Searches for BSM physics at CMS

Nadja Strobbe (University of Minnesota),
on behalf of the CMS experiment

The BSM landscape

The BSM landscape

The BSM landscape

Outline

- Combination of electroweak SUSY searches
- Search for SUSY with 1 photon, jets, and $p_{\mathrm{T}}^{\mathrm{miss}}$
- Search for Stealth SUSY with 2 photons and jets
- Low mass dimuons with scouting
- Search for inelastic dark matter
- Search for dark matter in W+W- events with $p_{\mathrm{T}}^{\mathrm{miss}}$
- Search for long-lived heavy neutral leptons decaying to jet + e/μ/τ
- Search for $W' \rightarrow tb$ in final states with electrons or muons
- Search for $b* \rightarrow tW$ with lepton+jets

All are NEW CMS results using the full Run 2 dataset

Delving deep, scouting wide, and climbing high!

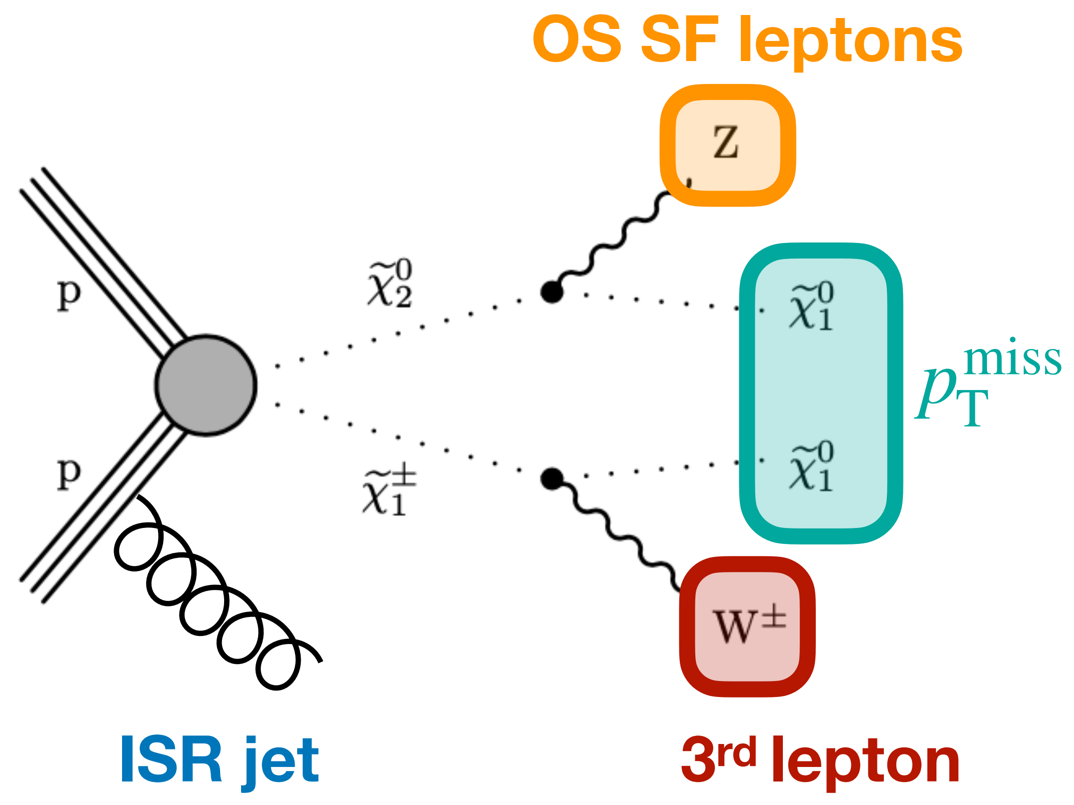
Combination of electroweak SUSY searches

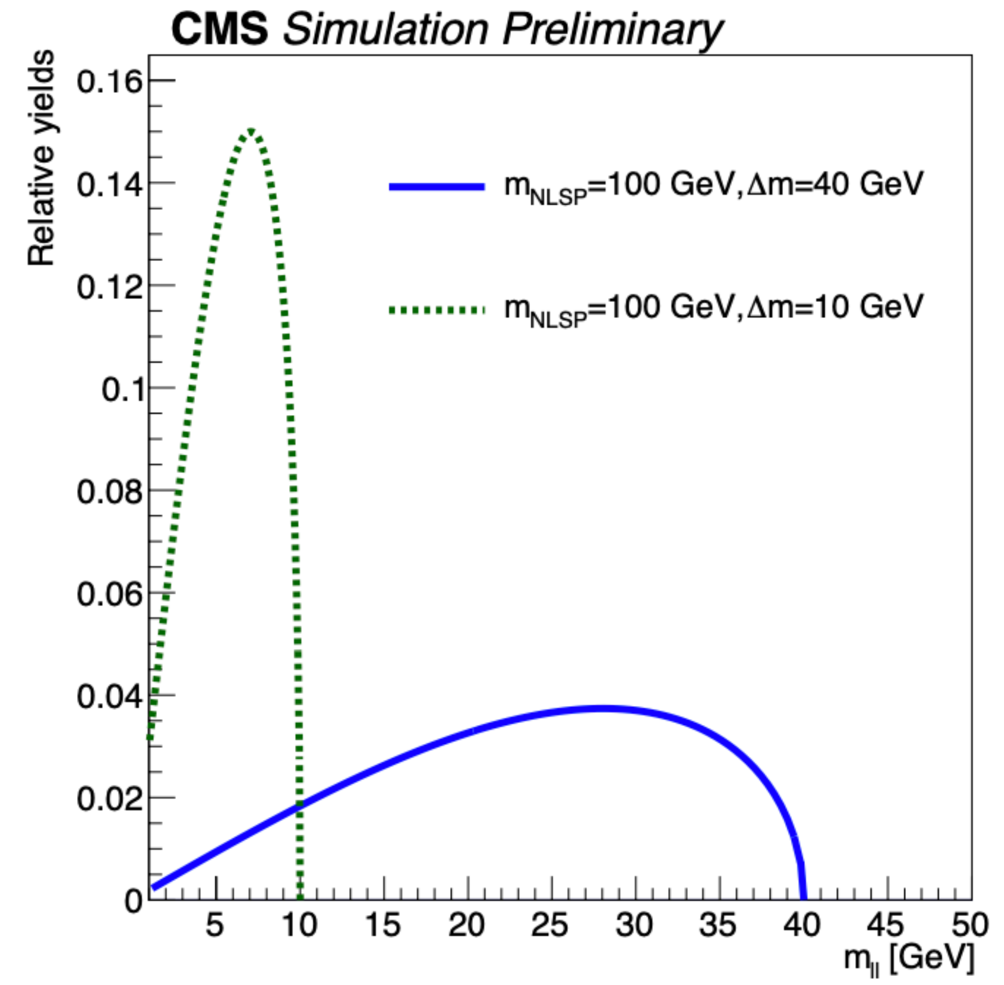
- Targets electroweak production of charginos and neutralinos, as well as sleptons for compressed and non-compressed mass spectra. Several new interpretations compared to earlier results.
- **Combines 6 searches using the full LHC Run 2 data set:**

OS/SS = opposite/same sign (charge)
SF = same flavor

Leptonic	**“2/3L soft”** 2 or 3 e(μ), including OS SF pair, 5(3.5)< lepton p_T < 30 GeV Targeting compressed spectra	**“≥ 3l”** 2 SS e/μ, or ≥3 leptons (up to 2 τ_{had}) Leading lepton p_T > 30 GeV	**“2l on-Z/non-resonant”** 2 e(μ) OS SF, Either on- or off-shell Z
(Semi) Hadronic	**“1l 2b” - WH** 1 e(μ), H→bb tag Targeting compressed spectra	**“4b” - HH** No leptons 2 tagged Higgs bosons (H→bb)	**“Hadr. WX”** Fully hadronic final state; ≥2 jets (AK8), and 2-6 jets (AK4)

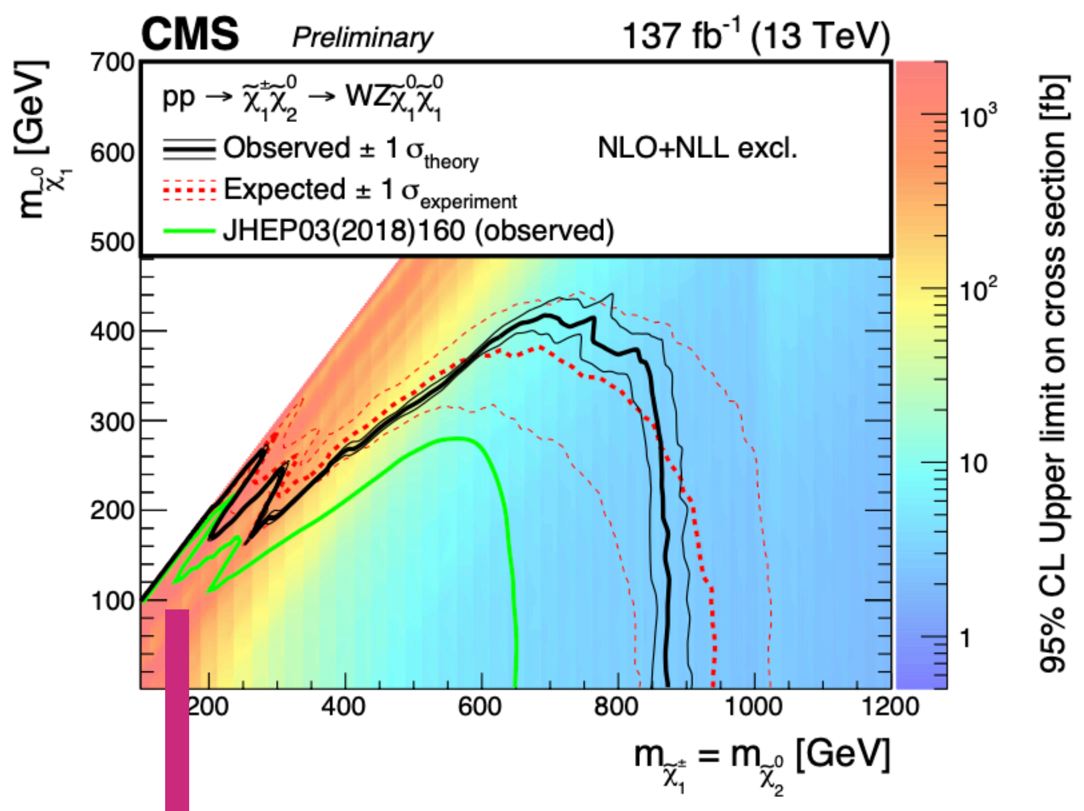
- Hadronic WX analysis is new addition to the combination, improving the sensitivity in the non-compressed region
- 2/3L soft was updated for the combination to include a parametric signal extraction which improves the sensitivity to compressed mass spectra
  - m_{ll} binning optimized per $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ signal hypothesis to exploit kinematic end point

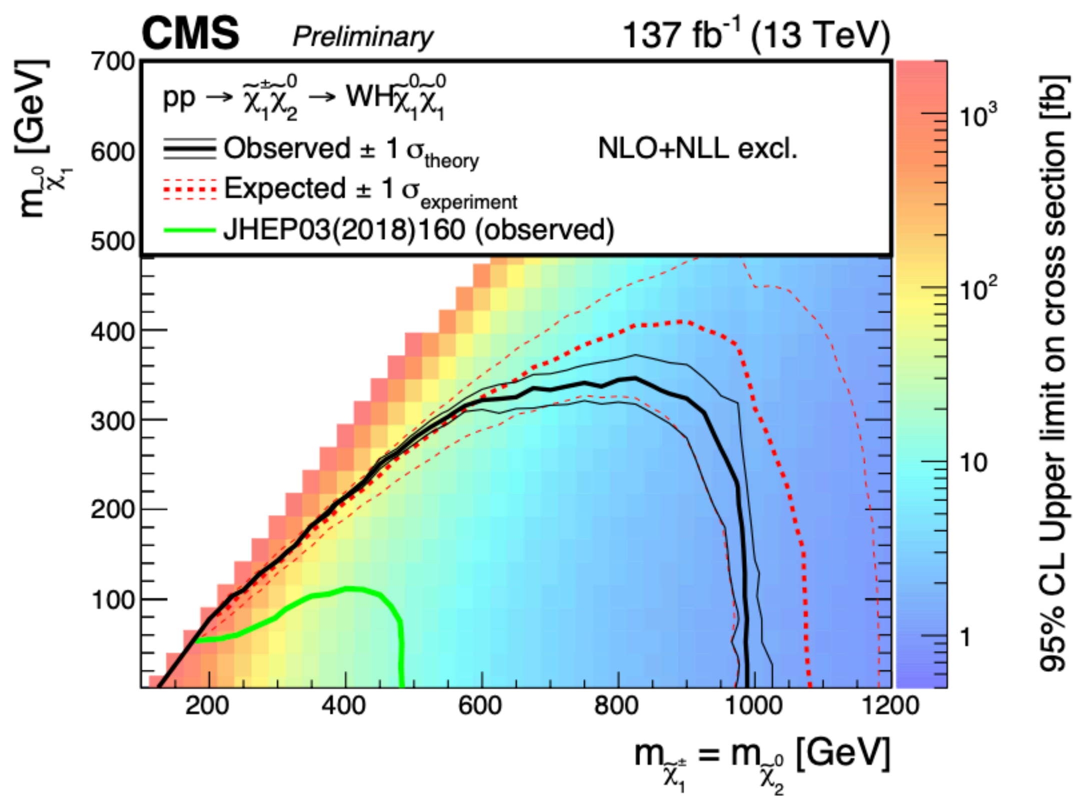


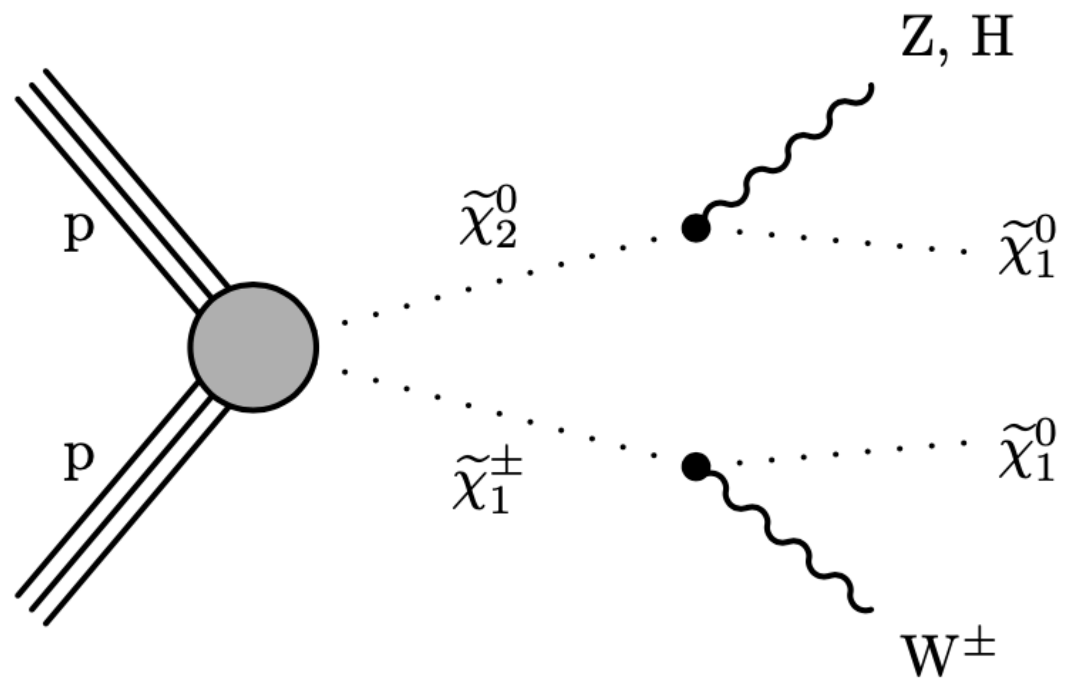


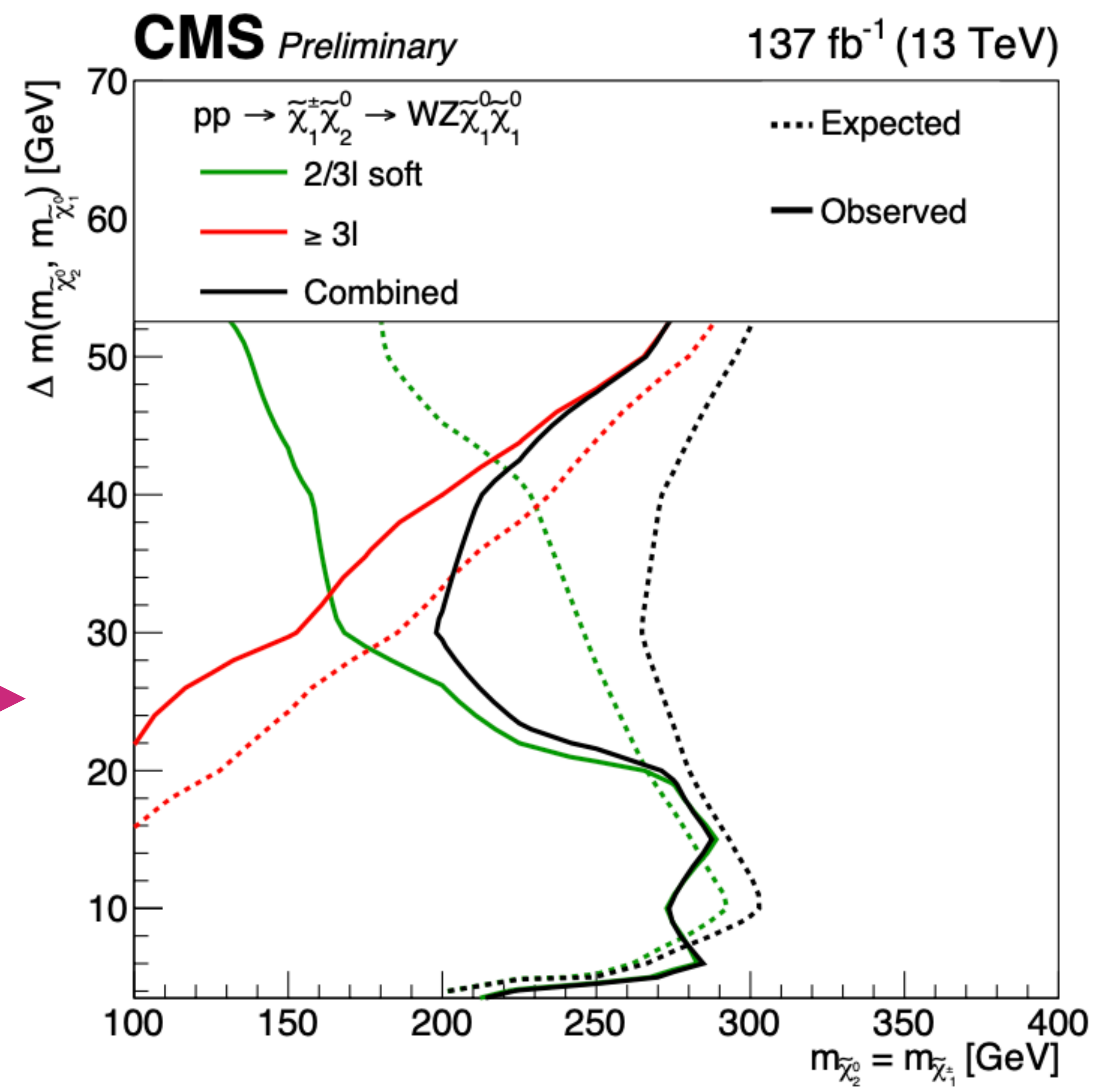
Combination of electroweak SUSY searches

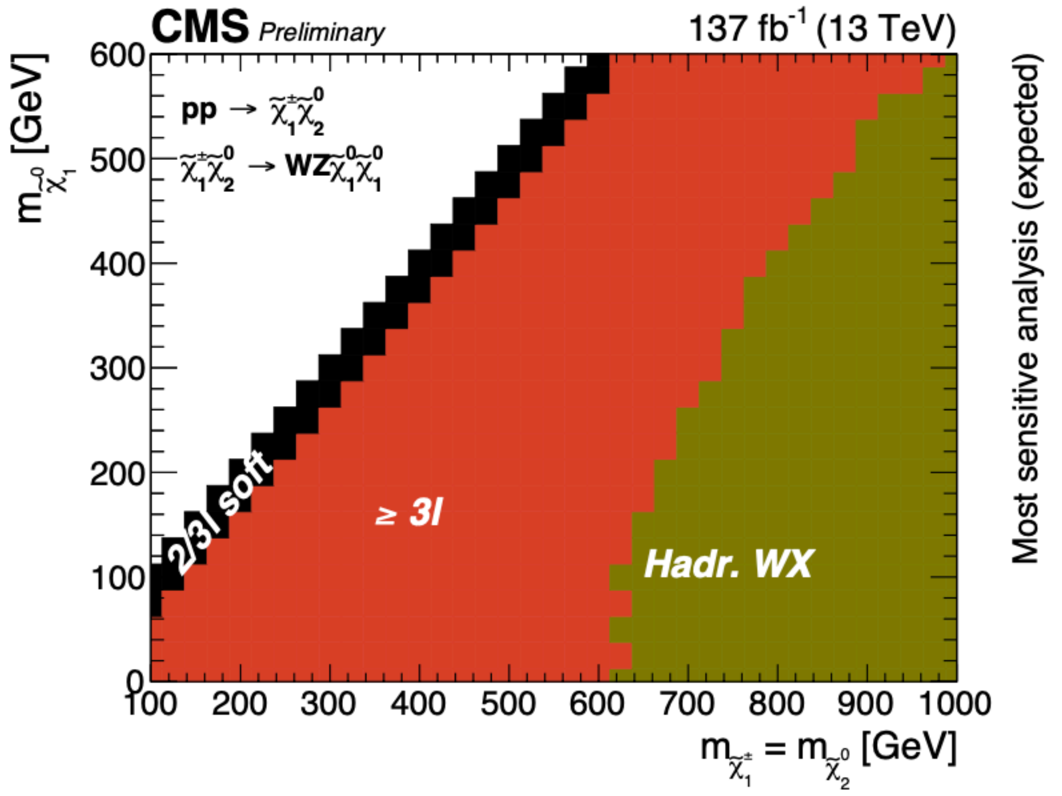
Results for wino-like $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_2^0$ (with bino-like $\tilde{\chi}_1^0$)

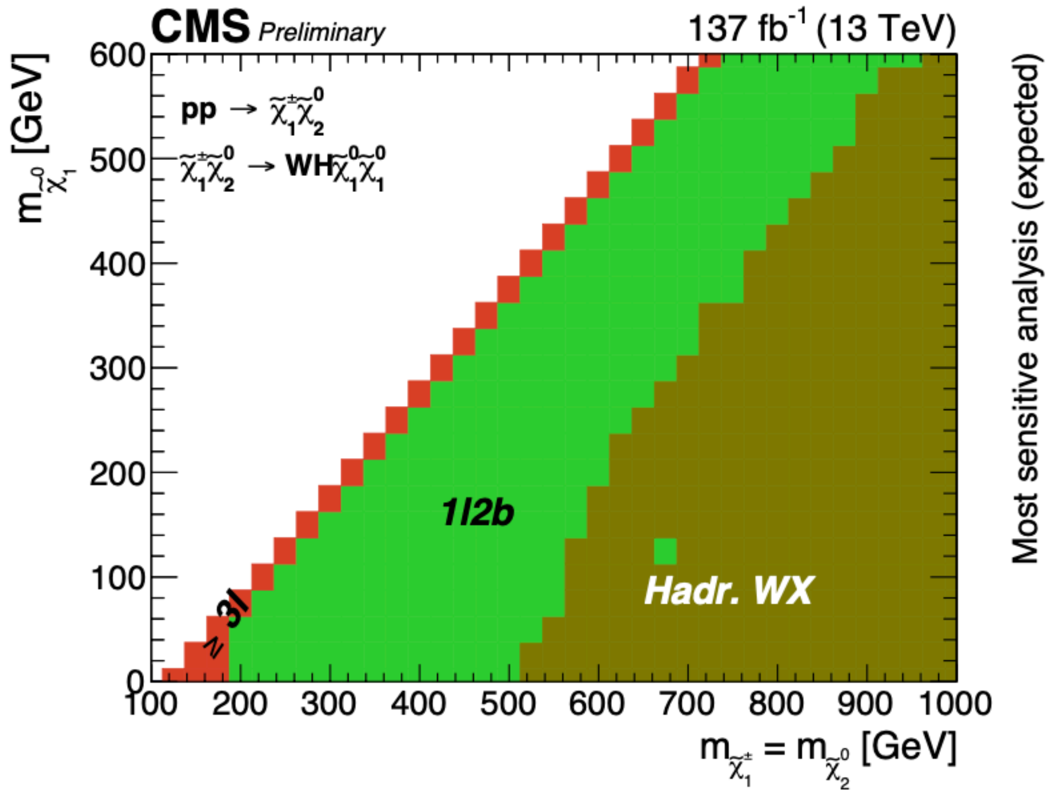












Zooming in on the compressed region

2/3L soft and ≥3L analyses are complementary

- orthogonal lepton p_T ranges
- Different selections (e.g. 2/3L soft requires p_T^{miss})

Combination closes the gap!

Mild excess observed around Δm = 30 and 40 GeV, stemming from both analyses

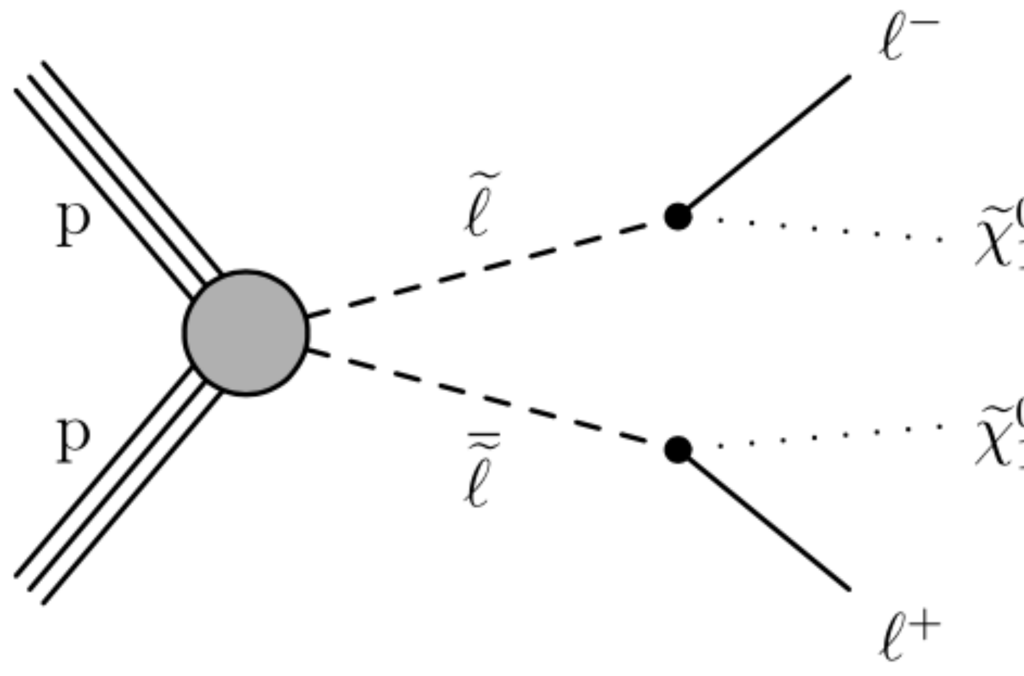
Addition of the **hadronic WX** search improves sensitivity to higher $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ masses in the uncompressed region

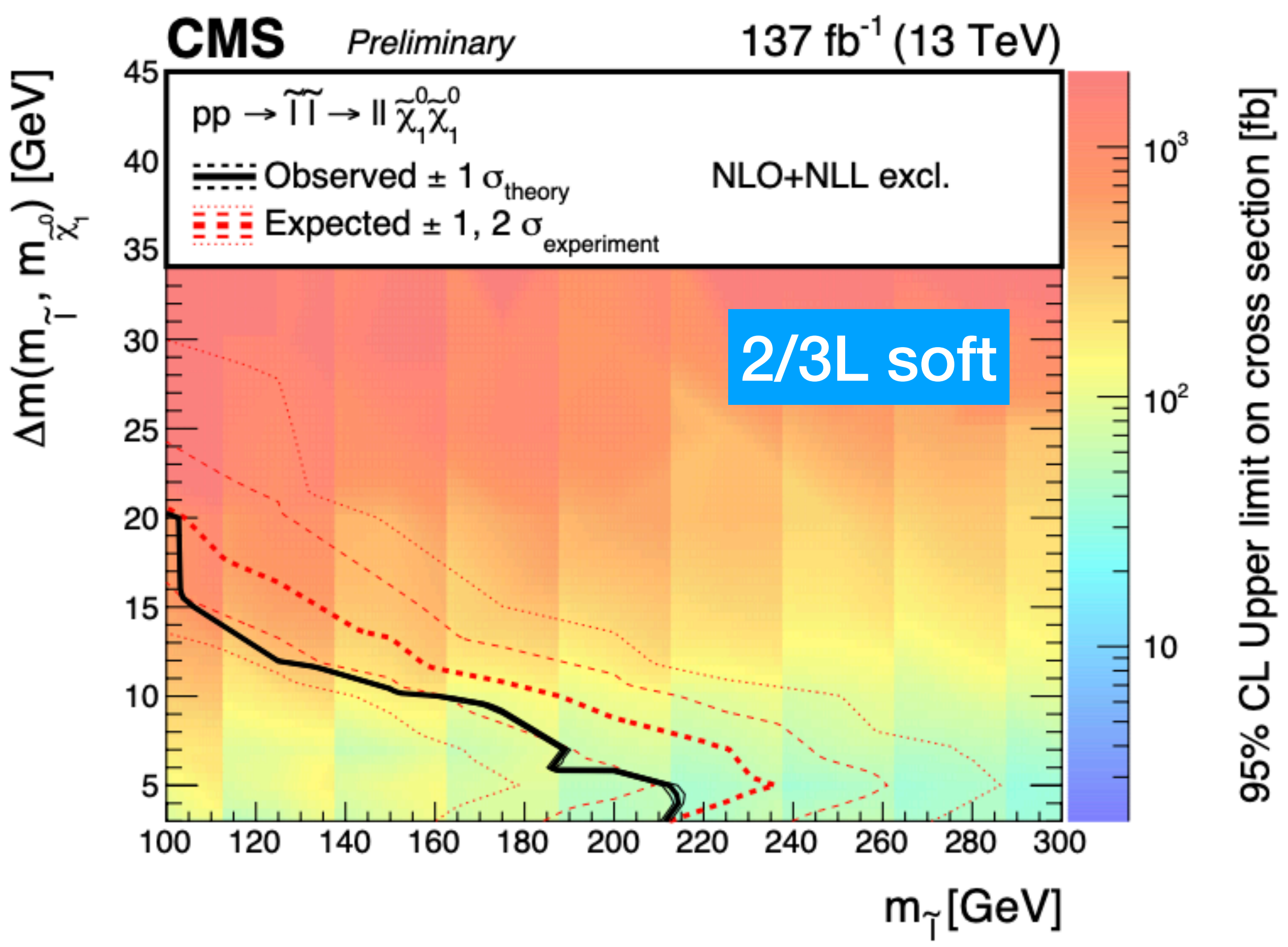
Results for higgsino-like $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_{2,3}^0$ (with bino-like $\tilde{\chi}_1^0$) in backup

Combination of electroweak SUSY searches

Results for sleptons & quasi-degenerate higgsinos in GMSB

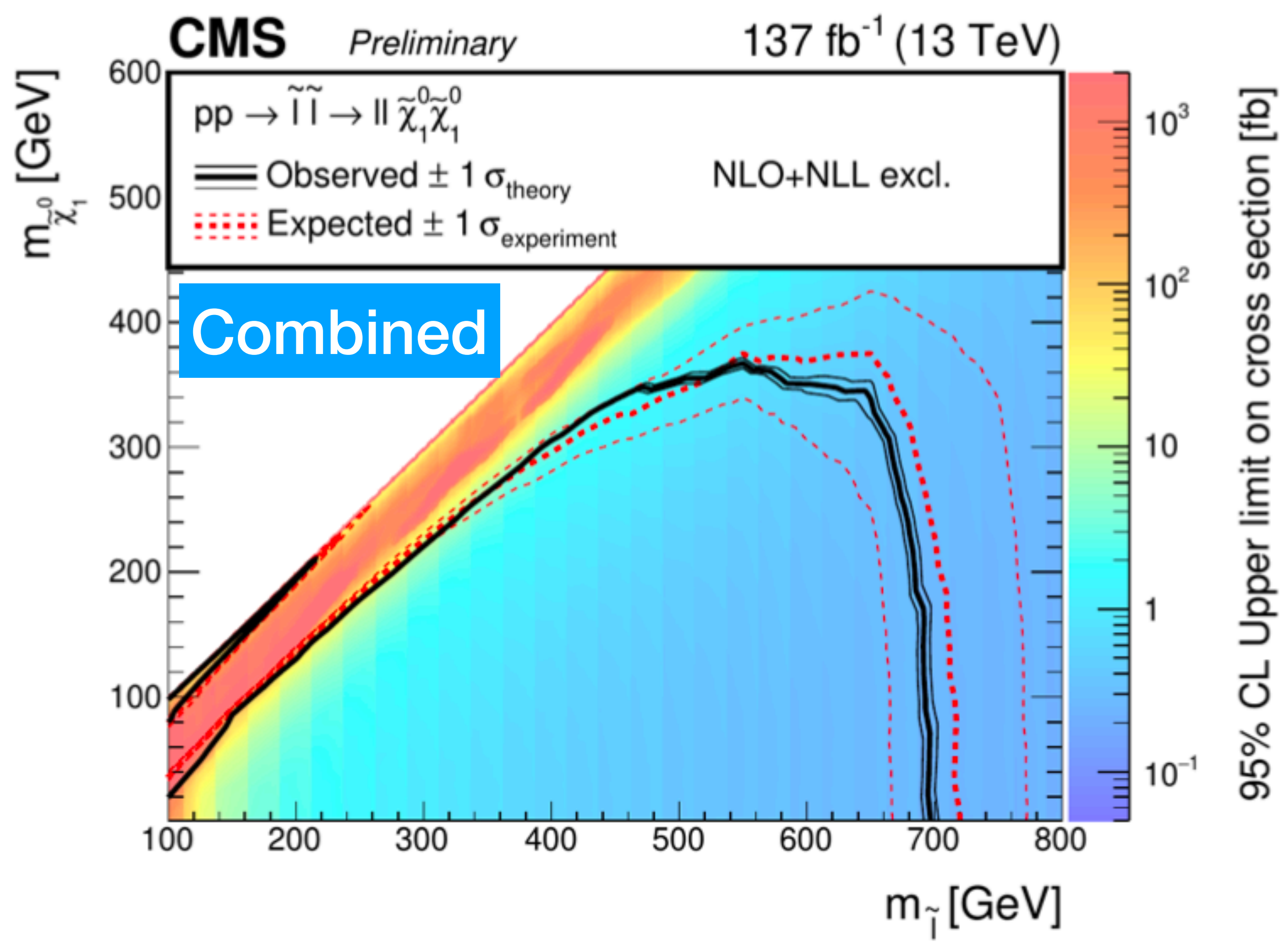
Sleptons (e/μ)





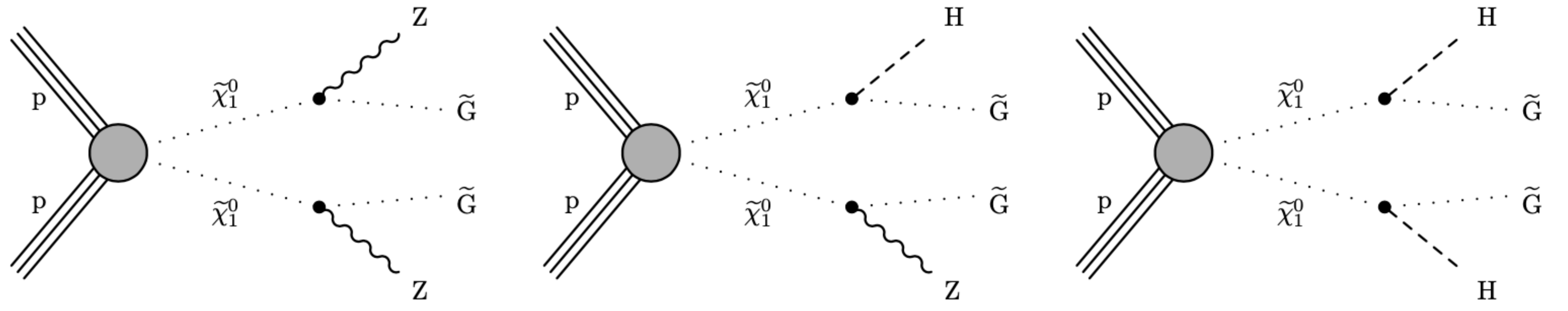
Uncompressed region covered by the 2-lepton non-resonant analysis

NEW: 2/3l soft analysis provides sensitivity to the compressed region (m_{ll} replaced by M_{T2})



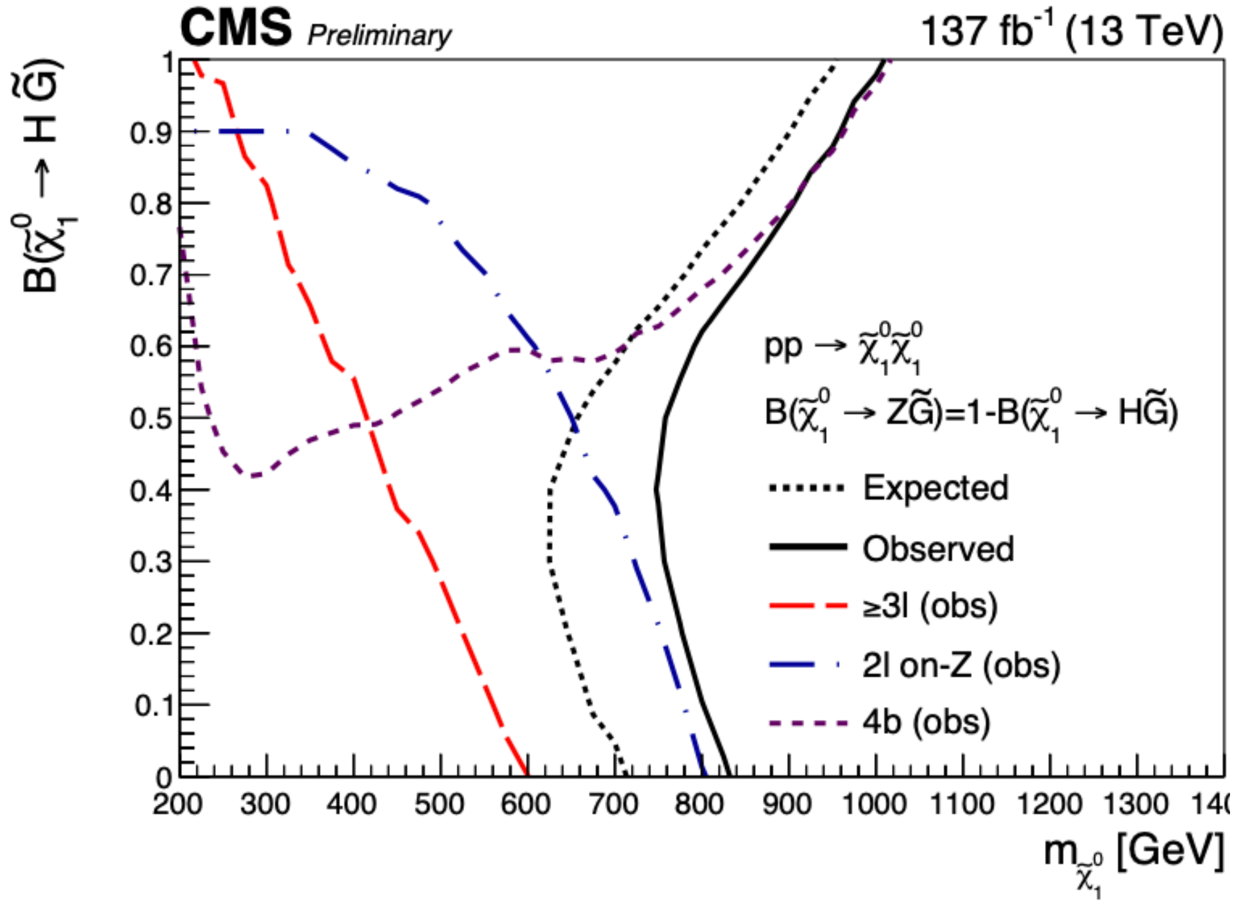
Sleptons excluded up to 215 (235) GeV at Δm=5 GeV

