Cos'è la materia per la fisica delle particelle e perché tentare di osservarne la creazione

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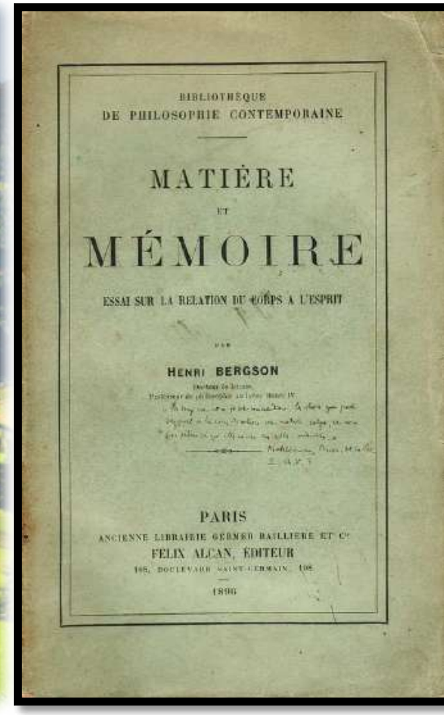


BIBLIOTHÈQUE
DE PHILOSOPHIE CONTEMPORAINE

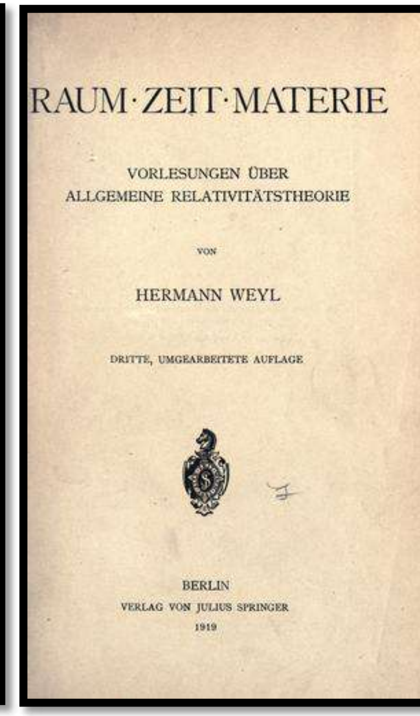
MATIÈRE
ET
MÉMOIRE

ESSAI SUR LA RELATION DU CORPS A L'ESPRIT

PAR

HENRI BERGSON

PARIS
ANCIENNE LIBRAIRIE GERMER BAILLIÈRE ET Cie
FÉLIX ALCAN, ÉDITEUR
108, BOULEVARD SAINT-GERMAIN, 108
1896



RAUM·ZEIT·MATERIE

VORLESUNGEN ÜBER
ALLGEMEINE RELATIVITÄTSTHEORIE

VON

HERMANN WEYL

DRITTE, UMGEARBEITETE AUFLAGE

BERLIN
VERLAG VON JULIUS SPRINGER
1919

Possiamo <u>far esperienza</u> della meraviglia del creato, e <u>ragionare</u> sulla natura delle cose percettibili.

Un argomento importante di dibattiti anche recenti
ruota intorno alla domanda: ***cosa è la "materia"***.

È innegabile che la chimica prima e la fisica poi abbiano dato contributi essenziali a questa discussione;
esamineremo allora certe questioni sollevate dalla <u>fisica delle particelle</u>, che credo meritino attenzione.

di cosa ragioneremo

- cosa sostiene la fisica delle particelle sulla natura della materia
- quali quadri concettuali ci fornisce per ordinare le osservazioni
- quali sono quelli più credibili, evidenziando quelle che suggeriscono che la materia sia in una qualche misura, impermanente

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è possibile osservare la creazione di particelle di materia in laboratorio?

cosa c'entrano i processi** (altrettanto ipotetici) **di disintegrazione della materia?

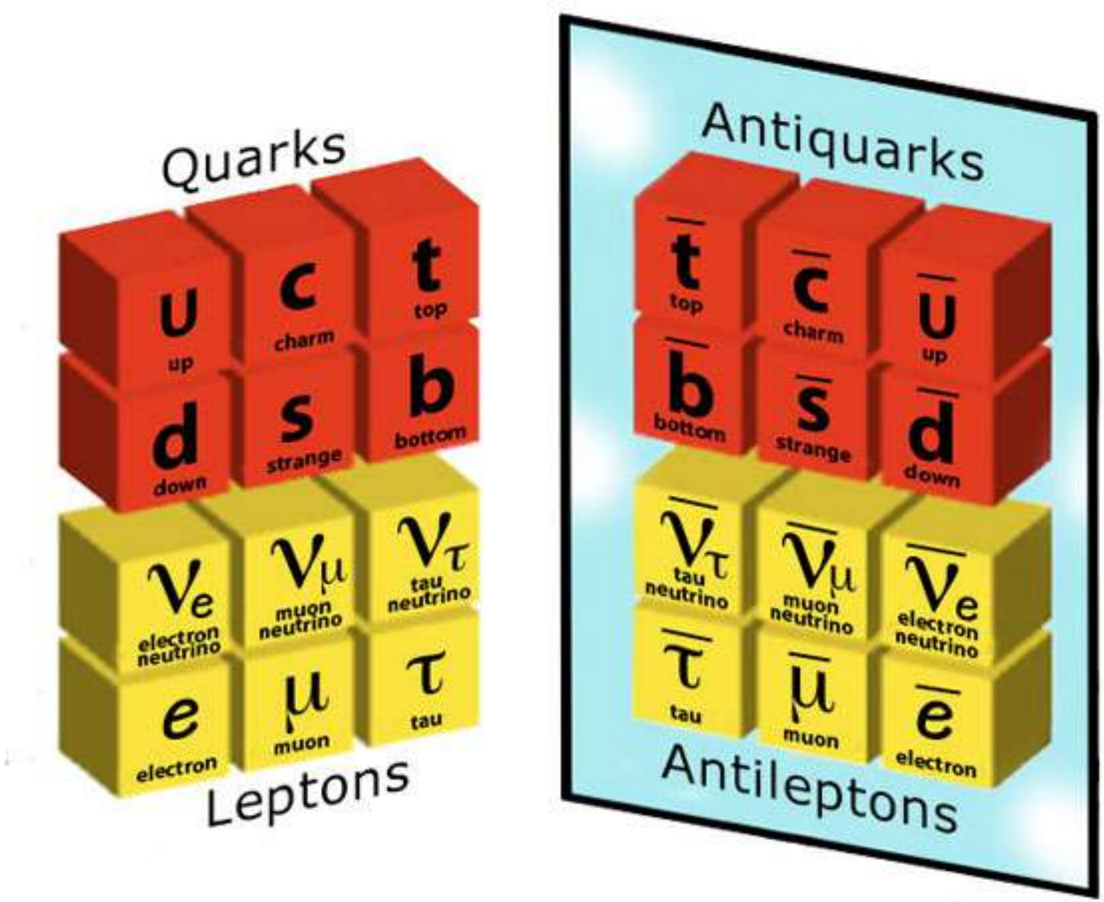
la materia per la fisica delle particelle [1]

- la materia sensibile è composta di parti ben definite, dette particelle elementari, ognuna caratterizzata dalle sue interazioni

- le particelle son descritte da rappresentazioni irriducibili e di dimensione finita del gruppo di Poincarè con spin e massa assegnati

- le particelle di materia (note) hanno spin ½

elettroni e nuclei atomici → leptoni e quark
da Thomson & Rutherford ai giorni nostri



meccanica ondulatoria e antiparticelle

$(P_a)^2 \, \boldsymbol{\varphi} = m^2 \, \boldsymbol{\varphi}$ dove $P_a = i \hbar \, d/dx_a$ [Schrodinger, Klein, Fock]

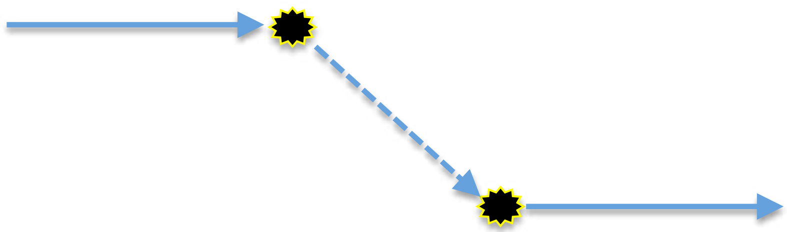
ha soluzioni $\boldsymbol{\varphi} \sim \exp(\pm i \, E \, t/\hbar)$

Gli stati con energie "negative" possono essere pensati come stati finali di una interazione, ovvero come $(\boldsymbol{\varphi}_{-})^*$

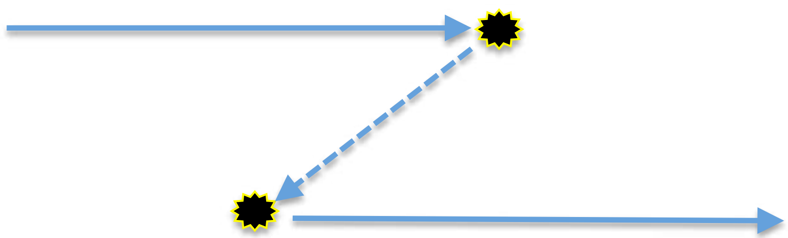
Ma hanno carica opposta alle particelle, in quanto

$P_a \rightarrow P_a - q \, A_a$ [Fock, Weyl, Yang-Mills]

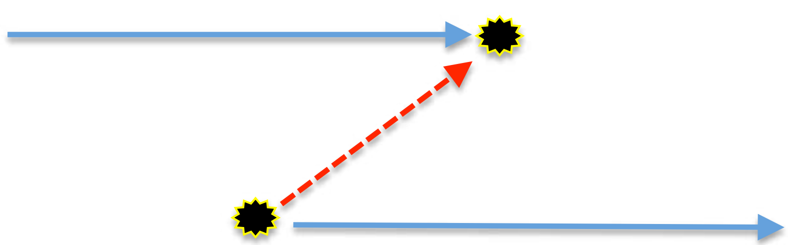
un altro argomento sulle antiparticelle (Feynman)



un elettrone che cambia direzione due volte interagendo con un potenziale esterno



per certe trasformazioni di Lorentz, lo stato intermedio si muoverebbe all'indietro nel tempo!



ammettendo che esista una particella di carica opposta si evita questa fastidiosa conclusione

equazione d'onda relativistica dell'elettrone

The Quantum Theory of the Electron.

By P. A. M. Dirac, St. John's College, Cambridge.

(Communicated by R. H. Fowler, F.R.S.—Received January 2, 1928.)

The new quantum mechanics, when applied to the problem of the structure of the atom with point-charge electrons, does not give results in agreement with experiment. The discrepancies consist of "duplexity" phenomena, the observed number of stationary states for an electron in an atom being twice the number given by the theory. To meet the difficulty, Goudsmit and Uhlenbeck have introduced the idea of an electron with a spin angular momentum of half a quantum and a magnetic moment of one Bohr magneton. This model for the electron has been fitted into the new mechanics by Pauli,* and Darwin,†

Dirac pensò ben tre anni prima di parlare così:

"Questo sarebbe un nuovo tipo di particella, sconosciuto alla fisica sperimentale, con la stessa massa e carica opposta dell'elettrone. Possiamo chiamare una tale particella un antielettrone"

impianto di tomografia a emissione di positroni (PET)

la morale che ne traggo: il fatto che ne facciamo tecnologia non significa che il concetto di antiparticella (e di antimateria) sia banale, o che non meriti discussione.

in effetti una osservazione apparentemente semplice ma importante fu formulata solo dopo nove anni

$\gamma^a P_a \; \psi = m\, \psi$ dove $P_a = i\hbar\, d/dx_a$ [Dirac '28]

ha soluzioni $\psi \sim \exp(\pm i\, E\, t/\hbar)$

Le soluzioni con energie "negative" possono essere pensate come stati finali di una interazione, ovvero come $(\psi_-)^*$

ψ_- e ψ_+ si possono identificare se la carica è nulla. Questa risulta chiaro nella base in cui le matrici γ^a sono immaginarie:

$$\psi_- = (\psi_+)^*$$ [Majorana '37]

la materia per la fisica delle particelle [2]

- la meccanica ondulatoria, applicata alle particelle, porta a pensare che ognuna di esse debba essere necessariamente accompagnata da una antiparticella

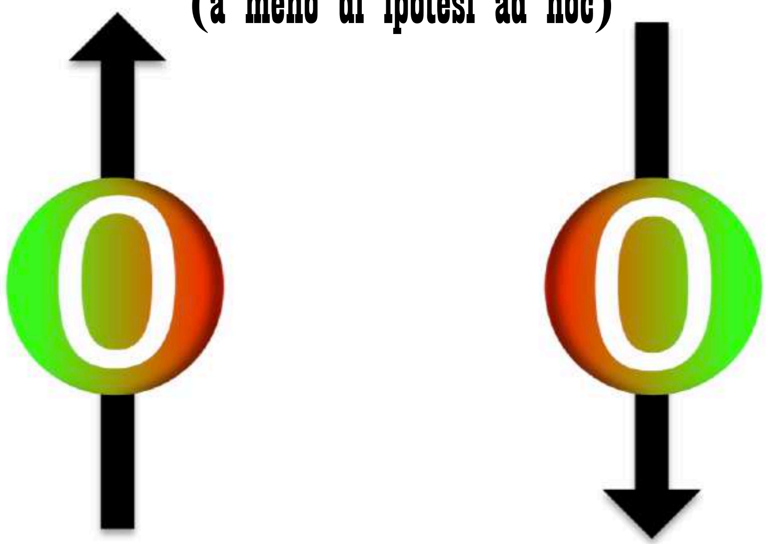
- alcune particelle neutre coincidono con le loro antiparticelle: p.e. il fotone, la Z^0 oppure il π^0

- tra le particelle di materia (ovvero, quelle con spin ½) l'unica che potrebbe obbedire a questa condizione e conformarsi all'ipotesi di Majorana è il neutrino

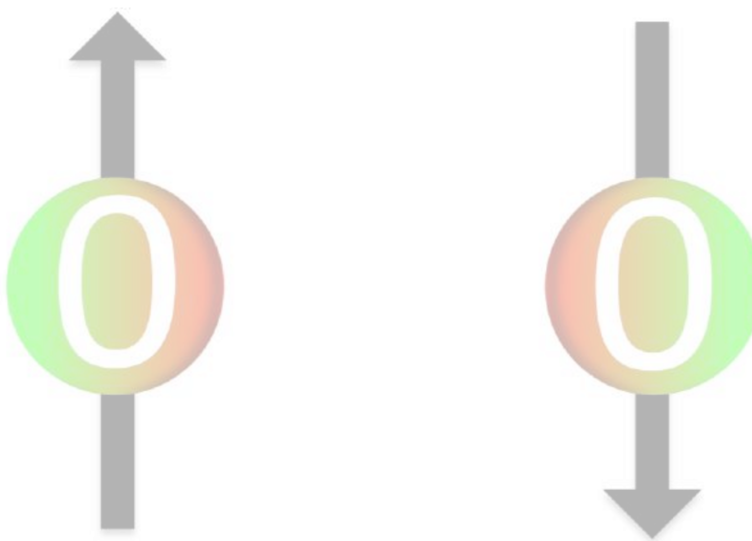
l'elicità distingue neutrini e antineutrini relativistici

ma se son fermi, come possiamo distinguerli?

