

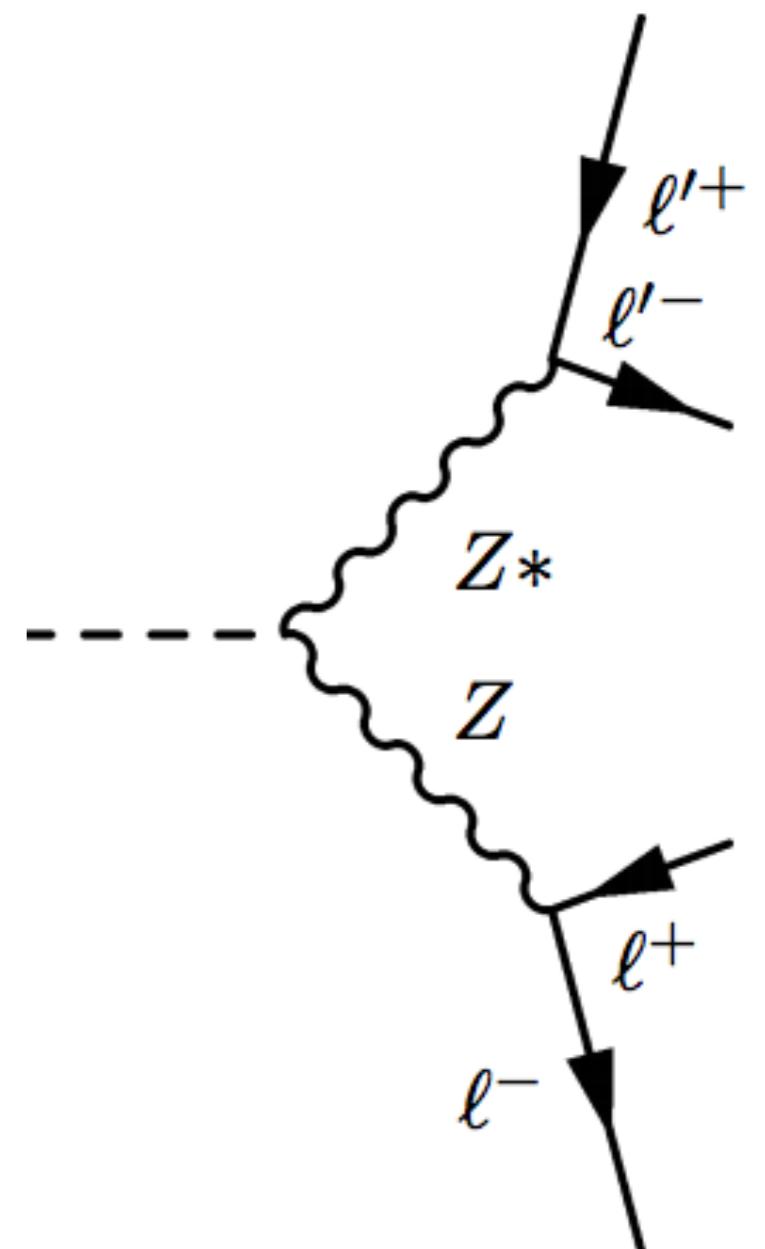


Higgs Boson Measurements and Extended Scalar Sector Searches in Bosonic Final States

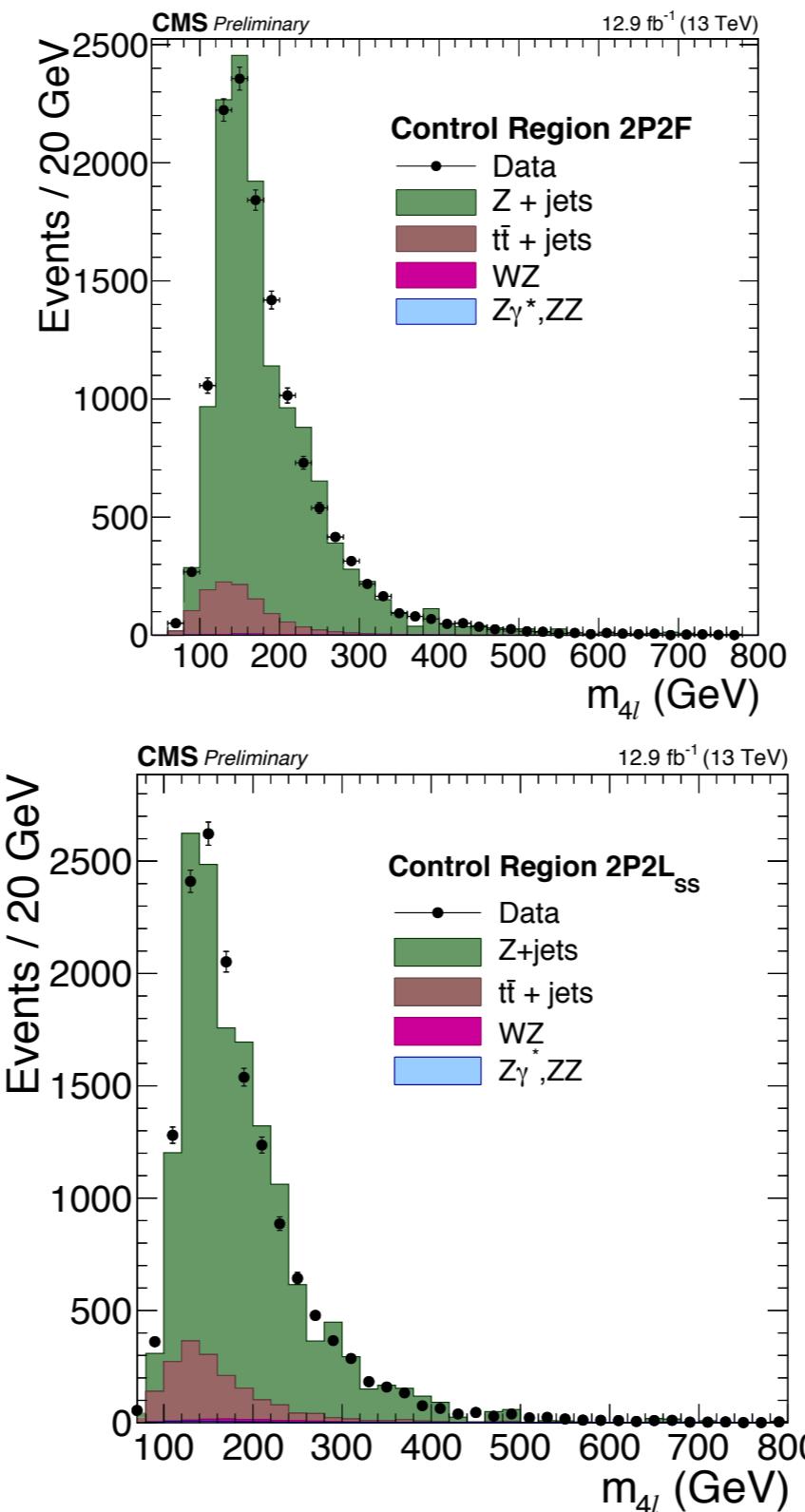
Seth Zenz, Imperial College London
On Behalf of the CMS Collaboration

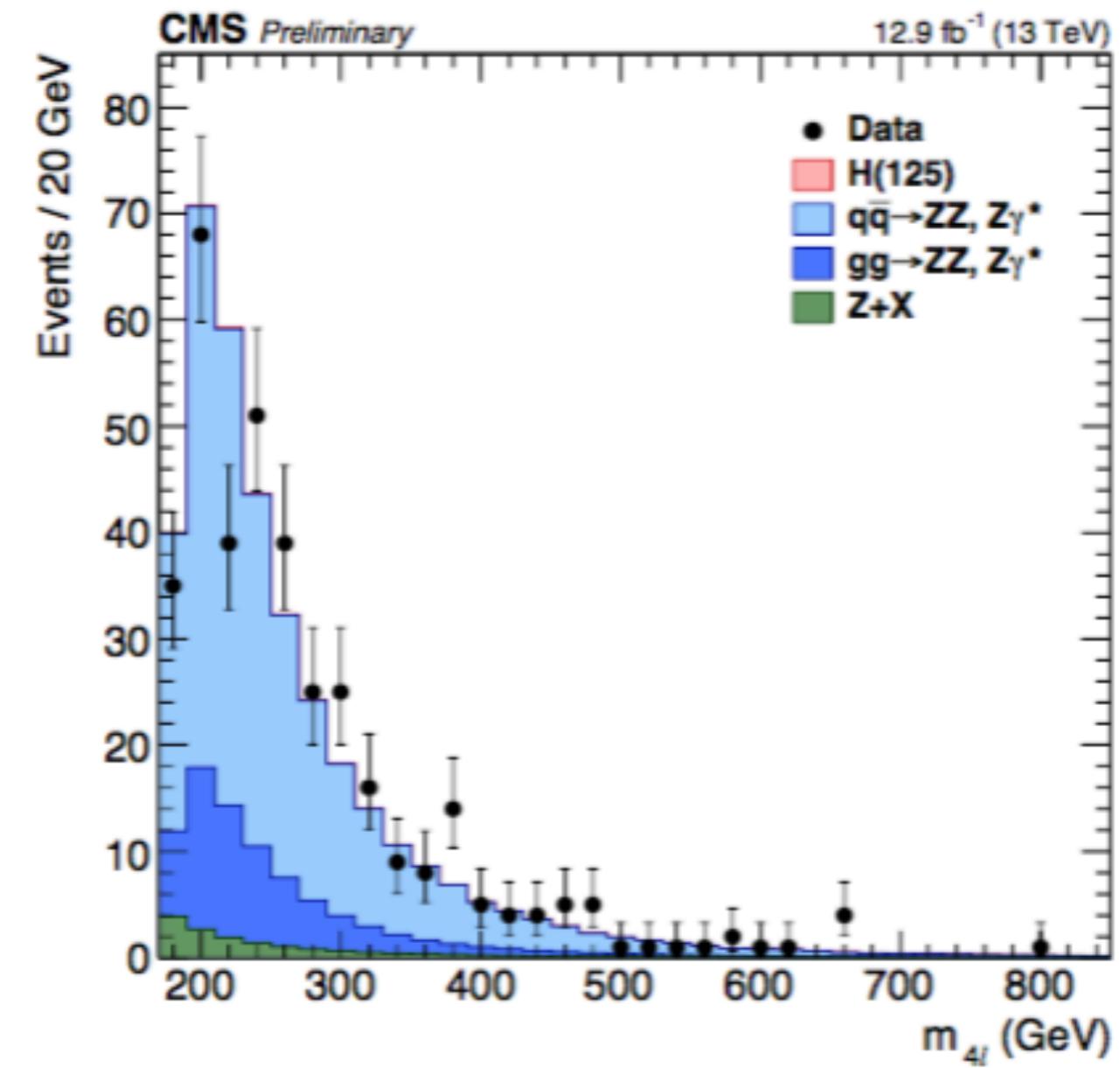
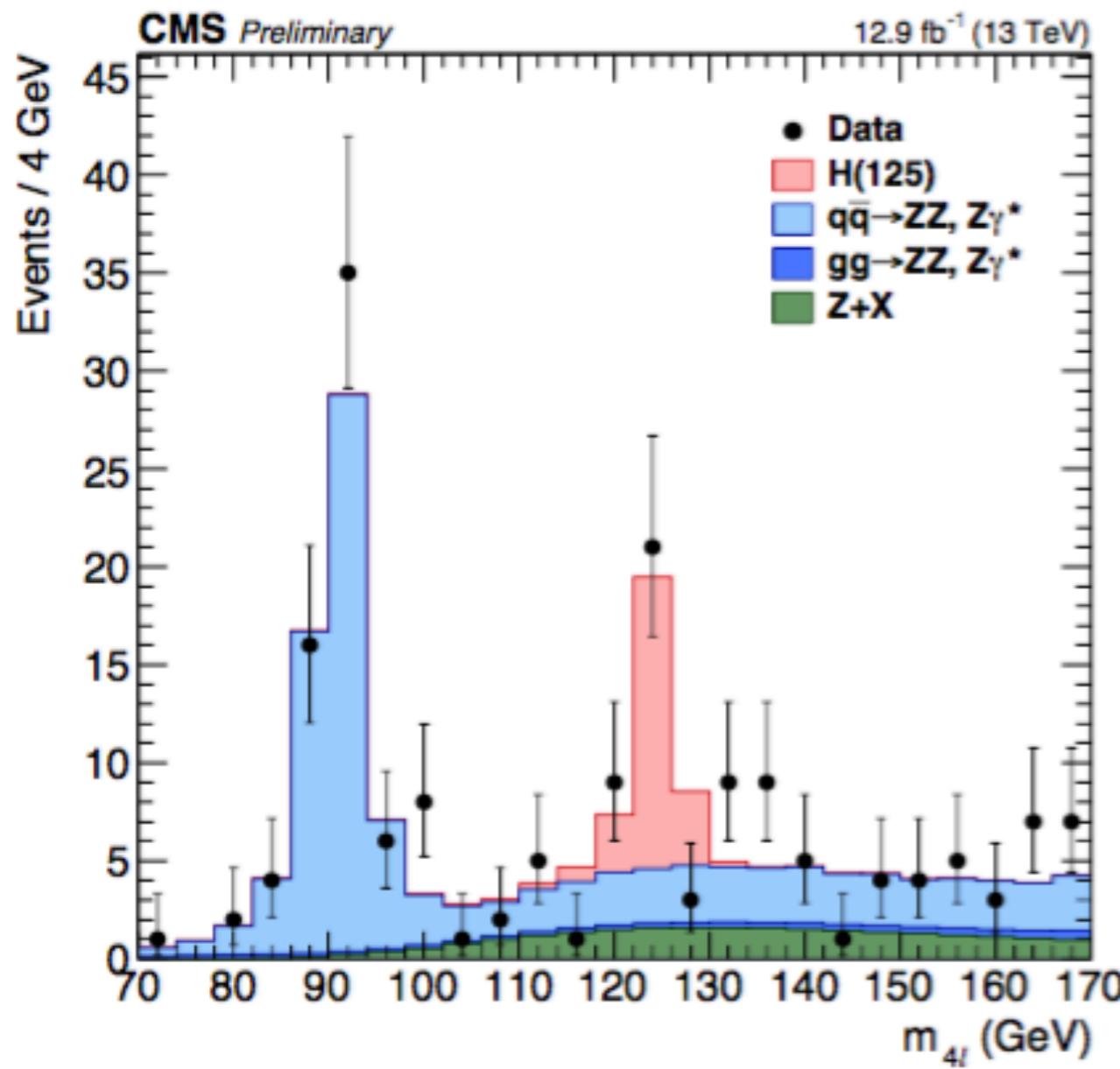
4 April 2017
DIS17 WG3

- $X \rightarrow ZZ^{(*)} \rightarrow 4\ell$, 12.9 fb^{-1} , CMS-PAS-HIG-16-033
 - Builds on SM Higgs analysis
 - $H(125)$ width measurements
 - High-mass resonance search
- $X \rightarrow ZZ \rightarrow \ell\ell qq$, 12.9 fb^{-1} , CMS-PAS-HIG-16-034
 - Merged and resolved jet selections
 - High mass resonance search
- $X \rightarrow WW \rightarrow 2\ell 2\nu$, 2.3 fb^{-1} , CMS-PAS-HIG-16-023
- More diboson resonance searches tomorrow
 - Search for new resonances decaying into W, Z and H bosons at CMS - Alberto Zuchetta
 - Searches for High Mass BSM Scalars in $Z\gamma$ and $\gamma\gamma$ Final States - Kyungwook Nam