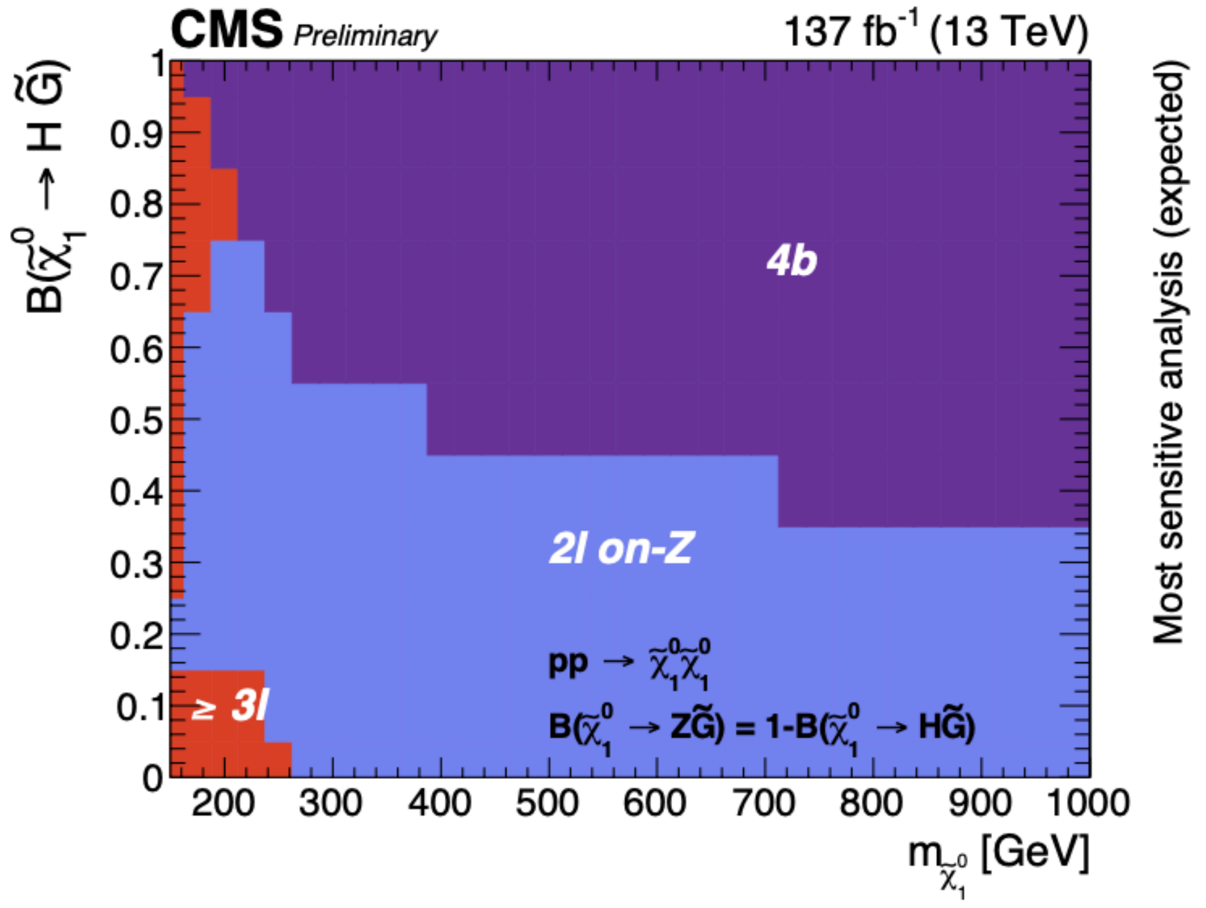
GMSB higgsinos



Higgsino triplet ($\tilde{\chi}_2^0, \tilde{\chi}_1^\pm, \tilde{\chi}_1^0$) with small Δm: results in effective $\tilde{\chi}_1^0\tilde{\chi}_1^0$ production, with $\tilde{\chi}_1^0 \rightarrow \tilde{G} + H/Z$

4b (HH) analysis most sensitive for large $\mathscr{B}(\tilde{\chi}_1^0 \rightarrow H\tilde{G})$

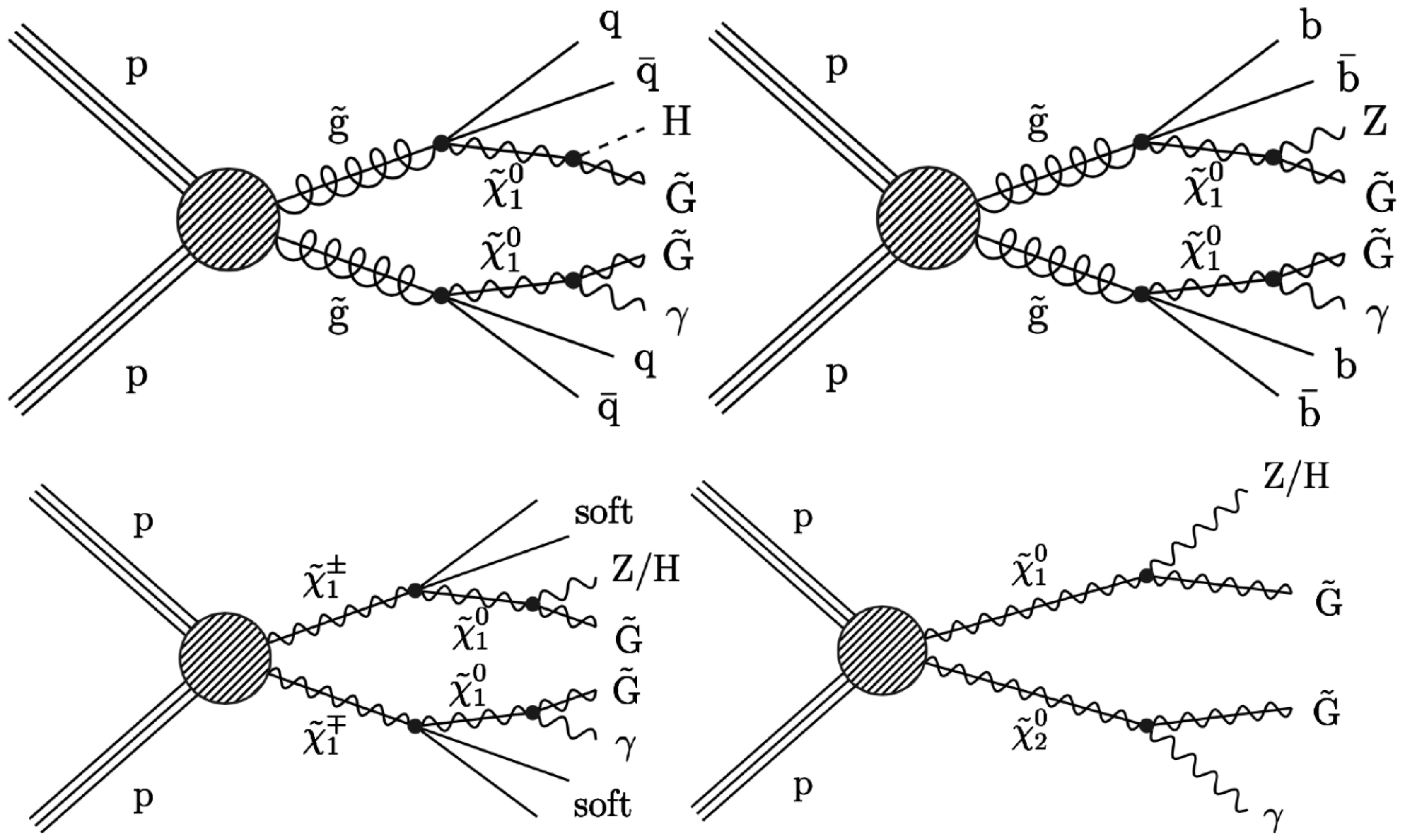




SUS-21-009

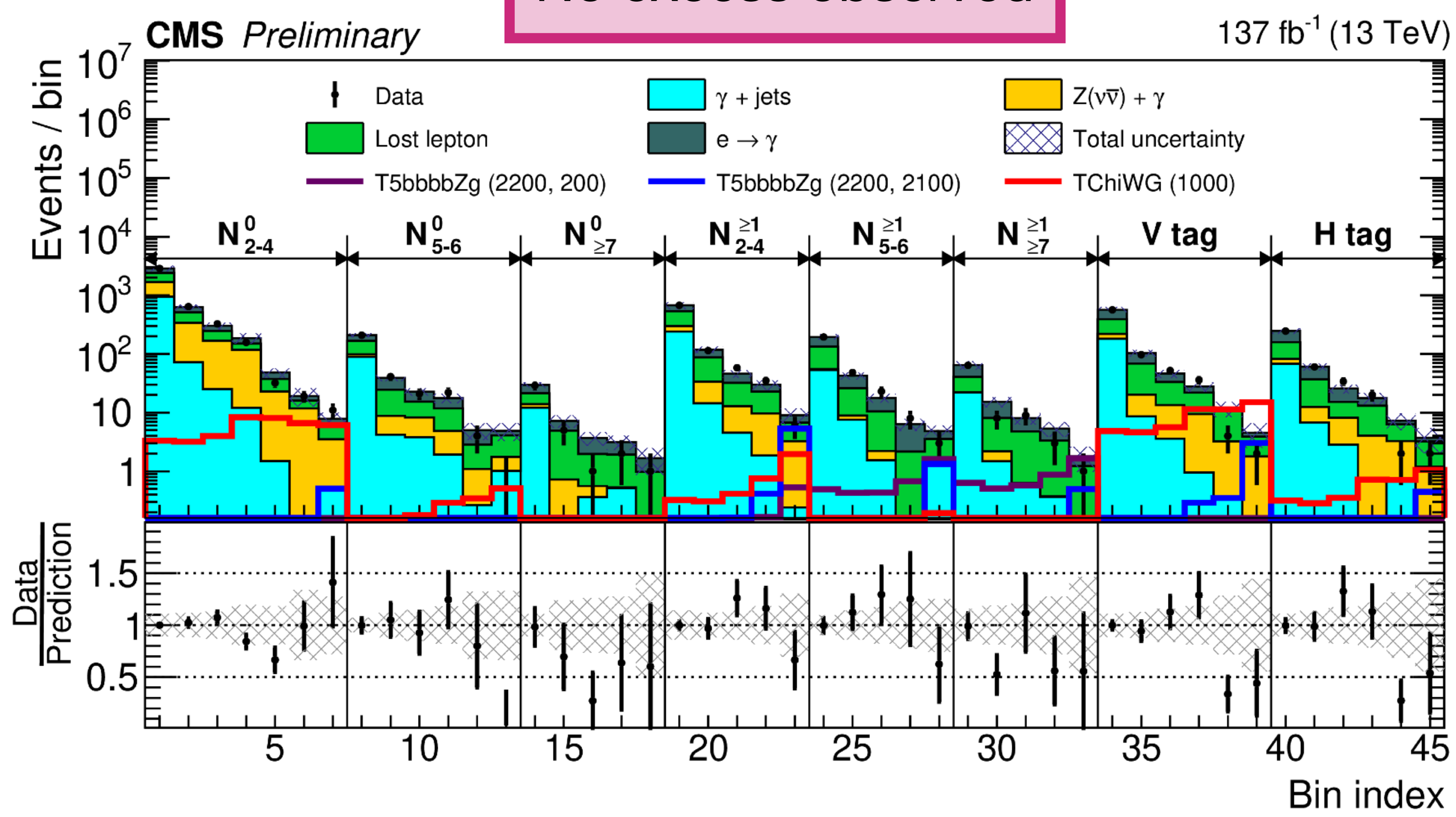
Search for SUSY with 1 photon, jets, and p_T^{miss}

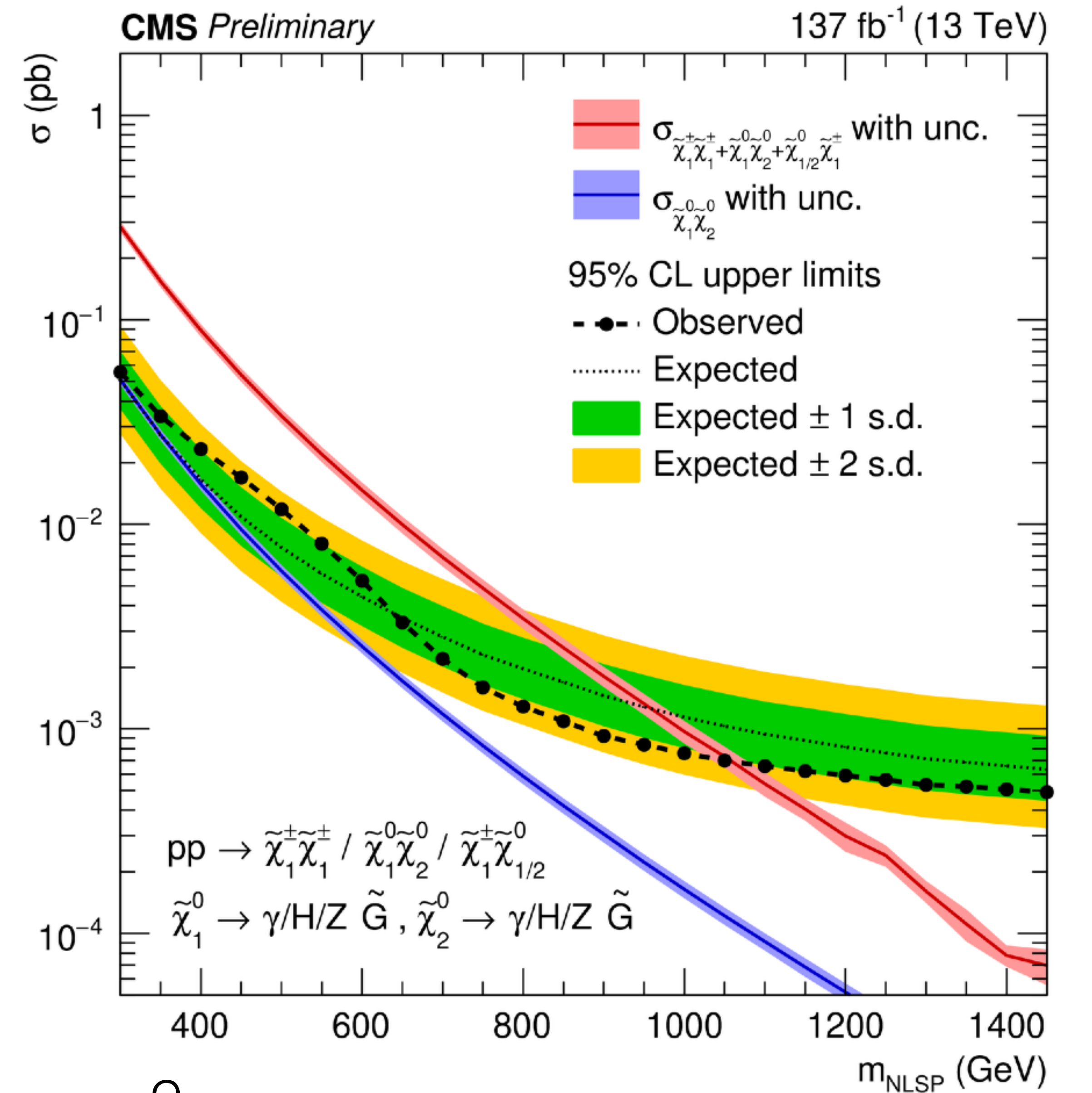
- Electroweak and strong production of neutralinos and charginos with fully hadronic final states and at least one photon from $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$ decays (GMSB)
- Select ≥ 1 photon, ≥ 2 jets, 0 leptons, and p_T^{miss} > 300 GeV
  Require S_T > 300 GeV (scalar p_T sum of ɣ + jets)
- 2 categories with/without tagged W/Z/H boson, binned in p_T^{miss} and N_{jets}
- Main backgrounds: ɣ+jets and Wɣ+jets, ttɣ+jets... (“lost leptons”)
  Data-driven estimations; ABCD-method or transfer factors

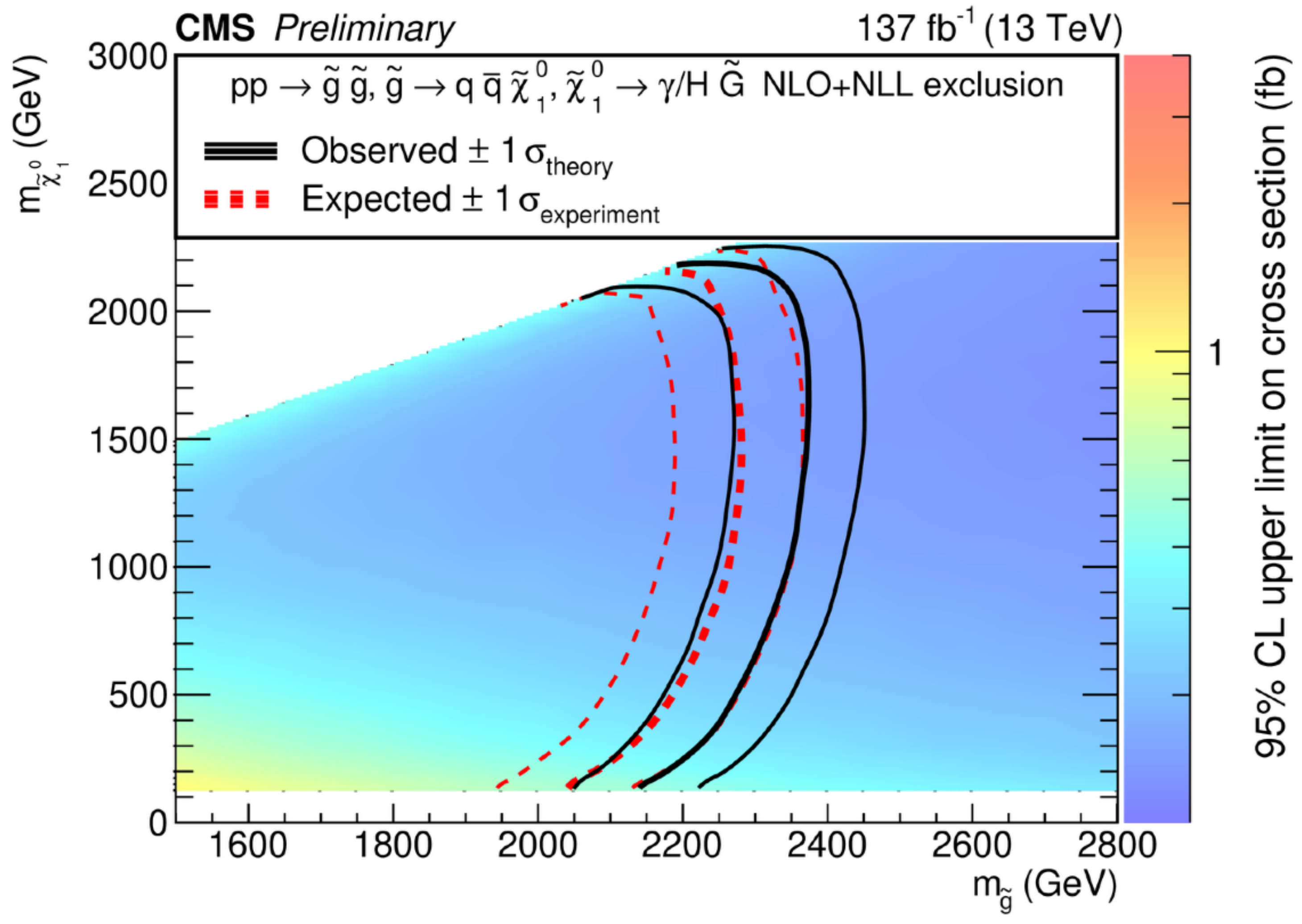


+ other models!

No excess observed







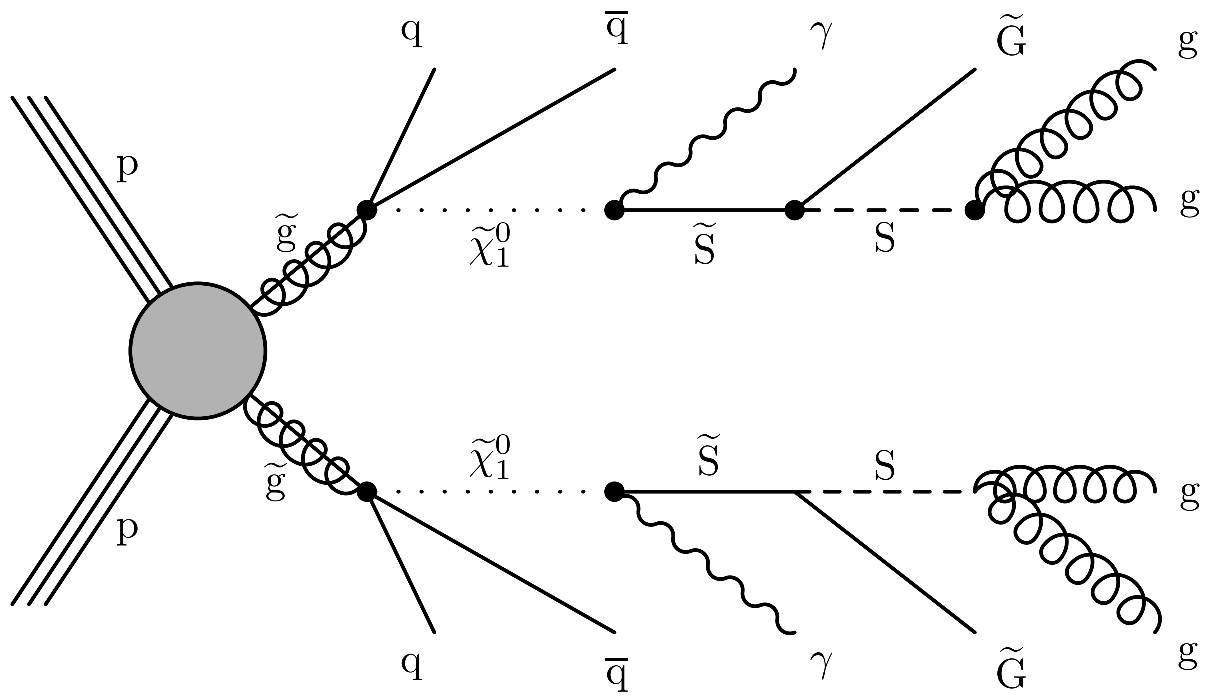
SUS-19-001

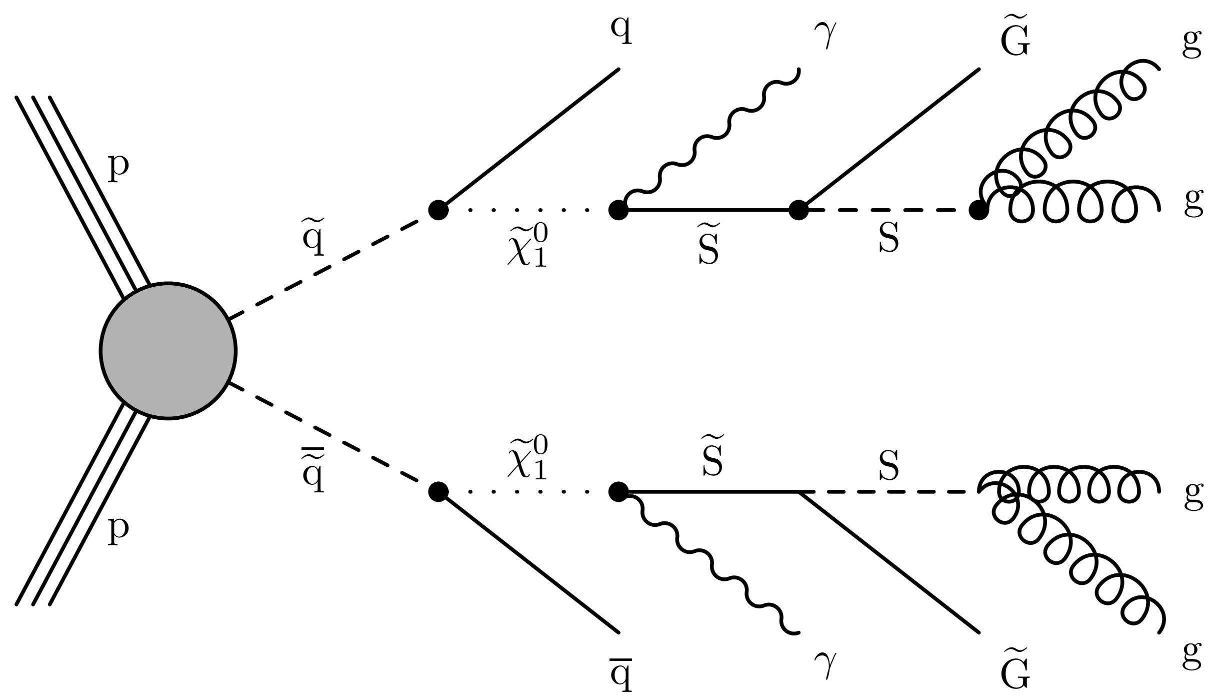
Search for Stealth SUSY with 2 photons and jets

Stealth SUSY: MSSM + light hidden sector containing singlino $\tilde{S}$ and singlet S, with gravitino LSP

→ naturally produces low p_T^{miss} signatures

Search looks for gluino and squark production with decays through the neutralino: $\tilde{\chi}_1^0 \to \gamma\tilde{S},\ \tilde{S} \to S\tilde{G},\ S \to gg$

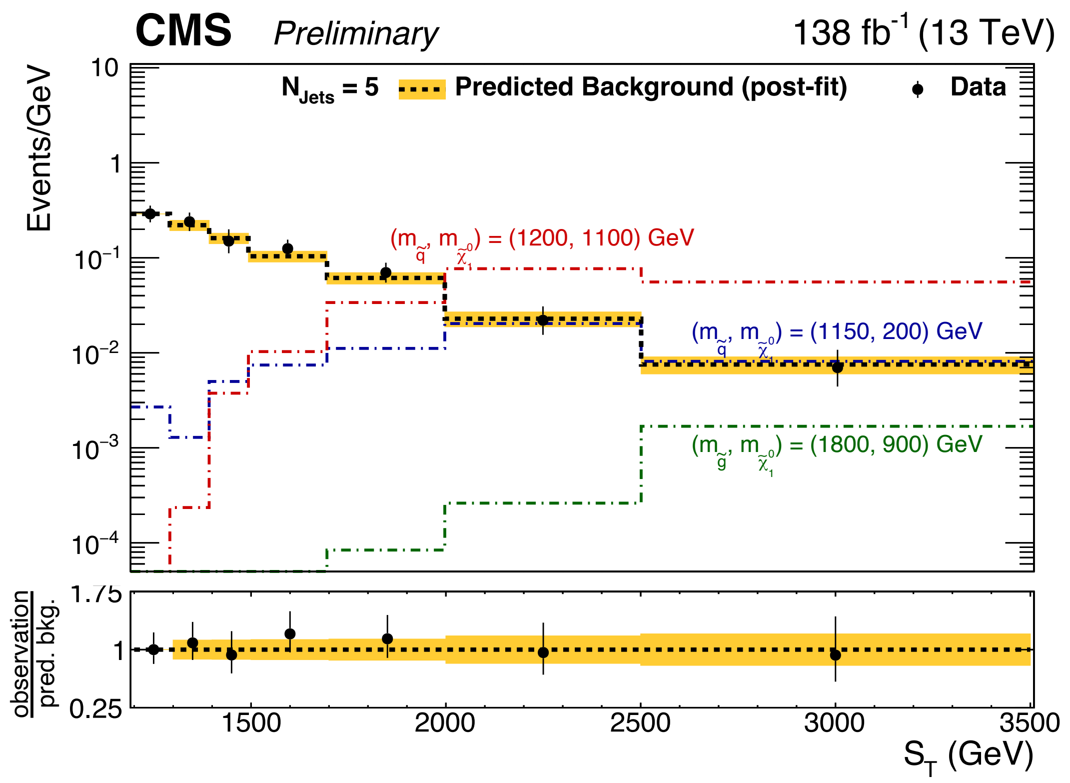


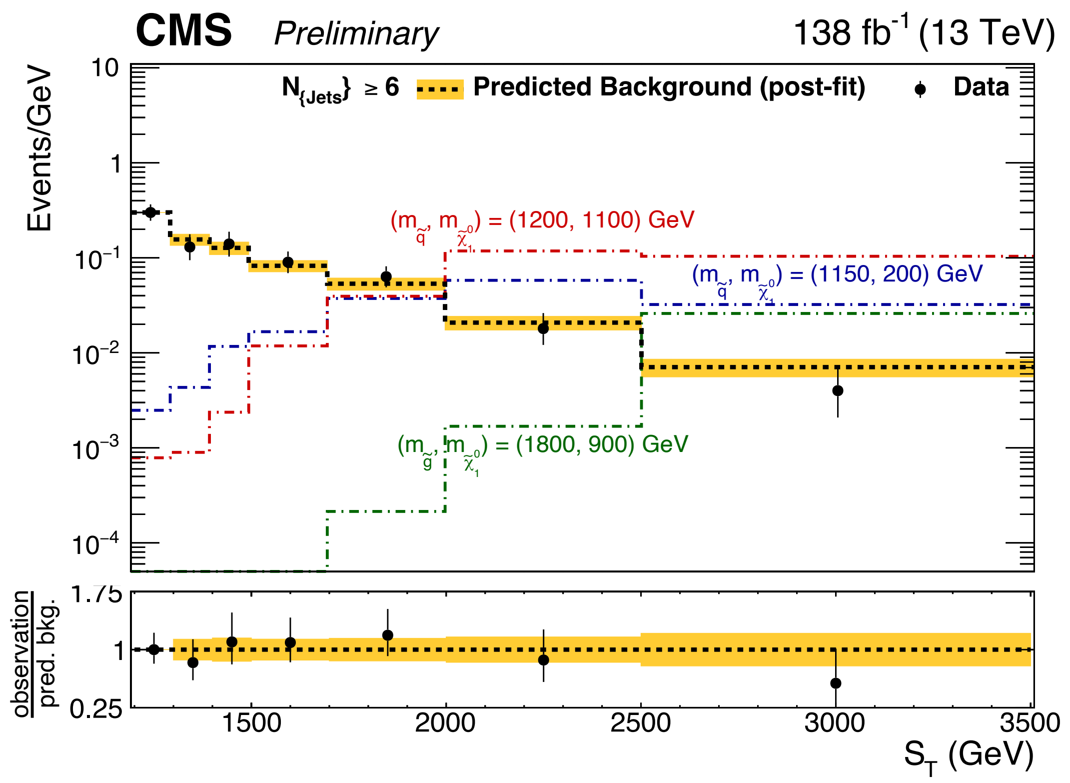


Selection:

- 2 photons and ≥ 2 jets
- No requirement on p_T^{miss}
- S_T > 1300 GeV (scalar p_T sum of all objects)

Signal extraction based on S_T and binned in jet multiplicity (4, 5, or ≥6 jets)

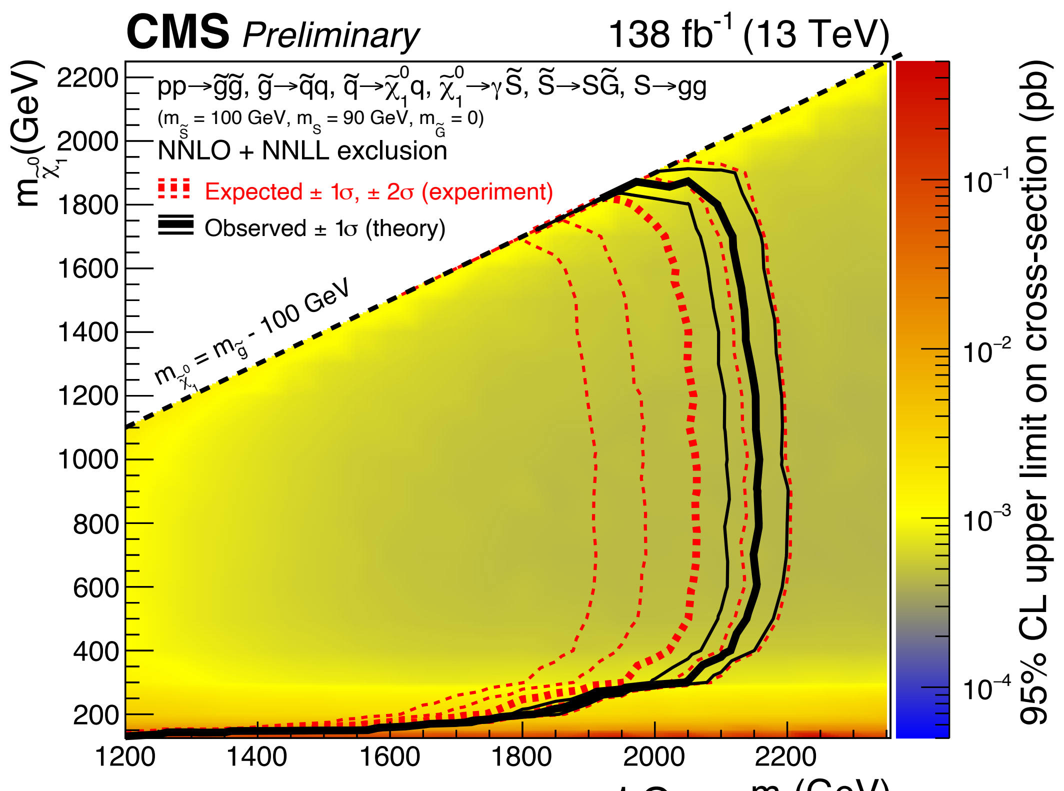




Main background: multijet events with 2 photons from the initial scattering

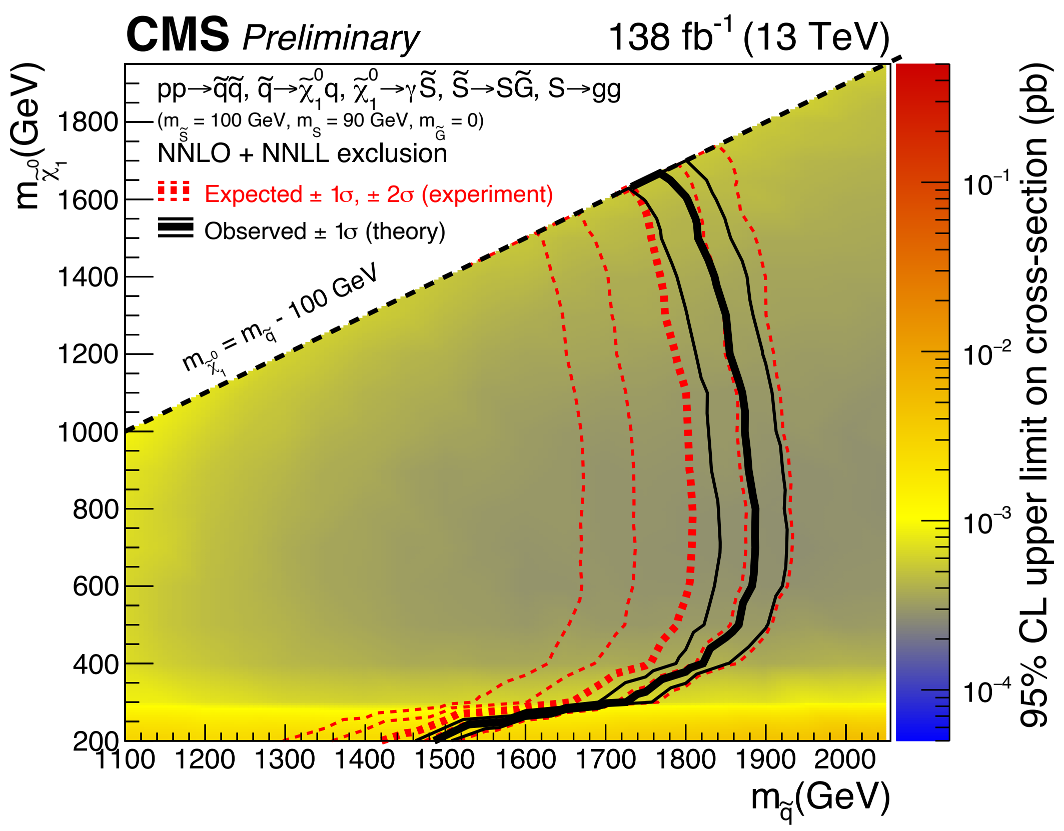
Data-driven background estimation using the S_T shape in events with low N_{jets}

- S_T shape is ~invariant at high S_T
- S_T shape modeled using Adaptive Gaussian Kernel estimation



Exclude gluinos & squarks with masses up to 2.15 & 1.85 TeV

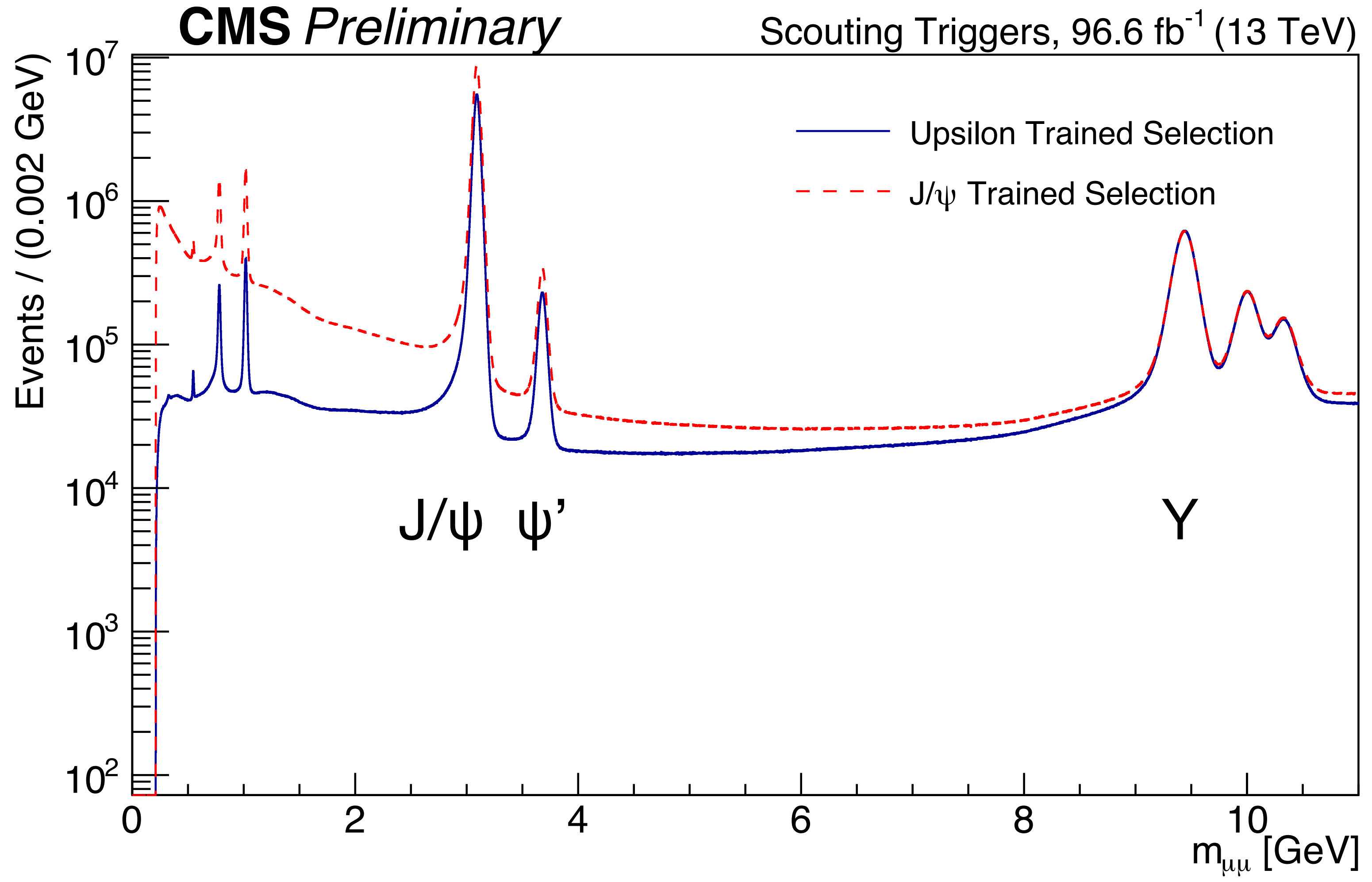
Strongest limits to date for these models!

