Are neutrinos still showing us the way?

perspectives on the physics beyond the SM, circa 2025

Francesco Vissani
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two news

on global analyses of oscillation data & cosmology and neutrinos

1. Global analyses 2024 - 2025

NuFit-6.0: updated global analysis of three-flavor neutrino oscillations

Regular Article - Theoretical Physics | Open access | Published: 30 December 2024

Ivan Esteban, M. C. Gonzalez-Garcia, Michele Maltoni, Ivan Martinez-Soler, João Paulo Pinheiro & Thomas Schwetz

Abstract

We present an updated global analysis of neutrino oscillation data as of September 2024. The parameters θ_{12}, θ_{13}, Δm^2_{21}, and $|\Delta m^2_{3\ell}|$ ($\ell = 1, 2$) are well-determined with relative precision at 3σ of about 13%, 8%, 15%, and 6%, respectively. The third mixing angle θ_{23} still suffers from the octant ambiguity, with no clear indication of whether it is larger or smaller than 45°. The determination of the leptonic CP phase δ_{CP} depends on the neutrino mass ordering: for normal ordering the global fit is consistent with CP conservation within 1σ, whereas for inverted ordering CP-violating values of δ_{CP} around 270° are favored against CP conservation at more than 3.6σ. While the present data has in principle $2.5-3\sigma$ sensitivity to the neutrino mass ordering, there are different tendencies in the global data that reduce the discrimination power: T2K and NOvA appearance data individually favor normal ordering, but they are more consistent with each other for inverted ordering. Conversely, the joint determination of $|\Delta m^2_{3\ell}|$ from global disappearance data prefers normal ordering. Altogether, the global fit including long-baseline, reactor and IceCube atmospheric data results into an almost equally good fit for both orderings. Only when the χ^2 table for atmospheric neutrino data from Super-Kamiokande is added to our χ^2, the global fit prefers normal ordering with $\Delta\chi^2 = 6.1$. We provide also updated ranges and correlations for the effective parameters sensitive to the absolute neutrino mass from β-decay, neutrinoless double-beta decay, and cosmology.

- T2K AND NOvA ARE **NOT** IN PERFECT AGREEMENT
- SUPER-KAMIOKANDE DATA PROVIDED TABLES OF χ^2 THAT HAVE A BIG WEIGHT
- SPECTRUM IS KNOWN ONLY WITHIN 2.2σ
- $\theta_{23} - 45°$ AND δ_{CP} ARE POORLY DETERMINED

Neutrino masses and mixing: Entering the era of subpercent precision

Francesco Capozzi, William Giarè, Eligio Lisi, Antonio Marrone, Alessandro Melchiorri, Antonio Palazzo

We perform an updated global analysis of the known and unknown parameters of the standard 3ν framework as of 2025. The known oscillation parameters include three mixing angles $(\theta_{12}, \theta_{23}, \theta_{13})$ and two squared mass gaps, chosen as $\delta m^2 = m_2^2 - m_1^2 > 0$ and $\Delta m^2 = m_3^2 - \frac{1}{2}(m_1^2 + m_2^2)$, where $\alpha = \mathrm{sign}(\Delta m^2)$ distinguishes normal ordering (NO, $\alpha = +1$) from inverted ordering (IO, $\alpha = -1$). With respect to our previous 2021 update, the combination of oscillation data leads to appreciably reduced uncertainties for θ_{23}, θ_{13} and $|\Delta m^2|$. In particular, $|\Delta m^2|$ is the first 3ν parameter to enter the domain of subpercent precision (0.8\% at 1σ). We underline some issues about systematics, that might affect this error estimate. Concerning oscillation unknowns, we find a relatively weak preference for NO versus IO (at 2.2σ), for CP violation versus conservation in NO (1.3σ) and for the first θ_{23} octant versus the second in NO (1.1σ). We discuss the status and qualitative prospects of the mass ordering hint in the plane $(\delta m^2, \Delta m^2_{ee})$, where $\Delta m^2_{ee} = |\Delta m^2| + \frac{1}{2}\alpha(\cos^2\theta_{12} - \sin^2\theta_{12})\delta m^2$, to be measured by the JUNO experiment with subpercent precision. We also discuss upper bounds on nonoscillation observables. We report $m_\beta < 0.50$~eV and $m_{\beta\beta} < 0.086$~eV (2σ). Concerning the sum of neutrino masses Σ, we discuss representative combinations of data, with or without augmenting the ΛCDM model with extra parameters accounting for possible systematics or new physics. The resulting 2σ upper limits are roughly spread around the bound $\Sigma < 0.2$~eV within a factor of three. [Abridged]

2. DESI Coll. 2025

bounds on neutrinos from CMB, BAO, SNIa...

- Observations within ΛCDM imply that $\Sigma < 64$ meV at 95% near to $\sqrt{\Delta m^2_{osc}}$
- But the fact that the prior $\Sigma \geq 0$ is so crucial puts us on notice.
- Using $p/\rho = w_0 + w_a(1-a)$, the limit weakens to $\Sigma < 163$ meV at 95%
- Number of neutrinos is stable 3 ± 0.2

[Submitted on 18 Mar 2025]

Constraints on Neutrino Physics from DESI DR2 BAO and DR1 Full Shape

The Dark Energy Spectroscopic Instrument (DESI) Collaboration has obtained robust measurements of baryon acoustic oscillations (BAO) in the redshift range, $0.1 < z < 4.2$, based on the Lyman-α forest and galaxies from Data Release 2 (DR2). We combine these measurements with external cosmic microwave background (CMB) data from Planck and ACT to place our tightest constraints yet on the sum of neutrino masses. Assuming the cosmological ΛCDM model and three degenerate neutrino states, we find $\sum m_\nu < 0.0642$ eV (95%). When accounting for neutrino oscillation constraints, we find a preference for the normal mass ordering and an upper bound of $m_l < 0.023$ eV (95%) on the lightest neutrino mass. However, we determine using frequentist and Bayesian methods that our constraints are in moderate tension with the lower limits derived from neutrino oscillations. Correcting for the physical boundary at zero mass, we report a 95% Feldman-Cousins upper bound of $\sum m_\nu < 0.053$ eV, breaching the lower limit from neutrino oscillations. Considering a more general Bayesian analysis with an effective cosmological neutrino mass parameter, $\sum m_{\nu,\mathrm{eff}}$, that allows for negative energy densities and removes unsatisfactory prior weight effects, we derive constraints that are in 3σ tension with the same oscillation limit. In the absence of unknown systematics, this finding could be interpreted as a hint of new physics not necessarily related to neutrinos. The preference of DESI and CMB data for an evolving dark energy model offers one possible solution. In the w_0w_aCDM model, we find $\sum m_\nu < 0.163$ eV (95%), resolving the neutrino tension. [Abridged]

not quite *bad* news, but:

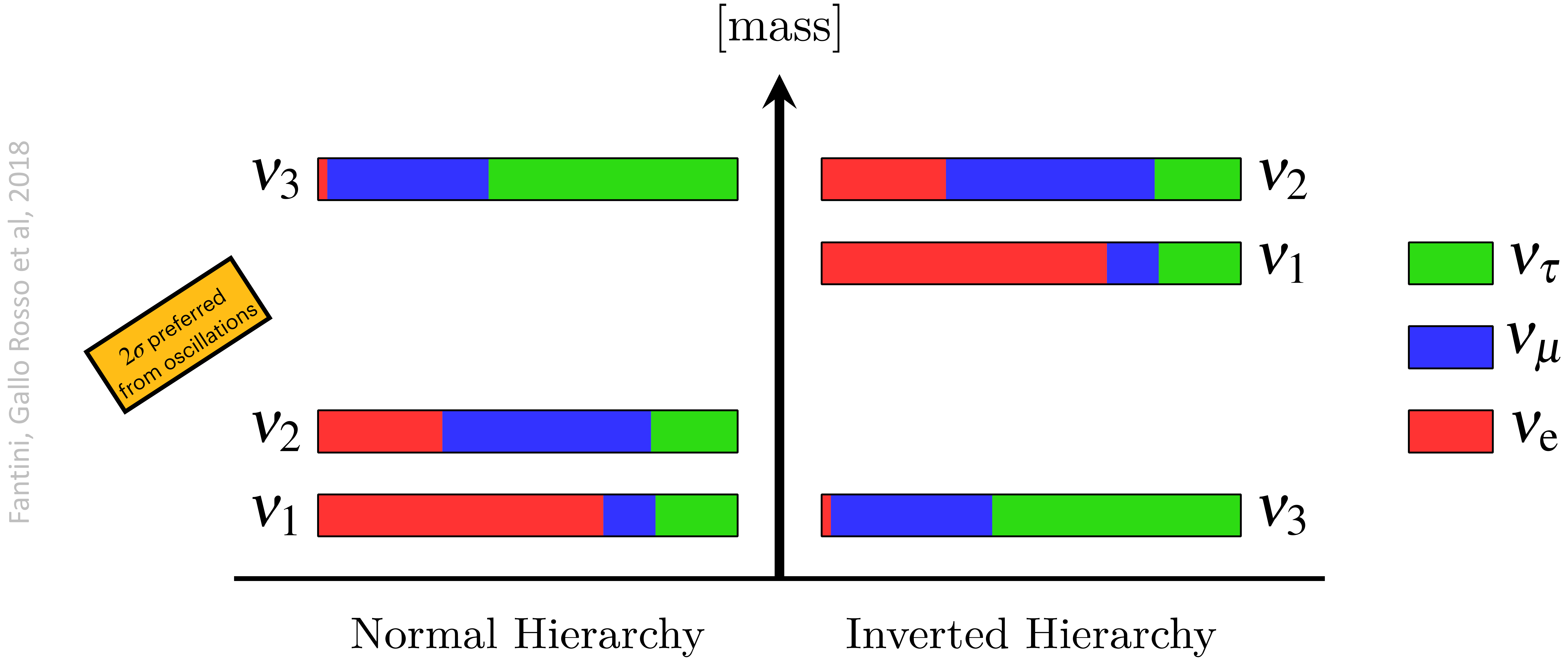
- Until recently, it seemed that neutrino data begin to converge towards a spectrum resembling the one of quarks with $m_{lightest} \lesssim \sqrt{\Delta m^2_{sol}} \sim 10$ meV.
- However, new *global analyses of oscillation data* have shown a deterioration in the quality of some alleged acquisitions, such as on the preference on "normal spectrum".
- Moreover, reasons are emerging to reconsider minimal cosmology (ΛCDM), which weakens the *inference on neutrino mass*.