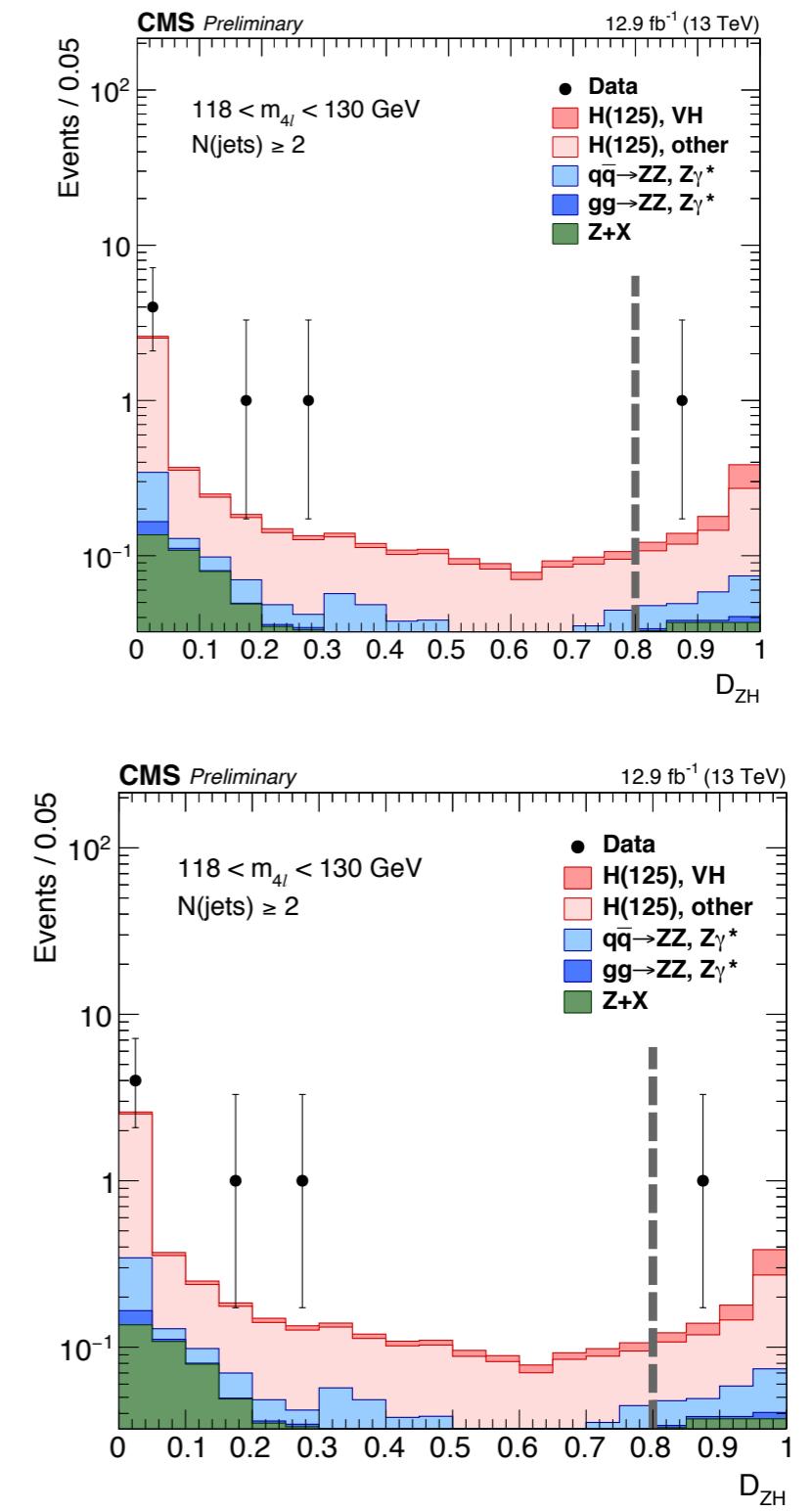
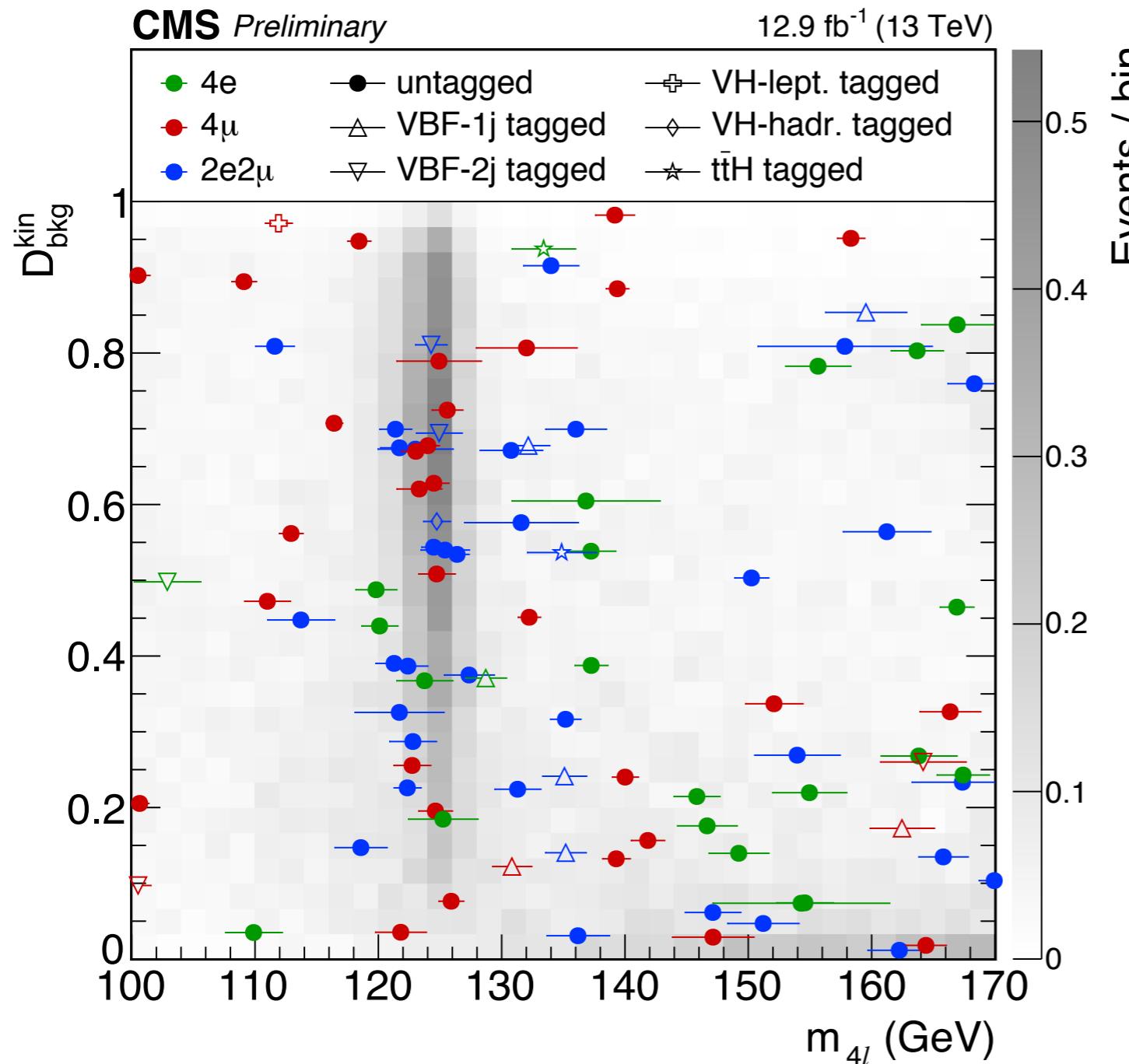


- $e (\mu) p_T > 7 (5)$ GeV, $|\eta| < 2.5 (2.4)$
- Leading 2 leptons: $p_T > 20, 10$ GeV
- FSR Recovery
- Irreducible background from simulation: SM ZZ
- Reducible background: secondary or fake leptons from jets
 - Rate measured in control regions

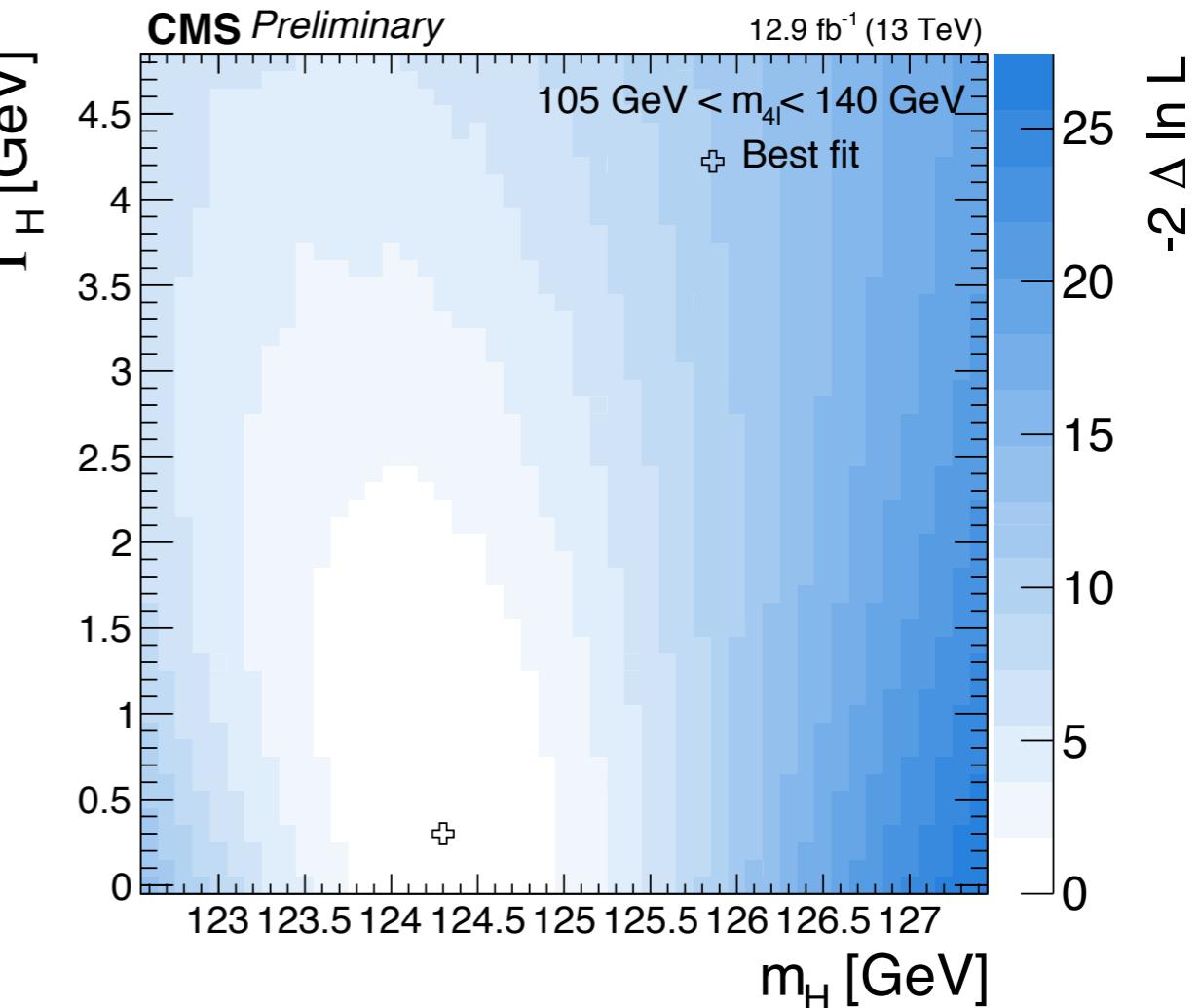
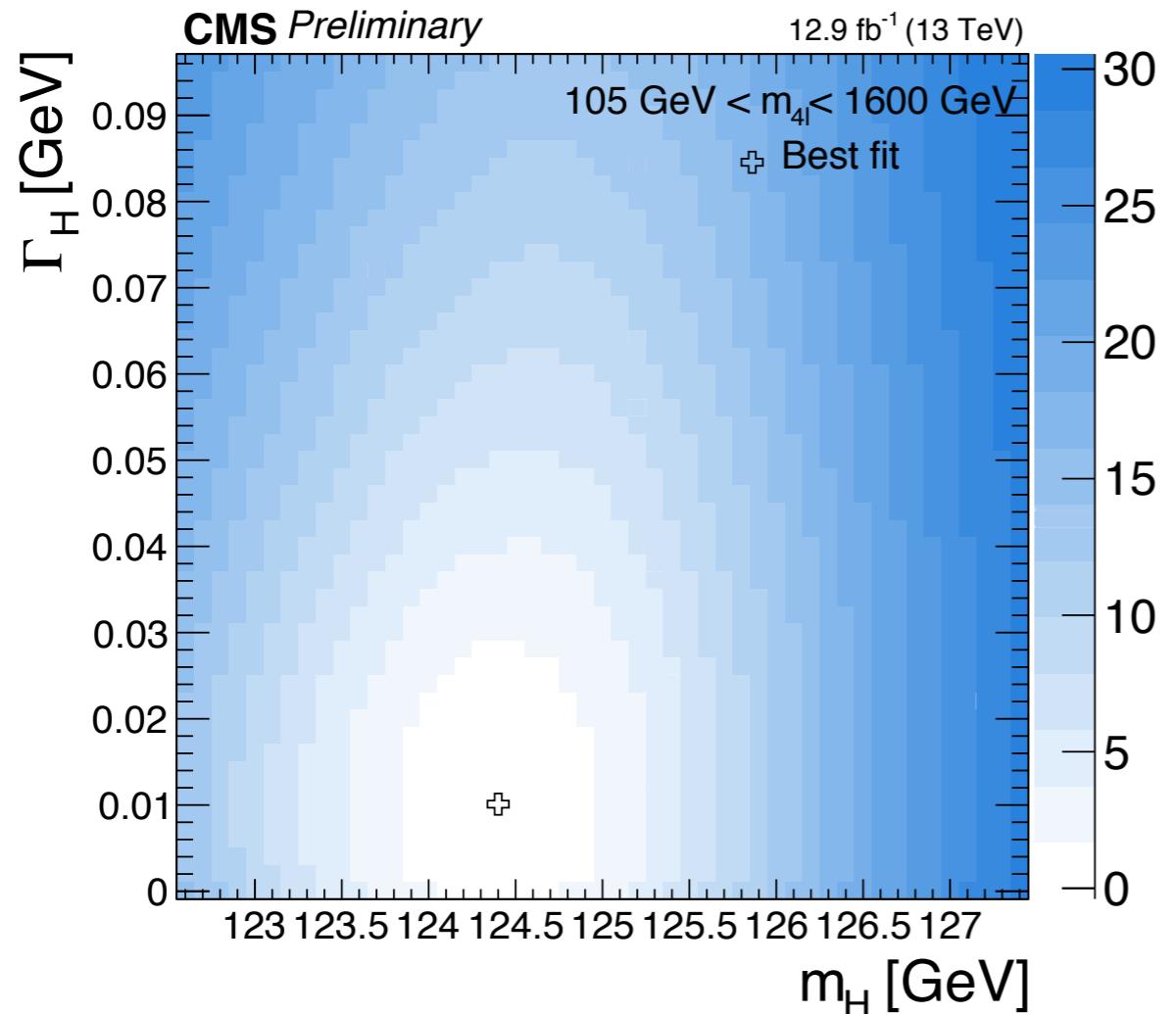


