Realistic Split Fermion Models

गिलाद पेरेज़

Gilad Perez

Weizmann Institute of Science

G. Perez, hep-ph/0208102, to appear in PRD ;

Y. Grossman and G. Perez, hep-ph/0210053, to appear in PRD .

Outline

- Introduction & motivation
- The basic idea: Split fermions in 5D
- The Arkani-Hamed-Schmaltz model
- A model with a finite compact dimension ??
- Construction of a realistic model
- Conclusions

Introduction

Why split fermions?

- *Alternative* solution of the flavor puzzle (requires extra dimensions).
- Mechanism which suppress proton decay.

Introduction

Why split fermions?

- ⊛ *Alternative* solution of the flavor puzzle.
- ⊛ Mechanism which suppress proton decay.
- ⊗ **Naive realistic models are unnatural!**

Main message

- Present a Model which solves the flavor puzzle naturally.
- In realistic models proton stability $\Rightarrow$ fine tuning of $\mathcal{O}\left(10^{-4}\right)$.

Split fermions - requirements

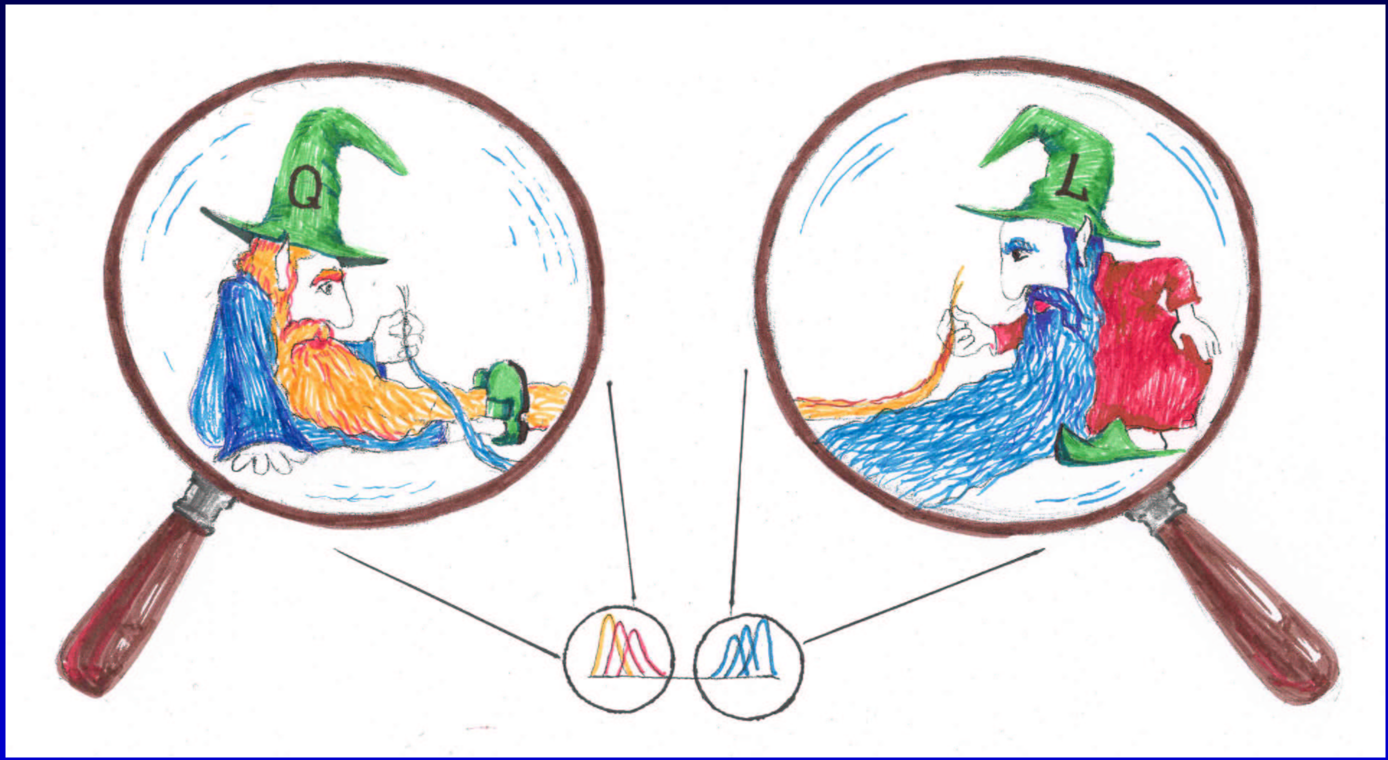
Extra (flat) dimensions

Separation (localization) -

To allow flavor hierarchy and proton longevity.

Split fermions - requirements

Separation



Quarks Leptons

Split fermions - requirements

Separation (localization) -

flavor hierarchy and proton longevity.

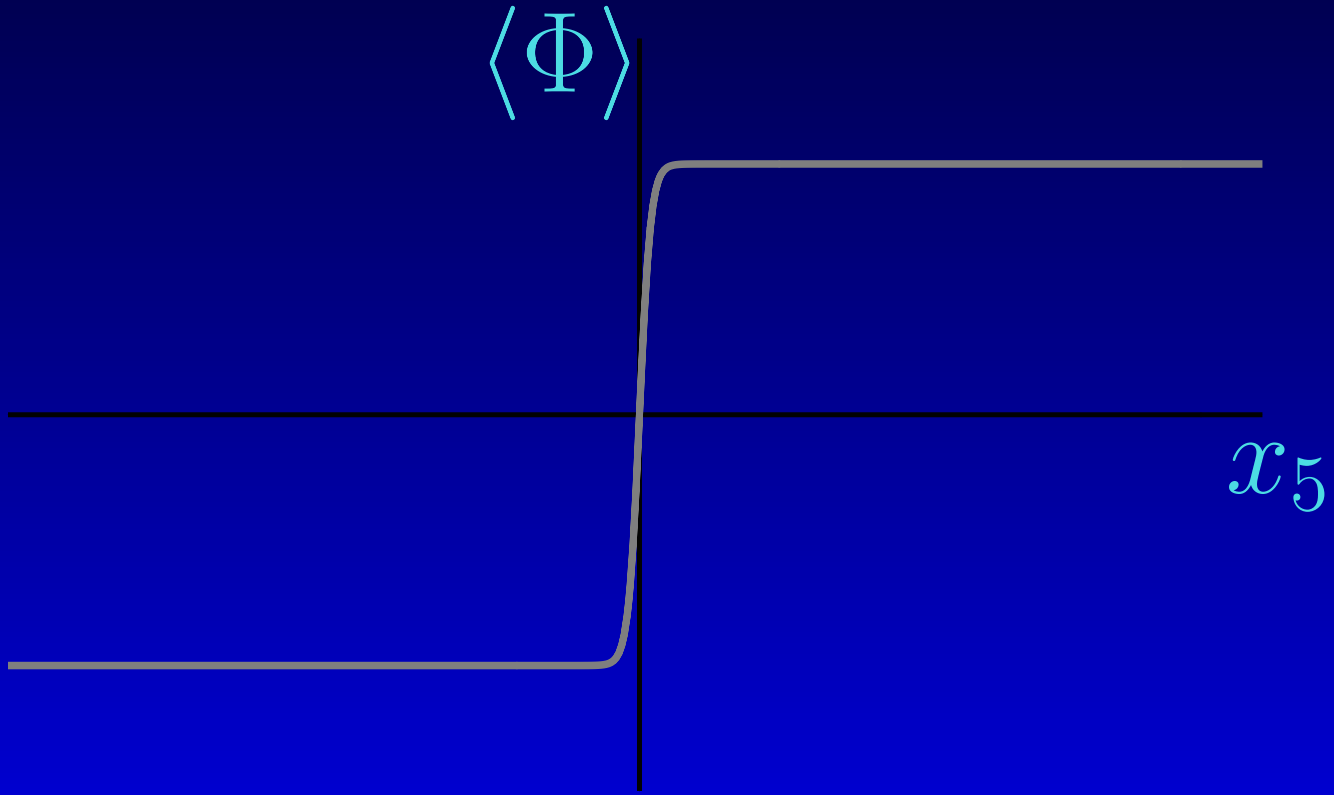
Chirality - To have SM in **4D**.

