SUSY searches at LHC

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Outline

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Introduction

- Huge amount of work by many people in several years
- Not possible to summarize all in one talk!
- Will mostly focus on direct searches with first year of LHC data taking
  - Searches requiring at least tens of fb^{-1} not mentioned
- Public results only. Mostly taken from
  - CMS TDR II (2007)
  - ATLAS CSC book (2008)

What can we do with first data?

Among other things, first data will be used to

- Validate detector simulation
- Improve understanding of SM processes
- Tune trigger for higher luminosities
- Focus on experimental signatures without strong SM background

Caveats

- Public results show simulations at 14 TeV, ≥ 1 fb^{-1}, often without pile-up[1]
- However, the first year of LHC data taking will be different
  - 10 TeV
  - 10^{31} cm^{-2} s^{-1} integrated up to $O(200)$ pb^{-1}
  - pile-up might happen since early collisions
- Work in progress to simulate enough events to understand differences

[1] In the CMS PTDR2, 5 interactions per bunch crossing are considered

Outline

Prerequisites for SUSY searches

- Will briefly outline prerequisites for SUSY searches
- They will take most efforts during next year or so, though are not the subject of this talk
- They will also be continuous activity for several years, even in case of discovery of new physics

Validation of detector simulations

- Noise and calibration in collisions
- Physics environment
  - Pile-up
  - Beam-gas, beam-halo, beam-pipe collisions
  - Cavern background, cosmic rays
- Trigger rates
  - At present, cross-sections have large uncertainties
  - Detector parameters and environmental effects (see above)

Improve understanding of SM processes

- Reduce theoretical uncertainties on
  - di-jet and multi-jets
  - W + jets events
  - Z + jets events
  - $t\bar{t}$ events
- Validate generators
  - X-sec of events above at 10–14 TeV
  - parton distribution functions
  - hadronization
- Evaluate SM background to SUSY searches
  - In addition to CMS TDR II and ATLAS CSC book, see
  - CMS PAS SUS-08-002
  - CMS PAS SUS-08-005

Tune trigger for higher luminosities

- Luminosity not constant in colliders
  - $\mathcal{L}$ falls $\sim$ exponentially each spill
  - LHC upgrades up to design luminosity in several steps
- In general, the trigger rate is not a linear function of $\mathcal{L}$
  - Need to study threshold effects
  - Need to study each signature
- Several trigger menus to be built to follow variations of $\mathcal{L}$
  - Impact on searches for new physics

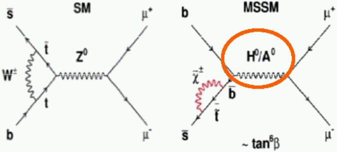
Outline

Searches for SUSY

- With first data, can only look for clear excess over SM
  - Most of parameter space not accessible
  - Excess can only be defined if the SM background is well known
- ATLAS, CMS simulations take lot of computing resources
  - Can not scan too many points in parameter space with full detector simulation: use fast simulation
  - Choice of mSUGRA reference points (different for ATLAS and CMS) for full simulation
  - In general, reference points are chosen to cover many different experimental signatures
- Will sort direct searches by experimental signature
- However, indirect evidence can also come from precision measurements (not covered here)
  - LHCb complements ATLAS and CMS

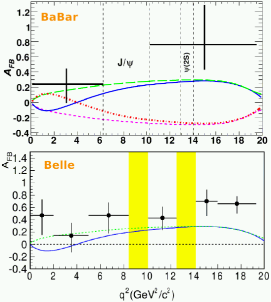
Indirect searches

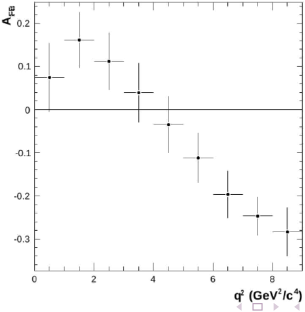
- New physics may induce effects in flavour changing neutral processes
- $B_s \to \mu^+\mu^-$ BR [E. López (LHCb), Lake Louise Winter Institute 2009]



