



# PHYSICS ANALYSIS AT THE CMS EXPERIMENT

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# BASIC EQUATIONS IN CERN:

**HIGGS  
BOSON**

**CERN'S  
PHYSICS**

**FITTING**

**HIGGS BOSON  $\neq$  X BOSON**

**PHYSICS IN CERN  $\approx$  COMPUTING**

**UNFITTED HISTOGRAM  $\neq$  GOOD HISTOGRAM**

# THE PROJECT

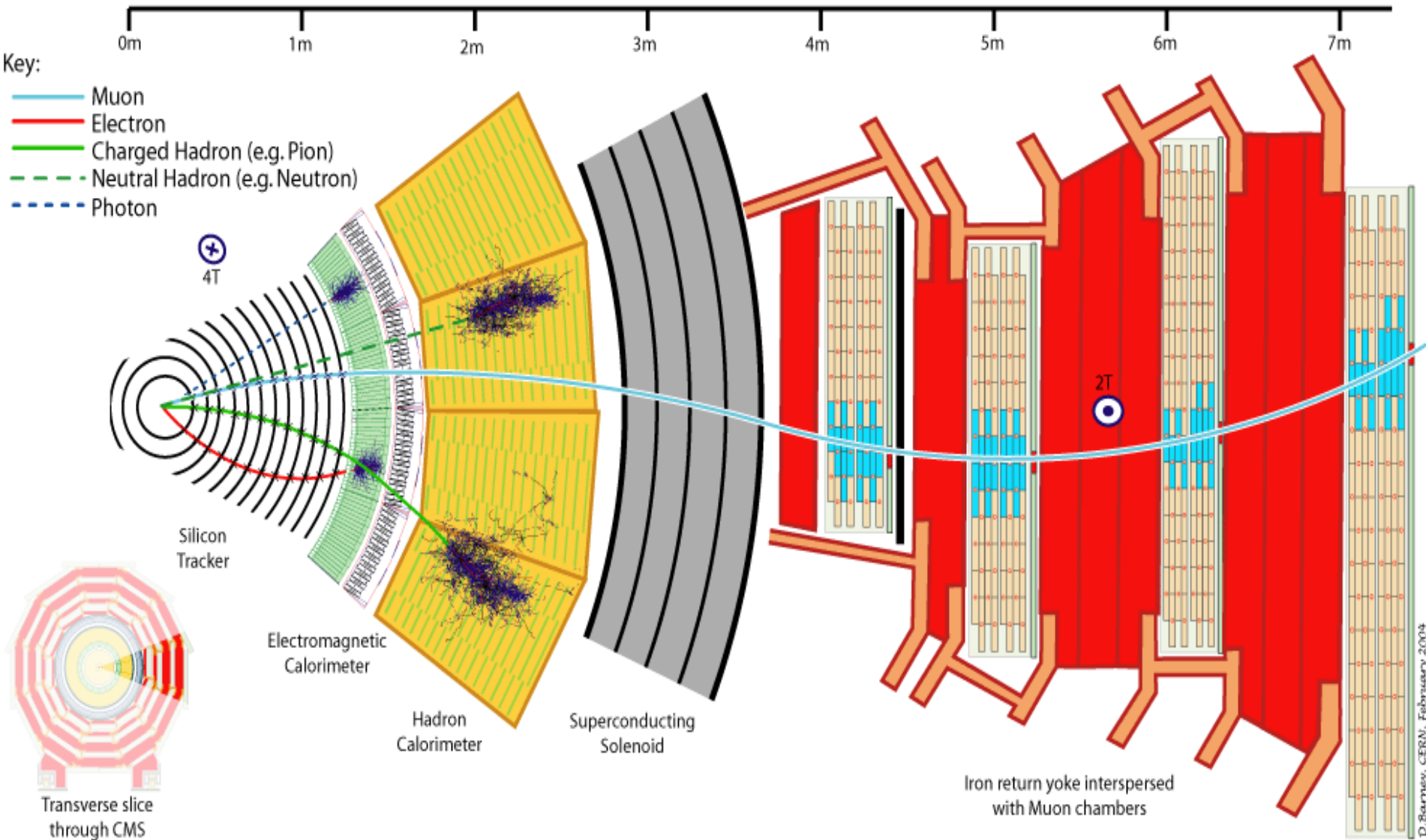
## WORK:

THE BASICS OF PHYSICS ANALYSIS AT THE CMS EXPERIMENT USING SOME OF THE SOFTWARE TOOLS TO VISUALIZE AND ANALYZE DATA

## TASK:

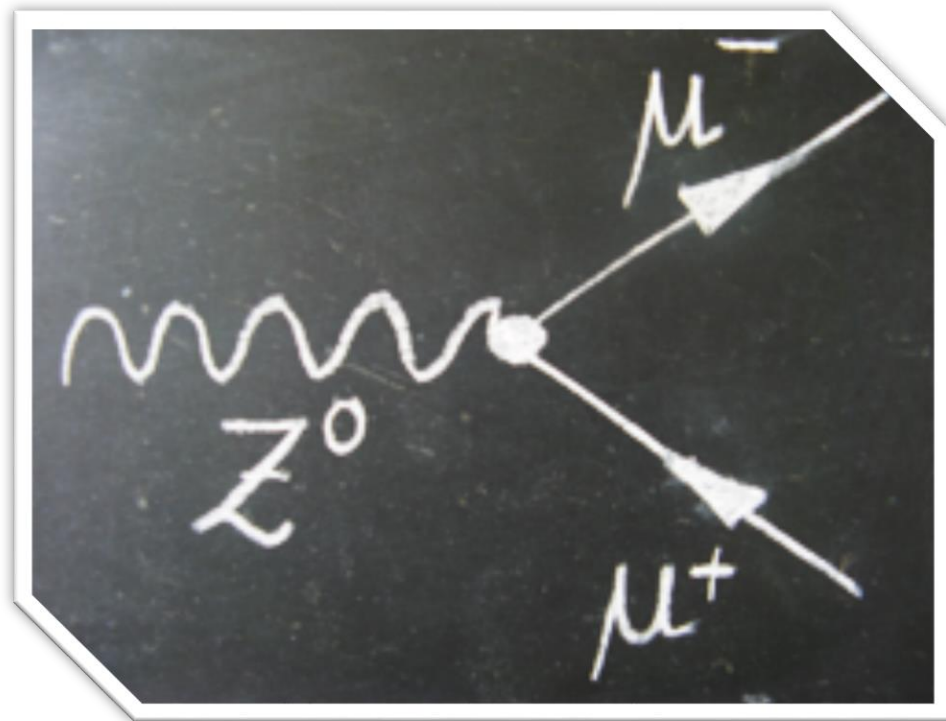
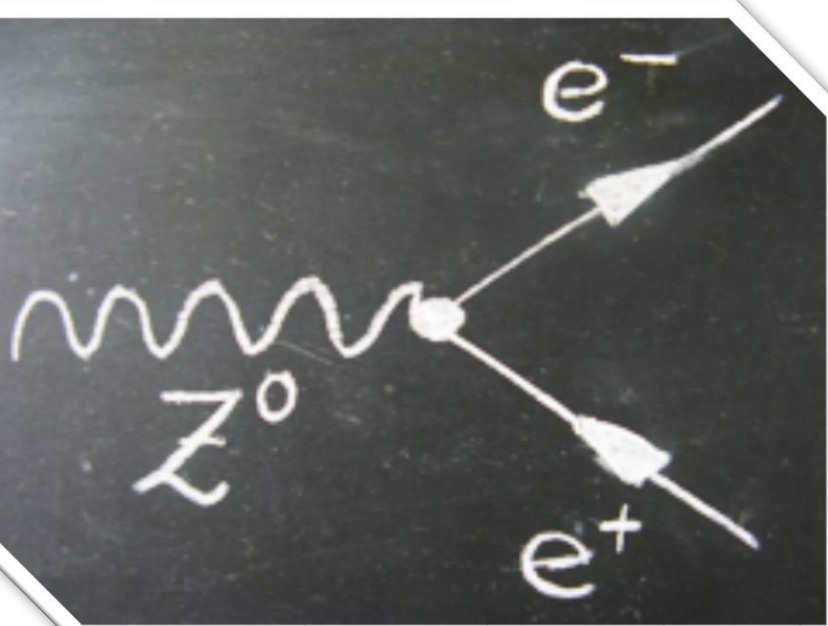
RECONSTRUCTION OF THE **Z BOSON**

# WHAT IS CMS ABOUT?



# HOW TO RECONSTRUCT THE Z BOSON?

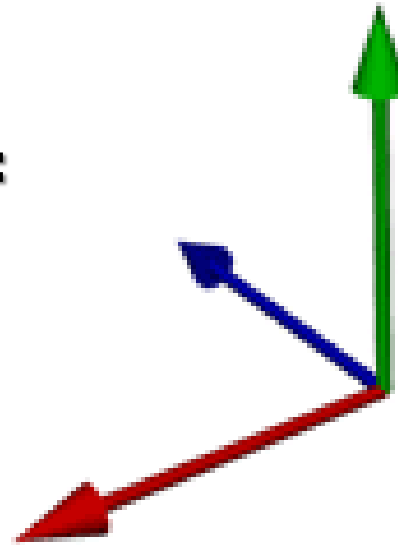
## WHAT IS Z BOSON?



