Neutrinos, Higgs & Flavour

João Penedo, CFTP/IST

7 Feb 2020

Fifth Lisbon mini-school on

Particle and Astroparticle Physics

FCT Fundação para a Ciência e a Tecnologia
DF DEPARTAMENTO DE FÍSICA TÉCNICO LISBOA
CFTP Centro de Física Teórica de Partículas
europa.eu European Union
QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
COMPETE PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE

Fields: Neutrinos, Higgs & Flavour

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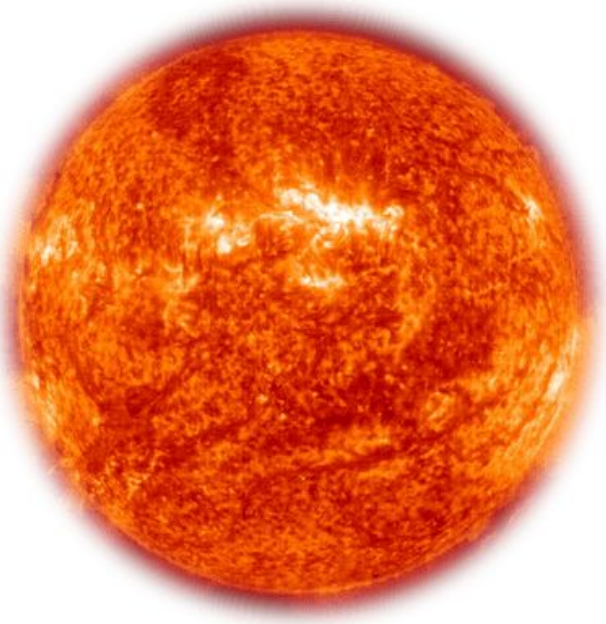
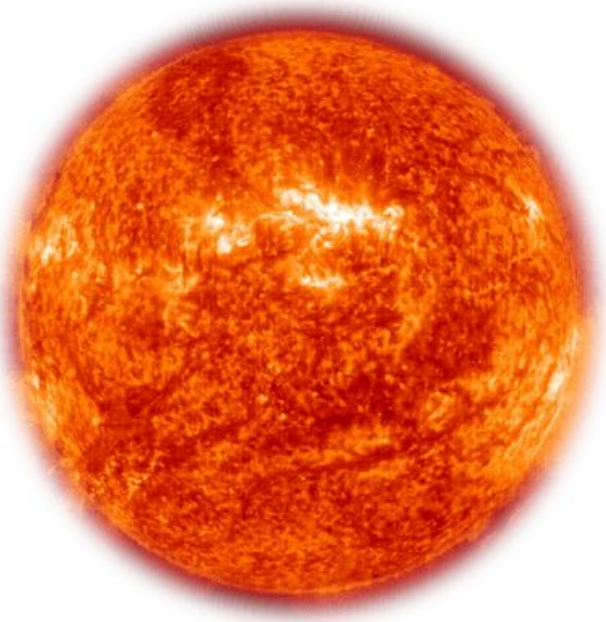
Neutrinos

