Search for new physics with tau final states at 13 TeV @CMS

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On behalf of CMS Collaboration

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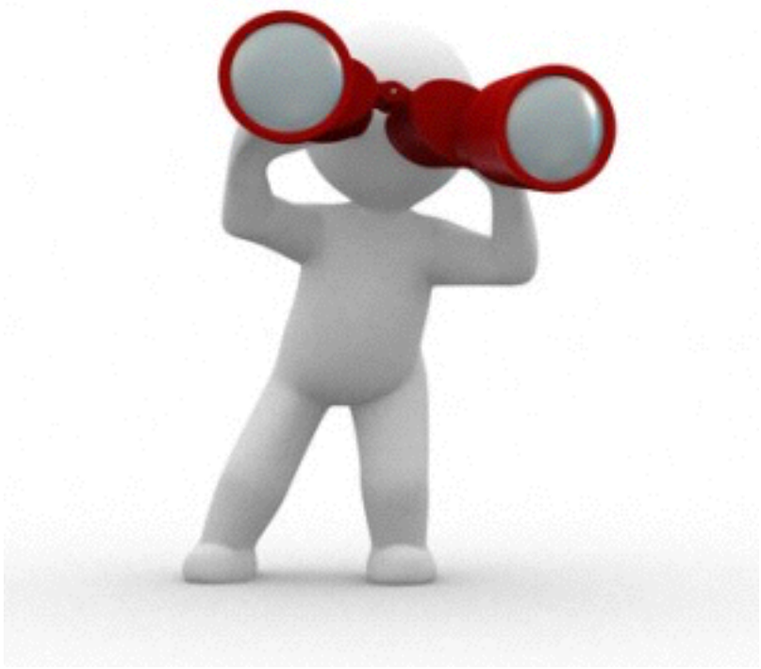
Outlines

- Introduction

  What are we looking for?

- 13 TeV Analysis
  - Z': EXO-16-008 *https://cds.cern.ch/record/2160363*
  - W': EXO-16-006 *https://cds.cern.ch/record/2140976*
  - W_R: EXO-16-016 *https://cds.cern.ch/record/2159374*
    EXO-16-023 *https://cds.cern.ch/record/2205270*
  - LQ3: EXO-16-016, EXO-16-023

Introduction



In the Exotica group, we look for massive non-SM particles (W', Z', W_R, LQ3) decaying to at least one tau in association with other leptons or jets.

	considered final states			
1 tau	τ_h			
2 taus	$\tau_h\tau_h$	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_e\tau_\mu$

since most of the non-SM particles couple to fermions equally, decays of X→ $\tau_{e/\mu}$ and X → $\tau_e\tau_e/\tau_\mu\tau_\mu$ are hard to distinguish from X → e/μ and X → ee/μμ and have a much smaller branching ratio. Thus, they're not considered in the studies I will present today.

W', Z' Introduction

Additional gauge bosons emerge in many extended gauge models :

- Sequential standard models (SSM) : *SM + additional massive boson with the same couplings constants as SM massive bosons.*

- LR model : *Extends the standard model gauge group with a right-handed charged boson as well as an additional neutral current.*

Some theories predict enhanced coupling to 3rd generation:

- Extended weak gauge group: *Extended SU(2)xSU(2) structure for weak interactions where the first two generations of fermions are charged under the weaker SU(2) and the third generation feels the stronger SU(2).*

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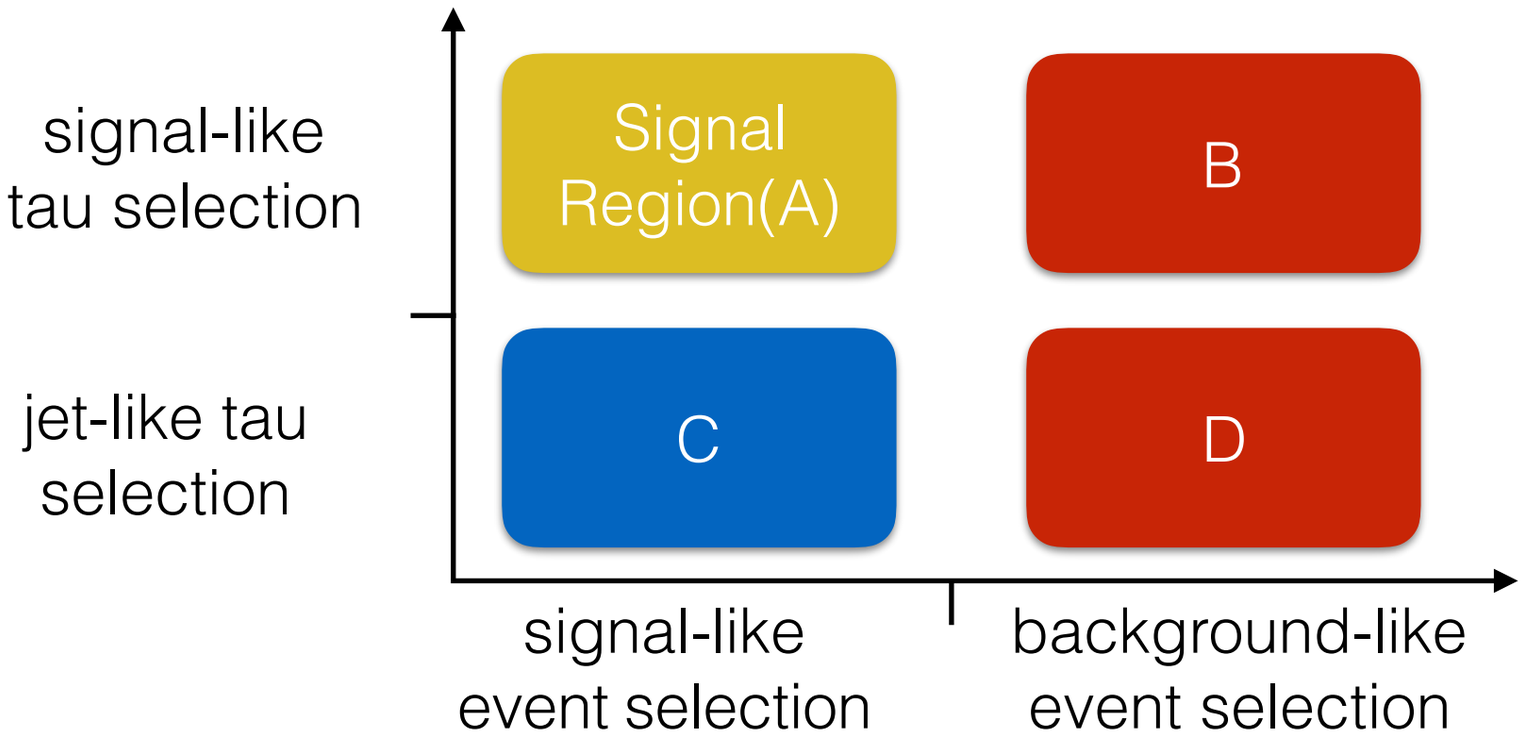
Typical Background Estimation

SM processes with taus (Drell-Yan / top / rare SM / W+jets*):

- simulate using Powheg/MadGraph + Pythia8 + detector. response
- derive scale factors and corrections
- validate/evaluate systematic uncertainties in control regions

SM processes with jets faking taus (QCD multi-jet/ W+jets*):

- "ABCD" data-driven method
- validate/evaluate syst. in control regions



- estimate jet->tau fake rate among regions B and D
- apply fake rate to region C

* different W+Jets estimation techniques were used depend on the analysis

Analysis: $Z' \to \tau^+\tau^-$

EXO-16-008

Signal sample:

- *Z' with invariant mass between 500 to 3000 GeV*

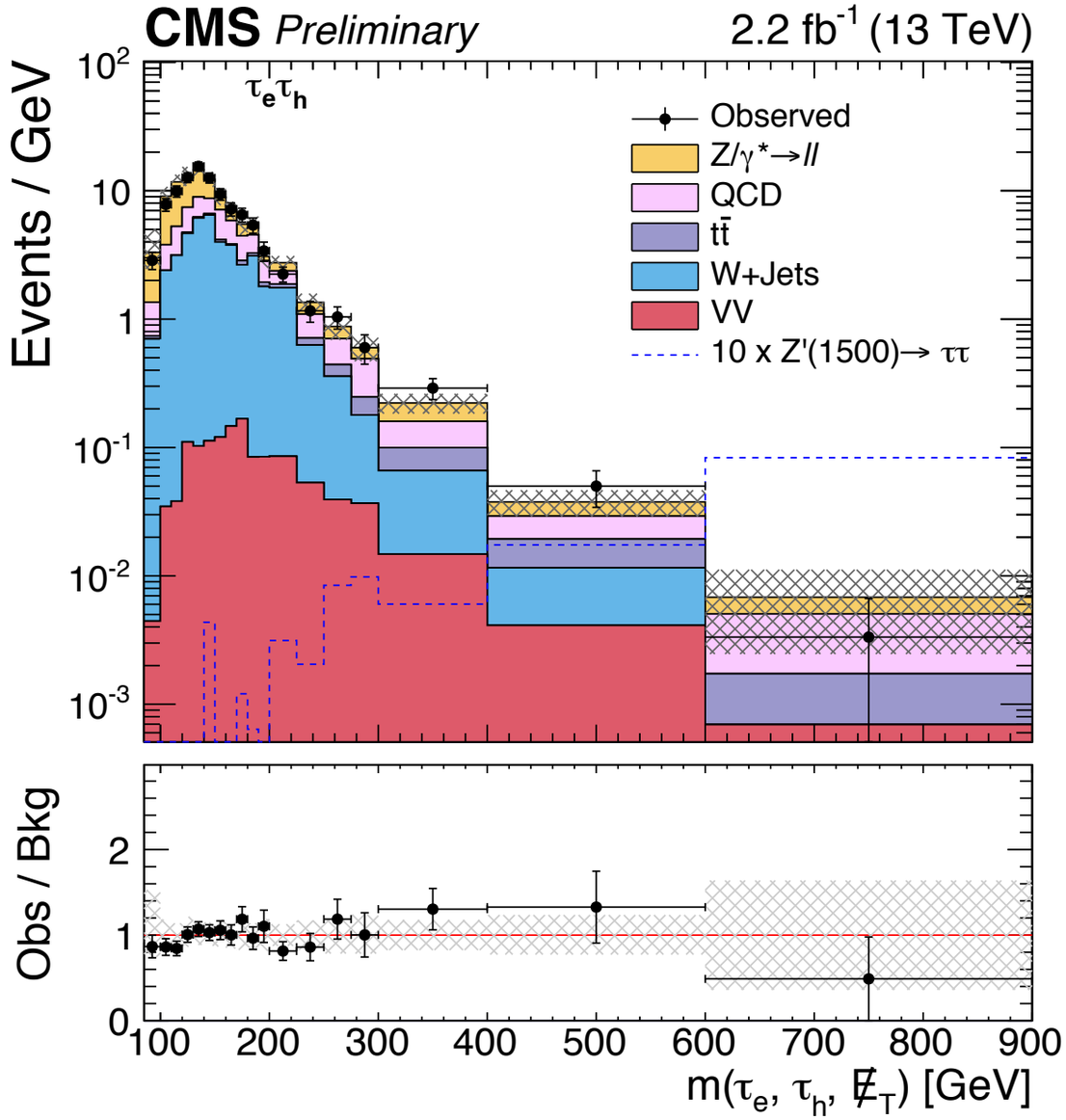
Final states:

- $\tau_h\tau_h$, $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_e\tau_\mu$

general di-τ new resonance search using SSM Z' as benchmark model

Selections:

- τ_h p_T > 20 ($\tau_\ell\tau_h$) 60 ($\tau_h\tau_h$) GeV
- *opposite electric charge*
- *back-to-back*
- *missing E_T > 30 GeV*
- *no b quarks*



Limit extraction variable:

$$m(\tau_1, \tau_2, \not{E}_T) = \sqrt{(E_{\tau_1} + E_{\tau_2} + \not{E}_{\mathrm{T}})^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{\not{E}}_{\mathrm{T}})^2}.$$

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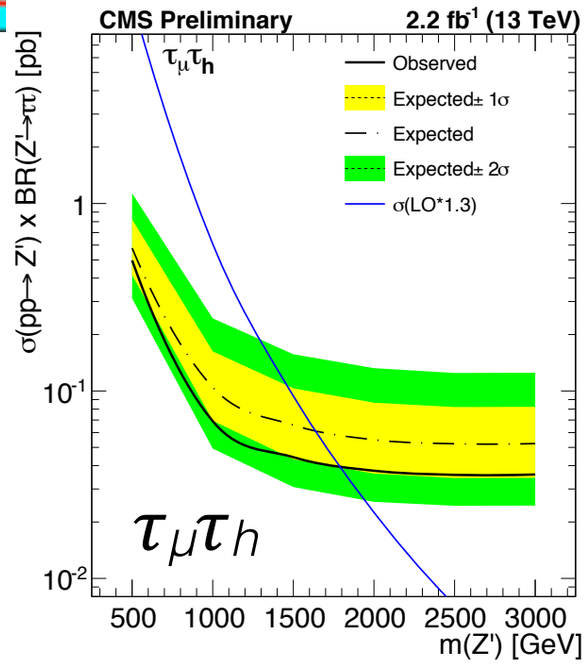
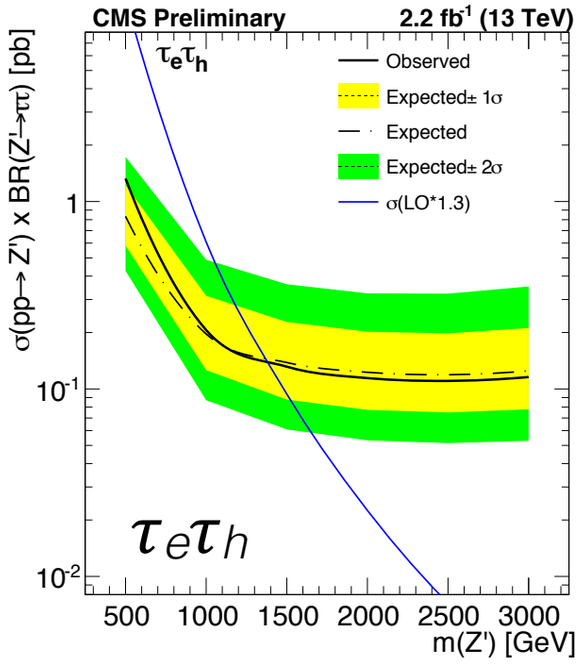
Results: $Z' \to \tau^+\tau^-$

