Prospects for measuring the di-Higgs coupling with the ATLAS detector at the HL-LHC

Primer Encuentro de Estudiantes e Investigadores en Física de Partículas

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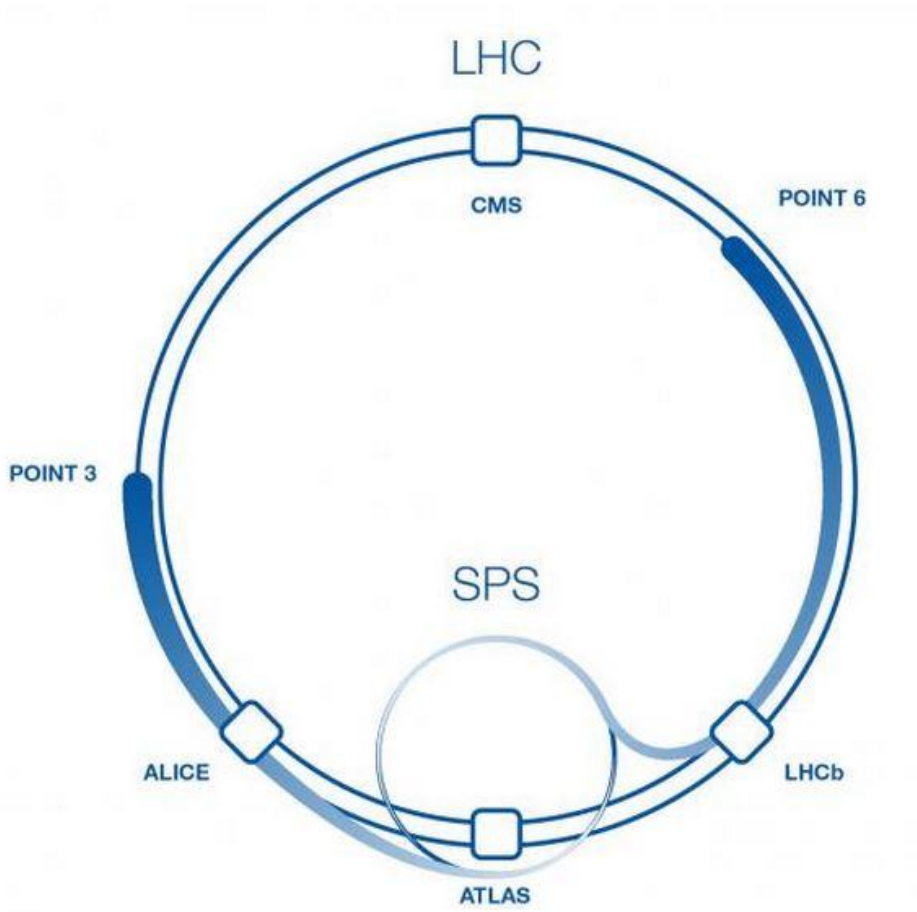
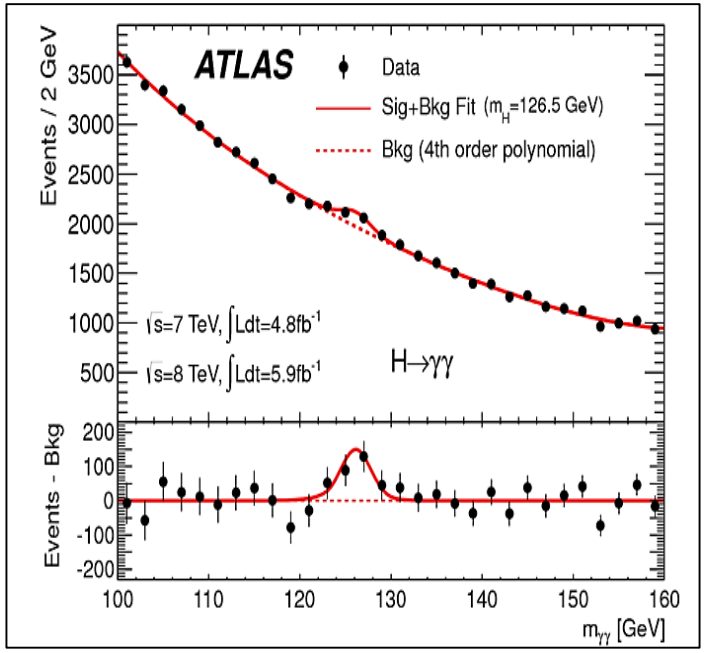
Introduction

