Searches for new physics with leptons in ATLAS

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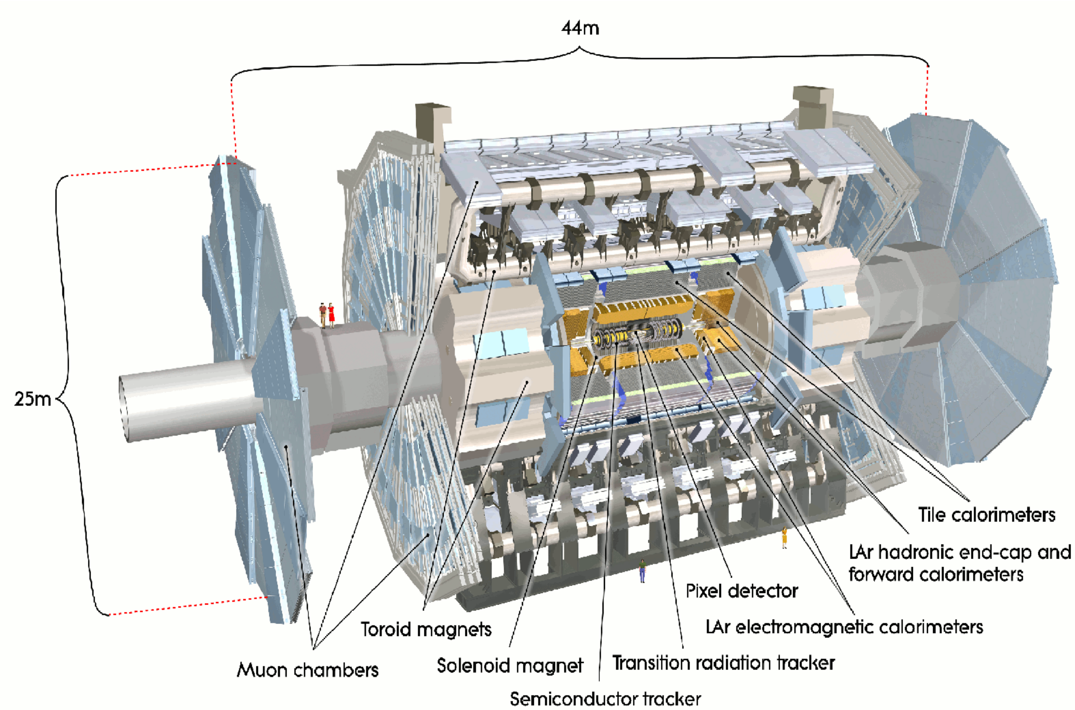
The ATLAS detector

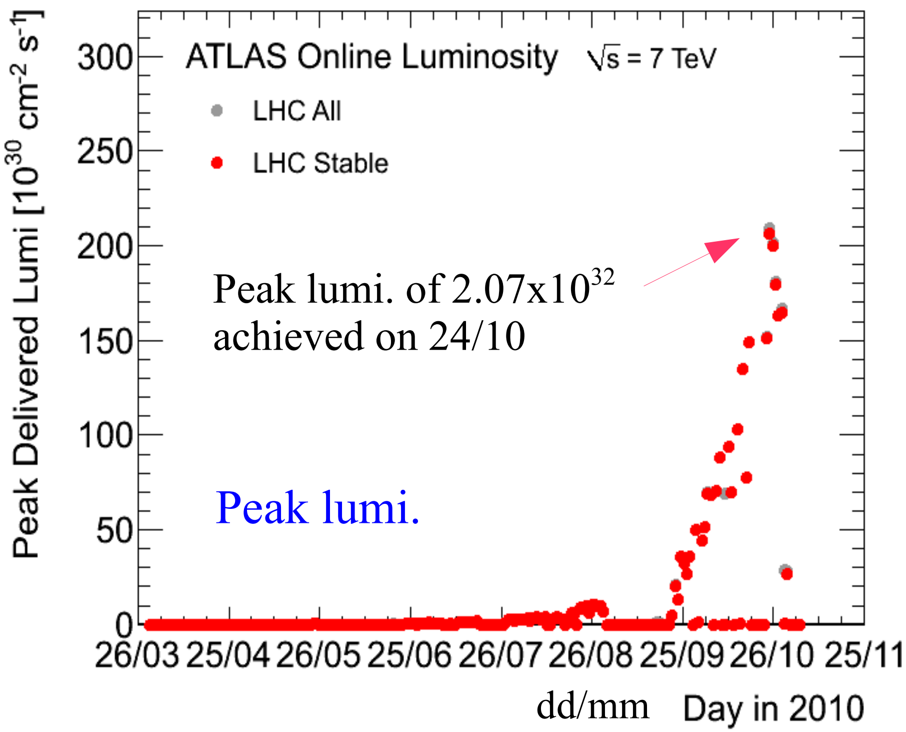


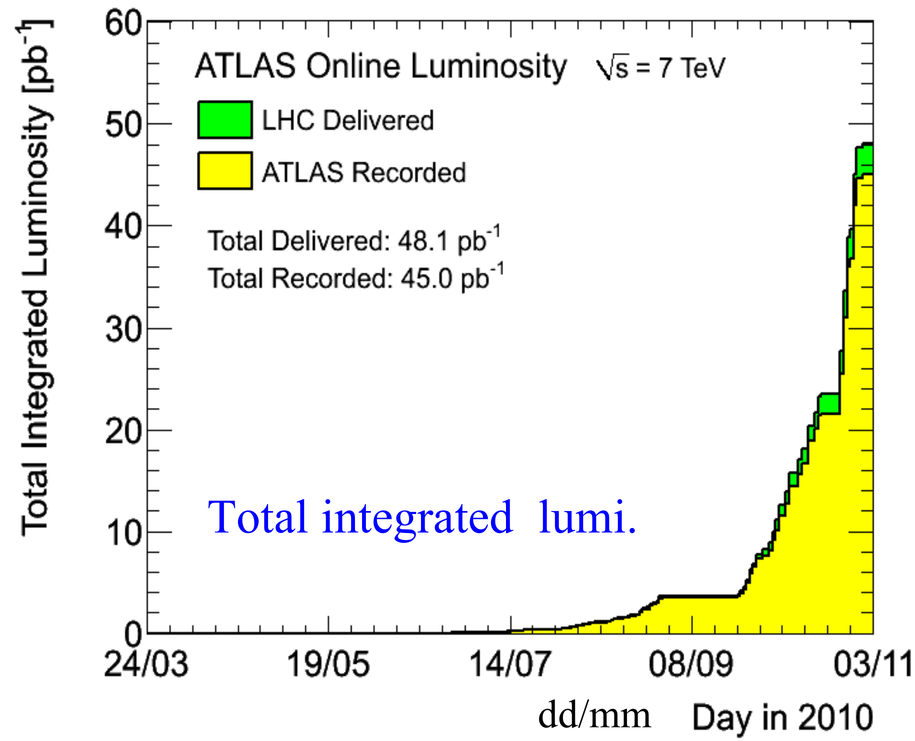
- Inner Detecter (InDet) tracking: semiconductors (pixel and SCT) and transition radiation tracker (TRT)
- Sampling-based calorimetry: lead+liquid argon for EM energy, steel+scintillator for Hadronic energy, copper/tungsten+liquid argon in the forward calorimeter
- 2 T magnetic field by a solenoid just enclosing the InDet
- One barrel and 2 end-cap torroids around the muon spectrometer provide fields to bend muons tracks in η

Expected performance (E and p_T in GeV):

Detector component	**Required resolution**	**η coverage** Measurement	**η coverage** Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\%\ p_T \oplus 1\%$	± 2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	± 3.2	± 2.5
Hadronic calorimetry (jets)			
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	± 3.2	± 3.2
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \|\eta\| < 4.9$	$3.1 < \|\eta\| < 4.9$
Muon spectrometer	σ_{p_T}/p_T=10% at p_T = 1 TeV	± 2.7	± 2.4

Luminosity



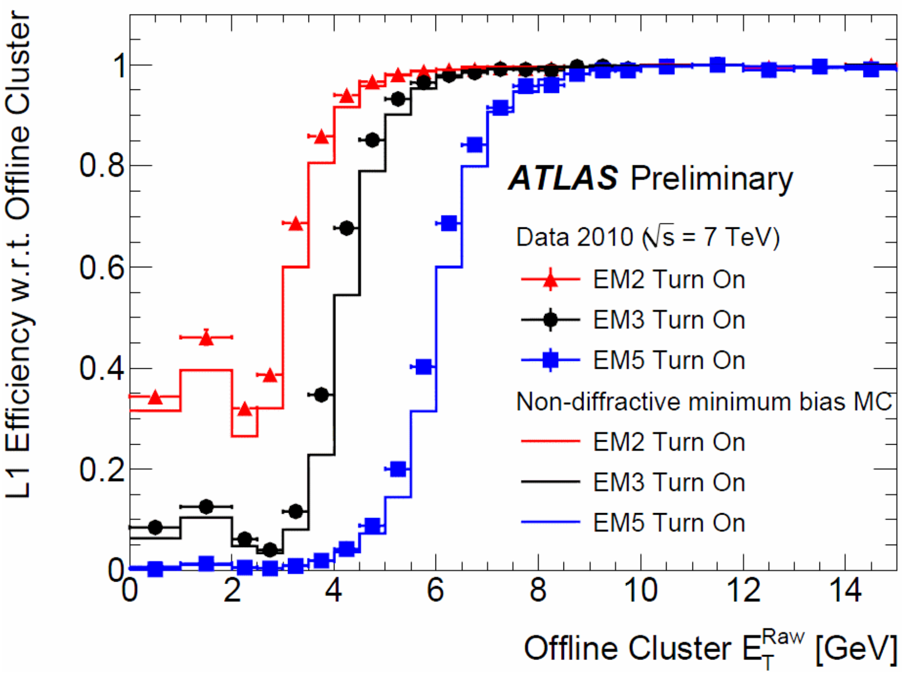


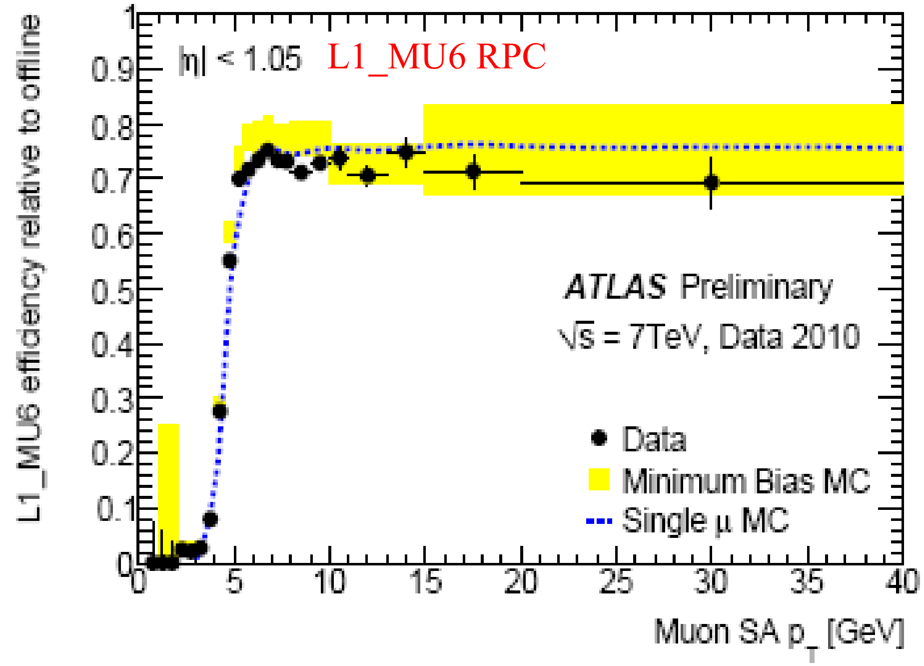
- ATLAS recorded about 45 pb^{-1} of p-p collision data ($\sqrt{s}=7\,\mathrm{TeV}$) this year from Mar. 30 through Nov. 4, after which Pb-Pb collisions took place
- p-p collisions at 7 TeV will resume from next Feb. and continue until 1 fb^{-1} of data acquired
- Results appearing in this talk, however, are based on low lumi. scenarios made public by ATLAS. Projections/prospects with high lumi. based on MC are also given (some of the results are still based on 14 TeV MC study. Most physics cross sections are increased by a factor of ~10 when going from 7 to 14 TeV)

