SUSY with tau final states

Models and Current Searches

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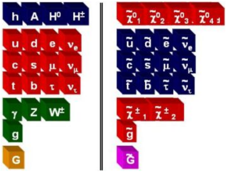
Geilo, Dec 17th 2012

Cold Dark Matter and SUSY

- Cold Dark Matter: distribution of additional mass in the universe,
  - electrically neutral ("dark")
  - not black holes or massive neutrinos
- Many SUSY models have candidate particle for Cold Dark Matter
  (their lightest stable particle, LSP)



- SUSY models are constrained from various sides:
  - Measurements
    SM observables, rare decays
  - Searches
    no superpartner observed yet
  - Discovery of Higgs-like boson
  - Cosmological
- Strongly restrict viable models/parameter space
- Interest in final states with tau leptons

SUSY with tau final states

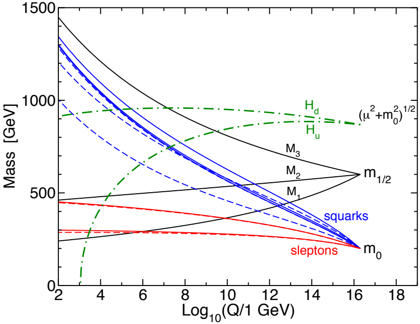
Third-generation final states favoured by many models

- Left-right mixing in SUSY

$$M^2_{\tilde{f}} = \begin{pmatrix} m^2_{\tilde{f}_L} & -m_f(A_f + \mu\tan\beta) \\ -m_f(A_f + \mu\tan\beta) & m^2_{\tilde{f}_R} \end{pmatrix}$$

  leads to lighter sfermion masses in 3rd generation

- RGE in MSSM, mSUGRA
- $\tilde{\tau}$ is NLSP in relevant GMSB parameter range
- Cosmological constraints



S. Martin, hep-ph/9709356

- RGE for 3rd gen

$$\frac{dm^2_{\tilde{t},\tilde{b}}}{dt} = \frac{1}{16\pi^2}|y_{t,b}|^2\left(m^2_{H_{u,d}} + m^2_{Q3} + m^2_{\tilde{t}_R,\tilde{b}_R}\right) + \ldots$$

$$t = \log(Q)$$

Gravity-mediated models (CMSSM/mSUGRA)

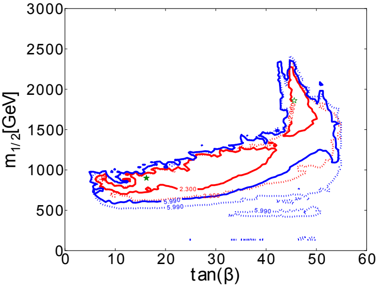
phenomenology

- SUSY-breaking model assumes hidden sector which couples to SM only through gravity
- assume universality of gaugino & sfermion masses at high scale
- leads small set of free par.

A_0: SSB universal trilinear coupling
M_0: universal scalar mass
$M_{1/2}$: universal gaugino mass
$\tan\beta$: ratio of VEVs
$\mathrm{sign}\mu$: mass parameter for Higgsino superfield mixing

- R-parity is conserved

- experimental constraints leave small allowed parameter region

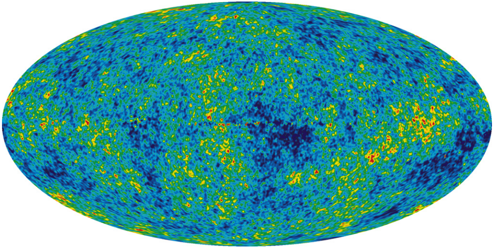


O. Buchmüller et al, arxiv:1207.7315

See also talk by J. Lindroos

Gravity-mediated models and taus

- In CMSSM/mSUGRA the $\tilde{\tau}$ is often the lightest sfermion
- at small M_0 exists region where $\tilde{\tau}$ and LSP are almost mass degenerate
- $\Rightarrow$ large co-annihilation cross-section in this region: $\tilde{\chi}^0 \tilde{\tau}_1 \rightarrow \tau\gamma$
- This region is favoured by cosmological constraints:
  agreement with observed relic density $\Omega_{\text{CDM}} h^2 \sim 0.12$ from WMAP
  (without co-annihiliation the predicted $\Omega_{\text{CDM}} h^2$ is too high)