# HOW TO RECONSTRUCT THE Z BOSON?

## WHAT IS INVARIANT MASS?

CHARACTERISTIC OF THE  
SYSTEM'S TOTAL **ENERGY**  
AND **MOMENTUM** THAT IS  
THE SAME **IN ALL FRAMES OF**  
**REFERENCE**



# WHAT DO YOU NEED?

- LINUX

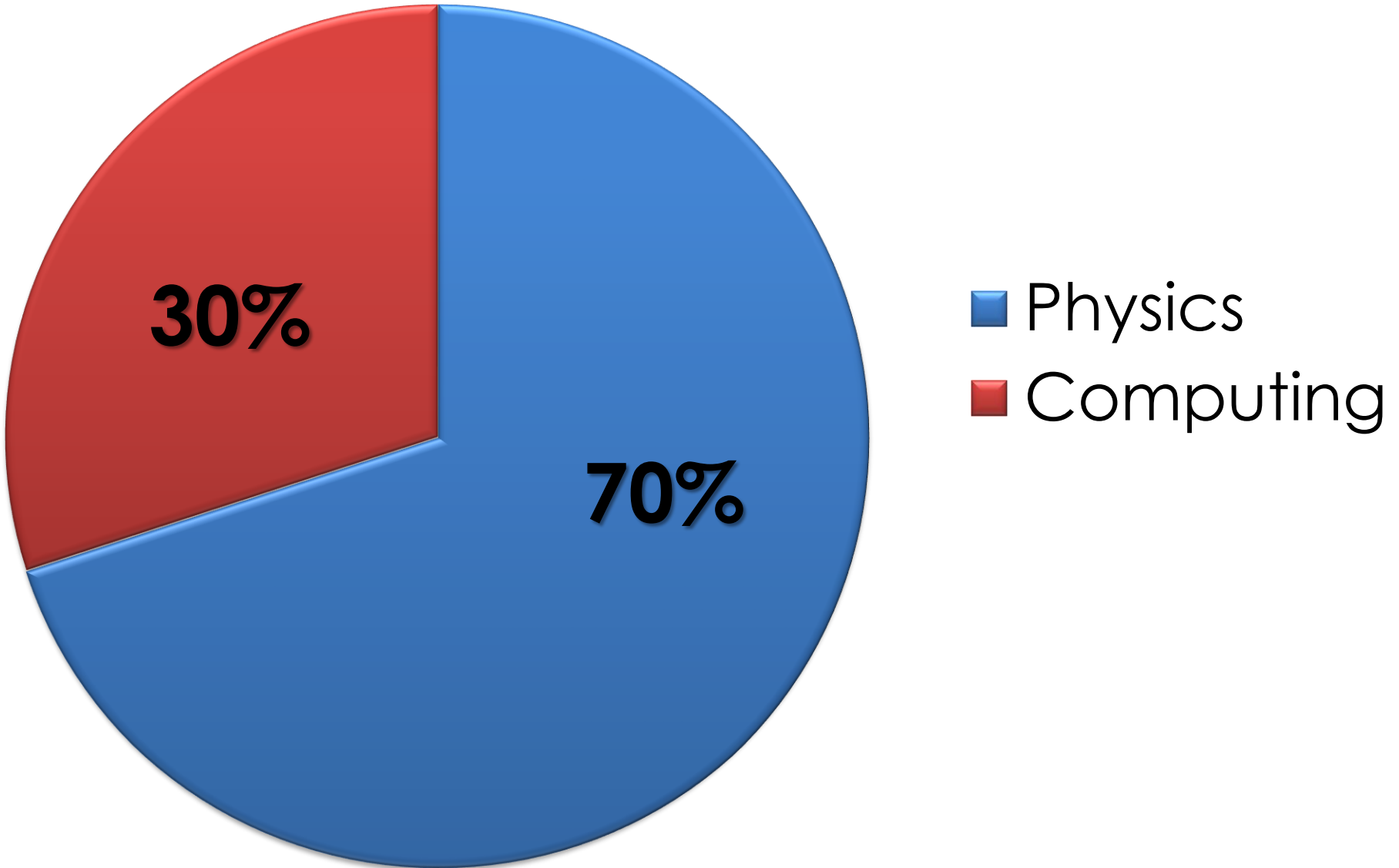
- LOGICAL THINKING

- PINCH OF PYTHON SKILLS

- 100 C++ PROGRAMING SKILLS

- CMSSW ACCESS (NEARLY IMPOSSIBLE)

# AS IN CERN WE LOVE THE DIAGRAMS..





# THEORETICAL EXPLANATION

## SPECIAL RELATIVITY?

ENERGY-MOMENTUM RELATION:

$$E^2 = (pc)^2 + (m_0 c^2)^2$$

**E** - ENERGY

**P** - MOMENTUM

**M<sub>0</sub>** - INVARIANT MASS

# THEORETICAL EXPLANATION

## SPECIAL RELATIVITY?

$$m^2 = \frac{E^2}{c^4} - \frac{p^2}{c^2}$$

Working in natural system :  $c = h = 1$

$$m_o = \sqrt{(E' + E'')^2 - (p' + p'')^2}$$

**E'** - ENERGY OF FIRST PARTICLE

**E''** - ENERGY OF SECOND PARTICLE

**P'** - VECTOR OF THE MOMENTUM OF FIRST PARTICLE

**P''** - VECTOR OF THE MOMENTUM OF SECOND PARTICLE

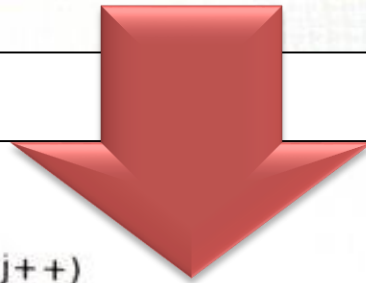
# THE IMPORTANCE OF COMPUTING

## “THE OLD-FASHIONED WAY”

```
for (uint i = 0; i < muons->size(); i++)
{ pat::Muon mu1 = (*muons)[i];
  for (uint j = i + 1; j < muons->size(); j++)
  { pat::Muon mu2 = (*muons)[j];
    if (!(mu1.charge() + mu2.charge() == 0)) continue;
    double energy1 = sqrt (mu1.px()*mu1.px() + mu1.py()*mu1.py() + mu1.pz()*mu1.pz() + MuMass*MuMass);
    double energy2 = sqrt (mu2.px()*mu2.px() + mu2.py()*mu2.py() + mu2.pz()*mu2.pz() + MuMass*MuMass);
    double mx = (mu1.px() + mu2.px())*(mu1.px() + mu2.px());
    double my = (mu1.py() + mu2.py())*(mu1.py() + mu2.py());
    double mz = (mu1.pz() + mu2.pz()*(mu1.pz() + mu2.pz()));
    double InvM = sqrt (((energy1 + energy2)*(energy1+energy2)) - (mx+my+mz));
```

