Recent results in Neutrino Physics

fefo

Universidad de Colima - FC - CUICBAS - DCPIHEP

XV Mexican School on Particles and Fields
Puebla, September 6 2012

A bit of History

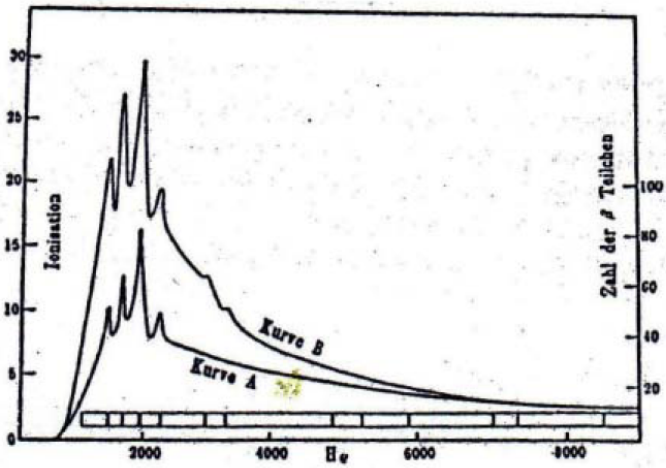

Figure 2: The continuous electron spectrum observed by Chadwick.

A bit of History

A bit of history… 1930 - Wolfgang Pauli

Dear Radioactive Ladies and Gentlemen….

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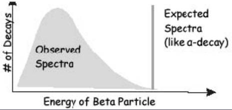
As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, how because of the "wrong" statistics of the N and Li6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that there could exist in the nuclei electrically neutral particles, that I wish to call neutrons, which have spin 1/2 and obey the exclusion principle and which further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger than 0.01 proton masses. The continuous beta spectrum would then become understandable by the assumption that in beta decay a neutron is emitted in addition to the electron such that the sum of the energies of the neutron and the electron is constant... ....

Unfortunately, I cannot appear in Tubingen personally since I am indispensable here in Zurich because of a ball on the night of 6/7 December. With my best regards to you, and also to Mr Back.

Your humble servant,

W. Pauli

Wolfgang Pauli



N. Bohr suggested energy not conserved in β decays
L. Meitner proposed β^- loses energy through secondary interactions in nulceus yielding gamma rays

A bit of History

First Calculation of Neutrino Cross Sections

Bethe-Peierls (1934): calculation of first cross-section for inverse beta reaction using Fermi's theory for:

$$\bar{\nu}_e + p \to n + e^+ \quad \text{or} \quad \nu_e + n \to p + e^-$$

yields:

$$\boxed{\sigma \approx 10^{-44}\ cm^2 \quad \text{for} \quad E(\bar{\nu}) = 2\ MeV}$$

This means that the mean free path of a neutrino in water is:

$$\lambda = \frac{1}{n\sigma} \approx 1.5 \times 10^{21}\ cm \approx 1600 \quad light - years$$

Experimentalists groaned - need a very intense source of ν's to detect inverse Beta decay

A bit of recent history

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- Experiments have shown that neutrinos oscillate $\rightarrow$ they have mass
- Few oscillation parameters are well measured
- Only upper limits on the absolute mass scale
- We do not know the their *nature*

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- Even tiny masses can have cosmological implications and current bounds set $M_\nu < 0.17 - 0.33$ eV (model dependent... Results from Planck should be available soon)
- Cannot replace direct lab. experiments

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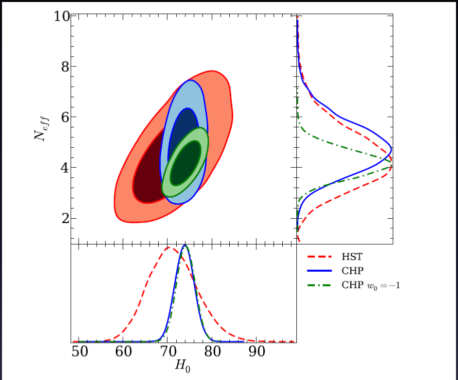

L. Freedman et al., Carnegie Hubble Program: A Mid-Infrared Calibration of the Hubble Constant, arXiv:1208.3281, Submitted. Aug 16, 2012.

