Study of Final States with τ - Leptons in GMSB Models at ATLAS

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May 21st 2008

Studentseminar

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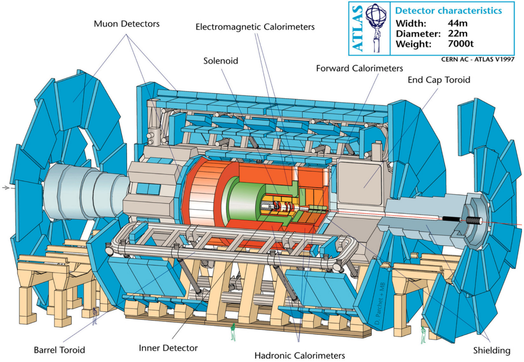
Outline

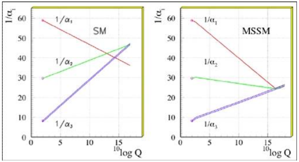
1. Introduction to SUSY and GMSB
2. The ATLAS Detector
3. Tau Identification
4. Discovery Potential
5. SUSY mass determination
6. Conclusion



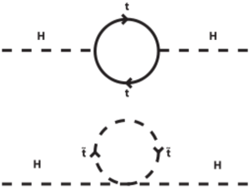
Motivation for SUSY

- Standard Model very successful - but incomplete
- SUSY - promising extension

- explanation for Dark Matter



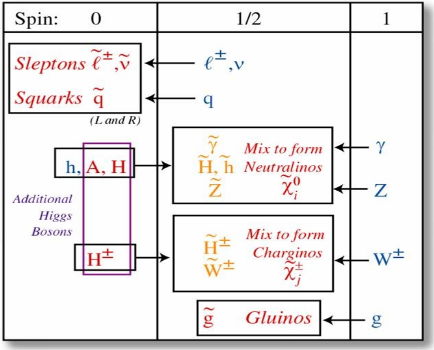
- for low-mass supersymmetric particles: unification of the coupling constants at the GUT scale $\approx 10^{16}$ GeV



- solution to the Hierarchy Problem of the Higgs mass

Supersymmetry

- Supersymmetry establishes a symmetry between fermions and bosons
- to every fermion there is a boson with the same charge, mass, interactions but **different spin**

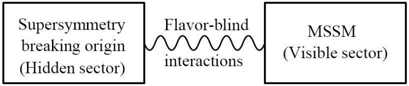


- 2 Higgs doublets necessary
  $\Rightarrow$ 5 Higgs bosons
- supersymmetry is not exact
  $\Rightarrow$ supersymmetry is broken
  $\Rightarrow M_{SUSY} > M_{SM}$
- additional multiplicative quantum number R-parity:
  $R = (-1)^{2S+3(B-L)}$
  $R_{SM} = 1$ vs. $R_{SUSY} = -1$
- R-parity conservation
  $\Rightarrow$ production of 2 SUSY particles at particle colliders
  $\Rightarrow$ Lightest SUSY Particle (LSP) is stable
- also R-parity violating models

SUSY Breaking

- Breaking mechanisms:
  - mSUGRA (minimal SUperGRAvity)
  - **GMSB** (Gauge Mediated Supersymmetry Breaking)
  - AMSB (Anomaly Supersymmetry Breaking)
- reduction to a few parameters
- sufficient for
  - mass spectra
  - physical processes (branching ratios, cross sections)

GMSB

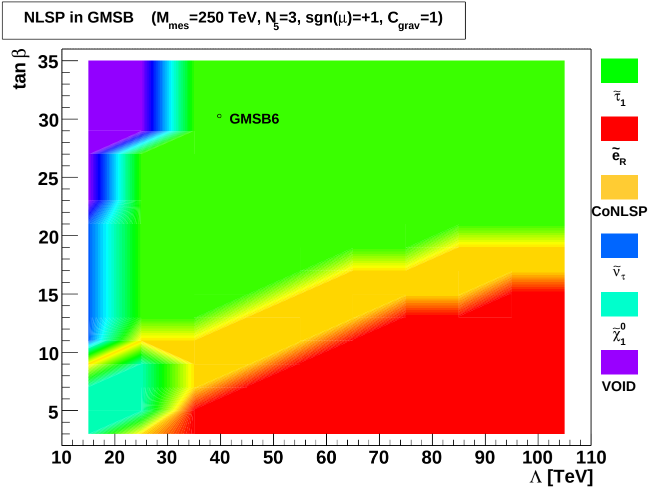


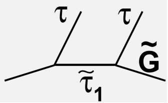
- breaking: in hidden sector and transmitted to visible MSSM fields through messenger sector via SM gauge interactions
- coupling of messenger particles gives mass to the super partners of the gauge bosons, quarks and leptons
- in presented analysis - assumption: R-Parity conservation

