UNIVERSITY OF LIVERPOOL

A Low-scale Z' in Heterotic String Models

SUSY 2014, Manchester
25th July

A. E. Faraggi and **Viraf M. Mehta**:
Physical Review **D84** (2011), arXiv:1106.3082[hep-ph]
Physical Review **D88** (2013), arXiv:1304.4230[hep-ph]
with P. Athanasopoulos: *Physical Review* **D89** (2014), arXiv:1401.7153[hep-th]

Motivation

Proton Stability

- B and L numbers accidentally preserved in SM
- SUSY introduces problematic operators: QLD, UDD, ...

- Bottom-up
  - Discrete symmetries
    Mohapatra 1986, Martin 1989,...
  - Gauged B and L
    Perez and Wise 2010,...
- Top-down
  - Gauged B-L
    Nanopoulos et al 1990, Ovrut 2005,...
  - R-symmetries
    Kobayashi et al 2006,...

Light *U(1)*s

Stringy $U(1)_{Z'}$: 2011/13 Proposal

- Combination of *B*-*L*, T_{3_R}, and $U(1)_\zeta \not\subset SO(10)$

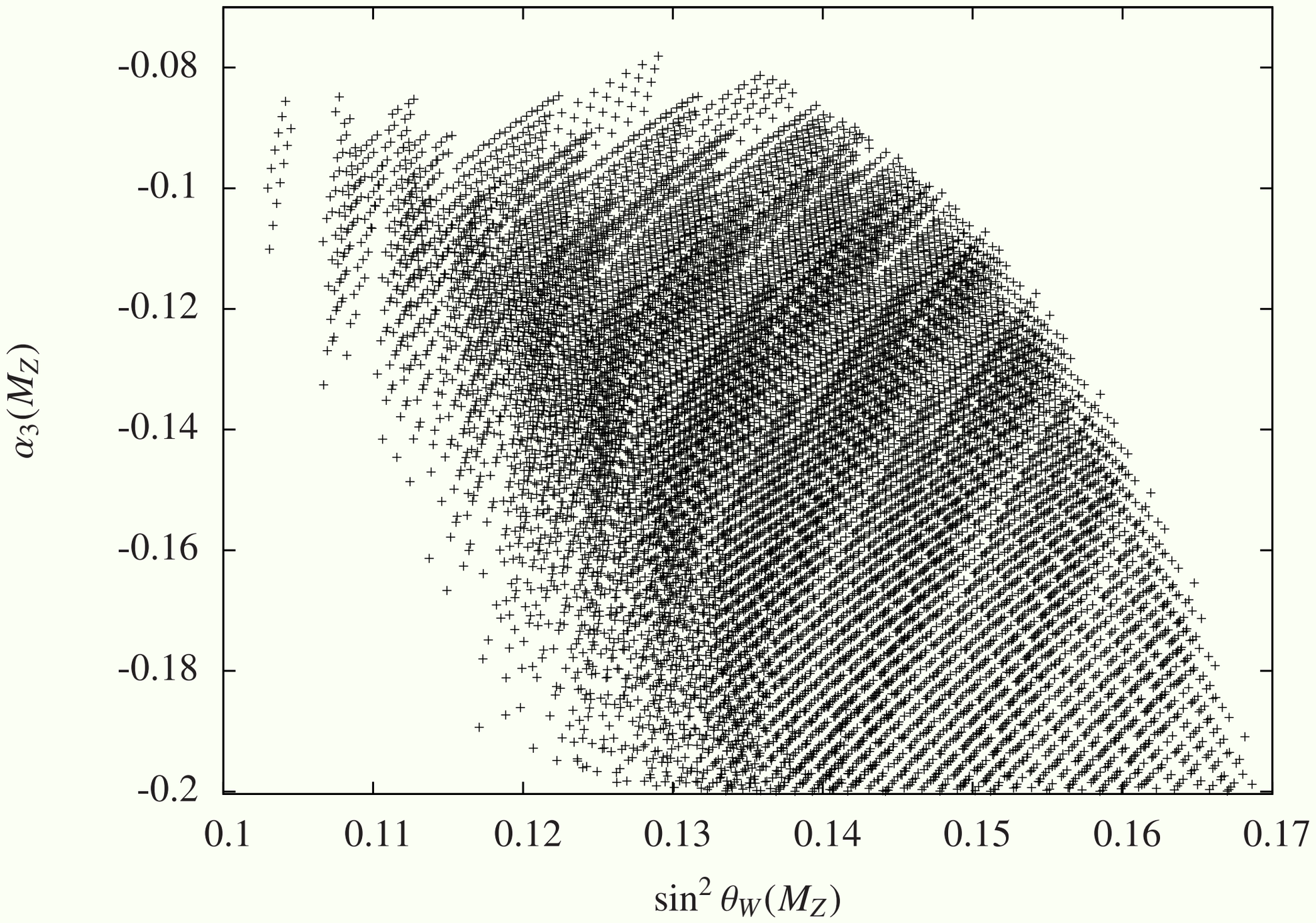
- Properties:

