# Topics in RCFT Orientifolds

# Orientifold Partition Functions

- Closed $$\frac{1}{2}\left[\sum_{ij}\chi_i(\tau)Z_{ij}\chi_i(\bar{\tau})+\sum_i K_i\chi_i(2\tau)\right]$$

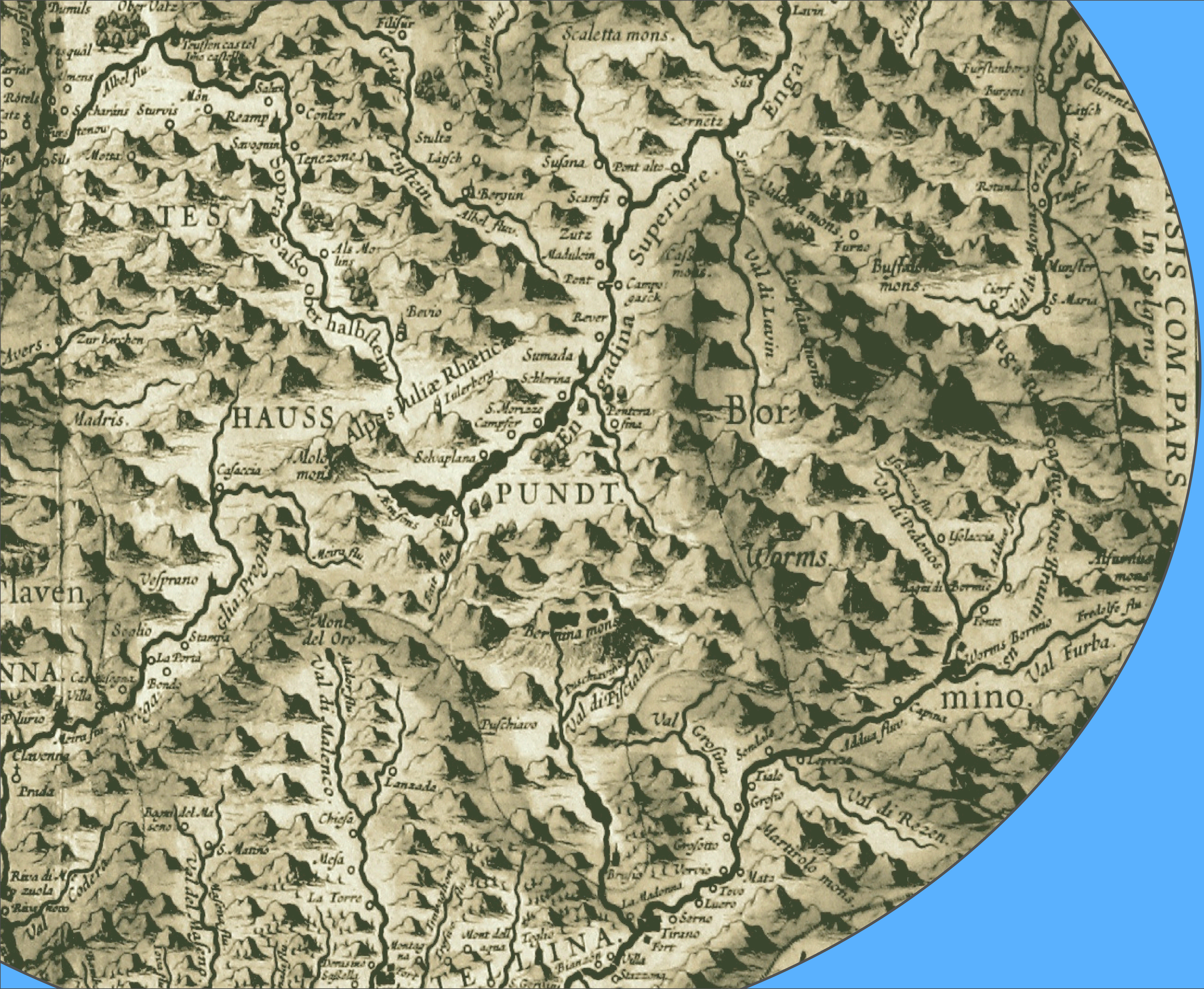
- Open $$\frac{1}{2}\left[\sum_{i,a,n}N_aN_bA^i{}_{ab}\chi_i(\frac{\tau}{2})+\sum_{i,a}N_aM^i{}_a\hat{\chi}_i(\frac{\tau}{2}+\frac{1}{2})\right]$$

$i:$ Primary field label (finite range)

$a:$ Boundary label (finite range)

$\chi_i:$ Character

$N_a:$ Chan-Paton (CP) Multiplicity



Scaletta mons.
Enga
Superiore.
Engadina
En
Sopra Salso
ober halbstein
Alpes Juliæ Rhæticæ
HAUSS
PUNDT.
Bor
mino.
Worms.
Zernetz
Sus
Lavin
Furstenberg
Burgeis
Glurentz
Latsch
Rotund
Taufer
Munster
S. Maria
Cierf
Val di Lavin
Val di Munster
Buffalora mons.
Furno
Valdera mons.
Casa mons.
Pont alto
Susana
Scamfs
Zutz
Madulein
Pont
Campogasck
Bever
Samada
Schlerina
Pontresina
S. Morizzo
Campfer
Selvaplana
Bergun
Albel flu.
Latsch
Stultz
Filisur
Conter
Tenezone
Savognin
Reamp
Sturvis
Mon
Salux
Als Mollins
Bevio
Julerberg
Molo mons
Casaccia
Maira flu.
Avers
Zur kirchen
Madris
Vespreno
Claven
Soglio
Stampa
La Porta
Bondo
Castasegna
Villa
Plurio
Clavenna
Prada
Bagni del Maseno
S. Martino
Riva di Mezzola
Codera
Val del Maseno
Val di Malenco
Chiesa
Mesa
La Torre
Lanzada
Mont del Oro
Bernina mons
Puschiavo
Val di Pisciadel
Val Grosina
Grosotto
Vervio
Brusio
Mata
Tevo
Lovero
Sernio
Tirano
La Madonna
Villa
Stazzona
Mont dell agua
Teglio
TELLINA.
Mortirolo mons.
Val di Rezen
Tiolo
Grosio
Sondalo
Capina
Addua flu.
Val Furba
Worms Bormio
Fredolfo flu.
Alfurnus mons
Bagni di Bormio
Ysolaccia
Val di Pedenos
Ysolaccia flu.
In Sulgen.
...SIS COM. PARS.


