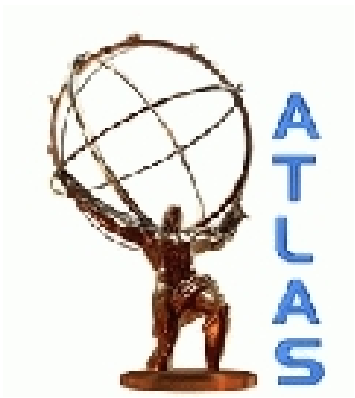


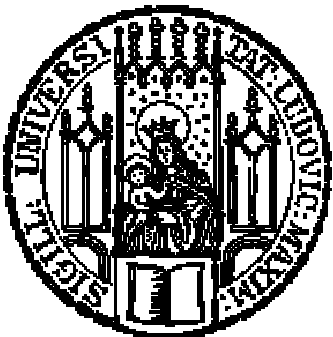
Early searches for Supersymmetry in ATLAS



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Outline

- 💧 Motivation
- 💧 SUSY search strategy and first measurements
- 💧 Prospects for SUSY discovery
- 💧 Conclusion & outlook



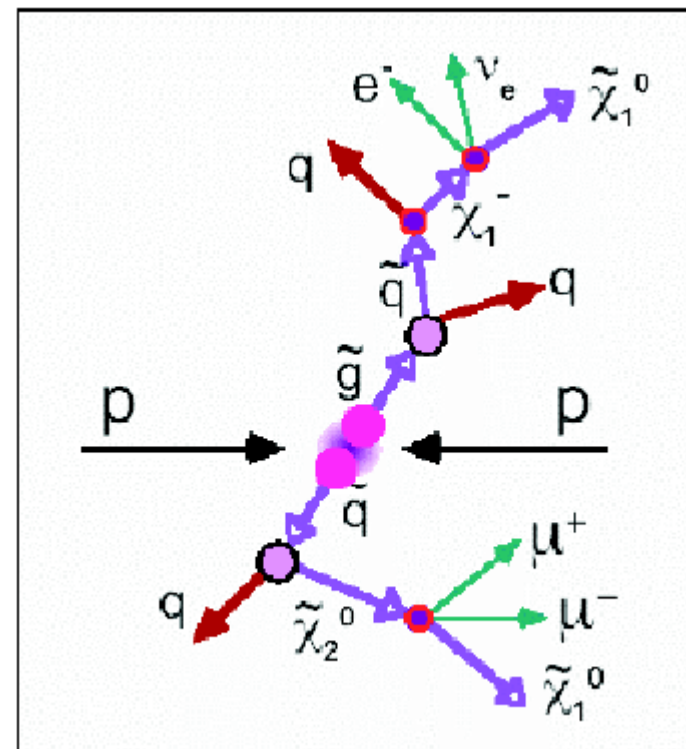
Inclusive SUSY searches : general considerations

Inclusive SUSY searches rely on fairly general features:

- SUSY production cross section can be calculated in the MSSM (xsec depends only on sparticle mass)
- gluinos/squarks are the heaviest sparticles, which decay give rise to high- p_T **jets**
- neutralinos/charginos often decay via emission of **leptons**(e/μ)
- LSP is stable(R-parity conservation) and neutral, escaping detector and gives large E_T^{miss} . Good candidate of Dark Mater

➤ Generic signatures:

Multi jets + leptons + large E_T^{miss}



➤ In this talk, R-parity violating and long-lived signatures are not included

Inclusive SUSY search strategy

- Search for SUSY is one of the most important goals of ATLAS detector
- Strategy: Search for deviation from SM
- The discovery of new physics can only be claimed when SM backgrounds are understood well or under control
- Background estimation should better be estimated from data (use data-driven method) because of imperfect knowledge of :
 - Underlying Event
 - Parton Showering
 - Cross-sections
 - Parton Distribution Functions
 - Detector Calibration (jets, $E_{T,miss}$)
 - Limited Monte Carlo statistics

Inclusive SUSY search strategy (cont.)

Only results with total integrated luminosity of 70nb^{-1} or 300nb^{-1} will be shown in this talk

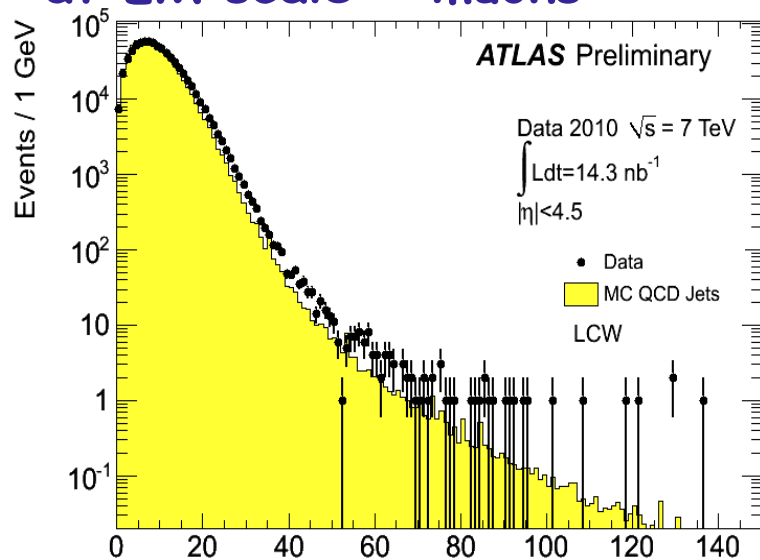
- ◆ Measurement of **SUSY-sensitive variables**
- ◆ Understand SM backgrounds
- ◆ No data-driven estimation for the backgrounds
- ◆ Kinematic distributions are compared for illustrative purpose to the prediction from SU4 (low mass point, close to Tevatron bound)
 - ✓ $m(\text{squarks, gluinos}) \sim 410\text{-}420\text{GeV}$; $\sigma(\text{NLO}) = 59.9\text{ pb}$
 - ✓ $m_0=200\text{GeV}$, $m_{1/2}=160\text{GeV}$, $A_0=-400\text{GeV}$, $\tan\beta=10$ and $\mu>0$
- ◆ Three SUSY channels with final states considered in this talk: jets + E_T^{miss} + :
 - ✓ no leptons
 - ✓ with one or more leptons
 - ✓ with b-tagging

SUSY Sensitive Variables

Missing transverse energy:

$$\vec{E}_T^{\text{miss}} \equiv (E_x^{\text{miss,calo}}, E_y^{\text{miss,calo}}) - \sum_j \mathbf{p}_T^{\mu,j}$$

- ◇ sum of calorimeter cells at EM scale + muons



- ✓ E_T^{miss} calculated from events with ≥ 1 jet with $p_T > 20 \text{ GeV}$ at EM scale.
- ✓ The tail is due to fake E_T^{miss} from jet energy mis-measurement

Effective mass (M_{eff}):

$$M_{\text{eff}} \equiv \sum_{i=1}^{N_{\text{jets}}} p_T^{\text{jet},i} + \sum_{j=1}^{N_{\text{lep}}} p_T^{\text{lep},j} + E_T^{\text{miss}}$$

