New Physics with the *ATLAS* detector: *experimental prospects*

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GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

BMBF-Forschungsschwerpunkt ATLAS Experiment

Physics on the TeV-scale at the Large Hadron Collider

FSP 101 ATLAS

Overview

Discuss results and preparations for early searches for New Physics with the *ATLAS* Experiment

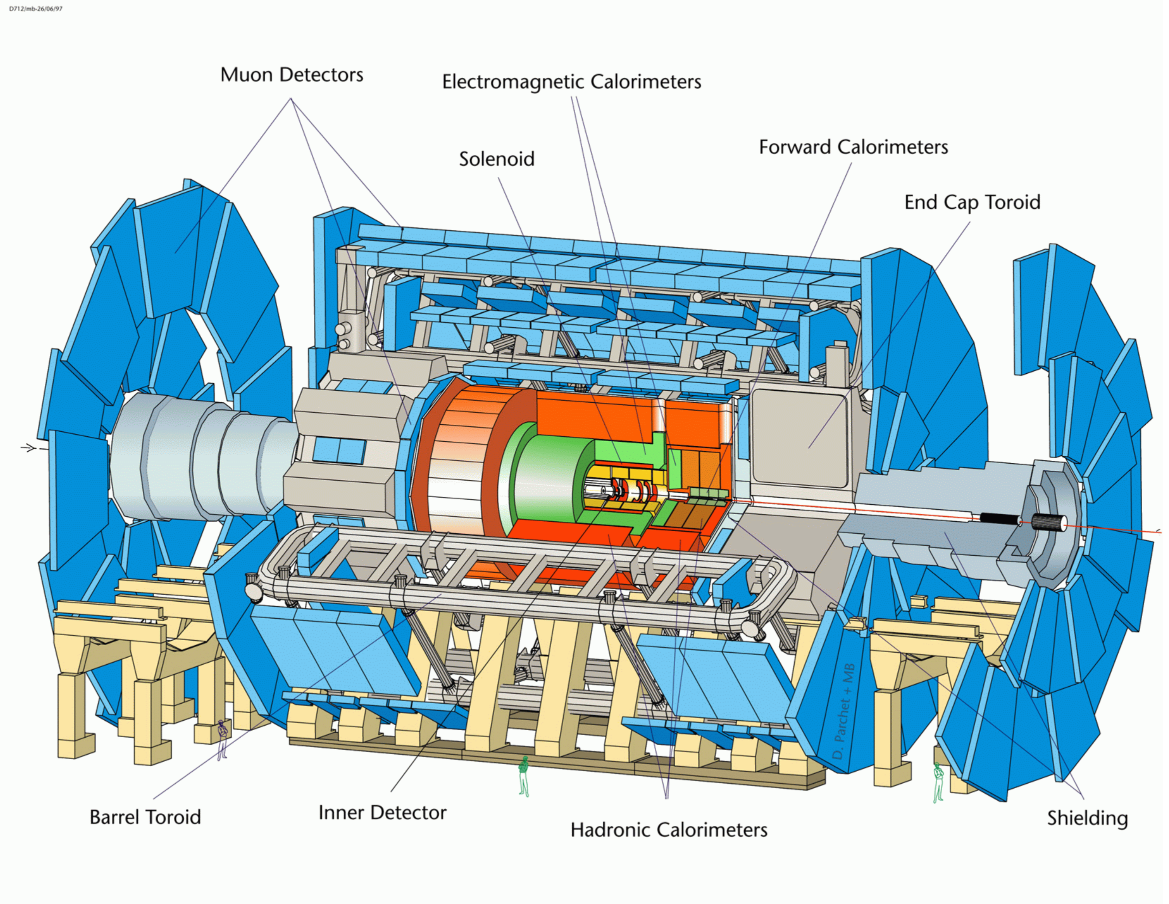
- Di-jet searches
  - high mass final states
  - angular distribution
- High mass Lepton + MET final states
- Universal Extra Dimensions: Di-photon + MET
- SUSY searches
- Conclusion

The *ATLAS* detector at the LHC

Machine parameters (in 2010)

- Center of Mass Energy
  - 7 TeV (*pp* collisions)
- Luminosity
  - L_{peak}=2.1 x 10^{32} $cm^{-2}s^{-1}$
    - up to 4 pile-up events
  - L_{int}~45 pb-1

- Three level trigger
- High resolution vertexing and tracking
- Finely segmented and hermetic calorimeters
- Muon Spectrometer in air core toroidal field



- General purpose detector
  - Optimised for a wide range of physics signatures
  - High p_T leptons, jets, MET

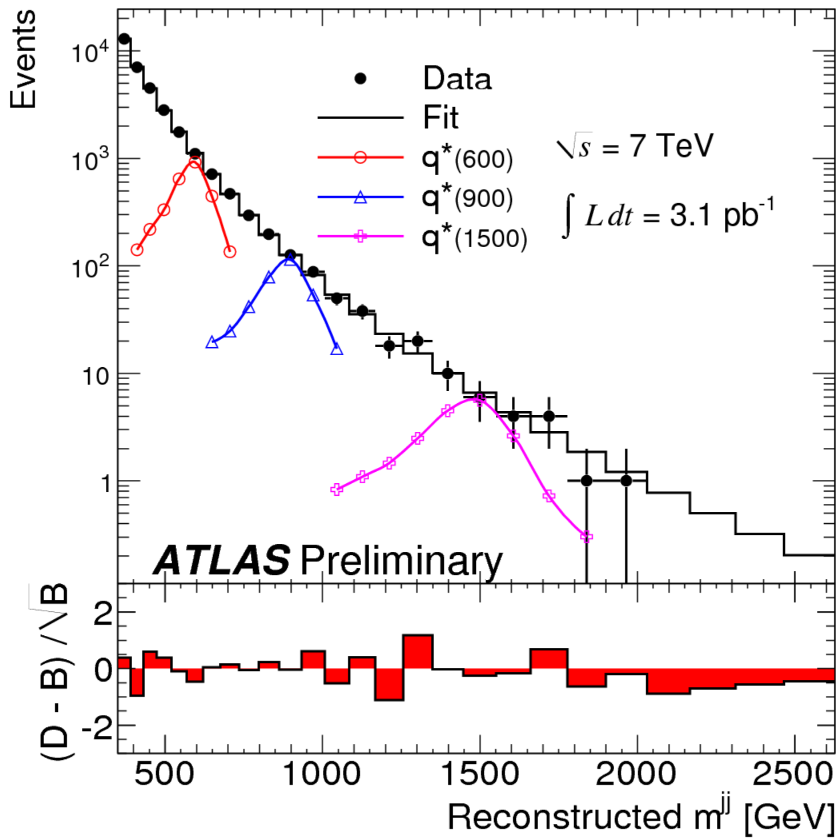
Di-jet searches: *high mass di-jet final states*

Phys. Rev. Lett. 105, 161801 (2010)

- Several theoretical models predict new heavy particles that decay into two energetic partons
  - Benchmark signal: excited quark (q*)
- Invariant mass (very sensitive to new physics)

$$m^{jj} = \sqrt{(E^{j_1} + E^{j_2})^2 - (\vec{p}^{\,j_1} + \vec{p}^{\,j_2})^2}$$

- Di-jet reconstruction and event selection
  - Anti-kT (R=0.6)
  - $p_T^{jet1} > 150$; $p_T^{jet2} > 30$; GeV;
  - $|\eta| < 2.5$; $|\Delta\eta| < 1.3$



Limit from Tevatron (95% CL)

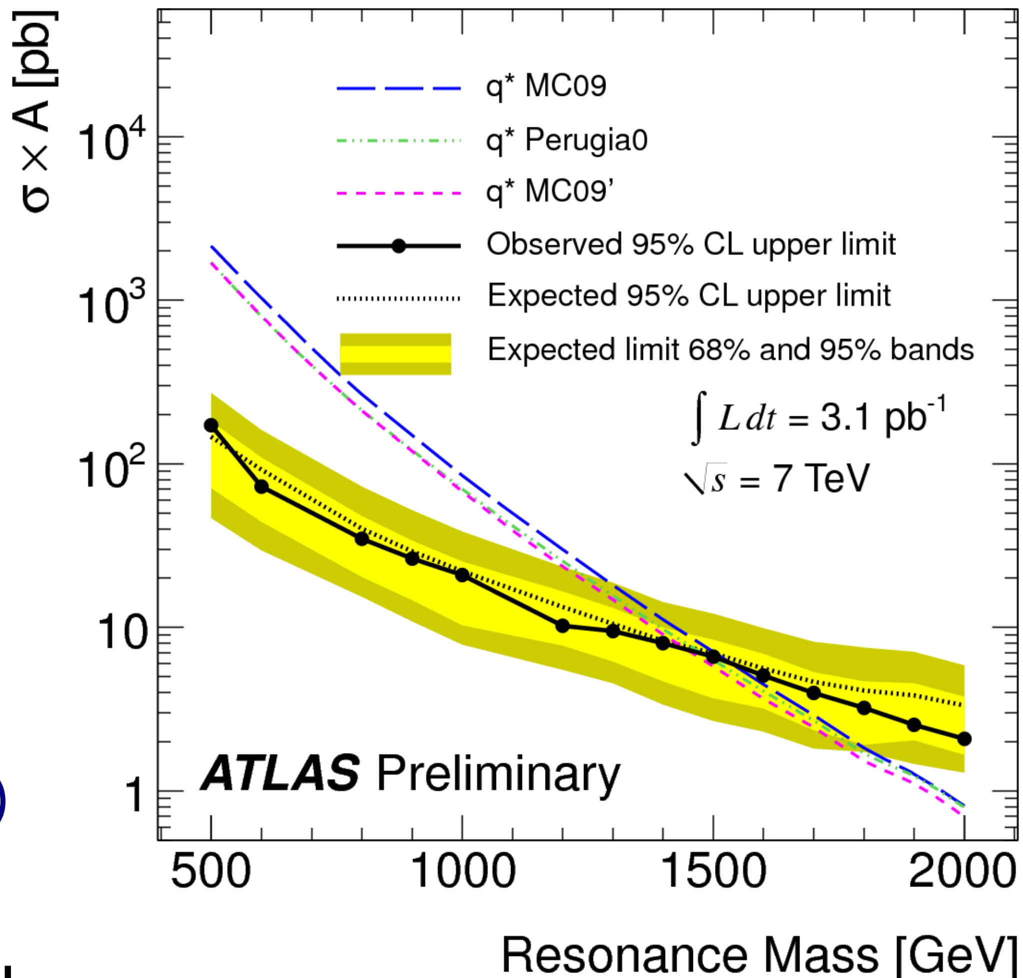
$m_{q*} > 870$ GeV

[CDF collaboration, PRD 79 (2009) 112002]

