Quarks and Leptons from Extra dimensions:

from general properties to numbers.

Qualitative results:

1 family in 6dim → 3 families in 4D

Quarks matrix

nearly diagonal,
strongly hierarchical

Same for charged fermions

Majorana neutrinos possible

→off-diagonal (large mixings)
→Inverted hierarchy
→Pseudo-Dirac (O$\nu 2\beta$ decay suppressed)
→ Θ_{13} predicted (before observation)

J.-M. Frère

Based on work with Maxim Libanov, Serguey Troitsky, Emin Nugaev,Ling Fu-Sin , Simon Mollet (more details on neutrinos in his talk) latest ref **JHEP 1308 (2013) 078**

Generic prediction : **large mixings, inverted hierarchy suppressed neutrinoless double beta decay**

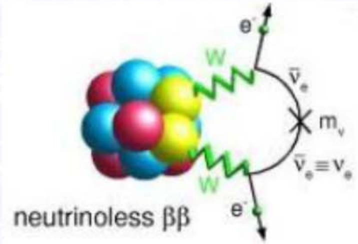
Neutrino-less double beta decay controlled by weighted sum of masses
(with phases/signs of mixings entering)

NEUTRINOS MASSES

$$M_\nu \sim \begin{pmatrix} \cdot & \cdot & \times \\ \cdot & \cdot & \cdot \\ \times & \cdot & \cdot \end{pmatrix}$$

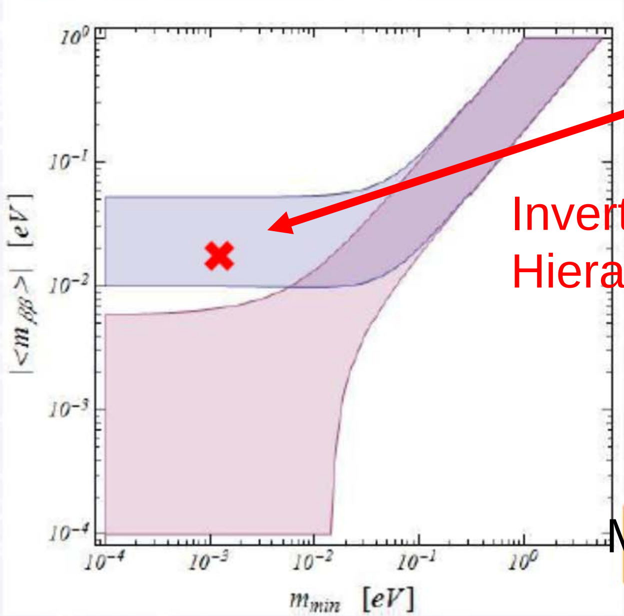
Automatically get

- Consequences of this structure
  - $0\nu\beta\beta$ decay



partial suppression

$$|\langle m_{\beta\beta}\rangle| \simeq \frac{1}{3}\sqrt{\Delta m^2_\oplus}$$



Inverted Hierarchy

Mass scale

At LHC ?

Current model not reachable,
but possible generalizations suggest looking for

for later …

From now on …

ordinary KK excitations Z' γ', or W', B'

e+ e- pairs

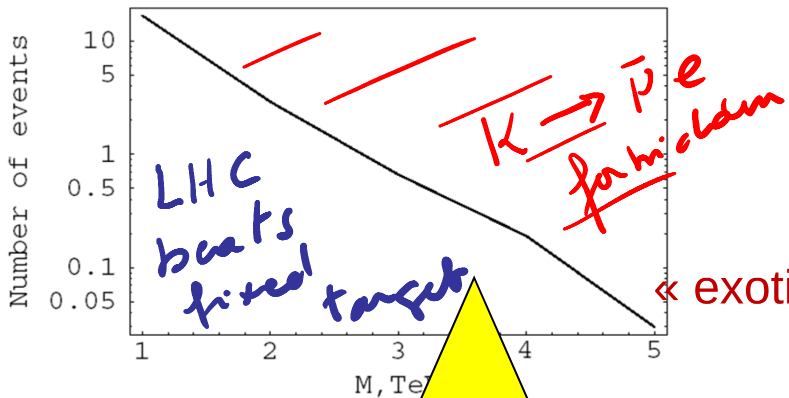


Fig. 1. Num … uc-
tion as a function … M, with
$\kappa = M/(100\text{TeV})$.

« exotic » Z'

μ+ e- pairs
(>> μ- e+)

Fermions in 6-D

Basically, a 8-component Dirac spinor,
Which can be split into 2 (4-components spinors)

$$\psi = \frac{1+\Gamma_7}{2}\psi_+ \; + \; \frac{1-\Gamma_7}{2}\psi_-$$

$$\psi = \begin{pmatrix} \psi_{+R} \\ \psi_{+L} \\ \psi_{-L} \\ \psi_{-R} \end{pmatrix}$$

If one thinks already in terms of (3+1) +2 dim, one can further show where the chiral L and R fermions of 4D would appear

There are NO Majorana particles in 6D, and scalar (or mass) terms always involve both + and – « 6-parities »

Still, we can generate 4D Majorana's !!!

We can indeed write 2 main types of 6D scalars:

$$\Phi \;\; \overline{\psi}\psi \rightarrow \Phi \;\; (\overline{\psi_{+L}}\psi_{-R} + \overline{\psi_{+R}}\psi_{-L} + \overline{\psi_{-R}}\psi_{+L} + \overline{\psi_{-L}}\psi_{+R})$$

Will lead to « Dirac » style 4D particles

$$\Phi \;\; \overline{\psi^C}\psi \rightarrow \Phi \;\; (\psi_{+R} \bullet \psi_{-R} + \psi_{+L} \bullet \psi_{-L} + \psi_{-L} \bullet \psi_{+L} + \psi_{-R} \bullet \psi_{+R})$$

Will lead to « Majorana » style 4D particles

What are Zero Modes ?

$$i\partial_A \, \gamma^A \Psi \quad = \quad \Phi \; \Psi$$

Dirac equation for fermion coupled
to scalar field

For 2 compact extra dim

$$\Psi(x^\mu, x^4, x^5) \;=\; \sum_{n,l} \psi_{n,l}(x^\mu)\; f_{n,l}(x^4, x^5)$$

$$\underbrace{i\partial_\nu \, \gamma^\nu \psi_{n,l}(x^\mu)\; f_{n,l}(x^4, x^5)}_{\text{4-d Dirac eq.}} \;=\; \psi_{n,l}(x^\mu)\underbrace{(\Phi - i\partial_4\, \gamma^4 \; - i\partial_5\, \gamma^5)}_{\text{large effective mass}}\; f_{n,l}(x^4, x^5)$$

$\gg 1$ TeV

if $= 0 \rightarrow$ zero mode

$x^4, x^5 \rightarrow \begin{cases} r \\ \varphi \end{cases}$

l

Kaluza - Klein "Tower"

n

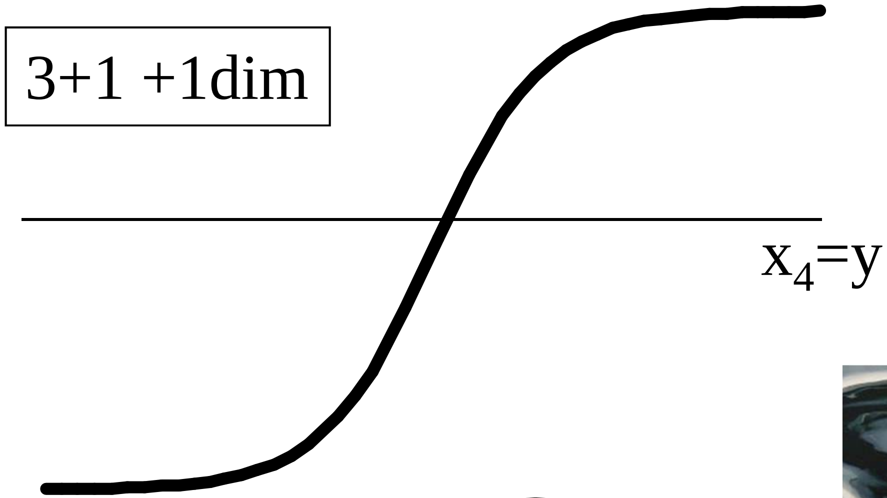
Look for zero modes …

Use of dimensional reduction obtain 3+1-dim chiral spinors (L) : use of topological singularities in the extra dimensions to get zero modes, break LR symmetry.