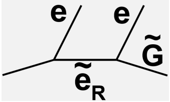
GMSB Parameters

- Λ - the SUSY breaking mass scale
  - determines predominantly the masses of the SUSY particles
- $\mathrm{M_{mes}}$ - mass of messenger particles
- $\mathrm{N_5}$ - number of equivalent messenger fields
  - complete representatives of SU(5)
  - masses of gauginos and sleptons/ squarks scale differently in $\mathrm{N_5}$
    $\Rightarrow \mathrm{N_5} = 1$ NLSP: $\tilde{\chi}^0_1$, $\tilde{\tau}_1$
    $\mathrm{N_5} = 3$ NLSP: $\tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_1$
  - NLSP also depends on tanβ
- tanβ - ratio of vacuum expectiation values of the two Higgs fields
- sgnμ - sign of the Higgsino mass term
- $\mathrm{C_{grav}}$ - scale factor for the gravitino mass
  - determines the NLSP lifetime

- LSP (Lightest Supersymmetric Particle)
  - nearly massless, neutral Gravitino $m(\tilde{G}) = \mathcal{O}(\mathrm{eV})$
- NLSP (Next-to-Lightest Supersymmetric Particle)
  - determines phenomenology



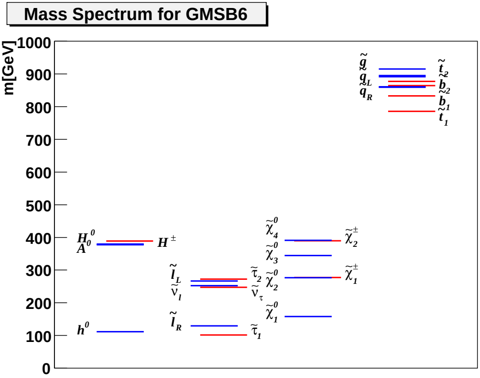




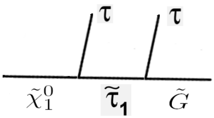
GMSB 6:
$\Lambda = 40$ TeV
$\tan\beta = 30$
$M_{mes} = 250$ TeV
$N_5 = 3$

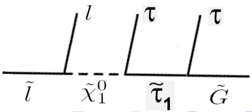
GMSB 6

$(\Lambda = 40\,\mathrm{TeV}, \tan\beta = 30\,, \mathrm{M_{mes}} = 250\,\mathrm{TeV}, \mathrm{N_5} = 3\,)$



- NLSP: $\tilde{\tau}_1$
  - $\mathrm{BR}(\tilde{\tau}_1 \rightarrow \tau\tilde{\mathrm{G}}) = 100\,\%$
  - all particels decay into $\tilde{\tau}_1$ eventually
- originates predominantly from $\tilde{\chi}_1^0$ and $\tilde{\mathrm{e}}_\mathrm{R}, \tilde{\mu}_\mathrm{R}$
- decay of
  - $\tilde{\chi}_1^0$ 2 body decay
  - $\tilde{\mathrm{e}}_\mathrm{R}, \tilde{\mu}_\mathrm{R}$ 3 body decay

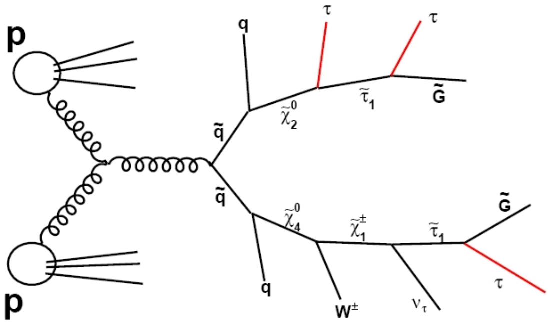




GMSB 6

$(\Lambda = 40\,\mathrm{TeV}, \tan\beta = 30\,, \mathrm{M_{mes}} = 250\,\mathrm{TeV}, \mathrm{N_5} = 3\,)$

