SEARCHES FOR EXOTICA AT CMS

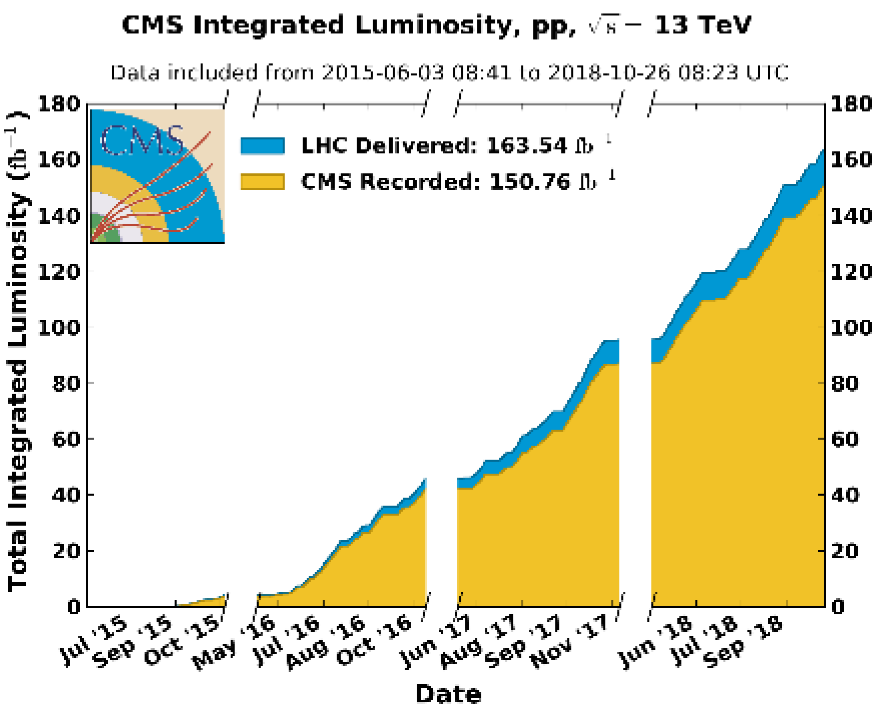
ANDREW ASKEW

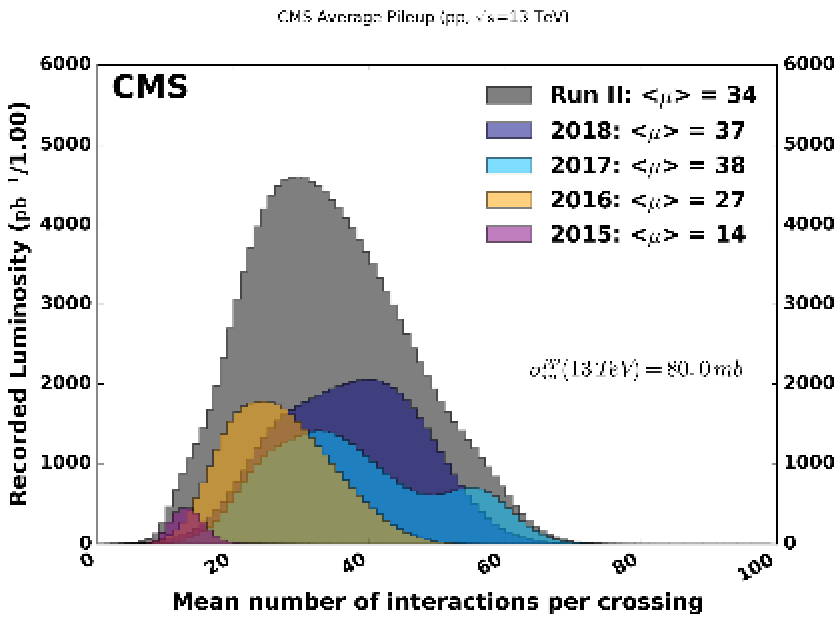
FOR THE CMS COLLABORATION

OVERVIEW

- 2022 marks the beginning of Run 3. All of the results I have to show you today make use of the full Run 2 dataset.
  - I will try to give some sense of the latest results across the Exotic landscape.
- Where we're going:
  - There is a vast expanse of LHC data yet to be taken and explored! We're back running RIGHT NOW.

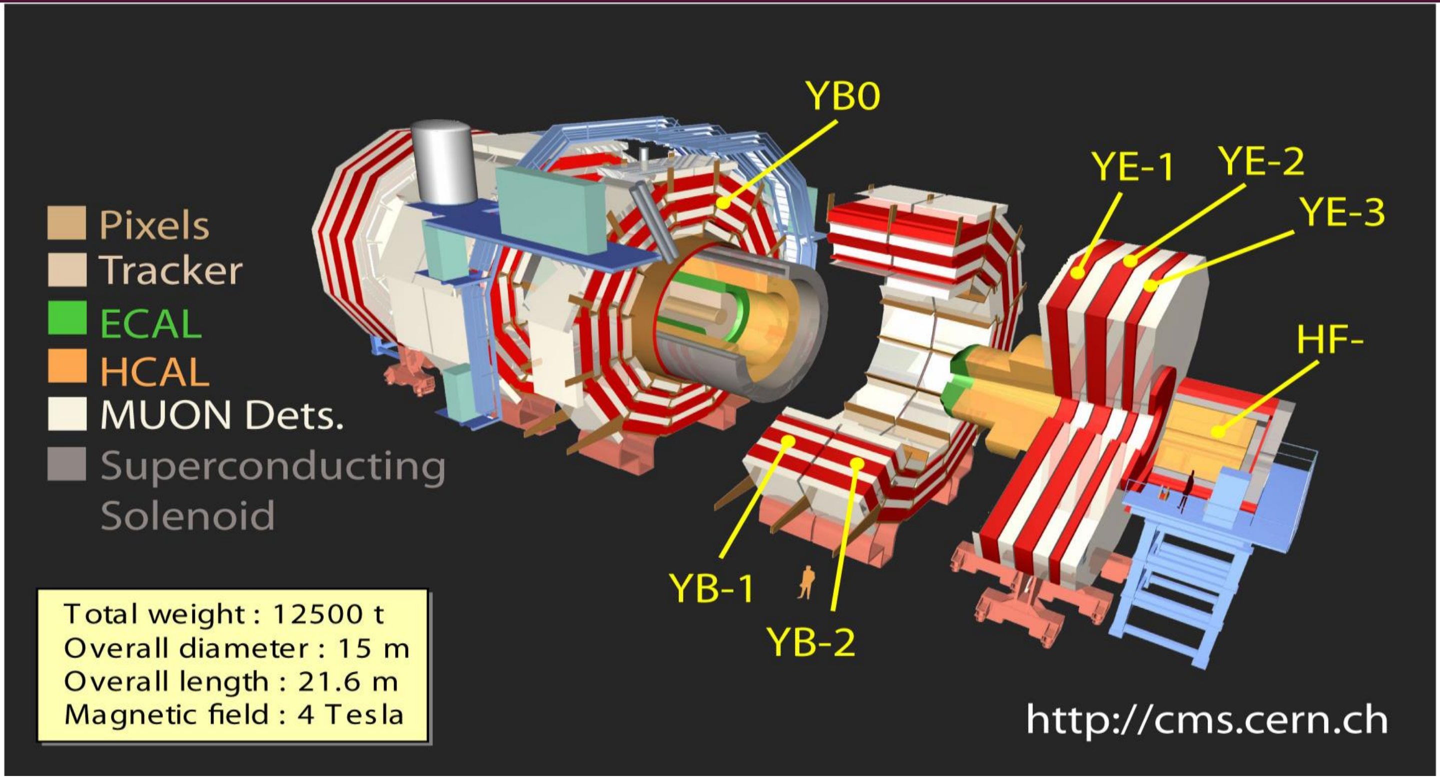
REMINDER: RUN 2





- Most of what I will highlight will utilize 138 fb^{-1} of data

NEVER COMPLETE WITHOUT:

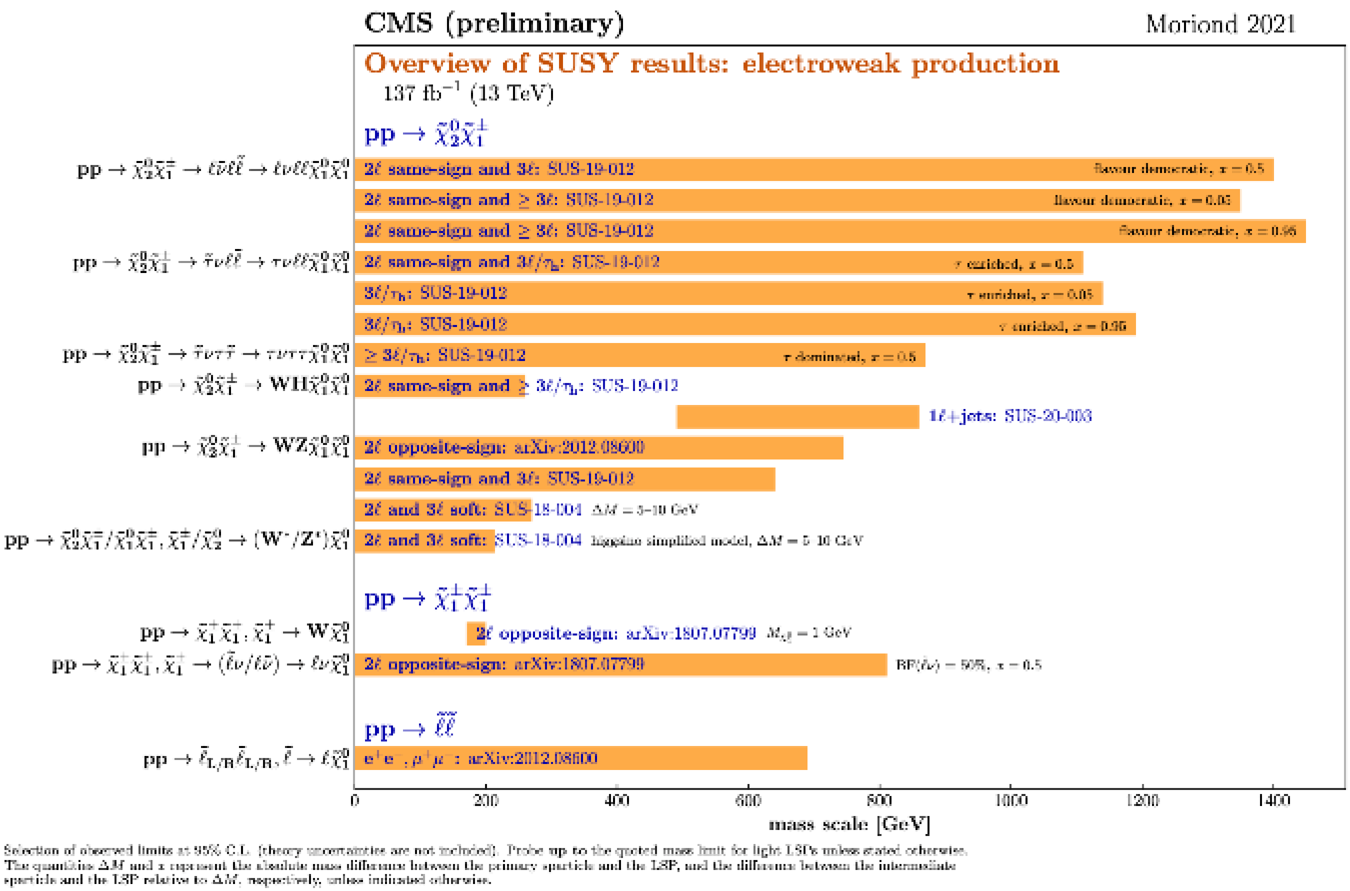


- An experimental talk is never complete without the star of our show.

OVERVIEW

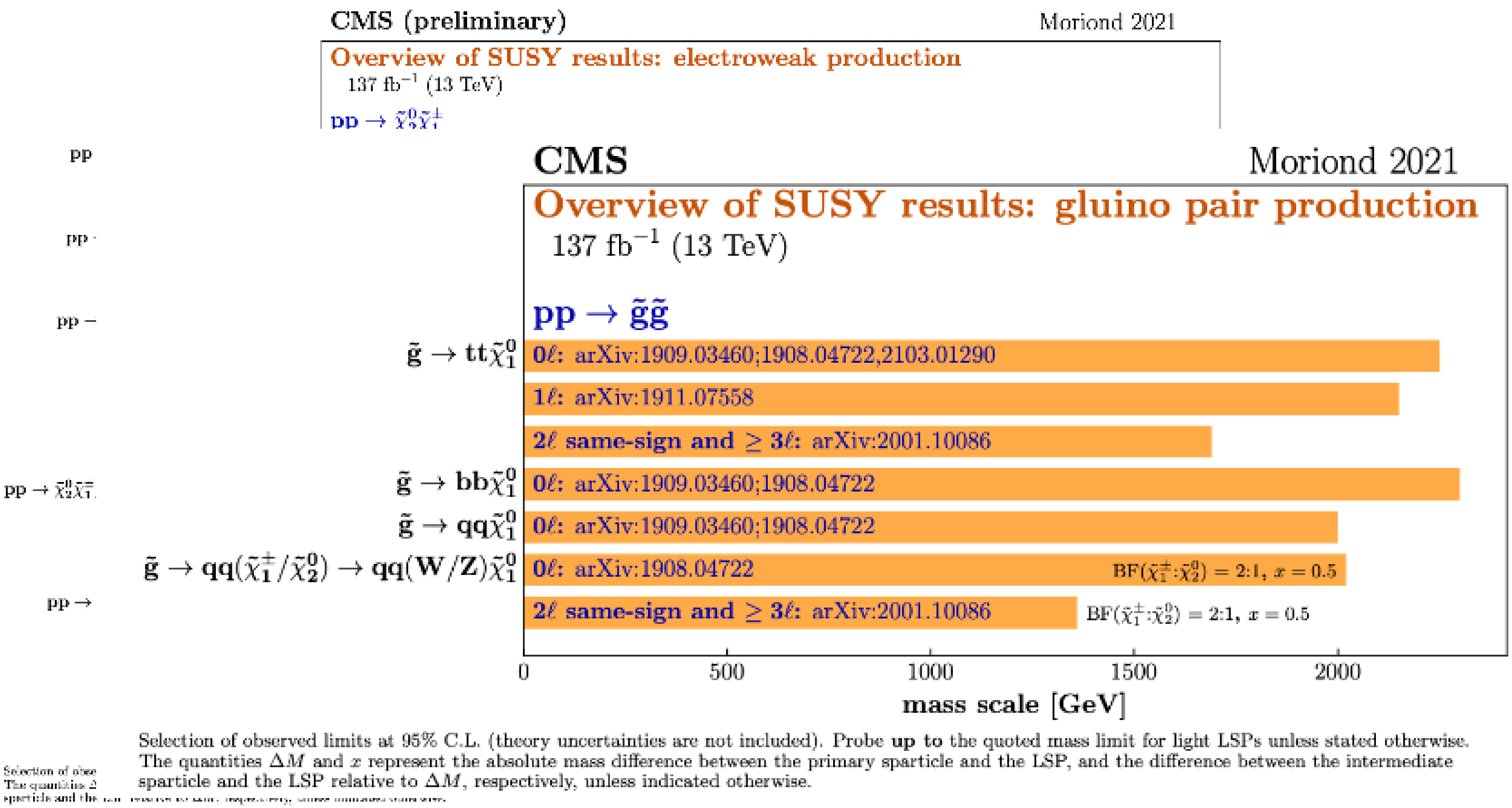
- Let me quickly summarize our results:

LANDSCAPE:

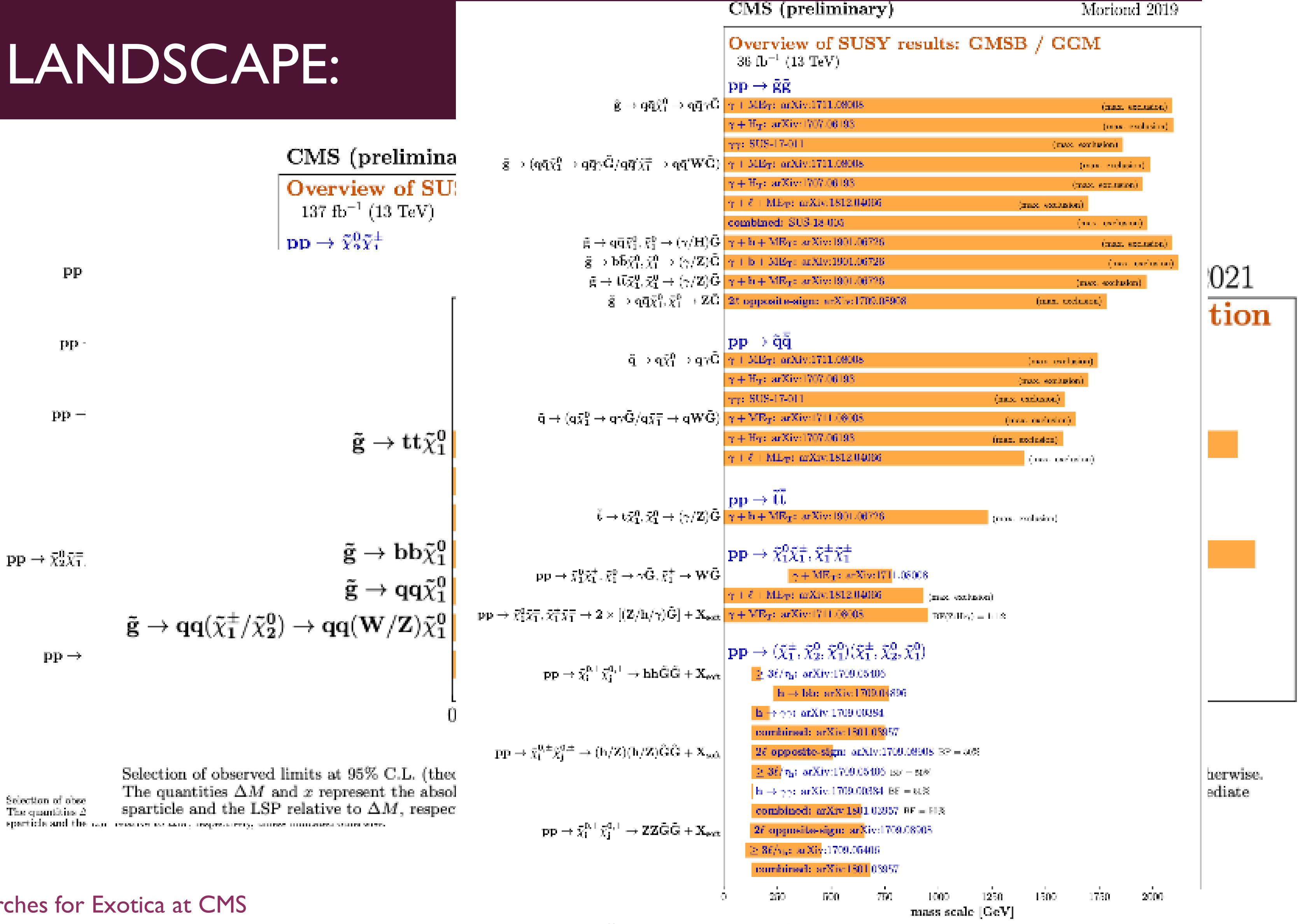


CMS (preliminary)
Moriond 2021
Overview of SUSY results: electroweak production
137 fb^{-1} (13 TeV)
pp → $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$
2ℓ same-sign and 3ℓ: SUS-19-012
2ℓ same-sign and ≥ 3ℓ: SUS-19-012
2ℓ same-sign and ≥ 3ℓ: SUS-19-012
2ℓ same-sign and 3ℓ/τ_h: SUS-19-012
3ℓ/τ_h: SUS-19-012
3ℓ/τ_h: SUS-19-012
≥ 3ℓ/τ_h: SUS-19-012
2ℓ same-sign and ≥ 3ℓ/τ_h: SUS-19-012
1ℓ+jets: SUS-20-003
2ℓ opposite-sign: arXiv:2012.08600
2ℓ same-sign and 3ℓ: SUS-19-012
2ℓ and 3ℓ soft: SUS-18-004
2ℓ and 3ℓ soft: SUS-18-004
pp → $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$
2ℓ opposite-sign: arXiv:1807.07799
2ℓ opposite-sign: arXiv:1807.07799
pp → $\tilde{\ell}\tilde{\ell}$
e^+e^-, $\mu^+\mu^-$: arXiv:2012.08600
0
200
400
600
800
1000
1200
1400
mass scale [GeV]

LANDSCAPE:

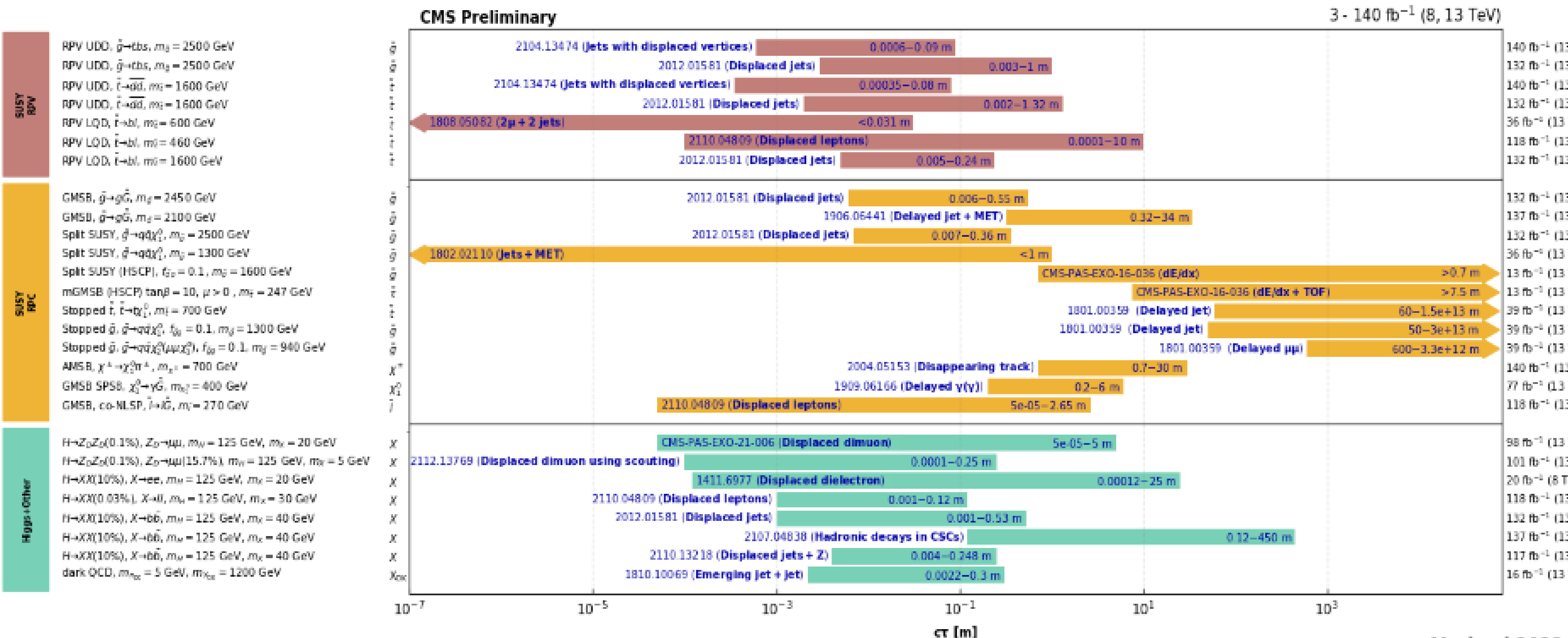

CMS (preliminary)
Moriond 2021
Overview of SUSY results: electroweak production
137 fb^{-1} (13 TeV)
CMS
Moriond 2021
Overview of SUSY results: gluino pair production
137 fb^{-1} (13 TeV)
pp → $\tilde{g}\tilde{g}$
$\tilde{g} \to tt\tilde{\chi}_1^0$
0ℓ: arXiv:1909.03460;1908.04722,2103.01290
1ℓ: arXiv:1911.07558
2ℓ same-sign and ≥ 3ℓ: arXiv:2001.10086
$\tilde{g} \to bb\tilde{\chi}_1^0$
0ℓ: arXiv:1909.03460;1908.04722
$\tilde{g} \to qq\tilde{\chi}_1^0$
0ℓ: arXiv:1909.03460;1908.04722
$\tilde{g} \to qq(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0) \to qq(W/Z)\tilde{\chi}_1^0$
0ℓ: arXiv:1908.04722
BF($\tilde{\chi}_1^\pm$:$\tilde{\chi}_2^0$) = 2:1, x = 0.5
2ℓ same-sign and ≥ 3ℓ: arXiv:2001.10086
BF($\tilde{\chi}_1^\pm$:$\tilde{\chi}_2^0$) = 2:1, x = 0.5
0
500
1000
1500
2000
mass scale [GeV]
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise.
The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate
sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

LANDSCAPE:



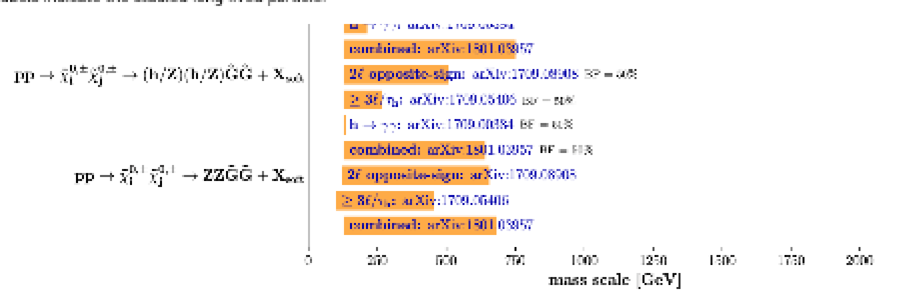
CMS (preliminary)
Moriond 2019
Overview of SUSY results: GMSB / GGM
36 fb⁻¹ (13 TeV)
pp → g̃g̃
pp → q̃q̃
pp → t̃t̃
mass scale [GeV]
CMS (prelimina
Overview of SU
137 fb⁻¹ (13 TeV)
g̃ → ttχ̃⁰₁
g̃ → bbχ̃⁰₁
g̃ → qqχ̃⁰₁
g̃ → qq(χ̃±₁/χ̃⁰₂) → qq(W/Z)χ̃⁰₁
Selection of observed limits at 95% C.L. (theo
The quantities ΔM and x represent the absol
sparticle and the LSP relative to ΔM, respec