(a meno di ipotesi ad hoc)



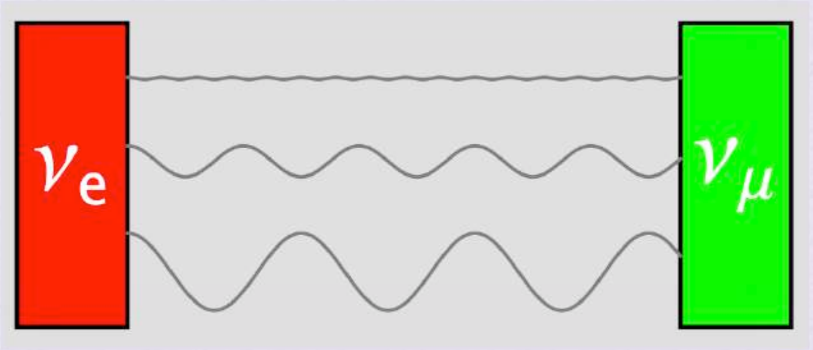
ipotesi: i neutrini sono materia e antimateria (Majorana)



dove abbiamo considerato che:

l'elicità dei neutrini, risp. antineutrini, è negativa, risp. positiva in accordo con la struttura V-A delle interazioni deboli
(notare che come regola si parla solo di particelle ultrarelativistiche)

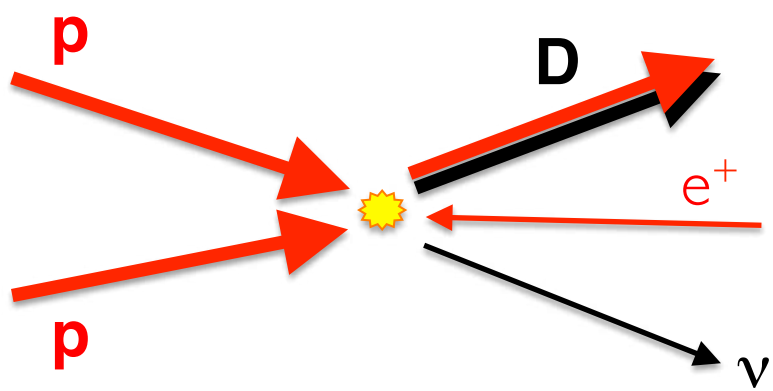
la massa dei neutrini è piccola ma non zero, come dimostrato usando il metodo suggerito da Pontecorvo (intendo le trasformazioni di sapore o oscillazioni, Nobel in fisica 2015)



di solito vale $E_\nu >> m_\nu c^2$

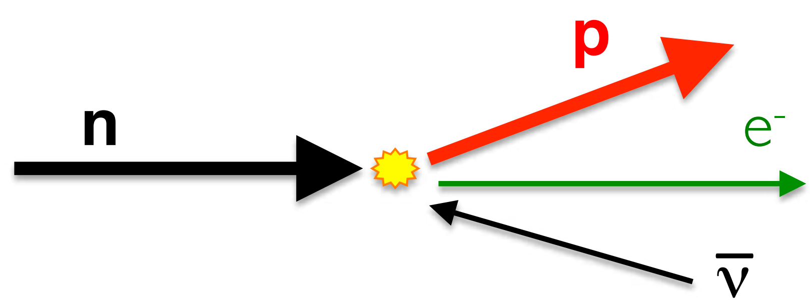
p+p → **D** + e^+ +ν

il neutrino va considerato come la particella di materia che accompagna l'antielettrone



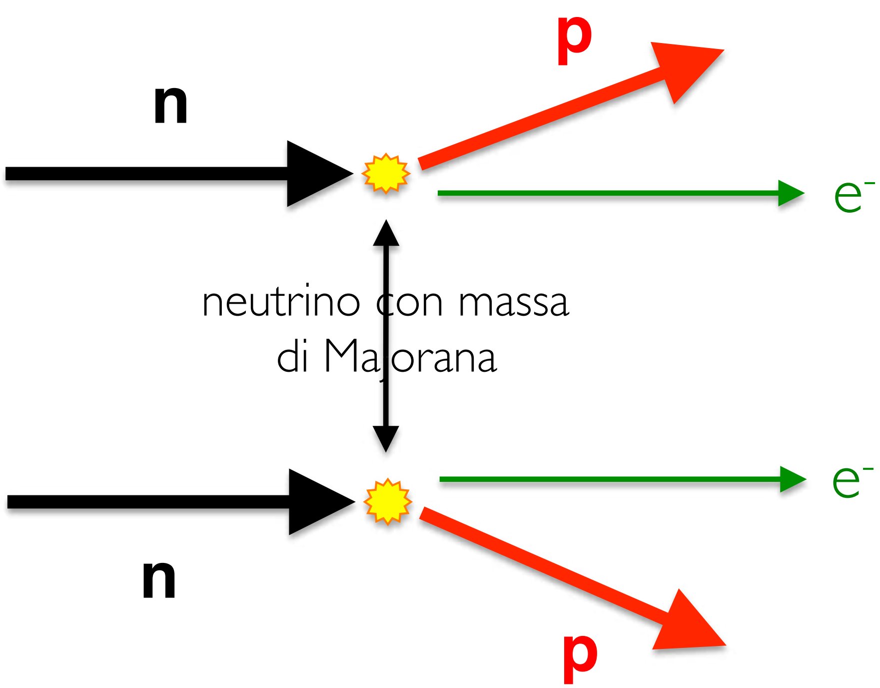
n → **p** + e + $\overline{\nu}$

l'antineutrino va considerato come la particella di antimateria che accompagna l'elettrone



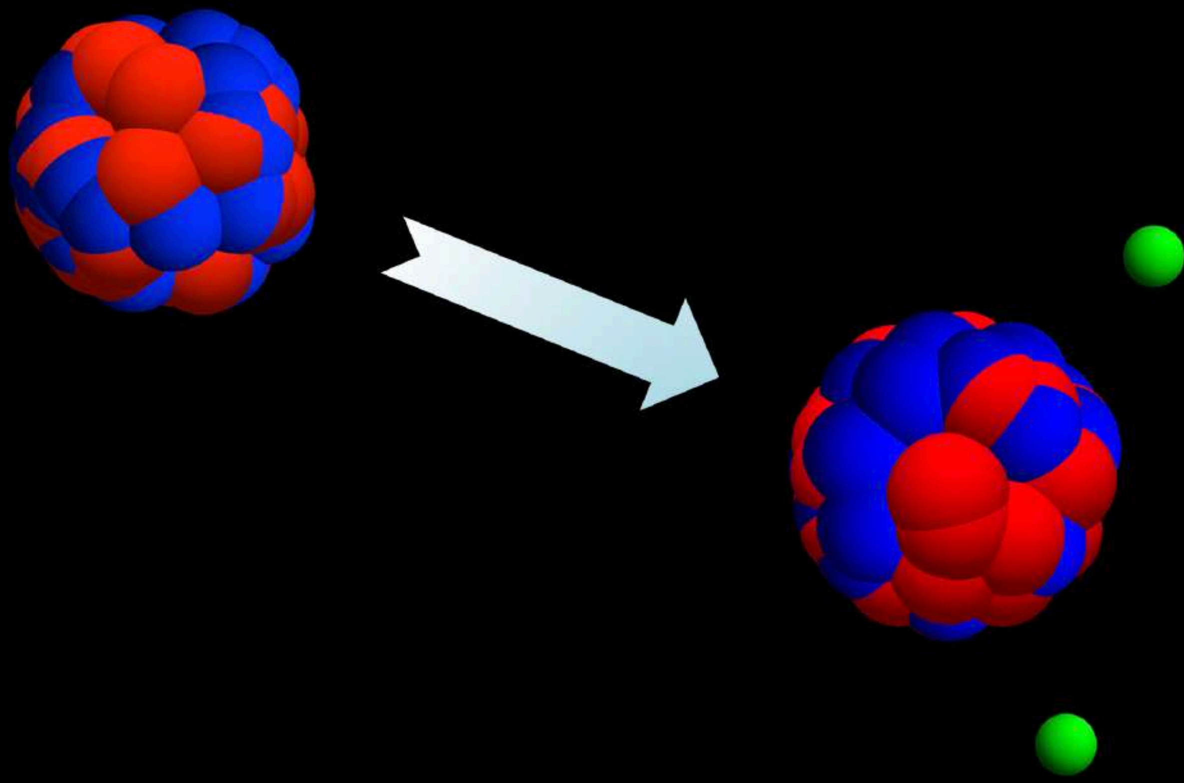
i neutrini di Majorana rendono possibili nuovi processi

$2\,\mathbf{n} \rightarrow 2\,\mathbf{p} + 2\,e$



comunemente chiamato “decadimento doppio β senza emissione di neutrini” [Furry ‘39]

Il neutrino di Majorana fa da ponte tra materia e antimateria



si possono creare 2 elettroni - 2 particelle di materia !!!

come chiarire le aspettative su 2n→2p+2e

La massa di Majorana che bisogna quantificare è questa,

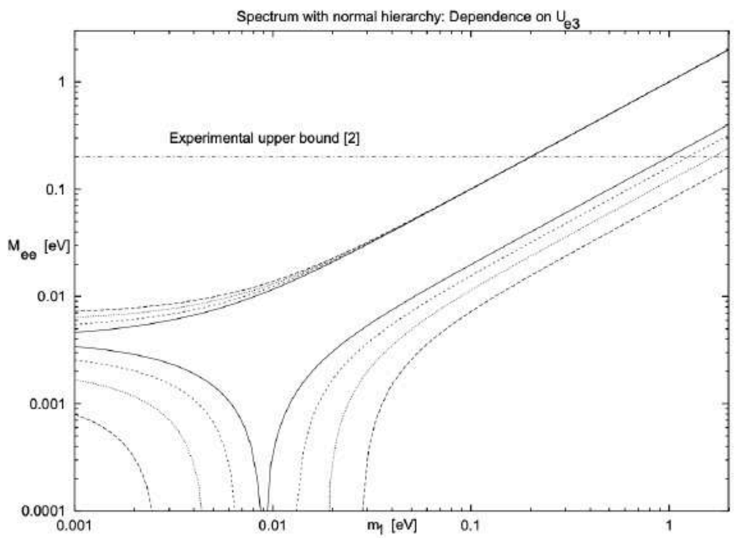
$$m_{\beta\beta} \equiv |(M_\nu)_{ee}| = \left| \sum_{i=1}^{3} |U_{ei}^2| \, e^{i\xi_i} \, m_i \right|$$

Simboli: il 1° è quello tradizionale, il 2° è l'elemento *e-e* della matrice di massa di Majorana

Le oscillazioni misurano solo i valori assoluti del mescolamento leptonico $|U_{ei}^2|$ e le differenze di massa quadrate, ma non la scala di **massa assoluta** e le **fasi** ξ_i.

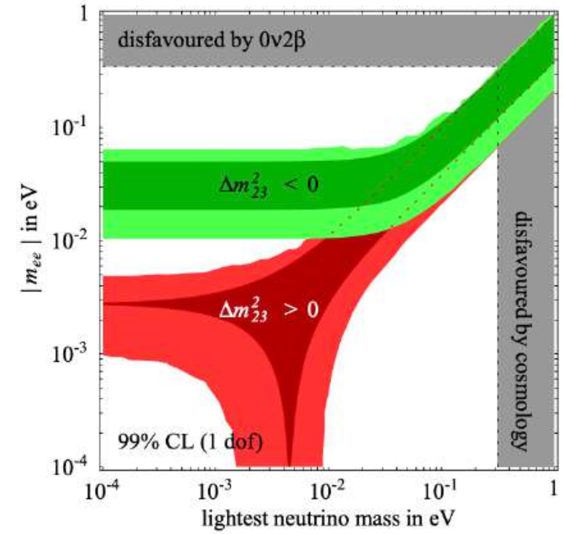
vincoli sulla massa di Majorana rilevante per 2n→2p+2e

Vissani, JHEP



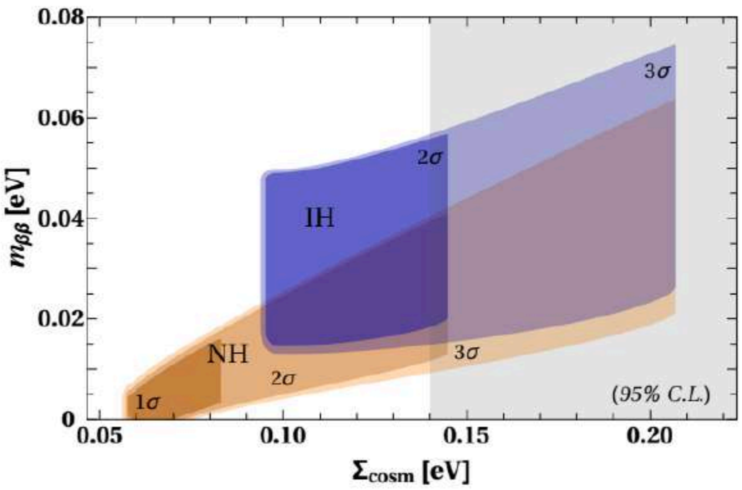
1999

Strumia,Vissani NPB



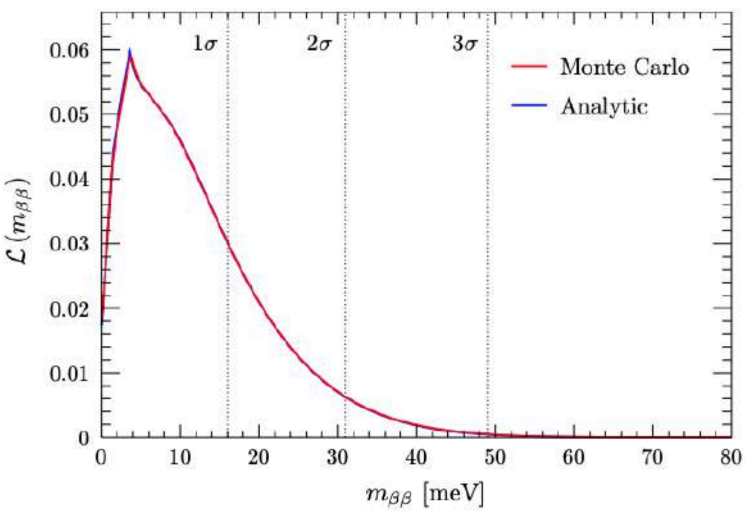
2005

Dell'Oro, Marcocci, Vissani, PRD



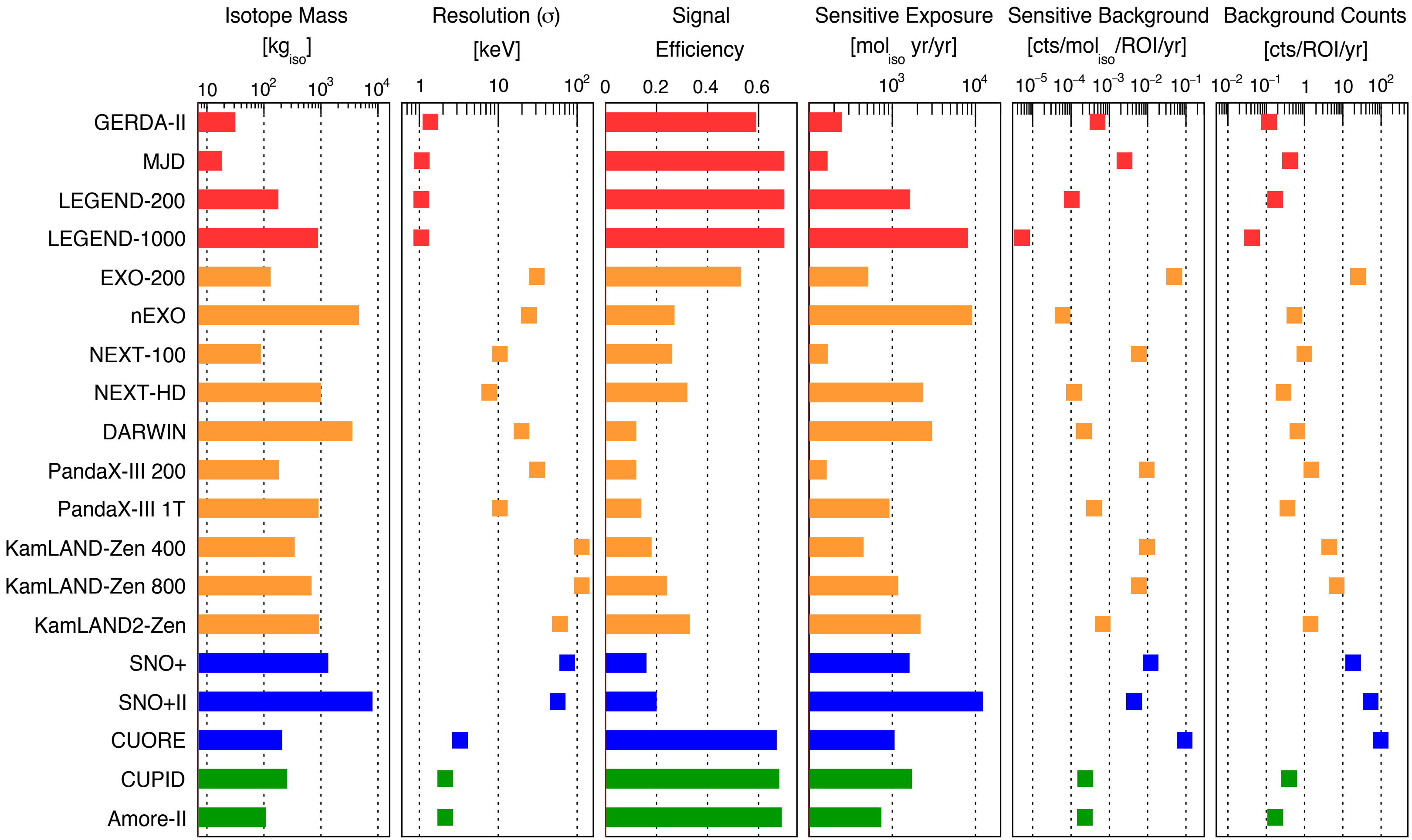
2015

Dell'Oro, Marcocci, Vissani, PRD



2019

in corso d'opera: studio sistematico delle sensibilità sperimentali



M. Agostini, G. Benato, J. A. Detwiler, J. Menendez, and F. Vissani, article in preparation

la materia per la fisica delle particelle [3]