Ongoing research programmes will ensure progress on these issues. However, this situation advises intensifying theoretical efforts and making the state of the art as clear as possible.

features of leptons

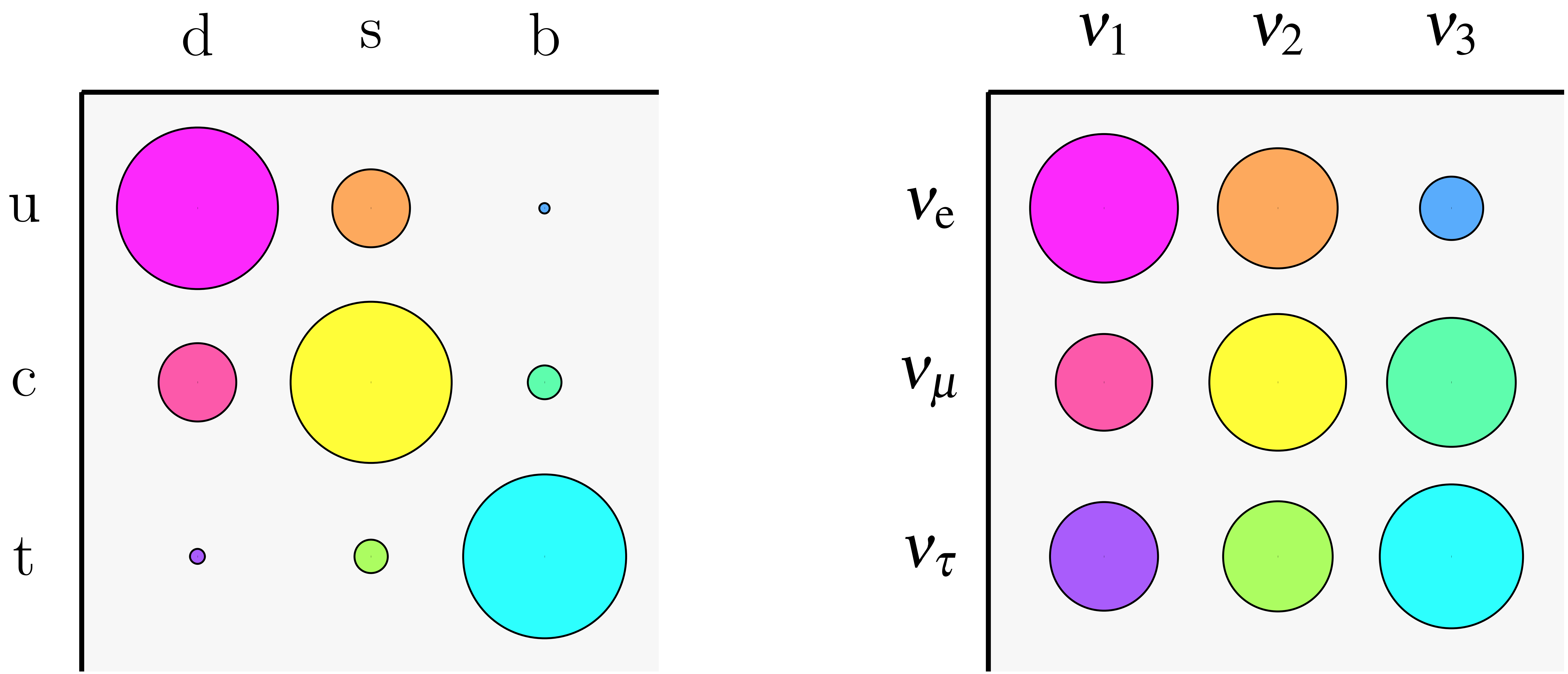
comparison with quarks ; various possibilities for leptonic CP violations

overview of neutrino masses and mixings



jargon nomenclature for neutrinos: hierarchy=spectrum type=order/ordering

overview of neutrino masses and mixings



Fantini, Gallo Rosso et al, 2018

the areas are proportional to $|V_{qq'}|$ and $|U_{\ell i}|$

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 tested with movable detector. Not supported by DANSS, Stereo, NEOS
- Adding sterile neutrinos ***does not*** help: the ensuing theory is predictive, leads to inconsistencies

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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]

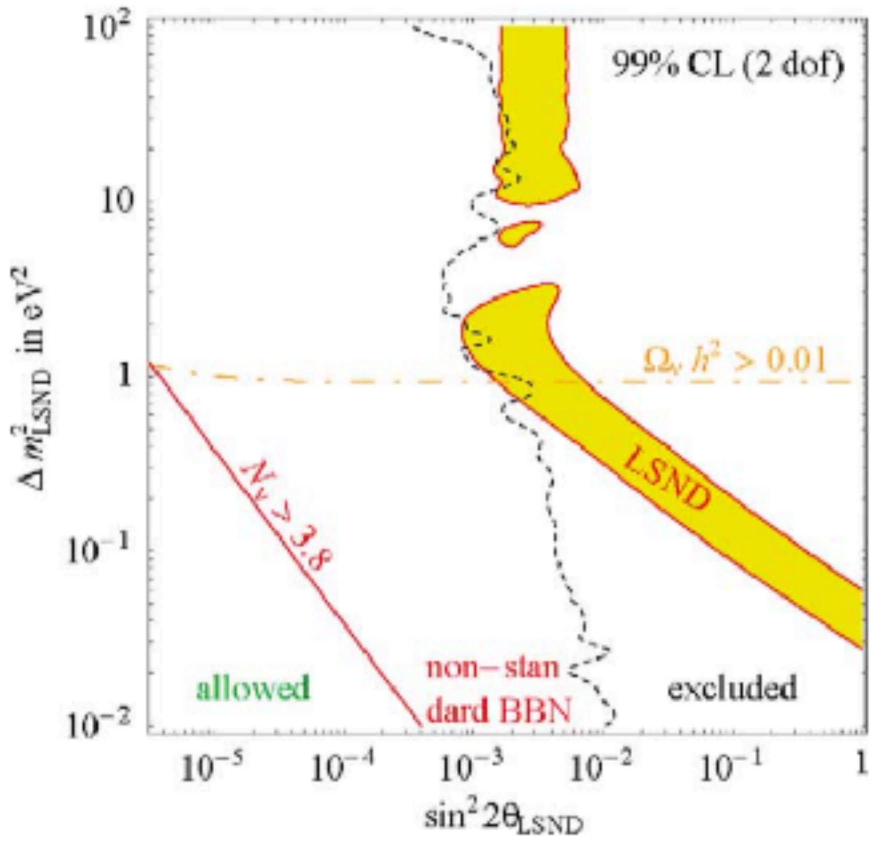

Fig. 13. The LSND anomaly interpreted as oscillations of $3+1$ neutrinos. Shaded region: suggested at 99% C.L. by LSND. Black dotted line: 99% C.L. global constraint from other neutrino experiments (mainly Karmen, Bugey, SK, CDHS). Continuos red line: $N_\nu = 3.8$ thermalized neutrinos. Dot-dashed orange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

JHEP

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

Mona Dentler,[a] Álvaro Hernández-Cabezudo,[b] Joachim Kopp,[a,c] Pedro Machado,[d] Michele Maltoni,[e] Ivan Martinez-Soler[e] and Thomas Schwetz[b]

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 $\Delta m^2_{41} \approx 1.3\,\text{eV}^2$ 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.

overview of neutrino masses and mixings

CP violation: analogies and differences with the case of hadrons/quarks [1/2]

1. CP violation manifestations **analogous to CKM** *(Cabibbo 1978)* are being tested.

2. Majorana neutrinos display *other* physical phases, as we can see easily

$$\delta \mathscr{L} = \frac{1}{2}\left(m_{11}\ \nu_1 \beta \nu_1 + m_{22}\ \nu_2 \beta \nu_2 + 2 m_{12}\ e^{i\varphi_{12}}\ \nu_1 \beta \nu_2 \right)$$

This can be tested studying "neutrinoless double beta decay" *(more later)*

3. **Right-handed neutrinos** may exhibit CP violation in decays as heavy mesons do

Aspects of CP violation in the leptonic sector
F. Vissani (Gran Sasso) (Nov, 1999)
Published in: *Frascati Phys.Ser.* 16 (1999) 337-352 • Contribution to: 3rd Workshop on Physics and Detectors for DAPHNE (DAPHNE 99), 337-352

CP violation: analogies and differences with the case of hadrons/quarks [2/2]

