Mesurement of the Higgs self-coupling through same-charge di-leptons channel

Journées de Rencontre des Jeunes Chercheurs

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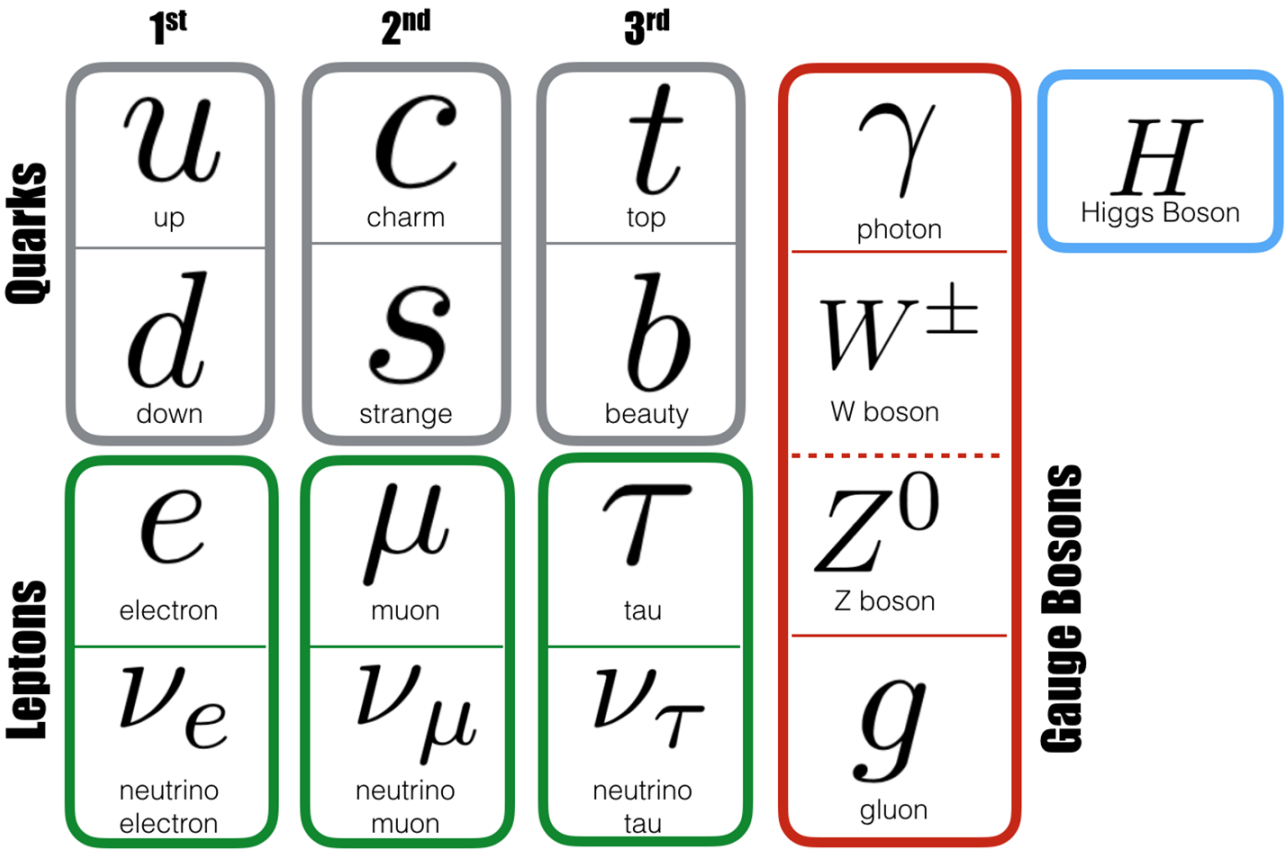
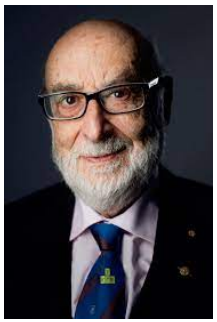
Introduction

The Standard Model



Introduction


François Englert


Robert Brout


Peter Higgs


Thomas Kibble


Gerald Guralnik


Carl Richard Hagen

- In 1964, 6 physicists proposed a mechanism granting mass to known particles and introduced a new particle:

" The Higgs boson or BEH boson "

- In 2012, a bosonic particle have been observed with a mass equals to 125GeV has been observed by ATLAS and CMS Collaborations at the LHC
- Since, physicists want to probe the various properties that we confer to the Higgs boson

Outline

What's the Higgs Field or Higgs boson?

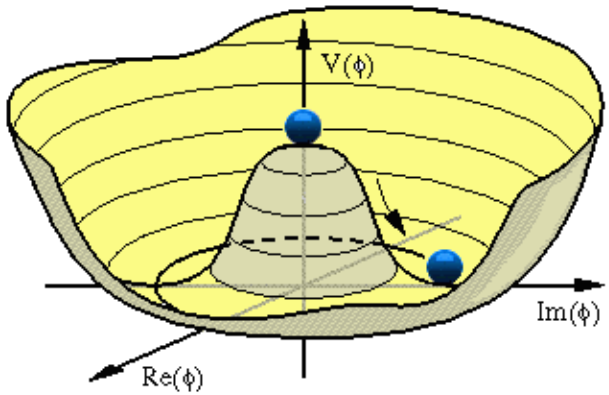
A room, full of physicists quietly chattering

The star will produce a cluster of admirers Increasing its resistance of movement

Higgs Field

Higgs Field could be described with a Lagrangian:

$$L_H = (D_\mu \phi)^\dagger (D^\mu \phi) - \mu^2 \phi^\dagger \phi - \lambda (\phi^\dagger \phi)^2$$

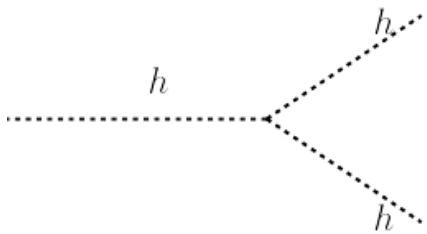


Higgs Field potential after Symmetry breaking:

$$V = V_0 + \underbrace{\lambda \nu^2 h^2}_{\text{mass}} + \underbrace{\lambda \nu h^3}_{\text{trilinear coupling}} + \underbrace{\frac{\lambda}{4} h^4}_{\text{quadrilinear coupling}} \quad \text{with} \quad \frac{\mu}{\sqrt{\lambda}} \equiv \nu$$

