Title: Quarks and Leptons as Nambu-Goldstone Fermions Under E_7/SO(10)

Date: Aug 26, 2011 01:00 PM

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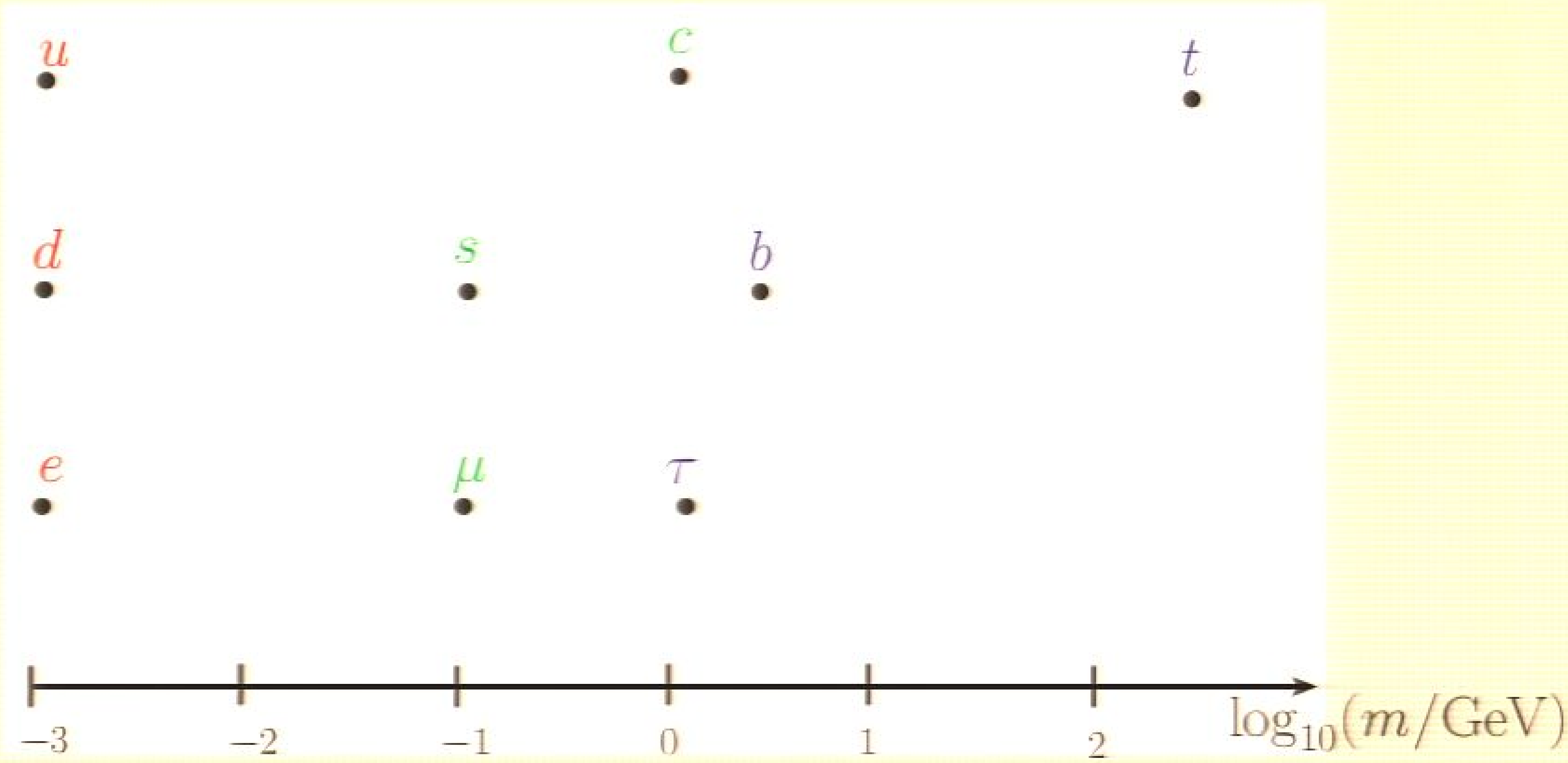
Abstract: The hierarchy of the Yukawa couplings is an outstanding problem of the standard model. We present a class of models in which the first and second generation fermions are SUSY partners of pseudo-Nambu-Goldstone bosons that parameterize an E_7/SO(10) Kahler manifold, explaining the small values of these fermion masses relative to those of the third generation. We consider experimental constraints on this scenario, and find that the simplest model with universal gaugino masses is already ruled out by the LHC. However, models with non-universal gaugino masses will likely be excluded only by direct dark matter searches.

Hierarchy of Yukawa couplings?



