



# ATLAS Searches for $VH$ , $HH$ , $VV$ , $V+\gamma/\gamma\gamma$ Resonances

Nicolò Vladi Biesuz

on behalf of the  
ATLAS COLLABORATION



# Overview

- Diboson searches in ATLAS:
  - $VV \rightarrow qq\bar{q}\bar{q}$ ,  $WV \rightarrow \ell\nu qq$ ,  $ZV \rightarrow \ell\ell qq$ ,  $\nu\nu qq$ ,  
 $WZ \rightarrow \ell\nu\ell\ell$ ,  $ZZ \rightarrow \ell\ell\ell\ell$ ;
  - $VH \rightarrow qq\bar{q}\bar{q}$ ,  $VH \rightarrow \ell\nu bb$ ,  $\ell\ell bb$ ,  $\nu\nu bb$ ;
  - $HH \rightarrow b\bar{b}b\bar{b}$ ,  $b\bar{b}\gamma\gamma$ ,  $\gamma\gamma WW^*(\rightarrow \ell\nu jj)$ ;
  - $Z\gamma \rightarrow \ell\ell\gamma$ ,  $q\bar{q}\gamma$ ;
  - $\gamma\gamma$ ;
- $V = W$  or  $Z$  boson,  $H = \text{Higgs boson}$ ,  $\ell = e, \mu$ ;

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#include <iostream>
#include <iterator>
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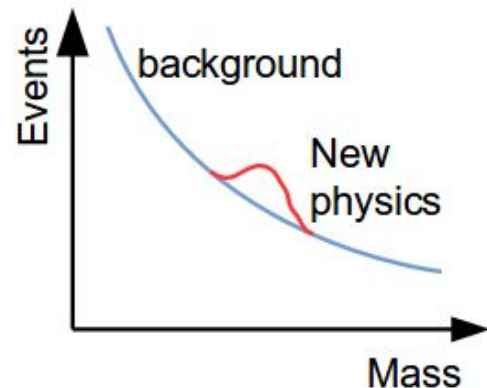
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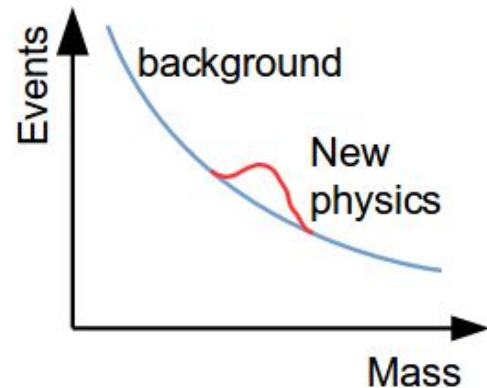
- **Reconstruct decay product of resonance X. Look for a peak on a smooth background.**



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- Benchmark models;
  - Spin-0: [extended Higgs sector](#);
  - Spin-1: [Heavy Vector Triplets \(HVT\)](#);
    - Model A:  $g_V=1$ ;
    - Model B:  $g_V=3$ ;
  - Spin-2: [Randall-Sundrum Gravitons \(RSG\\*\)](#).
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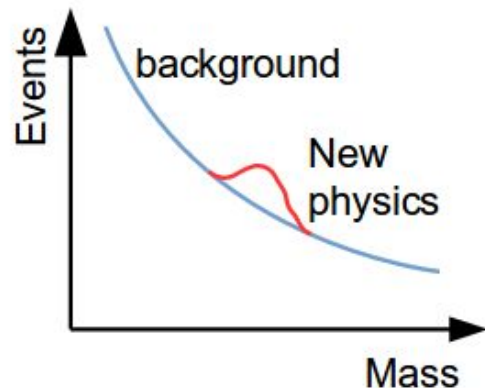
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- Based on **2015+2016 data at 13 TeV**:

- Boson decay topology:

- **Resolved**: low cross-section, low mass resonances.
- **Merged**: optimization for high mass resonances;

- **Reconstruct decay product of resonance X. Look for a peak on a smooth background.**



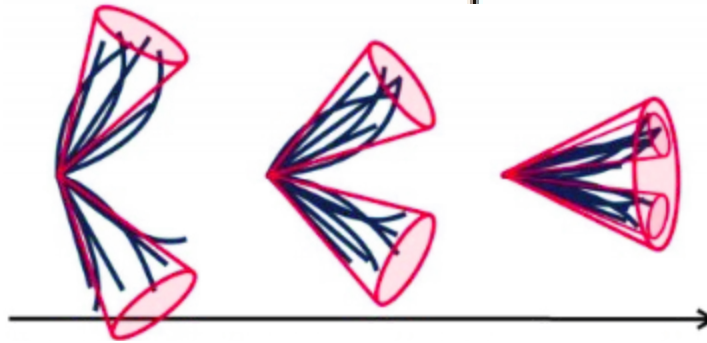
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# Special Ingredients: $V, H \rightarrow qq$

- Rule of thumb for angular separation of decay products:

$$\Delta R_{q_1 q_2} \sim \frac{2 \times M_V}{P_T}$$



Boson  $P_T$ : Increasing transverse momentum

- Resolved analysis:**  
reconstruct **two small jets** ( $\text{anti-}k_t$   $R=0.4$ ),  $j$ :
- Merged analysis:**  
decay products are detected as **one object**, a **large- $R$  jet** ( $\text{anti-}k_t$   $R=1.0$ ),  $J$ :

**$W, Z$  AND  $H$   
HADRONIC DECAYS:  
AT HIGH  $P_T$  DECAY  
PRODUCTS WILL MERGE  
IN A UNIQUE OBJECT!**

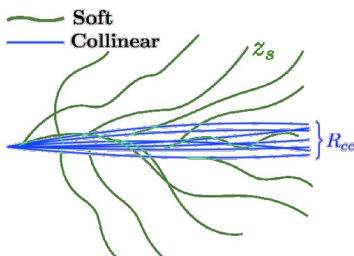




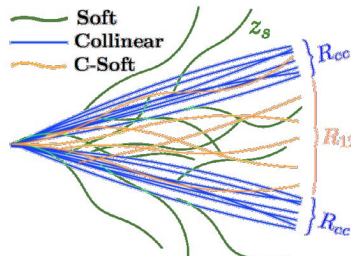
# Boson Identification in the boosted regime

- **W/Z tagger: [Mass] + [D2]**

- Based on jet substructure;



**QCD background  
jet substructure**



**V → qq  
jet substructure**

## D2 cut:

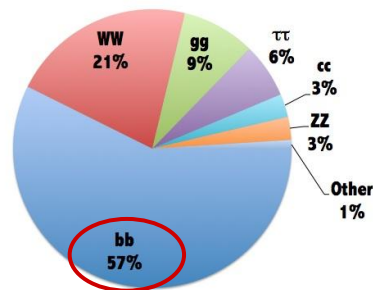
- two working points:
  - $\epsilon = 50\%$ ;
  - $\epsilon = 80\%$ ;
- e.g:  $\epsilon = 50\%$ , QCD rejection factor of 40-70 per jet;

[ATL-PHYS-PUB-2015-033](#)

- **H tagger: [Mass] + [b-tagging]**

- B-tagging on R=0.2 track based jets;

## Higgs decays at $m_H=125\text{GeV}$



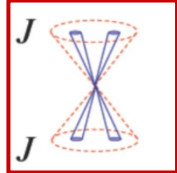
[ATL-PHYS-PUB-2015-035](#)

## Mass cut:

- Previous: use only calo information;
- New: combination of calo & track information:
  - by now used only VH → qqbb;
- W, Z & H mass cuts are not exclusive;

[JETM-2017-002](#)

DIFFERENT  
TECHNIQUES TO  
TAG DIFFERENT  
BOSONS... HOW  
CLEVER IS THAT?



# VV searches in fully hadronic final state ( $15.5 \text{ fb}^{-1}$ )

[ATLAS-CONF-2016-055](#)

## Merged regime only: $V \rightarrow qq$ identified as 1 large-R jet:

- $P_T > 450$  and  $200 \text{ GeV}$ ;
- $W/Z$  boson tagged:

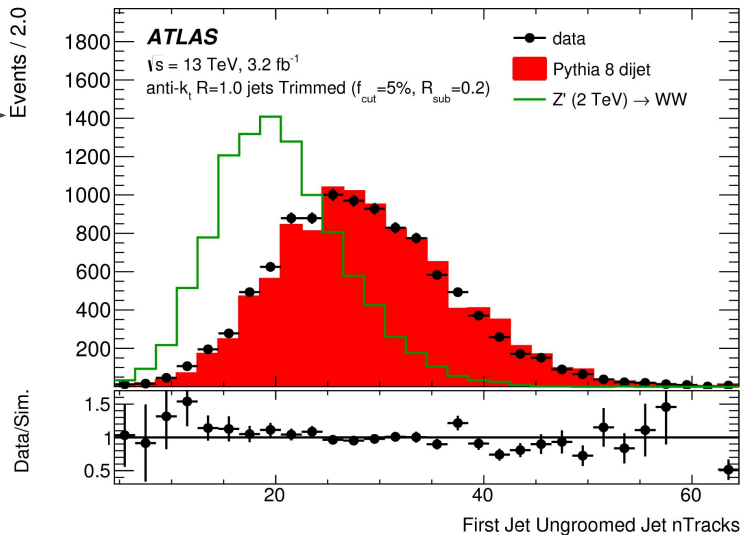
- ADDITIONAL CUTS TO REDUCE QCD BACKGROUND;  
- BACKGROUND WITH DATA-DRIVEN TECHNIQUES

## Need for additional QCD rejection;

- Single jet:
  - Number of tracks ghost-associated to the jet:  $N_{\text{trk}} < 30$ ;
- Topology selection:
  - $|\Delta y_{JJ}| < 1.2$ ;
  - $(P_{T,1} - P_{T,2}) / (P_{T,1} + P_{T,2}) < 0.15$

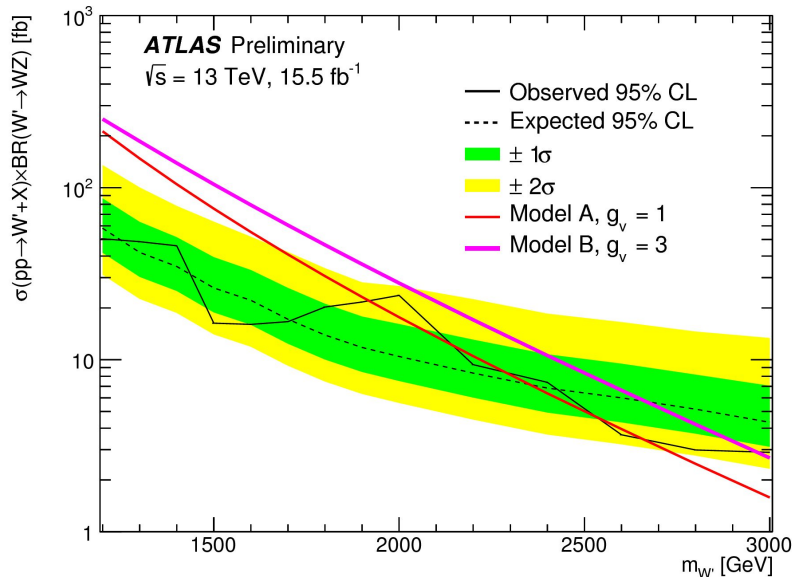
## Main background QCD:

- Data-driven estimation;
- Double polynomial fit to data;
- Validated in jet mass sidebands.



