SEARCHES FOR BSM (SUSY, EXO, BEYOND 2ND GENERATION) IN CMS

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Outline

- Searches for SUSY:
  - Introduction
  - Search strategy
  - Third generation
- Searches for Leptoquarks
  - Introduction
  - 1st and 2nd Generation
  - 3rd Generation
- Search for vector like quark
  - Introduction
  - Strategy

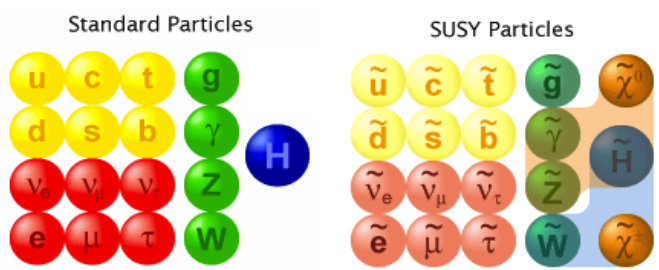
Supersymmetry

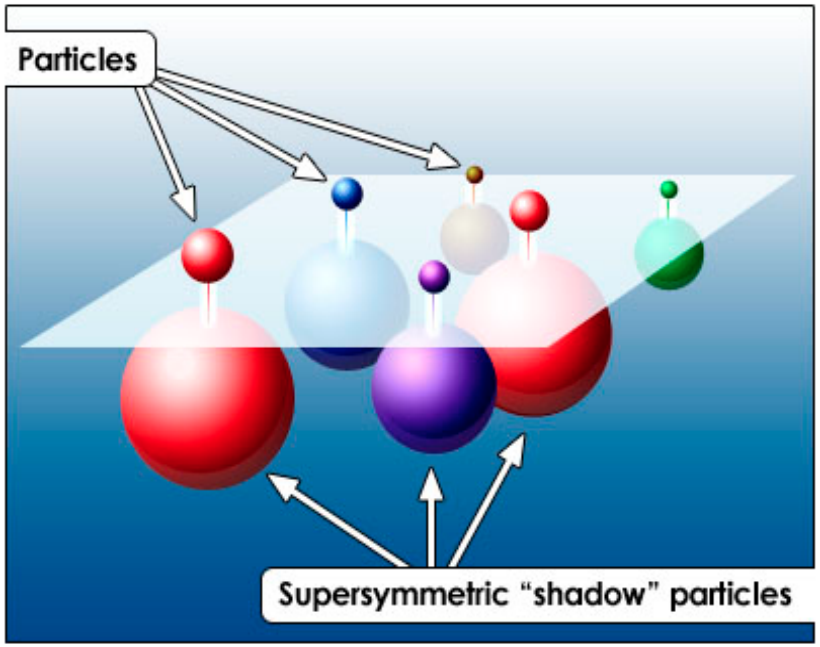
- Weak scale supersymmetry (SUSY) is one of the most extensively studied extensions of the Standard Model
- SUSY postulates superpartners for all the SM particles:

  SM fermion ⟷ SUSY boson

  SM boson ⟷ SUSY fermion

- Plethora of new particles to be observed in experiments

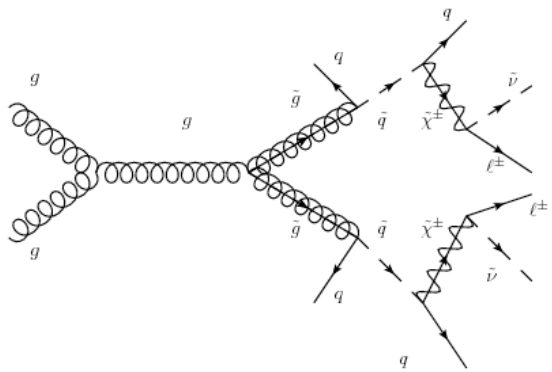




- SUSY can solve the hierarchy problem
- Unification of the gauge couplings at high scales
- If R parity conserved:
  - The lightest supersymmetric particle (LSP) is stable ⟶ Dark matter candidate
  - SUSY particles are produced in pairs

- No particles with same masses observed:
  SUSY must be a broken symmetry
  through a hidden sector with a messenger field: e.g. gravity (MSUGRA/CMSSM), gauge interactions (GMSB)

SUSY Search Strategy (Inclusive Search)



- Production:
  - Squark and gluino expected to dominate
  - Strong production ⇨ high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model

- Decay:
  - Details of decay chain depend on SUSY model (mass spectra, branching ratios, etc.)
  - Assume RP conserved ➔ decay to lightest SUSY particle (LSP)
  - Assume squarks and gluinos are heavy ➔ long decay chains

- Signature:
  - MET from LSPs, high-ET jets and leptons from long decay chain
  - b-quark jets

- Focus on simple signatures
  - Common to wide variety of models
  - Let Standard Model background and detector performance define searches not models

