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Prospects for the search for standard SUSY signatures at LHC

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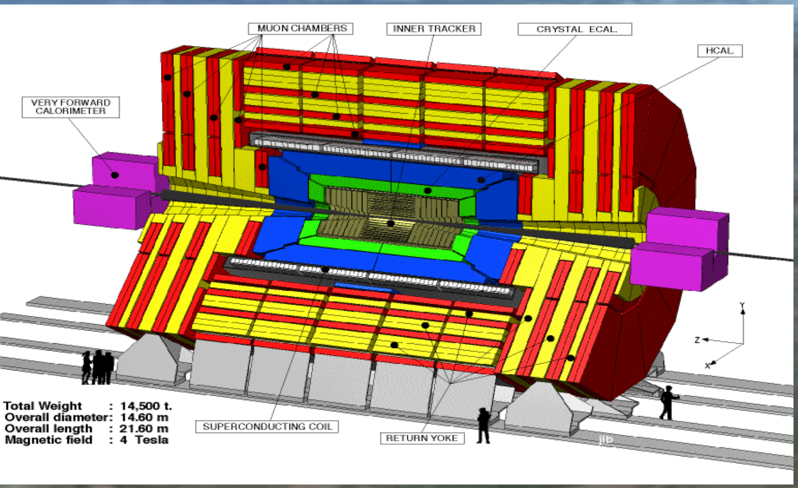
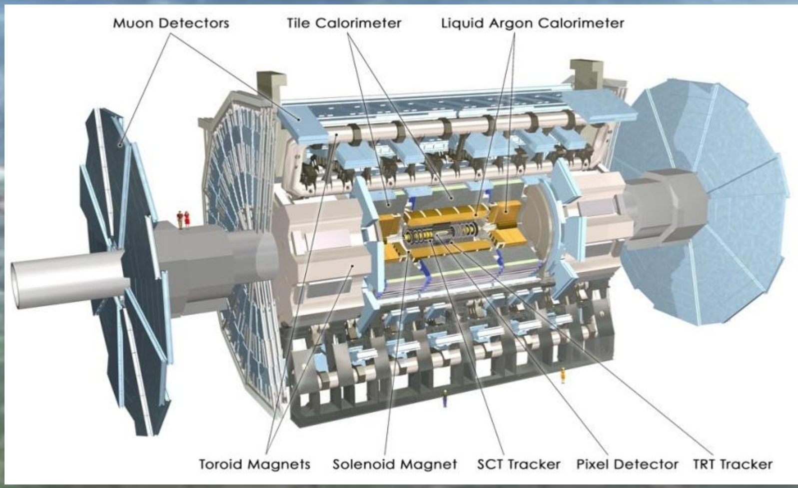
Outline

- Brief LHC, ATLAS and CMS status
- Inclusive Search and background expectations
- Prospects for given SUSY models
- Is this SUSY ? And the parameter determination ...

Brief LHC, ATLAS and CMS status





- Almost all LHC sectors are cooled down (2 sectors at this moment at 20-30K)
- Start at $\sqrt{s}$ = 10 TeV in 2008
- 2008 Luminosity about $5\cdot10^{31}$ cm^{-2}s^{-1} ➔ roughly 20 pb^{-1} of integrated luminosity
- 2009 Start with $\sqrt{s}$ = 14 TeV and luminosity of 10^{33} cm^{-2}s^{-1}
- ATLAS and CMS are ready
  - all major detectors installed and commissioned
  - cosmics, technical runs, milestone runs

Supersymmetry at the LHC

This talk: The "Standard assumptions":

Assume pair production of SUSY particles (R-parity conserved)
Due to strong force dominant production of squarks and gluinos (if not too heavy)
Cascade decay to lighter SUSY particles and finally the lightest SUSY particle (LSP)

The "Standard signals":

Missing transverse energy, jets, maybe leptons, maybe photon

General Approach: Find more events than expected and search in many channels

Challenge : control the background expectation for a new experiment

Supersymmetry at the LHC

This talk: The "Standard assumptions":

•Assume mostly 5-parameter *mSUGRA* as a quite "general " model for R-Parity conserving SUSY and test procedure with other scenarios (NUHM,GMSB,AMSB)

•Define benchmark points, e.g.:

LM1 m_0=60, $m_{1/2}$=250 , tan β=10, A_0=0, + ➔ m(squark) = 560 GeV, m(gluino) = 610 GeV, σ=55 pb

SU3 m_0=100, $m_{1/2}$=300 , tan β=6, A_0=-300, + ➔ m(squark) = 630 GeV, m(gluino) = 720 GeV, σ=28 pb

The "Standard signals":

Missing transverse energy, jets, maybe leptons, maybe photon

Signals studied at ATLAS (CSC 2008, new)

2, 3, 4 jets + 0 ,1, 2 leptons + missing pT, 3 leptons, taus, photon, …

Signals studied at CMS (TDR2 2006 and CSA07, new)

