Prospects for R-parity Conserving SUSY searches at the LHC

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EPS 2009

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

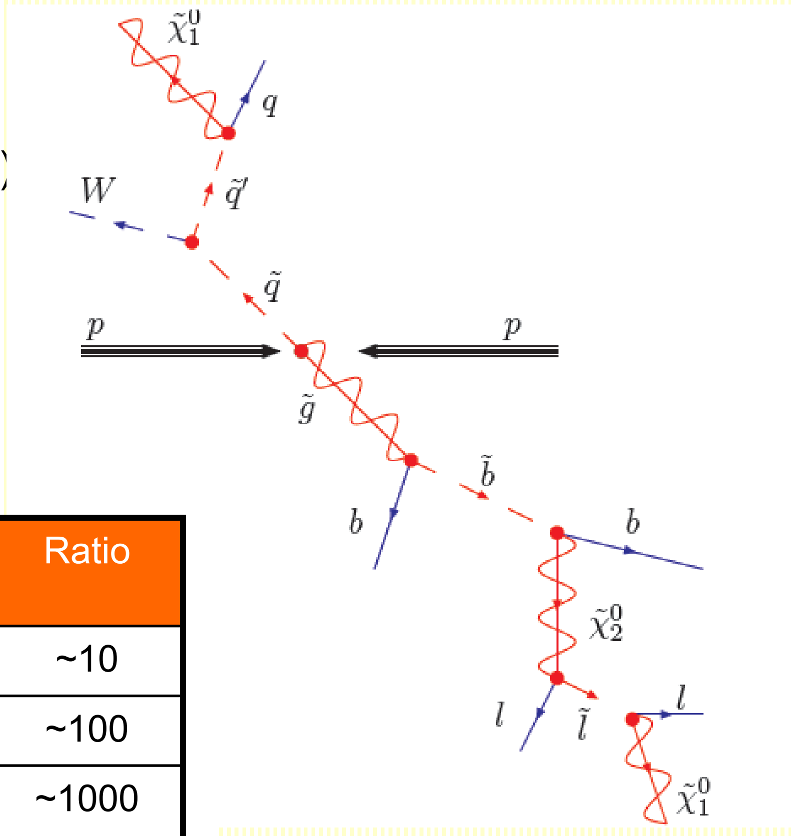
Excellence Cluster Universe

On behalf of the CMS and ATLAS collaborations

SUSY at the LHC

- Potentially long decay chains:
  - high-p_T jets
  - leptons (from charginos / neutralinos)
  - missing transverse energy (Lightest SParticle)
- Main backgrounds:
  - ttbar
  - QCD
  - W/Z+jets

→ Look for different types of signatures



	Tevatron: σ (pb)	LHC (√s=14 TeV): σ (pb)	Ratio
$W^{\pm}$ (80 GeV)	2600	20000	~10
ttbar (2x172 GeV)	7	800	~100
$\tilde{q}\tilde{q}$ (2x400 GeV)	0.05	60	~1000
$\tilde{g}\tilde{g}$ (2x400 GeV)	0.005	100	~20000

The different search channels

- 0-lepton channel (jets + E_T^{miss})
  - the least model-dependent SUSY signature search
  - Strong cuts to reduce the QCD background
  - Simple cuts for higher sensitivity
  - Main backgrounds: QCD, ttbar, W, Z
- 1-lepton channel (1 lepton + jets + E_T^{miss})
  - Requiring one lepton is a slightly less generic search but increases the robustness
    - → Golden channel at the beginning of data-taking
  - Main backgrounds: ttbar, W

The different search channels

- Multi-lepton channel (2/3 leptons)
  - Neutralinos/charginos in the decay chain → 2 or 3 leptons in the final state
  - 2 leptons:
    - Opposite sign: non-resonant excess but SM background
    - Same sign: low SM background but lower statistics
  - 3 leptons:
    - 1 jet (avoid cutting on E_T^{miss})
    - E_T^{miss} + Opposite Sign Same Flavour (probe the gaugino direct production)
- τ channel
  - Large tanβ favours light 3rd generation superpartners
  - Leptonically decaying τs indistinguishable from leptons (included in other channels)
  - Main backgrounds: ttbar, W, Z
- b channel
  - The presence of b-jets in SUSY cascades is also enhanced by tanβ
  - Asking for 2/3 b-jets in the final state
    (standard b-tagging in ATLAS: ε~50-60%)
  - Main background: ttbar (W,Z reduced)

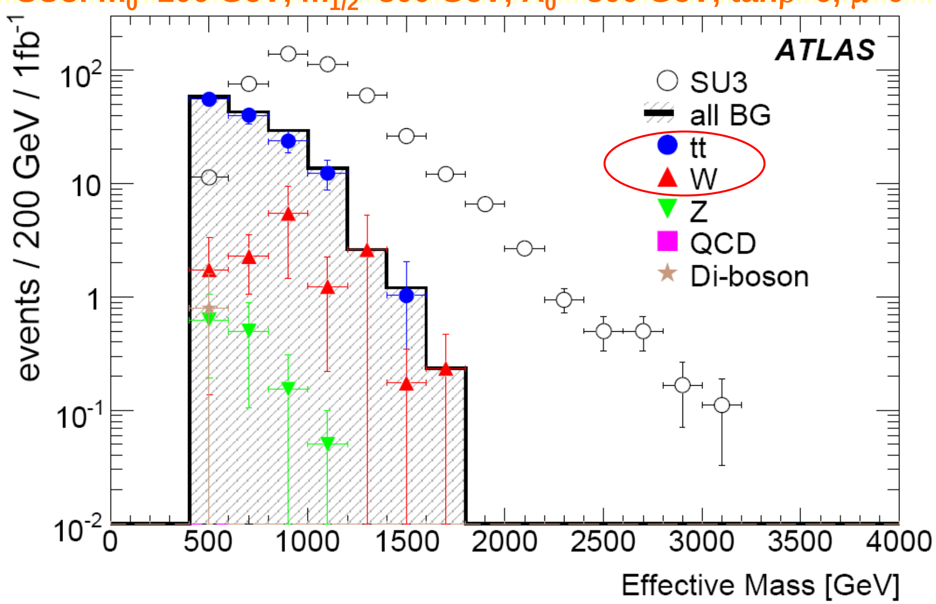
An example: the 1-lepton channel in ATLAS