High mass di-jet final states: *exclusion limit*

Phys. Rev. Lett. 105, 161801 (2010)

- Exclusion limit
  - Cross section x Acceptance
  - Bayesian analysis in the hypothesis that zero signal events are observed
- Systematic uncertainties
  - Jet energy scale (6-9%)
  - Jet energy resolution (14%)
  - Integrated luminosity (11%)



- Excluded at 95% CL

$$\boxed{0.5\ \mathrm{TeV} < m_{q*} < 1.53\ \mathrm{TeV}}$$

Di-jet searches: *angular distribution*

arXiv:1009.5069v1 [hep-ex]

- Goal: look for evidence of New Physics in non-resonant production of di-jets (with rapidities $y_{1,2}$ resp. at pseudo-rapidities $\eta_{1,2}$)
  - Benchmark *qq* contact interactions
- Observables (use together to constraint a signal):

$$\boxed{\chi = \exp(|y_1 - y_2|)}$$

Lorentz invariant related to the CM scattering angle (θ^*)

$$\boxed{R_C = \frac{N(|\eta_{1,2}| < 0.7)}{N(0.7 < |\eta_{1,2}| < 1.3)}}$$

Jet reconstruction algorithm used

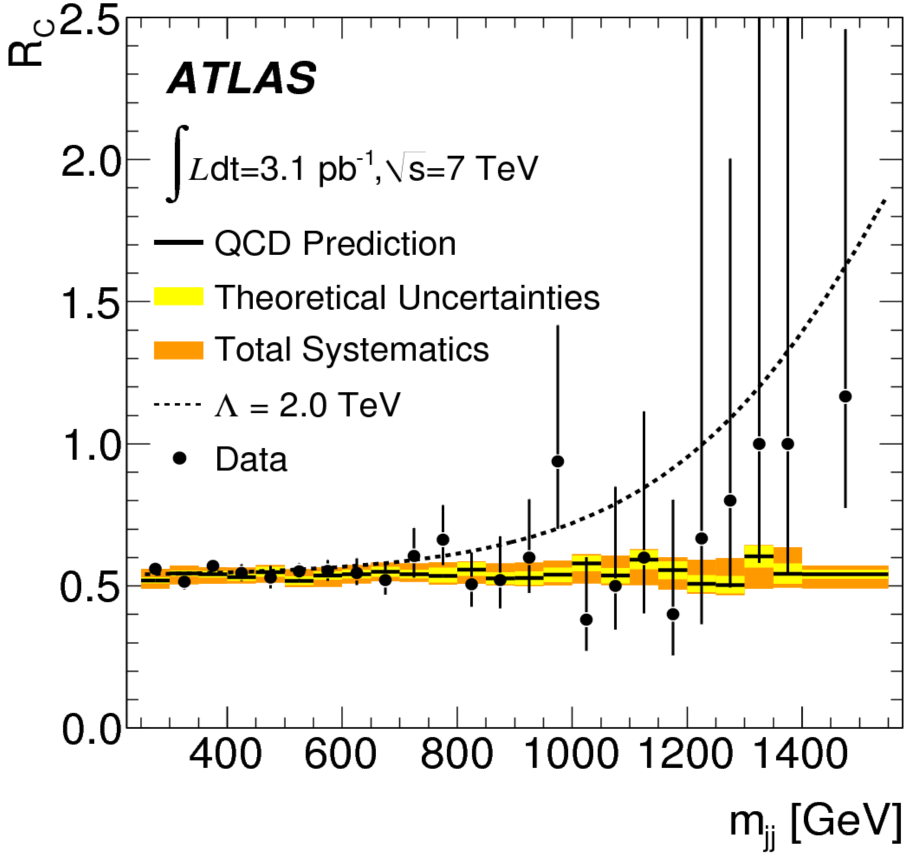
Anti-kT with R=0.6

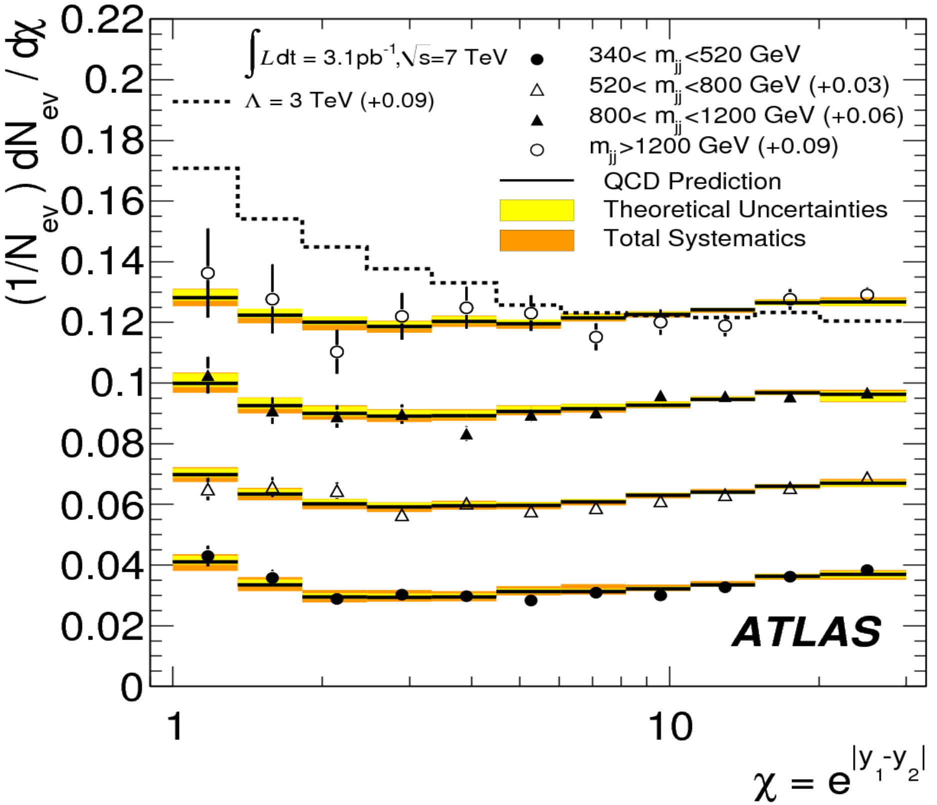
- Both observables are predicted to produce approximately flat distributions for QCD processes
  - Signal: deviation from flatness for di-jet masses above a certain threshold

Di-jet searches: *angular distribution (2)*

arXiv:1009.5069v1 [hep-ex]

- Event Selection:
  - $|\eta^{jet}|<2.8$; $p_T^{j1} > 60$ GeV; $p_T^{j2} > 30$ GeV





Angular distributions mostly independent from jet energy calibration and luminosity. Observed deviation from predicted background not statistically significant.

Di-jets angular distribution: *limit*

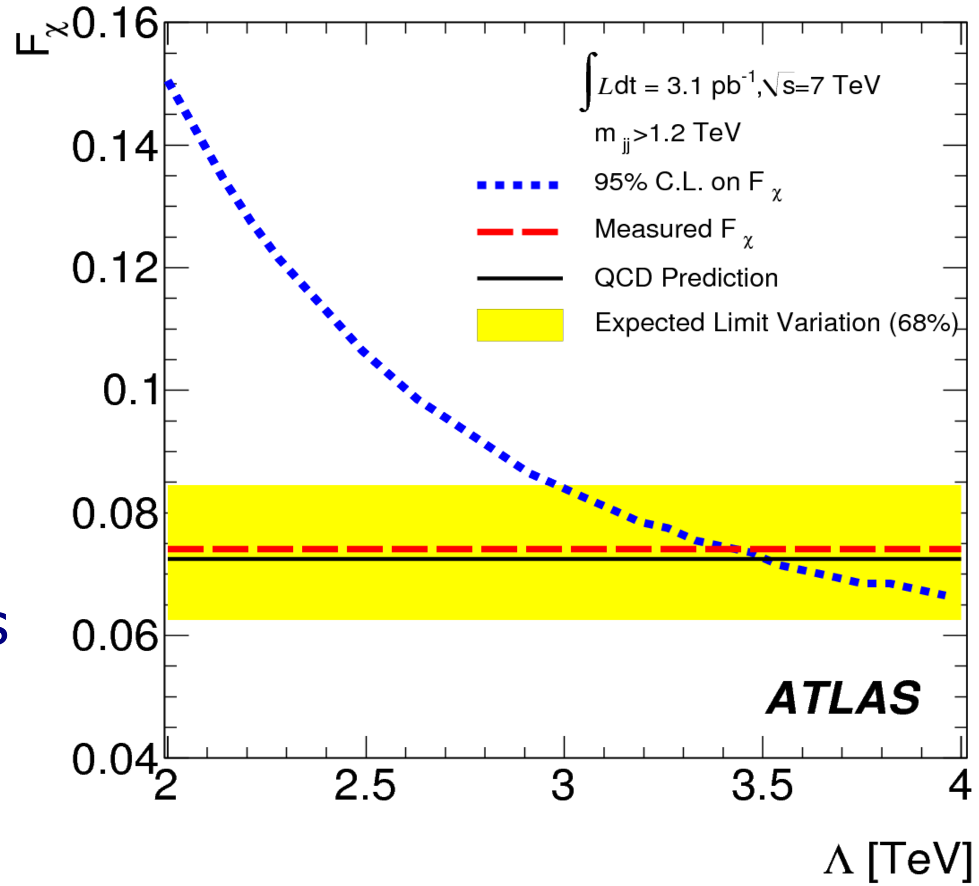
arXiv:1009.5069v1 [hep-ex]

