جامعة الحسن الثاني بالدار البيضاء
UNIVERSITÉ HASSAN II DE CASABLANCA

Laboratory of High Energy Physics and
Scientific Computing (PHENIS)

# Status of WV→$l\nu qq$ analysis & Preparation of realistic wildcards for FTK pattern banks

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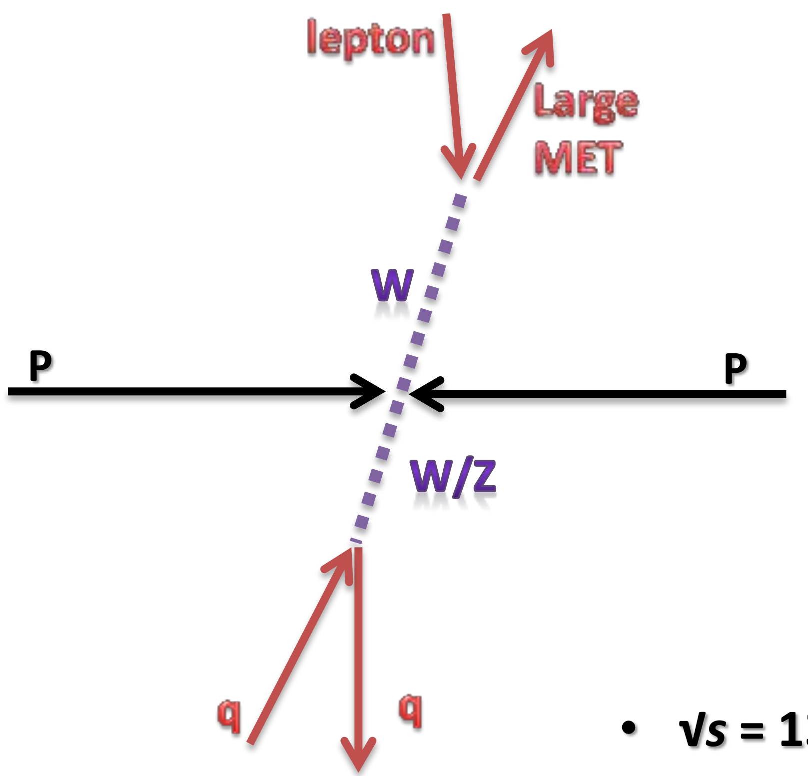
Journée Scientifique ATLAS/Maroc 24/04/2017

# *Search for diboson resonance in the $l\nu qq$ final state in pp collisions at √s = 13 TeV with the ATLAS detector*

on behalf of *lvqq* analysis team

# Introduction




Search for resonance productions of *WW* and *W Z* bosons in the $lvqq$ channel.

$$W \rightarrow lv \qquad (l = e, \mu)$$

$$W/Z \rightarrow q\bar{q}'$$

$(q\bar{q}' = u, d, c, s \; ou \; b)$

- √*s* = 13 TeV
- Luminosity = 36,5 fb$^{-1}$ collected by ATLAS detector in 2015 and 2016.

# Heavy Vector Triplet (HVT) model : spin 1

**HTV theory considers a real vector in addition to the SM fields and interactions.**

$$V_\mu^a,\ a = 1,2,3,$$

$$V_\mu^\pm = \frac{V_\mu^1 \mp i V_\mu^2}{\sqrt{2}}, \qquad V_\mu^0 = V_\mu^3$$

- **The dynamics of the new vector is described by a simple phenomenological Lagrangian :**

$$\begin{aligned}\mathcal{L}_V = & -\frac{1}{4} D_{[\mu} V_{\nu]}^a D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V_\mu^a V^{\mu\,a} \\ & + i\, g_V c_H V_\mu^a H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V_\mu^a J_F^{\mu\,a} \\ & + \frac{g_V}{2} c_{VVV} \epsilon_{abc} V_\mu^a V_\nu^b D^{[\mu} V^{\nu]c} + g_V^2 c_{VVHH} V_\mu^a V^{\mu\,a} H^\dagger H - \frac{g}{2} c_{VVW} \epsilon_{abc} W^{\mu\nu\,a} V_\mu^b V_\nu^c\end{aligned}$$

- **1[st] line : *V* kinetic and mass term + trilinear and quadrilinear interactions with the vector bosons from the covariant derivatives :**

$$D_{[\mu} V_{\nu]}^a = D_\mu V_\nu^a - D_\nu V_\mu^a, \qquad D_\mu V_\nu^a = \partial_\mu V_\nu^a + g\,\epsilon^{abc} W_\mu^b V_\nu^c$$

**Where *g* is the SU(2)$_L$ gauge coupling.**

# Heavy Vector Triplet (HVT) model : spin 1

$$+ i g_V c_H V^a_\mu H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V^a_\mu J^{\mu\, a}_F$$

- **<u>2nd line</u> contains direct interactions of *V* with the Higgs current**

$$i H^\dagger \tau^a \overleftrightarrow{D}^\mu H = i H^\dagger \tau^a D^\mu H - i D^\mu H^\dagger \tau^a H$$

$$\tau^a = \sigma^a/2$$

**And with the SM left-handed fermionic currents**

$$J^{\mu\, a}_F = \sum_f \overline{f}_L \gamma^\mu \tau^a f_L$$

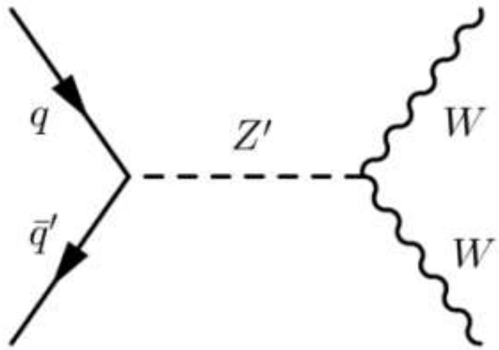
- $c_H$ **: controls the *V* interactions with the SM vectors and with the Higgs, and in particular its decays into bosonic channels.**
- $c_F$ **: describes the direct interaction with fermions.**

$$+ \frac{g_V}{2} c_{VVV} \epsilon_{abc} V^a_\mu V^b_\nu D^{[\mu} V^{\nu]c} + g_V^2 c_{VVHH} V^a_\mu V^{\mu\, a} H^\dagger H - \frac{g}{2} c_{VVW} \epsilon_{abc} W^{\mu\nu\, a} V^b_\mu V^c_\nu$$

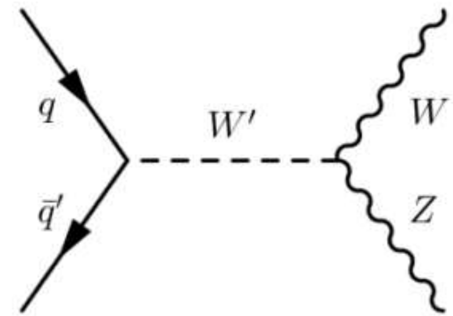
- **<u>3rd line</u> contains 3 new operators and free parameters, $c_{VVV}$, $c_{VVHH}$ and $c_{VVW}$. None of them, contains vertices of one *V* with light SM fields, thus they do not contribute directly to *V* decays.**

# Heavy Vector Triplet (HVT) model : spin 1

**$Z' \rightarrow WW$**




**$W' \rightarrow WZ$**




$$\begin{aligned}\mathcal{L}_V = & -\frac{1}{4} D_{[\mu} V^a_{\nu]} D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V^a_\mu V^{\mu\,a} \\ & + i\, g_V c_H V^a_\mu H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V^a_\mu J^{\mu\,a}_F \\ & + \frac{g_V}{2} c_{VVV} \epsilon_{abc} V^a_\mu V^b_\nu D^{[\mu} V^{\nu]c} + g_V^2 c_{VVHH} V^a_\mu V^{\mu\,a} H^\dagger H - \frac{g}{2} c_{VVW} \epsilon_{abc} W^{\mu\nu\,a} V^b_\mu V^c_\nu\end{aligned}$$

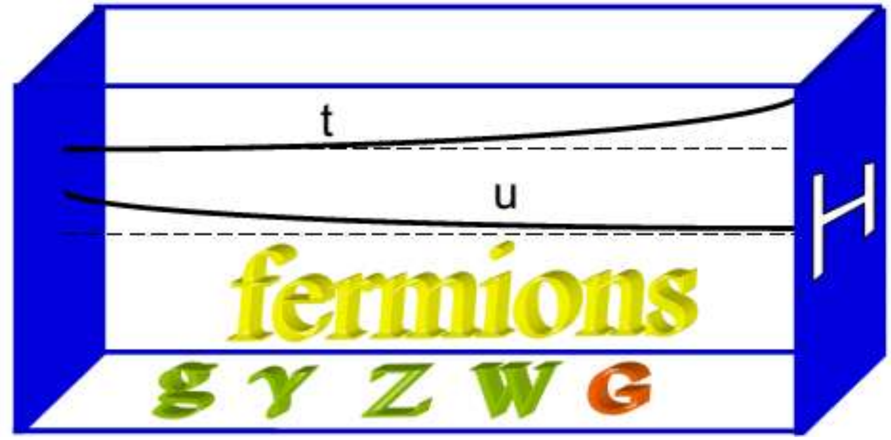
**The parameters $c_H$ and $c_F$ are expected to be on the order of unity in most models**

Simulation MC : MadGraph+Pythia8

# Kaluza-Klein (KK) graviton (G∗) : spin 2

$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

**k is a RS characteristic energy scale**

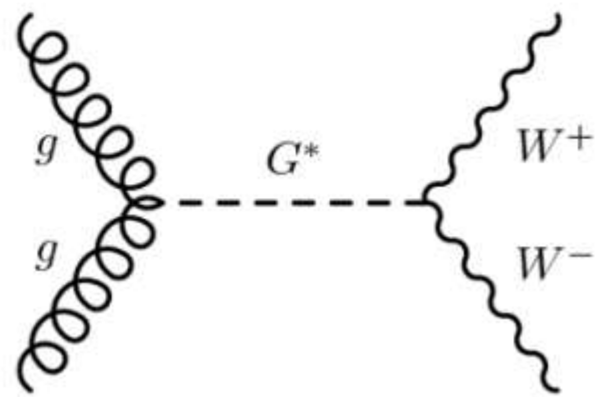



- **The Randall–Sundrum (RS) framework attempts to explain the hierarchy problem by introducing extra dimensions in which SM fields can propagate.**

- **This leads to a tower of Kaluza–Klein (KK) excitations of SM fields.**

- **KK excitations of the gravitational field appear as TeV-scale spin-2 Gravitons (G*)**

**G*→WW**



# Heavy Higgs bosons: spin 0

- The SM was made consistent by the introduction of the Higgs mechanism, which gave a theoretical explanation for the mass of elementary particles while preserving the gauge invariance

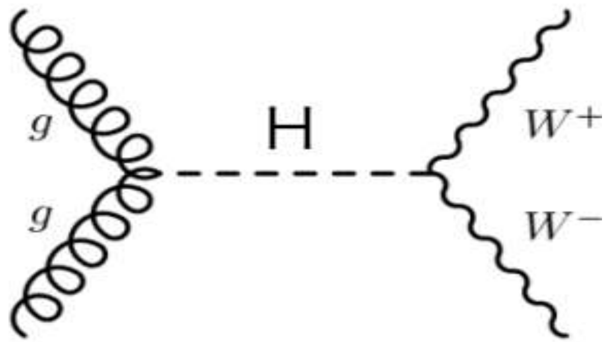

- The Higgs mechanism implied the existence of a new scalar particle, the Higgs boson, discovered in 2012 that seems to be consistent with the expected one.

- A single Higgs boson is only the simplest possible theoretical model, numerous extensions have been proposed that can be tested at the LHC, like : electroweak singlet model and the 2 Higgs-doublet model.

