SUSY 2016; MELBOURNE

# SEARCHES FOR BSM PHYSICS IN FINAL STATES WITH LEPTONS AND JETS AT CMS

On behalf of the CMS collaboration

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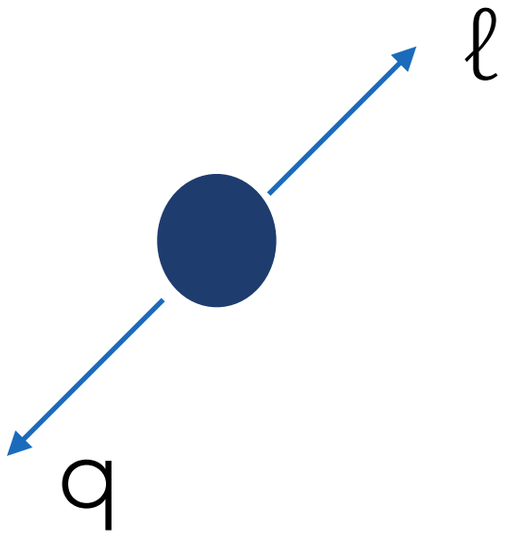
**Caltech**

# OUTLINE

- Searches for first and second generation leptoquarks at 8TeV
  - eejj and μμjj final states
  - eνjj and μνjj final states
- Second generation leptoquark production at 13 TeV
  - μμjj final state
- Search for heavy right-handed (W,neutrinos) and 3rd generation leptoquarks using $\tau_h$
- Summary

# LEPTOQUARKS AND LEPTONS

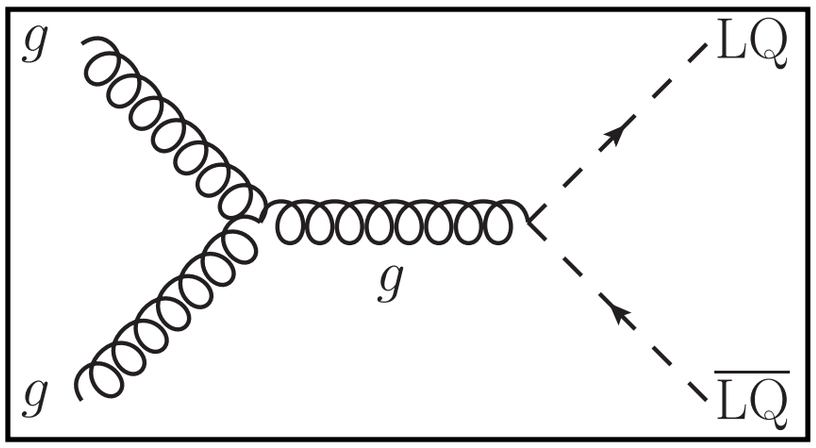
final states with leptons (e,μ) are clean final; significantly reduce mutijet QCD production

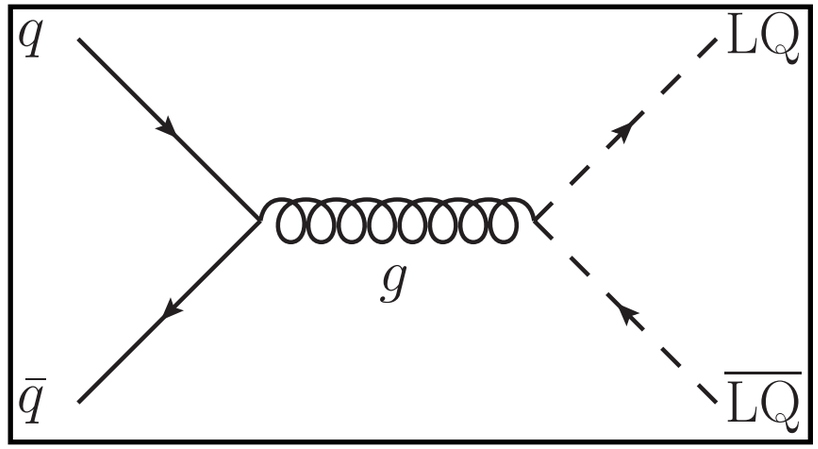



In case of a resonance decaying to ℓ+q; invariant mass resolution will benefit from extremely good resolution of leptons at CMS

# LEPTOQUARKS AT THE LHC

leptoquarks are pair produced at the LHC




leptoquark decay

$LQ \rightarrow \ell q$ or $LQ \rightarrow \nu q$

three different experimental signatures

$\ell \nu jj$

MET+jets

$\ell \ell jj$

fully reconstructed final state

$\nu \nu jj$

MET+jets

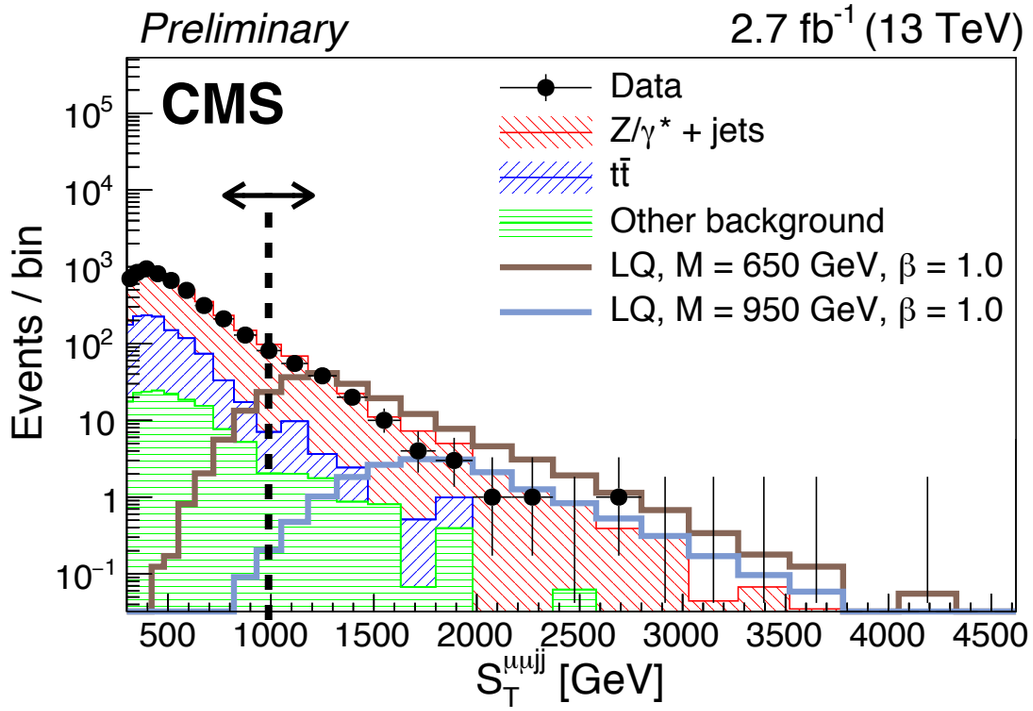
# EVENT SELECTION AND BKG ESTIMATION

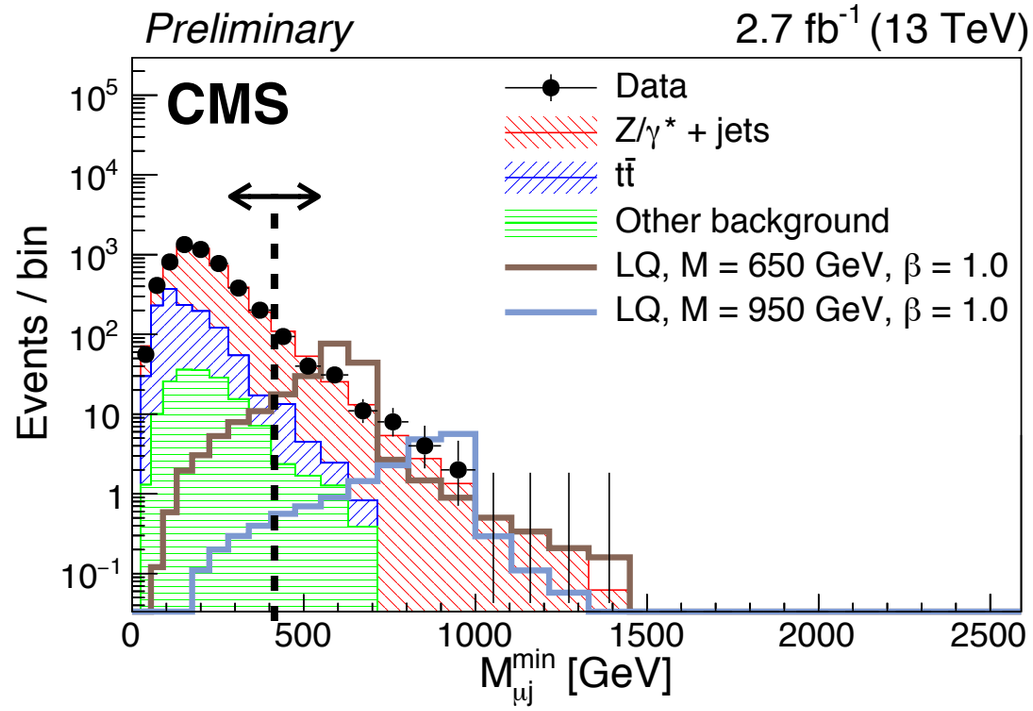
## $\ell\ell JJ$

- Opposite sign μ (e); $p_T > 50$ GeV && $|\eta| < 2.1$ ( $p_T > 45$ GeV && $|\eta| < 2.5$ )
- Leading (subleading) jet is required to have $p_T > 125$ (45) GeV ; $|\eta| < 2.4$
- Baseline $M_{\ell\ell} > 50$ GeV; $S_T > 300$ GeV

