BSM Searches in CMS

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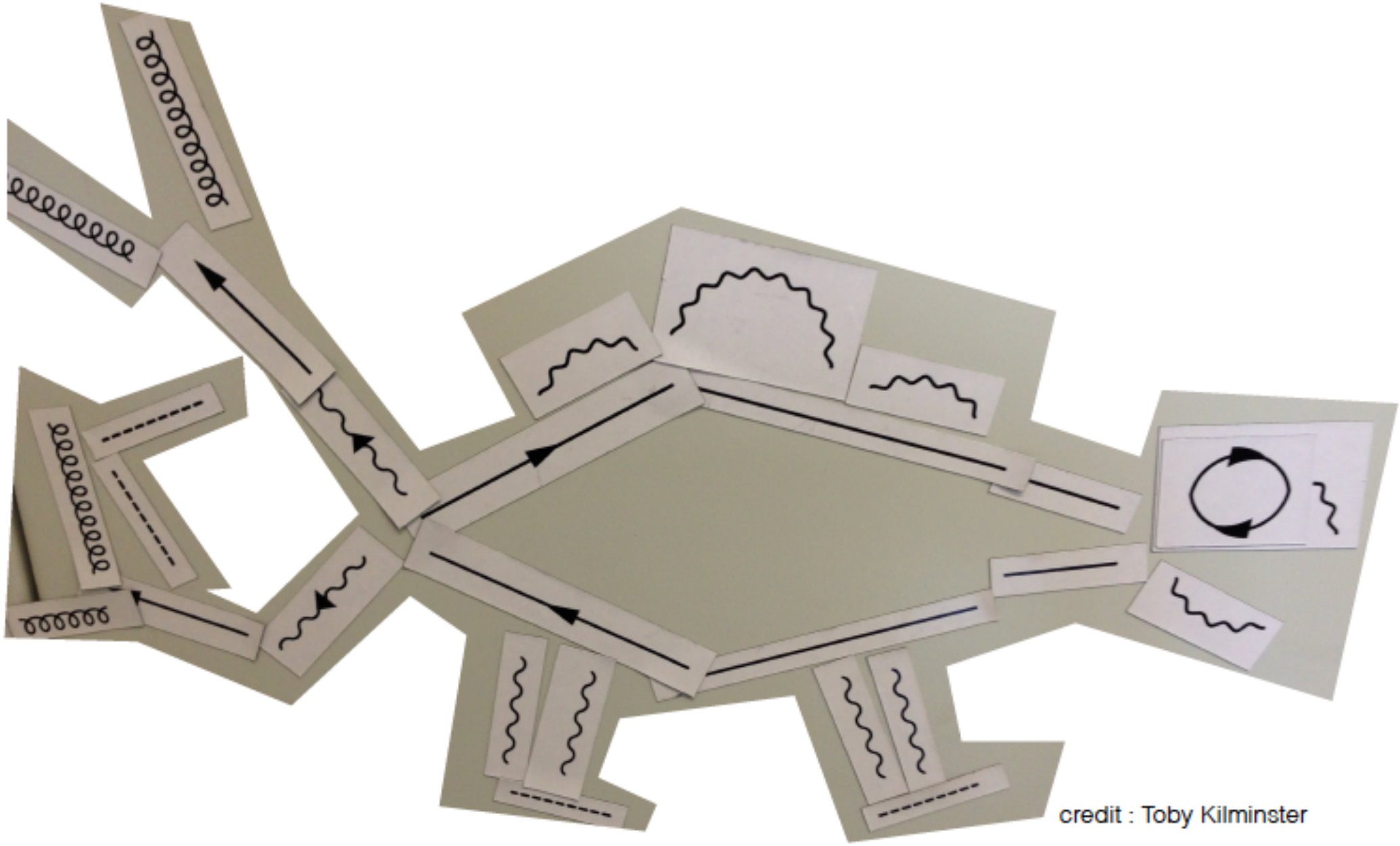
On Behalf of the CMS Collaboration

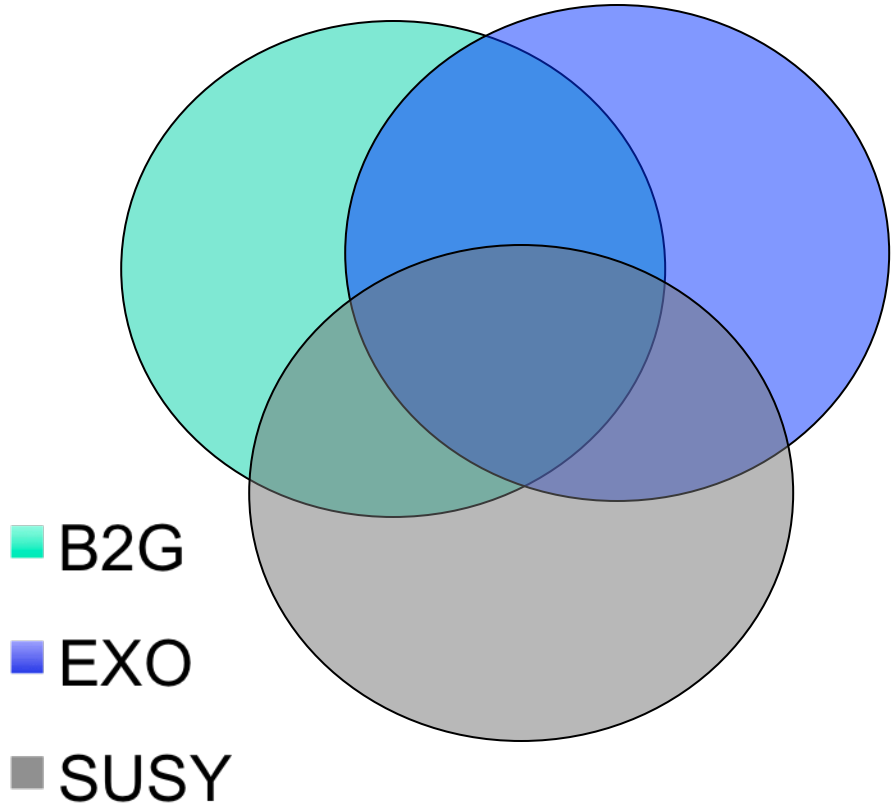
Introduction

- We know that the SM isn't the entire story, but so far searches at the LHC haven't given us much hint as to where to search
- We look for heavy particles because they appear in popular BSMs:
  - GUT, extradimension, composite top, . . .
  - … and they haven't been excluded by previous experiments
- Variety of theories:
  - Little Higgs/ Composite Higgs, string theory, SUSY, MSSM, RS models, extra dimesions
- Yield a variety of particles:
  - Dark matter candidates, sparticles, Vector-like quarks, Excited Quarks, gravitons, leptoquarks

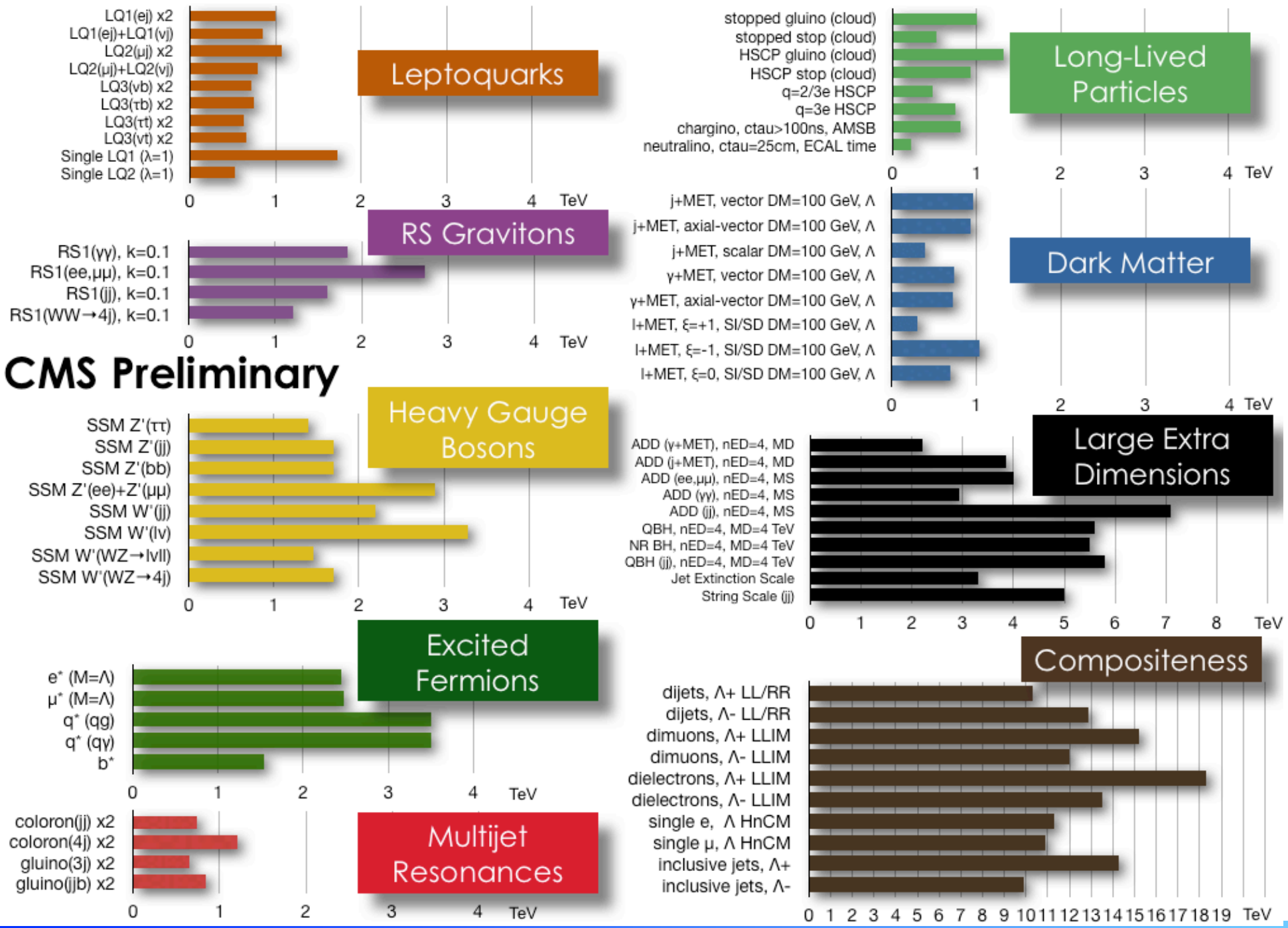
Exotasaurus



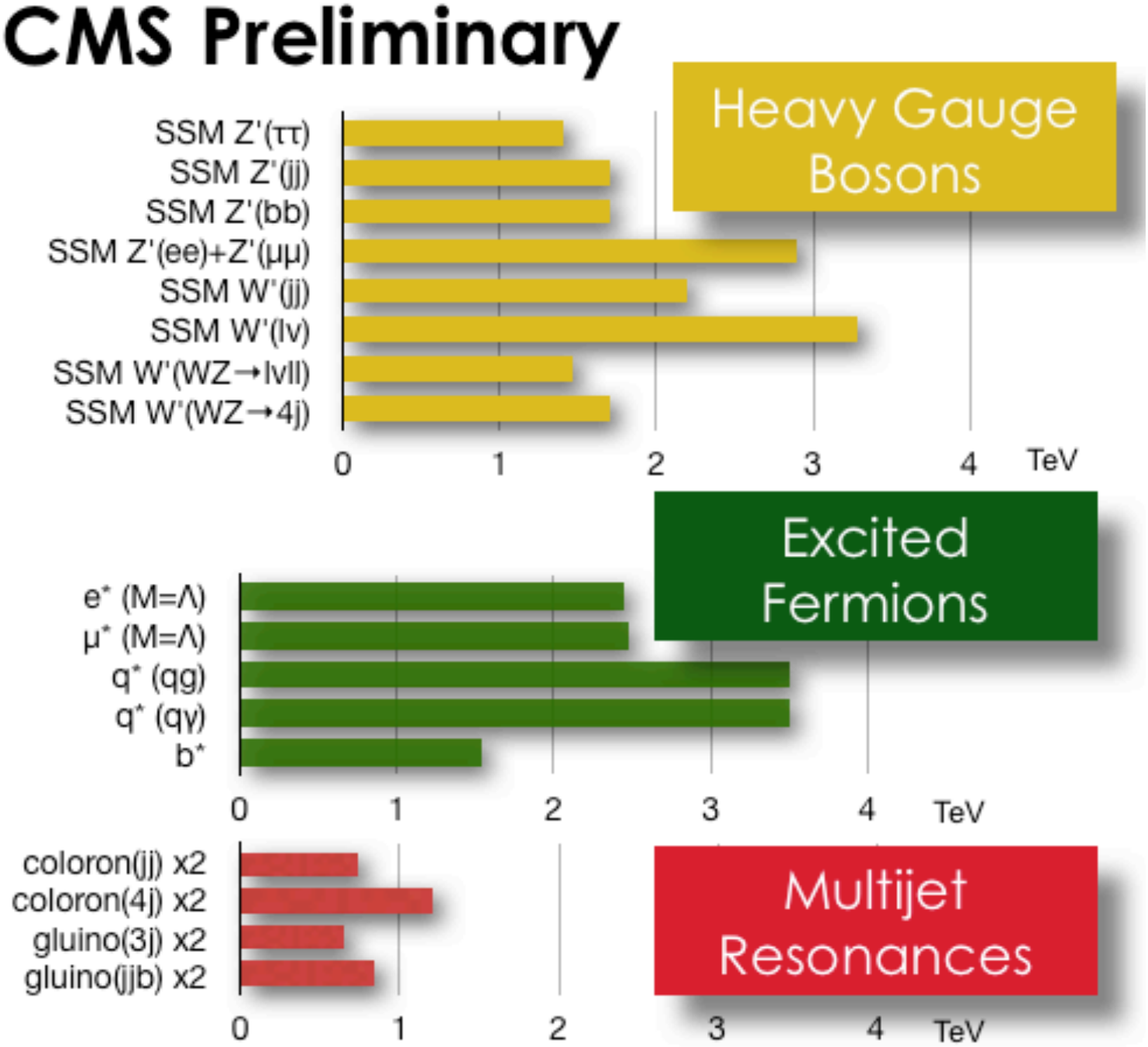
- 152 BSM publications from Run I (and counting)



