Inclusive SUSY Searches at ATLAS

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'Physics at the Terascale'

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Outline

- Inclusive search strategies
  - Search for deviation from the SM
  - Signatures with missing transverse energy
  - Estimation of SM backgrounds:
    Data-driven background estimates
- Propects for SUSY searches
  - Scans of the SUSY parameter space
  - Different models mSUGRA (constrained), GMBS, NUHM, etc.
- Summary / Outlook

The Freiburg SUSY Group

SUSY searches and scans:

0 leptons + jets	Janet Dietrich
1 lepton + jets	Riccardo-Maria Bianchi, Stephan Horner
2 leptons + jets	Stephan Horner
3 leptons + 1 jet	Riccardo-Maria Bianchi
τ + jets	Debra Lumb, Xavier Portell

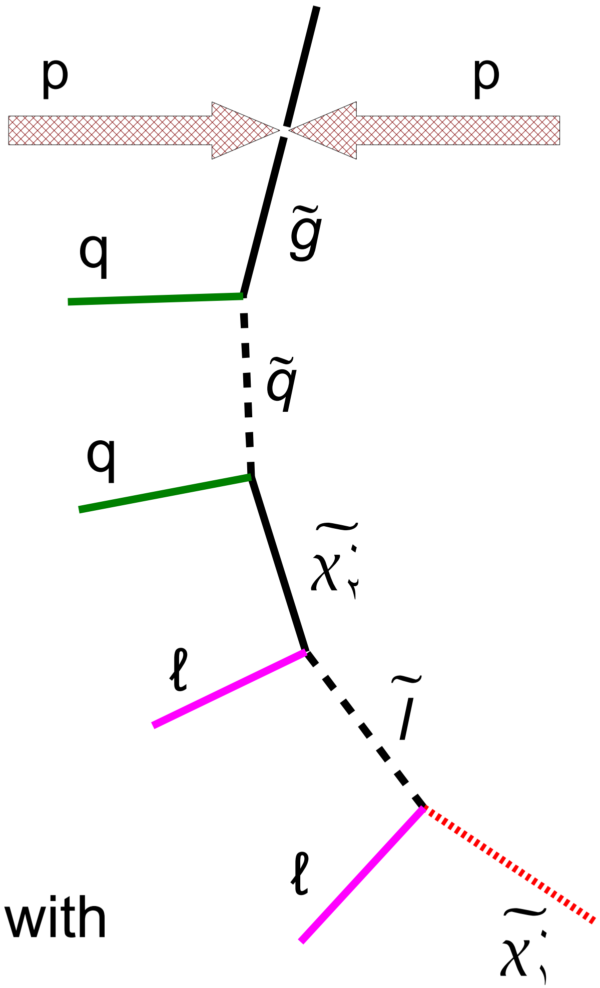
Background estimation in SUSY searches:

1 jet analysis	Florian Ahles
$Z \rightarrow \nu\nu$	Renaud Bruneliere, Janet Dietrich
$t\bar{t}$ decays	Stephan Horner, Tobias Rave, Jan Erik Sundermann
QCD background	Bernhard Meirose, Zuzana Rurikova, Kathrin Stoerig
ATLFAST corrections	Florian Ahles, Jan Erik Sundermann

Group leaders: Gregor Herten, Sascha Caron

SUSY Signatures

- Abundant pair production of squarks and gluinos through strong interactions (R-parity conserved)
- Cascade decays to lightest stable SUSY particle (LSP) which remains undetected
  - SUSY signature: Missing transverse energy, hard jets & possibly leptons or photons
- Search strategy:
  - *Search for deviations from the SM*
  - *Be as model independent as possible:* search in as many different channels as possible with a model-independent strategy
  - *Difficult to control background expectation in early data:* try to rely on data-driven background estimation techniques



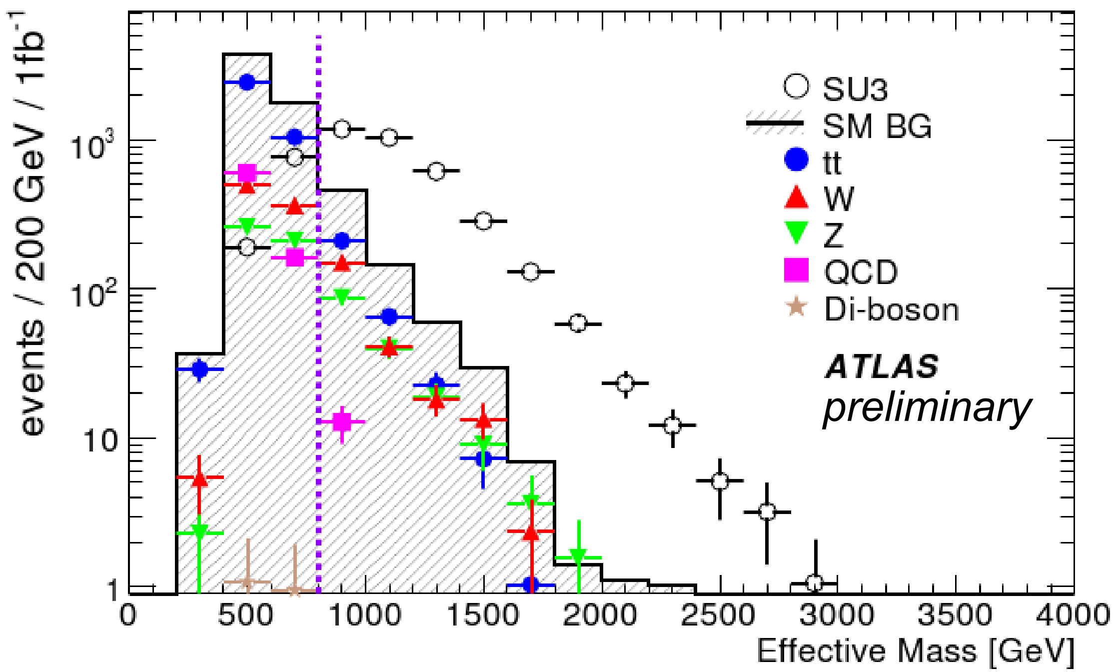
Inclusive SUSY Searches at ATLAS

CERN-OPEN-2008-020, Geneva, 2008, to appear

- SUSY-models considered in the following:
  - Assume mostly mSUGRA as five-parameter R-parity conserving SUSY model (LSP: lightest neutralino)
  - Test performance of searches with other scenarios: GMSB, NUHM, ...
  - Define benchmark points: e.g. SU3 with m_0=100GeV, $m_{1/2}$=300GeV, A_0=-300GeV, $\tan\beta$=6, sgn(μ)>0
- Signals studied by ATLAS (CSC 2008)
  - 2, 3, 4 jets & 0, 1, 2 leptons & missing p_T, 3 leptons, taus, photons, ...
- Improvements wrt. ATLAS TDR style analysis:
  - Background estimates using full detector simulation,
  - Search strategy: More channels (be less model-dependent)
  - In the following: all plots for $1fb^{-1}$

Jets & Missing E_T, *no leptons*

- Selection criteria:
  - *4 hard jets:*
    E_T > 100, 50, 50, 50 GeV
  - *Missing transverse energy:*
    E_T^{miss} > 100GeV, $0.2M_{eff}$
  - *Spherical Event:*
    transverse Sphericity: S_T>0.2
  - *QCD suppression:*
    $\Delta\phi(\text{jet} - E_T^{miss}) > 0.2$
  - *No isolated electron or muon*