- se il neutrino è particella ed antiparticella allo stesso tempo, secondo l'ipotesi di Majorana, esistono processi in cui si creano elettroni

- sappiamo che tali transizioni son molto rare. Non siamo ancora in grado di dire precisamente quanto, ma c'è margine per raffinare le aspettative

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esaminiamo da ultimo come si inseriscono queste aspettative nel quadro teorico di cui oggi disponiamo: il modello standard

[modello standard 1/2] definizione

- gruppo di gauge $SU(3)_c \times SU(2)_L \times U(1)_Y$ (Weyl, Yang-Mills… GWS)

- 3 famiglie di spinori: q_L, l_L, u_R, d_R, e_R [6+2+3+3+1=15 s. di Weyl]

- 1 doppietto scalare: H, la cui massa quadra negativa rompe spontaneamente $SU(2)_L$ x $U(1)_Y \rightarrow U(1)_{em}$ (Higgs; Brout-Englert, …)

si scrivano tutti i termini rinormalizzabili e si fissino i valori dei parametri operando tante misure quanti sono i parametri

[modello standard 2/2] implicazioni

- ☑ Una sola scala di massa (o due se contiamo anche la densità di energia)
  17 parametri senza dimensioni (o 18, contando θ_{CP})

- ☑ teoria calcolabile ad ogni ordine perturbativo

- ☑ regime non perturbativo per $SU(3)_c$ a basse energie (glueballs?).
  gli adroni più leggeri hanno vita media infinita come gli elettroni

- ☑ assenza di correnti neutre fondamentali che viòlino il sapore adronico;
  CP violata solo debolmente dalle correnti cariche

- ☑ 4 numeri globali, $\mathbf{B}, \mathbf{L_e}, \mathbf{L_\mu}, \mathbf{L_\tau}$ conservati in teoria delle perturbazioni.

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  B-L, L_e-L_μ, L_e-L_τ conservati esattamente, dove **$L=L_e+L_\mu+L_\tau$**

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- **i neutrini non hanno massa, fatto che contraddice le oscillazioni**

c'è solo 1 tipo di leptone fondamentale

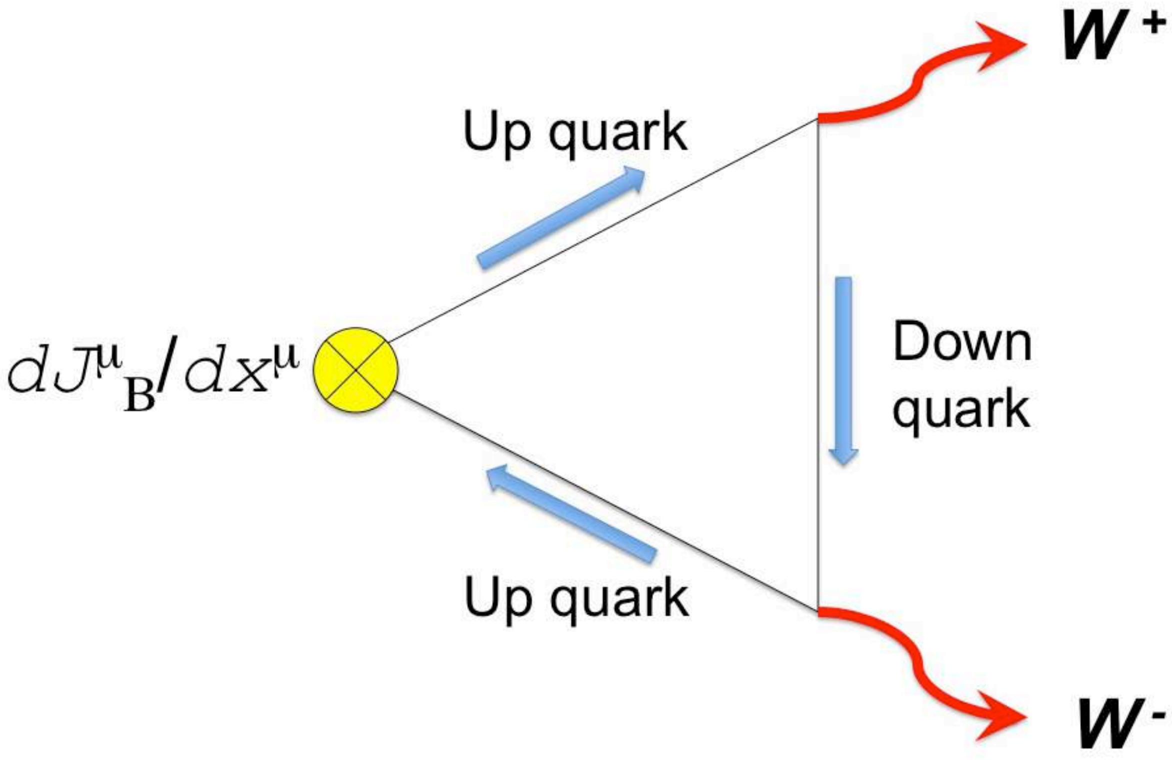
(=T2K, NOvA, OPERA, SK, DeepCore hanno provato che si conserva solo il numero totale L)

	ΔL_e	ΔL_μ	ΔL_τ	ΔL
$\nu_\mu \rightarrow \nu_e$	+1	-1	0	0
$\nu_\mu \rightarrow \nu_\tau$	0	-1	+1	0

Da questo punto di vista, ci sono 2 due tipi di **particelle di materia**: leptoni e quark.
Le sole simmetrie globali residue sono **L** e **B**.

nel “modello standard” B e L non sono conservati esattamente!

invece B-L lo è, fatto che collega leptoni & quarks



[Steinberger ‘49; Adler; Bell, Jackiw ‘69]

c'è solo 1 tipo di ~~leptone~~ fermione fondamentale

(=T2K, NOvA, OPERA, SK, DeepCore hanno provato che si conserva solo il numero totale L)

	$\Delta(L_e - L_\mu)$	$\Delta(L_\mu - L_\tau)$	$\Delta(L_\tau - L_e)$	$\Delta(B-L)$
$\nu_\mu \rightarrow \nu_e$	+2	-1	-1	0
$\nu_\mu \rightarrow \nu_\tau$	+1	-2	+1	0

Unendo esperimenti+teoria, concludiamo che tutte le simmetrie globali sono violate tranne una

Osservare di **2 n→ 2 p + 2 e** significherebbe che è violata anche l'ultima simmetria globale, **B-L**

oscillazioni e frontiere del modello standard

Weinberg 79

$$\delta\mathcal{L} = \frac{(\ell H)^2}{M} + \frac{\ell qqq}{M'^2} + \frac{(\ell q d^c)^2}{M''^5} \text{ with } \begin{cases} M < 10^{11}\ \text{TeV} & \text{for dim.5} \\ M' > 10^{12}\ \text{TeV} & \text{for dim.6} \\ M'' > 5\ \text{TeV} & \text{for dim.9} \end{cases}$$

- il 1° (dim.5) descrive masse di Majorana e viola B-L
- il 2° (dim.6) causa l'instabilità del protone ma conserva B-L
- il 3° (dim.9) viola il numero leptonico e contribuisce a 2n→2p+2e
- (A dim.7 la simmetria B-L è rotta; a dim.9 anche B è violata)

[discussione 1/3]: la prospettiva storica

- La fisica delle particelle elementari si configura come un significativo sviluppo della dottrina dell'atomismo, che costituisce una risposta al «problema dell'essere»: gli atomi, pur troppo piccoli da esser visti, sono i *baluardi esistenziali* della materia che ci costituisce.

- Gli aspetti ondulatori della meccanica quantistica invece possono essere idealmente collegati ai precetti delle dottrine pitagoriche: lo stesso Schrödinger diceva *all is waves.*

- Tali aspetti, nella teoria dello spazio-tempo di Einstein con la descrizione di gauge delle interazioni, implicano l'esistenza delle antiparticelle. L'antimateria da esse costituita risulta ben distinta dalla materia nella teoria di gauge di riferimento: il *modello standard.*

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La particolare natura del neutrino di Majorana implica che la materia, definita secondo il modello standard, può apparire o scomparire. Si riapre il dibattito sul «problema dell'essere», ma nasce una dinamica tra materia ed antimateria che sembra interessante se non addirittura desiderabile.

[discussione 2/3]: un tarlo della fisica moderna

come abbiamo visto, il matrimonio tra meccanica ondulatoria e relatività porta a credere nella inevitabilità dell'esistenza dell'antimateria. Inoltre, le idee di Friedmann (+LRW) e le osservazioni implicano che l'universo fosse un tempo caldissimo.

① certamente, l'antimateria pervadeva l'Universo nel lontano passato

② la cosmologia osservativa dice che l'antimateria in pratica è assente

③ come armonizzare queste storie? (Sakharov 1967)

④ il modello standard non è in grado di rispondere (nonostante **B+L** sia violata)

⑤ bisogna pensare a ulteriori violazioni di **B** e/o di **L**. Si noti che secondo caso è fortemente motivato dall'ipotesi di Majorana

[discussione 3/3]: aspettative e dubbi

- Dall'unificazione delle costanti di accoppiamento abbiamo degli indizi a favore di una teoria di gauge estesa, non una vera predizione. Sono ignoti i campi scalari, le scale di intermedie, gli effetti di soglia, ecc. Le masse dei fermioni sono uno dei pochi vincoli, la genesi della materia una domanda che può trovare risposte in questi contesti.

- Esistono nuove particelle? Qual'è la natura della materia oscura? Cosa pensare della supersimmetria? La guerra lampo del '70 è diventata una guerra di trincea. Non disponiamo di un «modello standard grande-unificato», ma abbiamo un'importante dato: sappiamo che i neutrini hanno massa. Sarebbe essenziale conoscerla meglio.

- Sembra ragionevole continuare a investigare se la materia possa essere creata, una possibilità suggerita molto tempo fa e che le migliori teorie oggi disponibili, nelle quali il neutrino ha massa di Majorana, concorrono ad indicare per plausibile.

Grazie per l'attenzione!

Di cosa è fatta la "materia"?

componenti elementari	caratteristica identificativa	vigenza teoria - esp.	ragione della inadeguatezza
atomi	**specie**, massa	fino 1838 - 1909	"atomi di elettricità"
nuclei & elettroni	**massa, carica**	fino 1933 - 1956	neutroni & neutrini
p, n, e, ν_e	**B, $L_{e,}$**, spin	fino 1961 - 1968	quark/SM
quark, leptoni	**B, L_e, L_μ, L_τ**, spin	fino 1967 - 2010	conversione sapore leptonico
quark-antileptoni	**B-L**, spin	fino 1937/1969 - ?	ν Majorana / 2n→2p+2e
fermioni	**spin**	fino ?? - ???	???

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JHEP 06 (1999) 022, 9906525

Implications of neutrino data circa 2005
con A. Strumia, Nucl.Phys.B 726 (2005) 294, 0503246

Neutrinoless double beta decay: 2015 review con S. Dell'Oro, S Marcocci, M. Viel
Adv.High Energy Phys. 2016 (2016) 2162659, 1601.07512

Empirical inference on the Majorana mass of the ordinary neutrinos
con S. Dell'Oro e S. Marcocci, Phys.Rev.D 100 (2019) 7, 073003

Da Pitagora all'antimateria, di Francesco Vissani, Published on July 28, 2019
https://www.linkedin.com/pulse/da-pitagora-allantimateria-francesco-vissani-phd/

A history of some recent attempts to go beyond the standard model, opening talk at the meeting *Gravity, Information and Fundamental Symmetries,* Munich, November 4-6, 2019,
https://www.mpi-hd.mpg.de/lin/events/ra-workshop/index.html

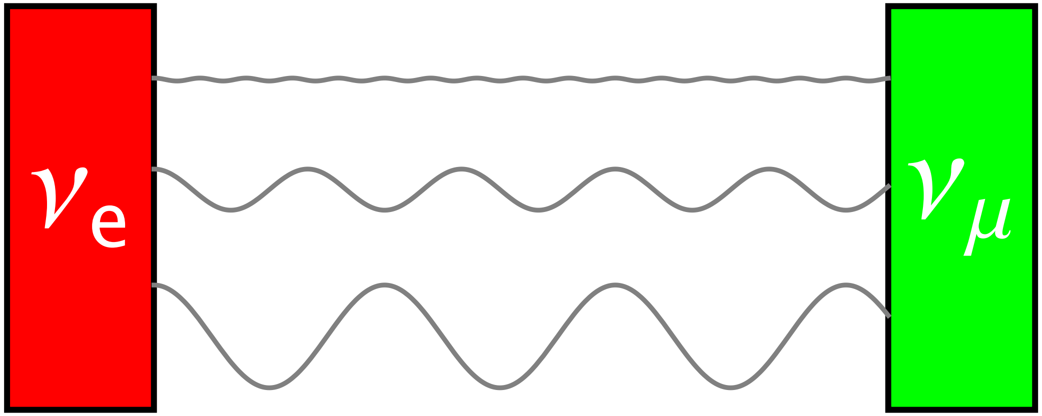
M. Agostini, G. Benato, J. Detwiler, J. Menendez, F. Vissani, rassegna in preparazione per RMP

materiale a suffragio

masse dei neutrini in cosmologia, oscillazioni,limiti sulla massa di Majorana, seesaw, storia

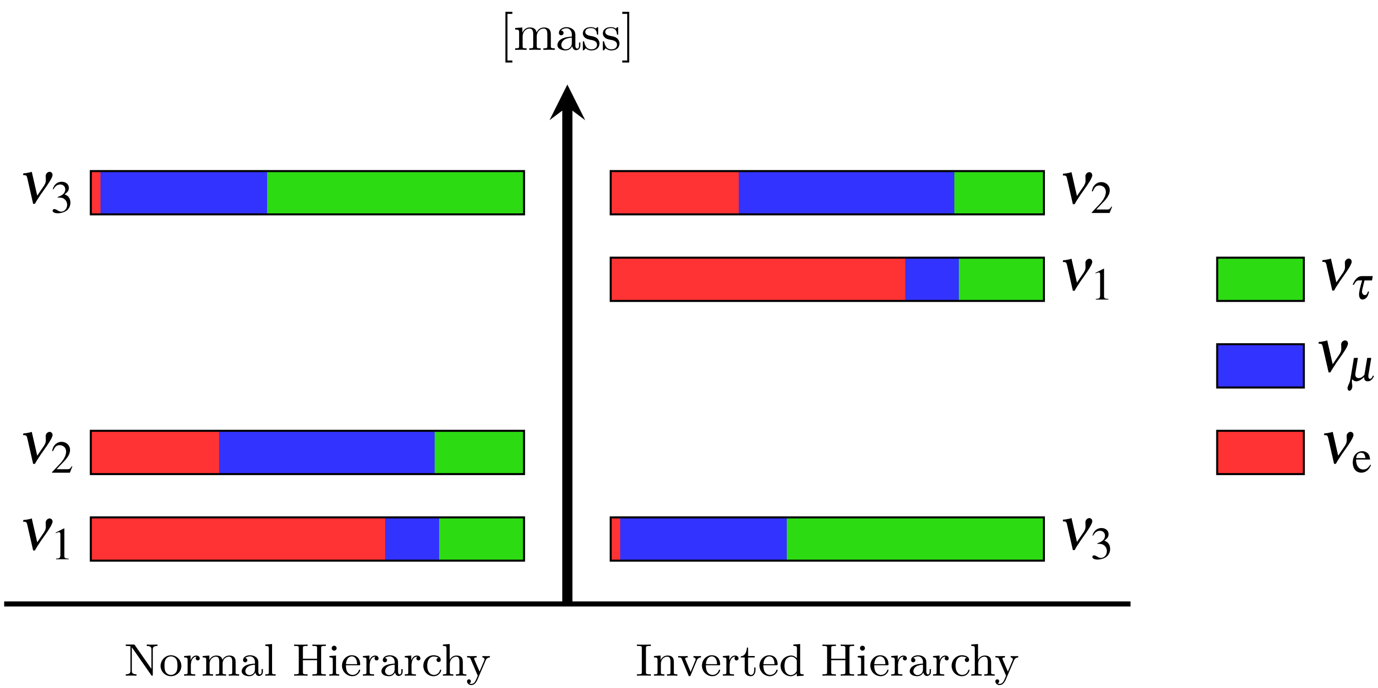
come funzionano le oscillazioni

Ogni neutrino vien prodotto come miscela di più onde, che descrivono particelle con masse diverse. Dunque le onde hanno velocità diverse, e così, quando si propagano, i neutrini cambiano natura.



