Early Searches for New Physics with Electrons and Muons with the ATLAS Detector at the Large Hadron Collider

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On behalf of the ATLAS Collaboration

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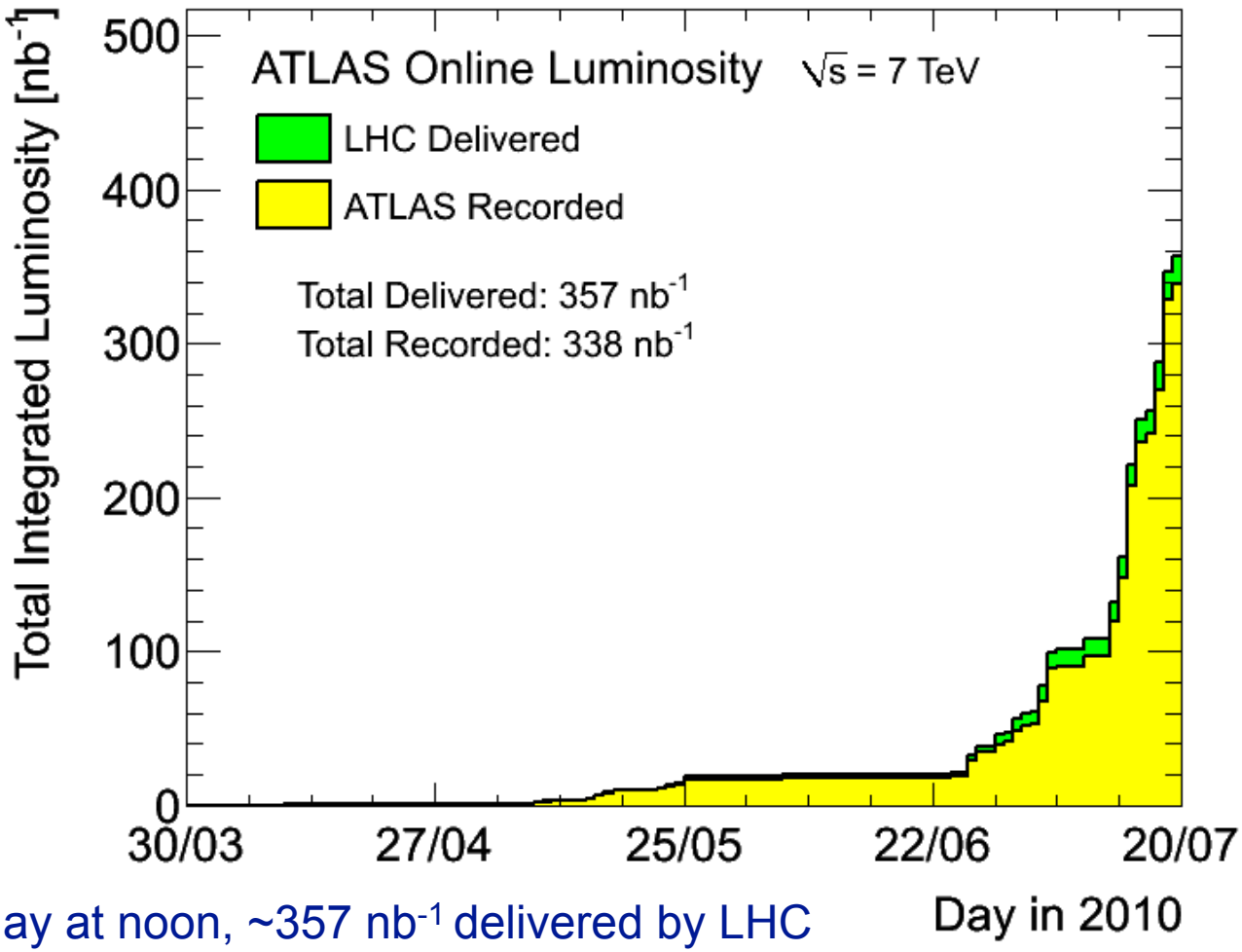
Outline

- Searches motivated by physics beyond the Standard Model
  - A new model can predict several signatures
- Analysis starts with search for interesting signatures
  - The (non-) observation of a signature can constrain several models
- Focus on the following signatures:
  - W' bosons $\rightarrow \mu\nu$ or $e\nu$
  - Z' bosons $\rightarrow \mu\mu$ or ee
- Above signatures require the precise measurement of very energetic leptons
  - Status of muon and electron reconstruction from SM W/Z
  - Steps ahead to precise and reliable high p and/or E measurements
  - Summarize expectation from latest MC studies
- Background studies for SUSY searches in channels with leptons

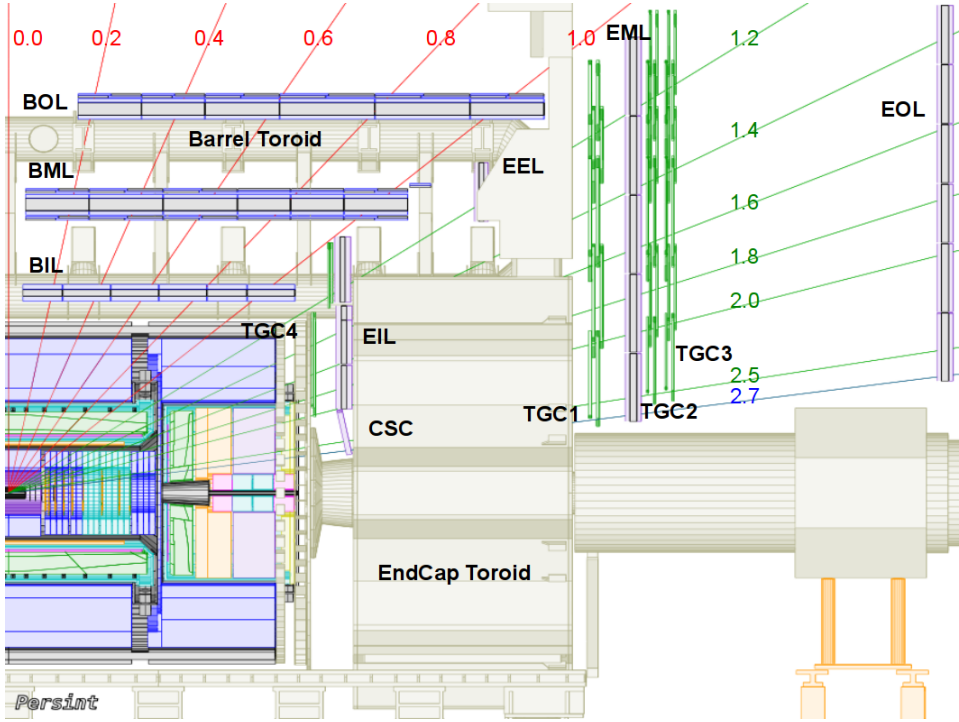
Luminosity



- As of Tuesday at noon, ~357 nb^{-1} delivered by LHC
  - 338 nb^{-1} recorded by ATLAS
- Luminosity used for analysis in this talk per channels
  - $W \rightarrow l\nu$ and $Z \rightarrow ll$: ~17 nb^{-1} (precision) to 300 nb^{-1} (observation)
  - SUSY studies: ~ 70 nb^{-1}

Muon reconstruction in ATLAS

- Steps for muon reconstruction
  - Track inside the muon spectrometer MS
  - Extrapolate to beam pipe and correct for energy loss in calorimeter
  - Combine with inner detector track
  - For p_T > 100 GeV, resolution from MS



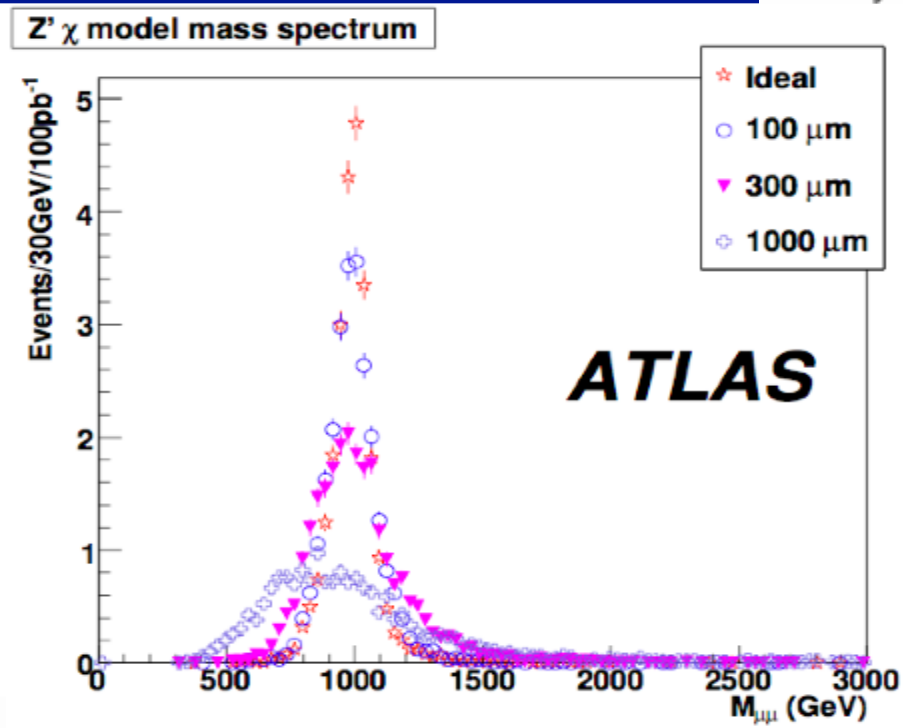
- Challenges
  - Complex toroidal B-field to be understood
  - Alignment of the MS
  - In-situ calibration of momentum scale with collisions:
    - low mass resonances: J/ψ → μμ, Υ → μμ
    - High mass resonances: Z → μμ (σ_{obs}~500 pb)
  - Trigger and reconstruction efficiency for high p_T
    - Tag-and-probe techniques using Z → μμ