for each LQ mass, select cuts that maximize $s/\sqrt{(s+b)}$

EXO-16-007



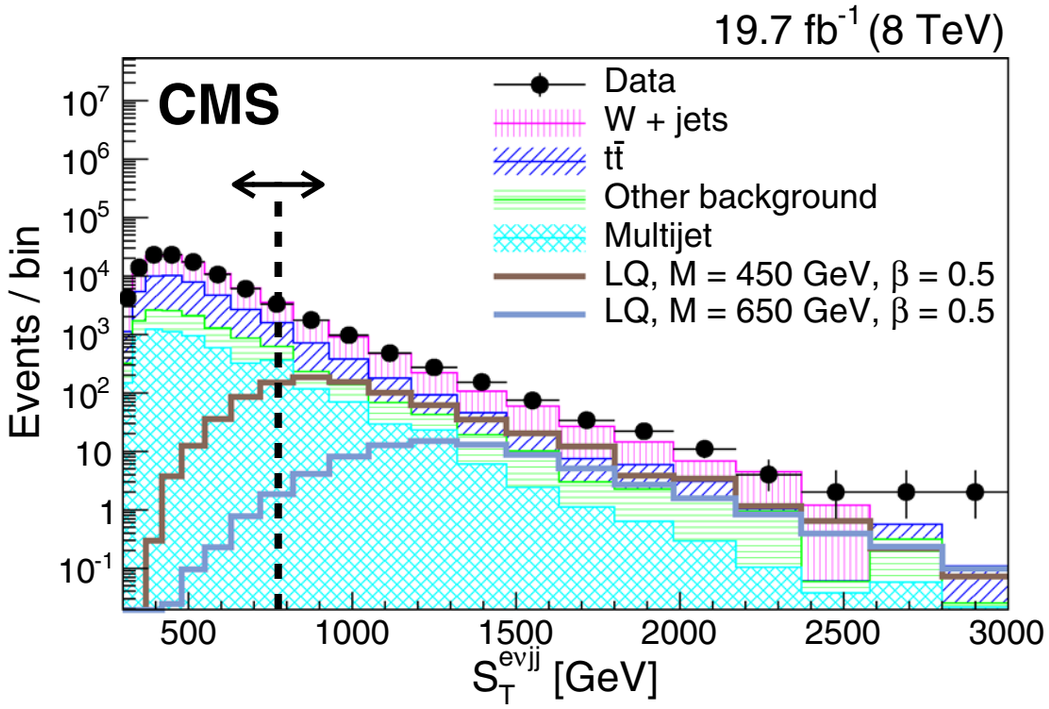
# EVENT SELECTION AND BKG ESTIMATION

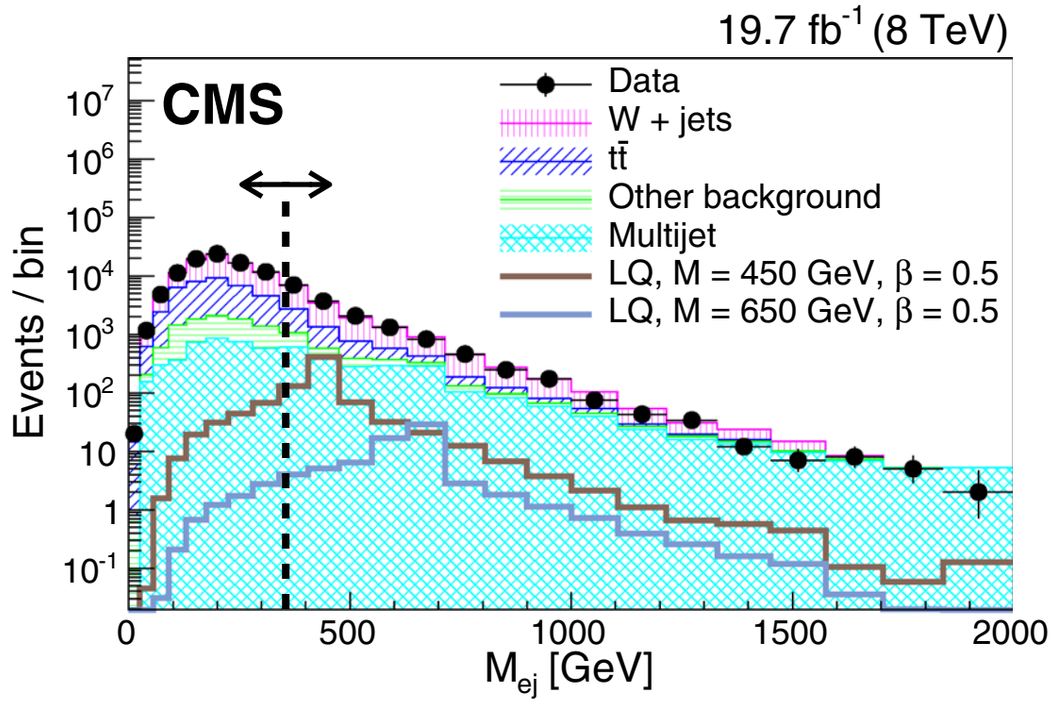
## $\ell \nu J J$

- Exactly one μ (e); $p_T > 45$ GeV && $|\eta| < 2.1$ ( $p_T > 45$ GeV && $|\eta| < 2.5$ )
- Leading (subleading) jet is required to have $p_T > 125$ (45) GeV ; $|\eta| < 2.4$
- MET > 50 GeV; $M_T > 50$ GeV; $\Delta\phi$(MET, j1) > 0.5; $\Delta\phi$(MET, $\ell$) > 0.8;
- $S_T > 300$ GeV