SUSY in the Third Generation Squarks

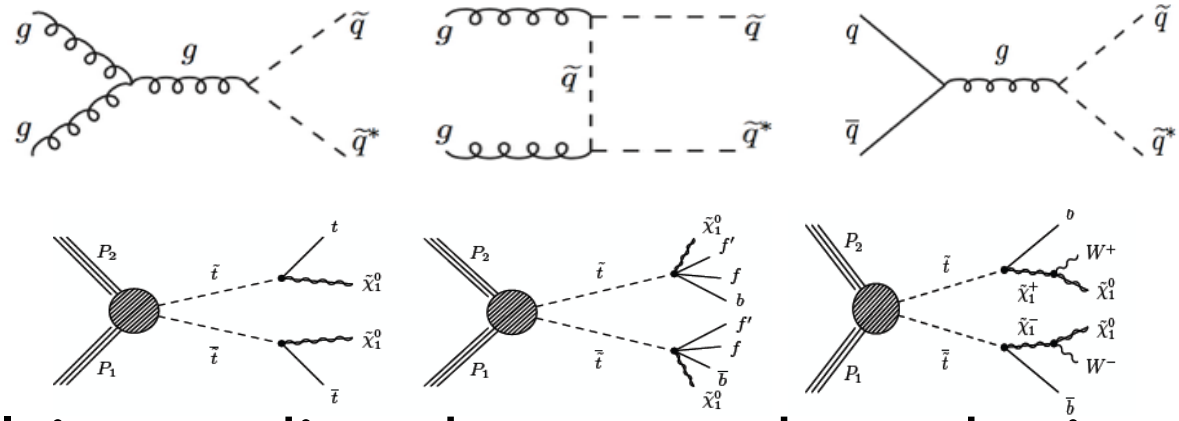
- Discovery of a Higgs boson near a mass of 125 GeV has reinforced the hierarchy problem in the SM
- Natural SUSY scenario is favored because it involves a small tuning in the theory
  - Stop is needed to solve the hierarchy problem
  - Gluino and 3rd generation squarks constrained to be not heavy
- Good prospects for experimental observation of SUSY in the third generation

Search for Stop

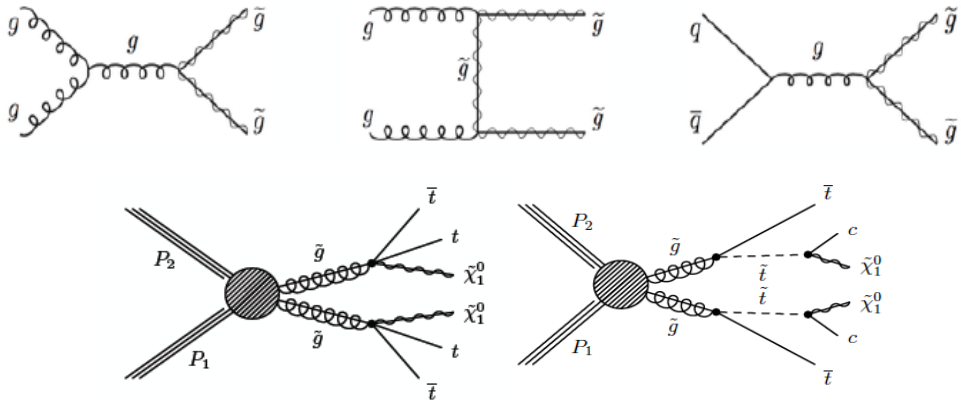
Dedicated and inclusive searches with varying lepton multiplicities

Stop (Production & Decays)

- Direct production (gg or qq initiated) & decays



- Gluino-mediated top squark production & decays



- Higher cross section
- Each gluino decays to qq → more particles in the final states

Stop (Signatures & Backgrounds)

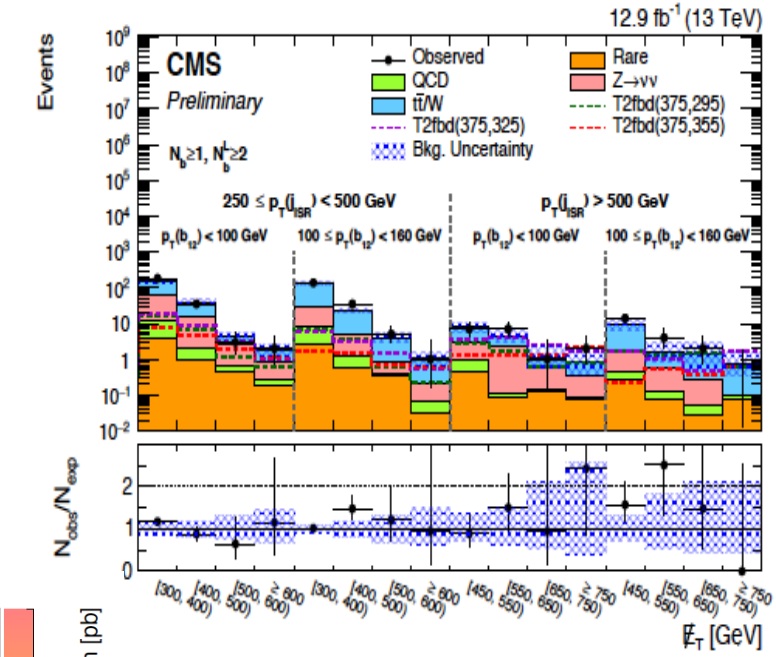
- 0-Leptopn : SUS-16-029, SUS-16-30
  - Signature:
    - Multi-jet: b-tagged jets from stop or top decay
    - missing transverse mass: from neutralino
  - Backgrounds:
    - Lsot Lepton from tt or W+jets:
      - leptons are not identified (misidentification, out of acceptance, hadronic tau)
      - Estimated: using 1-lepton control sample
    - Z(vv)+Jets:
      - Irreducible background
      - Estimated: using Z→ll & γ+Jets control sample
    - QCD:
      - Very large cross section, met from jet misidentification
      - Estimated: Low $\Delta\varphi(J_i, MET)$ control sample

