Search for Excited Leptons at CMS

SUSY 2015,
Lake Tahoe, California
Aug 23-29, 2015

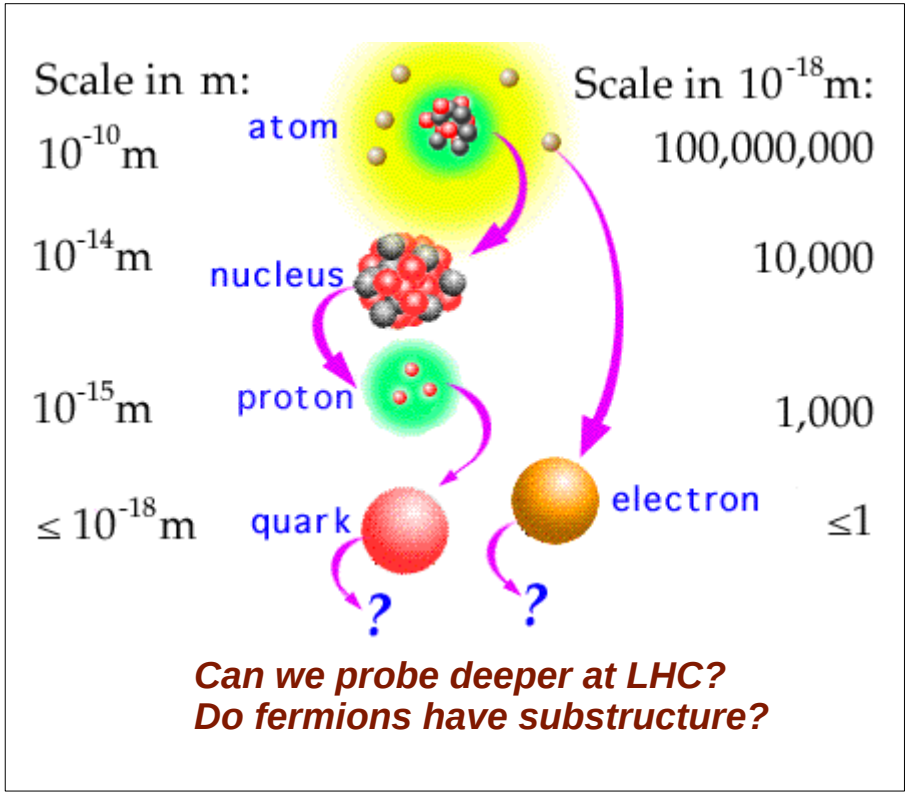
Lovedeep Kaur Saini (*),
Kansas State University

(*) On behalf of CMS collaboration

Motivation

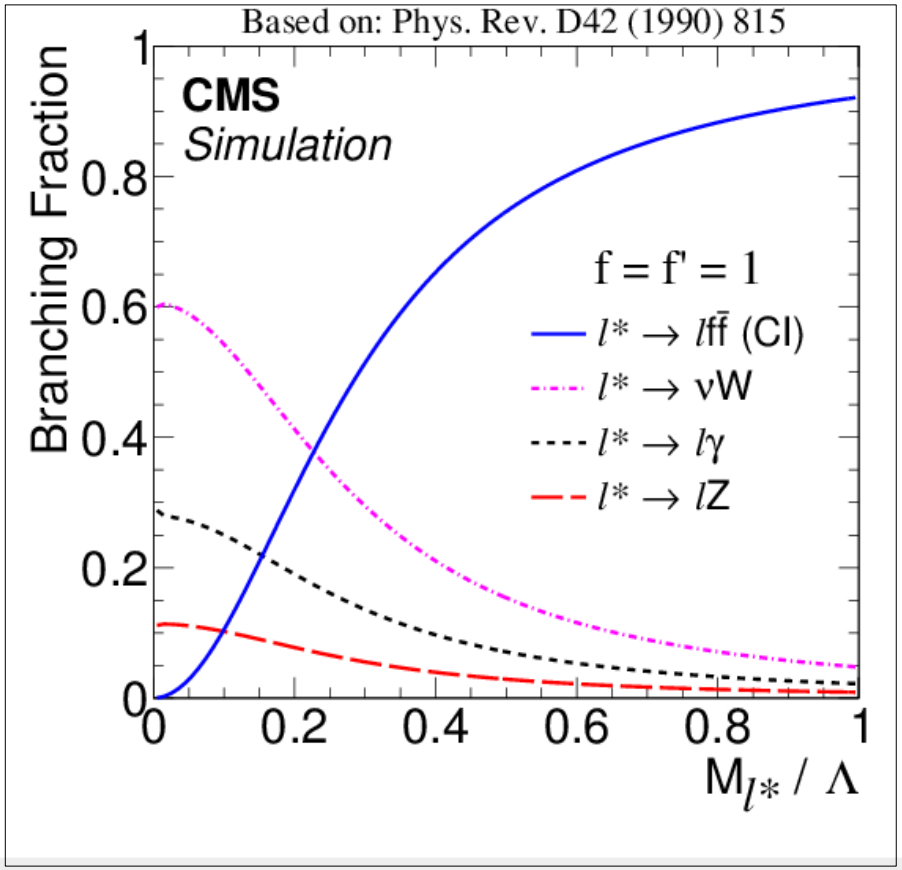
Compositeness Model

- Possible explanation of mass hierarchy in quarks and leptons
- **Quarks and leptons may not be fundamental particles**
  - Can be bound states of 3 fermions or a fermion and a boson
    - the supposed constituents called ”preons”
- Excited states of leptons (ℓ*)
  - a clear signature of composite structure