for each LQ mass, select cuts that maximize $s/\sqrt{(s+b)}$

PhysRevD.93.032004



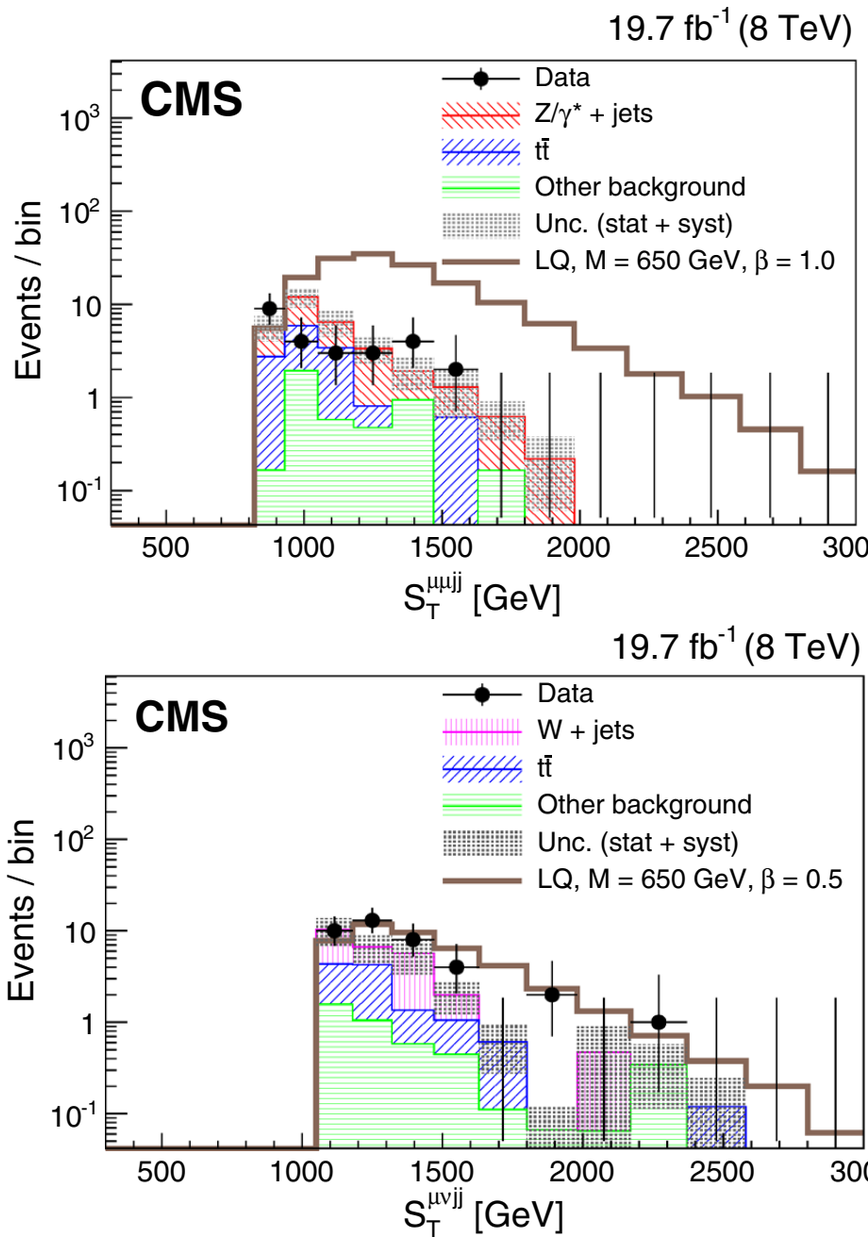
# RESULTS AND INTERPRETATION

## muon channels

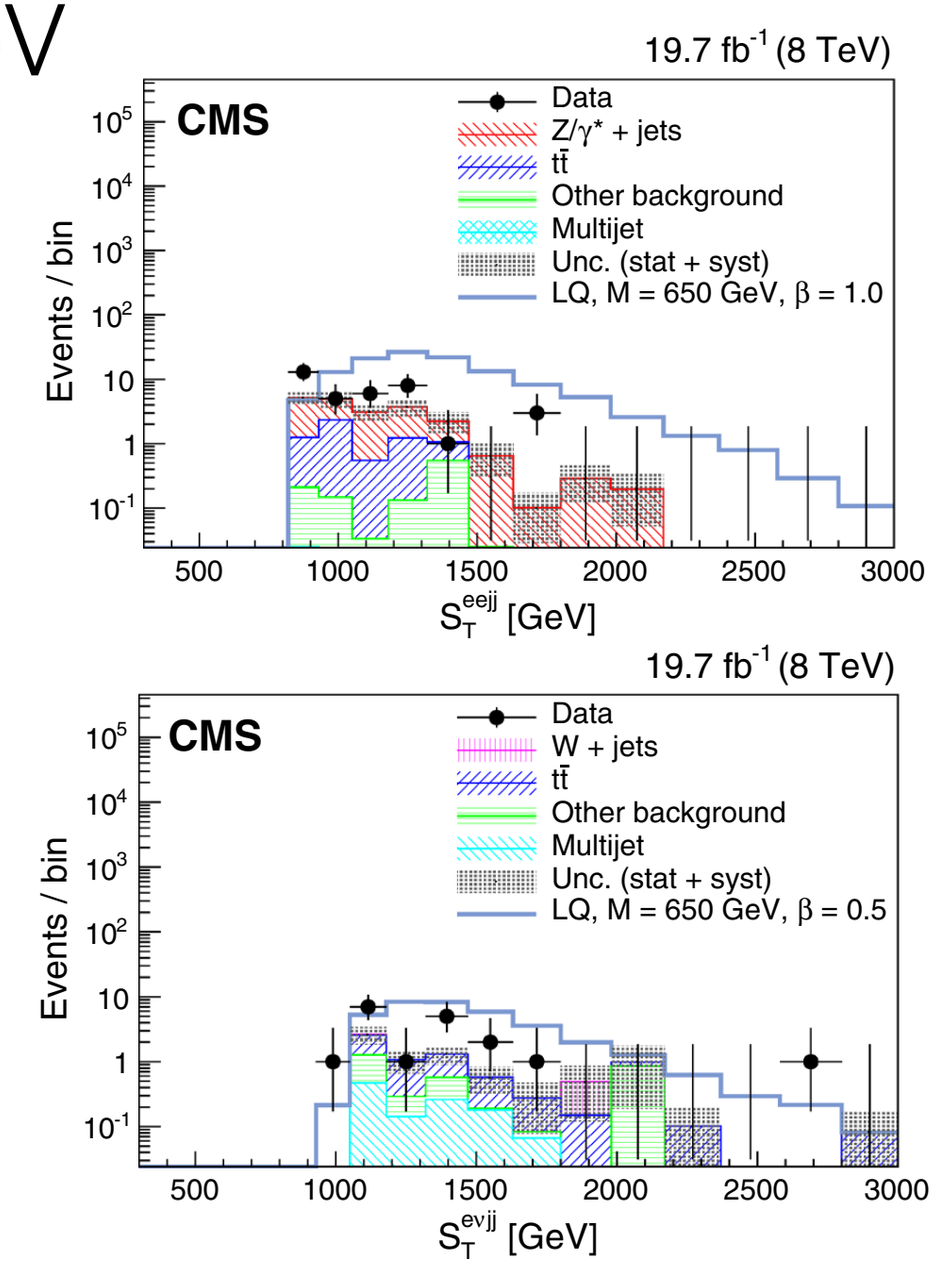
PhysRevD.93.032004

## electron channels

$M_{LQ} = 650$ GeV



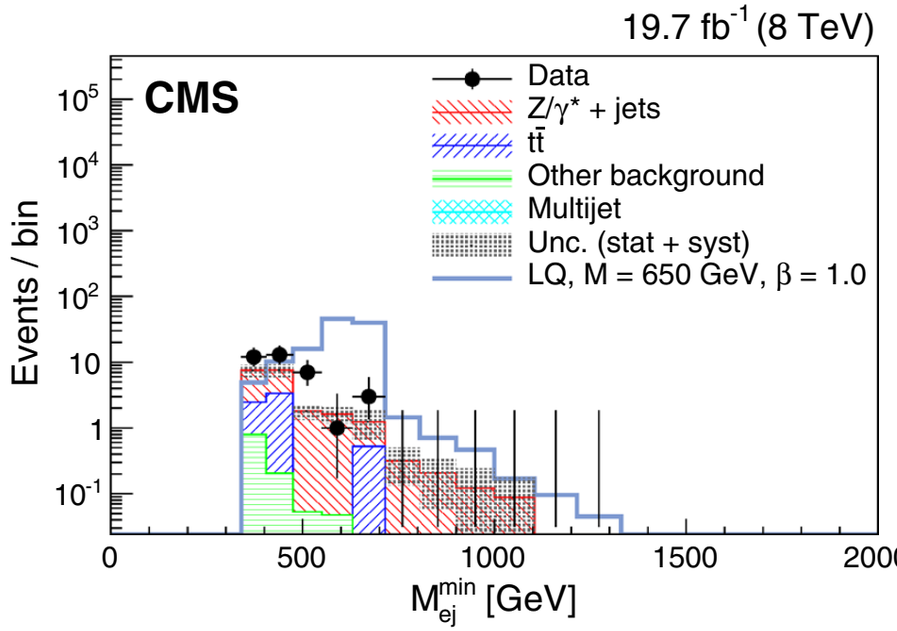

*no excess of events*