- Use the highest mass bin $m_{jj}>1200$ GeV
- $F_\chi = N_{\chi<3.3}/N_{tot}$
  - $N_{\chi<3.3}$ = number of events with $\chi < 3.3$
  - N_{tot} = total number of events

Previous limit from Tevatron

$\Lambda>2.8$ TeV

[PRL 103:191803,2009]



Contact Interactions below Λ=3.4 TeV excluded at 95% CL

Search for final states with *lepton and Missing E_T*

ATLAS-CONF-2010-089

- Heavy, charged gauge boson decaying into $l\nu$
  - *Benchmark: SSM W'*
  - High-pT lepton + MET, p_T ~ m(W')/2, MET ~ m(W')/2
- Search for evidence of resonances in the m_T spectrum

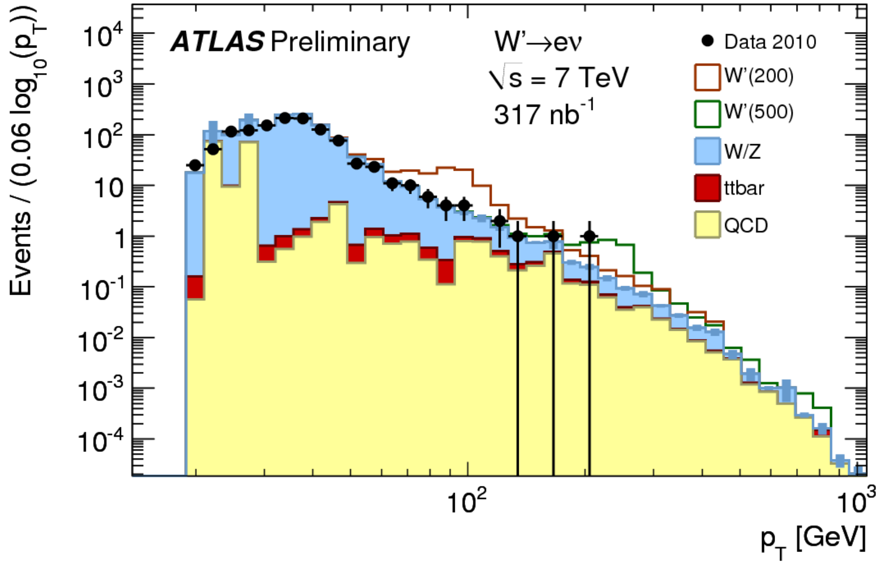
$$m_T = \sqrt{2 p_T \not{E}_T (1 - cos\Delta\phi_{\ell,\not{E}_T})}$$

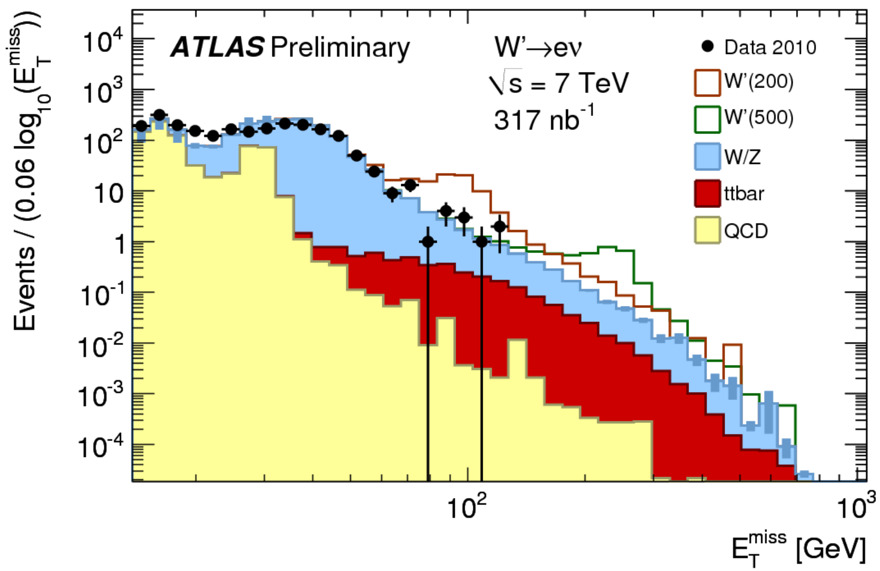
  - Set a limit on cross section times BR, as a function of m(W')
- Current limit: $m_{W'}$>1.0TeV at 95% CL
  - D0 Collaboration, Phys. Rev. Lett. **100** (2008) 031804
- Background dominated by W/Z, ttbar, QCD di-jets
  - QCD dominated by events with one fake electron and fake MET (from the mis-measurement of a jet)

Electron and MissingE$_T$ for high massive bosons

ATLAS-CONF-2010-089

- Use the W peak for detailed comparison with SM prediction
- Detailed study of the electrons with high p_T
  - Very good calorimeter resolution, high Trigger efficiency
  - electron identification cuts optimized for the high p_T regime
- MissingET in good agreement with data
  - Improvements expected from recoil studies on W and Z bosons

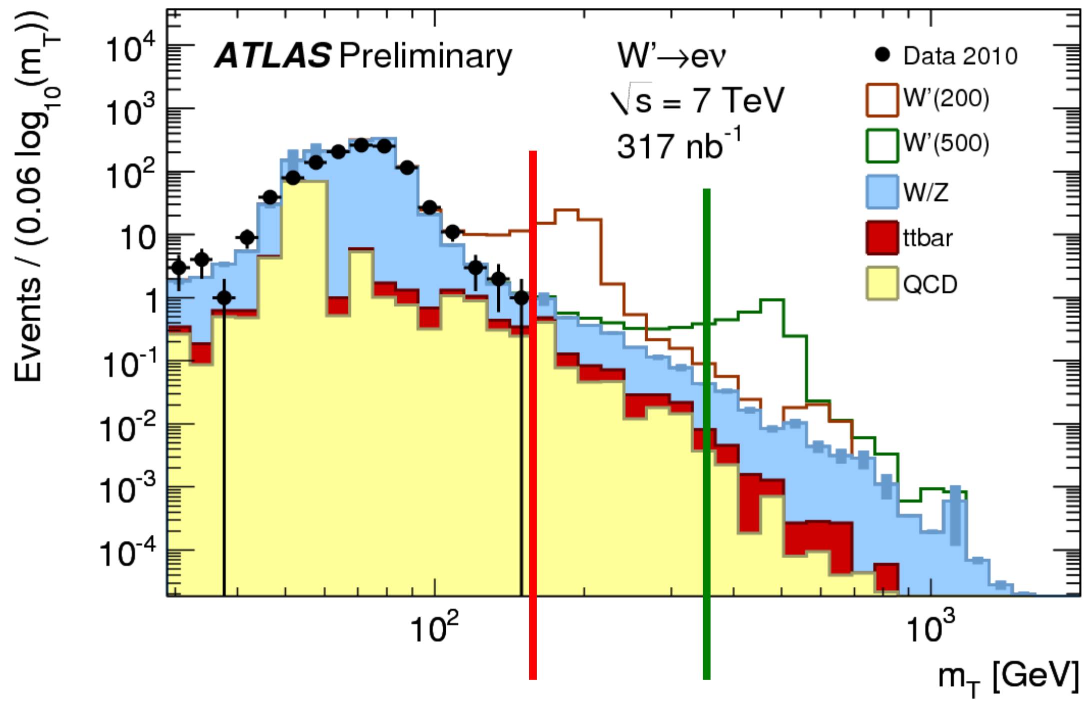




W' → eν : *final selection*

ATLAS-CONF-2010-089

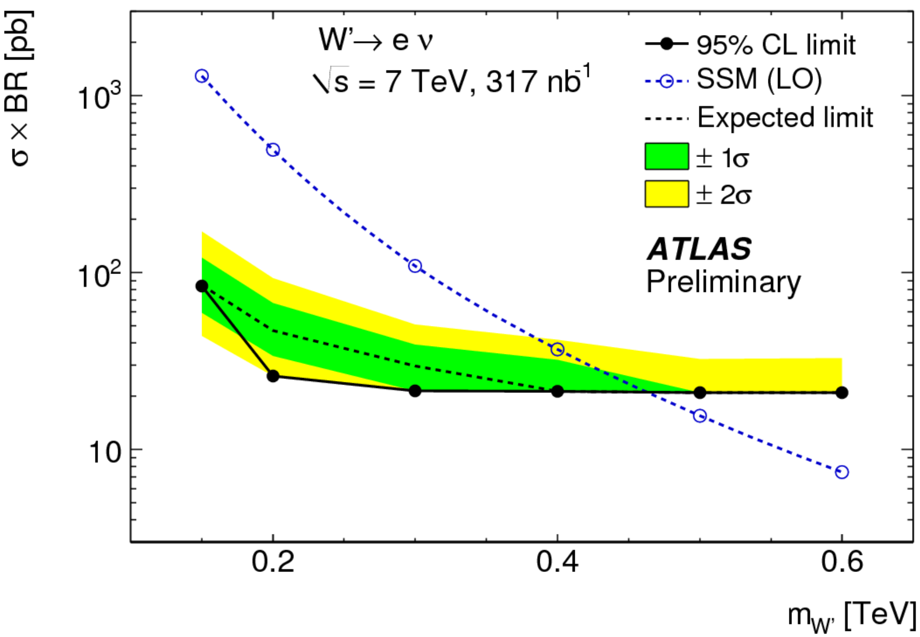
- Reject most of the QCD di-jet background requiring
  - MET > 25 GeV (dominated by fakes)
  - One isolated electron