# TLORENTZVECTOR- THE LOVED ONE

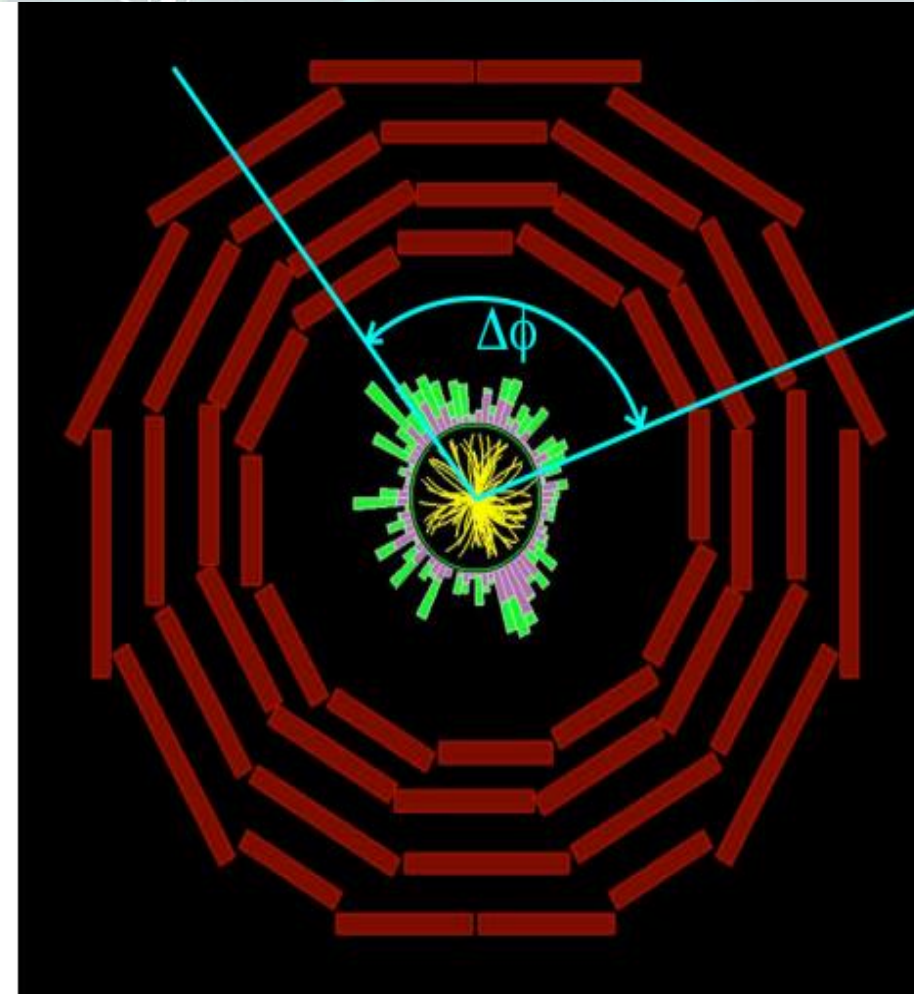
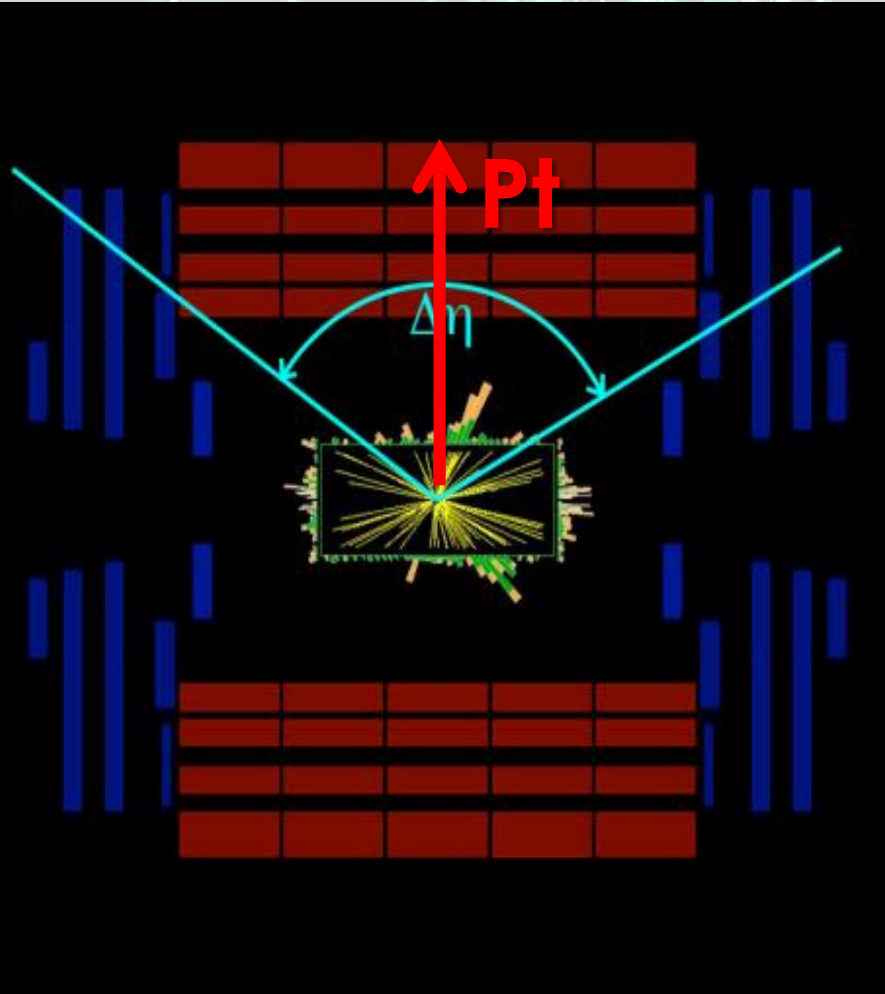
```
for (uint i = 0; i < muons->size(); i++)
{ pat::Muon mu1 = (*muons)[i];
  for (uint j = i + 1; j < muons->size(); j++)
  { pat::Muon mu2 = (*muons)[j];
    if (!(mu1.charge() + mu2.charge() == 0)) continue;
    double energy1 = sqrt (mu1.px()*mu1.px() + mu1.py()*mu1.py() + mu1.pz()*mu1.pz() + MuMass*MuMass);
    double energy2 = sqrt (mu2.px()*mu2.px() + mu2.py()*mu2.py() + mu2.pz()*mu2.pz() + MuMass*MuMass);
    double mx = (mu1.px() + mu2.px())*(mu1.px() + mu2.px());
    double my = (mu1.py() + mu2.py())*(mu1.py() + mu2.py());
    double mz = (mu1.pz() + mu2.pz()*(mu1.pz() + mu2.pz()));
    double InvM = sqrt (((energy1 + energy2)*(energy1+energy2)) - (mx+my+mz));
```



```
for (uint i = 0; i < muons->size(); i++)
{ pat::Muon mu1 = (*muons)[i];
  for (uint j = i + 1; j < muons->size(); j++)
  { pat::Muon mu2 = (*muons)[j];
    if (!(mu1.charge() + mu2.charge() == 0)) continue;
    if ( mu1.pt() < 3 || mu2.pt() < 3 ) continue;
    TLorentzVector lv1;
    TLorentzVector lv2;
    double energy1 = sqrt (mu1.px()*mu1.px() + mu1.py()*mu1.py() + mu1.pz()*mu1.pz() + MuMass*MuMass);
    double energy2 = sqrt (mu2.px()*mu2.px() + mu2.py()*mu2.py() + mu2.pz()*mu2.pz() + MuMass*MuMass);
    lv1.SetPxPyPzE(mu1.px(), mu1.py(), mu1.pz(), energy1);
    lv2.SetPxPyPzE(mu2.px(), mu2.py(), mu2.pz(), energy2);
```

# HISTOGRAMS AND PARAMETERS

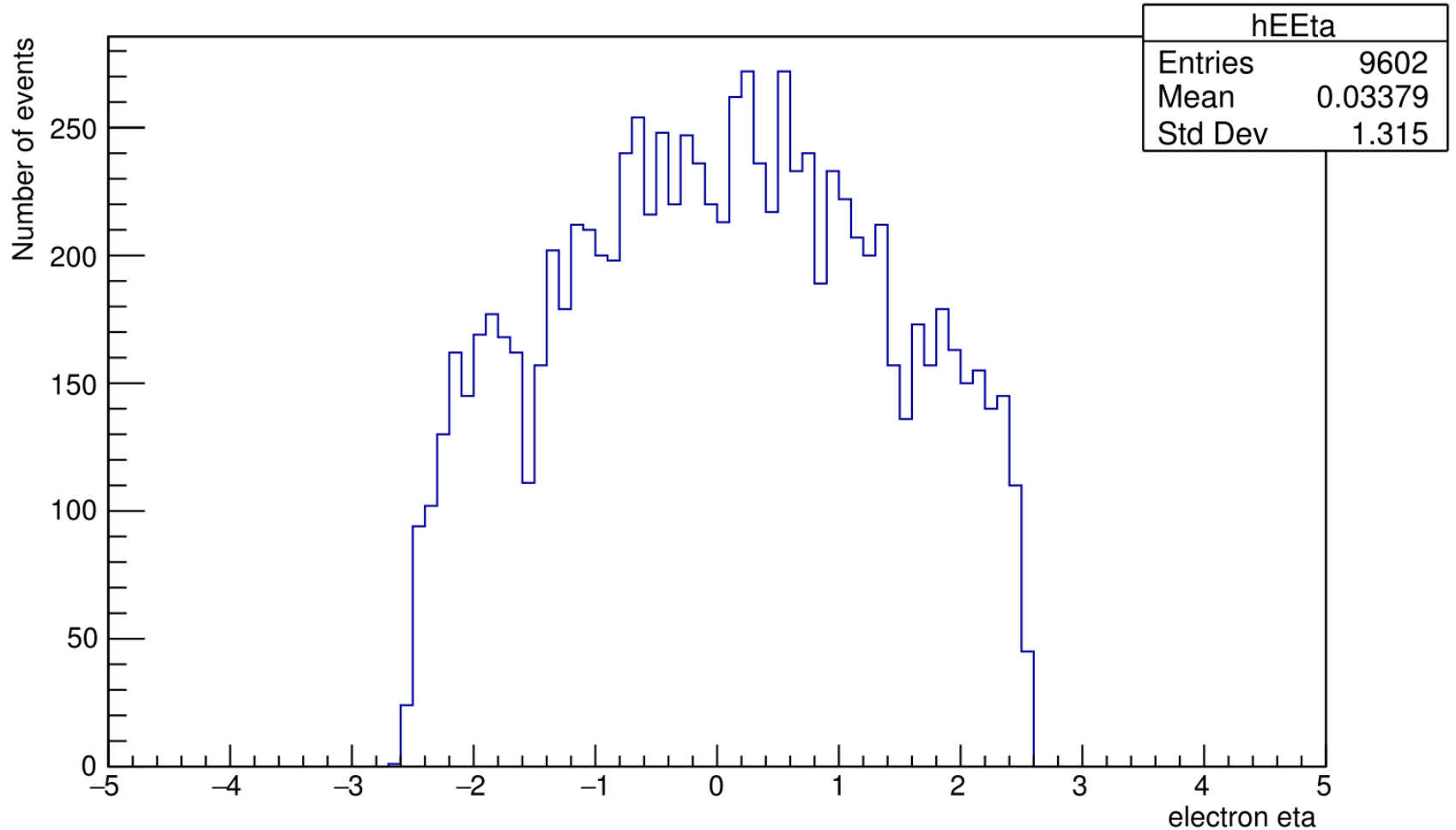
z(1, 3)



