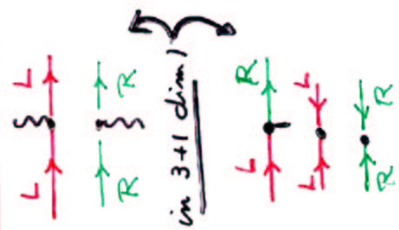
- INTRO
  - . is mass low-energy? (2)
- ν mass from susy (3a)
- ν and extra dim (3b)
- ν_R and $SU(2)_R$ dilution (3c)
- mass 4a
  extra dim
  CP 4b
- recreation:
  true ν telescope 5
- current work 6

JMF KITP 1 mai 03

Gathering ideas for a talk
to other neutrino fans.

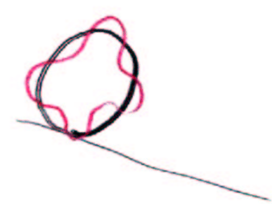
	EXTRA DIM	SUSY
	?	?



- gauge . CP ✓. "understood"
- mass "not understood"
  ~~CP~~
  - pattern?
- ν mass
  - Why small?

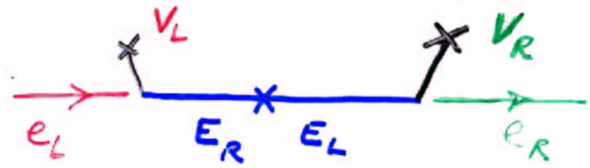
Possible {views / sources} of MASS. (mostly (fermions))

- Bare mass term → vectorlike th degenerate multiplets. × ×
- Min. energy of a particle
  ---- but only after choice of physical vacuum
- L-R transition (in 3+1 dim..)
  ... a low-energy phenomenon? not necessarily (see E. Ma) → 2.a
- Majorana (see below)
- Kaluza-Klein energy (extra-dim.)



2

a 2-scale model for all masses (cf. E.Ma)



↳ chiral sym. breaking at high energy (e.g. fundamental mass for singlet E)

+ same for all other particles.

$$m \sim \frac{V_L V_R}{M}$$

→ separate ~~group~~ chirality

2a

More questions with Neutrino mass.

- **Why so small?**
  - ν_R. see-saw → see later (3c)
  - MSSM
    - . nat. small... ν_L Maj. mass $\sim 10^{-3}$ eV $\xrightarrow{\text{Tr.-Lib.}}$ (3a)
    - . no $\cancel{\nu_R}$
  - SM : $<|\chi^0>$ $\quad <\chi^0> << v$
    (e.g. in LR models $<\chi_L^0> = v_L \sim \frac{v_1 v_2}{v_R}$
  - coupling to <u>large</u> extra-dim LED
    — funny oscillations patterns → (3b)

3

ν_L mass from MSSM

S. Troitsky
M. Lebenov
jnf 12/99

totally ν_R - free !
no particle added *

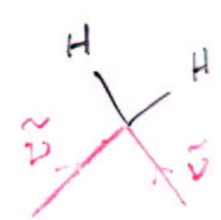
- F = susy breaking } gravity mediated.
- $M \sim 10^{19}$ GeV

usually keep $\frac{F}{M}$ .. here go to $\frac{F}{M^2} \sim h$

$h(\tilde{L}_i H_j \varepsilon_{ij})^2$

R-parity conserving

SU(2) singlet

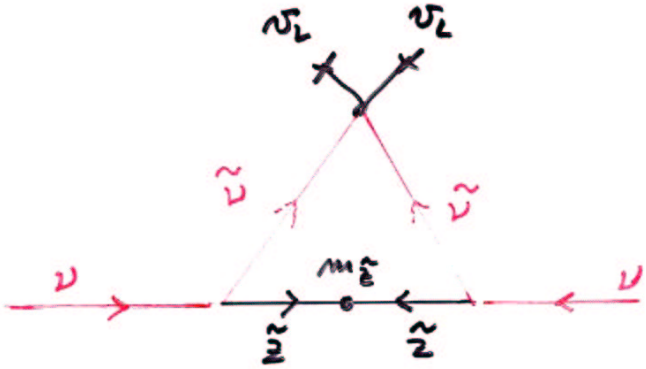


(* beyond MSSM jungle !)