# VV searches in fully hadronic final state ( $15.5 \text{ fb}^{-1}$ )

[ATLAS-CONF-2016-055](#)



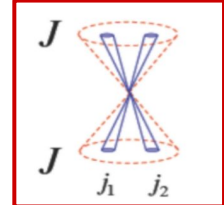
The most extreme  $p_0$ :  
 $1.9 \sigma$ : HVT  $W' \rightarrow W Z$  hypothesis,  $m_{W'}, 1.9 \text{ TeV}$ .

95% CL exclusion	HVT $W'$ $g_V=1$ ( $g_V=3$ ) $M_{W'}$ [TeV]	HVT $Z'$ $g_V=1$ ( $g_V=3$ ) $M_{Z'}$ [GeV]	RSG*: $M_{\text{RSG}^*}$ [GeV]
llqq	1.2-1.9 (1.2-3.0)	1.2-1.8 (1.2-1.9)	tested: <b>not sensitive</b> enough for exclusion

Sensitivity mainly limited by high  $P_T$  jets systematics.

# HH searches in fully hadronic final state ( $13.3 \text{ fb}^{-1}$ )

[ATLAS-CONF-2016-049](#)



## Merged regime:

$H \rightarrow b\bar{b}$  identified as 1 large-R jets:

## Resolved regime ( $300 < M_X < 1200 \text{ GeV}$ ):

$H \rightarrow b\bar{b}$  identified as 2 small jets:

- jets coupled minimizing distance w.r.t. expected H mass in  $M_{jj}^1 - M_{jj}^2$  plane;

## Categorized on number of B-tags:

- 2, 3, 4-btag categories;

MULTI-JET IS  
NOT WELL  
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USE DATA-DRIVEN  
TECHNIQUES

Signal Region

Control Region

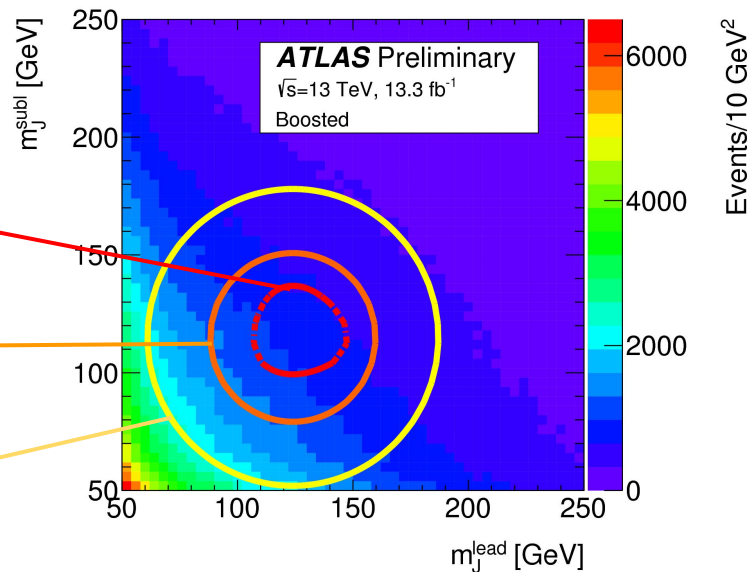
Sideband Region

## Main Backgrounds:

- QCD multijet ( $\sim 85\%$ );
  - Shape: Control region with exactly 0 b-tags;
- $t\bar{t}$  ( $\sim 15\%$ );
- $Z$  + jets ( $< 1\%$ );

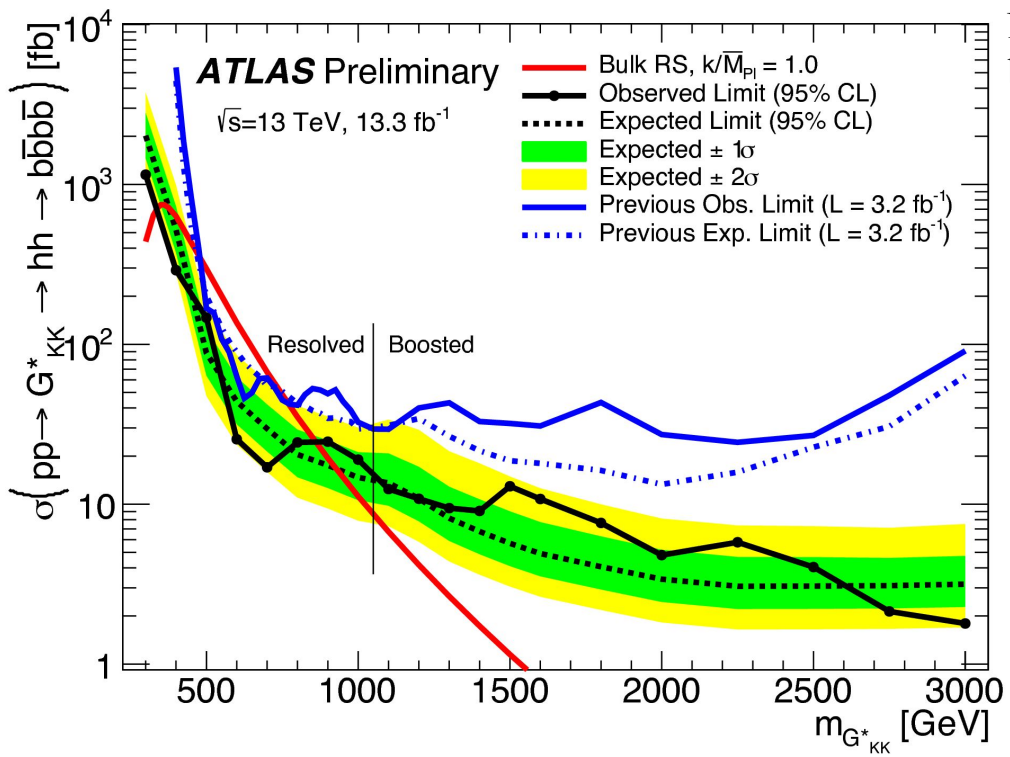
## Background normalization:

- extracted with a fit to the jet mass in sideband region;



# HH searches in fully hadronic final state ( $13.3 \text{ fb}^{-1}$ )

[ATLAS-CONF-2016-049](#)

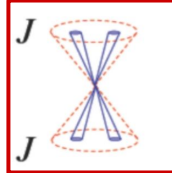


No significant excess with respect to background only hypothesis is found.

- non-resonant production (resolved analysis), the upper limit is 330 fb (at 95% CL): 29 times the Standard Model prediction  $11.3^{+0.9}_{-1.0} \text{ fb}$ .

95% CL exclusion	RS $G^*$ $M_{G^*}$ [GeV]
observed	360-860
expected	380-910





# VH searches in fully hadronic final state ( $36.1 \text{ fb}^{-1}$ )

[ATLAS-CONF-2017-018](#)

## Merged regime only:

Uses combined mass algorithm for boson tagging.

$V \rightarrow qq$  ( $H \rightarrow bb$ ) identified as 1 large-R jet:

- Highest mass jet: H tagged;
- Second highest mass jet: W/Z boson tagged;

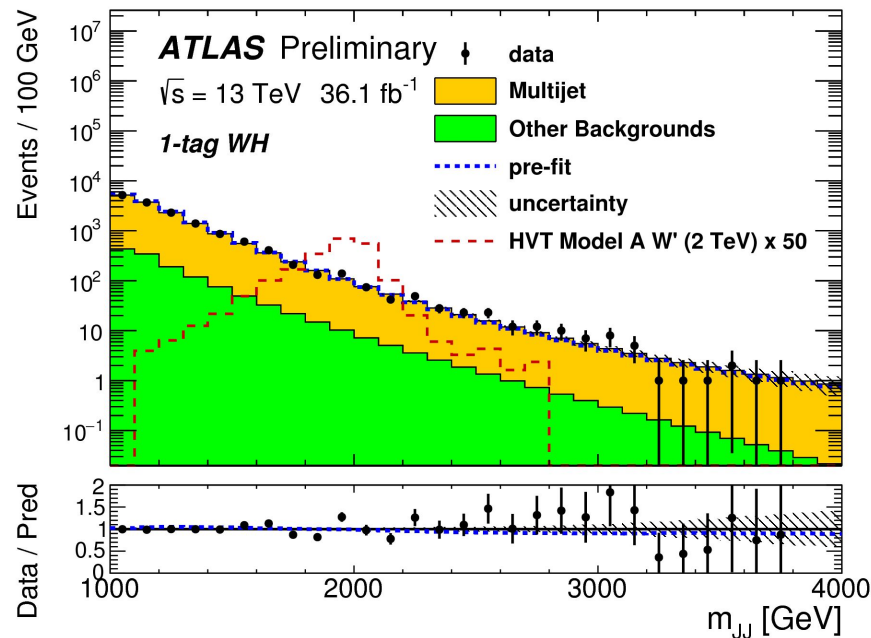
## Main background QCD:

- Data-driven estimation:
  - 0 b-tag sample;
  - reweighted to account for kinematic differences;
- Normalization using H-jet sideband.

