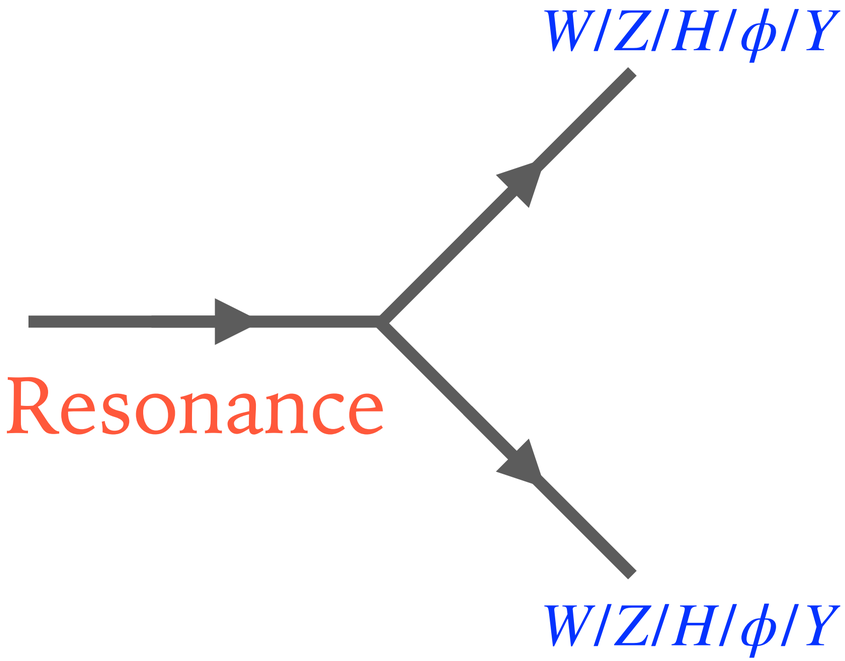
SEARCHES FOR DIBOSON RESONANCES

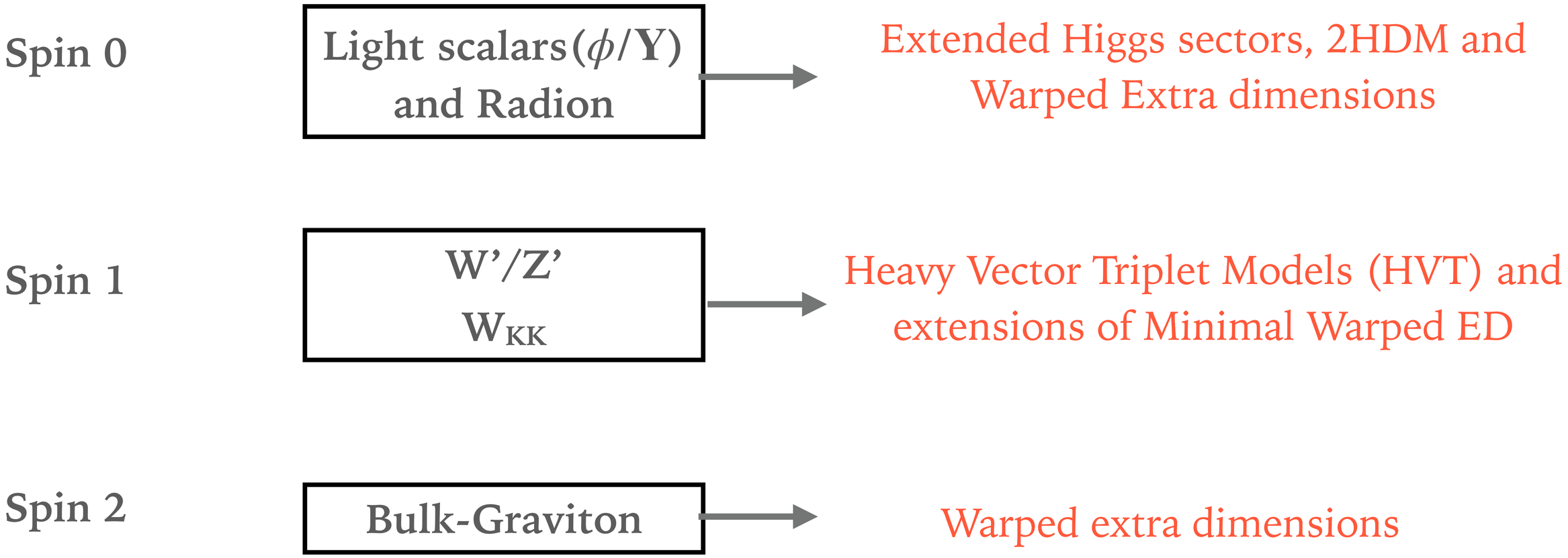


Cristina Mantilla Suarez
on behalf of the CMS collaboration

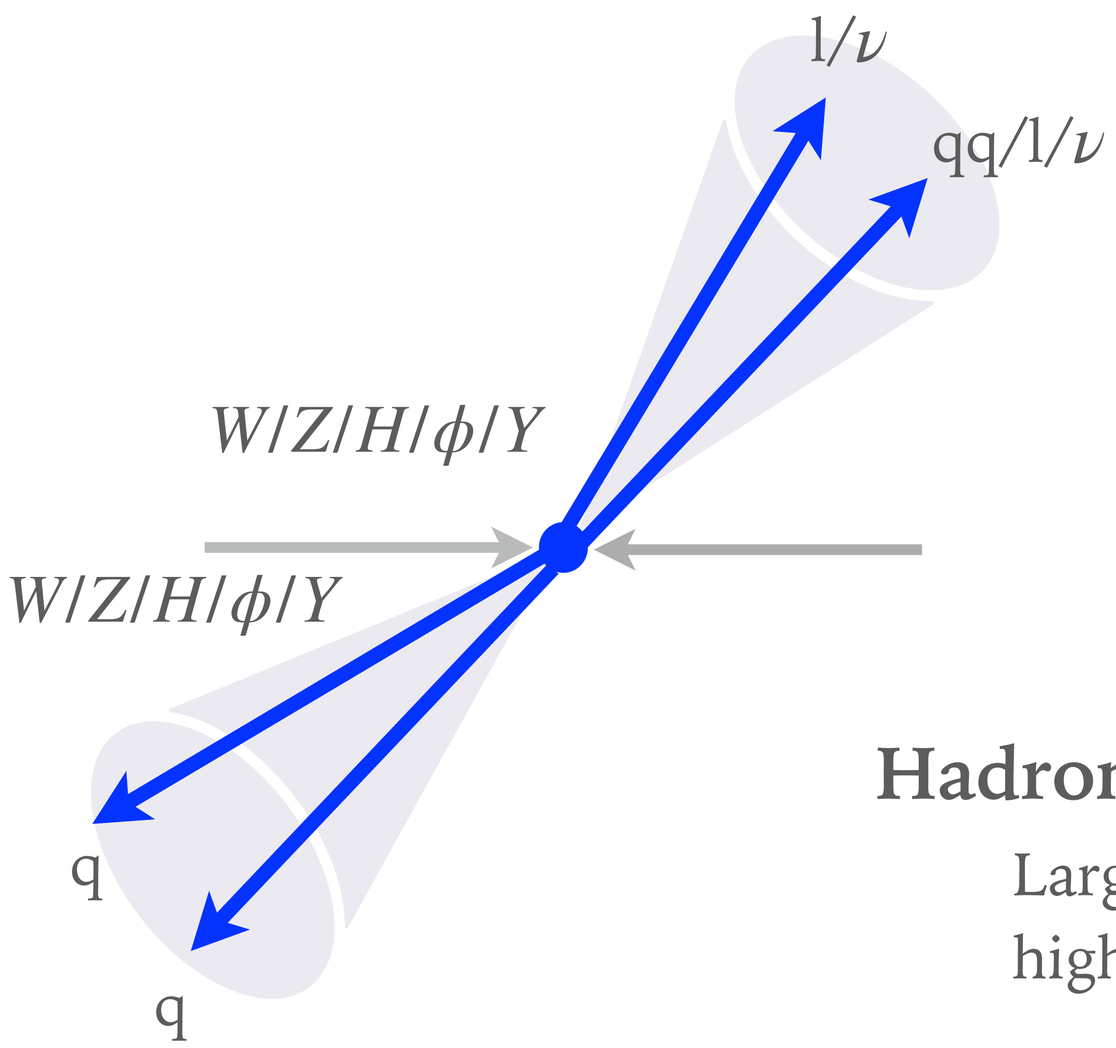
ICHEP
July 7th, 2022

Fermilab

DIBOSON SEARCHES COVER A WIDE RANGE OF MODELS



AND MANY FINAL STATES... - MOST OF THEM AT HIGH BOOST



Semi-leptonic and leptonic

Smaller BR but smaller background and lower trigger thresholds.

Hadronic

Largest BR but large background and high jet p_T trigger thresholds.

I WILL COVER THE 4 LATEST RESONANT SEARCHES WITH RUN 2 DATA

- X→ VV/VH →all-jets [CMS-B2G-20-009]
- X→WWW→all-jets [arXiv:2112.13090, arXiv:2201.08476]
- X→ Y(bb)H(bb) [arXiv:2204.12413]
- X→ Y(bb)H(γγ) [CMS-HIG-21-011] New!

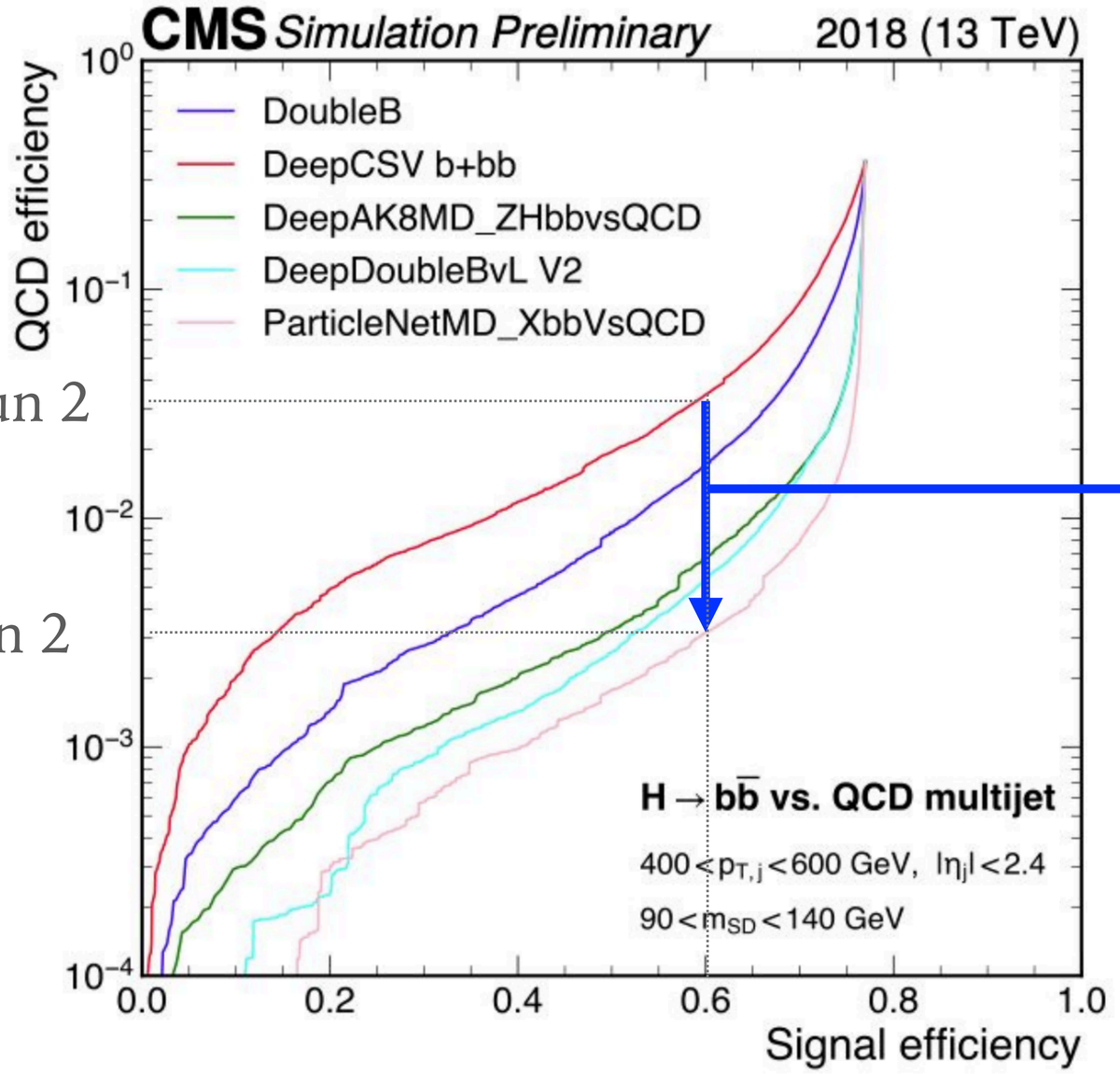
They all explore hadronic-like final states and share two common challenges: identifying the signal jets and estimating the background from data.

Also check out talks: resonant, non-resonant HH searches at CMS.

CHALLENGE 1: IDENTIFICATION OF SIGNAL W/Z/H/.. JETS

Start of Run 2

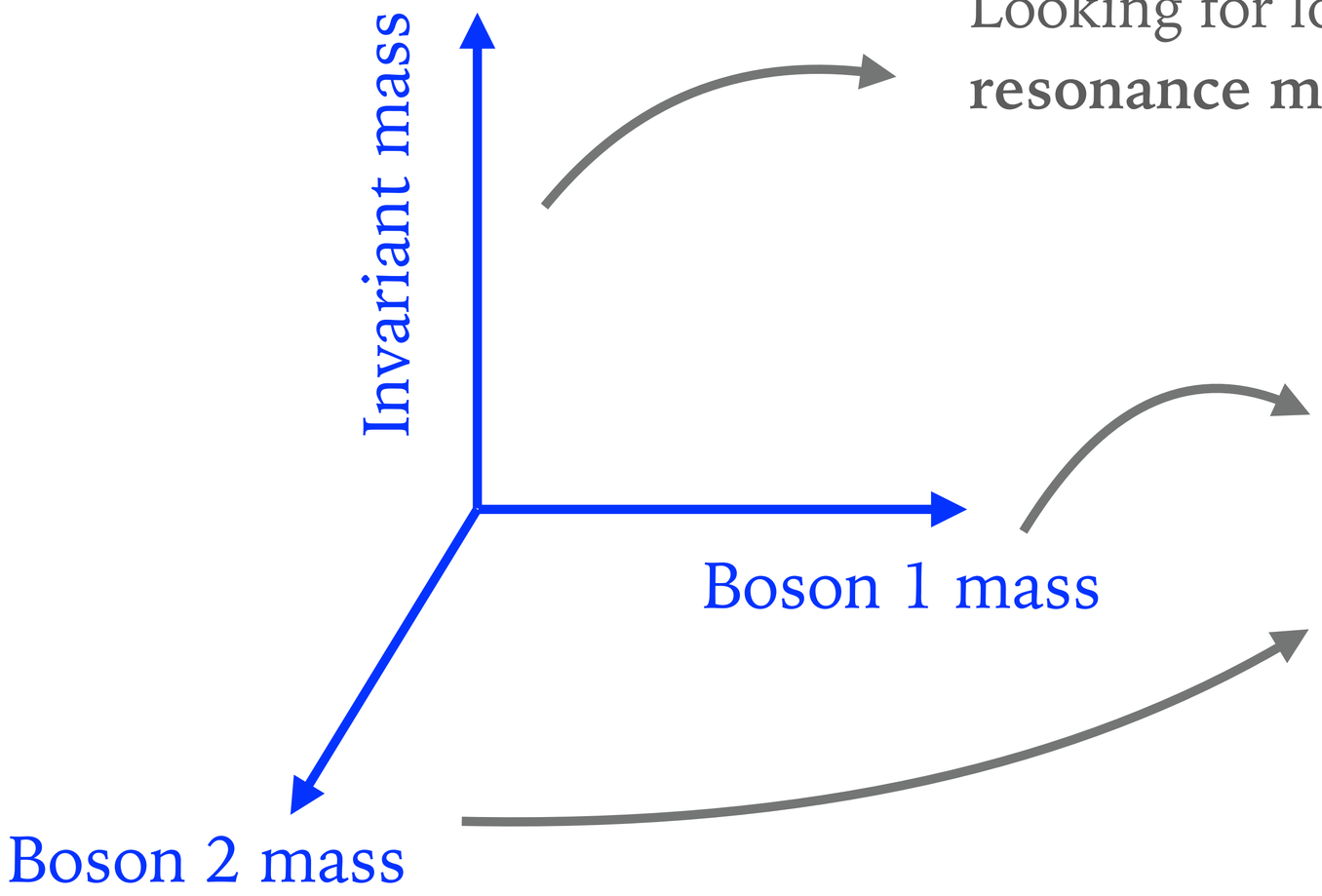
End of Run 2



Improved background rejection by 10x!

ParticleNet is the state of the art: a GNN trained on jet particles that outputs a classifier score for different signal jets.