3.a1

→ generate

$\frac{F}{M} \sim 1\,\mathrm{TeV}$



$$\frac{h}{32\pi^2} \frac{g^2 \langle H \rangle^2}{m_{\tilde{\nu}} \cdot \cos^2\theta_W} \underbrace{f\left(\tilde{m}_Z / \tilde{m}_\nu\right)}_{.2 \to .6}$$

$$\sim h\, g^2 \frac{\left(\frac{F}{M}\right)^2}{\left(\frac{F}{M}\right)} \sim \boxed{\frac{F^2}{M^3} \sim 10^{-3}\,\mathrm{eV}}$$

checks:

- no divergent contribution

⋮

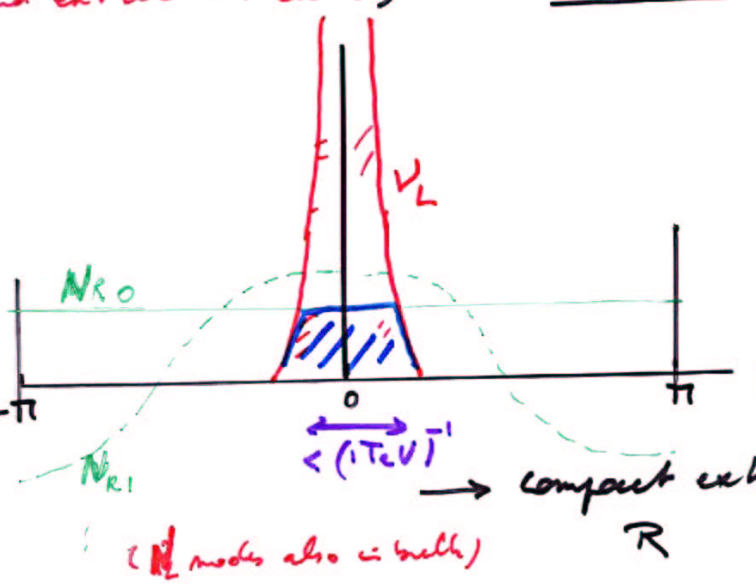
unrelated to m_e !

3.a.2

ν and extra-dim: strange oscillations and disappearance.

(CP and extra dim: later)

$1\,\mathrm{mm} : (10^{-3}\,\mathrm{eV})^{-1}$



→ compact extra dim, R

(N modes also in bulk)

$$\xi = \frac{m}{1/R} \quad \begin{array}{l} \leftarrow \text{Yukawa} \\ \leftarrow \text{KK mass} \end{array}$$

strength of mixing ...

$m \sim \lambda \langle v \rangle \cdot \frac{1/R}{1\,\mathrm{TeV}}$

small

3.b.1

Intuitive picture: (1 flavour).

$\xi \ll 1$

few modes, ~ harmonic

many modes → chaotic, spikes. → disappearance

→ "spread in extra-dim"

36.2

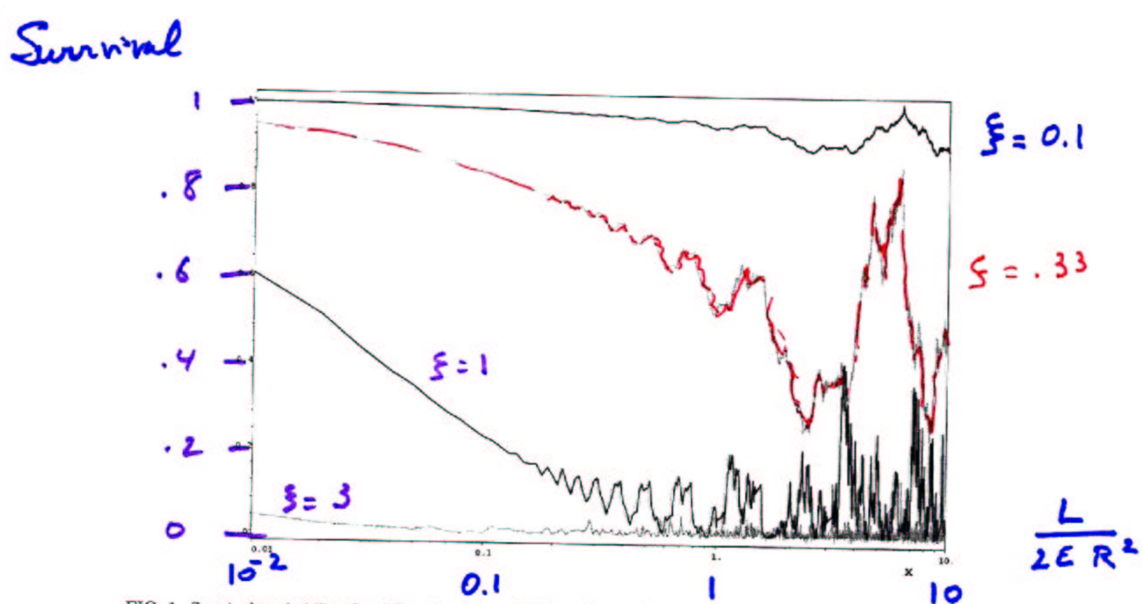


FIG. 1. Survival probability for different values of ξ ($\xi = 1/10, 1/3, 1, 3$ from top to bottom), as functions of $x = \frac{L}{2ER^2}$.

