A history of some recent attempts to go beyond the standard model

Francesco Vissani
INFN, Gran Sasso & GSSI

introduction

The standard model (SM) plays a role that resembles the one of thermodynamics, of Newton's, Maxwell's Einstein's theories or alike. I mean, it is a **principle-based theory**, which allows us to perform useful deductions concerning microphysics and to obtain expectations obeyed in most circumstances.

As usual, however, 1st rule is **to save the phenomena**, that in the specific field of competence of SM means the available experimental & observational facts of microphysics – the facts.

introduction

- Certain phenomena **contradict** SM's predictions, thereby calling particle physicists to maximum attention.
- Other facts go beyond the direct competences of the standard model, but **put it into play** along with other theories, especially in astrophysical/cosmological contexts.
- Some structural aspects of this theory raise **interesting questions,** which – even without amounting to actual problems - deserve consideration.

roots of standard model

the first W.I.N. revolution

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Abschrift/15.12.56 PM

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

...

Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7 Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

gez. W. Pauli

Asia Pacific Physics Newsletter | Vol. 01, No. 01, pp. 27-30 (2012)

Fermi's β-decay Theory

Chen Ning Yang

https://doi.org/10.1142/S2251158X12000045 | Cited by: 0

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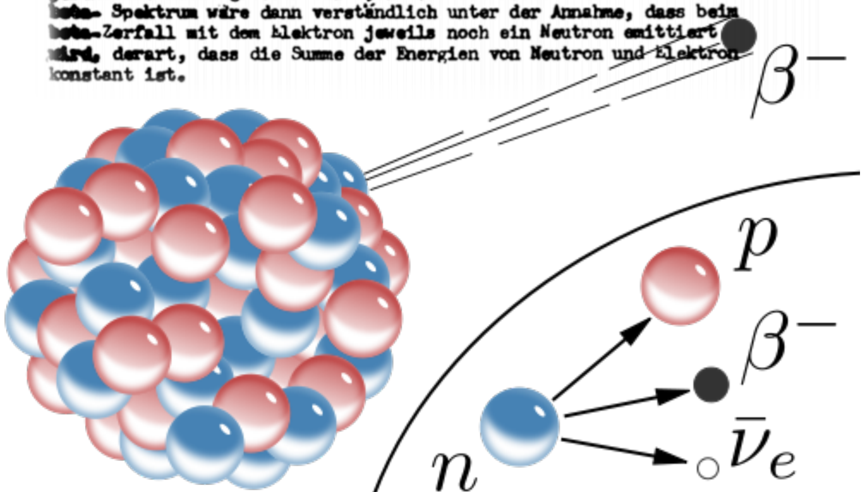

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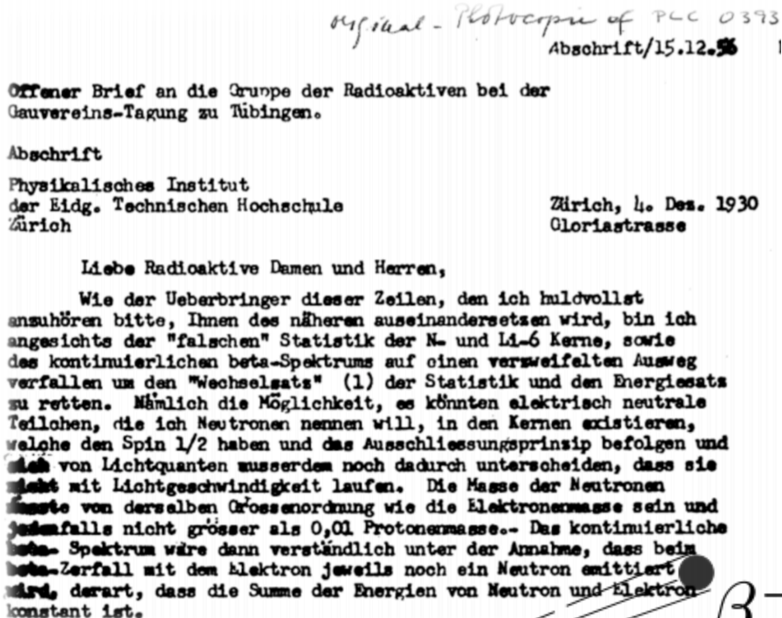

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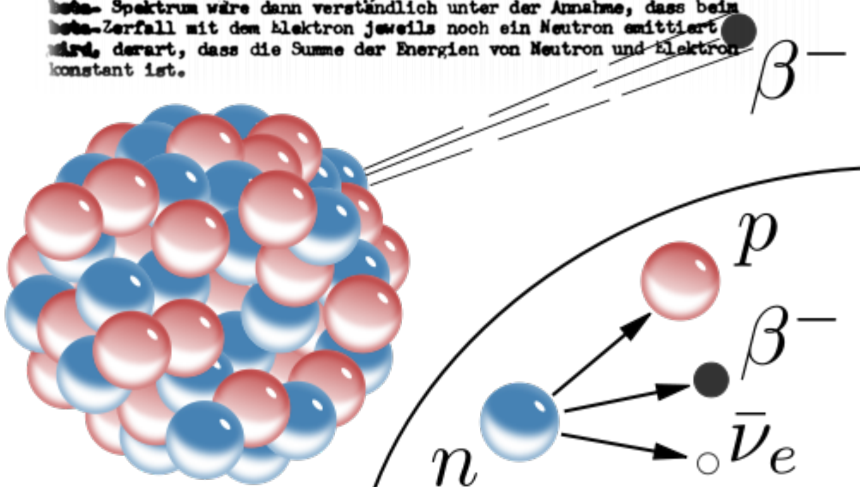

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Nobel to Reines 65 years later

the second W.I.N. revolution

A turning point in the understanding of weak interactions is the hypothesis that they violate parity, due to Lee and Yang (1956) a fact confirmed by the experiment of Wu (1957) and recognized by the Nobel committee in 1957. This was the key to understand the structure of weak interactions and it allowed Landau, Lee & Yang and Salam to conclude that, for neutrinos, the spin and the momentum have opposite directions while, for antineutrinos, the direction is the same one. One talks also of negative helicity of neutrinos and positive helicity of antineutrinos. The final proof of this picture was obtained by the impressive experiment of Goldhaber et al. (1958). Eventually, the theoretical picture was completed arguing for an universal vector-minus-axial (V–A) nature of the charged-current weak interactions (Sudarshan and Marshak, 1958; Feynman and Gell-Mann, 1958).

Introduction to the Formalism of Neutrino Oscillations
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Published in **Adv.Ser.Direct.High Energy Phys. 28 (2018) 37-119**

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Nobel to Lee & Yang 1957

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J. C. Ward

from 'Memoirs of a Theoretical Physicist'

"Quite soon after this triumph, the experiment of Mrs. C. S. Wu *et al.* at Columbia, acting upon the suggestion of Yang and Lee, definitely established the non-conservation of parity in weak interactions, surprising everyone.

I wrote a note to Abdus, telling him of the result, adding that Einstein must be spinning in his grave, clockwise presumably."

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

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

SM: ingredients and recipe

- $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge group
- three families of Weyl spinors: q_L , l_L , u_R , d_R , e_R (6+2+3+3+1=15)
- one scalar doublet: H, whose negative mass squared breaks spontaneously $SU(2)_L \times U(1)_Y \rightarrow U(1)_{em}$

write all possible renormalizable terms and fix the value of the parameters by as many measurements as the parameters

SM: major implications

- ☑ one single mass scale (or two, I mean also the energy density)
  17 dimensionless parameters (or 18, I mean also θ_{CP})

- ☑ baryon & leptons numbers, $\mathbf{B, L_e, L_\mu, L_\tau}$ conserved perturbatively.
  $\mathbf{B-L, L_e-L_\mu, L_e-L_\tau}$ conserved exactly ($\mathbf{L=L_e+L_\mu+L_\tau}$).

- ☑ calculable theory to any perturbation order.

- ☑ no flavor-changing neutral current at tree level.
  CP only mildly violated.

- ☑ non perturbative regime for $SU(3)_c$ at low energies (glueballs?).
  lightest hadrons - proton, nuclei - are stable as the electron.

- ☑ neutrinos are massless.

proton decay

the age of gauge (theories)

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PHYSICAL REVIEW LETTERS

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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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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.

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 […]

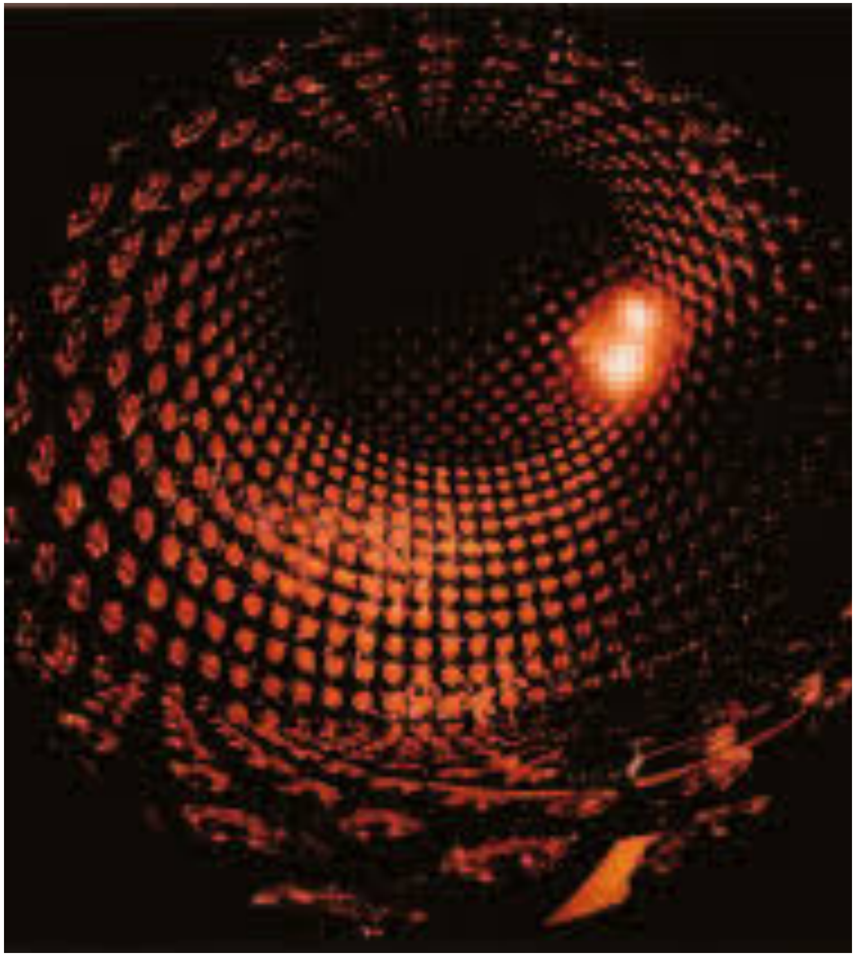
I predict that in the next 25 years we shall see the emergence of unified physical theories in which general relativity, group theory, and field theory are tied together with bonds of rigorous maths.

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!

KGF, IMB, NUSEX, KAMIOKANDE, ICARUS…



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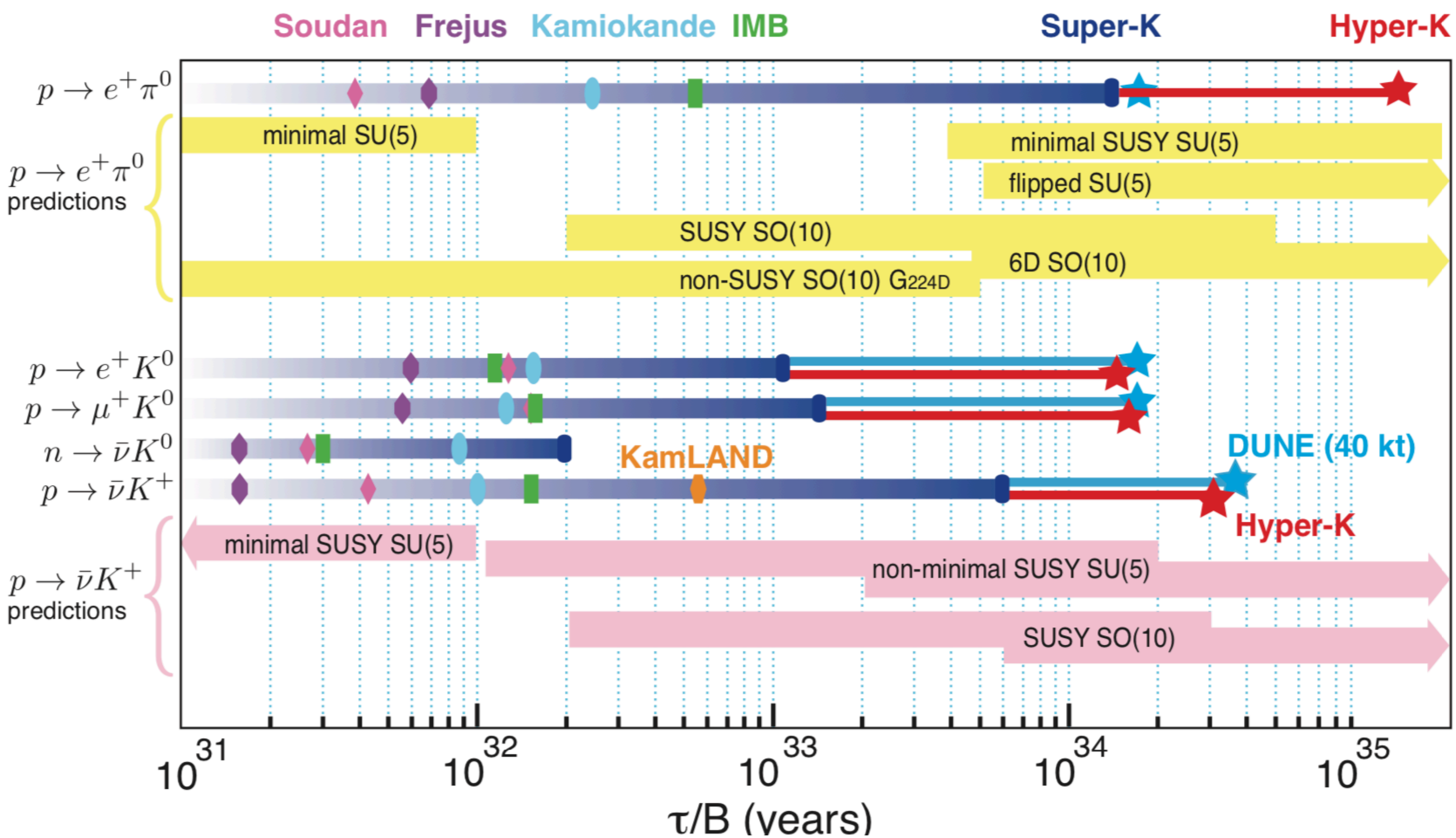

