UNIVERSITÀ DEGLI STUDI DI PADOVA

Degree in Physics
Introduction to Research activities

Use of machine learning algorithm to optimize the double Higgs signal identification from background on simulated events at a Muon Collider

Teachers: D. Lucchesi, L. Sestini

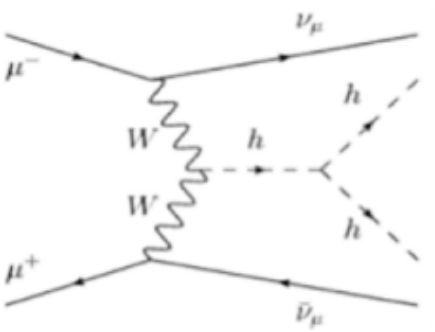
Student: Luca Castelli

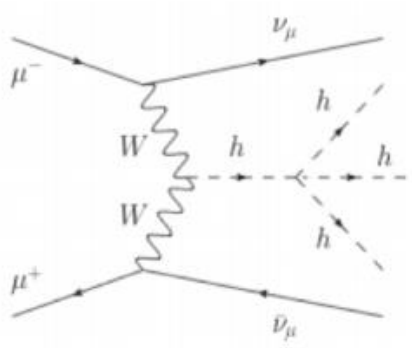
Introduction

The Muon Collider - 1 :

- *Study of a new accelerator facility;*
- *C.M. energies up to ≈10 TeV;*
- *Allow to study in detail, among other particle, the Higgs Boson and its potential:*

$$V_{Higgs} \approx -\frac{1}{2}m_H^2 \cdot h^2 + \lambda_3 \cdot h^3 + \lambda_4 \cdot h^4 + O(h^4)$$



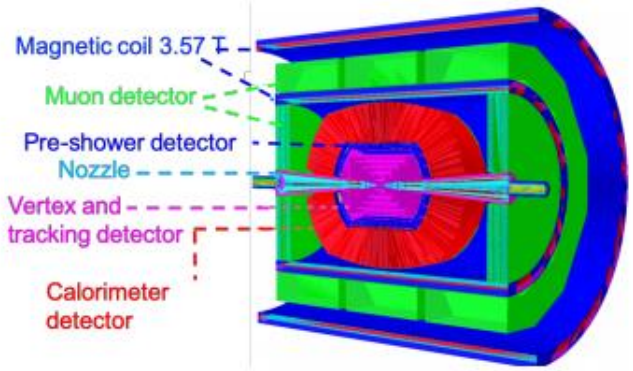


Three Higgs and Four Higgs events

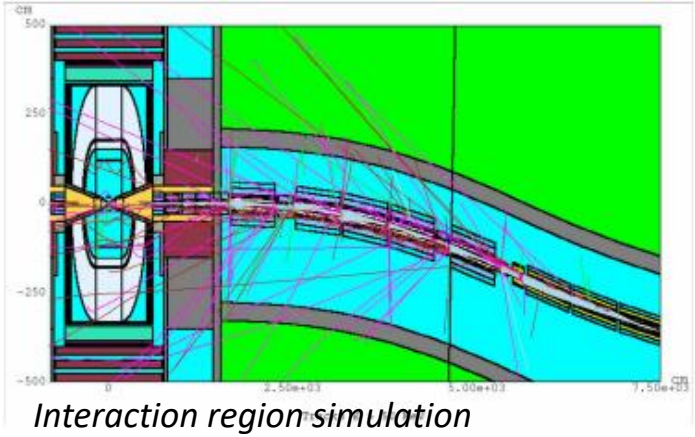
Introduction

The Muon Collider - 2 :

- We need to study the performance of the machine;
- Several kind of simulations has been done:
  - Detectors
  - Background
  - Muon cooling
  - Data



Detector scheme



Interaction region simulation

Introduction

Aim of this work: Signal or background?

- Studying the λ_3 parameter from $\mu^+\mu^- \to h^* \to hh$ events;
- We need to distinguish signal from background events like $\mu^+\mu^- \to Z^* \to Zh$ or $\mu^+\mu^- \to Z^* \to ZZ$;
- Done with Machine Learning algorithm;
- Older $\frac{\sigma}{signal\ fraction} \approx 40\%$*

**From Laura Bonincontri thesis*

Introduction

Tools:

- 10000 signal-like and background-like events simulated;
- Machine learning algorithm.

My work:

- Studying the best observables to use to train the M.L.;
- Analyzing the results.

Observables

Event requirement:

- Number of jets ≥ 4;
- $p_{\perp} > 10$ GeV for each jet;
- $\Delta r = \sqrt{\Delta\varphi^2 + \Delta\eta^2} \geq 0.5$, for each couple of jets;

Event reconstruction:

- Identifying the four jets that minimize:

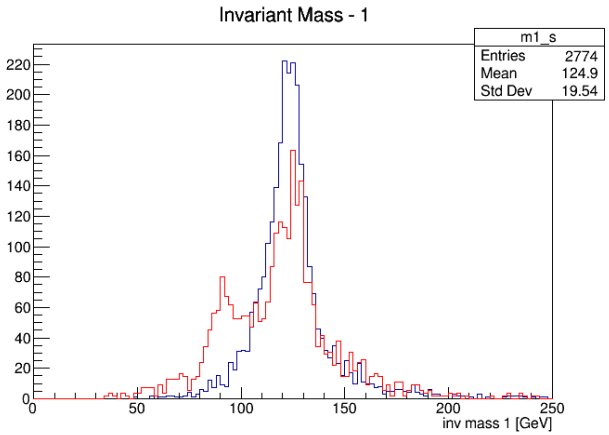
  $\Delta = (\boldsymbol{m_1} - \boldsymbol{m_{Higgs}})^2 + (\boldsymbol{m_2} - \boldsymbol{m_{Higgs}})^2$;

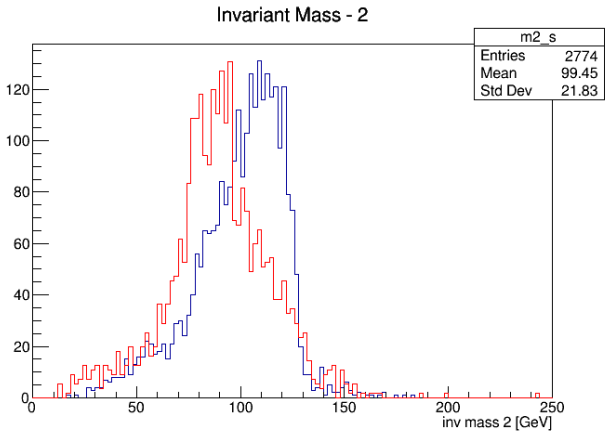
- Assigning index «**1**» to the **heavier** particle and «**2**» to the **other**;
- Same analysis has been performed for both signal and background;
- In the following plots **signal** is in blue, **background** in red.