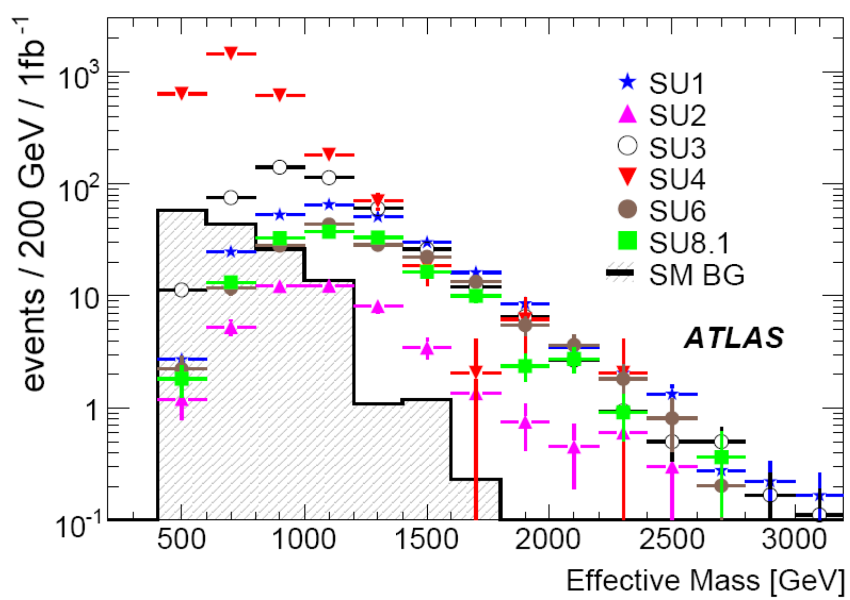
- One isolated lepton with $p_T > 20$ GeV and no other lepton with $p_T > 10$ GeV
- At least 4 jets with $p_T > 50$ GeV and $p_T^{J1} > 100$ GeV
- $E_T^{miss} > \max(100\text{ GeV}, 0.2M_{eff})$
- Transverse sphericity $S_T > 0.2$
- Transverse mass $M_T > 100$ GeV

$$M_{eff} = \sum_i p_T^{jet,i} + \sum_j p_T^{lepton,j} + E_T^{miss}$$

$$M_T = \sqrt{2 p_T^{lepton} E_T^{miss} (1 - \cos\varphi(\vec{p}_T^{miss}, \vec{p}_T^{lepton}))}$$

SU3: m_0=100 GeV, $m_{1/2}$=300 GeV, A_0=-300 GeV, $\tan\beta$=6, μ>0

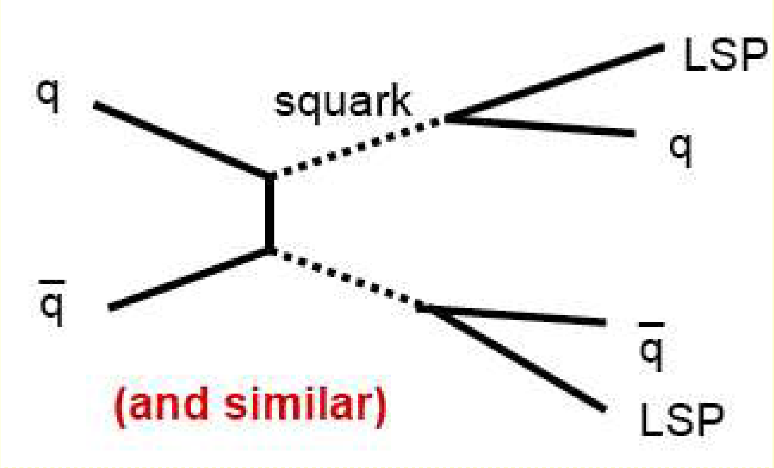


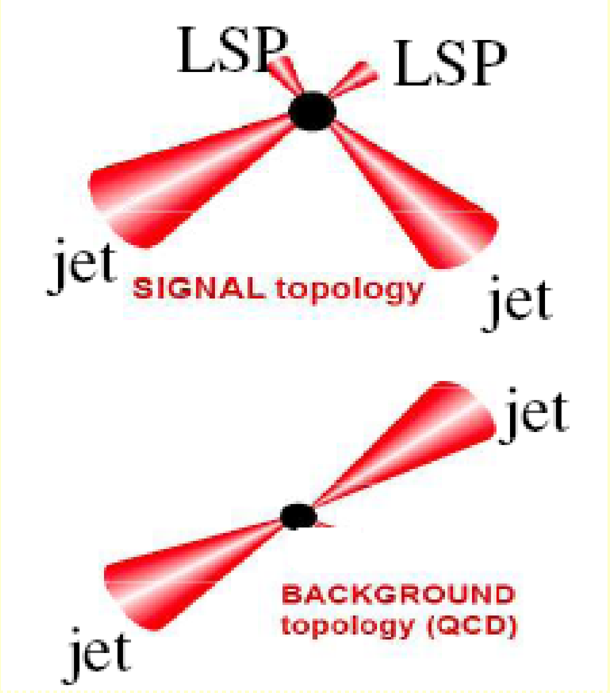


An example: the 0-lepton di-jet channel in CMS

Inspired by L.Randall & D.Tucker-Smith doi:10.1103/PhysRevLett.101.221803

- Probing the squark → quark + neutralino channel ($m_{squark} < m_{gluino}$)





- Topology: 2 jets + E_T^{miss}

An example: the 0-lepton di-jet channel in CMS

- Introduce α_T (= 0.5 for perfectly measured QCD events):