Free Fields
Scaletta mons.
Superiore.
Engadina
En
HAUSS
PUNDT.
Alpes Juliae Rhaeticae
Bor
Worms.
mino.
Val Furba.
Val di Lavin.
Val di Pedenos.
Val di Malenco.
Val di Pisciadel
Val Grosina
Bernina mons
Claven
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Sopra Salso
ober halbstein
Albel flu.
Zernetz
Pont alto
Susana
Scamfs
Zutz
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Sumada
Schlerina
S. Morizza
Campfer
Selvaplana
Sils
Casaccia
Vesprano
Soglio
Stampa
La Porta
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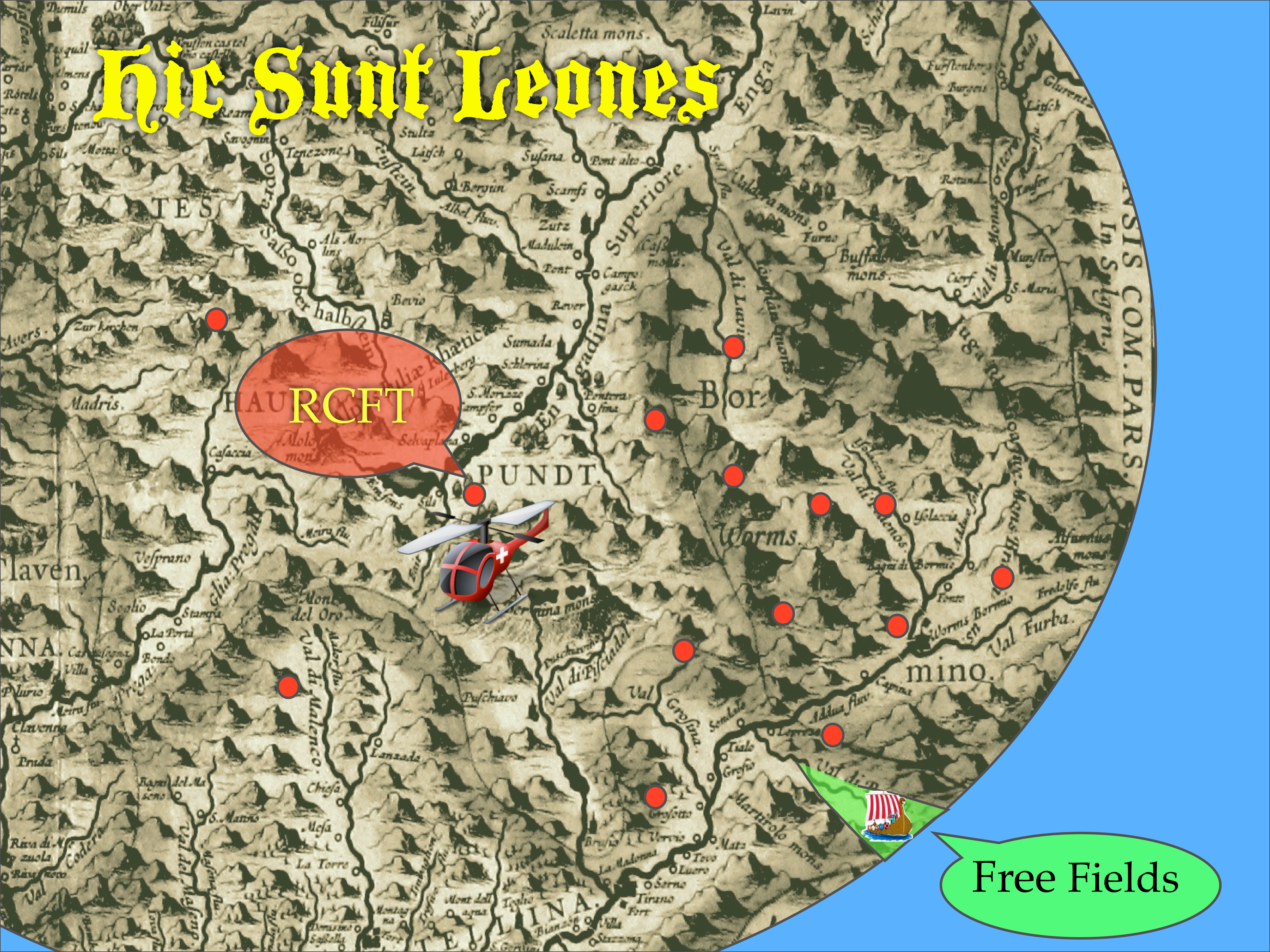
Puschiavo
Lanzada
Chiesa
Mesa
La Torre
Tirano
Sernio
Lovero
Mazo
Grosotto
Tiolo
Sondalo
Capina
Bagni di Bormio
Worms Bormio
Yolaccia
Burgeis
Munster
S. Maria
Furno
Buffalora mons.
Bergyin
Bevio
Tenezone
Savognin
Reamp
Conter
Stulta
Lavin
Sus
Furstenberg
Glurenz
Tausser
Rotund
Mon
Sturvis
Motta
Zur kirchen
Molo mons
Mont del Oro
Martirolo mons
Stazzona
Villa
Bianzon
Tellina
In Selgen.
COM. PARS.
Chiavenna
Prada
Riva di Mezzola


RCFT
Free Fields


Hic Sunt Leones
RCFT
Free Fields

## What we can compute

- Exact perturbative string spectra
- Gauge couplings in rational points

## What we can't do (yet)

- Compute Yukawa couplings
- Compute couplings to moduli
- Perturbations around rational points
- Moduli stabilization
- ...

# Algebraic choices

- Basic CFT (N=2 tensor[1], free fermions[2]...)
- Chiral algebra extension

  May imply space-time symmetry (e.g. Susy: GSO projection).

  **But this is optional!**

  Reduces number of characters.
- Modular Invariant Partition Function (MIPF)

  May imply bulk symmetry (e.g Susy), not respected by all boundaries.

  Defines the set of boundary states

  (Sagnotti-Pradisi-Stanev completeness condition)
- Orientifold choice

[1] Dijkstra, Huiszoon, Schellekens (2005);
Anastasopoulos, Dijkstra, Kiritsis, Schellekens (2006)

[2] Kiritsis, Lennek, Schellekens, to appear.

