# Supersymmetric tau final states

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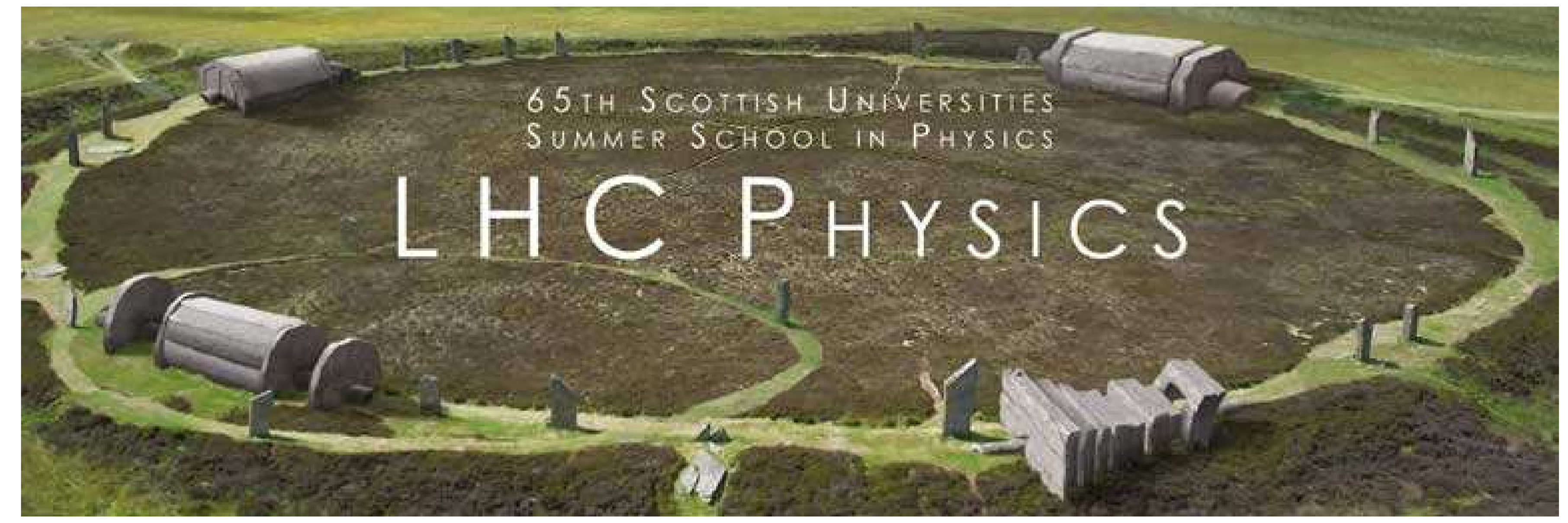
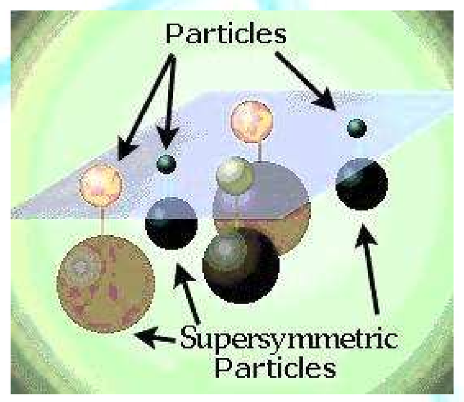



## Introduction

One aim of the LHC is to explore new physics beyond the Standard Model (SM). A very promising theory is Supersymmetry (SUSY):

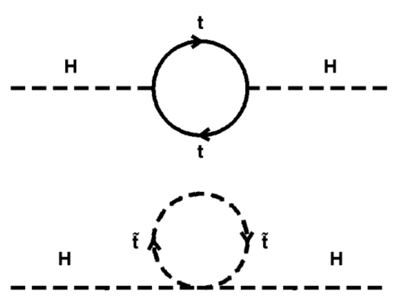
***What is SUSY?***

- Symmetry between fermions and bosons
- Predicts supersymmetric "partner" particle for each SM particle: same mass and quantum number, spin difference 1/2
- Not discovered yet ⇒ SUSY particles must be heavy ⇒ Broken symmetry
- Many models of SUSY breaking: various phenomenologies possible