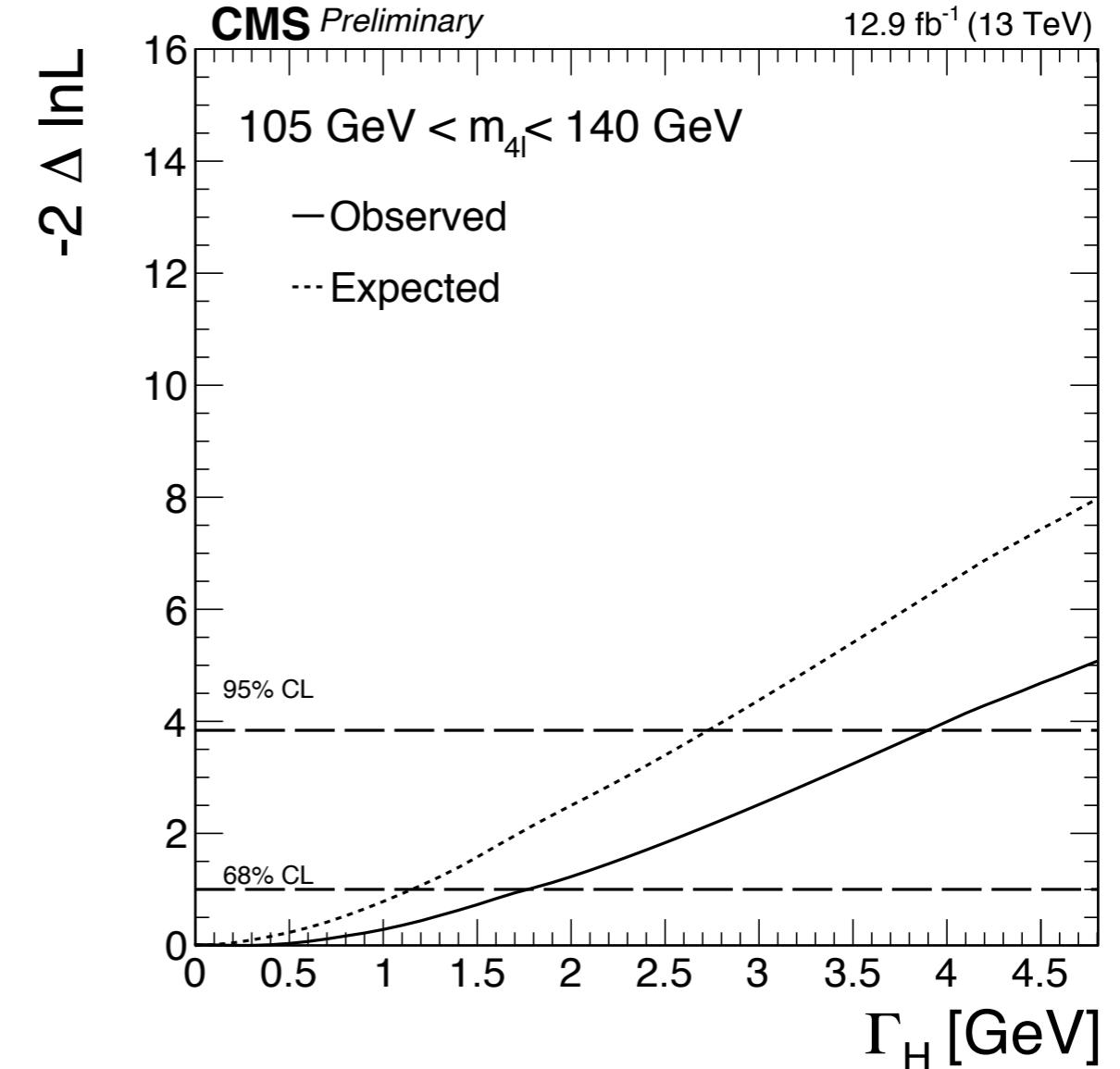
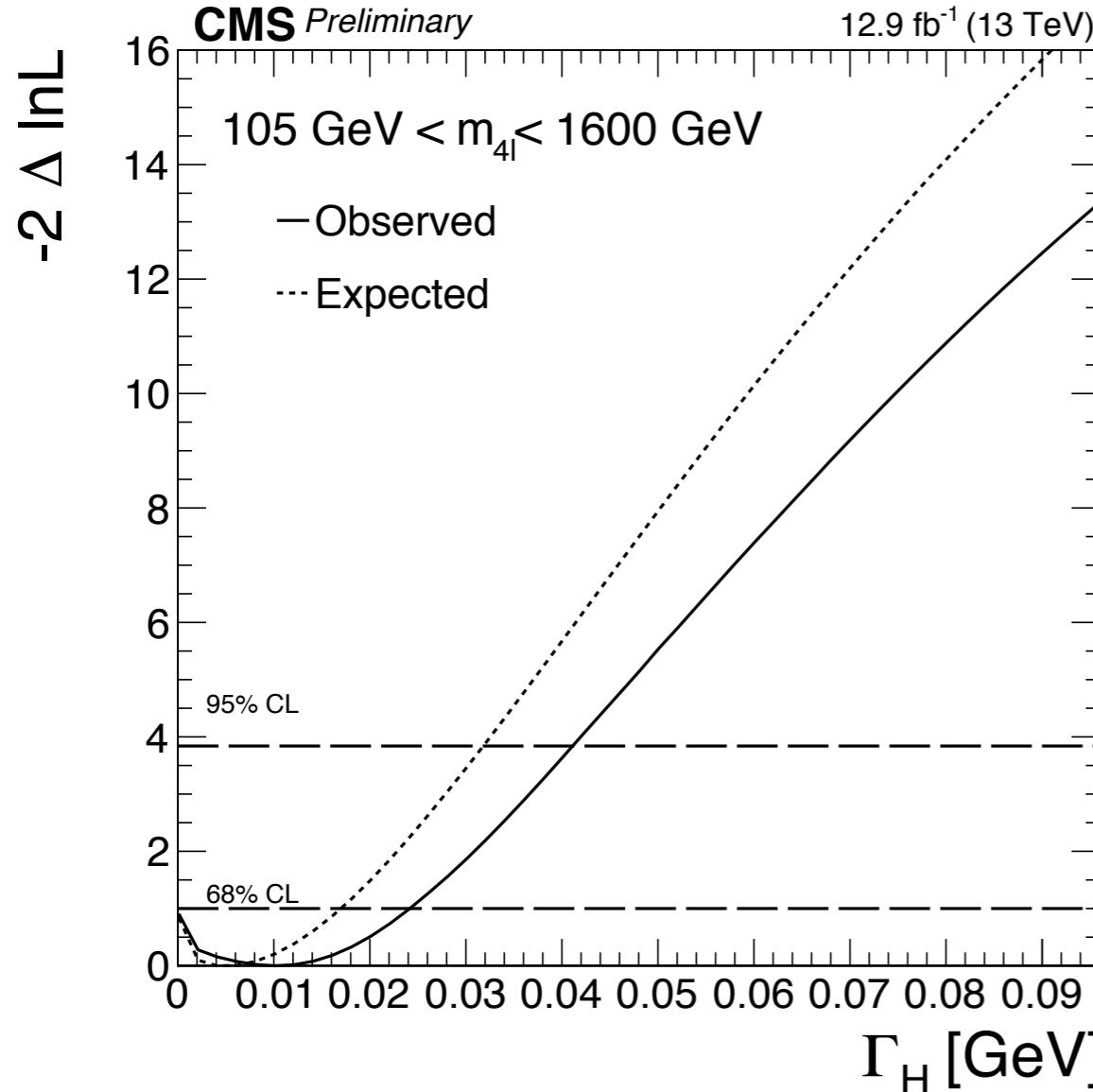


- Kinematic discriminants in 118-130 GeV



- In SM, $\Gamma_H = 4.1 \text{ MeV}$
- Measure Γ_H through likelihood fit to $m_{4\ell}$ including interference
- Fit using SM off-shell cross section prediction up to 1600 GeV: $\Gamma_H < 41 \text{ MeV}$
 - Assumes SM cross sections and no SM particles in loops
- Fit on-shell only: $\Gamma_H < 3.9 \text{ GeV}$ (no assumptions about BSM particles)

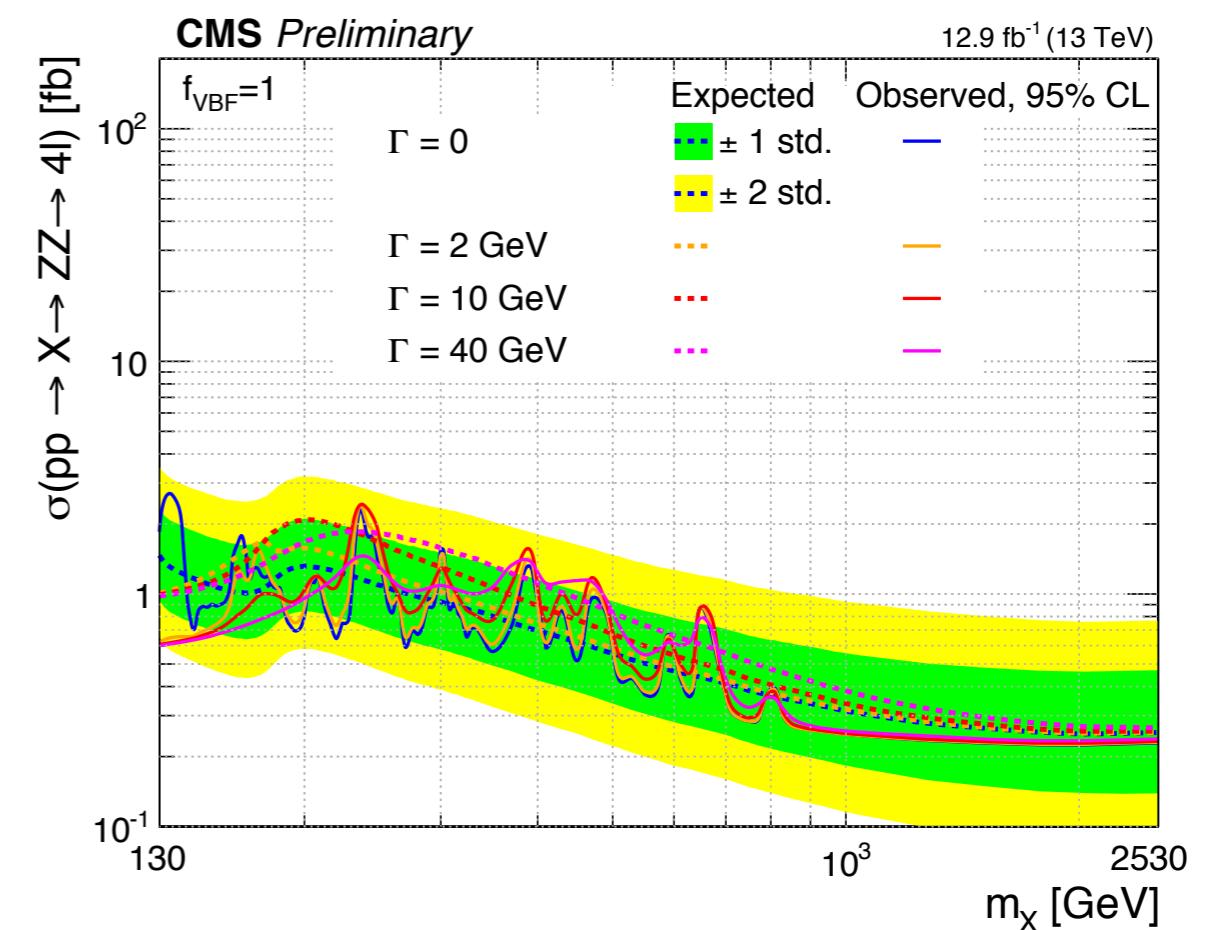
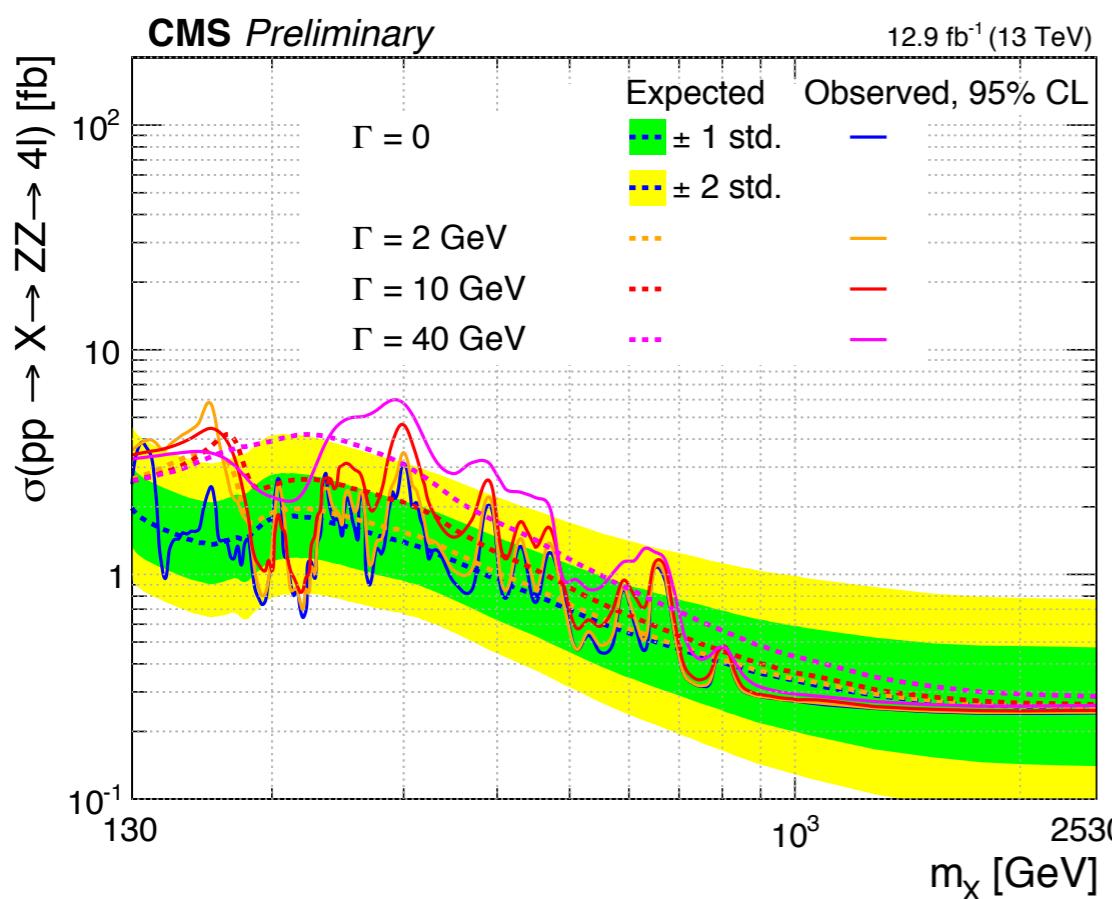