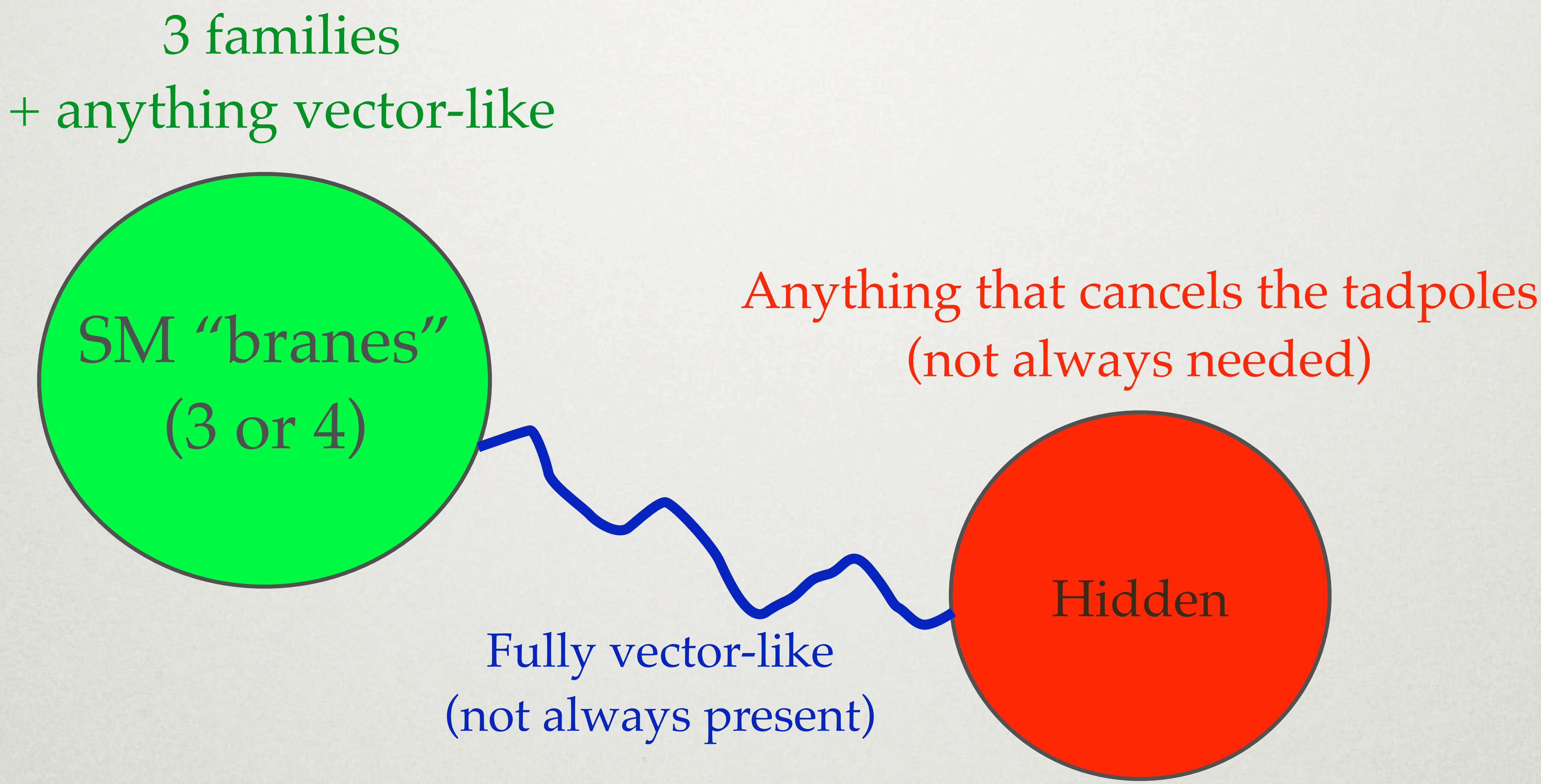
# Consistency conditions

- Tadpole cancellation
- Absence of axion mixing for Y
- Global anomalies*

Same as for all other orientifold models

(*) "probe branes" (Uranga)
B. Gato-Rivera and A.N Schellekens, Phys.Lett.B632:728-732,2006

# SM realization

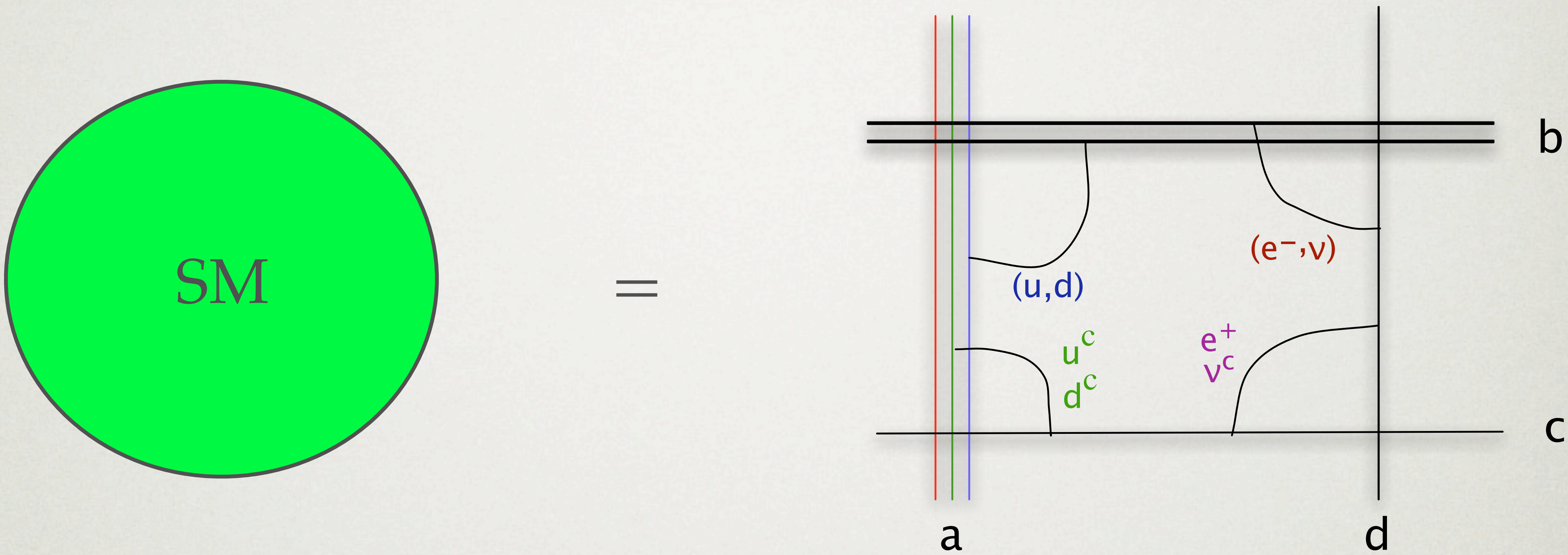



Vector-like: mass allowed by SU(3) × SU(2) × U(1)

Fully vector-like: mass allowed by all gauge symmetries

# DHS RESULTS (2004-2005)

Huiszoon, Dijkstra, Schellekens




210000 distinct tadpole-free spectra found

# Best imaginable result:

The exact MSSM spectrum

```
Gauge group: U(3) x Sp(2) x U(1) x U(1)

  7 x (V ,V ,0 ,0 ) chirality 3
  3 x (V ,0 ,V ,0 ) chirality -3
  3 x (V ,0 ,V*,0 ) chirality -3
  9 x (0 ,V ,0 ,V ) chirality 3
  5 x (0 ,0 ,V ,V ) chirality -3
  3 x (0 ,0 ,V ,V*) chirality 3
  6 x (V ,0 ,0 ,V )
 10 x (0 ,V ,V ,0 )
  2 x (Ad,0 ,0 ,0 )
  2 x (A ,0 ,0 ,0 )
  6 x (S ,0 ,0 ,0 )
 14 x (0 ,A ,0 ,0 )
 10 x (0 ,S ,0 ,0 )
  9 x (0 ,0 ,Ad,0 )
  6 x (0 ,0 ,A ,0 )
 14 x (0 ,0 ,S ,0 )
  3 x (0 ,0 ,0 ,Ad)
  4 x (0 ,0 ,0 ,A )
  6 x (0 ,0 ,0 ,S )
```

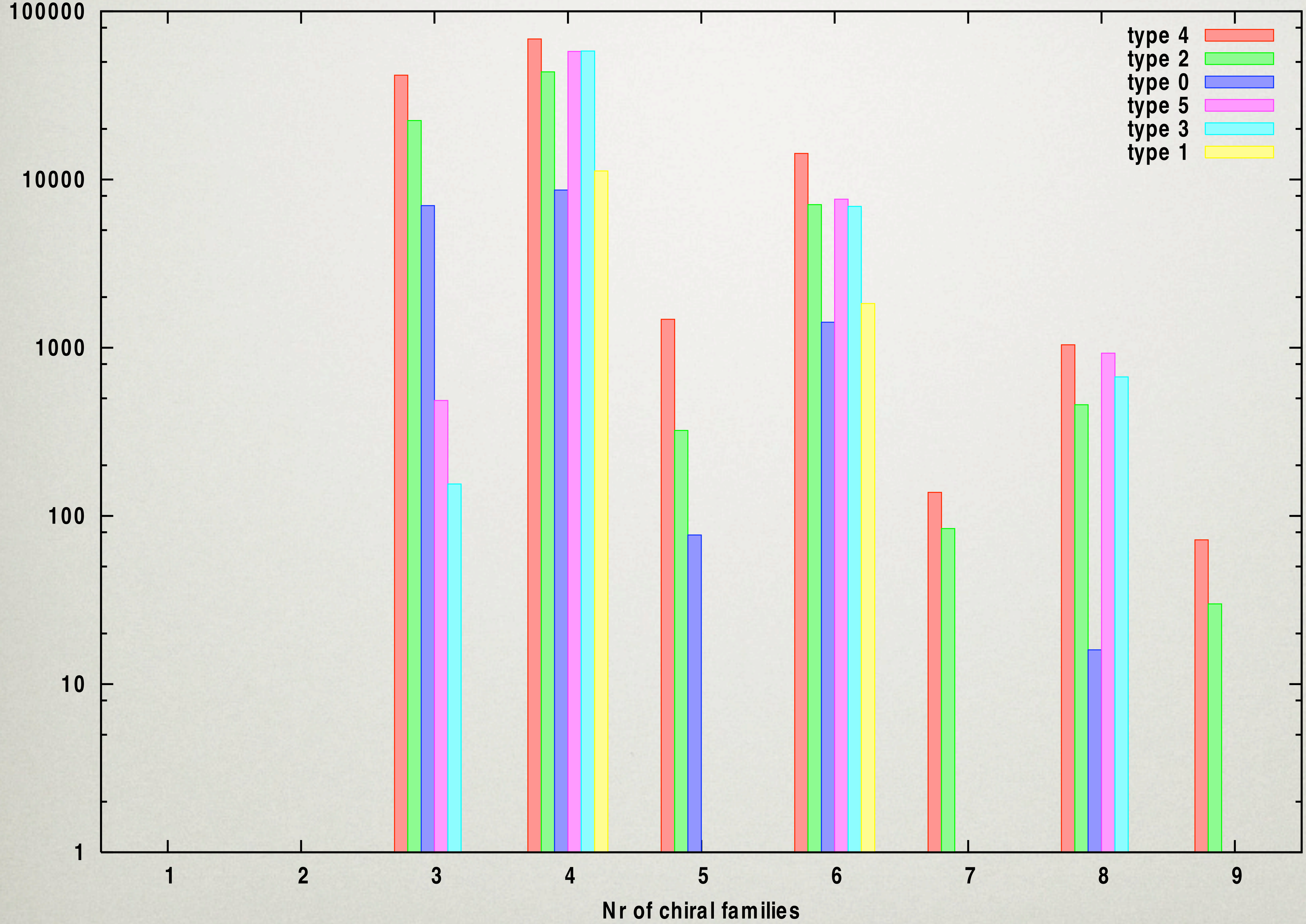
$$Y = \frac{1}{6}Q_{\mathrm{a}} - \frac{1}{2}Q_{\mathrm{c}} - \frac{1}{2}Q_{\mathrm{d}}$$

