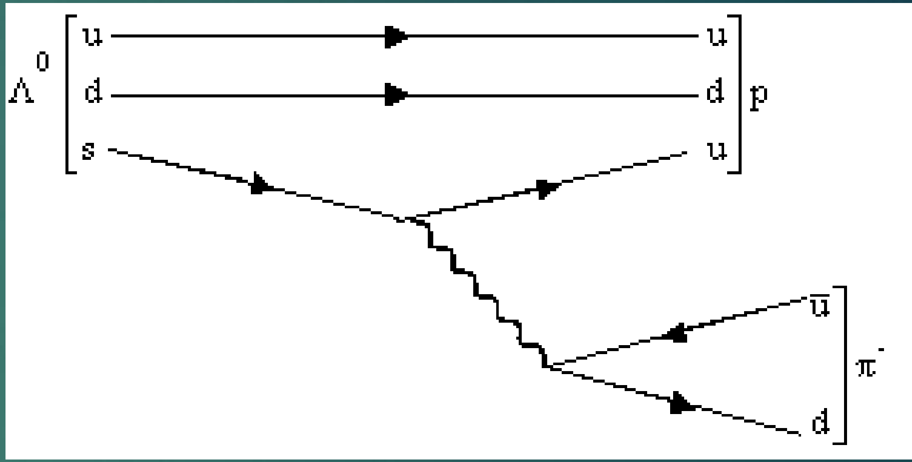
RELATIVISTIC RESONANCE DECAY

PHY 6860 – FINAL PROJECT

RESONANCE DECAY

- CONSIDER THE PROCESS $\Lambda^0 \rightarrow p^+ + \pi^-$
- $m_\Lambda = 1115.68 MeV/c^2$
- $m_p = 938.272 MeV/c^2$
- $m_\pi = 139.570 MeV/c^2$