  - ✓ Proton decay mediating operators forbidden
  - ✓ Seesaw mechanism for $m_\nu \sim 1\,\mathrm{eV}$
  - ✓ EW Yukawas invariant
  - ✓ Family Universal
  - ✓ Anomaly free

- Satisfies low-scale gauge coupling data?

Low-scale Gauge Couplings

Stringy $U(1)_{Z'}$: 2011/13 Proposal



E_6 Embedding Required!

A way out?

The Heterotic String

- 10D $\longrightarrow \mathbb{R}^4 \times \mathcal{M}^6$
  - $\mathcal{M}^6 = T^6/G$ Orbifolds
  - $\mathcal{M}^6 = \mathrm{CY}_3$ Calabi-Yau
- 4D
  - Gepner models
  - Free Fermionic constructions

Donagi, Faraggi, Florakis, Kiritsis, Kounnas, Wendland,...

Equivalent descriptions?

The Heterotic String

- 10D $\longrightarrow \mathbb{R}^4 \times \mathcal{M}^6$
  - $\mathcal{M}^6 = T^6/G$ Orbifolds
  - $\mathcal{M}^6 = \mathrm{CY}_3$ Calabi-Yau
- 4D
  - Gepner models
  - Free Fermionic constructions

Athanasopoulos, Faraggi, Groot Nibbelink, VMM 2014

Mapping

The Heterotic String

Free Fermions

superpartners of X^μ

"compactified" directions

hidden gauge group generators

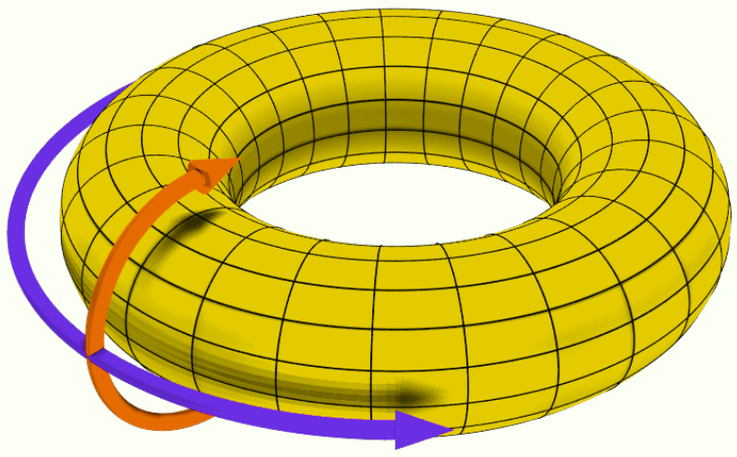
$$\psi^\mu, \chi^i, \overline{y^i, w^i | \overline{y}^i, \overline{w}^i}, \overline{\psi}^{1,\ldots,5}, \overline{\eta}^{1,2,3}, \overline{\phi}^{1,\ldots,8}$$

superpartners of compactification bosons

visible gauge group generators

The Heterotic String

Free Fermions



- Fermion phases describe these *i.e.*

$$f \to -e^{i\pi\alpha(f)} f$$

- $\mathcal{M}^6$ describes symmetry breaking, matter, SUSY, ...

- Basis vectors describe parallel transport of worldsheet fermions

- Basis vectors + GGSOs = Models

- Must satisfy *ABK rules* for modular invariance

Antoniadis, Bachas, Kounnas 1986

The Heterotic String

The NAHE Set

Antoniadis *et al.* 1987

SUSY

$\mathcal{N}=0$ $\quad \mathbb{1} = \{\mathrm{ALL}\}$

$\mathcal{N}=4$ $\quad \mathbf{S} = \{\psi^\mu, \chi^{1,\ldots,6}\}$

Fermions that appear are periodic *i.e.* do not transform

$\mathcal{N}=2$ $\quad \mathbf{b}_1 = \left\{\psi^\mu, \chi^{12}, y^{3,\ldots,6} \,|\, \overline{y}^{3,\ldots,6}, \overline{\psi}^{1,\ldots,5}, \overline{\eta}^1\right\}$