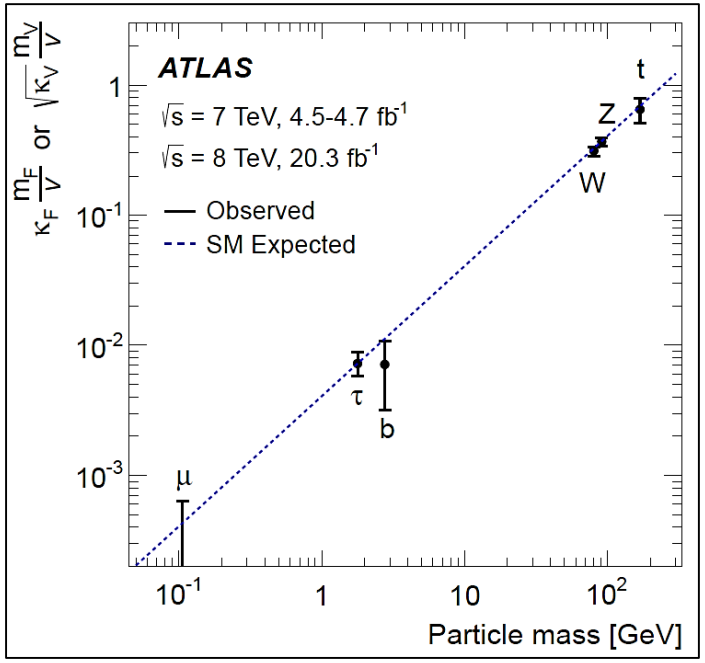
- The **LHC** is a proton collider designed for the study of high-energy physics.
- **ATLAS** is the largest detector of the LHC, which is designed for the discovery of new particles and for the study of already known processes.
- The **HL-LHC** will be a stage in the LHC, where the luminosity will be increased considerably.



Introduction

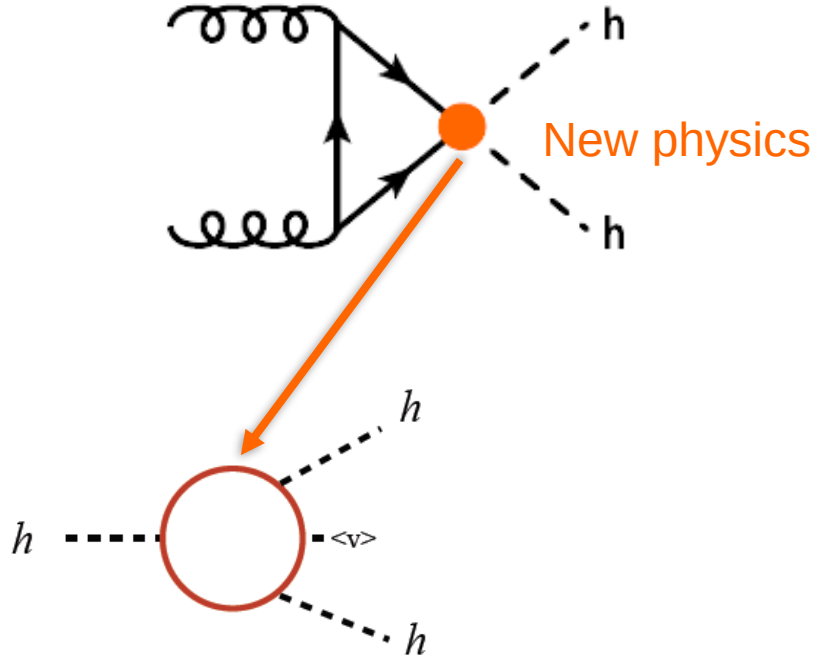
- In 2012 the analyzes of the data collected ATLAS and CMS reported the discovery of **the Higgs Boson**.
- Since then, several experiments have been done to determine its properties such as mass, parity, spin and couplings.