CHALLENGE 2: POSSIBLE SEARCH AND BACKGROUND STRATEGIES



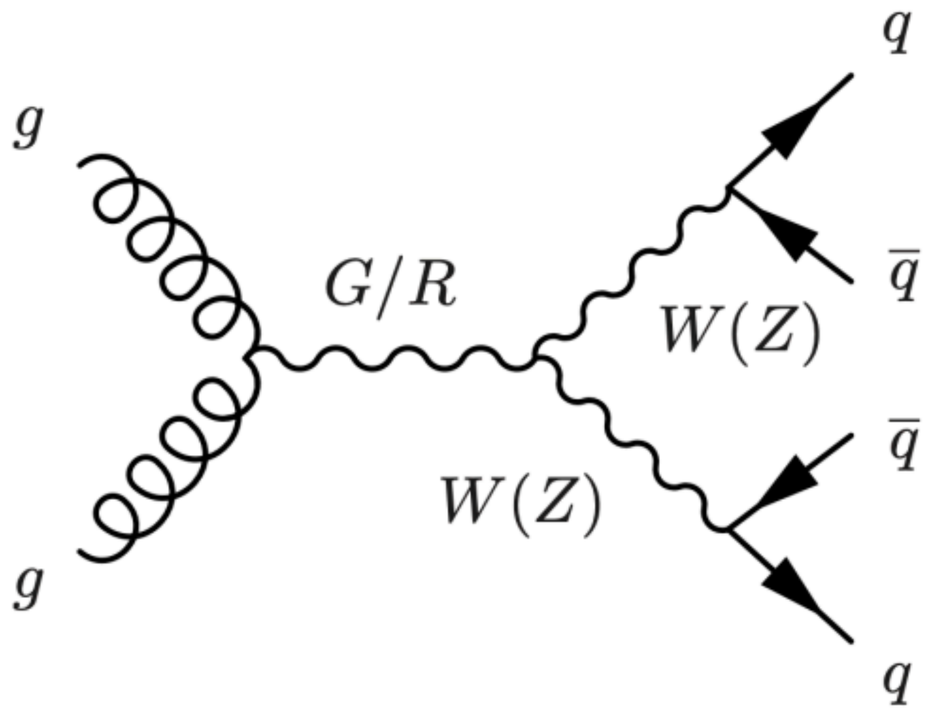
Looking for localized excess on the **resonance mass**

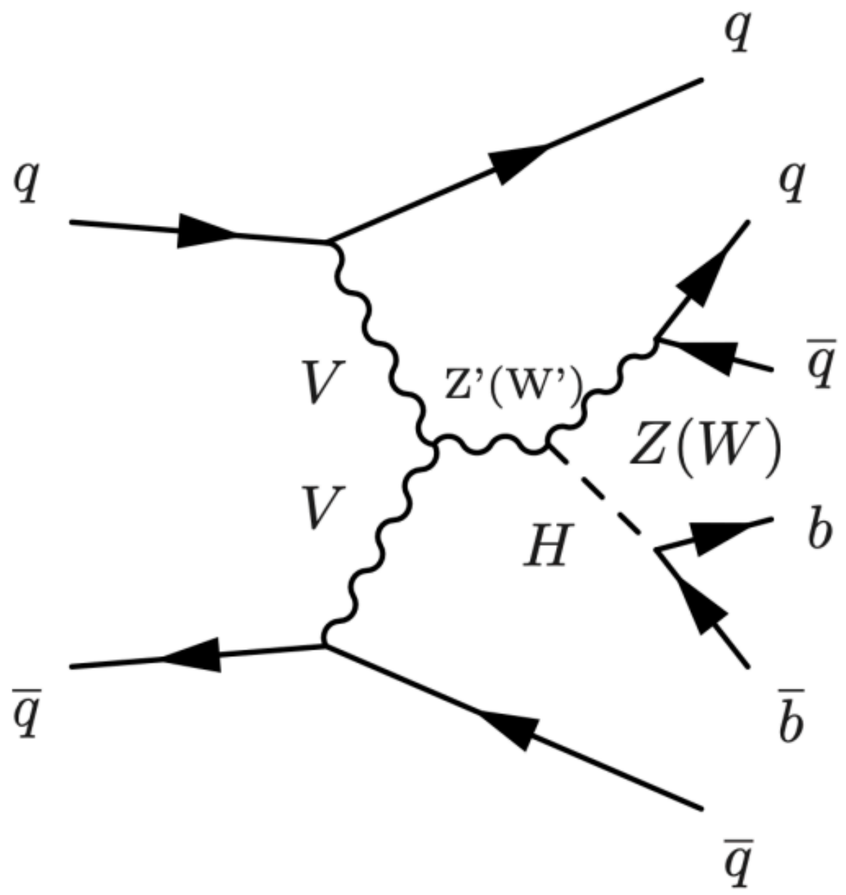
How many reconstructible bosons do we have?

Is the boson mass known? If not, looking for localized excesses becomes much more complicated.

X→ VV/VH →ALL-JETS: DY/GG + VBF

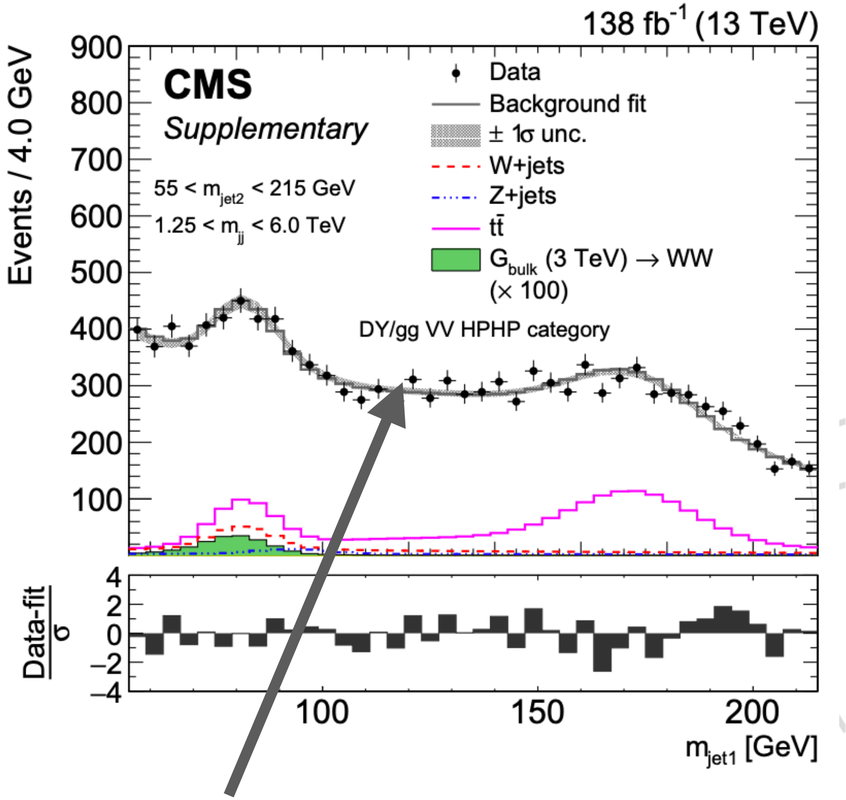
[CMS-B2G-20-009]

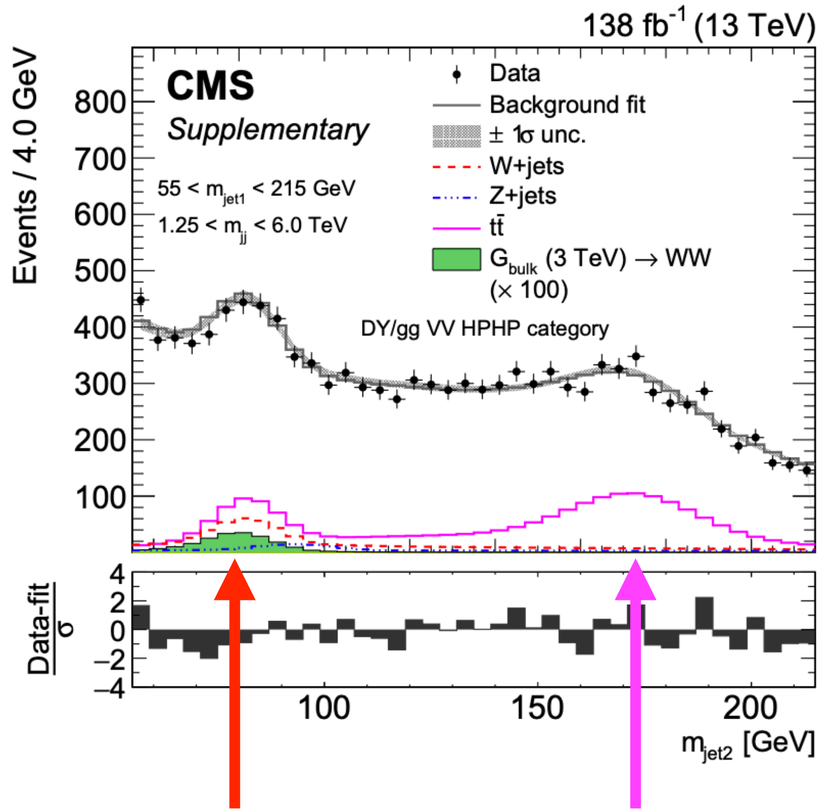


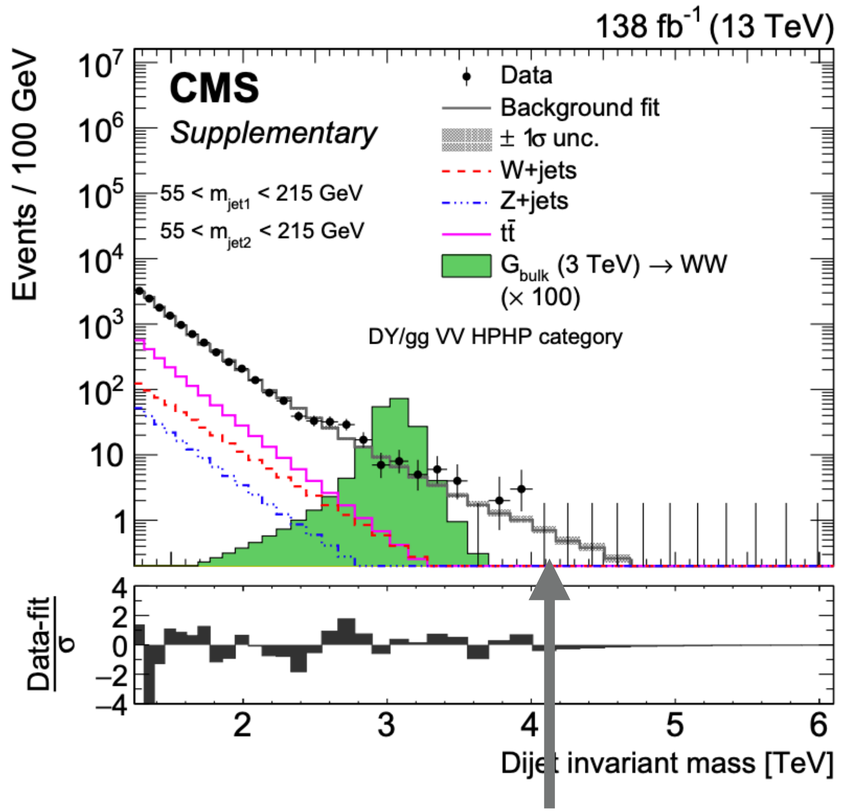


Tagging (2q) final states (w. bb category) using DeepAK8 tagger

3D BUMP HUNT: $M_{JET\,1}$ + $M_{JET\,2}$ + M_{JJ}







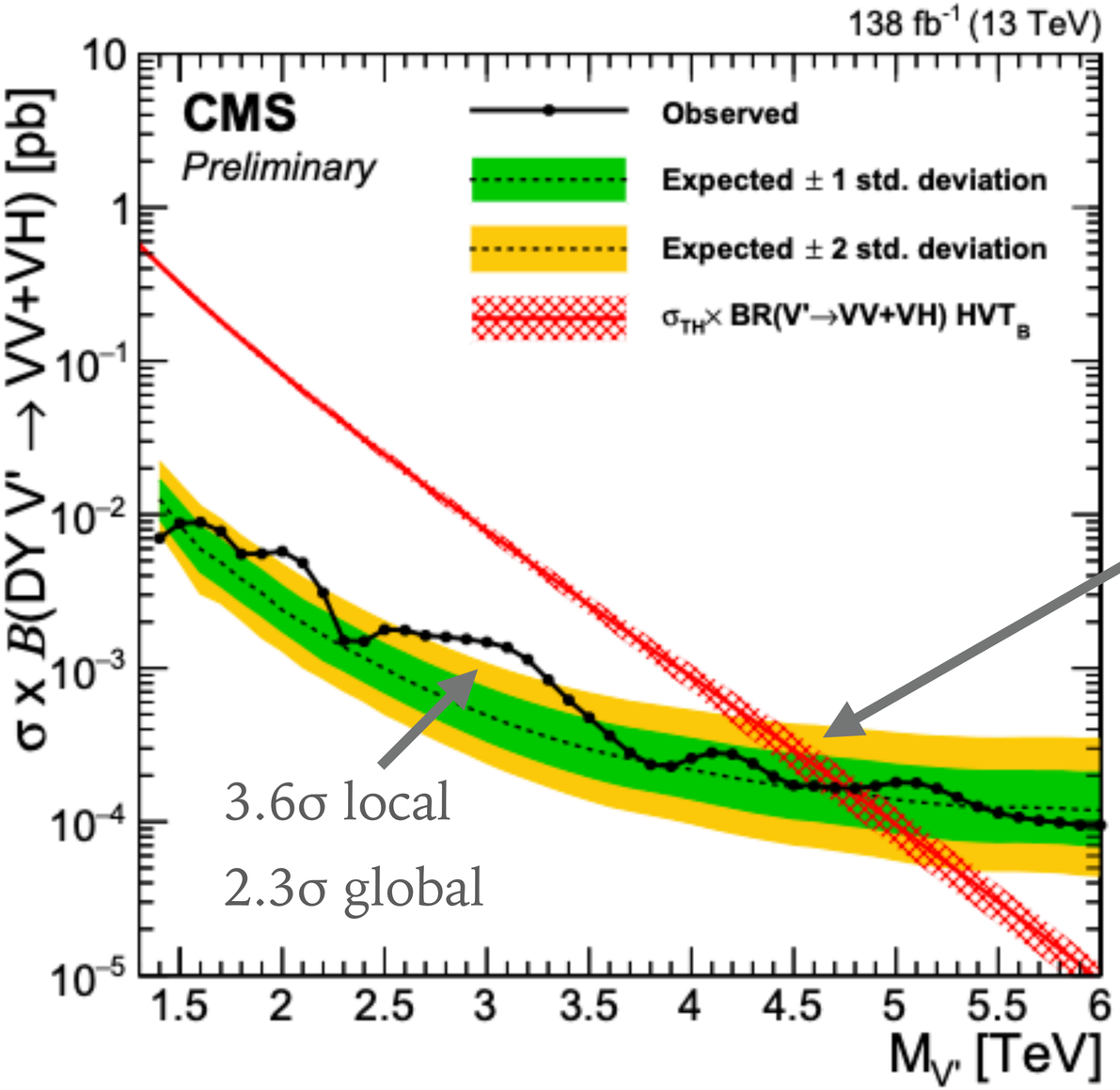
QCD model adapts to data, uses MC-based gaussian kernel templates with increased statistics

W/Z(qq)

Hadronic Tops

Probing up to 4.8 TeV

X→ VV/VH →ALL-JETS: RESULTS



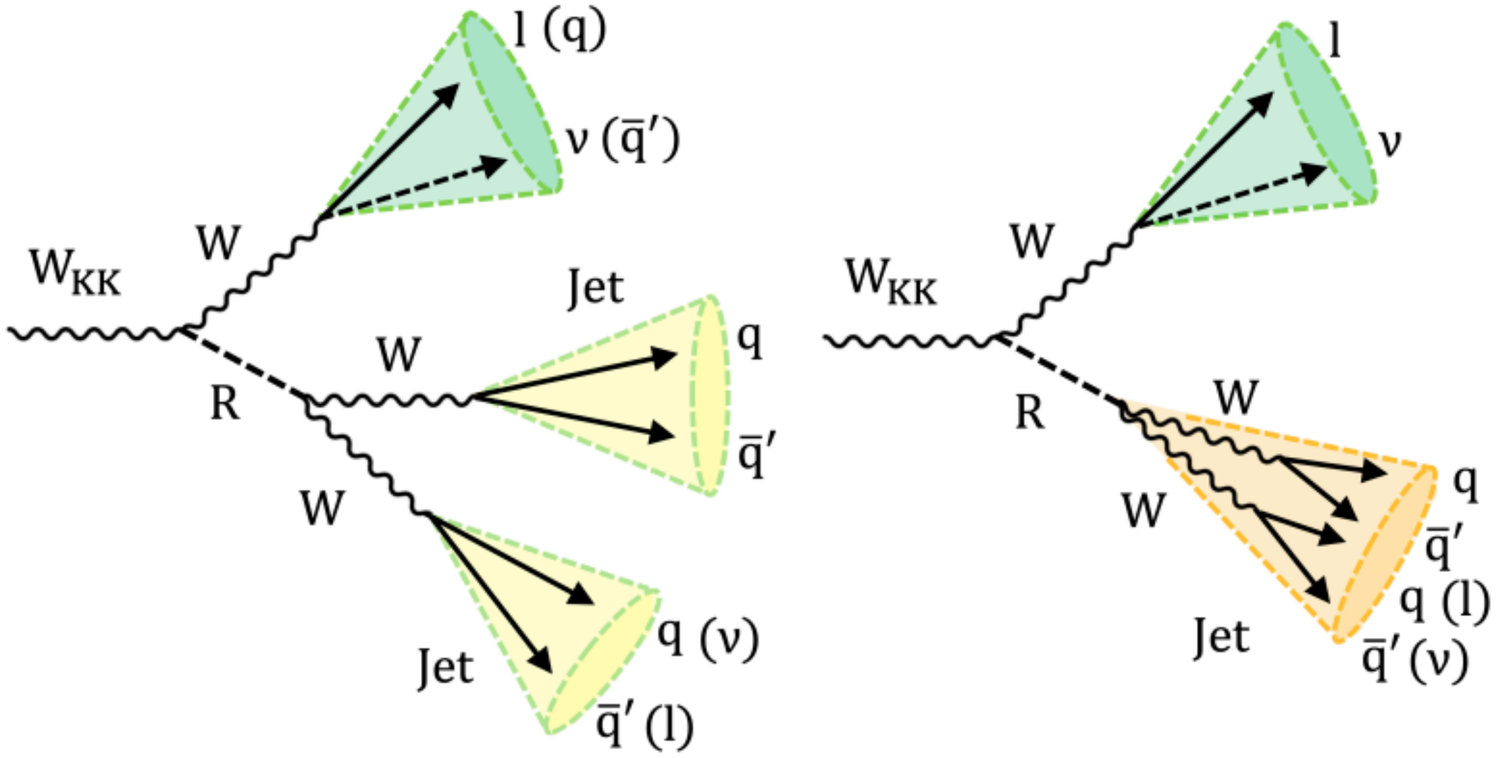
Most stringent limits on V' up to 4.8 TeV.