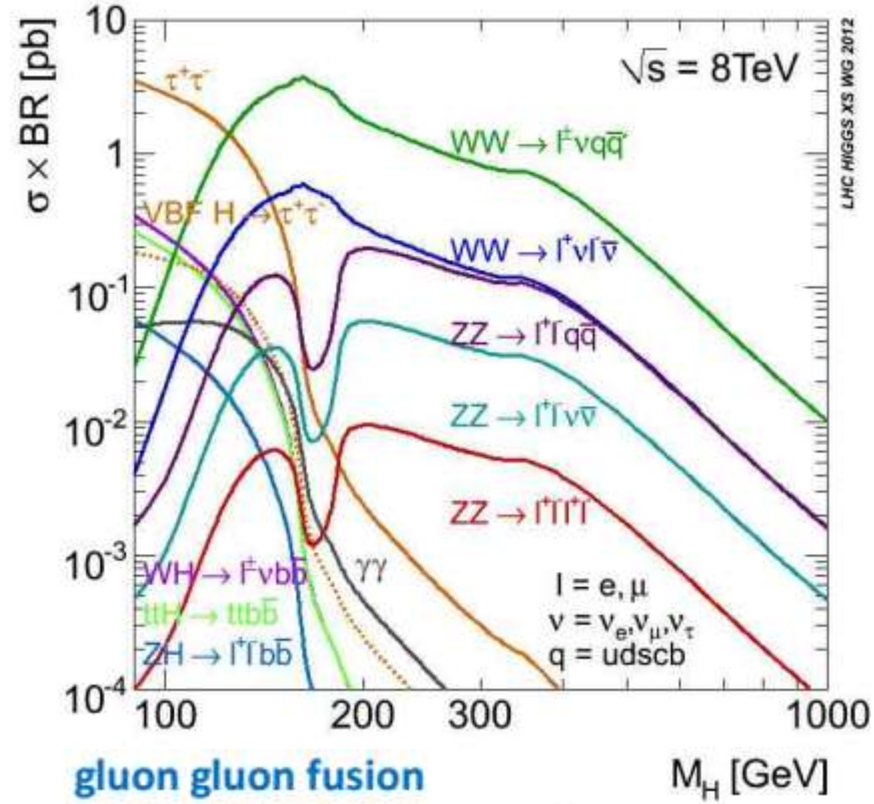
- All these models predict the existence of additional bosons.

# Heavy Higgs bosons: spin 0

$H \rightarrow WW$

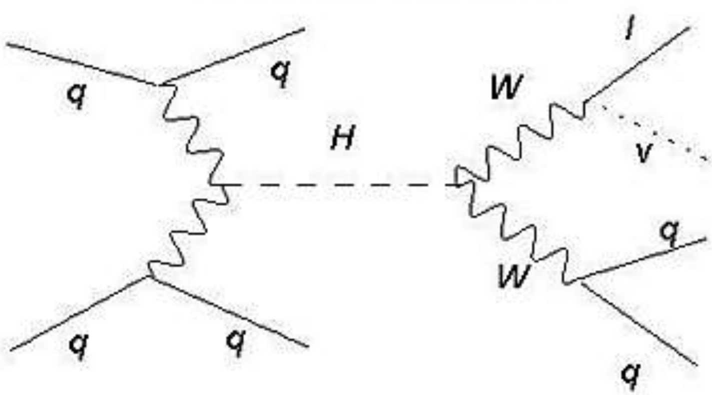


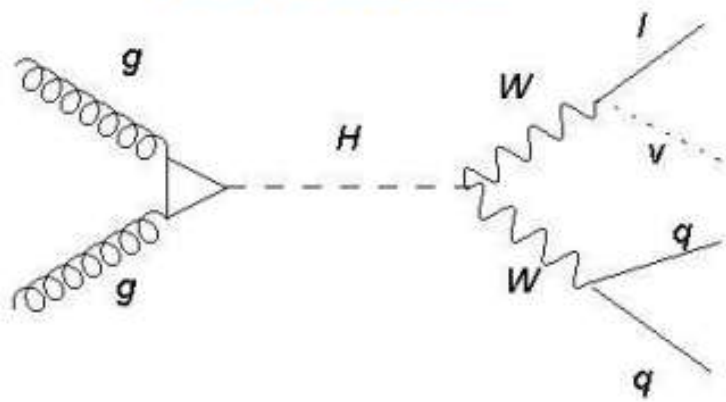

**Two main Higgs production modes, gluon-gluon fusion (ggF) and vector boson fusion (VBF), are considered in this presentation.**




vector boson fusion

gluon gluon fusion



# BOOSTED / RESOLVED

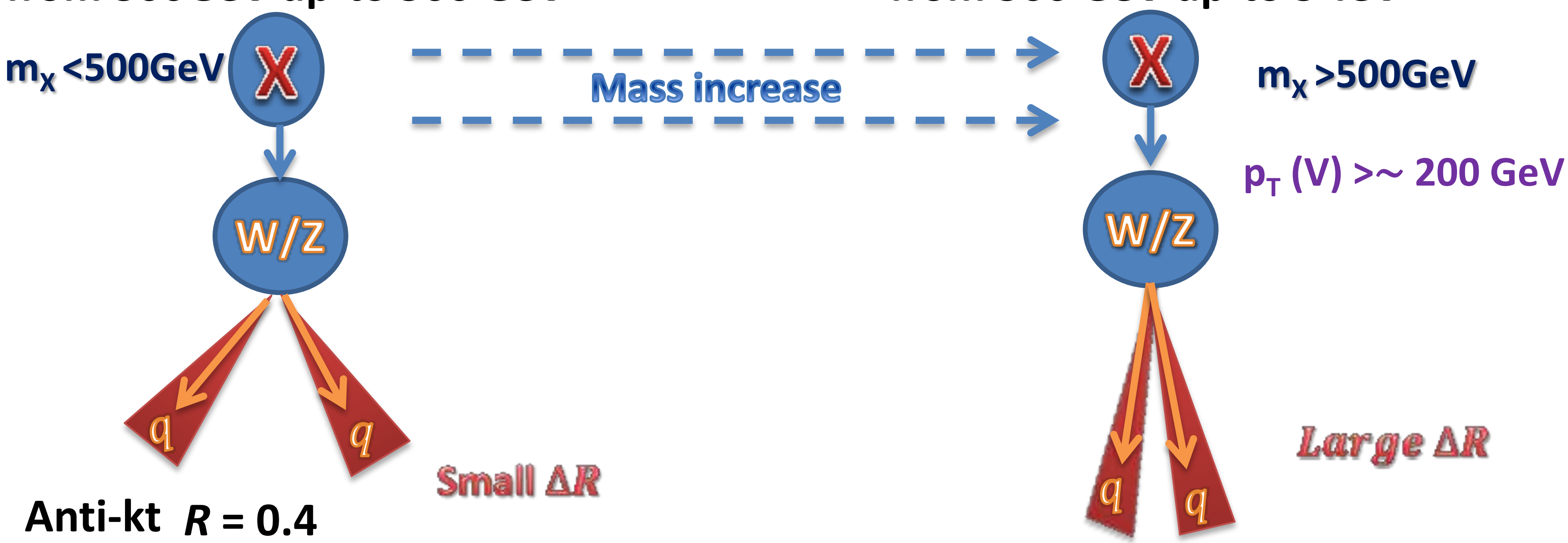
- In order to cover wide mass ranges from 300 GeV, two types of analyses are considered namely '**boosted**' and '**resolved**' analyses
- The angle between two quarks from the hadronic decay of *W*/*Z* boson is approximated to :

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = \frac{2m(V)}{p_T(V)}$$

*m* (*V*) and $p_T$ (*V*) are mass and transverse momentum of the *W*/*Z* boson

➢ **Resolved analysis**
from 300GeV up-to 500 GeV

➢ **Boosted analysis**
from 500 GeV up-to 5 TeV



# BOOSTED / RESOLVED

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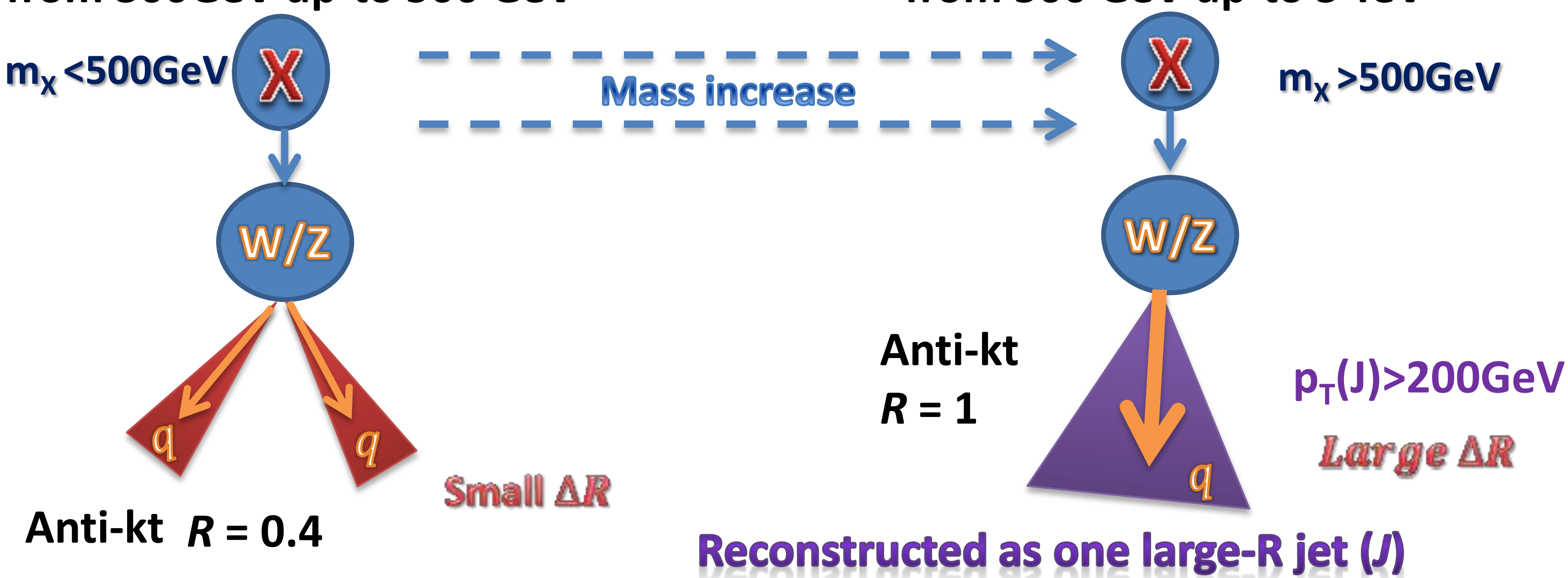
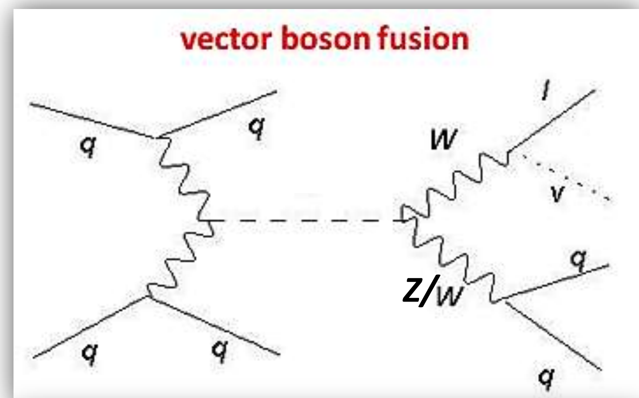
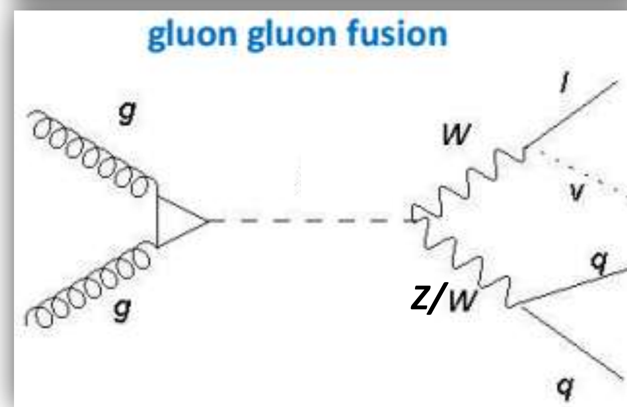
- **Resolved analysis**
  **from 300GeV up-to 500 GeV**
- **Boosted analysis**
  **from 500 GeV up-to 5 TeV**