# HISTOGRAMS AND PARAMETERS

z(1, 3)

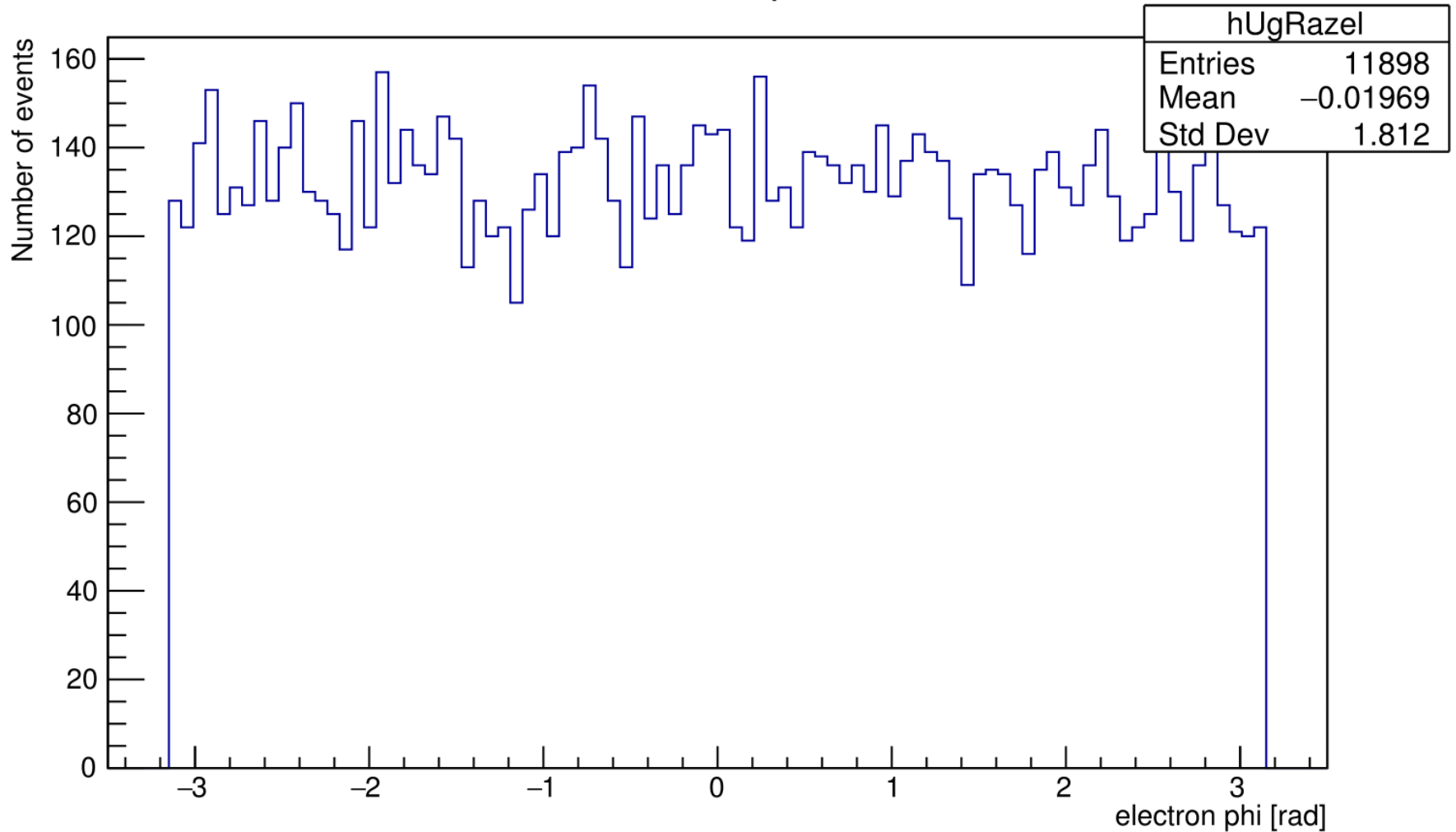
electron eta



# HISTOGRAMS AND PARAMETERS

z(1, 3)