3 jets + 0,1,2 leptons + missing pT, 3 leptons, taus, Z, top , photon …

➔ *Don't miss anything, but start with a countable number of channels*

Inclusive SUSY searches

Example : jets + 0 lepton channel baseline channel

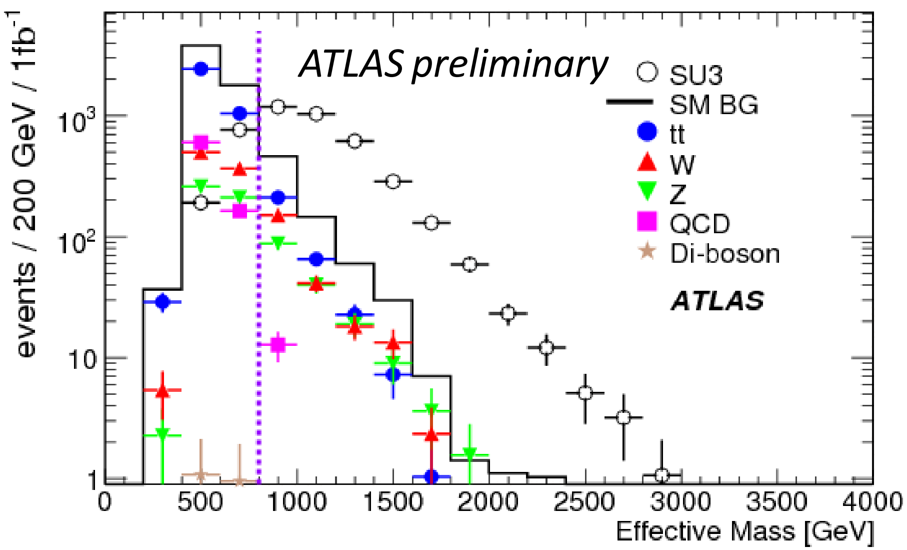
ATLAS baseline selection:

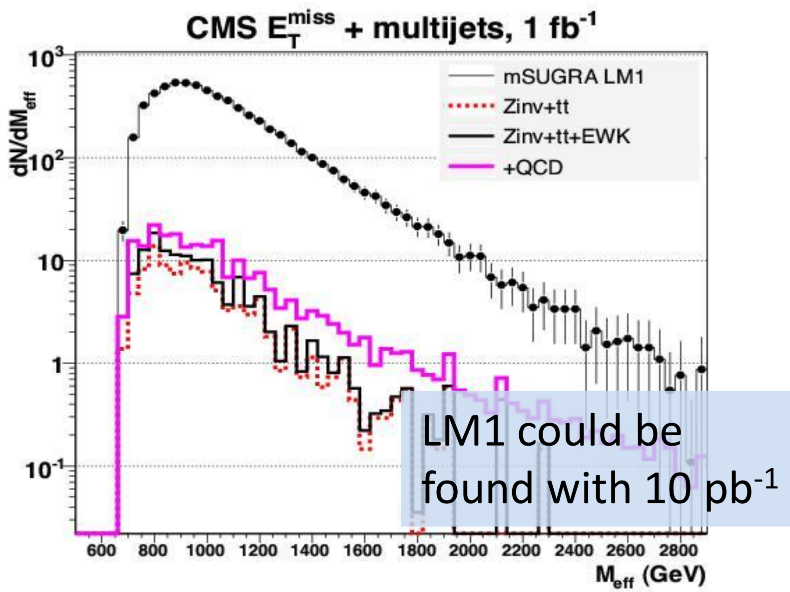
Trigger: jet pt > 70 GeV , Etmiss > 70 GeV
4 jets with E_T>100, 50, 50, 50 GeV
E_T^{miss} > 100 GeV and > 0.2 M_{eff}
Spherical: transverse Sphericity > 0.2
Exclusive to lepton channels: No e or μ
QCD removal: delta phi(jet, MET)>0.2

CMS baseline selection:

Trigger L1 : jet pt > 88 GeV, Etmiss > 46 GeV
3 jets with E_T>180, 110, 30 GeV
E_T^{miss} > 200 GeV

Exclusive to lepton channels: no isolated track
QCD removal: delta phi(jet, MET)>0.3





LM1 could be found with 10 pb^{-1}

M_{eff} = sum of the 4 jets + missing energy

Wait !!!

Before claiming any discovery we need to understand our expectations (MC, detector response)

… and we are looking at shapes, tails of distributions and high jet multiplicities

- Reduce background as much as possible
- Validate expectation with data in various control regions

➔ Various methods to estimate and control expectation with data developed by both CMS and ATLAS

➔ I show a few simple examples in the next few slides

Inclusive SUSY searches

Example : jets + 0 lepton channel baseline channel

Main backgrounds for 0 lepton search

QCD : missing P_T due to jet mis-measurements and jet resolutions

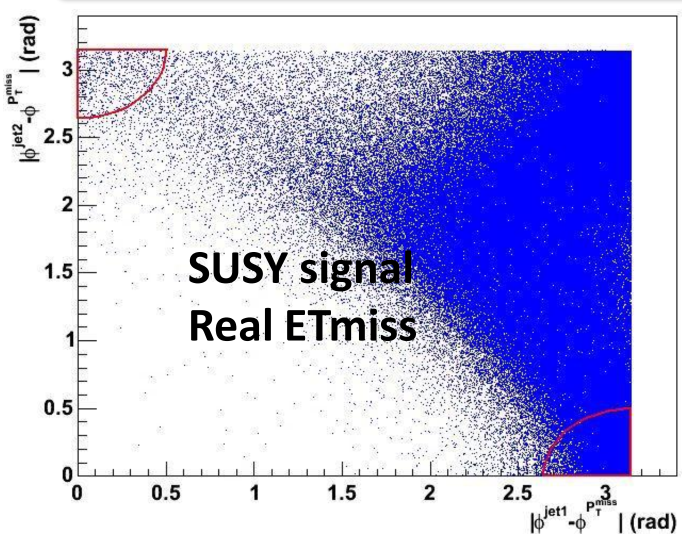
Z ➔ neutrinos : irreducible, we need to measure