- ◇ scalar sum of transverse momentum of main objects (elec, muon, jet)
→ Almost all detector components needed
- ◇ A simple estimate of the SUSY mass involved

Transverse Mass (m_T):

$$m_T^2 \equiv 2|\mathbf{p}_T^\ell| |E_T^{\text{miss}}| - 2\mathbf{p}_T^\ell \cdot \vec{E}_T^{\text{miss}}$$

- ◇ Suppress $w+t\bar{t}$ BG

Event Selection

Pre-selection:

- ✿ Good objects selection (e, mu, jet)
- ✿ Calorimeter jet trigger or lepton trigger applied
- ✿ Events from pp collisions (≥ 1 vertex with ≥ 5 tracks)
- ✿ Reject events with an electron in the calorimeter transition region ($1.37 < |\eta| < 1.52$)

Jets + MET :

Pre-selection:

- ✧ No lepton with $p_T > 10 \text{ GeV}$
- ✧ 2,3,4 jet channel: $\geq 2, 3, 4$ jets with $p_T > 70, 30 (30, 30) \text{ GeV}$

Final Selection:

- ✧ $E_{T}^{\text{miss}} > 40 \text{ GeV}$
- ✧ $\Delta\Phi(j, E_{T}^{\text{miss}}) > 0.2$
- ✧ $E_{T}^{\text{miss}}/M_{\text{eff}} > 0.3(2j), 0.25(3j), 0.2(4j)$

Leptons + Jets + MET:

Pre-selection:

- ✧ One lepton channel: 1 lepton with $p_T > 20 \text{ GeV}$, no 2nd lepton with $p_T > 10 \text{ GeV}$
- ✧ Two lepton channel: 2 leptons with $p_T > 20, 10 \text{ GeV}$
- ✧ 2 or more jets with $p_T > 30 \text{ GeV}$

Final Selection:

- ✧ $E_{T}^{\text{miss}} > 30 \text{ GeV}$
- ✧ $m_T > 100 \text{ GeV}$

Monte Carlo Samples

💧 QCD jet production: PYTHIA 6.4.21

- ✿ Normalized to data in QCD control sample
 - ✓ no-lepton mode: ≥ 2 jets with $p_T > 70, 30 \text{ GeV}$
 - ✓ one or 2 lepton mode: latter slides
- ✿ Compared to ALPGEN (2→5 Matrix elements)

💧 W/Z+jets: ALPGEN + HERWIG + JIMMY

- ✿ Normalized to integrated luminosity
- ✿ Overall W inclusive cross section taken from NNLO

💧 Top : MC@NLO+ HERWIG + JIMMY

- ✿ Normalized to integrated luminosity
- ✿ Overall cross section taken from approximate NNLO

💧 mSUGRA: HERWIG 2.4.2

- ✿ Normalized to integrated luminosity
- ✿ Overall cross section taken from NLO(prospino)

Main Systematic Uncertainty

💧 Jet energy scale uncertainty

- ✿ Dominant uncertainty in no lepton channel
- ✿ $\sim 10\%$ for $20 < p_T < 50 \text{ GeV}$, $\sim 7\%$ for large p_T value
- ✿ Propagated to Missing Transverse momentum
- ✿ Will improve with more data

💧 Uncertainty on the integrated luminosity

- ✿ 11% uncertainty propagated to W/Z/Top MC samples
- ✿ Not applied to QCD sample since data-driven

💧 Uncertainty on normalization factor

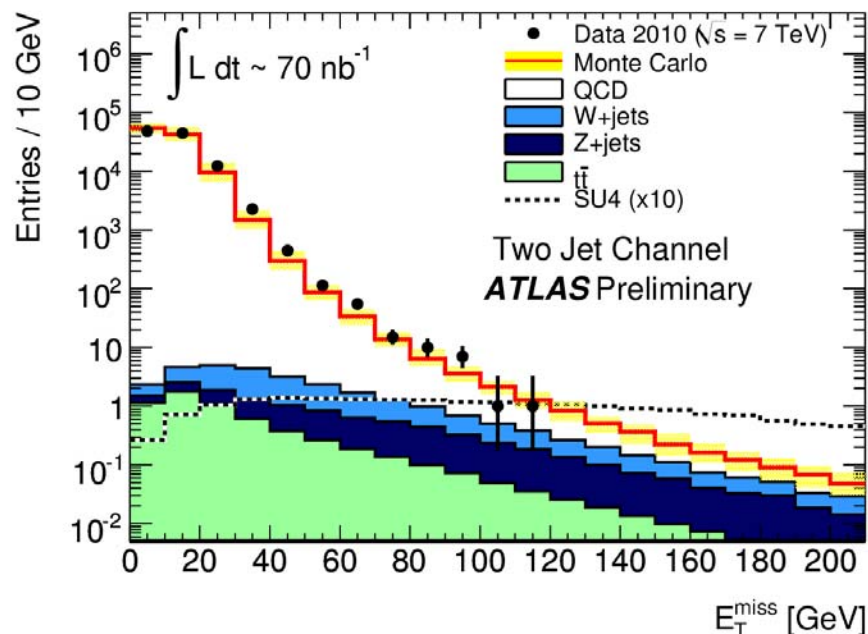
- ✿ QCD: 50% for 1lepton and 100% for 2lepton channel
- ✿ W/Z: 60% (only for 1/2 lepton channel)

💧 Other systematic uncertainty is small

Jets + $E_{\text{t}}^{\text{miss}}$

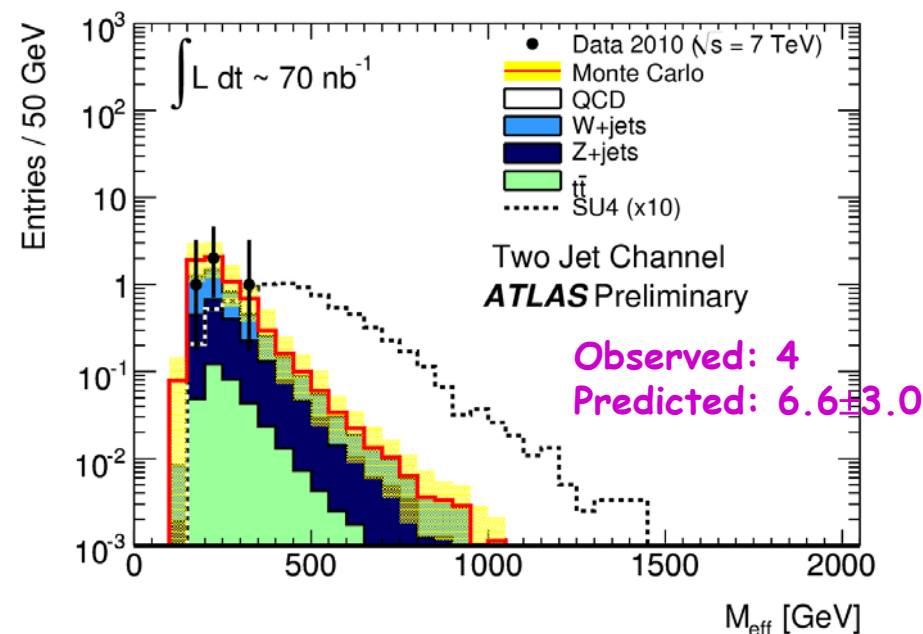


Jets + E_T^{miss} + No-Lepton (2jet channel)



