# RECONSTRUCTION OF W AND Z BOSONS MASS

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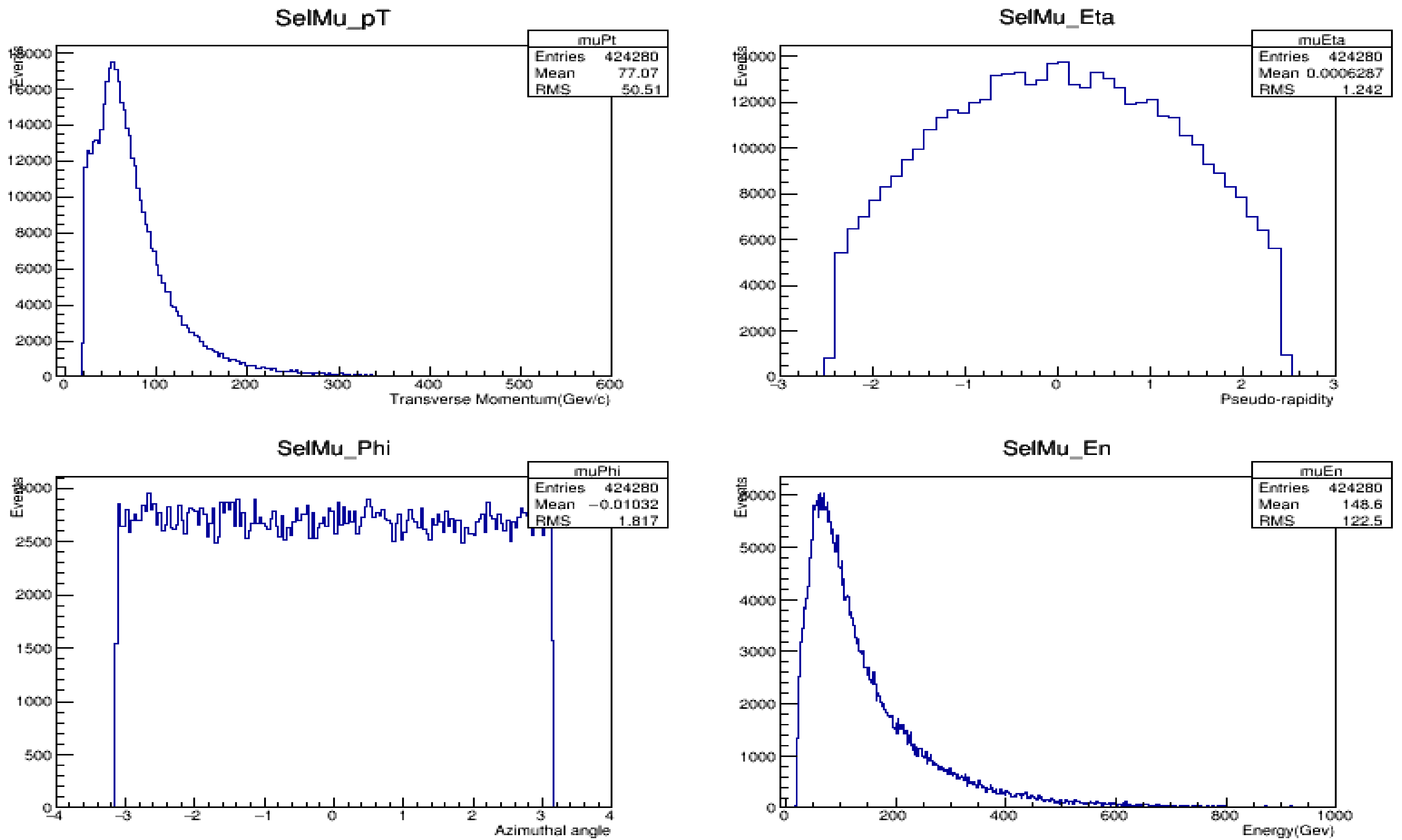
# READ AND ANALYZE ROOT FILE

```
// Header files
# include "TFile.h"
# include "TTree.h"
# include "TH1F.h"
# include "TBranch.h"
# include "TCanvas.h"
# include <iostream>
void SelMu()
{
// load root file
TFile *f = new TFile ("May26_2.root","READ");
//get the tree AnaTree from the file
TTree *t =(TTree*) f->Get("demo/AnaTree");
//Define variables
Float_t SelMu_pt, SelMu_eta, SelMu_phi, SelMu_en;
//Set the tree's branches to the local variables
t->SetBranchAddress("SelMu_pt", &SelMu_pt);
t->SetBranchAddress("SelMu_eta", &SelMu_eta);
t->SetBranchAddress("SelMu_phi", &SelMu_phi);
t->SetBranchAddress("SelMu_en", &SelMu_en);
//Declare histograms
TH1F *muPt =new TH1F("muPt", "SelMu_pT",200,-10,600);
TH1F *muEta =new TH1F("muEta", "SelMu_Eta",50,-3,3);
TH1F *muPhi =new TH1F("muPhi", "SelMu_Phi",200,-4,4);
TH1F *muEn =new TH1F("muEn", "SelMu_En",500,-10,1000);
//loop over each entry (event) in the tree
Long64_t nentries = t->GetEntries();
for(int i=0; i<nentries; i++)
{
t-> GetEntry(i);
//Filling Histograms
muPt->Fill(SelMu_pt);
```

```
//Filling Histograms
muPt->Fill(SelMu_pt);
muEta->Fill(SelMu_eta);
muPhi->Fill(SelMu_phi);
muEn->Fill(SelMu_en);
}
// Draw Histograms
TCanvas *c1 =new TCanvas("c1","Selected_Muons",800,600);
   c1->Divide(2,2);
   c1->cd(1);
   muPt->GetXaxis()->SetTitle("Transverse Momentum(Gev/c)");
   muPt->GetYaxis()->SetTitle("Events");
   muPt->Draw();

   c1->cd(2);
   muEta->GetXaxis()->SetTitle("Pseudo-rapidity");
   muEta->GetYaxis()->SetTitle("Events");
   muEta->Draw();

   c1->cd(3);
   muPhi->GetXaxis()->SetTitle("Azimuthal angle");
   muPhi->GetYaxis()->SetTitle("Events");
   muPhi->Draw();

   c1->cd(4);
   muEn->GetXaxis()->SetTitle("Energy(Gev)");
   muEn->GetYaxis()->SetTitle("Events");
   muEn->Draw();
}
```