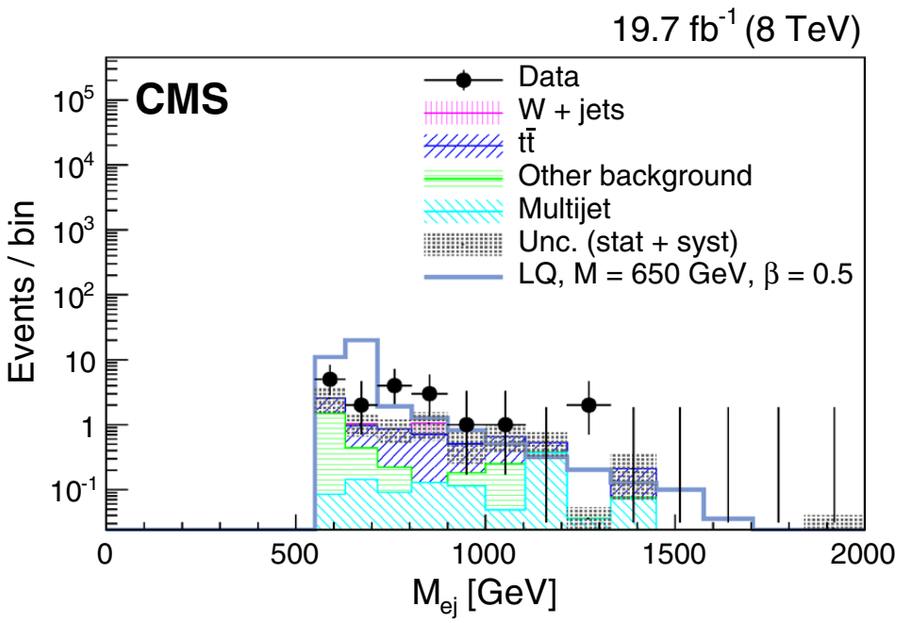



*broad excess of events*

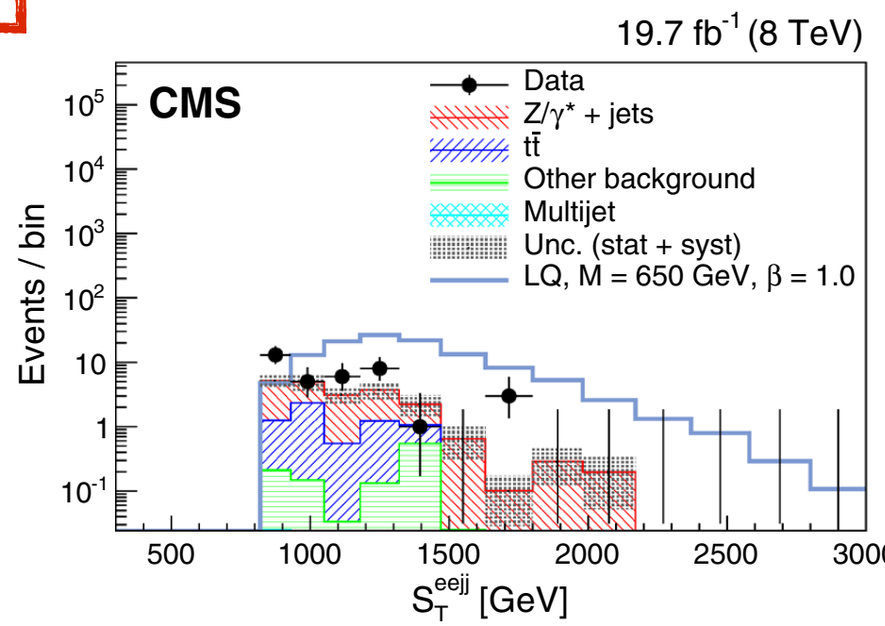
# $M_{LQ}$ = 650 GeV electron channel

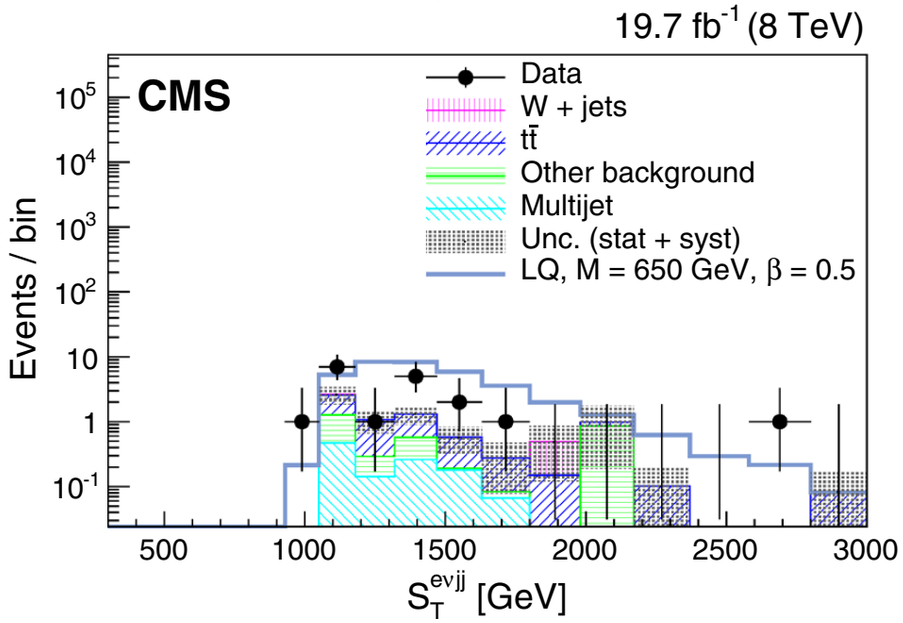
PhysRevD.93.032004




Not much peaking behavior in $M_{ej}$



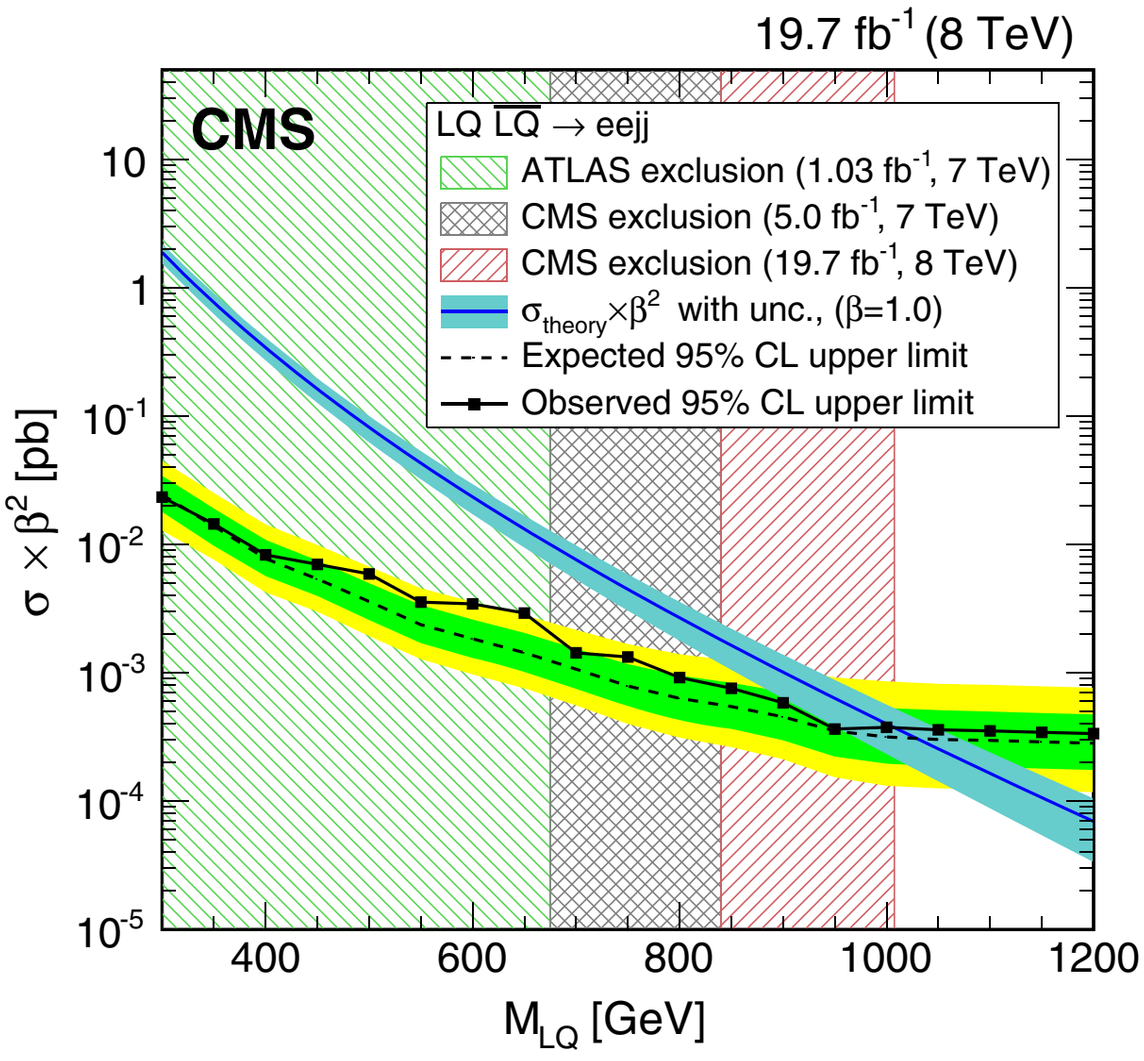



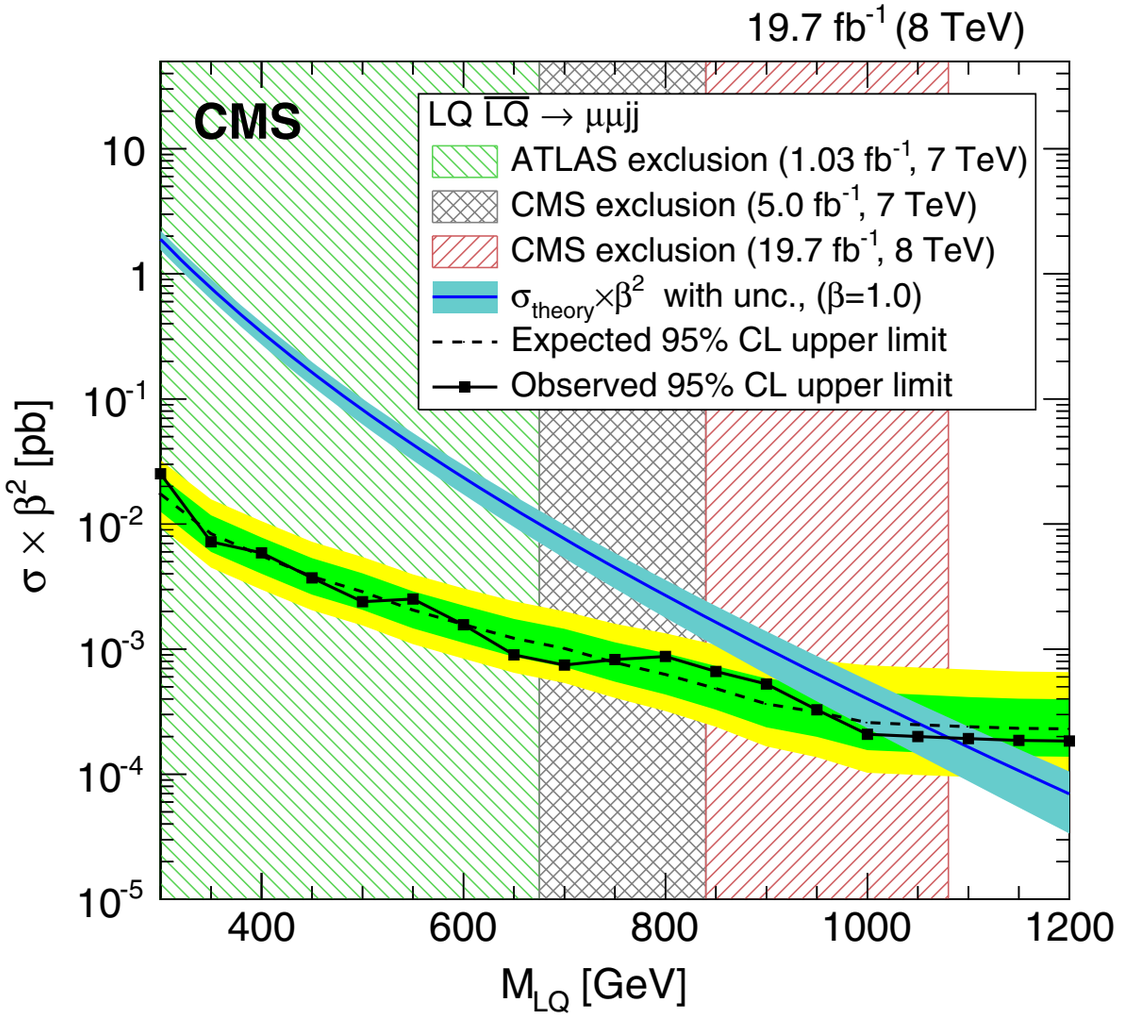

bkg like broad excess of events?