The role of leptons in New Physics

- Leptons appear in many New Physics (NP) models. Leptonic final states (electrons, muons and taus that decay leptonically) are experimentally cleaner for having much less QCD background (fake electron efficiency is about 10^{-2}-10^{-3}, and fake muon efficiency is about 10^{-3}, for lepton p_T>20 GeV)
  - W'(→lν) and Z'(→ll) bosons (GUT, LRSM, KK, Little Higgs, Technicolor)
  - Leptons from SUSY particle cascade decays. Signature is lepton(s) + multi-jets + MET (missing E_T)
  - Leptoquark pair production with decay LQ→l+q. Signature is 2 opposite-sign (OS) leptons + 2 jets
  - Majorana neutrinos with ΔL=2 in LRSM. Signature is 2 leptons (OS or SS) + 2 jets
  - Leptons from decays of diboson resonances in vector boson scattering
- The above is an incomplete list of models we are interested in

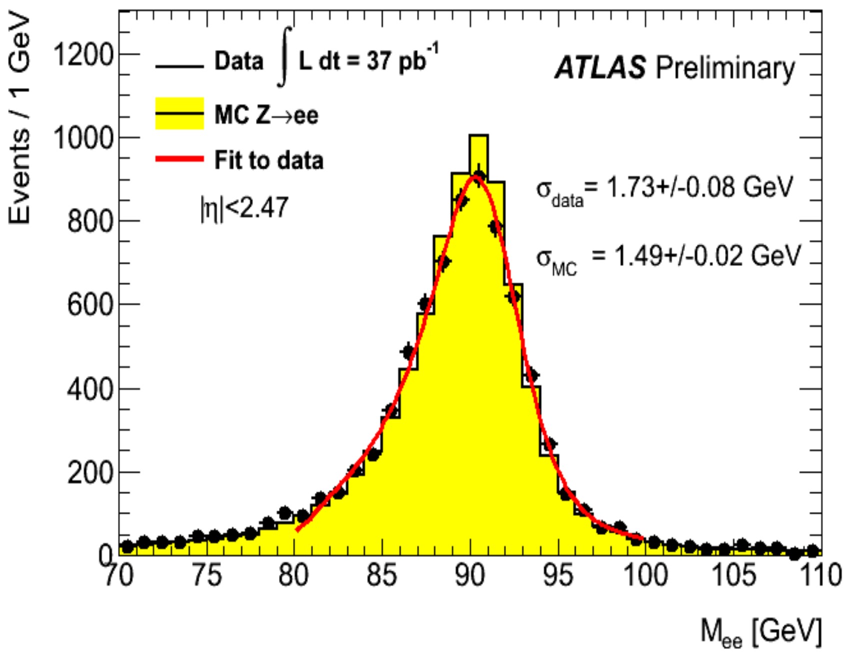
Lepton triggers

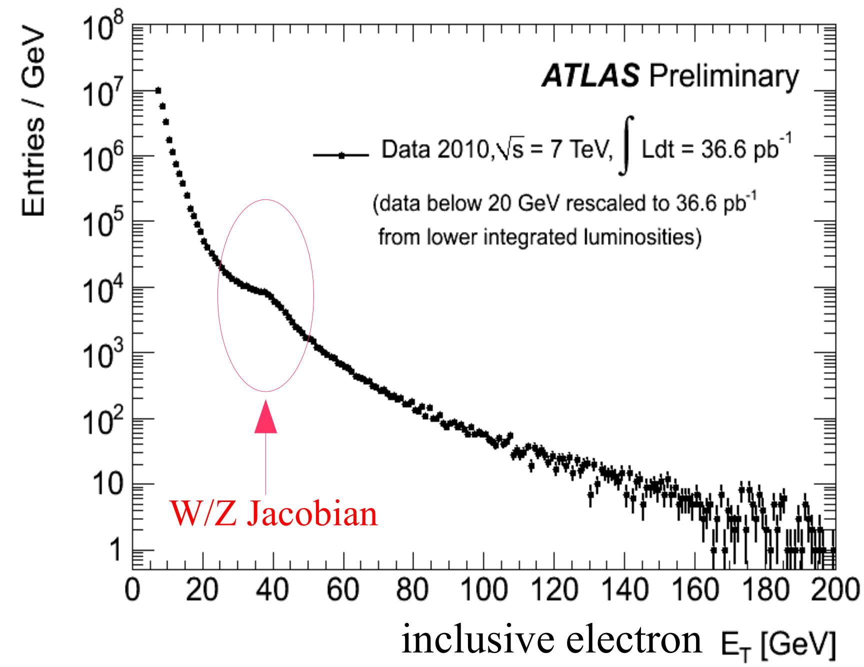




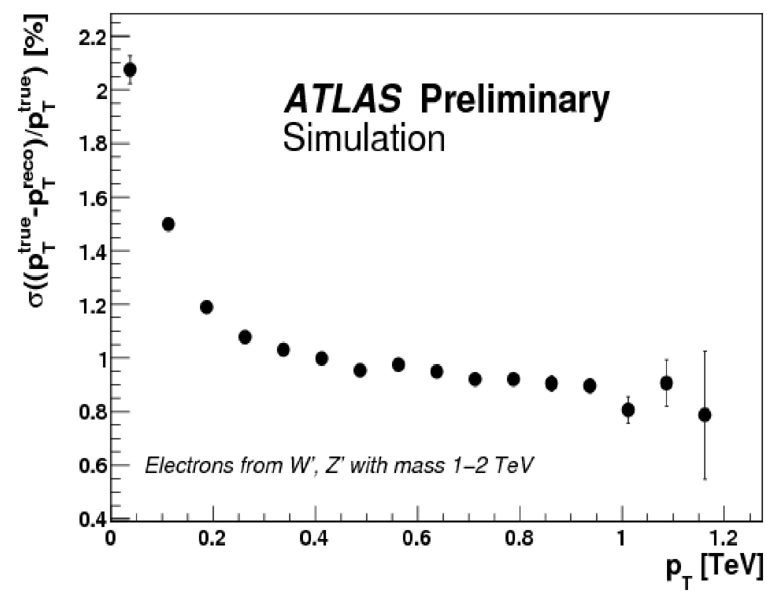
- Electrons and muons can be efficiently triggered by the 3-level trigger system (L1/L2/EF) of ATLAS. Muon L1 efficiency is limited to ~75% by the muon chamber (RPC) acceptance
- Good agreement between data and MC observed. Nice turn-on points at the trigger threshold specified. The lepton triggers can be complemented by others like jet and MET triggers

Z→ee

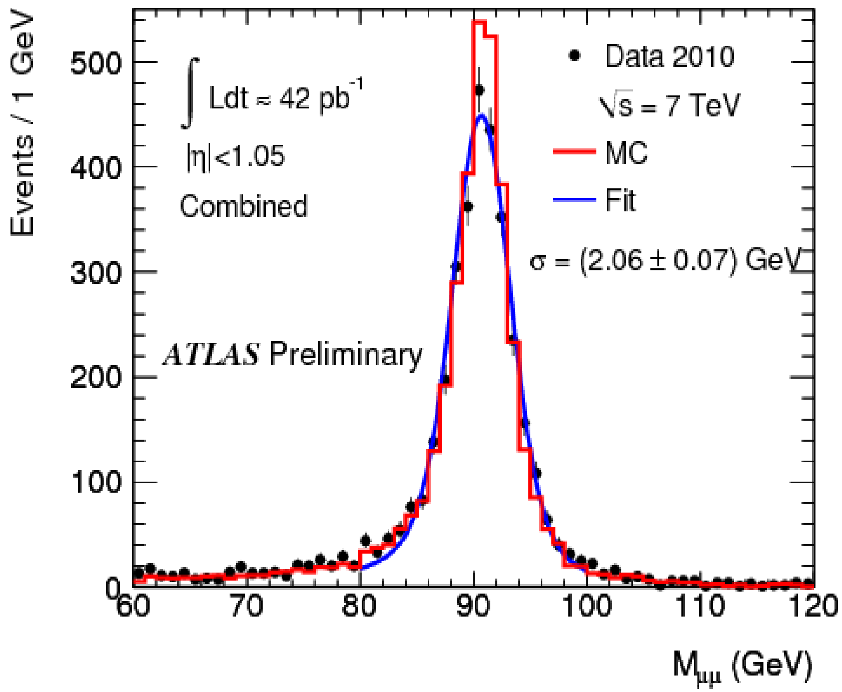


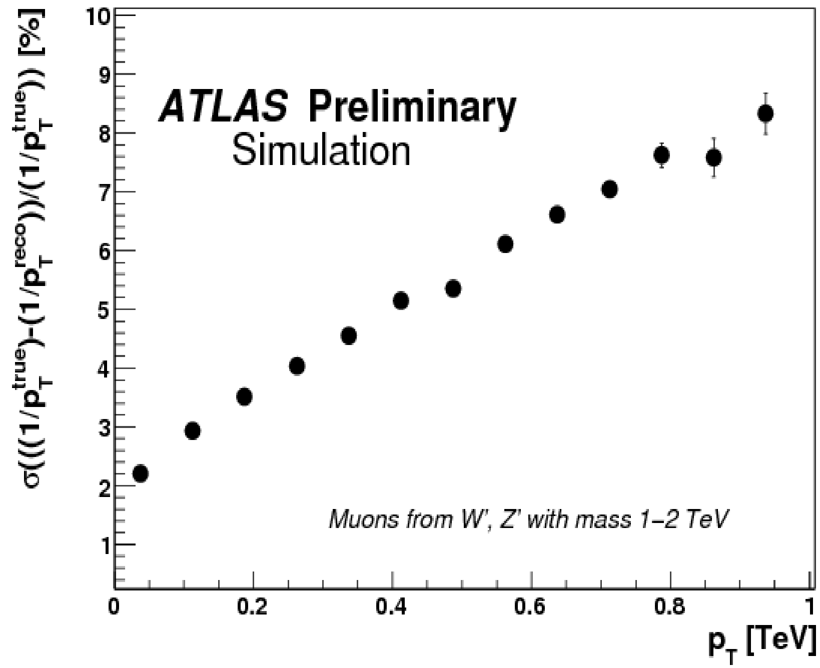


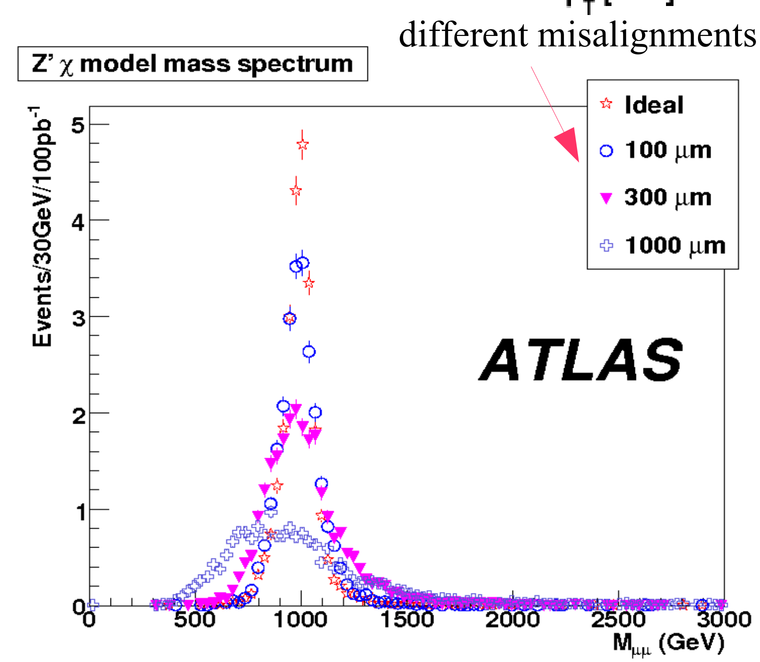
- SM W/Z signatures have been established. Seen agreement between data and MC in the m(ee) and electron E_T distributions – important for electron p_T calibration
- Fractional resolution of electron p_T plateaus around 1% for high p_T (determined by the EM-Calo) – better Z' mass resolution than in the μμ channel (see next)