Survival probability vs L

363

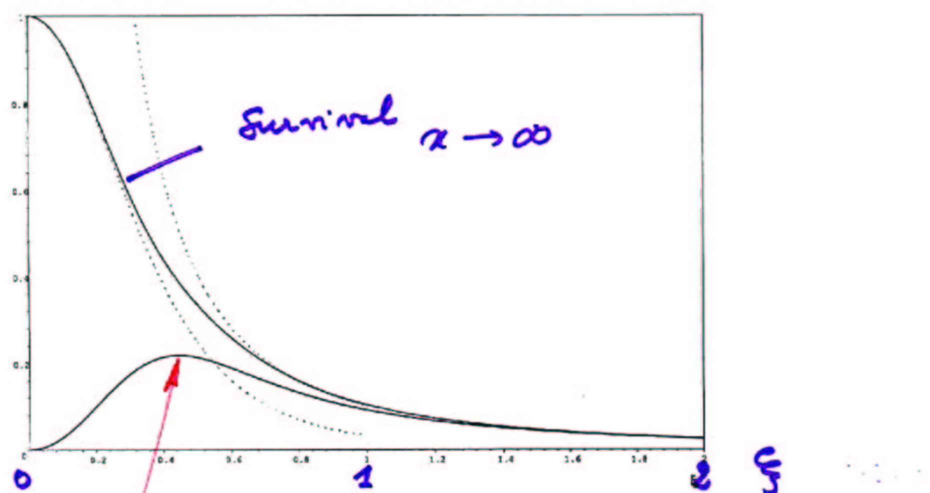


FIG. 3. Mean survival probability $\langle P_{\nu_1\nu_1}\rangle$ and fluctuations $\sigma(P)$ as functions of ξ. The dashed lines give the small ξ ($\langle P_{\nu_1\nu_1}\rangle \approx (U_{00})^4$), and the large ξ ($\langle P_{\nu_1\nu_1}\rangle \approx \frac{1}{\pi^2\xi^2}$) approximations.

$\sigma(P_{survival})$ fluctuations.

Cosme, JM, Gouverneur, Ling, Monderen, V. Elewyck. 2001 3.b.4

Possibility for mixing:

$\left.\begin{matrix}\nu_e \\ \nu_\mu\end{matrix}\right\rangle \nu_{bulk}$

$\frac{\nu_e + \nu_\mu}{\sqrt{2}}$ disappears

$\frac{\nu_e - \nu_\mu}{\sqrt{2}}$ stays

The $\left\{\begin{matrix}K2K \\ SNO\end{matrix}\right\} \rightarrow$ fine! (disappearance ..)

Supernova limit $\longrightarrow$ removed (Romanino et al)

Now:

× need std oscillations for SNO.

× allow max amount of disappearance compatible with ^8B uncertainty.

---

but might be the only way to explore LED ... 3.b.5.

ν_R see-saw. | Only particle with "Majorana" (self-) mass?

$\Rightarrow$ Who ordered ν_R?

SM $\longrightarrow$ arbitrary singlet

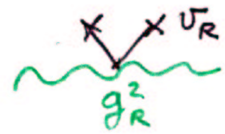
$SU(5) \supset SU(3) \times SU(2)_L \times U(1)$. $\left\{ \begin{matrix} 5 \\ \overline{10} \\ 1 = \nu_R \end{matrix} \right\}$

$SO(10) \supset SU(3) \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ 16

↳ anomaly-free

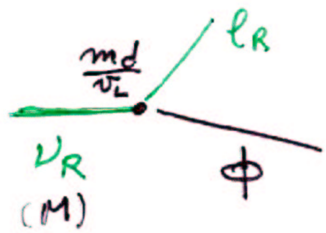
ν_R mass likely related to W_R mass

↳ $\lambda_{Ri}\, v_R$ $g_R\, v_R$



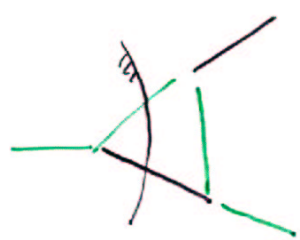
3.c.1

Dilution !



