

topics covered:

- this talk:
  - $Z' \rightarrow ll$
  - $W' \rightarrow l\nu$
  - $W' \rightarrow tb$
  - Excited Leptons
  - Type III SeeSaw
- Joerg's talk:
  - extra dimensions in dilepton
  - resonant  $ZZ \rightarrow llqq$
  - $WZ \rightarrow 3l$
  - ADD monojets
  - $tc \rightarrow Z\gamma$ ,  $W\gamma$  limits
- JP's talk:
  - dijets
  - top partners
  - T prime
  - B prime

# Searches for Heavy Resonances at the LHC

Moriond QCD

La Thuile, Italy

11/03/13

*Sam Harper (RAL)*

on behalf of the ATLAS + CMS Collaborations



# Introduction

- Heavy resonance searches are an exploration into the unknown
  - aim is to see what's out there!
  - leave no corner for new physics to hide

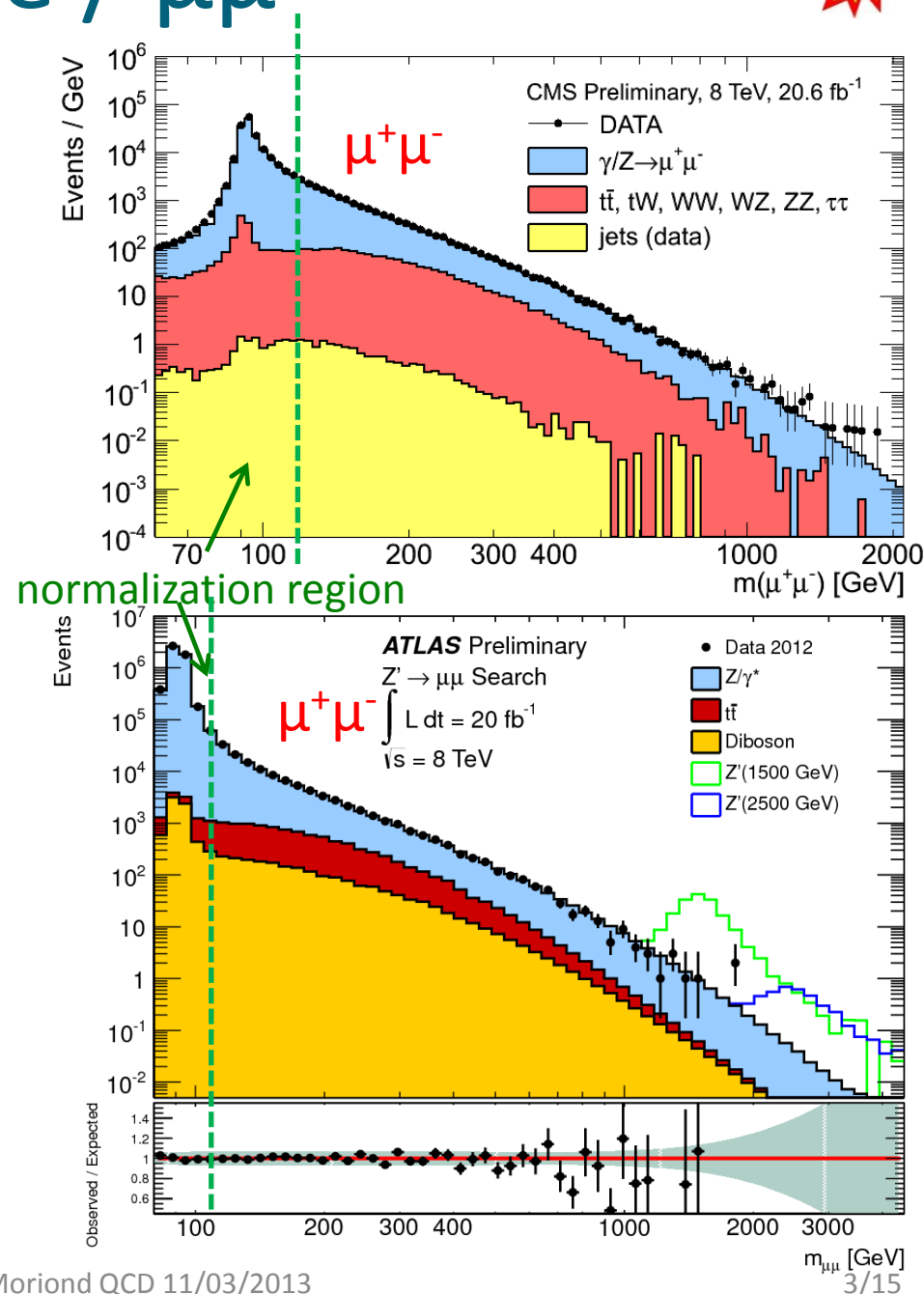


- Many heavy resonance results from CMS + ATLAS, today will focus on the **newest 8 TeV results involving leptons**
  - these results are just a fraction of our searches for new heavy particles
  - lepton = electron or a muon, not a tau

# $Z' \rightarrow ee / \mu\mu$



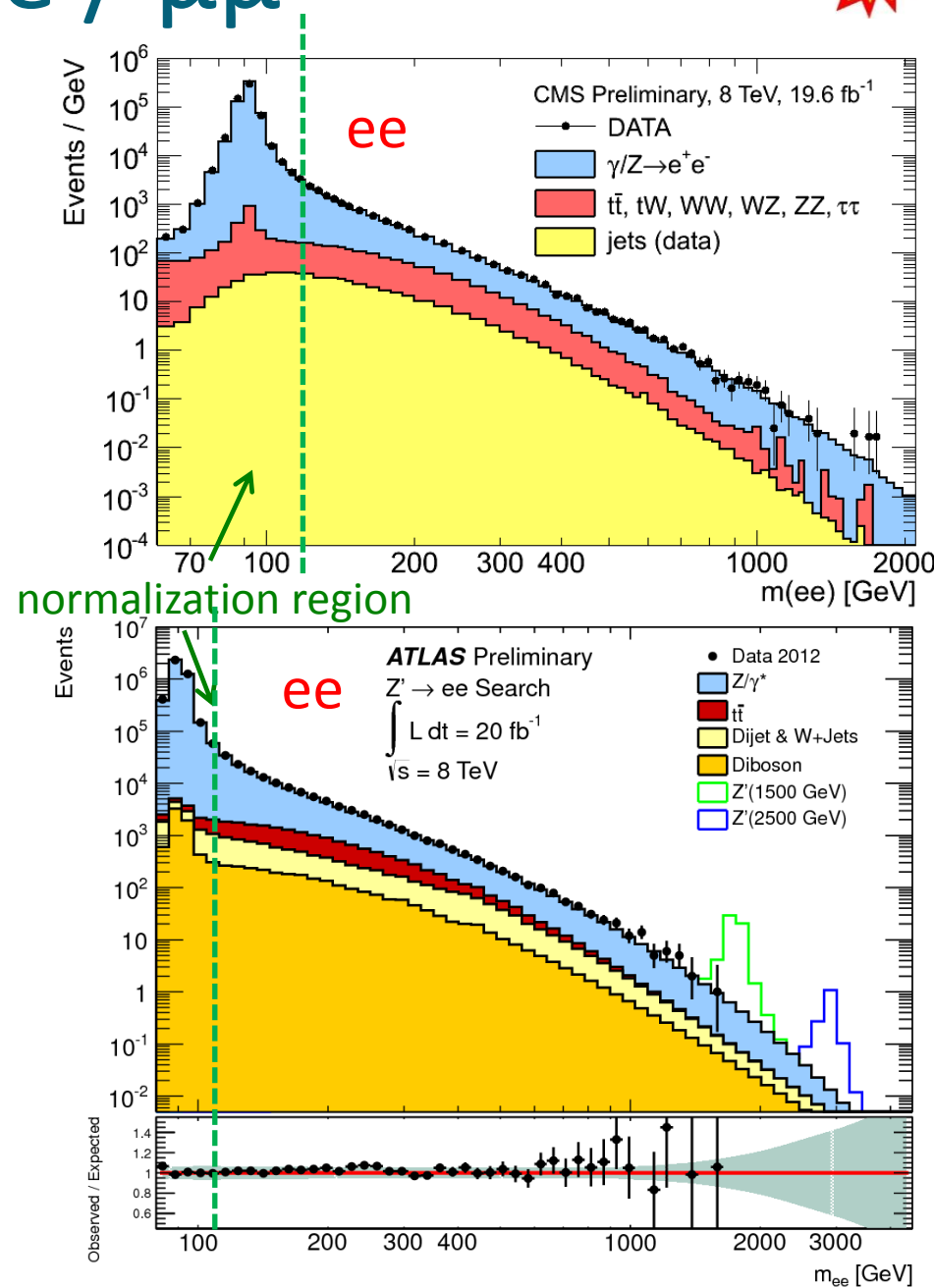
- inclusive search for new resonance
  - $\mu\mu$  channel doesn't even require calorimeters to be on
- similar approach ATLAS + CMS
  - normalise MC background to Z peak
  - estimate jet bkg from data
- CMS muons highly efficient,  $\sim 80\%$  eff x acceptance at 2 TeV
  - good for limits
- electron mass resolution  $\sim 1-1.5\%$  at high mass
  - good for discovery
- excellent data-SM agreement



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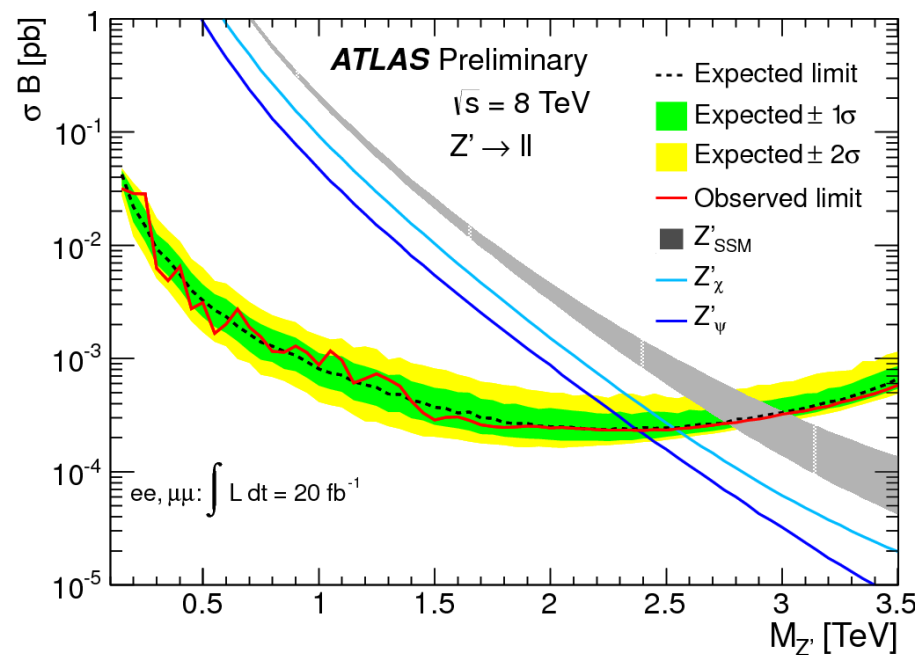
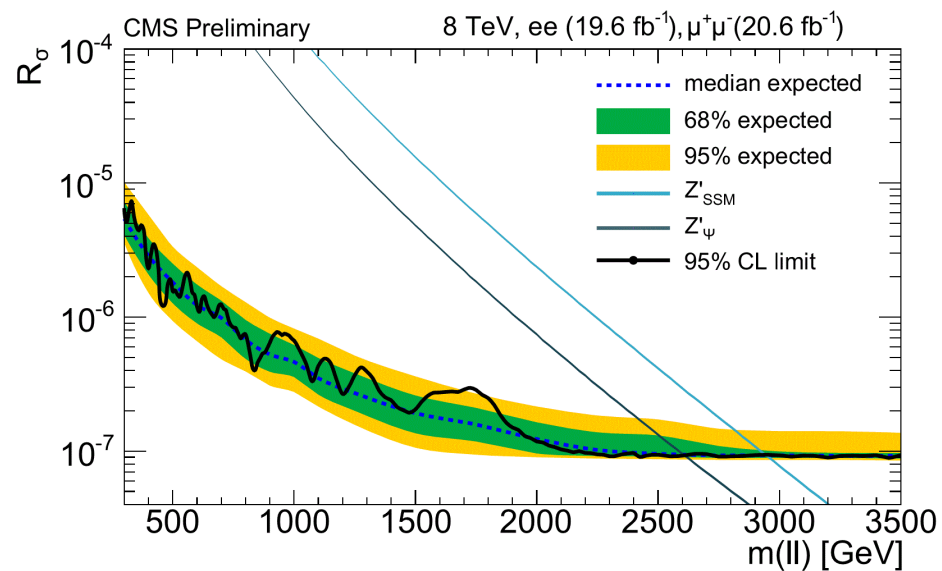