# VBF and ggF Categories

- Events are tested for presence of ‘VBF jets’
- Otherwise categorized as ggF event




## VBF jets

**Select highest $m(jj)$ pair**

**$(R = 0.4)$ with:**

- $\eta(j_1)\eta(j_2) < 0$
- $p_T(j_{1,2}) > 30\ GeV$
- $m(j_1, j_2) > 770\ GeV$
- $\Delta\eta(j_1, j_2) > 4.7$
- **Resolved: remove jets from $W/Z \rightarrow jj$ candidates**
- **Boosted: require $\Delta R(j_{1,2}, J) > 1.5$**

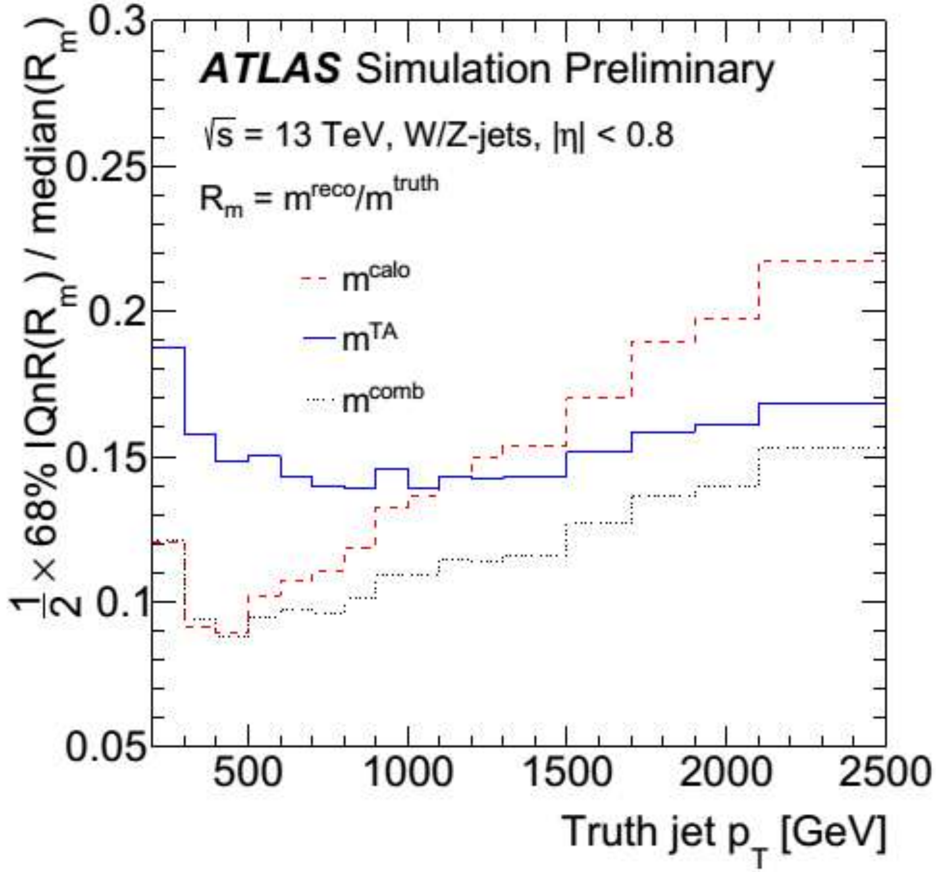
# Large-R jet for boson tagging

- **At high-$p$T region, boosted $W$ and $Z$ bosons are reconstructed as a single large-R jet**
- **Anti-$k$t / $R$ = 1.0. / jet grooming (remove underlying events and pileup)**
- **The track-assisted mass $m^{\mathrm{TA}}$ is defined as:**

$$m^{\mathrm{TA}} = m^{\mathrm{trk}} \times \frac{p_{\mathrm{T}}^{\mathrm{calo}}}{p_{\mathrm{T}}^{\mathrm{trk}}}$$

- **We use the combined mass as the nominal mass reconstruction algorithm in this analysis**

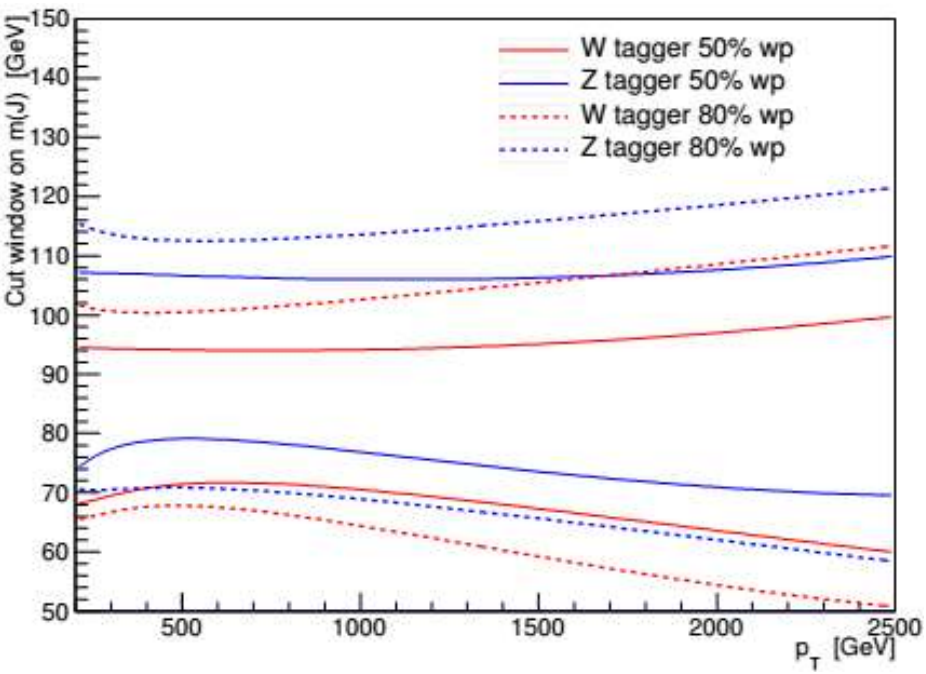
$$m^{\mathrm{comb}} = \frac{\sigma_{\mathrm{calo}}^{-2} m^{\mathrm{calo}} + \sigma_{\mathrm{TA}}^{-2} m^{\mathrm{TA}}}{\sigma_{\mathrm{calo}}^{-2} + \sigma_{\mathrm{TA}}^{-2}}$$

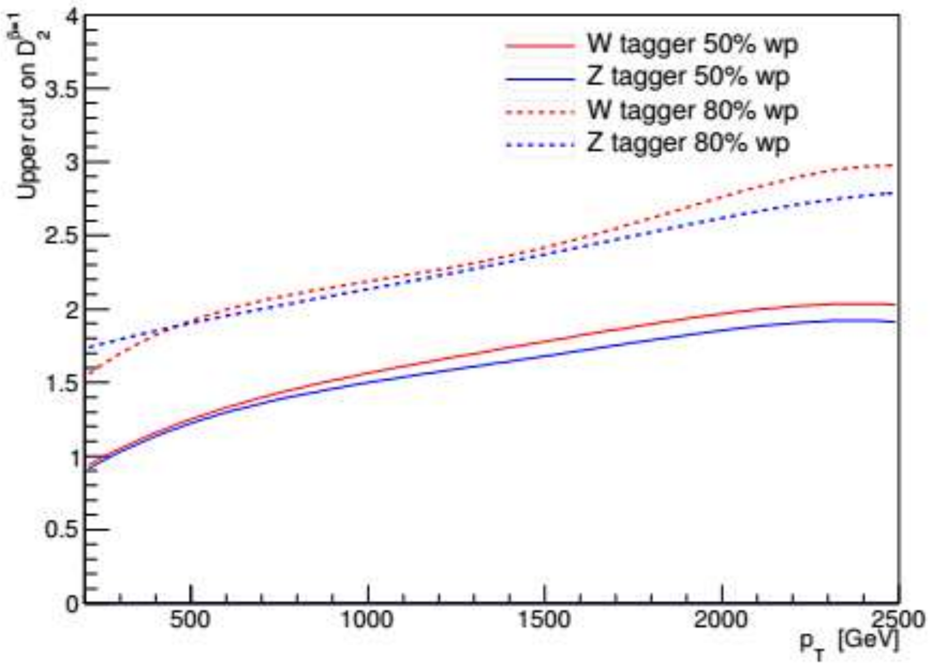


# Large-R jet for boson tagging

**The SmoothedWZTagger is used to select the large-R jet coming from decays of *W/Z* boson**

- **New recommendations to tag *W/Z* → *qq***
- **Mass window and upper cut on D2 are optimized using combined mass**
- **Can extend the analysis up to *p*T = 2.5 TeV**
- **Higher bkg rejection than old tagger, keeps signal efficiency**



# Event Selection - Boosted analysis

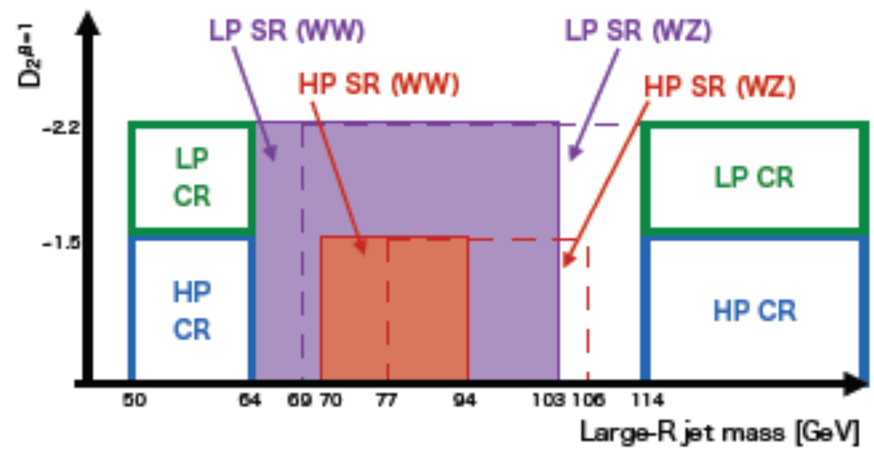
| Selection | | SR HP | SR LP | $W$ CR HP | $W$ CR LP | $t\bar{t}$ CR HP | $t\bar{t}$ CR LP |
|---|---|---|---|---|---|---|---|
| $W \to \ell\nu$ | Num of signal leptons | 1 | | | | | |
| | Num of vetoed leptons | 0 | | | | | |
| | $E_T^{miss}$ | > 100 GeV | | | | | |
| | $p_T(\ell\nu)$ | > 200 GeV | | | | | |
| $W/Z \to J$ | Num of large-$R$ jets | $\geq 1$ | | | | | |
| | $D_2^{(\beta=1)}$ 50 % WP | pass | fail† | pass | fail | pass | fail† |
| | $D_2^{(\beta=1)}$ 80 % WP | — | pass | — | pass | — | pass |
| | $W/Z$ mass 50 % WP | pass | fail † | — | — | pass | fail† |
| | $W/Z$ mass 80 % WP | — | pass | fail | fail | — | pass |
| Topology cuts | $p_T(\ell\nu)/m_{WV}$ <br> $p_T(J)/m_{WV}$ | > 0.3(0.4) for VBF (ggF) category | | | | | |
| Top-quark veto | Num of $b$-tagged jets | 0 | | | | $\geq 1$ | |
| Existence of VBF jets | | yes (no) for VBF (ggF) category | | | | | |

