
# LHCb Experiment and CP Asymmetry through data analysis

HSSIP Italy 2022

Students: Di Cara Giulia,Ferrari Davide

Supervisor: Barbara Sciascia

Genève,03/06/2022

# Topics we will discuss

- ➢ Symmetries in Nature and CP violation
- ➢ LHCb experiment at CERN
- ➢ Our analysis in Python with real data

# Symmetries in Nature

Continuous symmetries
Noether’s Theorem

*"If a system has continuous symmetry,then there are corresponding quantities preserved over time"*

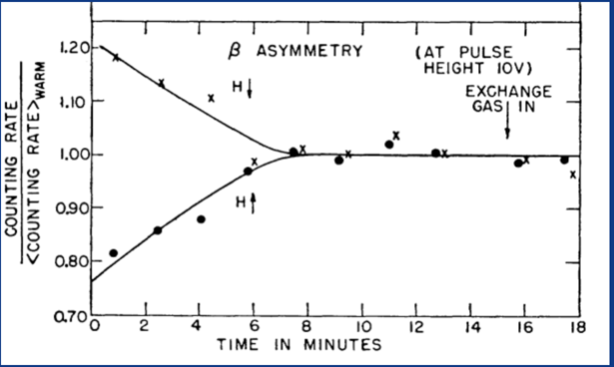
Discrete symmetries

A discrete symmetry describes a change non-continuous of a system

# P and C symmetries and the discovery of their violation

## P ( Parity) symmetry

Changing the signs of the three spatial coordinates doesn’t effect the particle.




Madame Wu experiment (1957)

## C (Charge) symmetry

Changing the charge of a particle does not affect the particle.

Lederman,Garwin and Weinrich experiment (1957)

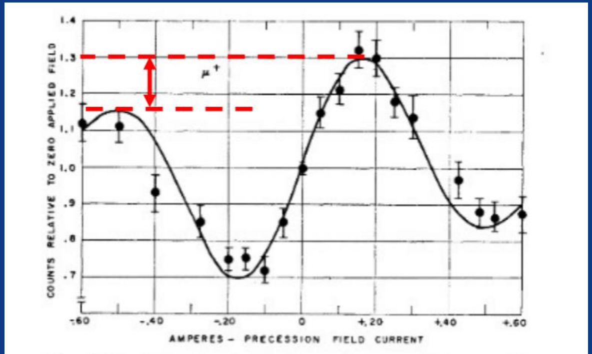
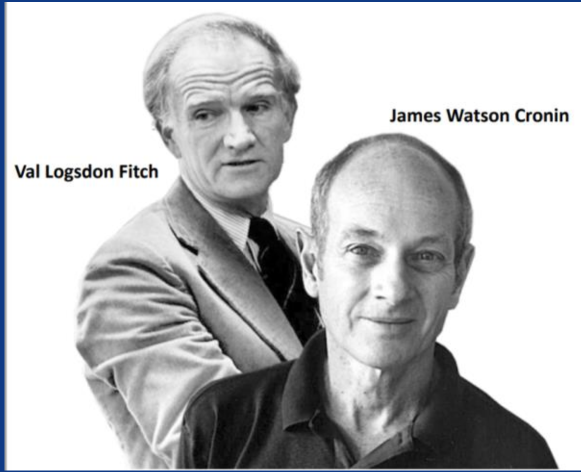