No hidden sector

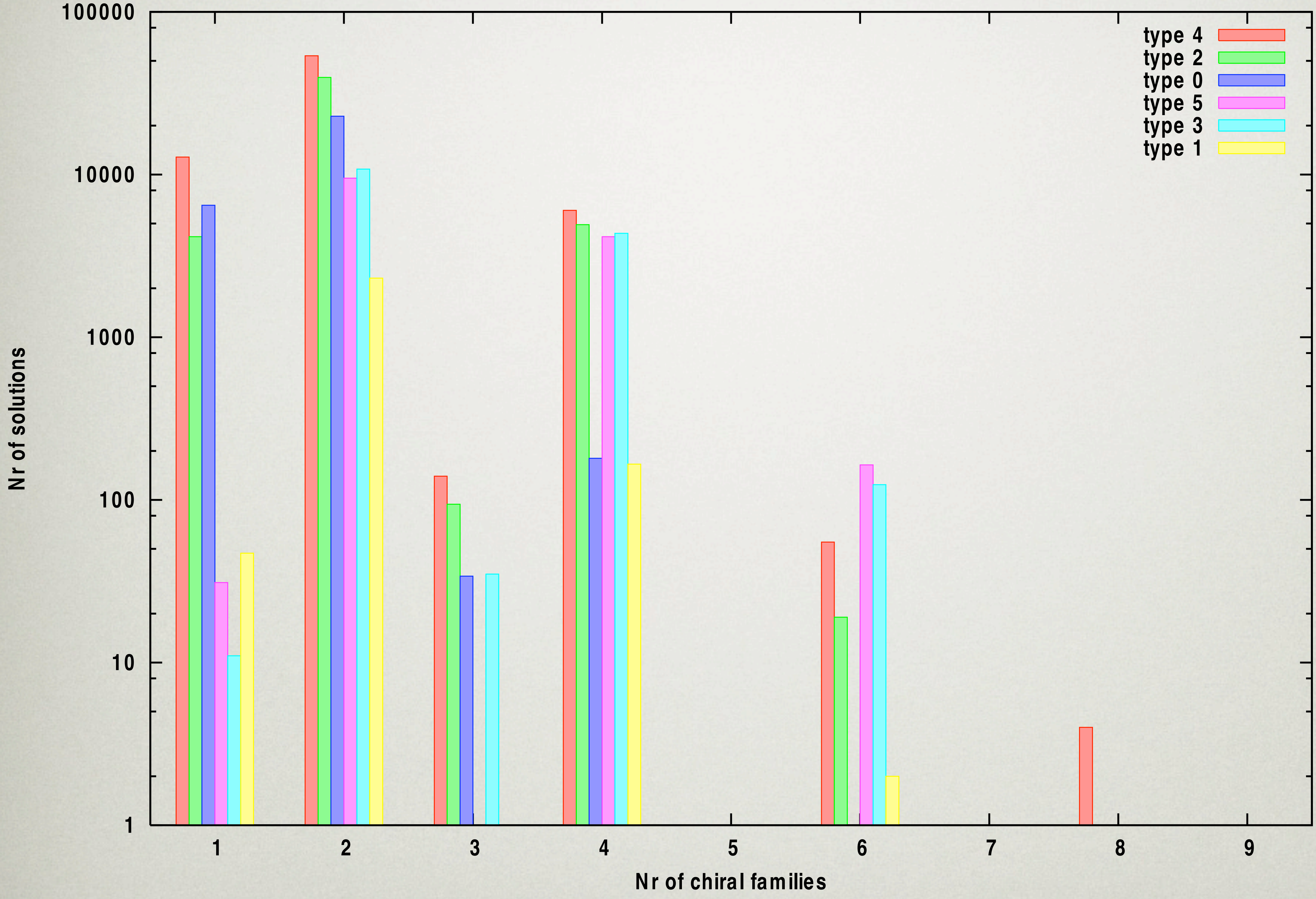
B-L Massive (axion mixing)

Gauge group:

Exactly SU(3)× SU(2)×U(1)



100000
10000
1000
100
10
1
1
2
3
4
5
6
7
8
9
Nr of chiral families
type 4
type 2
type 0
type 5
type 3
type 1




*cf. Gmeiner et. al.*

# ADKS RESULTS (2005-2006)

Anastasopoulos, Dijkstra, Kiritsis, Schellekens

# Search Criteria

Require only:

- U(3) from a single brane
- U(2) from a single brane
- Quarks and leptons, Y from at most four branes
- $G_{CP} \supset$ SU(3) × SU(2) × U(1)
- Chiral $G_{CP}$ fermions reduce to quarks, leptons (plus non-chiral particles)
- Massless Y

# Chan-Paton group

$$G_{CP} = U(3)_a \times \left\{ \begin{array}{c} U(2)_b \\ Sp(2)_b \end{array} \right\} \times G_c \quad (\times G_d)$$

Embedding of Y:

$$Y = \alpha Q_a + \beta Q_b + \gamma Q_c + \delta Q_d + W_c + W_d$$

Q: Brane charges (for unitary branes)

W: Traceless generators

# Classification

$$Y = (x - \frac{1}{3})Q_a + (x - \frac{1}{2})Q_b + x\underbrace{Q_C + (x-1)Q_D}_{\text{Distributed over c and d}}$$

Allowed values for $x$

| | |
|---|---|
| 1/2 | Madrid model, Pati-Salam, Flipped SU(5) |
| 0 | (broken) SU(5) |
| 1 | Antoniadis, Kiritsis, Tomaras model |
| -1/2, 3/2 | |
| any | Trinification ($x = 1/3$) (orientable) |

# Results

- 19345 chirally distinct spectra
  *(19 of Madrid type)*
- 1900 distinct ones with tadpole solutions
  *(≈ 1900 distinct hep-th papers)*

# Statistics

| Value of x | Total |
|---|---|
| 0 | 24483441 |
| 1/2 | 138837612 |
| 1 | 30580 |
| -1/2, 3/2 | 0 |
| any | 1250080 |

