Searches for Leptoquarks and Compositeness at CMS

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Introduction

Several CMS searches for leptoquarks and compositeness with pp data collected at 13 TeV at the LHC shown here:

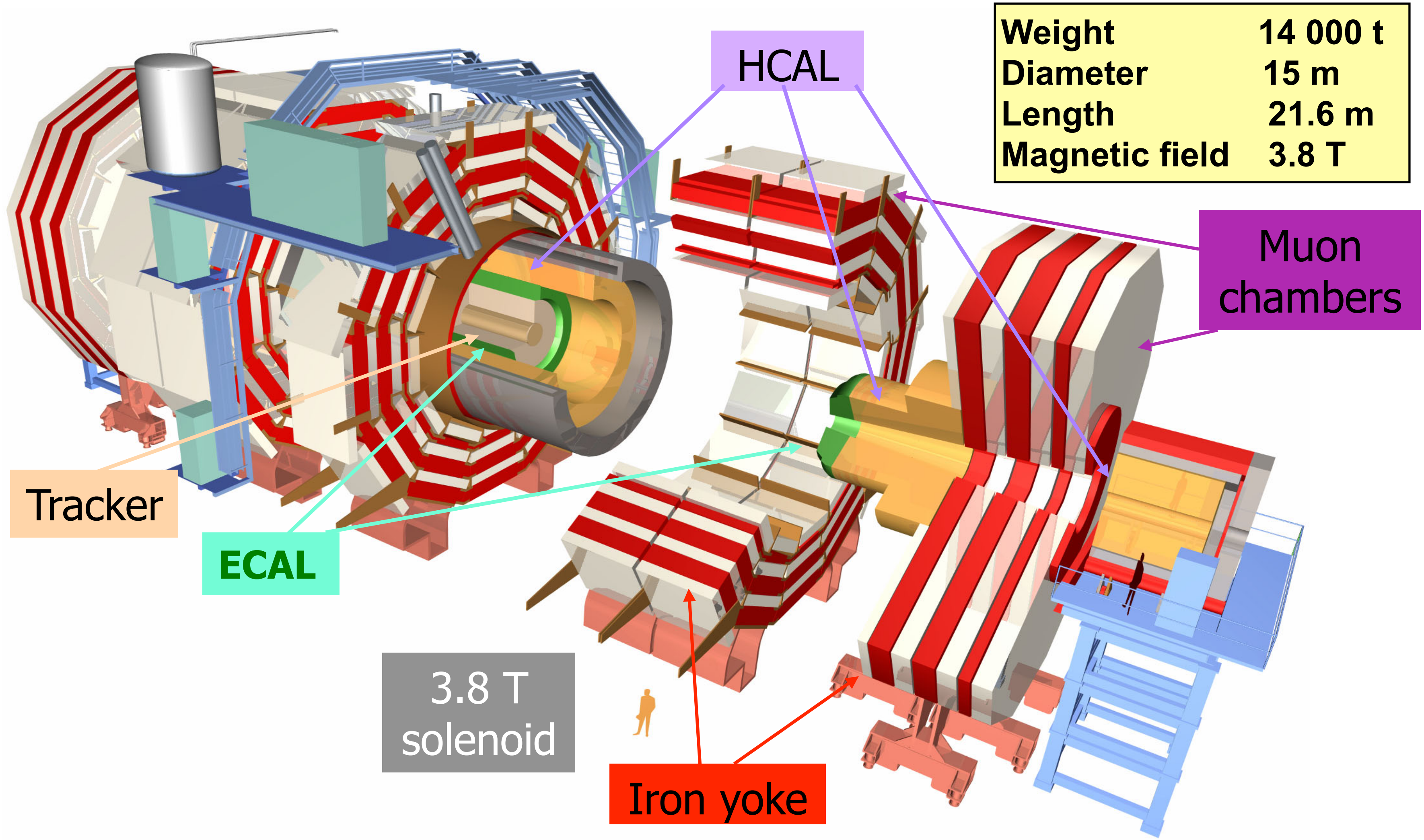
- First and second generation leptoquarks (2.6, 2.7 fb^{-1})
- Third generation leptoquarks (as part of W_R search) in two channels, including $\tau_{had}\tau_{had}bb$ and $\tau_{had}\ell bb$ channel (2.1, 12.9 fb^{-1})
- Excited leptons (2.7 fb^{-1})

Excited quarks presented in separate talk on multijets (S. Bhattacharya)

Three new results for ICHEP2016 in this talk [green]

Full list of CMS results:
http://cms-results.web.cern.ch/cms-results/public-results/publications/

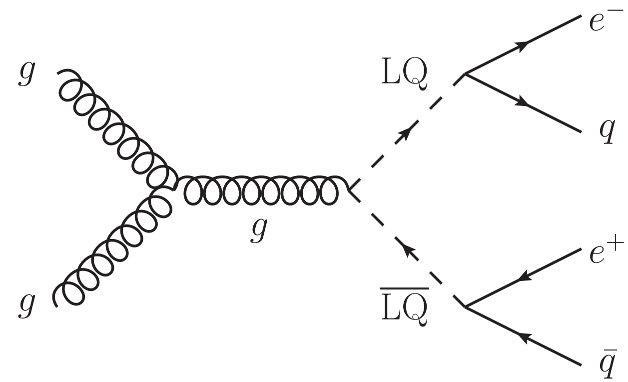
CMS Detector



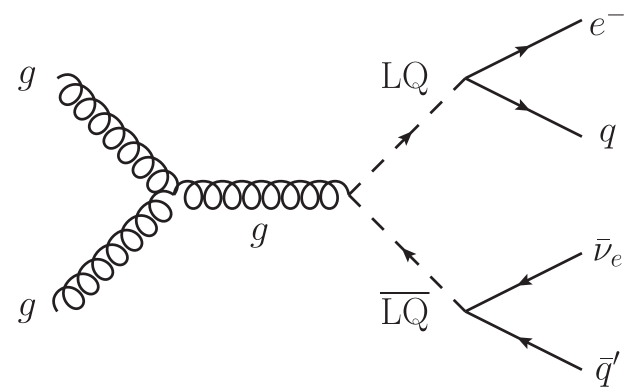
Leptoquarks: Theory in brief

- New symmetry between quarks and leptons. Some beyond the SM models predict leptoquarks arising from this symmetry (Pati-Salam, GUTs, technicolor, etc.)
- Leptoquark (LQ): boson coupling to both quarks and leptons (carries baryon and lepton numbers) and fractional electric charge. Concentrating on scalar case.
- Consider pair-produced particles: Dominant gg production mode at LHC is virtually independent of the lepton/quark/LQ coupling strength.
- Separate analysis by lepton generation: FCNC constraints imply no intergenerational mixing
- Branching ratio LQ → ℓq is treated as free parameter β
- Final states covered in this talk:
  - 1st/2nd generation: ℓj+ℓj, for ℓ=e,μ
  - 3rd generation: $\tau_{had}b\ell b$ for ℓ=e, μ; $\tau_{had}b+\tau_{had}b$

