



A computing exercise using ROOT

Aim: give a taste of data analysis ..

- What is ROOT ?
 - ROOT is an object-oriented C++ analysis package
 - User-compiled code can be called to produce 1-d, 2-d, and 3-d graphics...



Outline

- Variables used in the analysis of $p - p$ collisions
- Useful relations
- Concept of invariant mass: example: ‘inclusive’ Z boson production
- Kinematics of $p - p$ collisions

- Analysis in $p - p$ collisions :
 - * Signal:Production of a W and a Z
 - * Background: Production of a pair of top-antitop
- Example: Macro.C

In all the following slides we assume the speed of the light

$$c=1$$

Variables used in the analysis of $p - p$ collisions

A particle (Z, W, e+, e-, etc ...) is described by its **four-momentum**:

$$\tilde{p} = (E, p_x, p_y, p_z)$$

$$\text{The particle mass is } m = \sqrt{E^2 - p_x^2 - p_y^2 - p_z^2}$$

When dealing with $p\bar{p}$ collision the following variables are used:

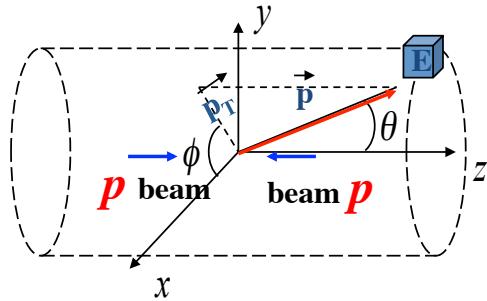
For each particle (Z, W, e+, e-, etc ...):

- **1. Transverse momentum/energy :** $p_T = p \sin \theta$ $E_T = E \sin \theta$

- **2. Rapidity** $Y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$

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

- **3. Azimuthal angle** Φ **Why?**



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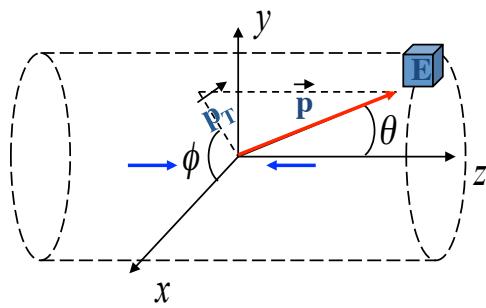
Variables used in the analysis of $p - p$ collisions

Why? Many reasons.



1. The longitudinal momentum of initial partons is unknown while we know that $\vec{p}_T^{\text{initial partons}} \sim 0$
 - To exploit momentum conservation use transverse quantities (in the plane ⊥ to the beam) → p_T
2. p_T and ΔY are invariants for Lorentz transformations along the z axis
3. $\sum^{\text{initial partons}} \vec{p}_T = \sum_{\text{vis}} \vec{p}_T + \sum_{\text{invis}} \vec{p}_T \approx 0$ → Allows to evaluate the p_T of particles not detected (v)
 - $\sum_{\text{invis}} \vec{p}_T = - \sum_{\text{vis}} \vec{p}_T$ $|\sum_{\text{invis}} p_T|$ is the “missing E_T ”
4. The “interesting” physics is due to hard scattering processes → high p_T particles (selection of high p_T particles assures “interesting” physics)