Overview of CMS long-lived particle searches



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

Selection of observed limits at 95% C.L. (the
The quantities ΔM and x represent the absol
sparticle and the LSP relative to ΔM, respec



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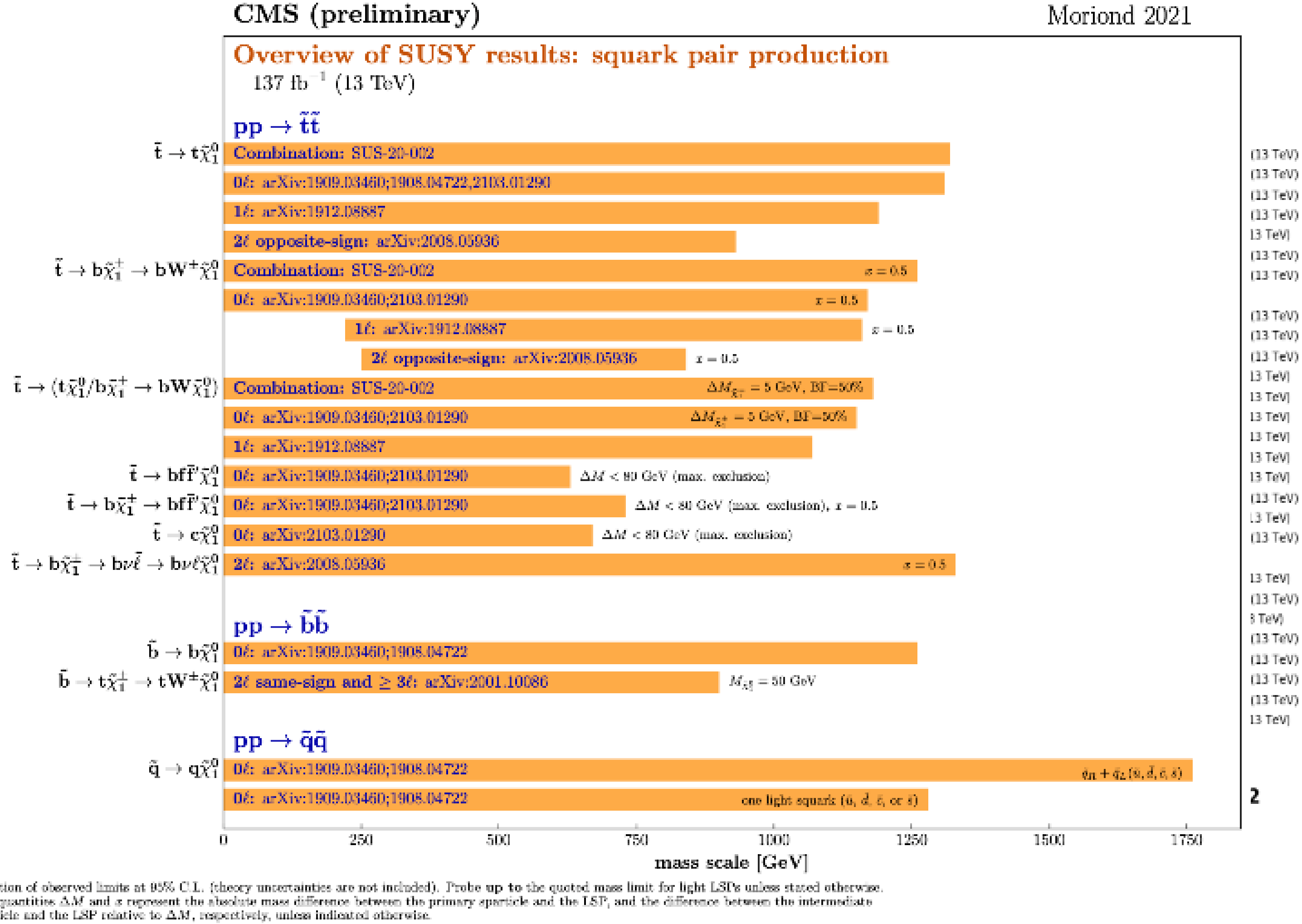
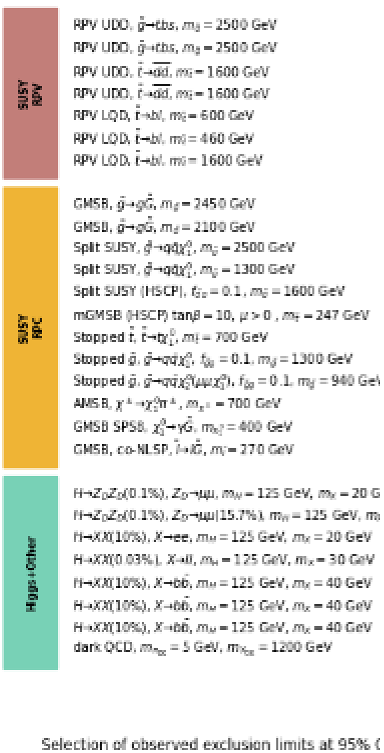
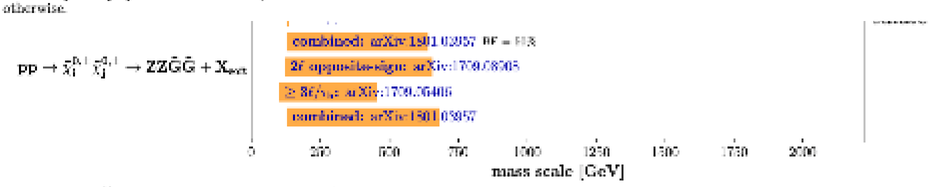

CMS (preliminary)
Moriond 2021
Overview of SUSY results: squark pair production
137 fb⁻¹ (13 TeV)
pp → t̃t̃
t̃ → tχ̃⁰₁
Combination: SUS-20-002
0ℓ: arXiv:1909.03460;1908.04722,2103.01290
1ℓ: arXiv:1912.08887
2ℓ opposite-sign: arXiv:2008.05936
t̃ → bχ̃⁺₁ → bW⁺χ̃⁰₁
Combination: SUS-20-002
x = 0.5
0ℓ: arXiv:1909.03460;2103.01290
1ℓ: arXiv:1912.08887
2ℓ opposite-sign: arXiv:2008.05936
t̃ → (tχ̃⁰₁/bχ̃⁺₁ → bWχ̃⁰₁)
Combination: SUS-20-002
ΔM = 5 GeV, BF=50%
0ℓ: arXiv:1909.03460;2103.01290
1ℓ: arXiv:1912.08887
t̃ → bff̄′χ̃⁰₁
0ℓ: arXiv:1909.03460;2103.01290
ΔM < 80 GeV (max. exclusion)
t̃ → bχ̃⁺₁ → bff̄′χ̃⁰₁
ΔM < 80 GeV (max. exclusion), x = 0.5
t̃ → cχ̃⁰₁
0ℓ: arXiv:2103.01290
t̃ → bχ̃⁺₁ → bνℓ̃ → bνℓχ̃⁰₁
2ℓ: arXiv:2008.05936
pp → b̃b̃
b̃ → bχ̃⁰₁
0ℓ: arXiv:1909.03460;1908.04722
b̃ → tχ̃⁺₁ → tW⁺χ̃⁰₁
2ℓ same-sign and ≥ 3ℓ: arXiv:2001.10086
M = 50 GeV
pp → q̃q̃
q̃ → qχ̃⁰₁
0ℓ: arXiv:1909.03460;1908.04722
one light squark (ũ, d̃, s̃, or c̃)
0 250 500 750 1000 1250 1500 1750
mass scale [GeV]
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe up to the quoted mass limit for light LSPs unless stated otherwise.
The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.



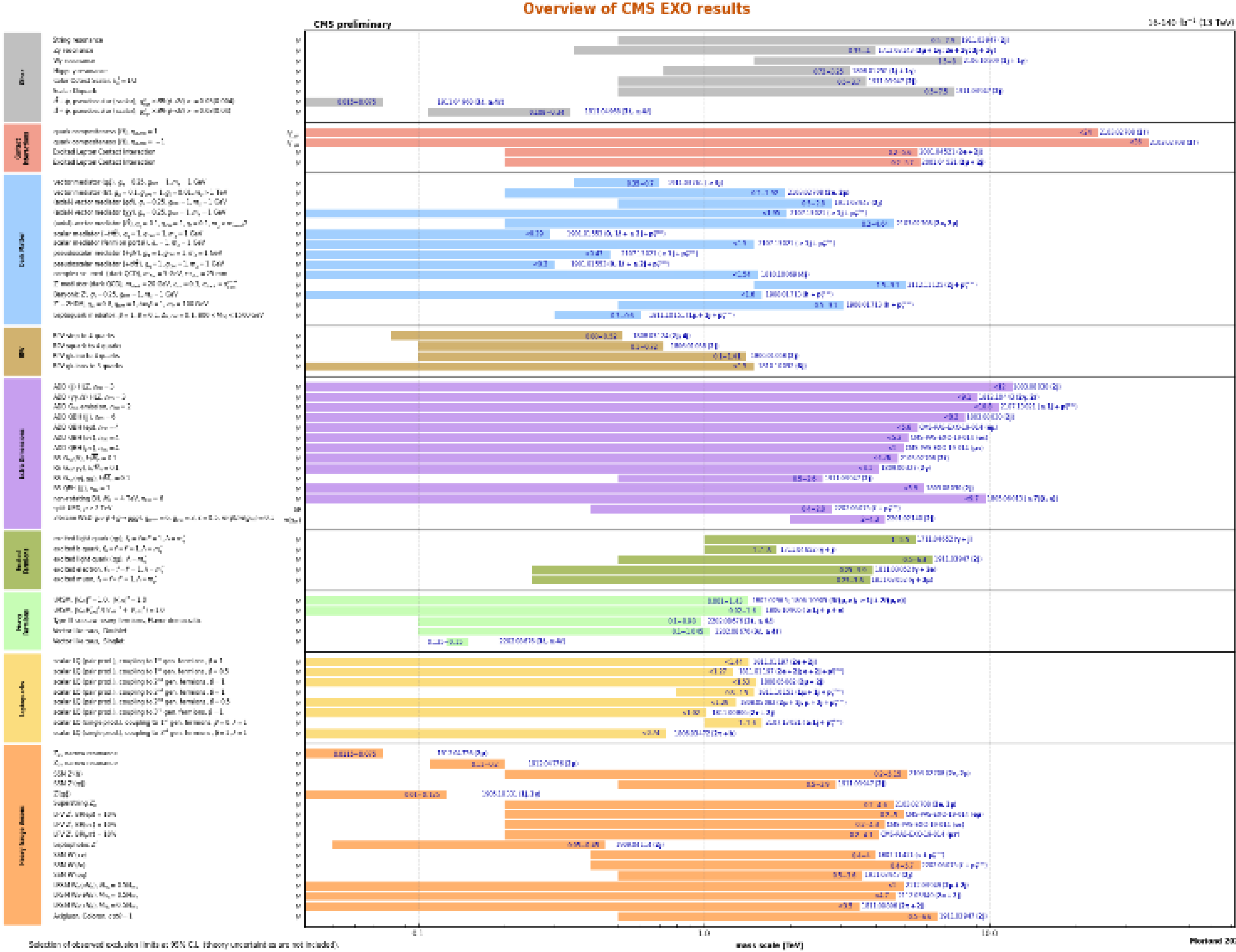


CMS (preliminary) Moriond 2021

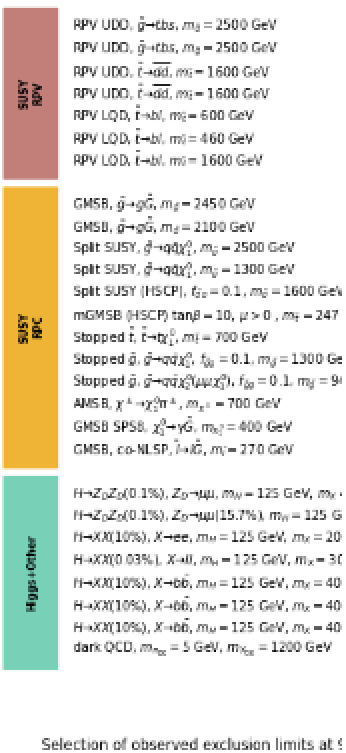
SUSY RPV	RPV UDD, $\tilde{g}\to tbs$, $m_{\tilde{g}} = 2500$ GeV RPV UDD, $\tilde{g}\to tbs$, $m_{\tilde{g}} = 2500$ GeV RPV UDD, $\tilde{t}\to \bar{d}\bar{d}$, $m_{\tilde{t}} = 1600$ GeV RPV UDD, $\tilde{t}\to \bar{d}\bar{d}$, $m_{\tilde{t}} = 1600$ GeV RPV LQD, $\tilde{t}\to bl$, $m_{\tilde{t}} = 600$ GeV RPV LQD, $\tilde{t}\to bl$, $m_{\tilde{t}} = 460$ GeV RPV LQD, $\tilde{t}\to bl$, $m_{\tilde{t}} = 1600$ GeV
SUSY RPC	GMSB, $\tilde{g}\to g\tilde{G}$, $m_{\tilde{g}} = 2450$ GeV GMSB, $\tilde{g}\to g\tilde{G}$, $m_{\tilde{g}} = 2100$ GeV Split SUSY, $\tilde{g}\to qq\tilde{\chi}_1^0$, $m_{\tilde{g}} = 2500$ GeV Split SUSY, $\tilde{g}\to qq\tilde{\chi}_1^0$, $m_{\tilde{g}} = 1300$ GeV Split SUSY (HSCP), $f_{\tilde{g}g} = 0.1$, $m_{\tilde{g}} = 1600$ Ge\ mGMSB (HSCP) $\tan\beta = 10$, $\mu > 0$, $m_{\tilde{\tau}} = 247$ Stopped $\tilde{t}$, $\tilde{t}\to t\tilde{\chi}_1^0$, $m_{\tilde{t}} = 700$ GeV Stopped $\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$, $f_{\tilde{g}g} = 0.1$, $m_{\tilde{g}} = 1300$ Ge Stopped $\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_2^0(\mu\mu\tilde{\chi}_1^0)$, $f_{\tilde{g}g} = 0.1$, $m_{\tilde{g}} = 9$ AMSB, $\chi^{\pm}\to\chi_1^0\pi^{\pm}$, $m_{\chi^{\pm}} = 700$ GeV GMSB SPS8, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, $m_{\tilde{\chi}_1^0} = 400$ GeV GMSB, co-NLSP, $\tilde{l}\to l\tilde{G}$, $m_{\tilde{l}} = 270$ GeV
Higgs+Other	$H\to Z_D Z_D(0.1\%)$, $Z_D\to\mu\mu$, $m_H = 125$ GeV, m_Z $H\to Z_D Z_D(0.1\%)$, $Z_D\to\mu\mu(15.7\%)$, $m_H = 125$ G $H\to XX(10\%)$, $X\to ee$, $m_H = 125$ GeV, $m_X = 20$ $H\to XX(0.03\%)$, $X\to ll$, $m_H = 125$ GeV, $m_X = 3($ $H\to XX(10\%)$, $X\to b\bar{b}$, $m_H = 125$ GeV, $m_X = 40$ $H\to XX(10\%)$, $X\to b\bar{b}$, $m_H = 125$ GeV, $m_X = 40$ $H\to XX(10\%)$, $X\to b\bar{b}$, $m_H = 125$ GeV, $m_X = 40$ dark QCD, $m_{\pi_{DK}} = 5$ GeV, $m_{X_{DK}} = 1200$ GeV

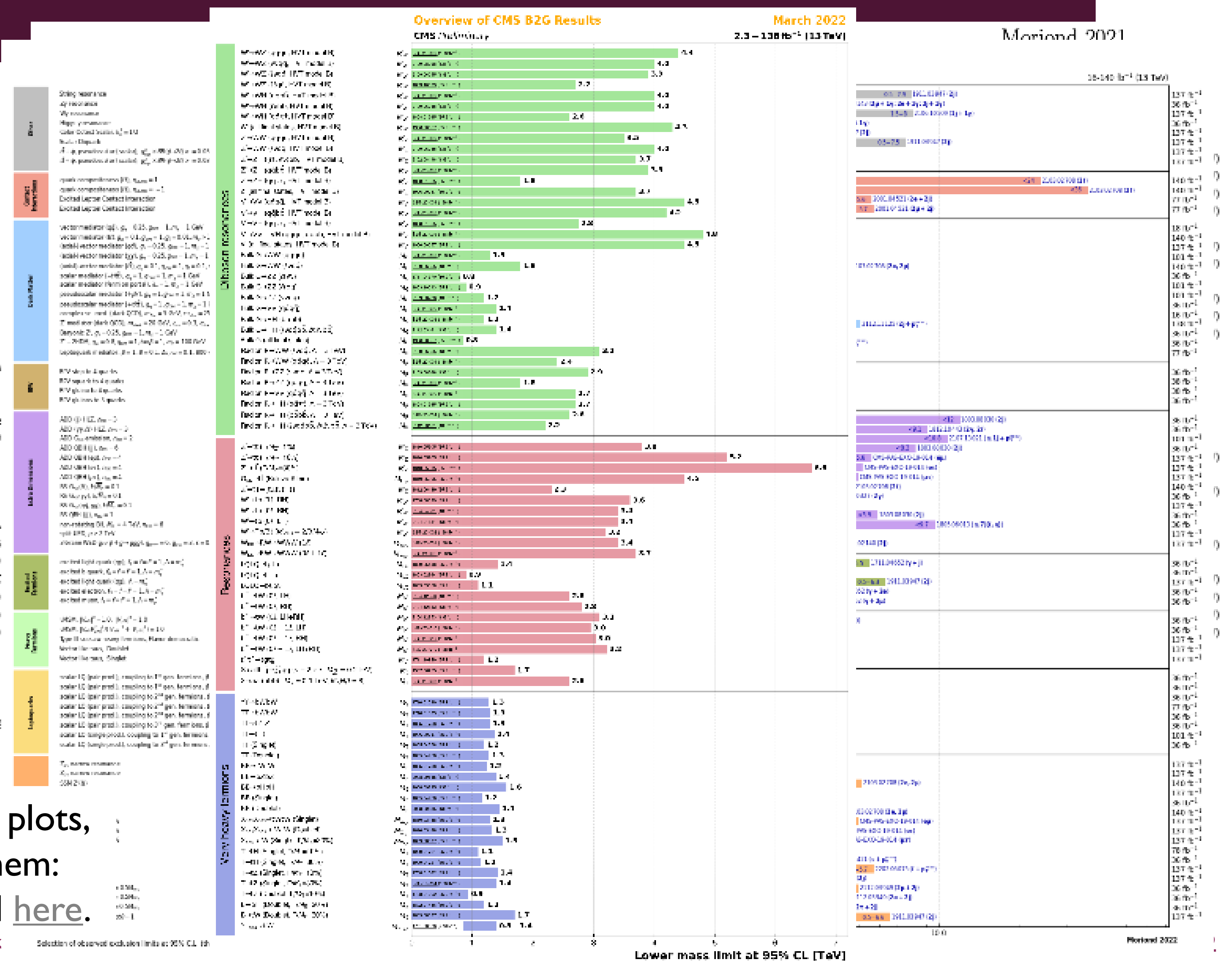
Selection of observed exclusion limits at 9

Selection of obse
The quantities 2
particle and the



Searches for Ex



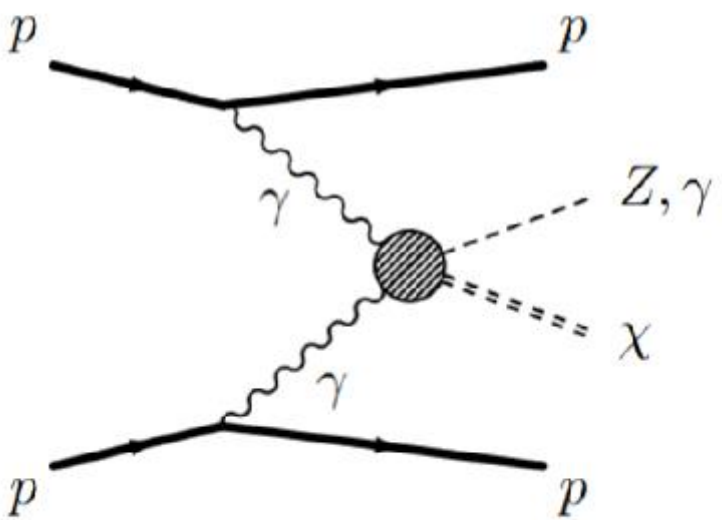


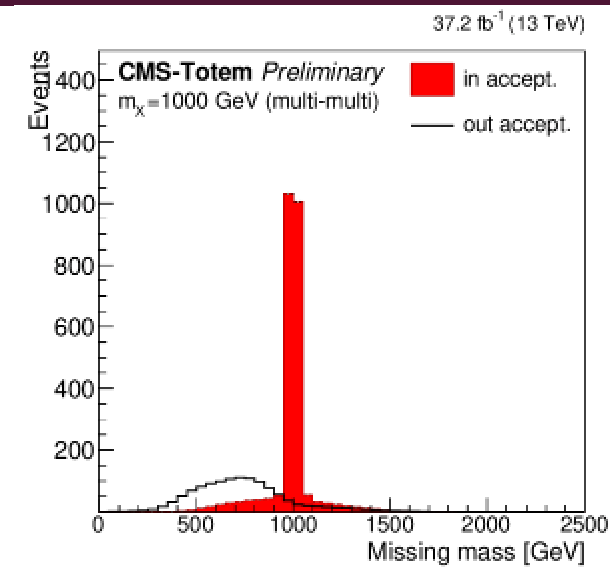
These are real plots, you can find them: here, here, and here.

KIDDING ASIDE

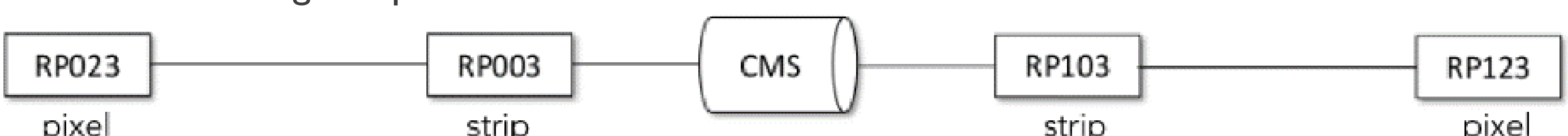
- I'm going to focus in on a subset of recent(-ish) analyses that either have been submitted, or soon will be submitted for publication.
- There are some interesting things starting to develop and I'll do my best to point out where those things live.
- I will largely organize things into:
  - Has one or more leptons (e,μ and sometimes τ).
  - Does not.
- This is influenced by how we select data events: leptons (well, e, μ at least) provide good handles for triggering. If you don't have one of those, you can trigger on things like the total energy in the calorimeters, or a large imbalance in the visible energy.

MISSING MASS



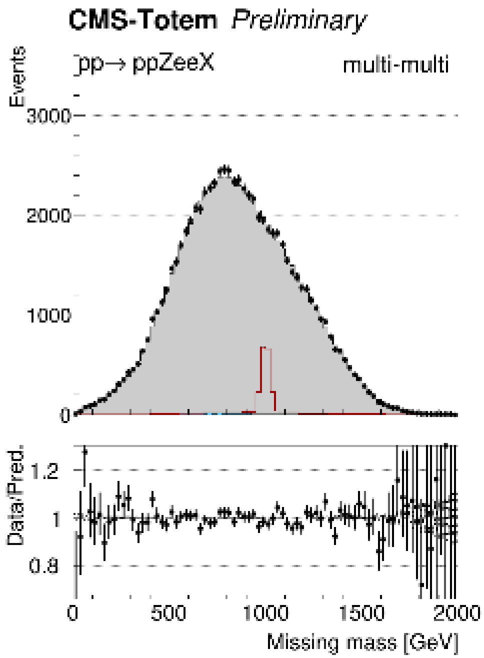


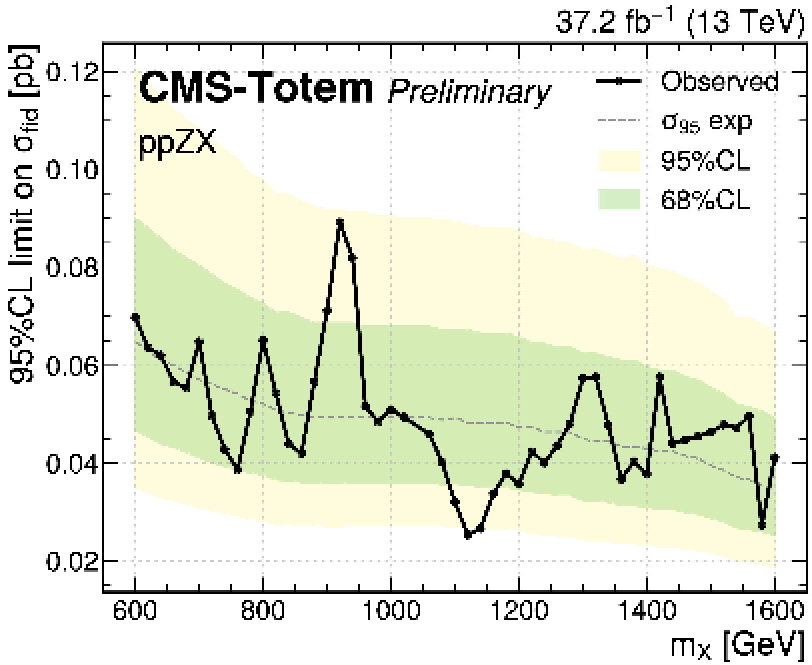
- This was the analysis that I referred to earlier as having a different luminosity, due to work performed to bring PPS into full operation.
- You have a leptonic decaying Z or γ, and measure the outgoing protons to infer if something escaped.