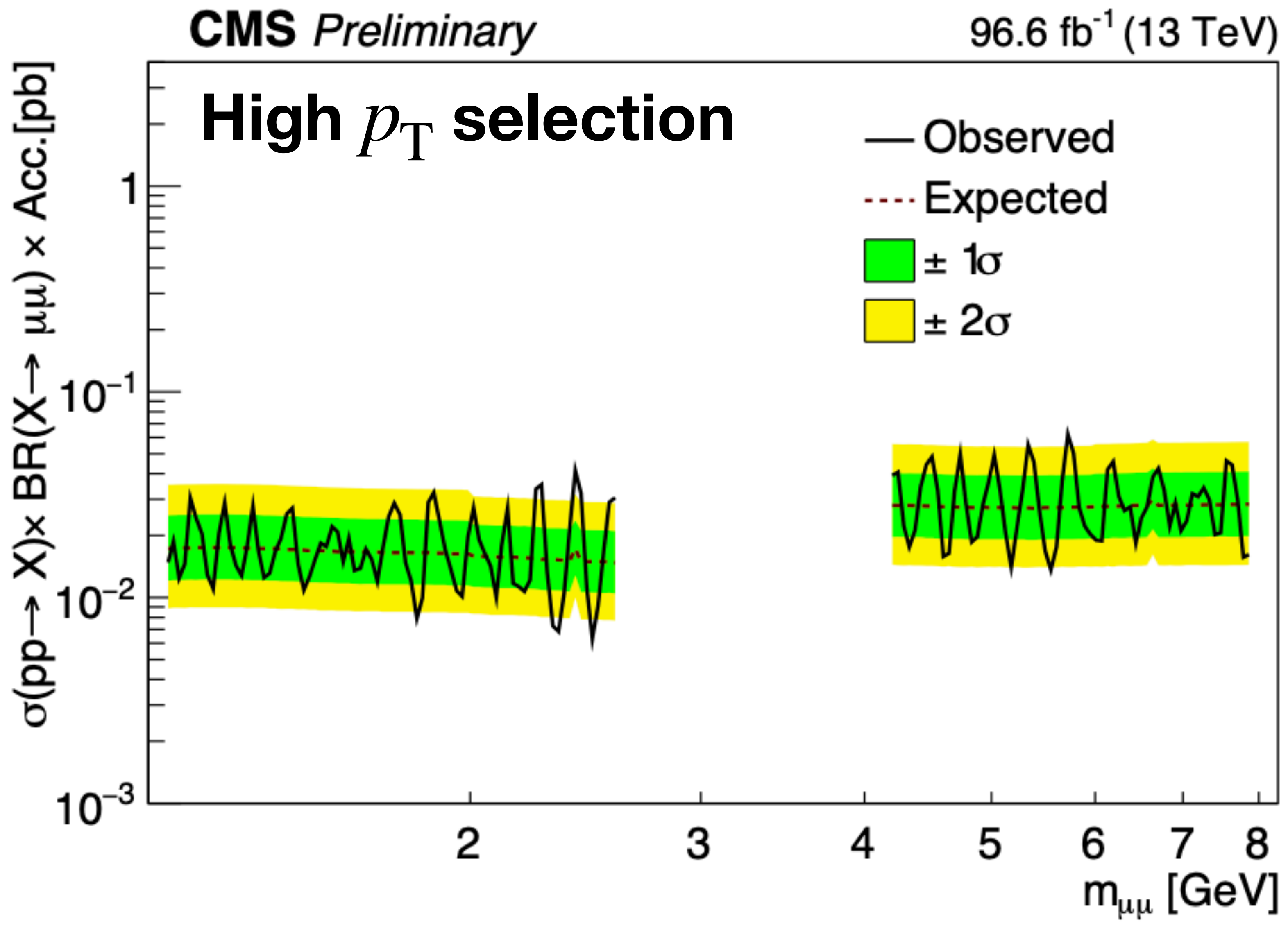


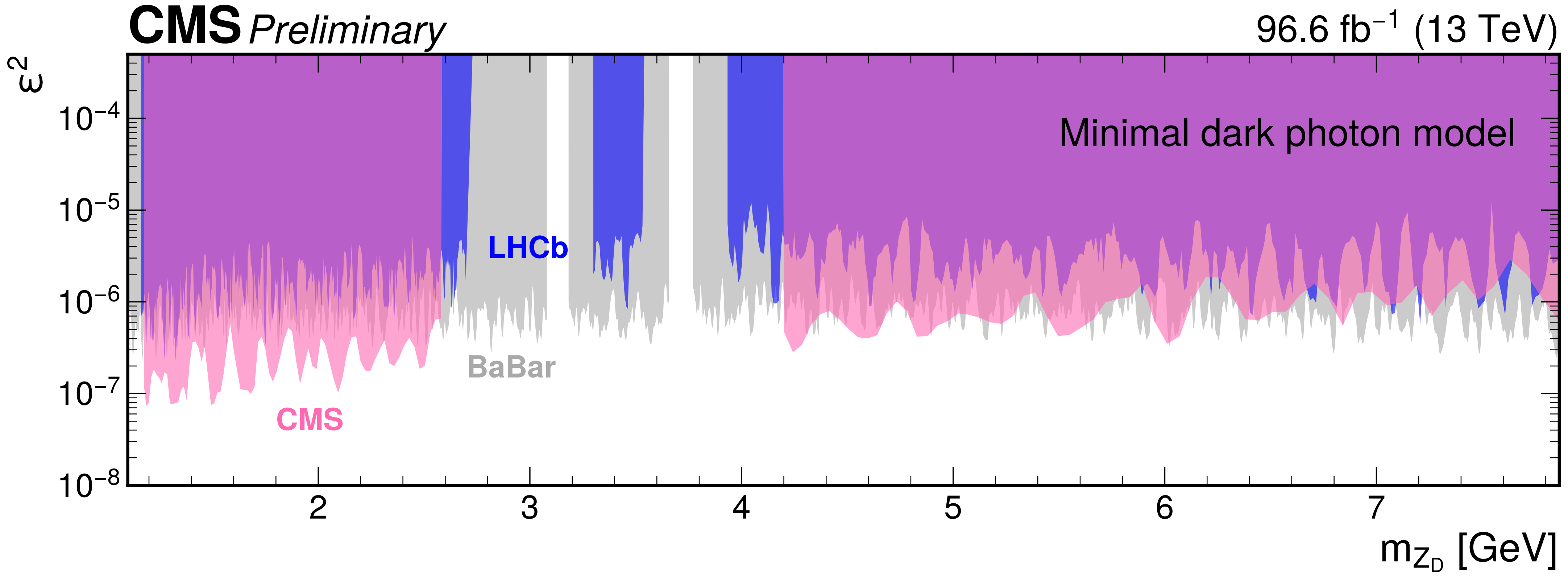
EXO-21-005

Low mass dimuons with scouting

- **Use data scouting to extend reach to lower mass dimuon resonances**
  - Mass range: 1.1-2.6 GeV and 4.2-7.9 GeV, excluding region of J/ψ, ψ' and Υ(1S)
  - Motivated by e.g. dark photons Z_D with kinetic mixing ε or 2HDM with extra scalar
  - Analysis assumes narrow resonance coming from the primary vertex
- Scouting trigger
  - Dedicated trigger stream storing **reduced event information** (4–8 kB/event instead of 1MB) **at higher rate** (2kHz instead of 0.45kHz for standard dimuon triggers)
  - Trigger selection: 2 muons with pT > 3 GeV; efficieny highest at low DR
- Offline analysis:
  - 2 muons with p_T > 4 GeV, |η|<1.9
  - Optimized muon identification for low masses using two BDTs
  - Fit to dimuon invariant mass spectrum in discrete mass windows of 5x experimental resolution (1.5%)







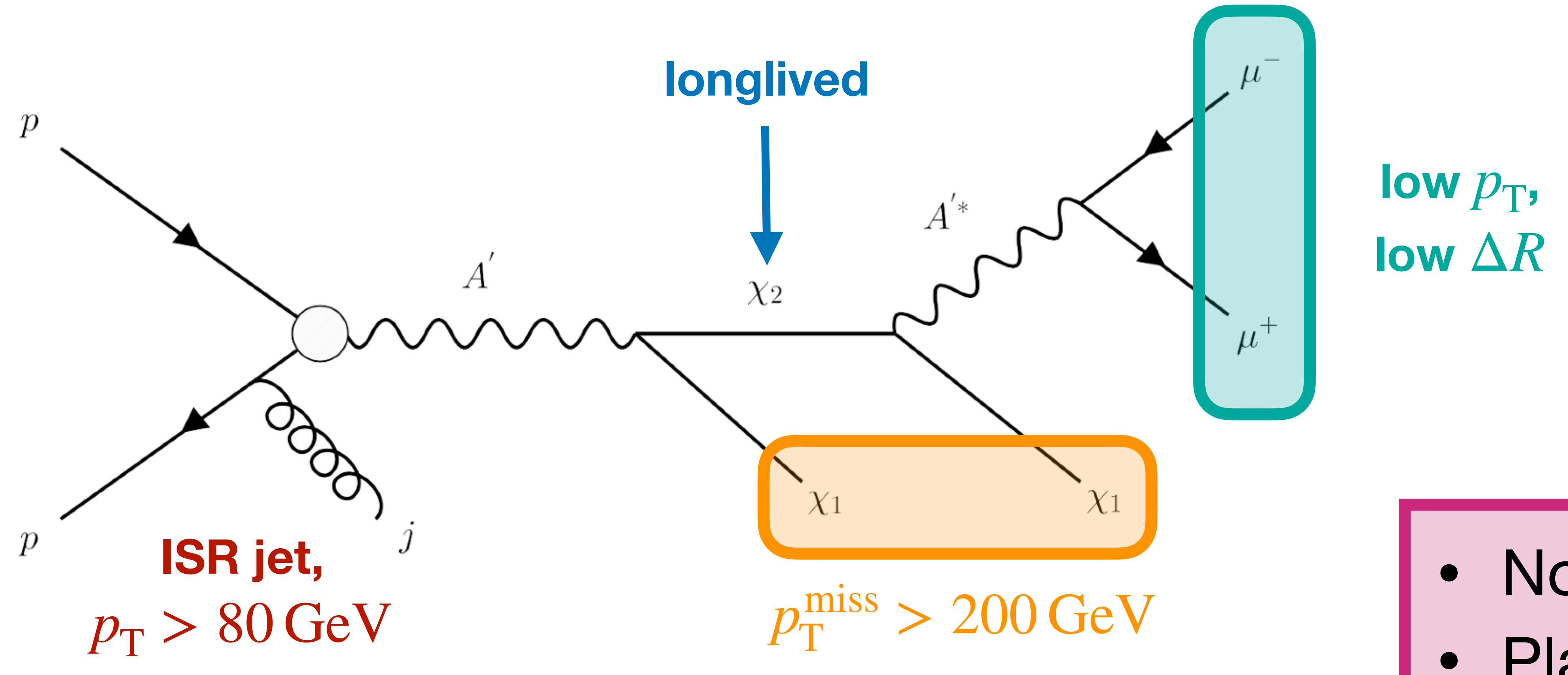
Largest excess at 2.41 GeV, local: 3.24σ, global: 1.27σ

side note: 3.1σ LHCb excess at 2.42 GeV

EXO-20-010

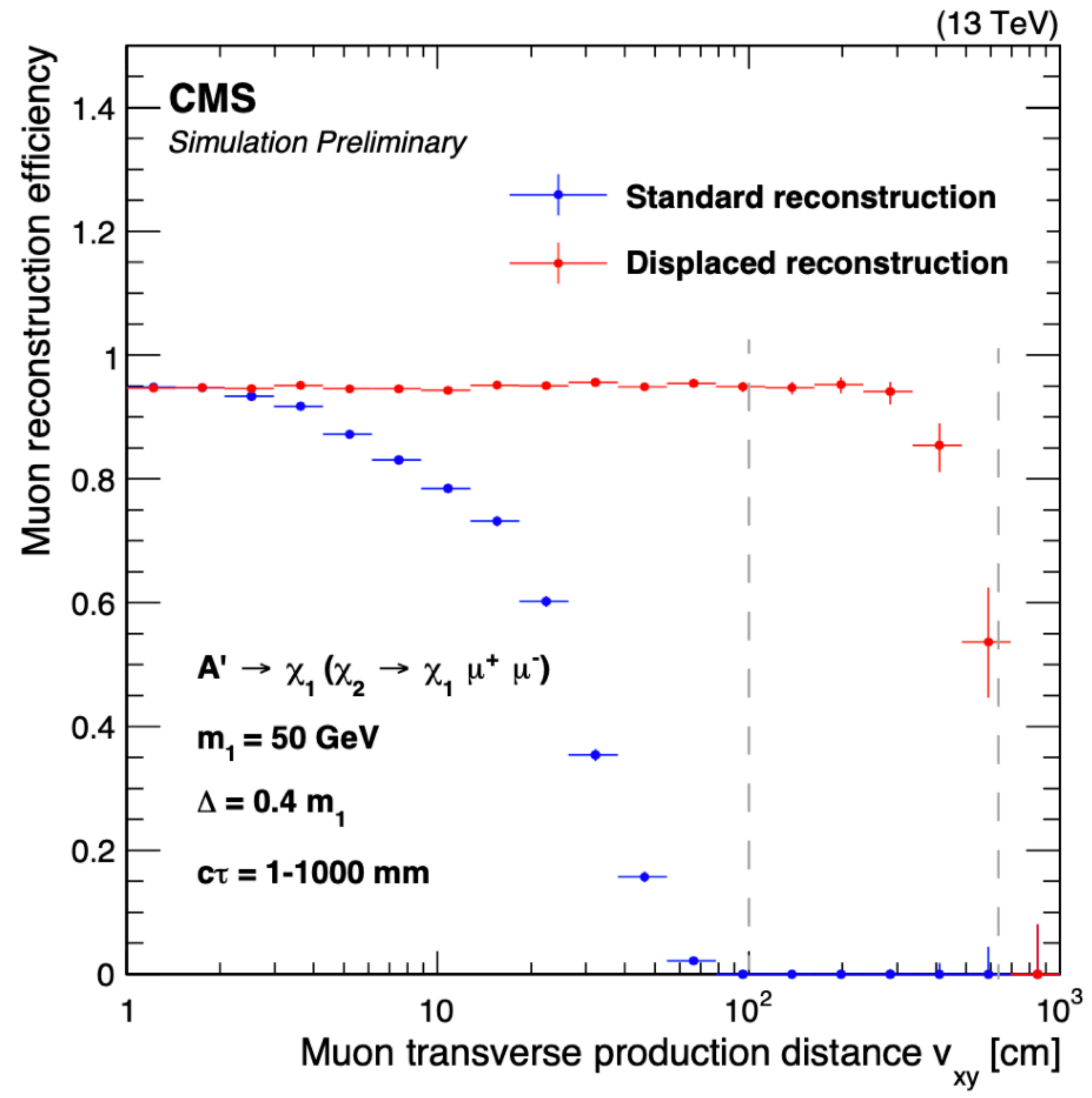
Search for inelastic dark matter

- **First search for inelastic DM at a hadron collider**
  - ≥2 DM states χ_1 & χ_2 + dark photon A' with kinetic mixing with SM hypercharge (ε)
  - Search targeting small $\Delta = m_{\chi_2} - m_{\chi_1} \in [0.1 - 0.4]m_{\chi_1}$
  - Large production cross section, small selection efficiency
- **Signature: $p_{\mathrm{T}}^{\mathrm{miss}}$ collimated with 2 displaced muons**

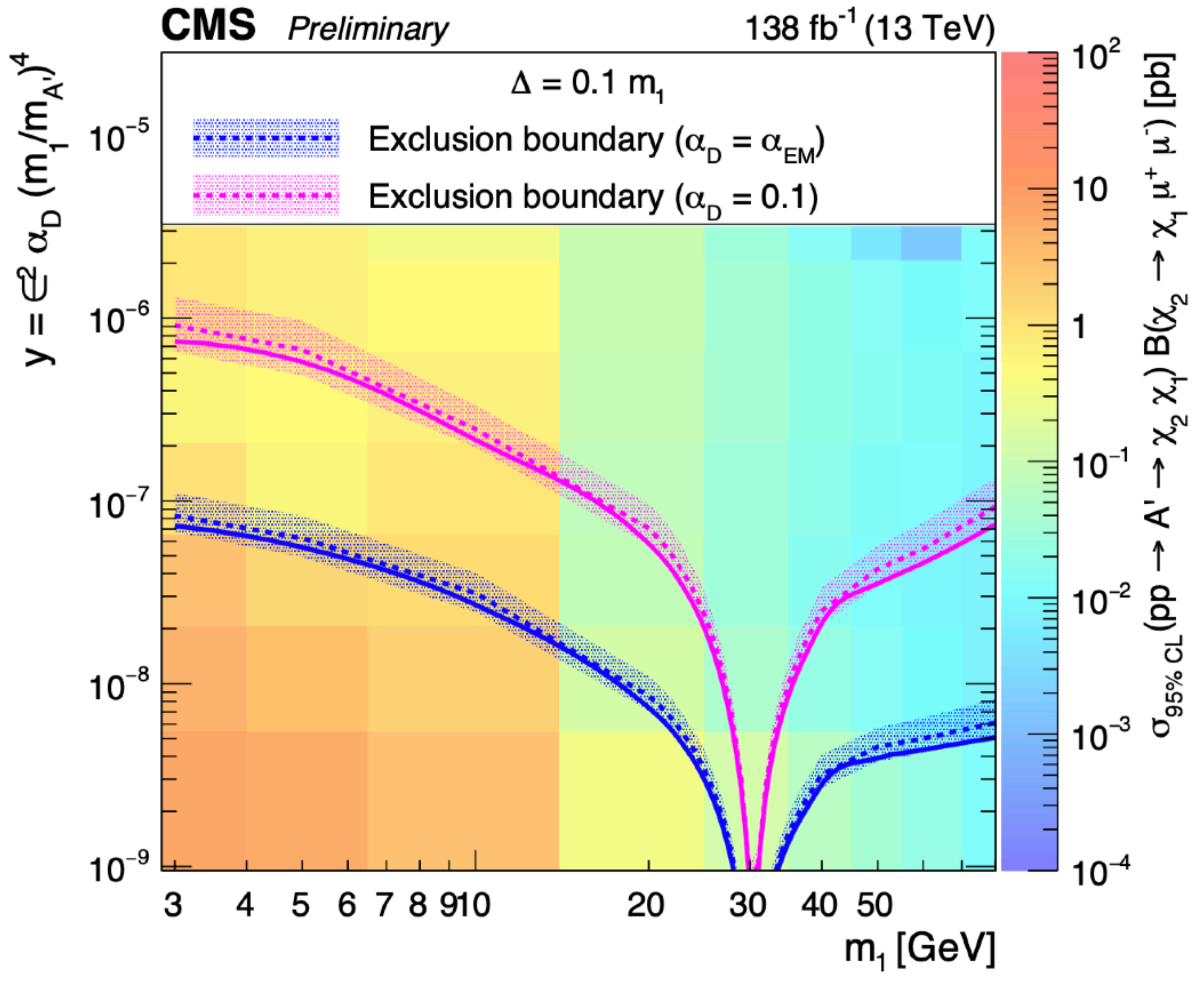


- Signal regions defined by number of displaced muons matched with standard muons
- Backgrounds predicted via ABCD method using min-d_{xy} vs. relative isolation or $\Delta\phi(\mu\mu, p_{\mathrm{T}}^{\mathrm{miss}})$

Dedicated displaced muon reconstruction
- Using only muon system
- Efficient up to large displacements (few meters)
- Require 2 displaced muons that form a good vertex



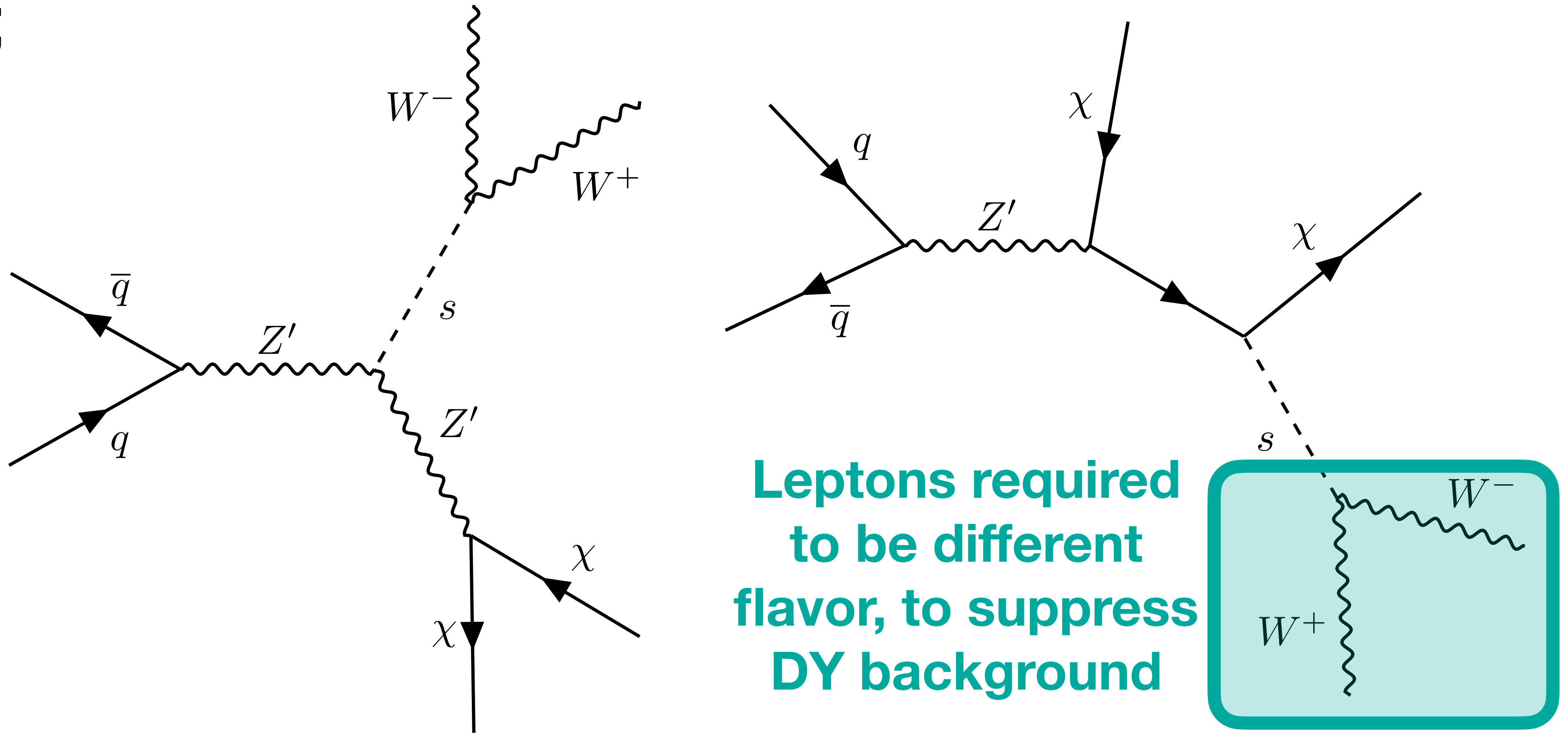
- No excess observed
- Place constraints on interaction strength vs DM mass
- Sensitivity enhanced at $m_{\chi_1} = 30$ GeV because of mixing between A' and Z ($m_{A'} = 3m_{\chi_1}$)



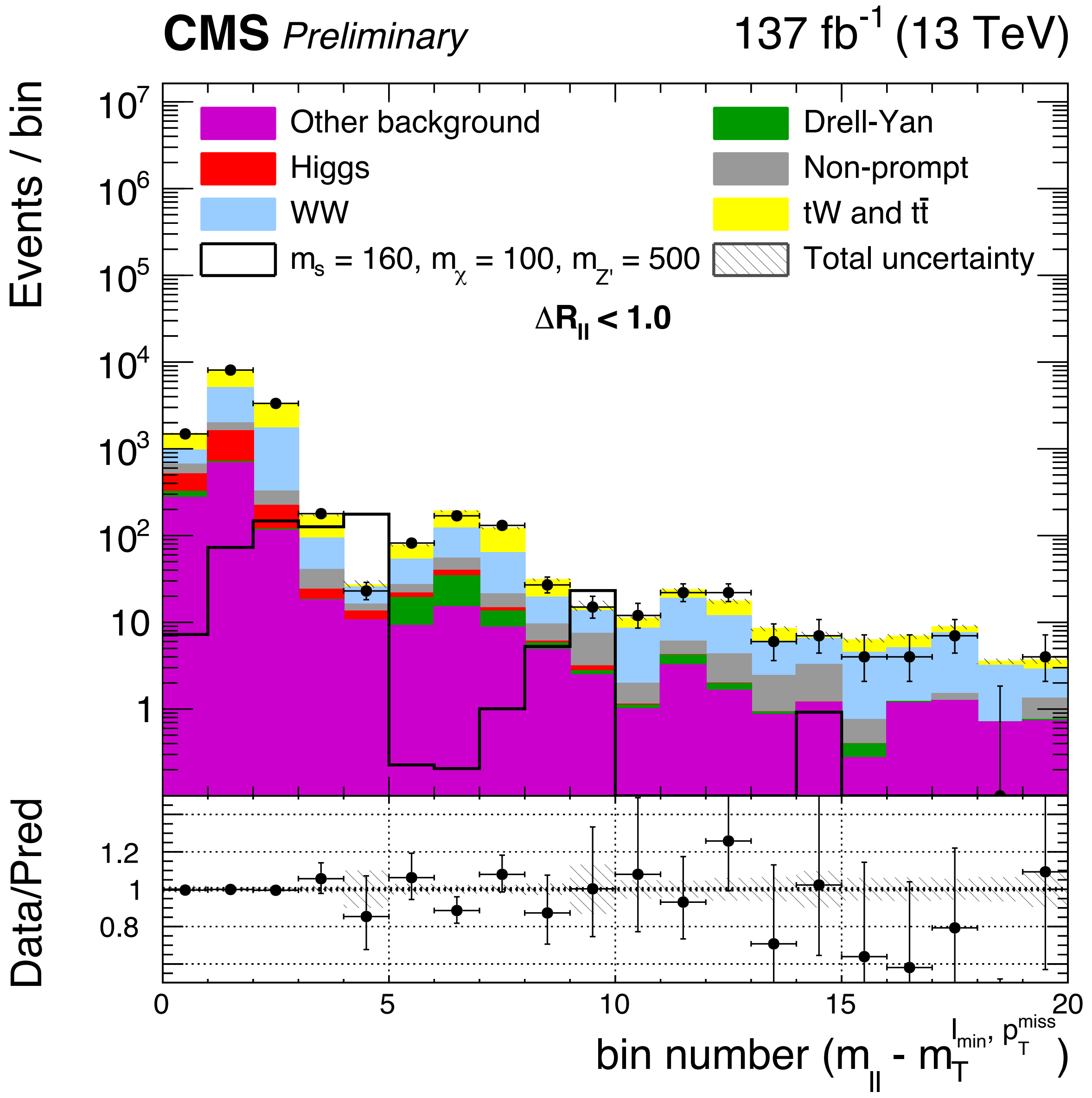
EXO-21-012

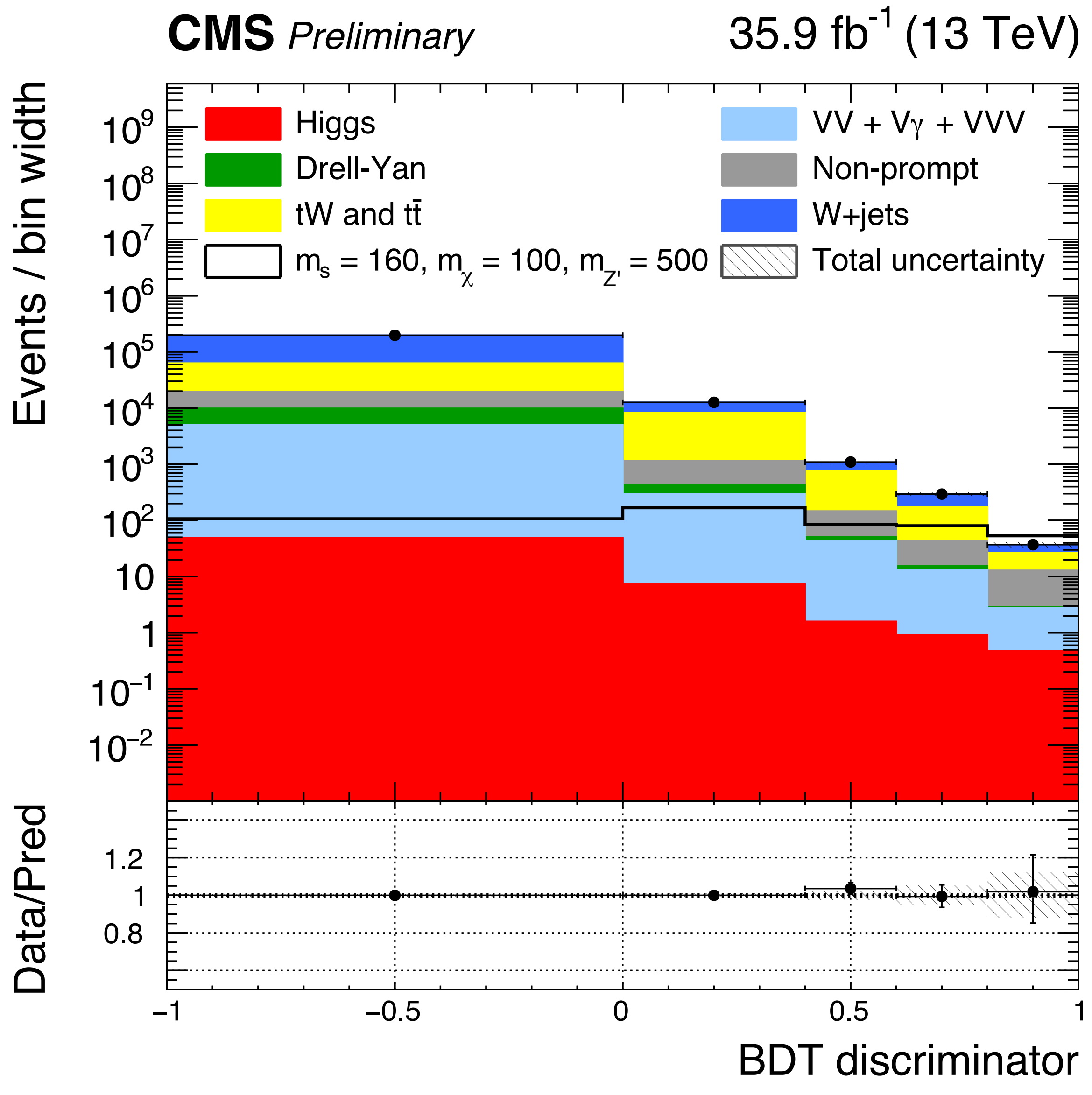
Search for dark matter in W+W- events with p_T^{miss}

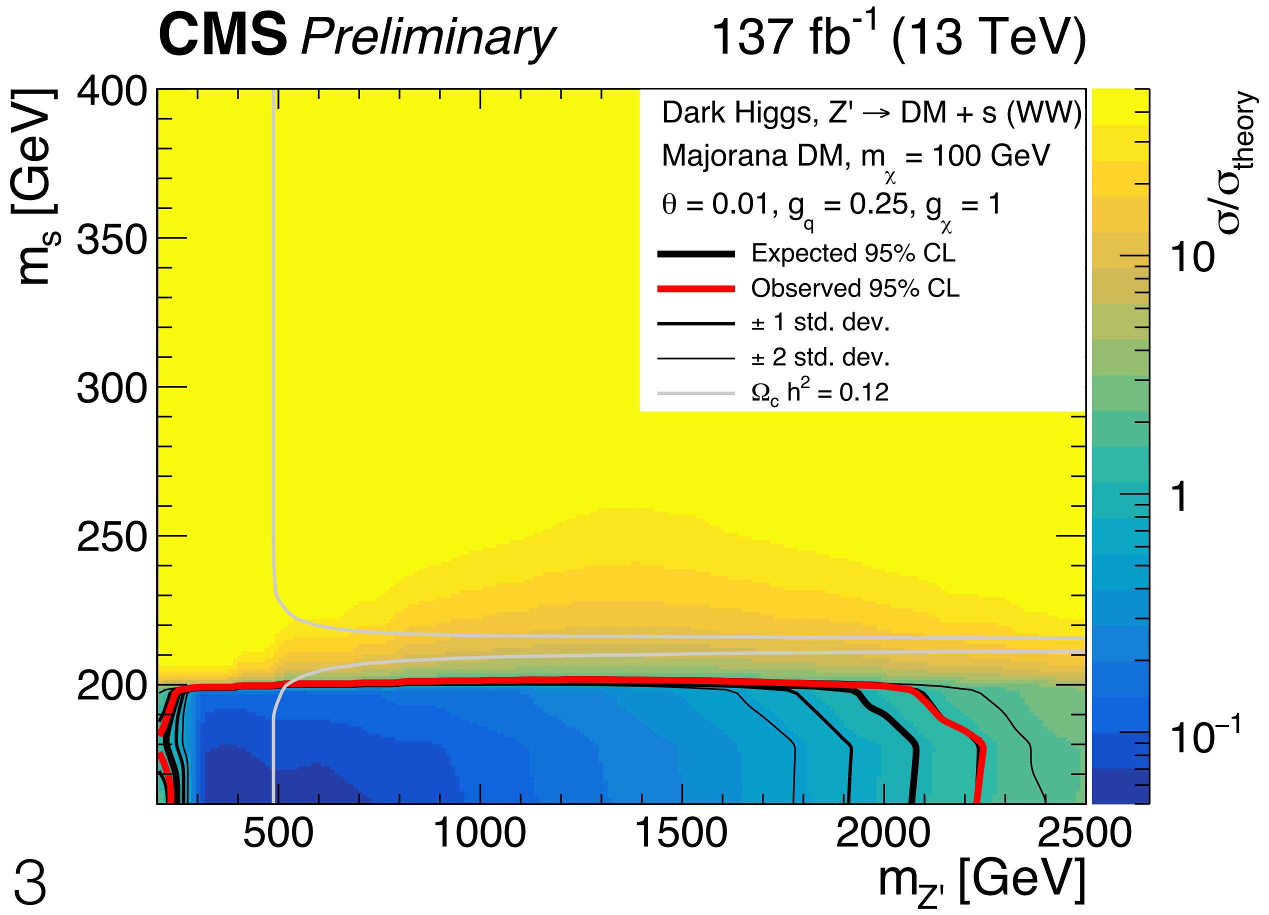
- Focuses on a Dark Higgs model including Dark Higgs s, Z', dark matter χ; assuming Z' production with decays to W^+W^- and two DM particles (dominant decay for $m_S > 160\,\mathrm{GeV}$)
- Selection: 1 or 2 leptons, no b-tagged jets
- 2-lepton final state: 2D profiled fit to $m_T(\ell_2, p_T^{miss})$ and $m_{\ell\ell}$
- 1-lepton final state: 1D binned fit to the shape of a BDT discriminant, trained for signal separation with kinematic variables related to the leptons and p_T^{miss}

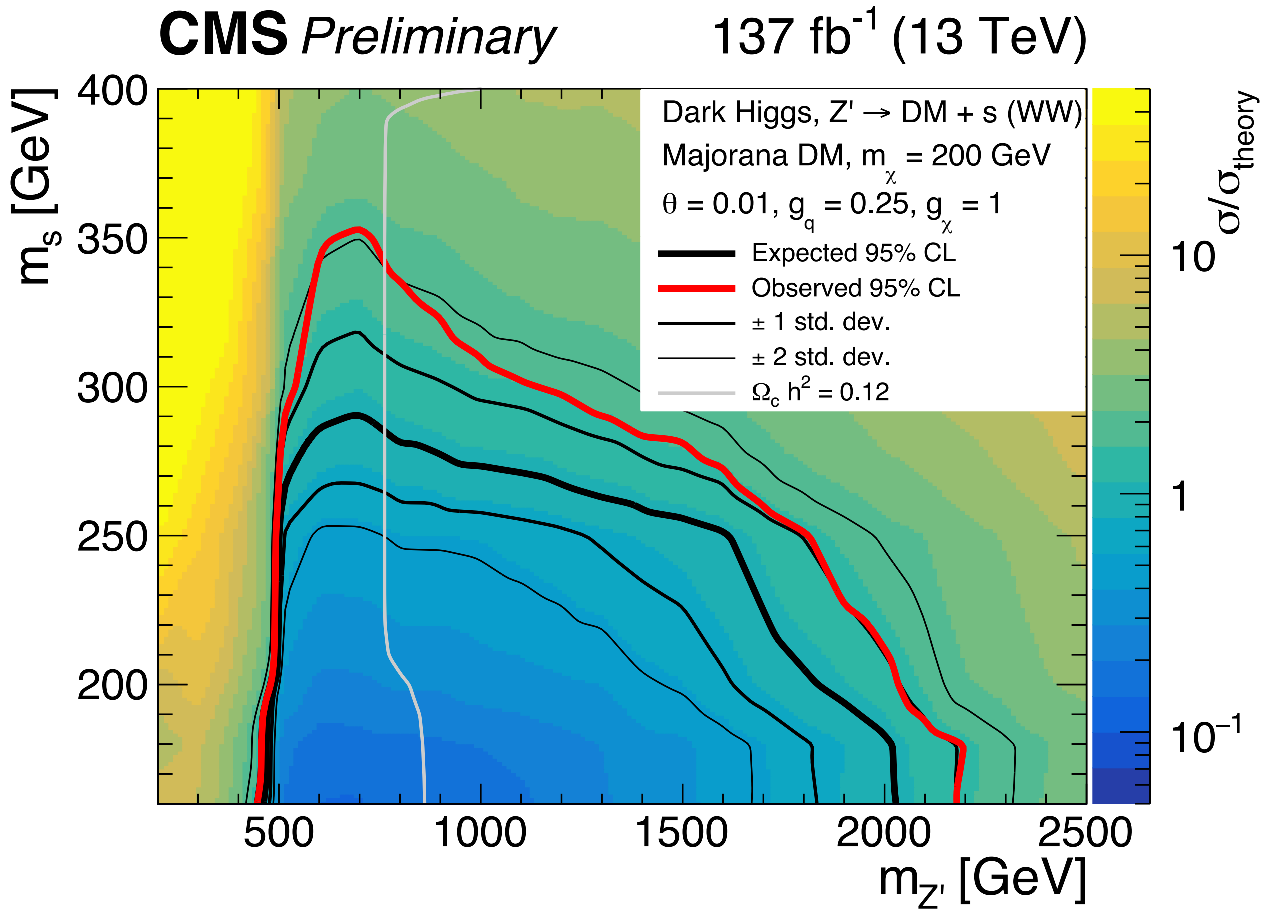


- No excess observed
- Strongest limit for $m_{DM} = 200\,\mathrm{GeV}$: exclude up to $m_S = 350(160)\,\mathrm{GeV}$ for $m_{Z'} = 700(2200)\,\mathrm{GeV}$