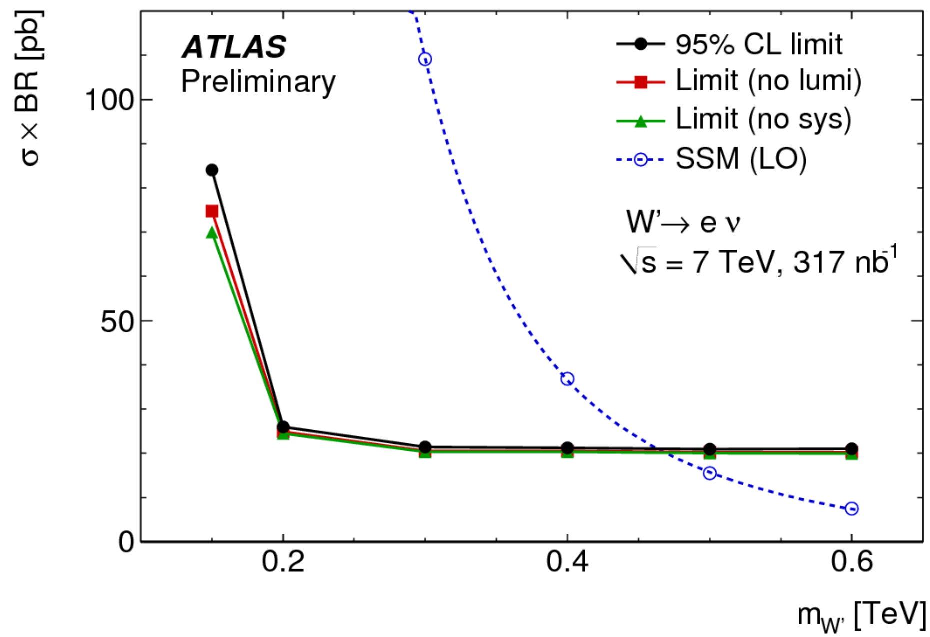


- The Transverse mass is a very powerful observable
  - Cut at 0.7*m(W')
  - With full 2010 statistics we expect to explore a large range in m_T (up to ~500 GeV)

W': *exclusion limit*

ATLAS-CONF-2010-089



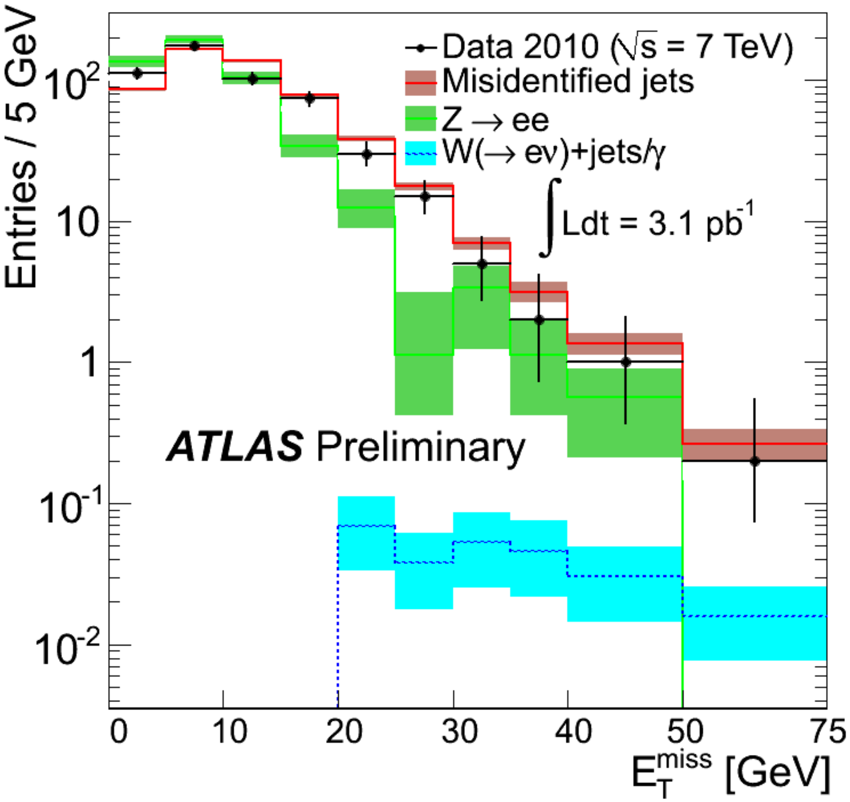


Analysed data equivalent to a luminosity of 317 nb^{-1}

- Systematic uncertainties
  - Luminosity, electron reconstruction, MET, theoretical
- Observed limit within the 2-sigma band
  - Mass limit *(at 95% CL)*: m(W') > 465 GeV
  - Competitive limit expected with the full 2010 statistics

Universal Extra Dimensions: *di-photon + MET*

- UED models postulate the existence of additional spatial dimensions in which SM particles can propagate (one is considered here)
  - Kaluza-Klein excitations
  - For the model considered here the largest UED signature is $\gamma\gamma$+MET+X
  - Limited SM backgrounds
    - $\gamma\gamma$, γ+jet, QCD di-jets
      - MET due to instrumental effects or resolution
    - W → eν (e misidentified as γ) + one real γ or a jet misidentified as a γ (W+jet)



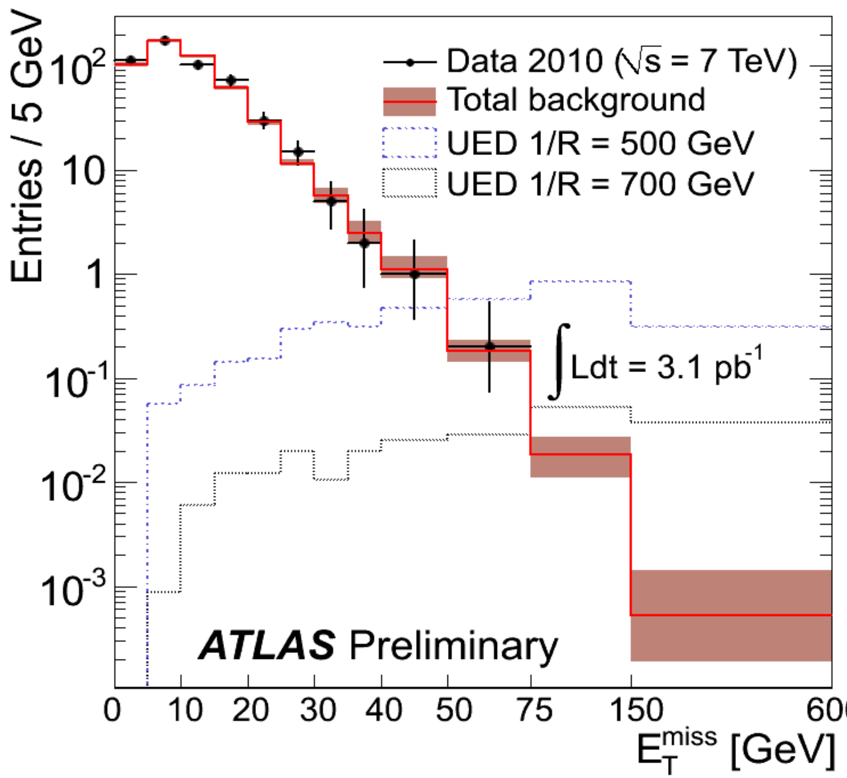
- Negligible background
  - W/Z + $\gamma\gamma$ with the EW boson decaying into a final state with neutrino

Universal Extra Dimensions: *di-photon + MET*

- Signal region MET > 75 GeV
  - Keep expected background below 1 event
- Theoretical model
  - $\Lambda R = 20$
    - Λ is the cut off on the calculation of the radiative corrections to the KK mass spectrum
    - R is the radius of the compactified extra dimension
  - N = 6 (extra dimensions in which only gravity can propagate)
  - M_D = 5 TeV (Planck scale)

Event selection. Two photons

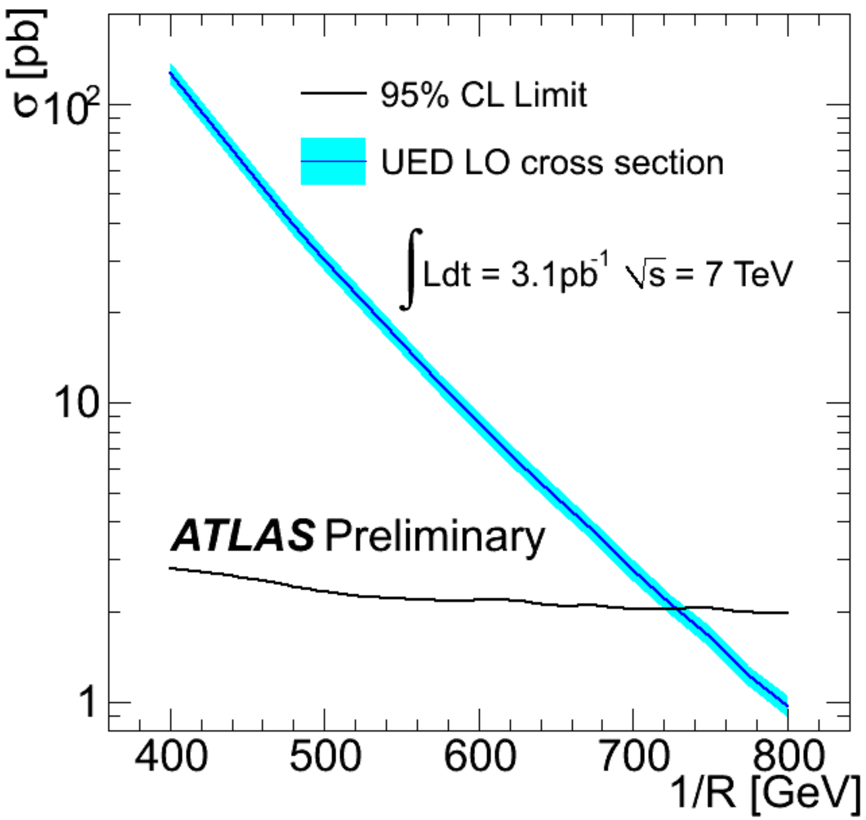
- $E_T > 25$ GeV
- $E_T^{had}/E_T < 0.2$
- $|\eta^\gamma| < 1.37$ or $1.52 < |\eta^\gamma| < 1.81$