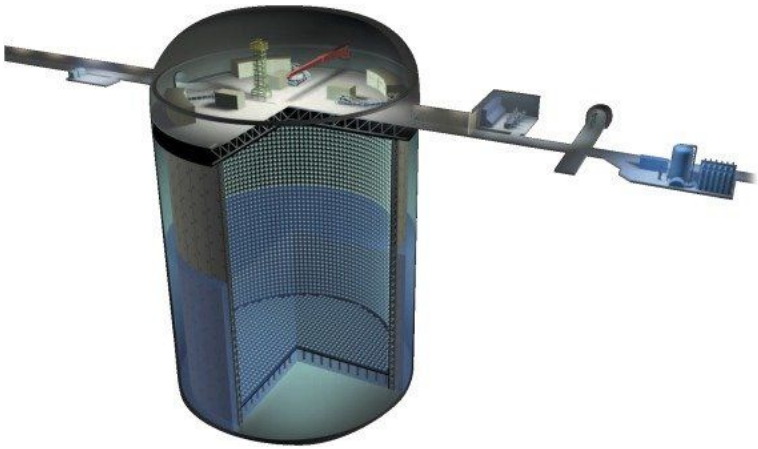
Neutrinos



$$\sim \; 70\,000\,000\,000 \;\; \mathrm{cm}^{-2} \; \mathrm{s}^{-1}$$

Neutrinos





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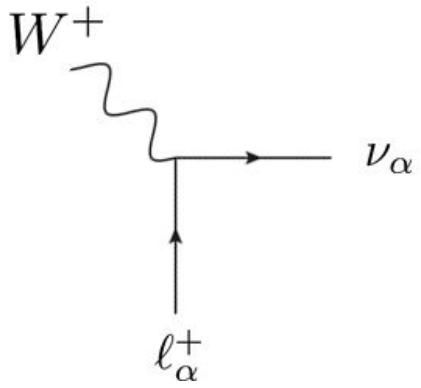
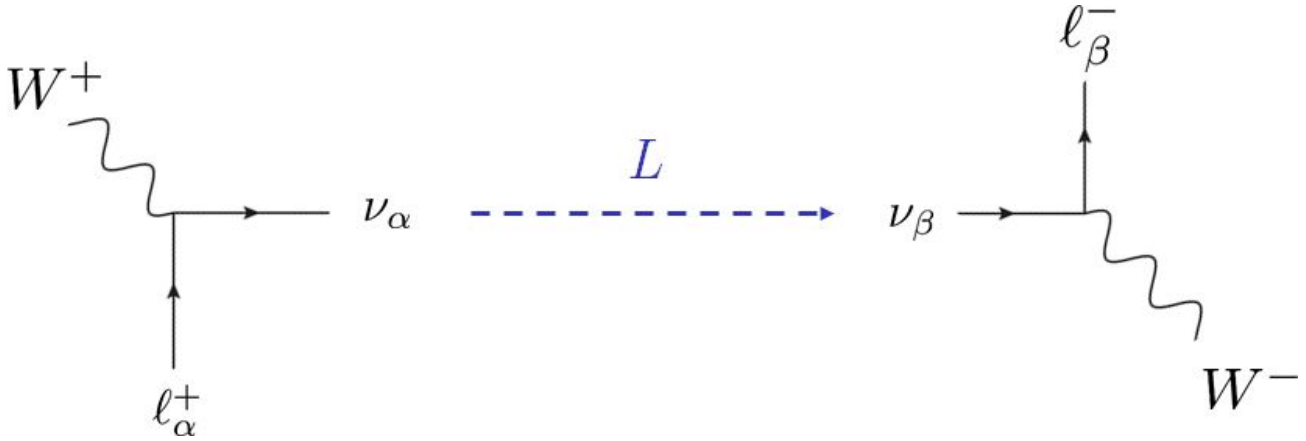
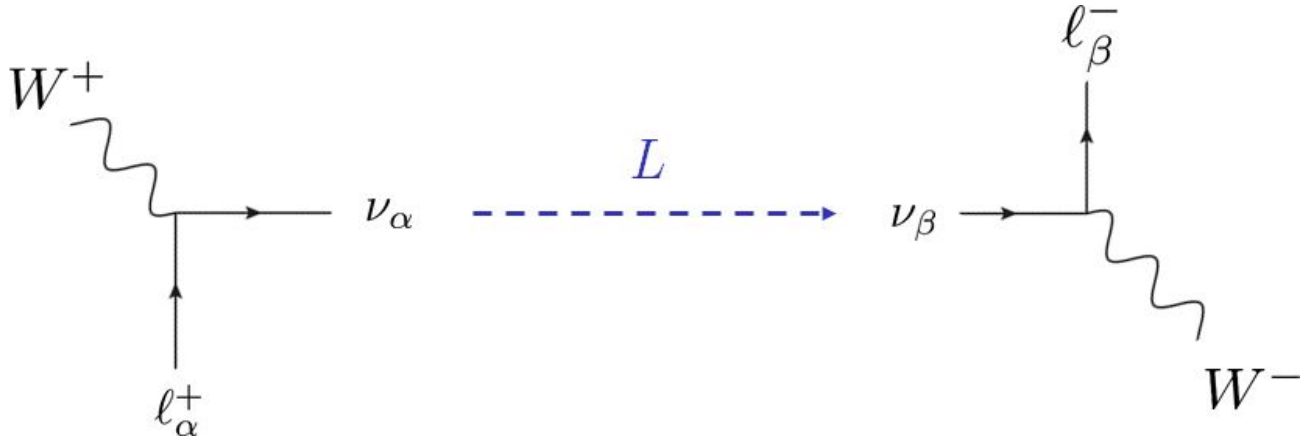


Neutrinos



$$|\nu_\alpha\rangle = (U_{\mathrm{PMNS}})^*_{\alpha k}\,|\nu_k\rangle$$

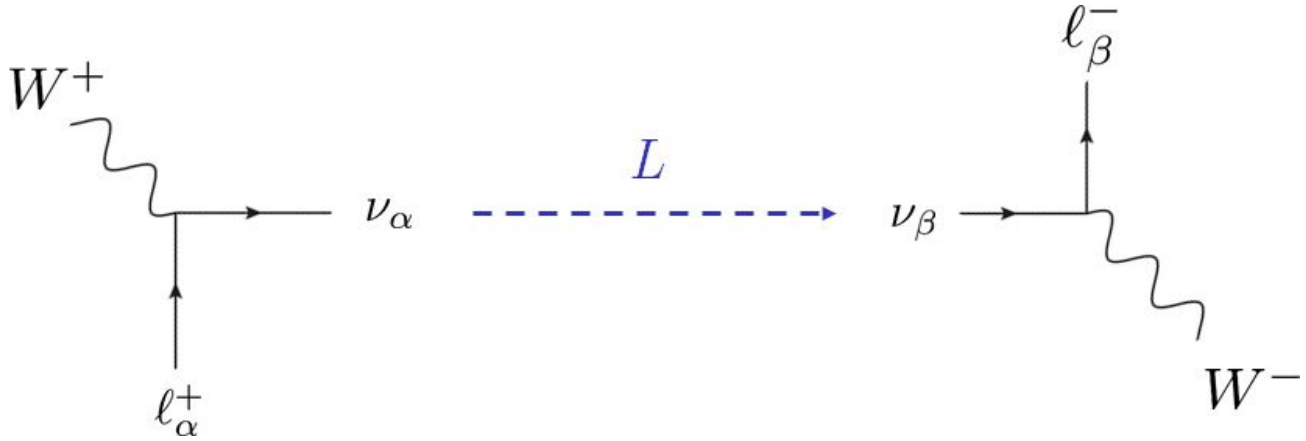
Neutrinos



$$|\nu_\alpha\rangle = (U_{\mathrm{PMNS}})^*_{\alpha k}\,|\nu_k\rangle$$

$$P(\nu_\alpha \to \nu_\beta) = (U_{\text{PMNS}})^*_{\alpha k} (U_{\text{PMNS}})_{\beta k} (U_{\text{PMNS}})_{\alpha j} (U_{\text{PMNS}})^*_{\beta j} \exp\left(-i\frac{\Delta m^2_{kj} L}{2E}\right)$$