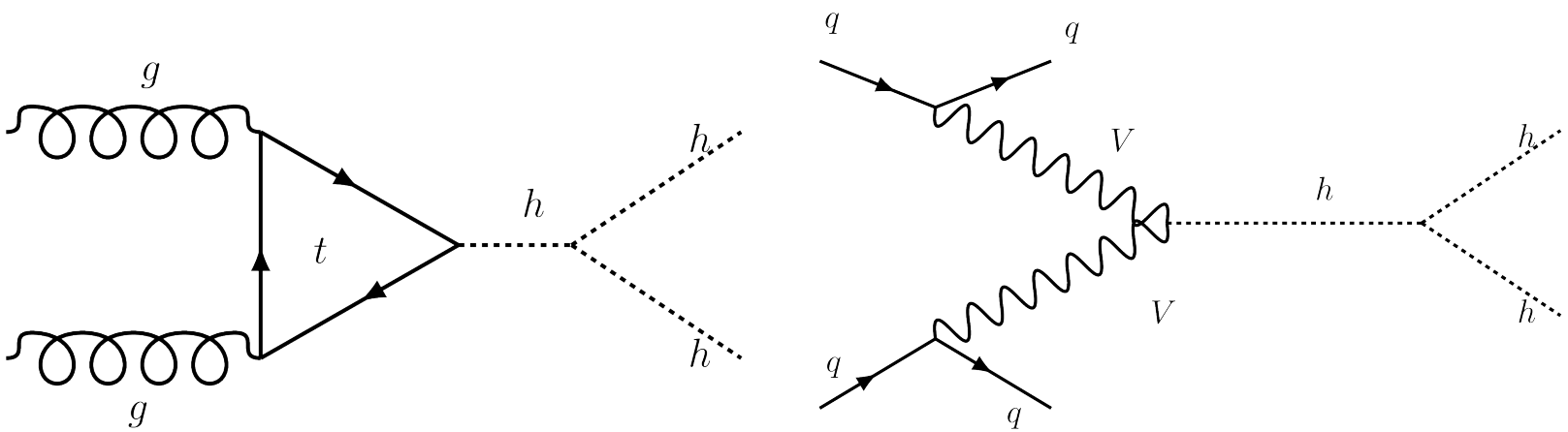
Aim of the study:

- Obtain a direct measurement of λ_{hhh}
- Proof of the Higgs Field potential shape



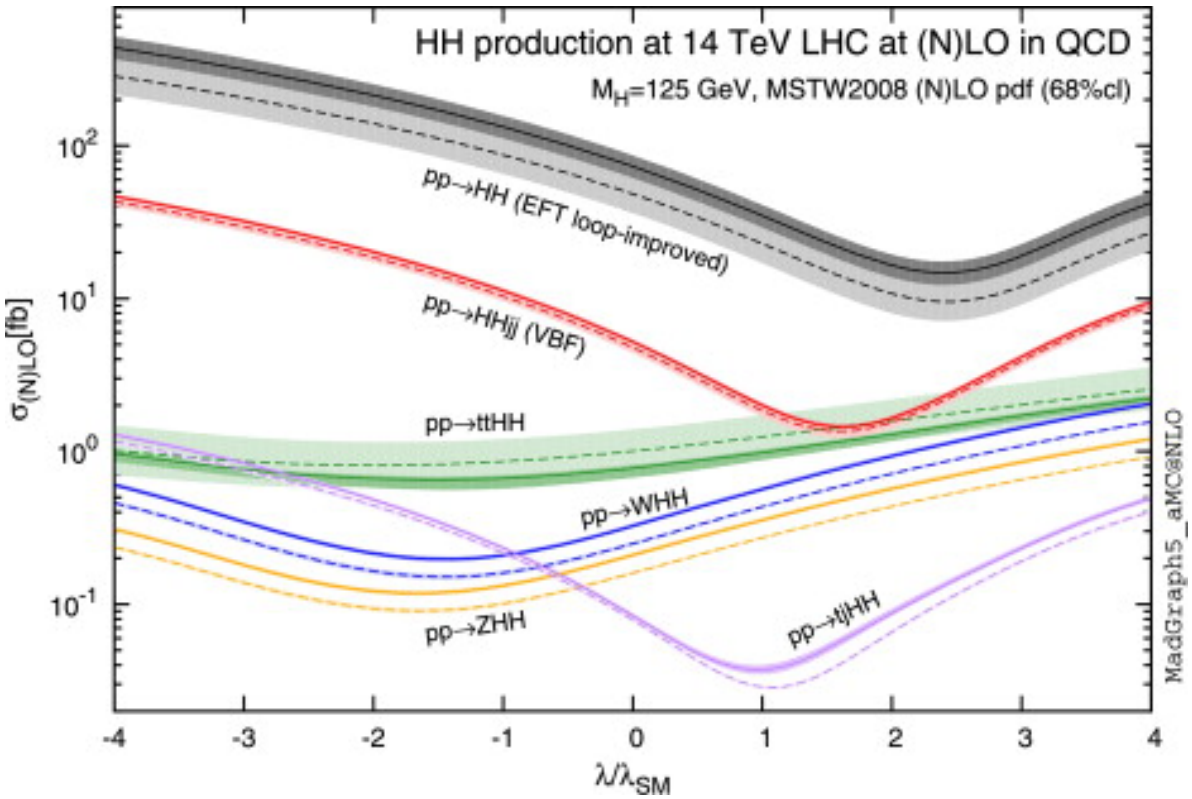
HH production at LHC

- At LHC the dominant HH production modes are: ($\sqrt{s}$= 13 TeV)
  1. Gluon-Gluon fusion (ggf) $\sigma = 30$ fb
  2. Vector boson fucion (VBF) $\sigma = 2$ fb
  3. t$\bar{t}$HH $\sigma = 1$ fb
  4. Double Higgs-strahlung (VHH) $\sigma = 1$ fb



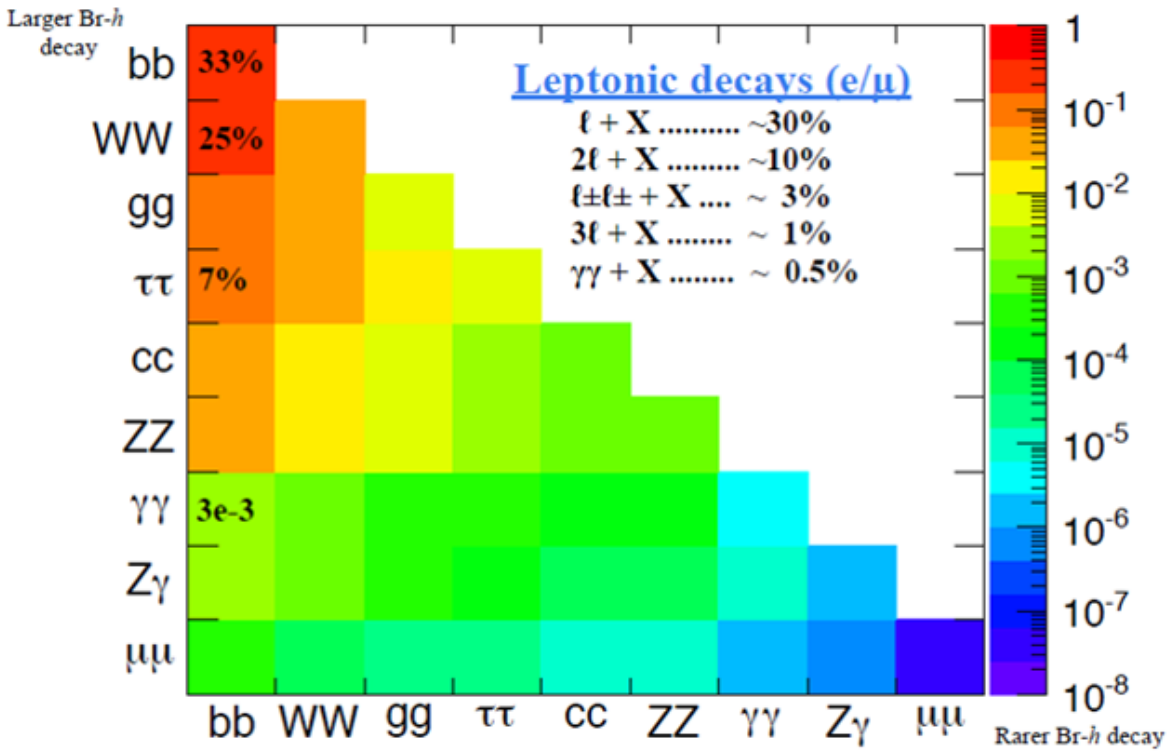
- Total cross section of the Higgs production at LHC = 57 pb