Parameter	$m_{4\ell}$ range	Observed	Expected
Γ_H (GeV)	[100, 1600]	$0.010^{+0.014}_{-0.010}$ [0.000, 0.041]	$0.004^{+0.013}_{-0.004}$ [0.000, 0.032]
Γ_H (GeV)	[105, 140]	$0.3^{+1.4}_{-0.0}$ [0.0, 3.9]	$0.0^{+1.1}_{-0.0}$ [0.0, 2.7]

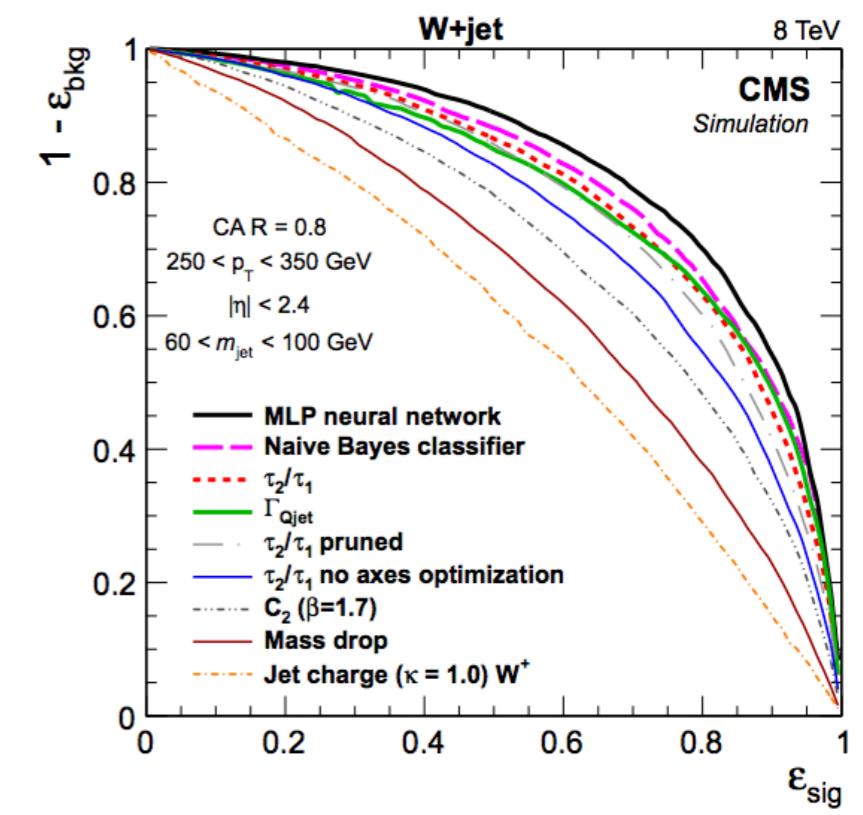
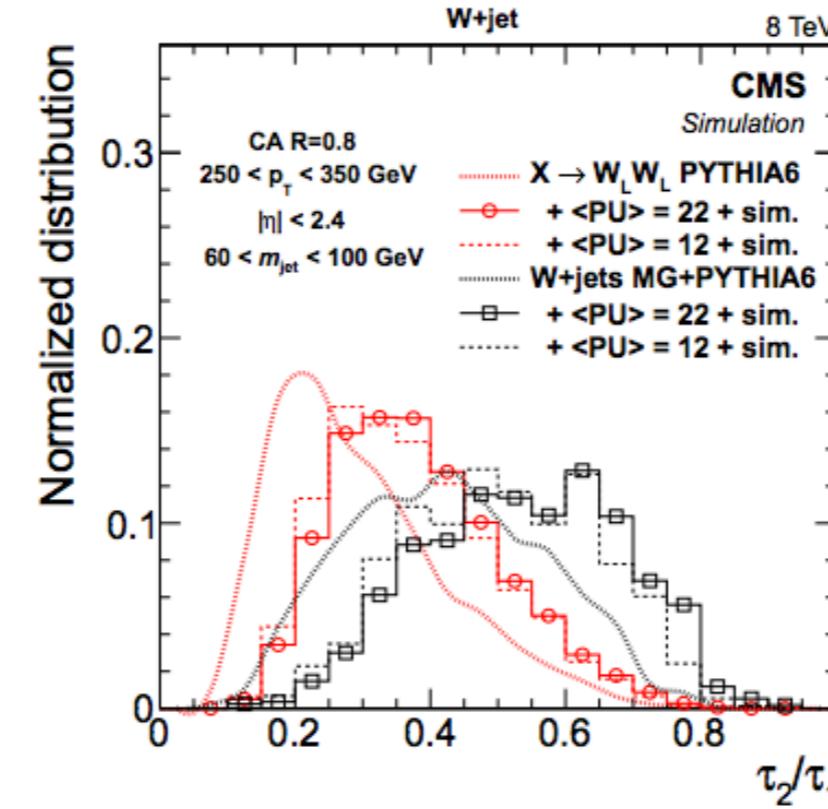
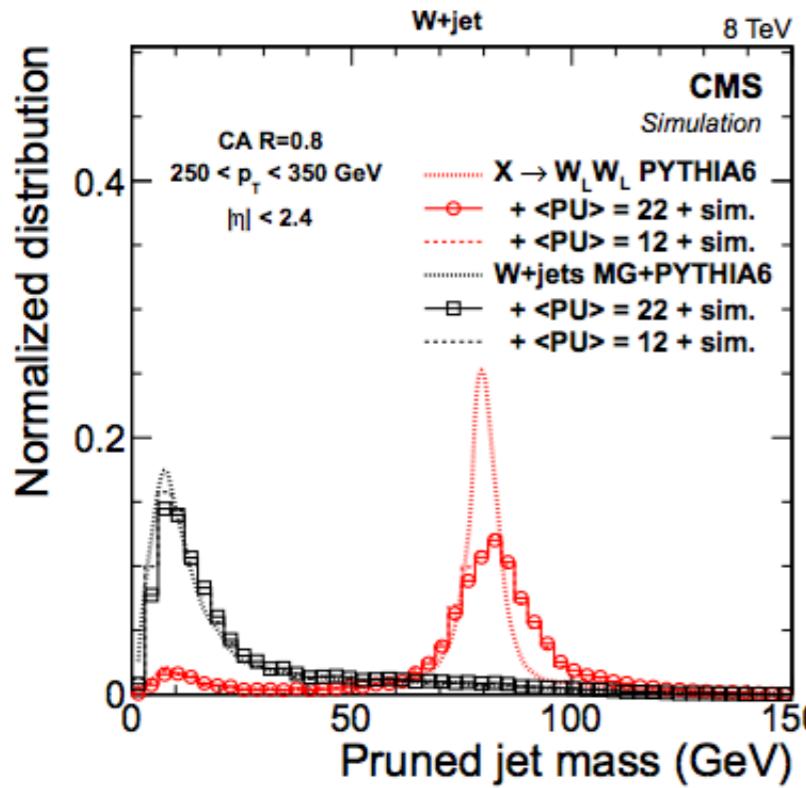
- $130 \text{ GeV} < m_X < 3000 \text{ GeV}$
- Relaxed electron selection allowed for $m_X > 300 \text{ GeV}$
- VBF fraction floating (left) or production mode fixed to all-VBF (right)

$$\mathcal{P}(m_{4\ell}|m_X, \Gamma_X, \sigma_X)$$

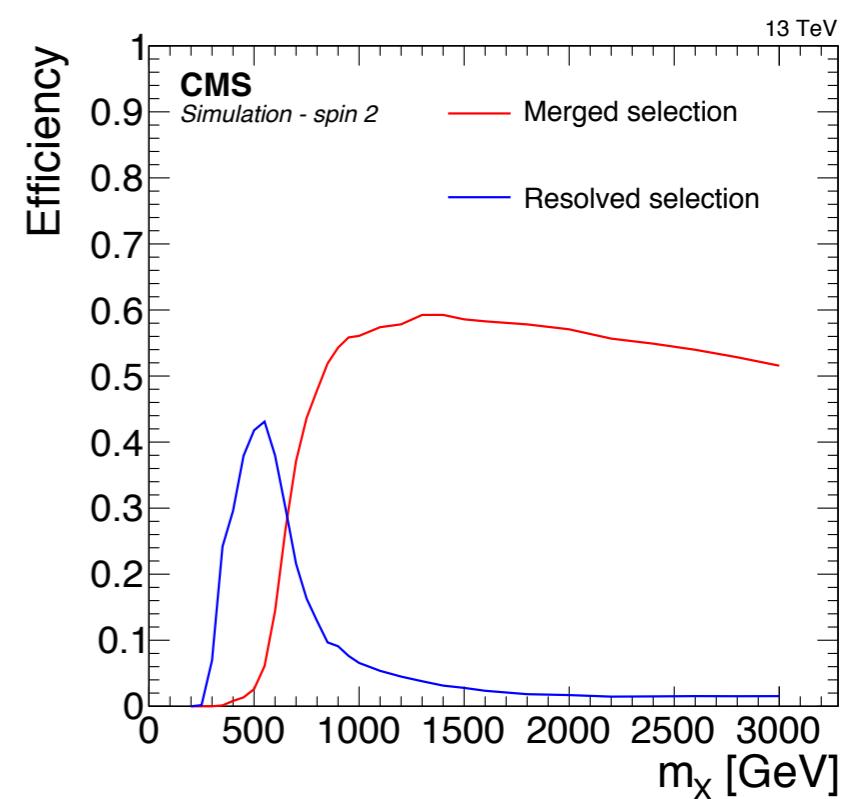
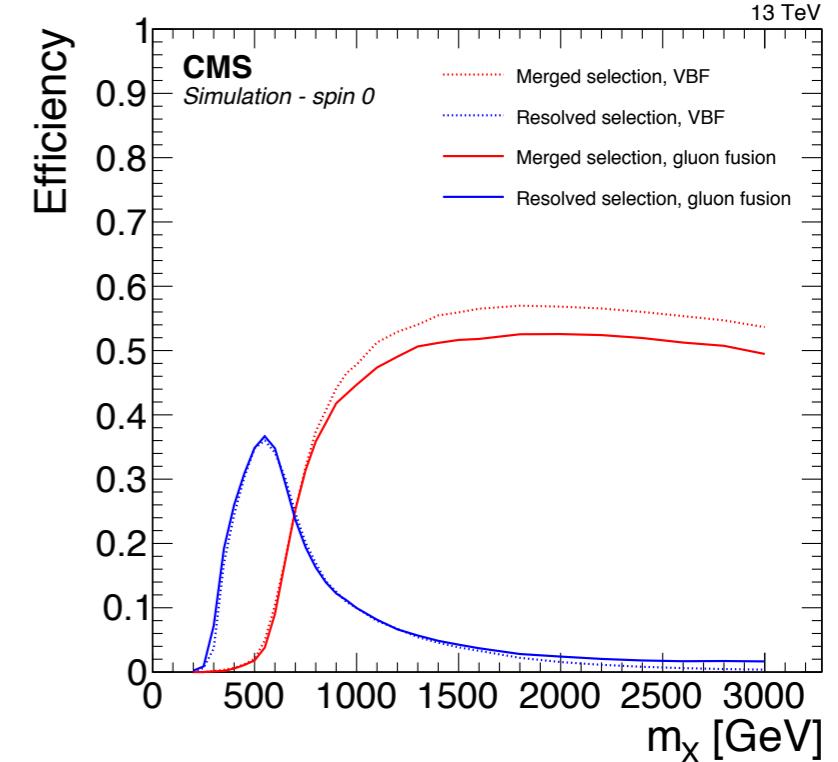


- CMS-PAS-HIG-16-034, 12.9 fb^{-1}
- $Z \rightarrow qq$ Selection:
 - 2 resolved jets, anti- k_T with $R = 0.4$
 - Merged jet, anti- k_T with $R = 0.8$, pruned mass m_j from 40 to 180 GeV