Observables

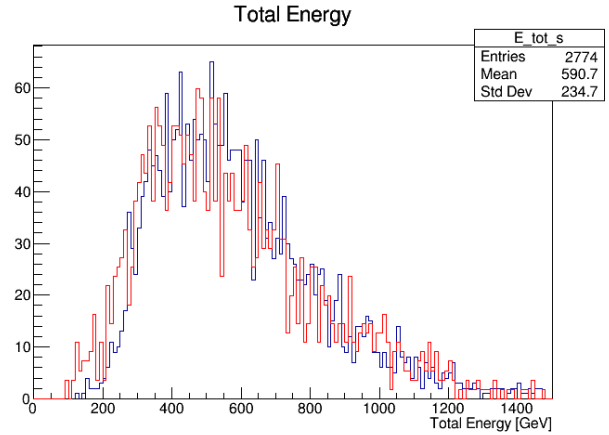
Observables - 1:

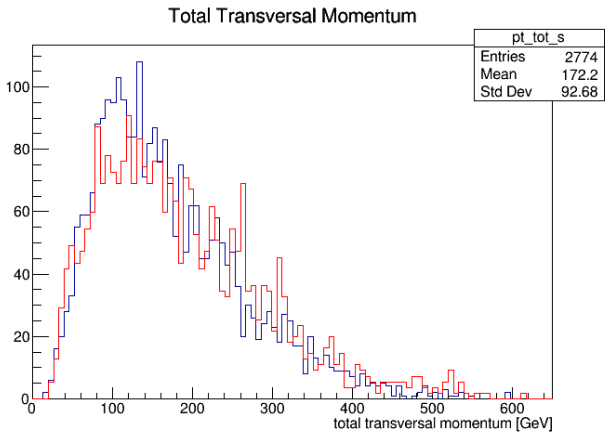
- Invariant mass: $m = \sqrt{E^2 - p^2}$;





- Total Energy and transversal momentum;

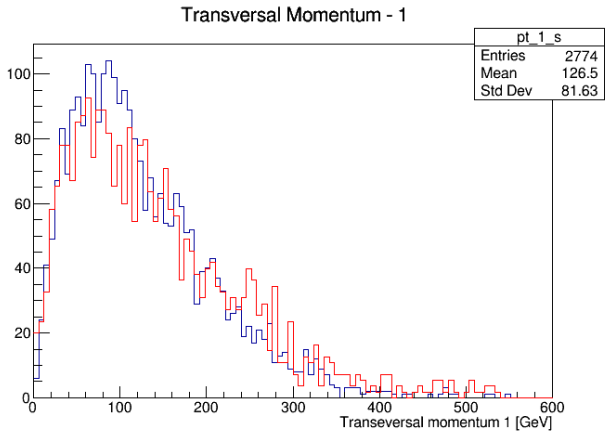


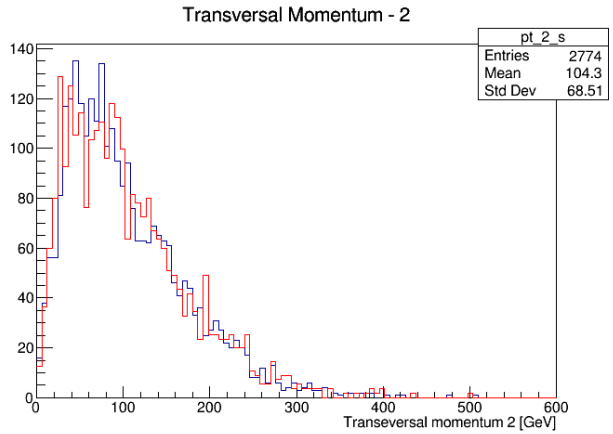


Observables

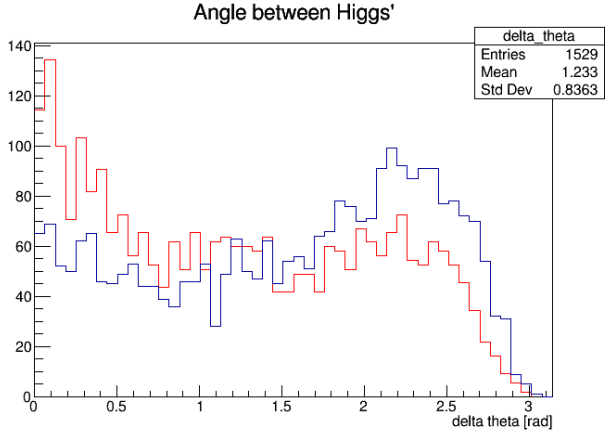
Observables - 2:

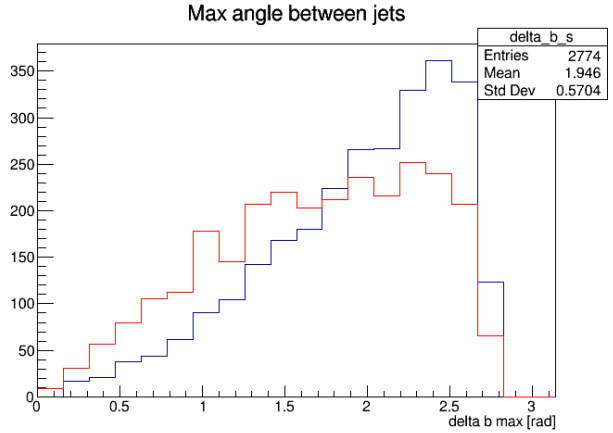
- Transversal momentum;





- Angle between Higgs bosons and maximum angle between jets.