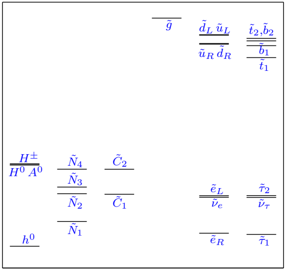


Gauge-mediated SUSY-Breaking

- SSB is transmitted to the SM world via messenger fields
- No scalar mass parameter M_0
- free parameters

Λ: scale
M_{mes}: messenger mass scale
N_5: nr of equivalent messengers
$\tan\beta$: ratio of VEVs
C_{grav}: Gravitino mass ratio
$\text{sign}(\mu)$: sign of mass parameter for Higgsino superfield mixing

- NLSP is either $\tilde{\chi}_1^0$, $\tilde{\tau}_1$ or $\tilde{e}_R/\tilde{\mu}_R$
- LSP is the gravitino $\widetilde{G}$



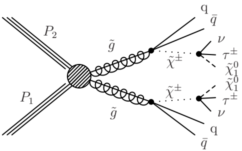
S. Martin – illustration

- typical $M_{\text{mes}} = 250$ GeV, $N_5 = 3$, sign$=+$, $C_{\text{grav}} = 1$.
- between 2 and 4 τ in final state $\tilde{\chi}_1^0 \to \tilde{\tau}^+\tau^- \to \tau^+\tau^-\widetilde{G}$.

Other models

Model-independent search:

- ad-hoc model of strong gluino pair production with decay chain to LSP



- gluino and LSP masses are free parameters
- decay through $\tilde{\chi}^0$ or $\tilde{\chi}^{\pm}$ with fixed mass ($\frac{1}{2}m_{\tilde{g}}$)
- used in CMS interpretation under the name "T5taunu" and "T3tauh"

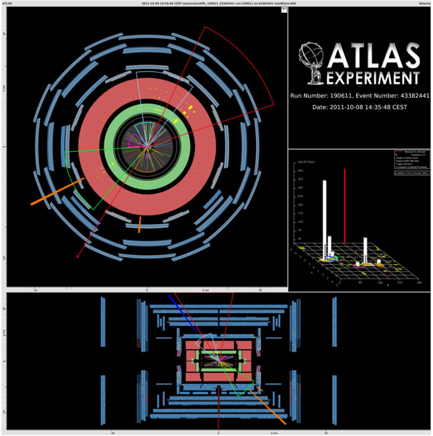
R-Parity violating models:

- lightest SUSY particle can decay
- additional symmetries needed to prevent proton decay
- However, existence of DM not argument against RPV SUSY:
  - ▷ very small $\not{R}$ coupling to LSP
  - ▷ gravitino DM

merits dedicated talk

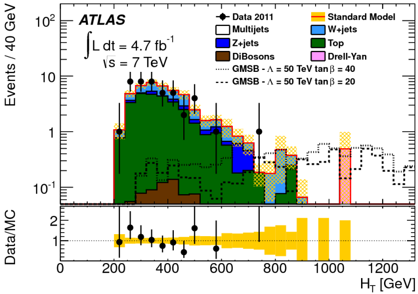
Experimental signatures

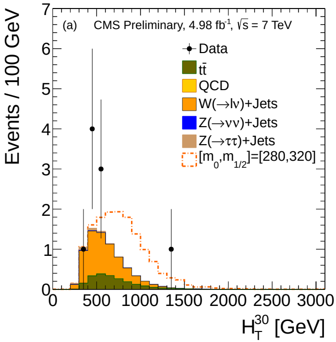
- final states with
  - τ_{had}, tau with hadronic decay (from SUSY decay chain)
  - jets (from strong production)
  - $E_{\mathrm{T}}^{\mathrm{miss}}$ (from LSP)
- typically ≥ 2 taus are produced, Second τ could be soft if $\Delta M(\tilde{\tau}_1, \tilde{\chi}_1^0) \lesssim 5\,\text{GeV}$
- low efficiency and high p_{T} threshold for identification: signatures with 1 and 2 taus
- jets + $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers (easier to trigger than τ)