# A curiosity

Gauge group $SU(3) \times SU(2) \times U(1) \times [\, U(2)_{Hidden})]$

| | U3 | S2 | U1 | U1 | U2 | | |
|---|---|---|---|---|---|---|---|
| 3 x | ( V | ,V | ,0 | ,0 | ,0 ) | chirality 3 | Q |
| 3 x | ( 0 | ,0 | ,V | ,V | ,0 ) | chirality -3 | E* |
| 1 x | ( V | ,0 | ,0 | ,V* | ,0 ) | chirality -1 | U* |
| 2 x | ( V | ,0 | ,V | ,0 | ,0 ) | chirality -2 | D* |
| 2 x | ( 0 | ,V | ,0 | ,V | ,0 ) | chirality 2 | L |
| 3 x | ( V | ,0 | ,0 | ,V | ,0 ) | chirality -1 | D*+(D+D*) |
| 3 x | ( 0 | ,V | ,V | ,0 | ,0 ) | chirality 1 | $L+H_1+H_2$ |
| 2 x | ( V | ,0 | ,V* | ,0 | ,0 ) | chirality -2 | U* |
| 1 x | ( 0 | ,0 | ,V | ,V* | ,0 ) | chirality 1 | N* |
| 4 x | ( A | ,0 | ,0 | ,0 | ,0 ) | | U+U* |
| 2 x | ( 0 | ,0 | ,0 | ,S | ,0 ) | | E+E* |

# A curiosity

Gauge group $SU(3) \times SU(2) \times U(1) \times [\,U(2)_{Hidden})]$

| | U3 | S2 | U1 | U1 | U2 | | |
|---|---|---|---|---|---|---|---|
| 3 x ( | V | ,V | ,0 | ,0 | ,0 ) | chirality 3 | Q |
| 3 x ( | 0 | ,0 | ,V | ,V | ,0 ) | chirality -3 | E* |
| 1 x ( | V | ,0 | ,0 | ,V* | ,0 ) | chirality -1 | U* |
| 2 x ( | V | ,0 | ,V | ,0 | ,0 ) | chirality -2 | D* |
| 2 x ( | 0 | ,V | ,0 | ,V | ,0 ) | chirality 2 | L |
| 3 x ( | V | ,0 | ,0 | ,V | ,0 ) | chirality -1 | D*+(D+D*) |
| 3 x ( | 0 | ,V | ,V | ,0 | ,0 ) | chirality 1 | $L+H_1+H_2$ |
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| 4 x ( | A | ,0 | ,0 | ,0 | ,0 ) | | U+U* |
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Truly hidden
hidden sector

# A curiosity

Gauge group $SU(3)\times SU(2) \times U(1) \times [\, U(2)_{\text{Hidden}})]$

| | U3 | S2 | U1 | U1 | U2 | | |
|---|---|---|---|---|---|---|---|
| 3 x | ( V | ,V | ,0 | ,0 | ,0 ) | chirality 3 | Q |
| 3 x | ( 0 | ,0 | ,V | ,V | ,0 ) | chirality -3 | E* |
| 1 x | ( V | ,0 | ,0 | ,V* | ,0 ) | chirality -1 | U* |
| 2 x | ( V | ,0 | ,V | ,0 | ,0 ) | chirality -2 | D* |
| 2 x | ( 0 | ,V | ,0 | ,V | ,0 ) | chirality 2 | L |
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| 3 x | ( 0 | ,V | ,V | ,0 | ,0 ) | chirality 1 | $L+H_1+H_2$ |
| 2 x | ( V | ,0 | ,V* | ,0 | ,0 ) | chirality -2 | U* |
| 1 x | ( 0 | ,0 | ,V | ,V* | ,0 ) | chirality 1 | N* |
| 4 x | ( A | ,0 | ,0 | ,0 | ,0 ) | | U+U* |
| 2 x | ( 0 | ,0 | ,0 | ,S | ,0 ) | | E+E* |

**Free-field realization with $(2)^6$ Gepner model**

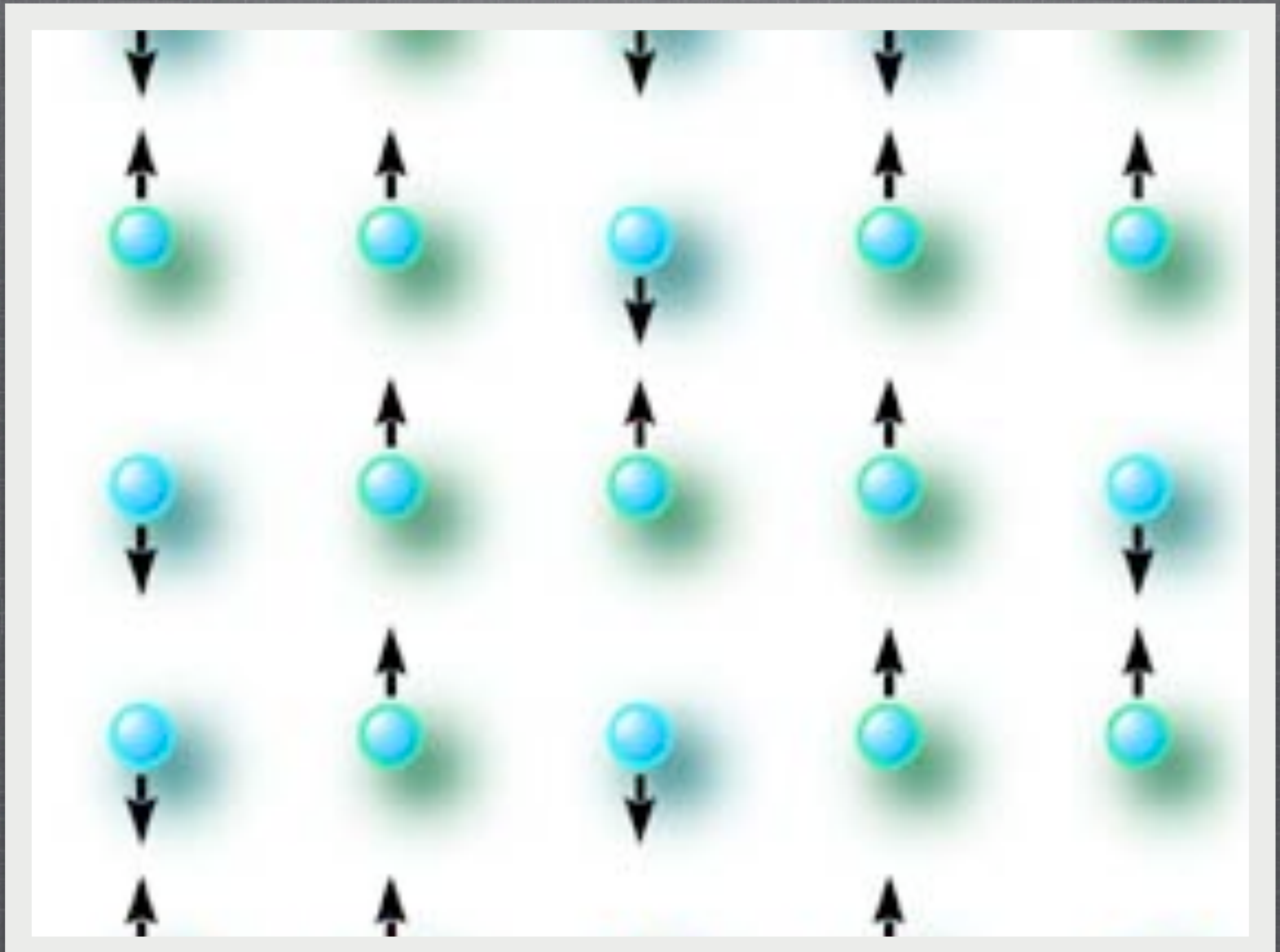
**(Kiritsis, Schellekens, Tsulaia, to appear)**