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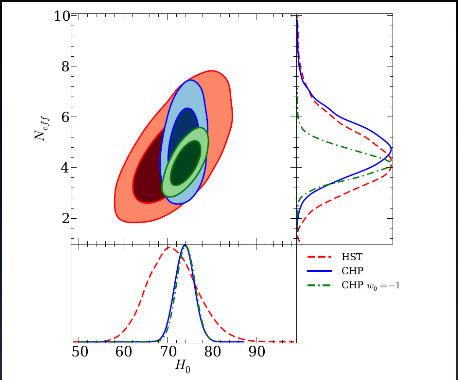
- Planck should confirm/refute these results in early 2013



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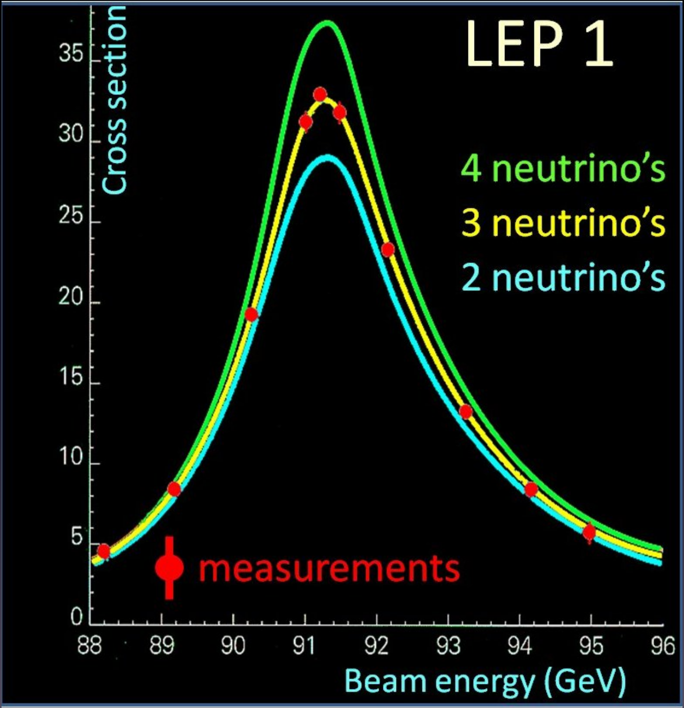

LEP 1
Cross section
35
30
25
20
15
10
5
0
88
89
90
91
92
93
94
95
96
Beam energy (GeV)
4 neutrino's
3 neutrino's
2 neutrino's
measurements

absolute mass scale

- Doble beta decay experiments at the *tail* can measure

$$m_{\nu_e}^2 = \sum_{1=1}^{3} |U_{ei}|^2 m_i^2$$

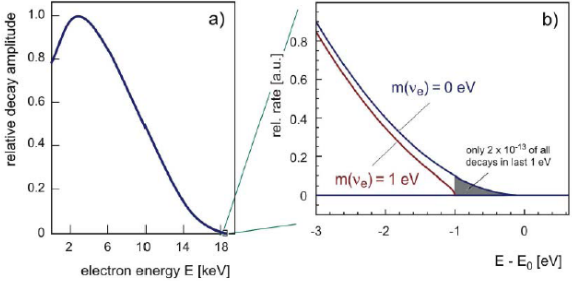
- current upper limit: $m_{\nu_e} < 2.3$ eV Krauss C *et al.* 2005 *Eur. Phys. J.* C40 447-468

absolute mass scale

ν_e Mass Measurements
(Tritium β-decay Searches)

- Search for a distortion in the shape of the β-decay spectrum in the end-point region.