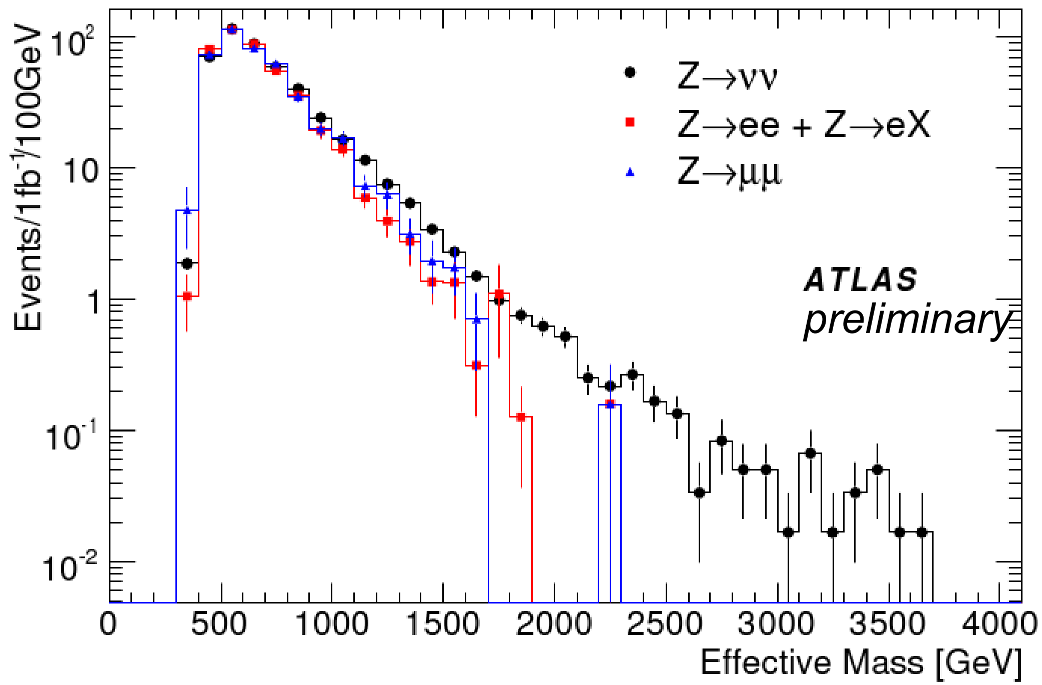
$$M_{eff} = \sum_{i=1}^{4} p_T^{jet,i} + E_T^{miss}$$

- Main backgrounds:
  - $t\bar{t}$ decays with one or two leptons not measured
  - $Z\rightarrow\nu\nu$ + jets: irreducible background, needs to be measured
  - $W\rightarrow\ell\nu$ + jets with one lepton not measured
  - QCD: missing E_T from jet mis-measurements

Jets & Missing E_T, *no leptons*

(data-driven $Z\to\nu\nu$ + jets background estimation)

- Estimation of $Z\to\nu\nu$ + jets from $Z\to\ell\ell$ + jets events:
  - *Additional corrections applied*:
    - fiducial volume $|\eta| > 2.5$
    - kinematic corrections, e.g. for Z-mass cut $81 > M_Z(\ell\ell) < 101$GeV
    - lepton ID efficiency
    - branching fractions

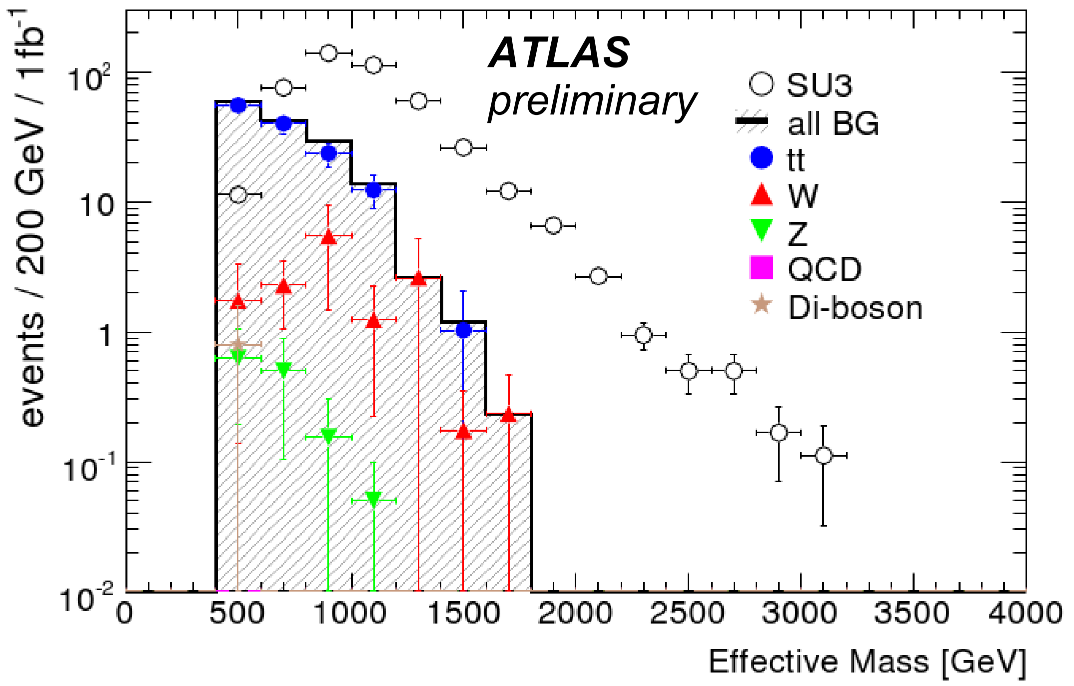


- Main uncertainties (for 1fb^{-1}):
  - Low statistics of control sample — ~13%
  - MC generator model (renormalization scale)
  - Description of the soft E_T^{miss} spectrum
  - Muon/electron ID efficiency

~8%

Jets & Missing E_T & *1 lepton*

- Selection criteria:
  - *Similar to 0-lepton analysis*
  - *1 isolated lepton:* p_T > 20GeV
  - *4 hard jets:*
    E_T > 100, 50, 50, 50 GeV
  - *Missing transverse energy:*
    E_T^{miss} > 100GeV, $0.2M_{eff}$
  - *Supression of $t\bar{t}$ / W background:*
    M_T(lepton, E_T^{miss}) > 100GeV
  - *Exclusive to other channels:*
    no other lepton with p_T>10GeV