SM: BR $= (3.35 \pm 0.32) \times 10^{-9}$
CDF: UL $= 47 \times 10^{-9}$ at 90% CL
SUSY: BR $\approx 20 \times 10^{-9}$ (NUHM, $\mu = 800$, $m_0 = 300$ GeV)
LHCb: reach SM prediction at 2 fb^{-1}

- $B_d \to K^*\mu^+\mu^-$ A_{FB} [B. Le Gac (LHCb), LISHEP 2009]





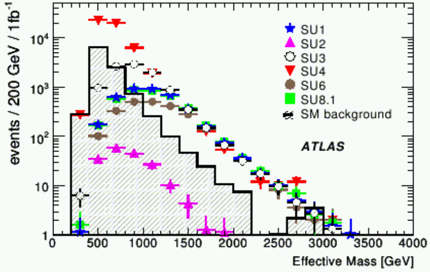
← LHCb with 2 fb^{-1}

Jets + MET

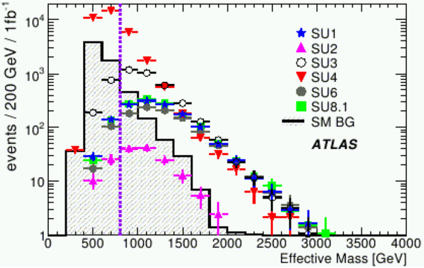
- The most inclusive signature for SUSY
- Background from QCD jets, $t\bar{t}$ events, W,Z boson production
- Can be triggered by jet+MET or jet+MHT
  (MHT = vector sum of jets p_T)

ATLAS event selection (1 fb^{-1}):

- 2, 3 jets, $p_T > 150, 100, 100$ GeV
- $E_T^{miss} > 100$ GeV, no lepton
- $E_T^{miss} > 0.3 M_{eff}$ or $> 0.25 M_{eff}$ not aligned with jets
- triggered by j70_xe70



- 4 jets, $p_T > 100, 50, 50, 50$ GeV
- $E_T^{miss} > 100$ GeV, no lepton
- $E_T^{miss} > 0.2 M_{eff}$ not aligned with jets
- trasverse sphericity $S_T > 0.2$
- triggered by j70_xe70

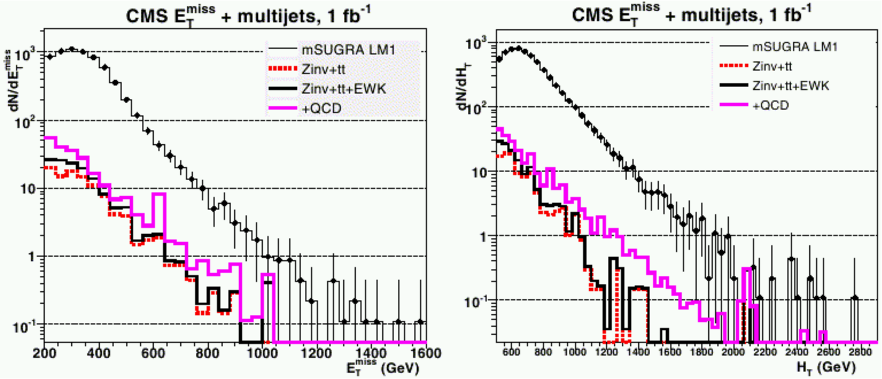


$M_{eff} = \sum_{\text{jets, leptons}} p_T^{(j)} + E_T^{miss}$

$S_T = 2\lambda_2/(\lambda_1 + \lambda_2)$ func. of eigenvectors of 2×2 tensor $S_{ij} = \sum_k {p_T}_i^{(k)} {p_T}_j^{(k)}$