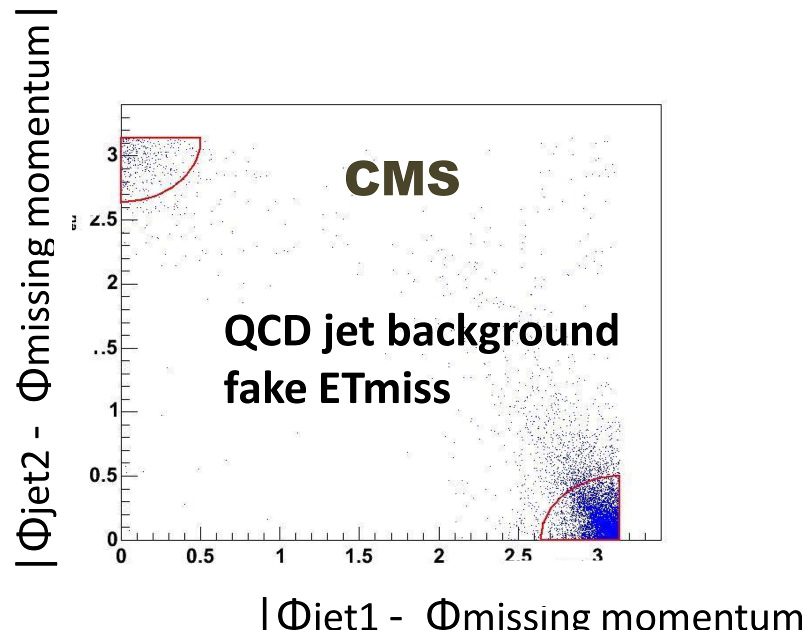
Top : 1 or 2 leptons not identified

W : 1 lepton not identified

QCD background reduction and control

Clean-up cuts against fake E_T^{miss}



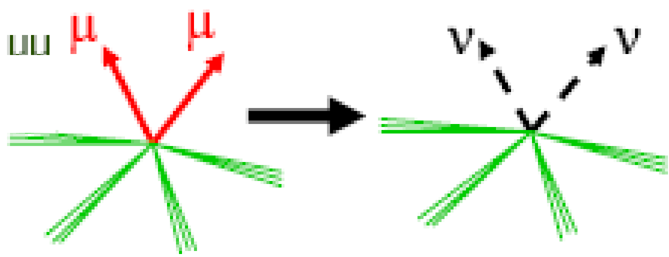


Inclusive SUSY searches

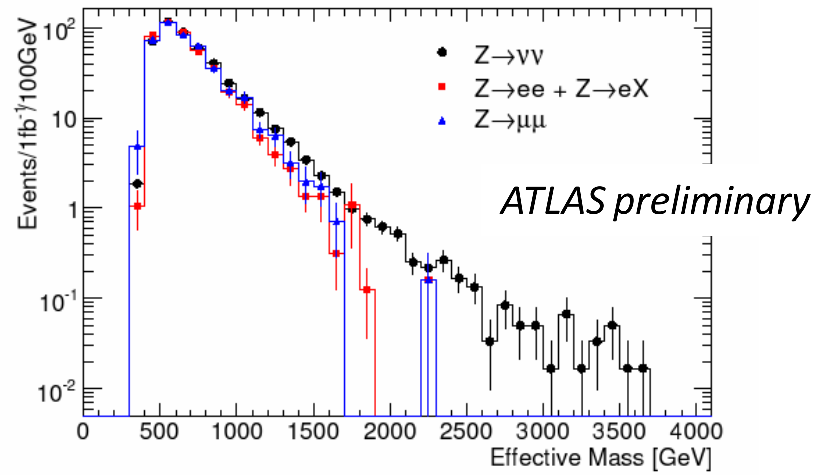
Example : jets + 0 lepton channel baseline channel

Estimate Z ➔ neutrinos background from data

ATLAS/CMS: From Z➔ ee or μμ events

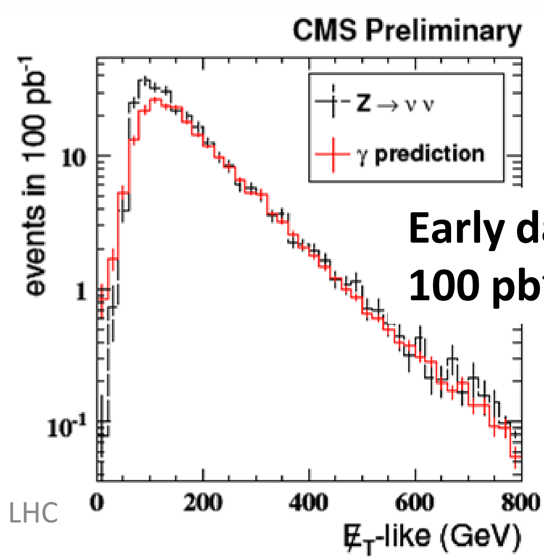


➔ Uncertainty roughly 20% for 1 fb^{-1}



CMS: From W and jet + photon events:

• Expect similar shapes for all types of bosons at high boson P_T
• **γ :** High statistics, relies on γ ID, good S/B
• **W:** High statistics, large backgrounds, signal contamination



