Flavour studies for SUSY leptonic sector: summary

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Slepton sector of report:

- Theoretical introduction
- Experimental introduction
- Effects of lepton flavour violation on di-lepton invariant mass spectra
- Lepton flavour violation in the long-lived NLSP scenario
- Neutralino decays in models with broken R-parity
- Reconstructing neutrino properties from collider experiments in a Higgs triplet mass model
- SUSY (s)lepton flavour studies with ATLAS
- Using the l^+l^- + EtMiss +jet veto signature for slepton detection
- Using the $e^{\pm}\,\mu^{-+}$ + EtMiss signature in the search for supersymmetry and lepton flavour violation in neutralino decays

Supersymmetry

SUSY at TeV mass scale is perhaps most attractive extension of Standard Model. Provides naturally light Higgs, grand unification, and cold dark matter.

For each Standard Model particle X, MSSM has partner $\tilde{X}$ with $\Delta J = \pm\frac{1}{2}$:

$$\begin{aligned} \text{Each massless gauge boson} \quad &\Leftrightarrow \quad \text{Massless gaugino} \\ \text{Each chiral fermion} \quad &\Leftrightarrow \quad \text{Massless sfermion} \end{aligned}$$

Also two Higgs doublets and corresponding $J = \frac{1}{2}$ Higgsinos.

No realistic dynamical SUSY breaking using just MSSM. Can break by hand: all SUSY particles have $SU(2) \times U(1)$ invariant mass terms. But most general breaking has 105+45 new parameters.

Random choice violates Standard Model accidental symmetries: gives weak scale proton decay, $\mu \to e\gamma$ and other flavor violation, new CP violation, $\ldots \Rightarrow$ Number of parameters severely restricted.

R-parity conservation:

$$\begin{aligned} R &\equiv (-1)^{3B-3L+2S} \\ &= +1 \quad \text{(all SM particles)} \\ &= -1 \quad \text{(all SUSY particles)} \end{aligned}$$

R-parity eliminates 45 parameters and implies:

- No proton decay.
- SUSY particles produced in pairs and decay to stable Lightest SUSY Particle (LSP), usually $\tilde{\chi}_1^0$. Must be neutral and weakly interacting, so escapes detector.

Conservation of just B or L rather than R possible, giving unstable LSP.*
But WMAP results indicate cold dark matter:

$$\Omega_b = 0.044 \pm 0.004, \quad \Omega_m = 0.27 \pm 0.04, \quad \Omega_\Lambda = 0.73 \pm 0.04$$

LSP is good candidate: naturally gives about observed $\Omega_m h^2$.

* In models with a gravitino or axino LSP the lifetime could be larger than the age of the universe, so that SUSY Dark Matter is still possible

Superpotential and SUSY breaking Lagrangian (MSSM, no RPV):

$$\begin{aligned} W_{MSSM} &= h^E_{ij}\hat{L}_i\hat{H}_d\hat{E}^c_j + h^D_{ij}\hat{Q}_i\hat{H}_d\hat{D}^c_j + h^U_{ij}\hat{H}_u\hat{Q}_i\hat{U}^c_j - \mu\hat{H}_d\hat{H}_u\,, \\ V_{MSSM} &= M^2_{\tilde{L},ij}\tilde{L}_i\tilde{L}^*_j + M^2_{\tilde{E},ij}\tilde{E}_i\tilde{E}^*_j + M^2_{\tilde{Q},ij}\tilde{Q}_i\tilde{Q}^*_j + M^2_{\tilde{U},ij}\tilde{U}_i\tilde{U}^*_j + M^2_{\tilde{D},ij}\tilde{D}_i\tilde{D}^*_j \\ &\quad + M^2_d H_d H^*_d + M^2_u H_u H^*_u - (\mu B H_d H_u + h.c.) \end{aligned}$$

Flavour violation = different matrices for fermions and sfermions to go from flavour to mass eigenstates

It is convenient to work in "superCKM" basis. FV appears as non-diagonal entries in sfermion mass matrices:

$$M^2_{\tilde{\ell}} = \begin{pmatrix} M^2_{LL} & M^{2\dagger}_{RL} \\ M^2_{RL} & M^2_{RR} \end{pmatrix}$$

CKM

$$\begin{aligned} M^2_{LL} &= K^\dagger \hat{M}^2_{\tilde{Q}} K + m^2_u + D_{u\,LL} \\ M^2_{RL} &= v_d \hat{T}^U - \mu^* m_u \cot\beta \\ M^2_{RR} &= \hat{M}^2_{\tilde{U}} + m^2_u + D_{u\,RR} \end{aligned}$$

u-type squarks

$$\begin{aligned} M^2_{LL} &= \hat{M}^2_{\tilde{Q}} + m^2_d + D_{d\,LL}\,, \\ M^2_{RL} &= v_u \hat{T}^D - \mu^* m_d \tan\beta \\ M^2_{RR} &= \hat{M}^2_{\tilde{D}} + m^2_d + D_{d\,RR}\,. \end{aligned}$$

d-type squarks

$$\begin{aligned} M^2_{LL} &= \hat{M}^2_{\tilde{L}} + m^2_l + D_{l\,LL}\,, \\ M^2_{RL} &= v_u \hat{T}^E - \mu^* m_l \tan\beta\,, \\ M^2_{RR} &= \hat{M}^2_{\tilde{E}} + m^2_l + D_{l\,RR}\,. \end{aligned}$$

charged sleptons

$$M^2_{LL} = \hat{M}^2_{\tilde{L}} + D_{\nu\,LL}$$

sneutrinos

- Flavour violation restricted by low-energy constraints!
- Minimal Flavour Violation models: at some energy scale (GUT?) mass matrices have the form

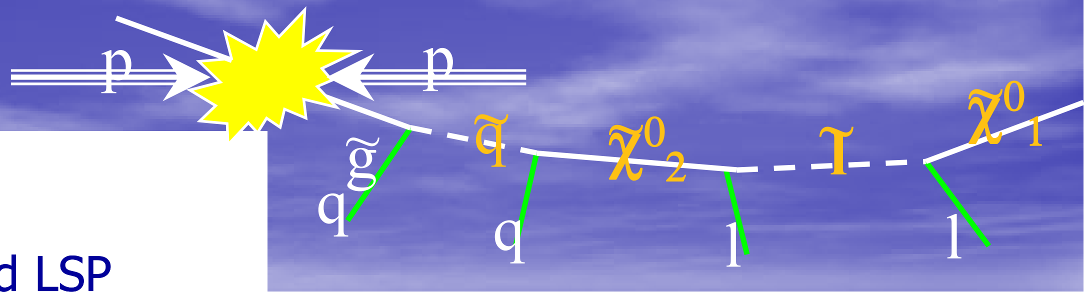
$$M_{\tilde{F}}^2 = M_0^2 \mathbb{1} \quad T_F = A_0 h_U$$