Exotica

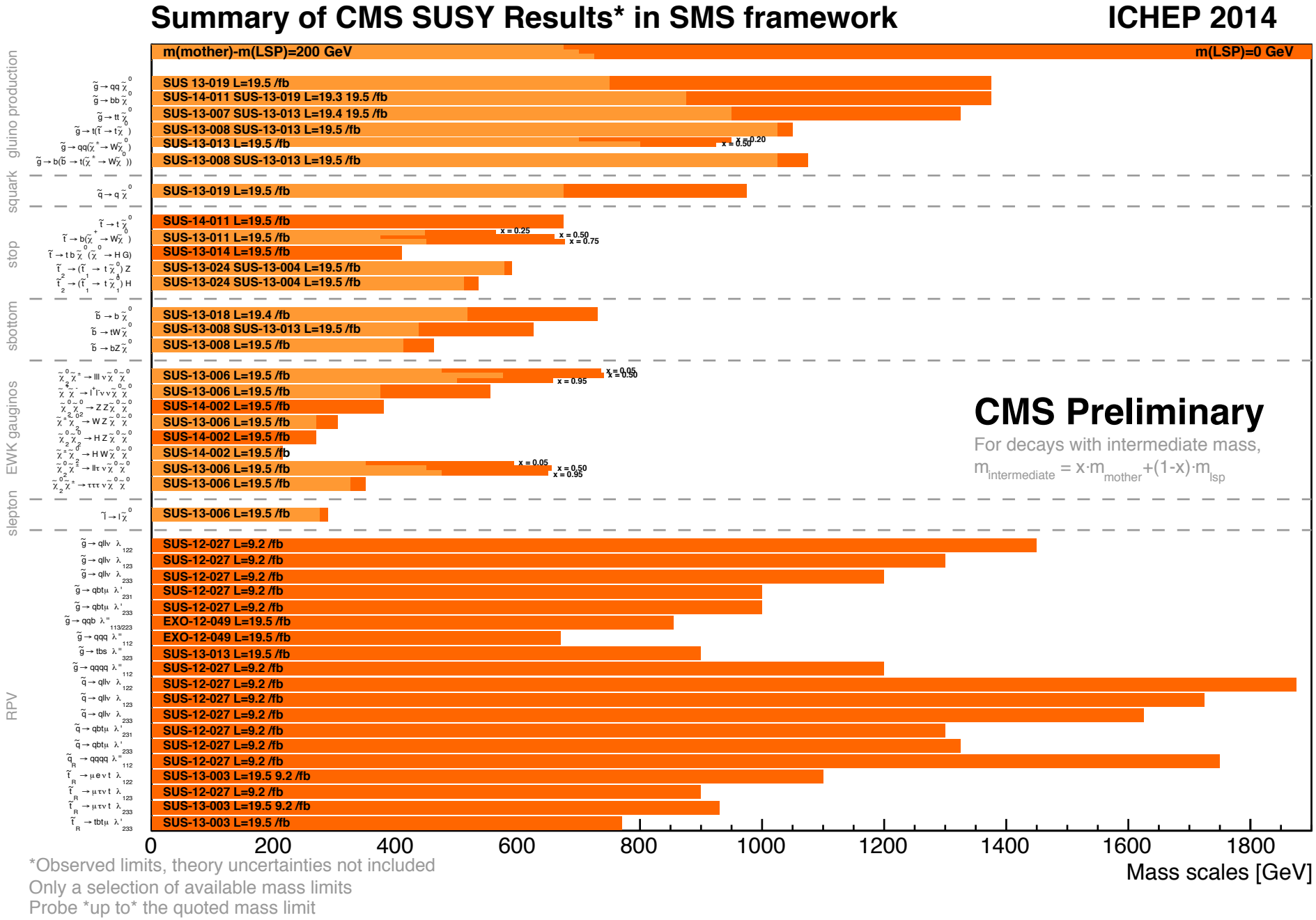

Leptoquarks
LQ1(ej) x2
LQ1(ej)+LQ1(νj)
LQ2(μj) x2
LQ2(μj)+LQ2(νj)
LQ3(νb) x2
LQ3(τb) x2
LQ3(τt) x2
LQ3(νt) x2
Single LQ1 (λ=1)
Single LQ2 (λ=1)
0 1 2 3 4 TeV
RS Gravitons
RS1(γγ), k=0.1
RS1(ee,μμ), k=0.1
RS1(jj), k=0.1
RS1(WW→4j), k=0.1
0 1 2 3 4 TeV
CMS Preliminary
Heavy Gauge Bosons
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(bb)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lν)
SSM W'(WZ→lνll)
SSM W'(WZ→4j)
0 1 2 3 4 TeV
Excited Fermions
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ)
b*
0 1 2 3 4 TeV
Multijet Resonances
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
0 1 2 3 4 TeV
Long-Lived Particles
stopped gluino (cloud)
stopped stop (cloud)
HSCP gluino (cloud)
HSCP stop (cloud)
q=2/3e HSCP
q=3e HSCP
chargino, ctau>100ns, AMSB
neutralino, ctau=25cm, ECAL time
0 1 2 3 4 TeV
Dark Matter
j+MET, vector DM=100 GeV, Λ
j+MET, axial-vector DM=100 GeV, Λ
j+MET, scalar DM=100 GeV, Λ
γ+MET, vector DM=100 GeV, Λ
γ+MET, axial-vector DM=100 GeV, Λ
l+MET, ξ=+1, SI/SD DM=100 GeV, Λ
l+MET, ξ=-1, SI/SD DM=100 GeV, Λ
l+MET, ξ=0, SI/SD DM=100 GeV, Λ
0 1 2 3 4 TeV
Large Extra Dimensions
ADD (γ+MET), nED=4, MD
ADD (j+MET), nED=4, MD
ADD (ee,μμ), nED=4, MS
ADD (γγ), nED=4, MS
ADD (jj), nED=4, MS
QBH, nED=4, MD=4 TeV
NR BH, nED=4, MD=4 TeV
QBH (jj), nED=4, MD=4 TeV
Jet Extinction Scale
String Scale (jj)
0 1 2 3 4 5 6 7 8 TeV
Compositeness
dijets, Λ+ LL/RR
dijets, Λ- LL/RR
dimuons, Λ+ LLIM
dimuons, Λ- LLIM
dielectrons, Λ+ LLIM
dielectrons, Λ- LLIM
single e, Λ HnCM
single μ, Λ HnCM
inclusive jets, Λ+
inclusive jets, Λ-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 TeV

Exotica



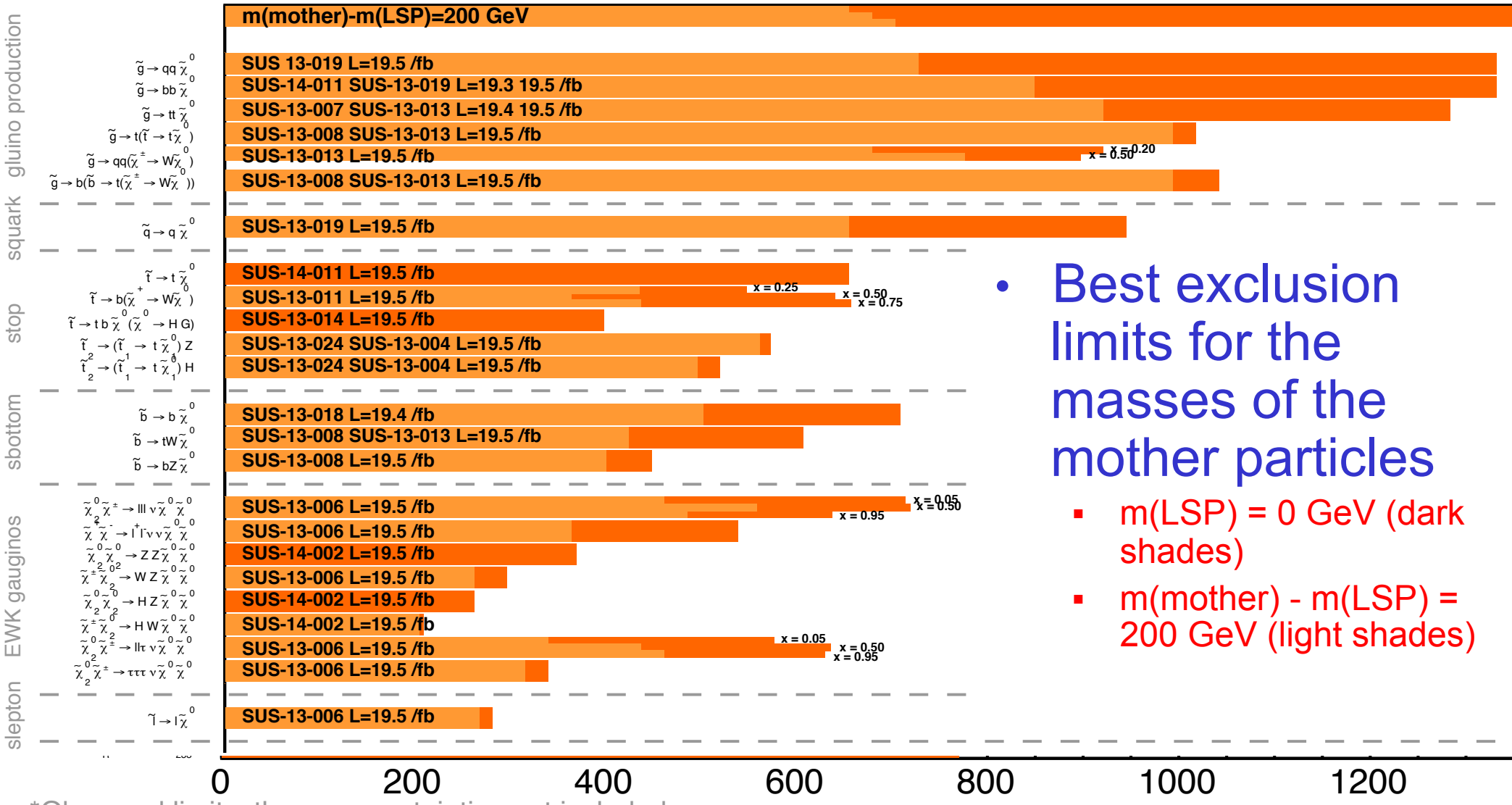
- Results from Moriond 2015

SUSY



*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Summary of CMS SUSY Results* in SMS framework



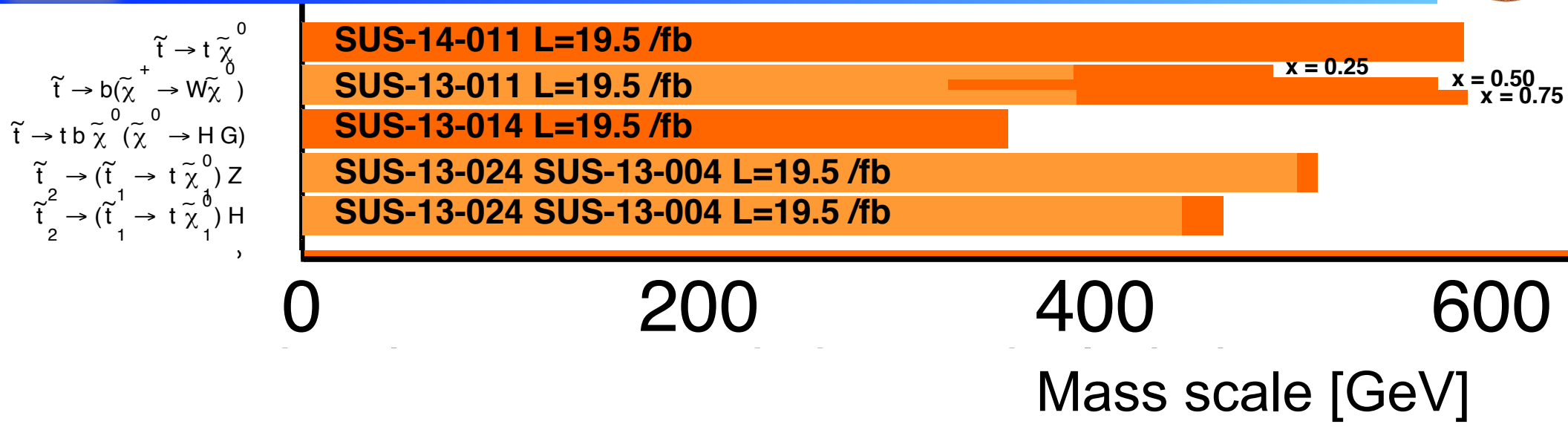
- Best exclusion limits for the masses of the mother particles
  - m(LSP) = 0 GeV (dark shades)
  - m(mother) - m(LSP) = 200 GeV (light shades)

*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

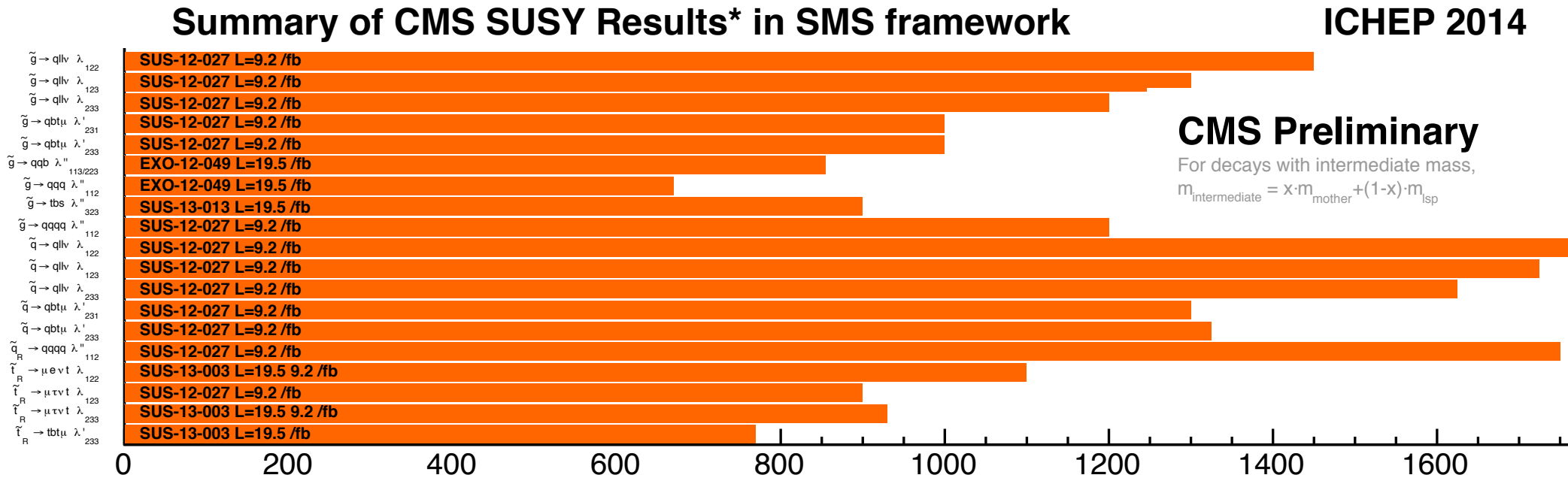
CMS Preliminary

For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$

Stops



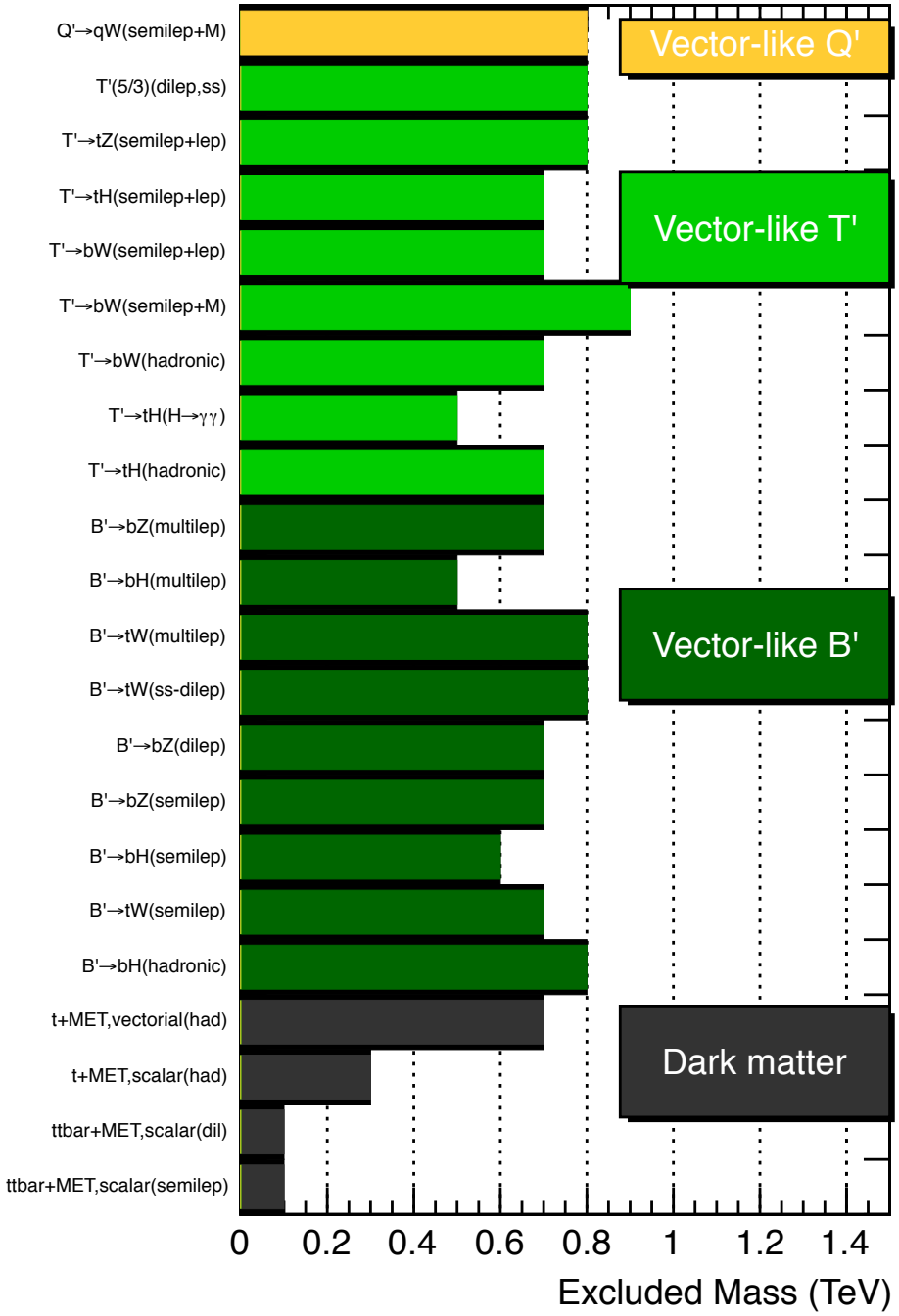
- Best exclusion limits for the masses of the mother particles for m_{LSP} = 0 GeV
- The lowest mass range is m_{mother} = 0, but results are available starting from a certain mass depending on the analyses and topologies
- $m_{intermediate} = x * m_{mother} + (1 - x) * m_{LSP}$