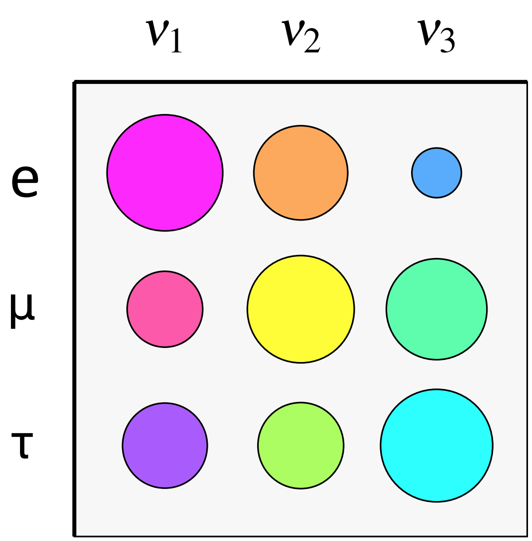
modello a tre sapori [2]

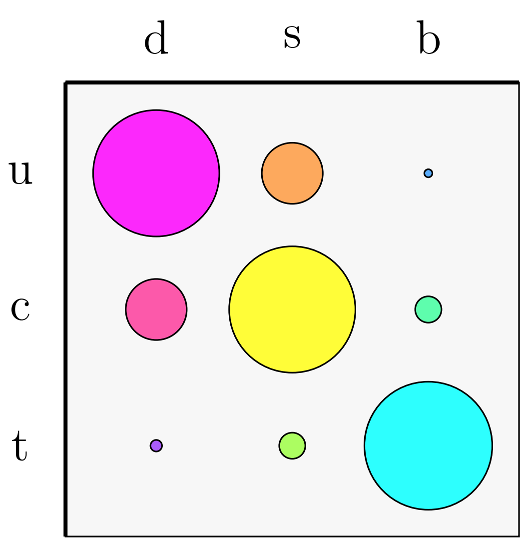
Fantini, Gallo Rosso et al, 2018



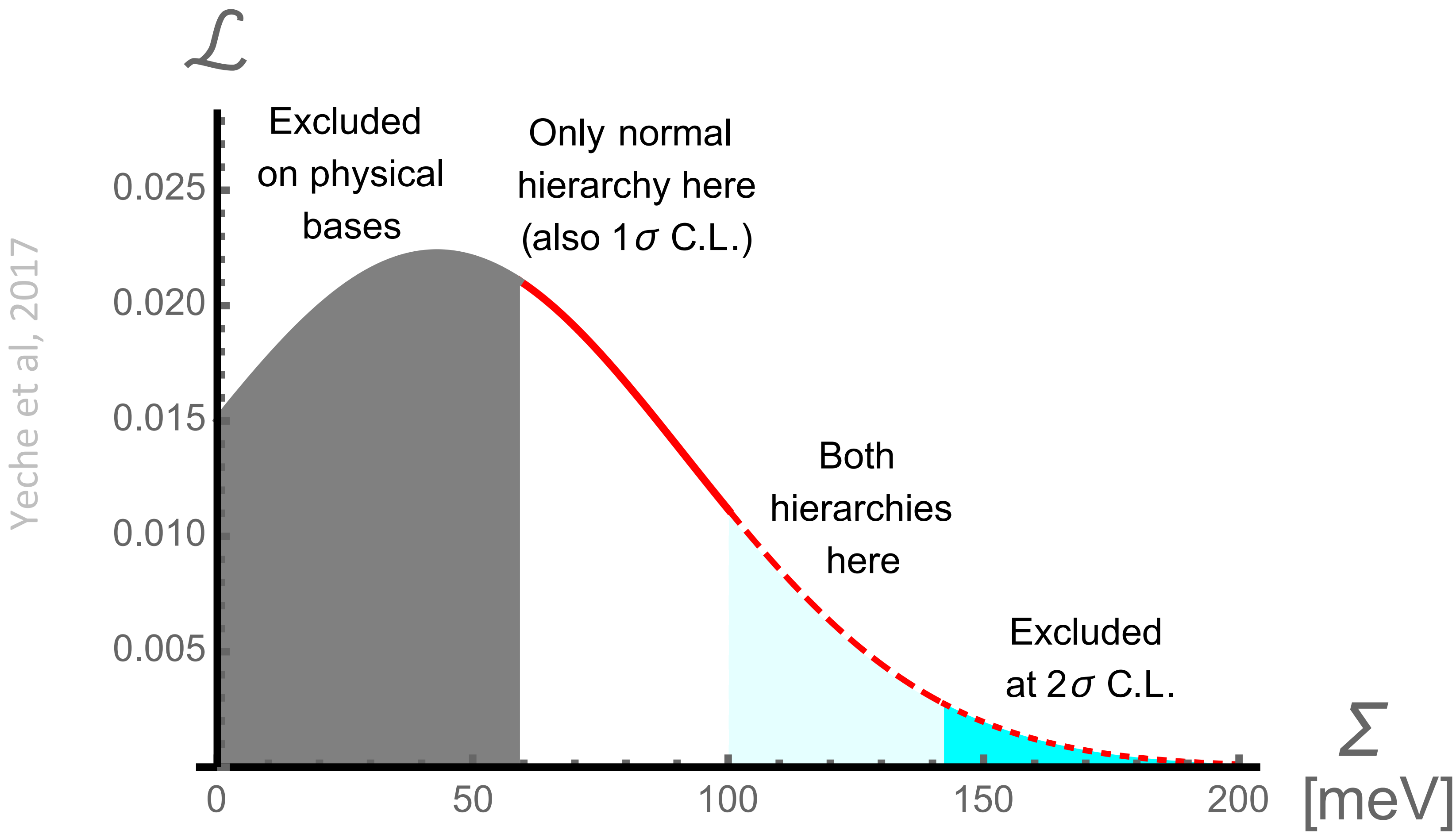
modello a tre sapori [1]

Fantini, Gallo Rosso et al, 2018

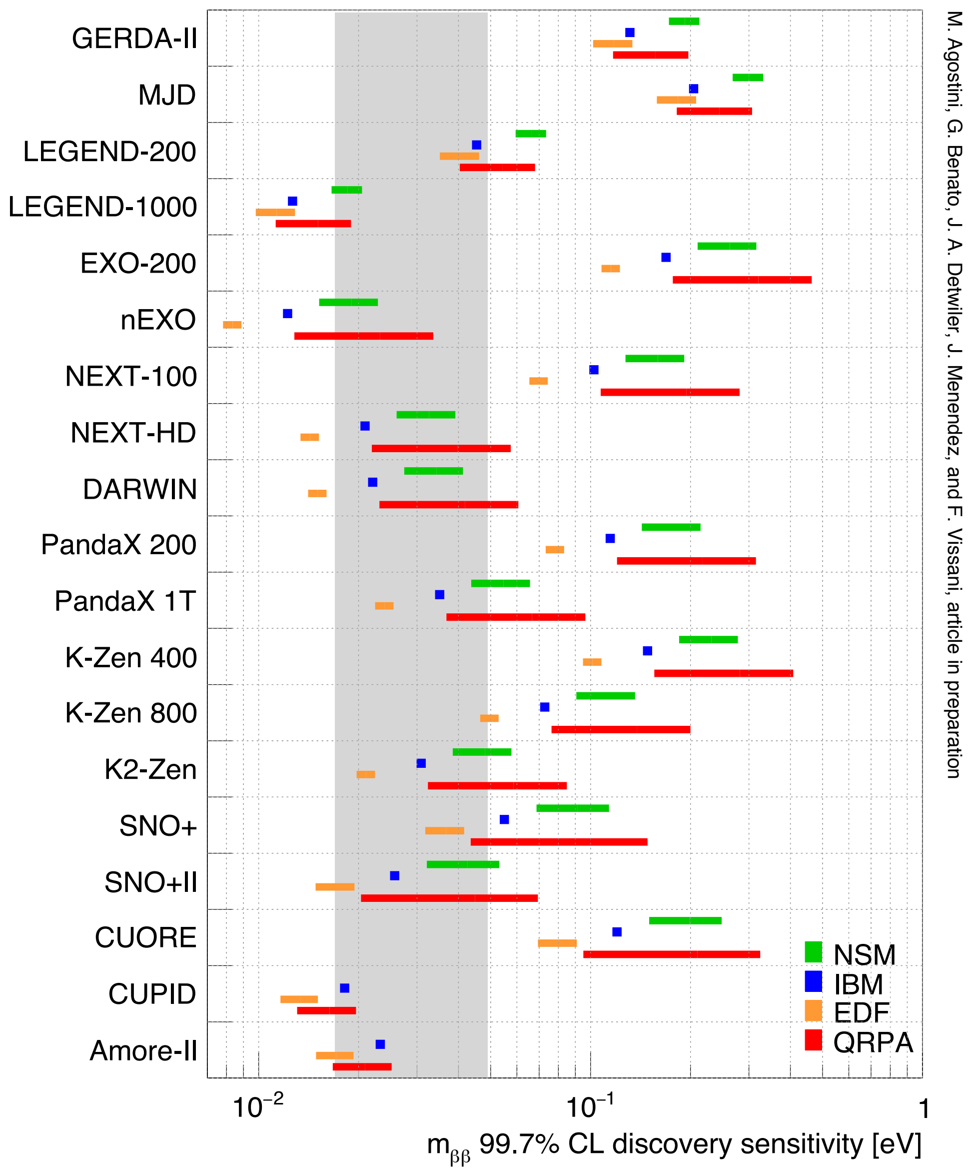




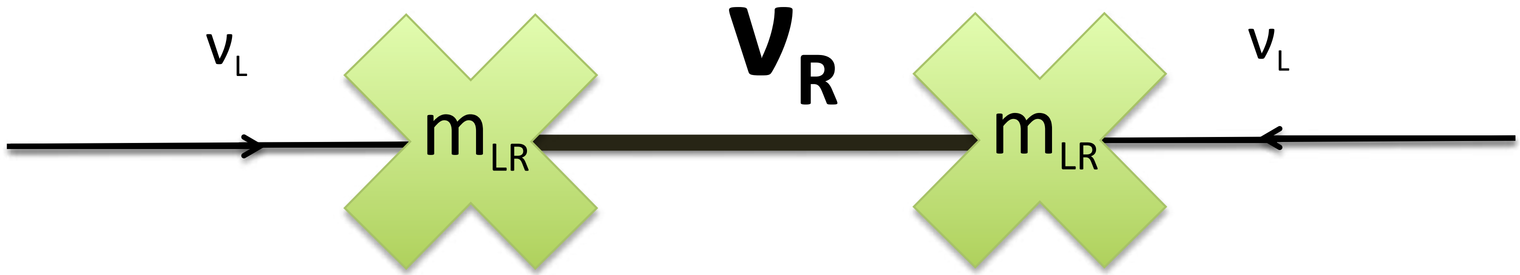
CMB permette di sondare $\Sigma = m_1 + m_2 + m_3$



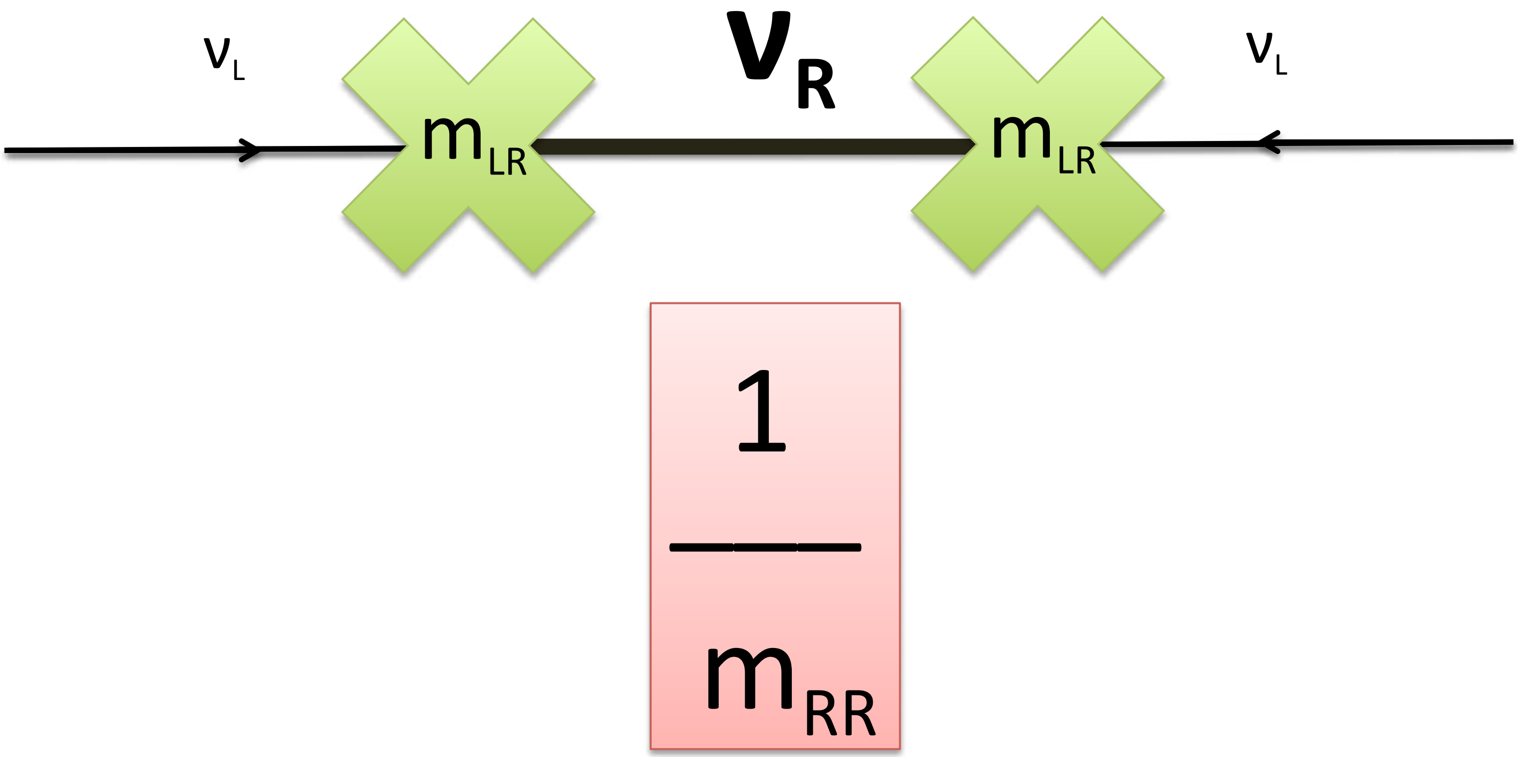
sensibilità alla massa di Majorana



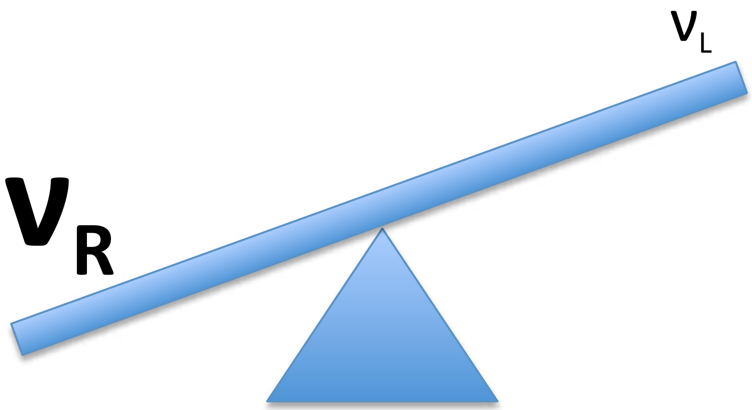
una spiegazione della piccolezza delle masse



una spiegazione della piccolezza delle masse



questo è chiamato “seesaw” (altalena)