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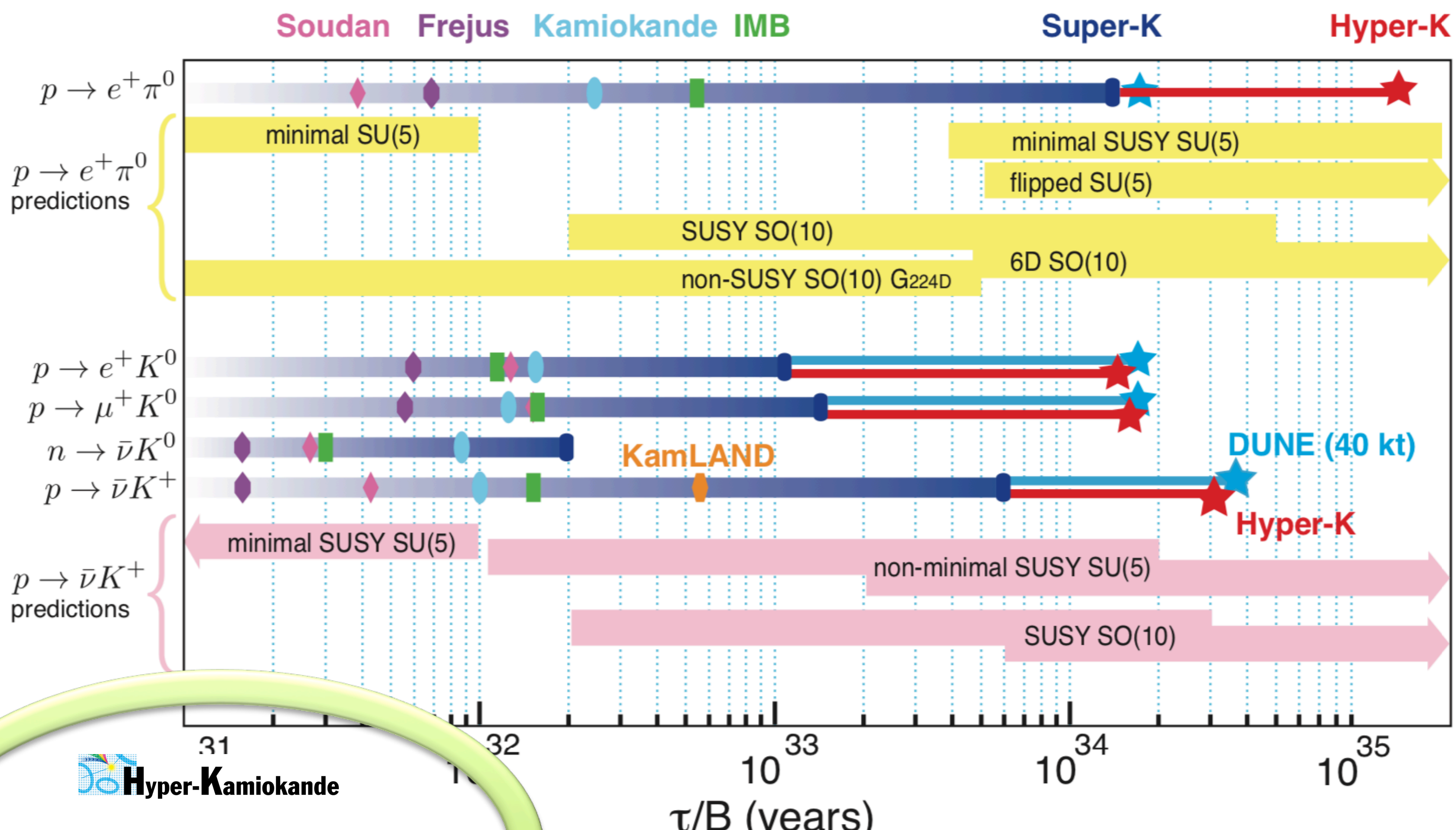

Hyper-Kamiokande

Design Report
(Dated: November 30, 2018)

[no references to theory]

on expectations

- we have hints of gauge coupling unification
- but a prediction requires a complete theory
- significant uncertainties from choice of the scalar field, intermediate scales, threshold effects, nuclear matrix elements
- fermion masses are one of the few constraint

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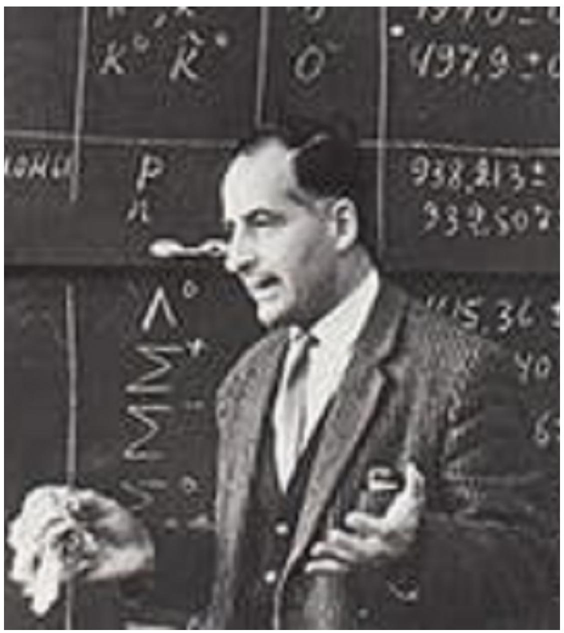
- significant uncertainties from choice of the scalar field, intermediate scales, threshold effects, nuclear matrix elements
- fermion masses are one of the few constraint
- (new particles? dark matter? supersymmetry? baryogenesis?)

What to some seemed a blitzkrieg *has become a trench warfare, with little room for progress: can we still fight the fight? Surely, we still have nothing like a "GUT standard model*".

neutrino masses

the idea that worked – neutrino oscillations - was proposed earlier (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
- moreover, the solar neutrino anomaly has long been ignored and it took 20 years before a test was conducted
  - in part it was distrust of astrophysics and nuclear physics
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Nobel prizes in physics (1967?), 2002, 2015

where we are now

tests with terrestrial experiments, from reactor to accelerator

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 should see true neutrino mass – we hope in 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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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).

SM seen as an effective theory

Weinberg 79

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

- the 1st is the SM-invariant formulation of Majorana neutrino masses
- the 2nd is one of the operators that cause the instability of the proton
- the 3rd violates lepton number


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

Authors Authors and affiliations

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Open Access | Regular Article - Theoretical Physics
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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)

residual global symmetries

there is only one basic type of lepton

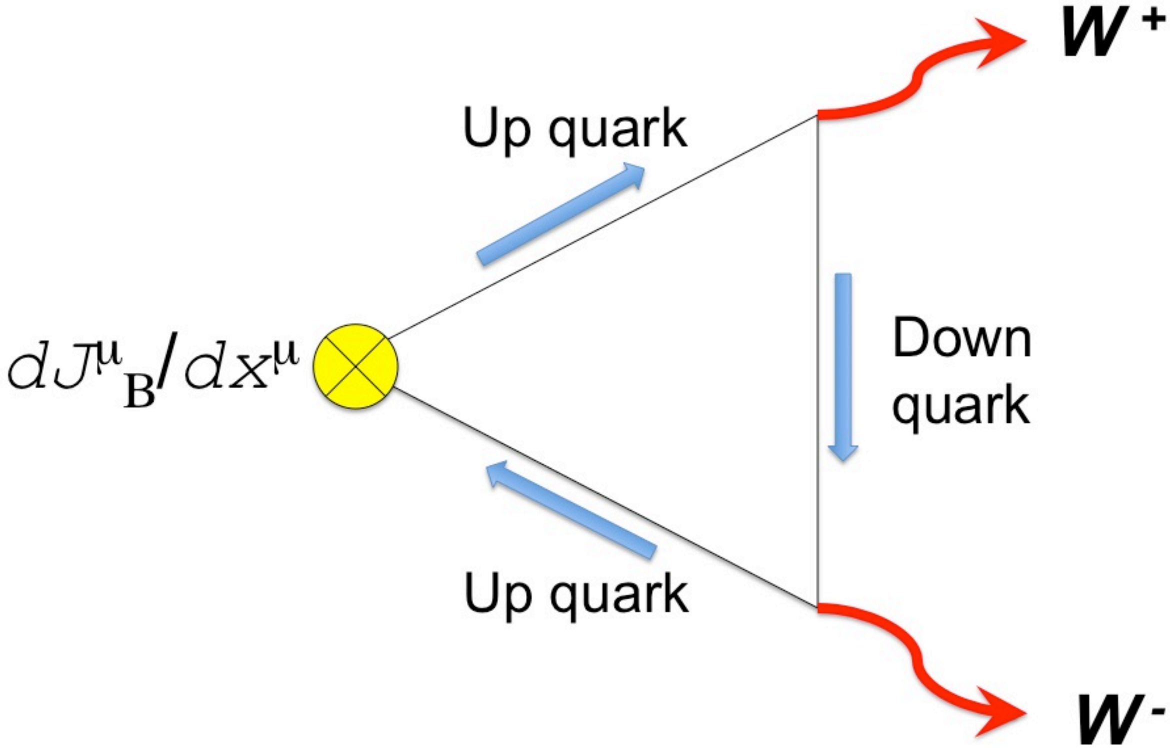
(=at the scrutiny of T2K, NOvA, OPERA, SK, DeepCore, only total lepton number L survived)

	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

Appearance experiments proved that all global symmetries of SM are violated, except L (with B). Conversion among families is possible, we have only two types of **matter particles**: leptons and quarks

In "standard model" B and L are not conserved individually.

Only B-L is conserved exactly, thus: light & heavy matter types are connected



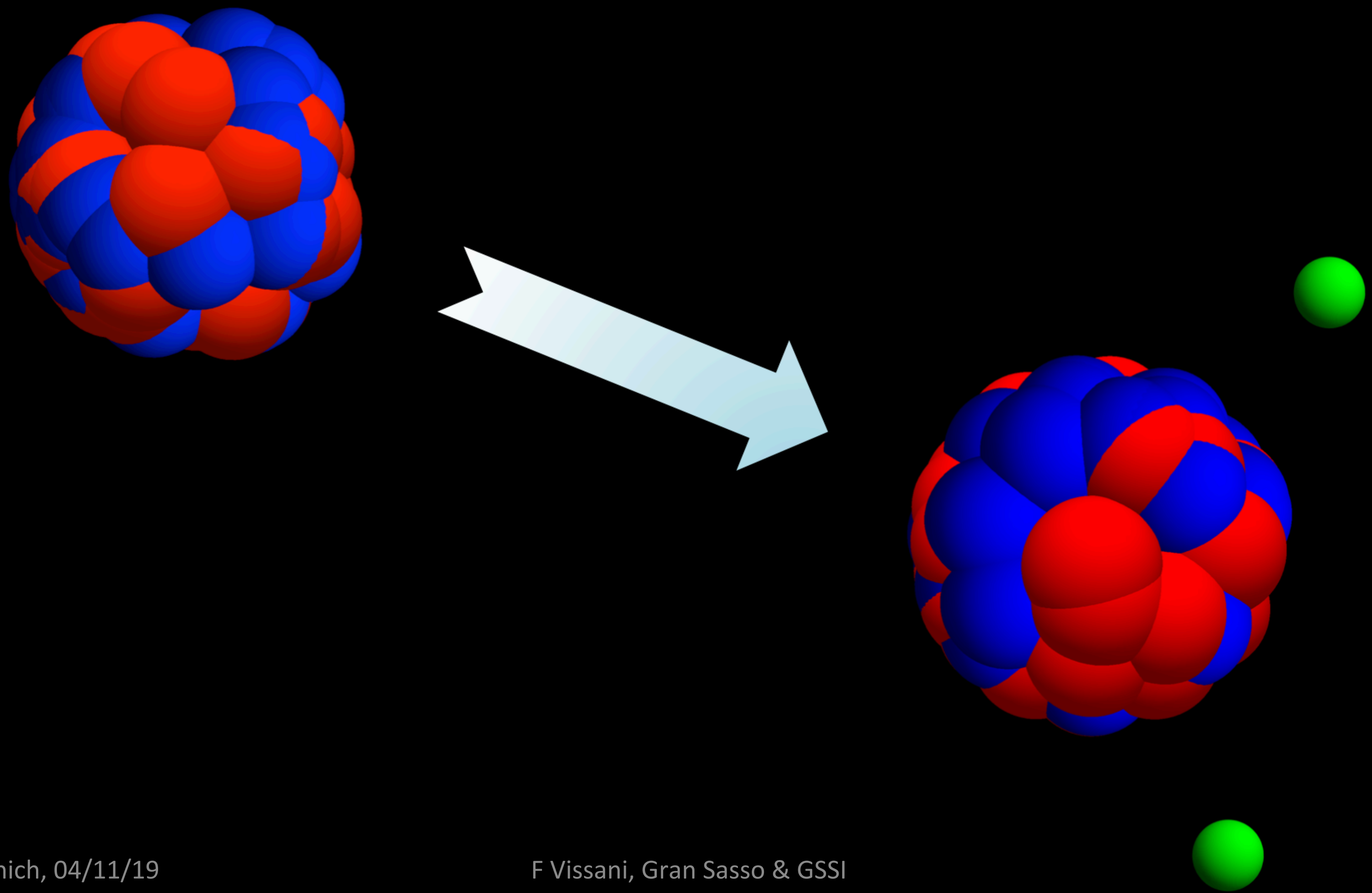
there is only one basic type of ~~lepton~~ fermion

(=at the scrutiny of T2K, NOvA, OPERA, SK, DeepCore, only total lepton number L survived)