Solitonic background: index theorem localizes one chiral Fermion ;
Alternatively, orbifold

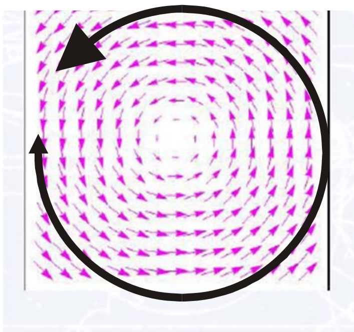
3+1 +1dim

e.g

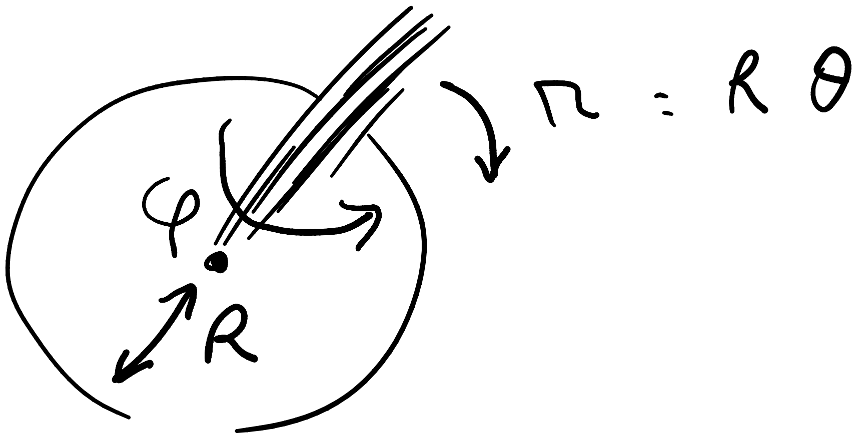


3+1 +2 dim

$$\Phi = e^{\,i\, n\varphi}$$



Vortex with winding number n localizes n chiral massless fermion modes in 3+1

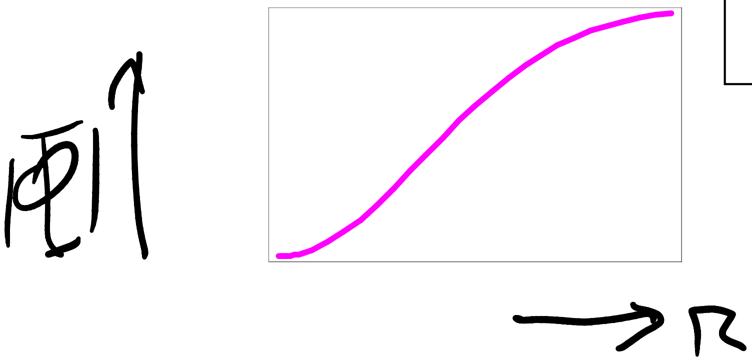


In fact, we work now with the 2 extra dimensions
on a sphere (of radius R) ,
The field profiles are pretty much the same.
Compared to the plane, we don't need an extra mechanism
to confine the gauge fields close to the vortex…

3 families from one in 5+1 dim

$$\Phi = e^{\,i\,n\varphi}$$

we assume a background scalar field Φ providing a vortex in the 2 extra dimensions;
It vanishes at the origin– where we live!



The 3 fermion modes have different shapes, and different winding properties in the extra dimension variable φ

For some reason, n=3 !!!

The transition from 6-D to the zero- modes of 4D dramatically affects

$\bar{\Psi}\, \Phi \frac{1-\Gamma_7}{2} \Psi$

Start from 4 * 2-components

$$\Psi = \begin{pmatrix} \psi_{+R} \\ \psi_{+L} \\ \psi_{-L} \\ \psi_{-R} \end{pmatrix}$$

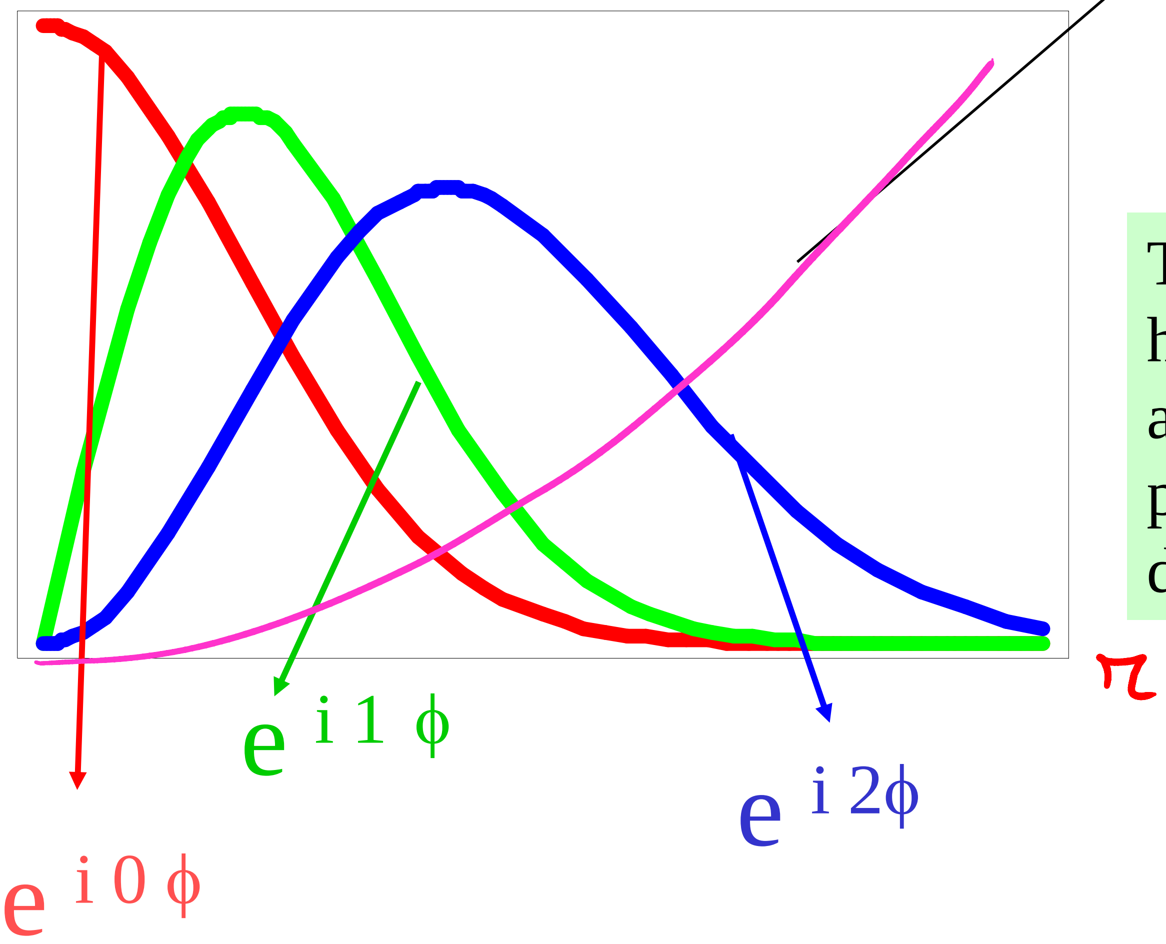
Each « zero » (massless) mode only has 2-spinor degrees of freedom:
For instance,

Redundant!

$$L \sim \sum_n \begin{pmatrix} 0 \\ f_{3-n}(r)\; e^{i(3-n)\phi} \psi_{Ln}(x^\mu) \\ f_{n-1}[r)\; e^{i(1-n)\phi} \psi_{Ln}(x^\mu) \\ 0 \end{pmatrix}$$

2× same 4-d chiral spinor!