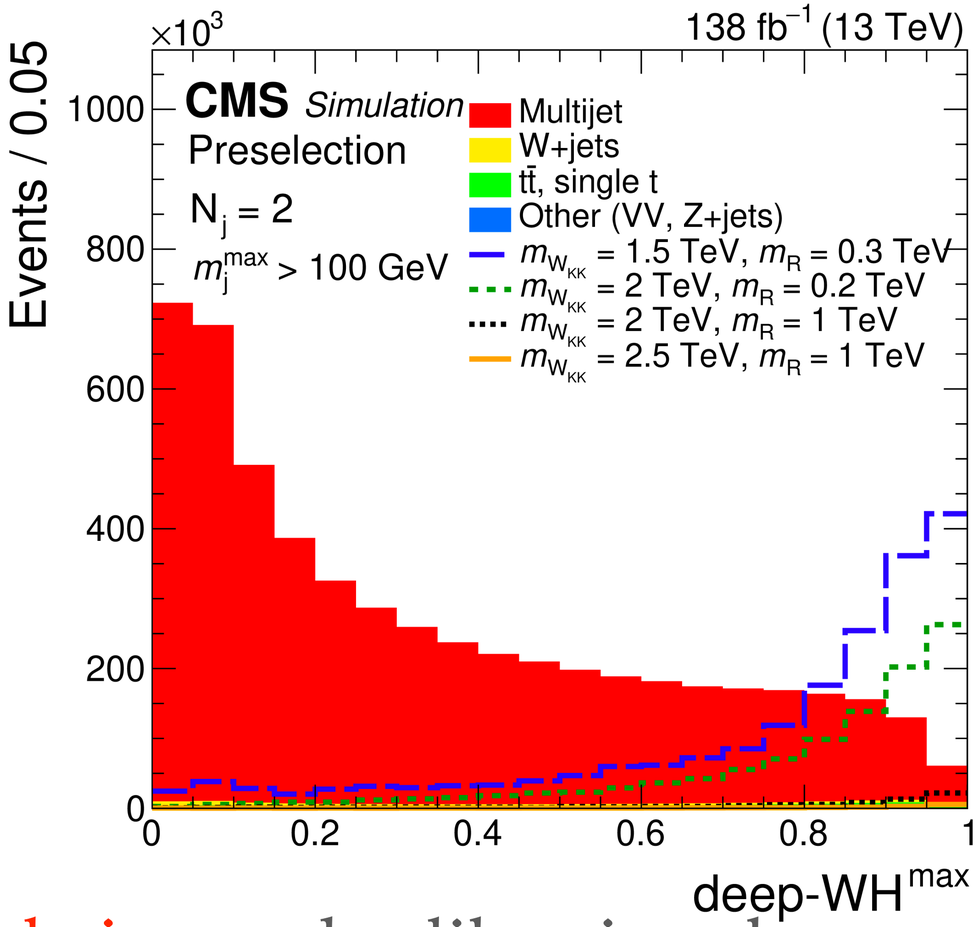
Also, first VBF limits (no exclusion) on all-hadronic search - see backup.

Up to 60% better sensitivity than 2016+2017 analysis.

X→WWW

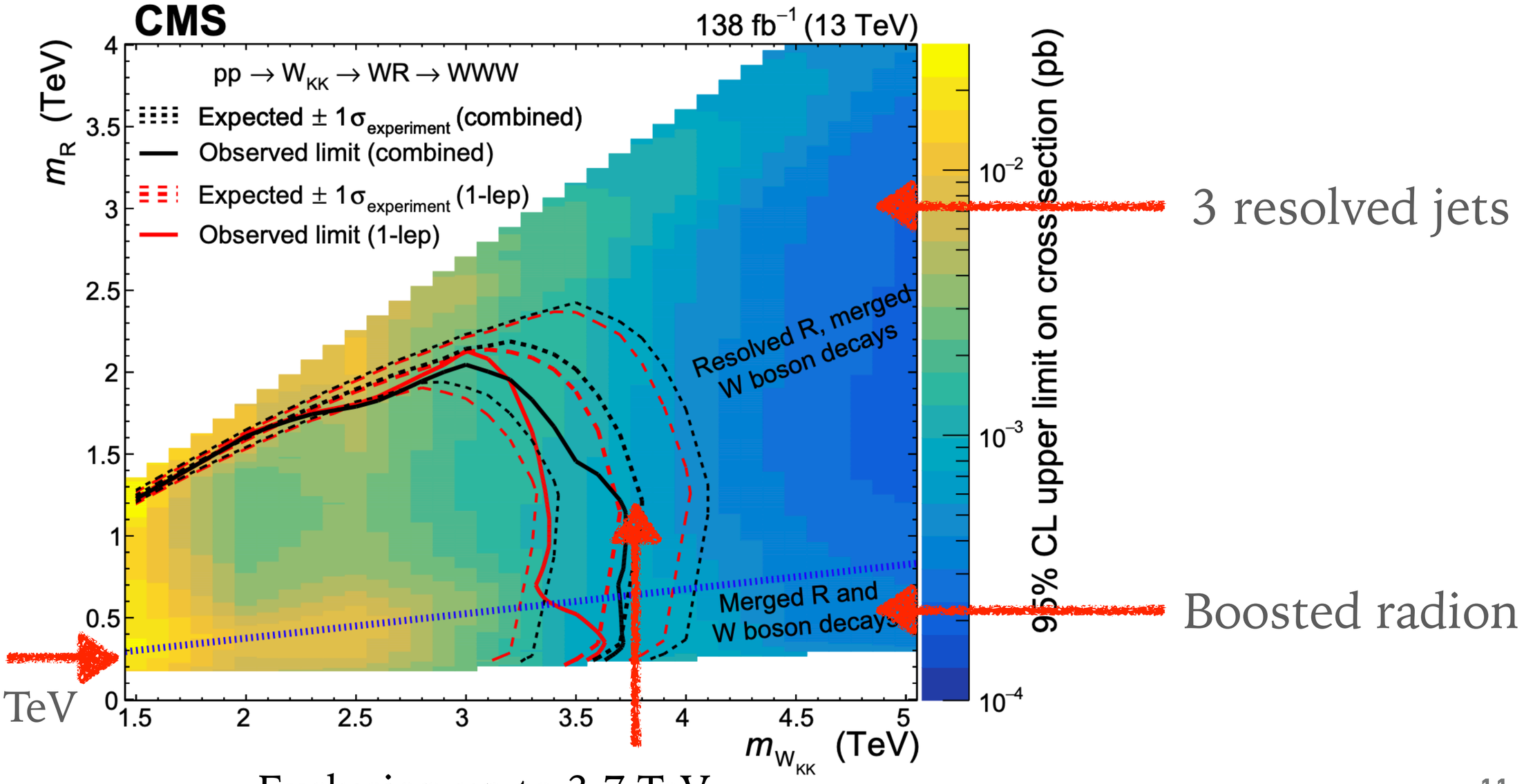
[arXiv:2112.13090, arXiv:2201.08476]





First time identifying WW→ qq qq in a single jet, and calibrating the tagger in data using W+jets and $t\bar{t}$ as proxies!

