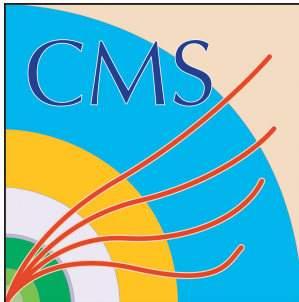


# BSM Higgs search at the LHC

***Tongguang Cheng***  
***on behalf of ATLAS and CMS***

***DM@LHC 2017***



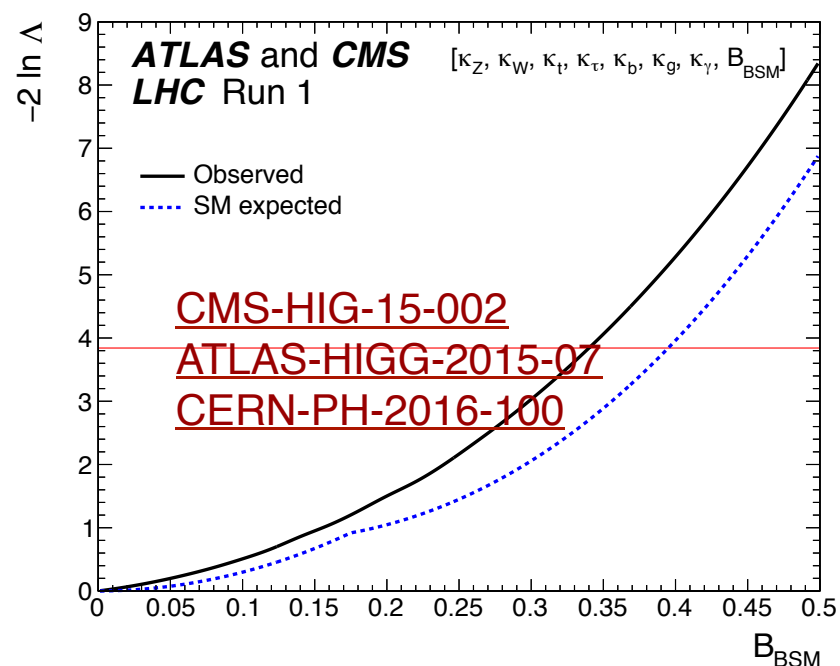
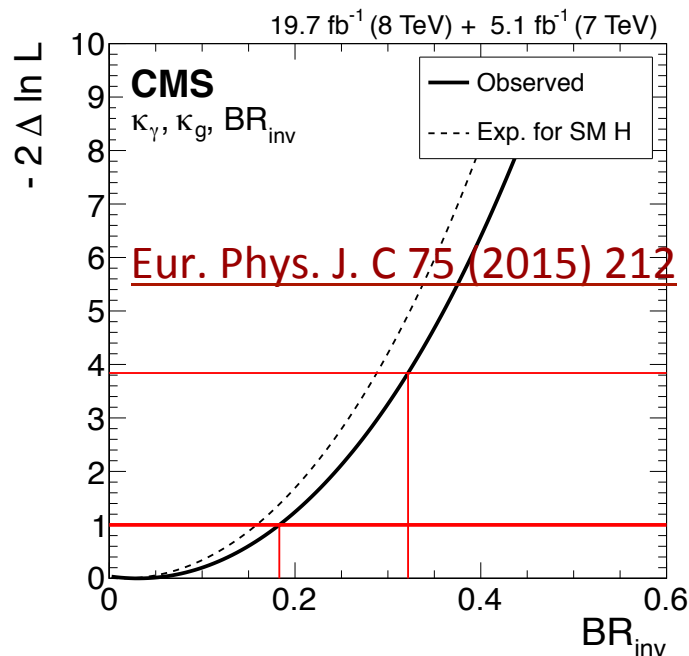
**PURDUE**  
**UNIVERSITY**  
**NORTHWEST**



# Higgs as a portal to **dark** sector

## - **invisible** Higgs decay and mono Higgs

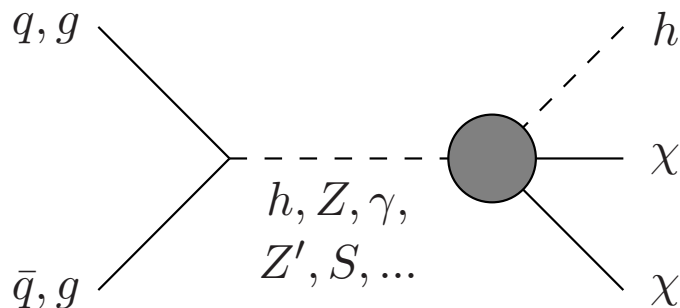
- Higgs related signatures at the LHC are a natural place to search for DM
- Invisible Higgs decay can be used to explore DM-Higgs coupling if decays are allowed by kinematics  
see talk by Kenji Hamano



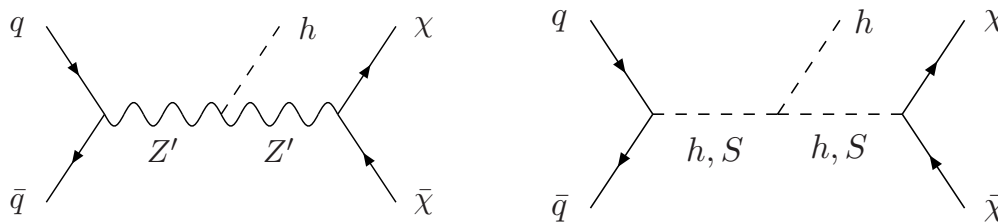
# Higgs as a portal to **dark** sector


## - **invisible** Higgs decay and mono Higgs

- Higgs related signatures at the LHC are a natural place to search for DM
- Mono-Higgs : Higgs produced associated with DM  
see talk by Nicolo Trevisani and Oleg Brandt on single boson+MET



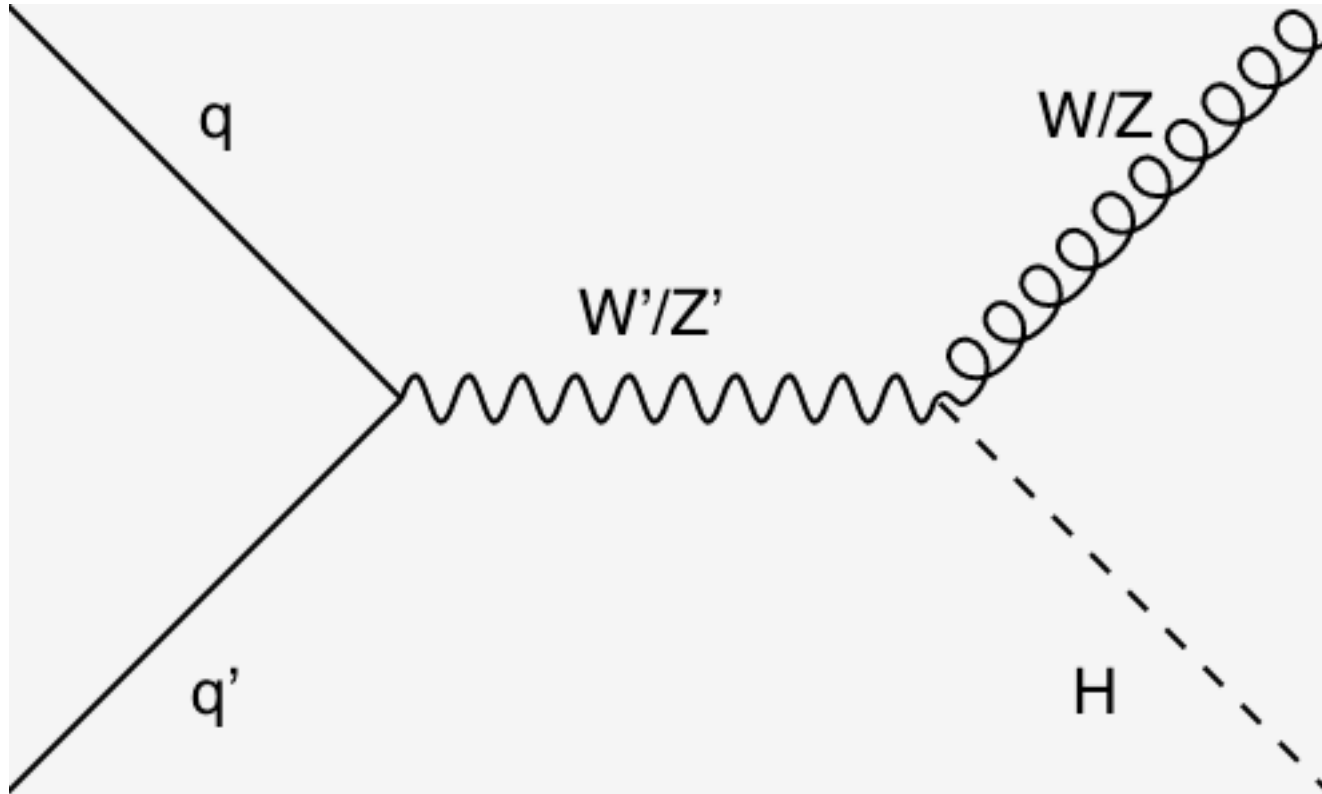
- Simplified models indicate vector and scale mediators  
more talks on mediators by Yangyang Cheng and Flip Tanedo





**This talk will present the latest published results from ATLAS and CMS on the mediator search in di-boson channel, where the boson can be W, Z or Higgs and its hadronic decay is in the boost regime**