SelMu_pT
muPt
Entries 424280
Mean 77.07
RMS 50.51
Events
Transverse Momentum(Gev/c)
SelMu_Eta
muEta
Entries 424280
Mean 0.0006287
RMS 1.242
Events
Pseudo-rapidity
SelMu_Phi
muPhi
Entries 424280
Mean −0.01032
RMS 1.817
Events
Azimuthal angle
SelMu_En
muEn
Entries 424280
Mean 148.6
RMS 122.5
Events
Energy(Gev)

# Pseudo-Rapidity, Azimuthal Angle and Transverse Momentum

**Pseudo-rapidity** η

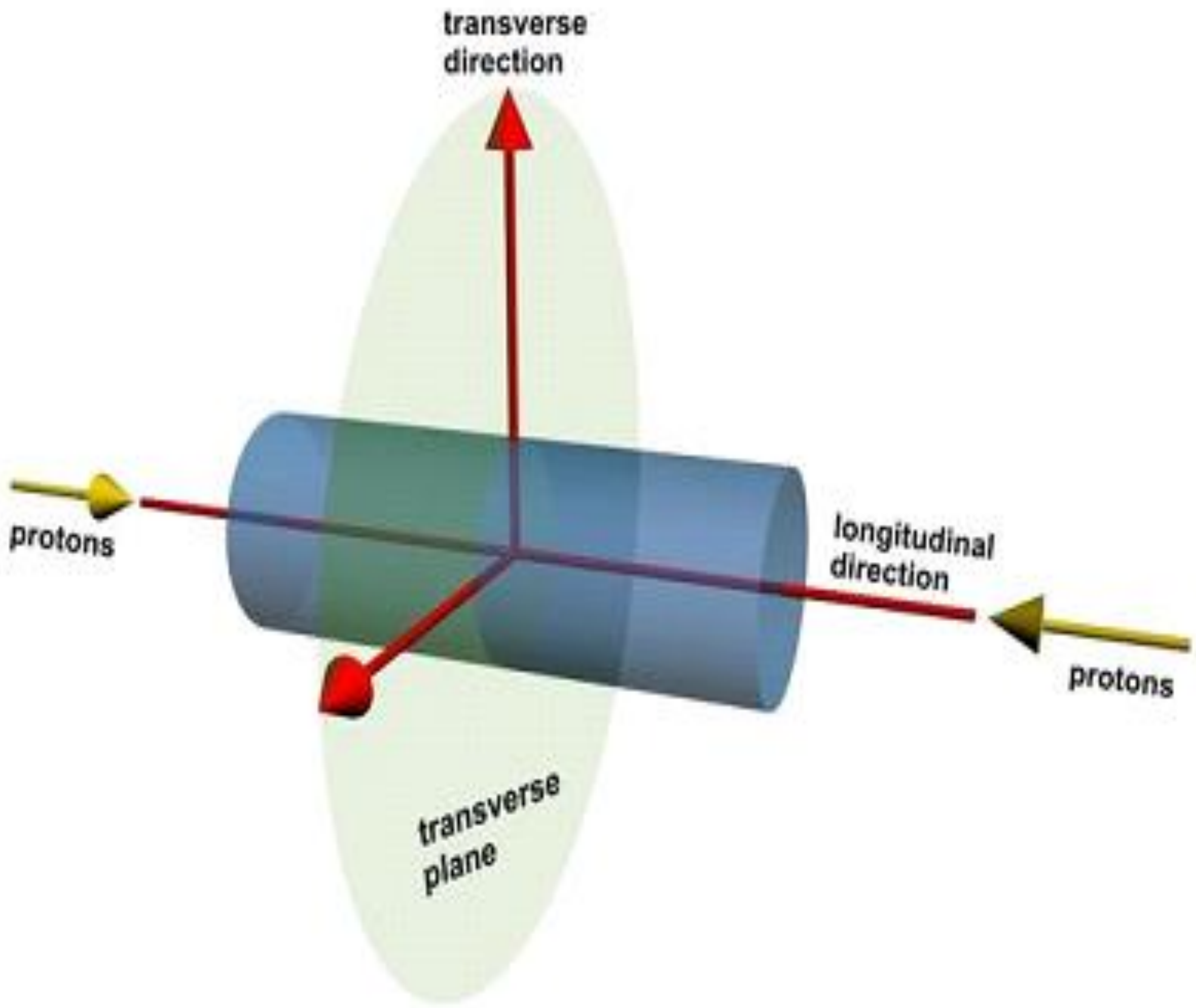