$$^3H \rightarrow {}^3He + \nu_e + e^-$$



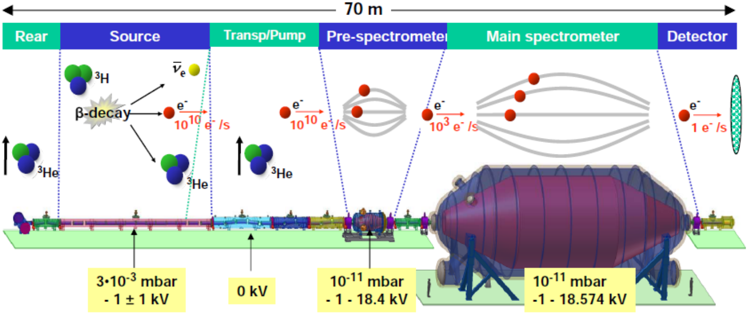
Current limit: $m_\nu < 2.2$ eV @ 95% CL (Mainz group 2000)

Next Generation β-decay Experiment (δm≈0.35 eV)

Karlsruhe Tritium Neutrino Experiment
(KATRIN)

next-generation experiment with sub-eV neutrino mass sensitivity

FH Fulda - FZ & U Karlsruhe - U Mainz - INP Prague - U Seattle - INR Troitsk



Arrival in Leopoldshafen: Nov 24, 2006

discovery potential:

m_ν = 0.35eV (5σ)

m_ν = 0.3eV (3σ)

sensitivity:

m_ν < 0.2eV (90%CL)

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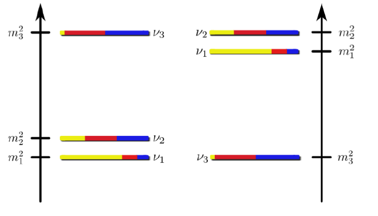
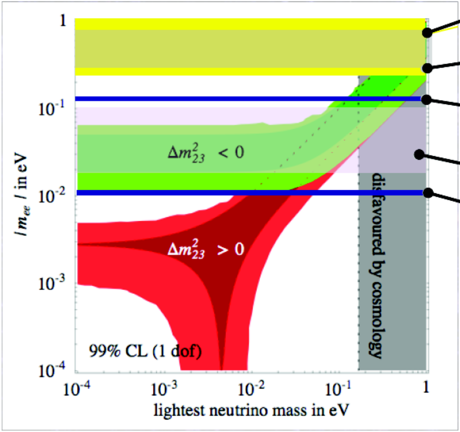
- Majorana vs Dirac
- can also probe the absolute mass scale
- in combination with oscillation experiments, can give hint of mass hierarchy





KKDC Claim
(best fit 0.32 eV)

Final Cuoricino limit
arXiv:1012.3266v1 [nucl-ex]

GERDA Target

CUORE Target

With SuperNEMO, SNO+, MAJORANA, many others should reach here in ~ 7-10 yrs.

Oscillation parameters

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- Oscillations are governed by a 3×3 unitary matrix and by mass differences
- The mixing angles **have been measured**
- mass differences **have been measured** (although not the hierarchy)
- CP violating phase is unknown.

Mixing parameters

- Conventional (PDG) parameterization for the mixing matrices U_{CKM} and U_{PMNS}:

"Dirac" CP phase δ

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot P_{Maj}$$

(eventually)

mixing angle θ_{23}

mixing angle θ_{13}

mixing angle θ_{12}

θ_{13}

- Accelerator experiments:

$$P(\nu_\mu \to \nu_e) = \mathcal{F}(\theta_{13}, \delta_{CP})$$

- A year ago T2K presented candidates for ν_e appearance - six events (on an expected background of 1.5 ± 0.3)

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- A year ago T2K presented candidates for ν_e appearance - six events (on an expected background of 1.5 ± 0.3)
- MINOS followed with 62 events (on a background of 49.6)

Abe K *et al.*. (T2K Collaboration) 2011 PRL 107 041801

Adamson P *et al.* (MINOS Collaboration) 2011 PRL 107 181802

θ_{13}

- Reactor experiments:

$$P(\bar{\nu}_e \to \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{\mathbf{13}} \sin^2(1.267 \Delta m^2_{13} L/E)$$