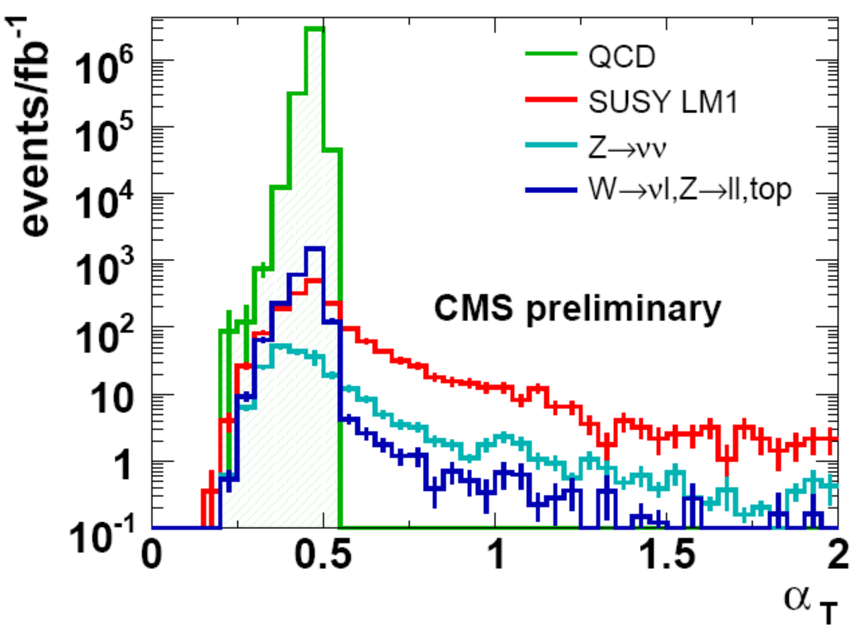
$$\alpha_T = \frac{E_T^{j2}}{\sqrt{2E_T^{j1}E_T^{j2}(1-\cos\Delta\phi)}} = \frac{\sqrt{E_T^{j2}/E_T^{j1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

E_T^{miss} is not the dominant search variable!

- $|\eta^{J1}| < 2.5$
- $E_T^{J1,J2} > 50$ GeV
- No e or μ with $p_T > 10$ GeV
- No 3rd jet with $p_T > 50$ GeV
- $\Delta\phi(-|\Sigma\vec{p}_T|, J_i) > 0.3$ for i=1,2,3
- $p_T^{J1} + p_T^{J2} > 500$ GeV

An example: the 0-lepton di-jet channel in CMS

- All cuts but α_T applied:

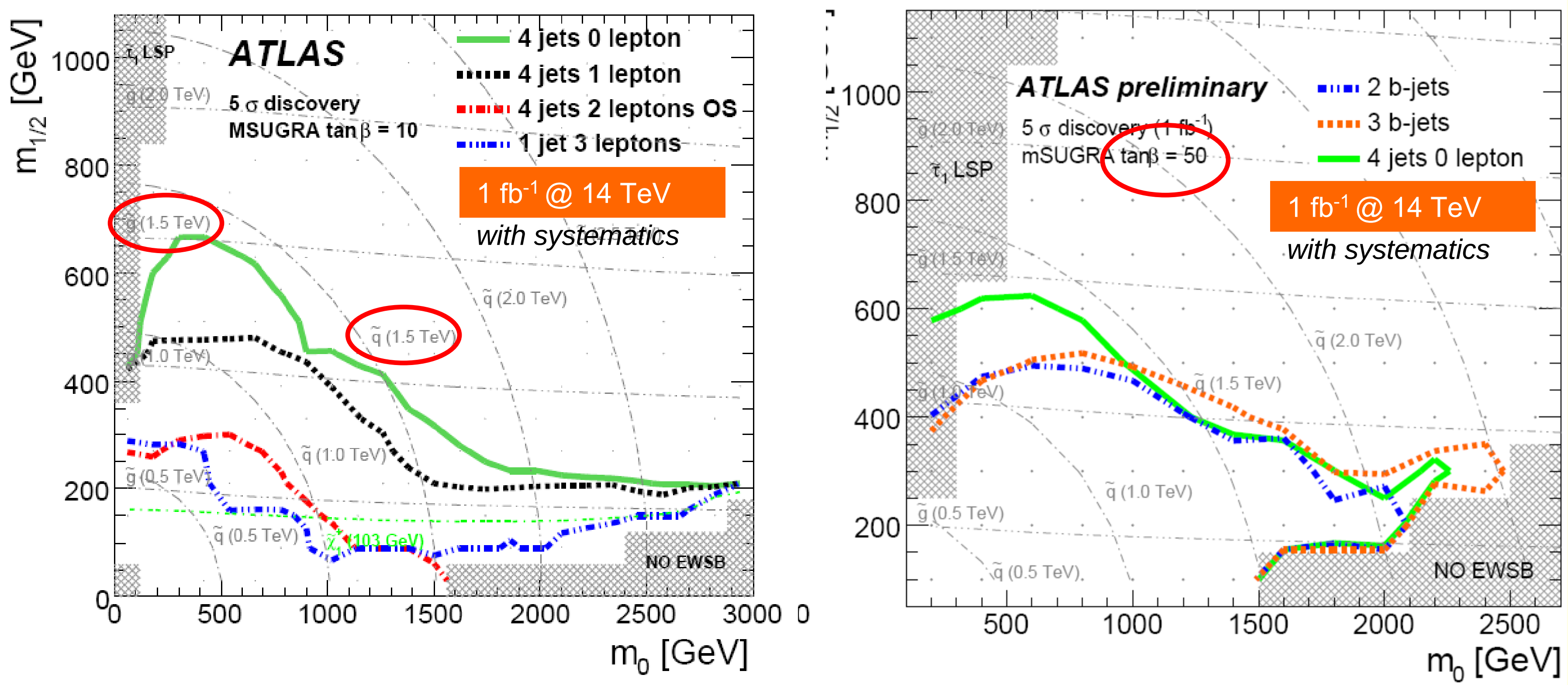


LM1: m_0=60 GeV, $m_{1/2}$=250 GeV, A_0=0, $\tan\beta$=10, μ>0

- Number of events for 1 fb^{-1} @ 14 TeV after $\alpha_T > 0.55$:

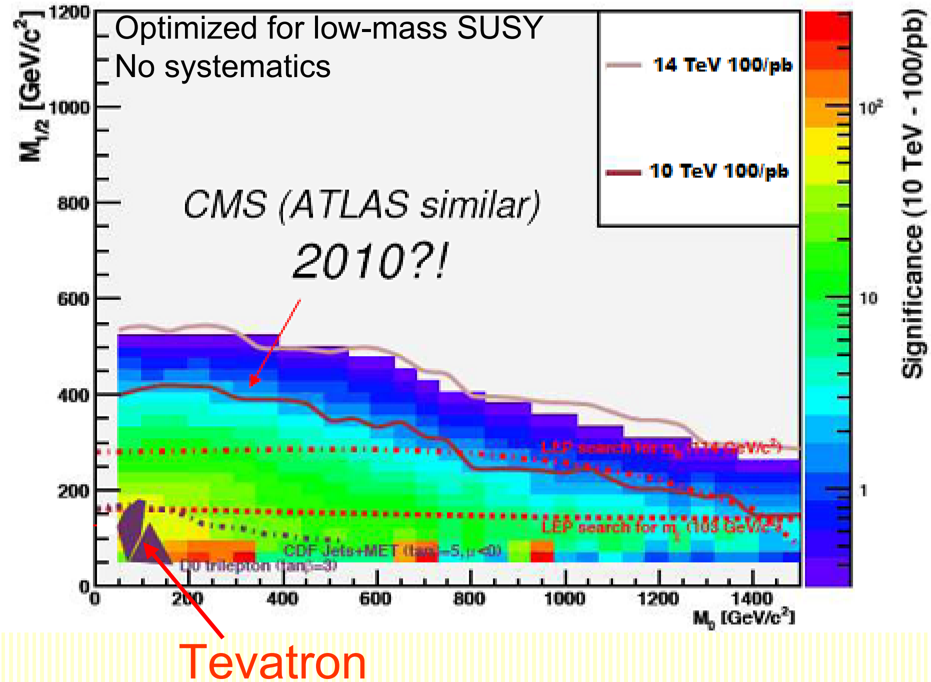
LM1	QCD	Z+jets	tt, W+jets
439	0	58	19

Discovery reach in ATLAS

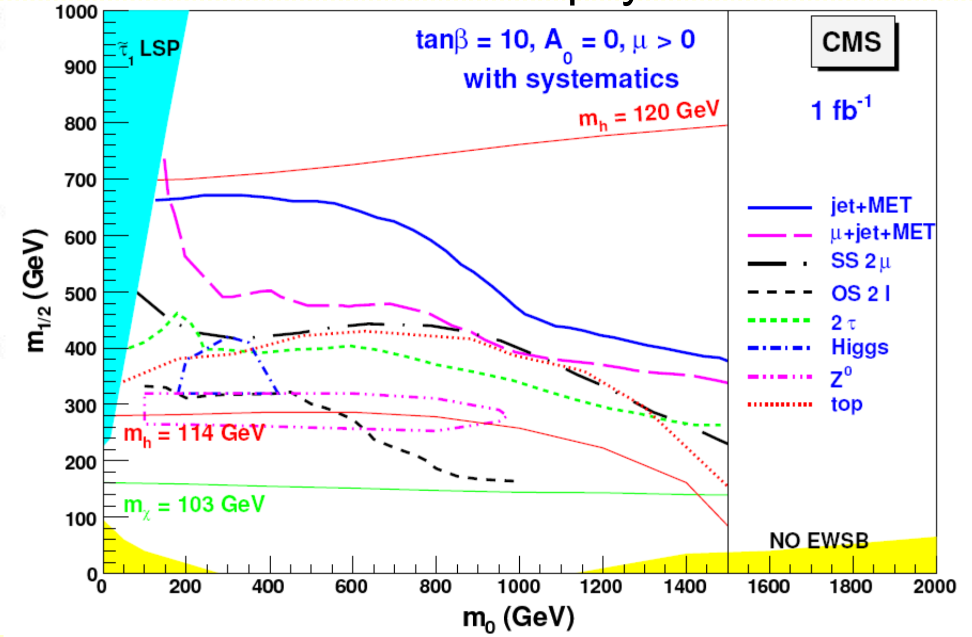


- The 0-lepton channel has the highest reach
- The 1-lepton channel is more robust against QCD
- The b-jet channel is competitive with the 0-lepton one at high tanβ (better reach at high m_0: 3-body decays of the gluinos involving t and b)

Discovery reach in CMS



CMS physics TDR Vol.II



- The most powerful channel in CMS is also the jets + E_T^{miss} channel
- With only 50 pb^{-1} of understood data @ 10 TeV, the LHC can go significantly beyond the reach of the Tevatron

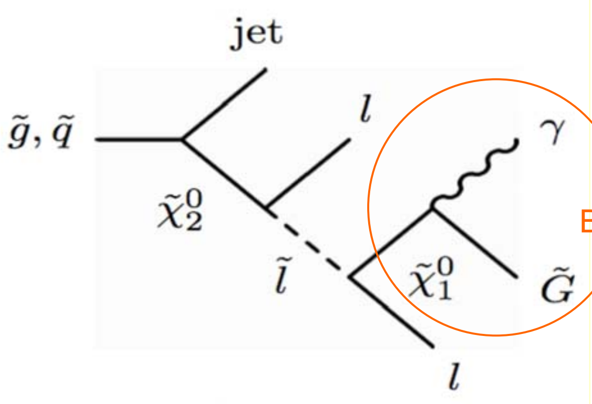
Gauge Mediated SUSY Breaking in ATLAS

- SUSY broken by gauge interactions through messenger gauge fields
- 6 free parameters:

Λ	SUSY breaking scale
M	Messenger mass scale
tanβ	Ratio of Higgs VEVs
N	Number of messenger multiplets
Sign(μ)	Sign of Higgs mass parameter
C_{grav}	Scale factor of Gravitino coupling

- If tanβ is low and N=1 : $\tilde{\chi}_1^0$ is the NLSP
- Signature:

  Jets, 2 leptons, E_T^{miss}, 2 γ

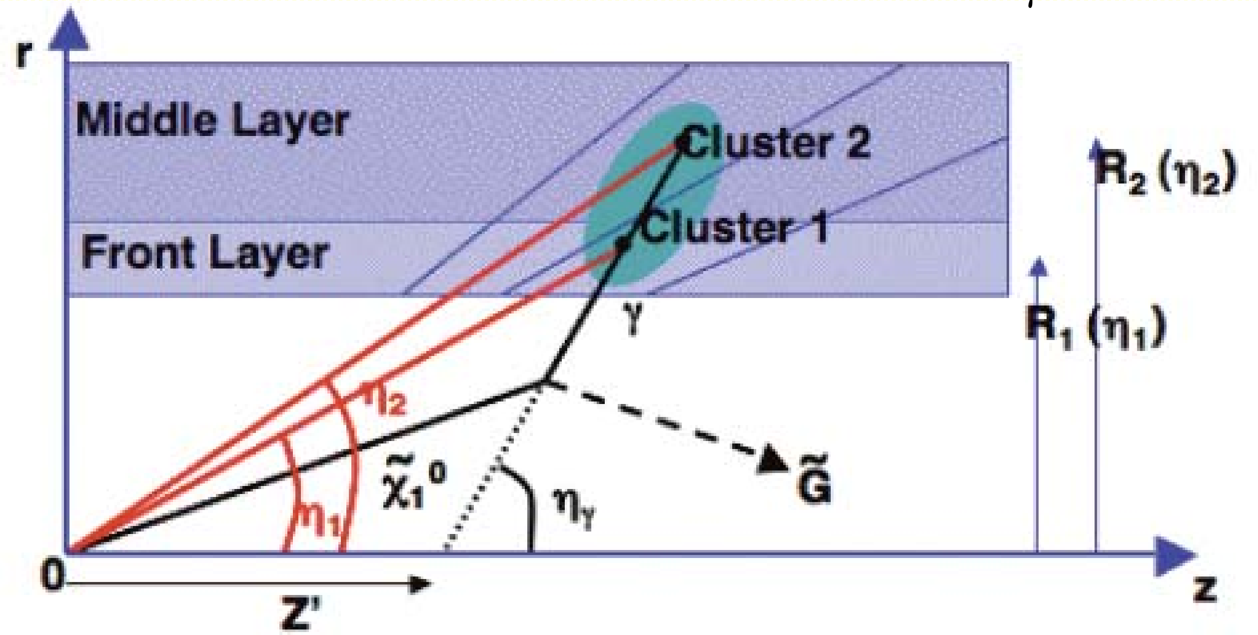


Branching ratio: 97%

Non-pointing photons in ATLAS

- If the decay length of the $\tilde{\chi}_1^0$ is comparable to the size of ATLAS inner detector, there could be high-p_T *non-pointing* photons:

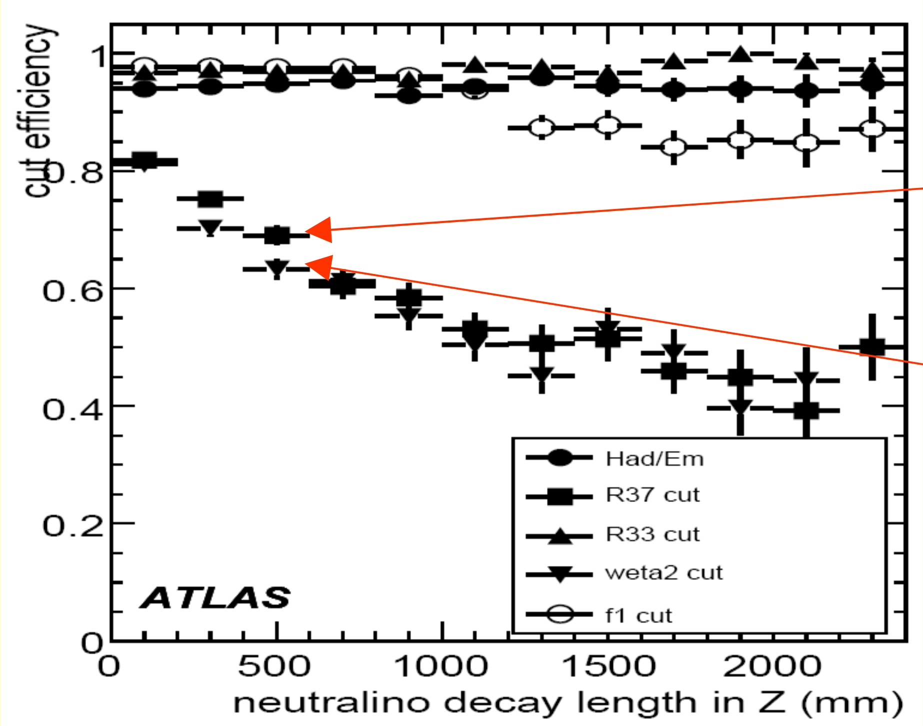
$$\eta_2 \text{ (« } \eta_{detector} \text{ ») } != \eta_\gamma \text{ (« } \eta_{true} \text{ »)}$$



Non-pointing photons can have a wider shower profile than pointing photons

Identifying non-pointing photons in ATLAS

- Idea:
  - only use the photon identification selections which are unbiased w.r.t. the neutralino decay length (losen the ID cuts)
  - this increases the fake rate from jets:
    - from 0.19 ± 0.03% to 0.70 ± 0.07%



For example:

$E_{3x7\ window}$ / $E_{7x7\ window}$ in the 2[nd] sampling layer

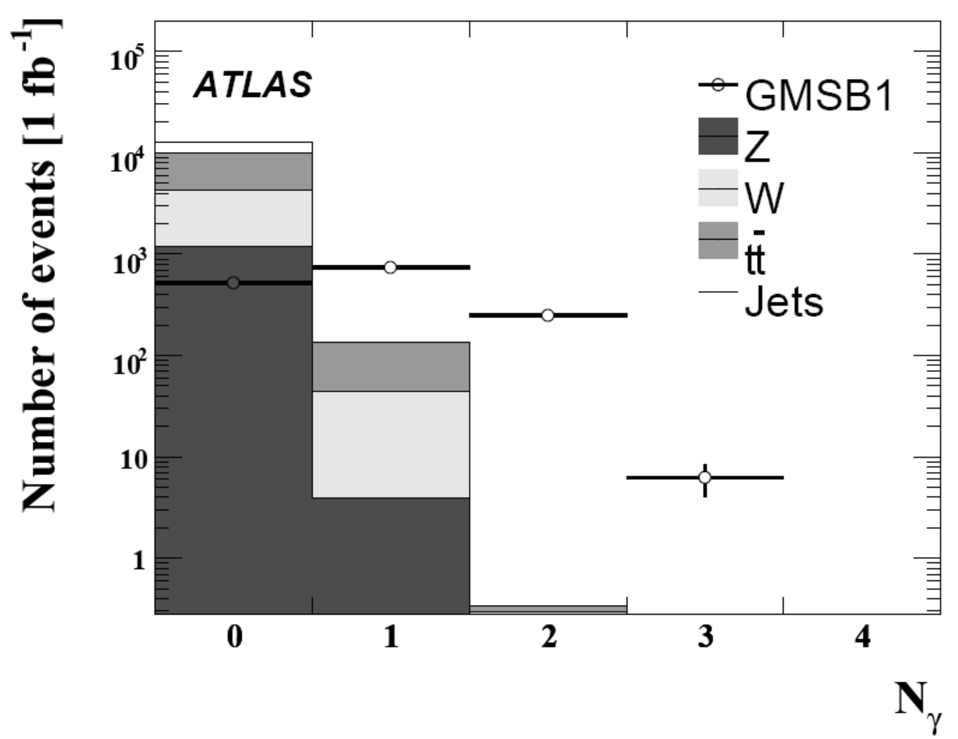
Width of the cluster in the 2nd sampling layer

Gauge Mediated SUSY Breaking in ATLAS

Selection:

- $N_{Jets} \geq 4$ with $p_T > 50$ GeV
- $p_T^{j1} > 100$ GeV
- $E_T^{miss} > max(100 \text{ GeV}, 0.2M_{eff})$

- ttbar is the main background



GMSB1: Λ=90 TeV, M_m=500 TeV, C_G=1.0, N_5=1, tanβ=5, μ>0

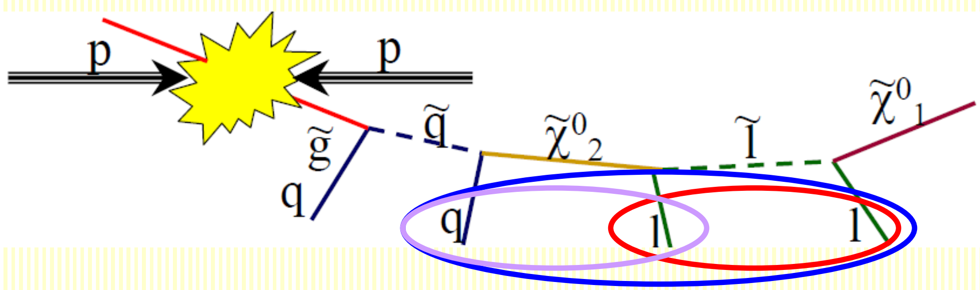
- Techniques are being developed to extract the lifetime of the neutralino using timing and directional information from LAr calorimeter
  → *talk by Andrea Giammanco in tomorrow's Higgs and New Physics session*

Exclusive measurements

- When SUSY is discovered (if SUSY exists!), the experimental emphasis will be put on measuring the sparticle mass spectrum and deriving the parameters of the model

- The strategy is to exploit kinematics of long decay chains

- The first chain likely to be reconstructed:



Consider mass hierarchy:

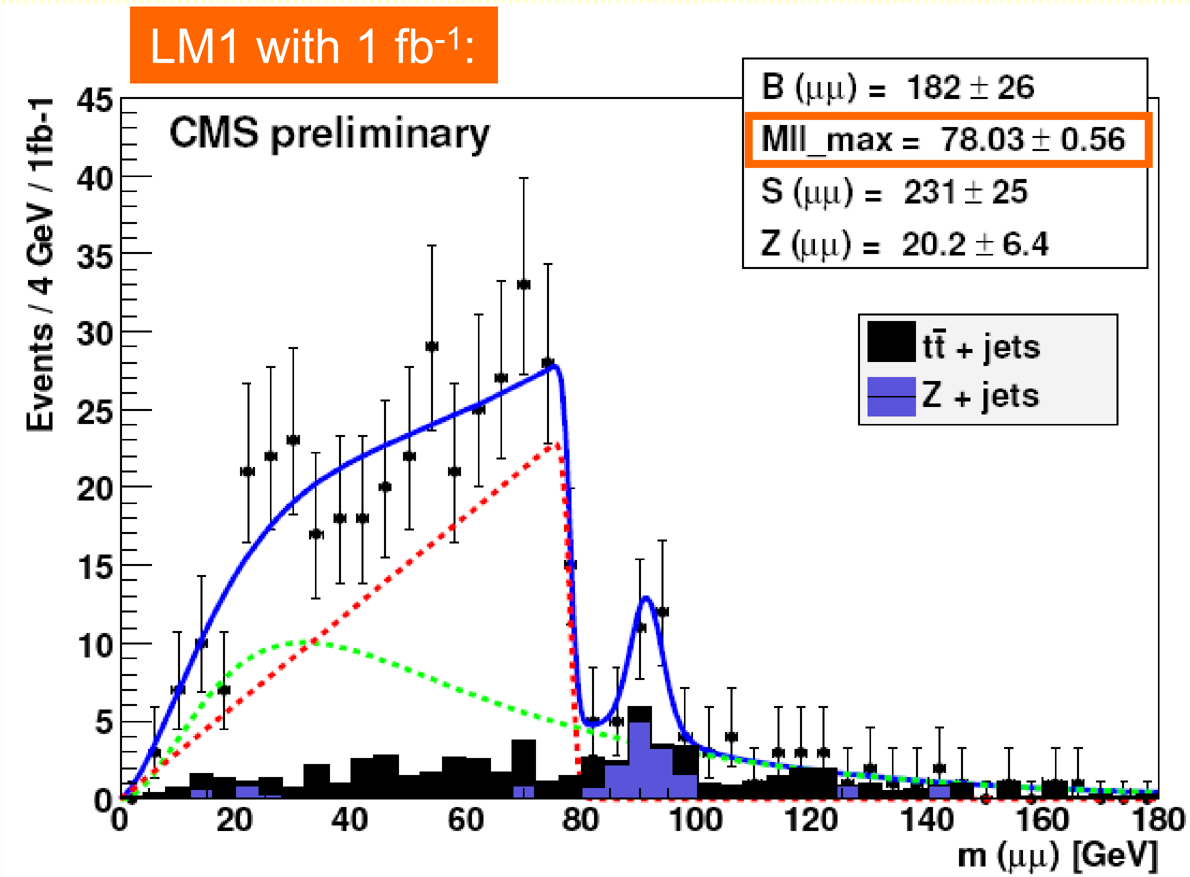
$\tilde{g} > \tilde{q} > \tilde{\chi}_2^0 > \tilde{l} > \tilde{\chi}_1^0$