- $\eta$ is spatial co-ordinate describing the angle of particle relative to beam axis (z-axis). It is defined as
- $\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$
- Where, θ is the polar angle between the particle three momentum and the positive direction of beam axis

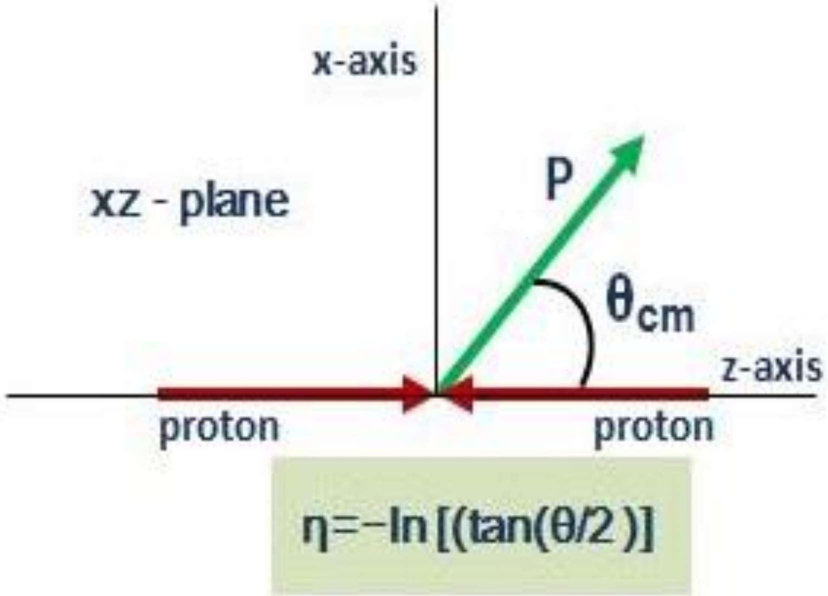
**Azimuthal angle**

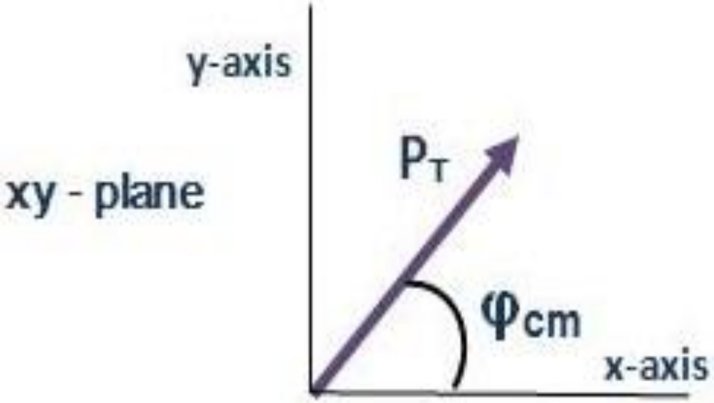
- φ is the angle between transverse momentum and x-axis.