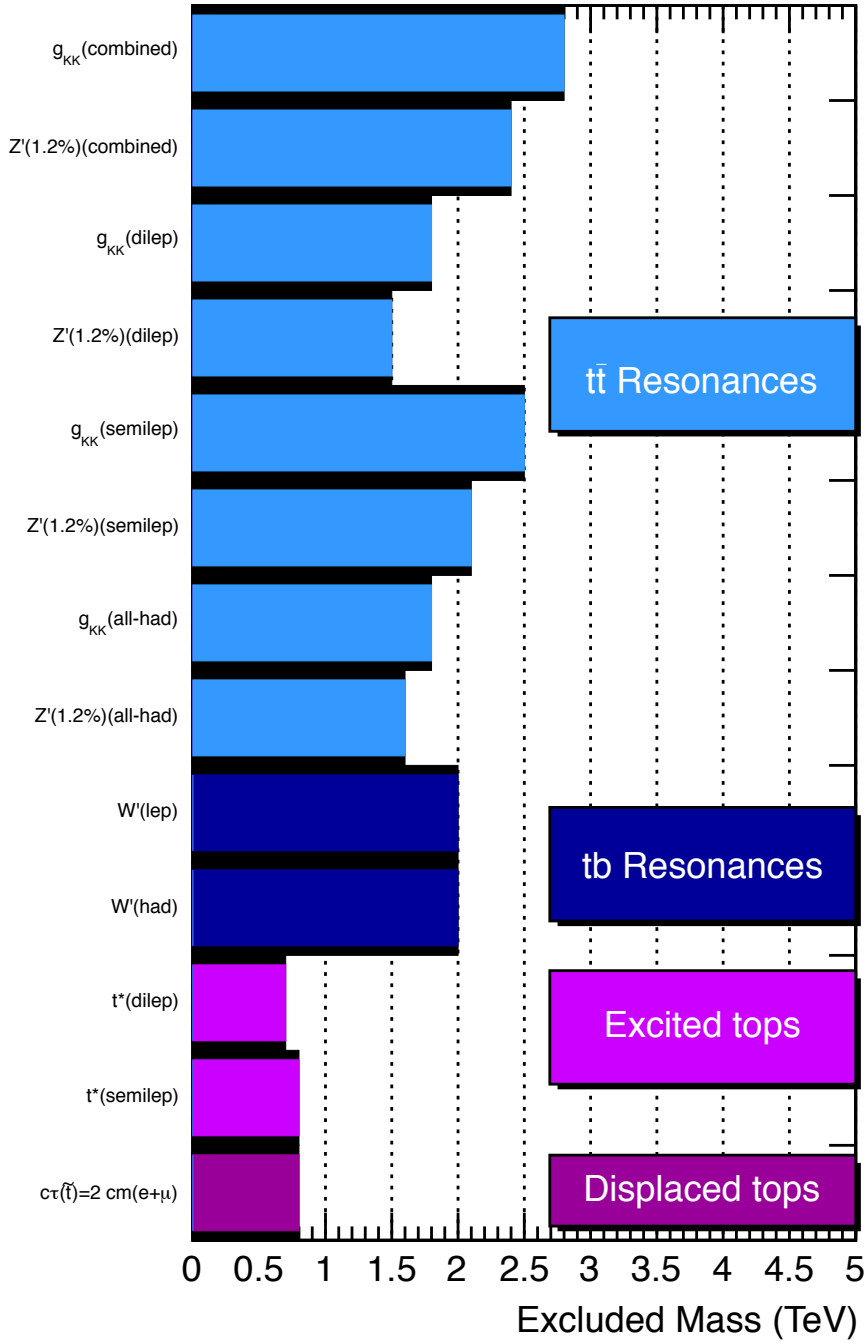


R-parity Violating SUSY

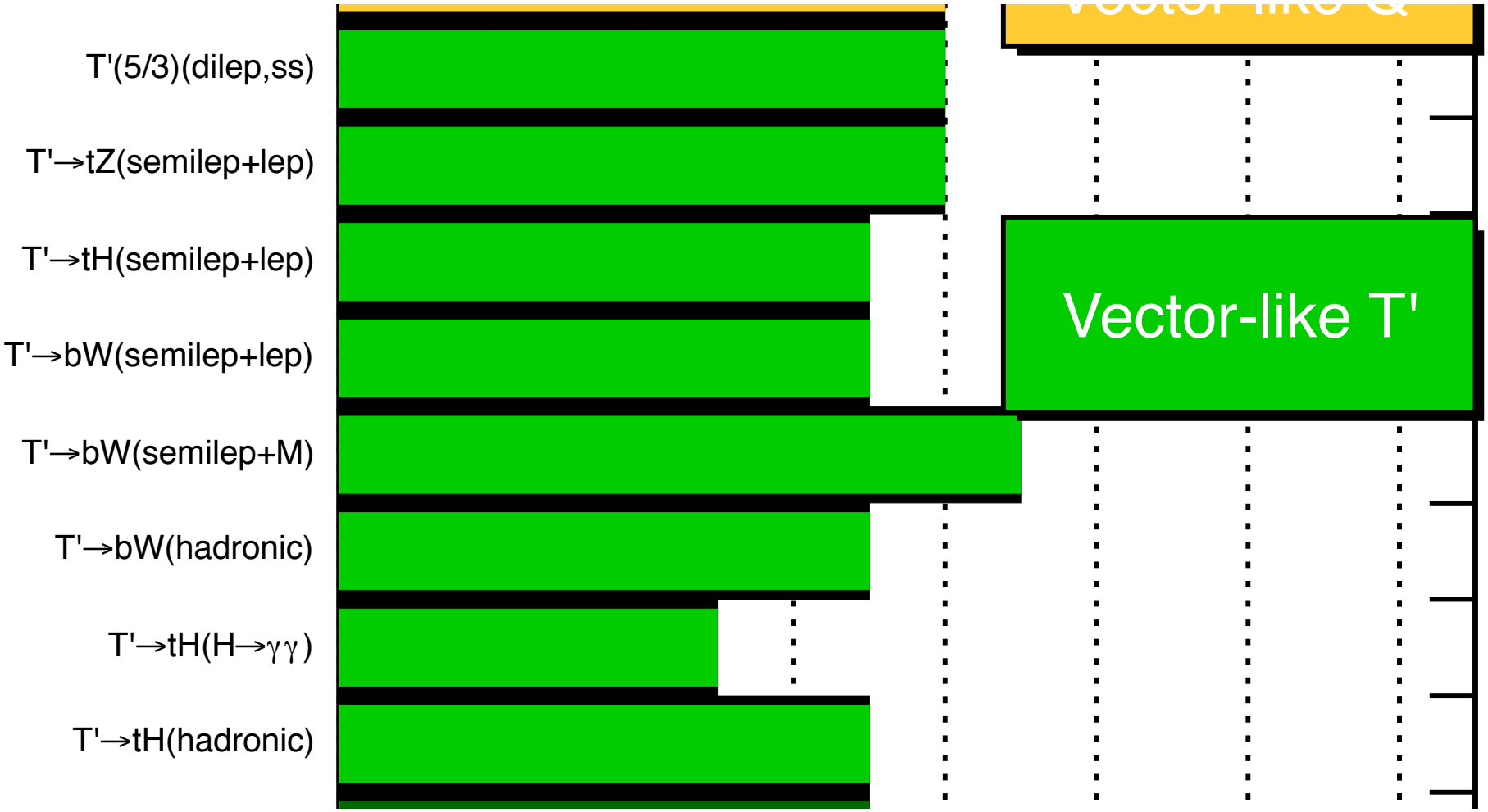
- Branching ratios of one are assumed
- values shown in plot are to be interpreted as upper bounds on the mass limits
- Theory uncertainties not included