Pre-selection (70nb^{-1}):

- $\geq 2\text{jets}$ with
 $p_T > 70, 30 \text{ GeV}$



Final-selection (signal region):

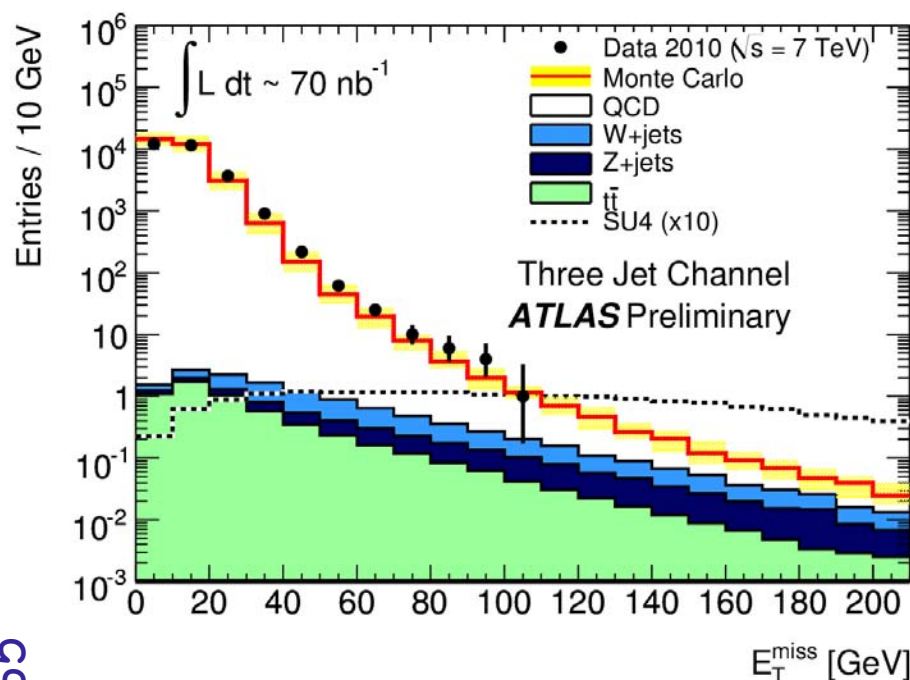
- $E_T^{\text{miss}} > 40 \text{ GeV}$,
- $\Delta\Phi(j, E_T^{\text{miss}}) > 0.2$,
- $E_T^{\text{miss}} / M_{\text{eff}} > 0.3$

• Dominant squark production, QCD dominant

• Good description of E_T^{miss} and M_{eff} shapes by MC

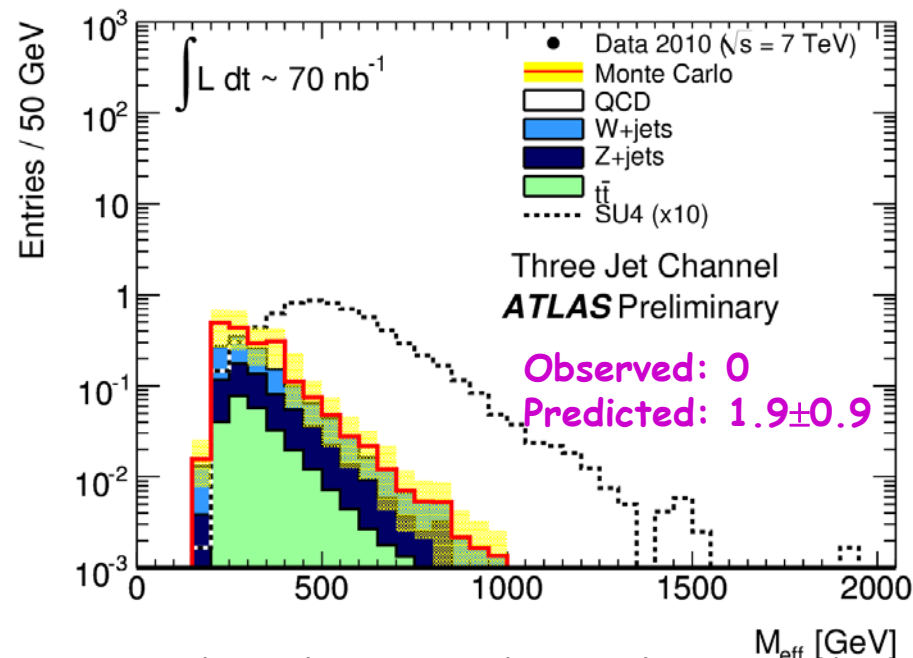
• Dominant backgrounds in signal region are W/Z+jets

Jets + E_T^{miss} + No-Lepton (3jet channel)



Pre-selection (70nb^{-1}):

- ✿ ≥ 3 jets with $p_T > 70, 30, 30 \text{ GeV}$

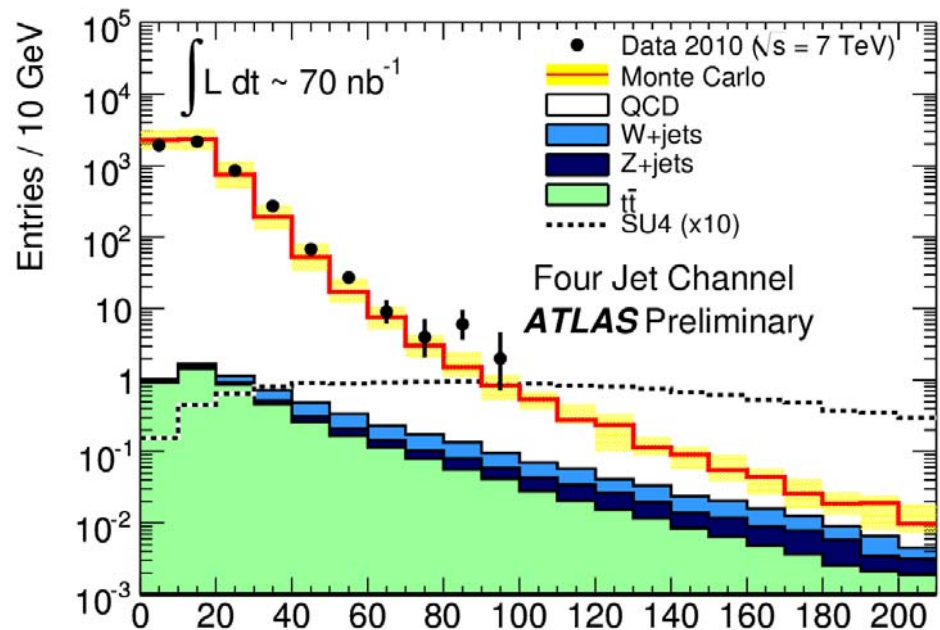


Final-selection (signal region):