## Other background sources from MC:

- tt;
- $V + \text{jets}$ ;

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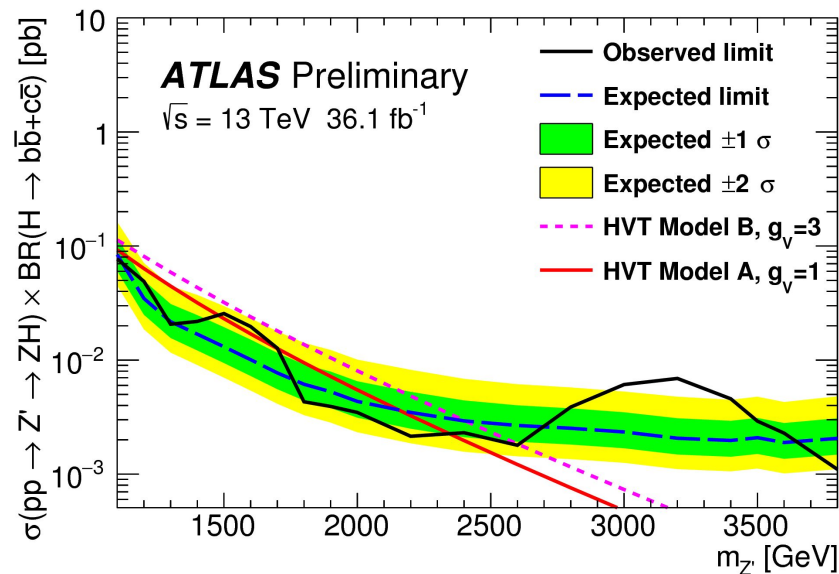
# VH searches in fully hadronic final state ( $36.1 \text{ fb}^{-1}$ )

[ATLAS-CONF-2017-018](#)

Largest excess is observed in the WH channel:

- $M_{\text{ZH}} \sim 3.0 \text{ TeV}$ ;
- local (global) significance:  $3.3\sigma$  ( $2.2\sigma$ ).

95% CL exclusion	$M_{\text{WH}}$ [GeV]	$M_{\text{ZH}}$ [GeV]
HVT Model A ( $g_V=1$ )	1100-2400	1100-1480; 1700-2350
HVT Model B ( $g_V=3$ )	1100-2500	1100-2600



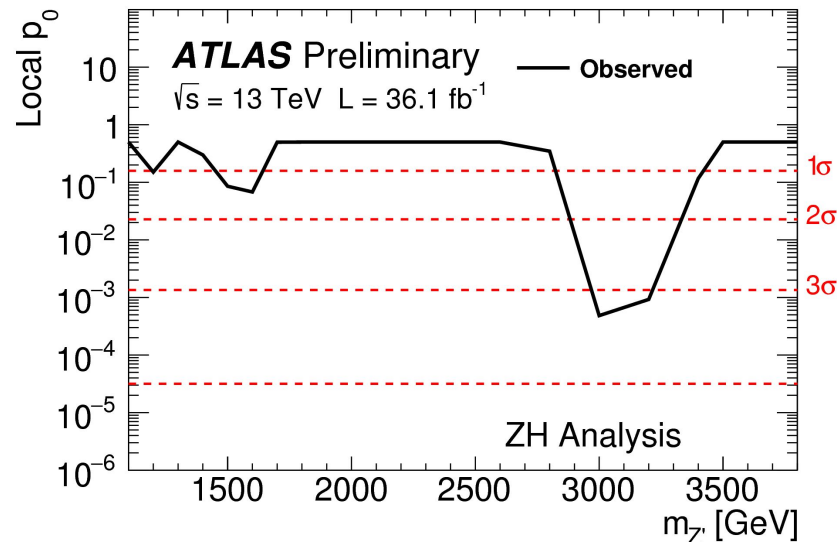
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# Searches in the $Z\gamma$ channel

[ATLAS-CONF-2016-044](#)

$e^+e^- \gamma$ :

- $\sigma(M_X) = 2 \text{ GeV}$  for  $M_X = 200 \text{ GeV}$  (1%);
- $\sigma(M_X) = 15 \text{ GeV}$  for  $M_X = 2.5 \text{ TeV}$  (0.6%).

- $Z \rightarrow \ell^+ \ell^-$ :  $m_{\ell\ell} \in \{m_Z \pm 15 \text{ GeV}\}$ ;

$\mu^+\mu^- \gamma$ :

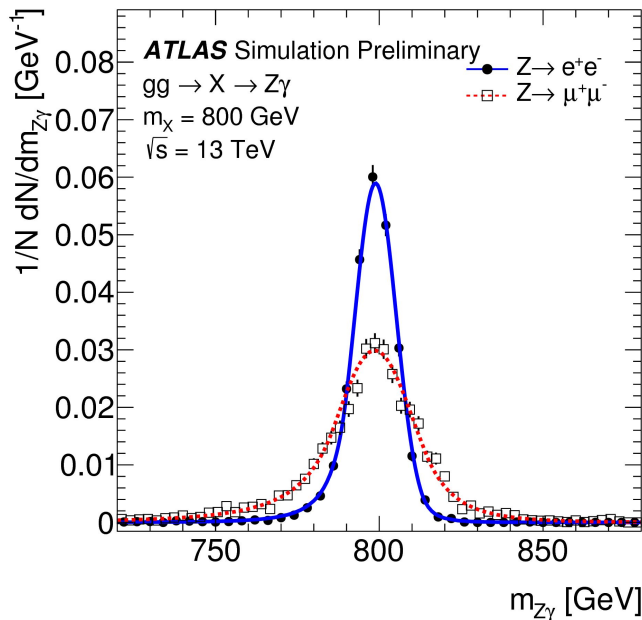
- $\sigma(M_X) = 2 \text{ GeV}$  for  $M_X = 200 \text{ GeV}$  (1%);
- $\sigma(M_X) = 35 \text{ GeV}$  for  $M_X = 2.5 \text{ TeV}$  (1.4%).

- Keep Z candidate with highest  $P_T$ .

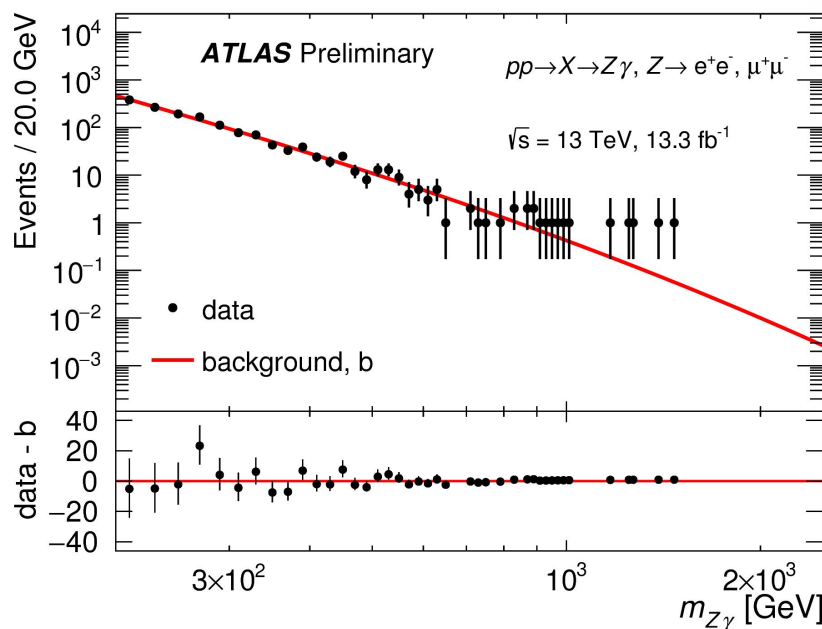
**2 FINAL STATES:**  
 - ENHANCE SENSITIVITY;  
 - DIFFERENT MASS  
 RESOLUTION AND  
 SYSTEMATICS.

**Signal** parameterization: double sided Crystal Ball:

- Gaussian peak with power-law tails.



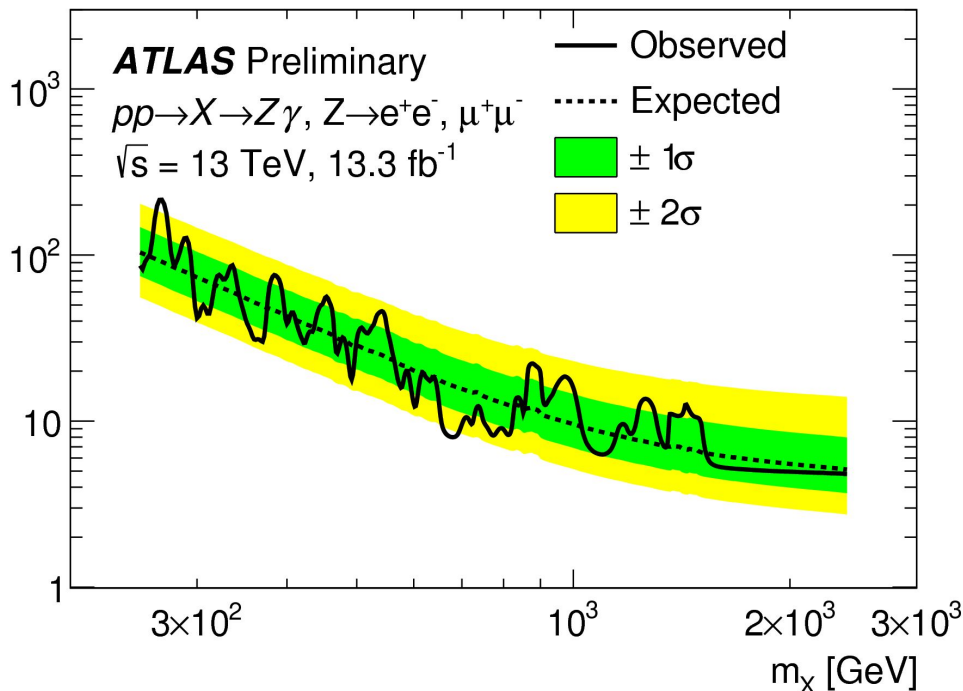
**Background** parameterization: double polinomial.