# Z' Limits



- set limits on Z' production
- CMS sets limits on narrow Z'
  - quasi model independent
  - slightly less power for a given model
  - mass window cut on wide Z' cross-section to approximate narrow Z'
- ATLAS set limits on a Z' with the width and couplings of the Z'\_{SSM}
- care must be taken when translating CMS's result to a wider Z' or ATLAS's to a different Z' model

*for extra dimension interpretations see Joerg's talk*

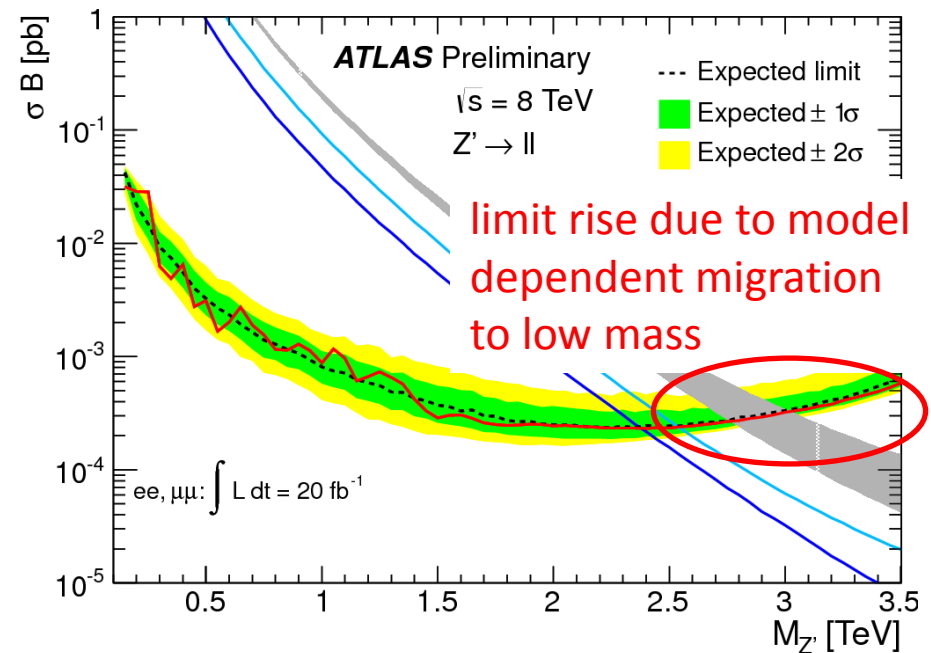
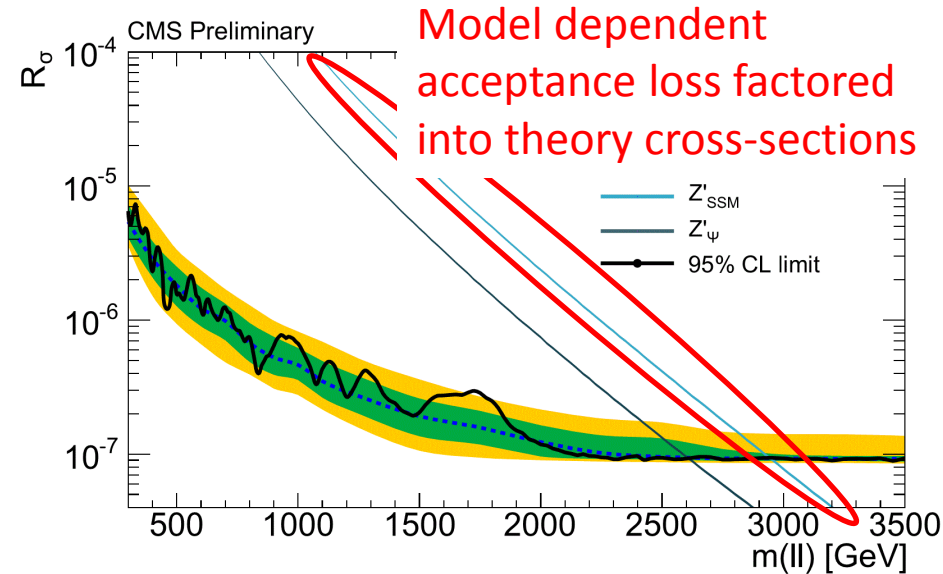


# Z' Limits

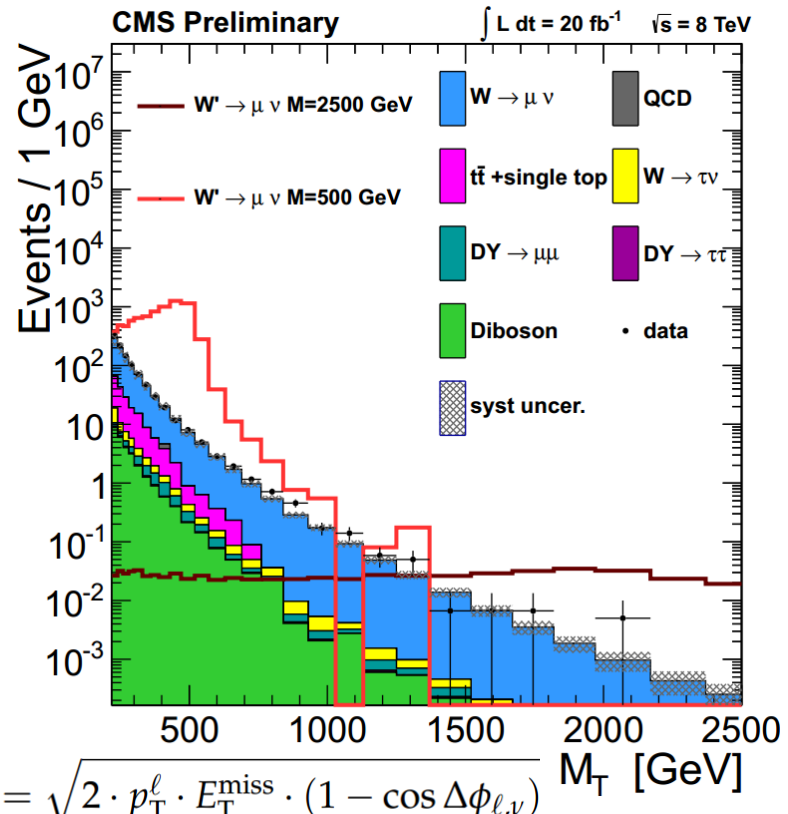
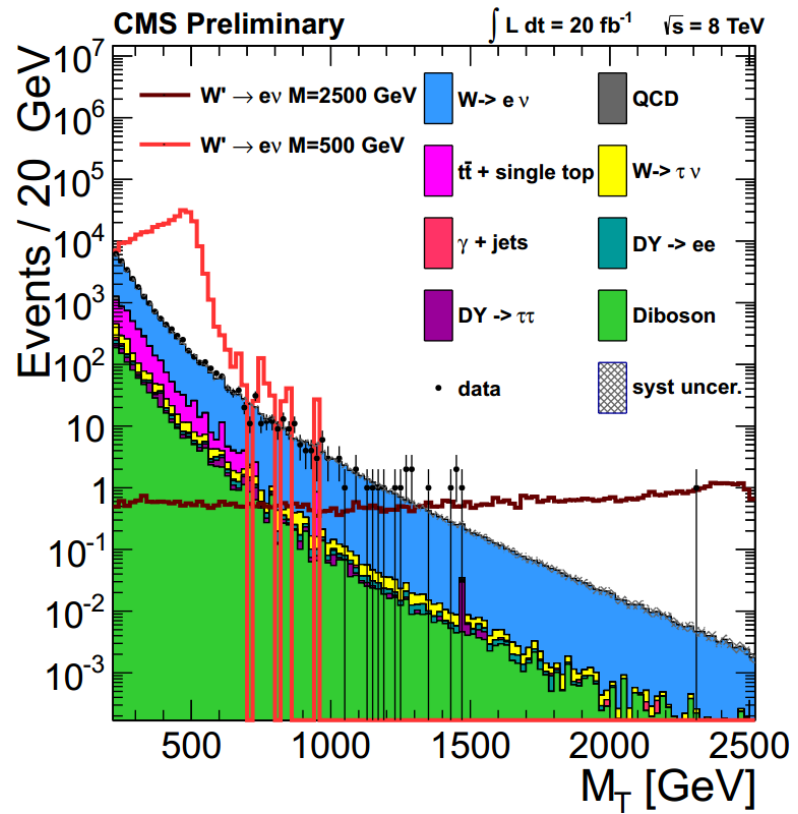


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# $W' \rightarrow e\nu / \mu\nu$



$$M_T = \sqrt{2 \cdot p_T^\ell \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

- search for high  $p_T$  ele ( $>100$  GeV) or muon ( $>45$  GeV) +  $E_T^{\text{miss}}$ 
  - remove jet bkg with  $0.4 < p_T / E_T^{\text{miss}} < 1.5$ ,  $\Delta\phi > 0.8\pi$  cuts
  - look for excess in high end tail
  - $W'$  accXEff:  $e\nu$  : 70-75%  $\mu\nu$  : 67-72%
- excellent agreement between SM and data



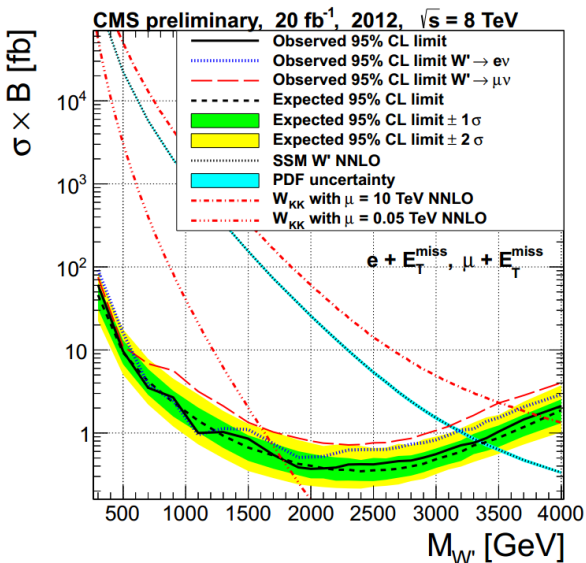
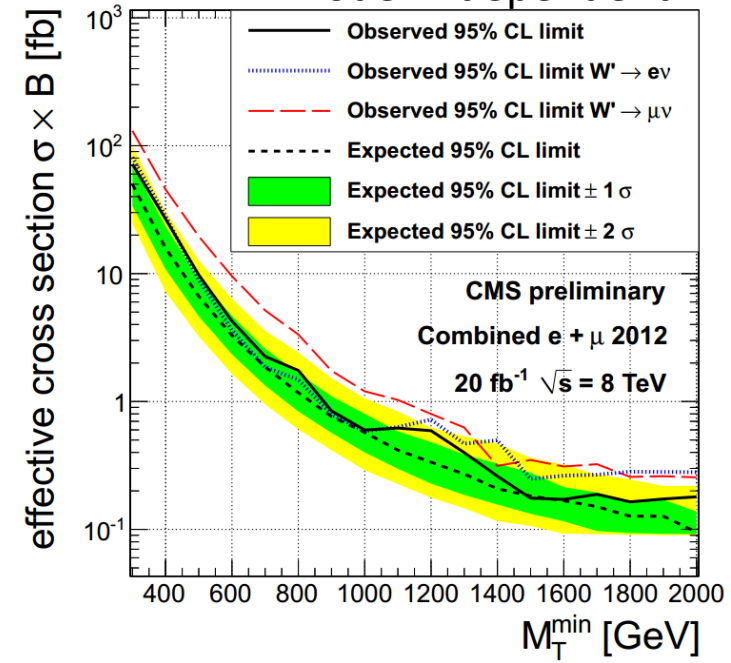
# W' interpretations