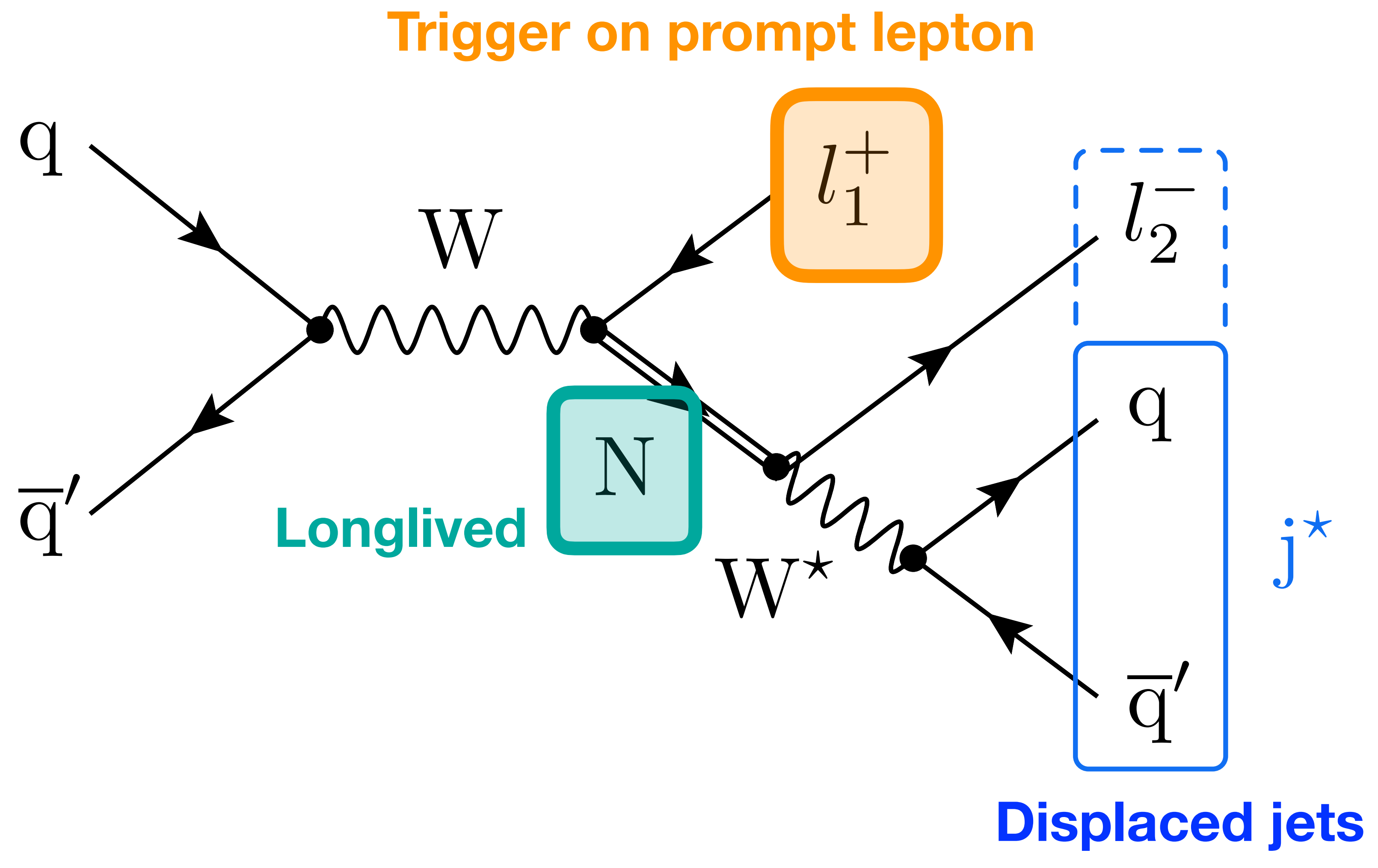


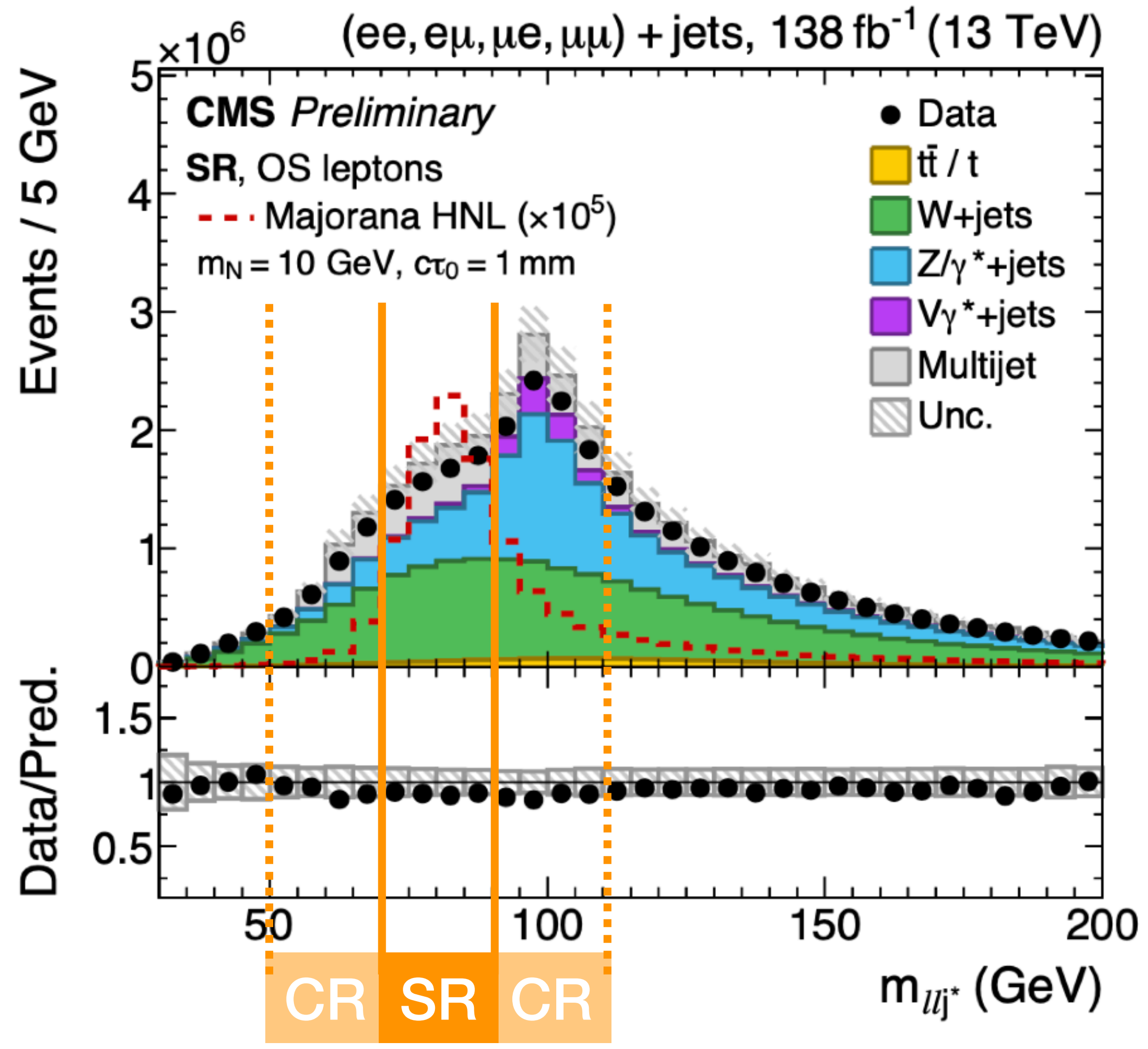


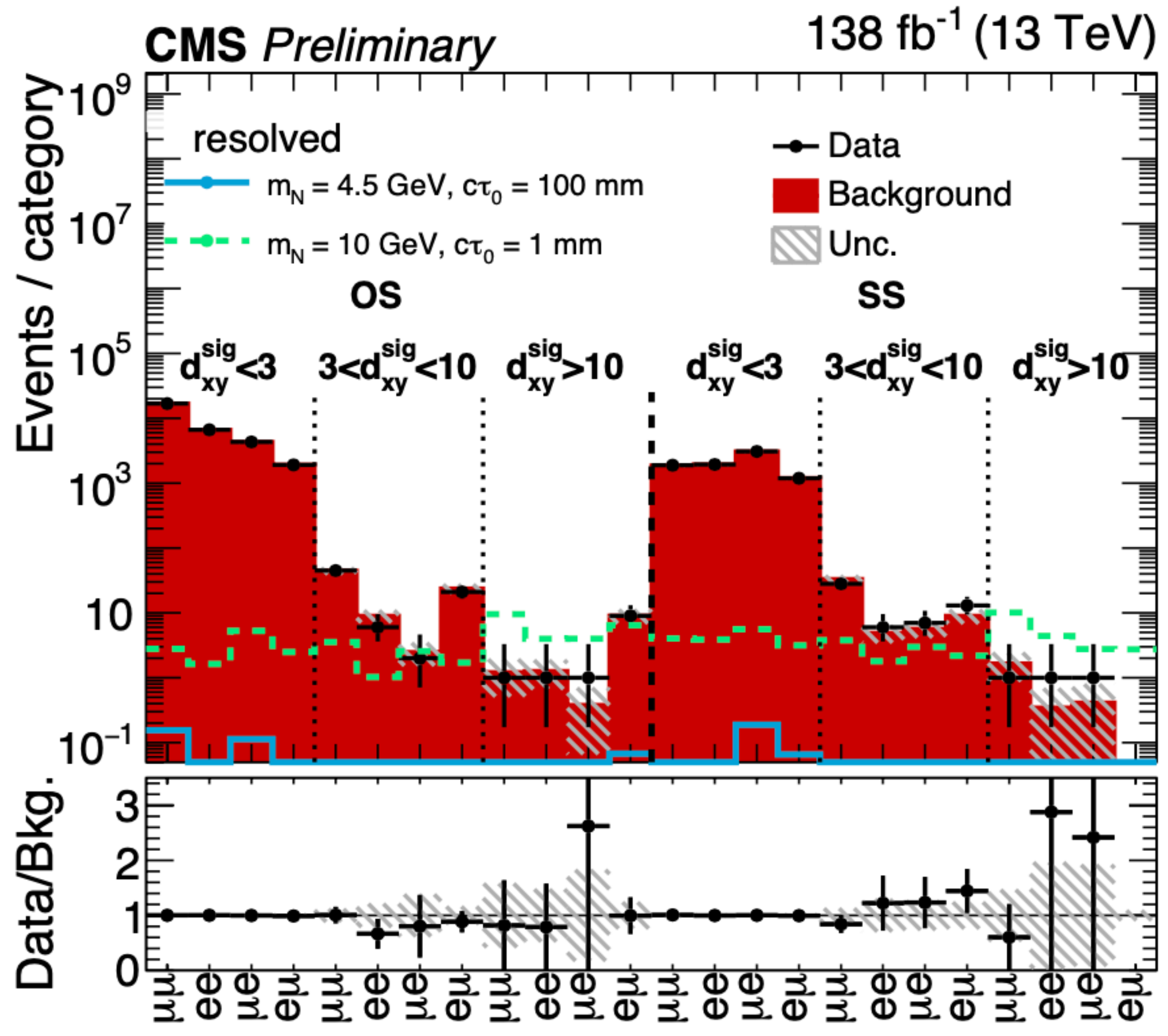
EXO-21-013

Search for long-lived heavy neutral leptons decaying to jet + e/μ/τ

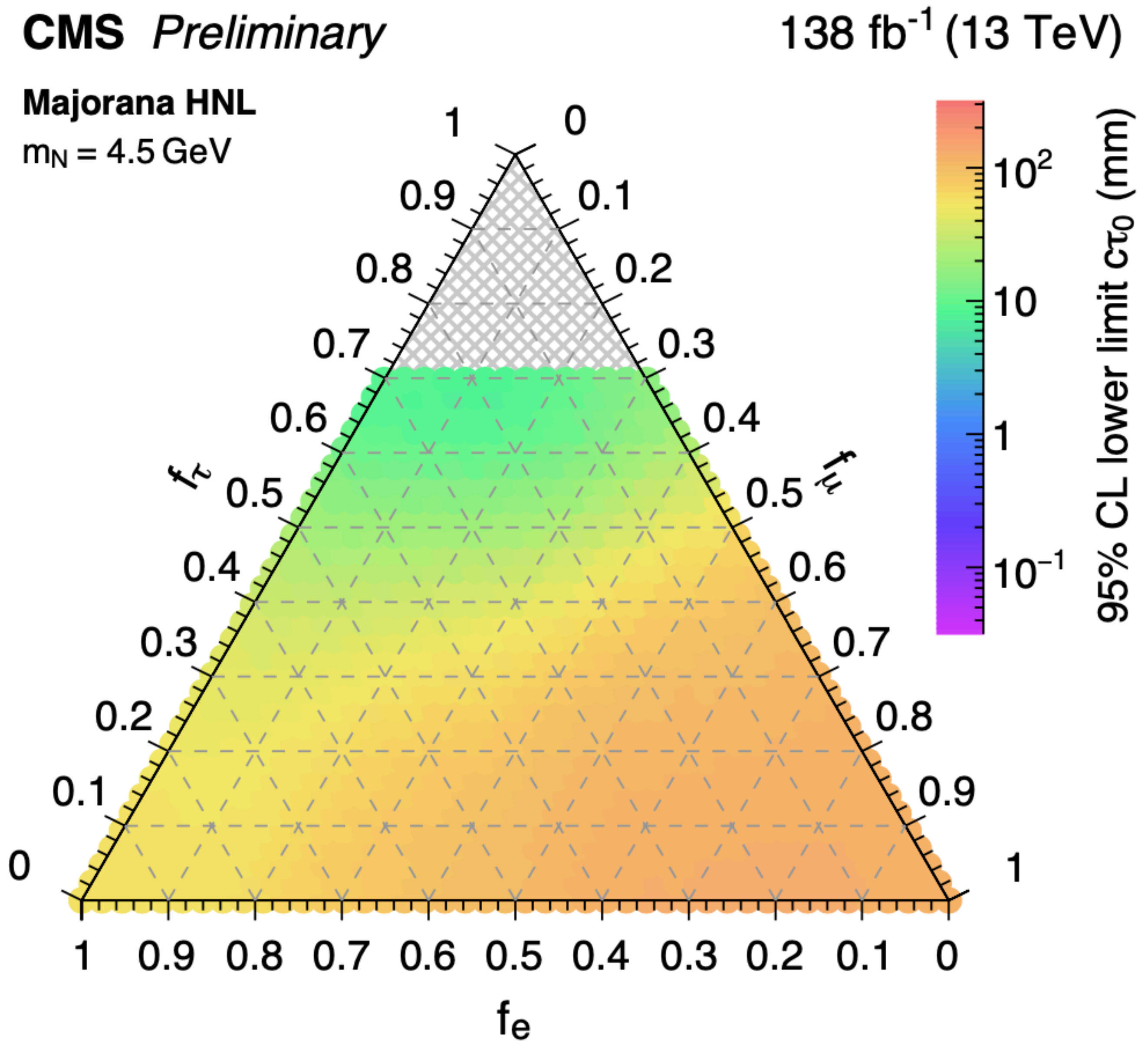
- HNL with small masses or couplings are longlived: Coupling not restricted to single generation $c\tau \propto \frac{1}{|V_{lN}|^2 (m_N)^5}$
- Search relies on **displaced jet tagger**
  - Deep neural network with convolution and dense layers, using domain adaptation to reduce effect from differences between data and simulation
  - Inputs are both jet-level quantities and jet constituent quantities
  - Multi-class output: jets from q/g, pileup, prompt lepton or photon, displaced jet with or without displaced lepton
- Search categories based on lepton flavor & charge, $\Delta R(l_2, \mathrm{jet})$, and displacement
- Backgrounds estimated via ABCD method in data using m_{llj^*} and NN score







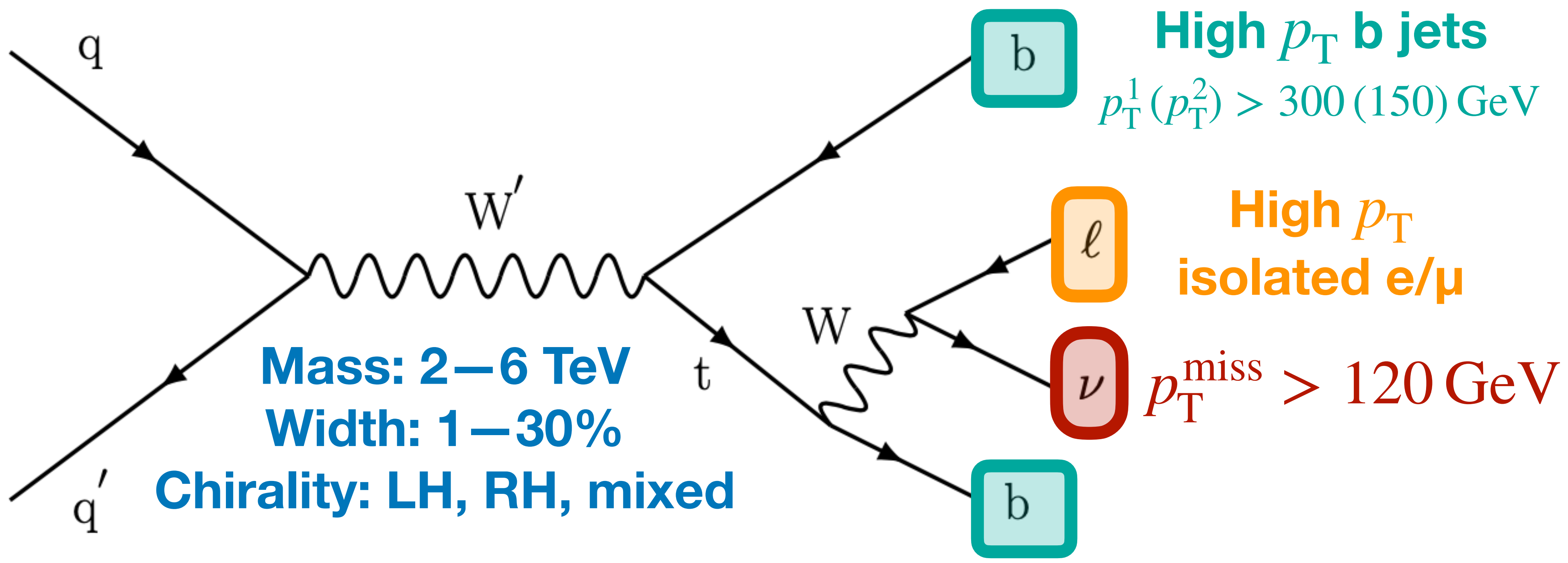
- No excess observed
- Best limit on the coupling strength for pure muon scenario, excluding values of $|V_{\mu N}|^2 > 5(4) \times 10^{-7}$ for Dirac (Majorana) HNLs with a mass of 10 GeV



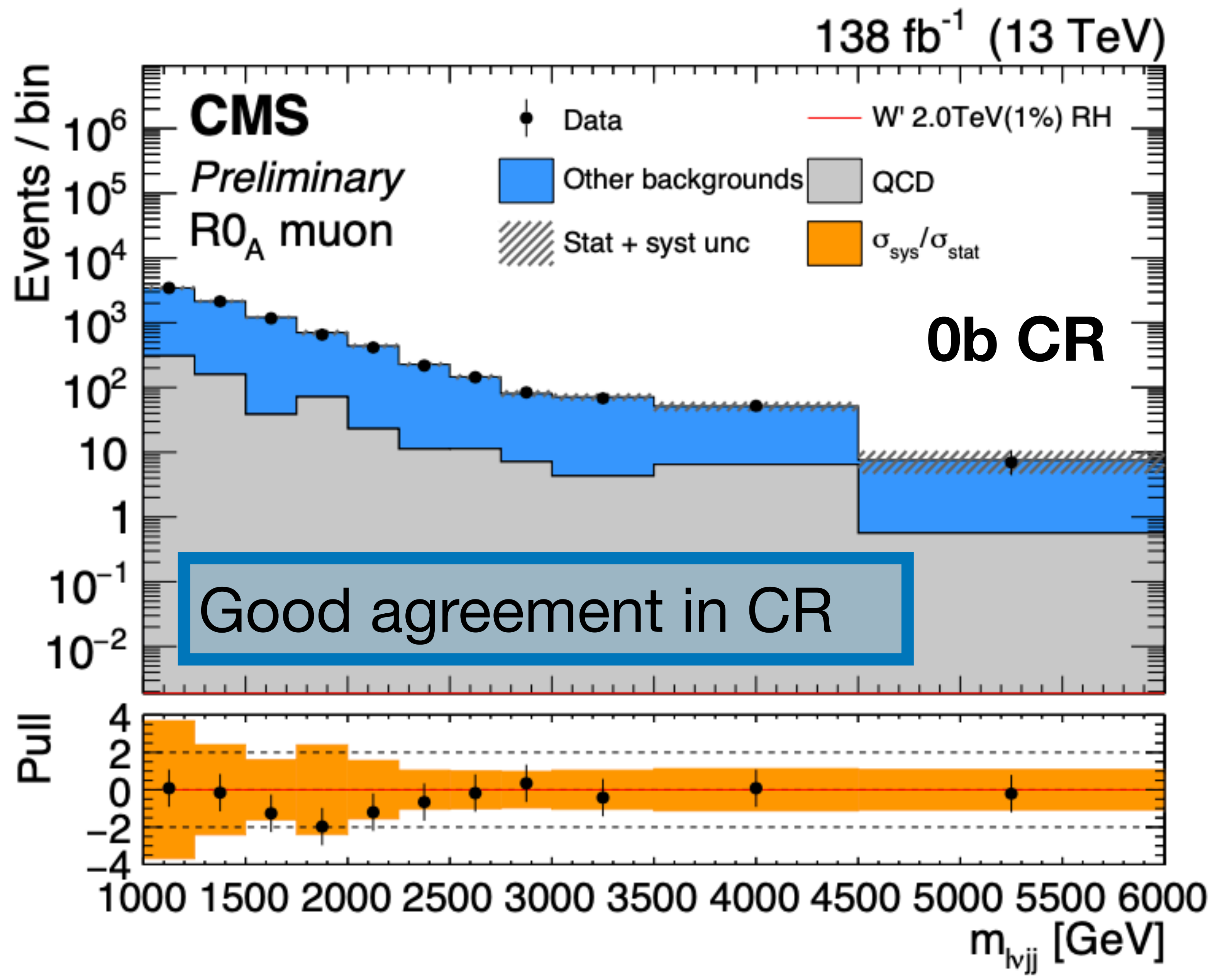
B2G-20-012

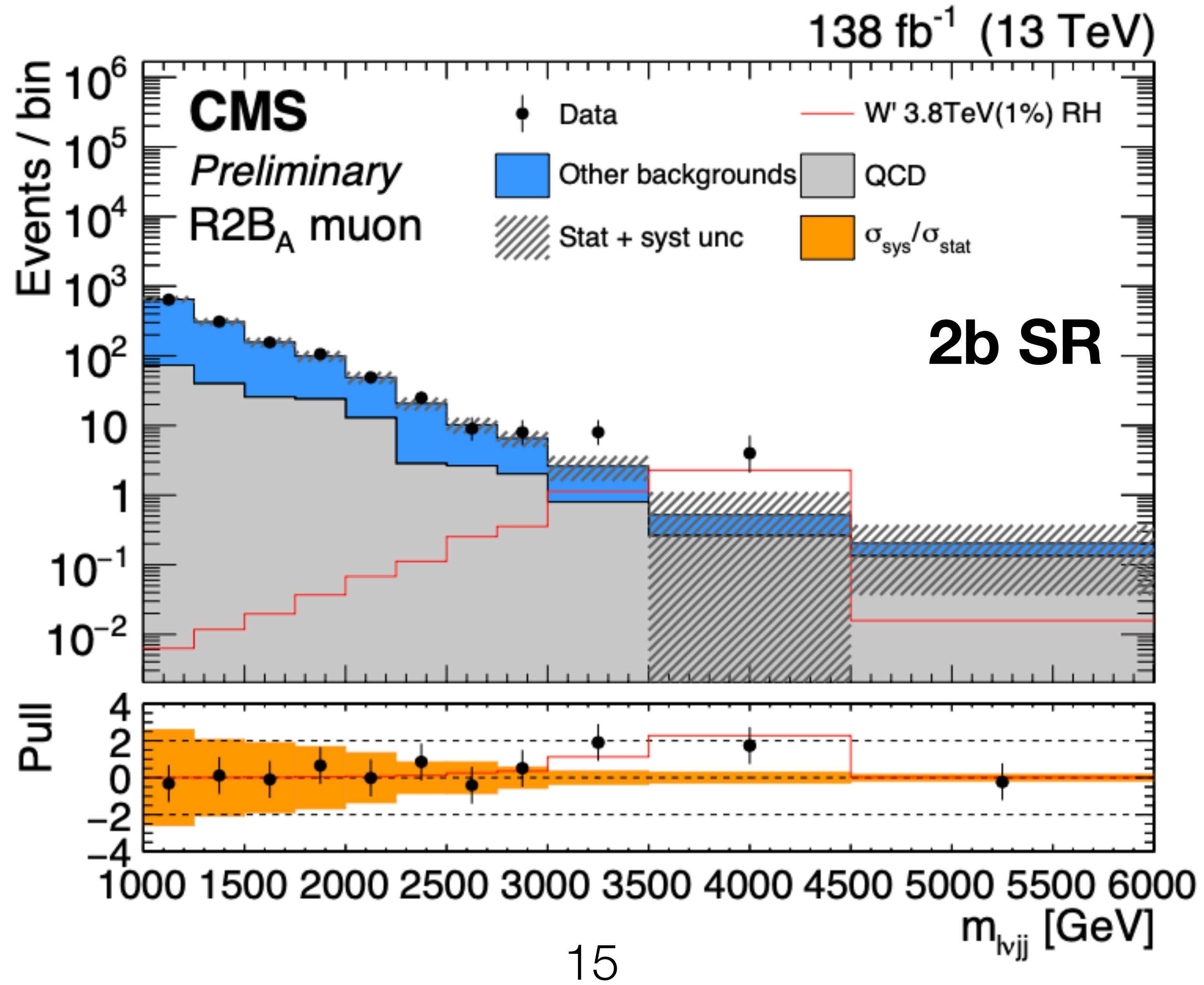
Search for $\mathrm{W}' \to \mathrm{tb}$ in leptonic final states

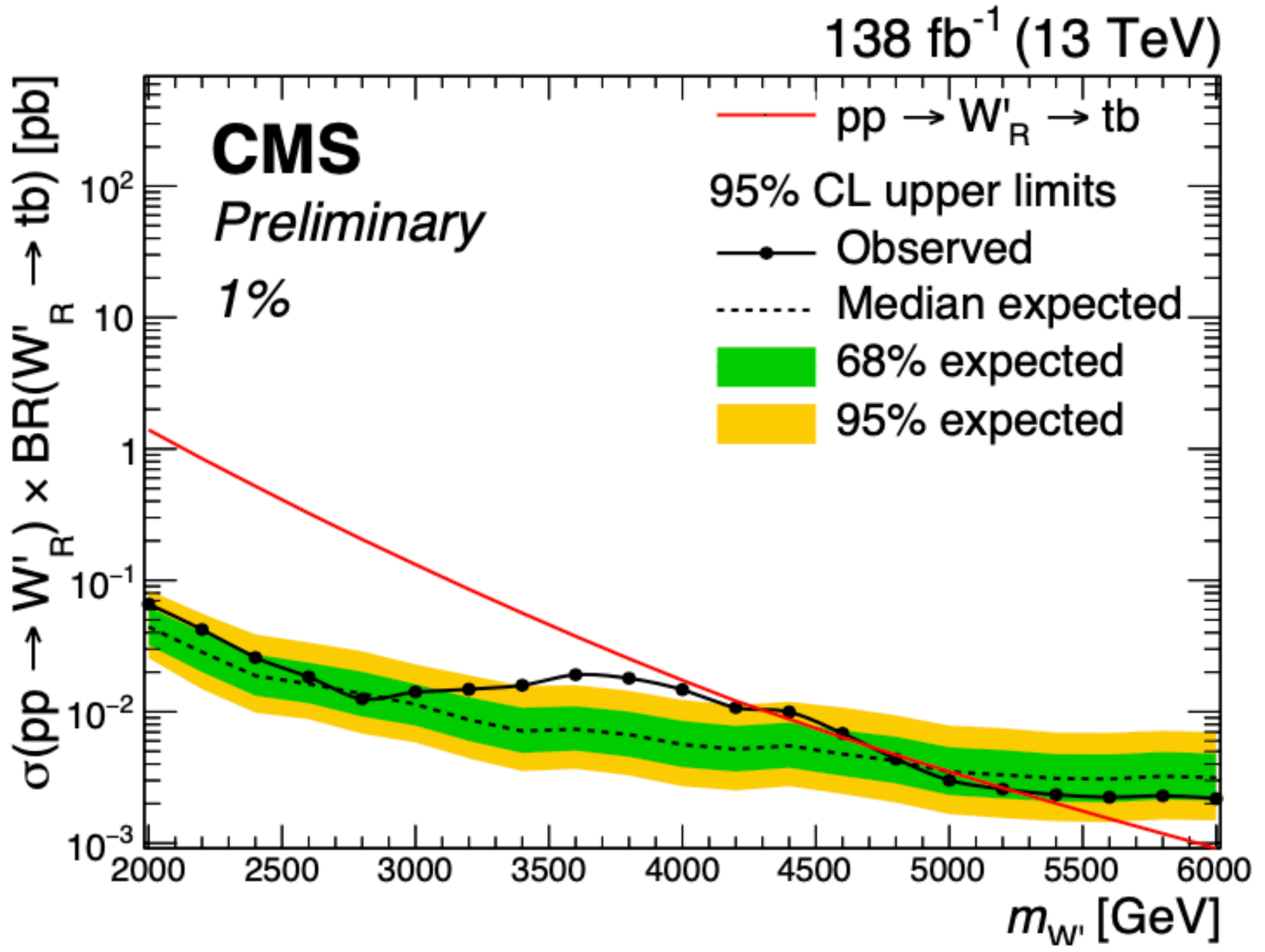
- **W' reconstruction:**
  - High p_T leptonic top quark recontruction using lepton, p_T^{miss}, and b jet:
    - Use m_W to constrain neutrino p_z
    - pick jet using combo of m_{top}, $\Delta R(\ell, j)$, subleading b jet
  - W' candidate = top candidate + leading b jet not already used
  - If less than 2 bjets, procedure is applied to full jet collection
- 0b events used as CR; SRs binned based on which jet is b-tagged
- Simultaneous maximum likelihood fit to the $m_{\ell\nu jj}$ distribution, with backgrounds estimated via data sidebands using m_{top} and $m_{SD,AK8}$ (AK8 jet closest to W' jet)



Observed 2.6σ local (2.0σ global) excess at 3.8 TeV, for narrow W' (RH chirality)