Tau+Jets+MissingE$_T$ signals

- Quantities sensitive to high masses of SUSY process
- Transverse scalar sum $H_T = \sum p_T^\tau + \sum p_T^{\text{jet}}$





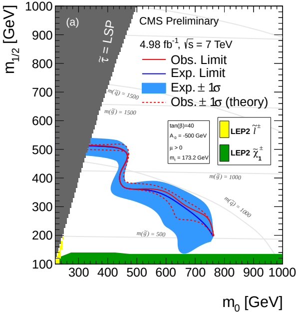
5 fb^{-1} of 7 TeV data

No excess of data events above SM backgrounds

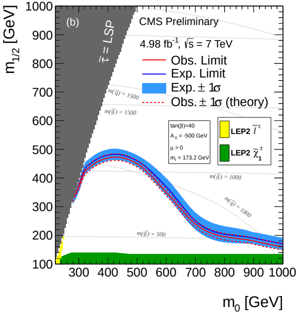
CMSSM limits from tau final states

- For $\tan\beta = 40$, $A_0 = 500$ GeV, $\mu > 0$
- High sensitivity in co-annihilation region
- $m_{\text{gluino}} < 1.15$ TeV for $M_0 < 400$ GeV
- CMS-PAS SUS-12-004

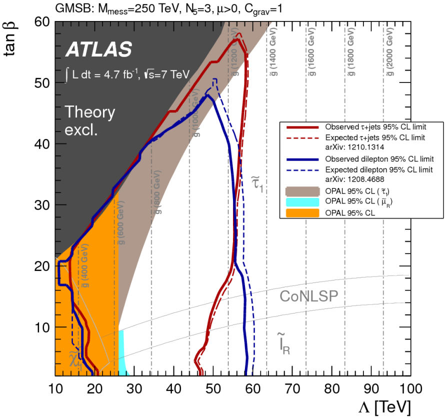
one tau



at least two tau



ATLAS GMSB Limits with taus

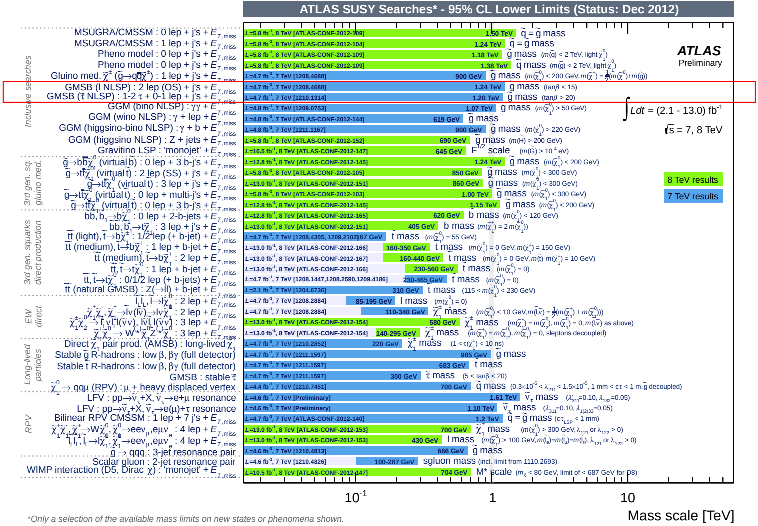


see talk by Ø. Dale
arxiv:1210.1314, 1208.4688 [hep-ex]