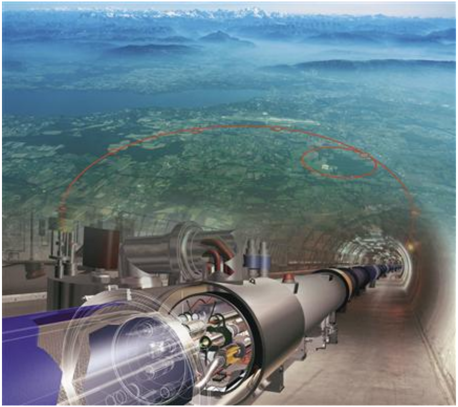
Possible decay chain at a pp-Collider



- production of squark pairs or gluinos via strong interactions
- final state: up to 4τ
- neutral gravitinos behave similar to neutrinos in a detector
  $\Rightarrow$ no interaction - cause missing transverse energy (MET)

$\Rightarrow$ unusual in SM processes

The LHC



The LHC at CERN

- pp-Collider at 14 TeV
- 27 km ring of superconducting magnets
- design luminosity: $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (up to 10^{11} protons in one bunch)
- bunch crossing rate: 40 MHz
- collision at four locations around the accelerator ring
  - ATLAS and CMS (general-purpose detectors)
  - ALICE and LHCb (specialised detectors)
- also collision of heavy ions

ATLAS - A Toroidal LHC ApparatuS

Physics

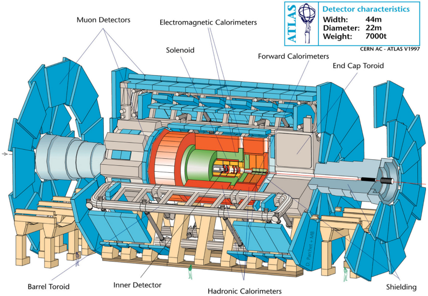
- more precise measurement of SM: EW interactions, QCD, Top, ...
- search for new physics phenomena: Higgs, SUSY, ...

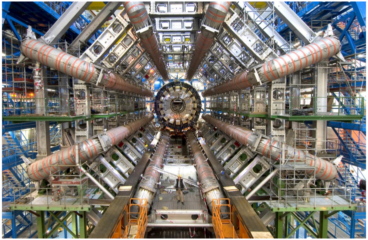
Components

- general design: barrel plus end caps
- inner tracker (yellow)
- calorimeter (orange and green)
- muon spectrometer (blue)
- magnet system (grey)

People

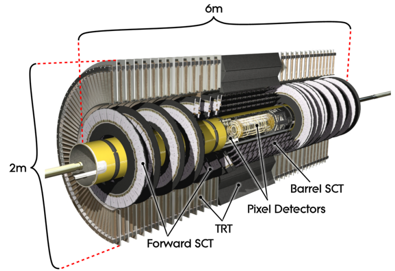
- 2700 scientists
- 37 countries
- 167 universities and labs

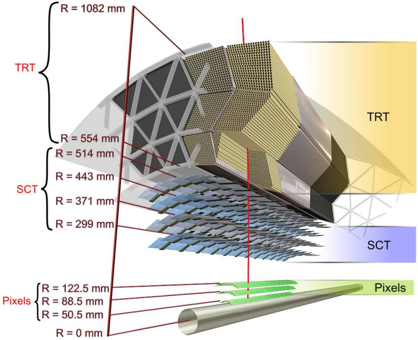




Innerdetector

- measurement of particle momentum, primary and secondary vertex
- 2 T magnet field
- **Pixel Tracker**
  - 3 layers
  - accuracy: 10 μm in $R - \phi$, 115 μm in z, R
  - $|\eta| < 2.5$
- **Silicon Microstrip Tracker** (SCT)
  - 4 double layers
  - 17 μm in $R - \phi$, 580 μm in z, R
  - $|\eta| < 2.5$
- **Transition Radiation Tracker** (TRT)
  - gaseous straw tubes
  - 130 μm in $R - \phi$
  - $|\eta| < 2.0$
  - electron identification





Electromagnetic Calorimeter ($|\eta| < 3.2$)

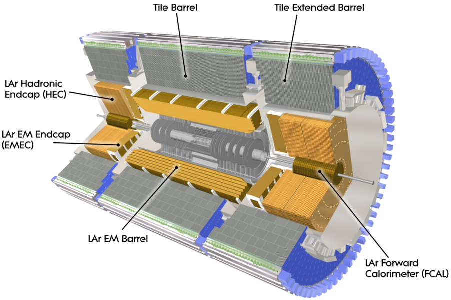
- precision measurements of $e^{\pm}, \gamma$
- lead-LAr detector
- accordion-shaped
  $\Rightarrow$ complete ϕ coverage