CMS-EXO-19-009

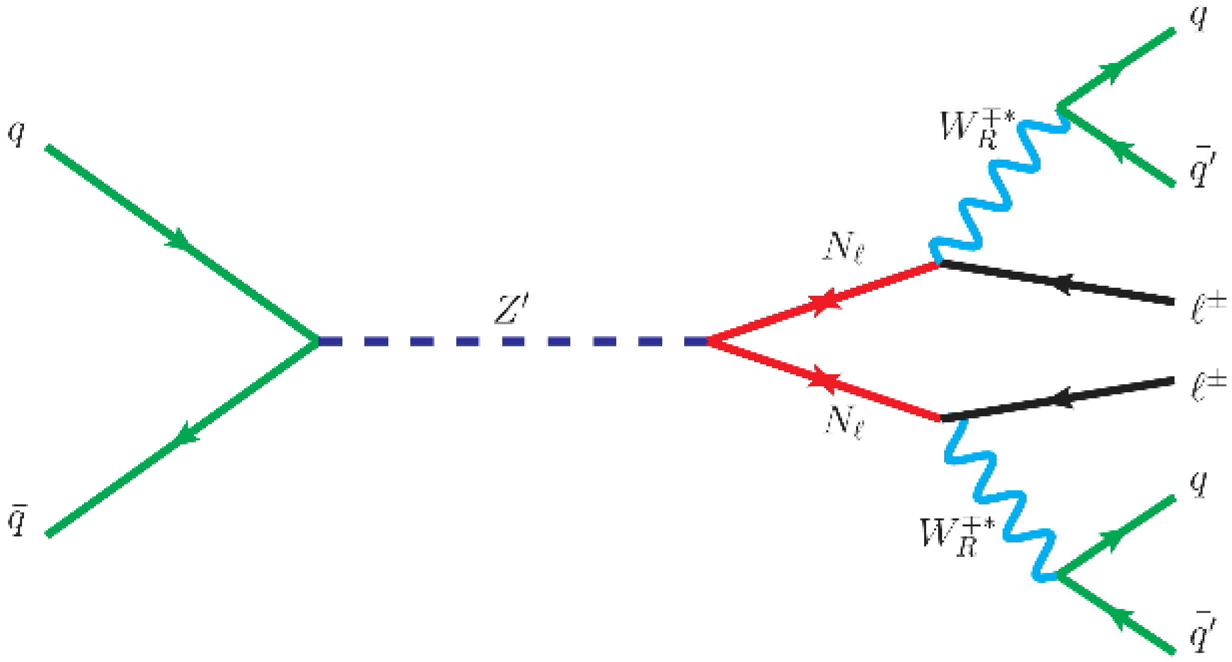
RESULT





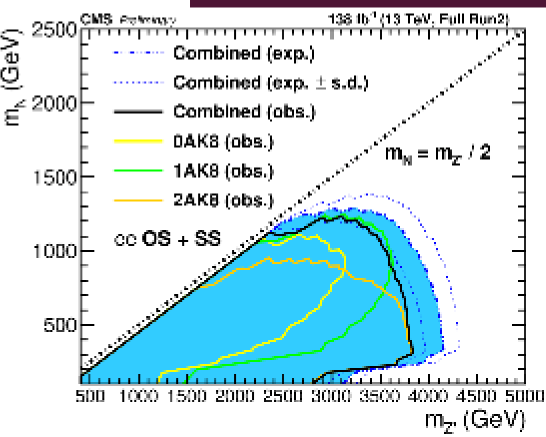
- This measurement is performed via all of the configurations of PPS (I'm showing you the best one above, for Z→ee. The combined leptonic channels allow you to set limits on an invisible particle being produced in association with the Z.

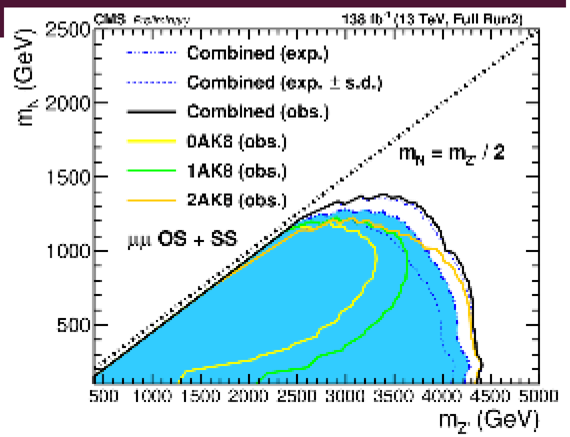
Z'

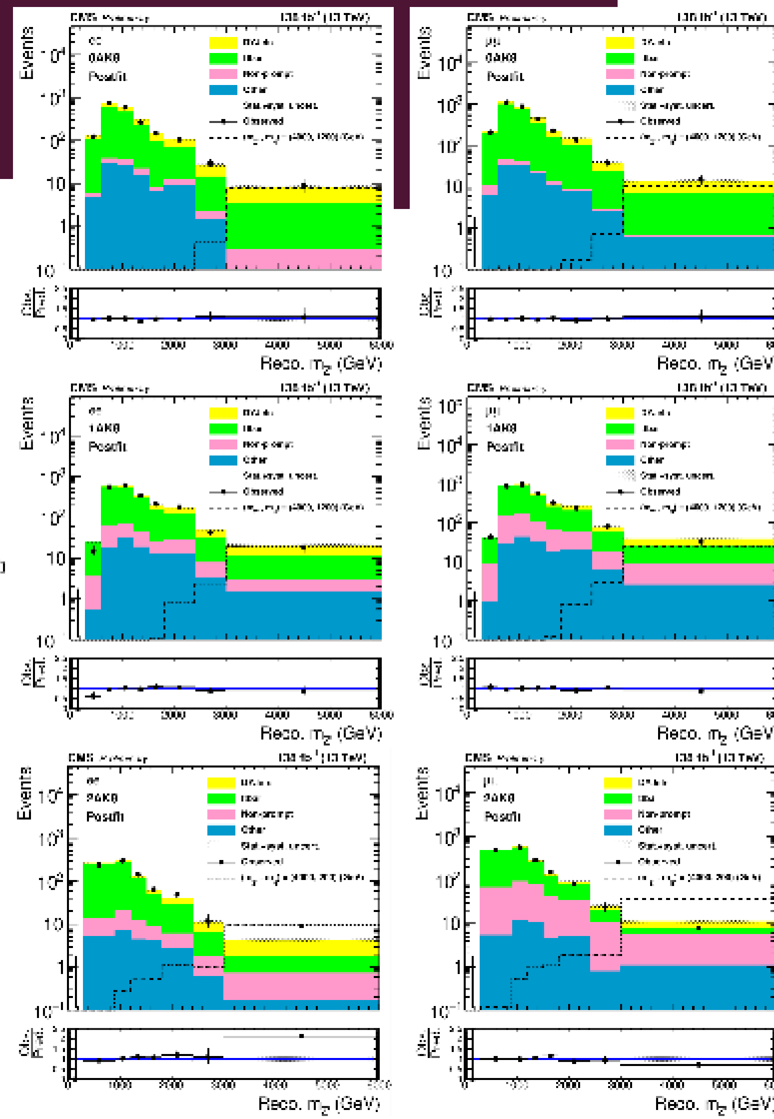


- Not just your generic Z' though, a Z' that decays to two heavy neutral leptons (Majorana). Both W_R are considered to be off-shell, and though this diagram shows the same charge for the final state lepton, both opposite sign and same sign are allowed

RESULT

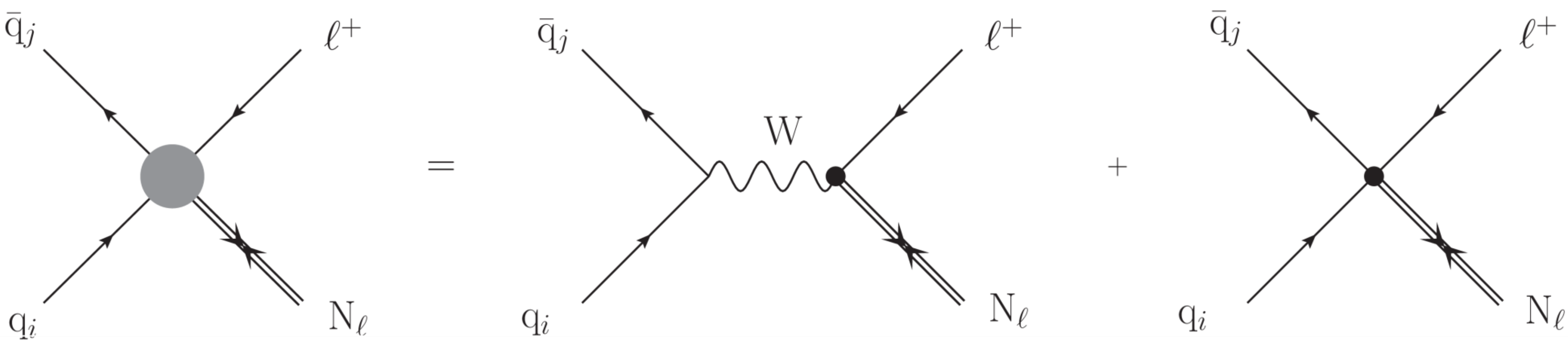






- Interesting to note that since the jets from the W decay can be at close angle, we allow for a fatter jet category that shows substructure. Thus we have the case where all four jets are resolved, only two are resolved and one fat jet, and both fat jets.

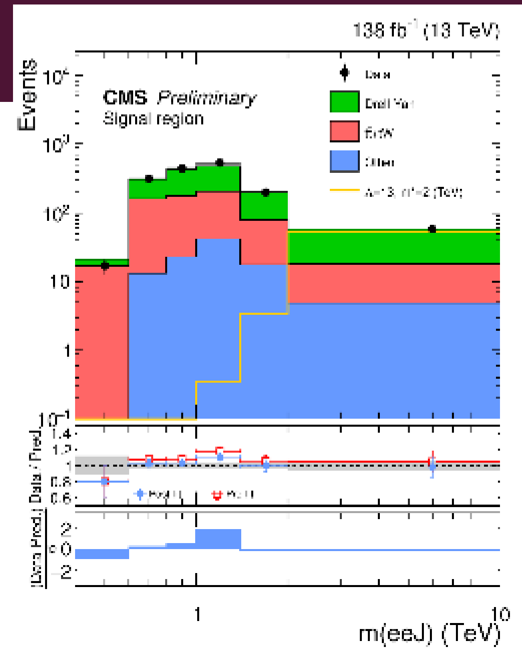
HEAVY COMPOSITE NEUTRINO

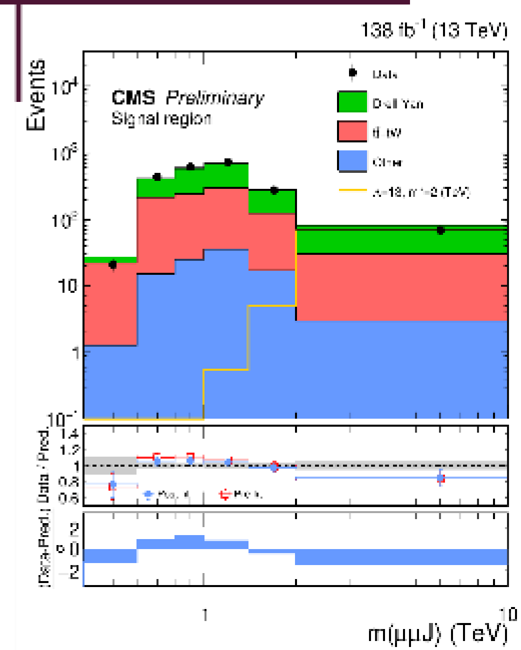


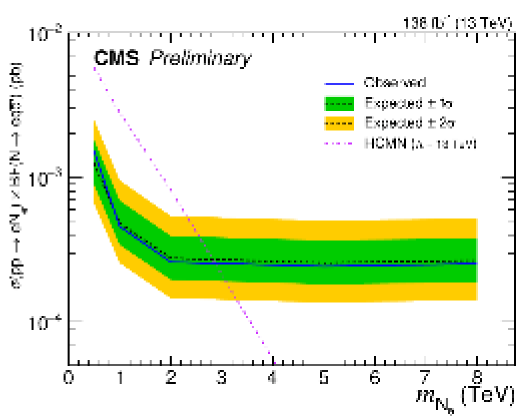
- In very much the same vein, we can search for the production and decay of heavy neutral Majorana neutrinos. One lepton will come from the original interaction, a second with accompanying two jets will come from the decay. Just as in the previous analysis, the two jets are in close proximity, thus we require one large jet with substructure.

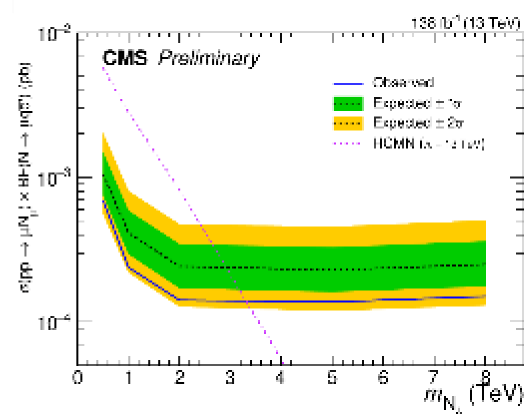
RESULT

- Control regions that are enriched in the largest backgrounds are selected in the data and then a simultaneous fit is performed . No significant excess is observed, and the limits on the mass of such a particle in both ee and μμ channels separately.

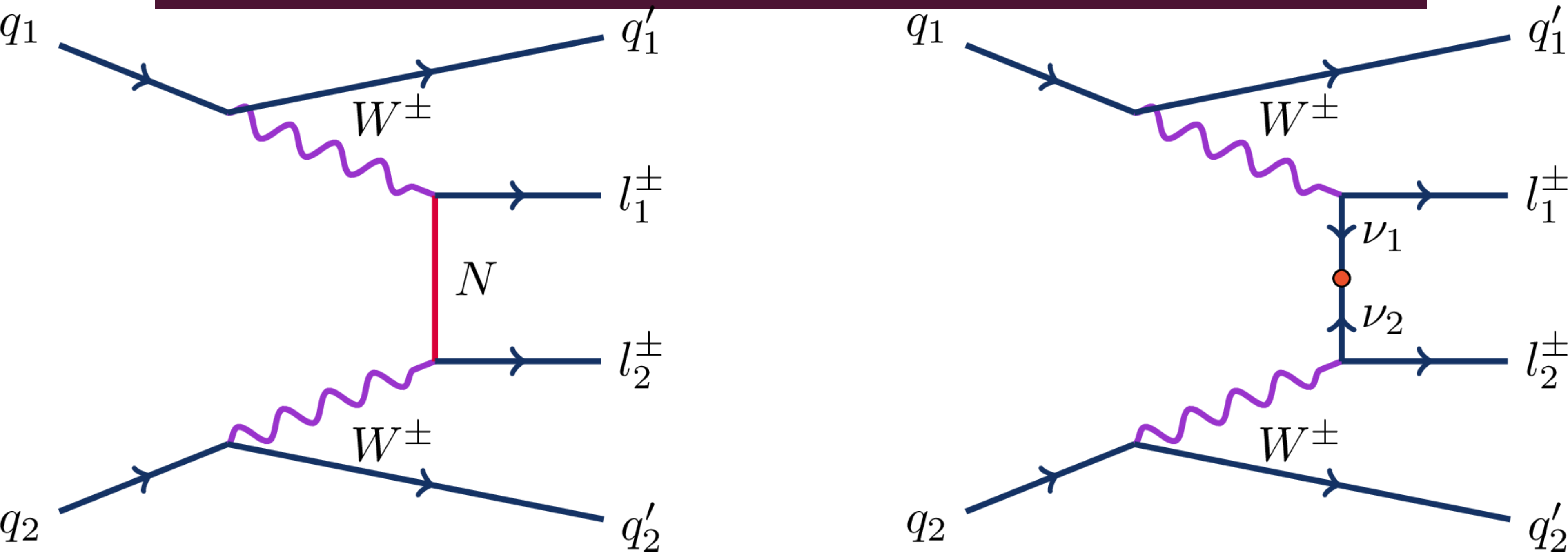






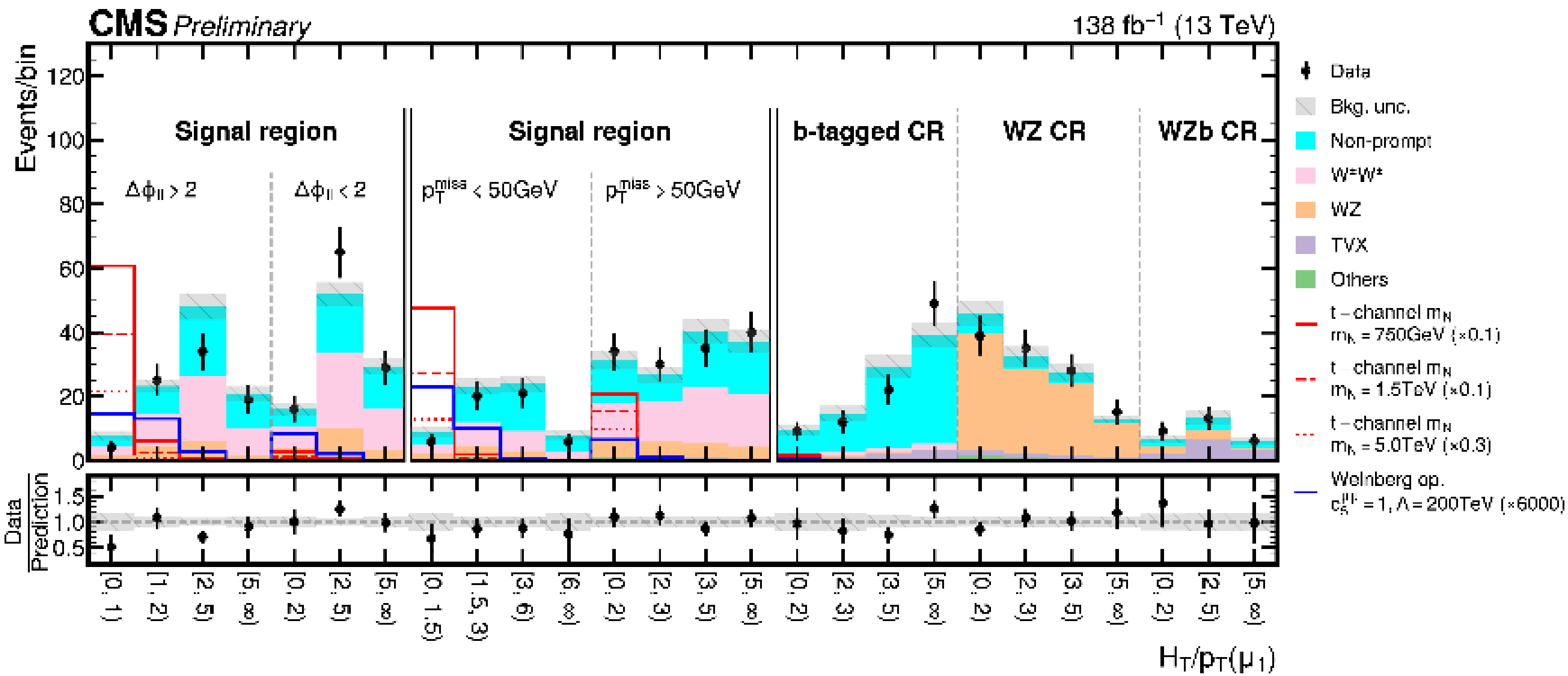


VBF HEAVY NEUTRINO



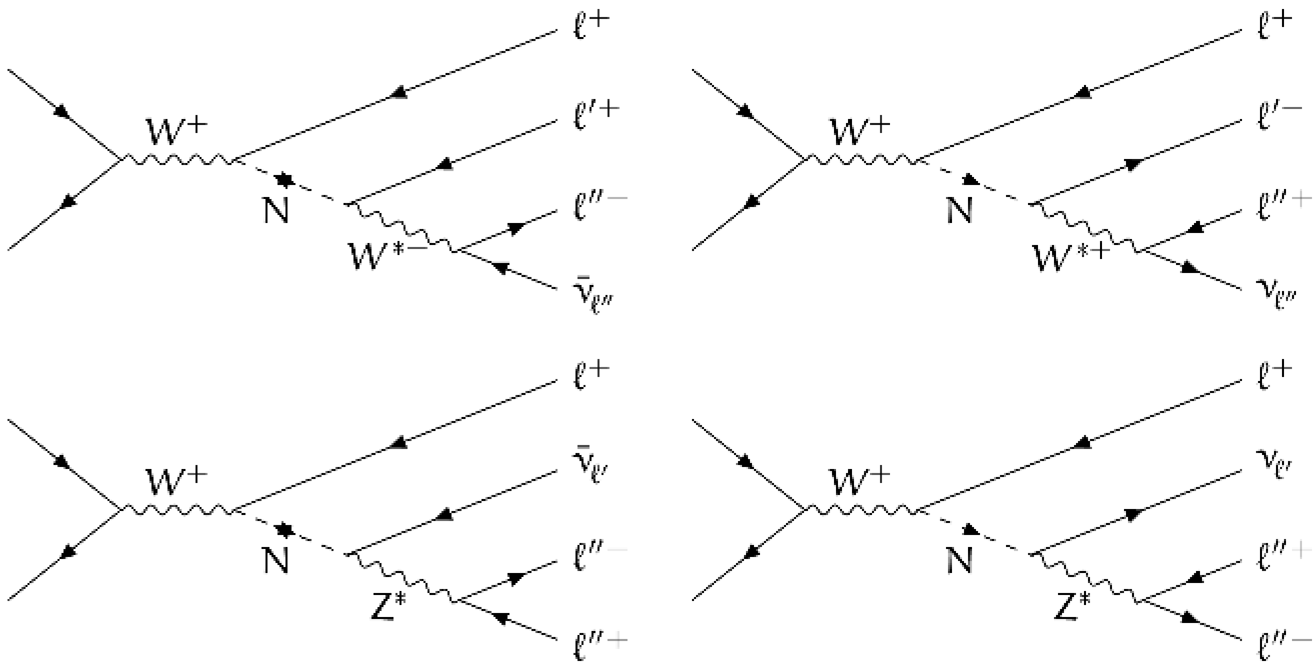
- Similar kind of final state as previous result except in same sign leptons (μμ), with the presence of large rapidity jets, searching for vector boson fusion events.
- Can also be a test of the Weinberg operator.

RESULT



- Here you can see both the signal regions, split out by azimuthal distance and missing transverse momentum, along with the separate control regions.

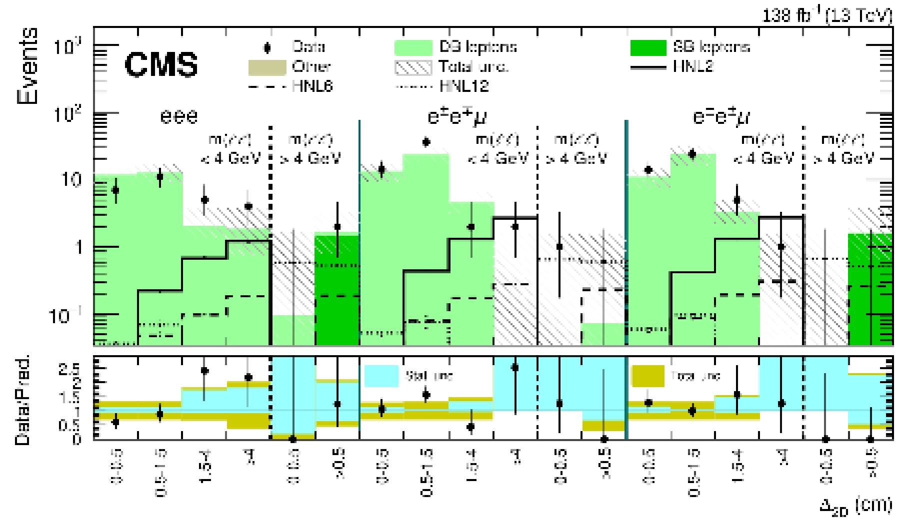
YET STILL MORE HNL

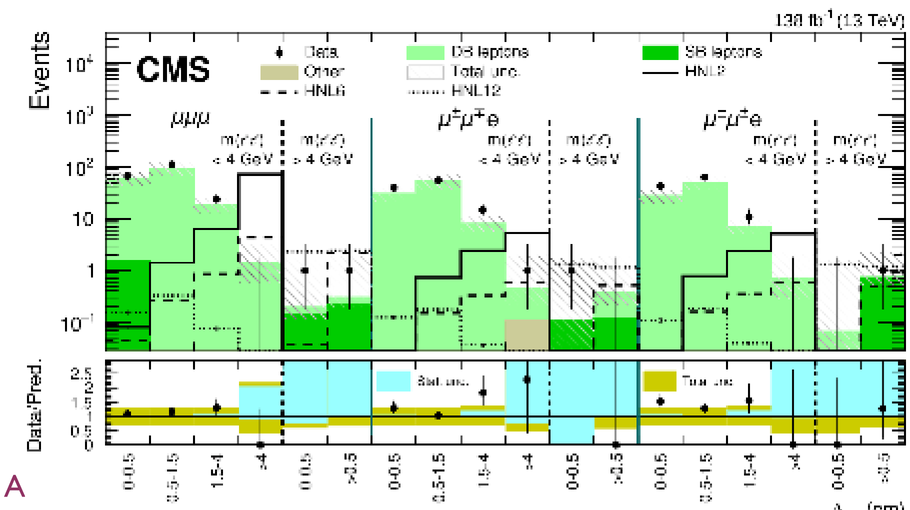


- Depending on the coupling of this heavy neutral lepton to its SM friends, the decay may not be immediate. Thus a search in the final state with one prompt lepton, and the subsequent decay creating a displaced lepton pair. On the left HNL is assumed to be Majorana, on the right it can be either Dirac or Majorana.