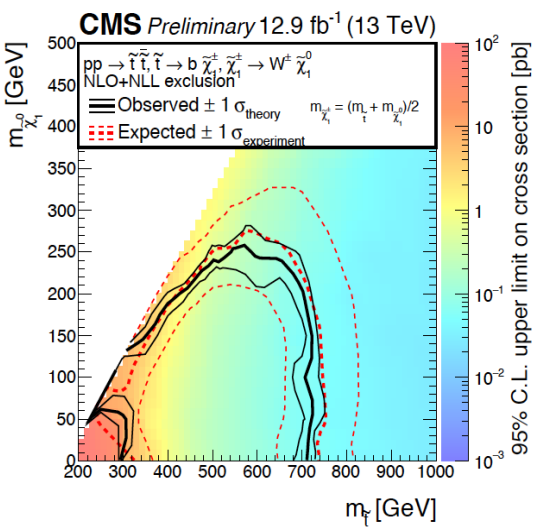
Stop (Signatures & Backgrounds)

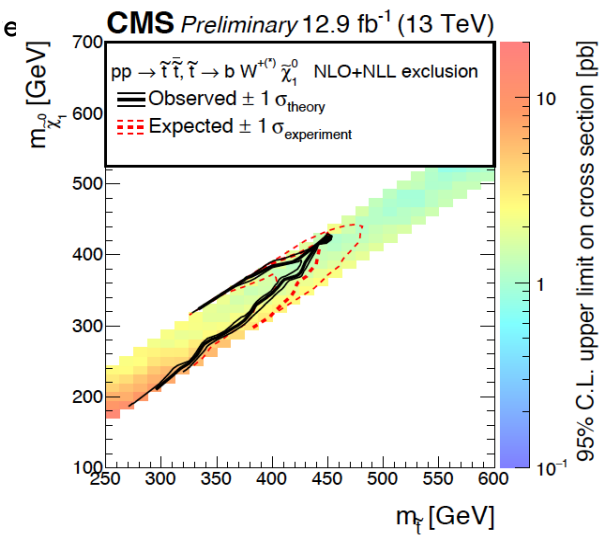
- 1-Leptopn : SUS-16-028
  - Signature:
    - Multi-jet: b-tagged jets from stop or top decay
    - missing transverse mass: from neutralino
    - Lepton: from stop, chargino and W decays
  - Backgrounds:
    - Lost lepton from tt & tW:
      - Lost Lepton due to misidentification→ M_T (transverse mass)>M_W
      - Estimation: using di-lepton control sample
    - 1-Lepton background from W+jets & WW
      - Off-sell W → M_T>M_W
      - Estimated: using 0b control saple
    - Smaller contribution from ttZ(vv), WZ

0-Lepton (direct stop production)

- Analysis strategies:
  - High Δm (stop, LSP):
    - m_T (b,MET), boosted W and top tagging, $N_{b\text{-jet}}$
  - Low Δm (stop, LSP):
    - Recoiling against hard ISR-jet, ISR-jet p_T, MET, $N_{b\text{-jet}}$
- Good agreement between data and prediction:





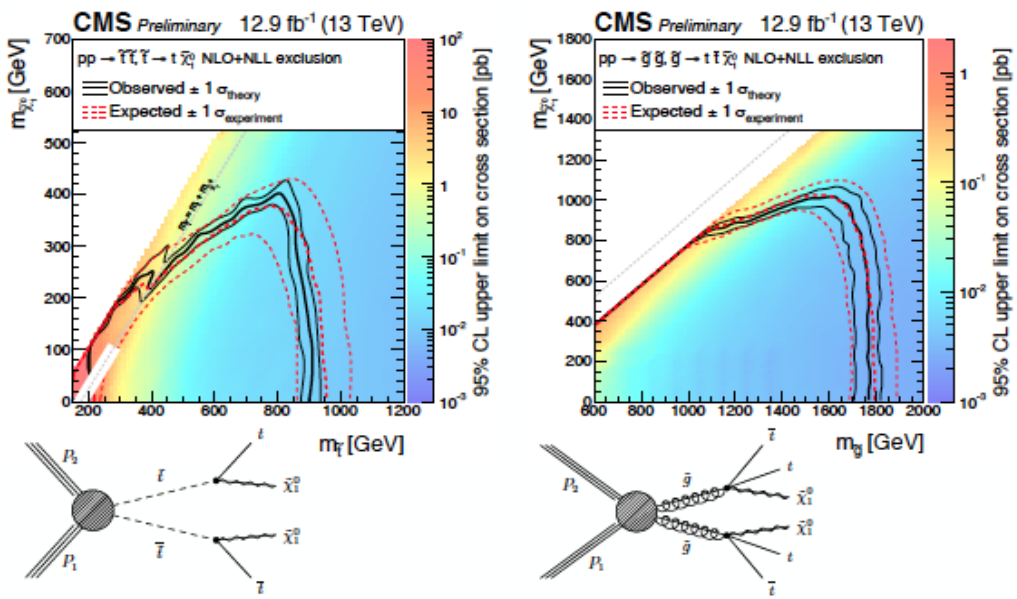


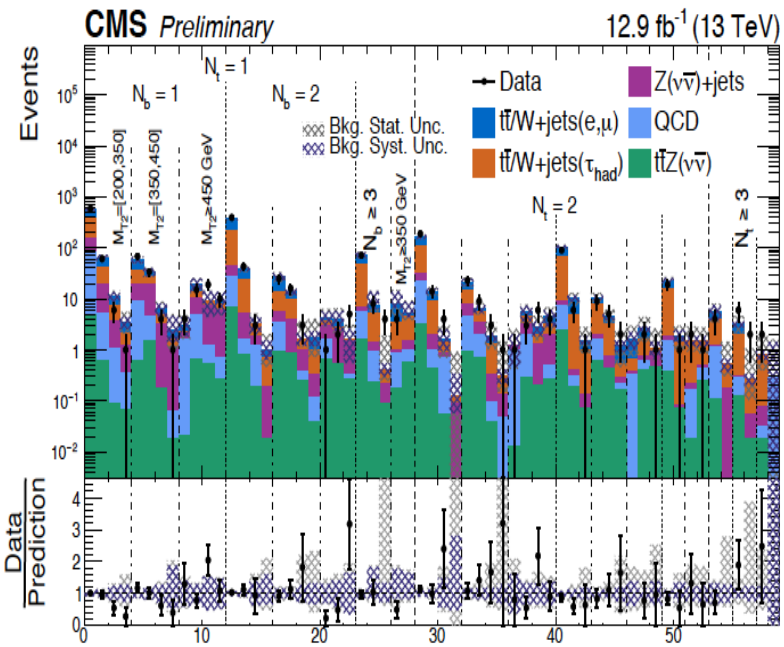
- Exclude top squark masses:
  - up to 450 GeV for very compressed model with 4-body decay
  - Up to 740 GeV when stop decays to b+chargino

0-Lepton (direct stop production)

SUS-16-030

- Analysis strategies:
  - top tagging to identify number of top quark, up to 2 top for direct production and up to 4 for gluino-mediated stop
  - kinematic variables and binning: M_{T2}, MET, $N_{b\text{-jet}}$, N_{top}
- Good agreement between data and prediction:
  - Interpretation: exclusion limits are set in the context of simplified models



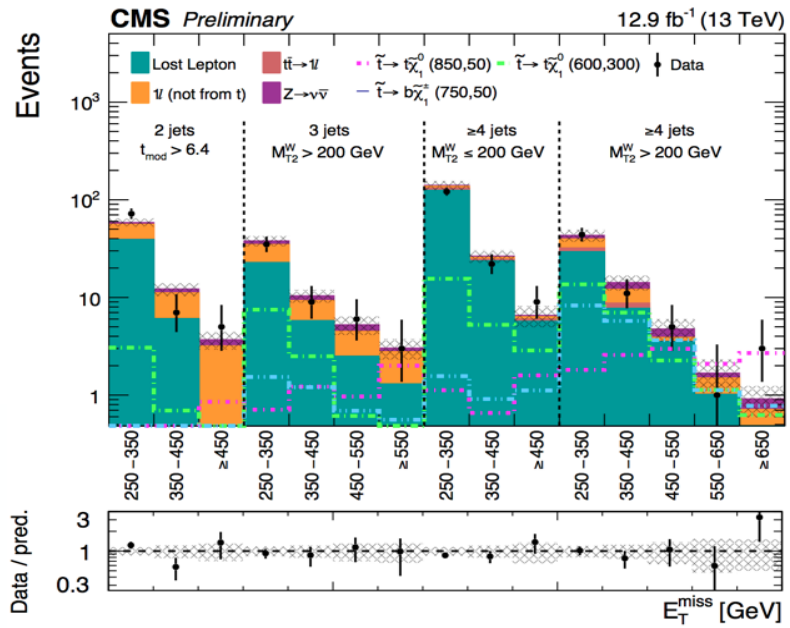


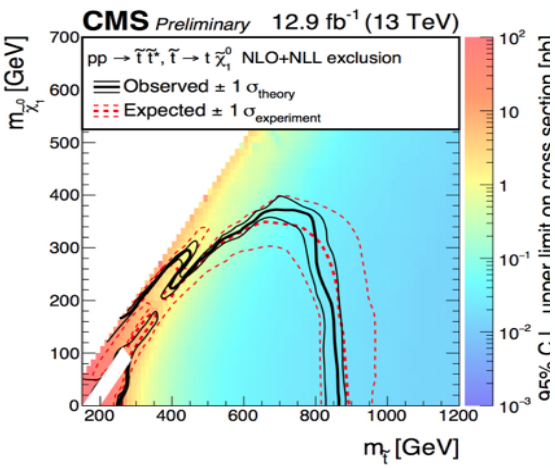
- Exclude top squark masses:
  - up to 910 GeV for neutralino masses up to 400
- Exclude gluino masses:
  - up to 1780 GeV for neutralino masses up to 1020

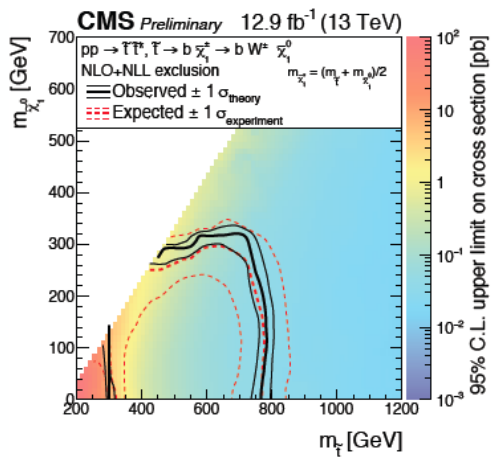
1-Lepton (direct stop production)