Vortex Profile $e^{i\,3\,\phi}$

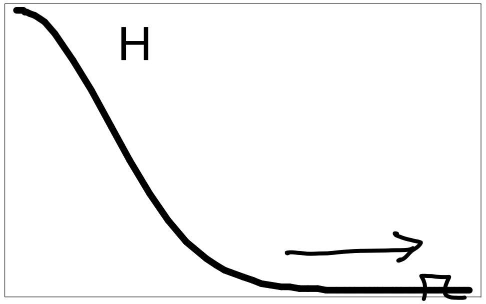


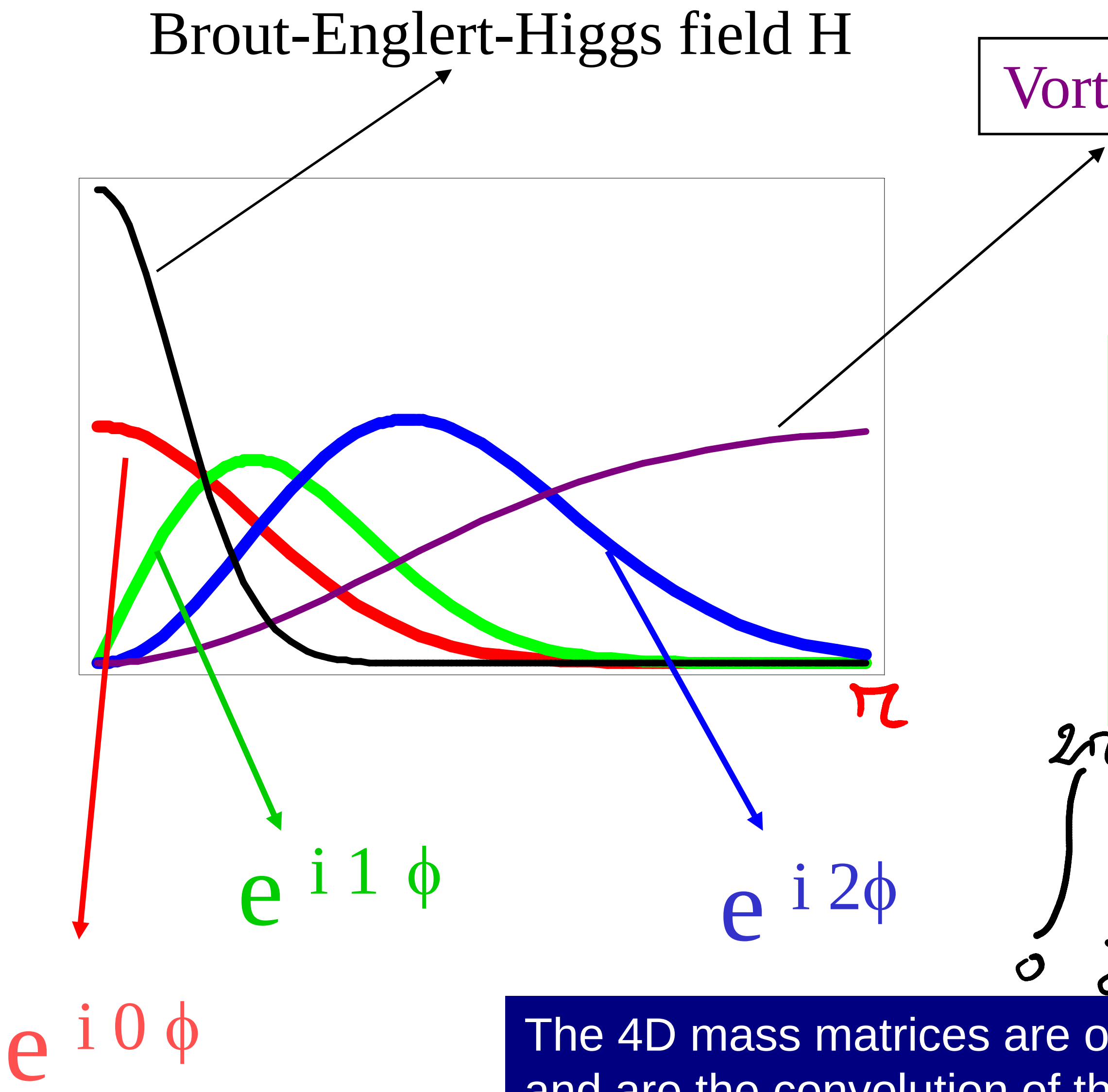
The 3 fermion modes have different shapes in r, and different winding properties in the extra dimension variable ϕ

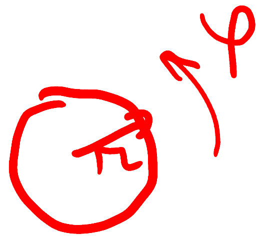
Turn to physics .. Introduce masses,

through the Standard Model Scalar H (Brout-Englert-Higgs field)

We also locate it on the vortex, with its proper shape:





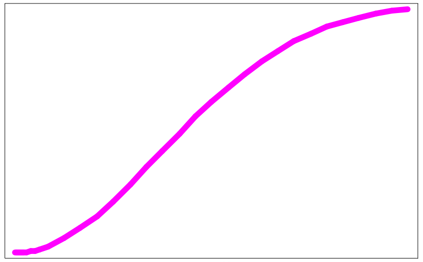


The 3 fermion modes have different shapes, and different winding properties in the extra dimension variable ϕ

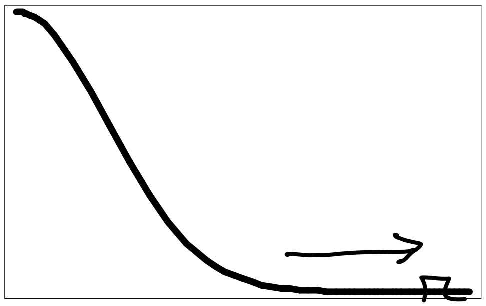
$$\int_0^{2\pi}\int_0^{R} \bar{\Psi}_n \Psi_n \cdot H\, r\, dr\, d\varphi$$

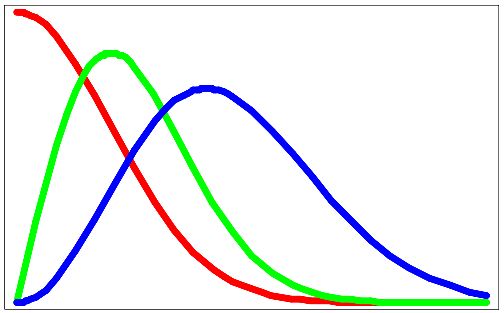
The 4D mass matrices are obtained by integrating r and ϕ, and are the convolution of these curves

Field Content



Field	Notation	$U(1)_g$	$U(1)_Y$	$SU(2)_w$	$SU(3)_c$
vortex scalar	Φ	$+1$	0	$\mathbf{1}$	$\mathbf{1}$
BEH boson	H	0	$+1/2$	$\mathbf{2}$	$\mathbf{1}$
auxiliary scalar	X	$+1$	0	$\mathbf{1}$	$\mathbf{1}$
quark $SU(2)_W$ doublet	(Q_+, Q_-)	$(3, 0)$	$1/6$	$\mathbf{2}$	$\mathbf{3}$
up-type quark $SU(2)_W$ singlet	(U_+, U_-)	$(0, 3)$	$2/3$	$\mathbf{1}$	$\mathbf{3}$
down-type quark $SU(2)_W$ singlet	(D_+, D_-)	$(0, 3)$	$-1/3$	$\mathbf{1}$	$\mathbf{3}$
lepton $SU(2)_W$ doublet	(L_+, L_-)	$(3, 0)$	$-1/2$	$\mathbf{2}$	$\mathbf{1}$
charged lepton $SU(2)_W$ singlet	(E_+, E_-)	$(0, 3)$	-1	$\mathbf{1}$	$\mathbf{1}$
sterile neutrino singlet	(N_+, N_-)	$(0, 0)$	0	$\mathbf{1}$	$\mathbf{1}$