CMS event selection for 1 fb^{-1} with 3 jets

- pre-selection: ≥ 1 primary vertex, $F_{\mathrm{em}} \geq 0.175$, $F_{\mathrm{ch}} \geq 0.1$
- ≥ 3 jets with $|\eta| < 1.7$ and $p_{\mathrm{T}} > 180, 110$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV not aligned with jets
- no isolated tracks, no e.m. jets
- $H_{\mathrm{T}} = \sum_{j>1} E_{\mathrm{T}}^{(j)} + E_{\mathrm{T}}^{\mathrm{miss}} = M_{\mathrm{eff}} - E_{\mathrm{T}}^{(1)} > 500$ GeV (H_{T} excludes leading jet)



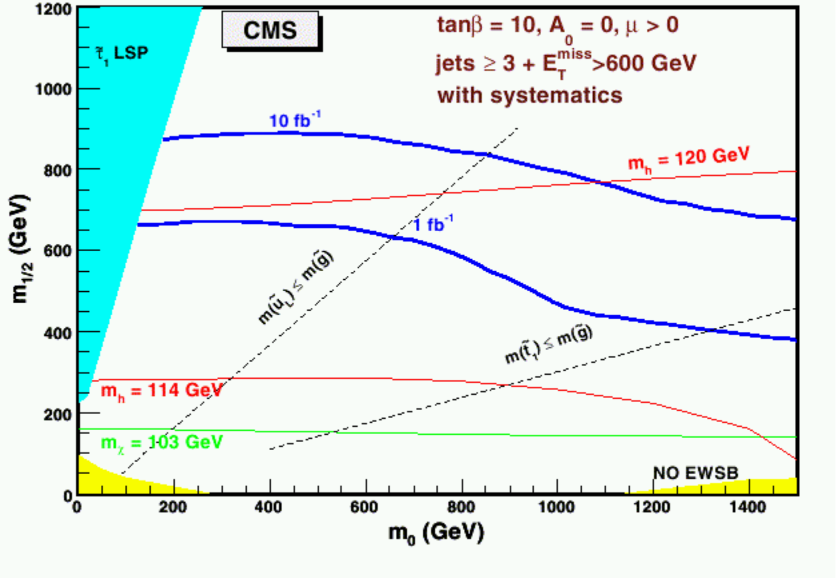
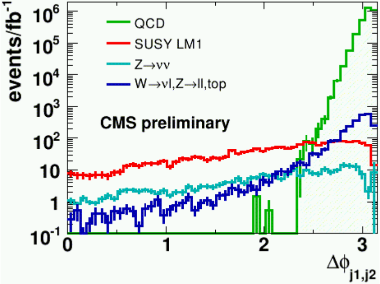
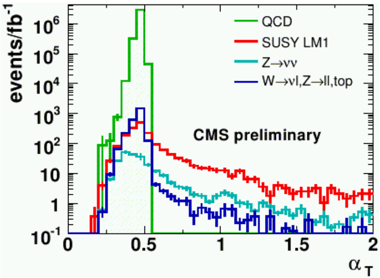
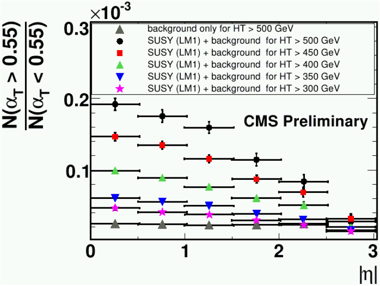


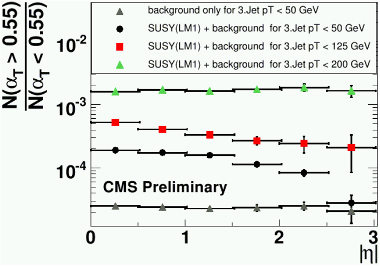
Figure 13.5. 5 σ reach for 1 and 10 fb^{-1} using multi-jets and missing transverse energy final state.