Basic Idea - fermion localization

- $\langle\Phi\rangle$ in a domain wall scenario:

$$\langle\Phi(x_5=\infty)\rangle = -\langle\Phi(x_5=-\infty)\rangle = V\,.$$

Domain wall configuration for $\langle\Phi\rangle$.



Localizing the fermions

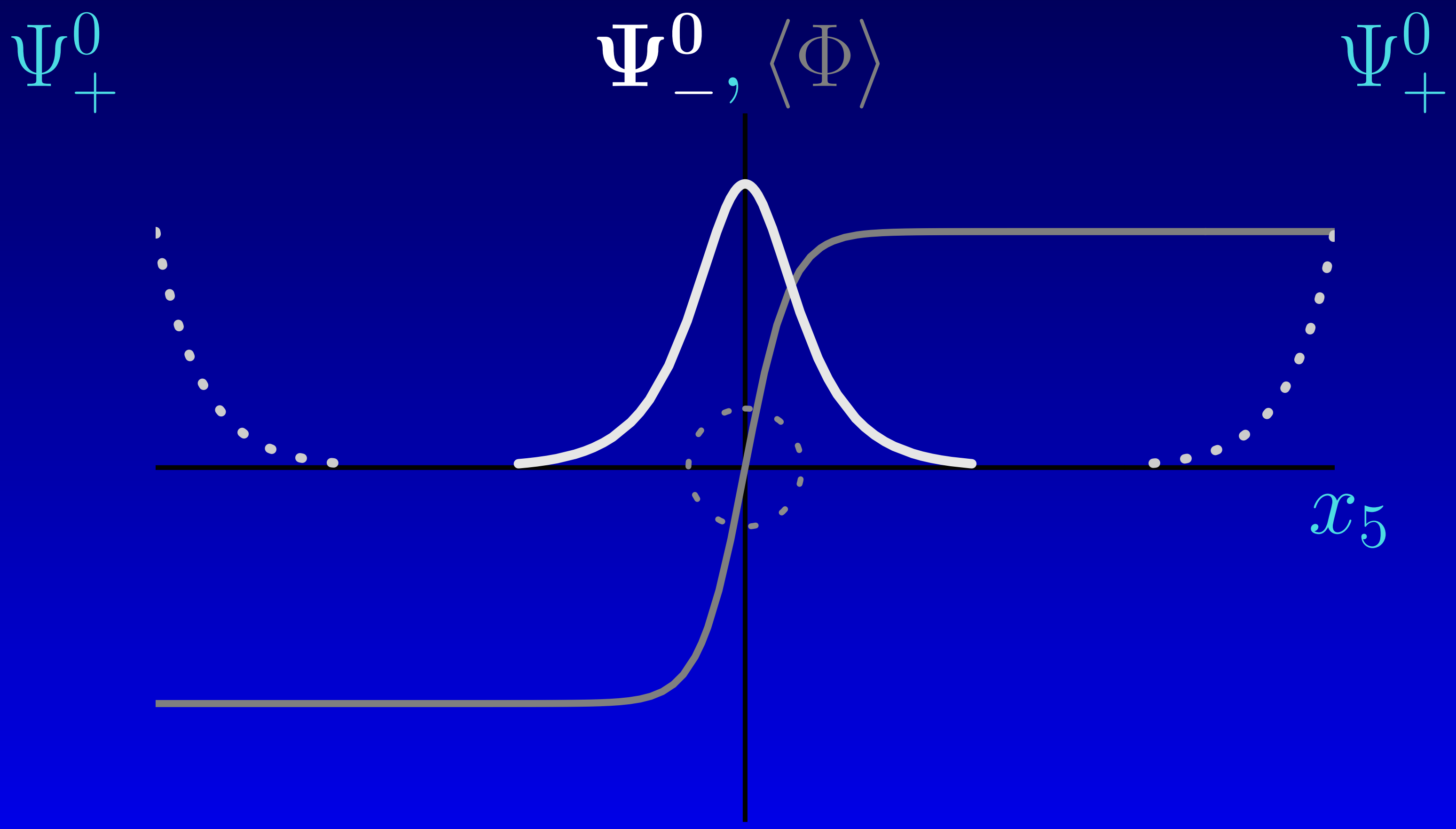
- $\langle \Phi(x_5) \rangle$ is of a domain wall shape.

- Yukawa interactions are:

$$\mathcal{S}_5 = \int dx_5 \bar{\Psi} \left[i\gamma^5 \partial_5 + \Phi(x_5) \right] \Psi$$

- Euler-Lagrange eqs. $\Rightarrow$ **2** zero modes.

A zero-mode is *localized* around the *"zero"* of $\langle \Phi \rangle$!!



Historic Overview

Arkani-Hamed-Schmaltz (AS) model

PRD **61**, 033005 (00).

Chiralty ? Separation ?

Historic Overview

Arkani-Hamed-Schmaltz (AS) model

PRD **61**, 033005 (00).

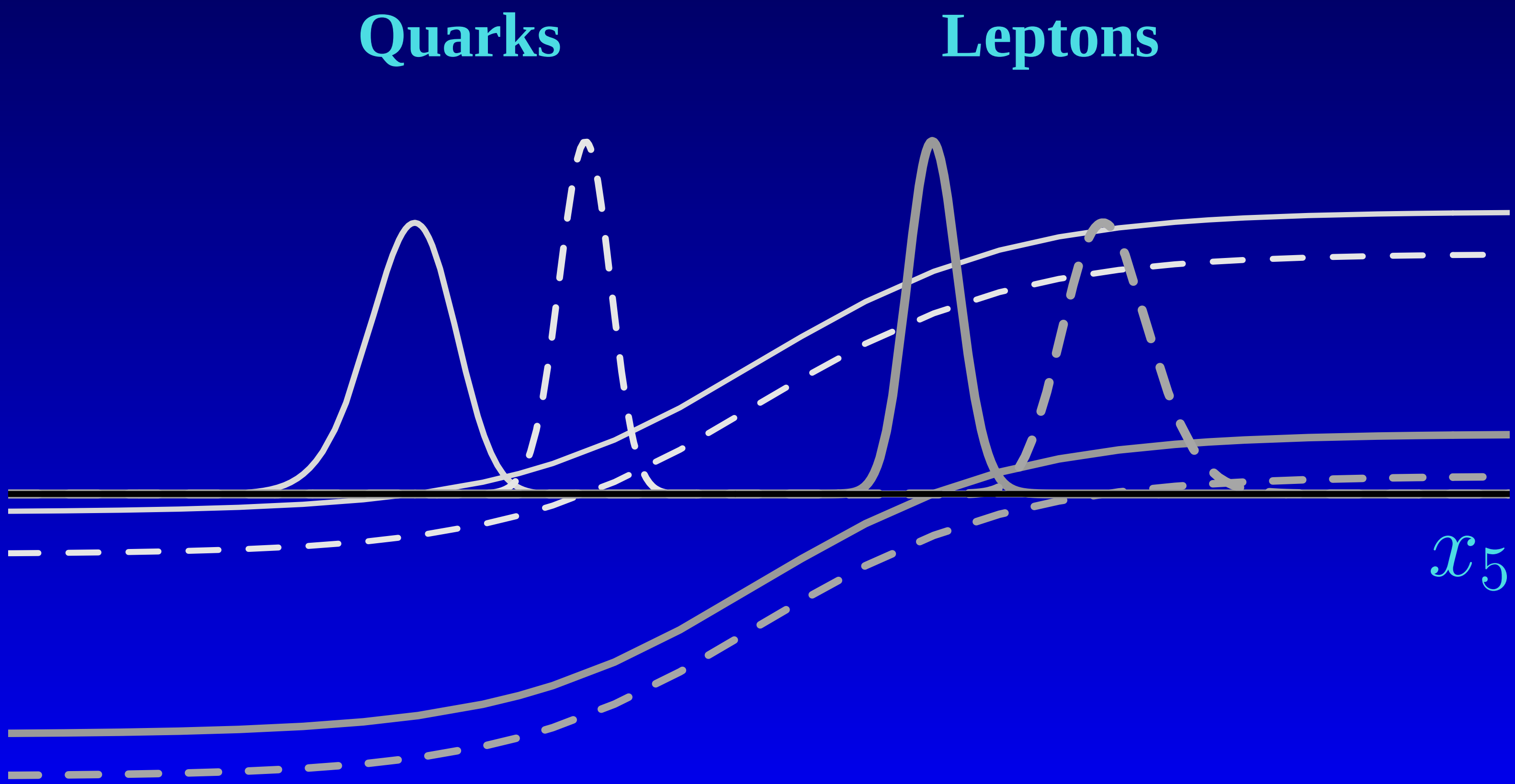
Chirality- Assume an infinite 5D:

Nonnormalizable zero-mode is projected.

Separation- Flavor dependent masses for Ψ_i:

$$\mathcal{S}_5 = \Sigma_i \left[\bar{\Psi}_i \left(\Phi + \mathbf{M}_i \right) \Psi_i \right]$$

The AS model



Model with a finite dimension?

- ☒ **Chirality**- The second zero mode is normalizable and physical!

- ☒ **Localization**- The second zero mode is delocalized!

Solutions ??

Model with a finite dimension?

☒ **Chirality**- The second mode is normalizable!

☒ **Localization**- The second mode is delocalized!

Solutions

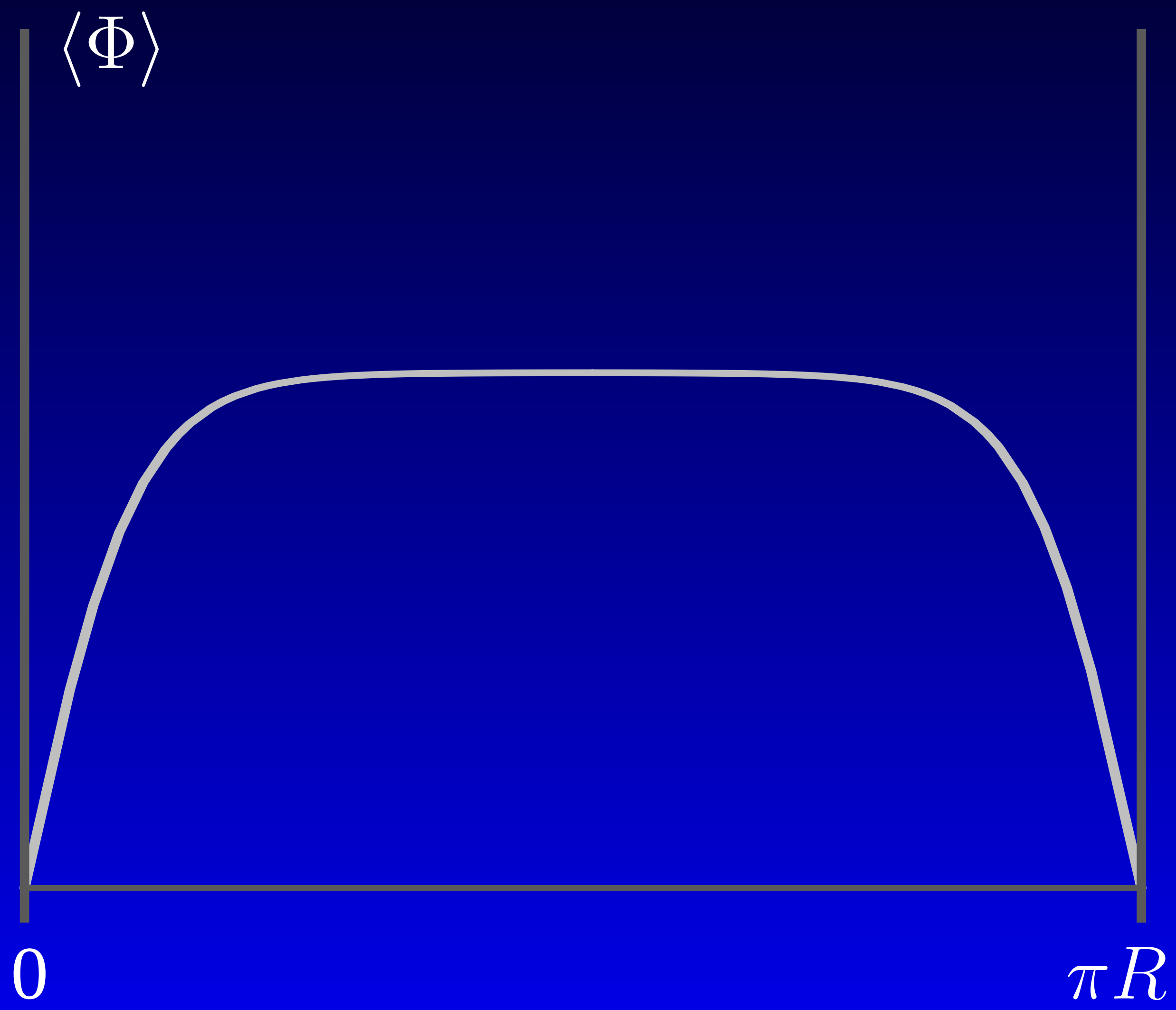
Georgi, Grant & Hailu, PRD **63**, (01);
Kaplan & Tait, JHEP **0111**, (01).

The 5D is orbifold: S_1/Z_2.

Project out a zero mode: $\Psi(-x_5) = \gamma_5 \Psi(x_5)$.

