Measuring SUSY with tau leptons

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using results by
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Introduction

- For good reasons taus from W/Z decays play dominant role in tau performance group:
  - These processes will be there for sure
  - There will be plenty of taus from these decays
  - They will probably be most important to understand how taus look like in ATLAS
- Nevertheless it might also be worth to keep an eye on new physics processes:
  - Taus from new physics sources might pose challenges to tau reconstruction which are different from those in SM processes
  - Desire to understand new physics might increase motivation to squeeze out more and more information from tau reconstruction

The role of taus in SUSY

There are numerous reasons to study SUSY with tau probes:

- $\tilde{\tau}_1$ (decaying to tau) is lightest slepton in models with high scale unification
- in mSUGRA large L-admixture in $\tilde{\tau}_1$ causes larger coupling to wino-like $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$

} $\Rightarrow$ might get significantly more taus than e/μ

- obtain stau mass information without relying on GUT relations (important to predict $\tilde{\chi}_1^0$ relic density)
- many other models (with large tan β, GMSB with stau NLSP, RPV SUSY with stau LSP, SUSY with LFV, ...) in which taus may play important role
- tau is only lepton that grants access to polarisation information

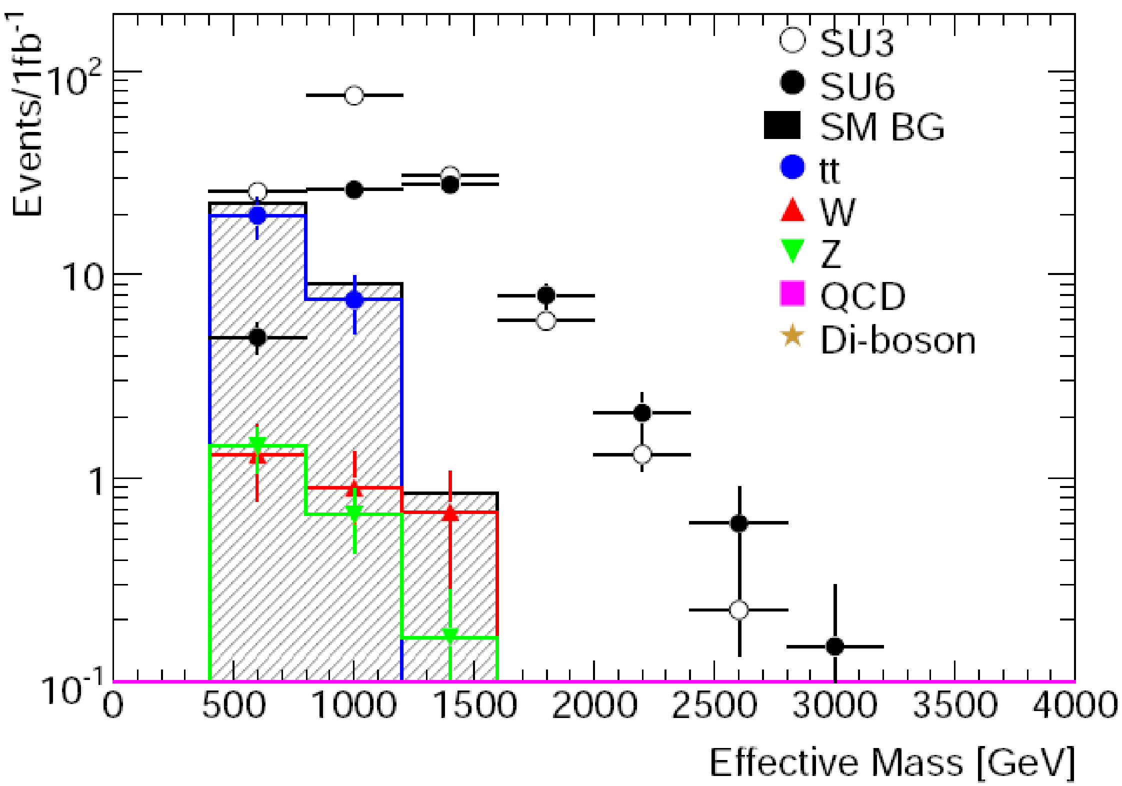
Taus for SUSY searches

Before SUSY can be studied, it needs to be discovered:

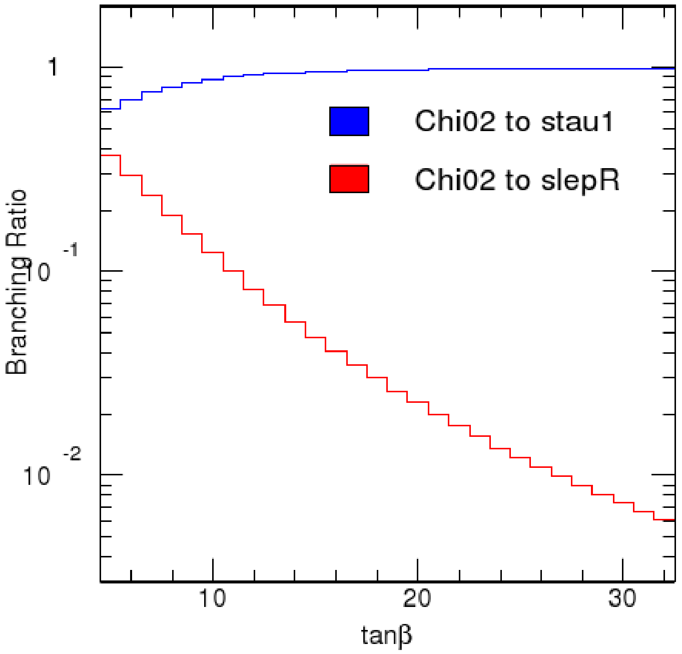
Inclusive searches in various different channels

