

Institut  
“Jožef Stefan”  
Ljubljana, Slovenija



# Searches for BSM resonances in ATLAS

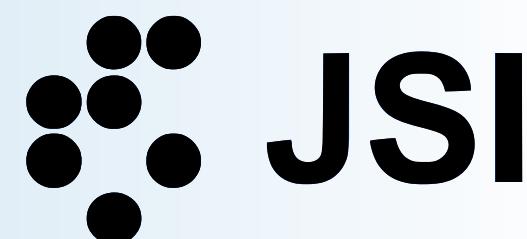
Blaž Leban  
on behalf of the ATLAS Collaboration

PHENO 2023

Latest topics in particle physics and related issues in astrophysics and cosmology

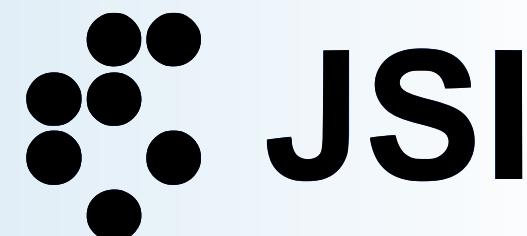
University of Pittsburgh May 8-10, 2023

# Overview and motivation



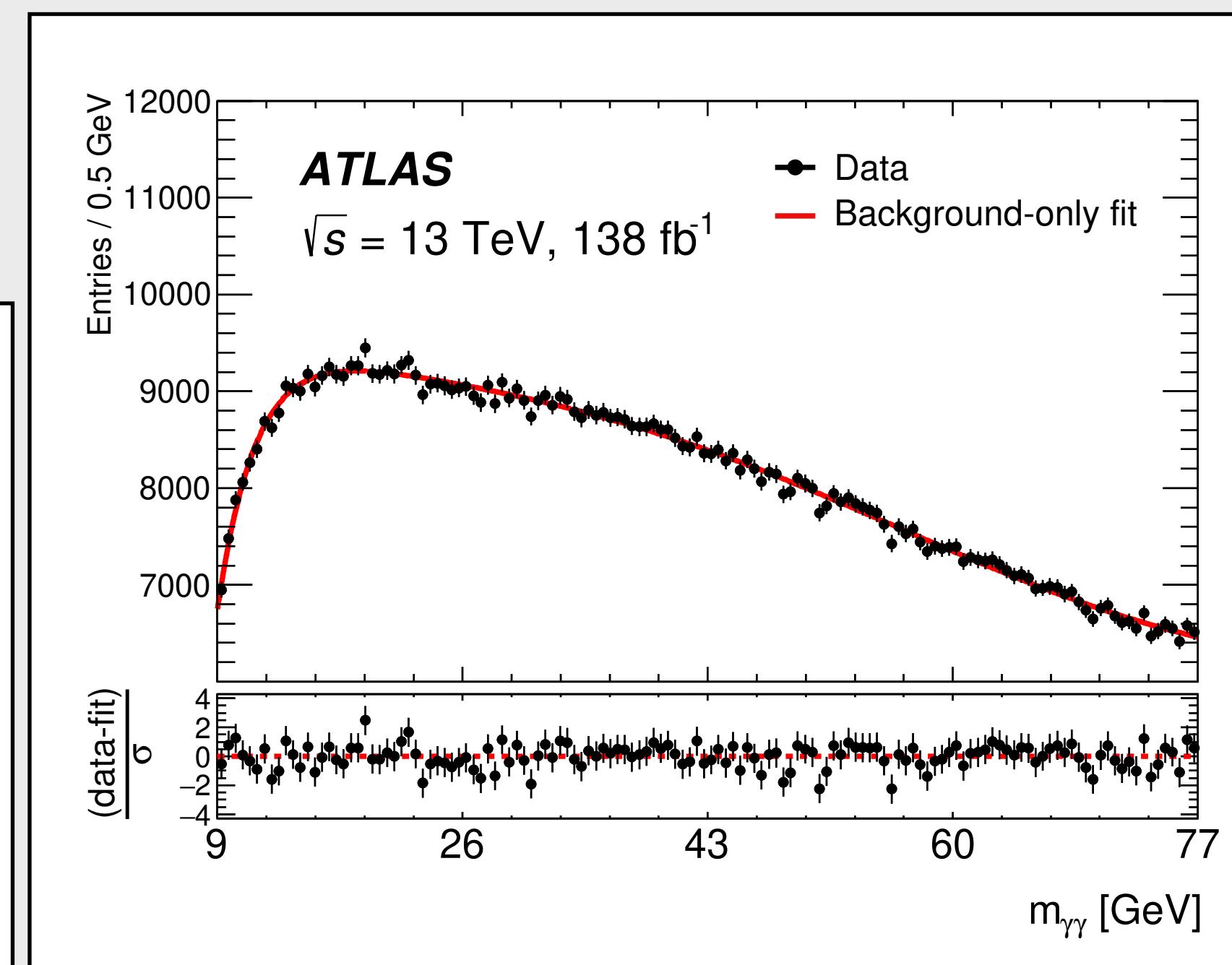
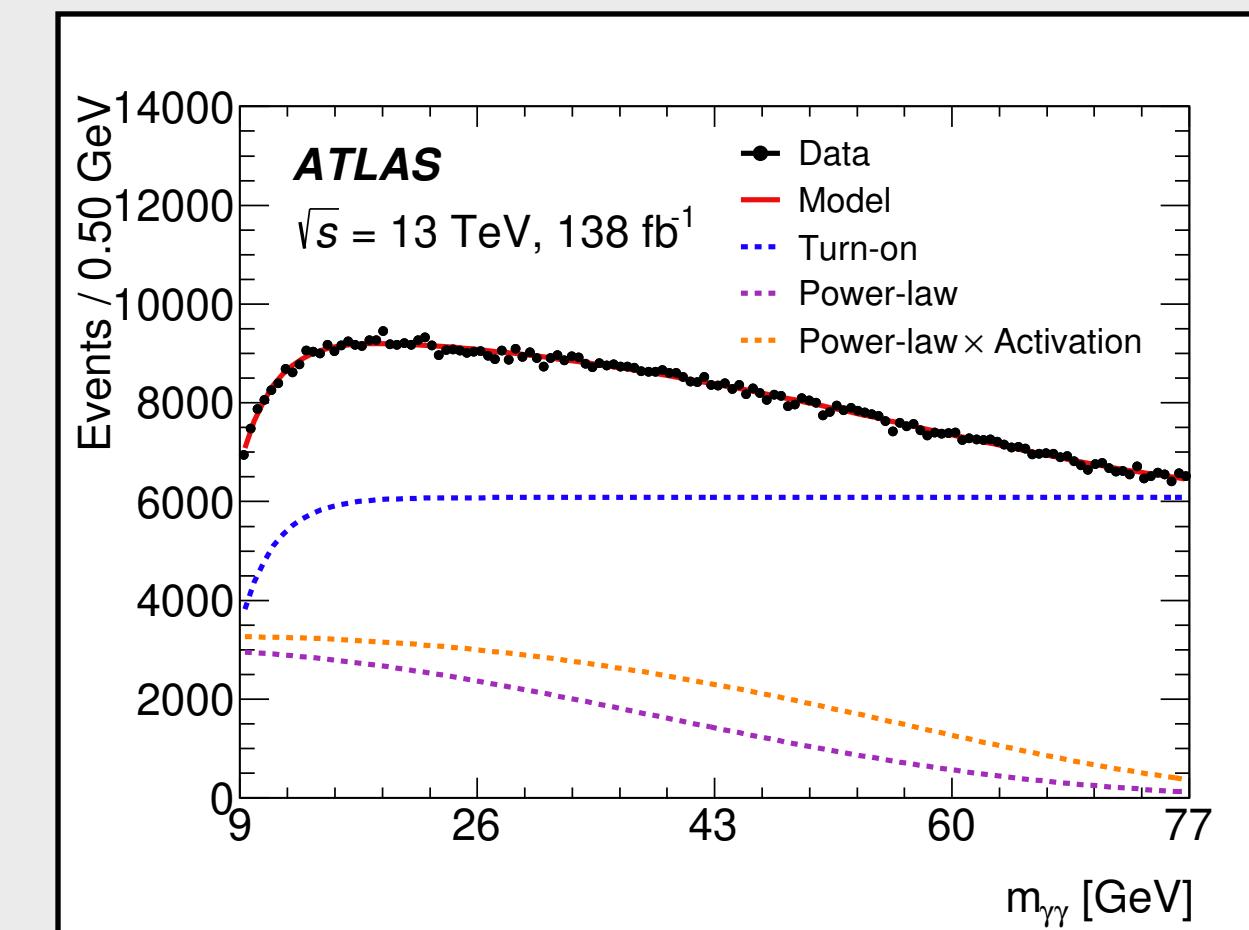
- One of the **key components** of the LHC physics programme is the search for **new resonances** predicted by hypotheses for BSM physics.
- Many public ATLAS papers and conference notes are available in [ATLAS public results](#).
- Focus on more recent ATLAS searches for BSM resonances:
  - **Low mass diphoton resonance search** [[arXiv:2211.04172](#)]:
    - ▶ provides the strongest bounds on the promptly decaying ALPs in low mass range.
  - **Axion-Like Particle (ALP) search with forward proton scattering** [[arXiv:2304.10953](#)]:
    - ▶ at least one tagged proton is required, giving increased sensitivity and higher experimental acceptance.
  - **Heavy neutrinos (LRSM)** [[arXiv:2304.09553](#)]:
    - ▶ constitutes the most stringent limits to date for the KS process.
  - **Vector-like top partners** [[ATLAS-CONF-2023-020](#)]:
    - ▶ limits significantly improve and are comparable between ATLAS and CMS.
  - **Neutral heavy resonances in  $W^+W^- \rightarrow e\nu\mu\nu$  decay channel** [[ATLAS-CONF-2023-020](#)]:
    - ▶ large interpretability, covers a lot of models.

# Low mass $\gamma\gamma$ resonance - motivation

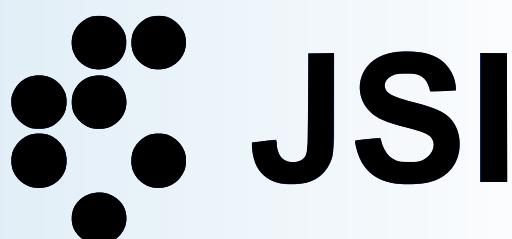


- A search for **diphoton narrow boosted resonances** in the low mass range (10 - 70 GeV), **previously unexplored** at hadron colliders because of the harsh environment at low masses and the trigger efficiency “turn-on” region (masses below 20 GeV).
- The natural targets of this search are pseudo Nambu-Goldstone bosons associated with spontaneously broken global symmetries, referred to as **axion-like particles (ALP)**:
  - A light ALP coupled to gluons would be abundantly produced in  $pp$  collisions,
  - Its suppressed coupling to photons presents experimental advantages that make the diphoton final state more desirable to look for at the LHC.

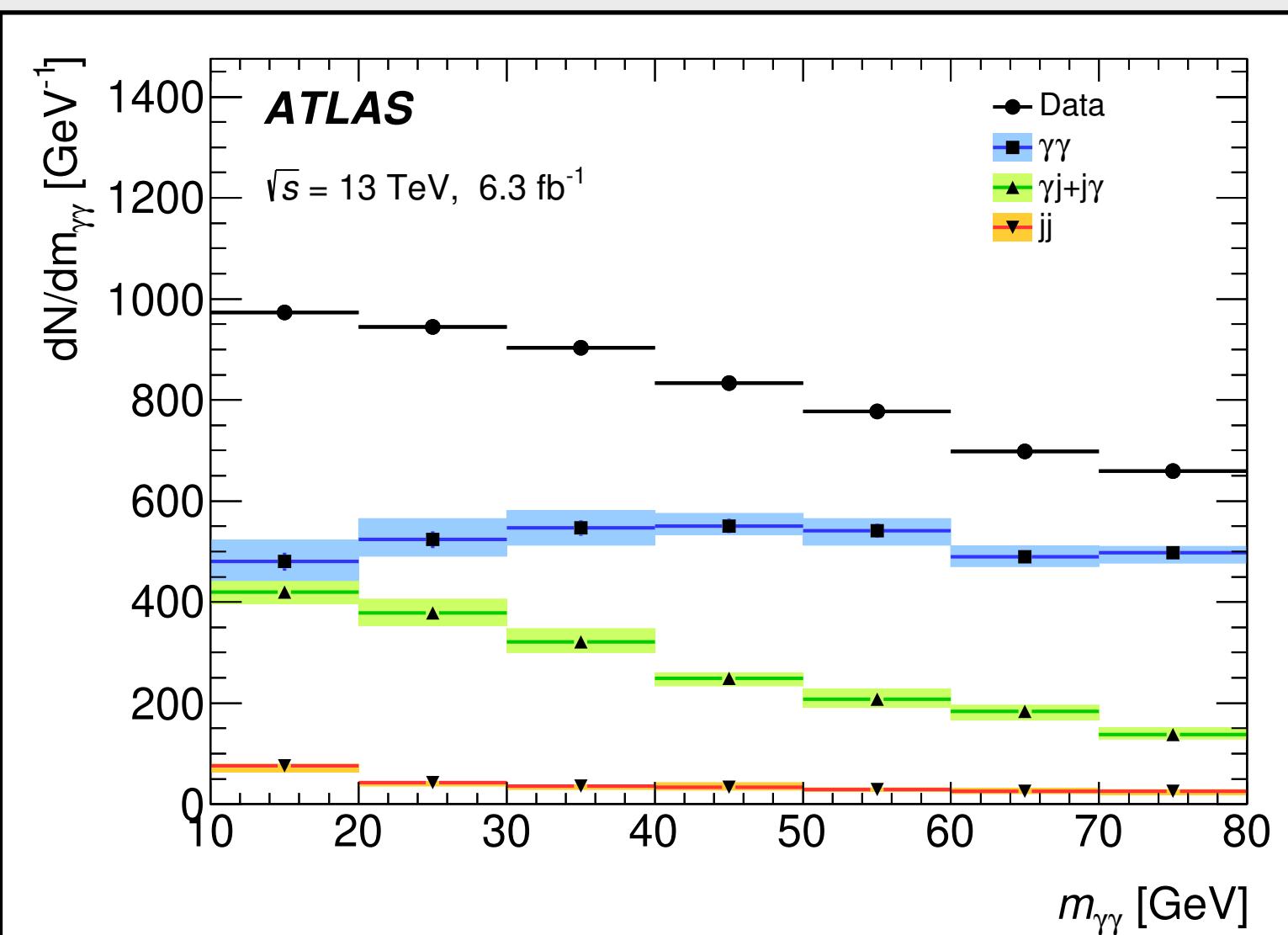
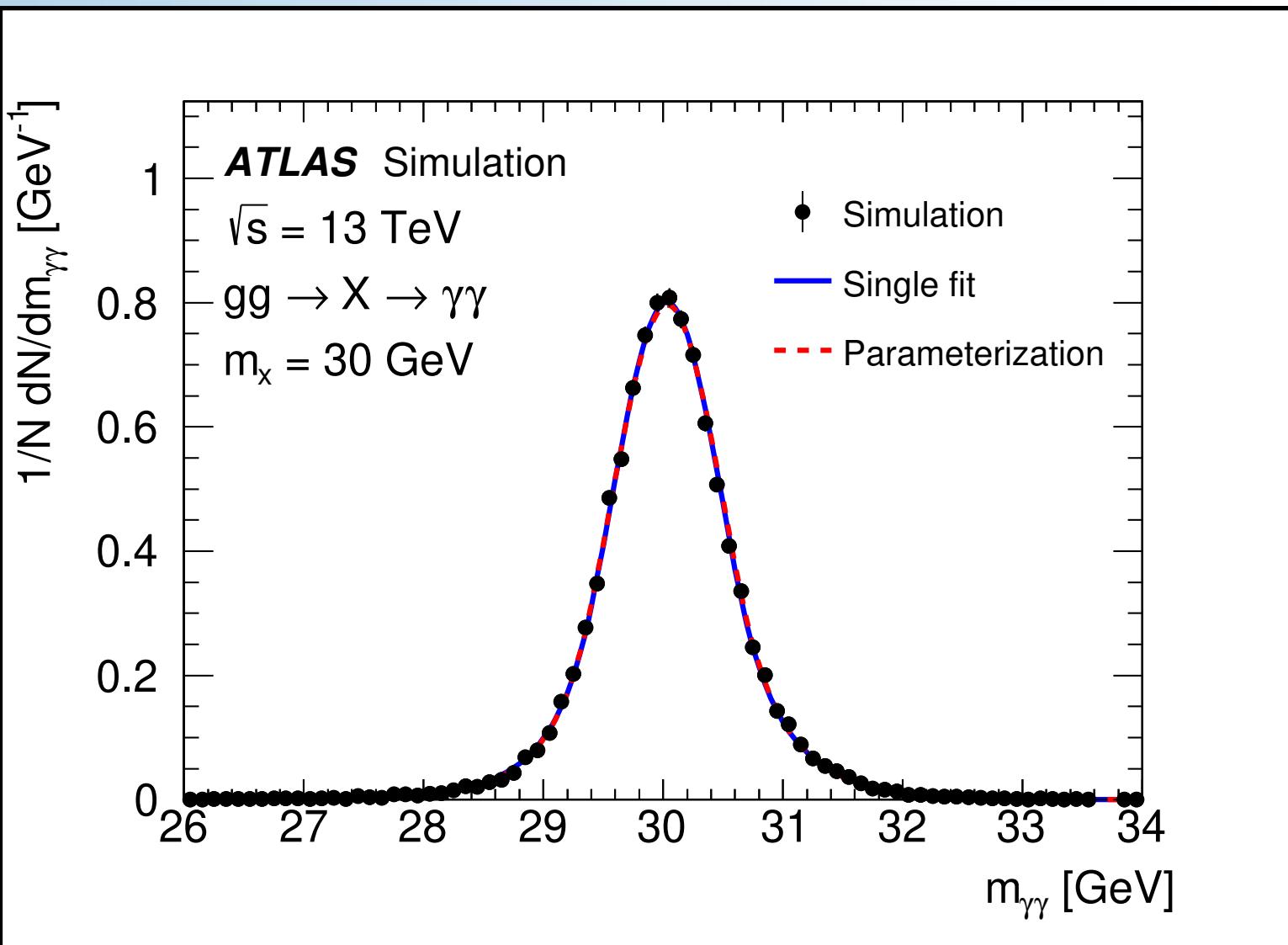
Distributions of the diphoton invariant mass for all events passing the analysis selections with the background-only fit superimposed.



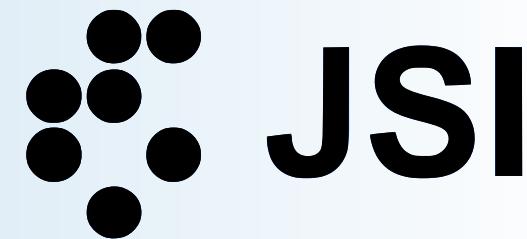
# Low mass $\gamma\gamma$ resonance - strategy



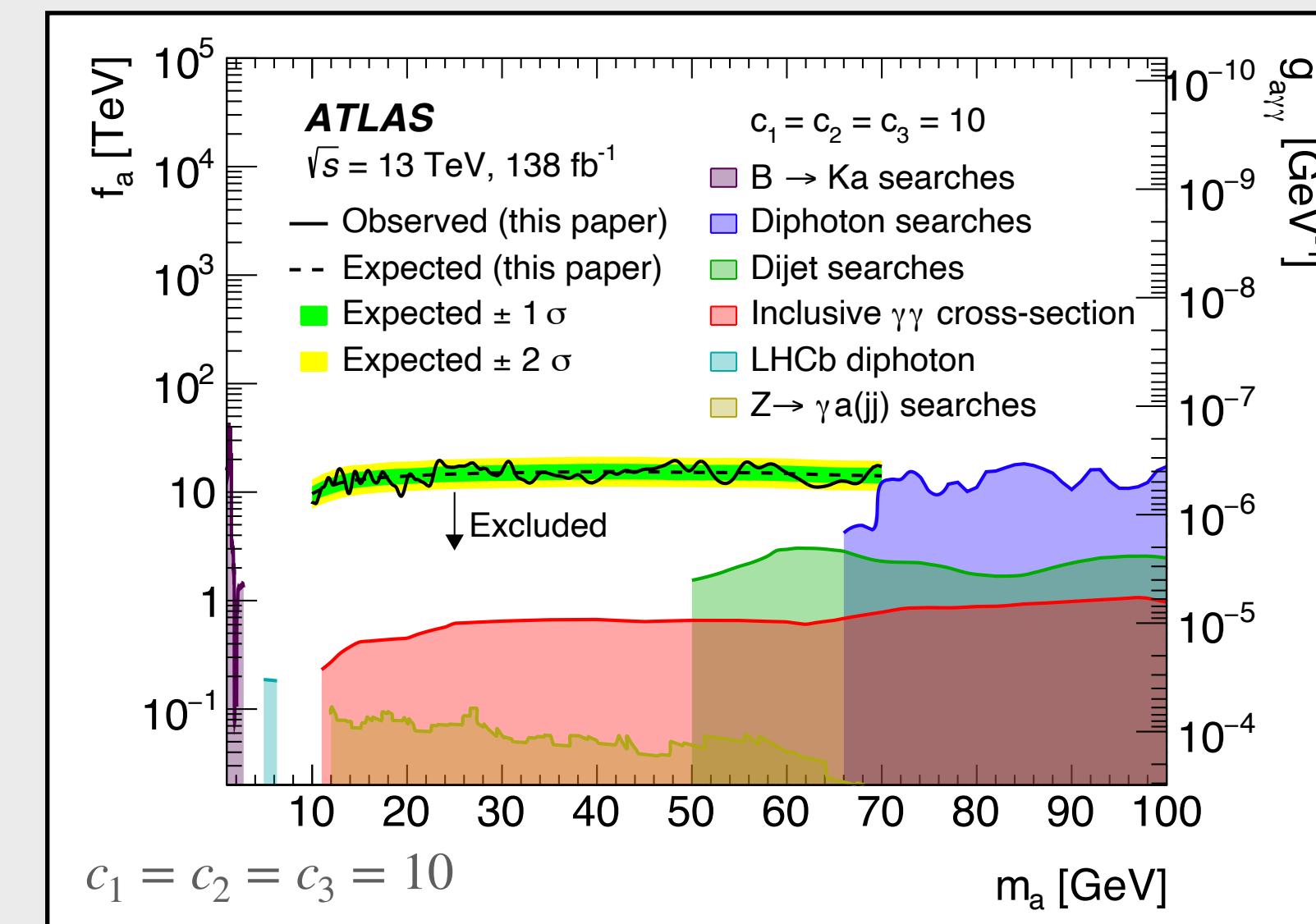
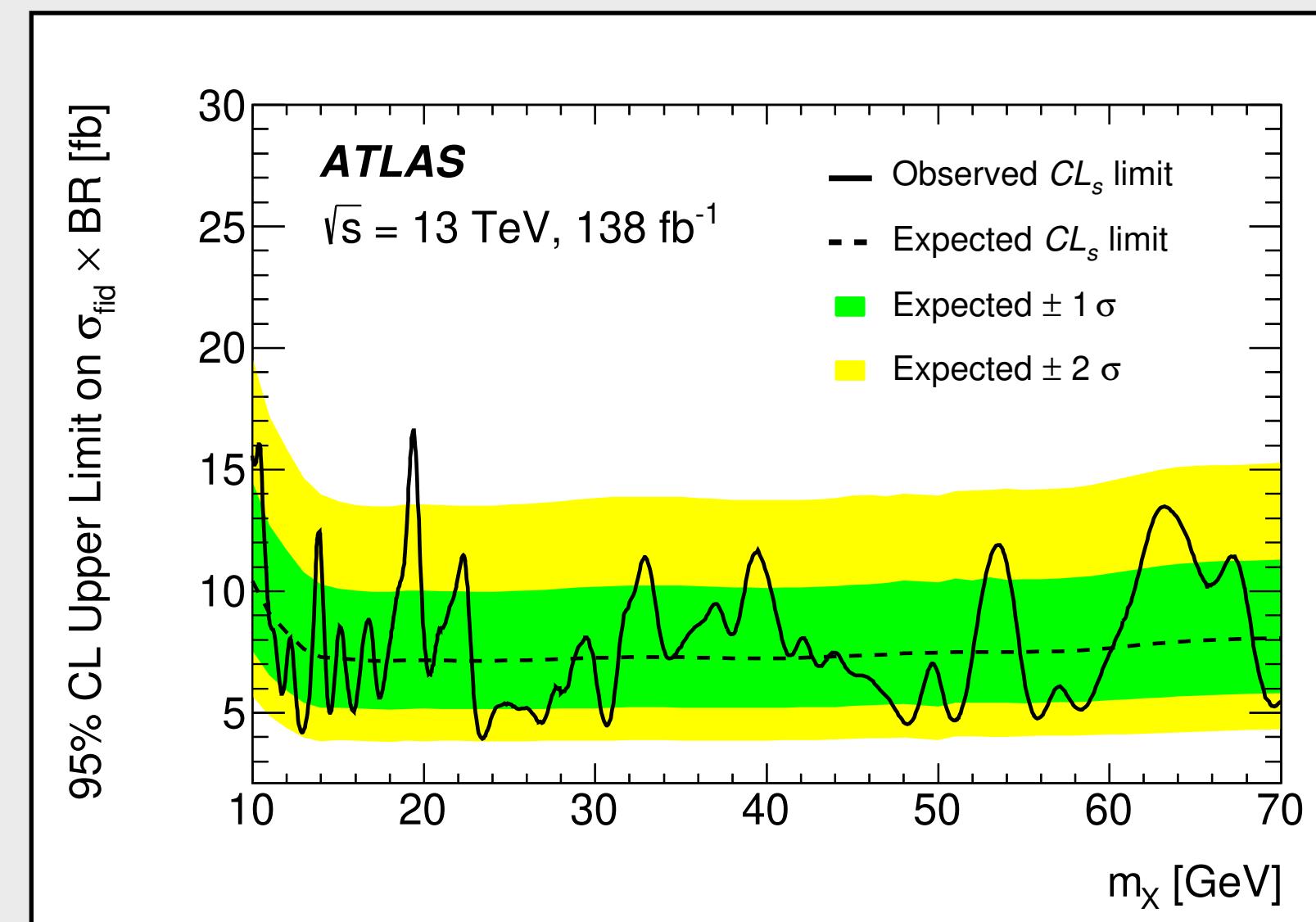
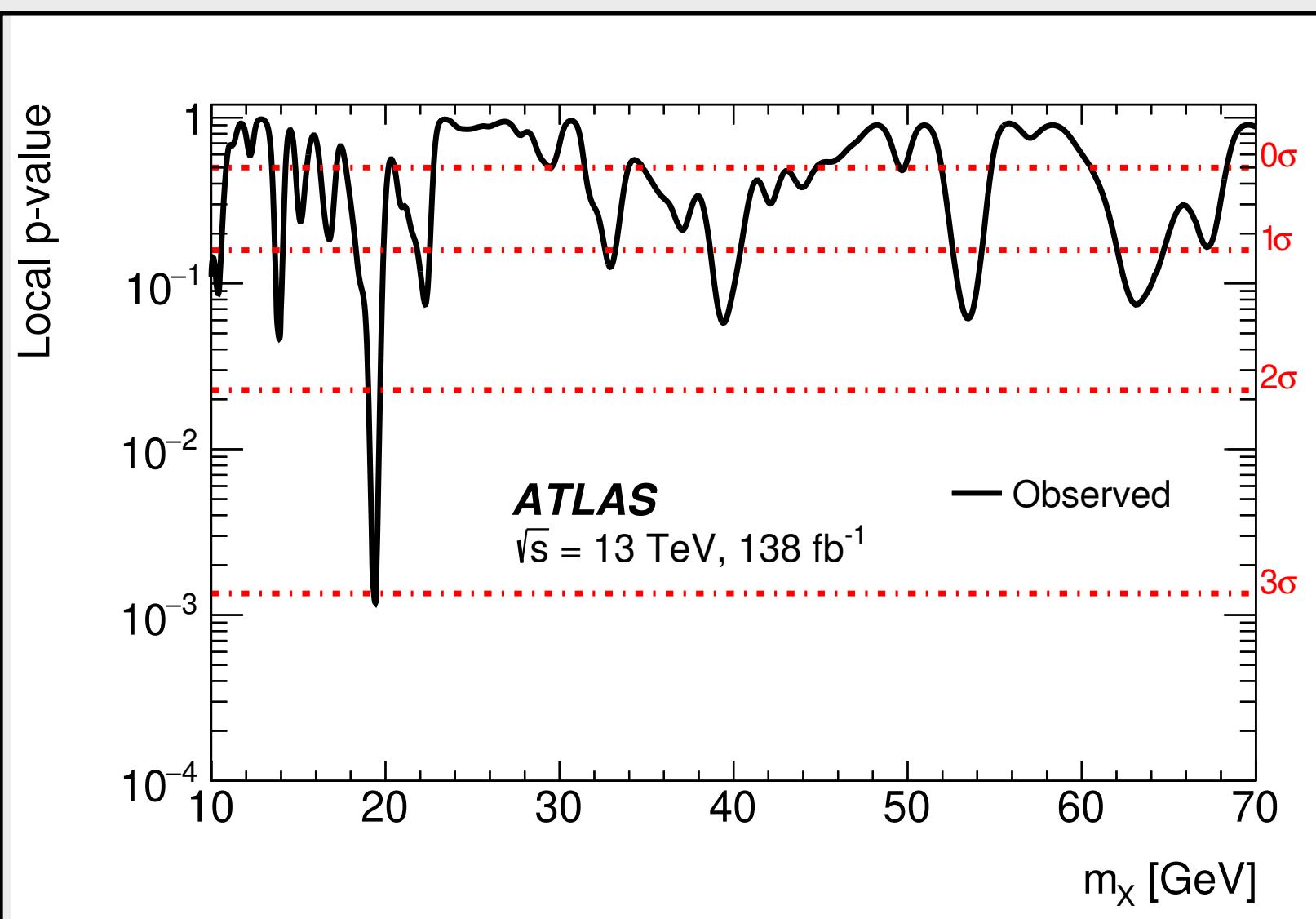
- **Diphoton invariant mass** is used as the discriminating variable, with the parameter of interest extracted from the data-driven fit being the fiducial cross-section times branching ratio  $\sigma_{fid.} \cdot \mathcal{B}(X \rightarrow \gamma\gamma)$ .
- Events with pairs of **closely spaced photons and large diphoton  $p_T^{\gamma\gamma}$**  ( $> 50$  GeV), typically arising from recoil against a jet, are selected. The  $p_T^{\gamma\gamma}$  threshold flattens the background shape, making it easier to describe with simple analytic functions.
- Main backgrounds: continuum  $\gamma\gamma$  production;  $\gamma j$  and  $jj$  events, where jets are misidentified as photons. Electrons faking photons are found to be negligible in the studied mass range.
- Gaussian processes are used to reduce the statistical fluctuations in the sample.