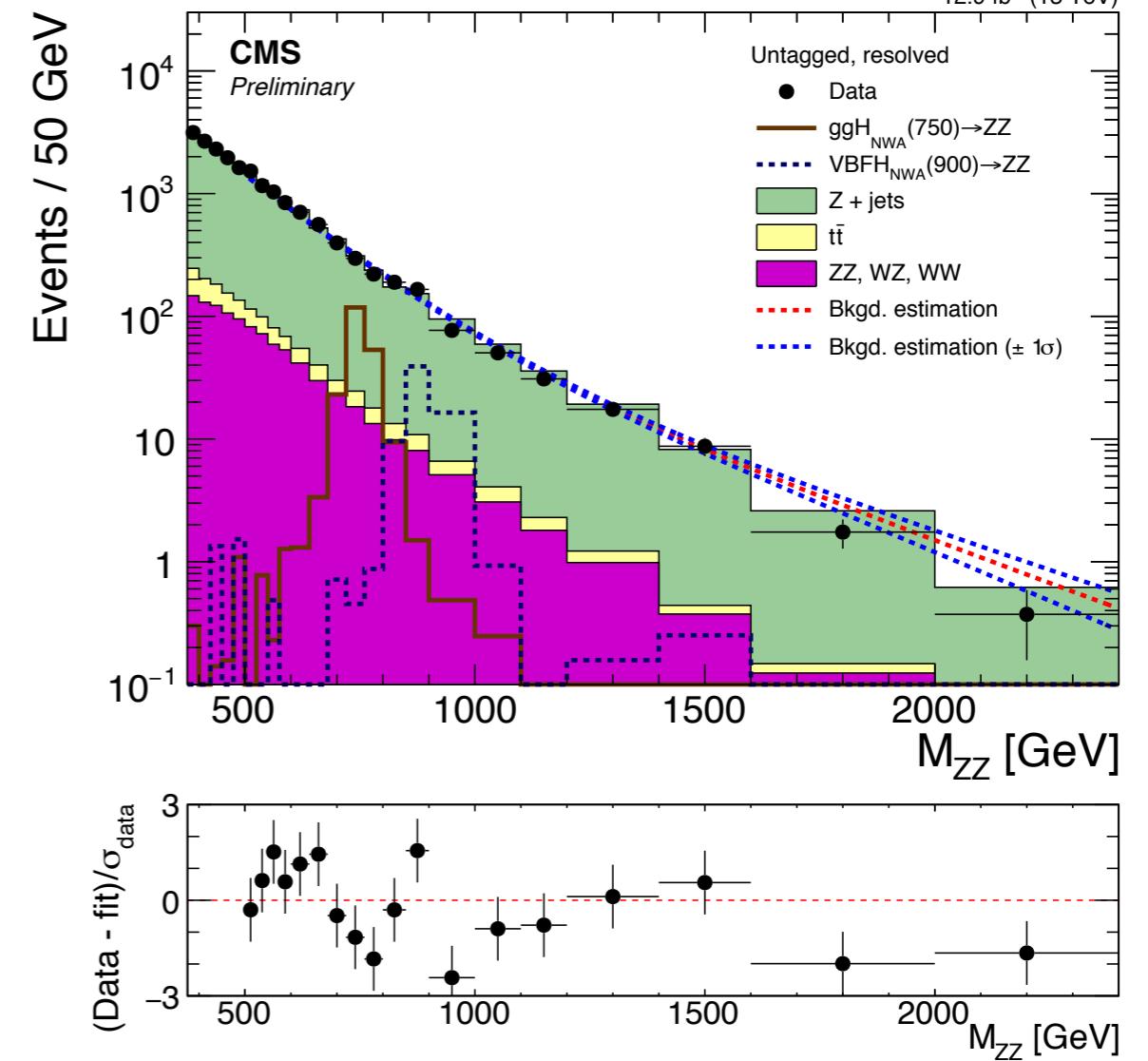
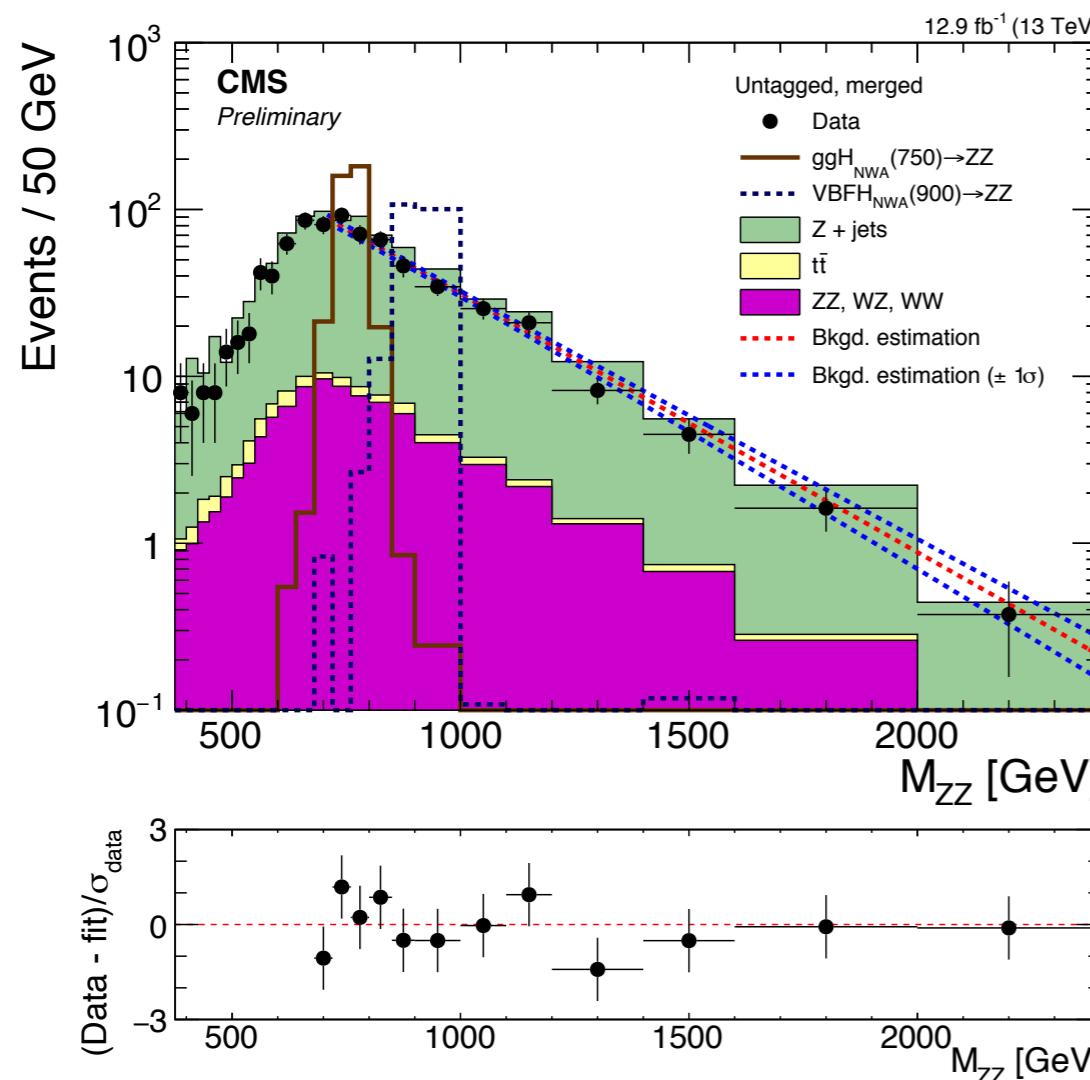
$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min(\Delta R_{1,k}, \Delta R_{2,k}, \dots, \Delta R_{N,k}) \quad \tau_{21} = \tau_2 / \tau_1 < 0.6$$



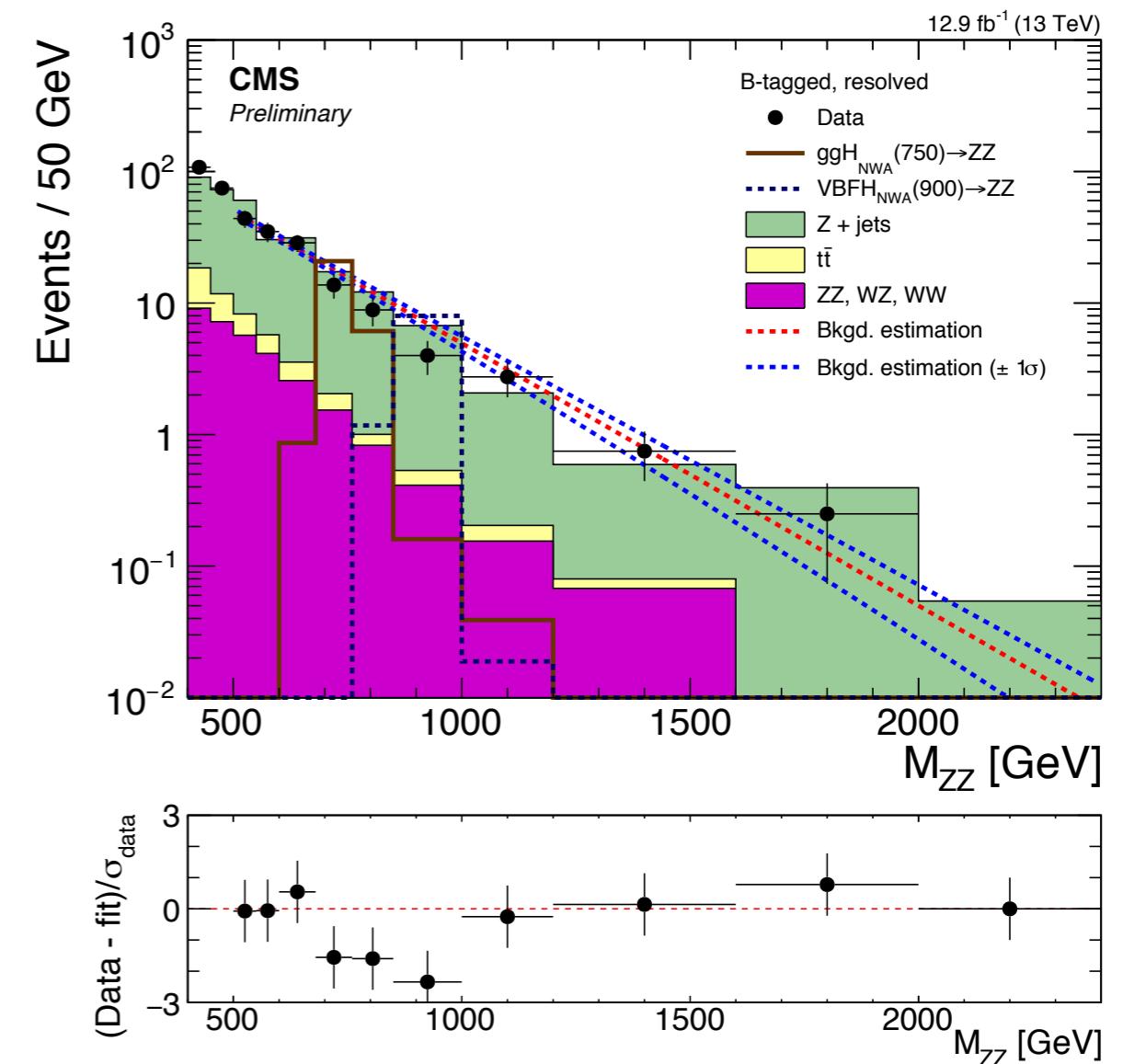
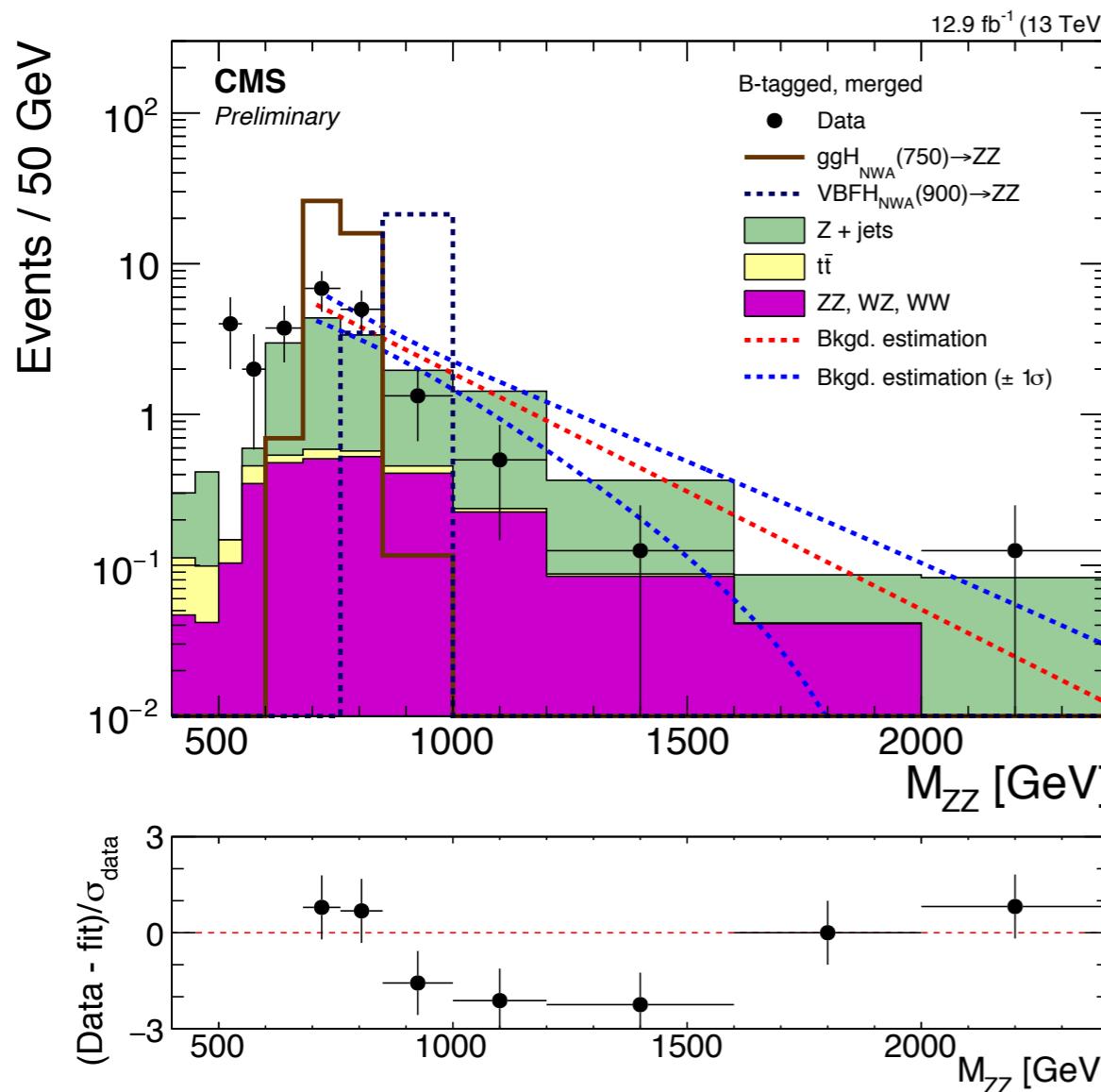
Observable	Selection
	Same lepton flavour, opposite charge
$p_T(\ell)$ (GeV)	> 24/40
$ \eta(\ell) $	(e) < 2.5, (μ) < 2.4
$M(\ell^+\ell^-)$ (GeV)	[60, 120]
$p_T(\ell^+\ell^-)$ (GeV)	> 100
p_T (jet) (GeV)	> 30
$ \eta(\text{jet}) $	< 2.4
$\Delta R(\ell, \ell)$	> 0.02
$\Delta R(\ell, \text{jet})$	> 0.4 (AK4 jets) > 0.8 (AK8 jets)
$M(Z_{\text{had}})$ (GeV)	[40, 70] (lower sideband) [70, 105] (signal region) [105, 135] (Higgs boson region, not used in this analysis) [135, 180] (upper sideband)
$p_T(Z_{\text{had}})$ (GeV)	> 100 (resolved) > 170 (merged) < 0.6 (merged only)
τ_{21}	
VBF-tagged	M_{ZZ} -dependent selection on $\mathcal{D}_{2\text{jet}}$
b-tagged	not VBF-tagged and two b-tagged components of Z_{had}
untagged	not VBF-tagged and not b-tagged