Relation between λ_{HHH} and σ_{HH}



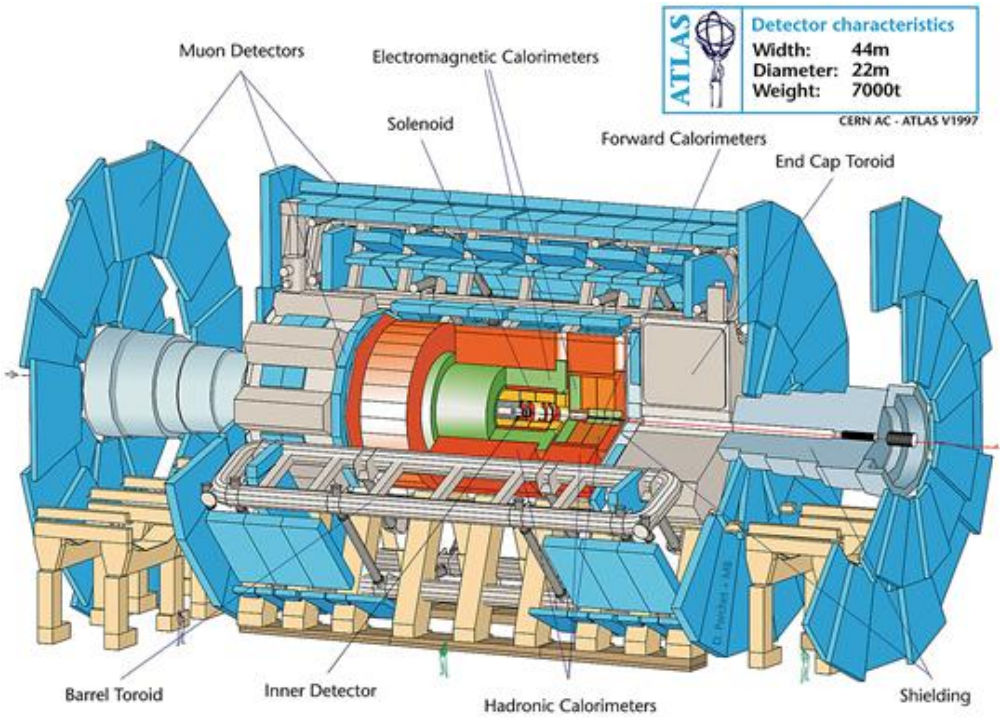
- **Aim of the analysis:** Search to measure the cross section of the HH production

HH decays

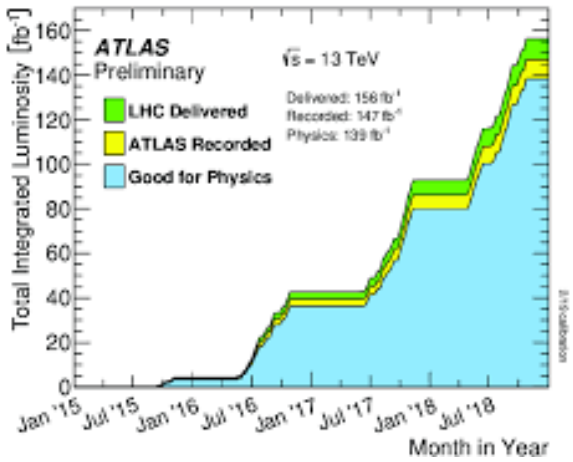


- Signal = Decay of HH into a specific signature
- Background = All processes, different from HH leading to the same signature
- Signature $\ell^{\pm}\ell^{\pm}$ or 2ℓSS $\rightarrow$ Reject a maximum of backgrounds
- Main Backgrounds: VV production, Boson V production and $t\bar{t}$

ATLAS experiment



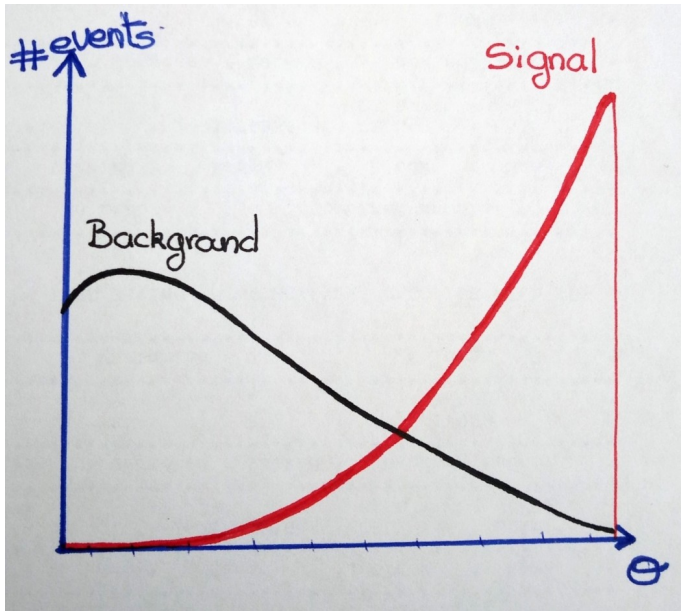
ATLAS detector



- Run II: From 2015 to 2018
- Integrated luminosity 139 fb−1

Analysis - Strategy

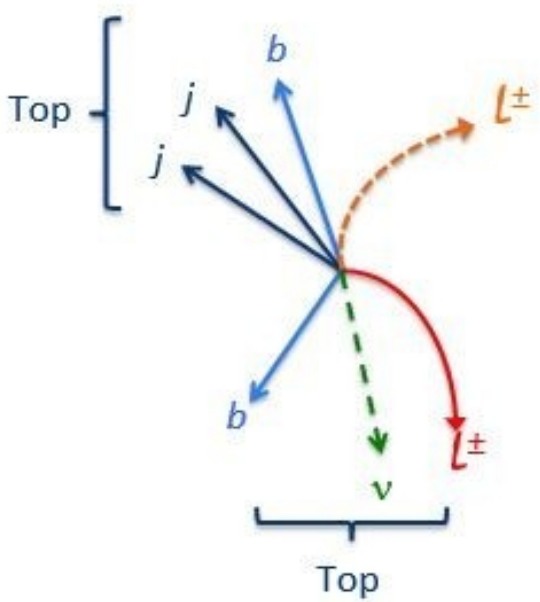
- Analysis is performed using Monte-Carlo Simulation
- Each event is described by a list of properties : pT, charge, Invariant mass...
- **Aim of this analysis** :