- THE Λ PARTICLE WILL BE CALLED THE MOTHER PARTICLE
- PROTON AND PION WILL BE THE CHILD1 AND CHILD2 PARTICLES

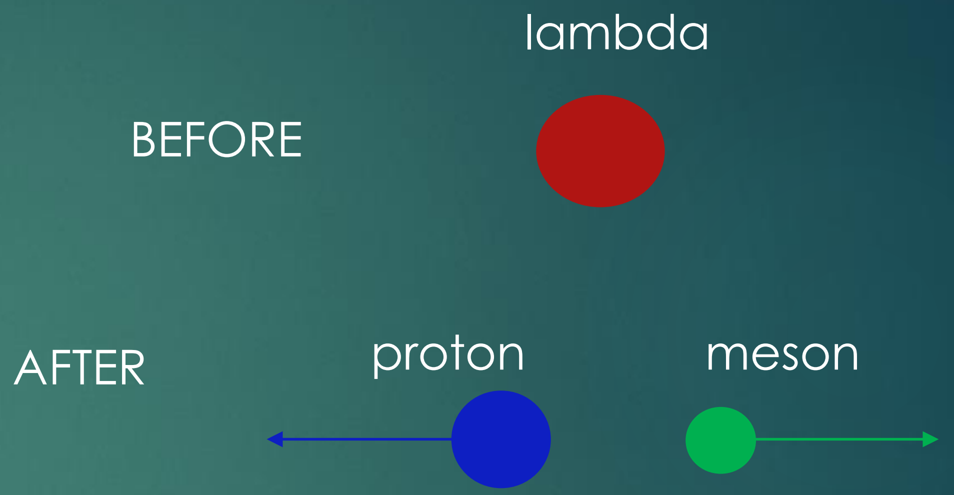
DECAY IN THE REST FRAME

REST FRAME OF MOTHER PARTICLE

LAMBDA -> $P_{lambda} = (m_{\Lambda}, 0,0,0)$

PROTON-> $P_{proton} = (E_1, 0,0, p_1)$

MESON-> $P_{meson} = (E_2, 0,0, -p_1)$



$$E_1 = \frac{m_{\Lambda}^2 + m_p^2 - m_{\pi}^2}{2m_{\Lambda}}$$

$$E_2 = m_{\Lambda} - E_1$$

$$p_1 = \sqrt{E_1^2 - m_p^2}$$

$$p_2 = -p_1$$

ISOTROPY OF THE DECAY IN REST FRAME

REST FRAME OF MOTHER PARTICLE

LAMBDA -> $P_{lambda} = (m_\Lambda, 0,0,0)$

PROTON-> $P_{proton} = (E_1, 0,0, p_1)$

MESON-> $P_{meson} = (E_2, 0,0, -p_1)$

Uniformly random $\theta\ and\ \phi$

$$p_{1x} = p1 \sin(\theta) \cos(\phi)$$
$$p_{1y} = p1 \sin(\theta) \sin(\phi)$$
$$p_{1z} = p1 \cos(\theta)$$

REST FRAME OF MOTHER PARTICLE

$$P_{proton} = (E_1, p_{1x}, p_{1y}, p_{1z})$$

$$P_{meson} = (E_2, -p_{1x}, -p_{1y}, -p_{1z})$$

BOOST IN LAB FRAME

LAB FRAME

$$P_{lambda} = (E, 0,0, p)$$

$$\gamma = \frac{E}{M}$$

$$P_{proton} = (E_{1lab}, p_{1x}, p_{1y}, p_{1zlab})$$

$$P_{meson} = (E_{2lab}, -p_{1x}, -p_{1y}, p_{2zlab})$$

$$\beta = \sqrt{1 - \frac{1}{\gamma^2}}$$

PROTON BOOST ->

$$E_{1lab} = \gamma(E_1 + \beta p_{1z})$$
$$p_{1zlab} = \gamma(p_{1z} + \beta E_1)$$

MESON BOOST ->

$$E_{2lab} = \gamma(E_2 + \beta p_{2z})$$
$$p_{2zlab} = \gamma(p_{2z} + \beta E_2)$$

MEASUREMENT IN LAB FRAME

REST FRAME OF MOTHER

$$P_{TOTREST} = (m_\Lambda, 0,0,0)$$

LAB FRAME

$$P_{proton} = (E_{1lab}, p_{1x}, p_{1y}, p_{1zlab})$$

$$P_{meson} = (E_{2lab}, -p_{1x}, -p_{1y}, p_{2zlab})$$

$$P_{TOTLAB} = (E_{1lab} + E_{2lab}, 0,0, p_{1zlab} + p_{2zlab})$$

$$P_{TOTREST} \cdot P_{TOTREST} = m_\Lambda^2$$

Invariance of 4-vector length

$$P_{TOTLAB} \cdot P_{TOTLAB} = P_{TOTREST} \cdot P_{TOTREST} = m_\Lambda^2$$

OUR FRAMEWORK

Lib directory

<u>vecLor class</u>

vecLor.h
vecLor .c

<u>event class</u>

event.h
event.c

Macros directory

<u>eventTest.C macro</u>

<u>eventTestRead.C macro</u>

```
#include "TLorentzVector.h"
#include <cmath>

//definition of our vecLor class
class vecLor : public TLorentzVector
```

vecLor inherits all the functionalities from root class TLorentzVector.h

vecLor.c

Includes vecLor.h

Important functionalities:

Vector addition

randomDirection(p,theta,phi)

boost(double gamma)

Length()

event.c

includes event.h

Variables:
double mother, child1 etc etc..

Setter functions:
Setmother(mass) etc etc..

Getter functions:
double GetMother() etc etc…

generateEvent(){

Tasks:

i. Introduce uncorrelated particles
ii. Assign_energy_to_Child1&2_E1,E2
iii. Calculate_momentum_for_chil1&2_p1,P2
iv. Create_4momentum_vecLor_class
v. Assign_randomAngles_theta,phi
vi. Boost_to_labFrame_along_Z
vii. Introduce_errors_in_labFrame
viii. Add_child1&child2
ix. Calculate_length_of_tracks

}

eventTest.C macro

Called functions:

Tfile()
Set mother(mass)
Set child1(mass)
Set child2(mass)
Set Elab(energy)
generateEvent()
Do sort()
Print Tracks()