Especially important for large tan β cases:

4 jets + ≥ 1 tau + missing E_T



Typical example:



RPV SUSY with stau LSP

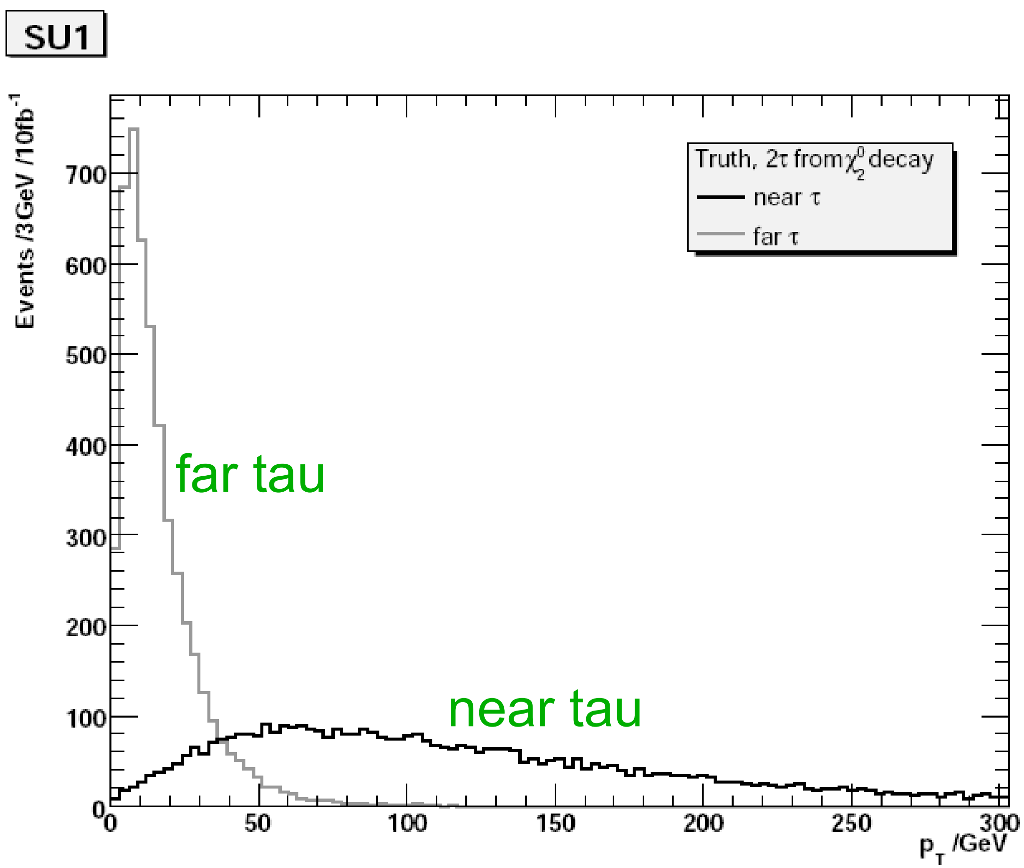
Taus are also important to discover SUSY in other, more exotic cases like e. g. R-parity violating SUSY with $\tilde{\tau}_1$ as lightest SUSY particle (LSP)

Example: BC1 benchmark point from `hep-ph/0609263`

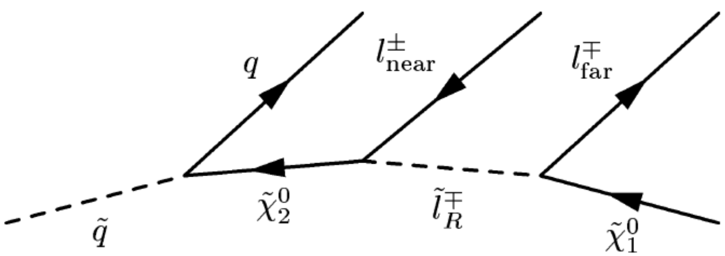
e^+/μ^+	e^-/μ^-	τ^+	τ^-	event fraction (%)
2	2	2	2	33.9 ± 0.3
3	2	2	2	12.2 ± 0.2
2	3	2	2	8.0 ± 0.1
3	3	2	2	7.6 ± 0.1
2	2	2	1	4.5 ± 0.1
2	2	3	2	4.4 ± 0.1
2	2	2	3	2.9 ± 0.1
2	2	1	2	2.9 ± 0.1
2	2	1	1	2.4 ± 0.1
3	2	2	3	1.7 ± 0.1

Challenges for tau reconstruction

In some SUSY scenarios (e. g. co-annihilation region) extremely soft taus are produced



tau transverse momentum (GeV)