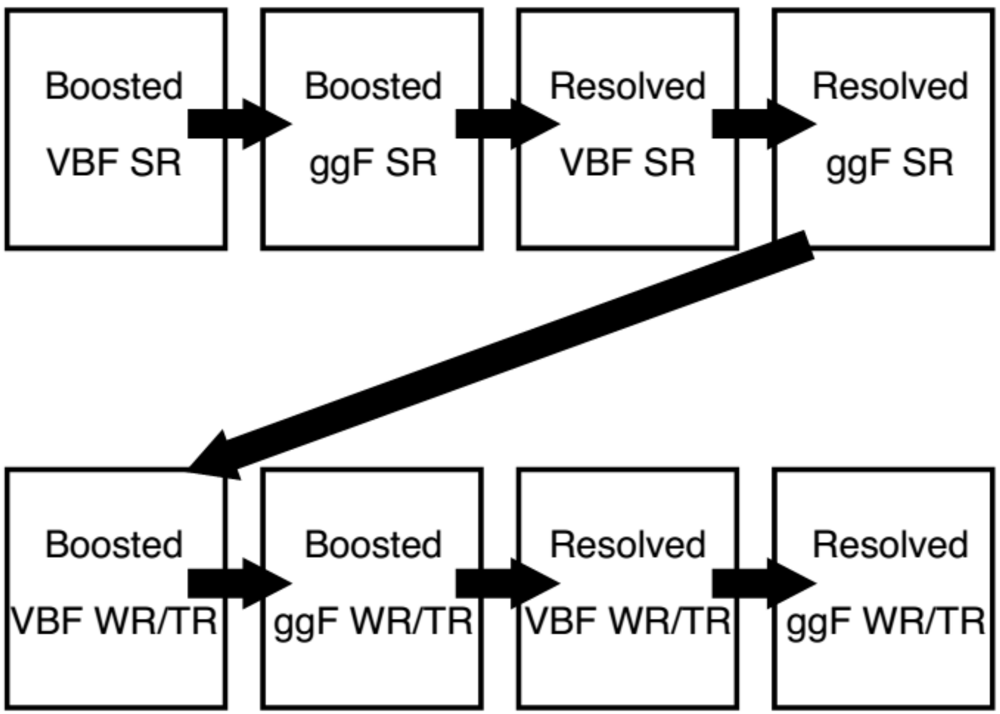
# Event Selection - Resolved analysis

<table>
<tr><td colspan="2">cuts</td><td>SR</td><td>WR</td><td>TR</td></tr>
<tr><td rowspan="4">$W \to \ell\nu$ selection</td><td>Number of signal leptons</td><td colspan="3">1</td></tr>
<tr><td>Number of veto leptons</td><td colspan="3">0</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$</td><td colspan="3">$> 60$ GeV</td></tr>
<tr><td>$p_{\mathrm{T}}(\ell\nu)$</td><td colspan="3">$> 75$ GeV</td></tr>
<tr><td rowspan="4">$W/Z \to jj$ selection</td><td>Number of small jets</td><td>$\geq 2$</td><td>$\geq 2$</td><td>$\geq 2$</td></tr>
<tr><td>$p_{\mathrm{T}}(j1)$</td><td colspan="3">$> 60$ GeV</td></tr>
<tr><td>$p_{\mathrm{T}}(j2)$</td><td colspan="3">$> 45$ GeV</td></tr>
<tr><td>$m_{jj}$</td><td>[66, 94] GeV (WW)<br>[82, 106] GeV (WZ)</td><td>$< 66$ GeV<br>and [106, 200] GeV</td><td>[66, 106] GeV</td></tr>
<tr><td rowspan="5">Topology cuts</td><td>$\Delta\phi(j,\ell)$</td><td colspan="3">$> 1.0$</td></tr>
<tr><td>$\Delta\phi(j,E_{\mathrm{T}}^{\mathrm{miss}})$</td><td colspan="3">$> 1.0$</td></tr>
<tr><td>$\Delta\phi(j,j)$</td><td colspan="3">$< 1.5$</td></tr>
<tr><td>$\Delta\phi(\ell,E_{\mathrm{T}}^{\mathrm{miss}})$</td><td colspan="3">$< 1.5$</td></tr>
<tr><td>$p_{\mathrm{T}}(\ell\nu)/m_{WV}$<br>$p_{\mathrm{T}}(jj)/m_{WV}$</td><td colspan="3">$> 0.3(0.35)$ for VBF (ggF) category</td></tr>
<tr><td>Top veto</td><td>Number of $b$-tagged jets</td><td colspan="2">0</td><td>$\geq 1$</td></tr>
<tr><td colspan="2">Existence of VBF jets</td><td colspan="3">yes (no) for VBF (ggF) category</td></tr>
</table>

# Combination of boosted and resolved analyses

- **6 Signal Regions in the fit**
  - **Boosted ggF: High-purity (HP) and Low-purity (LP)**
  - **Boosted VBF: HP and LP**
  - **Resolved ggF and VBF**
- **Priority to boosted analysis**

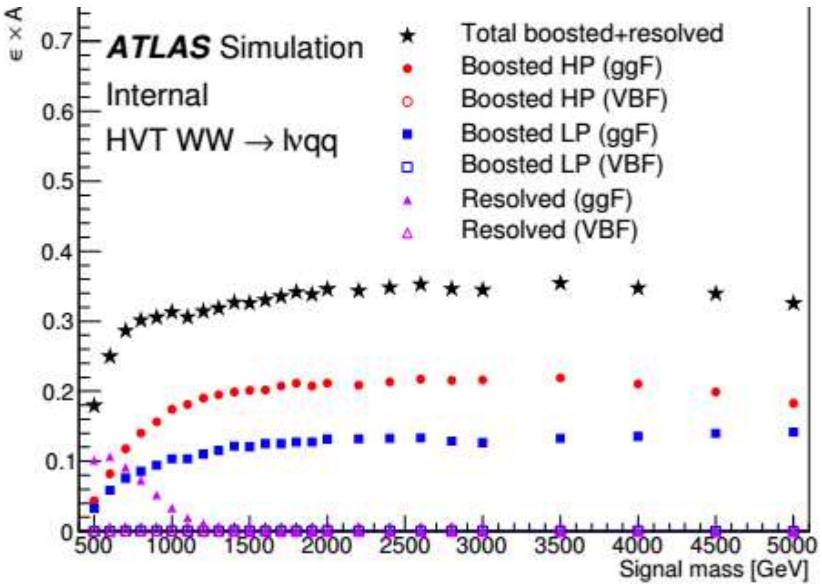


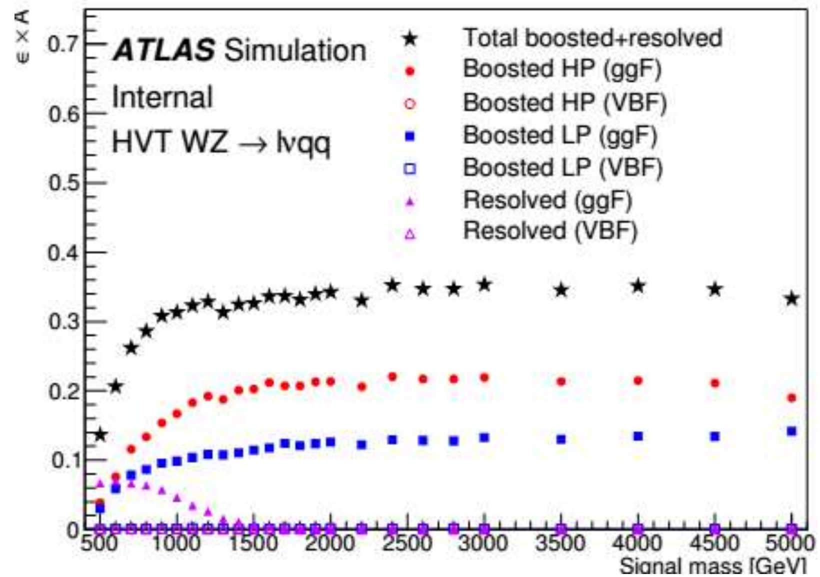



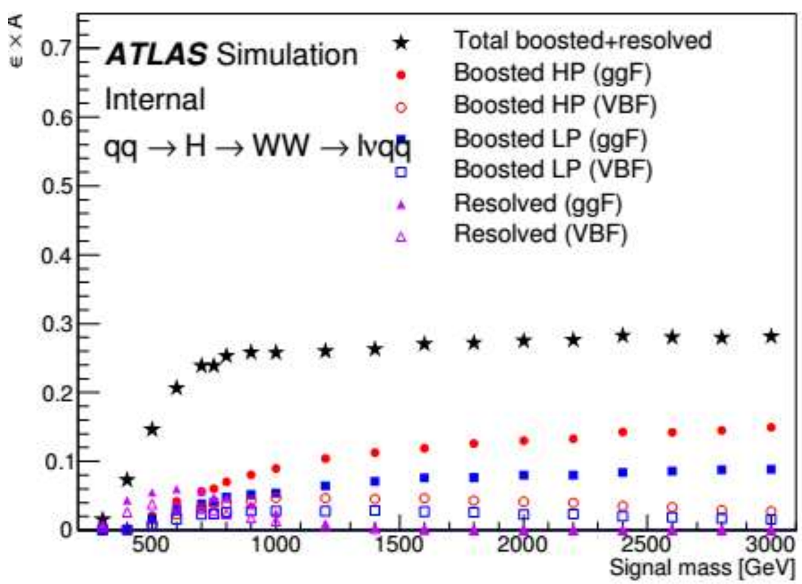

**The main background contributions:**

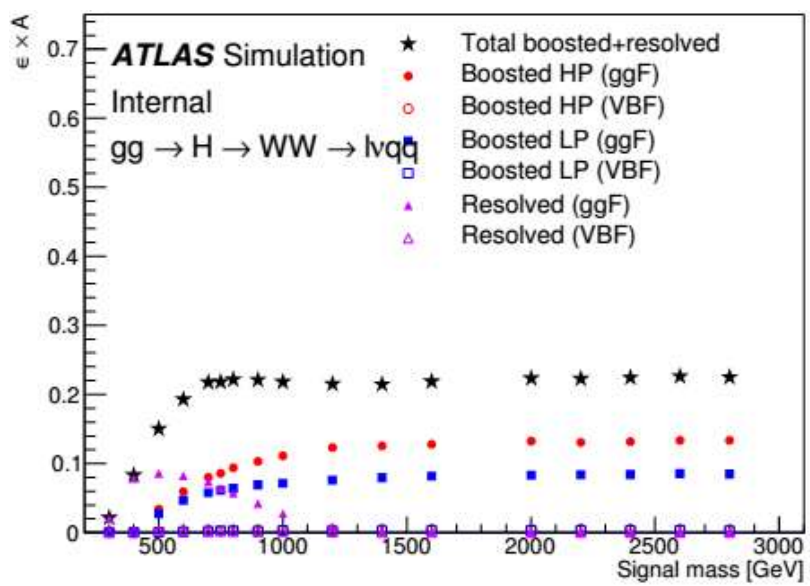
- *ttbar*
- **W+Jets**
- Multi-Jet
- Z+Jets
- SingleTop
- Di-Boson