Production and Decay Modes

- Production:
  - Single ℓ* production via contact interaction
    - pp → ℓℓ*, where ℓ = e, μ
- Decay:
  - Contact interaction
    - ℓ* → ℓff, f is fermion
  - Gauge interactions
    - Radiative decays, ℓ* → ℓγ
    - Charged current decays, ℓ* → νW
    - Neutral current decays, ℓ* → ℓZ



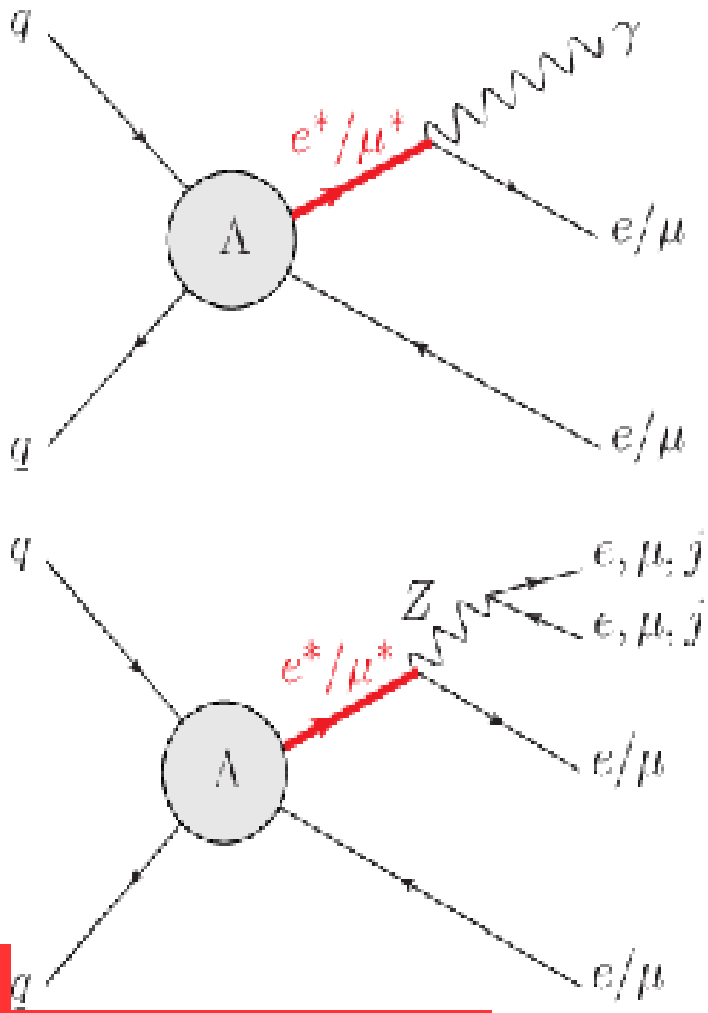
f, f' are couplings between SM leptons and excited leptons via gauge interactions

Results based on CMS EXO-14-015, interpreted for f = f' =1 and f = -f' = 1

Various Search Channels

Results based on CMS EXO-14-015

- $\ell\ell^* \rightarrow \ell\ell\gamma$
  - High branching ratio
  - Vanishes for f = -f'
- $\ell\ell^* \rightarrow \ell\ell Z$
  - Highly boosted Z-bosons
  - $Z \rightarrow jj$,
    - highly collimated jets, reconstructed as single ”fat-jet”
    - rely on jet substructure techniques
  - $Z \rightarrow \ell\ell$,
    - leptons collinear, need relaxed isolation



For first time at LHC from CMS!

Helps to probe f = -f' phase space, unexplored by previous seraches!