For Quarks and Dirac fermions, we get a mass matrix like :

$$\begin{pmatrix} small & \varepsilon & \\ & medium & \varepsilon \\ & & large \end{pmatrix}$$

Generation number n =	Winding
1	2
2	1
3	0

Additional couplings involving the vortex field, with winding $e^{i\phi}$ can give the small Cabibbo mixings ε

The scheme is very constrained, as the profiles are dictated by the equations, instead of being imposed by hand, like in multilocalisation

Neutrinos ARE different

In the same context (0th order in Cabibbo mixing), we will get indeed (see later):

$$M_\nu \sim \begin{pmatrix} \cdot & \cdot & m \\ \cdot & \mu & \cdot \\ m & \cdot & \cdot \end{pmatrix}$$

Where m >> μ
After 45° 1-3 rotation and 23 permutation, this leads to an inverted hierarchy, (minute solar mass difference found between the heavier neutrinos)

$$M_\nu \sim \begin{pmatrix} m & \cdot & \cdot \\ \cdot & -m & \cdot \\ \cdot & \cdot & \mu \end{pmatrix}$$

The – sign may be absorbed in the mixing matrix, *but contributes destructively to the effective mass for neutrinoless double beta decay* (Pseudo-Dirac structure when full Cabibbo-like mixing is introduced)

WHY the difference? --- return in more detail to the 6D spinors,

Zero modes

$$\Psi = \begin{pmatrix} \psi_{+R} \\ \psi_{+L} \\ \psi_{-L} \\ \psi_{-R} \end{pmatrix}$$

$$\bar{\Psi} \, \phi \, \frac{1-\Gamma_7}{2} \, \Psi \quad \Rightarrow \quad \begin{pmatrix} 0 \\ \psi_L \\ \psi_L \\ 0 \end{pmatrix} \quad \text{solutions} \quad (L)$$

$$\bar{\Psi} \, \phi \, \frac{1+\Gamma_7}{2} \, \Psi \quad \Rightarrow \quad \begin{pmatrix} \psi_R \\ 0 \\ 0 \\ \psi_R \end{pmatrix} \quad (R)$$

.

WHY the difference? --- return in more detail to the 6D spinors,

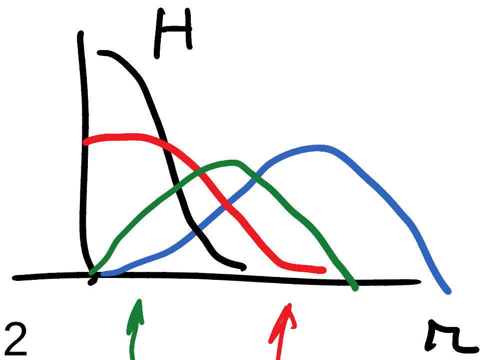
$$\Psi = \begin{pmatrix} \psi_{+R} \\ \psi_{+L} \\ \psi_{-L} \\ \psi_{-R} \end{pmatrix}$$

In each case, the massless mode only has 2-spinor degrees of freedom:
For instance,

$\neq e^{i\phi}$ Same 2+

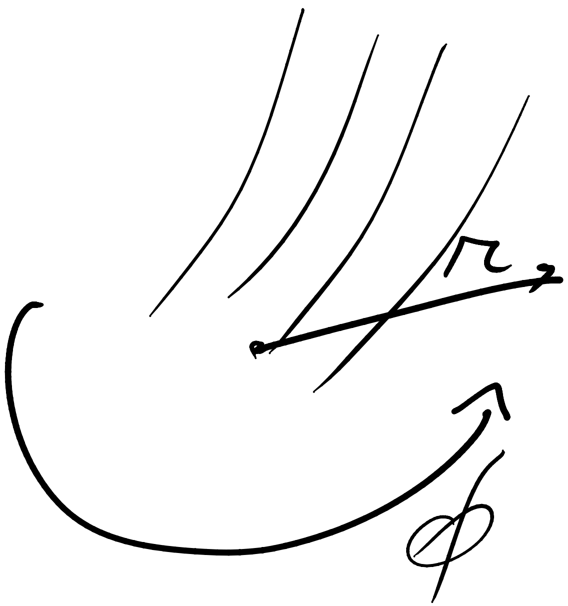
$$L \sim \sum_n \begin{pmatrix} 0 \\ f_{3-n}(r)\, e^{i(3-n)\phi}\psi_{Ln}(x^\mu) \\ f_{n-1}[r)\ e^{i(1-n)\phi}\psi_{Ln}(x^\mu) \\ 0 \end{pmatrix}$$

WHY the difference?



It comes from rotation invariance in the 2 extra dimensions…

Vortex



$$\int_0^{2\pi} d\phi \; \bar{\psi}_i(\phi)\, \psi_j(\phi)\, H$$

WHY the difference? --- return in more detail to the 6D spinors,

For the charged spinors, we have both L and R spinors bound to the vortex.

$$\Psi = \begin{pmatrix} \psi_{+R} \\ \psi_{+L} \\ \psi_{-L} \\ \psi_{-R} \end{pmatrix}$$

L $\bar{R}$

$$L \sim \sum_n \begin{pmatrix} 0 \\ f_{3-n}(r)\ e^{i(3-n)\phi}\psi_{Ln}(x^\mu) \\ f_{n-1}[r)\ e^{i(1-n)\phi}\psi_{Ln}(x^\mu) \\ 0 \end{pmatrix} \qquad R \sim \sum_n \begin{pmatrix} f_{n-1}[r)\ e^{i(1-n)\phi}\chi_{Rn}(x^\mu) \\ 0 \\ 0 \\ f_{3-n}(r)\ e^{i(3-n)\phi}\chi_{Rn}(x^\mu) \end{pmatrix}$$

Dirac mass

$$\bar{R}L = \sum_{n,n'} \bar{R}_{n'} L_n$$

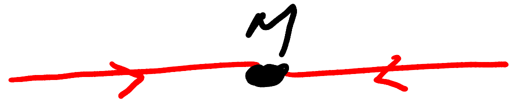
$$\Rightarrow \int dr \int_0^{2\pi} d\phi\, f_{3-n}\, f_{3-n'}^{*}\, e^{i(n'-n)\phi} \rightarrow \delta(n-n')$$

Effective Lagrangian : integrate over r and φ,

diagonal

For neutrinos (using only Majorana-type 4D mass term)
we will get (through see-saw discussed later)

$$\overline{L^c}\, L \Rightarrow \sum_{n\, n'} \overline{(L_{n'})^c}\, L_n$$



$$L \sim \sum_n \begin{pmatrix} 0 \\ f_{3-n}(r)\; e^{i(3-n)\phi} \psi_{Ln}(x^\mu) \\ f_{n-1}(r)\; e^{i(1-n)\phi} \psi_{Ln}(x^\mu) \\ 0 \end{pmatrix}$$

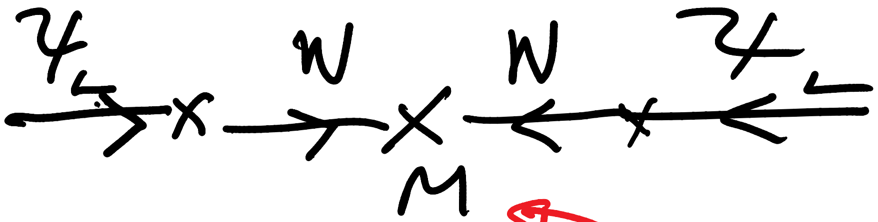
$$\Rightarrow \int_0^{2\pi} d\phi \; e^{i(4-n-n')\phi}$$