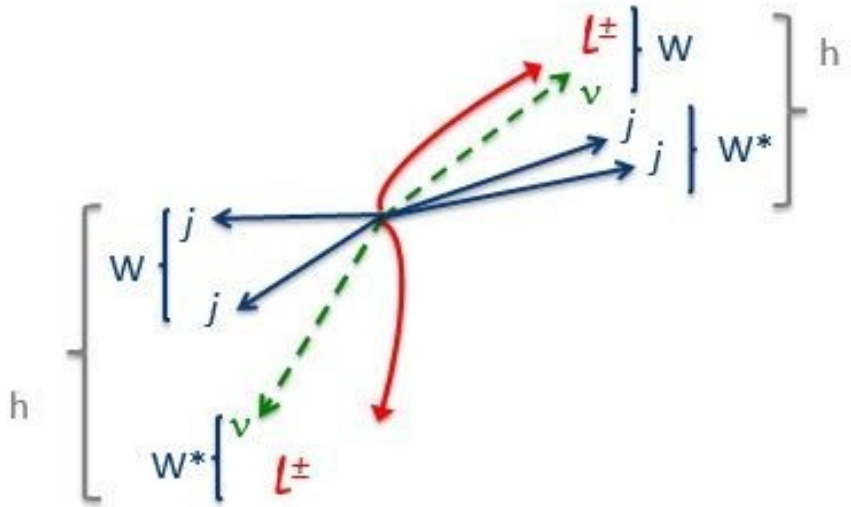


- 3 Main Backgrounds: VV production, Boson V production and $t\bar{t}$ $\rightarrow$ Various properties
- Train 3 specific BDTs, targeting each main background
- Combine them into a final discriminant variable

How can we distinguish Signal from Backgrounds?

2ℓSS - Choice of discriminating variables



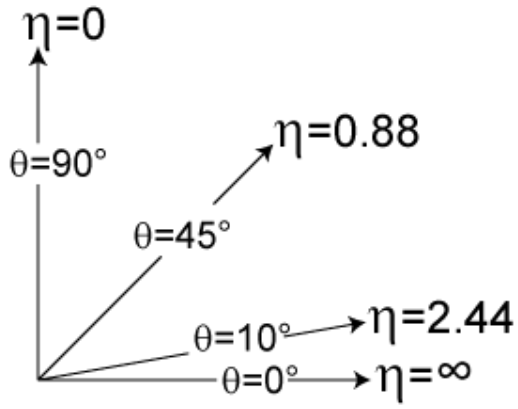


$t\bar{t}$ VS HH

- Number of jets
- Transverse missing energy
- Number of b-jets
- ΔR between lepton and jets

Discriminating variables

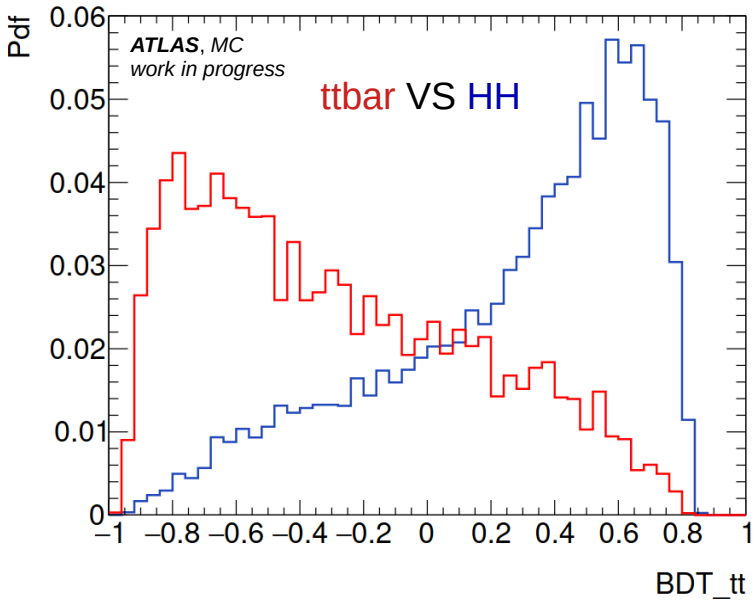
- Pseudo-rapidity η
- Masses ($\ell - \ell$ or ℓ-jets or total)
- Distance between particles ($\ell - \ell$ or ℓ-jets)
- Transverse momentum
- Identity of the particle
- Number of jets / particles
- Transverse missing energy : energy not detected (usually neutrinos production)

