Short exercise - part 1

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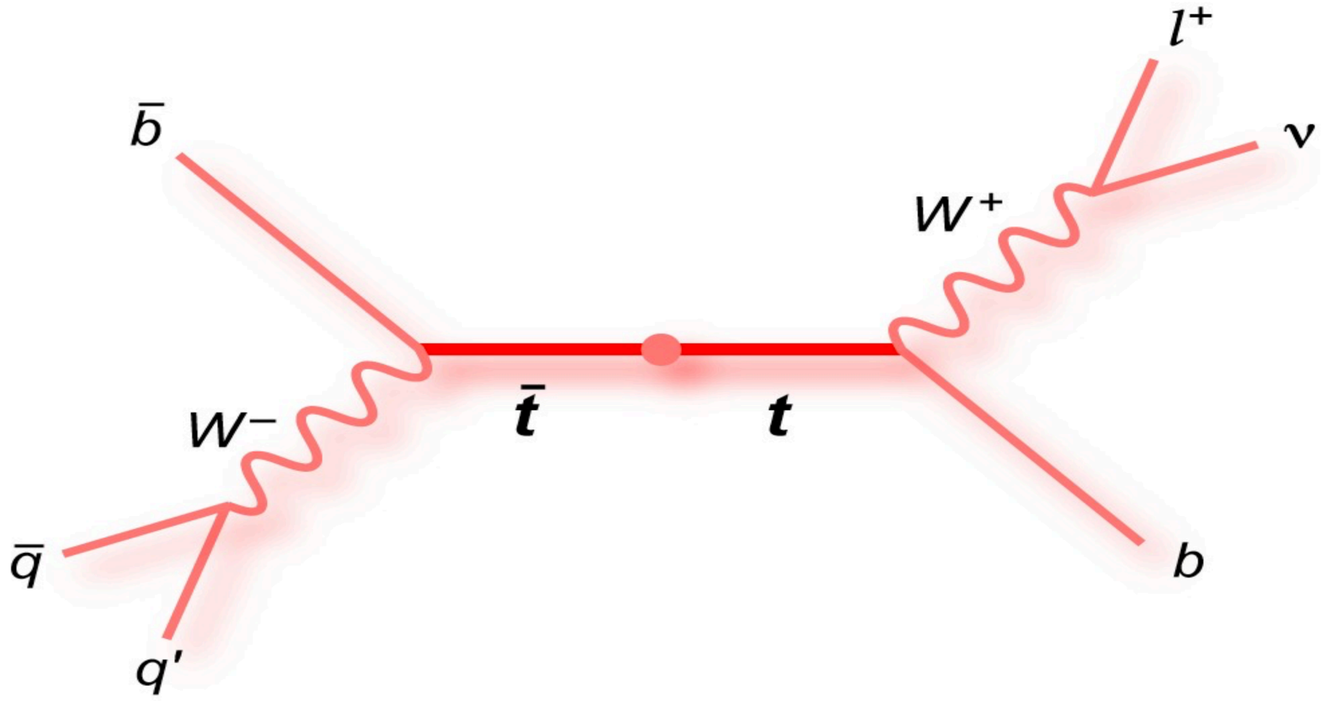
PHY451 Particle Physics I
13th April 2021

Short exercise - part 1

Introduction

- The short exercise consists in measuring the production cross section of top quark pairs performing a physics analysis of 50 pb^{-1} of data collected by the CMS experiment at the proton collider LHC
- The top quark mean lifetime is about $5x10^{-25}s$
  - too short to enable direct top quark reconstruction
  - the alternative is to measure final state decay products of top quark from energy deposits in the detector and indirectly reconstruct the top quark



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Hunt for $t\bar{t}$ production

- For this exercise only semileptonic decay of top-quark pair will be considered (in the muon channel)
  - expected signal final state: 4 jets out of which 2 from b quarks, 1 lepton and missing momentum from non-reconstructed neutrino
- The hunt for $t\bar{t}$ production (signal) consists in correctly identifying the final state products to distinguish the reconstructed final state from other processes which have similar signature (called background processes)
  - examples: QCD jet production, electroweak W or Z boson production in association to jets
  - moreover, additional objects such as jets from radiation or from overlapping collisions can be produced complicating the top reconstruction

- Physics analysis of experimental data workflow
  1. Study of kinematical properties distinguishing signal events against background using Monte Carlo simulation (or data driven)
  2. Define a selection strategy based on these studies to suppress background and select signal-like data
  3. Apply this selection on experimental data
  4. Measure! In this case, estimate $t\bar{t}$ production cross section