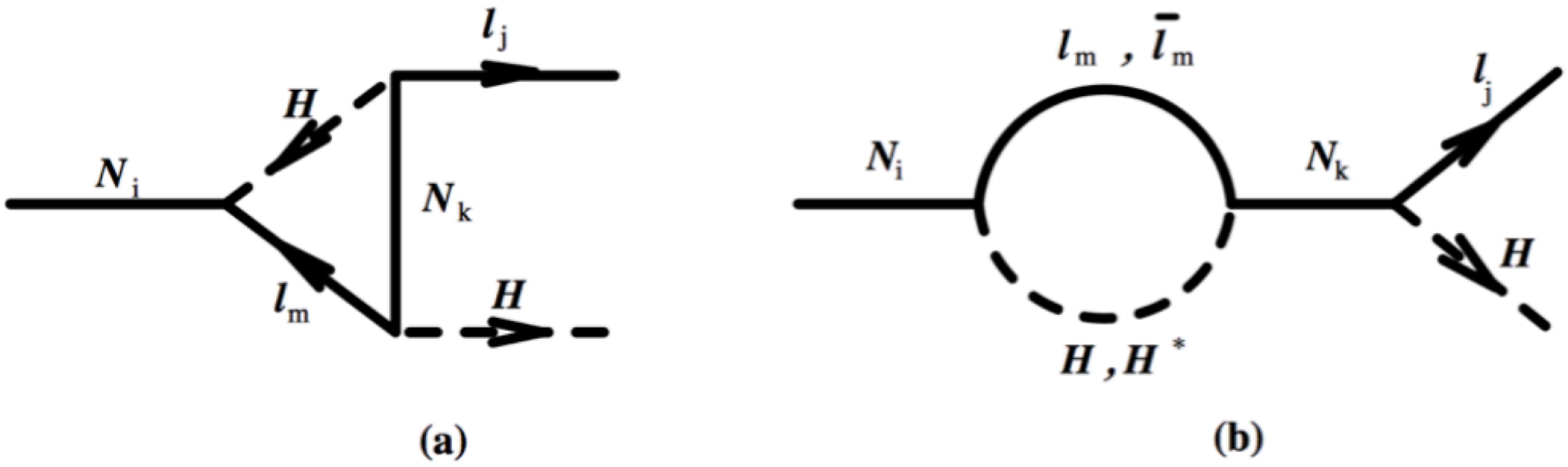
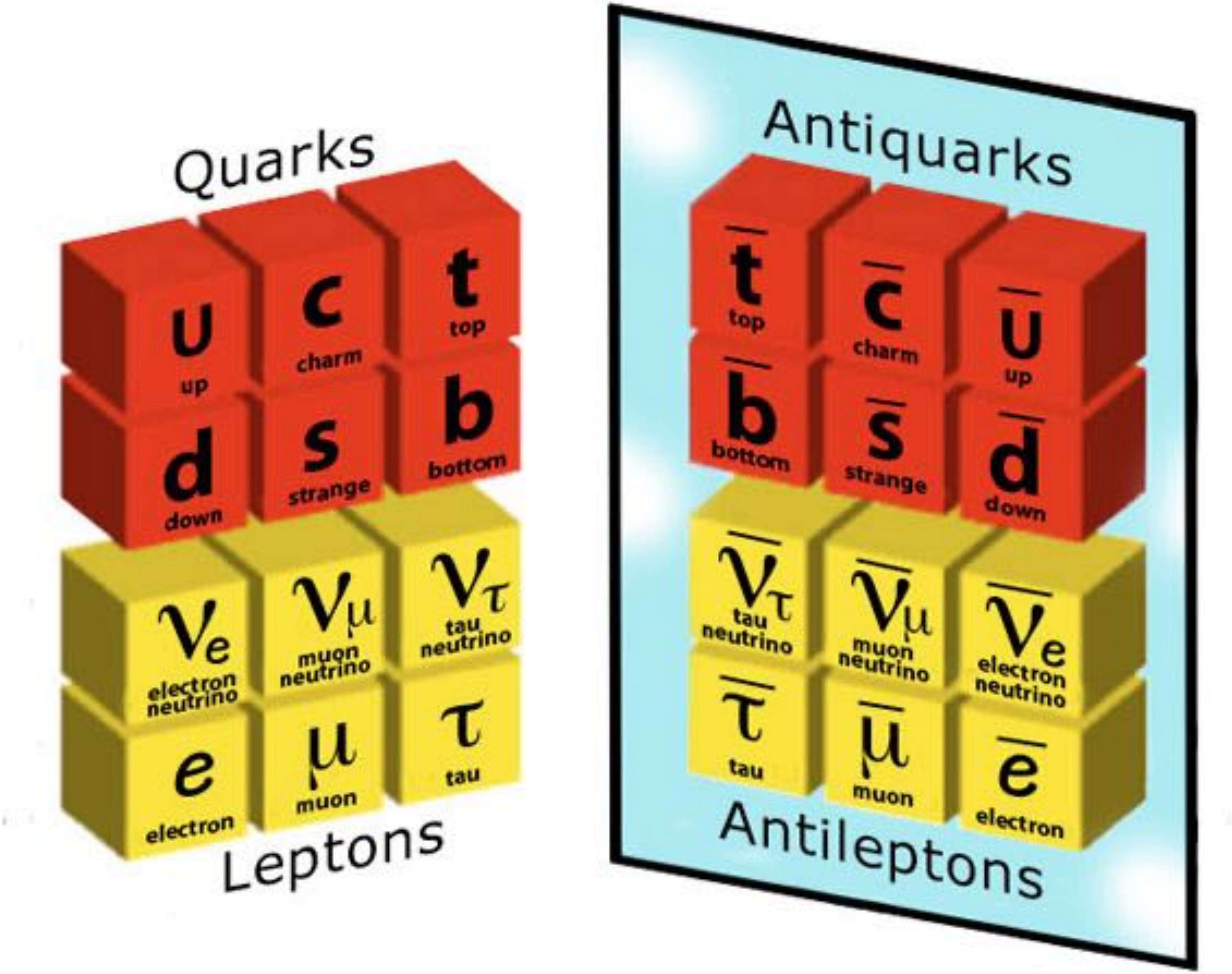


Figure 1: Diagrams contributing to the vertex (Fig. 1a) and wave function (Fig. 1b) CP violation in the heavy singlet neutrino decay.

CP violating decays in leptogenesis scenarios
Laura Covi (SISSA, Trieste), Esteban Roulet (SISSA, Trieste), Francesco Vissani (ICTP, Trieste) (May, 1996)
Published in: *Phys.Lett.B* 384 (1996) 169-174, *Phys.Lett.B* 384 (1996) 169-174 • e-Print: hep-ph/9605319 [hep-ph]