$\Gamma \sim \sum_j \left| \frac{md}{v}{}_{ij} \right|^2 . M.$

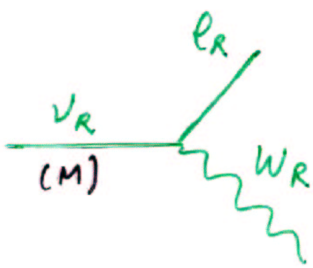
+



interference $\Rightarrow \cancel{CP}$

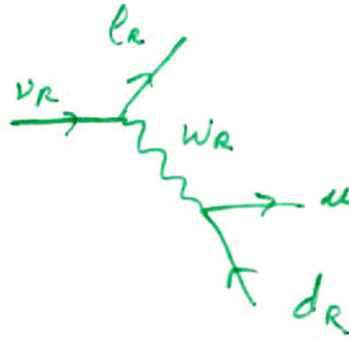
and leptogen.

$\frac{md}{v}$ small $\Rightarrow$ out-of-equil. decay.



OR

"FAST"



$\Gamma \sim g_R^2\, M$

$\Gamma \sim g_R^4 \cdot \frac{M^4}{M_{W_R}^4} . M.$

3.c.2

Dilution: usual result $\Big/ \left(1 + \dfrac{g_R^4 \dfrac{M^4}{M_{W_R}^4}}{\sum \left(\dfrac{m_{d_{ij}}}{M_{W_L}}\right)^2 \cdot g_L^2}\right)$

$$\Rightarrow \quad \frac{M_{\nu_R}}{M_{W_R}} < \sqrt[4]{\text{max dilution acceptable}} \cdot \sqrt{\frac{\sum |m_{d_{ij}}|}{M_{W_L}}}$$

"Worst case": lightest M_1 mostly related to ν_e by $\sim m_e$ $\quad \sqrt{\dfrac{m_e}{M_{W_L}}} \sim \dfrac{1}{400}$

on the other hand, helps in meeting out-of equil. condition ...

$$\left(\Gamma_{\nu_R}\right)^{-1} > \tau_{\text{expansion}} \simeq \sqrt{g_*} \cdot \frac{T^2}{M_{\text{Planck}}}$$

3.C.3

With "typical" matrix $\quad m_d \sim \begin{pmatrix} 0 & \sim\sqrt{m_e m_\mu} & 0 \\ \sqrt{m_e m_\mu} & \sim m_\mu & \sqrt{m_\mu m_\tau} \\ 0 & \sqrt{m_\mu m_\tau} & \sim m_\tau \end{pmatrix}$

and $\begin{pmatrix} M_1 & & \\ & M_2 & \\ & & M_3 \end{pmatrix}$ (max phase).

we get:

		$M/M_{W_R} <$	$M_i >$
if lightest is	M_1	$7 \cdot 10^{-3}$	10^7 GeV
	M_2	0.17	$3 \cdot 10^{11}$ GeV
	M_3	0.11	$4 \cdot 10^{11}$ GeV

(Carlier, JMF, Ling)

3.C.4

Mass and ~~CP~~ from Extradim ?

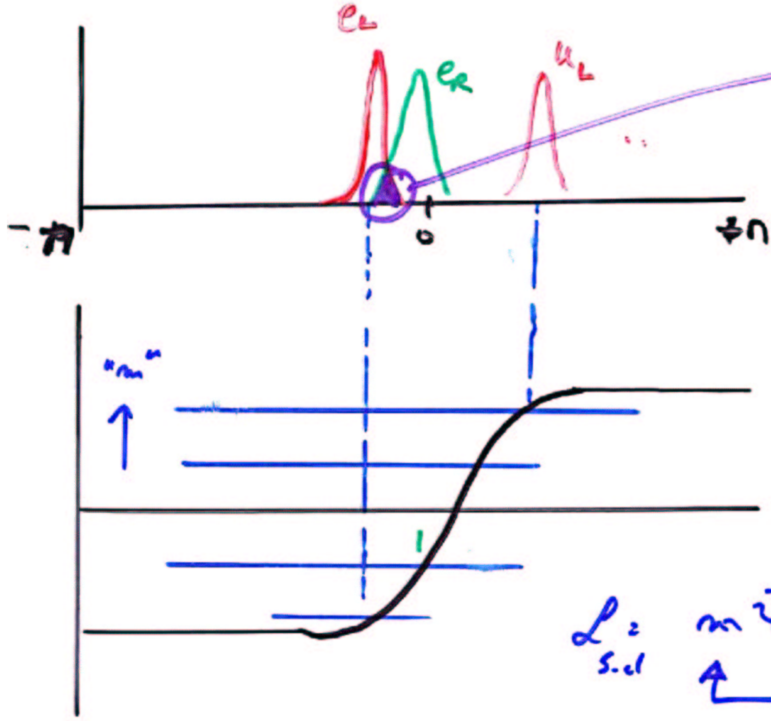
- how to generate mass pattern?
  - horiz. sym, textures (repres. independt?)
  - overlaps in Extra-dimentions → 4.a