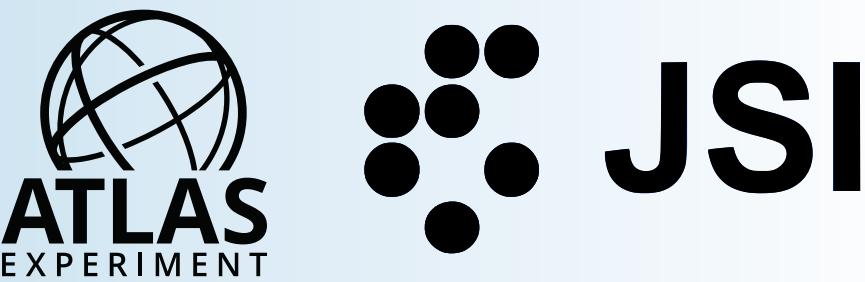
# Low mass $\gamma\gamma$ resonance - results



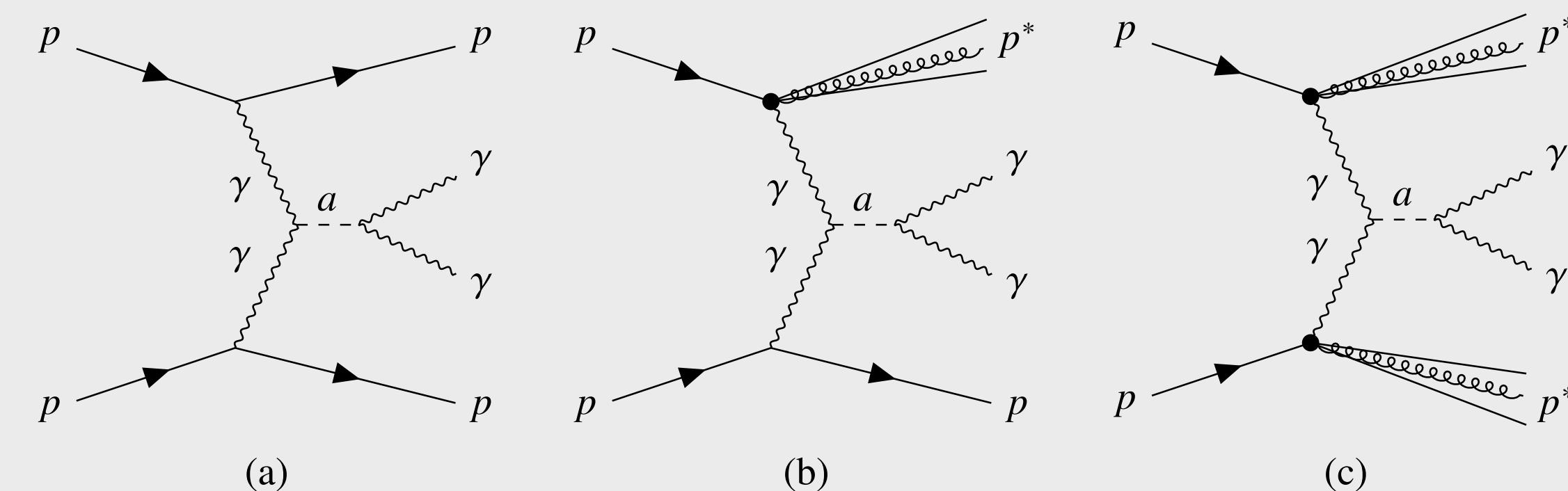
- $p$ -value scan: most significant **local** (**global**) deviation of  $3.1\sigma$  ( $1.5\sigma$ ) @  $m_X = 19.4$  GeV.
- The limits on  $\sigma_{fid} \cdot \mathcal{B}(X \rightarrow \gamma\gamma)$  range from 4 - 17 fb (variations due to statistical fluctuations).
- The observed limits are recast in the parameter space of an ALP (KSVZ-ALP) and provide the **strongest bound** on promptly decaying ALPs that couple to gluons and photons in this mass range.



# Diphoton resonance - motivation



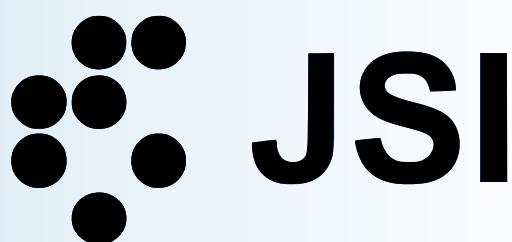
- Search for a narrow resonance in the diphoton mass distribution, corresponding to an ALP in the 150 - 1600 GeV mass range. Nicely complements “older” ATLAS  $X \rightarrow \gamma\gamma$  high mass search [[arXiv:2102.13405](https://arxiv.org/abs/2102.13405)].
- Studied process was light-by-light scattering,  $pp \rightarrow p(\gamma\gamma \rightarrow \gamma\gamma)p^{(*)}$ , with total 441 candidate signal events selected. Data recorded in 2017 was used, corresponding to an integrated luminosity of  $14.6 \text{ fb}^{-1}$ .



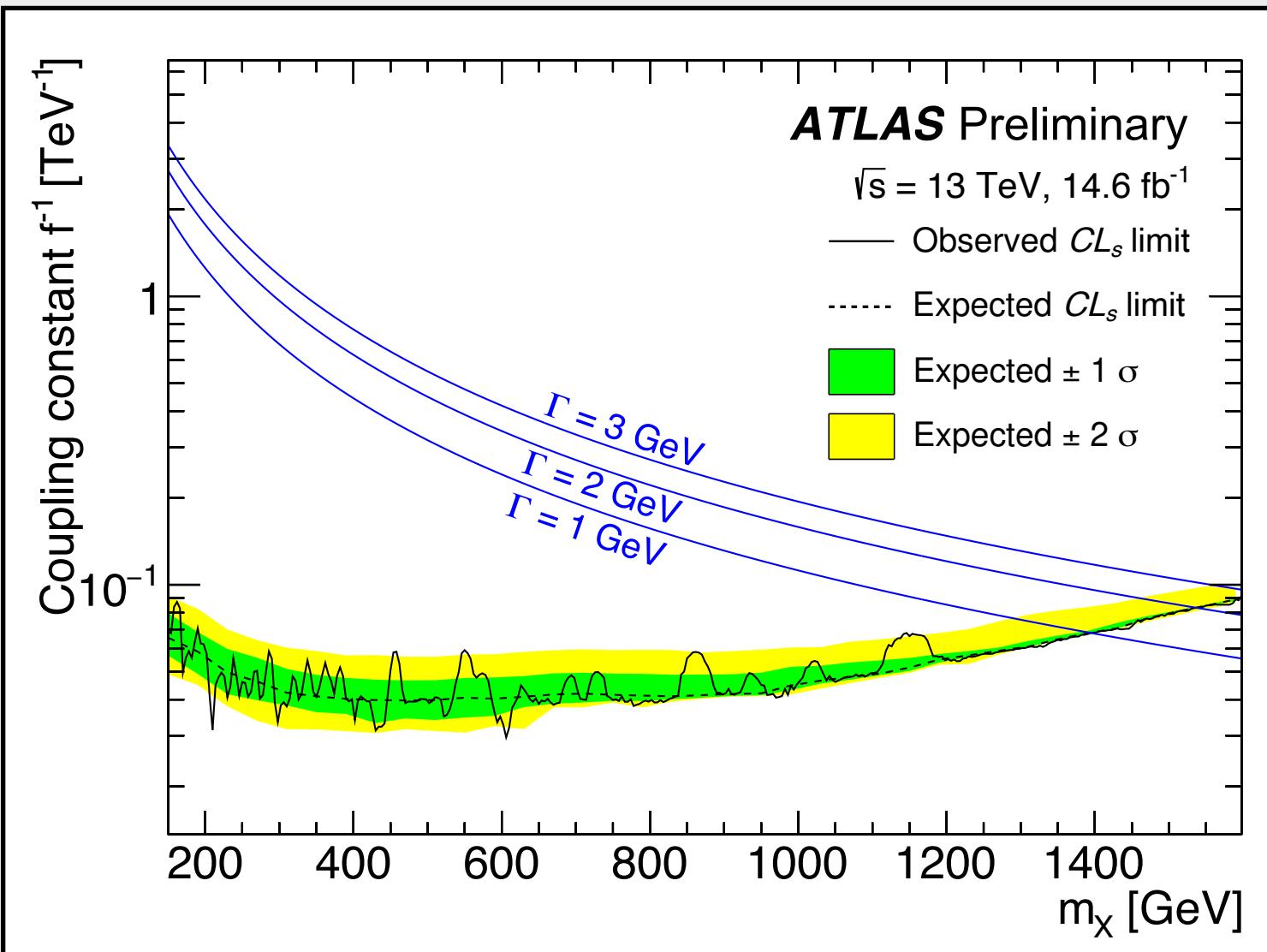
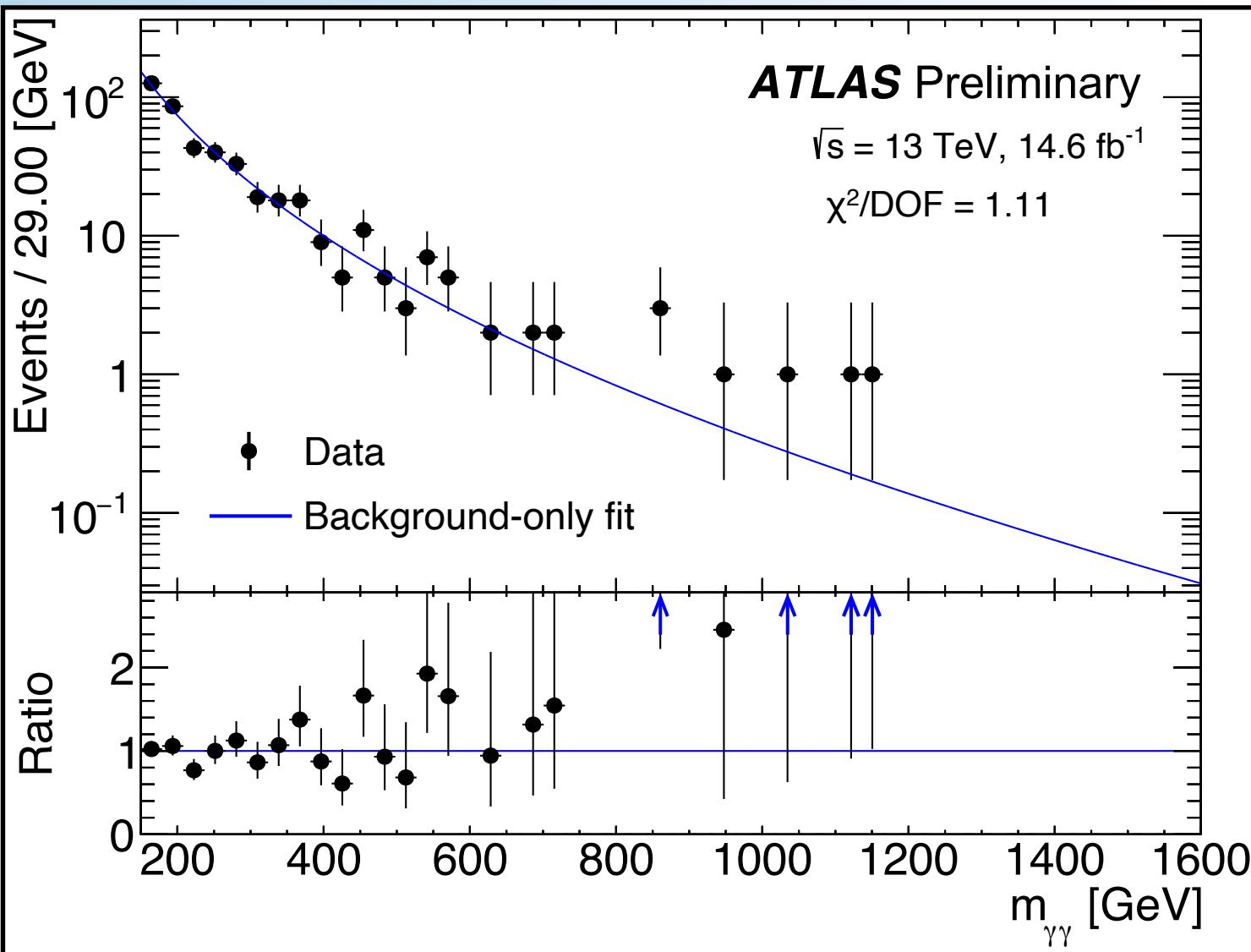
- a) exclusive light-by-light scattering,
  - b) single-dissociative (SD) light-by-light scattering,
  - c) double-dissociative (DD) light-by-light scattering.
- NOTE: outgoing photon pairs are mediated by an ALP denoted by a.

- **ATLAS Forward Proton spectrometer** (AFP) was used to detect **scattered protons** (referred to as proton tagging, which reduces background) and **ATLAS detector** to detect pairs of **outgoing photons**.

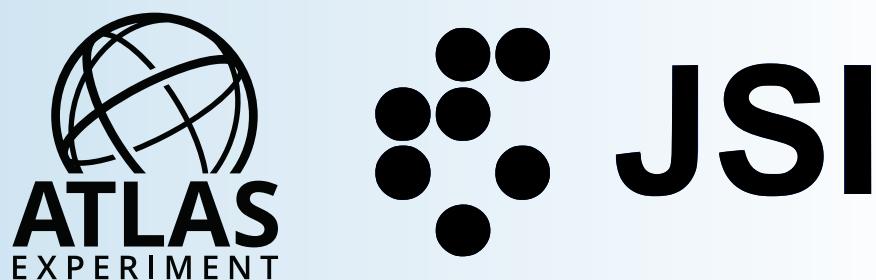
# Diphoton resonance - results



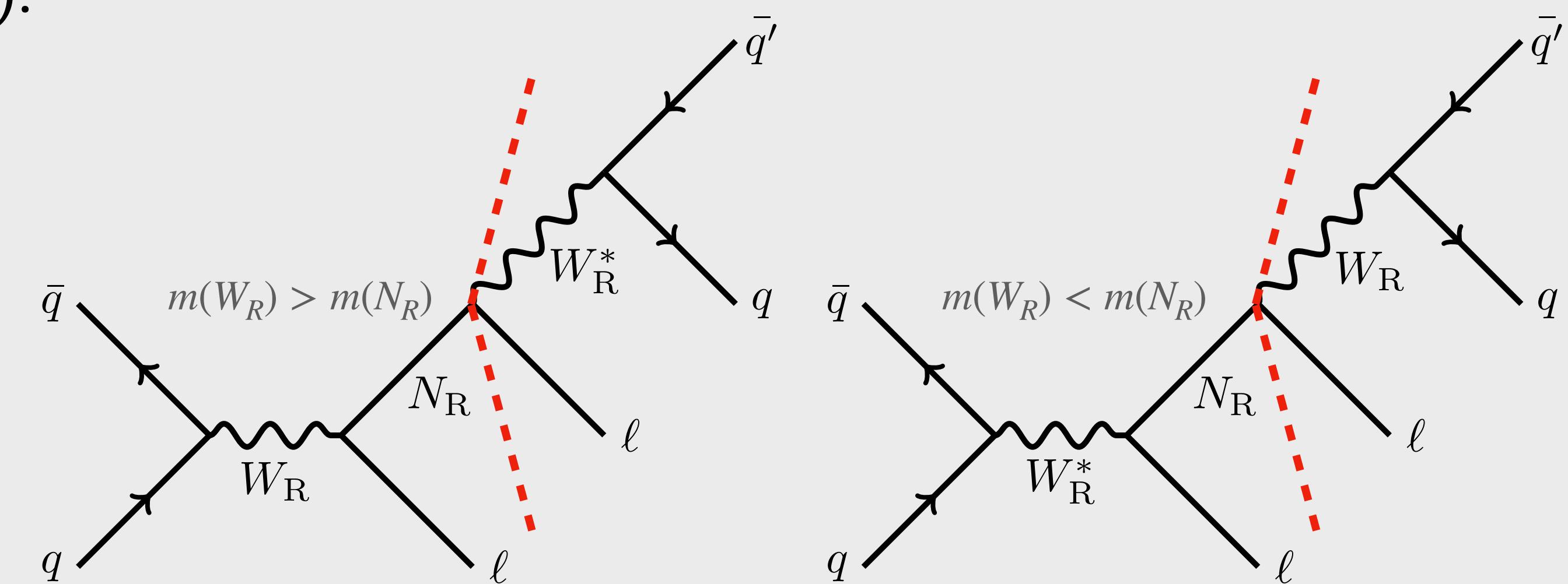
- Main backgrounds:
  - **Combinatorial:**  $\gamma\gamma$  is produced in a different  $pp$  interaction within the same bunch crossing → modelled using data-driven methods.
  - **Single-vertex:**  $\gamma\gamma \rightarrow \ell^+\ell^-$ ,  $\gamma\gamma \rightarrow \gamma\gamma$  (SM), gluon-initiated central exclusive productions were investigated using dedicated MC samples and were found to be negligible.
- No significant excess over SM prediction observed.
- Upper limits on the production cross-section of a narrow resonance are set, which are interpreted as upper limits on the ALP production coupling constant, assuming 100% decay branching ratio into two photons:  
**in the range  $0.04 - 0.09 \text{ TeV}^{-1}$  @ 95% CL**