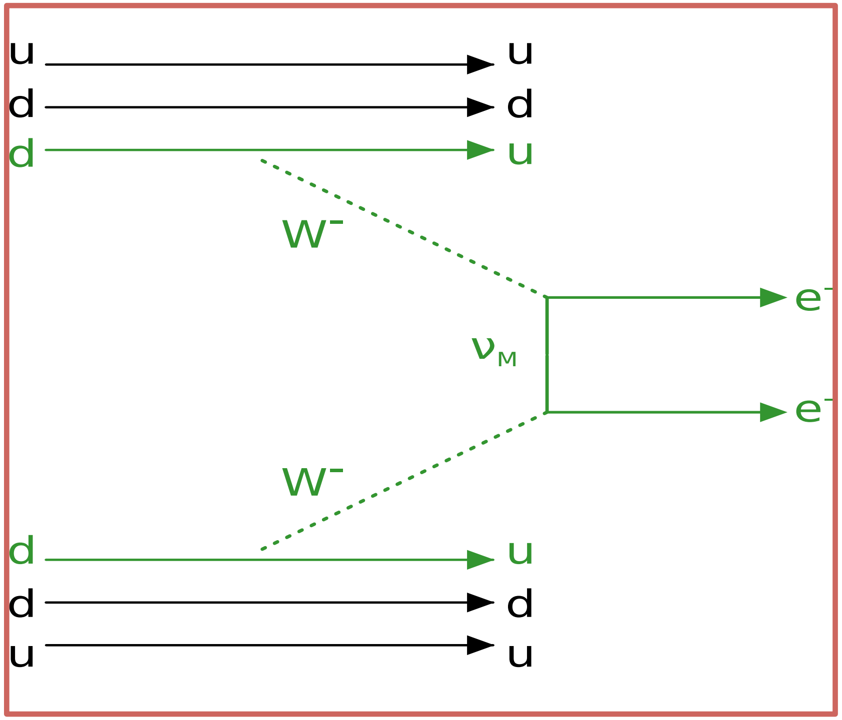
	$\Delta(L_e-L_\mu)$	$\Delta(L_\mu-L_\tau)$	$\Delta(L_\tau-L_e)$	$\Delta(B-L)$
$\nu_\mu \rightarrow \nu_e$	+2	-1	-1	0
$\nu_\mu \rightarrow \nu_\tau$	+1	-2	+1	0

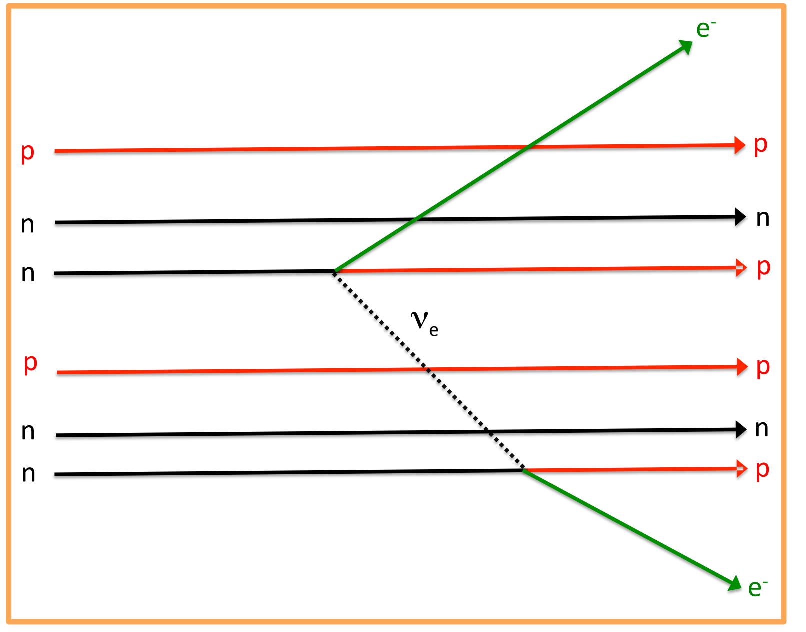
Appearance experiments proved that **all anomaly free symmetries** of SM are violated, except one.
B+L is not a conserved number in the Standard Model --- leptons and baryons conversion is possible

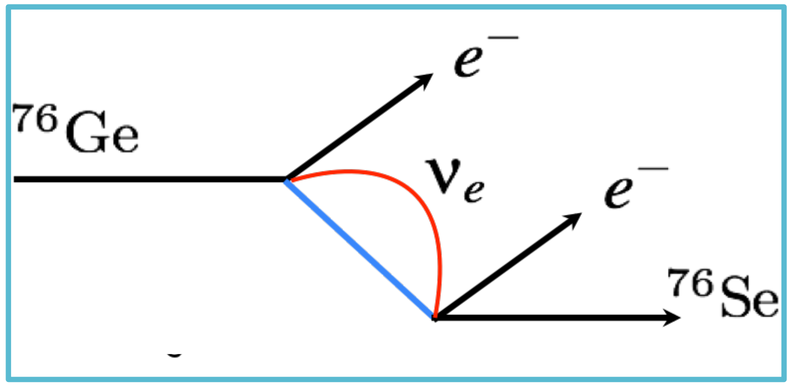
probe lepton number by neutrinoless double beta decay, i.e, by creation of electrons



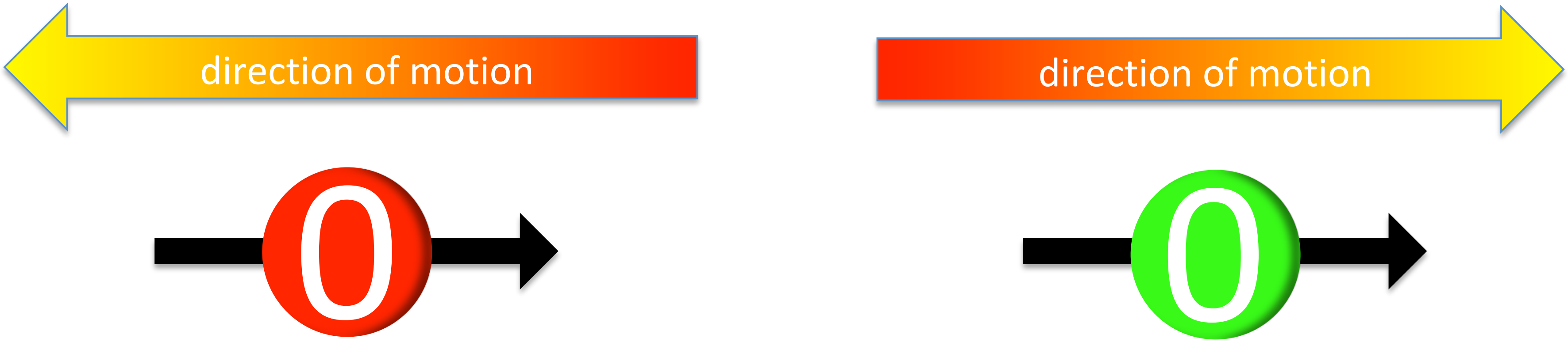
Majorana neutrinos and 0ν2β



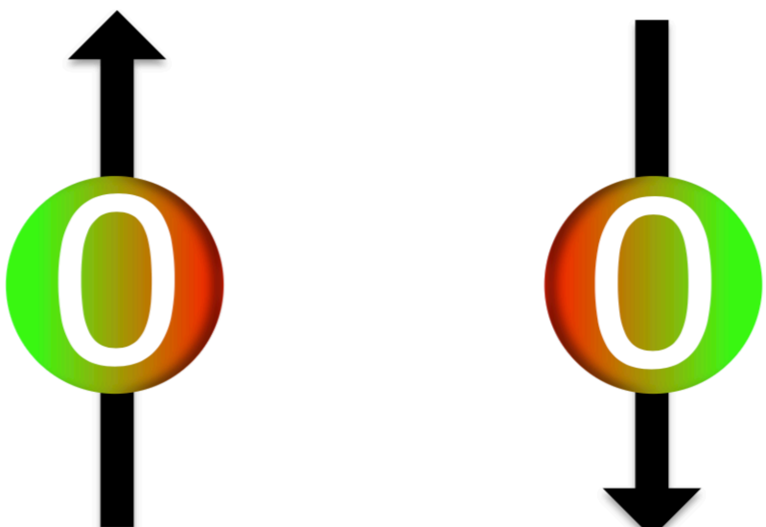




usually we see ultrarelativistic (anti) neutrinos



if we stopped them, we would see the spin states



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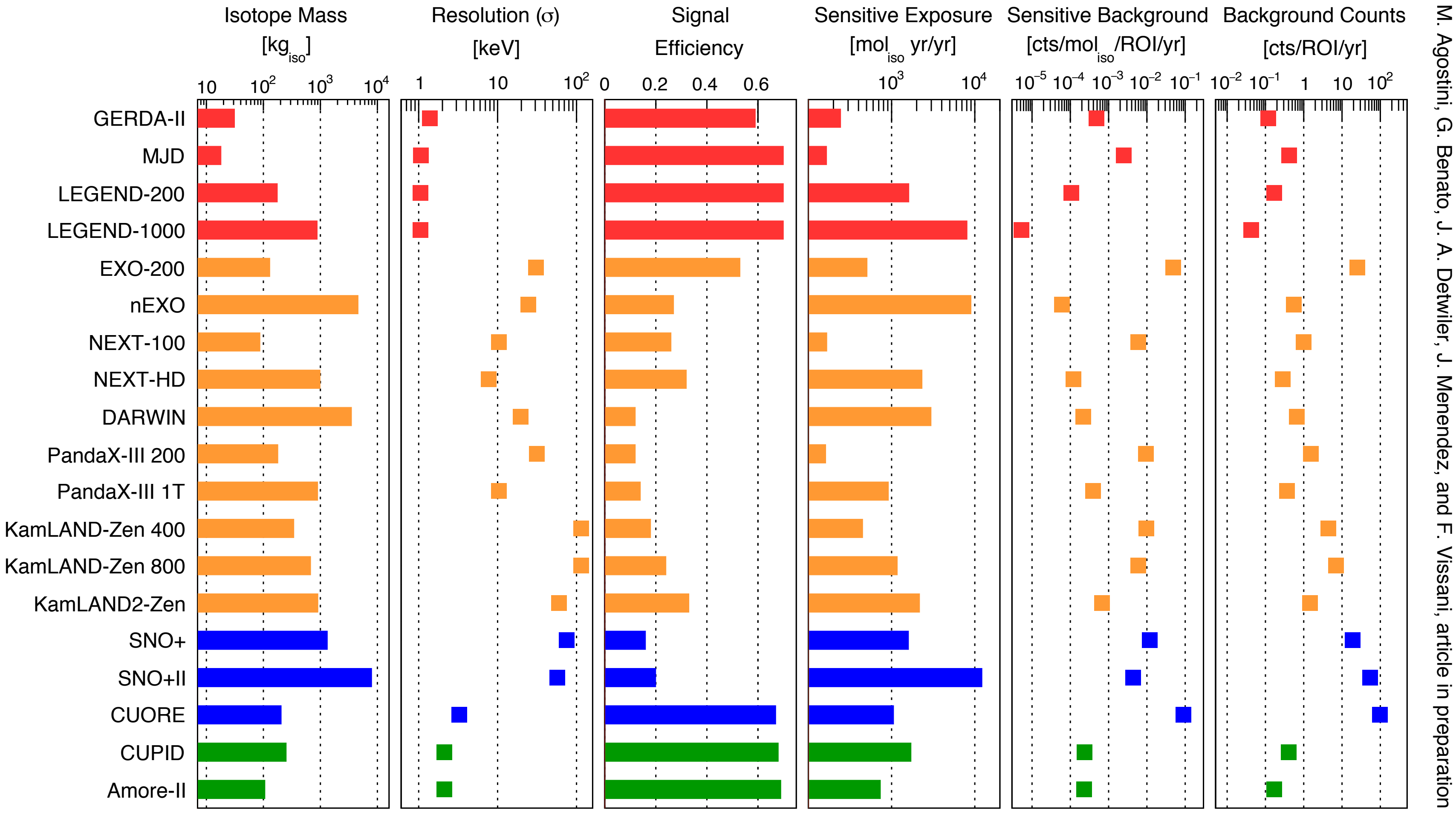
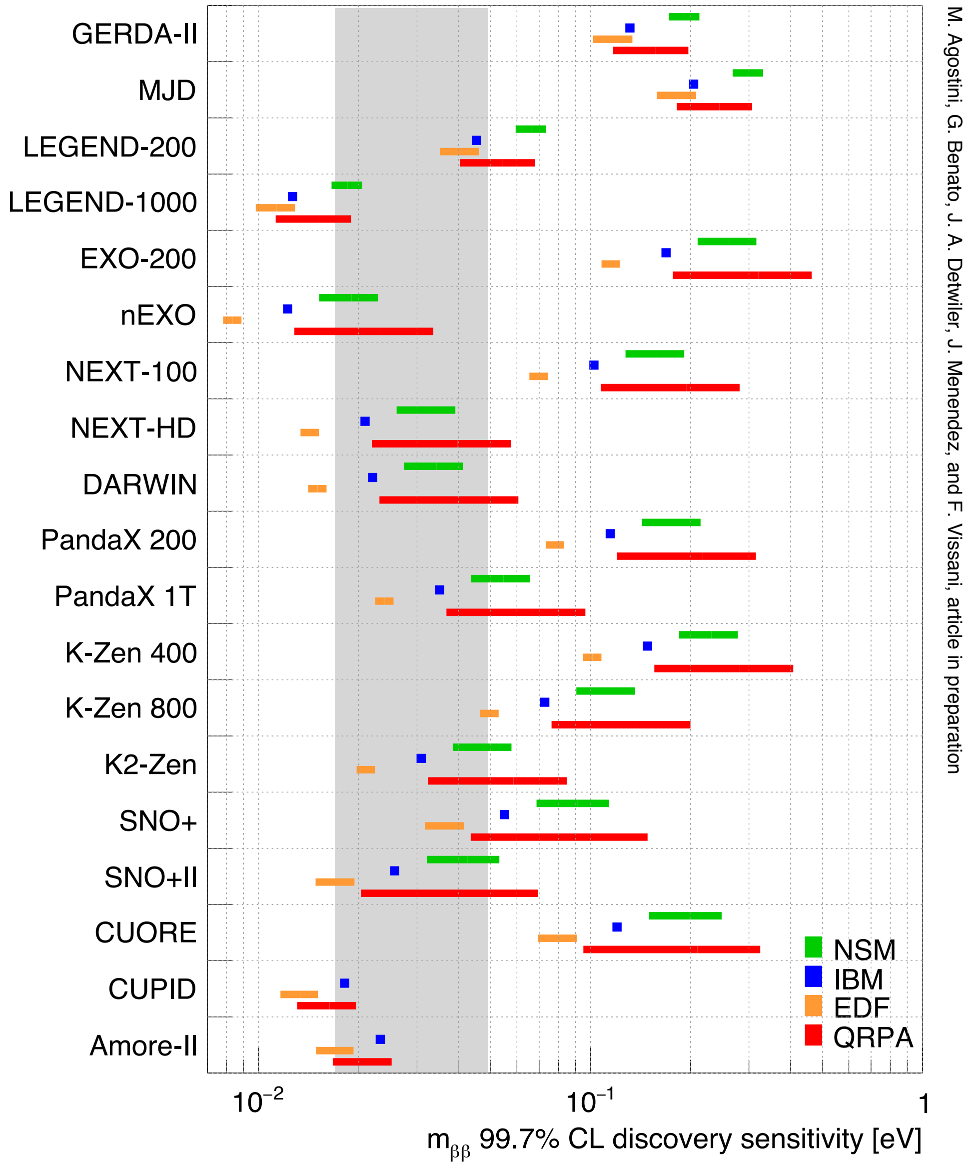
- the 1st is the SM-invariant formulation of Majorana neutrino masses which **violates B-L**
- the 2nd is one of the operators that cause the instability of the proton **but conserves B-L**
- the 3rd violates lepton number **and contributes to 0ν2β.**
- At dim.9 also **B violation** appears