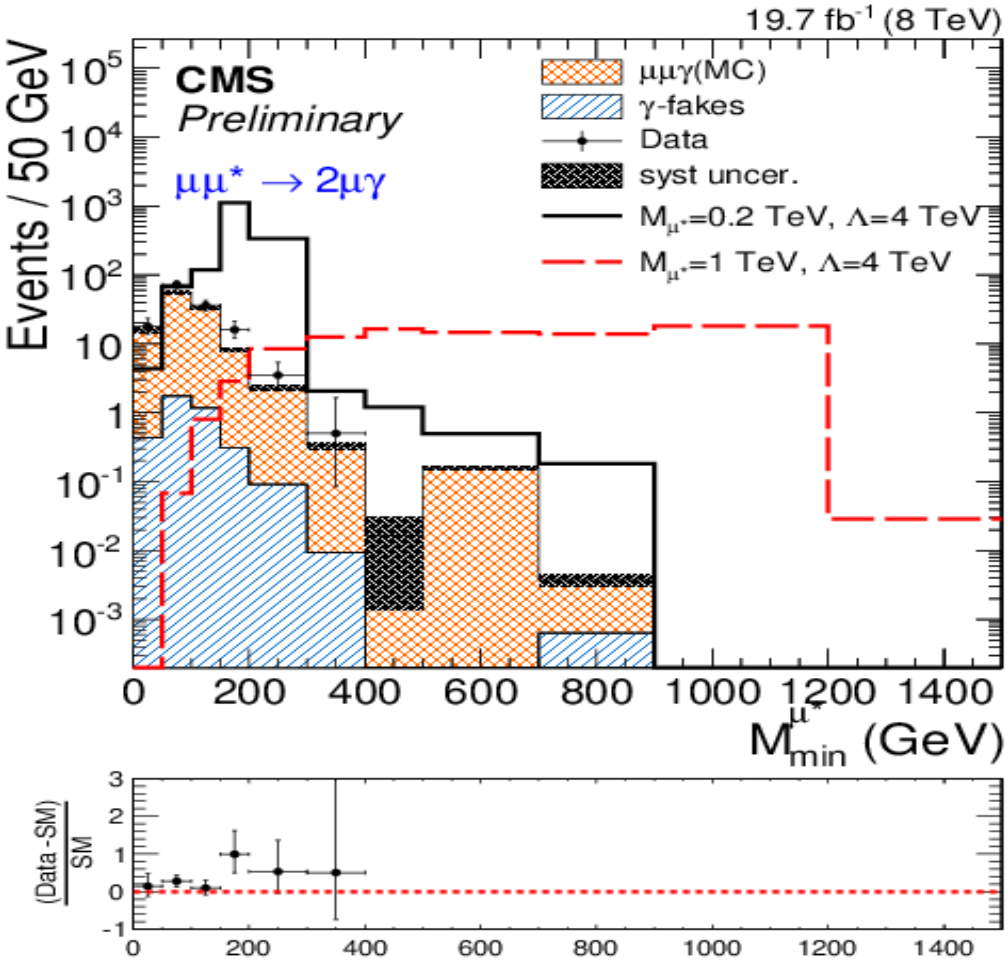
Physics Objects

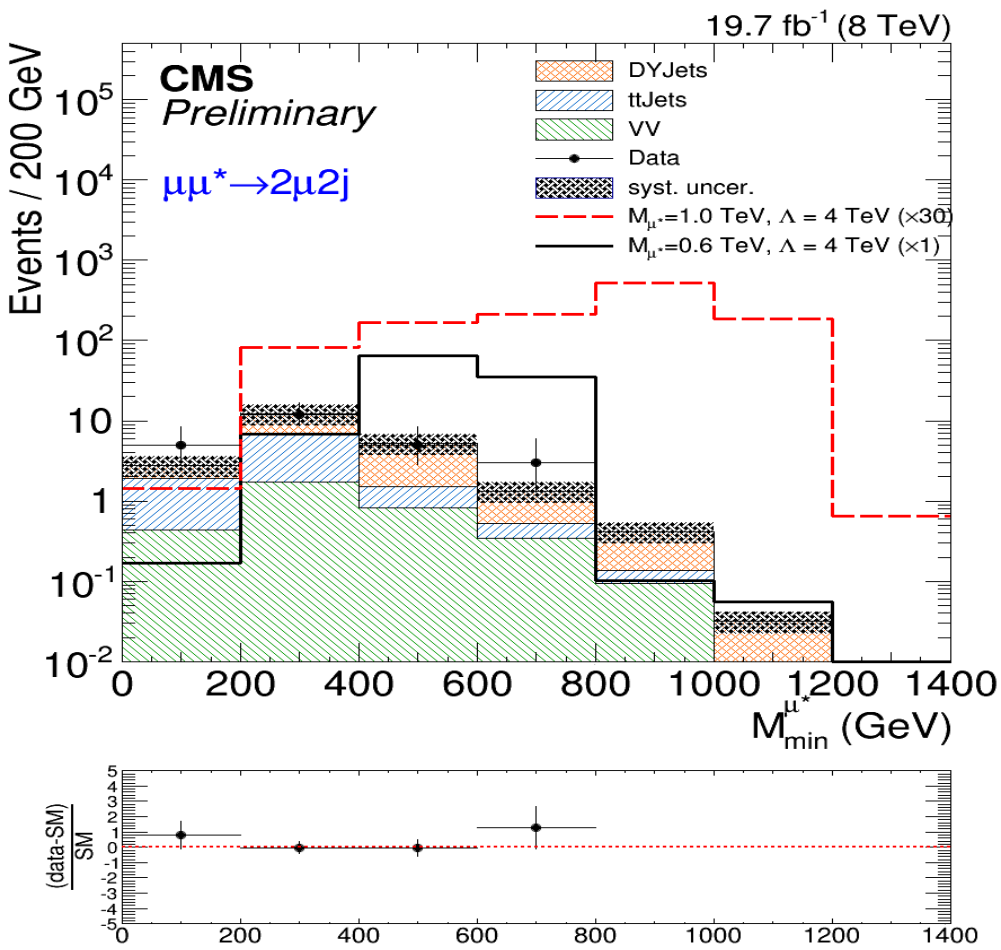
- **Leptons**
  - 2ℓ2j, ℓℓγ: Two same flavour isolated leptons within detector accepetance and p_T > 35 GeV
  - 4ℓ: Four isolated leptons within detector acceptance and p_T > 25 GeV
- **Photons**
  - ℓℓγ: one isolated high Et photon within central region of em-calorimeter and p_T > 35 GeV
- **Jets**
  - 2ℓ2j: p_T > 200 GeV and in detector acceptance
  - Z-tagging:
    - ”pruned” jet mass between 70 – 110 GeV, N-subjettiness (sum of angular distances of jet constituents to their nearest subjet axis) ratio < 0.5