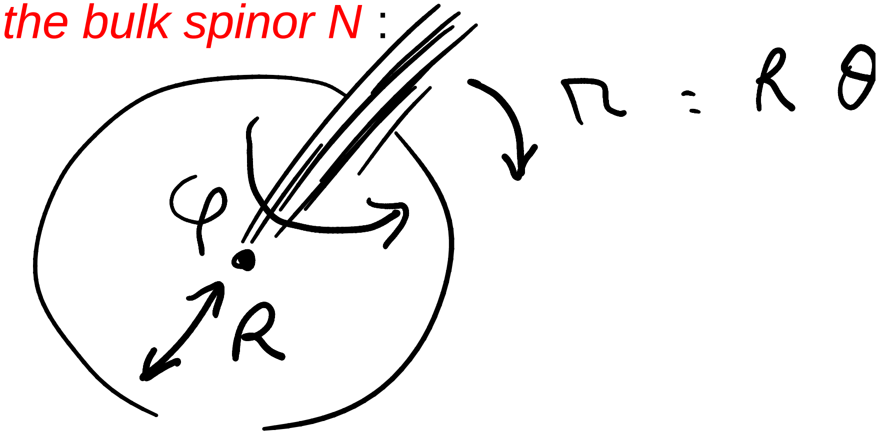
$$\Rightarrow \delta(n+n'-4)$$

$$\Rightarrow \begin{array}{cc} \begin{pmatrix} & & m \\ & \mu & \\ m & & \end{pmatrix} & \begin{array}{c} 1 \\ 2 \\ 3 \end{array} \end{array}$$

The Majorana term can be traced to the « Majorana mass term » in the Lagrangian (not to be confused with a non-existant 6D Majorana spinor) through a see-saw

It leads to a contribution proportional to the effective propagator after summing over a *large number of proper modes « n » of the bulk spinor N* :





$M \, \overline{N^c} N \Longrightarrow 4D$

Each mode n
of the bulk spinor N

$$\frac{M}{\not{p}^2 - \left(\frac{2\pi n}{R}\right)^2 - M^2}$$

Small m

$\rightarrow M \gg 1/R$

OR

$\rightarrow M \ll 1/R$ (GeV ok)

Neutrinos ARE different

In the same context (0th order in Cabibbo mixing), we will get indeed (see later):

$$M_\nu \sim \begin{pmatrix} \cdot & \cdot & m \\ \cdot & \mu & \cdot \\ m & \cdot & \cdot \end{pmatrix}$$

Where m >> μ
After 45° 1-3 rotation and 23 permutation, this leads to an inverted hierarchy, (minute solar mass difference found between the heavier neutrinos)

$$M_\nu \sim \begin{pmatrix} m & \cdot & \cdot \\ \cdot & -m & \cdot \\ \cdot & \cdot & \mu \end{pmatrix}$$

The – sign may be absorbed in the mixing matrix, *but contributes destructively to the effective mass for neutrinoless double beta decay* (Pseudo-Dirac structure when full Cabibbo-like mixing is introduced)

We can then introduce extra terms carrying winding, to generate the Cabibbo-like mixings,

In the present formulation, it amounts to factors (ΦX) , where Φ carries winding 1 and X none

$H(\Phi X^*) \sim e^{i\phi}$

$$\begin{pmatrix} small & & \\ & medium & \\ & & large \end{pmatrix}$$

H

$e^{i0\phi}$

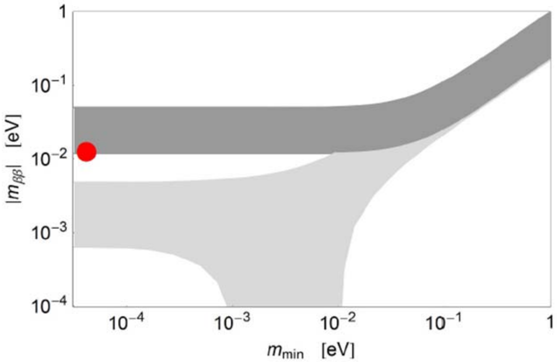
Fermion-vortex couplings	
g_L^Q	$0.020\ \ \Lambda_V^{-5}$
g_R^U	$0.005\ \ \Lambda_V^{-5}$
g_R^D	$0.063\ \ \Lambda_V^{-5}$
g_L^L	$0.013\ \ \Lambda_V^{-5}$
g_R^E	$0.013\ \ \Lambda_V^{-5}$
"Yukawa" fermion-scalars couplings	
$H\bar{Q}_+D_-$	$7.00\ \ \Lambda_V^{-1}$
$HX^*\Phi\bar{Q}_+D_-$	$14.0\ \ \Lambda_V^{-5}$
$\tilde{H}\bar{Q}_+U_-$	$850\ \ \Lambda_V^{-1}$
$\tilde{H}X^*\Phi\bar{Q}_+U_-$	$255\ \ \Lambda_V^{-5}$
$HX^*\Phi\bar{L}_+E_-$	$56\ \ \Lambda_V^{-5}$
$HX\Phi^*\bar{L}_+E_-$	$-160\ \ \Lambda_V^{-5}$
$\tilde{H}\bar{L}_-N_+$	$0.165\ \ \Lambda_V^{-1}$
$\tilde{H}X\Phi^*\bar{L}_-N_+$	$(0.91+1.04i)\cdot 10^{-2}\ \ \Lambda_V^{-5}$
$\tilde{H}(X^*)^4\Phi\bar{L}_+N_-$	$1.00\ \ \Lambda_V^{-11}$

(the last coupling is needed, but can be set to 1, as its value is redundant with others..)