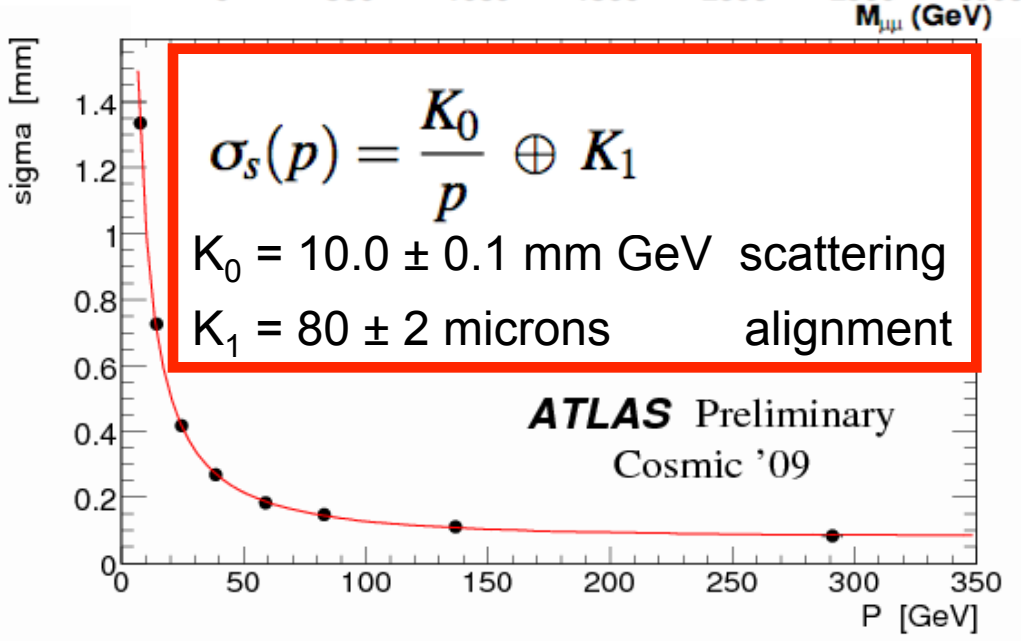
See yesterday's talk by Martin Woudstra on muons at ATLAS in session 1

Challenges for high p_T muons: alignment

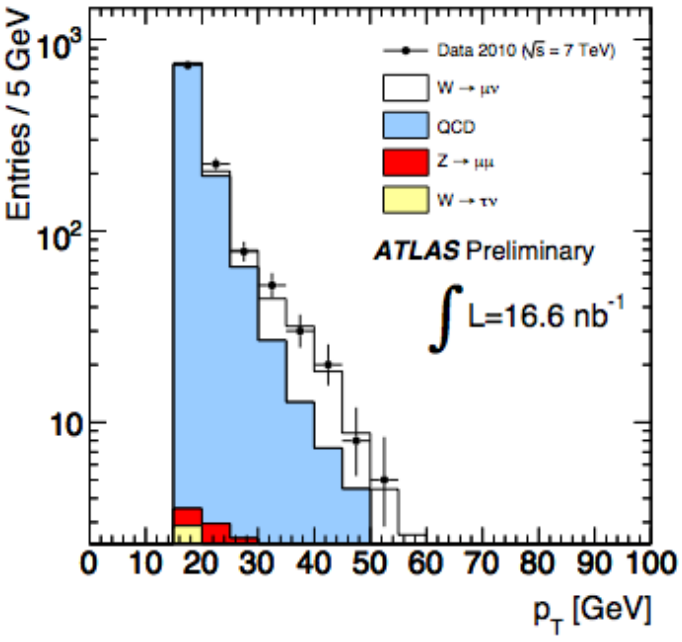
- 10% momentum resolution for 1 TeV muons
  - ~ 500 microns sagitta in ATLAS MS barrel
  - Chambers have 30-40 micron accuracy
  - Need position of chambers to within 30 microns
- Chamber installed within 5 to 10 mm of nominal
  - Improve knowledge of position by 2 orders of magnitude: alignment
- Study alignment with cosmic rays
  - Factor 2-3 from nominal performance
- Some regions of the detector need collisions
  - Track-based alignment
  - Validation

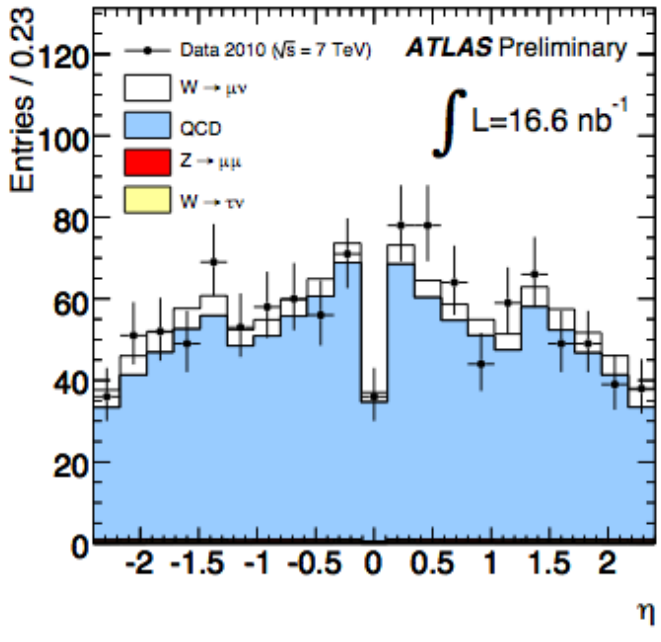
Expect nominal alignment with ~ 100 pb^{-1}

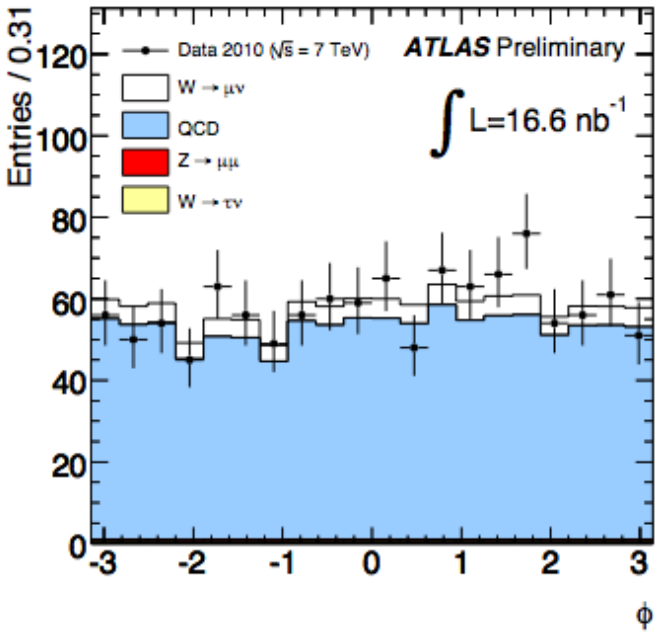




Muon spectrum from W → μν study







- Spectrum shown above is for muons satisfying the W → μν pre-selection
  - Momentum agreement between MS and ID measurements
  - Combined muon p_T > 10 GeV/c
  - Muon compatible with primary vertex

- MC scaled to number of entries in data
  - Rate dominated by QCD
  - Good shape agreement between data and MC
  - No high p_T outliers

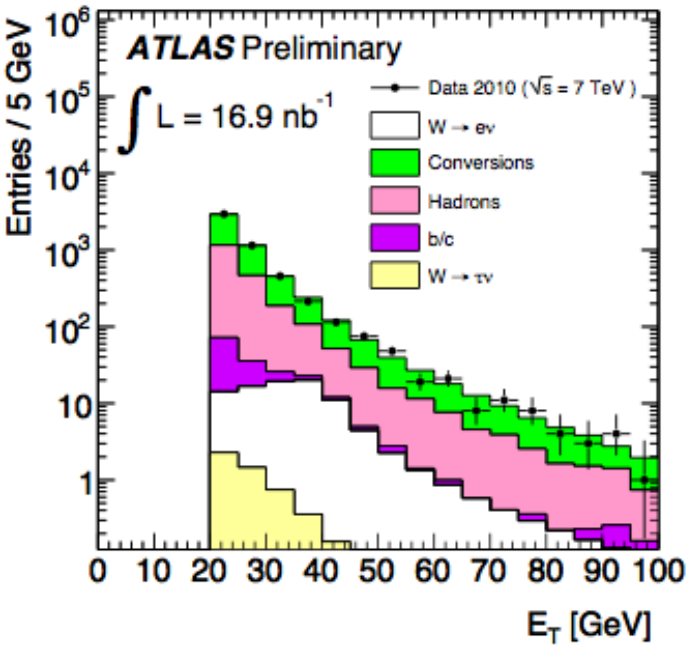
Electron reconstruction in ATLAS

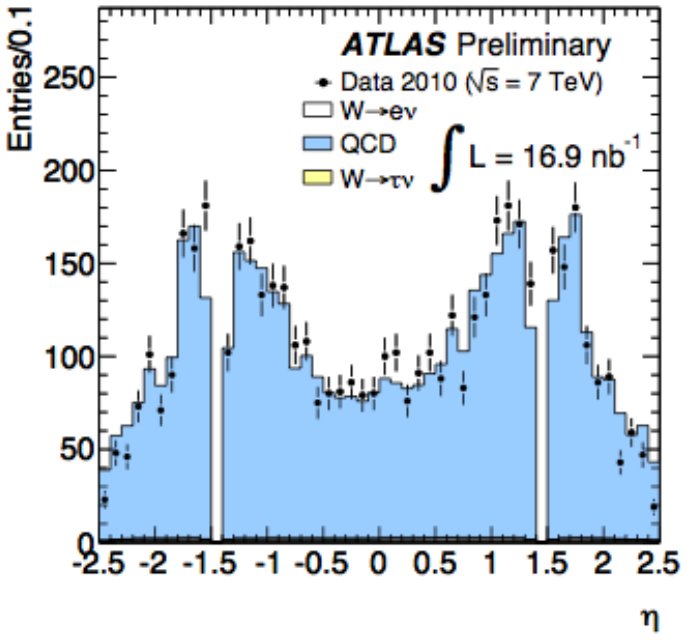
- Steps for electron reconstruction
  - Begins with a seed in the second layer of EM calorimeter using sliding window cluster
  - ID tracks extrapolated to seed and best match used
  - Total transverse energy of cluster is used for E_T
  - Corrected for energy loss in dead material and leakage outside cluster

