What $SO(10)$ SUSY GUTs look like at LHC

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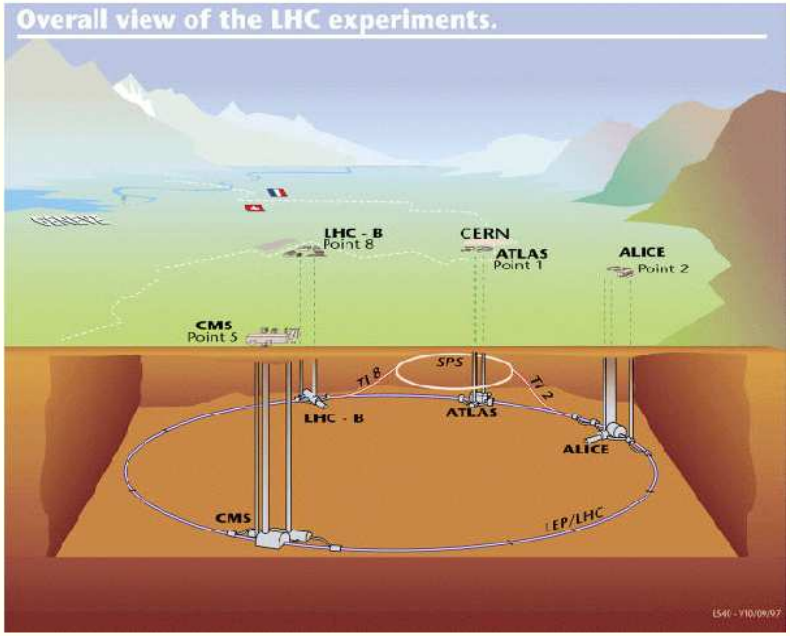
- ⋆ $SO(10)$: Yukawa unif'n
- ⋆ Spectrum of particles
- ⋆ Dark matter problem
  - – axino DM solution
- ⋆ cosmology of SUSY $SO(10)$
- ⋆ Early SUSY discovery at LHC
  - • $\not{E}_T$ replaced by $n(leptons)$
- ⋆ Yukawa unified SUSY soon to be



$SO(10)$ SUSYGUTs: motivation

- ⋆ In all the excitement of new models, it is easy to neglect the really good ideas from the past:
- ⋆ SUSYGUTs with $SO(10) \to SU(5) \to SU(3)_C \times SU(2)_L \times U(1)_Y$:
  - unification of forces
  - $SO(10)$ naturally anomaly free
  - explain ad-hoc SM hypercharge assignments (charge relations: *e.g.* why $m(proton) = -m_e$
  - unification of matter in $SO(10)$: $matter \in \psi(16)$, $higgs \in \phi(10)$ (simplest models)
  - The 16-dim'l spinor rep of $SO(10)$ contains *all* the matter in a single generation of the SM, plus a right-handed neutrino state.
  - break $SO(10)$: get see-saw νs!
  - simplest models: $t - b - \tau$ Yukawa unification

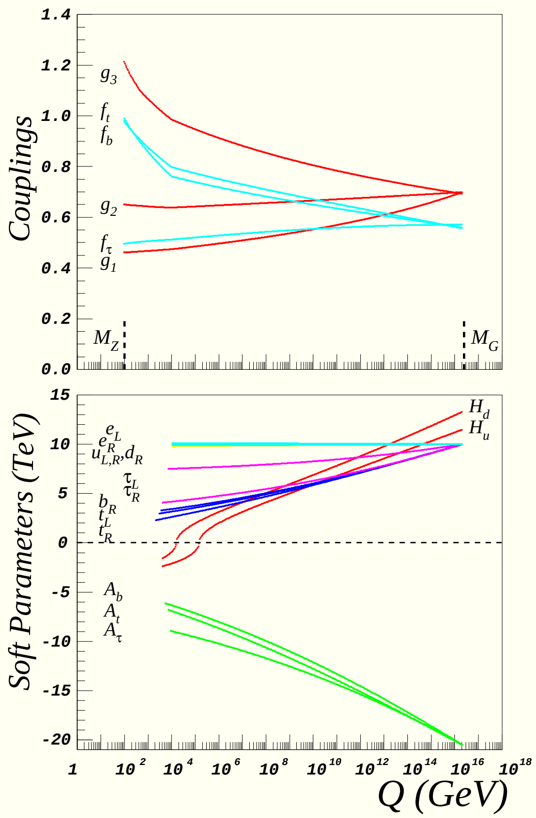
YU requires precision calculation of SUSY spectrum:

Hall, Rattazzi, Sarid; Pierce *et al.* (PBMZ)

- need full 2-loop RGE running
- full threshold corrections calculated at optimized scale
- off-sets Yukawa coupling RG trajectory
- use Isajet/Isasugra spectrum generator
- need large m_{16} to suppress threshold corrections

$t-b-\tau$ Yukawa unification in HS model!

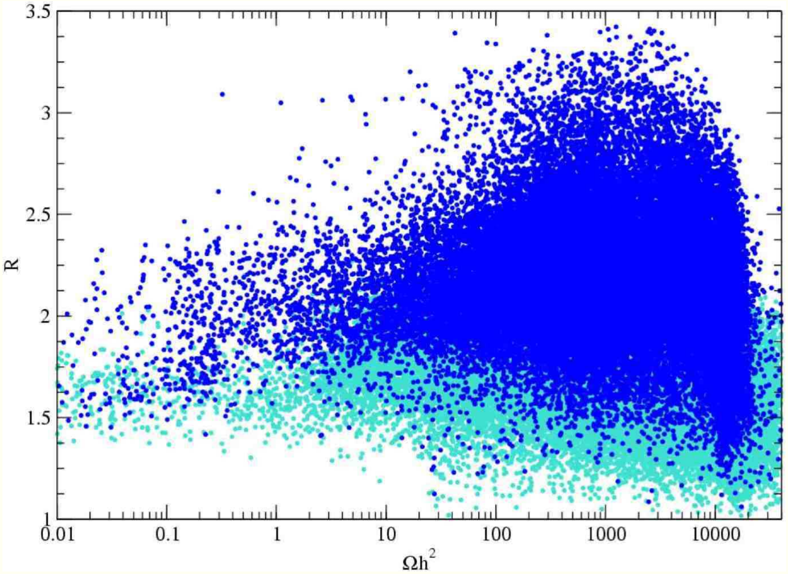
- need $m_{16} \sim 5-10$ TeV
- need $m_{10} \simeq \sqrt{2} m_{16}$
- $A_0 \simeq -2m_{16}$
- inverted scalar mass hierarchy: Bagger et al.
- split Higgs for EWSB: $m_{H_u}^2 < m_{H_d}^2$
- Auto, HB, Balazs, Belyaev, Ferrandis, Tata
- HB, Kraml, Sekmen, Summy
  - $m_{\tilde{q},\tilde{\ell}}(1,2) \sim 10$ TeV
  - $m_{\tilde{t}_1},\ m_A,\ \mu \sim 1-2$ TeV
  - $m_{\tilde{g}} \sim 300-500$ GeV
- related work: BDR, DRRR



Special SUSY spectrum from Yukawa unified models

- first/second gen. squarks/sleptons ~ 10 TeV
- third gen. scalars, μ, $m_A \sim 1-2$ TeV
- gluinos $\sim 350-500$ GeV
- charginos $\sim 100-150$ GeV
- $\widetilde{Z}_1$ or $\tilde{\chi}_1 \sim 50-70$ GeV