CMS EXO-12-060

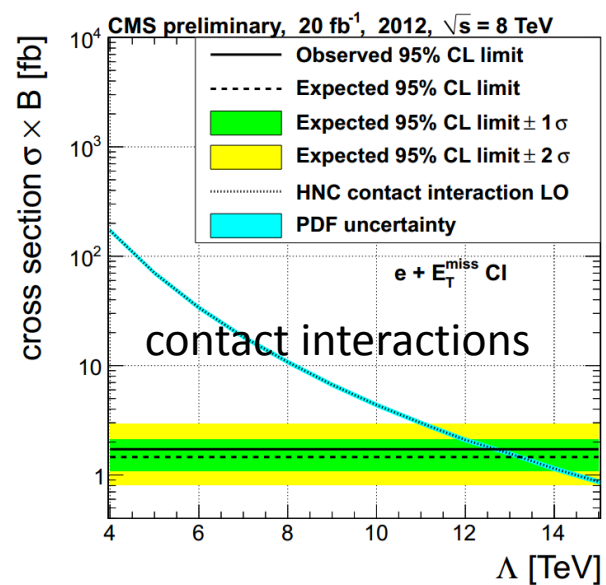
- interpret results in several models + also provide model independent limits
  - take your favourite model and calculate the cross-section above an appropriate min  $M_T$

SSM Model	mass limit (TeV)
no interference	3.35
constructive interference	3.60
destructive interference	3.10

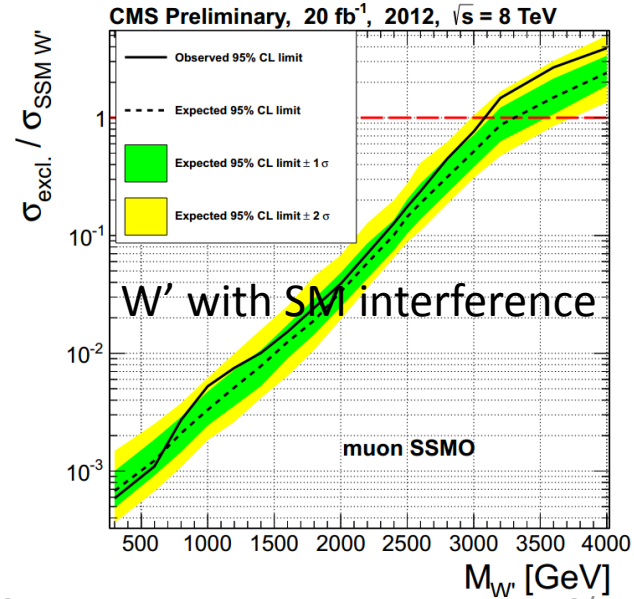
model independent



standard W' + split UED



contact interactions



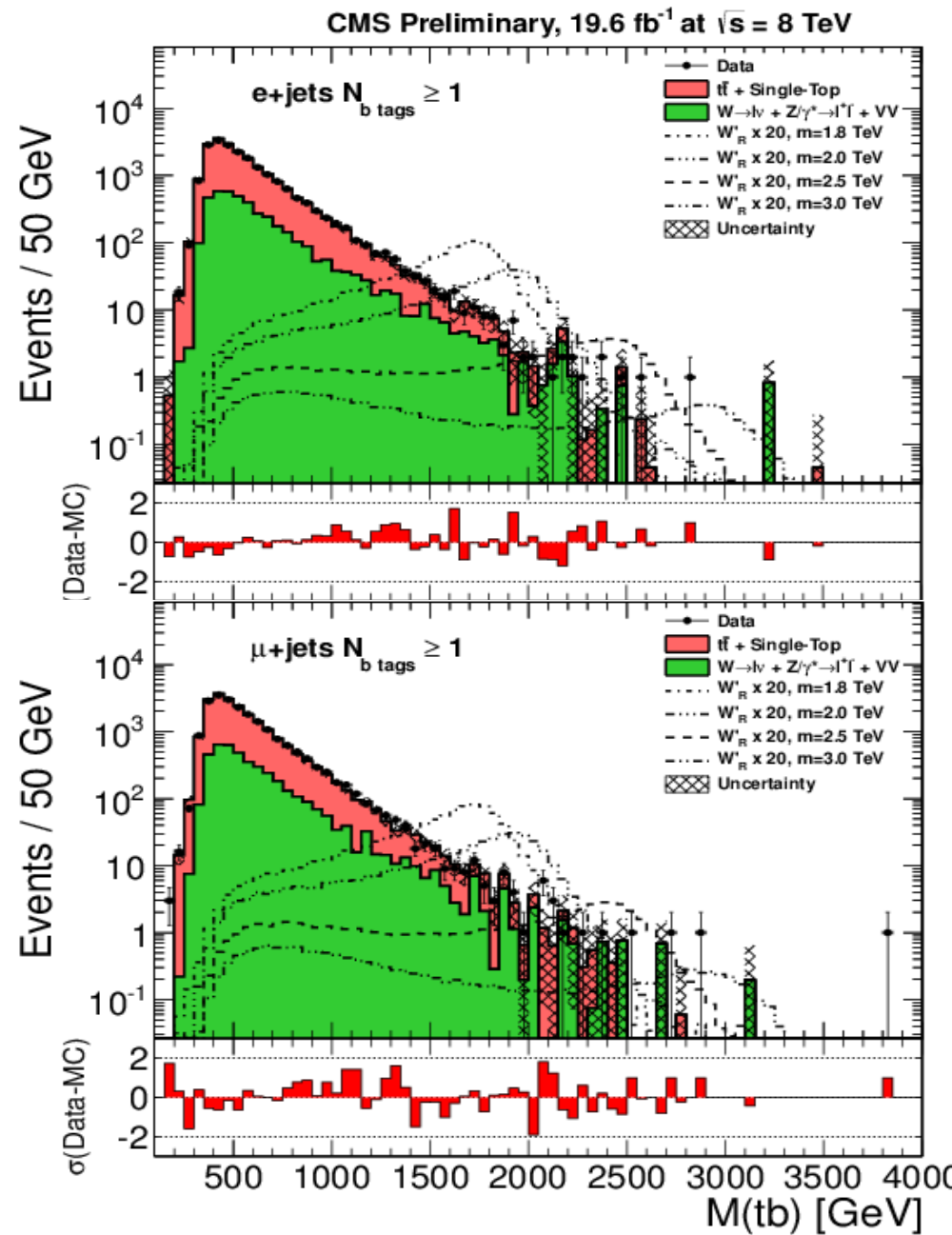
W' with SM interference



# W' → t+b



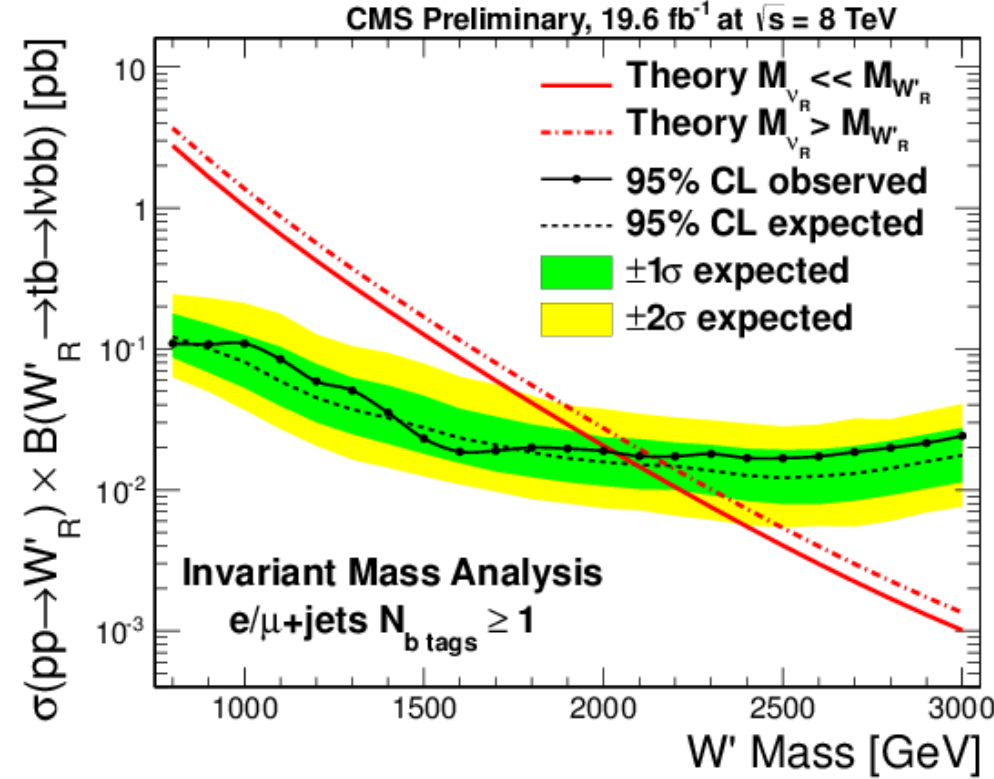
- also search for W' in t+b
  - not as sensitive as e/μ
  - but W' models can couple more strongly to 3<sup>rd</sup> gen /not to leptons
- selection:
  - 1 lepton p<sub>T</sub> > 50 GeV
  - 2 jets, p<sub>T</sub> > 120, 40 GeV, ≥1 b-tag
  - MET > 20 GeV + event kinematic cuts
- reconstructs W' mass:
  - constrain m(lv) to W mass
    - gives set of possible v p4
  - select jet + W p4 with best m<sub>top</sub>
  - take leading remaining jet to reconstruct W'



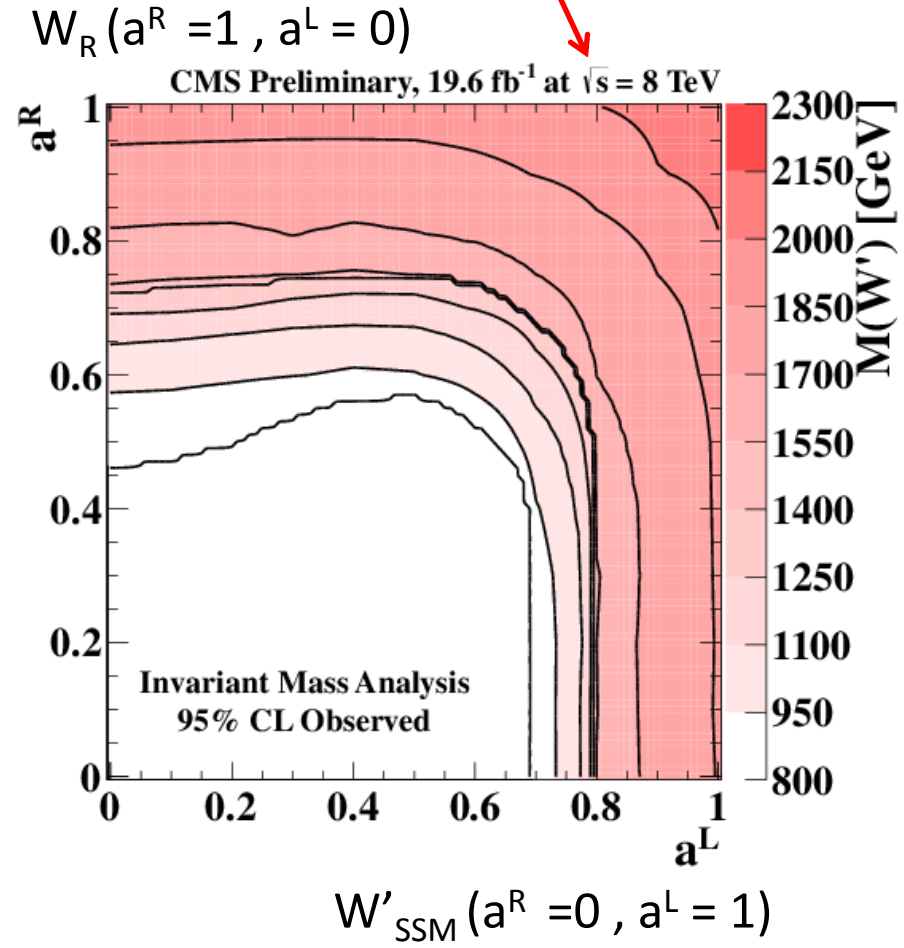


# W' → t+b Limits

CMS B2G-12-010

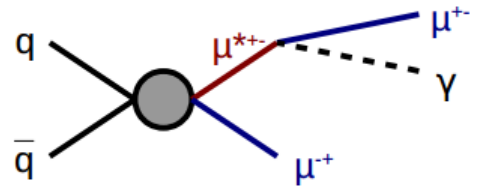


← limits on  $W_R \sigma \cdot Br$  vs  $M_{W'}$   
 limits on coupling to left/right handed fermions ( $a^R/a^L$ ) vs  $M_{W'}$