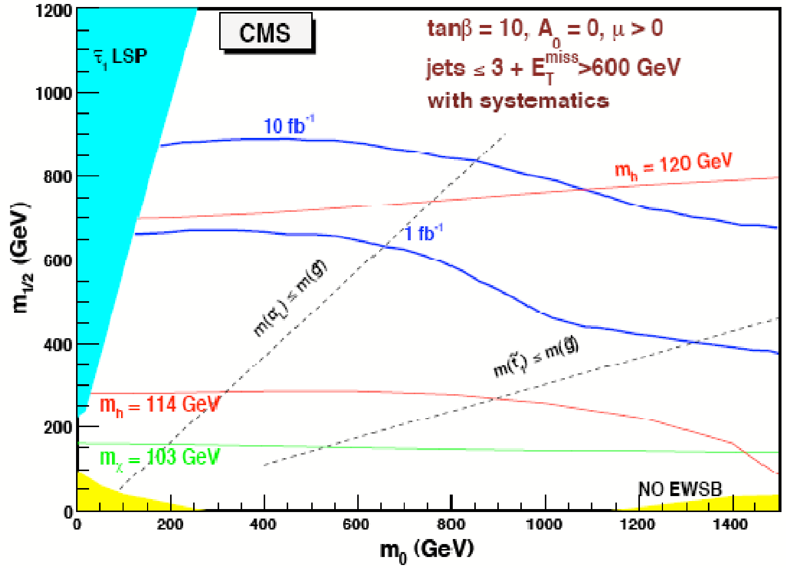
- results in negligible flavour violation in squark decays. Not necessarily the case for sleptons.
- Low-energy constraints still allow large branching ratios for the decays:

$$\begin{aligned} \tilde{l}_j &\longrightarrow l_i \tilde{\chi}_k^0 \\ \tilde{\chi}_k^0 &\longrightarrow \tilde{l}_j l_i \\ \tilde{\chi}_k^0 &\longrightarrow l_j l_i \tilde{\chi}_r^0 \end{aligned}$$

- Flavour identification **much** better (and backgrounds much smaller) for lepton sector at an hadron collider. LFV, if any, may be spotted in one of the above decays at the LHC.

- SUSY events at LHC (R-parity conserving):
  - Missing energy from undetected LSP
  - Coloured states (gluino/squark) dominates production and give energetic jets
  - Possibly leptons from decay chain. Photons in GMSB models.
- Most general (not only!) search strategy is jets+EtMiss+n-leptons (n=0,1,2…)
- Main backgrounds: SM events with hard neutrino
- If SUSY mass scale < 1000 GeV discovery requires very small (<< 1 fb-1) integrated luminosity (but **requires to understand background** normalization and distribution tails **first!)**
- If RPV no more missing energy, but additional jets (and possibly leptons) from neutralino decay. Discovery somewhat harder but should still be ok.





Discovery reach of order of 1500 GeV in squark/gluino mass with 1 fb^{-1} of (well understood) data.

Expected LHC luminosity:
Few fb^{-1} in 2008
10-20 fb^{-1} in 2009
100 fb^{-1}/year from 2010

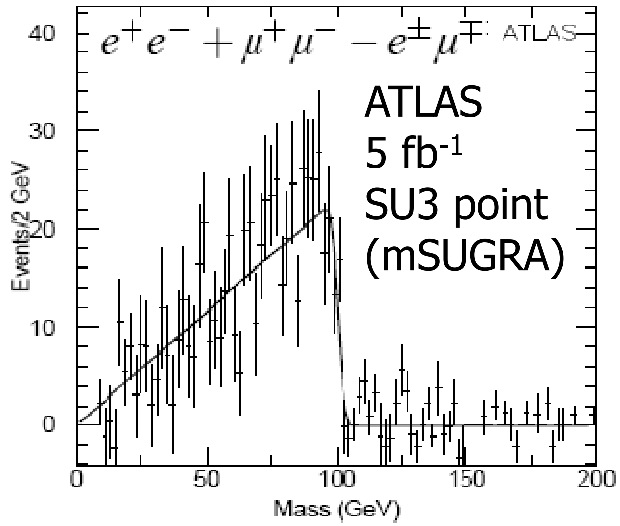
Following discovery, kinematical edges in invariant mass distributions will be seeked to identify decay chains and measure the mass of as many SUSY particles as possible.

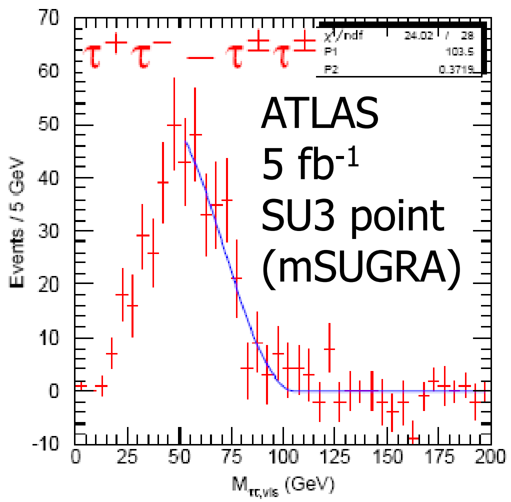
For $\tilde{\chi}_2^0 \to \tilde{\ell}^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^+ \ell^-$ find triangular mass distribution with

$$M(\ell^+\ell^-) \leq \sqrt{\frac{\left(M^2(\tilde{\chi}_2^0) - M^2(\tilde{\ell})\right)\left(M^2(\tilde{\ell}) - M^2(\tilde{\chi}_1^0)\right)}{M^2(\tilde{\ell})}}.$$

If no flavour violation, we expect same-flavour (ee, mm) pairs only for signal and an equal number of same-flavour and opposite-flavour pairs for background (leptons from two different decay chains, either for SUSY or SM events)

The edge in tt invariant mass can also be measured using the visible decay products of the taus

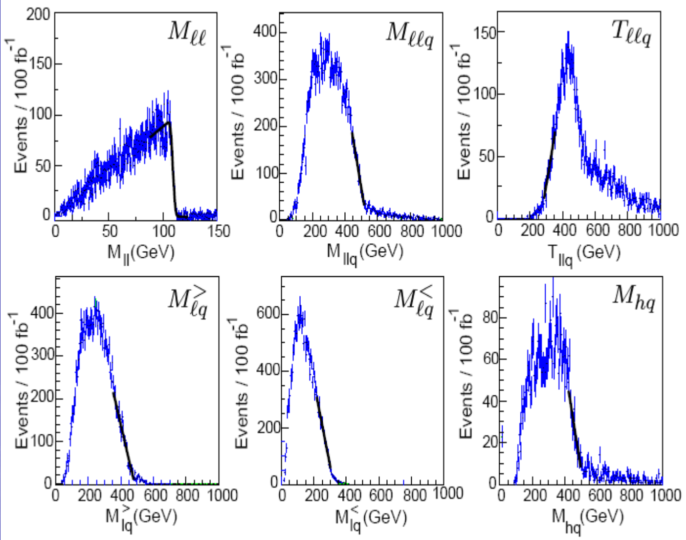




For the decay chain

$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{\ell}_R^\pm \ell^\mp q \to \tilde{\chi}_1^0 \ell^+ \ell^- q$$

lepton+jets invariant mass combinations may allow to measure enough kinematical endpoints to get the masses of all susy particles in the decay chain



Most experimental studies have focus on discovery (excess of events over Standard Model prediction) and measurement of masses in Minimal Flavour Violation Models

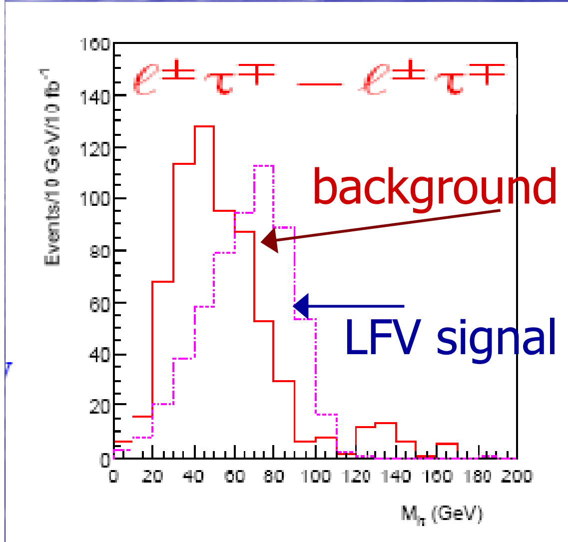
Some investigation of the possible measurement of spin effects (important to verify the new particles are indeed from Supersymmetry) and lepton flavour violation in neutralino decays:

[12] Barr, A. J., "Measuring slepton spin at the LHC", JHEP 02 (2006) 042 [hep-ph/0511115].