Di-photon + MET: *Exclusion limit*

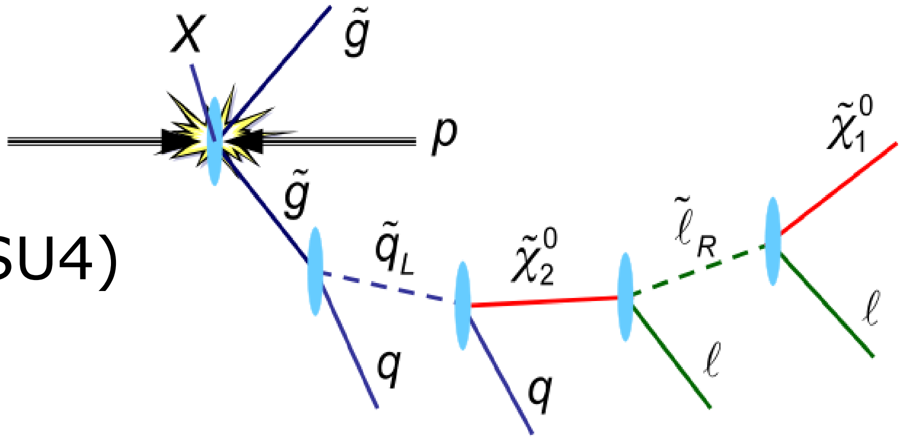
- Good agreement between data and expected backgrounds
  - Set a limit on the UED production cross section
  - Previous limit from Tevatron
    - 1/R < 477 GeV (excluded at 95% CL)

D0 Collaboration, expected for publication in Phys. Rev. Lett. [arXiv:1008.2133]



1/R < 728 GeV excluded at 95% CL

SUSY searches

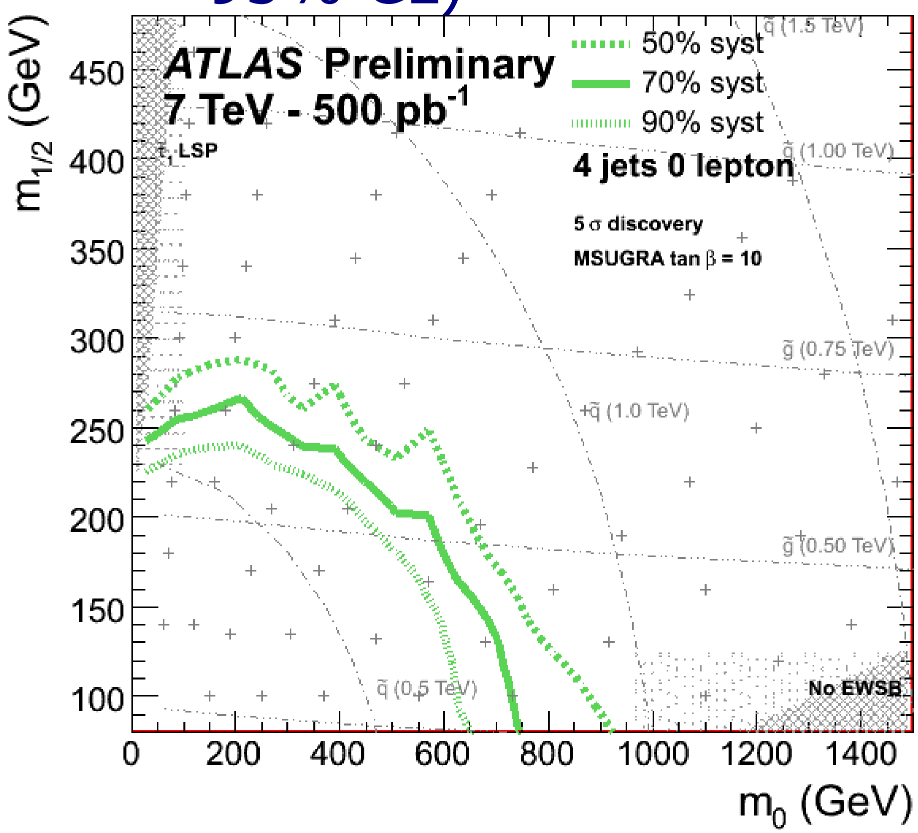


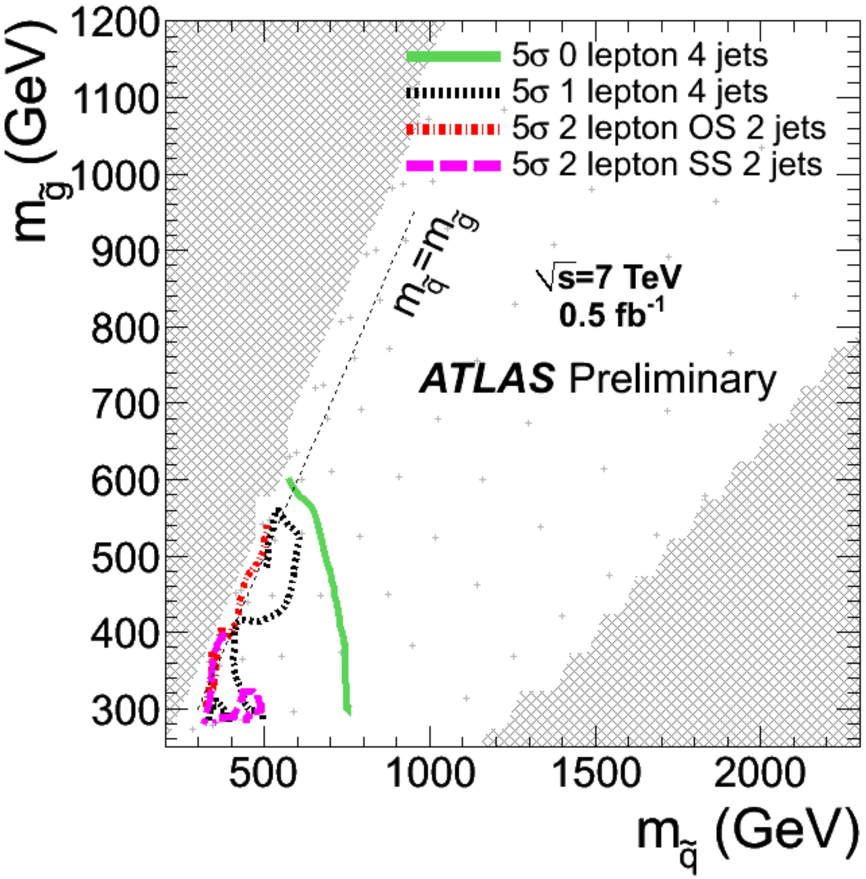
- Inclusive searches
  - Model independent
    - Benchmark model: mSugra (SU4)
  - Understand backgrounds
    - Multi jet final states at a new energy
- SUSY final states
  - MET from undetected LSP
  - hadronic jets, (b-jets)
  - Charged leptons
- Essentially background studies and physics performance so far
  - Check control regions
    - compare with background MC

SUSY signatures: *MET + 4 jets + 0 leptons*

ATLAS-CONF-2010-065 ATL-PHYS-PUB-2010-010

- Best discovery potential (up to ~500 nb^{-1})
  - Could discover up to m_{squark} ~ 700 GeV, m_{gluino} ~ 600 GeV
  - Improve reach of Tevatron (m_{gluino}>390 GeV excluded at 95% CL)

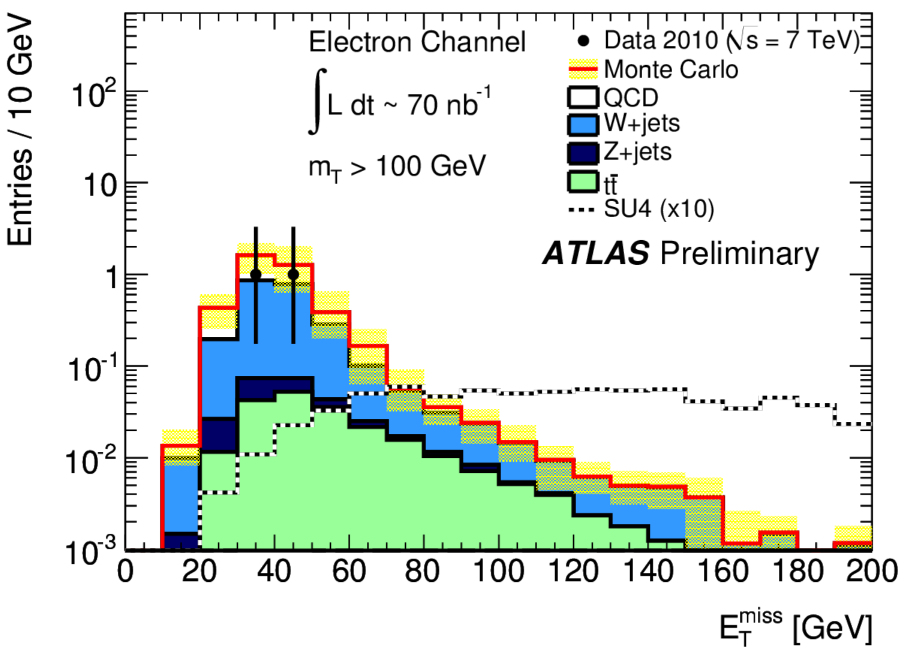


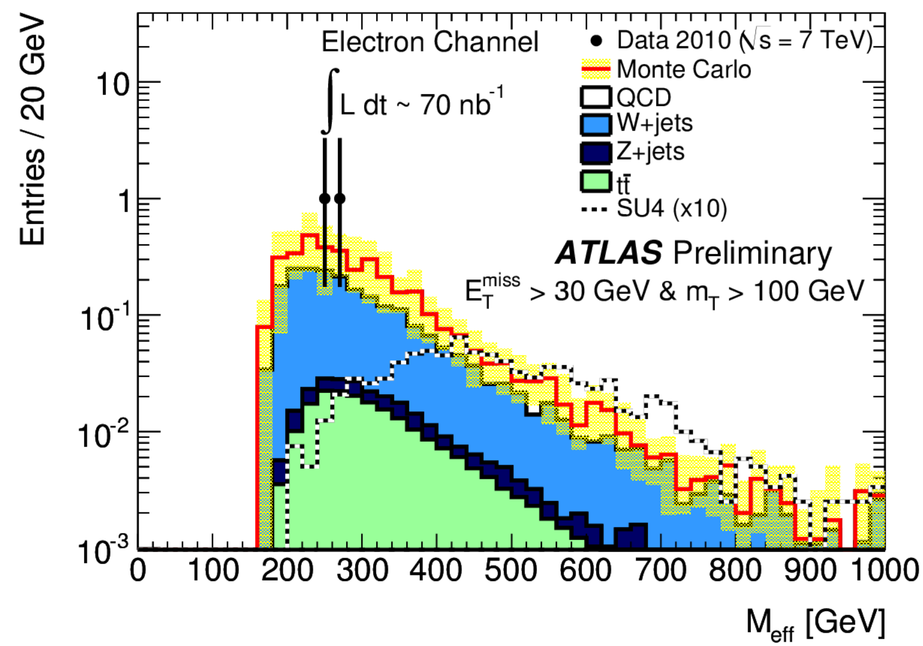


SUSY signatures: *MET + jets + 1 lepton*

ATLAS-CONF-2010-066

- Event selection
  - One lepton (e or μ) with p_T> 20 GeV
  - ≥2 jets with p_T > 30 GeV
  - MET > 30 GeV
- Background dominated by production of EW boson + jets
  - Expectation normalized in side-band regions