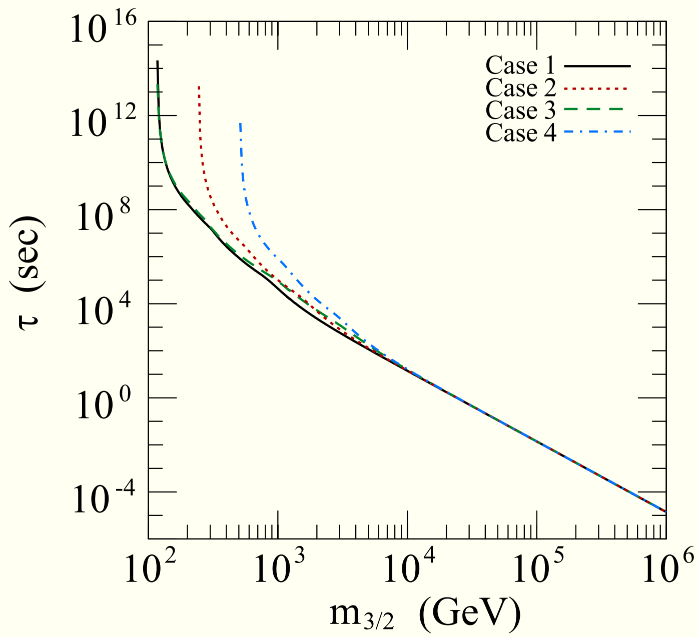
Problem reconciling DM with Yukawa unification

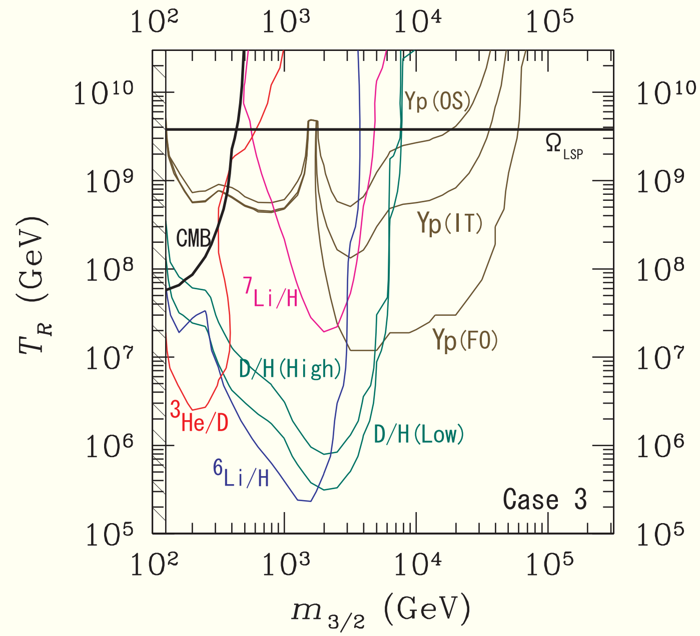


- one solution: axino DM instead of neutralino
- $\Omega_{\tilde{a}} h^2 \sim \frac{m_{\tilde{a}}}{m_{\widetilde{Z}_1}} \Omega_{\widetilde{Z}_1} h^2$: $\Rightarrow$ warm DM
- also thermal component depending on T_R: $\Rightarrow$ CDM

Consistent cosmology for SUSY $SO(10)$: gravitino problem

- gravitino problem in generic SUGRA models: overproduction of $\tilde{G}$ followed by late $\tilde{G}$ decay can destroy successful BBN predictons: upper bound on T_R





(see Kohri, Moroi, Yotsuyanagi; Cybert, Ellis, Fields, Olive)

Leptogenesis via inflaton decay

- Upper bound on T_R from BBN is below that for successful thermal leptogenesis: need $T_R \gtrsim 10^{10}$ GeV (Buchmuller, Plumacher)
- Alternatively, one may have non-thermal leptogenesis where inflaton $\phi \to N_i N_i$ decay
- additional source of N_i in early universe allows lower T_R:

$$\frac{n_B}{s} \simeq 8.2 \times 10^{-11} \times \left(\frac{T_R}{10^6 \text{ GeV}}\right) \left(\frac{2m_{N_1}}{m_\phi}\right) \left(\frac{m_{\nu_3}}{0.05 \text{ eV}}\right) \delta_{eff} \tag{1}$$

- WMAP observation: $n_b/s \sim 0.9 \times 10^{-10} \Rightarrow T_R \gtrsim 10^6$ GeV