# FREE THEORIES

# Motivation:

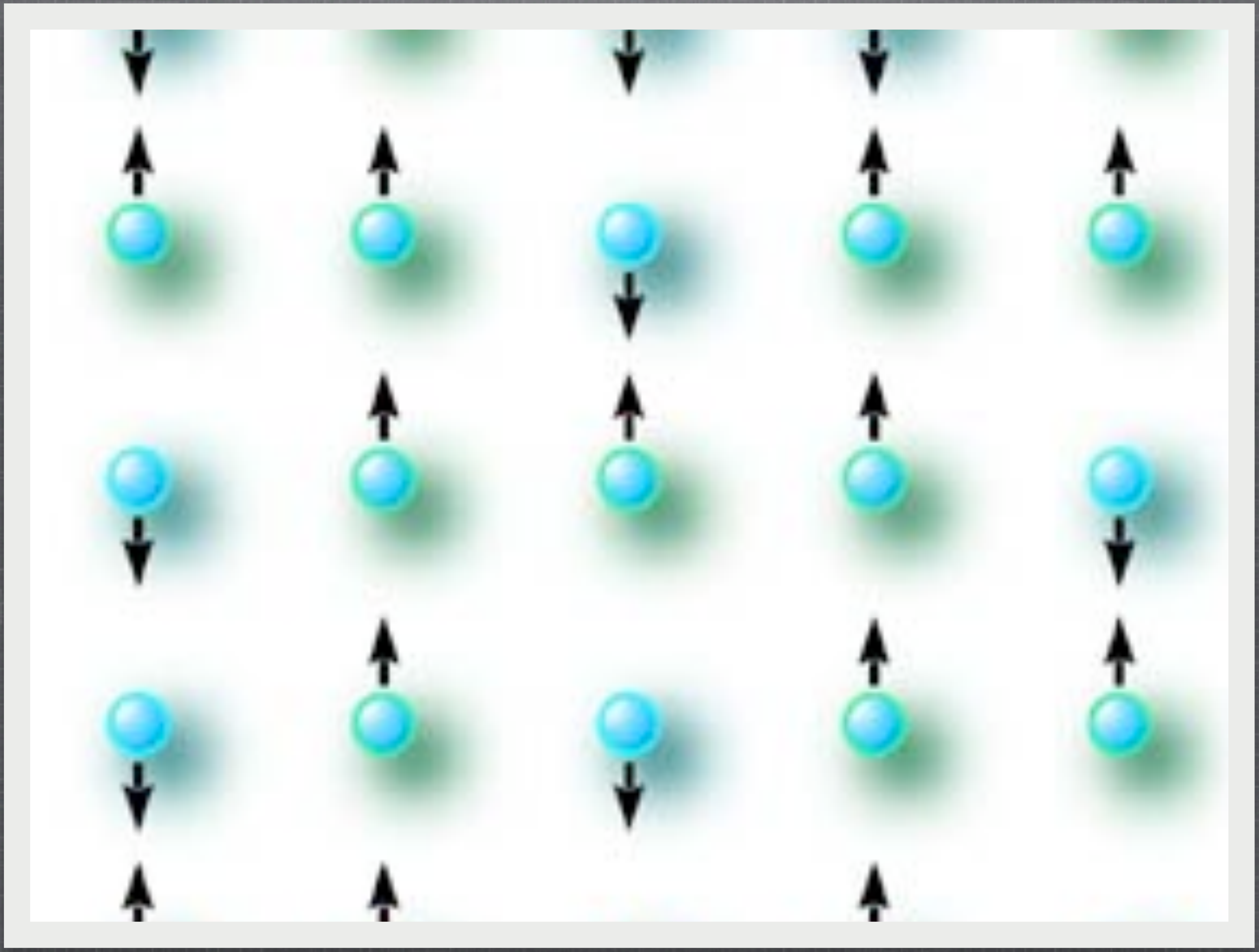
- Compare with other approaches
- Allow computation of more quantities

# FREE FERMIONS



# FREE FERMIONS

M. Lennek, E. Kiritsis, A.N. Schellekens



# NUMBER OF MIPFS

Tensor product of 18 real free fermions or “Ising Models”.
World-sheet susy via KLT-ABK “triplet constraint”.

Complex fermions: $(\text{Ising})^2 \rightarrow D_1$ (within triplets).

| | |
|---|---|
| $(\text{NSR})\ (D_1)^9$ | 685 MIPFs |
| $(\text{NSR})\ (D_1)^7\ (\text{Ising})^4$ | 7466 MIPFs |
| $(\text{NSR})\ (D_1)^5\ (\text{Ising})^8$ | 75427 MIPFs |
| $(\text{NSR})\ (D_1)^3\ (\text{Ising})^{12}$ | 534700 MIPFs |

Far more MIPFs than for Gepner Models ($\approx$ 5000)

# Hodge numbers

| | |
|---|---|
| 359 | (51,3,4) |
| 359 | (3,51,4) |
| 2962 | (31,7,4) |
| 2962 | (7,31,4) |
| 4066 | (27,3,4) |
| 4066 | (3,27,4) |
| 6 | (25,1,4) |
| 6 | (1,25,4) |
| 1720 | (21,9,4) |
| 1720 | (9,21,4) |
| 16866 | (19,7,4) |
| 16866 | (7,19,4) |
| 29118 | (17,5,4) |
| 29118 | (5,17,4) |
| 11132 | (15,3,4) |
| 11132 | (3,15,4) |
| 65072 | (12,6,4) |
| 65072 | (6,12,4) |

| | | |
|---|---|---|
| 917 | (21,21,8) | (K3 × T2) |
| 2214 | (19,19,4) | |
| 13225 | (15,15,4) | |
| 6152 | (13,13,8) | |
| 12 | (13,13,4) | |
| 92684 | (11,11,4) | |
| 1187 | (9,9,16) | (Tori) |
| 3550 | (9,9,8) | |
| 100838 | (9,9,4) | |
| 103414 | (7,7,4) | |
| 4252 | (5,5,8) | |
| 15018 | (5,5,4) | |
| 12209 | (3,3,4) | |
| 4 | (1,1,8) | |

cf. Donagi and Faraggi, 2004
($Z_2 \times Z_2$ orbifolds)

# SEARCH RESULTS

| | |
|---|---|
| (NSR) $(D_1)^9$ | SM configuration, no tadpole cancellation |
| (NSR) $(D_1)^7$ $(\text{Ising})^4$ | Nothing |
| (NSR) $(D_1)^5$ $(\text{Ising})^8$ | Nothing |
| (NSR) $(D_1)^3$ $(\text{Ising})^{12}$ | Nothing<br>(using random MIPF selection) |

# SM CONFIGURATION
## (FREE BOSONS)

| U(4) | U(2) | U(2) | mult. |
|---|---|---|---|
| 0 | V* | V | 2 |
| V* | 0 | V | 1 |
| V | V | 0 | 2 |
| V* | 0 | V* | 2 |
| V | V* | 0 | 1 |

Exact! No non-chiral states!