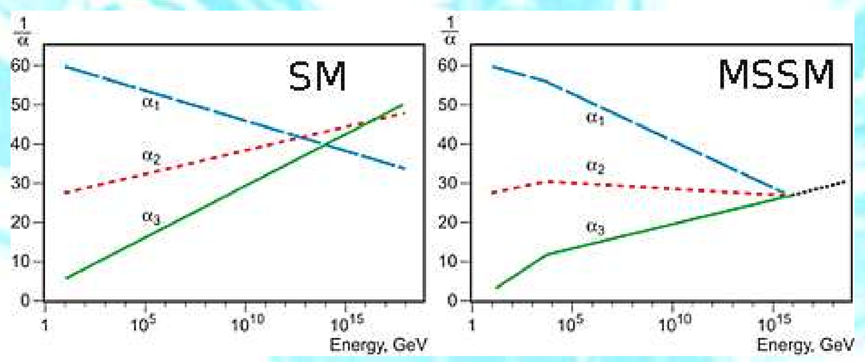



***Why SUSY?***

- SUSY solves major problems of the Standard Model: finetuning, unification of forces at the GUT scale:



*Finetuning: fermionic and bosonic terms cancel exactly*




*Unification: coupling constants meet at GUT scale in MSSM (Minimal Supersymmetric Standard Model)*

- Cold Dark Matter candidate: introduce R-parity $R = (-1)^{3(B-L)+2S}$ conservation to stabilize proton ⇒ lightest SUSY particle (LSP) must be stable

**Phenomenology:** Phenomenology varies strongly with different SUSY models. Focus on R-Parity conservation: heavy SUSY particles are pair-produced, long decay chains to LSP (invisble)
⇒ Spherical events, many jets, leptons and missing transverse energy $E_T^{miss}$
⇒ Easy to see at the LHC: $5\sigma$ deviation from SM possible with $\int Ldt \sim$ few pb$^{-1}$

**Discovery?** Investigation of the properties of new found physics essential to claim SUSY discovery!

- Distinguish from other SM extensions
- Determination of mass edges among the first possible measurements: first step towards SUSY parameters

⇒ Mass edges will play an important role in the distinction of Beyond the Standard Model theories

## The $\tau\tau$ invariant mass spectrum

### The special role of tau leptons

- $3^{rd}$ generation is special in SUSY: mixing of $\tilde{\tau}_L$, $\tilde{\tau}_R$ to $\tilde{\tau}_{1,2}$
  ⇒ $\tilde{\tau}_1$ often lightest slepton: enhanced $\tau$ production
- $m_{\tau\tau}$ endpoint carries information about $\tilde{\tau}$ masses: not accessible otherwise
- Triangular shape lost due to invisible neutrinos from $\tau$ decay
- Tau decay mode separation offers opportunity to measure tau polarization
  ⇒ Information about stau mixing angle [see JHEP04(2009)057]

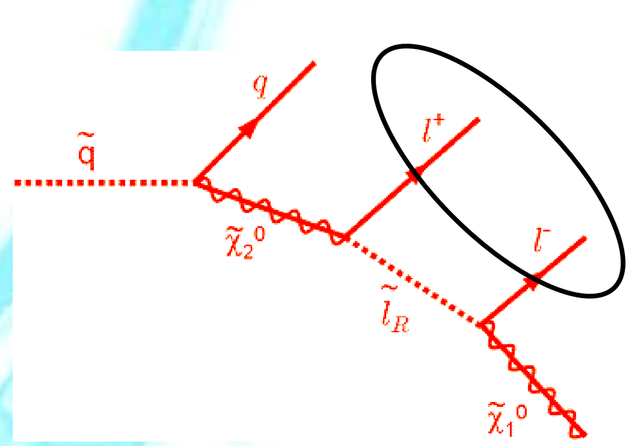
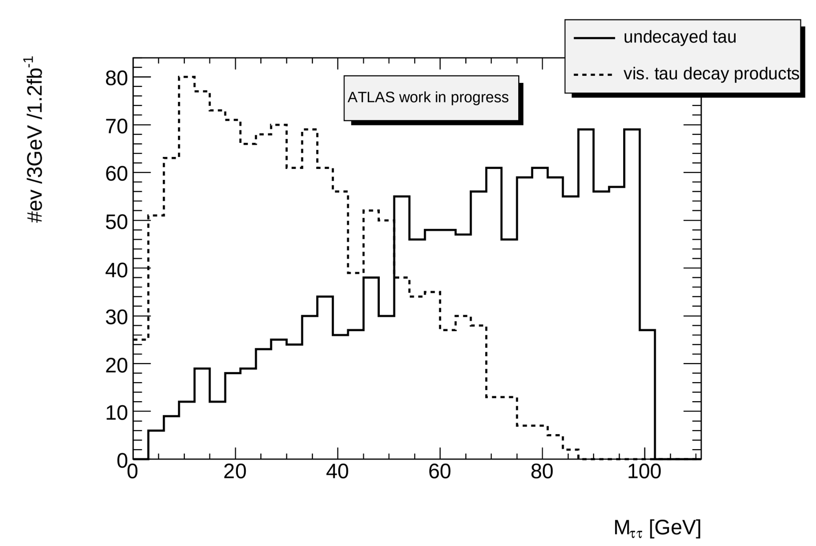