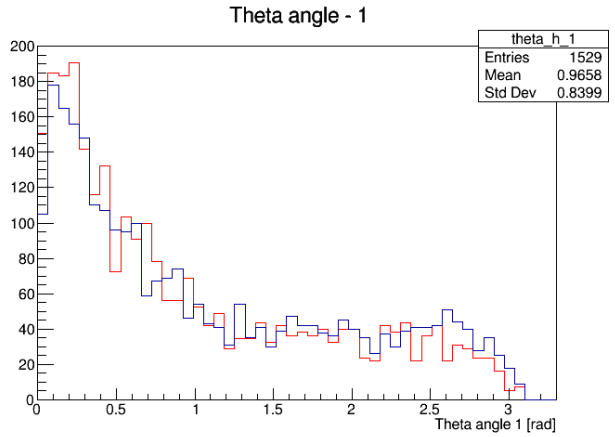


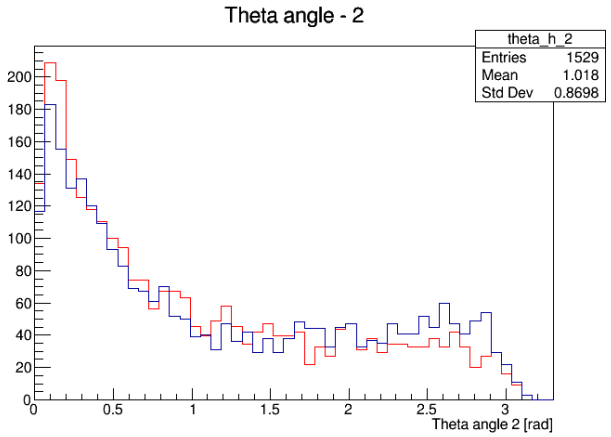


Observables

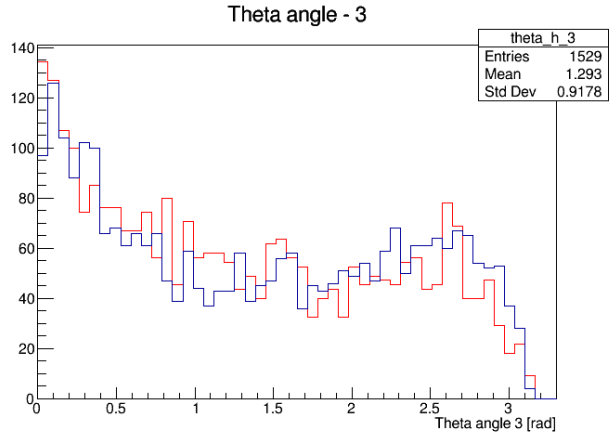
Observables - 3:

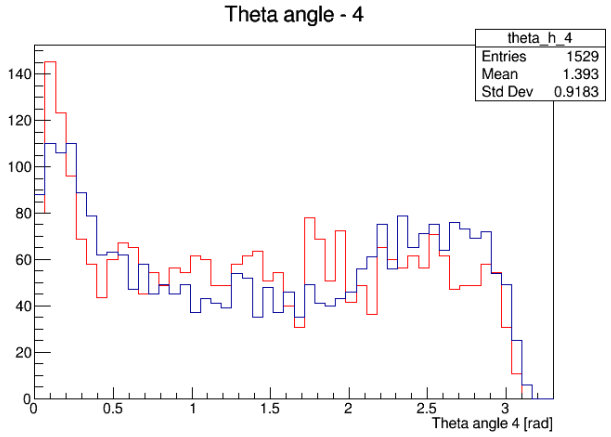
- Angle between b-jet and Higgs boson **;**





Higgs «1»



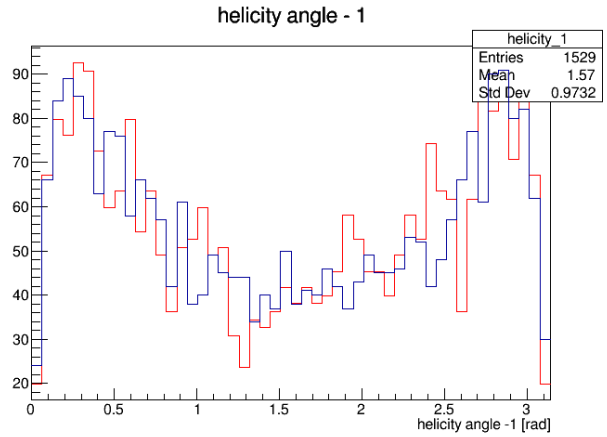


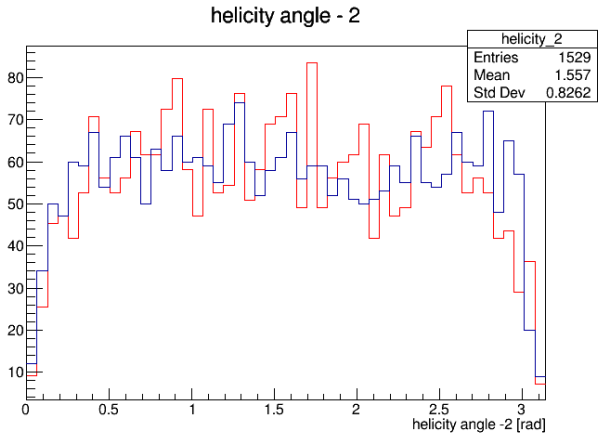
Higgs «2»

Observables

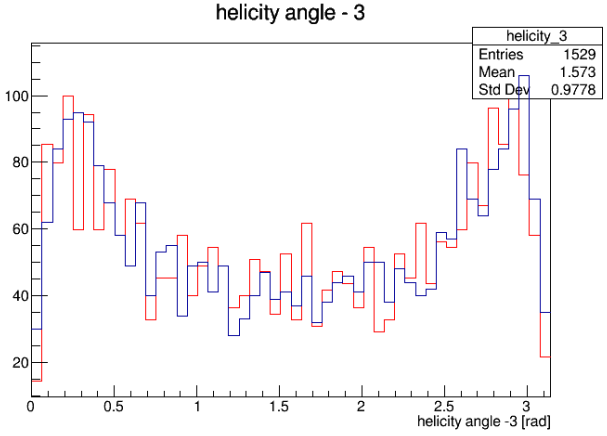
Observables - 4:

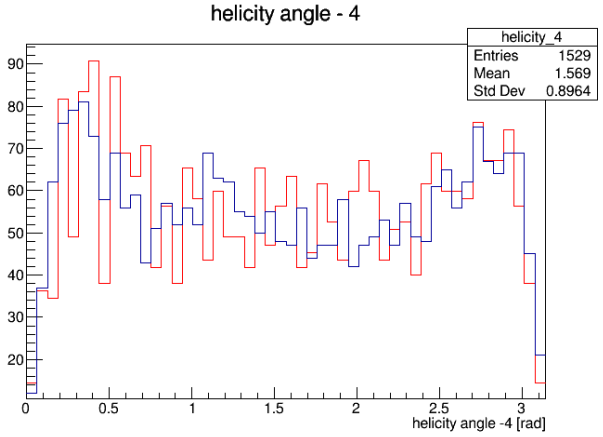
❖ Helicity angle between b-jet and Higgs boson **;**





Higgs «1»



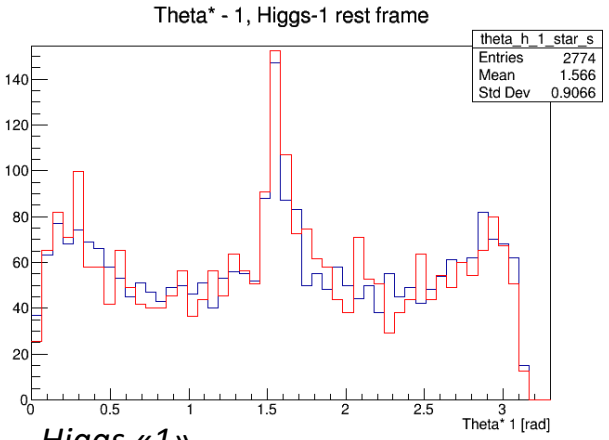


Higgs «2»

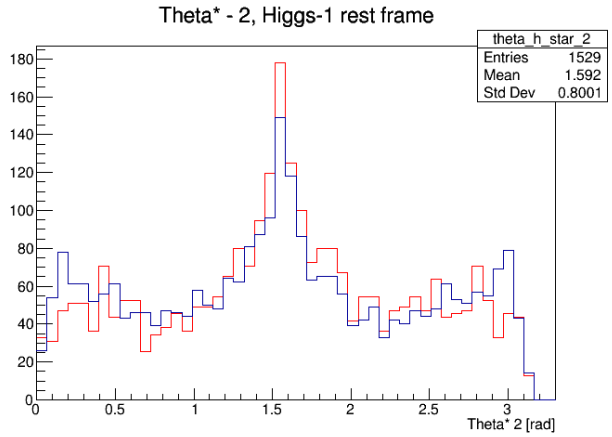
Observables

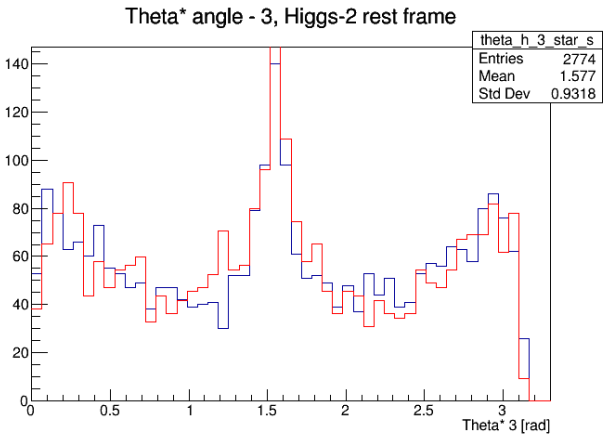
Observables - 5:

- Angle between b-jet and z-axis in Higgs boson rest frame **;**

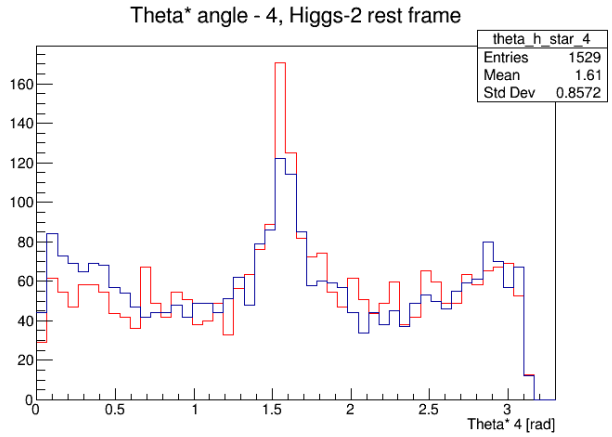


Higgs «1»





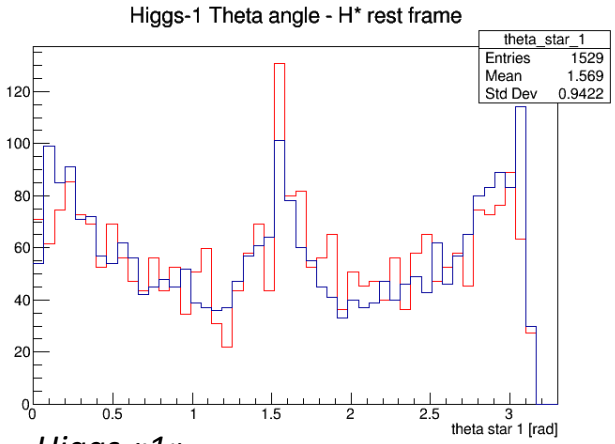
Higgs «2»



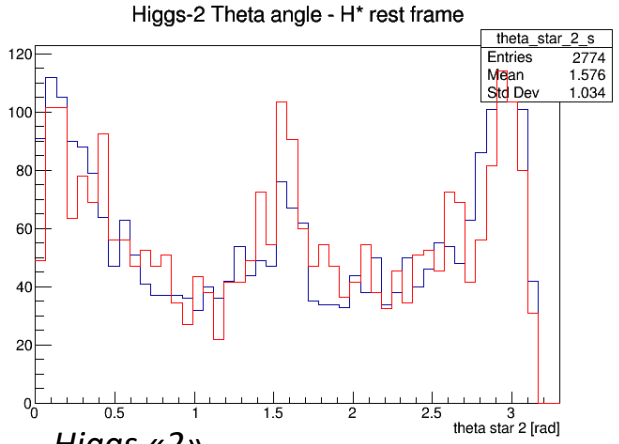
Observables

Observables - 6:

- Higgs angle* ≡ angle between Higgs' and z-axis in Higgs boson* rest frame ;

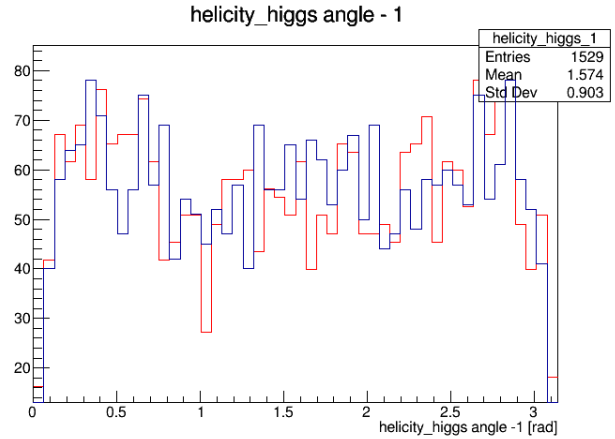


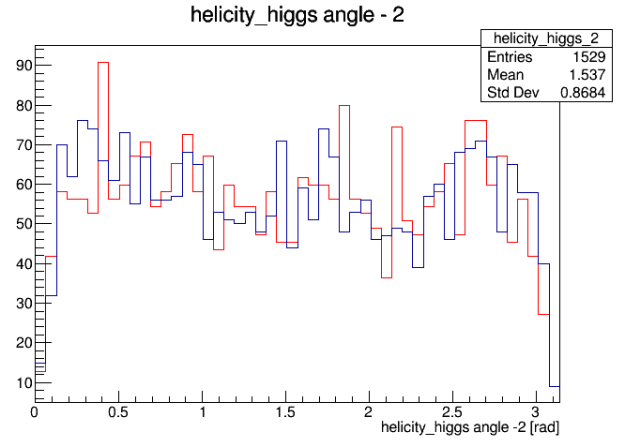
Higgs «1»



Higgs «2»

- Helicity angle between Higgs' and Higgs*.

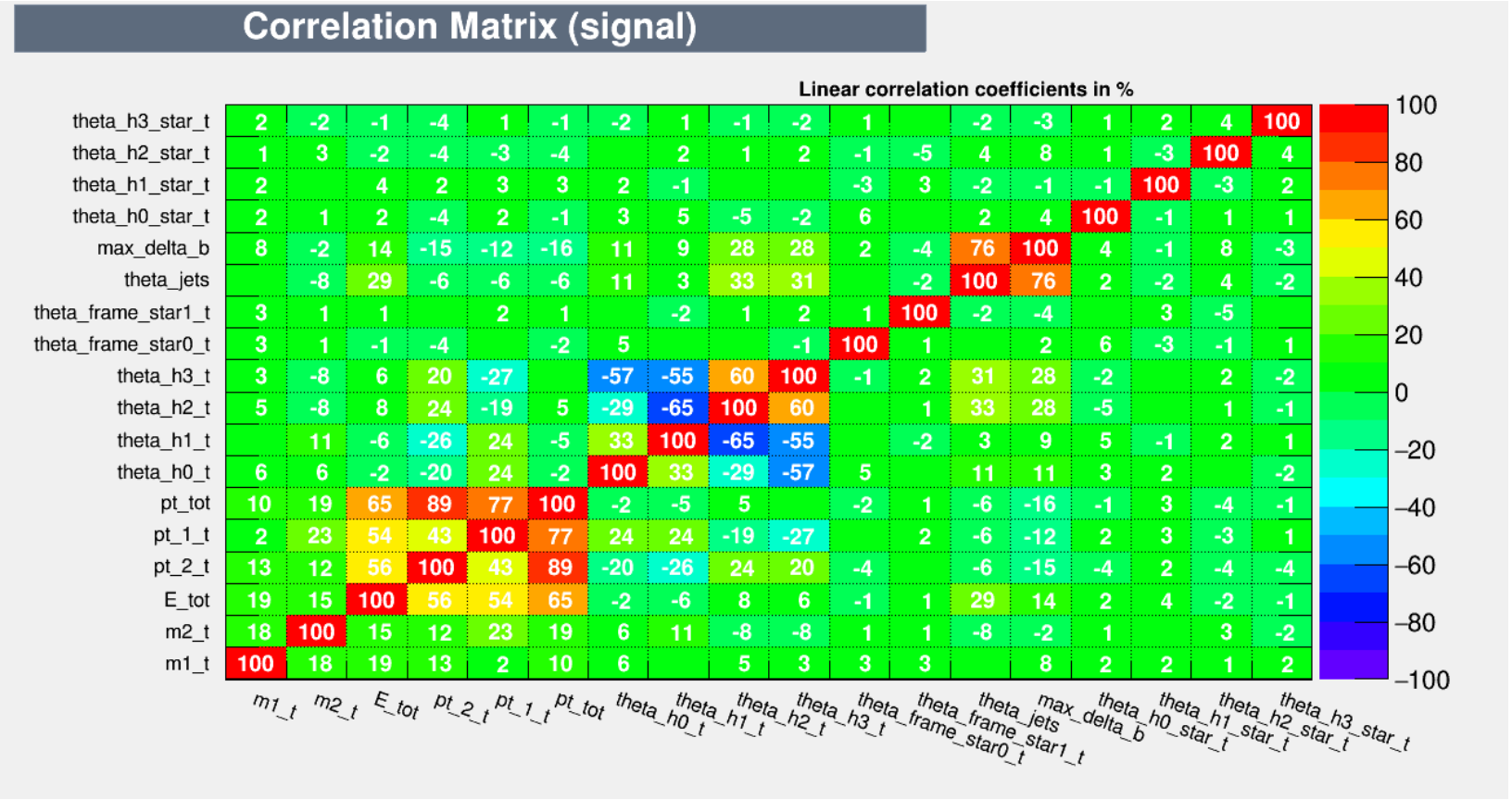




Machine Learning

Studying the correlation:

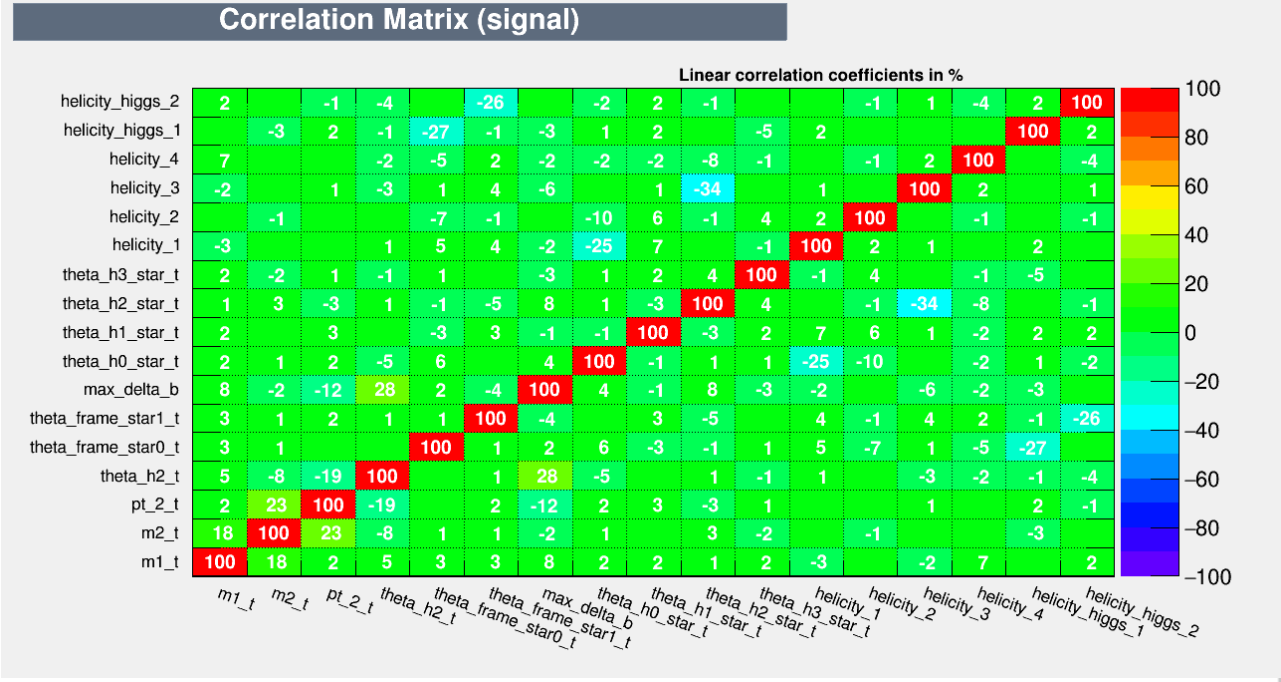
- To avoid overtraining we must exclude strongly correlated variables.



Machine Learning

Observables chosen:

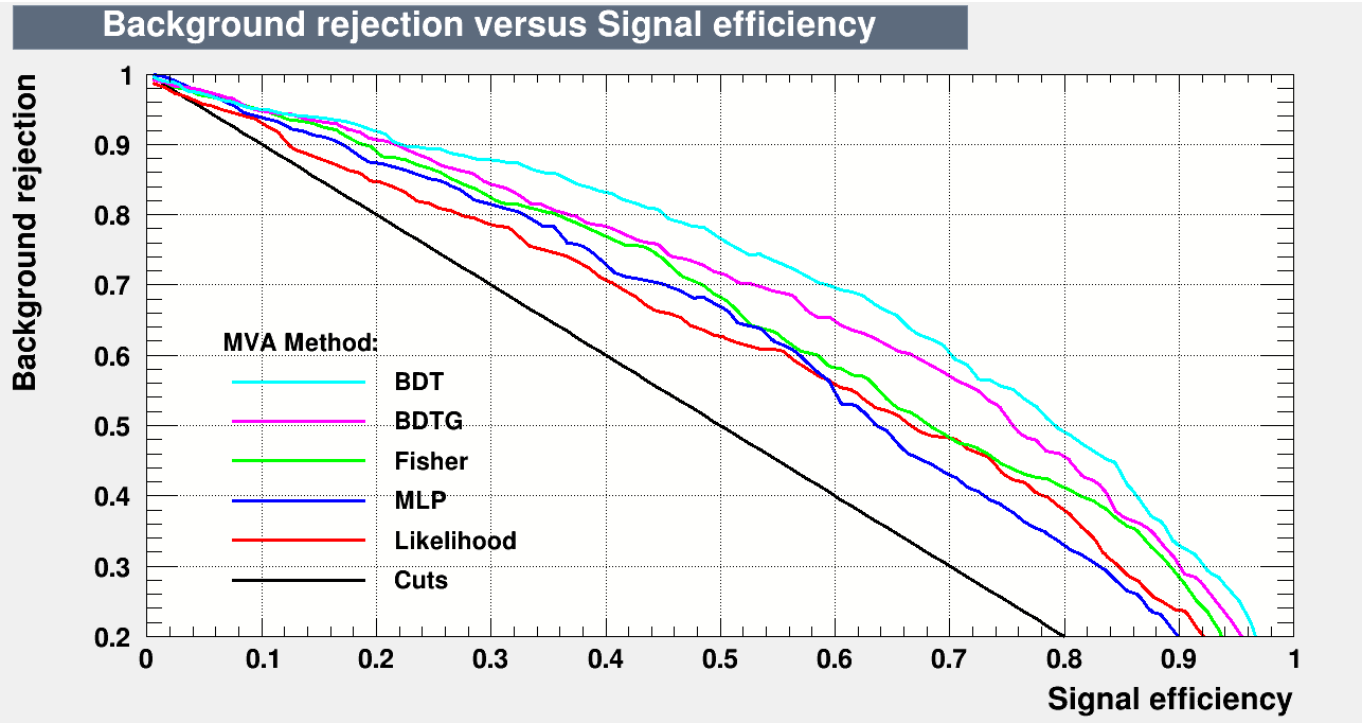
- Invariant mass 1 and 2;
- Transversal momentum 2;
- Angle b-jet2-Higgs;
- All angle b-jets* - Higgs;
- Both Higgs angle*;
- All helicity angles;
- Maximum angle between jets.