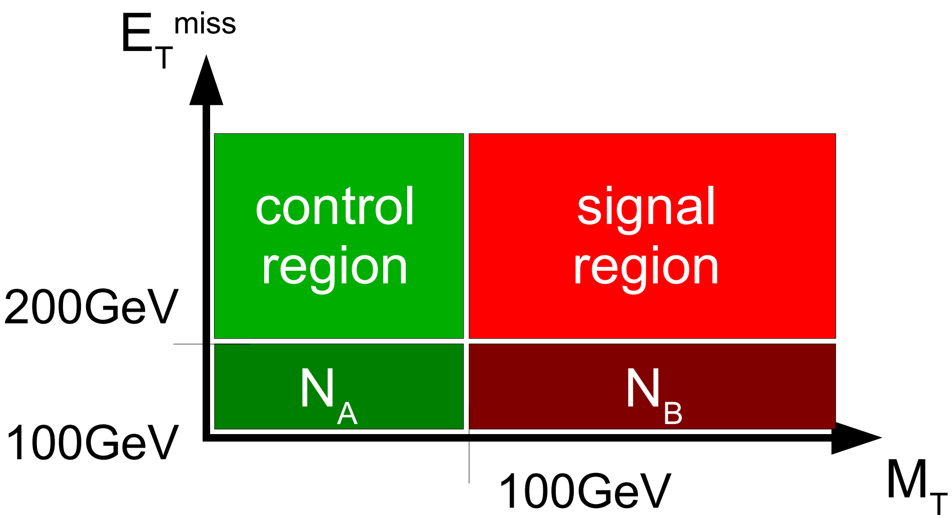


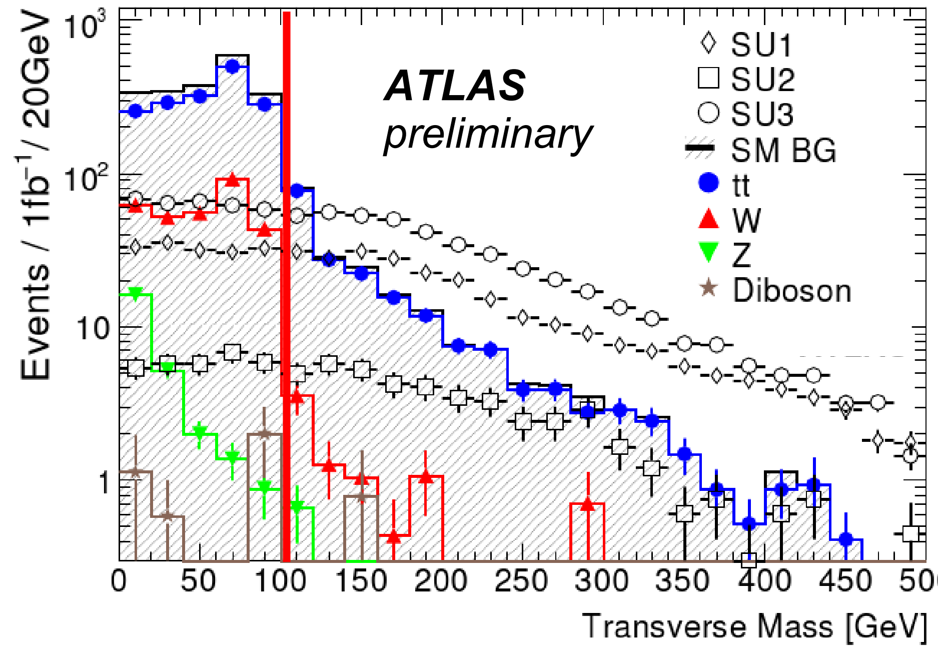
- Backgrounds:
  - Significantly reduced QCD background
  - Most important background: dileptonic $t\bar{t}$ + jets with one lepton unmeasured

Jets & Missing E_T & *1 lepton*

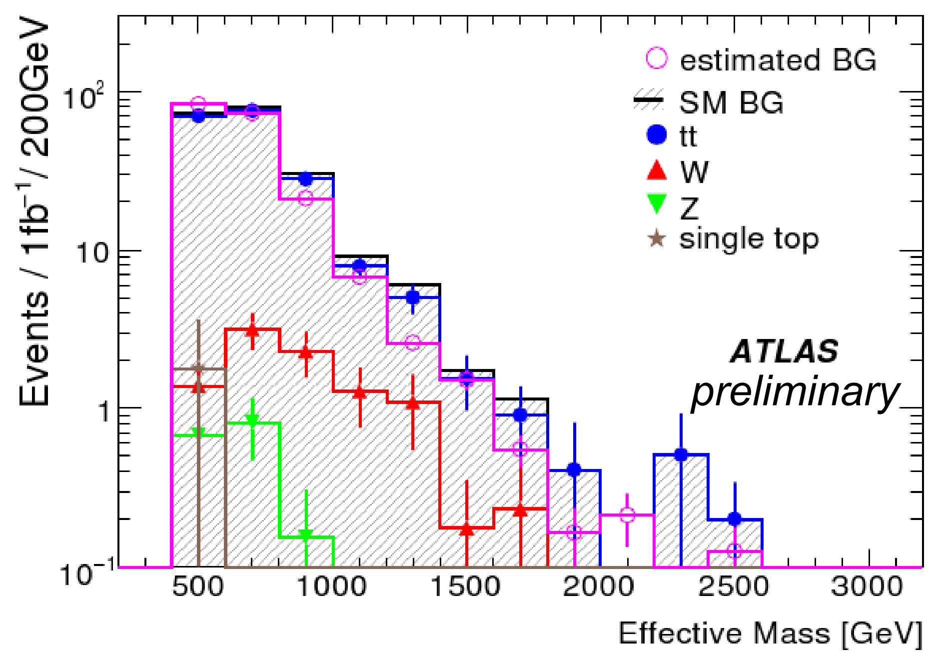
(data-driven estimation of $t\bar{t}$ background)

- CSC m_T-method (*Tokyo group*)
- Define control regions:





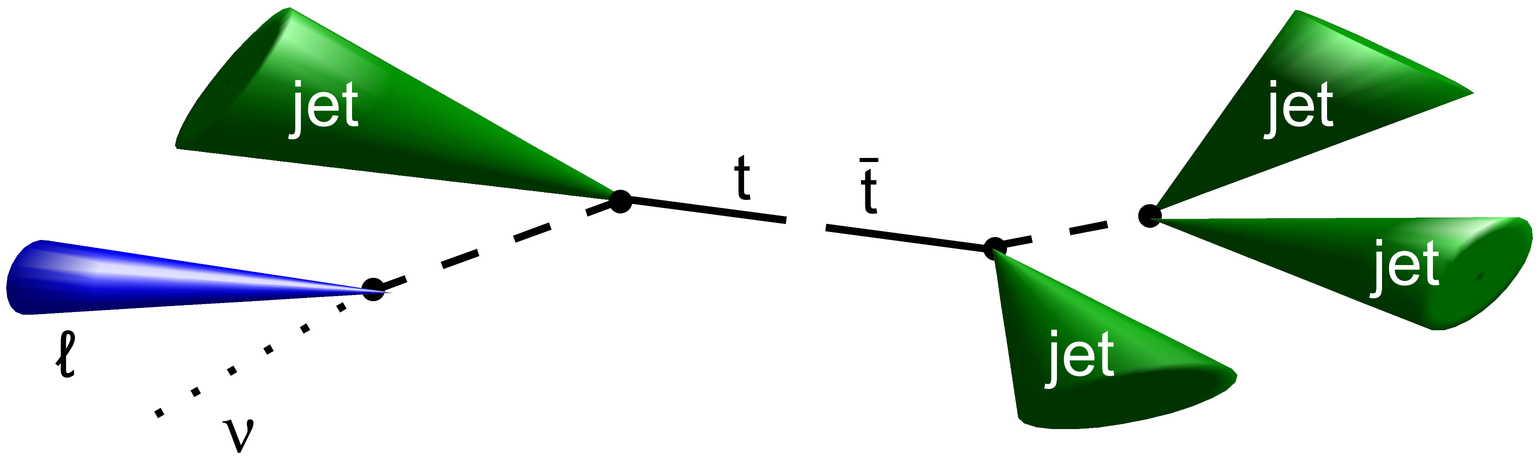
- Effective mass distribution in *control region (MT<100GeV)* can be used to predict distribution in *signal region (M_T>100GeV)*
- Normalization obtained with N_B / N_A



Jets & Missing E_T & *1 lepton*

(data-driven estimation of $t\bar{t}$ background)

- Further studies beyond the CSC results:
  - Separation of Top and W backgrounds in the 1-lepton channel
  - Investigation of two different approaches:
    - Kinematic fitting of semileptonic top-background (use $\chi 2$ as qualifier)
    - Likelihood approach



  - Combined fit of MC templates to extract background contributions

Jets & Missing E_T & *1 lepton*

(data-driven estimation of $t\bar{t}$ background)

- MC template reweighting technique:
  - MC might not be good enough for back-ground estimations in SUSY studies
  - Combined fit of top & MC templates in the control region
  - Correct shape of M_{eff}-templates with transfer functions depending on a set of adjustable parameters
  - Apply optimized transfer functions on (in general different) MC shapes in the signal Regions
  - Also applicable to estimate top/W background in the 0-lepton analysis

