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Data Analysis with Real Data

CMS open data with jupyter notebook

What is Data?

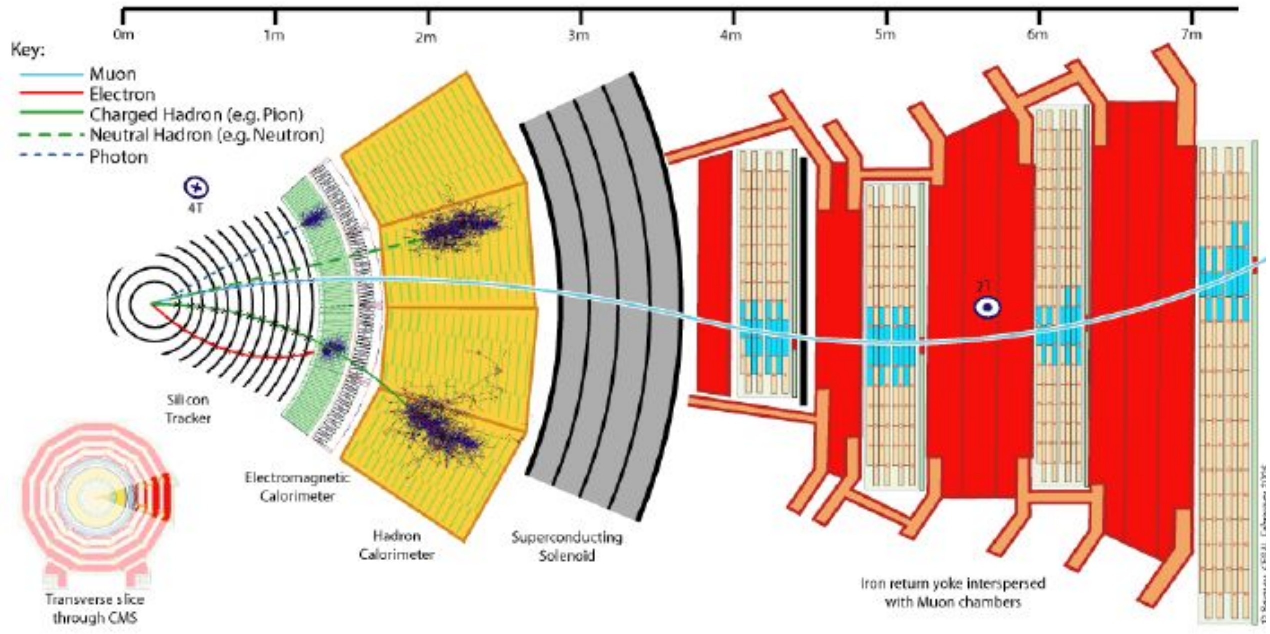
- Data collected from a particle detector for high energy particle physics
- In fact the format of data is highly correlated with the setup of the experiment and the target physics
- It is highly recommended that you understand the experiment!

Particles and their detection

- What particles can we detect:
    - Electron: A stable elementary particle belonging to the *fermion* family of particles. It has an electrical charge of -1, while its antiparticle **positron** has an electrical charge of +1. An electron has a mass of approximatively 0.5 MeV $/c^2$.
    - Photon: A stable elementary particle belonging to the *boson* family of particles. A photon is massless with no electrical charge. It is the carrier of the electromagnetic force. It’s represented by Greek letter γ (gamma).
    - Hadron: A “heavy” composite particle made of two or more quarks. They can carry a charge or be neutral. For example, protons and neutrons belong to this category.
    - Muon: An elementary particle. It has an electrical charge of -1. Muon is a lepton with properties that are similar to those of an electron but 200 times more mass. It is represented by Greek letter μ (mu). Muon’s antiparticle **antimuon** has an electrical charge of +1.

A little about CMS

- How can we detect particles?
  - There are different kinds of particle detectors but the basic principles are the same.
  - The Compact Muon Solenoid (CMS) is a detector that uses a huge magnet to bend the paths of particles produced in proton-proton collisions.