$Z \to \mu\mu$

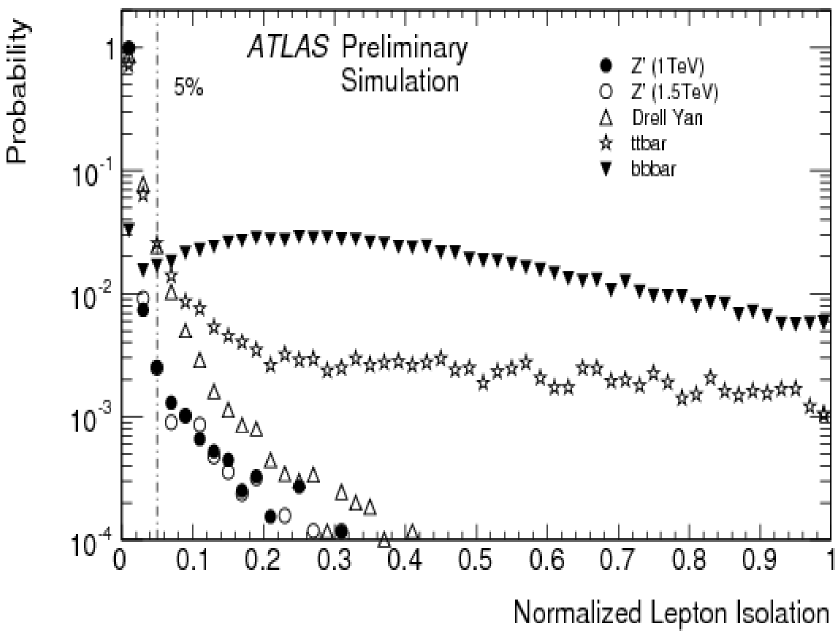


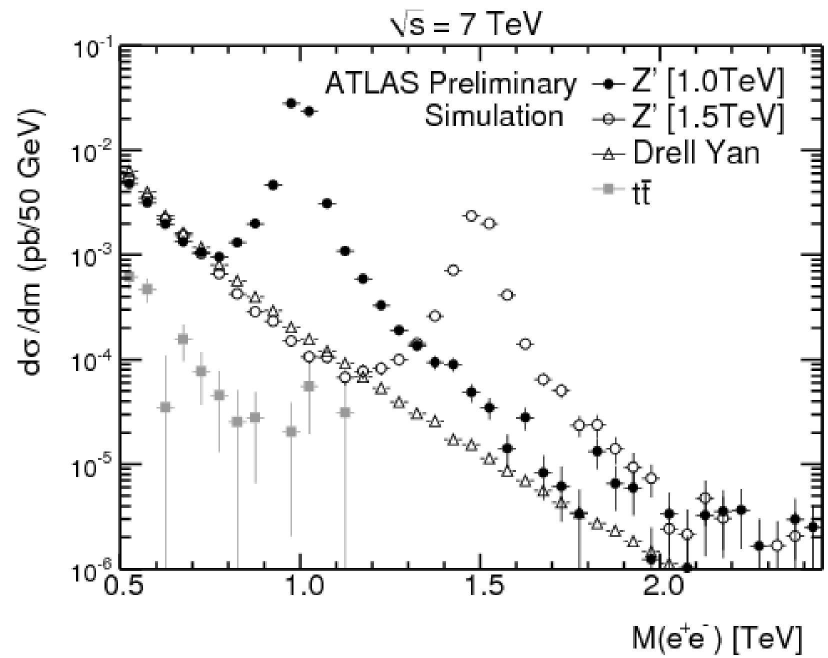




- Muon p_T resolution in MC seems a bit better than in data when comparing the $Z \to \mu\mu$ mass peak resolutions between them
- Fractional resolution of muon p_T goes up to about 8% for $p_T \sim 1$ TeV, which is the case for Z'
- Good tracking alignment is critical for the high p_T resolution of muons, and for Z' mass resolution in the $\mu\mu$ channel

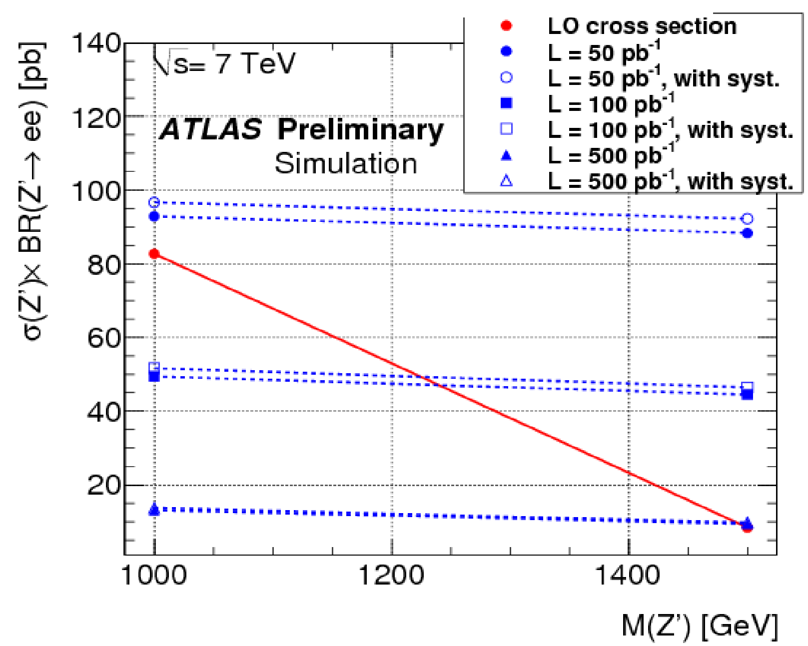
Z'→ee





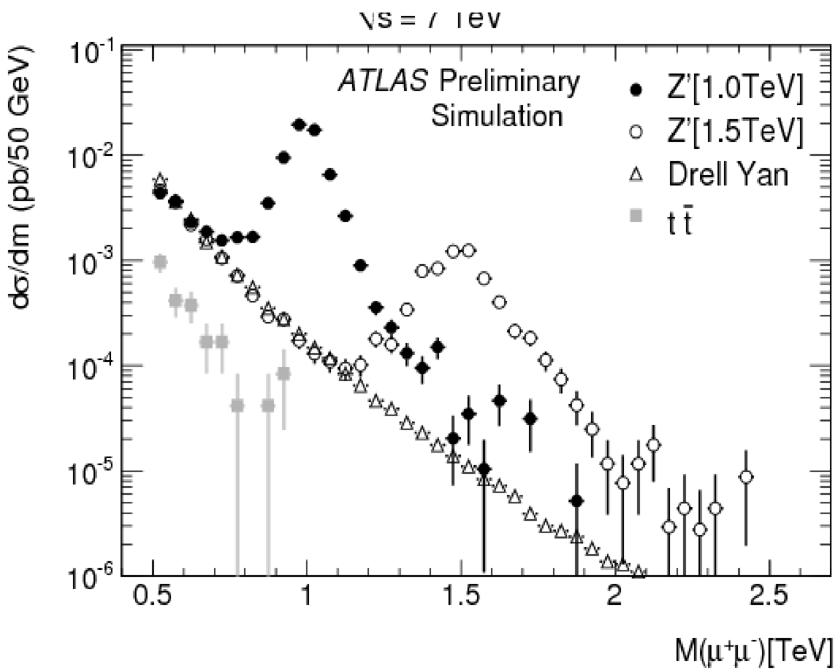
- Main backgrounds are Drell-Yan and ttbar after requiring 2 isolated electrons with $p_T > 20$ GeV under the Z' mass peak

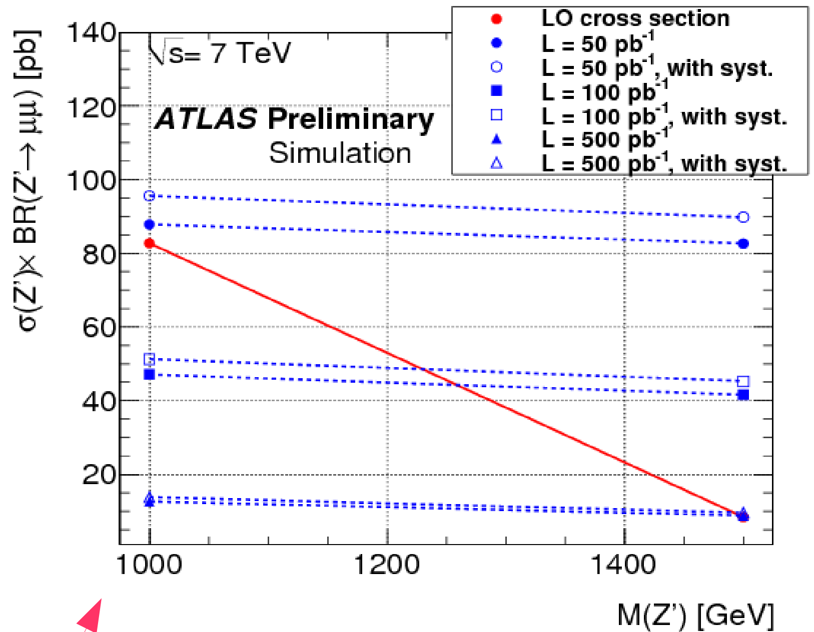
- Current CDF Z' limit is 1 TeV*. ATLAS expects to exclude a 1.5 TeV Z' (SM coupling with the SSM model) with 500 pb^{-1} of data in the ee channel alone