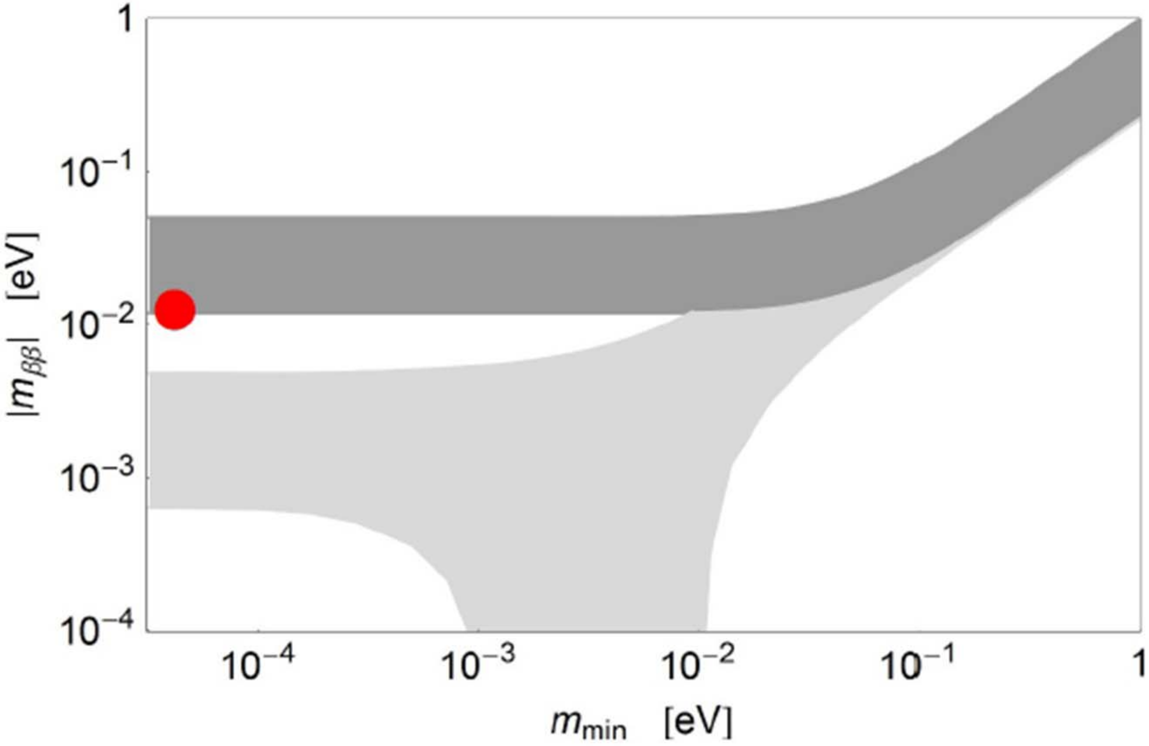
Quark masses at Z scale		
m_d	$0.01\,\mathrm{GeV}$	$(0.00282 \pm 0.00048)\,\mathrm{GeV}$
m_s	$0.051\,\mathrm{GeV}$	$(0.057^{+0.018}_{-0.012})\,\mathrm{GeV}$
m_b	$2.86\,\mathrm{GeV}$	$2.86^{+0.16}_{-0.06}\,\mathrm{GeV}$
m_u	$0.023\,\mathrm{GeV}$	$0.00138^{+0.00042}_{-0.00041}\,\mathrm{GeV}$
m_c	$0.72\,\mathrm{GeV}$	$0.638^{+0.043}_{-0.084}\,\mathrm{GeV}$
m_t	$172\,\mathrm{GeV}$	$172.1 \pm 1.2\,\mathrm{GeV}$
Quark mixing matrix		
$\lvert U_{\mathrm{CKM}}\rvert$	$\begin{pmatrix} 0.979 & 0.207 & 0.0015 \\ 0.206 & 0.9730 & 0.046 \\ 0.011 & 0.049 & 0.999 \end{pmatrix}$	$\begin{pmatrix} 0.97427 \pm 0.00015 & 0.22534 \pm 0.00065 & 0.00351^{+0.00015}_{-0.00014} \\ 0.22520 \pm 0.00065 & 0.97344 \pm 0.00016 & 0.0412^{+0.0011}_{-0.0005} \\ 0.00867^{+0.00029}_{-0.00031} & 0.0404^{+0.0011}_{-0.0005} & 0.999146^{+0.000021}_{-0.000046} \end{pmatrix}$
Charged-lepton masses		
m_e	$0.00061\,\mathrm{GeV}$	$0.0004866\,\mathrm{GeV}$
m_μ	$0.089\,\mathrm{GeV}$	$0.1027\,\mathrm{GeV}$
m_τ	$1.74\,\mathrm{GeV}$	$1.746\,\mathrm{GeV}$

Neutrino masses		
m_1	$5.46 \cdot 10^{-2}\,\mathrm{eV}$	—
m_2	$5.53 \cdot 10^{-2}\,\mathrm{eV}$	—
m_3	$4.17 \cdot 10^{-5}\,\mathrm{eV}$	—
Δm^2_{21}	$7.96 \cdot 10^{-5}\ \mathrm{eV}^2$	$(7.50 \pm 0.185) \cdot 10^{-5}\ \mathrm{eV}^2$
Δm^2_{13}	$2.98 \cdot 10^{-3}\ \mathrm{eV}^2$	$(2.47^{+0.069}_{-0.067}) \cdot 10^{-3}\ \mathrm{eV}^2$
Lepton mixing matrix		
$\lvert U_{\mathrm{PMNS}}\rvert$	$\begin{pmatrix} 0.76 & 0.63 & 0.13 \\ 0.39 & 0.58 & 0.72 \\ 0.52 & 0.52 & 0.68 \end{pmatrix}$	$\simeq \begin{pmatrix} 0.795-0.846 & 0.513-0.585 & 0.126-0.178 \\ 0.205-0.543 & 0.416-0.730 & 0.579-0.808 \\ 0.215-0.548 & 0.409-0.725 & 0.567-0.800 \end{pmatrix}$
$\langle m_{\beta\beta}\rangle$	$0.013\,\mathrm{eV}$	$\lesssim 0.3\,\mathrm{eV}$ [31]
J	0.019	$\lesssim 0.036$
θ_{12}	39.7°	$\simeq (31.09^\circ - 35.89^\circ)$
θ_{23}	46.5°	$\simeq (35.8^\circ - 54.8^\circ)$
θ_{13}	7.2°	$\simeq (7.19^\circ - 9.96^\circ)$

Note that CP phase is needed for lepton fit (see Simon Mollet's talk)



Note a non-vanishing θ_{13} was predicted (in previous version) *before observation*


1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$|m_{\beta\beta}|$ [eV]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
m_{min} [eV]

Some other developments :

- phenomenological implications of the excited modes..

- constraint on B-E-H boson (Libanov and Nugaev: LIGHT)
(the tuning of the vev simultaneously leads to a light Standard Model Scalar)

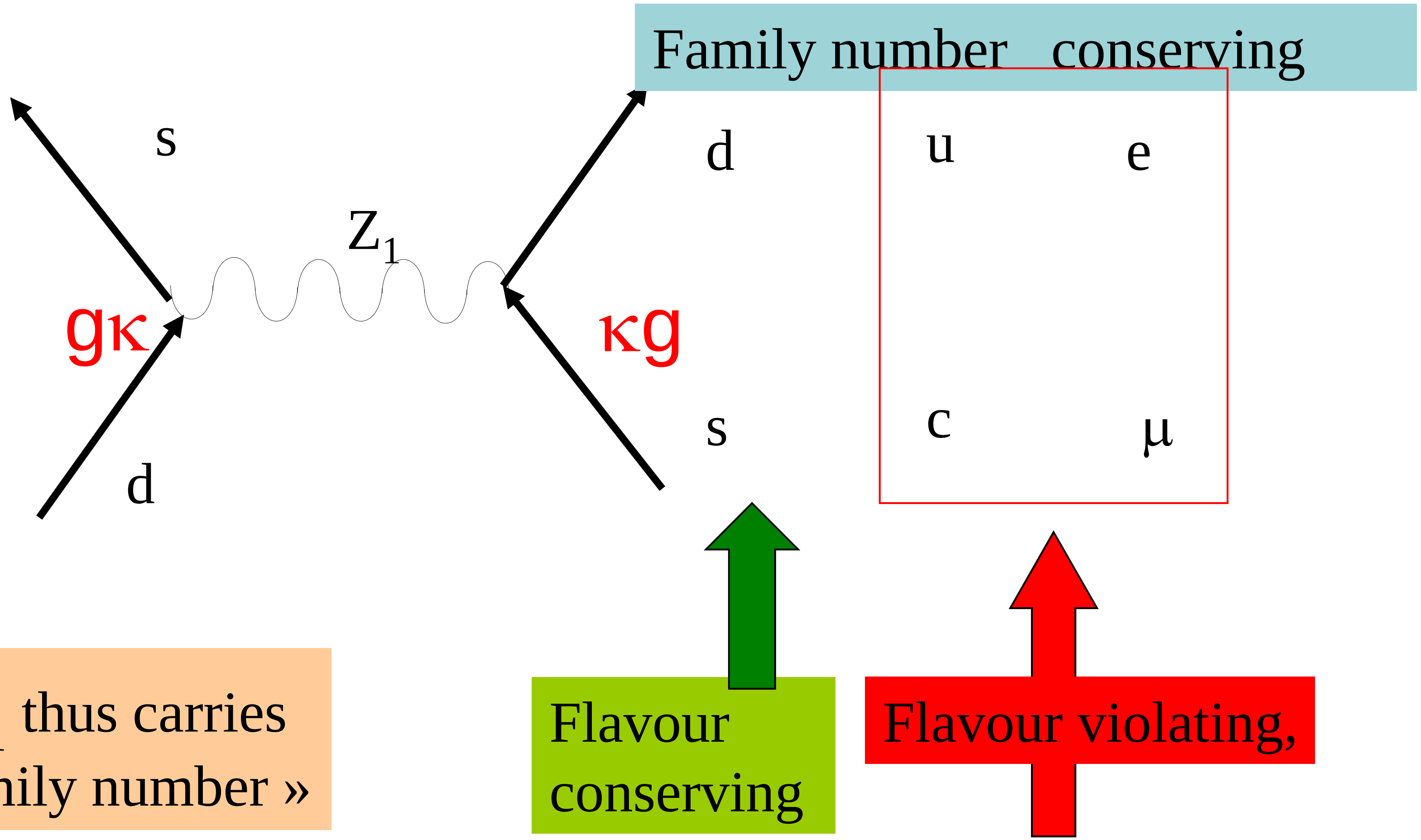
IMPORTANT : « family number » (n) is approximatively conserved ! - $e^{in\phi}$ plays somewhat like a U(1) horizontal symmetry