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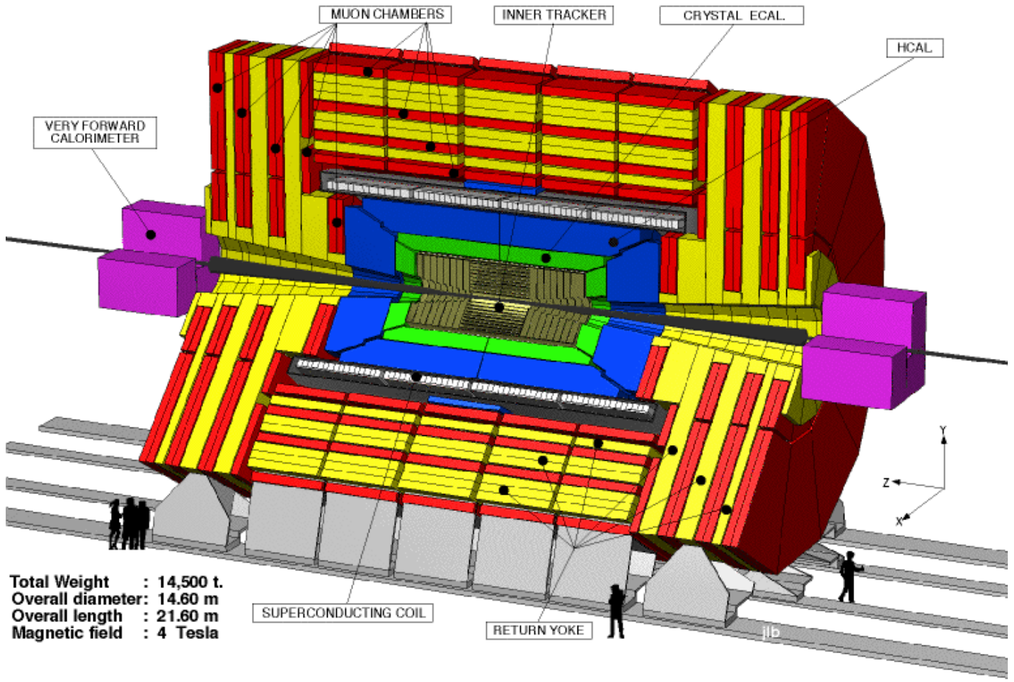
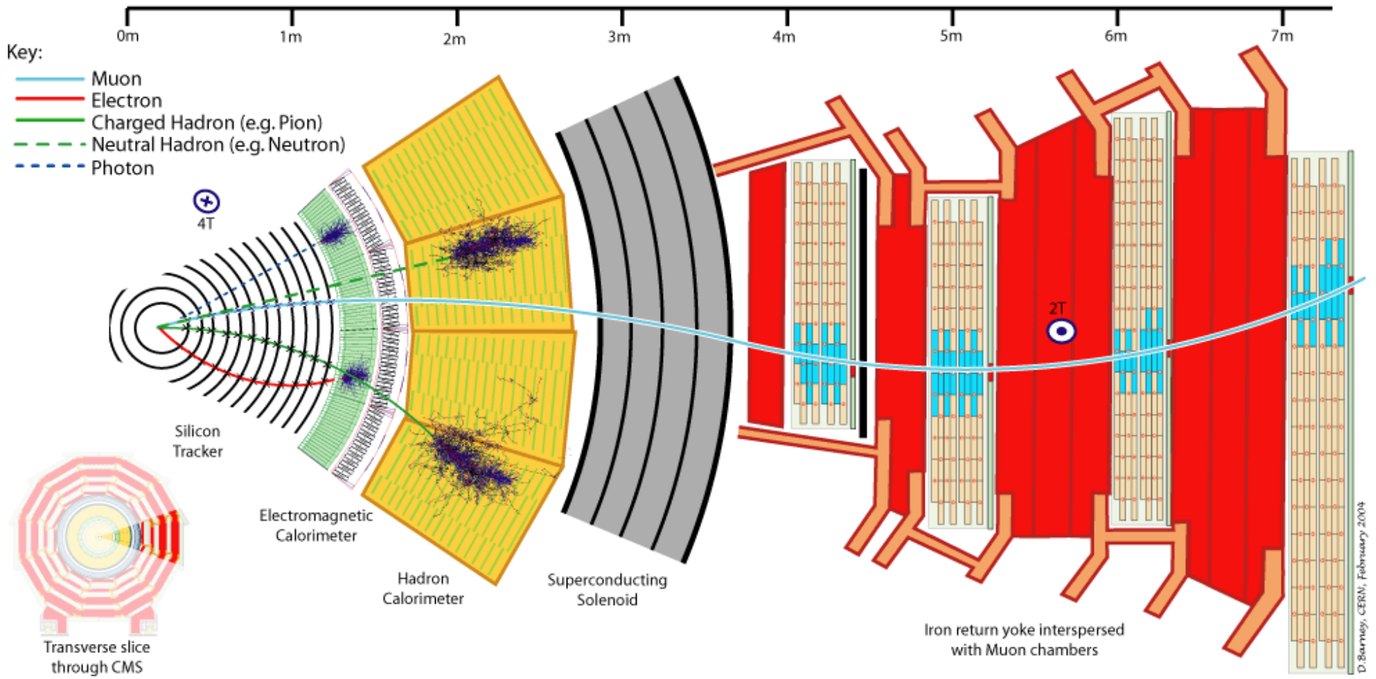
The CMS experiment