Useful relations



$$p_x = p_T^* \cos(\Phi);$$

$$p_y = p_T^* \sin(\Phi);$$

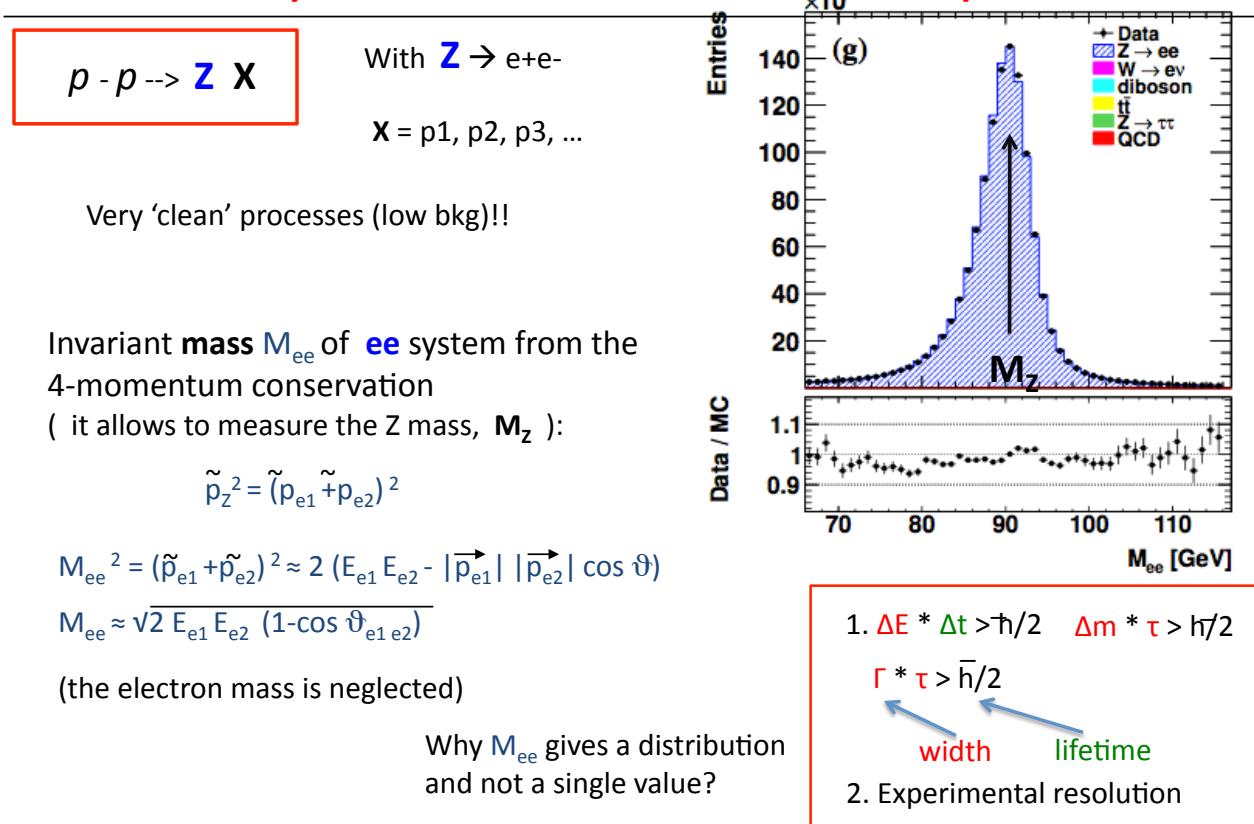
$$p_z = E^* \tanh(\eta);$$

$$p_T = p \sin \theta$$

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

- $m \ll E \rightarrow Y \approx \eta$ (η doesn't require particle identification)
- $m \ll E \rightarrow p_T \approx E_T \quad E_T = E \sin \theta$

Concept of invariant mass: inclusive Z boson production

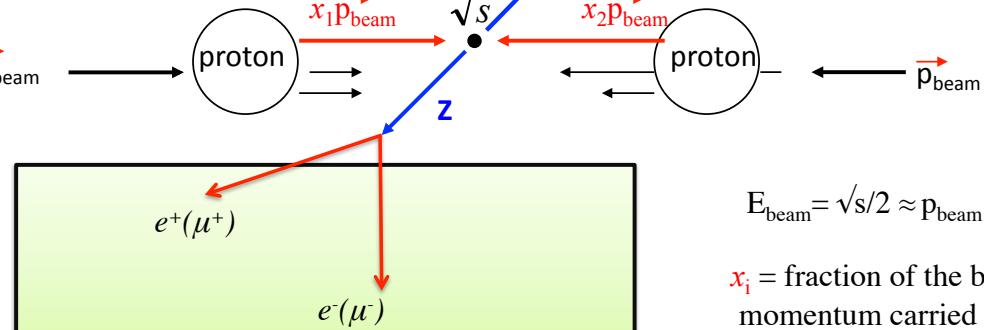


Our signal : Production of a W and a Z

$p-p$ 'hard' collisions in the $q_1 \bar{q}_2$ center of mass:

$p-p \rightarrow W Z X$
Our 'signal'

With $Z \rightarrow e^+ e^-$
and $W \rightarrow e^+ \nu_e$



$$E_{beam} = \sqrt{s}/2 \approx p_{beam}$$

x_i = fraction of the beam momentum carried by the parton i

Kinematics of $p-p$ collisions

* 4-mom of the initial partons : $[(x_1+x_2)E_{beam}, 0, 0, (x_1-x_2)p_{beam}]$

$$0 < x_{1,2} < 1$$

Our background: Production of a pair of top-antitop

$p-p$ 'hard' collisions. In the $q_1 \bar{q}_2$ center of mass:

$p-p \rightarrow t \bar{t} X$
Our 'background'