Beyond Two Generations



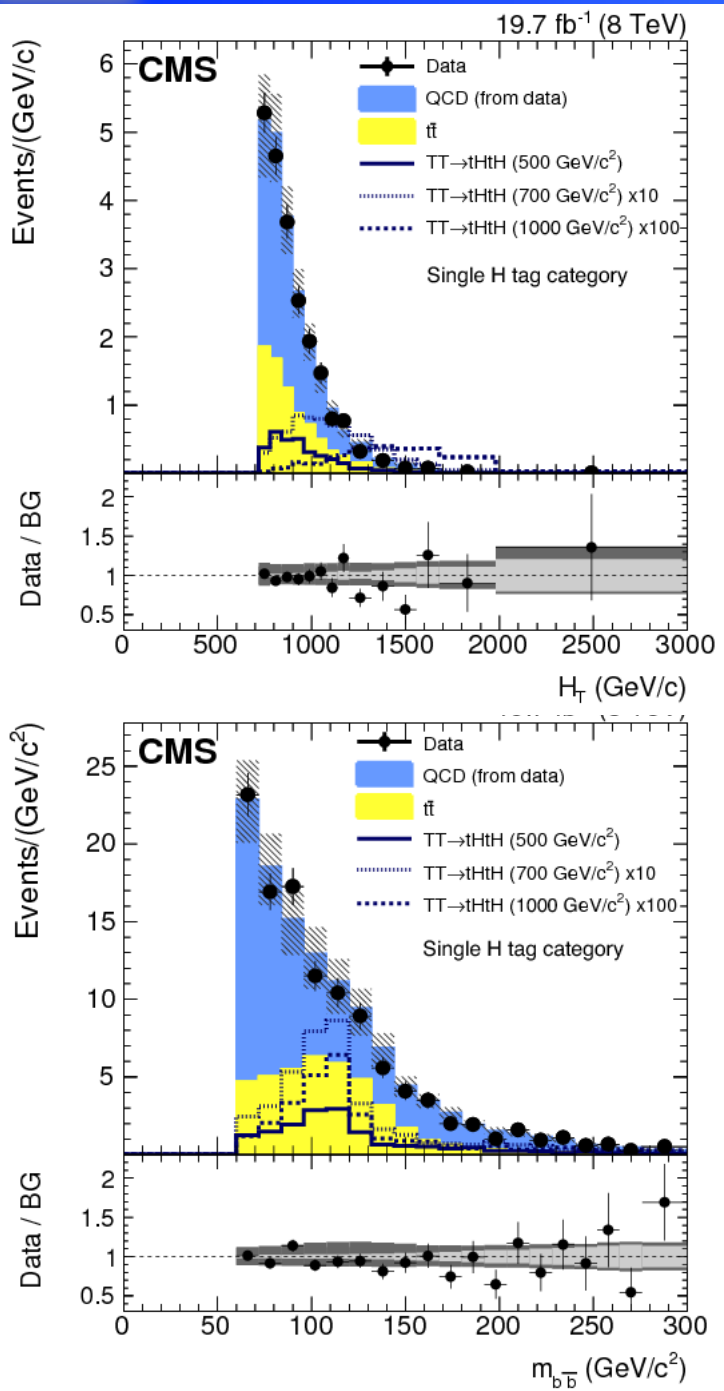


Beyond Two Generations

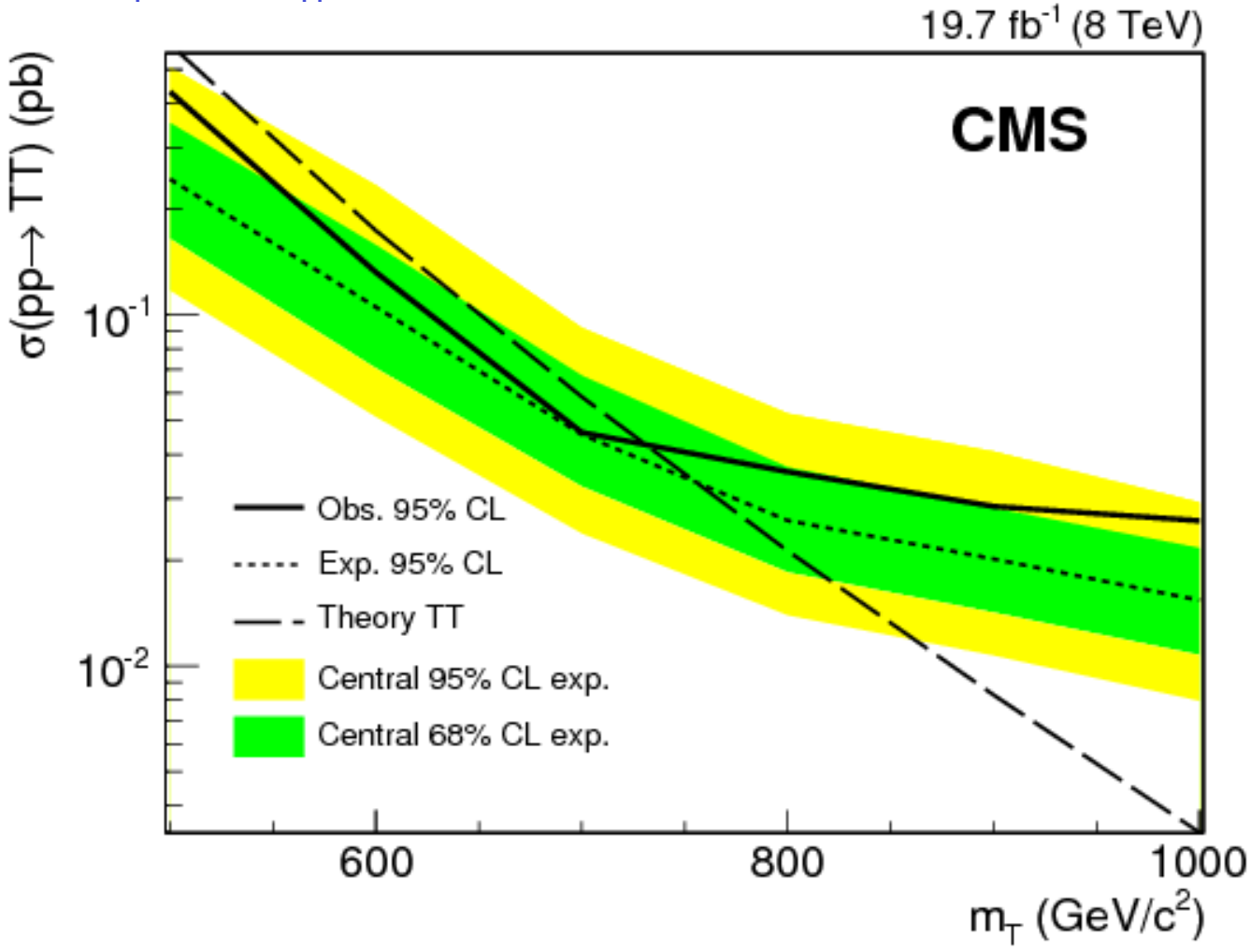


- 100% BR each line

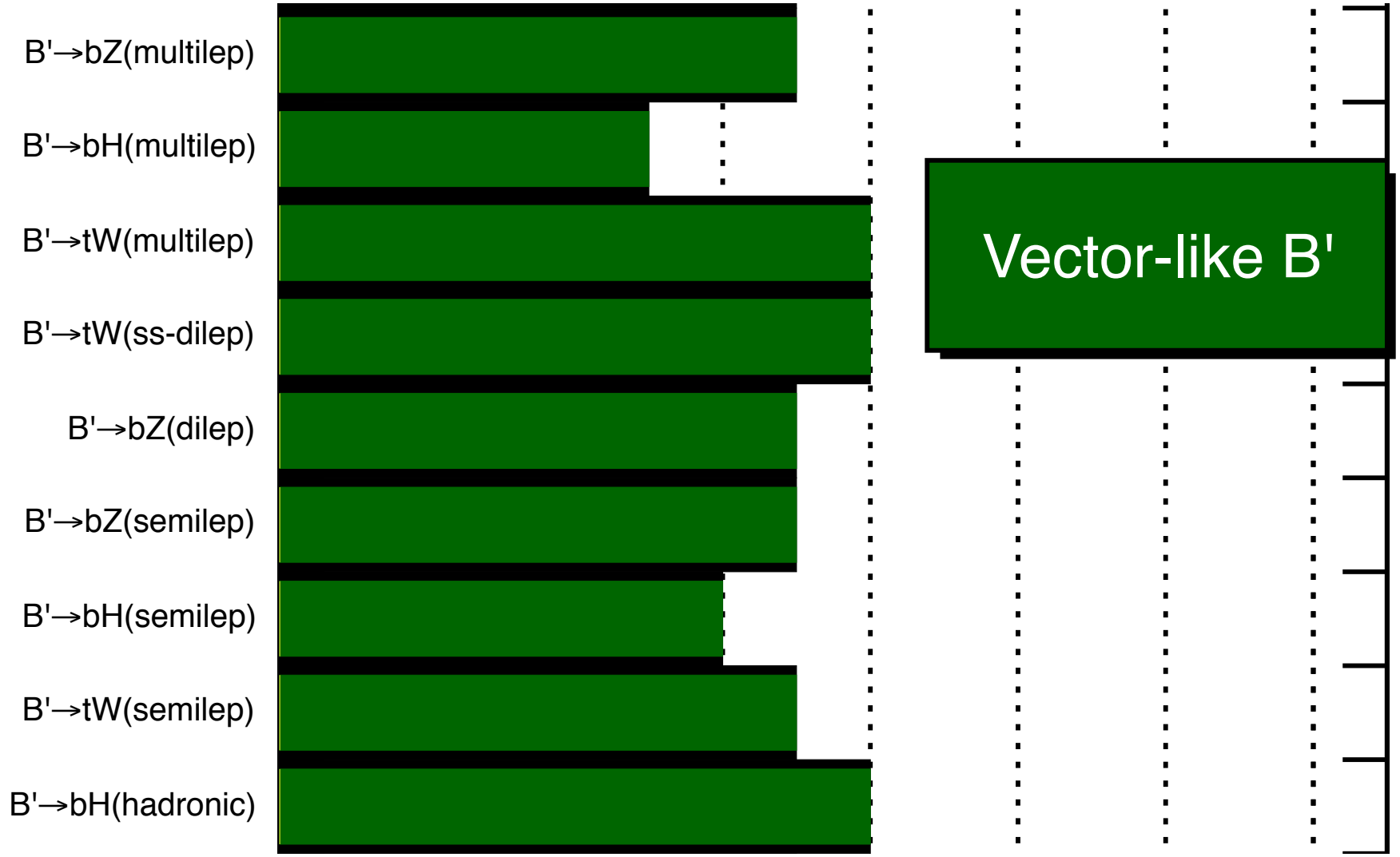
T' →tH



- Optimized for T' →tH
  - Top decays via Wb in all hadronic final state, Higgs→bb̄
- Background fit on likelihood discriminant based on H_T and m_H



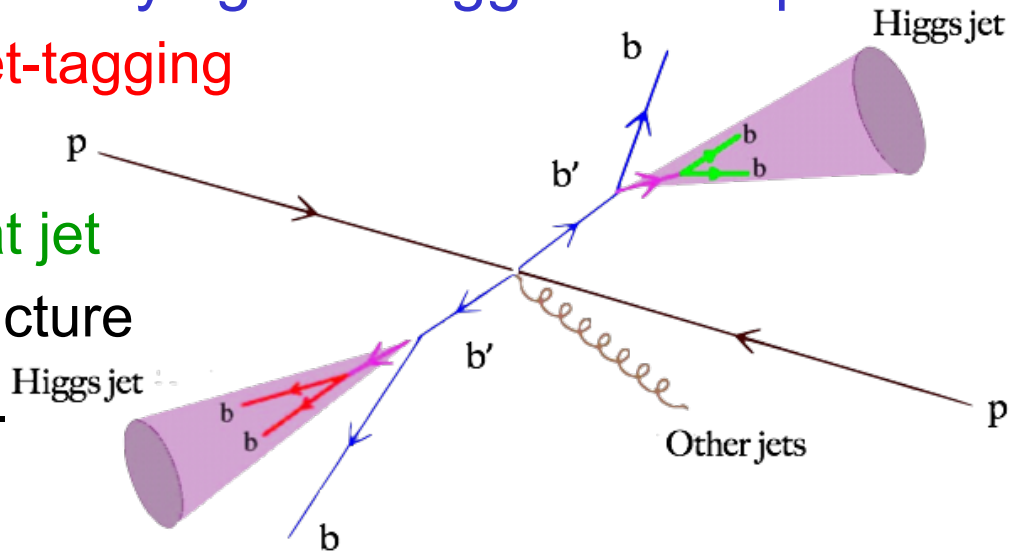
Beyond Two Generations

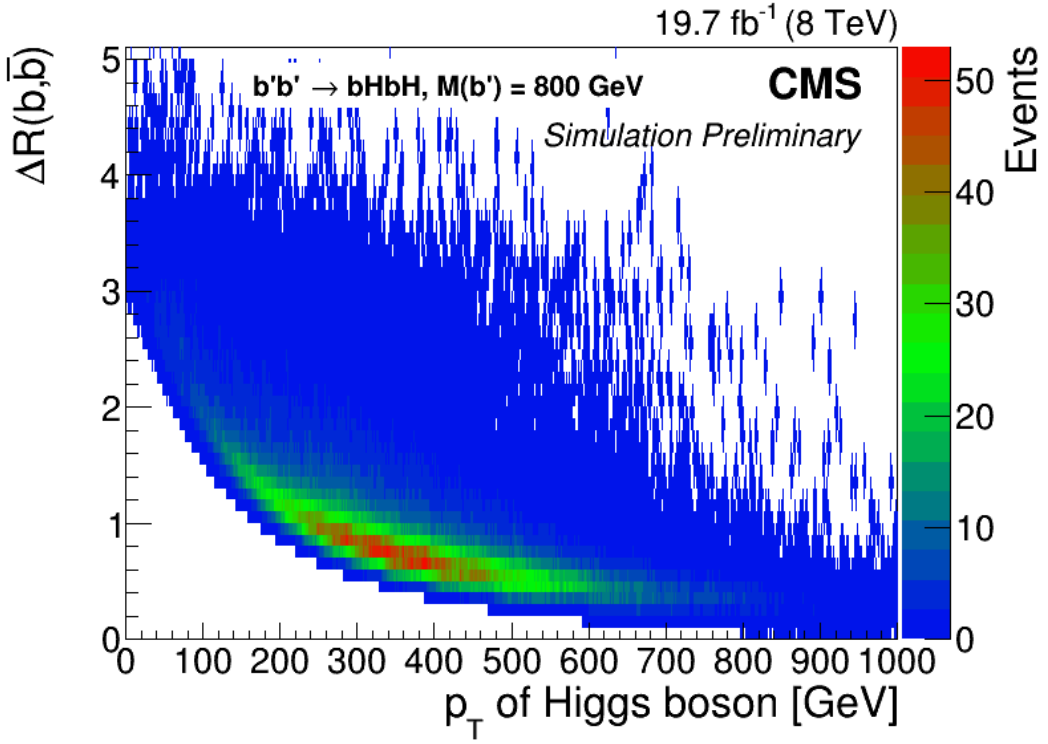


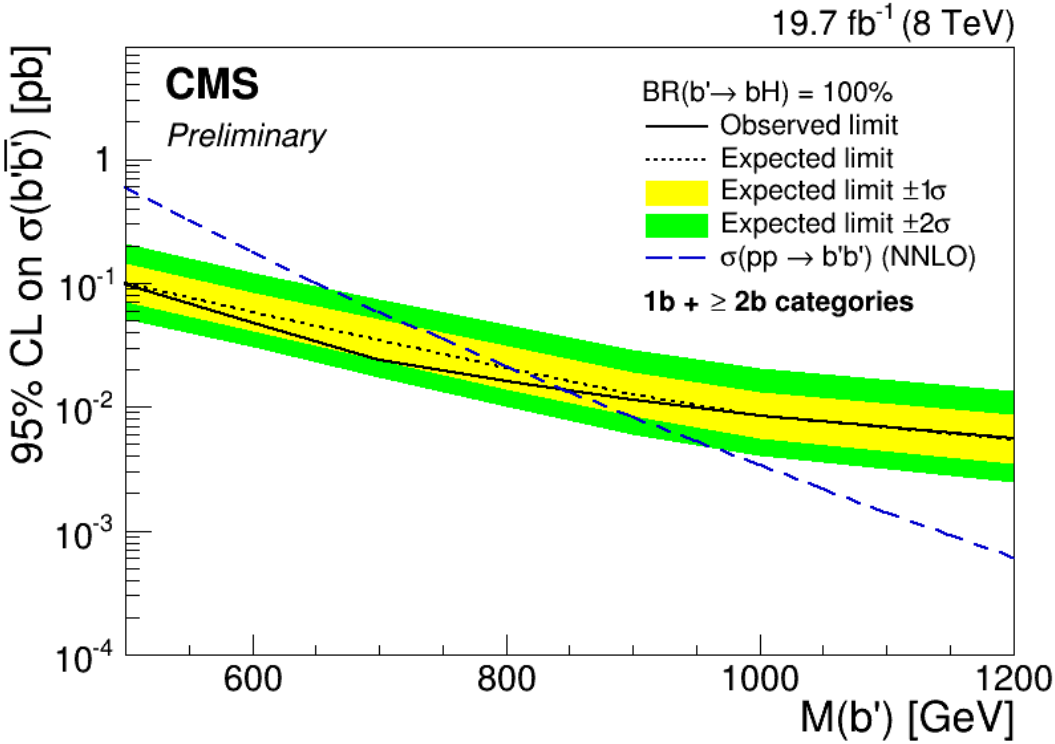
- 100% BR each line
- Combinations in pipeline for publication

Search for B' →bH

- Pair of heavy vector-like b-quarks decaying into Higgs and b-quark
  - Higgs→bb using boosted Higgs jet-tagging
  - Higgs is highly boosted
    - H->bb reconstructed as one fat jet
      - Identified using jet substructure
      - Both subjets are b-tagged.
  - Additional b-tagged jet required