eejj final state



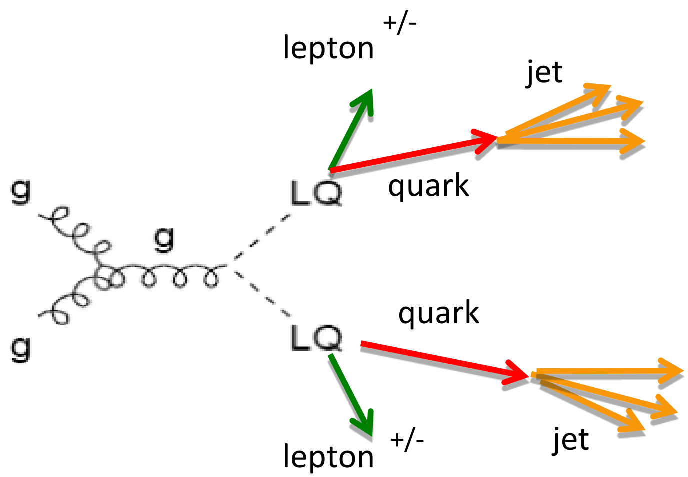
eνjj final state



LQ 1st and 2nd generation analysis overview

2 high p_T leptons and 2 high p_T jets are a striking signature

Use single electron or muon trigger

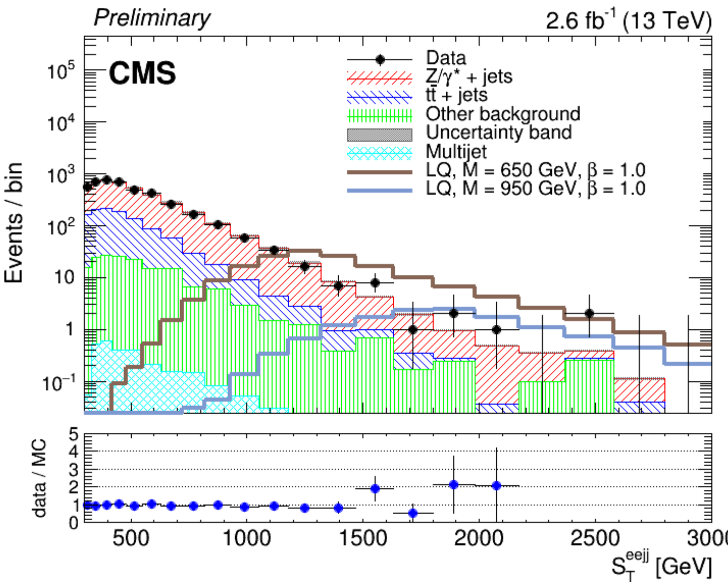


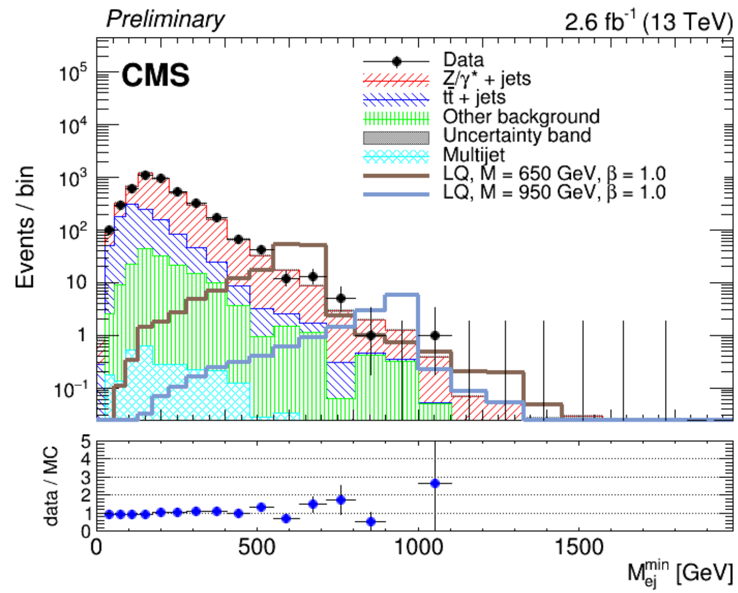
- 2 isolated high-p_T leptons (p_T > 50 GeV)
- 2+ high-p_T jets (p_T > 50 GeV)
- Final selection variables:
  - $S_T = \Sigma p_T(\ell, j)$ for $\ell 1, \ell 2, j1, j2$
  - $M_{min}(\ell j)$
  - $M(\ell\ell)$
- Minimal S_T requirement (300 GeV)
- Validate backgrounds vs. data at preselection
- Optimize final selections as a function of LQ mass

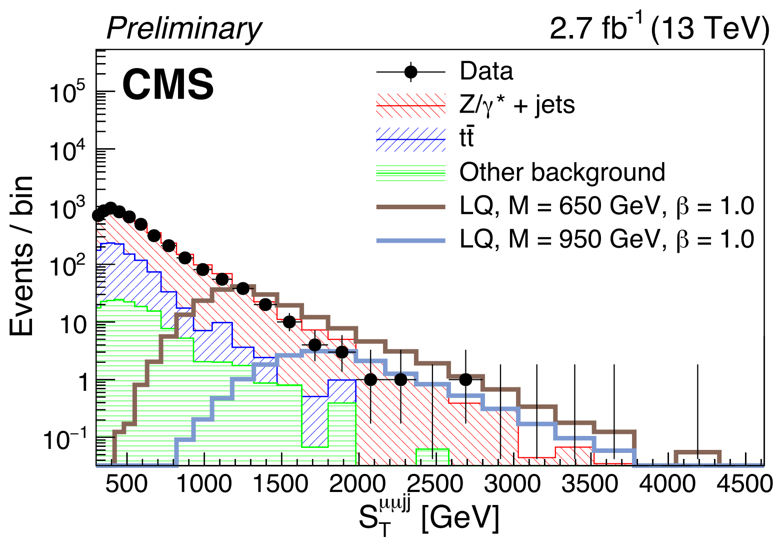
Backgrounds:
Z+Jets: MC shape, normalized in Z peak
TTbar+Jets: eμjj data-driven shape/normalization (LQ2); MC normalized to eμjj data (LQ1)
QCD Multijets (LQ1: data-driven fake rate)
Others: Diboson, single top, etc.: MC