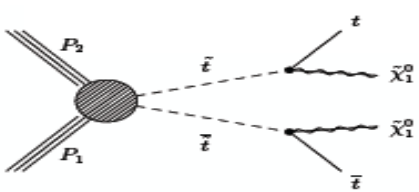
SUS-16-028

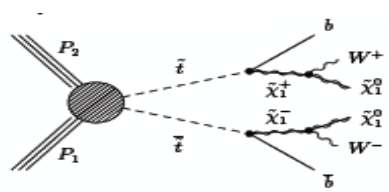
- Analysis strategies:
  - Kinematic variables: modified topness & MT_2^W
  - binning: M_{T2}, MET, N_{jet}
- Good agreement between data and prediction:
  - Interpretation: exclusion limits are set in the context of simplified models











- Exclude top squark masses:
  - masses up to 860 GeV for neutralino masses up to 380 GeV
  - Slightly weaker limits for models with intermediate chargino

Leptoquarks

Three generations, scalar and pair production

introduction

- Leptoquarks (LQ) are hypothetical particles that carry both lepton (L) and baryon (B) quantum

- LQ particles are hypothesized by a variety of BSM models:
  - New symmetry between quarks and leptons
  - Grand unification, extended technicolor models superstring-inspired models

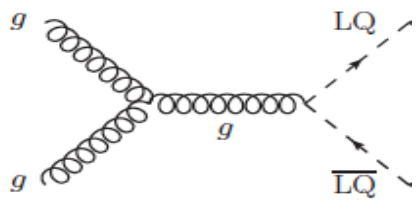
- LQs are assumed to couple to one generation of chiral fermions
  - Fractional electric charge, color triplets under SU(3),
    carrying either zero or one unit of spin

- For scalar LQs, the production cross section is determined by the color coupling between a LQ and a gluon

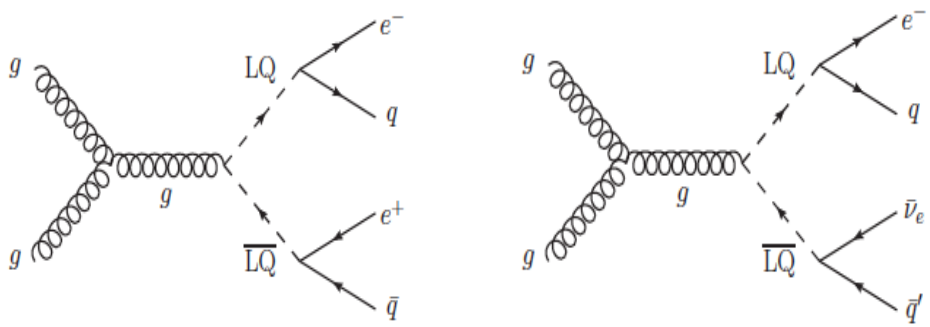
- Branching fraction of scalar LQ into ql (β) is treated as free parameter

LQs (Production & Decays)

- Consider pair production:
  - gg production is dominant in LHC



- Decay modes.
  - Llqq (l= e, μ , τ) or lvqq,
    - llqq final states are covered in this talk



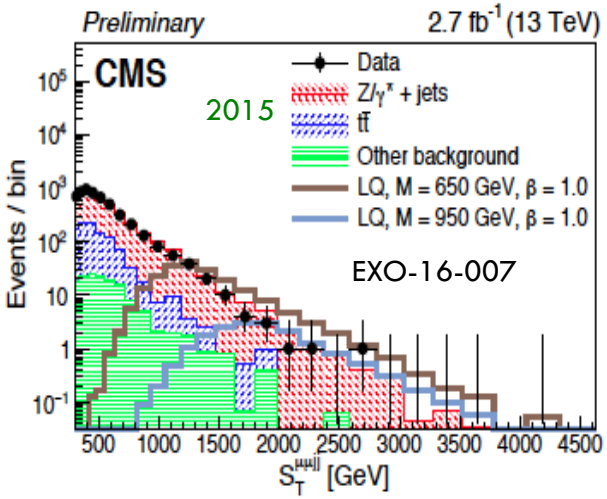
LQs (1st & 2nd Generation)

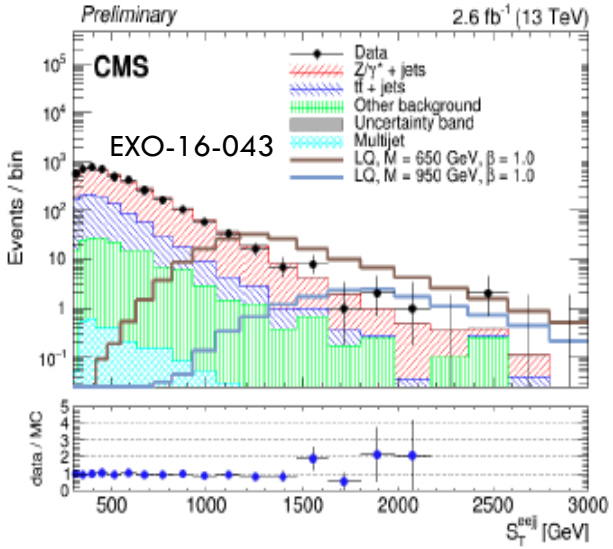
EXO-16-007,043

- Strategy:
  - Two hard leptons (e, μ) + two hard jets
  - Optimize final selections as a function of LQ mass
  - Kinemtaic variables :