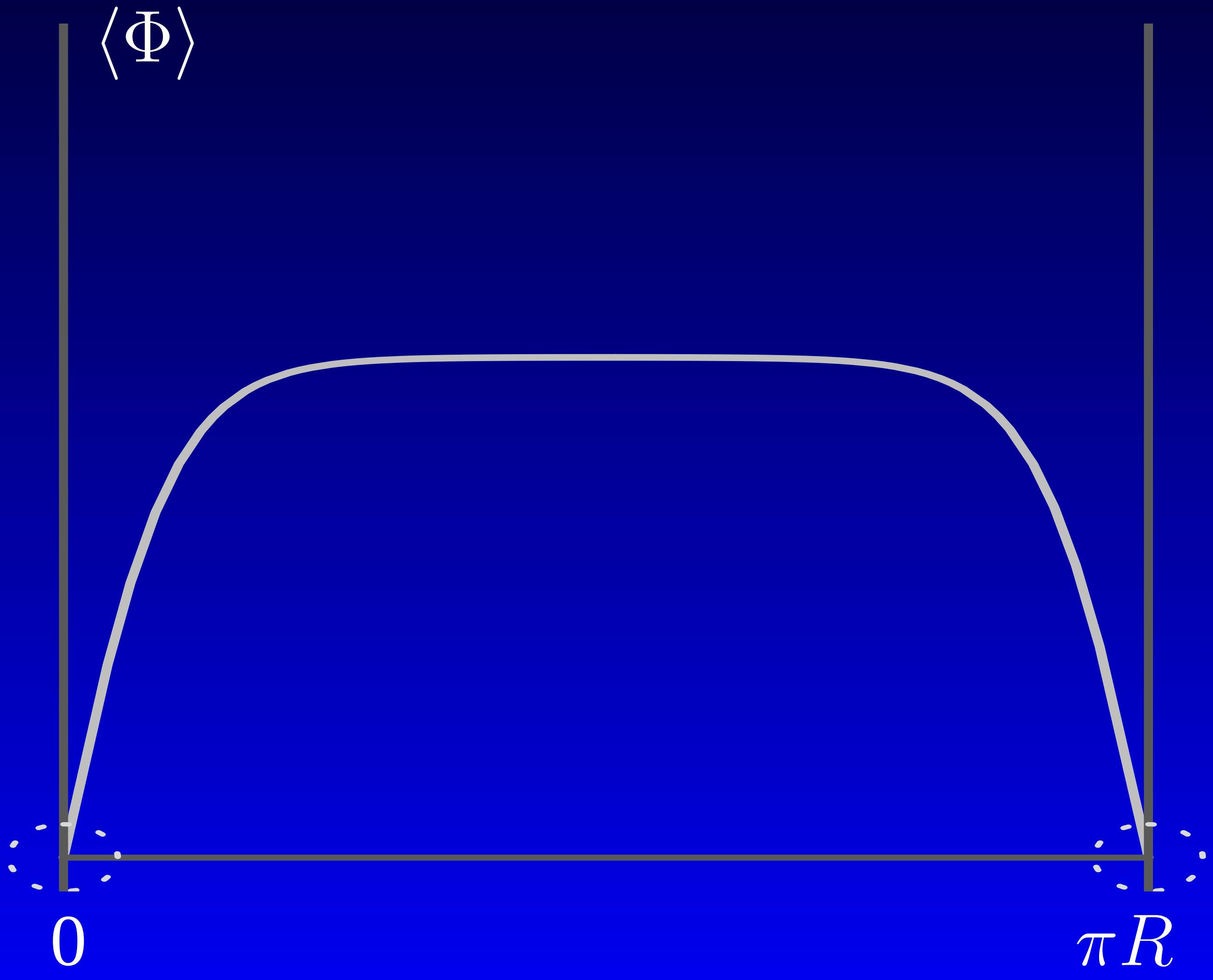
Scalar kink profile: $\Phi(-x_5) = -\Phi(x_5)$.

$\langle\Phi\rangle$ in S_1/Z_2 model



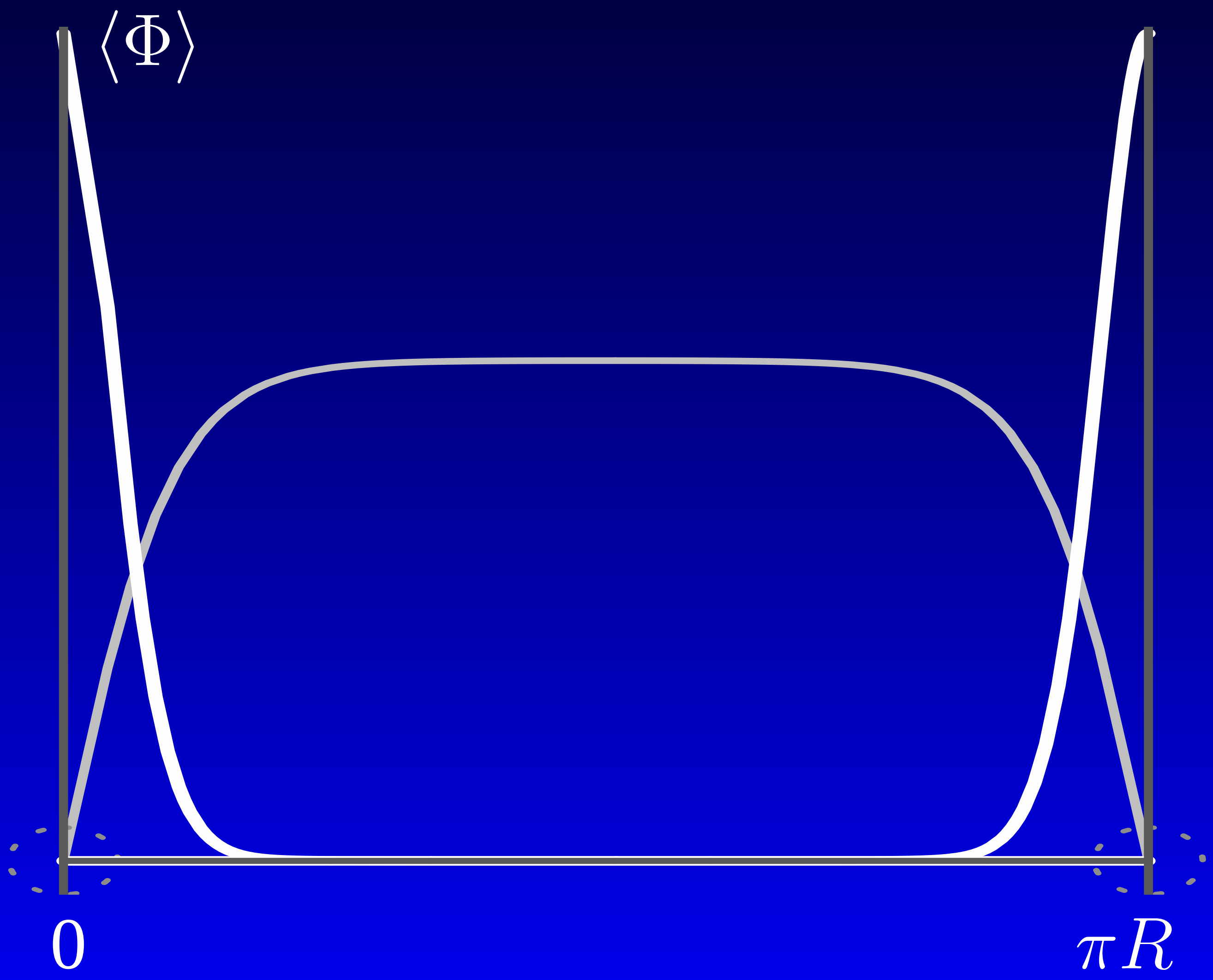
Separation ??

5D Mass is forbidden - ~~$\mathbf{M}$~~$_i$



☒ No separation !

Fermions are stuck at the fixed points.



A two scalar model

Y. Grossman & G.P., (02)

- The model contains: $\mathbf{\Phi_1}, \mathbf{\Phi_2}$.
- Yukawa interactions:

$$\mathcal{L}_Y = \bar{\Psi}\left(Y_1 \mathbf{\Phi_1} - Y_2 \mathbf{\Phi_2}\right)\Psi$$

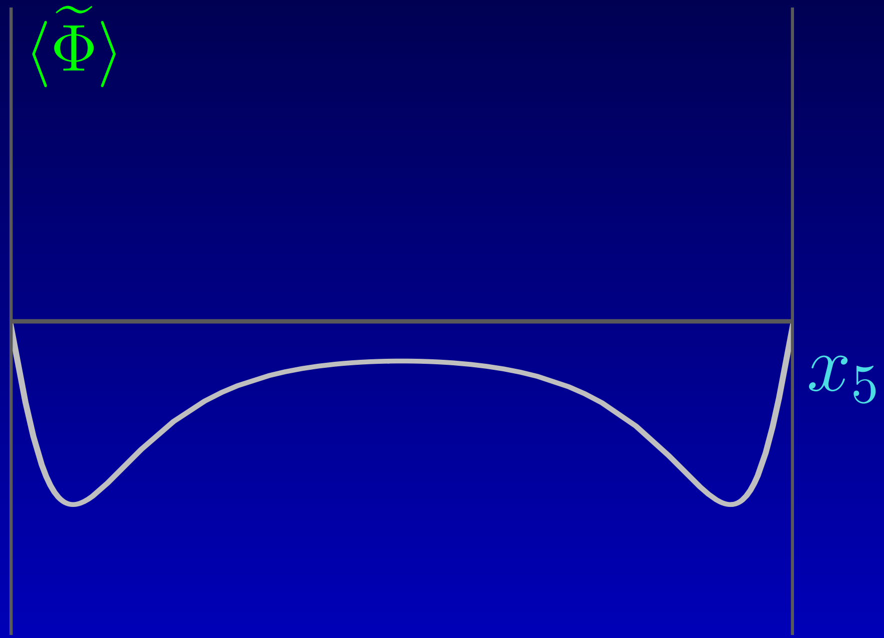
- Effective VEV is induced:

$$\langle \widetilde{\mathbf{\Phi}} \rangle \equiv Y_1 \langle \mathbf{\Phi_1} \rangle - Y_2 \langle \mathbf{\Phi_2} \rangle .$$