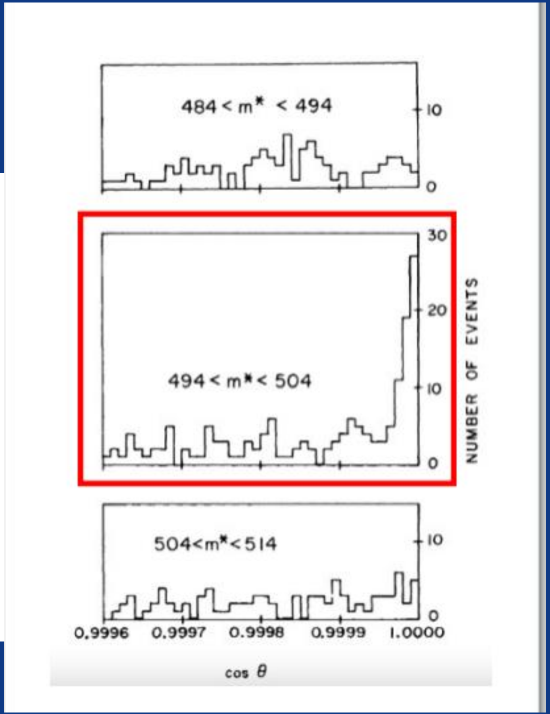

FIG. 2. Variation of gated 3-4 counting rate with magnetizing current. The solid curve is computed from an assumed electron angular distribution $1-\frac{1}{3}\cos\theta$, with counter and gate-width resolution folded in.

# CP asymmetry and the strange case K mesons

## Cronin and Ficht experiment (1964)

If CP symmetry was preserved, K1 could only decay into pairs of pions, while K2 could decay only in trio of pions.

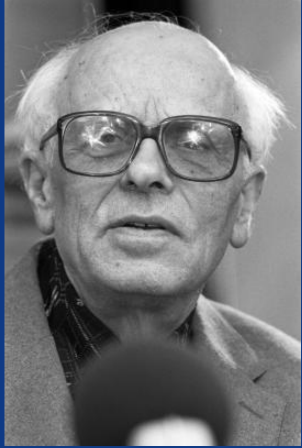



But there were some cases where K2 decayed into pairs pions instead of trios.

In the region of mass around the expected one (497.7 MeV / c2) an accumulation of events was observed in θ= 0

# Sakharov condition, Big Bang, matter and antimatter



- ➢ Violation of baryonic number
- ➢ Violation of CP symmetry
- ➢ Interactions out of thermal equilibrium

Why are we interested in CP violation?

Baryonic matter, in our Universe, is more than anti-matter and this asymmetry is not predicted by the Standard Model.

# LHCb experiment


LHCb detector is a huge "camera" able to reconstruct and analyze the 40 million pp collisions per second occurring in LHC accelerator at CERN in Geneva.

The very first idea of LHCb was made in 1995.

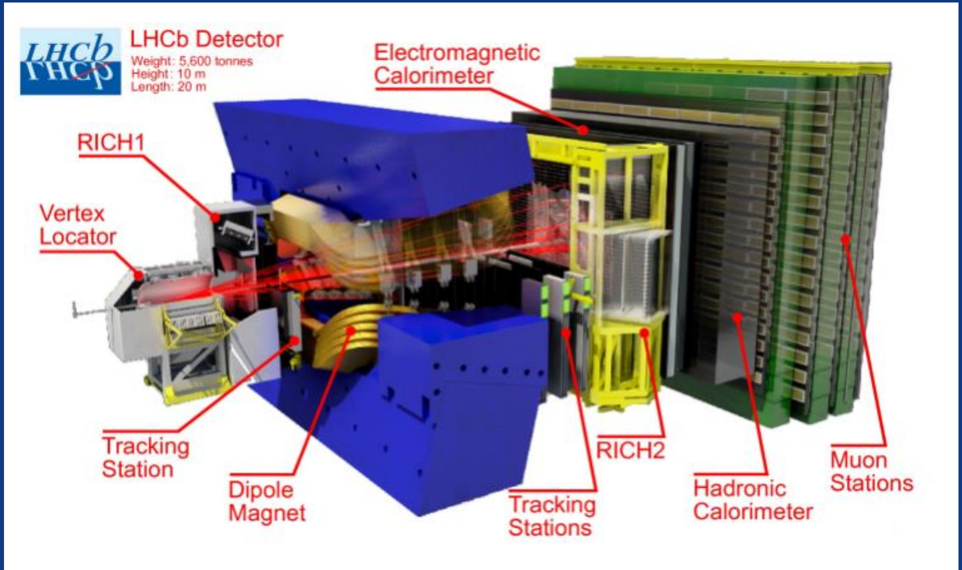
LHCb now counts about 1340 members from 80 institutes in 18 different countries.