**Transverse Momentum** Pt

- Pt is the momentum perpendicular to the path of the colliding particles.


transverse direction
protons
longitudinal direction
protons
transverse plane

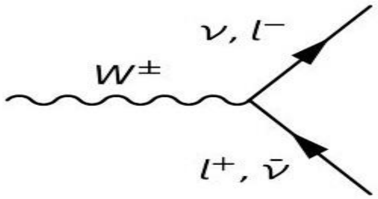

x-axis
xz - plane
P
$\theta_{cm}$
z-axis
proton
proton
$\eta = -\ln[(\tan(\theta/2))]$


y-axis
xy - plane
$P_T$
$\varphi_{cm}$
x-axis

# W and Z Bosons

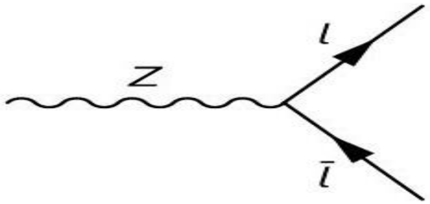
## W Boson

- Mediate weak interaction
- Electric charge $\pm 1$
- Mass 80.385±0.015 GeV/$c^2$
- Spin 1
- Half-life $3 \times 10^{-25}$ s
- Decay
- W boson decay into two quarks or lepton and its corresponding neutrino




## Z Boson

- Mediate weak interaction
- Neutral Particle
- Mass 91.1876±0.0021 GeV/$c^2$
- Spin 1
- Half-life $3 \times 10^{-25}$ s
- Decay
- Z boson decay into pair of quarks or leptons of the same flavor



# Invariant Mass of Z Boson

- In particle physics, the invariant mass is equal to the mass in rest frame of particle.

In Laboratory frame:

According to Law of Conservation of 4-Momentum,

$$P^{\mu} = P_1^{\mu} + P_2^{\mu}$$

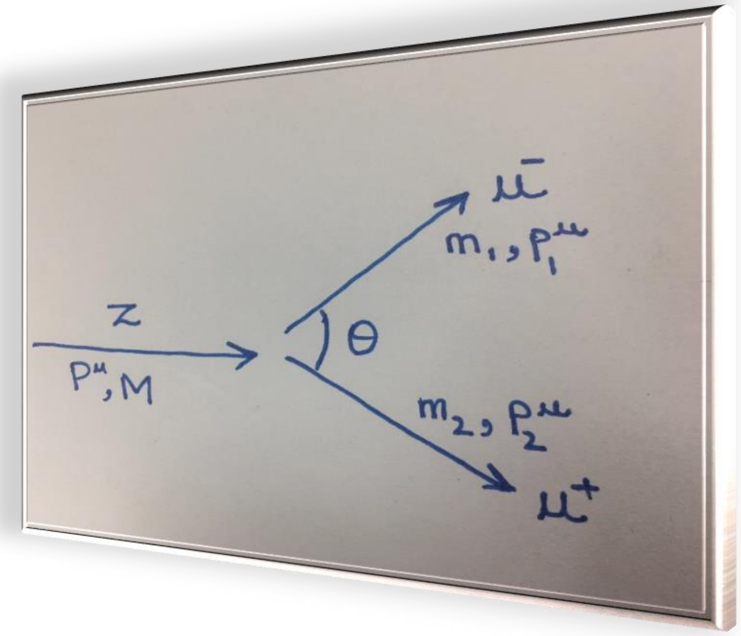
Taking Square on both sides, we have

$$(P^{\mu})^2 = (P_1^{\mu} + P_2^{\mu})^2$$

$$P^{\mu}.P_{\mu} = \left(P_1^{\mu} + P_2^{\mu}\right).(P_{1\mu} + P_{2\mu})$$

Where, $P^{\mu} = (E, 0)$, $P_1^{\mu} = (E_1, \vec{p}_1)$ and $P_2^{\mu} = (E_2, \vec{p}_2)$

$$E^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2$$



# Invariant Mass of Z Boson

$$E^2 = E_1^2 + E_2^2 + 2E_1E_2 - \vec{p}_1^2 - \vec{p}_2^2 - 2p_1p_2\cos\theta$$