# Searches in $Z\gamma$ channel

[ATLAS-CONF-2016-044](#)

95% CL limit on  $\sigma \times \text{BR}(X \rightarrow Z\gamma) [\text{fb}]$



## No significant excess found:

- largest deviation:  $M_X \sim 268 \text{ GeV}$   
 local significance of  $2.2\sigma$

## Model independent 95% CL limit on $\sigma$

$\times \text{BR}_{Z\gamma}$ :

- observed:
  - 215 fb for  $M_X = 270 \text{ GeV}$ ;
  - 5 fb for  $M_X = 2.4 \text{ TeV}$ .
- expected:
  - 103 fb for  $M_X = 250 \text{ GeV}$ ;
  - 5 fb for  $M_X = 2.4 \text{ TeV}$ .

# Searches in the $\gamma\gamma$ channel ( $15.4 \text{ fb}^{-1}$ )

[ATLAS-CONF-2016-059](#)

## Spin-0 selection:

- 2 High  $E_T$  isolated photons ( $E_T > 0.4 \text{ (0.3)} m_{\gamma\gamma}$ );

## Signal parameterization:

- Double sided Crystal Ball function:
  - Gaussian function with power-law tails on both sides.

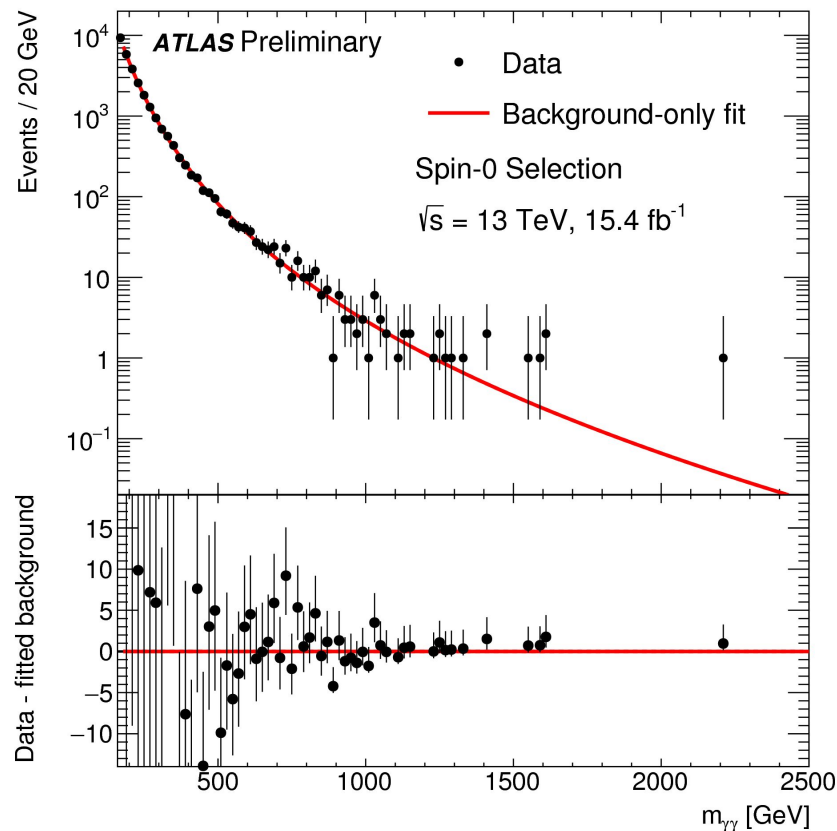
## Background parameterization:

$$f(k)(x; b, \{a_k\}) = N(1 - x^{1/3})^b x^{\sum_{j=0}^k a_j (\log x)^j}$$

- $x = M_{\gamma\gamma} / \sqrt{s}$ ;
- $a_K$ : free parameters
- $N$ : normalization



-THIS IS THE SPIN 0 ANALYSIS.  
-BOTH BACKGROUND AND SIGNAL ARE PARAMETRIZED

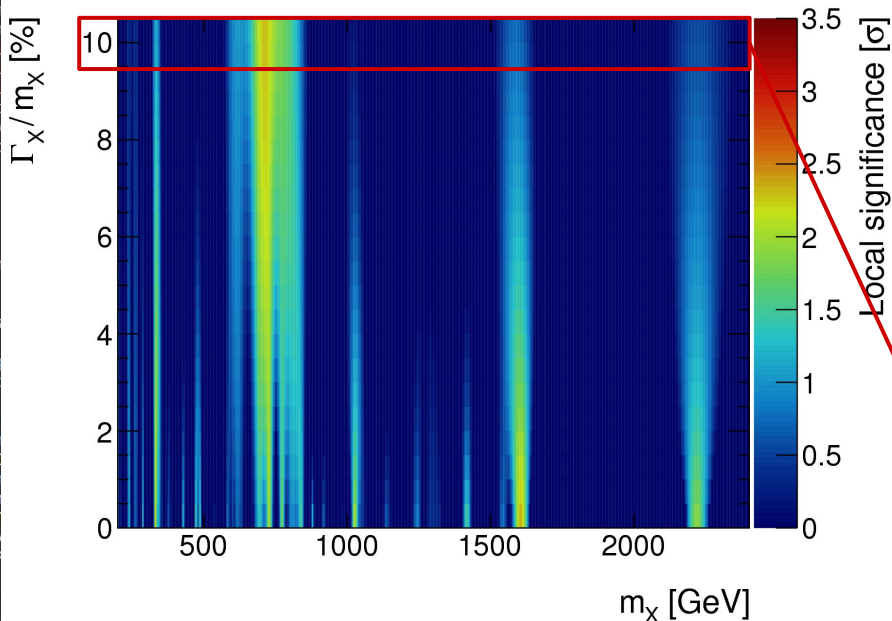




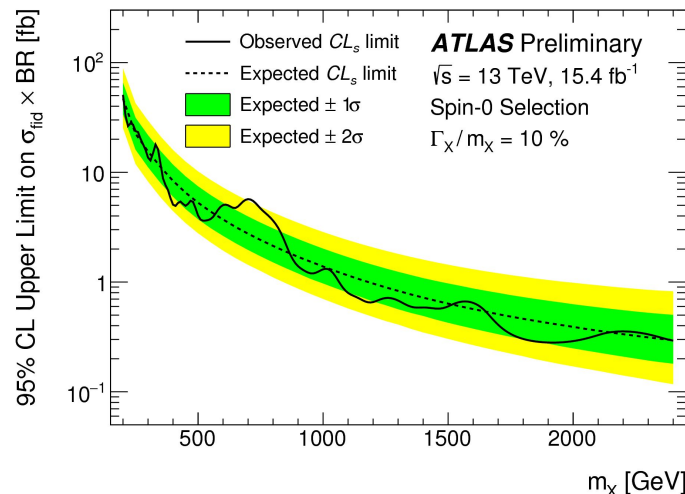
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[ATLAS-CONF-2016-059](#)

**ATLAS Preliminary**  $\sqrt{s} = 13 \text{ TeV}, 15.4 \text{ fb}^{-1}$  Spin-0 Selection



- Local significance is given as function of  $m_X$  and  $\Gamma_X$ ;
- 2015 data: reanalyzed with improved  $\gamma$  reconstruction;
  - Largest excess:  $m_X = 730 \text{ GeV}$ ,  $3.4 \sigma$  local, width 8%;
- Largest excess (2015+2016 dataset):
  - $m_X = 1600 \text{ GeV}$ ,  $2.4 \sigma$  local, narrow width;
- **In 700–800 GeV mass range:**
  - $m_X = 710 \text{ GeV}$ ,  $2.3 \sigma$  local, relative width 10%;
  - **Compatibility: 2015 - 2016:  $2.7\sigma$  @ 730 GeV.**





# Conclusion

- Results with 2015+2016 dataset have been presented;
- High mass tensions are present;
- More results on diboson resonance searches with 2016 full dataset will arrive in the coming months. Stay tuned!
- Can't wait for 100 fb<sup>-1</sup> dataset!



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```

// put your config
// that way they c
protected:
// float cutValue;
/// This is a pair
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/// This is a pair
const xAOD::Missin
BTaggingSelectionT
BTaggingEfficiency
std::unique_ptr<CP

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```

// variables that
// protected from
// node (done by t
public:
/// This is the ev
xAOD::TEvent* m_ev

```