- The **C**ompact **M**uon **S**olenoid, CMS
  - total weight: 14.5 t
  - overall diameter: 14.8 m
  - overall length: 21.6 m
  - internal magnetic field: 3.8 T
  - external magnetic field: 1.8 T



- CMS main features
  - superconducting solenoidal magnet High-quality tracker system:
  - high-performance electromagnetic calorimeter
  - superconducting coil
  - return Yoke
  - highly hermetic hadron calorimeter



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The LHC

- The **L**arge **H**adron **C**ollider is built at CERN (Geneva), on the Swiss-French border
  - accelerate bunch of protons through a circumference of 27 km up to 13 TeV c.m.e
  - this exercise makes use of 50 pb^{-1} of p—p collision data delivered by LHC at a $\sqrt{s}$ = 7 TeV

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Files

- Data and MC simulation samples together with a basic analysis framework are available at the following path:
  - /home/hep/steleo/PHY451/exercise
- The data samples for this exercise are stored in root trees, you can find them in the folder files
  - file names indicate which kind of simulated data are stored in the file (ttbar.root, qcd.root, etc.) or whether it contains real data (data.root)
  - data.root is a sample of real data collected by the CMS experiment in 2011
    - corresponding to 50 pb^{-1} of proton-proton collisions at $\sqrt{s}$ = 7 TeV
  - given the very large collision rate, not all produced data are stored
    - a selection is performed by the trigger system to store only “interesting” data
    - only events containing a reconstructed, isolated muon are saved
  - data are stored in files as ROOT trees
    - each tree contains a selection of variables useful for the analysis
    - a list of all variables stored in the trees follows
- The analysis framework will serve as base for your own analysis

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Structure of a ntuple

Event	Variables	Content (size of each vector indicates the number of candidates per event)
1	p_x p_y p_z	-138.0434 **126.42235** 30.451496 **-19.39185** -40.10309 **32.827720** 31.058544 **-23.21485** 9.2168264 **48.834972** -74.05298 **37.526317**
2	p_x p_y p_z	1.4830336 35.448909 159.64926
4	p_x p_y p_z	53.272769 **-46.61022** -34.74116 **18.753765** -363.9992 **49.854187**
....	p_x p_y p_z	candidate #1 .... **candidate #2**

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Tree structure - jets

Variable	Type	Content
NJet	Integer	Number of jets in the event
Jet_Px	vector of floats	x-component of jet momentum (only jets with p_T> 30GeV are stored)
Jet_Py	vector of floats	y-component of jet momentum (only jets with p_T> 30GeV are stored)
Jet_Pz	vector of floats	z-component of jet momentum (only jets with p_T> 30GeV are stored)
Jet_E	vector of floats	Energy of the jet (only jets with p_T> 30GeV are stored)
Jet_btag	vector of floats	b tag discriminator value
Jet_ID	vector of bools	Jet quality identifier - Used to reject jets from detector noise. A good jet has true value for this variable