Using Relativistic Energy-Momentum relation, $E^2 = |\vec{p}|^2 + m^2$

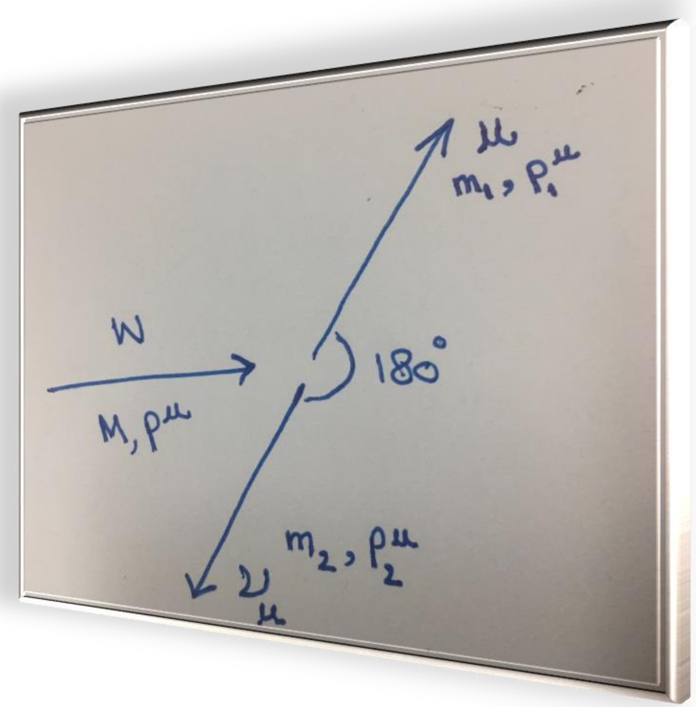
$$M^2 = \vec{p}_1^2 + m_1^2 + \vec{p}_2^2 + m_2^2 + 2E_1E_2 - \vec{p}_1^2 - \vec{p}_2^2 - 2p_1p_2\cos\theta$$

$$\boxed{M^2 = m_1^2 + m_2^2 + 2(E_1E_2 - p_1p_2\cos\theta)}$$

# Transverse Mass of W Boson

- Transverse mass used when one particle can not be detected directly but is only indicated by missing transverse momentum and energy.

According to Law of Conservation of 4-Momentum,




$$P^{\mu} = P_1^{\mu} + P_2^{\mu}$$

Taking Square on both sides, we have

$$(P^{\mu})^2 = (P_1^{\mu} + P_2^{\mu})^2$$

$$P^{\mu}.P_{\mu} = \left(P_1^{\mu} + P_2^{\mu}\right).(P_{1\mu} + P_{2\mu})$$

Where, $P^{\mu} = (E, 0)$, $P_1^{\mu} = (E_{1T}, \vec{p}_{1T})$ and $P_2^{\mu} = (E_{2T}, \vec{p}_{2T})$

# TRANSVERSE MASS OF W BOSON

$$E^2 = (E_{1T} + E_{2T})^2 - (\vec{p}_{1T} + \vec{p}_{2T})^2$$

$$E^2 = E_{1T}^2 + E_{2T}^2 + 2E_{1T}E_{2T} - \vec{p}_{1T}^{\,2} - \vec{p}_{2T}^{\,2} - 2p_{1T}p_{2T}\cos\theta$$

Using Relativistic Energy-Momentum relation, $E_T^2 = |\vec{p}_T|^2 + m^2$

$$M_T^2 = \vec{p}_{1T}^{\,2} + m_1^2 + \vec{p}_{2T}^{\,2} + m_2^2 + 2E_{1T}E_{2T} - \vec{p}_{1T}^{\,2} - \vec{p}_{2T}^{\,2} - 2p_{1T}p_{2T}\cos\theta$$

$$M_T^2 = m_1^2 + m_2^2 + 2(E_{1T}E_{2T} - p_{1T}p_{2T}\cos\theta)$$

For massless particles, $m_1 = m_2 = 0$ and $E_T = p_T$

$$\boxed{M^2 = 2E_{T1}E_{T2}(1 - \cos\theta)}$$

# LORENTZ VECTOR

- TLorentzVector is a general four-vector class, which can be used either for the description of position and time (x, y, z, t) or momentum and energy $(p_x, p_y, p_z, E)$.
- Motion of particles can be described with $(p_x, p_y, p_z, E)$ in Cartesian co-ordinates
- More common used: $(p_T, \eta, \phi, m)$ or $(p_T, \eta, \phi, E)$
- Conversion:

$$p_x = p_T \cos\phi$$
$$p_y = p_T \sin\phi$$
$$p_z = \frac{p_T}{\tan\theta} = p_T \sin h\eta$$
$$|p| = p_T \cos h\eta$$