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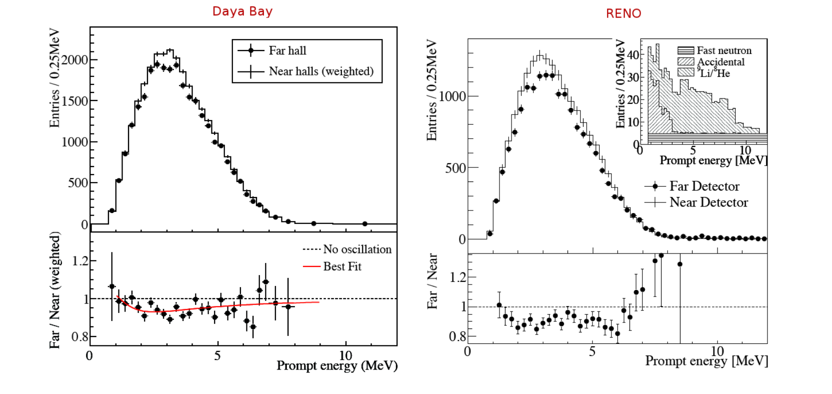
$\longrightarrow \theta_{13} \neq 0!$

An F *et al.*. (DAYA-BAY Collaboration) 2012 PRL 108 171803

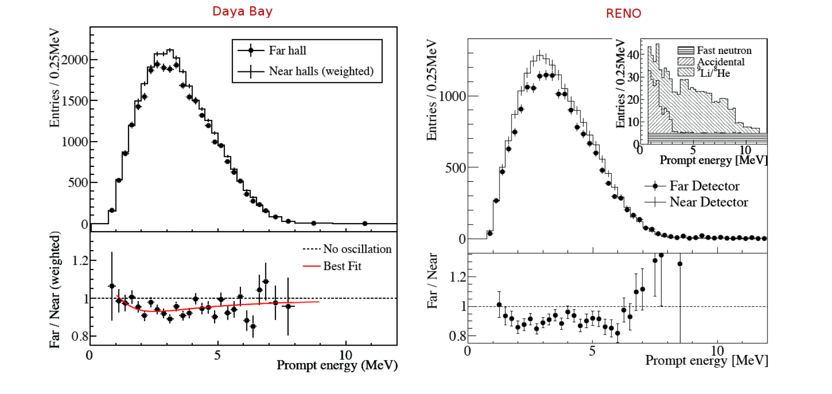
Ahn J *et al.* (RENO Collaboration) 2012 PRL 108 191802

θ_{13}



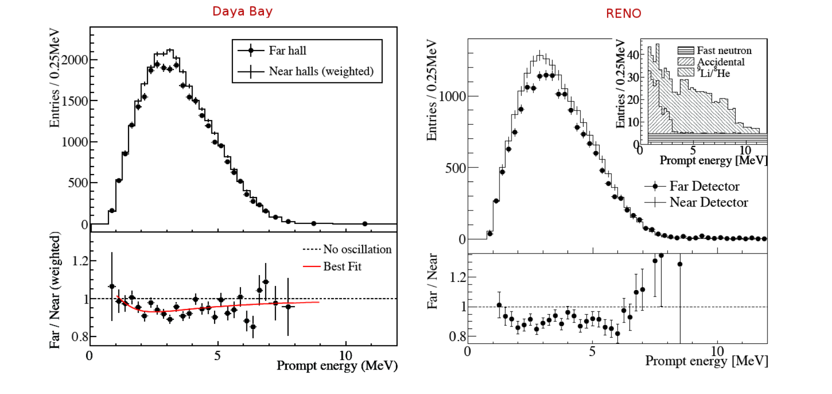
Daya Bay
RENO
Far hall
Near halls (weighted)
No oscillation
Best Fit
Entries / 0.25MeV
Far / Near (weighted)
Prompt energy (MeV)
Fast neutron
Accidental
^{9}Li/^{8}He
Prompt energy [MeV]
Far Detector
Near Detector
Far / Near