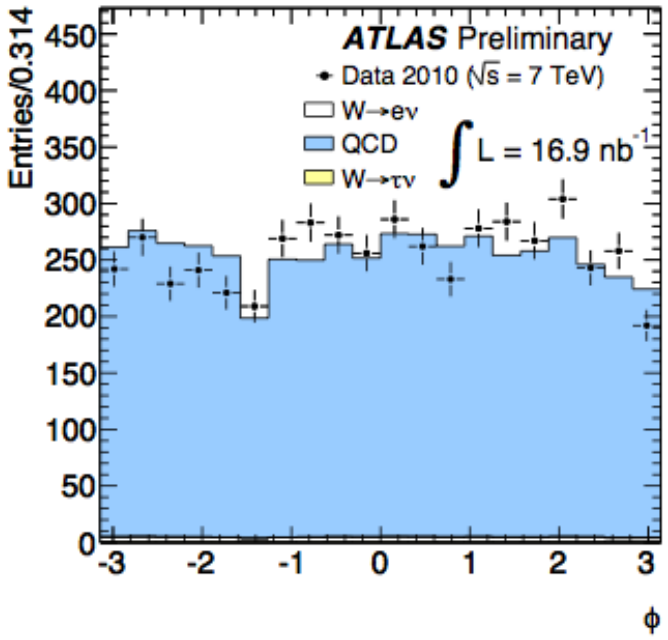
- Challenge with electrons similar to those with muons
  - Understanding fake rate: conversions, π^0, QCD
  - EM scale
    - Testbeam with 10 to 200 GeV electrons
    - In-situ calibration (similar method as for muon momentum scale):
      - low mass resonances: $J/\psi \rightarrow ee$, $\Upsilon \rightarrow ee$
      - High mass resonances: $Z \rightarrow ee$ (σ_{obs}~500 pb)
  - Reconstruction and trigger efficiency at very high p_T
    - Tag-and-probe techniques using $Z \rightarrow ee$

See yesterday's talk by Scott Snyder on electron and photons at ATLAS in session 1

Electron spectrum in W → eν





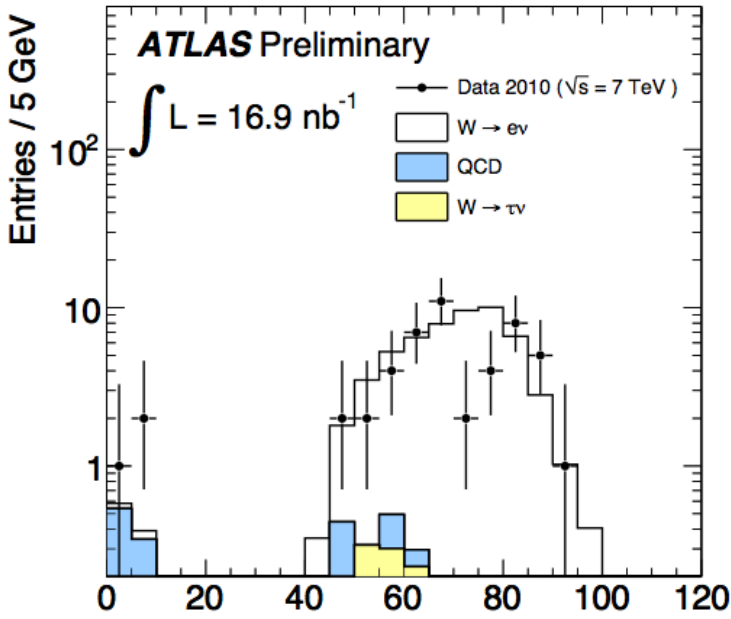


- Spectrum shown above is for electrons satisfying the W → eν pre-selection
  - Transverse energy E_T > 20 GeV
  - Exclude transition region between barrel / endcap EM calorimeters
  - Shower shape + hadronic leakage used as discriminant variables

- MC scaled to number of entries in data
  - Rate dominated by QCD
  - Good shape agreement between data and MC
  - No high E_T outliers

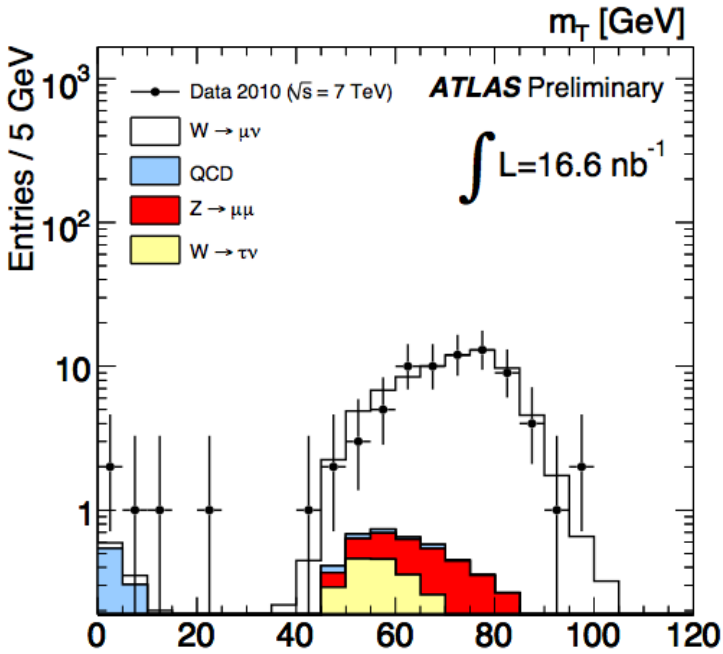
Standard Model W/Z observation at ATLAS

- Observation of 46 $W \rightarrow e\nu$ and 72 $W \rightarrow \mu\nu$ candidates for lumi of ~17 nb^{-1}
  - Lepton p_T > 20 GeV/c
  - Isolation cut
    - Electrons: absolute calorimeter isolation
    - Muons: relative track isolation
  - MET > 25 GeV
  - Transverse mass: $m_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$
  - Good agreement with MC predictions



- Observation of 14 $Z \rightarrow ll$
  - In agreement with expectation of 14.2

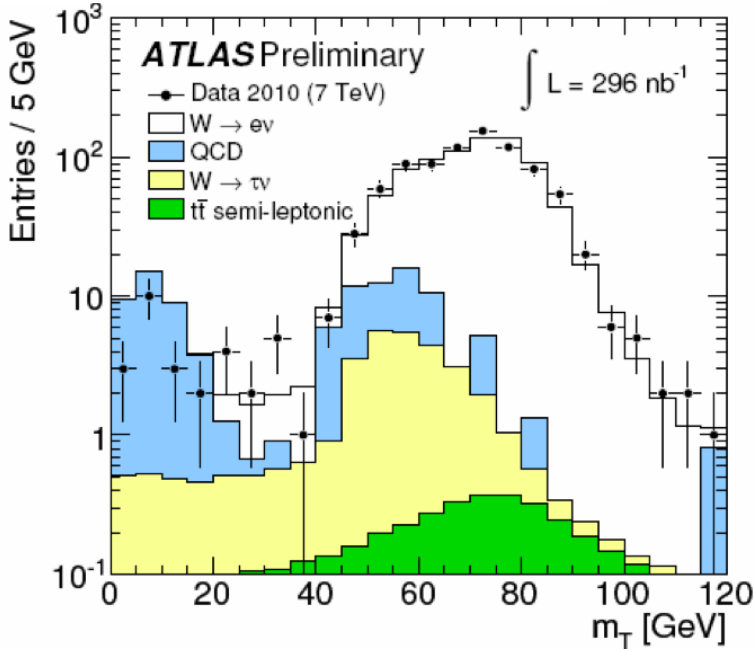
- Important results for exotic searches:
  - Analysis strategy for W' searches similar to SM
  - Will tune MC using SM regions



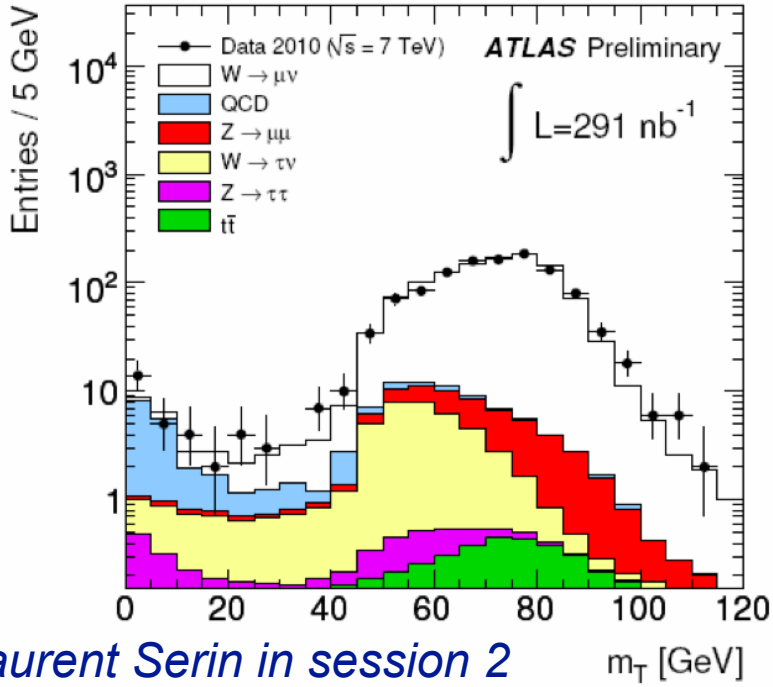
Details on W/Z to leptons at ATLAS in yesterday's talk from Laurent Serin in session 2

Standard Model W/Z observation at ATLAS

- Observation of 815 W → eν and 1111 W → μν candidates for lumi of ~300 nb^{-1}
  - Lepton p_T > 20 GeV/c
  - Isolation cut
    - Electrons: absolute calorimeter isolation
    - Muons: relative track isolation
  - MET > 25 GeV
  - Transverse mass: $m_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$
  - Good agreement with MC predictions



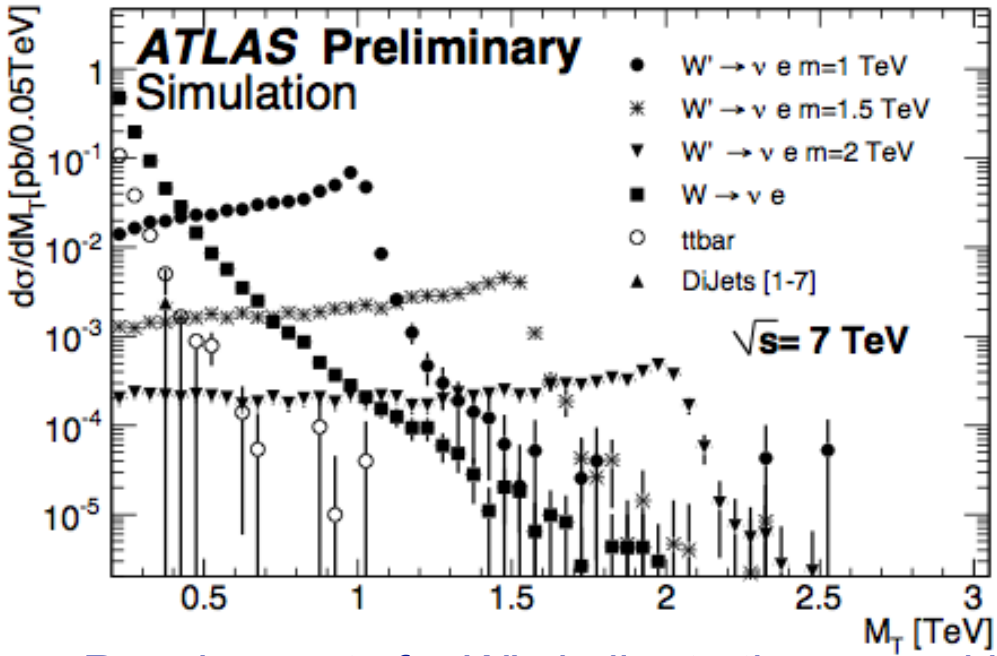
- Observation of 56 Z → ee and 106 Z → μμ with ~300 nb^{-1}
  - In agreement with NNLO expected x-section