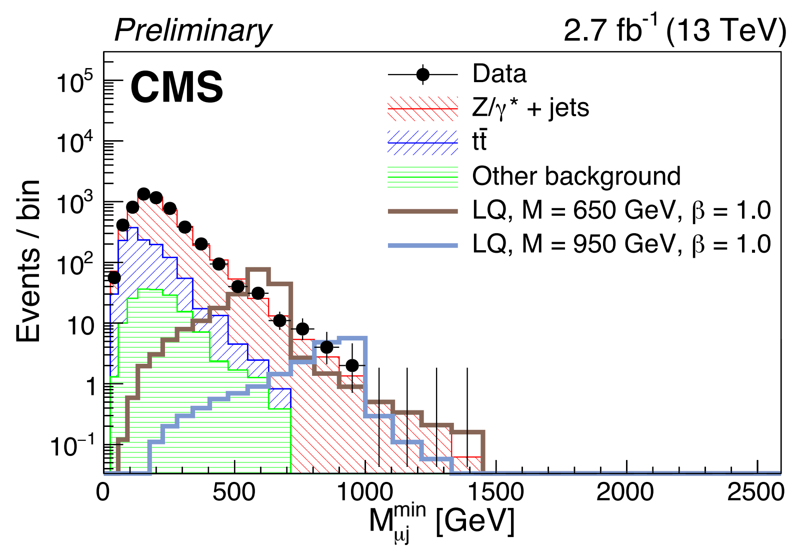
LQ 1st/2nd generation

CMS EXO-16-043
New for ICHEP2016









Good data/MC agreement observed at preselection

CMS EXO-16-007

LQ 1st / 2nd gen. results

CMS EXO-16-043
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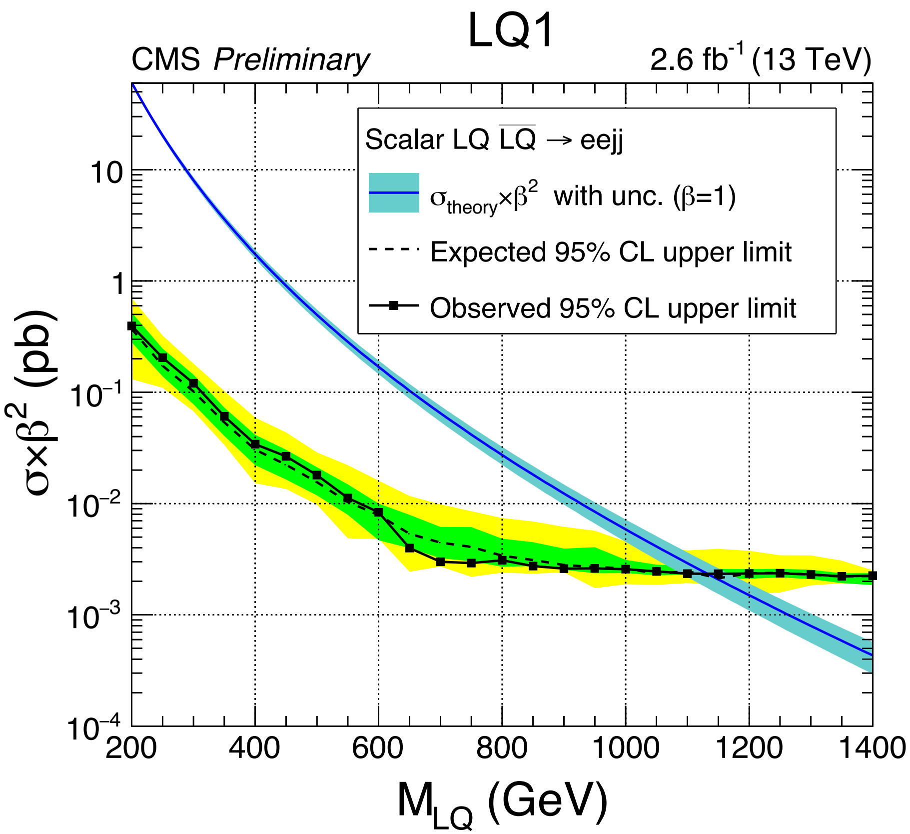
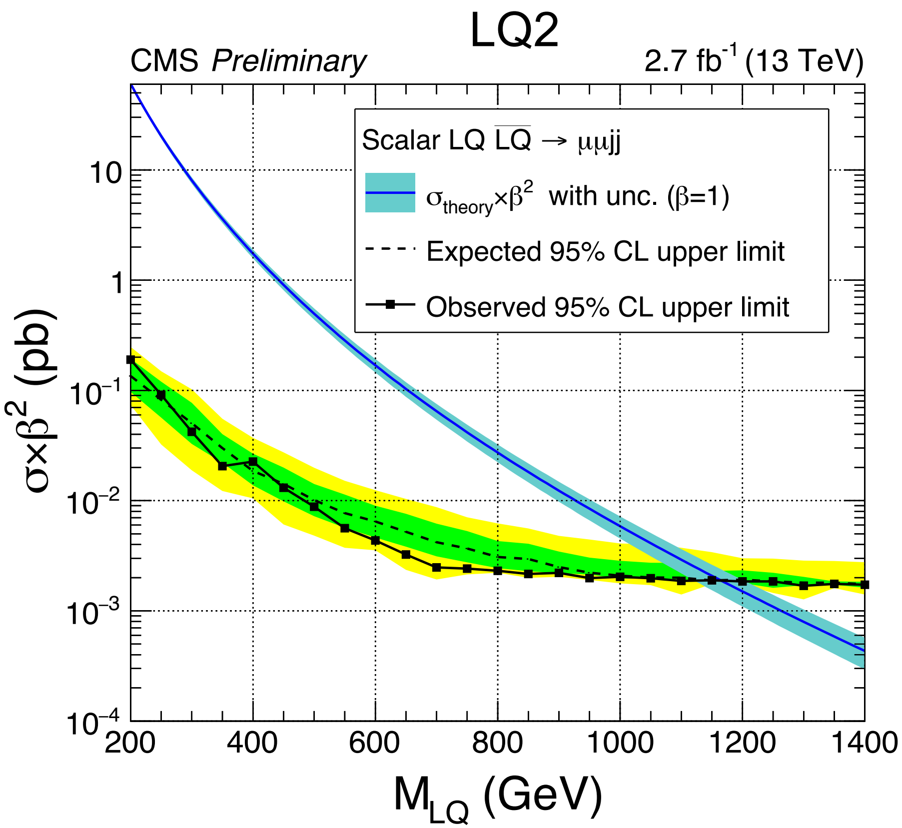