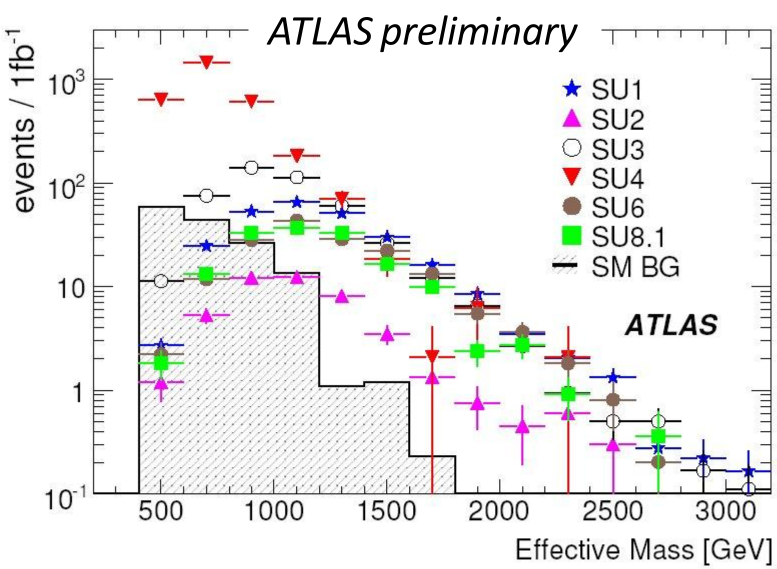
Early data study
100 pb^{-1}

Inclusive SUSY searches

Example : jets + 1 lepton channel

ATLAS:

Very similar selection as in 0 lepton channel
1 isolated electron or muon with P_T > 20 GeV
M_T (l, neutrino) > 100 GeV



CMS

cuts optimized with a "genetic" algorithm for LM1

Results:
E_T^{miss} > 130 GeV, E_T^{j1} and E_T^{j2} > 440 GeV
pseudorapidity jet cuts optimized
$\cos[\Delta\varphi(j1,j2)]<0.2$,
and cut on $\Delta\varphi(\text{jets},E_T^{miss})$

Optimization gives very good significance for low mass benchmark points

- **Less QCD background, very good sensitivity**
- **M_T (l, neutrino) < 100 GeV is most important control region**

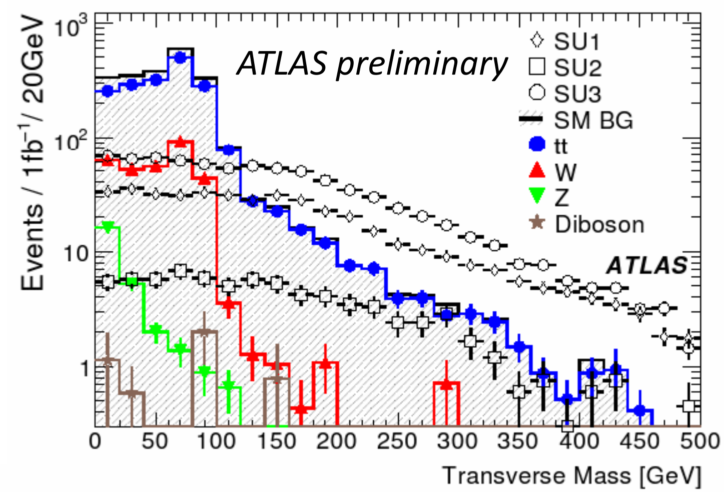
Inclusive SUSY searches

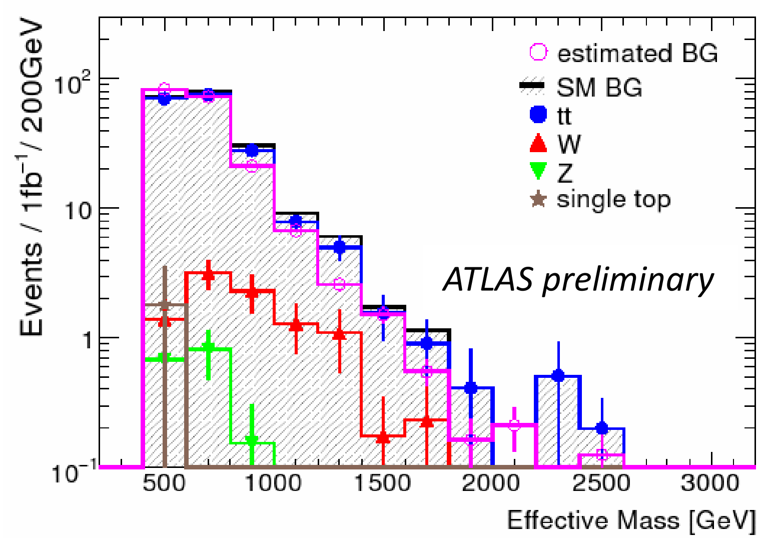
jets + 0 and 1 lepton channel

Estimate top and W background from data

ATLAS:
control region with M_T < 100 GeV
Here we have more SM events than new physics signal

effective mass distribution in control region can be used to predict distribution in signal region (M_T > 100 GeV)