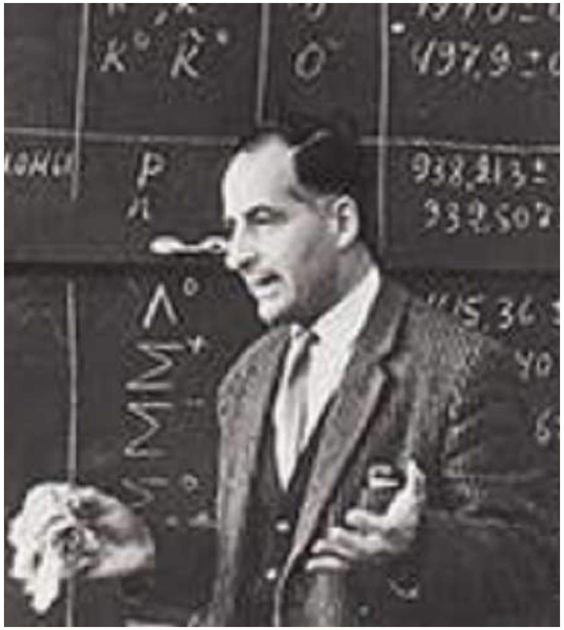
cronologia

- 1930-1933 scoperta neutrini
- 1937 peculiarità dei neutrini (Majorana)
- 1933-1958 interazioni deboli
- 1957-1998 "oscillazioni" di neutrino
- 1961-1974 modello standard
- 1939-… doppio β senza neutrini
- 1974-… estensione modello standard
- 1990-… massa e cosmologia

ancora sulle masse dei neutrini

dall’idea delle oscillazioni al Nobel 2015, l’odissea dei neutrini solari, analisi globali

the idea that worked – neutrino oscillations - was proposed early (late fifties / early sixties)



full recognition ½ a century later

solar neutrinos odyssey

- lot of resistance to the idea of solar neutrino experiments, see Bahcall
- then, the indications from solar neutrino experiment has long been ignored. It took 20 years before a test was conducted
  - in part it was distrust of astrophysics and nuclear physics
  - in part this was due to widespread prejudice against neutrino mass
  - acceptance begun when it was realized that small mixing could work

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  - in part this was due to widespread prejudice against neutrino mass
  - acceptance begun when it was realized that small mixing could work
- today, oscillation of solar neutrinos is considered an obvious thing
- (even if there are still doubts and things to do)

where we are now

terrestrial experiments, from reactor to accelerator, tested oscillations

overall consistency of the indications

important role of "global fits" – i.e., of taking seriously the hypothesis of massive neutrinos

also appearance was seen (more on that later)

first hints of "normal spectrum" - aka ordering, aka hierarchy

now, we would like to probe neutrino mass, beginning with KATRIN

ELSEVIER

Progress in Particle and Nuclear Physics
Volume 102, September 2018, Pages 48-72

Review

Current unknowns in the three-neutrino framework

F. Capozzi [a], E. Lisi [b], A. Marrone [c, b], A. Palazzo [c, b]

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https://doi.org/10.1016/j.ppnp.2018.05.005

Abstract

We present an up-to-date global analysis of data coming from neutrino oscillation and non-oscillation experiments, as available in April 2018, within the standard framework including three massive and mixed neutrinos. We discuss in detail the status of the three-neutrino (3ν) mass-mixing parameters, both known and unknown. Concerning the latter, we find that: normal ordering (NO) is favored over inverted ordering (IO) at 3σ level; the Dirac CP phase is constrained within $\sim 15\%$ ($\sim 9\%$) uncertainty in NO (IO) around nearly-maximal CP-violating values; the octant of the largest mixing angle and the absolute neutrino masses remain undetermined. We briefly comment on other unknowns related to theoretical and experimental uncertainties (within 3ν) or possible new states and interactions (beyond 3ν).

SpringerLink

Journal of High Energy Physics
August 2018, 2018:10 | Cite as

Updated global analysis of neutrino oscillations in the presence of eV-scale sterile neutrinos

Authors | Authors and affiliations

Mona Dentler, Álvaro Hernández-Cabezudo, Joachim Kopp, Pedro Machado, Michele Maltoni, Ivan Martinez-Soler, Thomas Schwetz

Open Access | Regular Article - Theoretical Physics
First Online: 03 August 2018

ABSTRACT

We discuss the possibility to explain the anomalies in short-baseline neutrino oscillation experiments in terms of sterile neutrinos. We work in a 3 + 1 framework and pay special attention to recent new data from reactor experiments, IceCube and MINOS+. We find that results from the DANSS and NEOS reactor experiments support the sterile neutrino explanation of the reactor anomaly, based on an analysis that relies solely on the relative comparison of measured reactor spectra. Global data from the ν_e disappearance channel favour sterile neutrino oscillations at the 3σ level with $\Delta m_{41}^{2} \approx 1.3$ eV^2 and $|U_{e4}| \approx 0.1$, even without any assumptions on predicted reactor fluxes. In contrast, the anomalies in the ν_e appearance channel (dominated by LSND) are in strong tension with improved bounds on ν_μ disappearance, mostly driven by MINOS+ and IceCube. Under the sterile neutrino oscillation hypothesis, the p-value for those data sets being consistent is less than 2.6×10^{-6}. Therefore, an explanation of the LSND anomaly in terms of sterile neutrino oscillations in the 3 + 1 scenario is excluded at the 4.7σ level. This result is robust with respect to variations in the analysis and used data, in particular it depends neither on the theoretically predicted reactor neutrino fluxes, nor on constraints from any single experiment. Irrespective of the anomalies, we provide updated constraints on the allowed mixing strengths $|U_{\alpha 4}|$ ($\alpha = e, \mu, \tau$) of active neutrinos with a fourth neutrino mass state in the eV range.

more light neutrinos?

various neutrino experiments found anomalous results

individually, many of them could be explained invoking new light neutrinos

however, when one takes this hypothesis seriously, contradictions emerge and this interpretation is not supported by the experiments

the current situation with cosmology is also contradictory

(on top of that, while new light neutrinos might exist, there is no strong theoretical argument in their favor)

teorie di gauge e decadimento del protone

teorie di gauge, la discussione negli anni 70-80, le ricerche del decadimento del protone

under the spell of gauge principle

① Yang+Mills 1954,

non abelian gauge theories

② Bludman, Leite Lopes 1958,

neutral currents interactions

③ Glashow 1961,

$SU(2)_L \times U(1)_Y$ *and the* Z^0 *boson*

④ Anderson, Higgs, Englert+Brout, Guralnik+Hagen+Kibble, 1962-67,

broken symmetries & gauge bosons mass

⑤ Salam+Ward, Weinberg, 1964-68,

a model of leptons

⑥ Glashow+Iliopoulos+Maiani 1970,

consistency and the 4^{th} *quark*

⑦ 't Hooft+Veltman, Lee, 1971,

renormalizability

⑧ Bouchiat+Iliopoulos+Meyer, Gross+Jackiw 1972,

anomaly cancellation

….

Nobel prizes in physics 1979, 1984, 1999, 2008, 2013

the age of gauge (theories)

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Unity of All Elementary-Particle Forces

Howard Georgi and S. L. Glashow
Phys. Rev. Lett. **32**, 438 – Published 25 February 1974

Article | PDF | Export Citation

ABSTRACT

Strong, electromagnetic, and weak forces are conjectured to arise from a single fundamental interaction based on the gauge group SU(5).

Received 10 January 1974

DOI: https://doi.org/10.1103/PhysRevLett.32.438

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ELSEVIER

Annals of Physics
Volume 93, Issues 1–2, 5 September 1975, Pages 193-266

Unified interactions of leptons and hadrons ☆

Harald Fritzsch, Peter Minkowski

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https://doi.org/10.1016/0003-4916(75)90211-0Get rights and content

Abstract

It is suggested that a unifying description of leptons and hadrons can be obtained within a nonabelian gauge theory where the gauge group is a symmetry group of a set of massless elementary fermions (leptons, quarks). We investigate the consequences of such an approach for the strong, electromagnetic, and weak interactions. We study both gauge theories with and without fermion number conservation, e.g., theories based on the groups $SU_n \times SU_n$ ($n = 8, 12, 16$) and SO_n ($n = 10, 14$).

from 1979 Nobel lectures

Salam:

That summer [1973, ed] Jogesh Pati and I had predicted proton decay within the context of what is now called GUT.

Glashow:

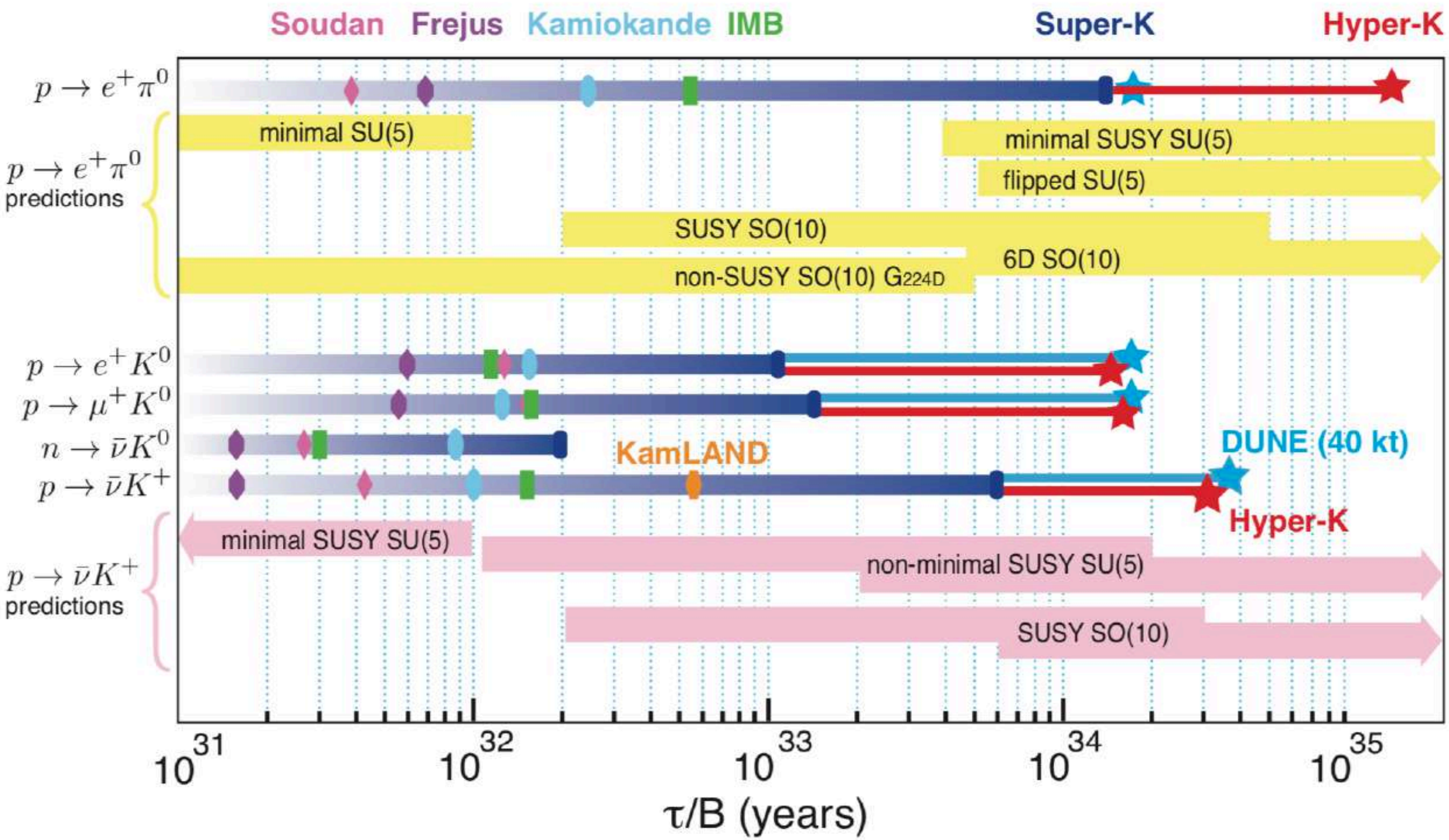
GUT - perhaps along the lines of the original SU(5) theory of Georgi and me - must be essentially correct. This implies that the proton, and indeed all nuclear matter, must be inherently unstable.

Weinberg:

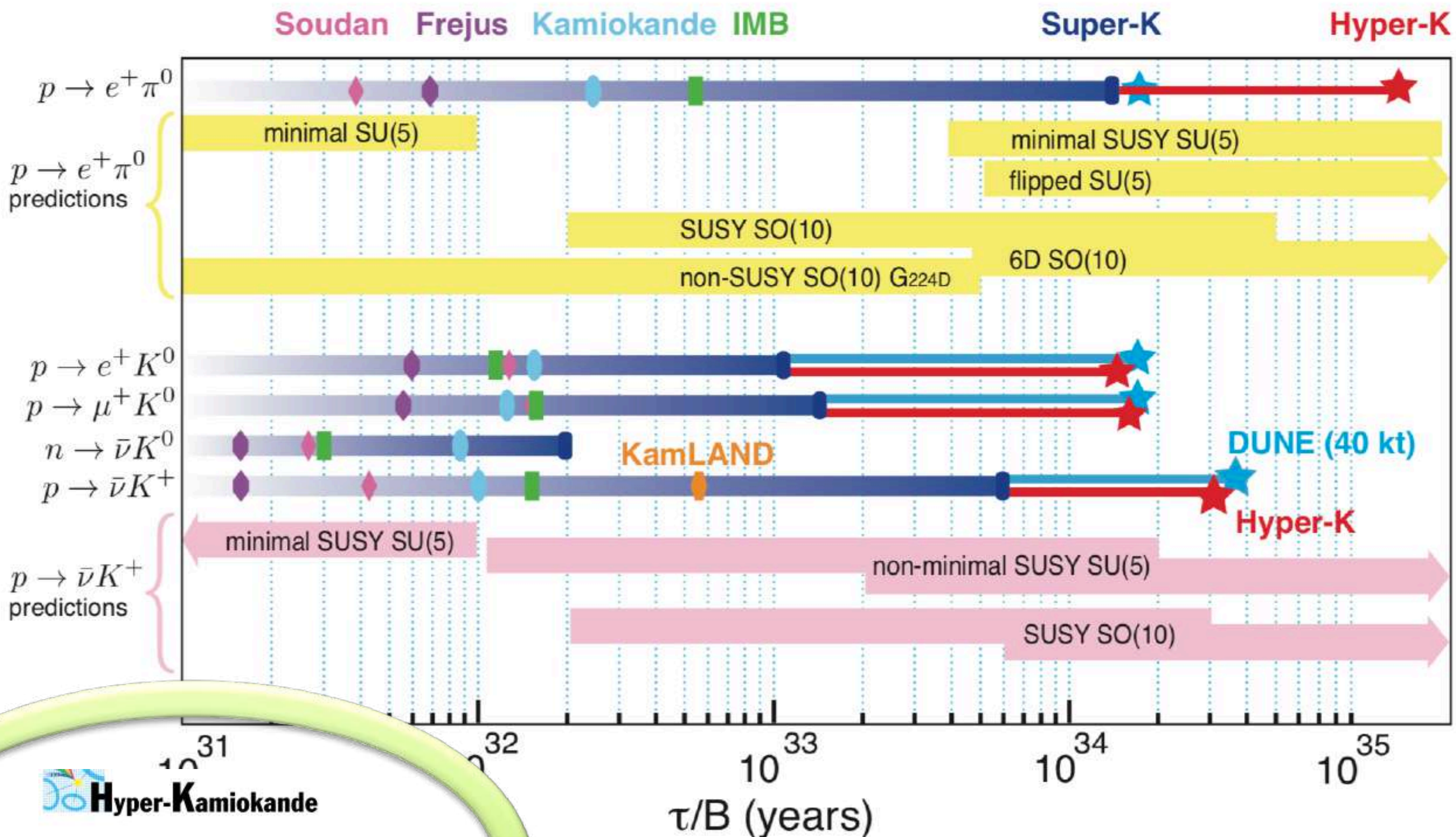
If effects of a tiny non-conservation of baryon or lepton number such as proton decay or neutrino masses are discovered experimentally, we will then be left with gauge symmetries as the only true internal symmetries of nature, a conclusion that I would regard as most satisfactory.