# V(W,Z)Higgs resonance



**Full hadronic final states (W/Z/H decays hadronically)  
with full 2016 data**

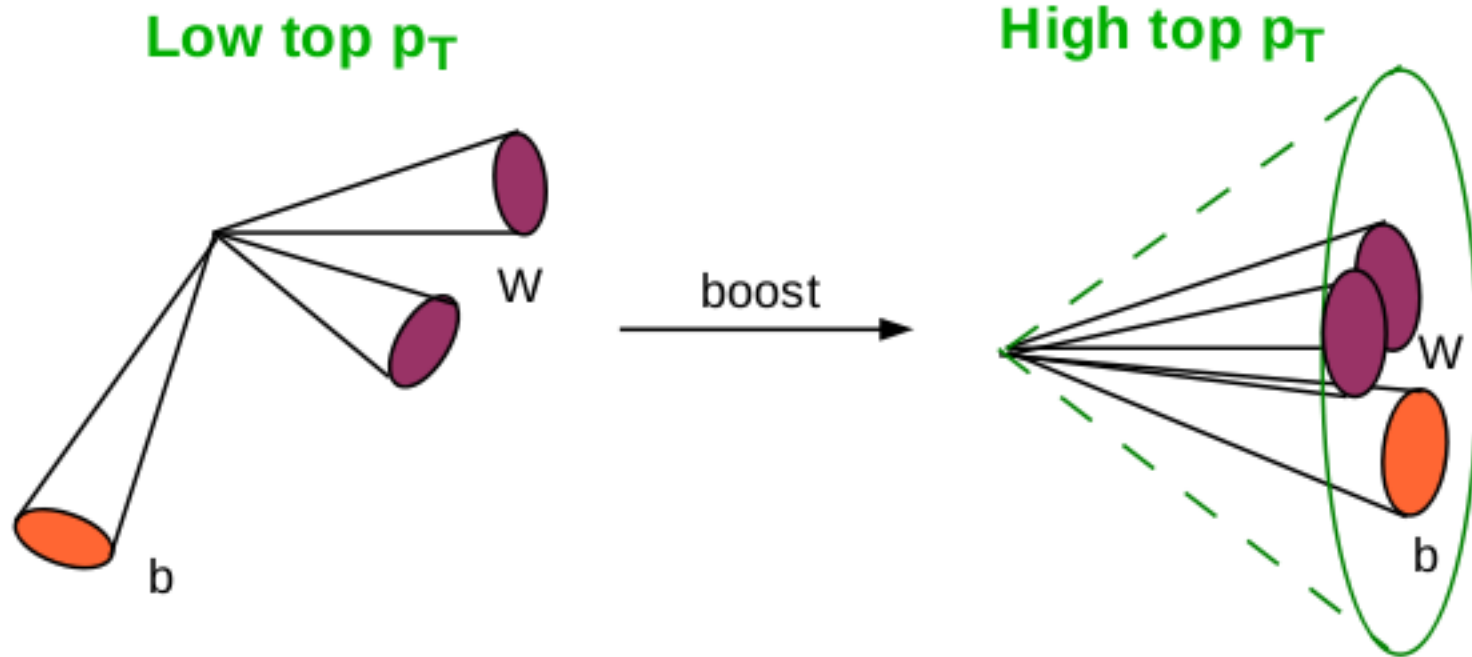
**ATLAS** [ATLAS-CONF-2017-018](#)

**CMS** [CMS-B2G-17-002](#)

# V(W,Z)Higgs resonance

## Boosted V-tagging

- Jet reconstructed with large cone size **R** (**1.0 for ATLAS and 0.8 for CMS**) that includes the particles decay from W,Z or Higgs



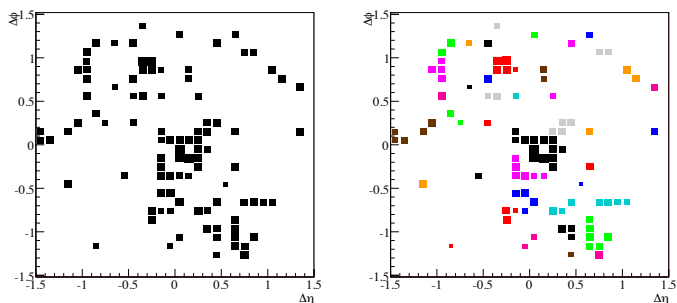
Plot from <http://www.quantumdiaries.org/tag/jets/>

# V(W,Z)Higgs resonance

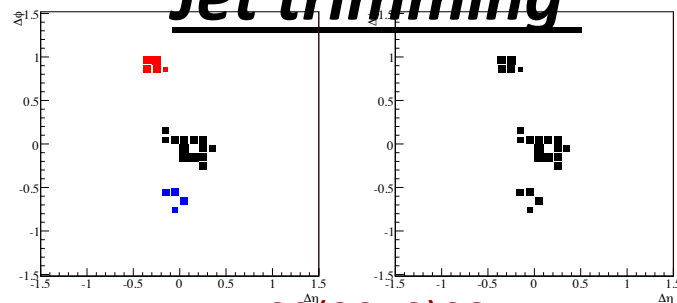
## Boosted V-tagging

	ATLAS-CONF-2017-018	CMS-B2G-17-002
Jet grooming algorithm	<u>Jet trimming</u>	<u>PUPPI+ Softdrop</u>
Jet mass	New algorithm combining calo and track-jet mass	Invariant mass associated with the soft drop jet four momentum

➔ Jet grooming :  
re-cluster to reduce pileup and soft contribution (UE)



**Jet trimming**



7

[JHEP02\(2010\)084](#)



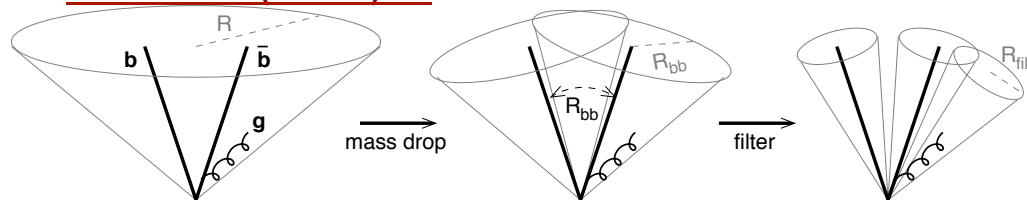
**PUPPI**



**Soft drop**

**Pileup Per Particle Identification**

[JHEP1410\(2014\)59](#)



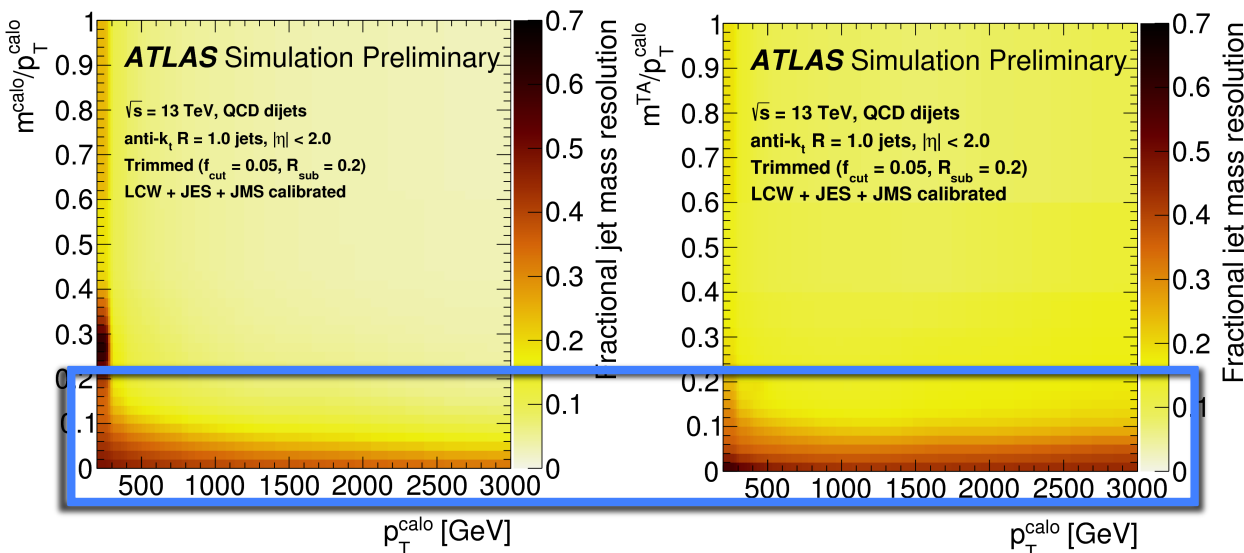
[PhysRevLett.100.242001](#)

# V(W,Z)Higgs resonance

## Boosted V-tagging

	ATLAS-CONF-2017-018	CMS-B2G-17-002
Jet grooming Algorithm	Jet trimming	PUPPI+ Softdrop
Jet mass	<u>New algorithm combining calo and track-jet mass</u>	Invariant mass associated with the soft drop jet four momentum

➔ Jet grooming :  
re-cluster to reduce pileup and soft contribution (UE)



ATLAS-JETM-2017-002

Jet mass is reconstructed from the jet with large cone size + jet grooming algorithm for boosted W/H/Z

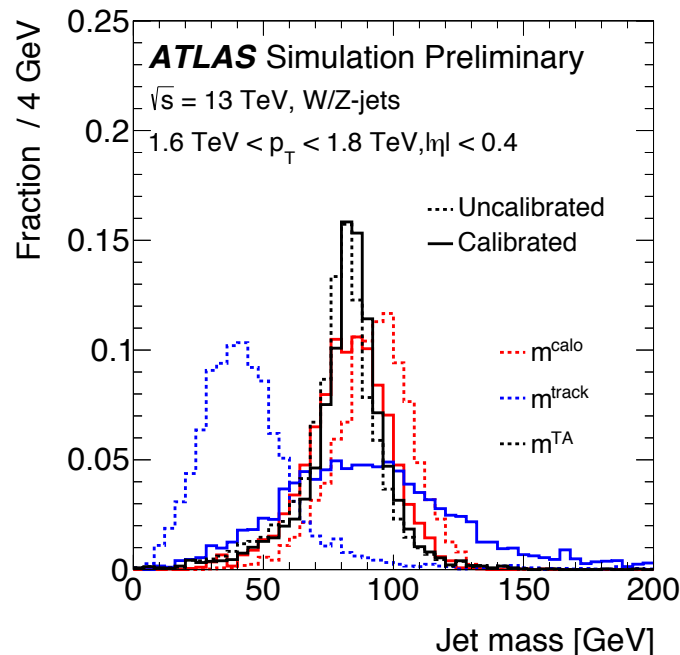


# V(W,Z)Higgs resonance

## Boosted V-tagging

	ATLAS-CONF-2017-018	CMS-B2G-17-002
Jet grooming Algorithm	Jet trimming	PUPPI+ Softdrop
Jet mass	<b><u>New algorithm combining calo and track-jet mass</u></b>	Invariant mass associated with the soft drop jet four momentum

➔ Jet grooming :  
re-cluster to reduce pileup and soft contribution (UE)



[ATLAS-CONF-2016-035](#)