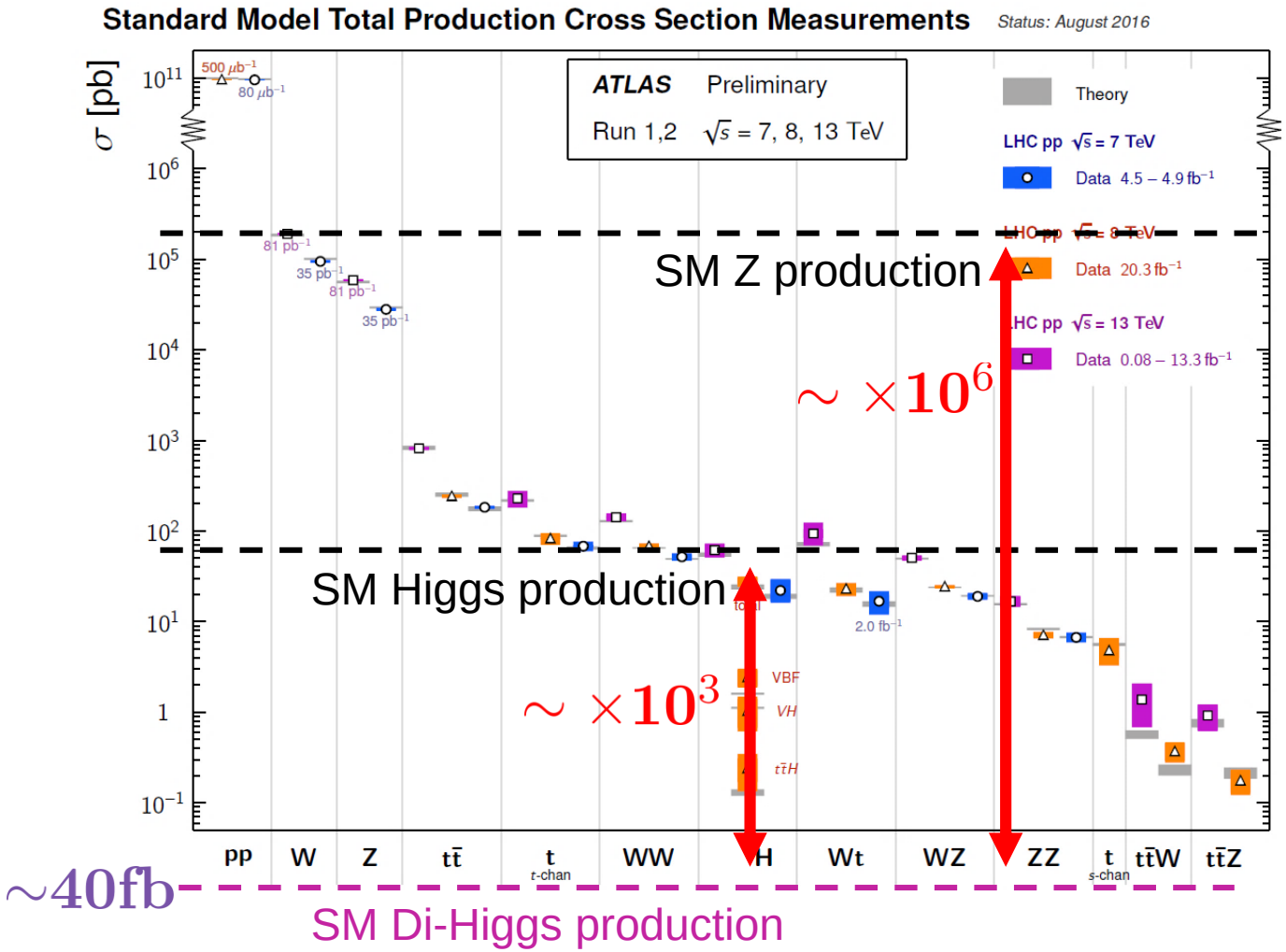
Introduction

- It has not yet been possible to measure the Higgs self-coupling.
- This property is very important to know the nature of the Higgs and the mass mechanism.
- To measure this coupling we have to study the production of bi-Higgs.
- **The production of bi-Higgs is not only associated with the study of Higgs self-coupling, but there may be contribution from BSM.**



Introduction

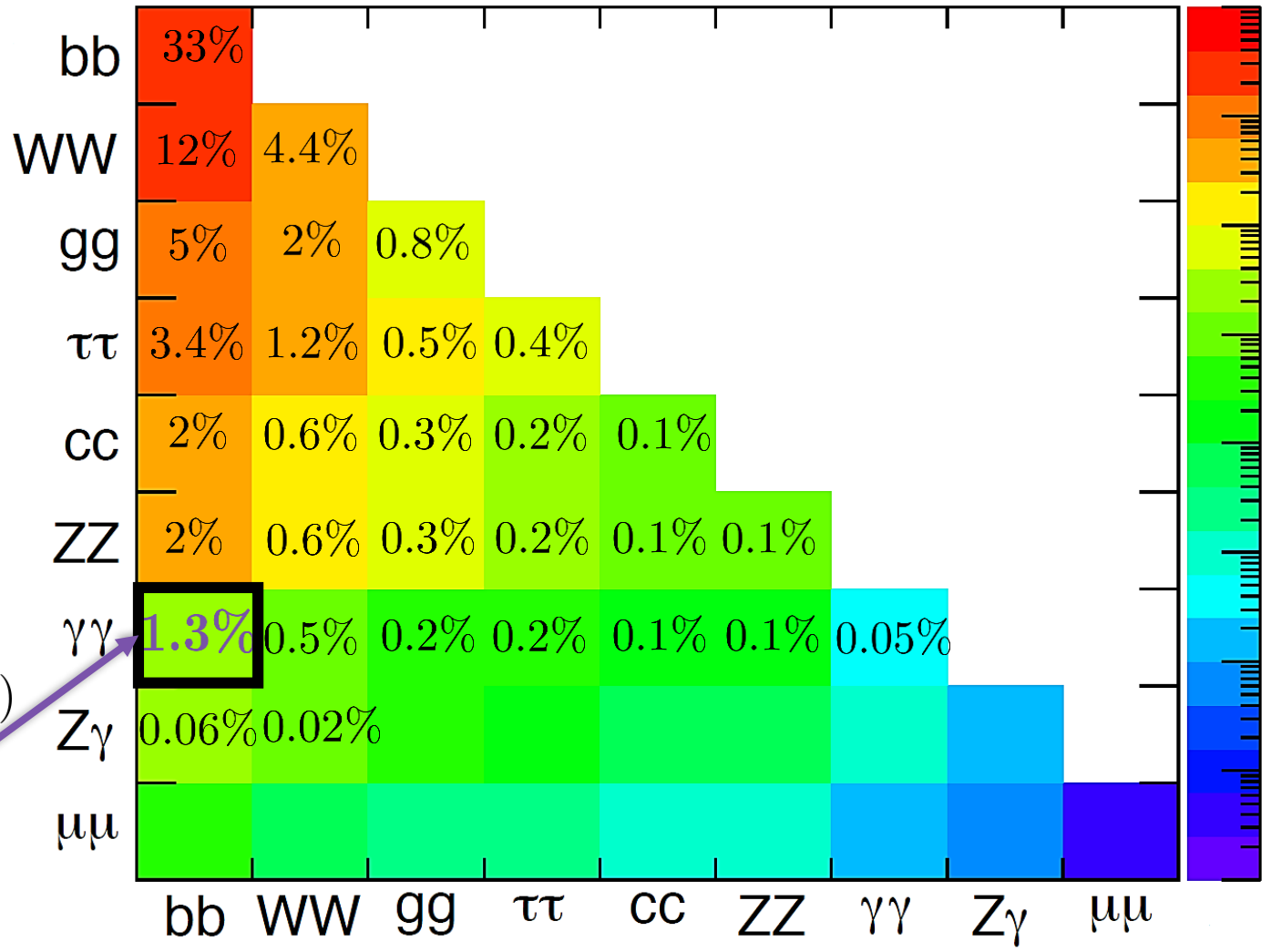
- The production of di-Higgs is much smaller than that of a single Higgs. Leaving only the possibility of a measurement in the era of HL-LHC.