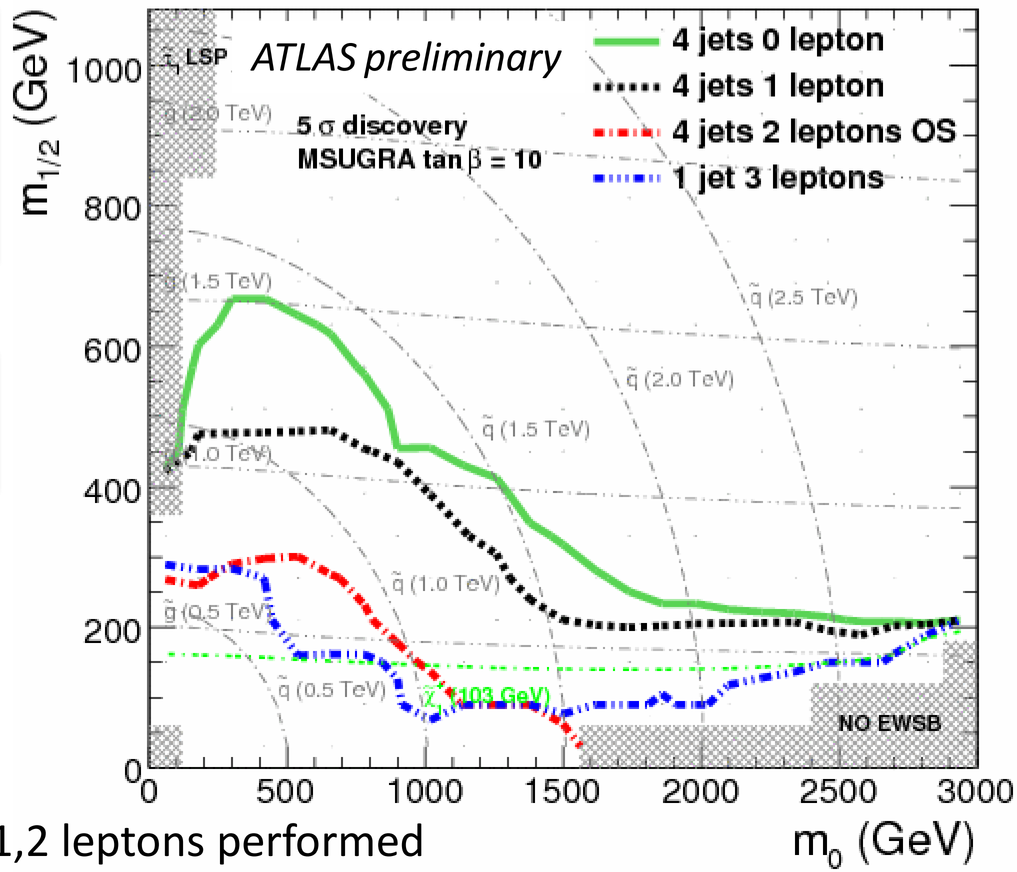
Prospects mSUGRA

Scan mSUGRA parameters:
Repeat search using many different mSUGRA signals

ATLAS Definition of "scan":

Cut on effective mass optimized to get best signal significance

Comparison of 0, 1, 2OS, and 3 lepton mode.

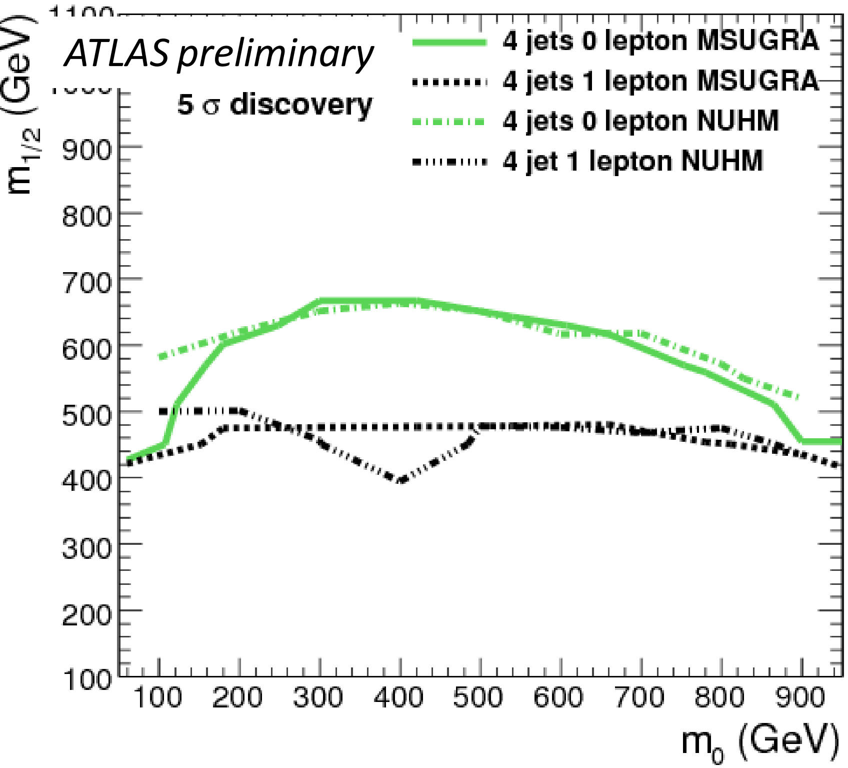


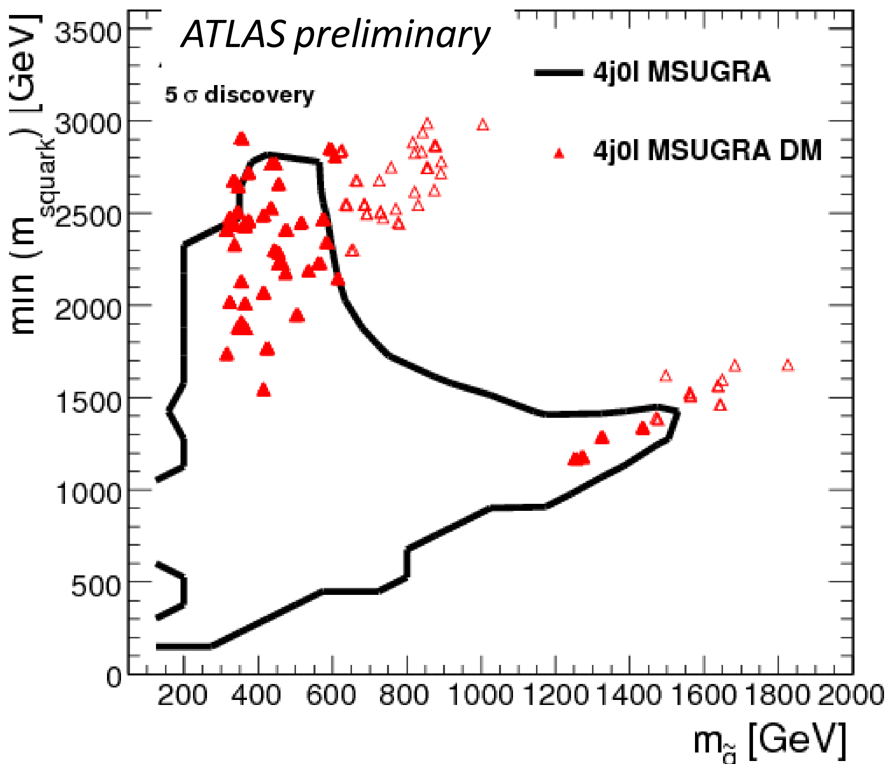
ATLAS: Comparison of 2,3,4 jets + 0,1,2 leptons performed
Sometimes better discovery potential with lower jet multiplicities