# LHCb structure

## Tracking systems

**Vertex Locator (VELO)**
Determines the point where particles collide and the point where they decay.

**Dipole magnet**
Curve the trajectories of charged particles before they collide




**Tracker Turicensis(TT)**
Determines the position of the charged particles that it cross.

**Tracking Stations (TS)**
Same TT function, but it's located after the dipole magnet.

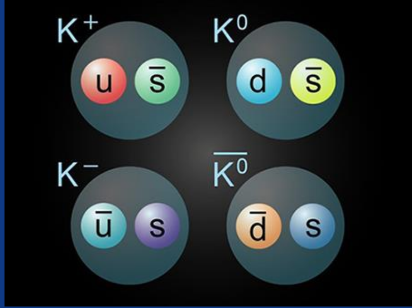
## Identification systems (PID)

**RICH 1 and RICH 2**
(Ring Imaging Cherenkov)
They produce rings of light more or less large depending on the mass of particles.

**ECAL & HCAL**
(Electromagnetic and Hadronic Calorimeters)
Determine particles' energy.

**Muon stations**
The innermost part determines the position of the most energetic particles that pass through.

# Data analysis of $B^0$ decays using Python




Our aim was to determine the CP asymmetries of the decays

$$B_0 \to K + \pi-$$

$$B_{0s} \to K - \pi +$$

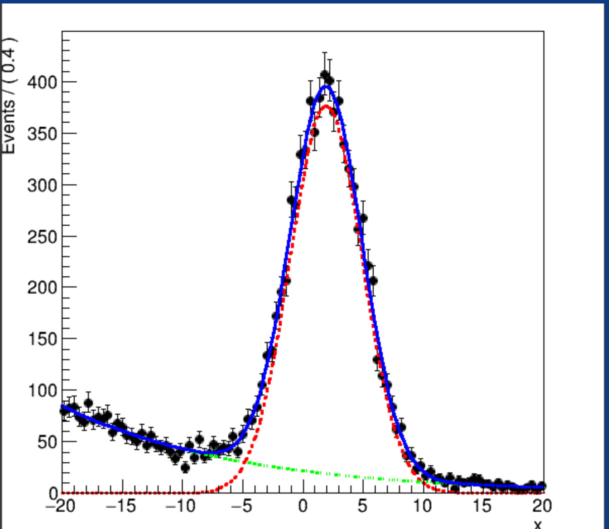
It is necessary to compare the number of decays of $B_0$ and $B_{0S}$

In the end, we should see in the final two graphs two different "peaks" which is the CP violation.

# First steps into data analysis

## Fit operation

To find CP asymmetries, we need to find curves that better suit the data. These curves are mathematical functions that depend on several parameters.




The fit operation is automatic.The software assigns a value for each parameter. This is called likelihood. The computer will turn the configuration with the highest likelihood.

```
[ ] c = ROOT.TCanvas("myCanvas2","The Canvas Title",800,600)
    c.Divide(2,1)
    c.cd(1)
    h = ROOT.TH1D("h","myHisto_h",100,5.2,5.8) #istogramma
    g = ROOT.TH1D("g","myHisto_g",100,5.2,5.8) #istogramma
    t.Draw("mass>>h","tag==+1") #mass>>h: con questo comando disegniamo la massa all'interno dell'istogramma con nome "h"
    t.Draw("mass>>g","tag==-1") #mass>>g: con questo comando disegniamo la massa all'interno dell'istogramma con nome "g"
    h.Draw("hist")
    h.SetLineColor(2) #colore della linea
    h.GetXaxis().SetTitle("massa del B [GeV/c2]") #titolo asse X
    h.GetYaxis().SetTitle("Eventi") #titolo asse Y
    g.Draw("pesame")
    g.SetMarkerStyle(21) #stile dei punti
    g.SetMarkerColor(4)  #colore dei punti
    g.SetMarkerSize(0.5) #grandezza dei punti
```