Control Region

all 4 jet/1 lepton cuts applied
Transverse Mass < 100GeV

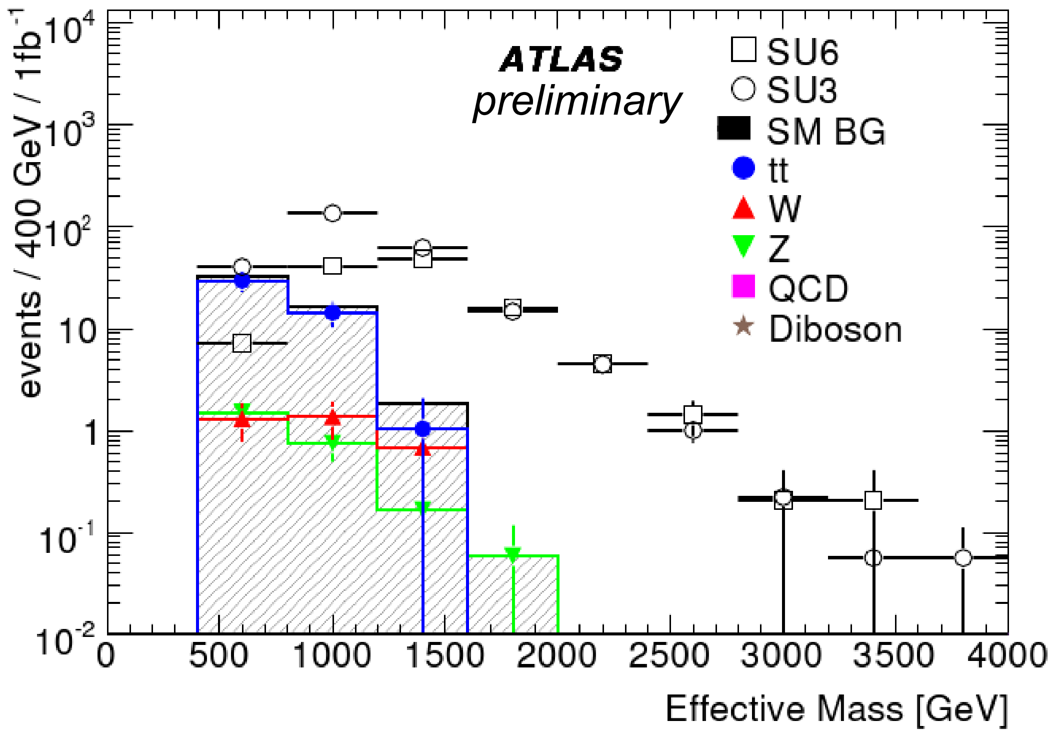
$\Sigma(\text{Shape}_i * \text{TF}_i)$

Signal Region

all 4 jet/1 lepton cuts applied
Transverse Mass > 100GeV

Jets & Missing E_T & *taus*

- SUSY channels generally violate $e/\mu/\tau$-universality:
  - $\tan\beta \gg 1$ yields potentially large τ abundance
- Selection criteria:
  - *Full overlap with 0-lepton analysis*
  - *4 hard jets*
  - *At least one τ:* p_T > 20GeV
    (efficiency: ~50%, purity: ~80%)
  - *No other isolated e or μ*
  - *Missing transverse energy*
  - *Supression of $t\bar{t}$ / W background*
    $M_T(\tau, E_T^{miss})$ > 100GeV



- Backgrounds:
  - Significantly reduced QCD background
  - Most important background: $t\bar{t}$ decays + jets

Prospects for SUSY Discovery

(Systematic uncertainties and statistical procedure)

- Systematic uncertainties (approximate for $1fb^{-1}$):
  - 50% for backgrounds from QCD multijet events
  - 20% for backgrounds $t\bar{t}$, W+jets, Z+jets, and W/Z pairs
  - Limited Monte-Carlo statistics

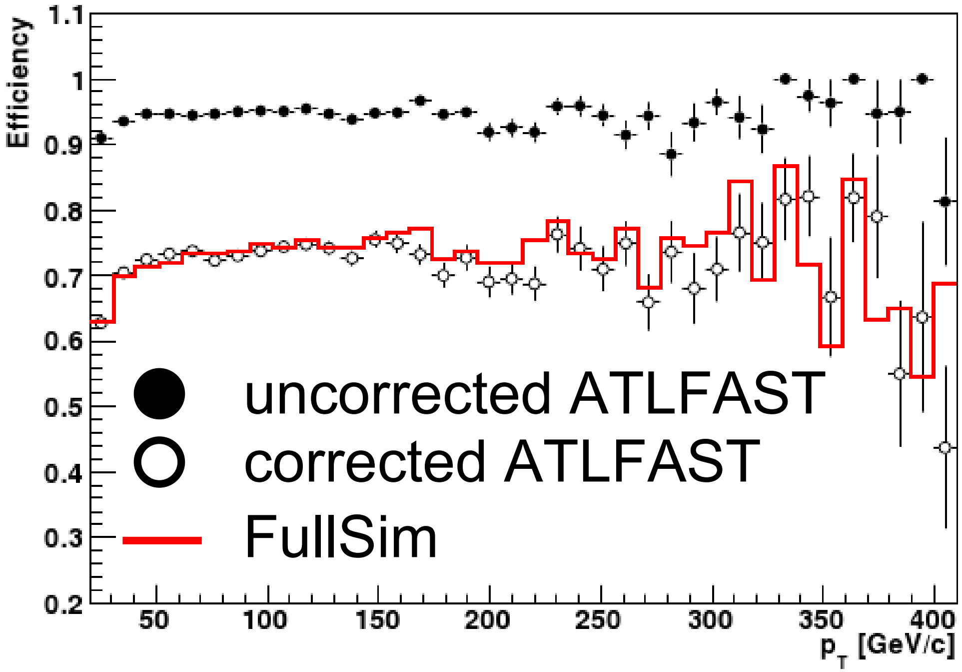
- Statistical treatment:
  - p-Value calculated as:

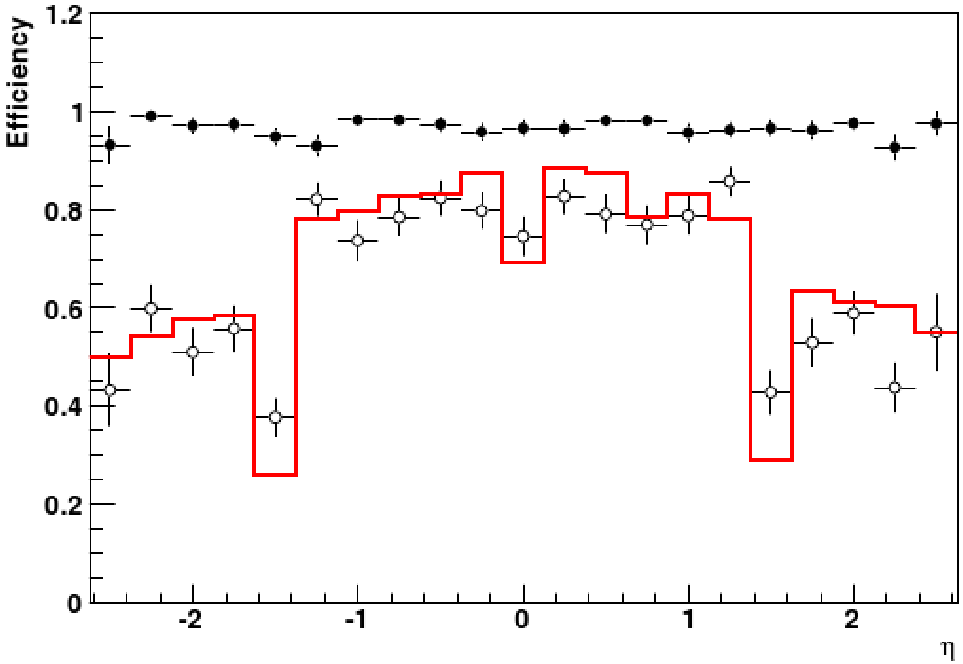
$$p = A \int_0^\infty db \, \underbrace{G(b; N_b, \delta N_b)}_{\text{Gaussian}} \sum_{i=N_{data}}^{\infty} \underbrace{\frac{e^{-b} b^i}{i!}}_{\text{Poisson probability}}$$

  - Multiple cuts on M_{eff} to find the smallest p-Value
  - Calculate significance Z_n corrected for “multiple comparison” (correction ~0.5 for Z_n=3)

Fast Simulation Correction

- Scans use fast parameterized simulation of the ATLAS detector for signal
- Applied additional corrections to electron reconstruction efficiencies as function of p_T and η