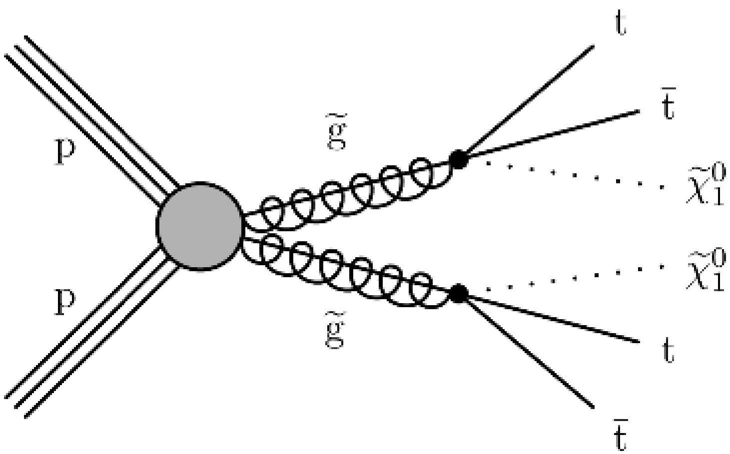
RESULT

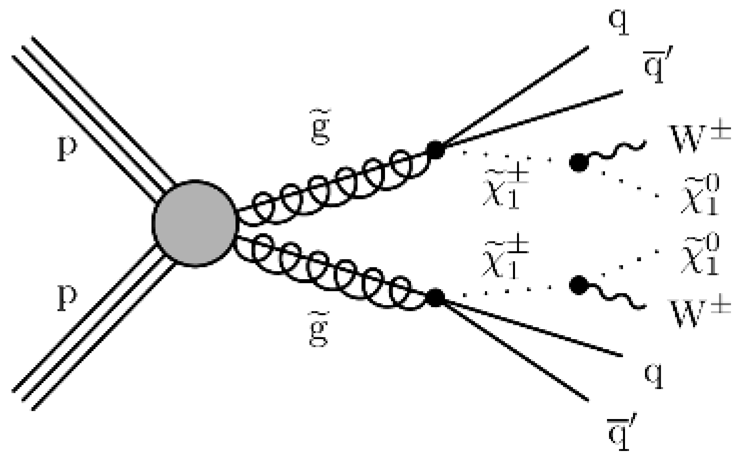
- Here are our observed and expected yields from each of the bins of mass and PV-SV distance.
- Good agreement is found, and limits are set as a function of HNL mass versus coupling for both of the scenarios on the prior slide.





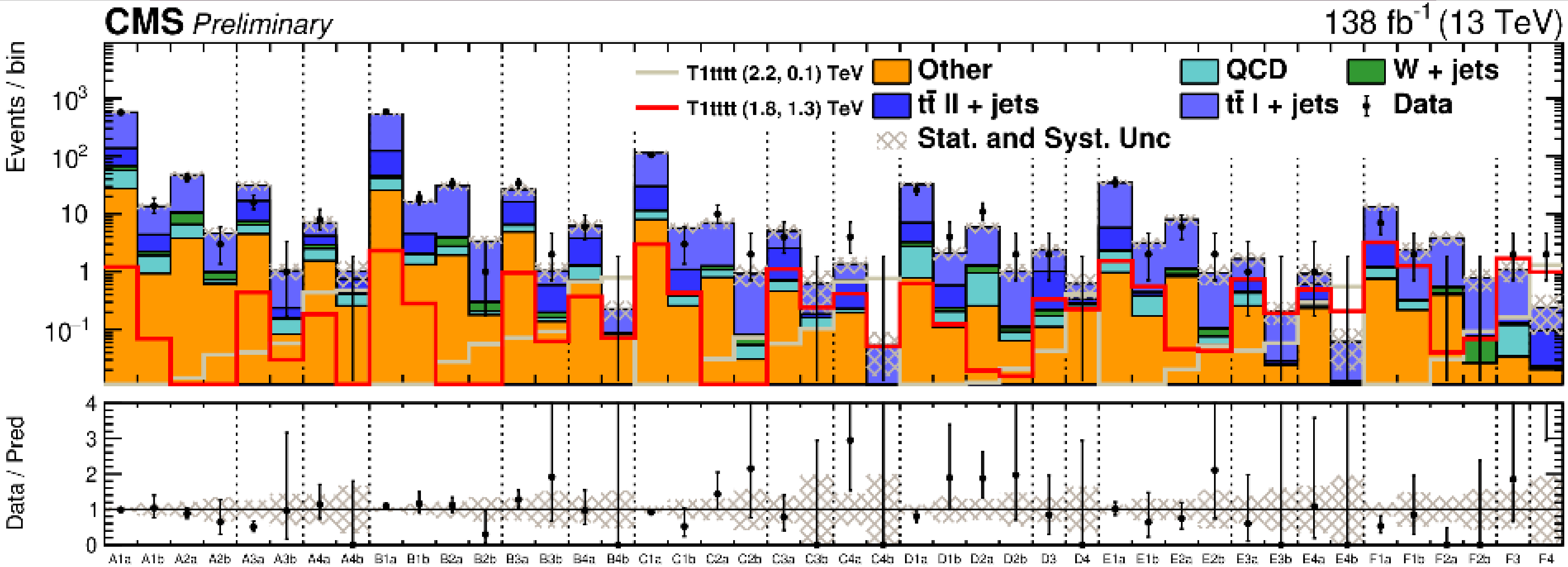
SINGLE LEPTON SUSY SEARCH





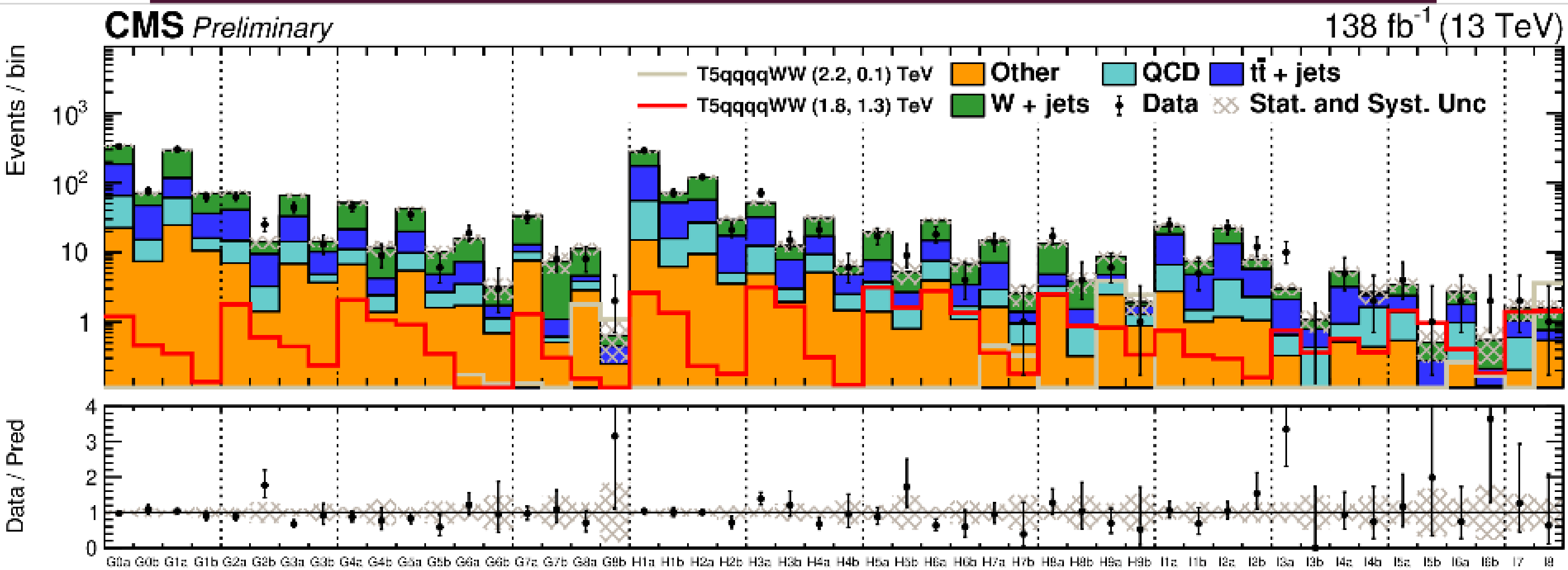
- The above picture says a thousand words about the complicated nature of this search. You're looking for very energetic events with high transverse momentum leptons and jets that may or may not have substructure.
- Think of the topology of these events as split up by angular correlation of the lepton, jet multiplicity and b-tag multiplicity.

RESULT (I)



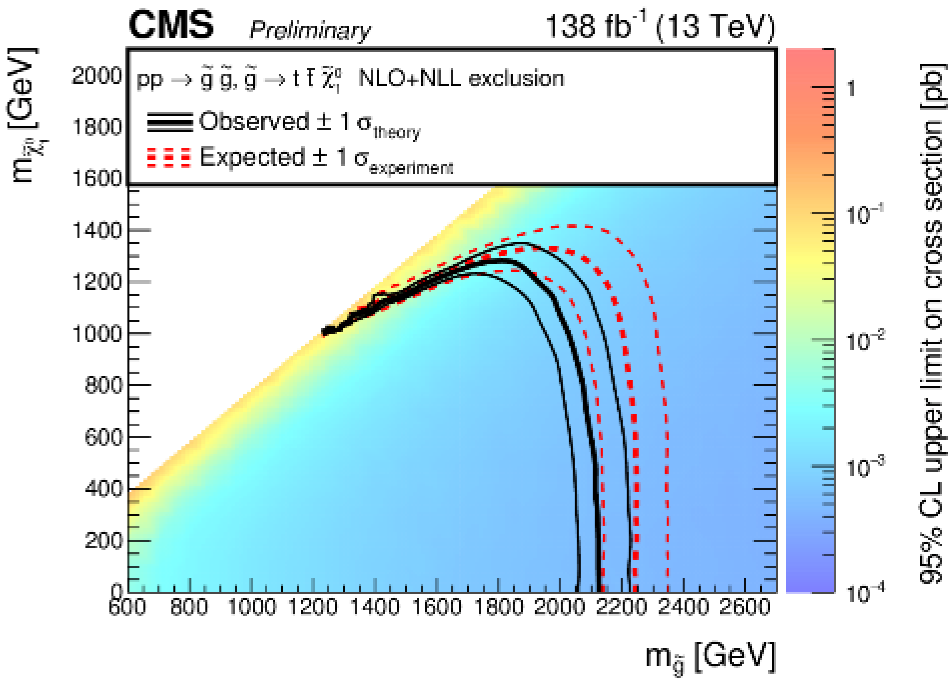
- Breaking my rule of one slide per analysis because I wanted to show this.

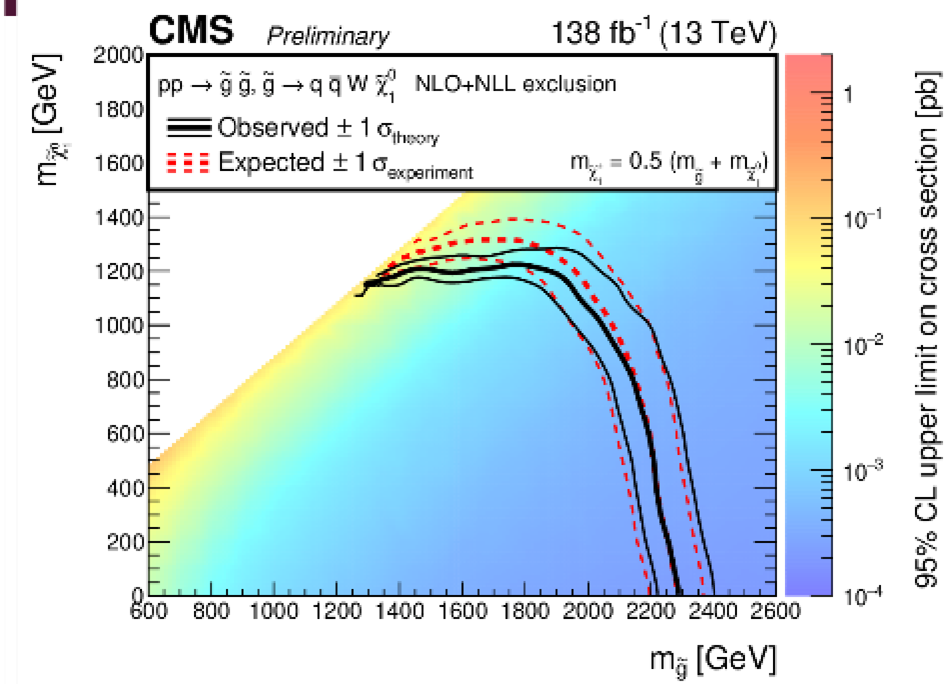
RESULT (I)



- Breaking my rule of one slide per analysis because I wanted to show this.

RESULT(2)





- As a result of the previous two slides, we can set limits.

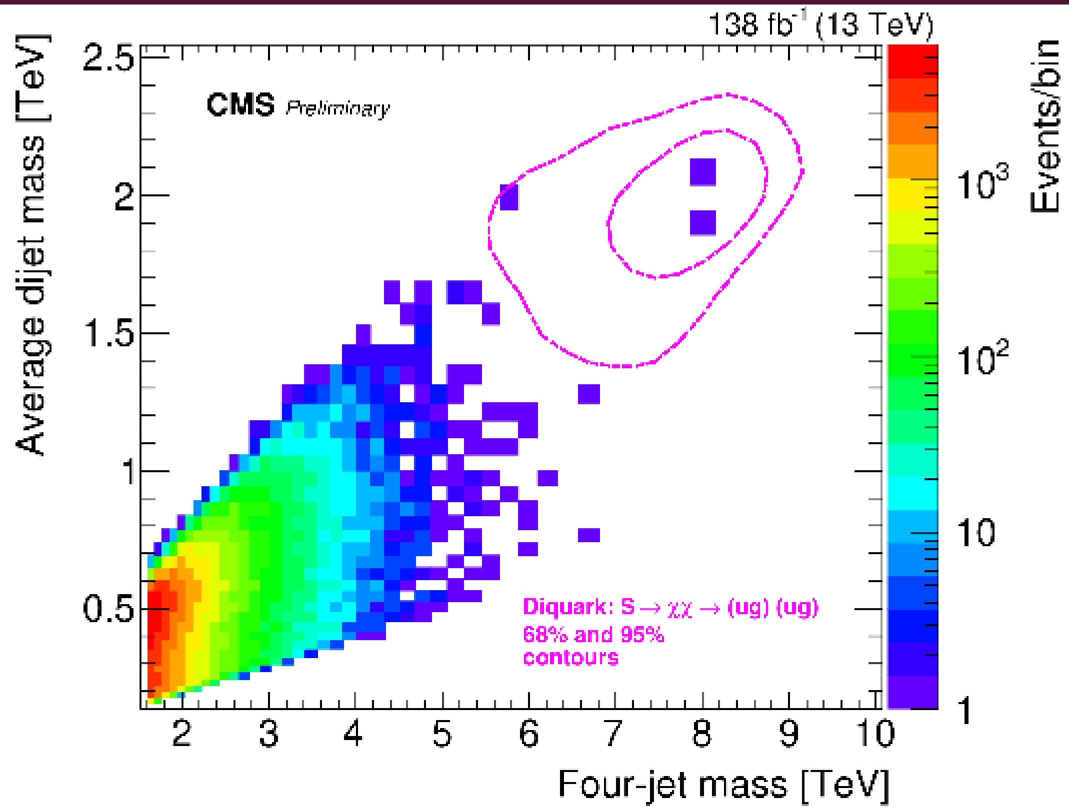
TRANSITIONING

- Here's where we break from requiring leptons and go all hadronic, and the first thing to look at is a very generic search.
- Search for resonant, or non-resonant pairs of jets. The "generic" idea is either you have a resonance that decays to two particles which each decay to pairs of jets, or you just non-resonantly pair produce particles which subsequently decay to jets.

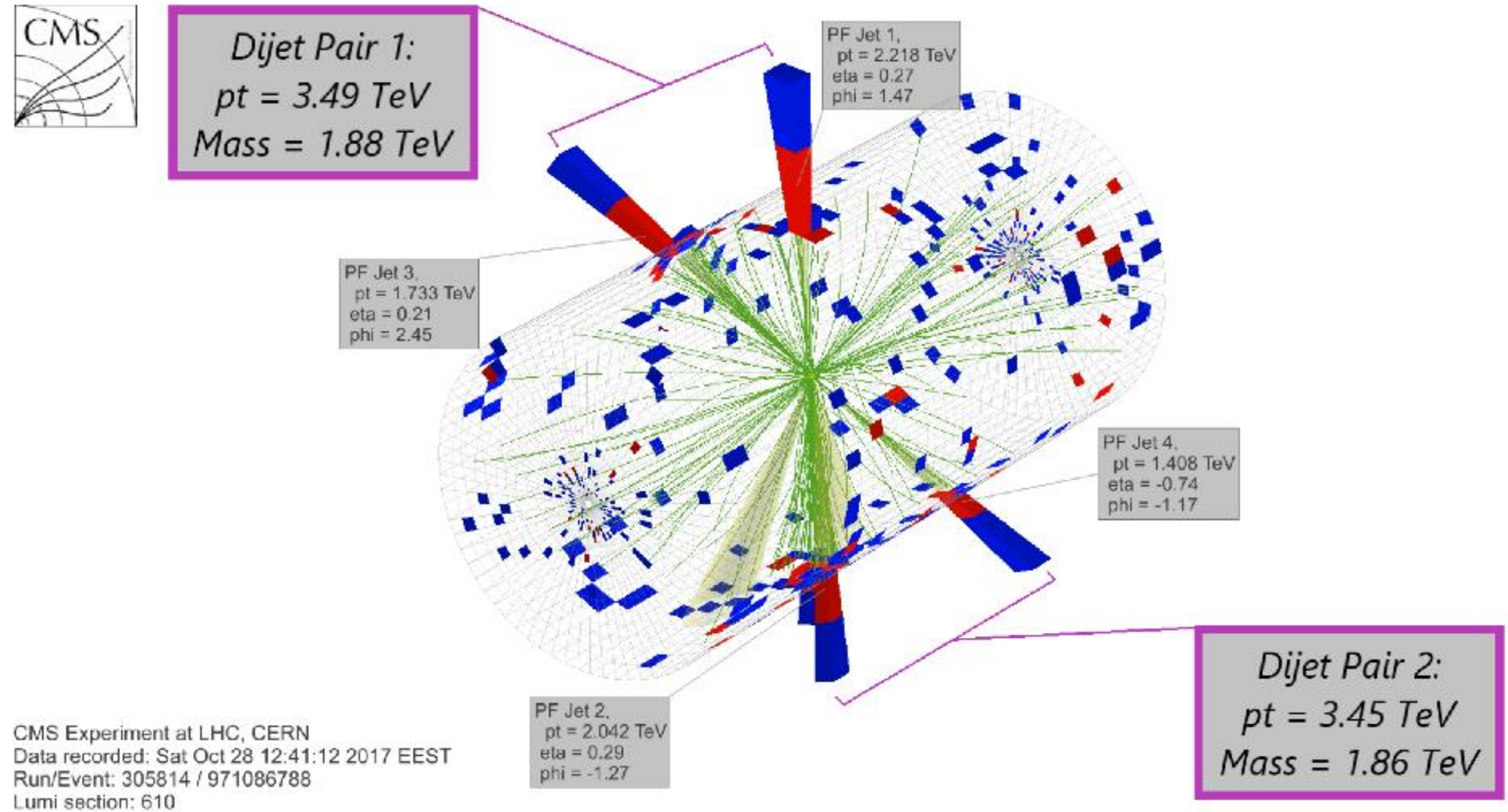
$$\mathrm{pp} \to \mathrm{Y} \to \mathrm{XX} \to (jj)(jj)$$

$$\mathrm{pp} \to \mathrm{XX} \to (jj)(jj)$$

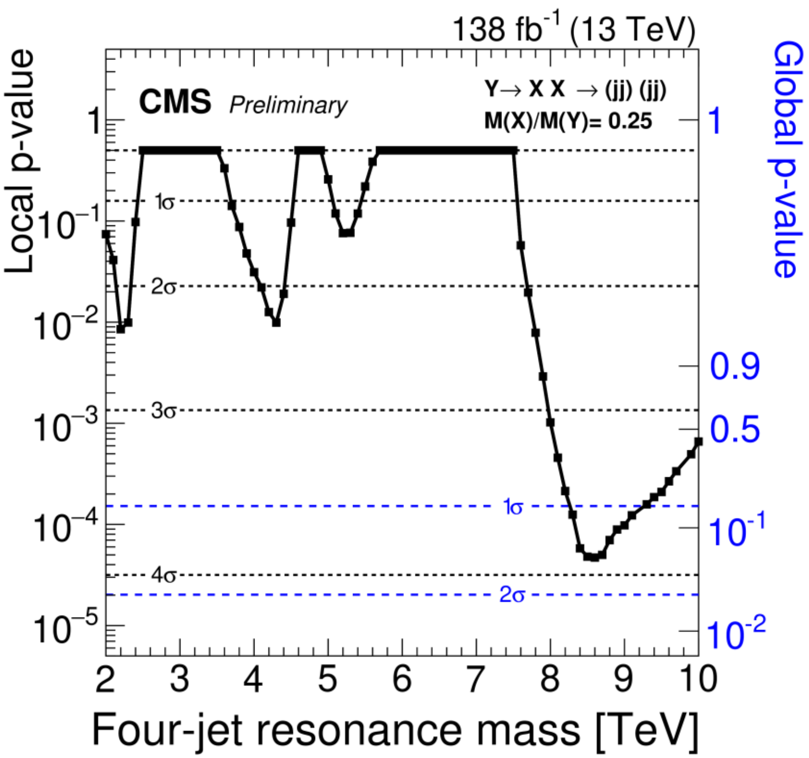
CROWDPLEASERS



- The couple of events that sparked a LOT of discussion.

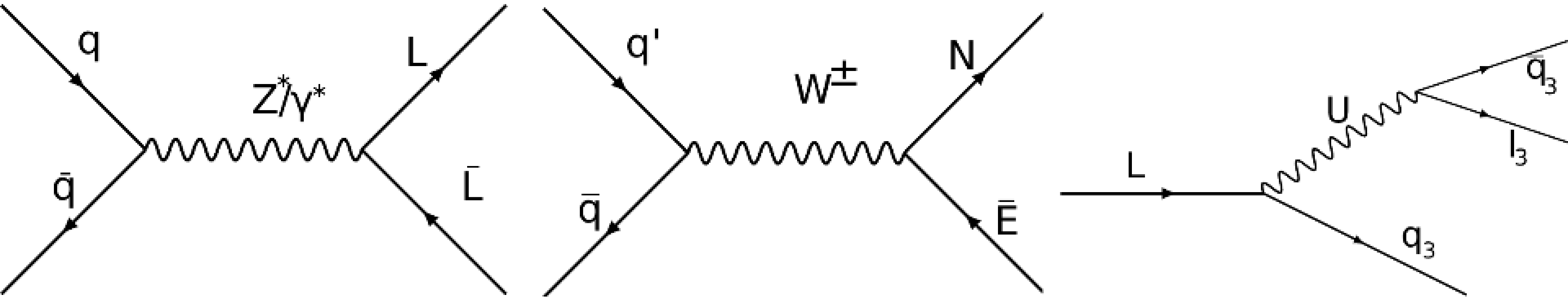

CMS
Dijet Pair 1:
pt = 3.49 TeV
Mass = 1.88 TeV
PF Jet 1,
pt = 2.218 TeV
eta = 0.27
phi = 1.47
PF Jet 3,
pt = 1.733 TeV
eta = 0.21
phi = 2.45
PF Jet 4,
pt = 1.408 TeV
eta = -0.74
phi = -1.17
PF Jet 2,
pt = 2.042 TeV
eta = 0.29
phi = -1.27
Dijet Pair 2:
pt = 3.45 TeV
Mass = 1.86 TeV
CMS Experiment at LHC, CERN
Data recorded: Sat Oct 28 12:41:12 2017 EEST
Run/Event: 305814 / 971086788
Lumi section: 610

SOMETHING TO WATCH FOR THE FUTURE:



- As you can imagine, this will be highly scrutinized for Run 3.

VECTOR-LIKE LEPTONS



- The scenario considered is influenced by the current B hadron "anomalies"
- Vector-like leptons are produced, and since the couplings are non-universal (kind of the entire point), the preferred decay modes are to the third generation.

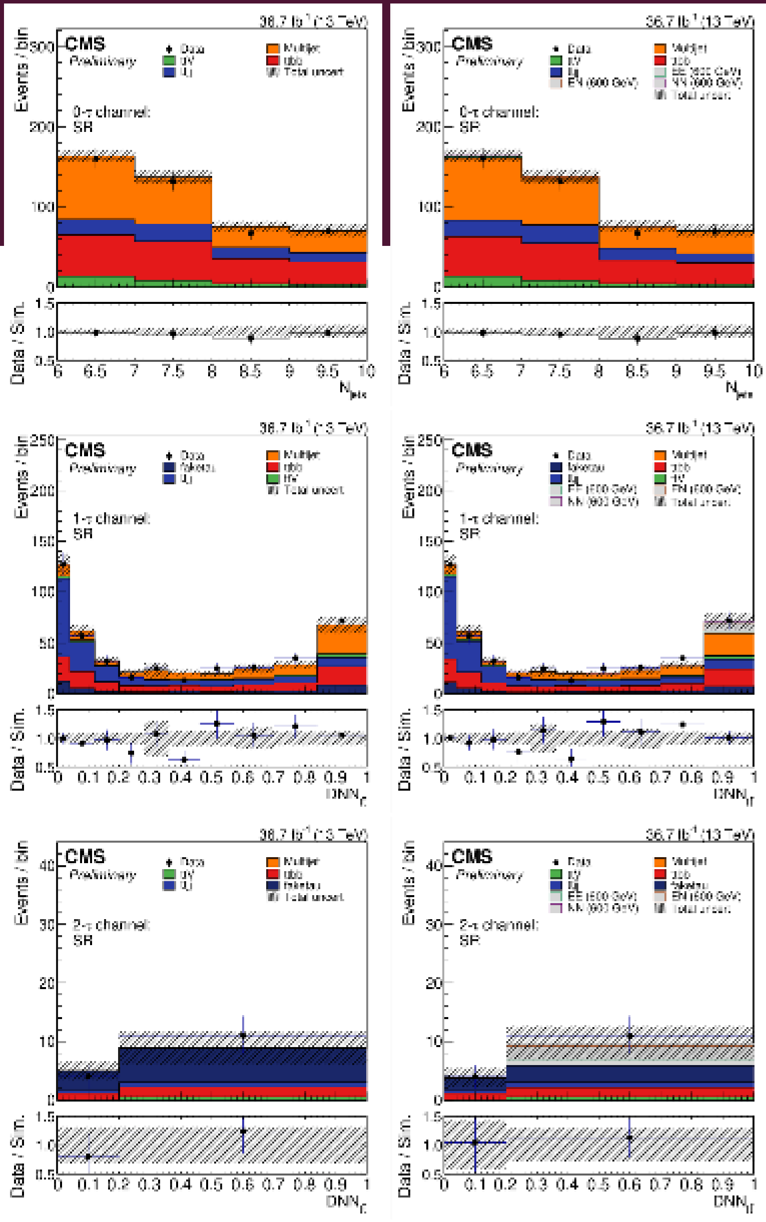
VECTOR-LIKE LEPTONS

tau multiplicity	production + decay mode	final state
$0\ \tau$	$EE \to b(t\nu_\tau)b(t\nu_\tau)$	$4b + 4j + 2\nu_\tau$
	$EN \to b(t\nu_\tau)t(t\nu_\tau)$	$4b + 6j + 2\nu_\tau$
	$NN \to t(t\nu_\tau)t(t\nu_\tau)$	$4b + 8j + 2\nu_\tau$
$1\ \tau$	$EE \to b(b\tau)b(t\nu_\tau)$	$4b + 2j + \tau + \nu_\tau$
	$EN \to b(t\nu_\tau)t(b\tau)$	$4b + 4j + \tau + \nu_\tau$
	$EN \to b(b\tau)t(t\nu_\tau)$	$4b + 4j + \tau + \nu_\tau$
	$NN \to t(b\tau)t(t\nu_\tau)$	$4b + 6j + \tau + \nu_\tau$
$2\ \tau$	$EE \to b(b\tau)b(b\tau)$	$4b + 2\tau$
	$EN \to b(b\tau)t(b\tau)$	$4b + 2j + 2\tau$
	$NN \to t(b\tau)t(b\tau)$	$4b + 4j + 2\tau$

- The scenario considered is influenced by the current B hadron "anomalies"
- Vector-like leptons are produced, and since the couplings are non-universal (kind of the entire point), the preferred decay modes are to the third generation.