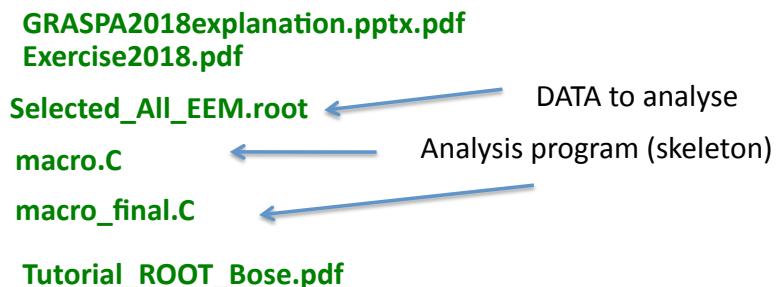
The b quarks flies few cm before desintegrating $\rightarrow e^+(\mu^+) \text{ from}$
b quark do not emerge from the primary vertex \rightarrow Higher distance from the primary vertex
(higher "impact parameter")

Aim of the exercise:

- 1) look at some important variables,
- 2) build the Z invariant mass,
- 3) how one can discriminate between the 'signal' and the 'background'

On the GRASPA 2018 Web page you will be given :

<https://indico.in2p3.fr/event/11292/other-view?view=standard>



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1) an **input file containing the physics:** **Selected_All_EEM.root**

```
==== MOST ENERGETIC LEPTON FROM THE Z
Br 4 :pt1 : pt1
Br 5 :eta1 : eta1
Br 6 :phi1 : phi1
Br 7 :E1 : E1

==== SECOND ENERGETIC LEPTON FROM THE Z
Br 8 :pt2 : pt2
Br 9 :eta2 : eta2
Br 10 :phi2 : phi2
Br 11 :E2 : E2

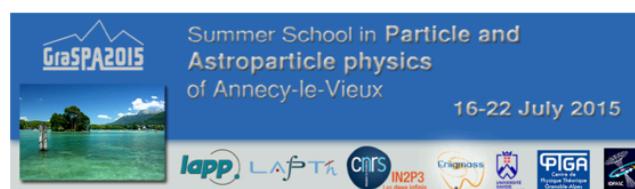
==== LEPTON FROM W
Br 12 :pt3 : pt3
Br 13 :eta3 : eta3
Br 14 :phi3 : phi3
Br 15 :E3 : E3
```

List of variables given
per each collision event
(kinematics of the final
state leptons)

2) Instructions to make the computing exercise : **Exercise2015.pdf**

GRASPA 2015

16-22 July 2015



COMPUTING EXERCISE Study of the production of a pair of gauge bosons (W and Z) at the LHC

The data to analyse are organised into a 'Root n-tuple' which we will provide to you. The Root n-tuple is a file containing information about the kinematics of

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3) A skeleton of an analysis program using ROOT: **macro.C**

```
#include "TCanvas.h"
#include "TROOT.h"
#include "TFile.h"
#include "TTree.h"
#include "TBrowser.h"
#include "TH2.h"
#include "TRandom.h"

void tree1r()
{
    // Read Selected_All_EEM.root file
    //Root file
    TFile *f = new TFile("Selected_All_EEM.root");

    // Signal events
    TTree *sig = (TTree*)f->Get("WZSignal");
    Double_t pt1, eta1, phi1, E1;
    Double_t pt2, eta2, phi2, E2;
    Double_t pt3, eta3, phi3, E3;
    Double_t MZ, MET, trackd0cutWMu, TrackIsoWmu;
    Double_t Weight;

    //get some variables for SIGNAL EVENTS
    sig->SetBranchAddress("pt1",&pt1);
```

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Look also to:

ROOT Tutorial

4) A ‘manual’ with ROOT instructions: [Tutorial_ROOT_Bose.pdf](#)

Tulika Bose
Brown University
NEPPSR 2007

Useful links about root:

<http://root.cern.ch/drupal/content/root-primer-534>
<http://root.cern.ch/drupal/content/root-users-guide-534>

Example of analysis program

macro.C

23/07/2013 00:21

```
#include "TCanvas.h"
#include "TROOT.h"
#include "TFile.h"
#include "TTree.h"
#include "TBrowser.h"
#include "TH2.h"
#include "TRandom.h"

void tree1r()
{
    // Read Selected_All_EEM.root file
    //Root file
    TFile *f = new TFile("Selected_All_EEM.root"); Open the input file

    // Signal events
    TTree *sig = (TTree*)f->Get("WZSignal");
    Double_t pt1, eta1, phi1, E1;
    Double_t pt2, eta2, phi2, E2;
    Double_t pt3, eta3, phi3, E3;
    Double_t MZ, MET, trackd0cutWMu, TrackIsoWmu;
    Double_t Weight;

    //get some variables for SIGNAL EVENTS
    sig->SetBranchAddress("pt1",&pt1);
    sig->SetBranchAddress("eta1",&eta1);
    sig->SetBranchAddress("phi1",&phi1);
    sig->SetBranchAddress("E1",&E1);
    sig->SetBranchAddress("MZ",&MZ);
    sig->SetBranchAddress("Weight",&Weight);
    // add other variables ... Variables per each lepton
```