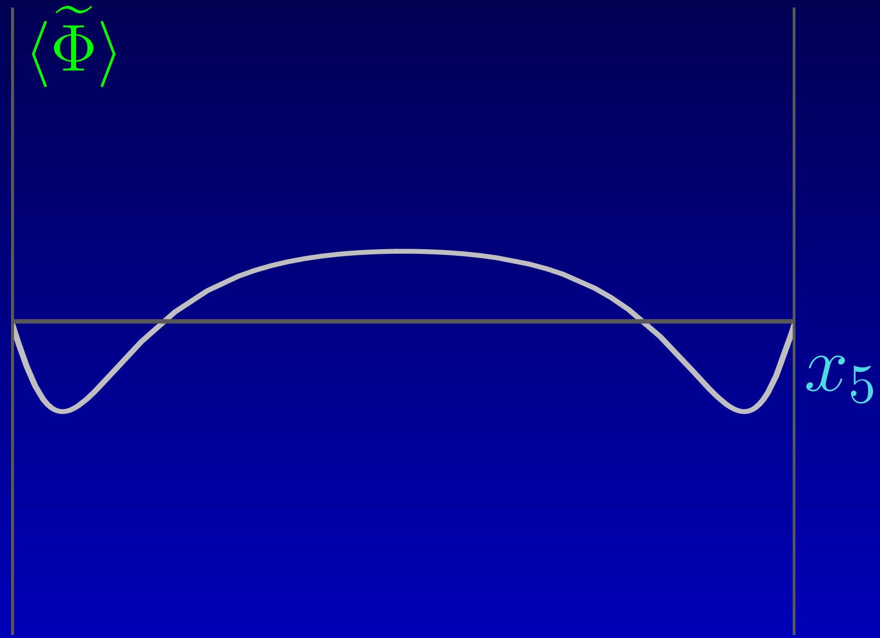
The VEV - $\langle\tilde{\Phi}\rangle$

$\otimes$ **No "zeros"**

$\oplus$ **Two "zeros" !**



$X > 1;\, X < 0$

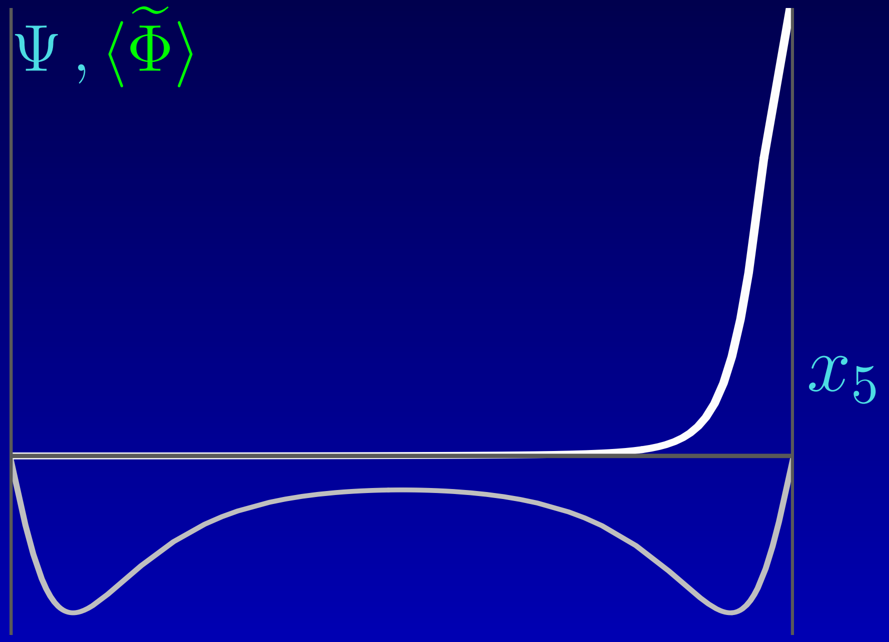


$0 \lesssim X \lesssim 1$

$$X \equiv \frac{Y_2}{Y_1}$$

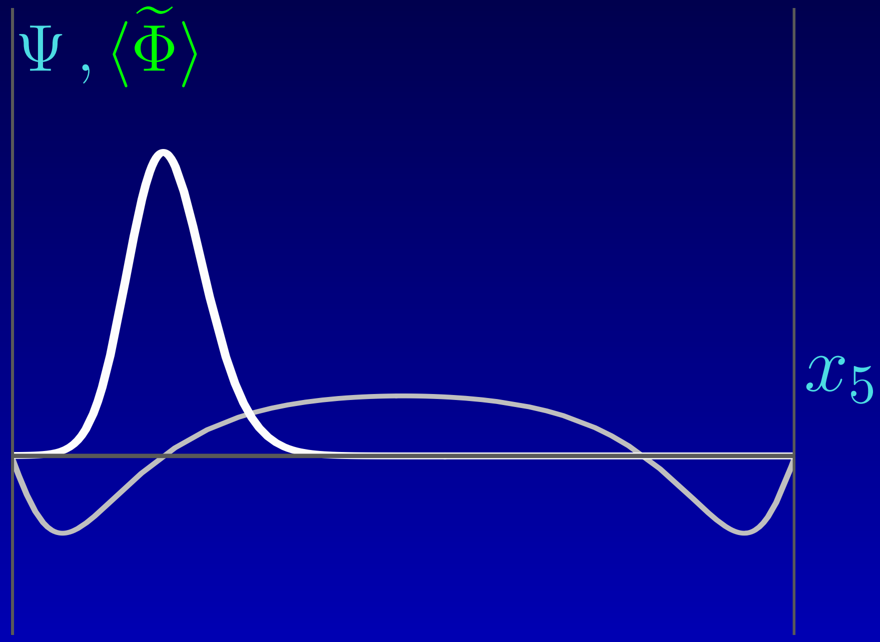
Fermion profiles

$\otimes$ **No "zeros"**



$$X > 1; X < 0$$

$\oplus$ **Two "zeros" !**