    S_T (scalar sum of lepton and jet p_T),

    Invariant mass of ql
- Backgrounds:
  - Z(ll)+Jets: MC shape, normalized in Z peak
  - ttJet:
    - LQ1, LQ2: using e μ +jets control sample.
      - LQ1: MC normalized to data
      - LQ2: data-driven shape/normalization
  - QCD: not negligible for LQ1
    - using same sign non-isolated leptons control sample
  - Diboson, single top: small contribution which is taken from MC

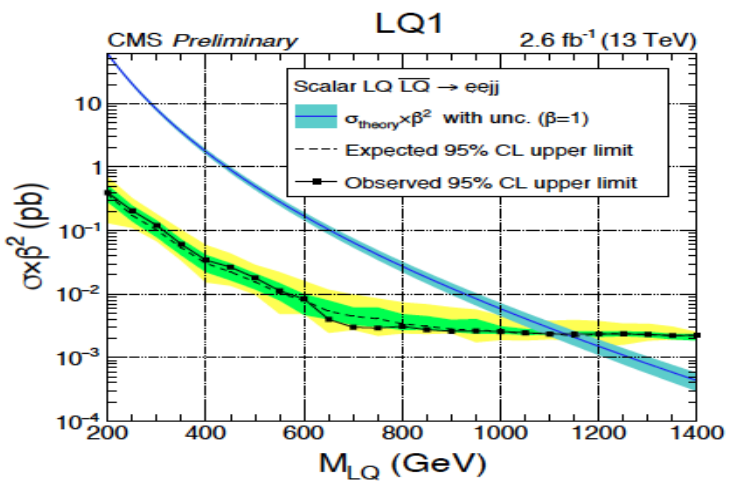


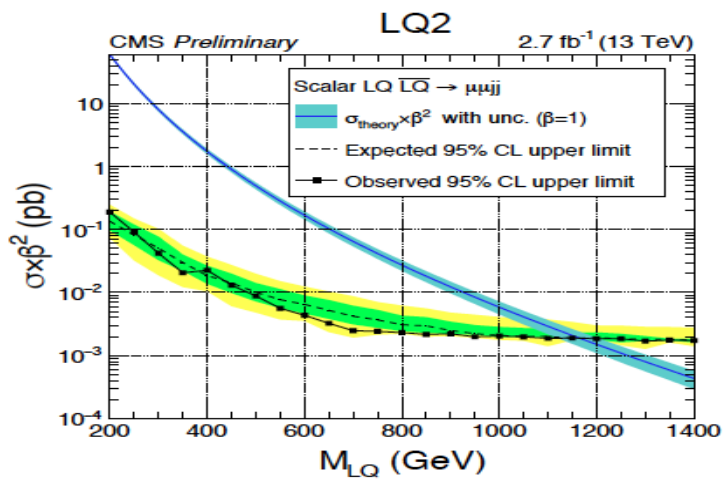


LQs (1st & 2nd generation) results

EXO-16-007,043

- Good agreement between the data and predicted BKG





- Excluded mass for $\beta = 1$
  - LQ1: 1st generation mass is excluded up to 1130 GeV
  - LQ2: slightly stronger limit on 2nd generation mass and it is excluded up to 1165 GeV

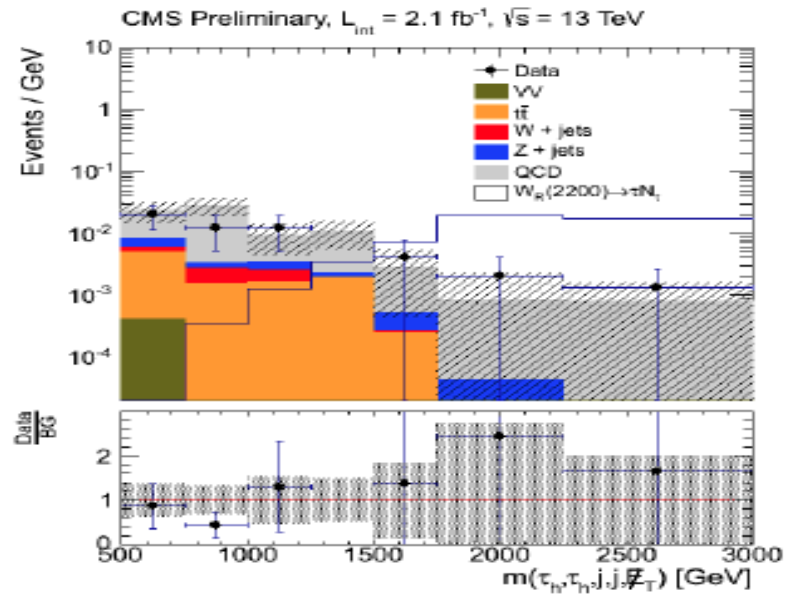
LQs (3rd Generation)