baryon & lepton numbers

matter in the SM ; its accidental symmetries ; their tests



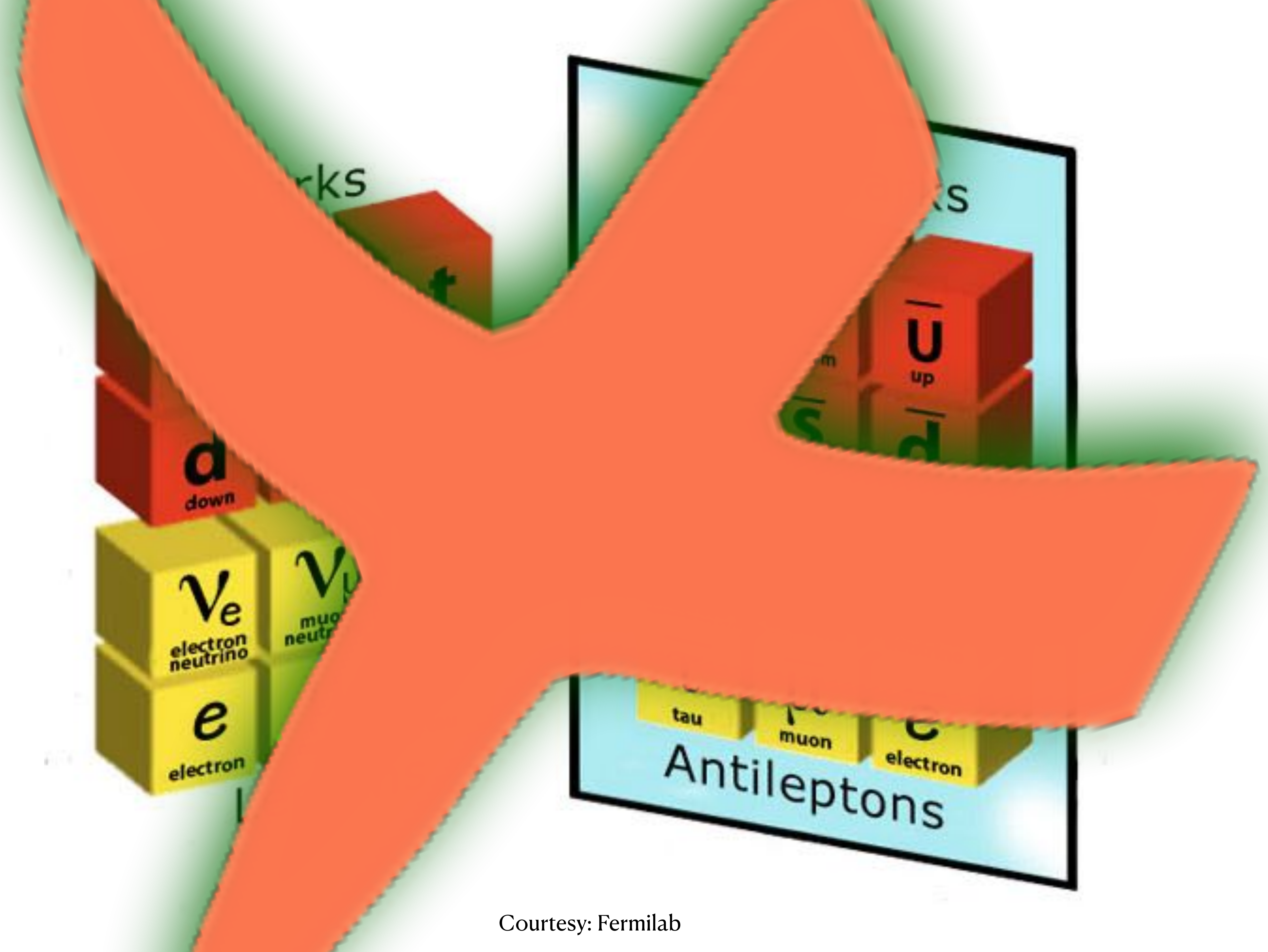
Courtesy: Fermilab

neutrinos tell us: SM global numbers are violated

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

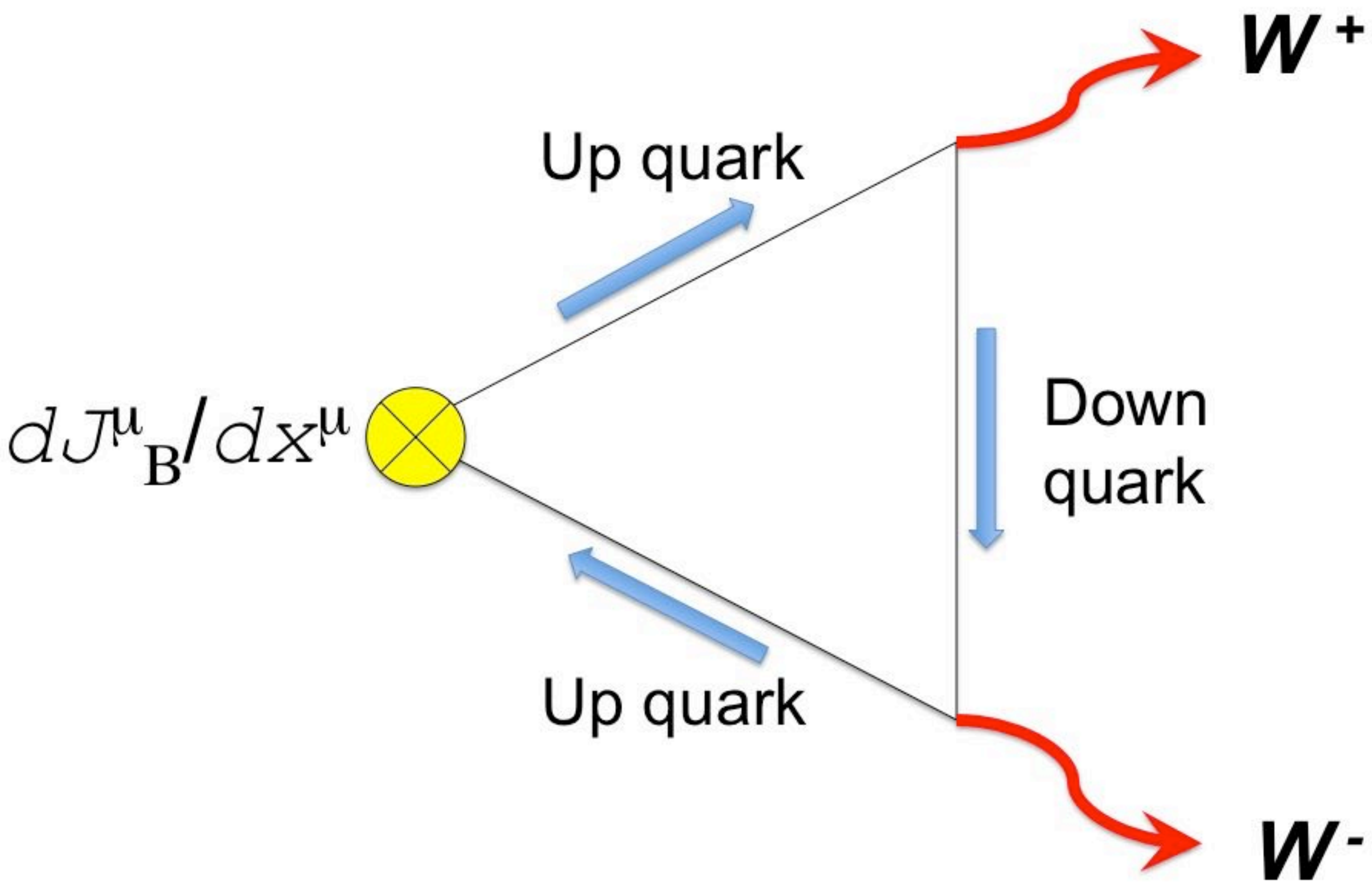
	ΔL_e	ΔL_μ	ΔL_τ	ΔL
$\nu_\mu \rightarrow \nu_e$	+1	-1	0	0
$\nu_\mu \rightarrow \nu_\tau$	0	-1	+1	0

We know empirically that all global symmetries of SM are violated, except **L** and **B**.
There are 2 types of **matter particles**: leptons and quarks



Courtesy: Fermilab

that's not all: B and L, alone, are not conserved exactly in SM



only B-L does; leptons & quarks are connected

there is just one exact global number untested

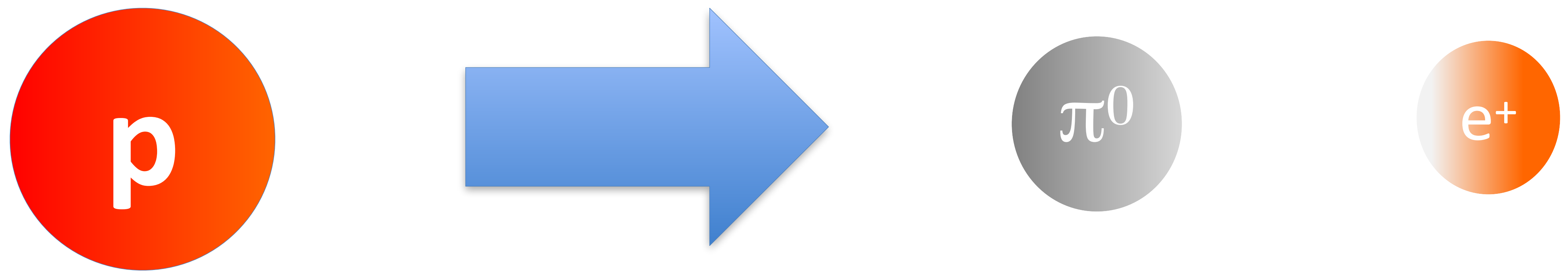
(=at the scrutiny of T2K, NOvA, OPERA, SK, DeepCore & in view of SM theoretical consistency)

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

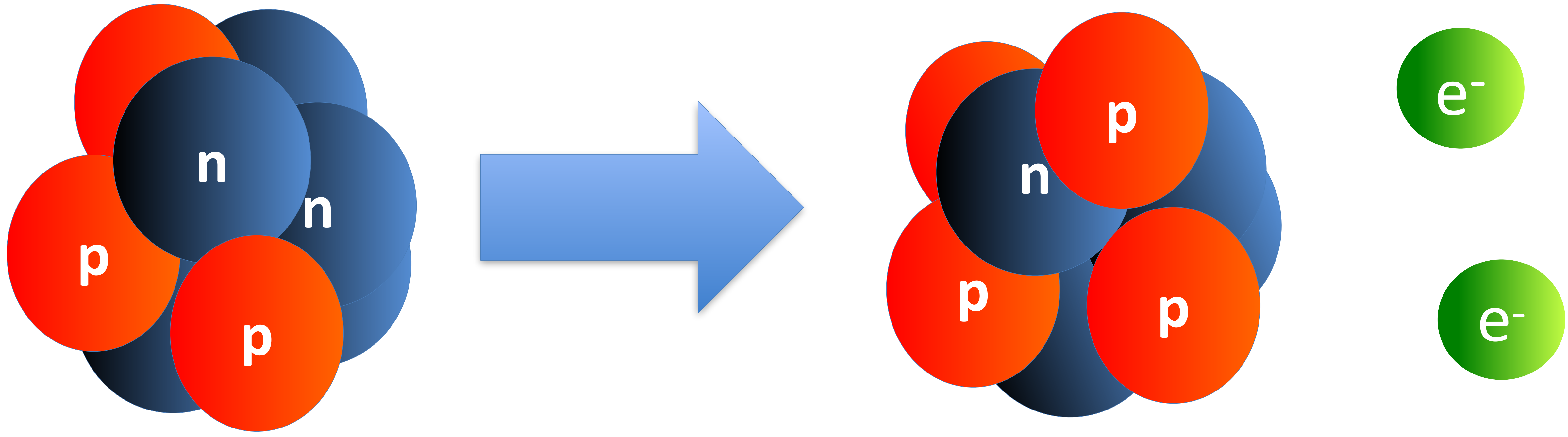
All anomaly free symmetries of SM are known to be violated except **B-L**

B+L is not a conserved number in the SM ; leptons and baryons conversion is **possible.**

(remark/reminder)



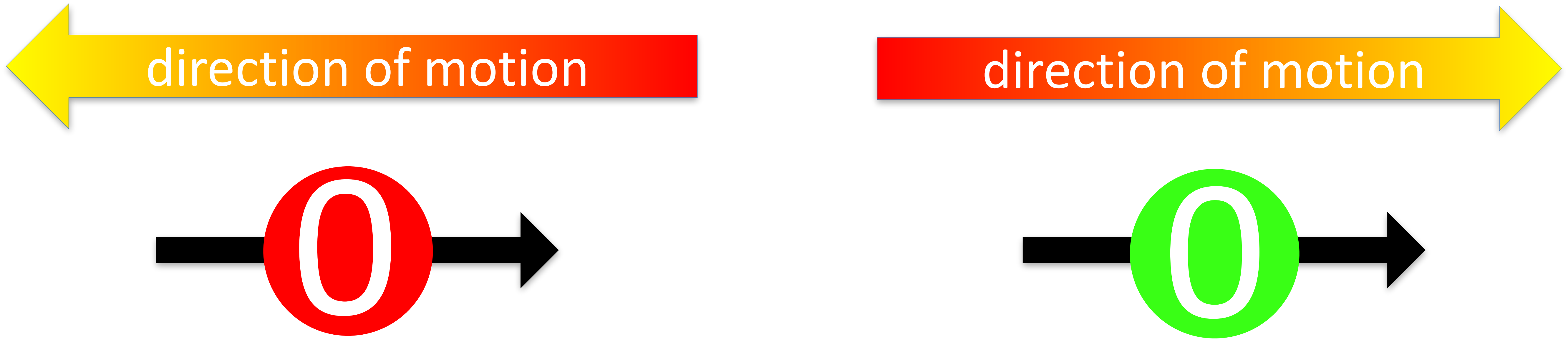
Proton decay (B-L conserved)