# LORENTZ VECTOR

- Lorentz vector corresponding to final state particles

TLorentzVector muon;

$(p_x, p_y, p_z, E)$ + Several built in functions

- Using TLorentzVector

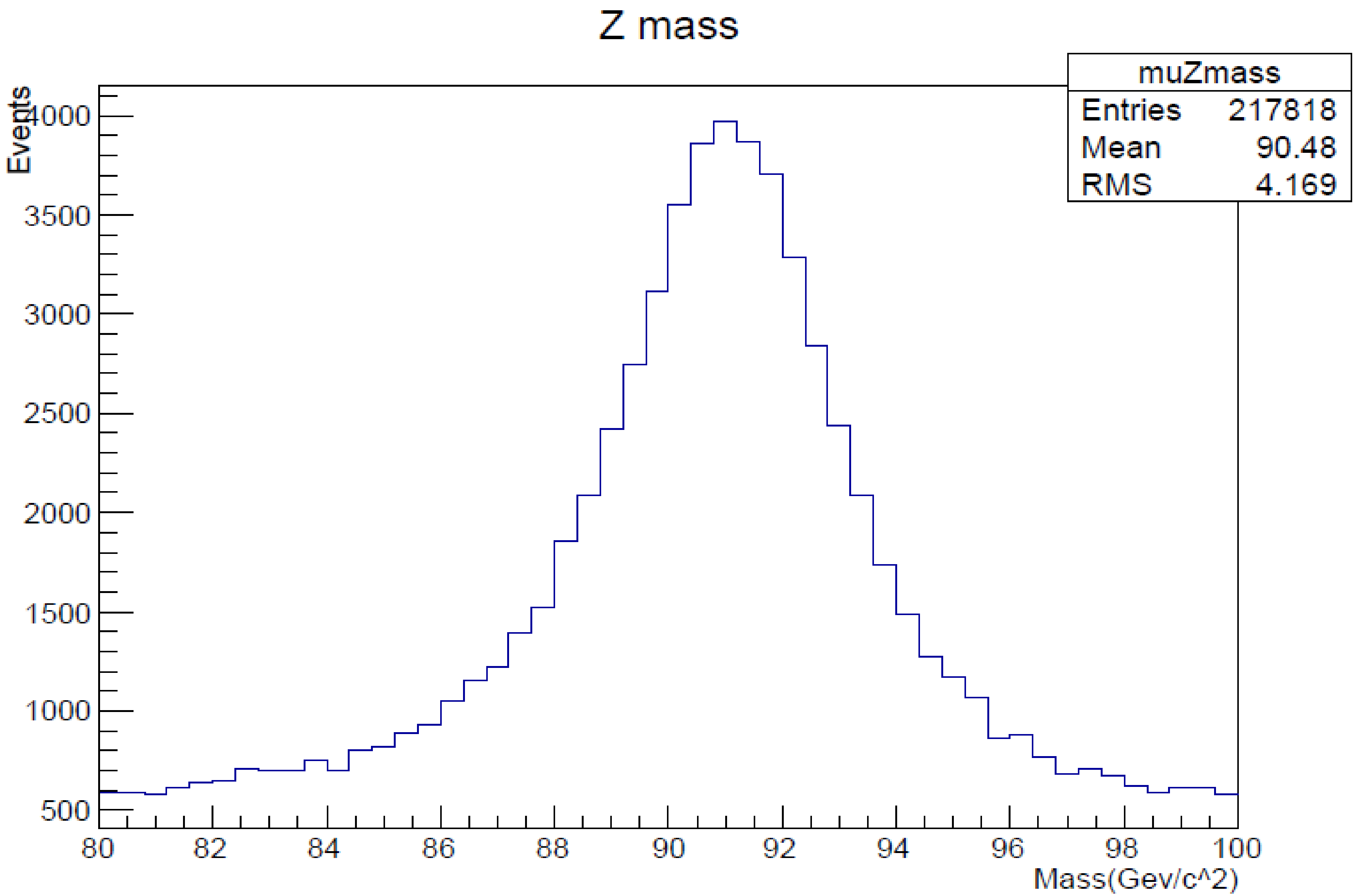
muon.SetPtEtaPhiE( );