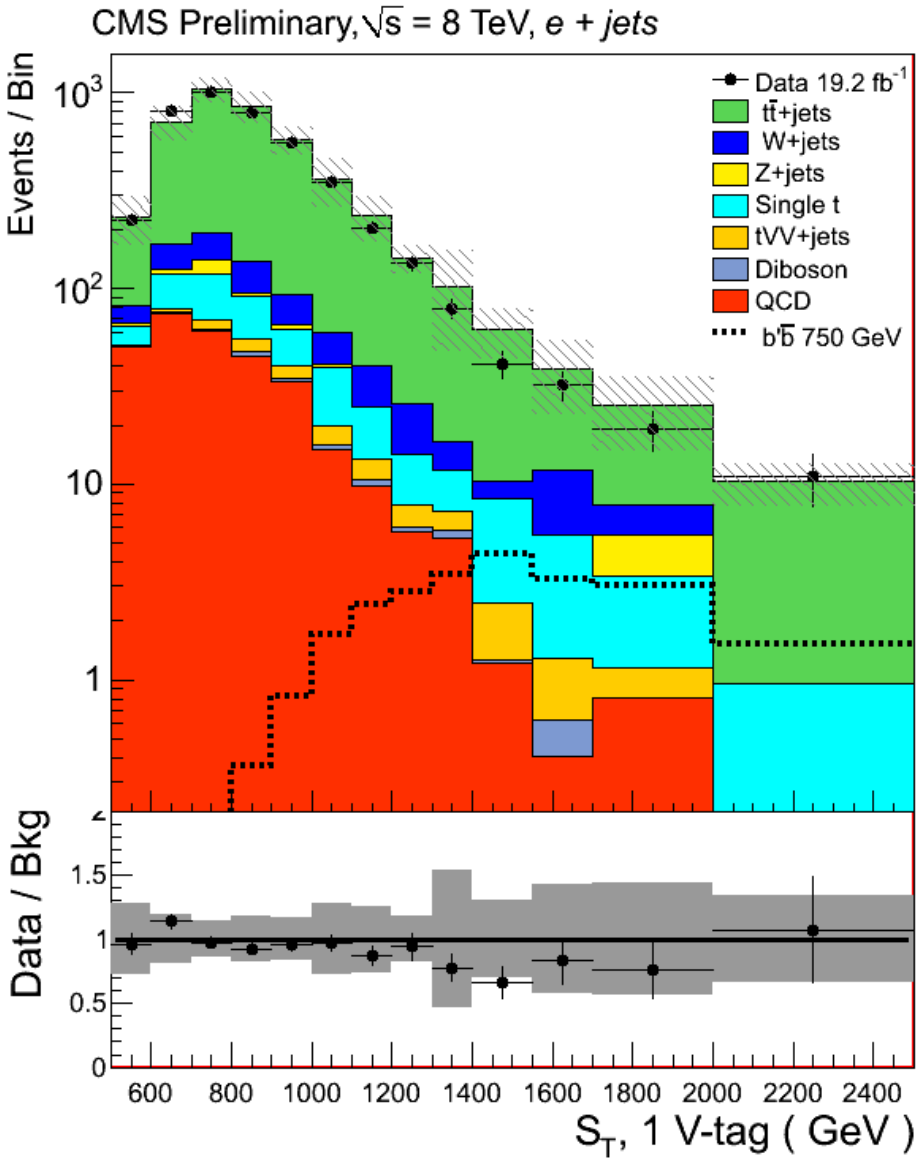




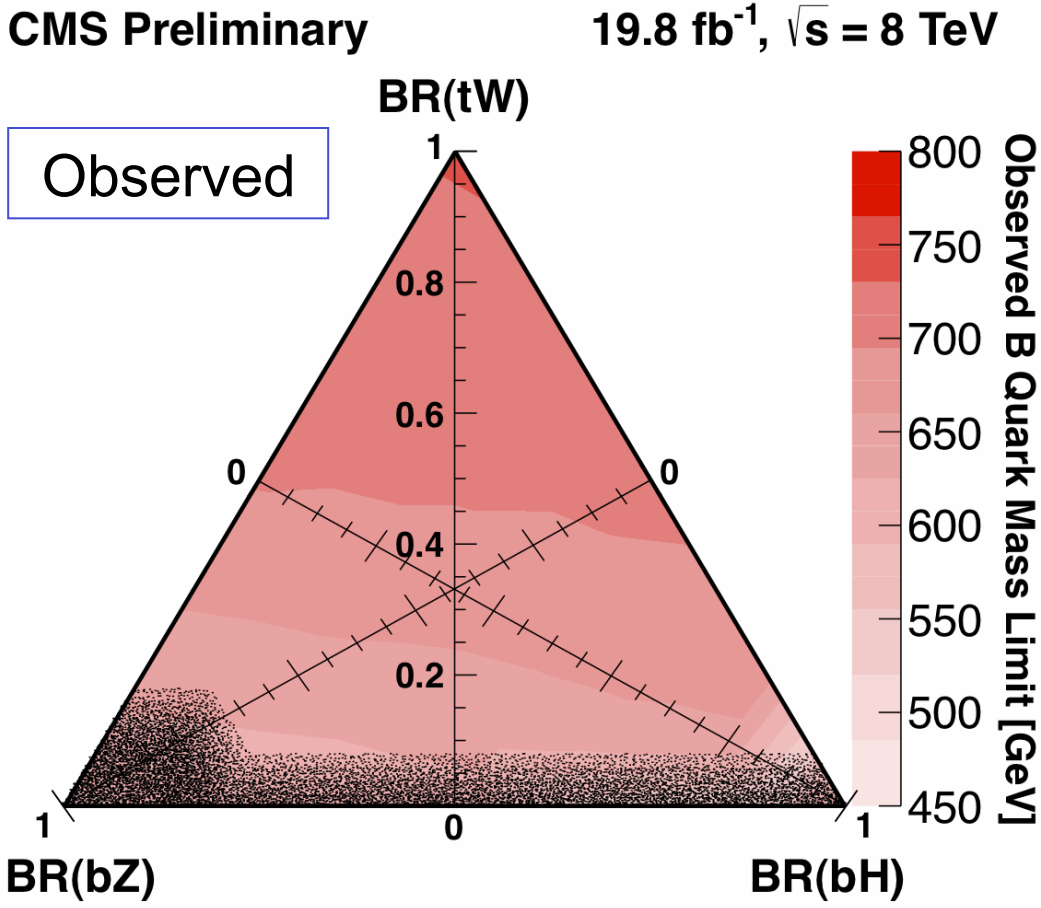


B' in semileptonic final state

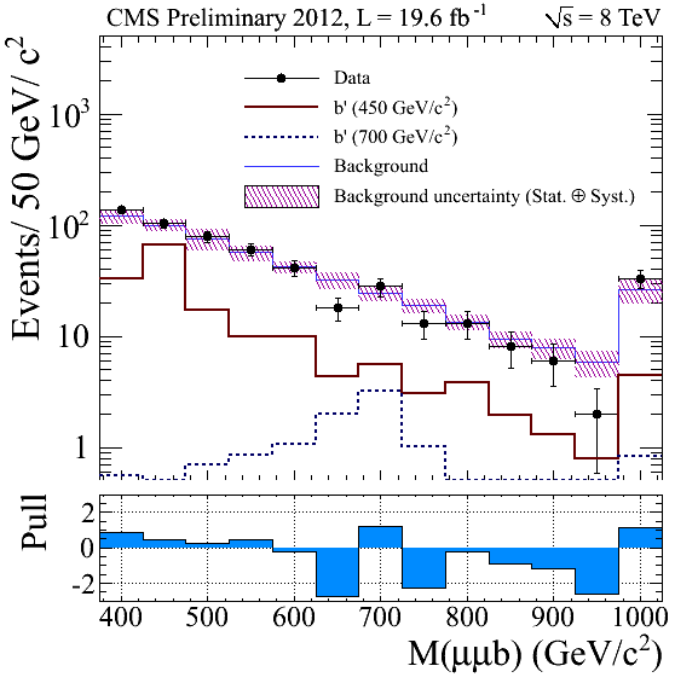
- Pair-produced vector-like quarks

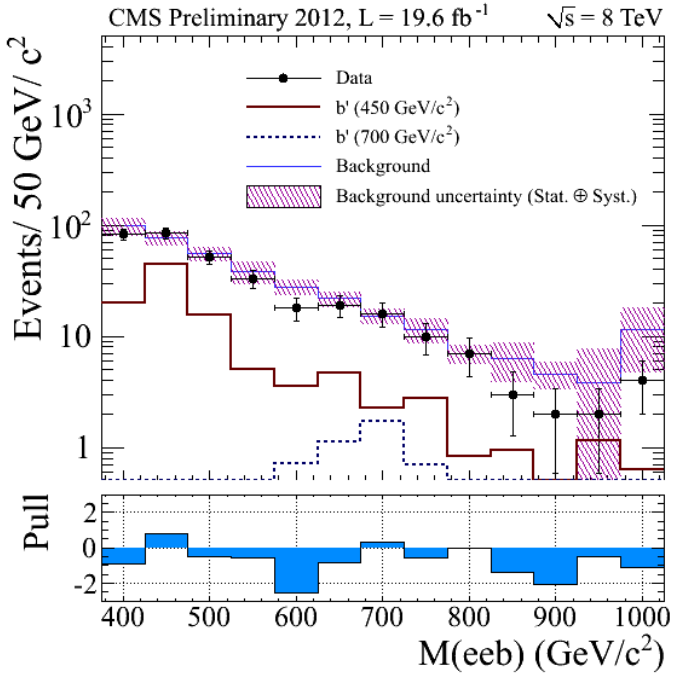


- B'→tW, bZ, and bH with final states containing one electron or one muon
- Fit S_T to measure the deviation between simulation and data



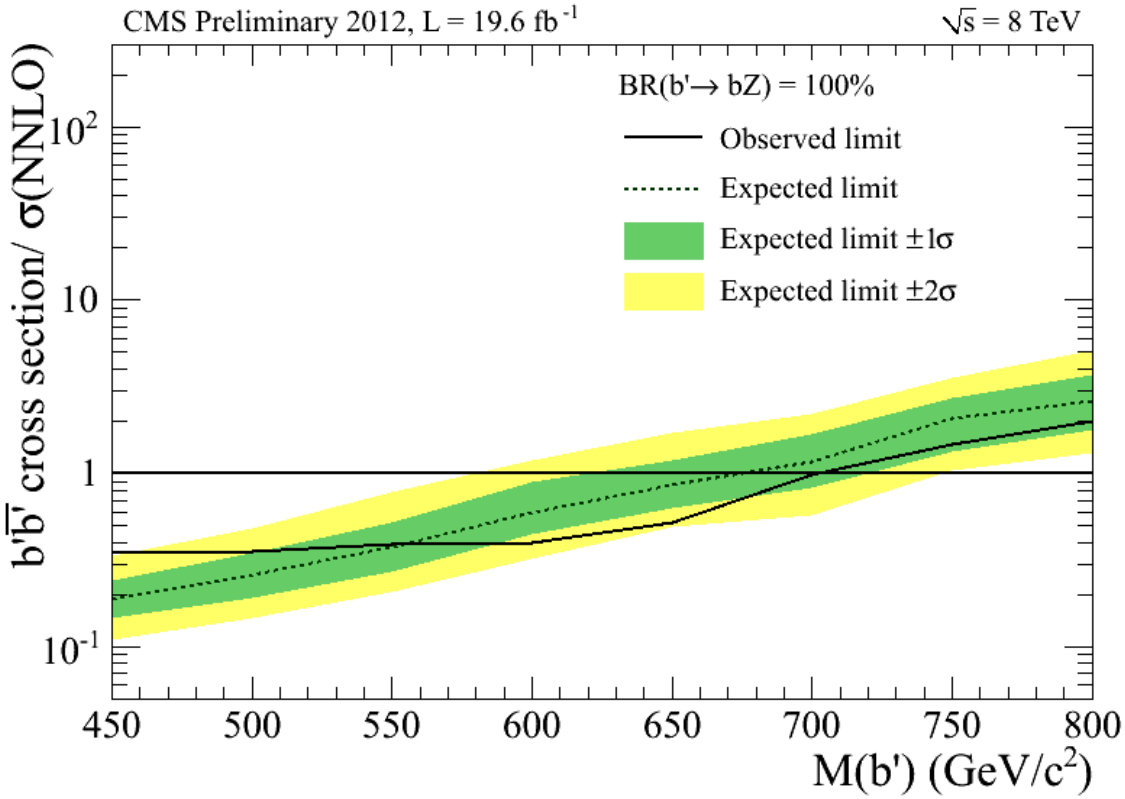
B' →bZ dilepton



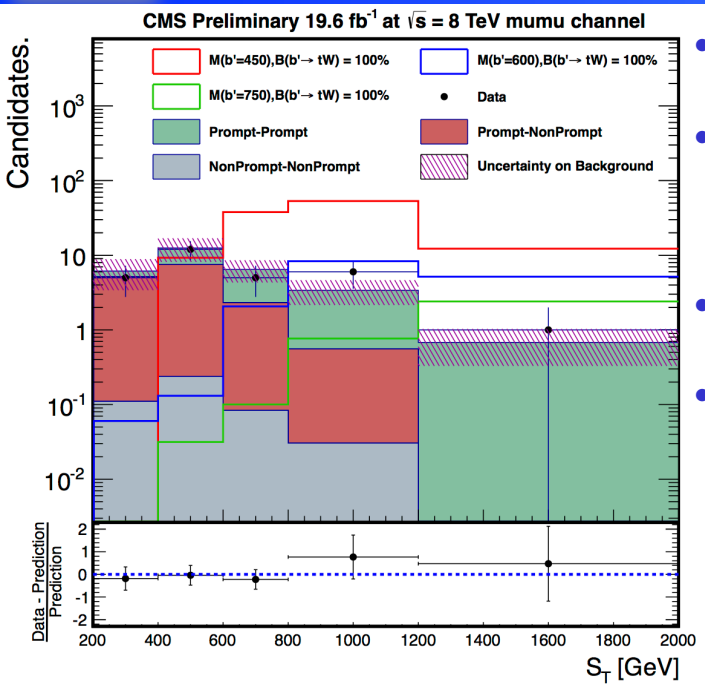


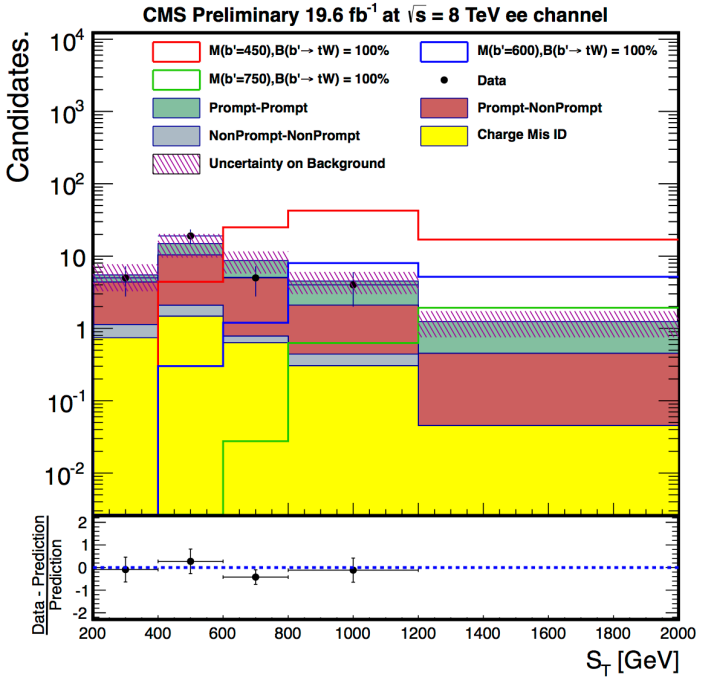
Pair-produced vector-like quarks of charge -1/3

- One B' forced to decay to bZ
- Other B' can decay to tW or bZ
  - At least one Z→ll per event
- Mass limit: Expected: 680 GeV, Observed: 700 GeV

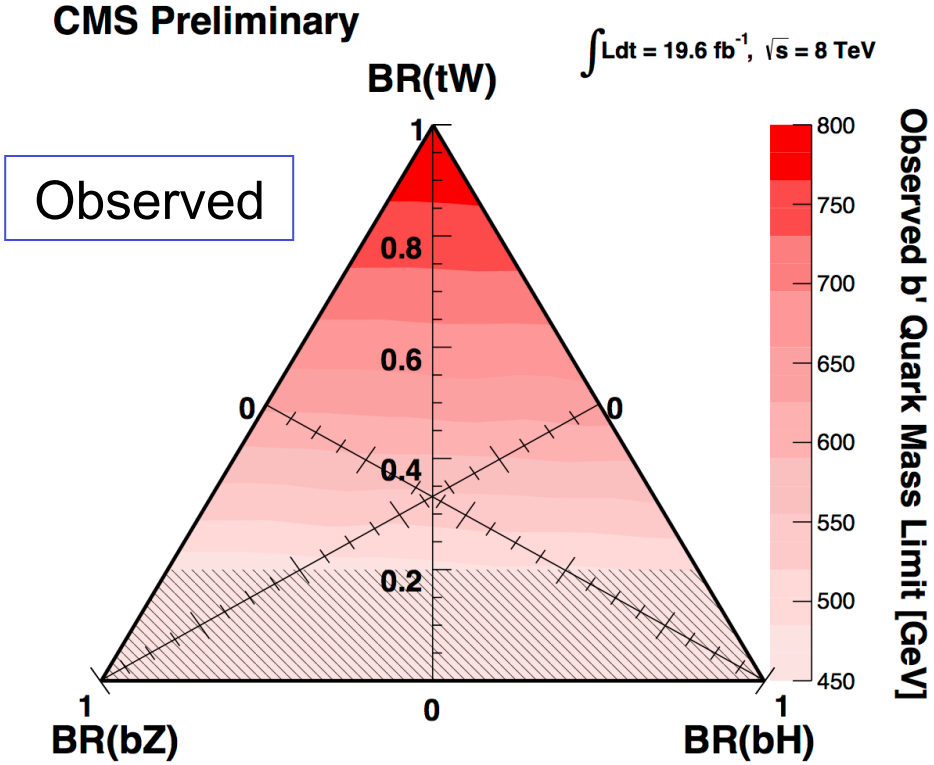


B' same-sign dilepton



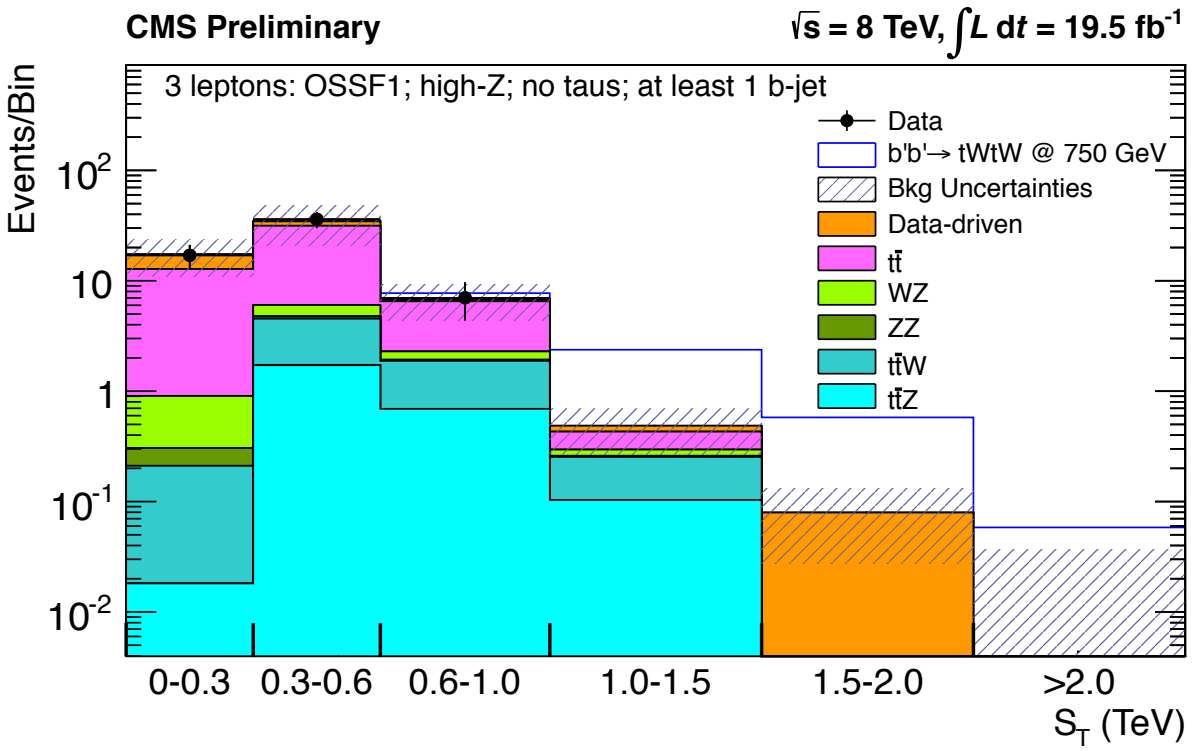


- Pair-produced vector-like quarks
- B' →tW, bH, and bZ with final states containing $\mu^{\pm}\mu^{\pm}$, $e^{\pm}e^{\pm}$, or $e^{\pm}\mu^{\pm}$
- Background fit to S_T distribution
- Data-driven methods used to estimate charge mis-identification and non-prompt leptons identified as prompt