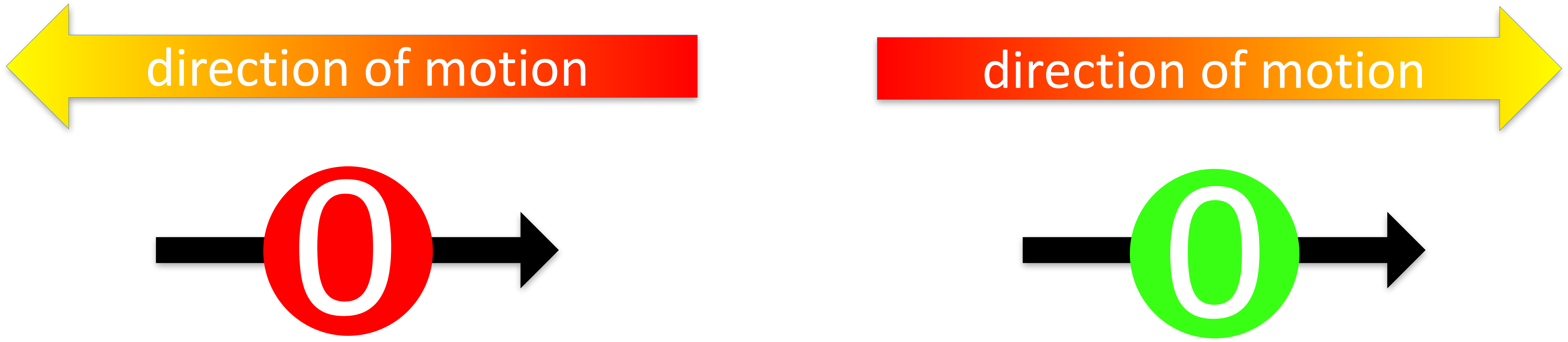
Electrons Creation (B-L violated)

Majorana mass

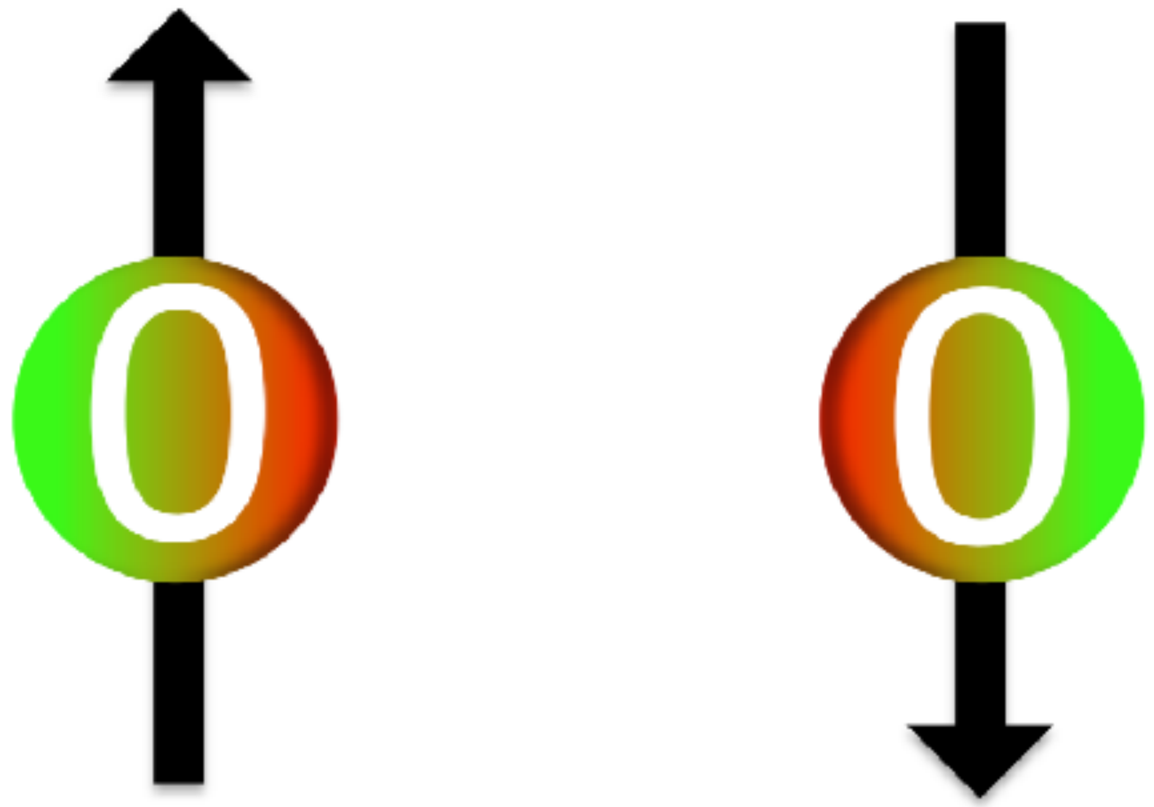
why in SM extensions & implications for electron creation



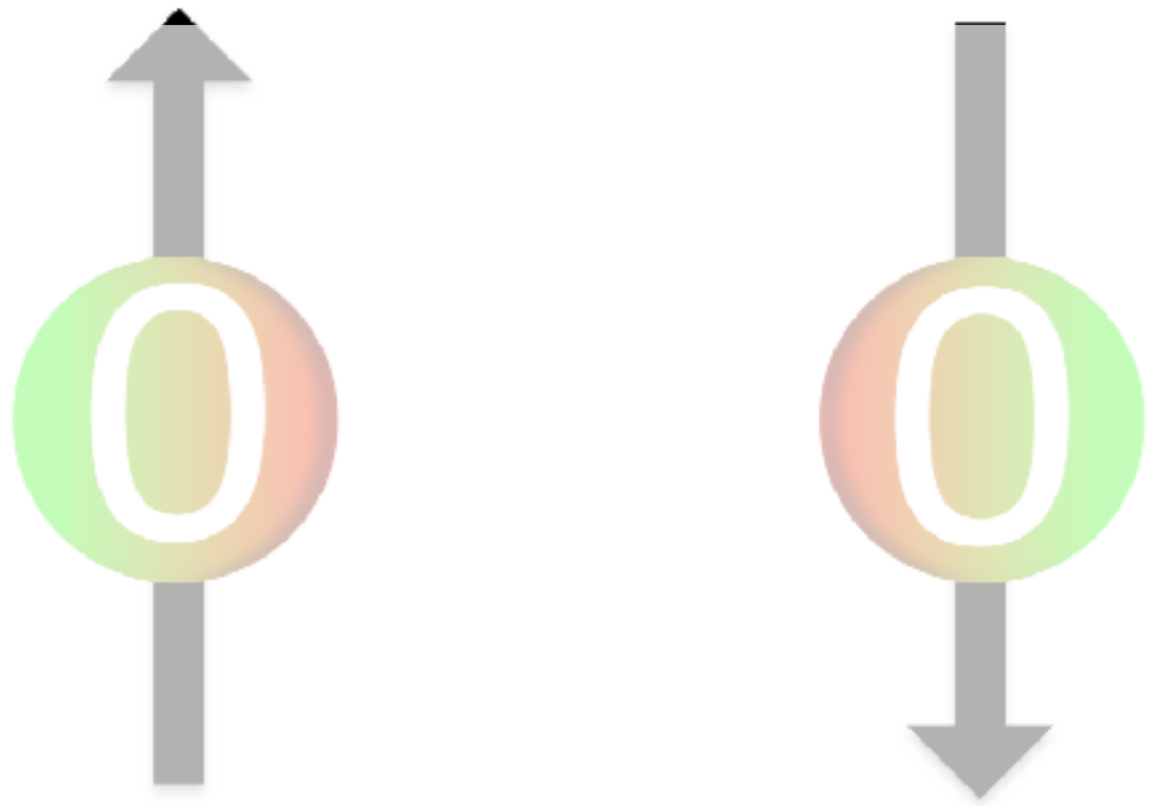
helicity tells neutrinos from antineutrinos