CMS event selection for 2 jets ($\alpha_T = E_T^{j2} / M_{\text{inv T}}^{j1,j2}$; see SUS-08-005)



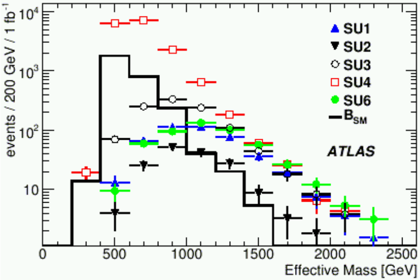






Jets + MET + b-jets

- SUSY processes almost always produce $b\bar{b}$ pairs
- ATLAS event selection: 4 jets with $p_T > 100, 50, 50, 50$ GeV, including 2 b-jets AND $E_T^{miss} > 100$ GeV AND $E_T^{miss} > 0.2 M_{eff}$ AND trasverse sphericity $S_T > 0.2$, triggered by j70_xe70

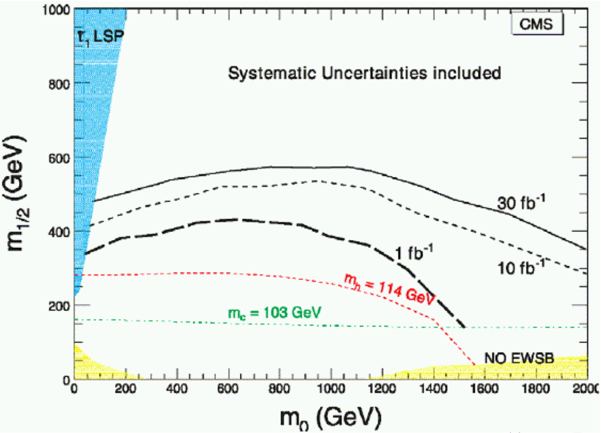


	S/B	Z_n for 0.1 fb^{-1}	Z_n for 1 fb^{-1}
SU1	3.8	6.0	9.3
SU2	1.3	2.3	5.0
SU3	6.2	7.5	13.0
SU4	13.4	12.6	21.7
SU6	4.9	7.1	11.2

ATLAS: M_{eff} distribution for 1 fb^{-1} and significance for $M_{eff} > 1$ TeV

CMS: analysis with top

- Jet + MET trigger: $p_T > 180$ GeV and $E_T^{miss} > 123$ GeV
- 4 jets with $p_T > 30$ GeV and $|\eta| < 2.5$
- one jet must be a b-jet
- $E_T^{miss} > 150$ GeV wth ≤ 2.6 rad separation from b-jet
- 1 isolated lepton with $p_T > 5$ GeV and $|\eta| < 2.5$



Jets + MET + leptons inclusive searches

- SUSY events may produce just 2 jets and 1 lepton (+ MET).
  Example: $\tilde{q}_L + \tilde{q}_R \rightarrow \tilde{\chi}_1^{\pm} q' + \tilde{\chi}_1^0 q$ with $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 \tilde{\ell}^{\pm} \nu$
- Can be triggered with jet + MET or leptons

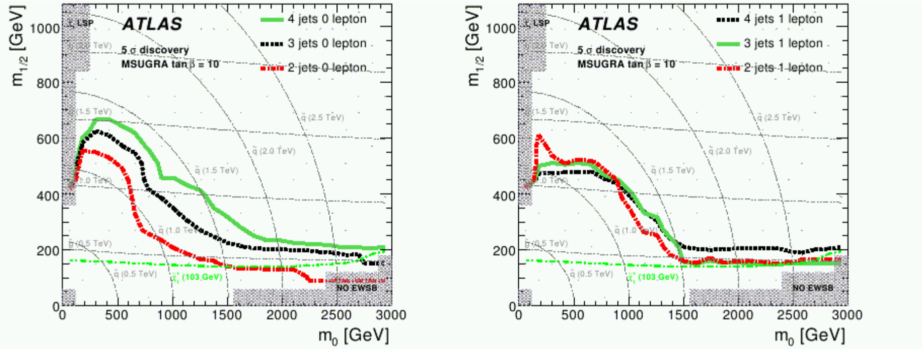


Figure 12: The 1 fb^{-1} 5σ reach contours for the 0-lepton and 1-lepton plus $E_{\mathrm{T}}^{\mathrm{miss}}$ analyses with various jet requirements as a function of m_0 and $m_{1/2}$ for the $\tan\beta = 10$ mSUGRA scan. The horizontal and curved grey lines indicate the gluino and squark masses respectively in steps of 500 GeV.