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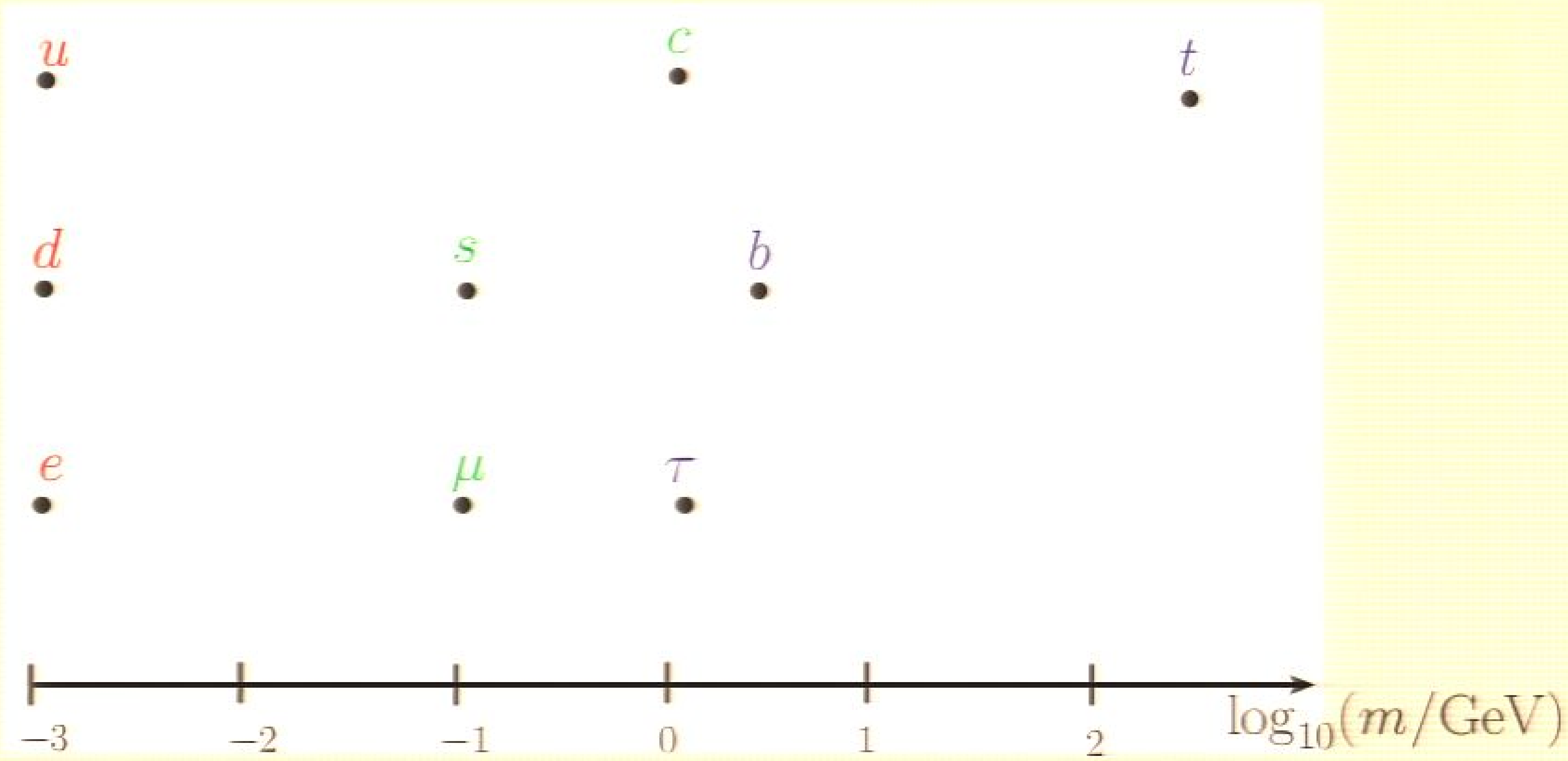

Ad-hoc ⇒ dynamical?

Field content of standard model

Gauged adjoint and light chiral fundamentals

- Gauge some group $H \subset G$ in real representation
- Where do light chiral fields in fundamental of H come from?

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Hint from pions

- Take $SU(2)/U(1)$ toy model
- Broken X and $Y \Rightarrow Z = X + iY$, $Z^* = X - iY$
- $SU(2) \sim S^3 \Longrightarrow S^3/U(1) \sim \mathbb{CP}^1$

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- $SU(2) \sim S^3 \Longrightarrow S^3/U(1) \sim \mathbb{CP}^1$
- Gauge $U(1)$, toy pions in fundamental complex representation
- Need fermionic analogue

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Problems of the Standard Model

- Higgs hierarchy problem
- Dark matter
- Gauge unification

  ⋮

Other problems ...

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Natural way to accomplish this? Follow hint ...

)utline

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   - Motivations
   - Coset Spaces
2. $E_7/SO(10)$ Model
   - Preliminaries
   - Model Aspects
   - GUT model
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3. Experimental constraints
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Coset spaces

- $M_P,\ M_{GUT},\ M_\Lambda \gg M_{SUSY}$

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How to construct one?

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Nonlinear σ model

Under global symmetry breaking $G \to H$,

$$\mathcal{L}_{NGB}^{NL} = -\left(\partial^{\mu}\pi_i\right) g^{ij}\left(\pi/f_{\pi}\right)\left(\partial_{\mu}\pi_j\right)$$

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Incorporate in supergravity ...

Broken d.o.f.'s parameterize Kähler manifold

he Kähler potential

Supersymmetric generalization of nonlinear σ model:

$$\mathcal{L}^{NL}_{SUSY} = K\left(\Phi, \Phi^\dagger\right)\Big|_{\theta\theta\bar{\theta}\bar{\theta}}$$

Then for scalars:

$$\mathcal{L}^{NL}_{SUSY} = -\partial^\mu \phi^{*i}\left[\frac{\partial^2 K\left(\phi^*, \phi\right)}{\partial\phi^{*i}\partial\phi^j}\right]\partial_\mu\phi^j$$

such that

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Technical points

Invariance of K

- Kähler transformation:

$$K(\Phi,\Phi^\dagger) \to K(\Phi,\Phi^\dagger) + F(\Phi) + F^\dagger(\Phi^\dagger)$$

- Under supergravity,

$$L = \left[\Sigma\Sigma^\dagger e^{-K(\Phi,\Phi^\dagger)}\right]_D + \left[\Sigma^3 W(\Phi)\right]_F$$

- For finite W, $\Sigma \to \Sigma e^F$ not sufficient!