Neutrinos



$$|\nu_\alpha\rangle = (U_{\text{PMNS}})^*_{\alpha k} |\nu_k\rangle$$

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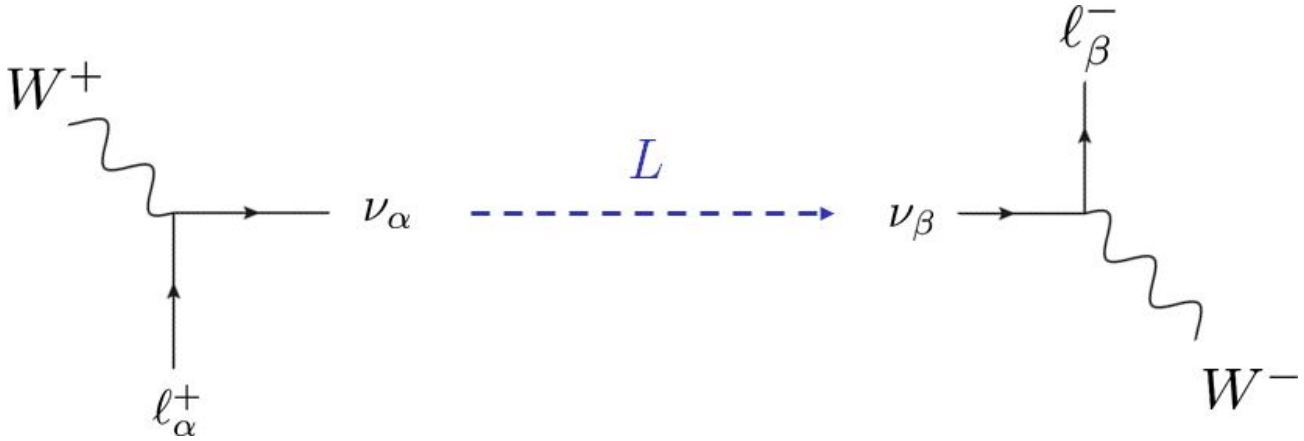
$$\Delta m^2_{kj} = m^2_k - m^2_j$$

Neutrinos



$$|\nu_\alpha\rangle = (U_{\text{PMNS}})^*_{\alpha k} |\nu_k\rangle$$

for Particle Physics since 1960

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Neutrinos, Higgs & Flavour

Higgs

The Higgs boson

Gotcha!

The hunt for physics's most elusive quarry is over

Jul 7th 2012 | From the print edition

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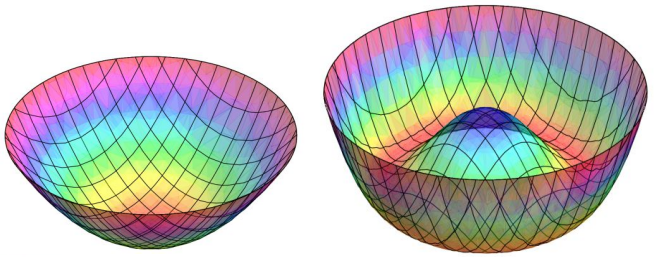


From: A.M.Coutinho
Master Thesis

Higgs

The Higgs boson

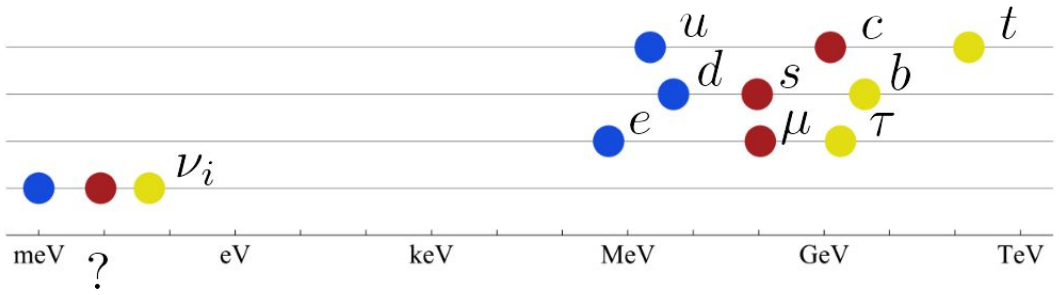
Gotcha!

The hunt for physics's most elusive quarry is over

Jul 7th 2012 | From the print edition

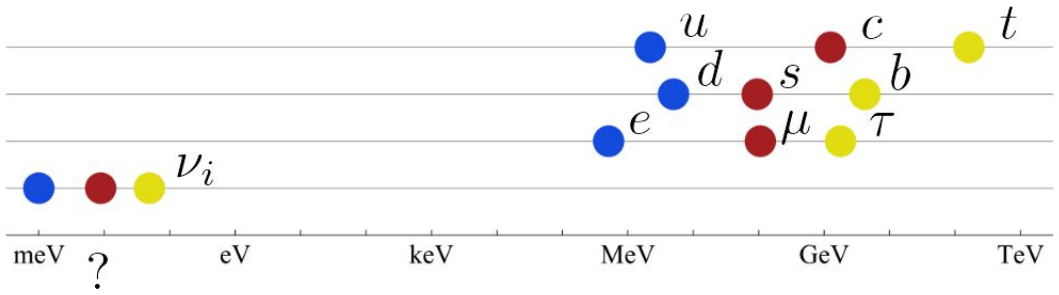
$$\rho = \frac{\sum_{i=1}^{n} \left[I_i \left(I_i + 1 \right) - \frac{1}{4} Y_i^2 \right] v_i}{\sum_{i=1}^{n} \frac{1}{2} Y_i^2 v_i}$$