- how to generate ~~CP~~ in fundamental, UNIFIED theory — gauge is CP-conserving ✓ → breaking? → Spontaneous ~~CP~~ / extradim.? → 4.b

  $\in$ V_1, V_2, V_3

4.

5th. dimension cartography? (a currently popular idea)



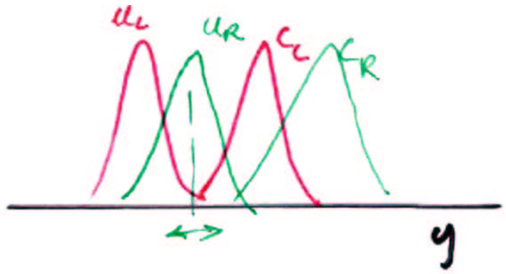
$M_e \propto$ overlap

← topological defect Φ

$\mathcal{L}_{s.d}$: $m\bar{\Psi}\Psi + \lambda\bar{\Psi}\Phi\Psi$

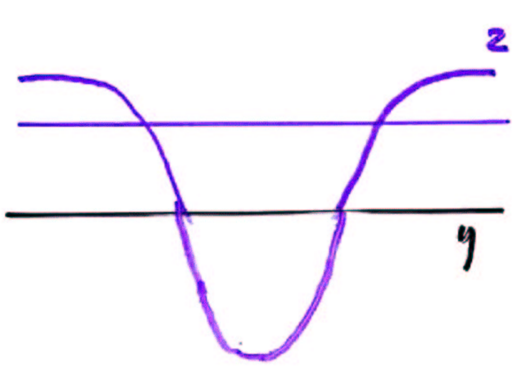
↑ determine location.

4.a.1



small y shift $\leftrightarrow$ large $m_{4\text{-}d}$ change!

NOT PREDICTIVE FOR MASSES (FIT).



Z : flavour - diagonal

Z' : F.C.N.C + non-universality

$\rightarrow$ LHC?

first possible prediction.

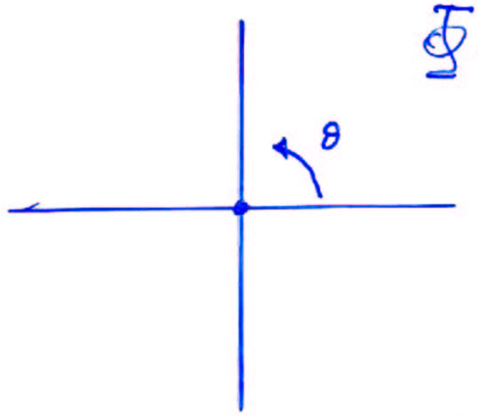
CP? by hand (Branco, Mohapatra . . .).

4.a.2

A more constrained scheme:

(Troitsky - Lebedev, JMF)

(3+1) + 2 dim.



$$\Phi \sim e^{i n \frac{\theta}{2\pi}} \cdot \phi(r)$$

"Vortex solution"

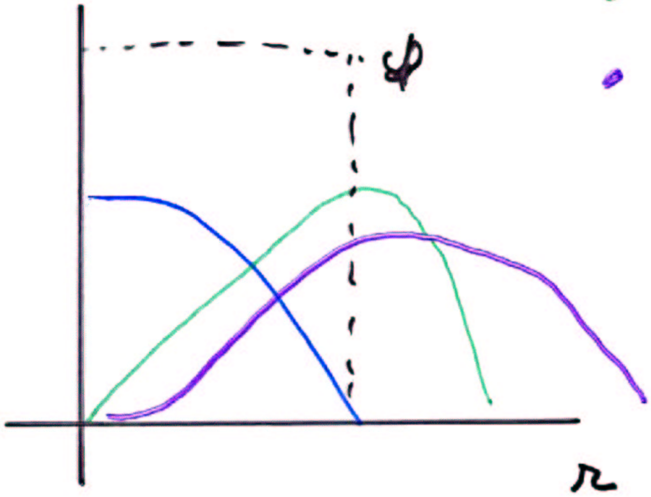
$\boxed{\text{index theorem : } n \text{ massless chiral fermions bound to vortex.}}$

$n=1$ $\bar{\psi} \Phi^3 \psi$ OR $n=3$ (choice)

3 (3+1.d) families from 1 6d family.