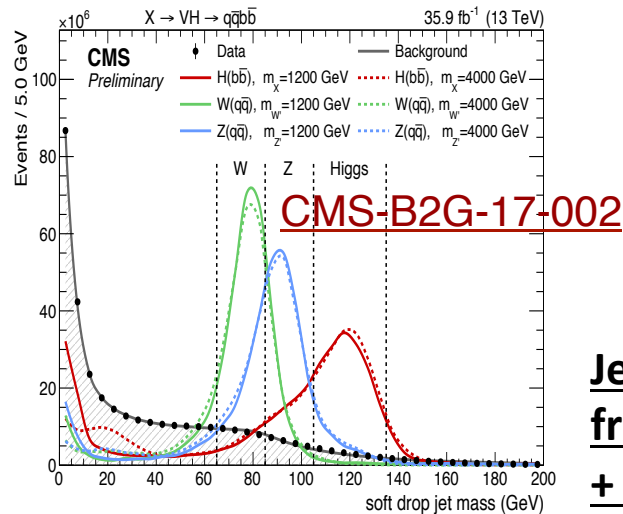
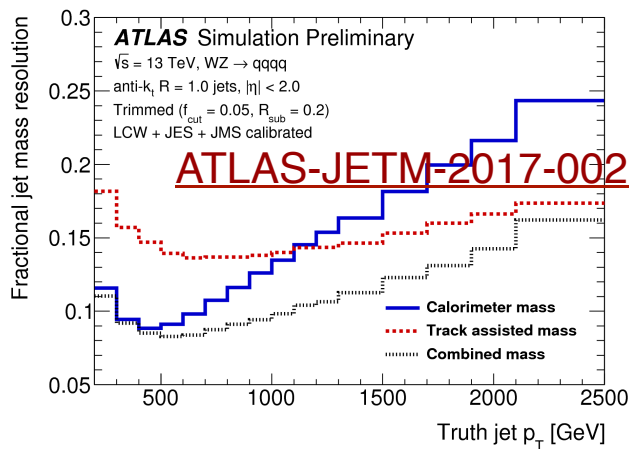
**Jet mass is reconstructed from the jet with large cone size + jet grooming algorithm for boosted W/H/Z**

# V(W,Z)Higgs resonance

## Boosted V-tagging

	ATLAS-CONF-2017-018	CMS-B2G-17-002
Jet grooming Algorithm	Jet trimming	PUPPI+ Softdrop
Jet mass	<u>New algorithm combining calo and track-jet mass</u>	<u>Invariant mass associated with the soft drop jet four momentum</u>

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re-cluster to reduce pileup and soft contribution (UE)



Jet mass is reconstructed from the jet with large cone size + jet grooming algorithm for boosted W/H/Z

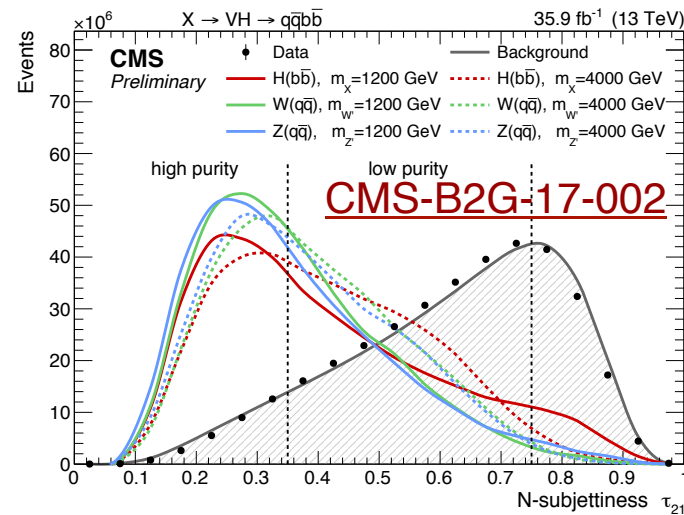
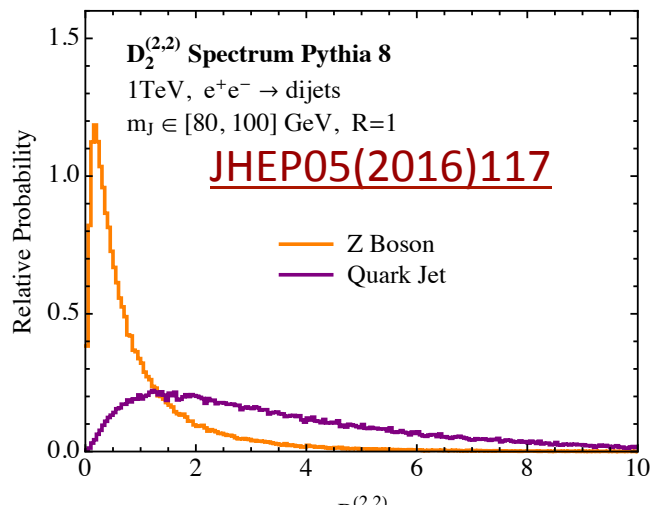
# V(W,Z)Higgs resonance

## Boosted V-tagging



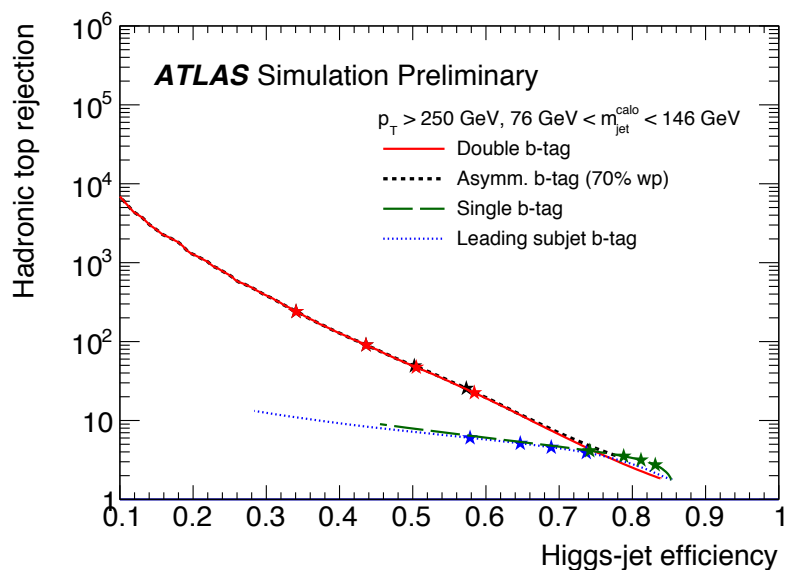
	ATLAS-CONF-2017-018	CMS-B2G-17-002
“2-prong” tagging	$D_2$ energy correlation ratio	$\tau_{21}$ N-subjettiness
Cut on tagging	$p_T$ dependent cut for W/Z	High purity/Low purity/Veto

➔ Discriminant to tag “two-prong” structure



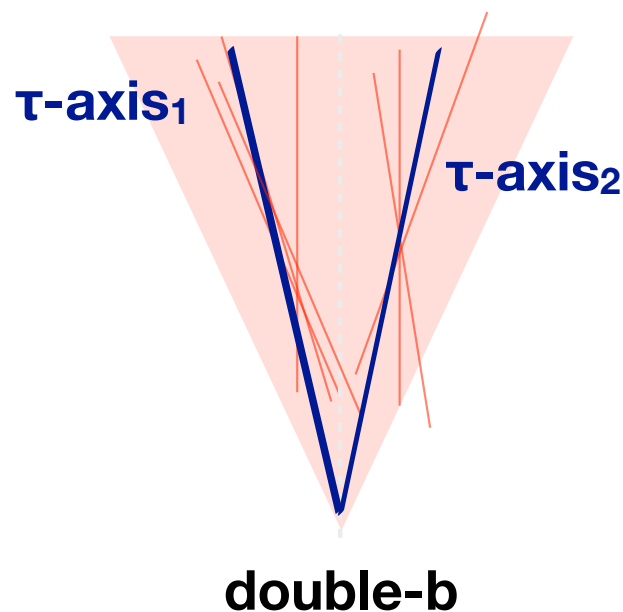
# V(W,Z)Higgs resonance

## Boosted H(to-bbar) tagging



[ATLAS-CONF-2016-039](#)

b-tagging on ghost associated anti-kt track-jets with  $R = 0.2$



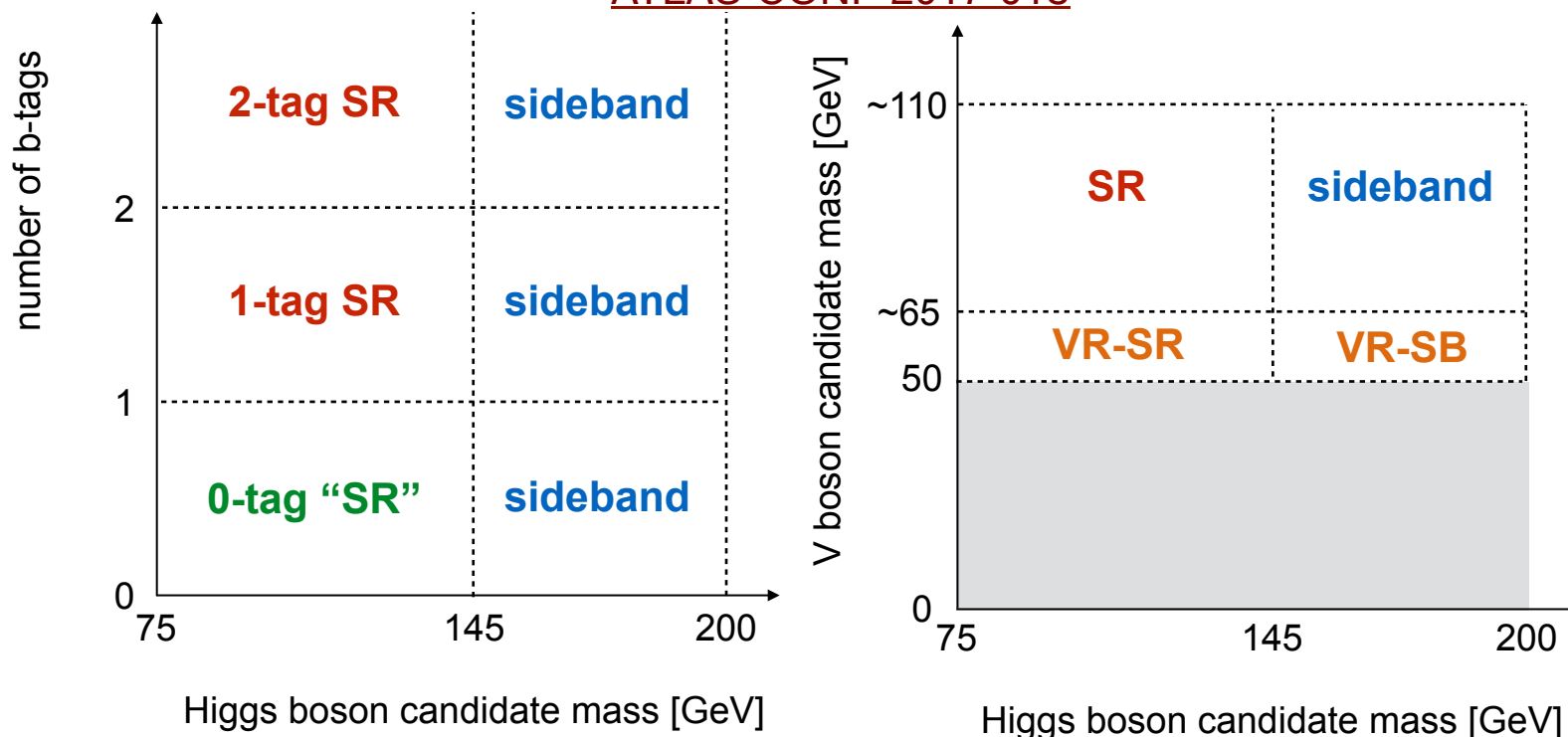
[CMS-BTV-15-002](#)