Neutrinos, Higgs & Flavour



From: A.Toorop PhD Thesis

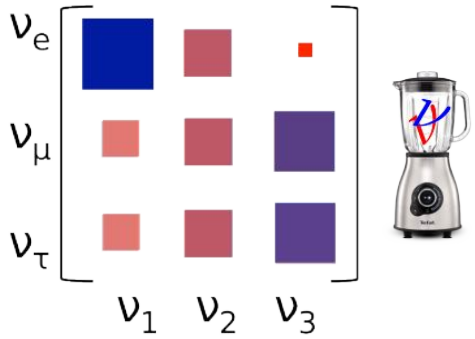
Flavour



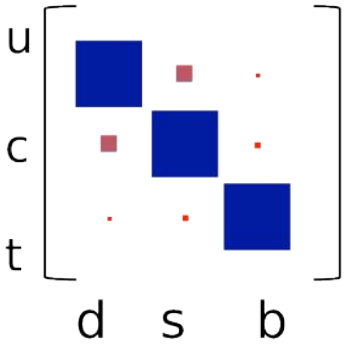
From: A.Toorop PhD Thesis

Flavour

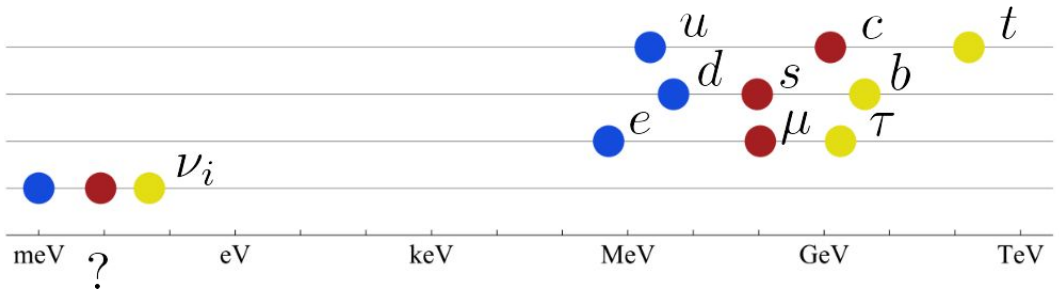
$U_{\mathrm{PMNS}} \sim$



$V_{\mathrm{CKM}} \sim$



From: P.Novichkov Discrete 2018 slides



From: A.Toorop PhD Thesis

From: I. Varzielas / F. Joaquim slides

Flavour

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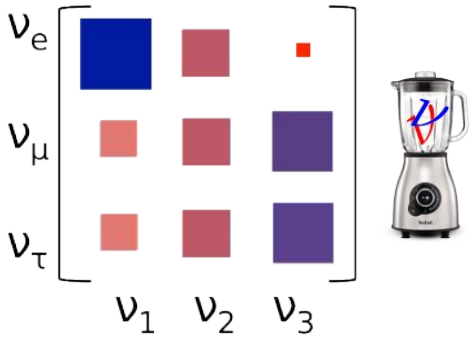

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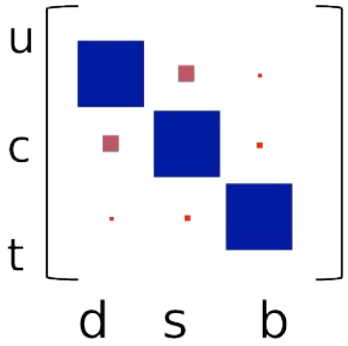

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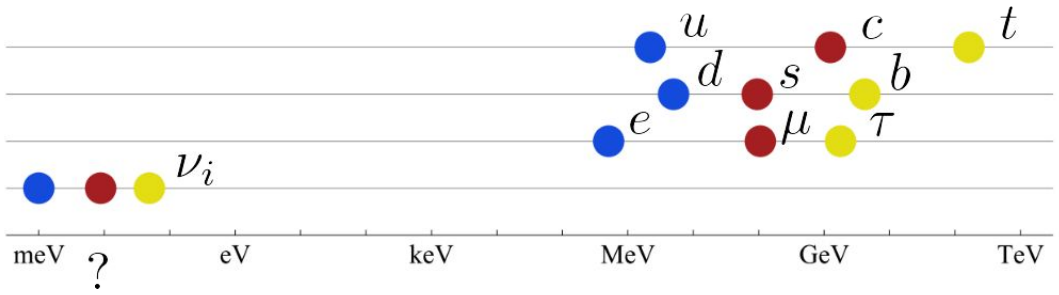

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Flavour

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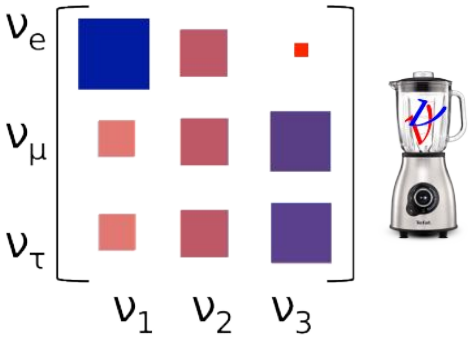

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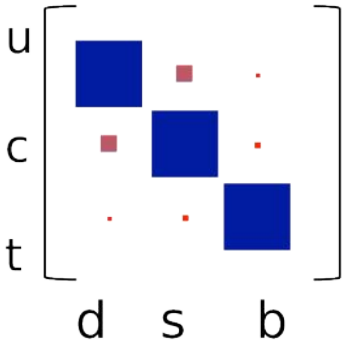
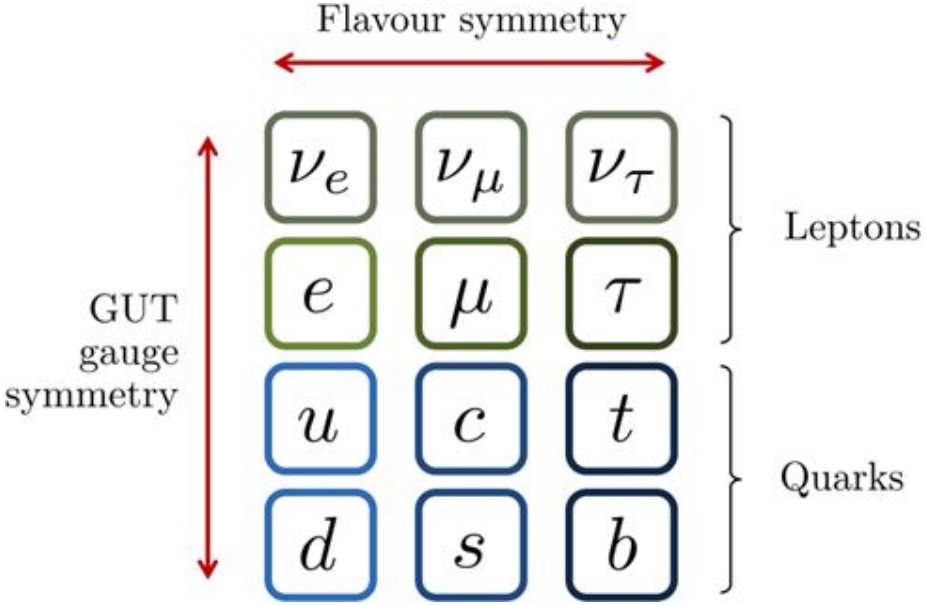