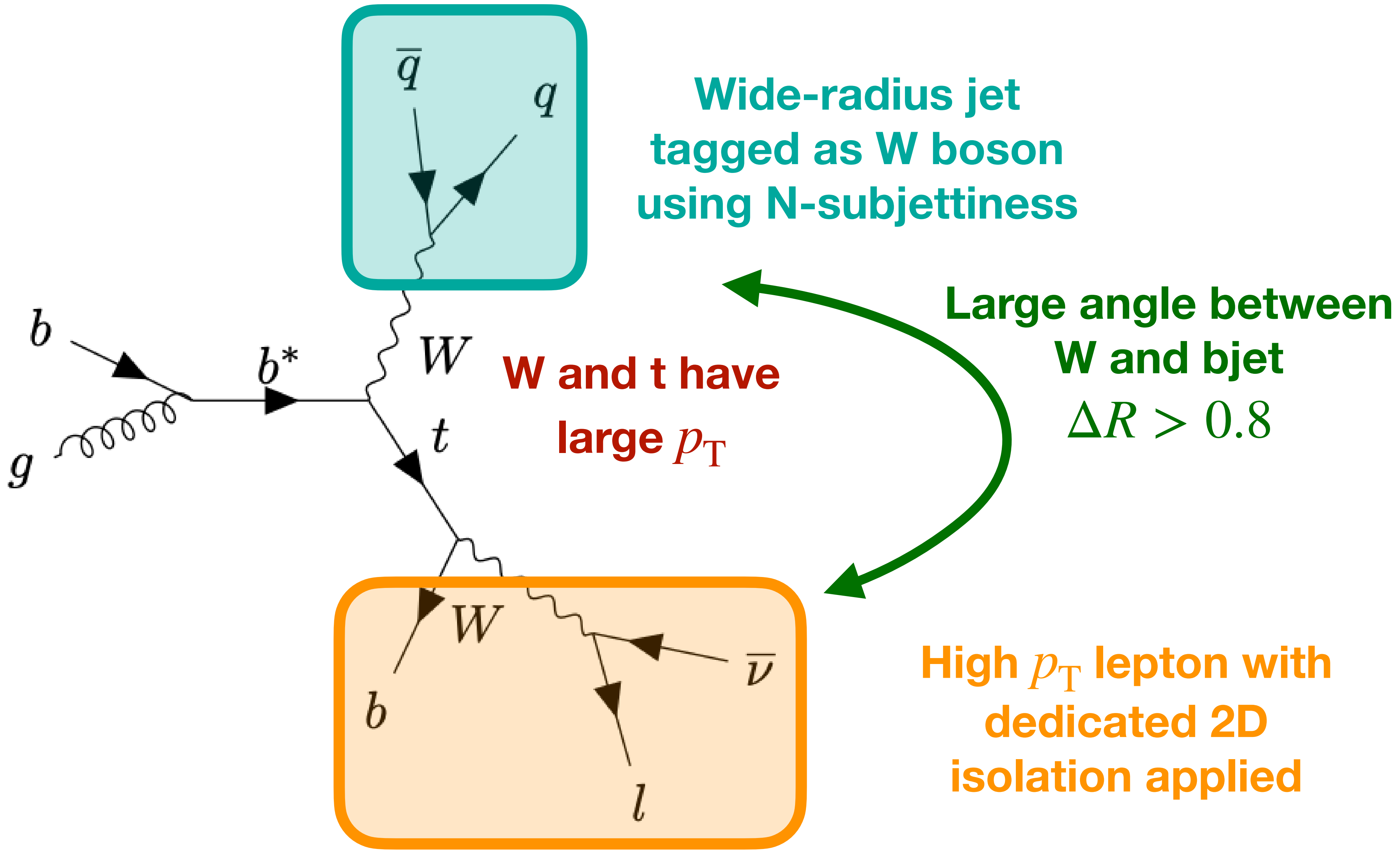


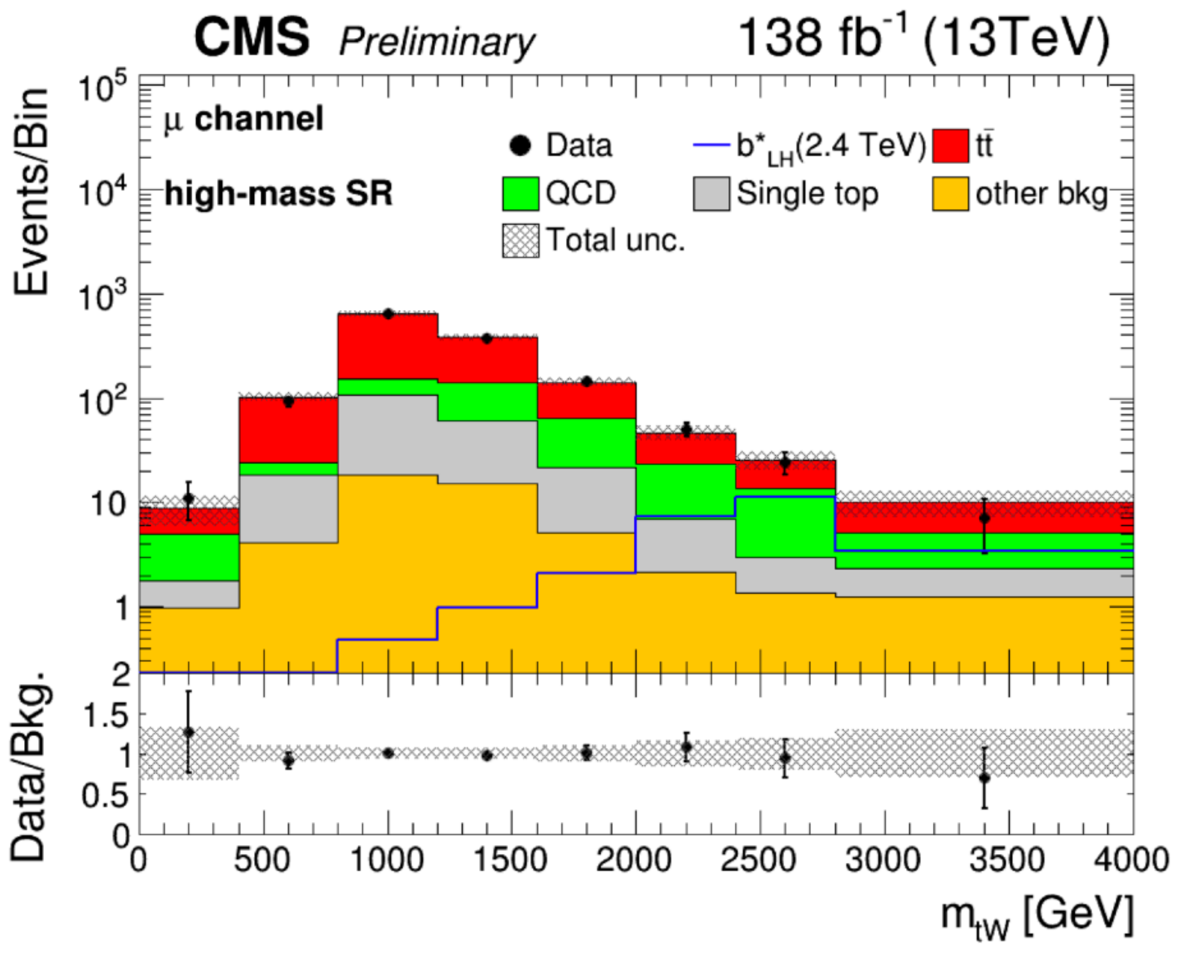


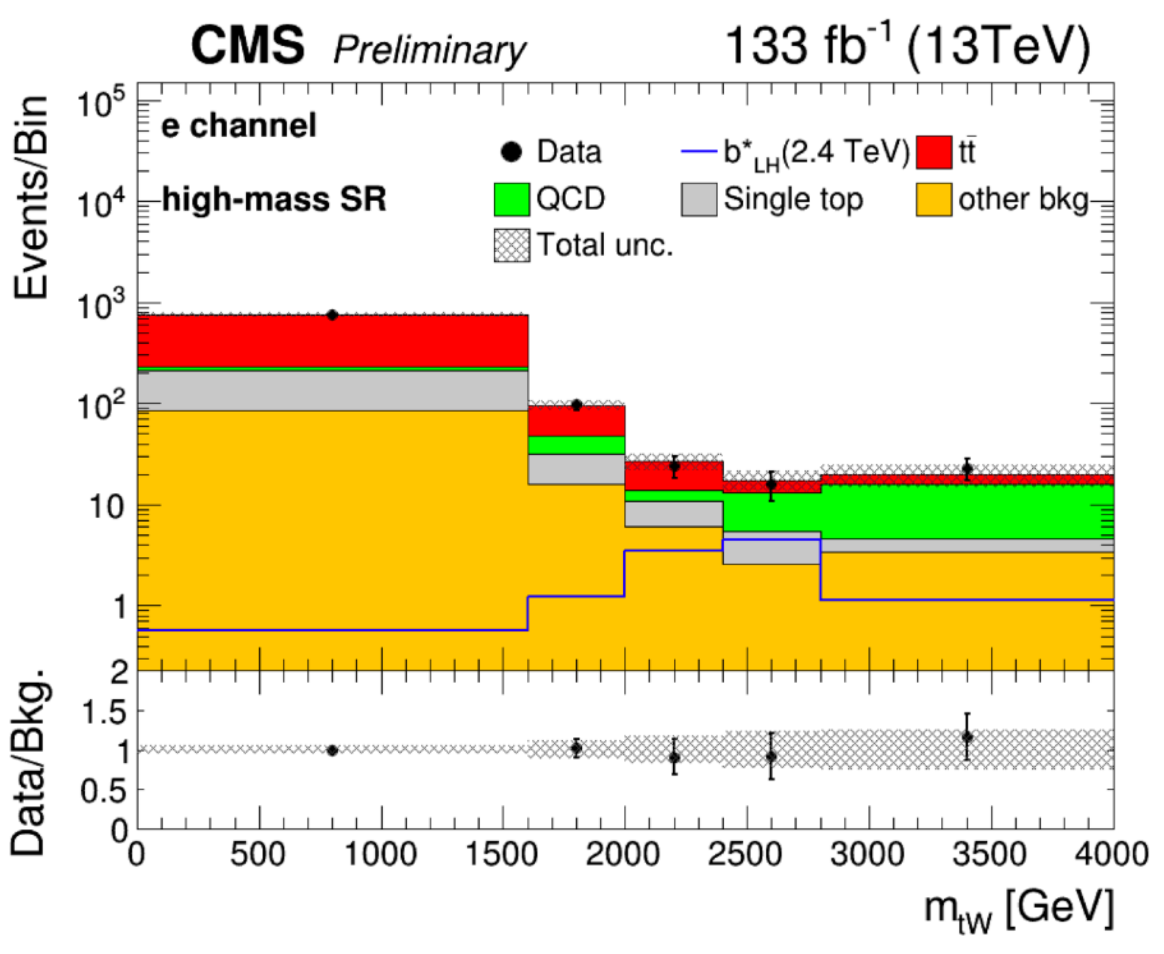
B2G-21-005

Search for $b^* \rightarrow tW$ with lepton+jets

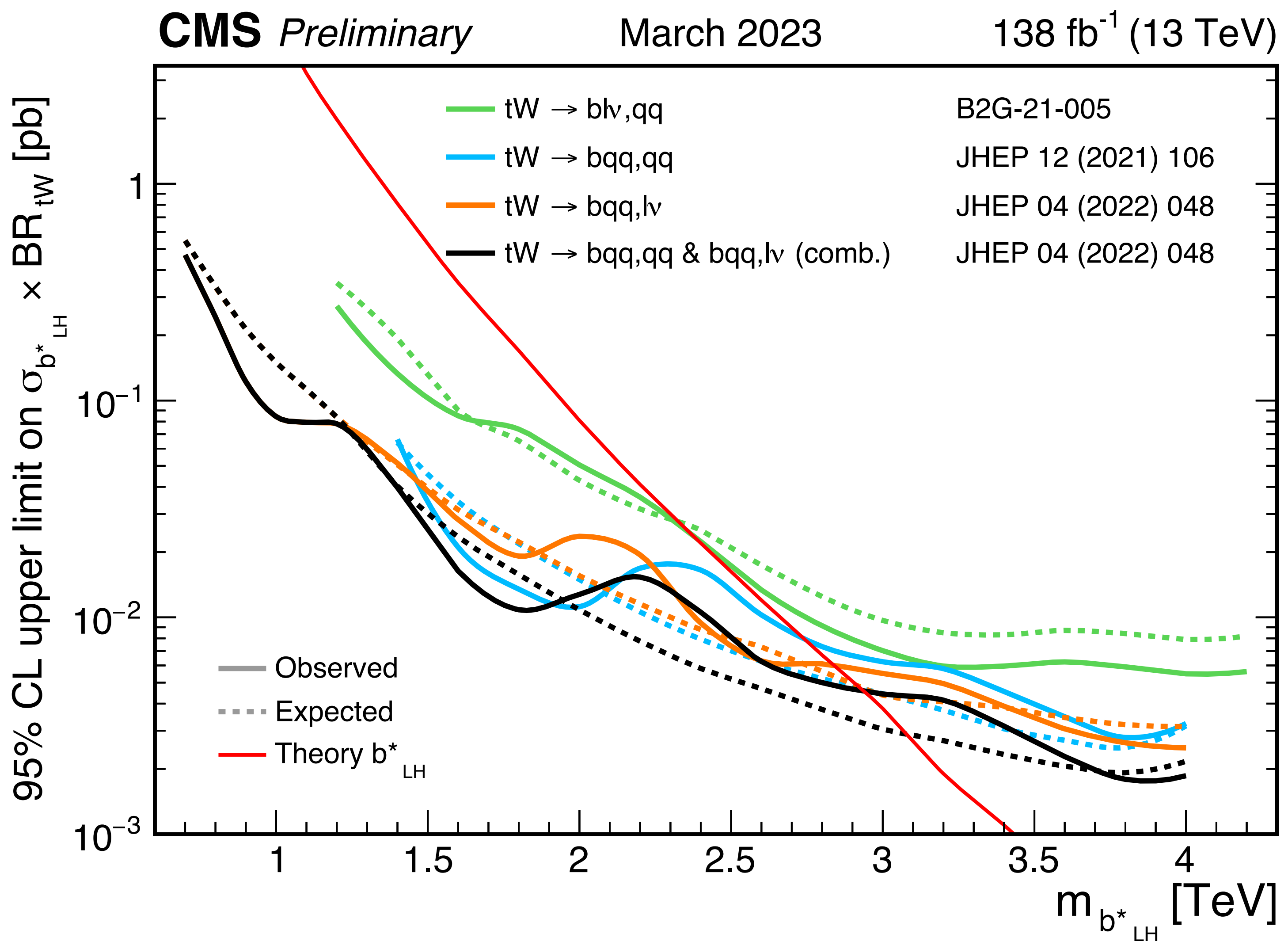
- Targeting excited b quark, b^*, decaying to top quark + W boson
  - Decay becomes dominant for $m_{b^*} >$ 700 GeV at 40% BF
  - m_{tW} reconstructed from tagged W boson and reconstructed top quark (from b, lepton, p_T^{miss}) and used as search variable
- 2 signal regions:
  - High-mass: $p_T^{miss} > 80$ GeV and $p_T^W > 400$ GeV
  - Low-mass: $p_T^{miss} < 80$ GeV or $p_T^W < 400$ GeV
- Backgrounds
  - $t\bar{t}$: constrained via control region
  - QCD multijet: estimated via ABCD method







- No excess observed
- Excited b quarks excluded up to 2.35, 2.77, 3.10 TeV for LH, RH, vector-like scenarios

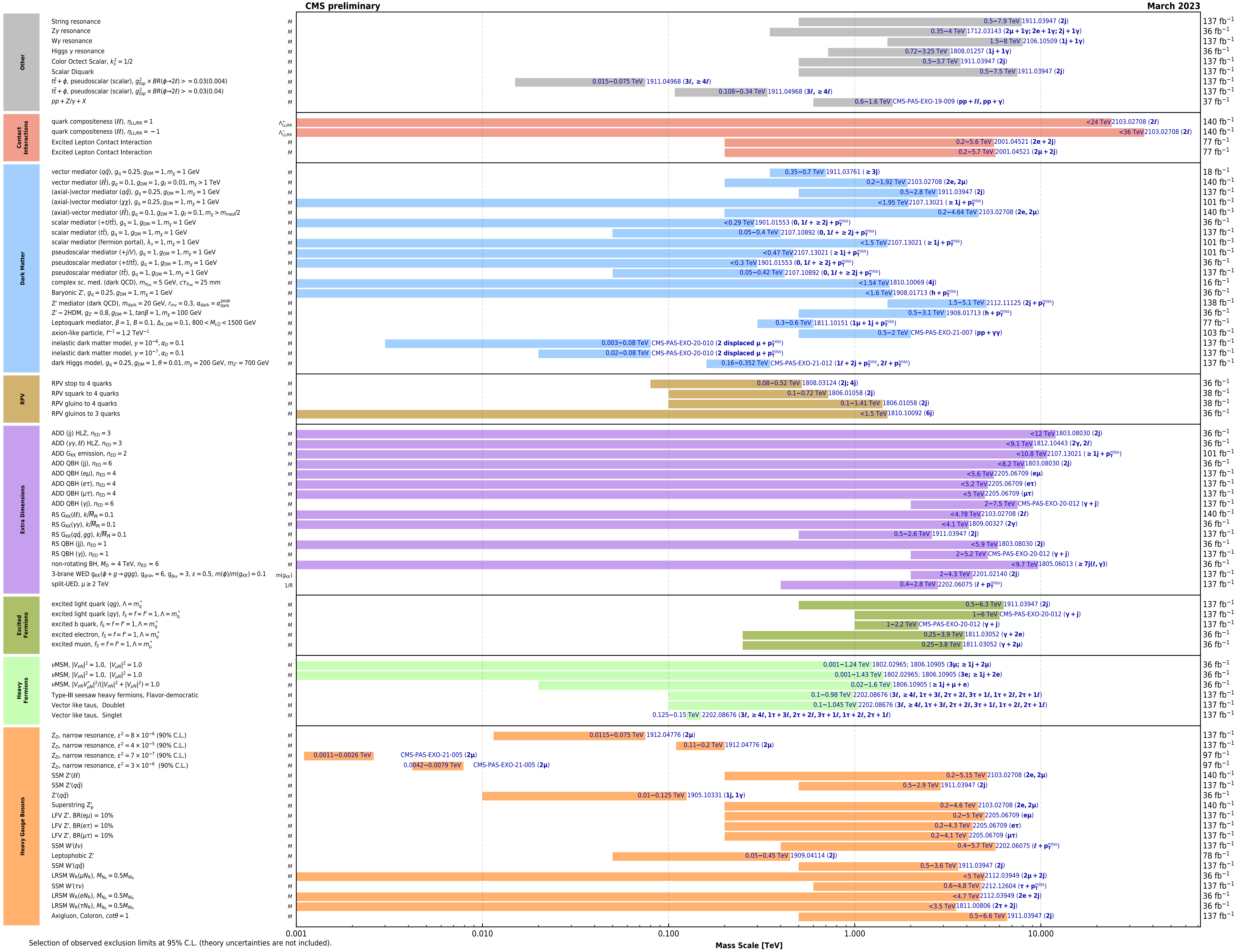


Conclusion

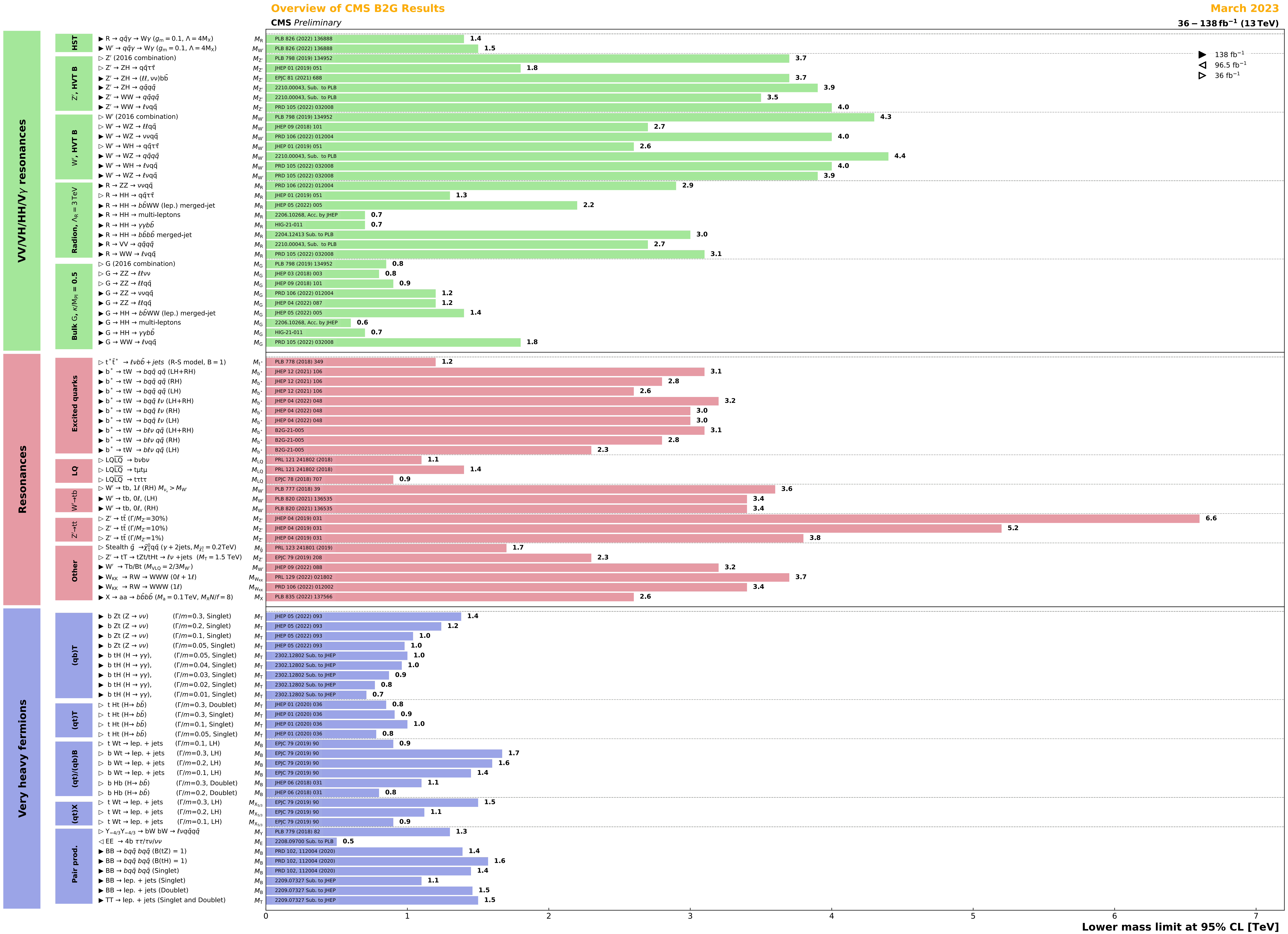
- CMS continues the exploration of the BSM physics landscape:
  Delving deep, scouting wide, and climbing high
- Analyses are using sophisticated analysis methods, including machine learning methods to extract the most from our excellent data
  - See also talk by J. Ngadiuba on Machine Learning in CMS
- For more results, please visit our public results web pages!
  And stay tuned for Run 3 results in the future!

Backup

Overview of CMS EXO results

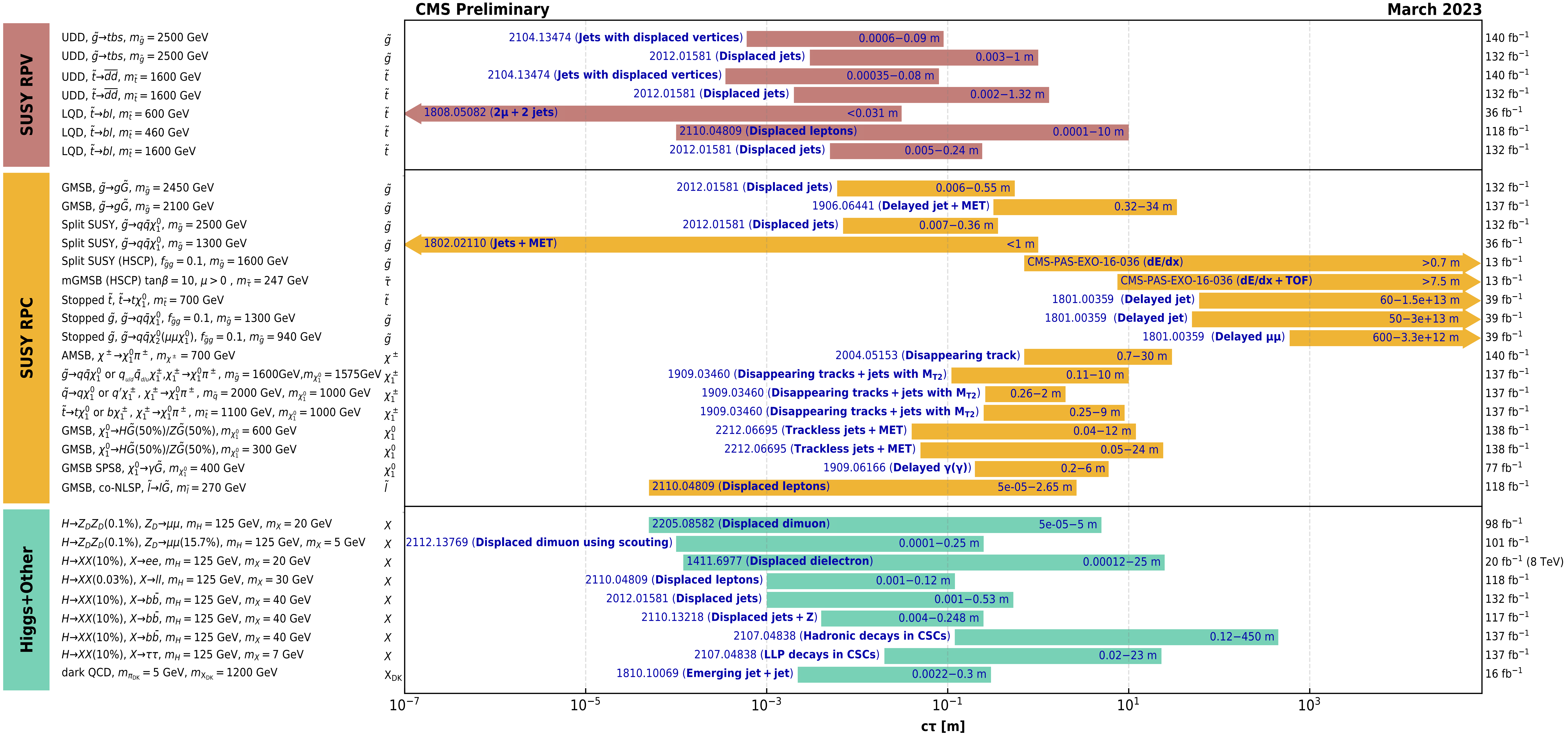


Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).



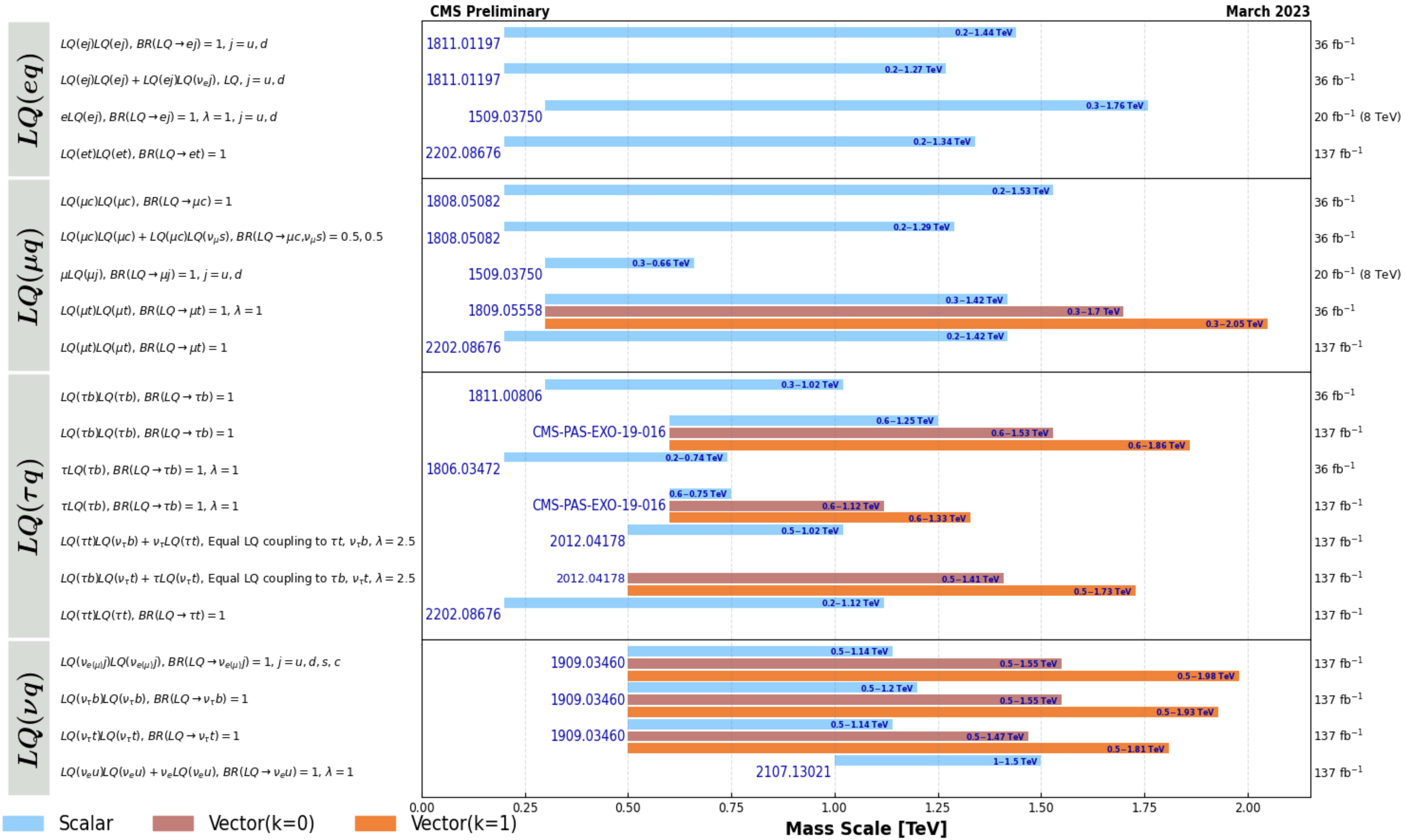
Overview of CMS B2G Results
March 2023
CMS Preliminary
$36 - 138\,\mathrm{fb}^{-1}$ (13 TeV)
▶ $138\,\mathrm{fb}^{-1}$
◁ $96.5\,\mathrm{fb}^{-1}$
▷ $36\,\mathrm{fb}^{-1}$
VV/VH/HH/Vγ resonances
HST
▶ $R \to q\bar{q}\gamma \to W\gamma$ ($g_m = 0.1, \Lambda = 4M_X$) M_R PLB 826 (2022) 136888 1.4
▶ $W' \to q\bar{q}\gamma \to W\gamma$ ($g_m = 0.1, \Lambda = 4M_X$) $M_{W'}$ PLB 826 (2022) 136888 1.5
Z', HVT B
▷ Z' (2016 combination) $M_{Z'}$ PLB 798 (2019) 134952 3.7
▷ $Z' \to ZH \to q\bar{q}\tau\bar{\tau}$ $M_{Z'}$ JHEP 01 (2019) 051 1.8
▶ $Z' \to ZH \to (\ell\ell, \nu\nu)b\bar{b}$ $M_{Z'}$ EPJC 81 (2021) 688 3.7
▶ $Z' \to ZH \to q\bar{q}q\bar{q}$ $M_{Z'}$ 2210.00043, Sub. to PLB 3.9
▶ $Z' \to WW \to q\bar{q}q\bar{q}$ $M_{Z'}$ 2210.00043, Sub. to PLB 3.5
▶ $Z' \to WW \to \ell\nu q\bar{q}$ $M_{Z'}$ PRD 105 (2022) 032008 4.0
W', HVT B
▷ W' (2016 combination) $M_{W'}$ PLB 798 (2019) 134952 4.3
▷ $W' \to WZ \to \ell\ell q\bar{q}$ $M_{W'}$ JHEP 09 (2018) 101 2.7
▶ $W' \to WZ \to \nu\nu q\bar{q}$ $M_{W'}$ PRD 106 (2022) 012004 4.0
▷ $W' \to WH \to q\bar{q}\tau\bar{\tau}$ $M_{W'}$ JHEP 01 (2019) 051 2.6
▶ $W' \to WZ \to q\bar{q}q\bar{q}$ $M_{W'}$ 2210.00043, Sub. to PLB 4.4
▶ $W' \to WH \to \ell\nu q\bar{q}$ $M_{W'}$ PRD 105 (2022) 032008 4.0
▶ $W' \to WZ \to \ell\nu q\bar{q}$ $M_{W'}$ PRD 105 (2022) 032008 3.9
Radion, $\Lambda_R = 3$ TeV
▶ $R \to ZZ \to \nu\nu q\bar{q}$ M_R PRD 106 (2022) 012004 2.9
▷ $R \to HH \to q\bar{q}\tau\bar{\tau}$ M_R JHEP 01 (2019) 051 1.3
▶ $R \to HH \to b\bar{b}WW$ (lep.) merged-jet M_R JHEP 05 (2022) 005 2.2
▶ $R \to HH \to$ multi-leptons M_R 2206.10268, Acc. by JHEP 0.7
▶ $R \to HH \to \gamma\gamma b\bar{b}$ M_R HIG-21-011 0.7
▶ $R \to HH \to b\bar{b}b\bar{b}$ merged-jet M_R 2204.12413 Sub. to PLB 3.0
▶ $R \to VV \to q\bar{q}q\bar{q}$ M_R 2210.00043, Sub. to PLB 2.7
▶ $R \to WW \to \ell\nu q\bar{q}$ M_R PRD 105 (2022) 032008 3.1
Bulk G, $\kappa/M_{Pl} = 0.5$
▷ G (2016 combination) M_G PLB 798 (2019) 134952 0.8
▷ $G \to ZZ \to \ell\ell\nu\nu$ M_G JHEP 03 (2018) 003 0.8
▷ $G \to ZZ \to \ell\ell q\bar{q}$ M_G JHEP 09 (2018) 101 0.9
▶ $G \to ZZ \to \nu\nu q\bar{q}$ M_G PRD 106 (2022) 012004 1.2
▶ $G \to ZZ \to \ell\ell q\bar{q}$ M_G JHEP 04 (2022) 087 1.2
▶ $G \to HH \to b\bar{b}WW$ (lep.) merged-jet M_G JHEP 05 (2022) 005 1.4
▶ $G \to HH \to$ multi-leptons M_G 2206.10268, Acc. by JHEP 0.6
▶ $G \to HH \to \gamma\gamma b\bar{b}$ M_G HIG-21-011 0.7
▶ $G \to WW \to \ell\nu q\bar{q}$ M_G PRD 105 (2022) 032008 1.8
Resonances
▷ $t^*\bar{t}^* \to \ell\nu b\bar{b}$ + jets (R-S model, B = 1) M_{t^*} PLB 778 (2018) 349 1.2
Excited quarks
▶ $b^* \to tW \to bq\bar{q}\,q\bar{q}$ (LH+RH) M_{b^*} JHEP 12 (2021) 106 3.1
▶ $b^* \to tW \to bq\bar{q}\,q\bar{q}$ (RH) M_{b^*} JHEP 12 (2021) 106 2.8
▶ $b^* \to tW \to bq\bar{q}\,q\bar{q}$ (LH) M_{b^*} JHEP 12 (2021) 106 2.6
▶ $b^* \to tW \to bq\bar{q}\,\ell\nu$ (LH+RH) M_{b^*} JHEP 04 (2022) 048 3.2
▶ $b^* \to tW \to bq\bar{q}\,\ell\nu$ (RH) M_{b^*} JHEP 04 (2022) 048 3.0
▶ $b^* \to tW \to bq\bar{q}\,\ell\nu$ (LH) M_{b^*} JHEP 04 (2022) 048 3.0
▶ $b^* \to tW \to b\ell\nu\,q\bar{q}$ (LH+RH) M_{b^*} B2G-21-005 3.1
▶ $b^* \to tW \to b\ell\nu\,q\bar{q}$ (RH) M_{b^*} B2G-21-005 2.8
▶ $b^* \to tW \to b\ell\nu\,q\bar{q}$ (LH) M_{b^*} B2G-21-005 2.3
LQ
▷ $LQ\overline{LQ} \to b\nu b\nu$ M_{LQ} PRL 121 241802 (2018) 1.1
▷ $LQ\overline{LQ} \to t\mu t\mu$ M_{LQ} PRL 121 241802 (2018) 1.4
▷ $LQ\overline{LQ} \to t\tau t\tau$ M_{LQ} EPJC 78 (2018) 707 0.9
W'→tb
▷ $W' \to tb$, 1ℓ (RH) $M_{\nu_r} > M_{W'}$ $M_{W'}$ PLB 777 (2018) 39 3.6
▶ $W' \to tb$, 0ℓ, (LH) $M_{W'}$ PLB 820 (2021) 136535 3.4
▶ $W' \to tb$, 0ℓ, (RH) $M_{W'}$ PLB 820 (2021) 136535 3.4
Z'→tt
▷ $Z' \to t\bar{t}$ ($\Gamma/M_{Z'}$=30%) $M_{Z'}$ JHEP 04 (2019) 031 6.6
▷ $Z' \to t\bar{t}$ ($\Gamma/M_{Z'}$=10%) $M_{Z'}$ JHEP 04 (2019) 031 5.2
▷ $Z' \to t\bar{t}$ ($\Gamma/M_{Z'}$=1%) $M_{Z'}$ JHEP 04 (2019) 031 3.8
Other
▷ Stealth $\tilde{g} \to \tilde{\chi}^0_1 q\bar{q}$ (γ + 2jets, $M_{\tilde{\chi}^0_1} = 0.2$TeV) $M_{\tilde{g}}$ PRL 123 241801 (2019) 1.7
▷ $Z' \to tT \to tZt/tHt \to \ell\nu$ +jets ($M_T = 1.5$ TeV) $M_{Z'}$ EPJC 79 (2019) 208 2.3
▶ $W' \to Tb/Bt$ ($M_{VLQ} = 2/3M_{W'}$) $M_{W'}$ JHEP 09 (2022) 088 3.2
▶ $W_{KK} \to RW \to WWW$ ($0\ell + 1\ell$) $M_{W_{KK}}$ PRL 129 (2022) 021802 3.7
▶ $W_{KK} \to RW \to WWW$ (1ℓ) $M_{W_{KK}}$ PRD 106 (2022) 012002 3.4
▶ $X \to aa \to b\bar{b}b\bar{b}$ ($M_a = 0.1$ TeV, $M_X N/f = 8$) M_X PLB 835 (2022) 137566 2.6
Very heavy fermions
(qb)T
▶ b Zt ($Z \to \nu\nu$) (Γ/m=0.3, Singlet) M_T JHEP 05 (2022) 093 1.4
▶ b Zt ($Z \to \nu\nu$) (Γ/m=0.2, Singlet) M_T JHEP 05 (2022) 093 1.2
▶ b Zt ($Z \to \nu\nu$) (Γ/m=0.1, Singlet) M_T JHEP 05 (2022) 093 1.0
▶ b Zt ($Z \to \nu\nu$) (Γ/m=0.05, Singlet) M_T JHEP 05 (2022) 093 1.0
▶ b tH ($H \to \gamma\gamma$), (Γ/m=0.05, Singlet) M_T 2302.12802 Sub. to JHEP 1.0
▶ b tH ($H \to \gamma\gamma$), (Γ/m=0.04, Singlet) M_T 2302.12802 Sub. to JHEP 1.0
▶ b tH ($H \to \gamma\gamma$), (Γ/m=0.03, Singlet) M_T 2302.12802 Sub. to JHEP 0.9
▶ b tH ($H \to \gamma\gamma$), (Γ/m=0.02, Singlet) M_T 2302.12802 Sub. to JHEP 0.8
▶ b tH ($H \to \gamma\gamma$), (Γ/m=0.01, Singlet) M_T 2302.12802 Sub. to JHEP 0.7
(qt)T
▷ t Ht ($H \to b\bar{b}$) (Γ/m=0.3, Doublet) M_T JHEP 01 (2020) 036 0.8
▷ t Ht ($H \to b\bar{b}$) (Γ/m=0.3, Singlet) M_T JHEP 01 (2020) 036 0.9
▷ t Ht ($H \to b\bar{b}$) (Γ/m=0.1, Singlet) M_T JHEP 01 (2020) 036 1.0
▷ t Ht ($H \to b\bar{b}$) (Γ/m=0.05, Singlet) M_T JHEP 01 (2020) 036 0.8
(qt)/(qb)B
▷ t Wt → lep. + jets (Γ/m=0.1, LH) M_B EPJC 79 (2019) 90 0.9
▷ b Wt → lep. + jets (Γ/m=0.3, LH) M_B EPJC 79 (2019) 90 1.7
▷ b Wt → lep. + jets (Γ/m=0.2, LH) M_B EPJC 79 (2019) 90 1.6
▷ b Wt → lep. + jets (Γ/m=0.1, LH) M_B EPJC 79 (2019) 90 1.4
▷ b Hb ($H \to b\bar{b}$) (Γ/m=0.3, Doublet) M_B JHEP 06 (2018) 031 1.1
▷ b Hb ($H \to b\bar{b}$) (Γ/m=0.2, Doublet) M_B JHEP 06 (2018) 031 0.8
(qt)X
▷ t Wt → lep. + jets (Γ/m=0.3, LH) $M_{X_{5/3}}$ EPJC 79 (2019) 90 1.5
▷ t Wt → lep. + jets (Γ/m=0.2, LH) $M_{X_{5/3}}$ EPJC 79 (2019) 90 1.1
▷ t Wt → lep. + jets (Γ/m=0.1, LH) $M_{X_{5/3}}$ EPJC 79 (2019) 90 0.9
Pair prod.
▷ $Y_{-4/3}Y_{-4/3} \to bW\,bW \to \ell\nu q\bar{q}q\bar{q}$ M_Y PLB 779 (2018) 82 1.3
◁ $EE \to 4b\ \tau\tau/\tau\nu/\nu\nu$ M_E 2208.09700 Sub. to PLB 0.5
▶ $BB \to bq\bar{q}\,bq\bar{q}$ (B(tZ) = 1) M_B PRD 102, 112004 (2020) 1.4
▶ $BB \to bq\bar{q}\,bq\bar{q}$ (B(tH) = 1) M_B PRD 102, 112004 (2020) 1.6
▶ $BB \to bq\bar{q}\,bq\bar{q}$ (Singlet) M_B PRD 102, 112004 (2020) 1.4
▶ BB → lep. + jets (Singlet) M_B 2209.07327 Sub. to JHEP 1.1
▶ BB → lep. + jets (Doublet) M_B 2209.07327 Sub. to JHEP 1.5
▶ TT → lep. + jets (Singlet and Doublet) M_T 2209.07327 Sub. to JHEP 1.5
0 1 2 3 4 5 6 7
Lower mass limit at 95% CL [TeV]

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.