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Solution criteria

- G/H must be non-compact [Bagger and Witten, Phys. Lett. B **118**, 103 (1982)]
- H must have no $U(1)$ factors [Kugo and Yanagida, Prog. Theor. Phys. **124**, 555 (2010)]

Technical points (cont'd)

- General form of Kähler potential:

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- For a simple example manifold similar to Pati-Salam, see:

SKM, Nojiri, Sudano, Yanagida, JHEP **01**, 131 (2011)

Supergravity and SUSY breaking

- Couple to supergravity:

$$\Delta\mathcal{L} = \frac{3}{4}\int d^2\theta d^2\bar{\theta}\mathcal{E}\,(\bar{\mathcal{D}}\bar{\mathcal{D}} - 8R)\exp\Big(\frac{1}{3}K(\Psi,\Psi^\dagger)\Big)$$

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$$K = K(\Psi,\Psi^\dagger) + Z^\dagger Z + ...$$

- NG bosons remain massless, but QNGB d.o.f.'s from broken $U(1)$'s inside Ψ get mass ⇒ "novino" superfields

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Choosing $G = E_7$

Formal motivations for E_7

- Appears in $N = 8$ supergravity
- Nonlinear realization gives the “simplest field theory” [Arkani-Hamed, Cachazo, Kaplan arXiv:0808.1446]

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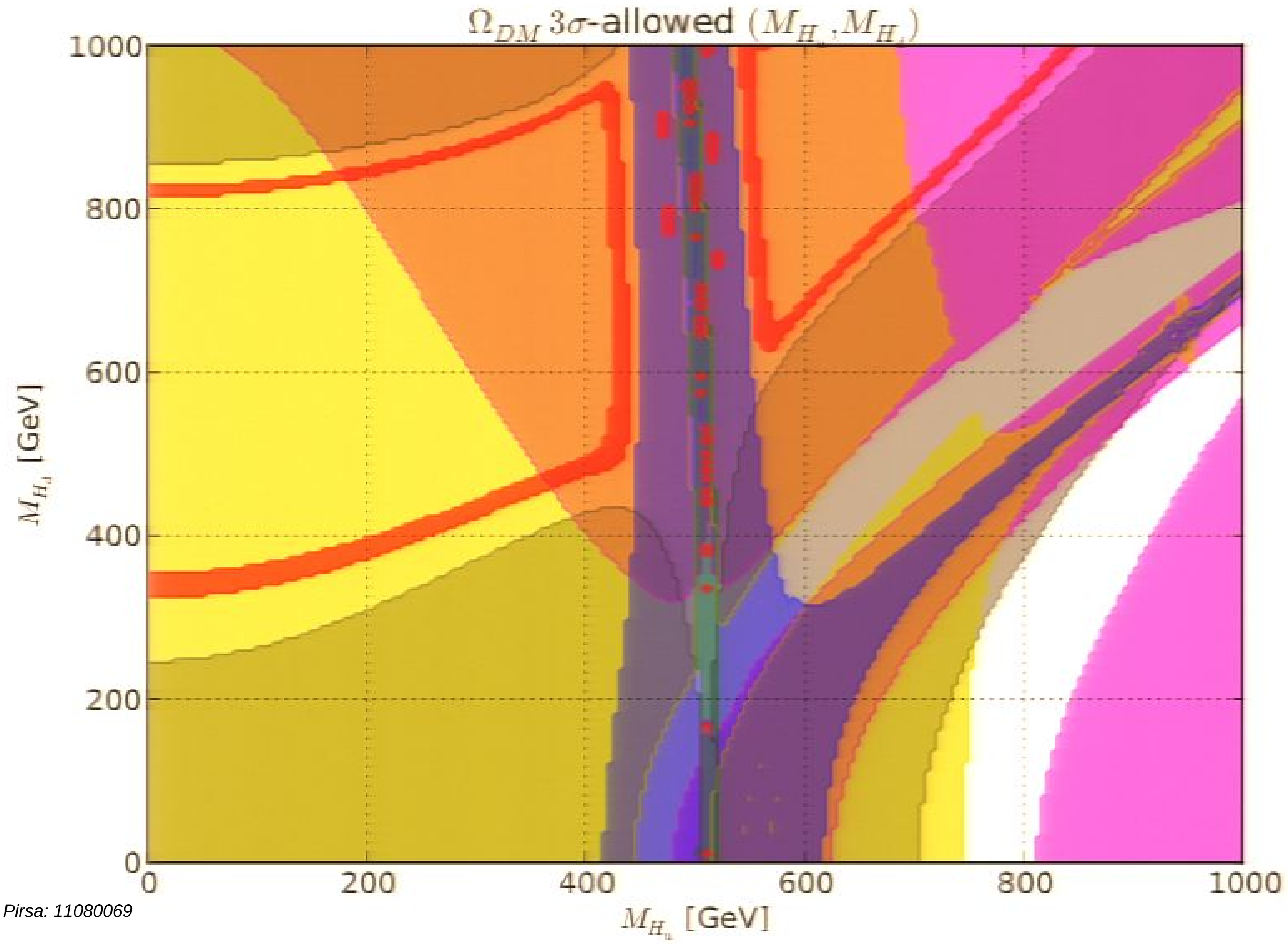
- E_6 too small, E_8 gives mirror families

Light 5*, Light 10 (3rd generation)