Cold and warm axino DM in the universe

- Non-thermal axino production via $\widetilde{Z}_1 \to \tilde{a}\gamma$ decay:
  $\Rightarrow$ warm DM for $m_{\tilde{a}} \lesssim 1$ GeV (Jedamzik, Lemoine, Moultaka)

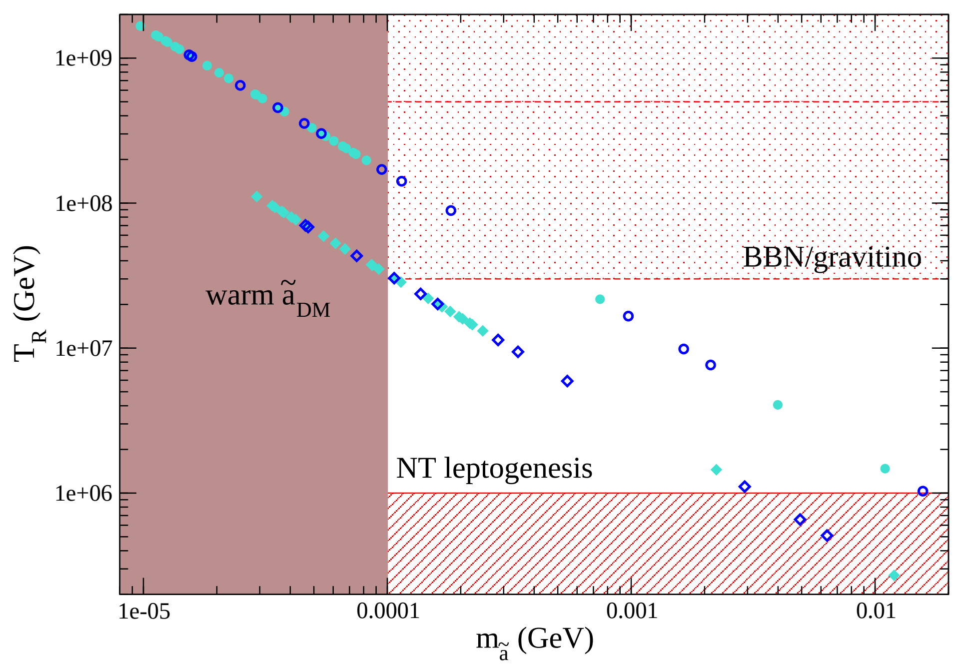
- thermal production of $\tilde{a}$: *cold* DM for $m_{\tilde{a}} > .1$ MeV (Brandenberg, Steffen)

$$\Omega_{\tilde{a}}^{TP} h^2 \simeq 5.5 g_s^6 \ln\left(\frac{1.108}{g_s}\right)\left(\frac{10^{11}\ \text{GeV}}{f_a/N}\right)^2\left(\frac{m_{\tilde{a}}}{0.1\ \text{GeV}}\right)\left(\frac{T_R}{10^4\ \text{GeV}}\right) \quad (2)$$