**Figure 1**: *Signal decay and $m_{\tau\tau}$ spectrum of two taus fom $\tilde{\chi}_2^0 \to \tilde{\tau}_{1,2}^{\pm}\tau^{\mp} \to \tilde{\chi}_1^0\tau^{\pm}\tau^{\mp}$, MC truth: undecayed taus (solid) vs. visible decay products (dotted).*

LSP escapes detection ⇒ no mass peaks ⇒ Measure *kinematic edge*:

$$m_{\tau\tau}^{\max} = \sqrt{\frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\tau}_{1,2}}^2)(m_{\tilde{\tau}_{1,2}}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{\tau}_{1,2}}^2}}$$

**Endpoint determination** Current $\tau$ identification algorithms focus on hadronic $\tau$ decays: only 42% of $\tau\tau$ combinations! Contributions from leptonically decaying taus via $e/\mu$ ID and opposite flavour combinations:

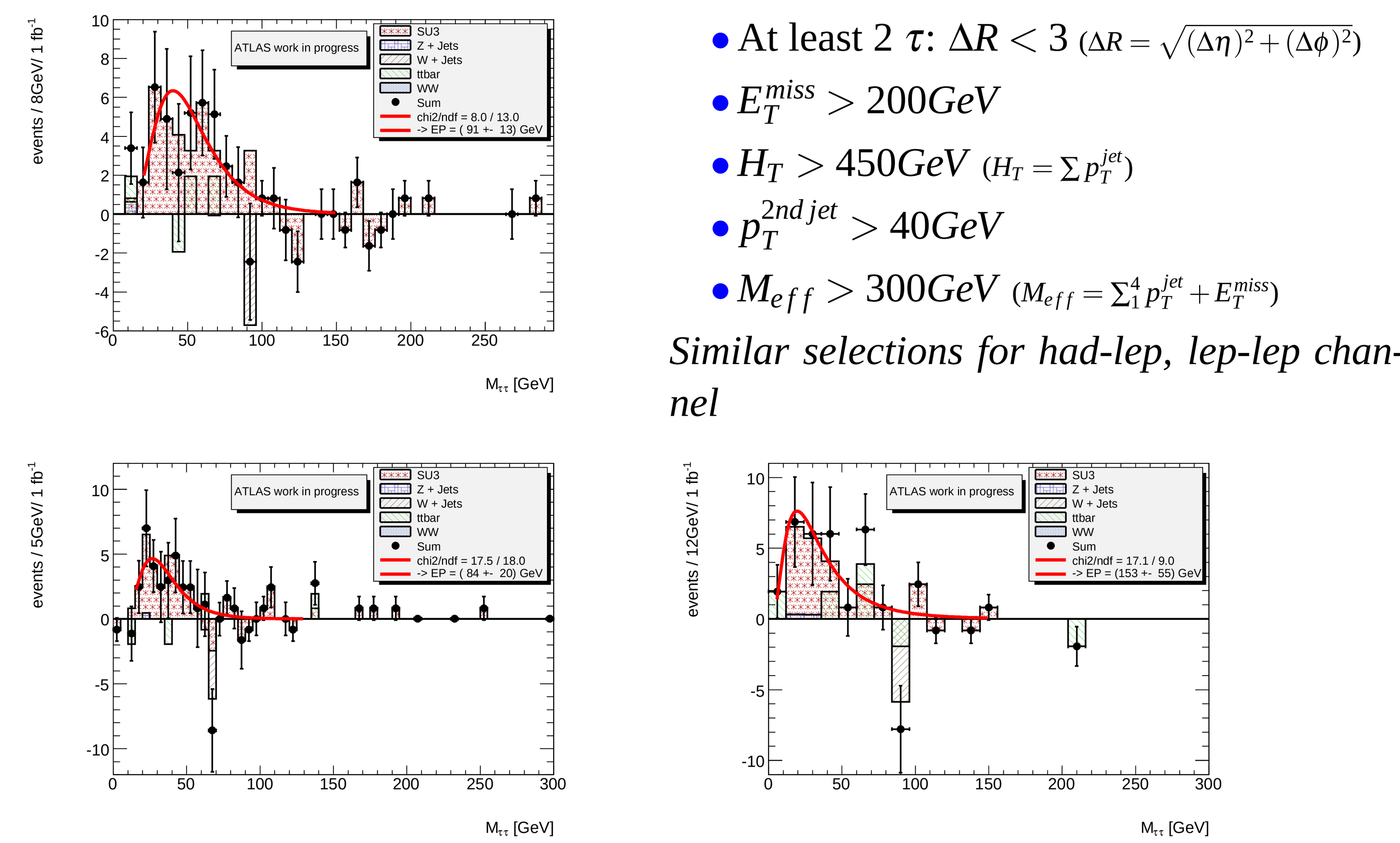
had-had $(\tau^{\pm}\tau^{\mp} - \tau^{\pm}\tau^{\pm})$
had-lep $(\tau^{\pm}\mu^{\mp} + \tau^{\pm}e^{\mp}) - (\tau^{\pm}\mu^{\pm} + \tau^{\pm}e^{\pm})$
lep-lep $(\mu^{\pm}e^{\mp} - \mu^{\pm}e^{\pm})$