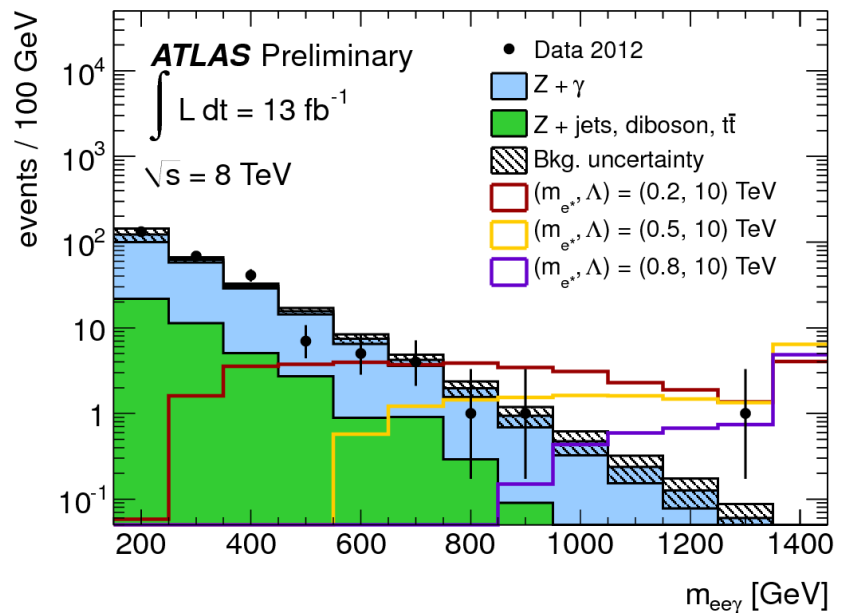
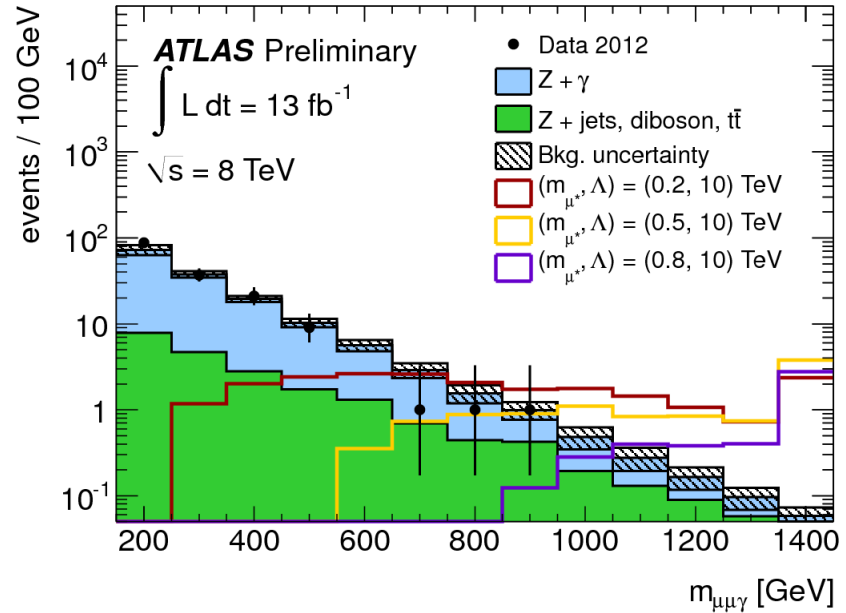
- if  $\nu_R$  heavier than  $W'_R$ , then can only decay to quarks
  - for coupling limits use  $\nu_R \ll M_{W'}$
- if LH couplings present ( $a^L \neq 0$ ), will interfere with SM  $W \rightarrow tb$

# Excited Leptons

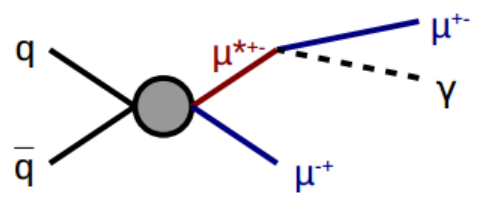


- selection:
  - Z' analysis with a >30 GeV  $\gamma$ ,  $|\eta| < 2.4$
  - veto  $R(l, \gamma) < 0.7$  to remove FSR
  - $m(l\gamma) > 110$  GeV
- $l^*$  mass is ambiguous, two possible choices
  - instead use total  $l\gamma$  mass
  - sig region:
    - $M(l\gamma) > M(l^*) + 150$  GeV OR
    - $> 1050$  GeV

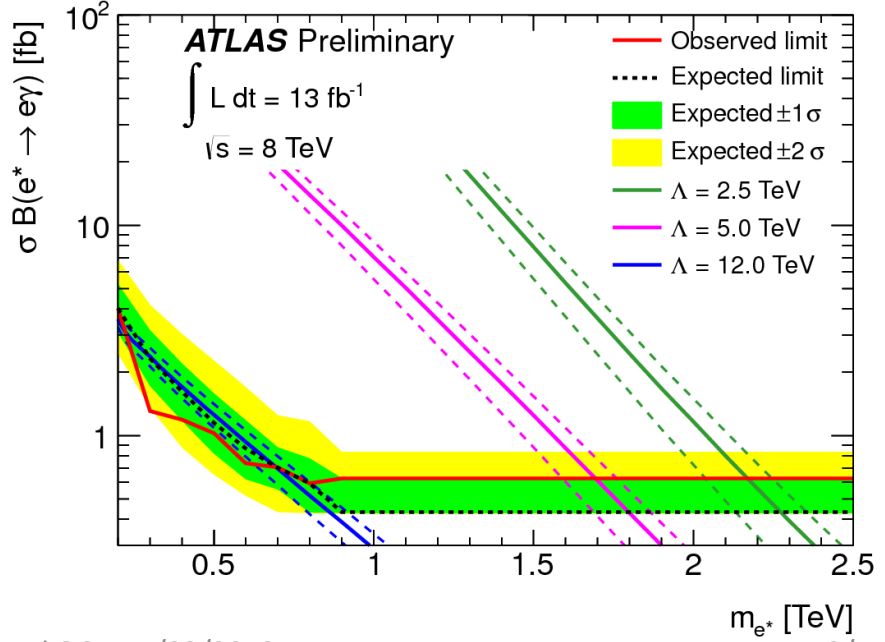
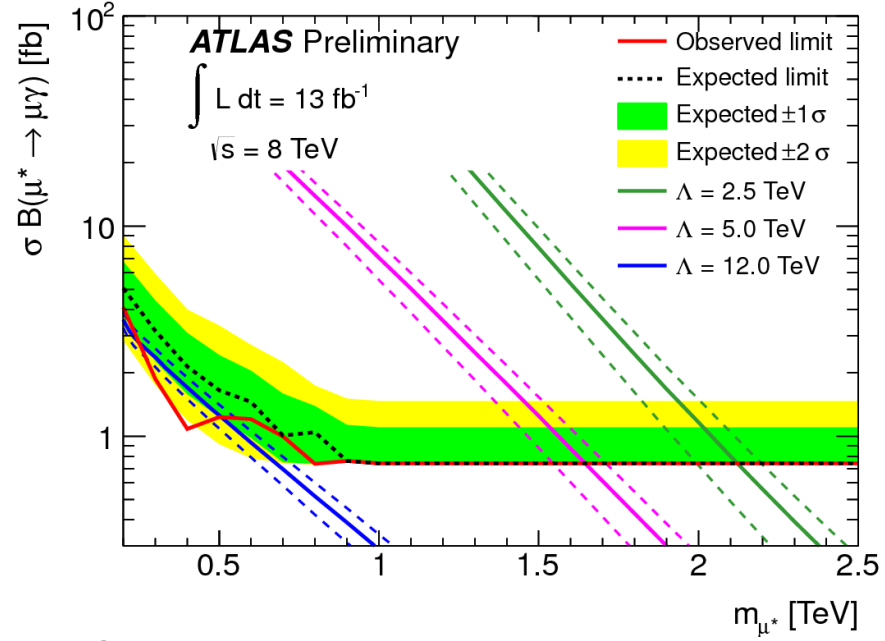
$\Lambda = 2.5$ TeV	$e^*$	$\mu^*$
expected limit (TeV)	2.28	2.13
observed limit (TeV)	2.17	2.13



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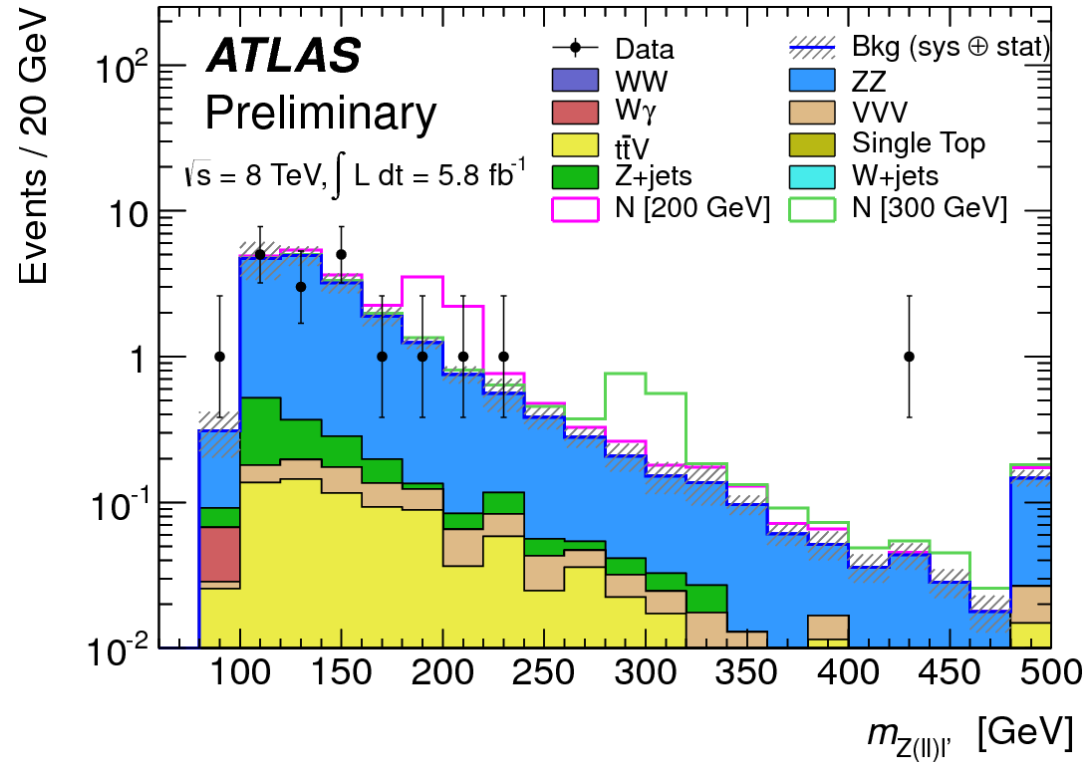
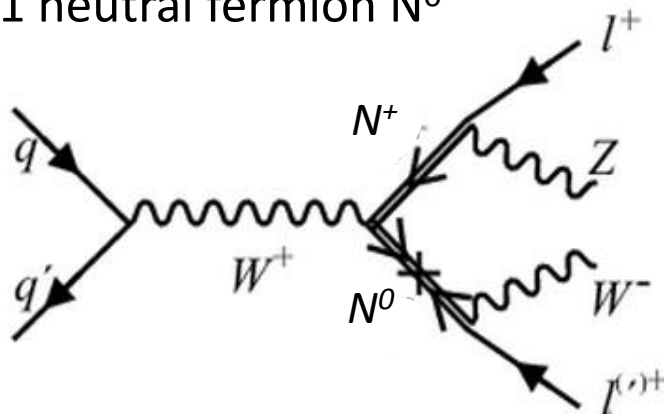