# LEPTOQUARK LIMITS

PhysRevD.93.032004

first generation β=1 second generation



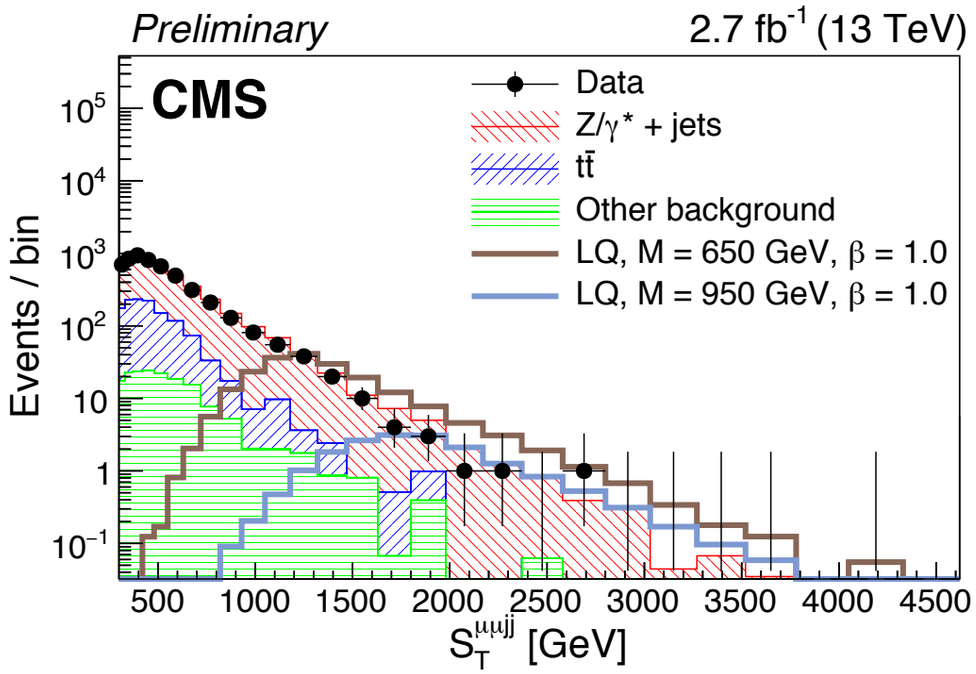




excluded below ~1TeV

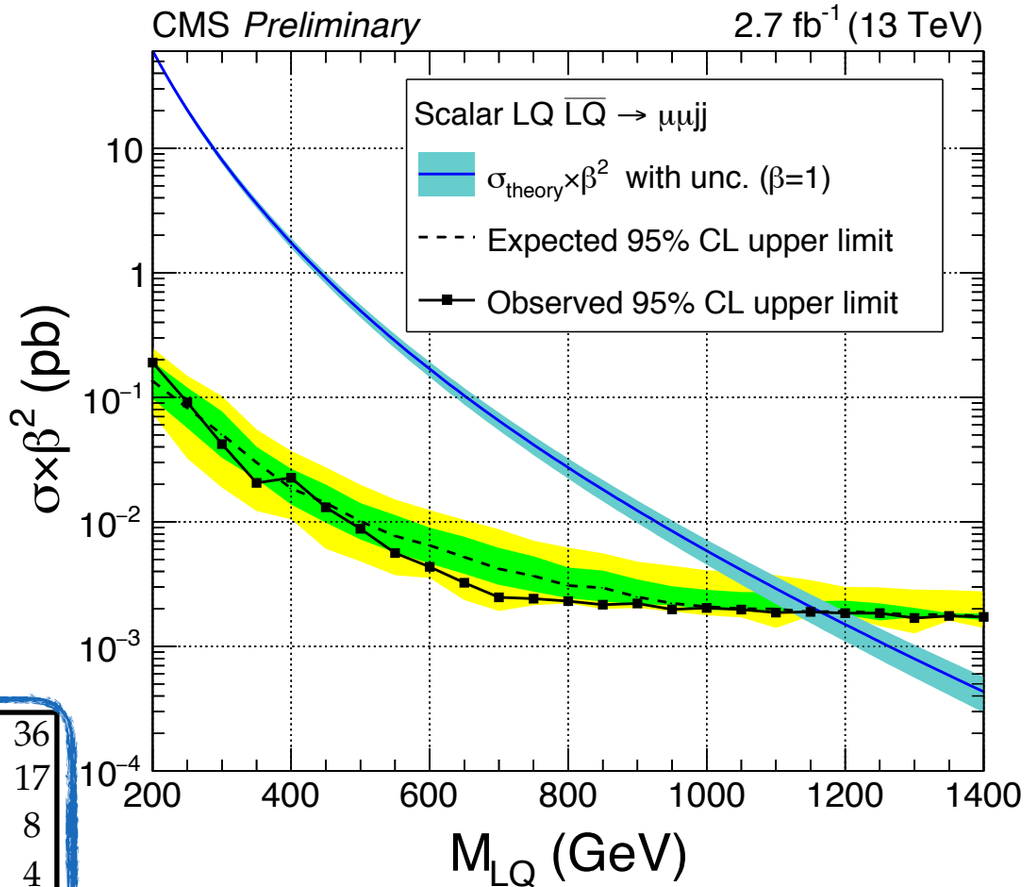
excluded below ~1.07 TeV

# 13 TEV RESULTS AND LIMITS

EXO-16-007




exclude leptoquarks up to 1165 GeV




| | | | | | | |
|---|---|---|---|---|---|---|
| 450 | $1089.1 \pm 7.3$ | $17.55 \pm 0.45$ | $14.84 \pm 2.58$ | $3.99 \pm 0.58$ | $36.4 \pm 2.7 \pm 1.8$ | 36 |
| 500 | $603.1 \pm 4.0$ | $10.43 \pm 0.34$ | $5.78 \pm 1.49$ | $2.14 \pm 0.42$ | $18.4 \pm 1.6 \pm 1.4$ | 17 |
| 550 | $350.6 \pm 2.3$ | $6.86 \pm 0.27$ | $4.41 \pm 1.33$ | $0.91\ ^{+0.30}_{-0.27}$ | $12.17\ ^{+1.39}_{-1.38} \pm 0.93$ | 8 |
| 600 | $206.2 \pm 1.4$ | $5.0 \pm 0.24$ | $1.91 \pm 0.78$ | $0.51\ ^{+0.22}_{-0.18}$ | $7.43 \pm 0.84 \pm 0.70$ | 4 |
| 650 | $126.72 \pm 0.83$ | $3.2 \pm 0.18$ | $1.353 \pm 0.677$ | $0.33\ ^{+0.21}_{-0.17}$ | $4.88\ ^{+0.73}_{-0.72} \pm 0.44$ | 1 |

no excess observed

***exceeded Run1 sensitivity***

# Search for heavy neutrinos and third generation LQ using $\tau_h$

# HEAVY NEUTRINOS AND THIRD GENERATION LQ USING $\tau_h$

EXO-16-016

## Left-right symmetry extension of the SM

Additional $SU(2)_R$ ⟶ $W_R^{\pm}$, Z′ and 3 heavy neutrinos $N_\ell(e,\mu,\tau)$

first and second generation has been searched for in the eejj and μμjj

One unexplored possible final state is

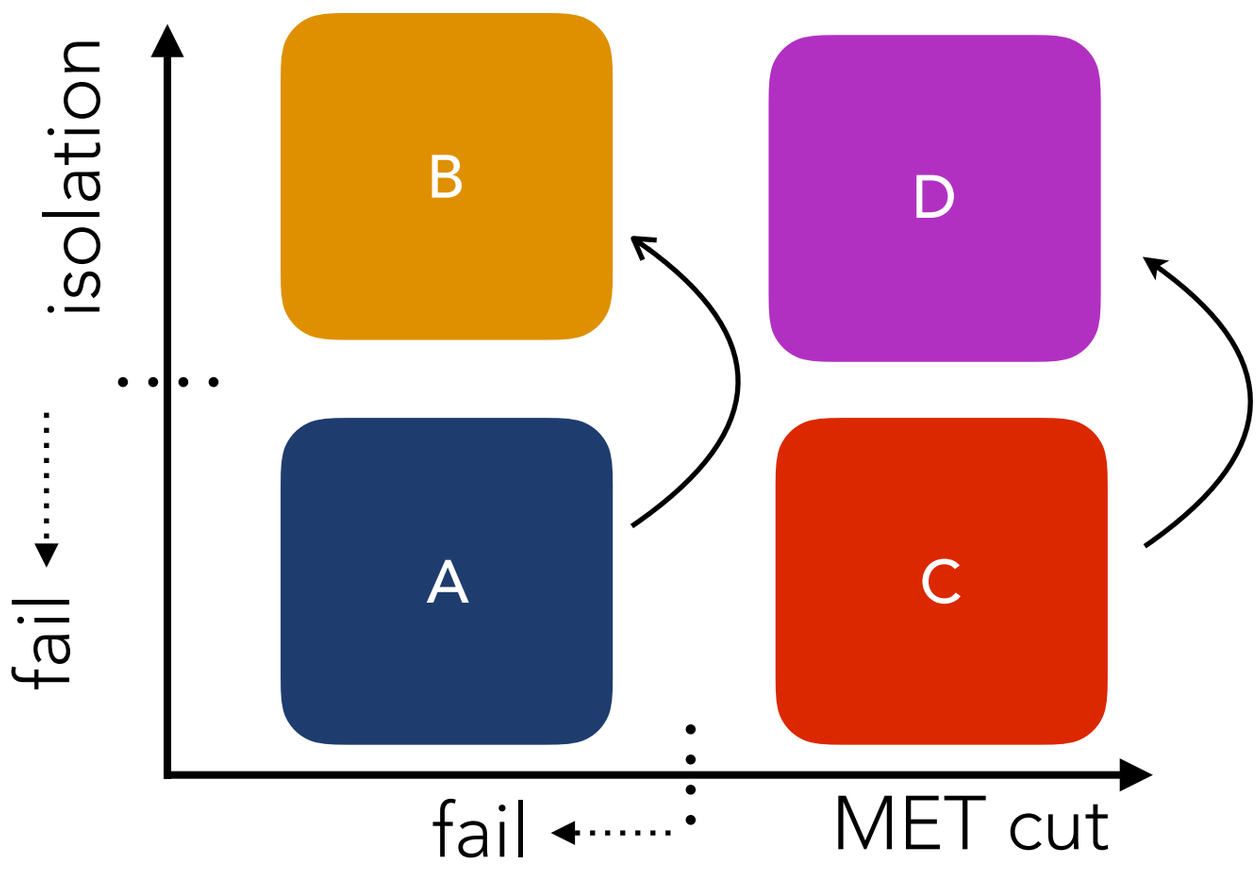
$$\boxed{W_R \to \tau + N_\tau \to \tau + \tau q q'}$$