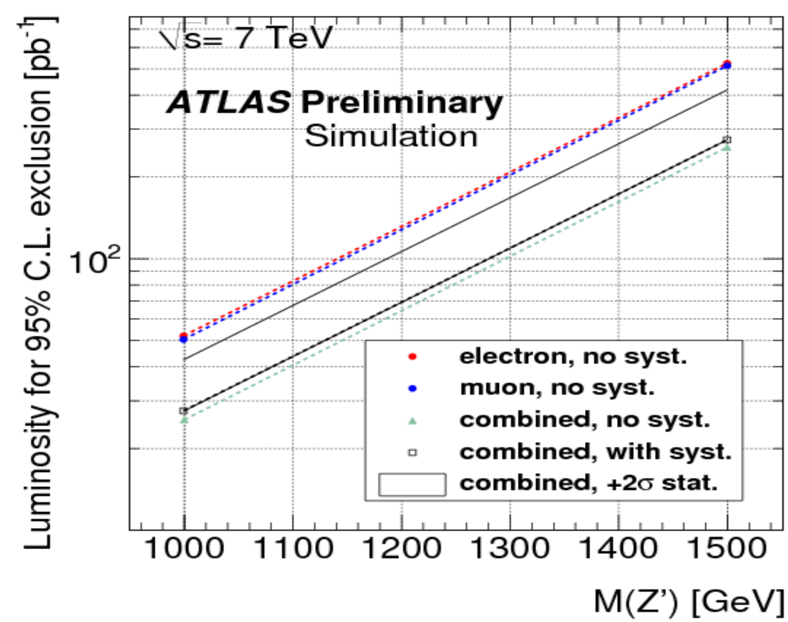
*) Phys. Rev. Lett. **102** (2009) 091805

Z'→μμ and dilepton combined

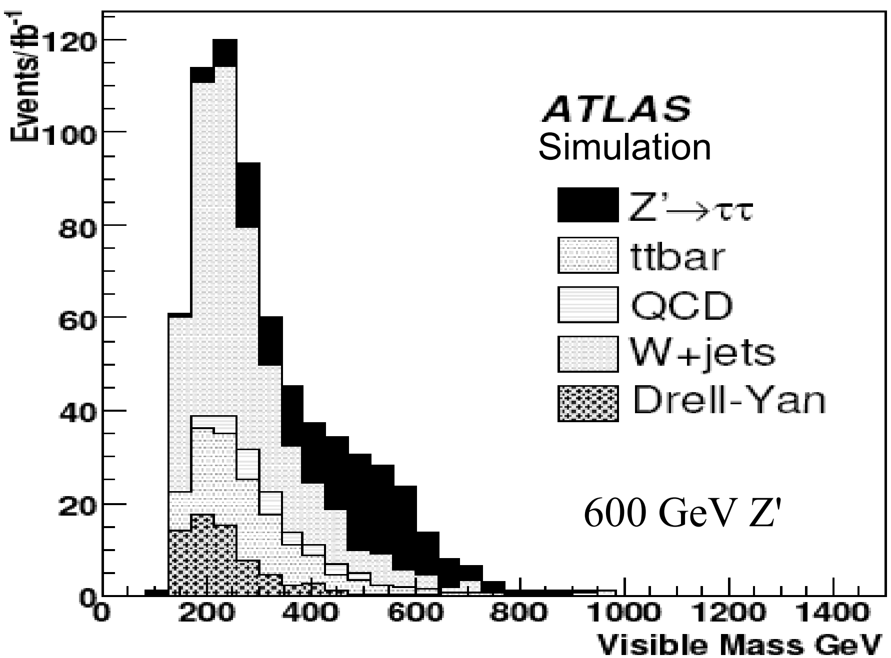


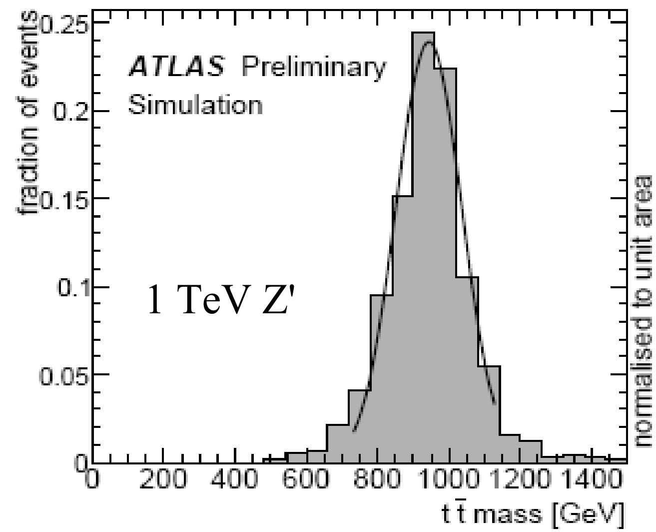


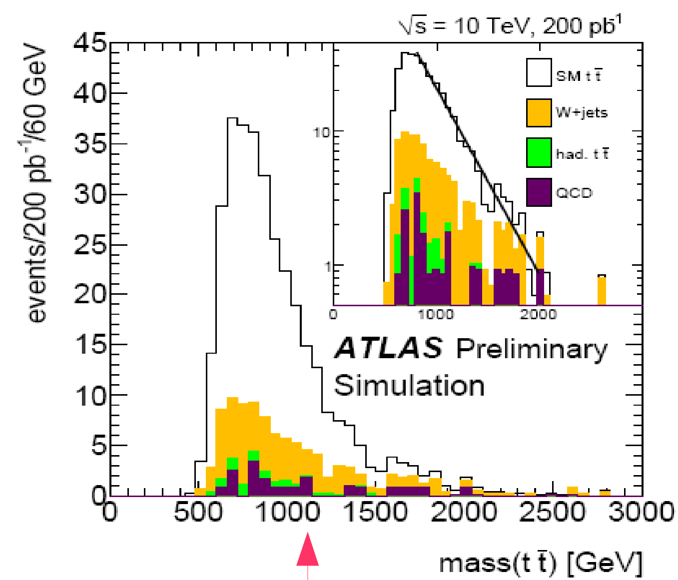
- Limits for Z'→μμ are a little bit worse than Z'→ee, because of different systematic errors for μμ (14%) and ee (21%) channels
- With Z'→ee,μμ combined, a 1.5 TeV Z' can be excluded with ~ 400 pb^{-1} of data with systematics



More difficult Z' decay channels



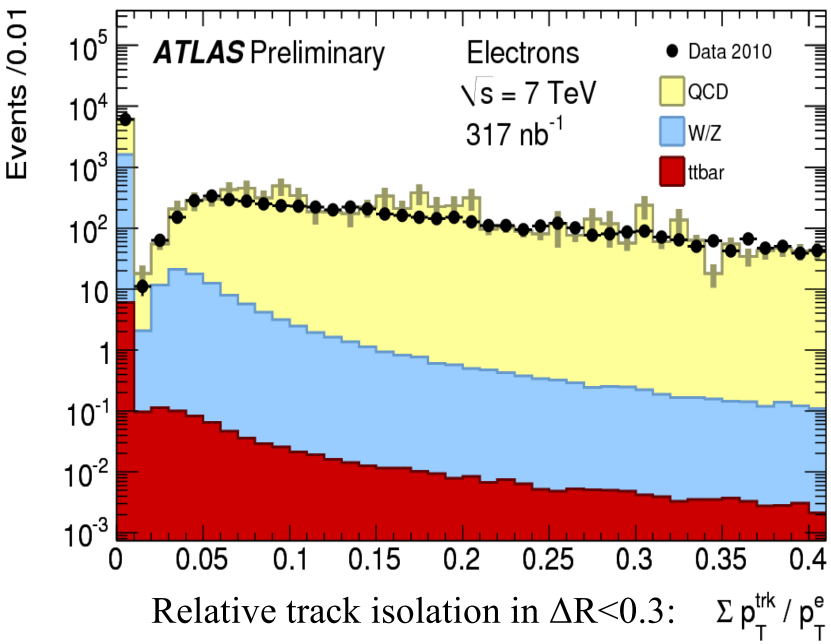


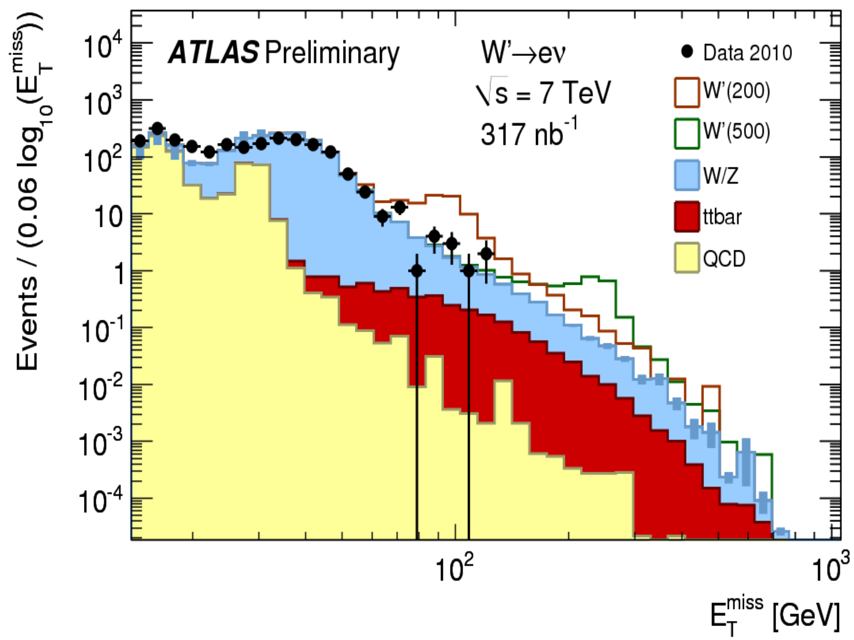


SM background

- Limits for Z'→ττ and Z'→ttbar are important if Z' prefers to couple with the 3rd generation
- For Z'→ttbar, jets/leptons from top decay tend to merge into mono-jets due to high boosts
- They are more difficult channels to reconstruct and separate from background, and need higher lumi. to observe

