\right) \\ &\quad - \frac{\epsilon^3}{48}\left((1+x)\left[6\,\mathrm{Li}_2(x) + 12\ln^2(1-x) - 3\pi^2\right] + 6(x+5)\ln(1-x)\right. \\ &\qquad + \frac{1}{1-x}\left[\frac{3}{2}(1+8x+3x^2)\ln x + 12(1+x^2)\ln x\ln(1-x)\right. \\ &\qquad\quad \left.\left. - \frac{1}{2}(1+7x^2)\ln^2 x + \frac{1}{4}(39-24x-15x^2)\right]\right) \end{aligned} \tag{15.36}$$



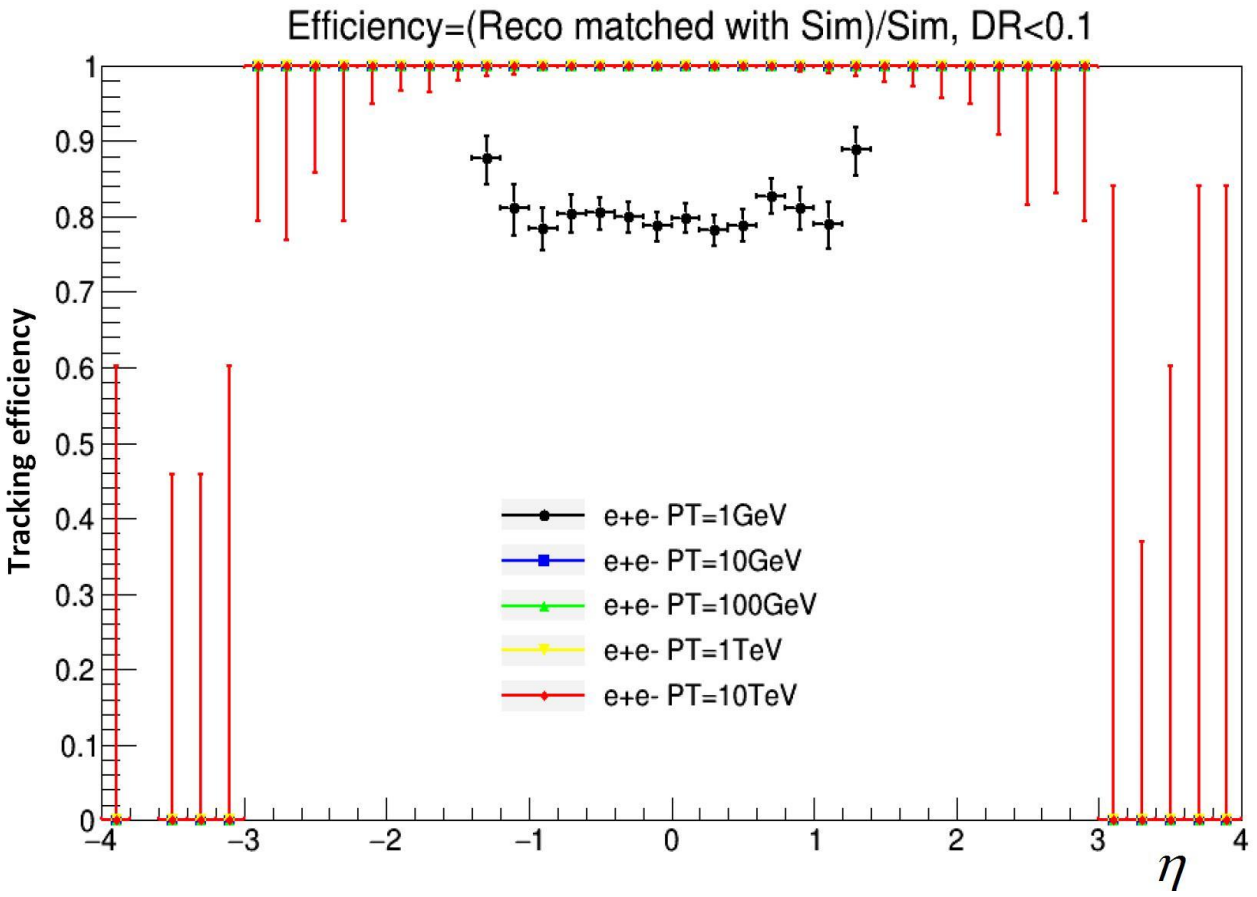

'Singular' region near X~1, to be improved more with Monte-Carlo Mapping

# Pythia8 Generate Events

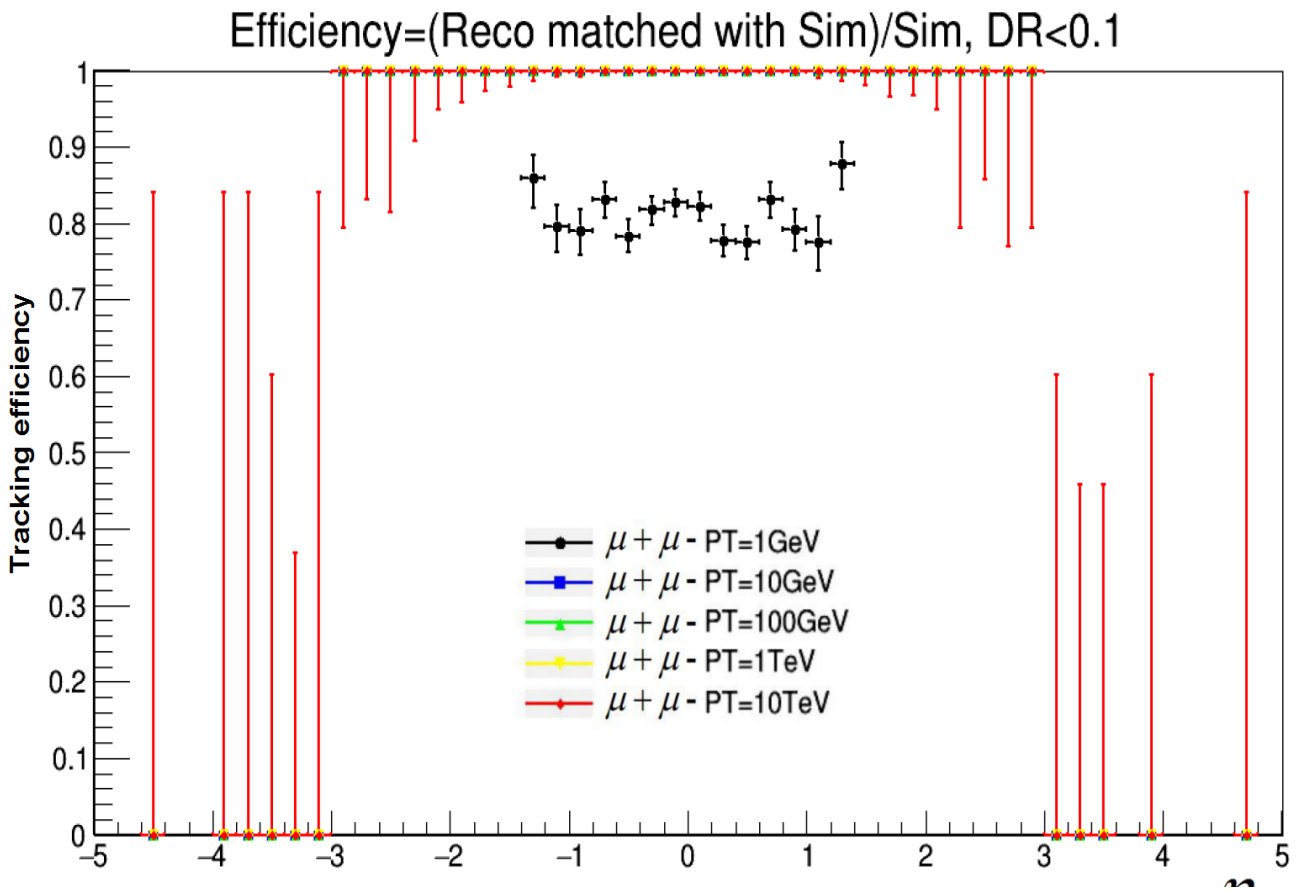
```
void fillParticle(int id, double pt, double thetaIn, double phiIn,
  Event& event, ParticleData& pdt, Rndm& rndm, bool atRest = false) {

  // Reset event record to allow for new event.
  event.reset();

  // Select particle mass; where relevant according to Breit-Wigner.
  double mm = pdt.mSel(id);

  if (atRest) {
   double ee = mm;
  double  pp = 0.;
  }
//cout<<atRest<<endl;
  // Angles as input or uniform in solid angle.
  double cThe, sThe, phi;
  if (thetaIn >= 0.) {
    cThe = cos(thetaIn);
    sThe = sin(thetaIn);
    phi  = phiIn;
  } else {double qq=0.1*(rand()%10)+0.01*(rand()%10)+0.001*(rand()%10)+0.0001*(rand()%10)+0.00001*(rand()%10);
    cThe = 1-2*qq;
    sThe = sqrtpos(1. - cThe * cThe);
    phi = 2. * M_PI * qq;
  }
double pp = pt/sThe;
double ee = sqrtpos(pp*pp + mm*mm);
  // Store the particle in the event record.
  event.append( id, 1, 0, 0, pp * sThe * cos(phi), pp * sThe * sin(phi),
    pp * cThe, ee, mm);
```

```
Pythia pythia;
Event& event      = pythia.event;

HepMC::Pythia8ToHepMC ToHepMC;

HepMC::GenEvent* hepmcevt = new HepMC::GenEvent();
ToHepMC.fill_next_event( pythia, hepmcevt );
```