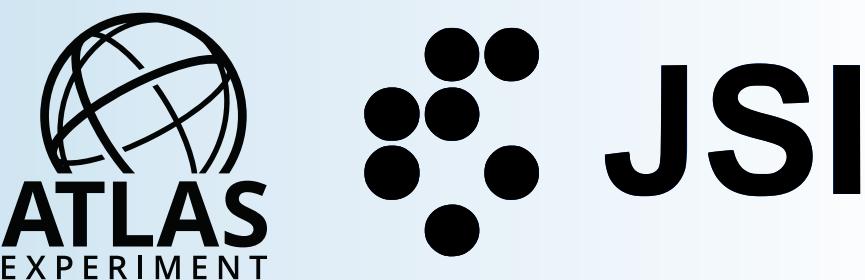
# LRSM heavy neutrino - motivation



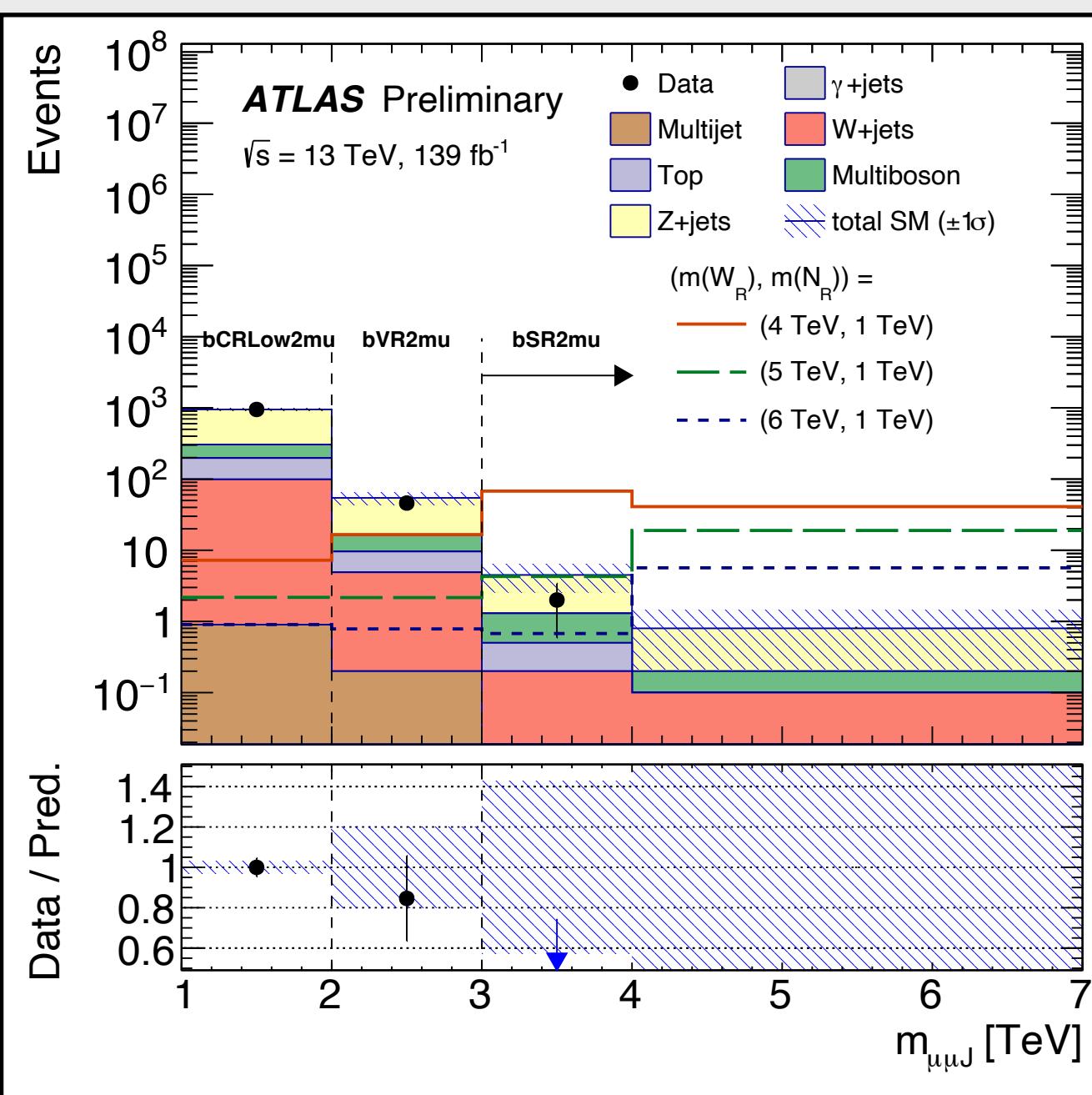
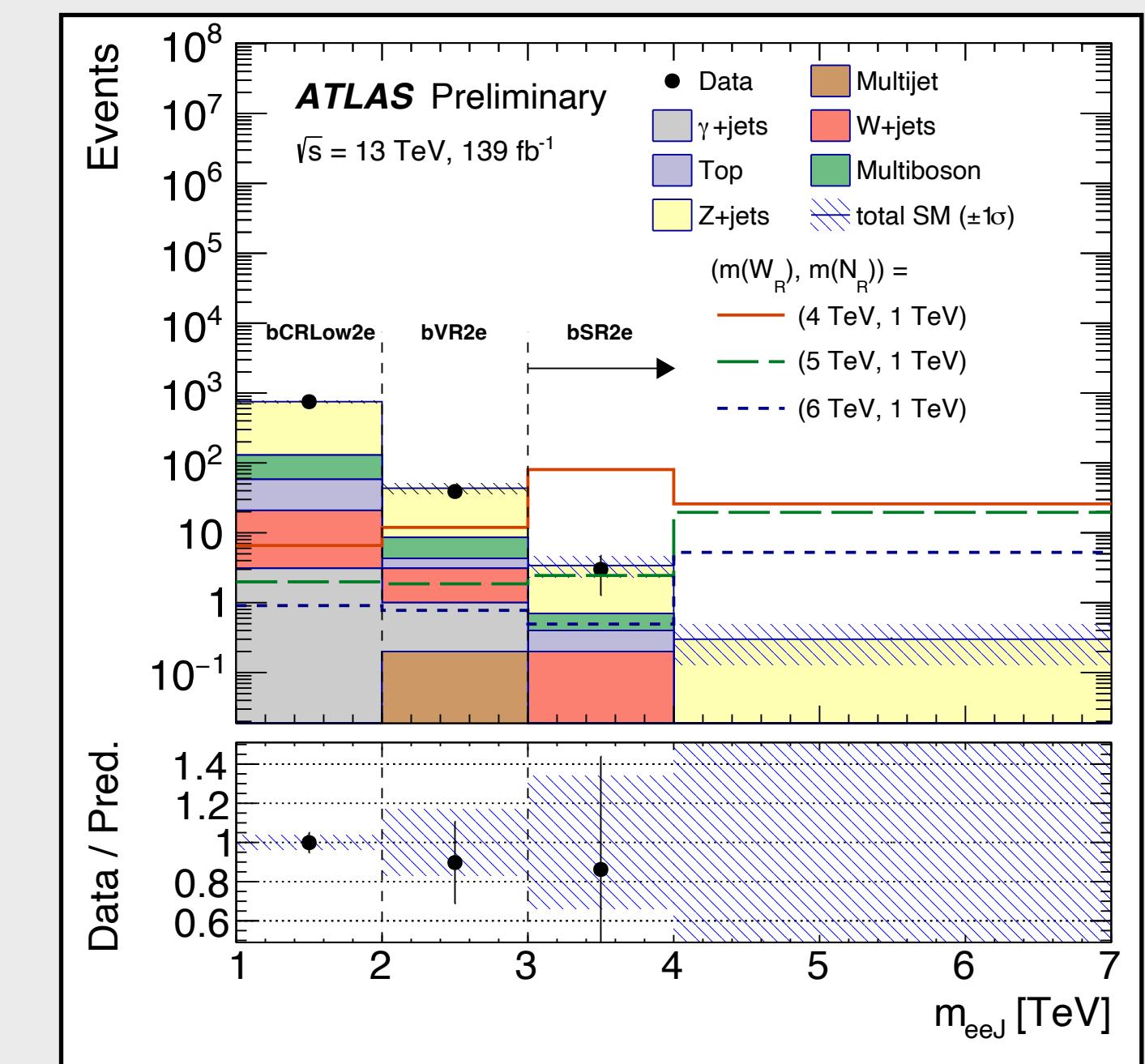
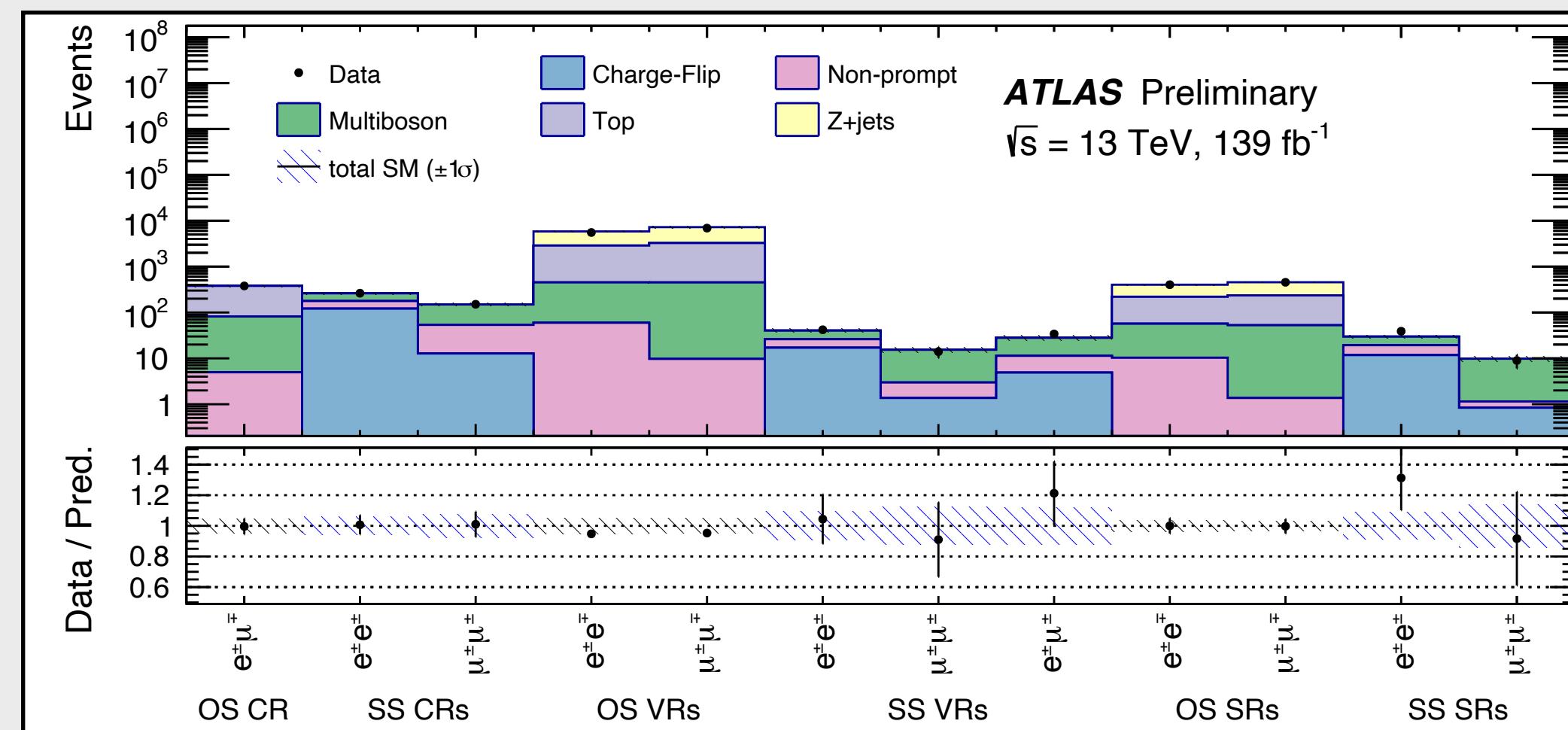
- Search for  $W_R$  bosons decaying to  $N_R$  and a charged lepton ( $\ell^\pm = e^\pm, \mu^\pm$ ) in a Keung-Senjanović (KS) process within the Left-Right Symmetric Model (LRSM).
- Two event topologies were studied:
  - **resolved channel:** two quarks are clearly separated and are reconstructed as two separate jets.
  - **boosted channel:** particles from the  $N_R$  decay are merged due to the Lorentz boost - single large-radius jet ( $m(W_R) \gg m(N_R)$  regime).
- The charge of the final state leptons is a key feature of the analysis, as it determines the Dirac or Majorana nature of  $N_R$ .



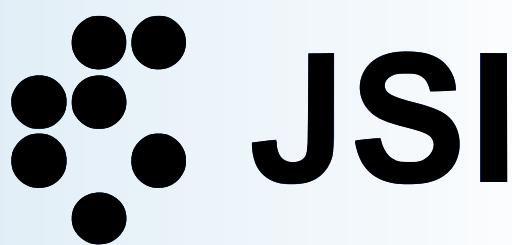
# LRSM heavy neutrino - strategy



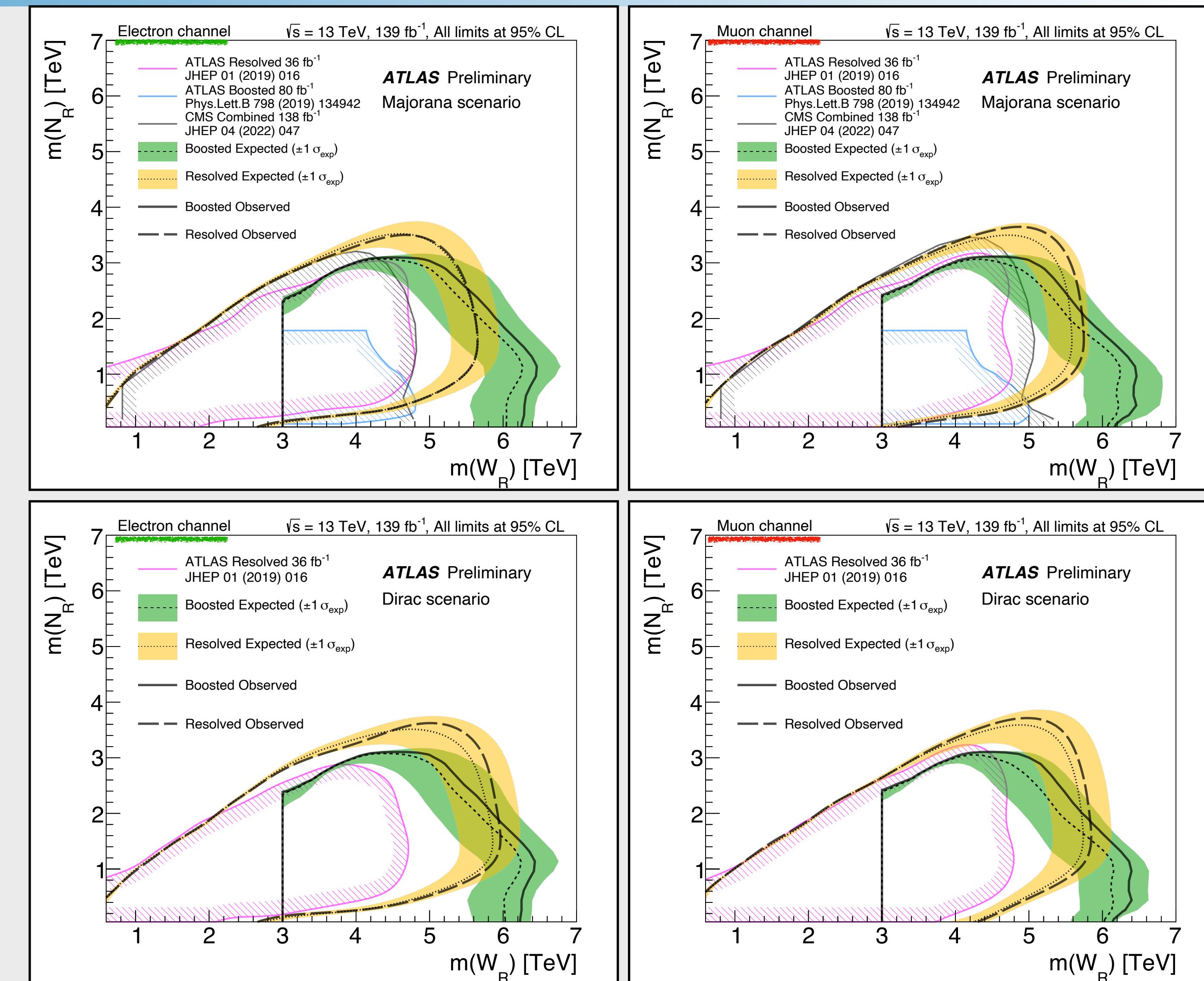
- If Majorana  $N_R$ : the final state appears with two **same-sign charged leptons** 50% of the time, violating the lepton number conservation.
- Main backgrounds estimated with semi data-driven approach normalising MC in dedicated control regions:
  - **resolved channel:**  $t\bar{t}$ ,  $Z+jets$ , diboson (OS); diboson, non prompt + charge mis-ID (SS)
  - **boosted channel:**  $Z+jets$ ,  $W+jets$ ,  $\gamma+jets$ .



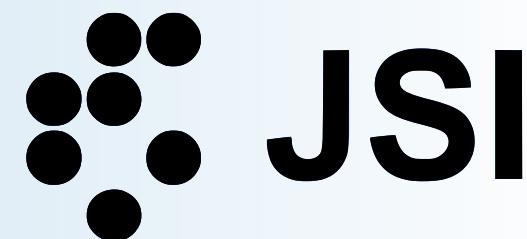
# LRSM heavy neutrino - results



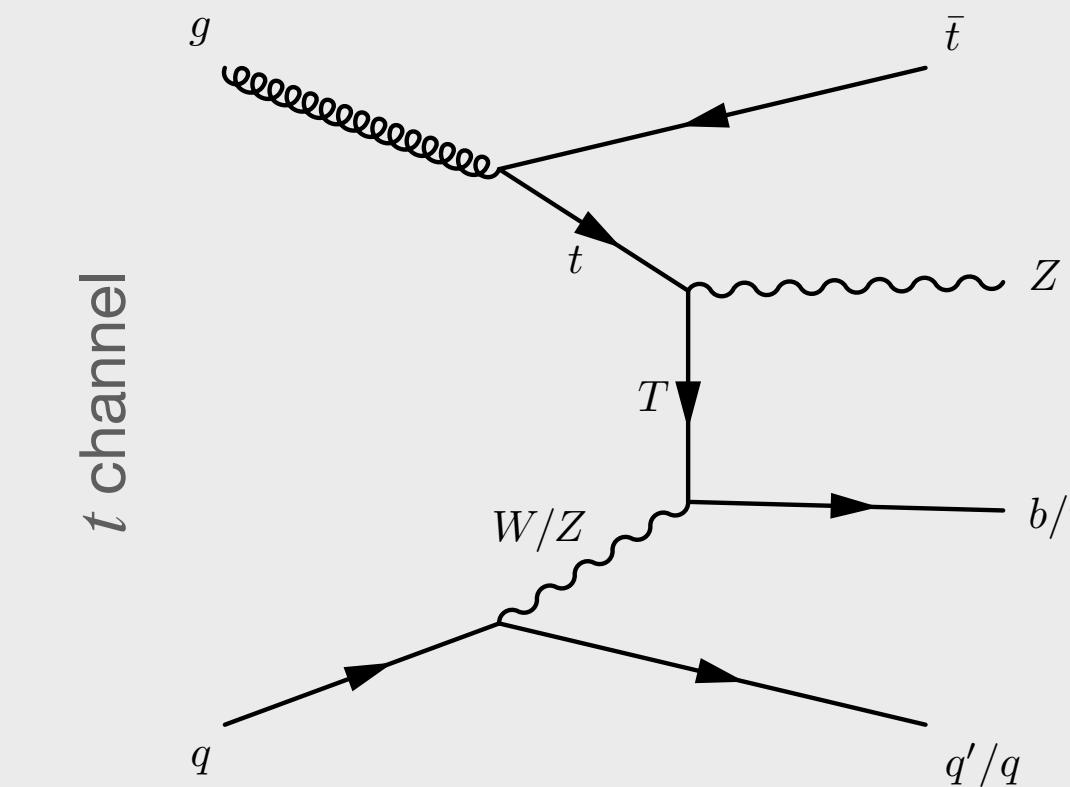
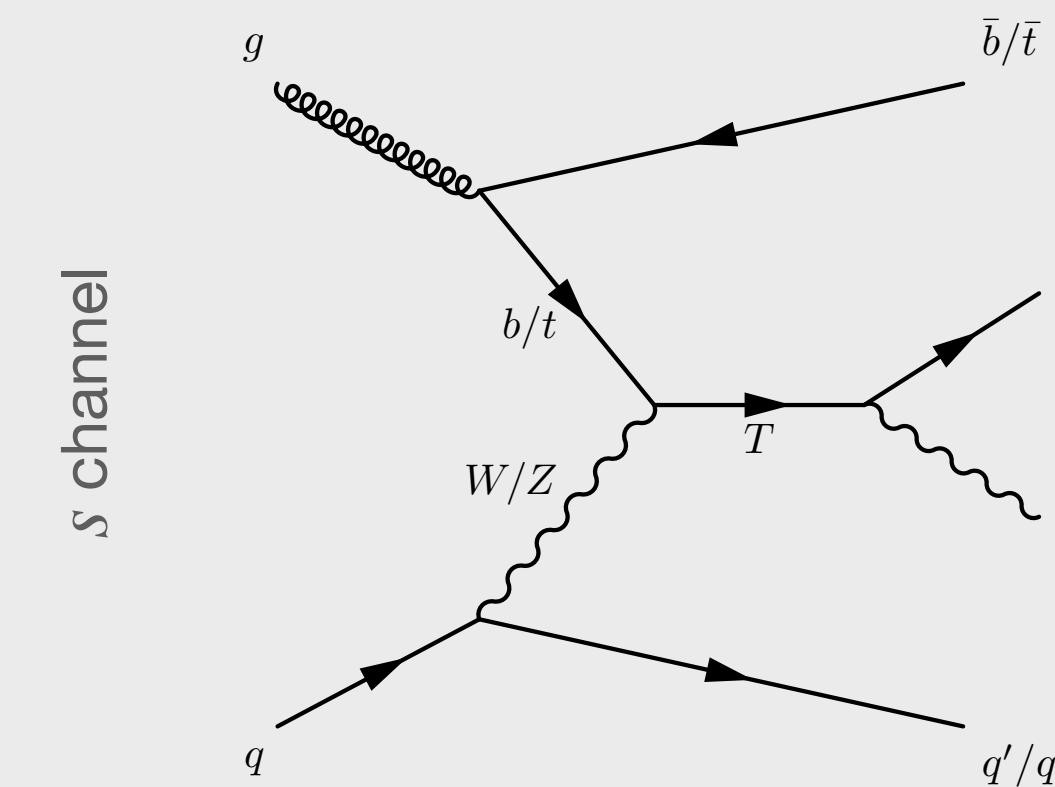
- **No evidence** of  $W_R$  bosons or Majorana or Dirac heavy neutrinos is found, assuming the KS process.
- **Most stringent limits** to date are set for the KS process, assuming  $g_L = g_R$ :
  - Majorana case:
    - up to 6.4 (5.6) TeV in boosted (resolved) channel on  $m(W_R)$  @  $m(N_R) \sim 1$  TeV,
    - up to 3.0 (3.6) TeV in boosted (resolved) channel on  $m(N_R)$  @  $m(W_R) \sim 4.8$  TeV.
  - Dirac case:
    - up to 6.4 (5.6) TeV in boosted (resolved) channel on  $m(W_R)$  @  $m(N_R) \sim 1$  TeV,
    - up to 3.0 (3.6) TeV in boosted (resolved) channel on  $m(N_R)$  @  $m(W_R) \sim 5$  TeV.



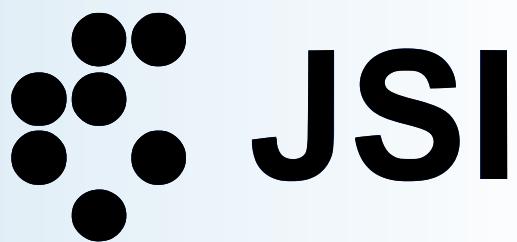
# Vector-like top partners - motivation



- Search for the single production of vector-like top partners ( $T$ ), with final state containing an **opposite-charge pair of electrons or muons** (forming a  $Z$  boson candidate) and a **b-tagged / forward jets**.
- Vector-Like Quarks (VLQs) can occur as singlets, doublets or triplets and usually couple to SM quarks - predominantly with the third generation - via an exchange of charged ( $W^\pm$ ) or neutral ( $Z, H$ ) bosons.
- **Single production** of VLQs, unlike pair production, can have a **larger cross-section at high masses** and is dominated by electroweak processes.

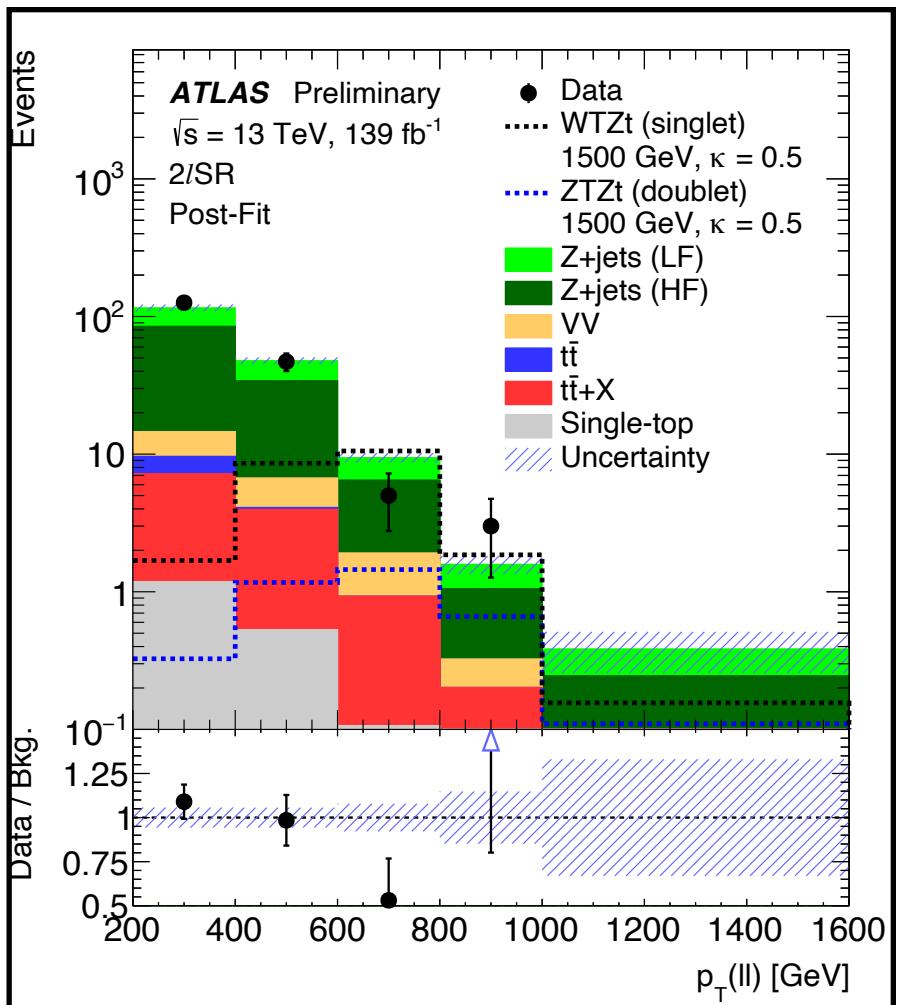
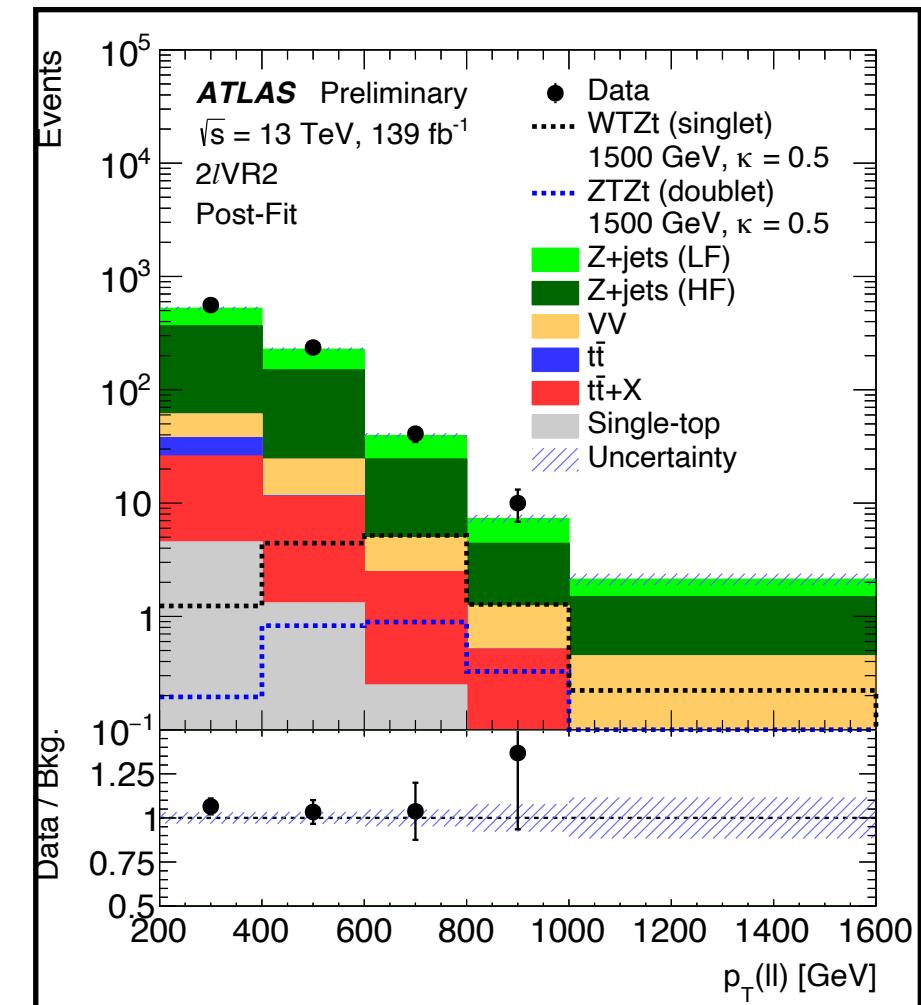
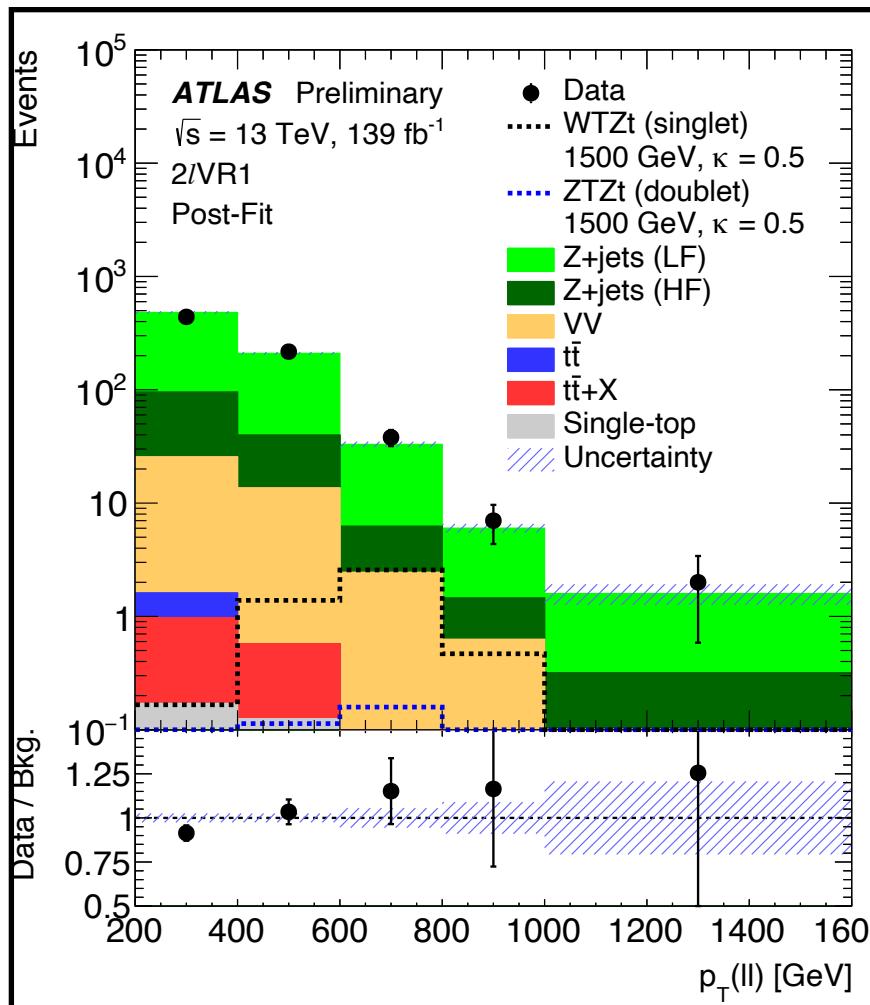