2 extra dim : → ll gauge bosons, possess 2 types of Kaluza- Klein excitations in particular, Z and Gluons

- radial Z'_0 (approx. flavour conserving) → From now on …
  - Almost the same couplings as Z
- angular : $Z'_{\pm 1}$ behaves like $e^{i\phi}$ → for later …
  - Flavour violating

$Z'_{\pm 1}$ thus carries « family number »

« family number » (n) is approximatively conserved ! - somewhat like U(1) horizontal symmetry $e^{i\phi}$



$Z_{\pm 1}$ thus carries « family number »

LIMITS

LIMITS

$K_L \rightarrow \mu^- e^+$ or $\mu^+ e^-$ B.R. $< 10^{-12}$

Expect thus typical mass scale $M_{Z1} / \kappa > (10^{12})^{1/4} M_Z$

$M(Z_1) > \kappa\ 100$ TeV

In fact, the small overlap of wave functions implies

some suppression of the coupling; $\kappa < 1$

In our calculations κ is « modest » (0.5) → inaccessible to LHC

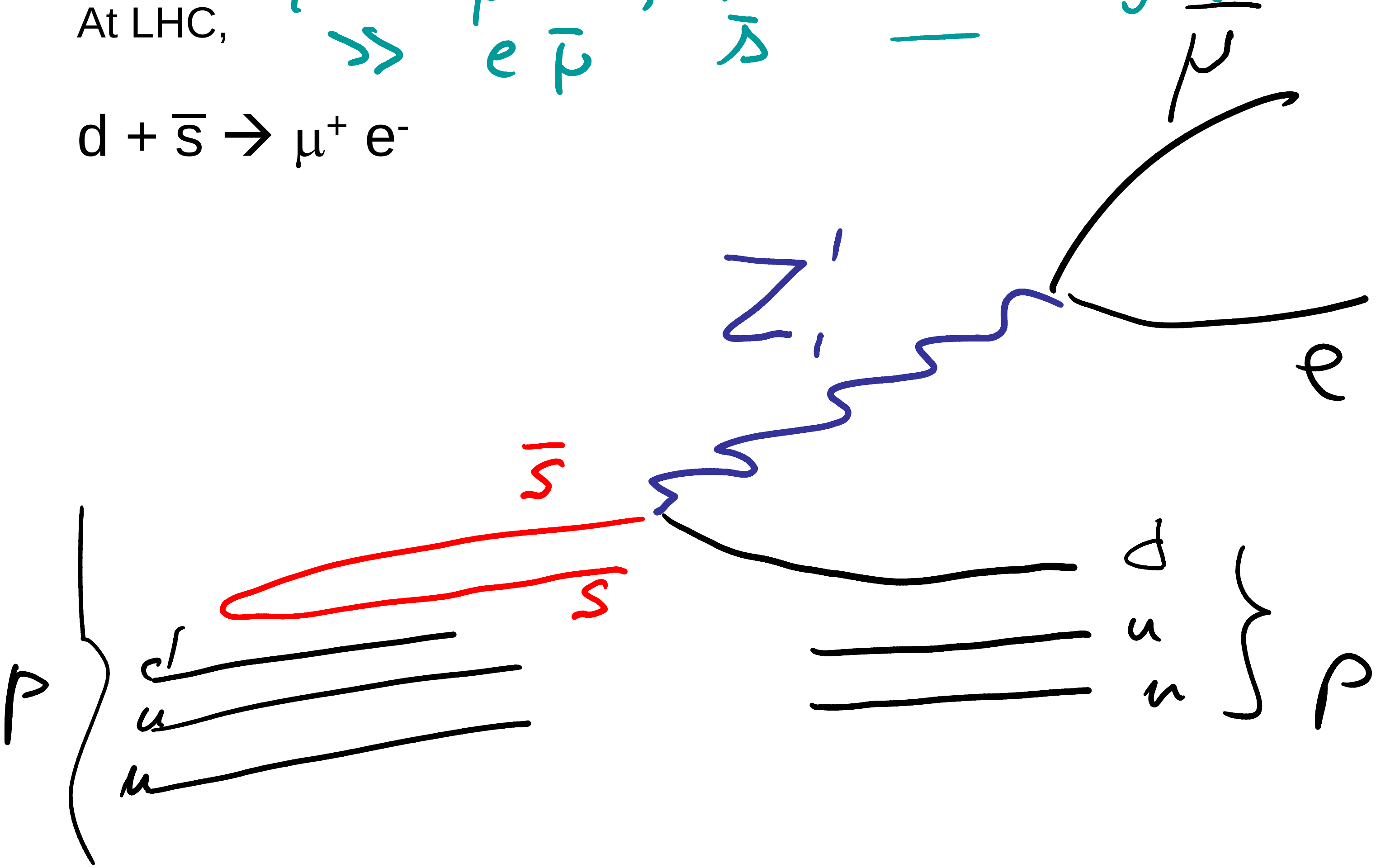
But this may be an example of a broader class of models, with different geometry….

So, explore the possibility in « model independent » way

Take κ from .01 to 0.5 →Plot for $M(Z_1)$>1TeV--

At LHC, nes $\bar{\mu} e$, s in underlying event
$\gg$ $e \bar{\mu}$ $\bar{s}$ —

$d + \bar{s} \rightarrow \mu^{+} e^{-}$



$$pp \longrightarrow \underbrace{\bar{\mu}\, e}_{\text{nes.}} + s + X$$
$$\hookrightarrow \Lambda, \bar{K}, ..$$

We saturate the bound on κ

$\kappa = 100\ \mathrm{TeV}/M_{Z1}$

$(100\ \mathrm{fb}^{-1},\ 14\mathrm{TeV})$

numbers for $\mu^- e^+$
are ONE ORDER below
at LHC,due to quark
content of protons