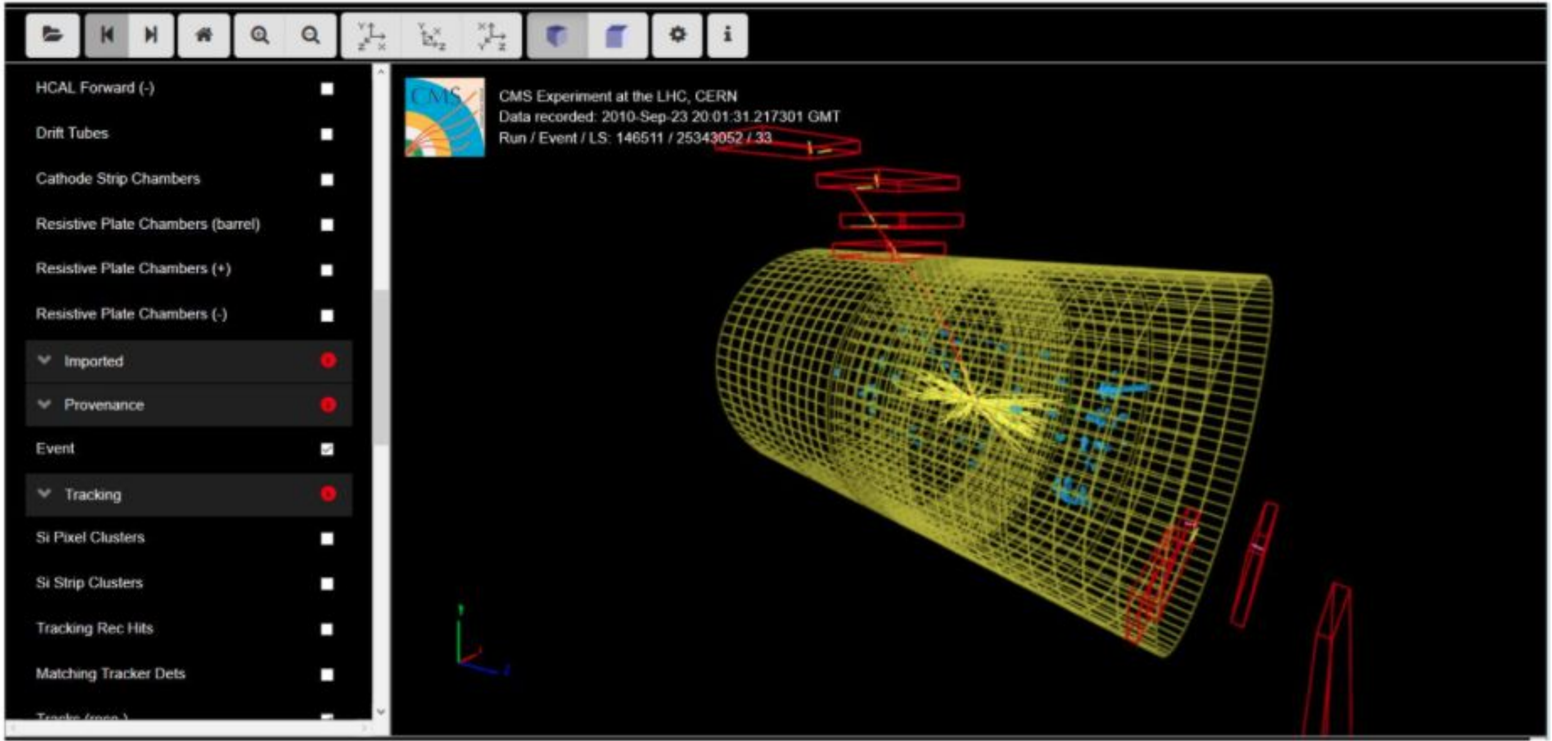


CERN Open Data

- CERN has a project to open its own data to general public. One can use the data to do research or education
- You may find some more details here: http://opendata.cern.ch
- The data from major four experiments are available online. You may be able to download them, together with the paired virtual machine (for the corresponding software, for example CMSSW) for user to perform their own analysis at home.
- CMS Open Data in the form of CSV files can be used in programming applications such as Jupyter notebooks.