- ✿ $E_T^{\text{miss}} > 40 \text{ GeV}$,
- ✿ $\Delta\Phi(j, E_T^{\text{miss}}) > 0.2$,
- ✿ $E_T^{\text{miss}} / M_{\text{eff}} > 0.25$

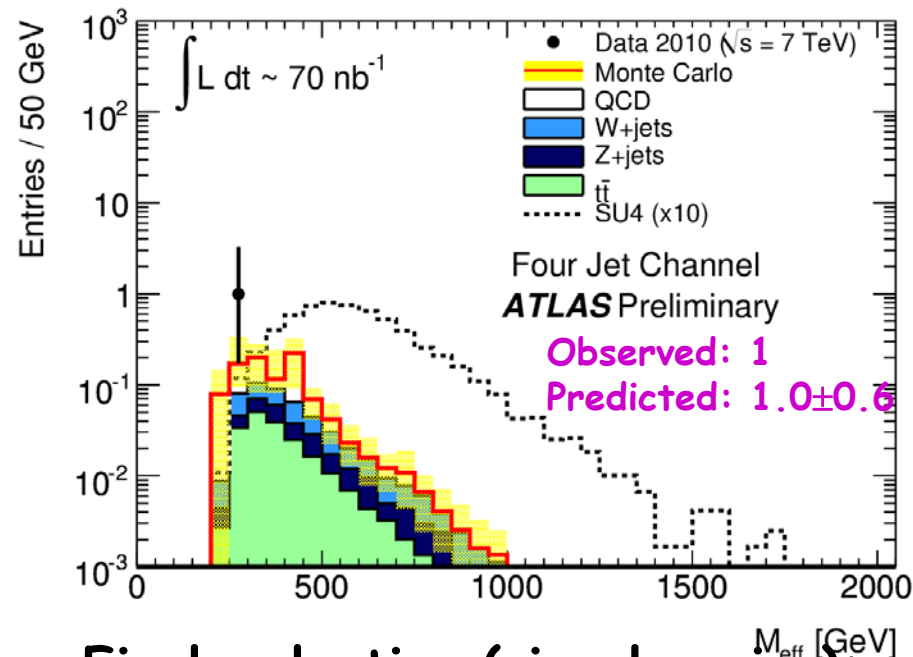
- ✿ Usual SUSY searches, W/Z BG dominant
- ✿ After pre-selection, qcd described well by MC

Jets + E_T^{miss} + No-Lepton (4jet channel)



Pre-selection (70nb^{-1}): E_T^{miss} [GeV]

☼ ≥ 4 jets with
 $p_T > 70, 30, 30, 30 \text{ GeV}$



Final-selection (signal region):

☼ $E_T^{\text{miss}} > 40 \text{ GeV}$,
☼ $\Delta\Phi(j, E_T^{\text{miss}}) > 0.2$,
☼ $E_T^{\text{miss}} / M_{\text{eff}} > 0.2$

☼ Most sensitive to mSUGRA type, W/Z dominant

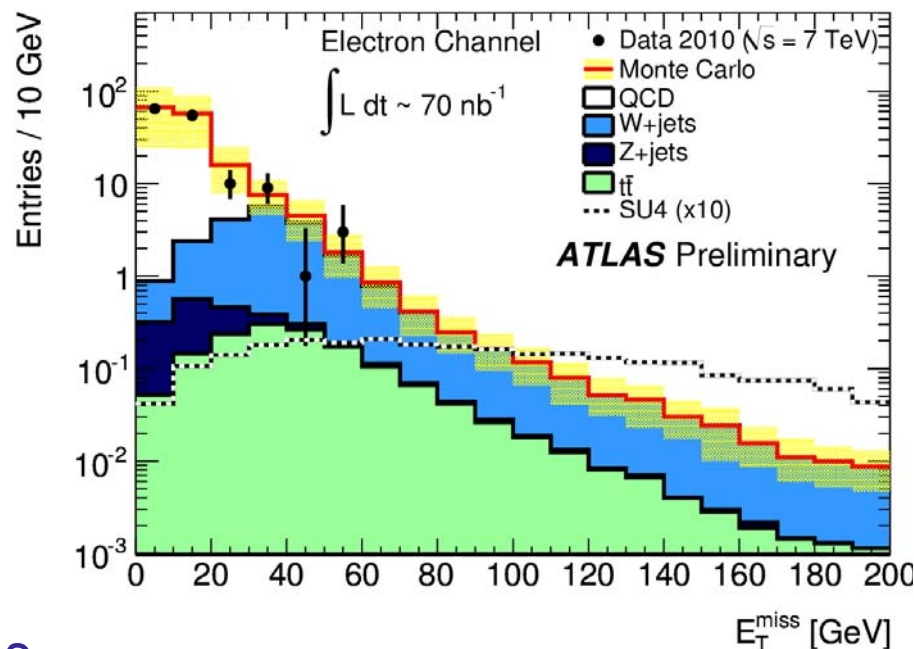
Conclusion for jet + E_T^{miss} + no lepton final states:

- ☼ Measured distributions of E_T^{miss} and M_{eff} show agreement with SM BG up to values of $E_T^{\text{miss}} \approx 100 \text{ GeV}$, $M_{\text{eff}} \approx 1500 \text{ GeV}$
- ☼ M_{eff} has good discrimination between mSUGRA and SM BGs

Jets + $E_{\text{T}}^{\text{miss}}$ + leptons



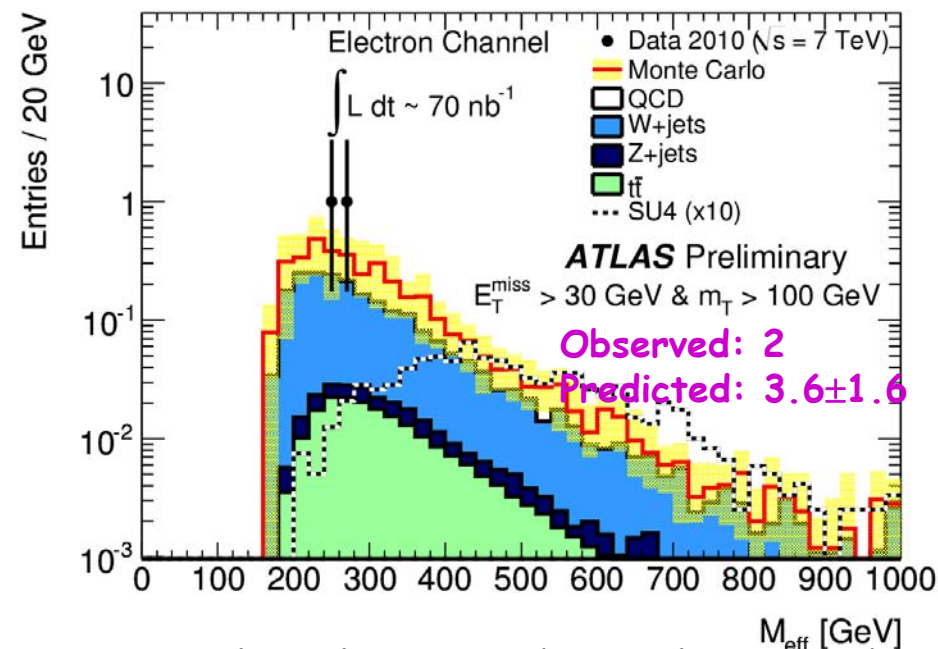
Jet + E_T^{miss} + One-Lepton (electron channel)