Event Selection

- **Z-veto**
  - $M_{\ell\ell}$ > 106 GeV in ℓℓγ and 4ℓ channels
  - $M_{\ell\ell}$ > 200 GeV for 2ℓ2j channels
- **Additional requirements** for ℓℓγ channel
  - For eeγ channel, remove events with $M_{e\gamma}$ with ±25 GeV of Z-boson mass
  - For μμγ channel, reject back-to-back cosmic muons by removing those with an angle above π-0.02
  - ΔR(lepton,γ) > 0.7, reduce FSR contribution
- **Reconstructing ℓ***
  - Two leptons in final state along with reconstructed Z-boson or photon
    - Two possible lepton-boson combination
  - So, two invariant masses: M_X^{Max} and M_X^{Min}

Invariant mass distribution (M_X^{Min})



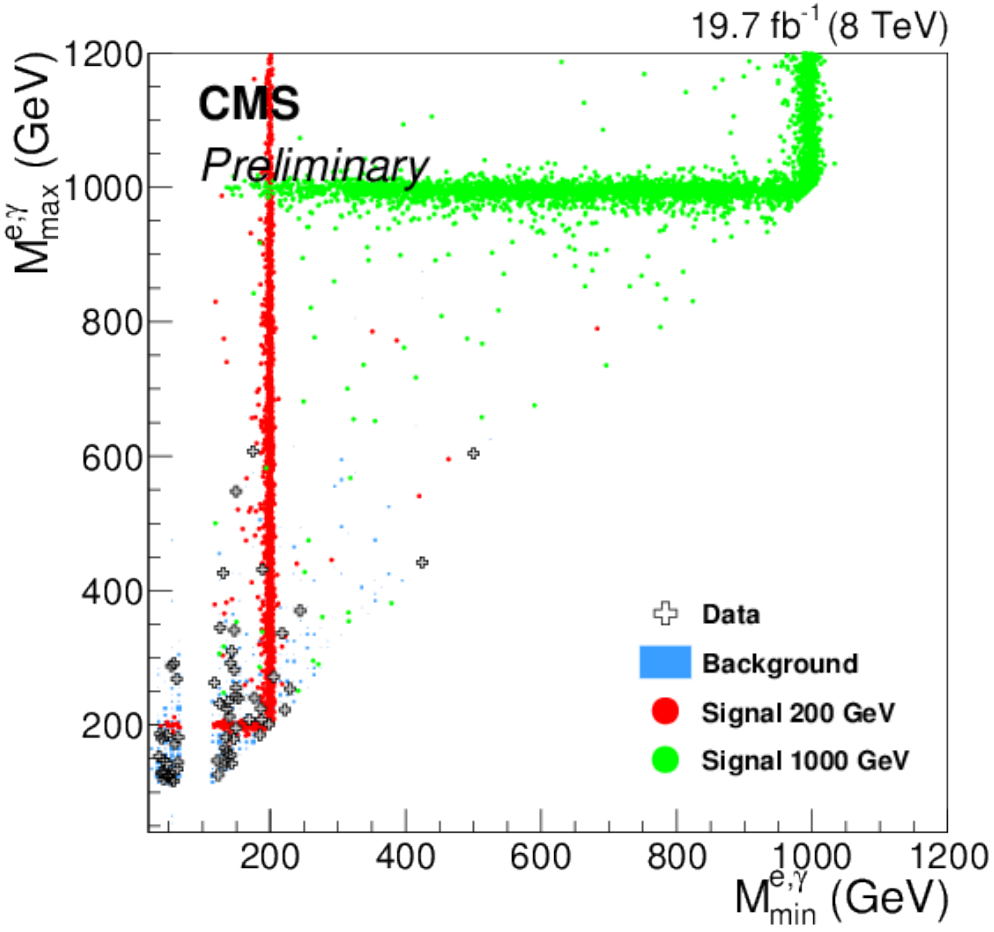


M_X^{Max} vs M_X^{Min} in 2D-plane, signal forms inverted "L" shape around considered M_{ℓ^*}

