李政道研究所

Search for heavy resonances in Z/W/H+γ final states at $\sqrt{s}$ = 13 TeV with 36fb^{-1} data

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On behalf of

Analysis Team

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Editorial Board

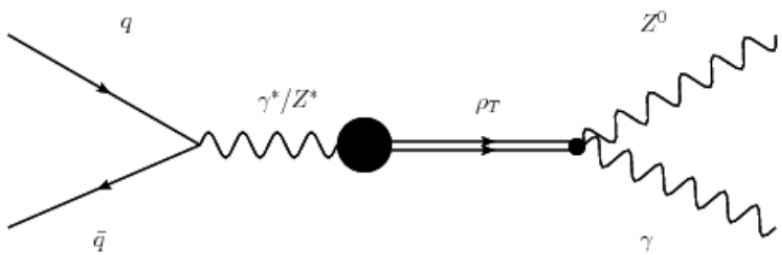
Short on motivations

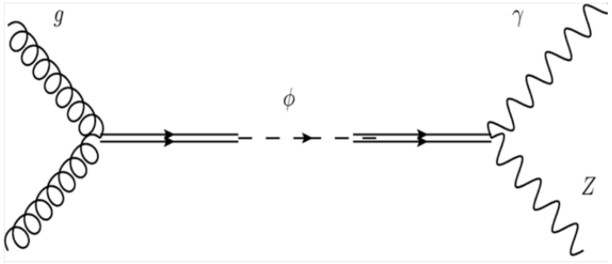
- Essential for exploring the source of EWSB despite Higgs is discovered but the precise nature is not yet well known

- A dynamical mechanism of EWSB and fermion mass generation may yet involve a variety of heavy bosons of vector, scalar or even tensor particles with narrow resonances

- Benchmark models provide acceptance and efficiencies info for the signals of the spin-2/1/0 fundamental/composite particles and the other models could be covered by their cross section normalizations

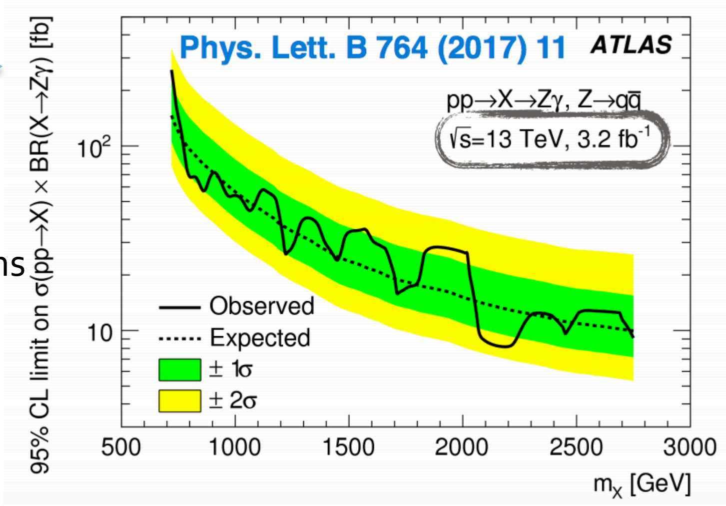
- **A model–independent search at 13TeV for narrow resonances decaying to final states of W/Z/H+γ in boosted hadronic channel: an updated results of 2015→2015+2016**





2015+2016 analysis outlines

- Goal: Search for heavy resonance decaying to V(qq)/H(bb)+γ final states
  - Only considered hadronic decay mode (~70%) and merge/boosted regime
  - Signature: Boosted large-R jet (R=1.0) and high p_T photon
- Benchmark models extended
  - Spin-0 Zγ NWA (same as 2015)
    - Motivated by the extension of Higgs sector
  - spin=2 Zγ NWA (**NEW**)
    - Splitted into qq and gg initial states, separate interpretations
    - Higgs Characterisation model
  - Spin-1 Wγ NWA (**NEW**)
    - Induced by HVT model
  - Spin-1 Hγ NWA (**NEW**)
    - Higgs effective coupling model



Analysis inputs

Signal configuration and modeling

Channel	Generator	Spin	Production	V Polarization
$Z\gamma$	Powheg+Pythia8	0	$gg\to X$	Transvers
$Z\gamma$	MadGraph+Pythia8	2	$gg\to X$	Transvers
$Z\gamma$	MadGraph+Pythia8	2	$qq\to X$	Transvers
$W\gamma$	MadGraph+Pythia8	1	$qq\to X$	Longitudinal
$H\gamma$	MadGraph+Pythia8	1	$qq\to X$	-

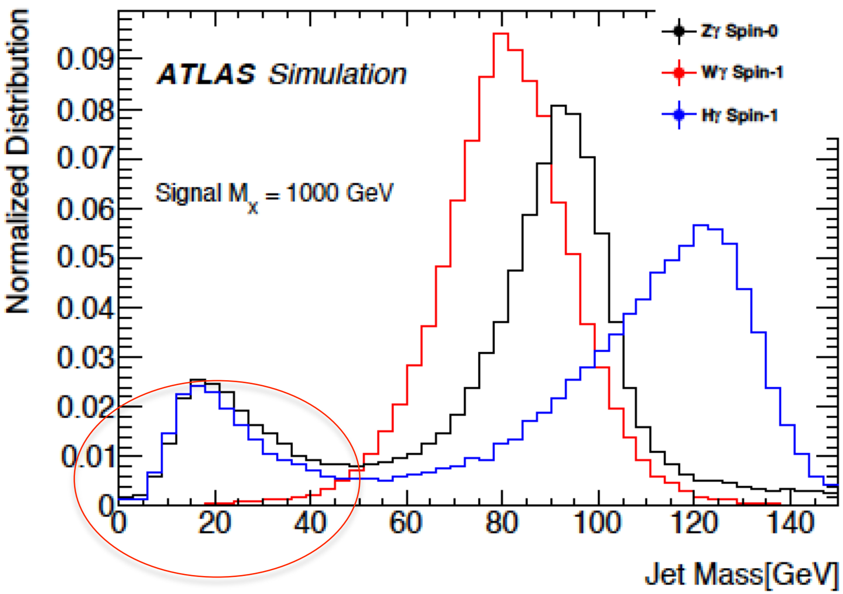
Main backgrounds

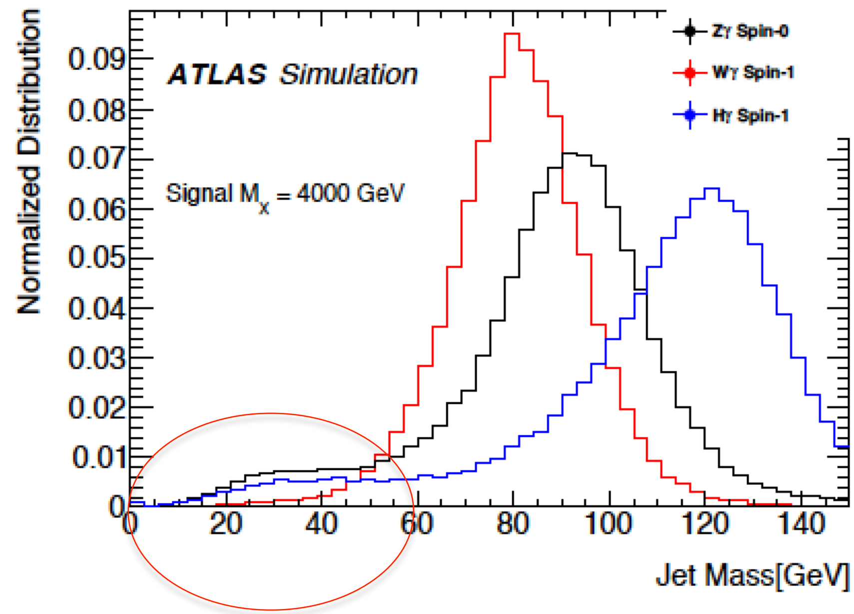
Channel	Generator
γ+jets ***dominant***	Sherpa
SM W+γ	Sherpa
SM Z+γ	Sherpa
tt+γ(all hadronic and no all hadronic)	MadGraph + Pythia8

Object definition

- Photon:
  - p_T>250 GeV and $|\eta|$<2.37 (without crack region [1.37, 1.52])
  - Pass tight photon ID selection and tight calorimeter only isolation
- Jet:
  - Anti-k_t large-R jet (R=1.0), Trimmed (f_{cut}<5%, R_{sub}=0.2)
  - p_T>200 GeV and $|\eta|$<2.0
  - Apply boson tagging according to signal type
  - ntrk<30 for Z/W+γ channel selection.
  - Anti-kT R=0.2 track-jet btagging using MV2c10 algorithm @70% efficiency.
- Overlap removal: remove large-R jet with $\Delta R(J, \gamma)$<1.0.

Boosted boson large-R Jet Mass: tagging inefficiency w.r.t. polarization

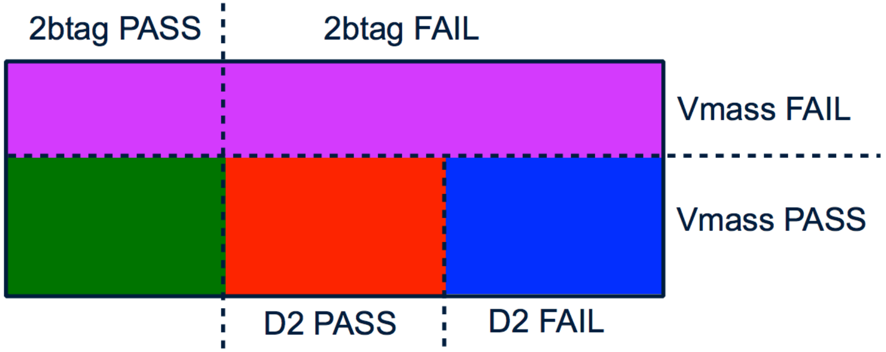




- **The inefficiency indicated in the jet mass spectra evolves as the heavy resonance goes lower**
- Official boson jet tagger leads to inefficiency in Zy spin-0/2 and Hy channel.
  - Should be revisited for next round
  - Less colliminating in dedicate polarization scheme