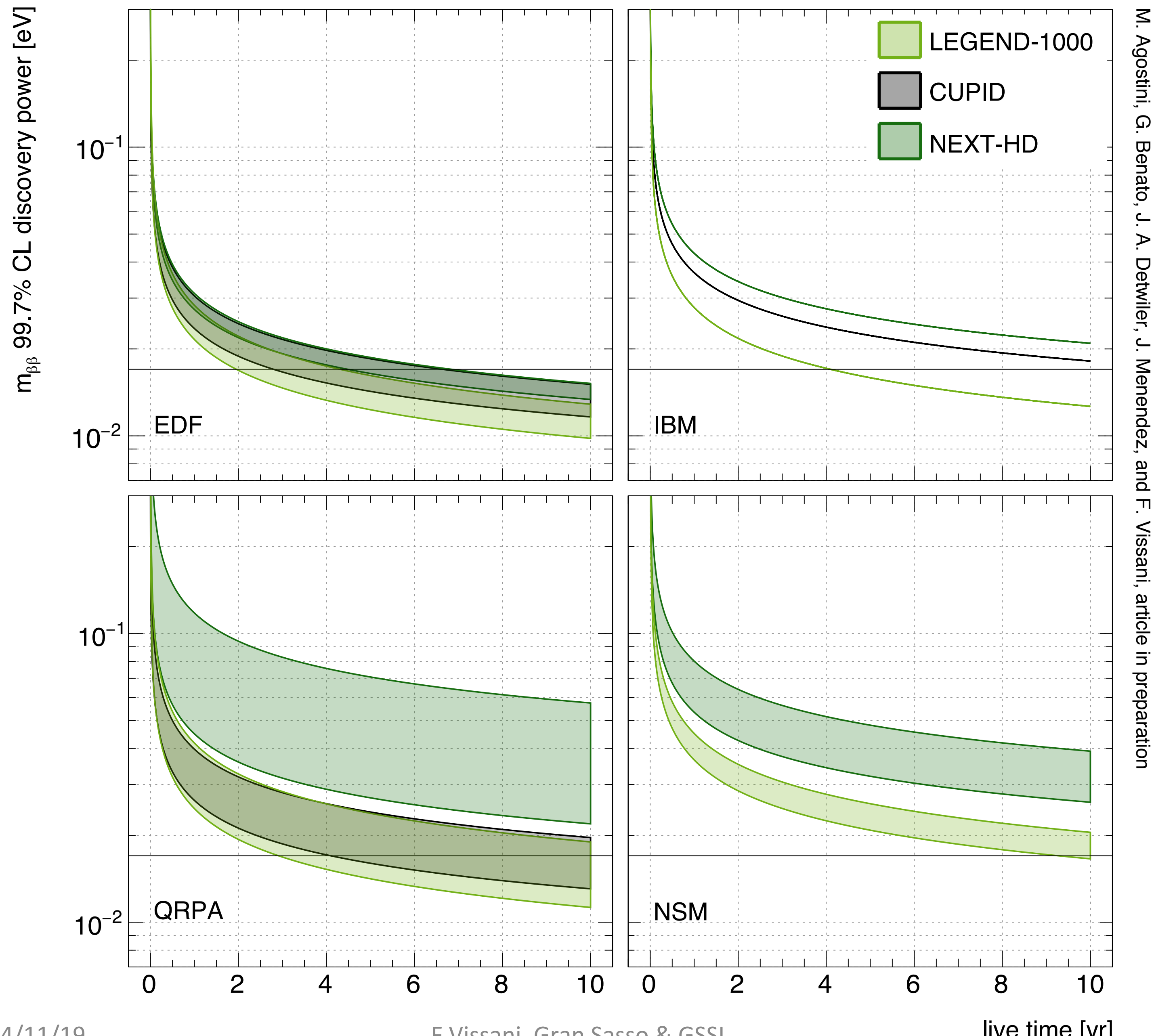
a systematic, updated study of 0ν2β



sensitivity to Majorana mass



prepared for APPEC meeting 2019



cosmology & SM

cosmology: FLRW → Λ-CDM

$$\rho_{\mathrm{crit.}} \equiv \frac{3(H_0)^2}{8\pi\, G_{\mathrm{N}}} \approx 5.0\, \frac{m_{\mathrm{p}}}{\mathbf{m}^3}$$

$$\rho_{\Lambda} \equiv \frac{\Lambda\, c^2}{8\pi\, G_{\mathrm{N}}} \approx 3.5\, \frac{m_{\mathrm{p}}}{\mathbf{m}^3}$$

$$\rho_{\mathrm{CDM}} + \rho_{\mathrm{bary.}} \approx 1.5\, \frac{m_{\mathrm{p}}}{\mathbf{m}^3}$$

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$$\rho_{\mathrm{CDM}} + \rho_{\mathrm{bary.}} \approx 1.5\,\frac{m_{\mathrm{p}}}{\mathbf{m}^3}$$

we have $1/\sqrt{\Lambda} \approx 3\ \mathrm{Gpc}$, similar in size to visible universe

cosmology: FLRW → Λ-CDM

$$\rho_{\text{crit.}} \equiv \frac{3(H_0)^2}{8\pi G_{\text{N}}} \approx 5.0 \, \frac{m_{\text{p}}}{\mathbf{m}^3}$$

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$$\rho_{\text{CDM}} + \rho_{\text{bary.}} \approx 1.5 \, \frac{m_{\text{p}}}{\mathbf{m}^3}$$

setting $\rho_\Lambda c^2 \equiv \mathcal{E}^4/(\hbar c)^3$ we get $\mathcal{E} \approx 2.2$ meV

cosmology: FLRW → Λ-CDM

$$\rho_{\text{crit.}} \equiv \frac{3(H_0)^2}{8\pi G_{\text{N}}} \approx 5.0 \, \frac{m_{\text{p}}}{\mathbf{m}^3}$$

$$\rho_\Lambda \equiv \frac{\Lambda c^2}{8\pi G_{\text{N}}} \approx 3.5 \, \frac{m_{\text{p}}}{\mathbf{m}^3}$$

$$\rho_{\text{CDM}} + \rho_{\text{bary.}} \approx 1.5 \, \frac{m_{\text{p}}}{\mathbf{m}^3}$$

most matter is non-baryonic $\rho_{\text{CDM}} \sim 5 \times \rho_{\text{bary.}}$

a few of SM-related questions

- **4.9% of baryons**

  Why anti-baryons are absent? Can we have a theory of that?

  No way to explain this with SM during big-bang

- **26.4% of non-relativistic matter / DM**

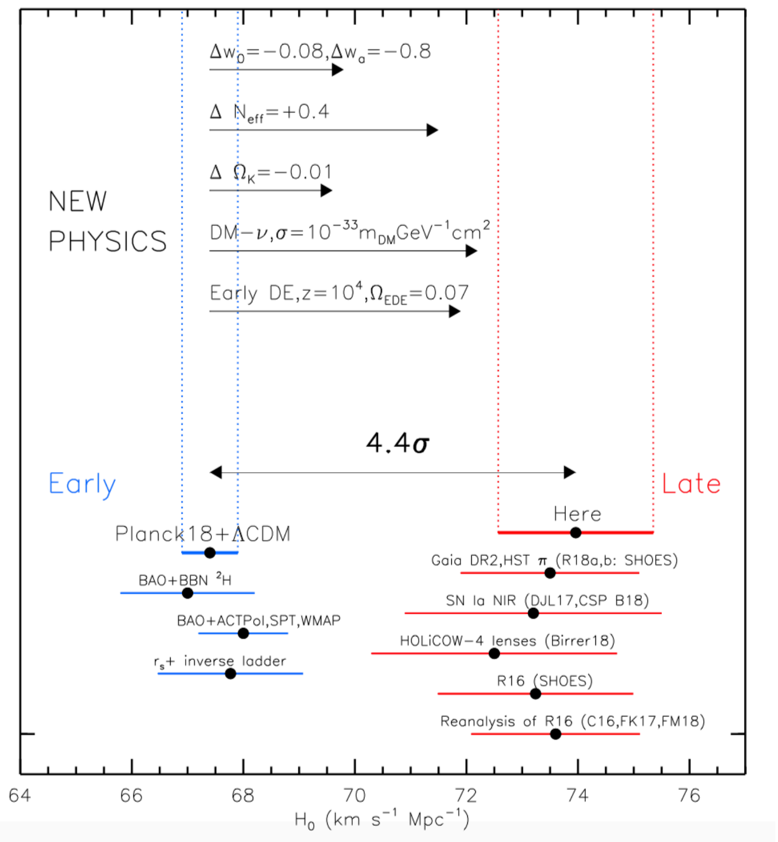
  What's this? Why it is similar to previous number? Can we see it in lab?

  No other massive particle in SM (except primordial BH or neutrinos)

- **68.7% of dark energy**

  How to know more about that?

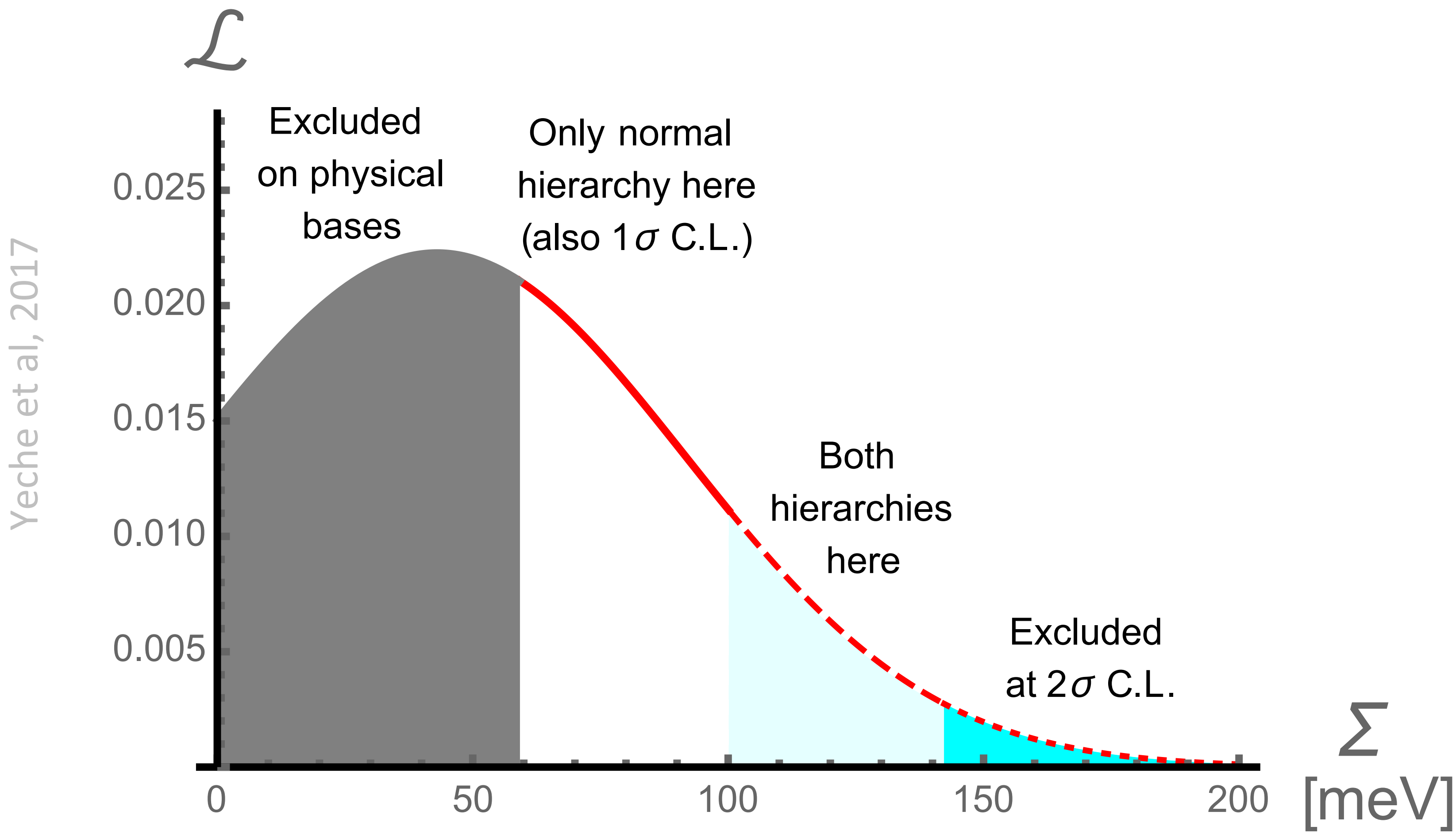
  No problem for SM to provide this, maybe the opposite problem



troubles with determination of H_0?

Adding some additional relativistic species help relieve the tension. In principle, new neutrinos could help, but their mass contribution should be negligible. Not a painless modification.