Machine Learning

Algorithm:

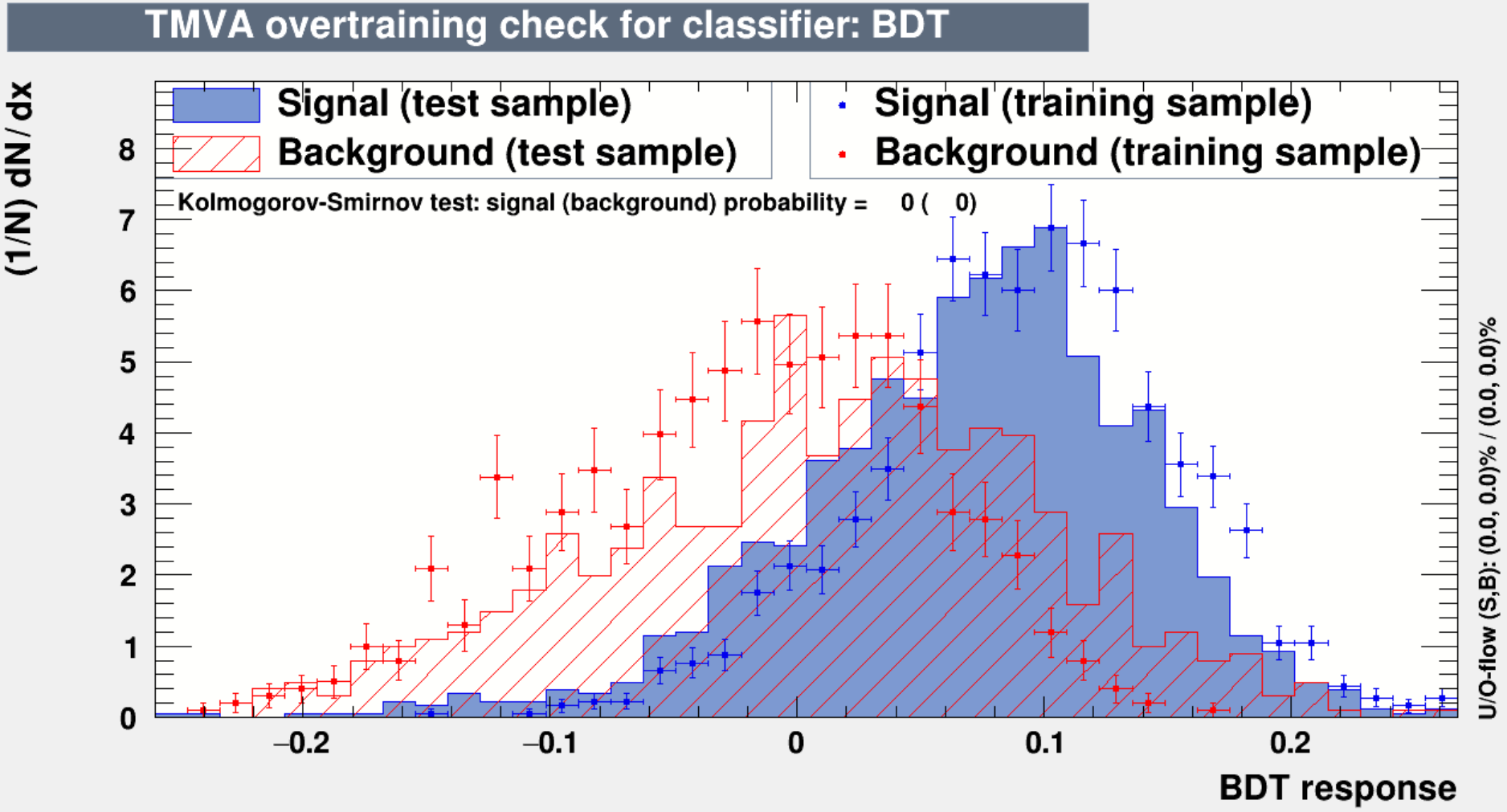
- Sevaral kinds of ML algorithm;
- We look the ROC curve to chose.



- BDT is cleary the best algorithm.