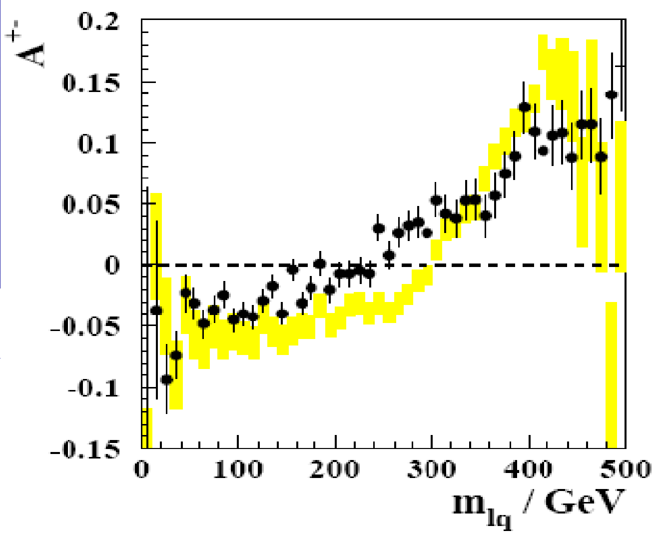
[13] Hinchliffe, I. and Paige, F. E., "Lepton flavor violation at the LHC", Phys. Rev. D63 (2001) 115006 [hep-ph/0010086].

[14] Bityukov, S. I. and Krasnikov, N. V., "The search for charged sleptons and flavor lepton number violation at LHC (CMS)", JETP Lett. 65 (1997) 148 [hep-ph/9806504].

More examples of flavour studies during this workshop (see later…)



Lepton sign asymmetry in lepton-jet invariant mass (neutralino spin effect) ATLAS 150 fb^{-1}



Effects of Lepton Flavour Violation on dilepton invariant mass spectra

Aim is study the effect of LFV on the invariant mass of two leptons from the decay chain: $\tilde{\chi}_2^0 \to \tilde{\ell}_i^+ \ell_j^- \to \ell_k^+ \ell_j^- \tilde{\chi}_1^0$.

Start from SPS1a' benchmark point:

$\tan\beta$	10	$M_{L,11} = M_{L,22}$	184 GeV	$M_{E,33}$	111 GeV
M_1	100.1 GeV	$M_{L,33}$	182.5 GeV	A_{11}	-0.013 GeV
M_2	197.4 GeV	$M_{E,11}$	117.793 GeV	A_{22}	-2.8 GeV
μ	400 GeV	$M_{E,22}$	117.797 GeV	A_{33}	-46 GeV

Relevant masses:

$m_{\tilde{\chi}_1^0} = 97.8$ GeV, $m_{\tilde{\chi}_2^0} = 184$ GeV, $m_{\tilde{e}_1} = 125.3$ GeV, $m_{\tilde{\mu}_1} = 125.2$ GeV, $m_{\tilde{\tau}_1} = 107.4$ GeV.

Add non-diagonal entries to slepton mass matrix:

$$M_{E,23}^2 = 600\ \text{GeV}^2\ M_{E,12}^2 = 30\ \text{GeV}^2,\ M_{E,13}^2 = 850\ \text{GeV}^2$$

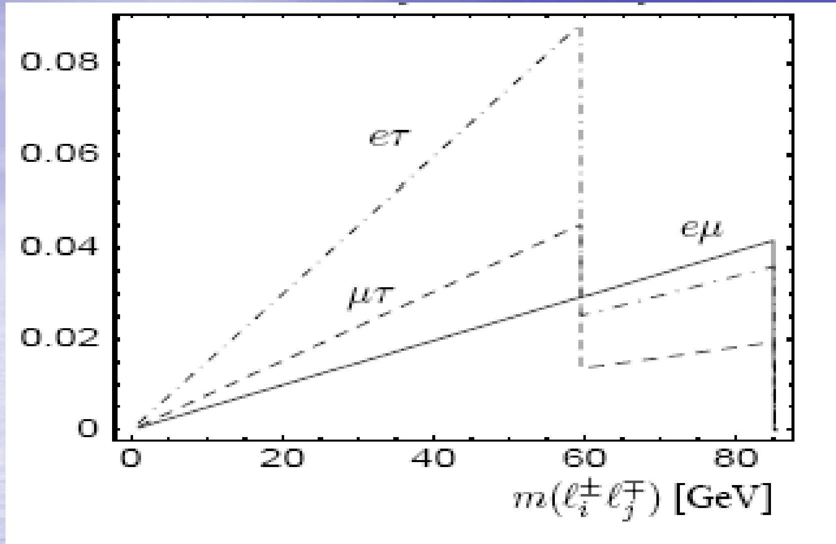
$$(m_{\tilde{\ell}_1}, m_{\tilde{\ell}_2}, m_{\tilde{\ell}_3}) = (106.4, 125.1, 126.2)\ \text{GeV}$$

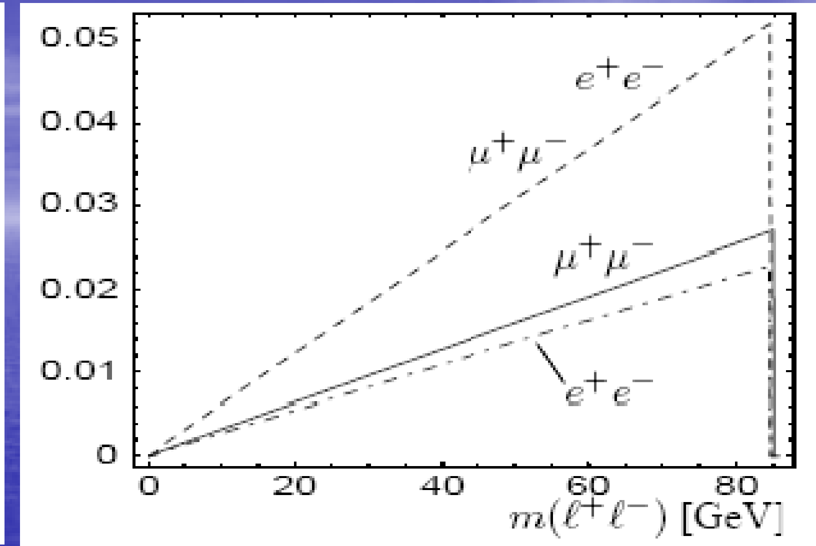
LFV low-energy decays within limits:

$$\text{BR}(\mu^- \to e^-\gamma) = 9.5 \times 10^{-12},\ \text{BR}(\tau^- \to e^-\gamma) = 1.0 \times 10^{-7}\ \text{BR}(\tau^- \to \mu^-\gamma) = 5.2 \times 10^{-8}.$$

Defining $\text{BR}(\ell_i\ell_j) \equiv \text{BR}(\tilde{\chi}_2^0 \to \ell_i\ell_j\tilde{\chi}_1^0)$. and summing over all contributing sleptons:

$$\underbrace{\text{BR}(e\mu) = 1.7\%\ \text{BR}(e\tau) = 3.4\%,\ \text{BR}(\mu\tau) = 1.8\%}_{\text{different flavour}},\ \underbrace{\text{BR}(e^+e^-) = 1\%,\ \text{BR}(\mu^+\mu^-) = 1.2\%,\ \text{BR}(\tau^+\tau^-) = 51\%}_{\text{same flavour}}$$





LFV modes: three edges appear in $e\mu$, $e\tau$ and $\mu\tau$ distributions

LFC modes: The BRs of ee and $\mu\mu$ are reduced w.r.t. the FC case (dashed line) and are no longer the same

In general, three conditions are required for the observability of multiple FV edges:
- $m(\chi^0_1) < m(l) < m(\chi^0_2)$ i.e. the decay chain is open…
- At least two contributing slepton flavour with a sizeable mass difference
- LFV entries in mass matrix large enough

In mSUGRA the first two conditions require $m_0 < 0.4\ m_{1/2}$ and $\tan\beta > 8$

Lepton Flavour Violation in the long lived stau NLSP scenario

- Scenario: gravitino LSP, next-to-LSP stau, long lived because decay through gravitational interactions is supressed.

$$m_{3/2} < m_{\tilde{\tau}_1} < m_{\tilde{e}_R,\,\tilde{\mu}_R} < m_{\chi^0_1}, m_{\tilde{e}_L,\tilde{\mu}_L}, m_{\tilde{\tau}_2} \cdots$$

- Can result in stau being long-lived enough to be directly detected. Speed less than c, heavily ionizing: very unique signature.
- Some staus would be trapped in the detector, to decay later, according to lifetime.
- There are also proposals to build large (1-10 kton) water tanks outside LHC or ILC detectors to trap staus. May collect several thousands taus at the LHC.