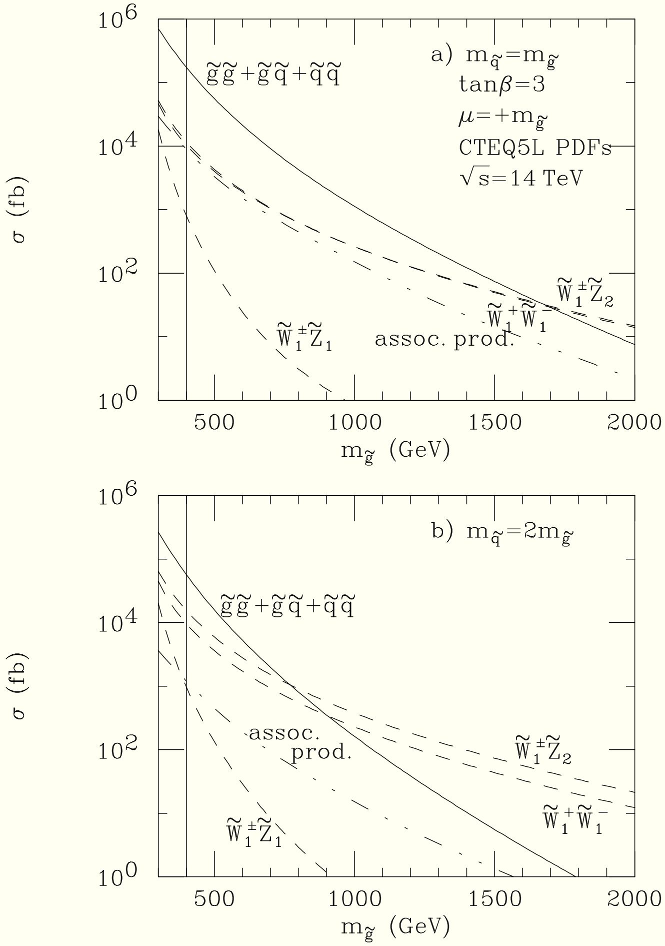
- with $0.1 \simeq \Omega_{\tilde{a}} h^2 = \Omega_{\tilde{a}}^{TP} h^2 + \frac{m_{\tilde{a}}}{m_{\widetilde{Z}_1}} \Omega_{\widetilde{Z}} h^2$, can calculate value of T_R needed given a PQ breaking scale $f_a/N \sim 10^{11}$ GeV

Consistent cosmology for $SO(10)$ SUSY GUTs with $\tilde{a}$ DM

- Happily, T_R falls into the right range to give *cold* axino DM with a small admixture of warm axino DM, preserve BBN predictions and have non-thermal leptogenesis!
- See HB and H. Summy, arXiv:0803.0510 (2008)



Production of sparticles at LHC



What $SO(10)$ SUSY GUTs look like at LHC

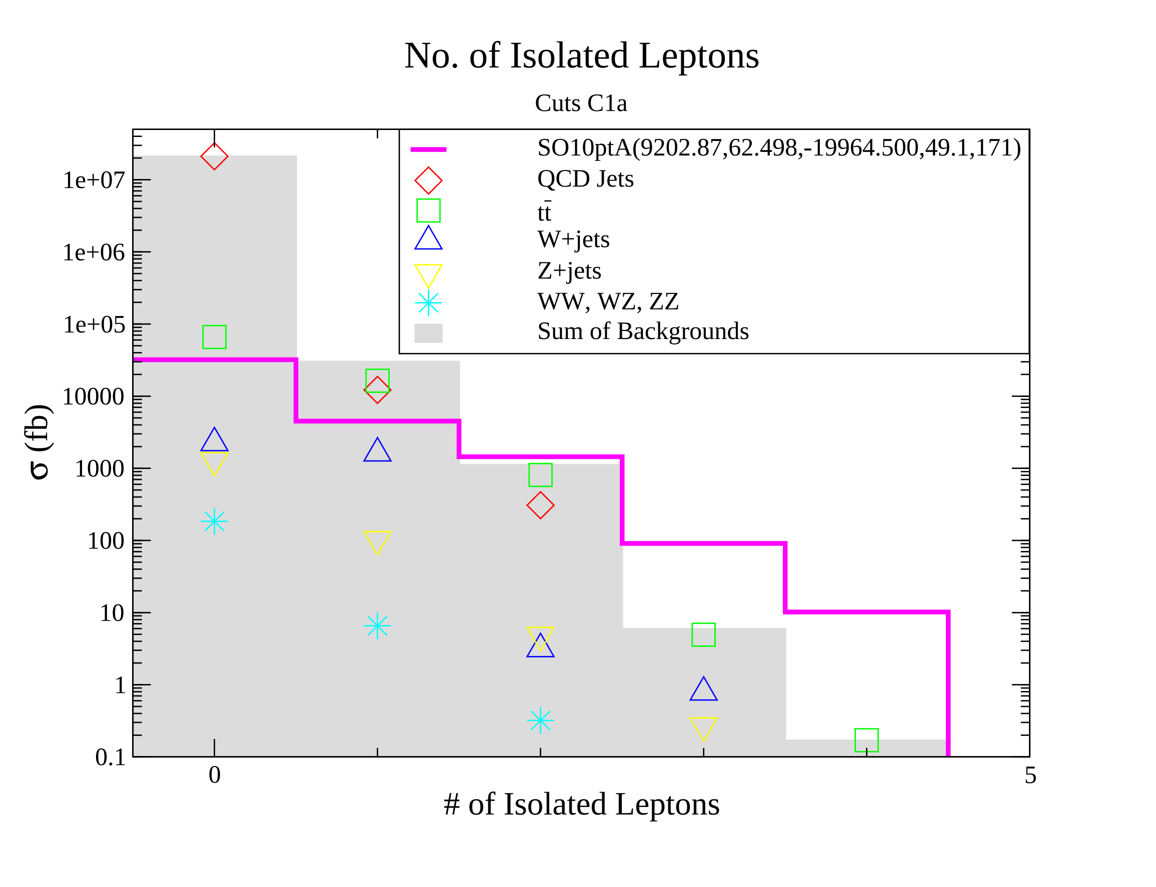
- with $m_{\tilde{g}} \sim 400$ GeV, expect $\sigma(pp \to \tilde{g}\tilde{g}X) \sim 10^5$ fb!
- LHC detectors would have LOTS of SUSY events!
- But, it will take time to measure many SM processes to reliably calibrate the entire detector for $jets + \not{E}_T$ search
- Could be a year or two if experience is similar to that of Tevatron D0 detector....