Built-in function that defines $(p_x, p_y, p_z, E)$ from $(p_T, \eta, \phi, E)$

# RECONSTRUCTION OF Z MASS

```
# include "TFile.h"
# include "TTree.h"
# include "TCanvas.h"
# include "TH1F.h"
# include "TBranch.h"
# include <iostream>
# include "TLorentzVector.h"
void Zmass()
{
//Load the file
TFile *f = new TFile("May26_2.root","READ");
f->cd();
//get AnaTree from the file
TTree *t1 =(TTree* )f->Get("demo/AnaTree");

//create local variables for the branches
Int_t SelMu;
Float_t SelMu_pt[4],SelMu_eta[4],SelMu_phi[4],SelMu_en[4];

 TLorentzVector M1(0,0,0,0);
 TLorentzVector M2(0,0,0,0);

//set the branches to the local variables
t1->SetBranchAddress("SelMu_pt", &SelMu_pt);
t1->SetBranchAddress("SelMu_eta", &SelMu_eta);
t1->SetBranchAddress("SelMu_phi", &SelMu_phi);
t1->SetBranchAddress("SelMu_en", &SelMu_en);
t1->SetBranchAddress("SelMu", &SelMu);
```

```
//declare Histograms
TH1F *Zmass =new TH1F("muZmass", "Z mass",50,80,100);

//get entries
Long64_t nEntries= t1->GetEntries();

//loop over each entry n in the event
for (int i=0;i<nEntries;i++)
{
t1->GetEntry(i);

for (int m=0;m<SelMu;m++)
{
// by applying cuts
if (fabs(SelMu_pt[m]<20)) continue;
if (SelMu_en[m]<25) continue;
if (SelMu_eta[m]<-2) continue;

if (m==0) M1.SetPtEtaPhiE(fabs(SelMu_pt[m]),SelMu_eta[m],SelMu_phi[m],SelMu_en[m]);
if (m==1) M2.SetPtEtaPhiE(fabs(SelMu_pt[m]),SelMu_eta[m],SelMu_phi[m],SelMu_en[m]);

double ZM = (M1+M2).M();
Zmass->Fill(ZM);
}
}
Zmass->GetXaxis()->SetTitle("Mass(Gev/c^2)");
Zmass->GetYaxis()->SetTitle("Events");

Zmass->Draw();
}
```