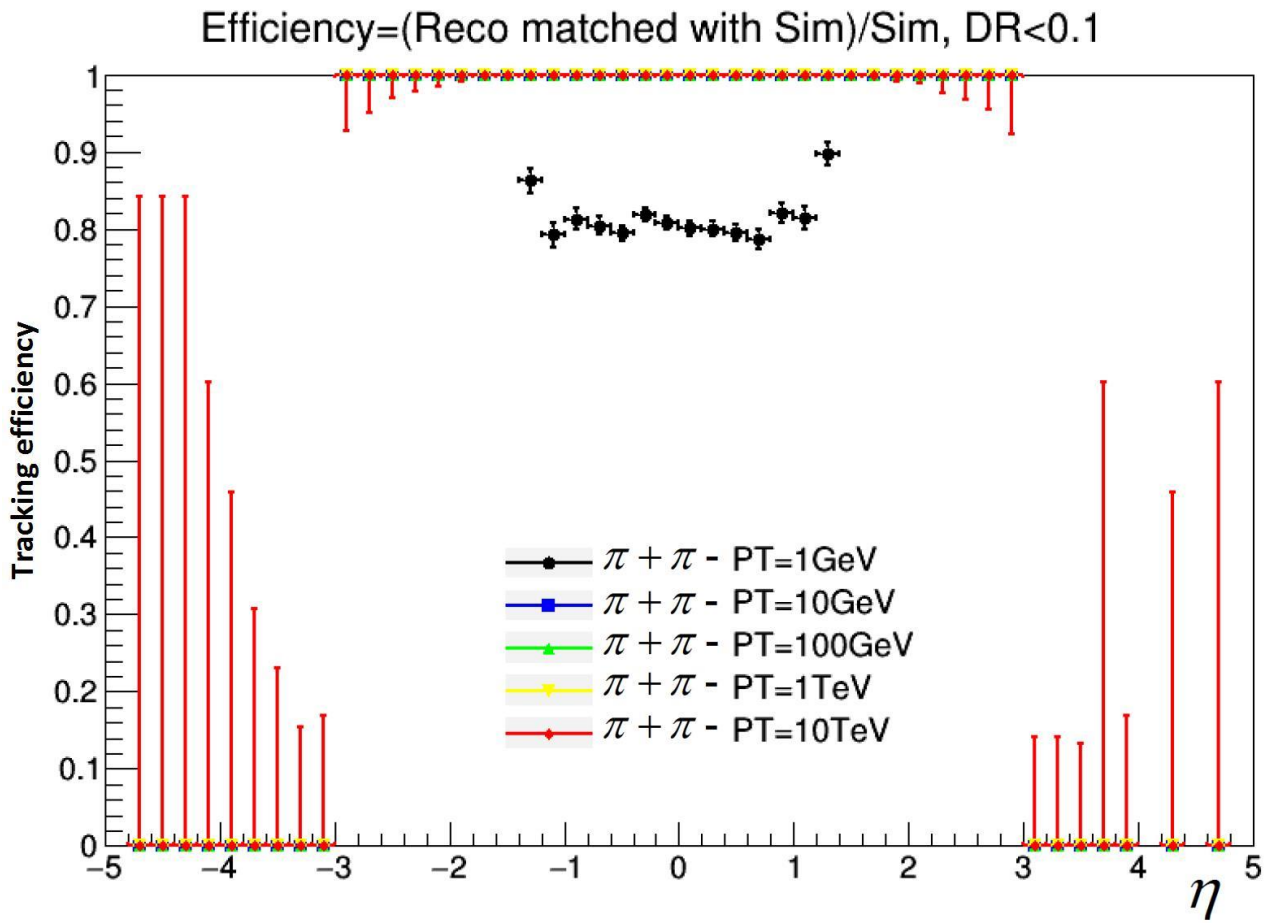
# Tracking Efficiency




```
# tracking efficiency formula for electrons
set EfficiencyFormula {
                                                  (energy <= 2.)    * (0.80) +
                        (abs(eta) <= 3.0)       * (energy > 2.)     * (1.00) +
                        (abs(eta) >  3.0)                           * (0.00)}
```