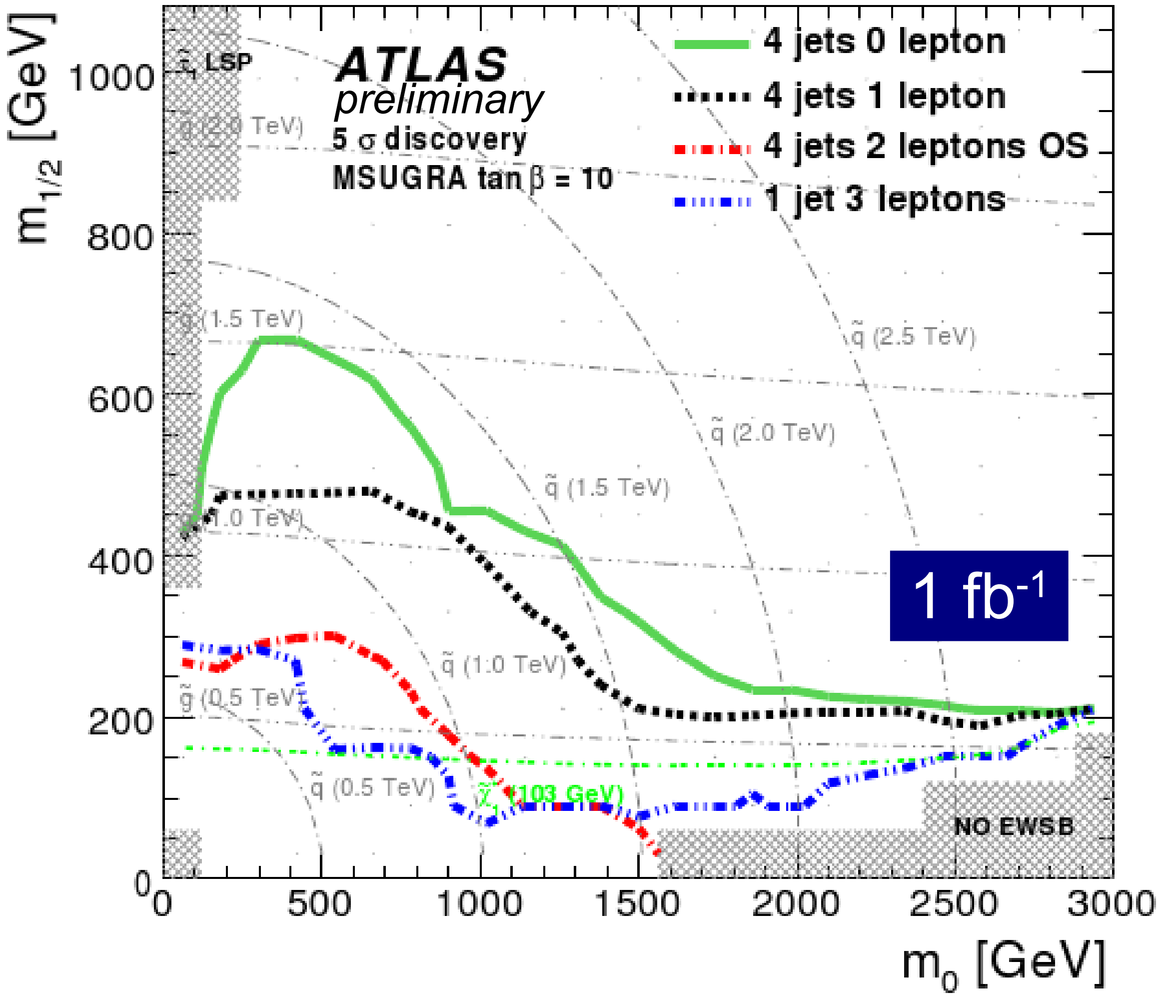




Discovery Reach for mSUGRA

mSUGRA with tanβ=10

- Scan of the $m_0/m_{1/2}$-plane
- 5σ discovery reach contours
- Comparison of different event topologies

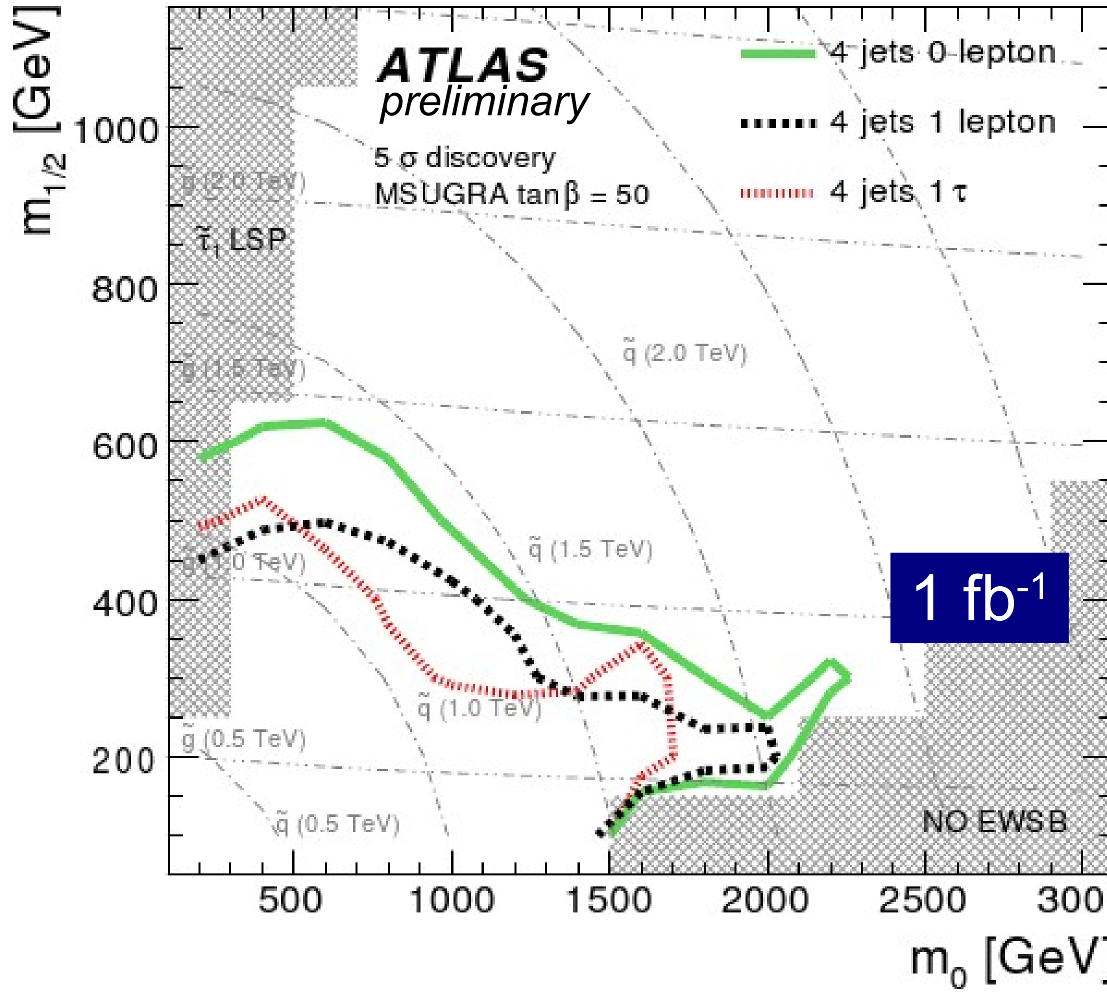


4 jets, 0-lepton channel most efficient (close to 1.5TeV)
but 1-lepton channel more robust against QCD backgrounds

