RICERCHE DI SUSY CON I PRIMI DATI DI LHC

TOPICS:

- Generalities on **Supersymmetry** and **mSUGRA**;
- **Topology** of SUSY events & **ATLAS performances**;
- **SUSY search's strategies** : Inclusive and Exclusive channels with early data (first fb-1..) ;
- An other scenario: **GMSB models**;

In this talk the performances of ATLAS detector will be analyzed; CMS has more or less the same discovery performances and the same strategies analysis.

Official schedule (BEFORE Triplet magnets problem):

November 2007: **Starting Pilot Run with** $\sqrt{s} = 900\ GeV$ **;**

Just to verify detectors and machine status… no SUSY…

Summer 2008: **Starting Run with** $\sqrt{s} = 14\ TeV$ **; some fb-1**

could be avalaible at the end of 2008. With these data the hunt

is on…

Supersymmetry

For every Standard Model fermion (boson) a bosonic (fermionic) partner is introduced.

Solves problems with **Higgs mass naturalness** if the new particles are **lighter than** about **1000 GeV**.

At least two Higgs doublets needed: **5 Higgs bosons** (+ 4 Higgsino fermions)

New particles:

Spin 0: scalar quarks, leptons, neutrinos

Spin ½: 4 neutralinos (mix of Zino, photino, Higgsino), 4 charginos (mix of Wino and Higgsino), gluino

Mass terms for the new particles can be added to the Lagrangian (SUSY breaking)

In general, **105** new masses, mixing angles, CPV phases

Minimal SUGRA (mSUGRA)

- **A random choice of the 105 MSSM parameters violates limits** from B/D/K physics, electric dipole moments, flavour-violating neutral currents, …
- **Need** some **assumption** on the structure **of SUSY breaking lagrangian**. As an example in **mSUGRA** (5 free parameters, most studied by ATLAS and CMS):
  - **Conserved R-parity** (+1 for SM, -1 for SUSY particles): SUSY particles are produced in pairs, lightest susy particle is stable (good candidate for Dark Matter)
  - **Common mass** m0 for susy scalars, m1/2 for fermions (at GUT scale).
  - **Common value** A0 for the trilinear coupling of the s-fermions with the 2 Higgs doublets.

Then 5 free parameters: $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}\,\mu$

mSUGRA constraints

Theoretical

- **ElectroWeakSymmetryBreaking(EWSB)**

excludes small $m_{1/2}$ and large m_0 region depending on m_{top} (Tevatron)

Experimental

- **Higgs mass (LEP)** $m_{ho}^{SM} > 114.4$ **GeV**
- **Chargino mass (LEP)** $m_{\chi\pm} > 103$ **GeV**
- **Br(bsγ) (CLOE,BELL,BaBar)** $(3.55 \pm 0.26)\ 10^{-4}$
- $\Delta\alpha_\mu = (22 \pm 10)\ 10^{-10}$ **(Muon g-2)**

excludes low mass region

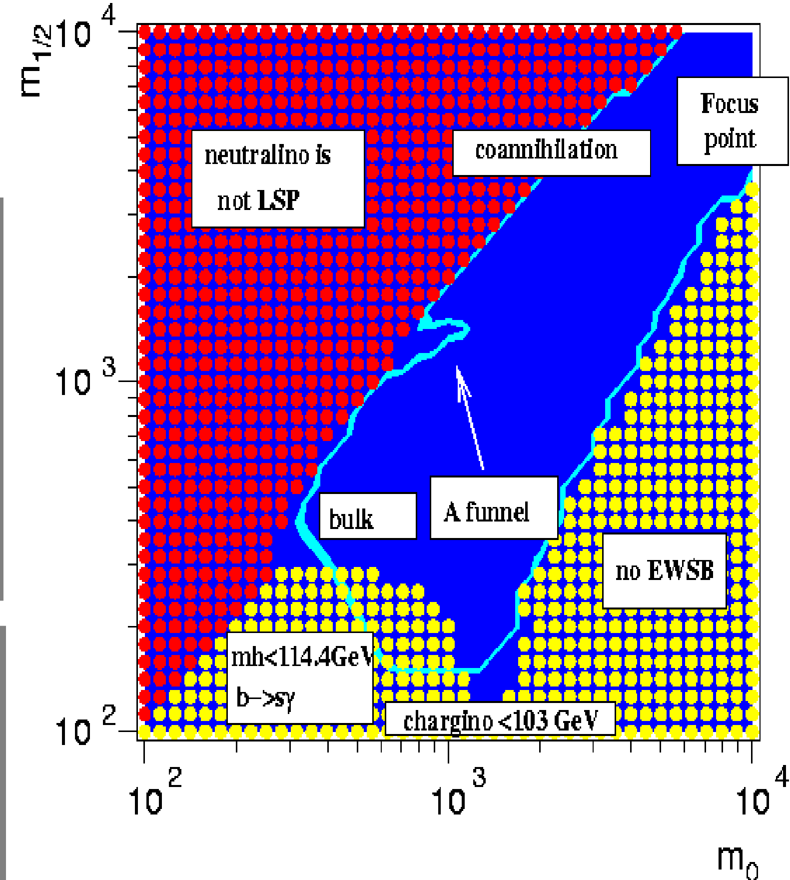
Dark Matter (if DM is supersymmetric)

- **stau is LSP (exclude low m_0)**
- **Relic Density(WMAP)** $\Omega_\chi h^2 = 0.113 \pm 0.009$

RD define a narrow band in m_0-$m_{1/2}$ plane at fixed tanβ (at large m_0, tanβ depends on EWSB parameters)

Indirect DM (EGRET) $m_{1/2}<250$, tanβ>50

$\Omega_\chi h^2$ [0.094 -0.130]



At tanβ < 20 only focus point and coannihilation regions are complaint with the RD

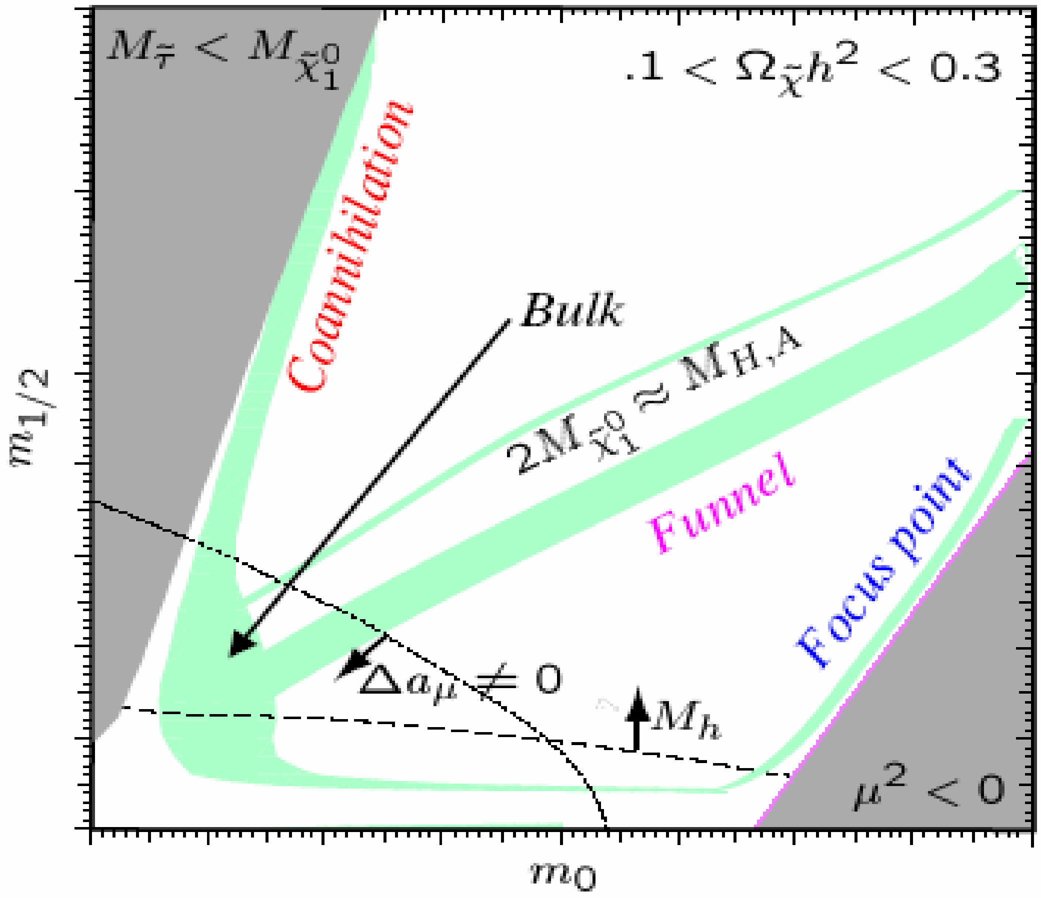
TeV-scale SUSY gives qualitatively right cold dark matter. Detailed calculation ⇒ need enhanced annihilation. Use mSUGRA as guide (qualitative picture — no mass scale):