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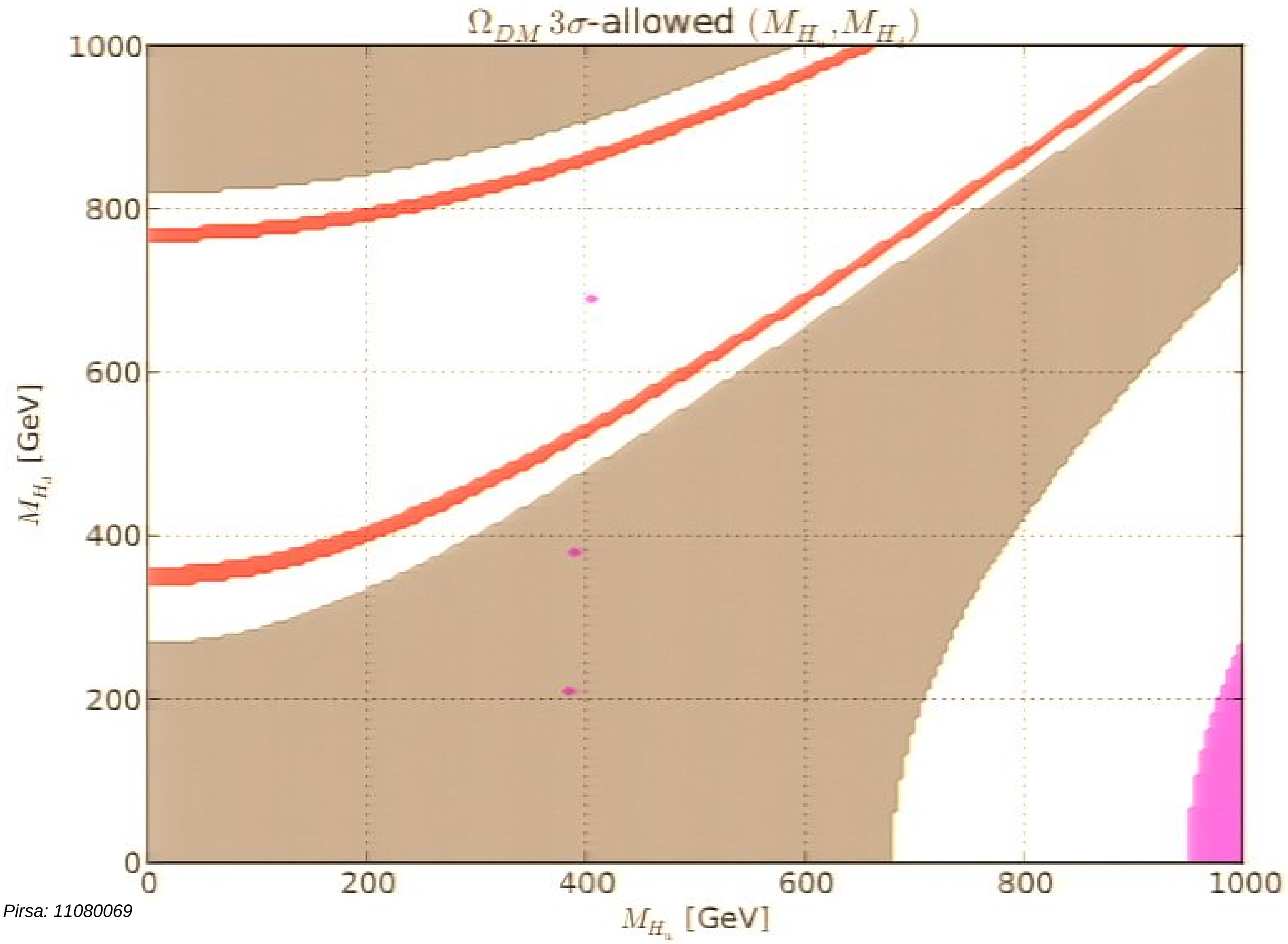