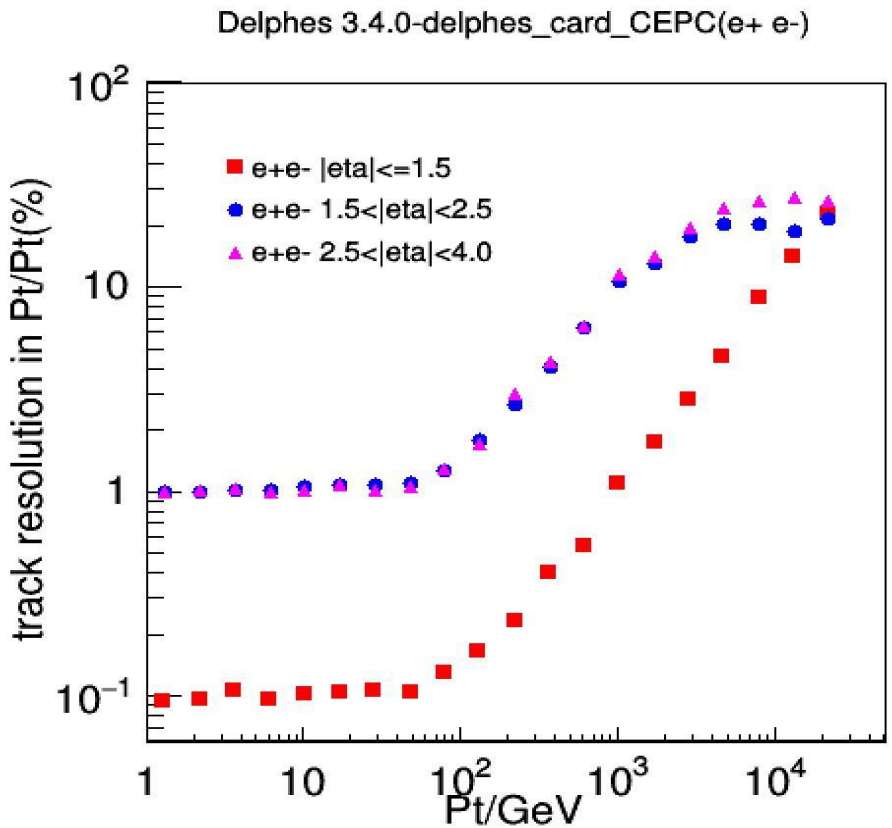



```
# tracking efficiency formula for muons
set EfficiencyFormula {
                                                  (energy <= 2.0)    * (0.80) +
                       (abs(eta) <= 3.0)        * (energy > 2.0)     * (1.00) +
                       (abs(eta) >  3.0)                             * (0.00)}
```