# Vector-like top partners - strategy



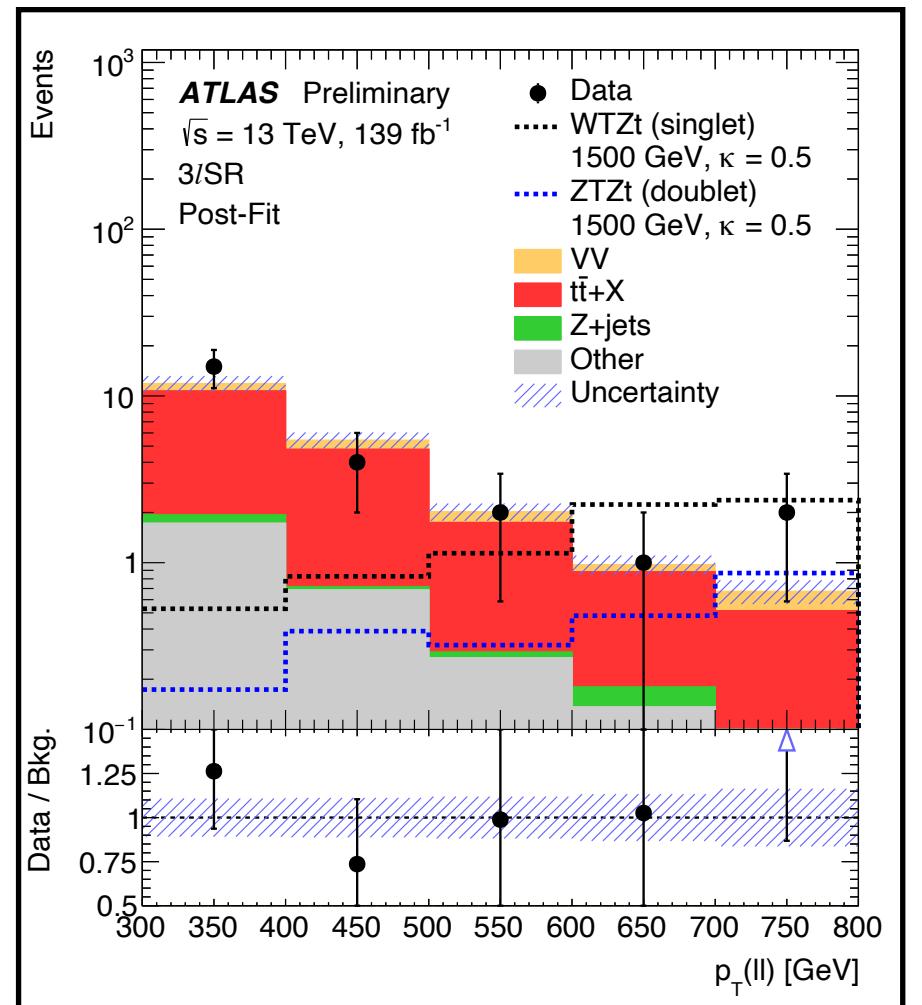
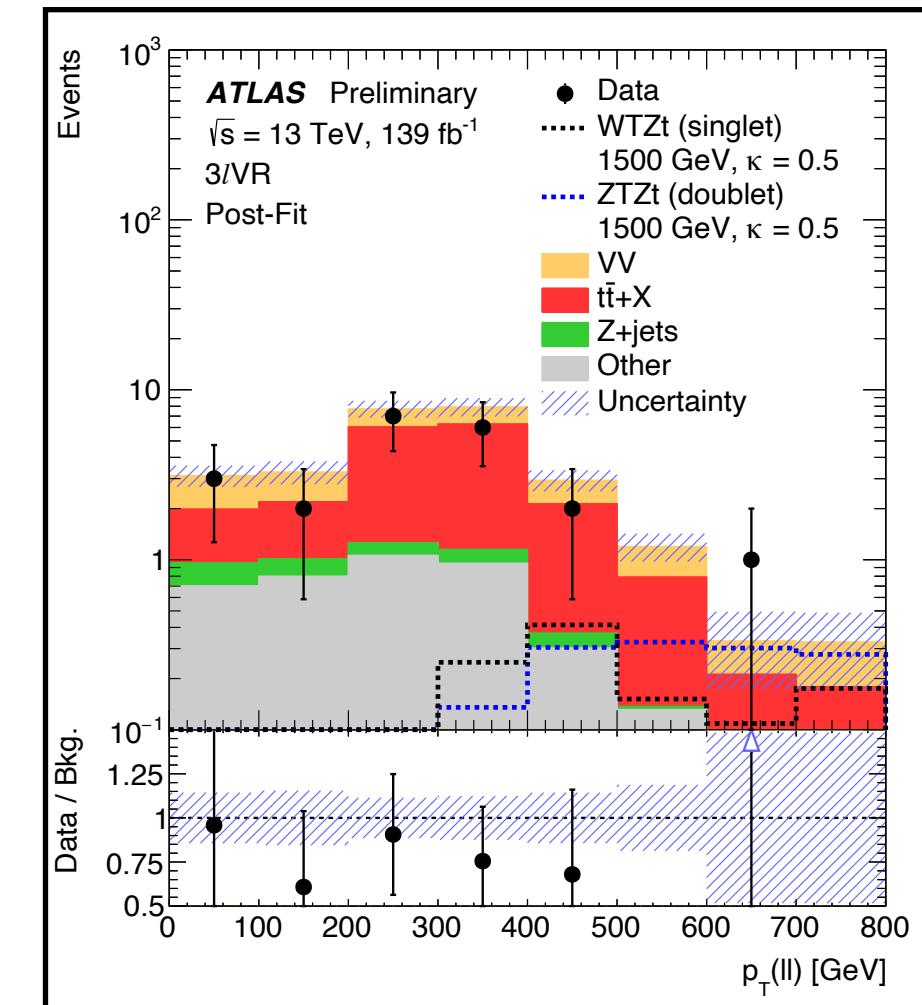
## Dilepton channel

- targeting events with exactly one pair of opposite-sign electrons or muons and a **hadronically decaying top quark**.
- Main backgrounds: **Z+jets**, **diboson**,  **$t\bar{t}$** ,  **$t\bar{t} + X$** .
- Discriminating variable:  $p_T(\ell^+\ell^-)_Z$ .

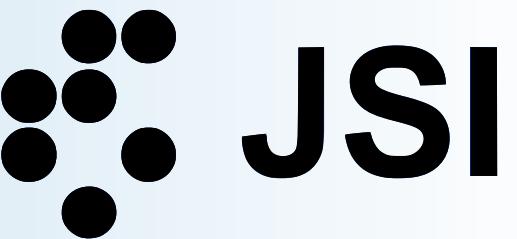


## Trilepton channel

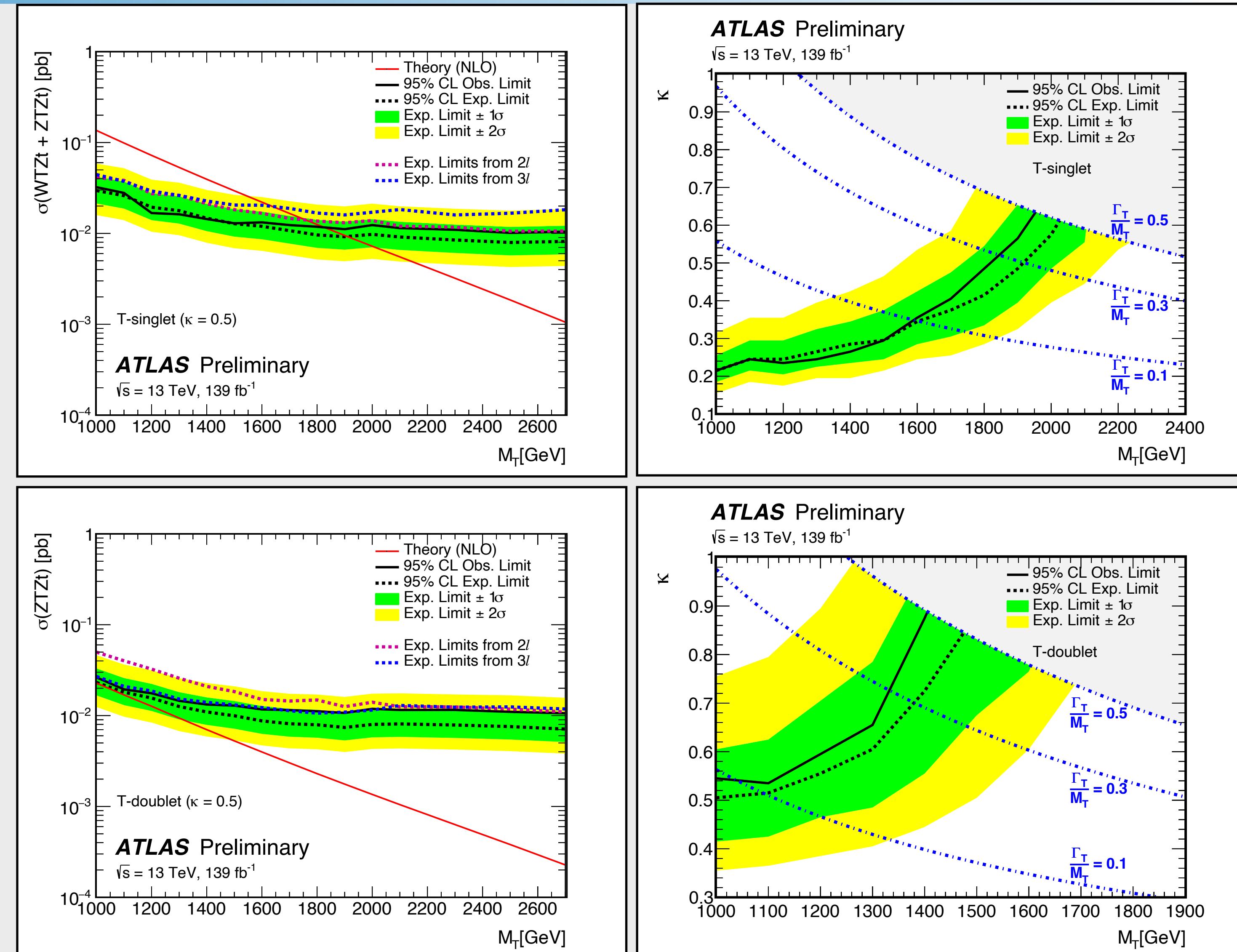
- in addition to the pair of opposite-sign electrons or muons, a third lepton from a **leptonically decaying top quark**.
- Main backgrounds: **diboson**,  **$t\bar{t} + X$** .
- Discriminating variable:  $p_T(\ell^+\ell^-)_Z$ .



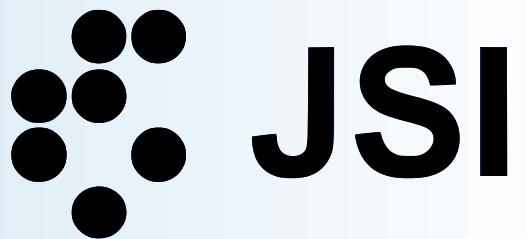
# Vector-like top partners - results



- No significant excess over the predicted background is observed.
- 95% CL limits on excluded masses and coupling strengths for two different EW representations are provided:
  - singlet:  $\kappa < 0.22$  ( $0.64$ ) for  $m(T) \sim 1000$  ( $1975$ ) GeV,
  - doublet:  $\kappa < 0.54$  ( $0.88$ ) for  $m(T) \sim 1000$  ( $1425$ ) GeV.



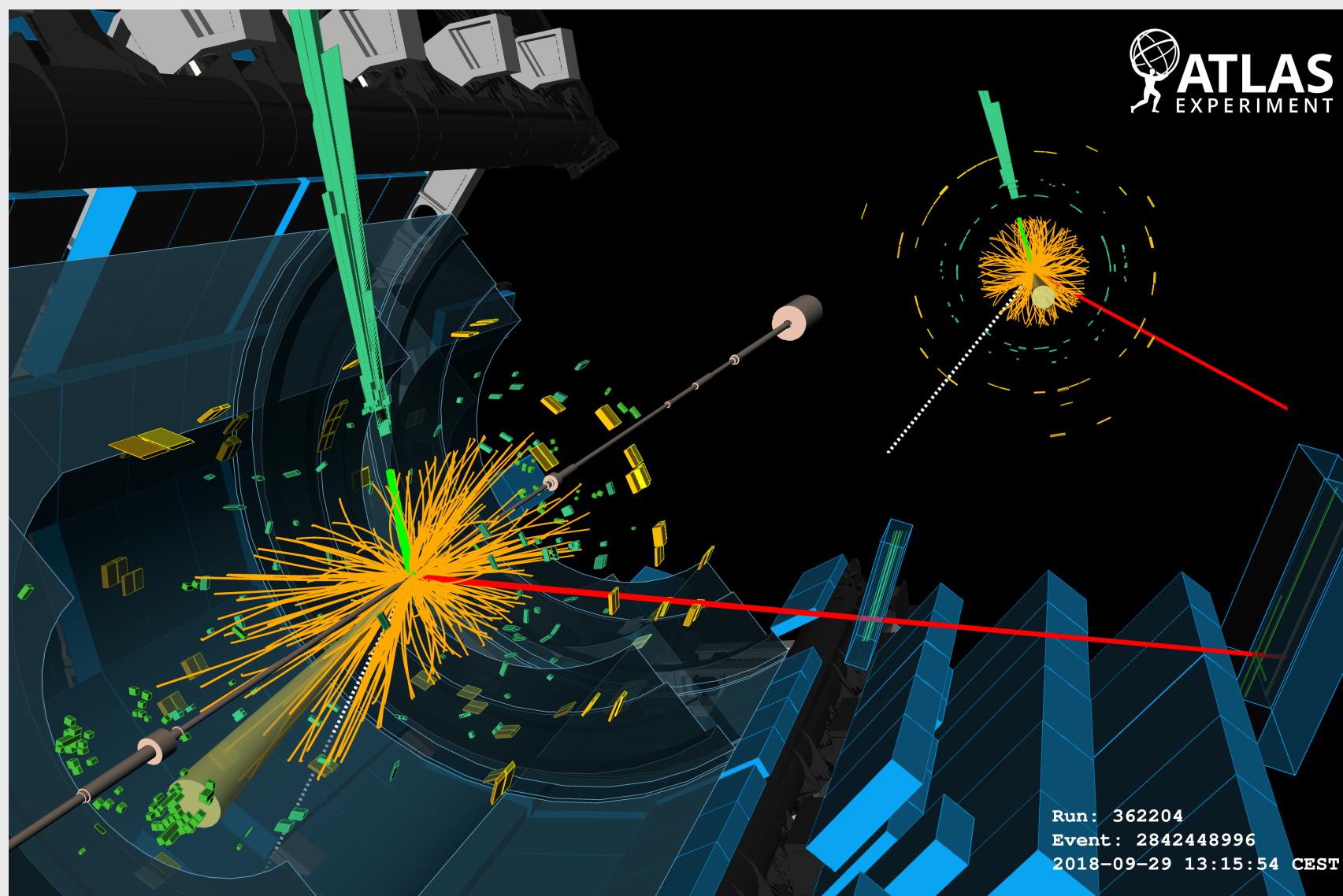
# Heavy resonances in $W^+W^- \rightarrow e\nu\mu\nu$



- A search for **neutral heavy resonances** ( $R$ ), decaying into two  $W$  bosons ( $WW \rightarrow e\nu\mu\nu$ ), produced through either gluon-gluon fusion (ggF), quark-antiquark annihilation (qqA), or vector-boson fusion (VBF).
- Results are obtained for, and compared to, the prediction of five different models:
  - **Scalar resonances:**
    - Higgs like narrow width scalar (NWA),
    - Higgs boson in the Georgi-Machacek model (GM),
    - radion particle from the bulk Randall-Sundrum model (Radion).
  - **Non-scalar resonances:**
    - spin-1 Heavy Vector Triplet (HVT),
    - spin-2 graviton.

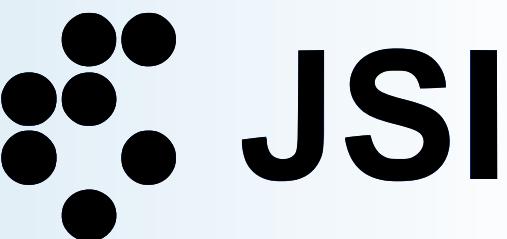
Model	Resonance spin	Production mode		
		ggF	qqA	VBF
NWA	Spin-0	x		x
GM			x	
Radion		x		x
HVT	Spin-1		x	x
RS $G_{KK}^*$	Spin-2	x		x

Summary of the different production modes for the signal models and resonances considered in the analysis.

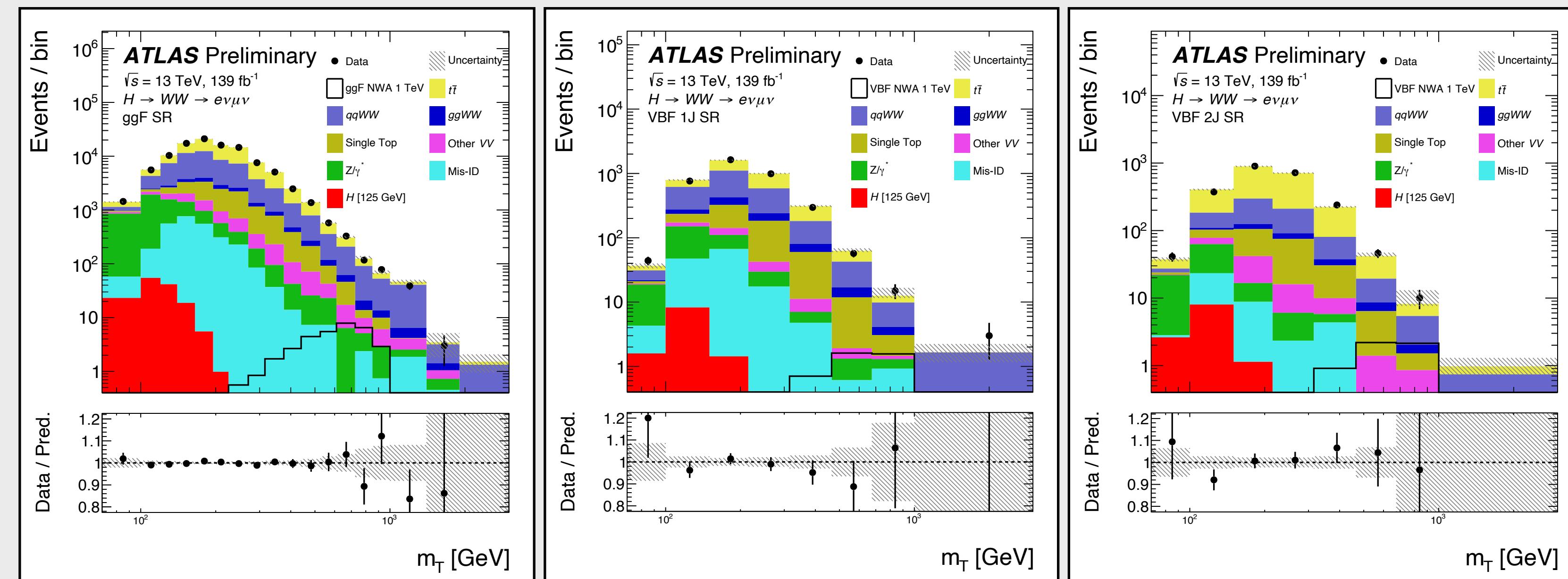


Production of a heavy neutral particle via VBF. Electron (green), muon (red), jet (yellow cone), large MET (dashed white) with one jet out of the detector acceptance.

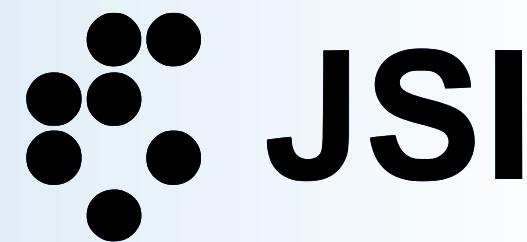
# Heavy resonances in $W^+W^- \rightarrow e\nu\mu\nu$



- Requiring two different flavour, opposite-sign leptons with each  $p_T^\ell > 25$  GeV.
- Discriminating variable is the transverse mass defined as  $m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\vec{p}_T^{\ell\ell} + \vec{E}_T^{miss}|^2}$ .
- Backgrounds considered:
  - major:** top quarks, non-resonant  $WW$  production (estimated using MC simulation + linear reweighting for  $t\bar{t}$ ),
  - minor:**  $W/Z+jets$ , multi-jets, diboson, SM Higgs.
- Data-driven estimation of non-prompt leptons for the  $W+jets$  and multi-jet backgrounds is performed.