Prospects: parameter dependence

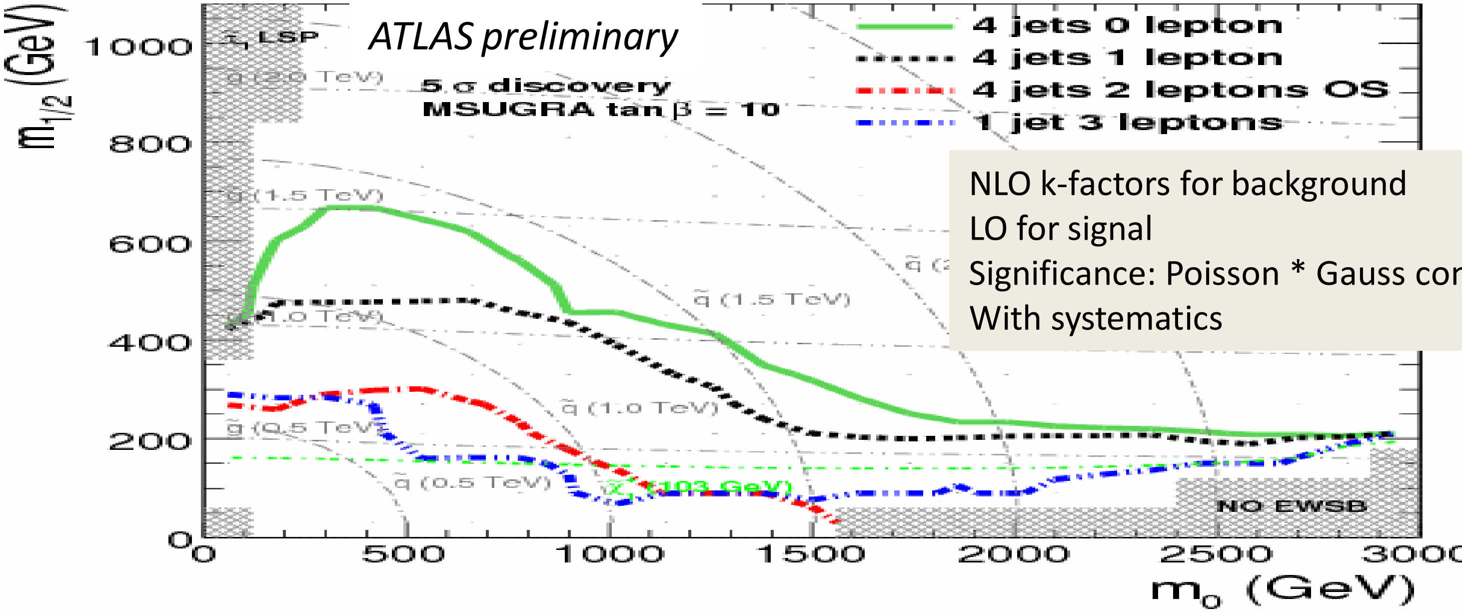
``mSUGRA vs NUHM''
NUHM here: fix M_A and tan β to values compatible with WMAP constraints

``mSUGRA + constraints''
mSUGRA scan, but satisfying WMAP, a_μ , M_h , $b \rightarrow s\gamma$, $B_s \rightarrow \mu\mu$, $\mu>0$