# Signal acceptance times efficiency



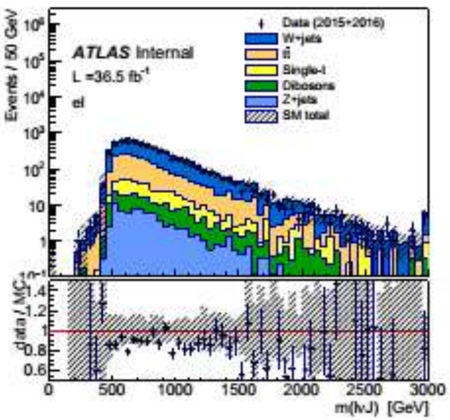



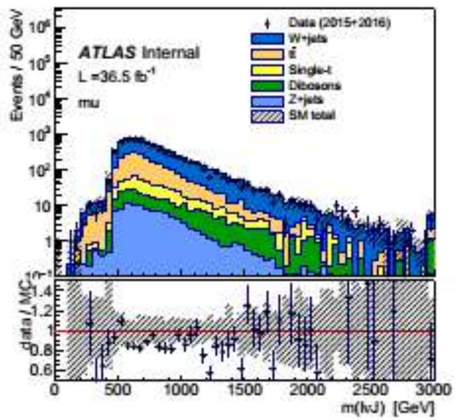
# Control region : Data/MC Comparison

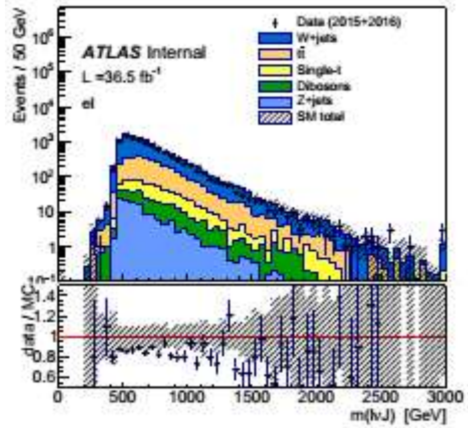
**Boosted HP ggF**

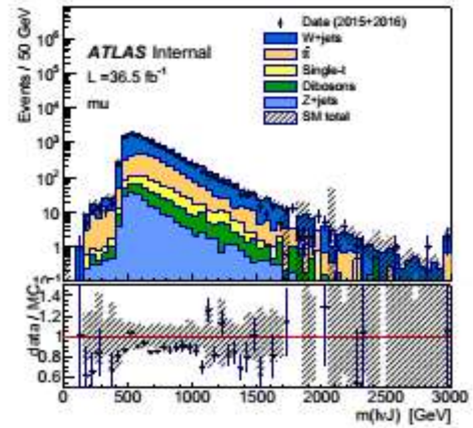
W+Jet CR

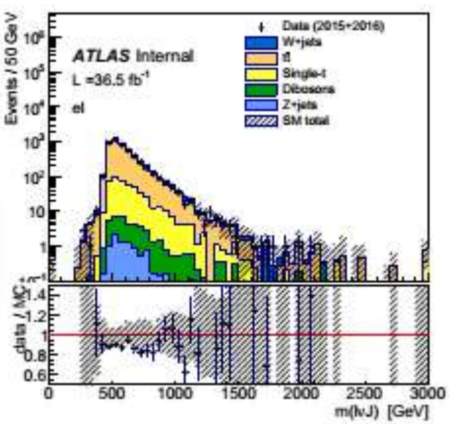
**Boosted LP ggF**

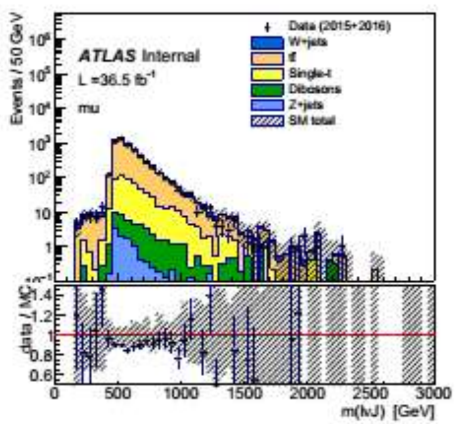


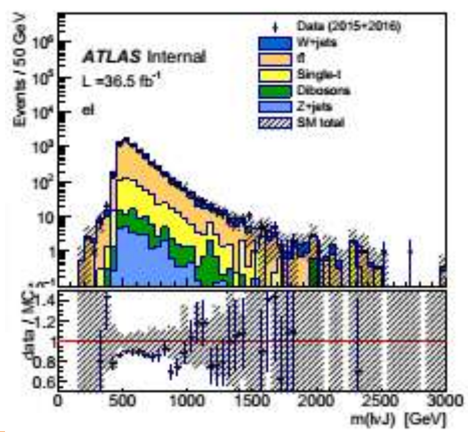



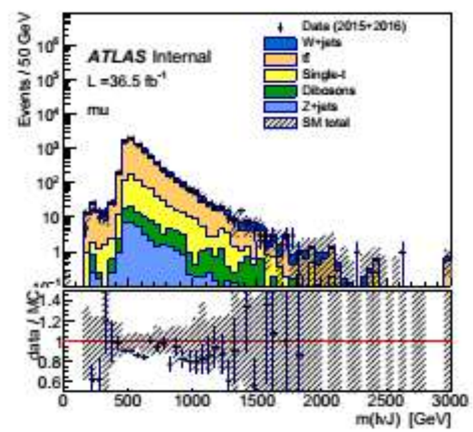

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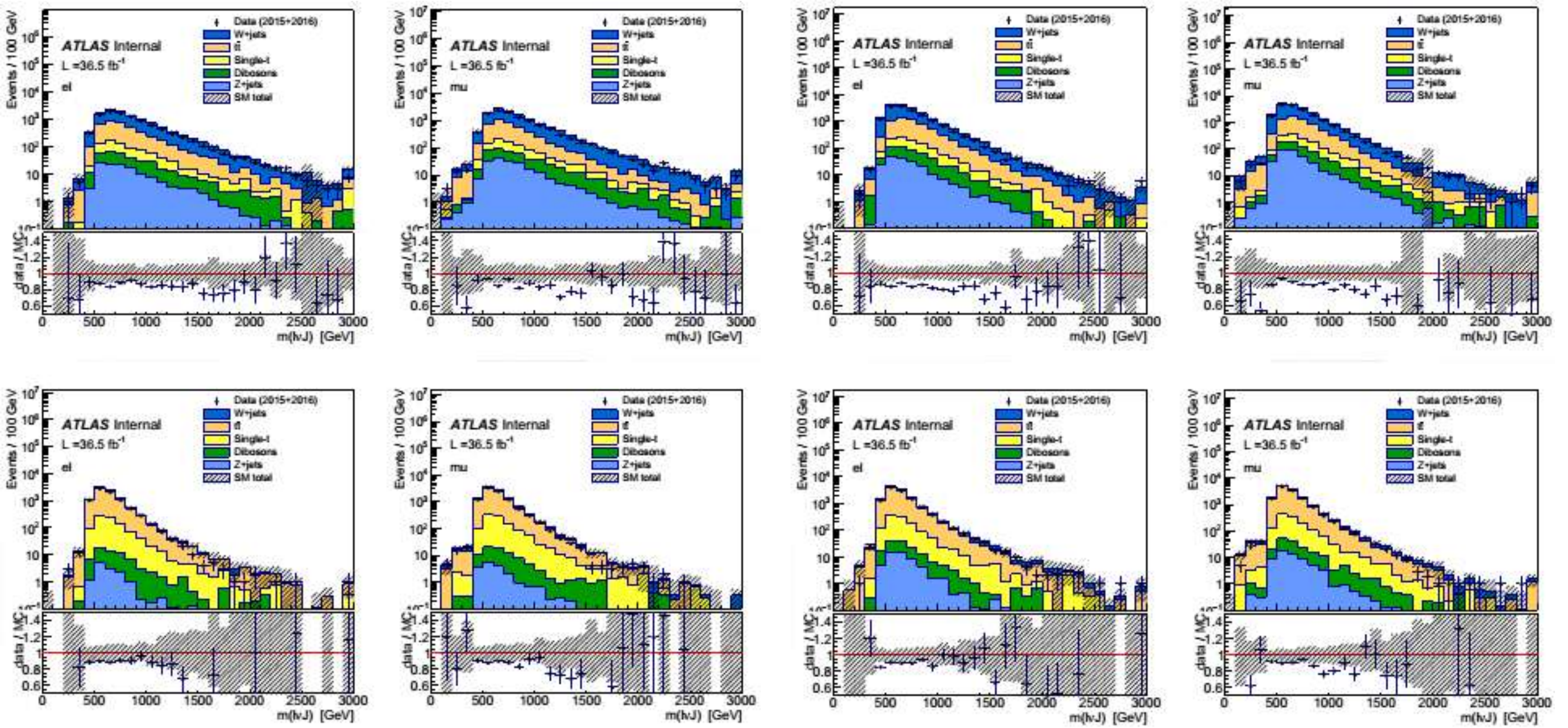
# Control region : Data/MC Comparison

**Boosted HP VBF**

W+Jet CR

**Boosted LP VBF**

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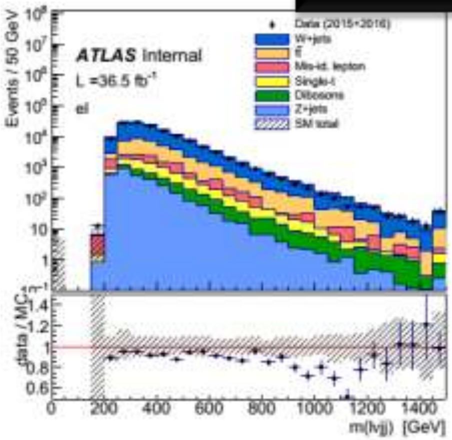
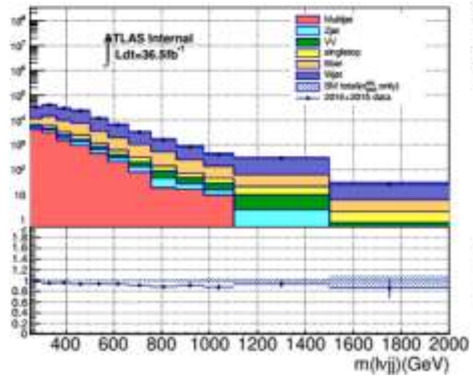
# Control region : Data/MC Comparison