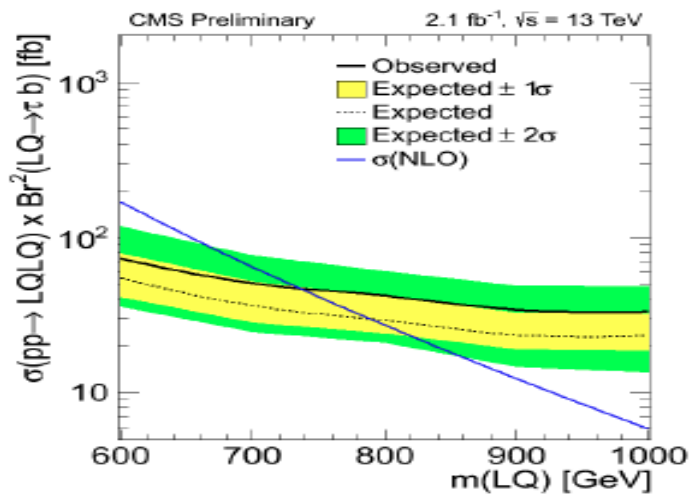
EXO-16-016

- Strategy:
  - LQ3->b τ
  - Two hard hadronic taus + two hard jets
  - Kinemtaic variables :

    S_T (scalar sum of lepton and jet p_T),

    the invariant mass of taus, jets and MET
- Backgrounds:
  - Multijet QCD:
    - is the dominant background
    - ABCD method, estimated using low MET and non-isolated taus control sample
  - ttJet: Diboson, single top:
    - small contribution which is taken from MC
- Results:
  - No excess above expectation from SM processes
  - limit on LQ3: > 740 GeV





Vector Like Quark

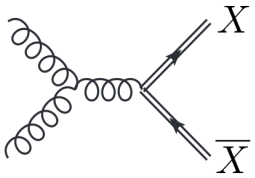
Dedicated searches based on single or pair production

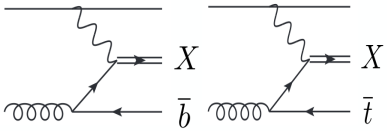
Introduction

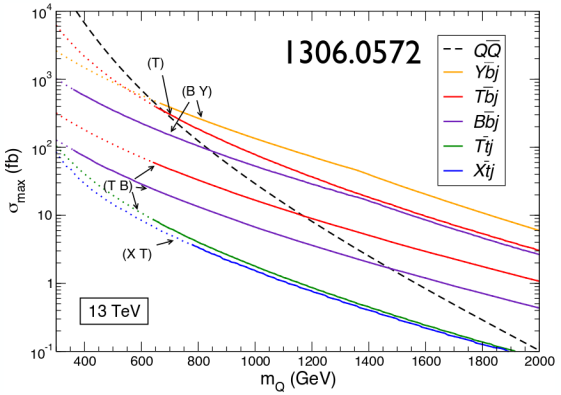
Weak multiplets(isospin$_{hypercharge}$)

Singlets	Doublets	Triplets
$1_{2/3} = T$	$2_{1/6} = \begin{pmatrix} T \\ B \end{pmatrix}$	$3_{2/3} = \begin{pmatrix} X \\ T \\ B \end{pmatrix}$
$1_{-1/3} = B$	$2_{7/6} = \begin{pmatrix} X \\ T \end{pmatrix}$	$3_{-1/3} = \begin{pmatrix} T \\ B \\ Y \end{pmatrix}$
	$2_{-5/6} = \begin{pmatrix} B \\ Y \end{pmatrix}$	

- Quarks that are not like quarks!
  - Spin1/2, colored, charged particles, left and right handed components have the same colour and electroweak quantum numbers.
  - do not receive their masses from Yukawa couplings to a Higgs doublet
    - Not ruled out by SM fits that exclude 4th gen chiral quarks
    - predicted by Little Higgs and Composite Higgs models
      - e.g. vector like top quark stabilize quantum corrections to the Higgs boson mass
  - pair production through QCD:
    - dominant in low mass
  - single production through EWK coupling:
    - dominant in high mass



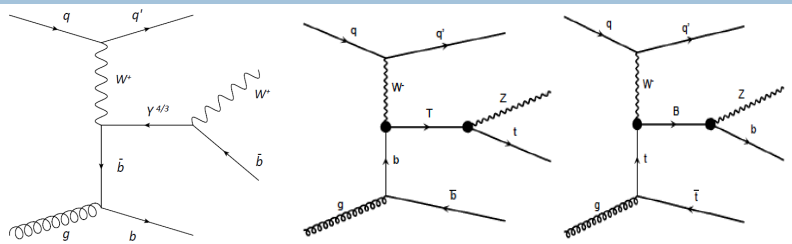


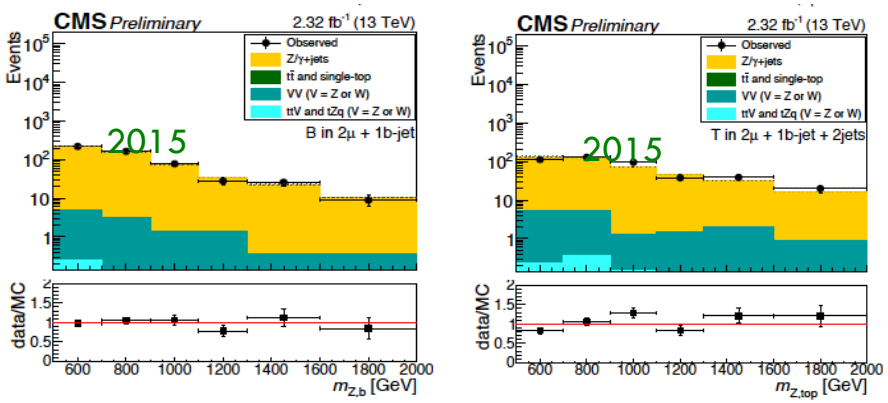


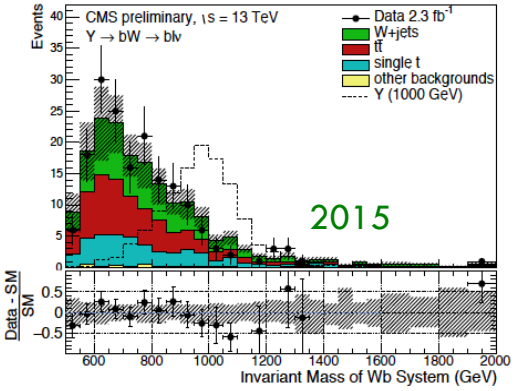
VLQ (strategy & BKG)