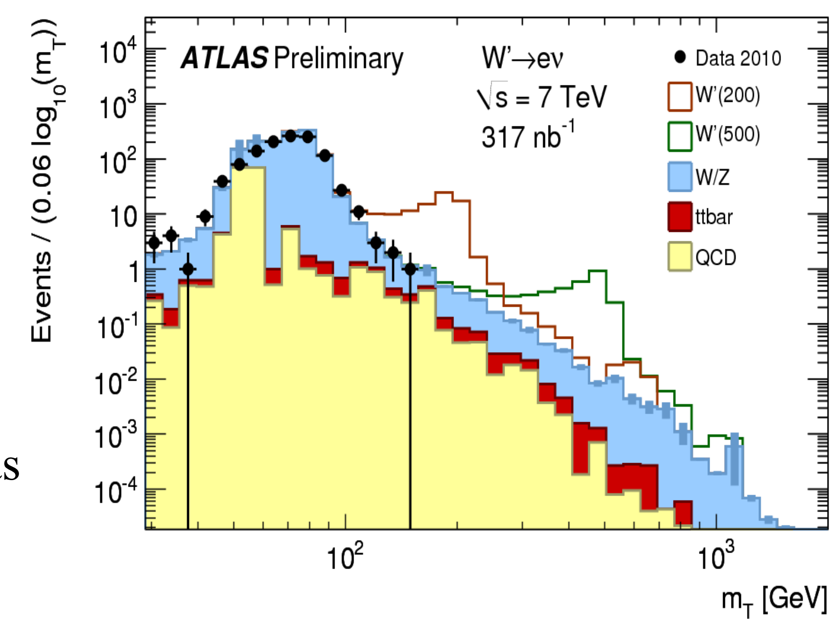
W'→eν



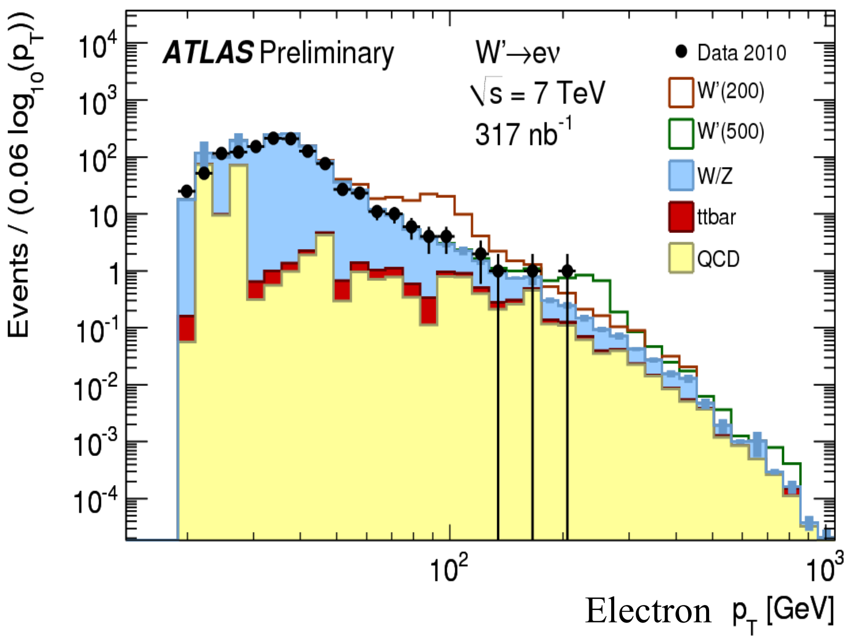


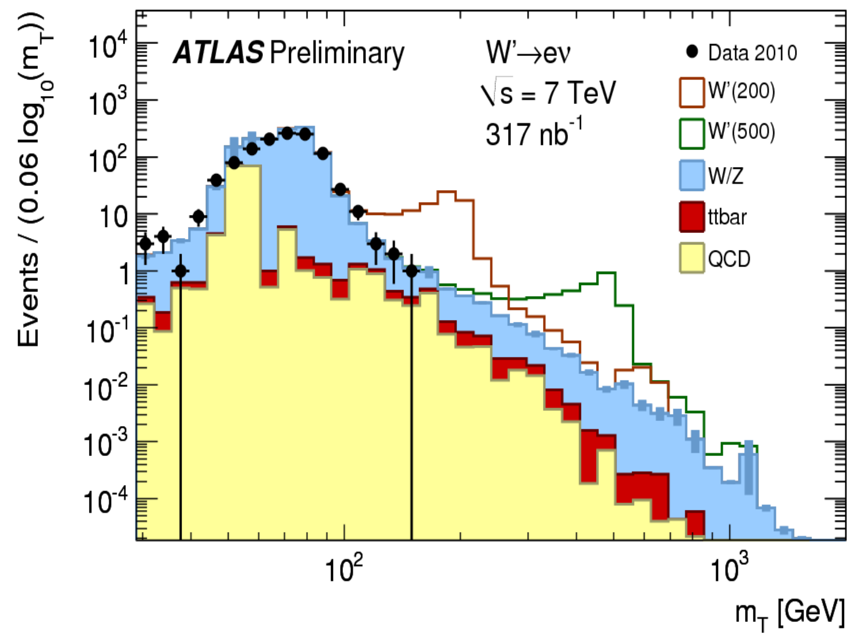
- Initial cuts: good run condition, a primary vertex (PV) with ≥ 3 tracks, veto events with bad/noisy jets, exaclty one medium electron with $p_T > 20$ GeV within acceptance, and the electron track near PV. Electrons near problematic EM-Calo regions are also removed

- The relative isolation, MET (with isolation cut) and transverse mass distributions after the initilal cuts are as shown in this slide. Good data-MC agreement is observed

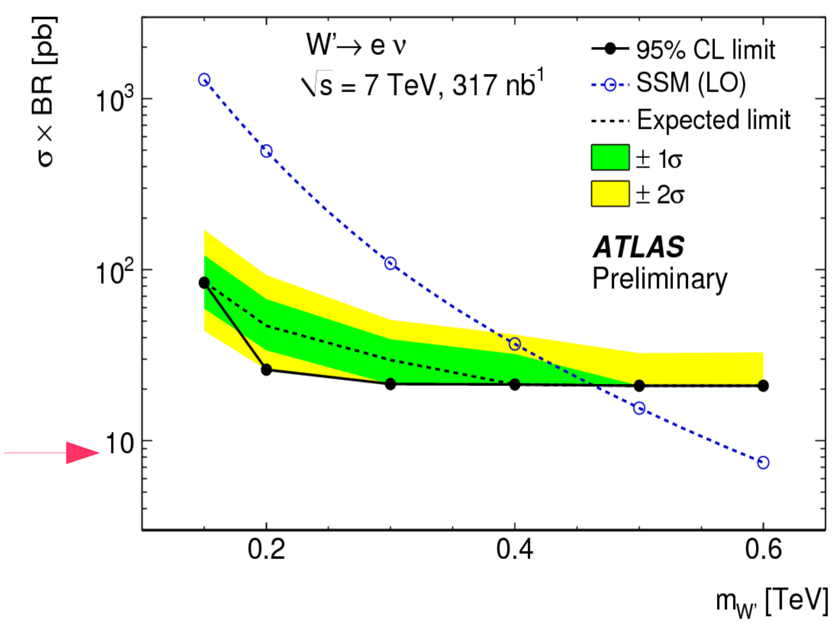


W'→eν



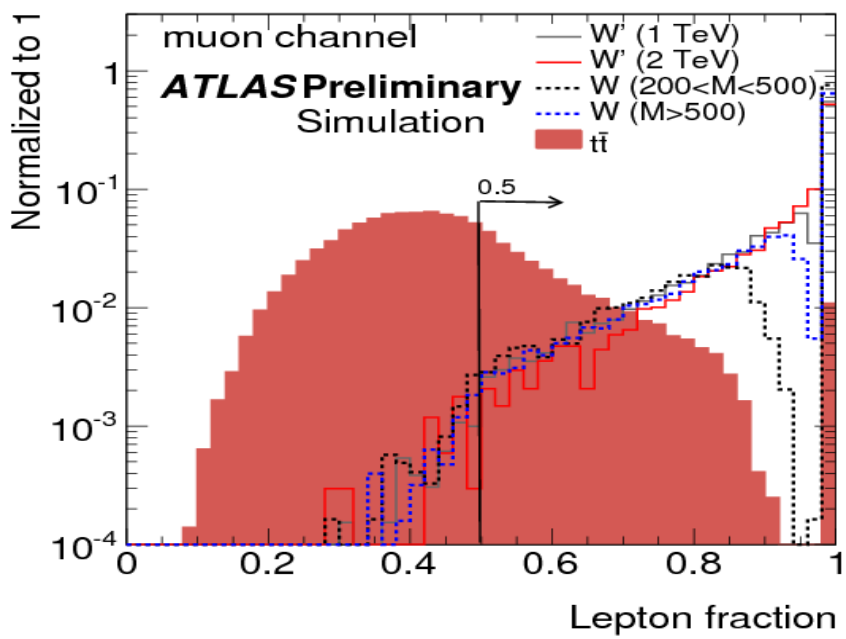


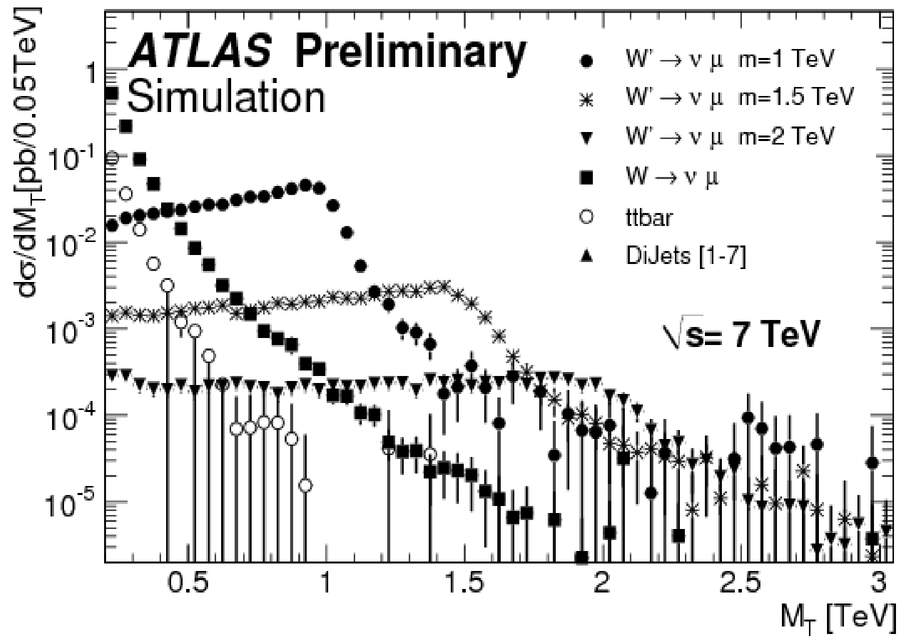
- After initial cuts, we require relative electron isolation < 0.05 in a cone of ΔR=0.3, MET > 25 GeV, and $m_T > 0.7 m_{W'}$ to suppress backgrounds. The electron p_T and m_T are as shown above
- Main backgrounds are W/Z, ttbar and QCD
- A 465 GeV W' (SM coupling with the SSM model) can be excluded with an early data of 0.317 pb^{-1} in the eν channel (consistent with the limit of 1 TeV from D0*)



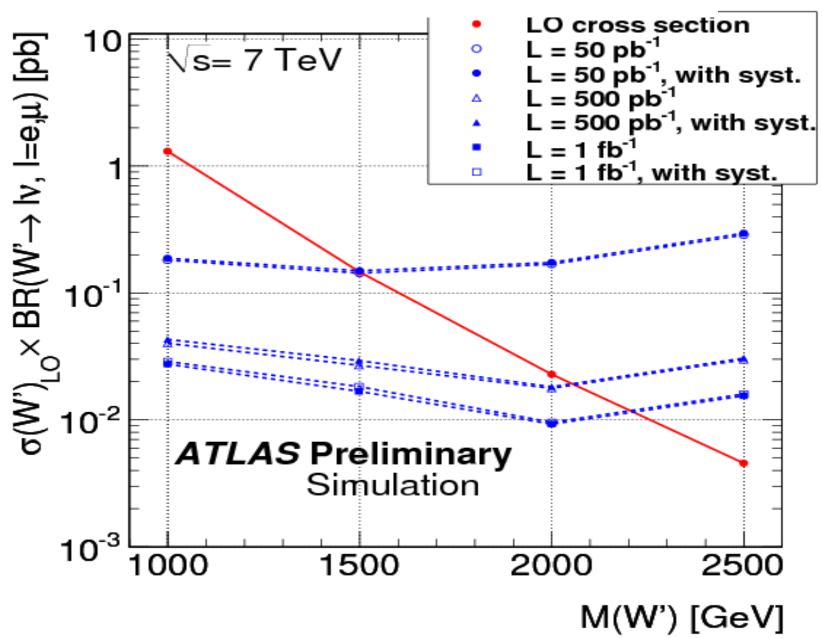
*) Phys. Rev. Lett. **100** (2008) 031804