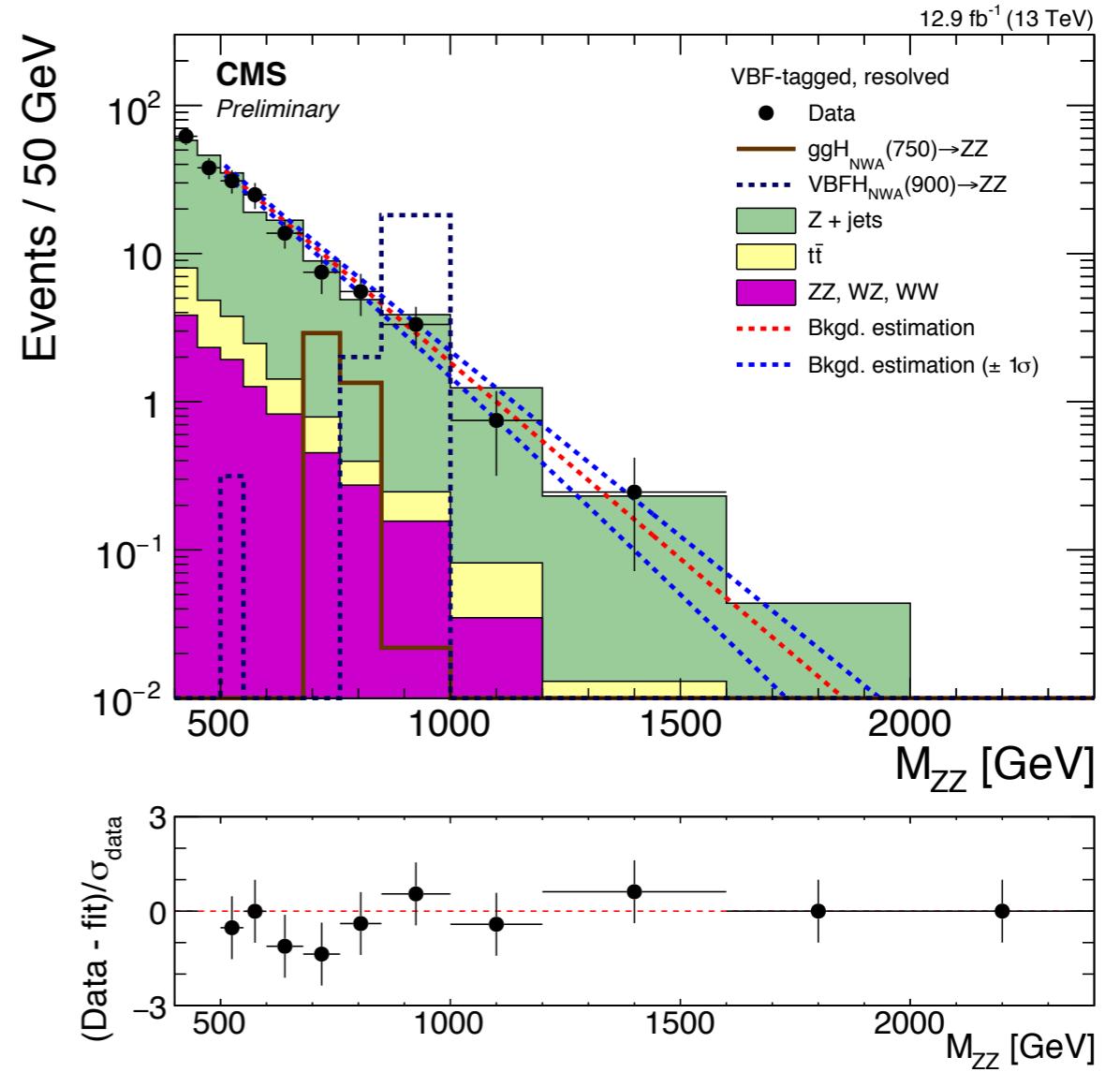
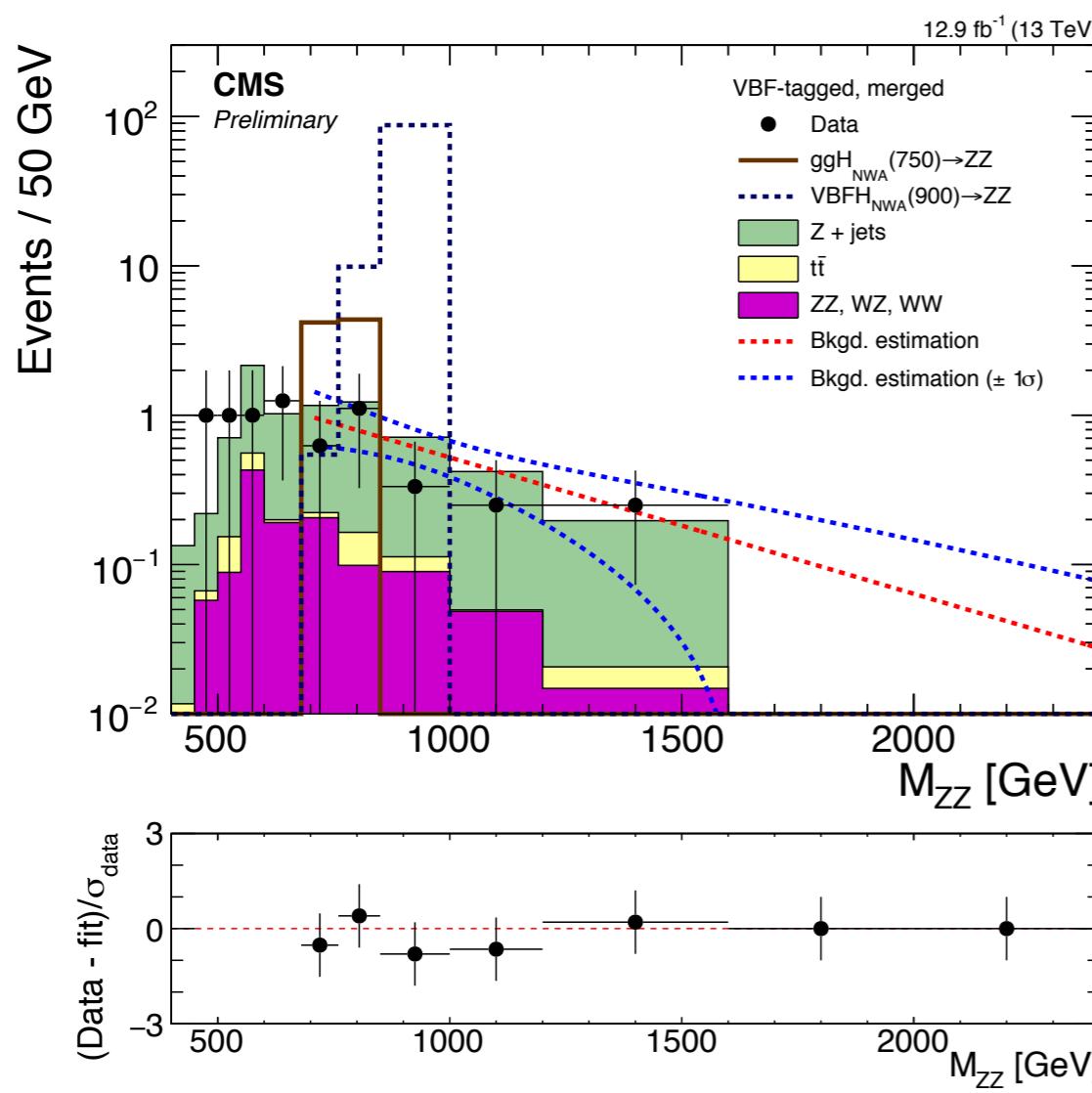


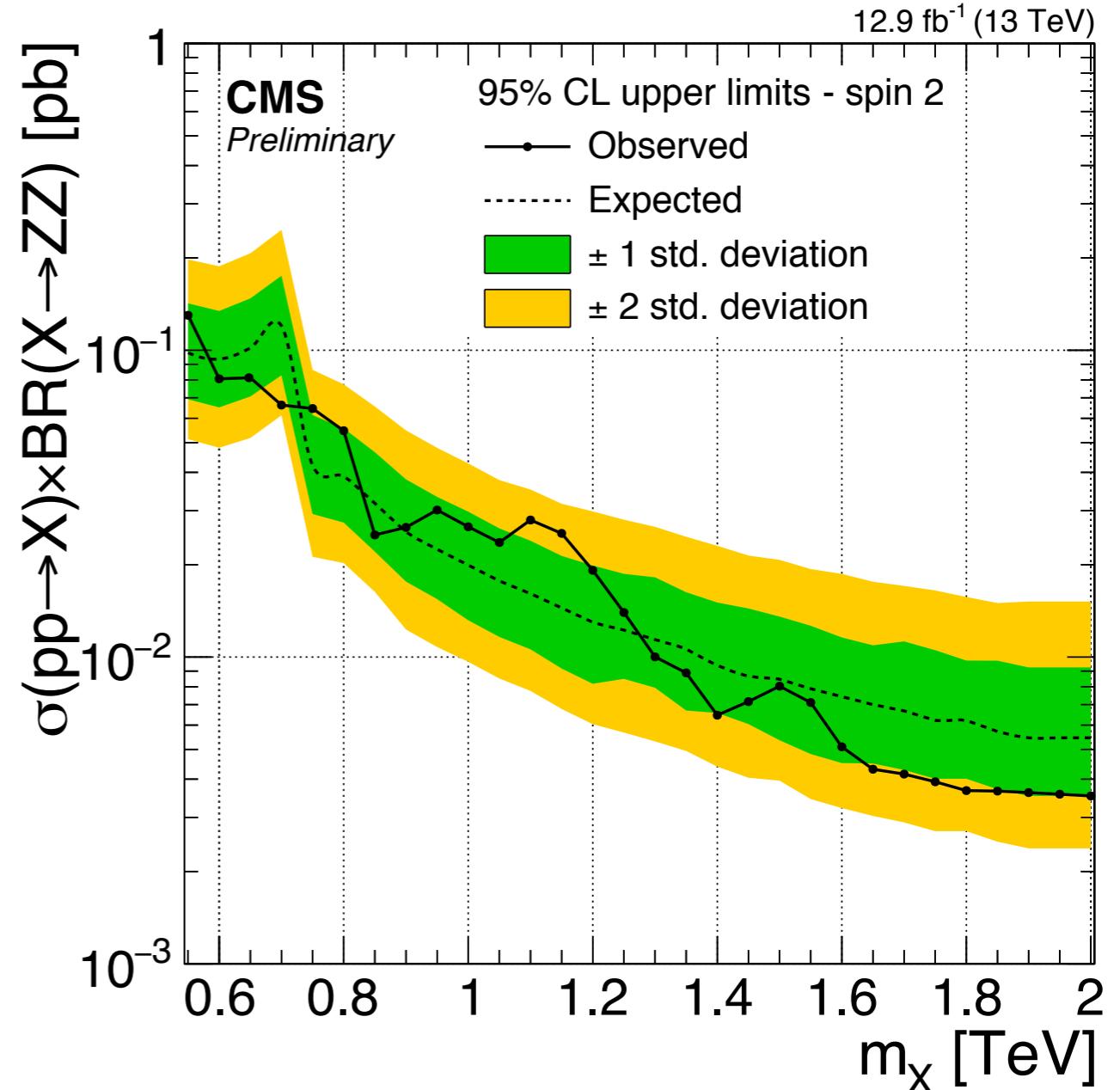
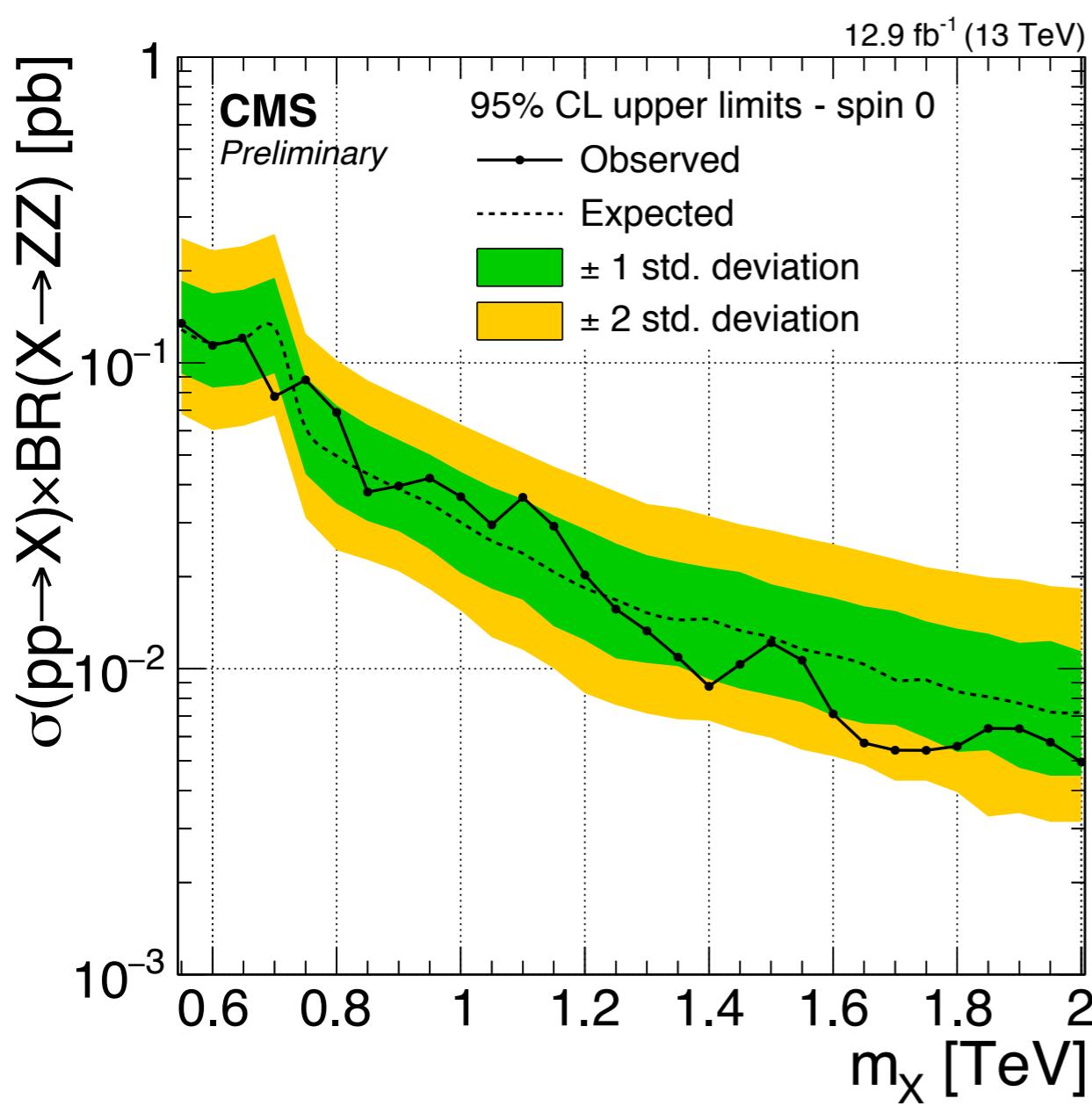
Untagged