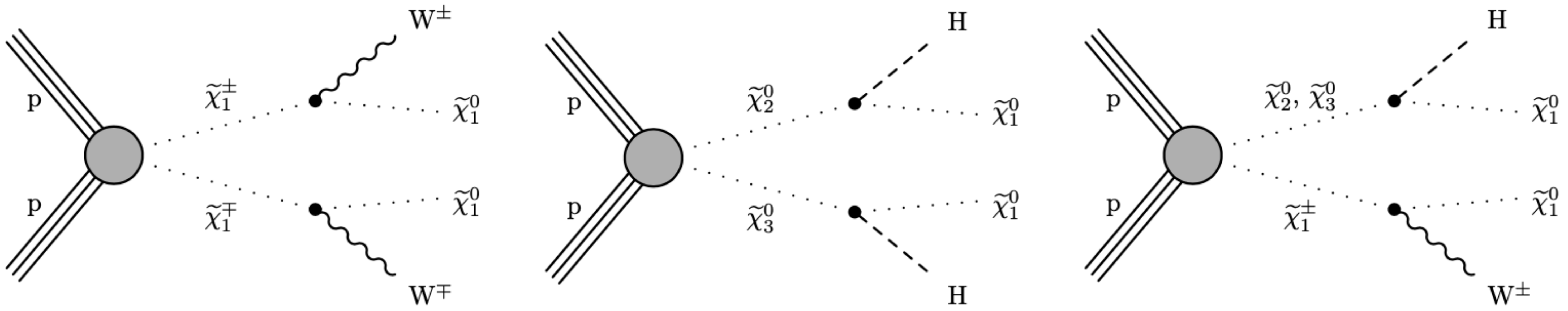
Overview of CMS leptoquark searches

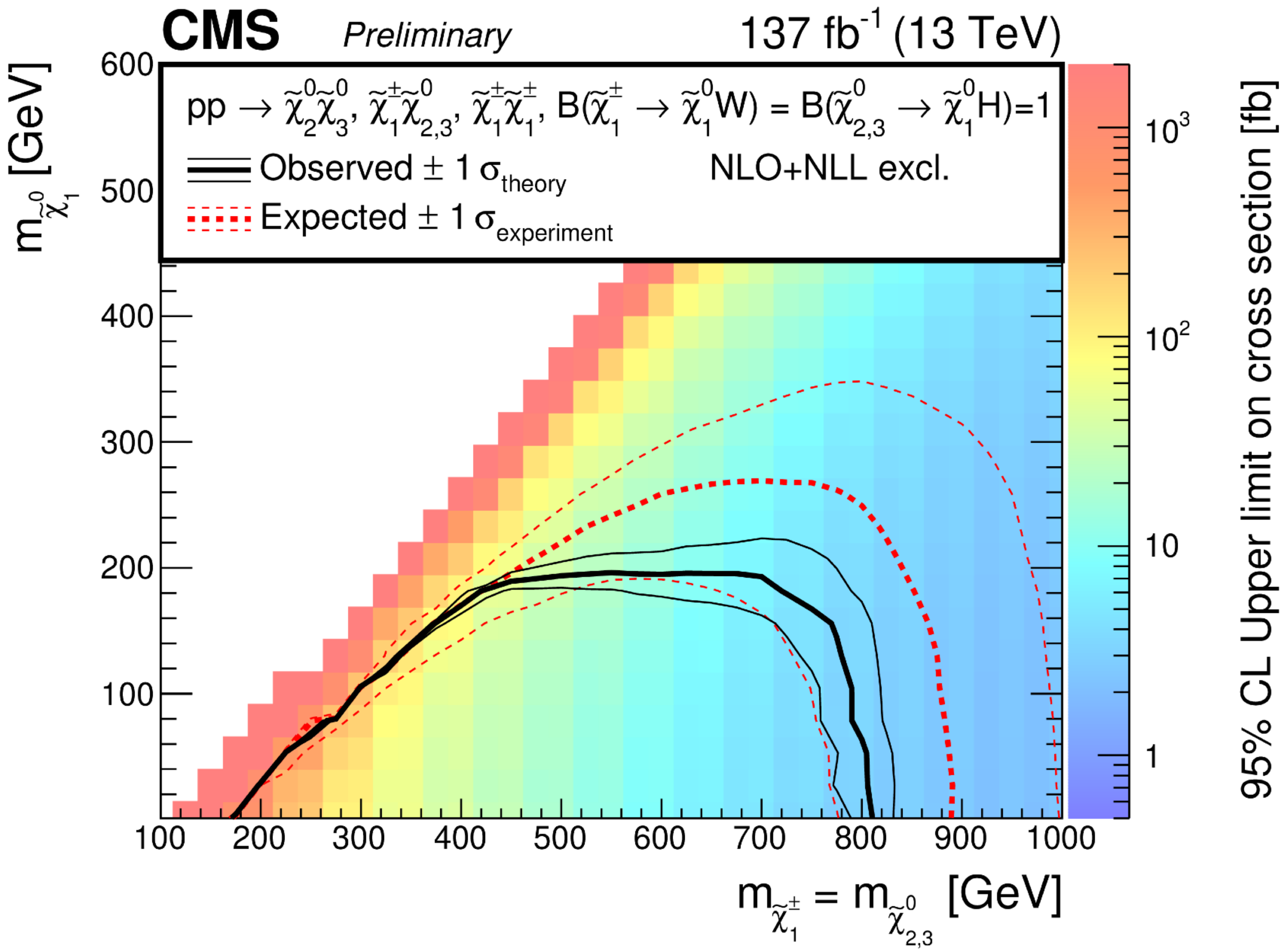


Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

Combination of electroweak SUSY searches

Results for higgsino-like $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_{2,3}^0$ (with bino-like $\tilde{\chi}_1^0$)





Search	gaugino WZ	gaugino WH	GMSB ZZ	GMSB HZ	GMSB HH	higgsino-bino WW	higgsino-bino HH	higgsino-bino WH	sleptons $\ell^+\ell^-$
2/3ℓ soft [17]	all								2ℓ soft
2ℓ on-Z [15]	EW		EW	EW					
2ℓ non-res. [15]									Slepton
$\geq$3ℓ [18]	SS, A(NN)	SS, A–F	all	all	all			SS, A–F	
1ℓ2b [16]		all						all	
4b [19]					all		3-b, 4-b, 2-bb		
Hadr. WX [20]	all	b-tag				b-veto		b-tag	

SUS-21-009

Search for SUSY with 1 photon, jets, and p_T^{miss}

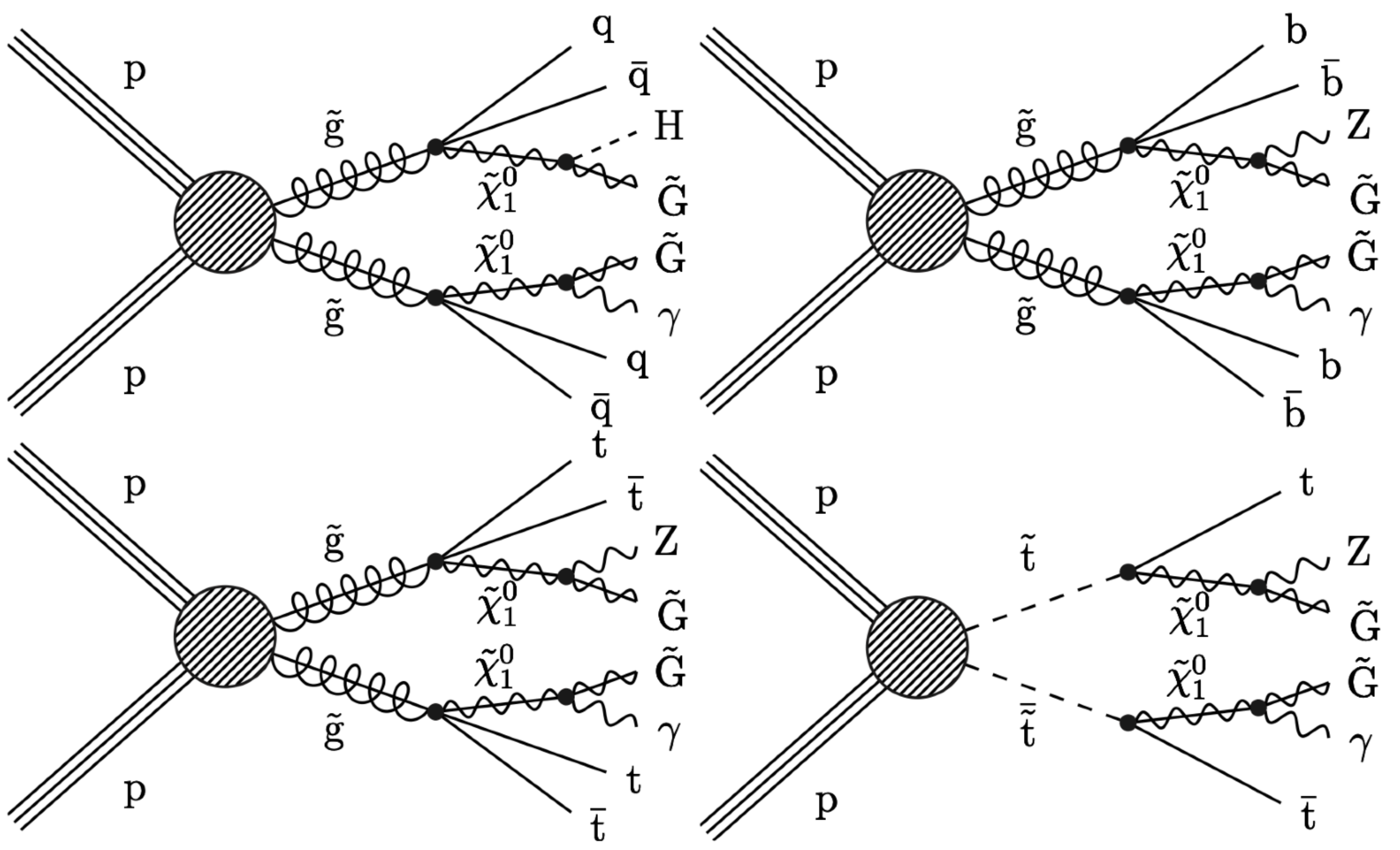


Figure 1: Diagrams of simplified models of gluino pair production: T5qqqqHG (top left), T5bbbbZG (top right), T5ttttZG (lower left), and top squark pair production: T6ttZG (lower right). The models are defined in the text.

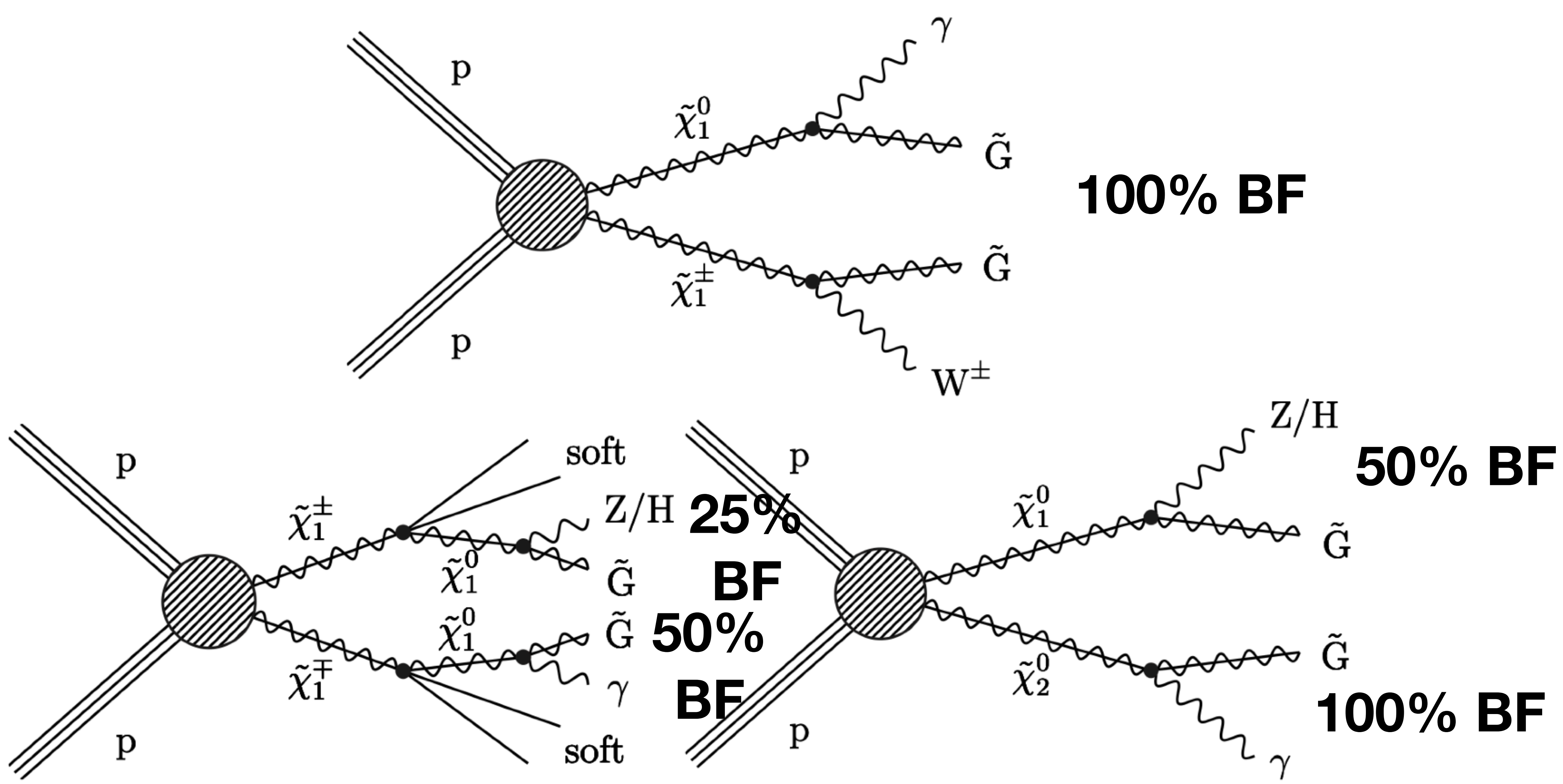
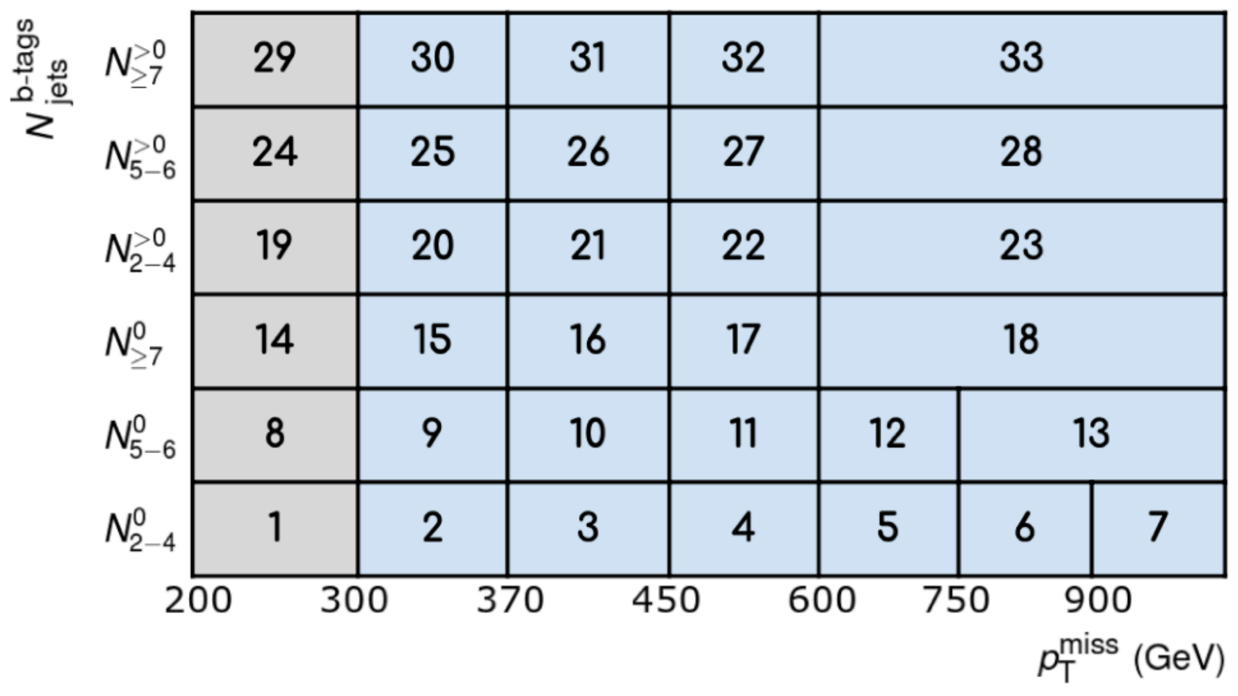


Figure 2: Diagrams of simplified models of electroweakino pair production: TChiWG (top), TChiNG (bottom left), and TChiNGnn (bottom right). Only the $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ cases are shown for the TChiWG and TChiNG models, respectively. The models are defined in the text.

SUS-21-009

Search for SUSY with 1 photon, jets, and p_T^{miss}

p_T^{miss}	> 300 GeV for SRs and $\in [200, 300]$ GeV for CRs
N_{jets} ($p_T > 30$ GeV, $\lvert\eta\rvert < 2.4$)	≥ 2
γ ($p_T > 100$ GeV, $\lvert\eta\rvert < 2.4$)	≥ 1
$S_T = \sum_{jets} p_T + p_T^{\gamma}$	> 300 GeV
$\Delta\phi(\text{jet}\vec{p}_T, \vec{p}_T^{miss})$	> 0.3 for 2 highest p_T jets
Number of leptons (e, μ)	0
Number of isolated tracks	0



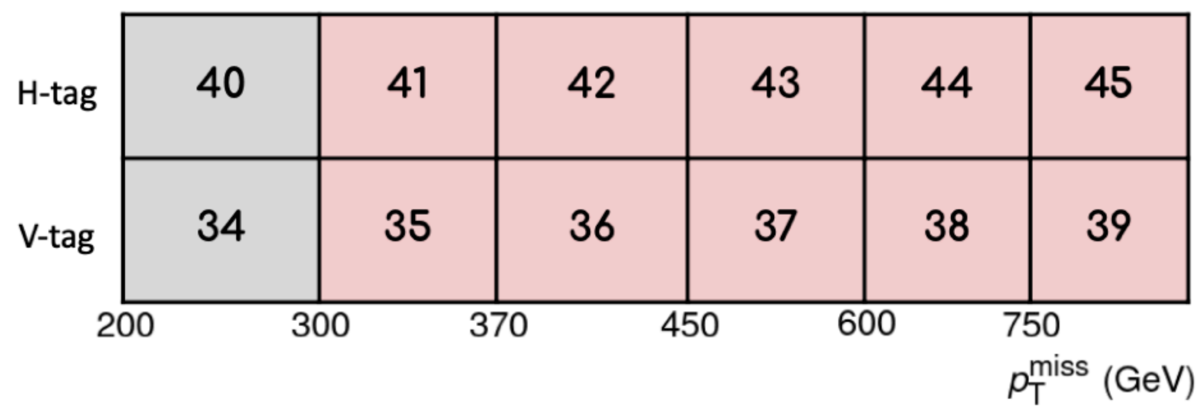
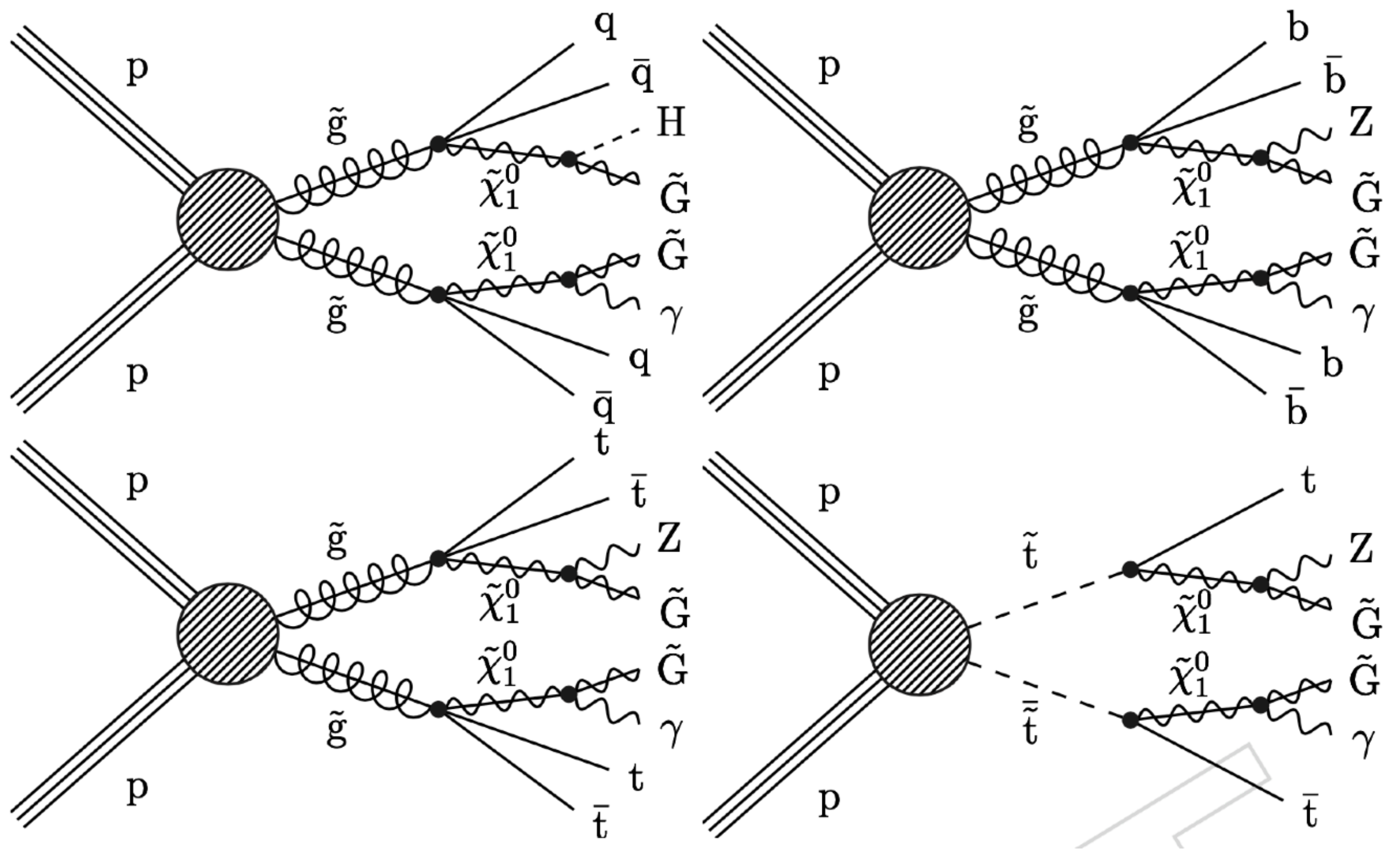
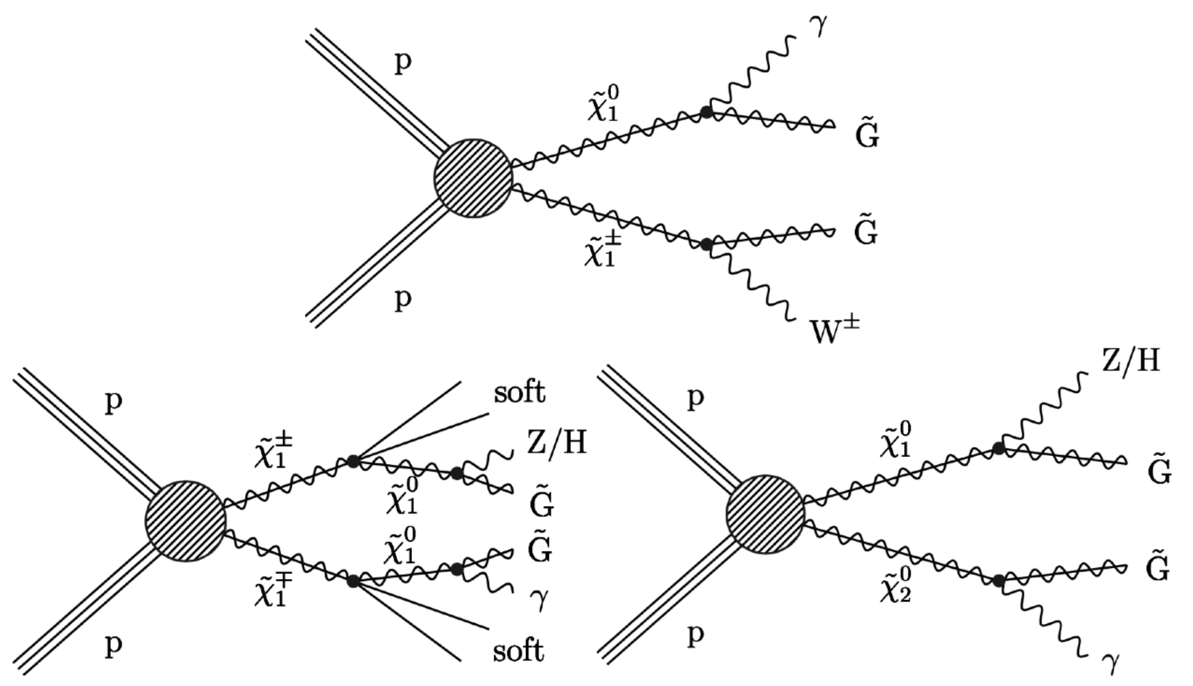


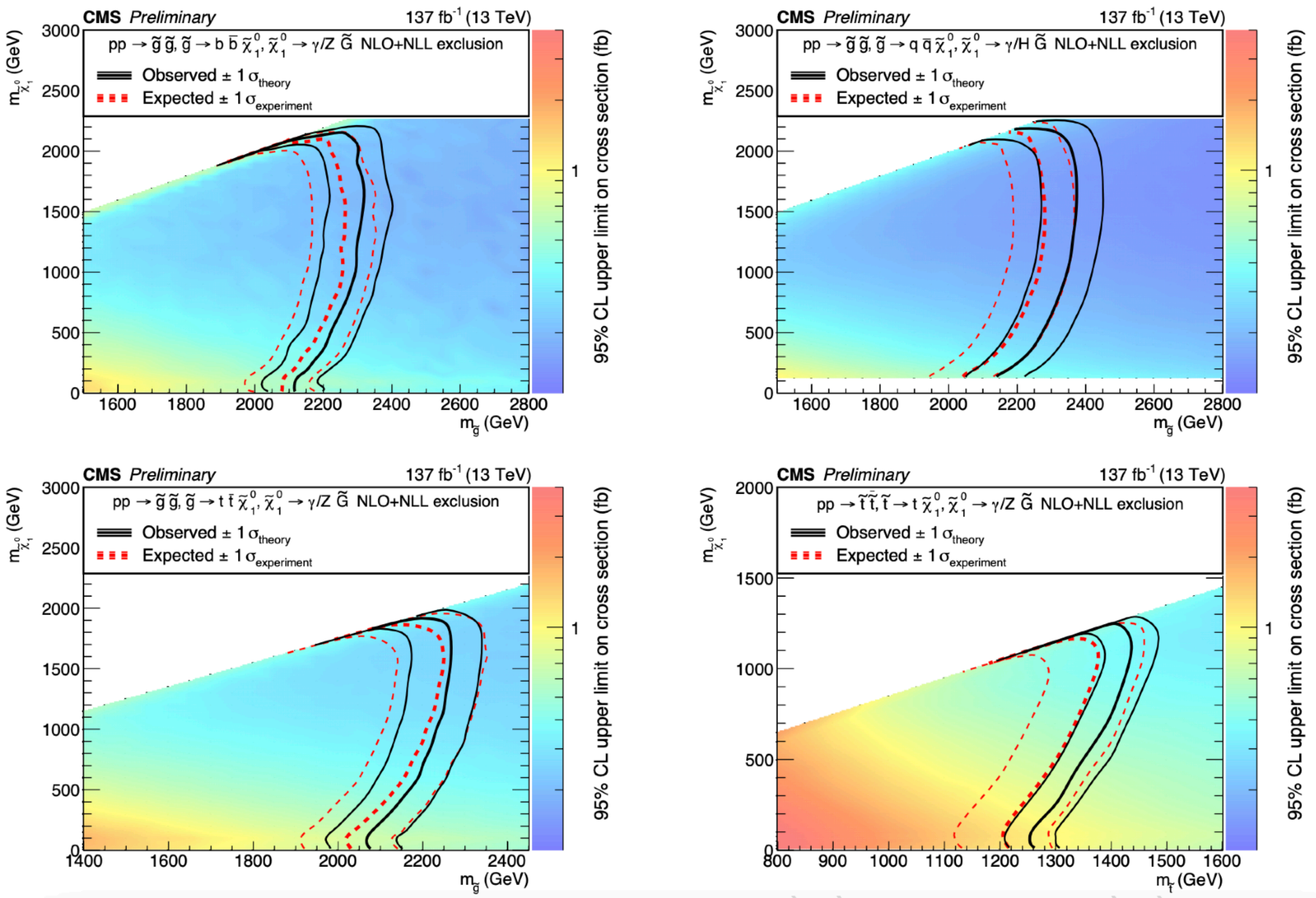
Table 2: The systematic uncertainties in the predicted background and signal event yields (in %). A dash (—) indicates that the source of uncertainty is not applicable or negligible.

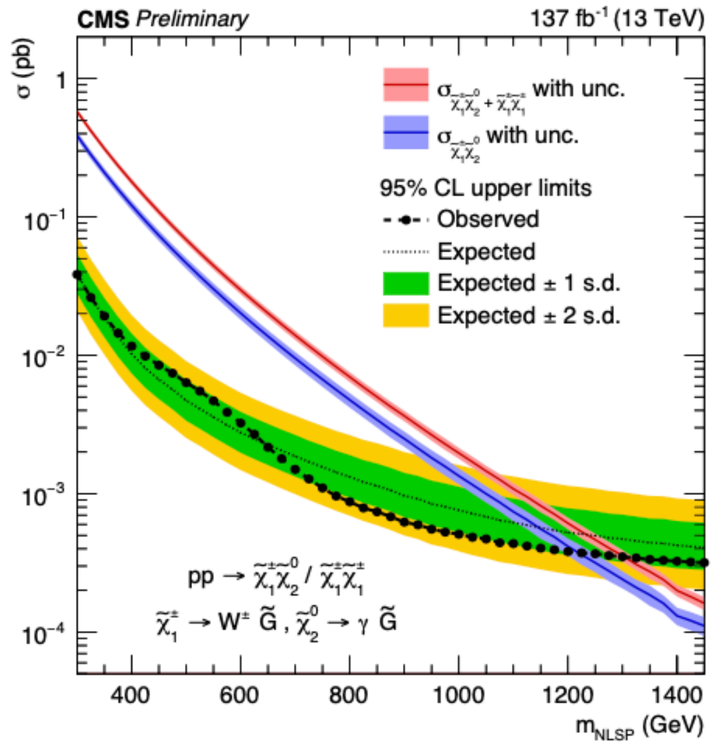
Source	Lost lepton	Misidentified e	$Z(\nu\nu)\gamma$	Multijet+γ	Signal
Luminosity	—	—	—	—	1.6
Limited number of CR events	3–100	5–20	8–28	2–100	—
Limited number of simulated events	2–10	2–20	2–70	10–50	0.7–38
b tagging	0–1	0–1	—	—	0–10
PDF	3	—	—	—	1–2
μ_R and μ_F scales	2	—	—	—	0.3–5
JEC	0–6	0–3	—	—	1–2
JER	0–6	0–4	—	—	1–2
Pileup	—	—	—	—	0.1-0.3
Trigger efficiency	—	—	—	—	3–10
Collinear γ	4	—	—	—	—
α	—	20	—	—	—
Modeling of γ p_T	—	—	18–40	—	—
κ modeling	—	—	—	10–36	—
low-p_T^{miss} C/A data stat.	—	—	—	10–50	—
Isolated track veto	—	—	—	—	2
Jet ID	—	—	—	—	1

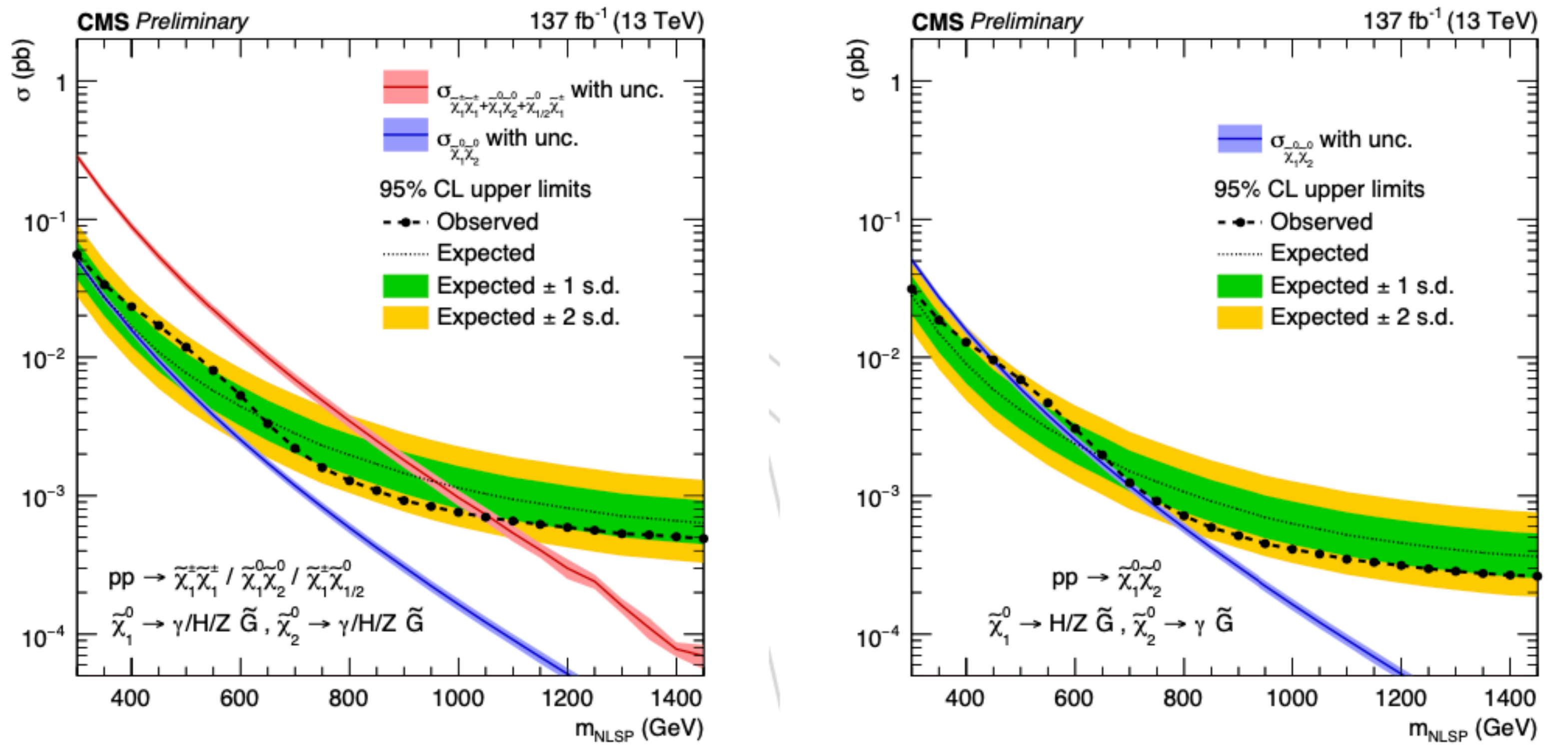
Search for SUSY with 1 photon, jets, and p_T^{miss}





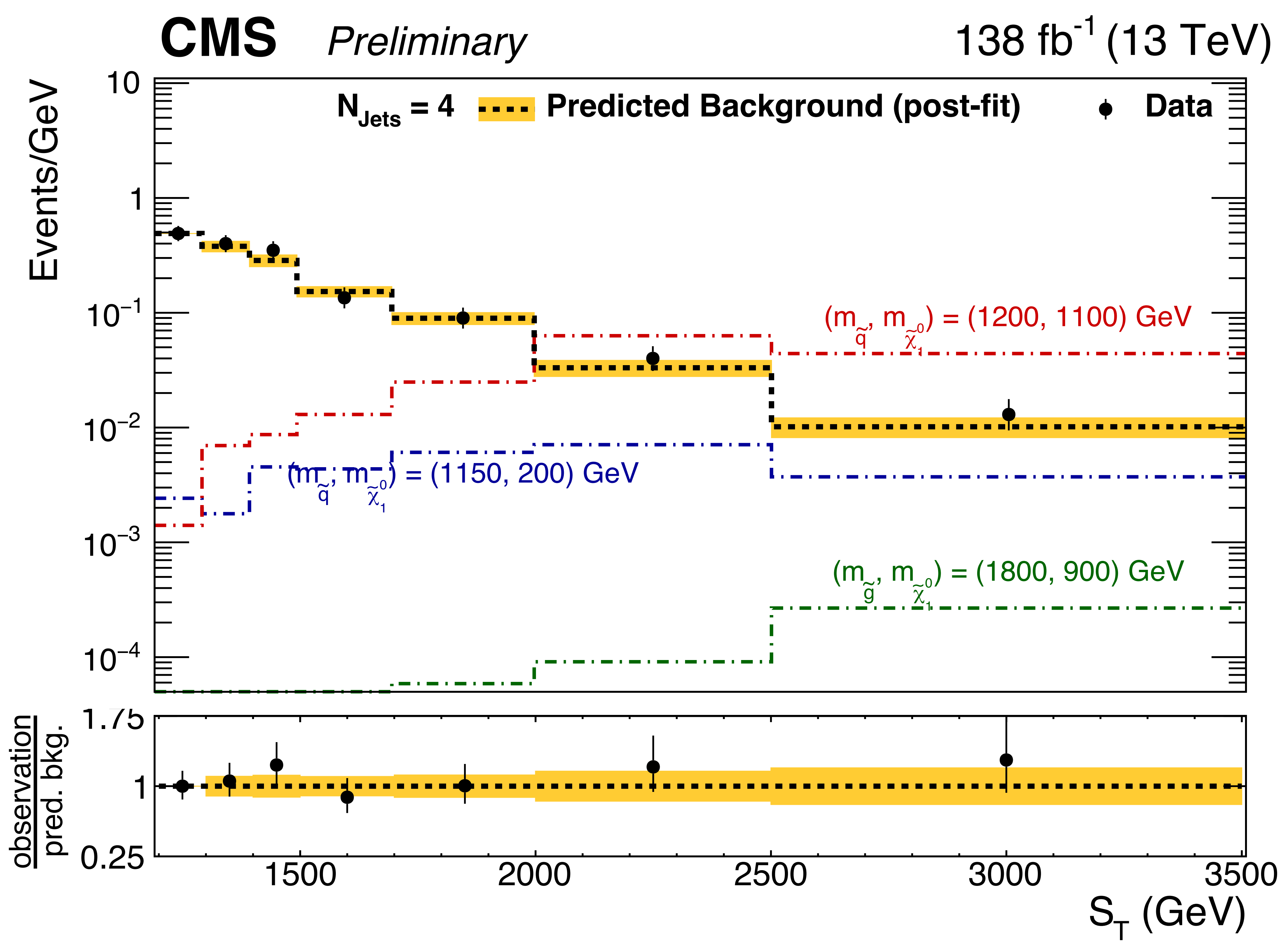


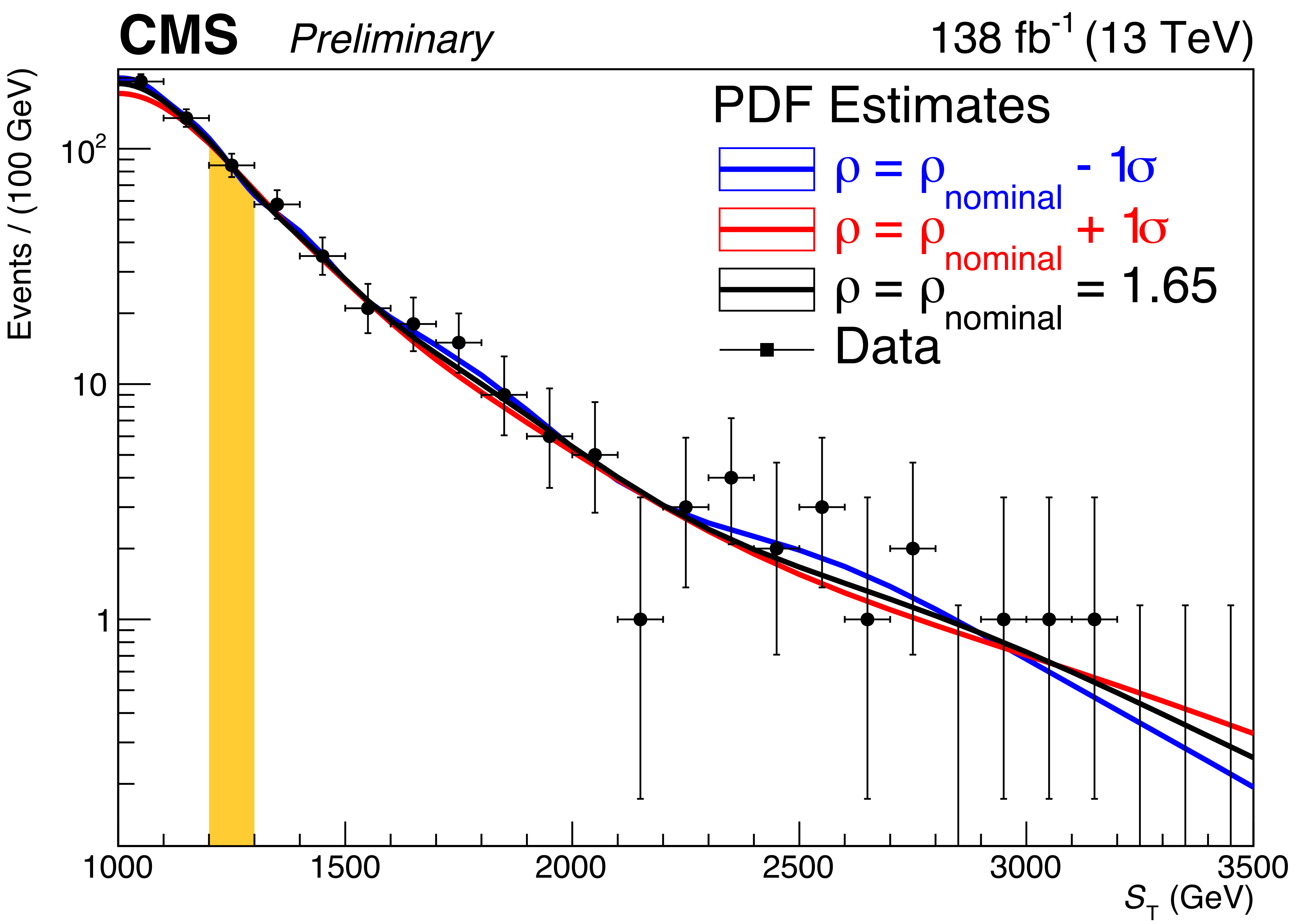




SUS-19-001

Search for Stealth SUSY with 2 photons and jets





EXO-21-005

Low mass dimuons with scouting

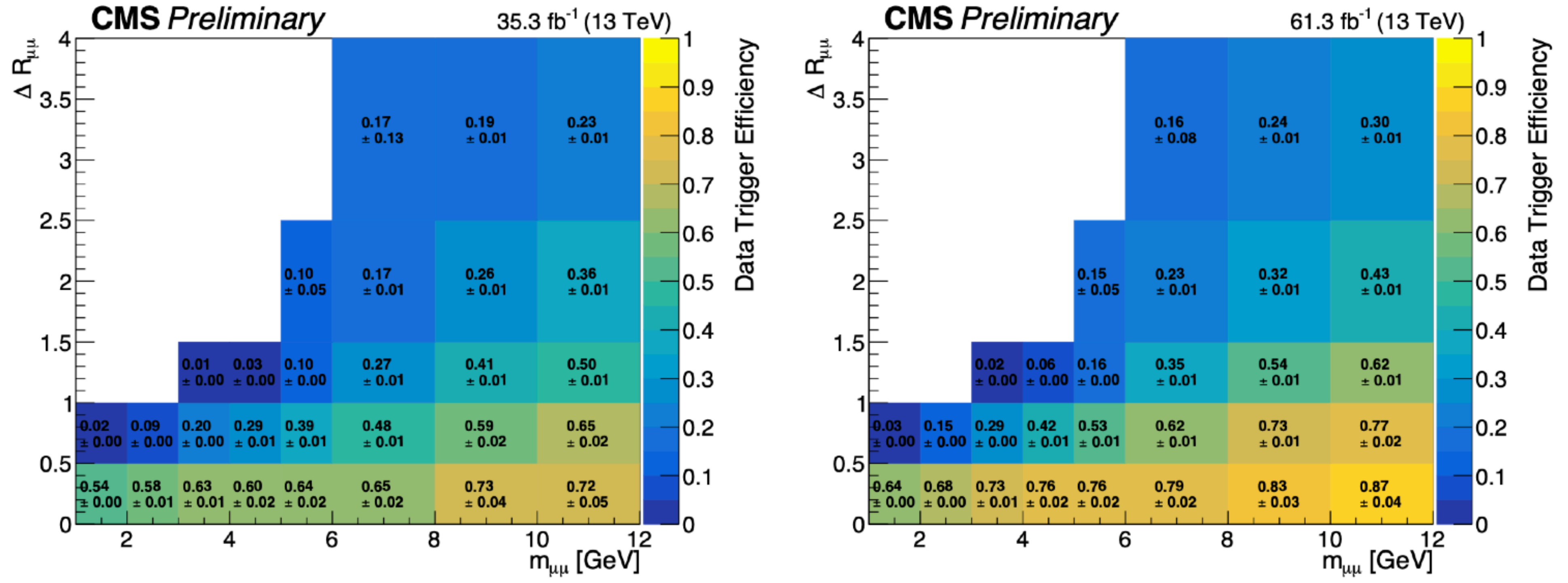


Figure 1: The 2017 (left) and 2018 (right) measured efficiencies of the dimuon scouting trigger and logical OR of all L1 triggers using 2017 data. The value of each cell shows the probability that a valid pair of muons which satisfy the trigger requirements will cause the dimuon scouting trigger to fire. The x-axis shows the dimuon mass and includes the entire relevant range for this analysis. The y-axis shows the angular separation, ΔR, between the two muons.