W'→μν and combined sensitivity

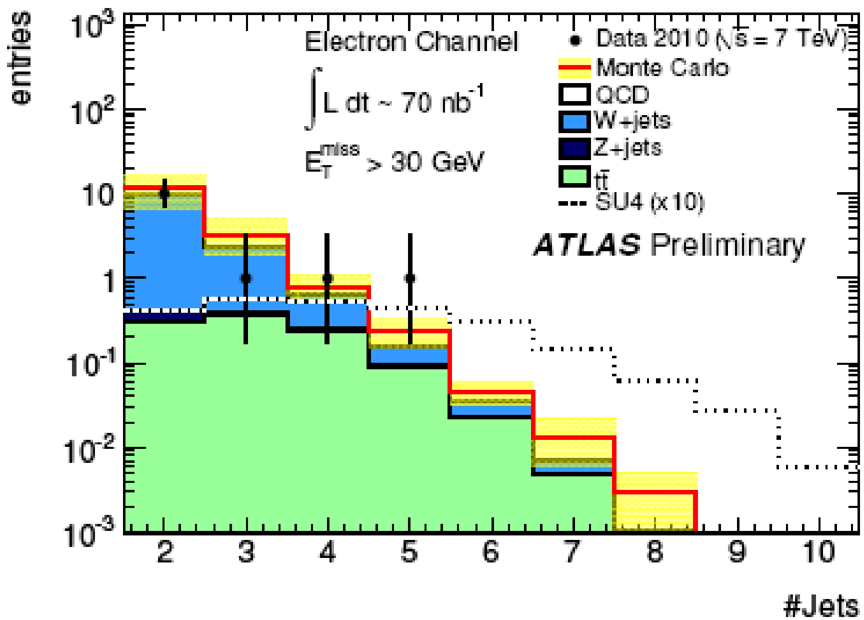


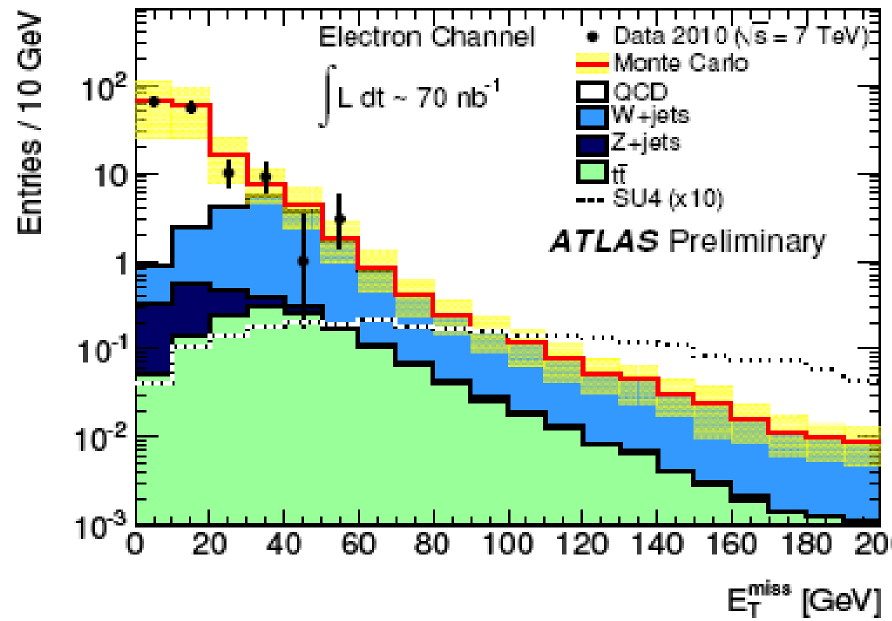


- For high lumi. scenarios, apply tighter cuts: an isolated electron with p_T > 50 GeV, MET > 50 GeV, lepton fraction $\frac{p_T^l + \not{E}_T}{p_T^l + \not{E}_T + \sum p_T^{\text{jets}}} > 0.5$
- Dominant background left is the W→lν tail, ttbar and QCD are largely suppressed
- ATLAS expects to exclude a 2 TeV W' (SSM) with ~500 pb^{-1} of data for ee and μμ combined

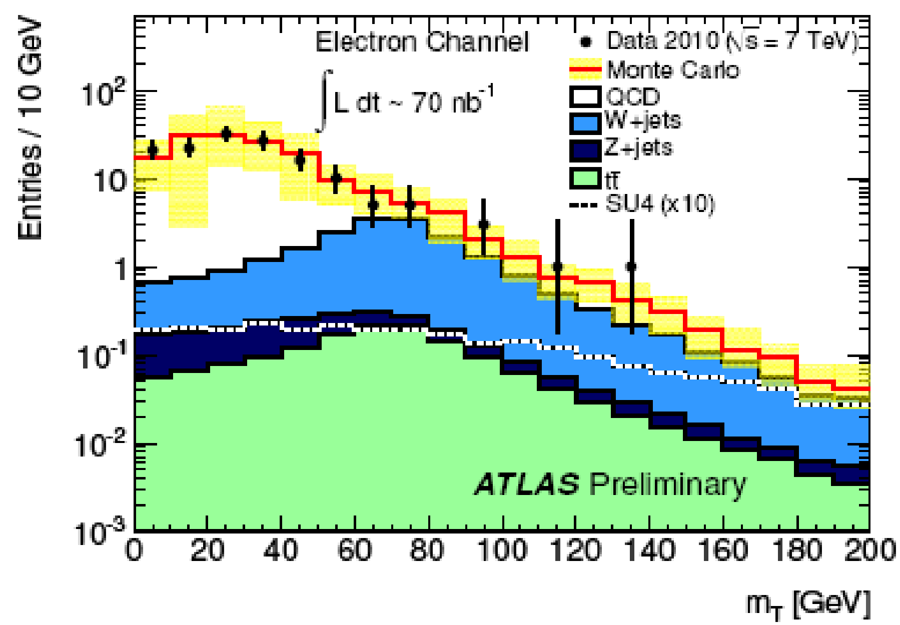


SUSY 1-lepton channel

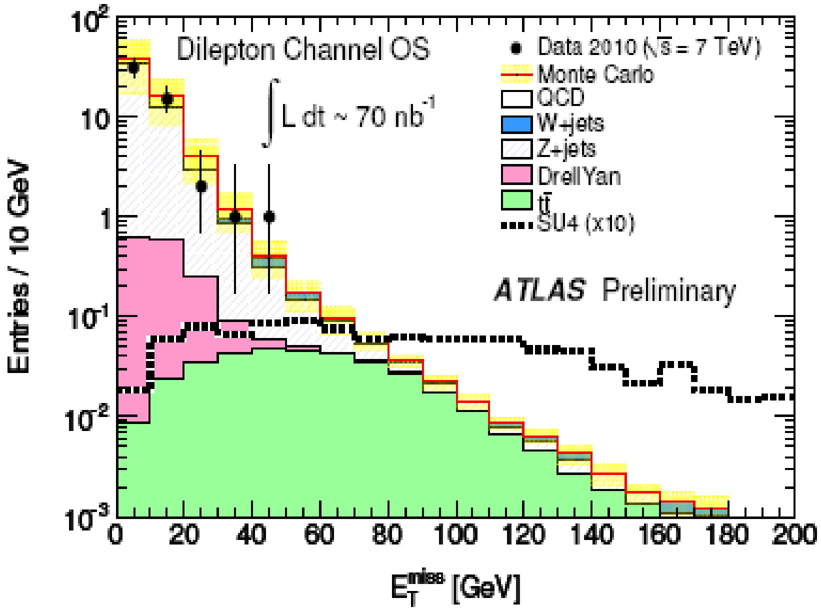


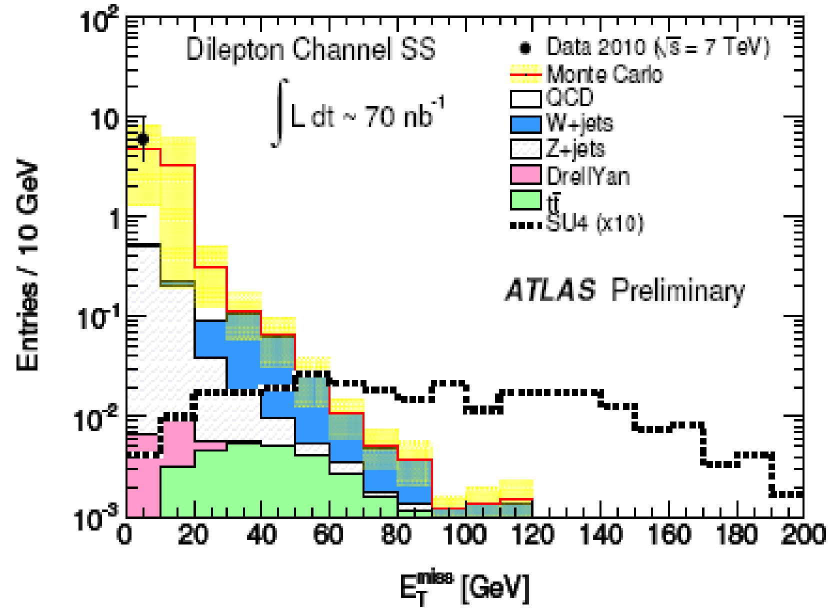


- SUSY protects the SM Higgs mass, unifies the electroweak and strong forces, and provides a dark matter candidate
- If SUSY exists, gluino/squark pairs can be copiously produced (subject to the mass scale) at LHC, and one or more leptons can be found in the cascade decays of the super particles, together with many jets and large MET
- The distributions of 1-electron channel is shown in this page atfter basic object selection cuts