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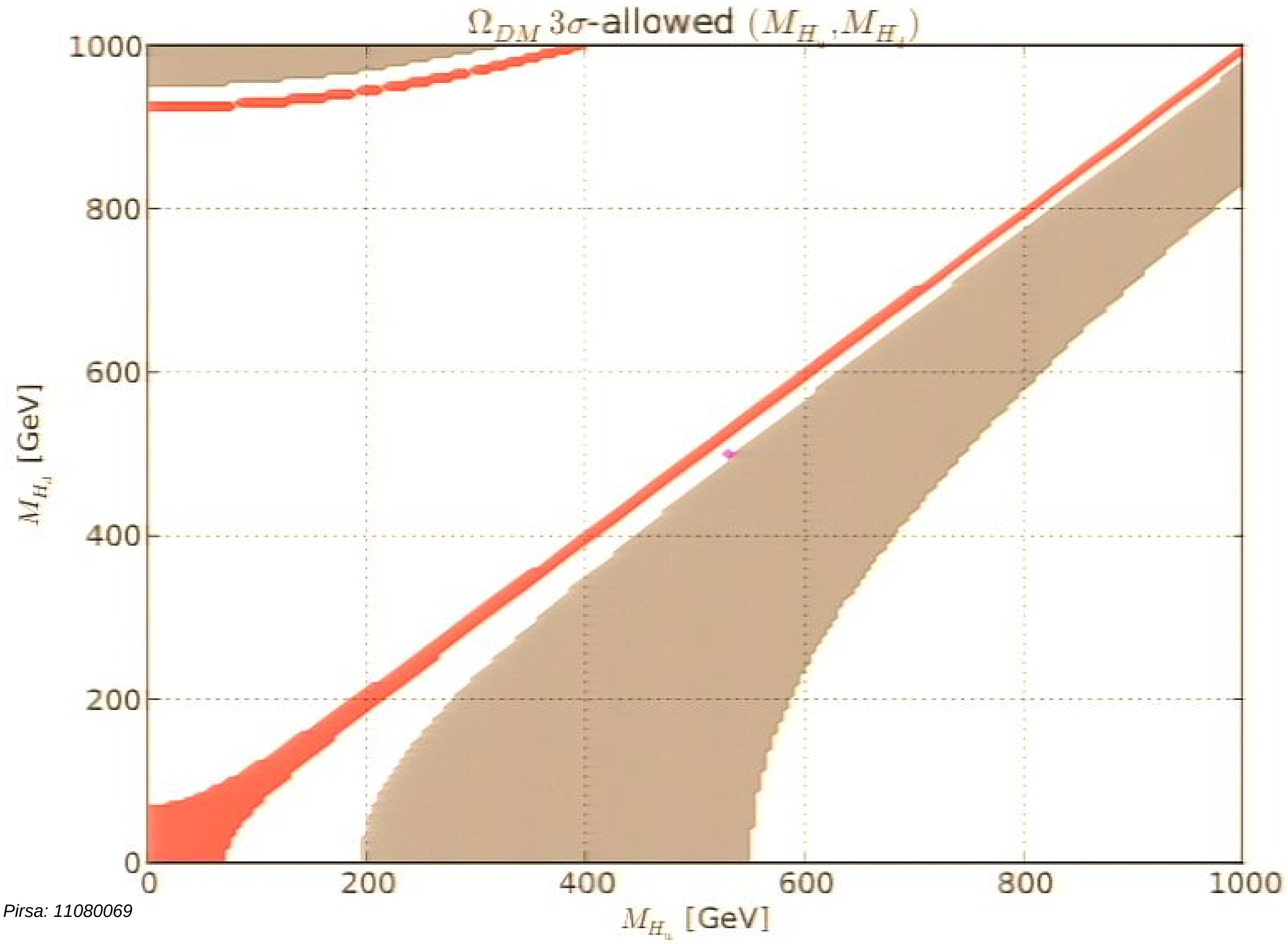

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$SU(5)$ of $E_7/SO(10)$

$SO(10) \rightarrow SU(5)$

- Global symmetry must be gauged anyway ⇒ gauge $SU(5) \subset SO(10)$
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- Superpotential:

$$W = W_Y + W_S + W_H$$

where

$$\begin{aligned} W_Y &= Y_u \cdot 10 \cdot 10 \cdot 5_H + Y_d \cdot 10 \cdot 5^* \cdot 5_H^* \\ W_S &= M_\nu \cdot 1 \cdot 1 + M_N \cdot N \cdot N \\ W_H &= \mu \cdot 5_H \cdot 5_{H*} \end{aligned}$$

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UT superpotential

Additions to superpotential

$$\Delta W = W_{\Sigma} + W_{H'}$$

where

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Outstanding issues

- Set right boundary conditions for Ω_{DM}
- Evade LHC bounds?

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$$\Sigma \sim 24 \supset (8,1) \oplus (1,3) \oplus (1,1) \oplus (3,2) \oplus (3^*,2)$$

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Choose: $\sim 10^{12}$ GeV

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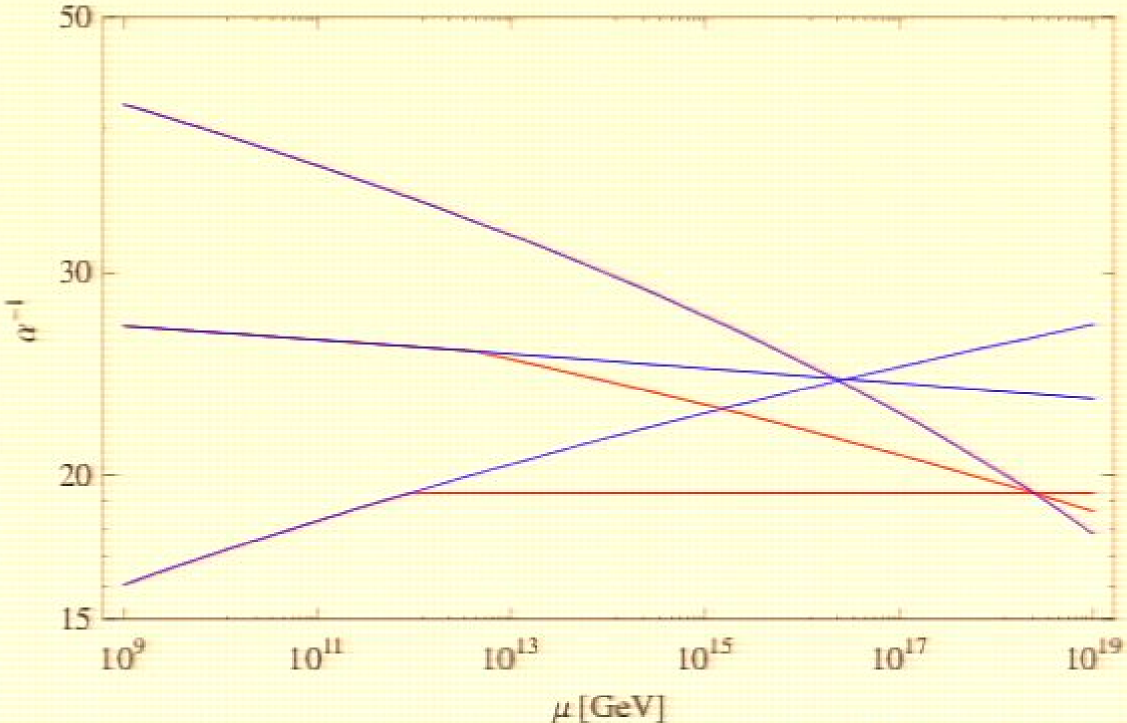

Solving the double-triplet splitting problem

Missing partner mechanism

- 50 of $SU(5)$ contains color $(3,1)$, not weak $(1,2)$
- Explicit triplet Higgs $5_H + 5^*_H$ to $50 + 50^*$ coupling

$$W_T = \lambda_T \cdot 5_H \cdot \langle 75 \rangle \cdot 50 + \text{c.c.}$$

- Huge threshold corrections?