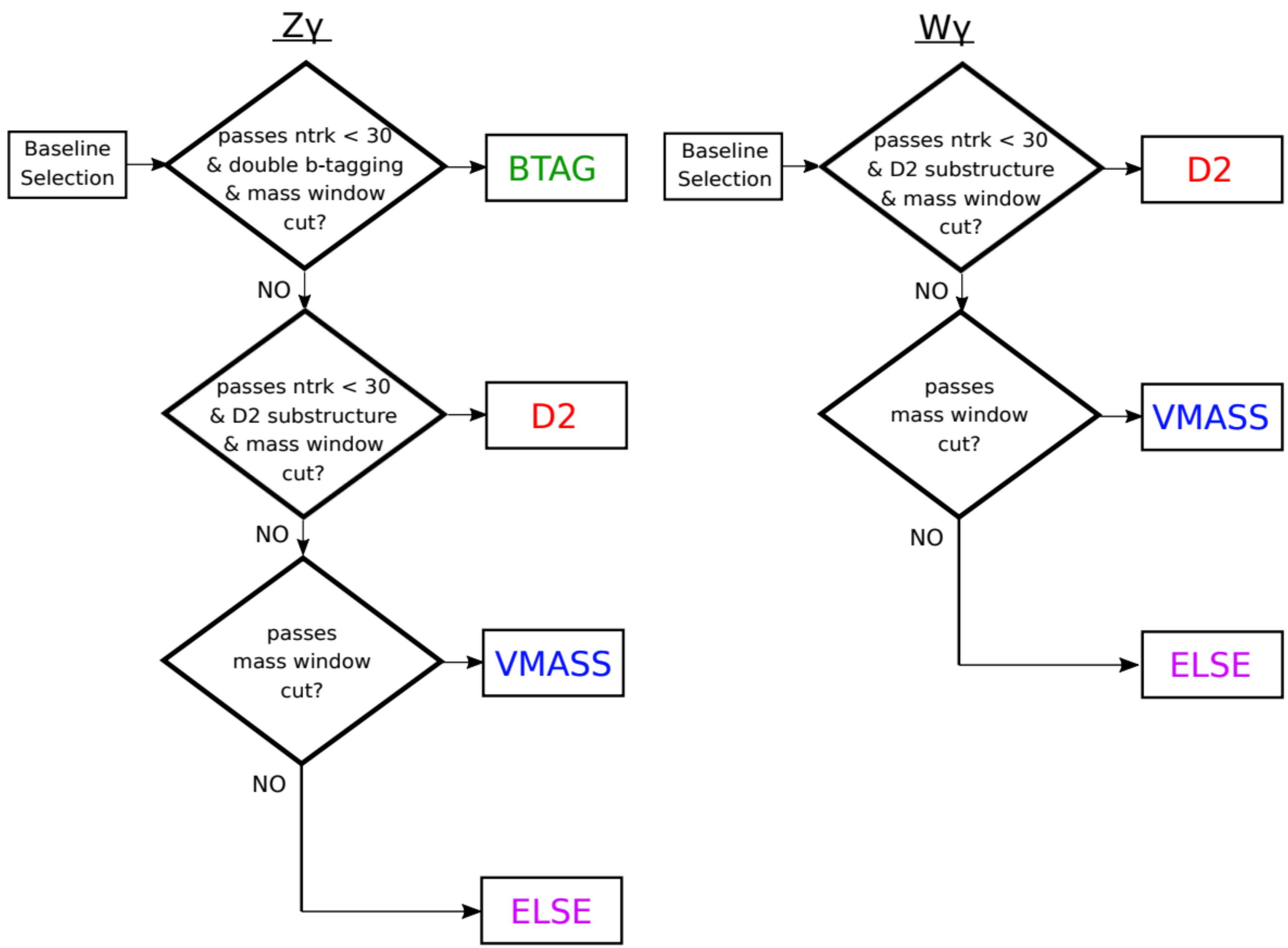
Event selection and categorization

- Baseline selection
  - high p_T photon trigger: HLT_g140_loose
  - Preselection: GRL + LooseBadJet cut on Resolved jets
  - At least one photon in barrel calorimeter ($|\eta|<1.37$)
  - 1 Tight Photon in the barrel & 1 Fat Jet (anti-kt R=1.0)
  - Jet and photon OR: $\Delta R(\text{jet}, \gamma) > 1.0$



- Categorization:
  - Zγ: btagged, D2, Vmass, else
  - Wγ: D2, Vmass, else
  - Hγ: btagged
  - Note: "Else" recover high mass eff.
  - Note: only H→bb is considered

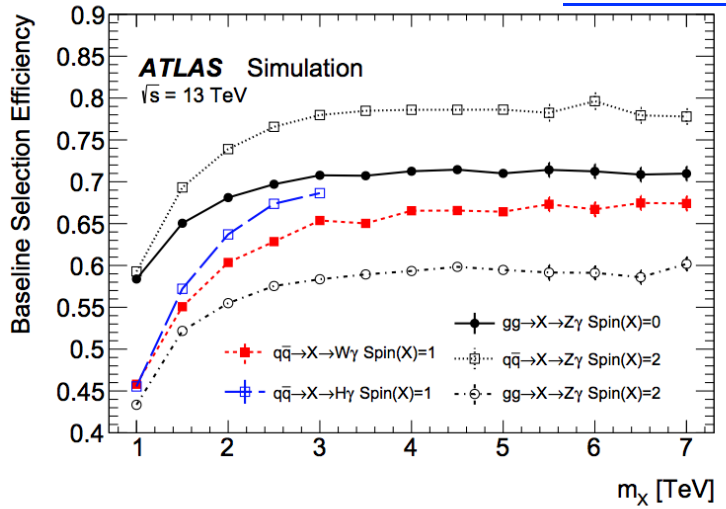
Categorization flow chart



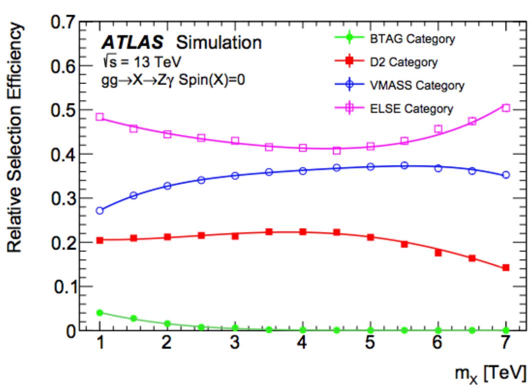
2015+2016 signal efficiency review

Baseline selection efficiency

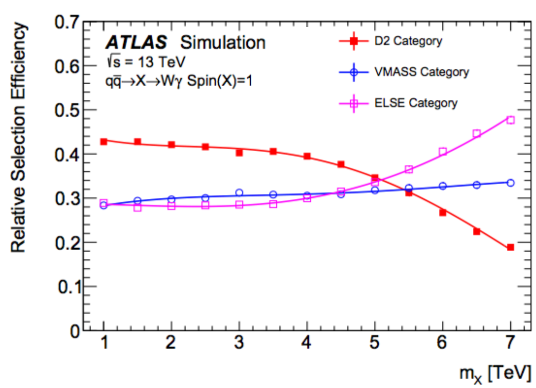
[Bo Liu, Zhijun Liang, Shu Li, et al. arXiv:1805.01908](arXiv:1805.01908)



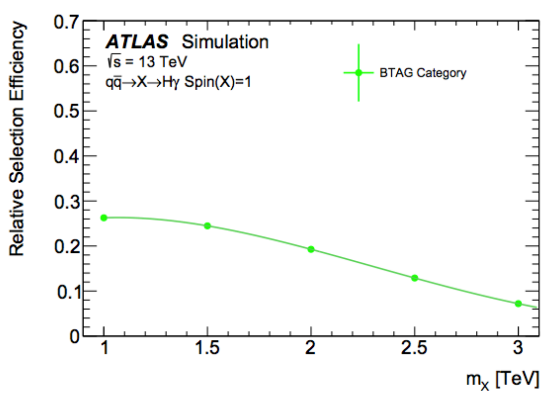
Zγ spin-2



Wγ spin-1



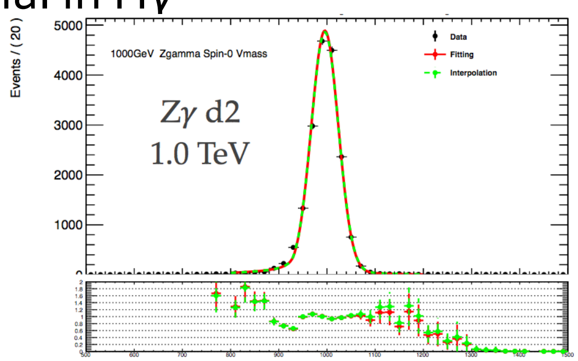
Hγ spin-1

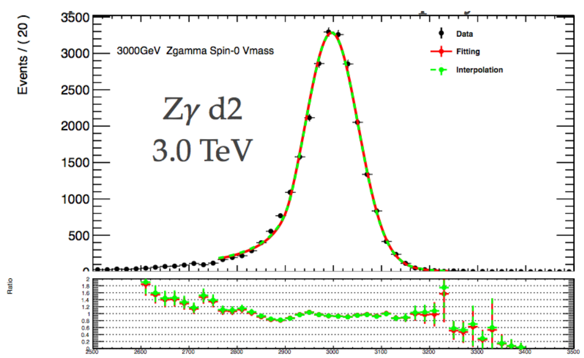


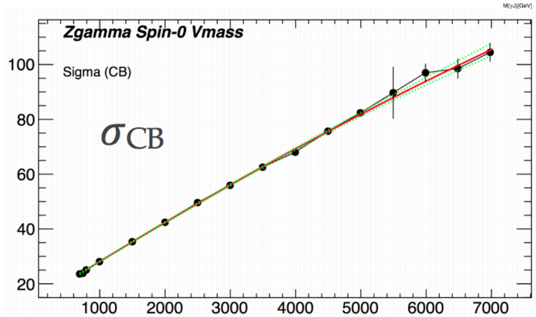
Signal shape modeling and parameterization

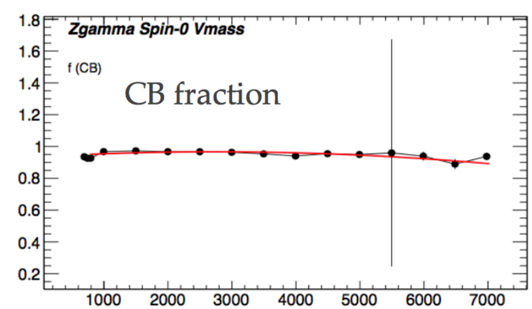
- Signal peak is modelled as Crystal ball + Gaussian function

  $f_{\mathrm{signal}}(m_{\gamma J}) = f_{\mathrm{CB}} \cdot \mathrm{CB}(m_{\gamma J}; \mu, \sigma_{\mathrm{CB}}, \alpha_{\mathrm{CB}}, n_{\mathrm{CB}}) + (1 - f_{\mathrm{CB}}) \cdot \mathrm{Gauss}(m_{\gamma J}; \mu, \sigma_{\mathrm{Gauss}})$
- Parameters are parametrised as polynomial function
- σ_{CB}, σ_{Gauss}, f_{CB} is parametrised with 2-order polynomial
- α_{CB} is parameterised with 3-order polynomial
- n_{CB} is fixed for Wγ and Zγ, but float and parameterised as 2-order polynomial in Hγ









Background fit

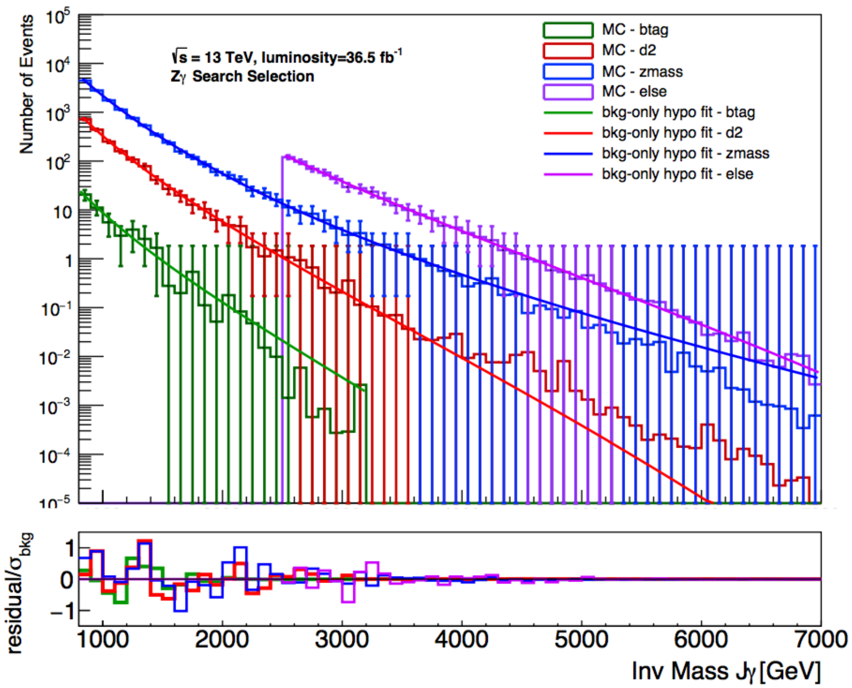
Dijet fit function adopted to benchmark the M(Jγ) fit