$\mathcal{N}=1$ $\quad \mathbf{b}_2 = \left\{\psi^\mu, \chi^{34}, y^{1,2}, w^{5,6} \,|\, \overline{y}^{1,2}, \overline{w}^{5,6}, \overline{\psi}^{1,\ldots,5}, \overline{\eta}^2\right\}$

$\mathcal{N}=1,0$ $\quad \mathbf{b}_3 = \left\{\psi^\mu, \chi^{56}, w^{1,\ldots,4} \,|\, \overline{w}^{1,\ldots,4}, \overline{\psi}^{1,\ldots,5}, \overline{\eta}^3\right\}$

$$\Rightarrow SO(10) \times SO(6)^3 \times E_8'$$

The Heterotic String

SO(10) breaking

- *SO(10)* breaking patterns defined by phases of $\overline{\psi}^{1,\ldots,5}$
  - I. FSU5, Pati-Salam, Standardlike

    Antoniadis *et al.* 1987-89, Leontaris *et al.* 1990, Nanopoulos *et al.* 1990
  - II. Left-Right Symmetric, $SU(4) \times SU(2) \times U(1)$

    Cleaver *et al.* 2000, Cleaver *et al.* 2003
- Both classes require basis vectors beyond NAHE, $\{\alpha, \beta, \gamma\}$

The Heterotic String

*U(1)*s from Free Fermions

- Generated by worldsheet currents
  - e.g. $J_\zeta = \overline{\eta}^{1*}\overline{\eta}^{1} + \overline{\eta}^{2*}\overline{\eta}^{2} + \overline{\eta}^{3*}\overline{\eta}^{3}$
- All gauge fermions may generate *U(1)*s similarly
  - *e.g. SO(6)*s broken to *U(1)*s
- NAHE based models *all* contain $U(1)_\zeta$
- Anomaly freedom relies on embedding

*U(1)*s in Heterotic String Models

Anomalies

I.

- Originate in $E_8 \times E_8 \times SO(12)$
- GGSOs and $\mathbf{b}_1, \mathbf{b}_2$ break to
$$SO(10) \times U(1)_\zeta \subset E_6$$
- **16**s or **10**s projected

$U(1)_\zeta$: Anomalous!

II.

- Originate in $E_7 \times E_7 \times SO(16)$
- $\mathbf{b}_1, \mathbf{b}_2$ break to
$$SO(10) \times U(1)_\zeta \not\subset E_6$$
- Components of **16** have charge of opposite sign

Anomaly free!

*U(1)*s in Heterotic String Models

- Low-scale coupling data demands E_6
- Nice features of $U(1)_\zeta$ lost
- 2 possible solutions:
  - Break E_6 to different subgroup e.g. $SU(6) \times SU(2)$
  - Subclass of E_6 models with **10+1**s and **16**s at different fixed points ➡ Fill **27** rep

Faraggi, Kounnas, Rizos 2006

*U(1)*s in Heterotic String Models

- Low-scale coupling data demands E_6
- ~~Nice features of $U(1)_\zeta$ lost~~
- 2 possible solutions:
  - Break E_6 to different subgroup e.g. $SU(6) \times SU(2)$
  - Subclass of E_6 models with **10+1**s and **16**s at different fixed points ➡ Fill **27** rep

Faraggi, Kounnas, Rizos 2006

Enhancement

The **x** vector

$$\mathbf{x} \equiv \left\{ \overline{\psi}^{1,\ldots,5}, \overline{\eta}^{1,2,3} \right\}$$