Root output file

eventTestRead.C macro

Called functions:

TH1D histogram
Fit()

Assigning energies and momenta

Task (i)

Introduce Uncorrelated particles:

```
EUncorrelated=gRandom->Uniform(lightestChild,2*(this->GetMother()));

vecLor *vUncorrelated=new vecLor(EUncorrelated,0,0,0);
```

Tasks (ii,iii)

Energy of child 1 (E1):

```
E1=((this->GetMother())*(this->GetMother())+(this->GetChild1())*(this->GetChild1())-(this->GetChild2())*(this->GetChild2()))/(2*(this->GetMother()));
```

Energy of child 2 (E2):

```
E2=(this->GetMother())-E1;
```

Momentum of child 1 (p1):

```
p1=sqrt(E1*E1-(this->GetChild1())*(this->GetChild1()));
```

Momentum of child 2 (p2):

```
p2=-p1;
```

Defining 4 –momentum using vecLor class

Tasks (iv)

```
//defining 4-momentum of child1 and child2

vecLor *v1=new vecLor(E1,0,0,p1);
vecLor *v2=new vecLor(E2,0,0,p2);
```

Child 1

Child 2

Energy p_x p_y p_z

Randomizing momentum direction and setting x,y and z components

Tasks (v)

```
//RANDOM DIRECTION
void vecLor::randomDirection(double p1,double theta,double phi)
{

        double p11=p1*sin(theta)*cos(phi);
        double p21=p1*sin(theta)*sin(phi);
        double p31=p1*cos(theta);

        SetP1(p11);
        SetP2(p21);
        SetP3(p31);

}
```

P_x

P_y

P_z

Boosting child 1 and 2 vectors to lab frame in z direction

Defining gamma :

```
Double_t gamma=(this->GetElab())/(this->GetMother());
```

Using Lorentz transformation:

```
//BOOST IN THE Z DIRECTION
void vecLor::boost(double gamma)
{
        double beta=sqrt(1-(1/(gamma*gamma)));

          double Eboost=gamma*(p0+beta*p1);
          double p3boost=gamma*(p1+beta*p0);

          SetP0(Eboost);
          SetP3(p3boost);

}
```

Tasks (vi)

Adding energy uncertainties in LAB frame

Tasks (vii)

```
//introducing uncertainty on the energies in LAB frame

        Double_t deltaE1=gRandom->Gaus(0,(this->GetDeltaEnergy()));
        Double_t deltaE2=gRandom->Gaus(0,(this->GetDeltaEnergy()));
        v1->SetP0((v1->GetP0())+deltaE1);
        v2->SetP0((v2->GetP0())+deltaE2);
```

Tasks (viii)

```
//adding the two 4-momenta
        vecLor *v=new vecLor();
        *v=(*v1)+(*v2);
```

Tasks (ix)

```
double Length() const {return sqrt(p0*p0-p1*p1-p2*p2-p3*p3);}
```

User interface macro (eventTest.C)

The eventTest.C macro only set the parameters of the analysis and save the output file.

```
 // distribute the number of tracks per event according to a poisson!!!
 Int_t nTracksPerEvent=gRandom->Poisson(meanTracksPerEvent);

 // Set mother
ev->SetMother(lambda);
// Set child1
ev->SetChild1(proton);
// Set child2
ev->SetChild2(piMeson);
// Set Energy lab frame
ev->SetElab(Elab);
// Set franction uncorrelated
ev->SetFraction(fractionUncorrelated);
// Set uncertainty energy
ev->SetDeltaEnergy(deltaEnergy);
// Set number of tracks per event
ev->SetTracksPerEvent(nTracksPerEvent);


 //GENERATE EVENTS
 ev->generateEvent();

 // sort them by length!!!
 ev->DoSort();

 t1->Fill();
```

Data analysis macro (eventTestRead.C)