KGF, IMB, NUSEX, KAMIOKANDE, ICARUS…

… JUNO, DUNE, HYPER-KAMIOKANDE



… JUNO, DUNE, HYPER-KAMIOKANDE



Hyper-Kamiokande

Design Report
(Dated: November 30, 2018)

[nessuna referenza alla teoria]

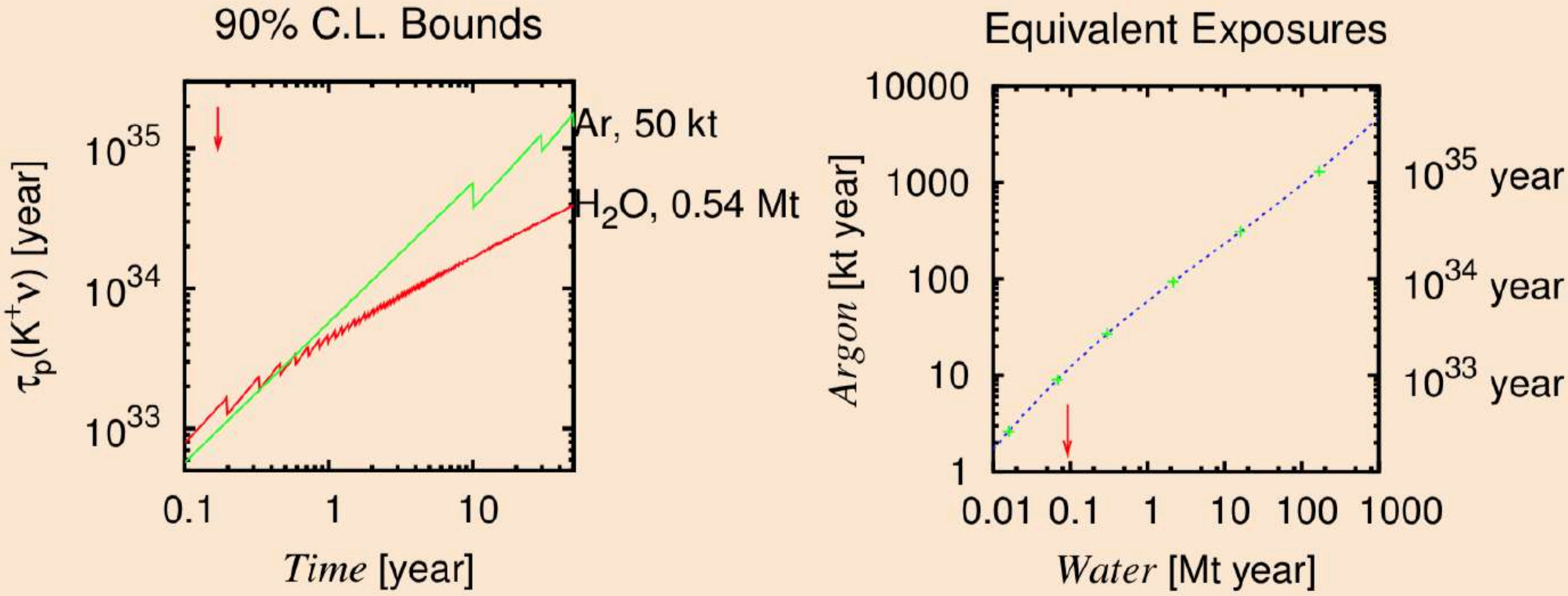
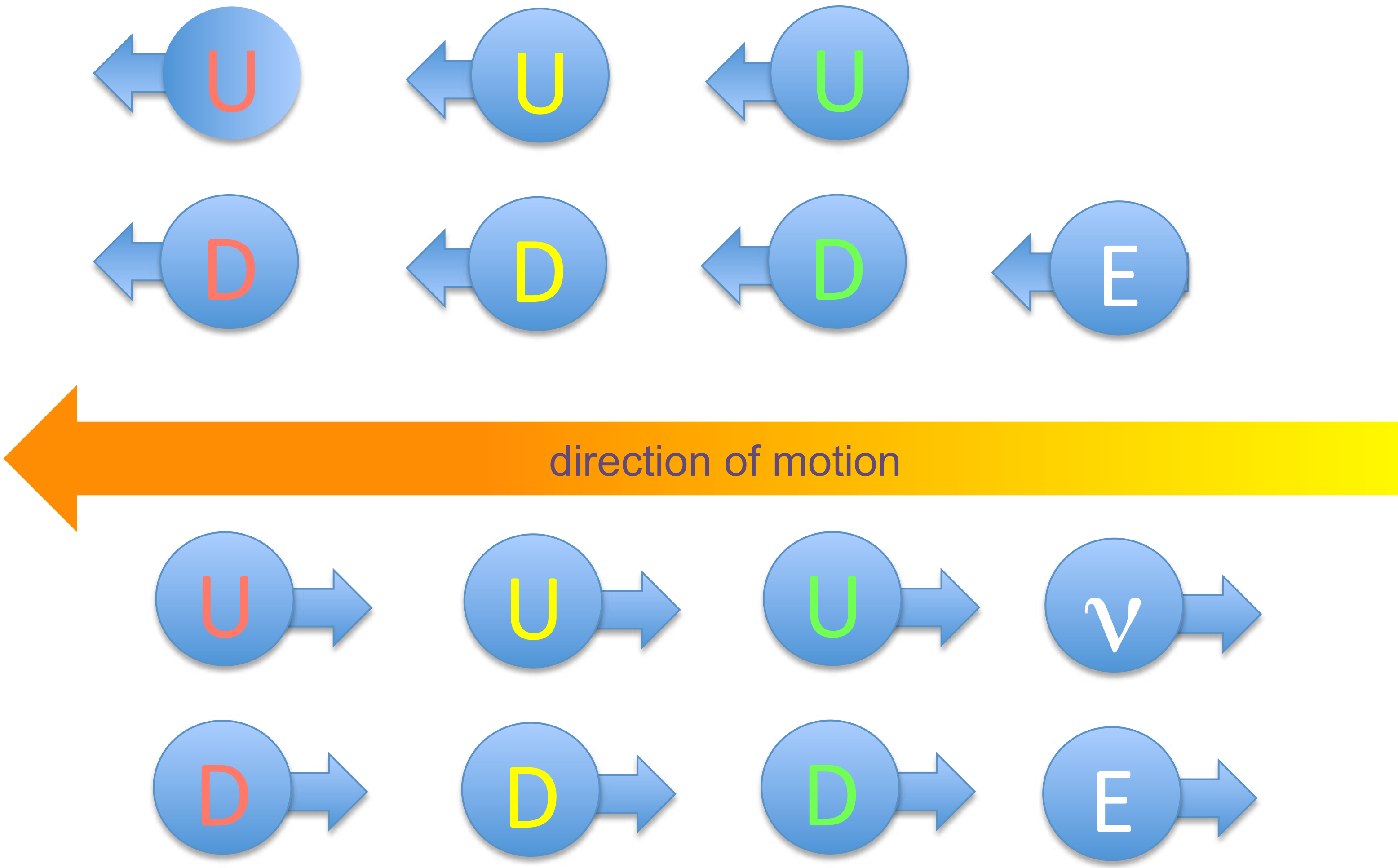


Figure 1: Sensitivity to $p \to K\bar{\nu}$; syst. not included. Water, $\epsilon = 14.6\%$ and $b = 14/(\mathrm{Mton\ y})$ (2 methods, summed); Argon, $\epsilon = 97\%$ and $b = 1/(\mathrm{Mton\ y})$. Impact of stat. fluctuations ≈ 2.

annotazioni teoriche

“manca qualcosa”, sui neutrini RH, sulla supersimmetria, sulle energie piu’ alte

matter particles in one family



Glancing beyond SM

- High dim. operators, invariant under SM symmetry, summarize new physics at ultra-high scales
- (They play exactly the same role of Fermi interactions)
- The one with lowest dimension describes Majorana neutrino masses
- Oscillations are matched by a huge mass, say, of GUT

$$m^{\nu}_{\text{overall}} \sim \frac{M_W^2}{M_{\text{GUT}}} = 65 \text{ meV} \times \frac{10^{14} \text{ GeV}}{M_{\text{GUT}}}$$

on right handed neutrinos

- it is plausible that right handed neutrinos exist
- if lighter $<10^{14\text{-}15}$ GeV, light neutrino masses can be explained
- they can also give reason of baryon asymmetry
- if heavier $>10^{7\text{-}8}$ GeV, they mean "hierarchy problem"
- (but plenty of similar problems with cosmological constant)
- with them, B-L can be promoted to a gauge symmetry and renewed hopes for grander gauge theory

PHYSICS REPORTS (Review Section of Physics Letters) 110, Nos 1 & 2 (1984) 1–162. North-Holland, Amsterdam

SUPERSYMMETRY, SUPERGRAVITY AND PARTICLE PHYSICS

H.P. NILLES*

Département de Physique Théorique, Université de Genève, 1211 Genève 4, Switzerland

and

CERN, Genève, Switzerland

Received 16 February 1984

future. Experiments within the next five to ten years will enable us to decide whether supersymmetry as a solution of the naturalness problem of the weak interactions scale is a myth or reality.

This far for the 100 GeV region. The extension of the models to higher energies is of course only

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2020-1984=36 y and 36/(5 to 10)≥3.6, thus
the CL of the 2nd option seems > 3.6σ (=0.03%) ☺

quosque tandem, gravity?

consider the mass that realizes

$$\boxed{\frac{e^2}{r} \equiv G_{\mathrm{N}} \frac{m_{\mathrm{S}}^2}{r}}$$

this defines the Stoney mass (1881)

$$\Rightarrow m_{\mathrm{S}} \equiv \sqrt{\frac{e^2}{G_{\mathrm{N}}}} \approx 2\mu g$$

energy at which gravity equates electric force

$$\Rightarrow E_{\mathrm{S}} \equiv m_{\mathrm{S}} \times c^2 \approx 10^{18}\ \text{GeV}$$

more info (and a couple of jokes too)

Thomson, Weyl & Yang; on "matter"; on **ν** mass; physics at ultrahigh masses; on chosen names; the story of V-A

1^{st} elementary matter particle (Thomson)

Hertz showed, however, that cathode particles possess another property which seemed inconsistent with the idea that they are particles of matter, for he found that they were able to penetrate very thin sheets of metal, e.g.

to the conclusion that the mass of the corpuscle is only about 1/1,700 of that of the hydrogen atom. Thus the atom is not the ultimate limit to the subdivision of matter; we may go further and get to the corpuscle, and at this stage the corpuscle is the same from whatever source it may be derived.

The corpuscle appear to form a part of all kinds of matter under the most diverse conditions; it seems natural therefore to regard it as one of the bricks of which atoms are built up.

Hermann Weyl

" in our time, there has been unloosed a cataclysm which has swept away space, time, and matter hitherto regarded as the firmest pillars of natural science, but only to make place for a view of things of wider scope, and entailing a deeper vision."

From *Space Time Matter*, 1918

C N Yang at the Centennial of MIT,1961

our present knowledge is sufficient to enable us to say with some certainty that great clarification will come in the field of weak interactions in the next few years. With luck on our side we might even hope to see some integration of the various manifestations of the weak interactions.

Beyond that we are on very uncertain grounds.

- ★ Is the continuum concept of space time extrapolatable to regions of space 10^{-14} cm to 10^{-17} cm, and to regions smaller than 10^{-17} cm?
- ★ What is the unifying basis of the strong, the electromagnetic and the weak interactions?
- ★ What is the role of the gravitational field relative to all these?

If it is difficult to locate singularities of functions by extrapolation, it is as difficult to predict revolutionary changes in physical concepts by forecasting.

round table "Einstein and the physics of the future"
published in Some Strangeness in the Proportion, ed. H. Woolf, 1980

Weinberg:

[…] the lifetime of the proton (this has been worked on by a number of people now) comes out to be of the order 10^{30} to 10^{32} years. The present experimental lower bound is 10^{29} years. Thus the time is ripe for an assault on the next few orders of magnitude in the proton lifetime.

Dyson:

[…] the modern view of particle theory, with the sub-nuclear world a playground of interlocking broken and unbroken symmetries, had its roots in Felix Klein's Erlanger Program of 1872 […]

I predict that in the next 25 years we shall see the emergence of unified physical theories in which general relativity, group theory, and field theory are tied together with bonds of rigorous maths.

Yang:

beautiful mathematics is the language of fundamental physics […]

Maybe it is my prejudice - maybe it is my ignorance - but I do not believe that any of these graded Lie algebras has the intrinsic and fundamental beauty of Lie algebras and Lie groups, not as yet!

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Matter

From Wikipedia, the free encyclopedia

This article is about the concept in the physical sciences. For other uses, see Matter (disambiguation).