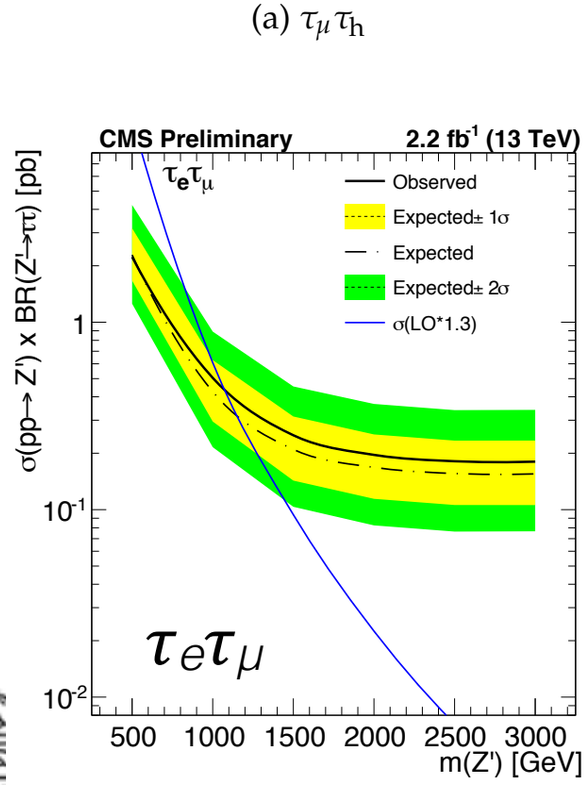
EXO-16-008



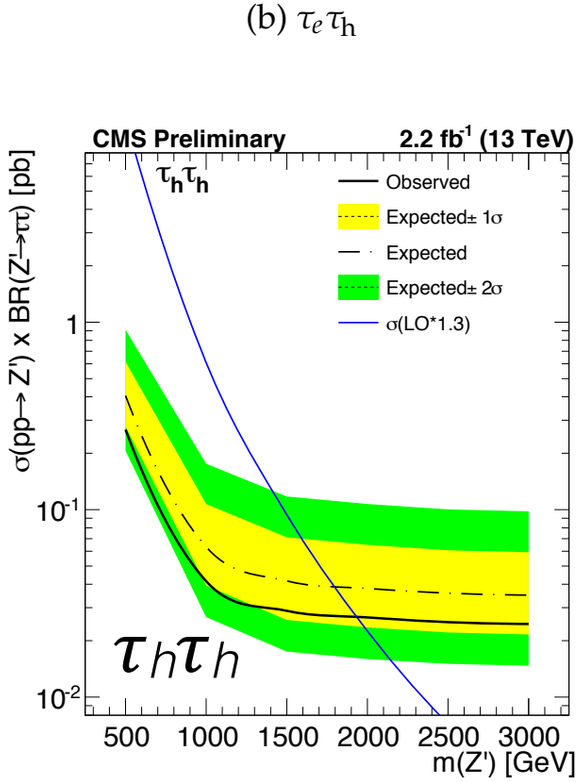
(a) $\tau_\mu\tau_h$



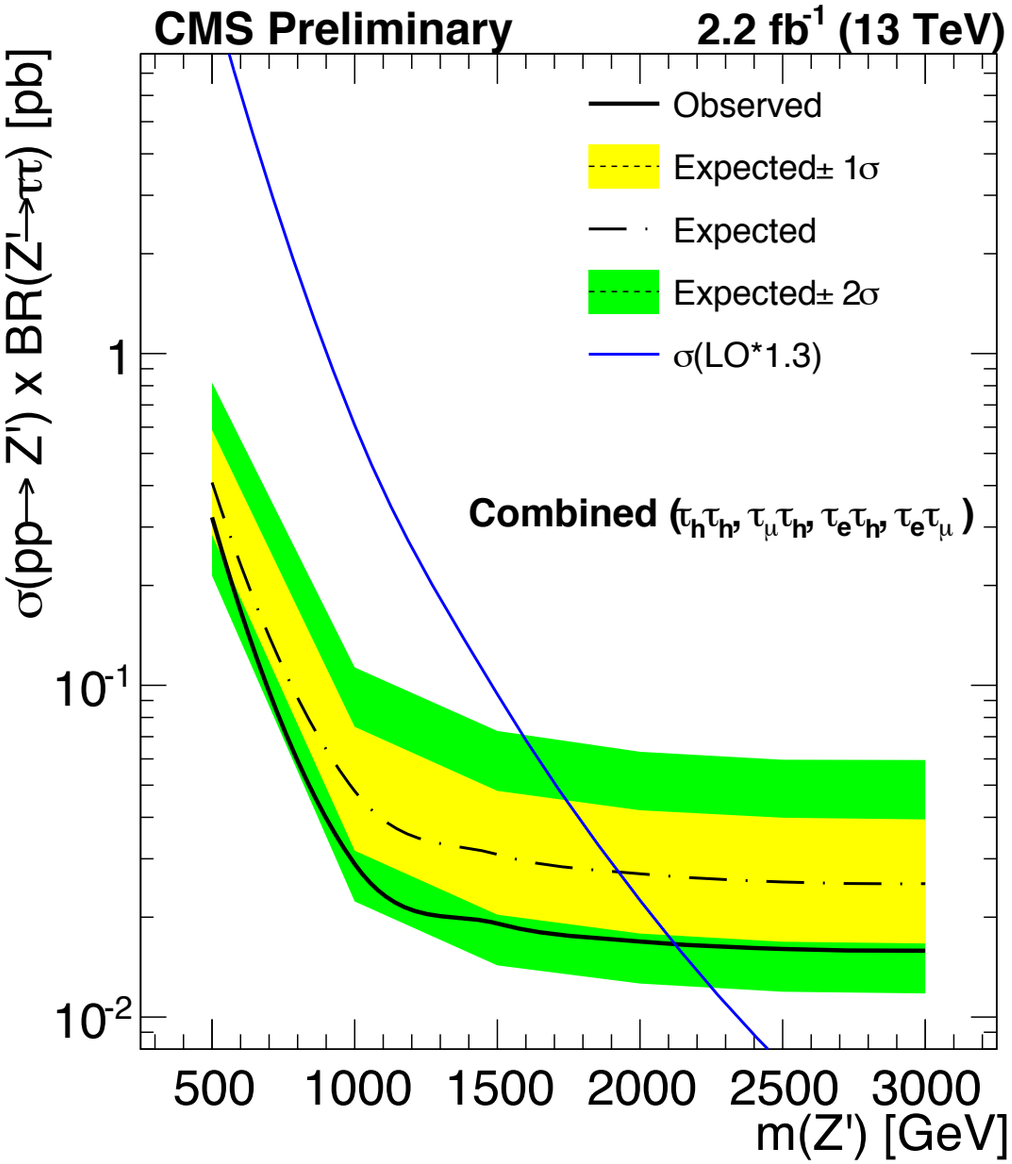
(b) $\tau_e\tau_h$



(c) $\tau_e\tau_\mu$



(d) $\tau_h\tau_h$



The presence of Z'_{SSM} bosons decaying into τ lepton pairs is excluded for masses below 2.1 TeV.

Analysis: $W' \to \tau\nu$

EXO-16-006

Signal sample:

- *W' with invariant mass between 1000 to 5800 GeV*

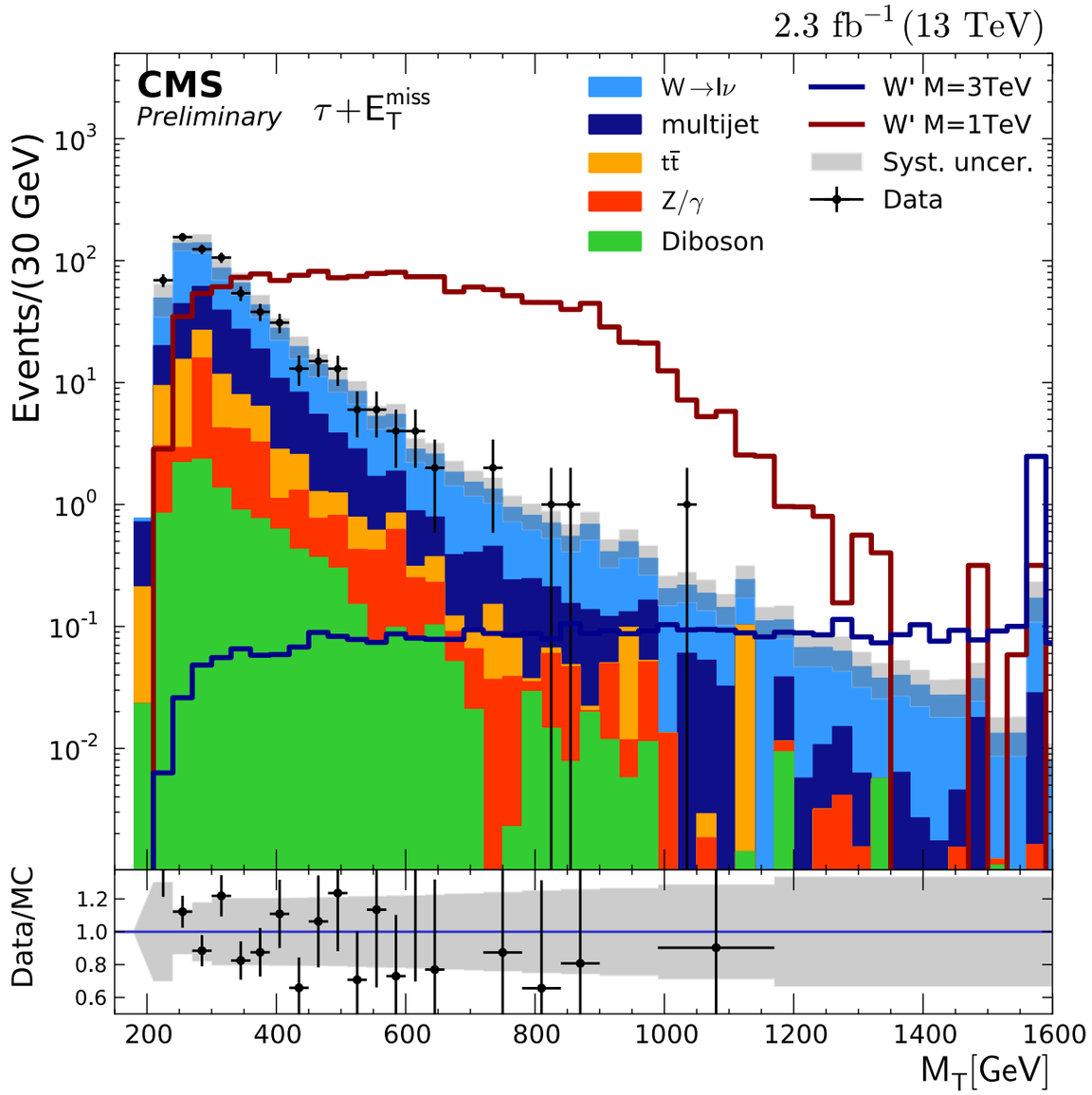
Final states:

- τ_h

general τ + MET new resonance search using SSM W' as benchmark model

Selections:

- τ_h p_T > 80 GeV
- missing E_T > 120 GeV
- large separation angle between τ_h and missing E_T
- 0.7 < p_T/missing E_T < 1.3