Also a U(3)×U(1) version

# NON-SUPERSYMMETRIC SPECTRA

B. Gato-Rivera and A.N. Schellekens, Phys.Lett.B656:127-131,2007
and to appear.

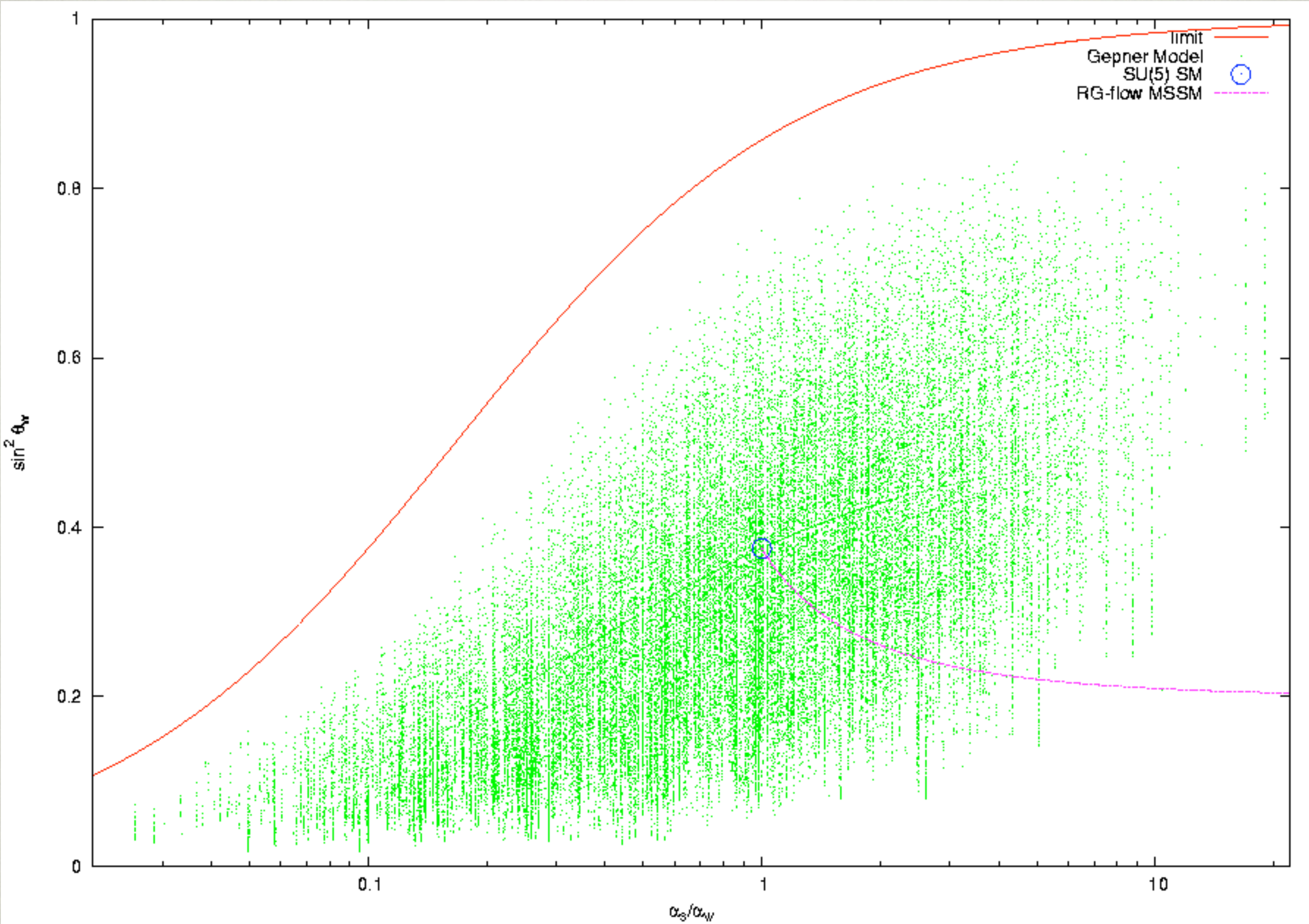
# Arguments in favor of Susy

- Stabilizes weak hierarchy
- Coupling convergence
- LSP and Dark Matter

# Arguments in favor of Susy

Not needed for C.C.

- ~~Stabilizes weak hierarchy~~
- Coupling convergence
- LSP and Dark Matter




Dijkstra, Huiszoon, Schellekens, **Nucl.Phys.B710:3-57,2005**

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- Stabilizes ~~weak~~ hierarchy
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Not needed for C.C.

- ~~Stabilizes weak hierarchy~~

Coincidence in orientifolds

- ~~Coupling convergence~~
- LSP and Dark Matter

# Arguments in favor of Susy

- ~~Stabilizes weak hierarchy~~ Not needed for C.C.
- ~~Coupling convergence~~ Coincidence in orientifolds
- LSP and Dark Matter

**For the record: I am NOT making an LHC prediction here!**

# Arguments in favor of Susy

Not needed for C.C.

- ~~Stabilizes weak hierarchy~~

Coincidence in orientifolds

- ~~Coupling convergence~~
- LSP and Dark Matter

**For the record: I am NOT making an LHC prediction here!**

*But: does string theory predict low energy supersymmetry or GUT unification at $10^{16}$ GeV?*

# Non-supersymmetric strings

Additional complications:

- Tachyons: Closed sector, Open sector
- Tadpoles: Separate equations for NS and R.

Best imaginable outcome:

- Exactly the standard model (open sector)

But even then, there will be plenty of further problems: tadpoles at genus 1, how to compute anything of interest without the help of supersymmetry, etc.

*cf. Ibañez, Marchesano, Rabadan*

# Closed sector

Four ways of removing closed string tachyons:

- Chiral algebra extension (non-susy)
  *All characters non-supersymmetric, but tachyon-free.*
- Automorphism MIPF
  *No tachyons in left-right pairing of characters.*
- Susy MIPF
  *Non-supersymmetric CFT, but supersymmetric bulk.*
  *Allows boundaries that break supersymmetry.*
- Klein Bottle
  *This introduces crosscap tadpoles. Requires boundaries with non-zero CP multiplicity.*

# Closed sector

Do these possibilities occur?

- Chiral algebra extension (non-susy)
- Automorphism MIPF
- Susy MIPF
- Klein Bottle

# Closed sector

Do these possibilities occur?

- Chiral algebra extension (non-susy) ✖
- Automorphism MIPF ✔ (44054 MIPFs)
- Susy MIPF ✔ (40261 MIPFs)
- Klein Bottle ✔ (186951 Orientifolds)

# EXAMPLES OF TADPOLE AND TACHYON-FREE SPECTRA

Orientifolds of tachyon-free non-supersymmetric oriented closed strings (automorphism MIPFs)

CFT 11111111, Extension 176, MIPF 35, orientifold 0

Gauge group Sp(4)
Bosons: 2 × (S)        (Symmetric Tensor)
Fermions: None

CFT 11111111, Extension 70, MIPF 56, orientifold 0

Gauge group Sp(4)
Bosons: None        (Symmetric Tensor)
Fermions: 2 x (S)

CFT 11111111, Extension 176, MIPF 21, orientifold 0

Gauge group Sp(4)
Bosons: None
Fermions: None

# CFT 1112410, Extension 157, MIPF 63, orientifold 0

## Gauge group O(4) × U(1) × U(2)

Fermions

2 x ( V ,0 ,V ) chirality -2
2 x ( 0 ,V ,V ) chirality 2
2 x ( 0 ,V ,V*) chirality -2
6 x ( 0 ,0 ,A ) chirality -2
4 x ( V ,V ,0 )
2 x ( S ,0 ,0 )
6 x ( 0 ,Ad,0 )
4 x ( 0 ,S ,0 )
2 x ( 0 ,0 ,Ad)

Bosons

2 x ( V ,0 ,V )
2 x ( A ,0 ,0 )
3 x ( V ,V ,0 )
6 x ( 0 ,Ad,0 )
3 x ( 0 ,A ,0 )
4 x ( 0 ,S ,0 )
3 x ( 0 ,0 ,Ad)
4 x ( 0 ,0 ,S )

Chiral!