third generation LQ can produce similar final state: $\tau\tau$bb

# HEAVY NEUTRINOS AND THIRD GENERATION LQ USING $\tau_h$

EXO-16-016

- Two $\tau$ lepton; $p_T > 70$ GeV and $|\eta| < 2.1$; $\Delta R(\tau_1, \tau_2) > 0.4$
- Hadronically decaying taus only ($\tau_h$)
- Two jets with $p_T > 50$ GeV and $|\eta| < 2.4$; $\Delta R(\tau_i, j) > 0.4$
- MET > 50 GeV; $M_{\tau\tau} > 100$ GeV (reduce Z background)



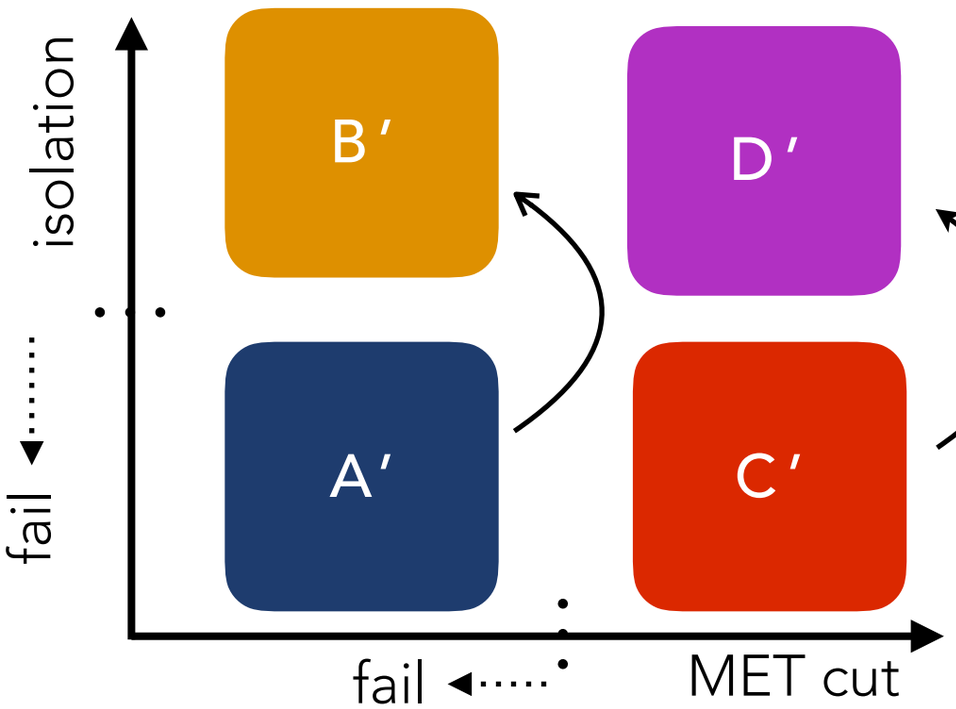

A,B,C → control regions

D → signal region

Isolation transfers factor

$$N^{D}_{\mathrm{QCD}} = N^{C}_{\mathrm{QCD}} \cdot (N^{B}_{\mathrm{QCD}} / N^{A}_{\mathrm{QCD}})$$

# BACKGROUND PREDICTION

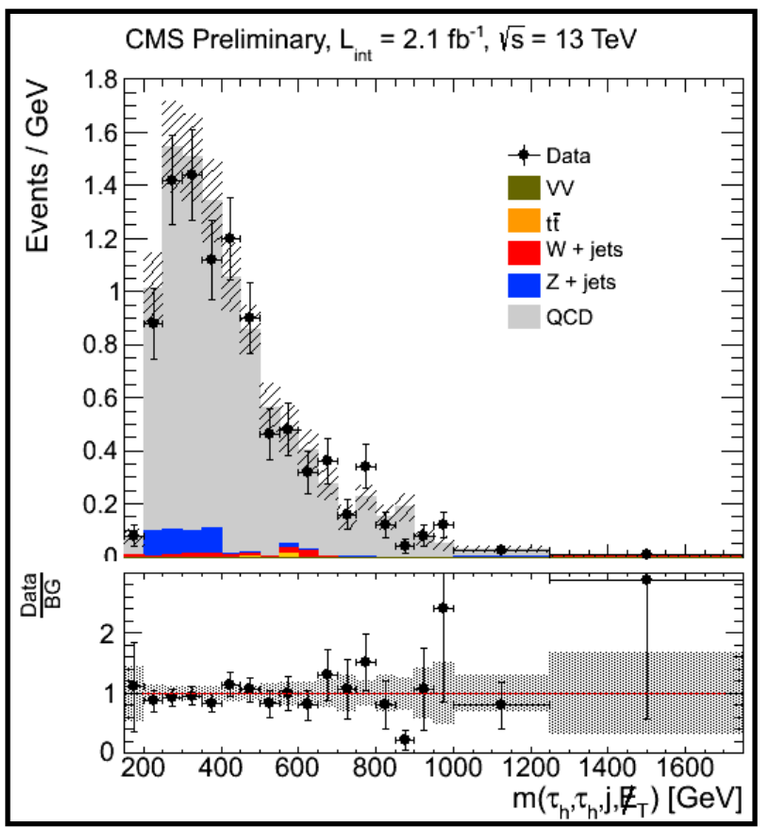



$$N_{\mathrm{QCD}}^{D} = N_{\mathrm{QCD}}^{C} \cdot (N_{\mathrm{QCD}}^{B} / N_{\mathrm{QCD}}^{A})$$