Pre-selection (70nb^{-1}):

- ✿ One **electron** with $p_T > 20 \text{ GeV}$
- ✿ ≥ 2 jets with $p_T > 30 \text{ GeV}$

- ✿ QCD and W+jets normalized to control sample from data:
 - ✿ QCD CS: $E_T^{\text{miss}} < 40 \text{ GeV}$ & $m_T < 40 \text{ GeV}$
 - ✿ W CS: $30 < E_T^{\text{miss}} < 50 \text{ GeV}$ & $40 < m_T < 80 \text{ GeV}$

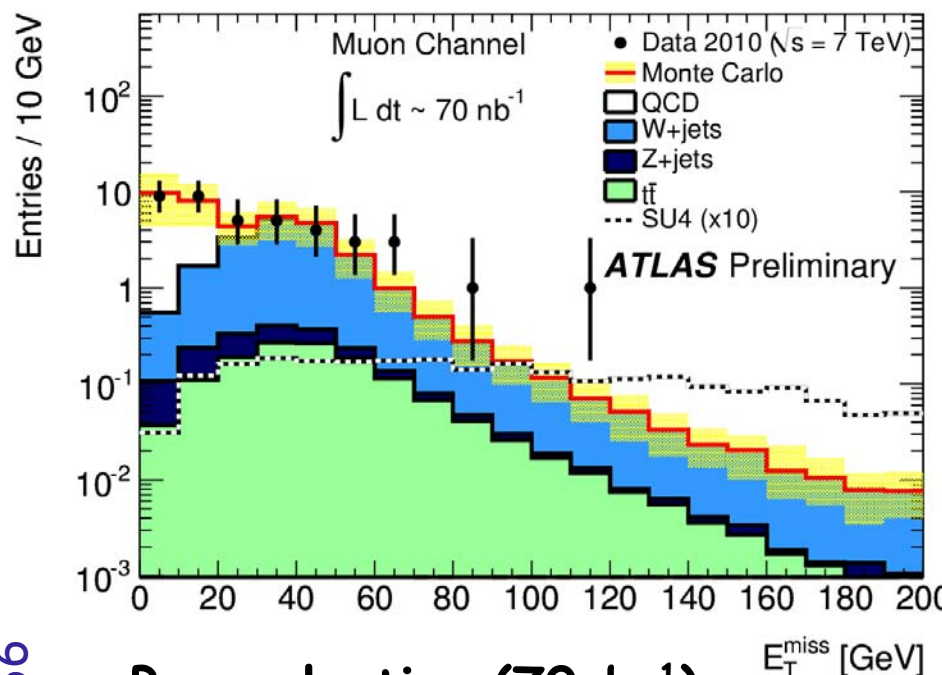


Final-selection (signal region):

- ✿ $E_T^{\text{miss}} > 30 \text{ GeV}$ (suppress QCD)
- ✿ $m_T > 100 \text{ GeV}$ (suppress W+ $t\bar{t}$)

- ✿ SM background described well by MC
- ✿ W dominant in signal region

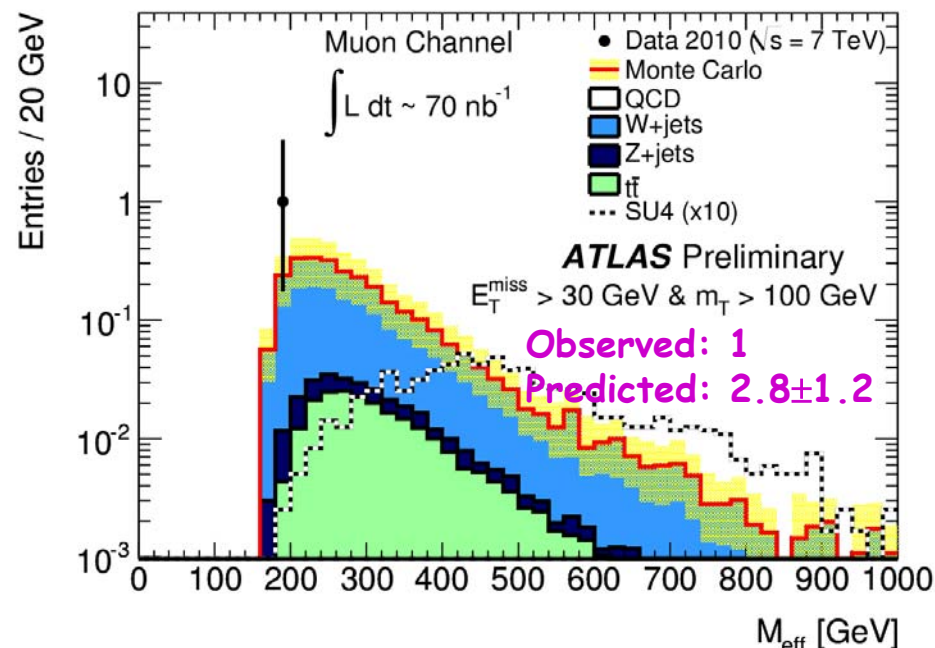
Jet + E_T^{miss} + One-Lepton (muon channel)



Pre-selection (70nb^{-1}):

- ✿ One **muon** with $p_T > 20 \text{ GeV}$
- ✿ ≥ 2 jets with $p_T > 30 \text{ GeV}$

- ✿ QCD and W+jets normalized to control sample from data:
 - ✿ QCD CS: $E_T^{\text{miss}} < 40 \text{ GeV}$ & $m_T < 40 \text{ GeV}$
 - ✿ W CS: $30 < E_T^{\text{miss}} < 50 \text{ GeV}$ & $40 < m_T < 80 \text{ GeV}$

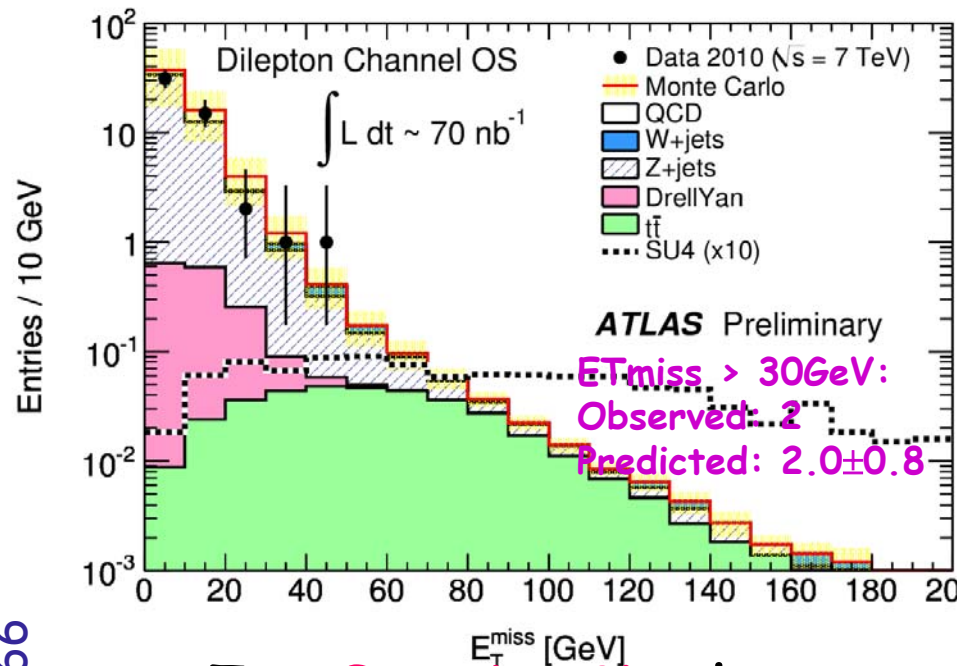


Final-selection (signal region):