The Data analysis macro opens the output file and fits the histogram that contains the length measurements.

```
TCanvas *c2=new TCanvas("c2","#2",800,600);

  hVecLength->GetXaxis()->SetTitle("Mass (GeV)");
  hVecLength->GetYaxis()->SetTitle("Number of measurement");
  hVecLength->GetYaxis()->SetTitleOffset(1.4);
  hVecLength->GetXaxis()->CenterTitle();
  hVecLength->GetYaxis()->CenterTitle();

 Double_t par[4];

 TF1 *total = new TF1("total","gaus(0)+[3]",0,2);

 total->SetParameters(1,1,1,0.1);
 hVecLength->Fit(total,"R+");

  hVecLength->DrawCopy();
```

RESULTS

Output

Event number:

Track lengths for 24 vectors

File Edit View Search Terminal Help

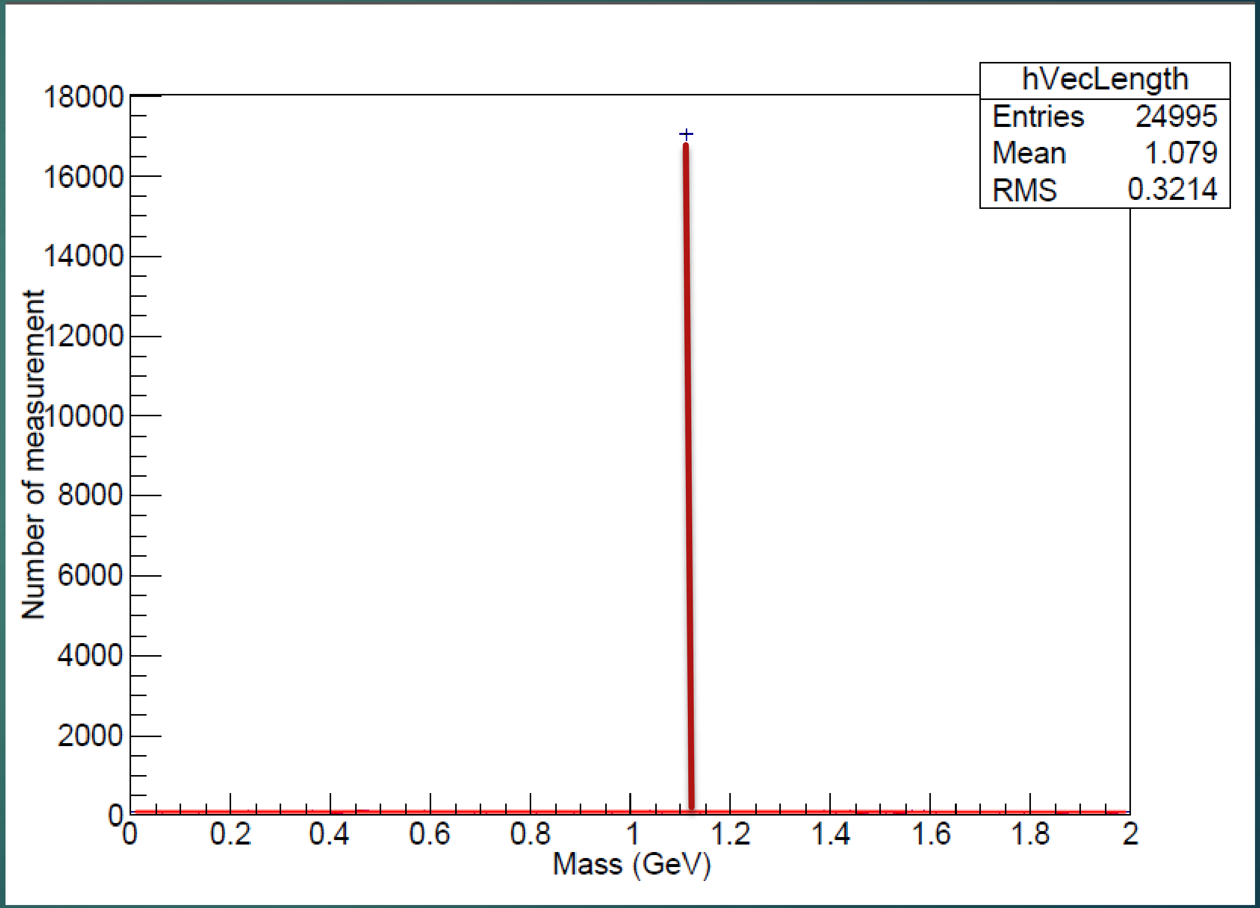
```
Event Class:
Event # = 8
# vecLor = 24
Track 0 with length 2.08587
Track 1 with length 1.79498
Track 2 with length 1.66701
Track 3 with length 1.66542
Track 4 with length 1.4794
Track 5 with length 1.36665
Track 6 with length 1.28225
Track 7 with length 1.27982
Track 8 with length 1.27145
Track 9 with length 1.23493
Track 10 with length 1.22258
Track 11 with length 1.16802
Track 12 with length 1.16787
Track 13 with length 1.14846
Track 14 with length 1.14695
Track 15 with length 1.10586
Track 16 with length 1.08366
Track 17 with length 1.07218
Track 18 with length 1.05925
Track 19 with length 1.01826
Track 20 with length 0.677356
Track 21 with length 0.223308
Track 22 with length 0.207758
Track 23 with length 0.11934

Event Class:
Event # = 9
# vecLor = 23
```