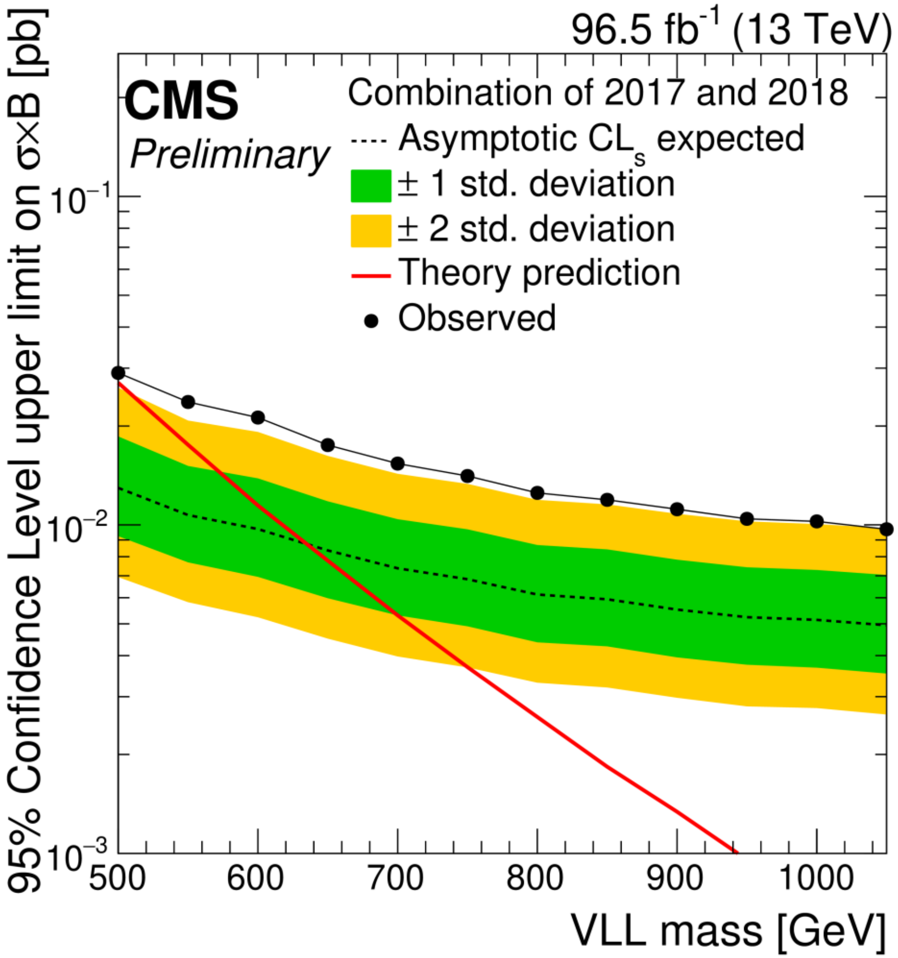
RESULT

- So in each plot you see here, there is a different τ multiplicity. The left column is the background only fit, the right column includes the signal (thus the fit gives you the best idea how likely there is to be signal present.

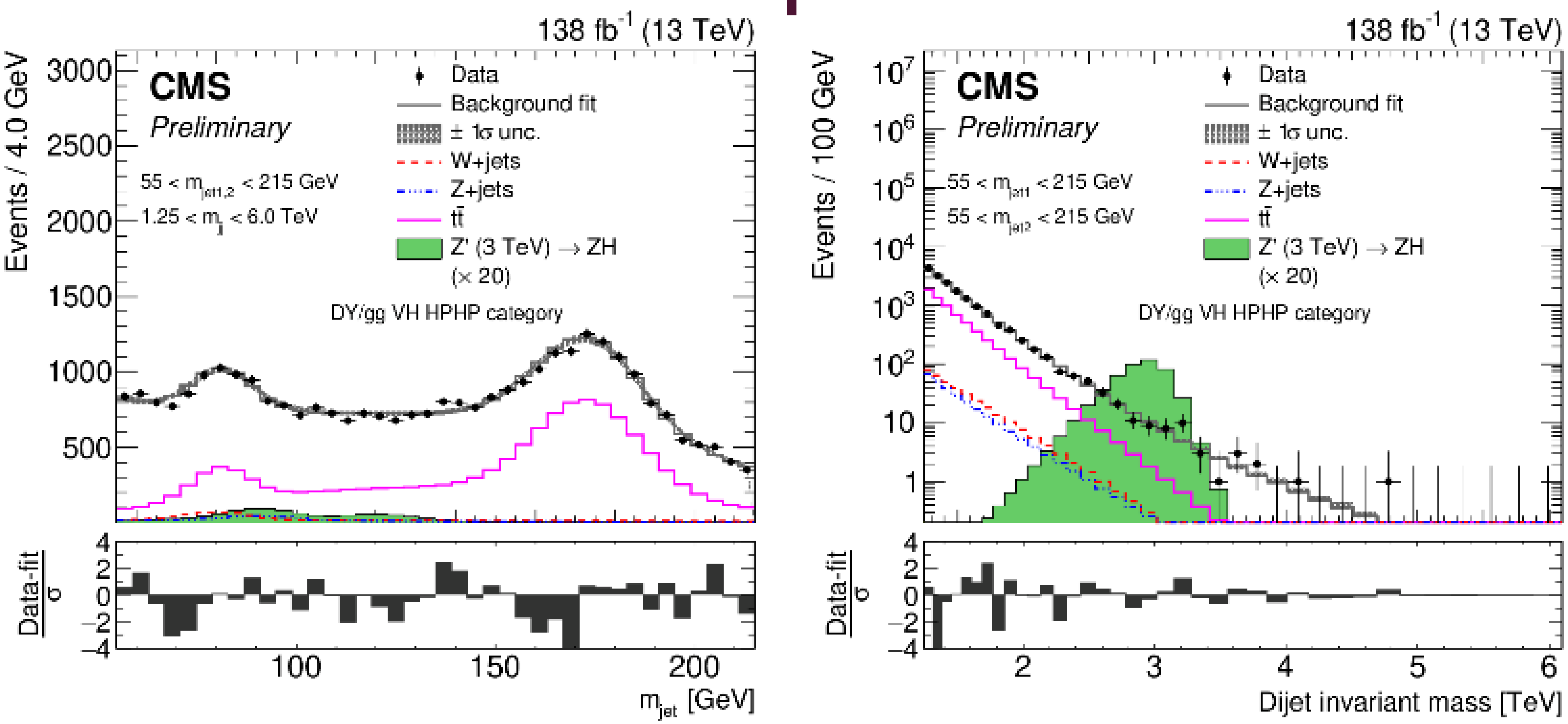


RESULT

- In this case, no VLL masses are excluded, even though the expected exclusion was ~650 GeV (~2.8σ effect)
- Again, something we'll definitely be revisiting in Run 3.

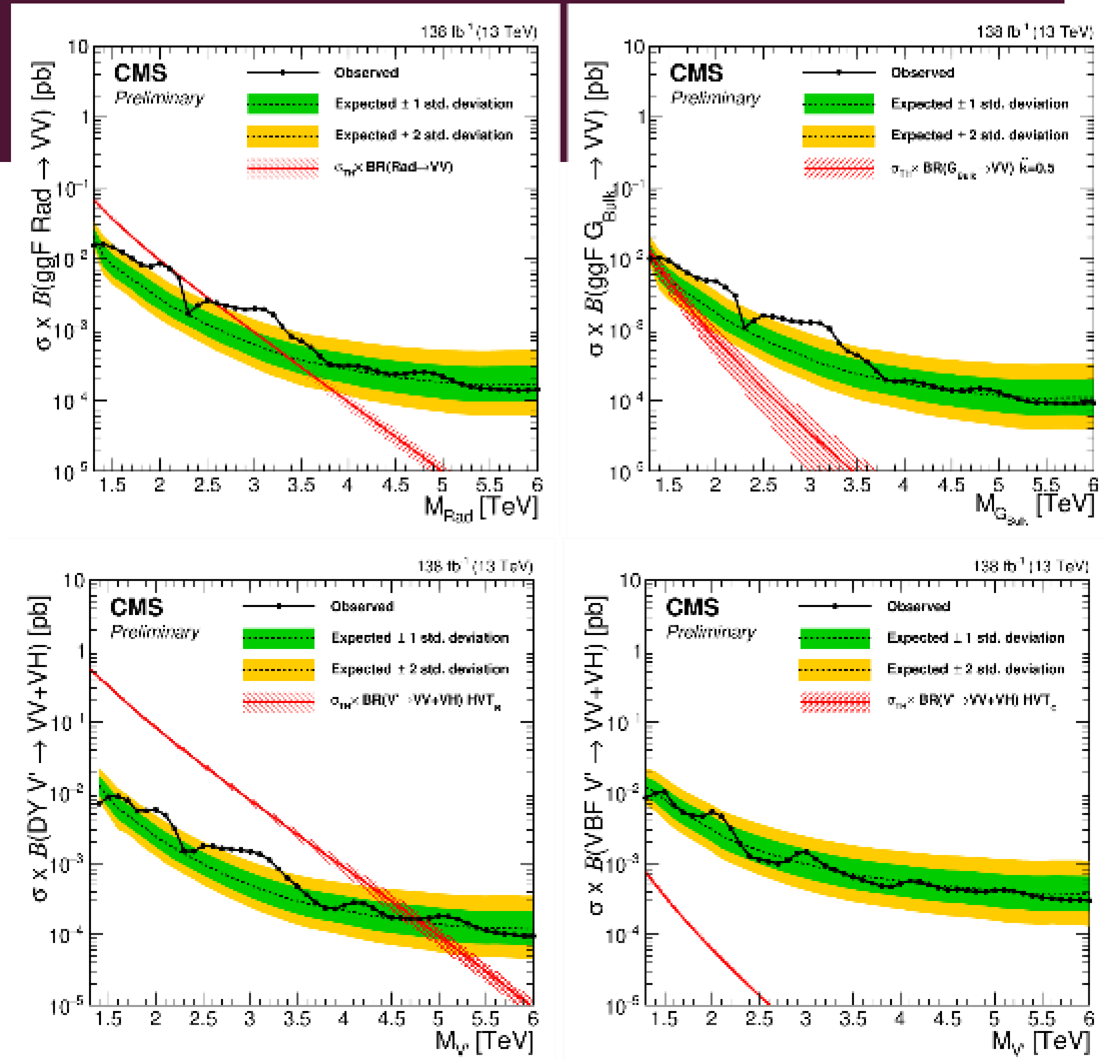


SUBSTRUCTURE GONE WILD



- I've referenced substructure a couple of times in this talk, this is one of the best examples of what we're able to do now. In all these cases, we look for two jets with substructure searching for all hadronic decays of WW, WZ, ZZ, WH, ZH.

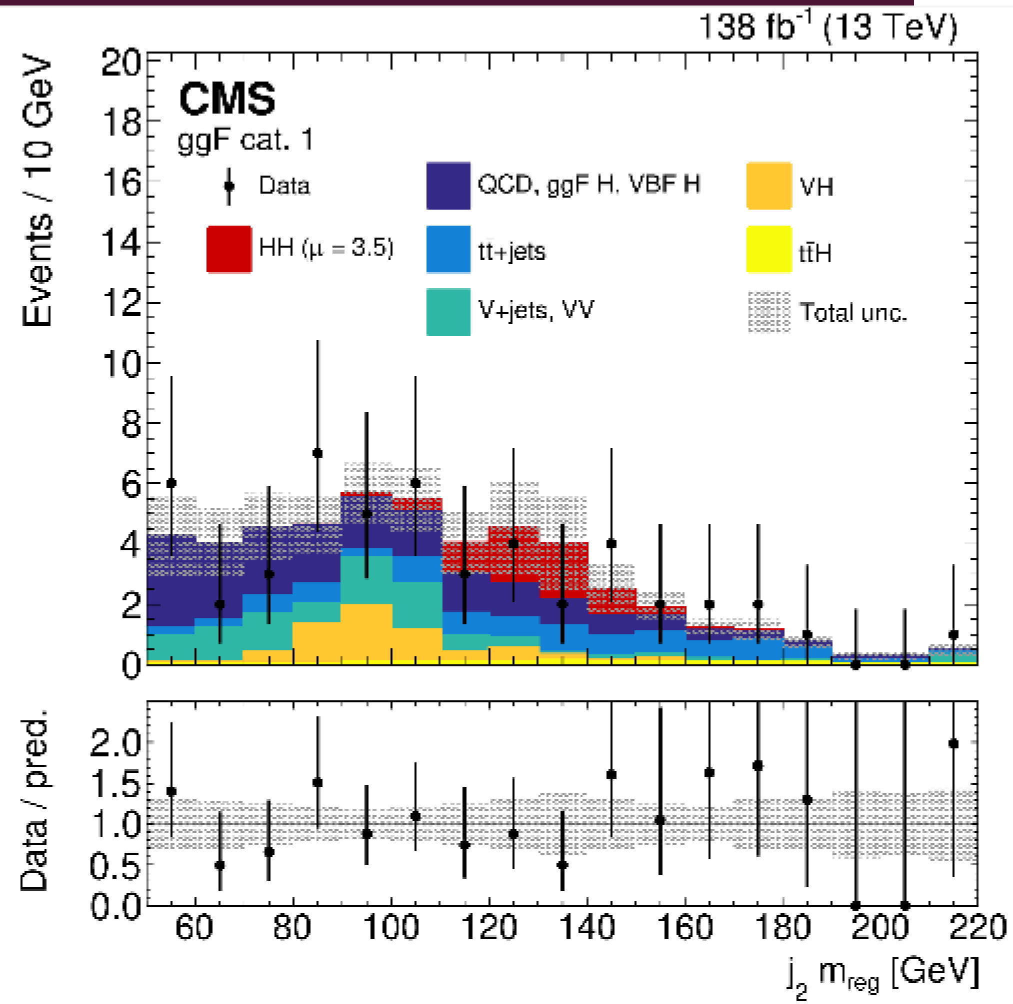
RESULT



- From the previous slide, besides a few wiggles, the dijet mass doesn't show evidence for any massive particle decaying to vector boson pairs, so here we set limits.

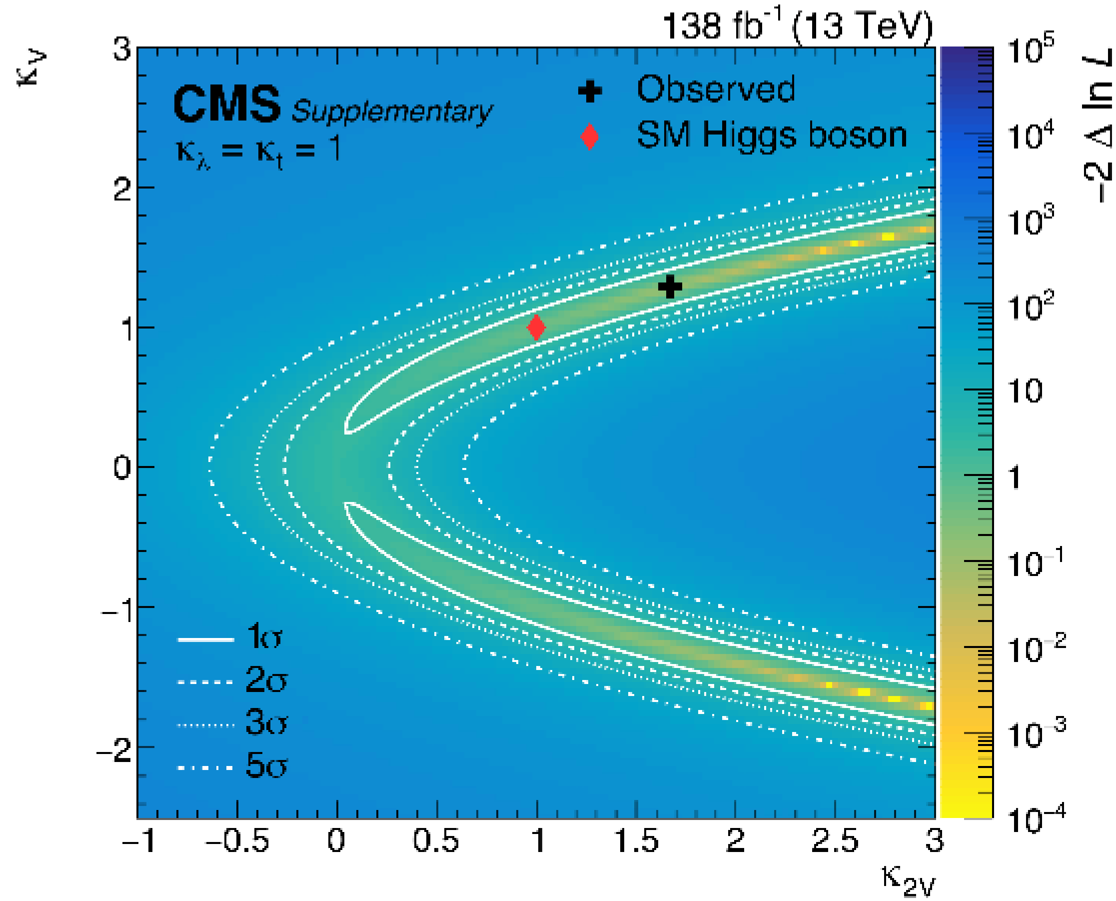
HH

- Conspicuously missing from the previous diboson list was HH. That's because for one, that cross section is supposed to be tiny, especially for the transverse momentum needed to have one jet per Higgs.
- We do our typical simultaneous fit, but surprisingly with the signal hypothesis included, the value is most consistent with 3.5 times the expected SM signal strength.



HH

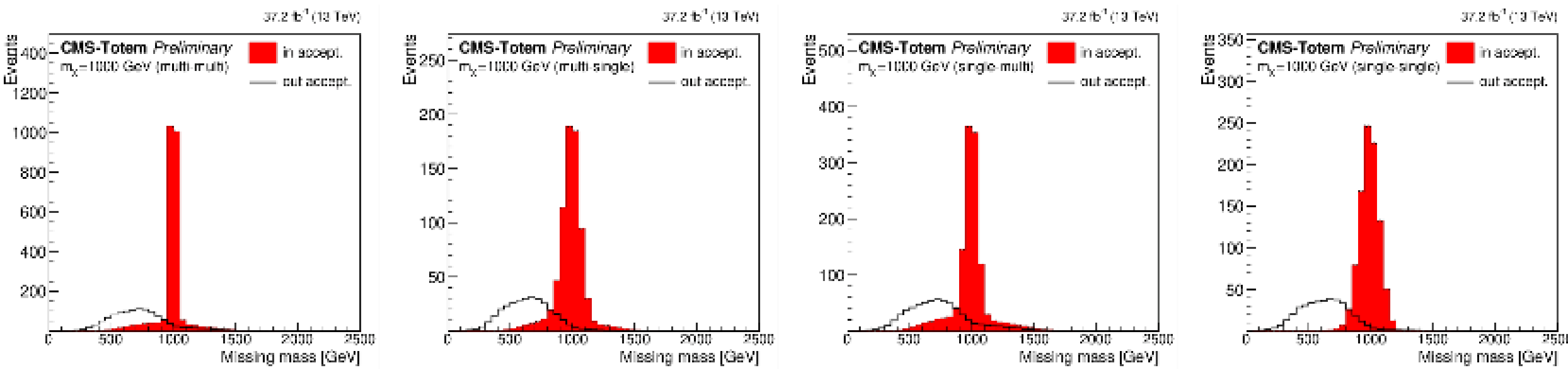
- So this is certainly intriguing, and when we examine the coupling parameters, we find that κ_{2V}=0 is strongly ruled out for the first time.
- The result is still statistically consistent with the background hypothesis, but the observed cross section limit is 9.9, as opposed to the expected limit of 5.1 (both relative to the SM cross section).