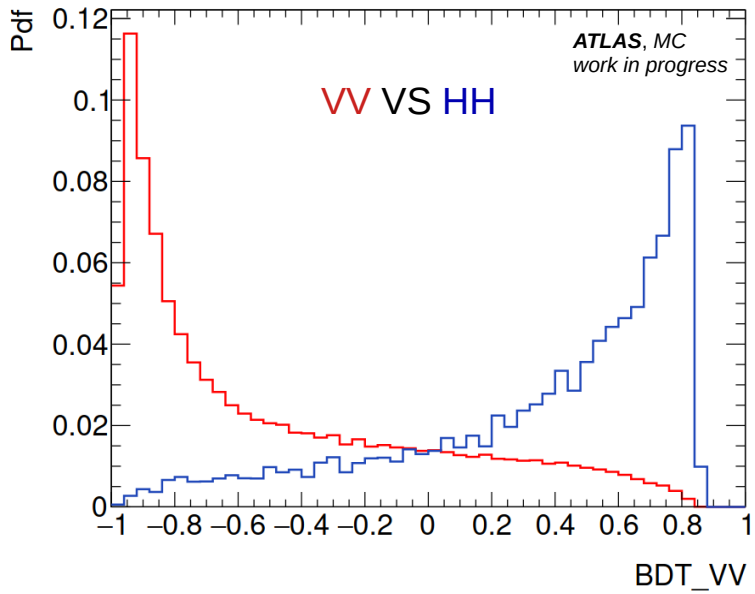


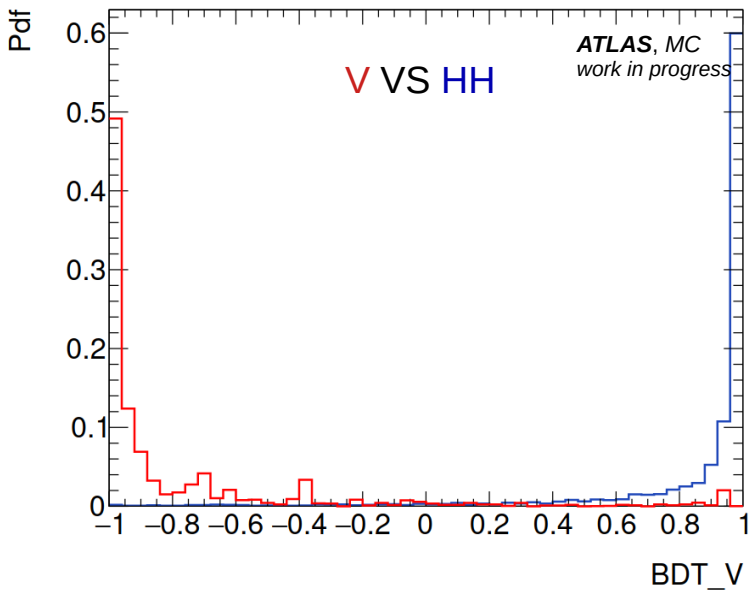
→ Between 10 and 12 variables identified per background
→ Use them as input of the BDT method

BDT: ML method using binary criteria

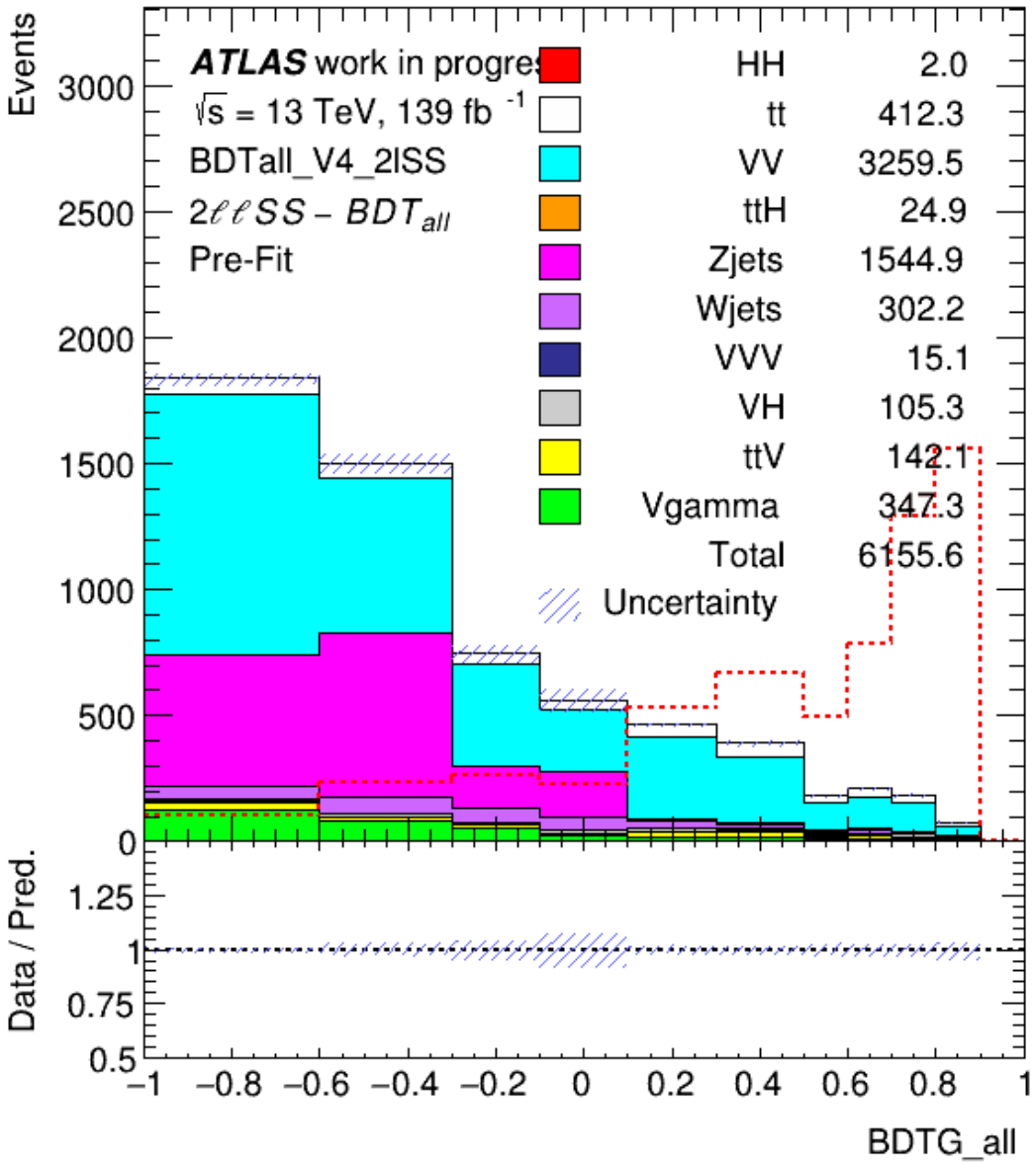
Specific BDTs







Combined BDT

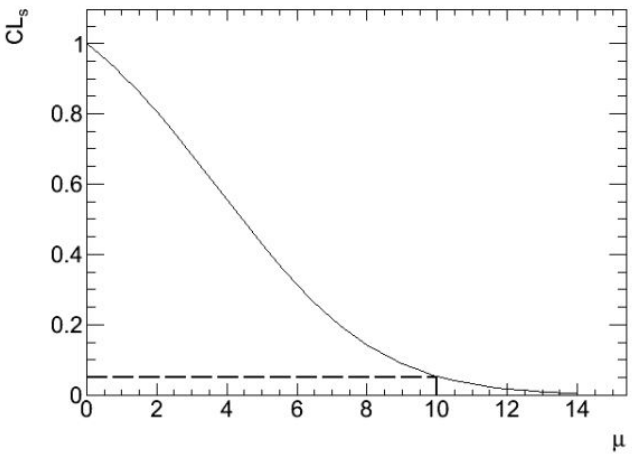


- Final BDT output estimated for all background - Stat only (no systematics)
- All shapes and normalisations from MC simulation
- Asimov fit with TRExFitter

Statistics and Cls method

Profile likelihood (TRExFitter)

- The signal strength is defined as $\mu = \frac{\sigma}{\sigma_{SM}}$
- Frequentist approach
- Use CL_s method