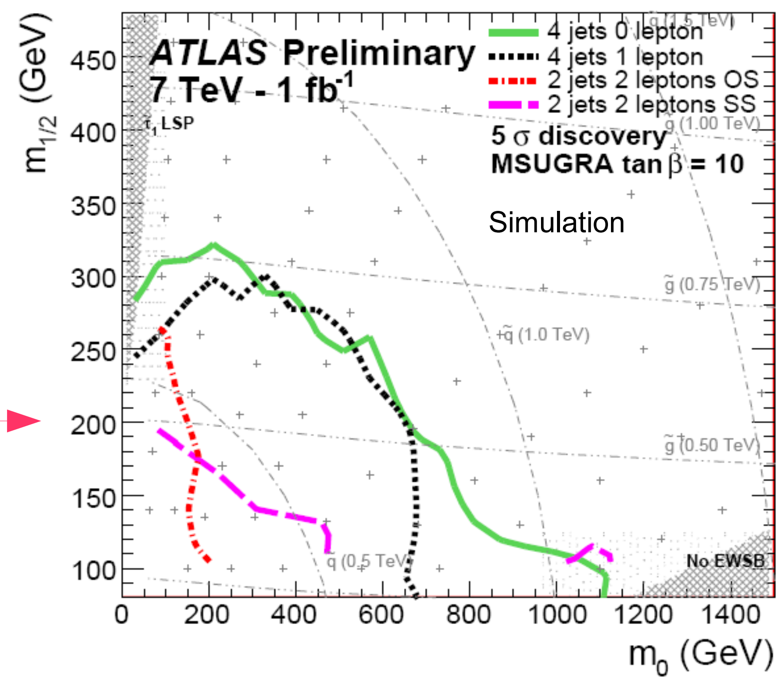


2-lepton SUSY and overall sensitivity

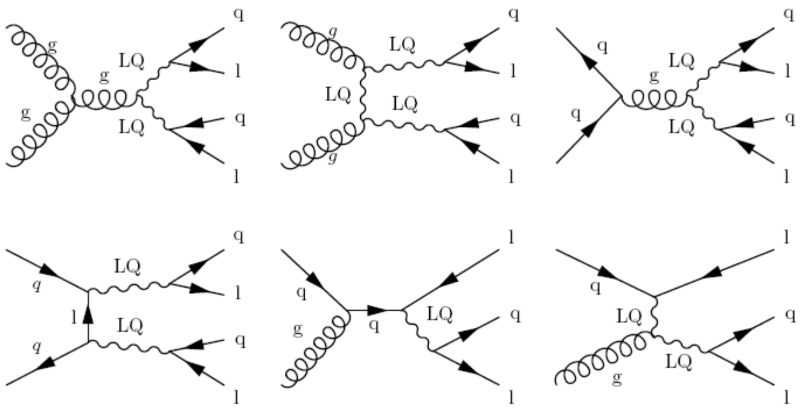


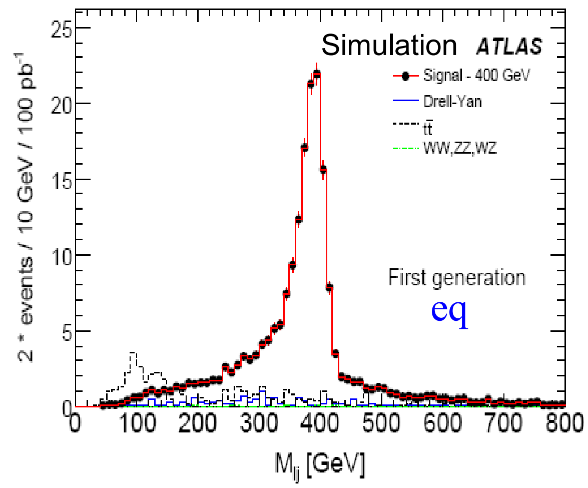


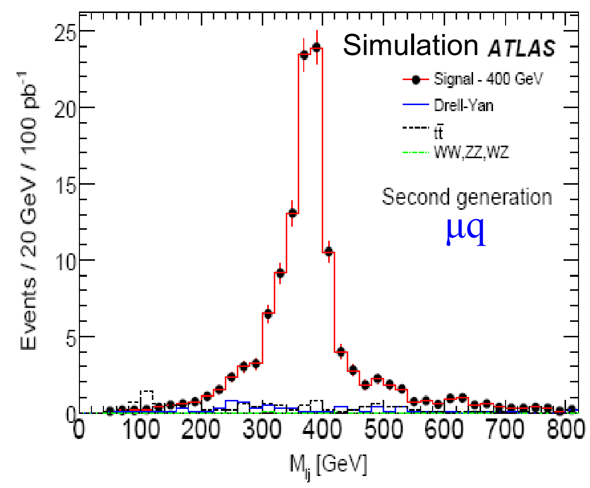
- The 2-lepton channel has much less QCD background, and other SM backgrounds are also smaller, especially in the 2-lepton same-sign (SS) channel
- With 1 fb^{-1} of data, a large corner in the m_0 vs. $m_{1/2}$ plane of the mSUGRA model can be discovered, which corresponds to gluino and squark masses of ~700 GeV at the EW scale



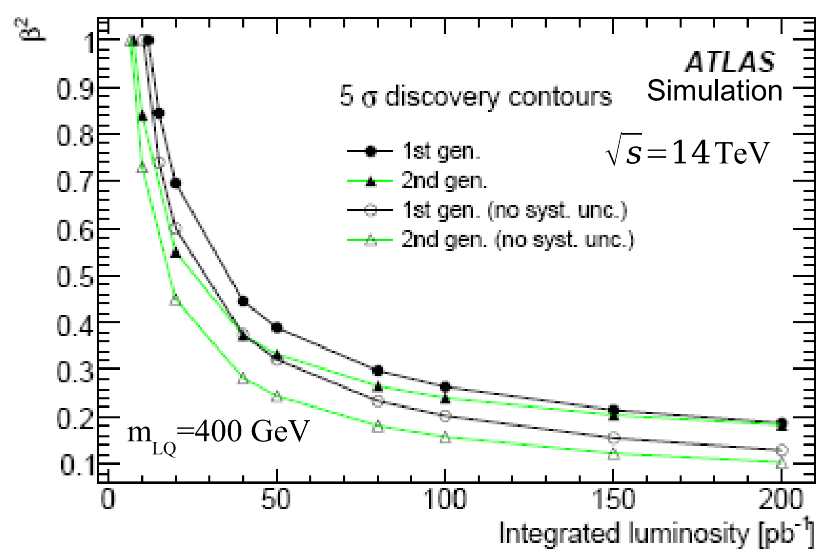
Leptoquark decay LQ→l+q (14 TeV)







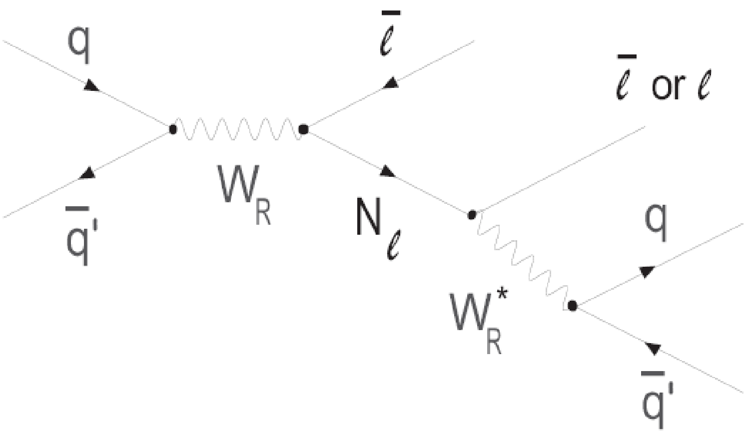
- LQ carries both lepton and baryon numbers, and can be pair-produced via QCD and LQ-lep-LQ couplings (set to 0.8 in simulation) at LHC



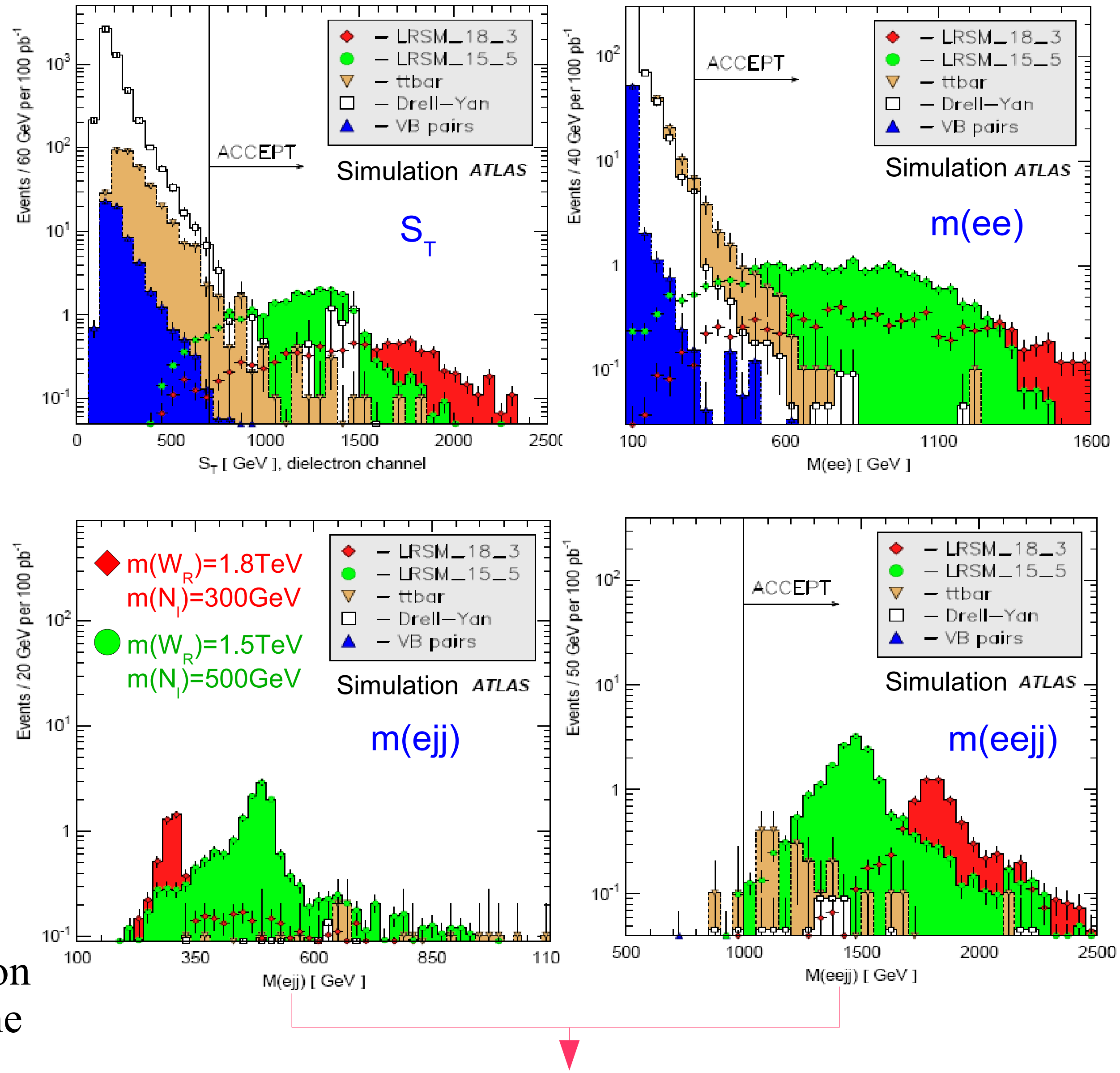
- Require at least 2 leptons and 2 jets, large p_T sum of leptons and jets ($S_T \gtrsim 500$ GeV), large dilepton mass ($\gtrsim 120$ GeV). Lepton-jet pair ambiguity resolved by minimizing the mass difference of such two pairs. Backgrounds are dominated by Z/γ* and ttbar
- For β=BR(LQ→lq)=1, D0 limit on the LQ mass is ~250 GeV*. ATLAS sensitivity will be higher

*) Phys. Lett. **B636** (2006) 183; Phys. Rev. **D71** (2005) 071104

$W_R \to eN_e \to eejj$ (14 TeV)

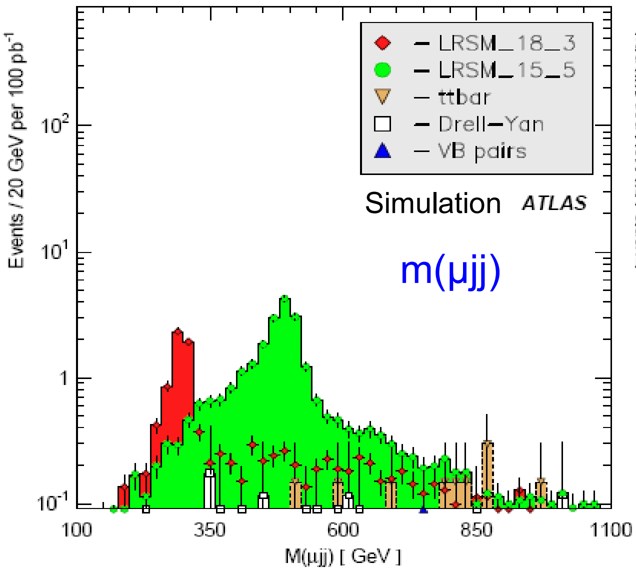


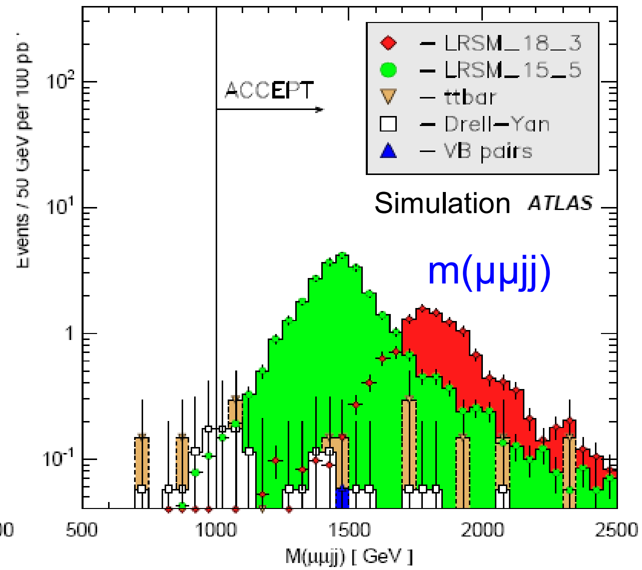
- LRSM: nonzero SM neutrino masses via 3 new heavy Majorana neutrinos ($N_{e,\mu,\tau}$) and lepton number violation (ΔL=2). A heavy W_R at TeV scale is also predicted
- Require at least 2 electrons and 2 jets, large p_T sum of leptons and jets (S_T>700 GeV), large dilepton mass (>300 GeV). Lepton+2jets combination ambiguity for N_l resolved by taking the one with smaller mass