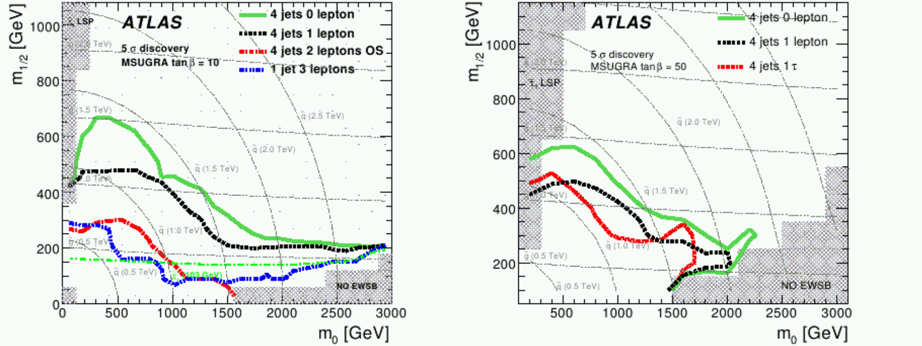
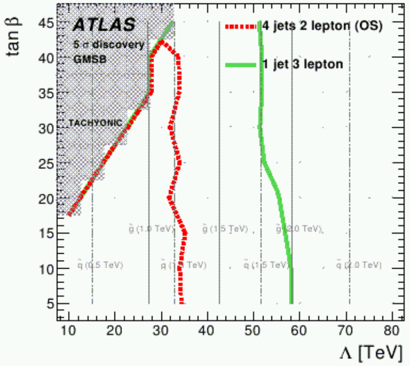


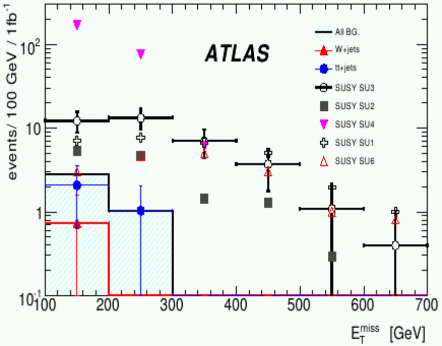
Figure 11: The 1 fb^{-1} 5σ reach contours for the 4-jet plus $E_{\mathrm{T}}^{\mathrm{miss}}$ analyses with various lepton requirements for mSUGRA as a function of m_0 and $m_{1/2}$. Left: $\tan\beta = 10$. Right: $\tan\beta = 50$. The horizontal and curved grey lines indicate gluino and squark mass contours respectively in steps of 500 GeV.



ATLAS 5σ discovery potential for GMSB with 1 fb^{-1} with 2-lepton and 3-lepton analyses

ATLAS event selection:

- 4 jets, $p_T > 100, 50, 50, 50$ GeV
- $E_T^{miss} > 100$ GeV
- $E_T^{miss} > 0.2 M_{eff}$
- 2 same-sign leptons, $p_T > 20$ GeV



