Z' in heterotic orbifolds

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In collaborations with R. Alapisco: arXiv:1407.xxxx

& M. Goodsell, A. Ringwald: arXiv:1110.6901

Z' in stringy models

In semi-realistic stringy constructions, one finds

$$G_{SM} \times G_{hidden} \times \mathrm{U}(1)^n$$

Kobayashi et al, Buchmüller et al, Nilles et al, Braun et al, Donagi et al...
Ibáñez et al, Honecker et al,...
Faraggi et al, Dienes et al; Schellekens et al,...

Two options:

- $\longrightarrow$ very heavy Z' $(M_{Z'} \sim M_{str})$
- $\longrightarrow$ "light" Z'

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pheno: dark matter? observable exotics?
new interactions?

Pros and cons of Z's

Additional $\mathrm{U}(1)$s can be good for

- hierarchy problems
- flavor structure
- anomalous $g_\mu - 2$
- origin of dark matter
- ...

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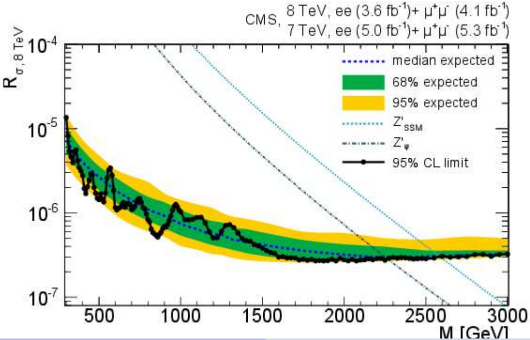
Only one problem:

CMS: 1212.6175



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Only one problem:

Can we call it advantage?

We can look for them at LHC right now!

Z' in stringy models

Very few aspects have been explored about stringy Z's

Faraggi et al; Antoniadis et al

- proton stability
- R-parity violation
- Light neutrinos
- E_6 unification compatibility
- ...

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In this talk...

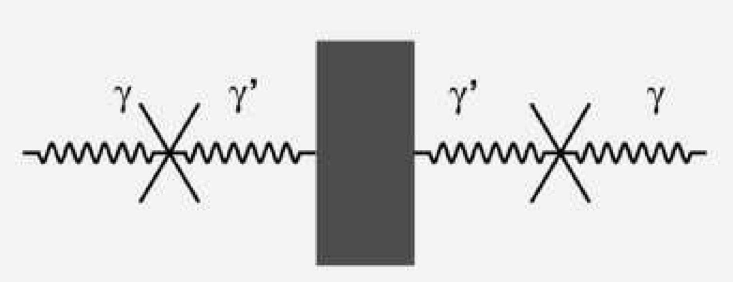
- kinetic mixing & dark matter
- gauge coupling magnitude & unification

Kinetic Mixing

& Dark Matter

Goodsell, SR-S, Ringwald

$$\mathcal{L} \supset -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{2}\chi F^{\mu\nu}B_{\mu\nu} + \frac{1}{2}{m_{\gamma'}}^2 B^{\mu}B_{\mu}$$



further: suppressed couplings to SM matter

Our scope

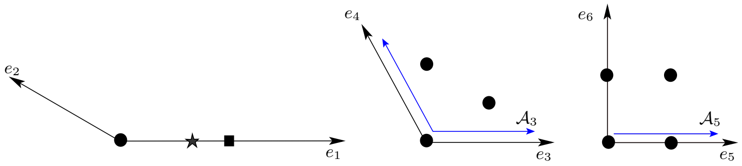
Compactify the heterotic string on $\mathbb{Z}_6$–II orbifolds

- Minilandscape $\rightarrow$ $\mathcal{O}$ (300) candidatos a MSSM

  Lebedev, Nilles, Raby, S.R-S., Ratz, Wingerter, Vaudrevange ('06-'08)

- 4D EFT is known

  Dixon, Friedan, Martinec, Shenker ('87), Kaplunovsky, Louis ('91), Mayr, Stieberger ('93),...