Challenges for tau reconstruction

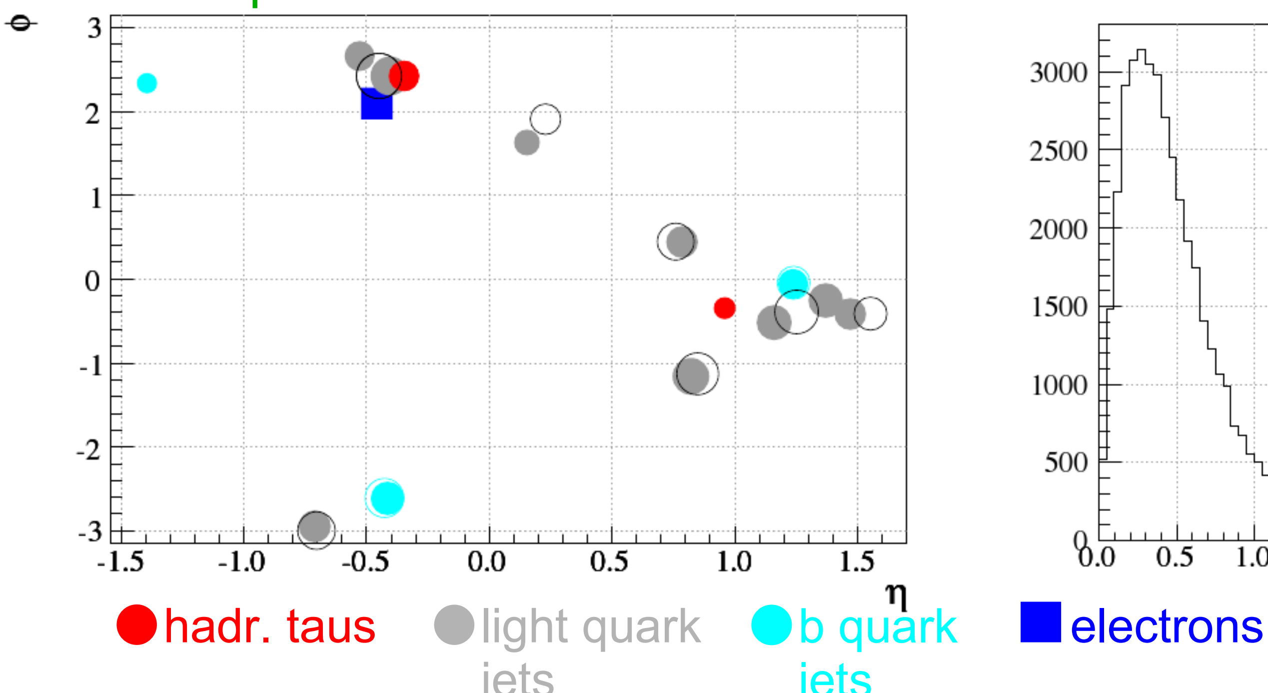
Other scenarios can produce taus extremely close to jets.

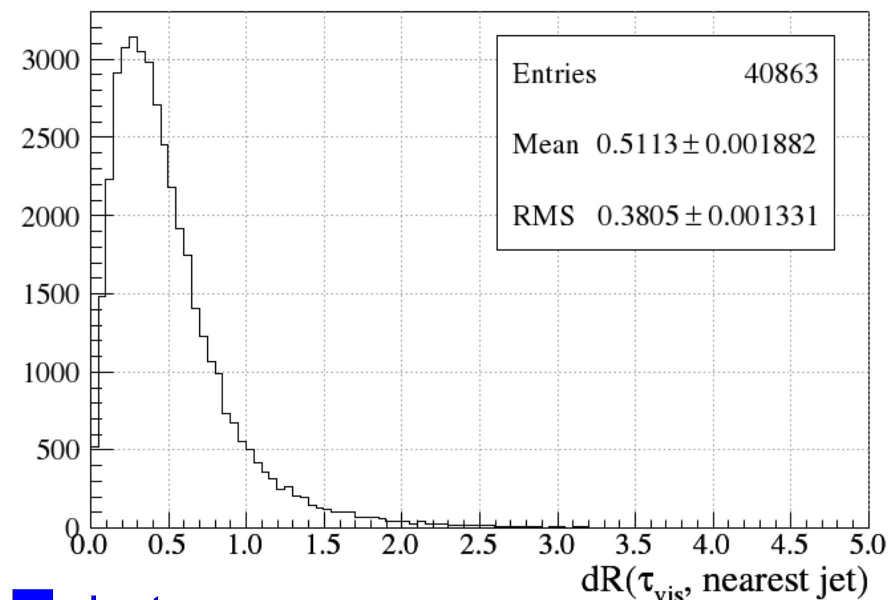
Example: R-parity violating mSUGRA benchmark point BC2 from `hep-ph/0609263`

Highly boosted sparticles decaying into taus and jets:

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

Example event:





Taus for exclusive measurements

Most important tau related SUSY parameter: $\tilde{\tau}_1$ mass measurement

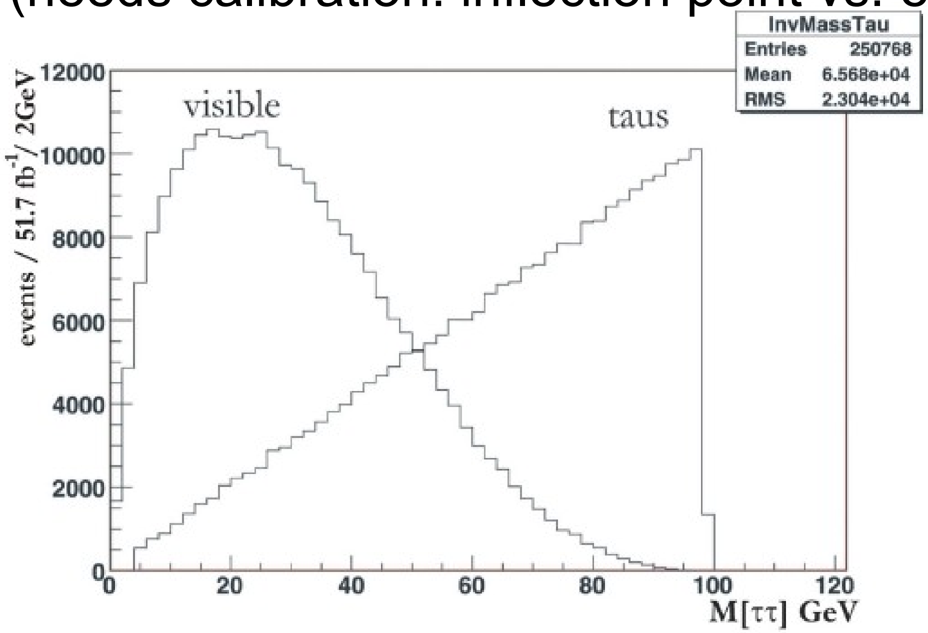
Obtained from di-tau invariant mass spectrum in decay chain

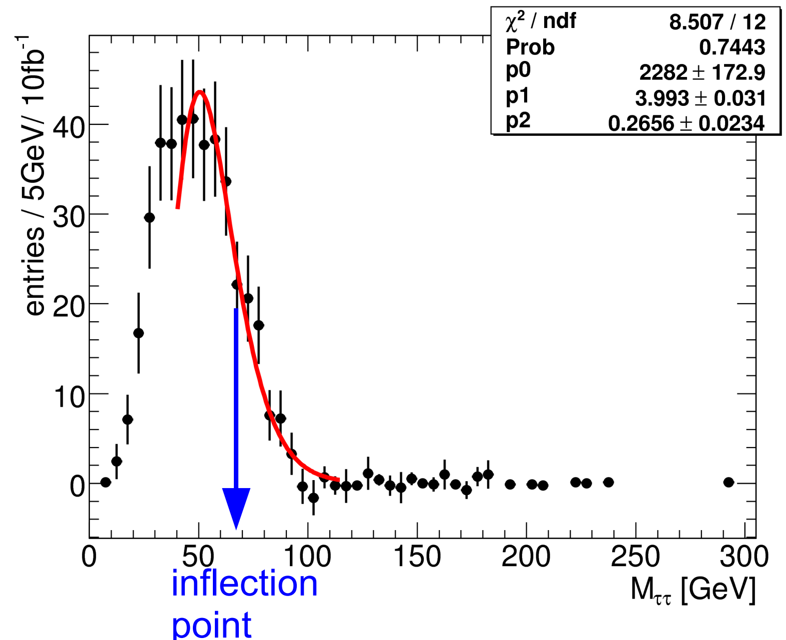
$$\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau \rightarrow \tilde{\chi}_1^0 \tau^\pm \tau^\mp$$

Endpoint of undecayed tau mass spectrum depends on $\tilde{\tau}_1$ mass.

Escaping neutrino energy in tau decays makes this endpoint hardly directly measurable

Choose e. g. inflection point of trailing edge as endpoint sensitive observable (needs calibration: inflection point vs. endpoint)