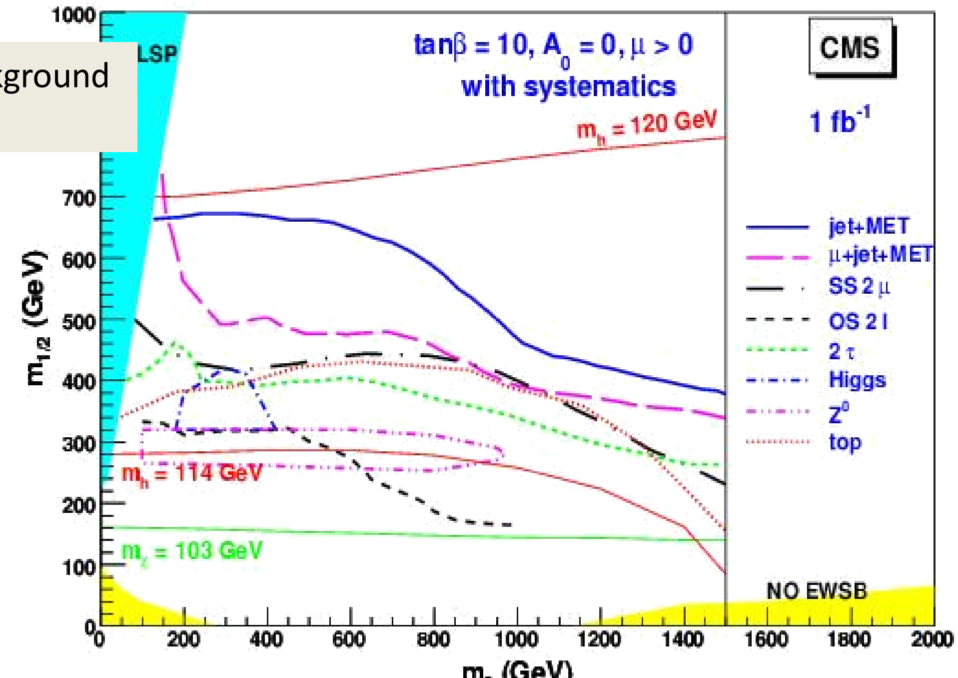




Open triangles: found
Closed triangles: not found



NLO k-factors for background
LO for signal
Significance: Poisson * Gauss convolution
With systematics



NLO k-factors for background
With systematics

tan β = 10 1 fb^{-1}

Very similar discovery potential estimate by ATLAS and CMS

Exclusive Measurements

"Observation of events with high missing transverse energy in pp collisions"

Is it really Supersymmetry ?

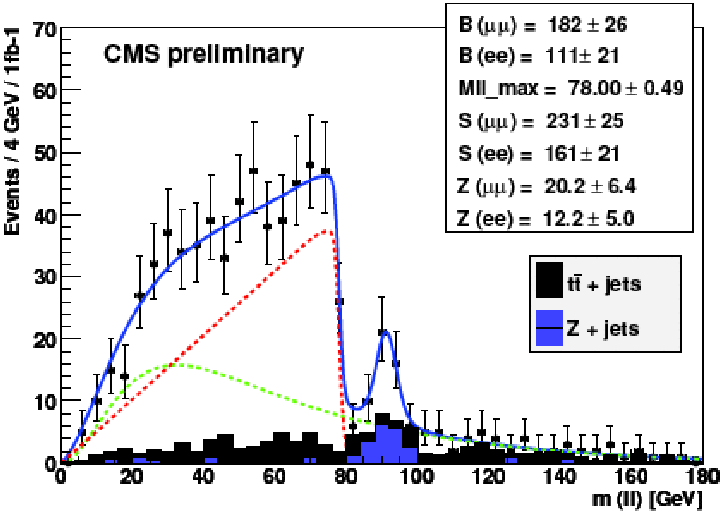
Perform a great many of exclusive measurements

Important example : Measurement of $\tilde{\chi}_2^o \rightarrow \tilde{\ell}_{L,R}\ell \rightarrow \ell\ell\tilde{\chi}_1^o$ in OS dilepton events

Due to missing energy no mass peaks, but shapes and endpoints of mass distribution provide mass information

$$m_{\ell\ell}^{max} = m_{\tilde{\chi}_2^o}\sqrt{1-\frac{m_{\tilde{\ell}_R}^2}{m_{\tilde{\chi}_2^o}^2}}\sqrt{1-\frac{m_{\tilde{\chi}_1^o}^2}{m_{\tilde{\ell}_R}^2}}$$

CMS



-Determine same flavor top and di-boson background from eμ data

-Determine dilepton endpoint using a 6 parameter fit to the ee and μμ mass distributions (there is also SUSY background)

$$\Delta m_{ee}^{max} = \pm 1.07(stat.) \pm 0.36(syst.) GeV/c^2$$

$$\Delta m_{\mu\mu}^{max} = \pm 0.75(stat.) \pm 0.18(syst.) GeV/c^2$$

Summary

- New studies with full ATLAS and CMS detector simulations
  various channels with missing transverse energy
  various background estimation strategies

- Signatures of gluinos and squarks with masses up to 1 TeV can be discovered with $1 fb^{-1}$

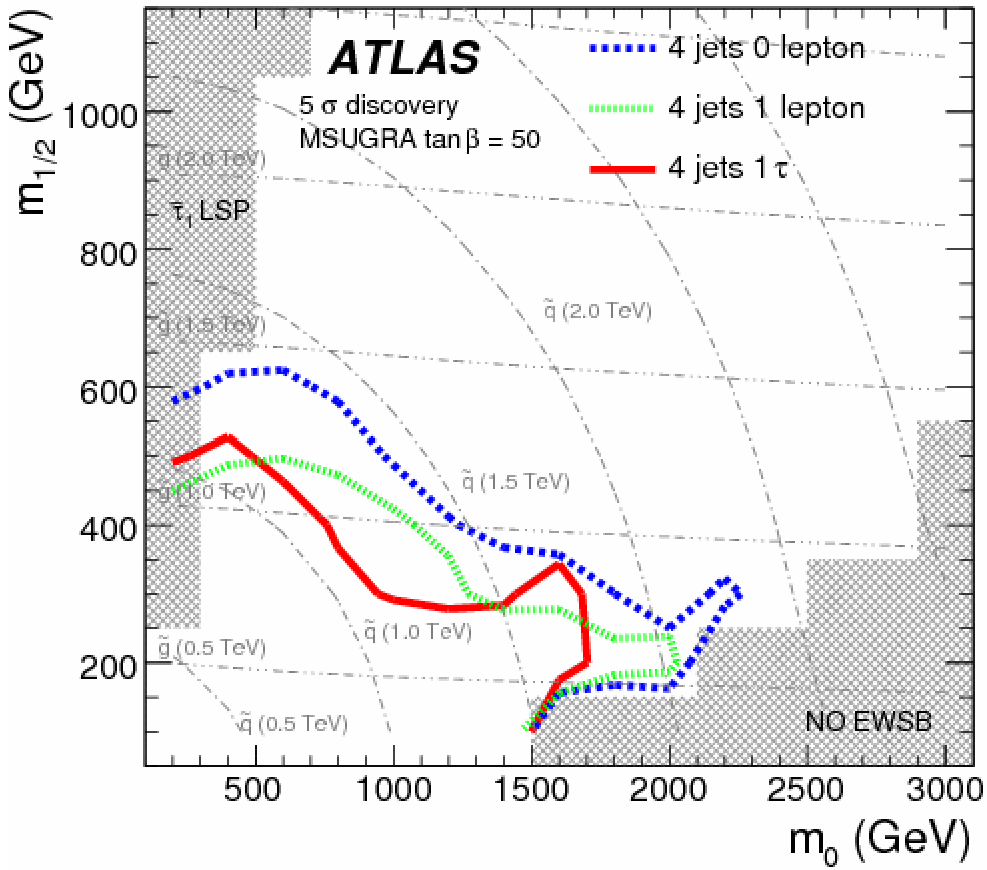
  (thus maybe already in 2009)