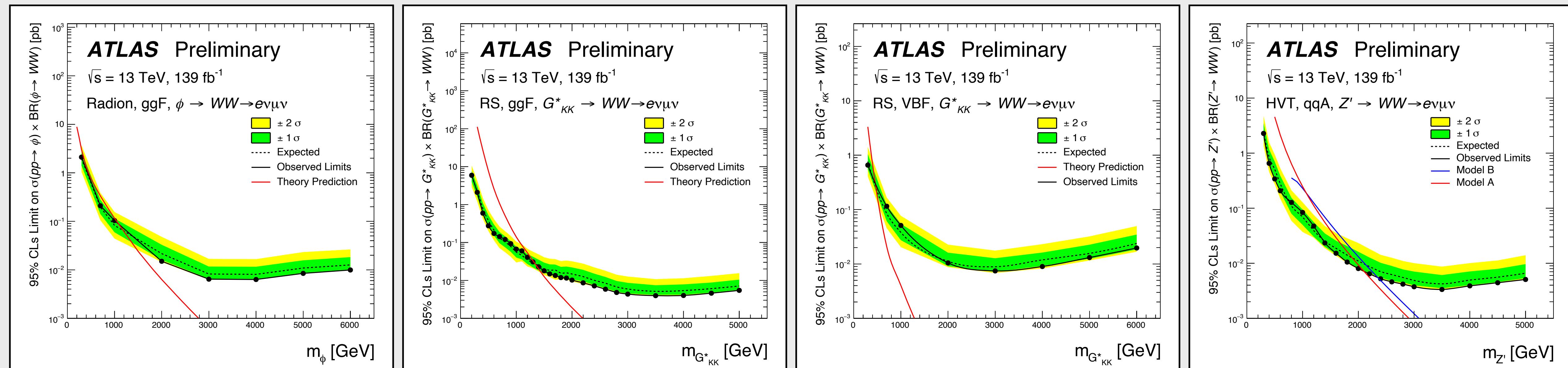


# Heavy resonances in $W^+W^- \rightarrow e\nu\mu\nu$

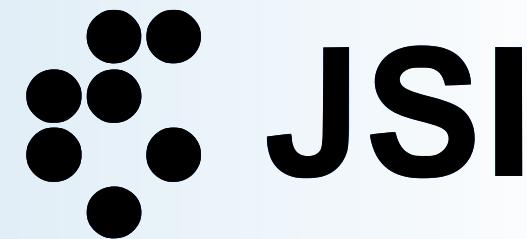


- **No significant excess** is found in the mass range between **200 GeV and 6 TeV**.
- A trend is seen in the higher mass limits where the **data has fewer events than expected**, leading to lower than expected limits.

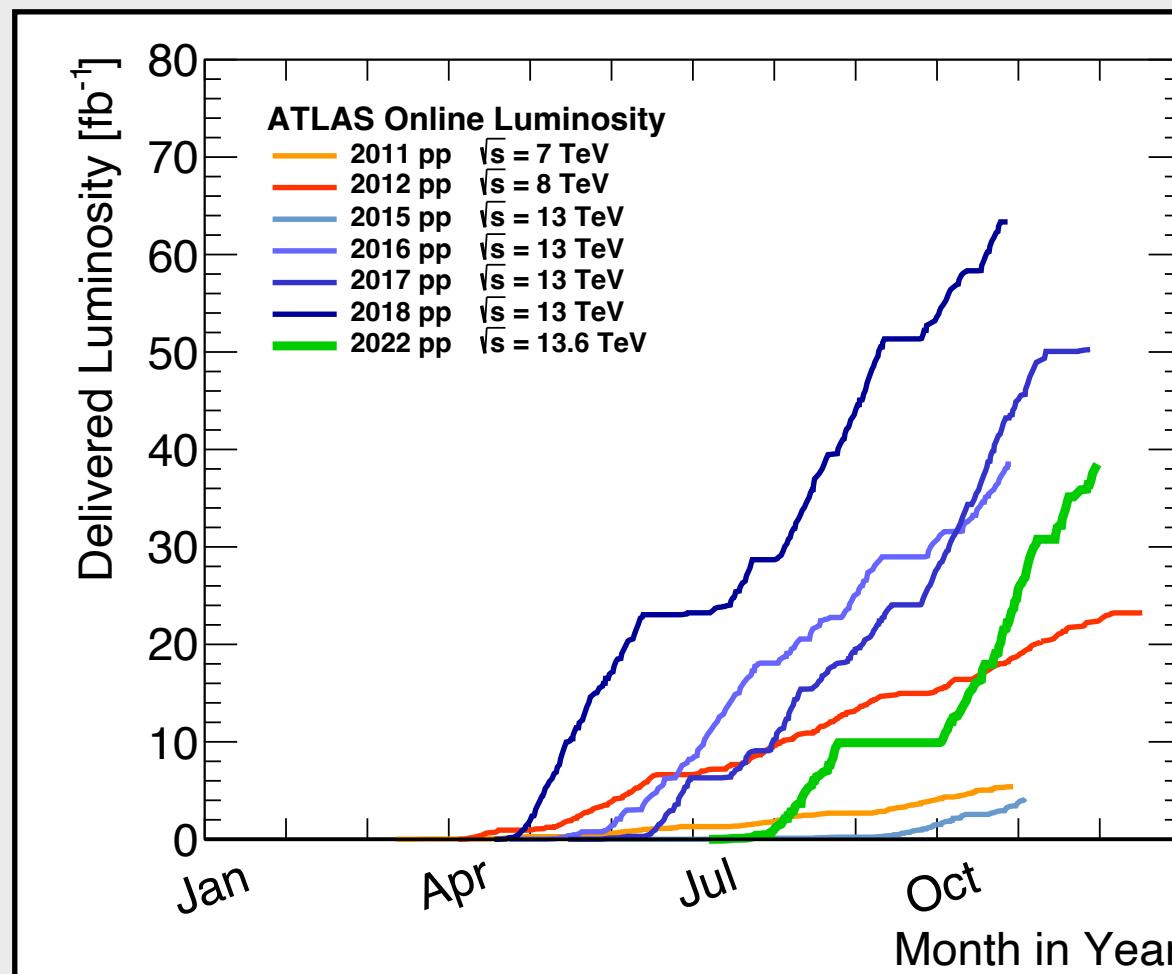
Model	Obs. limit [GeV]	Exp. limit [GeV]
Radion, ggF	1090	1190
Kaluza-Klein graviton, ggF	1340	1340
Kaluza-Klein graviton, VBF	500	500
HVT scenario A, qqA	2100	1890
HVT scenario B, qqA	2350	2130



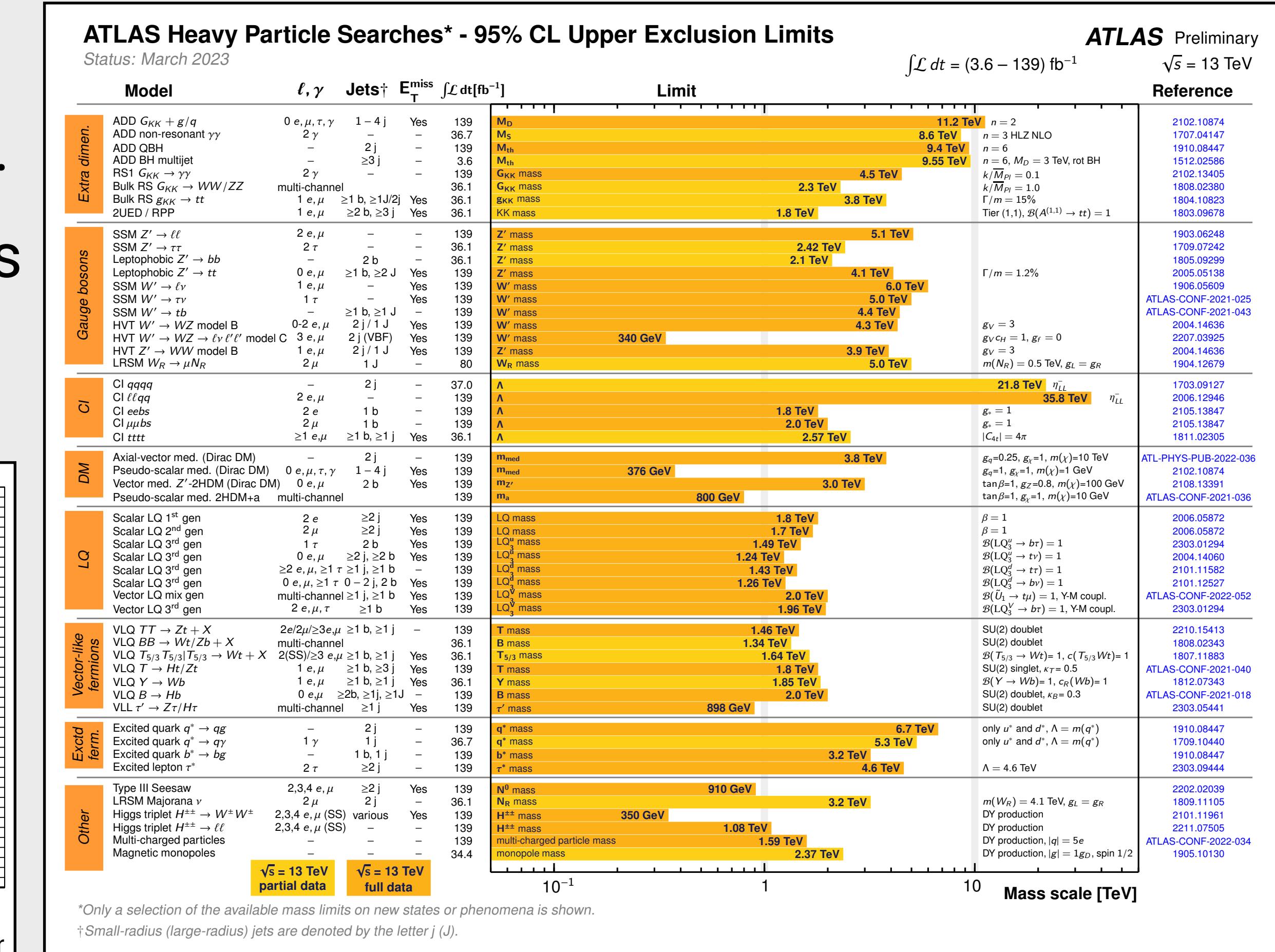
# Summary



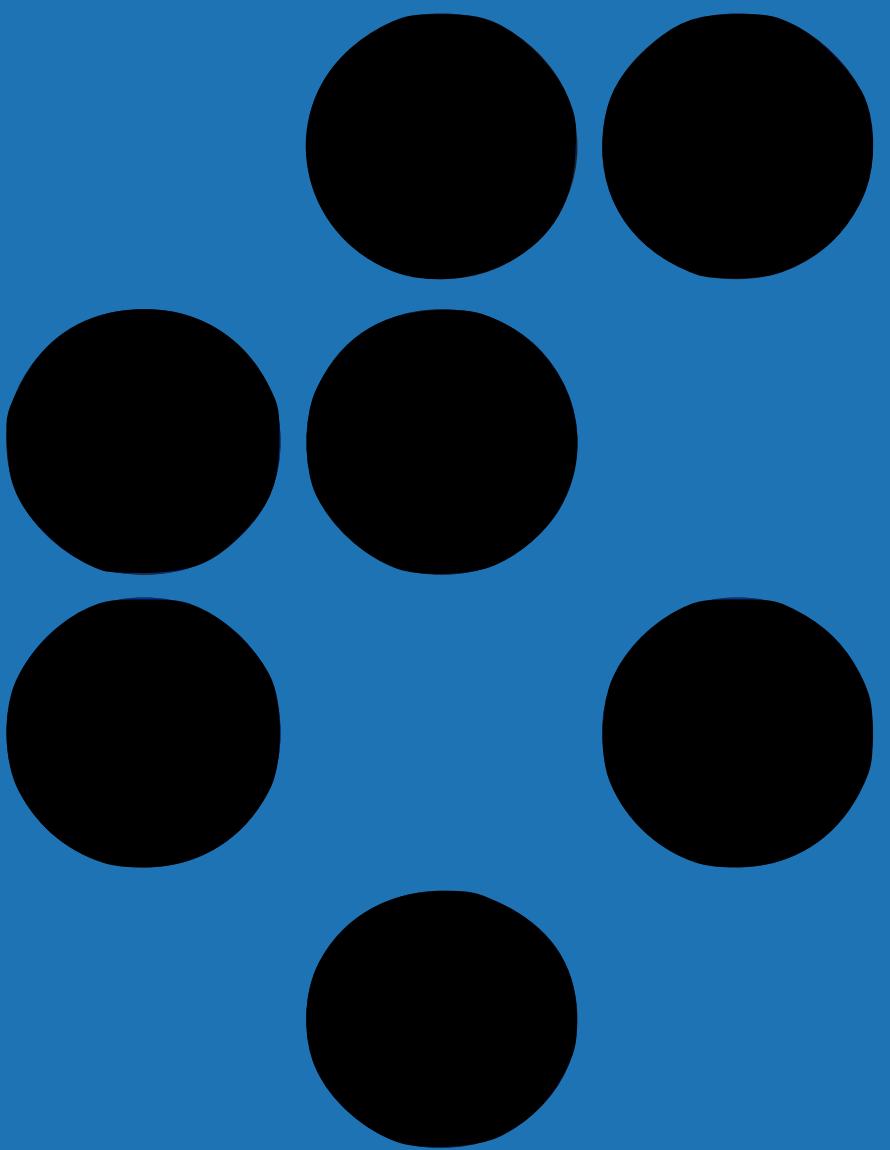
- ATLAS is searching for many final states which would arise from BSM resonances, but there is no evidence of new physics yet.
- The lower/upper limits are still improving as more and more data is available and new analysis techniques are developed.
- Cross sections for the studied models are so low that we need more luminosity.
- Stay tuned as Run 3 has just started!**



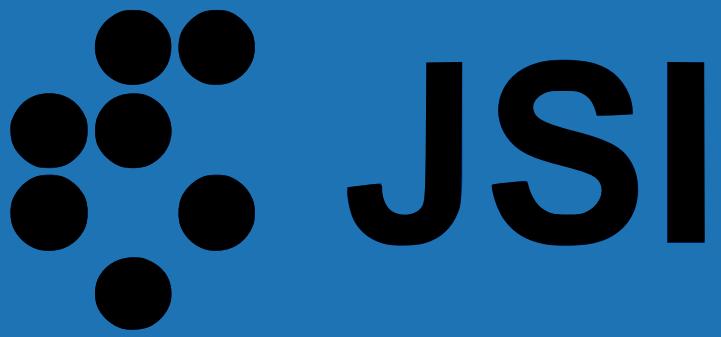
ATLAS integrated luminosity versus year.



Ranges of new particle masses or energy scales excluded at the 95% confidence level.

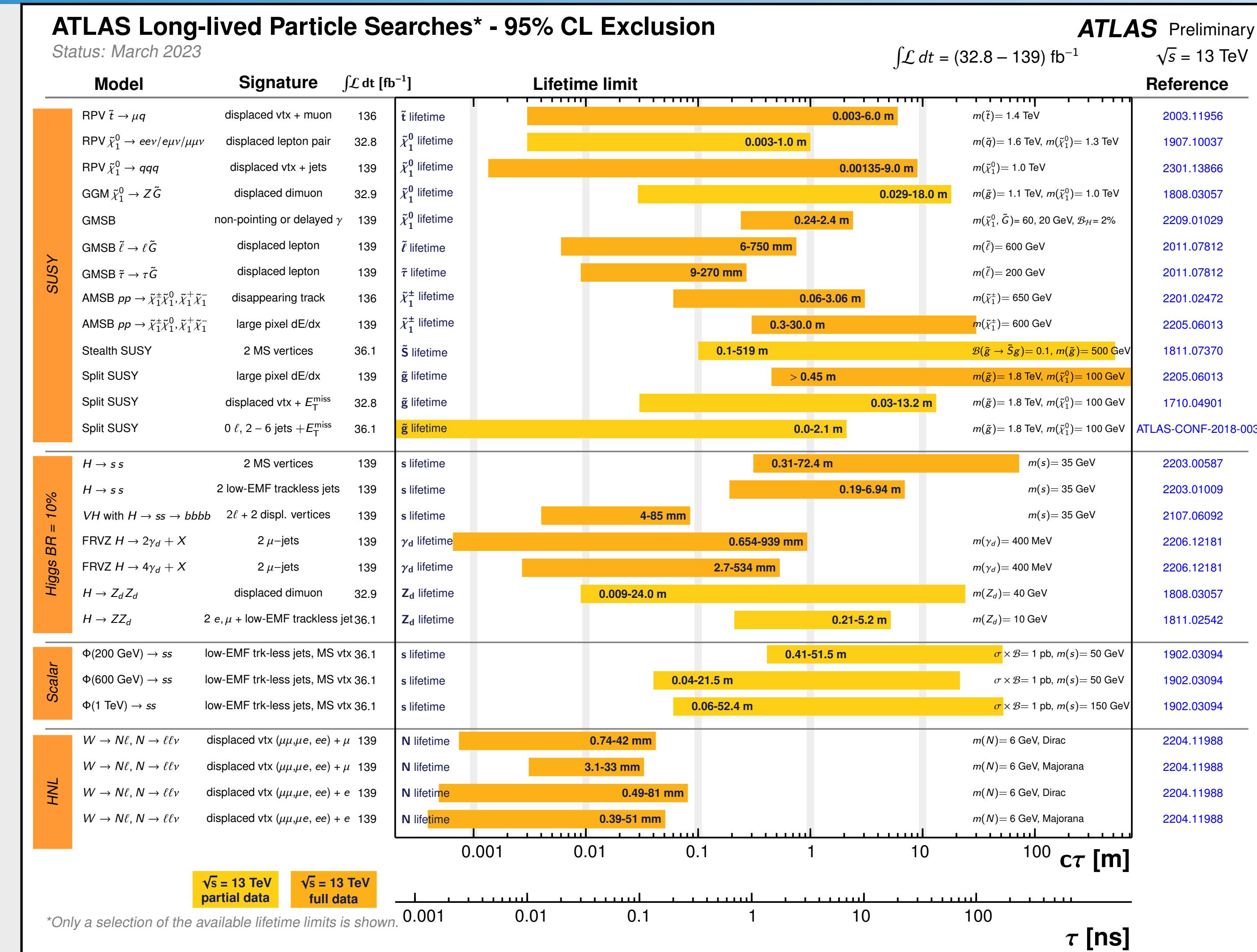
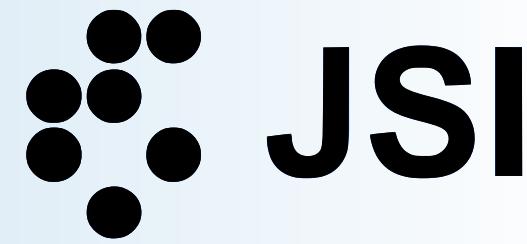


**JSI**



# ADDITIONAL MATERIAL

# Particle lifetimes summary plot



Ranges of new particle lifetimes excluded at the 95% confidence level.

# Search for boosted diphoton resonances in the 10 to 70 GeV mass range using 138 $\text{fb}^{-1}$ of 13 TeV pp collisions with the ATLAS detector

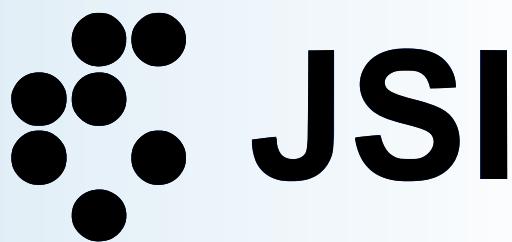
[HIGG-2019-23](#)

[CDS-2839865](#)

[arXiv:2211.04172](#)

A search for diphoton resonances in the mass range between 10 and 70 GeV with the ATLAS experiment at the Large Hadron Collider (LHC) is presented. The analysis is based on pp collision data corresponding to an integrated luminosity of  $138 \text{ fb}^{-1}$  at a centre-of-mass energy of 13 TeV recorded from 2015 to 2018. Previous searches for diphoton resonances at the LHC have explored masses down to 65 GeV, finding no evidence of new particles. This search exploits the particular kinematics of events with pairs of closely spaced photons reconstructed in the detector, allowing examination of invariant masses down to 10 GeV. The presented strategy covers a region previously unexplored at hadron colliders because of the experimental challenges of recording low-energy photons and estimating the backgrounds. No significant excess is observed and the reported limits provide the strongest bound on promptly decaying axion-like particles coupling to gluons and photons for masses between 10 and 70 GeV.

# Two-parts analytic function



- The turn-on region (TO):

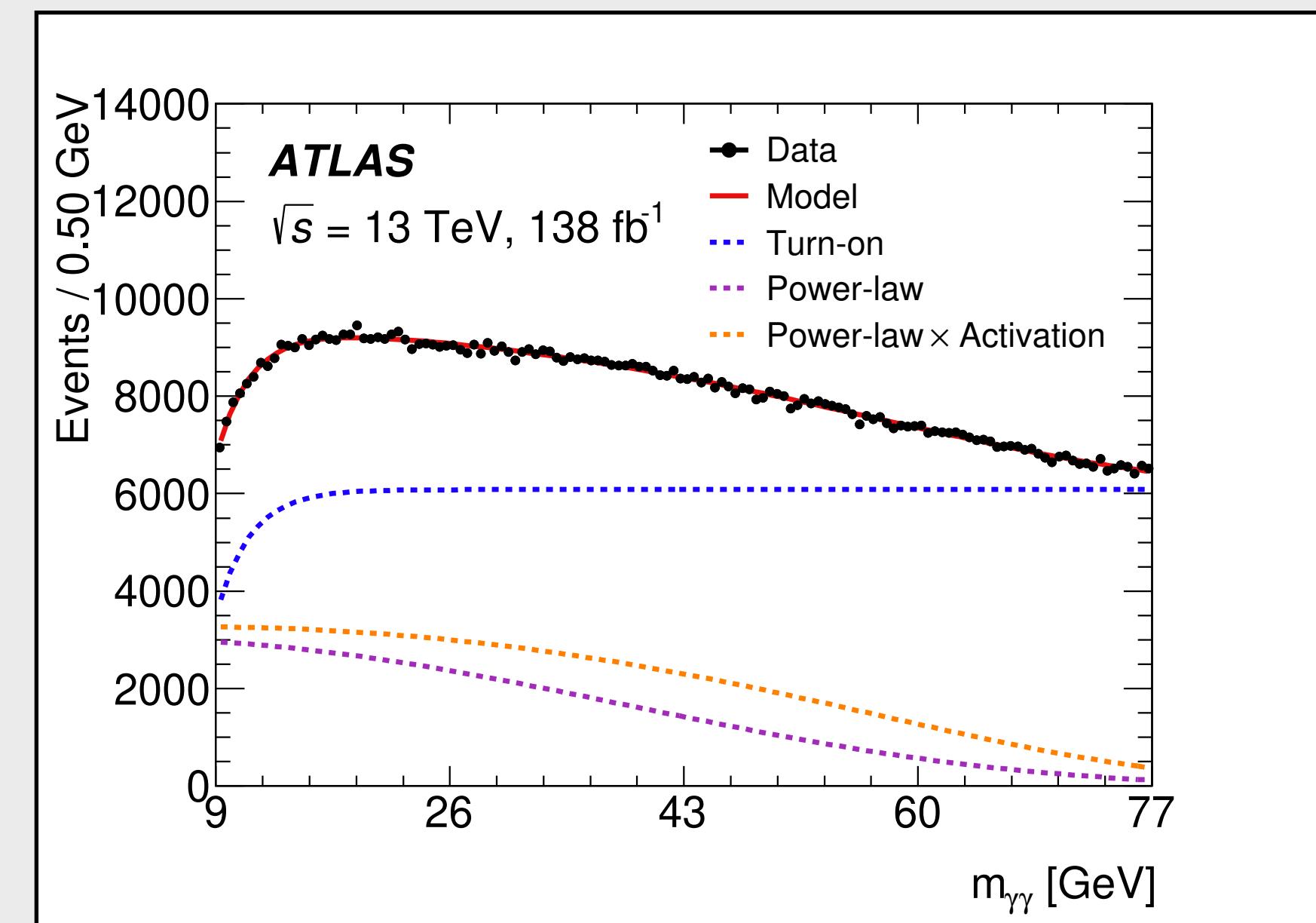
$$h_{\text{TO}}(m_{\gamma\gamma}; f_0, \tau_{\text{TO}}) = 1 - (1 - f_0) e^{-\frac{m_{\gamma\gamma}}{\tau_{\text{TO}}}}$$

- Power-law function times an activation function:

$$h_{\text{High}}(m_{\gamma\gamma}; c_1, a_0, c_0, \delta_{\text{tail}}, \tau_{\text{tail}}, \delta_{\text{thresh}}, \tau_{\text{thresh}}) = \underbrace{\left(1 - \left(\frac{m_{\gamma\gamma}}{c_1}\right)^{a_0}\right)^{c_0}}_{\text{Power-law}} \underbrace{\left(1 + \frac{e^{\frac{m_{\gamma\gamma} - \delta_{\text{tail}}}{\tau_{\text{tail}}}}}{1 + e^{-\frac{m_{\gamma\gamma} - \delta_{\text{thresh}}}{\tau_{\text{thresh}}}}}\right)}_{\text{Activation function}}$$

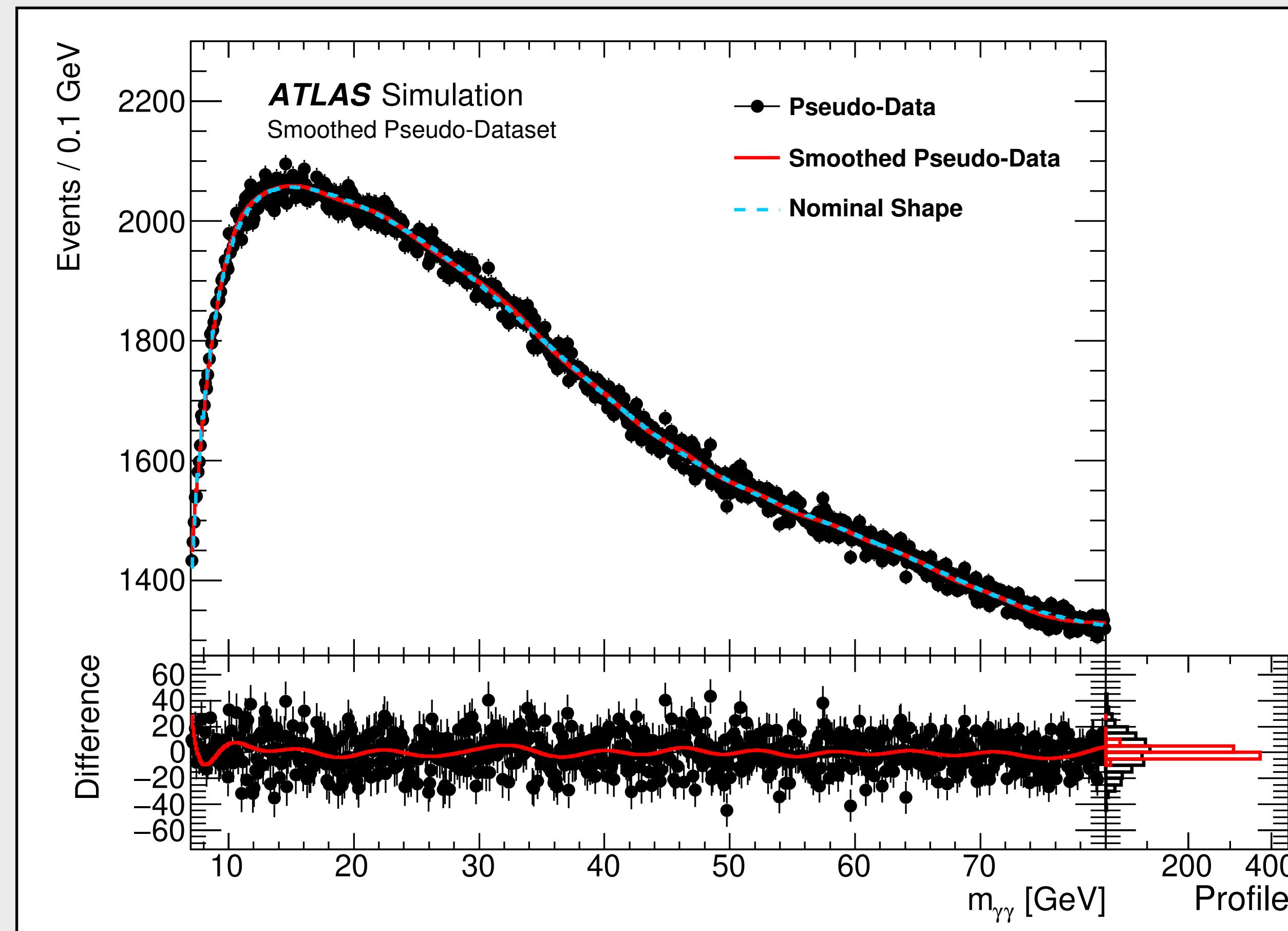
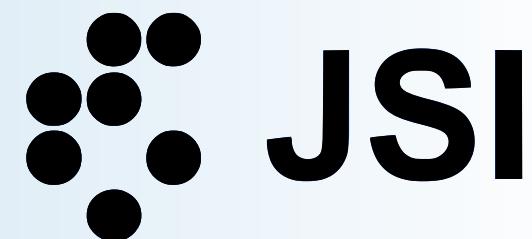
- A combination has ten parameters in total:

$$f(m_{\gamma\gamma}; \theta_{\text{TO}}, \theta_{\text{High}}, f_{\text{TO}}) = h_{\text{TO}}(\theta_{\text{TO}}) \cdot f_{\text{TO}} + (1 - f_{\text{TO}}) \cdot h_{\text{High}}(\theta_{\text{High}})$$



Distribution of the diphoton invariant mass for all events passing the analysis selections in the full Run 2 dataset with the background-only fit superimposed. The functional form is decomposed into the different pieces.

