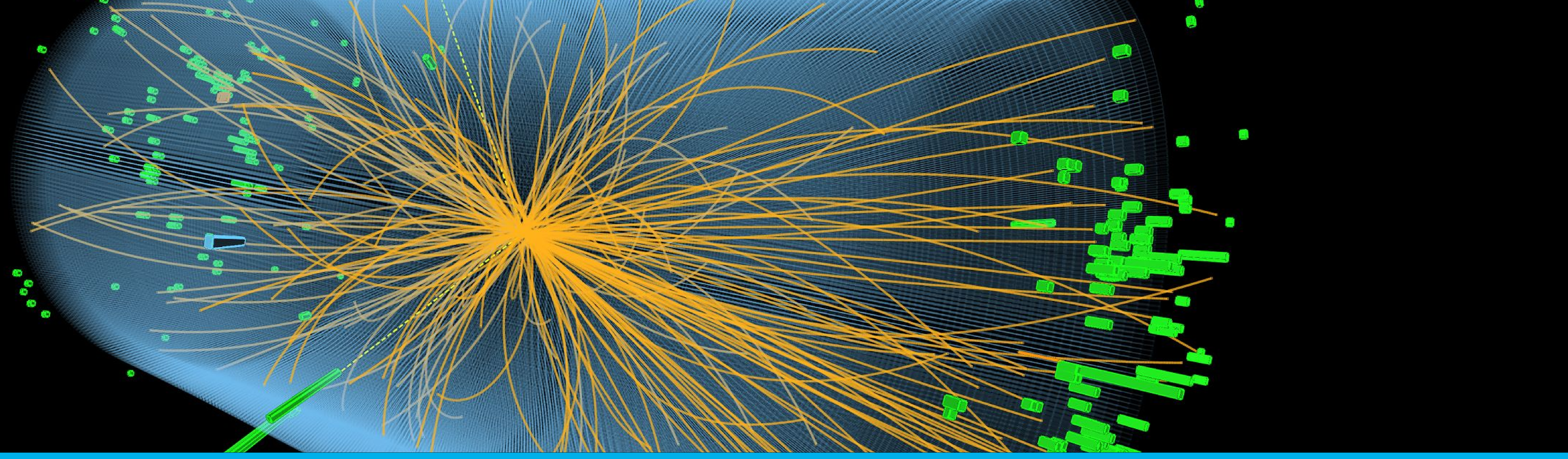

Open Data

S'Cool Lab Research Group

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Problem

- We examined the decay of a Z particle into either electron/positron pair or muon/antimuon pair.
- The aim was to probe the precision of the measurements
- The event samples were divided into categories as a function of the transverse momentum p_T of the decay products.

Hypothesis

- Muons' p_T is calculated from the curvature of their trajectory, which is determined more accurately when the radius is small, therefore when the muons have low energy. Thus we expect the peak of low energy muons to be narrower.
- Electrons' energy is measured in the electromagnetic calorimeter based on statistical data collection, therefore it is more accurate when the electrons have high energy. Thus we expect the peak of low energy electrons to be wider.

Project Overview

- Our aim was to analyse real data from the CMS detector, using Python as our programming language, and Jupyter Notebook as an interface.
- We have been working on opendata files ([1] & [2]) describing Z $\rightarrow e^- / e^+$ or Z $\rightarrow \mu^- / \mu^+$ decay.
- We plotted the histograms of the invariant mass of the decay pairs and focused on the region corresponding to the mass of the Z boson, around 91.2 GeV/c^2 [3] .
- From there, we studied the measurement precision of the CMS detector by dividing the sample in different sections based on the properties of decay particles.
- We sorted the muons based on their transverse momentum (p_T) : for muons, 'low p_T' is lower than 39 GeV/c, and 'high p_T' is higher. For electrons, 'low p_T' is lower than 40 GeV/c. We set both of these numbers to obtain two samples (high p_T, low p_T) of the same size.