θ_{13}



Daya Bay (left): Best-fit solution with $\sin^2 2\theta_{13} = 0.089$

θ_{13}



Daya Bay (left): Best-fit solution with $\sin^2 2\theta_{13} = 0.089$

RENO (right): Best-fit solution with $\sin^2 2\theta_{13} = 0.113$

Δm^2_{21} and θ_{12}

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- Current values

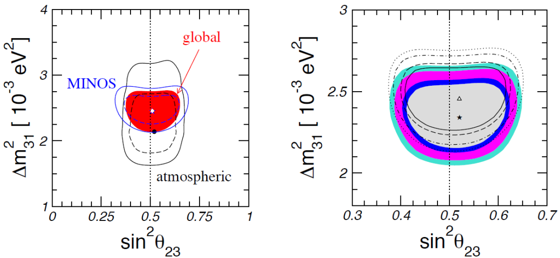
$$\Delta m^2_{21} = 7.59^{+0.20}_{-0.18} \times 10^{-5}\mathrm{eV}^2$$

$$\sin^2\theta_{12} = 0.312^{+0.017}_{-0.015}$$

Schwetz T, Tortola M and Valle J 2011 *New J. Phys* 13 063004

$|\Delta m^2_{31}|$ and θ_{23}

$$|\Delta m^2_{31}| = \begin{cases} 2.45 \pm 0.09 & \times 10^{-3}\ \text{eV}^2\ \ (\text{NH}) \\ 2.34^{+0.10}_{-0.09} & \times 10^{-3}\ \text{eV}^2\ \ (\text{IH}) \end{cases} \quad \text{and} \quad \sin^2\theta_{23} = 0.51 \pm 0.06$$



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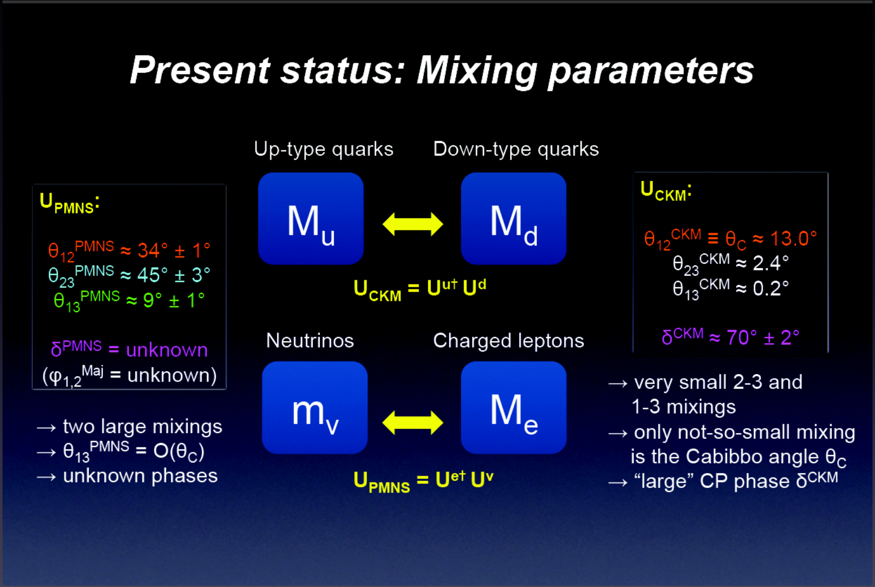

Stolen from Stefan Antusch @ Neutrino 2012

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$\Lambda \rightarrow$ LARGE mass scale.

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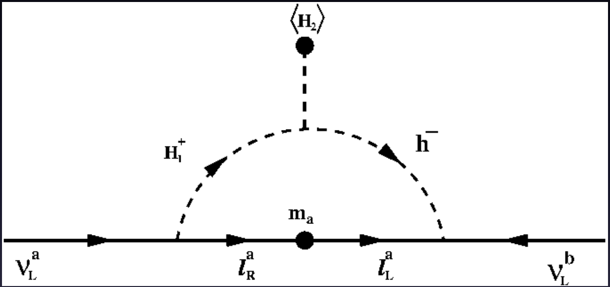
Requires introduction of new fields



$$m_{ab} = \kappa^{ab}(m_b^2 - m_a^2)\frac{\lambda_{12} v_2}{v_1} F(m_H^2, m_h^2)$$

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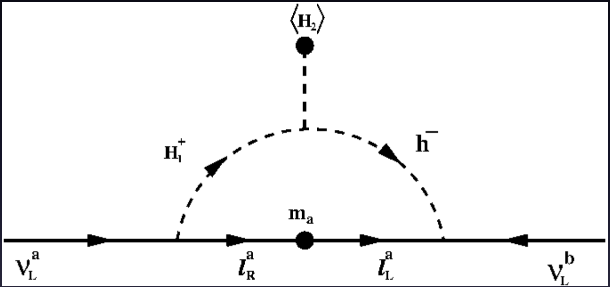