- Due to the LSPs, the decay chain cannot be completely reconstructed

- Edges, rather than mass peaks, are measured in the invariant mass distribution of the decay products (e.g. m_{ll}, m_{llq}, m_{lq}, etc)

Exclusive measurements in CMS

Measure the different endpoints, for example $m(\mu\mu)^{max}$:



- Fit
- Signal
- Flavour-symmetric background

$$\tilde{\chi}^o_2 \rightarrow \tilde{\ell}_{L,R}\ell \rightarrow \ell\ell\tilde{\chi}^o_1$$

$$m^{max}_{\ell\ell} = m_{\tilde{\chi}^o_2}\sqrt{1-\frac{m^2_{\tilde{\ell}_R}}{m^2_{\tilde{\chi}^o_2}}}\sqrt{1-\frac{m^2_{\tilde{\chi}^o_1}}{m^2_{\tilde{\ell}_R}}}$$

Exclusive measurements in ATLAS

Even with 1 fb^{-1} some measurements are possible:

Example point with 1 fb^{-1}:

Observable	SU3 m_{meas} [GeV]	SU3 m_{MC} [GeV]
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	118
$m_{\tilde{\chi}_2^0}$	$189 \pm 60 \mp 2$	219
$m_{\tilde{q}}$	$614 \pm 91 \pm 11$	634
$m_{\tilde{\ell}}$	$122 \pm 61 \mp 2$	155
Observable	SU3 Δm_{meas} [GeV]	SU3 Δm_{MC} [GeV]
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	100.7
$m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$	$526 \pm 34 \pm 13$	516.0
$m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}$	$34.2 \pm 3.8 \mp 0.1$	37.6

Error: MIGRAD + jet energy scale

However:

- The statistical errors are big

- The mass differences are better measured than the absolute masses

Similar findings in CMS

Exclusive measurements in ATLAS

<u>*Ultimate goal:*</u>
Determine SUSY parameters from endpoint measurements

- *Fittino* package to determine the mSUGRA parameters
- First results:
  - Sign(μ) > 0 is favoured but sign(μ) < 0 is not ruled out (χ^2=12.6 vs χ^2=15.4)
  - M_0 and $M_{1/2}$ are well constrained
  - A_0 and tanβ are more problematic: there is no information from the Higgs sector at low integrated luminosity

Similar findings in CMS

Example point with 1 fb^{-1}:

Parameter	SU3 value	fitted value	exp. unc.
	$\text{sign}(\mu) = +1$		
$\tan\beta$	6	7.4	4.6
M_0	100 GeV	98.5 GeV	±9.3 GeV
$M_{1/2}$	300 GeV	317.7 GeV	±6.9 GeV
A_0	−300 GeV	445 GeV	±408 GeV
	$\text{sign}(\mu) = -1$		
$\tan\beta$		13.9	±2.8
M_0		104 GeV	±18 GeV
$M_{1/2}$		309.6 GeV	±5.9 GeV
A_0		489 GeV	±189 GeV