I suppose that for LHC this would require major civil engineering work to enlarge the ATLAS and CMS caverns and several years of accelerator shutdown. Probably it will be considered seriously only after a massive, apparently stable, charged particle is detected.

- If LFV, the stau can decay into electrons or muons rather than taus only -> possibility to measure LFV from the decay of trapped staus.

Neutralino decays in models with broken R-parity

Neutrino masses can be generated adding an R-parity breaking term to the MSSM Suprpotential ($W = W_{\rm MSSM} + \epsilon_i \hat{L}_i \hat{H}_u$) and the corresponding terms in the soft SUSY breaking lagrangian.

The largest neutrino mass generated at tree level, the second one via radiative corrections.

This creates a relation between the neutrino masses and mixings and the decay of the LSP.

If the LSP is the neutralino:

$$\tan^2\theta_{\rm atm} \simeq \left|\frac{\Lambda_2}{\Lambda_3}\right|^2 \simeq \frac{BR(\tilde{\chi}_1^0 \to \mu^\pm W^\mp)}{BR(\tilde{\chi}_1^0 \to \tau^\pm W^\mp)} \simeq \frac{BR(\tilde{\chi}_1^0 \to \mu^\pm \bar{q}q')}{BR(\tilde{\chi}_1^0 \to \tau^\pm \bar{q}q')},$$

Also long, possibly measurable (with secondary vertices) neutralino lifetime. Can help to remove background and identify leptons from the LSP from prompt leptons in SUSY decayd chains.

If the ratio between μ and τ decays is measured, can check the connection with neutrino physics.

If LSP is the stau, its decay BRs are related to solar neutrino mixing angle.

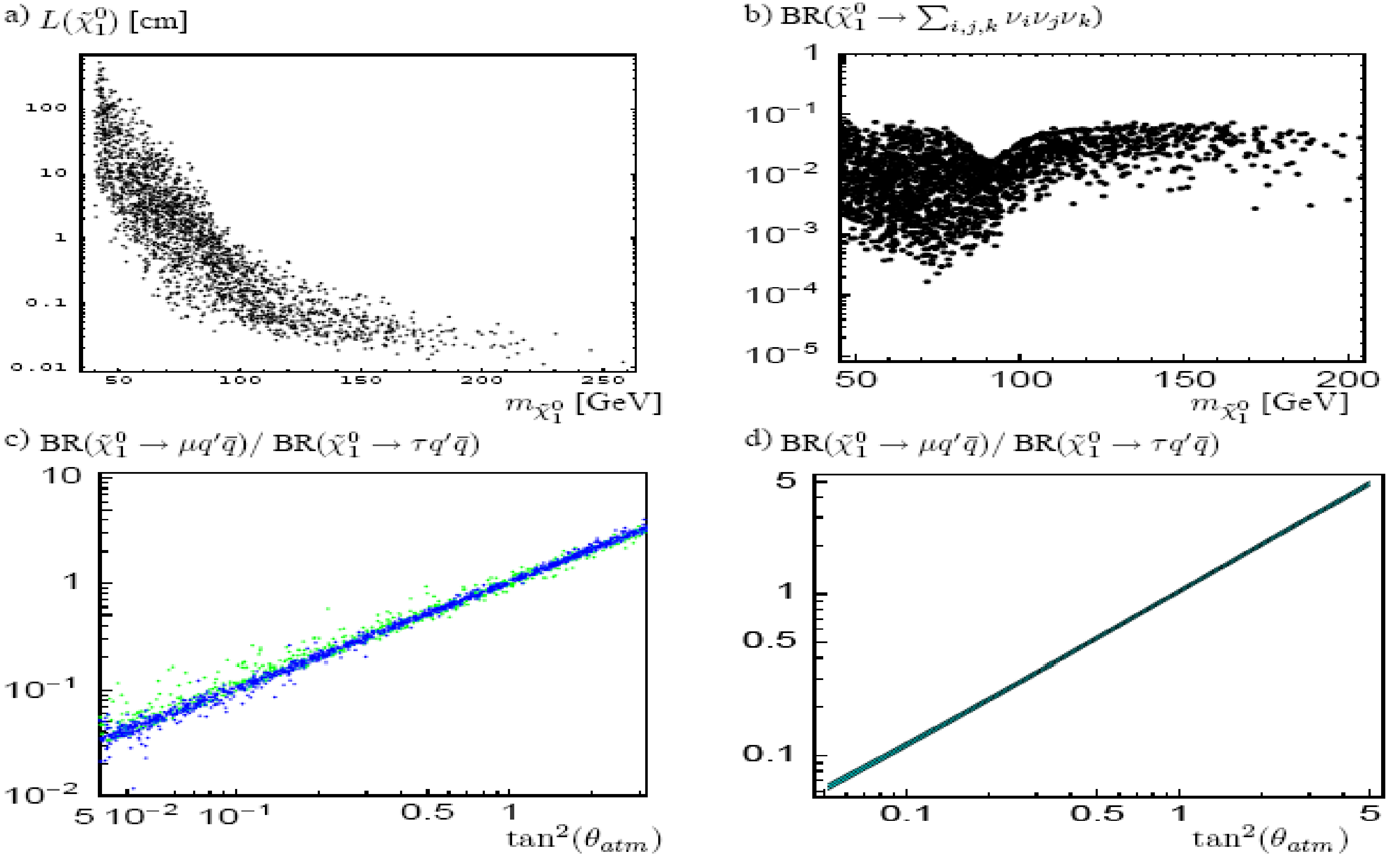


Fig. 2: Various neutralino properties: a) Neutralino decay length and b) invisible neutralino branching ratio summing over all neutrinos as a function of $m_{\tilde{\chi}_1^0}$; c) $\mathrm{BR}(\tilde{\chi}_1^0 \to \mu q' \bar{q})/\mathrm{BR}(\tilde{\chi}_1^0 \to \tau q' \bar{q})$ scanning over the SUSY parameter and d) $\mathrm{BR}(\tilde{\chi}_1^0 \to \mu q' \bar{q})/\ \mathrm{BR}(\tilde{\chi}_1^0 \to \tau q' \bar{q})$ for 10% variations around a fixed SUSY point as a function of $\tan^2(\theta_{atm})$.