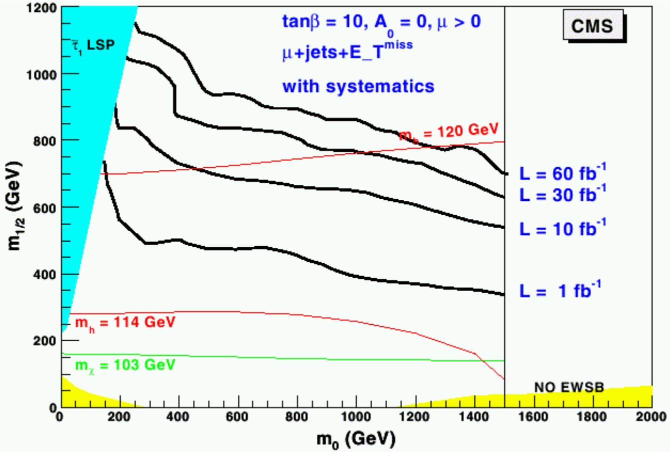


Figure 13.6. CMS discovery reach contours in the $m_0 - m_{1/2}$ plane using inclusive muons with jets and missing energy for 10 fb^{-1} (lower contour), 30 fb^{-1} (middle contour), and 60 fb^{-1} (upper contour) including systematics.

- Triggered by single muon or di-muon (both with isolation)
- Leading muon with $p_T > 30$ GeV, < 10 GeV in calo within $R = 0.3$
- 3 leading jets with $p_T > 50$ GeV

Multi-leptons + MET

- E.g. mSUGRA with neutralinos with significant gaugino component NLSP $\rightarrow$ 2 LSP + sleptons or leptons
- ATLAS selection: leptons (e or μ) with $p_T > 10$ GeV in $|\eta| < 2.5$, vetoed if near jet ($\Delta R < 0.4$) or if $M_{SFOS} < 20$ GeV, with calo and track isolation, passing L2_e22i or L2_mu20 triggers;
  ≥ 3 leptons (including one SFOS pair) required, with
  $|M_{SFOS} - m_Z| > 10$ GeV and $E_T^{miss} > 30$ GeV.
  Optional: no jet with $p_T > 20$ GeV

Table 7: Discovery potential, and integrated luminosity required for 5σ discovery. The jet veto is only applied in columns headed '+JV'. For a fuller description of the notation, see the text.

	SU1	SU2	SU3	SU4	SU8	SU2χ	SU3χ	SU2+JV	SU3+JV
$\mathscr{S}$, 10 fb^{-1}	7.7	5.9	17.2	69.3	1.9	3.3	1.6	1.9	1.4
$\int dt\,\mathscr{L}$ for 5σ	4.2	7.1	0.8	0.1	70.5	22.4	92.9	66.9	119.3

- CMS: LM1 point; ATLAS: SU2 point. 1 fb^{-1}, SFOS

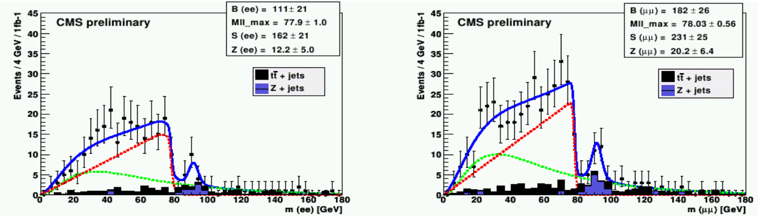


Figure 4: Unbinned likelihood fit of the dielectron (left) and dimuon (right) masses for $1 fb^{-1}$ of integrated luminosity; the Signal PDF (red), the flavor-symmetric Background PDF (green) and Z-peak background PDF (black) components are shown superimposed, as extracted from the Fit.