Di-Higgs branching fraction

- The Higgs is an **unstable particle** that has to be studied by its decay channels.
- Each decay channel has a probability of occurrence called **branching fraction** (BR).
- To calculate the BR that a pair of Higgs decay each one to a final state is particular we have to:

$$BR(H \to x_1 x_2) \cdot BR(H \to x_3 x_4)$$

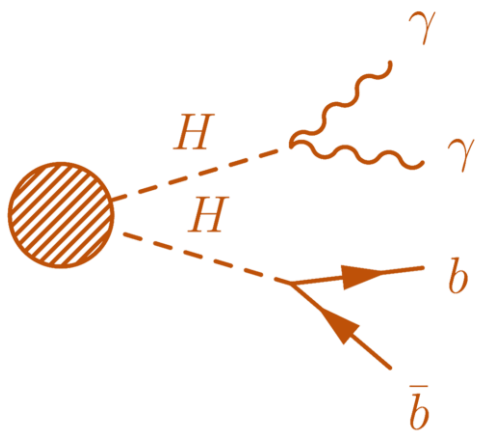


$b\bar{b}\gamma\gamma$

Signal and background samples

- The samples were made with a simulation by Monte Carlo, where the ATLAS response was emulated in the context of HL-LHC (3000 $\boldsymbol{fb^{-1}}$).

$hh \rightarrow b\bar{b}\gamma\gamma$



backgrounds

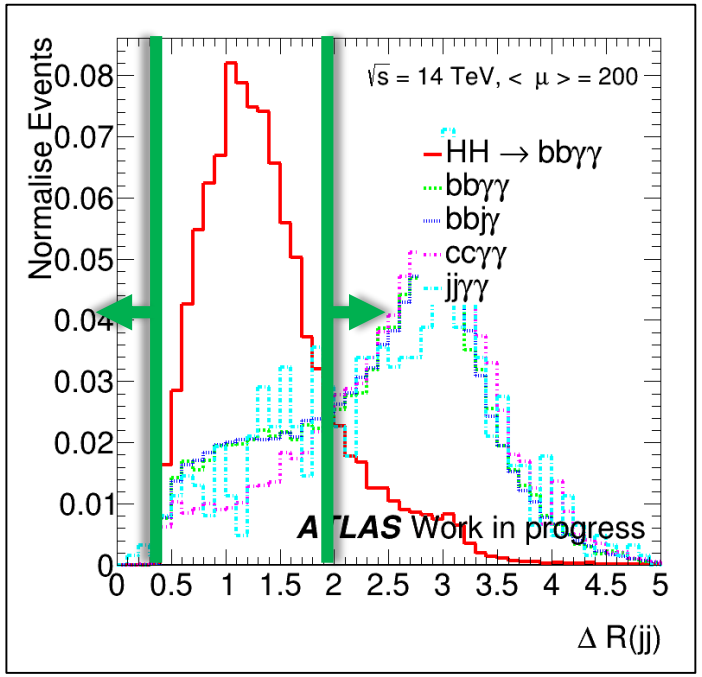
$b\bar{b}\gamma\gamma$
$\gamma j b\bar{b}$
$\gamma\gamma cc$
$\gamma\gamma jj$