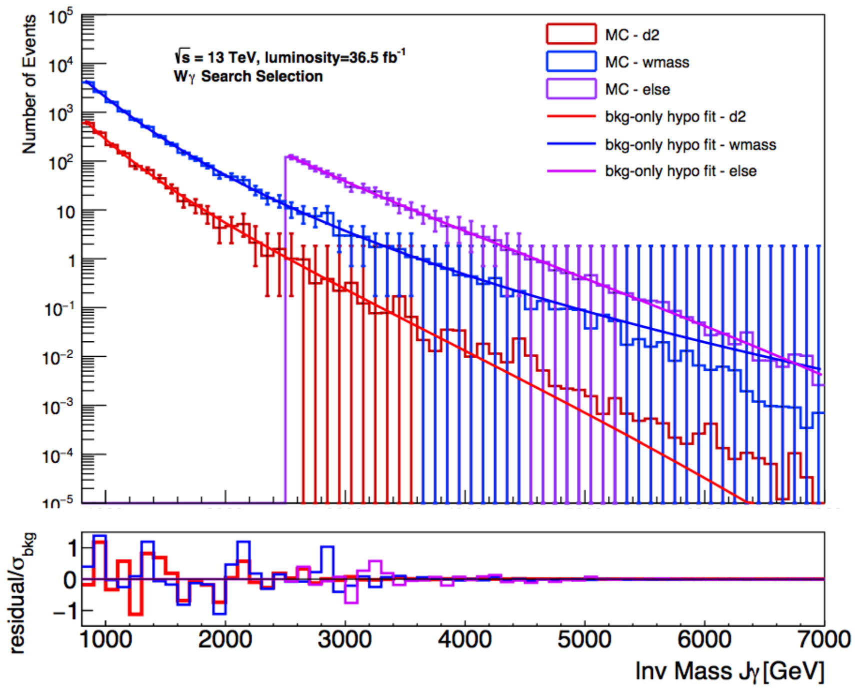
$$\frac{dn}{dx} = N(1-x)^{p_1} x^{p_2+p_3 log(x)+p_4 log^2(x)+O(log^3(x))}$$

# of fit param. choice driven by SS-tests and F-tests

(Unbinned) Fit range settings:

- btag: 800-3200 GeV
- d2: 800-7000 GeV
- zmass: 800 - 7000 GeV
- else: 2500 - 7000 GeV



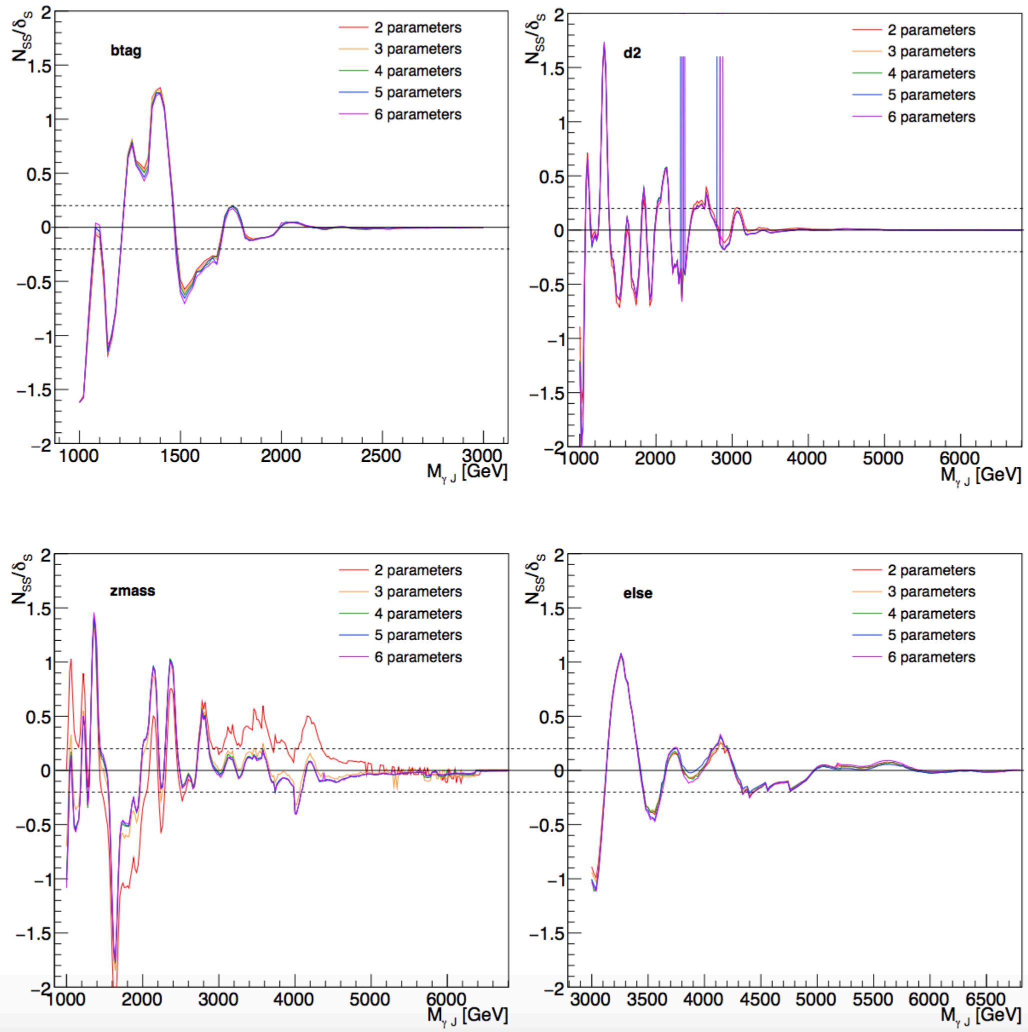


Spurious Signal test procedure

- Procedures of Spurious Signal Test:
  - (1) Fit with bkg+sig hypothesis on the MC (with expected error from data)
  - → numbers of spurious signal events (N_{SS}) & fitted background function
  - (2) A. Background event counting with 2 sigma around signal peak
  - → "background uncertainty", δ_S = Uncertainty in PoissonDistribution($B_{\mathbf{expected}}$)
  - B. Fix background parameters as fitted in (1), and fit again with bkg+sig hypothesis (with MC stat. error)
  - → 1-sigma, σss, error bands due to MC stat. power = uncertainty of NSS
  - (3) Plot N_{SS}/δ_S as a function of mJγ (tested from 860 GeV to 7 TeV, increment of 20 GeV)
- The conditions for a function to be accepted is that:
  - Minimal number of parameters when spurious signal converges
  - (In general) N_{SS} +/- σ_{SS} < 20% δ_S
- Abs(N_{SS}) is included as systematic uncertainties to obtain conservative limits.

MC based Spurious Signal test results: Zγ

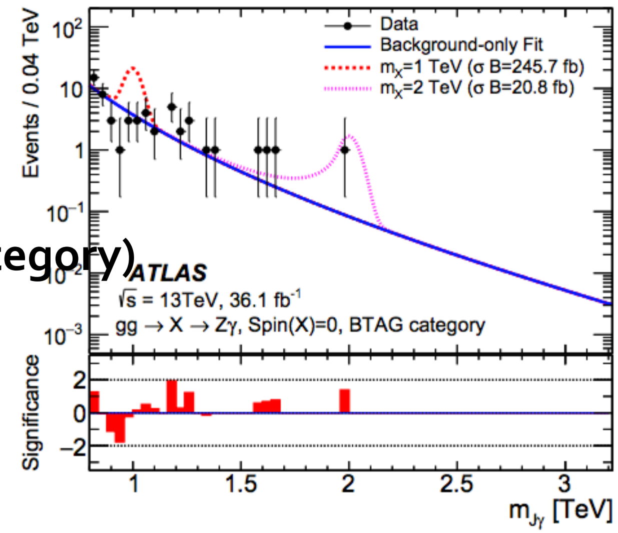
Choosing:	
btag	-> 2-parameter
d2	-> 2-parameter
vmass	-> 4-parameter
else	-> 2-parameter

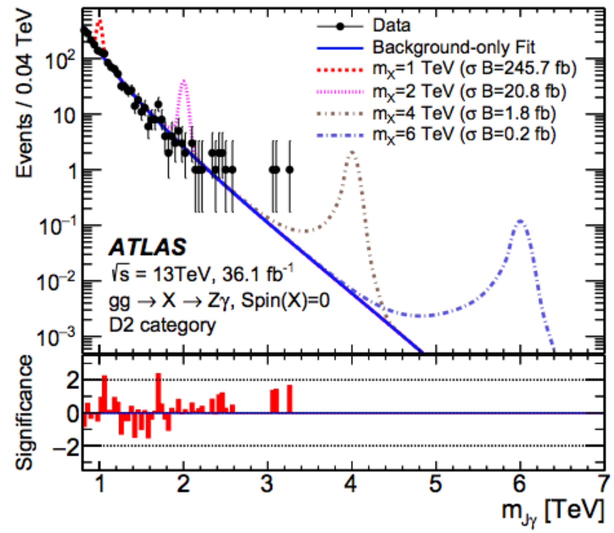


Large spurious signal at low mass due to MC fluctuation.