Coannihilation: Light $\tilde{\tau}_1$ in equilibrium with $\tilde{\chi}_1^0$, so annihilate via $\tilde{\chi}_1^0 \tilde{\tau}_1 \to \gamma\tau$.

Bulk: bino $\tilde{\chi}_1^0$; light $\tilde{\ell}_R$ enhances annihilation.

Funnel: *H,A* poles enhance annihilation for $\tan\beta \gg 1$.

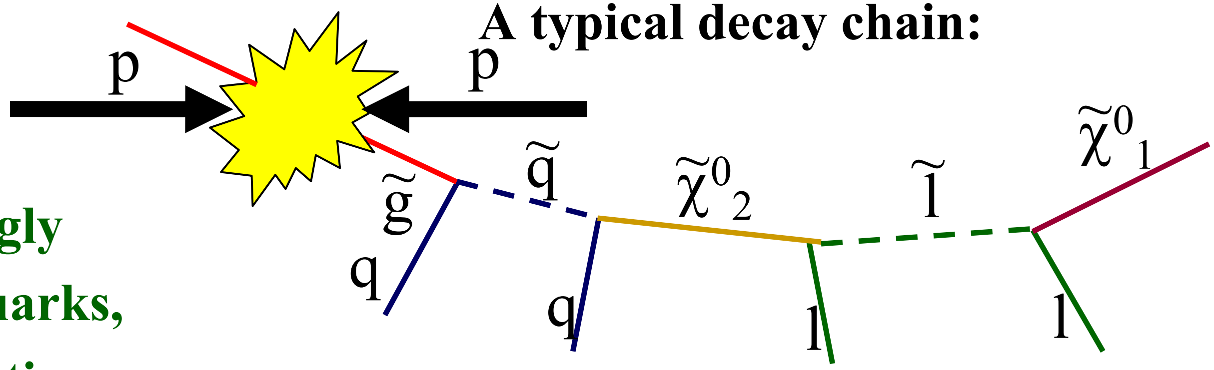
Focus point: Small μ^2, so Higgsino $\tilde{\chi}_1^0$ annihilate. Heavy s-fermions, so small FCNC.



May be too constrained. Experiments are mostly interested in identify signatures to develop and study search strategies

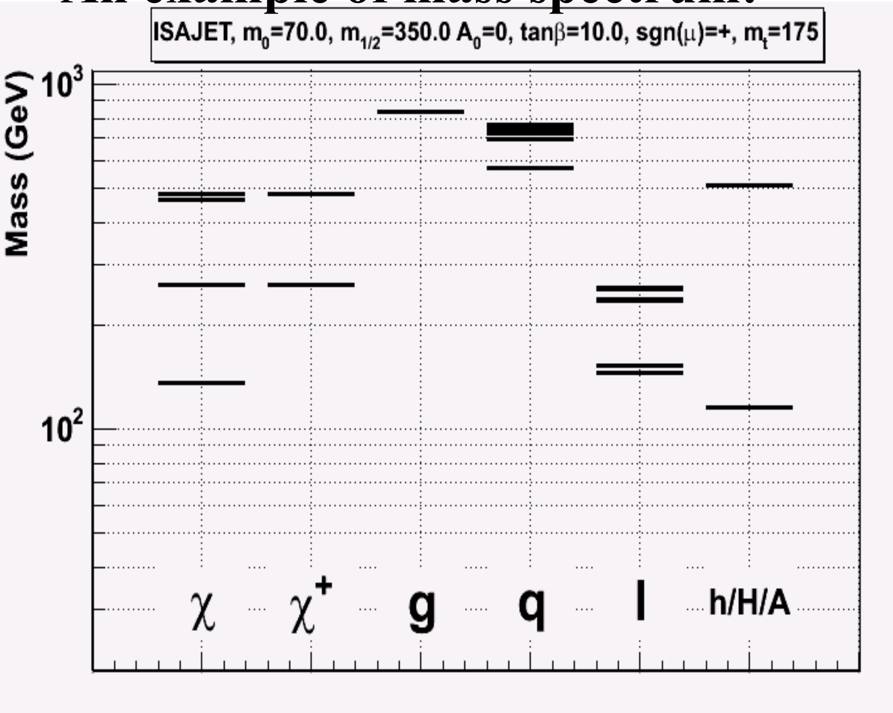
SUSY events topology

A typical decay chain:

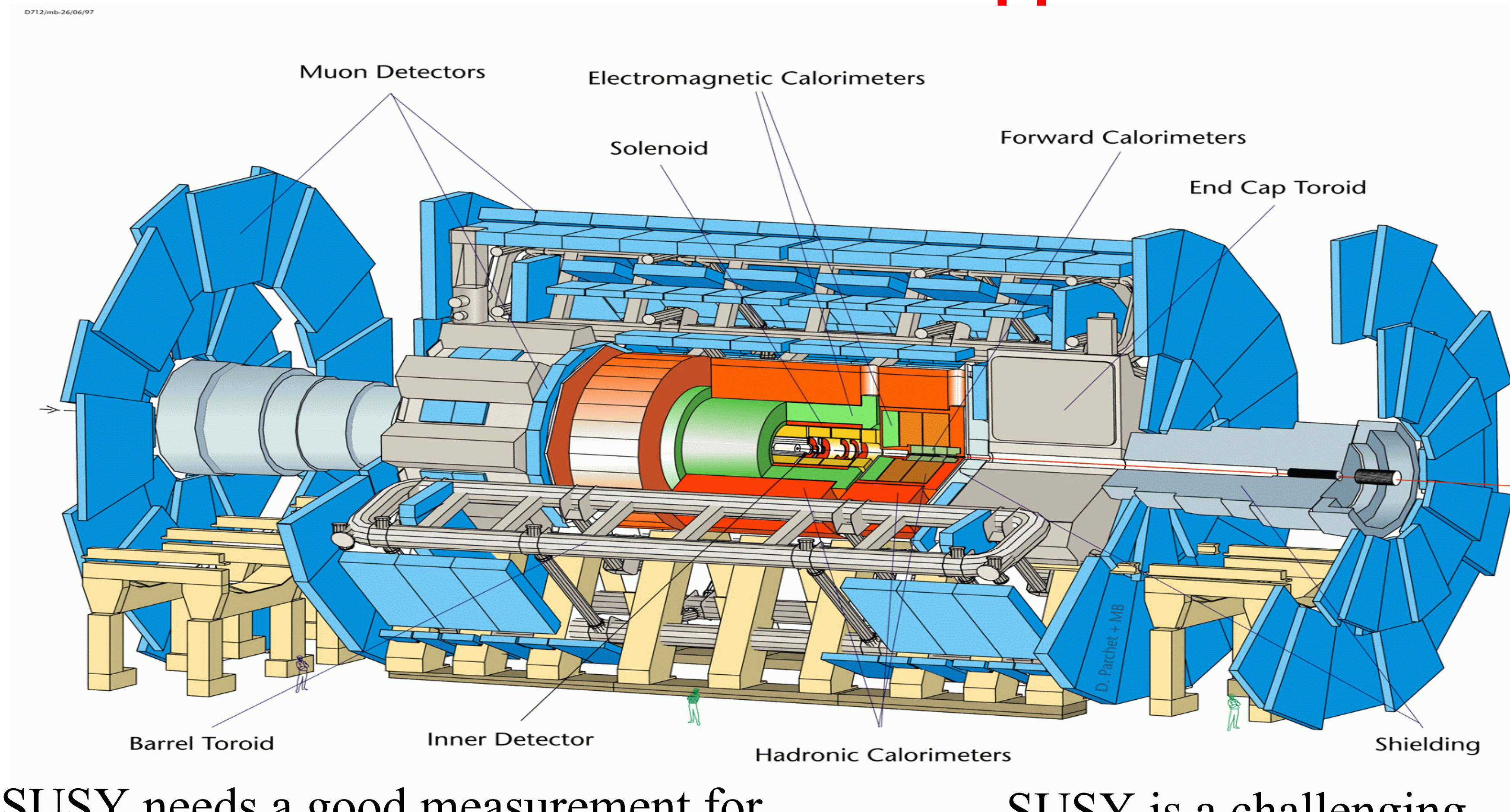


- In SUGRA models, strongly interacting sparticles (squarks, gluinos) dominate production.
- Cascade decays to the stable, weakly interacting lightest neutralino follows.
- Event topology:
  - High p_T jets (from squark/gluino decay)
  - Large E_T^{miss} signature (from LSP)
  - High p_T leptons, b-jets, τ-jets (depending on model parameters)

An example of mass spectrum:



ATLAS: A Toroidal Lhc ApparatuS



SUSY needs a good measurement for jets +EtMiss (EM + Hadronic Calo), leptons (EM CAlo+μ chambers+ID) and b-jets (Pixel Vertex Detector).

$\Rightarrow$

SUSY is a challenging scenario where ATLAS will exploit at highest level its components.

The standard discovery approach

Most general strategy: Jet + EtMiss + n leptons

- **Use a set of kinematical cuts to reduce SM backgrounds and plot some kinematical variable that shows a deviation from SM previsions;**
- **Backgrounds:**

  - Real missing energy from SM processes with hard neutrino (tt, W+jets, Z+jets events);

  - Fake missing energy or lepton from the detector;

  A good understanding of both SM physics and detector (missing energy expecially) critical to claim excess over SM predictions.

1 fb-1: Search Strategy

1. Inclusive searches

- Check any deviations from SM predictions already at low statistics (i.e. low L_{int});
- Try to define SUSY mass scale $M_{eff} \sim \min(\tilde{g}, \tilde{q})$;

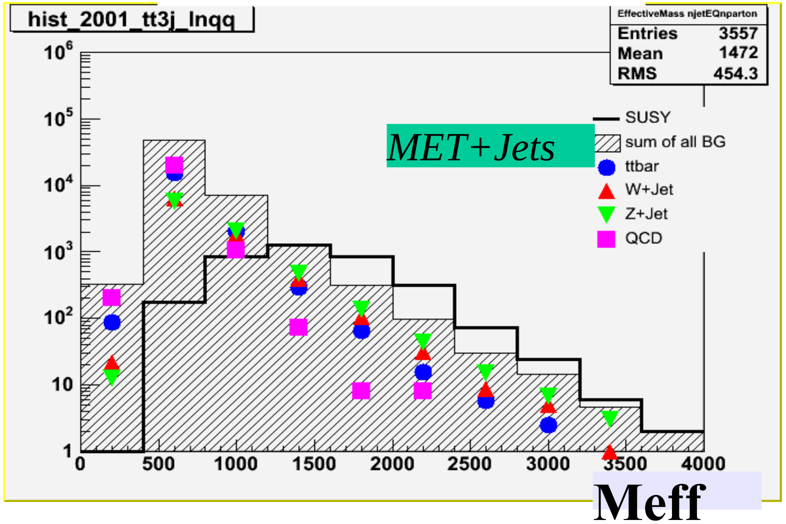
Counting like experiments.

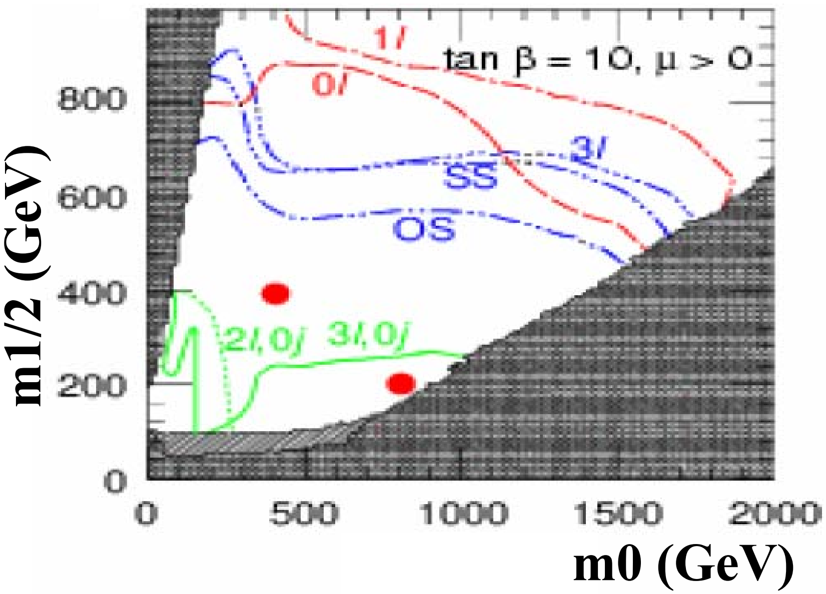
Watching for S/√B ratio.

Uncertainties are very important.

Difficult to constrain model parameters.