The significance was calculated as: $\sigma = \frac{S}{\sqrt{B}}$

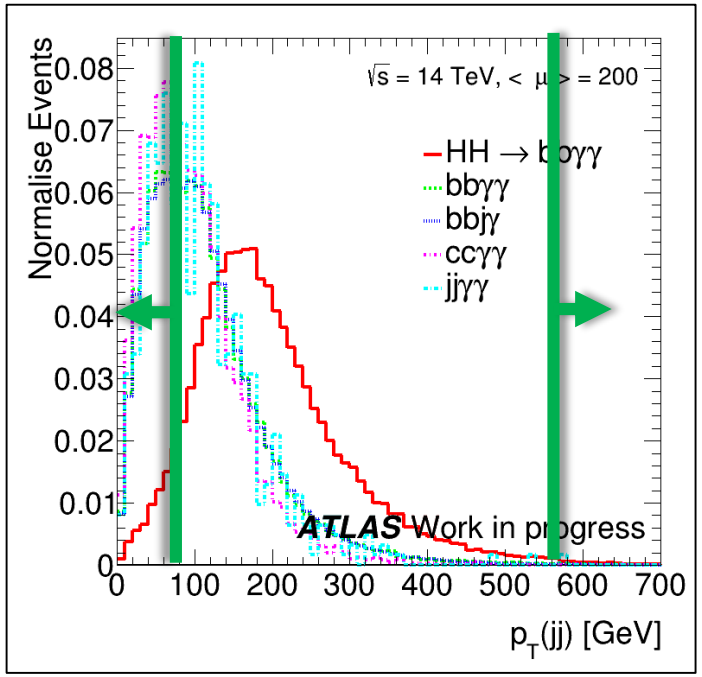
Variables and cuts selections

To reconstruct the signal and background events, different kinematic variables will be used, such as:

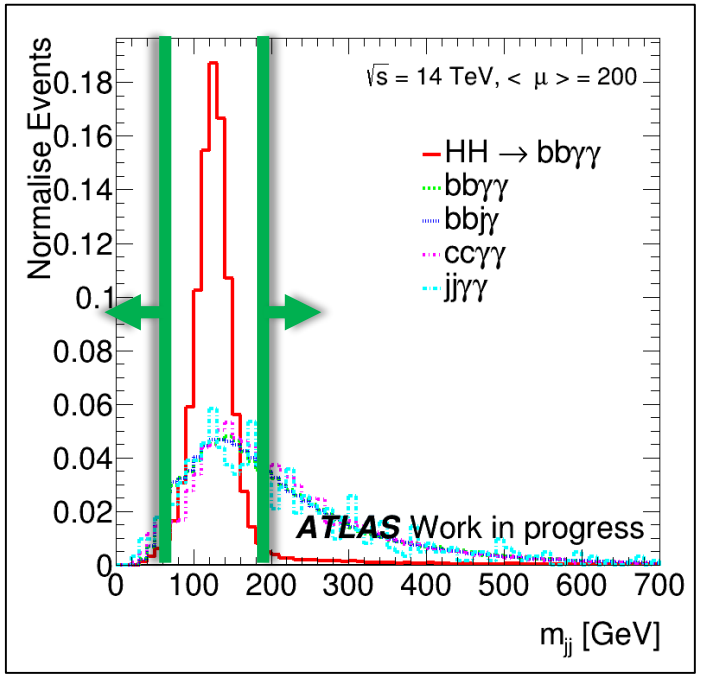
Momentum,



Angular distance,



Invariant mass.



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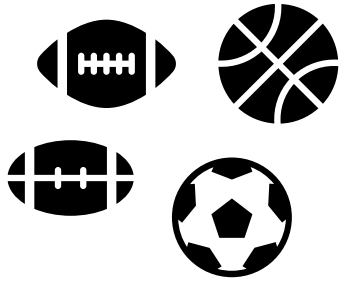
Objective

- The significance with this analysis in a previous work was of **1.05σ**.
- **The main objective of this work was to improve this sensitivity using multivariate analysis.**

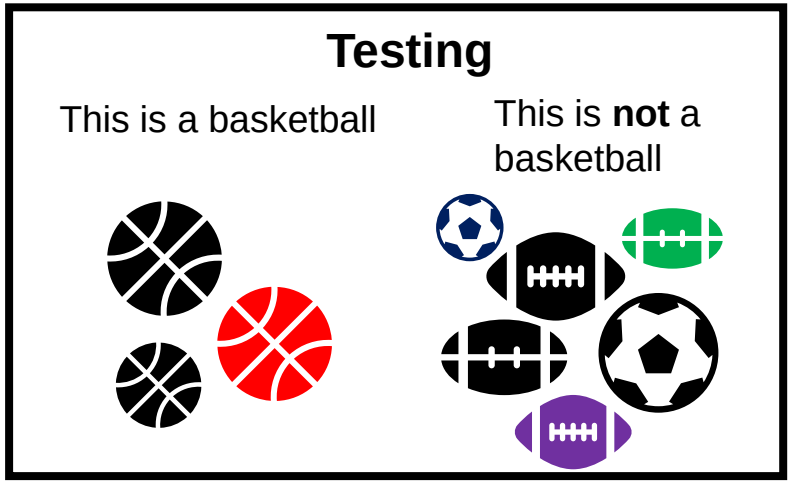
Multivariable analysis

The multivariate analysis (MVA) consists of considering the information of all the variables of the analysis to find new selection criteria.

If we want to teach a computer how to distinguish between different types of balls, the balls that are basketball.