X→WWW: FIRST RESULTS OF THIS MODEL AND SIGNATURE



3 resolved jets

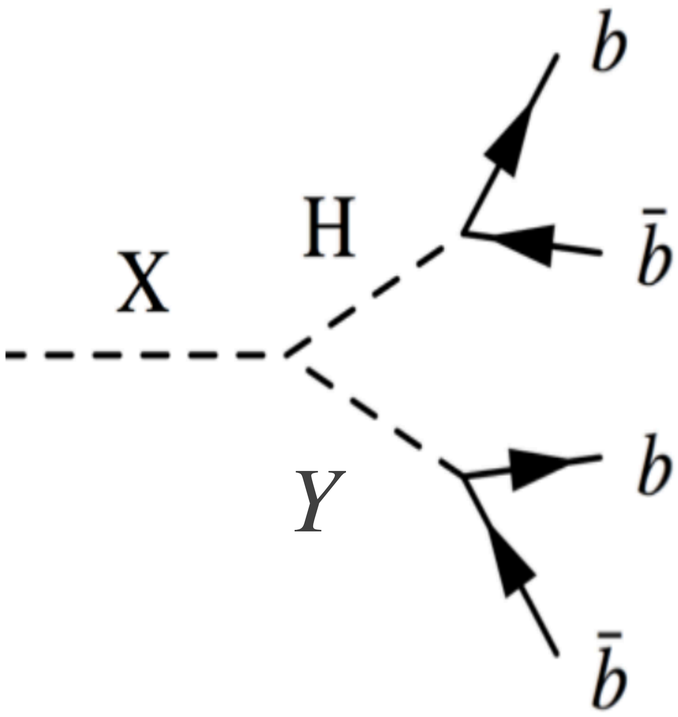
Boosted radion

R > 0.18 TeV

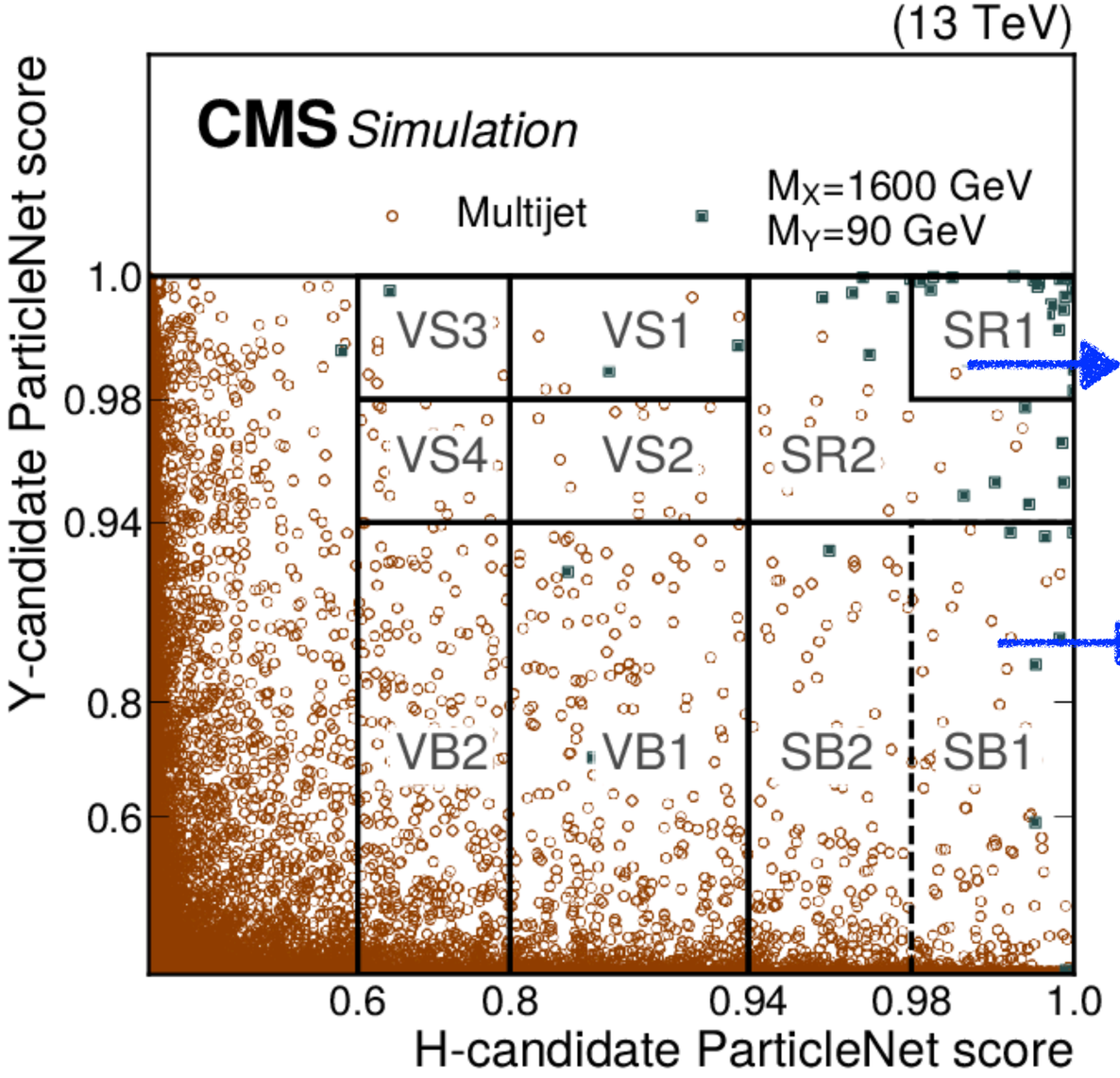
Exclusion up to 3.7 TeV

X→ YH→ 4B: TAGGING 2 BB-JETS

arXiv:2203.00480



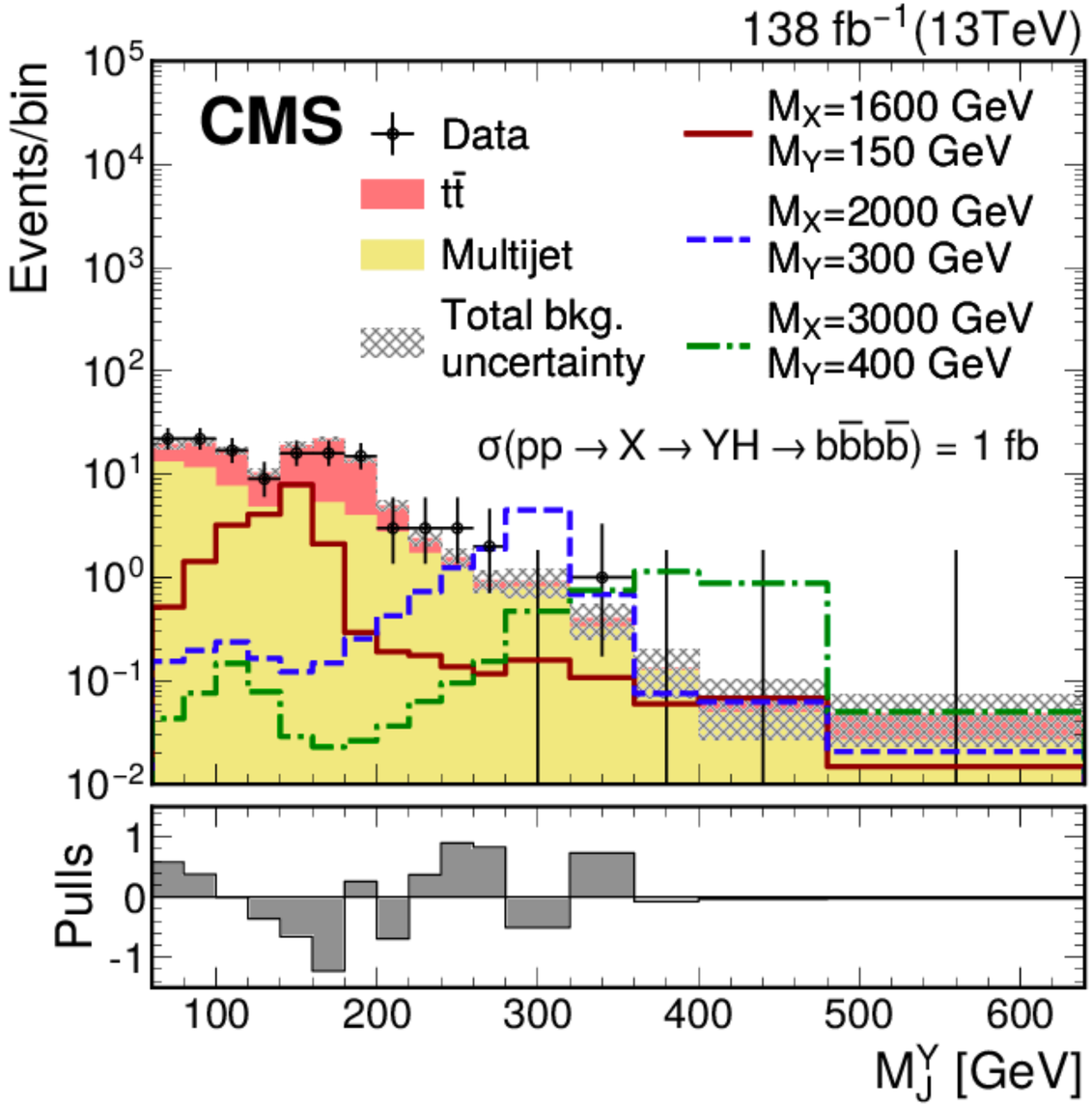
$m_Y < m_X - m_H$

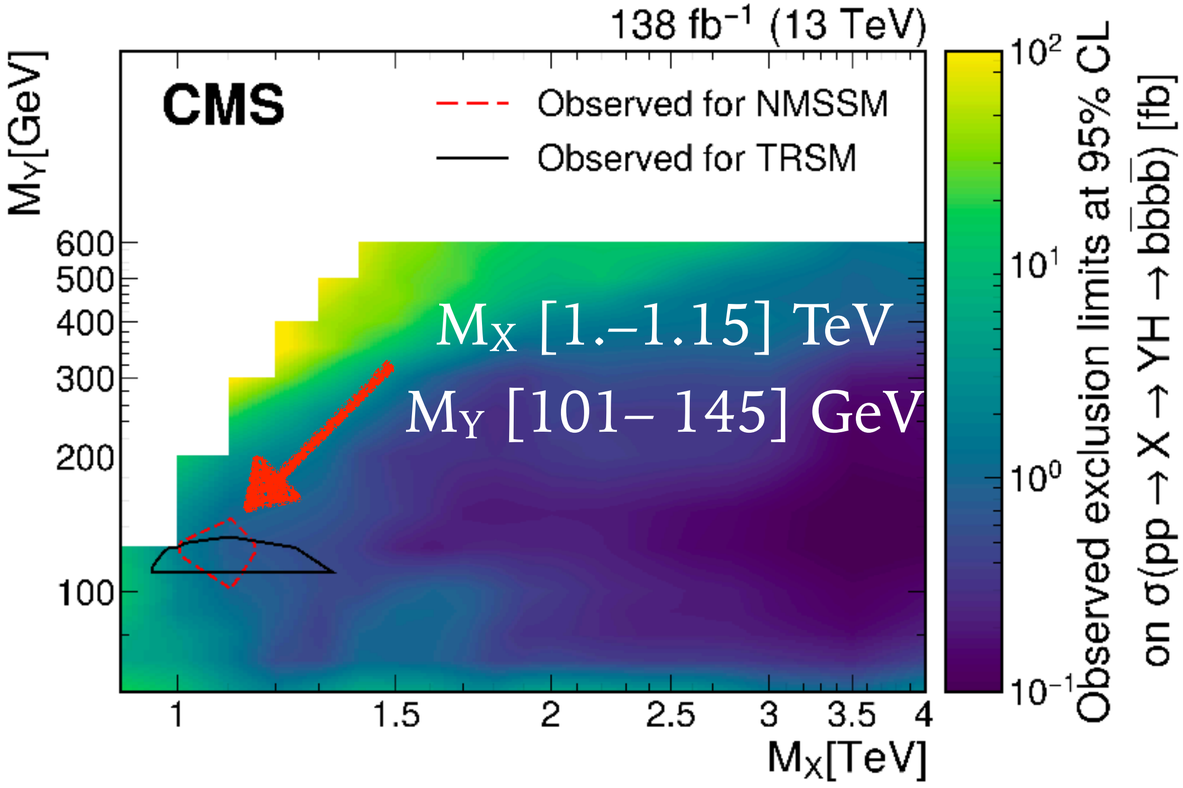


Signal Region (SR) has a ParticleNet tagger selection on both jets.

Sidebands (SB) used to estimate background

X→ YH→ 4B: FIRST LIMITS





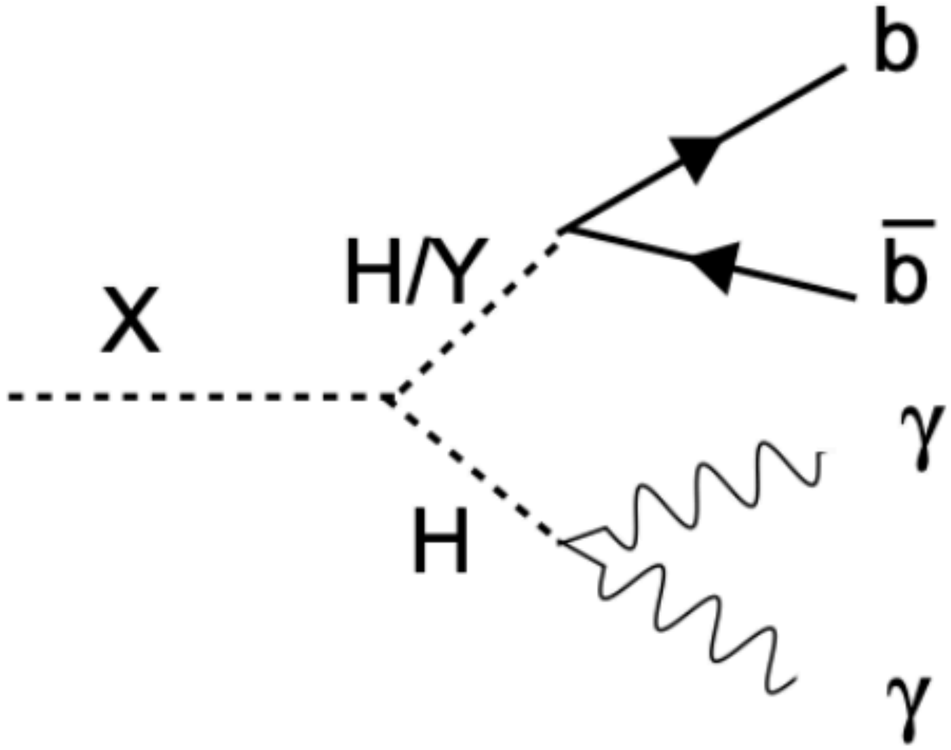
2D fit to MY and MX using sidebands to estimate QCD background.

At M_Y=125 GeV: 2x better than previous HH search because of ParticleNet.

X→ Y(BB)H(GG)

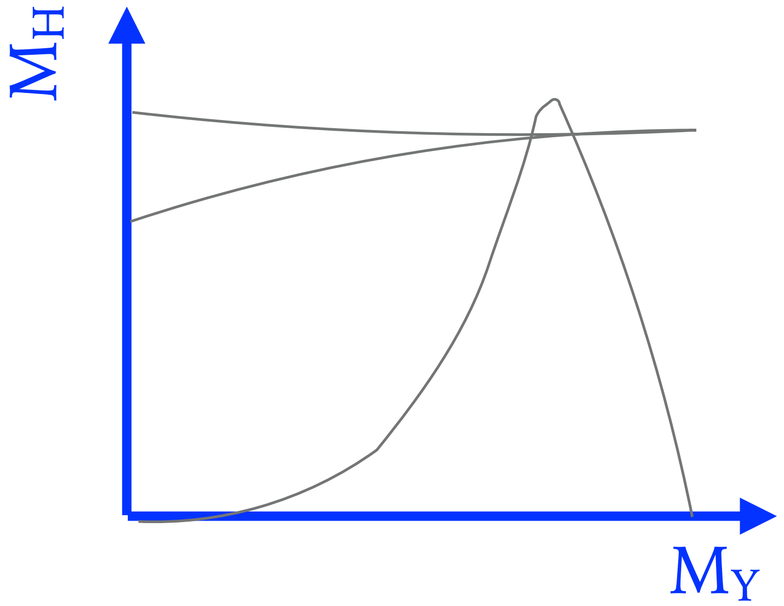
[CMS-HIG-21-011]

NEW!



$m_Y < m_X - m_H$

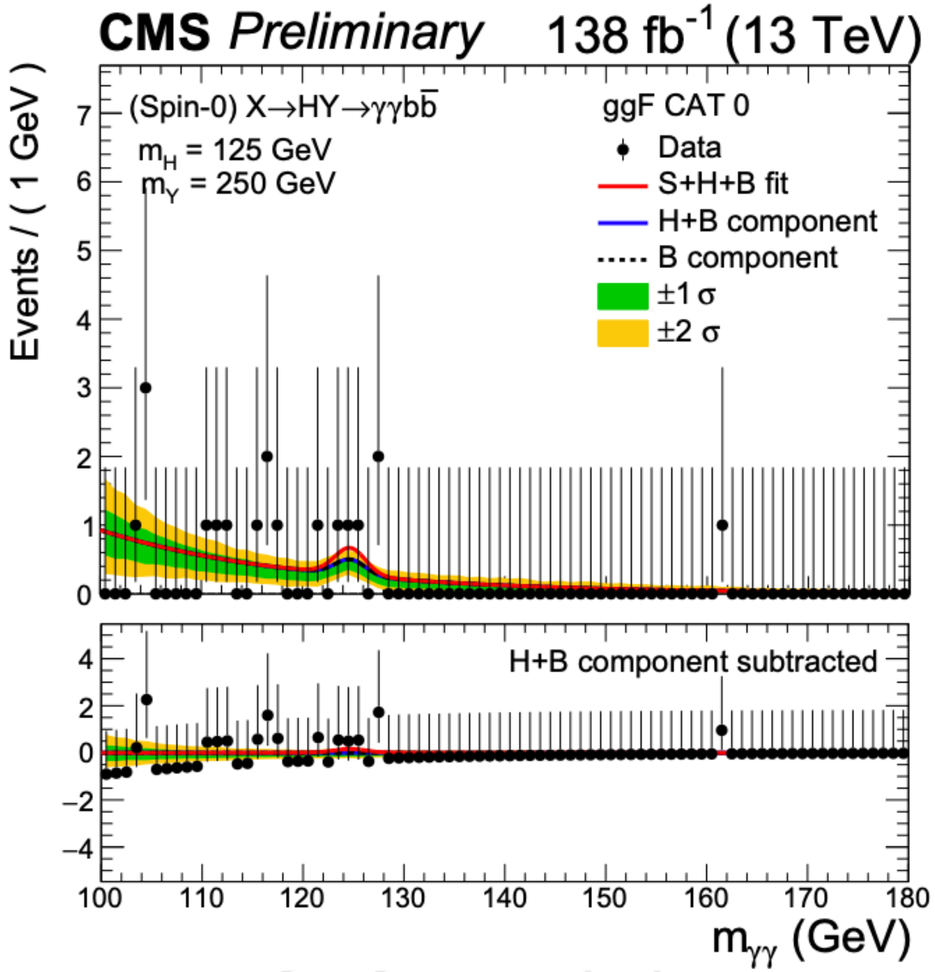
Signal identified with MVA using b-jet ID, photon ID and kinematic variables.

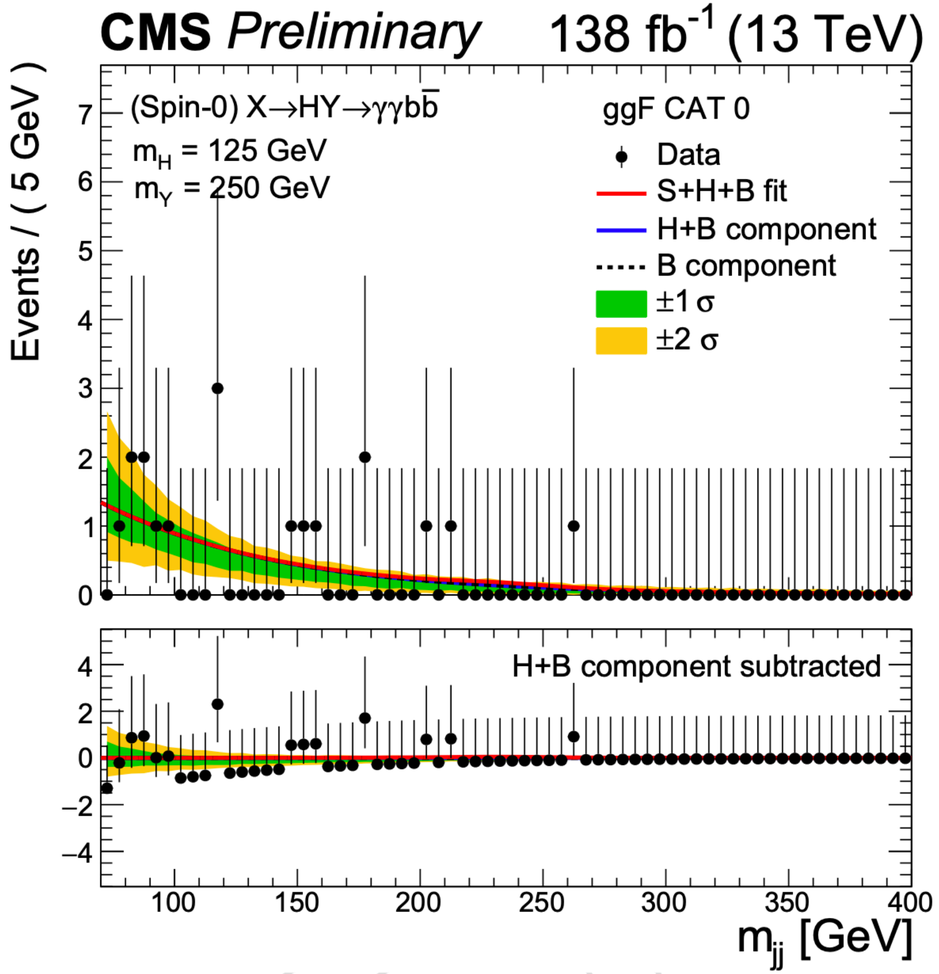


Then, extracted signal from 2D fit:

M_Y vs M_H, in windows of $\tilde{M}_X$.

X→ Y(BB)H(GG): 2D FIT





Non-resonant background from envelope-method, resonant background from gaussian model

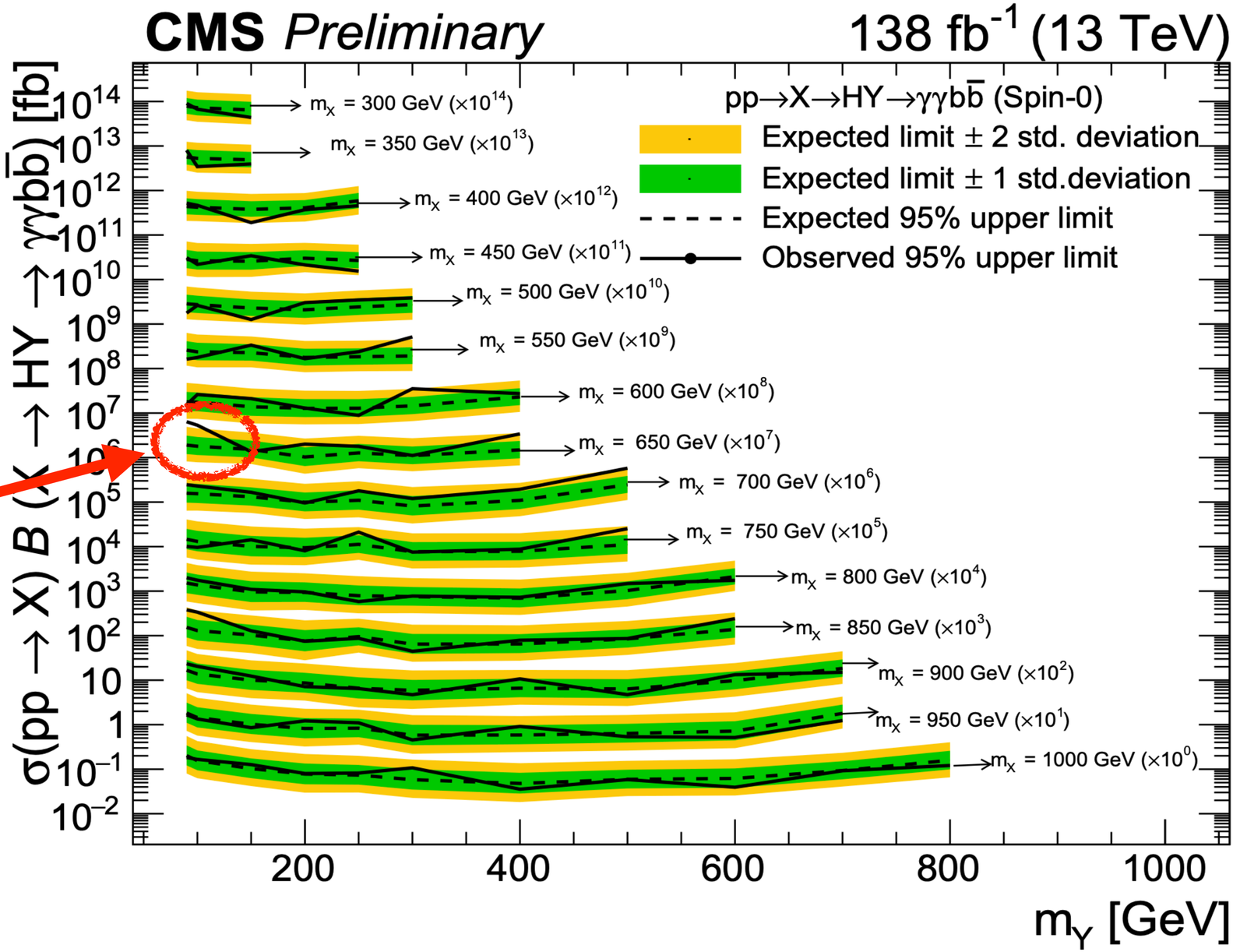
RESULTS:

MX=650 GeV

MY=90 GeV

3.8σ local

2.6σ global*



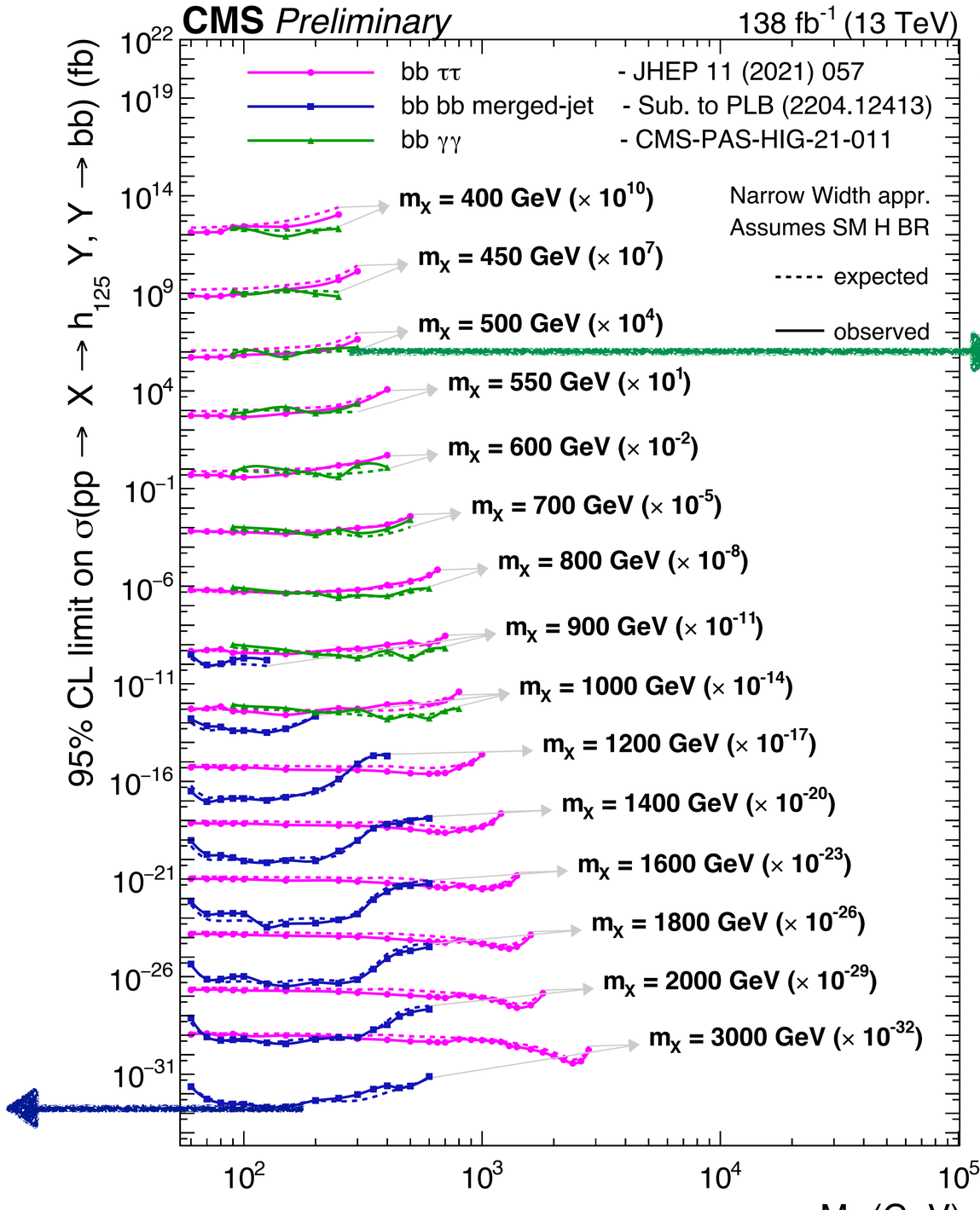
Consistent with local excesses @:

- Low mass $H(\gamma\gamma)$ @ 95 GeV
- High mass H(WW) @ 650 GeV
- $A(\tau\tau)$ @ 100 GeV

* Global sig. accounts only for $m_Y < 150$ GeV
Global sig. at MY=100 GeV of 3.5 σ

X→ YH COMPLIMENTARY SENSITIVITY

NEW!

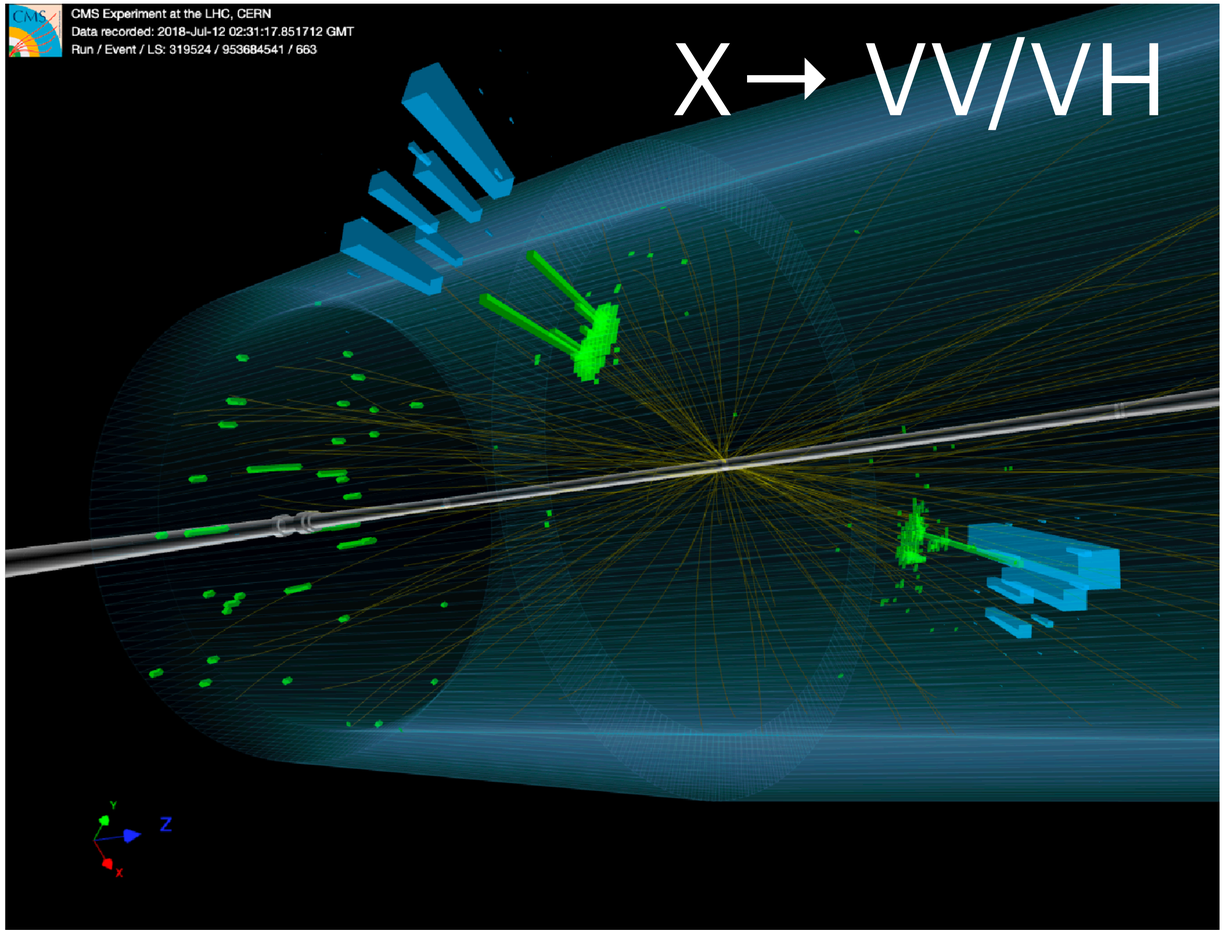


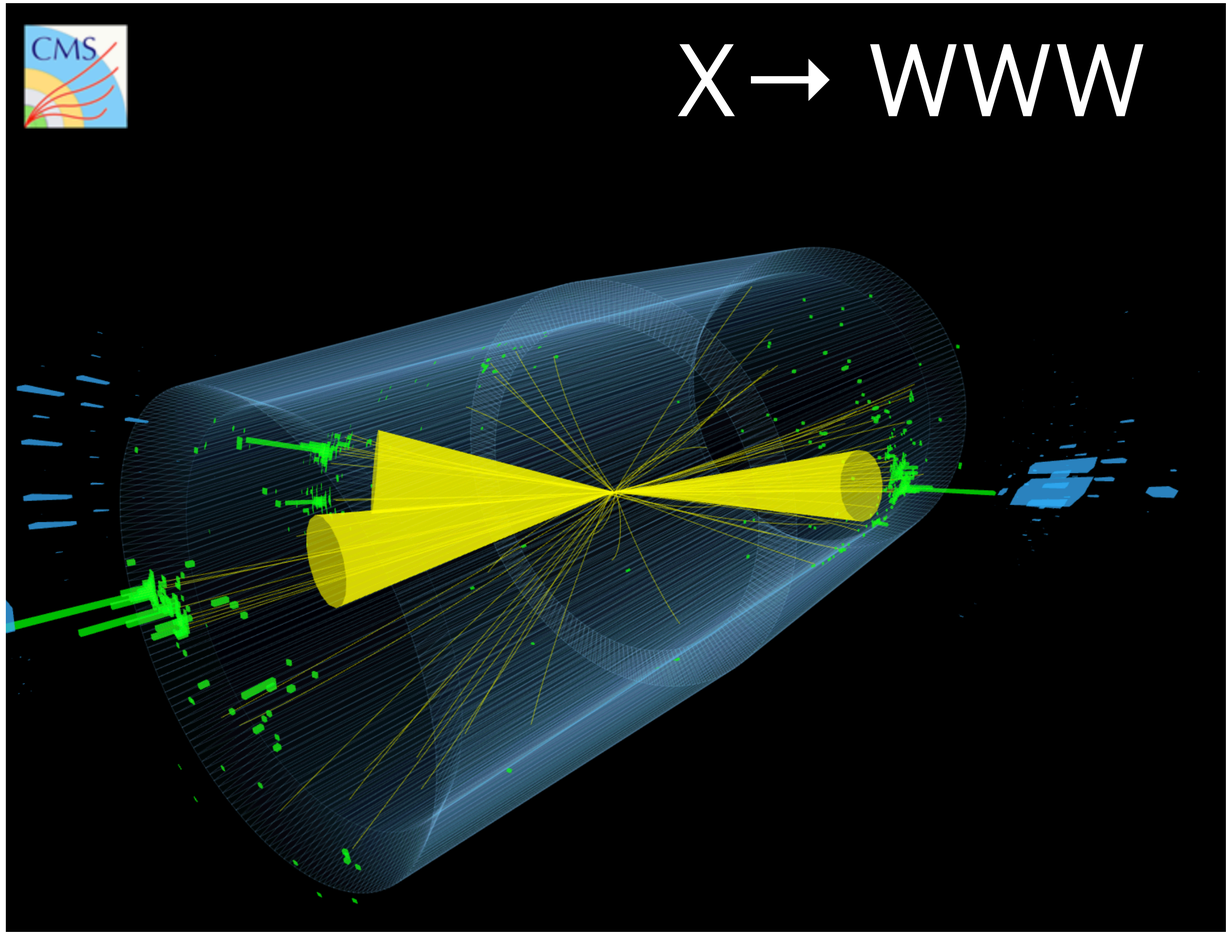
Y(bb)H(GG) most sensitive for $m_X < 600$ GeV

Y(bb)H(bb) most sensitive for high m_X

MORE SUMMARY PLOTS

- CMS has an active BSM-Higgs and diboson-resonance search program. See summary here.
- Most of the diboson final states already explored in Run-2 and a few interesting excesses present: looking forward to Run-3, better tagging techniques and new signatures!

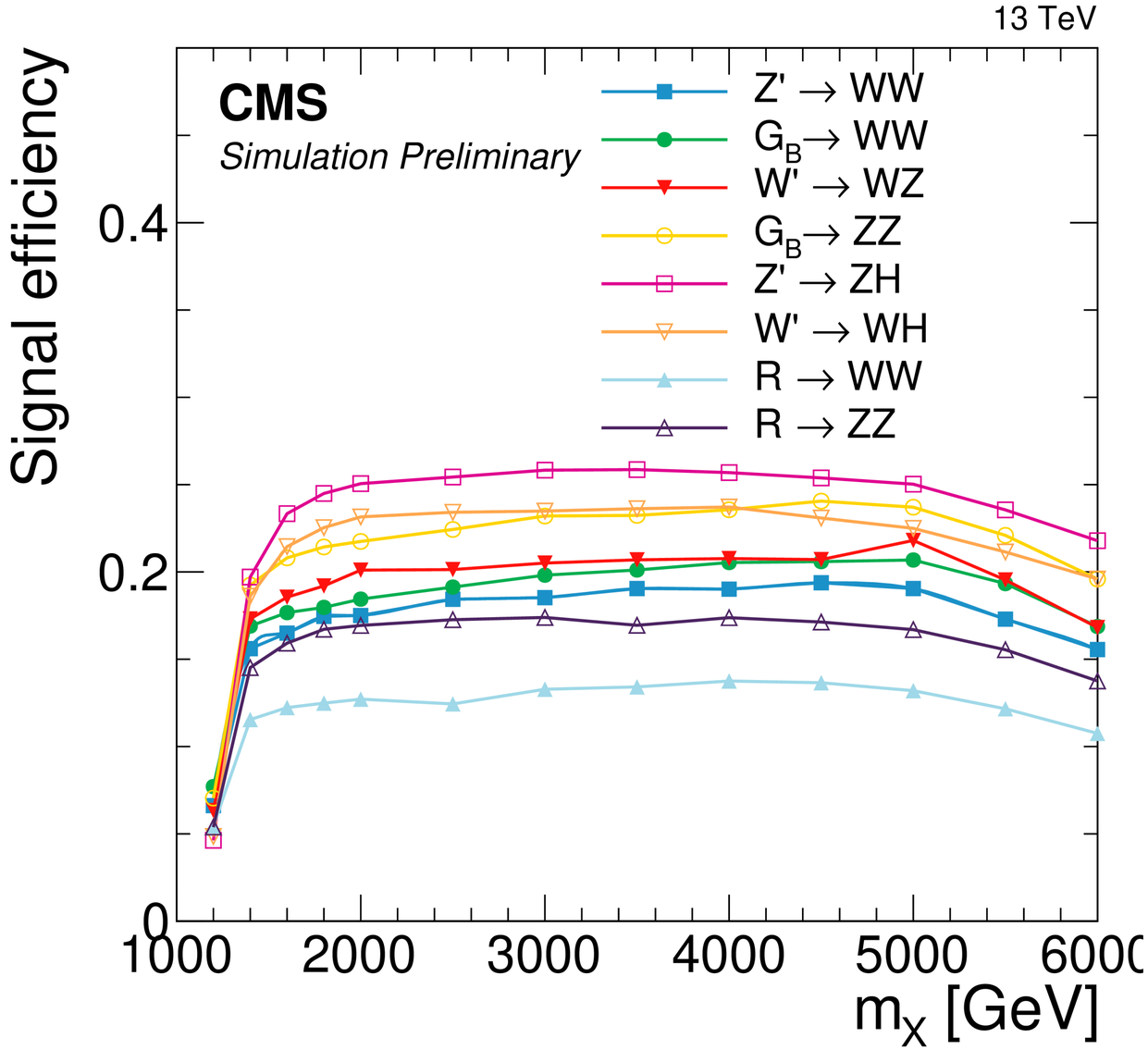

CMS Experiment at the LHC, CERN
Data recorded: 2018-Jul-12 02:31:17.851712 GMT
Run / Event / LS: 319524 / 953684541 / 663
X→ VV/VH
Y
Z
X

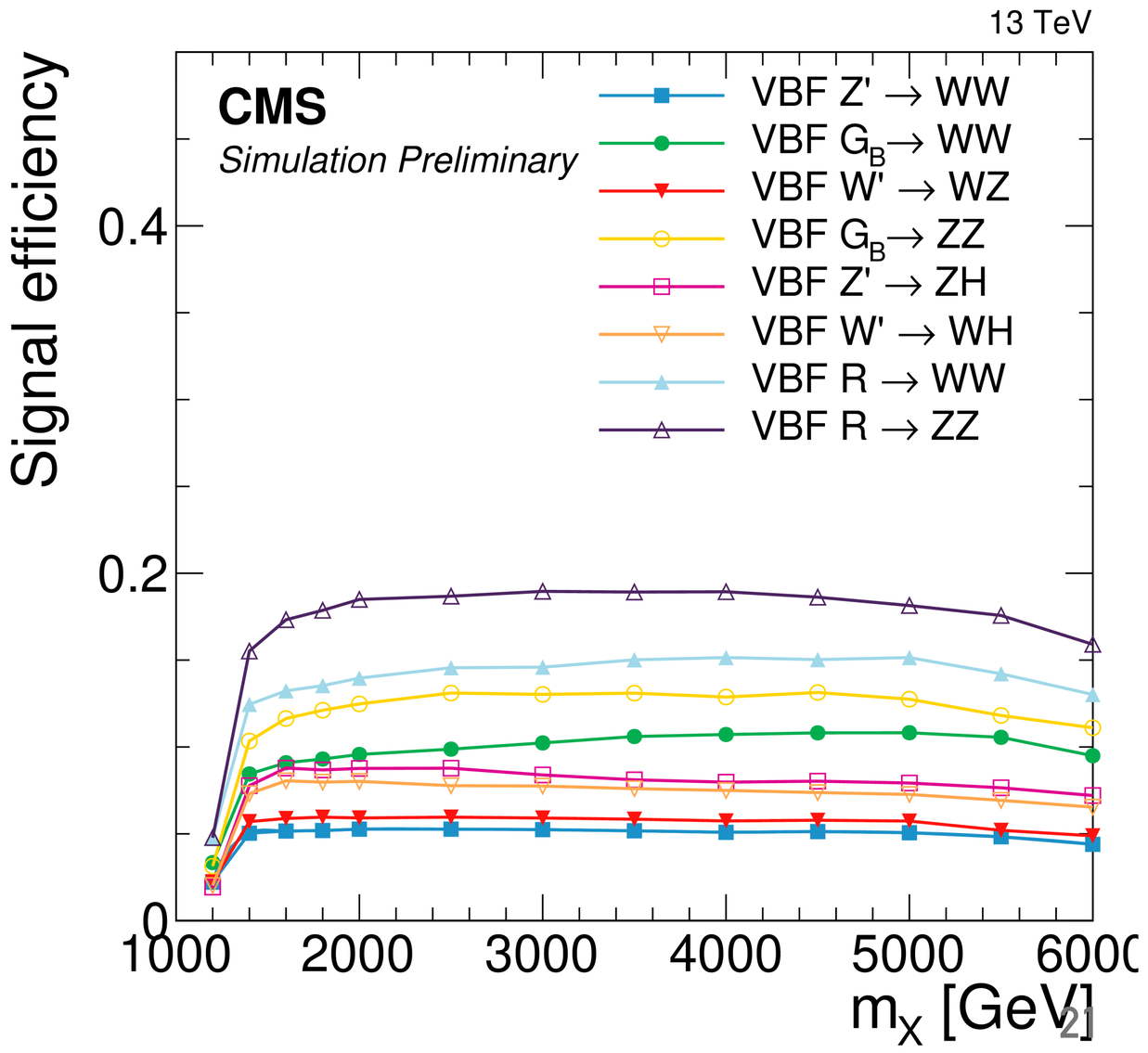

CMS
X→ WWW

THANKS!