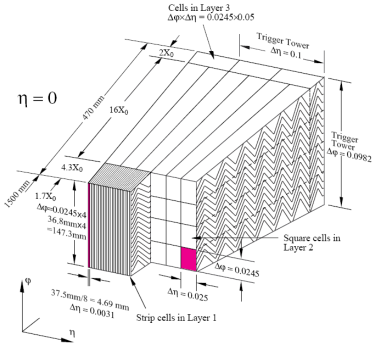
Hadronic Calorimeters ($|\eta| < 3.2$)

- jet reconstruction and $\not{E}_T$ measurements
- Tile Calorimeter
  - absorber: steel
  - active material: scintillating tiles
- LAr hadronic end-cap Calorimeter
  - with LAr gaps interleaved copper plates

LAr forward Calorimeter

- 1 module: copper for electromagnetic measurements
- 2 modules: tungsten for energy measurement of hadronic interactions
- $3.1 < |\eta| < 4.9$





Tau Decay

Decay modes for the τ-Lepton

leptonic	**(35.2 %)**
$\tau \longrightarrow e + \nu_e + \nu_\tau$	
$\tau \longrightarrow \mu + \nu_\mu + \nu_\tau$	
hadronic	
1 Prong	**(46.8 %)**
$\tau \longrightarrow \pi^\pm + \nu_\tau$	
$\tau \longrightarrow \pi^\pm + n \cdot \pi^0 + \nu_\tau$	
3 Prong	**(13.9 %)**
$\tau \longrightarrow \pi^\pm + \pi^\pm + \pi^\pm + \nu_\tau$	
$\tau \longrightarrow \pi^\pm + \pi^\pm + \pi^\pm + n \cdot \pi^0 + \nu_\tau$	
other	**(4.1 %)**

Issues for reconstruction

- not a unique signature
- reconstruction of hadronic decay modes only
  - difficult to distinguish leptonic decay modes from primary $e^\pm, \mu^\pm$
  - leptonic decay also leads to another neutrino
    $\Rightarrow$ loss of p_T information
- structure: tracks, energy from neutral objects
- distinction from QCD jets
  - based on low track multiplicity
  - in a narrow cone
  - characteristics of track system
  - shapes of calorimeter showers

General Ideas for τ - Reconstruction

Tracker

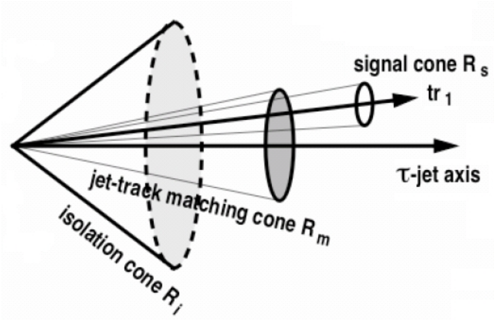
- Inner Detector provides track information, e.g. also charge of track(s)
- tracks should
  - not match track segments in muon spectrometer
  - not look like electron tracks
  - be well collimated in η, ϕ
  - have an invariant mass below τ mass

Calorimeter

- Calorimeter provides energy information
- narrow shower in EM Calorimeter
- calorimetric cluster should be isolated from rest of event

The calorimeter based algorithm

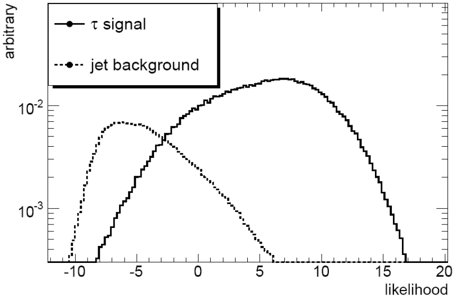
- Seed: calorimeter cluster with $E_T > 15\,\mathrm{GeV}$
- direction of the τ-jet is defined by axis of calorimeter jet
- tracks in matching cone of radius $R_m = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$ are considered
- tracks have to fulfill certain selection criteria, e.g. $p_T > 1\,\mathrm{GeV}$
- track with the highest p_T is defined as leading track (tr_1)
- no tracks with $p_T > p_{T_i}$ allowed inside a larger cone R_i