Theoretical Background

Invariant mass M

- The overall energy stored in the system of particles, and it is conserved.
- Except for the commonly used formula*, we use its modified version, which uses variables directly available in the file**

Pseudorapidity η

- A spacial coordinate describing describing the angle of a particle to the beam axis.
- It is defined as a function of θ,*** which is the angle between the beamline and the trajectory of the particle

Transverse momentum p_T

- The momentum in the plane perpendicular to the beam. It is the sum of the momenta in x and y coordinates (z being the beam).****

$*M = \sqrt{(E_1+E_2)^2 - (\vec{p_1}+\vec{p_2})^2}$

$**M = \sqrt{2p_{T1}p_{T2}(\cosh(\eta_1-\eta_2)-\cos(\phi_1-\phi_2))}$

$***\eta = -\ln\tan(\frac{\theta}{2})$

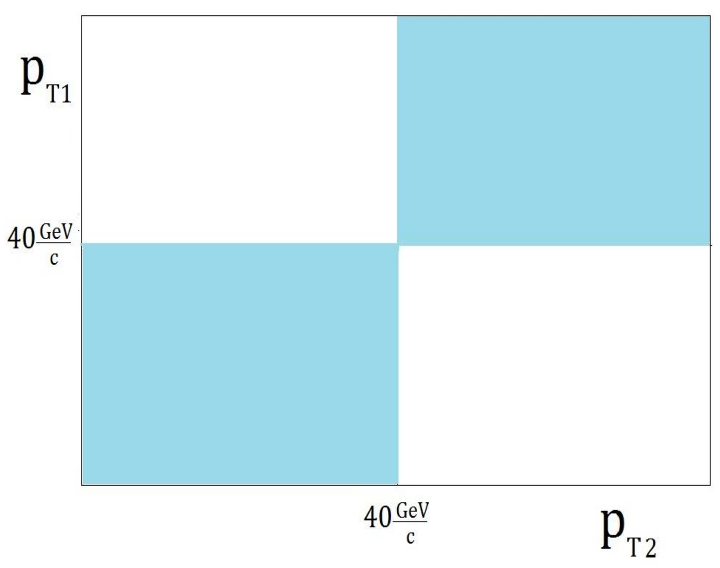
$****\vec{p_t} = \vec{p_x} + \vec{p_y}$

Data Selection

In order to select a given range in the invariant mass, and to distinguish between high and low |η| values, or high and low p_T values, we used the following codes:

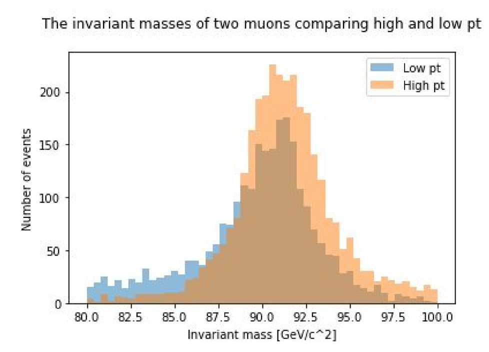
im_1 = dataset[(dataset.M>82.5)&(dataset.M<100)&(dataset.pt1>10)&(dataset.pt2>10)]
im_2 = dataset[(dataset.M>82.5)&(dataset.M<100)&(dataset.eta1>10)&(dataset.eta2>10)]

Unfortunately, this selection is not comprehensive: as one may observe in the diagram to the right, our selection leaves out a good portion of our data : when p_T1 > 40 GeV/c and p_T2 < 40 GeV/c, or when p_T1 < 40 GeV/c and p_T2 > 40 GeV/c.
This means that, by having a more precise selection on high (or low) values, we ignore a part of the experimental results. We tried other methods, which involved overlapping, but this one seems the most consistent.