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```
////get some variables for BACKGROUND EVENTS
TTree *ttbar = (TTree*)f->Get("ttbar");
Double_t pt1_bkg, eta1_bkg, phi1_bkg, E1_bkg;
Double_t MZ_bkg;
Double_t Weight_bkg;

//get some variables for ttbar
ttbar->SetBranchAddress("pt1",&pt1_bkg);
ttbar->SetBranchAddress("eta1",&eta1_bkg);
ttbar->SetBranchAddress("phi1",&phi1_bkg);
ttbar->SetBranchAddress("E1",&E1_bkg);
ttbar->SetBranchAddress("MZ",&MZ_bkg);
ttbar->SetBranchAddress("Weight",&Weight_bkg);
// add other variables ...

//create two histograms (for sig and ttbar)
TH1F *h_MZ      = new TH1F("h_MZ","MZ distribution All events",40,65,115);
TH1F *h_MZ_bkg   = new TH1F("h_MZ_bkg","MZ distribution BKG",40,65,115);
TH1F *h_MZ_sig   = new TH1F("h_MZ_sig","MZ distribution SIG",40,65,115);

//read all SIGNAL entries and fill the histograms
Int_t nentries = (Int_t)sig->GetEntries();

for (Int_t i=0;i<nentries;i++) {
    sig->GetEntry(i);
    h_MZ->Fill(MZ,Weight);
    h_MZ_sig->Fill(MZ,Weight); Access the background info
```

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Have fun !!



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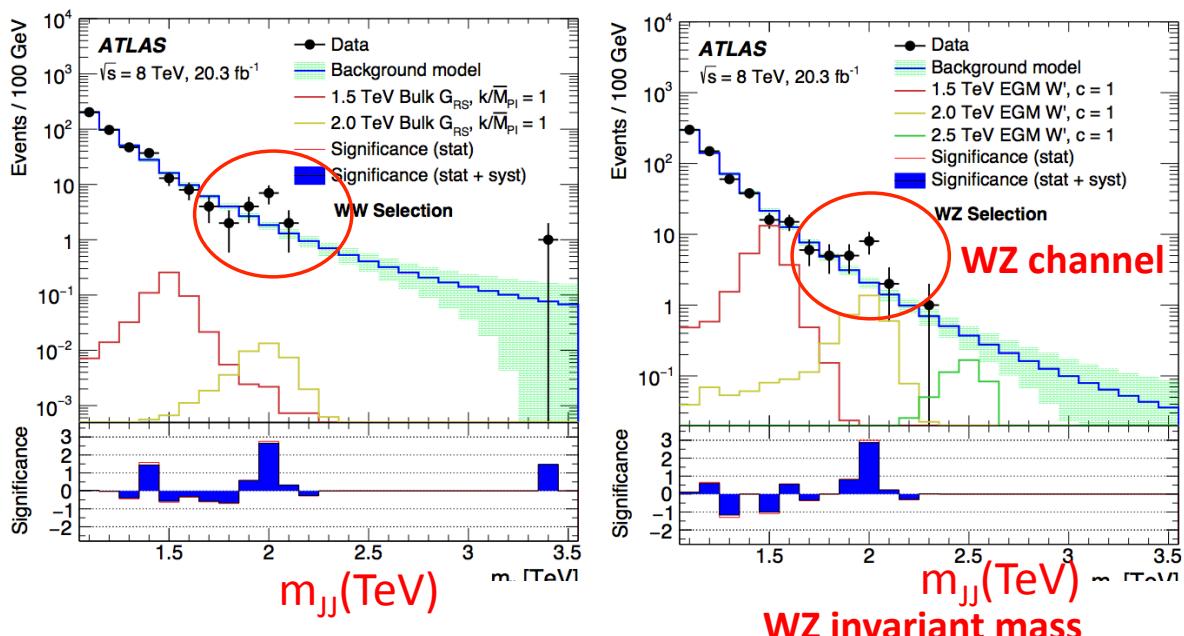
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$w(jj) z(jj)$

$jj = J$ (1 fat jet)

Another example: search for di-boson resonances

- Is there something hiding in the data, waiting to be discovered?



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