$\Rightarrow$ **τ-candidate**

Likelihood

- Final identification using a likelihood function
- if likelihood $> l_{cut}$
  $\Rightarrow$ candidate is accepted as τ
- typical $l_{cut} = 4$

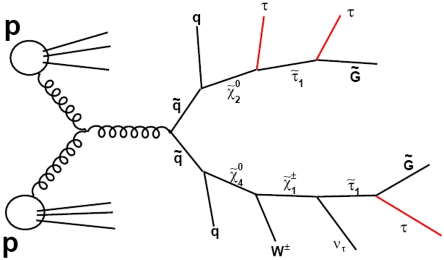


The 8 Likelihood variables are:

- Number of associated tracks (limited to be within [1,3])
- Radius of the cluster in the EM calorimeter
- Isolation: fraction of E_T between $0.1 < \Delta R < 0.2$ around the cluster center
- Number of hits in the η-strip with $E_T > 200\,\text{MeV}$
- Width of the profile in the η-strip
- τ electric charge
- lifetime signed impact parameter (2D) of the leading track
- E_T/p_{T1} - ratio of E_T of τ candidate to p_T of leading track

Analysis of a GMSB Model with a $\tilde{\tau}_1$ NLSP

- Characteristics:
  - many τ-Leptons
  - many jets
  - much missing transverse energy

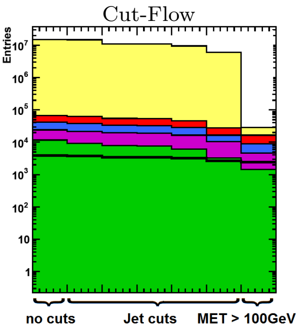


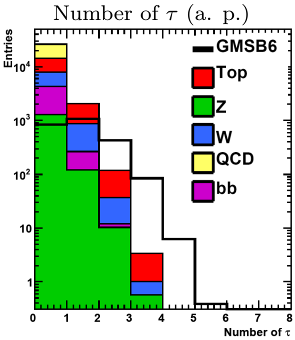
- Preselection to reduce QCD background
- look at the typical features of this GMSB Model
- find out significant cuts
- calculate invariant mass in order to determine SUSY masses

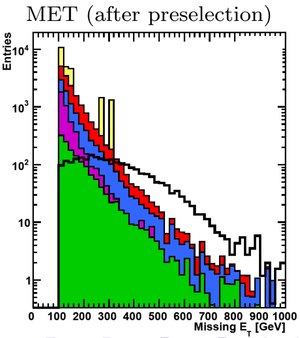
Cuts

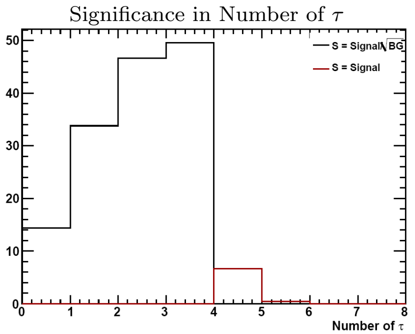
- Preselection cuts:
  - number of jets ≥ 4
  - 1 jet: $p_T > 100\,\text{GeV}$
  - 3 jets: $p_T > 50\,\text{GeV}$
  - $\not{E}_T > 100\,\text{GeV}$

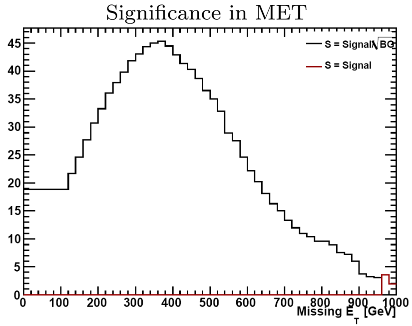
- reconstruction of hadronic τ-decays
- signal dominates in region of many τ and much MET
- $\mathscr{L} = 1\,\text{fb}^{-1}$