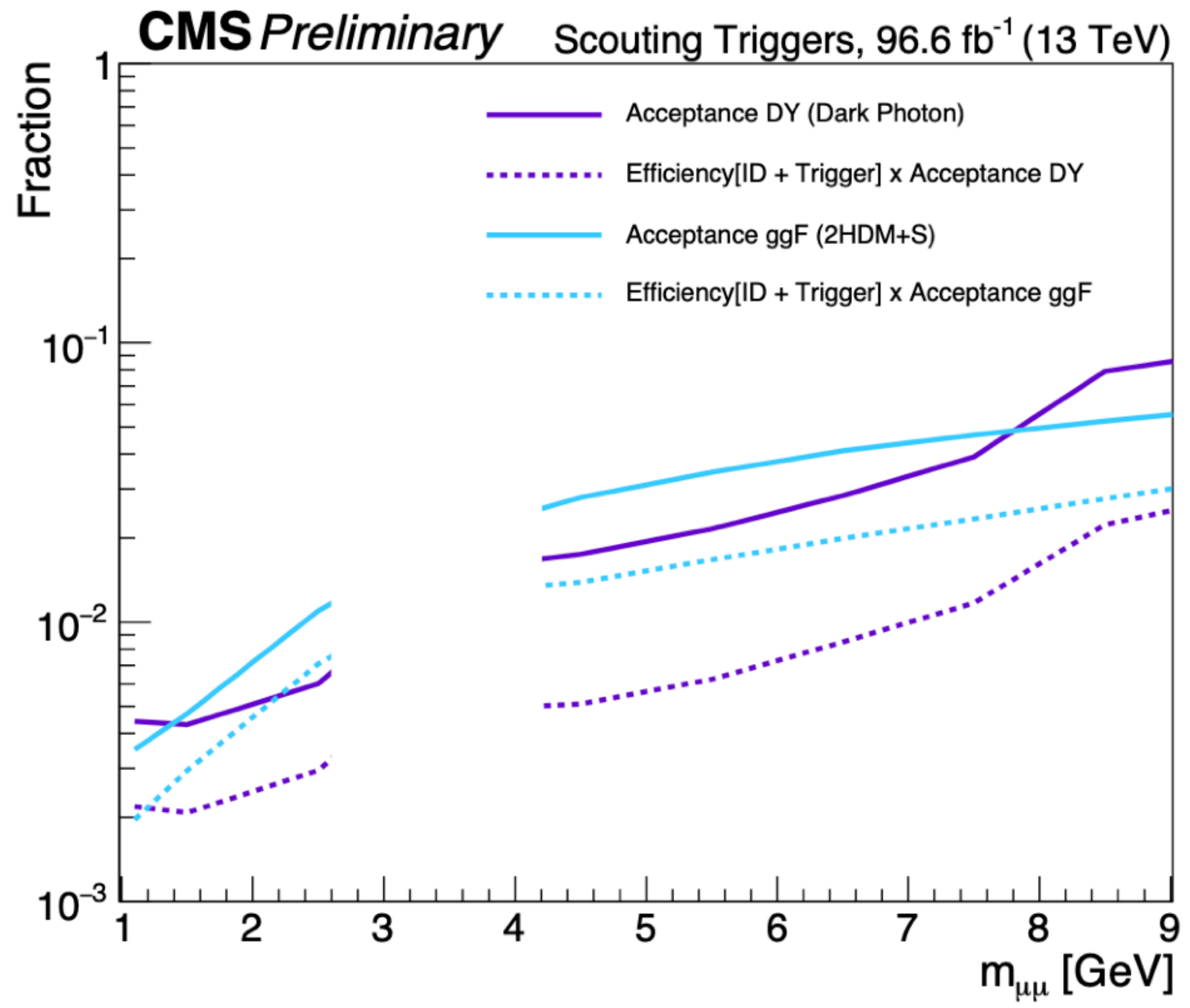


Figure 3: The signal acceptance and reconstruction efficiency are extracted from DY (purple) and pseudoscalar (cyan) simulations. The occluded region at 3.5–4.5 GeV indicates the transition between the J/ψ-trained and Υ(1S)-trained muon MVA identifications.

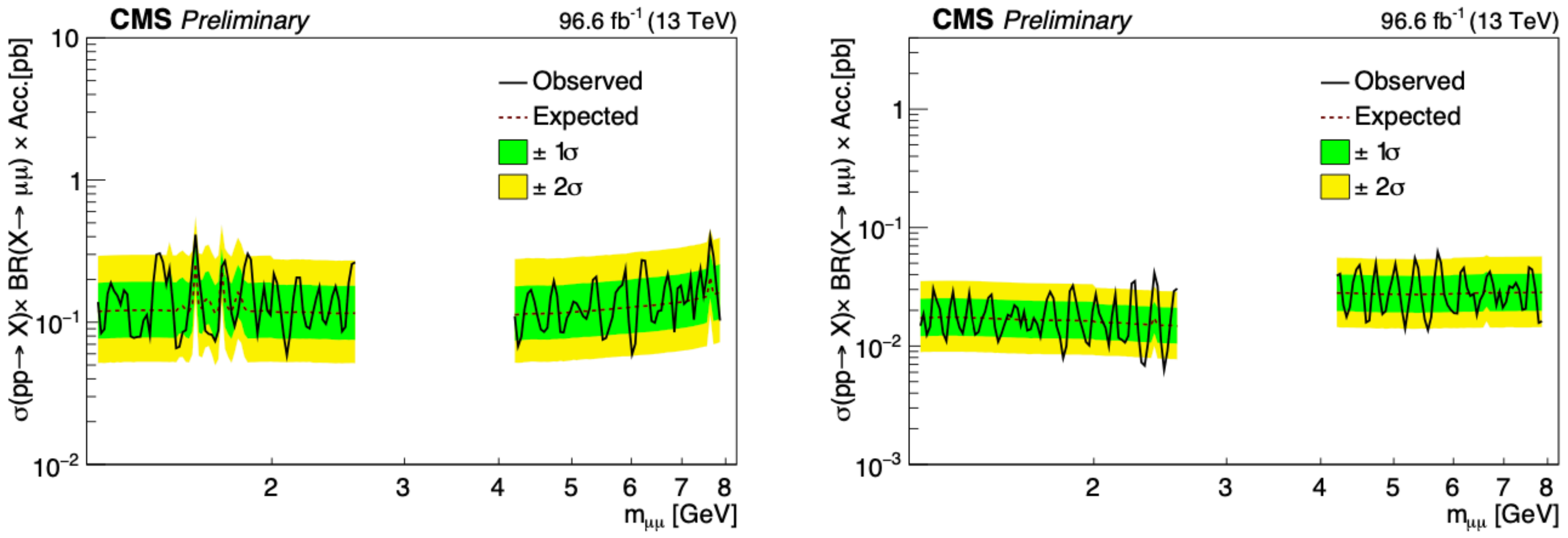
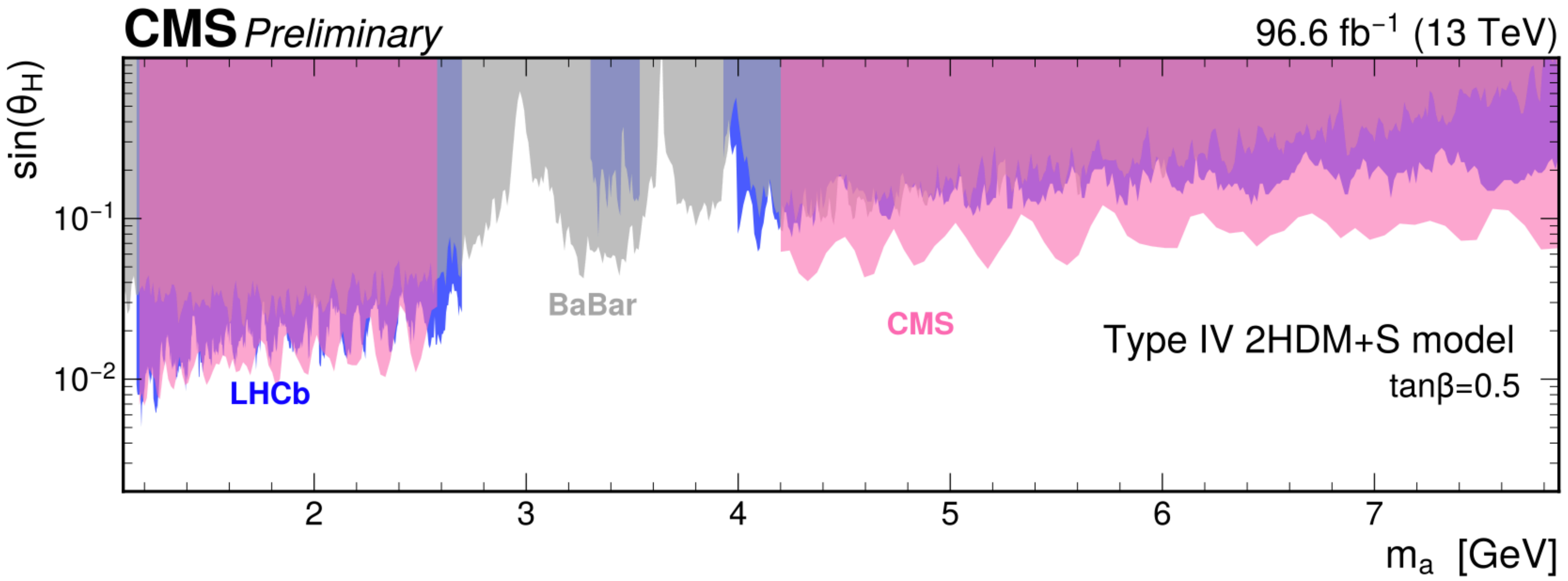


Figure 4: Left: Expected and observed model independent upper limits at 95% CL on the product of the signal cross section (σ) times branching fraction to a pair of muons for the inclusive dimuon selection. Right: The model independent limits for the high-p_T selection. The mass region dominated by the J/ψ and ψ' resonances is not considered in the fit.

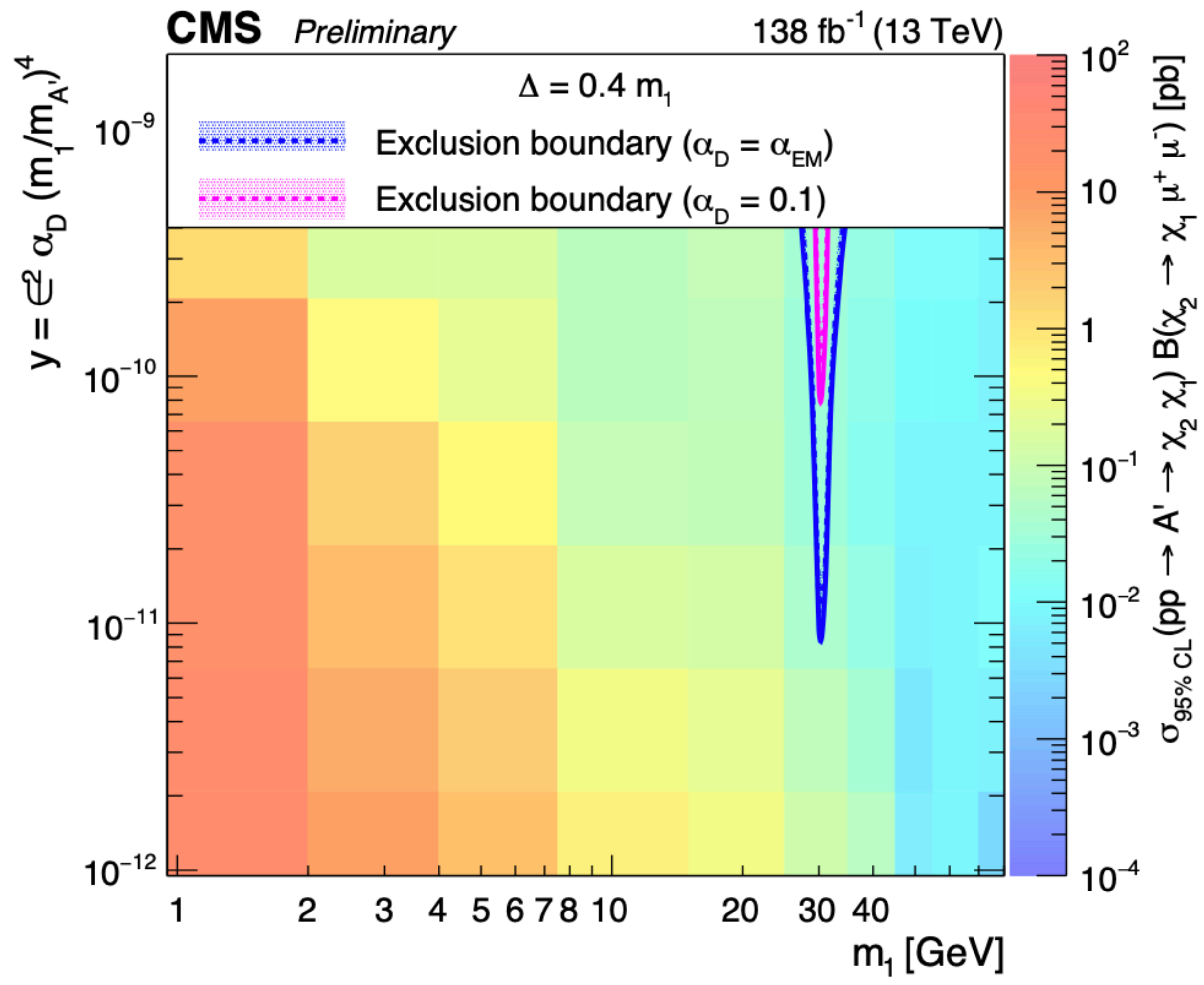


EXO-20-010

Search for inelastic dark matter

Table 1: Definition of ABCD bins and yields in data, per match category. The total signal systematic uncertainty averaged over all years is approximately 20%, 30%, and 40% for the 0-, 1-, and 2-match categories respectively (see supplemental material for a breakdown). The predicted yield in bin D is based on the assumption of zero signal.

Bin	0-match			1-match			2-match		
	$\Delta\phi_{\mu\mu}^{MET}$	min-d_{xy} [cm]	Events	$I_{\mathrm{PF}}^{\mathrm{rel}}$	min-d_{xy} [cm]	Events	$I_{\mathrm{PF}}^{\mathrm{rel}}$	min-d_{xy} [cm]	Events
Obs. A	0–0.1	3–15	68	> 0.25	0.02–0.75	716	> 0.25	0.02–0.15	424
Obs. B	0.1–0.5	3–15	9	< 0.25	0.02–0.75	33	< 0.25	0.02–0.15	22
Obs. C	0–0.1	> 15	9	> 0.25	> 0.75	12	> 0.25	> 0.15	10
Pred. D	0.1–0.5	> 15	1.2 ± 0.6	< 0.25	> 0.75	0.5 ± 0.3	< 0.25	> 0.15	0.5 ± 0.3
Obs. D			2			0			0



EXO-21-012

Search for dark matter in W+W- events with p_T^{miss}

Quantity	Selection
Number of leptons	2
Lepton flavors	eμ, μe
Lepton charges	Opposite
Additional leptons	0
$p_T^{\ell\,max}$	$> 25\,GeV$
$p_T^{\ell\,min}$	$> 20\,GeV$
$m_{\ell\ell}$	$> 12\,GeV$
$p_T^{\ell\ell}$	$> 30\,GeV$
p_T^{miss}	$> 20\,GeV$
$min(p_T^{miss,PF\ proj}, p_T^{miss,track\ proj})$	$> 20\,GeV$
$m_T^{\ell\ell,p_T^{miss}}$	$> 50\,GeV$
$\Delta R_{\ell\ell}$	< 2.5
Number of b-tagged jets	0

Table 2: Summary of the event preselection criteria in the di-leptonic channel.

Quantity	Selection
Number of leptons	1
Additional leptons	0
Number of jets	≥ 2
Non W-candidate b-tagged jets	0
m_{jj}	$> 65\,GeV, < 105\,GeV$
p_T^{miss}	$> 60\,GeV$
$p_T^{\ell jj}$	$> 60\,GeV$
$m_T^{\ell,p_T^{miss}}$	$> 80\,GeV$
$\Delta R_{\ell,jj}$	< 3
$\Delta\phi_{\ell,jj}$	< 1.8
$\Delta\phi_{\ell jj,p_T^{miss}}$	> 2

Table 4: Summary of the event preselection criteria for the semi-leptonic channel.

EXO-21-012

Search for dark matter in W^+W^- events with $p_{\mathrm{T}}^{\mathrm{miss}}$

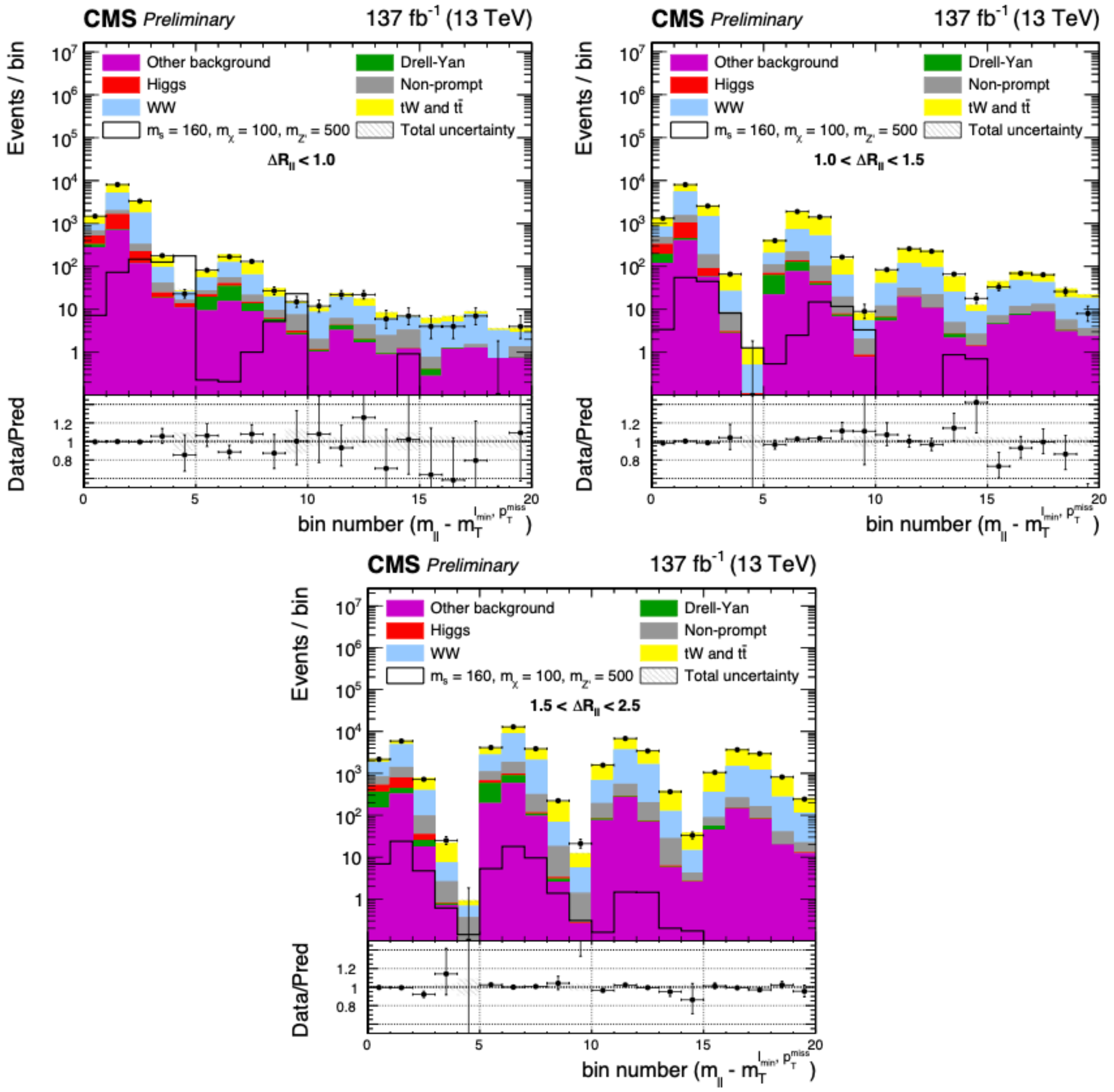


Figure 3: Unrolled $m_{\ell\ell}$-$m_{\mathrm{T}}^{\ell\,\mathrm{min},p_{\mathrm{T}}^{\mathrm{miss}}}$ post-fit distributions in the di-leptonic channel for three signal regions SR1 (top left), SR2 (top right), and SR3 (bottom), for the full data set. The histogram bins are spaced uniformly. Each group of five bins (from left to right) corresponds to the $m_{\mathrm{T}}^{\ell\,\mathrm{min},p_{\mathrm{T}}^{\mathrm{miss}}}$ distribution in a $m_{\ell\ell}$ region, placed in ascending order. The black line indicates the signal prediction for $m_s = 160\,\mathrm{GeV}$, $m_\chi = 100\,\mathrm{GeV}$, $m_{Z'} = 500\,\mathrm{GeV}$.

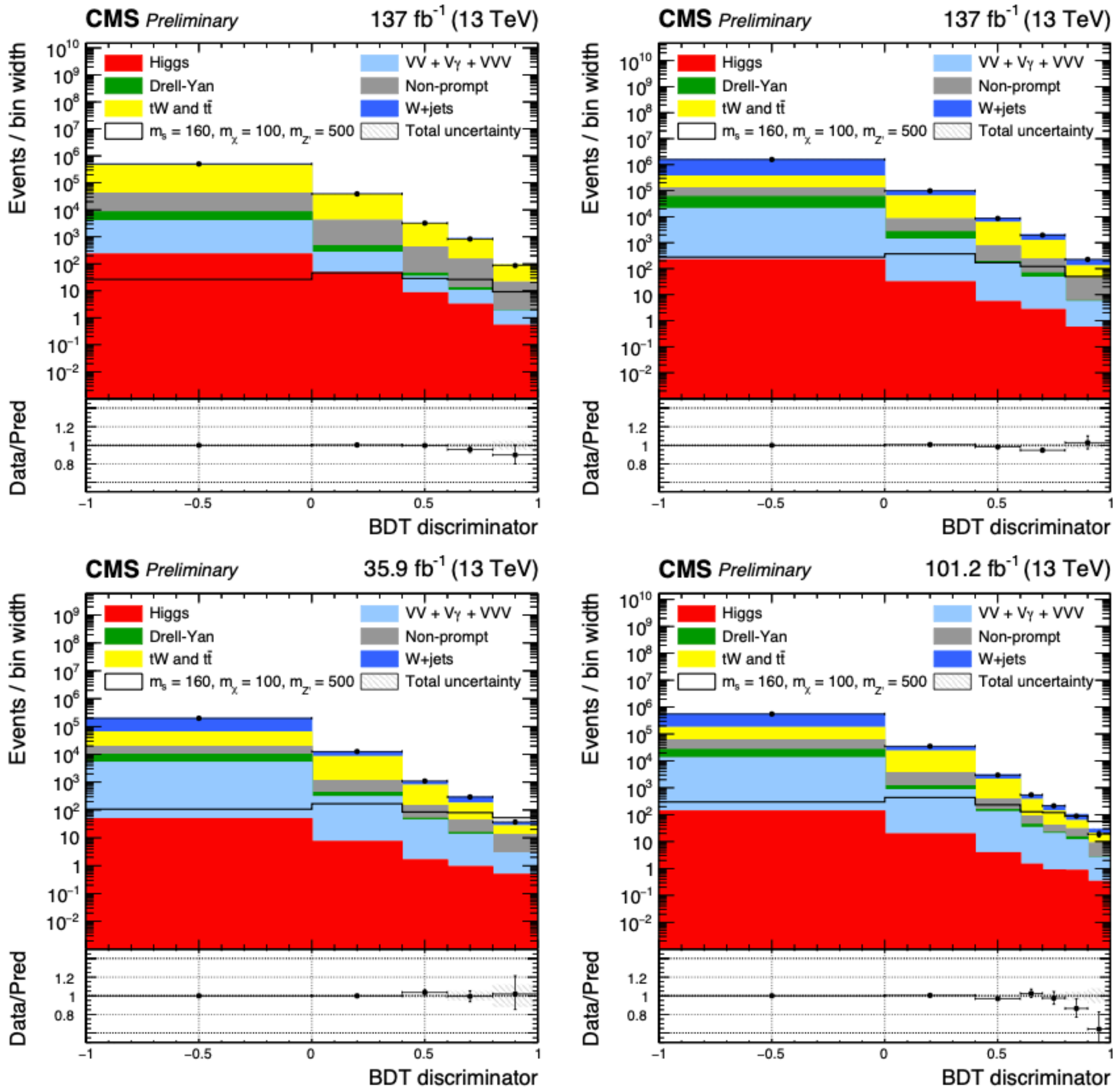


Figure 4: Post-fit BDT distributions in the semi-leptonic channel for the full data set in the top CR (top left) and W + jets CR (top right). The signal region has different binning in 2016 (bottom left) and 2017-2018 (bottom right) to ensure good statistical precision in all bins. The red line indicates the signal prediction when $m_s = 160\,\mathrm{GeV}$, $m_\chi = 100\,\mathrm{GeV}$, $m_{Z'} = 500\,\mathrm{GeV}$.

EXO-21-012

Search for dark matter in W+W- events with $p_{\mathrm{T}}^{\mathrm{miss}}$

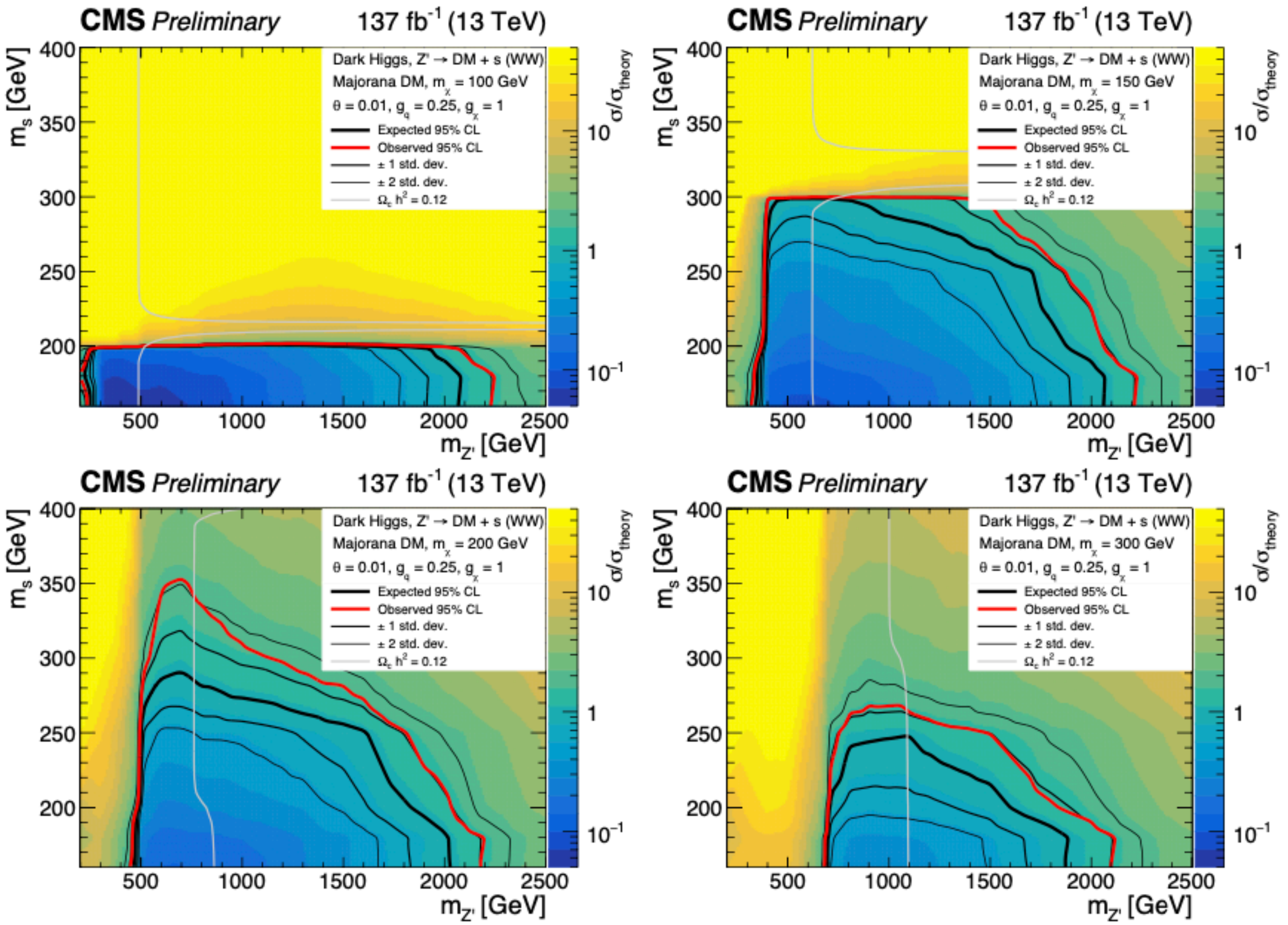


Figure 5: Observed (expected) exclusion regions at 95% CL for the dark Higgs model in the $(m_s, m_{Z'})$ plane, marked by the solid red (black) line. The expected $\pm 1\sigma$ and $\pm 2\sigma$ bands are shown as the thinner black lines. Upper left: $m_\chi = 100\,\mathrm{GeV}$, upper right: $m_\chi = 150\,\mathrm{GeV}$, lower left: $m_\chi = 200\,\mathrm{GeV}$, lower right: $m_\chi = 300\,\mathrm{GeV}$. The gray line indicates were the model parameters produce exactly the observed relic density $\Omega_c h^2 = 0.12$ [7].

In this analysis only the decay of the dark Higgs boson to a pair of visible W bosons is considered; this decay mode is dominant in the phase space analyzed. In the case where $m_s \geq 2m_\chi$, however, the dark Higgs boson decays predominantly to a pair of DM particles. The consequence of this change of decay mode can be seen in Fig. 5: there is a boundary reflecting a sharp drop of sensitivity in the upper-left (upper-right) plot corresponding to m_s equal to twice the DM particle mass of 100 GeV (150 GeV).

EXO-21-013

Search for long-lived heavy neutral leptons decaying to jet + e/μ/τ

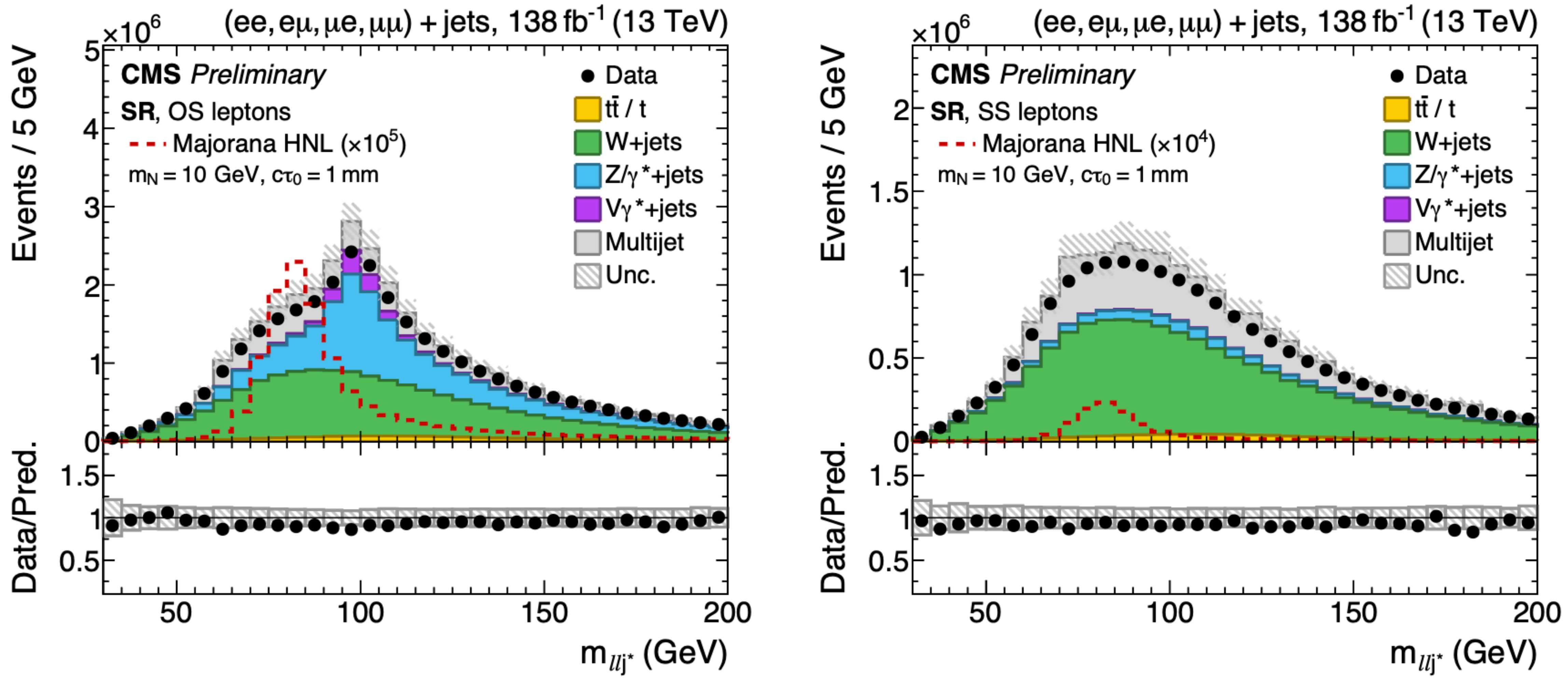


Figure 2: Distributions of $m_{llj^{\star}}$ for events with (left) opposite-sign (OS) and (right) same-sign (SS) leptons in the signal region. A representative signal scenario for Majorana HNL production with equal coupling to all lepton generations is overlaid with its expected cross section scaled up as indicated. The hatched band shows the total experimental systematic uncertainty on the simulated samples.