– see next slide

Final selection

- L-shape search window
  - discriminates efficiently against expected background
    - that tends to be at low invariant mass
  - High mass regions background free
  - Width depends on channel and M_{ℓ^*}
  - Optimised w.r.t best expected limit

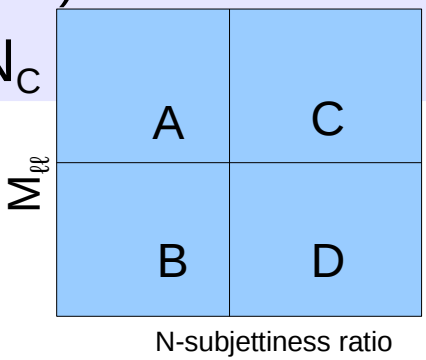


Sources of backgrounds

- $\ell\ell^* \rightarrow \ell\ell\gamma$
  - Major: Zγ, ~90% contribution
    - estimated by simulations
  - Reducible: having either fake electrons or fake photon
    - estimated using data
      - Electron fake rate
      - Photon fake rate

- $\ell\ell^* \rightarrow 4\ell$
  - Major: ZZ, ~ 90% contribution
  - Other small contributions from Tri-bosons, top pair + X (X = W/Z/γ)
  - All estimated using simulations

- $\ell\ell^* \rightarrow 2\ell 2j$
  - Major: DY+Jets, ttbar
    - Di-bosons, ~10% contribution
  - All estimated from data using ABCD method
    - relies on two independent variables, $M_{\ell\ell}$ and N-subjettiness ratio
    - Four disjoint regions in their 2D plane; A (signal rich), B/C/D (control regions)
  - $N_A = N_B/N_D * N_C$