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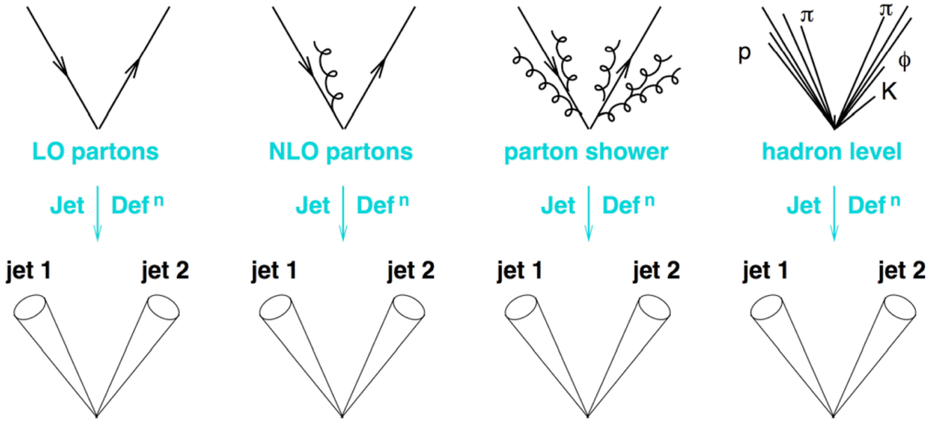
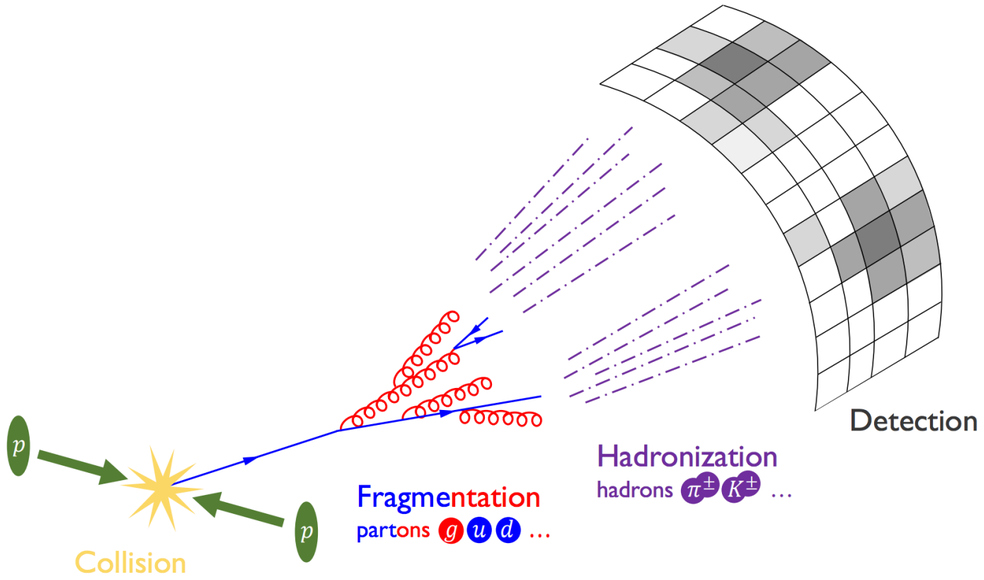
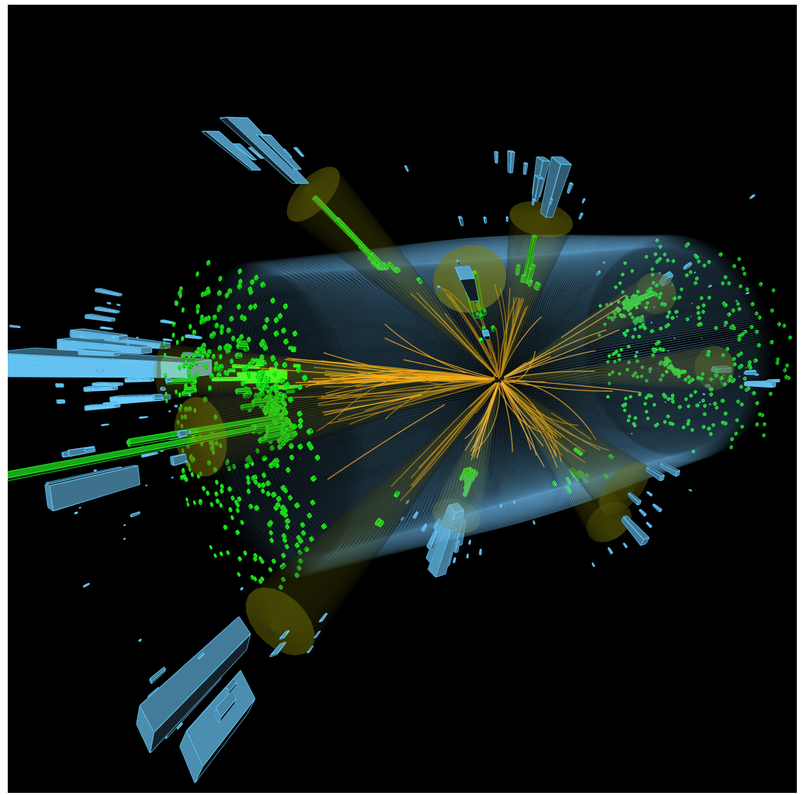
Short introduction to jets