1st generation LQ mass limit is set at 1130 GeV for β=1

- Previous CMS: 1010 GeV (8 TeV, 19.7 fb^{-1}); ATLAS 1100 GeV (13 TeV, 3.2 fb^{-1})

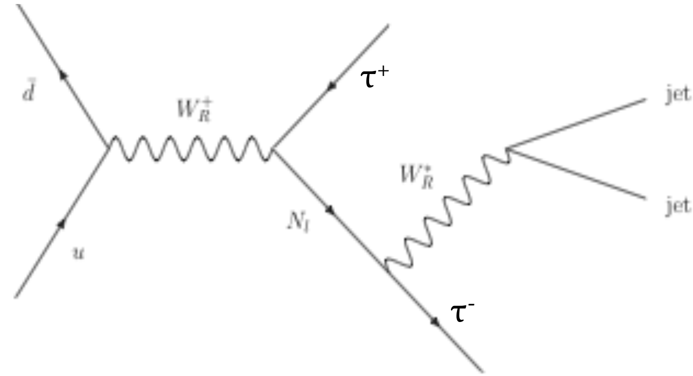
2nd generation LQ mass limit is set at 1165 GeV for β=1

- Previous CMS: 1080 GeV (8 TeV, 19.7 fb^{-1}); ATLAS 1050 GeV (13 TeV, 3.2 fb^{-1})

CMS EXO-16-007

W_R/LQ 3rd generation

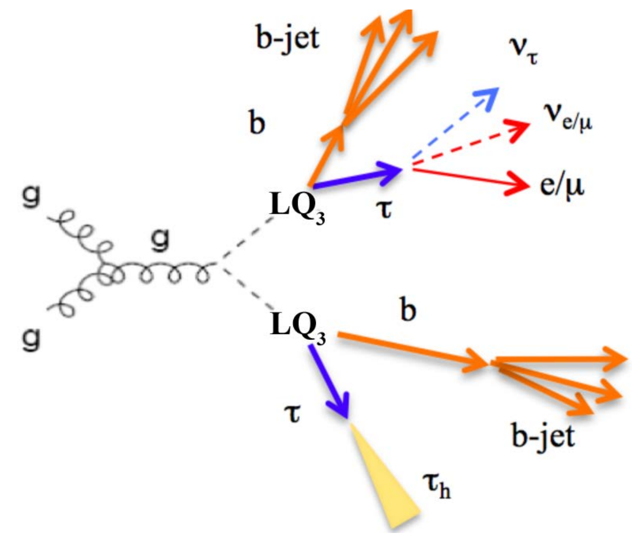
$\tau\tau jj$ final state



Left-Right Symmetric standard model

- Heavy right-handed neutrinos and right-handed W_R

Also sensitive to scalar leptoquarks decaying to $\tau\tau bb$



Require:

- 1 (or 2) isolated τ_{had} , high p_T (50-70 GeV)
- 2 high p_T jets (50 GeV)
- τ ,jet ℓ,jet τ,ℓ spatial separation

Calculate $S_T(\tau, \tau, j, j, MET)$

W_R/LQ 3rd generation: $\tau_{had}\tau_{had}bb$

CMS EXO-16-016

Trigger: double τ

M(ττ) > 100 GeV

MET > 50 GeV

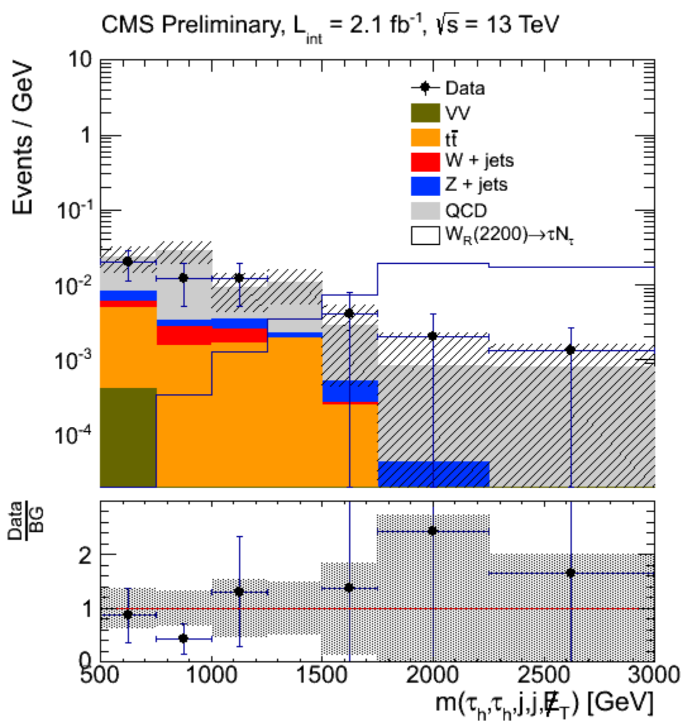
Examine S_T,

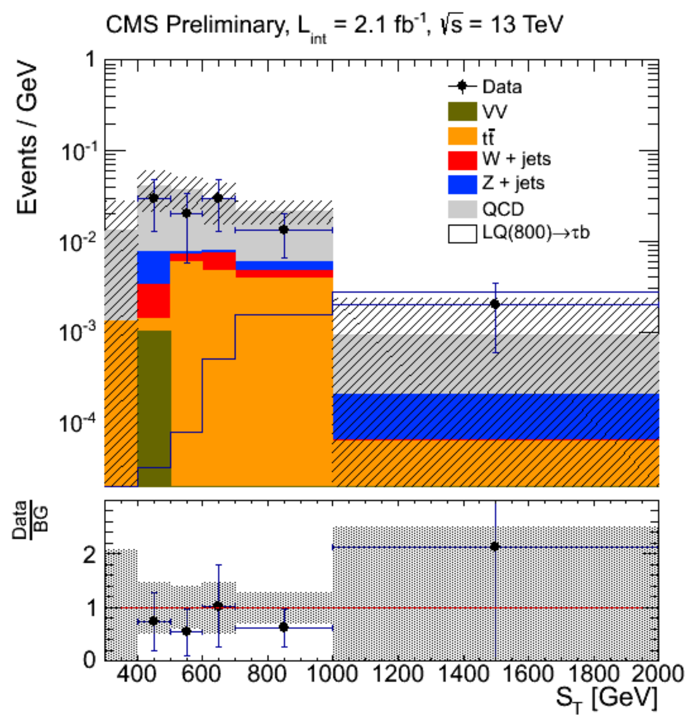
m(τ,τ,j,j,MET)