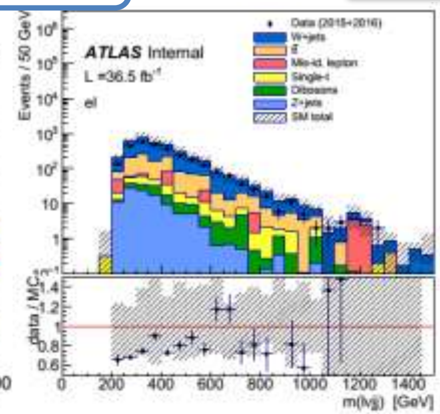
**Resolved ggF**

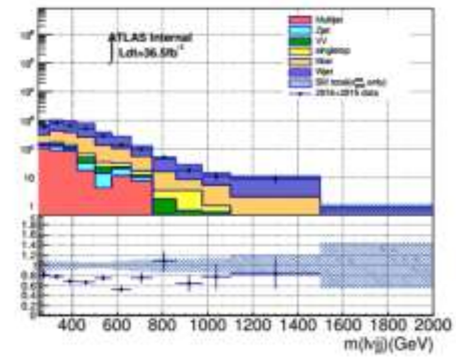
W+Jet CR

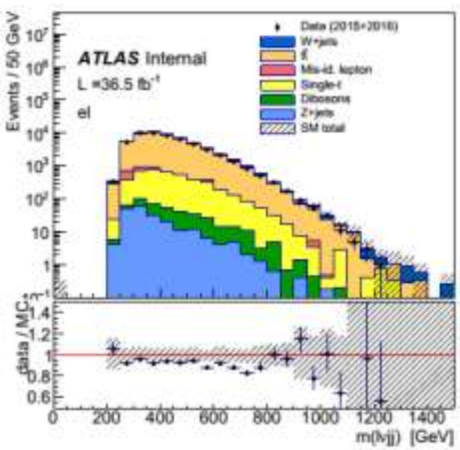
**Resolved VBF**

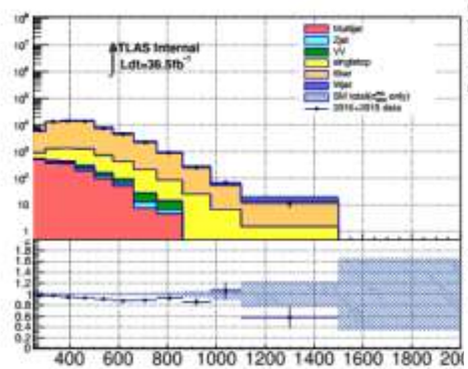


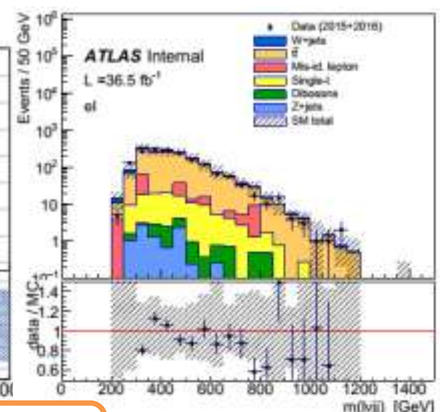



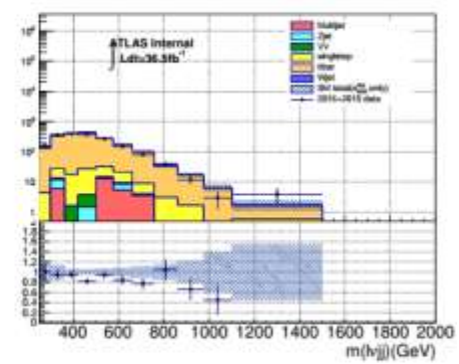

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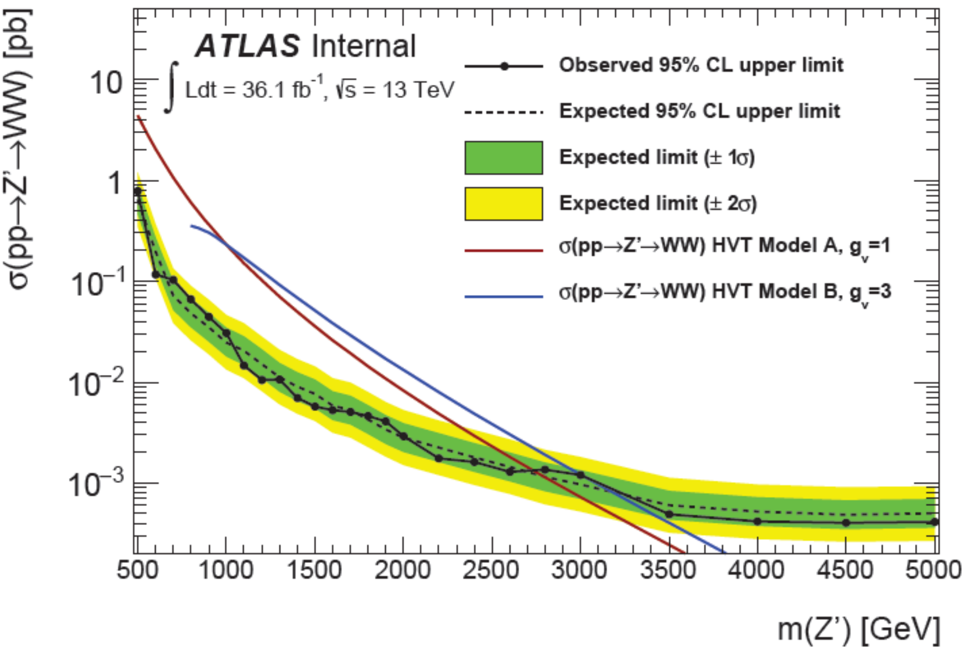
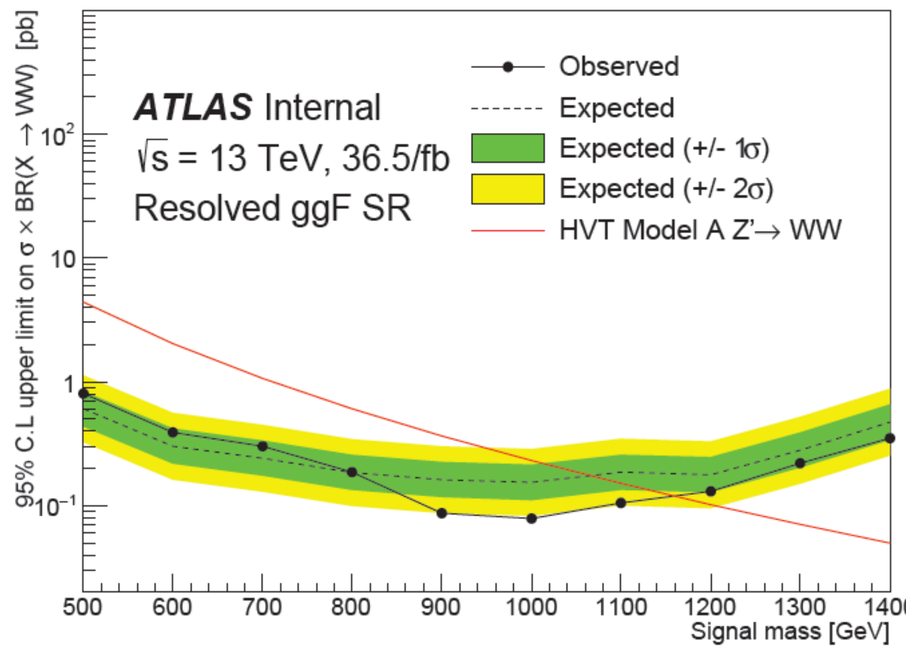
# Limit Results