CMB is sensitive to $\Sigma = m_1 + m_2 + m_3$



PHYSICAL REVIEW D **100,** 073003 (2019)

Empirical inference on the Majorana mass of the ordinary neutrinos

Stefano Dell'Oro,[1,*] Simone Marcocci,[2] and Francesco Vissani[3,4,5,†]

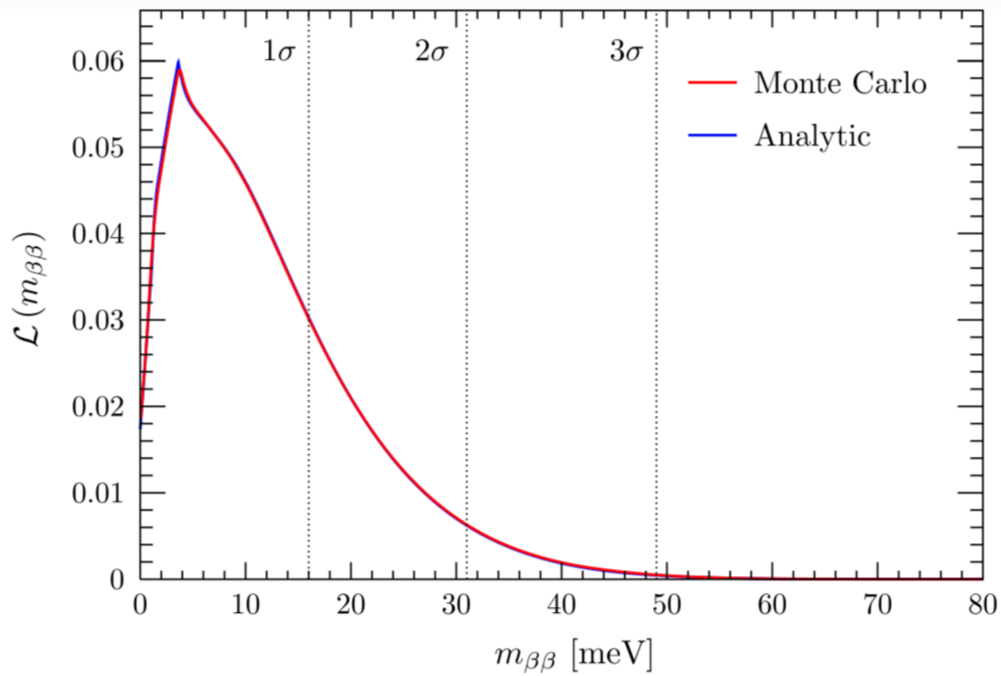
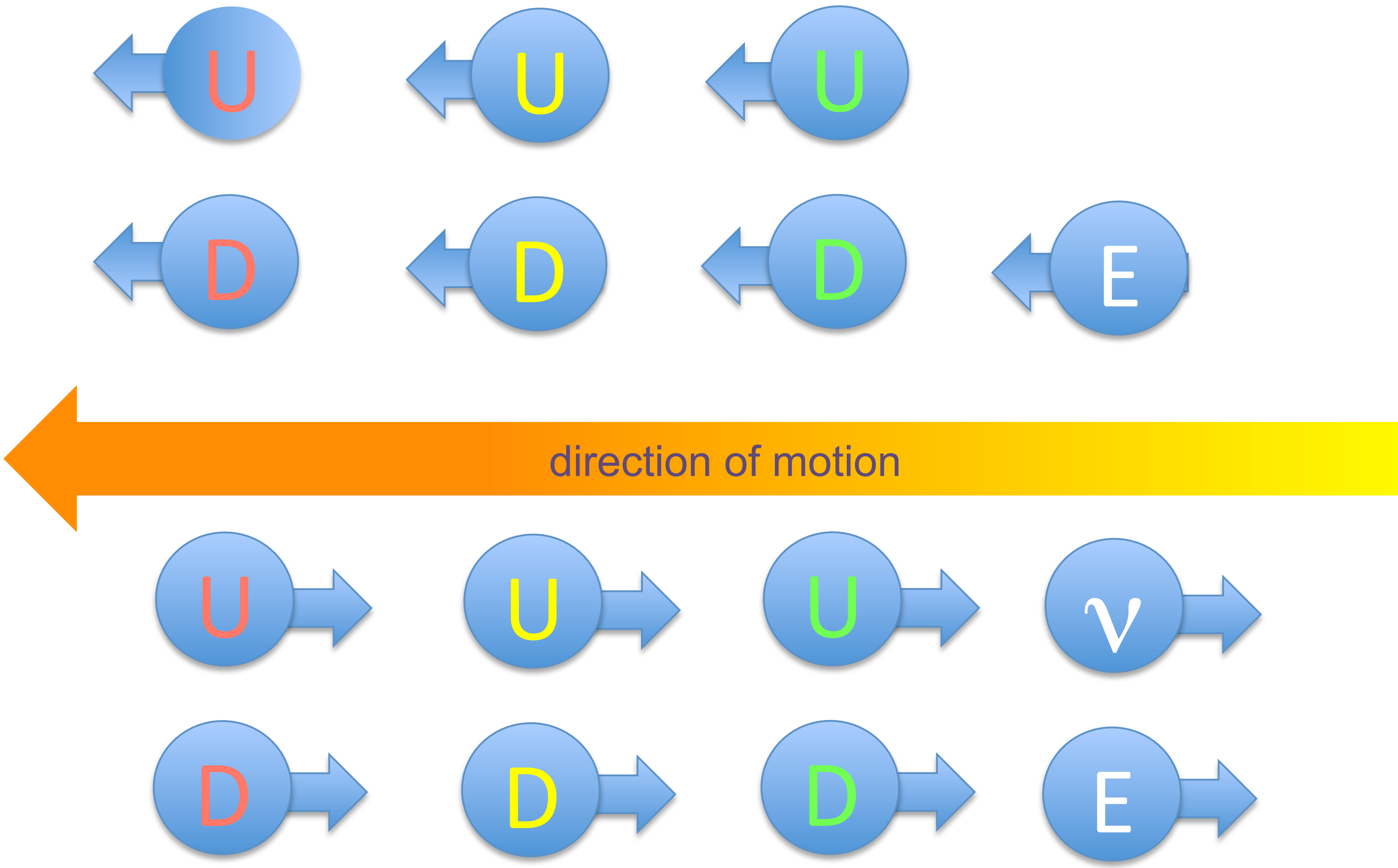


FIG. 2. Differential distributions of $m_{\beta\beta}$ obtained by projecting the density plot of Fig. 1 (red line) and as a result of the analytic procedure discussed in the text (blue line). The 1σ, 2σ and 3σ C. L. intervals are reported.

a few remarks

matter particles in one family



on right handed neutrinos

- it is plausible that right handed neutrinos exist
- with them, B-L can be promoted to a gauge symmetry
- 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)

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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2019-1984=35 y and 35/(5 to 10)≥3.5, thus the CL of the 2nd option seems > 3.5σ (0.05%) ☺

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

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

not the only pending issue

- B-physics, 3σ
- $(g\text{-}2)_\mu$, 4σ
- p-radius / μ-atoms, 6σ (?)
- ^{8}Be decay (Atomki), 6.8σ

- deficit of ν_e (gallium), 3σ
- deficit of reactor $\bar{\nu}_e$, 3σ
- $\bar{\nu}_e$ appearance (LSND + MiniBoone), 6σ

- nature of dark energy [doubt]
- nature of inflation [doubt]
- value of H_0 [cosm. problem]
- lithium abundance [problem]

- shape of high energy cosmic neutrino spectra, 2σ
- shape of solar neutrino spectra, 3σ
- nuclear recoils (DAMA), 11σ

Workshop on "Gravity, Information and Fundamental Symmetries"

Munich, MPQ, 04.-06.11.2019

Begin	End	Sunday		Monday		Tuesday		Wednesday
08:55	09:00		Chair: Klaus Blaum	Welcome	Chair: Ignacio Cirac		Chair: Dieter Lüst	
09:00	10:00			**Francesco Vissani, LNGS+Gran Sasso Inst.** Aspects, limitations and cracks of the standard model of elementary particles		**Jun Ye, Univ. of Colorado, Boulder** Quantum matter, clocks, and fundamental physics		**Cumrun Vafa, Harvard** Quantum Gravity and String Theory Landscape
10:00	10:45			**David DeMille, Yale** Probing PeV scale physics via particle electric dipole moments		**Piet Schmidt, PTB** Testing Fundamental Physics with Quantum Logic Spectroscopy of Highly Charged Ions		**Xiaoliang Qi, Stanford University** Operator growth in the SYK mode
10:45	11:15			*Coffee + Tea*		*Coffee + Tea*		*Coffee + Tea*
11:15	12:00			**Stefan Ulmer, RIEKEN+CERN** Antimatter under the Microscope - High Precision Comparisons of the Fundamental Properties of Matter/Antimatter Conjugates		**Tanya Zelevinsky, Columbia** Molecular clocks for precision metrology		**Silke Weinfurtner, Univ. of Nottingham** Quantum simulators of gravitational effects
12:00	12:45			**Martin Fertl, JGU Mainz** Precision low-energy physics with muons		**Ronald Walsworth, Harvard** Quantum Tools to Explore the Universe		**Kyriakos Papadodimas, ICTP Trieste** The black hole information paradox and space-time behind the horizon
12:45	14:00			*Lunch*		*Lunch*		*Lunch*
14:00	14:45	Arrival	Chair: Manfred Lindner	**Gustaaf Brooijmans, Columbia** Neutrons, Anti-Neutrons and Us	Chair: Allen Caldwell	**Javier Redondo, Zaragoza** Dark matter and axions	Chair: Ignacio Cirac	**Andrew Geraci, Northwestern University** Searching for gravitational waves, ultra-light dark matter, and "fifth" forces with levitated opto-mechanics
14:45	15:30			**Kate Scholberg, Duke** Interactions of Neutrinos with Matter		**Babette Döbrich, CERN** Axion searches across different mass scales		**Fernando Pastawski, PsiQuantum** Holography, locality and quantum error correction
15:30	16:00			*Coffee + Tea*		*Coffee + Tea*		*Coffee + Tea*
16:00	16:45			**Susanne Mertens, MPP+ TUM** Neutrino mass measurements		**Teresa Marrodan Undagoitia, MPIK** Dark Matter and neutrino physics with liquid xenon detectors		**Tadashi Takayanagi, Kyoto University** Entanglement Wedges and AdS/CFT
16:45	17:30			**Xianguo Lu, Oxford** Neutrino Physics with Accelerators		**Regina Caputo, NASA** Recent dark matter searches with Fermi-LAT		**Bryan Swingle, Univ. of Maryland** Black Hole Information Scrambling and Spacetime Locality
17:30	18:15			**Veronika Hubeny, UC Davis** Entanglement structure for holography		**Discussion**		**Discussion**
18:15	18:30			**Discussion**				
18:30	19:15							

summary and discussion

- **The SM is a theory, based on principles, that describes a huge amount of facts about microphysics. The hope that the gauge principle could take us much further than the SM, however, has not been realized.**
- **Neutrinos & weak interactions have been of key relevance for SM foundation and for demonstrating its incompleteness. Their study could provide further intellectual access on what is matter.**
- **There are several interesting experiments ongoing, there are many things still to understand, there is room for big surprises. It seems important to continue to work on observational cosmology. Perhaps we should put more efforts in building truly predictive theories.**
- **Is it so correct to decide *a priori* which are the most fundamental scientific goals and which are the more earthly ones instead, to be put aside? History has shown that this attitude is not w/o dangers.**

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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 ide particulate theory of matter, was first put forward by the Greek philosophers Leucippus (~490 BC) and Demo

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For much of the history of the natural sciences people have contemplated the exact nature of matter. The ide
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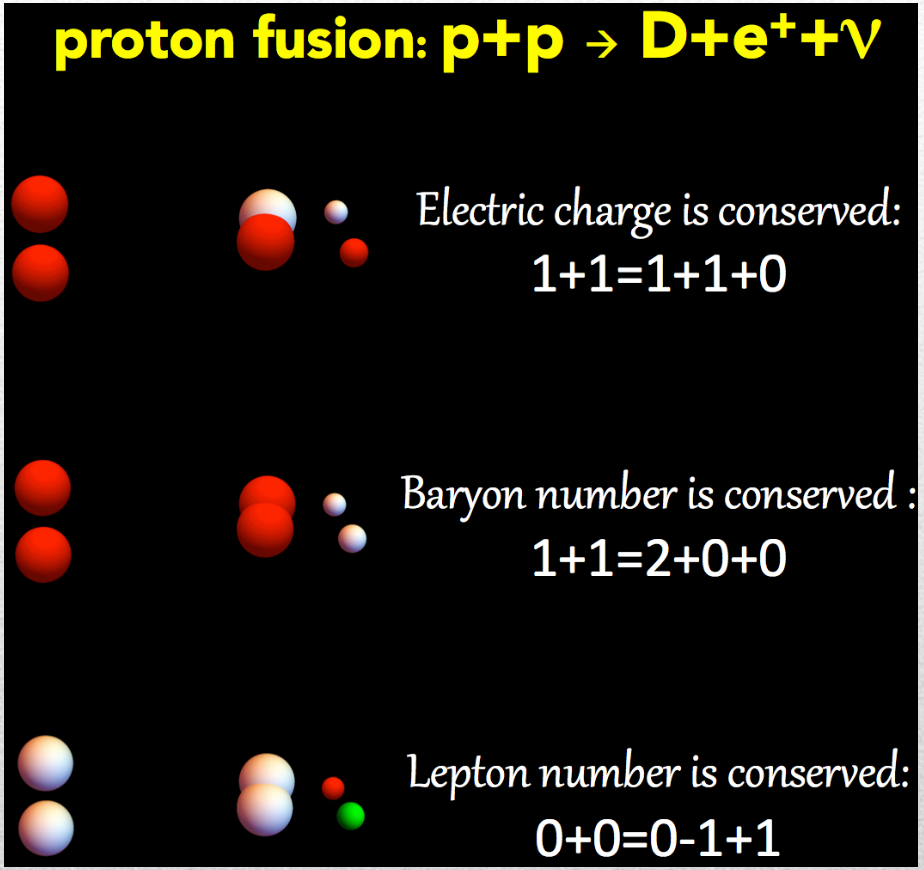
- In ordinary language we say: *matter does not disappear*
- In this panel, the main reaction that allows the Sun to work, that means that *neutrinos are* ***matter particles*** (leptons)
- Known physics says: *numbers of baryons and leptons do not change*
- Only B-L exactly conserved (SM)



what makes "matter"?

elementary components	identifying feature	time period theory (exp.)	reason of inadequacy
atoms	mass, type	till 1838 (1909)	"atoms of electricity"
nuclei & electrons	mass, charge	till 1933 (1956)	neutrons & neutrinos
p, n, e, ν_e	**B**, $\mathbf{L_e}$, spin	till 1961 (1968)	quarks / SM
quarks, leptons	**B**, $\mathbf{L_e}$, $\mathbf{L_\mu}$, $\mathbf{L_\tau}$, spin	till 1967 (2010)	neutrino appearance
quarks-antileptons	**B-L**, spin	till 1937!!! (??)	Majorana mass/$0\nu2\beta$
fermions	spin	till ???? (?????)	???????????

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.

1st 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.

universal V-A

Ruderman+Finkelstein 1949
Predictions of R(pi→enu)/R(pi→munu) in various hypotheses

Durbin+Loar+Steinberger 1951
pion parity from deuterium photodissociation

Lokathan+Steinberger 1955 & Anderson+Lattes 1957
apparently R(pi→enu) is just absent, ruling out standard model (!)