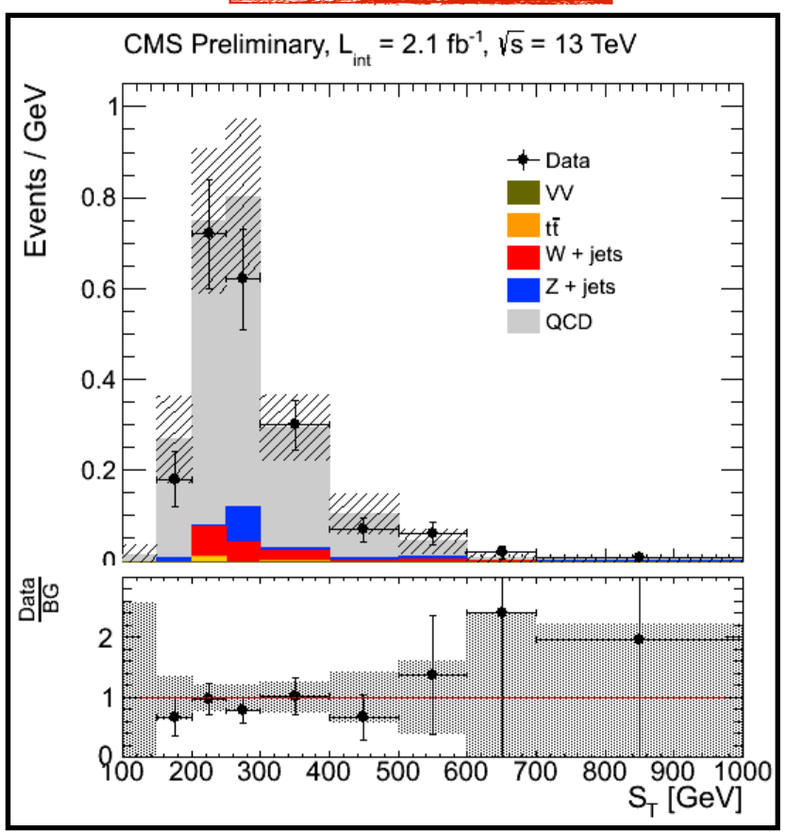
$N_j < 2$

cross-check bkg estimation in control region

EXO-16-016

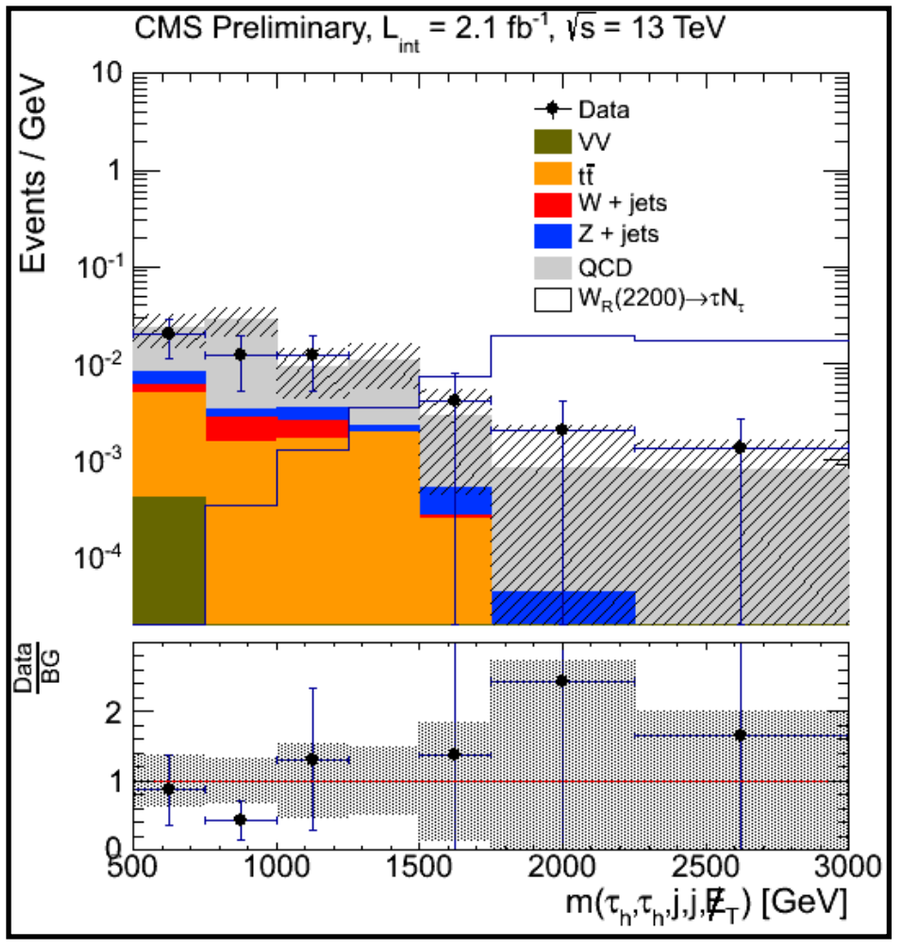



method works on partial mass variable (m) and $S_T$



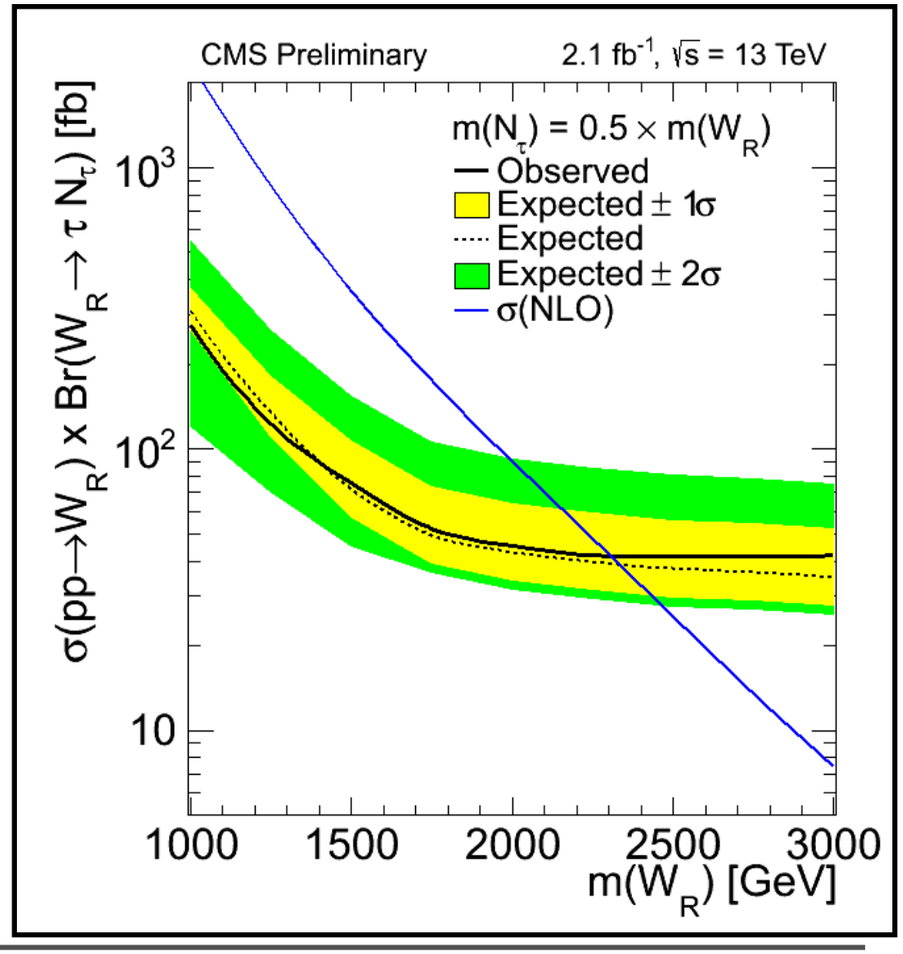
# RESULTS AND INTERPRETATION

EXO-16-016



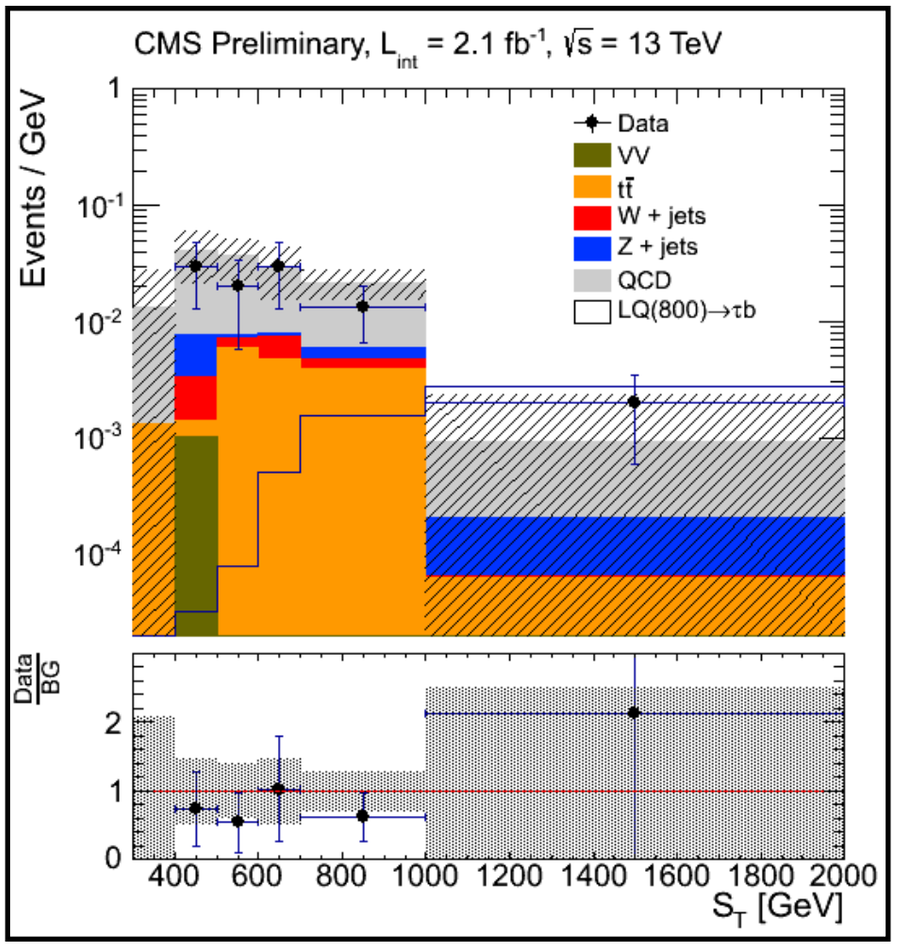

observation consistent with estimations

Limits on $W_R$




exclude $W_R$ up to ~2.4 TeV

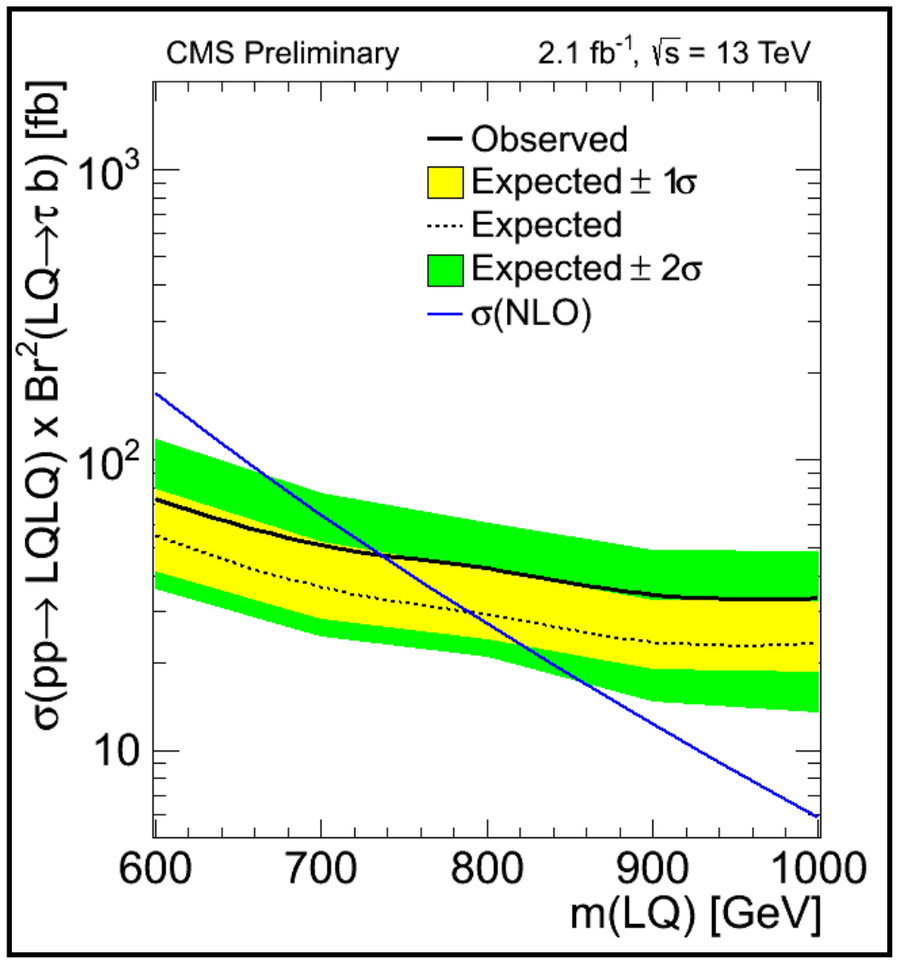
# RESULTS AND INTERPRETATION




observation consistent with estimations

Limits on LQ

exclude LQ up to ~750 GeV

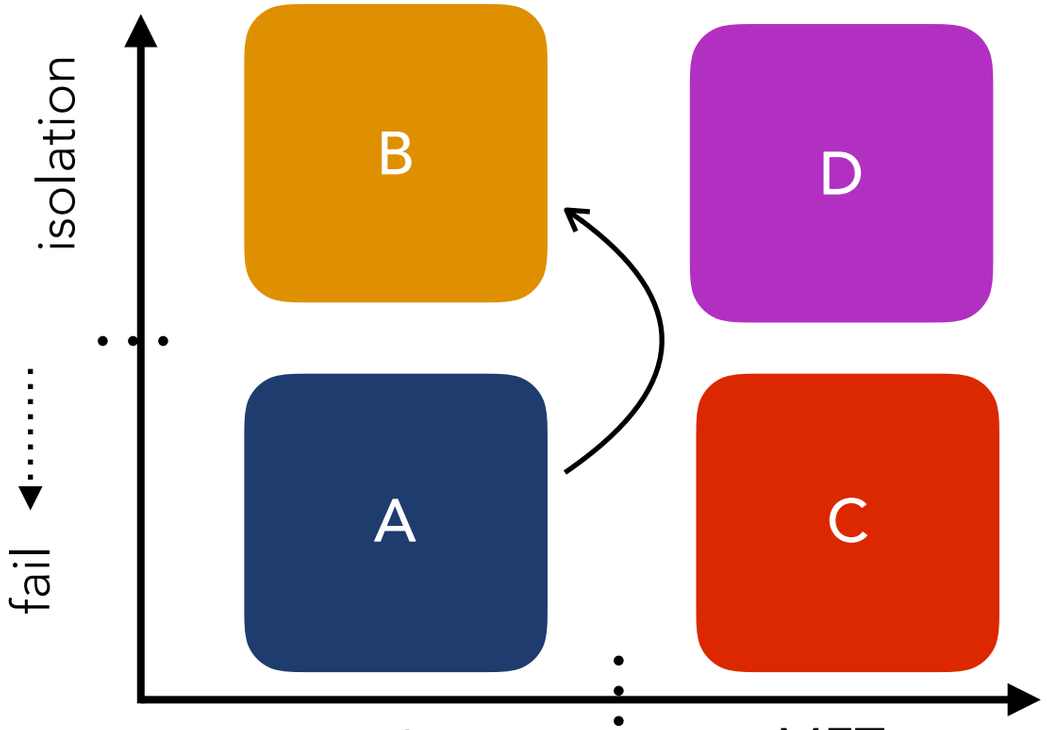


# SUMMARY

- Presented first and second generation leptoquarks results
  - electron and muon channels in 8TeV (1TeV exclusion)
  - muon channel update with 13 TeV data (better exclusion limits; 1.1 TeV)