Reconstructing neutrino properties from collider experiments in a Higgs triplet neutrino mass model

In this model, neutrino masses are generated both by the RPV bilinear couplings discussed previously and an additional Higgs triplet:

$$\begin{aligned} W &= W_{\mathrm{MSSM}} + \epsilon_i \hat{L}_i \hat{H}_u + W_\Delta \\ W_\Delta &= \mu_\Delta \widehat{\Delta}_u \widehat{\Delta}_d + h_{ij} \widehat{L}_i \widehat{L}_j \widehat{\Delta}_u \end{aligned}$$

Solar neutrinos mixing angle related to the couplings of the triplet to lepton doublet:

$$\tan(2\theta_{\mathrm{SOL}}) \simeq \frac{-2\sqrt{2}(h_{12} - h_{13})}{-2h_{11} + h_{22} + h_{33} - 2h_{23}} \equiv x$$

The model foresee a doubly charged Higgs boson Δ, which can be produced via

a) VBF: supressed because small higgs VEVs

β) $\Delta\Delta$ pair production: s(qq $\rightarrow \gamma/Z \rightarrow \Delta\Delta$) = 10 (1.5) fb for m = 300 (800) GeV

c) HΔ production: s(qq $\rightarrow W \rightarrow \Delta$H) = 35(0.3) fb for m= 300(800) GeV

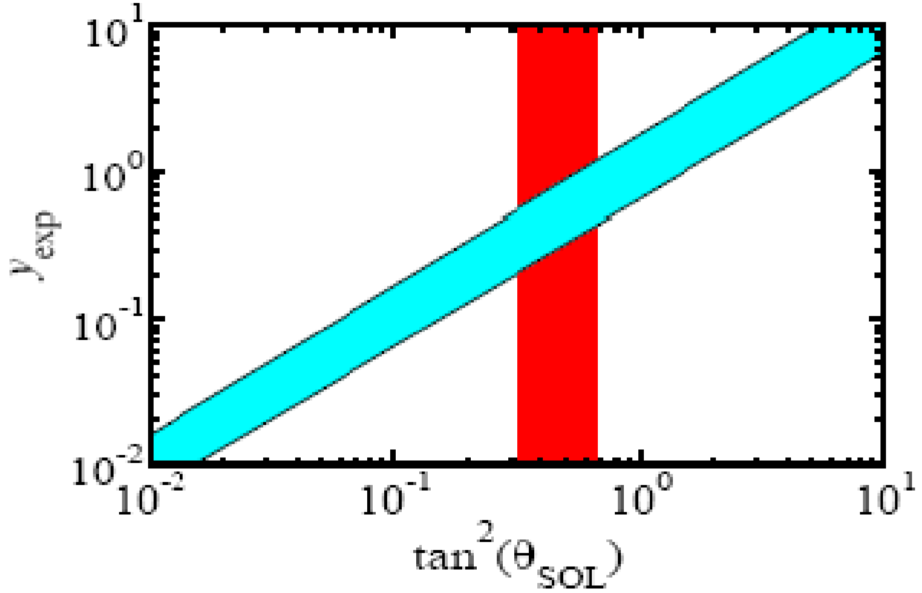
Defining

$BR_{i\,k}$ = BR($\Delta \to l_i\, l_k$)

$$x_{\rm exp} \equiv \frac{-2\sqrt{2}(\sqrt{\rm BR_{12}} - \sqrt{\rm BR_{13}})}{-2\sqrt{2\rm BR_{11}} + \sqrt{2\rm BR_{22}} + \sqrt{2\rm BR_{33}} - 2\sqrt{\rm BR_{23}}}$$

$$y_{\rm exp} \equiv \tan^2\left(\frac{\arctan(x_{\rm exp})}{2}\right)$$

The variable y is related to the solar mixing angle.

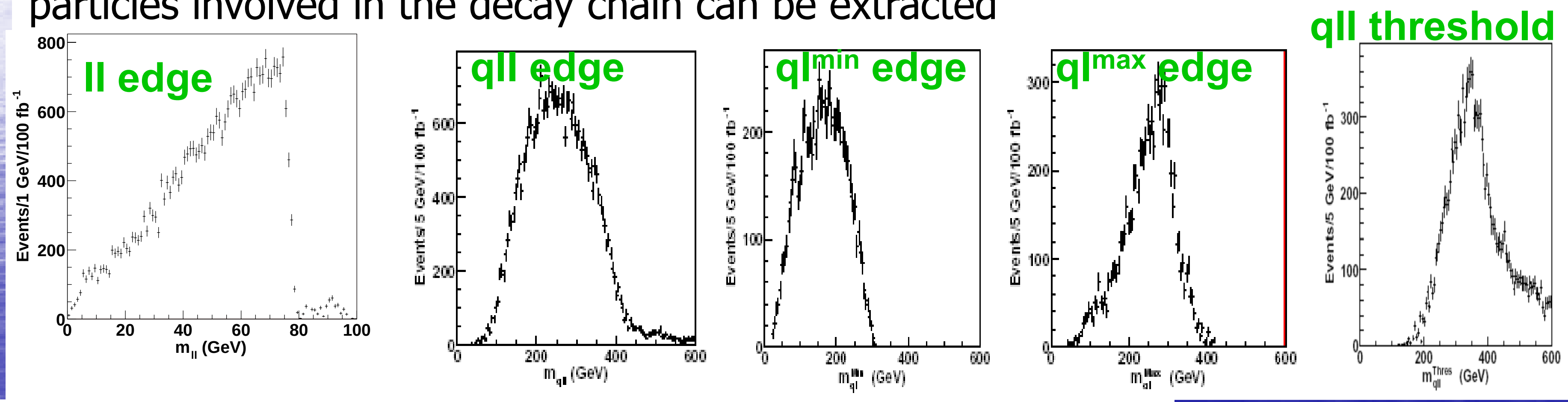


SUSY (s)lepton flavour studies with ATLAS

At the LHC, sleptons can be either produced directly or from the decay of heavier gauginos.
The latter is the most promising source for their study, in particular the decay chain:

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 \, q \rightarrow \tilde{l}_R \, l \, q \rightarrow llq \;\; \tilde{\chi}_1^0$$

has been studied in great detail. For the mSUGRA benchmark point SPS1a, several kinematics edes can be measured with 100 fb^{-1} and the masses of all the particles involved in the decay chain can be extracted



Gjelsten, Lytken, Miller, Osland, Polesello, ATL-PHYS-2004-007

L=**100 fb^{-1}**

5 relations
4 masses

SPS1a (bulk region)
m_0= 100 GeV,
$m_{1/2}$= 250 GeV,
A_0= -100 GeV,
$\tan(\beta)$=10 , μ>0

Expected errors on the masses

$\Delta m(\chi_1^0)$= 4.8 GeV, $\Delta m(\chi_2^0)$= 4.7 GeV,
$\Delta m(l_R)$ = 4.8 GeV, $\Delta m(q_L)$= 8.7 GeV

Direct slepton production

$$\tilde{l}_R \tilde{l}_R \;,\; \tilde{l}_L \tilde{l}_L \rightarrow l^+ l^- + E_T^{miss}$$

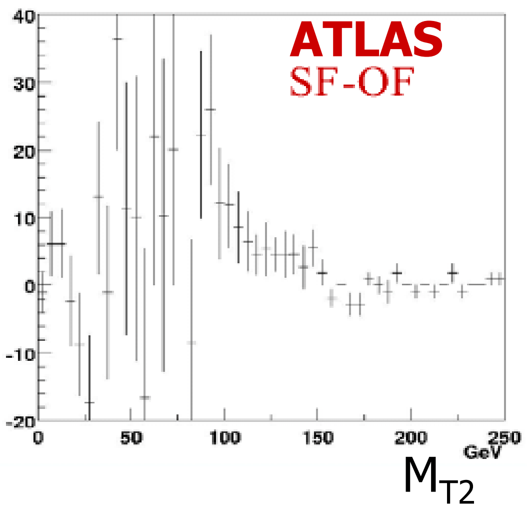
Stransverse mass:

$$\boxed{M_{T2} = \min_{E_T^{miss} = E_{T1}^{miss} + E_{T2}^{miss}} \left\{ \max \left\{ m_T^2\left(p_T^{l1}, E_{T1}^{miss}\right), m_T^2\left(p_T^{l2}, E_{T2}^{miss}\right) \right\} \right\}}$$

Has an endpoint which is a function of the mass difference between sleptons and LSP.