- From the theory point of view
  - jets of partons (gluons and quarks)
- From the experimental point of view
  - Quarks and gluons hadronize quickly and we detect sprays of hadronic particles in our detectors
  - observables are protons, neutrons, pions, photons, electrons, muons







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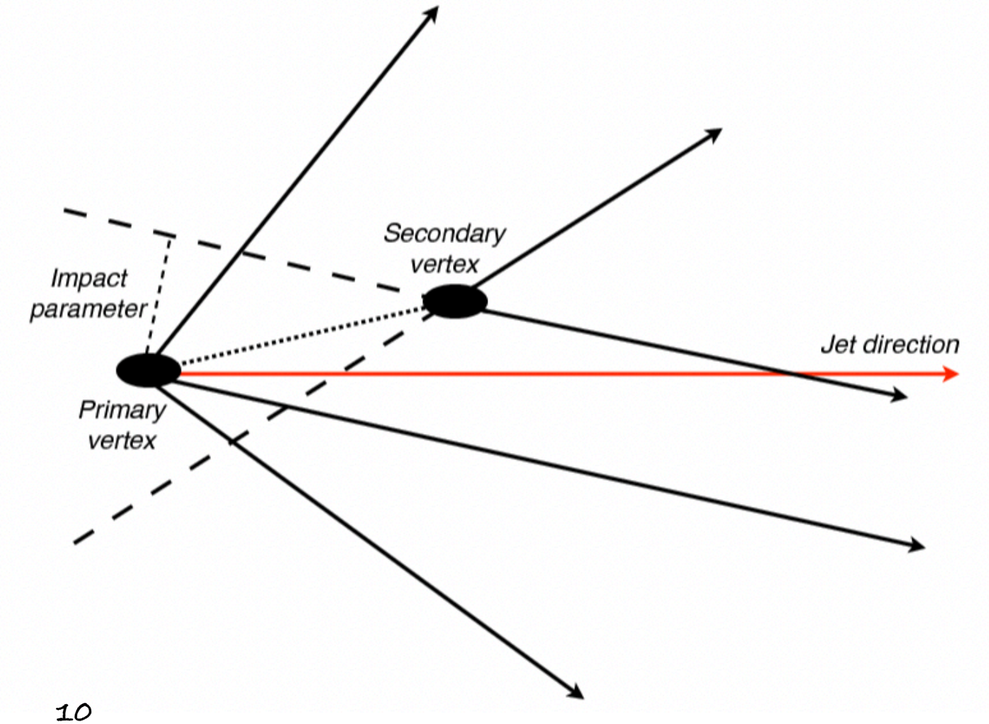
B-jet identification

- The long lifetime of B hadrons can be exploited to identify jets originating from b-quarks
  - the reconstruction of secondary vertex due to the decay of B mesons indicates the jet is a b-jet
- A b-tagging discriminator (Jet_btag) is obtained from an algorithm that identifies secondary vertices
  - higher values of b-tagging discriminator indicates a higher probability that the jet comes from a b-quark

- A jet is tagged as b-jet if b-tag discriminant is greater than 2.0 (Jet_btag > 2.0)



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Tree structure - muons

Variable	Type	Content
NMuon	Integer	Number of muons in the event
Muon_Px	vector of floats	x-component of muon momentum
Muon_Py	vector of floats	y-component of muon momentum
Muon_Pz	vector of floats	z-component of muon momentum
Muon_E	vector of floats	Muon energy
Muon_Charge	vector of integer	Muon charge
Muon_Iso	vector of floats	Muon isolation value