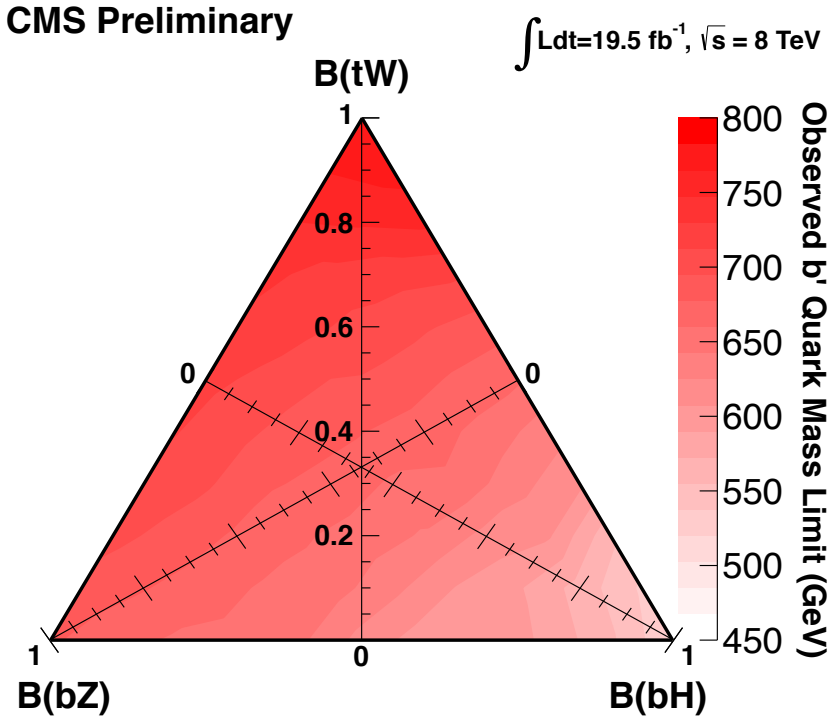


B’ in multilepton final state

- Vector-Like B' Pair Production
  - B’ →tW, bZ, and bH where all branching ratios are considered
  - Events are categorized by the number of opposite-sign same-flavor pairs
  - Fit S_T to measure the deviation between simulation and data
  - B’ mass limit: 520 to 785 GeV observed



Observed

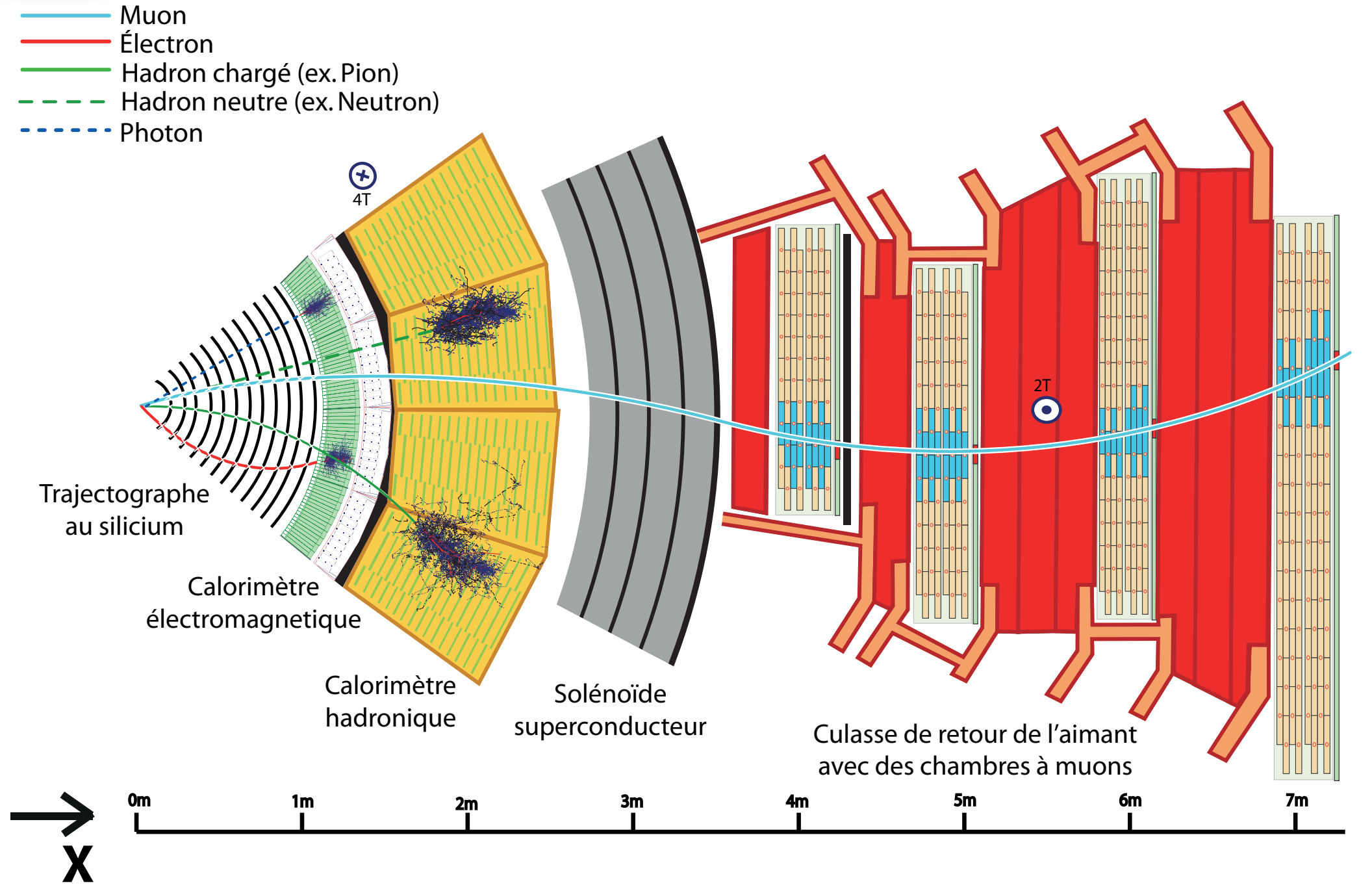


Summary

- CMS completed a robust and extensive probe of BSM physics at 8 TeV
  - More analyses and details at:
    - cms-results.web.cern.ch/cms-results/public-results/publications/EXO
    - cms-results.web.cern.ch/cms-results/public-results/publications/SUS
    - cms-results.web.cern.ch/cms-results/public-results/publications/B2G
  - Legacy combinations and a few other analyses still to come
- While no new particles were found at 8 TeV, CMS is probing this sector at $\sqrt{s}$ = 13 TeV
  - Boosted analyses becoming very interesting at 13 TeV
  - Run II has started, but need to wait for more data

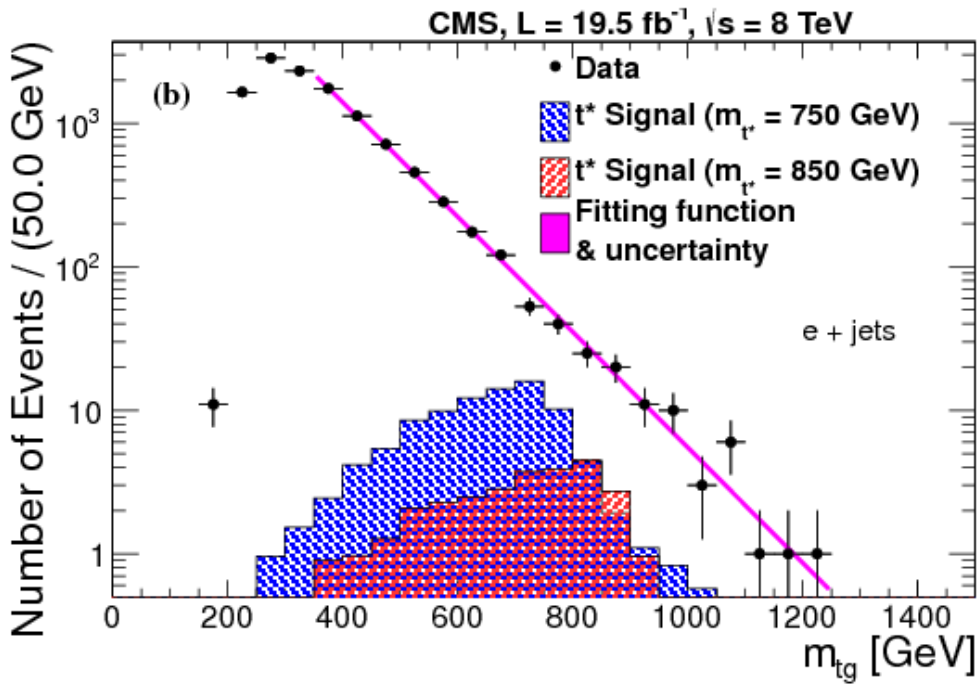
Thank you

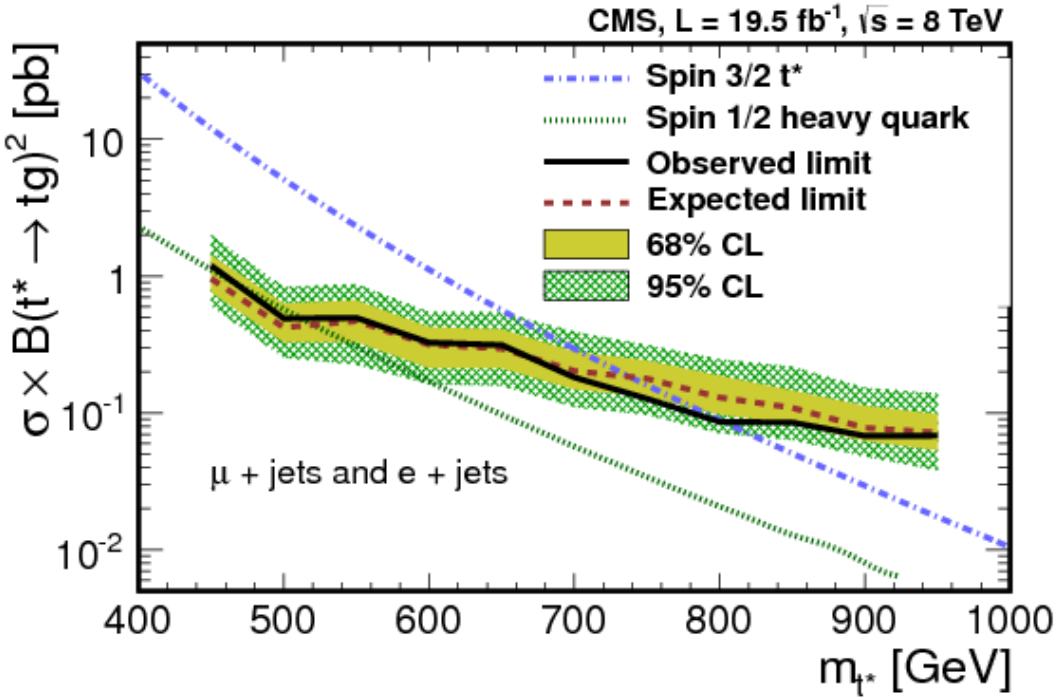
CMS Detector

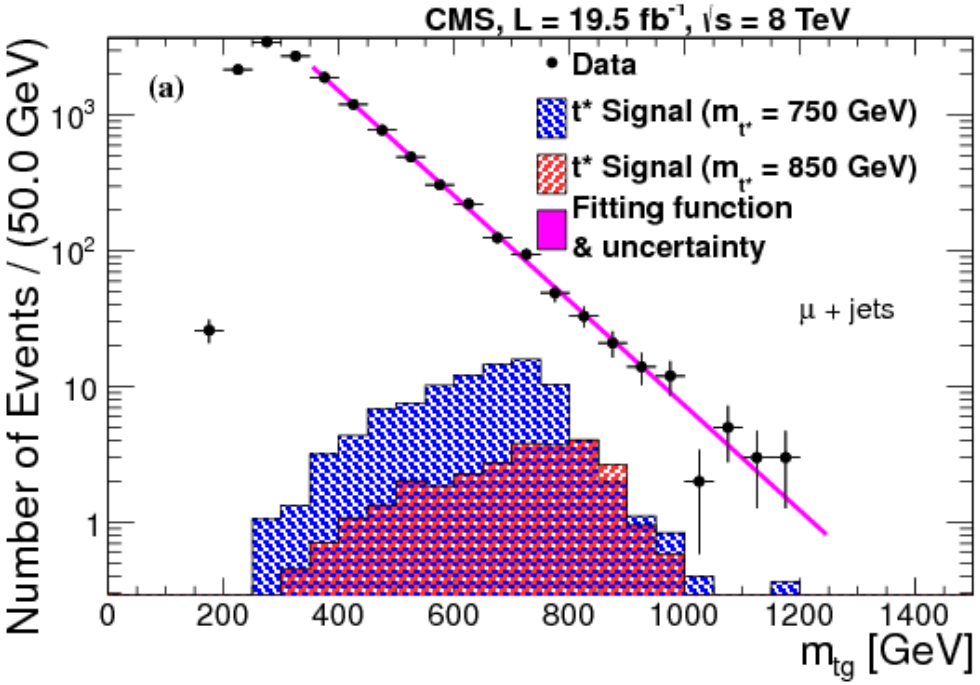


Excited Top Quarks l+jets

- $t^* \rightarrow tg$ in single lepton final states
  - Do not rely on simulation of bkgd
- Isolated lepton + ≥ 6 jets
  - Background fit of mass spectrum
    - m(lνbg)=m(qqbg)