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# Type III Seesaw

- Seesaw mechanism aims to explain  $\nu$  masses

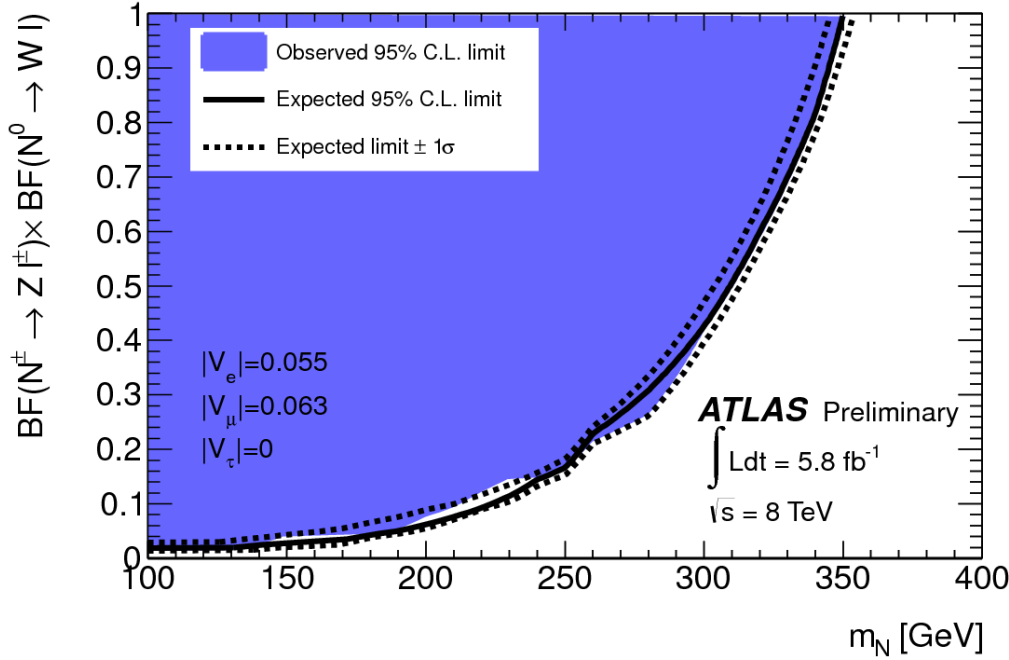
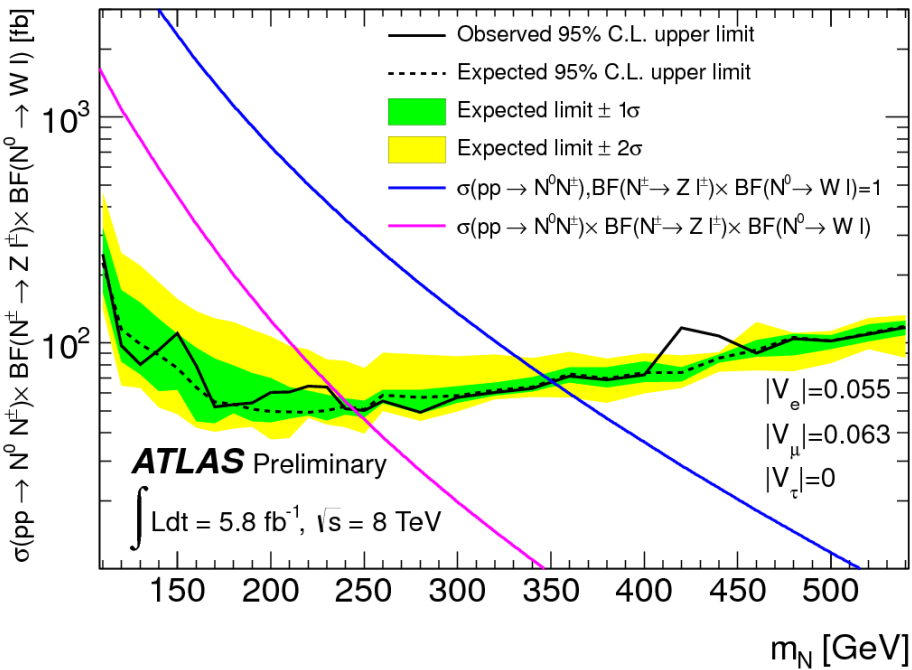
- introduces two fermionic triplets to generate  $M(\nu)$
- lightest fermion triplet: 2 charged fermions  $N^+ N^-$  and 1 neutral fermion  $N^0$



- look for two leptons which are a Z and two leptons which are not a Z
  - Z: two opposite sign same flavour leptons with  $81 < M(l)l' < 101 \text{ GeV}$
- fully reconstruct  $N^\pm$ , lepton from  $N^0$  just tag to reduce bkg



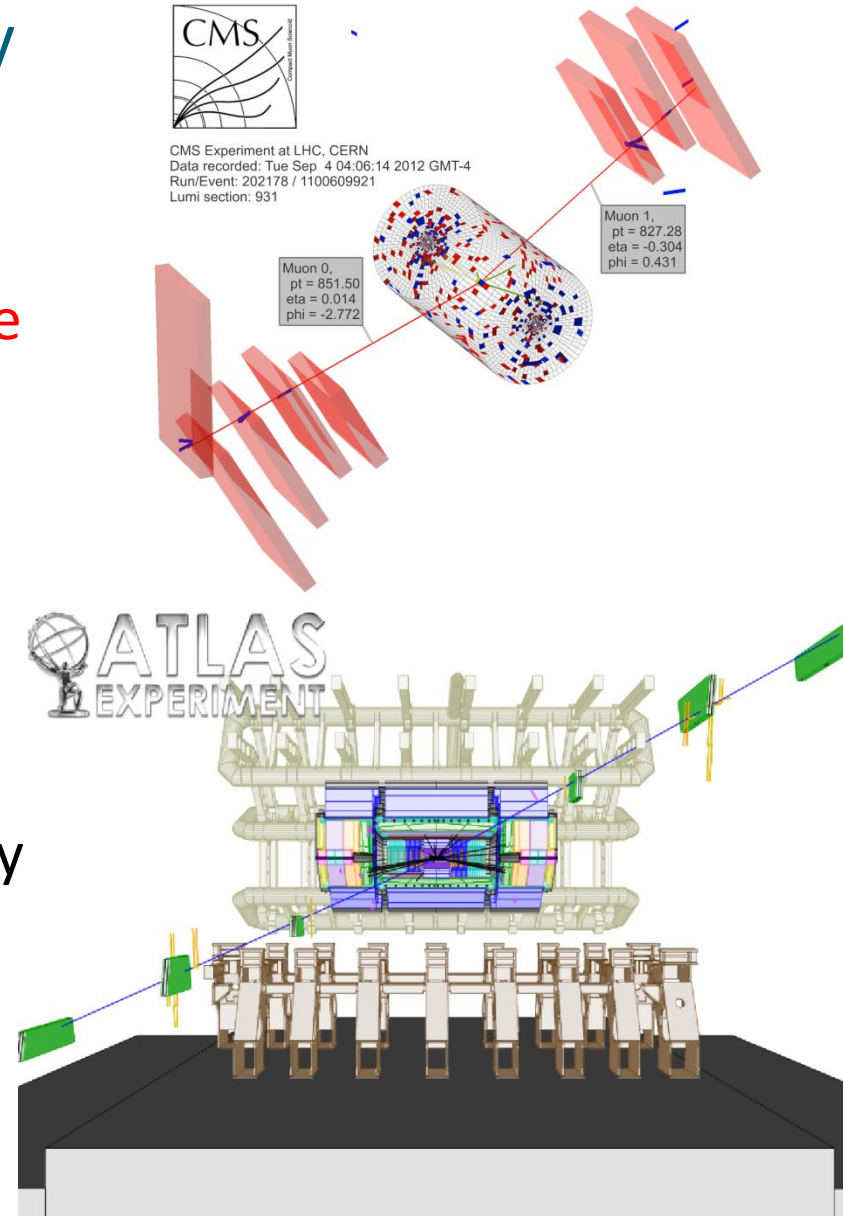
# Type III Seesaw



- BR of  $N^\pm \rightarrow Zl$ ,  $N^0 \rightarrow Wl$  dependent on mixing angles to SM leptons
  - pink curve is the nominal expected mass dependent BR
- limits are set using CLs
  - p-value at  $M_N = 420$  is 0.20
- exclude  $N^\pm$  with  $M > 245$  GeV

# Outlook

- showed latest searches for heavy resonances at LHC
  - many more on the way
  - beautiful results 😊 but no evidence for new physics 😞
- have lots of wonderful 7 & 8 TeV data and 2 years till 14 TeV....
  - now is the time for increased theory-expt collaboration
  - can we collaborate to more usefully present the data?
  - can we collaborate to extract more information from the data?



# And now....



## Intermission

- after the *physical exercise* break, lots of exciting results still to come
  - extra dimensions in dilepton, ZZ searches,  $WZ \rightarrow 3l$ , dijets
  - technicolor in  $Z\gamma$ ,  $W\gamma$
  - top partners,  $T'$ ,  $B'$



# Further Reading

All ATLAS EXO results can be found here:

- <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults>

All CMS EXO results (non-top) can be found here:

- <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>

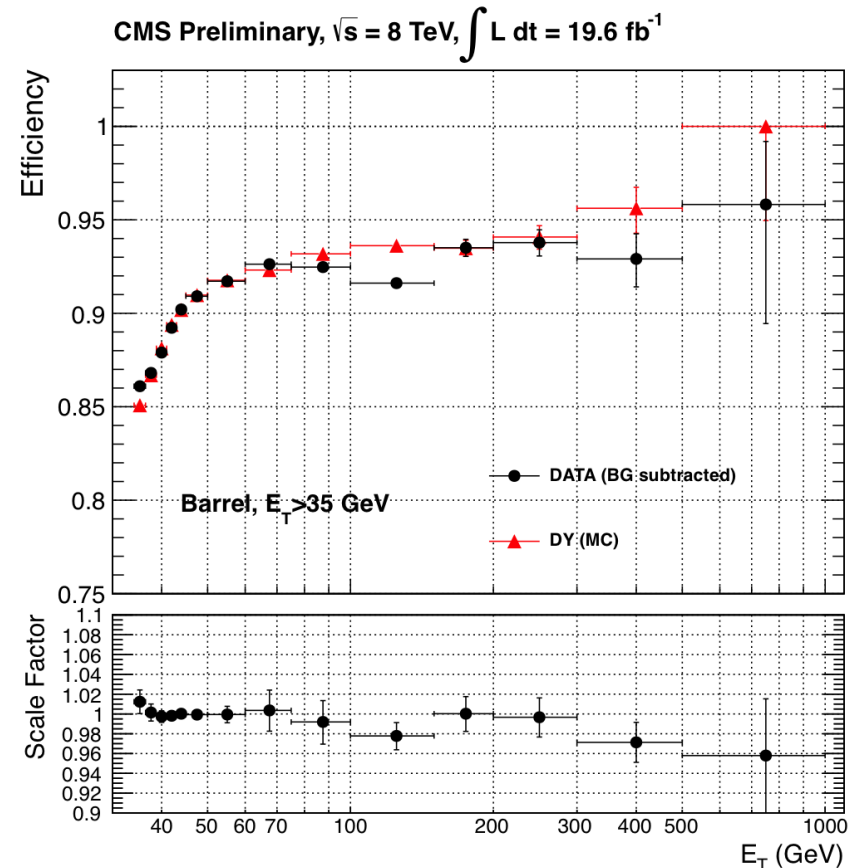
All CMS B2G results can be found here:

- <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G>

# backups

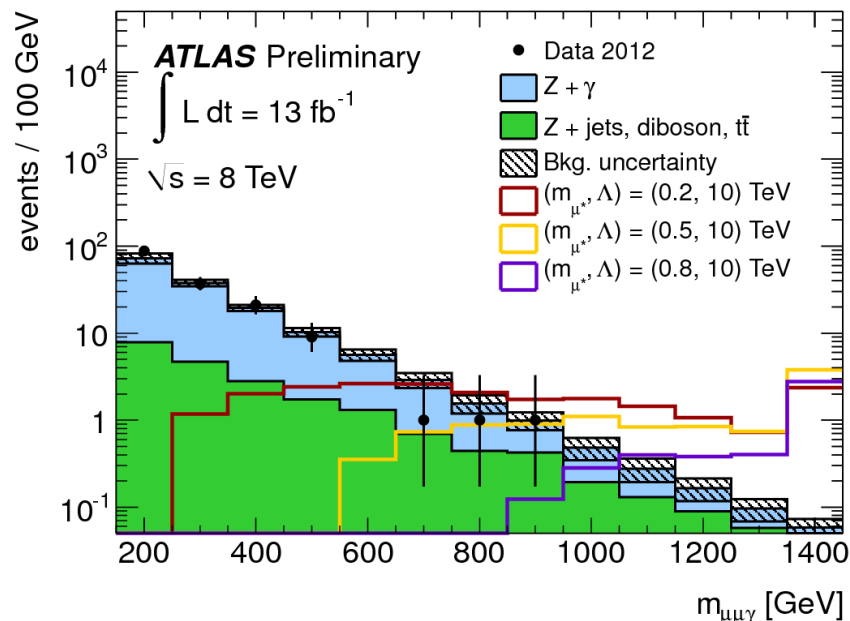
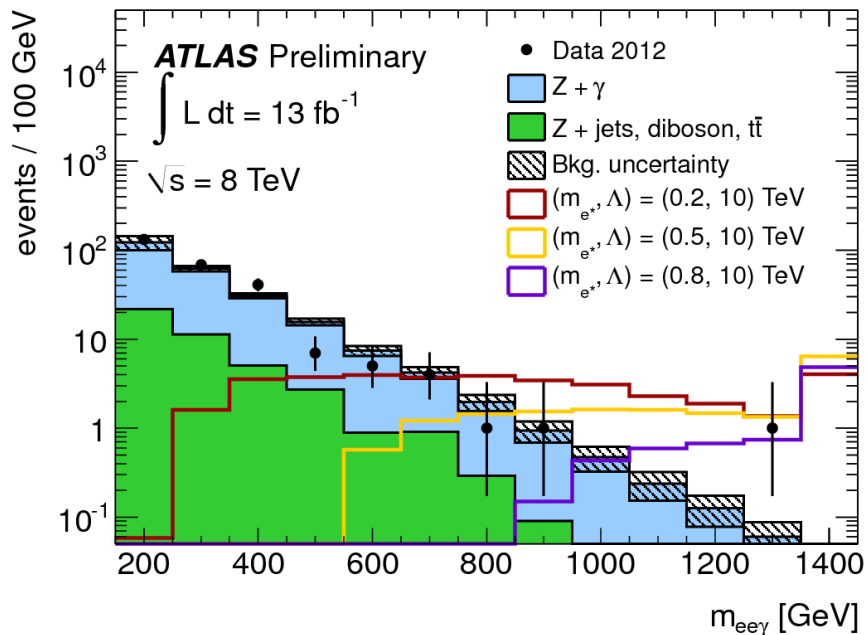
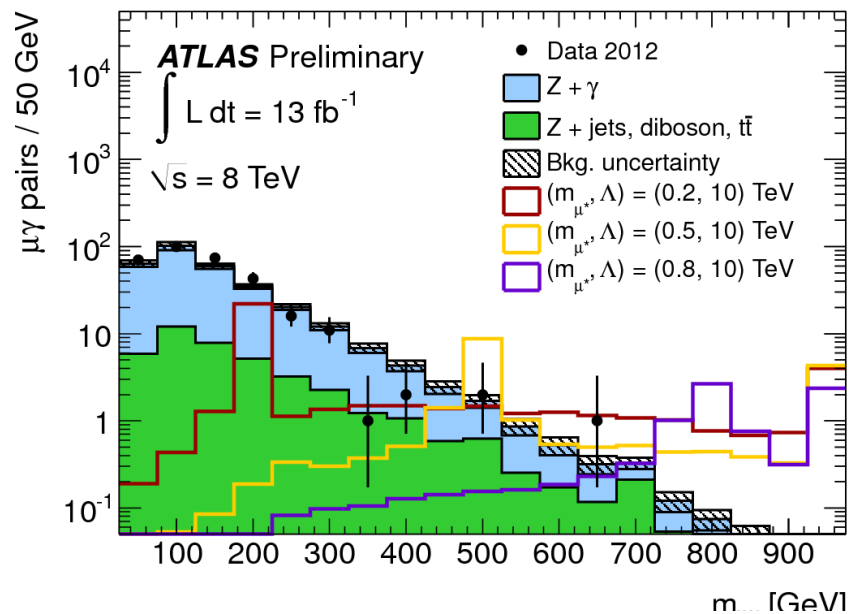
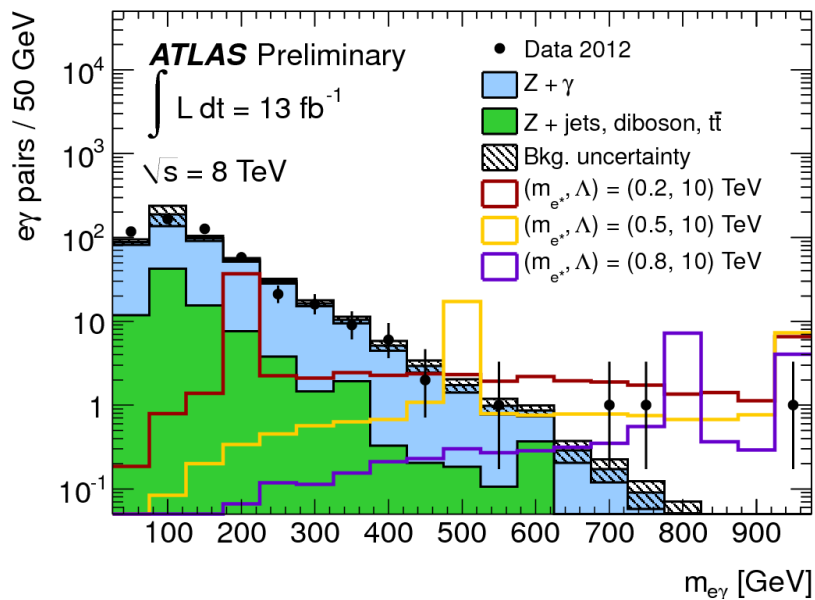
# Lepton ID at high Energy

- high  $p_T$  leptons are different to low  $p_T$  leptons
- ultimately have to rely on MC simulation to predict the efficiency
  - need to verify this with data
  - challenging as Z peak is far away from interesting region
- need to answer the question: do I not see a heavy resonance because
  - a) it does not exist
  - b) my lepton id efficiency is 0% at TeV scale

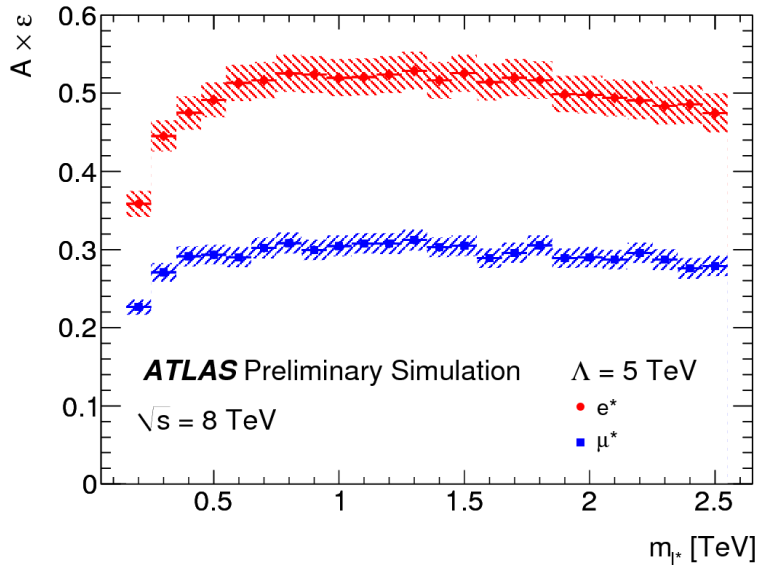
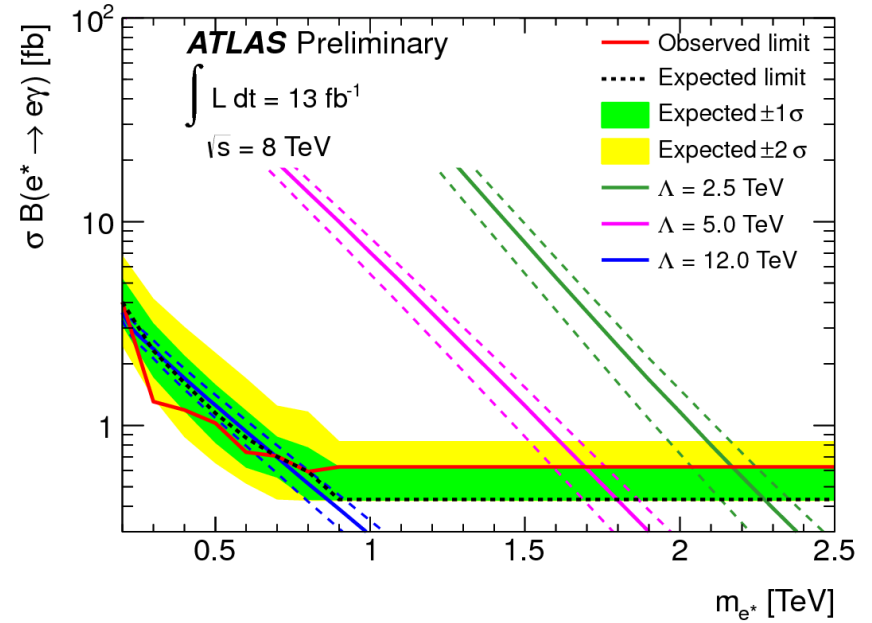
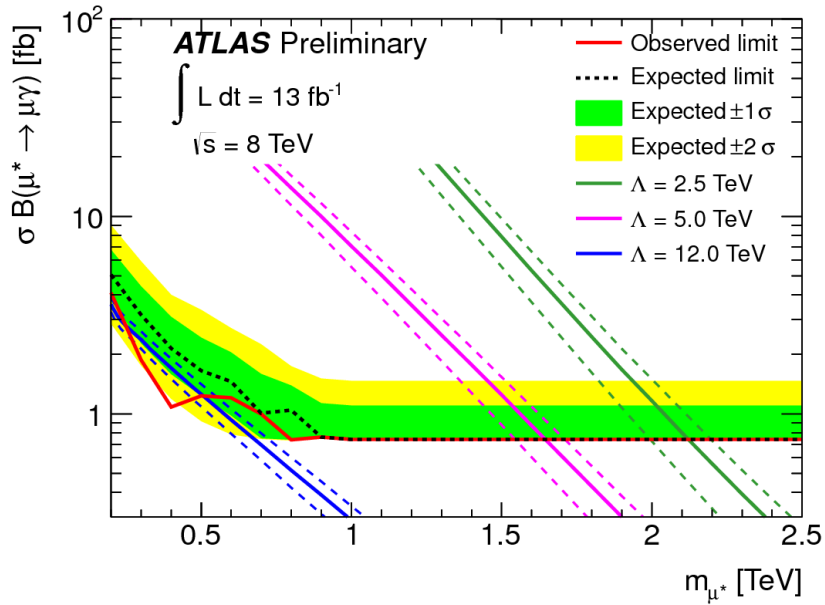