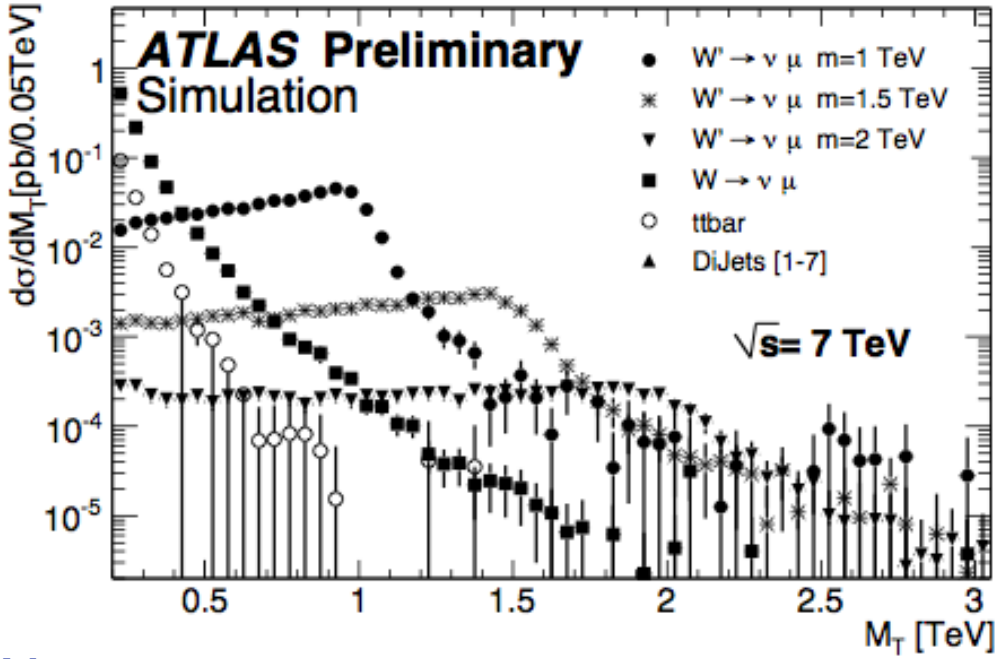


- Important results for exotic searches:
  - Analysis strategy for W' searches similar to SM
  - Will tune MC using SM regions

Details on W/Z to leptons at ATLAS in yesterday's talk from Laurent Serin in session 2

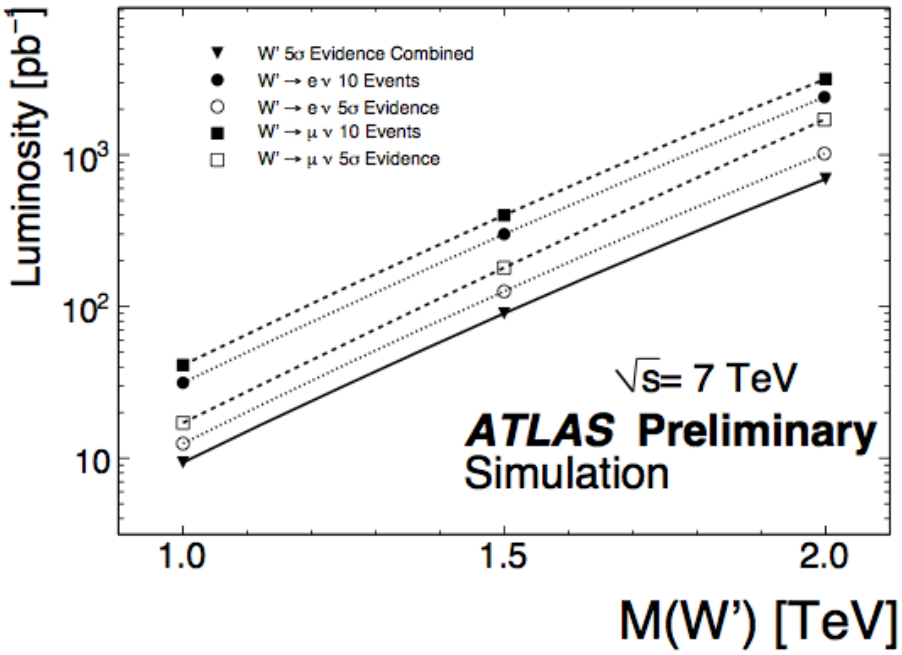
W' → lν expectation from simulations





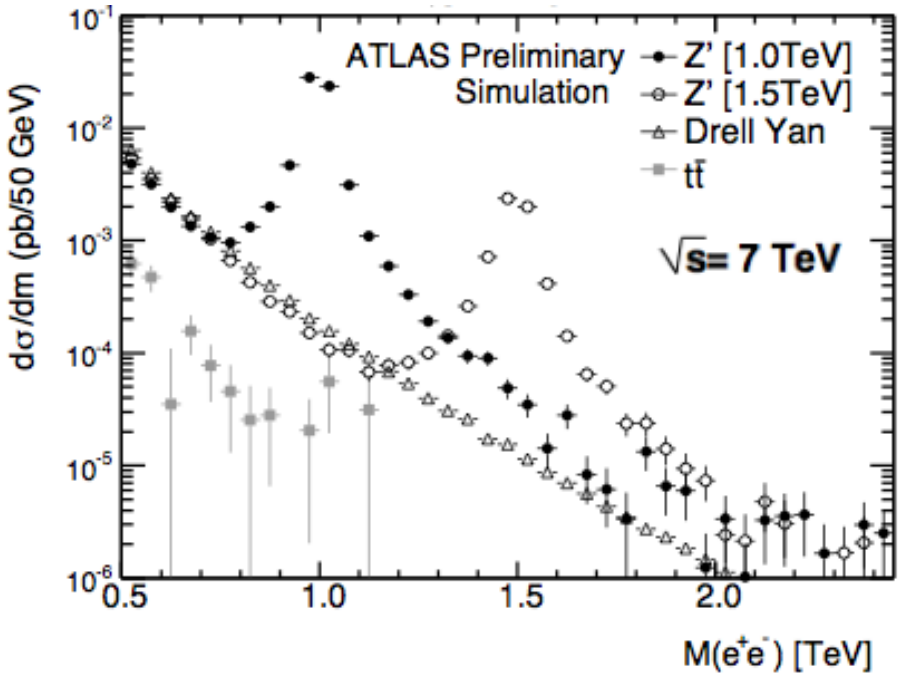
- Requirements for W' similar to those used in SM
  - Lepton p_T cut raised to > 50 GeV/c
  - Raise thresholds on MET to > 50 GeV
  - Apply central jet veto
  - Lepton fraction

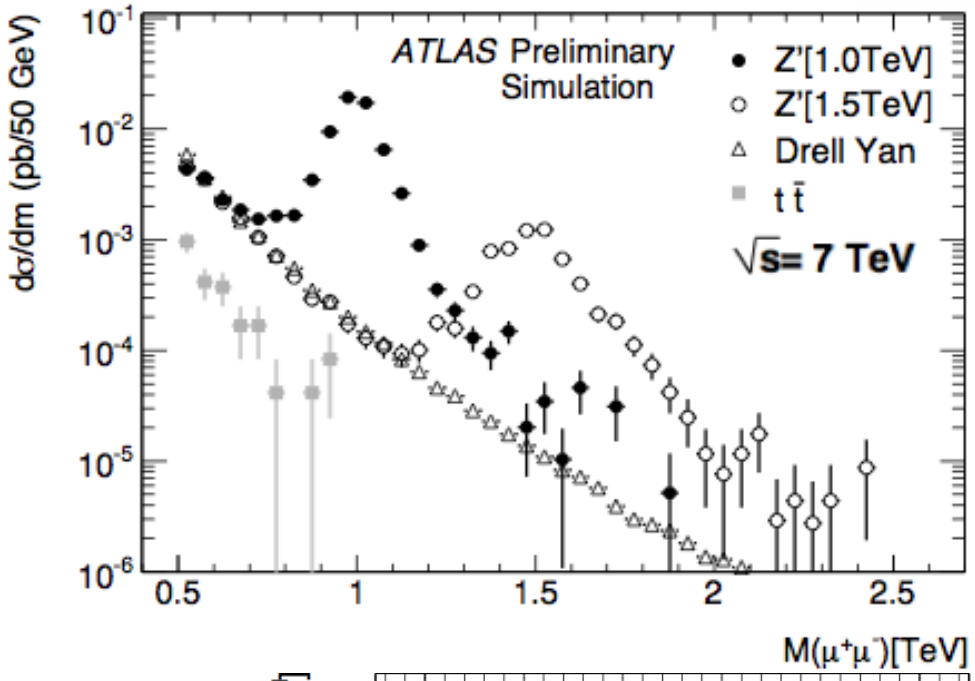
- Clear separation between signal and background in transverse mass spectrum



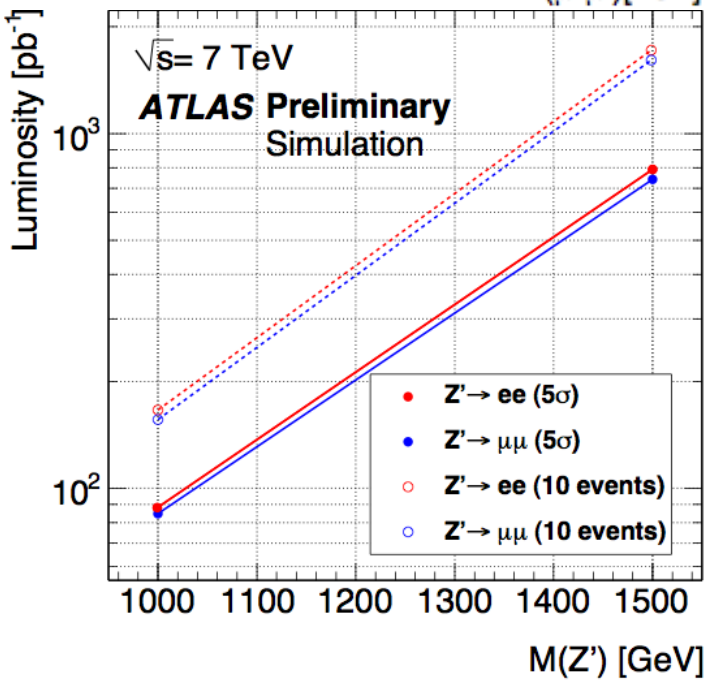
- Discovery possible with as little as ~ 10 pb^{-1}