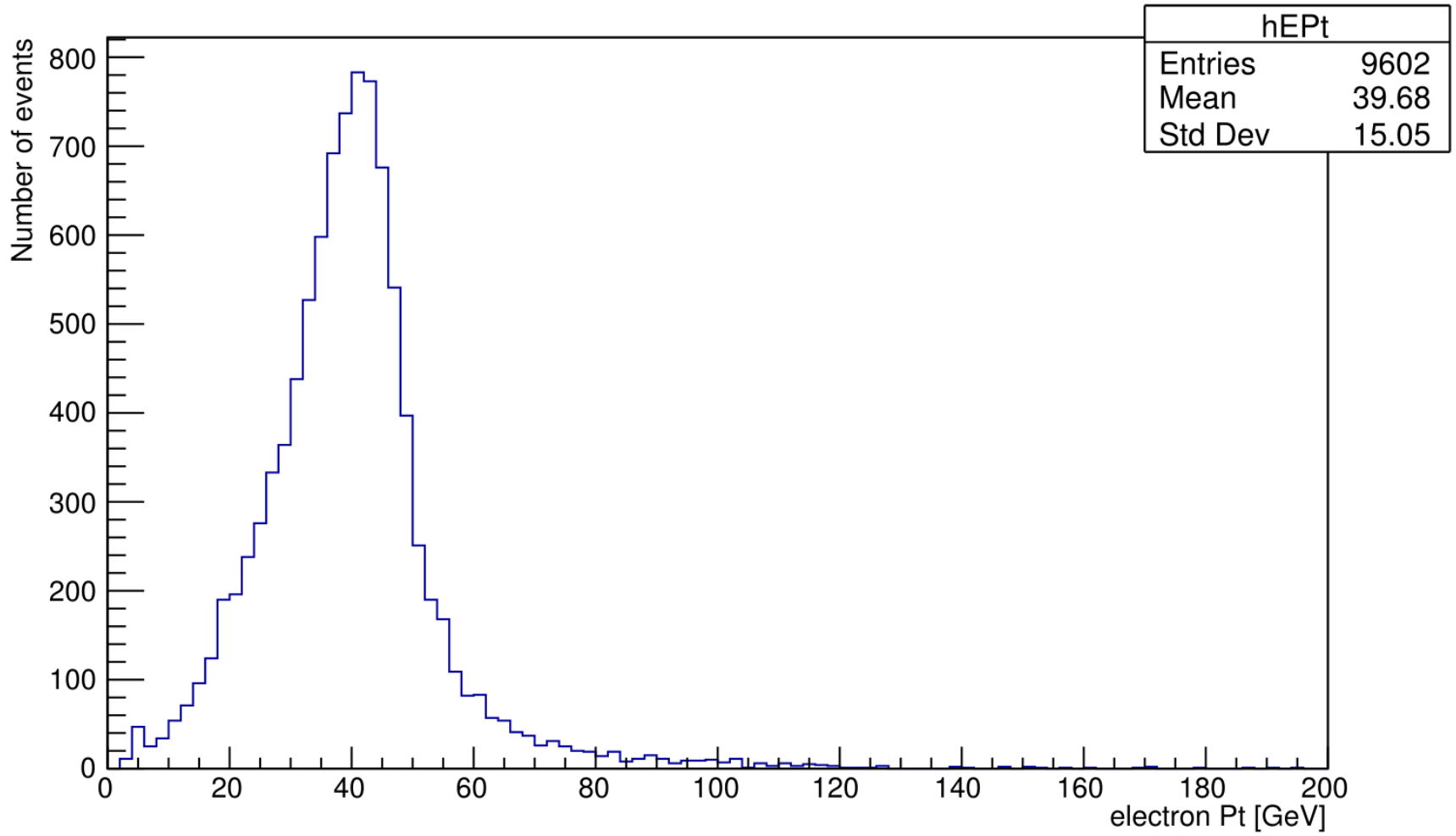
electron phi



# HISTOGRAMS AND PARAMETERS

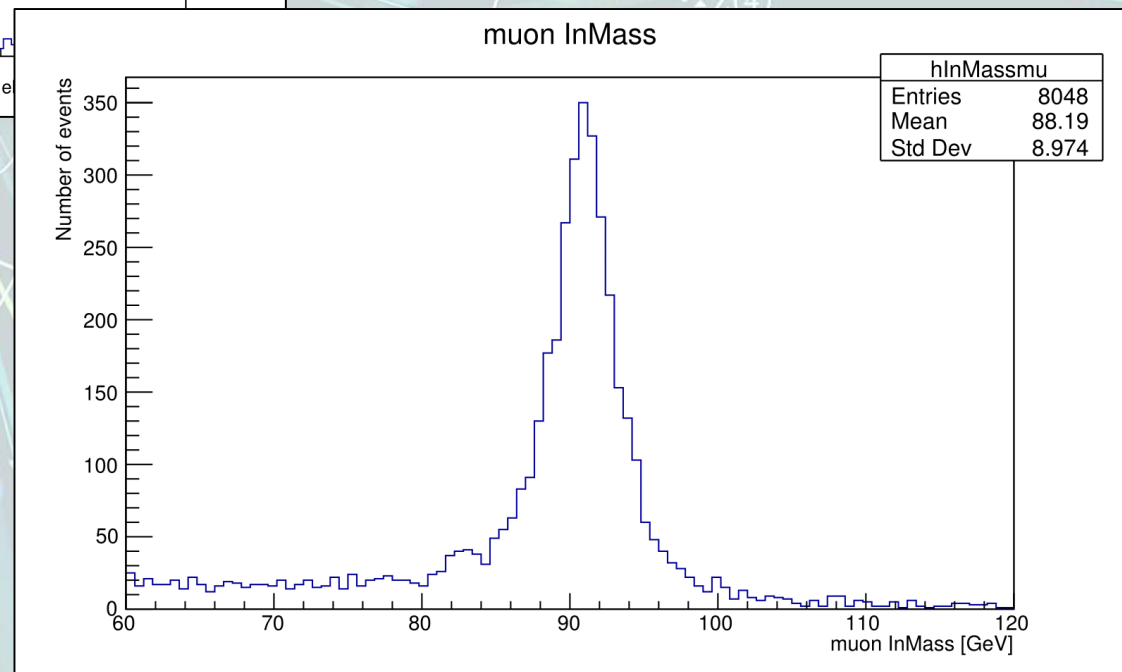
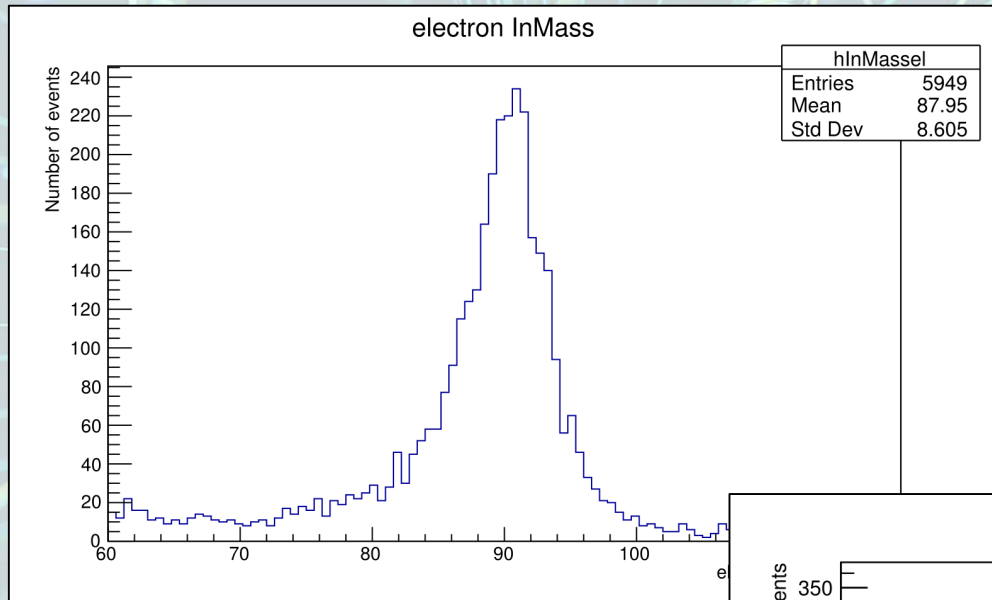
z(1, 3)

electron Pt





# HISTOGRAMS AND PARAMETERS



# FITTING HISTOGRAMS

## WHY BOTH GAUSS AND BREIT-WIGNER?

```
// Mean of the J/psi mass peak
RooRealVar mean("mean","mean", 91, hmin, hmax);

// Construct Gaussian1 PDF for signal
RooRealVar sigma1("sigma1","sigma1", 1, 0.01, 7);
RooGaussian gauss1("gauss1","gauss1", x, mean, sigma1);

// Construct Gaussian2 PDF for signal
RooRealVar sigma2("sigma2","sigma2", 0.02, 0.001, 7);
RooGaussian gauss2("gauss2","gauss2", x, mean, sigma2);

// Construct a double Gaussian function to fit the signal component
RooRealVar frac1("frac1","fraction1", 0.8, 0, 1); // fraction of gauss1 to gauss2 component
RooAddPdf signalModel("signal model","gauss1+gauss2",RooArgList(gauss1,gauss2),RooArgList(frac1));

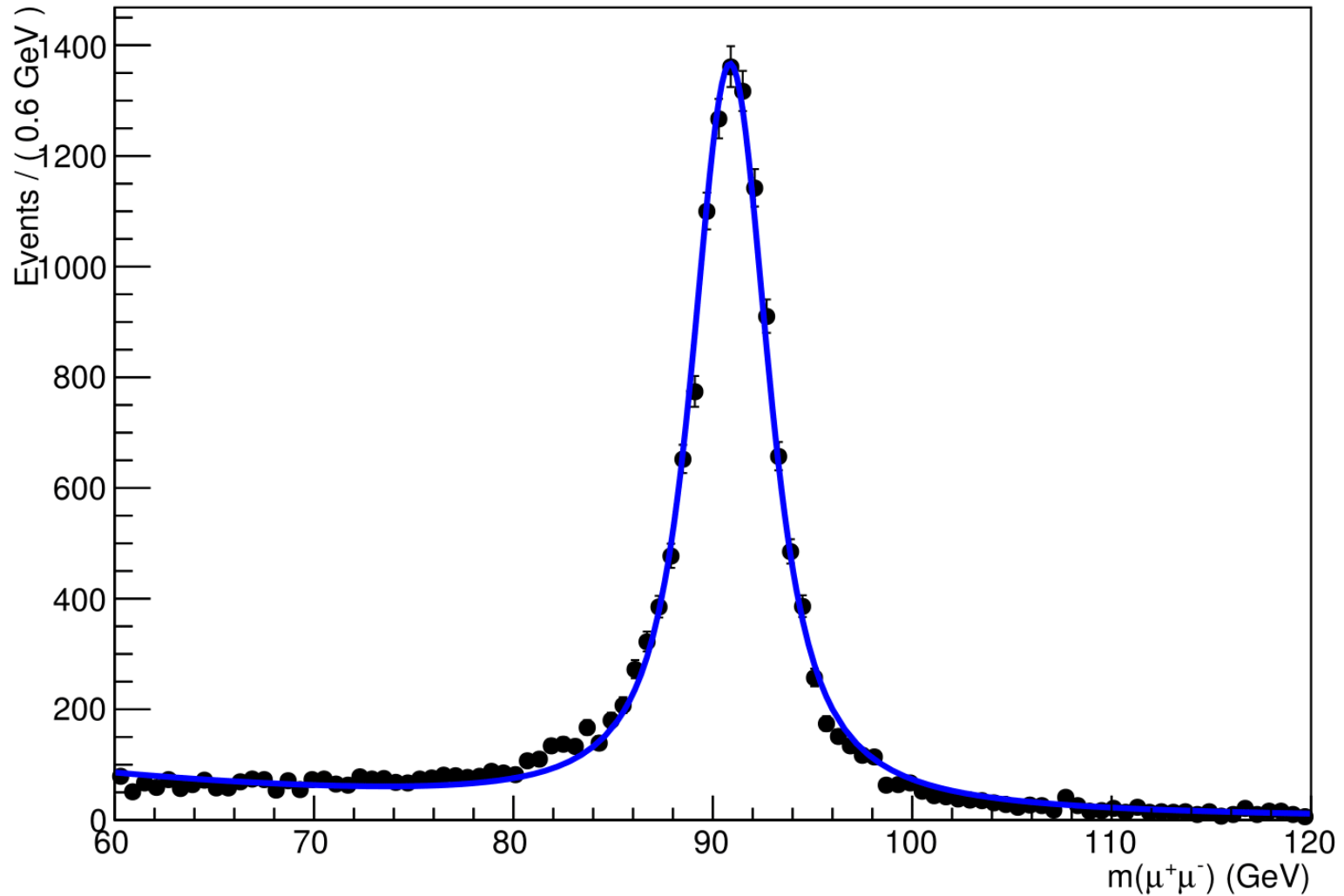
// Construct a Voigtian to fit the signal component
RooRealVar width("width","width", 0.2, 0.001,7);
RooRealVar sigma("sigma","sigma", 0.02, 0.001, 7);
RooVoigtian voigt("voigt","voigt",x,mean,width,sigma);

// Construct exponential PDF to fit the bkg component
RooRealVar lambda("lambda", "slope", -2, -5, 5);
RooExponential expo("expo", "exponential PDF", x, lambda);

// Construct signal + bkg PDF
RooRealVar frac2("frac2","fraction2", 0.8, 0, 1); // fraction of the signal to bkg component
```