# Gaussian processes smoothing



The upper panel shows a single pseudo-dataset (solid markers) generated from the nominal background modelling function described in the previous slide (blue dashed line). The GP-smoothed pseudo-dataset is shown with the red solid line. The bottom panel shows the difference between the unsmoothed and smoothed pseudo-datasets with respect to the nominal background shape. The horizontal axis of the plot utilises a wider diphoton invariant mass range than the one used in the analysis in order to mitigate the impact of edge effects from the GP smoothing technique. The lower right panel shows the profile of the difference between the unsmoothed (black) and smoothed (red) pseudo-datasets with respect to the nominal background shape.

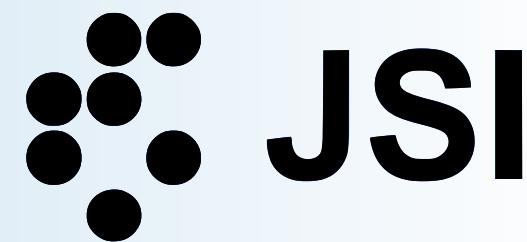
# Search for an Axion-Like Particle with forward proton scattering in association with photon pairs at ATLAS

[ATLAS-CONF-2023-002](#)

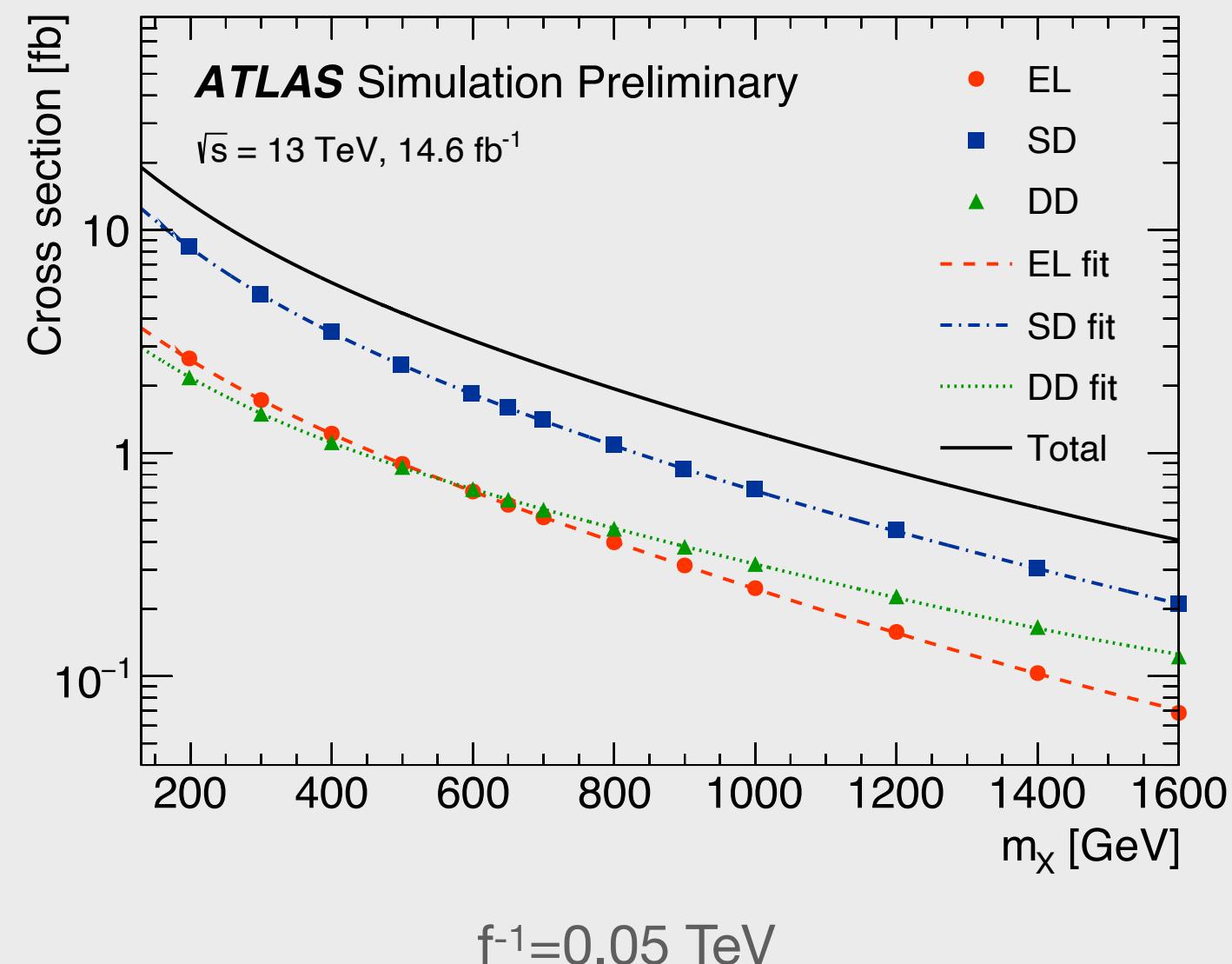
[CDS-2851708](#)

A search for forward proton scattering in association with light-by-light scattering mediated by an axion-like particle is presented, using the ATLAS Forward Proton spectrometer to detect scattered protons and the central ATLAS detector to detect pairs of outgoing photons. Proton-proton collision data recorded in 2017 at a centre-of-mass energy of  $\sqrt{s} = 13$  TeV were analysed, corresponding to an integrated luminosity of  $14.6 \text{ fb}^{-1}$ . A total of 441 candidate signal events were selected. A search was made for a narrow resonance in the diphoton mass distribution, corresponding to an axion-like particle (ALP) with mass in the range 150 - 1600 GeV. No excess is observed above a smooth background. Upper limits on the production cross section of a narrow resonance are set as a function of the mass, and are interpreted as upper limits of the ALP production coupling constant, assuming 100% decay branching ratio into a photon pair. The inferred upper limit on the coupling constant is in the range  $0.04\text{--}0.09 \text{ TeV}^{-1}$  at 95% confidence level.

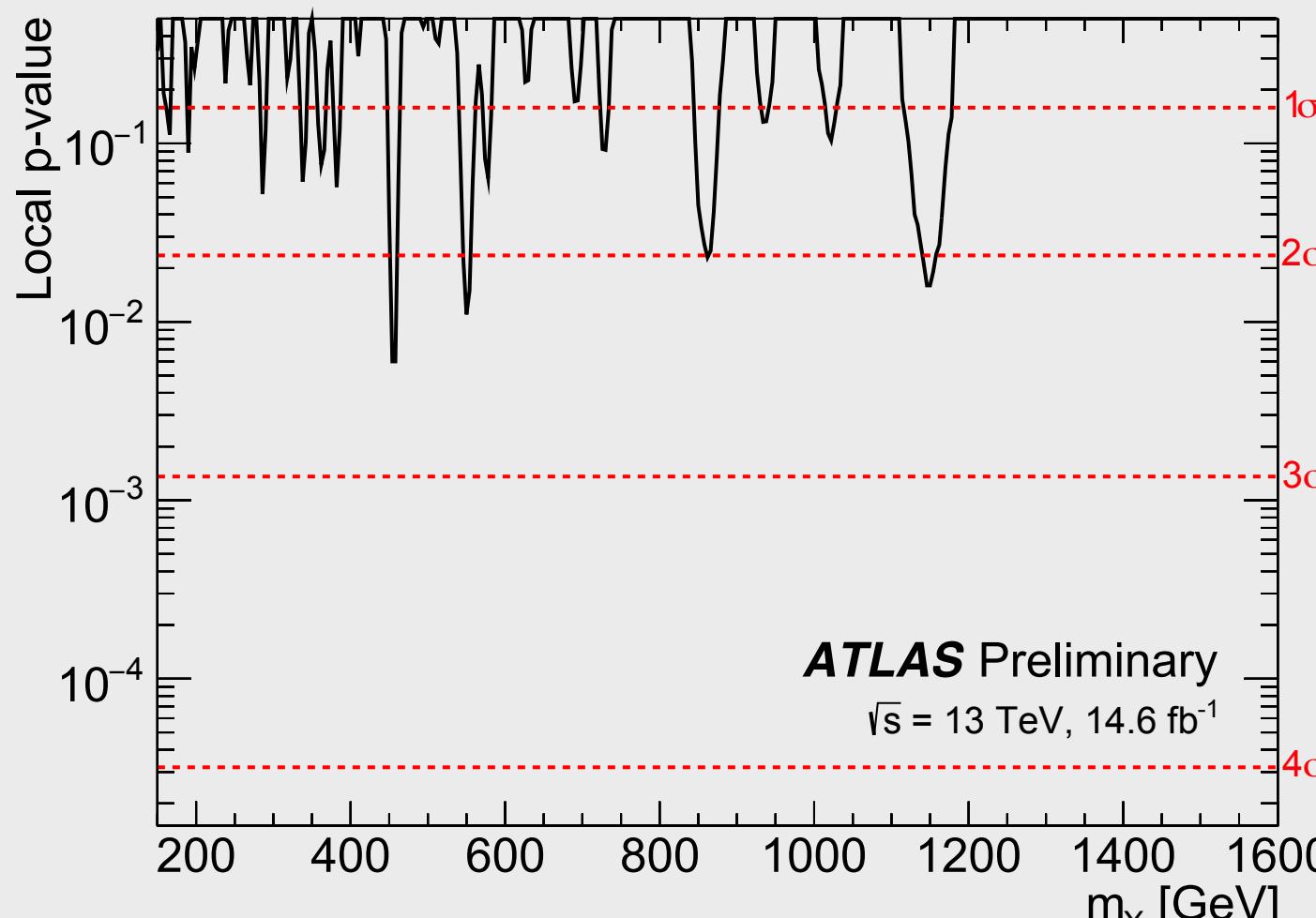
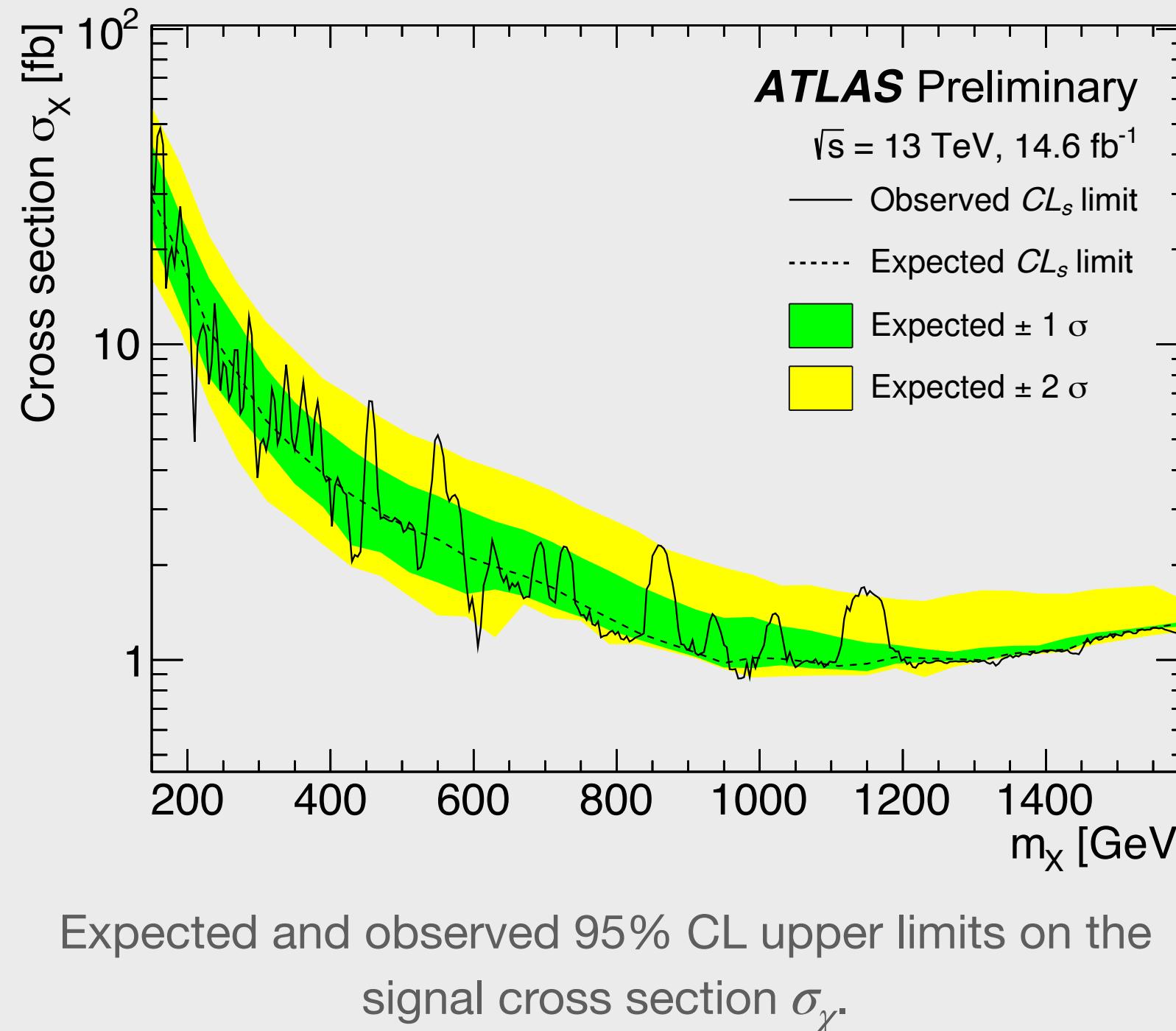
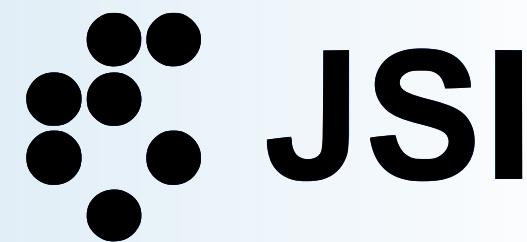
# Diphoton resonance with AFP tag



- The process  $\gamma\gamma \rightarrow \gamma\gamma$  can also occur through an intermediate fermion or  $W$  boson box diagram. Studied in other ATLAS Pb-Pb analyses [1, 2, 3, 4], but on a lower  $m_\chi < 100$  GeV range.
- At higher diphoton masses, the effective  $\gamma\gamma$  luminosity in  $pp$  collisions surpasses that of Pb-Pb collisions, although the scattering cross-section is lower than at lower masses.
- Typically, the SD production cross-section is approximately three times the exclusive, while the DD and exclusive cross-section are similar.

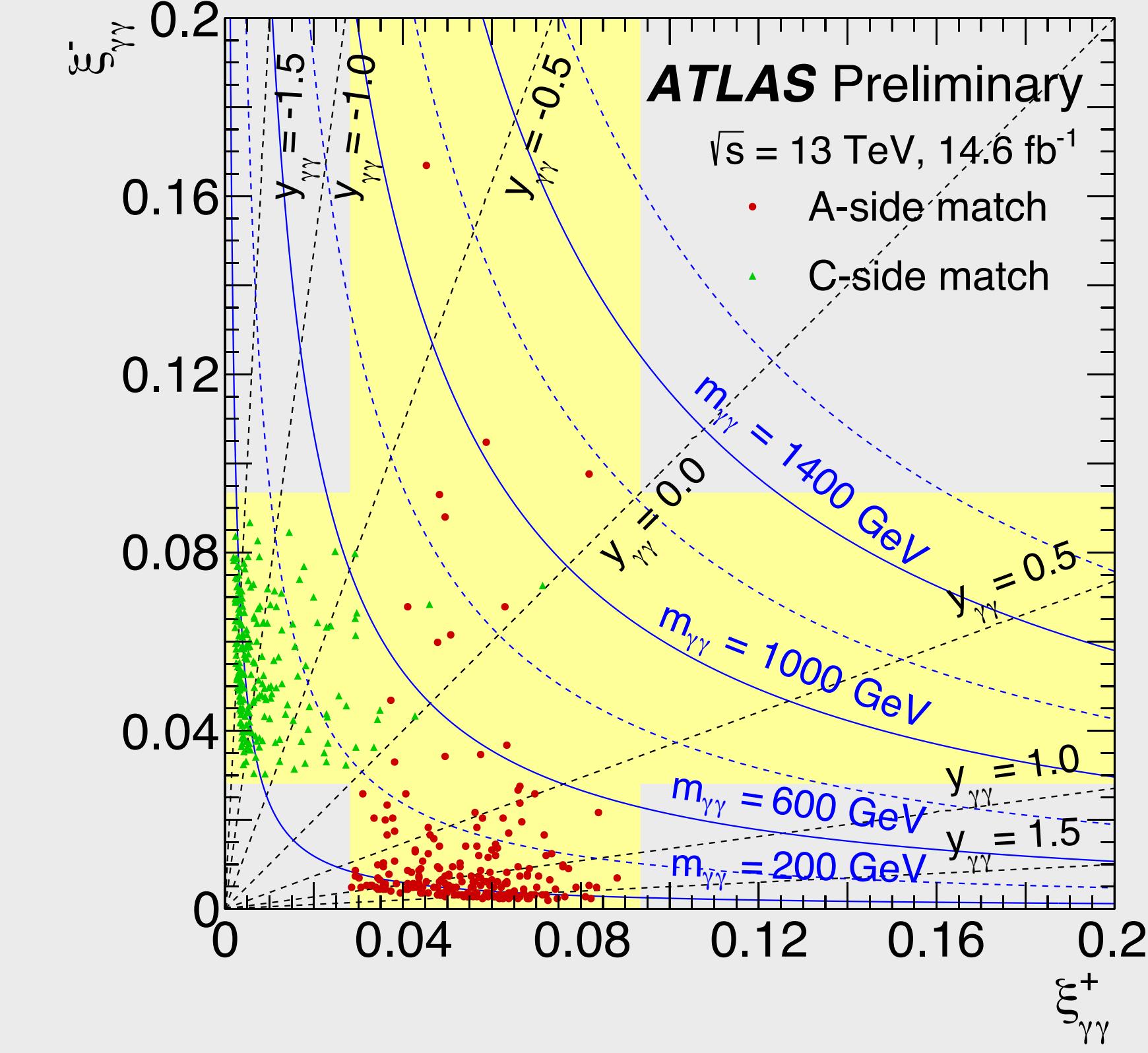


# Diphoton resonance with AFP tag IV



Source	Uncertainty
Signal yield uncertainty	
Pileup reweighting	$\pm 2.7\%$
Luminosity	$\pm 2.4\%$
Photon identification efficiency	$\pm 1.6\%$
Photon isolation efficiency	$\pm 1.5\%$
Beam optics between ATLAS central and AFP detectors	$\pm 0.8\%$
AFP global alignment	$\pm 10.0\%$
Proton reconstruction efficiency	$\pm 8.6\%$
Showering in the AFP	$\pm 3.0\%$
Background modelling (mass-dependent)	$\pm (0.02-0.7)$
Signal modelling	
Photon energy resolution	$\pm 14.1\%$
Photon energy scale	$\pm 4.8\%$
Signal cross section uncertainty	
Soft survival factor (exclusive process)	$\pm 2\%$
Soft survival factor (single-dissociative process)	$\pm 10\%$
Soft survival factor (double-dissociative process)	$\pm 50\%$

Summary of the systematic uncertainties.



$(\xi_{\gamma\gamma}^+, \xi_{\gamma\gamma}^-)$  distribution of the selected data candidates after the full event selection. No event passed the matching selection for both A and C-sides.

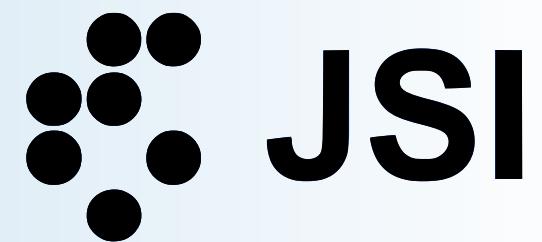
# Search for heavy Majorana or Dirac neutrinos and right-handed W gauge bosons in final states with charged leptons and jets at $\sqrt{s} = 13$ TeV with the ATLAS detector

[EXOT-2019-39](#)

[CDS-2843320](#)

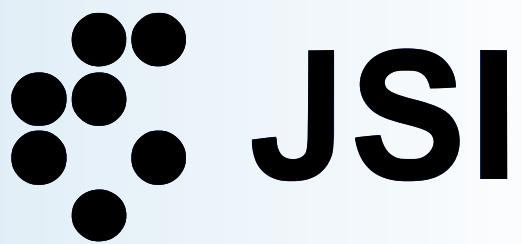
A search for heavy right-handed Majorana or Dirac neutrinos  $N_R$  and heavy right-handed gauge bosons  $W_R$  is performed in events with energetic electrons or muons, with the same or opposite electric charge, and energetic jets. The search is carried out separately for topologies of clearly separated final-state products (“resolved” channel) and topologies with boosted final states with hadronic products partially overlapping and reconstructed as a large-radius jet, caused by a large mass difference between  $W_R$  and  $N_R$  (“boosted” channel). The events are selected from pp collision data at the LHC with an integrated luminosity of  $139\text{ fb}^{-1}$  collected by the ATLAS detector at  $\sqrt{s} = 13$  TeV. No significant deviations from the Standard Model predictions are observed. The results are interpreted within the theoretical framework of a left-right symmetric model, and lower limits at 95% confidence level are set on masses in the heavy right-handed  $W_R$  boson and  $N_R$  plane. The excluded region extends to about  $m(W_R) = 6.4$  TeV for both Majorana and Dirac  $N_R$  neutrinos at  $m(N_R) < 1$  TeV.  $N_R$  with masses of less than 3.5 (3.6) TeV are excluded in the electron (muon) channel at  $m(W_R) = 4.8$  TeV for the Majorana neutrinos, and limits of  $m(N_R)$  up to 3.6 TeV for  $m(W_R) = 5.2$  (5.0) TeV in the electron (muon) channel are set for the Dirac neutrinos.