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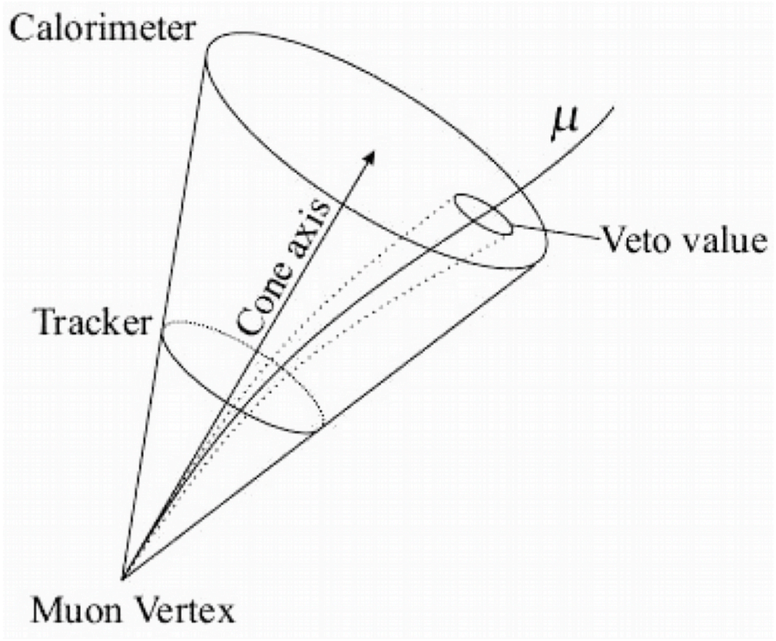
Isolation

- Muons originating from Z/W boson decay manifest themselves in the detector as a clean trajectory traversing the inner tracker up to the muon detectors
  - muons from b quark decay are instead produced within a jet
- The isolation, I (Muon_Iso), is defined as the sum of p_T of reconstructed particles within a cone of size $\Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$ around the muon. It is used to discriminate muons originated from Z/W decays from those produced in jets, which are surrounded by a multitude of particles



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Tree structure - MET

Variable	Type	Content
Met_Px	vector of floats	x-component of the missing energy
Met_Py	vector of floats	y-component of the missing energy
EventWeight	vector of floats	Weight factor to be applied to simulated events to account for **different sample cross sections**
triggerIsoMu24	vector of bools	Trigger bit, it is true if the event is triggered, and false if it is not

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Analysis framework

- Develop your own analysis using the framework available
- The framework consists of different modules
  - MyAnalysis.py ← you'll have to modify this
  - example.py ← you'll have to modify this
  - Samples.py ← you probably **don't have to** modify this
  - Plotter.py ← you probably **don't have to** modify this

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Analysis framework

- **MyAnalysis.py**
  - it's the **core of the analysis** implementation, here the selection strategy is implemented and histograms are booked and filled with selected events
  - two main functions:
    - bookHistos: where histograms are defined
    - processEvent: where histograms are filled according to analyst criteria

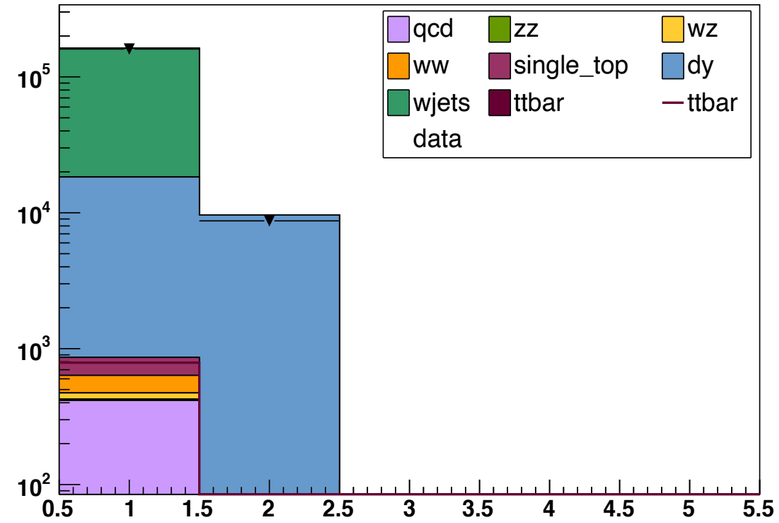
```
def bookHistos(self):
  h_nJet = ROOT.TH1F("NJet","#of jets", 6, -0.5, 6.5)
  h_nJet.SetXTitle("%# of jets")
  self.histograms["NJet"] = h_nJet
  ....
```