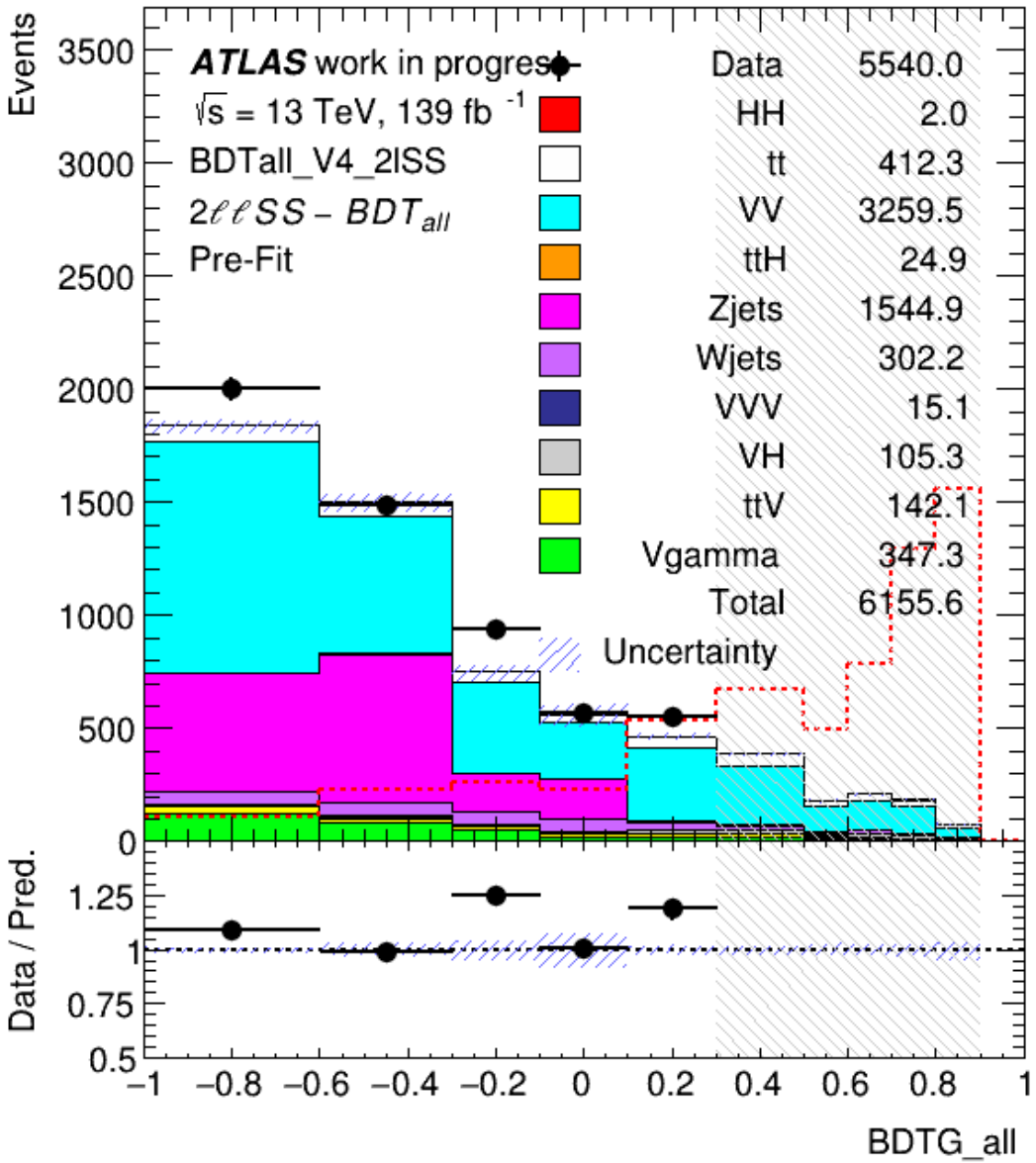


The CL_s method:

- 2 Hypothesis described by a likelihood based on poisson distribution:
  - H1 b: Background only
  - H0 s+b: Signal and Background
- Confidence level: CL_b and CL_{s+b} and $CL_s = \frac{CL_{s+b}}{CL_b}$
- Reject the hypothesis H1 with a 95% confidence level : $CL_s = 0.05$