MVA using observables from SV and tracks associated to each  $\tau$ -axis

# V(W,Z)Higgs resonance background estimation

- Events are categorized into 0-btag, 1-btag and 2-btag
- Kinematic corrections to the multijet background template are applied by reweighting events from the 0-tag sample derived in SB region

ATLAS-CONF-2017-018

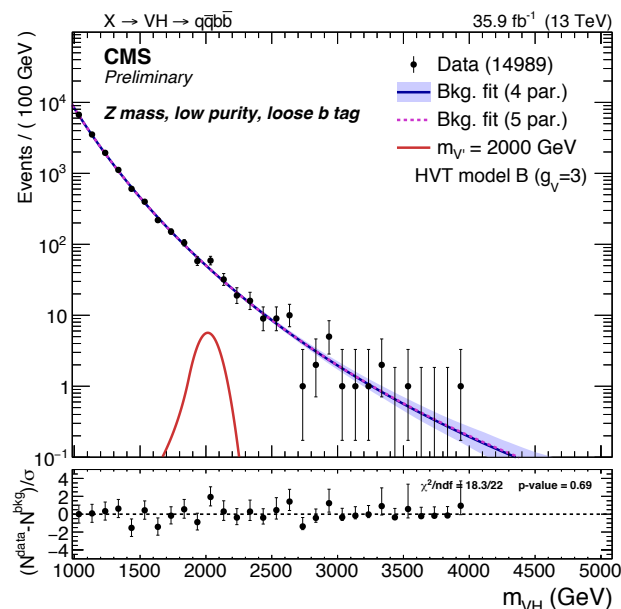
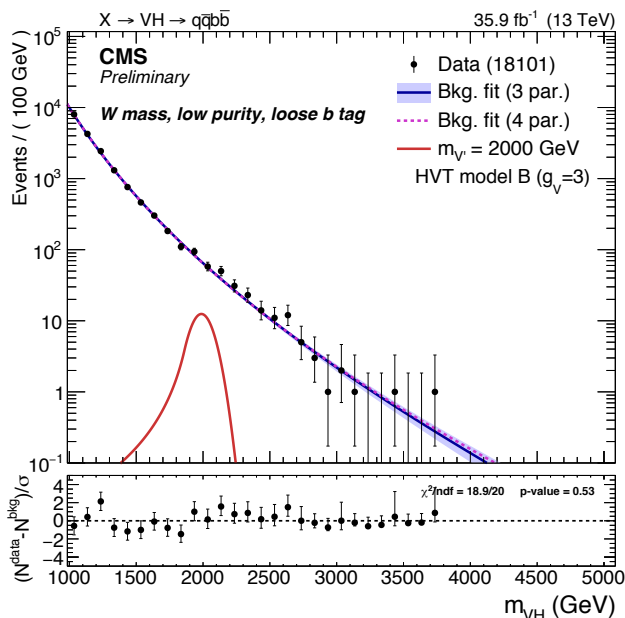


# V(W,Z)Higgs resonance background estimation



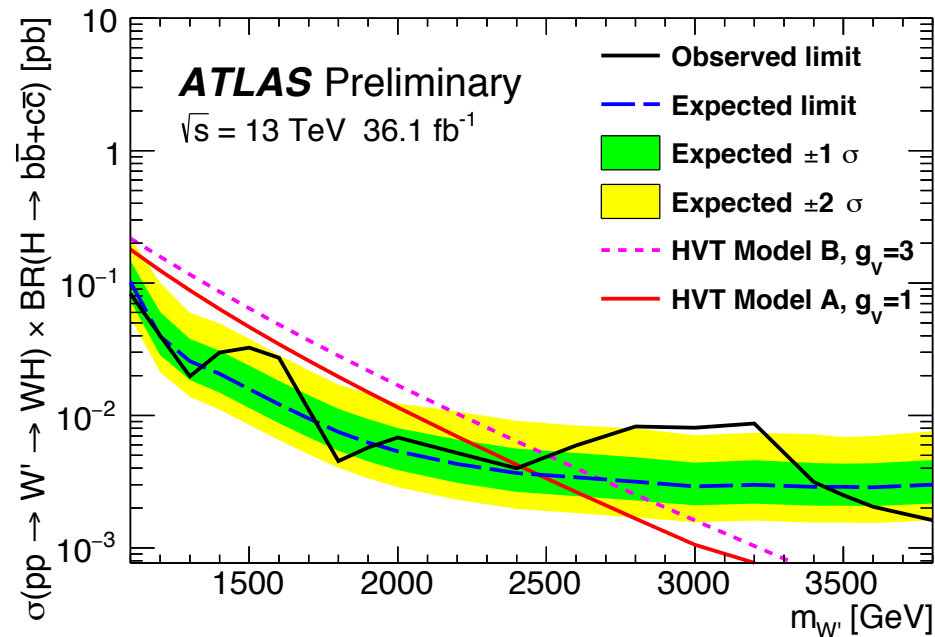
- 4 categories from  $\tau_{21}$  and double b-tagger for WH channel and ZH channel each.
- For each category,
  - Empirical functions are used to fit data
  - Number of parameters are decided by Fisher-test

## CMS-B2G-17-002

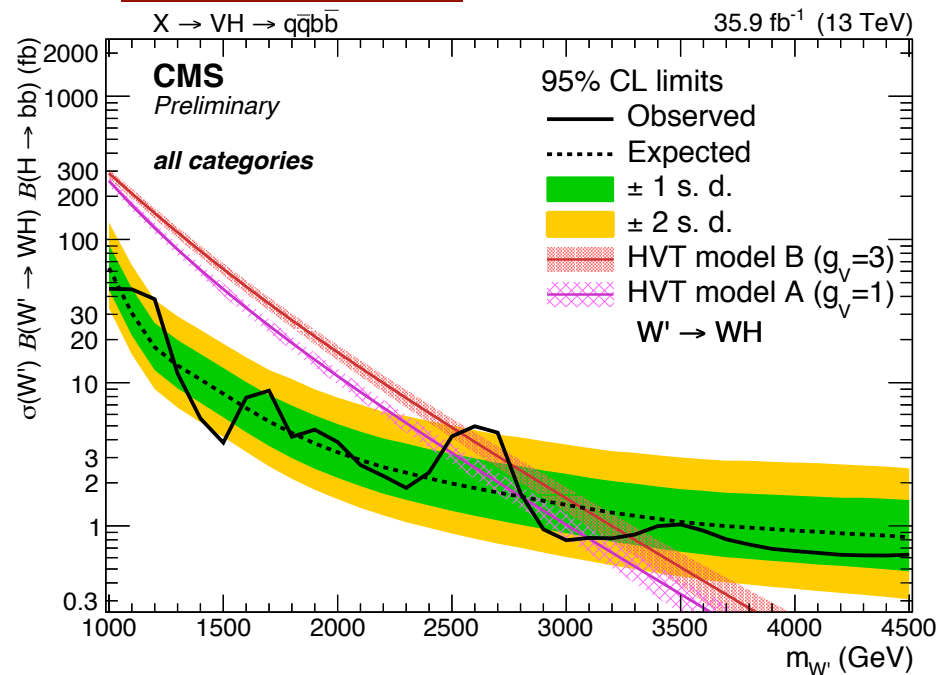


# V(W,Z)Higgs resonance results – W' limits

ATLAS-CONF-2017-018



CMS-B2G-17-002



**- ATLAS:**

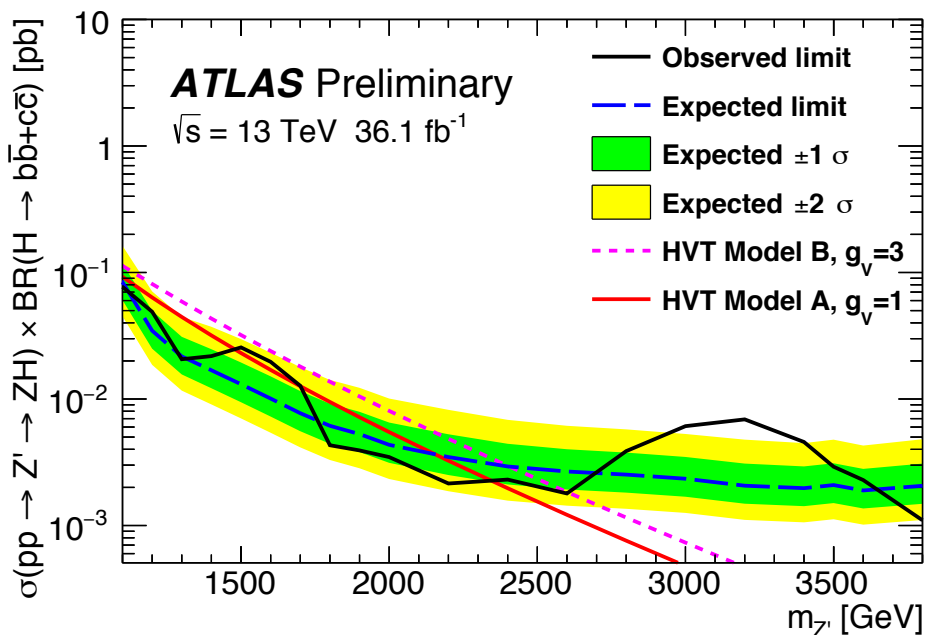
Exclude HVT model B(A) mass window **1.1 to 2.5(2.4)TeV** for **WH**  
 and **1.1 to 2.6(2.3)TeV** for **ZH**