2015+2016 Zγ mass spectra (spin-0)

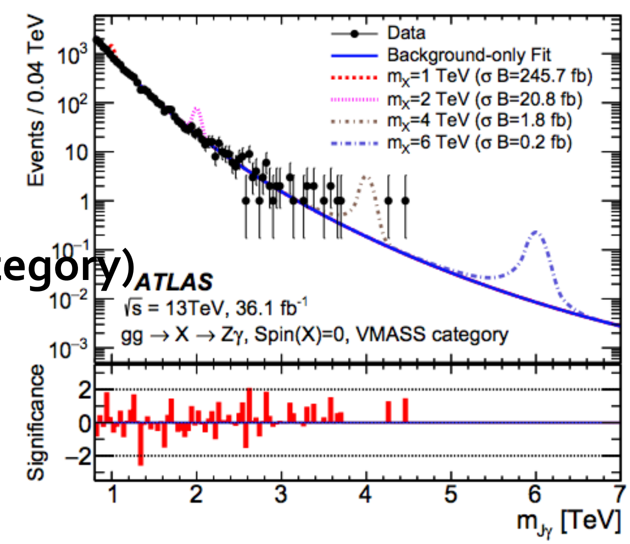
Zγ
(btagged category)

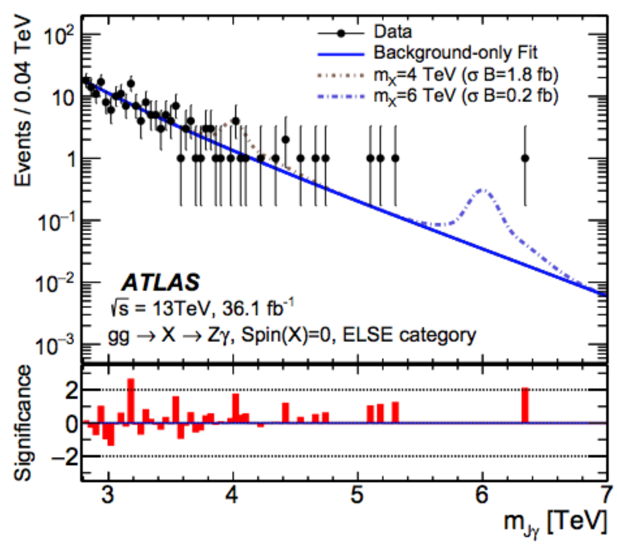




Zγ
(D2 category)

Zγ
(Vmass category)

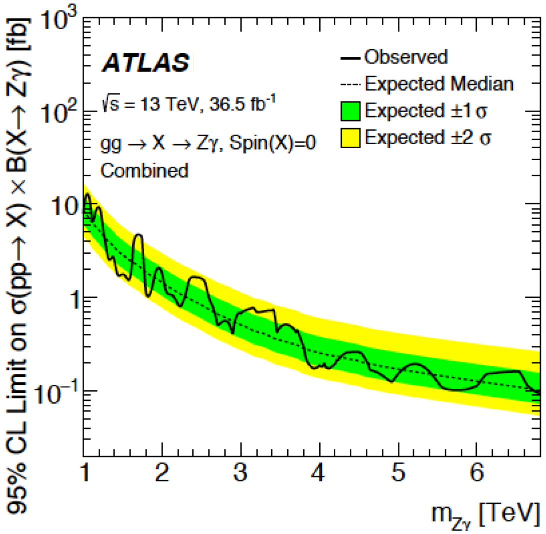


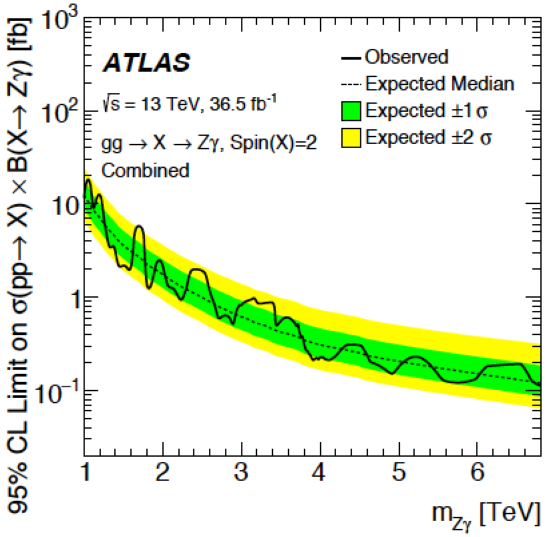


Zγ
(else category)

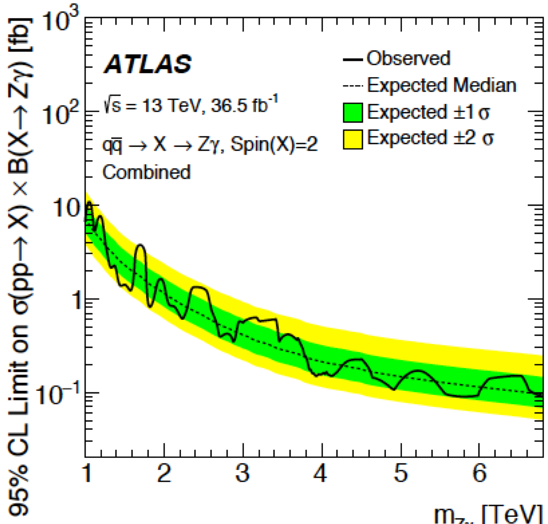
2015+2016 Zγ limits

gg→Zγ
spin-0





gg→Zγ
spin-2

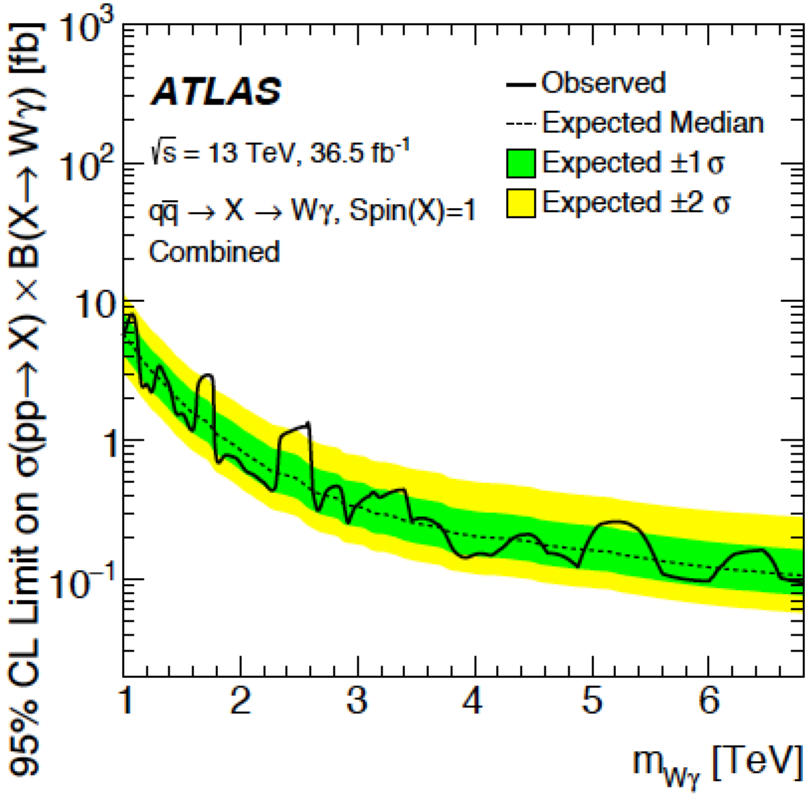


arXiv:1805.01908
ATLAS Physics Briefing [link]

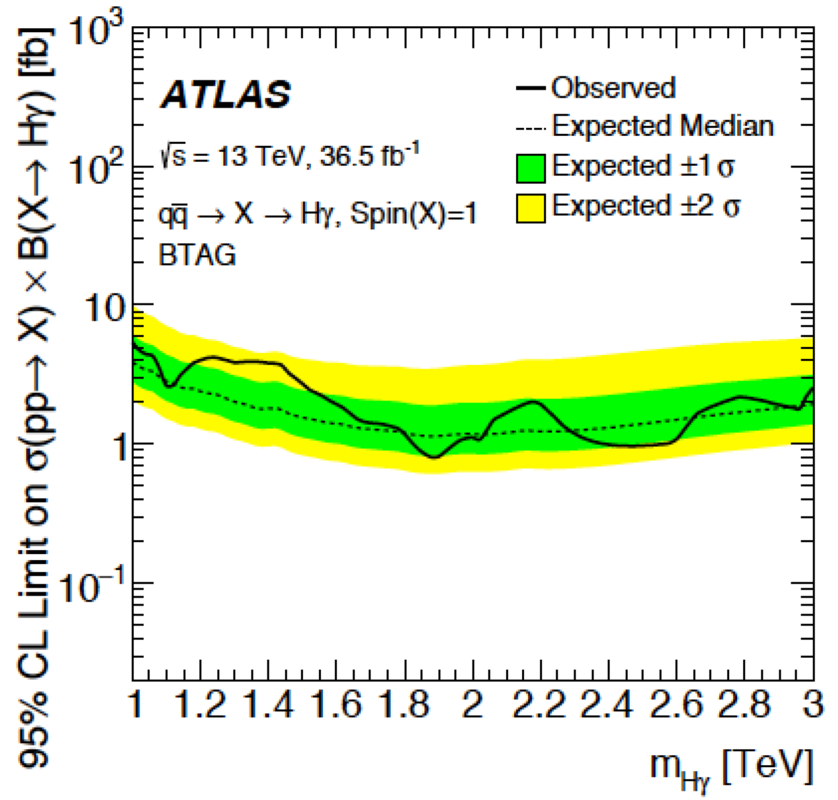
qq→Zγ
spin-2

2015+2016 Wγ and Hγ limits

Wγ (combined limits)



Hγ (combined limits)

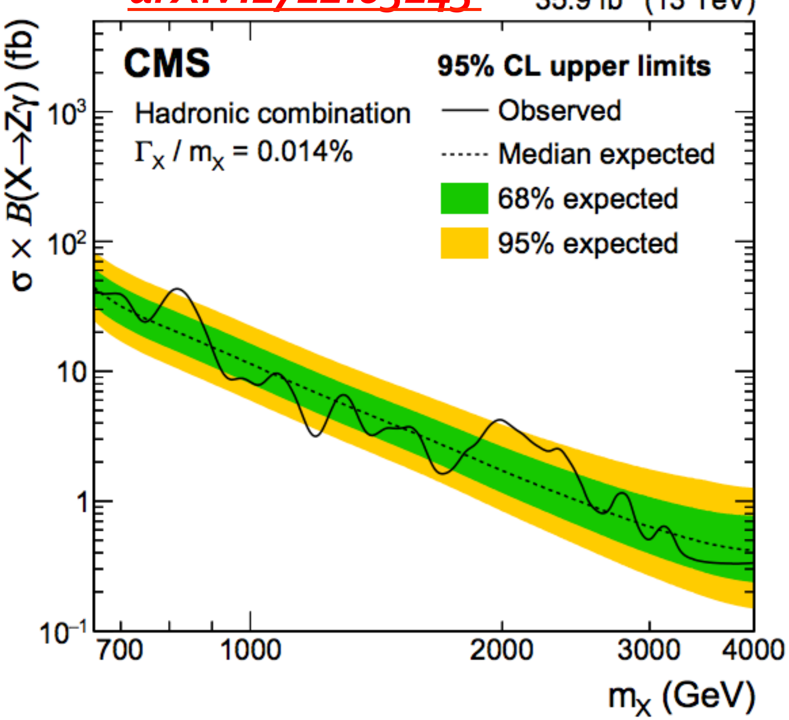


arXiv:1805.01908
ATLAS Physics Briefing [link]

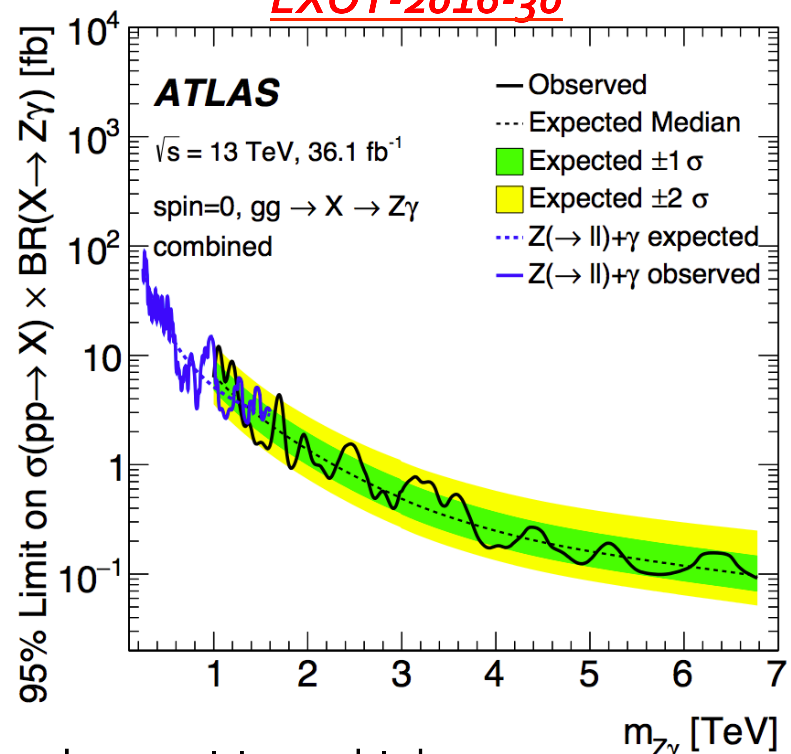
1st ever Hγ resonance search limits at LHC
CERN 2018 Physics Briefing highlight