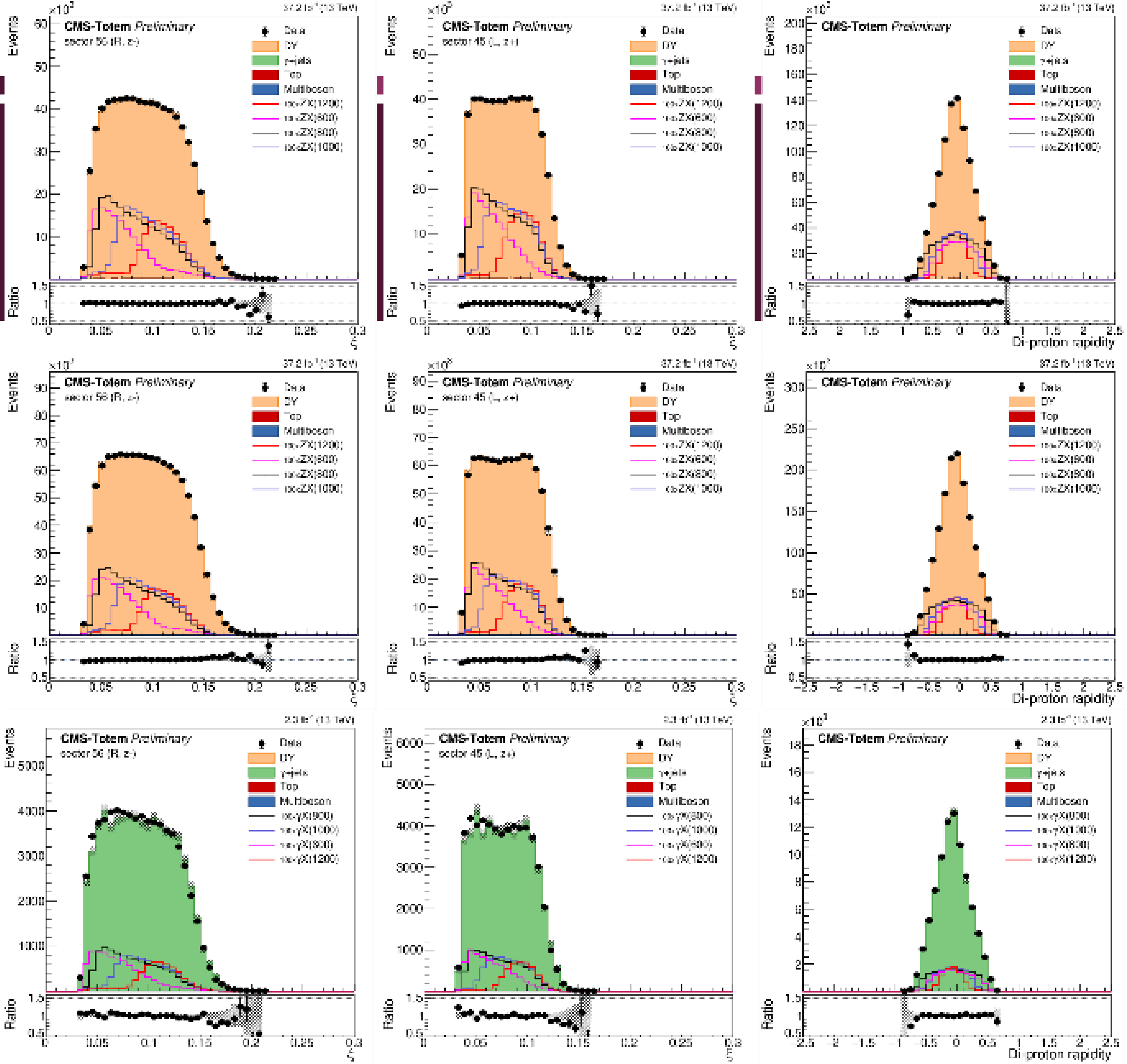


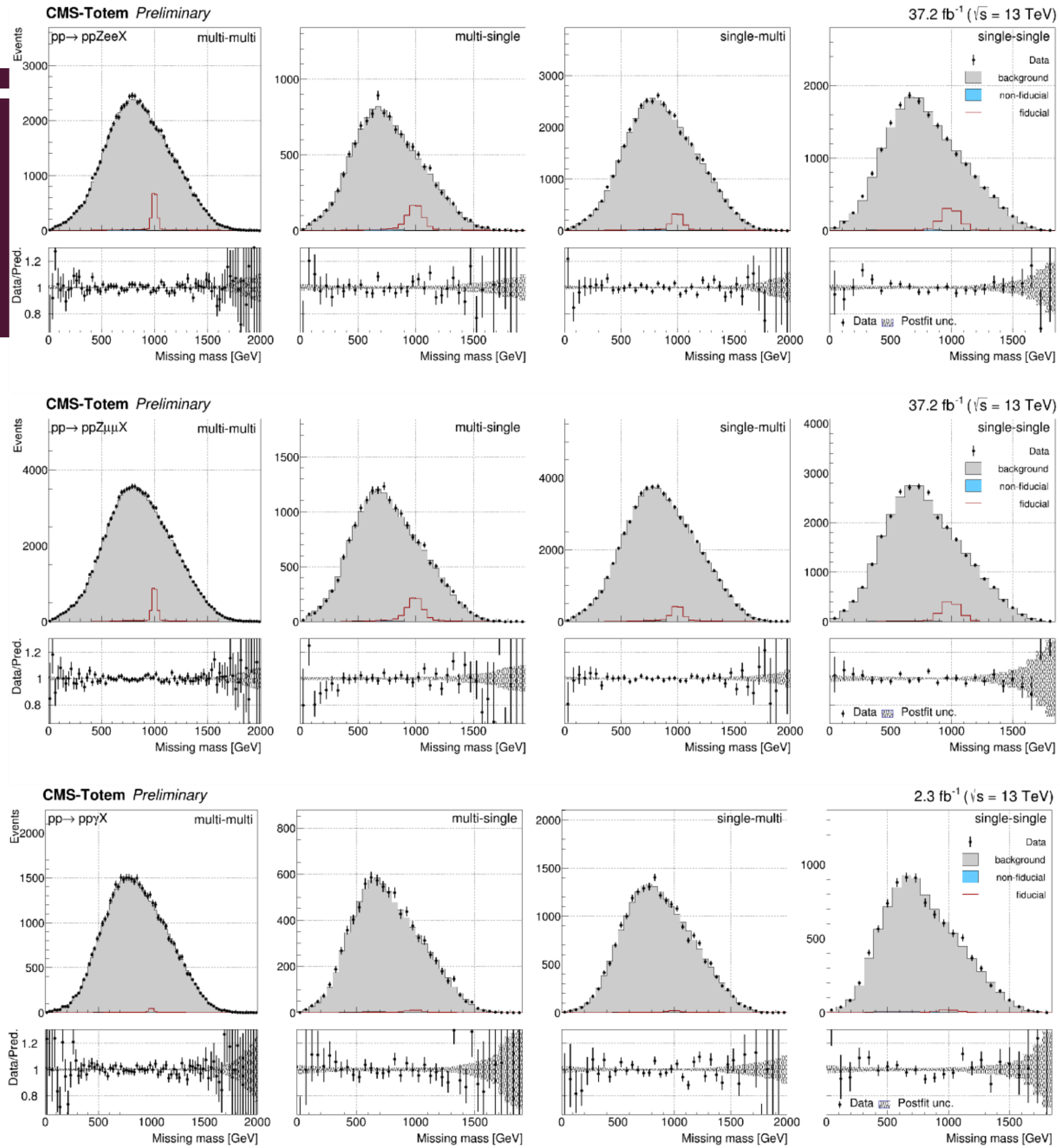
SUMMARY

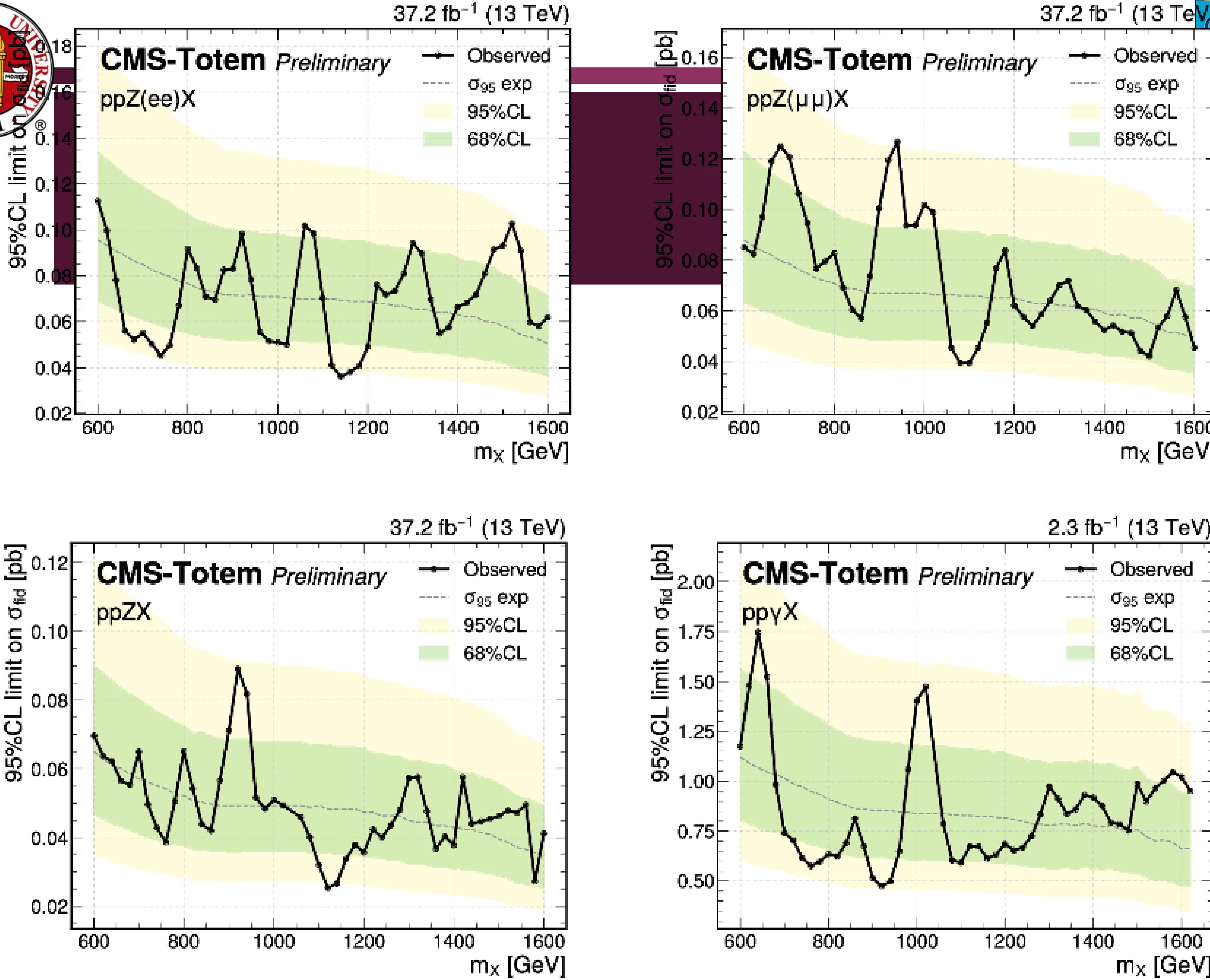
- We have done, and continue to do a very successful job widening our view into physics at the LHC.
- We starting to see what potentially could be some interesting phenomena. Run 3 has quite a few places to scrutinize.
- You'll be hearing more soon!

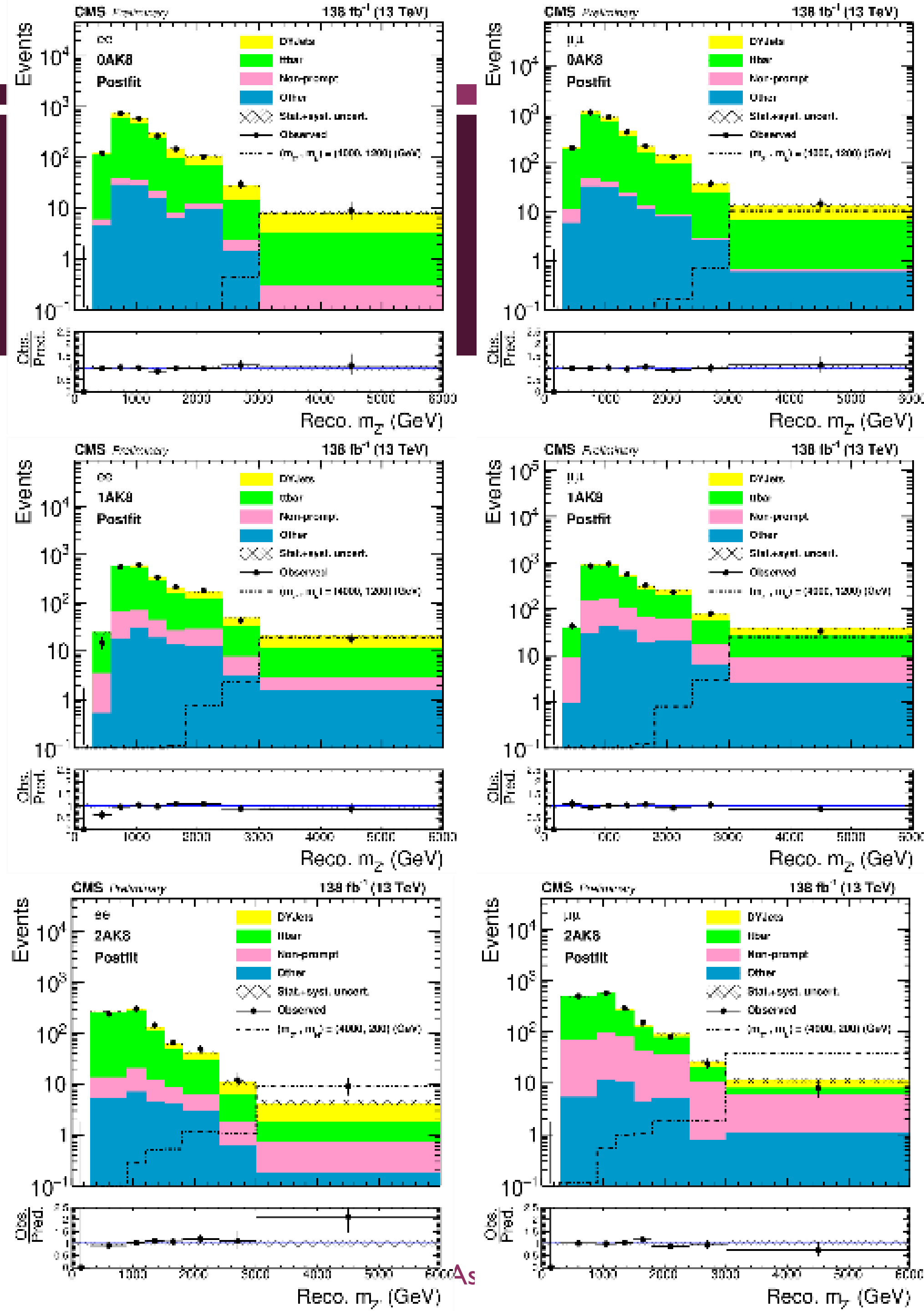
- BACKUPS

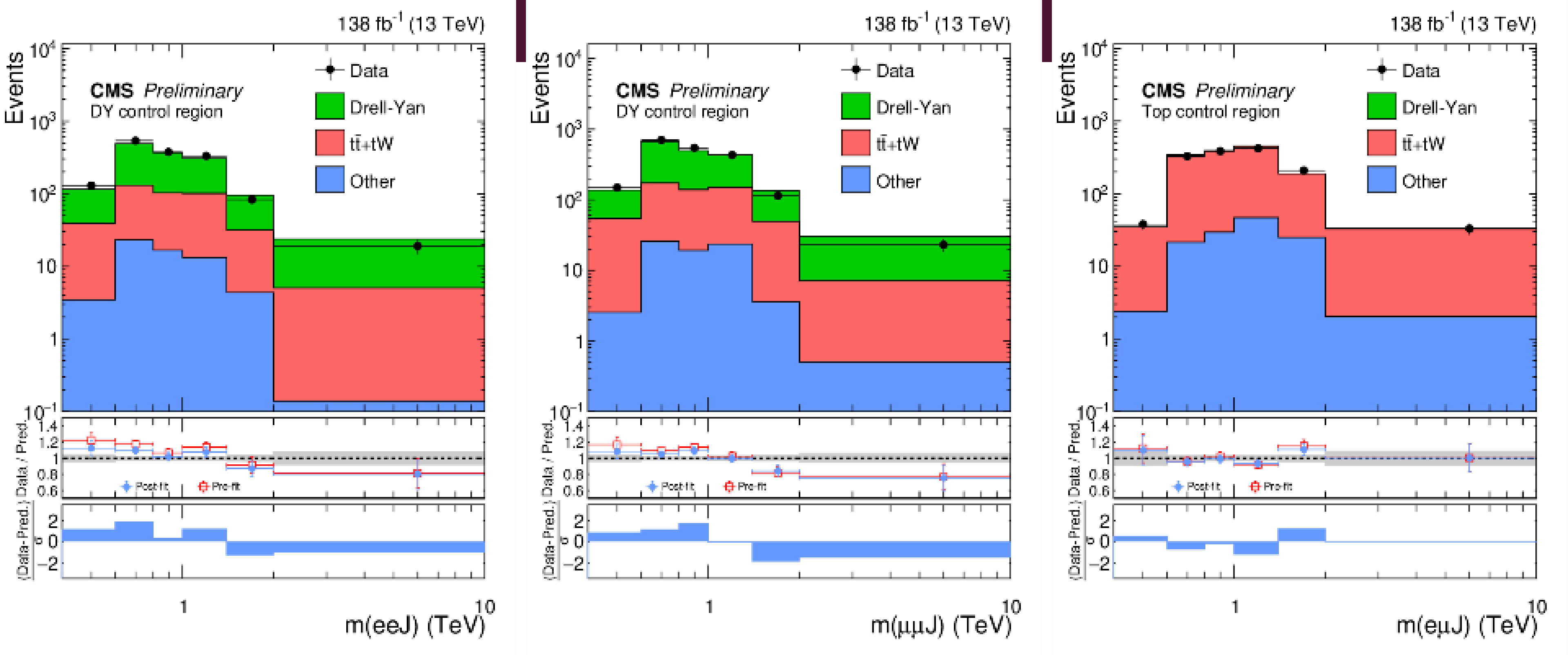

CMS-Totem Preliminary
37.2 fb-1 (13 TeV)
mX=1000 GeV (multi-multi)
mX=1000 GeV (multi-single)
mX=1000 GeV (single-multi)
mX=1000 GeV (single-single)
in accept.
out accept.
Events
Missing mass [GeV]

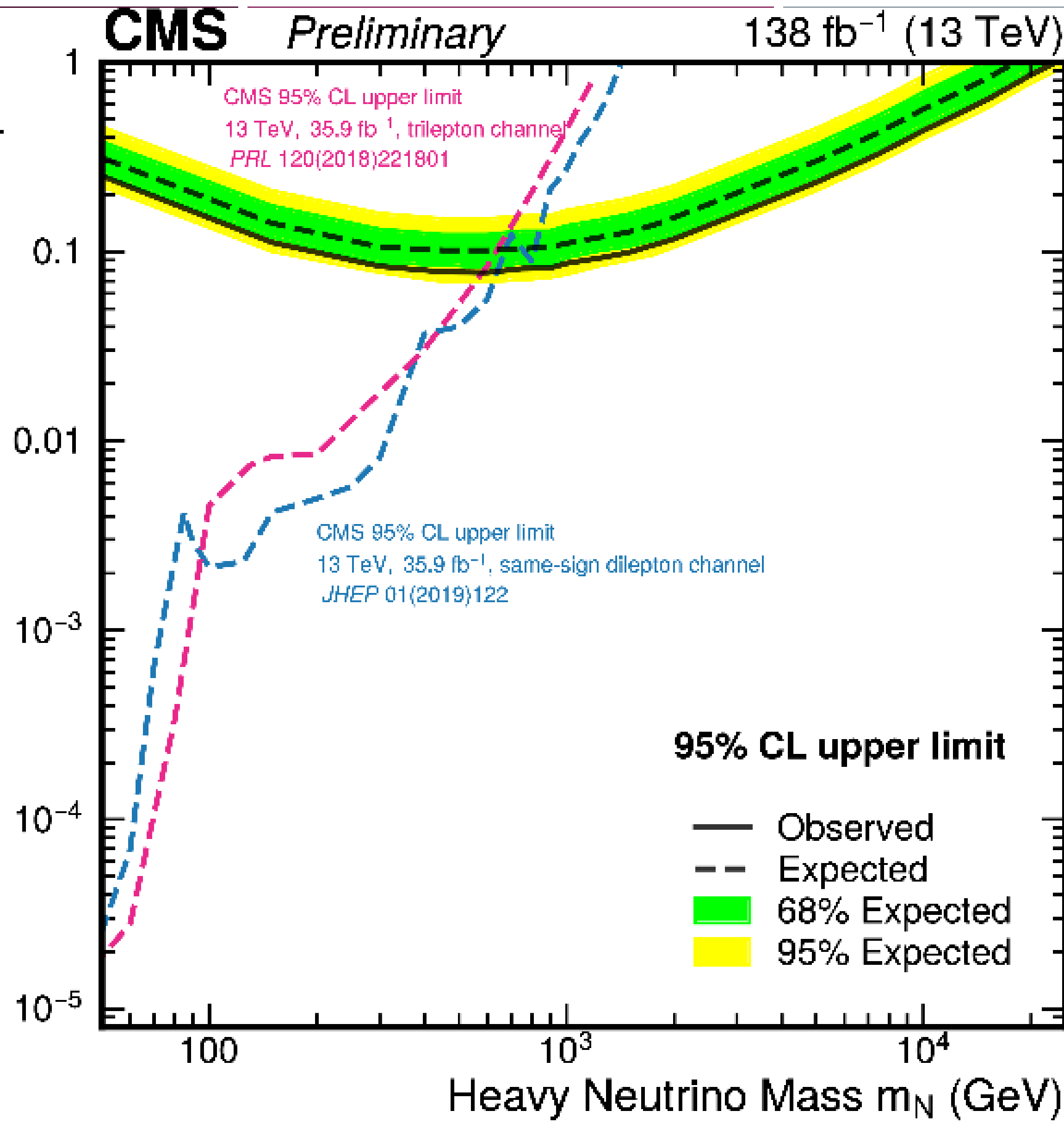

CMS-Totem Preliminary
sector 56 (R, z-)
sector 45 (L, z+)
Data
DY
γ+jets
Top
Multiboson
Events
Ratio
ξ
Di-proton rapidity
37.2 fb⁻¹ (13 TeV)


CMS-Totem Preliminary
37.2 fb-1 (√s = 13 TeV)
pp→ ppZeeX
multi-multi
multi-single
single-multi
single-single
Data
background
non-fiducial
fiducial
Events
Data/Pred.
Data
Postfit unc.
Missing mass [GeV]
CMS-Totem Preliminary
37.2 fb-1 (√s = 13 TeV)
pp→ ppZμμX
multi-multi
multi-single
single-multi
single-single
CMS-Totem Preliminary
2.3 fb-1 (√s = 13 TeV)
pp→ ppγX
multi-multi
multi-single
single-multi
single-single

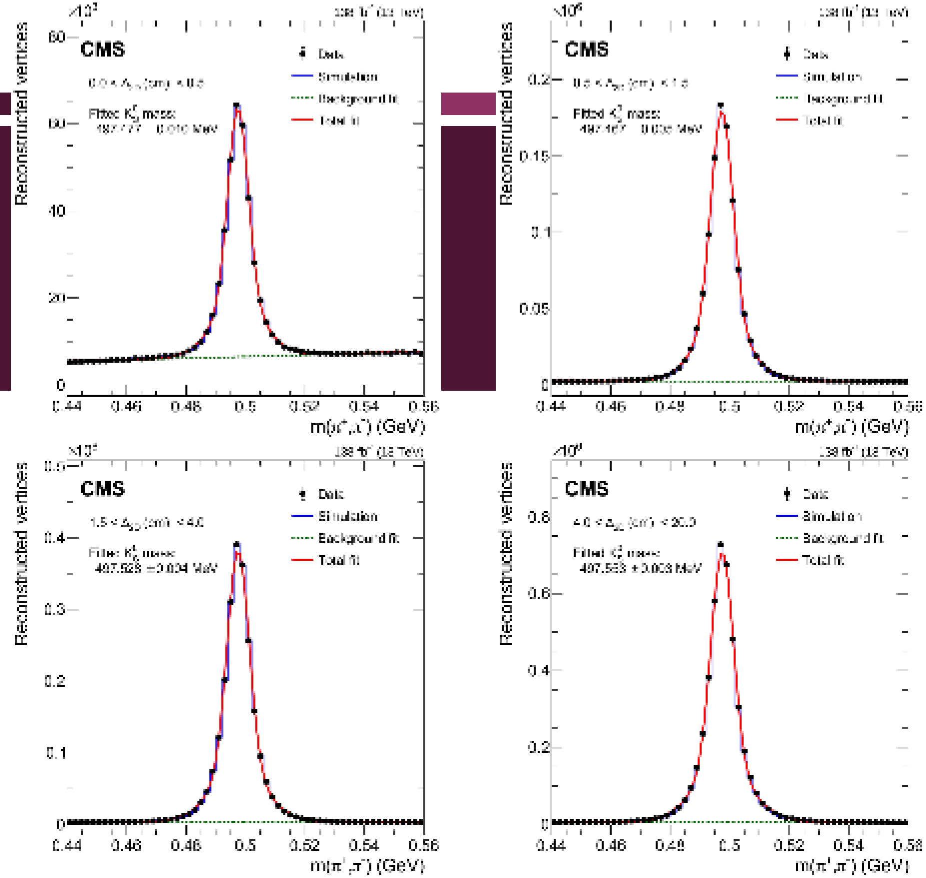

37.2 fb^{-1} (13 TeV)
CMS-Totem Preliminary
ppZ(ee)X
ppZ(μμ)X
ppZX
37.2 fb^{-1} (13 TeV)
2.3 fb^{-1} (13 TeV)
ppγX
Observed
σ_{95} exp
95%CL
68%CL
95%CL limit on σ_{fid} [pb]
m_X [GeV]
600
800
1000
1200
1400
1600

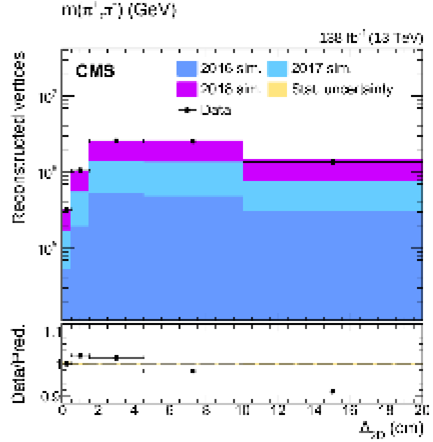

CMS
138 fb^-1 (13 TeV)
Events
ee
0AK8
Postfit
DYJets
ttbar
Non-prompt
Other
Stat.+syst. uncert.
Observed
Obs./Pred.
Reco. m_Z' (GeV)
μμ
0AK8
Postfit
ee
1AK8
Postfit
μμ
1AK8
Postfit
ee
2AK8
Postfit
μμ
2AK8
Postfit

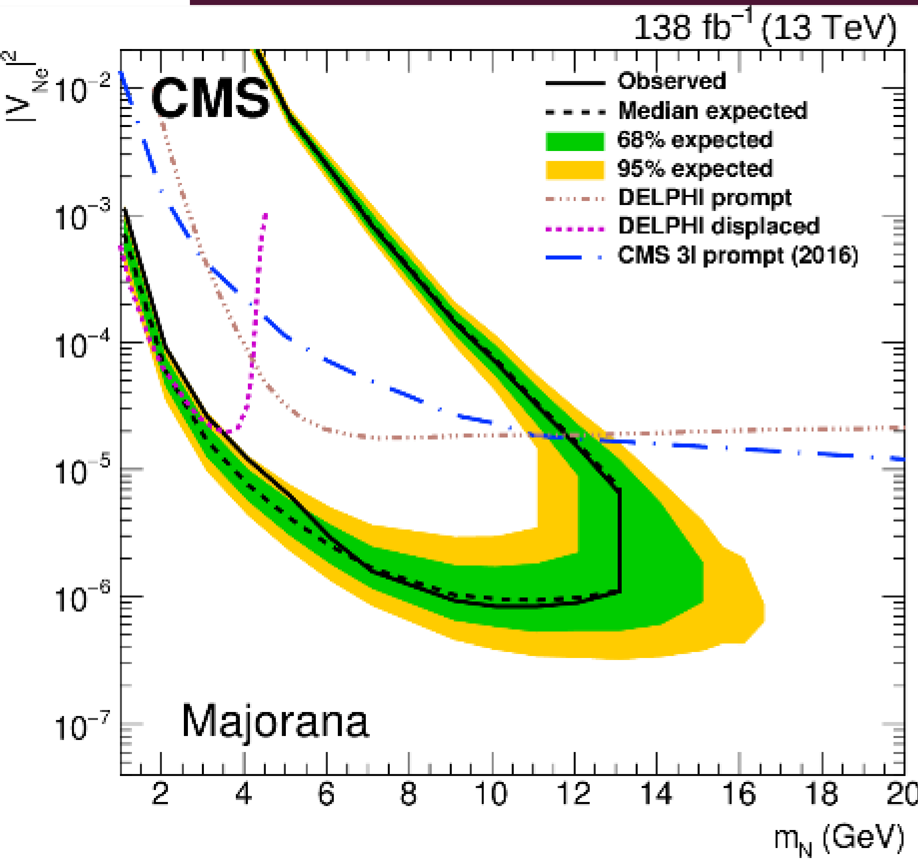

138 fb-1 (13 TeV)
CMS Preliminary
DY control region
Data
Drell-Yan
tt̄+tW
Other
Events
Data / Pred.
Post-fit
Pre-fit
(Data-Pred.)/σ
m(eeJ) (TeV)
138 fb-1 (13 TeV)
CMS Preliminary
DY control region
m(μμJ) (TeV)
138 fb-1 (13 TeV)
CMS Preliminary
Top control region
m(eμJ) (TeV)