$M_{eff} = MET + \Sigma P_T^j$

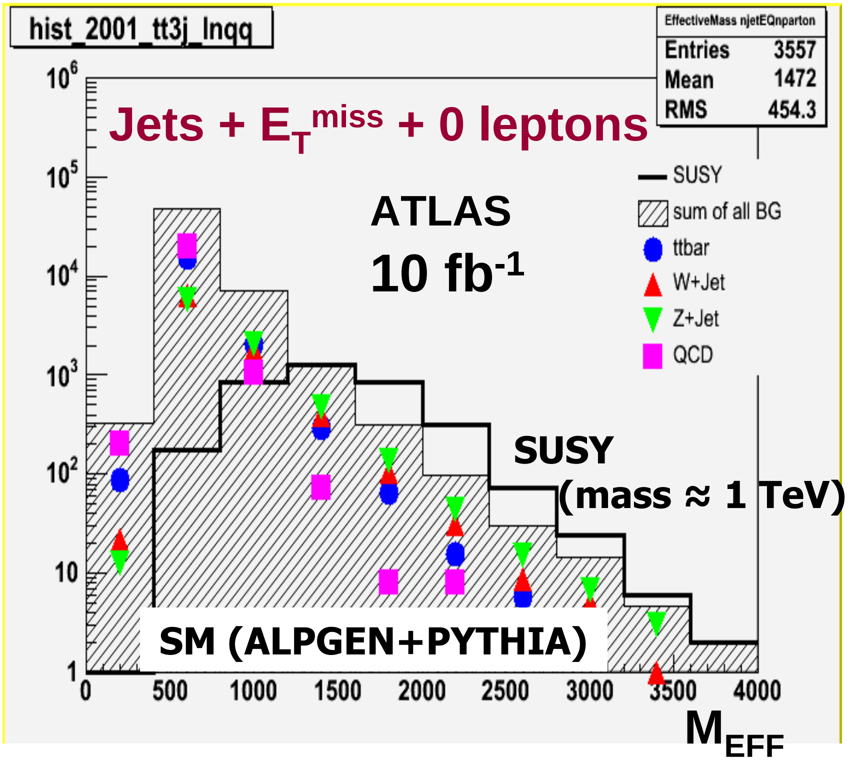




Example 1: 0 leptons channel

Effective Mass: $M_{eff} = \Sigma|p_T^i| + E_T^{miss}$.

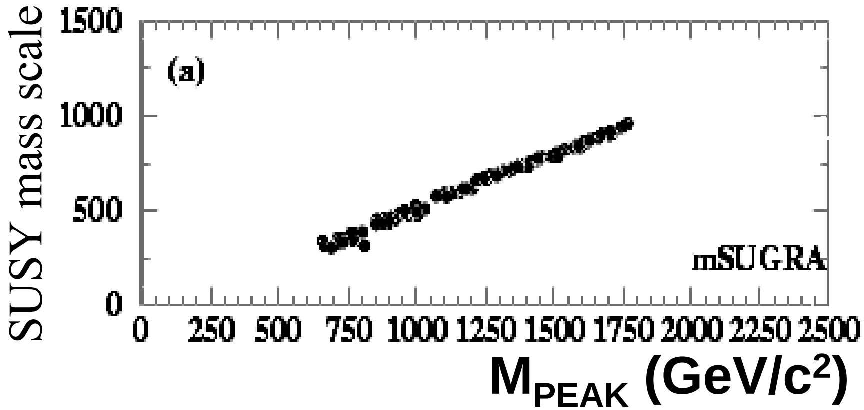
- Useful kinematical variable to discriminate SUSY from SM;
- tt dominates background, but QCD (jets from quarks and gluons, except tt) can strongly contribute.



SUSY selection cuts used in the pictures:

- 1 jet with p_T >100 GeV, 4 jets with p_T>50 GeV
- E^T_{MISS} > 100 GeV
- Transverse sfericity S_T>0.2
- No isolated muon or electron with p_T>20 GeV

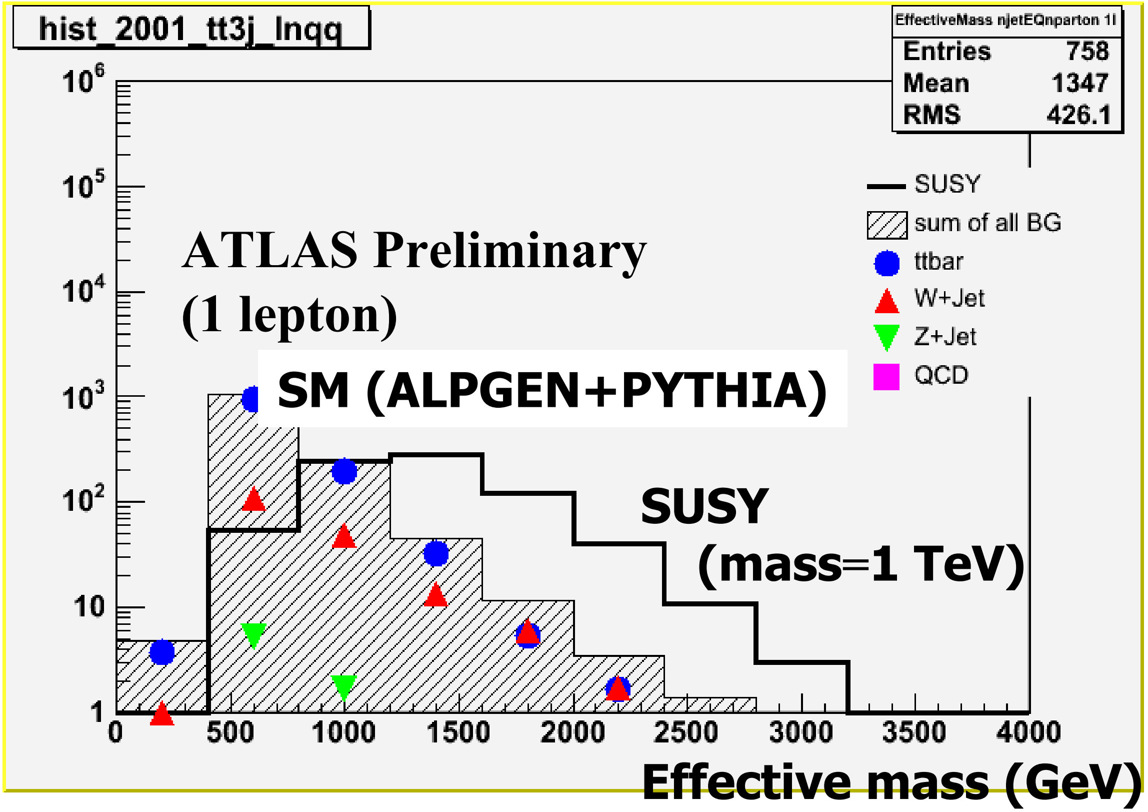
- The maximum is strongly correlated (in mSUGRA) with mass scale of the s-particles produced in pp collisions;



Example 2: 1 lepton channel

1-lepton channel more promising than 0-lepton

- Background decreases more than signal;
- Dominant background is top more controllable than QCD jets (see later).
- Moreover, top background is possible to estimate from data.