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

Fazzini *et al.* 1958
R(pi→enu)/R(pi→munu) confirms V-A

$(A\,,\ Z\,) \rightarrow (A\,, Z+1) + e^- + \bar{\nu}_e$	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

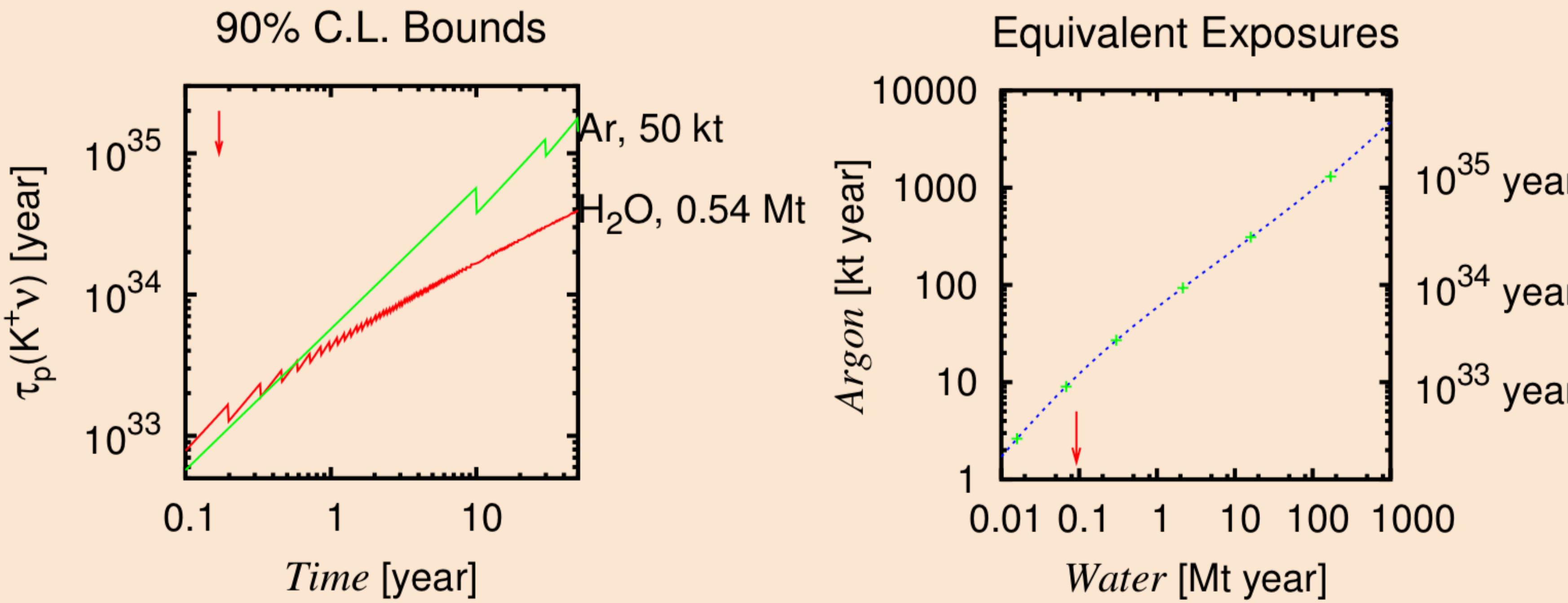
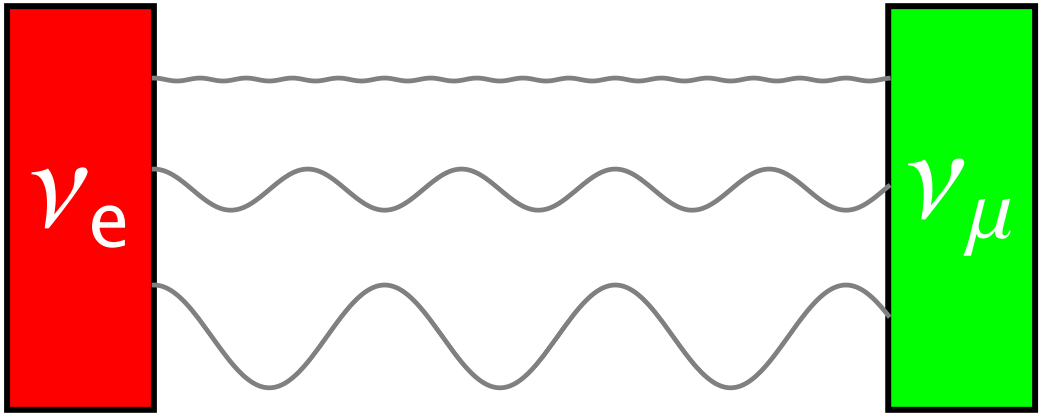


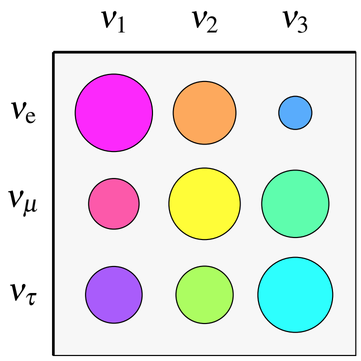
Figure 1: Sensitivity to $p \to K\bar{\nu}$; syst. not included. Water, $\epsilon = 14.6\%$ and $b = 14/(\mathrm{Mton\ y})$ (2 methods, summed); Argon, $\epsilon = 97\%$ and $b = 1/(\mathrm{Mton\ y})$. Impact of stat. fluctuations ≈ 2.

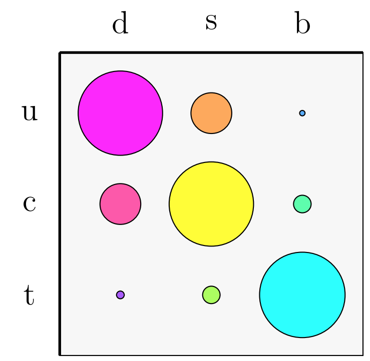
how oscillations work

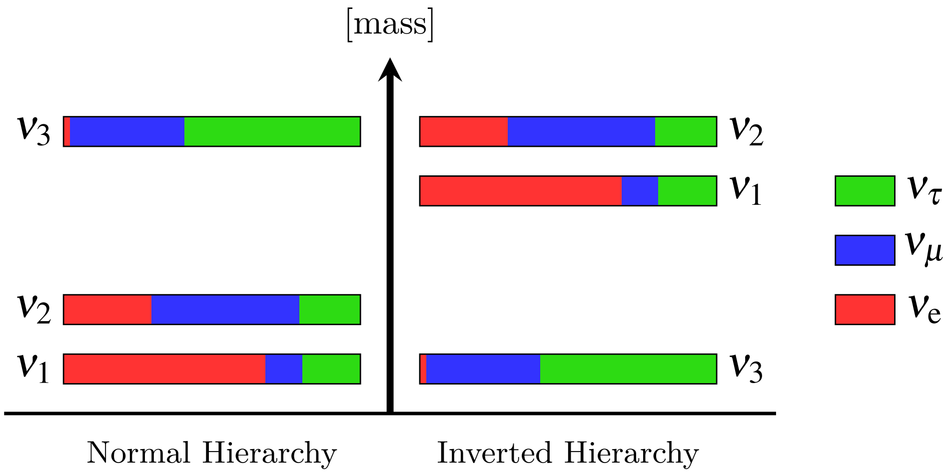
Each neutrino is produced and observed as a mixture of several waves, which describe particles with different masses. Particles with different masses have different speeds, thus neutrinos transform as they propagate.



what we know on masses and mixings





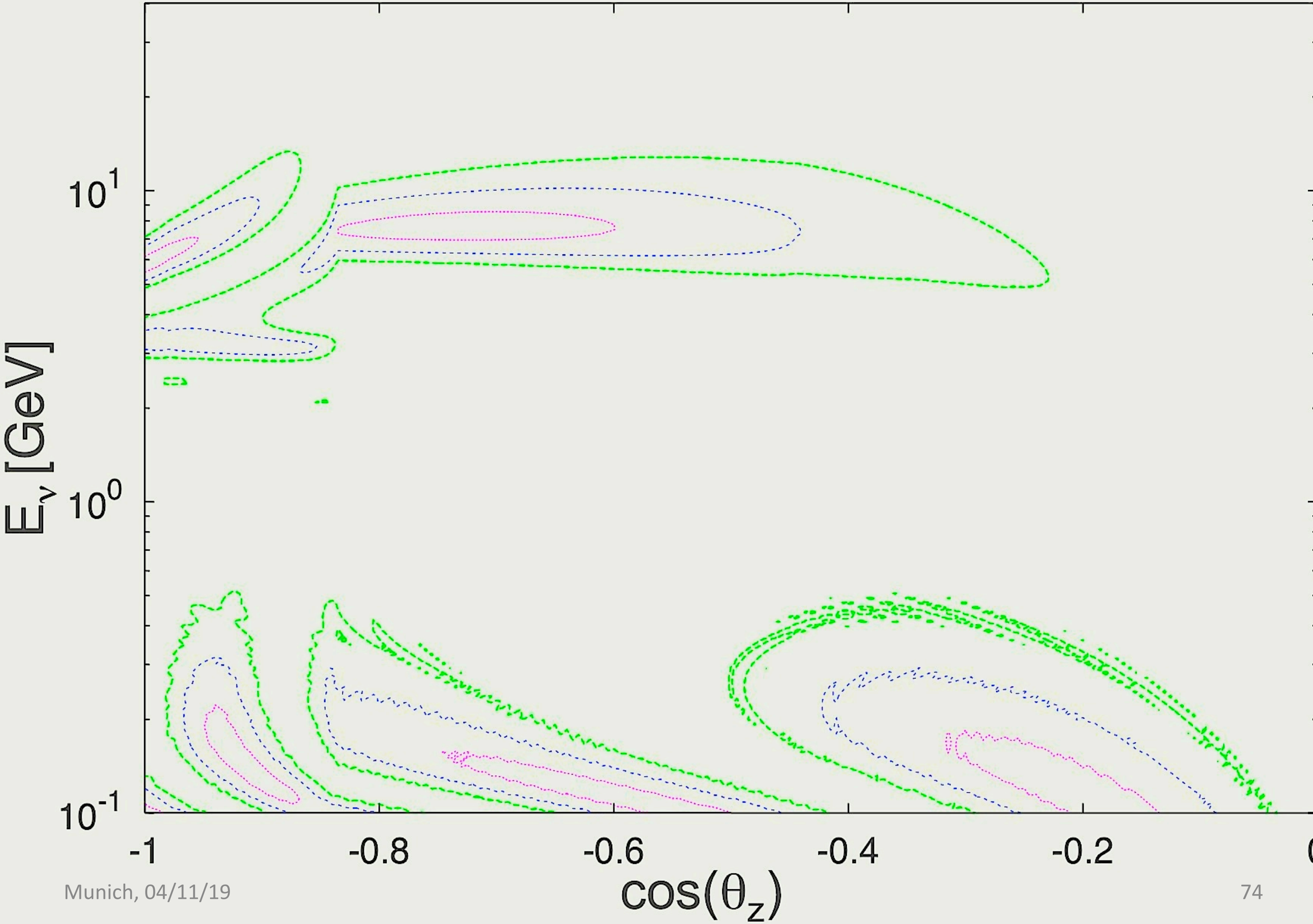


Fantini, Gallo Rosso et al, 2018

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***

the "electron neutrino" mass

If the mass of the light ν leads the transition, e.g. if new physics is at ultra-HE scale, the parameter that counts for 0ν2β is,

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

Symbols: first is the traditional one; second, ee-element of the ν mass matrix

The absolute mass scale and the (Majorana) **phases** ξ_i are not probed by oscillations: Only mass differences and electronic mixing $|U_{ei}^2|$ are measured.

STERILE NEUTRINOS?

◎LSND-MiniBooNe anomaly is with us since 1995; in latest data is mostly/only at lowest energies. 10 year later sterile neutrino were assessed by a global analysis w/o finding them

◎Ga- & reactor anomalies further tested with movable detector close to reactors. Not supported by DANSS, Stereo, NEOS

◎Adding sterile neutrinos does not help: the ensuing theory is predictive, leading to inconsistencies between these and other data

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Nuclear Physics B 708 (2005) 215–267

NUCLEAR PHYSICS B

Probing oscillations into sterile neutrinos with cosmology, astrophysics and experiments

M. Cirelli [a], G. Marandella [b], A. Strumia [c], F. Vissani [d]

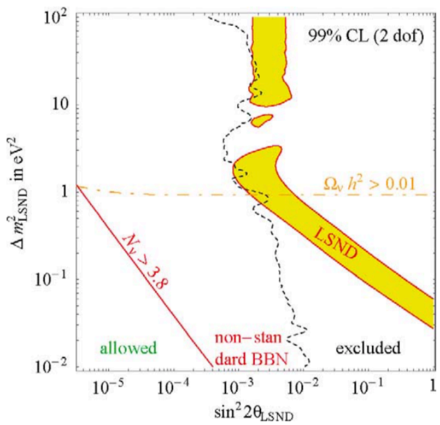
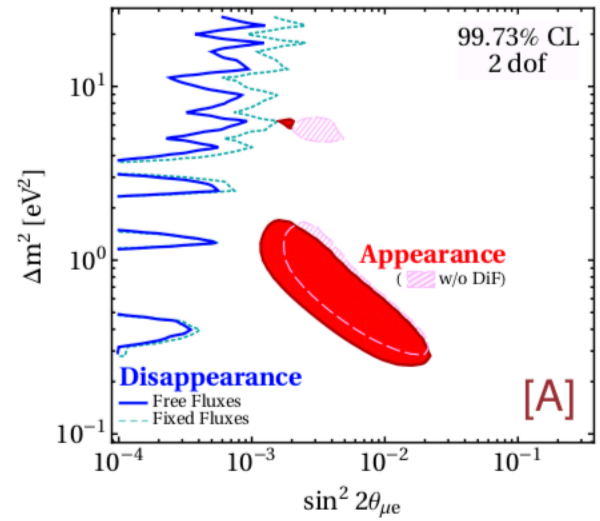
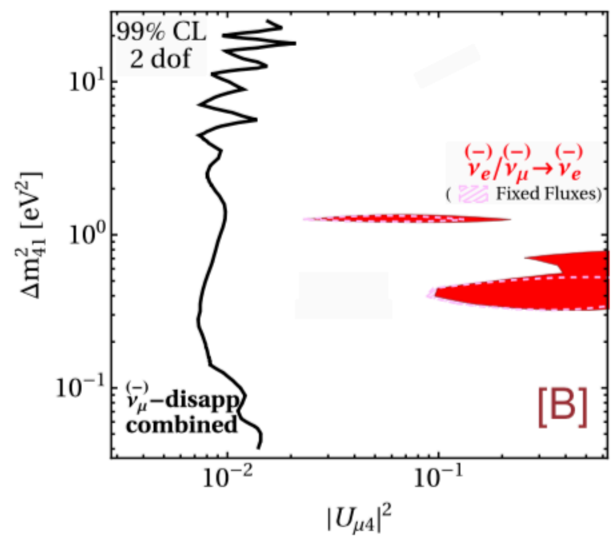


Fig. 13. The LSND anomaly interpreted as oscillations of 3 + 1 neutrinos. Shaded region: suggested at 99% C.L. by LSND. Black dotted line: 99% C.L. global constraint from other neutrino experiments (mainly Karmen, Bugey, SK, CDHS). Continuos red line: $N_\nu = 3.8$ thermalized neutrinos. Dot-dashed orange line: $\Omega_\nu h^2 = 0.01$.