**- CMS:**

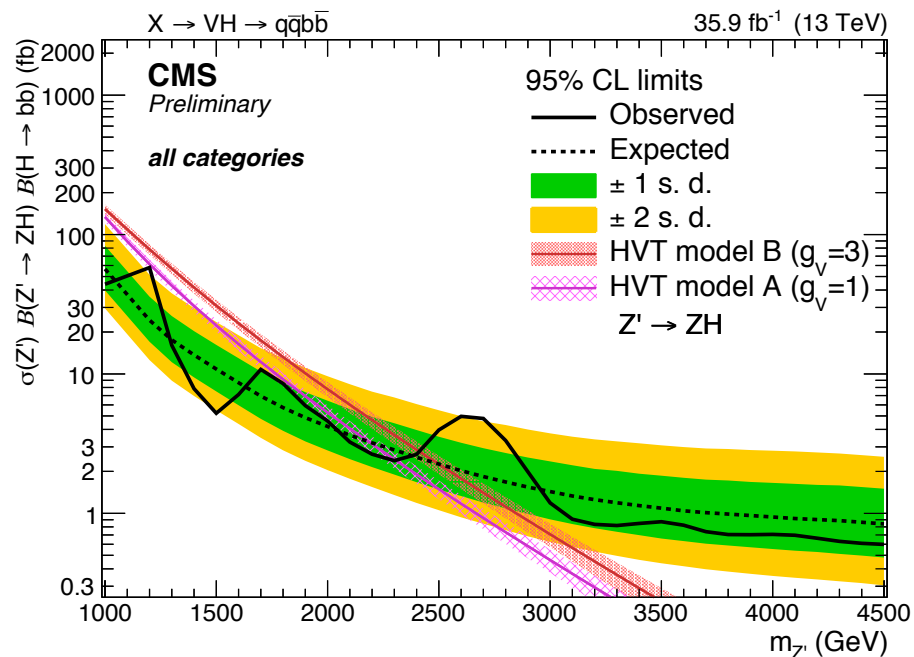
Exclude HVT model B(A) mass window **1.0 to 2.54(2.46)TeV** and **2.76(2.82)-3.3(3.1)TeV** for **WH**  
 and window **1.0 to 2.41(2.31)TeV** for **ZH**

# V(W,Z)Higgs resonance results – Z' limits

ATLAS-CONF-2017-018



CMS-B2G-17-002



**- ATLAS:**

Exclude HVT model B(A) mass window **1.1 to 2.5(2.4)TeV** for **WH**  
 and **1.1 to 2.6(2.3)TeV** for **ZH**

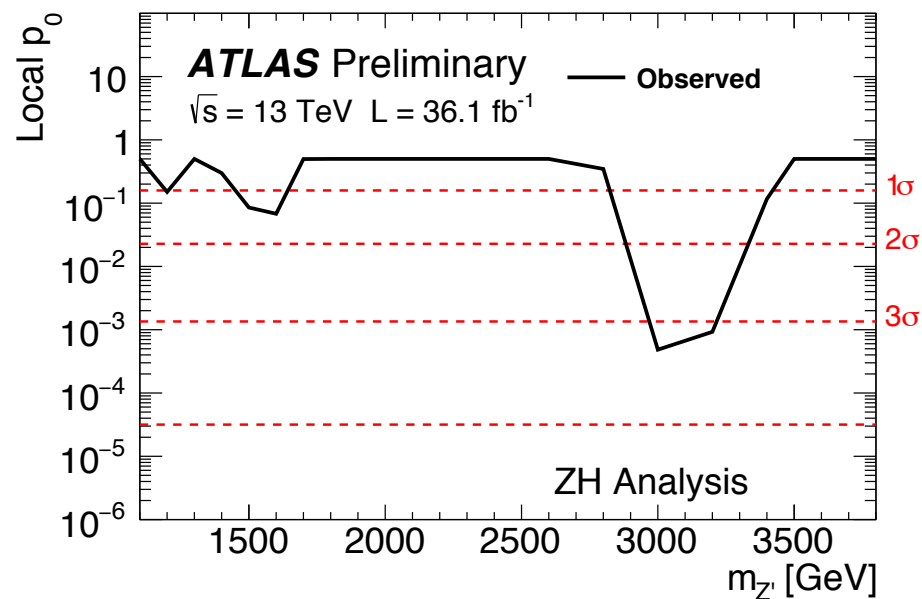
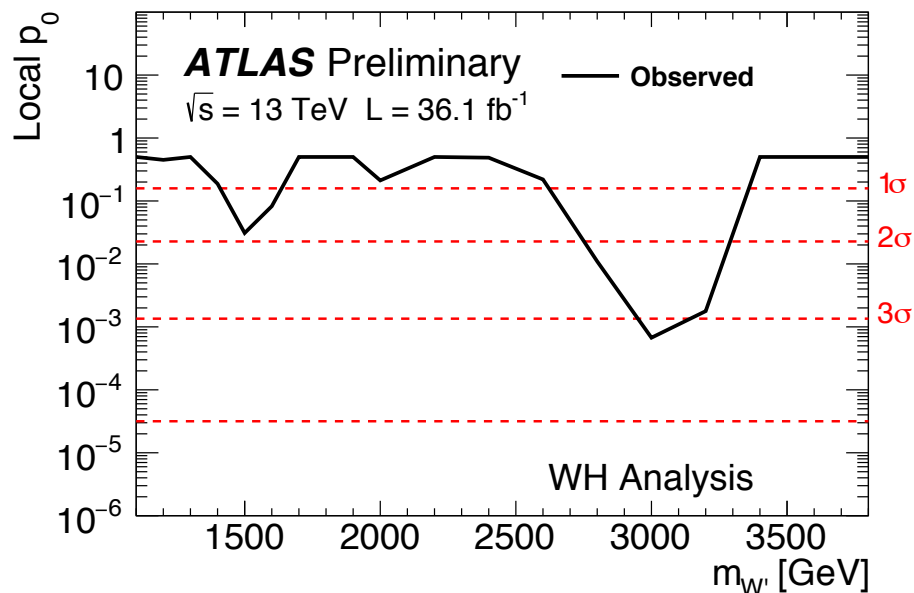
**- CMS:**

Exclude HVT model B(A) mass window **1.0 to 2.54(2.46)TeV** and **2.76(2.82)-3.3(3.1)TeV** for **WH**  
 and window **1.0 to 2.41(2.31)TeV** for **ZH**



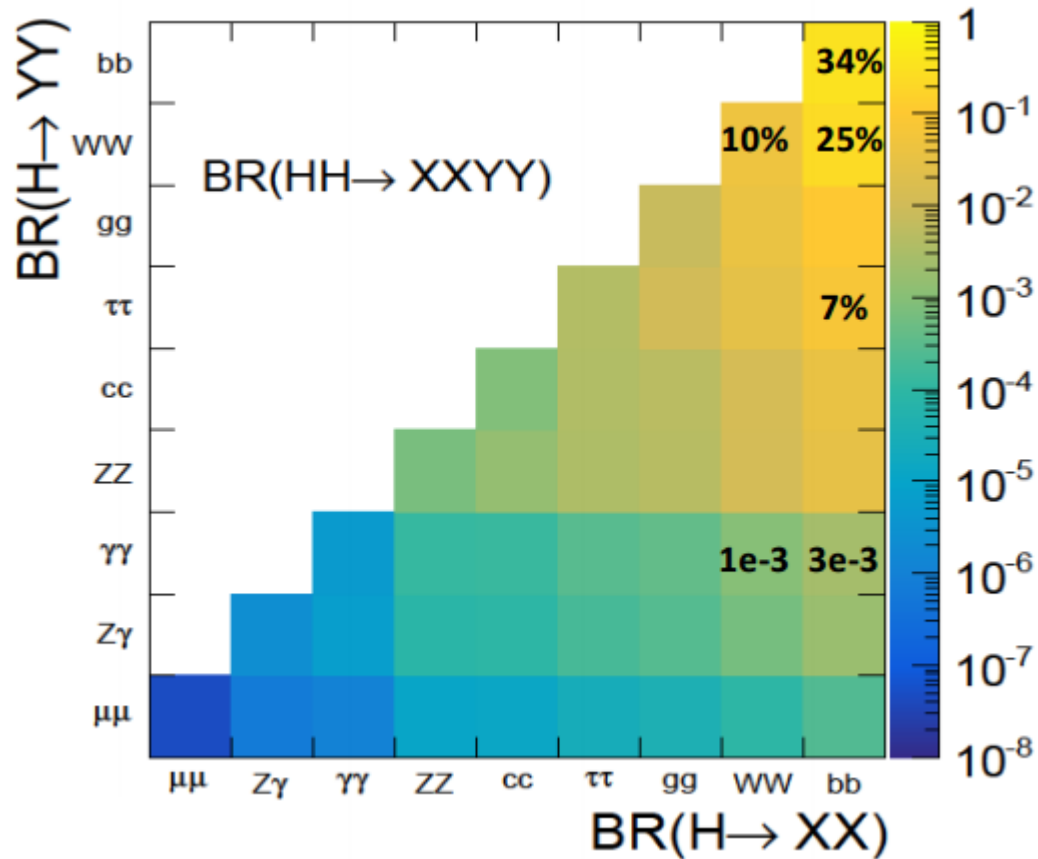
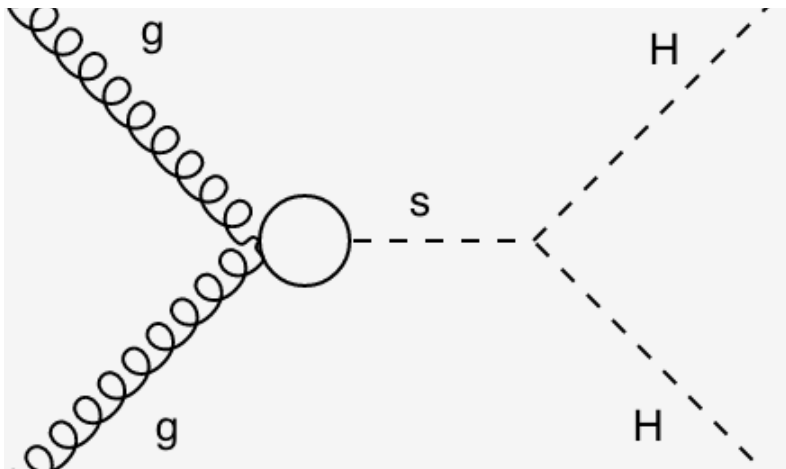
# V(W,Z)Higgs resonance results – significance