In classical physics and general chemistry, **matter** is any substance that has mass and takes up space by ha ultimately composed of atoms, which are made up of interacting subatomic particles, and in everyday as we made up of them, and any particles (or combination of particles) that act as if they have both rest mass and photons, or other energy phenomena or waves such as light or sound.[1][2] Matter exists in various states (al as solid, liquid, and gas – for example water exists as ice, liquid water, and gaseous steam – but other state fermionic condensates, and quark–gluon plasma.[3]

Usually atoms can be imagined as a nucleus of protons and neutrons, and a surrounding "cloud" of orbiting correct, because subatomic particles and their properties are governed by their quantum nature, which mea like waves as well as particles and they do not have well-defined sizes or positions. In the Standard Model o elementary constituents of atoms are quantum entities which do not have an inherent "size" or "volume" in a other fundamental interactions, some "point particles" known as fermions (quarks, leptons), and many comp particles under everyday conditions; this creates the property of matter which appears to us as matter taking

For much of the history of the natural sciences people have contemplated the exact nature of matter. The id particulate theory of matter, was first put forward by the Greek philosophers Leucippus (~490 BC) and Dem

Contents [hide]

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Main page
Contents
Featured content
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Random article
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Matter

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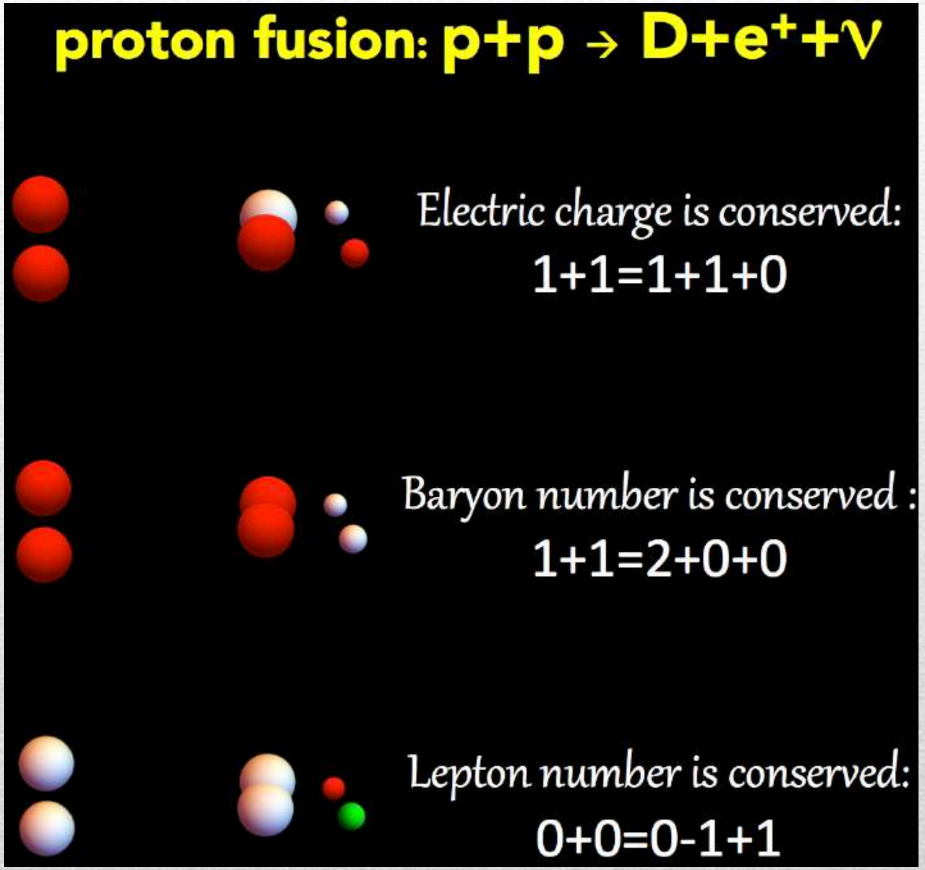
- In ordinary language we say: *matter does not disappear*
- In this panel, the main reaction that allows the Sun to work, that means that *neutrinos are* ***matter particles*** (leptons)
- Known physics says: *numbers of baryons and leptons do not change*
- Only B-L exactly conserved (SM)



$(A, Z) \rightarrow (A, Z+1) + e^- + \bar{\nu}_e$	All OK
$(A, Z) \rightarrow (A, Z+2) + 2\, e^-$	L changes
$n \rightarrow e^- + p$	L and spin change
$p \rightarrow e^+ + \pi^0$	B and L change
$n \rightarrow e^- + K^+$	B and L change
$e^- \rightarrow \gamma + \nu_e$	Charge changes
$n \rightarrow \bar{n}$	B changes

direct search of big-bang neutrinos

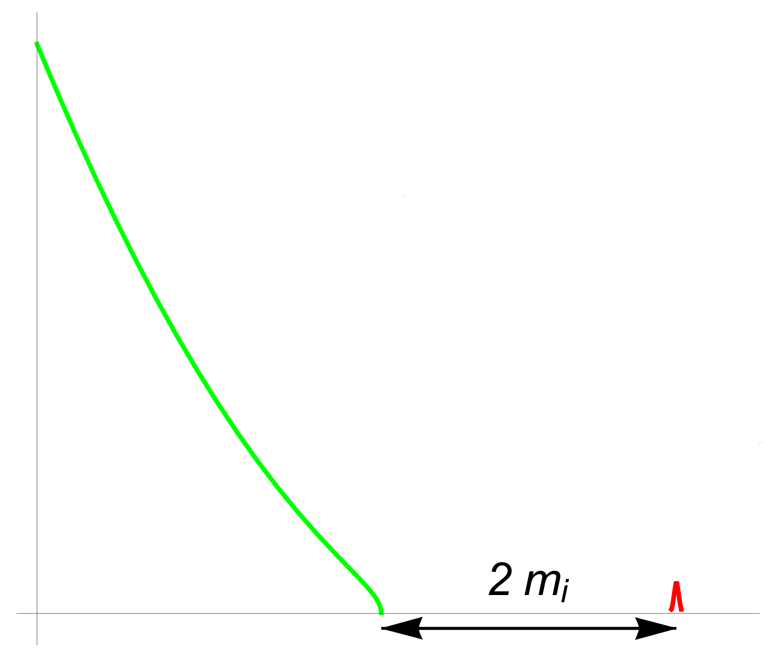
big-bang neutrinos produce 3 **neutrino-capture** lines for a radioactive target

their positions depend on m_i ; their intensity on $|U_{ei}^2|$

lightest neutrino gives the most intense line for normal hierarchy

Needs

- great energy resolution
- big target mass, ≥100g of tritium



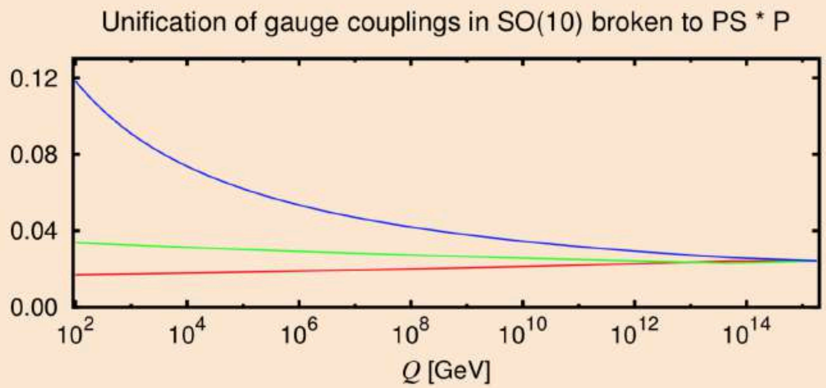


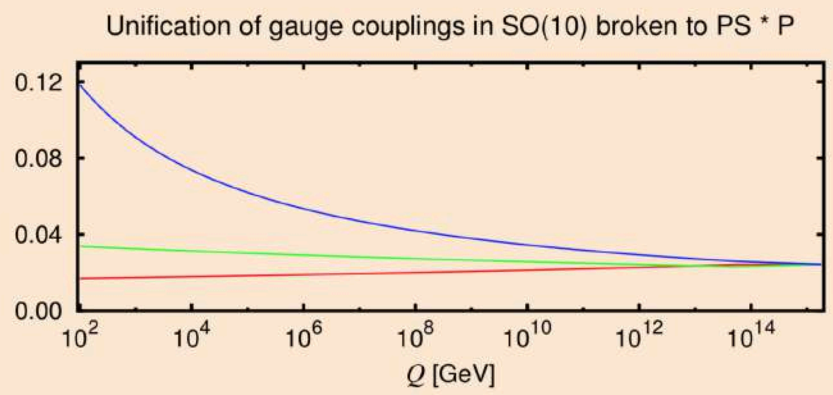
Figure 2: Evolution of the gauge coupling constants in a GUT model with intermediate scale. Here, $M_{\text{interm.}} \approx 5 \times 10^{13}$ GeV.

Bajc et al 2005; Bertolini et al 2009-2011; Joshipura et al 2011; Buccella et al 2012; Dueck et al 2013; Altarelli et al 2013; Ohlsson et al 2019

minimal SO(10)

(principled model)

- ★ 16-plet coupled to 10 and 126 higgs: heavy right-handed neutrinos
- ★ (Peccei Quinn symmetry to address strong CP and dark matter)



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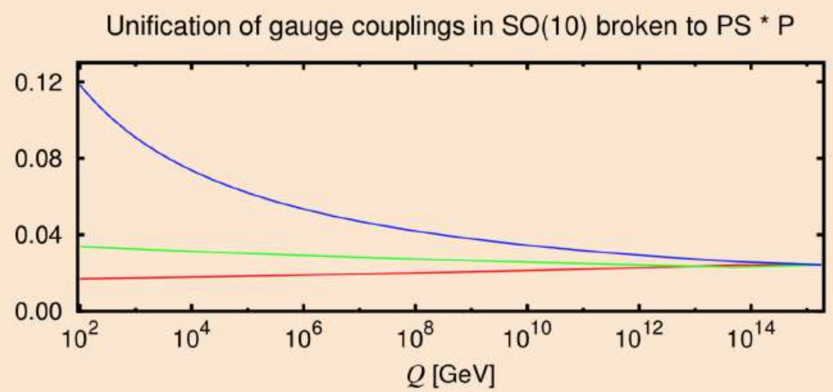

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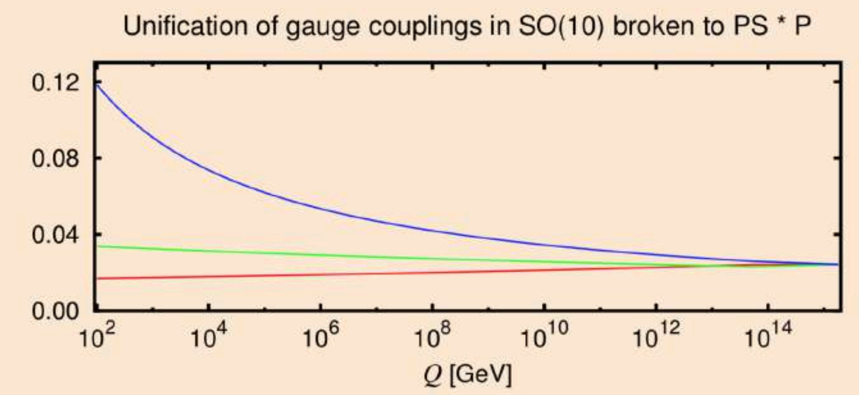
- ★ normal mass hierarchy; $m_{\beta\beta}$ in the few meV range



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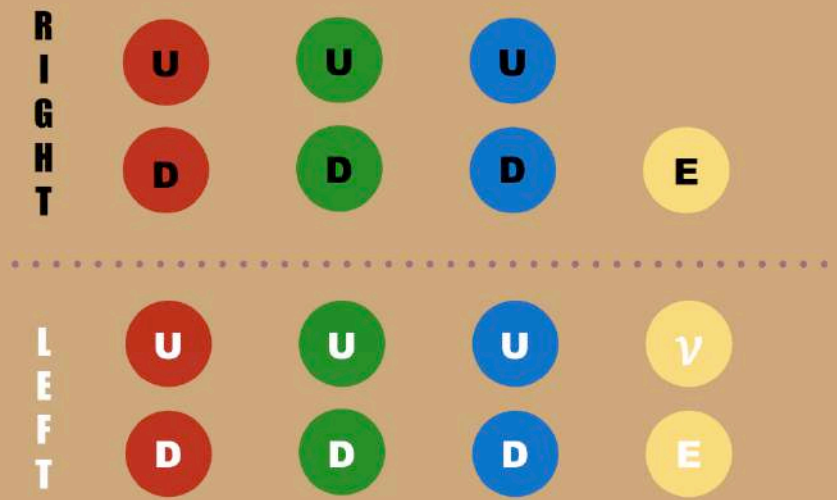
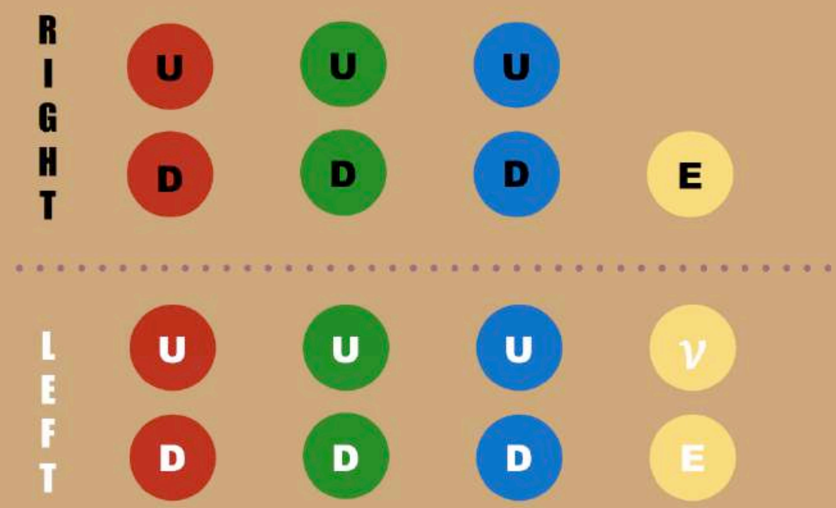
- ★ neutrinos are massive and fermion masses constrained
- ★ normal mass hierarchy; $m_{\beta\beta}$ in the few meV range
- ★ (potentially interesting expectations for proton decay)

15 particles per family

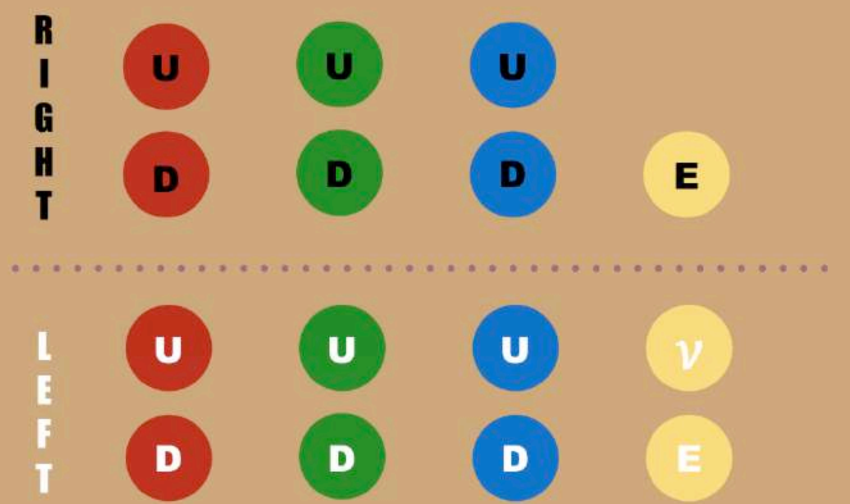


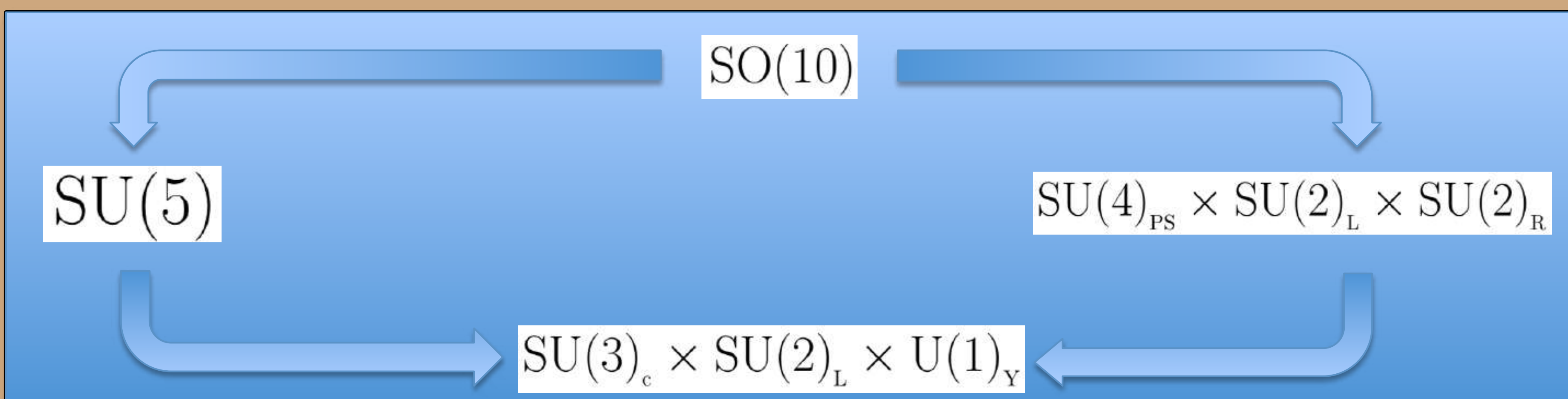
15 particles per family



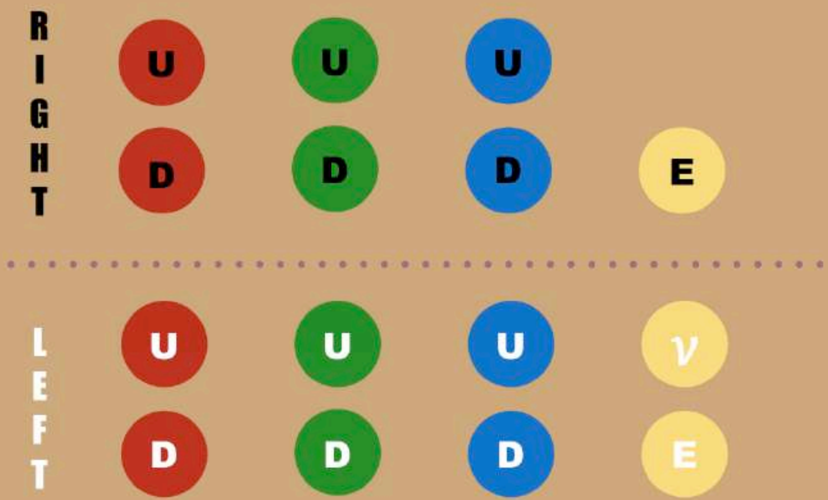
$$\mathrm{SU}(2)_L \text{ acts on } \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \quad \text{while} \quad \mathrm{SU}(2)_R \text{ acts on } \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$$