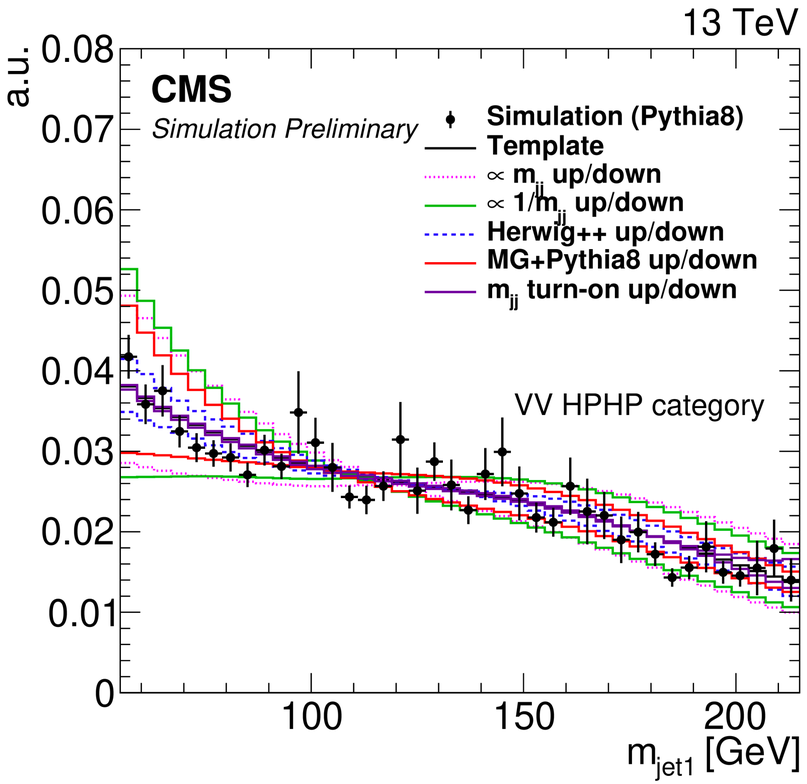
EXTRA MATERIAL

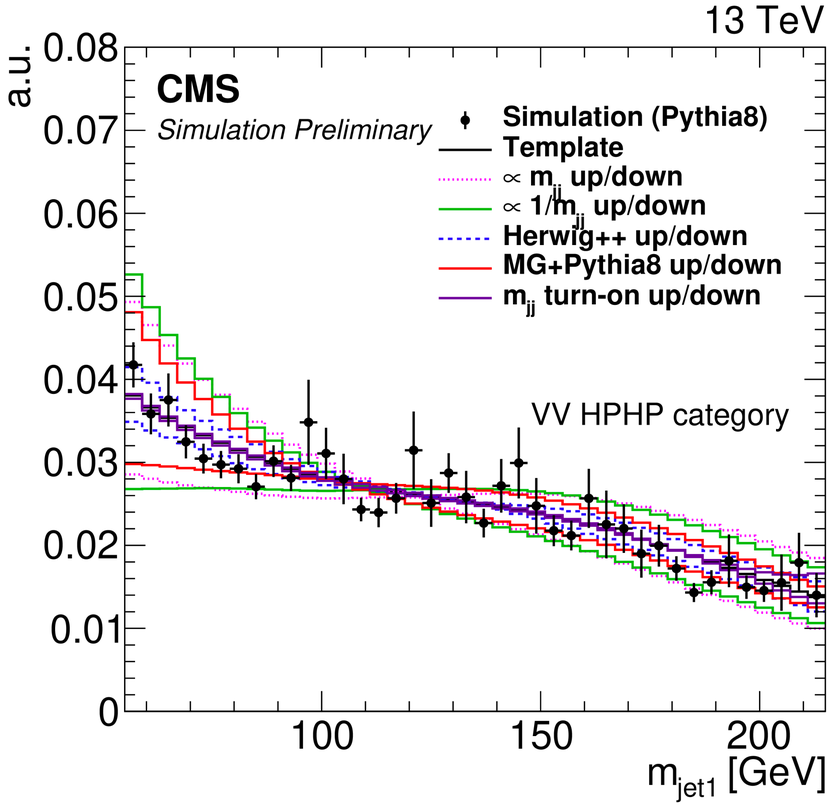
X→ VV/VH →ALL-JETS: SIGNAL EFFICIENCY

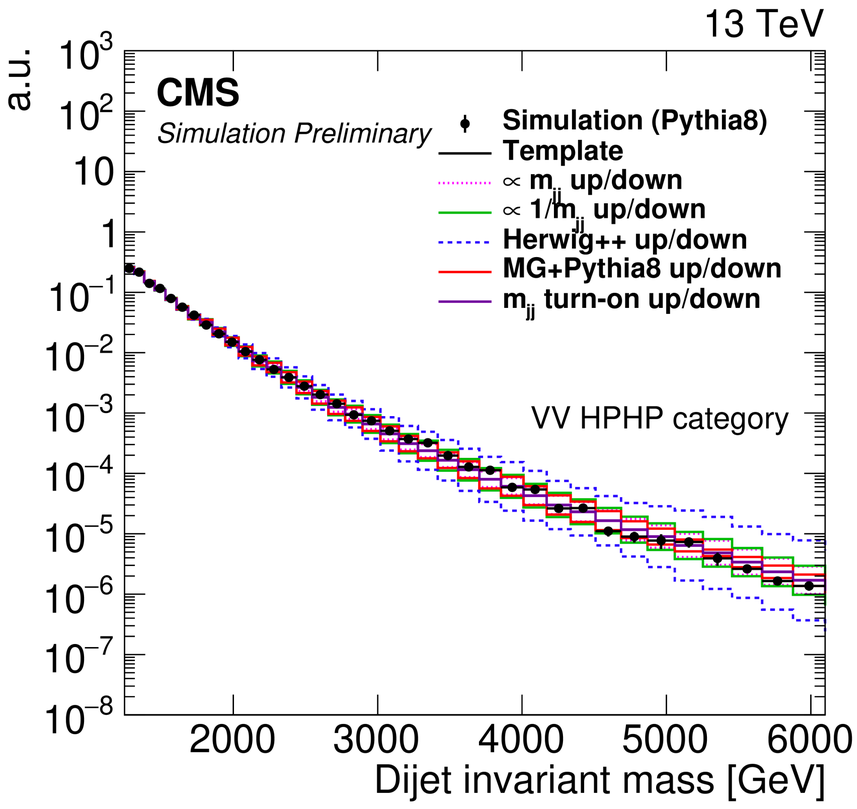




X→ VV/VH →ALL-JETS: QCD TEMPLATES AND VARIATIONS





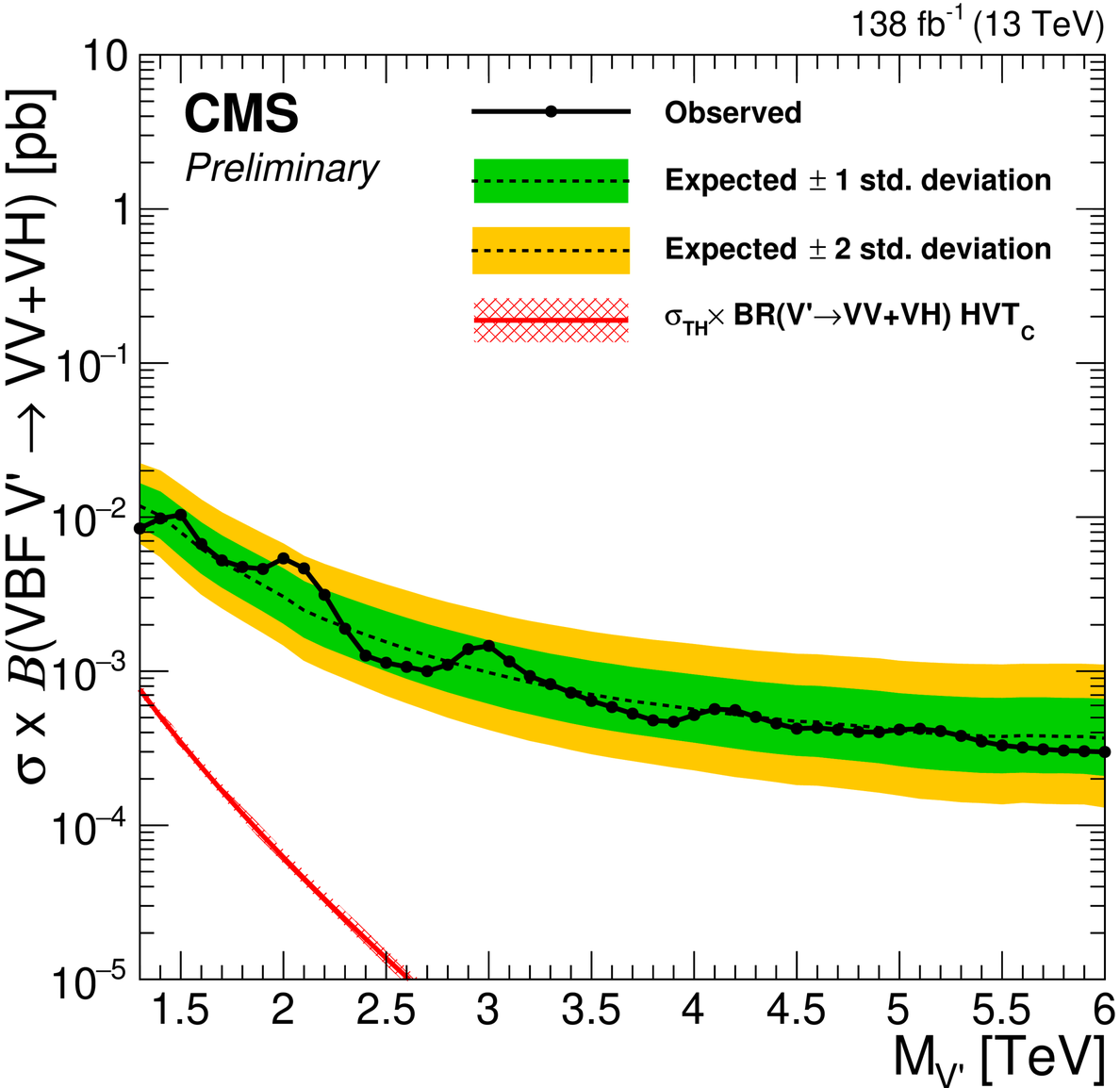


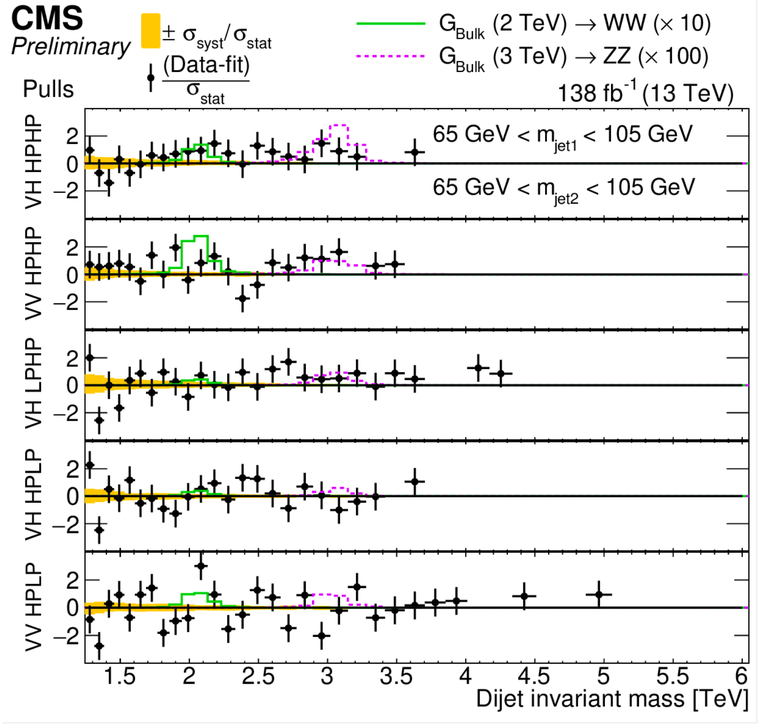
X→ VV/VH →ALL-JETS: LIMITS FOR DIFFERENT MODELS

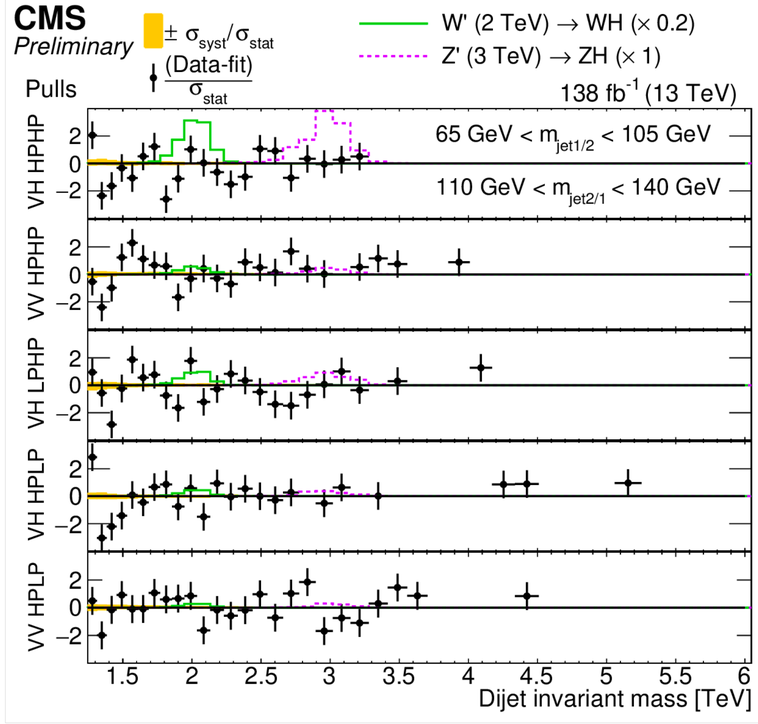
Model		Observed limit (TeV)	Expected limit (TeV)
Radion DY/gg	VV	2.7	3.4
HVT model B, W'	WZ / WH	4.4 / 4.0	4.3 / 4.3
HVT model B, Z'	WW / ZH	(1.3–3.1, 3.3–3.5) / 3.9	3.8 / 3.8
HVT model B, V'	VV+VH / VV / VH	4.8 / 4.5 / 4.2	4.8 / 4.5 / 4.5
G_{bulk} ($\tilde{\kappa} = 0.5$) DY/gg	VV	1.4	1.5