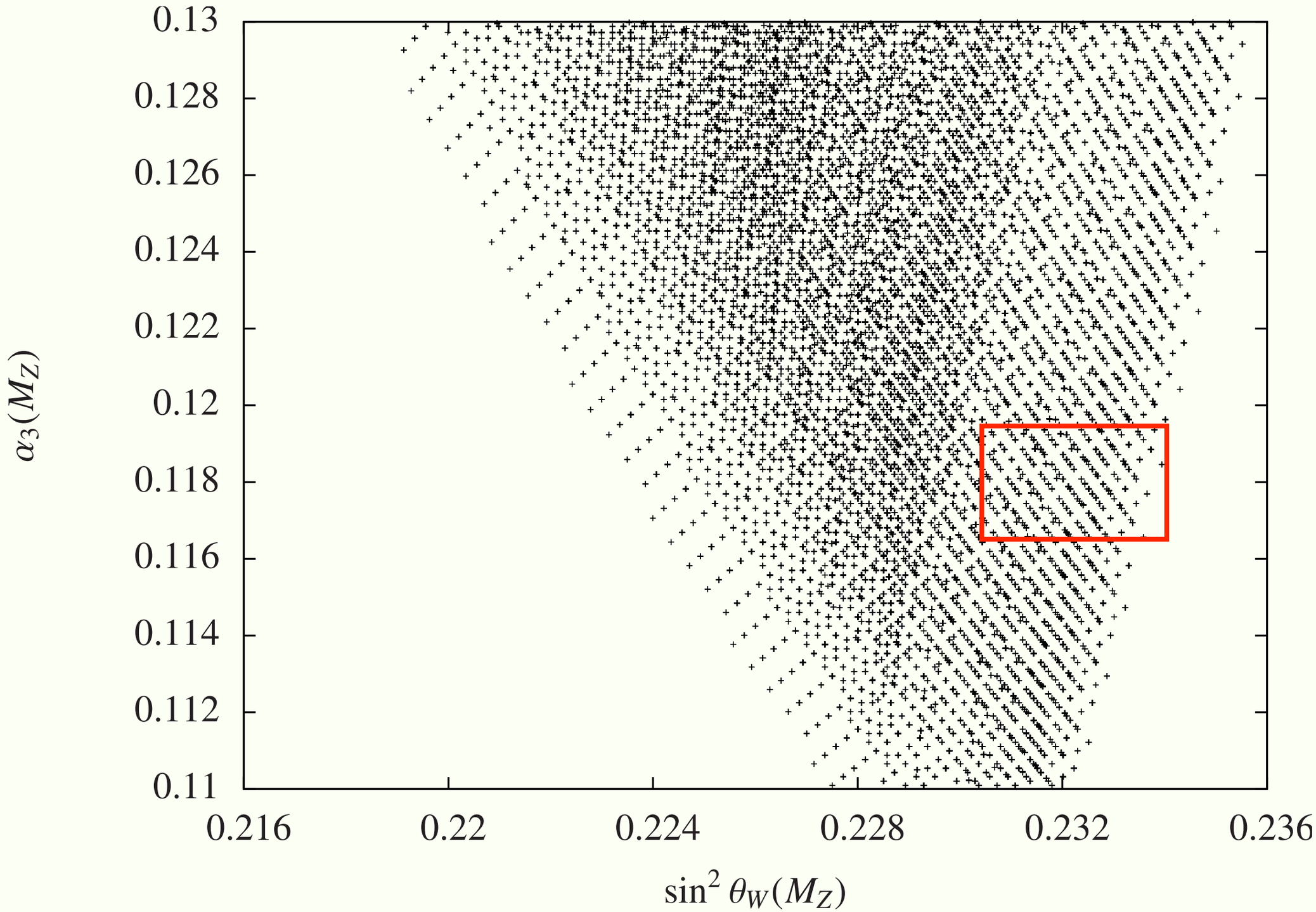
- Enhancing gauge bosons
- Projected out in NAHE based models
- Keep them to lift $SU(2) \times U(1)^4 \to SU(3) \times SU(2) \times U(1)^2$
- Allows $U(1)_{\zeta'}$ to be linear combination of B-L, T_{3_R}, and $U(1)_\zeta$
- NICE FEATURES REMAIN!

Model Highlights

- Full **27** up to Z'-scale
- NMSSM-like spectrum
  - + r.h. neutrino
  - + heavy triplets/doublets
  - + singlets

Low-scale Gauge Couplings

Stringy $U(1)_{Z'}$: 2014 Proposal



Conclusions and Outlook

2013

- E_6 required for matching of low-scale gauge coupling data
- E_6 disfavoured for anomaly free *U(1)*
- $U(1)_\zeta$ combination cannot be light
- Must lift to E_6 embedding but preserve full **27**
  - **Difficult with heterotic description...**

Conclusions and Outlook

2014

... but not impossible.

- Enhance with **x** basis vector
- Possible to allow for full **27** to remain
- Models accommodate low-scale gauge couplings
- Field theory analysis being conducted using `SARAH`

Ashfaque, Faraggi, Mehta, *To appear*, August 2014

- Explicit E_6 string model to be computed

Mehta, *To appear*, 2014

Thank you