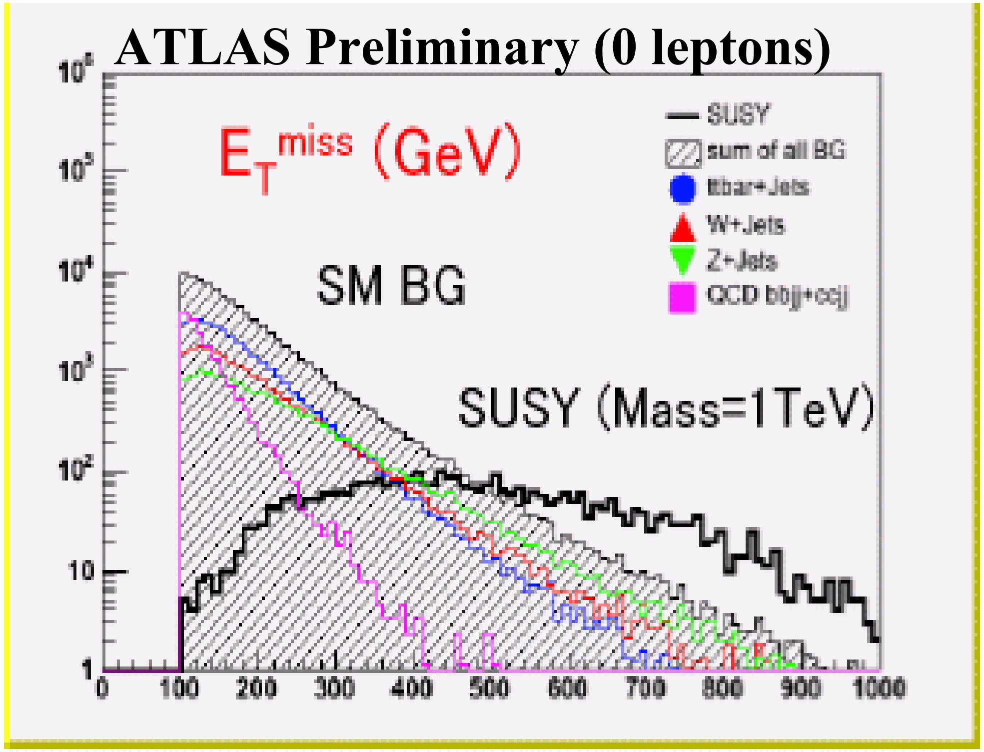


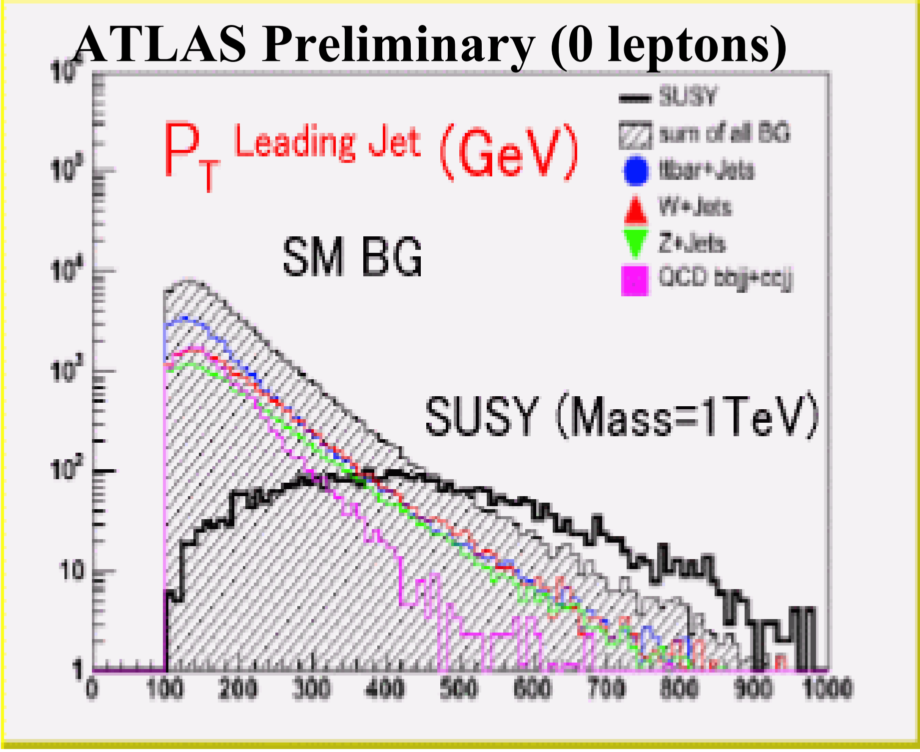
SUSY selection cuts used in the pictures:

- 1 jet with p_T >100 GeV, 4 jets with p_T>50 GeV
- E^T_{MISS} > 100 GeV
- Transverse sfericity S_T>0.2
- 1 isolated muon or electron with p_T>10 GeV

E_T^{MISS} & JETS

- Unexpected additional jets could appear from QCD processes, but not missing energy in background process: **importance of missing energy crucial.**

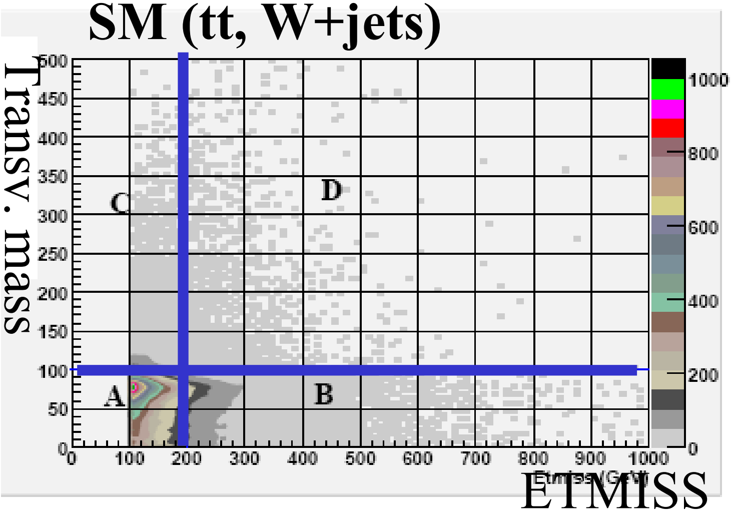




Background estimation from data

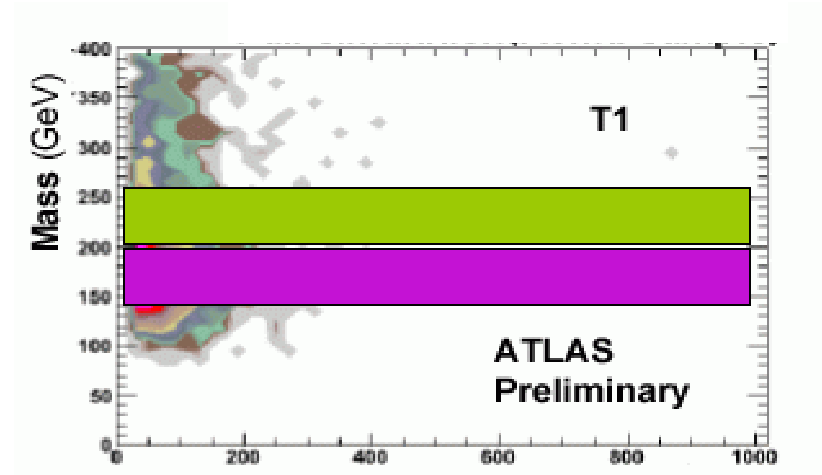
1) Z+jets: big contribution from Z → νν;
One can use Z →ee, apply same cuts as analysis, substitute $E^T(ee)$ with E^T_{MISS} and rescaled by BRs.