Electron ID efficiency measuring using T&P at the Z peak

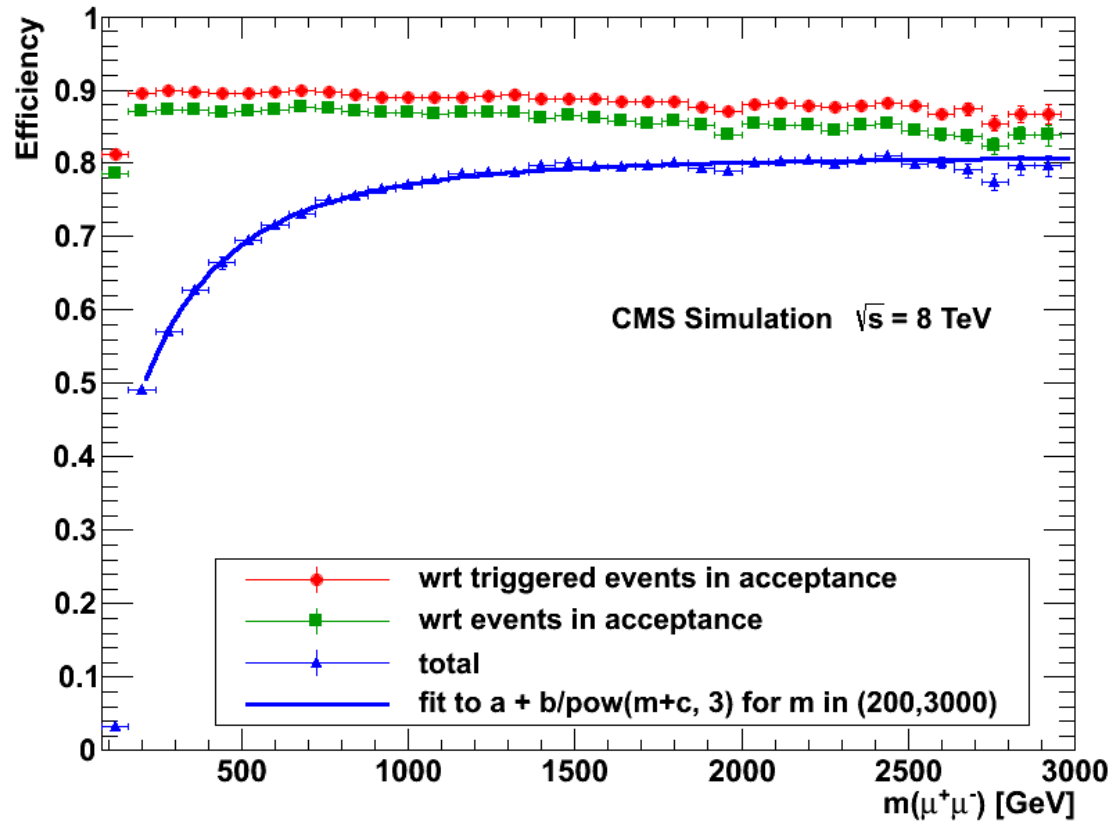
# $e^*/\mu^*$



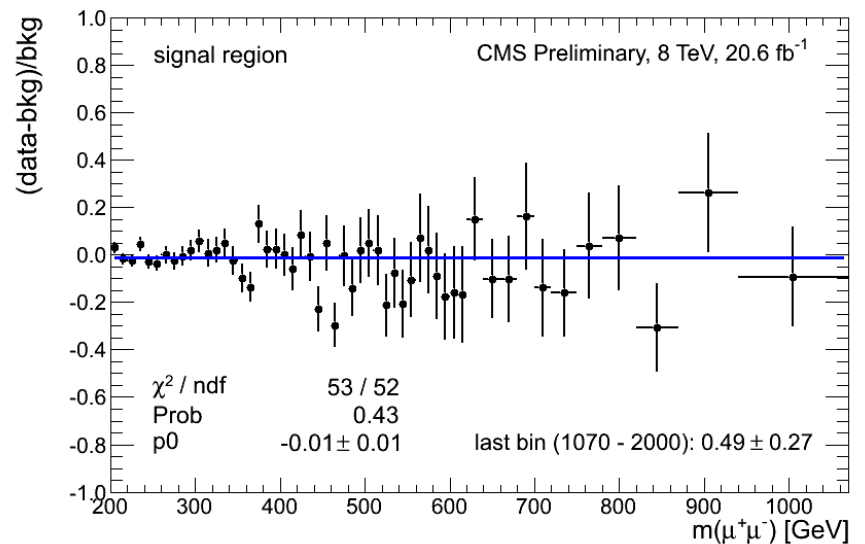
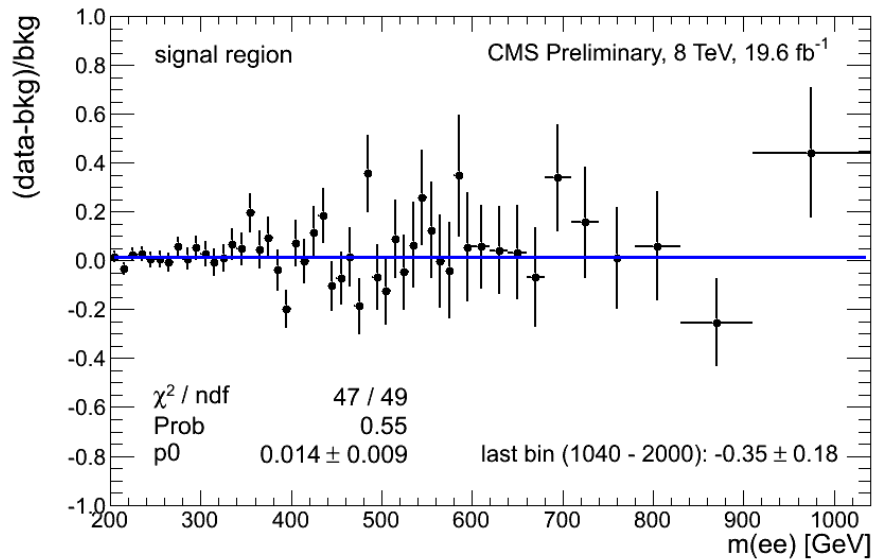
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# $Z' \rightarrow \mu\mu$

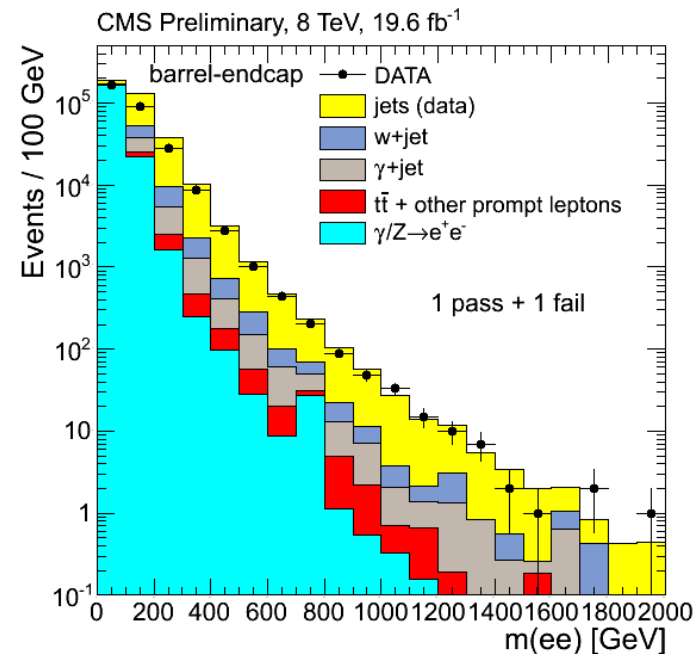
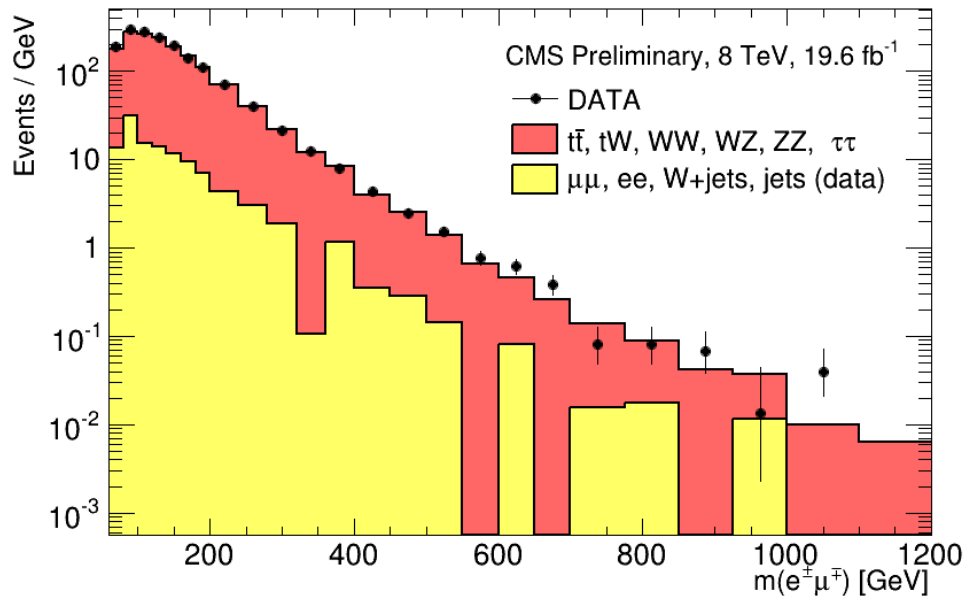
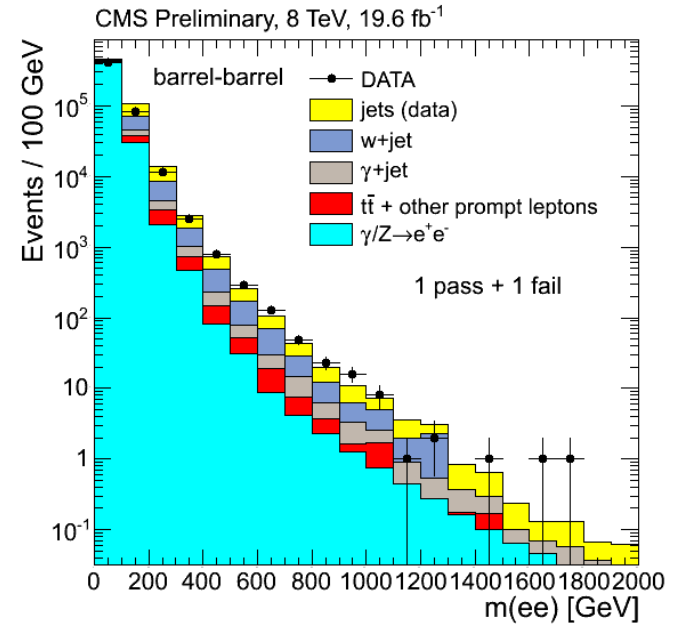
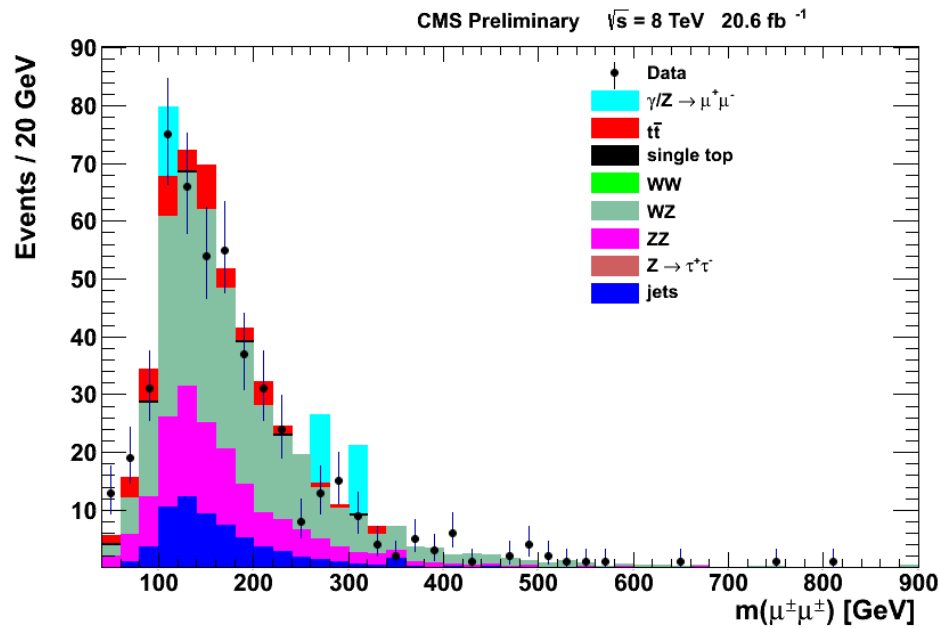