  … if we can estimate all backgrounds and understand our detectors

Inclusive SUSY searches

Scan mSUGRA parameters:
Repeat search using many different mSUGRA signals

High tan beta
Comparison of 0, 1 and tau channel



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 $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow WW$.

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

CMS LM benchmark points

- Point LM1 :
  - Same as post-WMAP benchmark point B′ and near DAQ TDR point 4.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant
  - $B(\tilde{\chi}_2^0 \to \tilde{l}_R l) = 11.2\%$, $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 46\%$, $B(\tilde{\chi}_1^{\pm} \to \tilde{\nu}_l l) = 36\%$
- Point LM2 :
  - Almost identical to post-WMAP benchmark point I′.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant ($\tilde{b}_1 b$ is 25%)
  - $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 96\%$ $B(\tilde{\chi}_1^{\pm} \to \tilde{\tau}\nu) = 95\%$
- Point LM3 :
  - Same as NUHM point γ and near DAQ TDR point 6.
  - $m(\tilde{g}) < m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is forbidden except $B(\tilde{g} \to \tilde{b}_{1,2} b) = 85\%$
  - $B(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0) = 3.3\%$, $B(\tilde{\chi}_2^0 \to \tau\tau\tilde{\chi}_1^0) = 2.2\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 100\%$
- Point LM4 :
  - Near NUHM point α in the on-shell Z^0 decay region
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant with $\tilde{g} \to \tilde{b}_1 b = 24\%$
  - $B(\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0) = 97\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 100\%$
- Point LM5 :
  - In the h^0 decay region, same as NUHM point β.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant with $B(\tilde{g} \to \tilde{b}_1 b) = 19.7\%$ and $B(\tilde{g} \to \tilde{t}_1 t) = 23.4\%$
  - $B(\tilde{\chi}_2^0 \to h^0\tilde{\chi}_1^0) = 85\%$, $B(\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0) = 11.5\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 97\%$
- Point LM6 :
  - Same as post-WMAP benchmark point C′.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant
  - $B(\tilde{\chi}_2^0 \to \tilde{l}_L l) = 10.8\%$, $B(\tilde{\chi}_2^0 \to \tilde{l}_R l) = 1.9\%$, $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 14\%$, $B(\tilde{\chi}_1^{\pm} \to \tilde{\nu}_l l) = 44\%$
- Point LM7 :
  - Very heavy squarks, outside reach, but light gluino.
  - $m(\tilde{g}) = 678\,\mathrm{GeV/c^2}$, hence $\tilde{g} \to$ 3-body is dominant
  - $B(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0) = 10\%$, $B(\tilde{\chi}_1^{\pm} \to \nu l\tilde{\chi}_1^0) = 33\%$
  - EW chargino-neutralino production cross-section is about 73% of total.
- Point LM8 :
  - Gluino lighter than squarks, except $\tilde{b}_1$ and $\tilde{t}_1$
  - $m(\tilde{g}) = 745\,\mathrm{GeV/c^2}$, $M(\tilde{t}_1) = 548\,\mathrm{GeV/c^2}$, $\tilde{g} \to \tilde{t}_1 t$ is dominant
  - $B(\tilde{g} \to \tilde{t}_1 t) = 81\%$, $B(\tilde{g} \to \tilde{b}_1 b) = 14\%$, $B(\tilde{q}_L \to q\tilde{\chi}_2^0) = 26 - 27\%$,
  - $B(\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0) = 100\%$, $B(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 100\%$
- Point LM9 :
  - Heavy squarks, light gluino. Consistent with EGRET data on diffuse gamma ray spectrum, WMAP results on CDM and mSUGRA [674]. Similar to LM7.
  - $m(\tilde{g}) = 507\,\mathrm{GeV/c^2}$, hence $\tilde{g} \to$ 3-body is dominant
  - $B(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0) = 6.5\%$, $B(\tilde{\chi}_1^{\pm} \to \nu l\tilde{\chi}_1^0) = 22\%$
- Point LM10 :
  - Similar to LM7, but heavier gauginos.
  - Very heavy squarks, outside reach, but light gluino.
  - $m(\tilde{g}) = 1295\,\mathrm{GeV/c^2}$, hence $\tilde{g} \to$ 3-body is dominant
  - $B(\tilde{g} \to t\bar{t}\tilde{\chi}_4^0) = 11\%$, $B(\tilde{g} \to tb\tilde{\chi}_2^{\pm}) = 27\%$