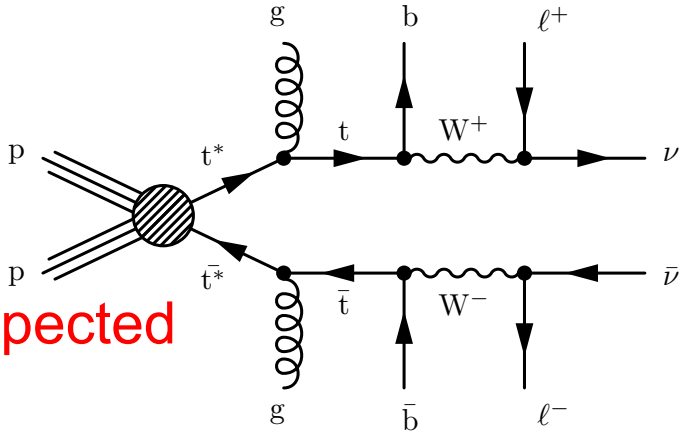


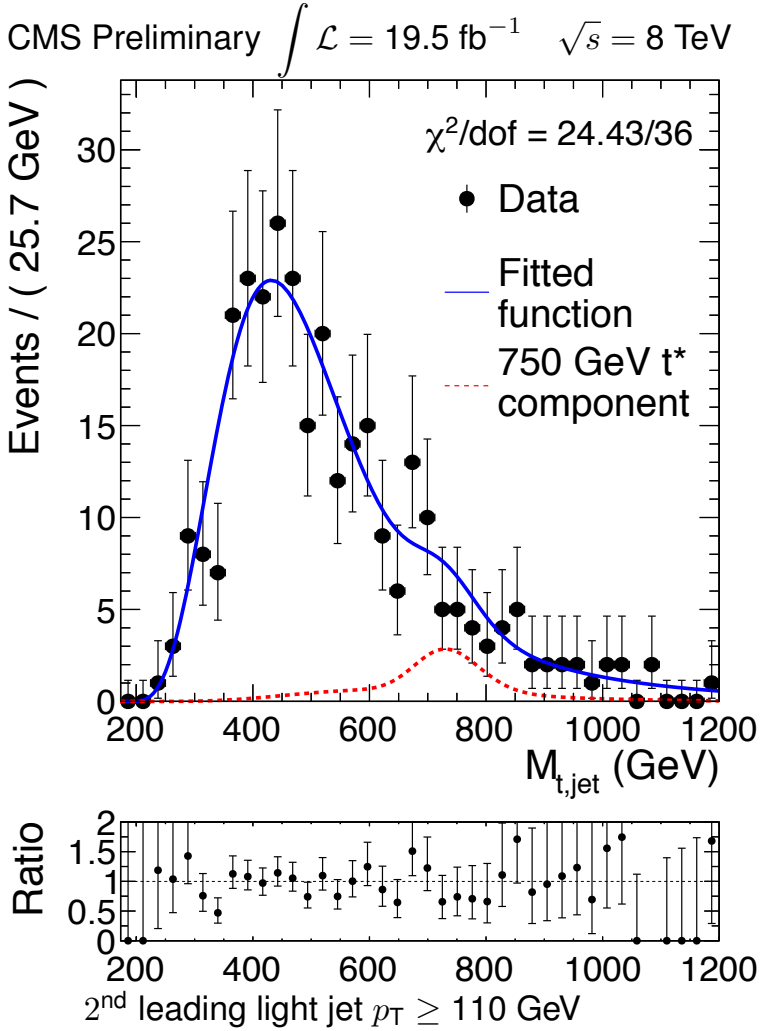


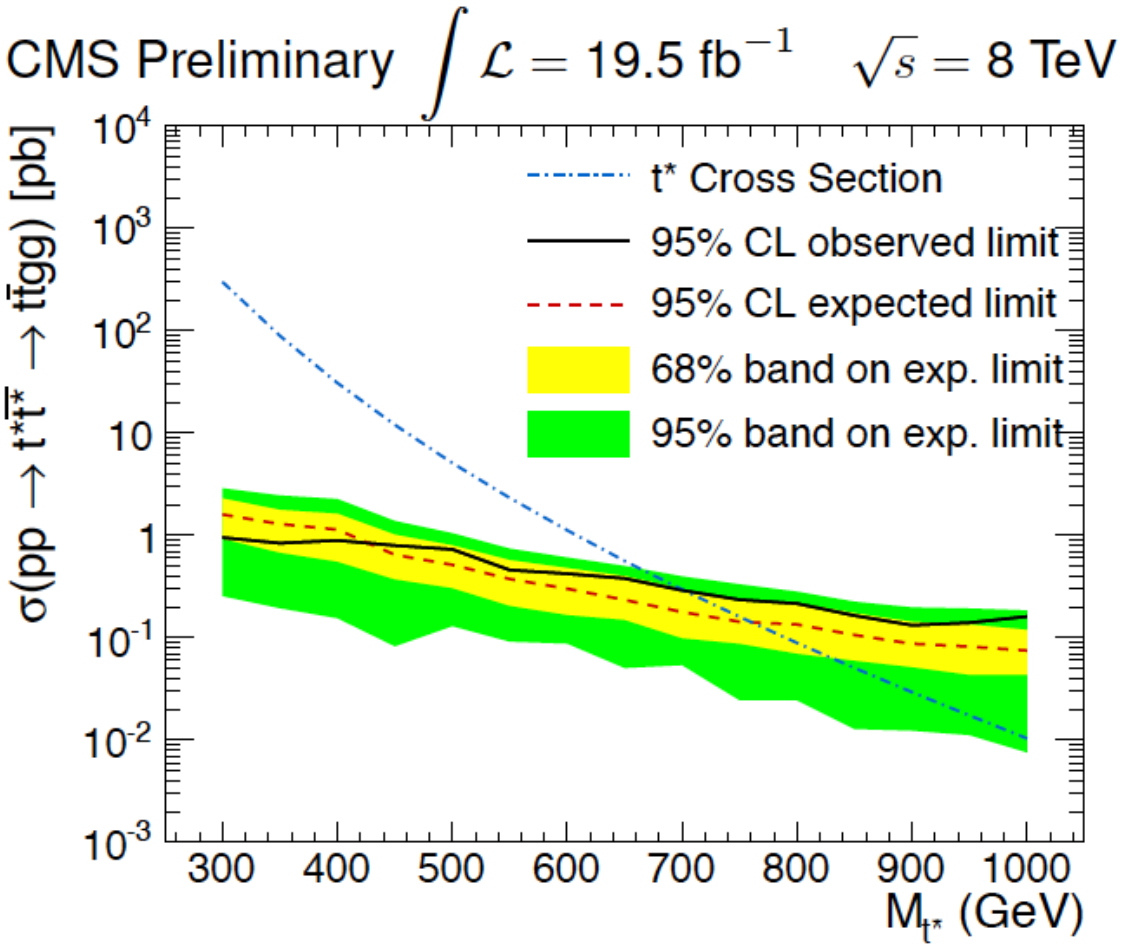


Excited Top Quarks dilepton

- t*→tg in dilepton final states
  - 2 b-jets, 2 lights jets
  - background fit of jet p_T distribution
  - t* mass limits: 703 GeV observed, 763 GeV expected

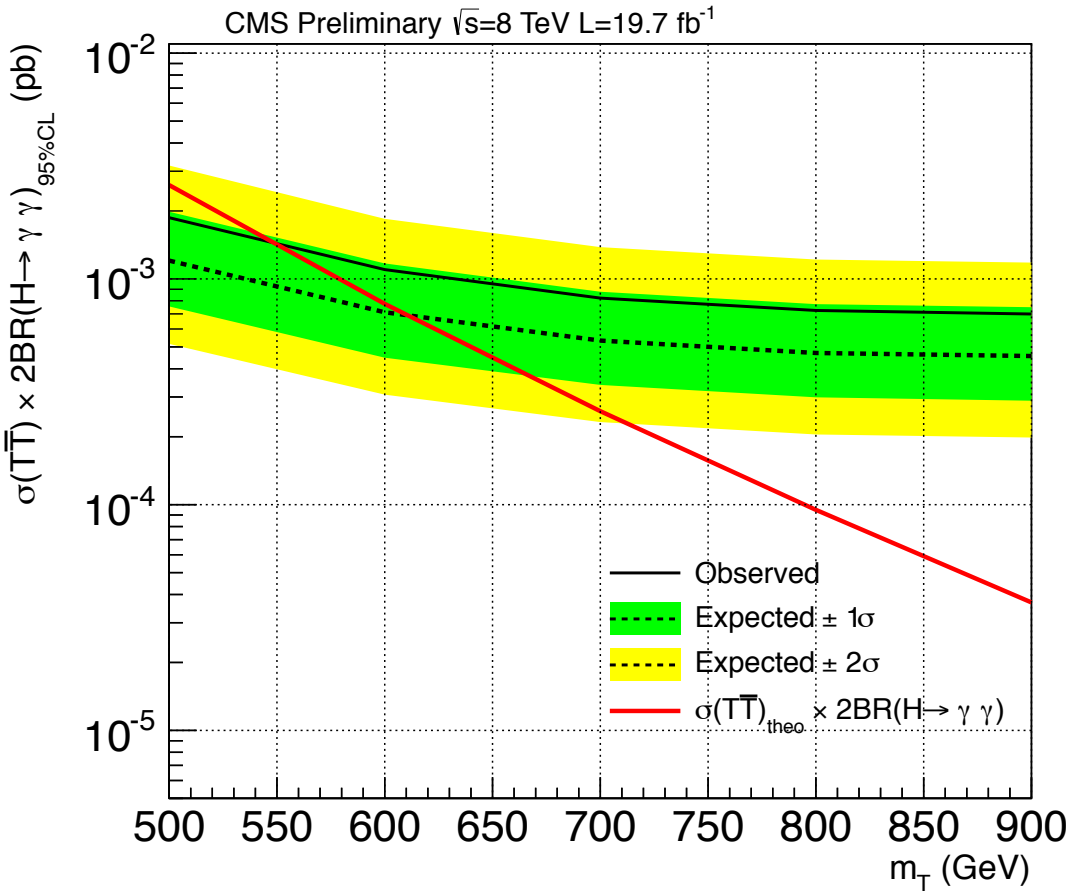


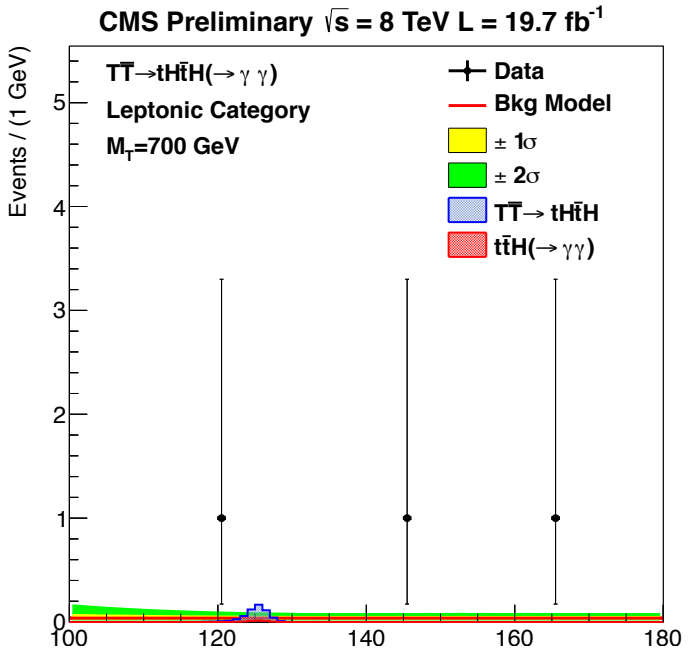


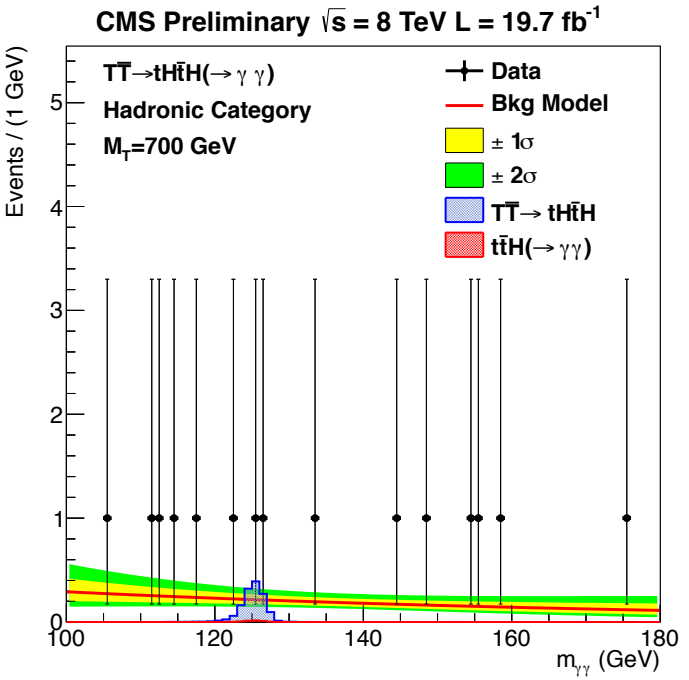


tH where H→γγ

- Search for vector-like top quark partners produced in association with Higgs bosons in the diphoton final state
  - T' mass limit:
    - 540 GeV observed, 607 GeV expected

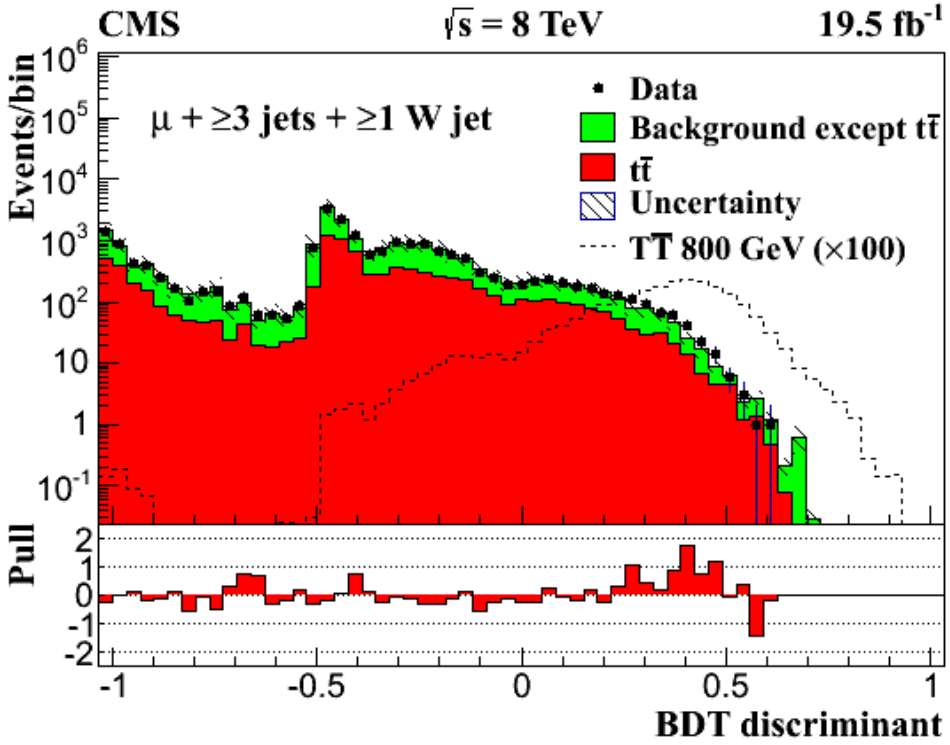


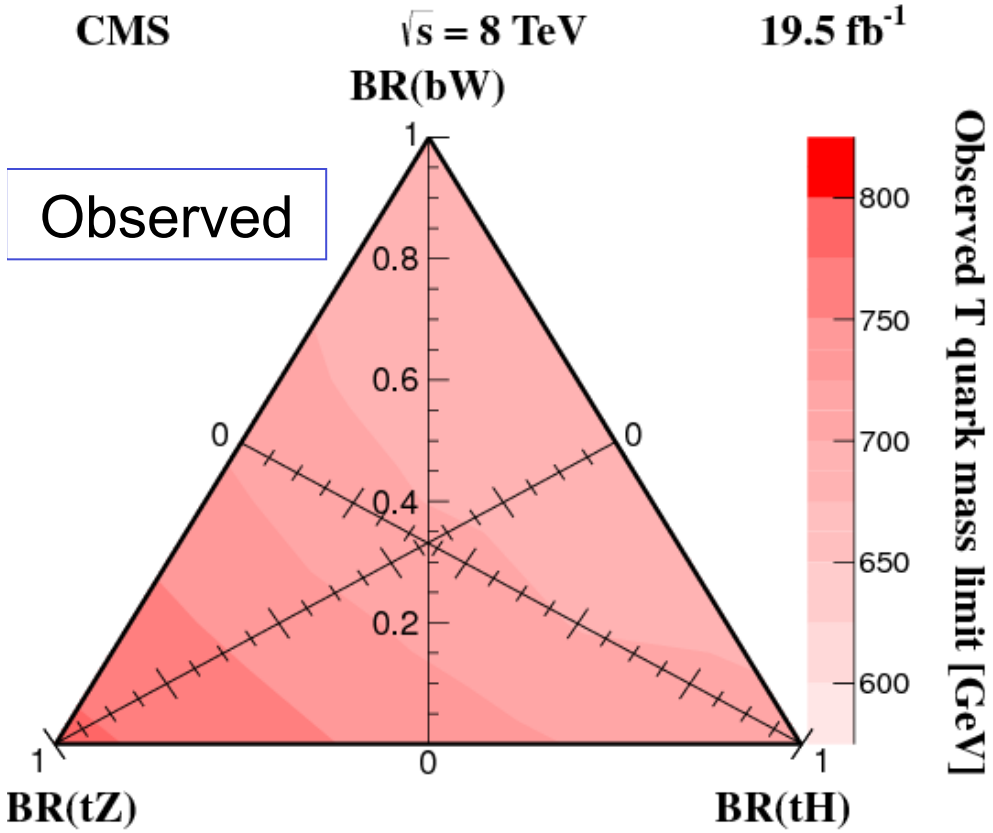




Vector-like Tops where final state has lepton(s)