Use opposite sign minus same sign subtraction to suppress combinatorical background and fake taus.

No sharp drop-off at maximum value of $m_{\tau\tau}$ spectrum ⇒ Attempt to approximate shape:

- Describe trailing edge with log-normal function
- Use inflection point as measurable trait
- Calibrate with different SUSY masses

Leptonic $\tau$ decays involve additional neutrino
⇒ Peak of spectrum shifted, separate calibrations required




Signal selection (had-had):

- At least 2 $\tau$: $\Delta R < 3$ ($\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$)
- $E_T^{miss} > 200GeV$
- $H_T > 450GeV$ ($H_T = \sum p_T^{jet}$)
- $p_T^{2nd\,jet} > 40GeV$
- $M_{eff} > 300GeV$ ($M_{eff} = \sum_1^4 p_T^{jet} + E_T^{miss}$)

*Similar selections for had-lep, lep-lep channel*

**Figure 2**: *$m_{\tau\tau}$ spectra (had-had, had-lep and lep-lep) for 1fb$^{-1}$ of 10 TeV data (MC): spectrum composition (red: signal, other: SM background) and log-normal fits.*

⇒ 3 independent measurements of the $m_{\tau\tau}$ endpoint.

## Results

For a tested SUSY point with true $m_{\tau\tau}$ endpoint at 99 GeV, above procedure yields the following results:

**had-had:** $(91 \pm 13^{\text{stat}} \pm 10^{\text{syst}})$ GeV
**had-lep:** $(84 \pm 20^{\text{stat}} \pm 11^{\text{syst}})$ GeV
**lep-lep:** $(152 \pm 55^{\text{stat}} \pm 48^{\text{syst}})$ GeV

combined measurement: $(91 \pm 13)$ GeV

Statistical error contains the fitting procedure and the jet energy scale uncertainty (assumed to be 5% at 1fb$^{-1}$)

Poor statistics in spectra makes endpoint measurement challenging:

- Lep-lep channel (only 6% of $\tau\tau$ pairs) hardly contributes
- Dominant source of systematic uncertainty: histogram binning

## Conclusions

- Measurement of SUSY masses is the first step towards SUSY parameter determination ⇒ crucial for "SUSY discovery"
- Ditau mass endpoint yields information about $\tilde{\tau}$ masses
- With 1fb$^{-1}$ and 10 TeV: endpoint measurable with ≈ 15% precision

**References:**

[1] ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics*, CERN-OPEN-2008-020, Geneva, 2008.