## Expected limits Z' (HVT) WW



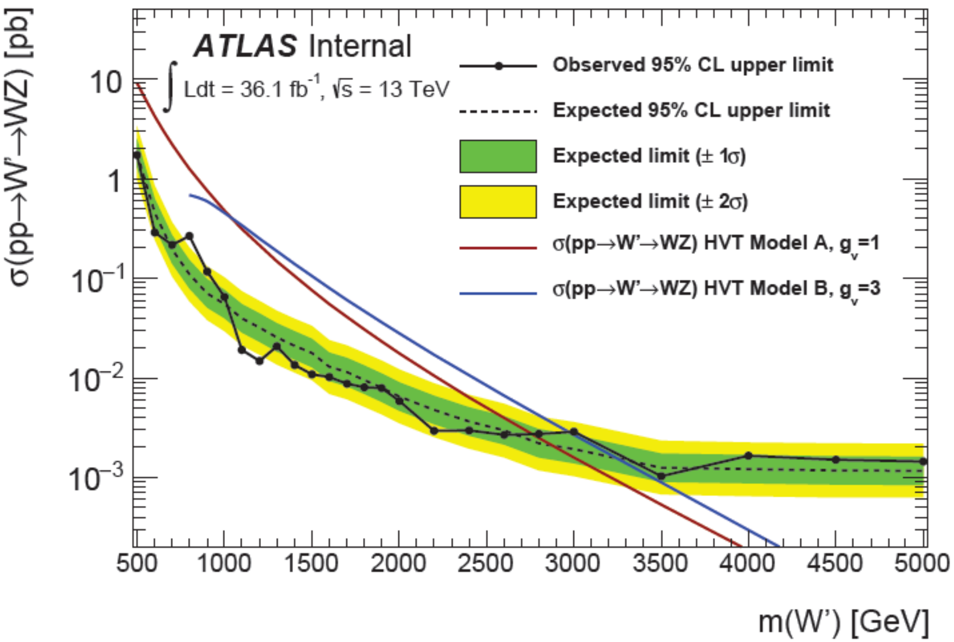

Boosted

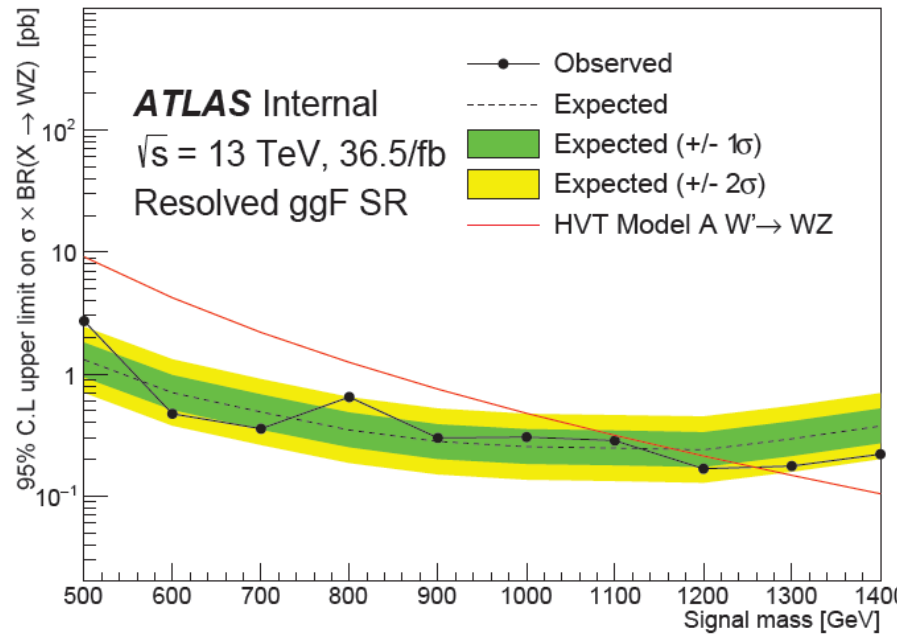



Resolved

# Limit Results

## Expected limits W' (HVT) WZ



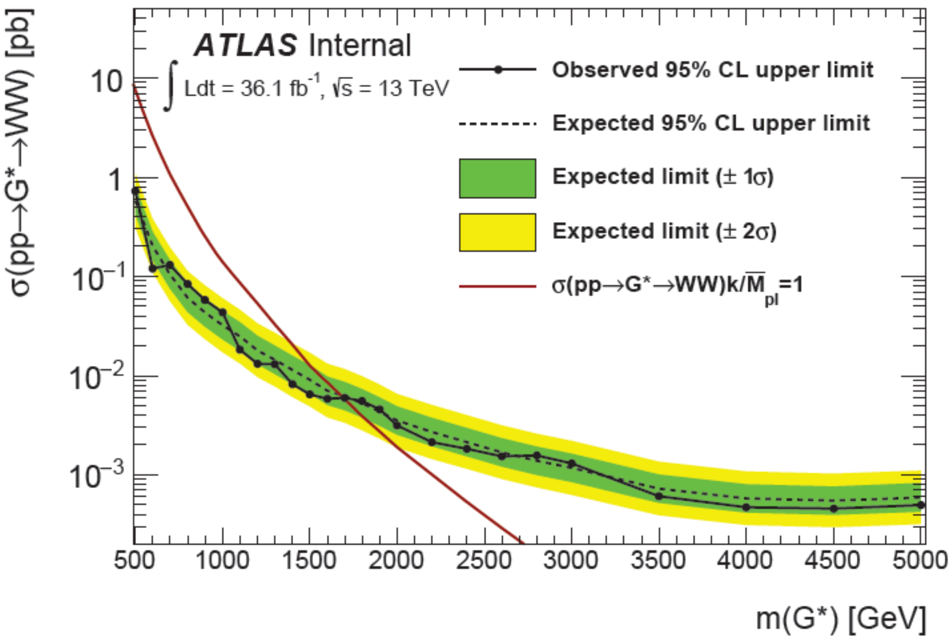



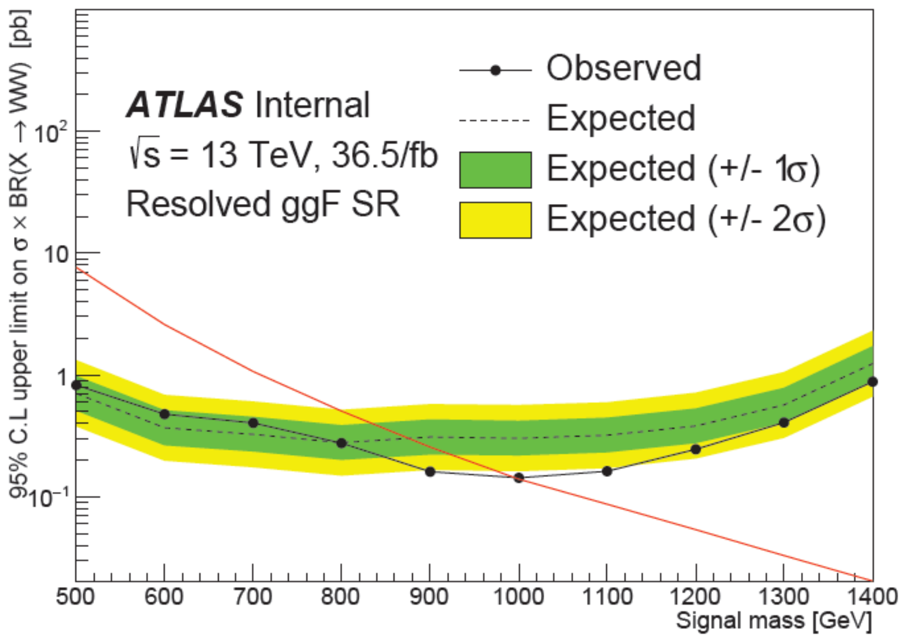

**Boosted**

**Resolved**

# Limit Results

## Expected limits G* WW



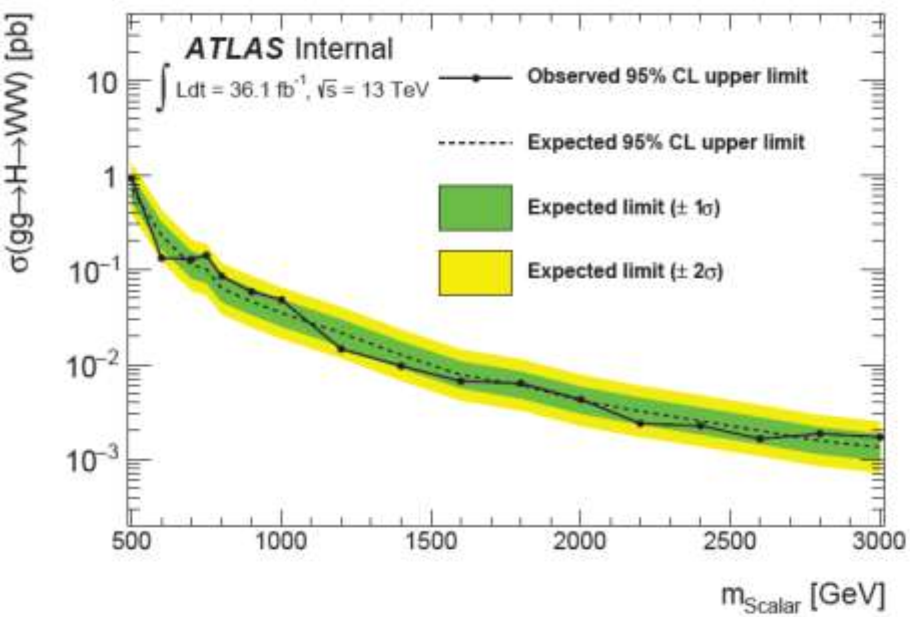

**Boosted**

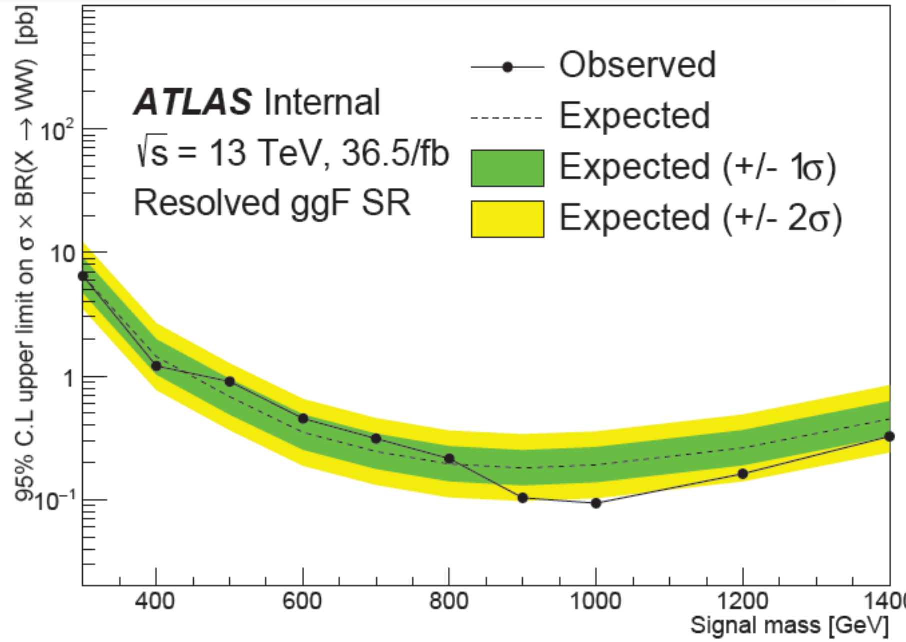
**Resolved**

# Limit Results

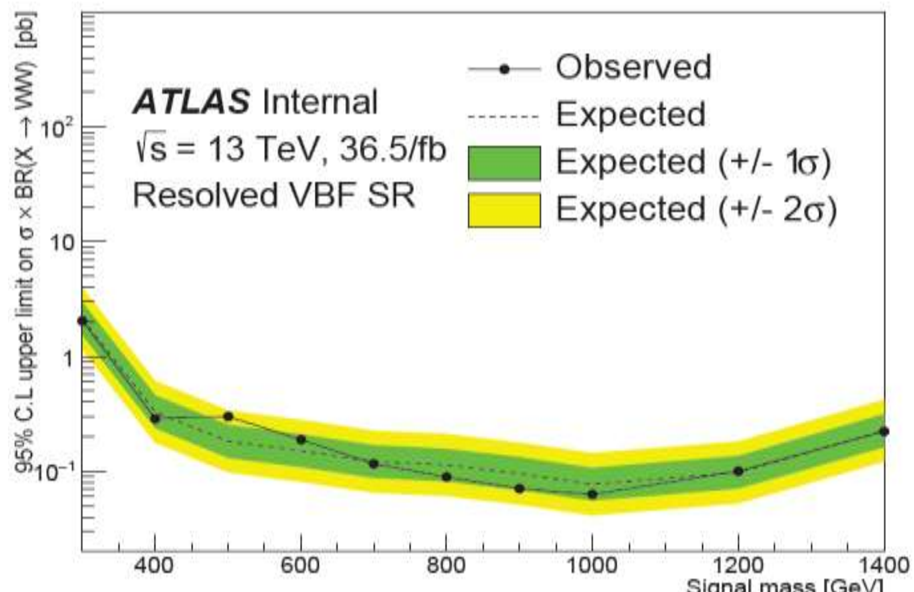
## Expected limits - ggH WW, VBF WW

**Boosted**



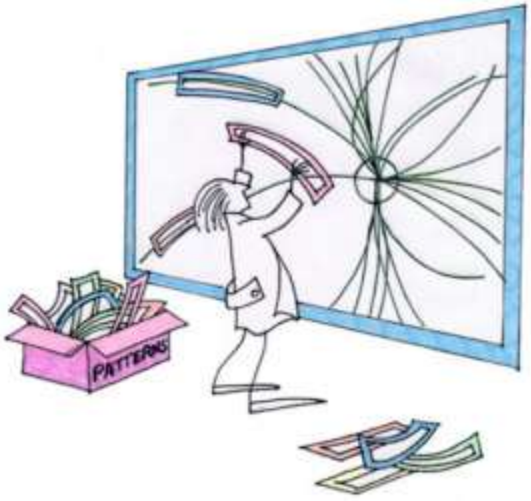




**Resolved**



# Summary

- **Search for resonance productions of WW and W Z bosons in the $l\nu$ $qq$ channel have performed using 36,5 fb$^{-1}$ of integrated luminosity collected by ATLAS detector in 2015 and 2016.**
- **No significant excess is observed.**
- **The combination (boosted and resolved channels) is work in progress.**
- **The first version of the paper draft is currently examined by the EB.**



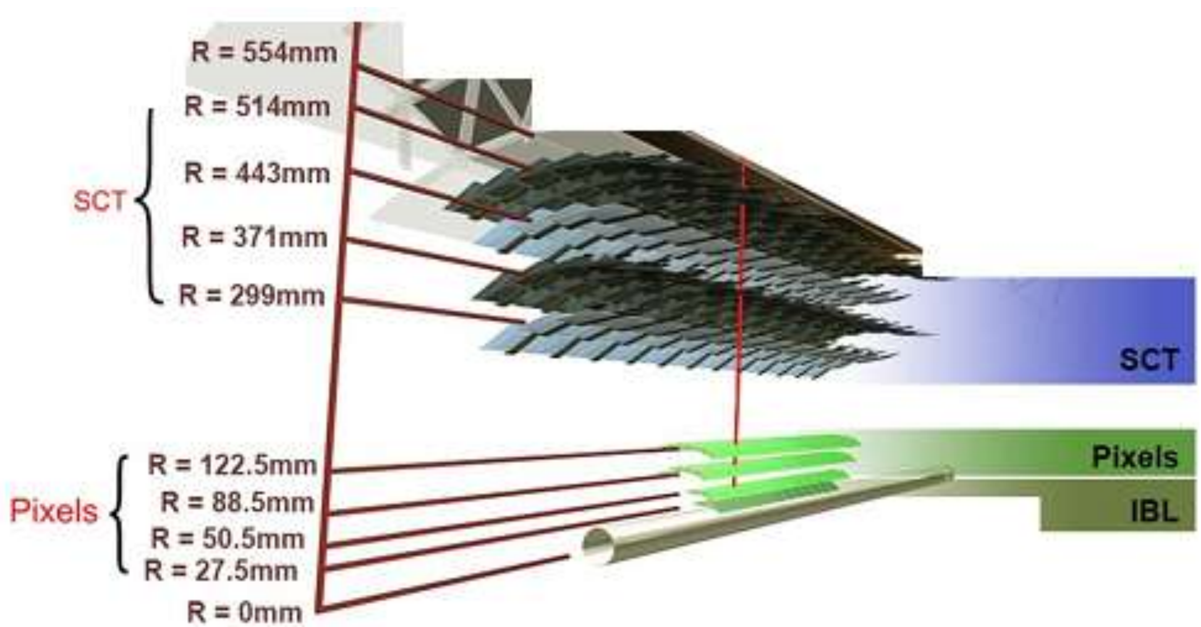

# *Preparation of realistic wildcards for FTK pattern banks*

## Qualification task

# Fast TracKer (FTK)

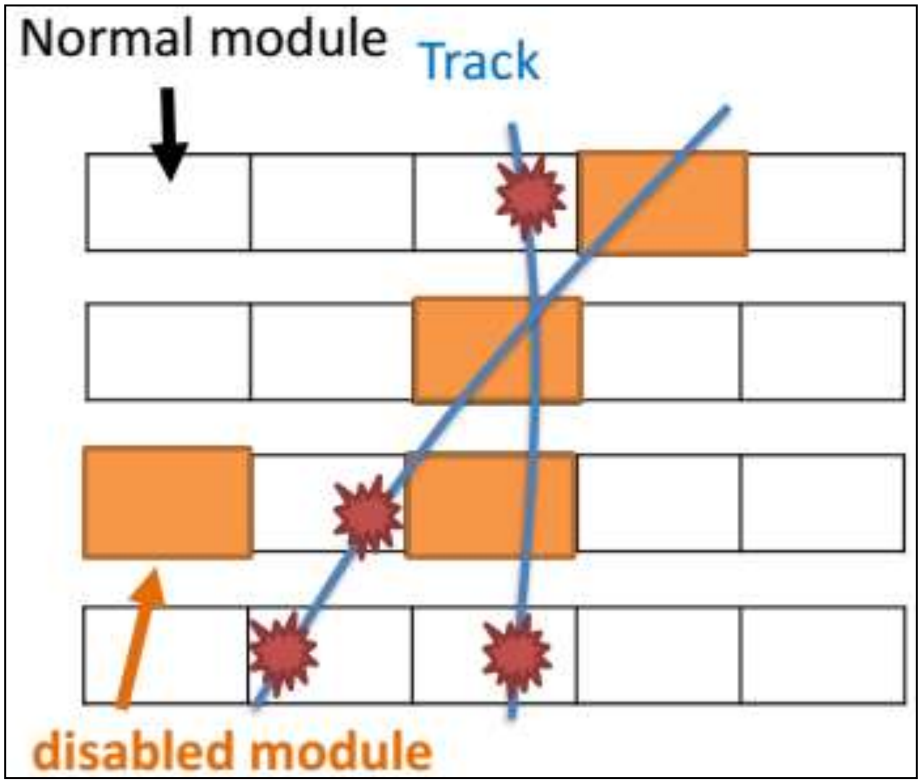
**The Fast Tracker (FTK) is a new ATLAS trigger component, implemented between the Level 1 trigger and the High Level Trigger (HLT), to reconstruct charged particles with pT > 1 GeV in the full silicon-detector acceptance for every event accepted by the Level 1 trigger. And provide full tracking for the (HLT).**