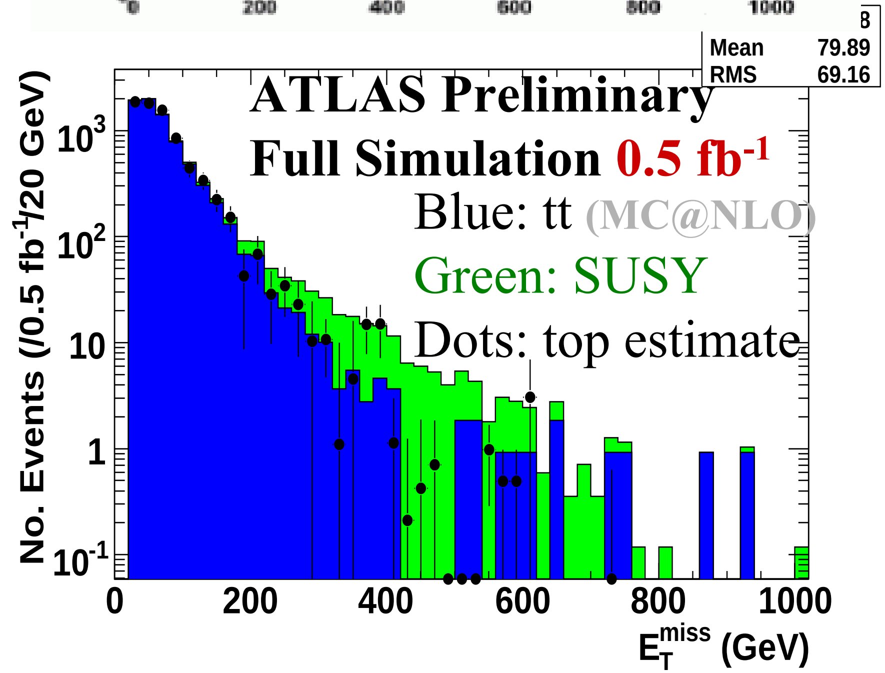
2) Choose 2 uncorrelated variables (ex. E^T_{MISS} and $M_{TRANSV.}(\ell\nu)$); SUSY lying in D region; the shape of E^T_{MISS} distribution is measured in A,B regions, then normalized such that the integral of the distribution in A and C regions are the same.
This then allow an estimation of background level in D region, where the signal is dominant.



Background estimation from data (2)

- Top mass reasonably uncorrelated with E^{T}_{MISS} ;
- Select events with m(lj) in top window (with W mass constraint – **no b-tag used**). Estimate combinatorial background with sideband subtraction.
- Normalize to low E^{T}_{Miss} region (where SUSY small)
- **Procedure gives estimate consistent with top distribution also when SUSY is present**





Background from detector

- Jet resolution not critical for SUSY searches, **non-gaussian tails** are much more critical
  - Can **map badly behaving cells** (ϕ symmetry, Z+jets balance, …);
  - **Avoid problematic regions** (events with jet in crack);
  - **Veto events** with E^{T}_{MISS} vector along a jet;
  - Jet cross section very large, problems from a very small fraction of events in tails that are difficult to simulate with enough statistics in order to estimate their effects;
- Light Jets misidentified as leptons can contribute to 1-lepton channel background
- Lepton efficiency less critical
  - But reduces significance of 1-lepton channel if low
  - Also 3-lepton channel may be promising for discovery
  - Must be understood for reconstruction of specific decays (see di-lepton channel later…)

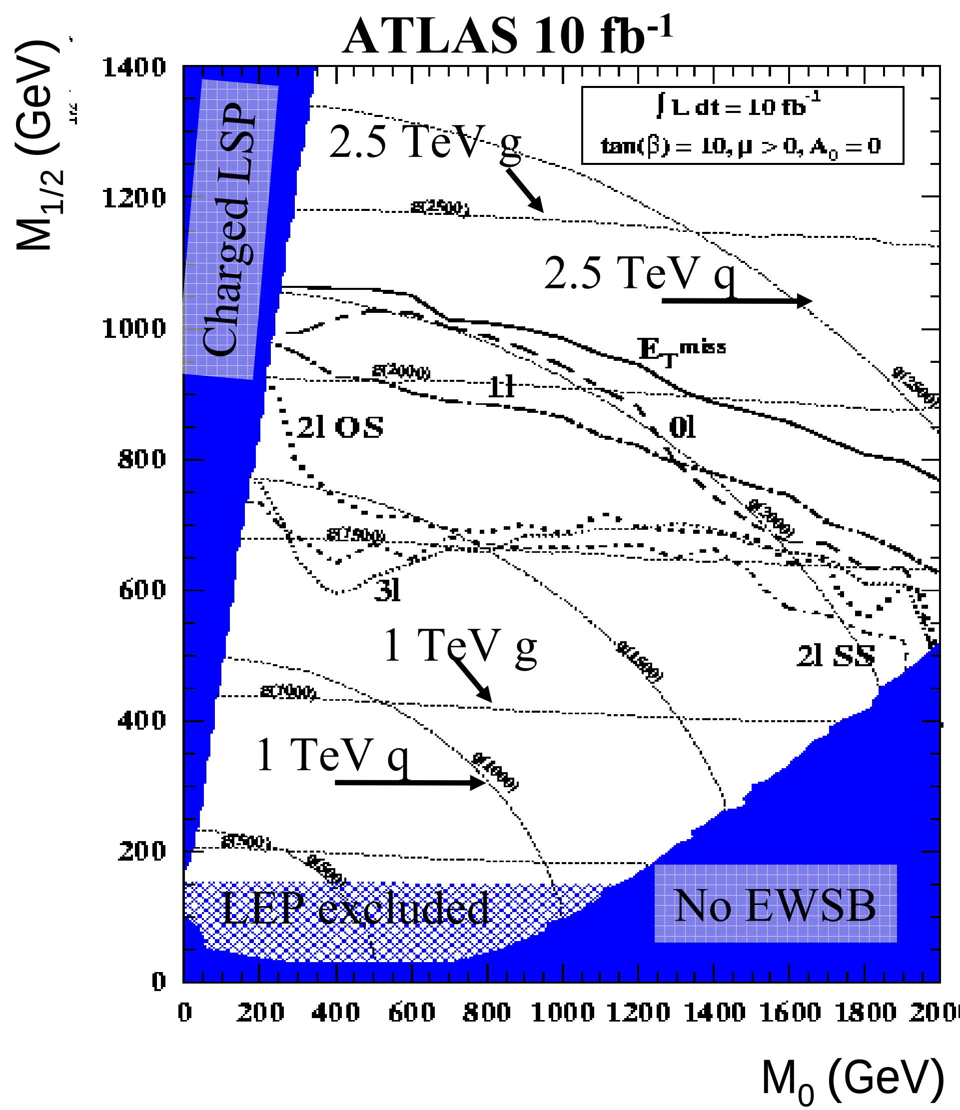
LHC discovery reach

• **LHC discovery potential** for Supersymmetry **well documented** since several years

• **1 fb^{-1} of data already allows discovery if squark or gluino mass < 1.5 TeV** (as it should, because of naturalness).

• Those studies assumed a **perfectly known SM physics** (only stat. errors on background rate) and **ideal detector** (nominal asymptotic performance).

• SUSY discovery likely to depend not on statistic but on the **understanding of SM physics background and detector systematic** with early data.