Z' → 2l expectation from simulations



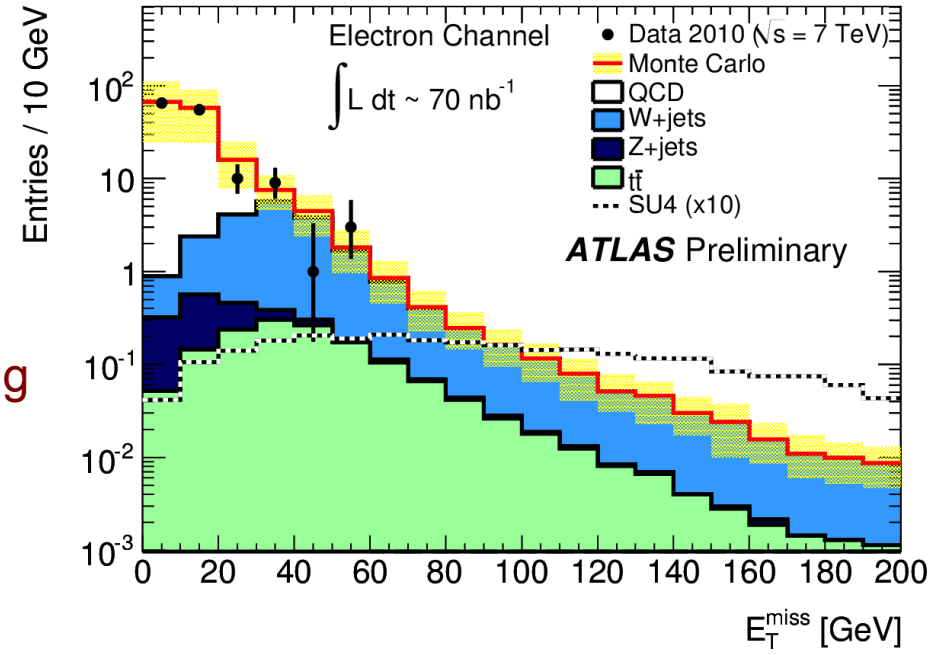


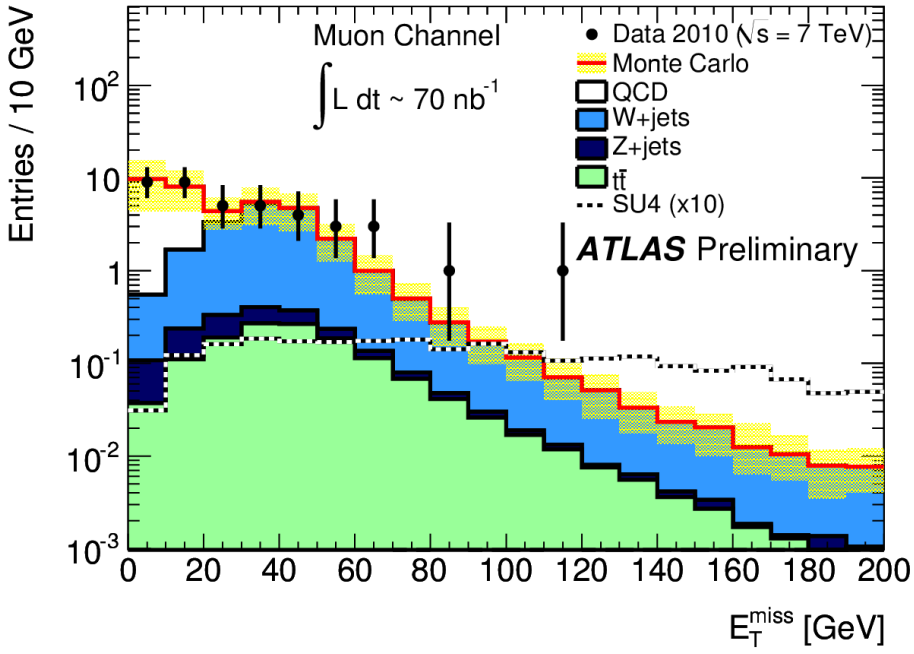
- Z' → 2l is a simple clean signature
  - Two oppositely charged, same flavor leptons
  - Lepton p_T > 20 GeV/c
  - Isolation cuts to suppress QCD and ttbar
- Clear separation between signal and background in invariant mass spectrum
- Discovery possible with ~ 50 pb^{-1}



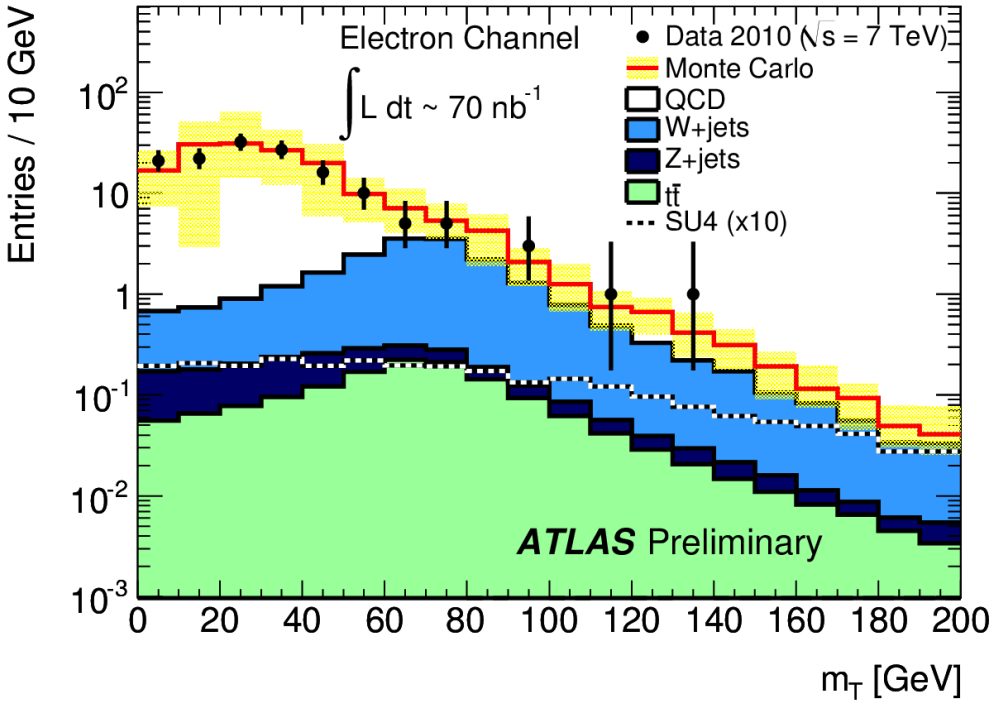
SUSY searches

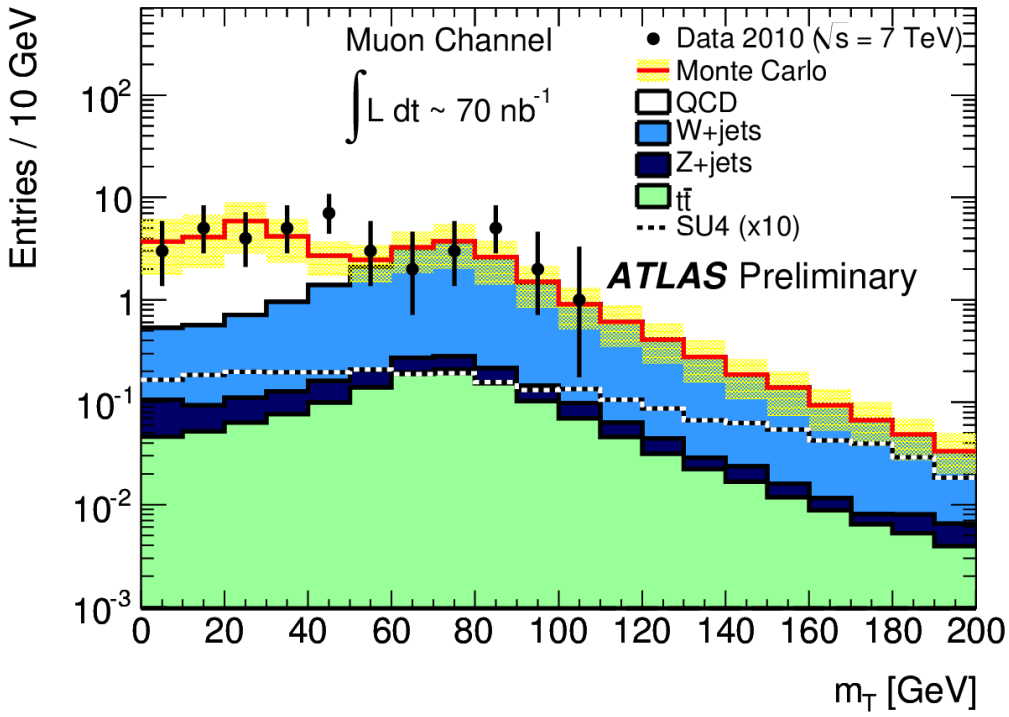
- Aim: Test SM background simulation
  - Data integrated lumi 70 ± 8 nb^{-1}
- Measurements sensitive to SUSY in final states with jets + leptons + MET
  - Sensitive to any model with strongly interacting particles decaying to semi-invisible states
- Supersymmetric mSUGRA SU4 point
  - m_{squark} ~ 400 GeV (Tevatron limit)
  - Inclusive SUSY events σ ~ 60 pb at NLO
- Control regions used for normalizing MC expectations for single lepton channels
  - Pythia QCD:
    - MET < 40 GeV and m_T < 40 GeV
  - Alpgen W + jets:
    - 30 GeV < MET < 50 GeV and 40 GeV < m_T < 80 GeV