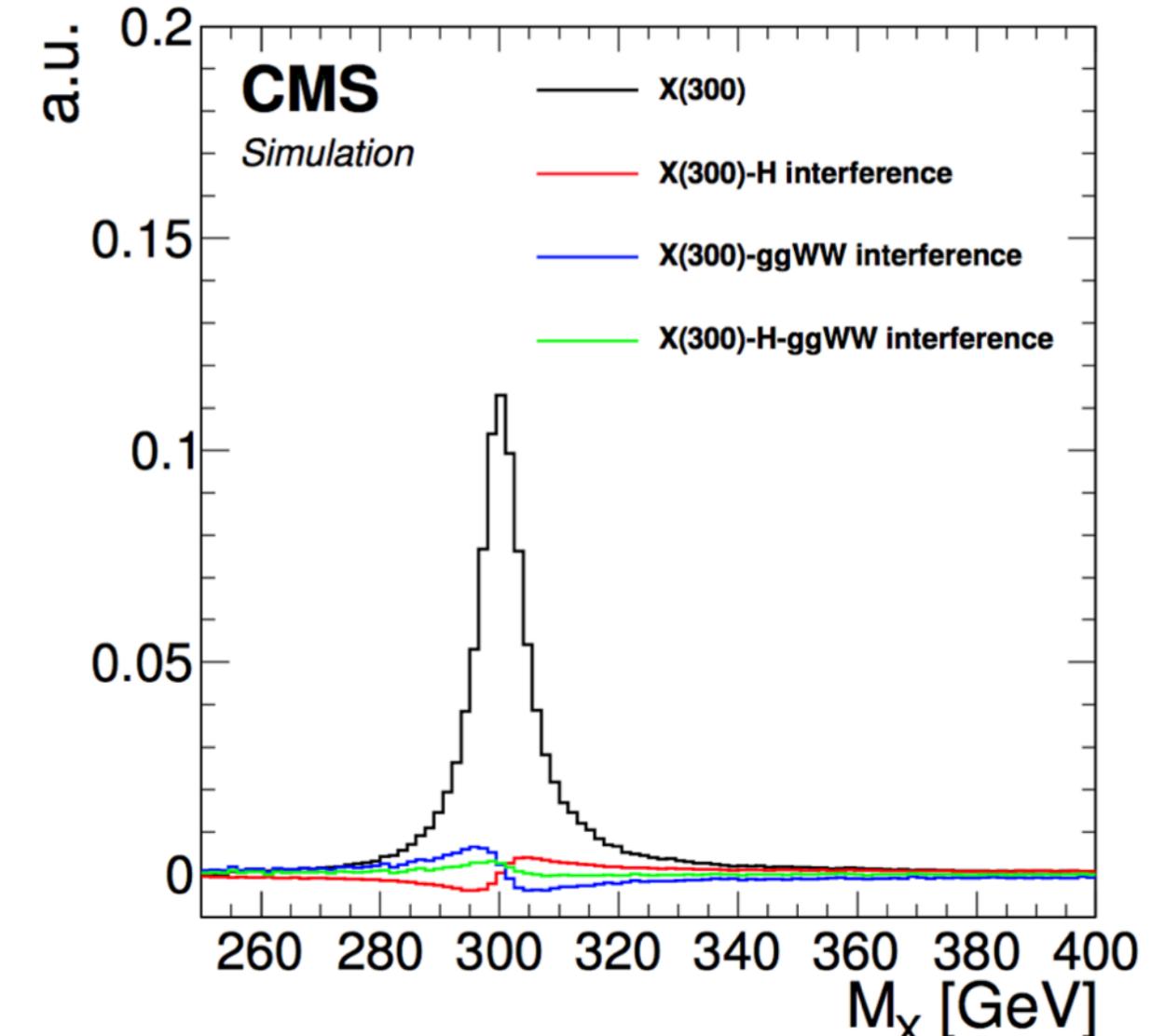
B-Tagged



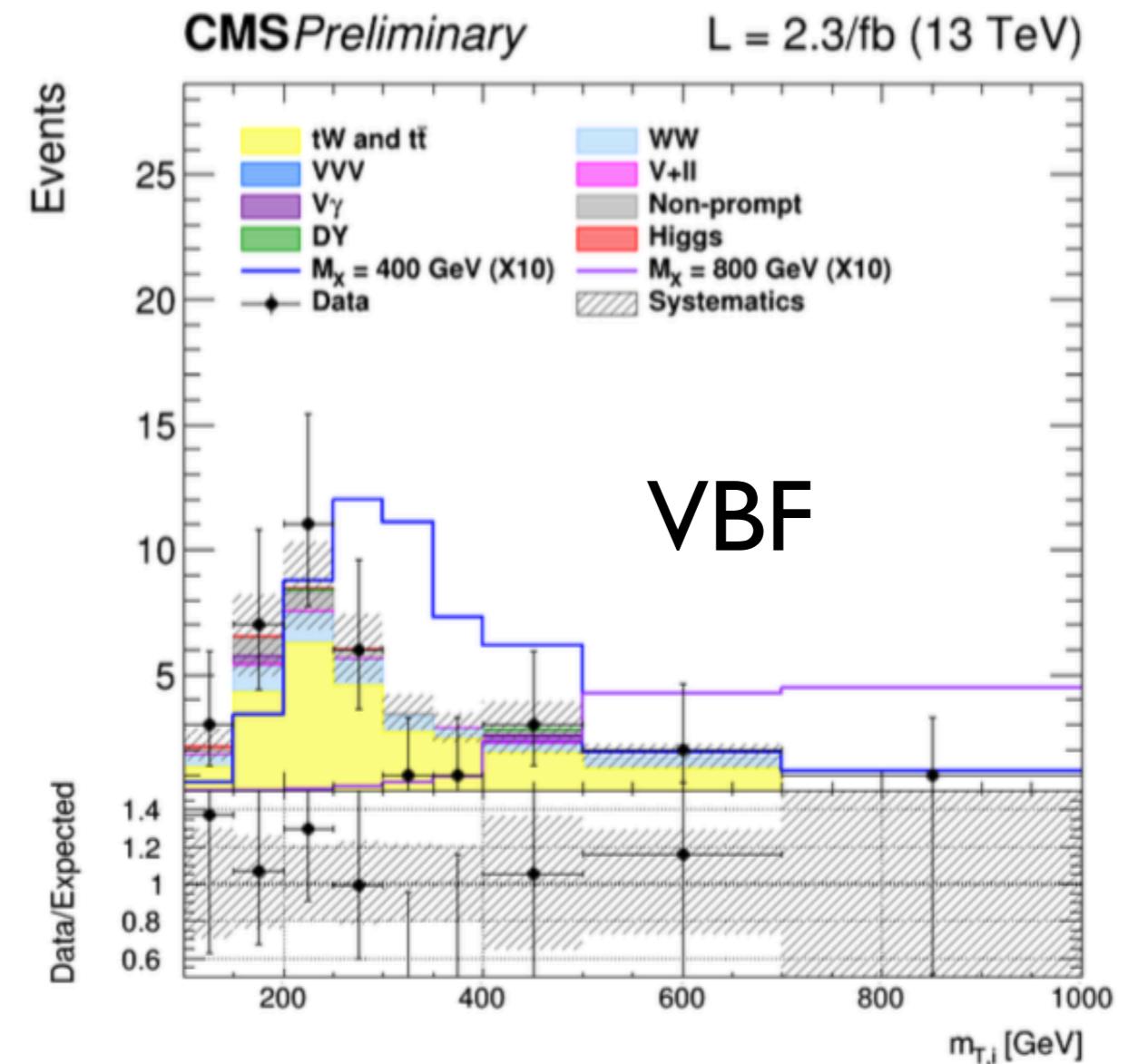
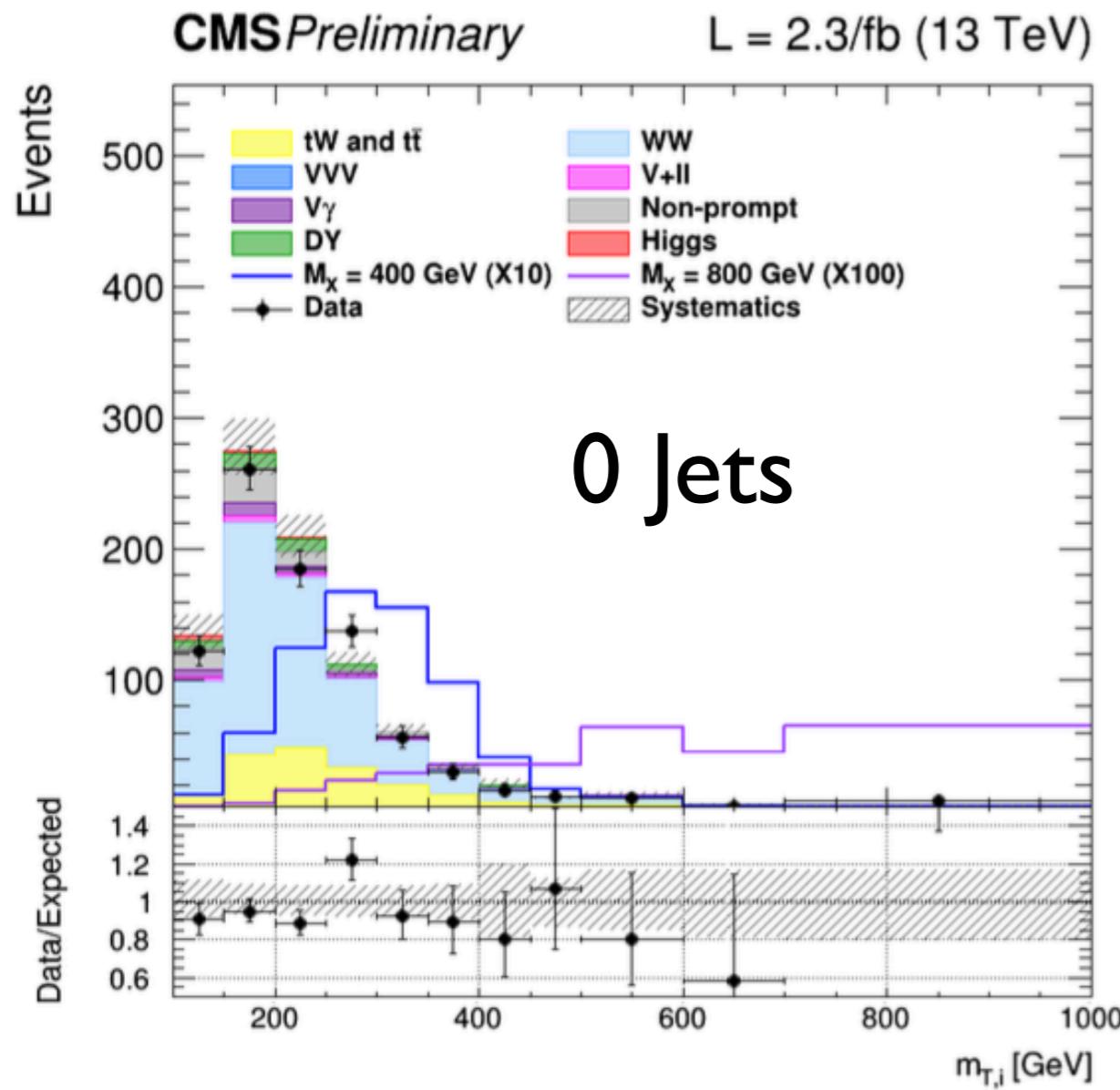




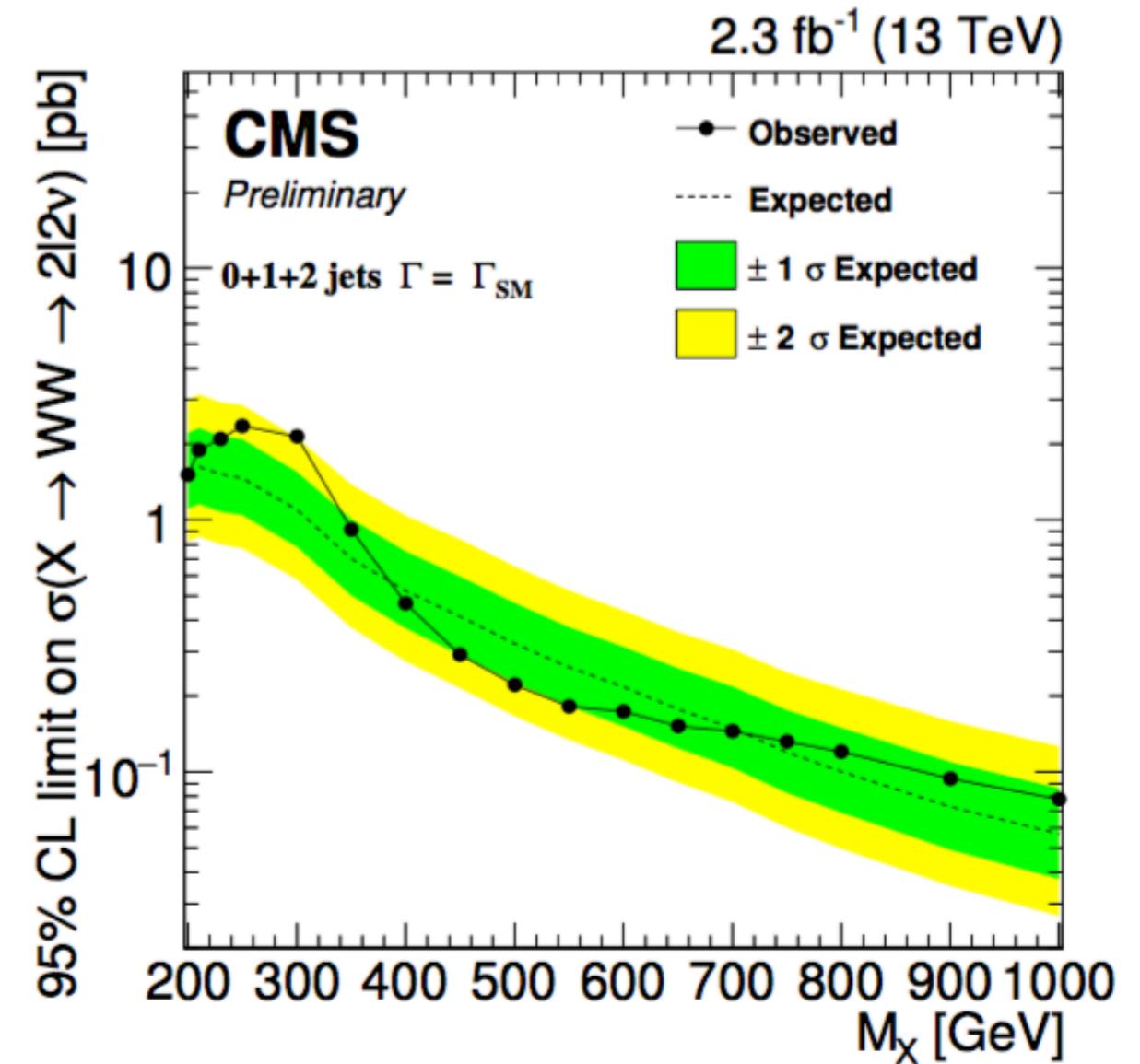
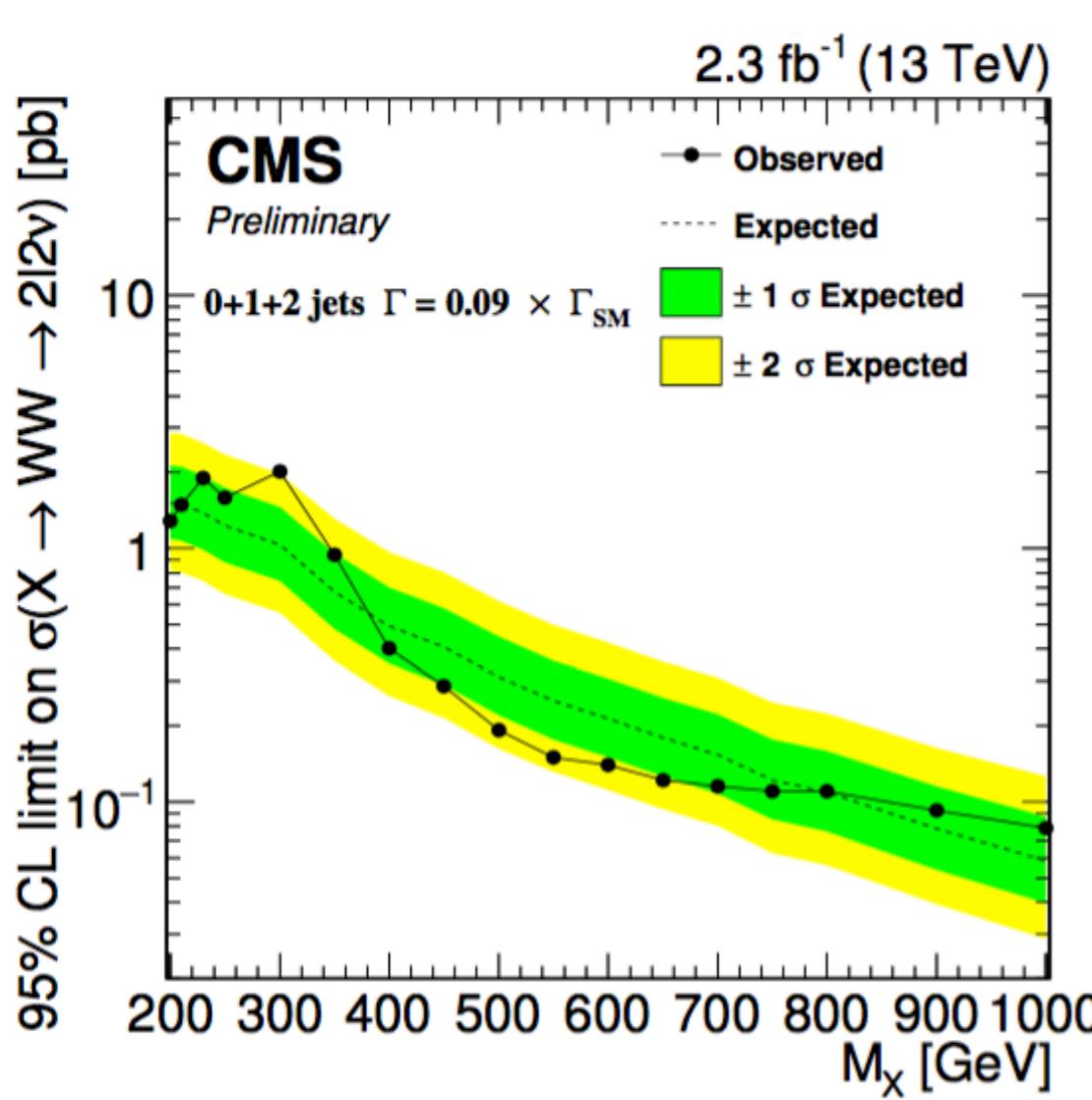
- Search for Spin 0 Resonance
- $200 \text{ GeV} < m_X < 1000 \text{ GeV}$
- $\geq 1 e, \geq 1 \mu$ with $p_T > 20 \text{ GeV}$
 - Additional leptons rejected
 - Reject $WW \rightarrow 2\tau 2\nu: m_T > 60 \text{ GeV}$
 - Reject leptonic top: no b-jets
- VBF: 2 jets with $p_T > 30 \text{ GeV}$,
 $|\Delta\eta| > 3.5, m_{jj} > 500 \text{ GeV}$
- Estimate background normalizations
from control regions with inverted cuts
- Extract final signal and background
yields from fit to m_T in 0-jet, 1-jet, VBF
categories



$$m_T = \sqrt{2p_T^{\ell\ell} E_T^{\text{miss}} (1 - \cos \Delta\phi(\ell\ell, \vec{p}_T^{\text{miss}}))}.$$