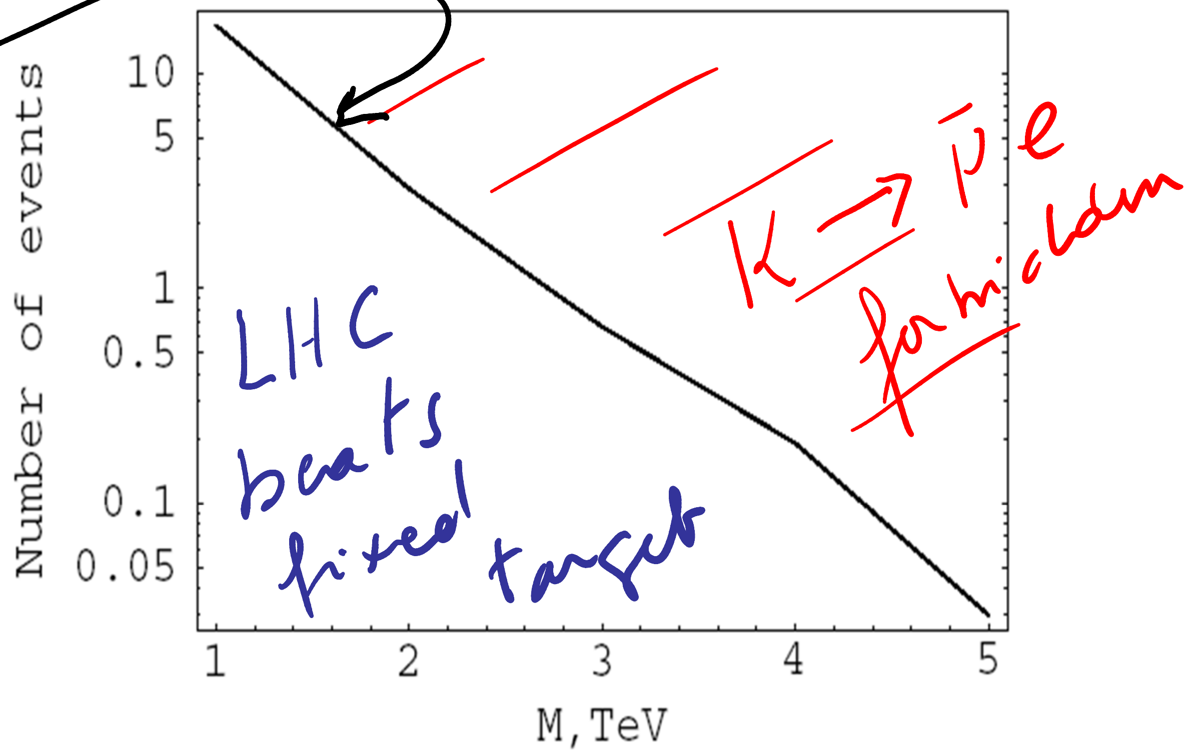


Fig. 1. Number of events for $(\mu^+ e^-)$ pairs production as a function of the vector bosons mass M, with $\kappa = M/(100\mathrm{TeV})$. (also s left in underlying event)

See.**JETP Lett.79:598-601,2004, Pisma Zh.Eksp.Teor.Fiz.79:734-737,2004**.
JMF, M Libanov, S Troitsky, E Nugaev **hep-ph/0404139**

LHC thus has the potential (in a specific model, of course) to beat even the very sensitive fixed-target $K \rightarrow \mu\, e$ limit!

$\bar{t} + c$ or $\bar{b} + s$ are similarly produced by the **gluon excitations**,

Expect a **few 1000's events ---** but must consider background!

From now on …

$M(Z'_0) = M(Z'\pm) > \kappa\ 100$ TeV
$\kappa\ 0.01\ldots0.3$

Find the Z'_0 ,W'_0,

…also expect gluon recurrences

An « ordinary » Z' (with same couplings as Z)

No κ suppression

for later …

Find the Z'±,
κ suppressed

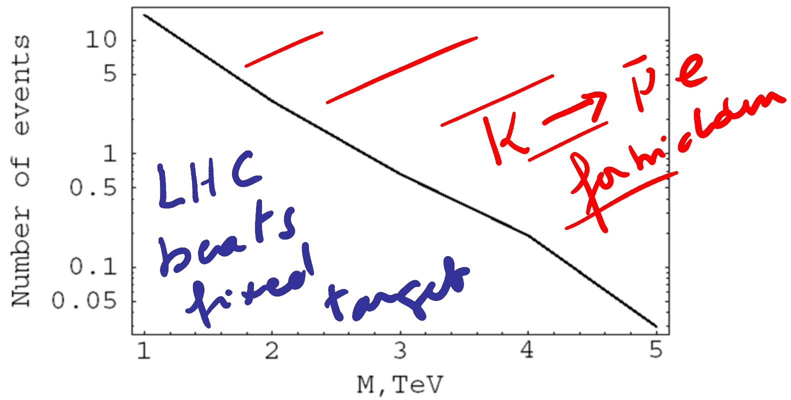
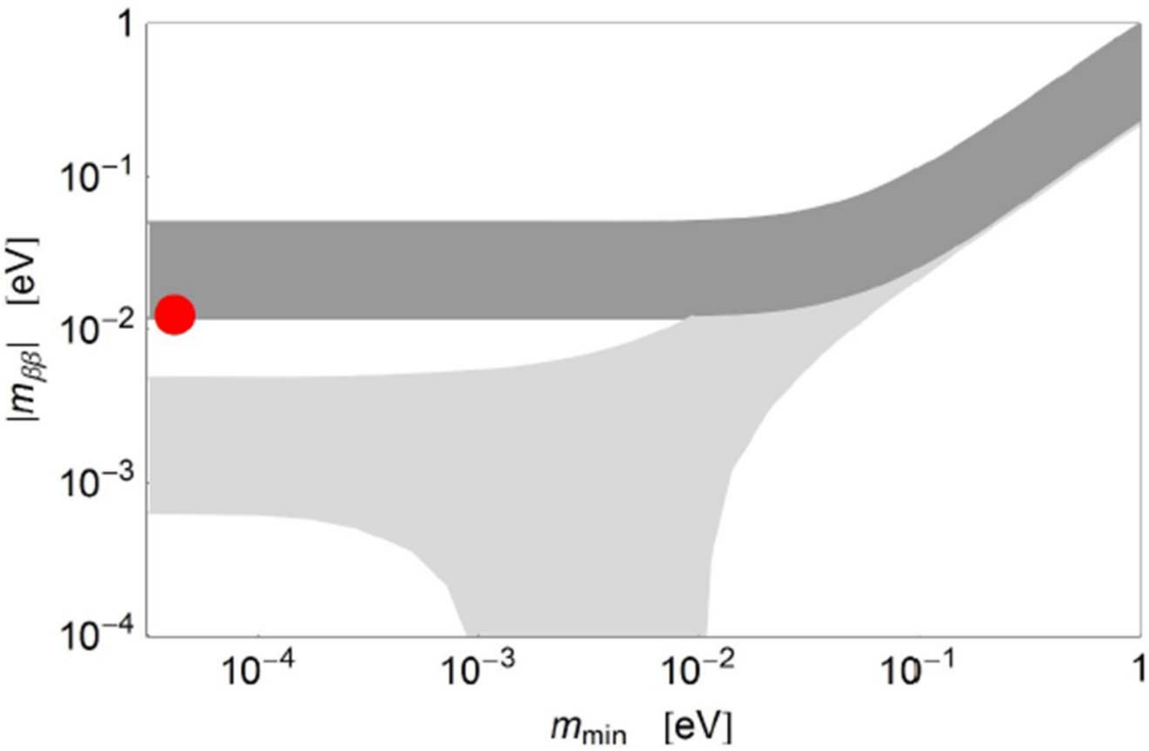


Fig. 1. Number of events for $(\mu^+ e^-)$ pairs production as a function of the vector bosons mass M, with $\kappa = M/(100\mathrm{TeV})$.

(100 fb^{-1}, 14TeV)

Returning to our 6D model, most striking result:
Neutrino masses ARE different, and we get inverted hierarchy, pseudo-Dirac, and large mixings as automatic features



In a nutshell:

One family in 6D and proper boundary conditions → 3 families in 6D

•At lowest order in Cabibbo mixing Charged fermion masses are

- Diagonal
- Strongly hierarchical

•At same order, we get 4D Majorana neutrinos with

Antidiagonal mass matrix

•This yields, in a generic way:

Large mixings in the neutrino sector

Inverted Hierarchy

Pseudo- Dirac structure (further suppression of neutrinoless double beta decay)

•Not as automatic, but typical : measurable Θ_{13}

Canonical model beyond LHC reach, but variants could result in std model like Z' and later more exotic signals (Z'± → μ^+e^- >> $\mu^- e^+$)