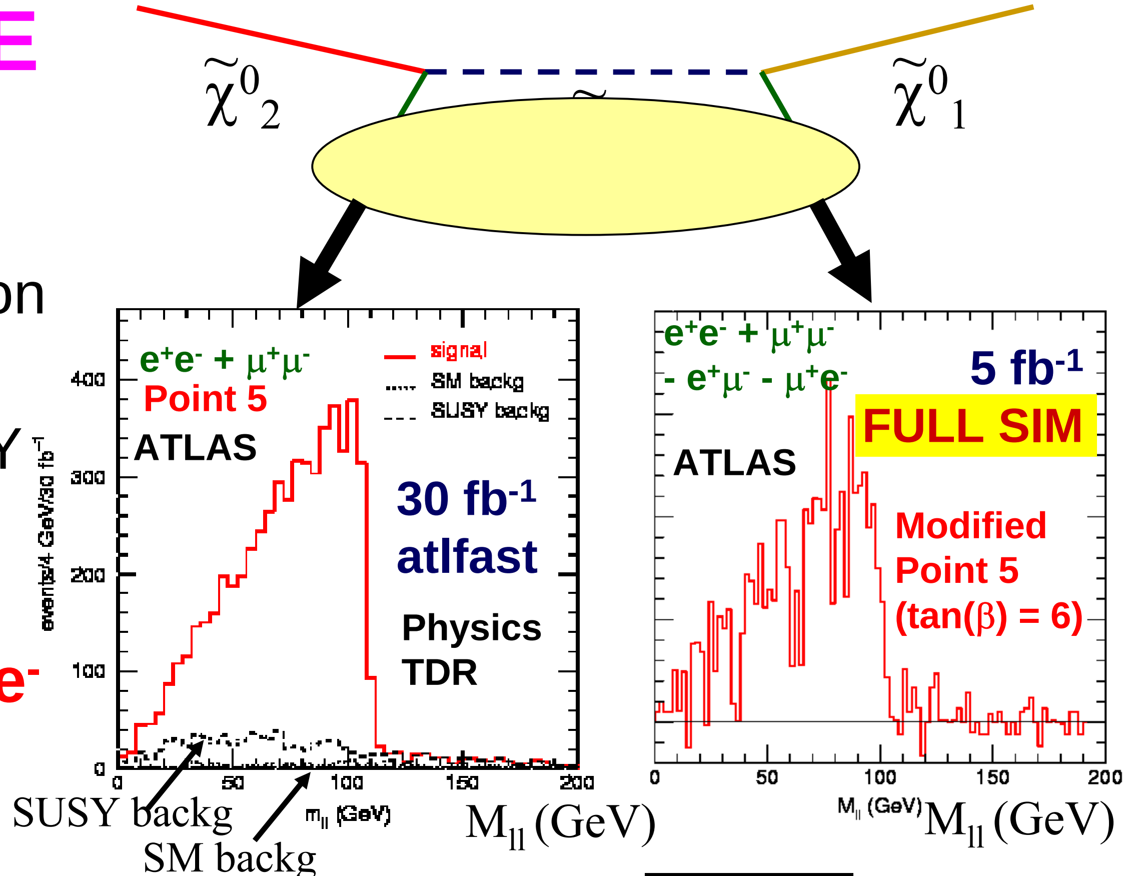
SUSY EXCLUSIVE SEARCHES

DILEPTON EDGE

- Clear signature, easy to trigger: starting point of many mass reconstruction analyses.
- Can perform SM & SUSY background subtraction using OF distribution

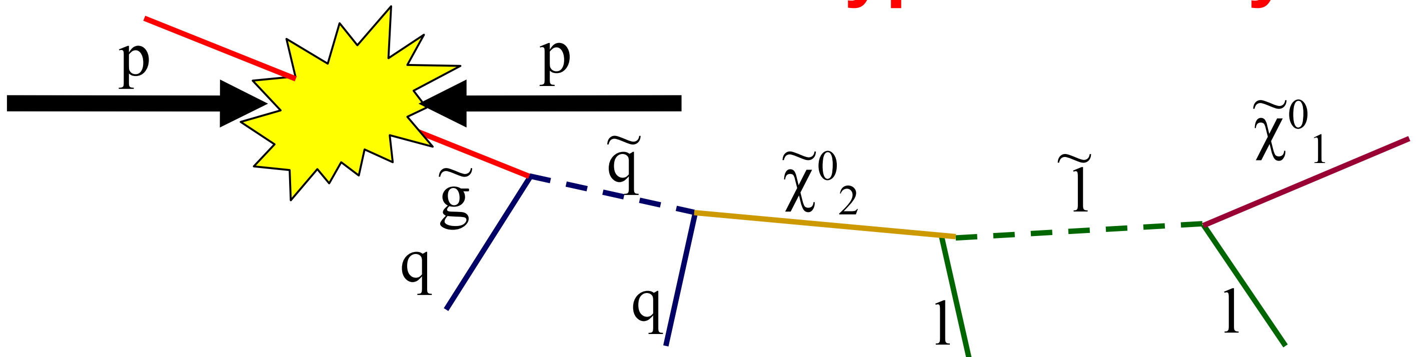
$e^+e^- + \mu^+\mu^- - e^+\mu^- - \mu^+e^-$

- Position of edge (LHC Point 5) measured with precision ~ 0.5% (30 fb^{-1}).



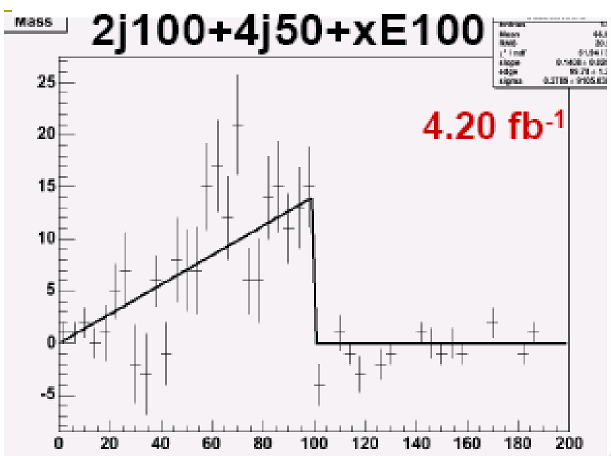
$$M_{ll}^{max} = M(\tilde\chi_2^0)\sqrt{1-\frac{M^2(\tilde l_R)}{M^2(\tilde\chi_2^0)}}\sqrt{1-\frac{M^2(\tilde\chi_1^0)}{M^2(\tilde l_R)}} = 108.93\ \mathrm{GeV}$$

Mass Reconstruction: Typical decay channel

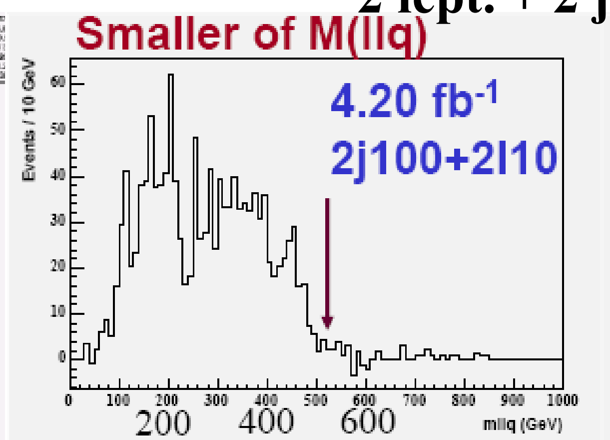


The invariant mass of each combination has a minimum or a maximum which provides one constraint on the masses of $\chi^0{}_1$ $\chi^0{}_2$ l q