For SP1a:

$$M(\tilde{\chi}_1^0) = 96\,GeV, M(\tilde{l}_R) = 143\,GeV, M(\tilde{l}_L) = 202\,GeV$$



3-4 GeV precision on $\tilde{l}_L$ mass

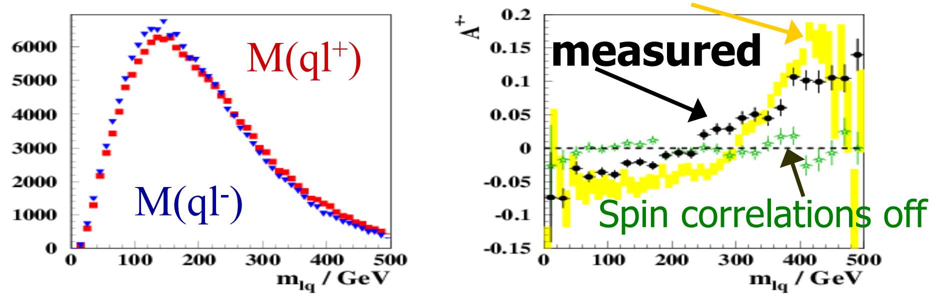
Spin asymmetries

It is vital to measure the spins of the new particles to demonstrate that they are indeed super-partners.

$$\tilde{q}_L \rightarrow q\,\tilde{\chi}_2^0 \rightarrow q\,\tilde{l}_R\, l^{near} \rightarrow q\, l^+ l^- + \tilde{\chi}_1^0$$

Due to neutralino spin 1/2, angular distrib. of slepton is not spherically symmetric, invariant mass $M(ql^{near})$ is charge asymmetric.

ATLAS simulation, LHCC 300 fb^{-1}



Cannot tag l^{near}; instead, study $M(l^-q)$ and $M(l^+q)$ distributions. Because LHC is pp collider (more quarks then antiquarks) a residual asymmetry between the two distributions exists.

Using the $l^+l^- + E^T_{miss}$ + jet veto signature for slepton detection

This is a study on the possibility of discovery a deviation from SM in this channel, which is sensible to the direct slepton production $\tilde{l}_R\tilde{l}_R\ ,\ \tilde{l}_L\tilde{l}_L \rightarrow l^+l^- + E_T^{miss}$

Signal: mSUGRA point LM1 (detailed CMS simulation) and scan of mSUGRA parameter space (parametrized CMS simulation). All Supersymmetric processes are simulated (not just slepton direct production).

Background: tt, ZZ, WW, Wt, Zbb, DY2e, DY2τ, WZ (detailed CMS simulation), DY2μ, W+jets (parametrized CMS simulation)

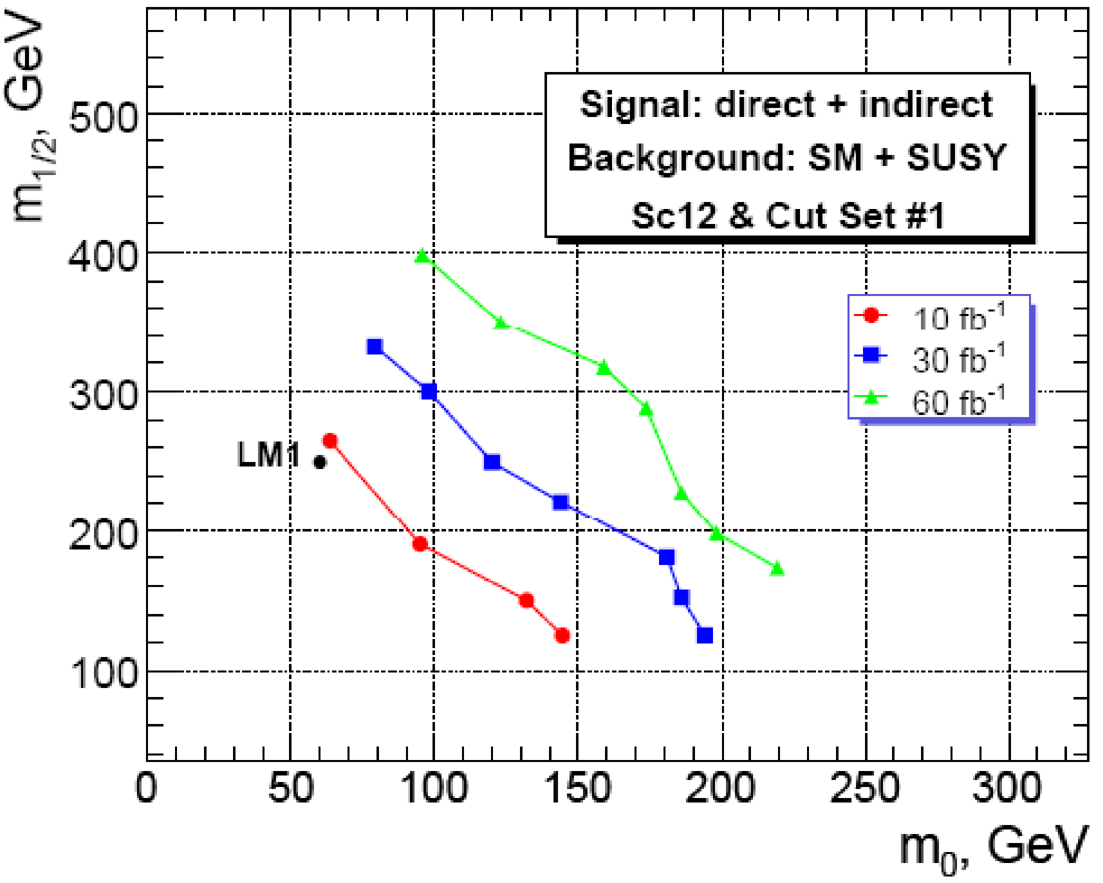
Selection Cuts:

- Two leptons with pt > 20 GeV, isolated (cuts on calorimeter energy and tracks in cone of width $\Delta R<0.3$)
- Lepton invariant mass outside Z peak
- Leptons not back-to-back ($\phi < 140^0$)
- EtMiss > 135 GeV, $\Delta\phi$(EtMiss, ll) > 170^0 (EtMiss and leptons back-to-back)
- No jet with E_t > 30 GeV and η < 4.5

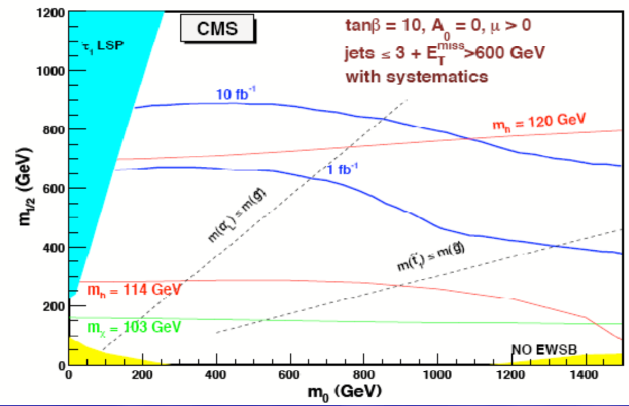
Main SM background is tt and WW.

Non-slepton SUSY production also contributes, but as the object of the investigation is the Sensitivity to "new physics" it is considered as a signal.