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Product group unification

- $SU(5)_G \to SU(5)_G \times SU(3)_H \times U(1)_H$
- Diagonal

$$SU(3)_c \subset SU(3)_G \times SU(3)_H$$

$$U(1)_Y \subset U(1)_G \times U(1)_H$$

Product group unification (1/2)

Breaking

$$\bar{Q}(m+\lambda\Sigma)Q+\frac{1}{2}m_{\Sigma}\mathrm{Tr}(\Sigma^2)+hHQ\bar{q}+c.c.$$

where

$$Q\sim(5^*,3,1)\ ,\ q\sim(1,3,1)$$

and

$$\langle Q\rangle\sim vI_3\ ,\ \langle\Sigma\rangle\sim\mathrm{diag}(3,3,-2,-2,-2)$$

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Gaugino mass splitting

Modified soft breaking

$$\begin{aligned}\Delta\mathcal{L}_{SSB}= & -\frac{1}{2}M_G\lambda_G\lambda_G-\frac{1}{2}M_{H3}\lambda_{H3}\lambda_{H3}\\ & -\frac{1}{2}M_{H1}\lambda_{H1}\lambda_{H1}+c.c.\end{aligned}$$

Product gauge unification (2/2)

Gaugino mass splitting

- Re-weighted SM gaugino soft masses:

$$M_3 \Longrightarrow g_3^2 \left(\frac{M_{H3}}{g_{H3}^2} + \frac{M_G}{g_G^2} \right)$$

$$M_1 \Longrightarrow g_1^2 \left(\frac{M_{H1}}{15 g_{H1}^2} + \frac{M_G}{g_G^2} \right)$$

- Changes in low-energy phenomenology:

$$M_3 = M_{1/2} \Longrightarrow M_3 \sim 2 \times M_{1/2}$$

$$M_1 \sim M_{1/2}$$

Outline

MSSM analysis

Soft masses

- $m_{3/2} = m_{0(3)} = 1$ TeV
- $m_{0(1,2)} = 0$
- $A_0 = 0$, $m_{H_u} = m_{H_d} = 0$
- $M_{input} = M_P$

MSSM analysis

Soft masses

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Uncertainties in $\tan\beta$

- b term depends on details of Kähler potential
- Spectrum unaffected, except for small shift in $\tilde{t}$, $\tilde{b}$ masses
- Direct detection cross section varies from $4 \times 10^{-47}\,\text{cm}^2$ $(\tan\beta = 10)$ to $4 \times 10^{-46}\,\text{cm}^2$ $(\tan\beta = 50)$