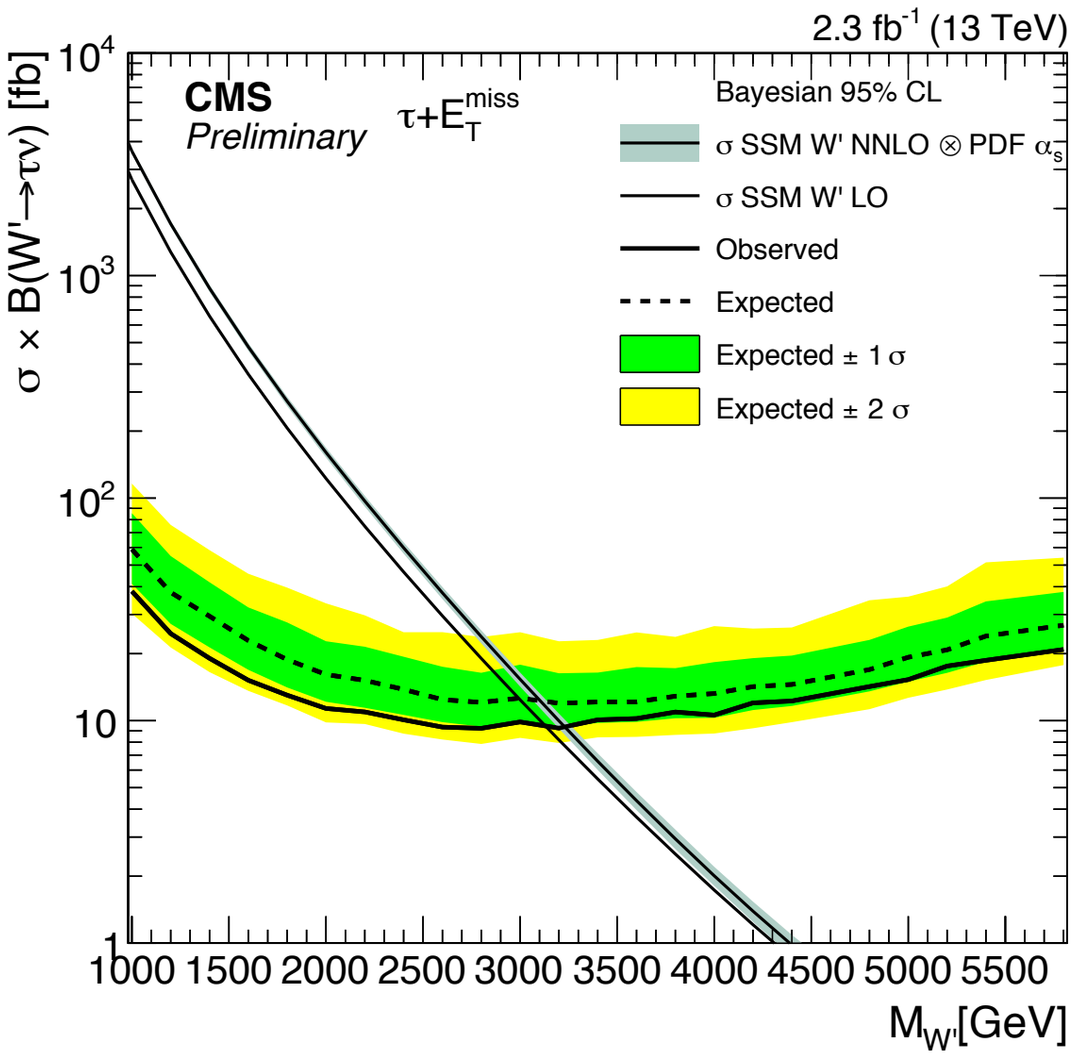


Limit extraction variable:

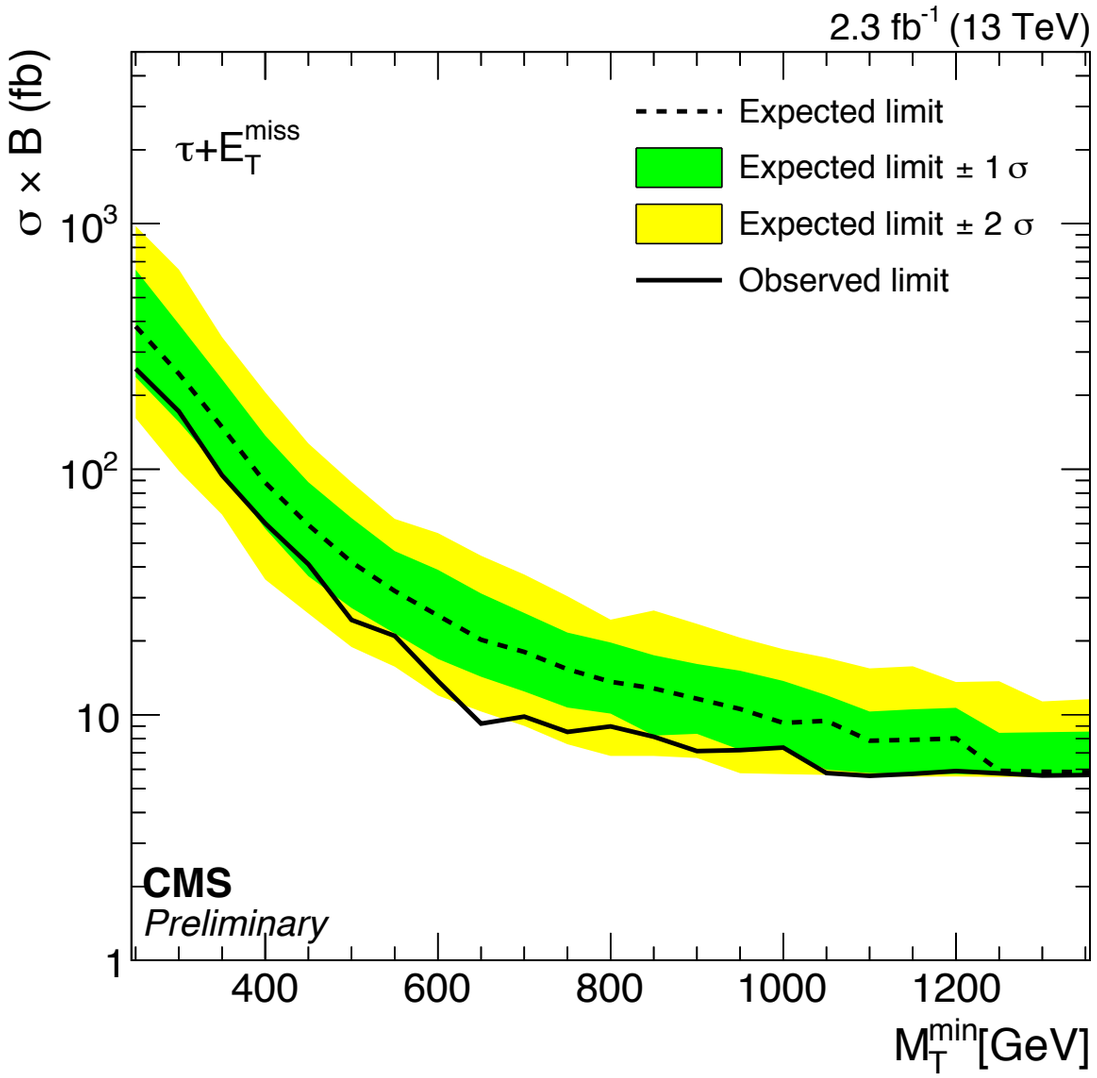
$$M_{\mathrm{T}} = \sqrt{2\, p_{\mathrm{T}}^{\tau}\, E_{\mathrm{T}}^{\mathrm{miss}}\, (1 - \cos\Delta\phi(\tau, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}))},$$

Results: $W' \to \tau\nu$

EXO-16-006



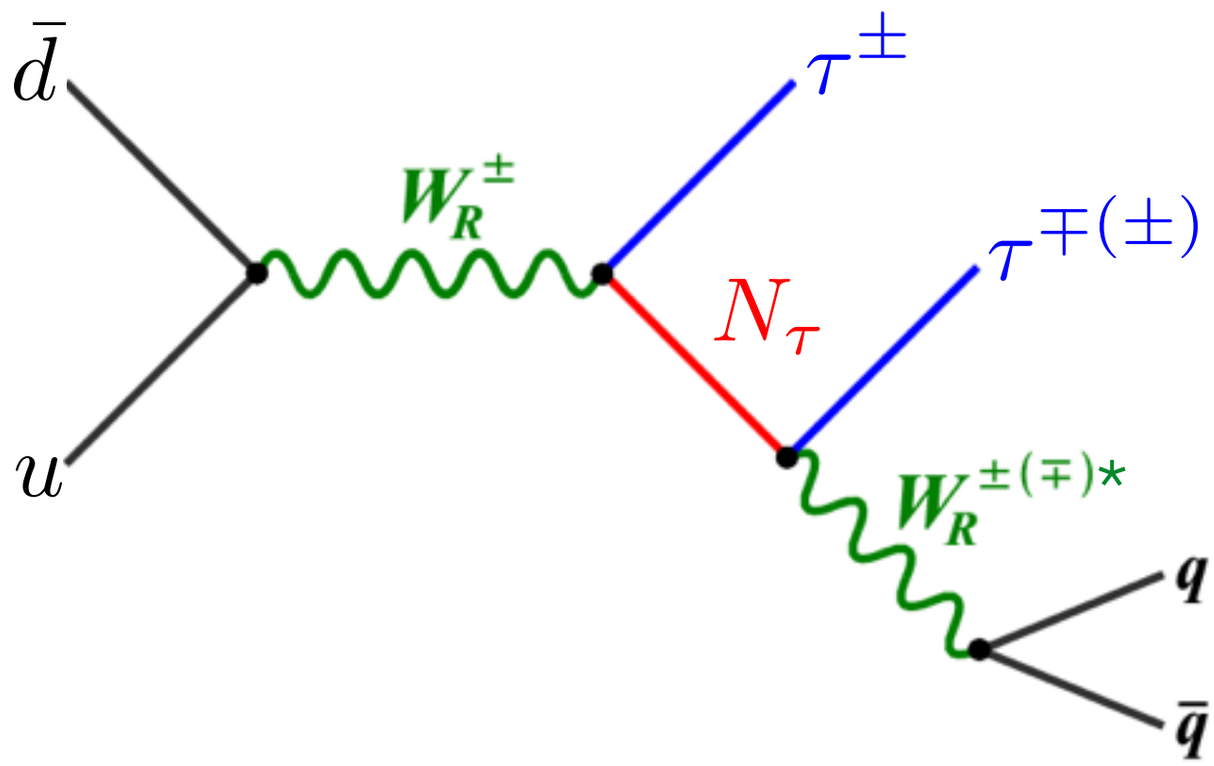
An SSM W′ boson is excluded in the mass range 1 TeV < $M_{W'}$ < 3.3 TeV at 95% confidence level



Model-independent limits, on the effective cross section for a W′-like signal.

W_R Introduction

Results from neutrino oscillation experiments imply neutrinos have mass. One way to confer mass to neutrinos, in the context of the "seesaw" mechanism, is provided by the left-right symmetry extension (LRSM), which predicts the existence of three new gauge bosons, $W_R^{\pm}$ and Z'.