Discovery Reach for mSUGRA

mSUGRA with tanβ=50

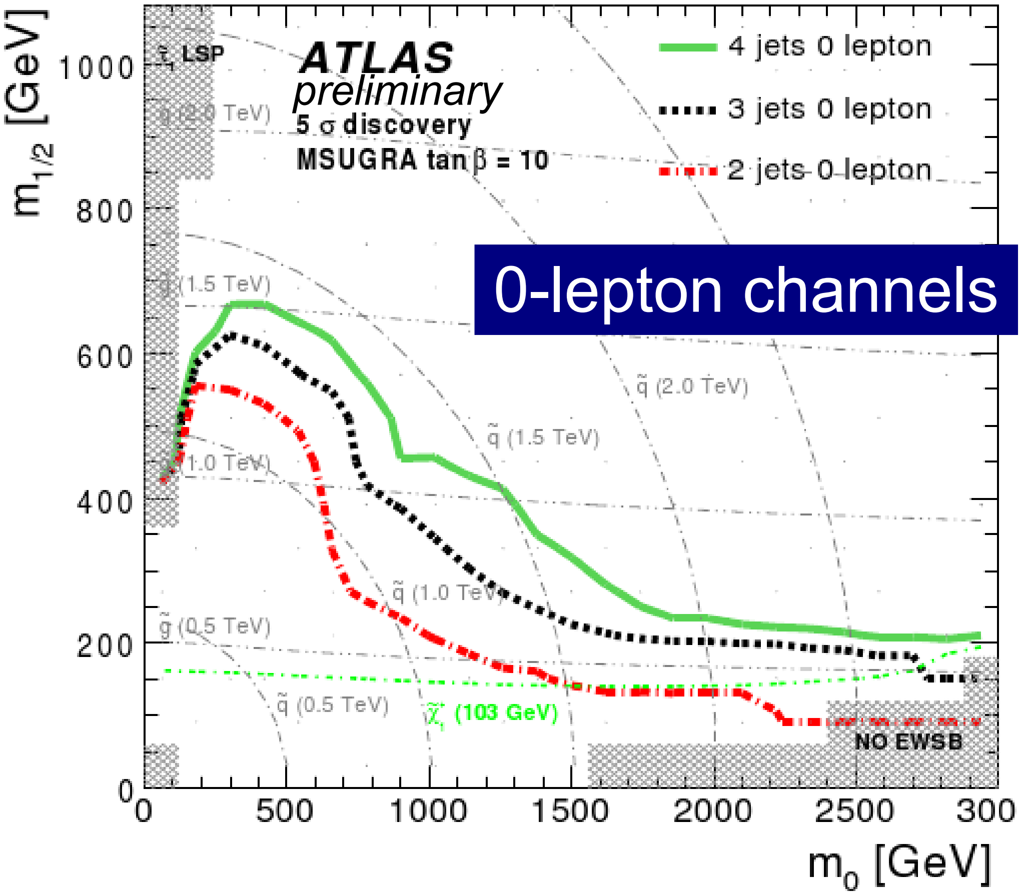
- Scan of the $m_0/m_{1/2}$-plane
- 5σ discovery reach contours
- Comparison of different event topologies

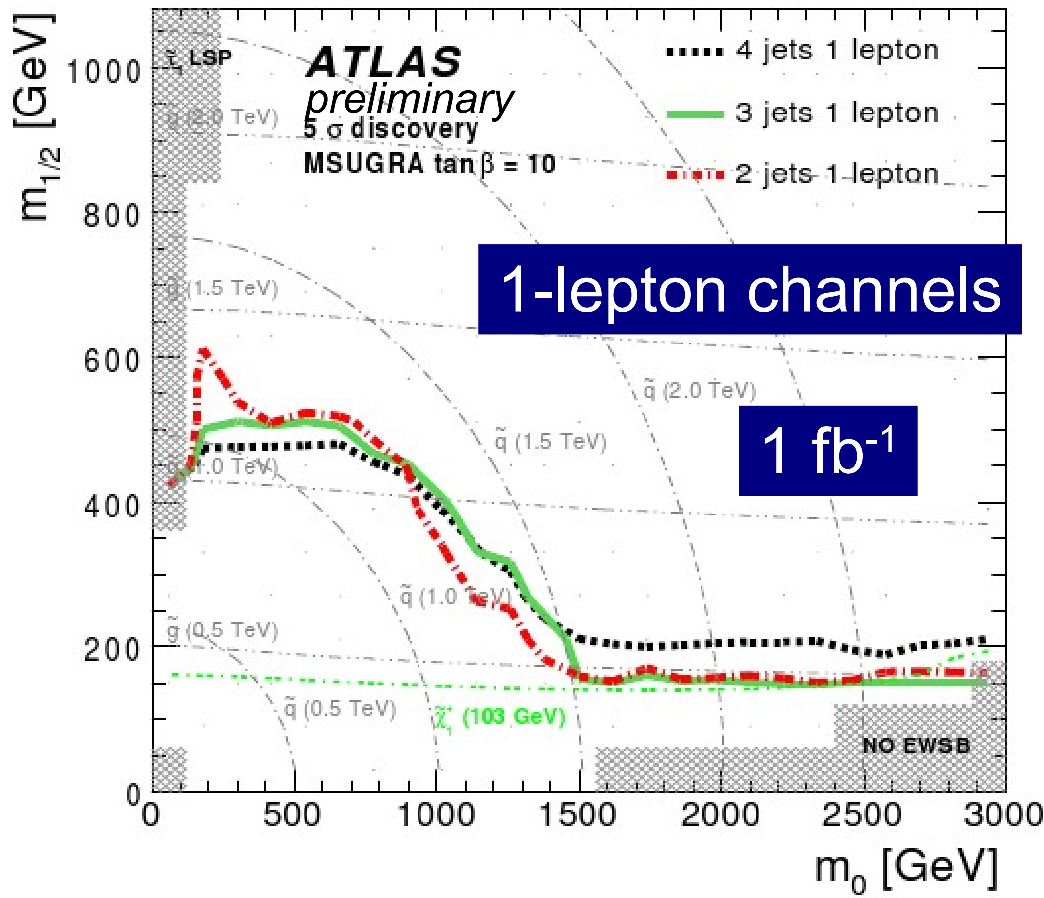


4 jets, 0-lepton channel most efficient,
reach of tau-channel channel slightly worse due to fake tau background
==> improved in next software release