```

// this is a stand
PisaxAODAnalysis (

```

# BaCk-Up

# References

- $VV \rightarrow qq\bar{q}\bar{q}$ : [[ATLAS-CONF-2016-055](#)], **Search for resonances with boson-tagged jets in 15.5 fb<sup>-1</sup> of  $pp$  collisions at  $\sqrt{s}=13$  TeV collected with the ATLAS detector**, ATLAS collaboration, 08 Aug 2016. - mult. p., [38th International Conference on High Energy Physics](#), Chicago, IL, USA, 03 - 10 Aug 2016;
- $WV \rightarrow \ell\nu qq$ : [[ATLAS-CONF-2016-062](#)], **Search for diboson resonance production in the  $\ell\nu qq$  final state using  $pp$  collisions at  $\sqrt{s}=13$  TeV with the ATLAS detector at the LHC**, ATLAS collaboration, 08 Aug 2016. - mult. p.;
- $ZV \rightarrow \ell\ell qq, \nu\nu qq$ : [[ATLAS-CONF-2016-082](#)], **Searches for heavy  $ZZ$  and  $ZW$  resonances in the  $\ell\ell qq$  and  $\nu\nu qq$  final states in  $pp$  collisions at  $\sqrt{s}=13$  TeV with the ATLAS detector**, ATLAS collaboration, 08 Aug 2016. - mult. p., [38th International Conference on High Energy Physics](#), Chicago, IL, USA, 03 - 10 Aug 2016;
- $WW \rightarrow \ell\nu\ell\nu$ : [[ATLAS-CONF-2016-074](#)], **Search for a high-mass Higgs boson decaying to a pair of  $W$  bosons in  $pp$  collisions at  $\sqrt{s}=13$  TeV with the ATLAS detector**, ATLAS collaboration, 08 Aug 2016. - mult. p., [38th International Conference on High Energy Physics](#), Chicago, IL, USA, 03 - 10 Aug 2016;
- $VH \rightarrow qqbb$ : [[ATLAS-CONF-2017-018](#)], **Search for Heavy Resonances Decaying to a  $W$  or  $Z$  Boson and a Higgs Boson in the  $qq^{-} (^{*}bb^{-})$  Final State in  $pp$  Collisions at  $\sqrt{s}=13$  TeV with the ATLAS Detector**, ATLAS collaboration, 22 Mar. 2017. - mult. p.;
- $VH \rightarrow \ell\nu bb, \ell\ell bb, \nu\nu bb$ : [[arXiv:1607.05621](#)], **Search for new resonances decaying to a  $W$  or  $Z$  boson and a Higgs boson in the  $\ell+\ell-bb^{-}, \ell\nu bb^{-}$ , and  $\nu\nu^{-}bb^{-}$  channels with  $pp$  collisions at  $\sqrt{s}=13\sim 14$  TeV with the ATLAS detector**, ATLAS collaboration, 10 February 2017, Pages 32–52, [Physics Letters B Volume 765](#);

# References

- $HH \rightarrow b\bar{b}b\bar{b}$ : [[ATLAS-CONF-2016-049](#)], Search for pair production of Higgs bosons in the  $b\bar{b}b\bar{b}$  final state using proton–proton collisions at  $\sqrt{s}=13$  TeV with the ATLAS detector, ATLAS collaboration, 08 Aug 2016. - 32 p., [38th International Conference on High Energy Physics](#), Chicago, IL, USA, 03 - 10 Aug 2016;
- $HH \rightarrow b\bar{b}\gamma\gamma$ : [[ATLAS-CONF-2016-004](#)], Search for Higgs boson pair production in the  $b\bar{b}\gamma\gamma$  final state using pp collision data at  $\sqrt{s}=13$  TeV with the ATLAS detector, ATLAS collaboration, 14 Mar 2016. - 20 p., [50th Rencontres de Moriond on Electroweak Interactions and Unified Theories](#), La Thuile, Italy, 14 - 21 Mar 2015;
- $HH \rightarrow \gamma\gamma WW^*(\rightarrow l\nu jj)$ : [[ATLAS-CONF-2016-071](#)], Search for Higgs boson pair production in the final state of  $\gamma\gamma WW^*(\rightarrow l\nu jj)$  using 13.3 fb<sup>-1</sup> of pp collision data recorded at  $\sqrt{s}=13$  TeV with the ATLAS detector, ATLAS collaboration, 08 Aug 2016. - mult. p.;
- $Z\gamma \rightarrow \ell\ell\gamma$ : [[ATL-COM-PHYS-2016-1807](#)], Searches for the Standard Model Higgs boson and new high-mass resonances decaying to a photon and a Z boson in pp collisions at  $\sqrt{s}=13$  TeV with the ATLAS detector, ATLAS collaboration, 21 Dec 2016. - mult. p.;
- $\gamma\gamma$ : [[ATLAS-CONF-2016-059](#)], Search for scalar diphoton resonances with 15.4 fb<sup>-1</sup> of data collected at  $\sqrt{s}=13$  TeV in 2015 and 2016 with the ATLAS detector, ATLAS collaboration, 08 Aug 2016. - mult. p.;

# References

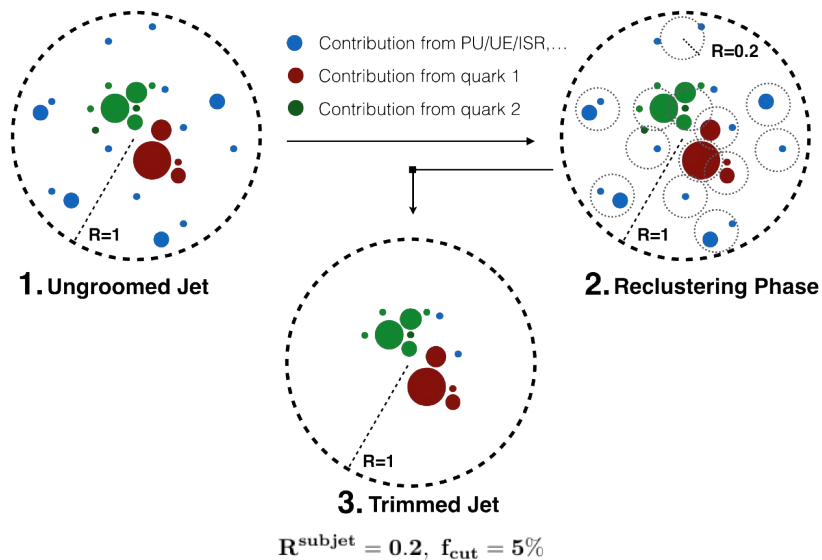
## Theoretical models:

- **Anatomy of a composite Higgs model**, Michael J. Dugan, Howard Georgi, David B. Kaplan, Nuclear Physics B, Volume 254, 1985, Pages 299-326, <http://www.sciencedirect.com/science/article/pii/0550321385902214>.
- **Heavy Vector Triplets: Bridging Theory and Data**, Pappadopulo, Duccio and Thamm, Andrea and Torre, Riccardo and Wulzer, Andrea. JHEP, 09, 2014, 060, 10.1007/JHEP09(2014)060, DOI 1402.4431 <https://arxiv.org/abs/1402.4431>.
- **A Large Mass Hierarchy from a Small Extra Dimension**, Randall, Lisa and Sundrum, Raman. Phys. Rev. Lett., 83, 1999, 3370-3373, 10.1103/PhysRevLett.83.3370", arXiv[hep-ph] 9905221, <https://arxiv.org/abs/hep-ph/9905221>.

# Trimming:

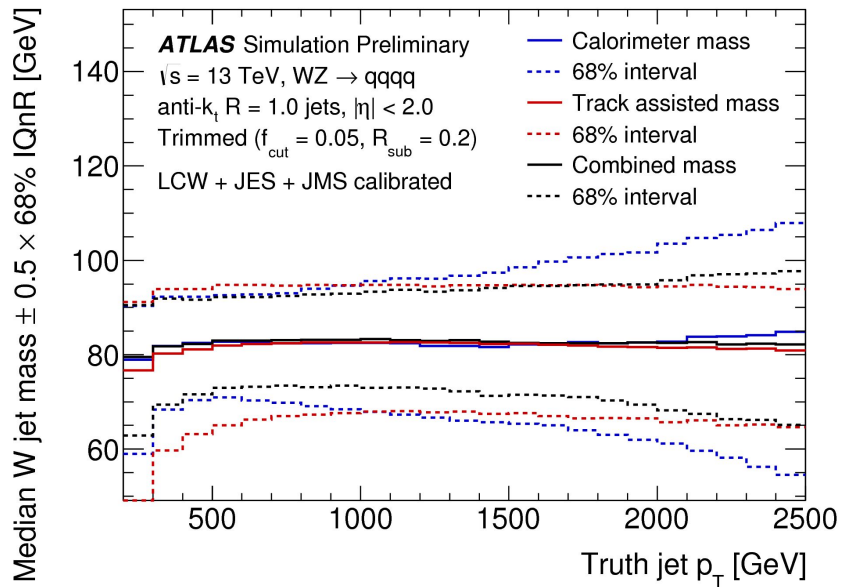
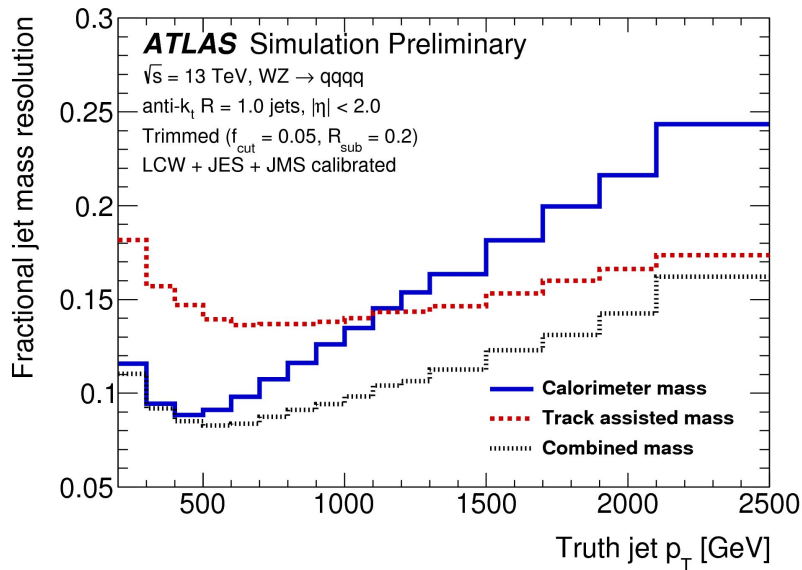
**Grooming** for pile-up suppression;

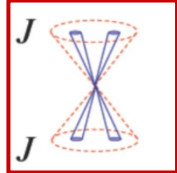
- Example: **Trimming** ( $R_{\text{sub}} = 0.2$ ,  $f_{\text{cut}} = 5\%$ );
- Build Kt jets with  $R=0.2$  using Anti-Kt 1.0 jet clusters;
- Drop sub-jets carrying less than 5% of large-R jet total momentum;