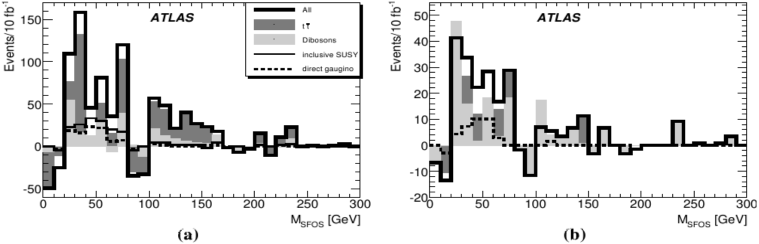
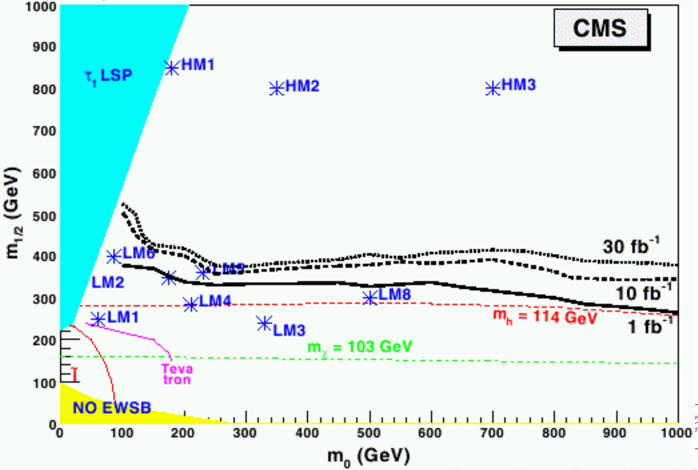


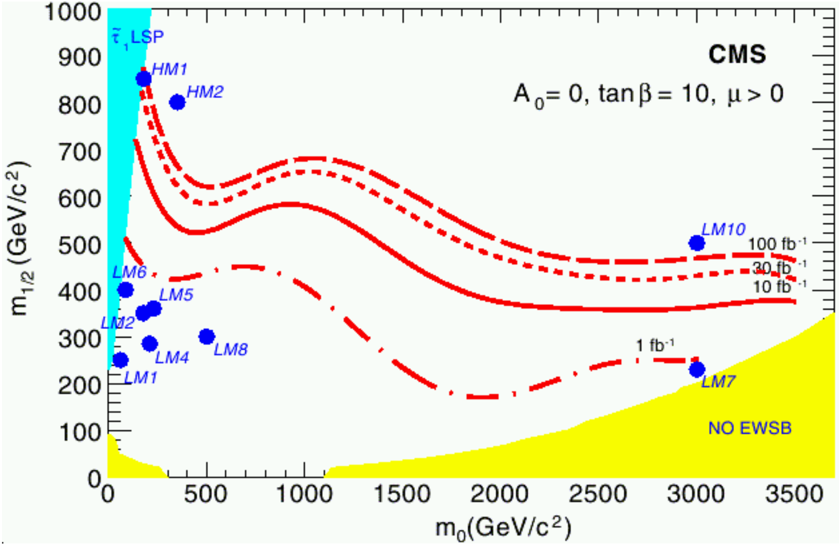
Figure 7: Distributions of the OSSF dilepton invariant mass after all selections have been applied **(a)** without the jet veto and **(b)** including a jet veto.

CMS: opposite sign di-muon analysis

- Events triggered by di-muon HLT (7 GeV thr.)
- muons with $p_T > 10$ GeV separated by $\Delta R \geq 0.01$
- track and calo muon isolation
- 3 jets, $p_T > 175, 130, 55$ GeV
- $E_T^{miss} > 200$



CMS: same sign di-muon analysis



CMS: di-tau analysis

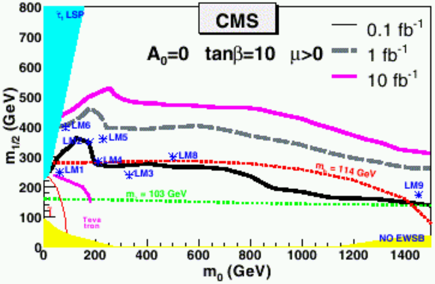


Figure 13.14. Inclusive ditau analysis discovery potential for mSUGRA between 0.1 and 30 fb^{-1} for $\tan\beta = 10$ where both statistical and systematic uncertainties are taken into account.

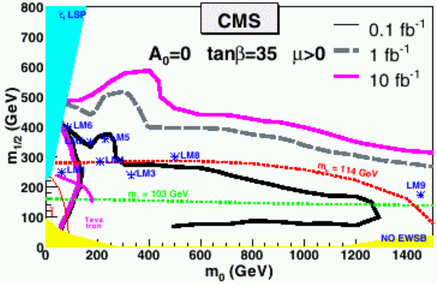


Figure 13.15. Inclusive ditau analysis discovery potential for mSUGRA between 0.1 and 30 fb^{-1} for $\tan\beta = 35$ where both statistical and systematic uncertainties are taken into account.