Analysis: $W_R \to \tau_h \tau_h qq$

EXO-16-016

Signal sample:

- *W_R with invariant mass between 1000 to 3000 GeV with mass of N_T between 0.1 to 0.8 x mass of W_R*

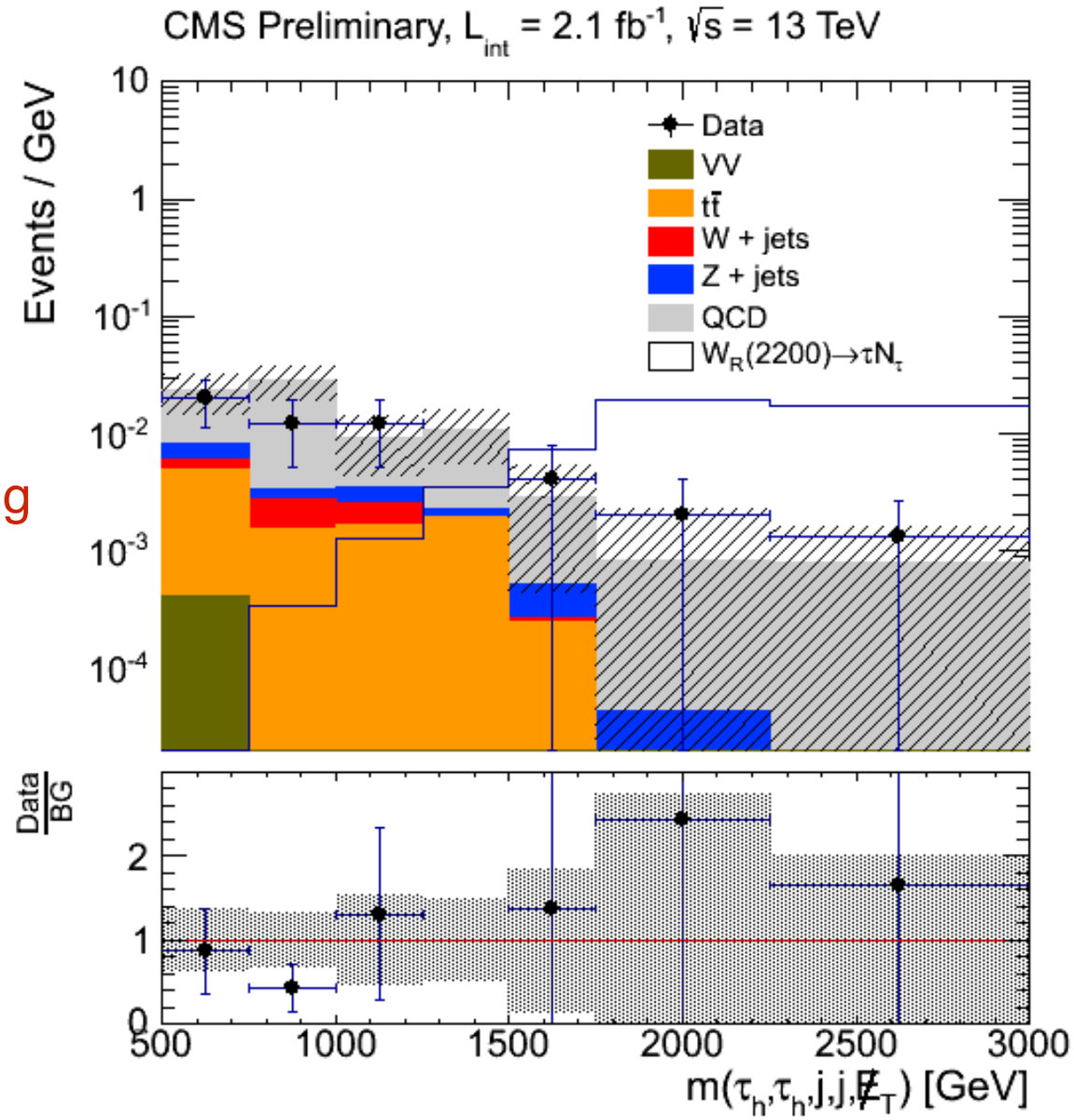
Final states:

- $\tau_h \tau_h qq$

general di-τ + di-jet new resonance search probing massive neutrino with W_R

Selections:

- *2 τ_h with p_T > 70 GeV*
- *2 jets with p_T > 50 GeV*
- *missing E_T > 50 GeV*
- *invariant mass of $\tau_h \tau_h$ > 100 GeV*



Limit extraction variable:

$$m(\tau_1, \tau_2, j_1, j_2, E_T^{\text{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{j_1} + E_{j_2} + E_{\text{T}}^{\text{miss}})^2 - (\overrightarrow{p_{\tau_1}} + \overrightarrow{p_{\tau_2}} + \overrightarrow{p_{j_1}} + \overrightarrow{p_{j_2}} + \overrightarrow{\not{E}_{\text{T}}})^2}.$$

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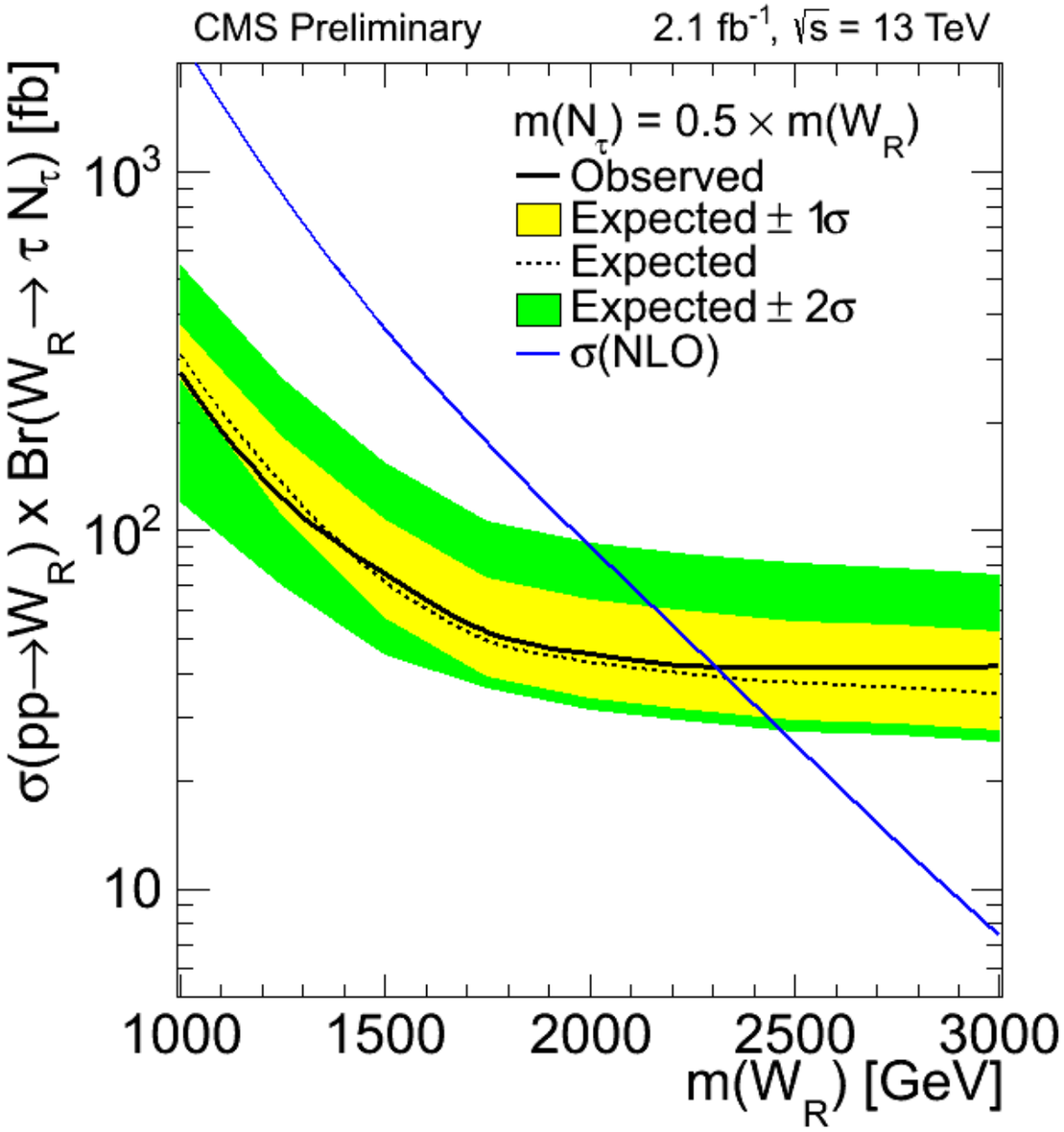
Results: $W_R \to \tau_h \tau_h qq$

EXO-16-016



Expected and observed limits, at 95% confidence level, as functions of m(W_R) mass with m(N_τ) = 0.5 m(W_R)

Assuming only N_τ flavor contributes significantly to the W_R decay width, W_R masses below 2.35 (1.63) TeV are excluded at a 95% confidence level, assuming the N_τ mass is 0.8 (0.2) times the mass of W_R boson

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Analysis: $W_R \to \tau_l \tau_h qq$

EXO-16-023

Signal sample:

- *W_R with invariant mass between 1000 to 4000 GeV with mass of N_T = 0.5 x mass of W_R*