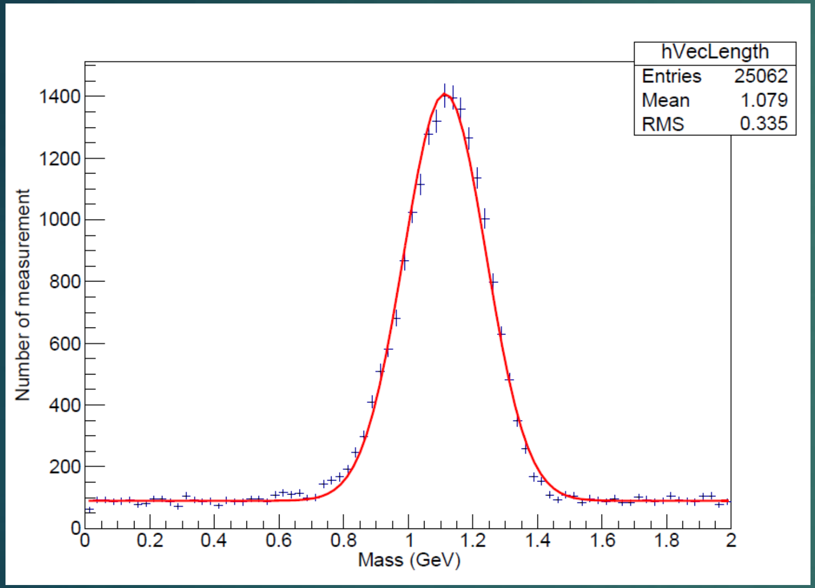
Number of vectors for this event

Uncertainty in the energy: 0 GeV

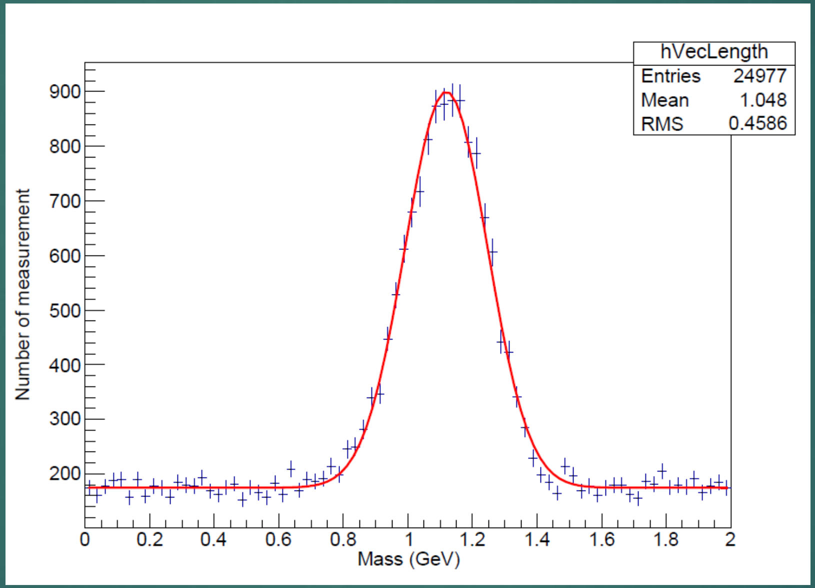
With zero uncertainty in the particle energy measurement, we get a delta function centered on the mother Mass.