but in rest system that exists they look the same

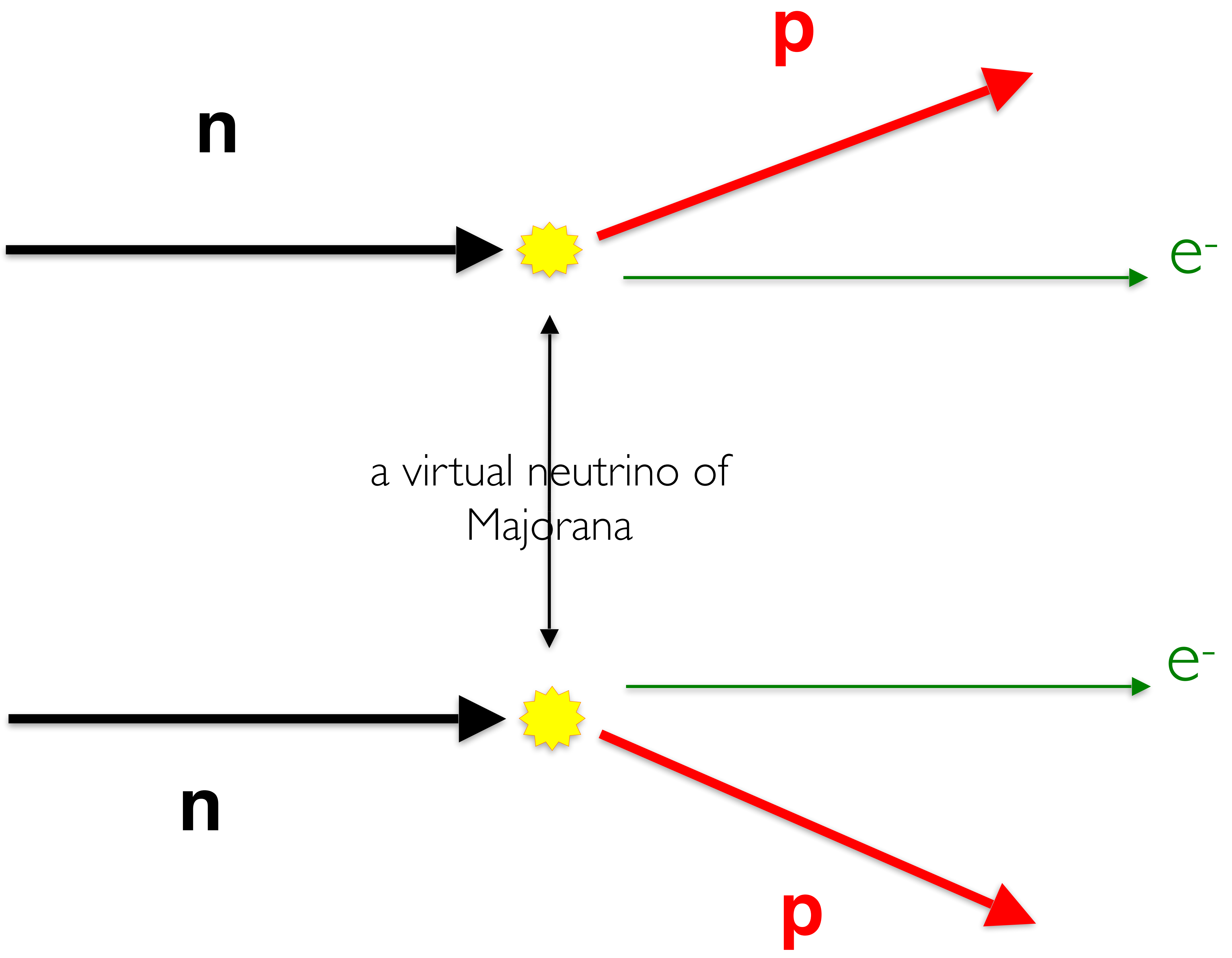


Majorana 1937: neutrinos are matter & antimatter



Majorana's neutrinos enable electron creation

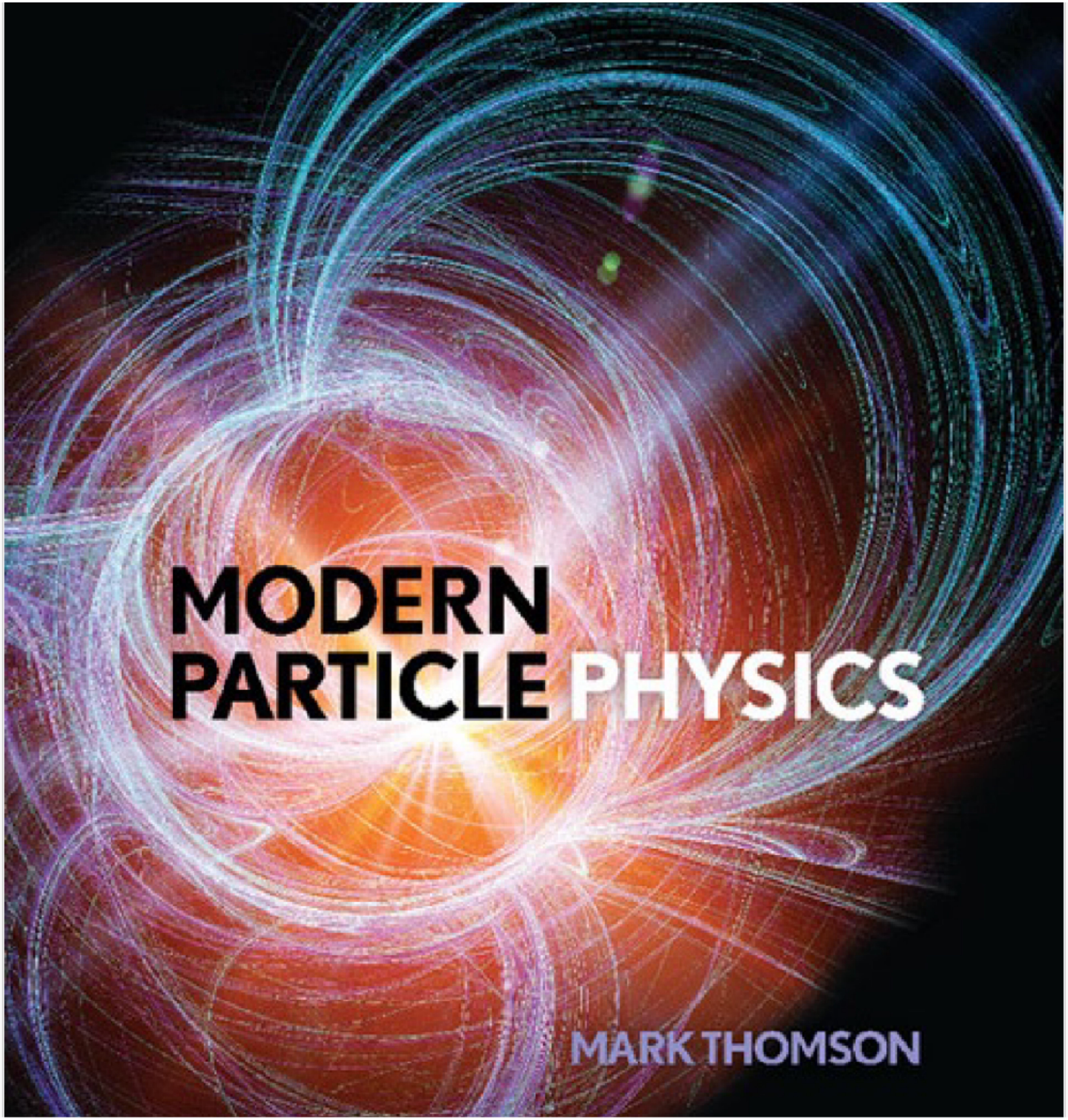
$$2\,\mathbf{n} \rightarrow 2\,\mathbf{p} + 2\,e^-$$



Courtesy: Fermilab

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 (from Nobel lecture, 1979)

Courtesy: Fermilab



Cambridge U. Pr, 2013

18 The Standard Model and beyond

18.1 The Standard Model

18.2 Open questions in particle physics

18.2.1 What is dark matter?

18.2.2 Does supersymmetry exist?

18.2.3 Can the forces be unified?

18.2.4 What is the nature of the Higgs boson?

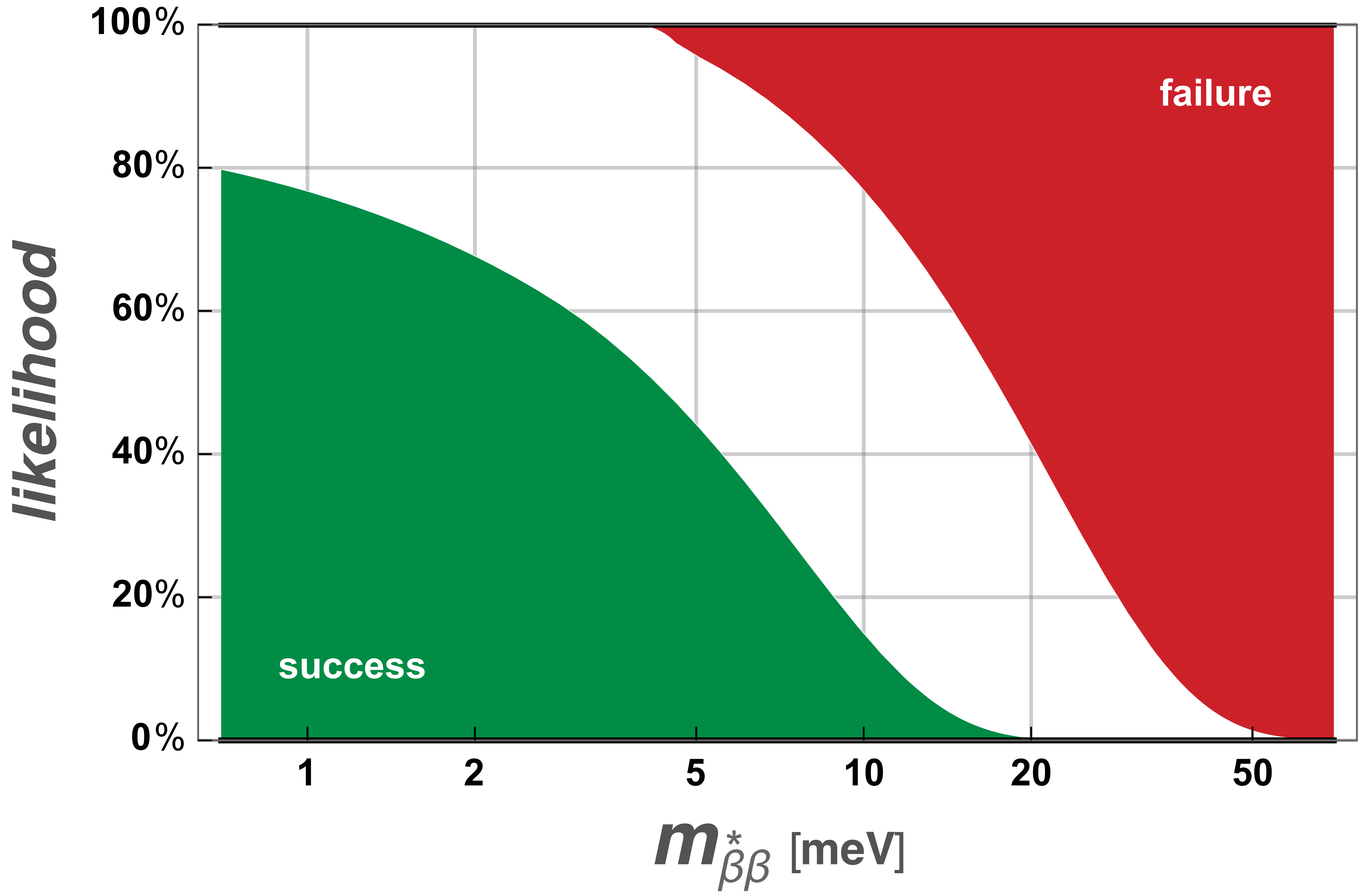
18.2.5 Flavour and the origin of CP violation