QCD multijet background dominates

- Data-driven ABCD method (MET, isolation of τ)

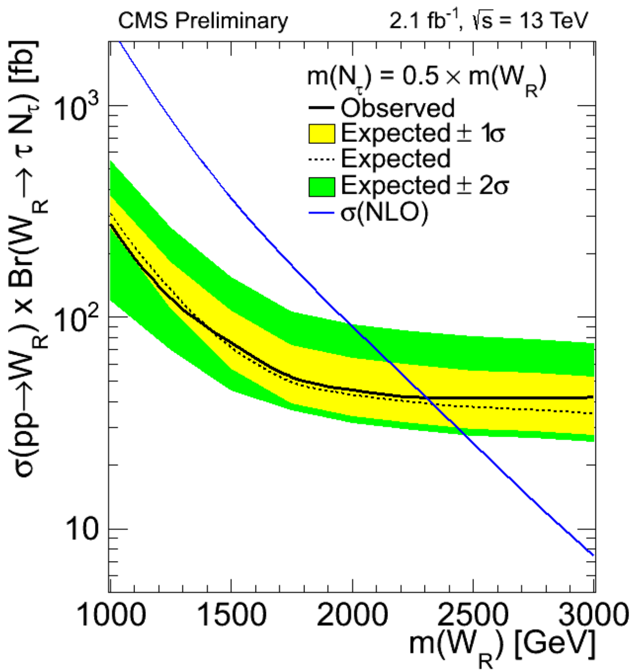
Others (ttbar+jets, DY+jets, etc., via MC)

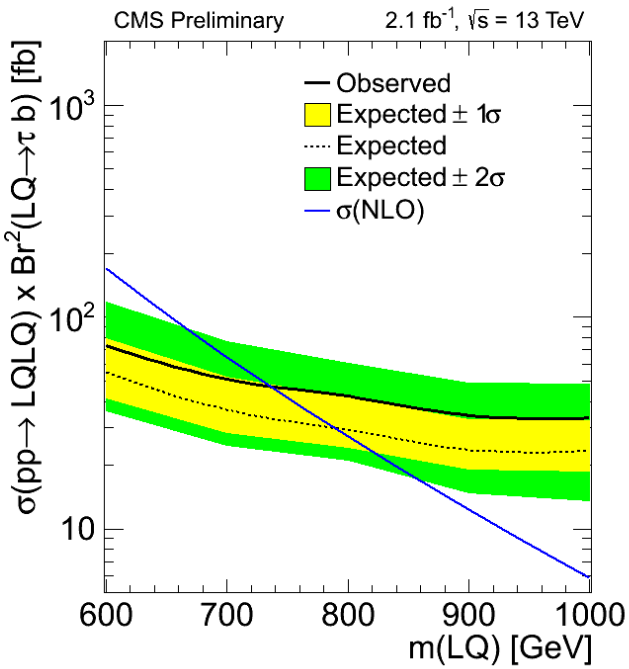




W_R/LQ 3rd generation: $\tau_{had}\tau_{had}bb$

CMS EXO-16-016





Limit $M(LQ_3) > 740$ GeV

Limit $M(W_R) > 2.31$ TeV [$m(N\tau) = 0.5\, m(W_R)$]

W_R/LQ 3[rd] generation: $\tau_{had}\ell bb$

CMS EXO-16-023

New for ICHEP2016

2016 pp data

$\tau_{had}\ell bb$ channel

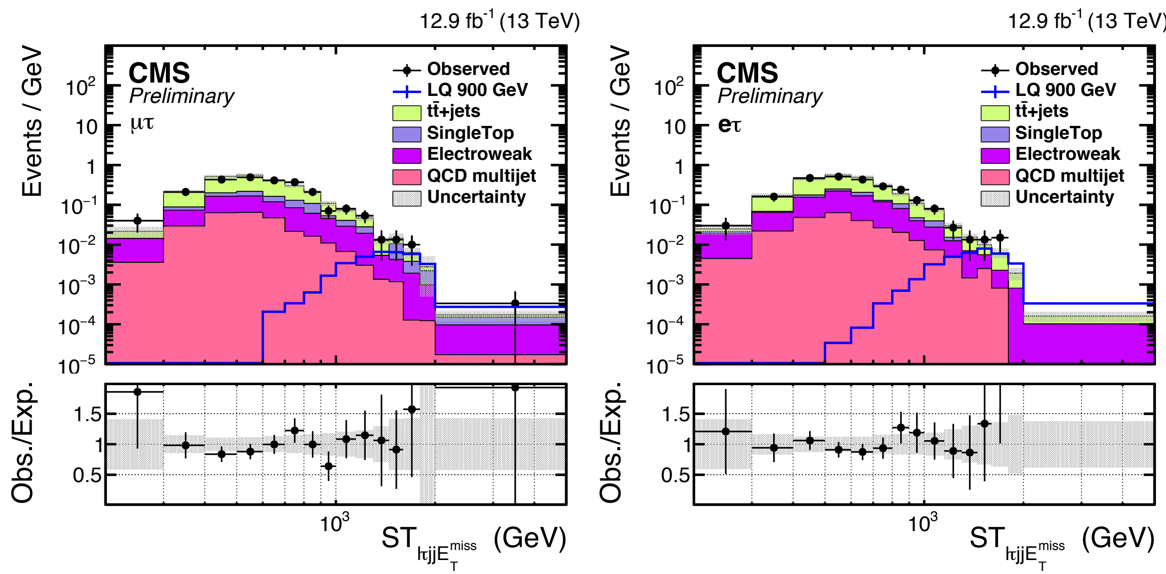
Trigger: single e/μ

Require 1 b-tagged jet (LQ)