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$m_h \to$ LARGE

A. Zee, Phys. Lett 93B, 389 (1980)

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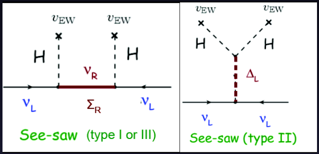
Dirac and Majorana mass terms are now possible

$$M_\nu = \begin{pmatrix} m_L & m_D \\ m_D & m_R \end{pmatrix}$$



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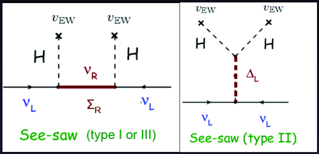

m_R must be large

$$m_\nu \sim m_D^2 / m_R$$

P. Minkowsli, Mohapatra, Senjanovic, Yanagida,

Gell-Mann, Ramond, Slansky, Schechter, Valle,

....

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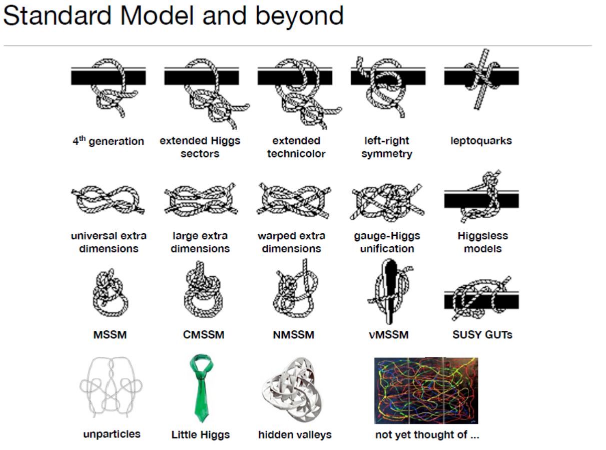

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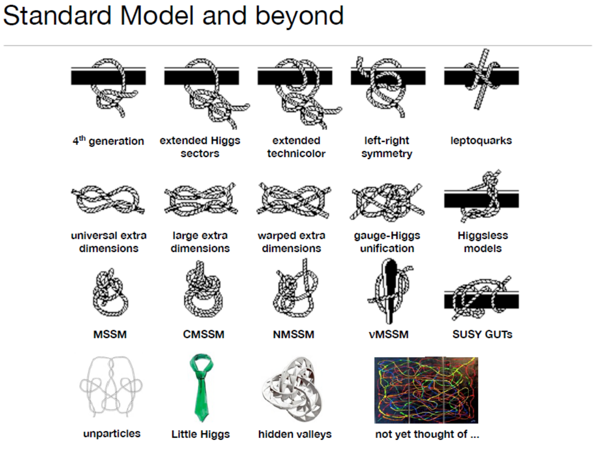
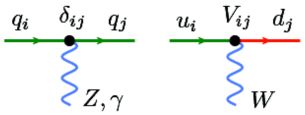


- Of course, masses of all fermions must be explained!

Mixing angles?



δ: unit matrix *V*: CKM matrix

$$V \approx \begin{array}{cc} \begin{array}{ccc} d & s & b \end{array} & \\ \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ -\lambda^3 & -\lambda^2 & 1 \end{pmatrix} & \begin{array}{c} u \\ c \\ t \end{array} \end{array}$$

λ ≈ 0.22: Cabibbo angle

Mixing angles?

Tri-bimaximal mixing

Harrison, Perkins, Scott ('02)

$\theta_{13} = 0°$

$$U_{TB} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix} P$$

$\theta_{12} = 35.3°$

$\theta_{23} = 45°$

Stolen from Stefan Antusch @ Neutrino 2012

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$$U_{PMNS} = U_l^\dagger U_\nu \approx U_{TB}$$

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If charged leptons are *diagonal*

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If charged leptons are *diagonal*

$$U_{PMNS} = U_\nu \approx U_{TB}$$

$\rightarrow M_\nu$ is *magical* and $2-3$ *symmetric*

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Z_2, Z_4, S_3, Q_4,

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Z_2, Z_4, S_3, Q_4, S_4,

Mixing angles?