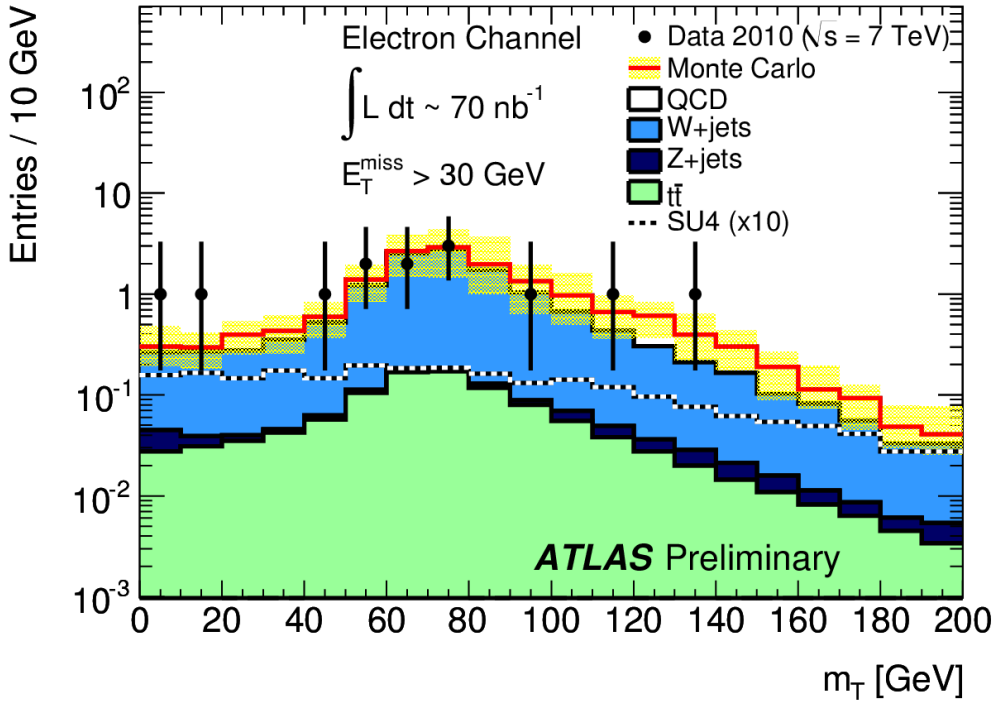
SUSY searches: single lepton channel

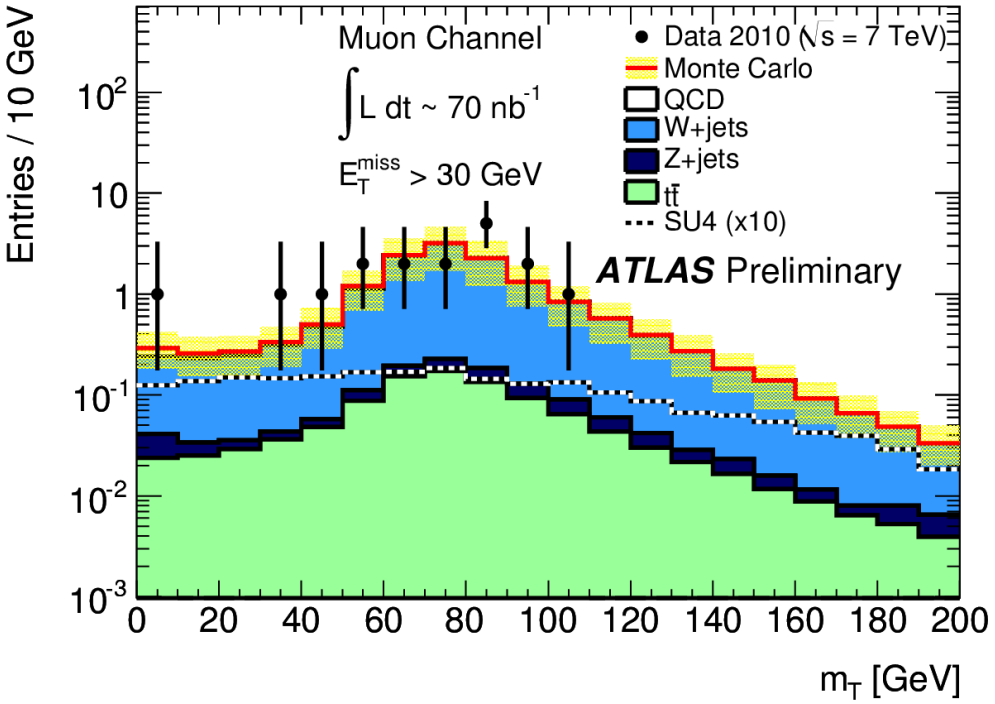




- Required 1 lepton with p_T > 20 GeV and 2 jets with p_T > 30 GeV
  - Normalized MC using control regions
- Electron channel: 143 events in data compared to 157 ± 85 from MC
- Muon channel: 40 events in data compared to 37 ± 14 from MC