# Mass definition:



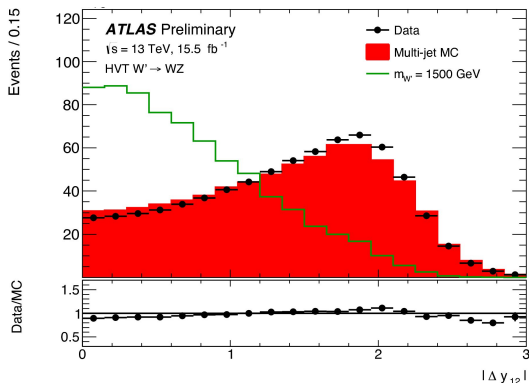
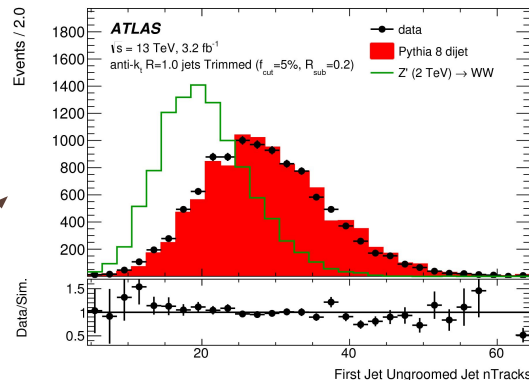


# VV searches in fully hadronic final state ( $15.5 \text{ fb}^{-1}$ )

[ATLAS-CONF-2016-055](#)

## Merged regime only: $V \rightarrow q\bar{q}$ identified as 1 large-R jet:

- $P_T > 450$  and  $200 \text{ GeV}$ ;
- W/Z boson tagged:
  - D2 cut:
    - 50% efficiency WP;
    - QCD rejection factor of 40-70 per jet;
  - $M_{W,Z}$  mass cut:
    - 68% efficiency WP;
    - W and Z mass window overlap;
- Additional QCD rejection by requiring:  $N_{\text{trk}} > 30$ ;
  - $N_{\text{trk}}$ : number of tracks ghost-associated to the jet.



- ADDITIONAL CUTS TO REDUCE QCD BACKGROUND;  
- BACKGROUND WITH DATA-DRIVEN TECHNIQUES



## Topology selection:

- $|\Delta y_{JJ}| < 1.2$ ;
- $(P_{T,1} - P_{T,2}) / (P_{T,1} + P_{T,2}) < 0.15$

## Main background QCD:

- Data-driven estimation;
- Functional form fit to data:

$$\frac{dn}{dx} = p_1 (1-x)^{p_2 + \xi p_3} x^{p_3}$$

$$x = m_{JJ} / \sqrt{s}$$

# HH searches in fully hadronic final state:

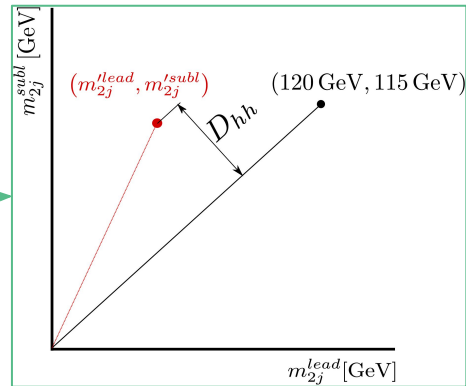
## Merged regime:

$H \rightarrow b\bar{b}$  identified as 1 large-R jets:  $P_T > 450$  (250) GeV;

## Resolved regime ( $300 < M_X < 1200$ GeV):

$H \rightarrow b\bar{b}$  identified as 2 small jets:

- jets coupled minimizing  $D_{HH}$
- cut on  $\Delta R_{jj}$  and  $\Delta \eta_{jj}$



## Signal region definition:

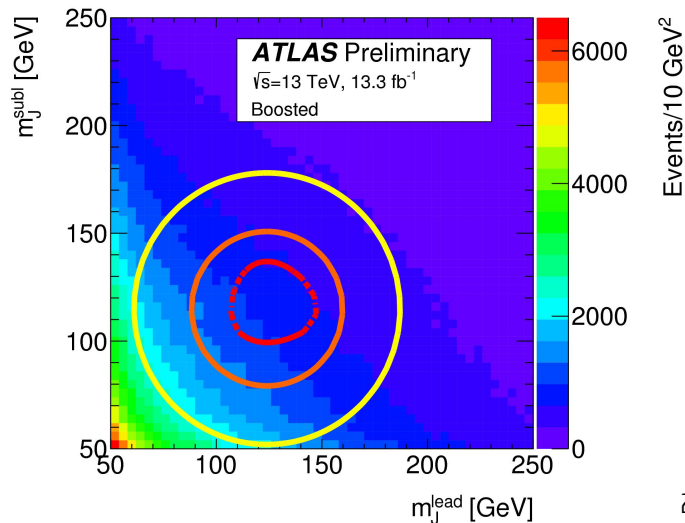
- $X_{hh} = \sqrt{\left(\frac{m_j^{lead} - 124 \text{ GeV}}{\sigma(m_j^{lead})}\right)^2 + \left(\frac{m_j^{subl} - 115 \text{ GeV}}{\sigma(m_j^{subl})}\right)^2}$
- $X_{hh} < 1.6$ ;

## Control region definition (top):

- $R_{hh} = \sqrt{(m(J_1) - 124 \text{ GeV})^2 + (m(J_2) - 115 \text{ GeV})^2}$
- $X_{hh} > 1.6$  &  $R_{hh} < 35.8 \text{ GeV}$

## Sideband region:

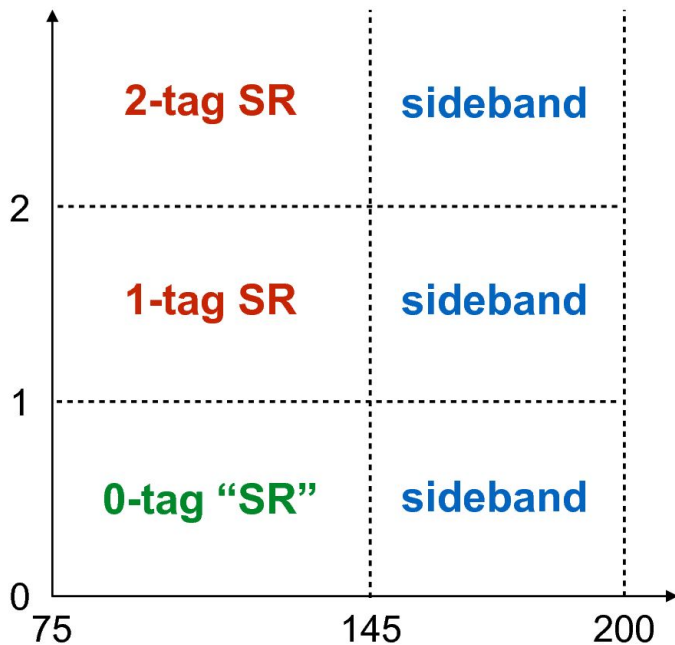
- $X_{hh} > 1.6$  &  $35.8 < R_{hh} < 63 \text{ GeV}$



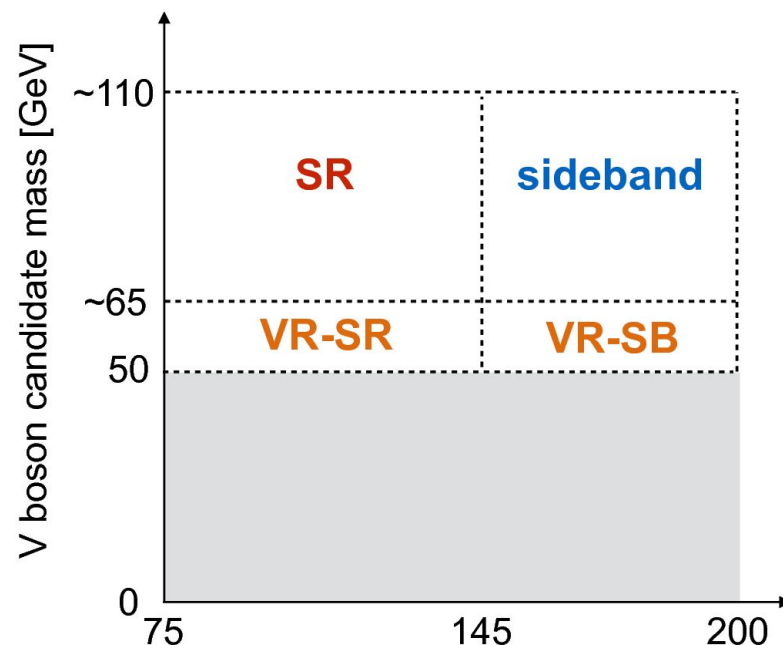
# VH searches in fully hadronic final state:

[ATLAS-CONF-2016-083](#)

number of b-tags



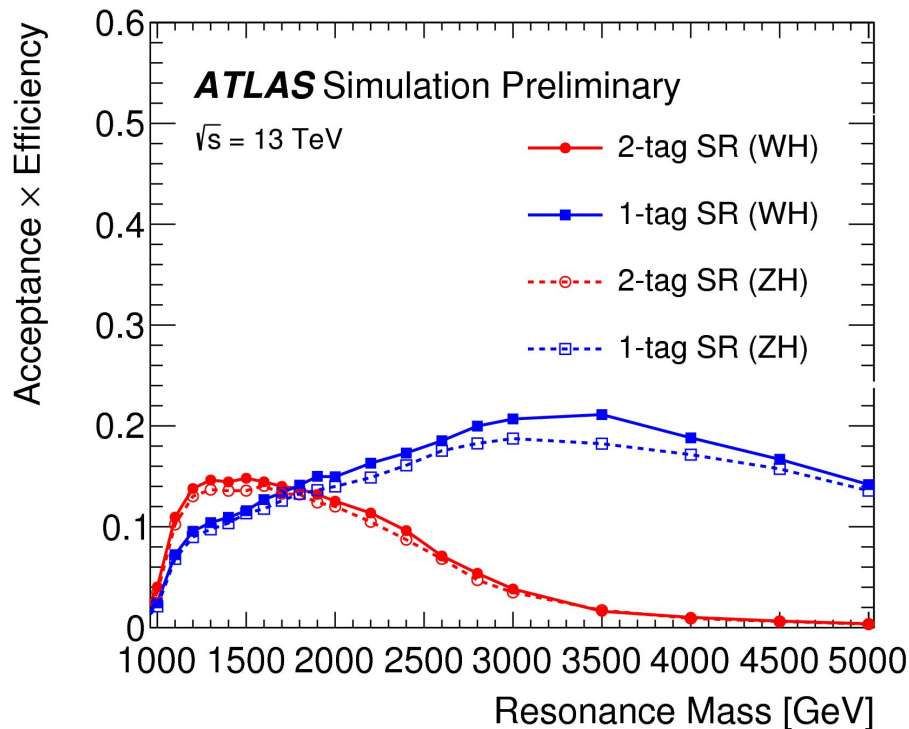
Higgs boson candidate mass [GeV]



Higgs boson candidate mass [GeV]

# VH searches in fully hadronic final state:

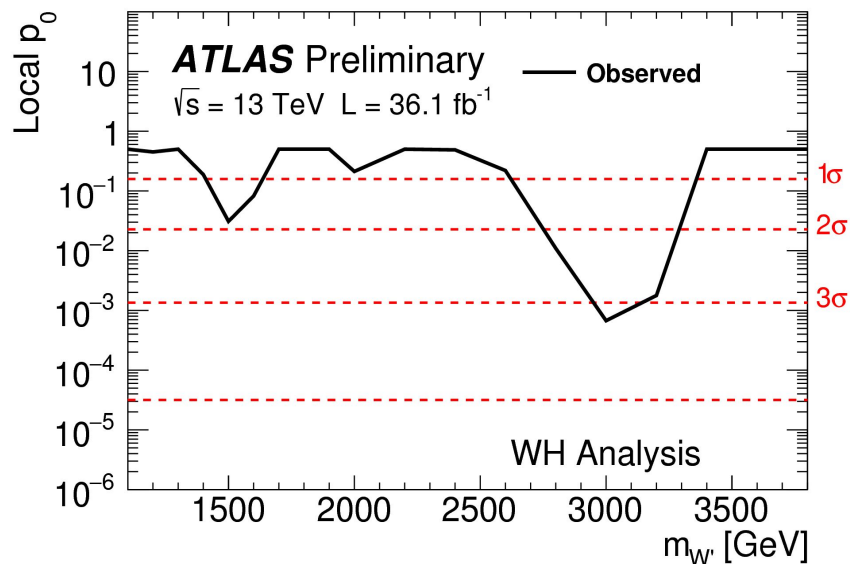
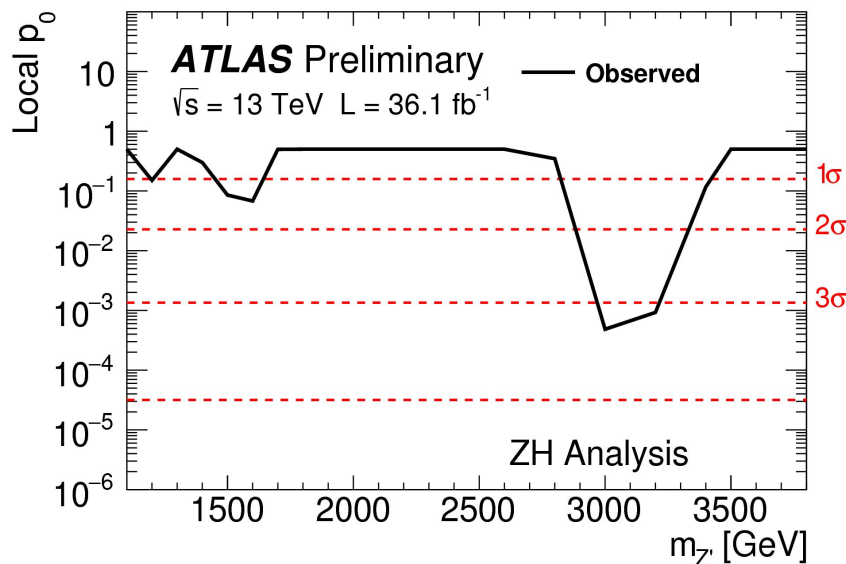
[ATLAS-CONF-2016-083](#)





# VH searches in fully hadronic final state:

[ATLAS-CONF-2016-083](#)





# VH searches in fully hadronic final state:

[ATLAS-CONF-2016-083](#)

Selection	Description
Lepton veto	Remove events with leptons
$> 1$ large- $R$ jets	$p_T > 250$ GeV, $ \eta  < 2.0$
Leading large- $R$ jet $p_T$	$> 450$ GeV
$V/H$ assignment	larger mass jet is $H$ -jet, smaller mass jet is $V$ -jet
Rapidity difference	$ \Delta y_{12}  < 1.6$
$E_T^{\text{miss}}$ veto	Remove events with $E_T^{\text{miss}} > 150$ GeV and $\Delta\phi(\vec{E}_T^{\text{miss}}, H - \text{jet}) > 120$ degrees
Higgs tagging	mass window, track-jet b-tagging
W/Z-tagging	mass window + $D_2^{\beta=1}$ selection
Dijet mass	$m_{JJ} > 1$ TeV

# VH searches in fully hadronic final state:

[ATLAS-CONF-2016-083](#)

2-tag Sample	Sideband Region	Validation Region (Signal Region-Like)		Validation Region (Sideband Region-Like)	
		No $D_2^{\beta=1}$	With $D_2^{\beta=1}$	No $D_2^{\beta=1}$	With $D_2^{\beta=1}$
Multijet	1410 $\pm$ 10	14700 $\pm$ 20	875 $\pm$ 5	7150 $\pm$ 10	460 $\pm$ 5
$t\bar{t}$	220 $\pm$ 10	115 $\pm$ 10	12 $\pm$ 3	250 $\pm$ 15	26 $\pm$ 4
V+jets	35 $\pm$ 15	250 $\pm$ 30	14 $\pm$ 6	30 $\pm$ 10	3 $\pm$ 3
Total	1670 $\pm$ 20	14050 $\pm$ 35	900 $\pm$ 8	7430 $\pm$ 20	485 $\pm$ 6
Data	1667	15013	934	7200	426

1-tag Sample	Sideband Region	Validation Region (Signal Region-Like)		Validation Region (Sideband Region-Like)	
		No $D_2^{\beta=1}$	With $D_2^{\beta=1}$	No $D_2^{\beta=1}$	With $D_2^{\beta=1}$
Multijet	12350 $\pm$ 50	138500 $\pm$ 160	8820 $\pm$ 40	62600 $\pm$ 100	3970 $\pm$ 30
$t\bar{t}$	2200 $\pm$ 30	1030 $\pm$ 30	115 $\pm$ 7	1700 $\pm$ 35	210 $\pm$ 10
V+jets	300 $\pm$ 40	1480 $\pm$ 90	120 $\pm$ 25	420 $\pm$ 50	35 $\pm$ 13
Total	15000 $\pm$ 75	140900 $\pm$ 190	9050 $\pm$ 50	64700 $\pm$ 120	4200 $\pm$ 30
Data	14973	135131	8685	66896	4418

# VH searches in fully hadronic final state:

[ATLAS-CONF-2016-083](#)

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include "xAODBTaggi
include "xAODBTaggi
include "MuonSelect
include "PathResolv
include "TEfficienc
include "TH1.h"
include "TH1F.h"
include "TH1D.h"
include "TTree.h"
include "TFile.h"
include "TStopwatch
include <iostream>
include <iterator>
class PisaxAODAnalysis

// put your config
// that way they c
protected:
// float cutValue;
/// This is a poin
const xAOD::EventI
/// This is a poin
const xAOD::Missir
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std::unique_ptr<CP

// variables that
// protected from
// node (done by t
public:
/// This is the ev
xAOD::TEvent* m_ev

// this is a stand
PisaxAODAnalysis (