$M(\tau_{had},j)$ > 250 GeV (LQ)

MET > 50 GeV (W_R)

$M(\tau_{had},\ell)$ > 150 GeV (W_R)

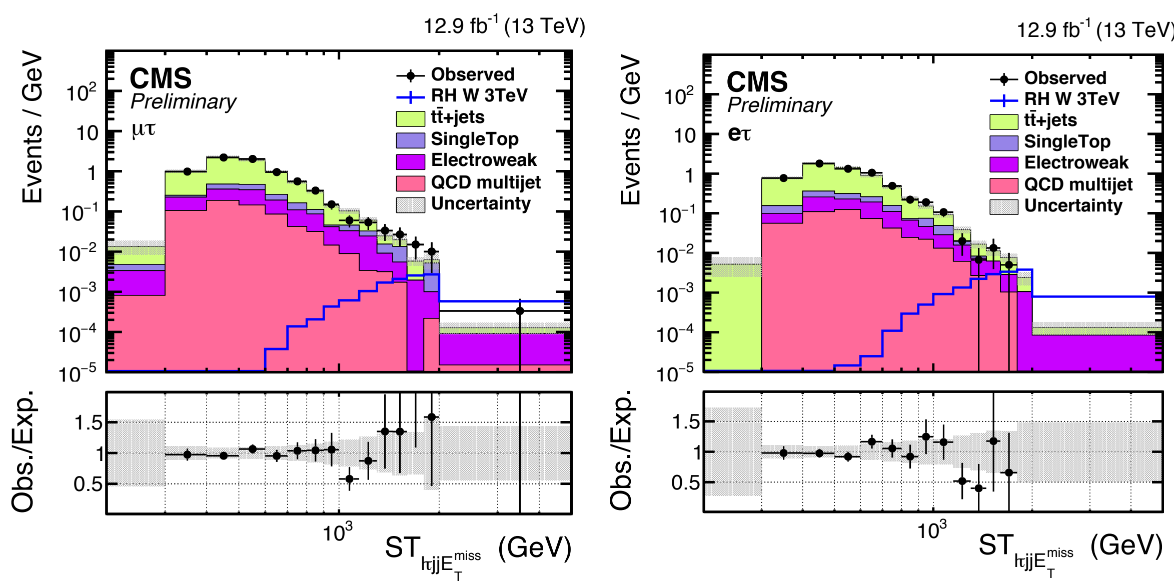


LQ

ttbar background dominates

- MC, checked with eμ data

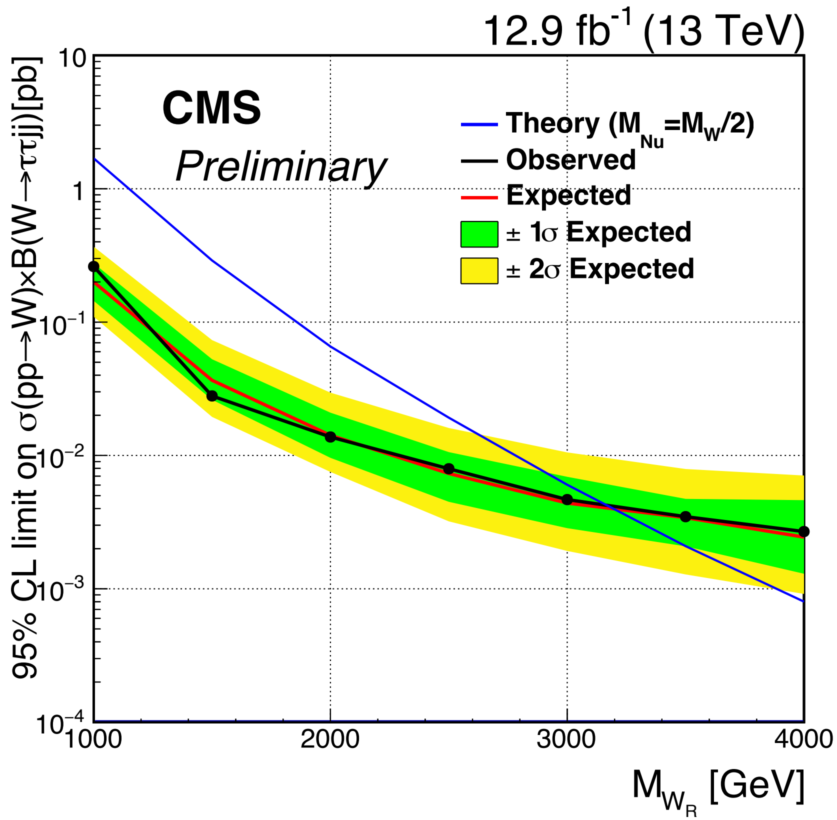
Others (W+jets, DY+jets, QCD, etc., via MC)

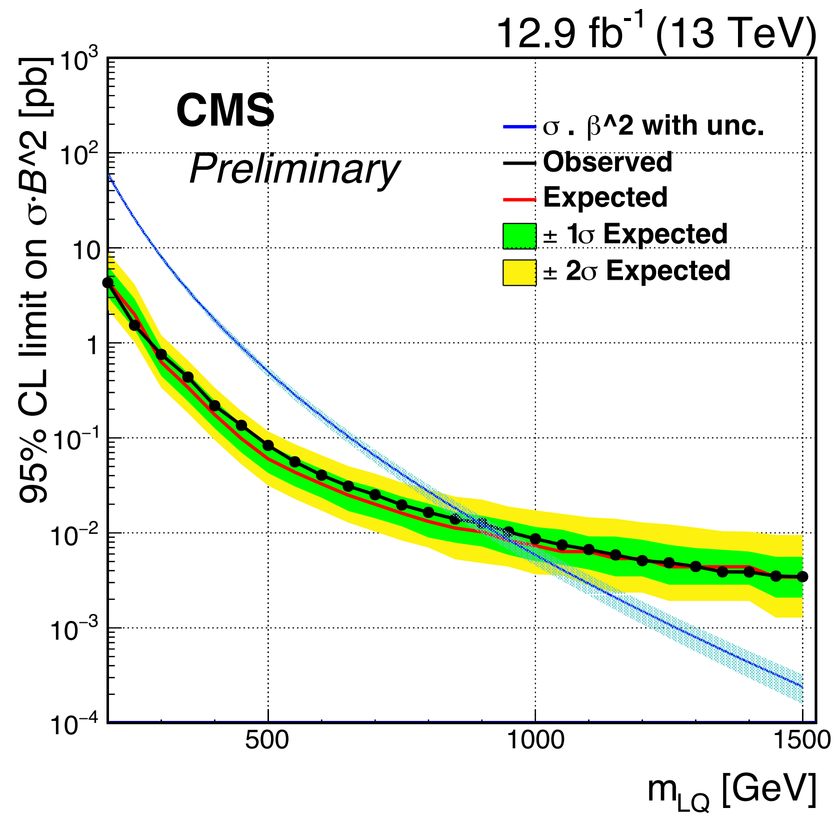


W_R

W_R/LQ 3rd generation: $\tau_{had}\ell bb$

CMS EXO-16-023
New for ICHEP2016





Limit $M(LQ_3) > 900$ GeV

Limit $M(W_R) > 3.2$ TeV [$m(N\tau) = 0.5\, m(W_R)$]