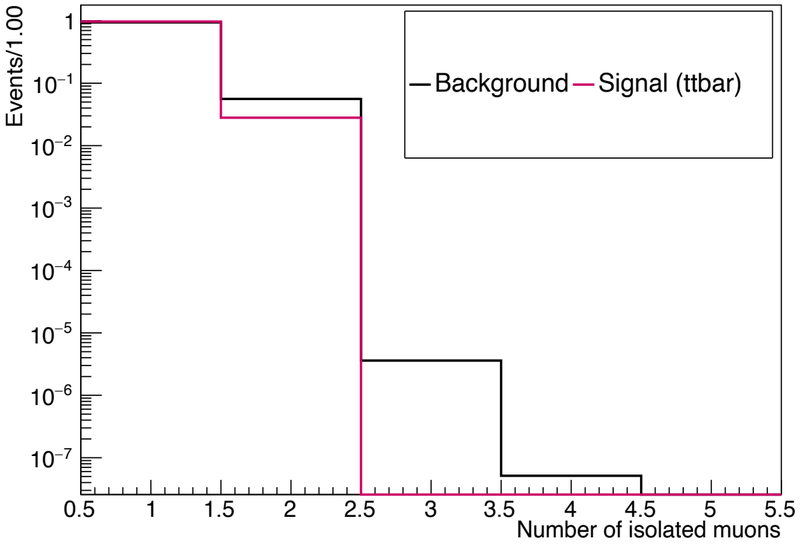
```
  def processEvent(self, entry):
    tree = self.getTree()
    tree.GetEntry(entry)
    w = tree.EventWeight
    ....
    for m in xrange(tree.NMuon):
      muon=ROOT.TLorentzVector(tree.Muon_Px[m],tree.Muon_Py[m], tree.Muon_Pz[m], tree.Muon_E[m]
      self.histograms["Muon_Iso"].Fill(tree.Muon_Iso[m], w)
```

Analysis framework

- **example.py**
  - it's the **main python file**. It calls the other modules and is used to define the actions, which samples should be processed, and which plots should be created.
  - it returns .pdf files with plots for all indicated variables
  - two kind of plots are produced:
    - a plot representing the sum of background plus signal and comparison to data
    - signal vs background distribution normalized to unity

```
for v in vars:
    print "Variable: ", v
    ### plotShapes (variable, samples,logScale )
    plotShapes(v, samples,  True)
    ### plotVar(variable, samples,isData, logScale )
    plotVar(v, samples,  True, True)
```