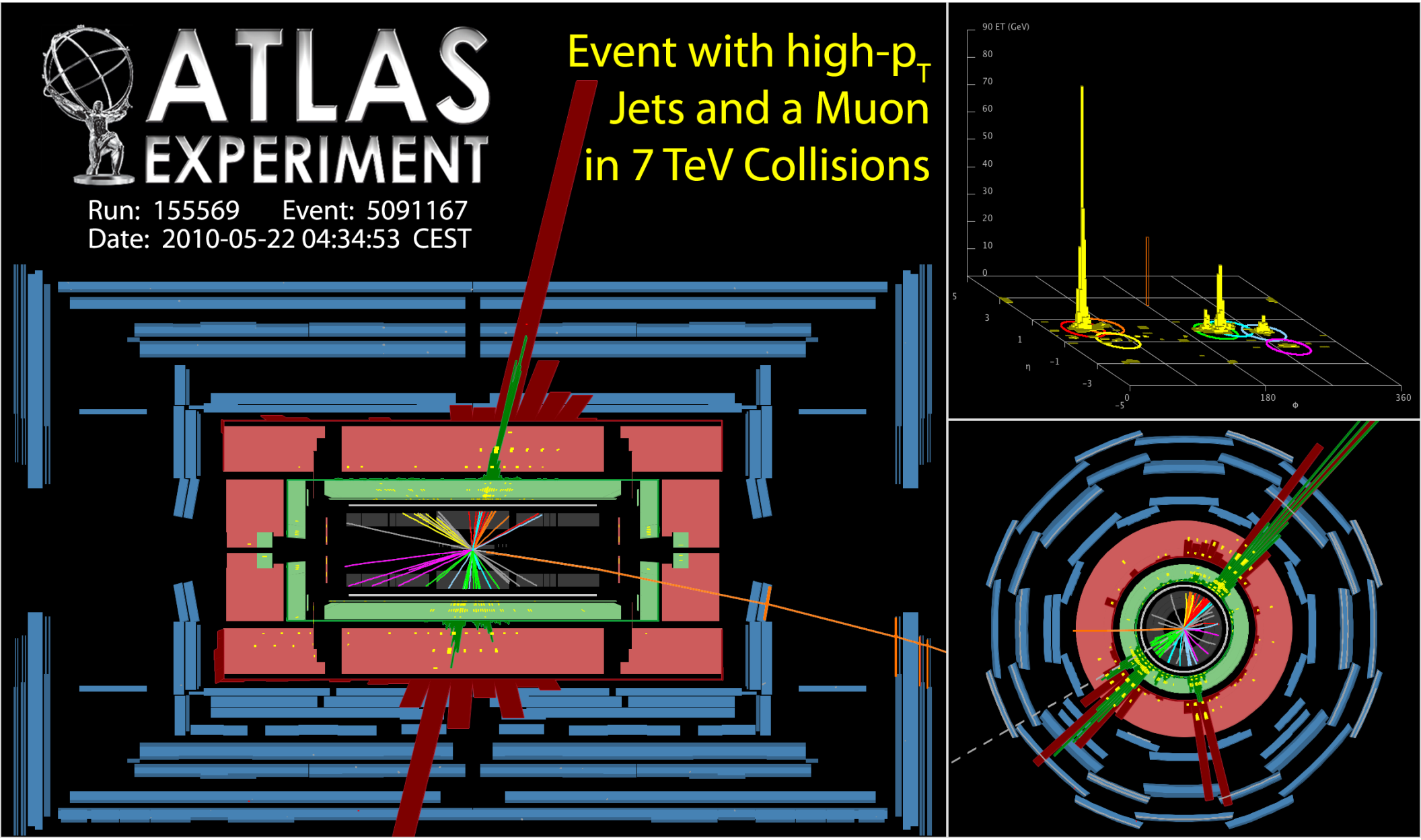
SUSY searches: single lepton channel



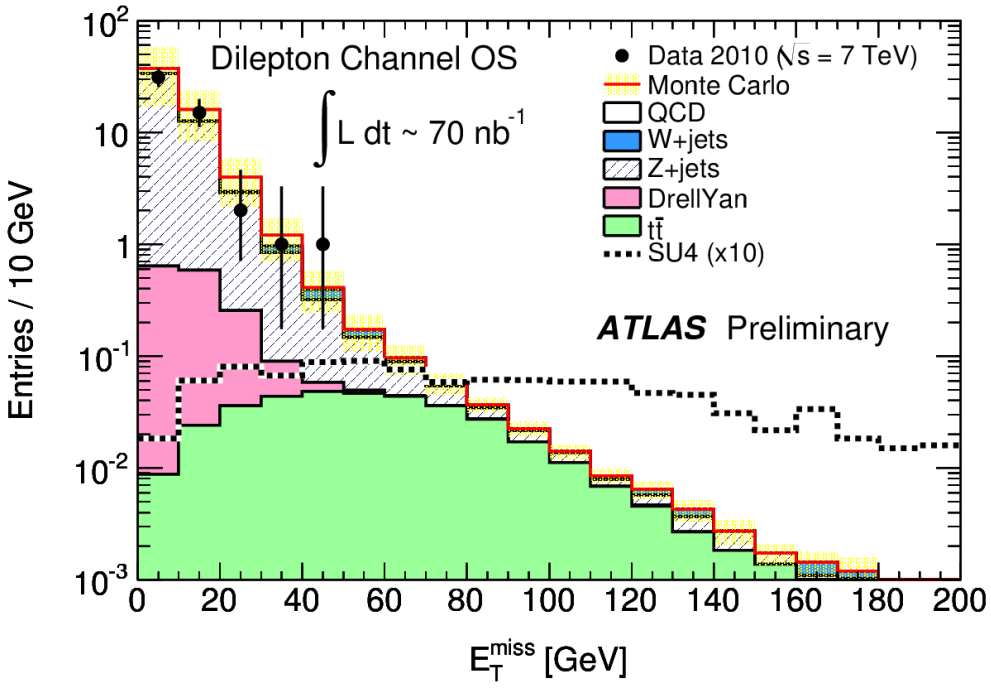


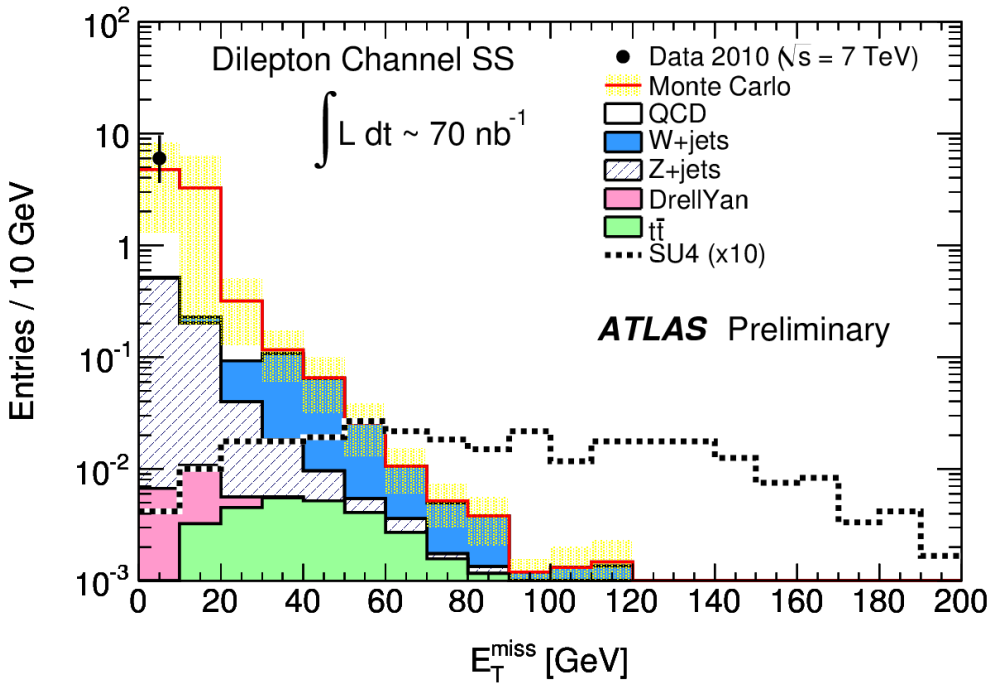
- Required 1 lepton with p_T > 20 GeV and 2 jets with p_T > 30 GeV and MET > 30 GeV
  - Normalized MC using control regions
- Electron channel: 13 events in data compared to 16 ± 7 from MC
  - Requiring m_T > 100 GeV: 2 data events survive compared with 3.6 ± 1.6
- Muon channel: 17 events in data compared to 15 ± 7 from MC
  - Requiring m_T > 100 GeV: 1 data event survives compared with 2.8 ± 1.2

SUSY searches: single lepton channel



SUSY searches: di-lepton channel

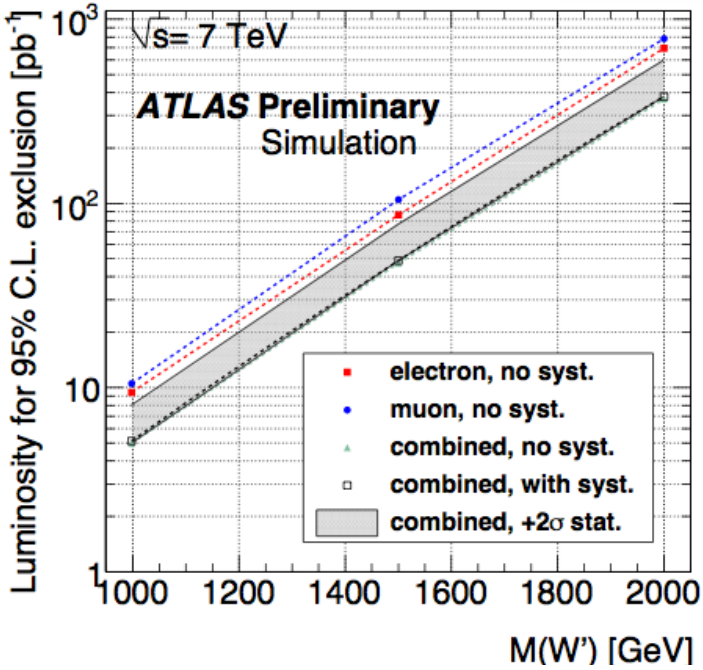


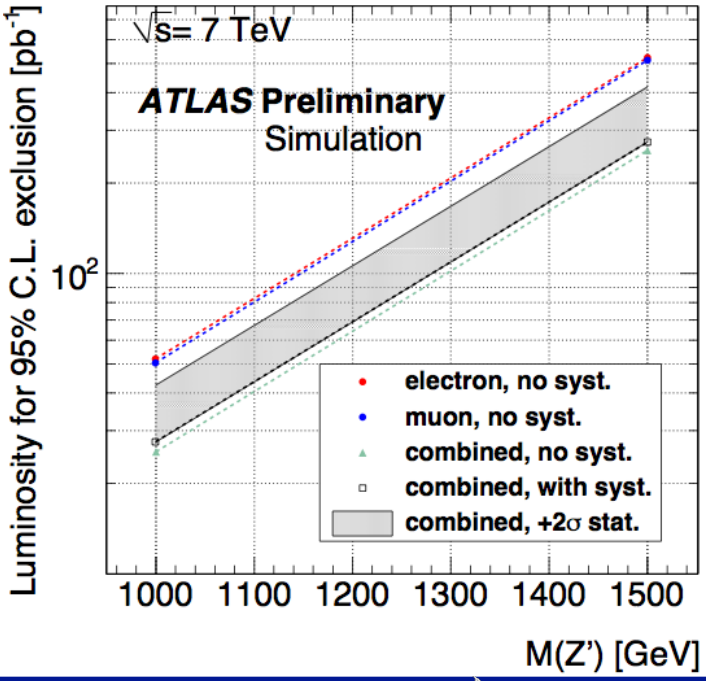


- Require a 2nd lepton (electron or muon) with p_T > 10 GeV/c
- MC Alpgen W + ≥2 jets normalized to QCD cross section
  - Checked rates consistent in QCD dominiated control region
    - 5 GeV < m_{ll} < 15 GeV; MET < 15 GeV
- Requiring MET > 30 GeV
  - Two event remains in OS channel, consistent with MC background predictions 2 ± 0.8

Outlook

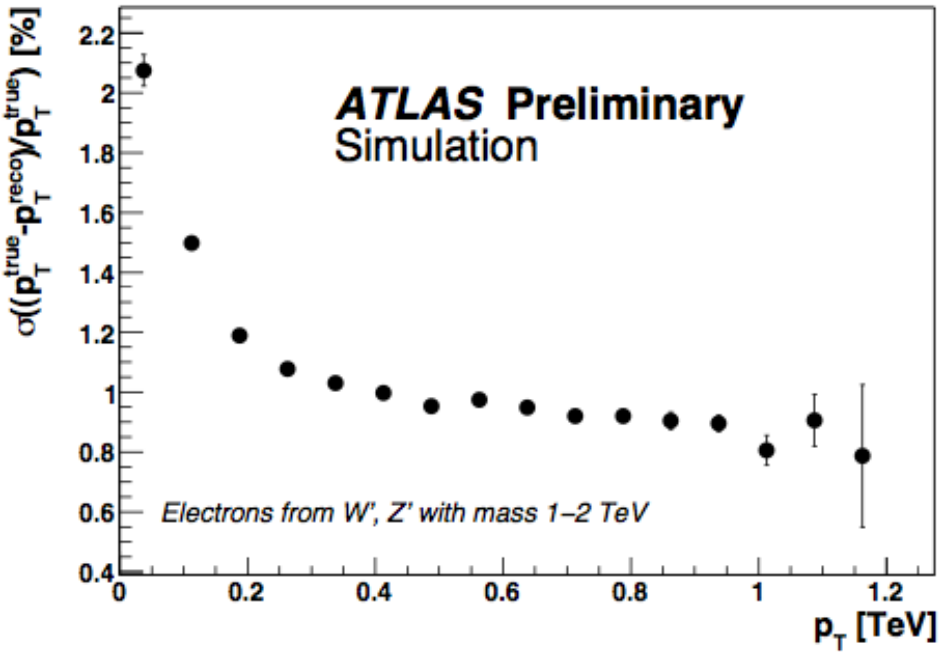
- First results from W/Z observations and SUSY searches indicate that SM background simulations are well tuned
- Data needed to achieve nominal performance
  - Muon momentum scale
  - EM calorimeter energy scale
- Reconstruct about 500 $Z \rightarrow \mu\mu$ / ee per pb^{-1}
  - Nominal performance with ~ 100 pb^{-1}
- Simulations show that W'/Z' exclusion possible with
  - 10 pb^{-1}: $m_{W'} < 1.2$ TeV
  - 100 pb^{-1}: $m_{W'} < 1.6$ TeV; $m_{Z'} < 1.3$ TeV
  - 1000 pb^{-1}: $m_{W'} < 2.5$ TeV; $m_{Z'} < 2.0$ TeV
- Inclusive SUSY searches with leptons:
  - Probe region beyond Tevatron limits with 50 pb^{-1}
- Sensitive to new physics with leptons this fall !