# Boosted Decision Tree

## Multivariate data selection

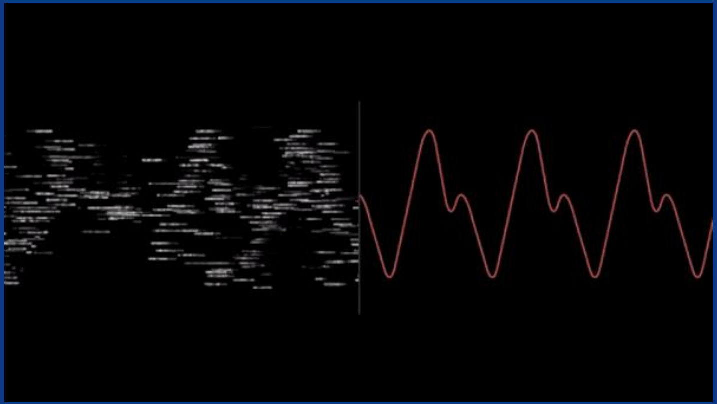
BDT is an algorithm that makes consecutive cuts. The algorithm classifies real signal or in background noise.

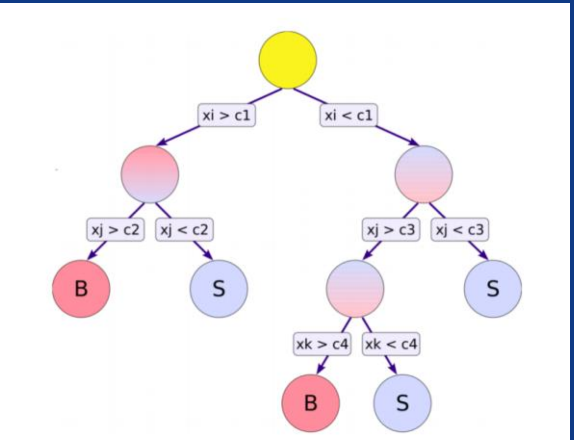
The procedure is repeated hundreds of times using different combinations.

BDT is more efficient than manual cuts.

# Training the signal

The algorithm is “trained” to recognise signals with a particular method. You give him pure signal (MonteCarlo Simulation e.g.) and background samples.





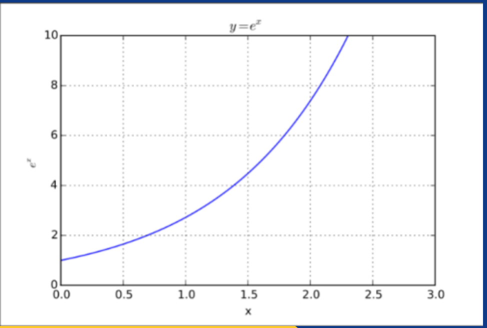

Once trained, it can be applied to real raw data and it efficiently selects without losing good data.

# Analysis with real data

One of the most common functions that is used to describe signal events is Gaussian distribution.
It depends on two parameters, called mean (μ) and sigma (σ).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-(x-\mu)^2/(2\sigma^2)},$$