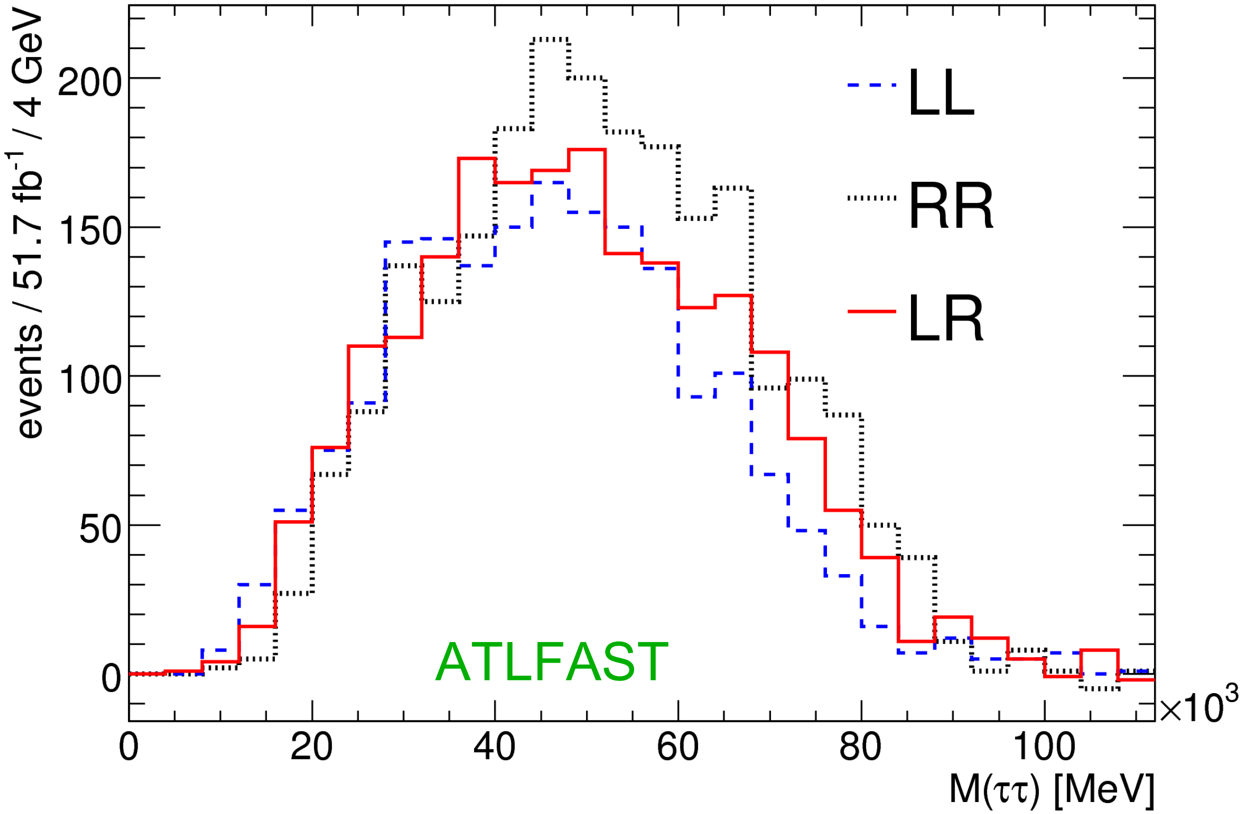




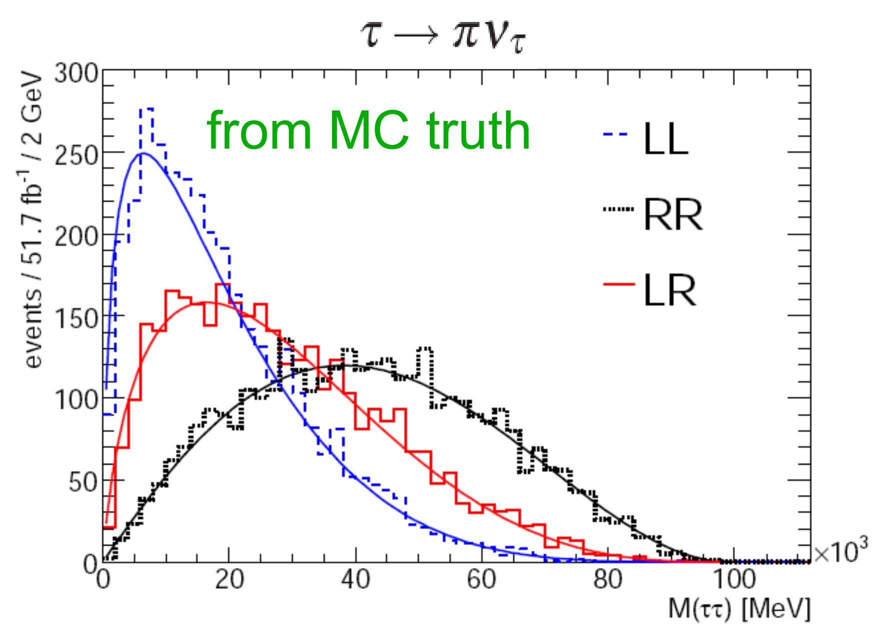
Polarisation dependence

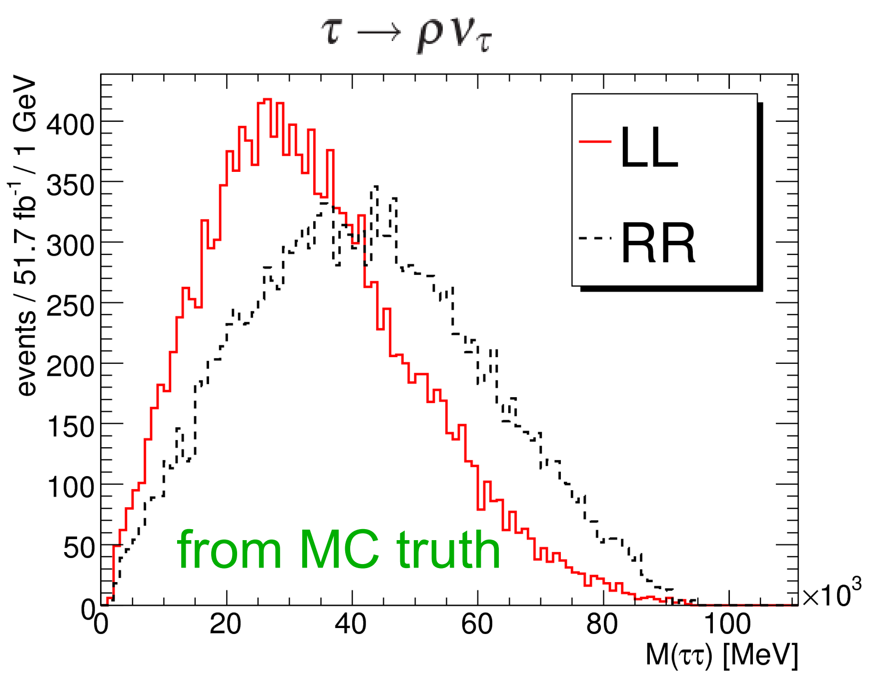
Now comes the tricky part:

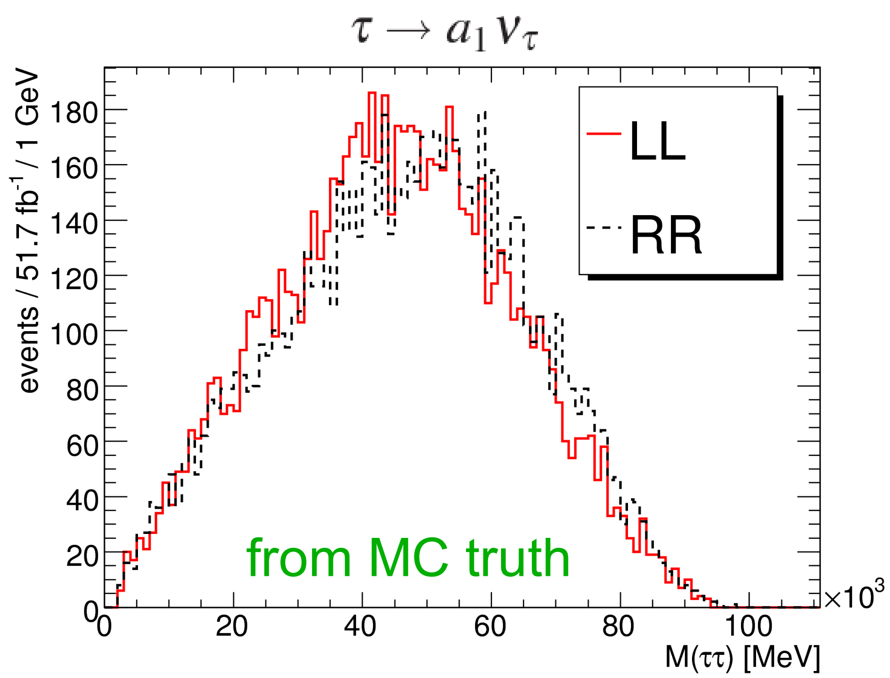
Mass spectrum does not only depend on $\tilde{\tau}_1$ mass (and neutralino masses) but also on the (SUSY model dependent) couplings of the neutralinos which in turn determine the polarisation of the taus



Decay mode dependence







Try to disentangle mass from polarisation effects by:

- using shape differences
- exploiting different polarisation dependence of different tau decay modes

Polarisation of taus from stau decays

So far only considered combined polarisation information from both taus in decay

$$\tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp \to \tilde{\chi}_1^0 \tau^\pm \tau^\mp$$

Also interesting to measure polarisation of particular taus.

Polarisation of taus from stau decay $\tilde{\tau}_1^\pm \to \tau^\pm \tilde{\chi}_1^0$ is a probe of the $\tilde{\chi}_1^0$ composition and can be used to discriminate between different models of SUSY breaking:

- Universal SUGRA models: $P_\tau \simeq +1$
- For most non-universal SUGRA models: $P_\tau \simeq \cos^2\theta_\tau - \sin^2\theta_\tau$
- AMSB models: $P_\tau \simeq -1$
- For many GMSB models: $P_\tau = \sin^2\theta_\tau - \cos^2\theta_\tau$

Main $\tilde{\tau}_1$ sources (typically):

$$\tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp \to \tilde{\chi}_1^0 \tau^\pm \tau^\mp$$

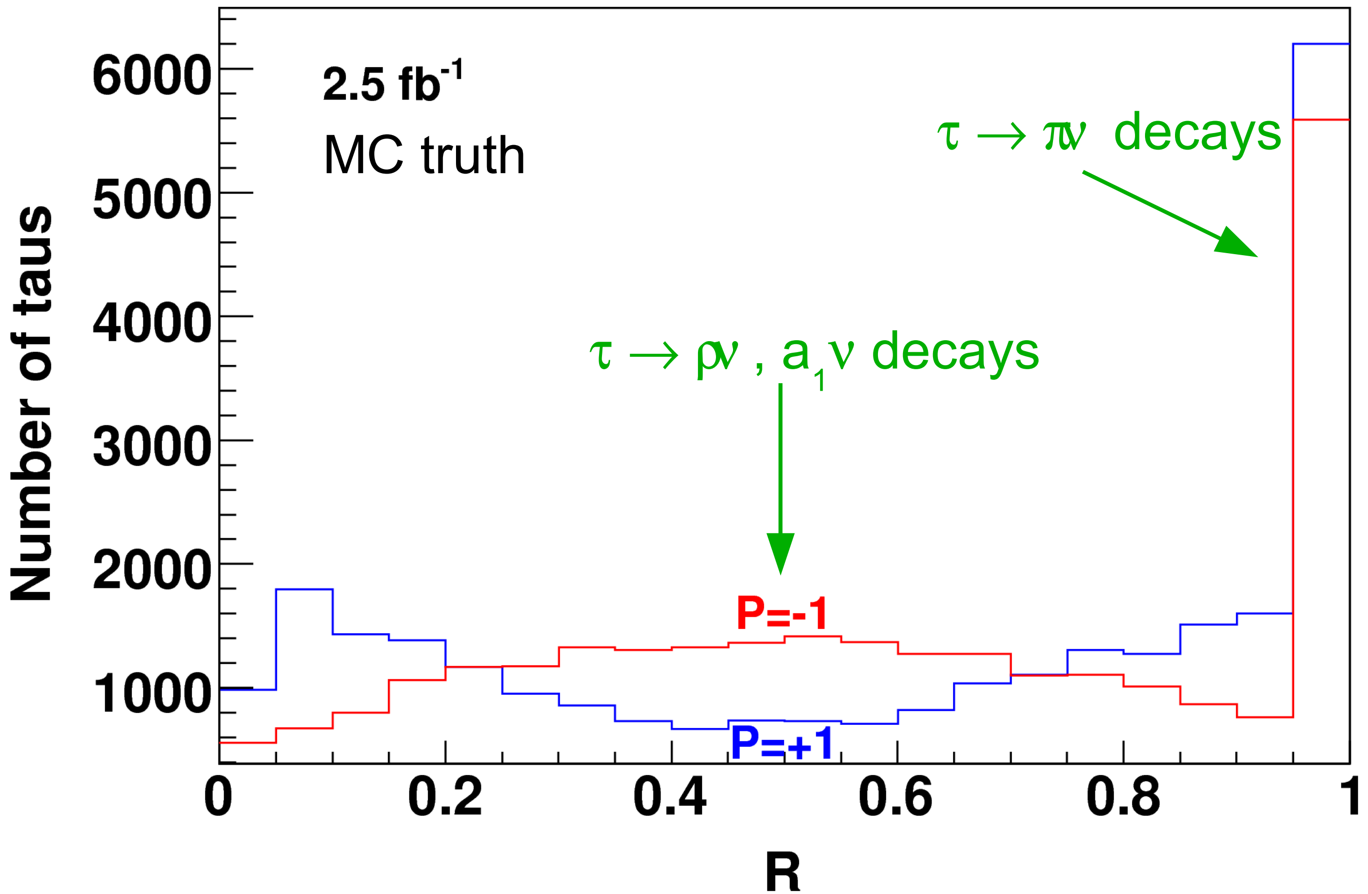
$$\tilde{\chi}_1^\pm \to \tilde{\tau}_1^\pm \nu_\tau \to \tilde{\chi}_1^0 \tau^\pm \nu_\tau$$