(3+1): tension among data samples

- Limits on $\nu_e \to \nu_e$ and $\nu_\mu \to \nu_\mu$ disappearance imply a bound on the $\nu_\mu \to \nu_e$ appearance probability;
- such bound is stronger than what is required to explain the LSND and MiniBooNe excesses [A];
- hence, severe tension arises between **APP** and **DIS** data: $\chi^2_{\text{PG}}/\text{dof} = 29.6/2 \Rightarrow \text{PG} = 3.7 \times 10^{-7}$ [17];
- a similar result is visible when comparing "ν_e-data" ($\nu_e \to \nu_e$ and $\nu_\mu \to \nu_e$) and "ν_μ-data" ($\nu_\mu \to \nu_\mu$) [B];
- note: tension between **APP** and **DIS** data first pointed out in 1999 [34]. Full global fit in 2001 [35] cornered (3+1) models. No conceptual change since then. . .





[17] M. Dentler *et al.*, arXiv:1803.10661.
[34] S.M. Bilenky *et al.*, PRD **60** (1999) 073007 [hep-ph/9903454].
[35] MM, Schwetz, Valle, PLB **518** (2001) 252 [hep-ph/0107150].

direct search of big-bang neutrinos

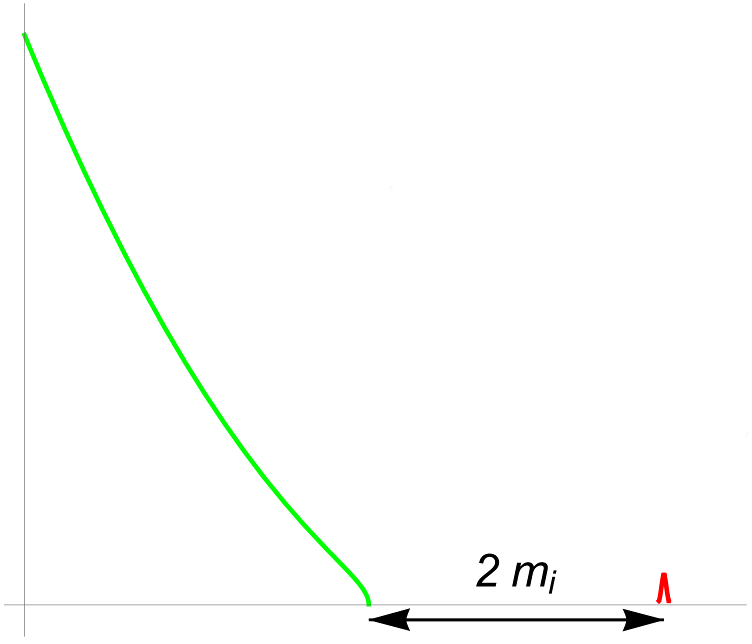
big-bang neutrinos produce 3 **neutrino-capture** lines for a radioactive target

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

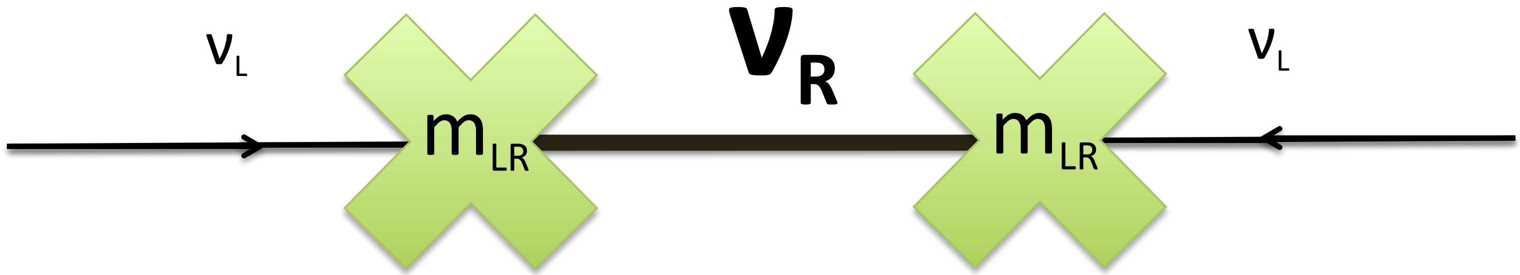


Glancing beyond SM

- 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

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

an explanation of small of neutrino masses



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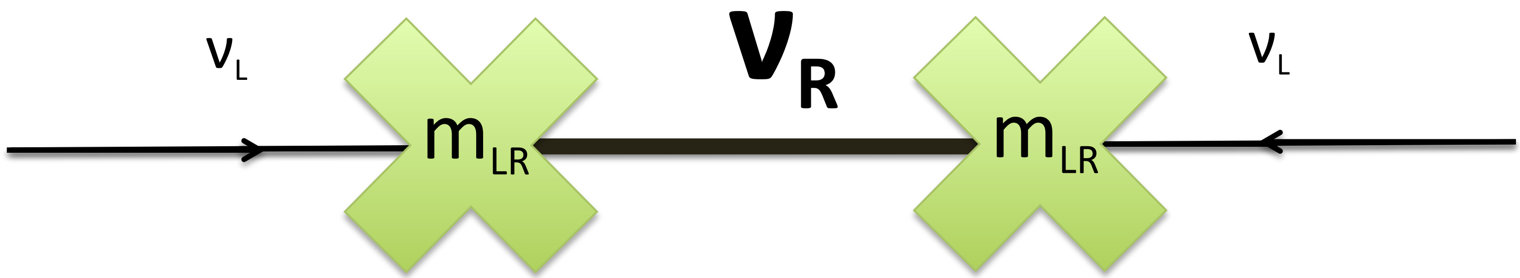
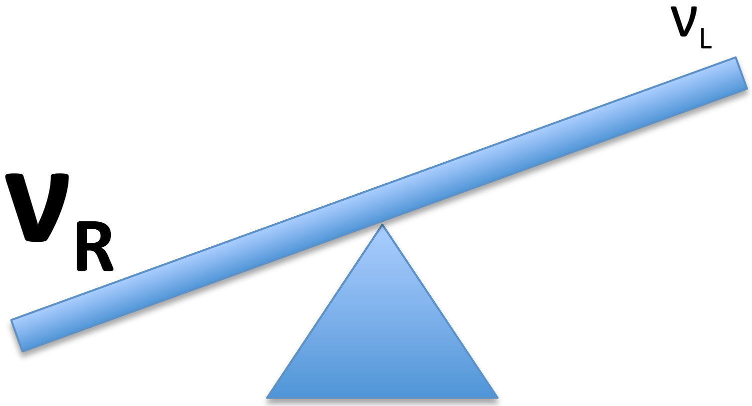


$$\frac{1}{m_{RR}}$$

this is called “seesaw”



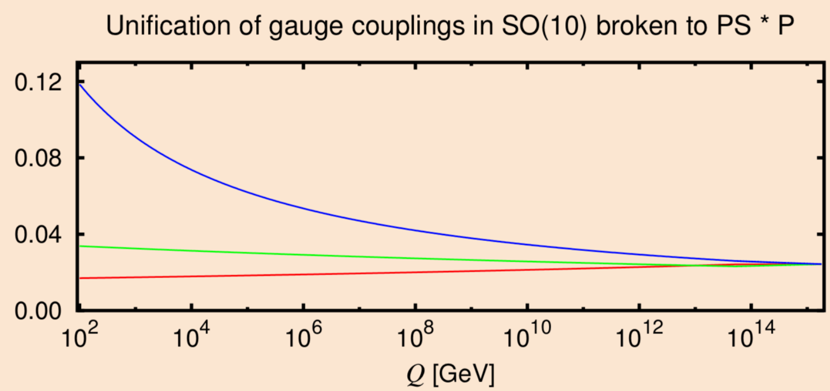


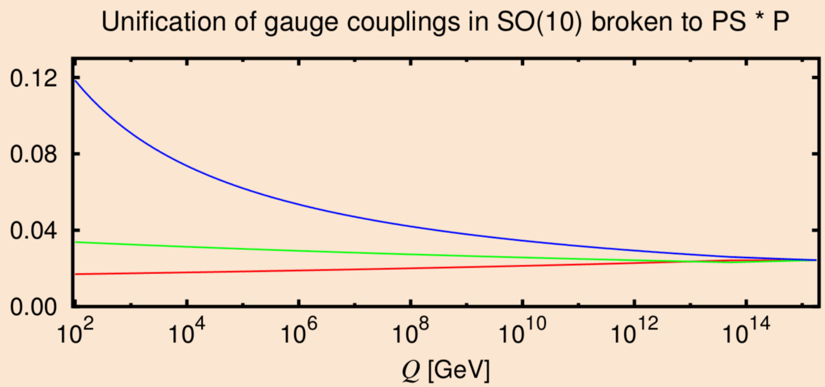
Figure 2: Evolution of the gauge coupling constants in a GUT model with intermediate scale. Here, $M_{\mathrm{interm.}} \approx 5 \times 10^{13}$ GeV.

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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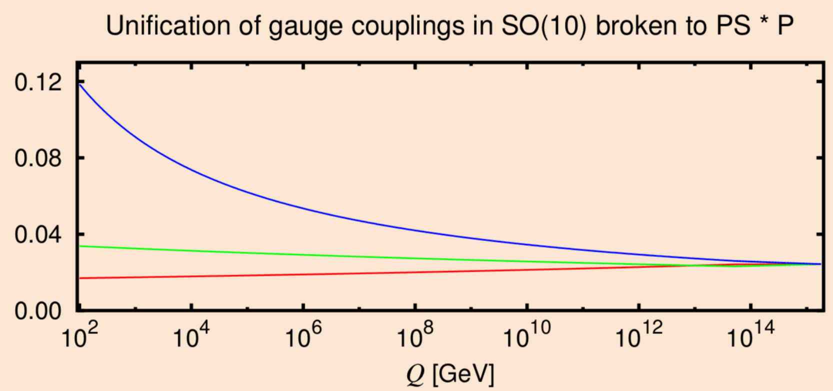

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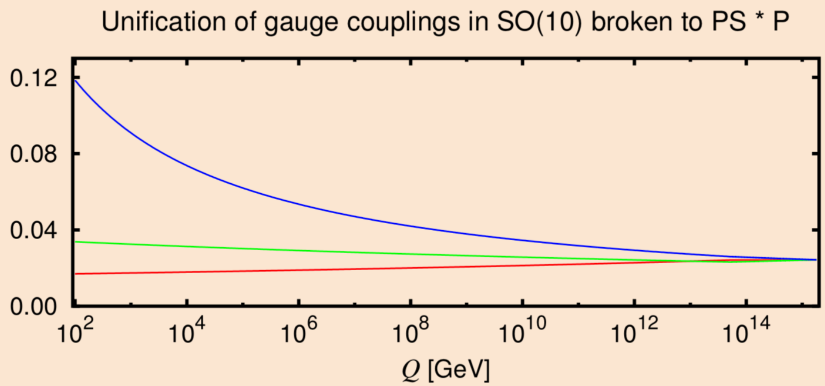

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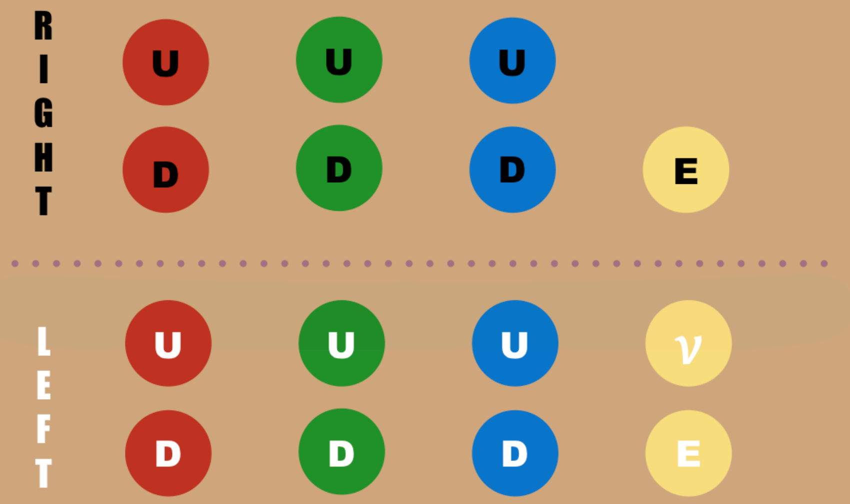
- ★ (Peccei Quinn symmetry to address strong CP and dark matter)
- ★ neutrinos are massive and fermion masses constrained
- ★ normal mass hierarchy; $m_{\beta\beta}$ in the few meV range
- ★ (potentially interesting expectations for proton decay)