From: P.Novichkov Discrete 2018 slides

Neutrinos, Higgs & Flavour

Neutrinos, Higgs & Flavour

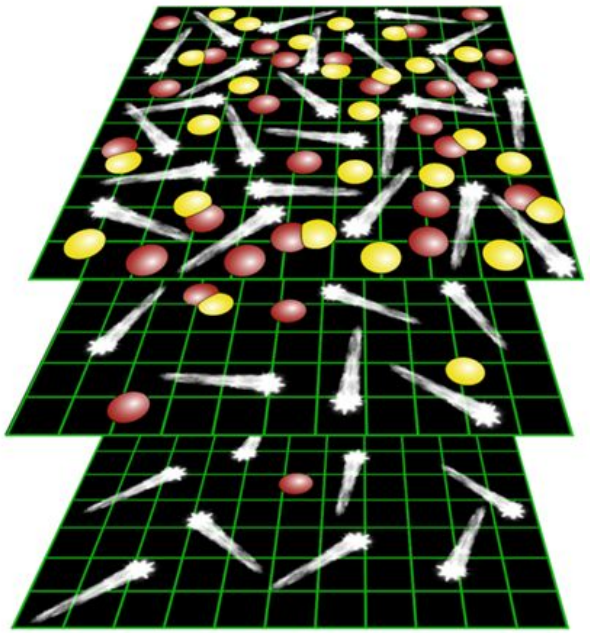
Motivated by a common question:

Why are we here?

$$n_B \equiv n_b - n_{\overline{b}}$$

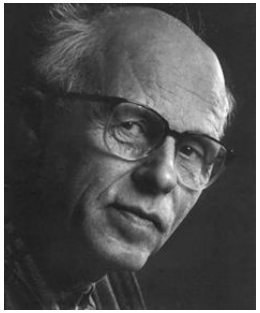
$$\eta \equiv \frac{n_B}{n_\gamma} = \frac{n_b - n_{\overline{b}}}{n_\gamma} \approx \frac{n_b}{n_\gamma}$$

$$\eta = (6.21 \pm 0.16) \times 10^{-10}$$



From: A.Toorop PhD Thesis

$30\,000\,000$ *vs.* $30\,000\,001$ (at $t = 1$ s)



B Violation
C and CP violation
Departure from thermal equilibrium

Neutrinos, Higgs & Flavour

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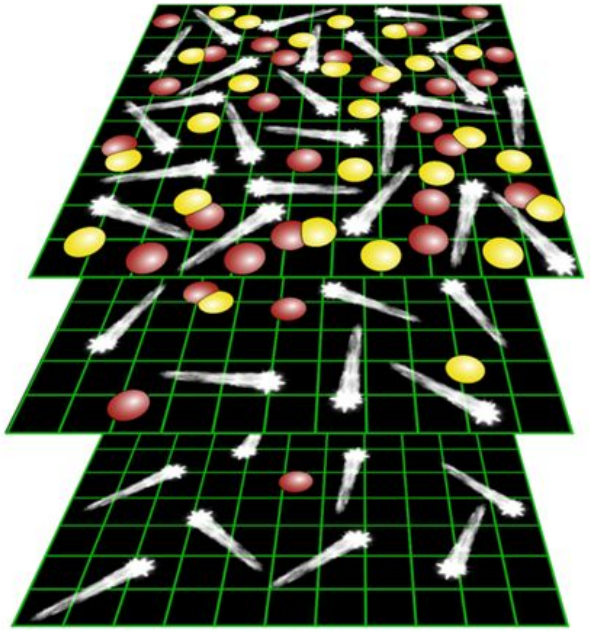

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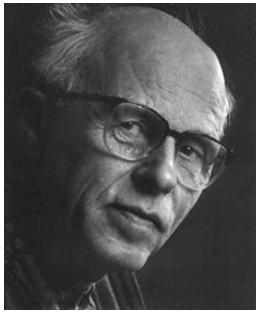
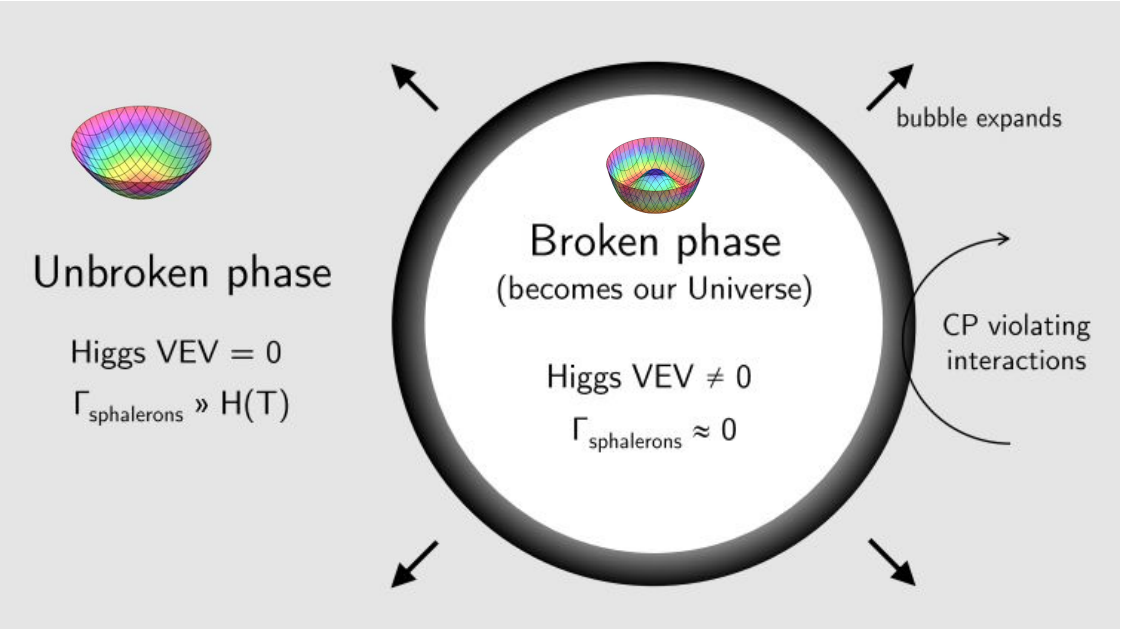