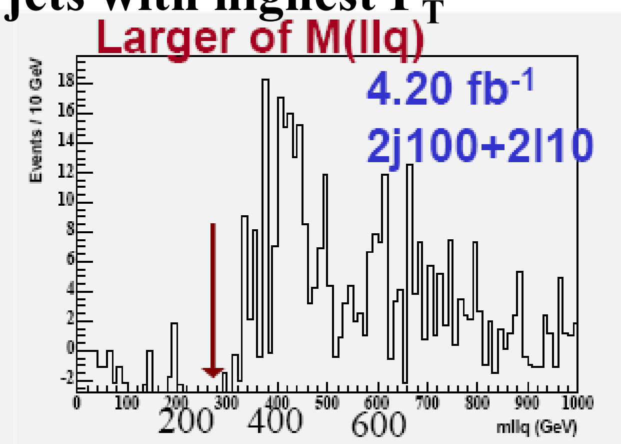
2 lept. + 2 jets with highest P_T



Edge after cuts: 99.8 ± 1.2 GeV



M_{llq}^{max} =501 GeV



M_{llq}^{min} =271 GeV

$$M_{ll}^{max} = M(\tilde\chi_2^0)\sqrt{1-\frac{M^2(\tilde l_R)}{M^2(\tilde\chi_2^0)}}\sqrt{1-\frac{M^2(\tilde\chi_1^0)}{M^2(\tilde l_R)}}$$

$$M_{llq}^{max} = \left[\frac{(M^2_{\tilde q_L}-M^2_{\tilde\chi_2^0})(M^2_{\tilde\chi_2^0}-M^2_{\tilde\chi_1^0})}{M^2_{\tilde\chi_2^0}}\right]^{1/2}$$

$$(m_{llq}^{min})^2 = \left\{ \begin{array}{l} [\ 2\tilde l(\tilde q-\tilde\xi)(\tilde\xi-\tilde\chi)+(\tilde q+\tilde\xi)(\tilde\xi-\tilde l)(\tilde l-\tilde\chi) \\ -(\tilde q-\tilde\xi)\sqrt{(\tilde\xi+\tilde l)^2(\tilde l+\tilde\chi)^2-16\tilde\xi\tilde l^2\tilde\chi}\ \ ]/(4\tilde l\tilde\xi) \end{array}\right.$$

Formulas in Allanach et al., hep-ph/0007009

GMSB scenario

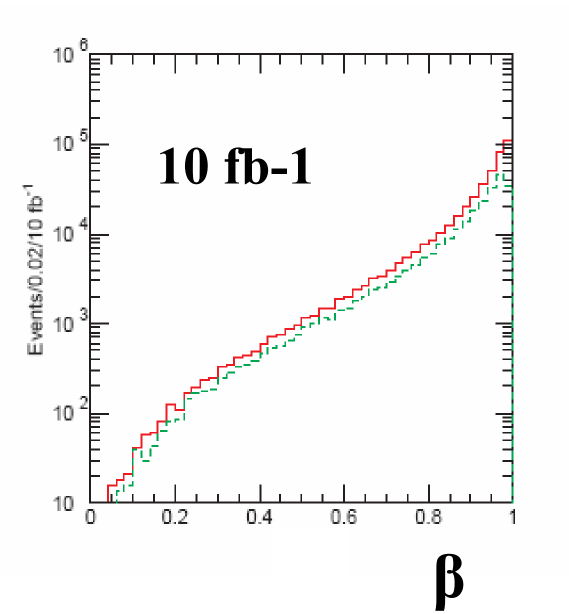
In gauge mediated supersymmetry breaking models, the lightest SUSY particle is the **gravitino**.
Phenomenology depends on nature and lifetime of the second lightest state (NLSP):

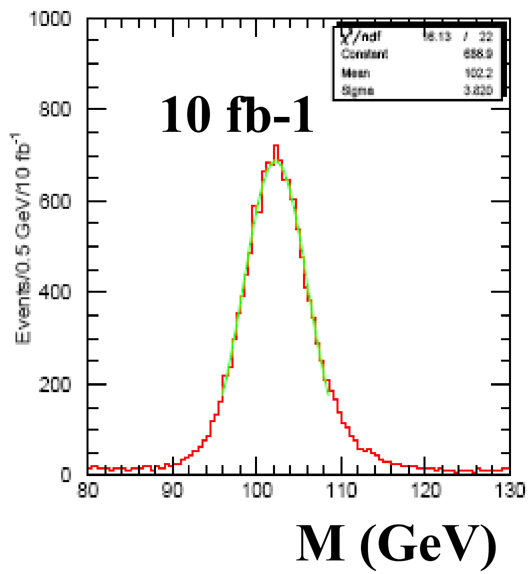
	$\tilde{\tau}$ **is NLSP**	$\tilde{\chi}_1$ **is NLSP**
$c\tau \gg L$	**Like an heavy μ**	**Like mSUGRA**
$c\tau \approx L$	**NLSP decays in the detector, lifetimes measurements.**	
$c\tau \ll L$	Decays into 2 τ	Decays into 2 γ

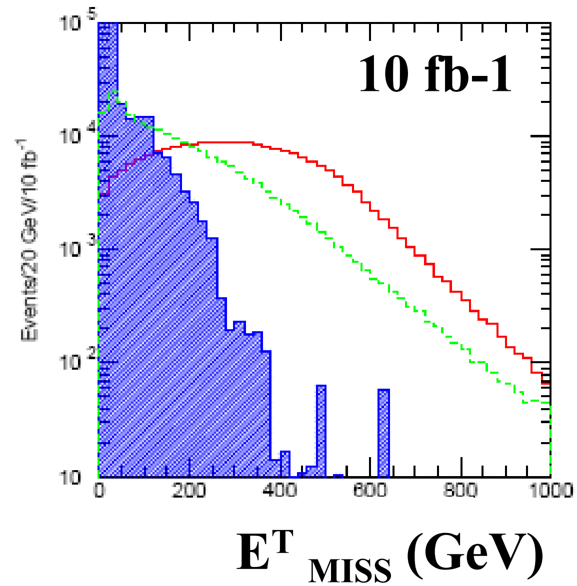
- **τ trigger and reconstruction** in early data not trivial
- **Decay into 2γ promising** (good ECAL performance early enough?)
- **Lifetime measurements**: need to understand **vertexing** in early data
  - For longer lifetimes, need to understand **background:**
    - Hard radiation from high-p_T cosmic muons
    - Delayed hadronic showers (K^0_L and neutrons)

GMSB Performances

- Heavy slow "stable" leptons can be tagged with Time-Of-Flight measurements in muon drift tubes.
- Large calorimetric E^T_{MISS} due to quasi-stable leptons, like in mSUGRA.
- Timing/triggering issues most critical?







Summary

- **After understanding the SM at LHC energy, can start searching for SUSY.**

- **Main signal signature: *MET +high PT jets + leptons* can be distinguished from the SM channels (ttbar, wjets, zjets, QCD)**

- **LHC is expected to see mSUGRA sparticles production up to 2 TeV range at $L_{int} \leq 10$ fb^{-1} in inclusive searches.**
  The lower mass region < 1000 GeV can be early seen at $L_{int} < 1$ fb^{-1} .

- **GMSB models are also studied at LHC, and their signatures are very peculiar to be detected (2 photons or long lived sleptons) with few fb^{-1} .**

- **The identification of mSUGRA topologies will be possible already in inclusive searches and the model parameters can be precisely reconstructed in exclusive channels using kinematic end points at $L_{int} > 30$ fb^{-1} for low mass region.**