Discovery Reach for mSUGRA

mSUGRA with tanβ=10



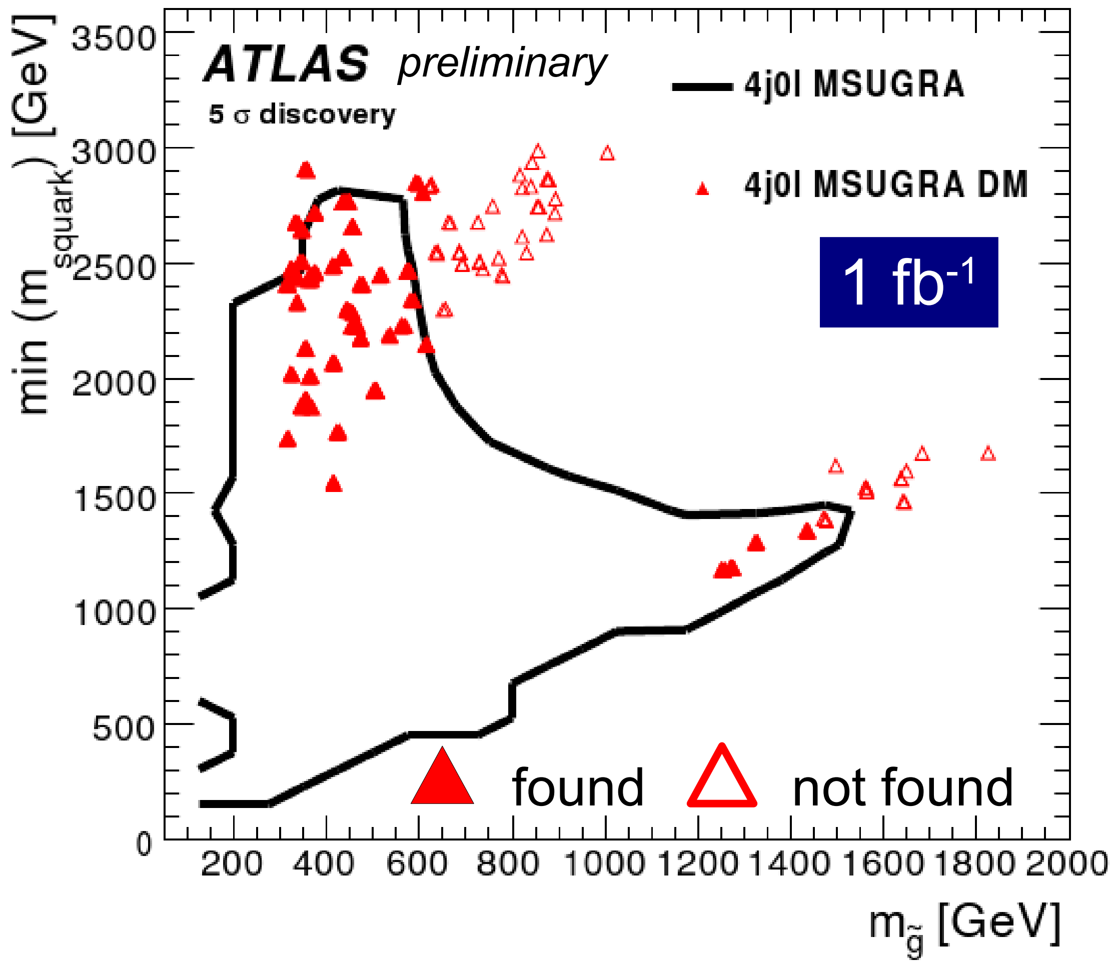


0-lepton channels: 4-jets channel gives highest reach
1-lepton channels: 2,3,4-jets channels with comparable sensitivity
For 100 pb^{-1} low jet multiplicities very promising also in 0 lepton mode

Discovery Reach for mSUGRA

mSUGRA + constraints

- "Random" scan of the $\min(m_{\bar{q}})/m_{\bar{g}}$-plane
- Random generation of mSUGRA points satisfying: m_H, WMAP DM limit, $Br(b \rightarrow s\gamma)$, $Br(B_s \rightarrow \mu\mu)$, a_μ

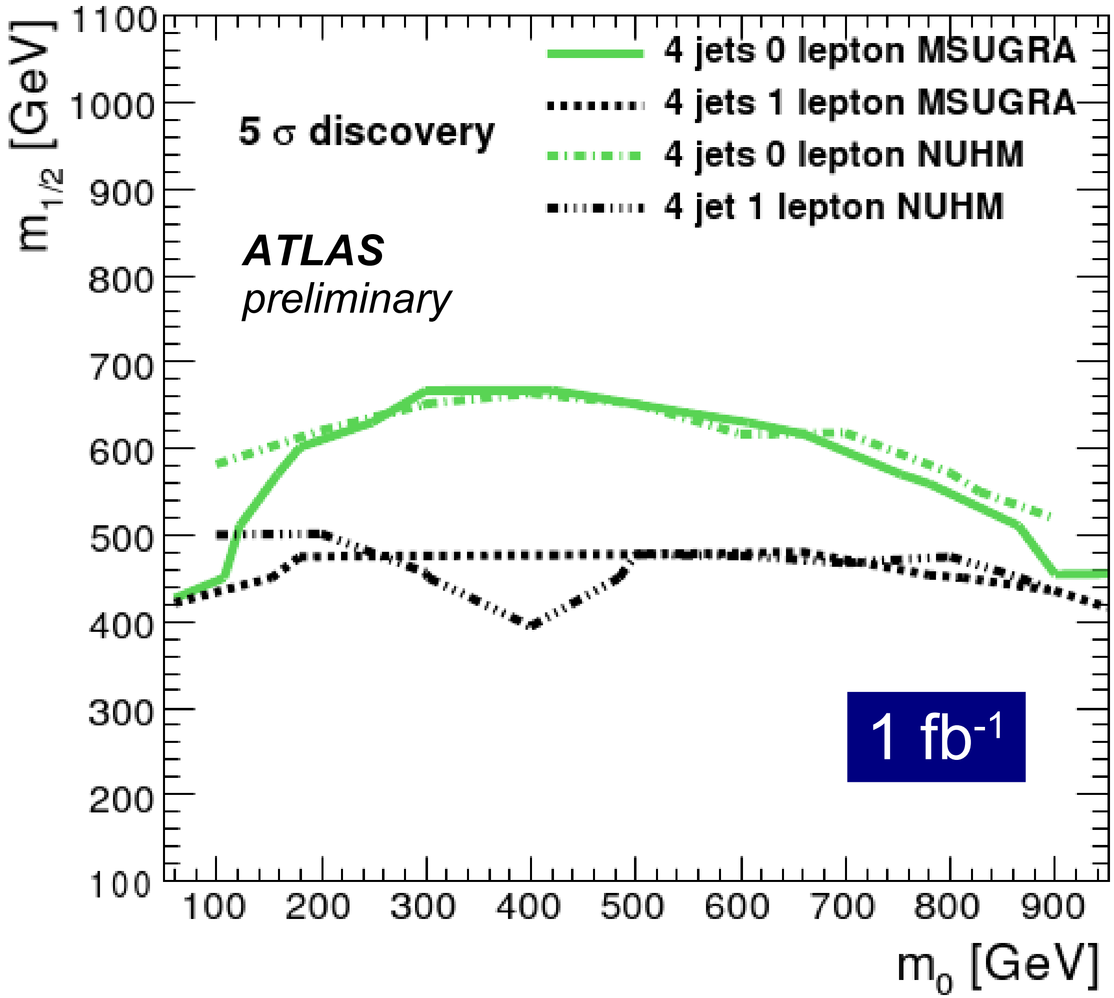


Comparison with mSUGRA-scans yields comparable sensitivity (production xsection depends mostly on $m_{\bar{q}}/m_{\bar{g}}$-masses)

Discovery Reach for NUHM

mSUGRA vs. NUHM

- NUHM (non-universal-higgs-model): Adjust values of μ and M_A to be compatible with CDM constraints
- 5σ discovery reach contours
- Comparison of 0 and 1-lepton measurements