# LRSM HN - strategy

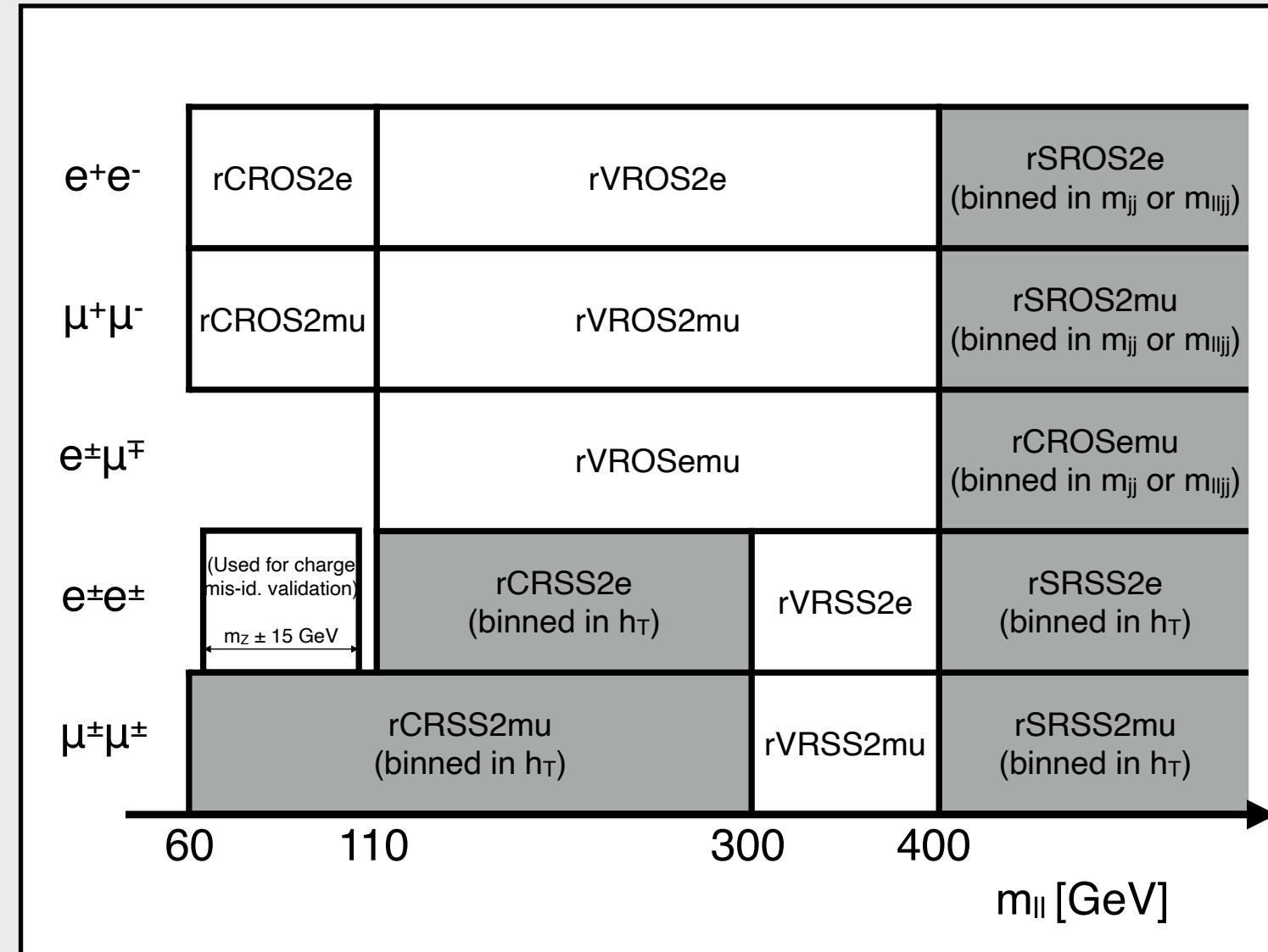


- Focus on hadronic decays of the  $W_R$  because of the high branching fractions.
- Simulation assumes Majorana nature of  $N_R$ , thus for the Dirac case, only opposite-charge leptons are considered and the cross-sections are rescaled.
- Lepton universality: branching ratios are set to  $e, \mu, \tau = 1/3$ .
- At very low  $N_R$  masses - its decay length can be greater than 1 mm and can be studied in the future.

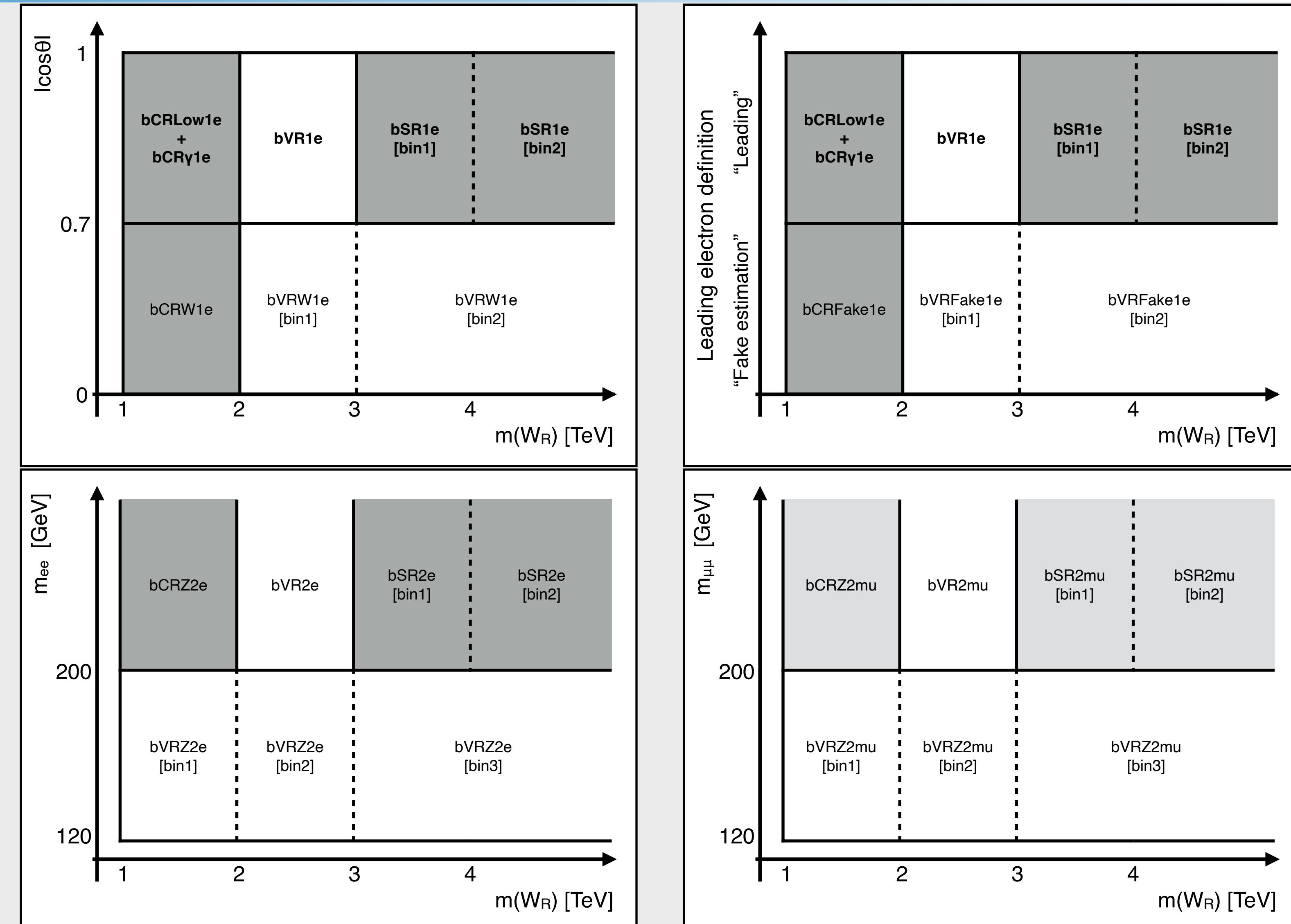
# LRSM HN - region definitions I



Resolved channel



Boosted channel



# LRSM HN - region definitions II

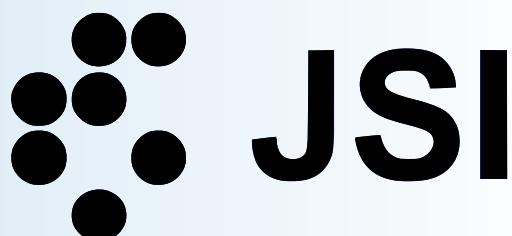


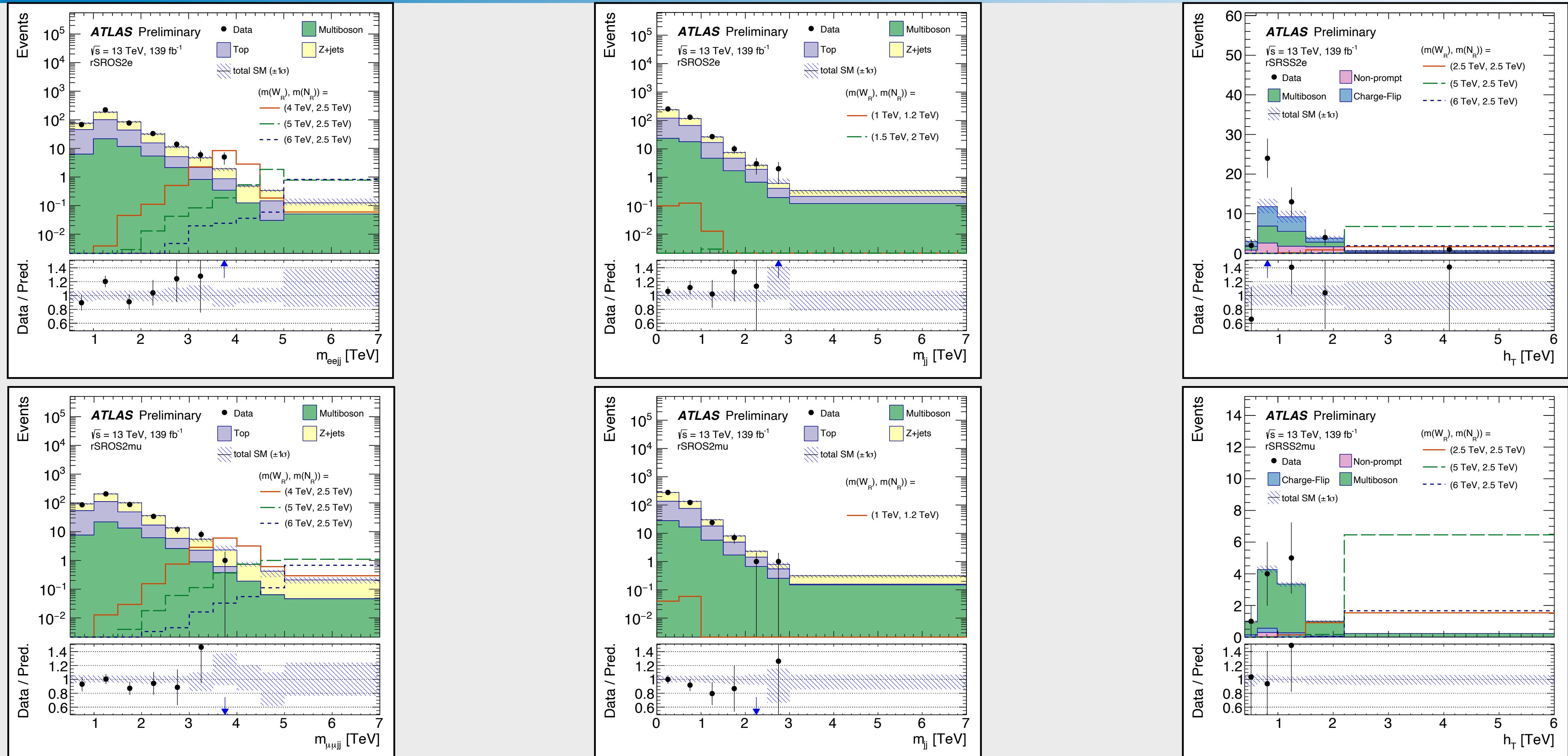
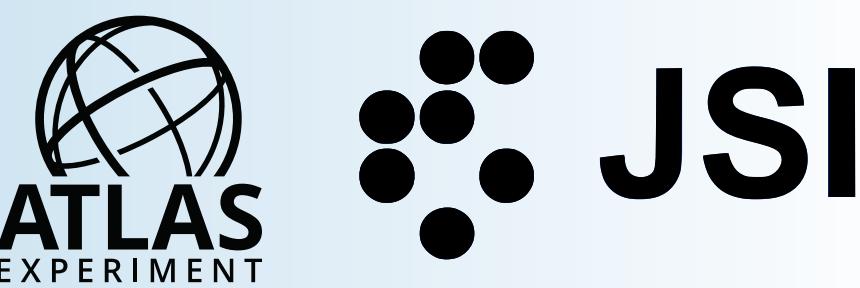
Table 4: Definition of signal regions in the resolved channel.

Variable	rSRSS2e	rSRSS2mu	rSROS2e	rSROS2mu
Number of electrons	2	0	2	0
Number of muons	0	2	0	2
Lepton charge	same sign		opposite sign	
Leading lepton $p_T$ [GeV]		> 40		
Dilepton mass $m_{\ell\ell}$ [GeV]		> 400		
$\Delta R_{\ell\ell}$	< 3.9		—	
Number of small- $R$ jets with $p_T > 100$ GeV		$\geq 2$		
Number of $b$ -tagged jets		0		
Dijet mass $m_{jj}$ [GeV]		> 110		
$h_T \equiv p_T(\ell_1) + p_T(\ell_2) + p_T(j_1) + p_T(j_2)$ [GeV]		> 400		

Table 5: Definition of the signal regions in the boosted analysis. Two regions in the electron channel cover higher- and lower- $\Delta m$  regions, where  $\Delta m$  denotes the mass difference between  $W_R$  and  $N_R$ .

Region	bSR1e (higher $\Delta m$ )	bSR2e (lower $\Delta m$ )	bSR2mu
Number of large- $R$ jets		1	
Number of electrons	1	2	0
Number of muons	0	0	2
Leading lepton $p_T$ [GeV]		> 200	
$E_T^{\text{miss}}$ [GeV]	< 200		—
$ \cos \theta $	> 0.7	—	—
$\Delta\phi_{J,\ell_1}$		> 2.0	
$\Delta\eta_{J,\ell_1}$	< 2.0	—	—
Dilepton $p_T$ (GeV)	—	—	> 200
Dilepton mass $m_{\ell\ell}$ [GeV]	—		> 200
Number of $b$ -tagged small- $R$ jets		0	

# LRSM HN - SR distributions



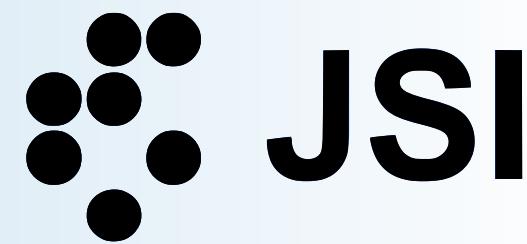
# Search for singly produced vector-like top partners in multilepton final states with $139 \text{ fb}^{-1}$ data collected from pp collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector

[ATLAS-CONF-2023-020](#)

[CDS-2853176](#)

A search for the single production of vector-like top partners ( $T$ ) optimised for final states with a  $Z$  boson decaying to a pair of electrons or muons is presented, using the full Run 2 dataset corresponding to  $139 \text{ fb}^{-1}$  of pp collisions at  $\sqrt{s} = 13 \text{ TeV}$ , collected in 2015–2018 with the ATLAS detector at the Large Hadron Collider. The targeted final state is characterised by the presence of a pair of electrons or muons with opposite-sign charges which form a  $Z$  boson candidate, as well as by the presence of b-tagged jets and forward jets. Events with exactly two or at least three leptons are categorised into two independently optimised analysis channels. No significant excess above the background expectation is observed and the results from the two channels are statistically combined to set exclusion limits at 95% confidence level on the masses and couplings of  $T$  for benchmark models as well as generalised representations.

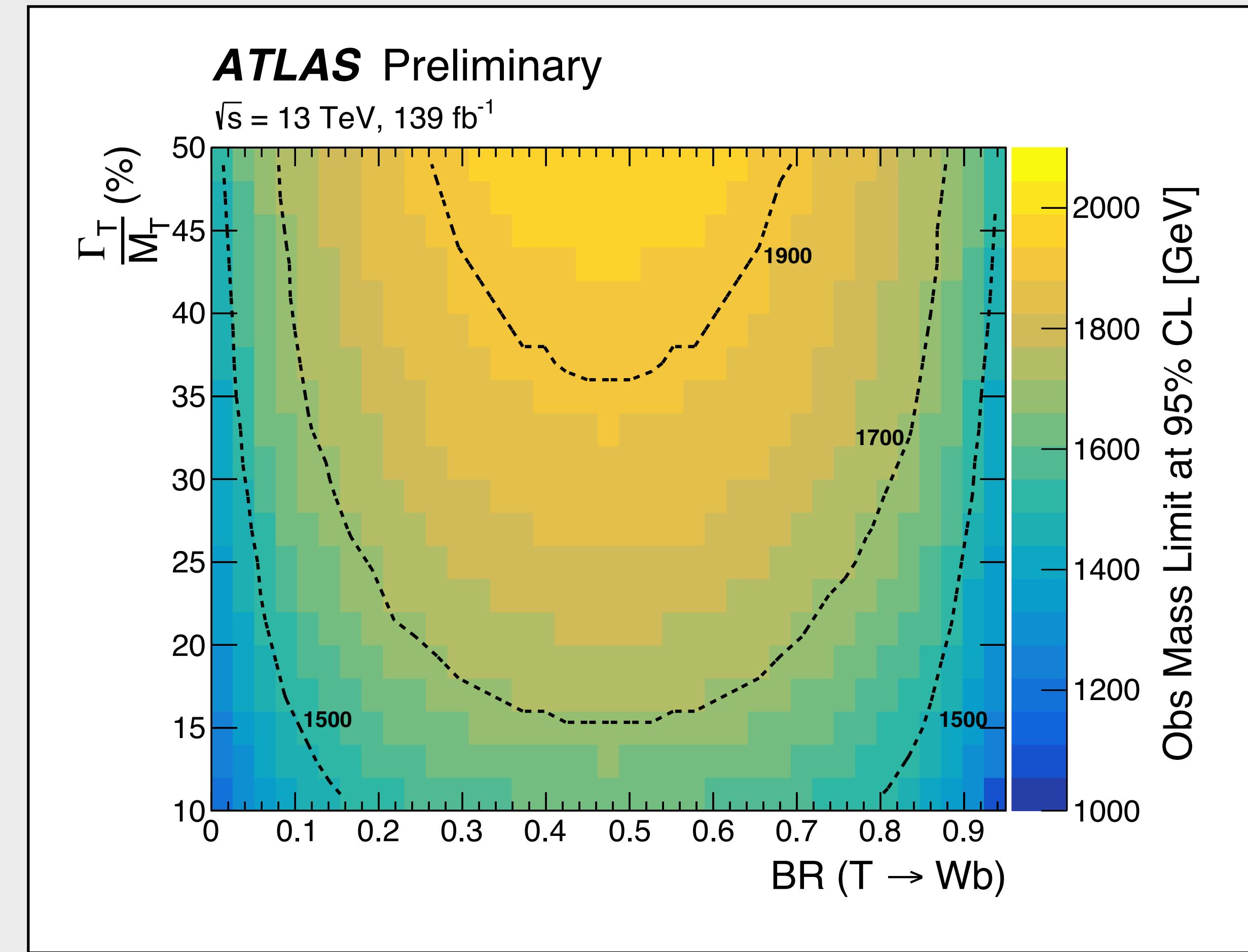
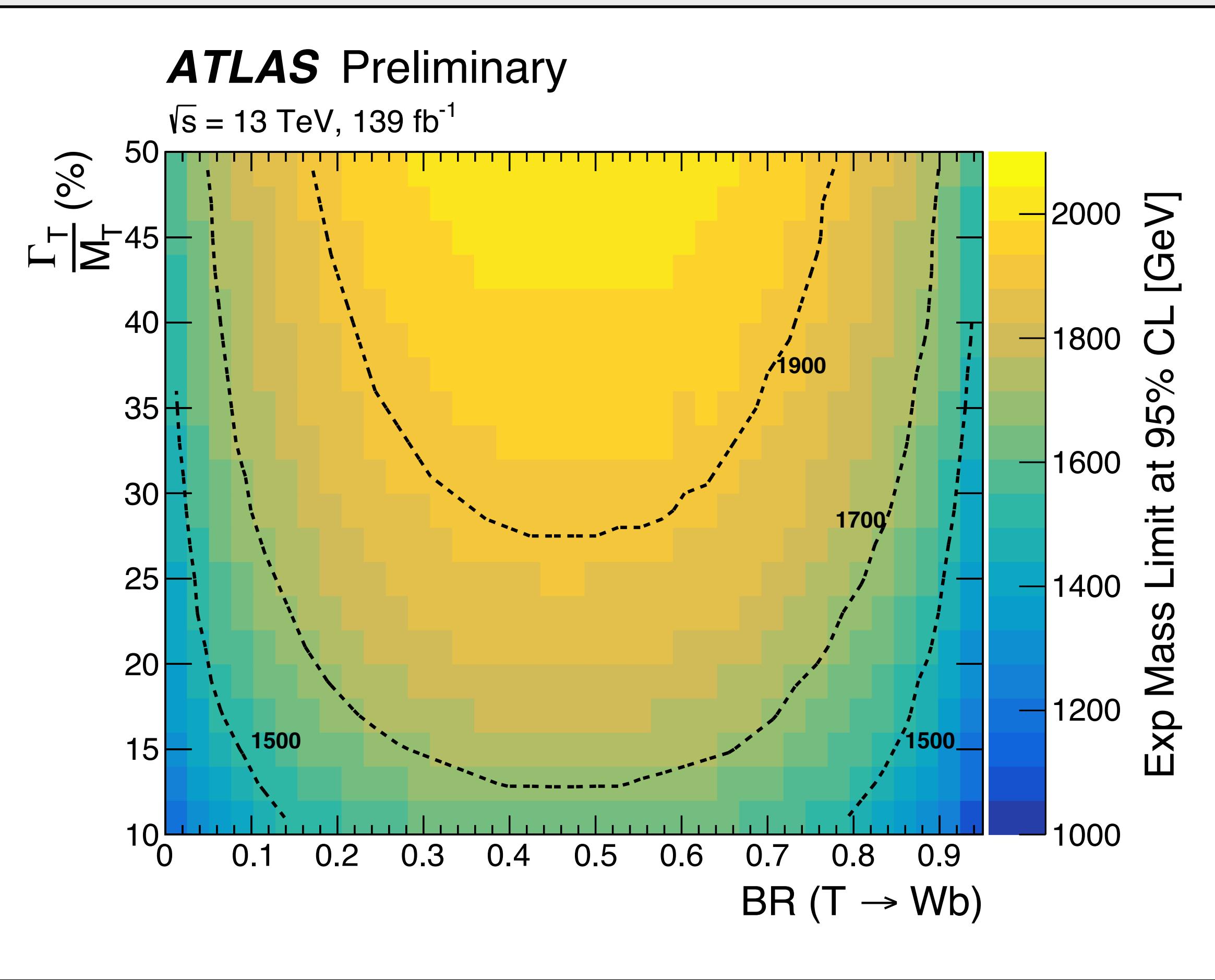
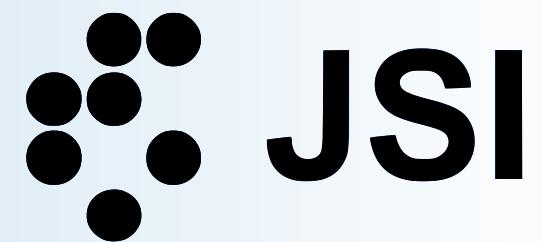
# Selections for CR / VR / SR



	2ℓCR1	2ℓCR2	2ℓCR3	2ℓVR1	2ℓVR2	2ℓSR
Preselection	1 pair of OS-SF leptons with $ m(\ell\ell) - m_Z  < 10$ GeV $p_T(\ell\ell) > 200$ GeV, $H_T > 300$ GeV $\geq 1$ vRC jet $H_T + E_T^{\text{miss}} < m_{\ell\ell J}$					
forward jets	$\geq 1$	0	0	$\geq 1$	0	$\geq 1$
$b$ -tagged jets	0	$\geq 1$	0	0	$\geq 1$	$\geq 1$
top-tagged jets	-	-	$\geq 1$	$\geq 1$	$\geq 1$	$\geq 1$
top-vetoed jets	$\geq 1$	$\geq 1$	-	-	-	-

	3ℓVV	3ℓMixed	3ℓttX	3ℓVR	3ℓSR
Preselection	$\geq 3$ leptons $\geq 1$ pair of OS-SF leptons with $ m(\ell\ell) - m_Z  < 10$ GeV				
$b$ -tagged jets	0	1	$\geq 2$	$\geq 1$	$\geq 1$
forward jets	-	0	0	$\geq 1$	$\geq 1$
$\Delta\phi$ selections	-	$\Delta\phi(Z, \ell_3) < 2.6$	$\Delta\phi(Z, \ell_3) < 2.6$	$\Delta\phi(Z, \ell_3) < \frac{\pi}{2}$ OR $\Delta\phi(Z, b_{\text{lead}}) < \frac{\pi}{2}$	$\Delta\phi(Z, \ell_3) > \frac{\pi}{2}$ AND $\Delta\phi(Z, b_{\text{lead}}) > \frac{\pi}{2}$
other selections	-	-	-	-	$\max(p_T(\ell)) > 200$ GeV $p_T(\ell\ell) > 300$ GeV $H_T \cdot n(\text{jets}) < 6$ TeV

# Branching ratio exclusion regions



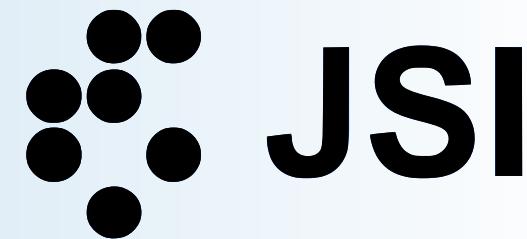
# Search for heavy resonances in the decay channel $W^+W^- \rightarrow e\nu\mu\nu$ in pp collisions at $\sqrt{s} = 13$ TeV using $139\text{ fb}^{-1}$ of data with the ATLAS detector

[ATLAS-CONF-2022-066](#)

[CDS-2842518](#)

A search for neutral heavy resonances ( $R$ ) is made in the  $W^+W^- \rightarrow e\nu\mu\nu$  decay channel using pp collision data corresponding to an integrated luminosity of  $139\text{ fb}^{-1}$ , collected at a centre-of-mass energy of 13 TeV by the ATLAS detector at the CERN Large Hadron Collider. No evidence of any heavy resonances is found. Upper limits on  $\sigma_R \times \mathcal{B}(R \rightarrow WW)$  are obtained as a function of the resonance mass ranging from 300 GeV to 4 TeV for five different models: a Higgs-like narrow width scalar, a Higgs boson in the Georgi–Machacek model, a radion particle arising in the bulk Randall–Sundrum model, a spin-1 heavy vector triplet, and a spin-2 graviton, all with the resonance produced through either gluon-gluon fusion, quark-antiquark annihilation, or vector-boson fusion.