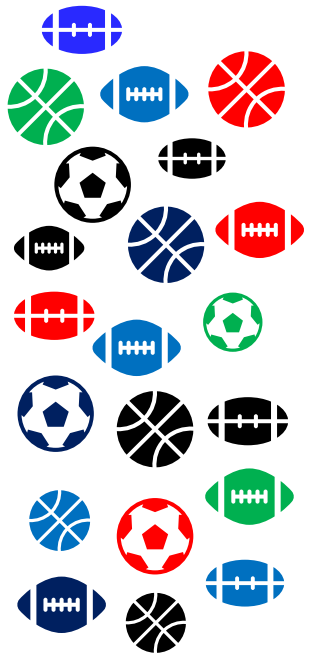


- You have to consider variables: shape, size, color, mass, etc.
- From these designate **samples of testing and training.**



Multivariable analysis

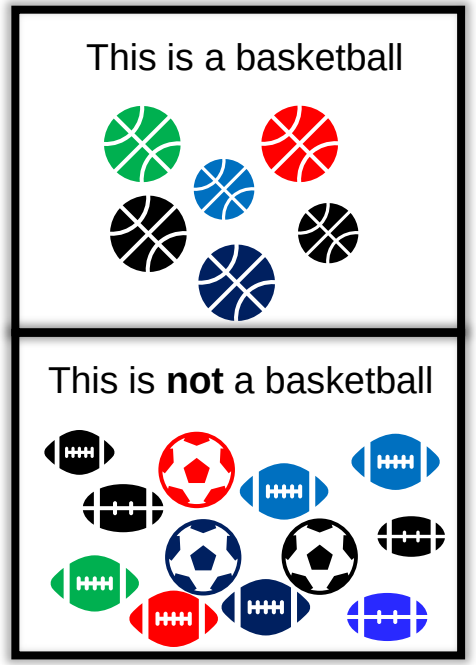
Data



Selection criteria

Color	Shape	Mass
Signal	Signal	Signal
Background	Background	Background

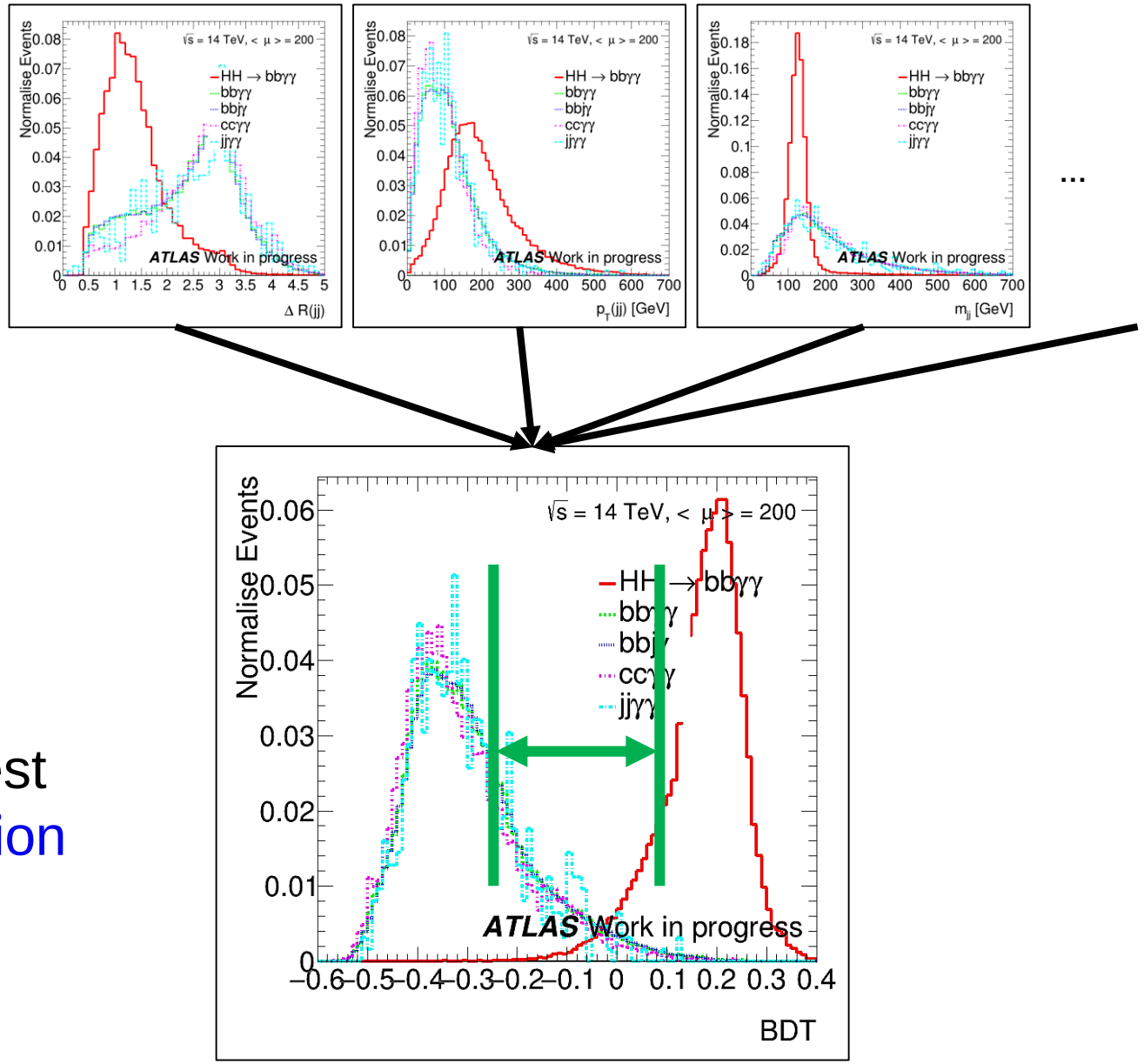
If all these criteria are considered, the computer will be able to know that:



Multivariable analysis

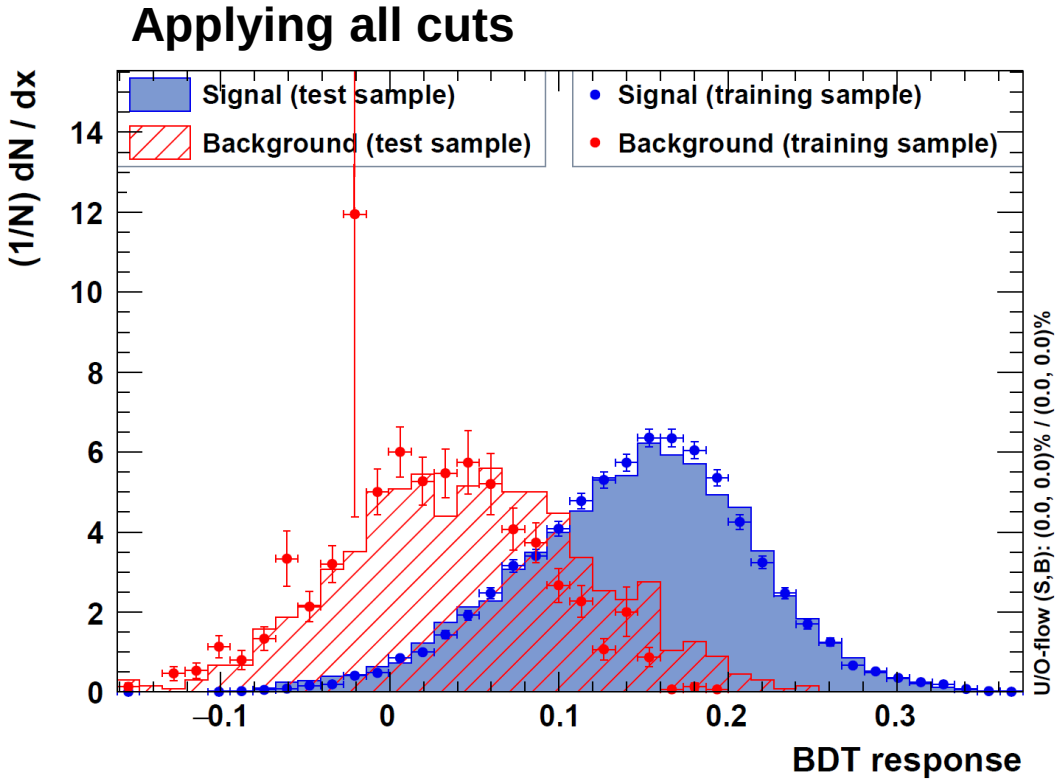
- The multivariate analysis (MVA) consists of considering the information of all the variables of the analysis **to find new selection criteria**.

- The MVA method that had the best performance was Boosted Decision Tree (BDT)



Multivariable analysis

- The response is affected by the **number of events** used for the analysis.
- The **MVA needs to be trained**, using test and train samples.
- If the train performance exceeds the test there is **over-training**.