```

	<i>ZH</i> 2-tag	<i>ZH</i> 1-tag
Multijet	1440 ± 60	13770 ± 310
Other Backgrounds	135 ± 45	1350 ± 270
Total Backgrounds	1575 ± 40	15120 ± 130
Data	1574	15112
<i>Model B</i> , M=2 TeV	25 ± 7	29 ± 10
	<i>WH</i> 2-tag	<i>WH</i> 1-tag
Multijet	1525 ± 65	13900 ± 290
Other Backgrounds	110 ± 45	1310 ± 260
Total Backgrounds	1635 ± 40	15220 ± 120
Data	1646	15212
<i>Model B</i> , M=2 TeV	51 ± 10	62 ± 16

# Searches in the $Z\gamma$ channel

ATLAS-CONF-2016-044

$e^+e^- \gamma$ :

- $\sigma(M_X) = 2 \text{ GeV}$  for  $M_X = 200 \text{ GeV}$  (1%);
- $\sigma(M_X) = 15 \text{ GeV}$  for  $M_X = 2.5 \text{ TeV}$  (0.6%).

$\mu^+\mu^- \gamma$ :

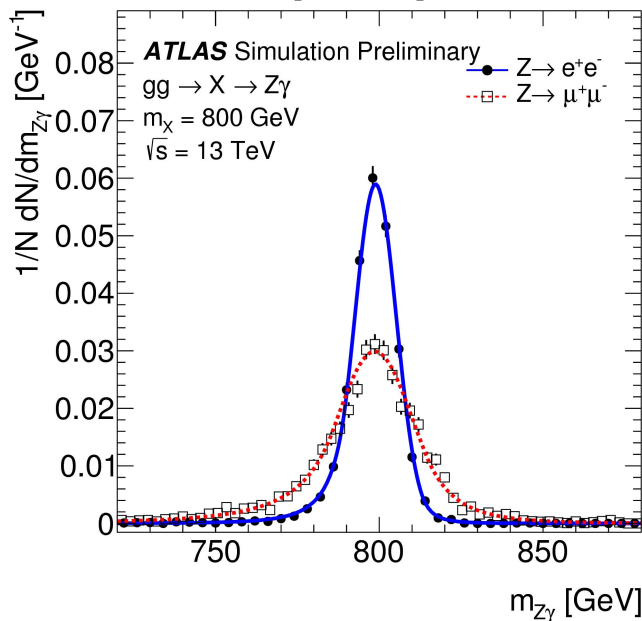
- $\sigma(M_X) = 2 \text{ GeV}$  for  $M_X = 200 \text{ GeV}$  (1%);
- $\sigma(M_X) = 35 \text{ GeV}$  for  $M_X = 2.5 \text{ TeV}$  (1.4%).

- $Z \rightarrow \ell^+ \ell^-$ :  $m_{\ell\ell} \in \{m_Z \pm 15 \text{ GeV}\}$ ;

- Keep Z candidate with highest  $P_T$ .