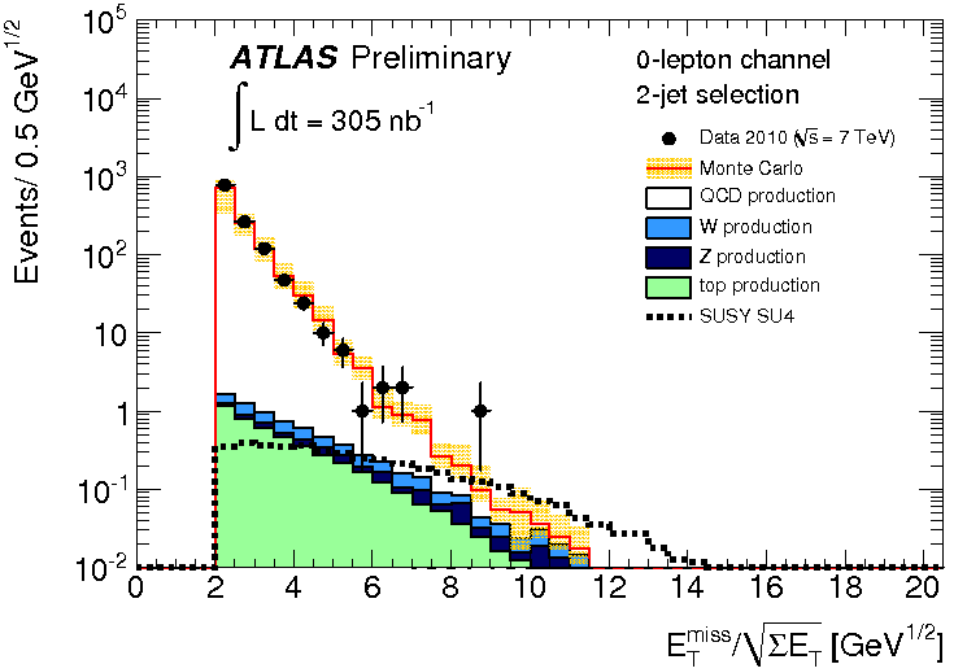


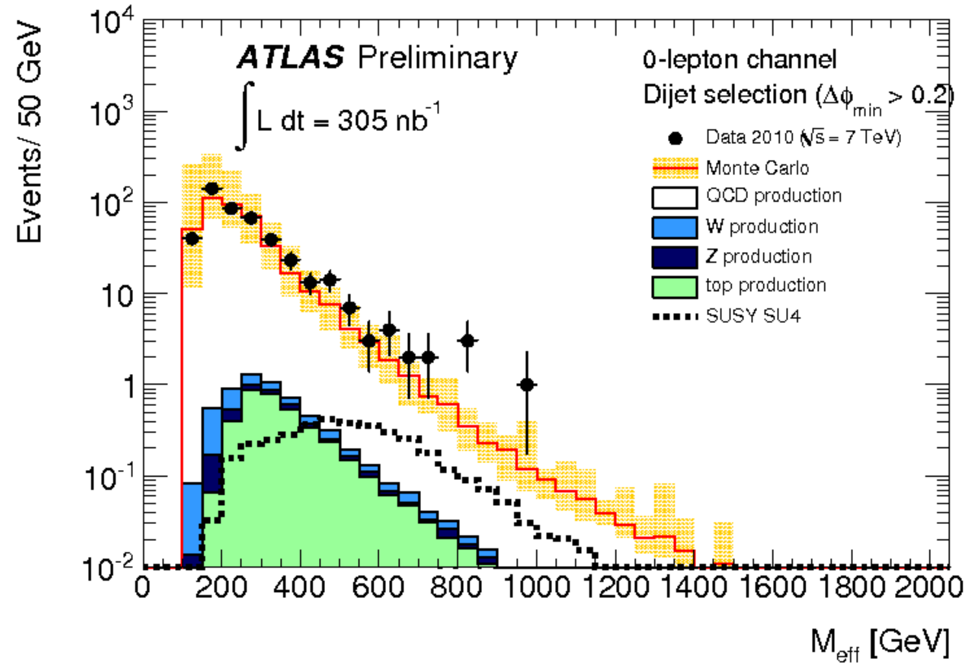


SUSY signatures: *MET + b-jets*

ATLAS-CONF-2010-079

- SUSY signals typically rich in b quarks
  - b-tagging algorithm: reconstructed secondary vertices
    - decay length significance: L/σ > 6
    - Efficiency ~O(50%)
  - Cut on MET significance: **MET/$\sqrt{\Sigma E_T}$ > 2 √GeV**





Conclusion and Outlook

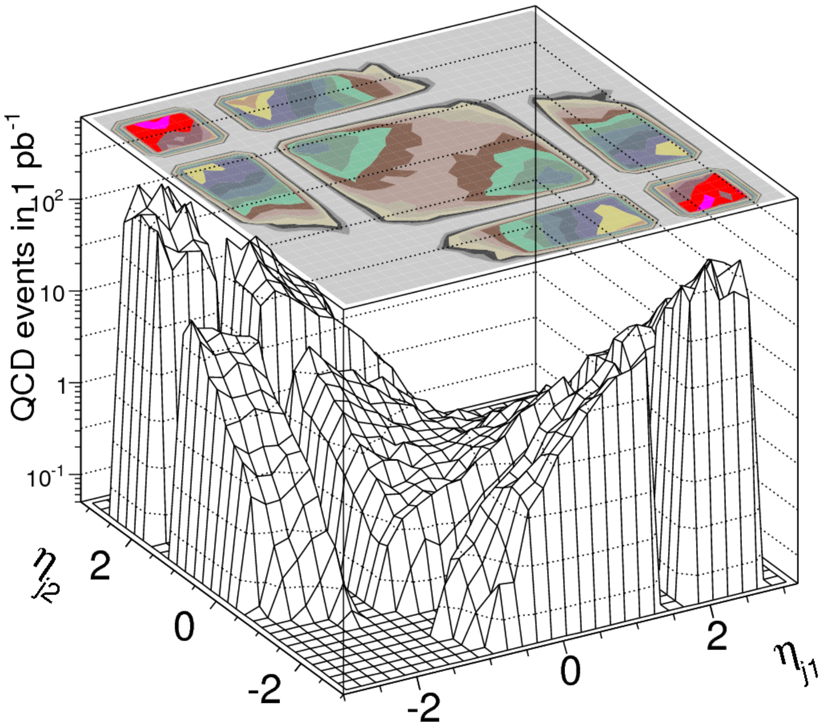
- ATLAS is exploring uncharted territory at the TeV scale
  - In 2010 more than 40/pb of *pp* collisions have been collected at a CM energy of 7 TeV
  - Detector working nicely, performance under control, things progressing very quickly
- Extended limits for New Physics beyond previous experiments
- Important benchmark searches like W′,Z′
- SUSY searches are under way
- Sensitivity to New Physics supported by a very good understanding of backgrounds

Many thanks for your attention!

Spares

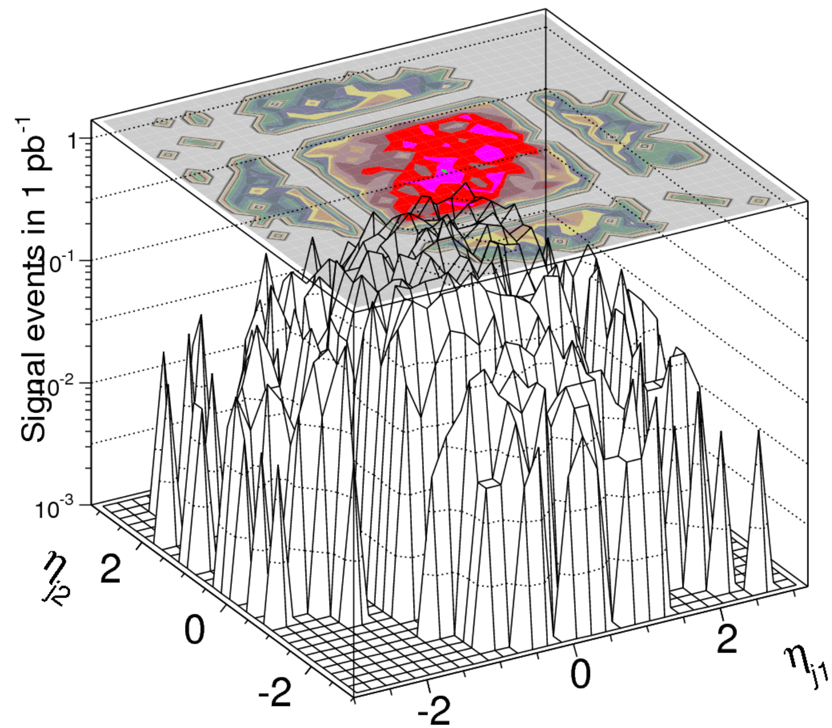
Di-jet final states: *event topology*

QCD
875 <mjj< 1020 GeV



ATLAS Preliminary

q* (1 TeV) signal



ATLAS Preliminary

QCD di-jets are forward (large $\Delta\eta$)

Signal is central

High mass di-jet final states: *event selection and background fit*

- Jet reconstructed with Anti-Kt algorithm (R=0.6)
  - $p_T^{j1} > 150$ GeV, $p_T^{j2} > 30$ GeV
    - Veto events with a third jet with $p_T > 15$ GeV
  - $|\eta^{jet}| < 2.5$ ← **Reject the QCD background**
  - $|\Delta\eta| < 1.3$ ←
  - excluded region $1.3 < |\eta| < 1.8$
  - $m^{jj} > 350$ GeV ← **Prevent kinematic biases**
- Background fitted with:

$$\boxed{f(x) = p_0 \frac{(1-x)^{p_1}}{x^{p_2 + p_3 \ln(x)}} ;\ x = m^{jj}/\sqrt{s}}$$

Also used in Phys. Rev. D 79 (2009) 112002.