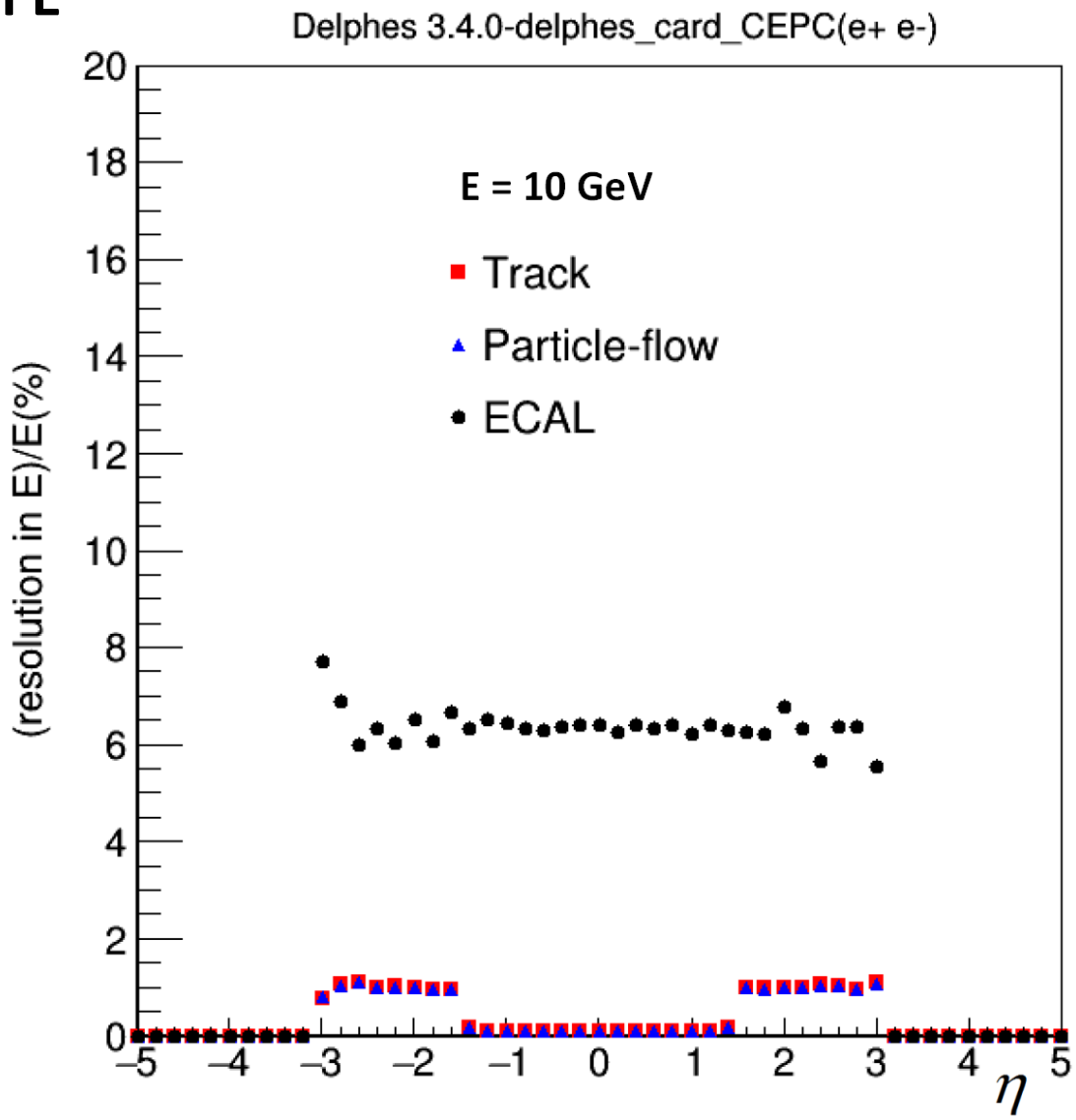

```
# tracking efficiency formula for charged hadrons
set EfficiencyFormula {
                                                  (energy <= 2.0)    * (0.80) +
                                (abs(eta) <= 3.0) * (energy > 2.0)    * (1.00) +
                                (abs(eta) >  3.0)                     * (0.00)}
```