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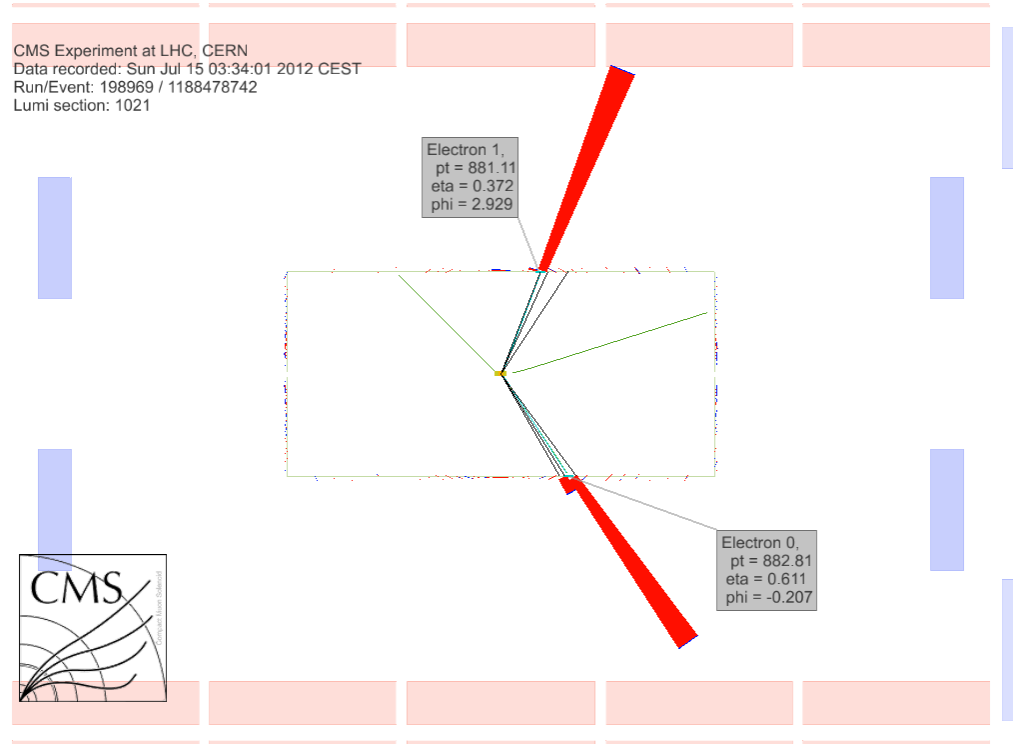
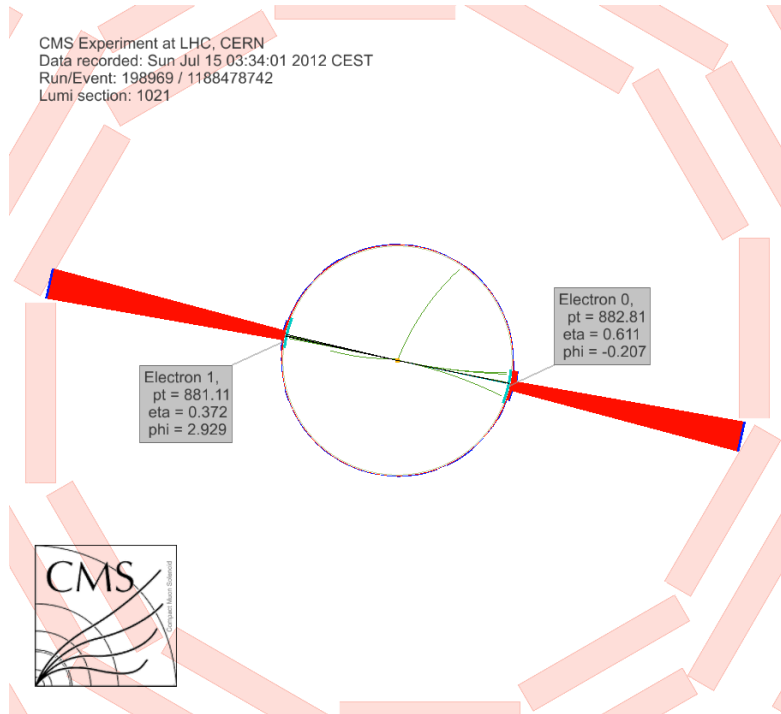
- data-mc / mc for CMS
- binning is so minimum of 20 events expected and a minimum bin size of 10 GeV

# Z' Bkg Control Plots

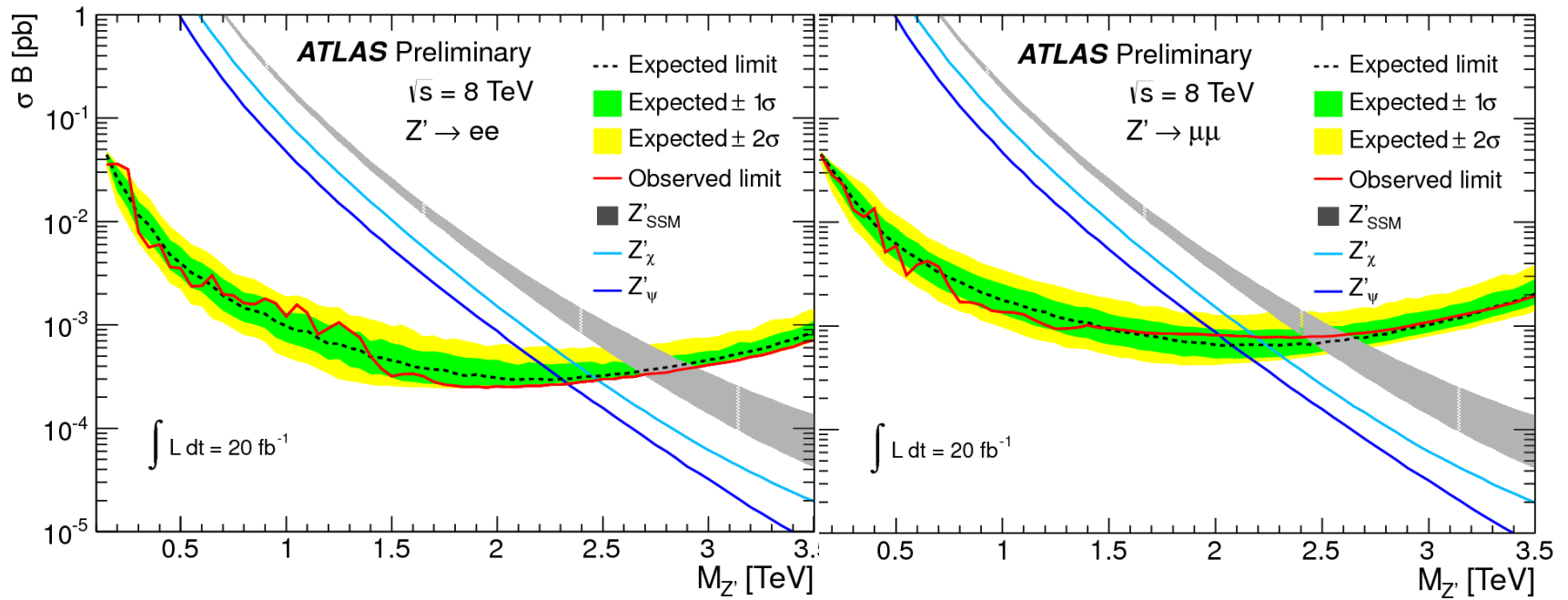




# $Z' \rightarrow ee$ Event Display

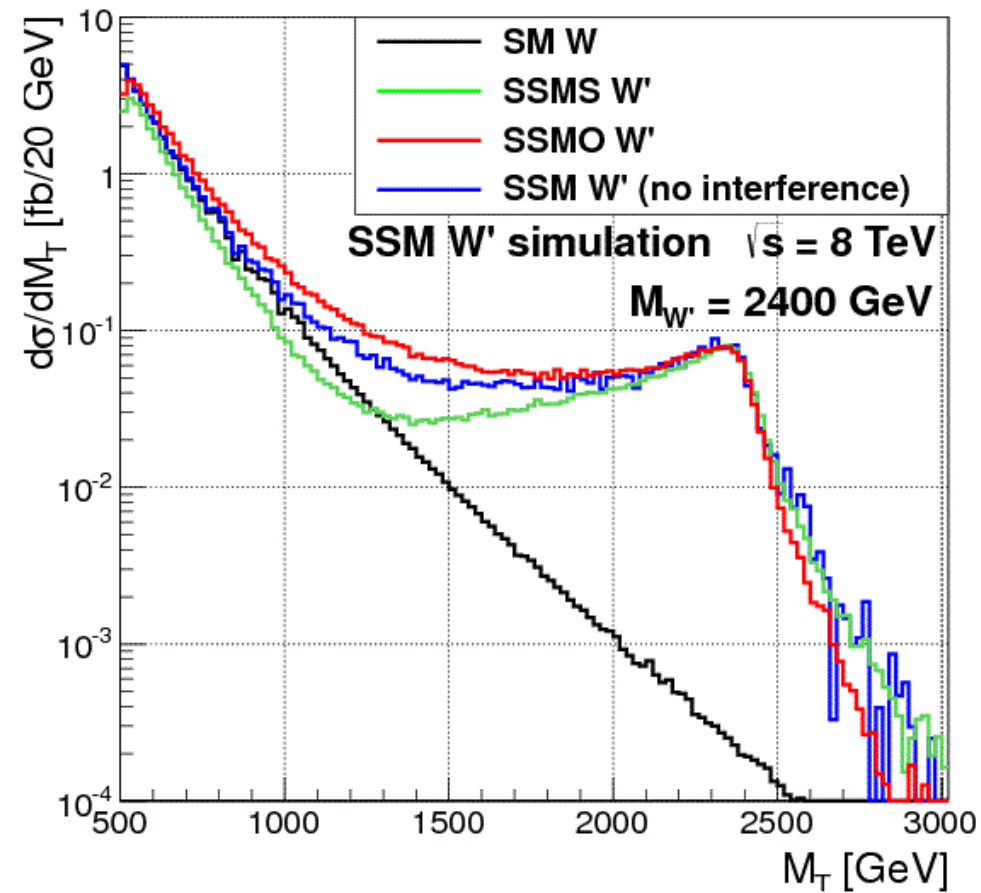


# ATLAS $Z'$ $ee/\mu\mu$ limits

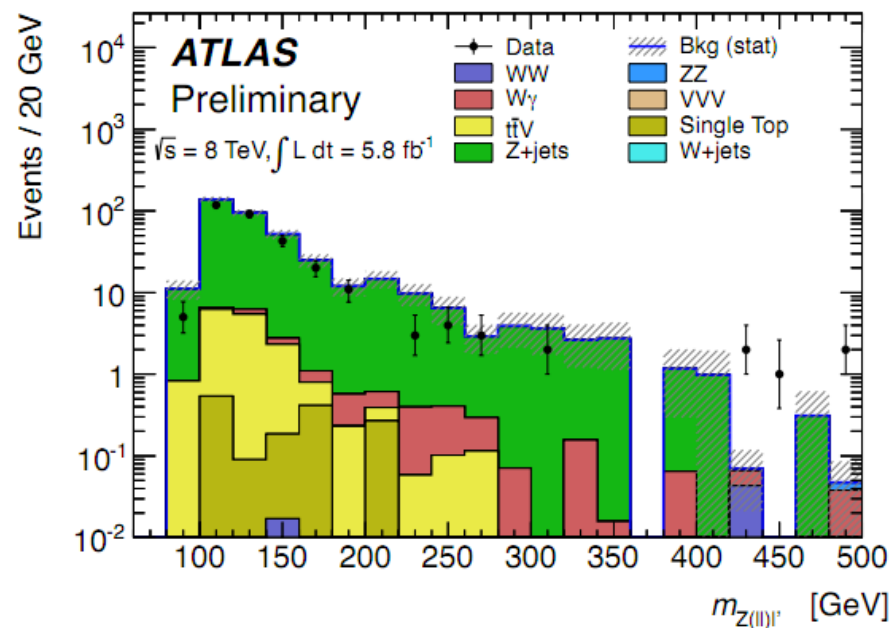
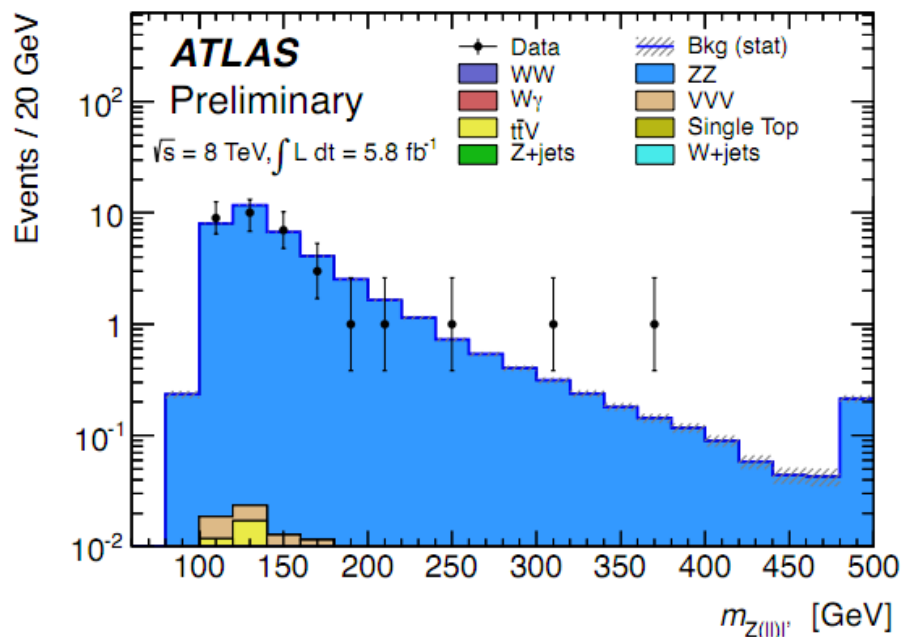


# $W' \rightarrow e\nu/\mu\nu$

- interference effects



# Type III See-Saw Control Regions



- ZZ control region: reverse second Z veto
- Z+jets control region:
  - only 3 more leptons required
  - reversed impact parameter cut and loosened isolation on third lepton