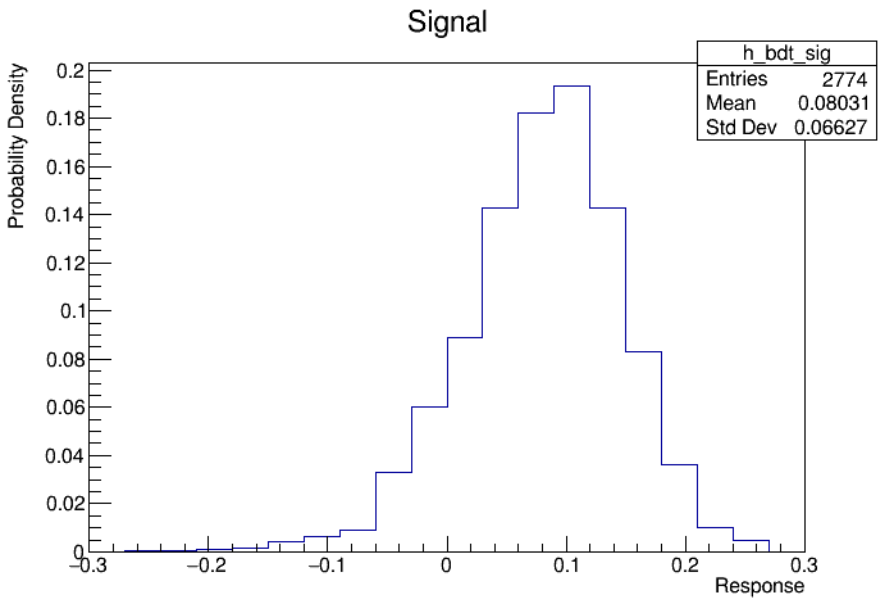
Machine Learning

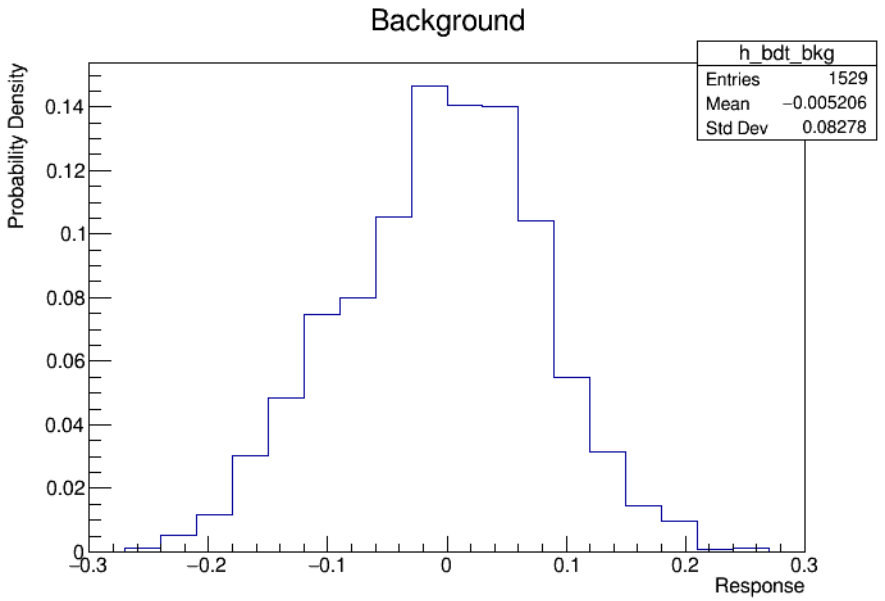
Overtraining check



Data Analysis

Histos from the BDT – 1:

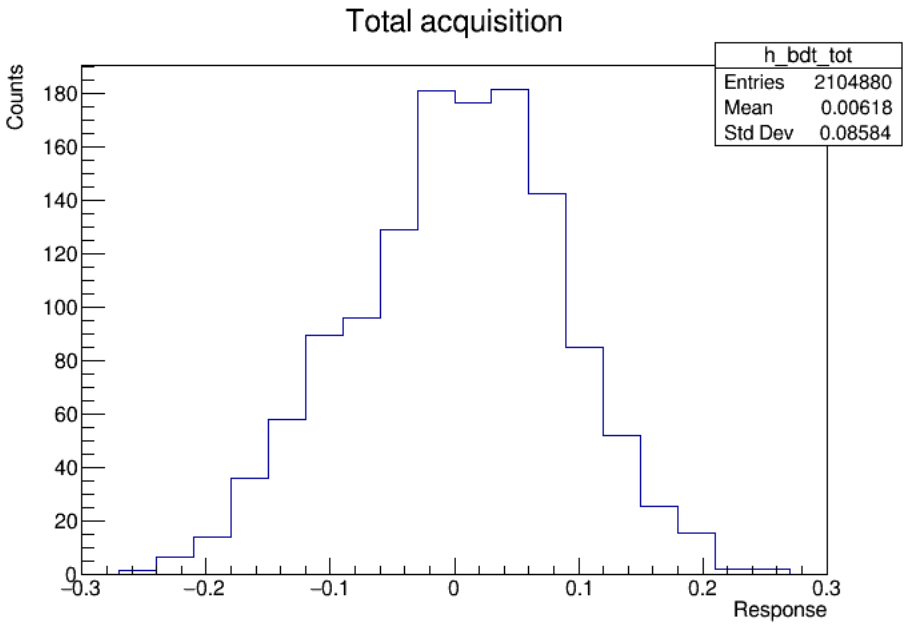




Response ≡ Output of BDT

Data Analysis

Histos from the BDT – 2:



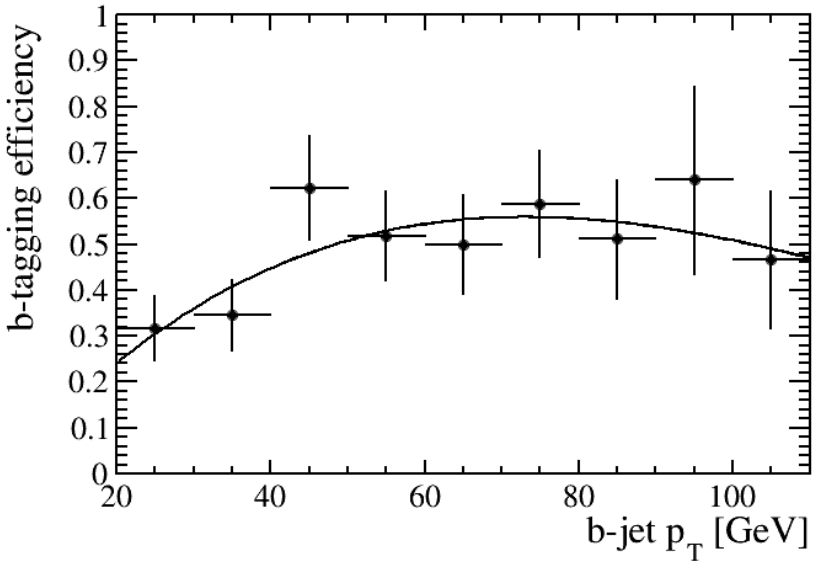
- Weight sum of the previous histograms;
  - $weight = L \cdot \sigma \cdot \varepsilon$;
- Should reproduce what we actually get from the experiment.

Event	L	σ	ε	Counts
Signal	1300 fb^{-1}	0,28 fb	15,10%	55
Background	1300 fb^{-1}	6,00 fb	8,05%	628

Data Analysis

B-tagging:

- Algorithm that identify b-jet in the detector;
- Justify the background we consider;
- It has an efficiency that depends on transversal momentum;



- The probability to detect an event is

$$p = [1 - (1 - \varepsilon_1) \cdot (1 - \varepsilon_2)] \cdot [1 - (1 - \varepsilon_3) \cdot (1 - \varepsilon_4)],$$

with ε_i the «*b-tag efficiency*» of the i-jet.

Data analysis

Final Analysis:

- Performed with RooFit;
- The program deduce signal and background pdf from their histograms;
- Fit the total histogram to get the **signal fraction** value.

$$\frac{\sigma}{signal\ fraction} = 39,37\%$$