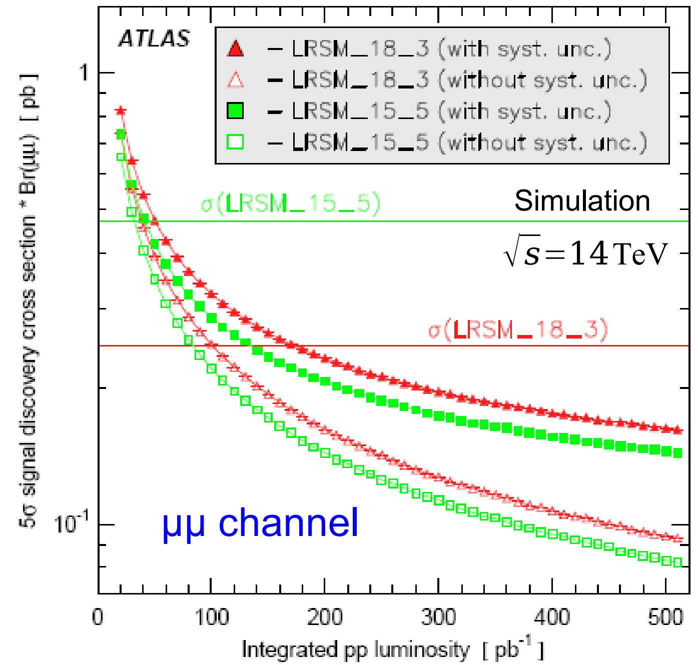


Invariant N_e and W_R masses after background suppression (ee channel)

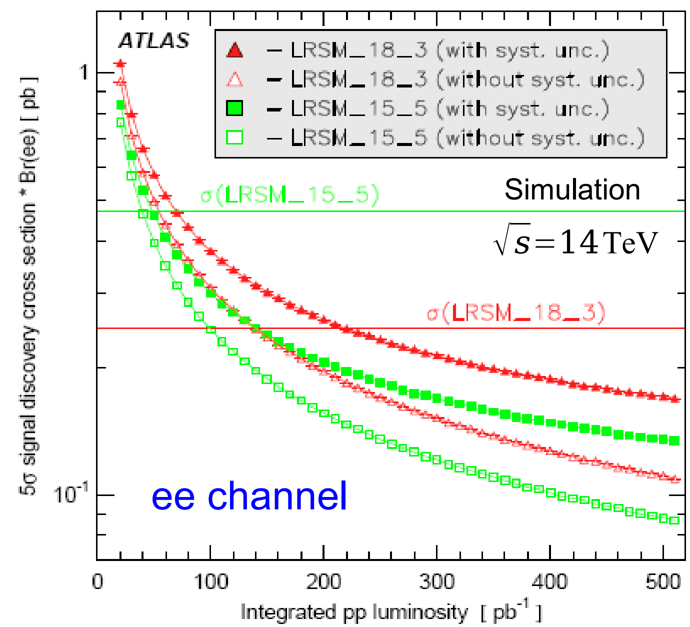
$W_R \rightarrow \mu N_\mu \rightarrow \mu\mu jj$ and sensitivities (14 TeV)





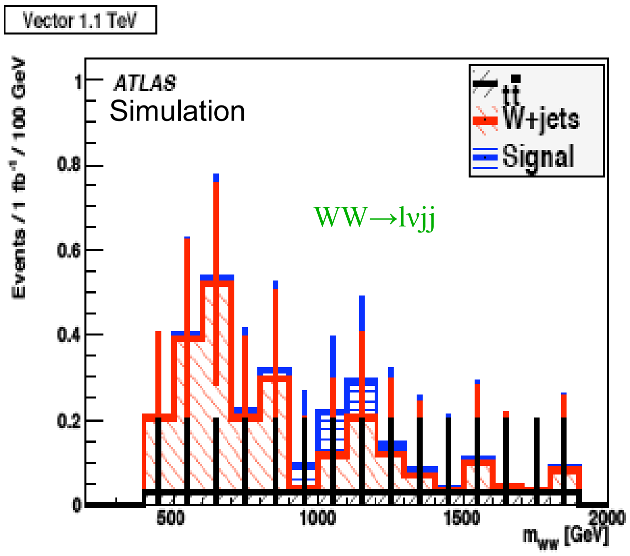


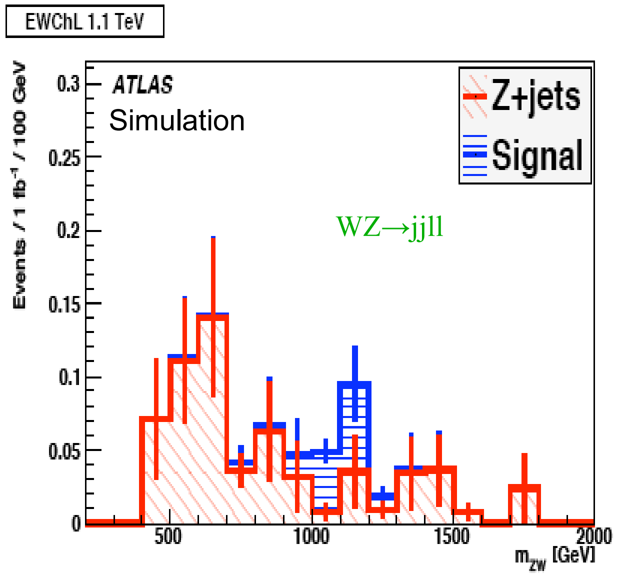
- Two signal samples investigated (with SM couplings): (1) $m(W_R)$=1800 GeV, $m(N_l)$=300 GeV (2) $m(W_R)$=1500 GeV, $m(N_l)$=500 GeV. When the W_R mass is much larger than N_l, the lepton from N_l decay tends to merge with the jets
- No flavor mixing for Nl. The mass distributions in the dimuon channel are similar to the dielectron channel
- D0 limit on W_R is ~750 GeV* in the decay channel of W'→tb. The ATLAS discovery sensitivities of W_R of 1.5 and 1.8 TeV are given (for $\sqrt{s}=14\,\text{TeV}$)

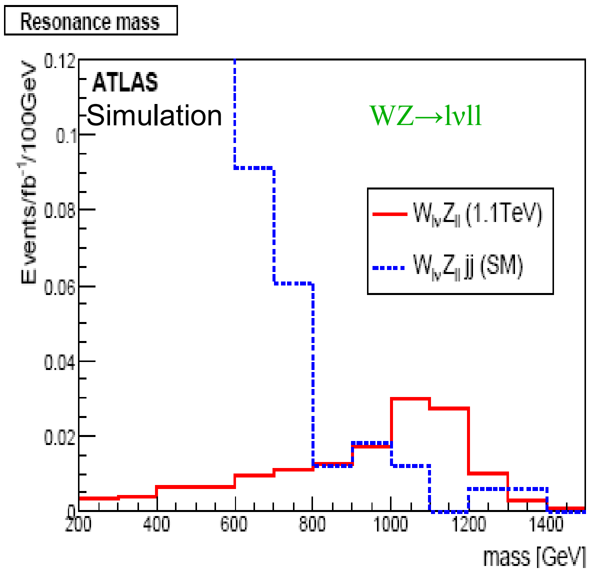


*) Phys. Rev. Lett. **100** (2008) 211803

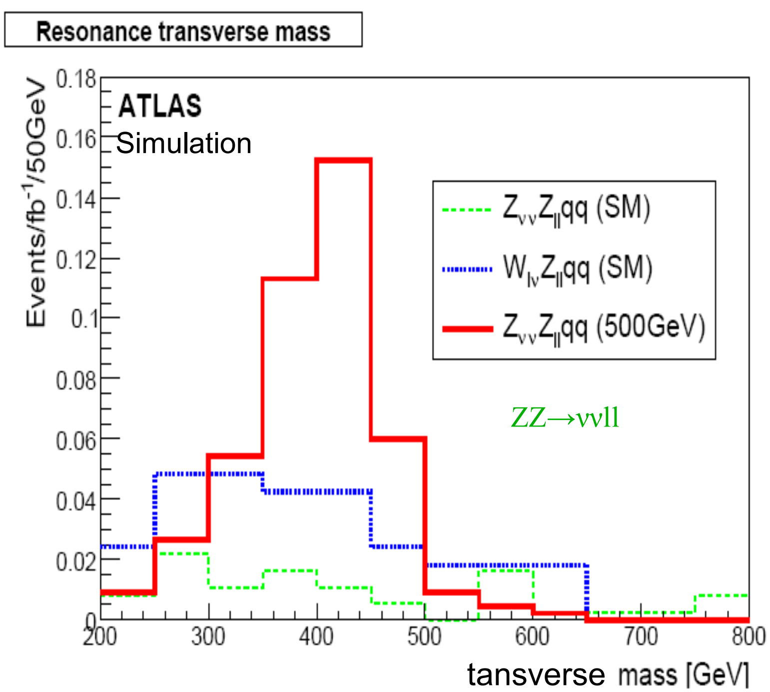
Diboson resonance (14 TeV)







- In the absence of a light Higgs ($m_H \lesssim$ 700 GeV), NP must exist at some high energy scale based on vector boson scattering unitarity arguments, possibly in the form of diboson resonances
- Generate diboson resonance signals with an effective Chiral Lagrangian. Require 2 forward tagging jet + central extra jet veto. Main backgrounds are W/Z+4jets, diboson+2jets. Signal can be reconstructed in the subchannels of WW/WZ→lνjj, WZ→jjll/lνll and ZZ→ννll
- Not an early sensitivity analysis. Need 55~235 fb^{-1} of data (@14 TeV) to establish a discovery of these subchannels



Summary and outlook

- Many New Physics models include leptons in the final state. The early data collected by ATLAS this year begins to shed light on some of the truth (either dicover or exclude a New Physics model or part of the parameter space of that model)

- Leptons can be efficiently triggered by ATLAS. The early data of SM W/Z benchmark is available to calibrate the leptons and check against the MC prediction and detector simulation. In general, our MC is well tuned and agrees with data well

- A W' with SM coupling and mass 465 GeV is excluded by 0.317 pb^{-1} of data. Distributions of SUSY-sensitive variables show no evidence of SUSY based on 70 nb^{-1} of early data (more details in the talk of *Xuai Zhuang*). Prospects and expected sensitivities of searches for W', Z', SUSY, Leptoquark, LRSM Majorana neutrinos and diboson resonances are also given in this talk

- Results based on higher luminosities have yet to be shown, but the sensitivities will surpass Tevatron in many New Physics search channels as new data continues to be collected until 1 fb^{-1} is reached next year