B2G-16-001, 006

- VLQ decay modes
  - Single & Di lepton final states
    - Categorized by boosted objects, or by lepton flavor for non-boosted topologies
  - reconstructing $M_{T/B}$ using leptons and boosted jets & M_Y using b jet and leptonic W decay
- Background estimation:
  - VLQ (T & B) search:
    - estimate all background all together, using a control sample with 0b
  - VLQ (Y) search:
    - validate MC simulation using 2 and 0 b-tagged control samples

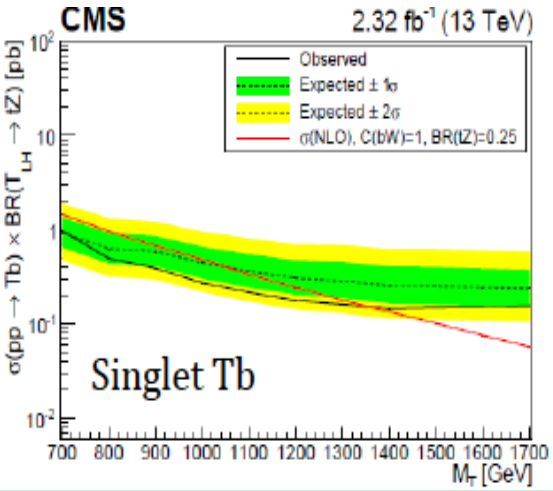


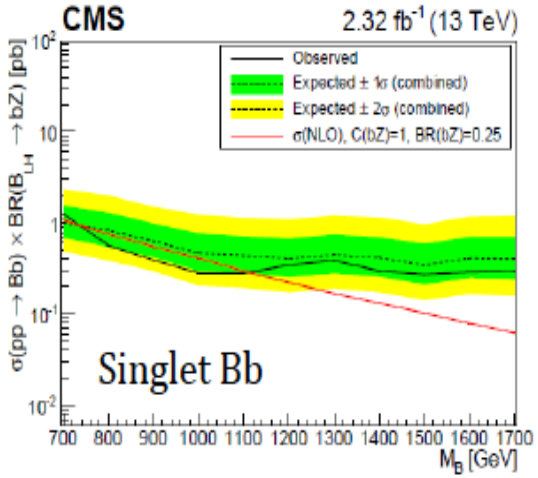




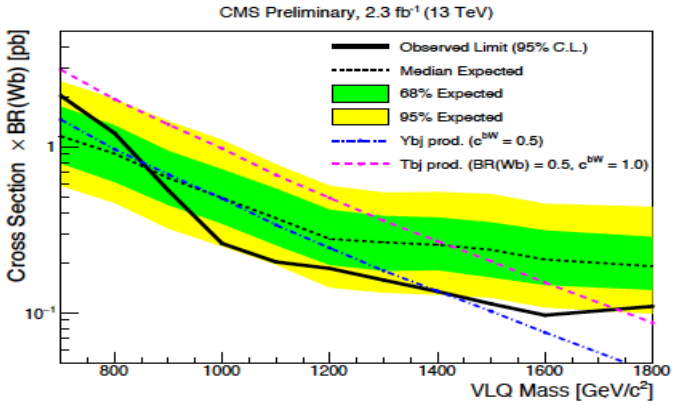
VLQ (results)

- No excess is observed





- Exclude T singlet below 1350 GeV
- Exclude B singlet below 1120 GeV



- Exclude $Y_{-4/3}$ singlet below 1.4 GeV

Summary

- CMS conducts beyond of Standard Model searches in a broad and complementary signatures
- No significant excesses observed, set limits on BSM parameters
- Searches now extended to more challenging scenarios
- More data to come→ stay tuned

Back up

MT2 Definition

$$M_{\mathrm{T2}} \equiv \min_{\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}(1)} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}(2)} = \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}} \left[\max\left(M_{\mathrm{T}}^{(1)}, M_{\mathrm{T}}^{(2)} \right) \right]$$

- Find minimum for heavy particle mass for topologies where each heavy particle decays to a visible (eg top squark) and invisible (eg neutralino) component, by varying how the MET is distributed over the two invisible components

- Has edge at the top squark mass for direct top squark production with decay to top + neutralino

W & Top Tagging

- N-subjettiness

$$\tau_N = \frac{1}{R_0 \sum_k p_{T,k}} \sum_k p_{T,k} \min(\Delta R_{1,k}, \Delta R_{2,k}, ...\Delta R_{N,k}),$$

  - Value is small if the original jet is consistent with having N or fewer subjets, because almost every jet constituent will be close in ΔR to its own true subjet.

- Soft-drop
  - Revert jet clustering step by step, and discard softest subjet if the following condition does not hold

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \cdot (\frac{\Delta R_{12}}{R})^{\beta}$$