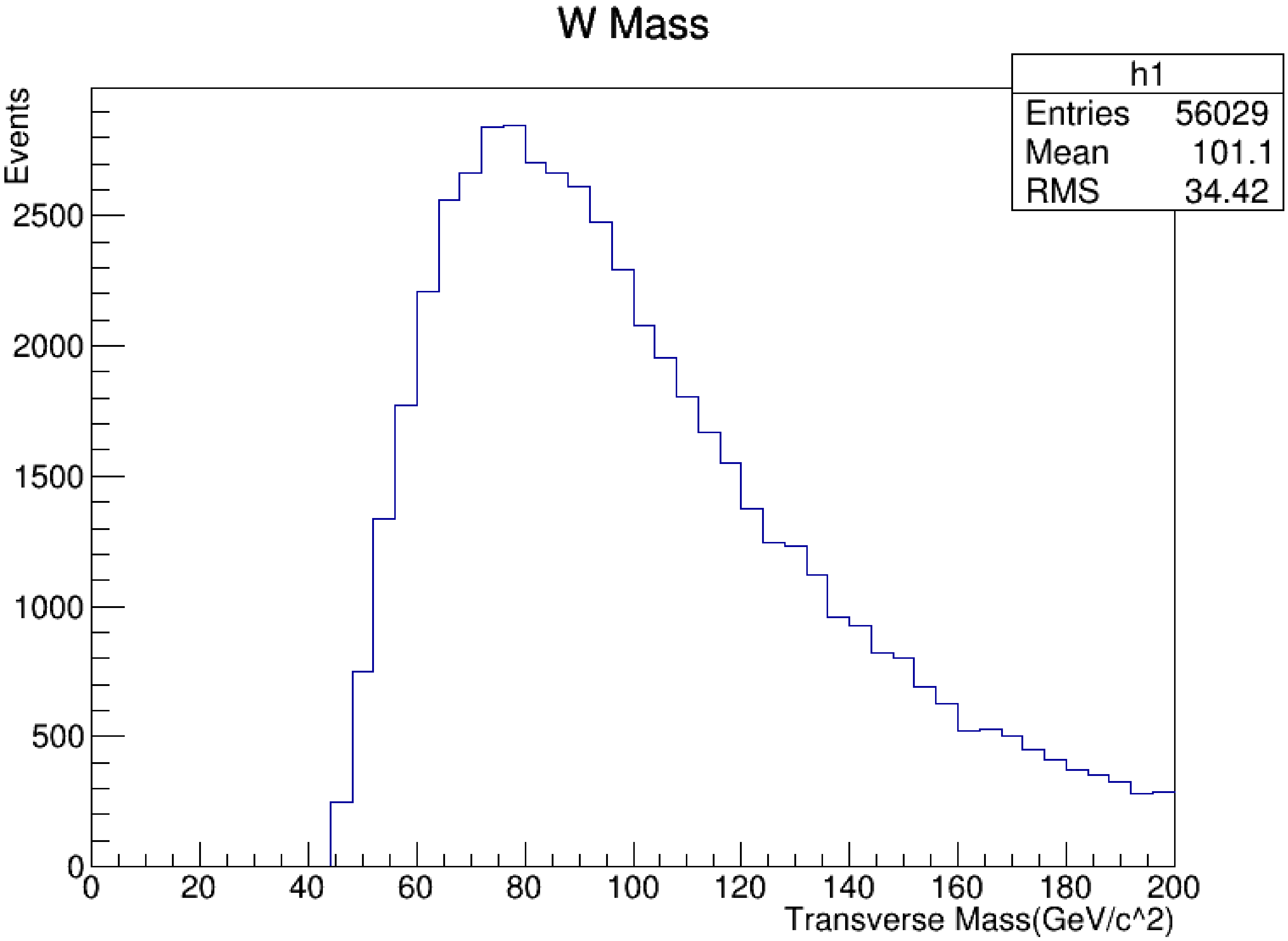


Z mass
muZmass
Entries 217818
Mean 90.48
RMS 4.169
Events
4000
3500
3000
2500
2000
1500
1000
500
80
82
84
86
88
90
92
94
96
98
100
Mass(Gev/c^2)

# RECONSTRUCTION OF W MASS

```cpp
# include "TFile.h"
# include "TTree.h"
# include "TCanvas.h"
# include "TH1F.h"
# include "TBranch.h"
# include <iostream>
# include "TLorentzVector.h"
void Wmass()
{
//Define Canvas
TCanvas *c1=new TCanvas("c1","Transverse Mass",800,600);
c1->cd();
//Load the file
TFile *f = new TFile("May26_2.root","READ");
f->cd();
//get AnaTree from the file
TTree *t= (TTree*)f->Get("demo/AnaTree");
//create local variables for the branches
TLorentzVector mu;
TLorentzVector neu;
Float_t met_pt,met_phi,SelMu_pt[4],SelMu_eta[4],SelMu_phi[4],SelMu_en[4];
Int_t SelMu;
//set the branches to the local variables
t->SetBranchAddress("met_phi", &met_phi);
t->SetBranchAddress("met_pt", &met_pt);
t->SetBranchAddress("SelMu", &SelMu);
t->SetBranchAddress("SelMu_pt", &SelMu_pt);
t->SetBranchAddress("SelMu_eta", &SelMu_eta);
t->SetBranchAddress("SelMu_phi", &SelMu_phi);
t->SetBranchAddress("SelMu_en", &SelMu_en);
//declare Histograms
TH1F *h1 = new TH1F("h1", "W Mass",50,0,200);
```

```cpp
//get entries
Long64_t nentries = t->GetEntries();
//loop over each entry n in the event
for (int i=0;i<nentries;i++)
{
t->GetEntry(i);
//by applying cut
if (met_pt<20) continue;
if (SelMu < 2) continue;
neu.SetPtEtaPhiM(met_pt,0,met_phi,0);
neu.SetPz(0);
neu.SetE(neu.Pt());

for(int m=0;m<SelMu;m++)
{
if (SelMu_en[m]<25) continue;
if (m==2) mu.SetPtEtaPhiE(fabs(SelMu_pt[m]),SelMu_eta[m],SelMu_phi[m],SelMu_en[m]);
}
Double_t TM = (neu+mu).Mt();
h1->Fill(TM);
}
h1->GetXaxis()->SetTitle("Transverse Mass(GeV/c^2)");
h1->GetYaxis()->SetTitle("Events");

// Draw histogram
h1->Draw();
}
```


W Mass
h1
Entries 56029
Mean 101.1
RMS 34.42
Events
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
140
160
180
200
Transverse Mass(GeV/c^2)

# CONCLUSION

- Read Events $\longrightarrow$ Identify final state particles and get their kinematics information
- Reconstruction algorithm is used to identify different short-lived particles which decay without being directly observed
- Missing energy and momentum are used to infers the presence of non-detectable particles


Thank you