$$0 \lesssim X \lesssim 1$$

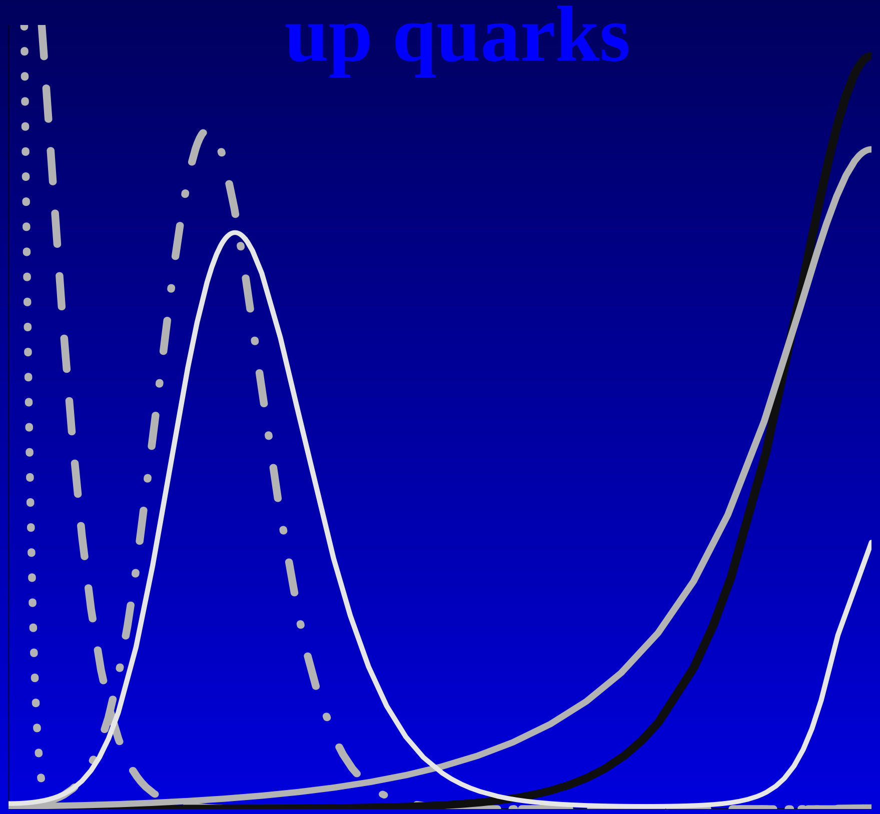
Realistic model

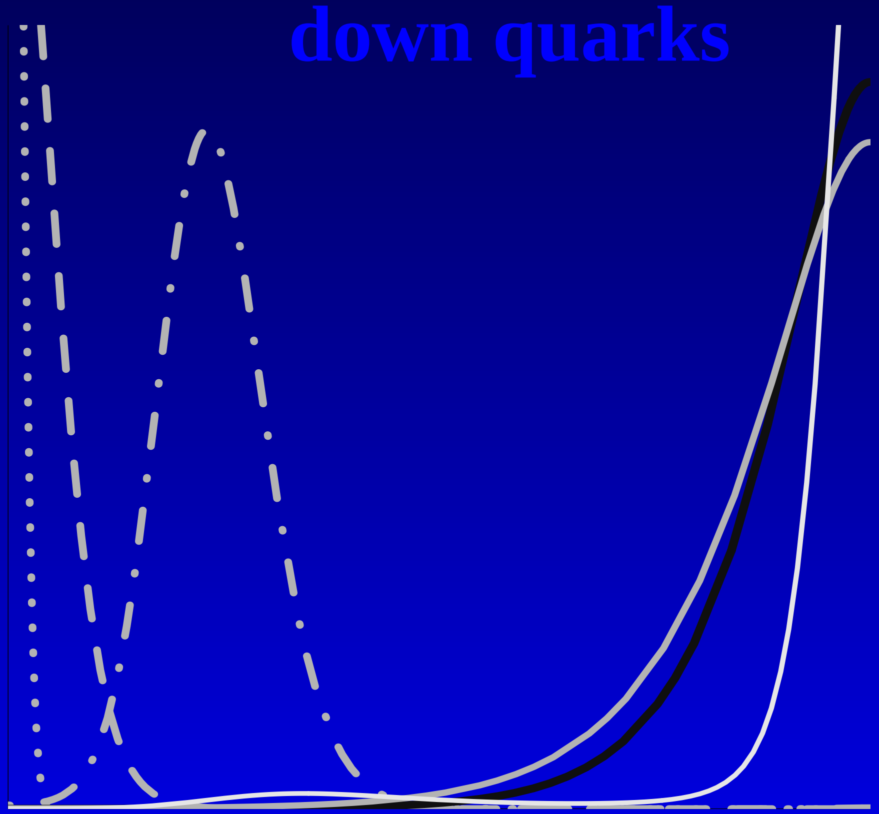
- The Yukawas, $Y_{1,2}$, are promoted to flavor matrices:

$$\mathcal{L}_Y = \bar{\Psi}^i \left(Y_1^{ij} \mathbf{\Phi_1} - Y_2^{ij} \mathbf{\Phi_2} \right) \Psi^j$$

A Realistic model

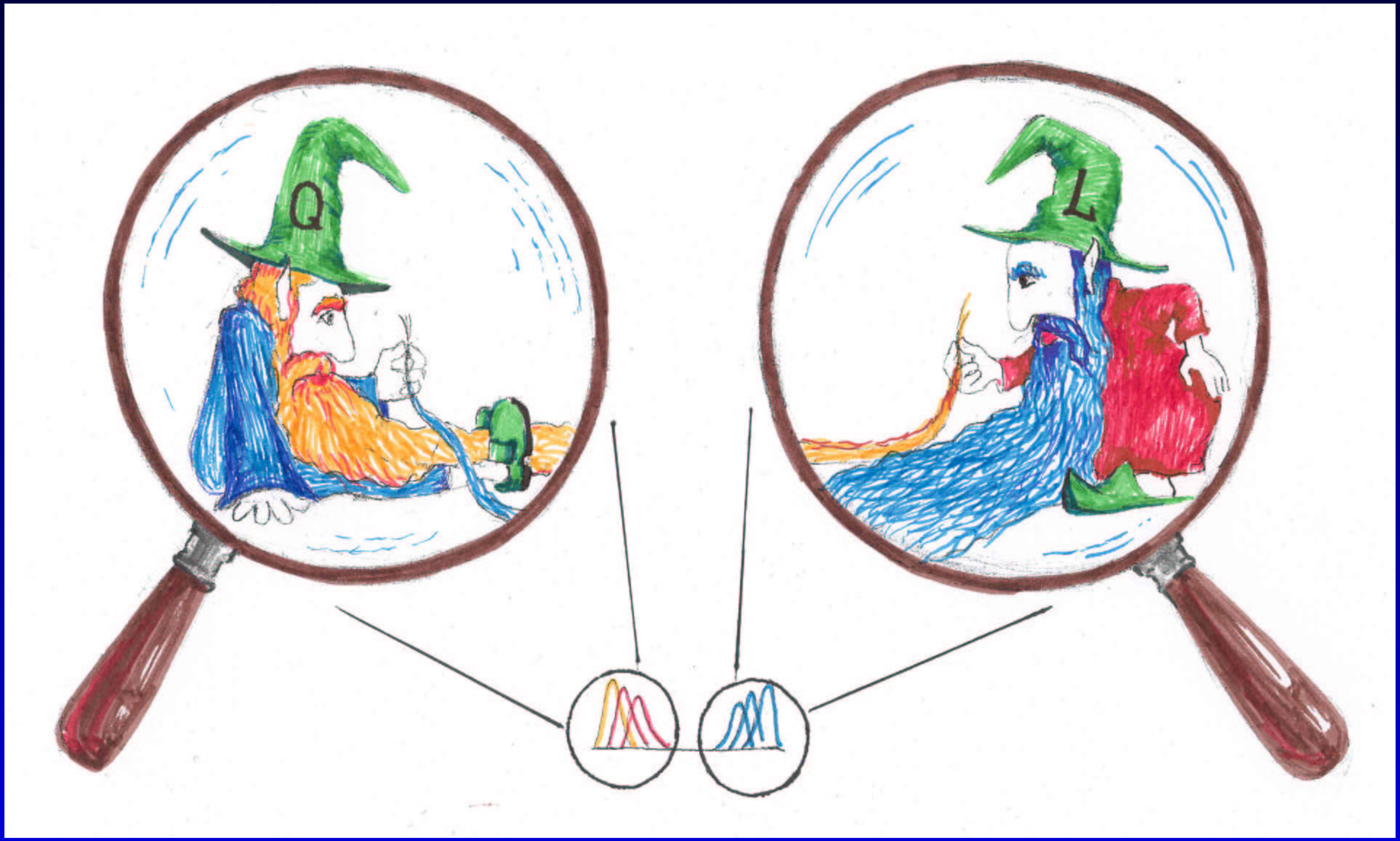
♣ $Y_{1,2}$ $\Rightarrow$ flavor matrices !