# Tracking Resolution

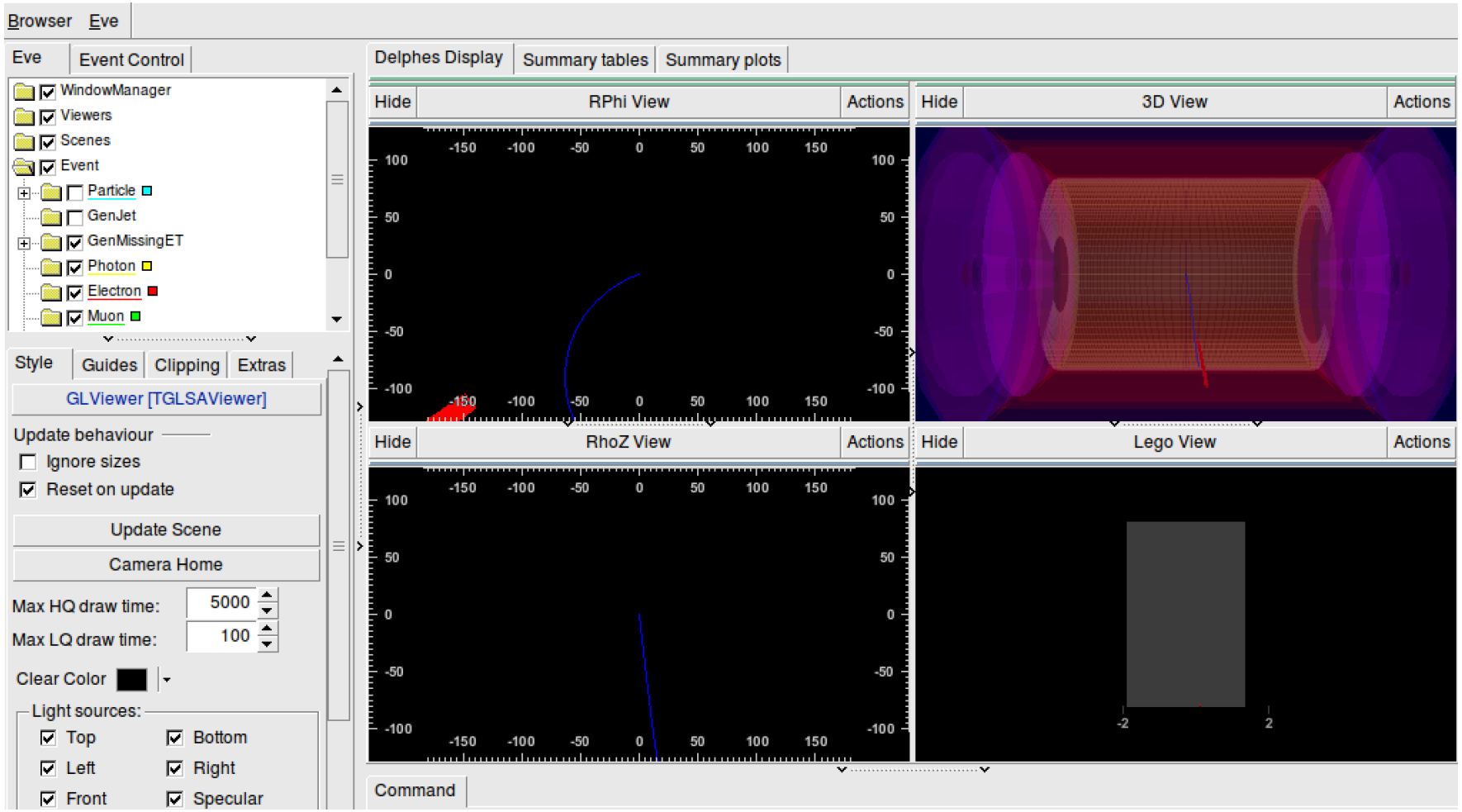



```
 # resolution formula for electrons
set ResolutionFormula {    (abs(eta) <= 1.5)                    * sqrt(0.001^2 + pt^2*1.e-5^2) +
                           (abs(eta) > 1.5 && abs(eta) <= 4.0) * sqrt(0.01^2 + pt^2*1.e-4^2)}
```