**Pixels close to interaction region**



# Detector disabled modules

**In real environment, detectors are not perfect, there were disabled modules. Some are temporary, and some are for the long time.**




- **Hit information cannot be sent from the disabled modules.**
- **In case disabled modules are distributed as left figure, the blue tracks cannot be reconstructed, which results in inefficiency.**

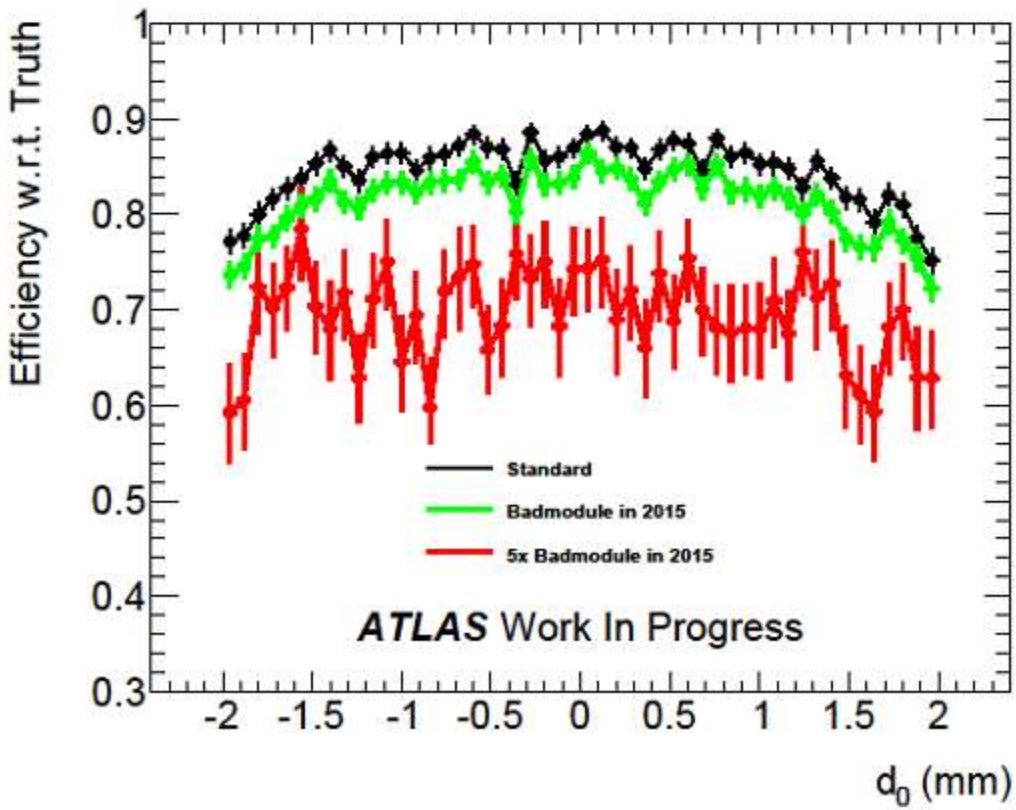
# Disabled modules distribution

| RUN # (DATE) | PIX | SCT |
|---|---|---|
| 266905 (2015.Jun.3) | 37 | 35 |
| 276262 (2015.Aug.16) | 37 | 35 |
| 284484 (2015.Nov.2) | 37 | 38 |
| 297730 (2016.Apr.29) | 88 | 42 |
| 303304 (2016.Jul.4) | 85 | 42 |
| 308084 (2016.Sep.9) | 90 | 42 |

**Total #modules**
**PIX: 1744**
**SCT: 4088**

- **The number of disabled modules of PIX increased during LHC shutdown, that of SCT did not change so much.**
- **The disabled modules are a few % in total modules, but this is not guaranteed in higher luminosity. Need to keep monitoring.**

# Impact of the disabled modules



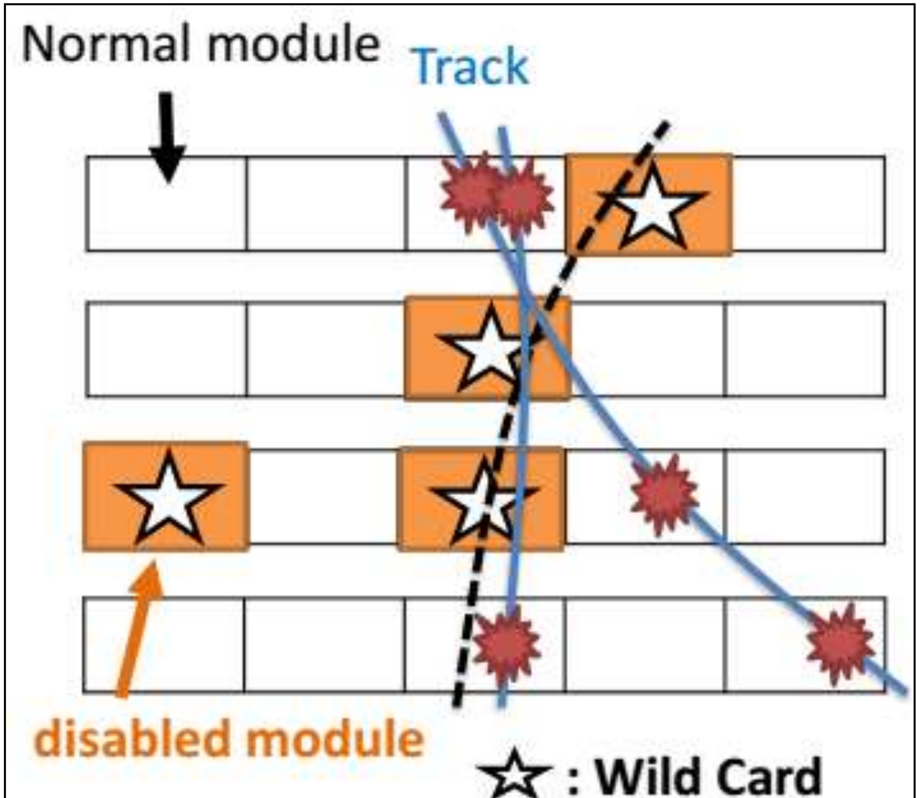

**bank: test_run2.v0.0**
**sample: single muon**

- **If we do not treat disabled modules, ~4 % of inefficiency can be seen.**

- **If bad modules increase 5 times (though it is very pessimistic), efficiency loss will be ~15 %.**

# How to cope: Wild Card

To recover inefficiency by disabled modules, **Wild Card (WC) algorithm** will be implemented in the FTK.




- The modules which WC algorithm is applied are **assumed to have hits always**.
- In case WC algorithm are applied as left figure, blue tracks are recovered. But the black dotted track maybe reconstructed also, if actually there is not.

**WC algorithm can recover inefficiency by disabled modules, but several correlated parameters need to be checked.**

# Parameters to be optimized

**It is necessary to optimize how to apply the WC algorithm to achieve better performance among several parameters.**

| parameters | Wild Card | |
|---|---|---|
| | Larger | Smaller |
| Efficiency | **Higher** | Lower |
| Fake Rate | Higher | **Lower** |
| Process Time | Longer | **Shorter** |

**WC algorithm should be applied with the best compromise of these parameters.**

# Summary

- There are disabled modules in the real detector, which results in inefficiency of FTK track reconstruction.
- Wild Card algorithm will be applied to the disabled modules, which assumes to have hits always in the modules.

# Plan

**Preparation of realistic wildcards for FTK pattern banks, including their effect on efficiency and dataflow and the sensitivity of the system to dead modules.**

**Validate the correlated parameters precisely.**

- Number of WC
- How to apply WC

(All the disabled modules? Only specific region??)

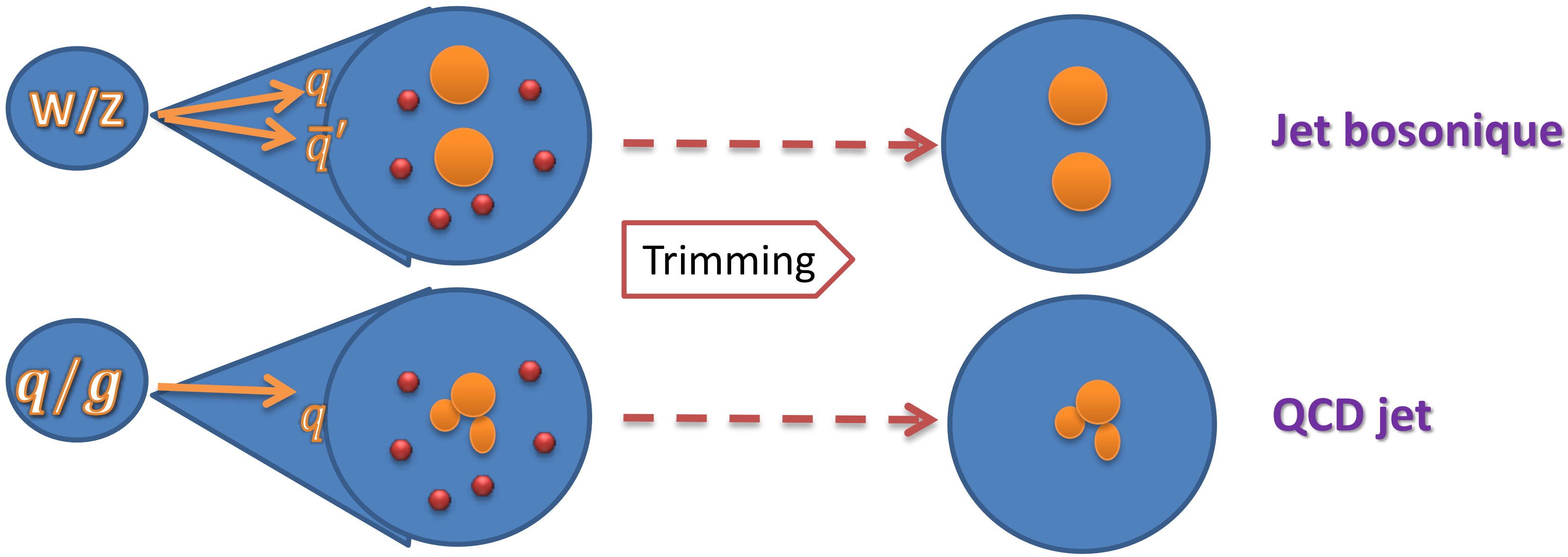
V.S.

- Reconstruction efficiency
- Fake rate
- Resolution
- Process time

# backup

# Trimming algorithme

➔ **Identifier la contamination (pile-up / événement sous-jacent) et les retirer du Large R-jet**




1. **Les constituants sons regroupés en sous-jets plus petits (R = 0,2)**
2. **Les sous-jets sont éliminés s'ils portent moins de 5% du $p_T$ de jet d'origine**
3. **les sous-jets restants sont ensuite utilisés pour calculer le quadrivecteur du Large R-jet**

# Définition du variable D2

$D_2^{\beta=1}$ **est largement utilisé pour distinguer les W/Z qui se désintègrent hadroniquement des jets issus de quarks et de gluons.**

$$D_2^{\beta=1} = E_{\mathrm{CF3}} \left( \frac{E_{\mathrm{CF1}}}{E_{\mathrm{CF2}}} \right)^3$$

$$E_{\mathrm{CF1}} = \sum_i p_{\mathrm{T},i}$$

$$E_{\mathrm{CF2}} = \sum_{ij} p_{\mathrm{T},i} p_{\mathrm{T},j} \Delta R_{ij}$$

$$E_{\mathrm{CF3}} = \sum_{ijk} p_{\mathrm{T},i} p_{\mathrm{T},j} p_{\mathrm{T},k} \Delta R_{ij} \Delta R_{jk} \Delta R_{ki}$$