Reminder: High mass resonance search in X->Zγ final states, leptonic vs hadronic

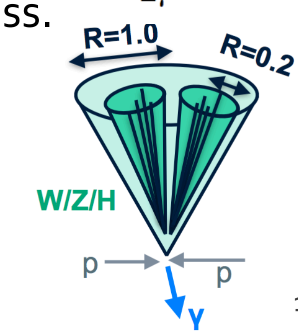
[arXiv:1712.03143](#)



[EXOT-2016-30](#)

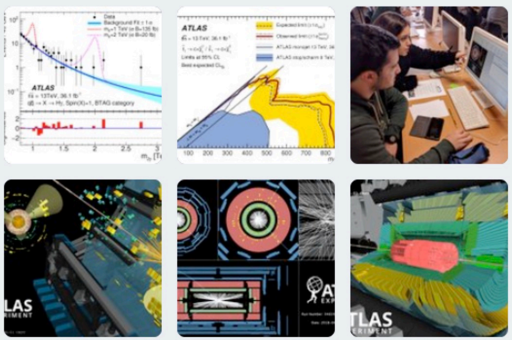


- The hadronic V/H+γ search analysis is designed to be sensitive at high mass.
  - Cross point of leptonic vs hadronic Zγ: m(X)~1.5TeV.
- The 2016 analysis of hadronic channel makes use of categorization in combination of btagged category to enhance the low mass sensitivity
  - W/H+γ channels are done for the 1st time!



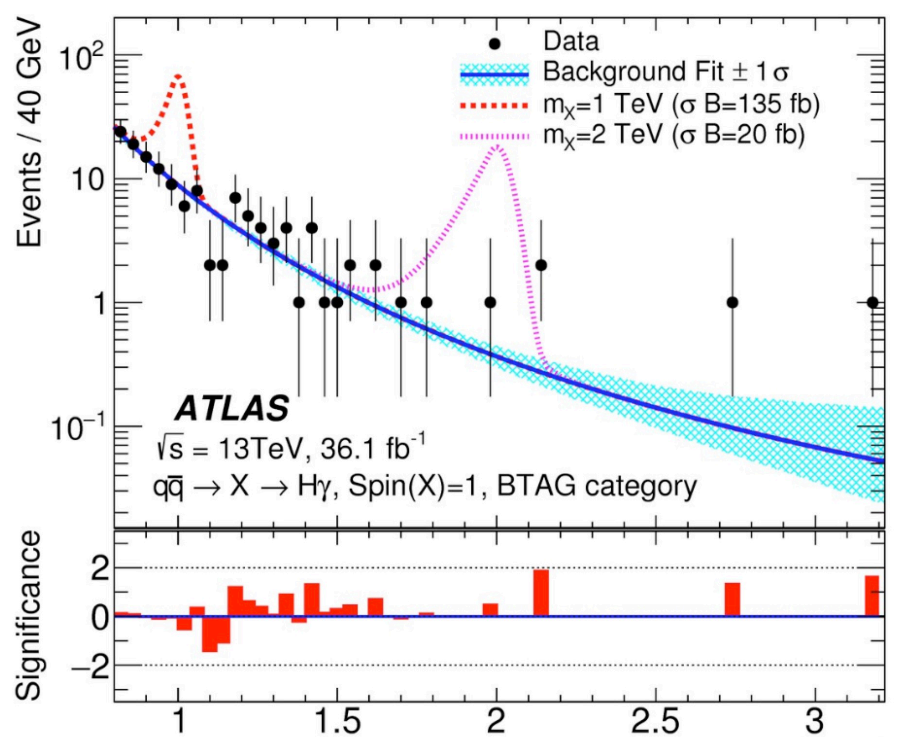
Physics Briefing highlight

882 Photos and videos



ATLAS Experiment @ATLASexperiment · 53m

[Physics Briefing] Searching for forces beyond the Standard Model: a new ATLAS measurement extends searches for new bosons up to masses about 70 times the mass of the Z boson. Find out more: cern.ch/go/p9Zj



arXiv:1805.01908
ATLAS Physics Briefing [link]
ATLAS Official twitter highlight [link]

Summary

- W/Z/H+γ resonance search updated with full 2015+2016 pp collision dataset at ATLAS
- **Upper limits are set on the production cross section times decay branching ratio to Z/W(H) + γ of new resonances with mass between 1.0 and 6.8(3.0) TeV.**
- The results extend the mass range and broaden the scope of previous searches for massive boson resonances decaying to **Zγ, Wγ and Hγ** final states. **And Wγ/Hγ limits are done for the first time!**

Spare

Search for $Z\gamma$, $W^{\pm}\gamma$ and $H\gamma$ resonances in boosted large-R jet plus photon final states with 36.5 fb^{-1} pp collision data at $\sqrt{s}$ = 13 TeV collected by the ATLAS detector

Ayana Arce[a], Andrea Bocci[a], Wojtek Fedorko[c], Minyu Feng[a], Alfred Goshaw[a], Enrique Kajomovitz[a], Evgeniy Khramov[d], Ashutosh Kotwal[a], Shu Li[a], Bo Liu[b,e], Zhijun Liang[b], Xinchou Lou[b], Wei Tang[a], Vincent Wong[c]

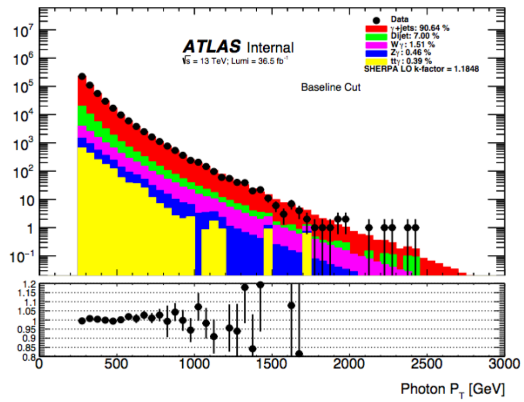
[a] *Duke University*
[b] *IHEP ,Beijing*
[c] *University of British Columbia*
[d] *JINR Dubna*
[e] *Iowa State University*

Support Note: https://cds.cern.ch/record/2227222
Paper v1.0: https://cds.cern.ch/record/2298713/files/EXOT-2016-30-001.pdf

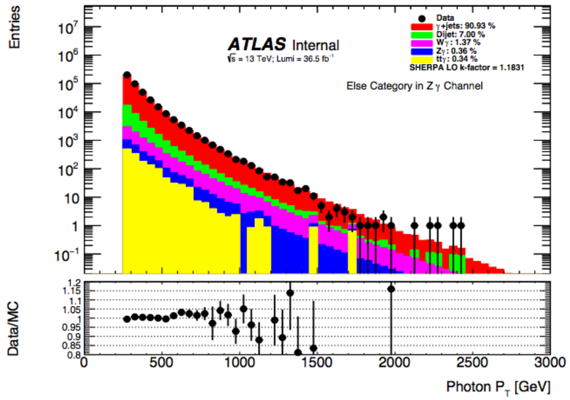
Background modeling and DATA/ MC agreement