4.a.3

- $\psi_1 \quad e^{i0\theta} \sim r^0$
- $\psi_2 \quad e^{i\frac{\theta}{2\pi}} \sim r^1$
- $\psi_3 \quad e^{i\frac{2\theta}{2\pi}} \sim r^2$



overlap with φ

$$\rightarrow \begin{pmatrix} m_1 & \times & \\ \times & m_2 & \times \\ & \times & m_3 \end{pmatrix}$$

hierarchy of masses.

⚠ selection rule by winding nb.

add 1 scalar field → × terms.

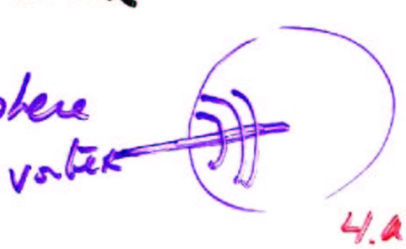
4.a.4

- scheme is constrained, but ∃ solutions. !
- Z': dominant $\sim e^{i\theta/2\pi}$

fast FCNC ⟶ $K_L \to \bar{\mu} e$

$m_{Z'} > 100\,\text{TeV}$

- ν can be embedded.
  e.g: leave ν_R in bulk
- Currently: formulation on 2d sphere to have compact space.



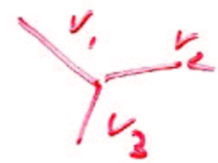
4.a.5.

~~CP~~ in fundamental theories?

- gauge $\leftrightarrow$ CP
- if fund. th. rests on gauge (N=2 susy, .. extradim...

$\Rightarrow$ Why is CP broken?

$\rightarrow$ several "condensates" $\rightarrow$ Spontaneous ~~CP~~



$\rightarrow$ geometrical $\rightarrow$ toy model 5D

4.6.1

(N. Cosme, Laura Lopez-H., jmf

5 dim : $(3+1)+1$

$$\mathcal{L} = \bar{\Psi}\underbrace{(i\partial^B + g A^B)}_{CP\text{-}cons.}\gamma_B \Psi - \bar{\Psi} \underset{\substack{\downarrow \\ \text{real}}}{M} \Psi$$

(odd. .. can explain)

$\gamma_4 = i\gamma_5$

$5 \rightarrow 4$ dim. $\quad A^{0,1,2,3} \Rightarrow A^\mu$

$\qquad\qquad\qquad A^4 \Rightarrow \phi$

$\Rightarrow$ can have $\quad \bar{\Psi}\gamma_4 \phi \Psi = i\bar{\Psi}\gamma_5\Psi\phi$

4.6.2

⇒ mass term becomes:

$$\bar{\Psi}\Psi \; (M) + i \; \bar{\Psi}\gamma_5\Psi \langle\phi\rangle$$

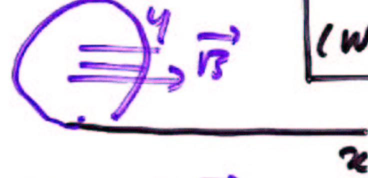
... complex

but $\langle\phi\rangle = \langle A^4\rangle$ <u>not gauge inv t !!</u>

-- in fact, $\int dy \; A^4(y)$ ⇒ gauge invariant

if y compact, $-\pi \to +\pi$

$\boxed{\text{HOSOTANI (Wilson)}}$



$$\oint A^4(y)\, dy$$

= (virtual) flux of $\vec{B}$ in loop ⇒ gauge OK

4.6.3

⇒ generate $M \in \mathbb{C}$ for 1 fermion

⇒ CP phase may be gauged away!

⇒ must involve internal group

$$\bar{\Psi}\,(i\,\partial^a + g\,\tau_i\,\gamma^B A^i_B)\,\Psi$$

⇒ Hosotani loop → breaks internal group
→ ~~CP~~

⇒ Toy example with SU(2) → edm / realistic? SO(11)

can be extended to ν ...