- Presented search for heavy right-handed $W_R$ and heavy neutrinos using hadronically decaying $\tau$
  - no excess is observed, results are interpreted as limits on $W_R$ mass (2.4 TeV limit)
  - alternative third generation leptoquark interpretation. (760 GeV limit)

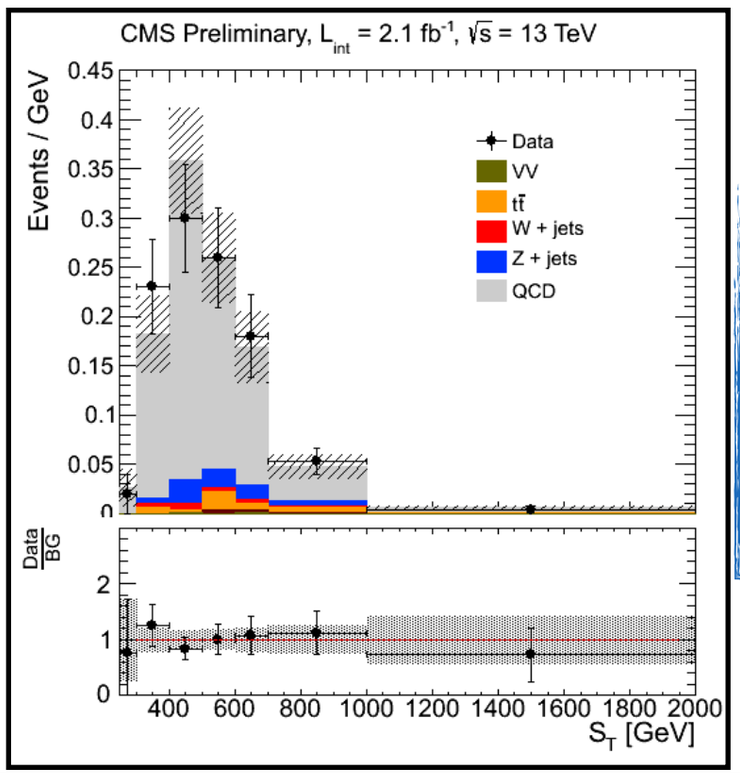
# BACKUPS

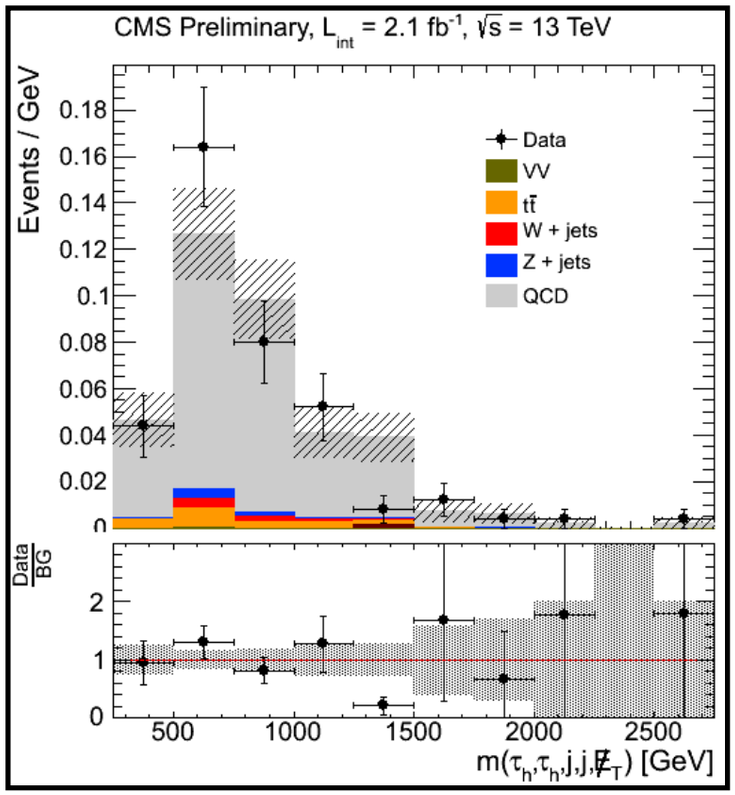
# BACKGROUND PREDICTION




cross-check isolation extrapolation in $N_j >= 2$

isolation extrapolation works on partial mass variable (m) and $S_T$



$$m(\tau_{h,1}, \tau_{h,2}, j, j, E_{\mathrm{T}}^{\mathrm{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{j_1} + E_{j_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\overrightarrow{p_{\tau_1}} + \overrightarrow{p_{\tau_2}} + \overrightarrow{p_{j_1}} + \overrightarrow{p_{j_2}} + \overrightarrow{\not{E}_{\mathrm{T}}})^2}.$$

Expected to be large for the heavy $W_R$ case