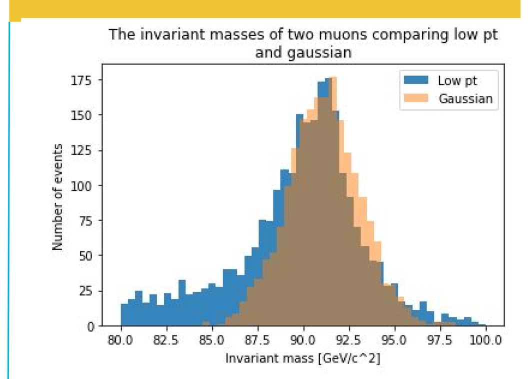
Muon Decay

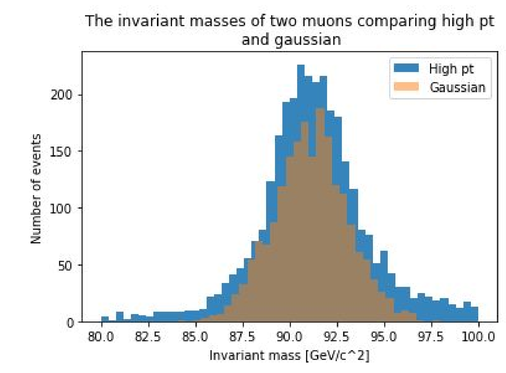
Method no.1



Narrower peak : low p_T
→ use them to measure the original particle's mass
→ obtain a more precise result

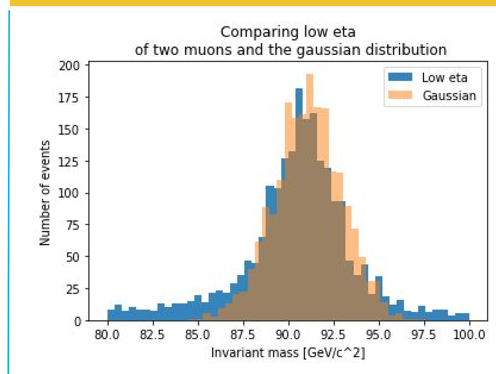
Method no.2

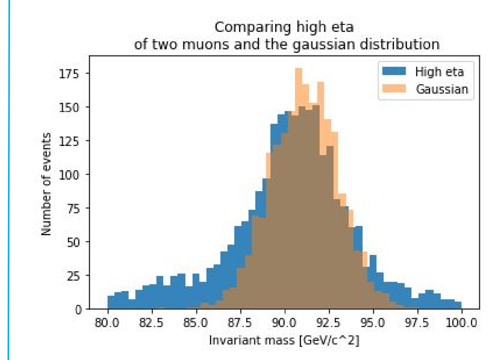




At lower p_T
→ narrower distribution
→ easier observation
According to our estimates based on Gaussian distribution :
→ standard deviation = 2 Gev/c^2

Method no.3



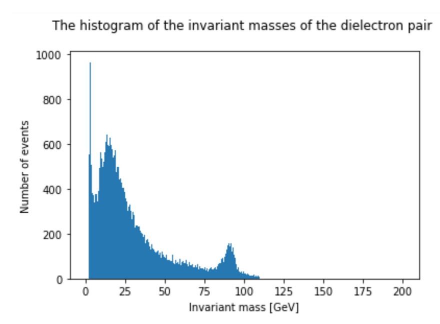


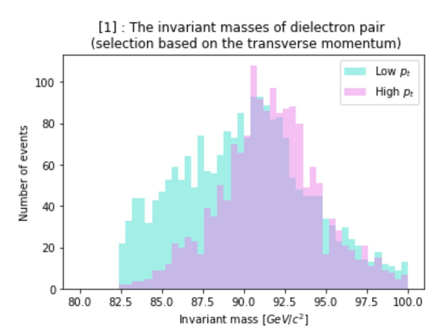
At lower η
(central part of the detector)
→ more like Gaussian Distribution
→ better particle detection
→ We also studied the effect of muon η, defining high η sample with both muons with |η| > 0.9, and low eta sample with both muons with |η| < 0.9

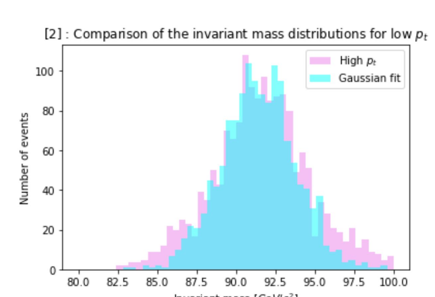
Electron Decay

In order to examine the decay of Z bosons into e- / e+ pairs we imported the dielectron.csv dataset. From there we plotted the invariant masses of the dielectron pairs.