ATLAS-CONF-2017-018



**Local excess with  $3.3\sigma$  (global  $2.2\sigma$ ) at  $\sim 3\text{TeV}$   
is not observed in CMS result**

# Di-Higgs resonance



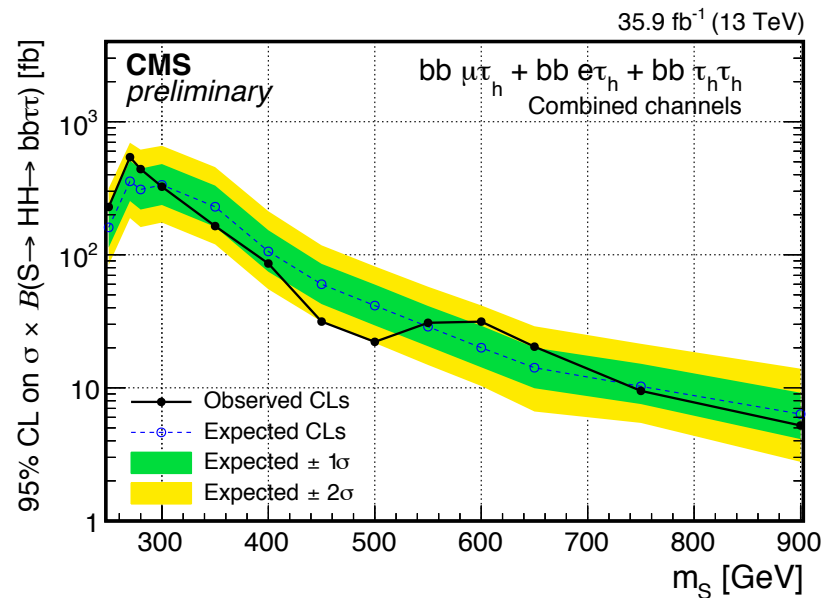
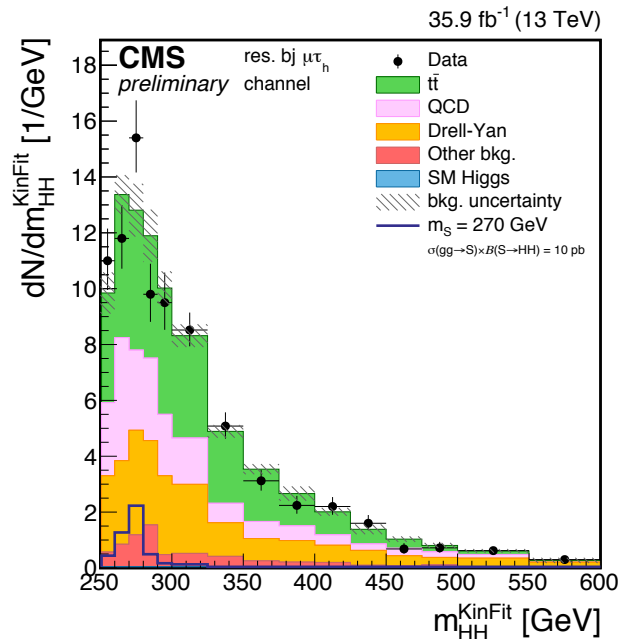
# Di-Higgs resonance

## HIG-17-002 - $bb\tau\tau$ using full 2016 data



- Three  $\tau\tau$  final states are considered
  - $\tau_h\tau_h / \tau_e\tau_h / \tau_\mu\tau_h$
- Events are categorized based on b-tagged of “Higgs” jet
  - 2 b-tagged jets, 1b-tagged+1untagged jets, “boost” b tag
- Kinematic information is used to reconstruct di-Higgs decay
- Limit is set on cross section of a scalar resonance

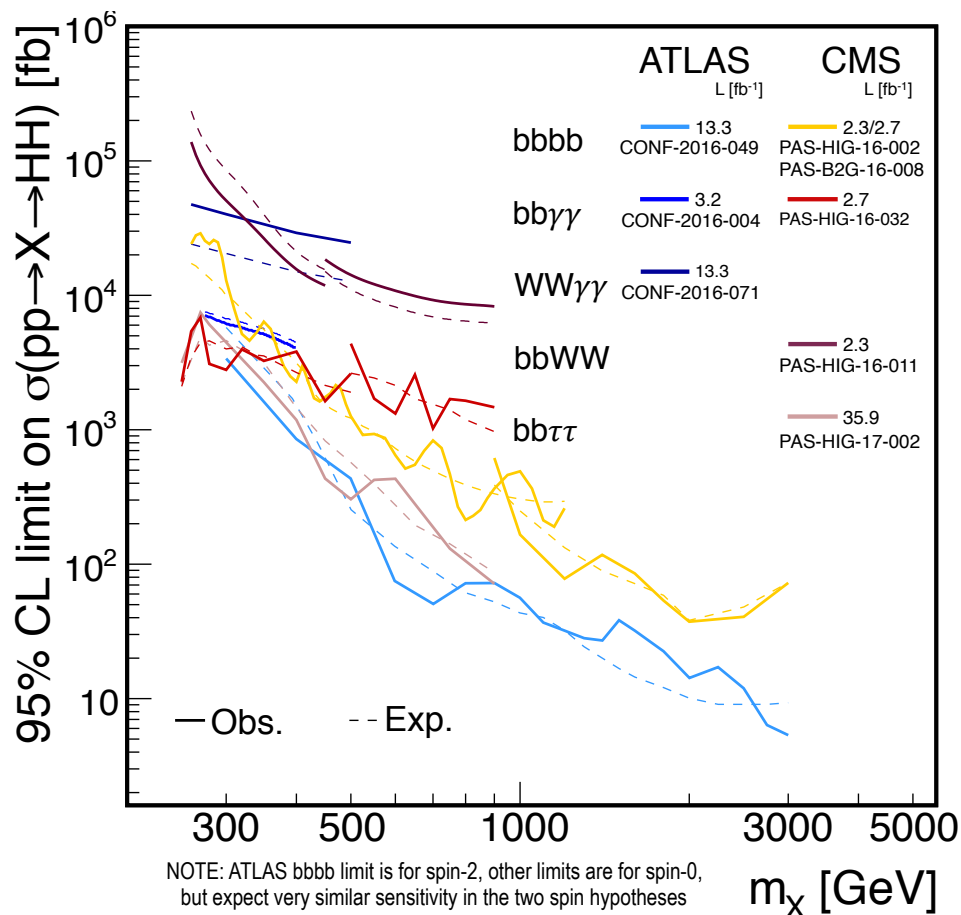
New



# Di-Higgs resonance summary of public results

➤ The resonance search results are summarized in MoriondEWK  
<https://indico.in2p3.fr/event/13763/session/0/contribution/53/material/slides/0.pdf>

➤ Recent result comes from  $bb\tau\tau$  using full 2016 data (CMS)



# WW,WZ,ZZ resonance

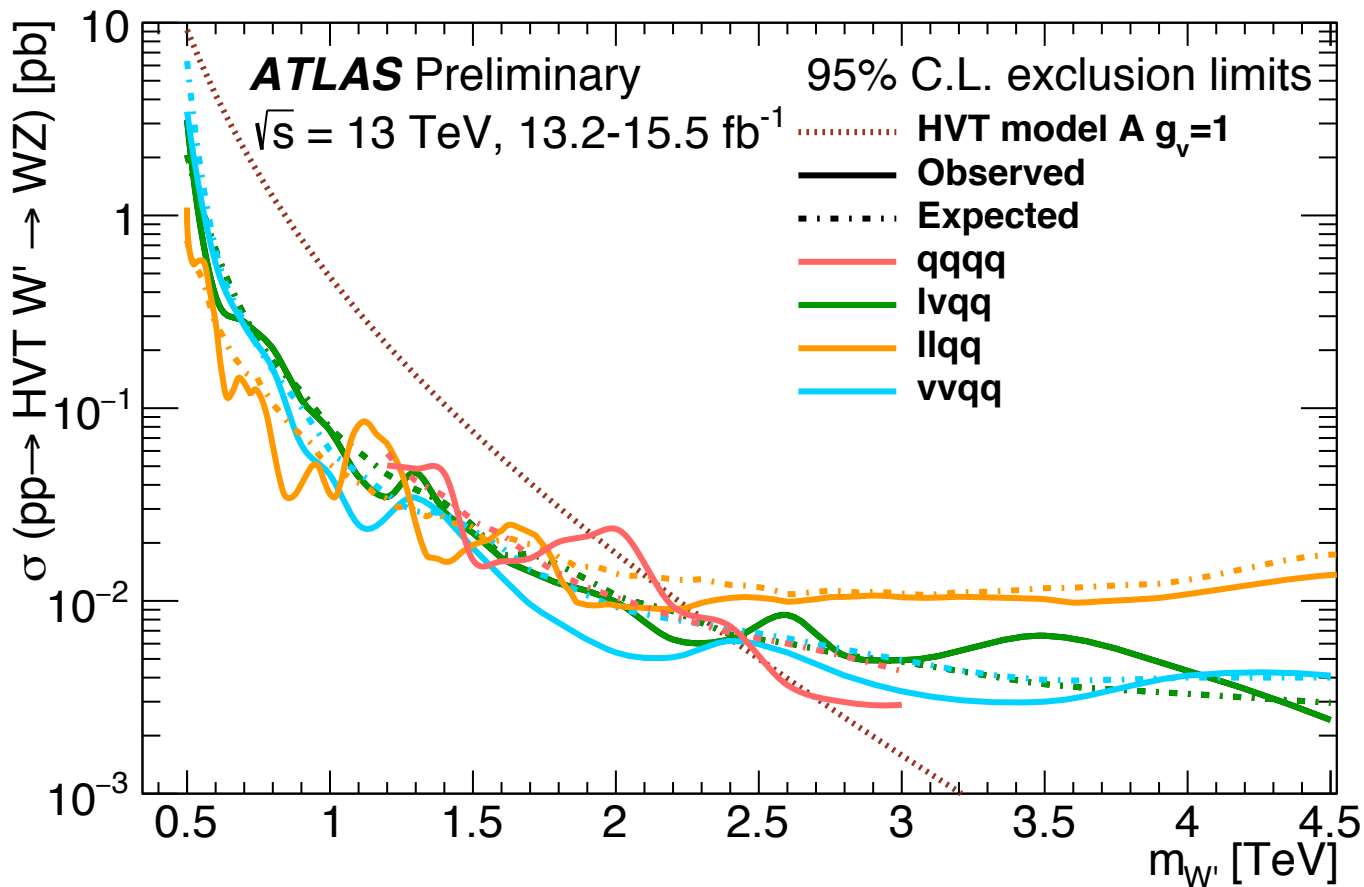


➔ Summary of search with different decay final states

Analysis ATLAS	Final state	Process	Resonance search	Data
ATLAS-CONF-2016-082	qqll qqvv	ZZ,WZ	W', Spin-0, Bulk Graviton	13.2fb <sup>-1</sup> 2016
ATLAS-CONF-2016-062	lvqq	WZ,WW	W', Z' Spin-0, Bulk Graviton	13.2fb <sup>-1</sup> 2016
ATLAS-CONF-2016-055	Full hadronic	ZZ,WZ,WW	W', Z' Bulk Graviton	15.5fb <sup>-1</sup> 2016