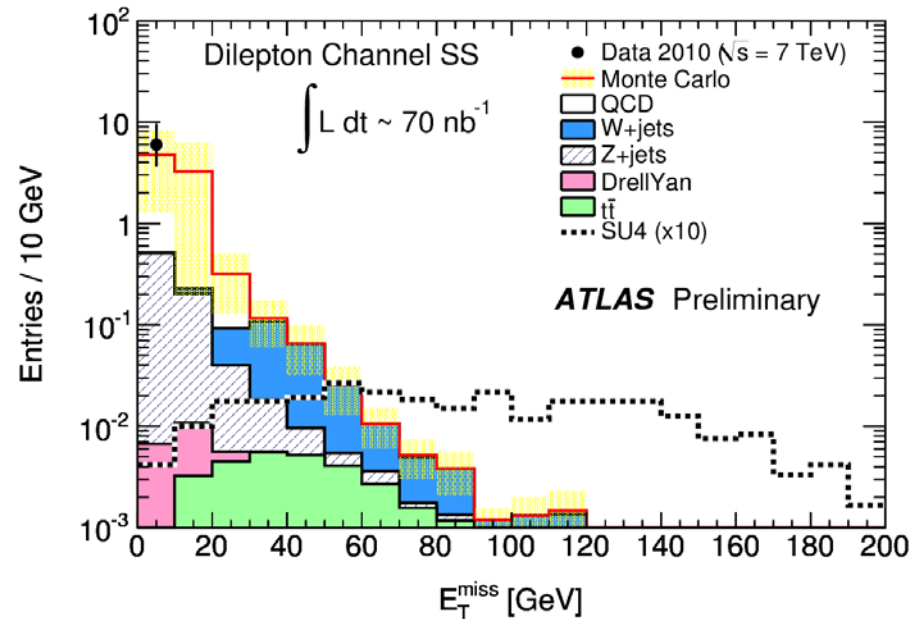
- ✿ $E_T^{\text{miss}} > 30 \text{ GeV}$ (suppress qcd)
- ✿ $m_T > 100 \text{ GeV}$ (suppress W+tt)

- ✿ SM background described well by MC
- ✿ W dominant in signal region

Jet + E_T^{miss} + two-Leptons



✿ Two **Opposite Sign** leptons
with $p_T > 20, 10 \text{ GeV}$



✿ Two **Same Sign** leptons with
 $p_T > 20, 10 \text{ GeV}$

- ✿ QCD and W+jets normalized to control sample from data:
 - ✿ QCD CS: $E_T^{\text{miss}} < 15 \text{ GeV}$ & $5 < m_{ll} < 15 \text{ GeV}$
 - ✿ W CS: $30 < E_T^{\text{miss}} < 50 \text{ GeV}$ & $40 < m_T < 80 \text{ GeV}$

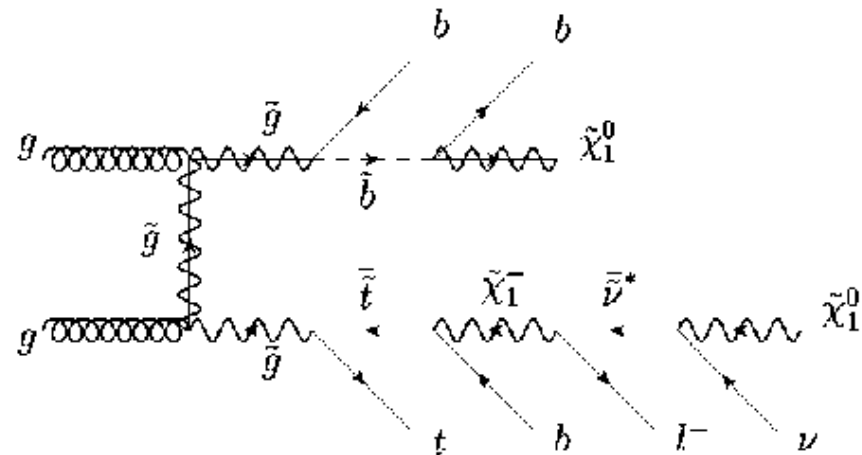
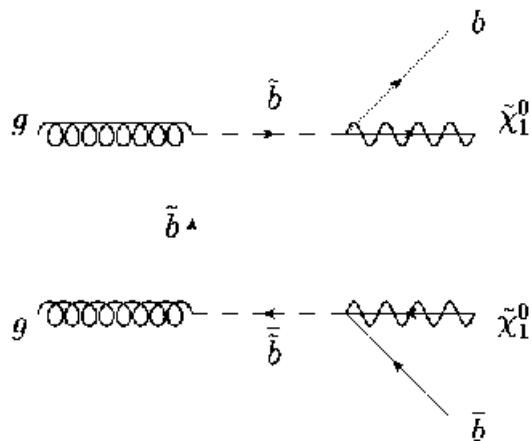
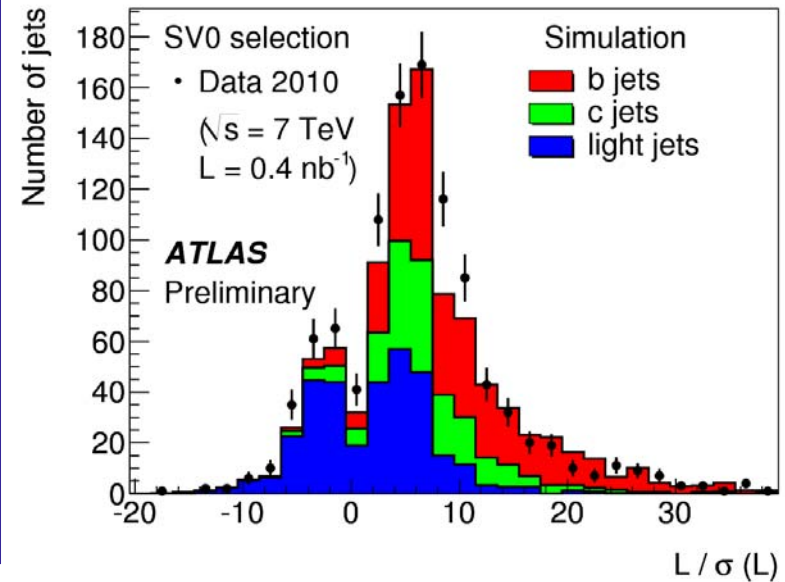
✿ **SM background**
described well by MC