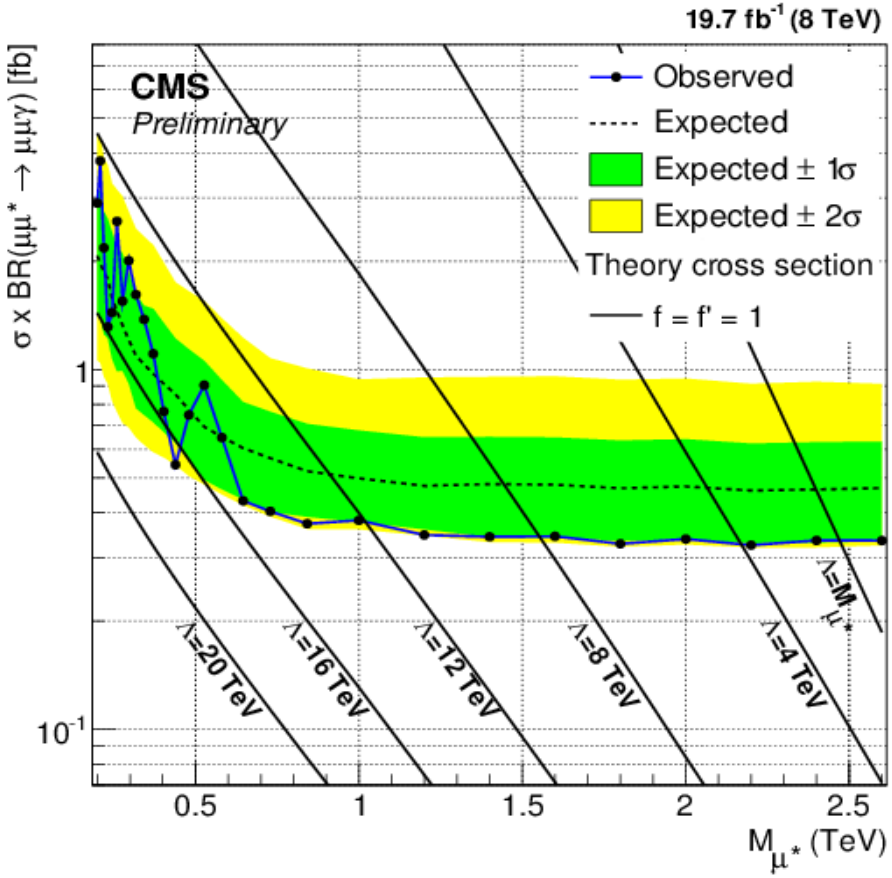
Systematic Uncertainties

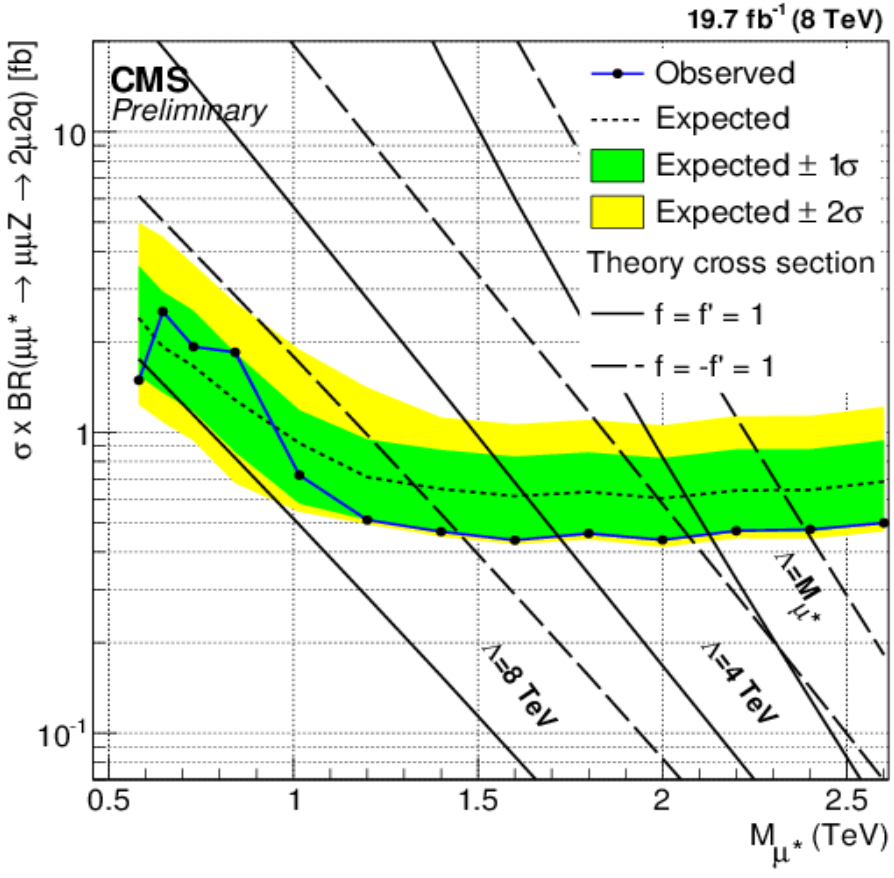
- $\ell\ell^* \rightarrow \ell\ell\gamma$
  - Dominant uncertainty: PDF's, renormalization and factorization scale in background processes: ~10%
  - Pileup simulation ~5%
  - Data driven background estimates ~50% for fake photons, but impact ~4% on yields being small contribution of this background
- $\ell\ell^* \rightarrow 2\ell 2j$
  - Data driven background estimation ~30% due to signal contamination in control regions
  - Difference between Z-tagging efficiency in data and simulation ~10%
- $\ell\ell^* \rightarrow 4\ell$
  - Dominant uncertainty: ZZ background cross-section ~15%
  - Electron energy scale: impact on background yield ~12%
  - Electron selection efficincy ~6%, muon efficiencies ~3%

All other theory and experiment related uncertainties are taken care in various channels, but have small impact on yields

Limits on Cross-section * BR

- Data agree with SM expectation, no evidence for new physics
- 95% CL upper limit on ℓ* production cross-section times BR has been set
  - using a single bin counting method using Bayesian approach