B Violation ✓
C and CP violation ✗
Departure from thermal equilibrium ✗

Neutrinos, Higgs & Flavour

Problem in the Standard Model



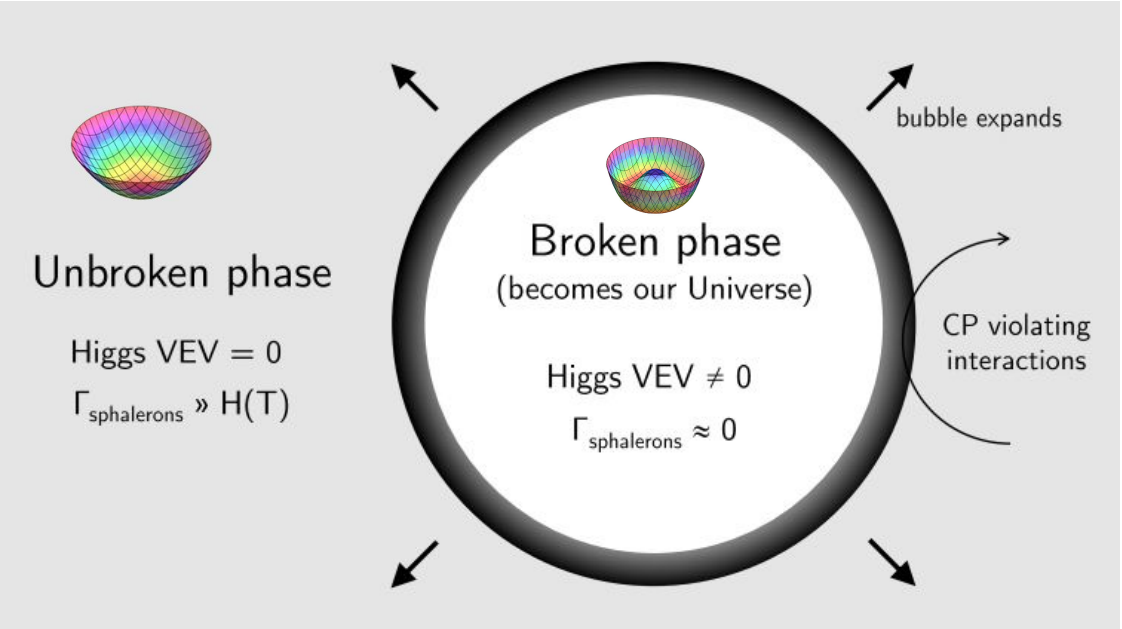
B Violation ✓
C and CP violation ✓
Departure from thermal equilibrium ✓

Neutrinos, Higgs & Flavour

Solution using Higgses:

Electroweak baryogenesis

(see e.g. 1704.08911)



Citation: K. Nakamura *et al.* (Particle Data Group), JPG **37**, 075021 (2010) (URL: http://pdg.lbl.gov)

LIGHT UNFLAVORED MESONS
($S = C = B = 0$)

For $I = 1$ (π, b, ρ, a): $u\overline{d}$, $(u\overline{u}-d\overline{d})/\sqrt{2}$, $d\overline{u}$;
for $I = 0$ (η, η', h, h', ω, ϕ, f, f'): $c_1(u\overline{u} + d\overline{d}) + c_2(s\overline{s})$

$\pi^{\pm}$

$I^G(J^P) = 1^-(0^-)$

Mass $m = 139.57018 \pm 0.00035$ MeV (S = 1.2)
Mean life $\tau = (2.6033 \pm 0.0005) \times 10^{-8}$ s (S = 1.2)
$c\tau = 7.8045$ m

$\pi^{\pm} \to \ell^{\pm}\nu\gamma$ form factors [a]

$F_V = 0.0254 \pm 0.0017$
$F_A = 0.0119 \pm 0.0001$
F_V slope parameter $a = 0.10 \pm 0.06$
$R = 0.059^{+0.009}_{-0.008}$

π^- modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the section on Searches for Axions and Other Very Light Bosons.

π^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\mu^+\nu_\mu$	[b]	(99.98770 ± 0.00004) %		30
$\mu^+\nu_\mu\gamma$	[c]	(2.00 ± 0.25) $\times 10^{-4}$		30
$e^+\nu_e$	[b]	(1.230 ± 0.004) $\times 10^{-4}$		70
$e^+\nu_e\gamma$	[c]	(7.39 ± 0.05) $\times 10^{-7}$		70
$e^+\nu_e\pi^0$		(1.036 ± 0.006) $\times 10^{-8}$		4
$e^+\nu_e e^+e^-$		(3.2 ± 0.5) $\times 10^{-9}$		70
$e^+\nu_e\nu\overline{\nu}$		< 5 $\times 10^{-6}$	90%	70

DARK MATTER

$J =$?

Mass $m =$?
Mean life $\tau =$?

DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
?	?	?	?