Compositeness: theory overview

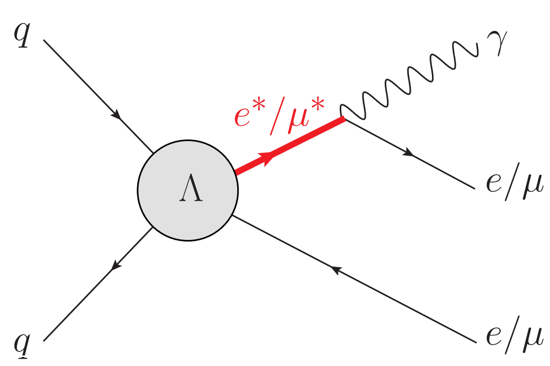
As far as we know, quarks and leptons are elementary particles

But if they in fact have substructure, it could help answer some open questions in the standard model, such as the mass hierarchy of quarks and leptons

Constituents known as <u>preons</u>, bounded by a new strong gauge interaction of scale Λ (Pati and Salam)

Can lead to production of excited quarks and leptons

- Direct evidence of compositeness



Known ℓ, q: ground states

Flavor shared with SM particle

Look in $\ell\ell\gamma$ final state

$$\mathcal{L}_{CI} = \frac{g^{*2}}{2\Lambda^2} j^\mu j_\mu$$

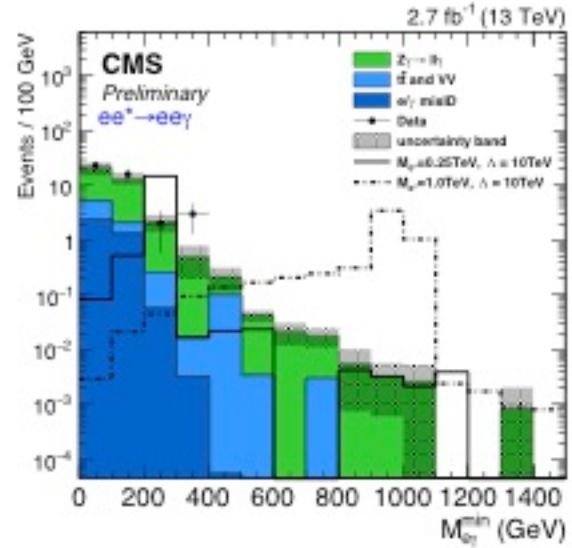
where g^{*2} is chosen to be 4π, Λ is the compositness scale, and j^μ is the fermion current.

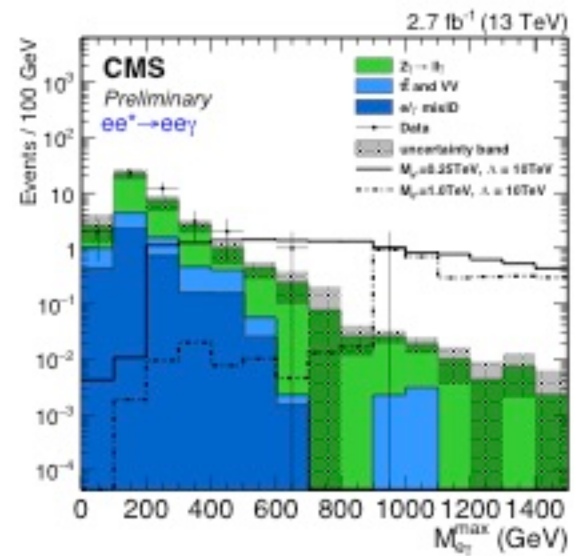
Excited leptons: analysis overview

CMS EXO-16-009
New for ICHEP2016

- Use double electron or double muon trigger
- Select photon
- Impose photon/lepton separation $\Delta R > 0.7$
- Veto Z peak: $M(\ell\ell) > 116$ GeV
- Two highest-p_T leptons paired with photon: $M_{\ell\gamma}$ min, max

- Background: DY, diboson, ttbar+jets
  - Data-driven QCD jet background, misidentified photon from MC (checked with data)