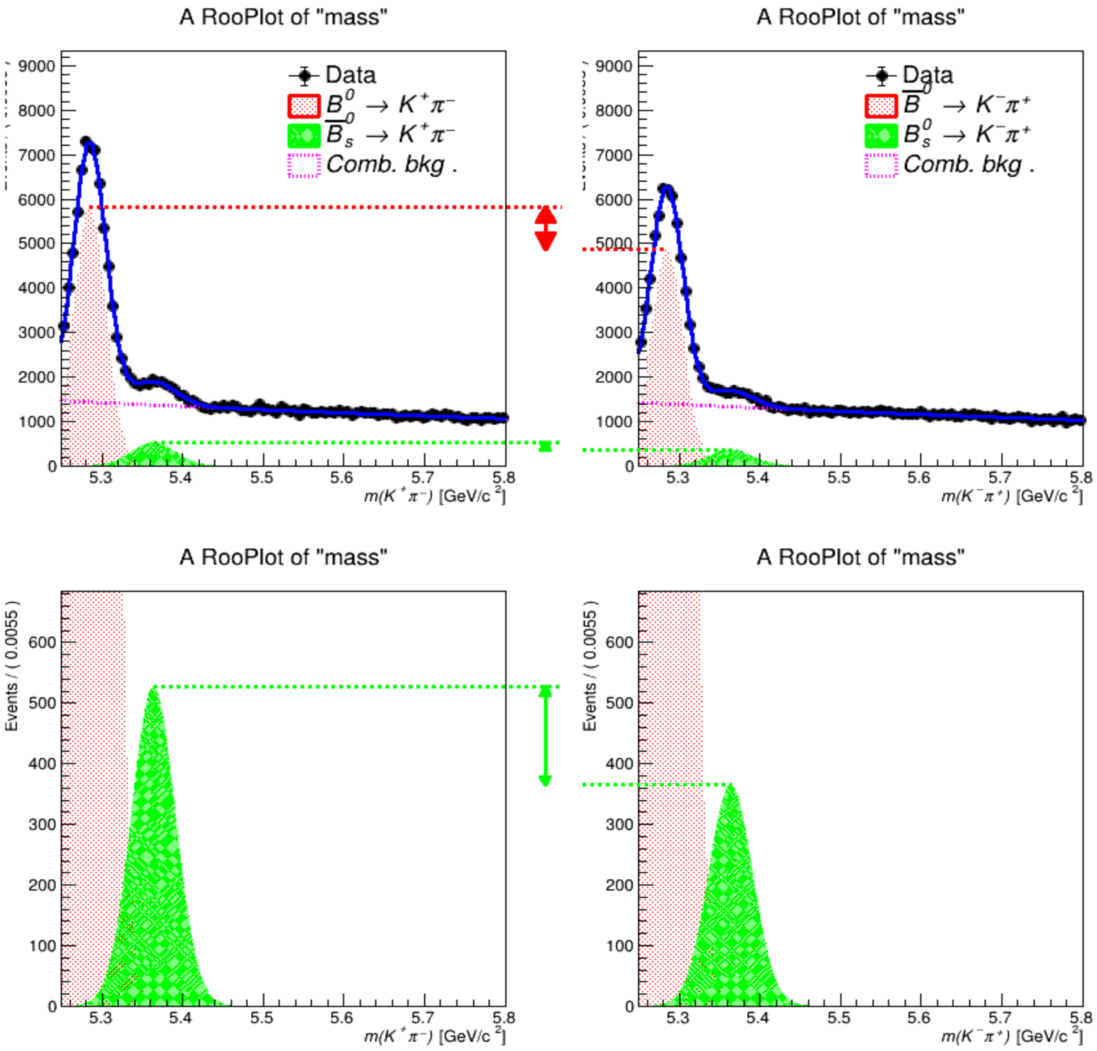
Mean indicates where the peak of the function is, sigma indicates how wide this distribution is.




We described the background noise using an exponential function, which depends on his slop.

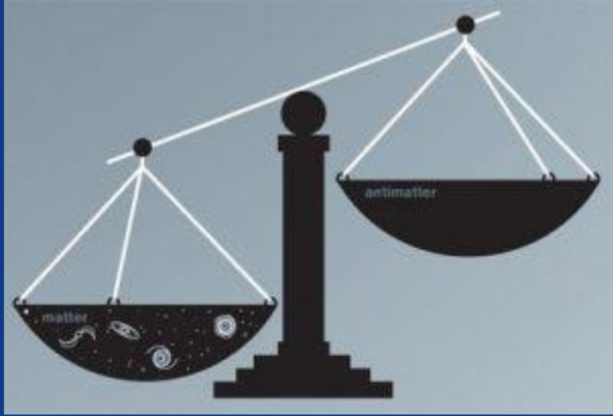
# The final graphs

The difference between the peaks is striking.




In blue the total distribution,in red and green the two gaussians. In purple the exponential.

# Nature has her own favourite




We found some CP asymmetry in

$B_0$: (-8.938226 土 0.399662)%

$B_{0S}$: (18.073184 土  2.530849)%.


We can also calculate CP asymmetry using

$$A = \frac{N_{\overline{B}^0} - N_{B^0}}{N_{\overline{B}^0} + N_{B^0}}$$


# Thank you!

*"Why is Nature so nearly symmetrical? No one as an idea why.*
*We might like think that the true explanation of the near symmetry of Nature is this: that God made the laws only nearly symmetrical so that we should not be jealous of His perfection"*
-Richard Feynman

Genève,03/06/2022

CERN

Supervisor: Barbara Sciascia

Students: Di Cara Giulia,Ferrari Davide