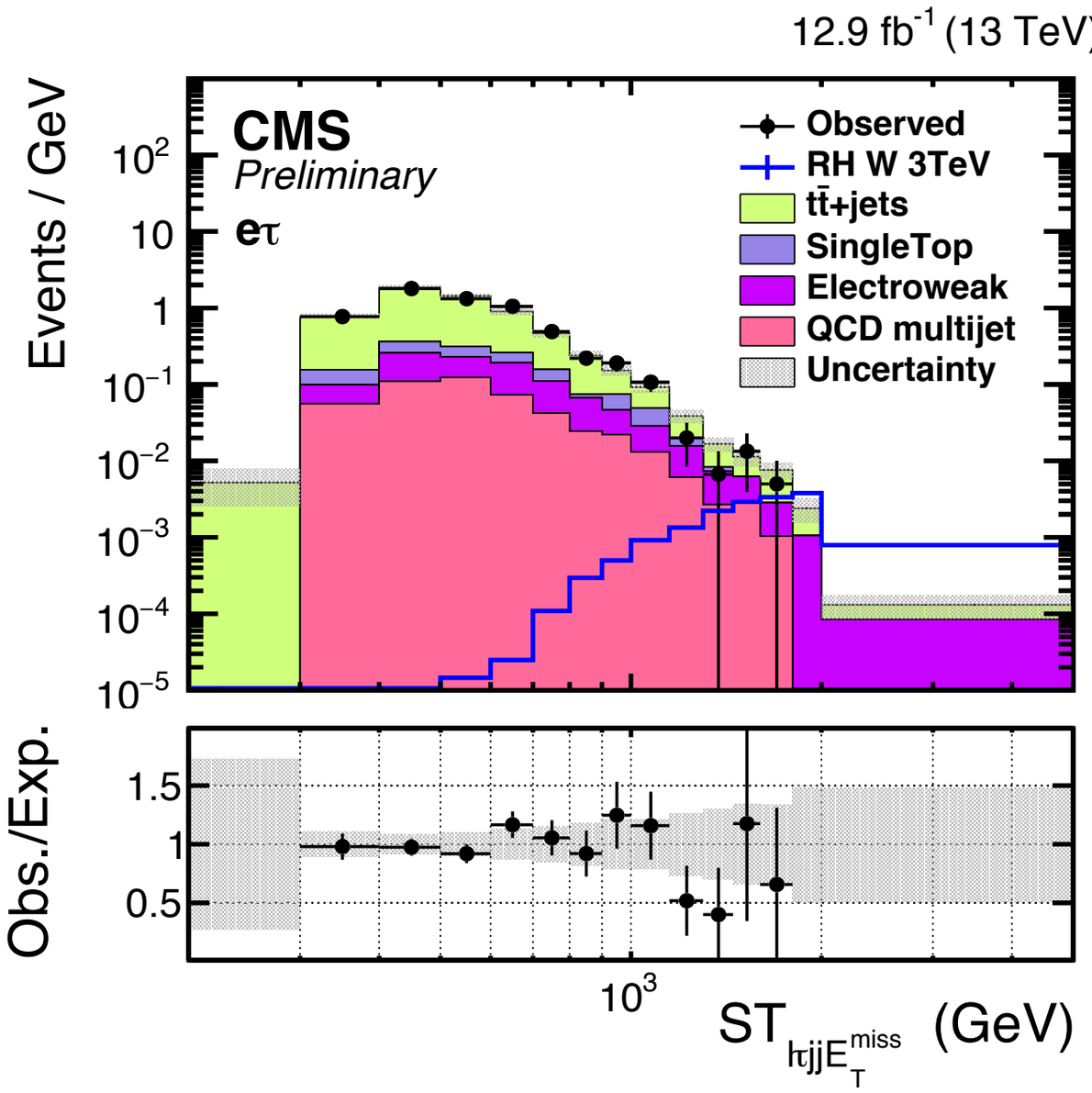
Final states:

- $\tau_\mu \tau_h qq$, $\tau_e \tau_h qq$

general di-τ + di-jet new resonance search probing massive neutrino with W_R

Selections:

- *τ_h with p_T > 60 GeV*
- *2 jets with p_T > 50 GeV*
- *missing E_T > 50 GeV*
- *invariant mass of $\tau_\ell \tau_h$ > 150 GeV*

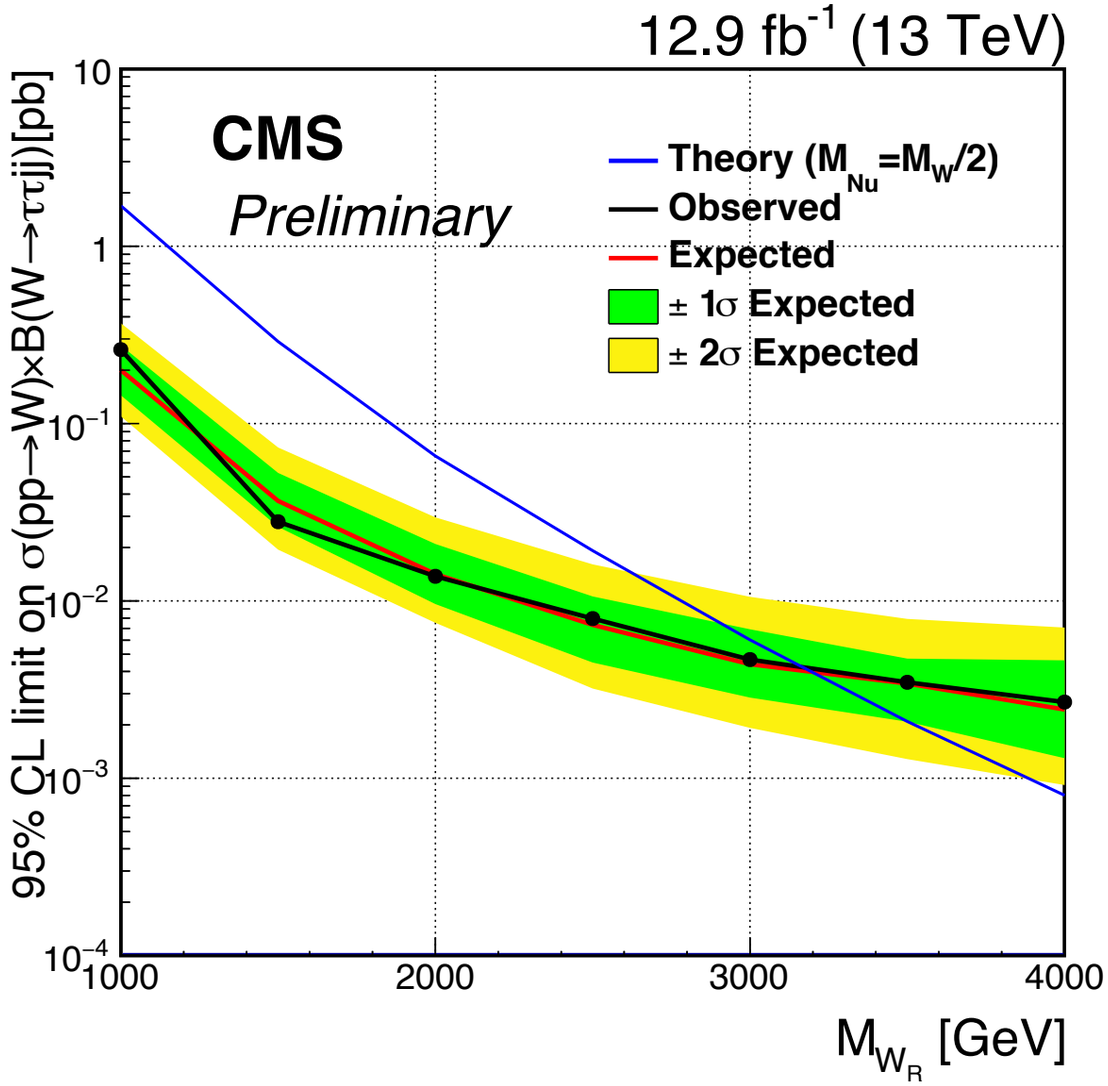


Limit extraction variable:

$$S_{\mathrm{T}} = p_T(\ell) + p_T(\tau_{\mathrm{h}}) + p_T(jet_1) + p_T(jet_2) + E_{\mathrm{T}}^{\mathrm{miss}}$$

Results: $W_R \to \tau_l \tau_h qq$

EXO-16-023



Assuming the mass of neutrino to be half of the mass of right-handed W boson, W_R boson masses below 3.2 TeV are excluded at 95% CL.