Sensitivity in mSUGRA parameter space
$\tan\beta = 10$, $\mathrm{sgn}(\mu)>0$, $A=0$



In mSUGRA squark and gluino production will be discovered much more easily than slepton direct production (but we would like to see both of course)



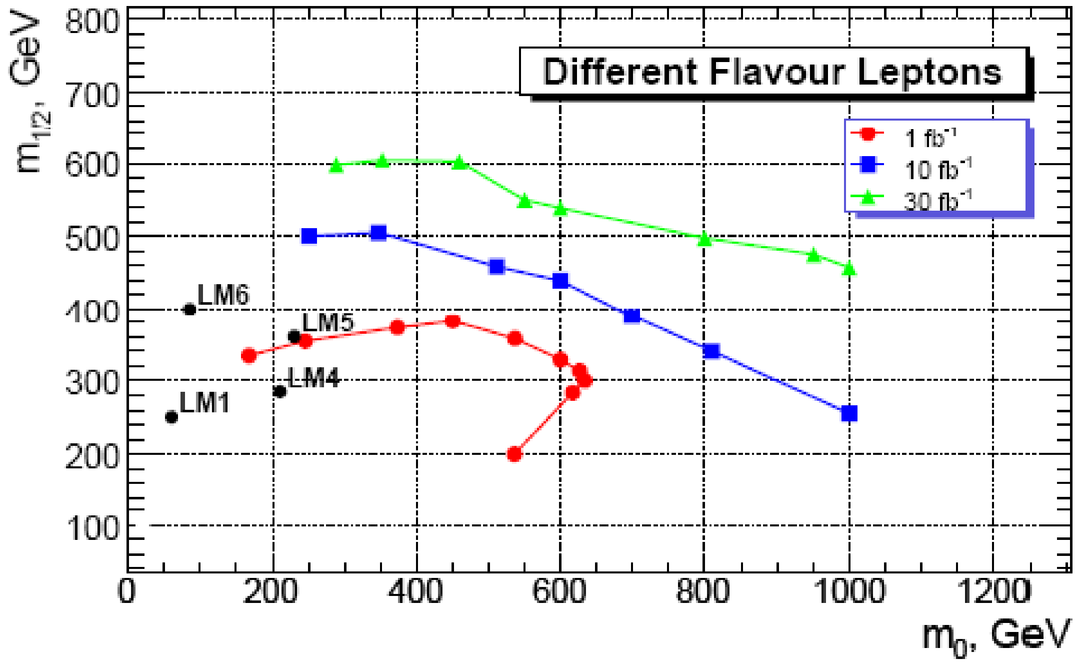
Using the $e^{\pm}m^{-}+E^{T}_{miss}$ signature in the search for Supersymmetry and lepton flavour violation in neutralino decay

The opposite-sign, opposite-sign signature can easily appear even in flavour conserving SUSY, the two lepton being produced by the two independent decay chains

A search was performed using the CMS detector simulation. The optimal cut set was found to be:

- Isolated leptons with p_t > 20 GeV
- EtMiss > 300 GeV

Main background is found to be ttbar. Discovery reach in mSUGRA parameter space is Shown in the plot.



If the eμ pairs come from a LFV violating decay of the neutralino, then an edge should be present in the invariant mass distribution.

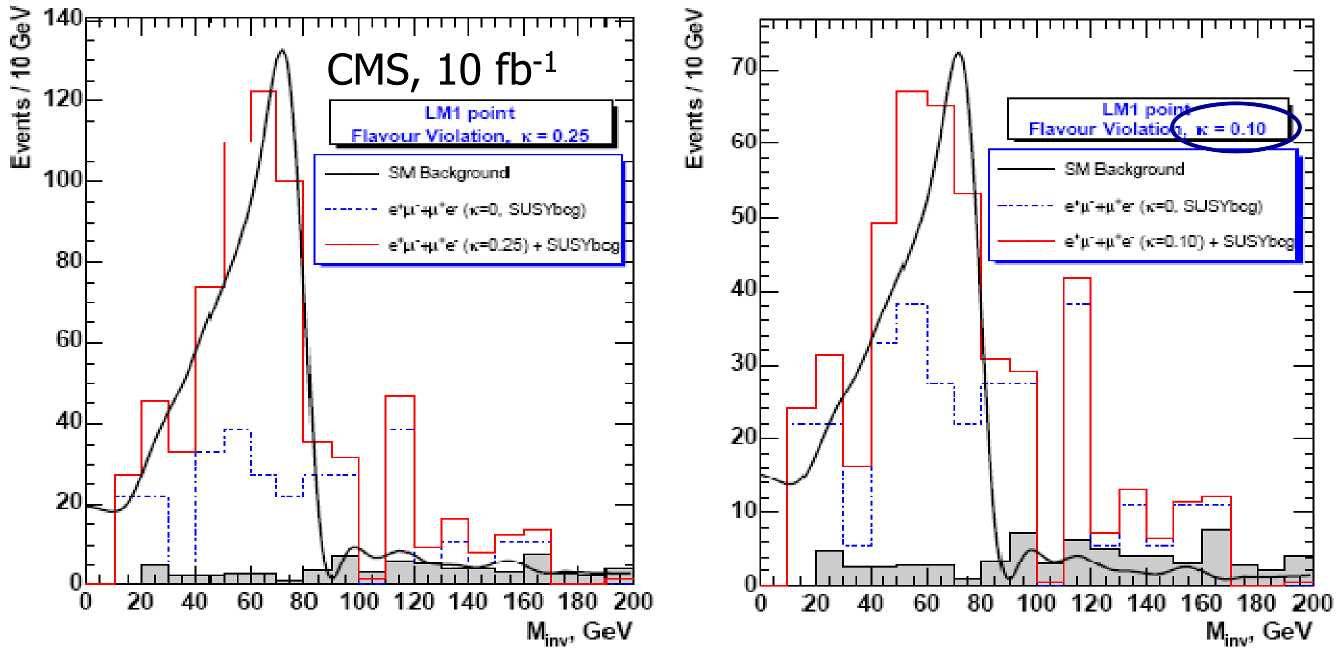
$$\mathrm{BR}(\ell_i\ell_j) \equiv \mathrm{BR}(\tilde{\chi}_2^0 \to \ell_i\ell_j\tilde{\chi}_1^0)$$

k = BR(eμ)/[BR(ee)+BR(μμ)] (opposite sign implied)

$$\kappa = 2x\sin^2\theta\cos^2\theta,$$

$$x = \frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\Delta m^2_{\tilde{e}\tilde{\mu}} + \Gamma^2},$$

θ is the e-μ mixing angle
Γ is the slepton decay width



Conclusions

•The leptonic decay of the neutralino-2 is a promising channel at the LHC for the reconstruction of superpartners masses and searches for lepton flavour violation effects.

• Branching ratios for LFV decays comparable to LFC ones are still compatible with present constraints from muon and tau decays.

• Good statistics and purity are expected at the LHC in this channel. For point LM1, for example, sensitivity to BR(LFV)/BR(LFC) ratios of a few per cent can be reached.

• A connection between SUSY phenomenology at the LHC and neutrino physics is possible. The model with RPV, for example, predict a correlation between the leptonic decay branching ratios of the lightest neutralino with the atmospheric mixing angle.