# Summary of the selections used

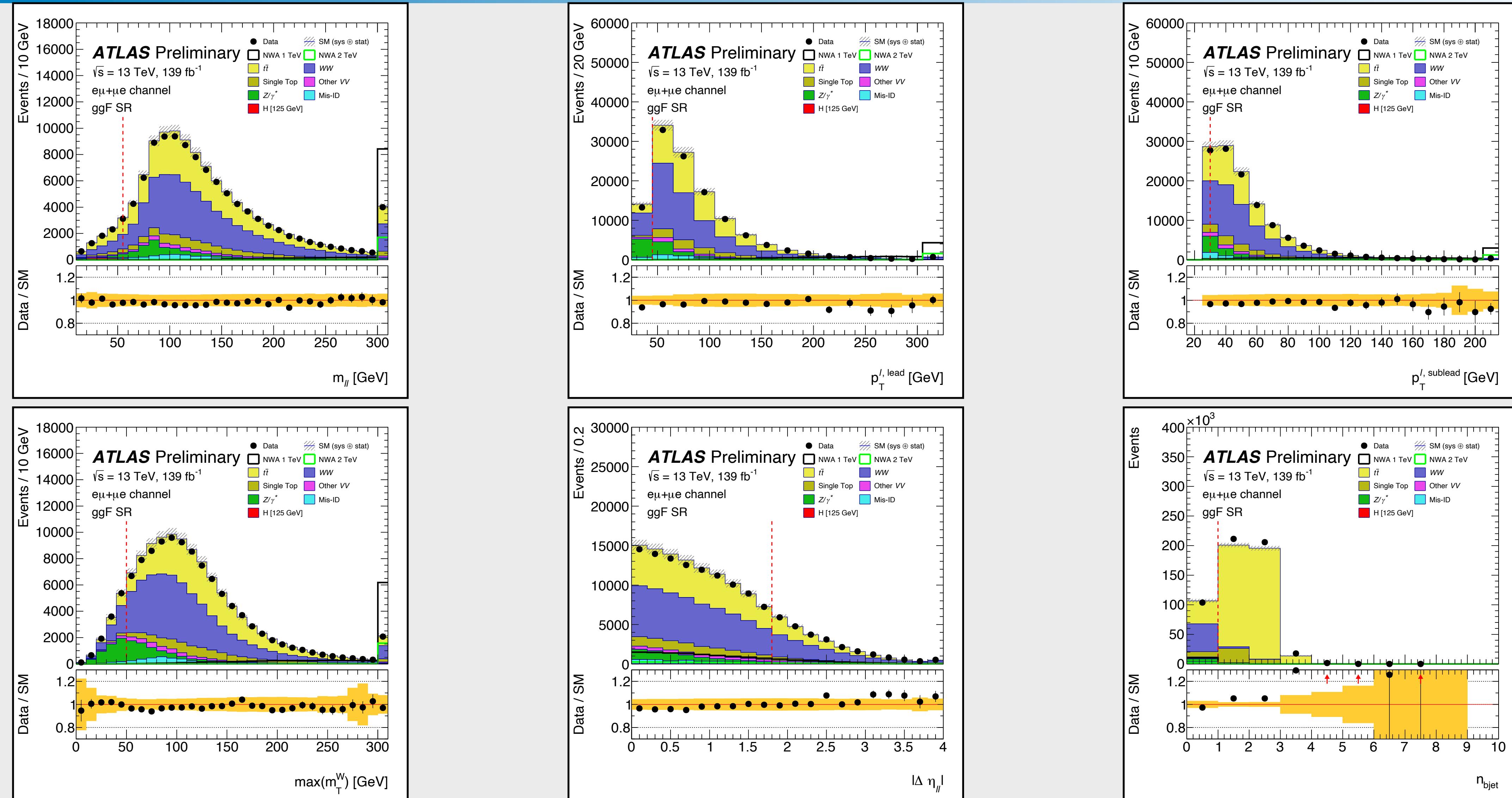
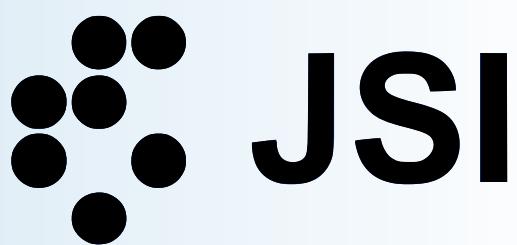


Pre-Selection		
Two Different Flavour, Opposite Sign Leptons, $p_T^\ell > 25 \text{ GeV}$		
Third lepton veto, $p_T^\ell > 15 \text{ GeV}$		
Common Selection		
$N_{b\text{-tag}} = 0$		
$ \Delta\eta_{\ell\ell}  < 1.8$		
$m_{\ell\ell} > 55 \text{ GeV}$		
$p_T^{\ell,\text{lead}} > 45 \text{ GeV}$		
$p_T^{\ell,\text{sublead}} > 30 \text{ GeV}$		
$\max(m_T^W) > 50 \text{ GeV}$		
SC <sub>ggF</sub>	SC <sub>VBF1J</sub>	SC <sub>VBF2J</sub>
Inclusive in $N_{\text{jet}}$ but excluding SC <sub>VBF1J</sub> and SC <sub>VBF2J</sub>	$N_{\text{jet}} = 1$ and $ \eta_j  > 2.4$ , $\min( \Delta\eta_{j\ell} ) > 1.75$	$N_{\text{jet}} \geq 2$ and $m_{jj} > 500 \text{ GeV}$ , $ \Delta y_{jj}  > 4$

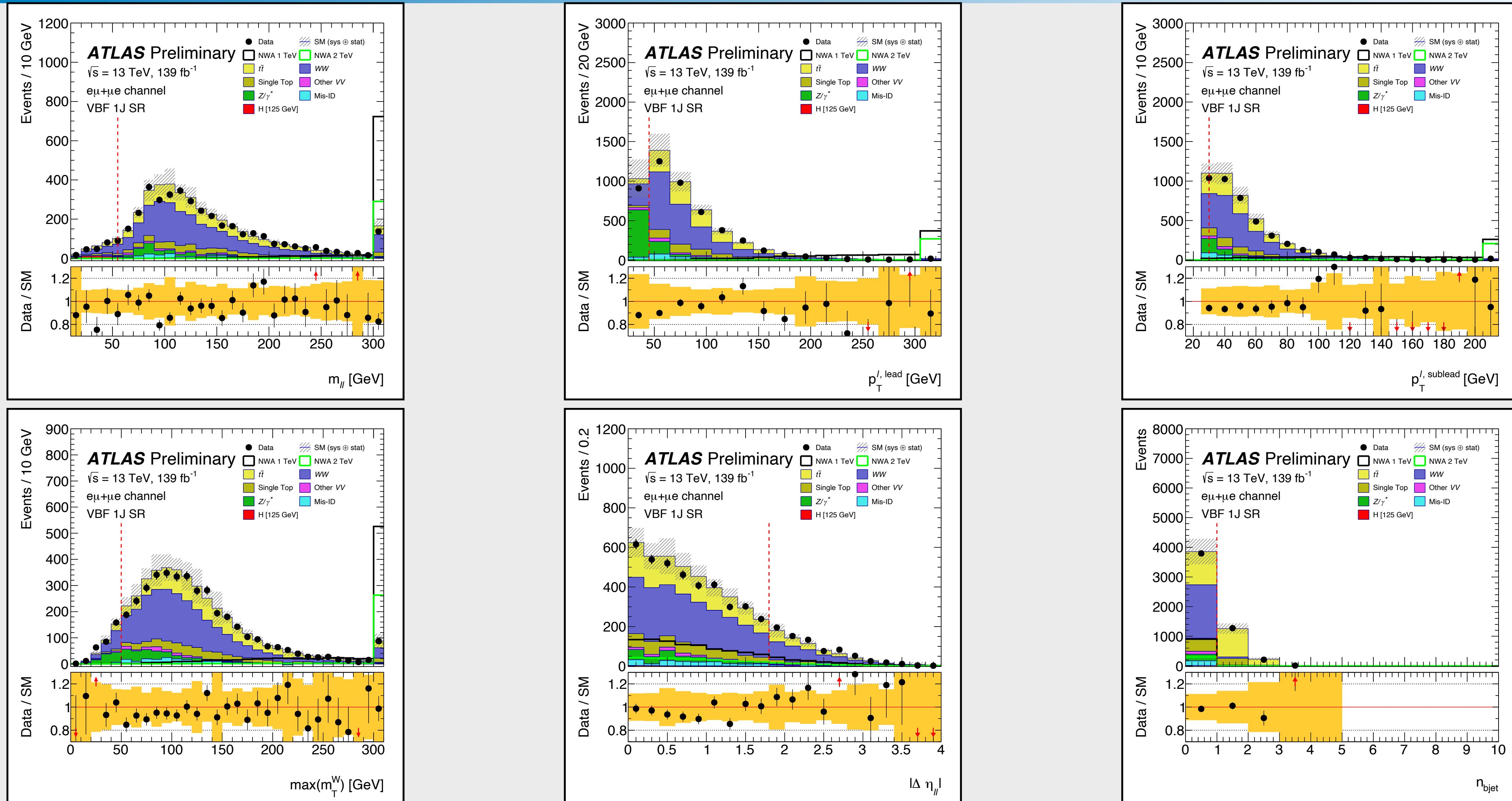
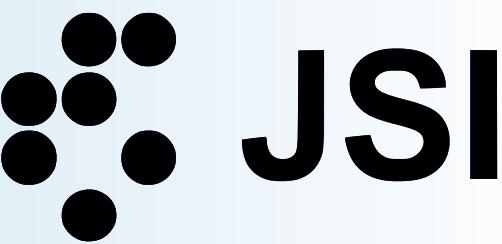
Signal region selections.

Control region selections.			
Pre-Selection			
Two Different Flavour, Opposite Sign Leptons, $p_T^\ell > 25 \text{ GeV}$			
Third lepton veto, $p_T^\ell > 15 \text{ GeV}$			
WW CR <sub>ggF</sub>	Top CR <sub>ggF</sub>	WW CR <sub>VBF1J</sub>	Top CR <sub>VBF</sub>
$N_{b\text{-tag}} = 0$	$N_{b\text{-tag}} = 1$	$N_{b\text{-tag}} = 0$	$N_{b\text{-tag}} \geq 1$
$ \Delta\eta_{\ell\ell}  > 1.8$	$ \Delta\eta_{\ell\ell}  < 1.8$	( $ \Delta\eta_{\ell\ell}  > 1.8$ or $10 \text{ GeV} < m_{\ell\ell} < 55 \text{ GeV}$ )	$ \Delta\eta_{\ell\ell}  < 1.8$
$m_{\ell\ell} > 55 \text{ GeV}$		—	$m_{\ell\ell} > 55 \text{ GeV}$
$p_T^{\ell,\text{lead}} > 45 \text{ GeV}$		—	$p_T^{\ell,\text{lead}} > 45 \text{ GeV}$
$p_T^{\ell,\text{sublead}} > 30 \text{ GeV}$		—	$p_T^{\ell,\text{sublead}} > 30 \text{ GeV}$
$\max(m_T^W) > 50 \text{ GeV}$		—	$\max(m_T^W) > 50 \text{ GeV}$
METSigRatio $> 0.8 \text{ GeV}^{-1}$	—	—	—
Excluding VBF1/2J phase space	VBF1J phase space	VBF1/2J phase space	VBF1/2J phase space

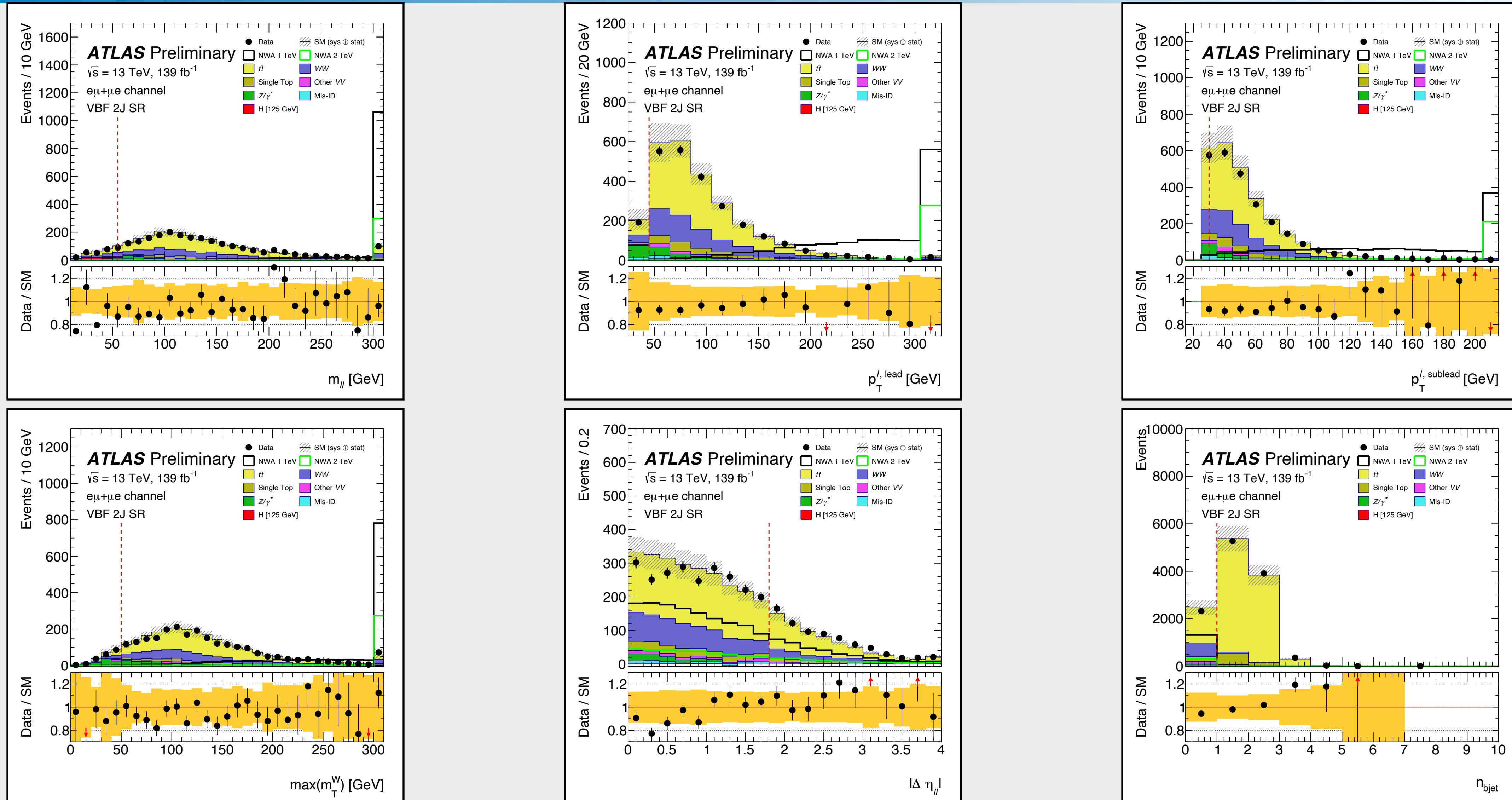
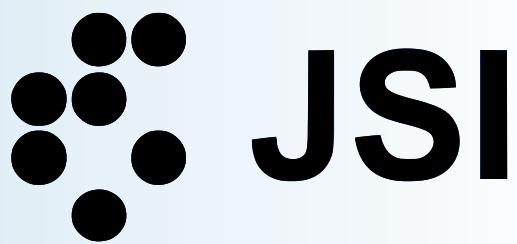
# ggF signal category



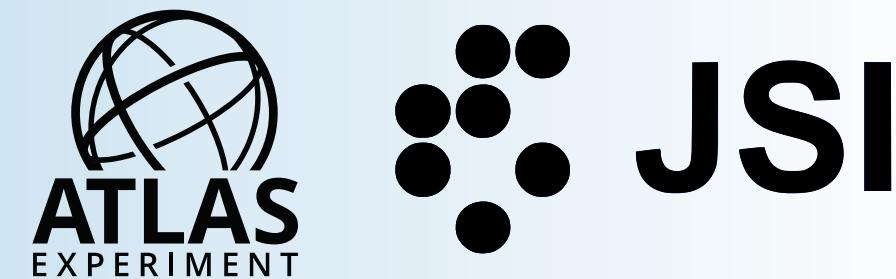
# VBF 1-jet signal category



# VBF 2+ jet signal category

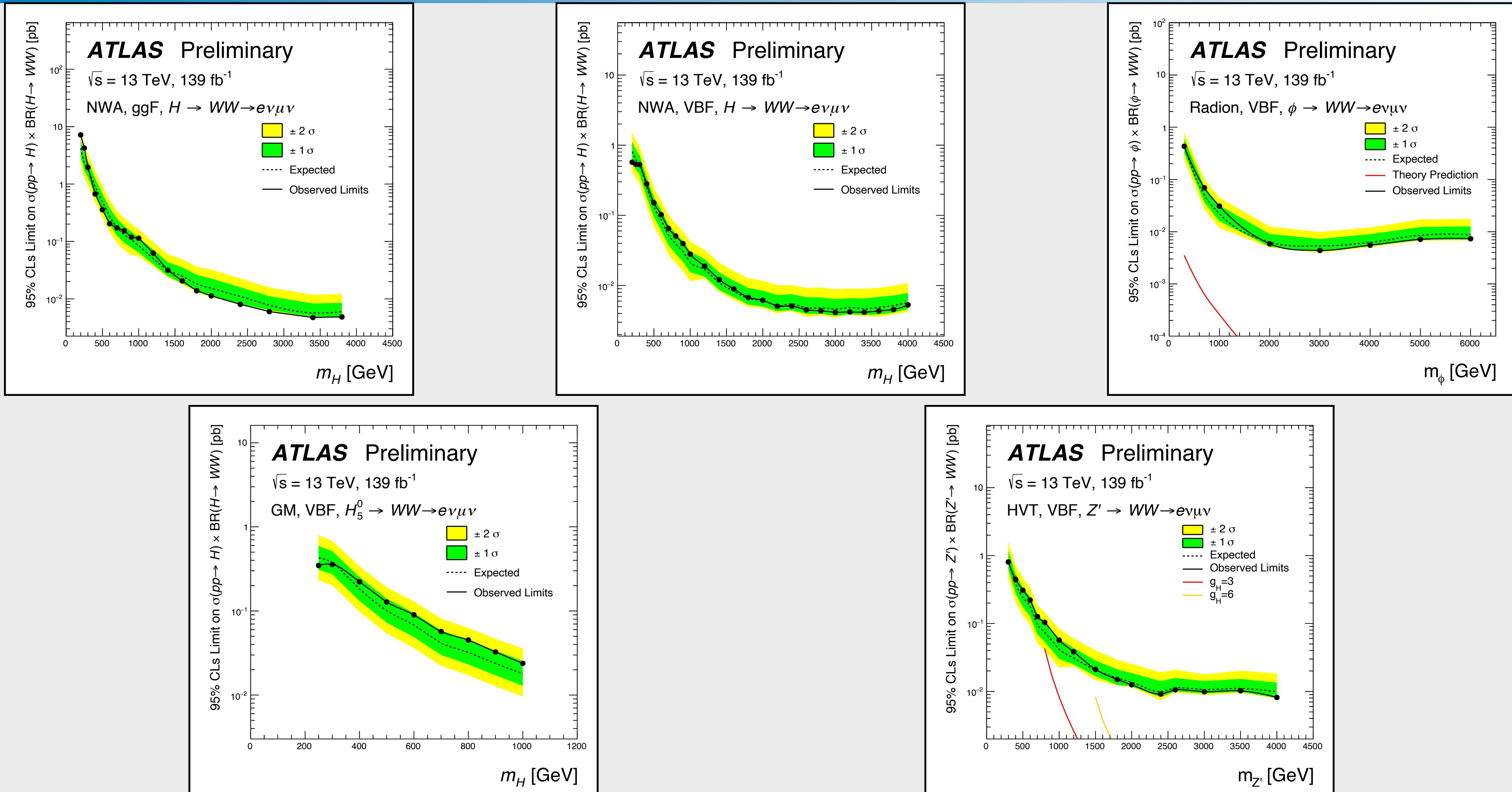
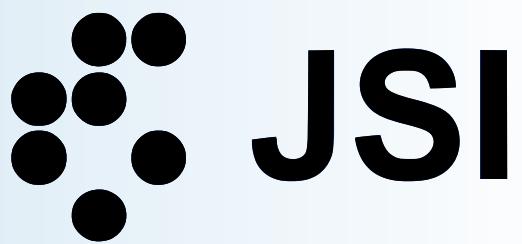


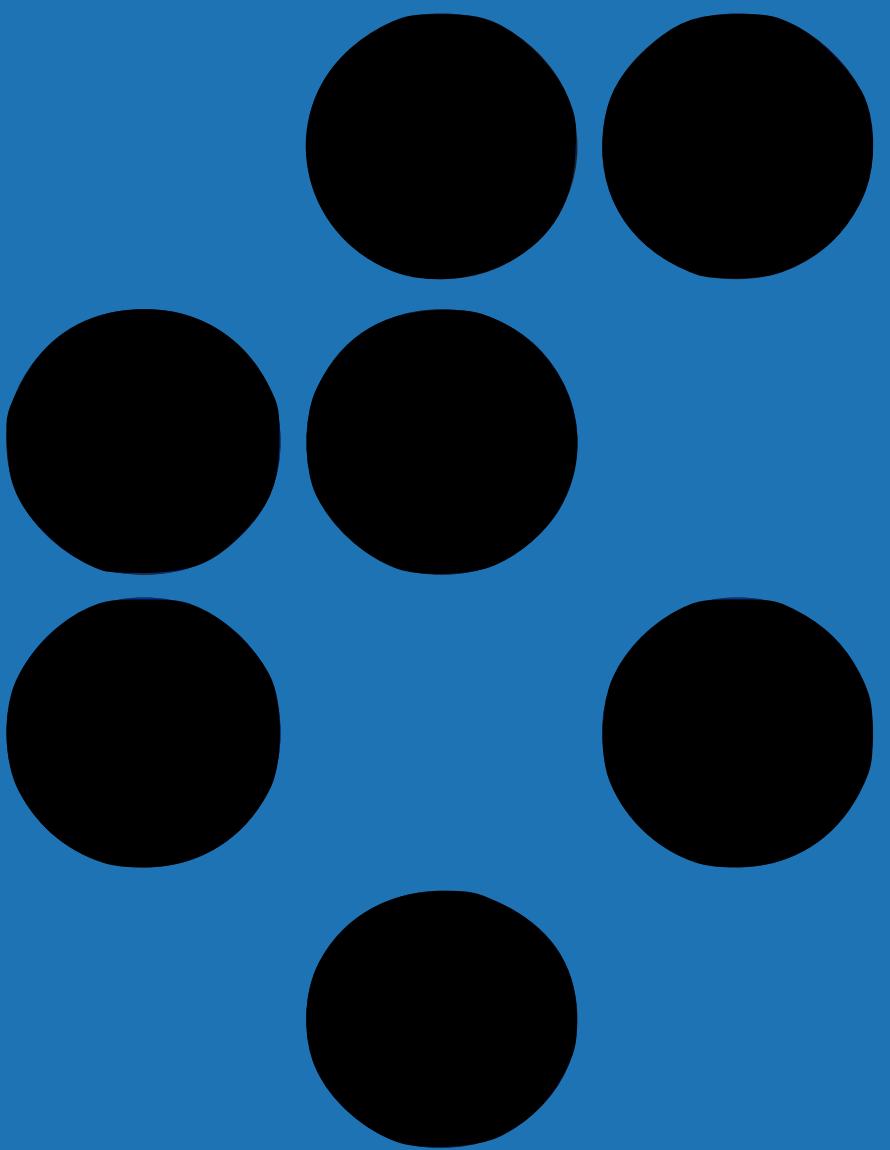
# Leading systematic uncertainties



ggF Production		VBF Production	
Systematic Source	Impact (%)	Systematic Source	Impact (%)
$m_H = 300 \text{ GeV}$			
Flavour tagging: $b$ -jets	11	$WW$ QCD Scale	14
$WW$ QCD Scale	10	$Wt$ Shower	12
JES: $b$ -jets	9	$Wt$ Matrix Element	10
Floating Normalizations: $WW$	8.77	JES: Pile-up $\mu$ Offset	7.97
Data stat. uncertainty	9	Data stat. uncertainty	16
Total Syst. uncertainty	33	Total Syst. uncertainty	40
$m_H = 1000 \text{ GeV}$			
$WW$ Shower: Recoil	6	$WW$ Scale	4
$e$ fake factor stat. uncertainty	5	$Wt$ Shower	3.4
$Wt$ Interference	5	$WW$ Shower: CKKW	3.4
$WW$ QCD Scale	4	$t\bar{t}$ Final-state Rad.	2.9
Data stat. uncertainty	17	Data stat. uncertainty	25
Total Syst. uncertainty	20	Total Syst. uncertainty	10
$m_H = 3000 \text{ GeV}$			
$WW$ Shower: Recoil	20	$WW$ Scale: QSF	7
$WW$ Scale: QSF	19	$WW$ Shower: Recoil	6
$WW$ Shower: CKKW	16	$WW$ Shower: CKKW	5
$Wt$ Interference	7	Floating Normalizations: $WW$	1
Data stat. uncertainty	22	Data stat. uncertainty	18
Total Syst. uncertainty	21	Total Syst. uncertainty	15

# Other limits





**JSI**