Early SUSY discovery at LHC without $\not{E}_T$

- Can we make early discovery of SUSY at LHC *without* $\not{E}_T$?
- Expect $\tilde{g}\tilde{g}$ events to be rich in jets, b-jets, isolated ℓs, τ-jets,....
- These are *detectable*, rather than inferred objects
- Inferred objects like $\not{E}_T$ require knowledge of complete detector performance
  - dead regions
  - "hot" cells
  - cosmic rays
  - calorimeter mis-measurement
  - beam-gas interactions

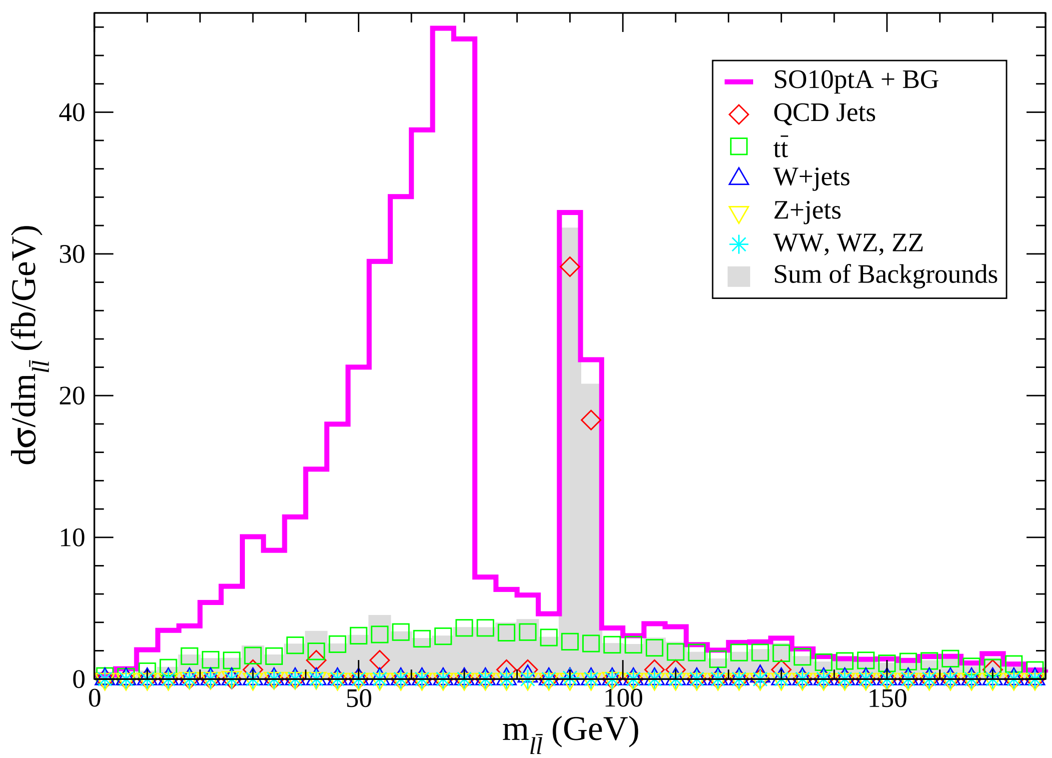
Require simple cuts:

- ≥ 4-jets $E_T > 100, 50, 50, 50$ GeV; $S_T \geq 0.2$



HB, Prosper, Summy, arXiv:0801.3799

Cuts C1′ plus $\geq 2\ OS/SF\ \ell$

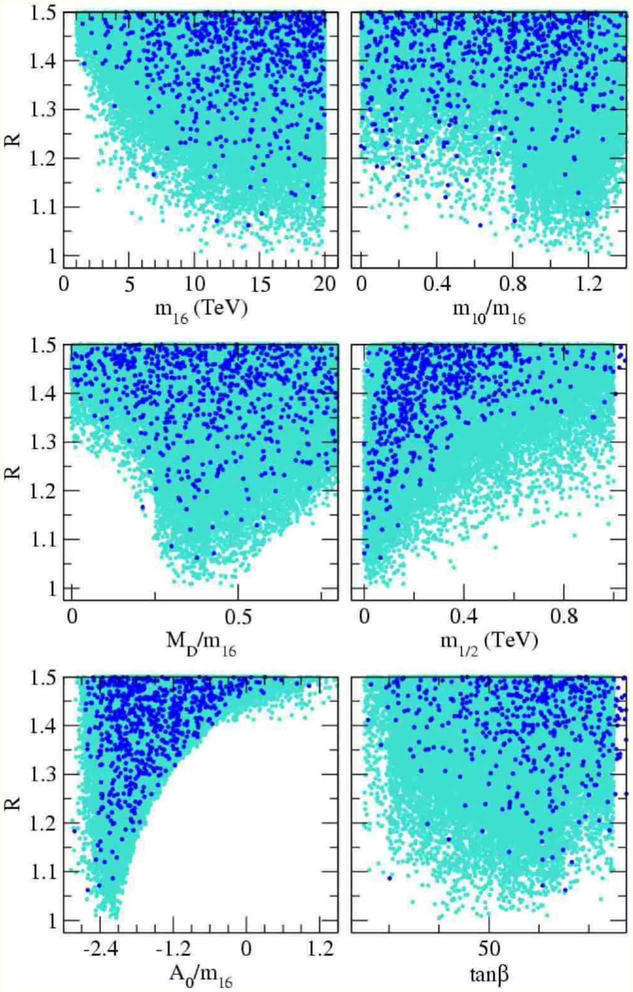


Conclusions

- ⋆ $SO(10)$ Yukawa unified SUSY: highly motivated
- ⋆ Special spectrum of superpartners
  - First/second gen. scalars ~ 10 TeV
  - Third gen. scalars, μ, $m_A \sim 1-2$ TeV
  - gluino $\sim 350-500$ GeV
  - bino-like neutralino $\sim 50-80$ GeV
- ⋆ $\Omega_{\widetilde{Z}_1} h^2 \sim 10^2 - 10^4$
  - Can reconcile with DM abundance: $e.g.$ $\widetilde{Z}_1 \to \tilde{a}\gamma$
  - solve gravitino problem and non-thermal leptogenesis!
- ⋆ If correct, LHC will be awash in $\tilde{g}\tilde{g}$ events
- ⋆ Can see signal with only 0.1 fb^{-1} of integrated luminosity in jets $+OS/SF$ leptons or $\geq 3\ell$ channel

⋆ We will soon know if Yukawa unified SUSY is correct theory of weak scale physics! LHC turn-on scheduled for summer 2008!

Sparticle masses for HS model with $\mu > 0$



HB, Kraml, Sekmen, Summy