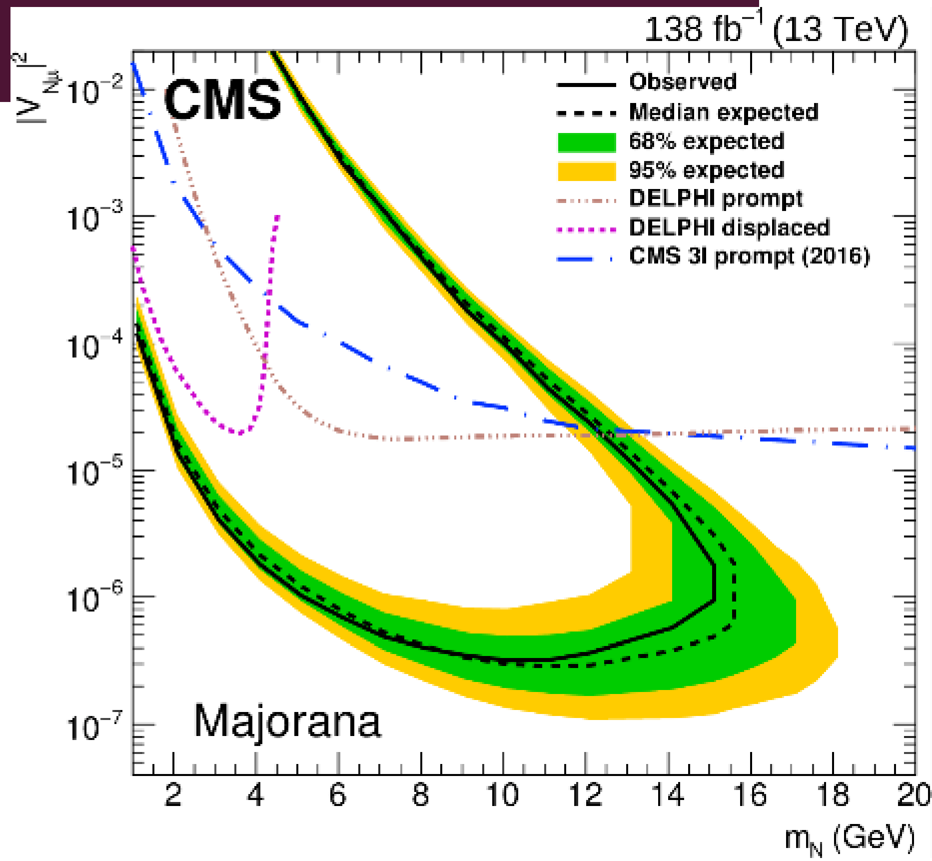


CMS Preliminary
138 fb^{-1} (13 TeV)
$|V_{\mu N}|^2$
CMS 95% CL upper limit
13 TeV, 35.9 fb^{-1}, trilepton channel
PRL 120(2018)221801
CMS 95% CL upper limit
13 TeV, 35.9 fb^{-1}, same-sign dilepton channel
JHEP 01(2019)122
95% CL upper limit
Observed
Expected
68% Expected
95% Expected
Heavy Neutrino Mass m_N (GeV)

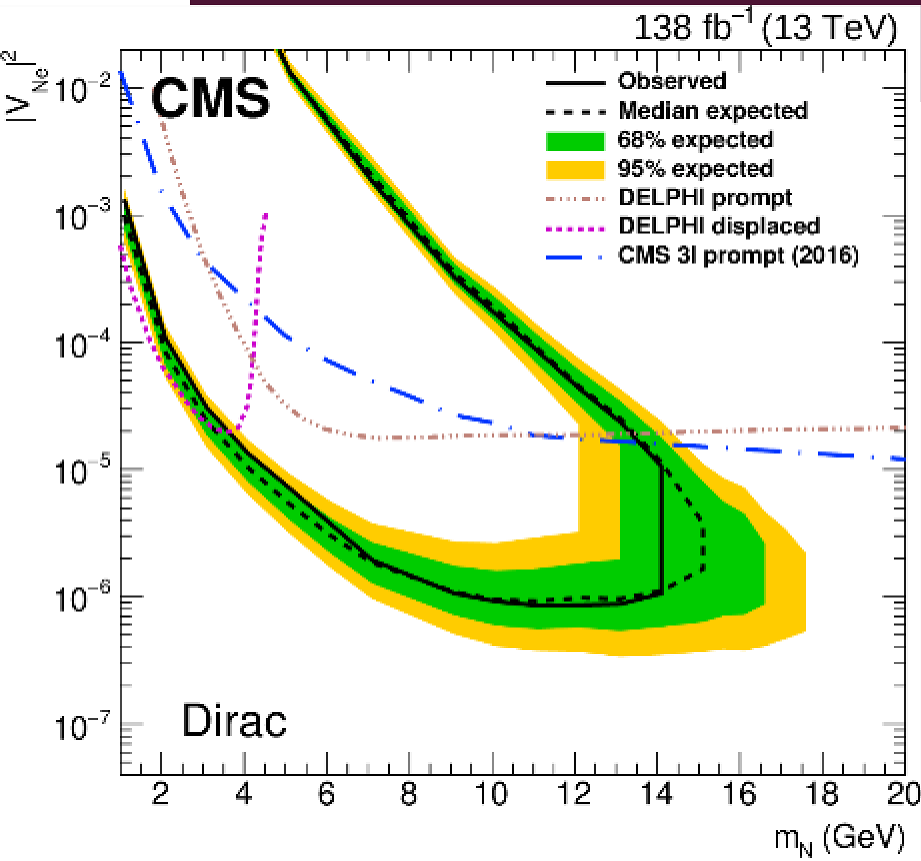


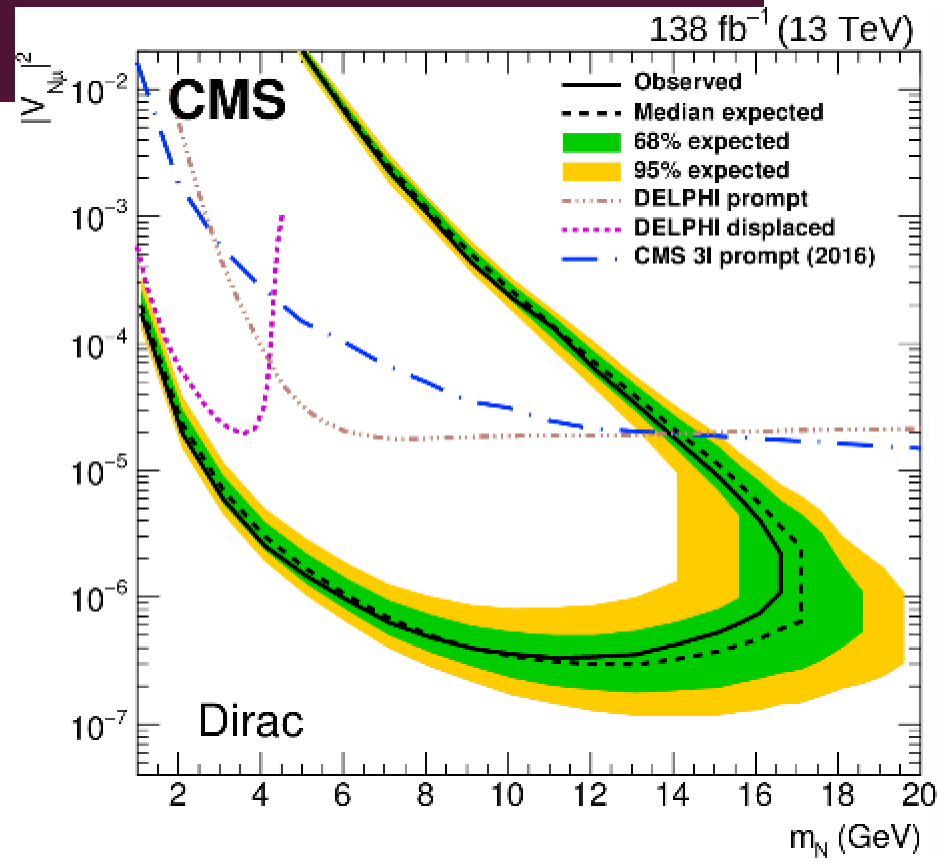


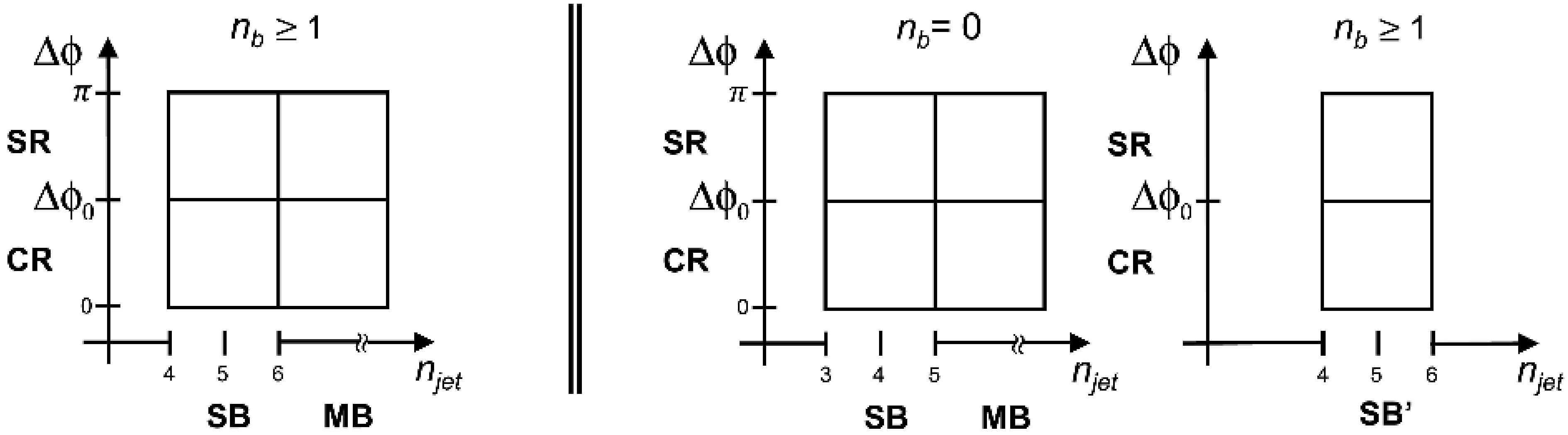




CMS-EXO-20-009


138 fb^{-1} (13 TeV)
CMS
Observed
Median expected
68% expected
95% expected
DELPHI prompt
DELPHI displaced
CMS 3l prompt (2016)
Dirac
$|V_{Ne}|^2$
m_N (GeV)


138 fb^{-1} (13 TeV)
CMS
Observed
Median expected
68% expected
95% expected
DELPHI prompt
DELPHI displaced
CMS 3l prompt (2016)
Dirac
$|V_{N\mu}|^2$
m_N (GeV)

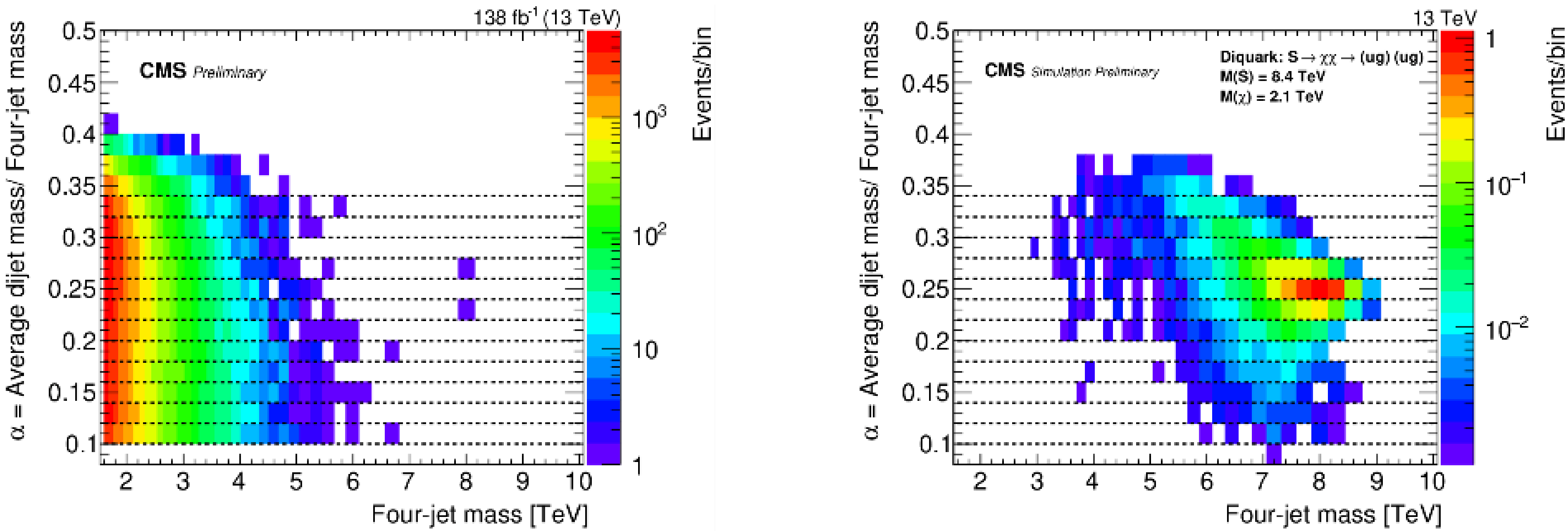

$n_b \geq 1$
$\Delta\phi$
π
SR
$\Delta\phi_0$
CR
0
4
5
6
n_{jet}
SB
MB
$n_b = 0$
$\Delta\phi$
π
SR
$\Delta\phi_0$
CR
0
3
4
5
n_{jet}
SB
MB
$n_b \geq 1$
$\Delta\phi$
SR
$\Delta\phi_0$
CR
4
5
6
n_{jet}
SB'

n_{jet}	n_b	L_T [GeV]	H_T [GeV]	n_t	Bin name	T1tttt signal events (1.8, 1.3) TeV	T1tttt signal events (2.2, 0.1) TeV	Predicted background events	Observed events
[6, 8]	1	[250, 450]	[500, 1500]	1	A1a	1.2 ± 0.1	<0.1	576 ± 29	570
				≥2	A1b	0.07 ± 0.02	<0.1	13 ± 2	14
			≥1500	1	A2a	<0.1	0.01 ± 0.01	47 ± 7	42
				≥2	A2b	<0.1	0.04 ± 0.01	5 ± 1	3
		[450, 600]	≥500	1	A3a	0.44 ± 0.06	0.04 ± 0.01	31 ± 6	16
				≥2	A3b	0.03 ± 0.02	0.06 ± 0.01	1.0 ± 0.3	1
		≥600	≥500	1	A4a	0.18 ± 0.04	0.44 ± 0.02	7 ± 2	8
				≥2	A4b	<0.1	0.48 ± 0.02	1.0 ± 0.5	0
	2	[250, 450]	[500, 1500]	1	B1a	2.3 ± 0.1	0.01 ± 0.01	532 ± 26	586
				≥2	B1b	0.28 ± 0.04	0.01 ± 0.01	16 ± 2	19
			≥1500	1	B2a	<0.1	0.03 ± 0.01	30 ± 5	34
				≥2	B2b	<0.1	0.06 ± 0.01	3.4 ± 0.8	1
		[450, 600]	≥500	1	B3a	1.0 ± 0.1	0.07 ± 0.01	27 ± 6	34
				≥2	B3b	0.06 ± 0.02	0.09 ± 0.01	1.1 ± 0.5	2
		≥600	≥500	1	B4a	0.37 ± 0.05	0.67 ± 0.03	6.2 ± 1.6	6
				≥2	B4b	0.07 ± 0.02	0.80 ± 0.03	0.23 ± 0.08	0
	≥3	[250, 450]	[500, 1500]	1	C1a	3.0 ± 0.1	0.01 ± 0.01	115 ± 7	105
				≥2	C1b	0.43 ± 0.06	<0.1	6 ± 1	3
			≥1500	1	C2a	0.01 ± 0.01	0.03 ± 0.01	7 ± 2	10
				≥2	C2b	<0.1	0.07 ± 0.01	1.0 ± 0.4	2
		[450, 600]	≥500	1	C3a	1.1 ± 0.1	0.06 ± 0.01	5 ± 1	4
				≥2	C3b	0.24 ± 0.04	0.10 ± 0.01	0.63 ± 0.43	0
		≥600	≥500	1	C4a	0.42 ± 0.05	0.67 ± 0.02	1.4 ± 0.4	4
				≥2	C4b	0.05 ± 0.02	0.76 ± 0.03	0.05 ± 0.04	0
≥9	1	[250, 450]	[500, 1500]	1	D1a	0.62 ± 0.06	<0.1	32 ± 3	26
				≥2	D1b	0.12 ± 0.03	<0.1	2.1 ± 0.6	4
			≥1500	1	D2a	0.02 ± 0.01	0.01 ± 0.01	6 ± 1	11
				≥2	D2b	0.02 ± 0.01	0.02 ± 0.01	1.0 ± 0.3	2
		[450, 600]	≥500	≥1	D3	0.34 ± 0.05	0.04 ± 0.01	2.3 ± 0.6	2
		≥600	≥500	≥1	D4	0.23 ± 0.04	0.40 ± 0.02	0.6 ± 0.3	0
	2	[250, 450]	[500, 1500]	1	E1a	1.5 ± 0.1	0.01 ± 0.01	35 ± 3	33
				≥2	E1b	0.55 ± 0.06	<0.1	3.2 ± 0.7	2
			≥1500	1	E2a	0.05 ± 0.02	0.02 ± 0.01	8 ± 2	6
				≥2	E2b	0.04 ± 0.02	0.05 ± 0.01	1.0 ± 0.4	2
		[450, 600]	≥500	1	E3a	0.75 ± 0.07	0.04 ± 0.01	1.7 ± 0.5	1
				≥2	E3b	0.19 ± 0.03	0.06 ± 0.01	0.2 ± 0.1	0
		≥600	≥500	1	E4a	0.50 ± 0.05	0.30 ± 0.02	0.9 ± 0.4	1
				≥2	E4b	0.21 ± 0.04	0.55 ± 0.02	0.06 ± 0.04	0
	≥3	[250, 450]	[500, 1500]	1	F1a	3.2 ± 0.1	0.01 ± 0.01	13 ± 2	7
				≥2	F1b	1.27 ± 0.08	<0.1	2.4 ± 0.8	2
			≥1500	1	F2a	0.04 ± 0.02	0.03 ± 0.01	4 ± 1	0
				≥2	F2b	0.07 ± 0.02	0.09 ± 0.01	0.7 ± 0.3	0
		[450, 600]	≥500	≥1	F3	1.7 ± 0.1	0.16 ± 0.01	1.1 ± 0.4	2
		≥600	≥500	≥1	F4	1.0 ± 0.1	1.30 ± 0.03	0.2 ± 0.2	2

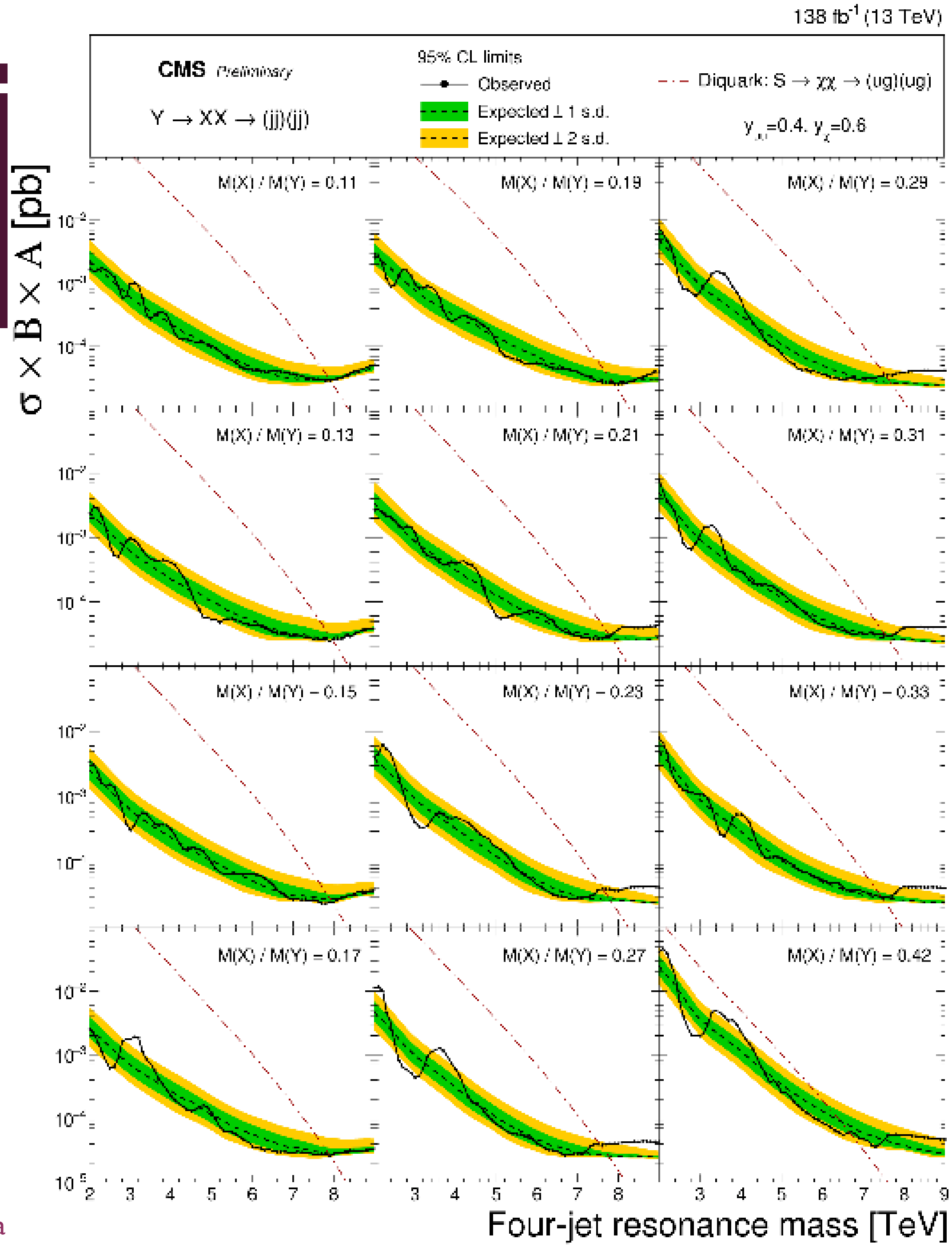
CMS-SUS-21-007

n_{jet}	L_T [GeV]	H_T [GeV]	$\Delta\phi$	n_W	Bin name	T5qqqqWW signal events (1.8, 1.3) TeV	T5qqqqWW signal events (2.2, 0.1) TeV	Predicted background events	Observed events
5	[250, 350]	[500, 750]	>1	0	G0a	1.2 ± 0.1	<0.1	342 ± 24	333
				≥1	G0b	0.46 ± 0.08	<0.1	70 ± 8	77
		≥750		0	G1a	0.35 ± 0.07	0.03 ± 0.01	292 ± 22	304
				≥1	G1b	0.14 ± 0.04	0.02 ± 0.01	69 ± 10	62
	[350, 450]	[500, 750]	>1	0	G2a	1.8 ± 0.2	<0.1	71 ± 8	63
				≥1	G2b	0.60 ± 0.09	<0.1	14 ± 5	25
		≥750		0	G3a	0.44 ± 0.08	0.04 ± 0.01	66 ± 8	44
				≥1	G3b	0.24 ± 0.06	0.03 ± 0.01	14 ± 4	13
	[450, 650]	[500, 750]	>0.75	0	G4a	2.1 ± 0.2	<0.1	52 ± 7	45
				≥1	G4b	1.1 ± 0.1	<0.1	12 ± 3	9
		[750, 1250]		0	G5a	0.9 ± 0.1	0.03 ± 0.01	42 ± 6	35
				≥1	G5b	0.35 ± 0.07	<0.1	10 ± 3	6
		≥1250		0	G6a	<0.1	0.17 ± 0.02	16 ± 3	19
				≥1	G6b	<0.1	0.13 ± 0.02	3 ± 1	3
	≥650	[500, 1250]	>0.5	0	G7a	1.3 ± 0.1	0.13 ± 0.02	33 ± 8	32
				≥1	G7b	0.30 ± 0.06	0.04 ± 0.01	7 ± 2	8
		≥1250		0	G8a	0.15 ± 0.05	1.78 ± 0.07	11 ± 3	8
				≥1	G8b	0.04 ± 0.02	1.08 ± 0.05	0.6 ± 0.4	2
[6, 7]	[250, 350]	[500, 1000]	>1	0	H1a	2.6 ± 0.2	<0.1	281 ± 22	292
				≥1	H1b	1.3 ± 0.1	<0.1	71 ± 9	71
		≥1000		0	H2a	0.23 ± 0.06	0.05 ± 0.01	121 ± 11	121
				≥1	H2b	0.18 ± 0.05	0.02 ± 0.01	29 ± 5	21
	[350, 450]	[500, 1000]	>1	0	H3a	3.1 ± 0.2	<0.1	51 ± 6	71
				≥1	H3b	1.6 ± 0.2	0.01 ± 0.01	12 ± 3	15
		≥1000		0	H4a	0.31 ± 0.07	0.09 ± 0.01	31 ± 7	21
				≥1	H4b	0.12 ± 0.04	0.08 ± 0.01	6 ± 2	6
	[450, 650]	[500, 750]	>0.75	0	H5a	3.1 ± 0.2	<0.1	19 ± 4	17
				≥1	H5b	1.6 ± 0.2	<0.1	5 ± 2	9
		[750, 1250]		0	H6a	2.8 ± 0.2	0.01 ± 0.01	29 ± 4	18
				≥1	H6b	1.4 ± 0.1	<0.1	7 ± 2	4
		≥1250		0	H7a	0.4 ± 0.07	0.45 ± 0.03	15 ± 3	14
				≥1	H7b	0.2 ± 0.05	0.33 ± 0.03	3 ± 1	1
	≥650	[500, 1250]	>0.5	0	H8a	2.5 ± 0.2	0.09 ± 0.01	13 ± 3	17
				≥1	H8b	0.9 ± 0.1	0.05 ± 0.01	4 ± 1	4
		≥1250		0	H9a	0.8 ± 0.1	3.9 ± 0.1	9 ± 3	6
				≥1	H9b	0.34 ± 0.07	2.44 ± 0.06	2 ± 1	1
≥8	[250, 350]	[500, 1000]	>1	0	I1a	0.8 ± 0.1	<0.1	23 ± 5	25
				≥1	I1b	0.33 ± 0.07	<0.1	7 ± 3	5
		≥1000		0	I2a	0.30 ± 0.07	0.04 ± 0.01	22 ± 5	23
				≥1	I2b	0.16 ± 0.05	0.01 ± 0.01	8 ± 2	12
	[350, 450]	[500, 1000]	>1	0	I3a	0.8 ± 0.1	<0.1	3.0 ± 0.7	10
				≥1	I3b	0.36 ± 0.07	<0.1	1.1 ± 0.4	0
		≥1000		0	I4a	0.57 ± 0.09	0.07 ± 0.01	5 ± 1	5
				≥1	I4b	0.36 ± 0.07	0.06 ± 0.01	3 ± 1	2
	[450, 650]	[500, 1250]	>0.75	0	I5a	1.5 ± 0.1	<0.1	3.4 ± 0.9	4
				≥1	I5b	1.0 ± 0.1	<0.1	0.5 ± 0.3	1
		≥1250		0	I6a	0.40 ± 0.07	0.26 ± 0.03	2.6 ± 0.8	2
				≥1	I6b	0.18 ± 0.05	0.17 ± 0.02	0.5 ± 0.3	2
	≥650	[500, 1250]	>0.5	≥0	I7	1.4 ± 0.1	0.02 ± 0.01	1.5 ± 0.6	2
		≥1250			I8	1.4 ± 0.1	3.58 ± 0.09	1.5 ± 0.7	1