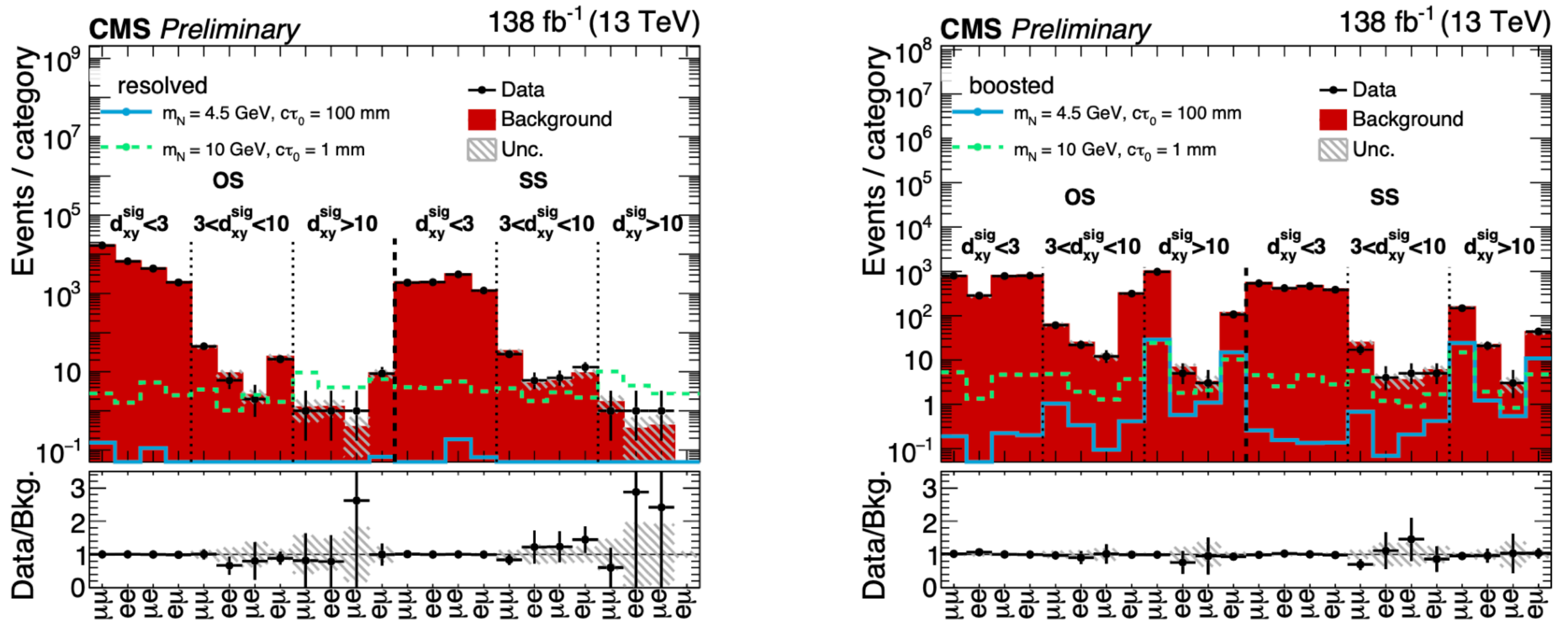
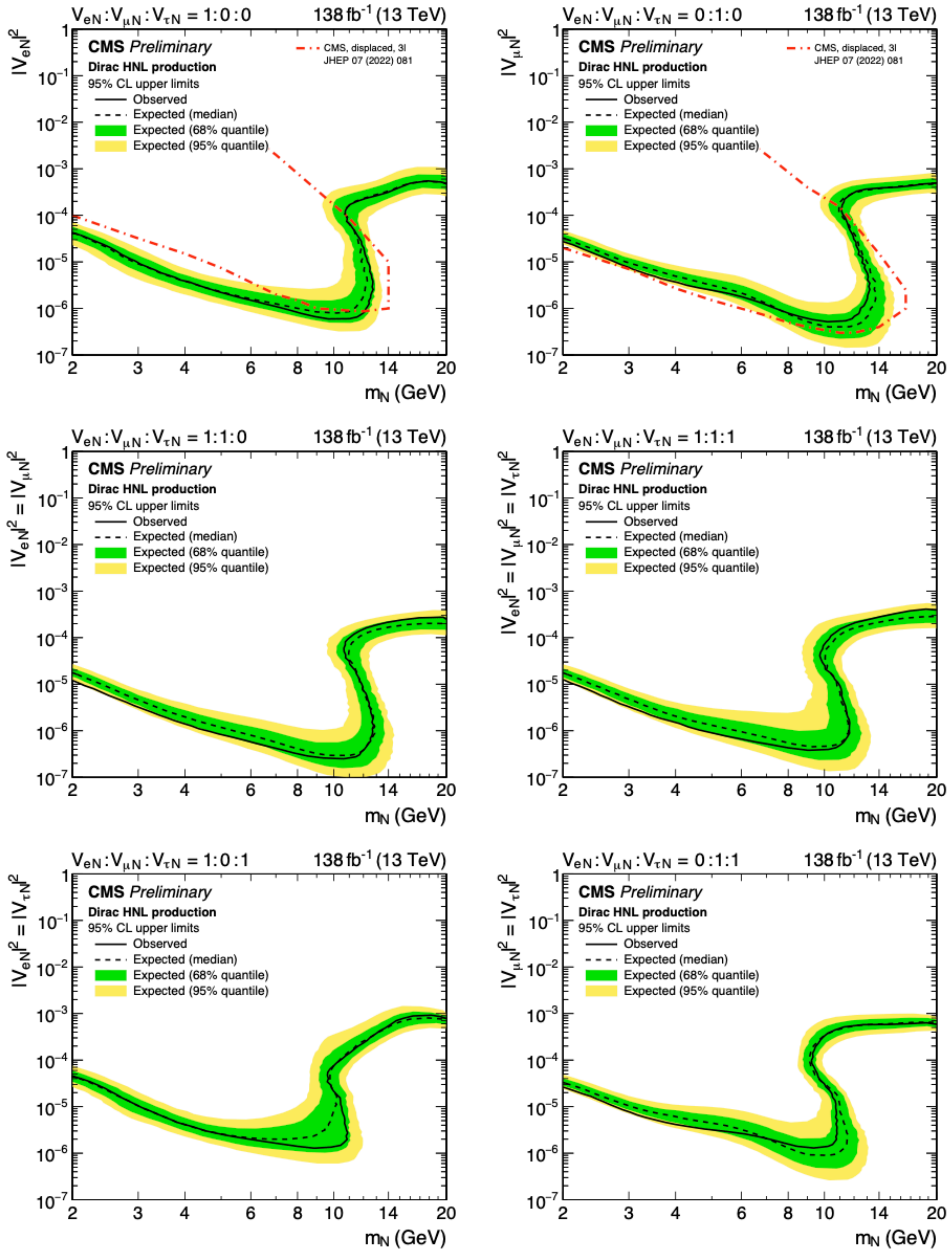
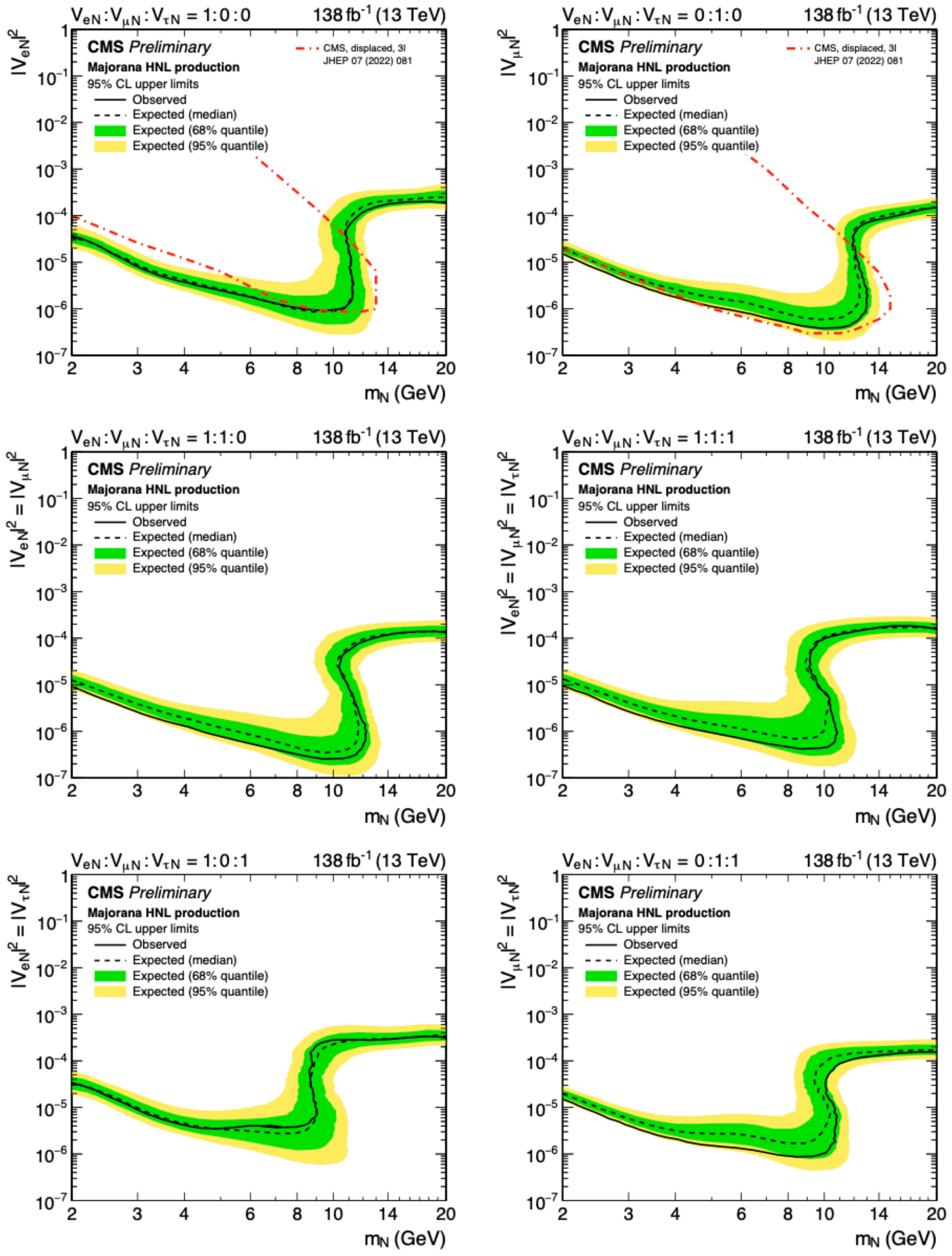


Figure 4: Observed number of events and predicted number of background events per category for (left) resolved and (right) boosted categories. Two representative signal scenarios for Majorana HNL production with equal coupling to all lepton generations are overlaid. The bottom panel shows the ratio of the data over the predicted background. The hatched band shows the total systematic uncertainty on the predicted background.

EXO-21-013

Search for long-lived heavy neutral leptons decaying to jet + e/μ/τ





EXO-21-013

Search for long-lived heavy neutral leptons decaying to jet + e/μ/τ

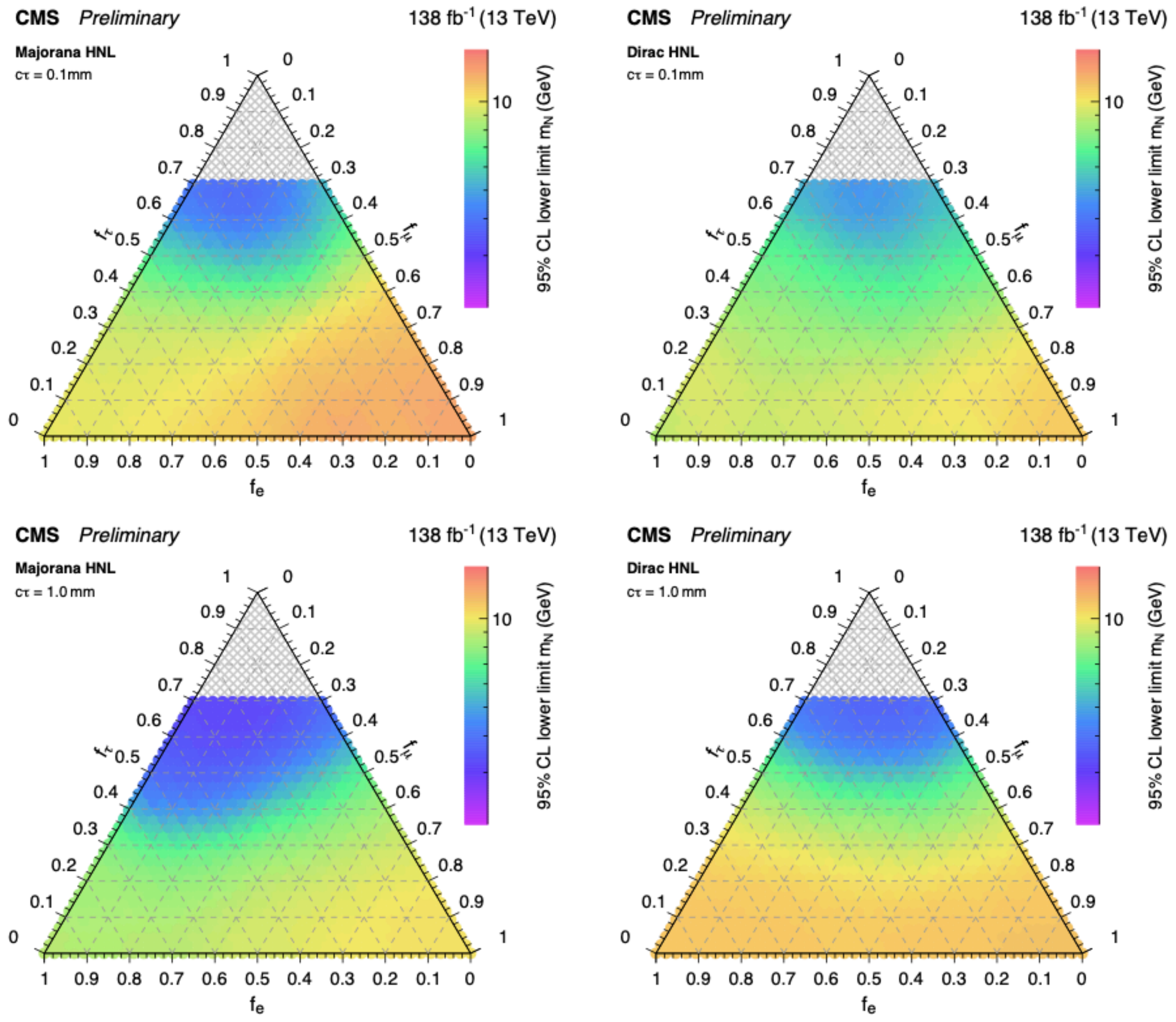


Figure 7: Observed 95% CL lower limits on the (left column) Majorana and (right column) Dirac HNL mass as a function of the relative coupling to the three lepton generations considering a fixed proper lifetime of (top row) 0.1 mm and (bottom row) 1 mm. The limits are determined within $2 < m_N < 20$ GeV.

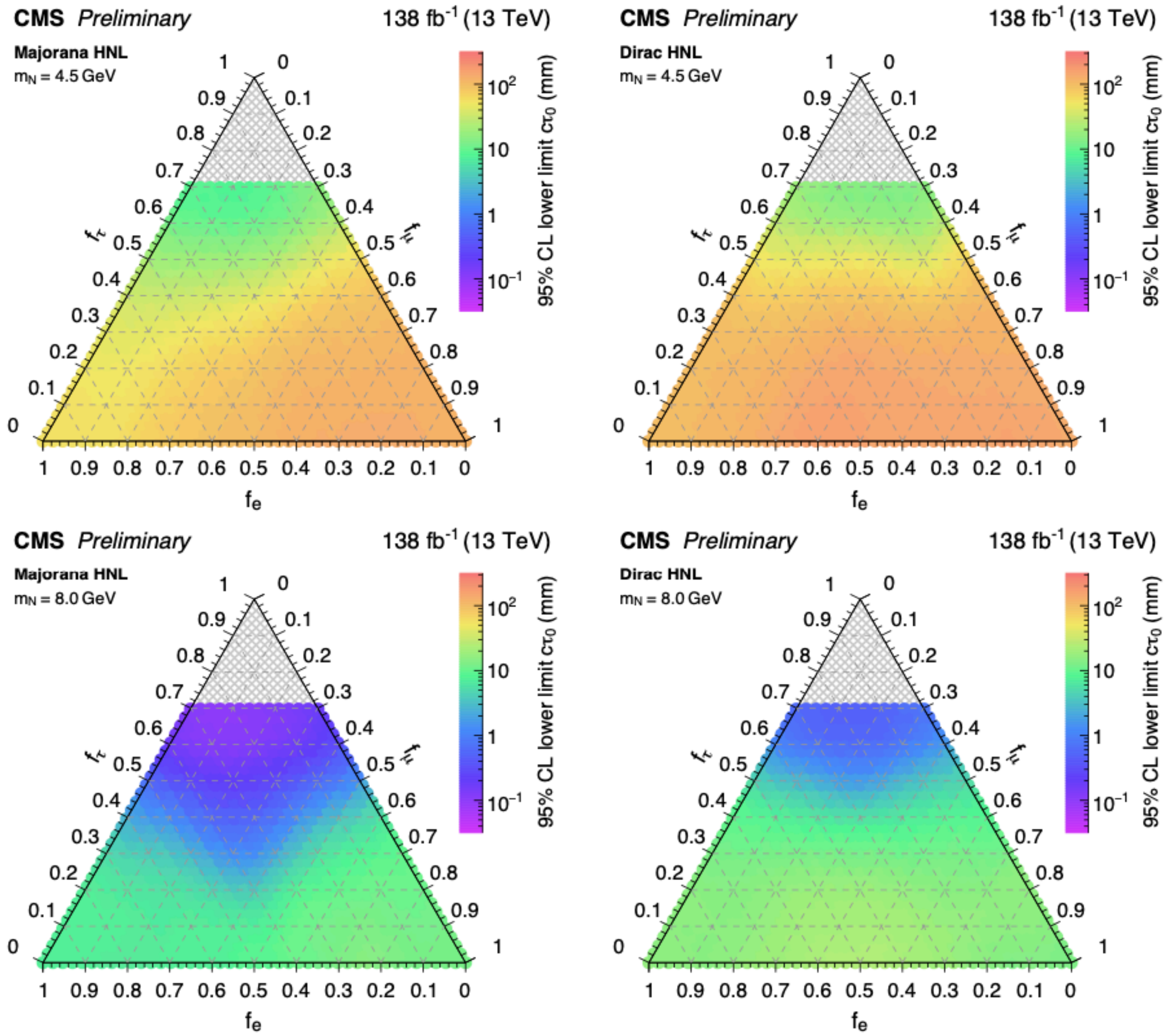
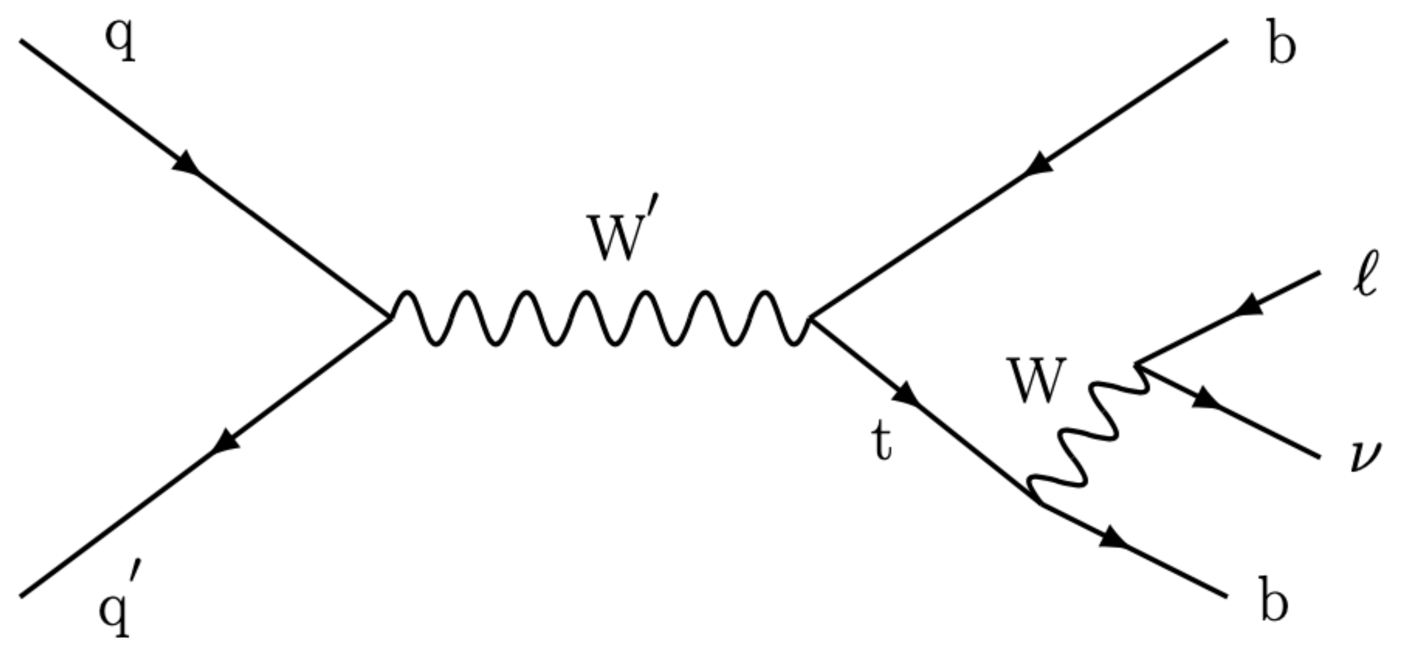
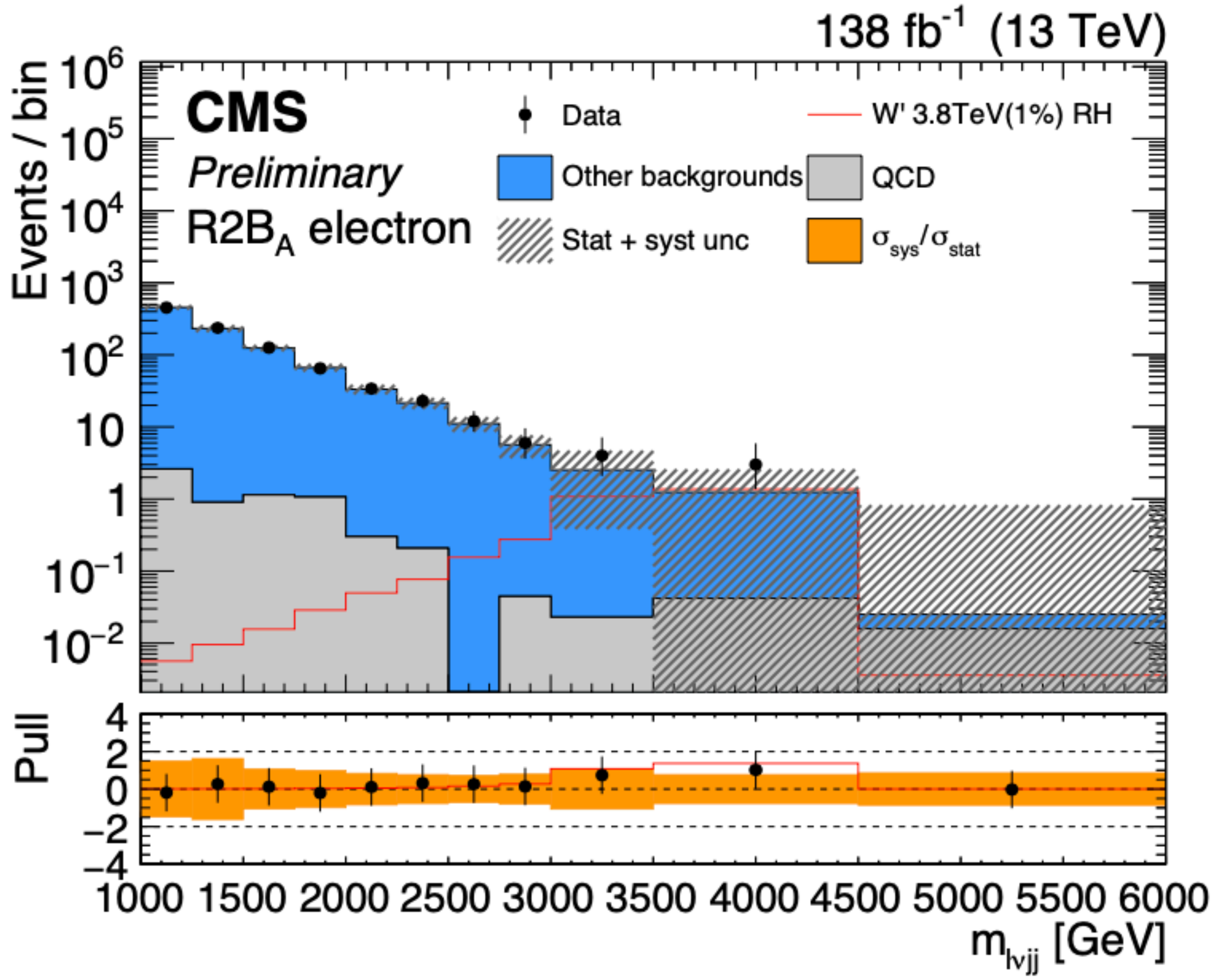


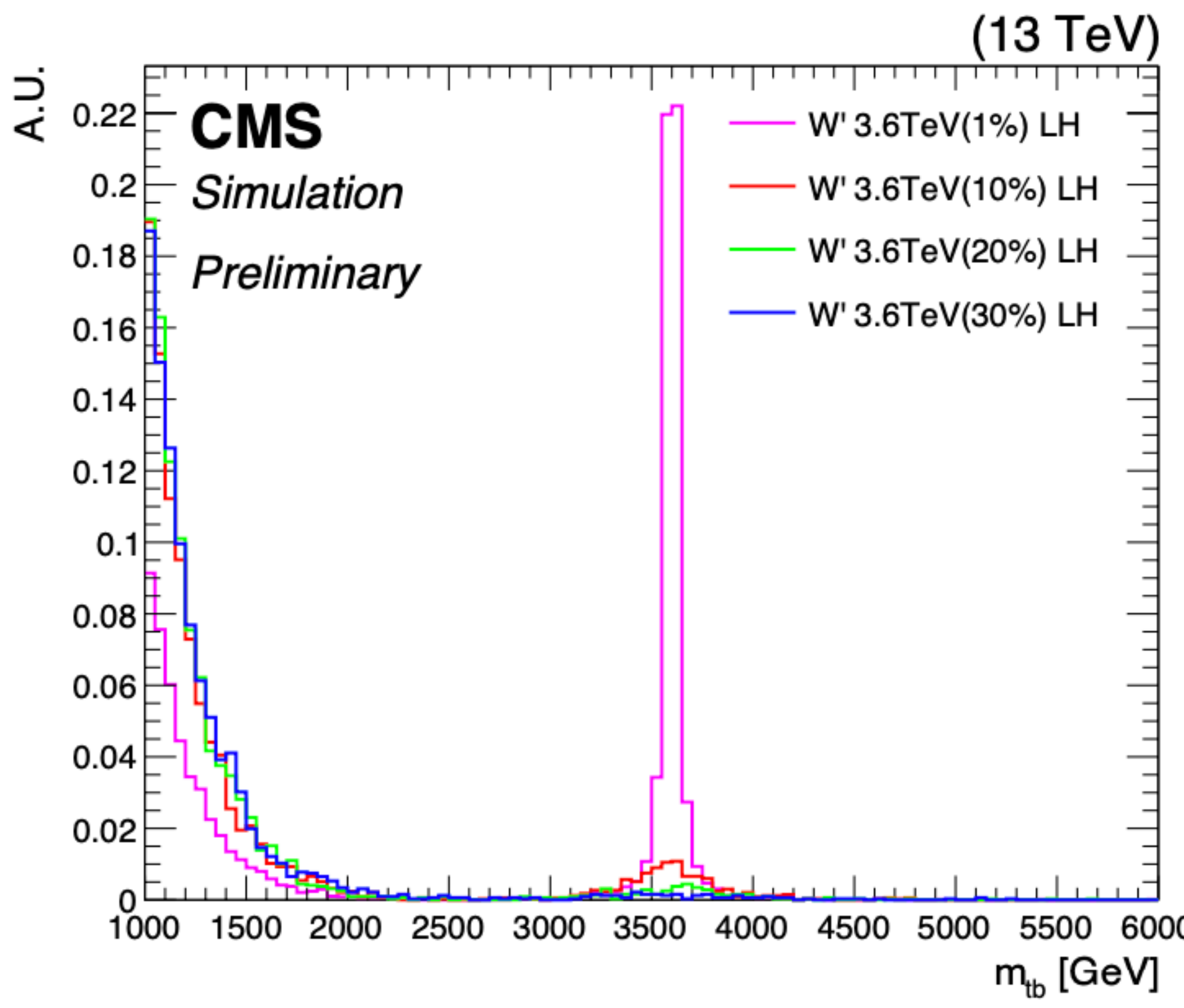
Figure 8: Observed 95% CL lower limits on the (left column) Majorana and (right column) Dirac HNL proper lifetime as a function of the relative coupling to the three lepton generations considering a fixed mass of (top row) 4.5 GeV and (bottom row) 8.0 GeV.

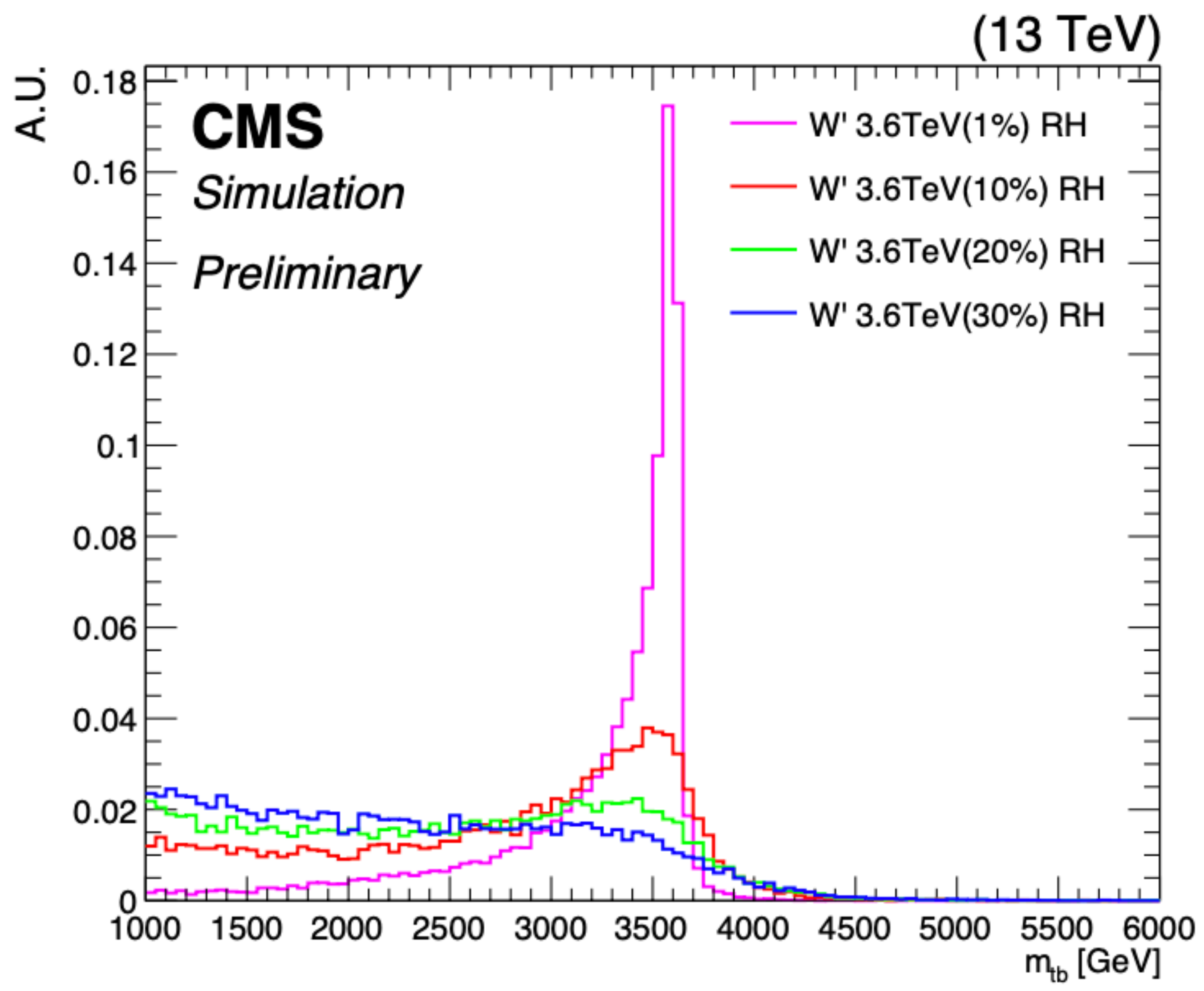
B2G-20-012

Search for $W' \to tb$ in leptonic final states







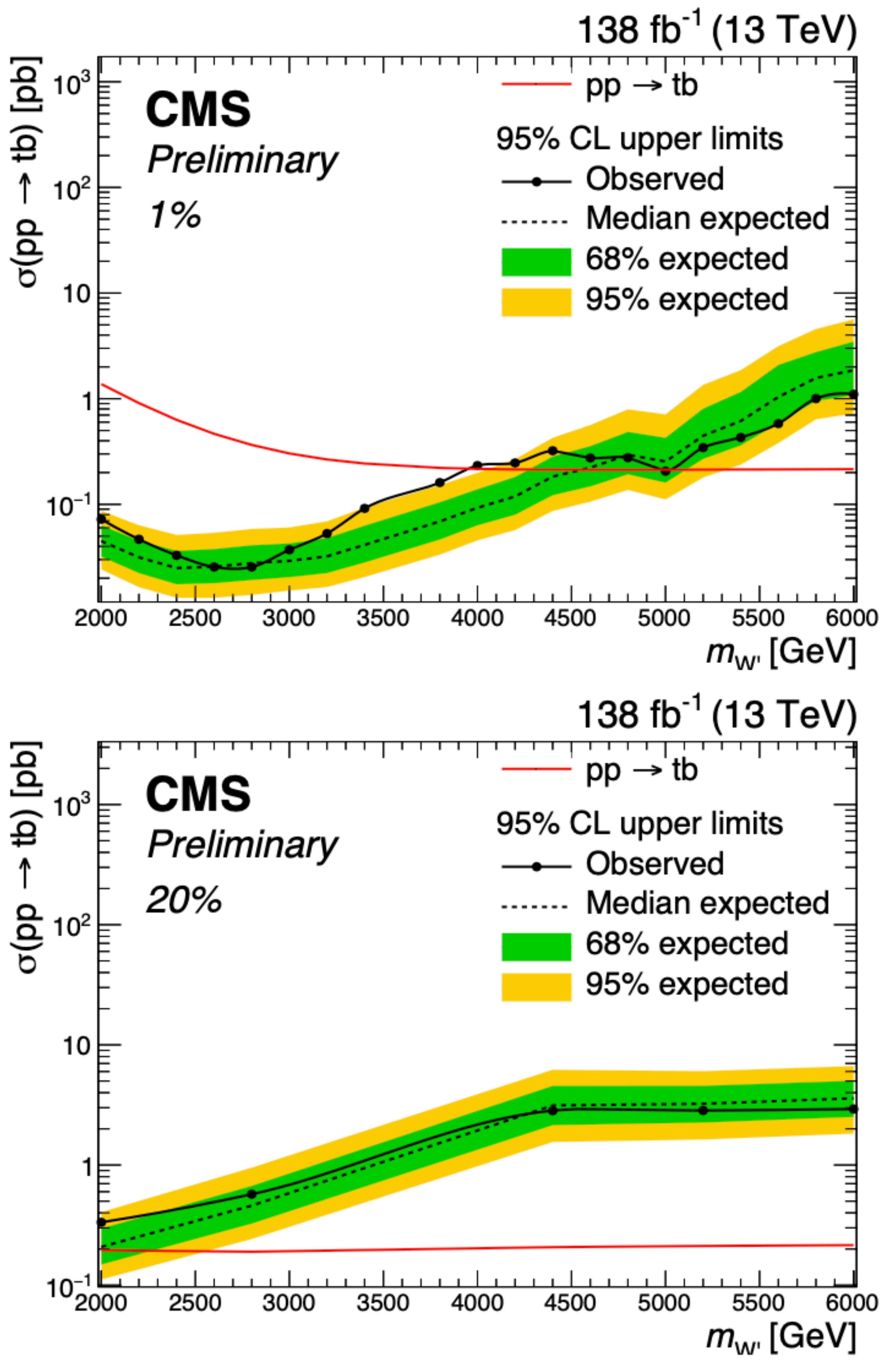


For the left-handed hypothesis, the region of the W′ boson mass spectrum below 2 TeV is dominated by the standard model *s*-channel production of a top-bottom quark pair. The width of the W′ affects the reconstructed mass distribution, resulting in a broader peak and an asymmetry favoring lower values. This is quite visible for the cases with large decay width, where the tail towards small masses is dominant because of off-shell W′ production, enhanced by rapidly increasing parton density functions for decreasing partonic momentum fractions.

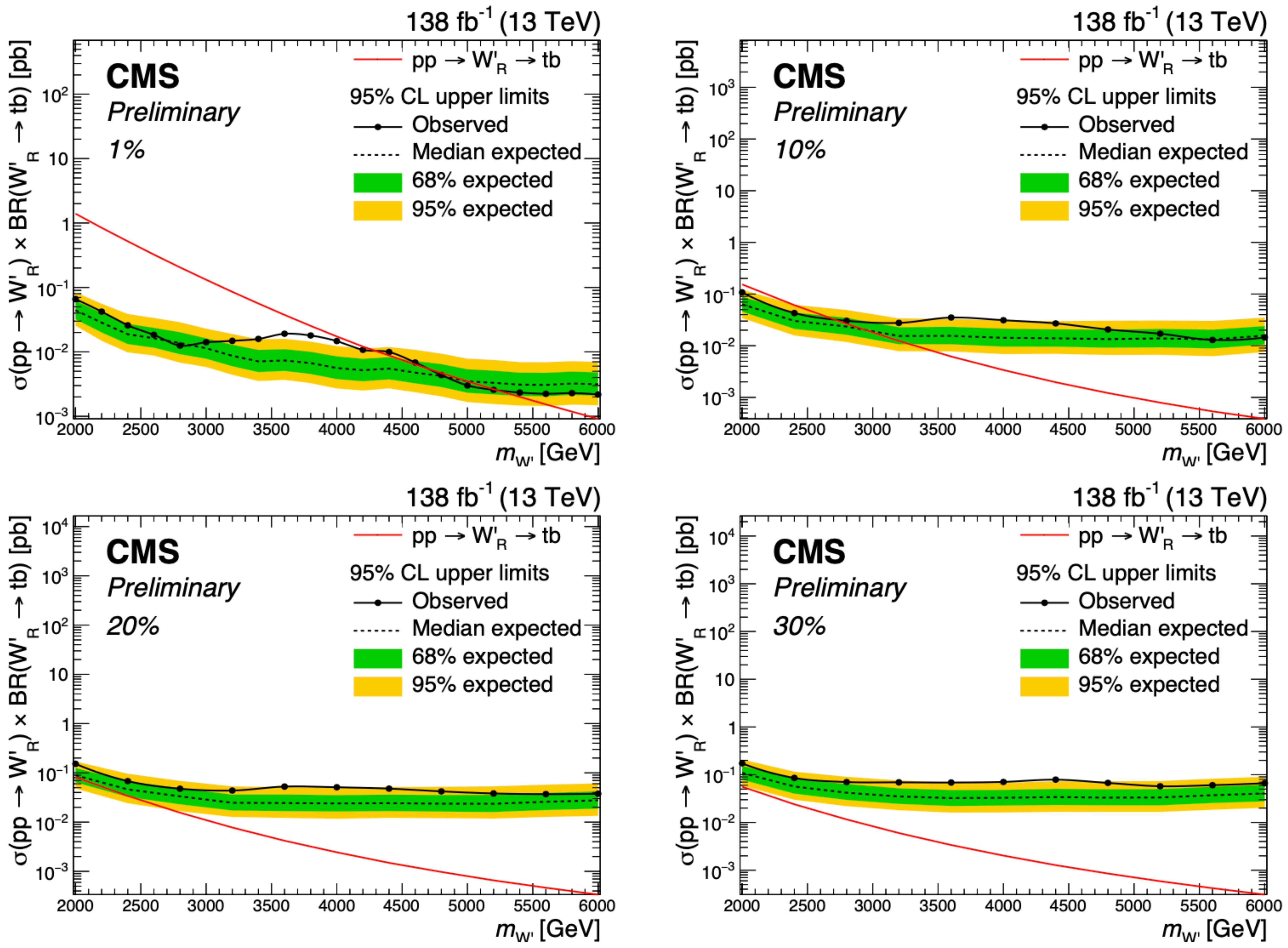
B2G-20-012

Search for $W' \to tb$ in leptonic final states

Left handed



Right handed



Search for $b^* \rightarrow tW$ with lepton+jets