B-Jets + E_{miss} + (leptons)

B-Jet + E_T^{miss}

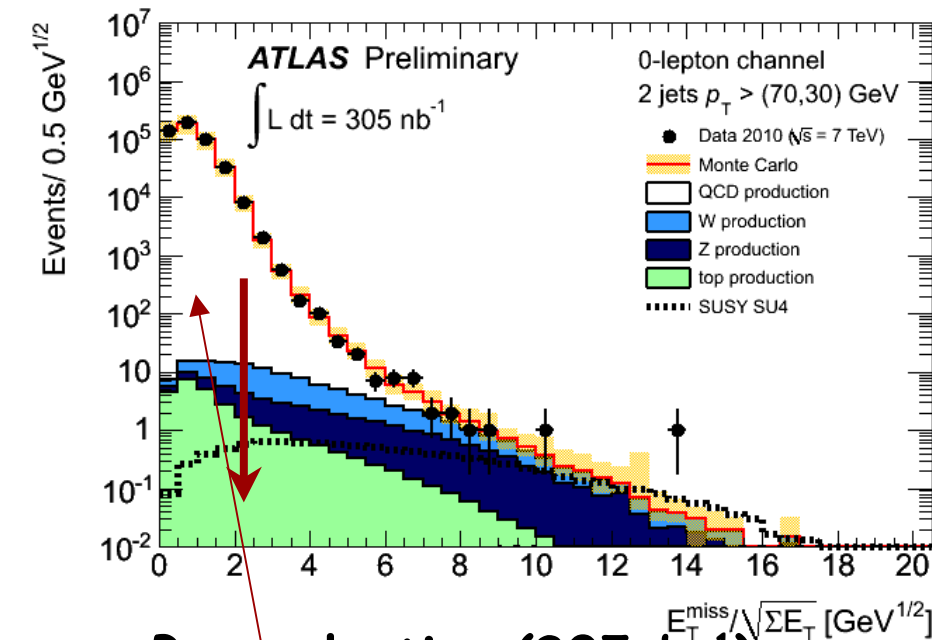
ATLAS-CONF-2010-066

- ✿ In MSSM, the production of third generation squarks could be favoured
- ✿ B-tagging algorithm: explicitly reconstruct the second vertices
 - ✓ Decay length significance: $SV0 > 6$
 - ✓ $\epsilon_{\text{btagging}} \sim O(50\%)$



ATLAS-CONF-2010-079

B-Jet + E_T^{miss}

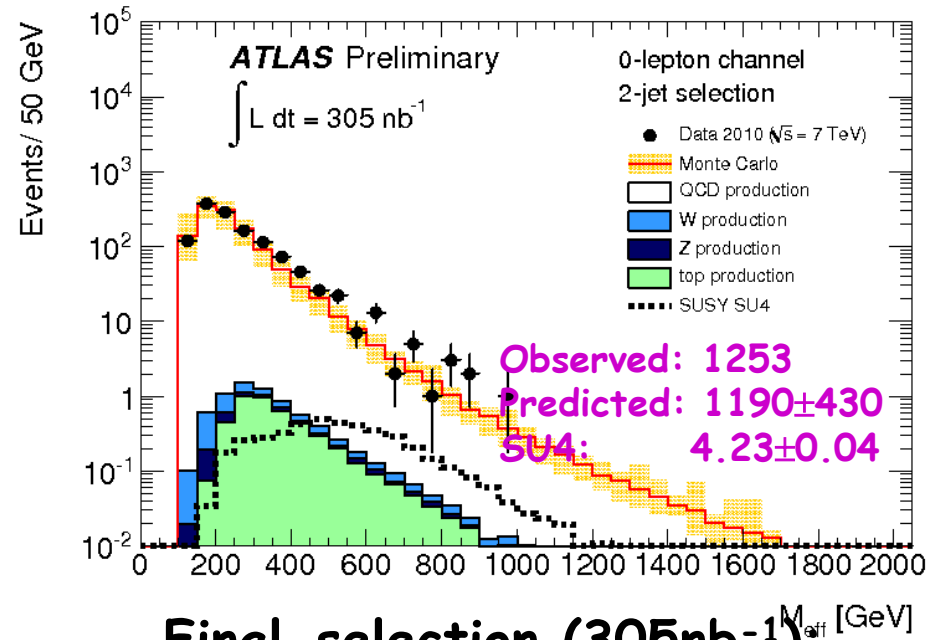


Pre-selection (305 nb^{-1}):

✿ $\geq 2 \text{ jets with } p_T > 70, 30 \text{ GeV}$

✿ QCD normalized to control sample from data:
 $E_T^{\text{miss}} / \sqrt{\sum E_T} < 2 \sqrt{\text{GeV}}$

✿ Data agrees with MC at the whole region



Final-selection (305 nb^{-1}):

✿ $\geq 1 \text{ btag with } \text{SV0} > 6$

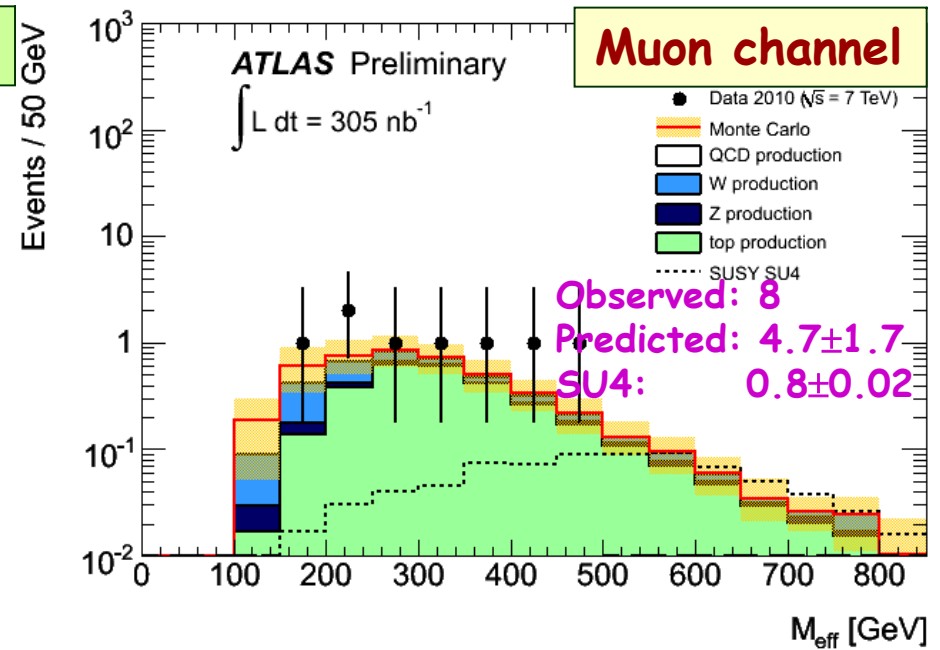
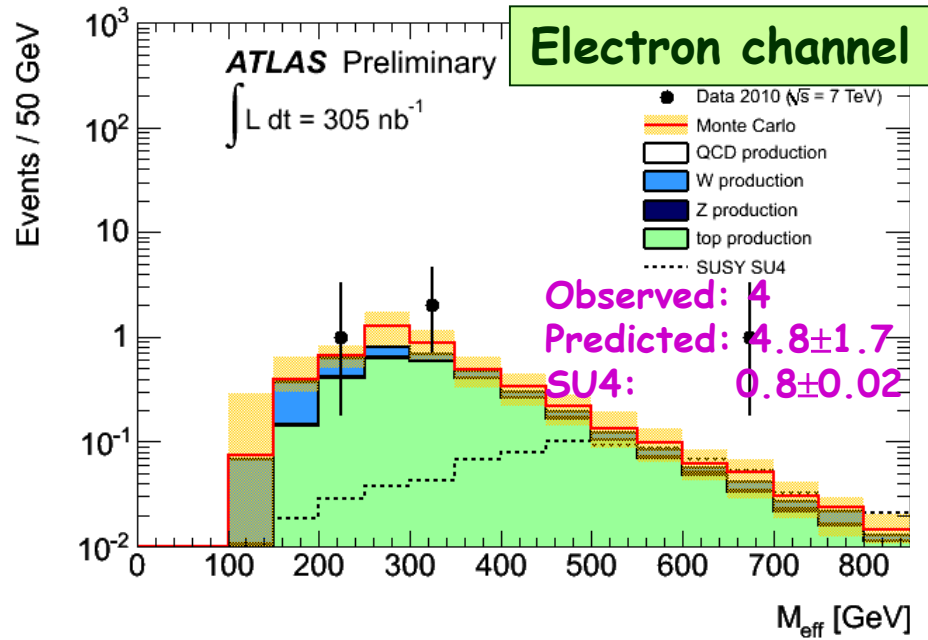
✿ $E_T^{\text{miss}} / \sqrt{\sum E_T} > 2 \sqrt{\text{GeV}}$