Kinetic mixing

In SUSY theories

$$\mathcal{L}_{\text{canonical}} \supset \int d^2\theta \left\{ \frac{1}{4} W_a W_a + \frac{1}{4} W_b W_b - \frac{1}{2} \chi_{ab} W_a W_b \right\}$$

con

$$\frac{\chi_{ab}}{g_a g_b} = \frac{b_{ab}}{16\pi^2} \log \frac{M_S^2}{\mu^2} + \Delta_{ab}$$

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Stringy kinetic mixing ☺

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Result 1: In heterotic orbifolds, stringy threshold corrections:

$$\Delta_{ab} = \sum_i \frac{b^i_{ab} |G^i|}{16\pi^2 |G|} \left[\log \left(|\eta(T_i)|^4 \text{Im}(T_i) \right) + \log \left(|\eta(U_i)|^4 \text{Im}(U_i) \right) \right]$$

$$b^i_{ab} = \frac{1}{2} \left(-2\, \text{tr}^i_{V,\mathcal{N}=2}(Q_a Q_b) + \text{tr}^i_{H,\mathcal{N}=2}(Q_a Q_b) \right)$$

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$$\frac{\chi_{ab}}{g_a g_b} = \frac{b_{ab}}{16\pi^2} \log \frac{M_S^2}{\mu^2} + \Delta_{ab}$$

Result 2: We find for all MSSM candidates of the minilandscape[a]

$$\Delta_{XY} \neq 0, \qquad 10^{-2} \lesssim \Delta_{XY} \lesssim 10^{-1}$$

Contrary to previous findings

Dienes, Kolda, March-Russell ('96)

[a] Supposing T-moduli stabilization $\langle T \rangle \sim \mathcal{O}(1)$

Dundee, Raby, Westphal; Parameswaran,SR-S,Zavala; Kappl, Petersen, Raby, Ratz, Schieren, Vaudrevange

Toy scenario of 'dark forces': dark matter

Simplest promising scenario

Morrissey, Poland, Zurek (2009)

$$W \supset \mu' \xi^+ \xi^-$$

lightest combination of ξ^+, ξ^- can lead to acceptable dark matter for $m_{\gamma'} \sim \mu' \sim m_{3/2} \sim 10\ GeV$

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In generic Minilandscape models with hidden photons:

- $G_{hidden} = \mathrm{SU}(N+1) \times \mathrm{U}(1)_x$, $\mathrm{SU}(N+1)$ gets strong int.
- few hidden “quarks” $h, \bar{h}$ in the fund. rep. of $\mathrm{SU}(N+1)$
- singlets with VEVs (such that $D = F = 0$), $\langle s_0 \rangle \sim \mathcal{O}(0.1)$
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$$W = \frac{s_0^n}{M_S}(\xi^+ \xi^-)(h\bar{h}) + s_0^m\, M_S\, (h\bar{h}) + N \left(\frac{\Lambda^{3N+2}}{\langle h\bar{h} \rangle} \right)^{1/N}$$

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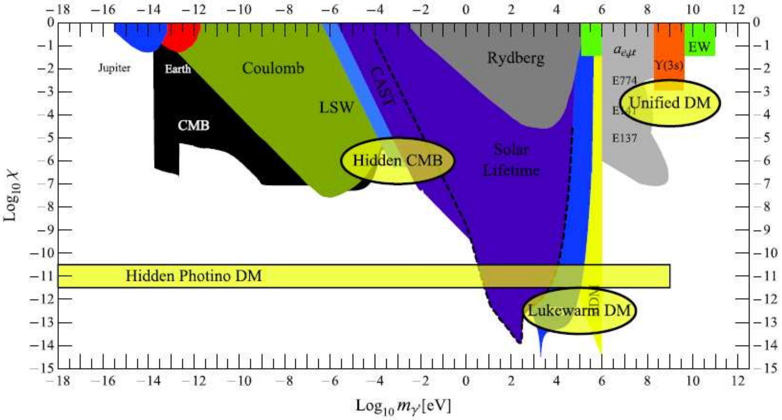
If e.g. $N = 7, n = 5, m = 8 \longrightarrow m_\xi \sim 10$ GeV para $z \sim 10^7$ ☺

Models of this type exist!! ☺

Feasible?

$$\mathcal{L} \supset -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{2}\chi F^{\mu\nu}B_{\mu\nu} + \frac{1}{2}m_{\gamma'}^2 B^\mu B_\mu$$



Goodsell, Jaeckel, Redondo, Ringwald (2009)