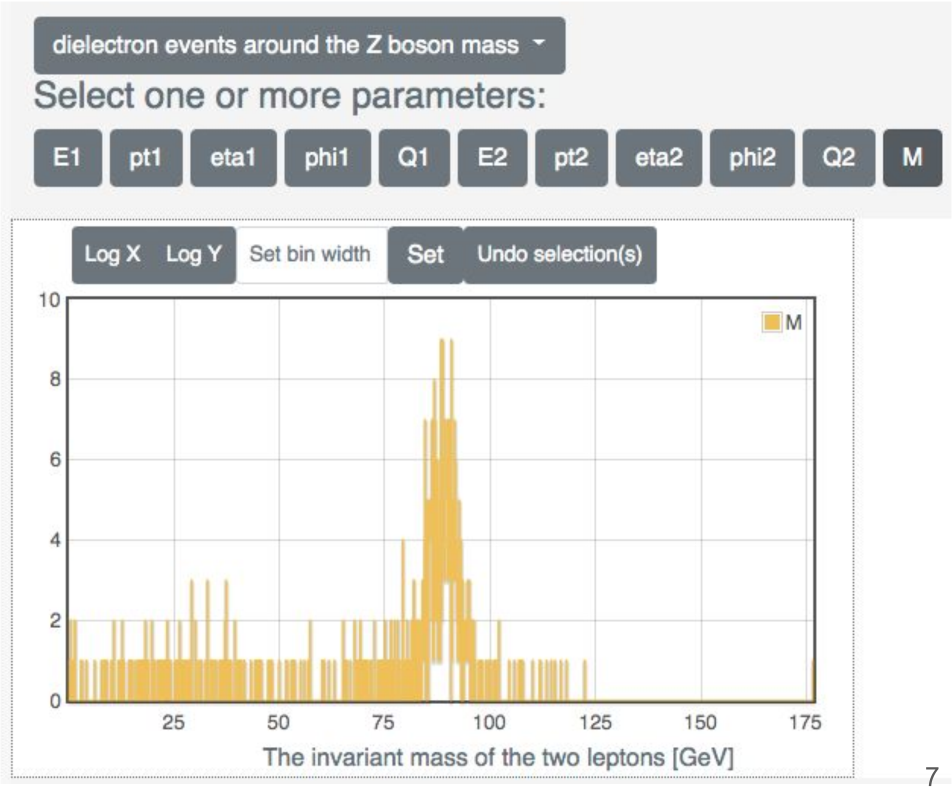
First play: Look into CMS data online

- There is an online version (=simplified) of CMS event display available.
  - See: http://opendata.cern.ch/visualise/events/cms



Second play: Look into the already prepared histograms

- Some of the typical histograms prepared with CMS data are available online as well: http://opendata.cern.ch/visualise/histograms



Online Open Data Analysis

- You can explore CERN open datasets and physics analyses in the form of CSV files can be used in programming applications such as Jupyter notebooks
  - CMS: https://github.com/cms-opendata-education/cms-jupyter-materials-english
  - Atlas: https://github.com/atlas-outreach-data-tools/notebooks-collection-opendata
- For today:

https://github.com/Analise-Dados-FAE/Aula-Analysis-CMS-Opendata/blob/main/aula-cms-open-data.ipynb

Exercises

Now we have created from the real CMS data the two histograms of the invariant masses. With the help of the histograms and the theory part of the notebook think about the following questions:

1) In which way you can see the effect of the pseudorapidity to the measurement resolution of the CMS detector?

2) Do your results show the same than the theory predicts? After answering to the questions you can try to change the conditions for the large and small pseudorapidities in the first code cell. The conditions are named *cond1* and *cond2*. Make sure you choose conditions in a way that there will be nearly same amount of events in both of the groups.

3) After the changes run the code again. How do the changes affect to the number of the events? And how to the histograms?

4) Write a function that represents Breit-Wigner distribution to the values of the histogram. To get information about mass and lifetime of the detected resonance, a function that describes the distribution of the invariant masses must be fitted to the values of the histogram. In our case the values follow a Breit-Wigner distribution:

$$N(E) = \frac{K}{(E-M)^2 + \frac{\Gamma^2}{4}},$$

where E is the energy, M the maximum of the distribution (equals to is detected in the resonance), Γ the full width at half maximum (FWHM) or the decay width of the distribution and K a constant. The Breit-Wigner distribution can also be expressed as described in the left figure, where the constant K is written open.The decay width Γ and the lifetime τ of the particle detected in the resonance are related as described in the right figure.

$$\frac{\dfrac{2\sqrt{2}M\Gamma\sqrt{M^2(M^2+\Gamma^2)}}{\pi\sqrt{M^2+\sqrt{M^2(M^2+\Gamma^2)}}}}{(E^2-M^2)^2+M^2\Gamma^2},$$

$$\Gamma \equiv \frac{\hbar}{\tau},$$

5) Calculate the lifetime τ of the Z boson with the uncertainty by using the fit. Compare the calculated value to the known lifetime of the Z. What do you notice? What could possibly explain your observations?