Polarisation sensitive observable

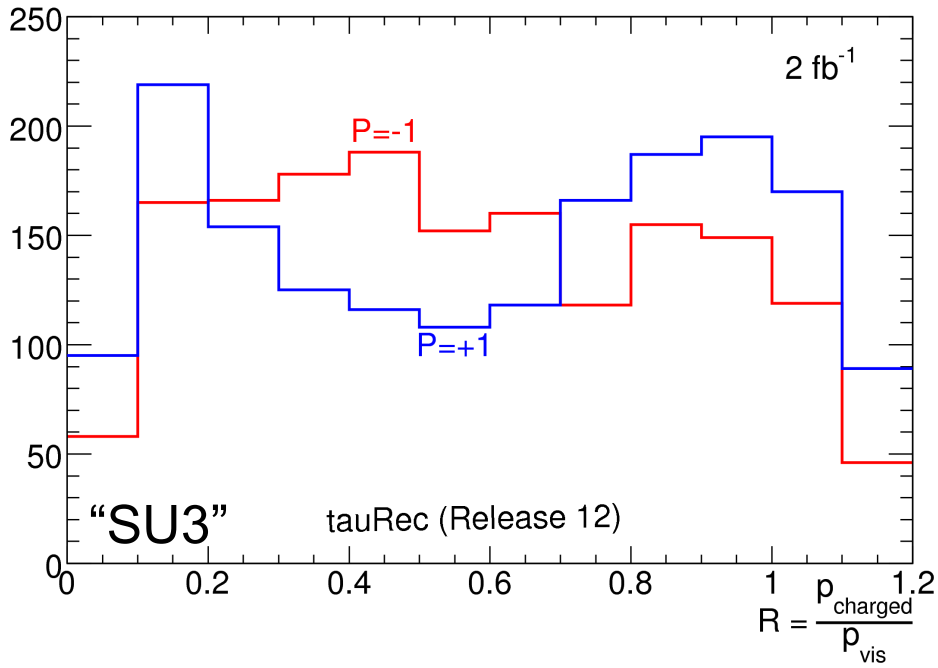
As polarisation dependent observable Guchait and Roy proposed to use ratio of charged and total tau jet momentum *R* (hep-ph/0109096):

$$R = p_{\pi^\pm}/p_{\tau-\mathrm{jet}}$$

~ boost invariant



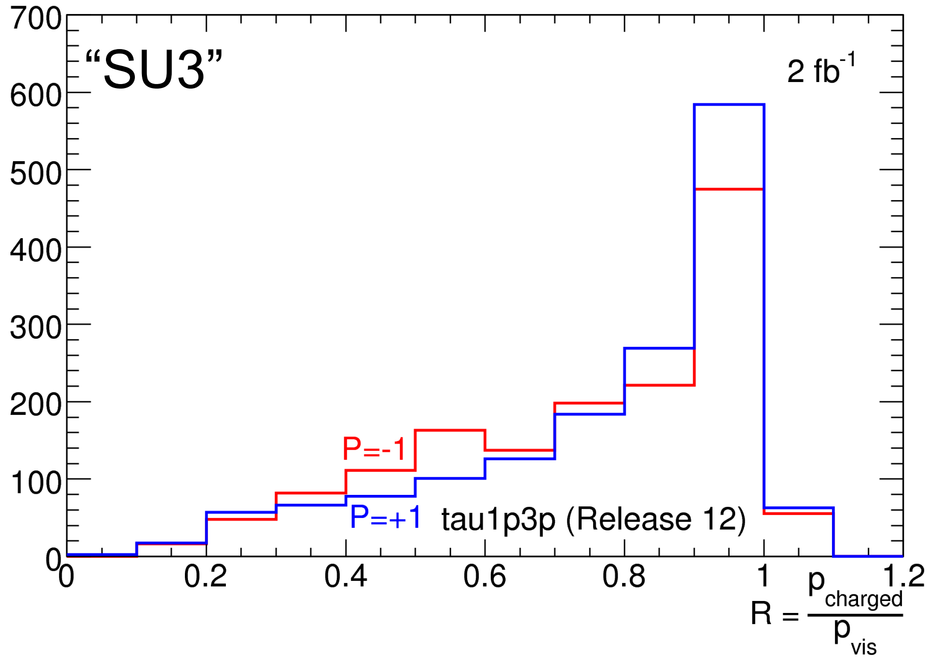
Reconstructed R distribution



Clearly there is separation power for both algorithms:

tauRec:

- poorly measured $\tau \rightarrow \pi\nu$ decays (poor calo resolution at low energies)
- good efficiency up to low R values

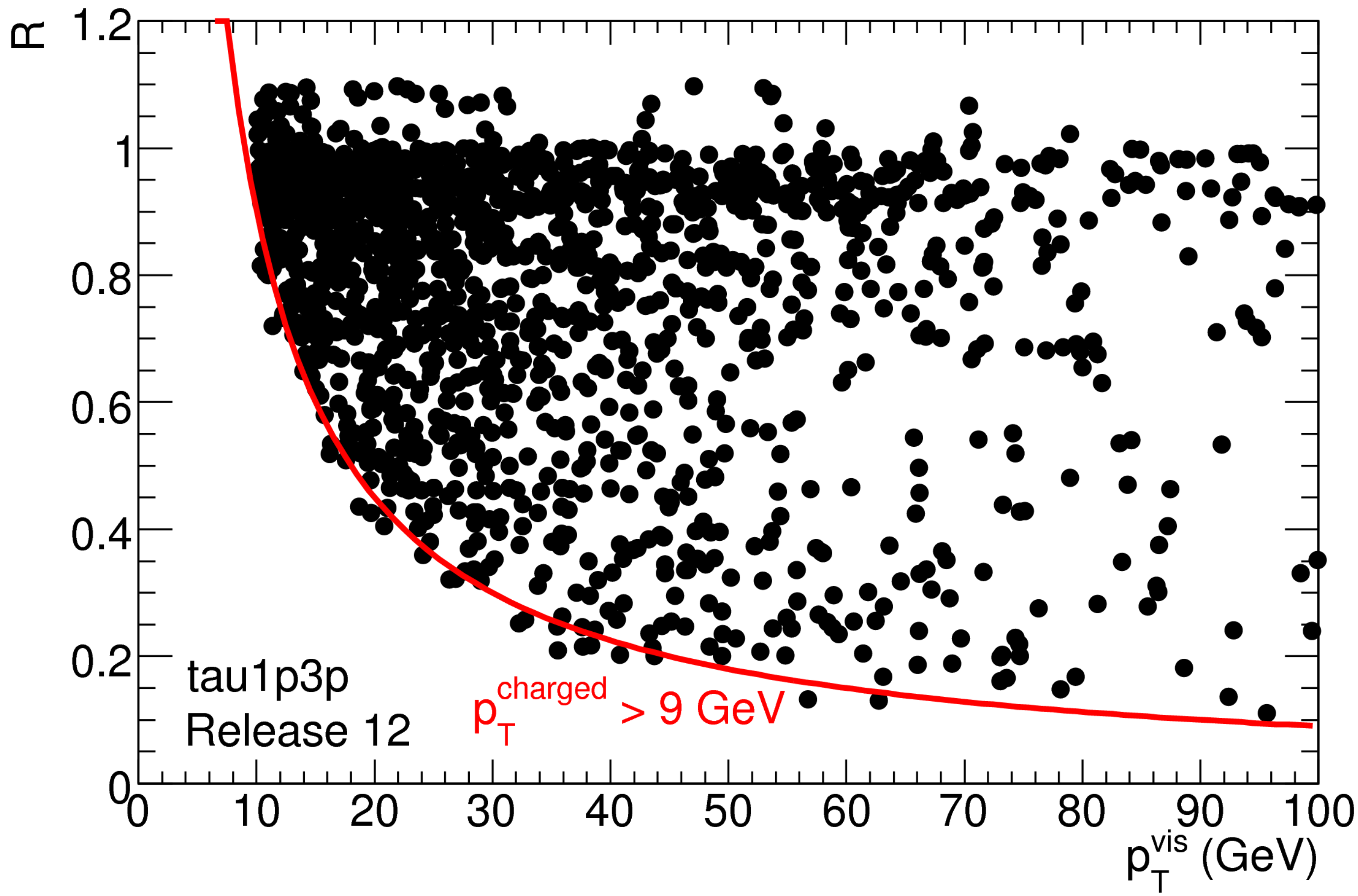


tau1p3p:

- well measured $\tau \rightarrow \pi\nu$ decays (easy case for eflow algorithm)
- distribution fades out at low R values

Neither of the algorithms seems ideal for this measurement

Impact of tau1p3p track p_T cut



Example: $p_T^{charged}$ > 9 GeV translates into p_T^{vis} > 45 GeV at R = 0.2

Track p_T cut in tau1p3p diminishes reconstruction efficiency for vector meson decay modes at low p_T^{vis}

Summary

- Taus are very interesting probes for SUSY physics often providing complementary information not accessible in other measurements.
- They are much more than just “simple leptons” or “narrow jets”.
- SUSY provides physics case for:
  - reconstruction of very soft taus (including vector meson decay modes)
  - reconstruction of taus in a very dense environment (close to jets)
  - separate individual tau decay modes ($\tau \to \pi\nu$, $\to \rho\nu$, $\to a_1\nu$)