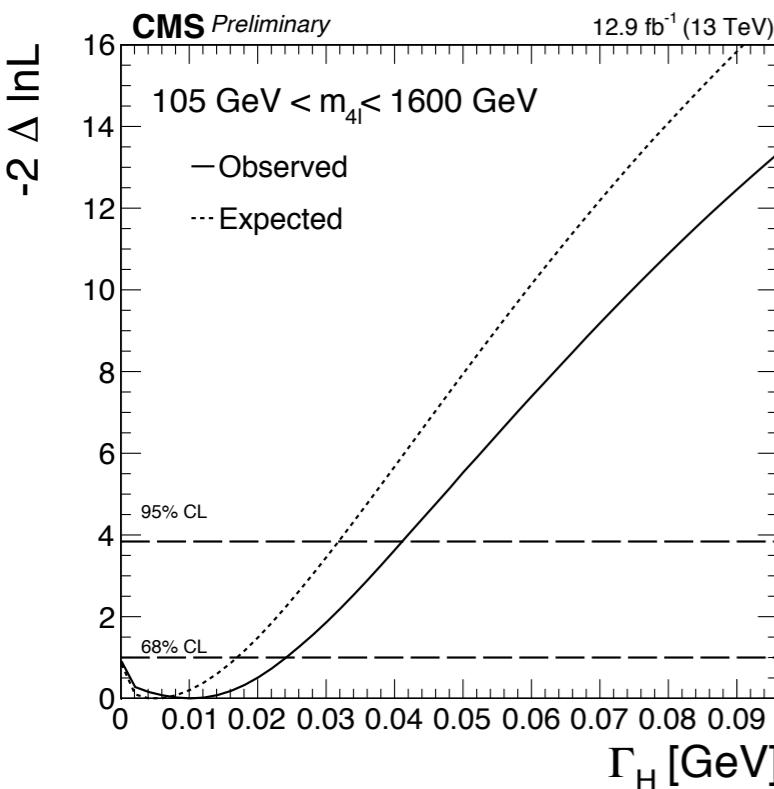
- Limits set for several signal width hypotheses



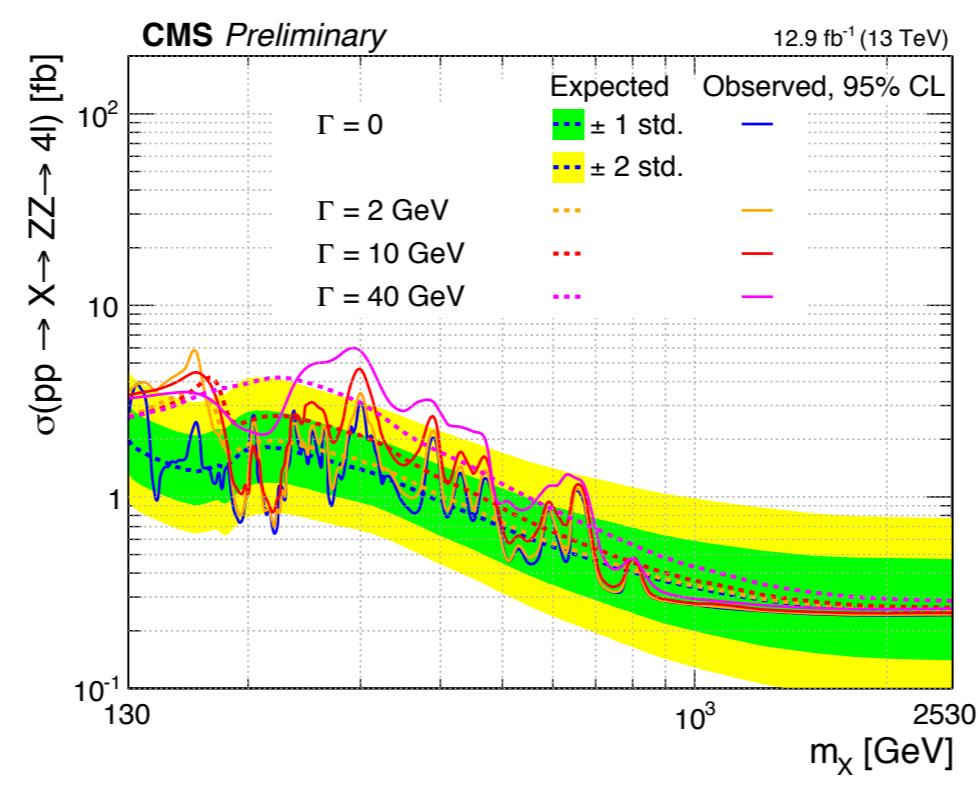
Conclusions

- Techniques used to discover and measure the SM Higgs have direct applications to searches for high-mass neutral BSM particles
- No new diboson resonances found (yet!)

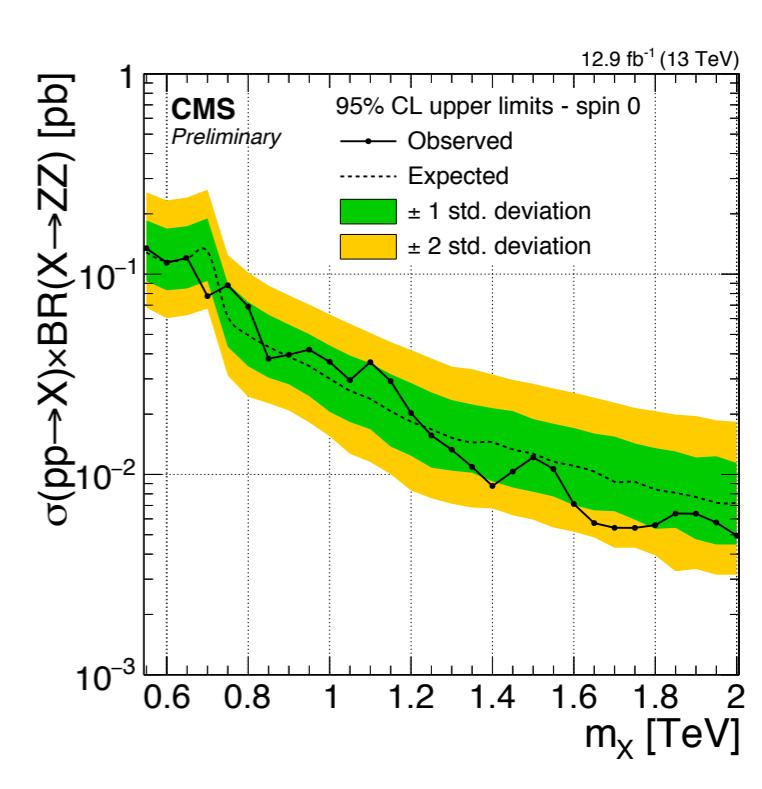
Width from $H^{(*)} \rightarrow ZZ \rightarrow 4\ell$



$X \rightarrow ZZ \rightarrow 4\ell$



$X \rightarrow ZZ \rightarrow \ell\ell qq$



Extras

Table 5: Summary of the systematic uncertainties in the $H \rightarrow 4\ell$ measurements.

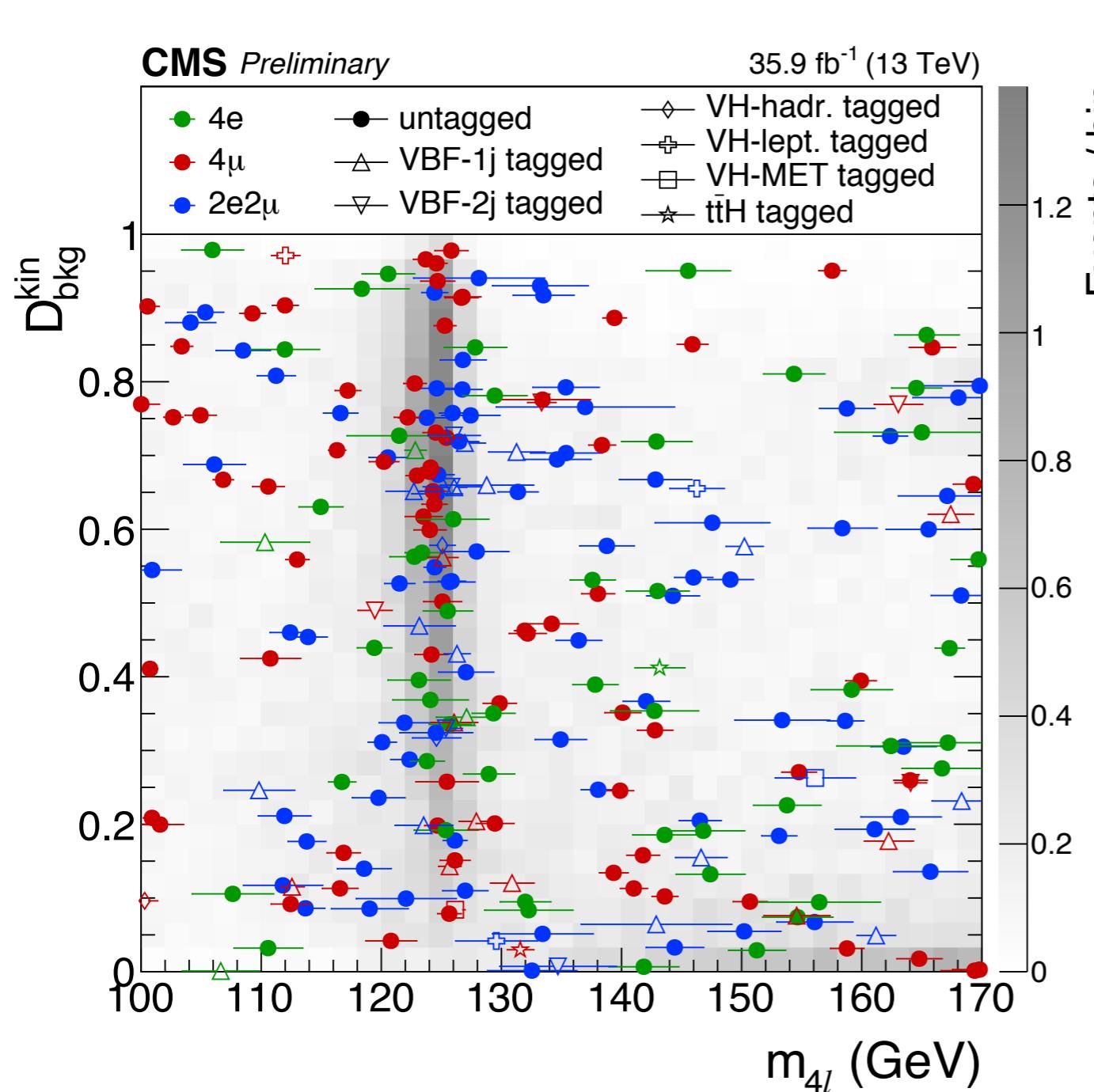
Summary of relative systematic uncertainties	
Common experimental uncertainties	
Luminosity	6.2 %
Lepton identification/reconstruction efficiencies	6 – 11 %
Background related uncertainties	
QCD scale ($q\bar{q} \rightarrow ZZ$, $gg \rightarrow ZZ$)	3 – 10 %
PDF set ($q\bar{q} \rightarrow ZZ$, $gg \rightarrow ZZ$)	3 – 5 %
Electroweak corrections ($q\bar{q} \rightarrow ZZ$)	1 – 15 %
$gg \rightarrow ZZ$ K factor	10 %
Reducible background ($Z+X$)	40 – 55 %
Event categorization (experimental)	2 – 18 %
Event categorization (theoretical)	3 – 20 %
Signal related uncertainties	
QCD scale ($q\bar{q} \rightarrow VBF/VH$, $gg \rightarrow H/t\bar{t}H$)	3 – 10 %
PDF set ($q\bar{q} \rightarrow VBF/VH$, $gg \rightarrow H/t\bar{t}H$)	3 – 4 %
$BR(H \rightarrow ZZ \rightarrow 4\ell)$	2 %
Lepton energy scale	0.04 – 0.3 %
Lepton energy resolution	20 %
Event categorization (experimental)	2 – 15 %
Event categorization (theoretical)	8 – 20 %

Table 2: Summary of systematic uncertainties on the signal normalisation in the resolved and boosted analyses.

Source	Resolved	Boosted	Comment
Luminosity		6.2%	
Electron trigger & ID	8.0%	8.0%	Tag-and-probe study
Muon trigger & ID	4.0%	4.0%	Tag-and-probe study
Electron energy scale	0.3%	0.3%	
Muon momentum scale	0.1%	0.1%	
Electron resolution	20%	20%	
Muon resolution	20%	20%	
Jet reconstruction	1%	1%	Jet energy scale
	10%	10%	Jet resolution
b tagging efficiency	5%	20%	Anti-correlated between b-tagged and untagged categories
VBF tagging efficiency	10%(ggH)/5%(VBF)	10%	Anti-correlated among VBF tagged and untagged/b-tagged categories
Boosted V tagging	-	3%	Merged jet only
Acceptance	2%	2%	
2D templates (JEC)	shape	shape	
2D templates (parton shower)	-	shape	

Table 3: Summary of systematic uncertainties on the background for each component.

Source	DY+jets	$t\bar{t}$	Dibosons (ZZ/WZ/WW)
Luminosity	-	-	6.2%
Electron trigger & ID	-	-	8%
Muon trigger & ID	-	-	4%
b tagging efficiency	-	-	7%-20%
VBF tagging efficiency	-	-	10%
Boosted V tagging	-	-	3% (merged)
Diboson cross section	-		10%
$t\bar{t}$ normalisation	-	stat. unc. of $e\mu$ data	-
Z+jets α factor (JEC)	3%-10%	-	-
Z+jets α factor (binning)	4%-30%	-	-
Z+jets spectrum	fit covariance matrix	-	-
Z+jets alternative function	shape uncertainty	-	-
2D templates	shape	shape	shape



CMS-PAS-HIG-16-041