# WW, WZ, ZZ resonance

➔ Summary of search with different decay final states



# WW,WZ,ZZ resonance



➔ Summary of search with different decay final states

Analysis	Final state	Process	Resonance search	Data
HIG-16-034	qqll	ZZ	Spin-0, Spin-2	12.9 fb <sup>-1</sup> 2016
B2G-16-022	qqll	WZ	W'	12.9 fb <sup>-1</sup> 2016
B2G-16-020	lvqq	WZ,WW	W'	12.9 fb <sup>-1</sup> 2016
B2G-17-001	full hadronic	WW, WZ, ZZ, qW/Z	W' Z' excited quark Bulk Graviton	35.9 fb <sup>-1</sup> 2016

New

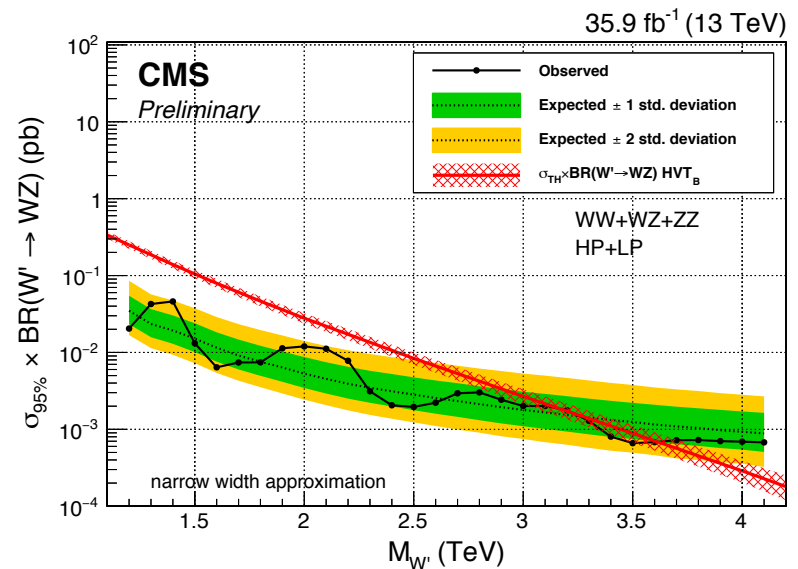
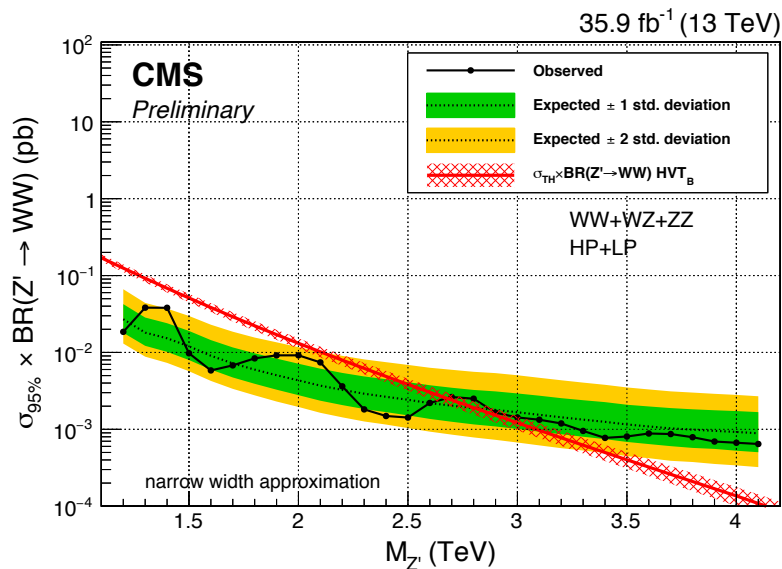
# WW, WZ, ZZ resonance



➔ Summary of search with different decay final states

Analysis	Final state	Process	Resonance search	Data
B2G-17-001	full hadronic	WW, WZ, ZZ, qW/Z	W' Z' excited quark Bulk Graviton	35.9 fb <sup>-1</sup> 2016

New





# Summary

- The searches for vector mediator using full 2016 data are presented in
  - VH all hadronic (ATLAS and CMS)
  - VV all hadronic (CMS)
  - In VH, ATLAS VH observes an excess with local(global) excess of  $3.3 \sigma$  ( $2.2 \sigma$ ) at  $\sim 3$  TeV, but CMS does not.
- Results in di-Higgs resonance search are summarized including the updates in  $bb\tau\tau$  from CMS.
- Resonance searches in  $VV(V=W,Z)$  channel are also used to set upper limits on  $W'/Z'$  cross sections.
- More results are under preparation and combination between different channels/analyses can be expected.



Hope the Higgs boson can guide us the way to BSM sector

# Backup slides

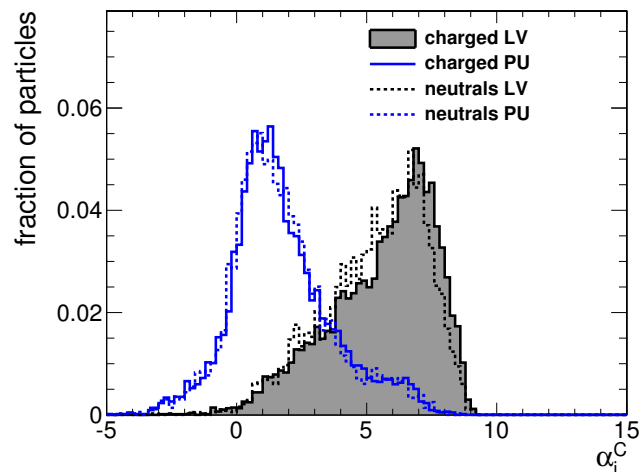
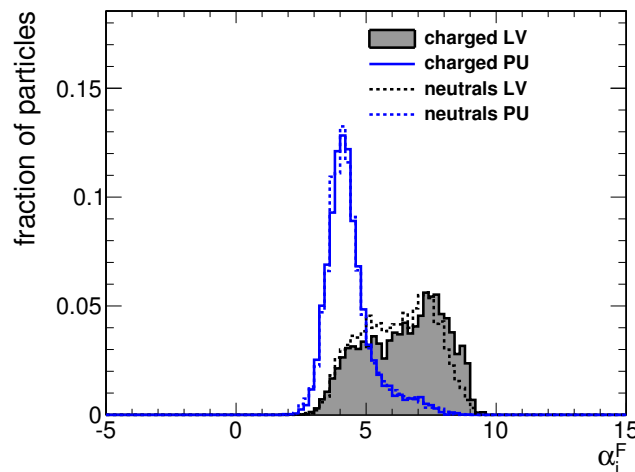
# PUPPI (pileup per particle identification)

## Particle distance definition

$$\alpha_i = \log \sum_{j \in \text{event}} \xi_{ij} \times \Theta(R_{\min} \leq \Delta R_{ij} \leq R_0),$$

$$\text{where } \xi_{ij} = \frac{p_{Tj}}{\Delta R_{ij}}.$$

[JHEP10\(2014\)059](#)



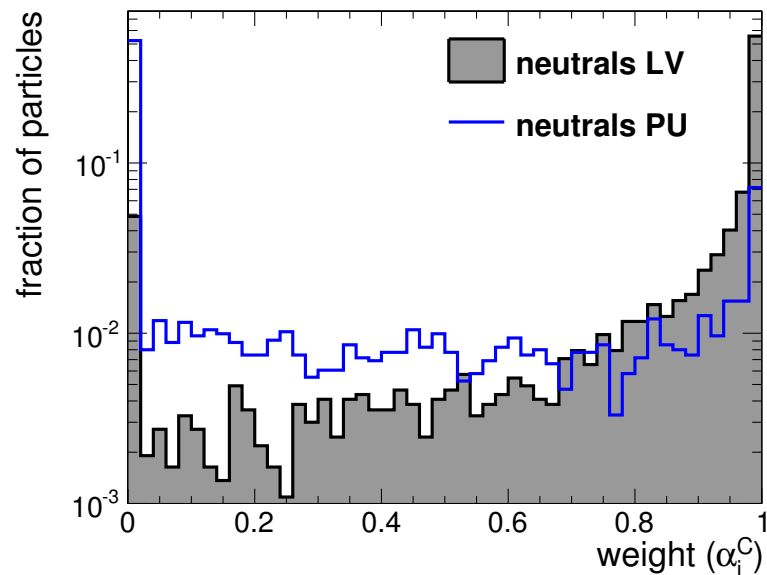
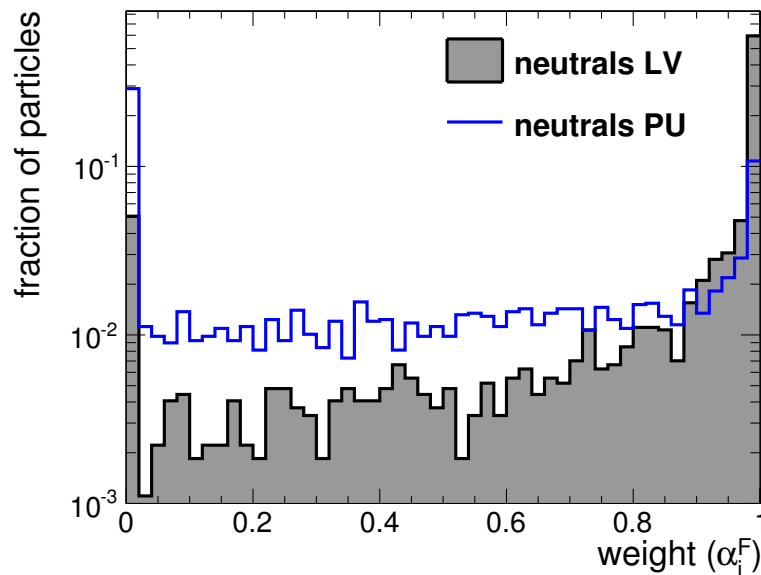
$$\alpha_i^C = \log \sum_{j \in \text{Ch, LV}} \xi_{ij} \Theta(R_{\min} \leq \Delta R_{ij} \leq R_0),$$

$$\alpha_i^F = \log \sum_{j \in \text{event}} \xi_{ij} \Theta(R_{\min} \leq \Delta R_{ij} \leq R_0).$$