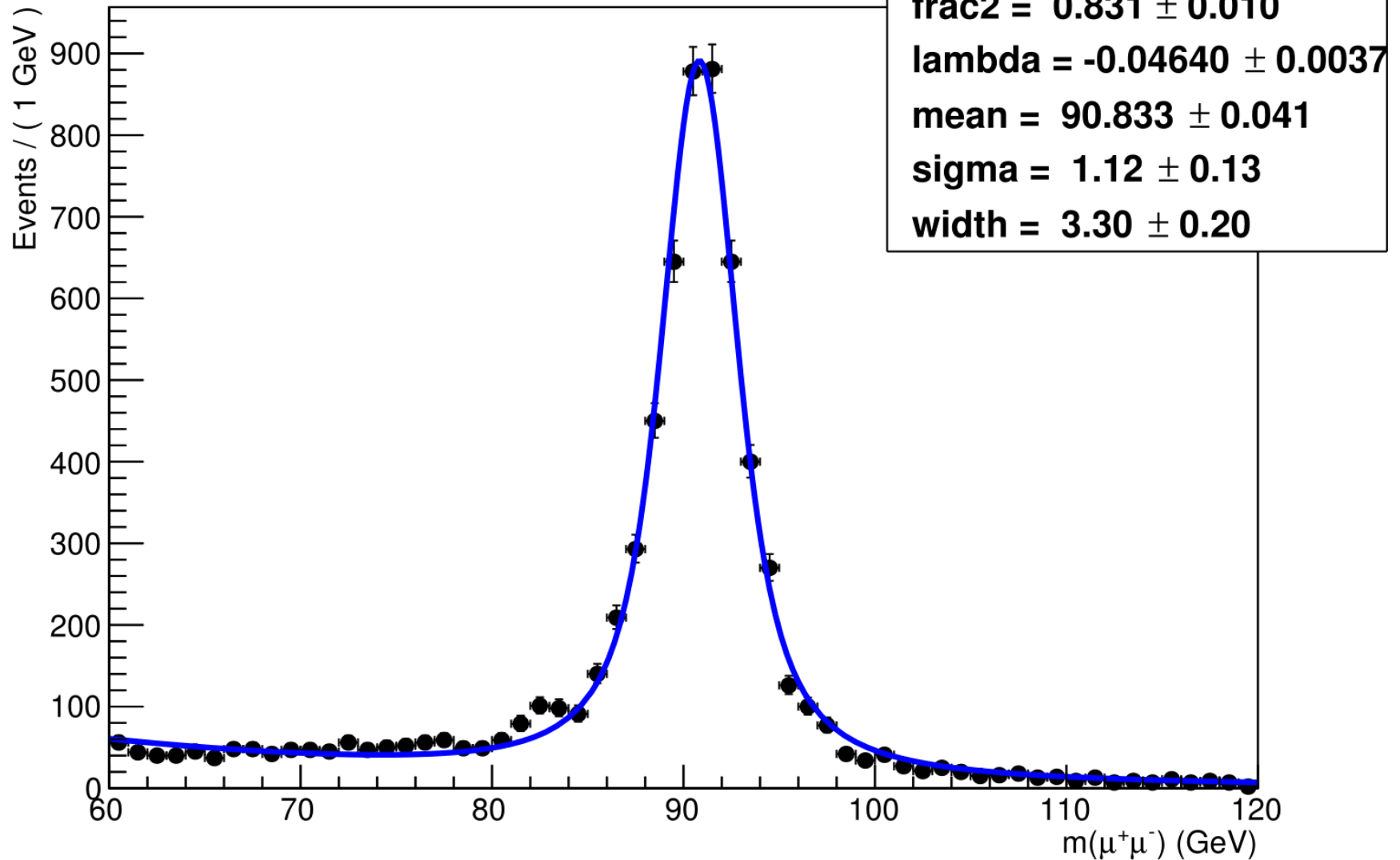
# FITTING HISTOGRAMS

A RooPlot of " $m(\mu^+\mu^-)$ "



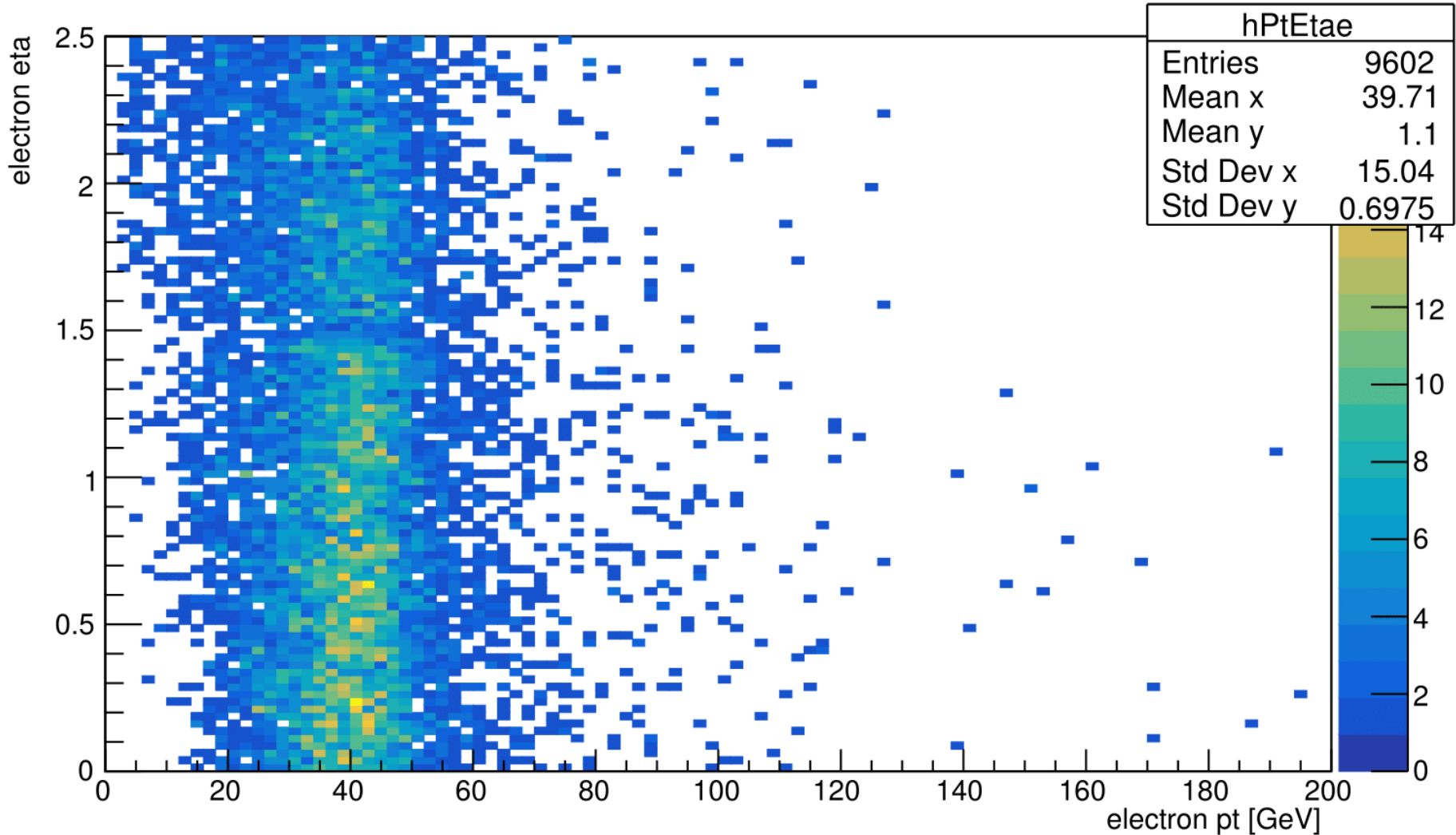
# FITTING HISTOGRAMS

A RooPlot of " $m(\mu^+\mu^-)$ "