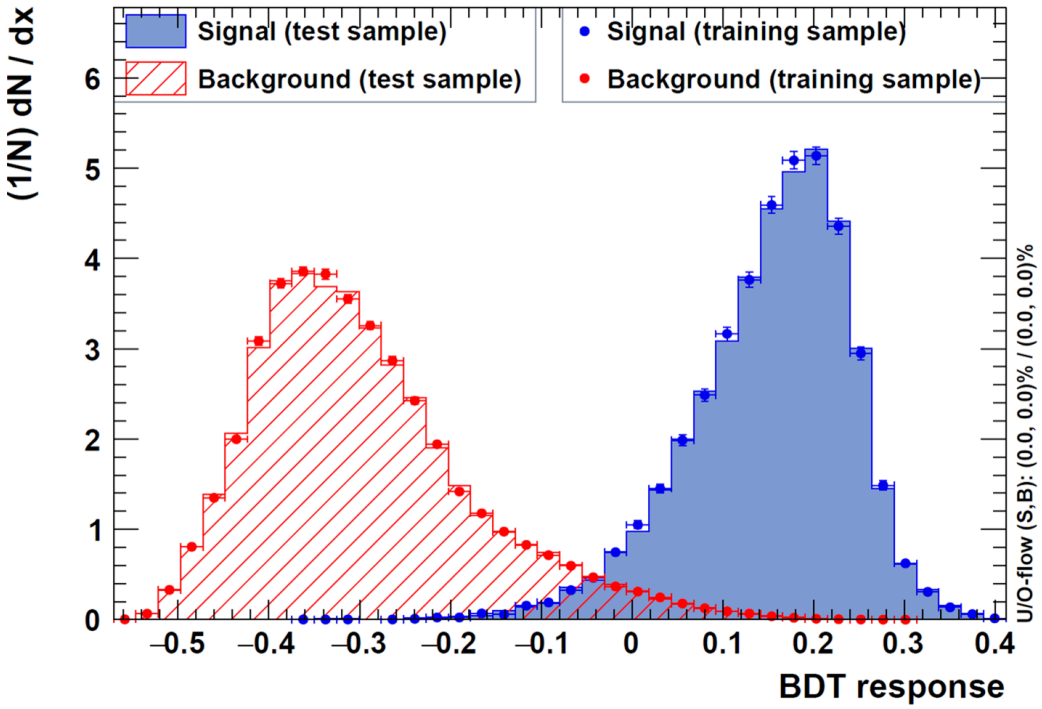
Significances

The table shows the improvement of the significance calculated with **MVA** compared with the **cut-based** analysis only.

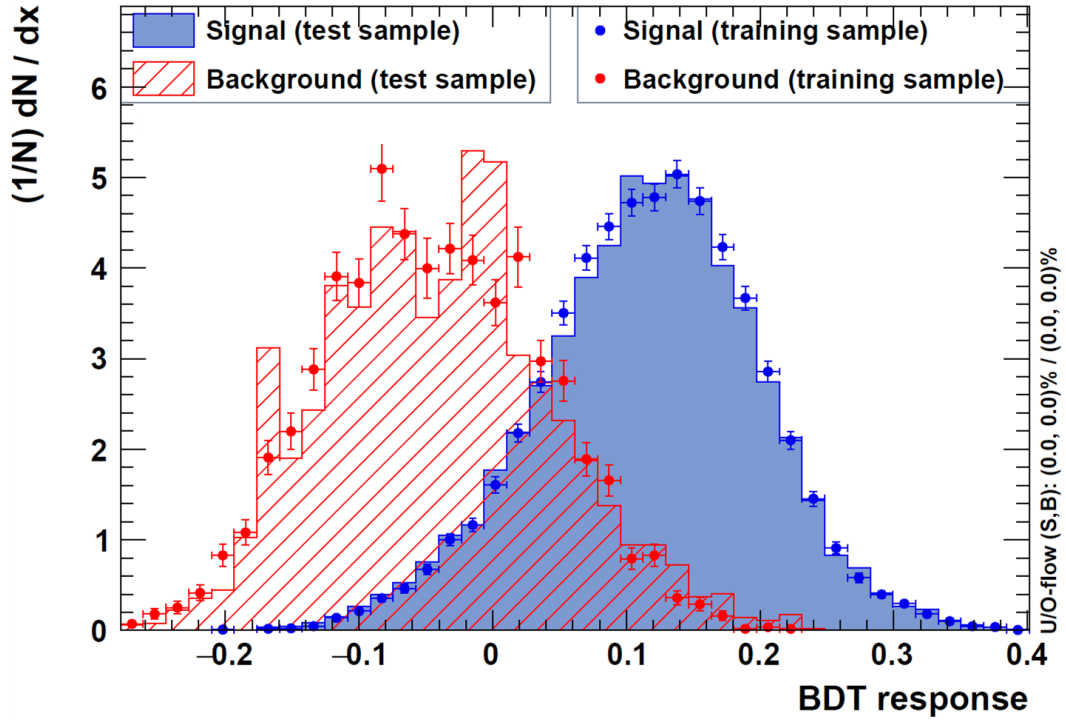
Selection criteria	Cut-based[σ]	Cut-based+MVA[σ]
No. fotons min.	0.03	1.72
No. fotons max.	0.03	1.72
No. jets min.	0.03	2.14
No. bjets min.	0.13	2.58
leading bjet p_T min.	0.14	2.63
No. bjets max.	0.14	2.63
No. electrons	0.13	2.45
No. muons	0.13	2.41
$\Delta R_{b\bar{b},\gamma\gamma,b\gamma}$	0.13	2.41
$m_{\gamma\gamma}$ min.	0.28	2.60
$m_{\gamma\gamma}$ max.	0.44	2.90
$m_{b\bar{b}}$ min.	1.04	2.57
$m_{b\bar{b}}$ max.	1.13	2.56
$p_T^{\gamma\gamma}$	1.39	2.60
$p_T^{b\bar{b}}$	1.40	2.79

Over-training Discriminator

Significance **2.63σ**



Significance **2.90σ**



Conclusions

- The multivariate analysis shows a considerable improvement in the results compared with only the cut-based implementation.
- The BDT method showed the best performance, which reached a significance of **2.63σ** (twice better than the significance calculated with cut-based).

Future works

- Verify results with new and more optimistic versions of the ATLAS detector simulations in the HL-LHC.
- Improve this sensitivity considering more variables in the analysis.
- Verify the results with a shape analysis.

Gracias