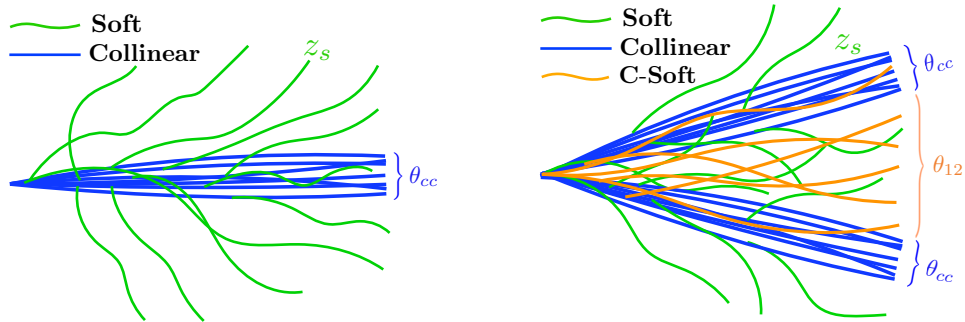
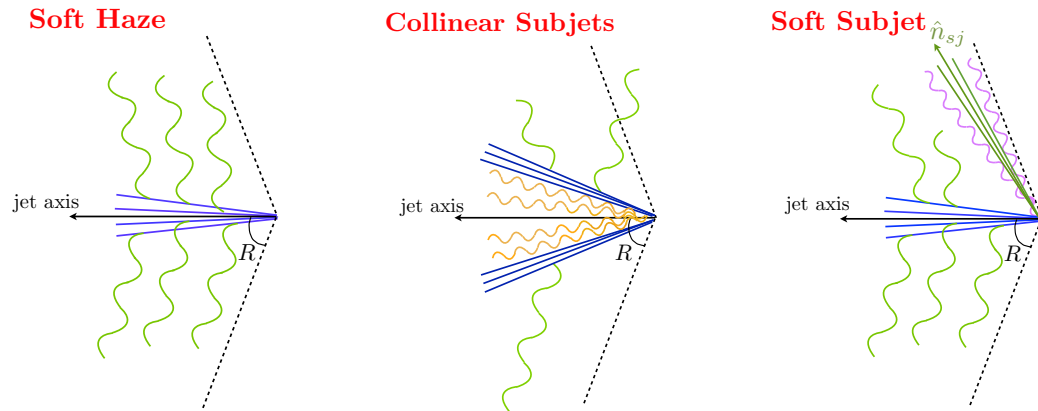
# PUPPI (pileup per particle identification)

## Weight for neutral particles

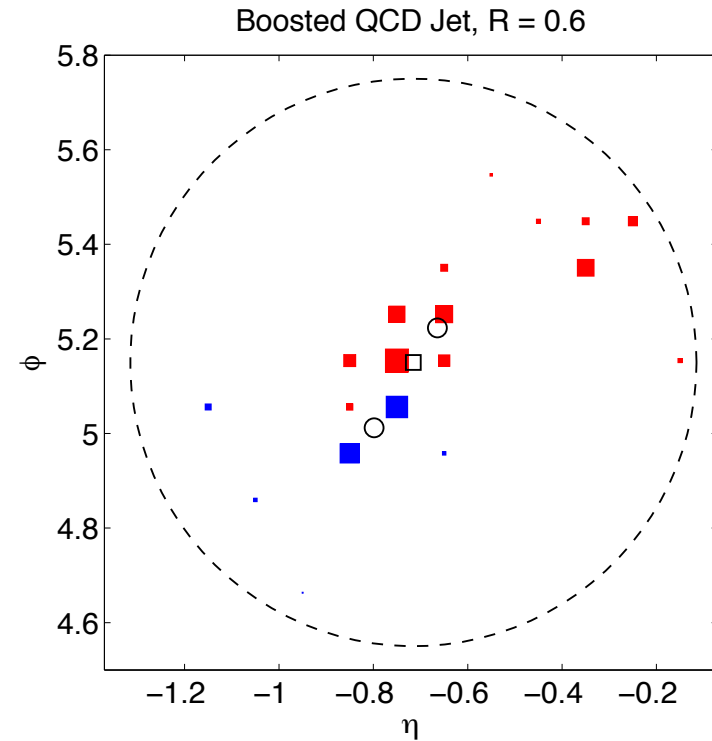
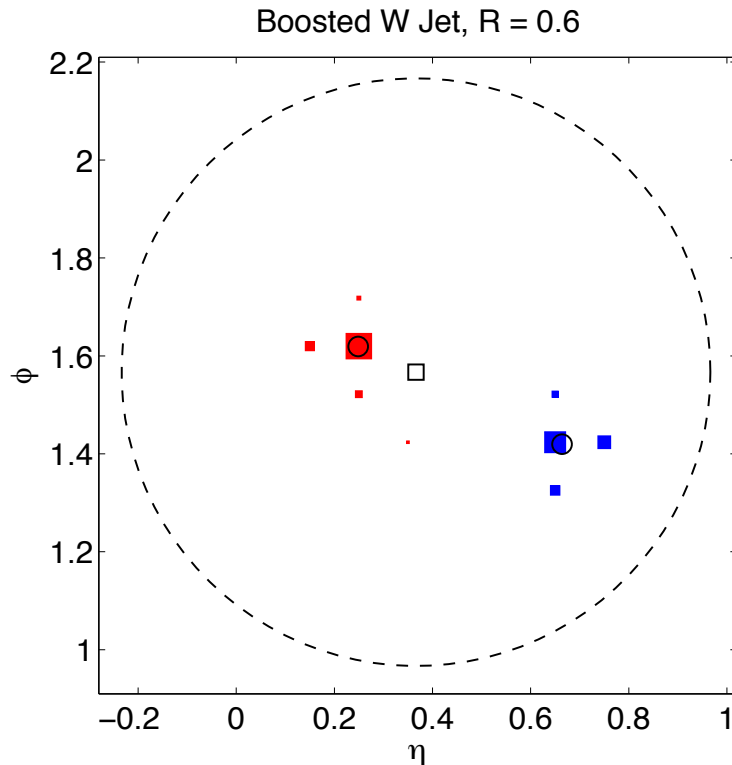
[JHEP10\(2014\)059](#)



# Energy correlation



# N-subjettiness

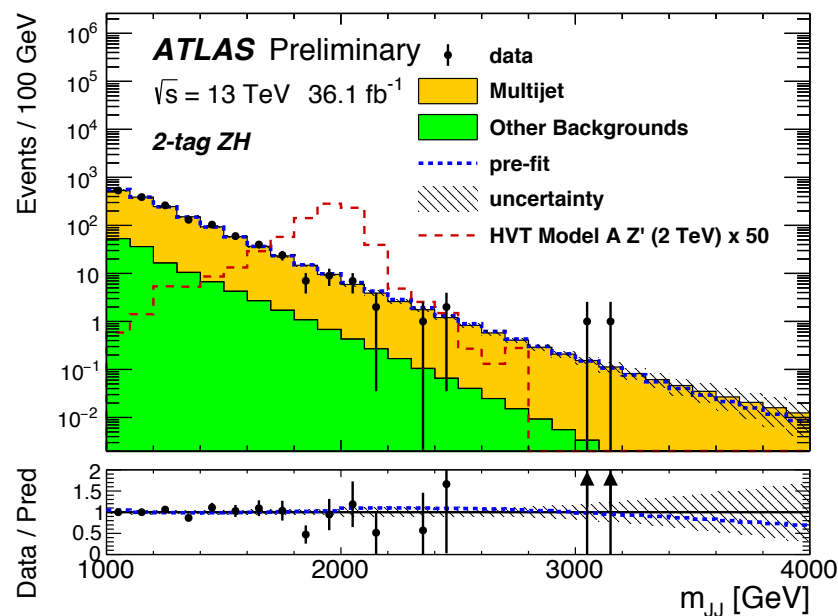
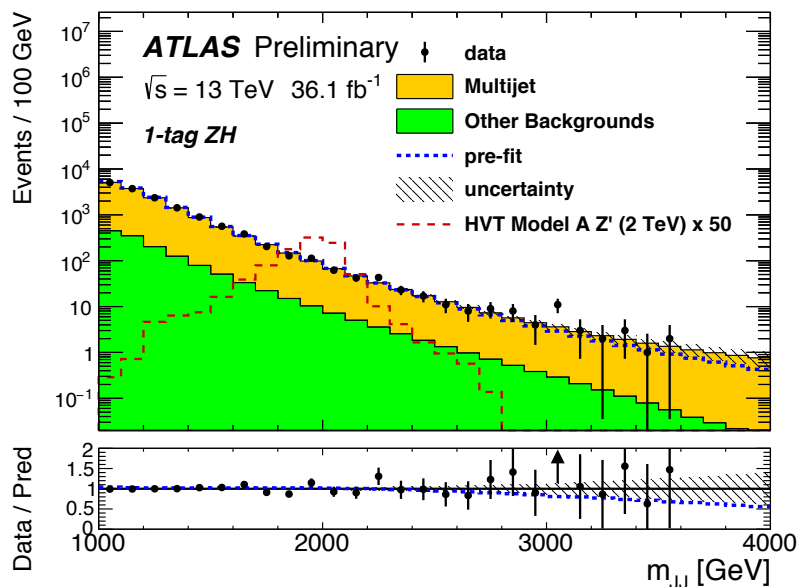


$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min \{ \Delta R_{1,k}, \Delta R_{2,k}, \dots, \Delta R_{N,k} \}$$

# V(W,Z)Higgs resonance background estimation

- Events are categorized into 0-btag, 1-btag and 2-btag
- Kinematic corrections to the multijet background template are applied by reweighting events from the 0-tag sample derived in SB region

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







Analysis	Final state	Process	Resonance search	Data
B2G-16-022	$qq\bar{l}l$	WZ	$W'$	12.9 fb <sup>-1</sup> 2016
B2G-16-020	$\bar{l}vqq$	WZ,WW	$W'$	12.9 fb <sup>-1</sup> 2016