$\rightarrow$ $\mu_{95\%}$

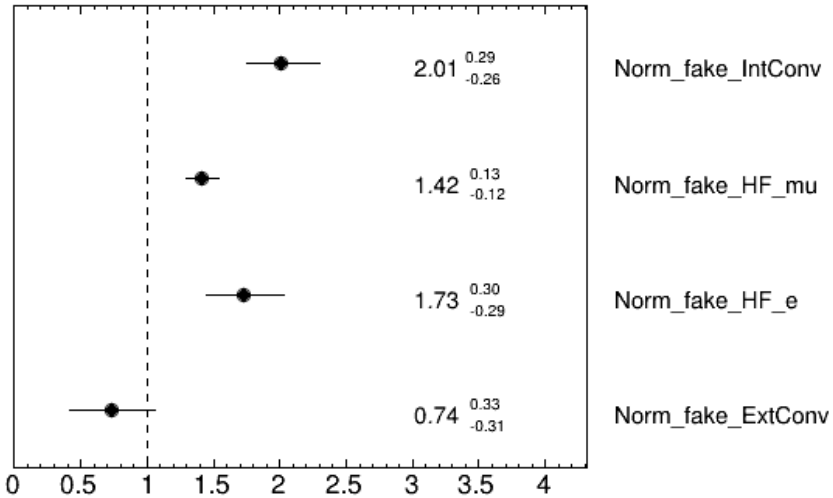
Combined BDT

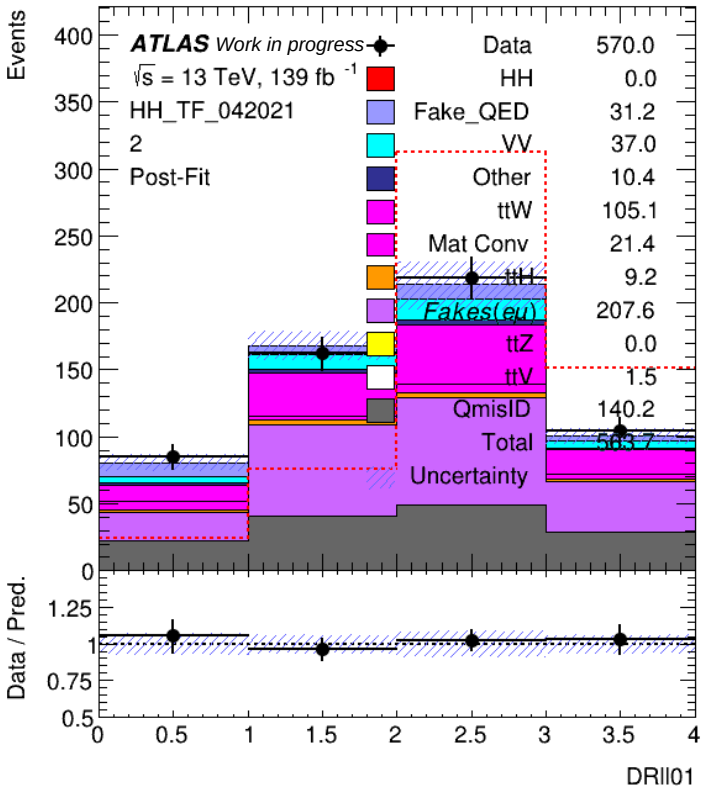


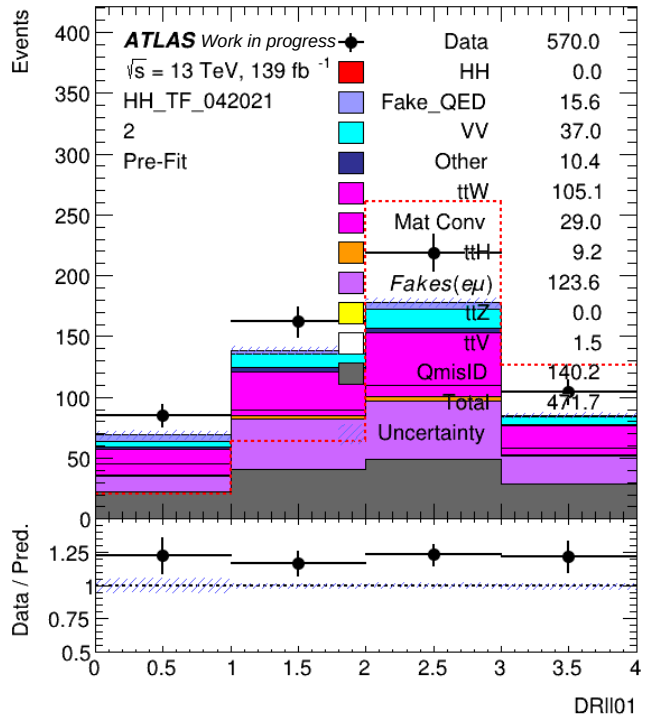
- Final BDT output estimated for all background - Stat only (no systematics)
- All shapes and normalisations from MC simulation
- Asimov fit using profile likelihood (TRExFitter)
- Using BDT bins: $\mu_{95\%} = 30.9$

Instrumental background estimation

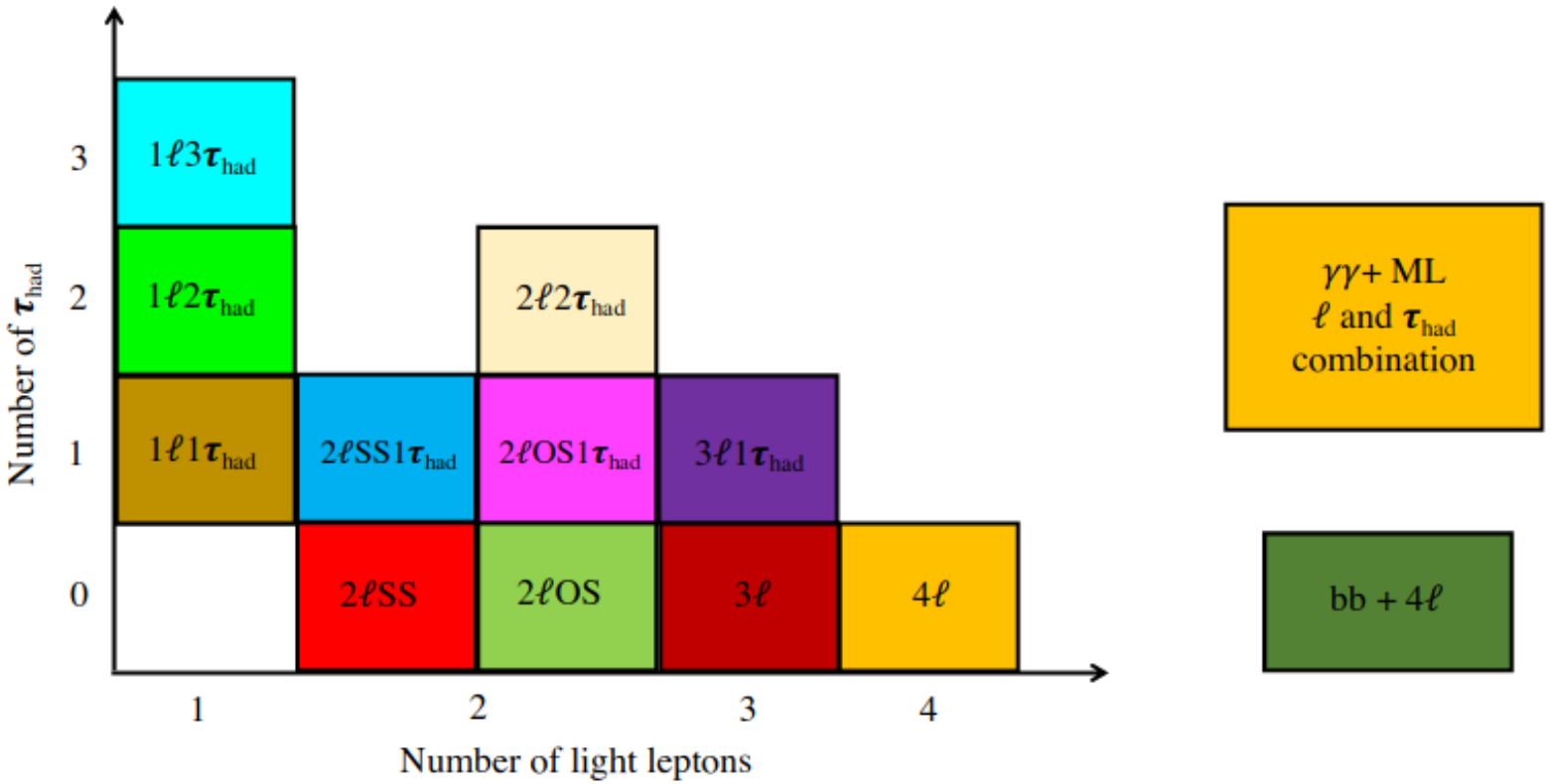
- Estimation of the instrumental background
- Use data driven method
- For instance: Photon conversion







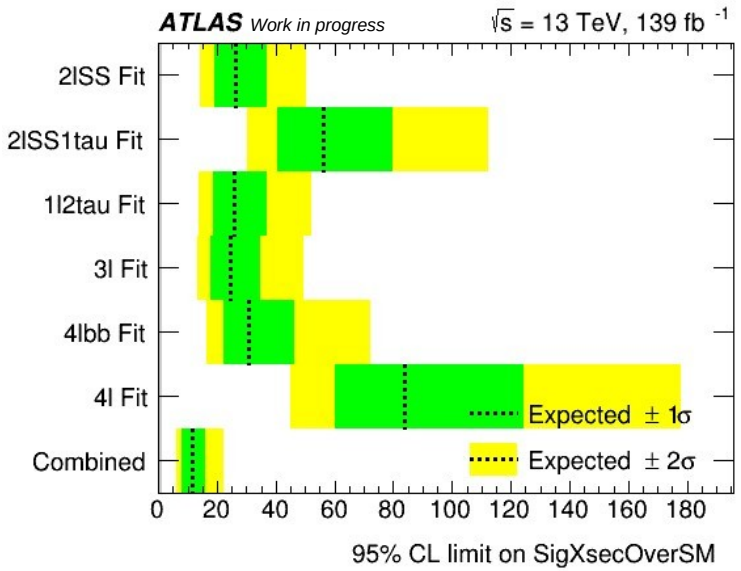
Combination



- 2ℓSS analysis in included into a global analysis
- Each channel with it own strategy