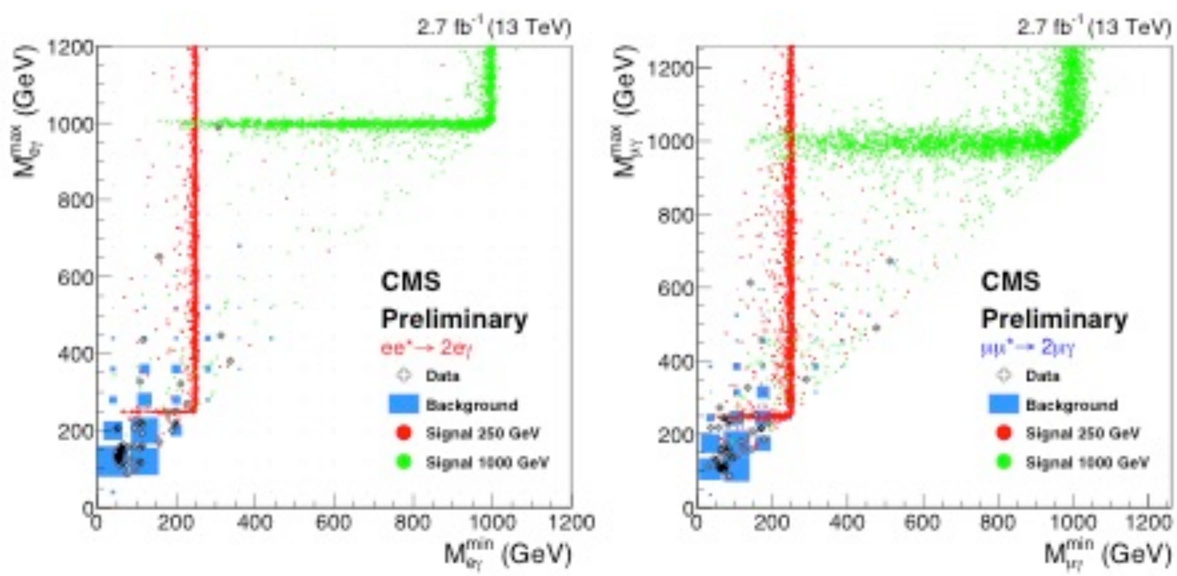


Excited leptons: analysis overview

CMS EXO-16-009
New for ICHEP2016

Signal forms an "L" shape in $M_{\ell\gamma}$ min vs. max

- Create signal region from 2-D regions



Excited leptons: results

CMS EXO-16-009
New for ICHEP2016

Search windows defined in $M_{\ell\gamma}$ min, max

Limits on cross-section(x)branching ratio for excited leptons

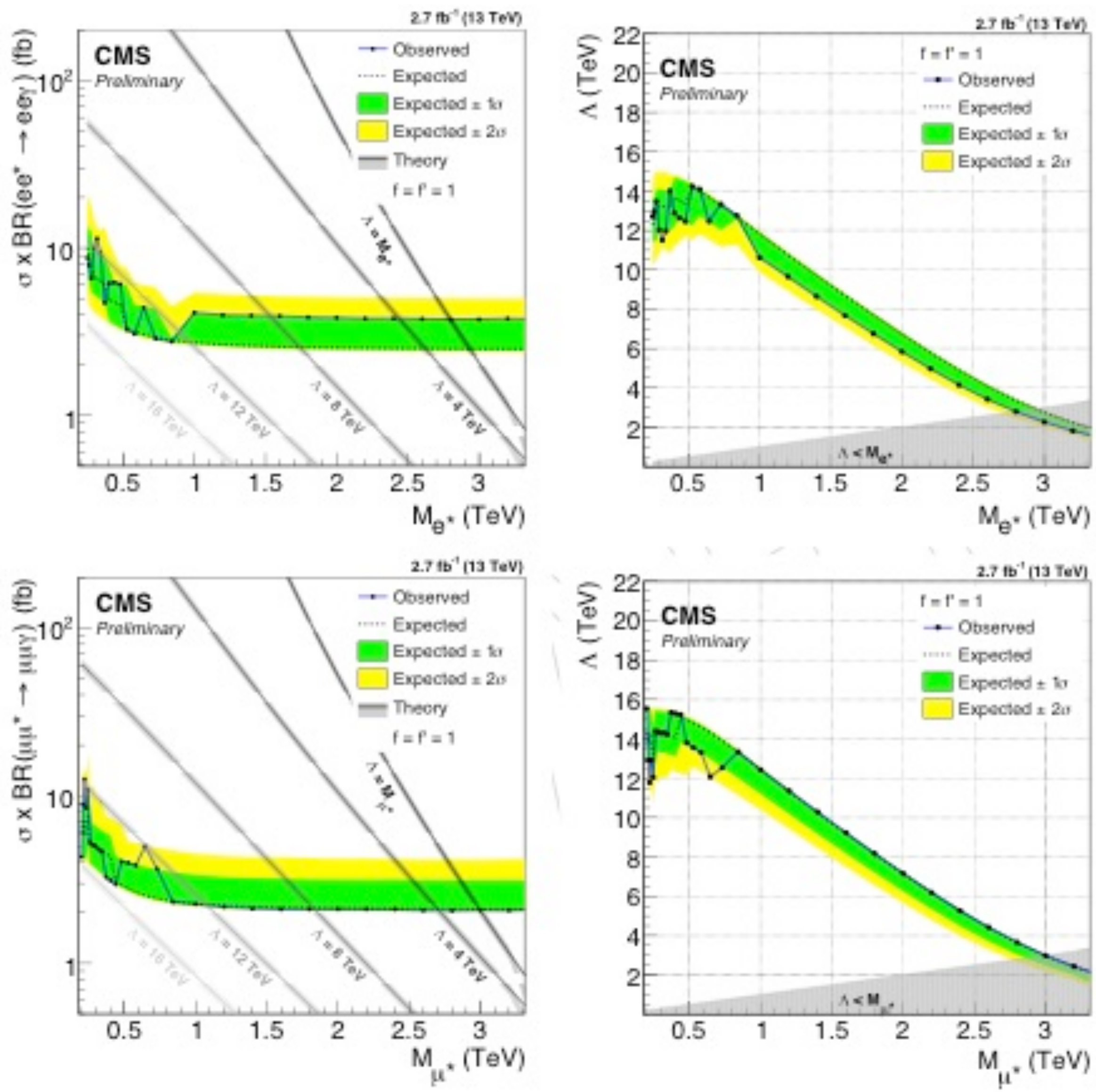
$M(e^*) > 2.8$ TeV (electron)

$M(\mu^*) > 3.0$ TeV (muon)

(8 TeV CMS mass limit: 2.5 TeV)

Also limits on Λ itself:

Λ > 15 TeV



Summary

Wide range of CMS results on 2015 and 2016 data from leptoquark and compositeness searches

- Leptoquark searches extend previous LHC Run I limits with 2015 data (1st gen., 2nd gen.)
- LQ3 in two channels also extend previous limits, with the $\tau_{had}\ell bb$ channel results using 2016 data
- Excited lepton results extend limits on the compositeness scale to ~15 TeV

Overall, 3 new results for ICHEP2016 [green] presented here

Expect results with 2016 data from all analyses

Backup

Optimized Thresholds (LQ2)

M_{LQ}	$S_T >$	$M_{\mu\mu} >$	$M_{min}(\mu,\text{jet}) >$
200	300	100	100
250	330	100	140
300	420	100	190
350	510	110	240
400	595	130	290
450	680	150	335
500	760	170	375
550	835	190	415
600	910	210	450
650	985	225	485
700	1055	240	515
750	1120	255	540
800	1185	270	565
850	1245	285	585
900	1305	300	605
950	1360	315	620
1000	1415	325	635
1050	1465	335	640
1100	1515	350	650
1150	1560	360	650
1200	1605	365	650
1250	1645	375	650
1300	1680	385	650
1350	1715	390	650
1400	1750	400	650