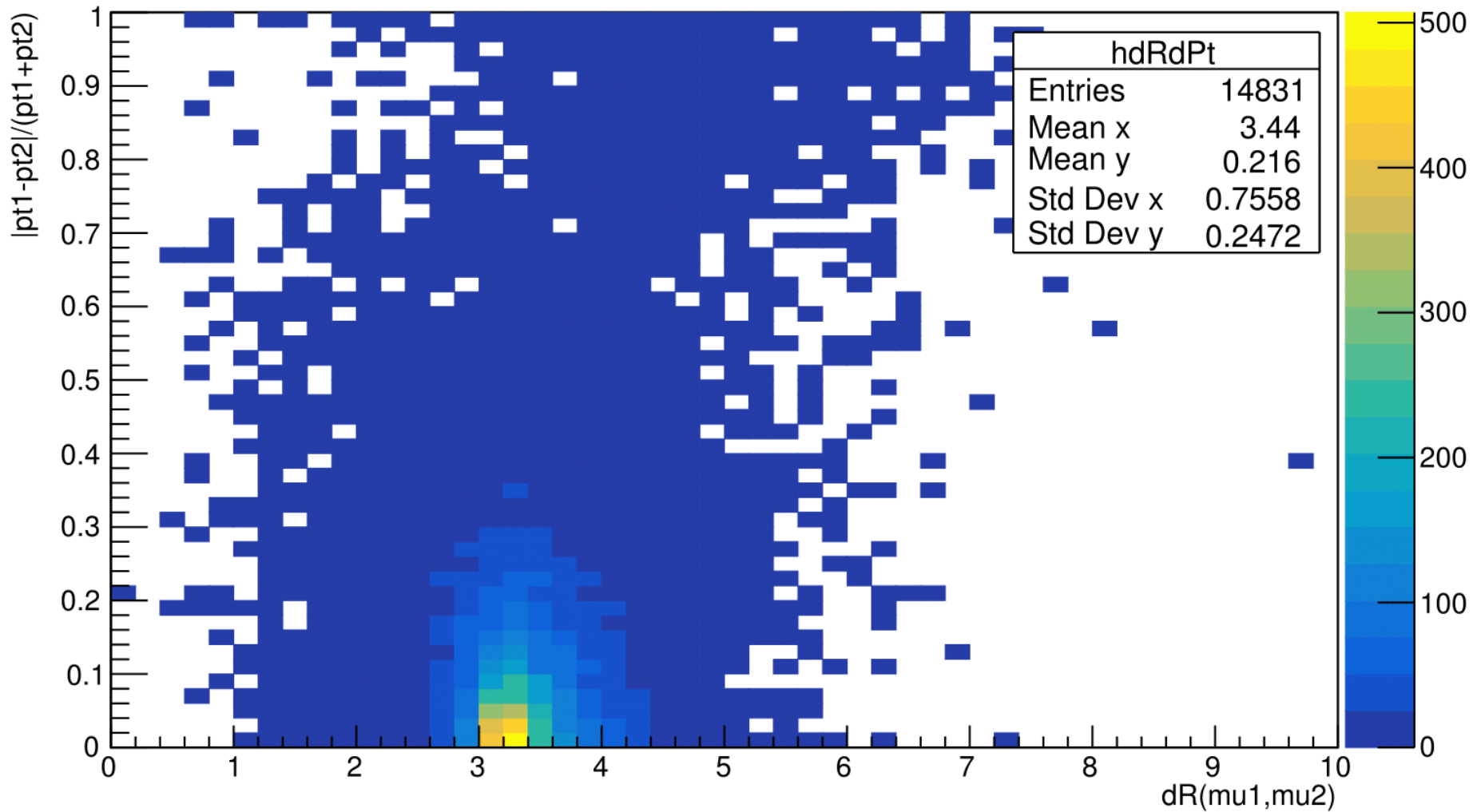
# 2D HISTOGRAMS

electron eta/Pt



# 2D HISTOGRAMS

dR vs dPt



# DIGITAL VISUALISATION

The screenshot displays the CMS Invariant Mass Dialog interface. At the top, the status bar shows 'Run 1', 'Lumi 1957', 'Event 391250', and the date 'Thu Jan 1 01:00:01 1970 CET'. The dialog title is 'Invariant Mass Dialog'. The main content area shows '2 items in selection' and a table of muon properties. The table has columns for px, py, pz, pT, and Collection. The data rows are:

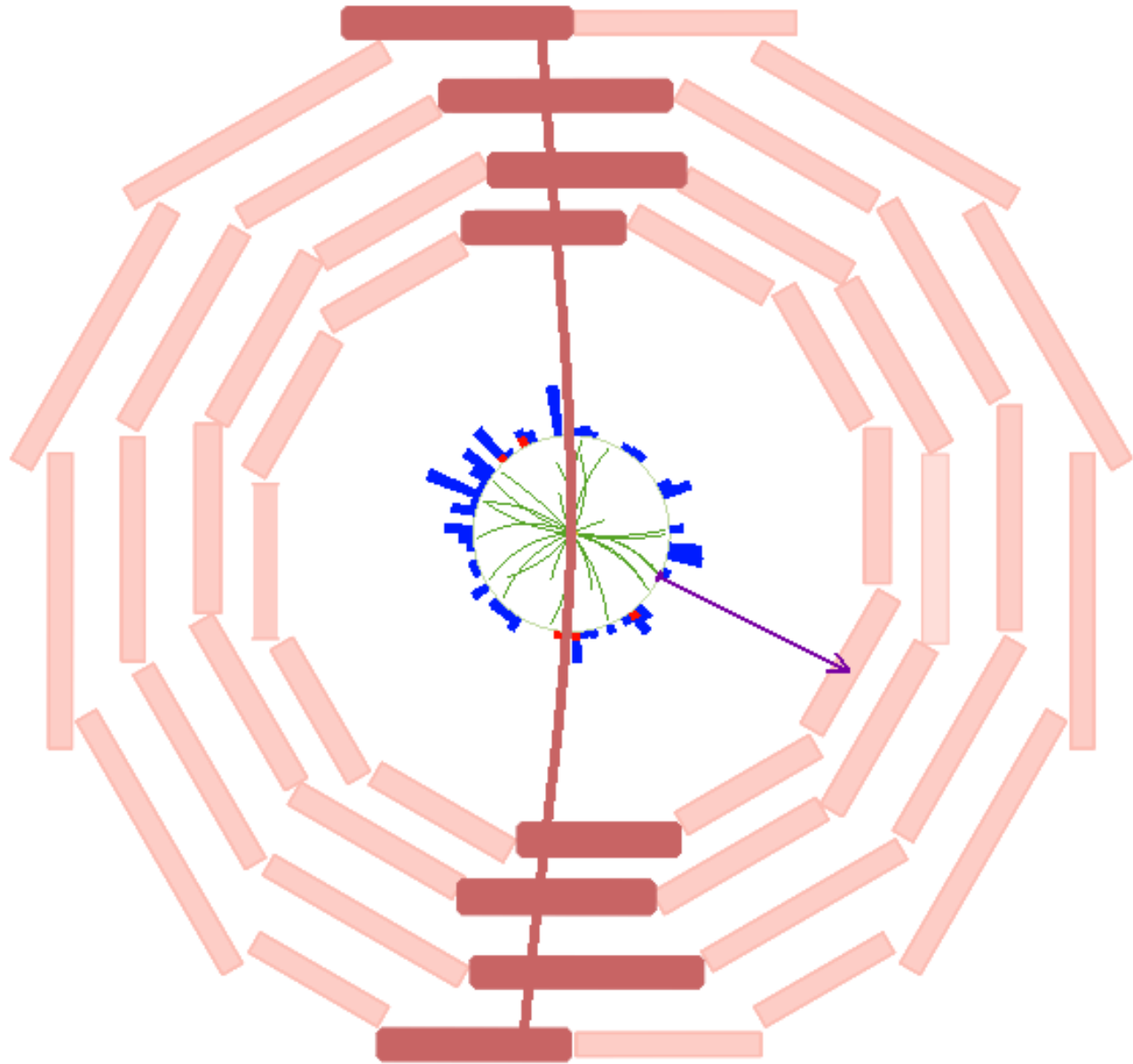
px	py	pz	pT	Collection
-0.046	+47.247	-8.168	47.247	Muons [0]
-1.328	-43.386	+8.887	43.406	Muons [1]
-1.374	+3.861	+0.719	4.098	Sum