Method no. 1







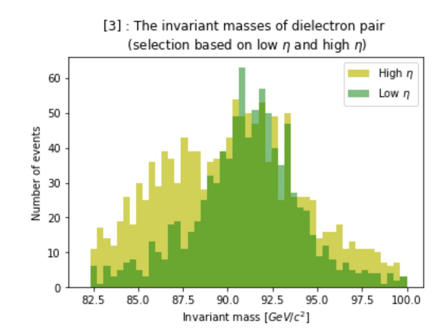
The Z boson mass is 91.2 GeV/c^2. Thus, we should look for a peak in the plot of the dielectron invariant mass located around 91.2 GeV/c^2. For that, we have selected all values within *[82;100]*. We also selected the events where both electrons fall within the electromagnetic calo- rimeter barrel (|η|<1,4). This allows greater measurement precision.

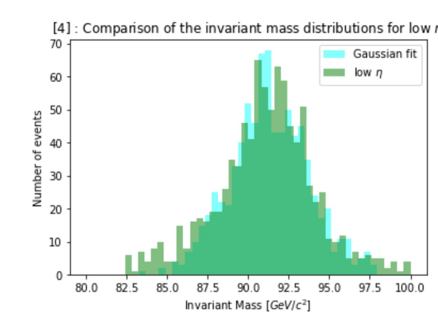
Following our hypothesis, we expect greater measurement precision for high transverse momentum values. Thus, we have plotted two overlaid histograms, one describing the invariant mass for low p_T values, and the other one for high p_T values (the division was made to build two comparable histograms). The plot is conclusive with regards to the hypothesis.

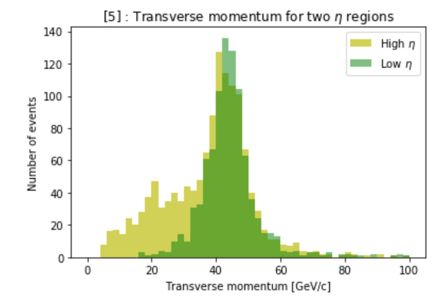
From there, we have focused on the invariant mass for high p_T values. In order to quantify the measurement precision, we built a Gaussian distribution, in order to determine the standard deviation and the mean value of our peak.

<u>Results from the comparison (High p_T selection):</u>
Standard deviation : 2.35 GeV/c^2
Mean : 91.5 GeV/c^2

Mrethod no.2







Another way of improving the measurement precision is to select the events with both decay electrons in low and high |η| regions.

For that, we again plotted two overlaid histogram, one describing the invariant mass of electrons in low |η| regions, another one describing invariant mass in high |η| regions. As shown in graph [3], measurement seems to be more precise for electrons in <u>lower |η| regions.</u>

As we did for transverse momentum, we have tried to quantify the measurement precision with a new Gaussian distribution ([4] ; [6]).

We also studied the correlation between the two methods of selection. Graph [5] shows that there is indeed a correlation between the transverse momentum and the |η| selections. If there were no correlation, the two histograms would be equal.

<u>Results from the comparison (High |η| selection):</u>
Standard deviation : 2.4 GeV/c^2
Mean : 91.3 GeV/c^2

```
x = [random.gauss(91.3,2.4) for _ in range(800)]
bins = np.linspace(80,100,50)
plt.xlabel('Invariant Mass [$GeV/c^2$]')
plt.ylabel('Number of events')
plt.title('[4] : Comparison of the invariant mass distributions for low $\eta$')
plt.hist(x, bins, alpha = 0.5,color = 'cyan', label = 'Gaussian fit')
plt.hist(newsetlowE2 ['M'], bins=50, range=(80,100),alpha=0.5, color = 'g', label='low $\eta$')
plt.legend (loc='upper right')
plt.show()
```

[6] : <u>Extract from code for plotting comparison with Gaussian random distribution</u>

Conclusion

As seen, Z bosons decaying into low p_T muons form a significantly narrower peak than Z decaying into high p_T muons. Muons in the low η region form a narrower peak than the those in the high η region.
→ <u>Which confirms our hypotheses</u>

Unlike muons, Z bosons decaying into high p_T electrons form a significantly narrower peak than the low p_T. However, once again, electrons in the low η region form a narrower peak than the those in the high η region.
→ The improved measurement of Z mass confirms our knowledge of lepton properties and the effect of electron and muon detection systems.

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References:
[1] http://opendata.cern.ch/record/304
[2] http://opendata.cern.ch/record/545/files/Zmumu.csv
[3] The Particle Data Group, http://pdg.lbl.gov/