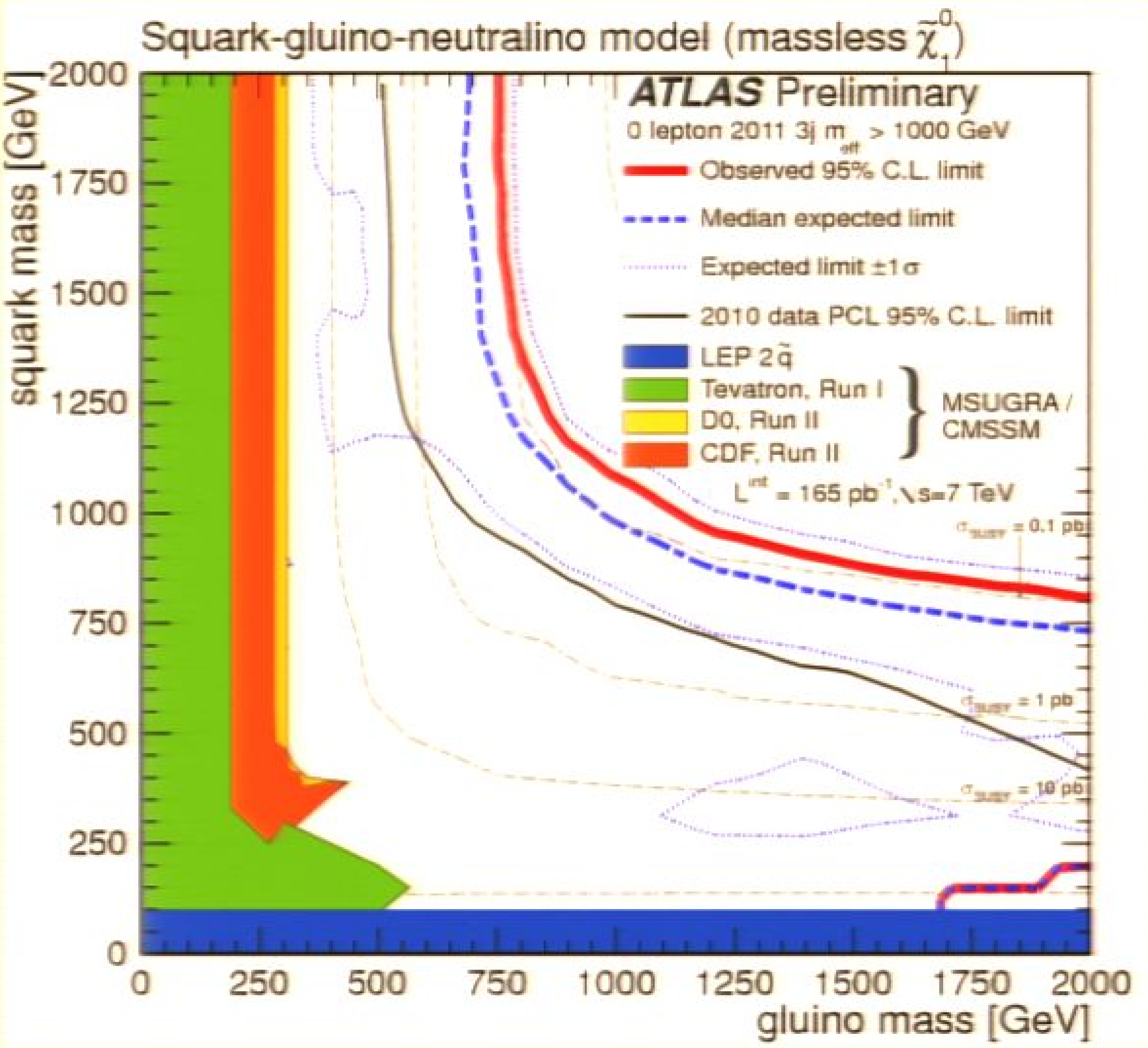
Spectra

Choose SPS1a for comparison since slepton/light gaugino spectra similar:

Field	SPS1a	$M_3 = M_{1/2}$	M_3 =500 GeV
$\tilde{\chi}_1^0$	100	100	100
$\tilde{\chi}_2^0$, $\tilde{\chi}_1^\pm$	200	200	200
$\tilde{l}_{R(1,2)}$	140	140	120
$\tilde{l}_{L(1,2)}$	200	200	200
H_0, A_0, $H^\pm$	400	1000	1000
$\tilde{\chi}_2^\pm$, $\tilde{\chi}_{3,4}^0$	380	1000	1000
$\tilde{\tau}$,$\tilde{\nu}_\tau$	200	1000	1000
$\tilde{b}_2$,$\tilde{t}_2$	550	1100	1450
$\tilde{g}$	600	830	1300
$\tilde{q}_{1,2}$	550	720	1150

utline

Newest model-independent constraints



Constraint on model points

Jets + missing E_T

≥ 3-jet signal region only 10 ± 2 SM events at $165 \mathrm{pb}^{-1}$:

	SPS1a	$M_3 = M_{1/2}$	M_3 =500 GeV
Prod. σ	4.5 pb	0.6 pb	16 fb
Efficiency	12%	28%	29%
$\mathfrak{L}(2\sigma)$	$7 \mathrm{pb}^{-1}$	$15 \mathrm{pb}^{-1}$	$10 \mathrm{fb}^{-1}$

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Multiplicities

Mistag rates: τ-jet (8%), b-jet (5%)

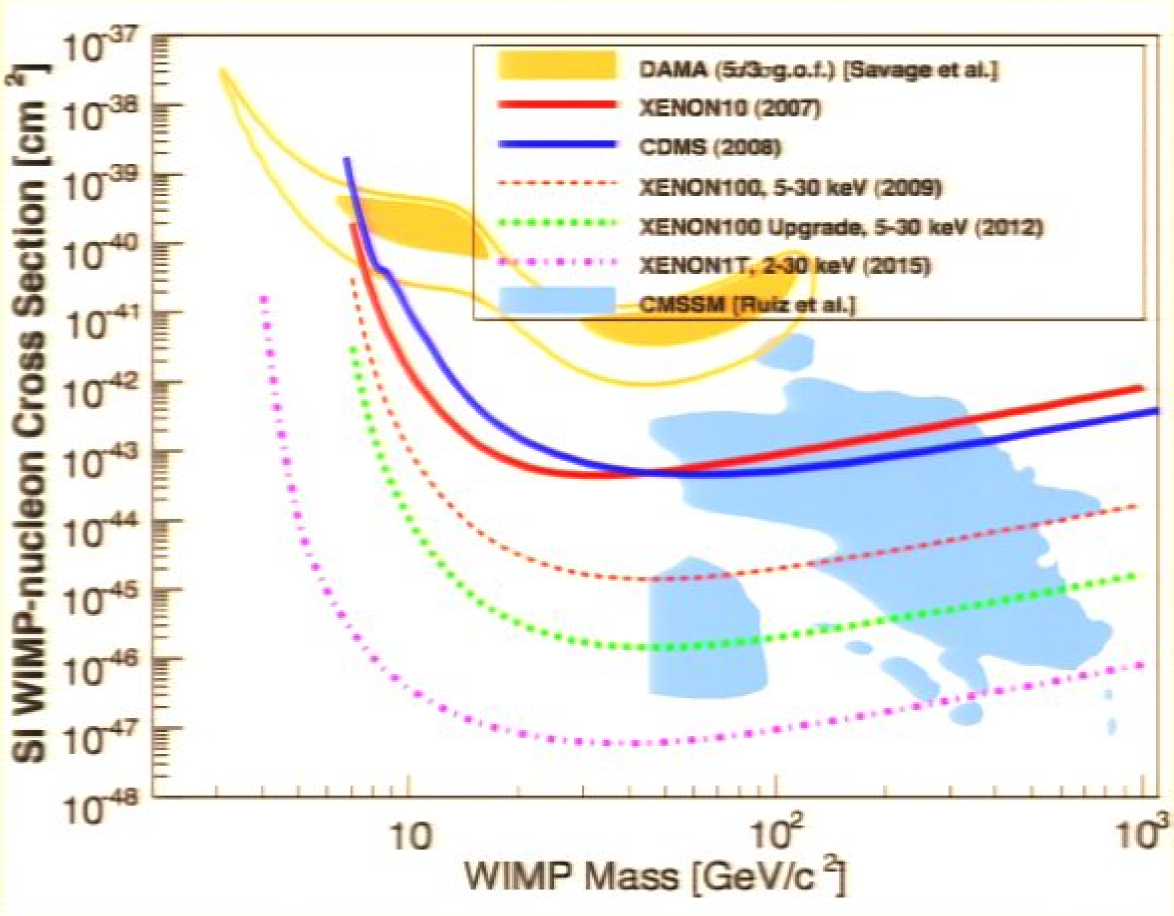
	SPS1a	$M_3 = M_{1/2}$	M_3 =500 GeV
b-jets	18%	5%	5%
τ-jets	8%	9%	9%
$n_l \geq 2$	8%	14%	14%