Selection: $E_T^{miss} > 150$ GeV, 2 τ with $\Delta r < 2$, 2 jets with $p_T > 150$ GeV

CMS: Z^0 analysis

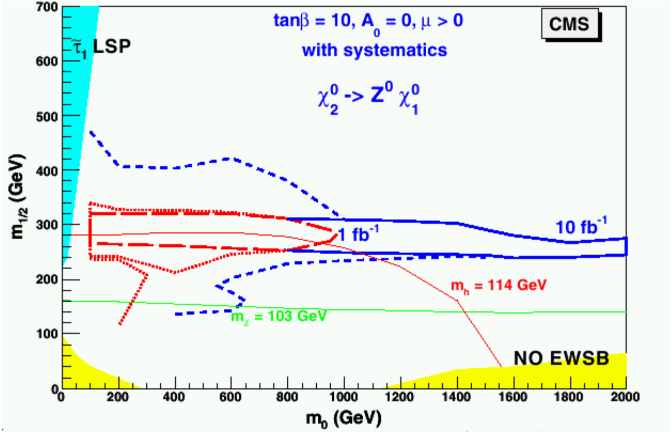


Figure 13.21. The 5σ significance contours of final states with Z^0 for $1\,\mathrm{fb}^{-1}$ (dashed line) and $10\,\mathrm{fb}^{-1}$ (full line) integrated luminosities, taking into account systematic uncertainties, in the region where the $\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0$ decay takes place. Also indicated as dotted and short dashed lines are the extensions at higher and lower $m_{1/2}$ where the Z^0 is off-shell.

Selection: HLT di-electron or di-muon trigger, $E_T^{miss} > 230$ GeV, SFOS leptons with 81 GeV $< M_{eff} <$ 96.5 GeV and $\Delta R < 2.65$

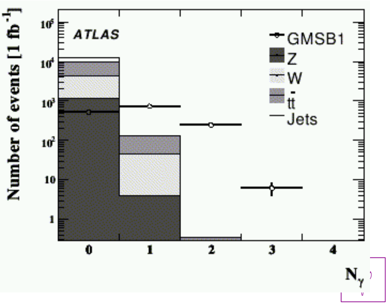
2 photons + MET + jets

- E.g. GMSB with NLSP = neutralino, LSP = gravitino
- ATLAS selection: 2γ with $p_T > 20$ GeV in $|\eta| < 2.5$ AND 4 jets with $p_T > 100, 50, 50, 50$ GeV AND $E_T^{miss} > 100$ GeV

Trigger item	Efficiency	Trigger item	Efficiency
2EM13	98.71 ± 0.11	XE70	81.39 ± 0.39
EM100	83.00 ± 0.38	J70+XE30	93.64 ± 0.25
EM18+XE15	98.79 ± 0.12	2J42+XE30	93.98 ± 0.24
J100	91.43 ± 0.28	4J23	92.27 ± 0.27

ATLAS triggers for GMSB1 and $\mathcal{L} = 10^{31}\,\text{cm}^{-2}\,\text{s}^{-1}$

ATLAS: number of photons after jet+MET selection for 1 fb^{-1} →



Outline

Summary

- Low mass SUSY might appear already with $O(100)$ pb^{-1}
- Knowledge of SM background crucial for discovery
- Cleaner experimental signatures to be looked at first
- Some signature looks very promising, but relies on b-tagging and τ reconstruction
- High-energy photon production limited to small subset of parameter space, but very clear signature

Acknowledgments

- Work done by too many people to be listed here
- Thanks to Oliver Buchmueller, Dave Charlton, Paul de Jong, Clara Matteuzzi, George Redlinger, Alex Tapper for their precious comments

- Thank you!