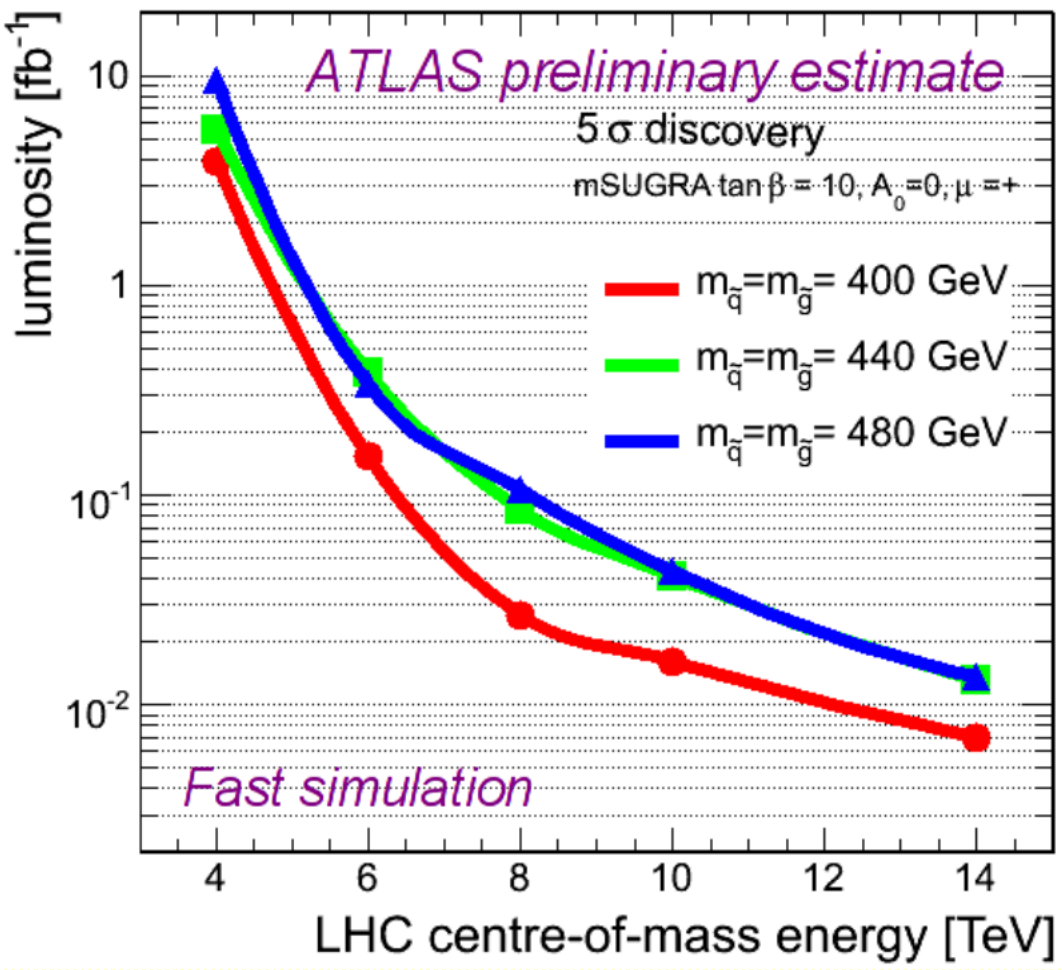
Conclusion

- Looking for excesses in inclusive search channels is the first step towards finding SUSY at the LHC
- Strategies are being developed for different scenarios, e.g. the non-pointing photons in GMSB
- The LHC should be able to discover squarks and gluinos with masses up to 1-1.5 TeV (if systematics are as expected for $1fb^{-1}$)
- Backgrounds and detectors need to be understood
- After a discovery, the next step would be to select specific SUSY decay chains to measure the properties of new particles
- Some masses can already be measured with $1fb^{-1}$ for low-mass SUSY scenarios

Backup slides

Different centre-of-mass energies

- Discovery sensitivity possible for SUSY, in an mSUGRA model with equal mass squarks and gluinos.
- The lepton plus jets plus missing-ET channel is employed, as this should be understood more rapidly than the statistically more powerful inclusive jets+missing-Et channel.
- The current published Tevatron limits in this model are around 400 GeV



The SUSY points in this talk

- mSUGRA:

Point	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	tanβ	sign(μ)
Coannihilation (SU1)	70	350	0	10	+
Focus Point (SU2)	3550	300	0	10	+
Bulk (SU3)	100	300	-300	6	+
Low Mass (SU4)	200	160	-400	10	+
Funnel (SU6)	320	375	0	50	+
Coannihilation (SU8.1)	210	360	0	40	+

Particle	SU1	SU2	SU3	SU4	SU6	SU8.1	SU9
$\tilde{d}_L$	764.90	3564.13	636.27	419.84	870.79	801.16	956.07
$\tilde{u}_L$	760.42	3563.24	631.51	412.25	866.84	797.09	952.47
$\tilde{b}_1$	697.90	2924.80	575.23	358.49	716.83	690.31	868.06
$\tilde{t}_1$	572.96	2131.11	424.12	206.04	641.61	603.65	725.03
$\tilde{d}_R$	733.53	3576.13	610.69	406.22	840.21	771.91	920.83
$\tilde{u}_R$	735.41	3574.18	611.81	404.92	842.16	773.69	923.49
$\tilde{b}_2$	722.87	3500.55	610.73	399.18	779.42	743.09	910.76
$\tilde{t}_2$	749.46	2935.36	650.50	445.00	797.99	766.21	911.20
$\tilde{e}_L$	255.13	3547.50	230.45	231.94	411.89	325.44	417.21
$\tilde{\nu}_e$	238.31	3546.32	216.96	217.92	401.89	315.29	407.91
$\tilde{\tau}_1$	146.50	3519.62	149.99	200.50	181.31	151.90	320.22
$\tilde{\nu}_\tau$	237.56	3532.27	216.29	215.53	358.26	296.98	401.08
$\tilde{e}_R$	154.06	3547.46	155.45	212.88	351.10	253.35	340.86
$\tilde{\tau}_2$	256.98	3533.69	232.17	236.04	392.58	331.34	416.43
$\tilde{g}$	832.33	856.59	717.46	413.37	894.70	856.45	999.30
$\tilde{\chi}_1^0$	136.98	103.35	117.91	59.84	149.57	142.45	173.31
$\tilde{\chi}_2^0$	263.64	160.37	218.60	113.48	287.97	273.95	325.39
$\tilde{\chi}_3^0$	466.44	179.76	463.99	308.94	477.23	463.55	520.62
$\tilde{\chi}_4^0$	483.30	294.90	480.59	327.76	492.23	479.01	536.89
$\tilde{\chi}_1^+$	262.06	149.42	218.33	113.22	288.29	274.30	326.00
$\tilde{\chi}_2^+$	483.62	286.81	480.16	326.59	492.42	479.22	536.81
h^0	115.81	119.01	114.83	113.98	116.85	116.69	114.45
H^0	515.99	3529.74	512.86	370.47	388.92	430.49	632.77
A^0	512.39	3506.62	511.53	368.18	386.47	427.74	628.60
H^+	521.90	3530.61	518.15	378.90	401.15	440.23	638.88
t	175.00	175.00	175.00	175.00	175.00	175.00	175.00

Label	σ^{LO} (pb)
SU1	8.15
SU2	5.17
SU3	20.85
SU4	294.46
SU6	4.47
SU8.1	6.48
SU9	2.46

Sample	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0	$\tan\beta$	sign(μ)	σ NLO (pb)	(LO) (pb)	lightest $\tilde{q}$ (GeV)	χ_1^0 (GeV)
LM1	60	250	0	10	+	54.86	(43.28)	410 ($\tilde{t}_1$)	97

- GMSB:

name	NLO (LO) σ [pb]	Λ [TeV]	M_m [TeV]	C_G	$c\tau$ [mm]	$M_{\tilde{\chi}_1^0}$ [GeV]
GMSB1	7.8 (5.1)	90	500	1.0	1.1	118.8

$N_5 = 1, \tan\beta = 5, \mathrm{sgn}(\mu) = +$