18.2.6 Are neutrinos Majorana particles?

18.3 Closing words

discovery potential of electron creations

as a function of the experimental sensitivity



PRD 103, 033008 (2021)

models of new physics?

on the richness of the heavy right-handed neutrino hypothesis :
"seesaw" ; leptogenesis ; naturalness/hierarchy

GAUGE THEORIES AND THE SMALLNESS OF m_ν

Existence of heavy right handed neutrinos is quite reasonable in GUT; they endow m_ν with small Majorana mass!

Their masses M_R have nothing to do with the one of SM $\propto M_W$

Just as W boson mass leads to $\frac{G_F}{\sqrt{2}} = \frac{g^2}{8M_W^2}$ in SM, they lead to $m_\nu \propto \frac{M_W^2}{M_R}$

see-saw was known to ancient Greeks
(for recent usage: P. Minkowski 77 *et al*)

guessing RH neutrino mass scales

- High dim. operators, invariant under SM symmetry, resume the effects of 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 $\sqrt{\Delta m^2}$ point to **huge** masses

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

leptogenesis: a natural option for the origin of baryons

(Fukugita-Yanagida's implementation of Sakharov's program)

(1) During big-bang, the decay of heavy (right-handed) neutrinos create ΔL

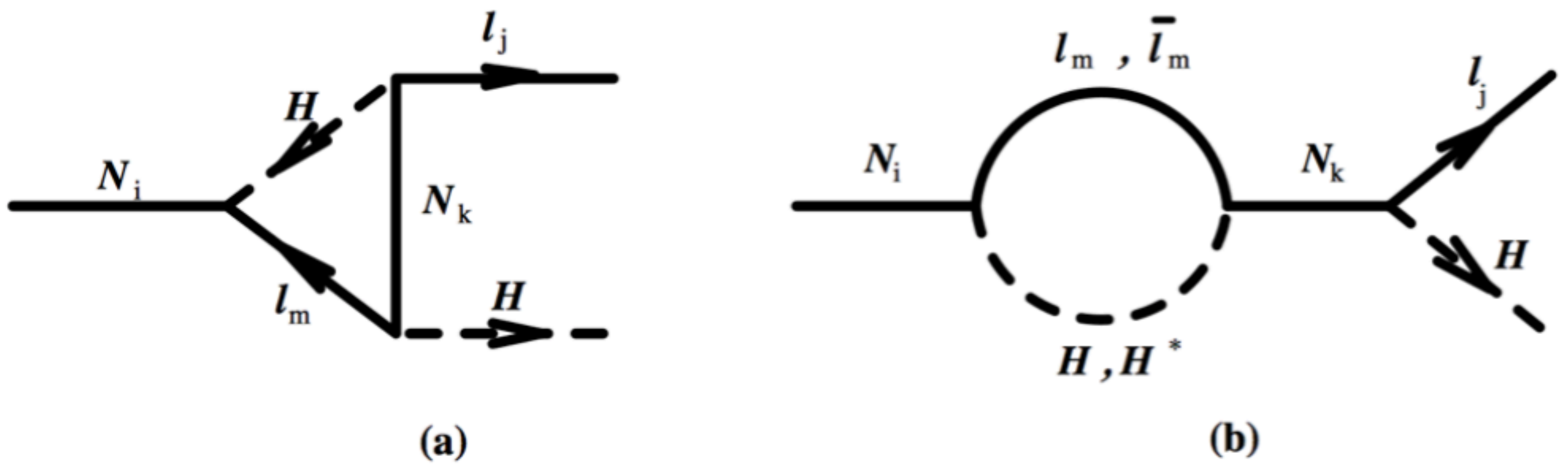


Figure 1: Diagrams contributing to the vertex (Fig. 1a) and wave function (Fig. 1b) CP violation in the heavy singlet neutrino decay.

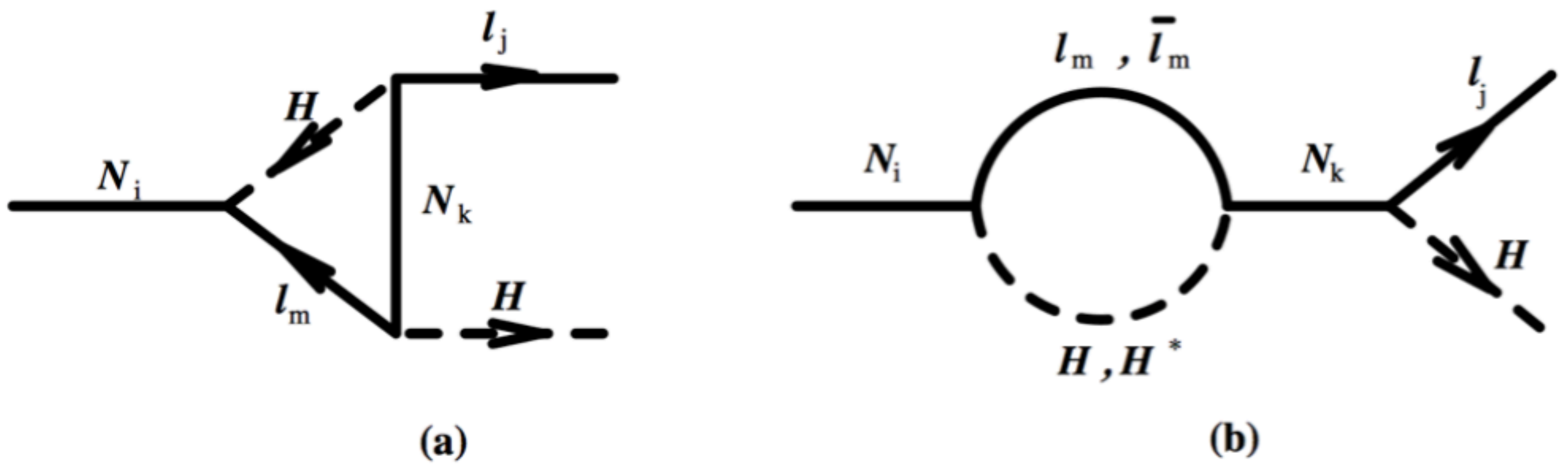
Covi et al. '96

leptogenesis: a natural option for the origin of baryons

(Fukugita-Yanagida's implementation of Sakharov's program)

(1) During big-bang, the decay of heavy (right-handed) neutrinos create $\Delta\mathbf{L}$

(2) Subsequently, $\mathbf{B}+\mathbf{L}$ violating effects convert it into $\Delta\mathbf{B}$