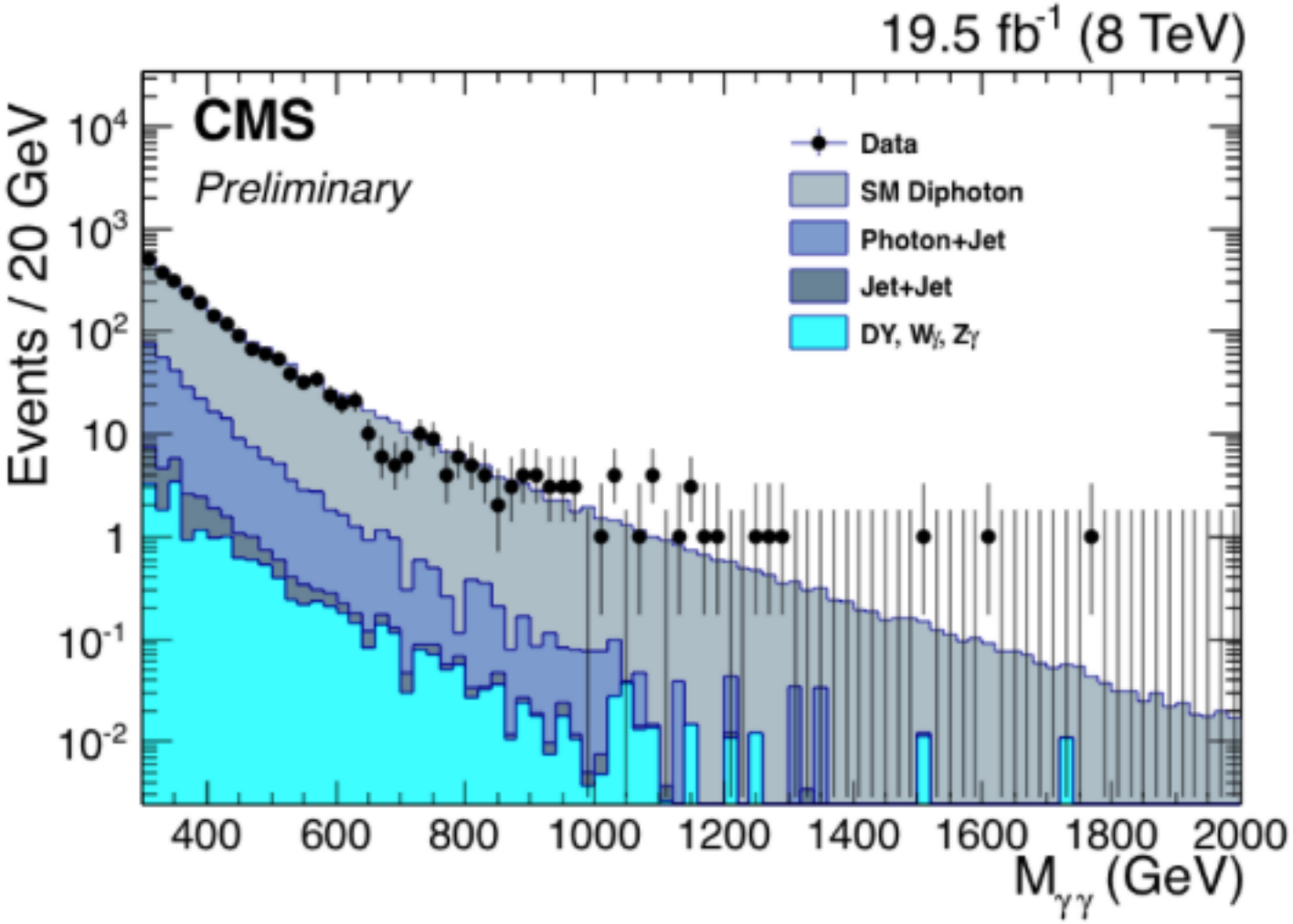
- Inclusive T' →bW, tZ, and tH search where at least one of the W decays leptonically
  - Single lepton, opposite sign dilepton, same sign dilepton, trilepton
  - Jet substructure methods used for highly boosted t, W, and Z
    - CMS top-tagger and Boosted W-tagging
  - Background fit of BDT discriminant



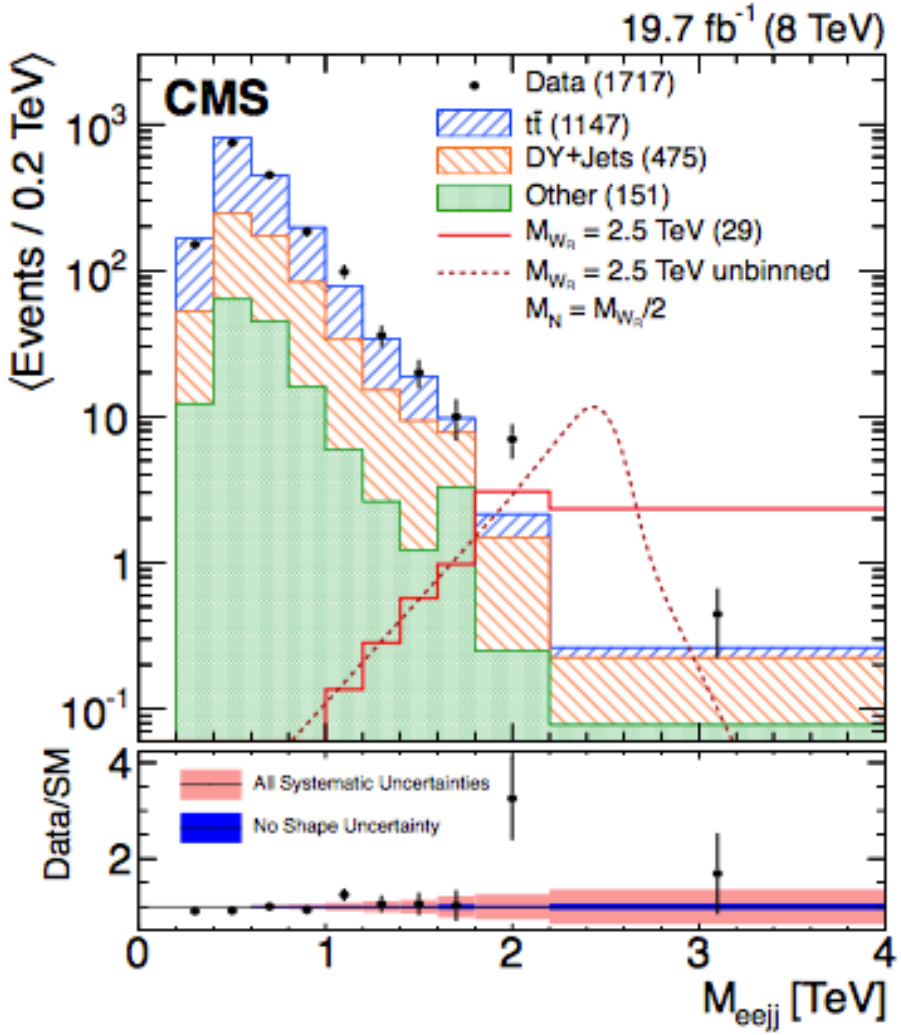


Diphoton Resonances

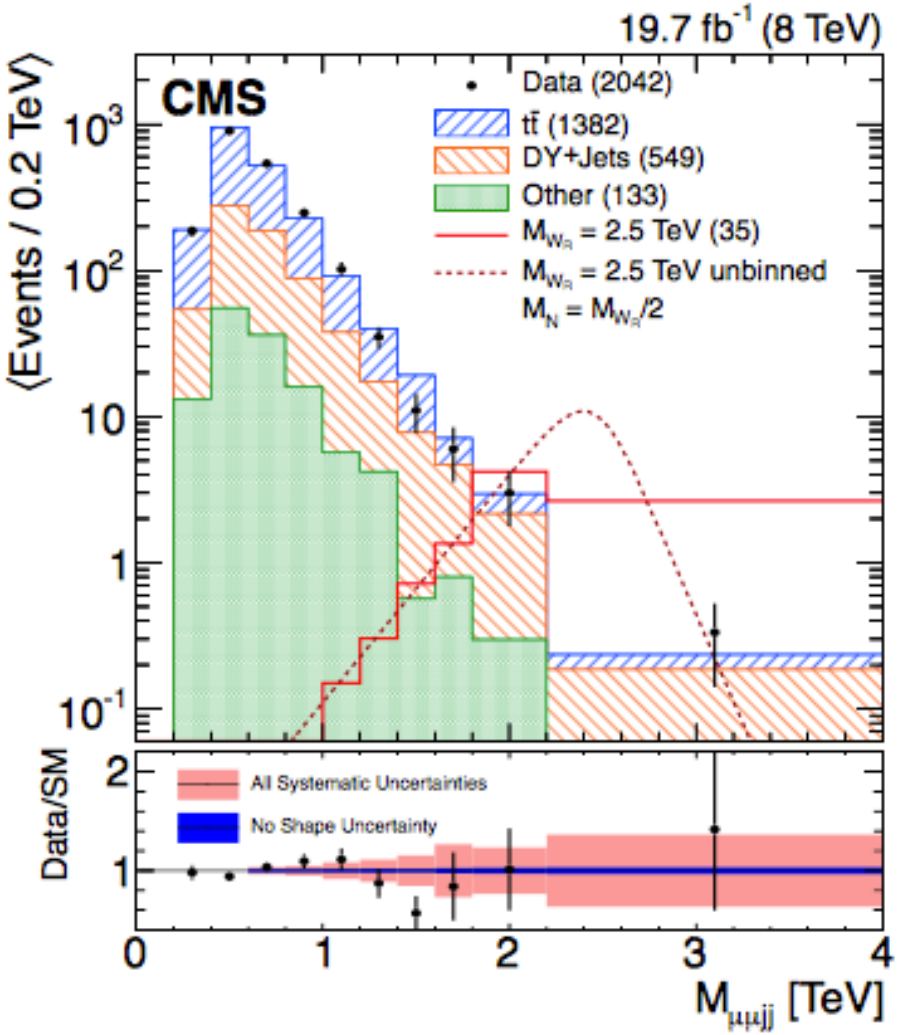
- Search for High-Mass Diphoton Resonances in pp Collisions at $\sqrt{s}$ = 8 TeV with the CMS Detector
  - **CMS PAS EXO-12-045**
  - local significance of 3.27σ



- Search for heavy neutrinos and W bosons with right-handed couplings in proton-proton collisions at $\sqrt{s}$ = 8 TeV
  - local significance of 2.8σ

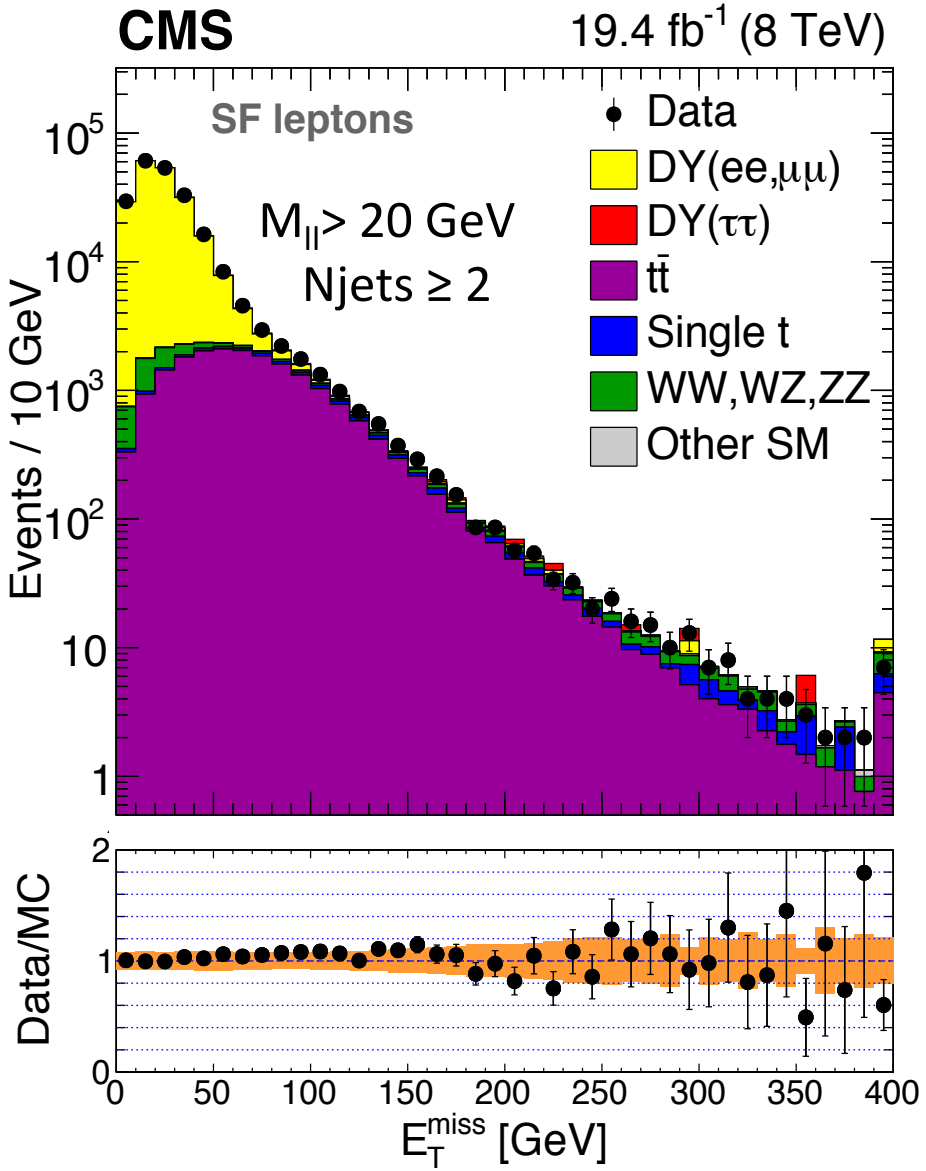


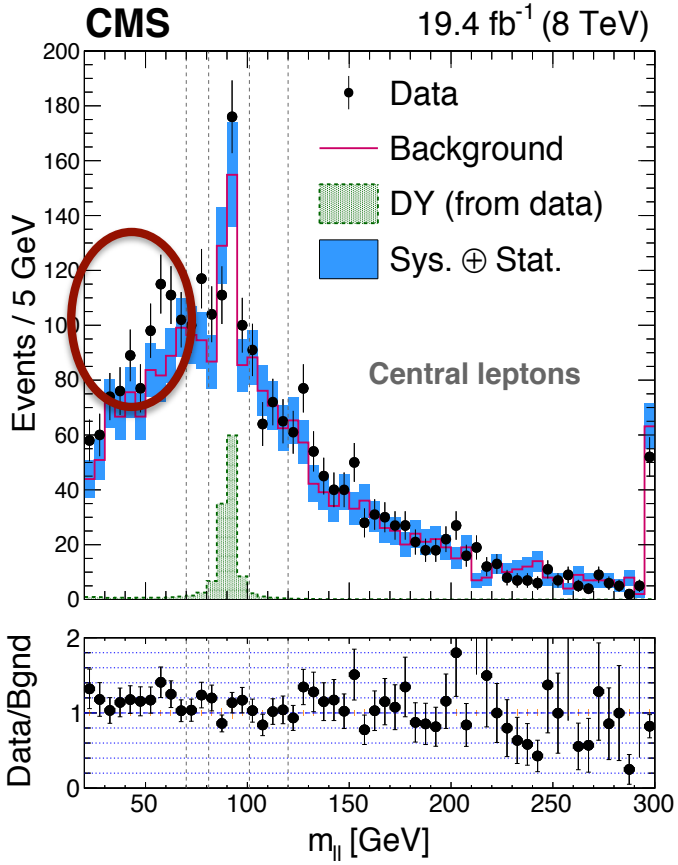
CMS-EXO-13-008



SUSY search w/ two leptons, jets and E_T^{miss}

arXiv:1502.06031





Low mass significance: 2.6σ

No evidence for a statistically significant signal

Bibliography

- Excited top quarks
  - In semileptonic (JHEP **06** 2012 125) and dileptonic (B2G-12-008) final states
- Search for vector-like tops:
  - Hadronic final state (arxiv:1503.01952)
  - In tH where H→$\gamma\gamma$ (B2G-14-003)
  - Leptonic and semileptonic final states (PLB **729** 2014 149)
    - Decaying via bW, tH, and tZ
- Search for vector-like b-quarks:
  - Hadronic final state (B2G-14-001)
  - In semileptonic final state (B2G-12-019)
    - Decaying to tW, bH, and bZ
  - In bZ dilepton final state (B2G-12-021)
  - In tW same-sign lepton final state (B2G-12-020)
  - In multi-leptonic final states (B2G-13-003)
    - Decaying to tW, bH, and bZ

All results use data at $\sqrt{s}$ = 8 TeV from the LHC

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G#Published_Results_2012_Run