From: A.Ibarra ICTP Summer School talk

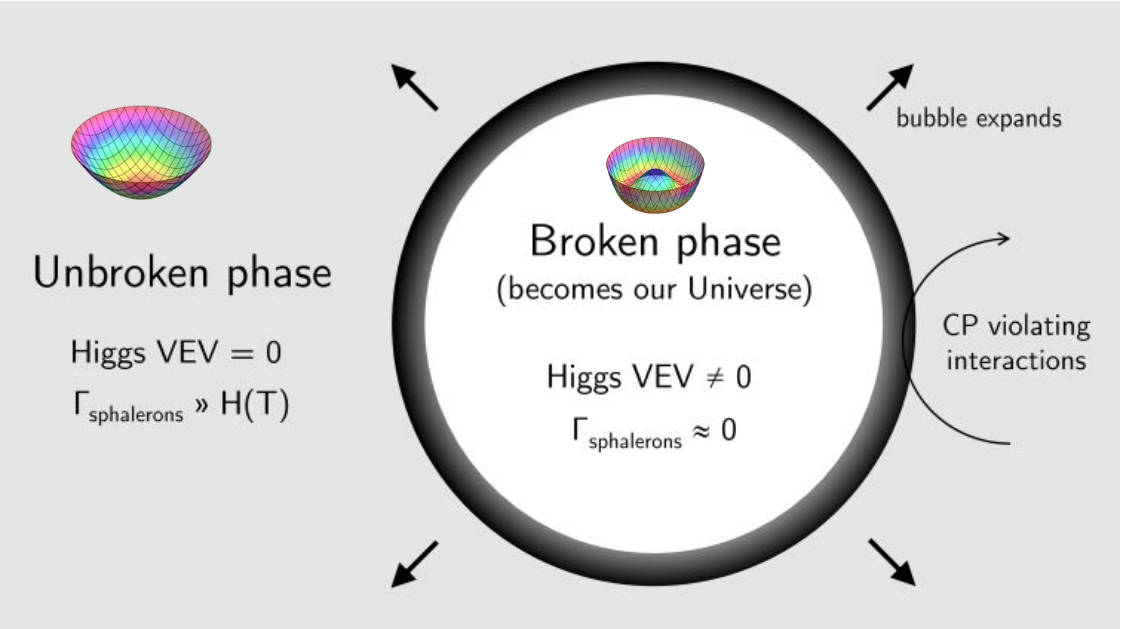
B Violation ✓
C and CP violation ✓
Departure from thermal equilibrium ✓

Neutrinos, Higgs & Flavour

Solution using Higgses:

Electroweak baryogenesis

(see e.g. 1704.08911)



B Violation ✓
C and CP violation ✓
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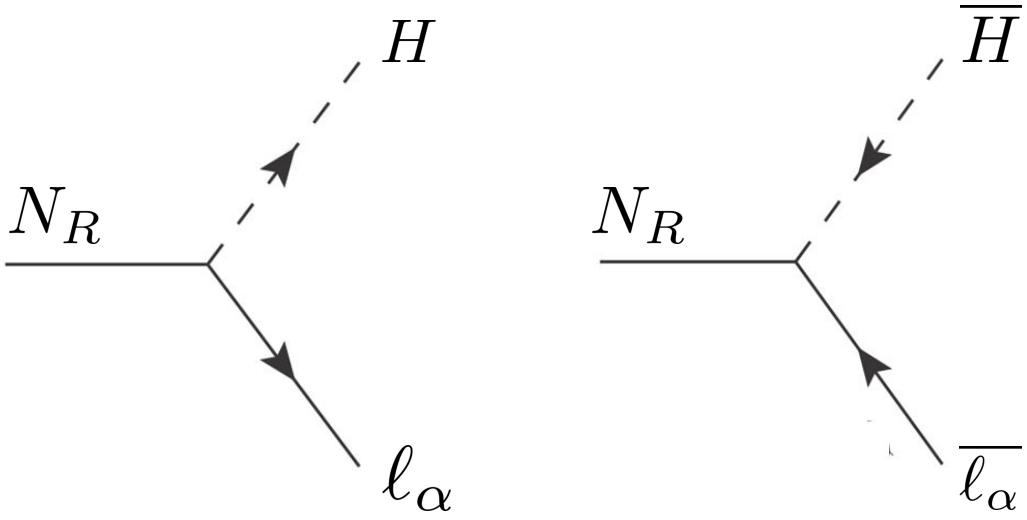
Neutrinos, Higgs & Flavour

Solution using neutrinos:

Leptogenesis



B Violation ✓
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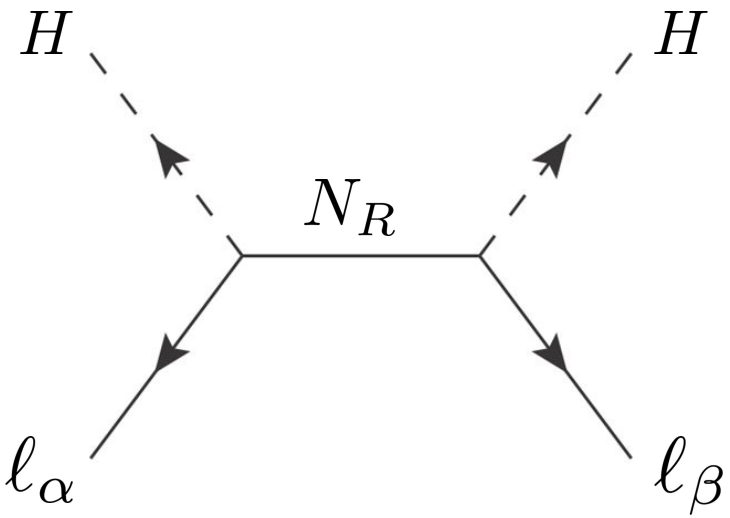
Departure from thermal equilibrium ✓

Neutrinos, Higgs & Flavour

Solution using neutrinos:

Leptogenesis
& type I seesaw



$$\mathbf{M}_\nu = -\left(\mathbf{Y}_N\right)^T \frac{v^2}{\mathbf{M}_N} \mathbf{Y}_N$$