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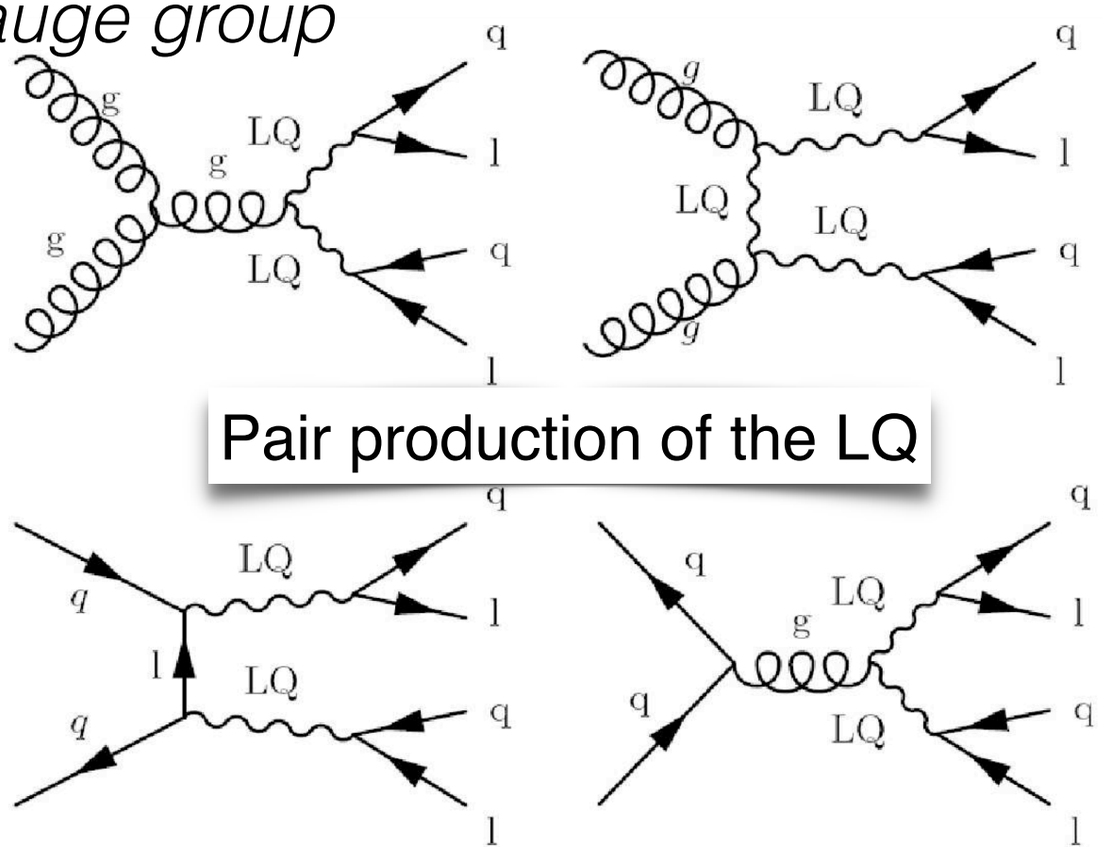
Leptoquark Introduction

Many extensions of the standard model (SM) predict new scalar or vector bosons, called leptoquarks (LQ), which carry non-zero lepton and baryon numbers:

- SU(5) grand unification: *the standard model gauge groups SU(3) × SU(2) × U(1) are combined into a single simple gauge group—SU(5)*
- Pati–Salam SU(4): *the lepton-ness (non-quark-ness) of leptons is identified as the 4th color, "lilac," of a larger $SU(4)_c$ gauge group*



Pair production of the LQ

Analysis: $LQ\overline{LQ} \to \tau\tau bb$

EXO-16-016
EXO-16-023

Signal sample:

- *LQ3 with invariant mass between 200 to 1500 GeV*

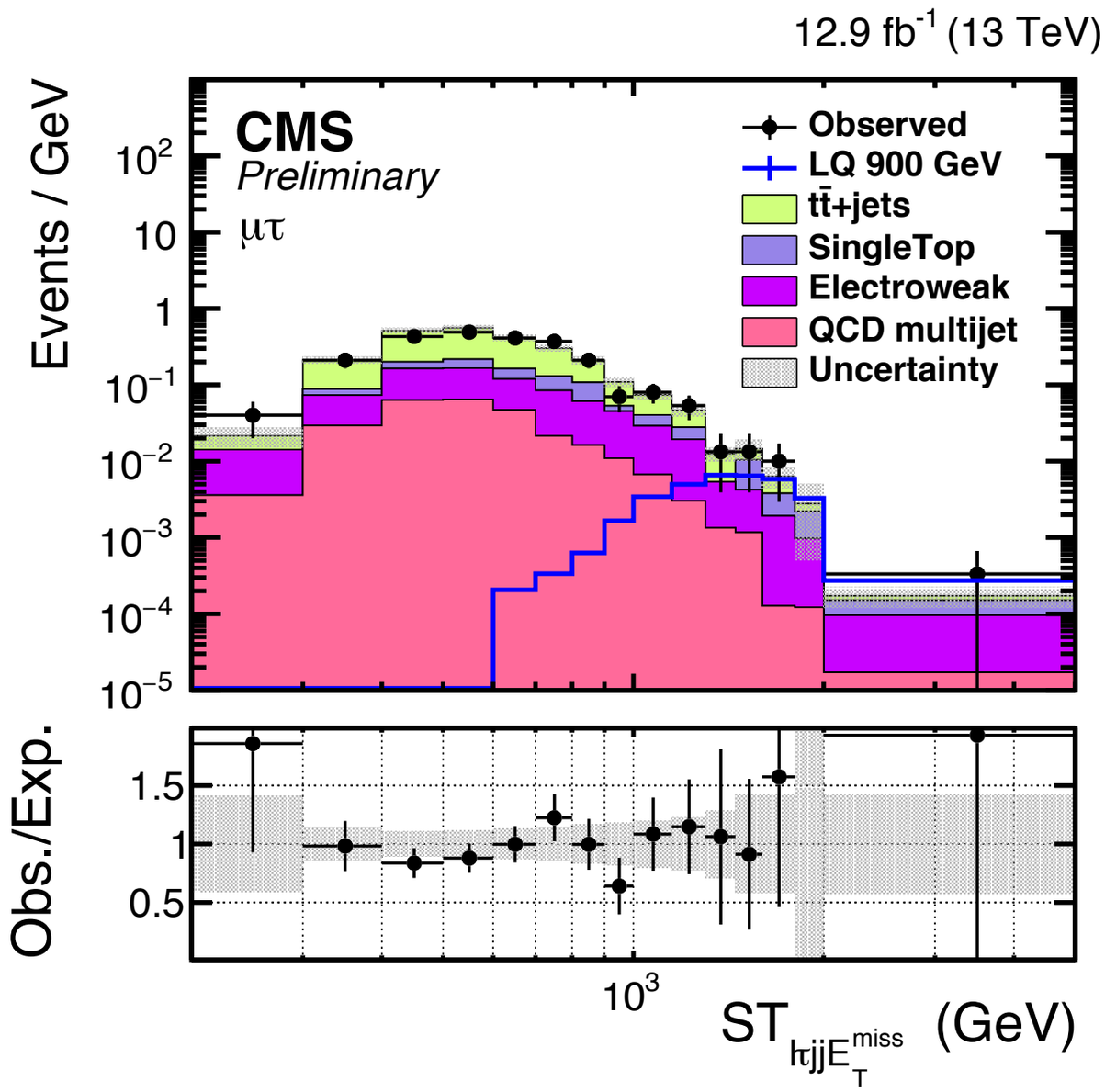
Final states:

- $\tau_h\tau_h bb$, $\tau_\mu\tau_h bb$, $\tau_e\tau_h bb$

reinterpretation of the previous di-τ + di-jet new resonance search

Selections:

- τ_h *with* $p_T > 50$ *GeV*
- *2 jets with high* p_T
- *at least on b jet* *
- *missing* $E_T > 50$ *GeV*
- *opposite electric charge* *
- *cuts to reject top events*



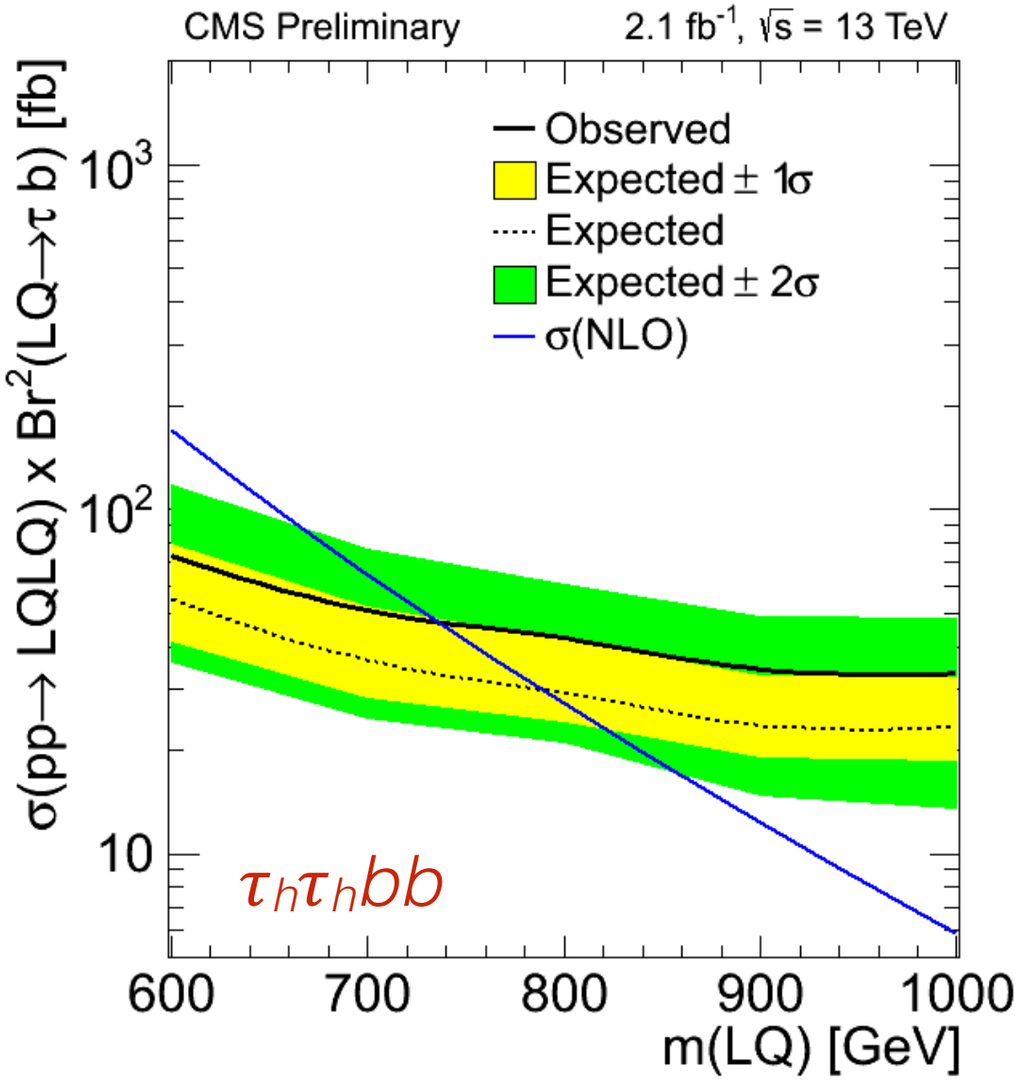
Limit extraction variable:

$$S_{\mathrm{T}} = p_T(\ell) + p_T(\tau_{\mathrm{h}}) + p_T(jet_1) + p_T(jet_2) + E_{\mathrm{T}}^{\mathrm{miss}}$$

* applied in EXO-16-23 only

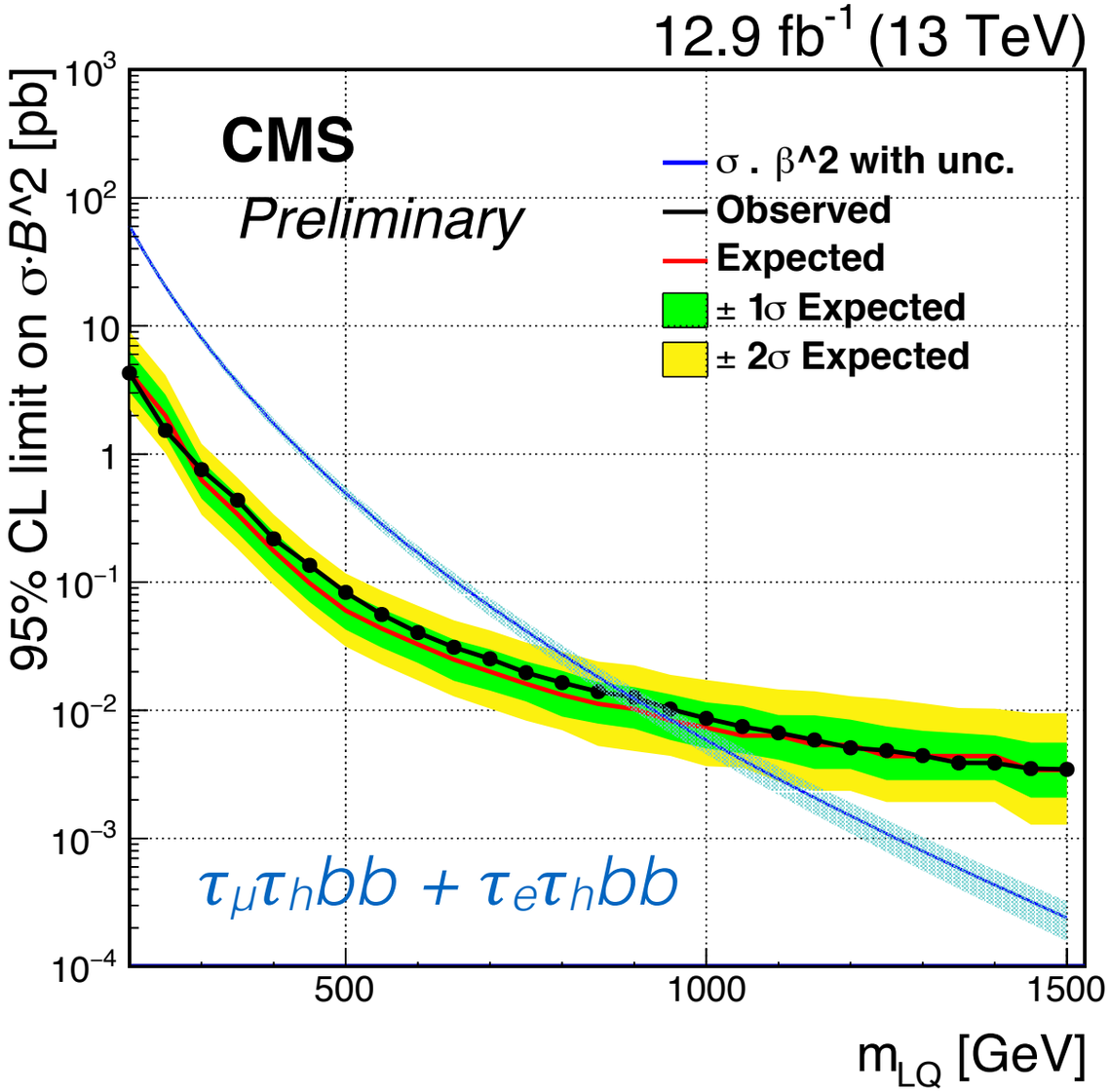
Results: $LQ\overline{LQ} \to \tau\tau bb$

EXO-16-016



Third-generation scalar leptoquarks with masses below 740 GeV are excluded, assuming a 100% branching fraction for the leptoquark decay to a τ lepton and a bottom quark.

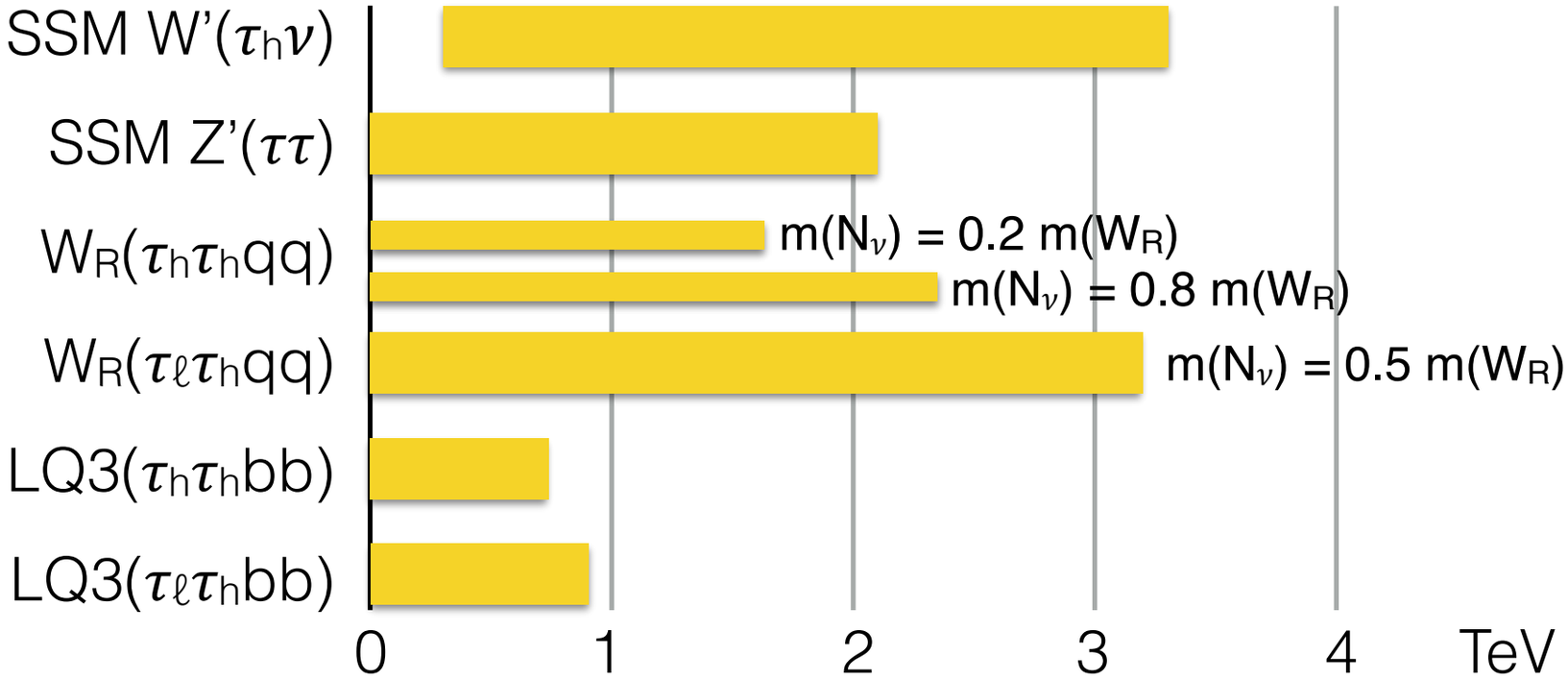
EXO-16-023



Assuming 100% branching fraction for the leptoquark decay to a τ lepton and a bottom quark, the third-generation leptoquarks with masses below 900 GeV are excluded at 95% CL

Summary

- Many exciting search results from the 13 TeV run



- More 13 TeV results coming soon

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