Realistic *Quark* model!

(Proton decay ?)



Quarks Quarks

Gaussian WF + Realistic Model?

Requires localization in the linear part of $\langle\phi\rangle$. G.P., (02)

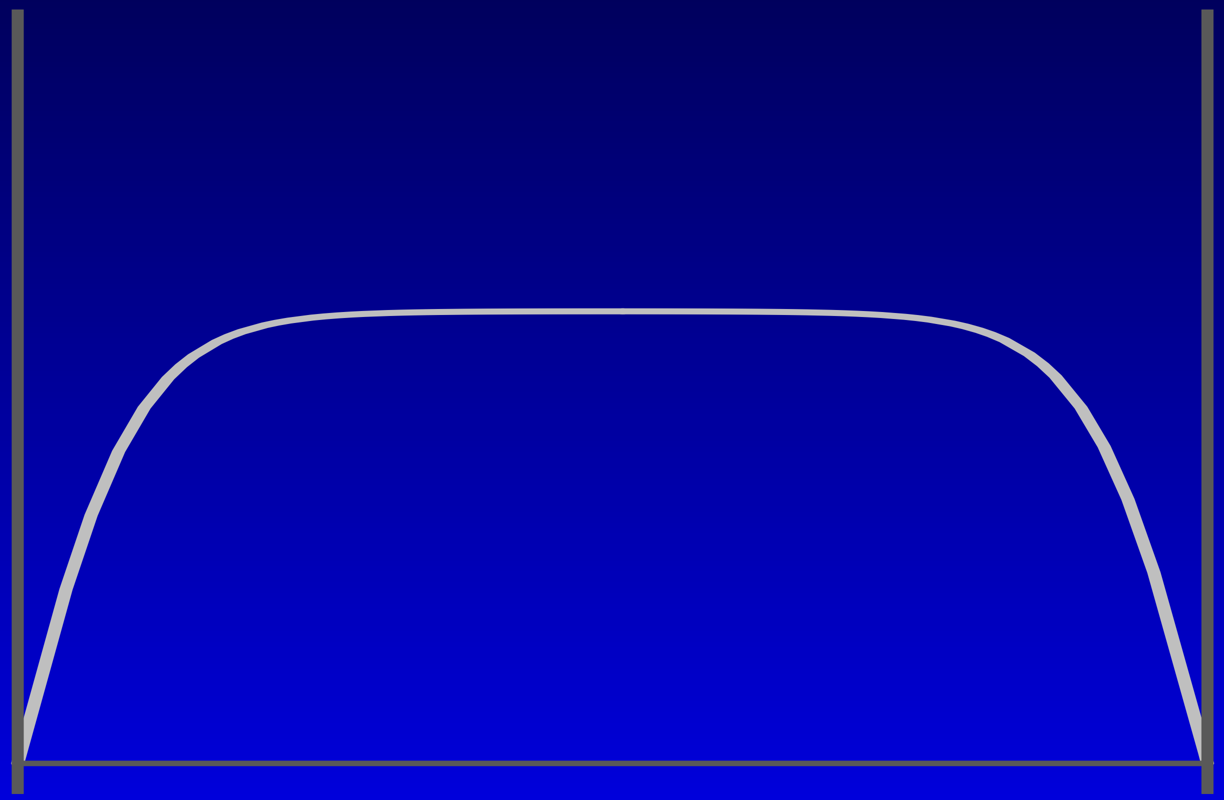
$$\langle\phi\rangle \simeq v\,\tanh[a(u)]\,\tanh[a(1-u)]\,, \qquad u = \frac{x_5}{L}$$

$$u \ll 1/a\,, \qquad a = a(R, M_*, v, \lambda)$$

Gaussian WF + Realistic Model?

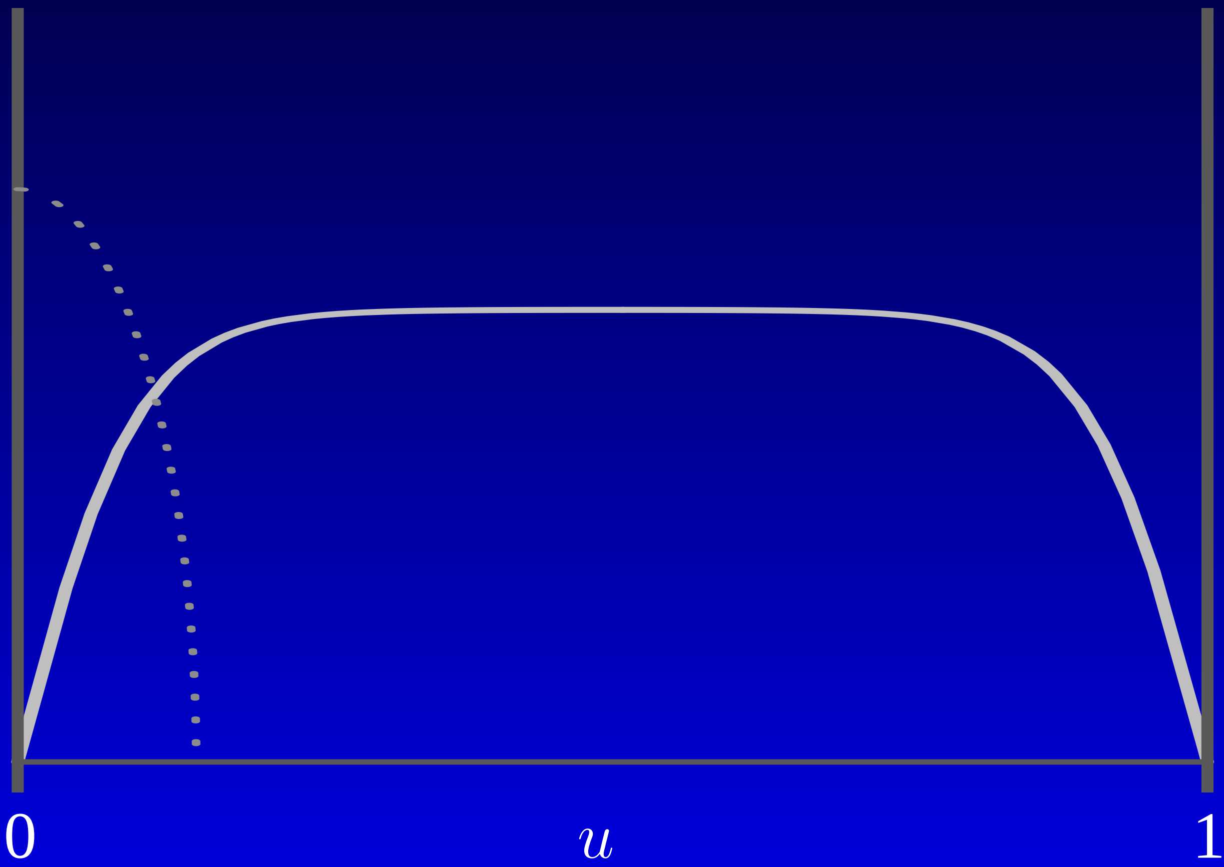
Requires localization in the linear part of $\langle\phi\rangle$.