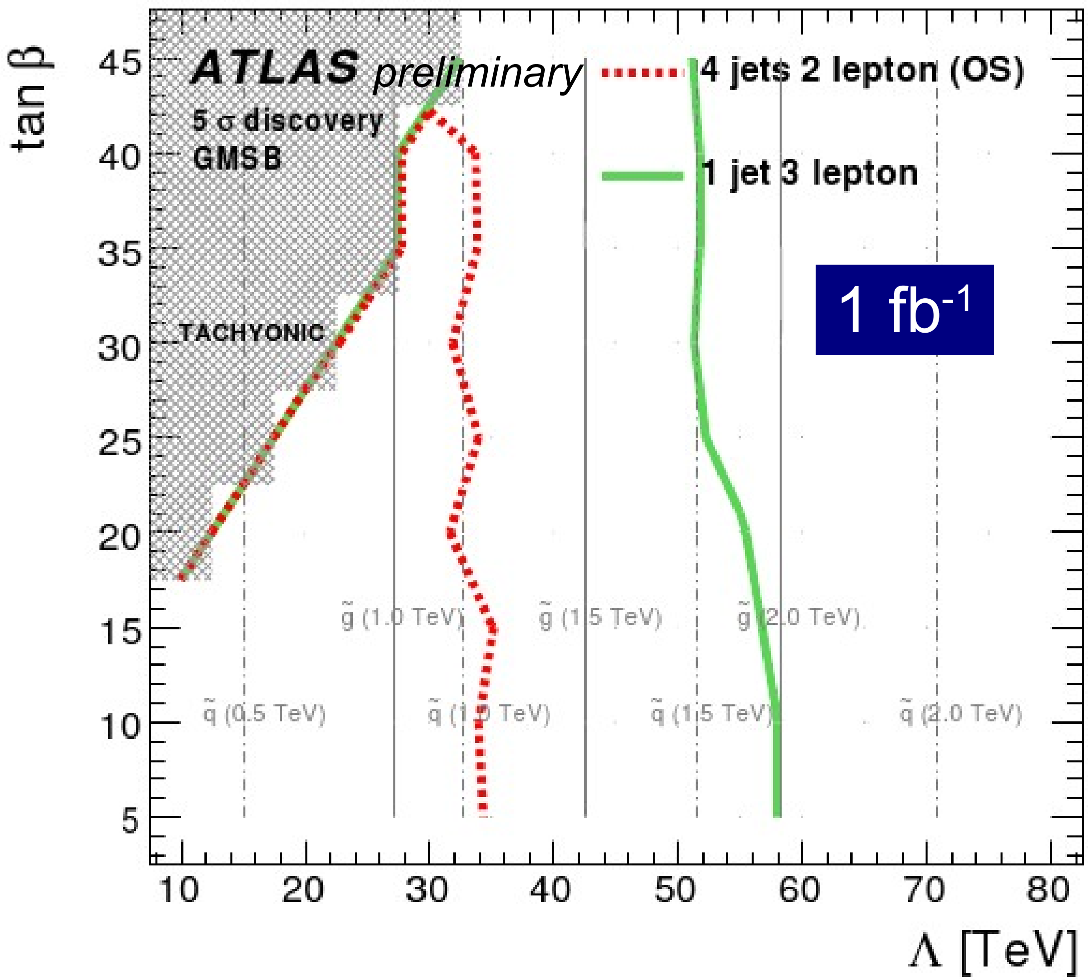


mSUGRA vs. NUHM: reach in 0 and 1-lepton channels comparable

Discovery Reach for GMSB

GMSB

- GMSB (gauge mediated SUSY breaking)
- Models considered have at least two leptons
  - Easy to distinguish from SM background
- 5σ discovery reach contours



reach of 3 lepton channel extends well beyond 2TeV for gluinos

Summary

- Freiburg works on inclusive (model-independent) searches for BSM signals with missing transverse momentum
- Recent studies using full detector simulation published in ATLAS performance book:
  - Various channels with different event topologies (jets, leptons, taus, missing transverse energy)
  - Data-driven background estimation strategies
  - Signatures with gluino/squark masses up to 1.5TeV could be discovered with $1fb^{-1}$ (if detector is well understood)

--- Backup Slides ---

The mSUGRA Model

- SUSY breaking mediated by gravitational interactions
- LSP: lightest neutralino

- 5 Parameters:
  - $m_{1/2}$: universal symmetry breaking gaugino mass
  - m_0: soft symmetry breaking scalar mass (defines slepton , squark mass etc.)
  - A_0: universal coupling (trilinear scalar interaction)
  - $\tan\beta$: ratio of the vacuum expectation values of the two Higgs doublets
  - sgn(μ): sign of the Higgsino mass parameter

SUSY Benchnark Points

- Points defined in terms of mSUGRA parameters at the unification scale:

ATLAS Benchmark Points

SU1	$m_0 = 70$ GeV, $m_{1/2} = 350$ GeV, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$. Coannihilation region where $\tilde{\chi}_1^0$ annihilate with near-degenerate $\tilde{\ell}$.
SU2	$m_0 = 3550$ GeV, $m_{1/2} = 300$ GeV, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$. Focus point region near the boundary where $\mu^2 < 0$. This is the only region in mSUGRA where the $\tilde{\chi}_1^0$ has a high higgsino component, thereby enhancing the annihilation cross-section for processes such as $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WW$.
SU3	$m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $A_0 = -300$ GeV, $\tan\beta = 6$, $\mu > 0$. Bulk region: LSP annihilation happens through the exchange of light sleptons.
SU4	$m_0 = 200$ GeV, $m_{1/2} = 160$ GeV, $A_0 = -400$ GeV, $\tan\beta = 10$, $\mu > 0$. Low mass point close to Tevatron bound.
SU6	$m_0 = 320$ GeV, $m_{1/2} = 375$ GeV, $A_0 = 0$, $\tan\beta = 50$, $\mu > 0$. The funnel region where $2m_{\tilde{\chi}_1^0} \approx m_A$. Since $\tan\beta \gg 1$, the width of the pseudoscalar Higgs boson A is large and τ decays dominate.
SU8.1	$m_0 = 210$ GeV, $m_{1/2} = 360$ GeV, $A_0 = 0$, $\tan\beta = 40$, $\mu > 0$. Variant of coannihilation region with $\tan\beta \gg 1$, so that only $m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$ is small.
SU9	$m_0 = 300$ GeV, $m_{1/2} = 425$ GeV, $A_0 = 20$, $\tan\beta = 20$, $\mu > 0$. Point in the bulk region with enhanced Higgs production

SUSY Cross-Sections

- Leading order and next-to-leading order cross-sections as calculated with PROPINO:

Label	σ^{LO} (pb)	σ^{NLO} (pb)	N	L (fb^{-1})
SU1	8.15	10.86	200 K	18.4
SU2	5.17	7.18	50 K	7.0
SU3	20.85	27.68	500 K	18.1
SU4	294.46	402.19	200 K	0.50
SU6	4.47	6.07	30 K	4.9
SU8.1	6.48	8.70	50 K	5.7
SU9	2.46	3.28	40 K	12.2

SUSY Grids

mSUGRA fixed grid, $\tan\beta = 10$, $A_0 = 0$, $\mu > 0$: A 25×25 grid was made varying m_0 from 60 GeV to 2940 GeV in 25 steps of 120 GeV, and $m_{1/2}$ from 30 GeV to 1470 GeV in 25 steps of 60 GeV. SUSY spectra were generated using ISAJET 7.75 [21] with a top quark mass of 175 GeV. Out of the 625 possible points, a spectrum could be successfully generated for 600; the other 25 failed for theoretical reasons. For each good point 20k events were produced using ATLFAST. Constraints other than from direct searches were ignored. While constraints such as the dark-matter relic density constrain specific SUSY-breaking models such as mSUGRA, they are much less restrictive for generic models.

mSUGRA fixed grid: $\tan\beta = 50$, $A_0 = 0$, $\mu < 0$: Large $\tan\beta$ increases the mixing of $\tilde{b}_{L,R}$ and $\tilde{\tau}_{L,R}$, leading to enhanced b and τ production. A grid of 25×25 points with was generated with m_0 varied from 200 to 3000 GeV in steps of 200 GeV and with $m_{1/2}$ varied from 100 to 1500 GeV in steps of 100 GeV. The top mass was fixed at 175 GeV. Constraints other than from direct searches were again ignored.

mSUGRA random grid with constraints: In this sample all mSUGRA parameters were varied in two regions[2)] previously found [22] to be compatible with dark-matter and other constraints with $\mu > 0$ and $m_t = 175$ GeV.

The mSUGRA parameters were chosen randomly (with $\mu > 0$) and their properties calculated using ISAJET 7.75. All selected points satisfy the LEP Higgs mass limit, $m_h > 114.4$ GeV [23]; the WMAP total dark matter limit, $\Omega h^2 < 0.14$ [24]; within 3σ the branching ratio limits $B(b\to s\gamma) = (3.55\pm 0.26)\times10^{-4}$ [25] within 3σ and $B(B_s\to\mu^+\mu-) < 1.5\cdot10^{-7}$ [26]; and with δa_μ less than the 3σ upper limit from the muon anomalous magnetic moment measurement $a_\mu = (11659208\pm6)\times10^{-10}$ [27].

GMSB grid: $M_{\mathrm{mess}} = 500$ TeV, $N_{\mathrm{mess}} = 5$, $C_{\mathrm{grav}} = 1$: With $N_{\mathrm{mess}} = 5$ the NLSP is a slepton which decays promptly to leptons or τ's. A fixed grid was made varying Λ was varied from 10 TeV to 80 TeV in steps of 10 TeV and $\tan\beta$ from 5 to 40 in steps of 5.

NUHM grid: The NUHM model is similar to the mSUGRA model but does not assume that the Higgs masses unify with the squark and slepton ones at the GUT scale. This allows more gaugino/Higgsino mixing at the weak scale and so relaxes the mSUGRA dark matter constraints. The scan uses a step size of 100 GeV in both m_0 and $m_{1/2}$. For each point the values of μ and M_A at the weak scale are adjusted to give acceptable cold dark matter.