- Statistical tests indicate agreement between data and a smooth monotonically decreasing function

W': *event selection*

Initial selection	
Data quality: detector, beam spot, luminosity monitors	
Trigger	
Primary vertex with three good tracks and $\|z\| < 150$ mm	
Jet cleaning	
1 medium electron with $p_T > 20$ GeV	1 combined muon with $p_T > 20$ GeV
electron $\|\eta\| < 1.37$ or $1.52 < \|\eta\| < 2.47$	muon $\|\eta\| < 2.0$
electron in fiducial region	
	$0.5 < p^{MS}/p^{ID} < 2$
	$N_{hit}^{pixel} > 0$, $N_{hit}^{strip} > 3$, $(N_{hit}^{pixel} + N_{hit}^{strip}) > 5$
lepton close to primary vertex: $\|r_0^{PV}\| < 1$ mm, $\|z_0^{PV}\| < 5$ mm	
Exactly one candidate electron	Exactly one candidate muon
Final selection	
Isolation: $R_{isol} < 0.05$	
$E_T^{miss} > 25$ GeV	
Transverse mass bin	
$m_T > 0.7 m_{W'}$	

W': *statistical treatment*

Limits on $\sigma \times$ BR are set for each mass and decay channel (e, μ, e or μ)

- For each mass hypothesis $m_{W'}$, we count the number of events over $0.7m_{W'}$ *(optimized for significance)*
- This number is used to obtain the limit using $CL_s = CL_{s+b}/CL_b$ ("Modified Frequentist Confidence Level") T. Junk, NIM A434 (1999) 435.
- Likelihood ratios built from the Poisson probability for the number of events
  - signal and background uncertainties are integrated over (assuming Gaussian PDF's).

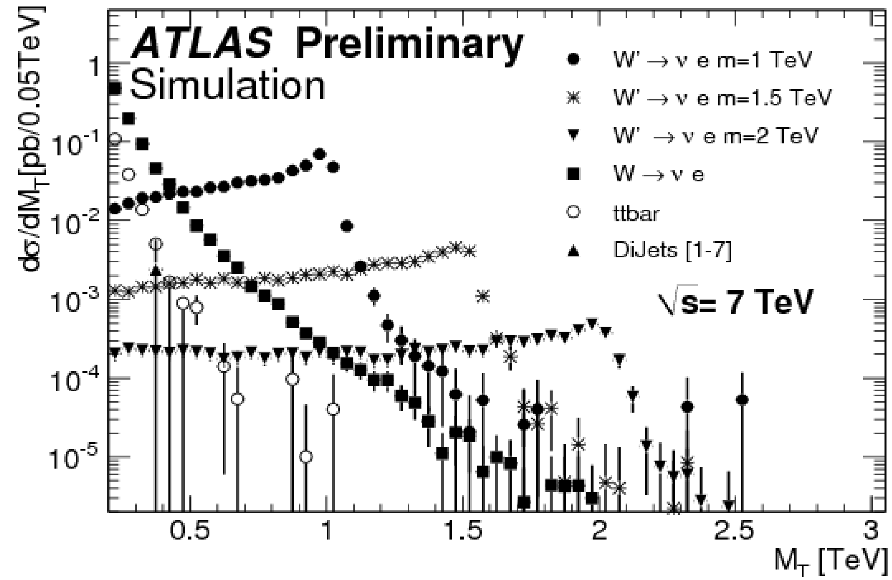
W': *systematic uncertainties*

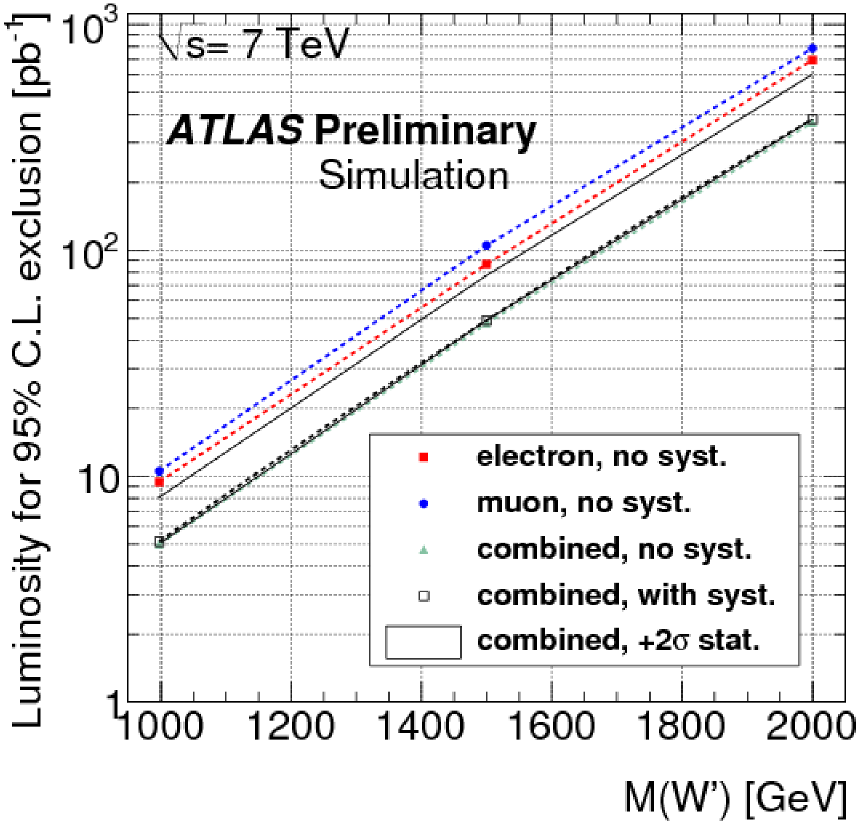
Systematic uncertainties

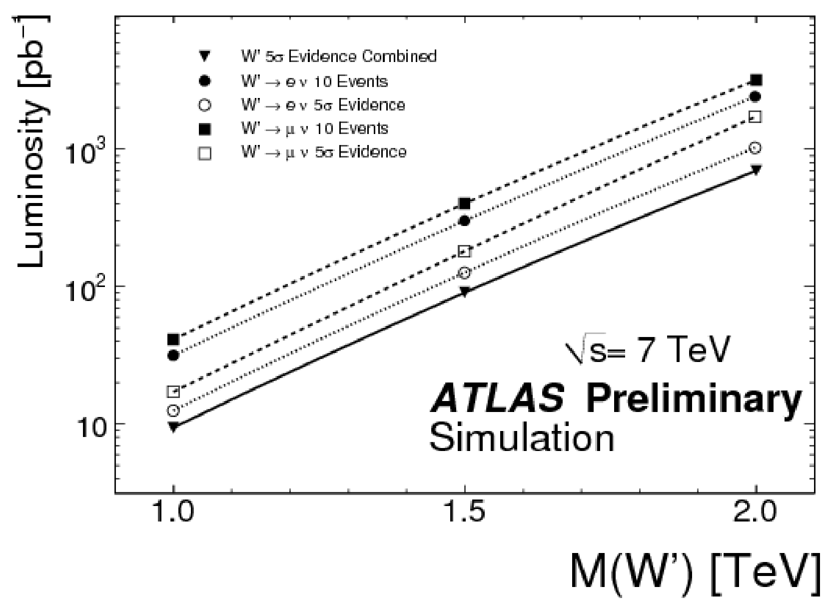
- Luminosity: 11%
- W boson tail cross section: 7% (Mass dependence, scale variation, PDF uncertainties, uncertainty on the W boson width)
- On QCD cross section: 40%
- Electron identification: 6% efficiency reduction
- Uncertainty from material effects, fiducial cuts, scale and other sources: 8%
- Degradation at high pT: from 0.3% to 1.7%
- Low energy component of MET: 0.6%