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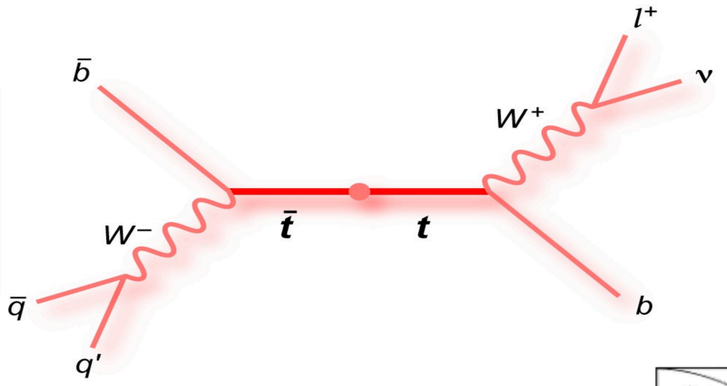
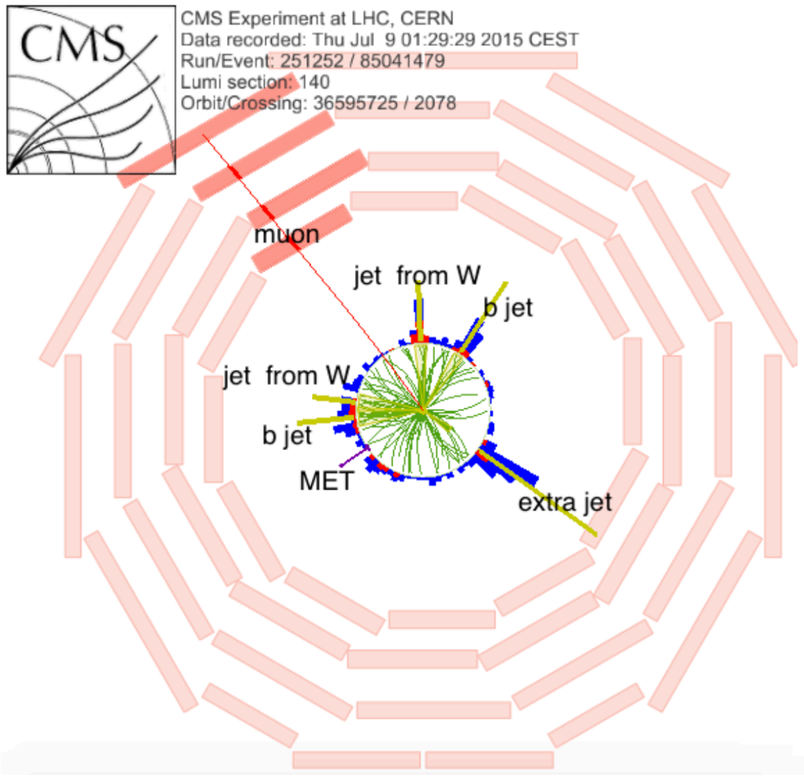
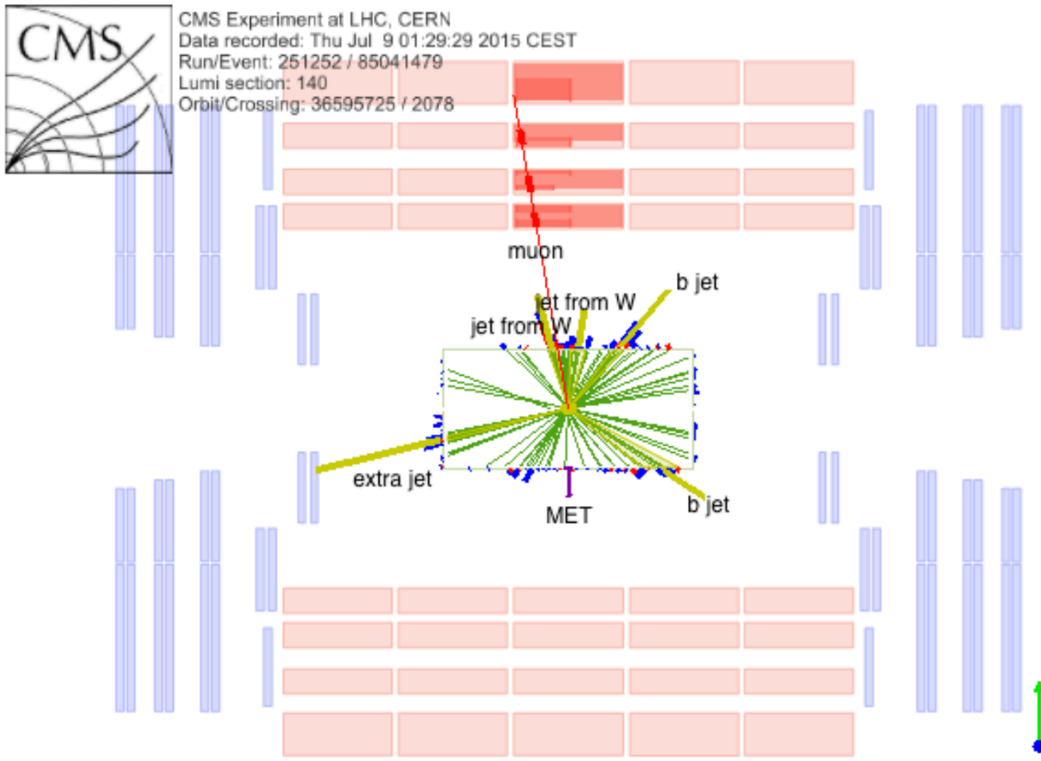
Reminder of the process







Short exercise - part 1

Objectives – part 1

1. Open the files data.root and ttbar.root and inspect them
   - look interactively at the distributions of variables:
     - NJet, NMuon, Jet_Px/Py/Pz, Muon_Px/Py/Pz, Muon_Iso, Met_px/py
     - which is the most probable value for the number of Jets (NJet) and for the number of Muons (NMuon) in data? And in simulated $t\bar{t}$ events?
   - pay attention to the variable triggerIsoMu24
     - which values can you observe for data? And for MC?
2. Using the analysis framework select events with at least one isolated muon:
   - Relative isolation (Muon_Iso/ Muon_PT) < 0.05
   - Muon_PT > 25 GeV
3. Compare the shapes of several distributions for the signal (ttbar) and the background (e.g number of jets, number of tagged jets)
   - which ones provide best discrimination between signal and background?
4. Find the most discriminating variables and choose a cut to apply in order to reject the background. Optimise the selection choosing the cut that gives the highest $S/\sqrt{S+B}$

Objectives – part 2

5. Produce the histograms of these variables comparing MC simulation and data
   - use the function plotVar(v, samples, True, True) in example.py
6. Apply this selection to MC and data
   - what is the highest $S/\sqrt{S+B}$ you can get (based on simulation)

BACKUP