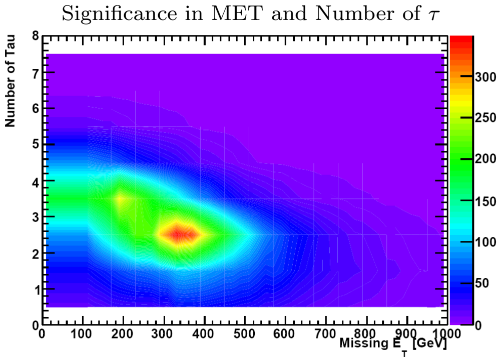








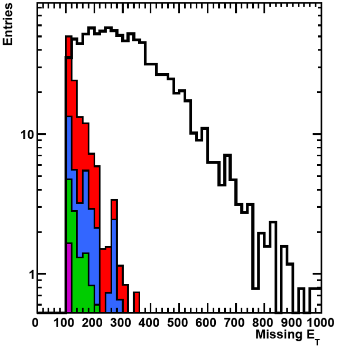
- Significance $\sigma = \frac{\#\text{ of Signal events}}{\sqrt{\#\text{ of BG events}}}$
- rises with number of τ
  (no background events with 4τ)
- maximum in MET at $\approx 300\,\text{GeV}$
- 2dim: max. at 2τ, MET $> 320\,\text{GeV}$



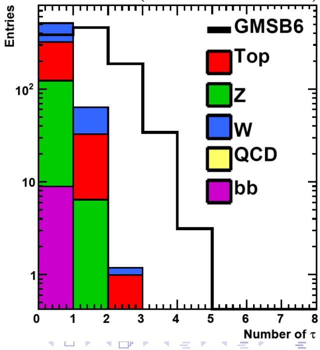
Final Cuts

- Cuts applied one by one
  - MET requiring 2τ
  - number of τ requiring MET $> 320\,\text{GeV}$
- biggest residual background: Top
- very high discovery potential

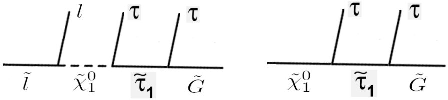
MET (more than 1τ)



Number of τ (MET $> 320\,\text{GeV}$)



SUSY mass determination



- Invariant mass of $2\tau \rightarrow$ mass edge

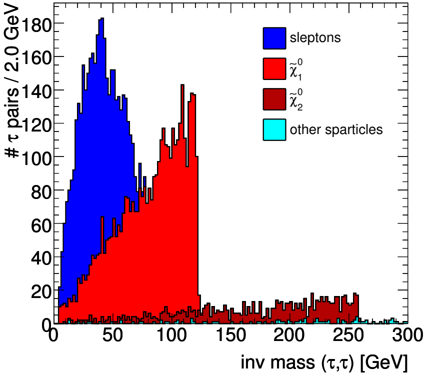
$$M^2_{\tau\tau,\max} = \frac{(m^2_X - m^2_{\tilde{\tau}_1})(m^2_{\tilde{\tau}_1} - m^2_{\tilde{G}})}{m^2_{\tilde{\tau}_1}}$$

$$\overset{m_{\tilde{G}}=2.41\text{eV}}{\Longrightarrow}$$

$$M^2_{\tau\tau,\max} = m^2_X - m^2_{\tilde{\tau}_1}$$

$$M_{\tau\tau,\max} = \sqrt{m^2_{\tilde{\chi}^0_1} - m^2_{\tilde{\tau}_1}} = 121.57\,\text{GeV}$$

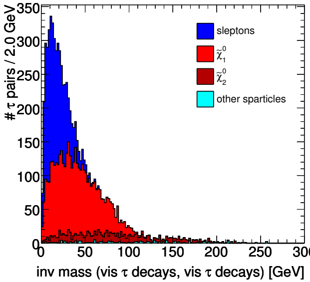
Invariant mass of 2τ (Generator Level)



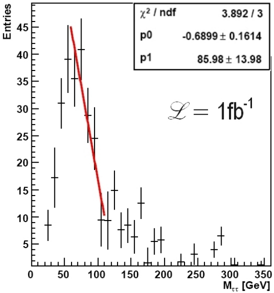
Fit of mass edge

- Distribution smeared out because of neutrinos
- apply analysis cuts
- plot invariant mass of 2τ
- first approximation: linear fit
- very sensitive to fit range
- $M_{\tau\tau,\max} = \frac{85.98\,\text{GeV}}{0.6899} = 124.6\,\text{GeV}$

Visible part of the invariant mass of 2τ (Generator Level)



Invariant mass of 2τ (Reconstruction Level)



Conclusion

- Supersymmetry can provide answers to some open issues
- GMSB - one possible Supersymmetric model
- LHC will start running this summer
- ATLAS and CMS will be able to discover supersymmetry and further beyond the SM physics phenomena if realised in nature
- $\tilde{\tau}_1$ like GMSB Models have high discovery potential in first data because of number of τ and missing transverse energy
- analysis and discovery potential here explicitely shown for GMSB 6 Model