5 tagging categories based on purity/production mode

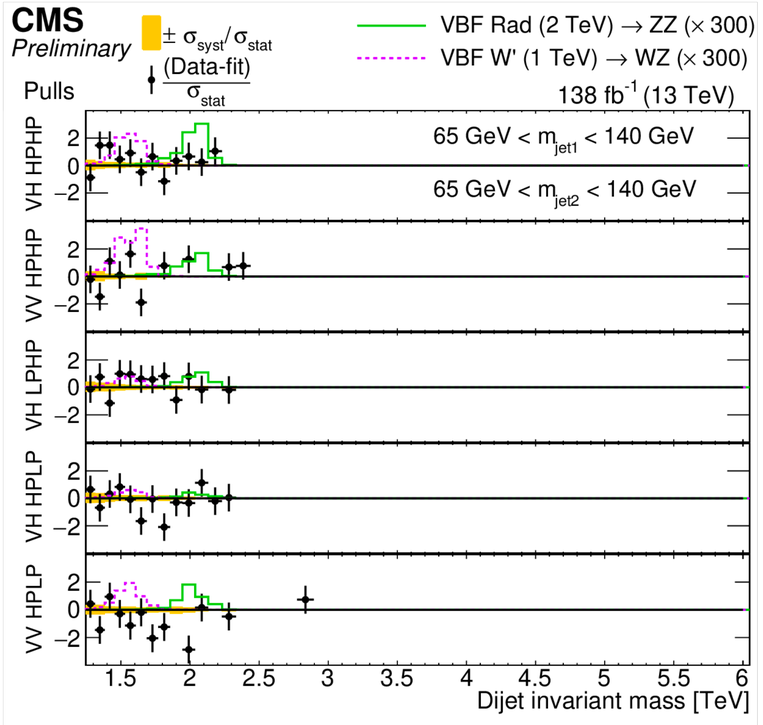
X→ VV/VH →ALL-JETS: RESULTS IN VBF MODE







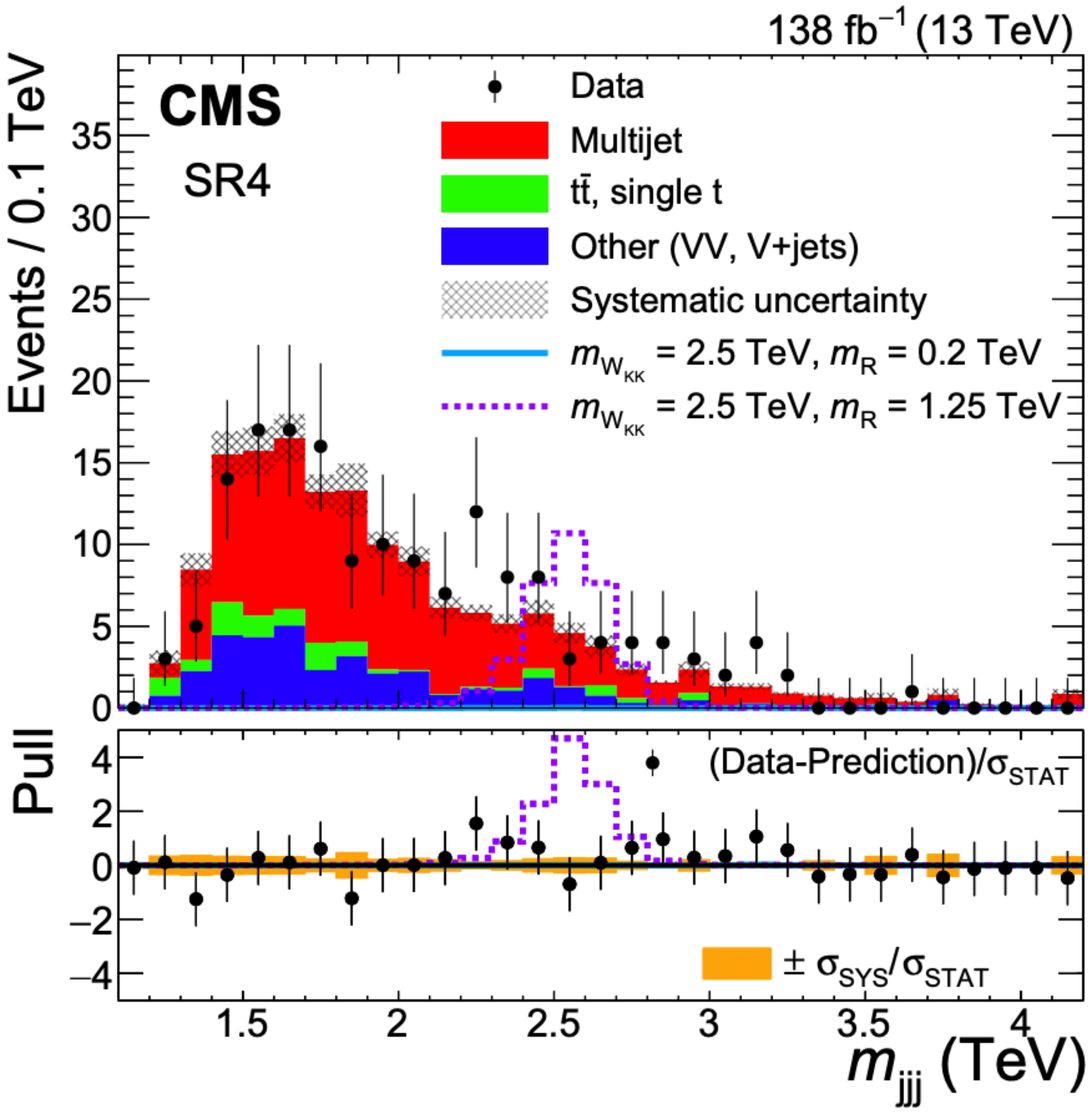
X→ VV/VH DY/GG VV

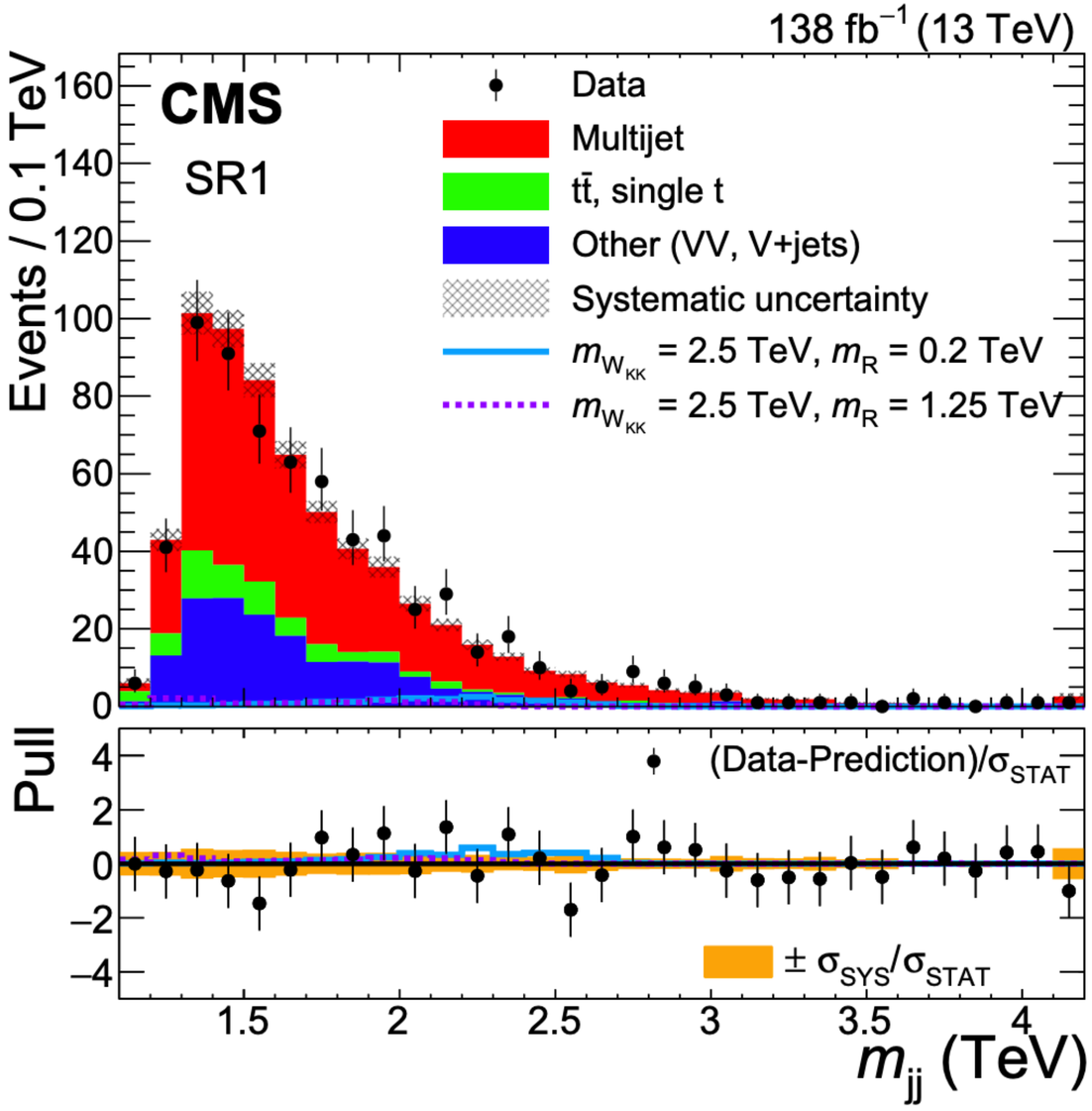


X→ VV/VH DY/GG VH

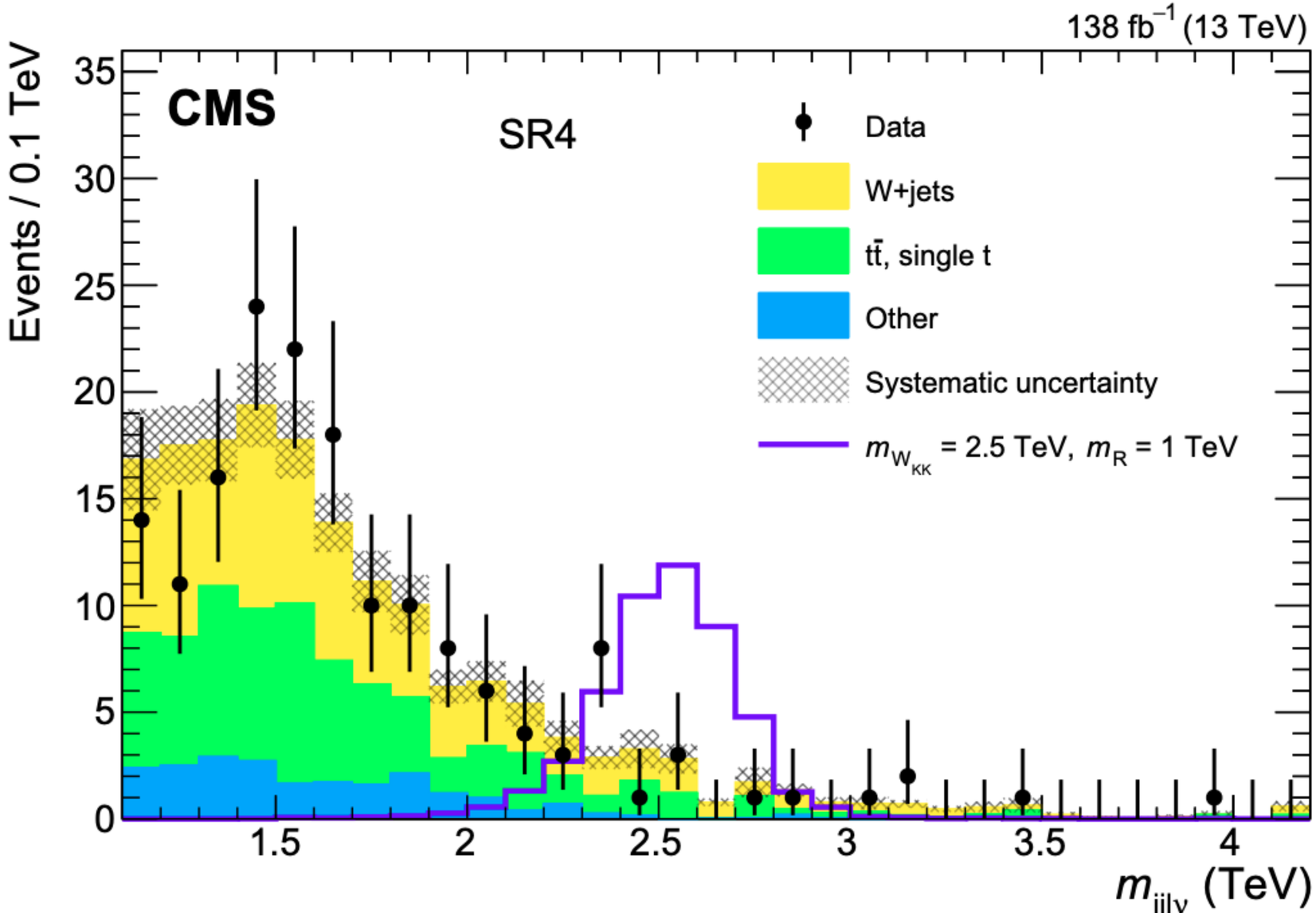
X→ VV/VH VBF VV/VH

X→WWW: MASS DISTRIBUTION

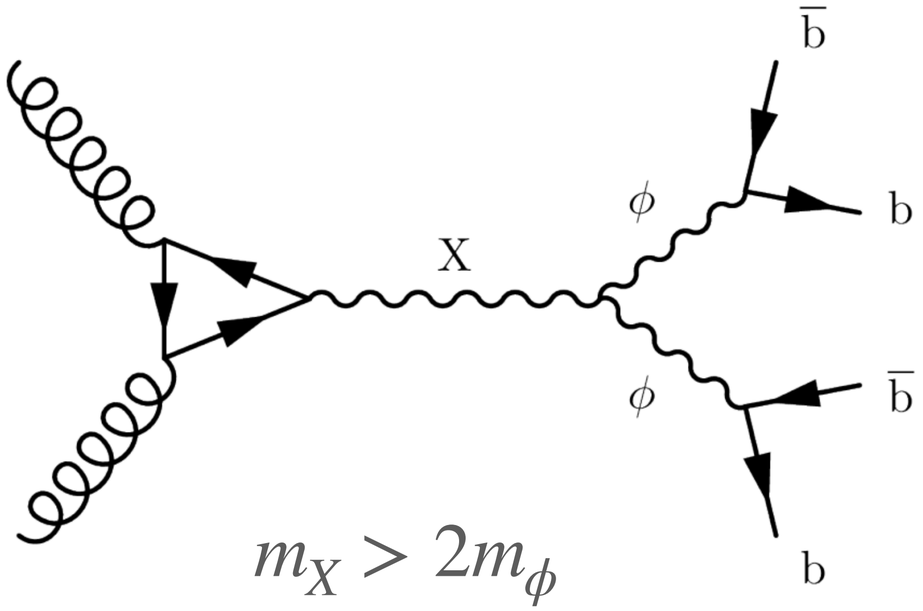


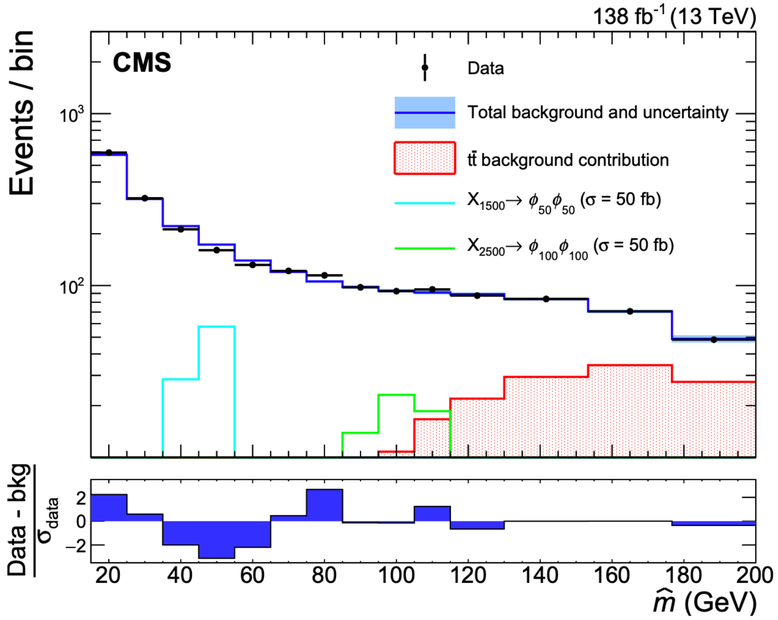


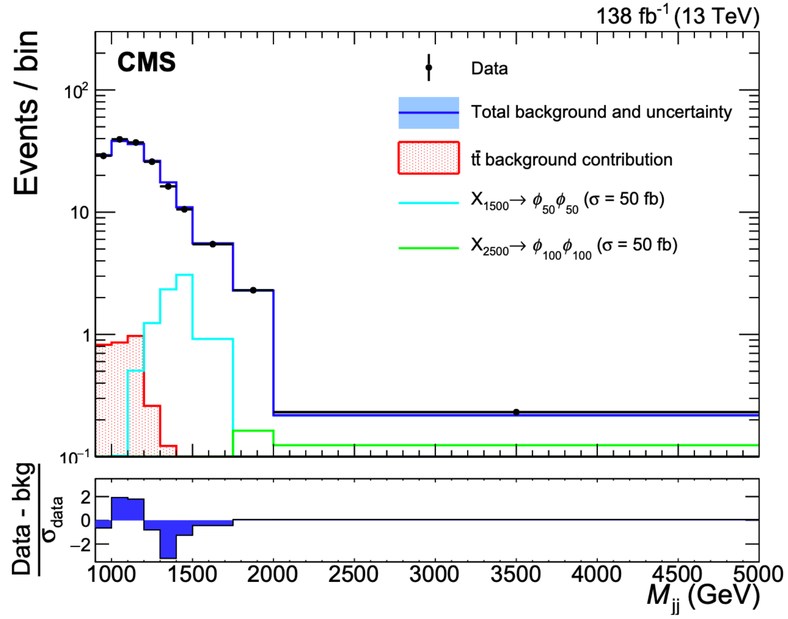
X→WWW: MASS DISTRIBUTION (SEMI-LEPTONIC)