Leading photon pT distribution in Zγ channel

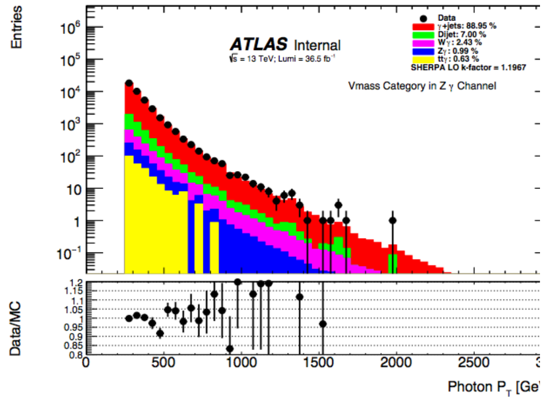
Baseline



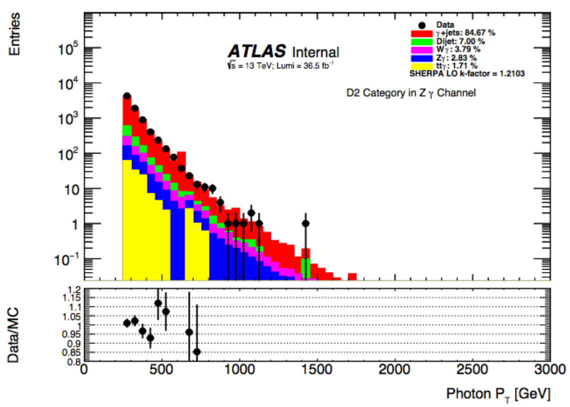
Else



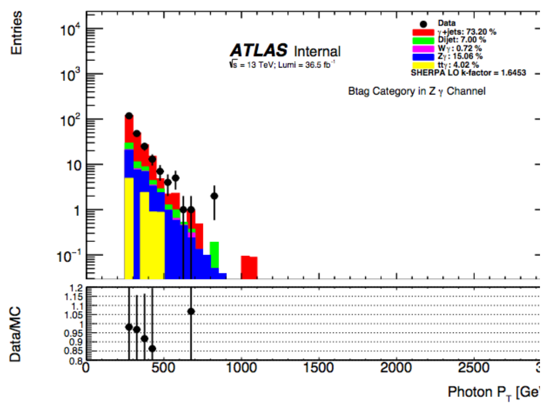
Vmass



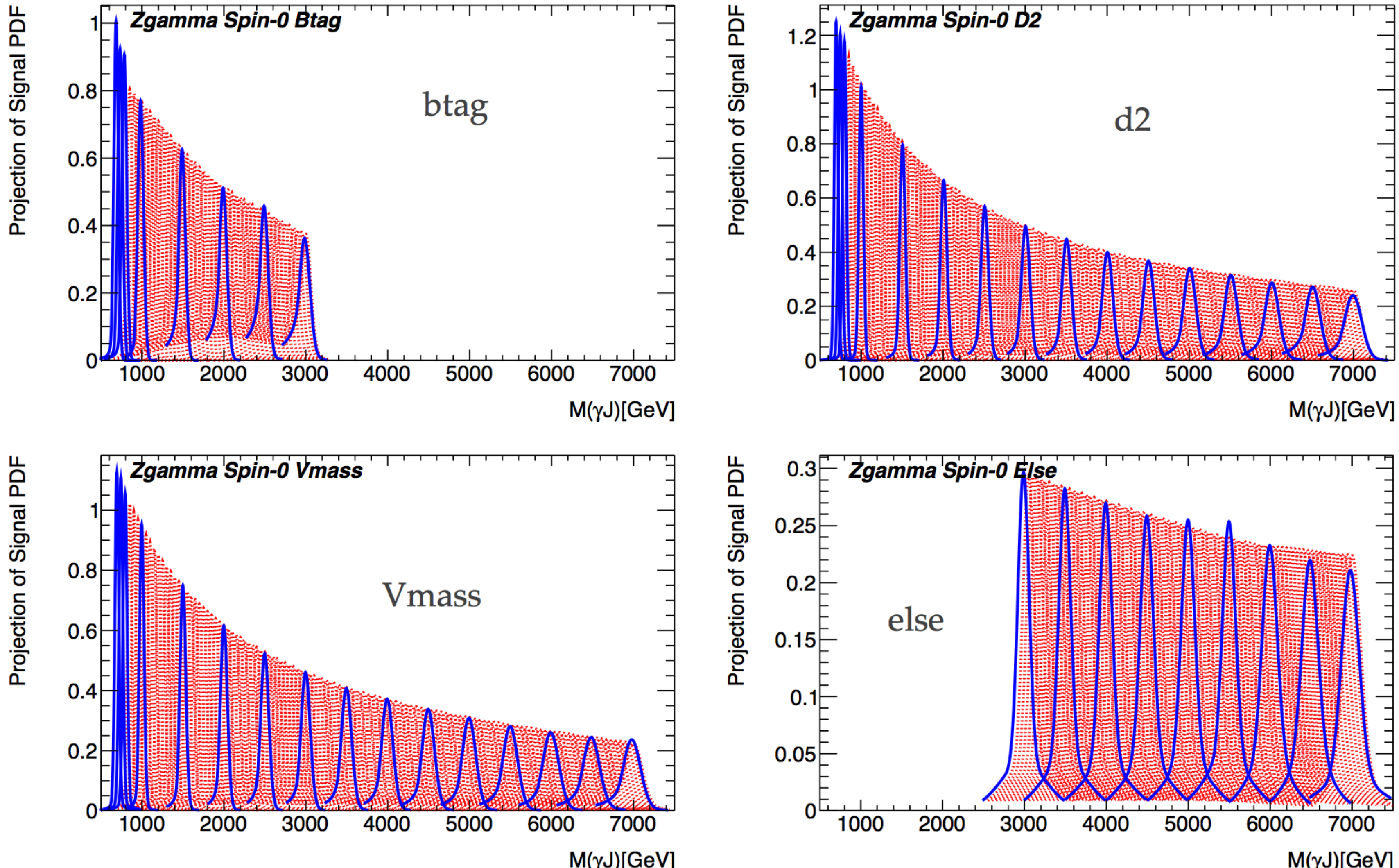
D2



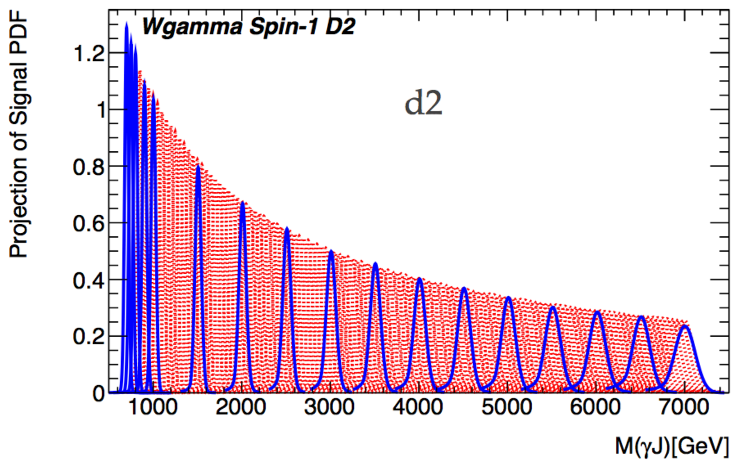
Btag

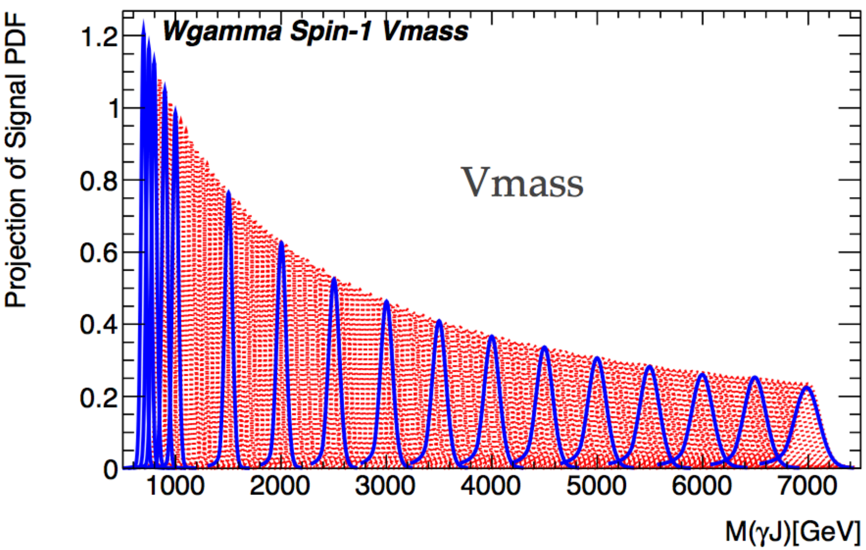


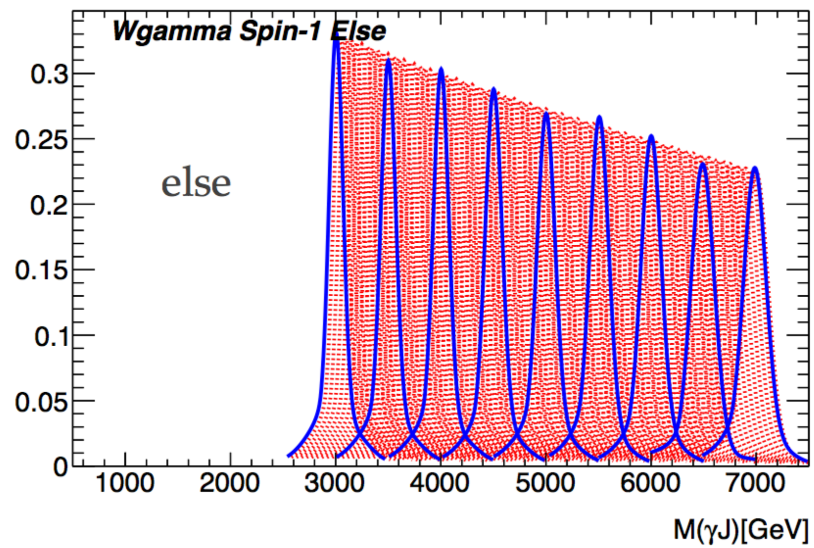
Zγ signal shape modeling



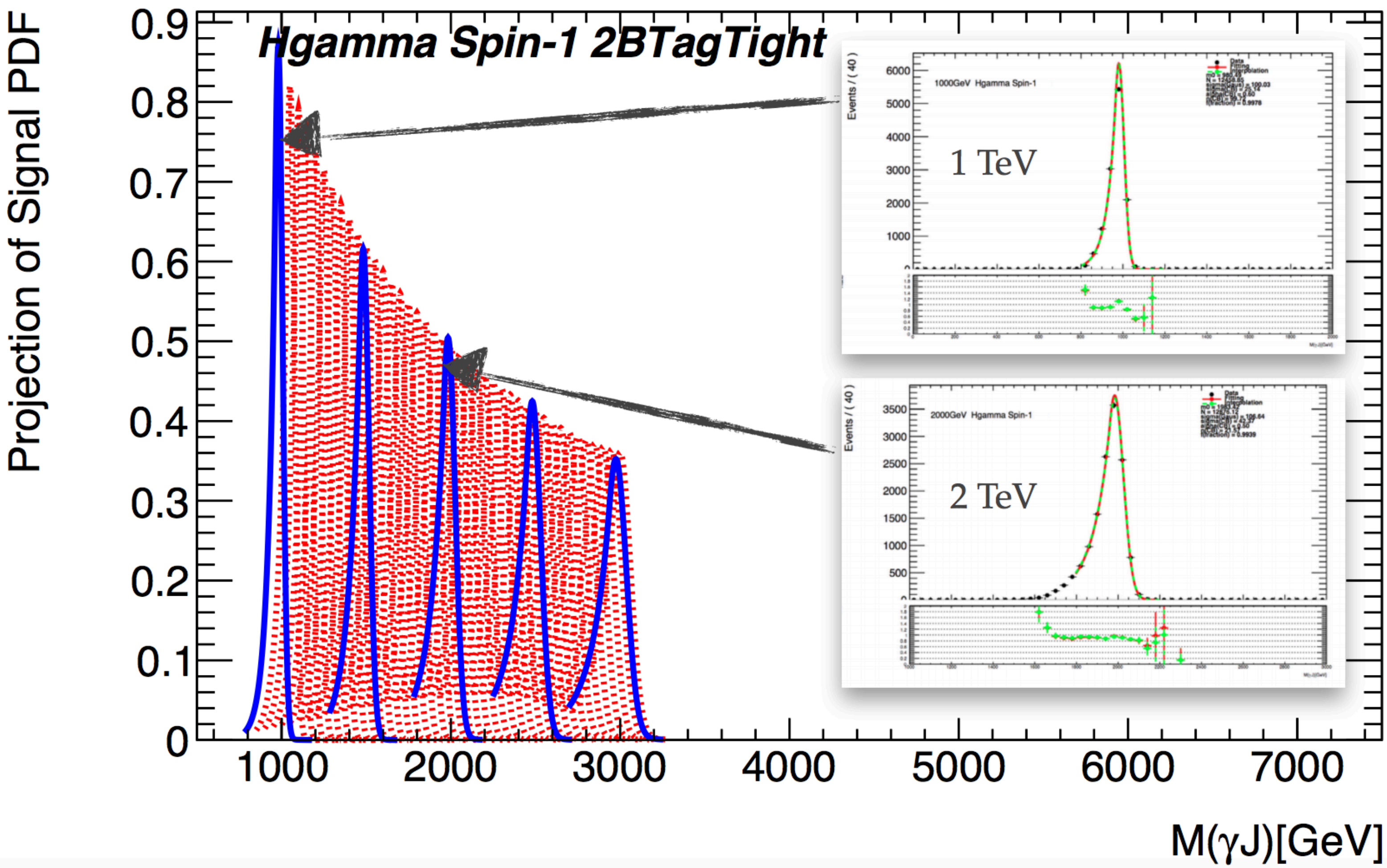
Wγ signal shape modeling





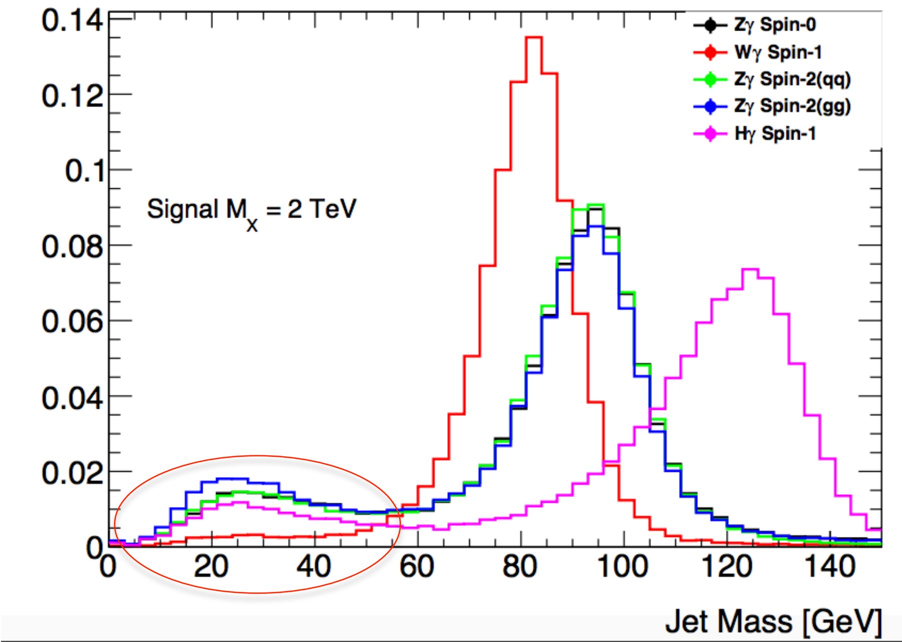


Hγ signal shape modeling



Boosted boson large-R Jet Mass: tagging inefficiency w.r.t. polarization

- W/Z large-R jets' mass sensitive to polarization of the given model
- Official boson jet tagger leads to inefficiency in Zγ spin-0/2 and Hγ channel.
  - Should be revisited for next round
  - Less colliminating in dedicate polarization scheme
  - May also need to test of pruning effect