utline

Dark matter phenomenology

Detection

- $\sigma_{\chi N}$ excludable by XENON1T
- χ_1^0 mostly bino, $<\sigma v>_{\chi\chi}$ is p-wave suppressed



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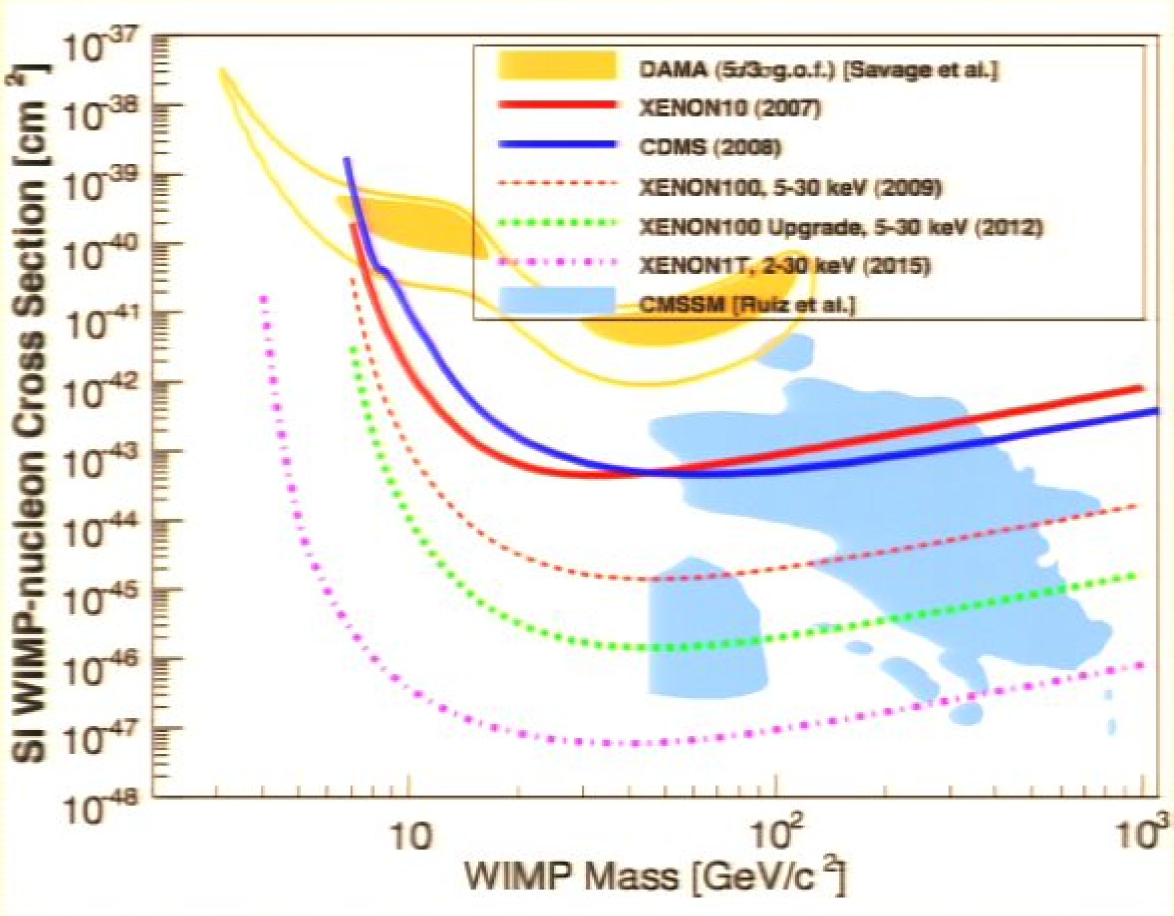

Outline

CP anomalies/flavor constraints

B_s–$\bar{B}_s \to \mu^+\mu^+(\mu^-\mu^-)$ anomaly

- 3.2σ deviation from SM prediction
- Oscillations $M(B_q) - M(\bar{B}_q)$ constrained to be small
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- Endo, Shirai, Yanagida [arXiv:1009.3366]
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- EDMs suppressed by heavy 3rd generation plus hermiticity
- Predicted lepton flavor violations in reach of future experiments

ummary

Created consistent $E_7/SO(10)$ coset model with distinctive collider signatures

Evading LHC constraints weakens flavor predictions

Can be ruled out direct detection in 2–5 years