Z_2, Z_4, S_3, Q_4, S_4, A_4,

Mixing angles?

Z_2, Z_4, S_3, Q_4, S_4, A_4, T', ...

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Z_2, Z_4, S_3, Q_4, S_4, A_4, T', ...

Altarelli, Araaki, Antusch, Bazzocchi, Bonilla, Branco, Chen, Datta, Frampton, Fukugita, Feruglio, Gupta, Gross, Hagedorn, Kim, King, Kobayashi, Kumar, Lavoura, Lam, Ma, Mohapatra, Mondragon, Morisi, Okada, Peinado, Petcov, Ramos, Romanino, Rojas, Ross, Seo, Shimizo, Takahashi, Tanimoto, Valle, Wang, Watanabe, Yanagida, Yang, Zee, ...

Mixing angles?

Z_2, Z_4, S_3, Q_4, S_4, A_4, T', ...

Altarelli, Araaki, Antusch, Bazzocchi, Bonilla, Branco, Chen, Datta, Frampton, Fukugita, Feruglio, Gupta, Gross, Hagedorn, Kim, King, Kobayashi, Kumar, Lavoura, Lam, Ma, Mohapatra, Mondragon, Morisi, Okada, Peinado, Petcov, Ramos, Romanino, Rojas, Ross, Seo, Shimizo, Takahashi, Tanimoto, Valle, Wang, Watanabe, Yanagida, Yang, Zee, ...

But $\theta_{13} \neq 0$

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Could it come from modifications to U_ν?

Could it come from modifications to U_l?

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Could it come from modifications to U_ν?

Could it come from modifications to U_l?

... from both?

Mixing angles?

$$U_{PMNS} = U_l^\dagger U_\nu \sim U_{TB}$$

Could it come from modifications to U_ν?

Could it come from modifications to U_l?

... from both?

Yes ...

a small step for M_ν, a giant leap for ?

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minimizing the number of scalar fields leads to the possibility of using the group Q_4 **with 4 SU(2) doublets and radiative masses for the neutrinos** (which costs an additional singlet charged scalar).

AA, Bonilla, Ramos, Rojas

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- Finaly, they are my favorite particles!


Ride
VIRGINIA

addvertisement 1

2012
08.30

2013 DCPIHEP workshop

Category: Uncategorized / Tags: no tag / Add Comment

Neutrino Physics

January 7 – 18 @ Colima

Invited Lectures

André de Gouvêa (Northwestern U.): **Neutrino Physics (theory)**
Stefano Morisi (IFIC – Valencia) **Neutrino mass models**
TBC: Jonathan Paley (Argonne Natl. Lab.): **Neutrino Physics (experiment)**

Preliminary Program

The purpose of the workshop is to bring together people interested in BSM physics. There will be a series of lectures and abundant time for discussion and actual work. Organization of informal seminars and talks are encouraged. If you are interested in leading a specific discussion session please send us the topic and hourly sessions needed. The time table for the lectures is shown below. Information regarding other activities will be posted as it becomes available. **Please note that some of the informal talks and discussion sessions will be organized while at the workshop.**

addvertisement 2

Postdoctoral position

The High Energy group at the University of Colima has an opening for a postdoctoral position. There is no fixed starting date (except that it is expected to be available not before October 2012) and it is for one year with the possibility of extension for an additional year.

We are looking for candidates interested in any aspect of theoretical and/or phenomenological high energy physics, specially those associated with physics beyond the Standard Model. Candidates must posses a Ph. D. in physics.

Interested candidates should prepare an application consisting of

- A brief research statement specifying previous research experience as well as future research interests.

- An updated Curriculum Vitae.

- Two (at least) letters of recommendation. Letters should be sent electronically and directly by the reference person.

Please send all material (and ask for the letters of recommendation to be sent) electronically to the attention of Alfredo Aranda to the following email address: fefo.aranda at gmail.com

Applications will be accepted and reviewed until the position is filled. First offers are expected to be made in late September.