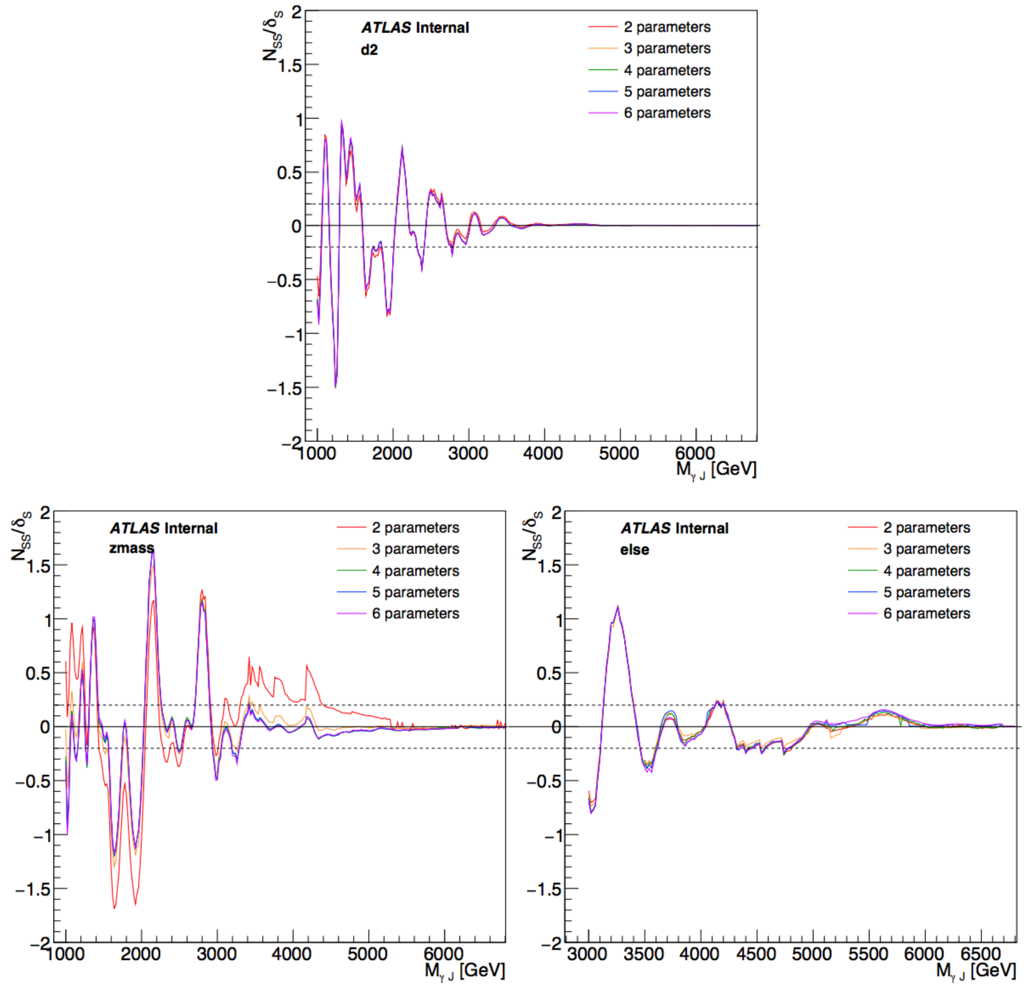


Channel	Generator	Spin	Production	V Polarization
Zγ	Powheg+Pythia8	0	gg→X	Transvers
Zγ	MadGraph+Pythia8	2	gg→X	Transvers
Zγ	MadGraph+Pythia8	2	qq→X	Transvers
Wγ	MadGraph+Pythia8	1	qq→X	Longitudinal
Hγ	MadGraph+Pythia8	1	qq→X	-

MC based Spurious Signal test results: Wγ

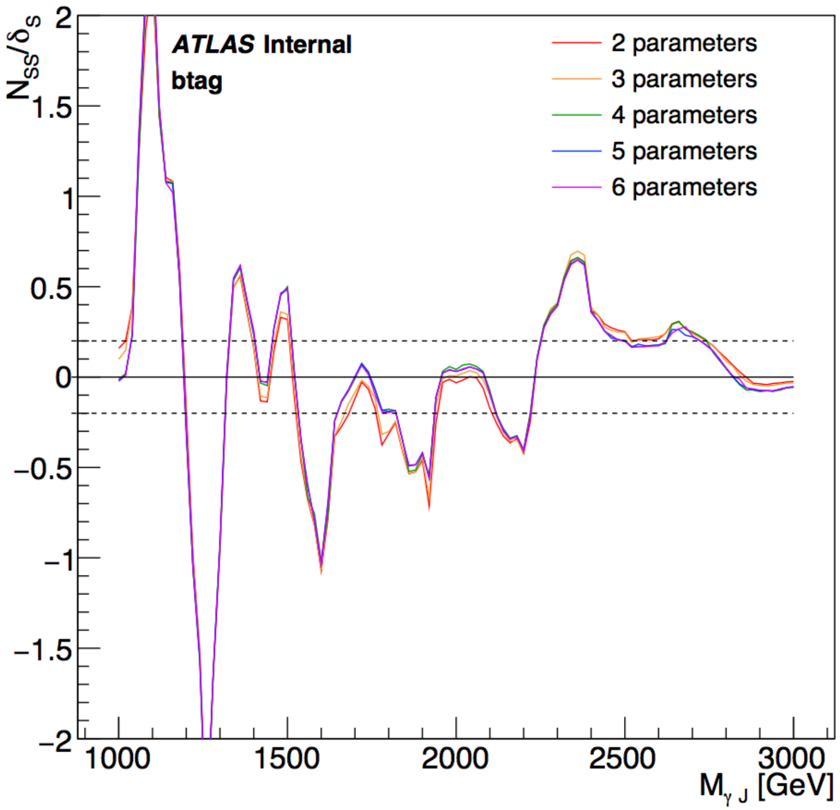
Choosing:

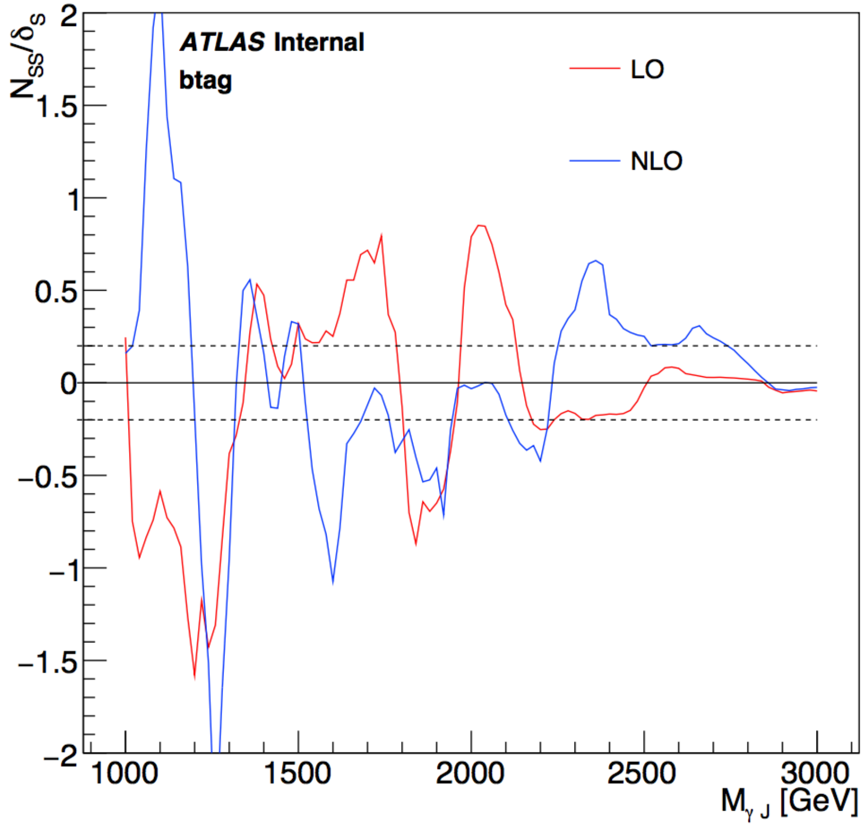
d2	-> 2-parameter
vmass	-> 4-parameter
else	-> 2-parameter



Large spurious signal at low mass due to MC fluctuation.