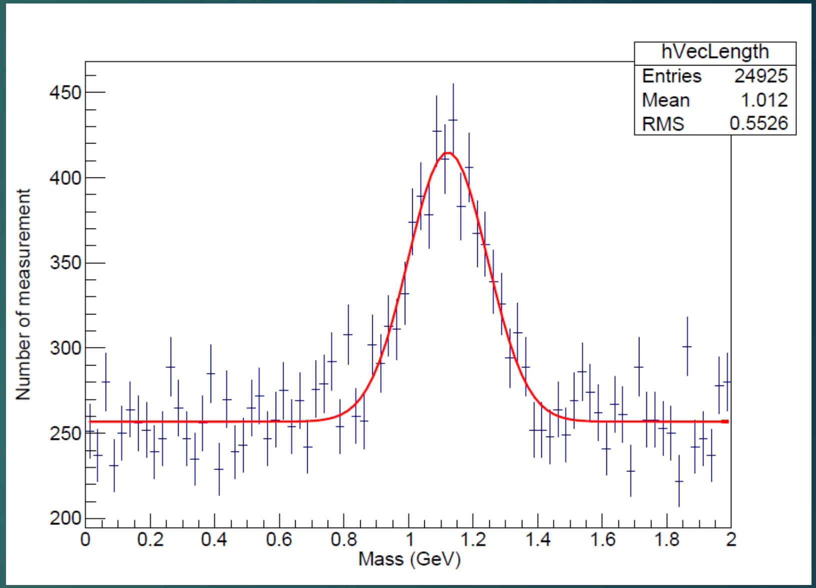
Uncertainty in the energy: 0.01 GeV



30 % of uncorrelated events

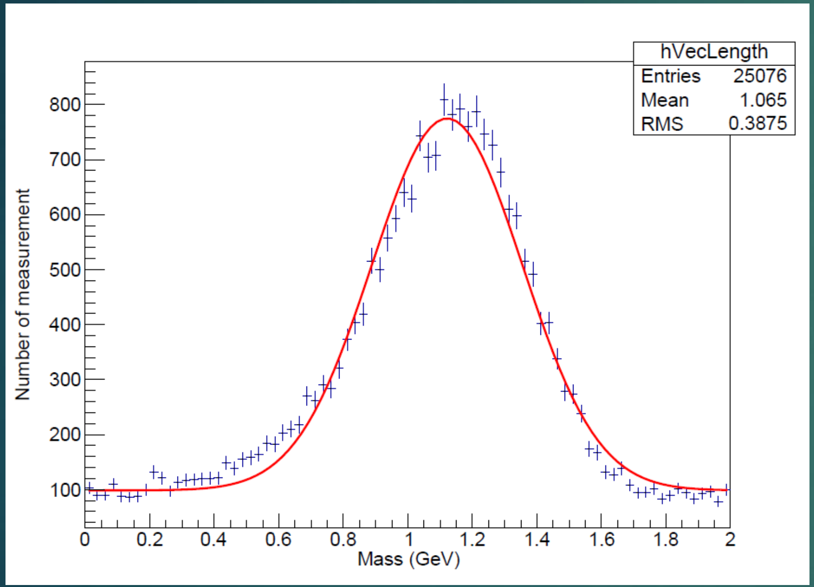


60 % of uncorrelated events

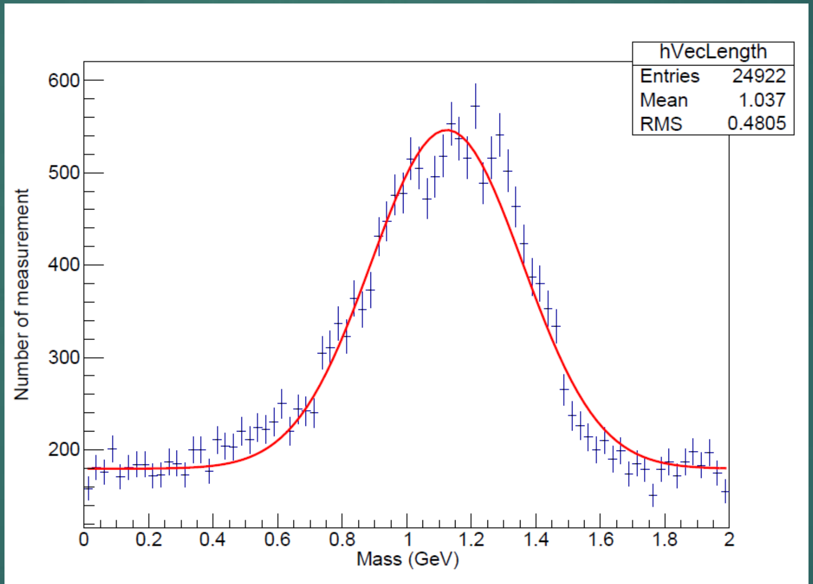