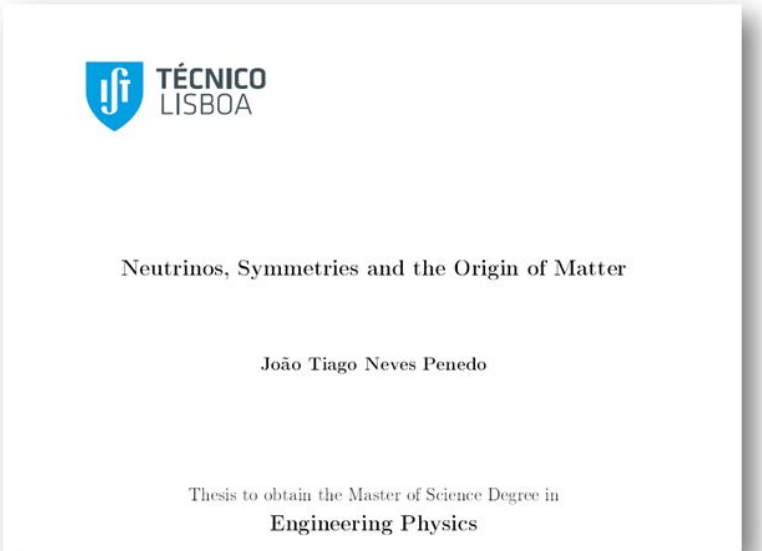
B Violation ✓
C and CP violation ✓
Departure from thermal equilibrium ✓

Neutrinos, Higgs & Flavour

$$\frac{1}{\Gamma_{\Delta_i}}\left(\Gamma(\Delta_i^* \to \ell_\alpha\,\ell_\beta) - \Gamma(\Delta_i \to \overline{\ell_\alpha}\,\overline{\ell_\beta})\right)$$

Solution using all 3:

Flavoured
Leptogenesis
w/ type II seesaw



TÉCNICO LISBOA

Neutrinos, Symmetries and the Origin of Matter

João Tiago Neves Penedo

Thesis to obtain the Master of Science Degree in
Engineering Physics

We've touched some exciting open questions...

Research opportunities @ CFTP

*CP violation. What are the new **sources**?*

*How do fermions get **mass**?*

*How to explain the **baryon asymmetry** of the Universe?*

*What is the nature of **Dark Matter**?*

*How do **neutrinos** get mass?*

*Is there an extended **Higgs sector**?*

*What is the role of **flavour symmetries**?*

and many more...

Possible Work Programmes
in the domain of ***Theoretical Particle Physics***

Research opportunities @ CFTP

The Higgs boson and the origin of fermion masses: the role of symmetries

Beyond the Standard Model with Multi-Higgs

Neutrino Physics and Future Experiments

CP violation in the quark and lepton sectors

Supervisors

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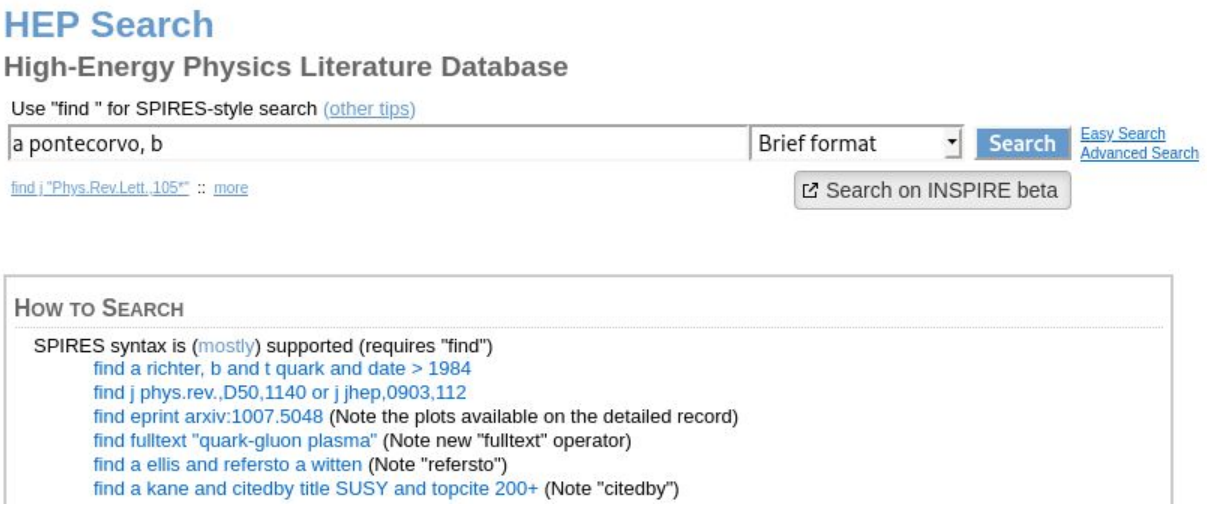

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PUBLICATIONS AND OUTPUT

STATS

Personal Details (HepNames)

Name	Bruno Pontecorvo
Links	http://pontecorvo.jinr.ru/
Fields	HEP-PH
Identifiers	BAI: B.Pontecorvo.1 INSPIRE: INSPIRE-00158012

Period	Rank	Institution
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Name Variants

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Publications Datasets External

1. Neutrinos today in the universe and in
2. NEUTRINOS TODAY
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   REACTOR NEUTRINO OSCILLATIO
4. RECOLLECTIONS ON THE ESTABLI
   INTERACTION NOTION
5. Neutrinos from Decays of Intermediat
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Co-Authors

S.M.Bilenky.1 (28)
A.Kulikov.1 (5)
A.V.Kuptsov.1 (4)
D.Khazins.1 (4)
E.P.Hincks.1 (4)
L.L.Nemenov.1 (4)

Citations Summary

89 papers found, 69 of them citeable (published or arXiv)

	Citeable papers	Published only
Number of papers analyzed:	69	68
Number of citations:	9250	9250
Citations per paper (average):	134.1	136.0
h_{HEP} index [?]	24	24

Breakdown of papers by citations:

	Citeable papers	Published only
Renowned papers (500+)	5	5
Famous papers (250-499)	0	0
Very well-known papers (100-249)	7	7

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Thank you!

gbranco@tecnico.ulisboa.pt
rebelo@tecnico.ulisboa.pt

until end of February 2020:

00 41 22 767 2821 (GCB), CERN, TH Dept
00 41 22 767 3206 (MNR), CERN, TH Dept

after 29 February 2020:

21 841 7933 (GCB), CFTP, IST
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