15 particles per family



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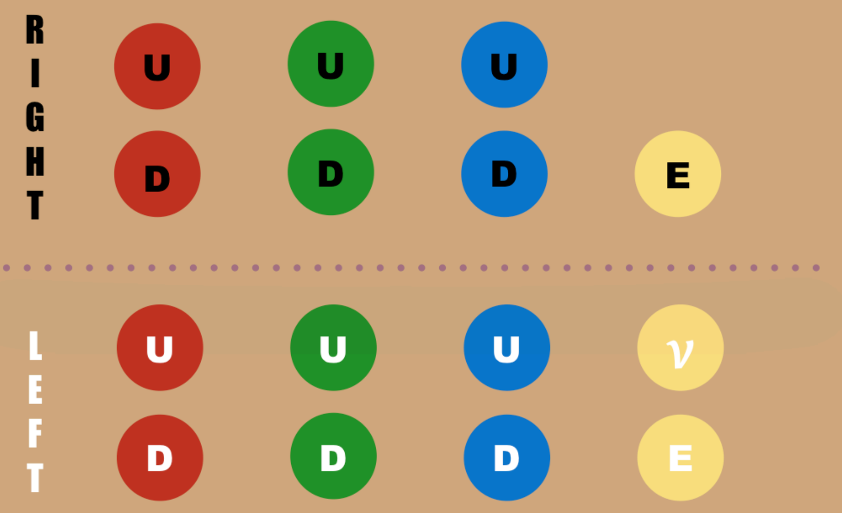
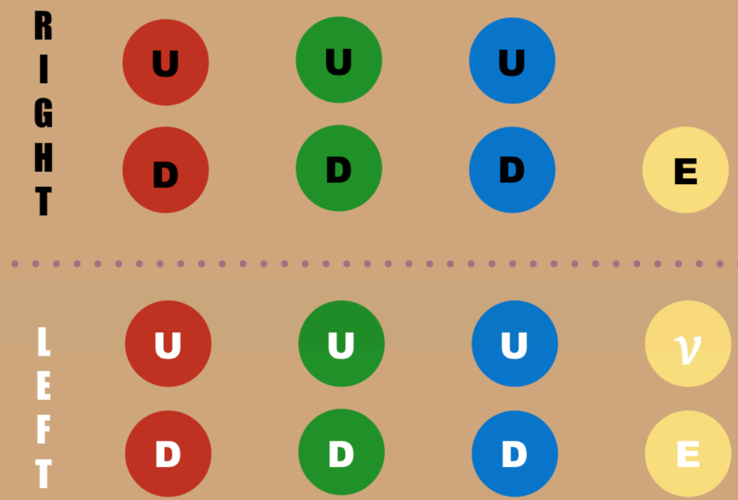
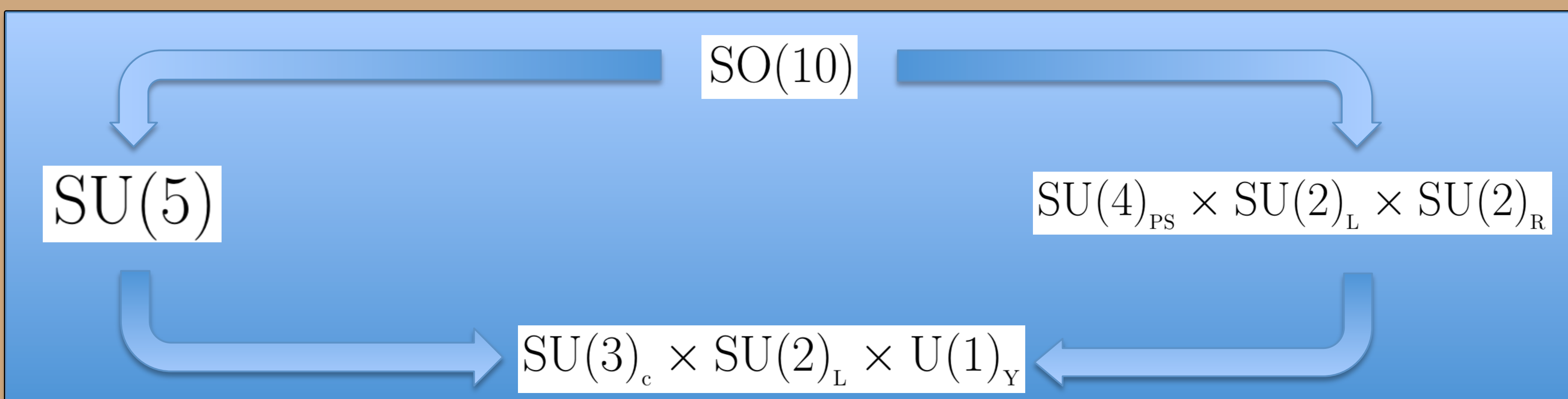


$$\mathrm{SU}(2)_{\mathrm{L}} \text{ acts on } \begin{pmatrix} \nu_{\mathrm{L}} \\ e_{\mathrm{L}} \end{pmatrix} \quad \text{while} \quad \mathrm{SU}(2)_{\mathrm{R}} \text{ acts on } \begin{pmatrix} \nu_{\mathrm{R}} \\ e_{\mathrm{R}} \end{pmatrix}$$

15 particles per family





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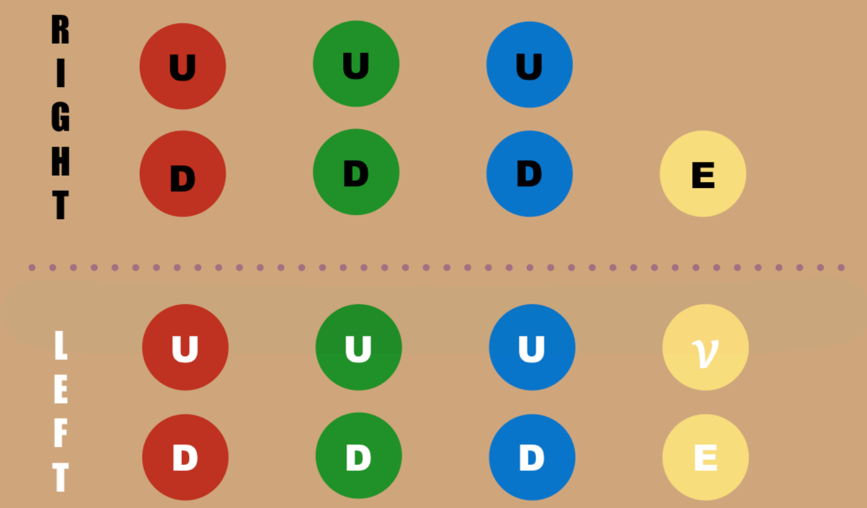
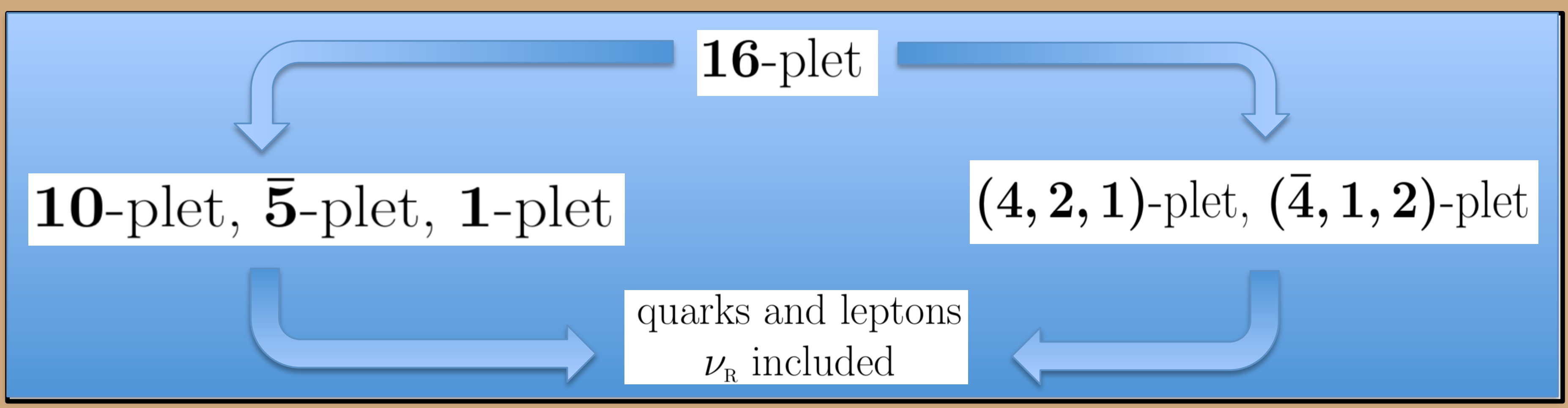




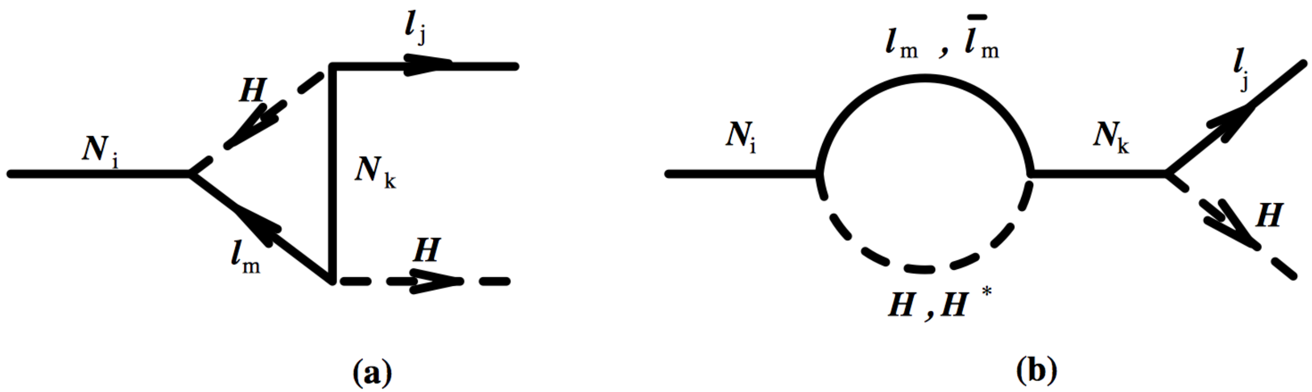


Figure 1: Diagrams contributing to the vertex (Fig. 1a) and wave function (Fig. 1b) CP violation in the heavy singlet neutrino decay.

Covi et al. '96

Heavy RH neutrinos

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

PHYSICAL REVIEW D VOLUME 57, NUMBER 11 1 JUNE 1998

Do experiments suggest a hierarchy problem?

Francesco Vissani
International Centre for Theoretical Physics, Strada Costiera 11, I-34013 Trieste, Italy
(Received 18 September 1997; published 14 April 1998)

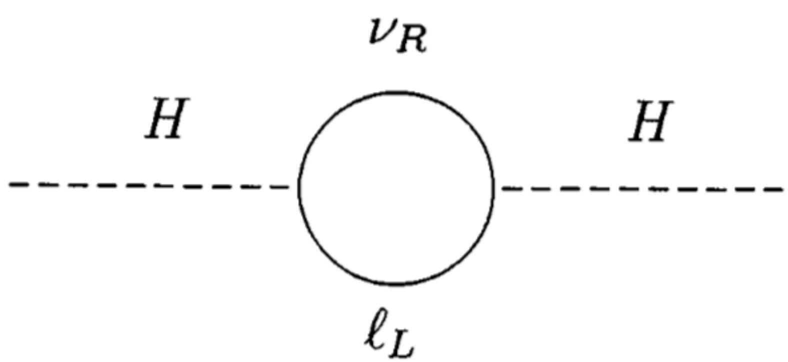


FIG. 1. The Feynman diagram originating the corrections in Eq. (1); ν_R denotes the right-handed neutrino of mass M_R, $\ell_L = (\nu_L, e_L)$ the leptonic and H the Higgs doublets.

OK, but what about the cosmological constant?

arXiv:hep-ph/0007040v1 5 Jul 2000

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.

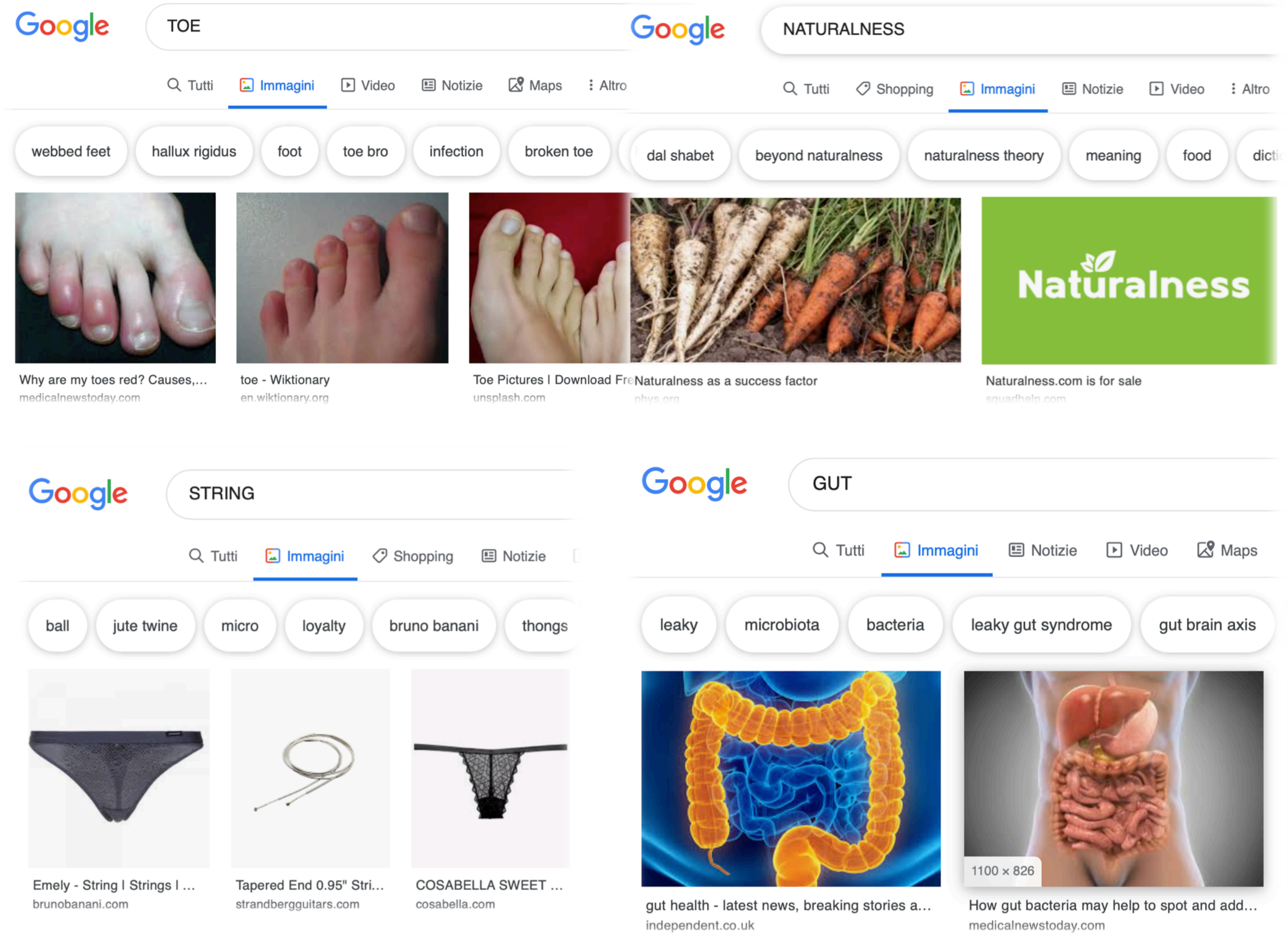
3 (Not quite a) conclusion

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!

$$\left\{ \begin{array}{c} R_\mathrm{S} \equiv \dfrac{2G_\mathrm{N}M}{c^2}\,,\ M \equiv \dfrac{4\pi}{3}R_\mathrm{S}^3 \times \rho \ \Rightarrow \\[2ex] \rho \equiv \dfrac{3\ c^2}{8\pi G_\mathrm{N} R_\mathrm{S}^2};\ \textbf{imposing}\ \rho < \rho_\mathrm{crit.} \ \Rightarrow \\[2ex] R_\mathrm{S} < \dfrac{c}{H_0} \equiv R_\mathrm{H} = 4.4\ \mathrm{Gpc} \end{array} \right\}$$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loyalty
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thongs
Emely - String | Strings | ...
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cosabella.com
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GUT
Tutti
Immagini
Notizie
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microbiota
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How gut bacteria may help to spot and add...
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