90 % of uncorrelated events

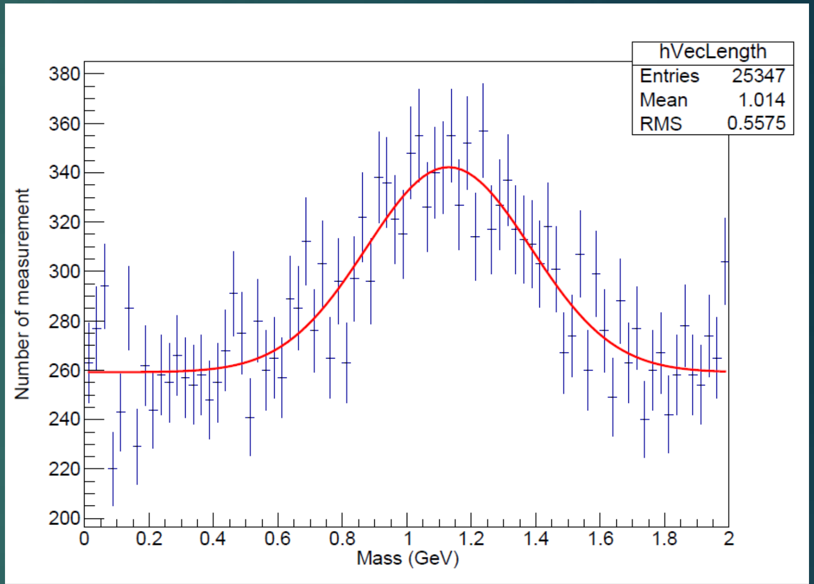
Uncertainty in the energy: 0.02 GeV



30 % of uncorrelated events

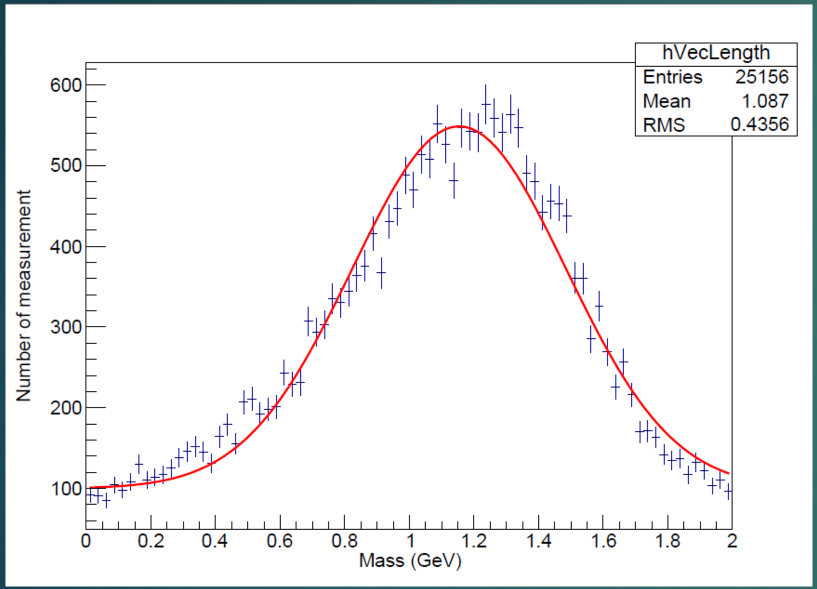


60 % of uncorrelated events

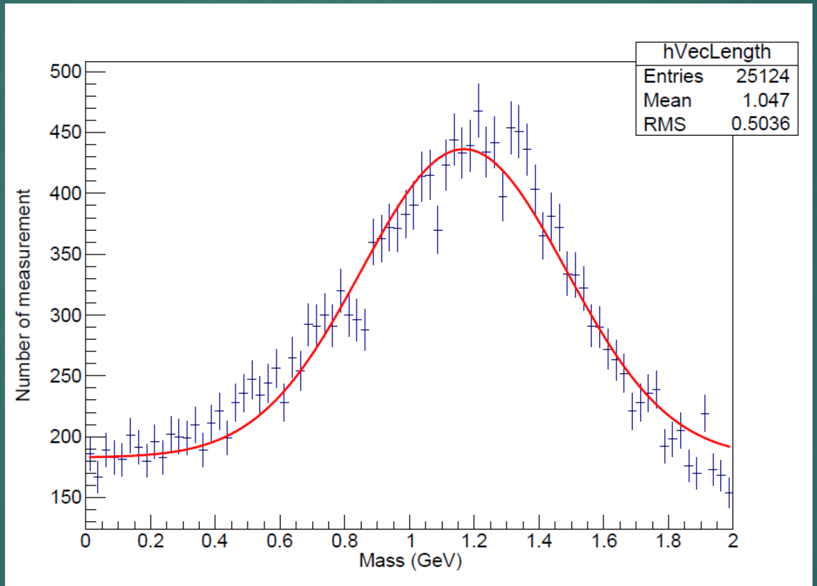