Backup

Reach of different channels

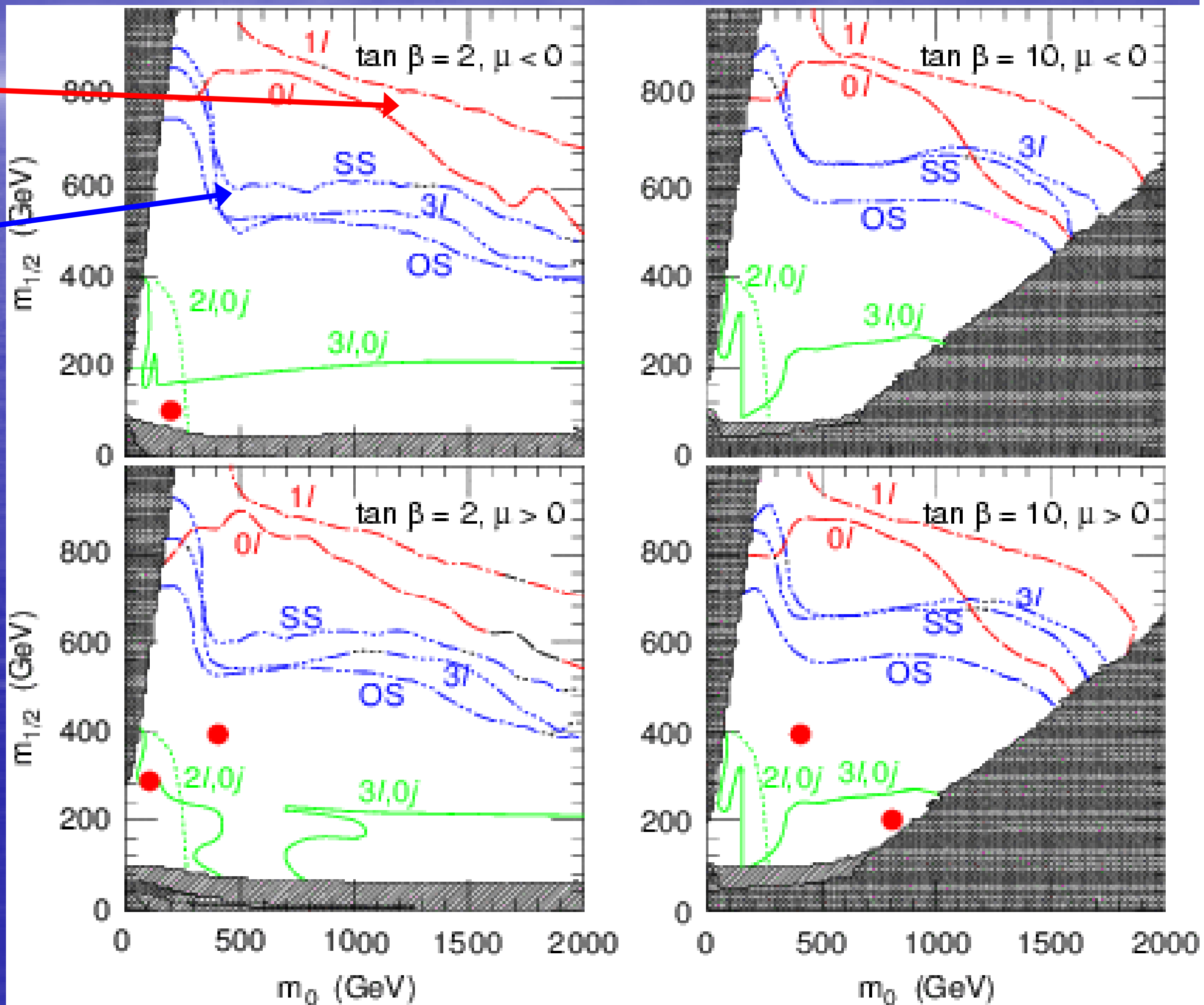
Inclusive E_T^{Miss} + jet:

- Best signature
- Important for high ∫L limit

Multi-lepton n(≥1) ℓ:

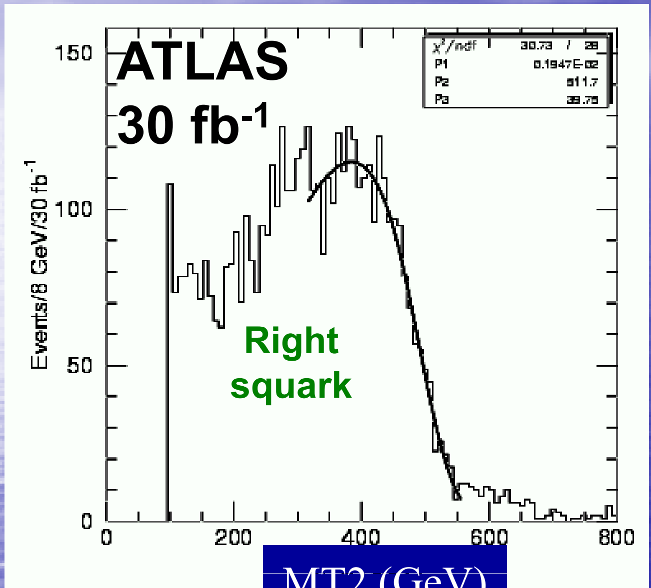
- Less powerful
- But may be very **useful for early discovery:**
  - Signal confirmed in several channels
  - Better S/B, leptons better measured/understood than jets at the beginning – **can be important in early searches**

Esempio: 2μSS



Other mass measurements

$\tilde{q}_R \rightarrow \chi^0_1 q$



MT2 (GeV)

2 hard jets and lots of E_T^{miss}.

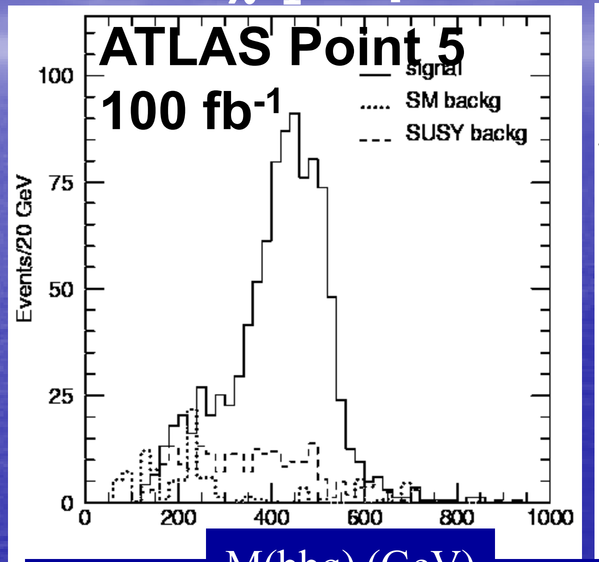
Reconstruct with

$$M_{T2}^2 = \min_{\not p_1+\not p_2=\not p_T}\left[\max\left\{m_T^2(p_T^{\ell_1}, \not p_1), m_T^2(p_T^{\ell_2}, \not p_2)\right\}\right]$$

$m(\tilde{q}_R)$-$m(\chi^0_1) = (424.2 \pm 10.9)$ GeV

Also works for sleptons.

$\tilde{q}_L \rightarrow \chi^0_2 q \rightarrow \chi^0_1 hq \rightarrow \chi^0_1 bbq$



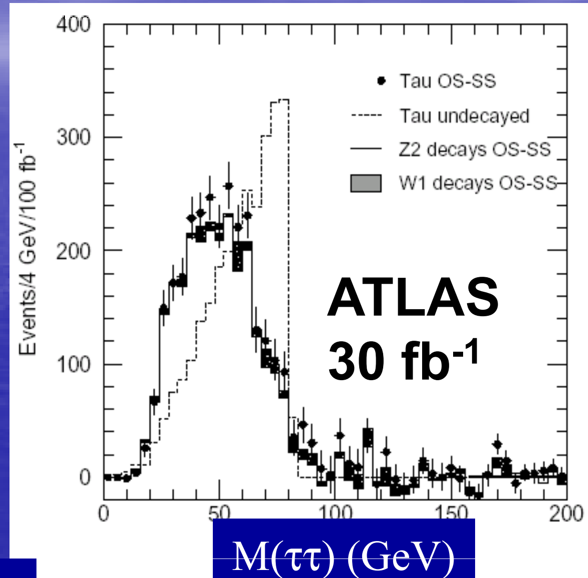
M(bbq) (GeV)

Two body decay of χ^0_2 to higgs and χ^0_1.

Reconstruct higgs mass (2 b-jets) and combine with hard jet.

Get additional mass constraint.

$\chi^0_2 \rightarrow \tilde{\tau}\tau \rightarrow \chi^0_1\ \tau\tau$



M($\tau\tau$) (GeV)

Tau decay dominates neutralino BR at large tanβ.

No sharp edge because of ν, but end-point can still be measured.