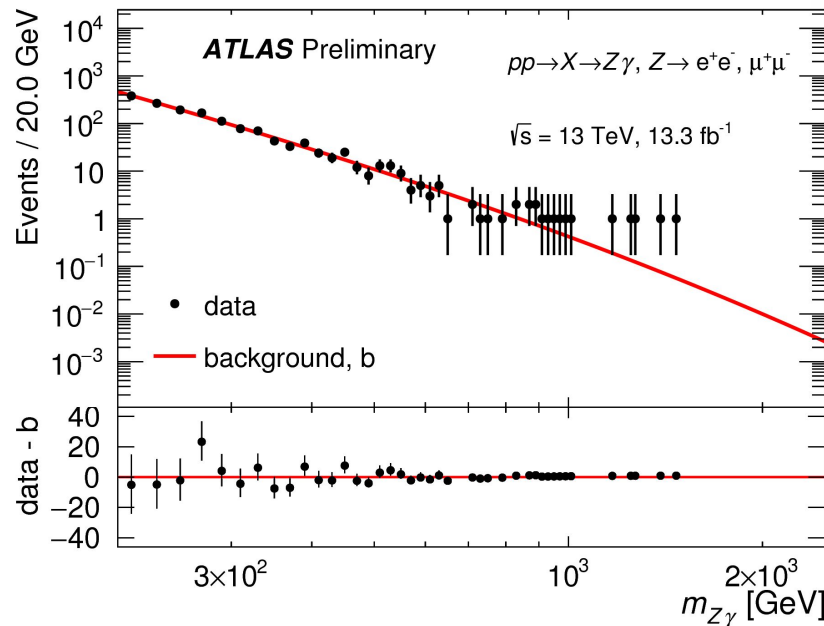
Signal parameterization: double sided Crystal Ball:

- Gaussian peak with power-law tails.



Background parameterization:  $f_{\text{bkg}}(x) = N(1-x_k)^{p_1} x^{p_2}$ ;

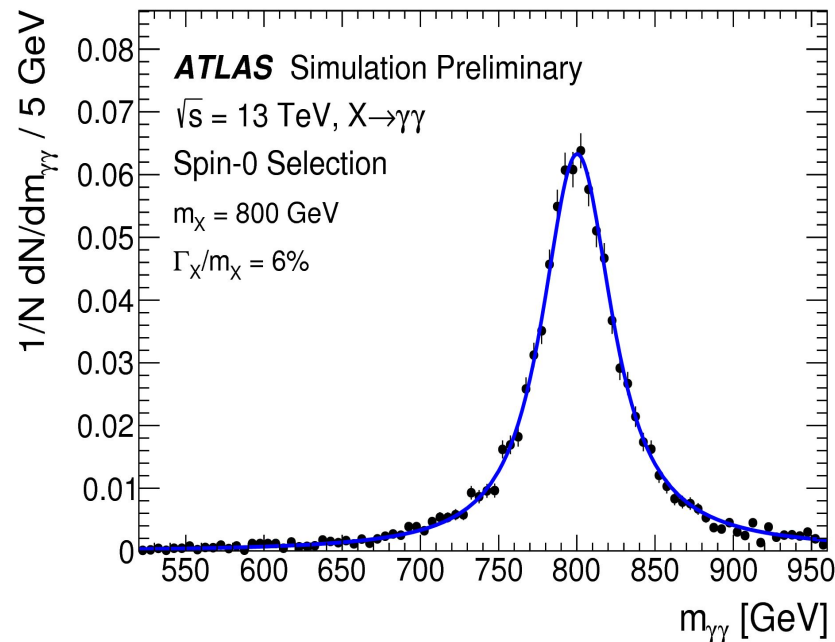
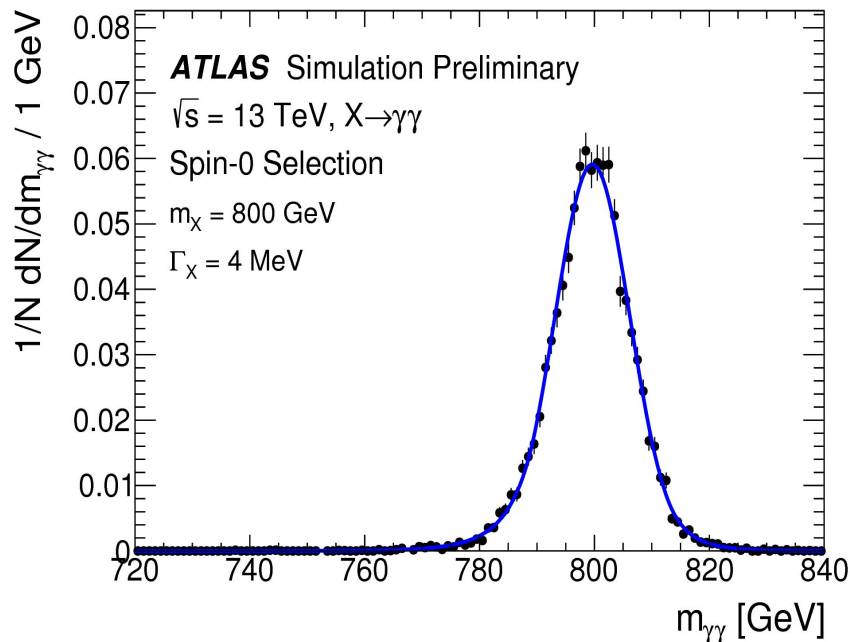
- $x = m_{Z\gamma}/\sqrt{s}$



**2 FINAL STATES:**  
- ENHANCE SENSITIVITY;  
- DIFFERENT MASS  
RESOLUTION AND  
SYSTEMATICS.

# Searches of resonances in the $\gamma\gamma$ channel

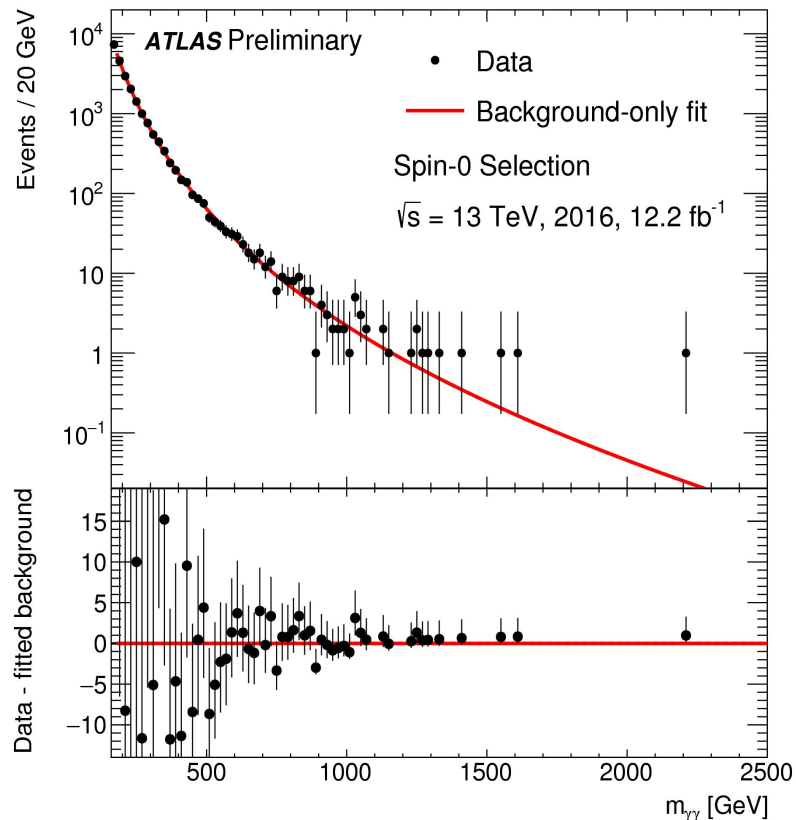
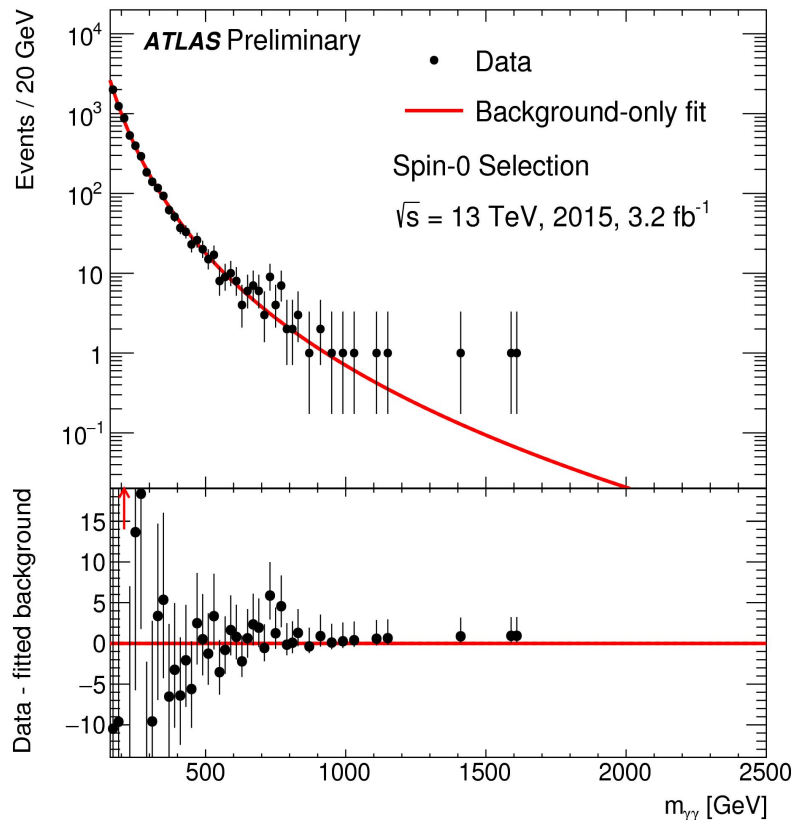
[ATLAS-CONF-2016-059](#)





# Searches of resonances in the $\gamma\gamma$ channel

ATLAS-CONF-2016-059



ATLAS Searches for VH, HH, VV, V $\cdot$  $\gamma$ / $\gamma\gamma$  Resonances - Nicolò Vladi Biesuz - DIS 2017