# CFT 11111111, Extension 67, MIPF 508, orientifold 0

## Gauge group Sp(2) × U(1)

**Fermions**

8 x ( V ,V )
6 x ( S ,0 )
6 x ( 0 ,Ad)
8 x ( 0 ,S )

**Bosons**

8 x ( V ,V )
5 x ( S ,0 )
5 x ( 0 ,Ad)
8 x ( 0 ,S )

# FINDING THE SM

# Search for non-susy SM Configurations

Total number of tachyon-free boundary state combinations satisfying our criteria:

3456601

Subdivided as follows

| | | |
|---|---|---|
| Bulk Susy | 3389835 | 98.1% |
| Tachyon-free automorphism | 66378 | 1.9% |
| Tachyon-free Klein bottle projection | 388 | 0.01% |

# An example

CFT 44716, Extension 124, MIPF 27, Orientifold 0

N=1 Susy Bulk symmetry

Spectrum type 20088 (Not on ADKS list)

Gauge Group $U(3) \times U(2) \times Sp(4) \times U(1)$

(broken by axion couplings to $SU(3) \times SU(2) \times Sp(4) \times U(1)$)

| | |
|---|---|
| 3 x ( A ,0 ,0 ,0 ) chirality 3 | 3 x ( S ,0 ,0 ,0 ) |
| 3 x ( 0 ,A ,0 ,0 ) chirality 3 | 3 x ( 0 ,S ,0 ,0 ) |
| 4 x ( 0 ,0 ,0 ,A ) chirality -2 | 4 x ( 0 ,0 ,0 ,A ) |
| 5 x ( 0 ,0 ,0 ,S ) chirality -3 | 5 x ( 0 ,0 ,0 ,S ) |
| 3 x ( V ,0 ,V ,0 ) chirality -1 | 3 x ( V ,0 ,V ,0 ) |
| 1 x ( V ,0 ,0 ,V ) chirality 1 | 2 x ( V ,0 ,0 ,V ) |
| 1 x ( 0 ,V ,0 ,V ) chirality 1 | 2 x ( 0 ,V ,0 ,V ) |
| 1 x ( 0 ,0 ,V ,V ) chirality 1 | 3 x ( 0 ,0 ,V ,V ) |
| 5 x ( V ,V ,0 ,0 ) chirality 3 | 5 x ( V ,V ,0 ,0 ) |
| 1 x ( 0 ,V ,V ,0 ) chirality -1 | 1 x ( 0 ,V ,V ,0 ) |
| 3 x ( Ad,0 ,0 ,0 ) | 2 x ( Ad,0 ,0 ,0 ) |
| 3 x ( 0 ,Ad,0 ,0 ) | 2 x ( 0 ,Ad,0 ,0 ) |
| 4 x ( 0 ,0 ,0 ,Ad) | 3 x ( 0 ,0 ,0 ,Ad) |
| 2 x ( 0 ,0 ,A ,0 ) | 1 x ( 0 ,0 ,S ,0 ) |
| 4 x ( S ,0 ,0 ,0 ) | 4 x ( A ,0 ,0 ,0 ) |
| 4 x ( 0 ,S ,0 ,0 ) | 4 x ( 0 ,A ,0 ,0 ) |
| 2 x ( V ,0 ,0 ,V*) | |
| 2 x ( 0 ,V ,0 ,V*) | |
| 2 x ( V ,V*,0 ,0 ) | 2 x ( V ,V*,0 ,0 ) |

| | |
|---|---|
| 3 x ( A ,0 ,0 ,0 ) chirality 3 | 3 x ( S ,0 ,0 ,0 ) |
| 3 x ( 0 ,A ,0 ,0 ) chirality 3 | 3 x ( 0 ,S ,0 ,0 ) |
| 4 x ( 0 ,0 ,0 ,A ) chirality -2 | 4 x ( 0 ,0 ,0 ,A ) |
| 5 x ( 0 ,0 ,0 ,S ) chirality -3 | 5 x ( 0 ,0 ,0 ,S ) |
| 3 x ( V ,0 ,V ,0 ) chirality -1 | 3 x ( V ,0 ,V ,0 ) |
| 1 x ( V ,0 ,0 ,V ) chirality 1 | 2 x ( V ,0 ,0 ,V ) |
| 1 x ( 0 ,V ,0 ,V ) chirality 1 | 2 x ( 0 ,V ,0 ,V ) |
| 1 x ( 0 ,0 ,V ,V ) chirality 1 | 3 x ( 0 ,0 ,V ,V ) |
| 5 x ( V ,V ,0 ,0 ) chirality 3 | 5 x ( V ,V ,0 ,0 ) |
| 1 x ( 0 ,V ,V ,0 ) chirality -1 | 1 x ( 0 ,V ,V ,0 ) |
| 3 x ( Ad,0 ,0 ,0 ) | 2 x ( Ad,0 ,0 ,0 ) |
| 3 x ( 0 ,Ad,0 ,0 ) | 2 x ( 0 ,Ad,0 ,0 ) |
| 4 x ( 0 ,0 ,0 ,Ad) | 3 x ( 0 ,0 ,0 ,Ad) |
| 2 x ( 0 ,0 ,A ,0 ) | 1 x ( 0 ,0 ,S ,0 ) |
| 4 x ( S ,0 ,0 ,0 ) | 4 x ( A ,0 ,0 ,0 ) |
| 4 x ( 0 ,S ,0 ,0 ) | 4 x ( 0 ,A ,0 ,0 ) |
| 2 x ( V ,0 ,0 ,V*) | |
| 2 x ( 0 ,V ,0 ,V*) | |
| 2 x ( V ,V*,0 ,0 ) | 2 x ( V ,V*,0 ,0 ) |

| | |
|---|---|
| 3 x ( A ,0 ,0 ,0 ) chirality 3 | 3 x ( S ,0 ,0 ,0 ) |
| 3 x ( 0 ,A ,0 ,0 ) chirality 3 | 3 x ( 0 ,S ,0 ,0 ) |
| 4 x ( 0 ,0 ,0 ,A ) chirality -2 | 4 x ( 0 ,0 ,0 ,A ) |
| 5 x ( 0 ,0 ,0 ,S ) chirality -3 | 5 x ( 0 ,0 ,0 ,S ) |
| 3 x ( V ,0 ,V ,0 ) chirality -1 | 3 x ( V ,0 ,V ,0 ) |
| 1 x ( V ,0 ,0 ,V ) chirality 1 | 2 x ( V ,0 ,0 ,V ) |
| 1 x ( 0 ,V ,0 ,V ) chirality 1 | 2 x ( 0 ,V ,0 ,V ) |
| 1 x ( 0 ,0 ,V ,V ) chirality 1 | 3 x ( 0 ,0 ,V ,V ) |
| 5 x ( V ,V ,0 ,0 ) chirality 3 | 5 x ( V ,V ,0 ,0 ) |
| 1 x ( 0 ,V ,V ,0 ) chirality -1 | 1 x ( 0 ,V ,V ,0 ) |
| 3 x ( Ad,0 ,0 ,0 ) | 2 x ( Ad,0 ,0 ,0 ) |
| 3 x ( 0 ,Ad,0 ,0 ) | 2 x ( 0 ,Ad,0 ,0 ) |
| 4 x ( 0 ,0 ,0 ,Ad) | 3 x ( 0 ,0 ,0 ,Ad) |
| 2 x ( 0 ,0 ,A ,0 ) | 1 x ( 0 ,0 ,S ,0 ) |
| 4 x ( S ,0 ,0 ,0 ) | 4 x ( A ,0 ,0 ,0 ) |
| 4 x ( 0 ,S ,0 ,0 ) | 4 x ( 0 ,A ,0 ,0 ) |
| 2 x ( V ,0 ,0 ,V*) | |
| 2 x ( 0 ,V ,0 ,V*) | |
| 2 x ( V ,V*,0 ,0 ) | 2 x ( V ,V*,0 ,0 ) |

# FINDING HIDDEN SECTORS

# A tachyon-free, tadpole-free hidden sector could be found for 896 of the 3456601 SM configurations.

All of these have bulk susy.

“Statistically” 16 would be expected for the tachyon-free automorphism, 0 for tachyon-free Klein bottles.

All 896 have a supersymmetric spectrum (exact boson fermion matching). They are probably identical to supersymmetric models from earlier searches.

# Conclusions

- Non-supersymmetric, tadpole and tachyon-free standard models must exist, but are still hidden in the noise.
- Better chance with 1, 2 or 4 families.
- Supersymmetry is very persistent.