Z' gauge couplings

& unification

Alapisco, SR-S

Broadening our framework

See e.g. Patrick Vaudrevange's talk

There are plenty of MSSM candidates beyond the minilandscape

P	lattice	# MSSM-like models
$\mathbb{Z}_6$-I	1	31
$\mathbb{Z}_6$-I	2	31
$\mathbb{Z}_8$-I	1	271
$\mathbb{Z}_8$-I	2	164
$\mathbb{Z}_8$-I	3	402
$\mathbb{Z}_8$-II	1	1264
$\mathbb{Z}_8$-II	2	448

Compare to models found by Nilles+Vaudrevange (1403.1597) and by Groot-Nibbelink+Orestis (1308.5145)

Priors and goals

Facts:

- $\sin^2\theta_w \sim 0.23\,,\ \alpha_{em}^{-1} \sim 128\,,\ \alpha_3^{-1} \sim 8.4 \quad @\ M_Z \sim 91\ GeV$
- in our models: $G_{SM} \times G_{hidden} \times \mathrm{U}(1)^n\,, \quad 2 \leq n \leq 8$

  $+$ a bunch of (SM-vectorlike) exotics

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- there is unification at large energies
- SUSY is broken due to gaugino condensation in G_{hidden} and gravitationally mediated

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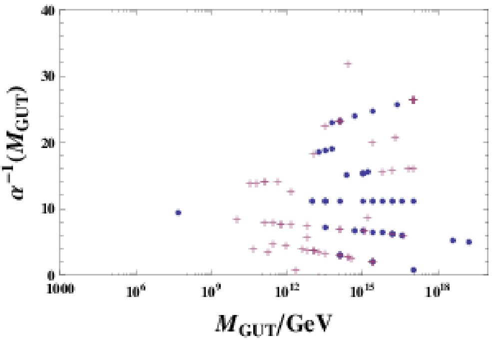
Main questions

- What's the size of g_s @ M_{GUT}?
- What's the size of $\alpha_{Z'}$ @ low energies?

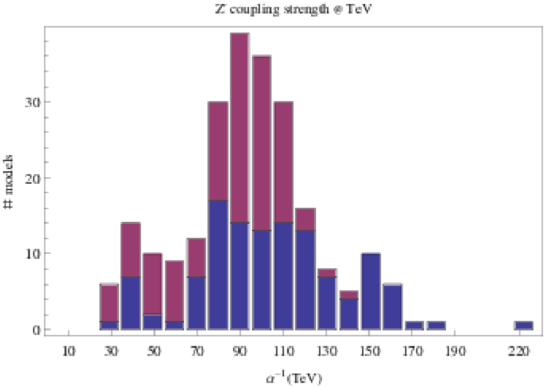
Results



based on 1-loop RGEs

$$\Longrightarrow \quad \alpha_s^{-1}(M_{GUT}) = \frac{4\pi}{g_s^2(M_{GUT})} = 4\pi\langle S\rangle \in (1,25)$$

Results



with $\Lambda \sim M_{GUT} e^{-2\pi\alpha_s^{-1}(M_{GUT})/b}$,

$$m_{3/2} \sim \Lambda^3/M_{Pl}^2$$

and letting $\alpha_{Z'}$ run down according to the RGEs

$$\Longrightarrow \quad g_{Z'}^2 \in (1/20, 1/2)$$

Conclusions

- Broadening the search for (inequivalent) MSSM-like models, one finds many more models ☺ $\rightarrow$ full classification still missing
- Many Z' candidates in string models, some of which may be light
- There are couplings in semi-realistic models that may lead to admissible dark matter scenarios ☺
- Computing the running of couplings, unification still possible with additional $\mathrm{U}(1)$s ☺
- @ M_{GUT}, $4\pi\langle S\rangle \in (1, 25)$ $\rightarrow$ dilaton constraint? ☺
- @ $\sim TeV$, $g^2_{Z'} \in (1/20, 1/2)$!! ☺
- $m_{Z'}$ very difficult to obtain without a new hierarchy ☹

Conclusions

To be done

- Threshold corrections ?
- Phenomenology and classification of Z's (Lebedev, SR-S)
- Full classification of orbifold models with Z' (Escalante, SR-S)
- Hierarchy associated to accidental symmetries?
- Stability and constraints due to Higgs/cosmological data?
- Proper study of proton stability in the various cases?