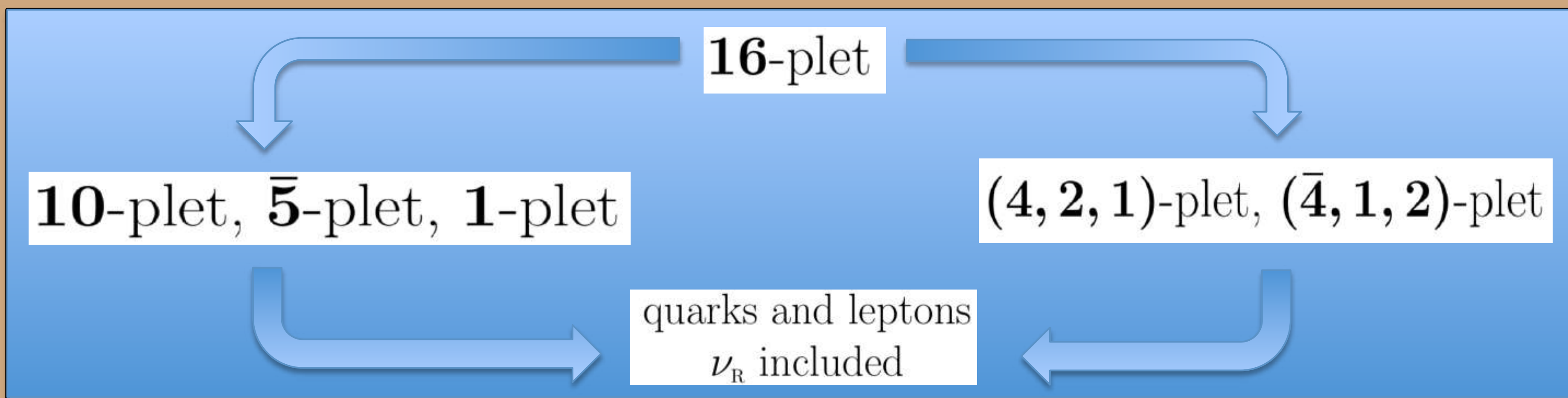
15 particles per family





15 particles per family





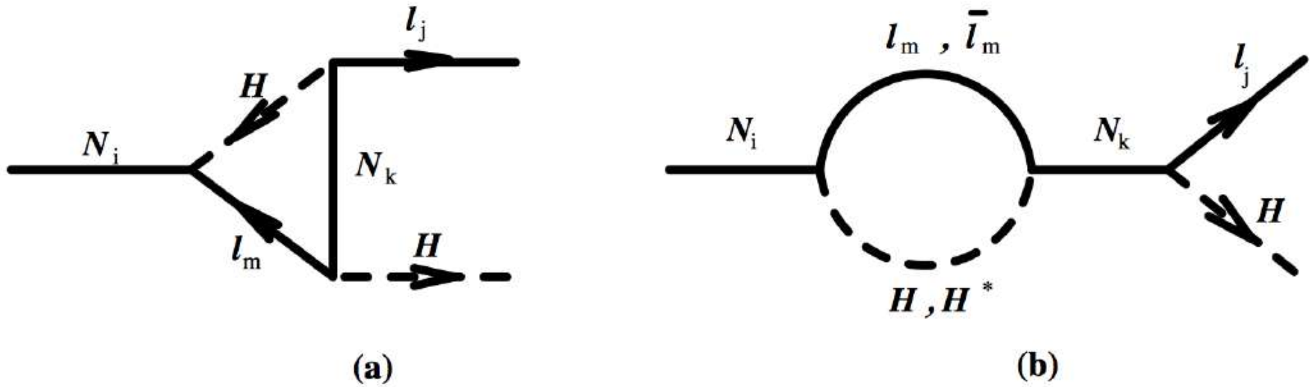


Figure 1: Diagrams contributing to the vertex (Fig. 1a) and wave function (Fig. 1b) CP violation in the heavy singlet neutrino decay.

Covi et al. '96

Heavy RH neutrinos

can prefer to decay into antileptons; then, converted into baryons by the SM effects described previously

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Do experiments suggest a hierarchy problem?

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(Received 18 September 1997; published 14 April 1998)

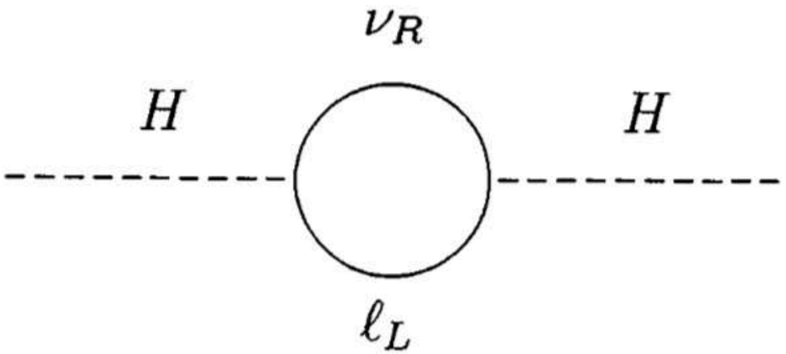


FIG. 1. The Feynman diagram originating the corrections in Eq. (1); ν_R denotes the right-handed neutrino of mass M_R, $\ell_L = (\nu_L, e_L)$ the leptonic and H the Higgs doublets.

OK, but what about the cosmological constant?

the standard model. So (if a joke is permitted) we present a prediction for LHC:

$$m_H = 135 \pm 5 \text{ GeV} \tag{14}$$

the reason is that this value will increase the entropy in the minds of several theorists. Note, however, that the decay of a standard and supersymmetric HIGGS particles with the same mass (or also the production rate–"cross-sections") could be rather different; thence, these measurements would offer a possibility to distinguish between the SM and its supersymmetric extension even in this tricky case.

3 (Not quite a) conclusion

We would like to close this pages by spending few words of caution, to remind that failures of the standard model have been often claimed in the past years (today, several of them are considered dubious or simply wrong tracks). Here is an arbitrary selection:

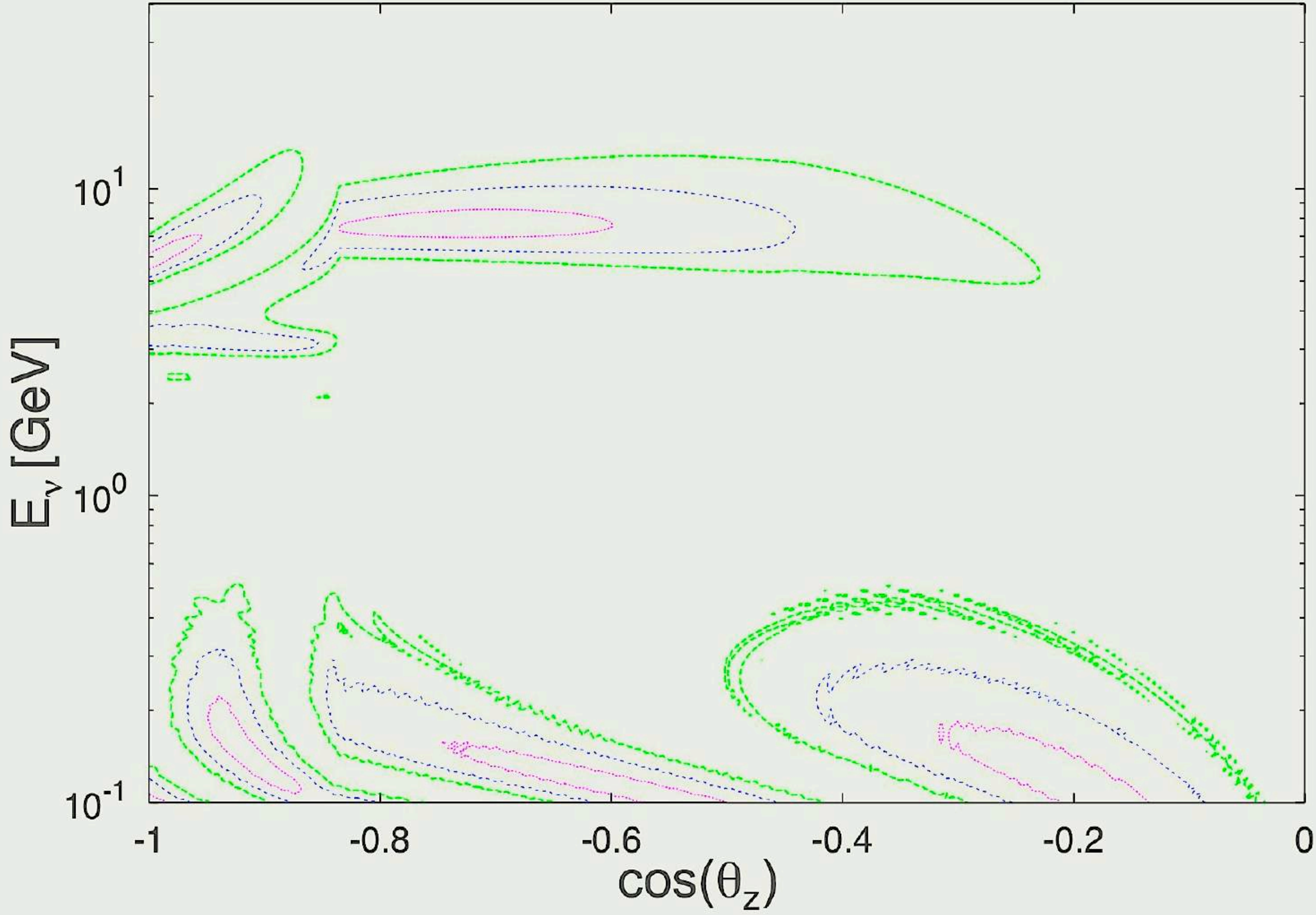
THEORETICAL INTERPRETATION		EXPERIMENTAL ANOMALY
leptoquark	....	High x and Q^2 events at HERA
compositeness	....	Excess of 4-jet events at ALEPH
light gravitino	....	$ee\gamma\gamma\not{E}$ event at CDF
17 keV neutrino	....	bump in β spectra (SIMPSON, ...)
monopole	....	induced currents (CABRERA)
proton decay	....	contained multitrack events at KGF
...	....	...

Is there any moral behind these stories? Maybe not; however:
1) they suggest to go slowly and carefully from data to theories and back (because of possible pitfalls of interpretation, of suggestion, *etc.*);
2) they witness how hard is to reach the frontiers of standard model; and, also, how strong is the desire of particle physicists to find them!

NH → NO

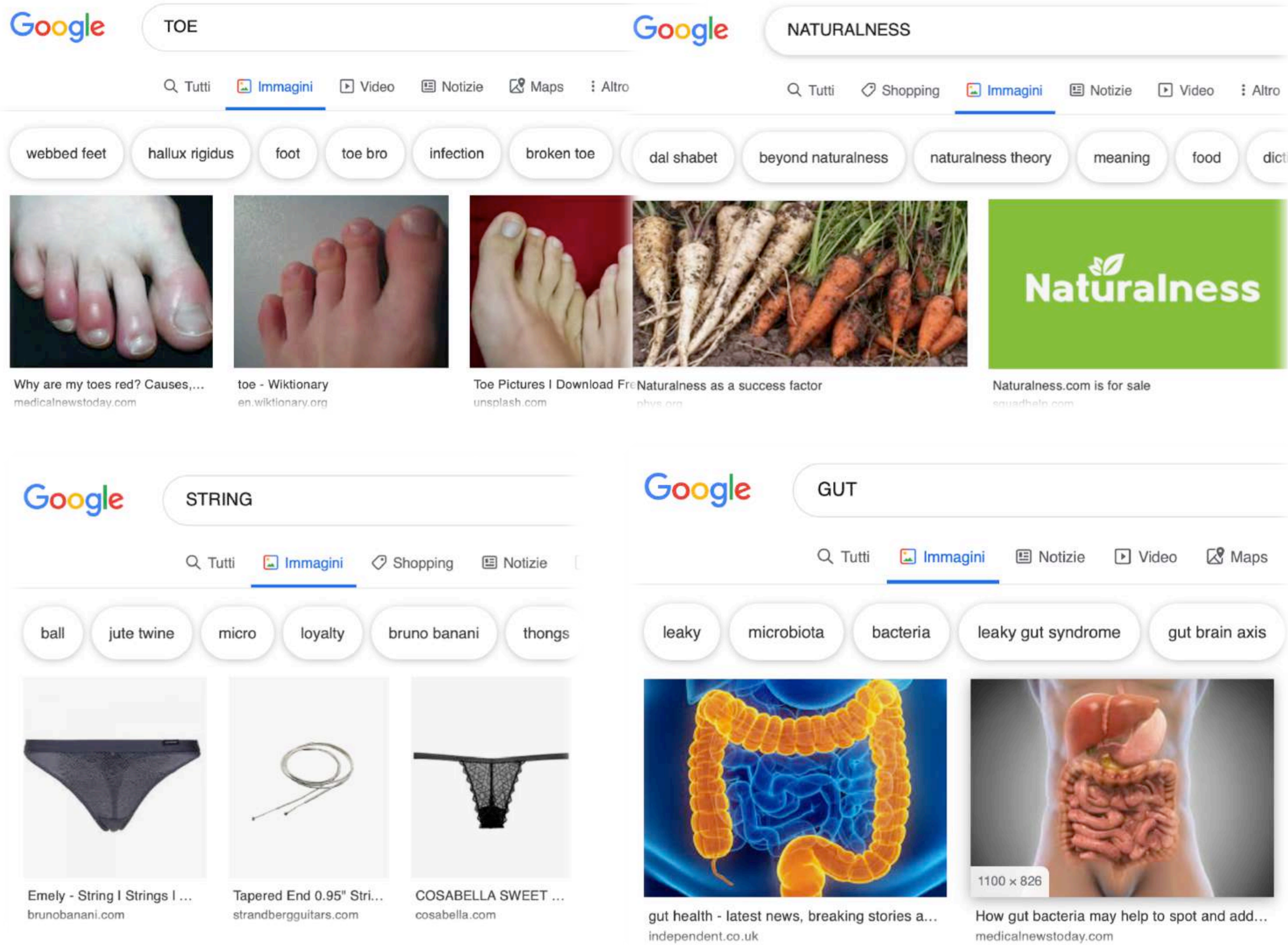
Normal hierarchy → Normal ordering

P_{ee}=0.7, 0.5, 0.3 through the Earth (La Thuile 2003)



NO → YES

Normal ordering → Yearningly Expected Spectrum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infection
broken toe
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Immagini
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Maps
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microbiota
bacteria
leaky gut syndrome
gut brain axis
1100 × 826
gut health - latest news, breaking stories a...
independent.co.uk
How gut bacteria may help to spot and add...
medicalnewstoday.com

universal V-A

Ruderman+Finkelstein 1949
Predictions of R(π→e+ν)/R(π→μ+ν) in various hypotheses

Durbin+Loar+Steinberger 1951
pion parity from deuterium photodissociation

Lokanathan+Steinberger 1955 & Anderson+Lattes 1957
apparently R(π→e+ν) is just absent, ruling out V-A ☹

Sudarshan+Marshak 1957 & Feynman+Gell-Mann 1958
theory first! V-A implies that previous result is inaccurate

Fazzini *et al.* 1958
R(π→e+ν)/R(π→μ+ν) confirms V-A ☺