MC based Spurious Signal test results: Hγ





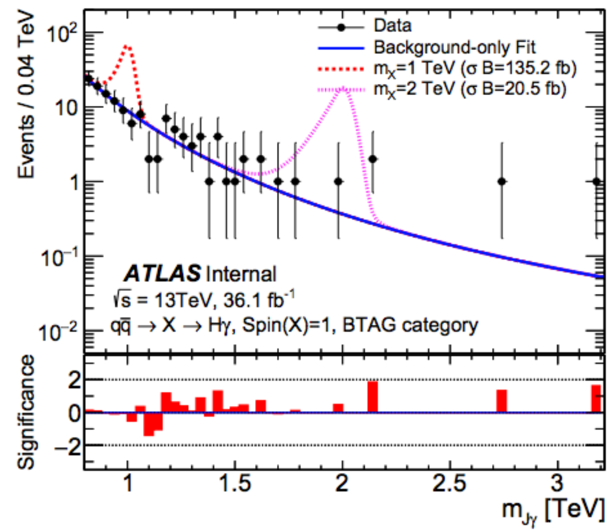
2-param does sufficiently well,
Consistent choice as it does for Zγ

Tested against LO and NLO γ+jets MC,
No explicit correlation spotted.
Help to justify the fluctuation "hypo" to be blamed

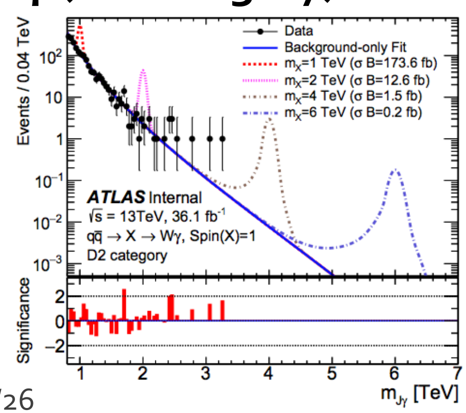
Unblinded results: Wγ and Hγ

Selection	Event yield			
Baseline	135305			
	Category			
	BTAG	D2	ZMASS	ELSE
$Z\gamma$ search	55	1923	12680	120647
$H\gamma$ search	138	NA	NA	NA
$W\gamma$ search	NA	1683	11867	121755

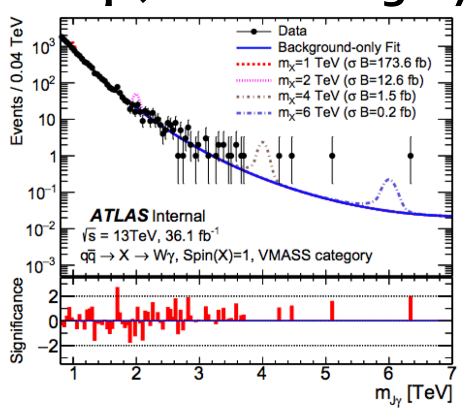
Hγ (btagged category)



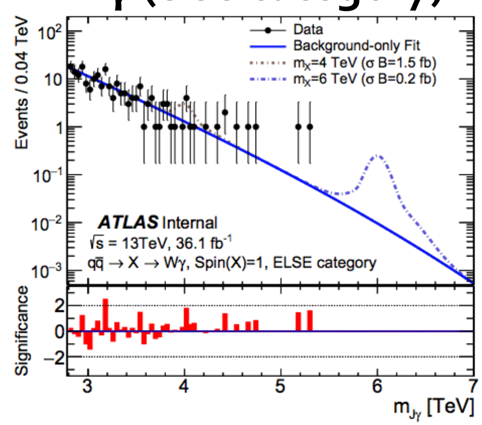
Wγ (D2 category)



Wγ (Vmass category)

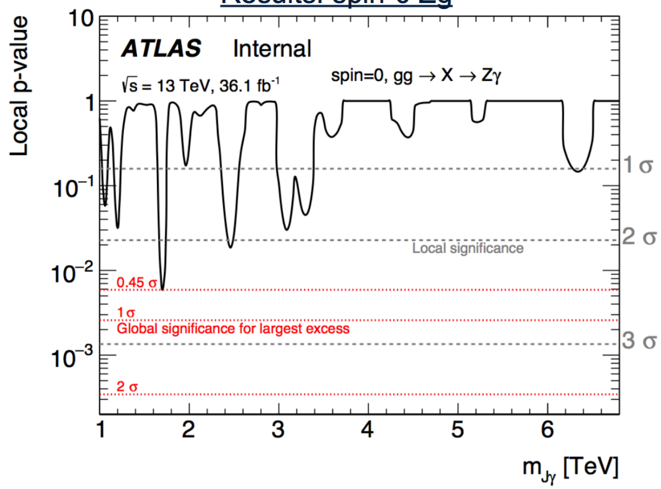


Wγ (else category)

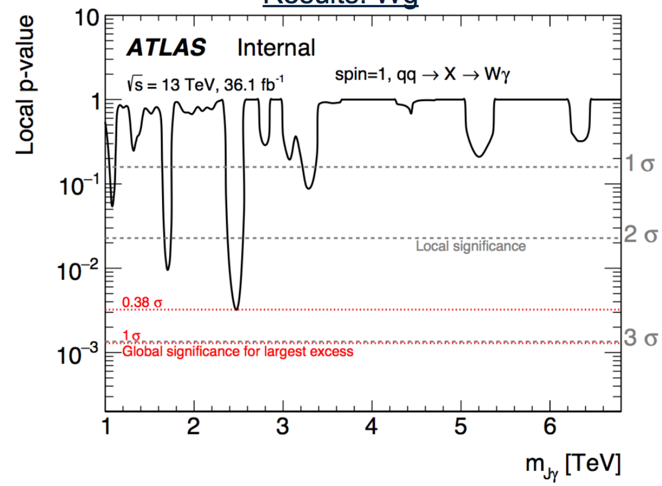


P-value per channel

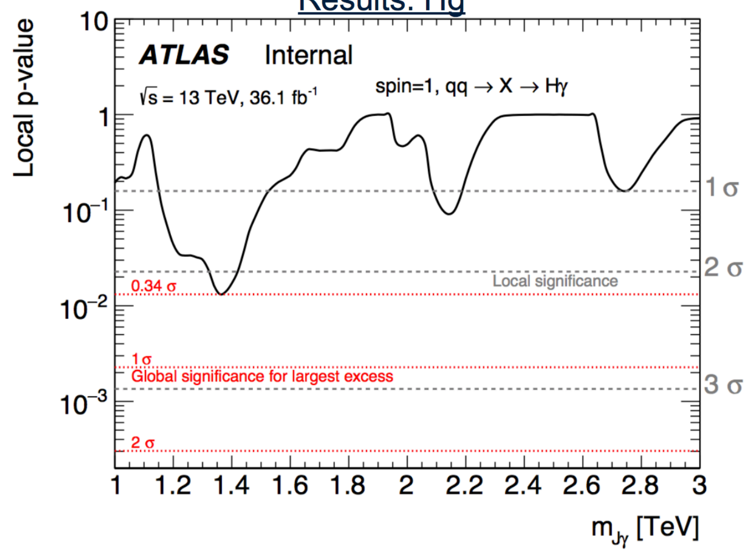
Results: spin-0 Zg



Results: Wg

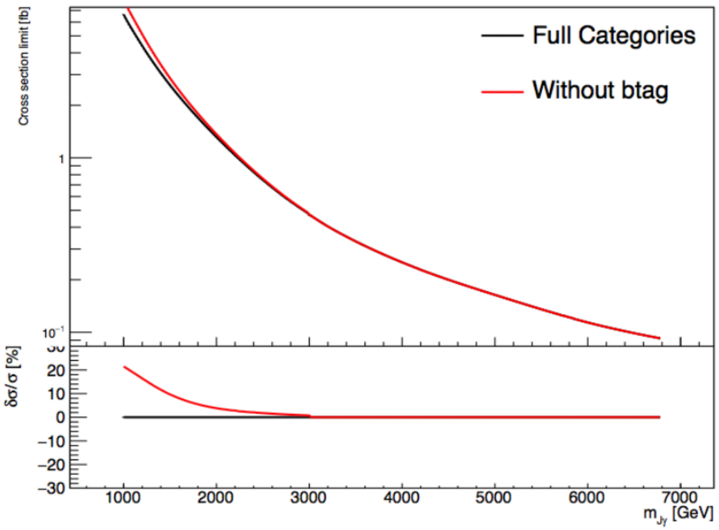


Results: Hg

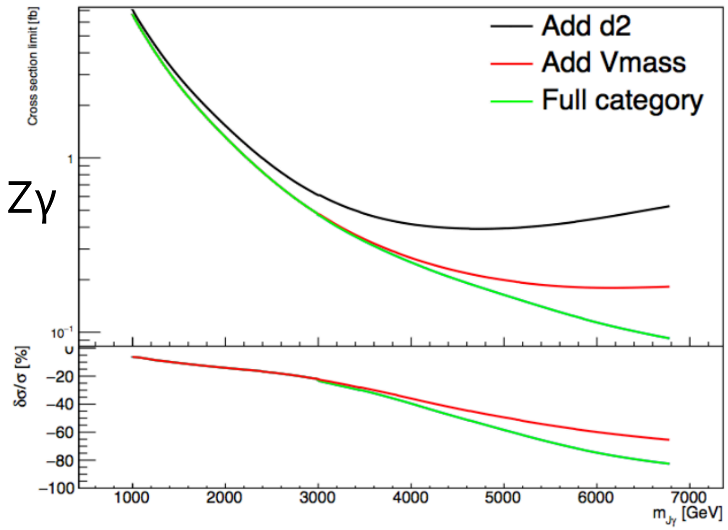


Summary of the categorization power

Zγ



Zγ

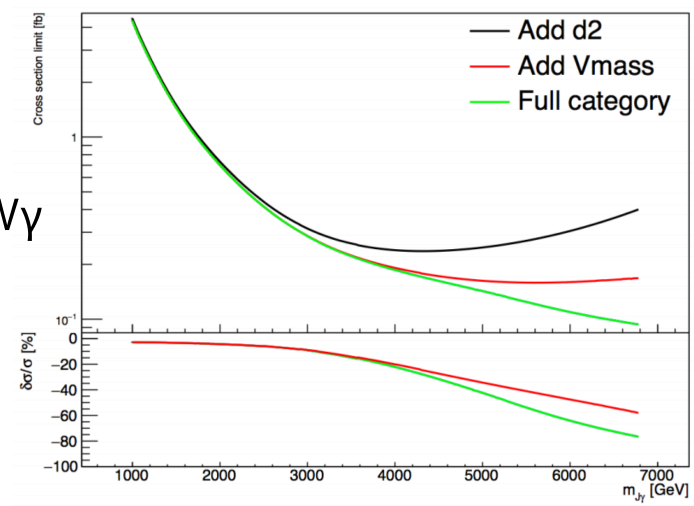


In 2015 analysis, only D2 category was considered.

Big improvement at low mass after adopting btagging

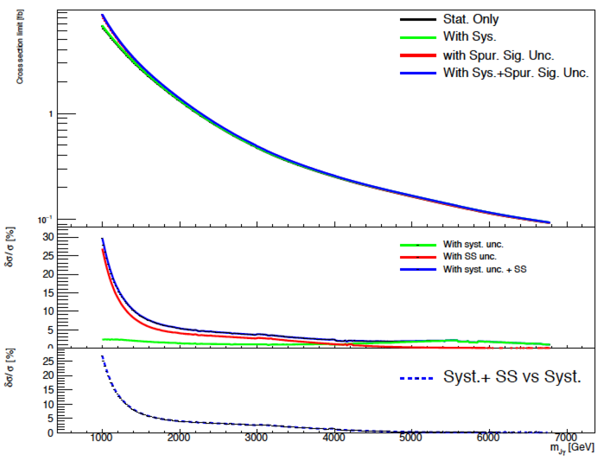
Big improvement and high mass extension after adopting else category to recover the signal acceptance in a bgd free region

Wγ

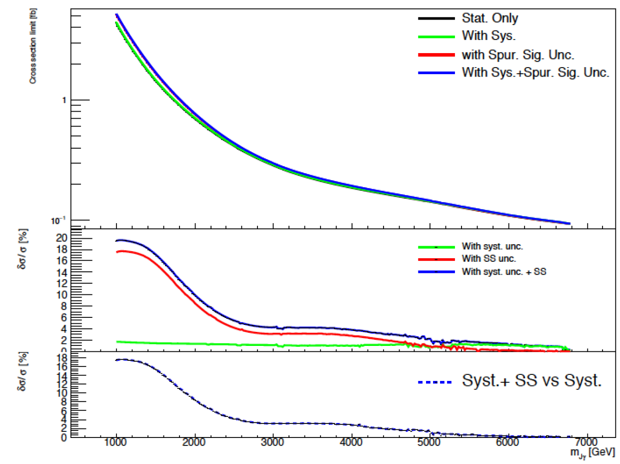


Impact of systematics uncertainties

Zγ
Spin-0



Wγ
Spin-1



Hγ
Spin-1