W': *discovery potential*

- Expected sensitivity to heavy bosons decaying into l+ν

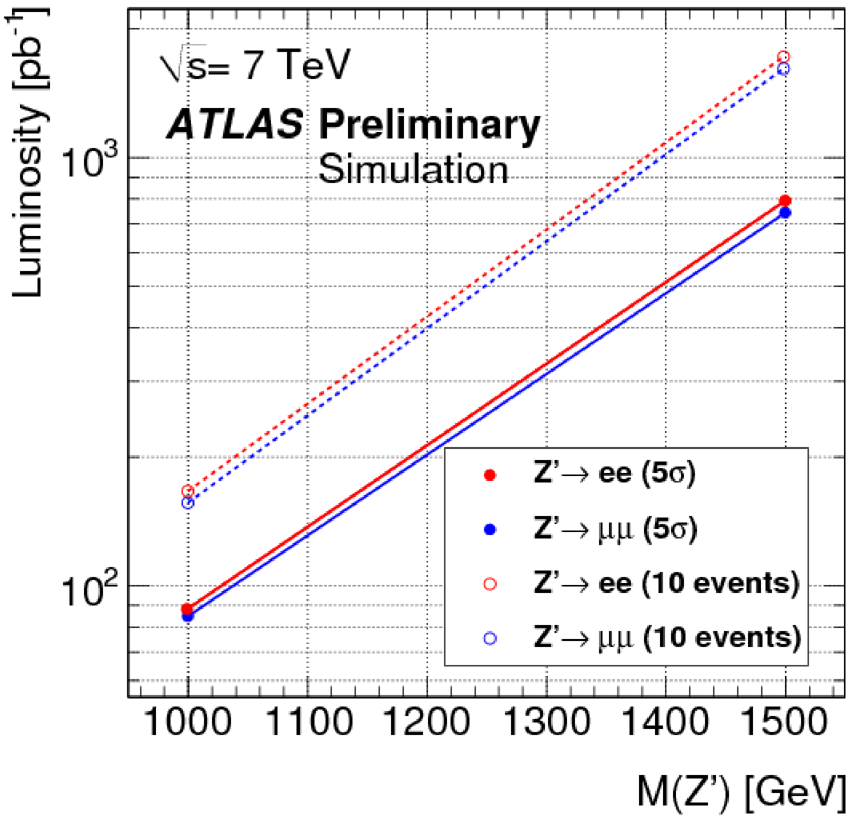


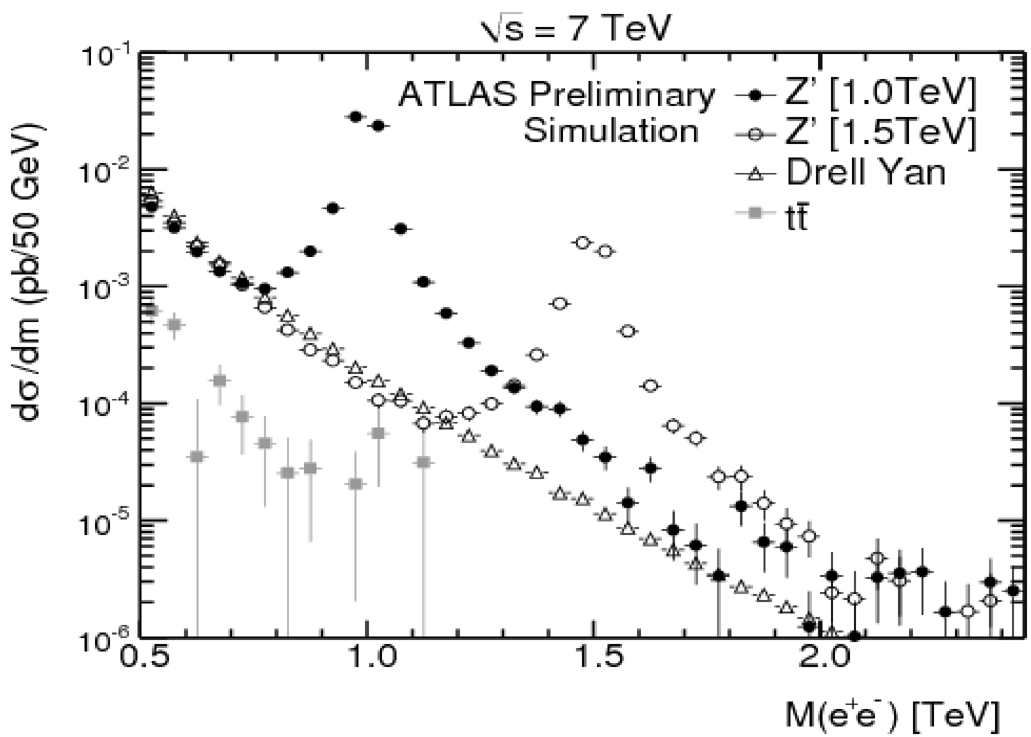




Di-lepton resonances: *Z′*

- Z′ → 2l is a simple clean signature
  - Two oppositely charged, same flavour leptons
  - Needed ~100pb^{-1} for first sensitive studies





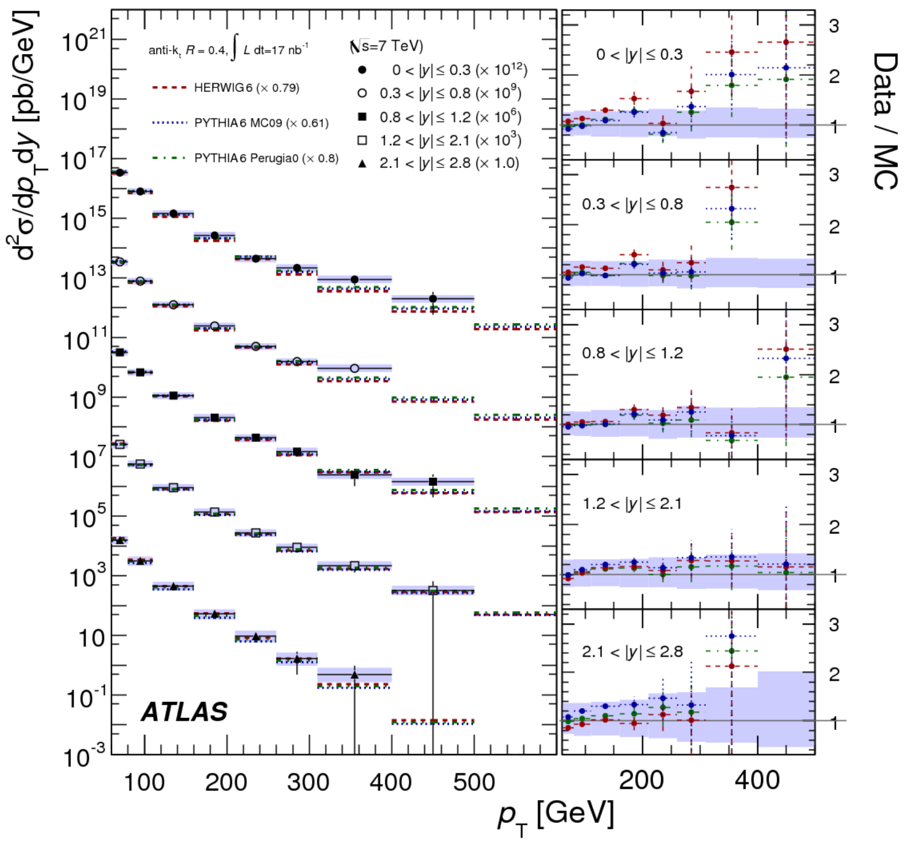
SUSY benchmark point

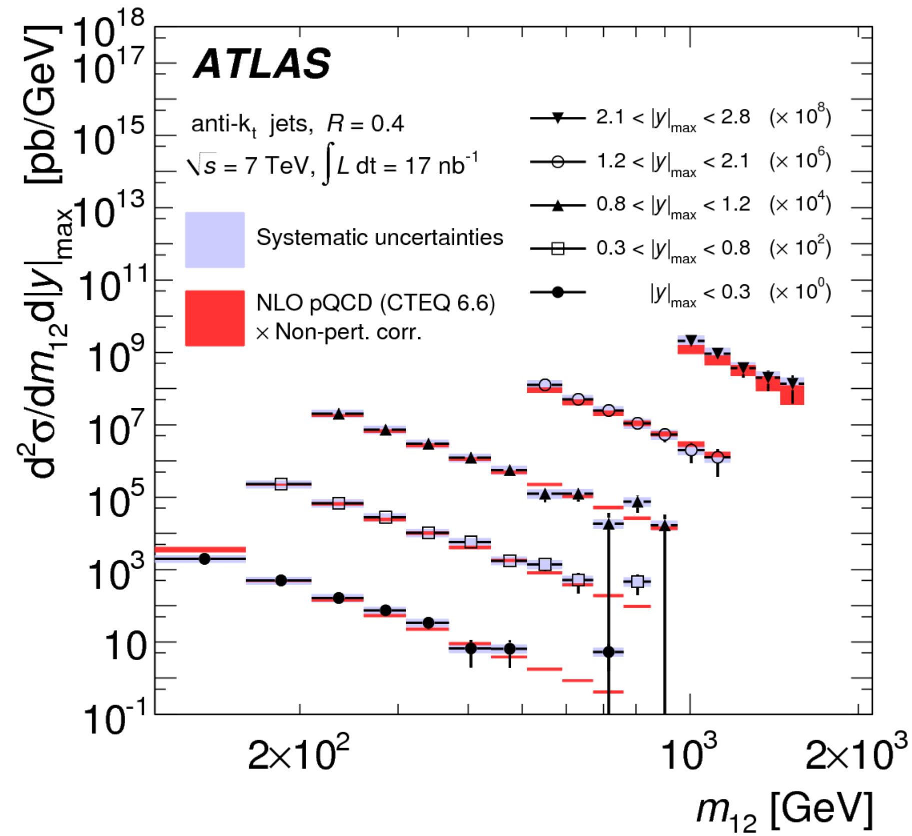
- MSUGRA (SU4)
  - Low mass point close to Tevatron bounds
    - m0 = 200 GeV
    - m1/2 = 160 GeV
    - A0 = −400 GeV
    - tan(β) = 10
    - $\mu > 0$

SUSY signatures: Event selection

- Cuts loosened to allow studies with low luminosity
  - Two or jets with p_T>70 (30) GeV
  - MET > 40 GeV
  - $\Delta\phi$ (jet, MET) > 0.2
  - MET > 0.3* M_{eff}
- Found good agreement between data/MC

Jet Performance





- Data and theory consistent in all rapidity regions over wide jet p_T and di-jet mass range

Exclusion limit: *Likelihood ratio*

$$L_\nu(d|b_\nu, s) \equiv \frac{\prod_i e^{-[b_i(\nu)+s_i(\nu)]}[b_i(\nu)+s_i(\nu)]^{d_i}}{d_i!}$$

- "ν" observable
- "i" combination (e.g. muon and electron channel)
- d = observed, b = background, s = signal (events)
- Systematic uncertainties treated as nuisance parameters (parametrized by a Gaussian)

$$L_{\nu,\theta_1,\theta_{2,\dots},\theta_N} = L_\nu \prod_i g_i(\theta_i)$$