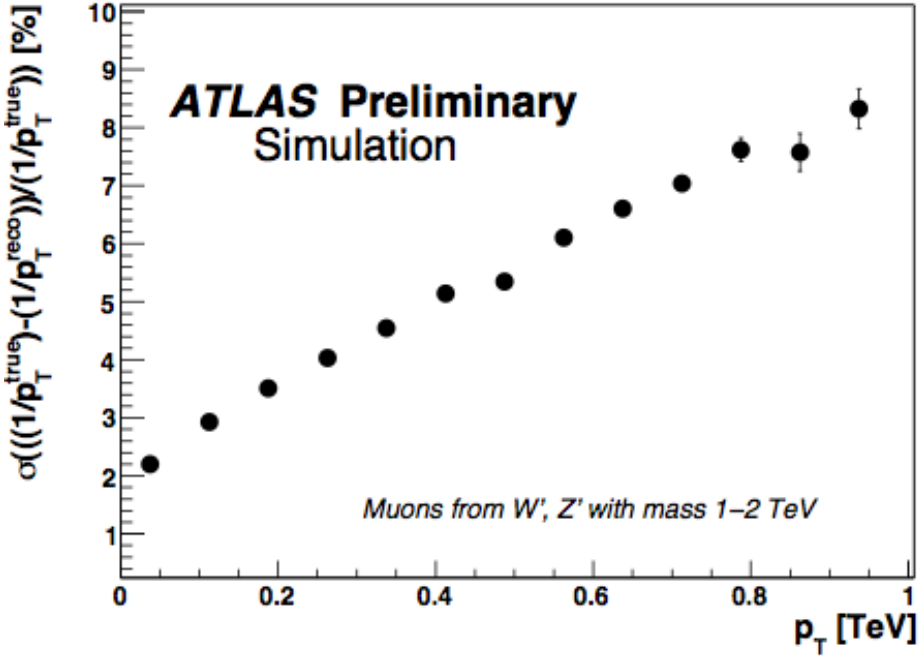




Backup material follows

Expectation from simulations



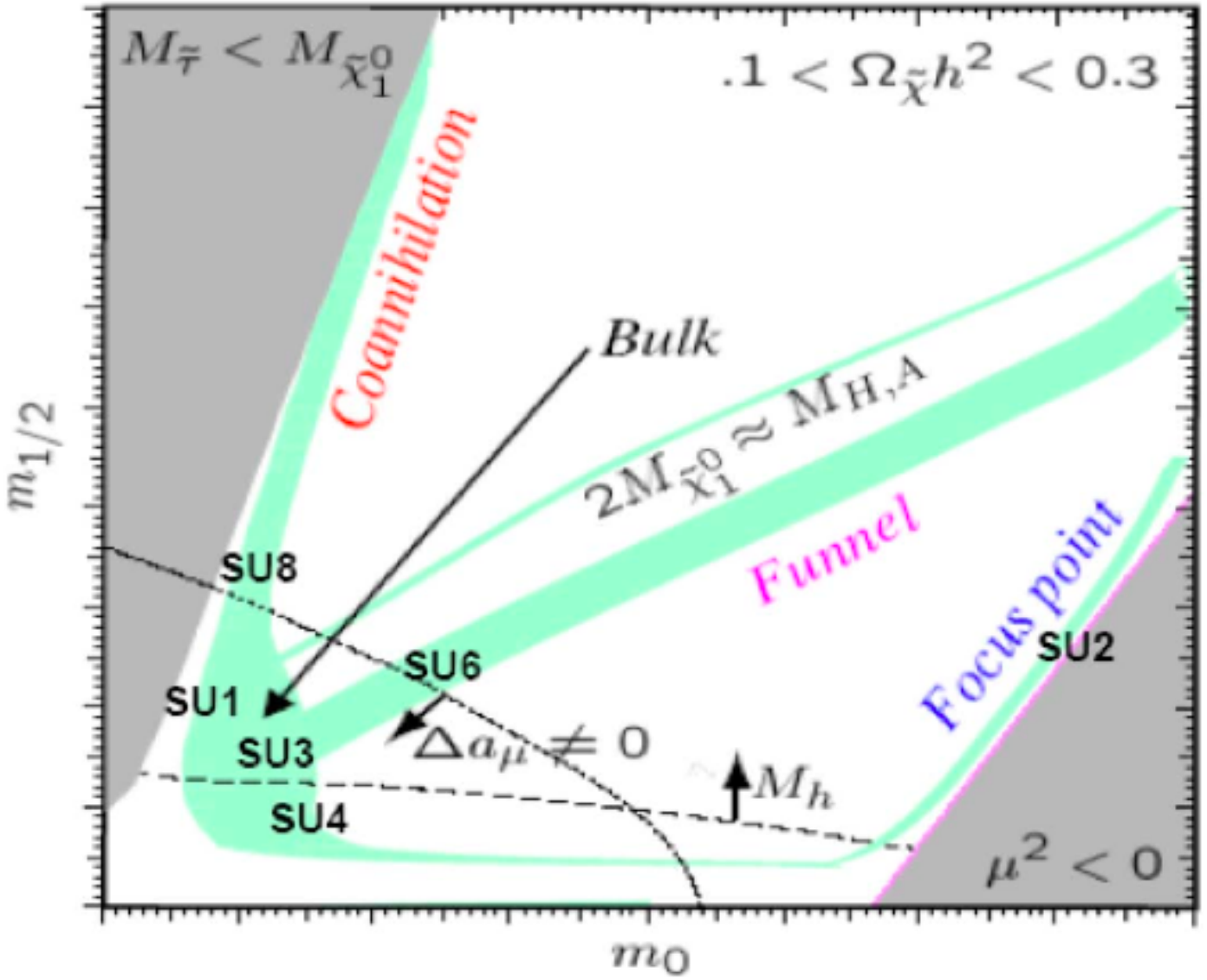


- Assuming 10 pb^{-1}, what can we expect for uncertainties in W'/ Z' to leptons ?
  - Reconstruction +ID efficiency for electrons: 5%
  - Reconstruction +ID efficiency for muons: 10%
  - Energy and momentum scale: 3%
  - Energy and momentum resolution: 100%
  - Jet energy scale: 10% (enters MET computation in W' searches)
  - Overall, 11-20% experimental uncertainties on signal and backgrounds

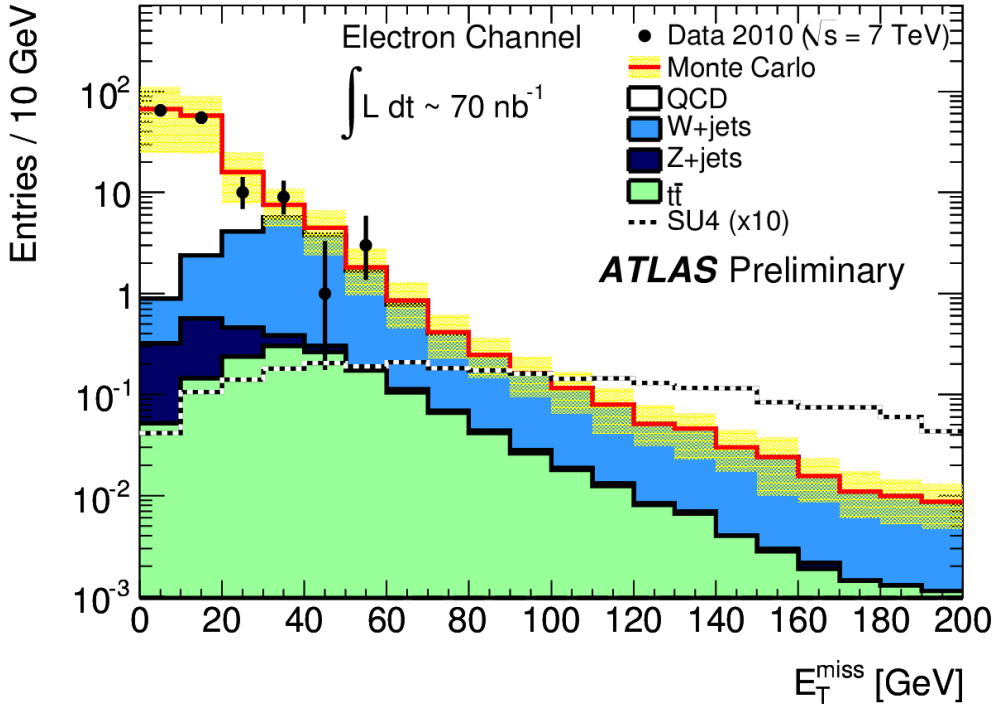
- Significance estimator used in next few slides: $S = \sqrt{2((s+b)\ln(1+s/b)-s)}$

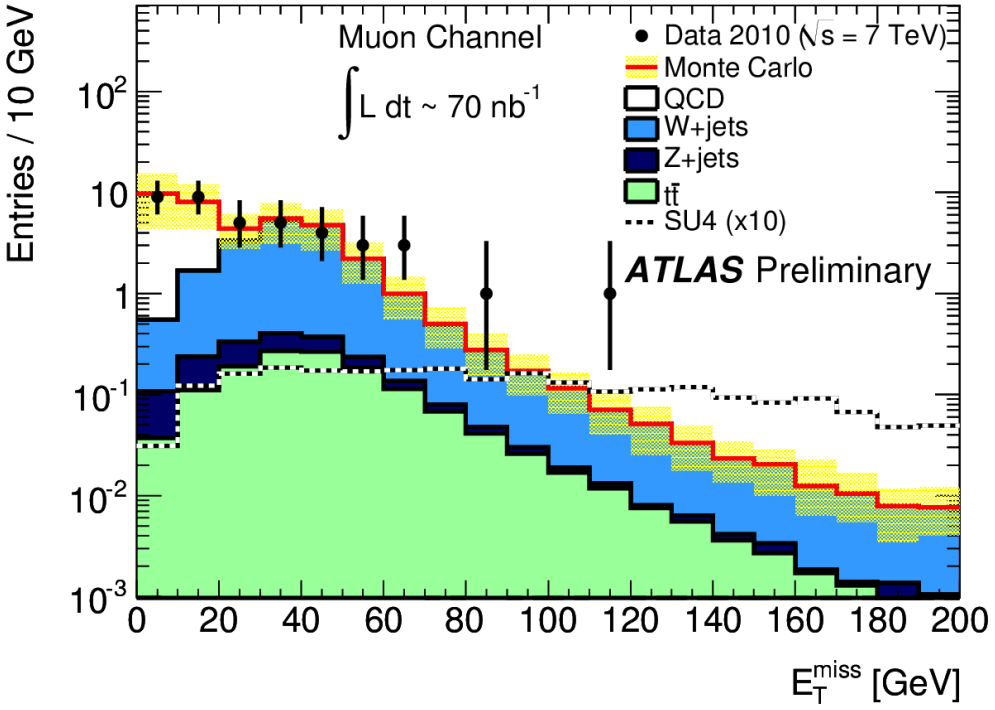
mSUGRA SU4 Point

- SU4 point: low mass point close to Tevatron bound:
  - m_0 = 200 GeV
  - $m_{1/2}$ = 160 GeV
  - A_0 = -400 GeV
  - tan β= 10
  - μ > 0
- Inclusive SUSY events simulated:
  - σ ~ 42 pb at LO
  - σ ~ 60 pb at NLO



Control regions for scaling 1-lepton





- Nice agreement in shape between MC backgrounds and data in control regions
- Scaled MC using ratio of data/MC yields in control regions
  - Pythia QCD (LO): MET < 40 GeV; m_T < 40 GeV
    - Factor for electron channel: 71 / 144.8 = 0.49
    - Factor for muon channel: 12 / 18.5 = 0.65
  - Alpgen W+jets: 30 GeV < MET < 50 GeV; 40 GeV < m_T < 80 GeV
    - Factor 8 / 3.8 = 2.5 ±1.5
    - Limited statistics + compatible with one

SUSY: more plots for 1-lepton channel