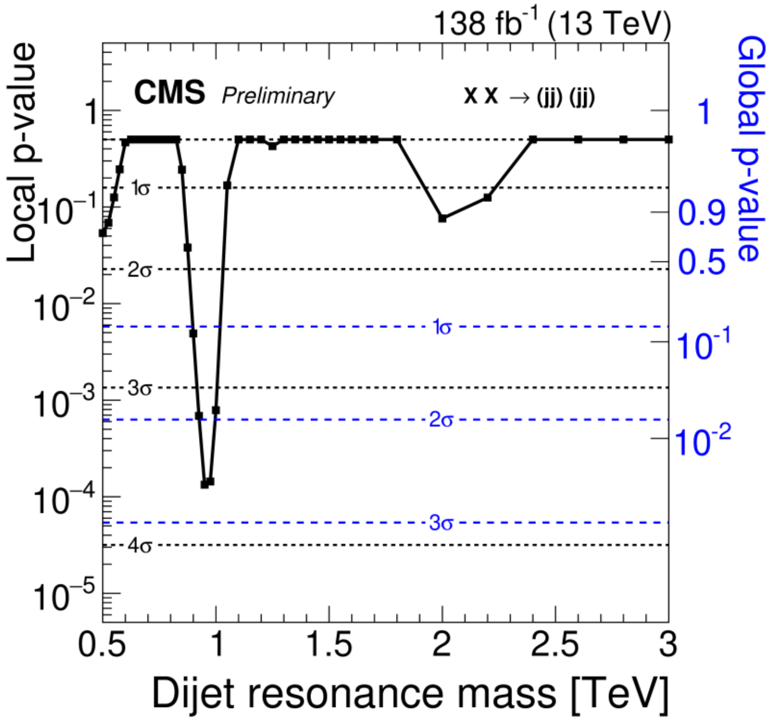
CMS-SUS-21-007

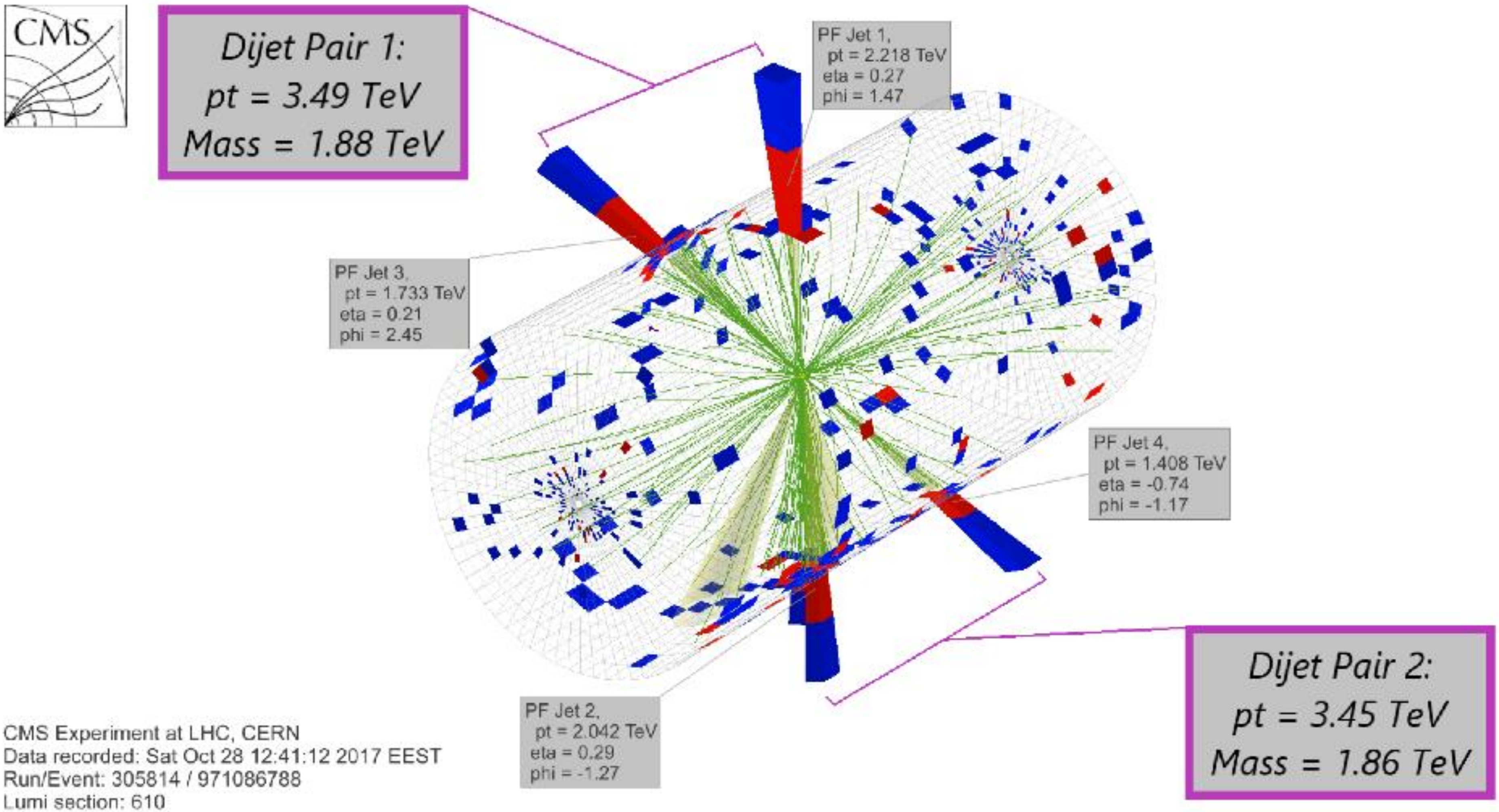


138 fb-1 (13 TeV)
CMS Preliminary
α = Average dijet mass/ Four-jet mass
Four-jet mass [TeV]
Events/bin
13 TeV
CMS Simulation Preliminary
Diquark: S → χχ → (ug) (ug)
M(S) = 8.4 TeV
M(χ) = 2.1 TeV

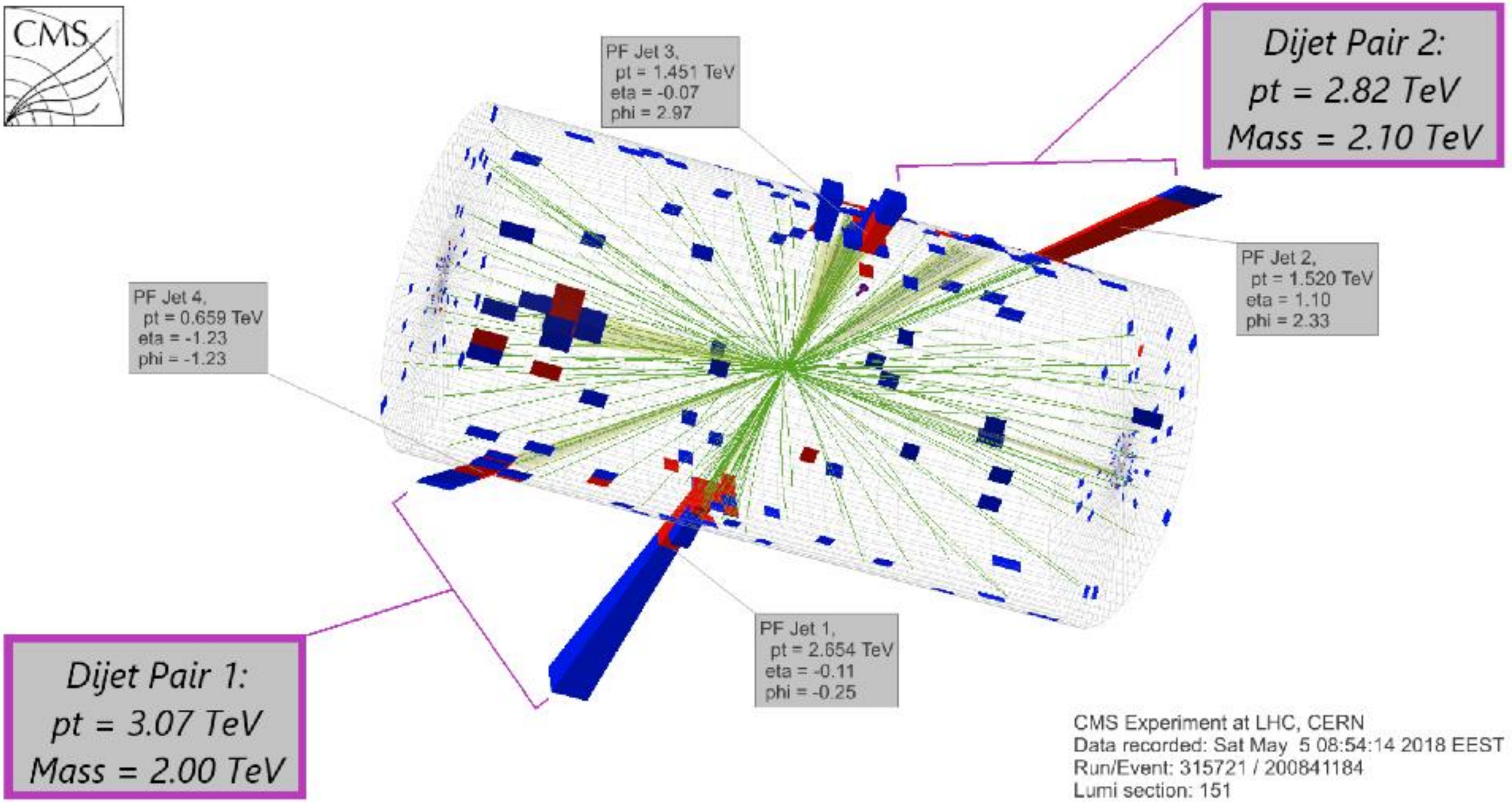


CMS-EXO-21-010


138 fb^{-1} (13 TeV)
CMS Preliminary
X X → (jj) (jj)
Local p-value
Global p-value
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0.9
0.5
1σ
2σ
3σ
4σ
0.5
1
1.5
2
2.5
3
Dijet resonance mass [TeV]



CMS
Dijet Pair 1:
pt = 3.49 TeV
Mass = 1.88 TeV
PF Jet 1,
pt = 2.218 TeV
eta = 0.27
phi = 1.47
PF Jet 3,
pt = 1.733 TeV
eta = 0.21
phi = 2.45
PF Jet 4,
pt = 1.408 TeV
eta = -0.74
phi = -1.17
PF Jet 2,
pt = 2.042 TeV
eta = 0.29
phi = -1.27
Dijet Pair 2:
pt = 3.45 TeV
Mass = 1.86 TeV
CMS Experiment at LHC, CERN
Data recorded: Sat Oct 28 12:41:12 2017 EEST
Run/Event: 305814 / 971086788
Lumi section: 610


PF Jet 3,
pt = 1.451 TeV
eta = -0.07
phi = 2.97
Dijet Pair 2:
pt = 2.82 TeV
Mass = 2.10 TeV
PF Jet 2,
pt = 1.520 TeV
eta = 1.10
phi = 2.33
PF Jet 4,
pt = 0.659 TeV
eta = -1.23
phi = -1.23
PF Jet 1,
pt = 2.654 TeV
eta = -0.11
phi = -0.25
Dijet Pair 1:
pt = 3.07 TeV
Mass = 2.00 TeV
CMS Experiment at LHC, CERN
Data recorded: Sat May 5 08:54:14 2018 EEST
Run/Event: 315721 / 200841184
Lumi section: 151

0 taus	1 tau	2 taus

Fit Region

0 taus

CR1: $DNN_{QCD} > 0.6$, $p_T^{miss} < 160$ GeV

SR: $DNN_{QCD} > 0.6$, $p_T^{miss} > 160$ GeV

CR2: $DNN_{QCD} < 0.6$, $p_T^{miss} < 160$ GeV

CR3: $DNN_{QCD} < 0.6$, $p_T^{miss} > 160$ GeV

1 tau

CR : Loose tau ID

SR : Tight tau ID

2 taus

CR : Loose tau ID

SR : Medium tau ID

Determination Regions

1 tau

CR : 1 tight muon, Loose tau ID

SR : 1 tight muon, Tight tau ID

$t\bar{t}$ enhanced

CR : QCD Selection, Loose tau ID

SR : QCD Selection, Tight tau ID

QCD enhanced

2 taus

CR : 1 tight muon, Loose tau ID

SR : 1 tight muon, Medium tau ID

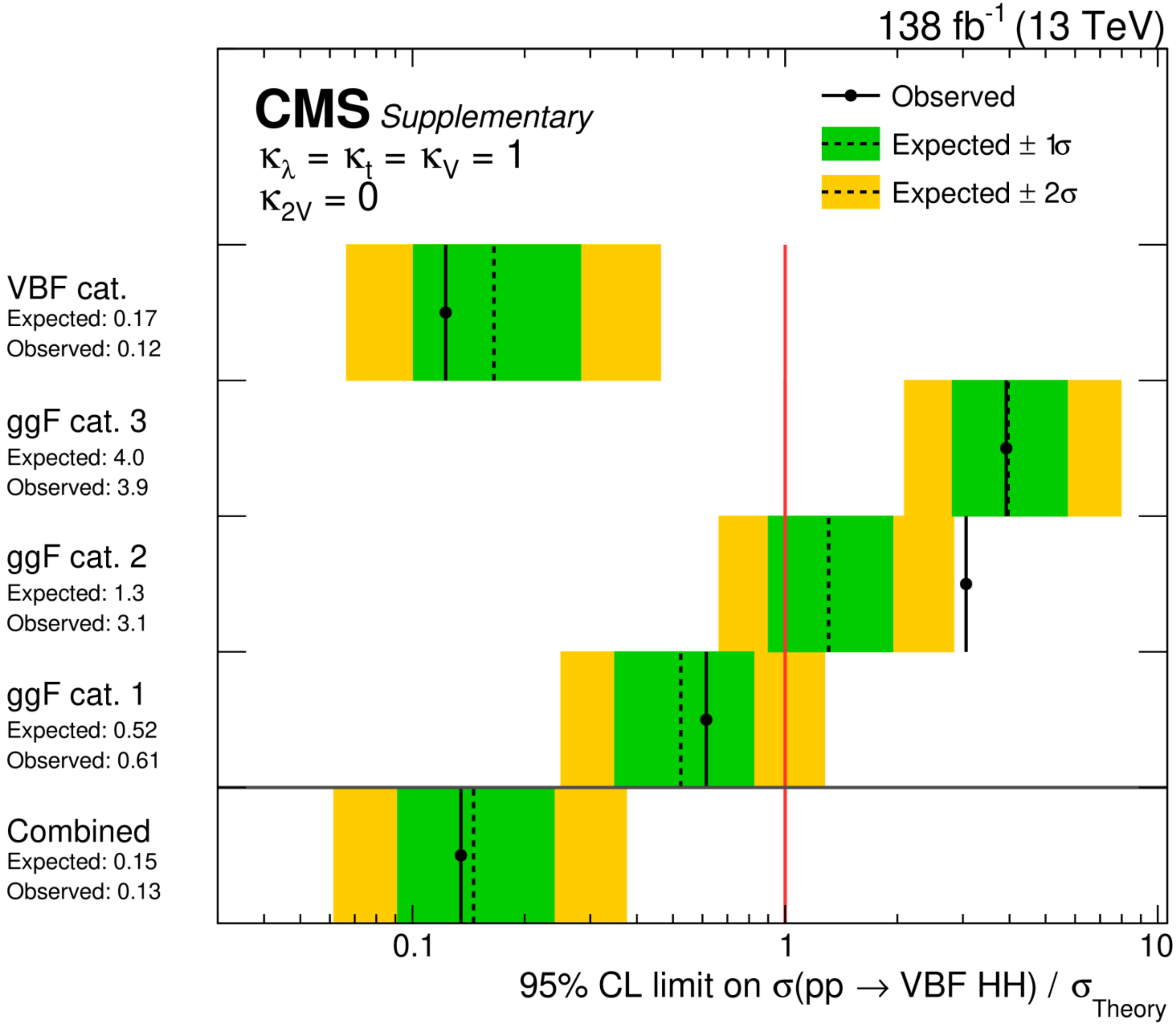
tt enhanced

CR : QCD Selection, Loose tau ID

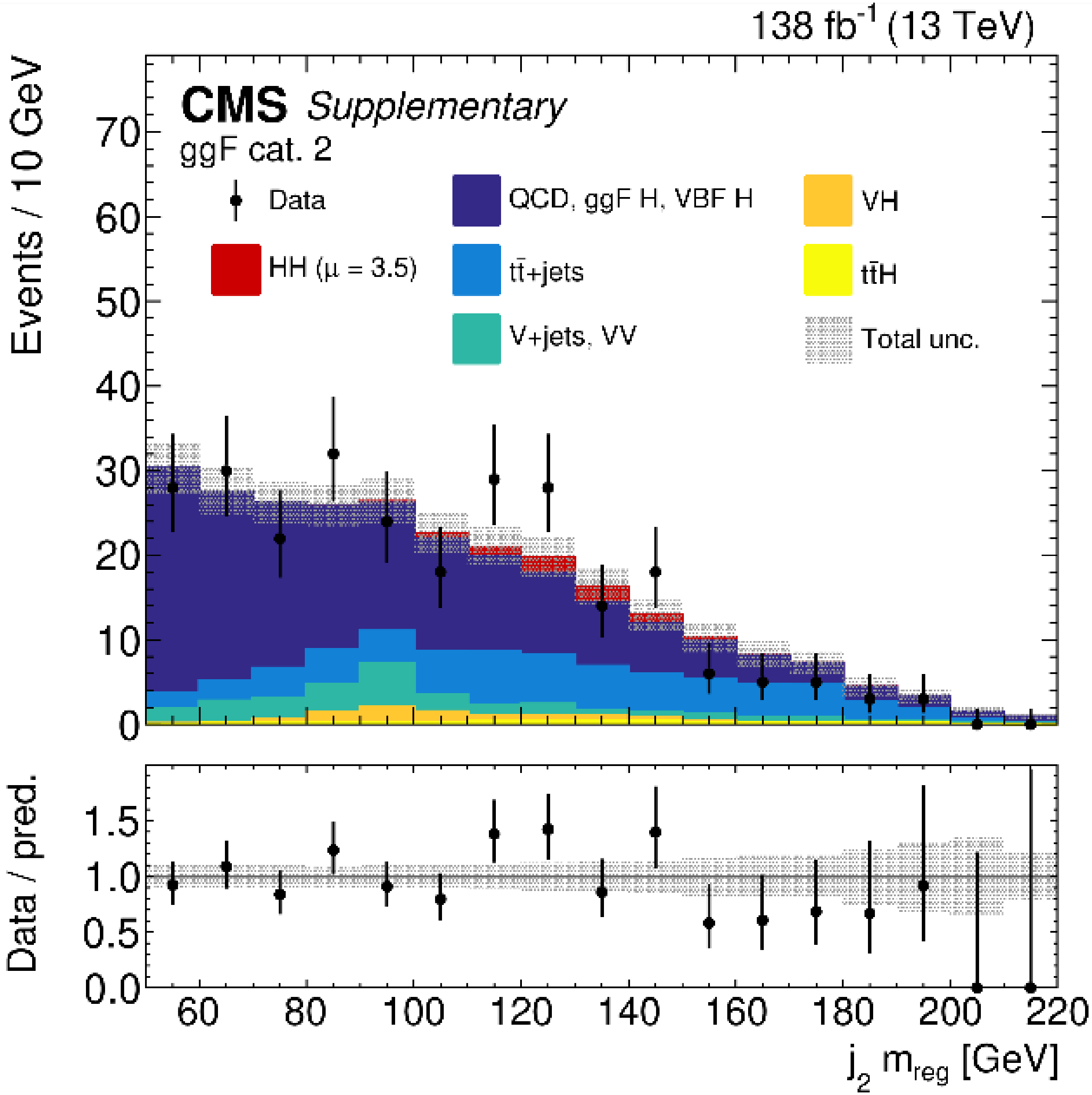
SR : QCD Selection, Medium tau ID

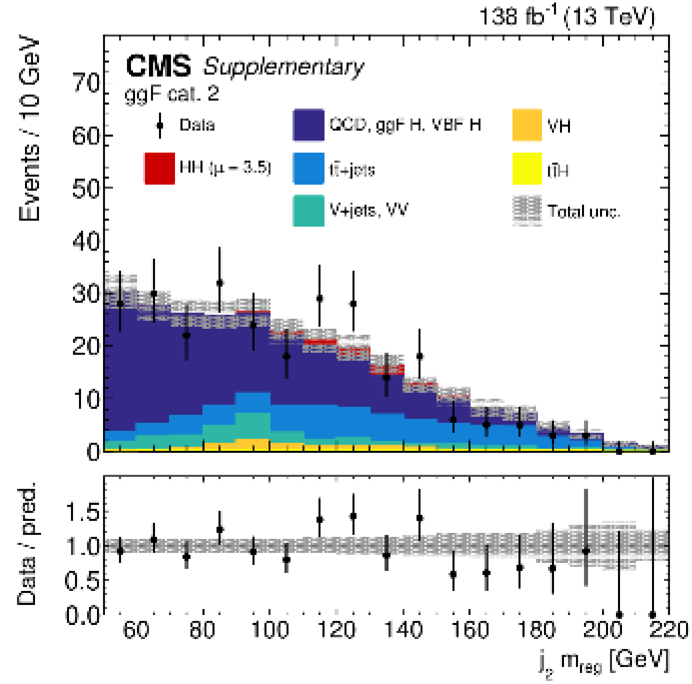
QCD enhanced

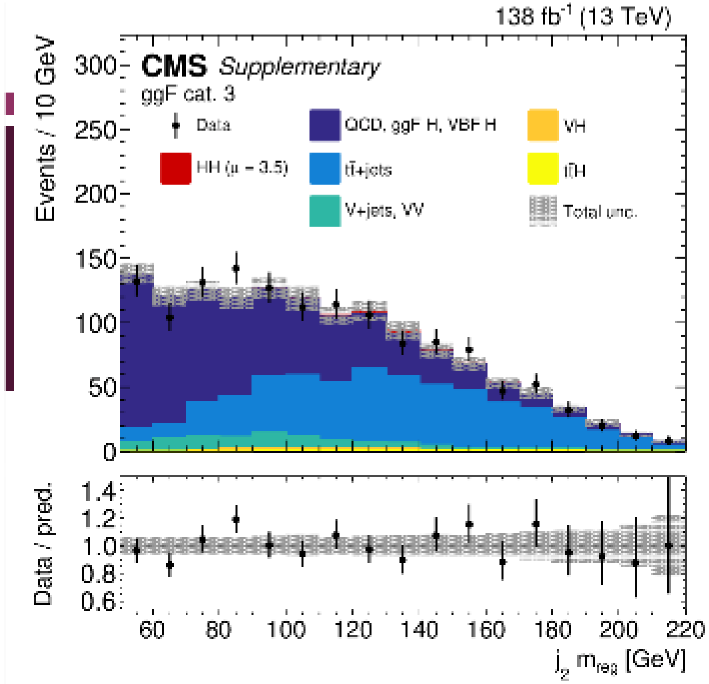
CMS-B2G-21-004

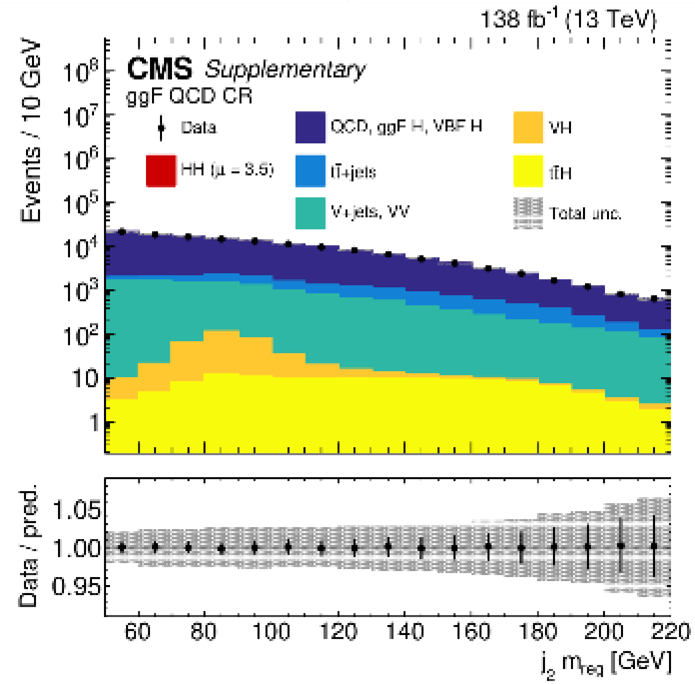


CMS-B2G-22-003


138 fb^{-1} (13 TeV)
CMS Supplementary
ggF cat. 2
Data
QCD, ggF H, VBF H
VH
HH (μ = 3.5)
$t\bar{t}$+jets
$t\bar{t}$H
V+jets, VV
Total unc.
Events / 10 GeV
Data / pred.
j_2 m_{reg} [GeV]







CMS-B2G-22-003