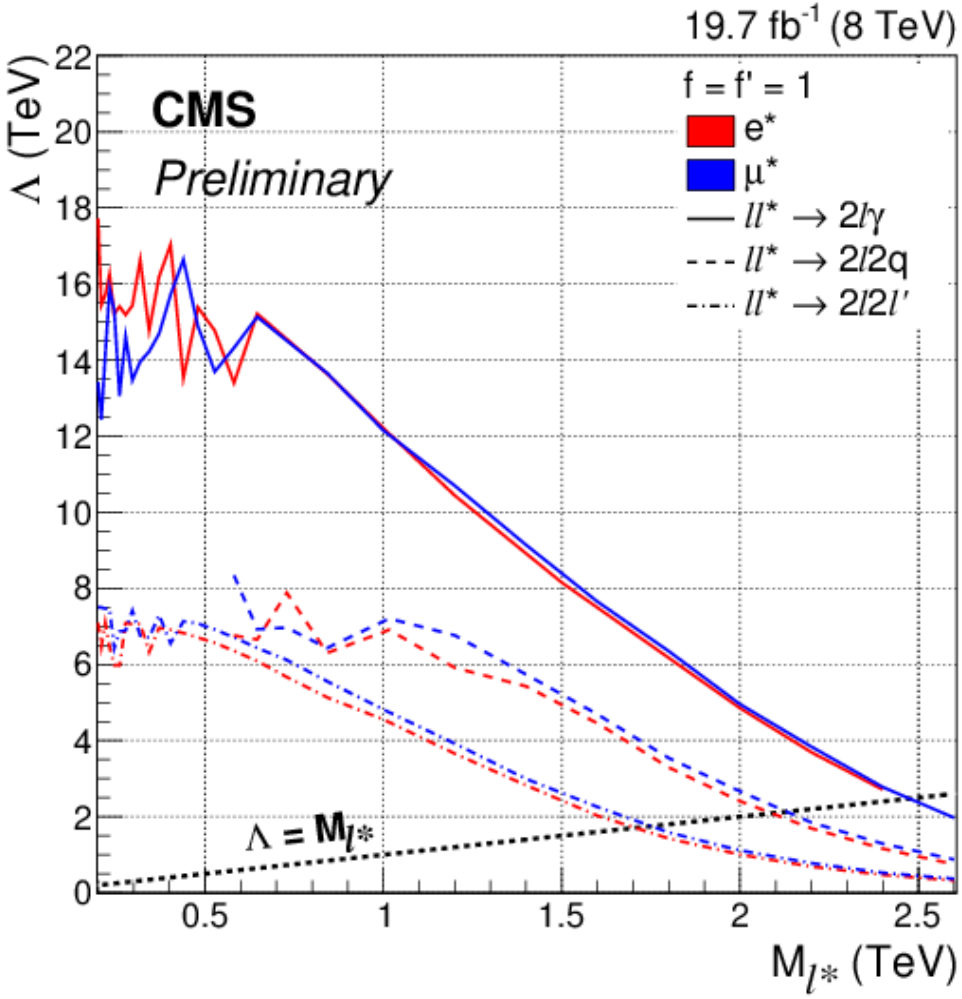


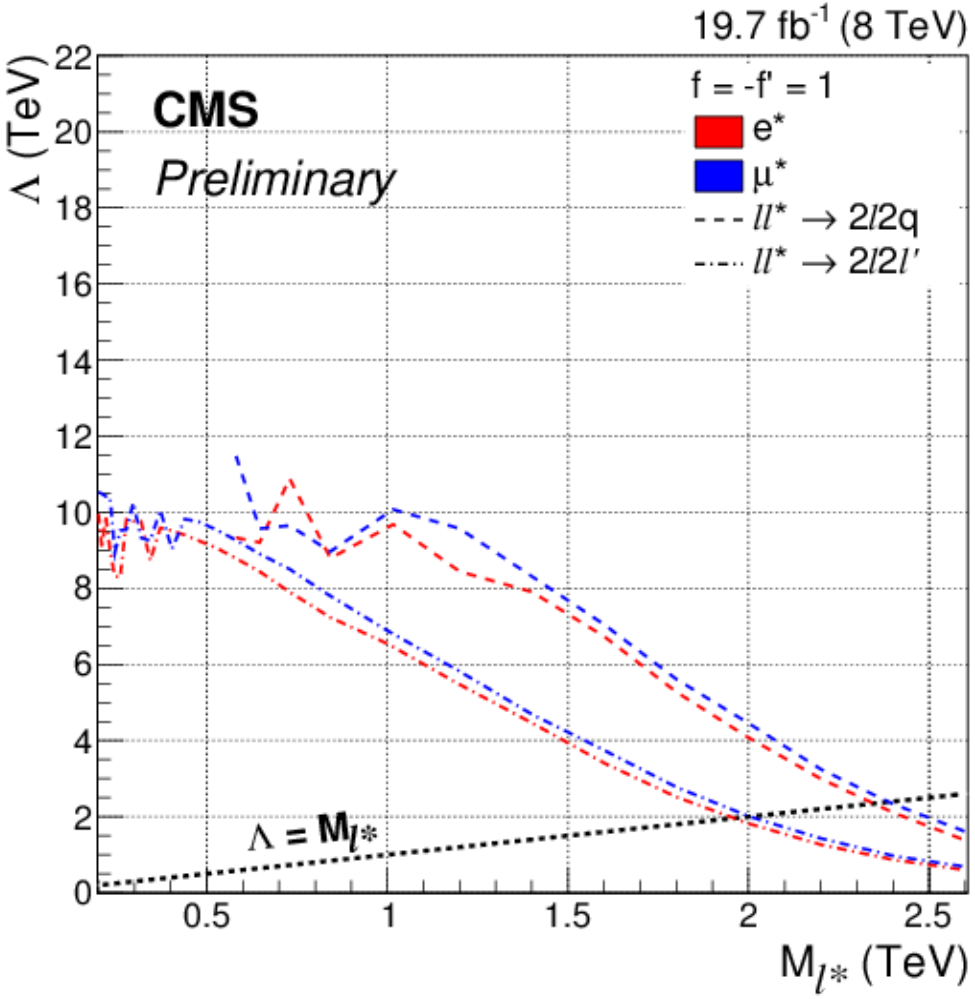


More plots in EXO-14-015

Limits on Compositeness Scale Λ

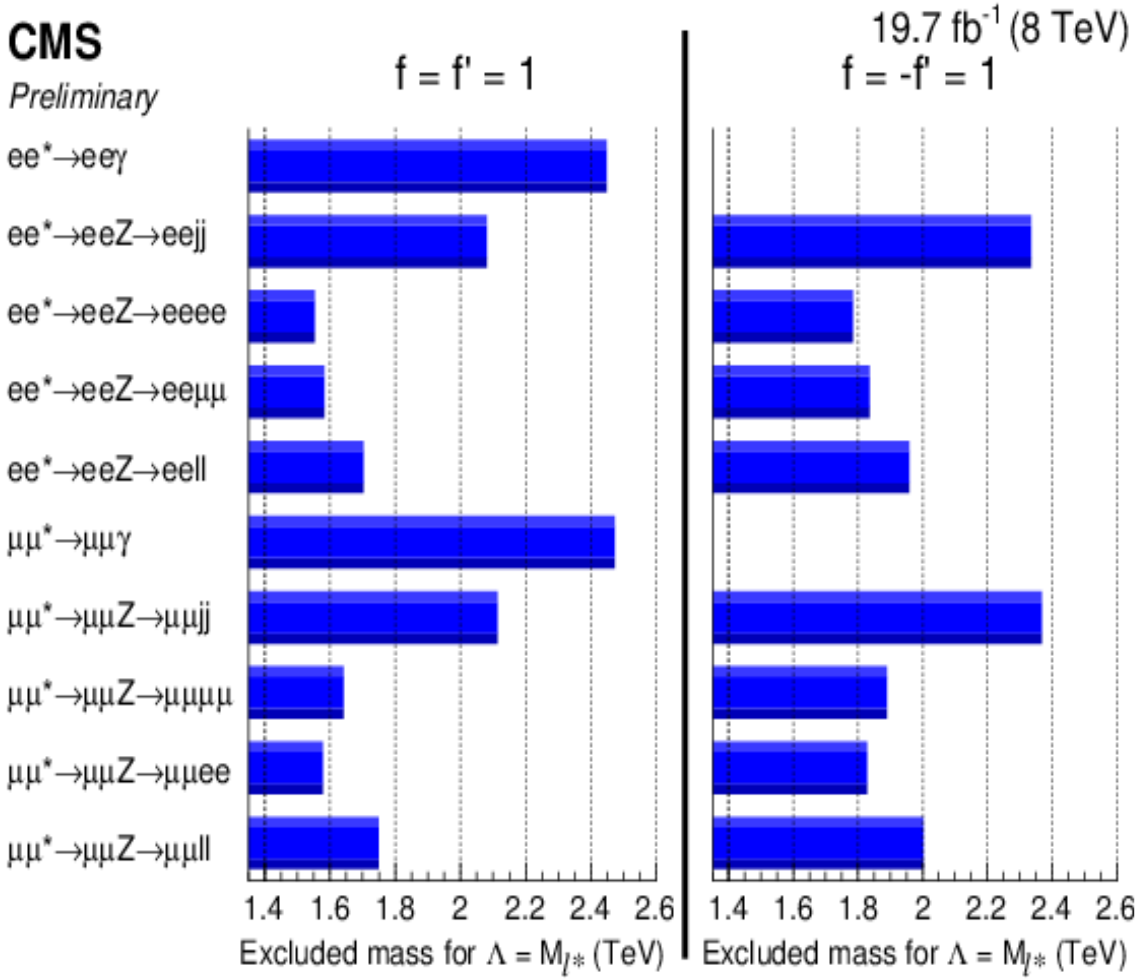
For the case of SM-like couplings (left) low masses, Λ upto 16TeV can be excluded





Mass limits for $M_{\ell^*} = \Lambda$

- $\ell\ell\gamma$:
  - maximum sensitivity
  - excludes $M_{\ell^*} < 2.45$ (2.48) TeV for e(μ)
- Improves existing ATLAS limit
  - excludes $M_{l^*} < 2.2$ TeV
- $\ell\ell Z$:
  - sensitive for f= -f'
  - $2\ell 2j$ most sensitive among other channels
  - excludes $M_{\ell^*} < 2.35$ (2.38) TeV for e(μ)



Summary

- A search for excited leptons in various channels performed using the full 19.7 fb^{-1} of Run-1 data collected by CMS.
- None of the search channels shows a sign of new physics.
- Exclusion limits are set on the compositeness scale as a function of M_{ℓ^*}
  - Mass exclusion limits are provided for the case when $M_{\ell^*} = \Lambda$
- $\ell\ell^* \rightarrow \ell\ell\gamma$ provides best exclusion limit for mass of e* (μ*) of 2.45 (2.48) TeV
- For the first time at hadron colliders, ℓ^* decays via Z-boson radiation are studied
  - Sensitive for the case when the couplings to SM fermions and excited fermions are opposite (f = -f').
  - Observed 95% exclusion limits reach upto 2.35 (2.38) TeV for e* (μ*)