Limits on free model parameters

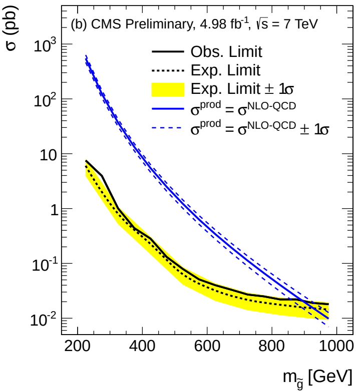
- $\Lambda < 50\ldots60$ TeV excluded at 95 % CL over almost entire allowed $\tan\beta$ region
- results from τ and di-lepton analyses: comparable limits, complementary regions

Tau results as part of ATLAS SUSY Searches



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

CMS GMSB Limits with taus



CMS-PAS SUS-12-004

- Figure shows exclusion limits as function of gluino mass
- Gluino mass < 860 GeV is excluded at 95% CL

CMS Razor

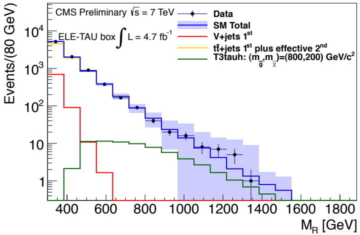
Razor variable:

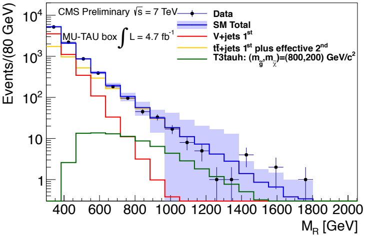
- Captures kinematics of the generic process of pair production of two heavy particles.
- Event forced into dijet signature
- M_R characterizes the presence of a heavy particle mass scale

$$M_R = \sqrt{\left(p^{\text{jet1}} + p^{\text{jet2}}\right)^2 - \left(p_z^{\text{jet1}} + p_z^{\text{jet2}}\right)^2}$$

- Razor $R =$

$$\frac{\sqrt{E_{\mathrm{T}}^{\mathrm{miss}}\left(p_T^{\text{jet1}} + p_T^{\text{jet2}}\right) - \vec{E}_{\mathrm{T}}^{\mathrm{miss}}\left(\vec{p}_T^{\,\text{jet1}} + \vec{p}_T^{\,\text{jet2}}\right)}}{M_R}$$



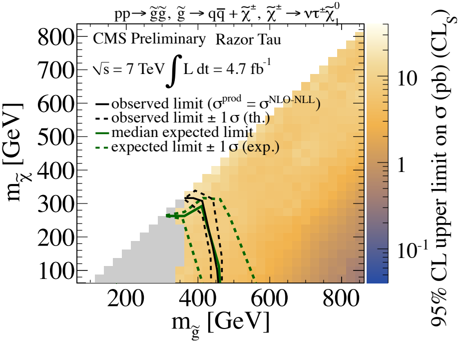


CMS-PAS SUS-11-029

CMS Razor II

Model-indep. interpretation

- Interpretation in simplified models
- $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$ decaying to τs
- limit set on gluino mass



Summary

- Motivations for finding SUSY in tau final states: from theory itself but also from DM density
- Another motivation: ability to distinguish a tau-enriched SUSY signal from that of a general multi-lepton signal
- ATLAS & CMS tau ID performs well
- Several analyses and model-(in)dependent interpretations
- Translated to gluino mass, data requires $m_{\tilde{g}} > 1.15 \ldots 1.25$ TeV
- ATLAS & CMS public results currently from 7 TeV data.
  Expect results from 22 fb^{-1} @ 8 TeV data next year!

SUSY searches at the LHC 2015-2022

- Increase in mass scale reach from high collision energy (14 TeV) and high lumi ($3000\,\mathrm{fb}^{-1}$)
- If SUSY is discovered: subsequent determination of model parameters should allow prediction of relic density with precision similar to WMAP with $\sim 30\,\mathrm{fb}^{-1}$
  (for mSUGRA, Arnowitt et al, PRL 100 231802 (2008))
- if SUSY is not discovered: increasing difference between SM mass scale and remaining allowed regions for SUSY masses
  $\Rightarrow$ *little hierarchy problem.*