Combination

Channel	Exp. limit $\mu_{95\%}$
3ℓ	24.5
2ℓSS	29.9
2ℓOS	92.6
4 ℓ	83.7
4 ℓ + bb	31.6
2ℓSS1τ	55.96
$1\ell 2\tau$	25.60
Combination	11.50



- All systematics are ignored in this stage
- All strategies are based on BDT distribution to discriminate Signal from Background

Summary

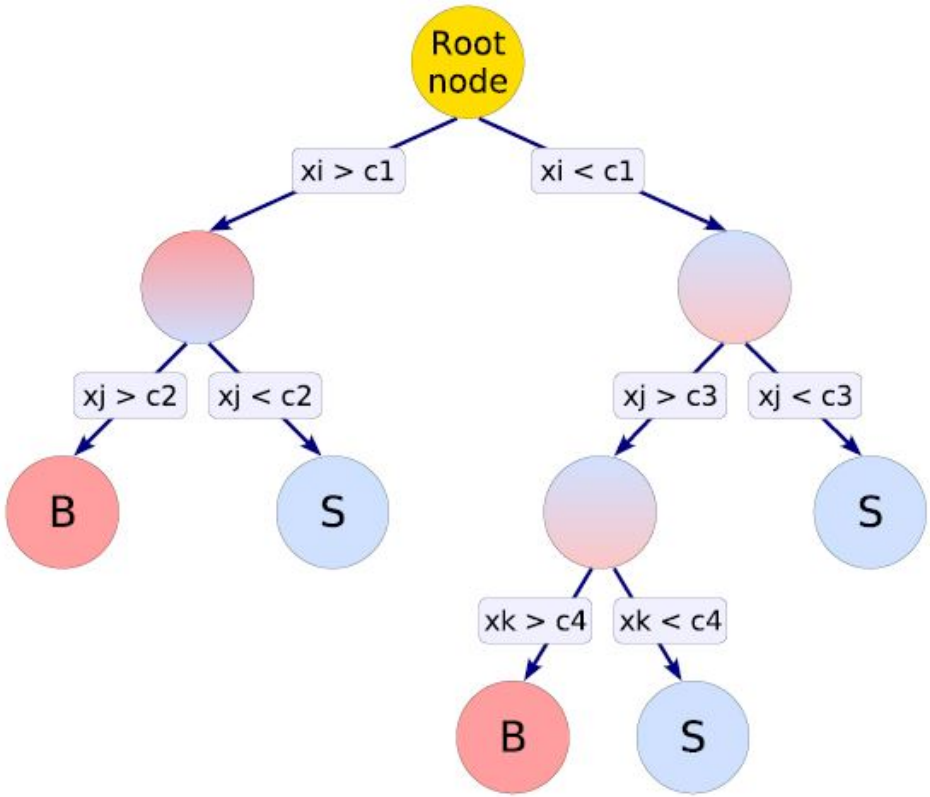
- The measurement of the Higgs self coupling will bring a proof of the Higgs Field potential shape

- My work is focused on 2ℓSS:
  1. Identification of discriminating variables
  2. Build a final discriminant variable using BDT method (leads to $\mu_{95\%} = 30.9$ - stat only)
  3. Refine estimation of instrumental backgrounds

- Next step: Include systematics + refine estimation of instrumental backgrounds

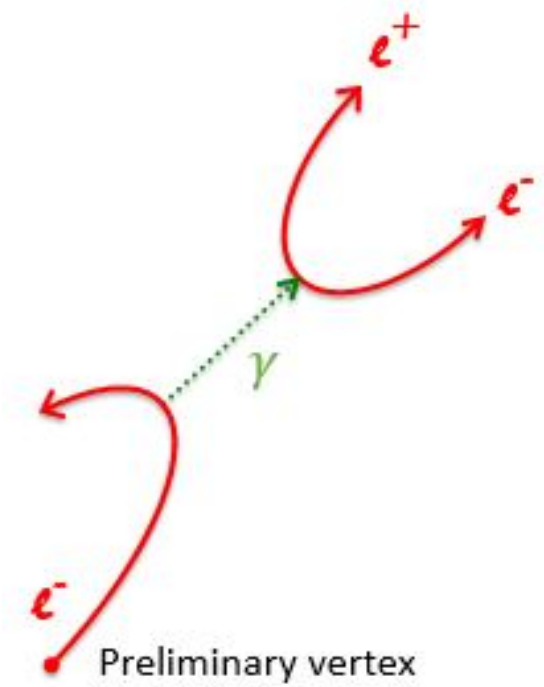
Backup Slides

Boosted Decision Trees

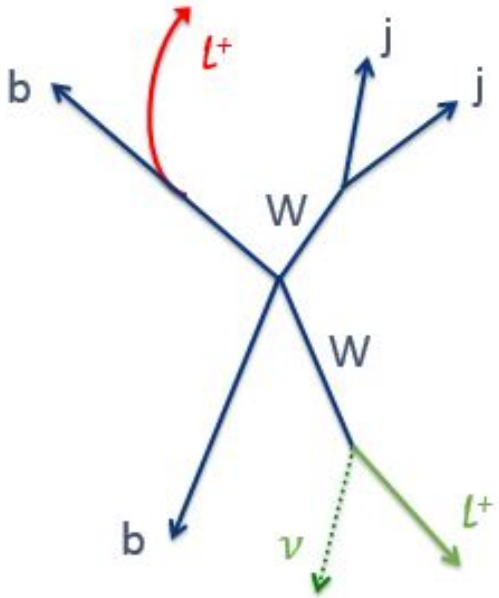


- A node = a binary criteria
- Each level = Put variables in order and
- Training: Adress ± 1 if signal or backgrounds

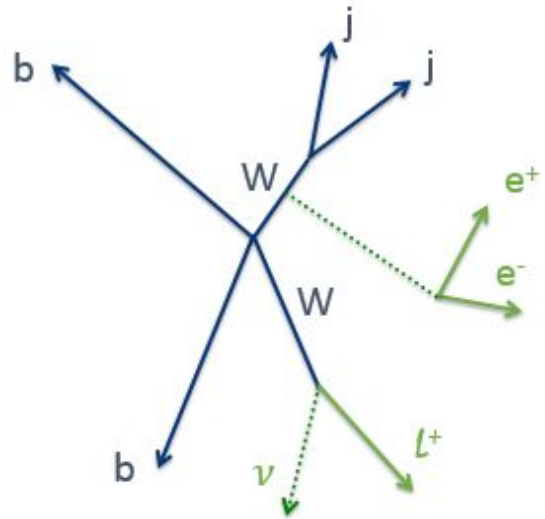
2ℓSS - Choice of discriminating variables



Trident



Semi-leptonic conversion



Photon conversion

Backup - Background