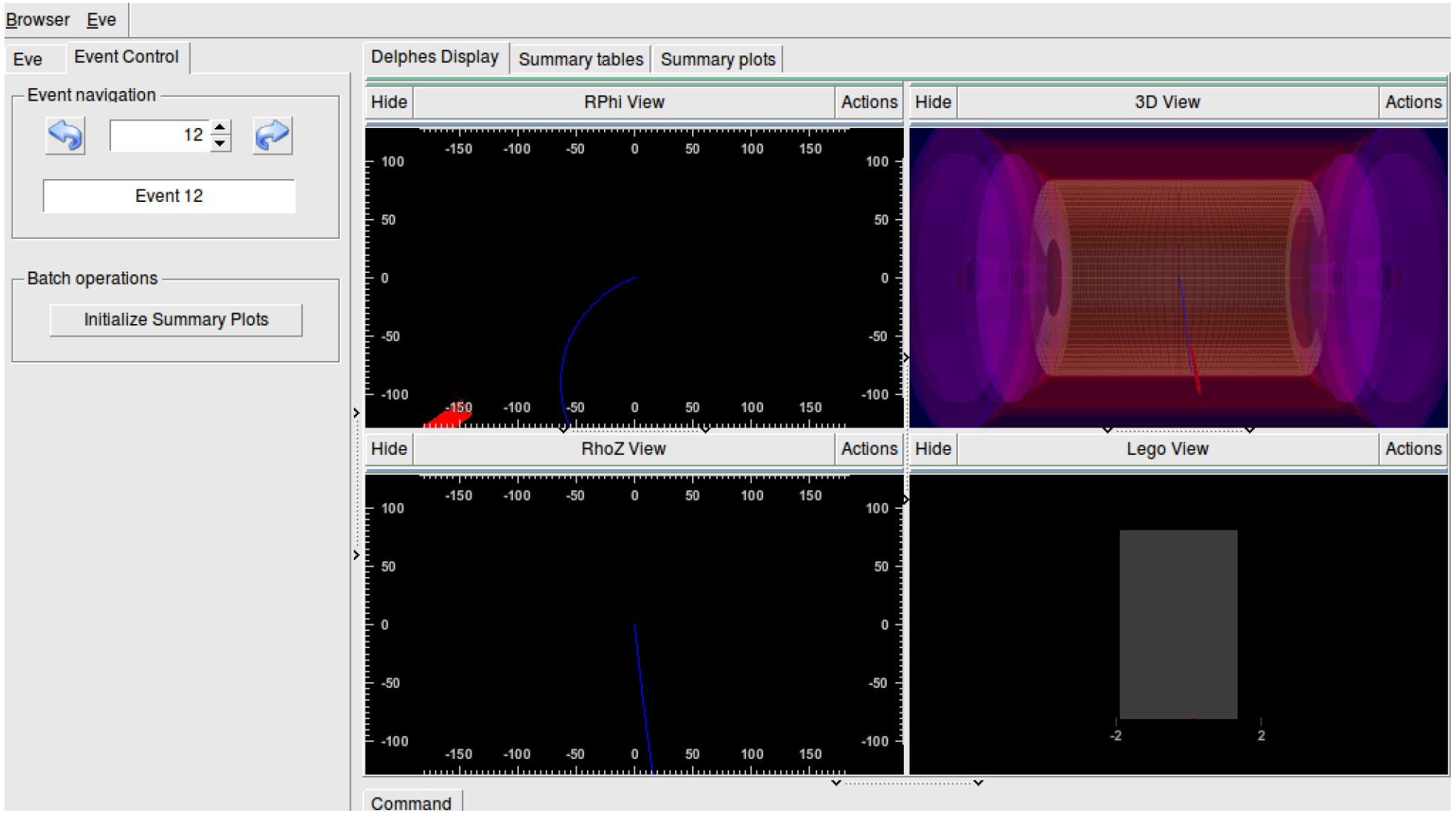
# Resolution in E

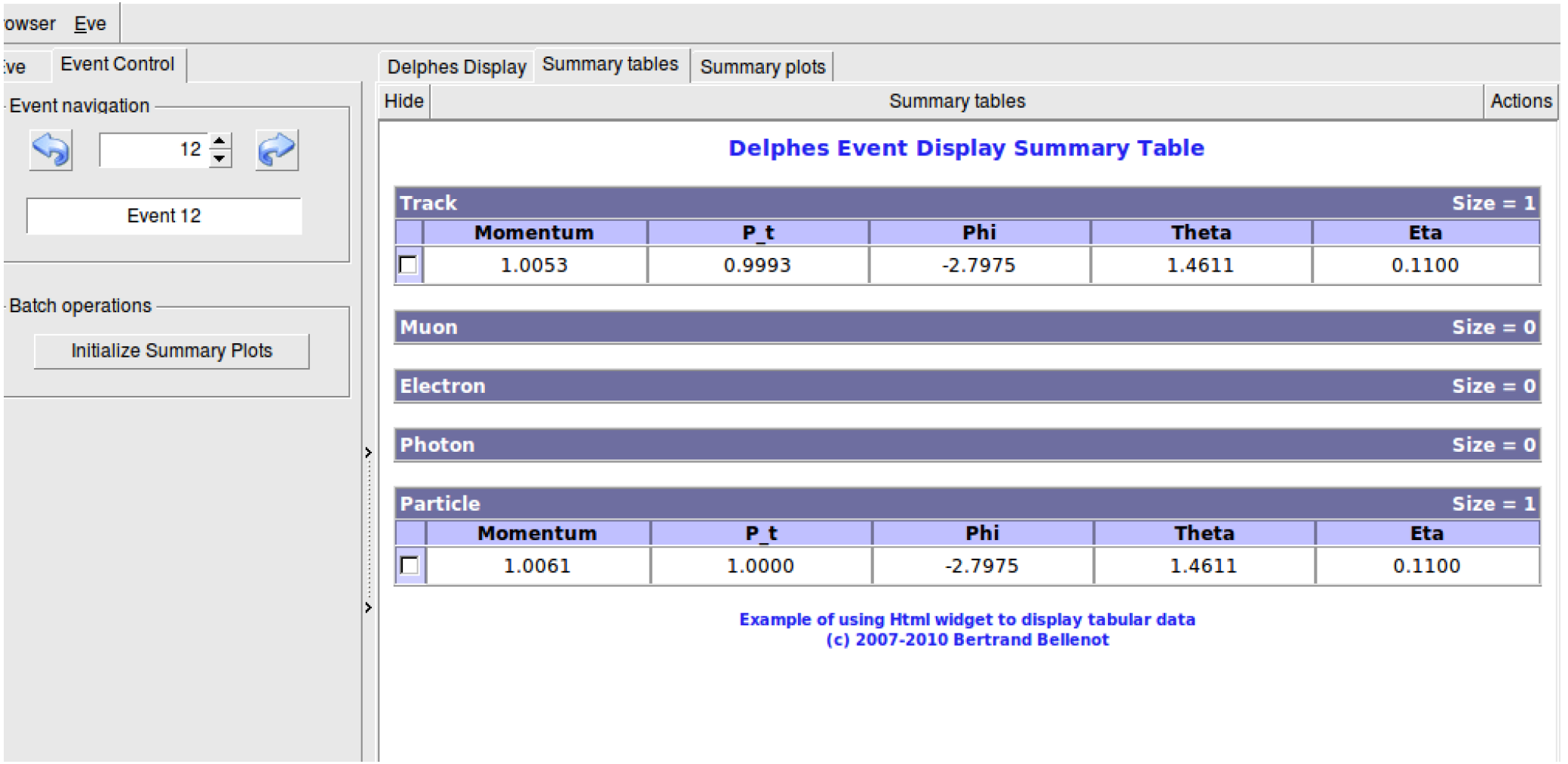


# Event display




error： display.C ”Calorimeters”change to”ECal,HCal”


Browser
Eve
Eve
Event Control
Event navigation
12
Event 12
Batch operations
Initialize Summary Plots
Delphes Display
Summary tables
Summary plots
Hide
RPhi View
Actions
Hide
3D View
Actions
Hide
RhoZ View
Actions
Hide
Lego View
Actions
Command


owser Eve
ve
Event Control
Event navigation
12
Event 12
Batch operations
Initialize Summary Plots
Delphes Display
Summary tables
Summary plots
Hide
Summary tables
Actions
Delphes Event Display Summary Table
Track Size = 1
Momentum P_t Phi Theta Eta
1.0053 0.9993 -2.7975 1.4611 0.1100
Muon Size = 0
Electron Size = 0
Photon Size = 0
Particle Size = 1
Momentum P_t Phi Theta Eta
1.0061 1.0000 -2.7975 1.4611 0.1100
Example of using Html widget to display tabular data
(c) 2007-2010 Bertrand Bellenot

# Next:

- **Delphes compare with CEPC Full simulation(Z->mumu)**
- **CEPC Delphes Card**
- **Fully validated and ready for use in Wuhan workshop (April 19th)**