Below the table, the following variables are calculated:

- m = 92.160
- mT = 90.560
- HT = 90.653
- deltaPhi = -3.1100
- deltaEta = -0.3754
- deltaR = 3.1326

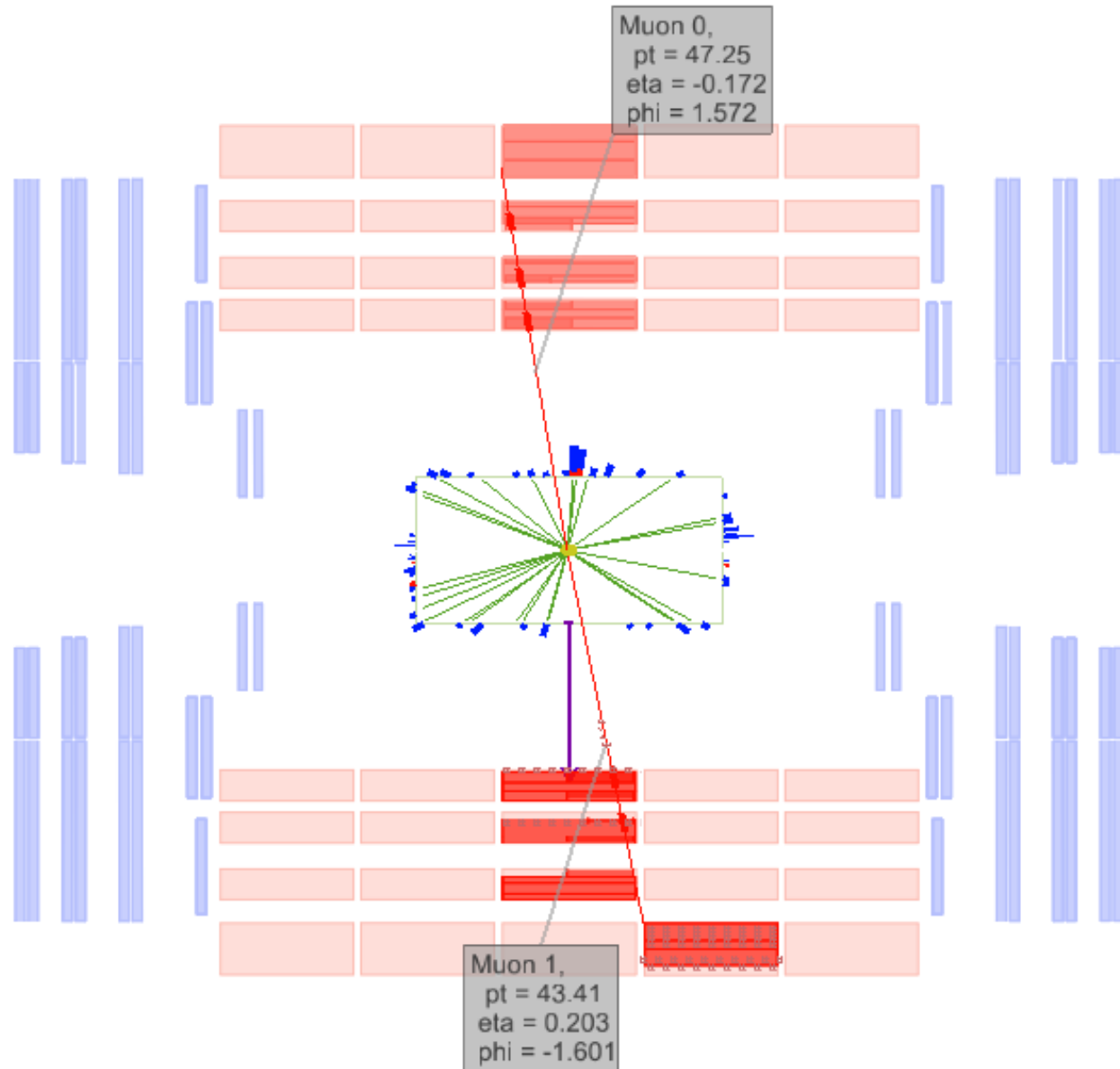
The value '92.160' for 'm' is circled in red. At the bottom of the dialog, there is a 'Calculate' button. The interface also includes a sidebar on the left with various selection criteria like 'Muon 0', 'Muon 1', 'Muon 2', 'Primary', 'Electron', 'ME', 'Photon', 'Track', and 'Pseudo'.

# DIGITAL VISUALISATION

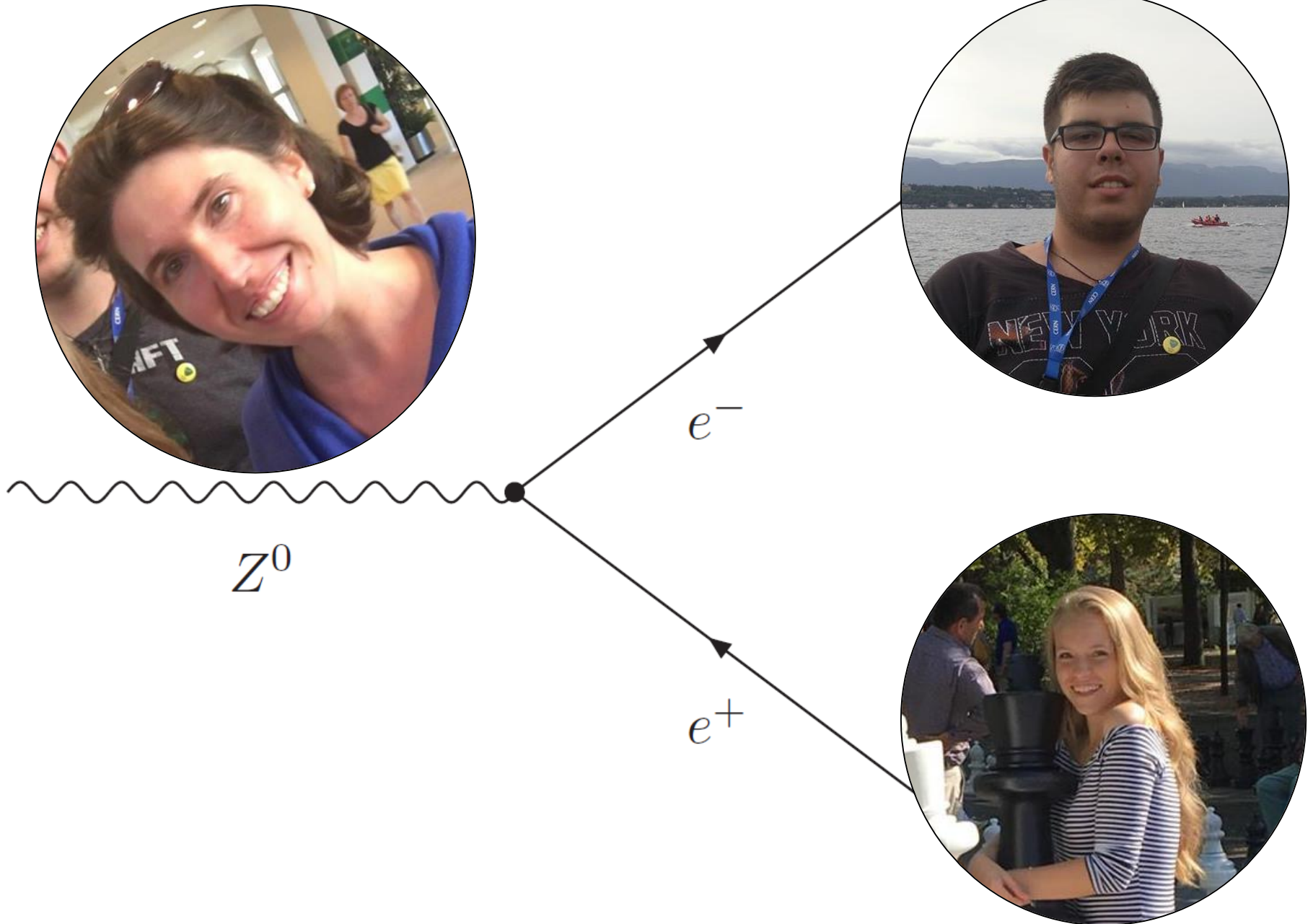




# DIGITAL VISUALISATION



# WHAT IS THE Z BOSON DECAY?





**THANK YOU!**