$$\langle\phi\rangle = v\tanh(au)\tanh[a(1-u)]$$



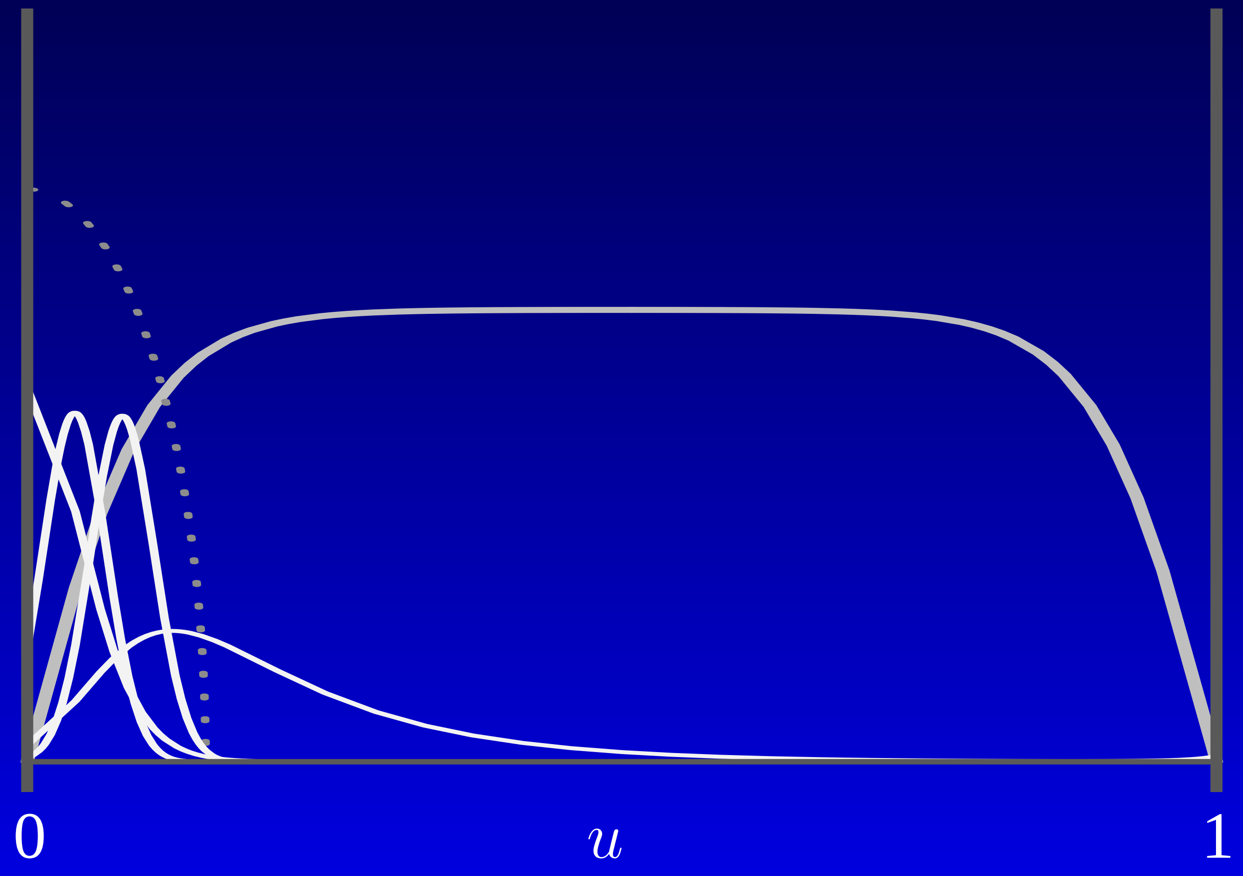
Gaussian WF + Realistic Model?

Linear part - $u \ll 1/a$, $a = a(R, M_*, v, \lambda)$



Gaussian profiles ?

Flavor puzzle $\Rightarrow$ the fermion must be **separated**.



Gaussian WF + Realistic Model?

- Linear part- $0 < u_{\max} \lesssim \frac{1}{3} \cdot \frac{1}{a}$
- Width- $\Gamma(\Psi)^{-1} \sim \sqrt{\mathbf{Y}} \frac{a}{\sqrt{2}}$
- Flavor puzzle- $u_{\max}\Gamma(\Psi)^{-1} \gtrsim 18$

Mirabelli, schmaltz PRD **61**, 113011 (00).

$$\Downarrow$$

$$\mathbf{Y} \gtrsim 10^4$$

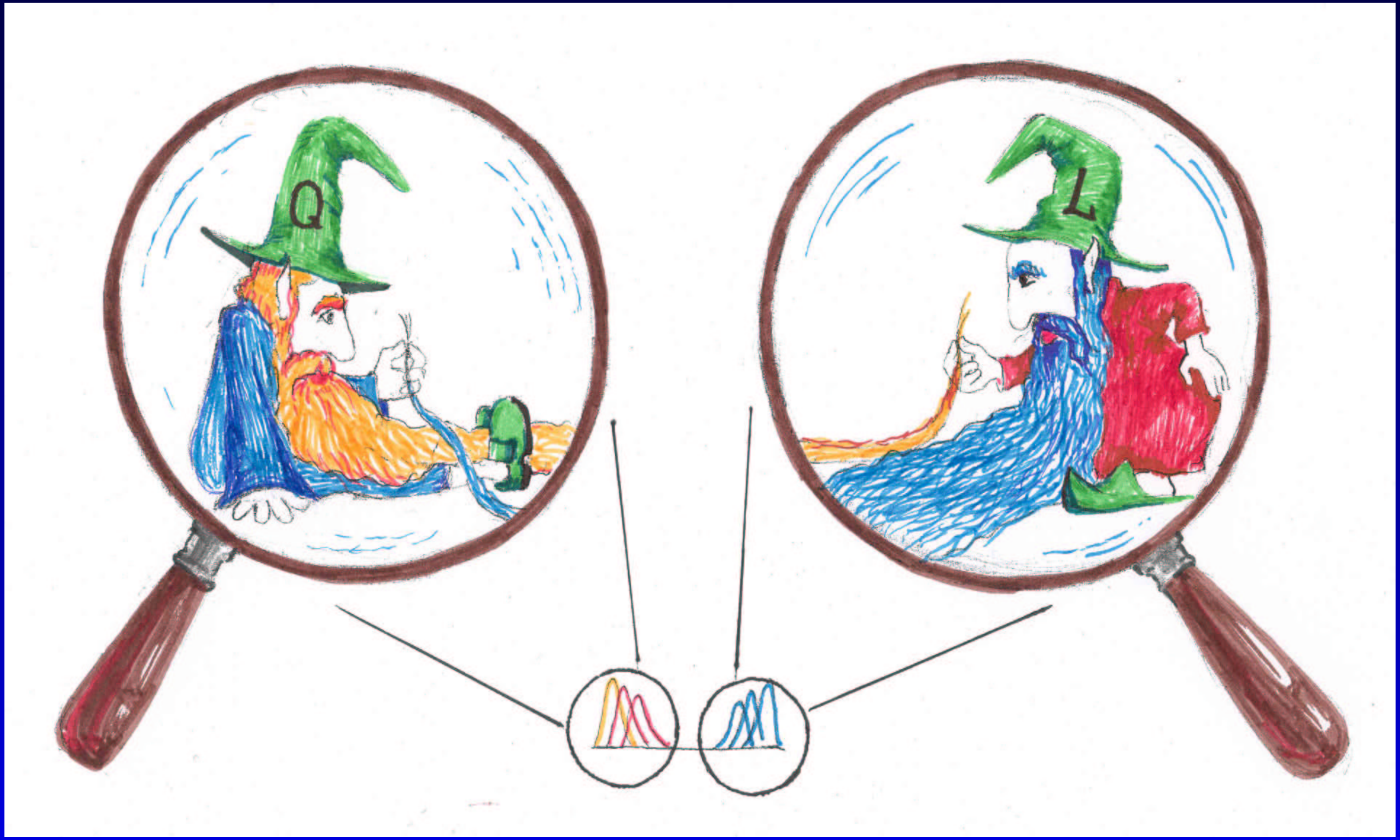
Grossman, Perez (02).

Conclusions

- Two scalar models yield separation - solve the flavor puzzle + enough CPV.
- Proton longevity (within split fermion): Solution requires Gaussian profiles $\Rightarrow$ fine tuning of $\mathcal{O}\left(10^{-4}\right)$.

Realistic split fermions model

Gilad Perez



Quarks Quarks