4.6.4

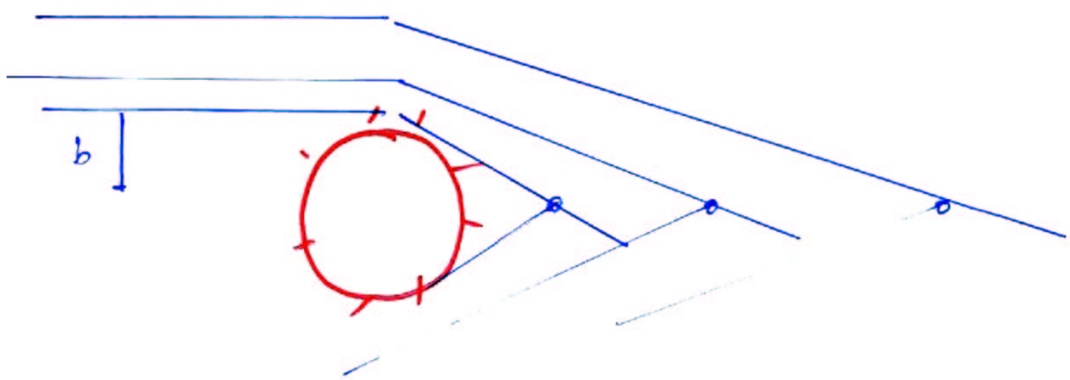
For fun: a TRUE ν "telescope"

↳ (refractor)

gravitational lensing of γ:

defl. ↘ with b

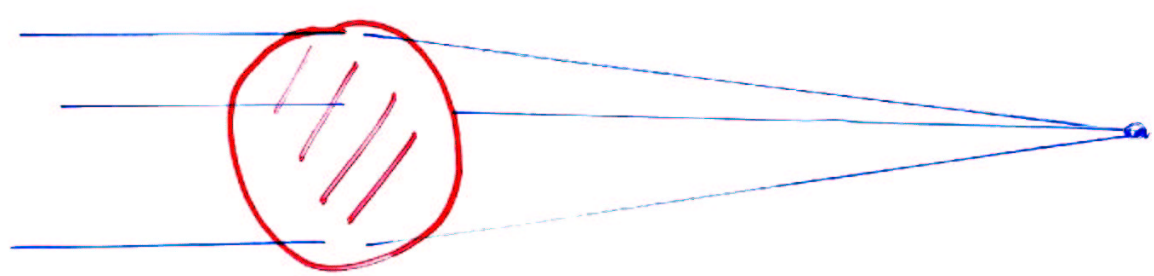
⇒ no focusing!



5.1

ν can cross through matter

deflection ↗ with b for $b < R$ ($E \ll 100$ GeV)



→ good focusing possible!

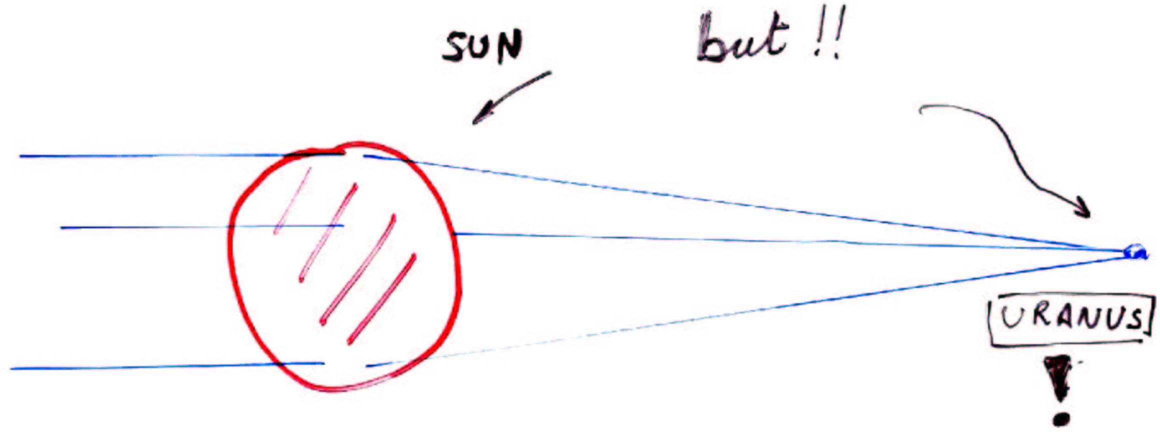
5.2

ν can cross through matter

$(E \ll 100\ \text{GeV})$

deflection $\nearrow$ with b for $b < R$

but !!