90 % of uncorrelated events

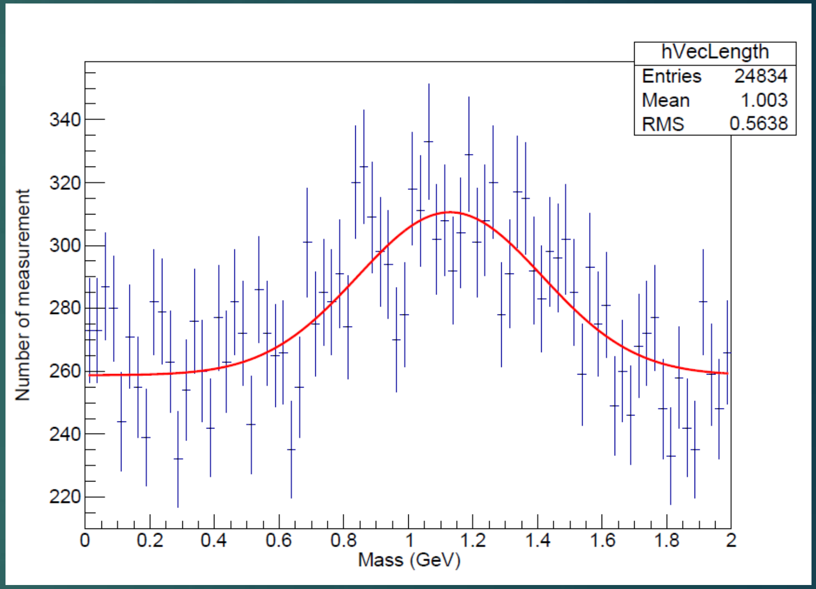
Uncertainty in the energy: 0.03 GeV



30 % of uncorrelated events



60 % of uncorrelated events



90 % of uncorrelated events


thank you!