X→ ΦΦ→ 4B

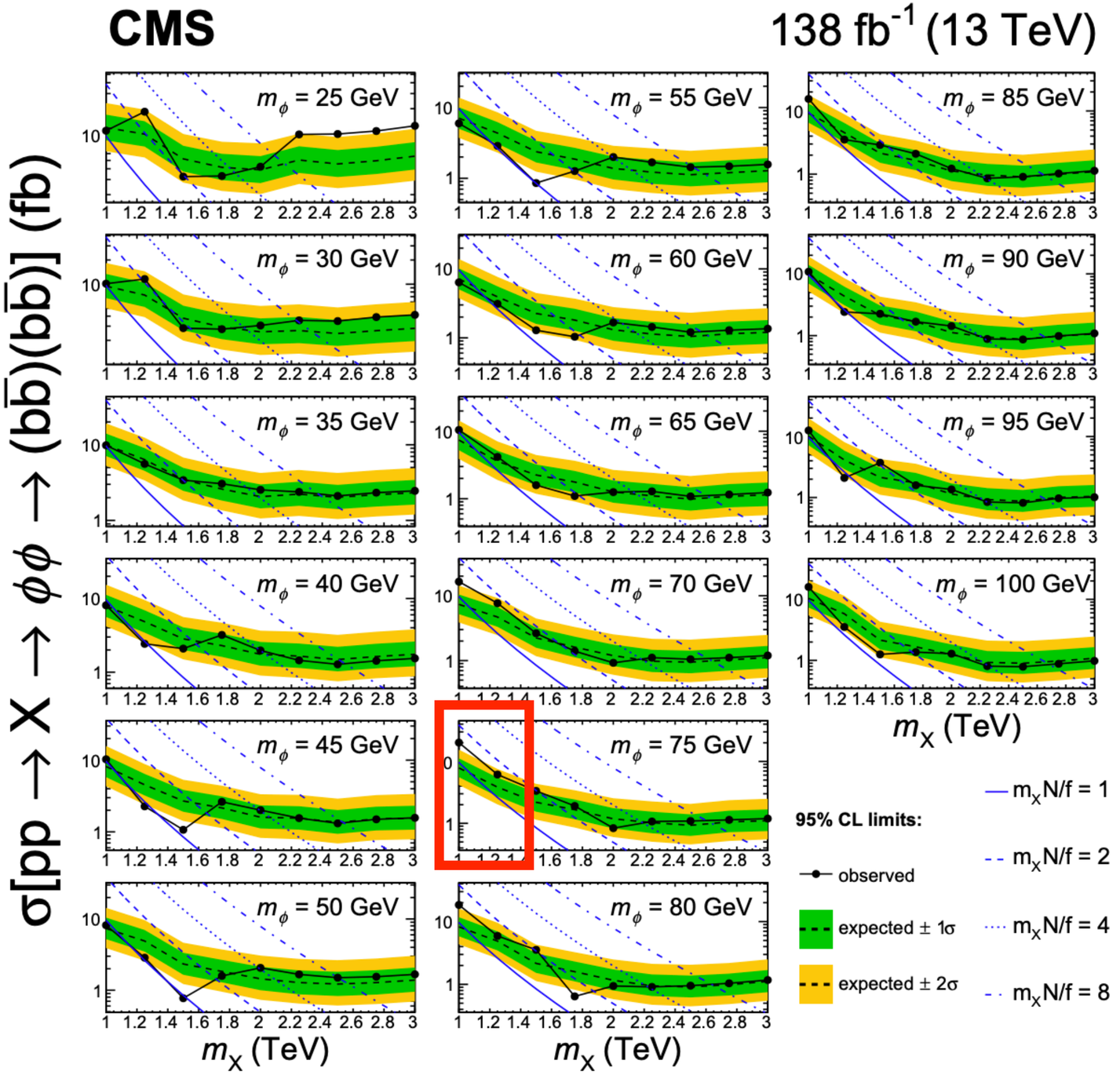






Tagging 2 (2b) final states using Double-b tagger and a 2D fit on average jet mass & dijet mass Mjj.

Ranges explored: $M_X > 1$TeV and $M\phi$: 25-100 GeV

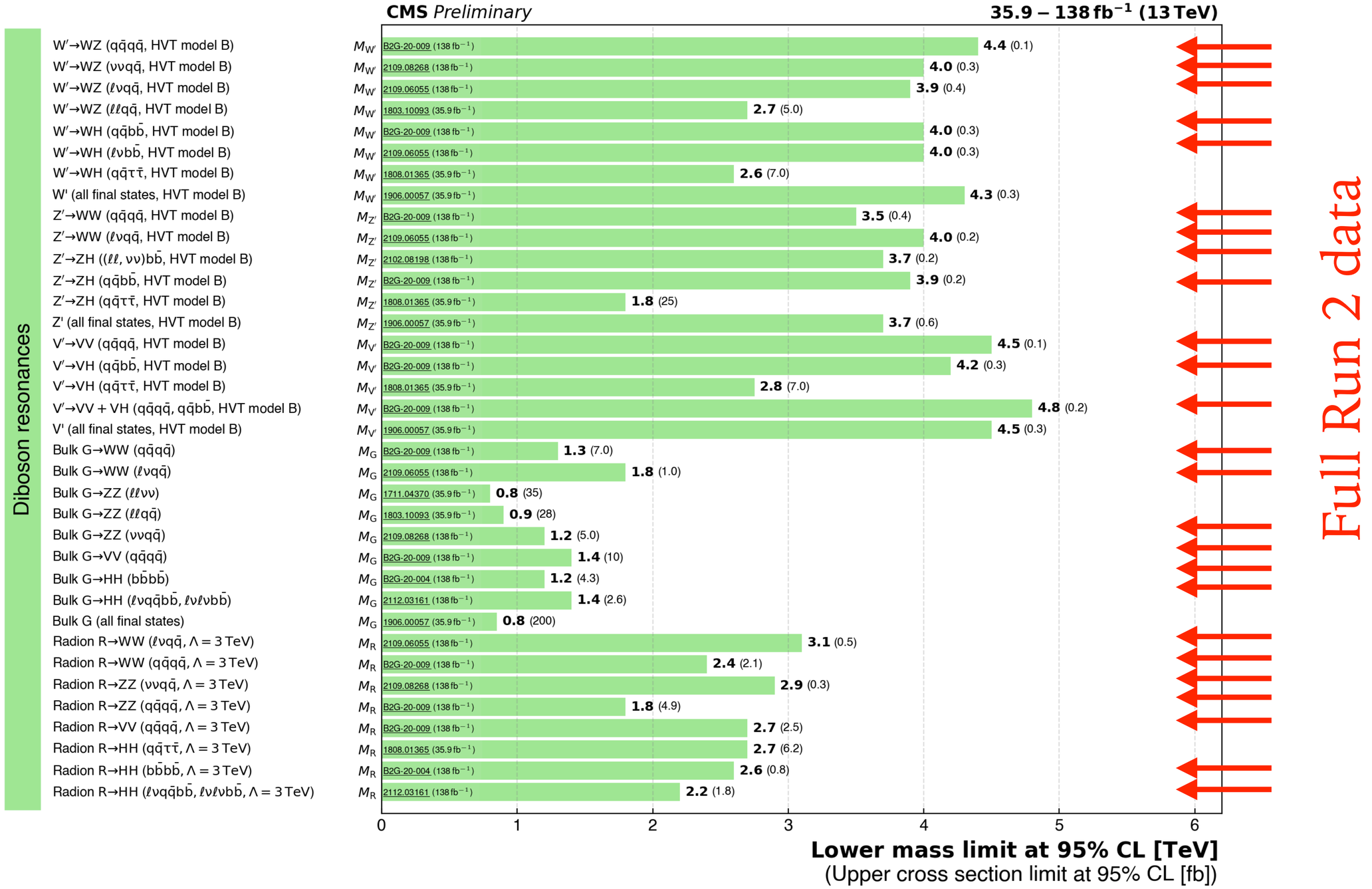


Assuming 100% BR.

3.1 local

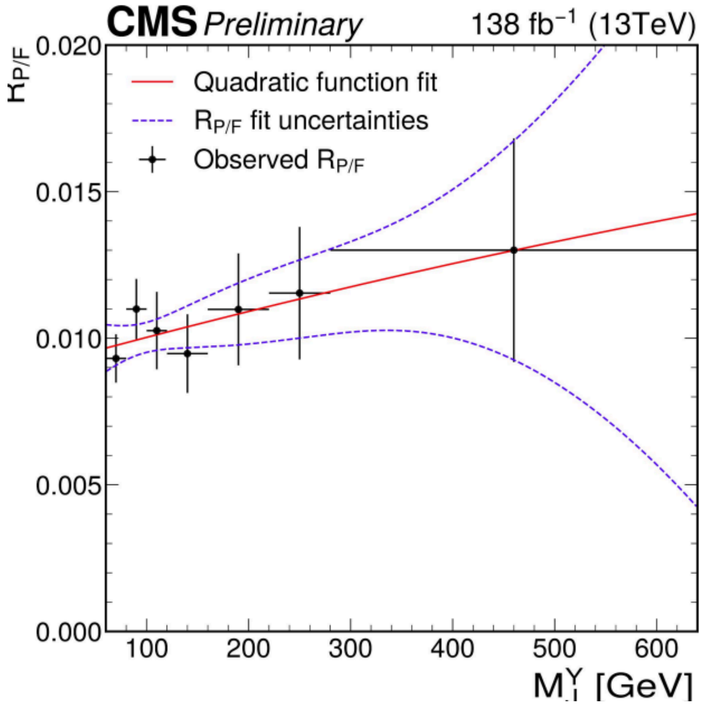
1.3 global

Cross section depends on the coupling of X to gluons: therefore on the number of flavors of quarks (N) that receive all their mass from X vacuum exp. value.


CMS Preliminary
35.9 – 138 fb^{-1} (13 TeV)
Diboson resonances
W′→WZ (qq̄qq̄, HVT model B)
W′→WZ (νν̄qq̄, HVT model B)
W′→WZ (ℓνqq̄, HVT model B)
W′→WZ (ℓℓqq̄, HVT model B)
W′→WH (qq̄bb̄, HVT model B)
W′→WH (ℓνbb̄, HVT model B)
W′→WH (qq̄ττ̄, HVT model B)
W' (all final states, HVT model B)
Z′→WW (qq̄qq̄, HVT model B)
Z′→WW (ℓνqq̄, HVT model B)
Z′→ZH ((ℓℓ, νν)bb̄, HVT model B)
Z′→ZH (qq̄bb̄, HVT model B)
Z′→ZH (qq̄ττ̄, HVT model B)
Z' (all final states, HVT model B)
V′→VV (qq̄qq̄, HVT model B)
V′→VH (qq̄bb̄, HVT model B)
V′→VH (qq̄ττ̄, HVT model B)
V′→VV + VH (qq̄qq̄, qq̄bb̄, HVT model B)
V' (all final states, HVT model B)
Bulk G→WW (qq̄qq̄)
Bulk G→WW (ℓνqq̄)
Bulk G→ZZ (ℓℓνν)
Bulk G→ZZ (ℓℓqq̄)
Bulk G→ZZ (νν̄qq̄)
Bulk G→VV (qq̄qq̄)
Bulk G→HH (bb̄bb̄)
Bulk G→HH (ℓνqq̄bb̄, ℓνℓνbb̄)
Bulk G (all final states)
Radion R→WW (ℓνqq̄, Λ = 3 TeV)
Radion R→WW (qq̄qq̄, Λ = 3 TeV)
Radion R→ZZ (νν̄qq̄, Λ = 3 TeV)
Radion R→ZZ (qq̄qq̄, Λ = 3 TeV)
Radion R→VV (qq̄qq̄, Λ = 3 TeV)
Radion R→HH (qq̄ττ̄, Λ = 3 TeV)
Radion R→HH (bb̄bb̄, Λ = 3 TeV)
Radion R→HH (ℓνqq̄bb̄, ℓνℓνbb̄, Λ = 3 TeV)
$M_{W'}$ B2G-20-009 (138 fb^{-1}) 4.4 (0.1)
$M_{W'}$ 2109.08268 (138 fb^{-1}) 4.0 (0.3)
$M_{W'}$ 2109.06055 (138 fb^{-1}) 3.9 (0.4)
$M_{W'}$ 1803.10093 (35.9 fb^{-1}) 2.7 (5.0)
$M_{W'}$ B2G-20-009 (138 fb^{-1}) 4.0 (0.3)
$M_{W'}$ 2109.06055 (138 fb^{-1}) 4.0 (0.3)
$M_{W'}$ 1808.01365 (35.9 fb^{-1}) 2.6 (7.0)
$M_{W'}$ 1906.00057 (35.9 fb^{-1}) 4.3 (0.3)
$M_{Z'}$ B2G-20-009 (138 fb^{-1}) 3.5 (0.4)
$M_{Z'}$ 2109.06055 (138 fb^{-1}) 4.0 (0.2)
$M_{Z'}$ 2102.08198 (138 fb^{-1}) 3.7 (0.2)
$M_{Z'}$ B2G-20-009 (138 fb^{-1}) 3.9 (0.2)
$M_{Z'}$ 1808.01365 (35.9 fb^{-1}) 1.8 (25)
$M_{Z'}$ 1906.00057 (35.9 fb^{-1}) 3.7 (0.6)
$M_{V'}$ B2G-20-009 (138 fb^{-1}) 4.5 (0.1)
$M_{V'}$ B2G-20-009 (138 fb^{-1}) 4.2 (0.3)
$M_{V'}$ 1808.01365 (35.9 fb^{-1}) 2.8 (7.0)
$M_{V'}$ B2G-20-009 (138 fb^{-1}) 4.8 (0.2)
$M_{V'}$ 1906.00057 (35.9 fb^{-1}) 4.5 (0.3)
M_{G} B2G-20-009 (138 fb^{-1}) 1.3 (7.0)
M_{G} 2109.06055 (138 fb^{-1}) 1.8 (1.0)
M_{G} 1711.04370 (35.9 fb^{-1}) 0.8 (35)
M_{G} 1803.10093 (35.9 fb^{-1}) 0.9 (28)
M_{G} 2109.08268 (138 fb^{-1}) 1.2 (5.0)
M_{G} B2G-20-009 (138 fb^{-1}) 1.4 (10)
M_{G} B2G-20-004 (138 fb^{-1}) 1.2 (4.3)
M_{G} 2112.03161 (138 fb^{-1}) 1.4 (2.6)
M_{G} 1906.00057 (35.9 fb^{-1}) 0.8 (200)
M_{R} 2109.06055 (138 fb^{-1}) 3.1 (0.5)
M_{R} B2G-20-009 (138 fb^{-1}) 2.4 (2.1)
M_{R} 2109.08268 (138 fb^{-1}) 2.9 (0.3)
M_{R} B2G-20-009 (138 fb^{-1}) 1.8 (4.9)
M_{R} B2G-20-009 (138 fb^{-1}) 2.7 (2.5)
M_{R} 1808.01365 (35.9 fb^{-1}) 2.7 (6.2)
M_{R} B2G-20-004 (138 fb^{-1}) 2.6 (0.8)
M_{R} 2112.03161 (138 fb^{-1}) 2.2 (1.8)
0
1
2
3
4
5
6
Lower mass limit at 95% CL [TeV]
(Upper cross section limit at 95% CL [fb])
Full Run 2 data

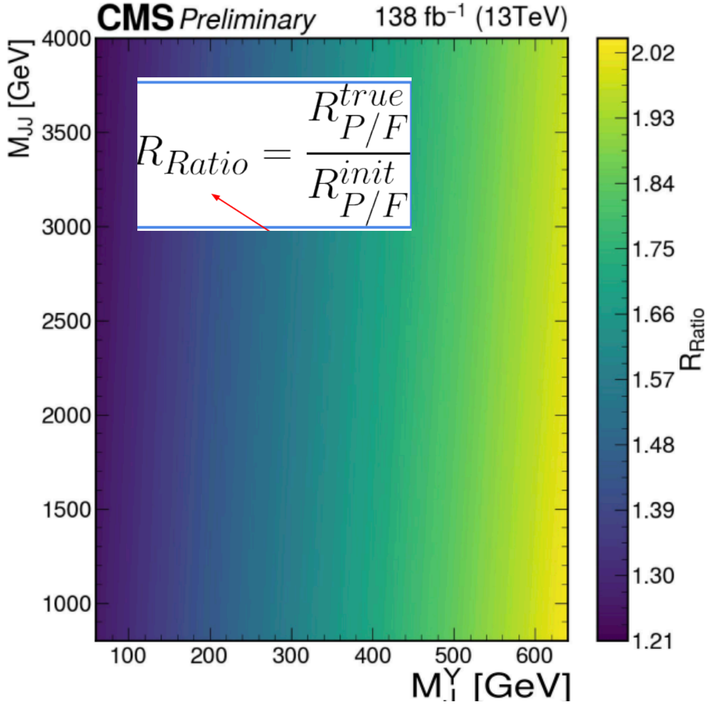
X→ YH→ 4B: QCD M(JJ) AND M(Y) SHAPE ESTIMATE:

Translate between regions that pass and fail jet tagger



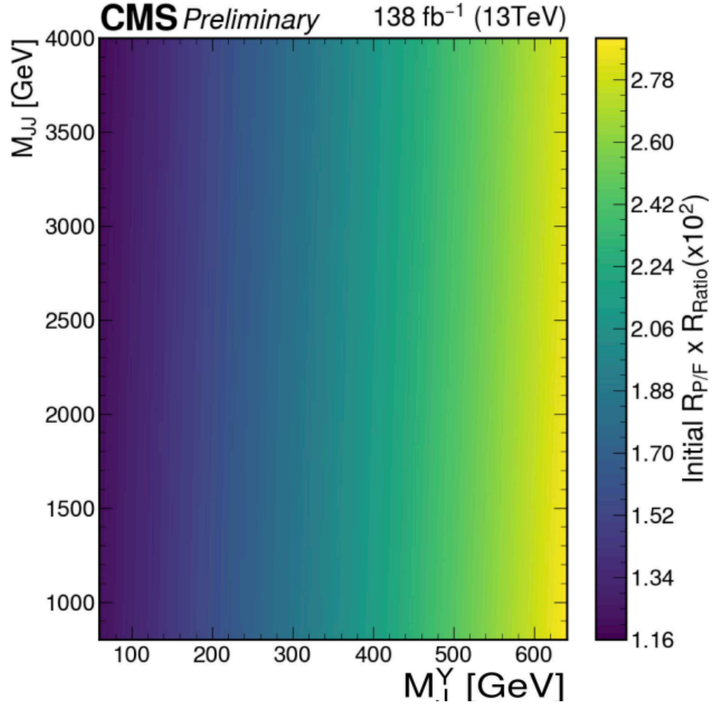
Observed pass to fail ratio

X



Difference between signal and sideband regions

=



"Transfer function".

Pass = Transfer function x Fail

X→ Y(BB)H(GG): OBSERVED LOCAL P VALUE