B-tag is rejecting of

✿ light quark jets $\sim 98-99\%$

✿ Charm jets $\sim 80-90\%$

B-Jet + E_T^{miss} + 1 lepton



- ✿ One electron or muon with $p_T > 20 \text{ GeV}$
- ✿ ≥ 2 jets with $p_T > 30, 30 \text{ GeV}$
- ✿ 1 b-tag with $SV0 > 6$
- ✿ $E_T^{\text{miss}} / \sqrt{\sum E_T} > 2 \sqrt{\text{GeV}}$

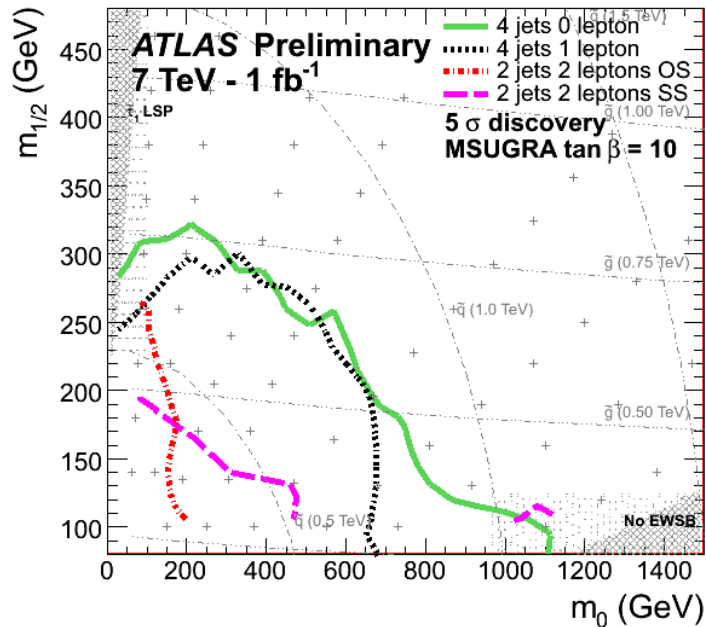
✿ QCD normalized to control sample from data:
 $E_T^{\text{miss}} / \sqrt{\sum E_T} < 2 \sqrt{\text{GeV}}$ & $m_T < 40 \text{ GeV}$

- ✿ Data reasonably consistent with MC
- ✿ Only few events in Signal Region
- ✿ No sensitivity for mSUGRA signal yet

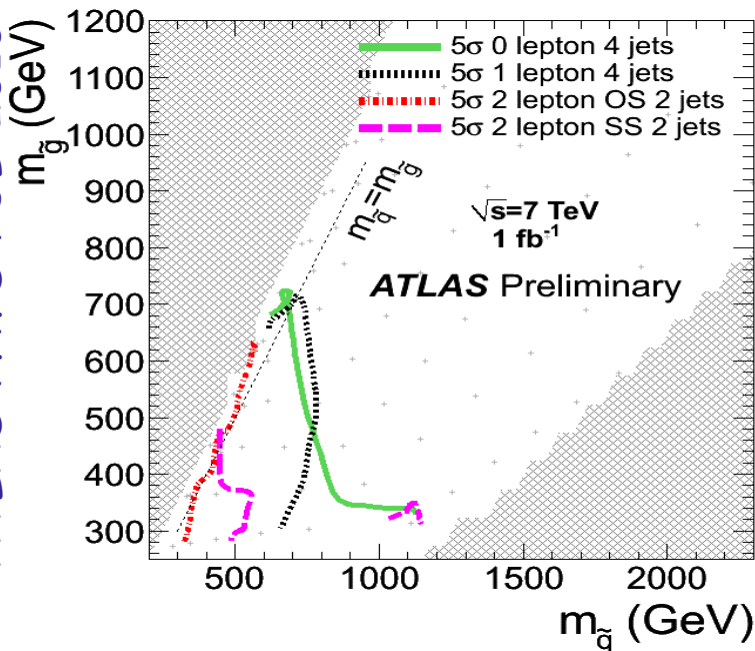
Prospects on SUSY Discovery



Prospects for SUSY discovery



- ❖ Scan of m_0 - $m_{1/2}$ (m_{gluino} - m_{squark}) plane
- ❖ 5σ discovery reach contours
- ❖ Optimised on effective mass to get best signal significance
- ❖ Background uncertainties from data-driven methods (assuming 1 fb^{-1}) # $\text{top}/W/Z$ (20%) + QCD (50%)



With 1 fb^{-1} :

- ❁ ATLAS can discover squark and gluino with masses up to 700 GeV in mSUGRA scenario
- ❁ 0-lepton and 1-lepton channels are much sensitive
- ❁ Improve the reach of Tevatron ($m_{\text{gluino}} > 390 \text{ GeV}$)

Summary and Outlook

- Measured distributions of SUSY sensitive variables show agreement with the Standard Model background
- No sensitivities to mSUGRA discovery yet with up to 300 nb^{-1}
- ATLAS could discover squarks and gluinos with masses up to 700 GeV with 1 fb^{-1} integrated luminosity in mSUGRA scenario (i.e. by end of 2011)
- With more data:
 - Refine and reduce experimental uncertainty
 - Further improving our understanding of SM predictions
 - Providing increased sensitivity to new physics

Thanks