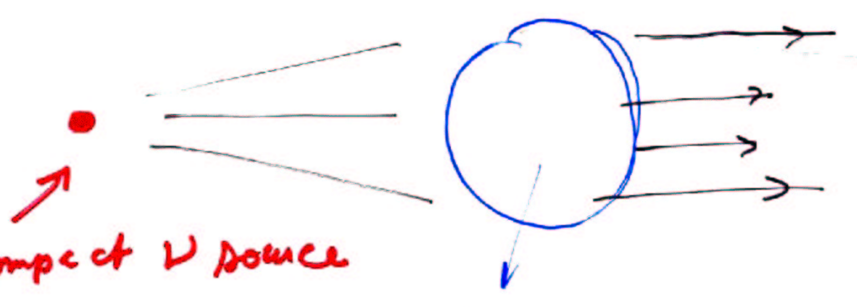
$\rightarrow$ good focusing possible !

(too bad !)

5.3.bis

only possibility :

ν light house :



compact ν source

large companion star

focused beam.

5.3

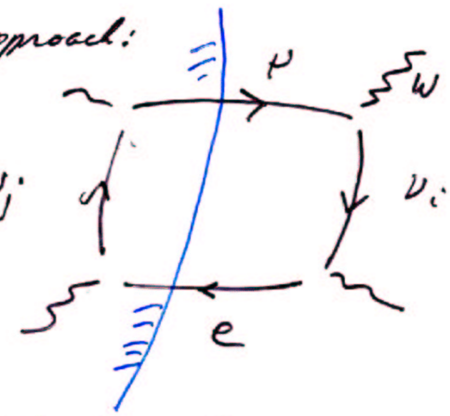
Current work:

How to make Jarlskog determinants appear explicitly in $\not{CP}$?

Cecilia

e.g.: $\nu_\mu \to \nu_e \neq \bar{\nu}_\mu \to \bar{\nu}_e$

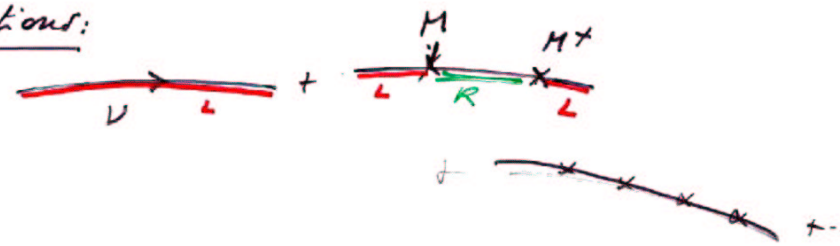
try "unitary graph" approach:



similar to $\mu \to e$ in W background.

6.1

expand in mass insertions:



... but why does the same process not $\Rightarrow \mu \to e\gamma \neq \bar{\mu} \to \bar{e}\gamma$?

Would violate TCP: no compensating channel..

→ check indeed: mass expansion in cut graphs → 0

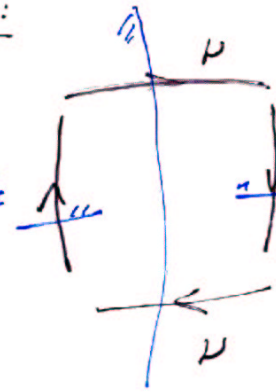
at order $(MM^+)^3$: $\left[(MM^+)(MM^+)\right]_{21} \left[MM^+\right]_{12} + \left[MM^+\right]_{21} \left[(MM^+)(MM^+)\right]_{12}$

⇒ real

→ need to put ν on-shell (impossible in $\mu \to e\gamma$)

6.2

With ν on shell:



$\frac{1}{p^2 - m^2 + i\varepsilon}$ $\quad \frac{1}{p^2 - m^2 - i\varepsilon}$

$e^{+i\frac{m_i^2 L}{2E}}$ $\quad \hookrightarrow e^{-ipx} \rightarrow e^{-i\frac{m_i^2 L}{2E}}$

$\Rightarrow$ get at same order: $\propto \left[(MM^\dagger)(MM^\dagger)\right]_{21} \left[MM^\dagger\right]_{12}$

$$- (MM^\dagger)_{21} \left[(MM^\dagger)(MM^\dagger)\right]_{12}$$

$\rightarrow \quad (m_1^2 - m_3^2)(m_2^2 - m_3^2)(m_2^2 - m_1^2) . \,\mathrm{Im}\left(U_{11}^\dagger U_{22}^\dagger U_{12} U_{21} \right)$

6.3

(exact result $\propto$ $\mathrm{Im}(U \ldots) . \sin \frac{m_{12}^2 L}{4E} . \sin \frac{m_{23}^2 L}{4E} \sin \frac{m_{31}^2 L}{4E}$

(in a way, compensation is in time dependence, – or L-dependence – not visible in momentum space).

6.4