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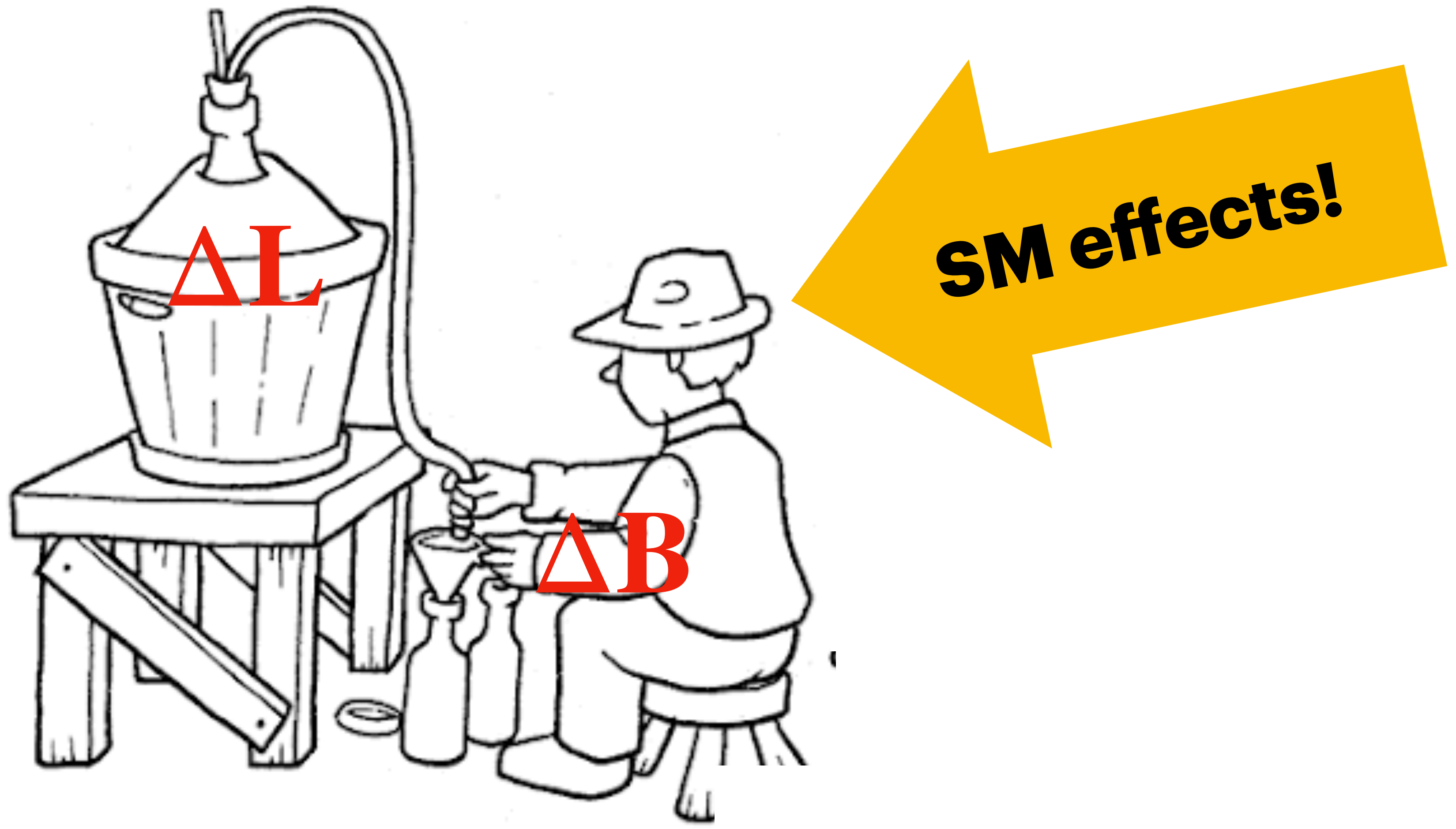
Covi et al. '96



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)

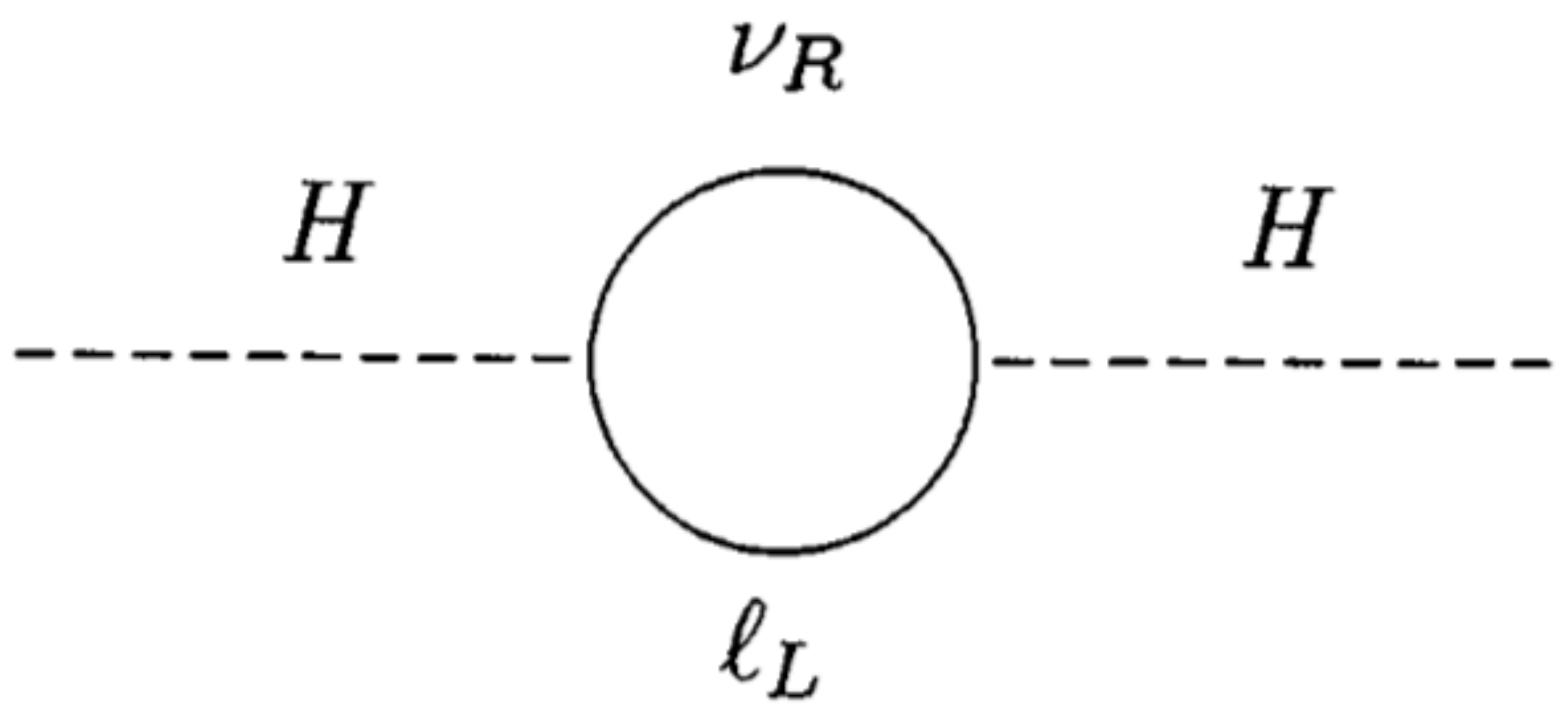


FIG. 1. The Feynman diagram originating the corrections in Eq. (1); ν_R denotes the right-handed neutrino of mass M_R, $\ell_L = (\nu_L, e_L)$ the leptonic and H the Higgs doublets.

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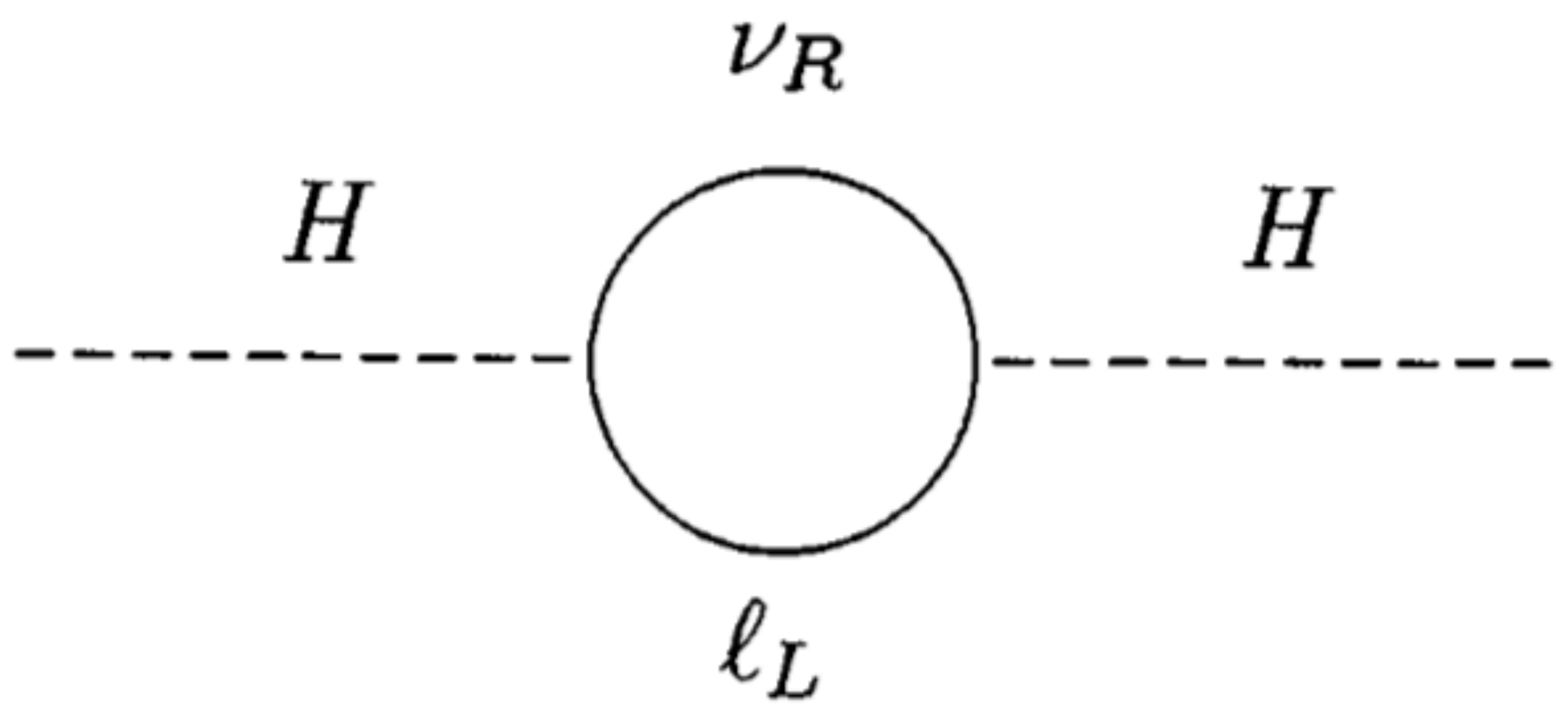


FIG. 1. The Feynman diagram originating the corrections in Eq. (1); ν_R denotes the right-handed neutrino of mass M_R, $\ell_L = (\nu_L, e_L)$ the leptonic and H the Higgs doublets.

OK, but what about the cosmological constant?

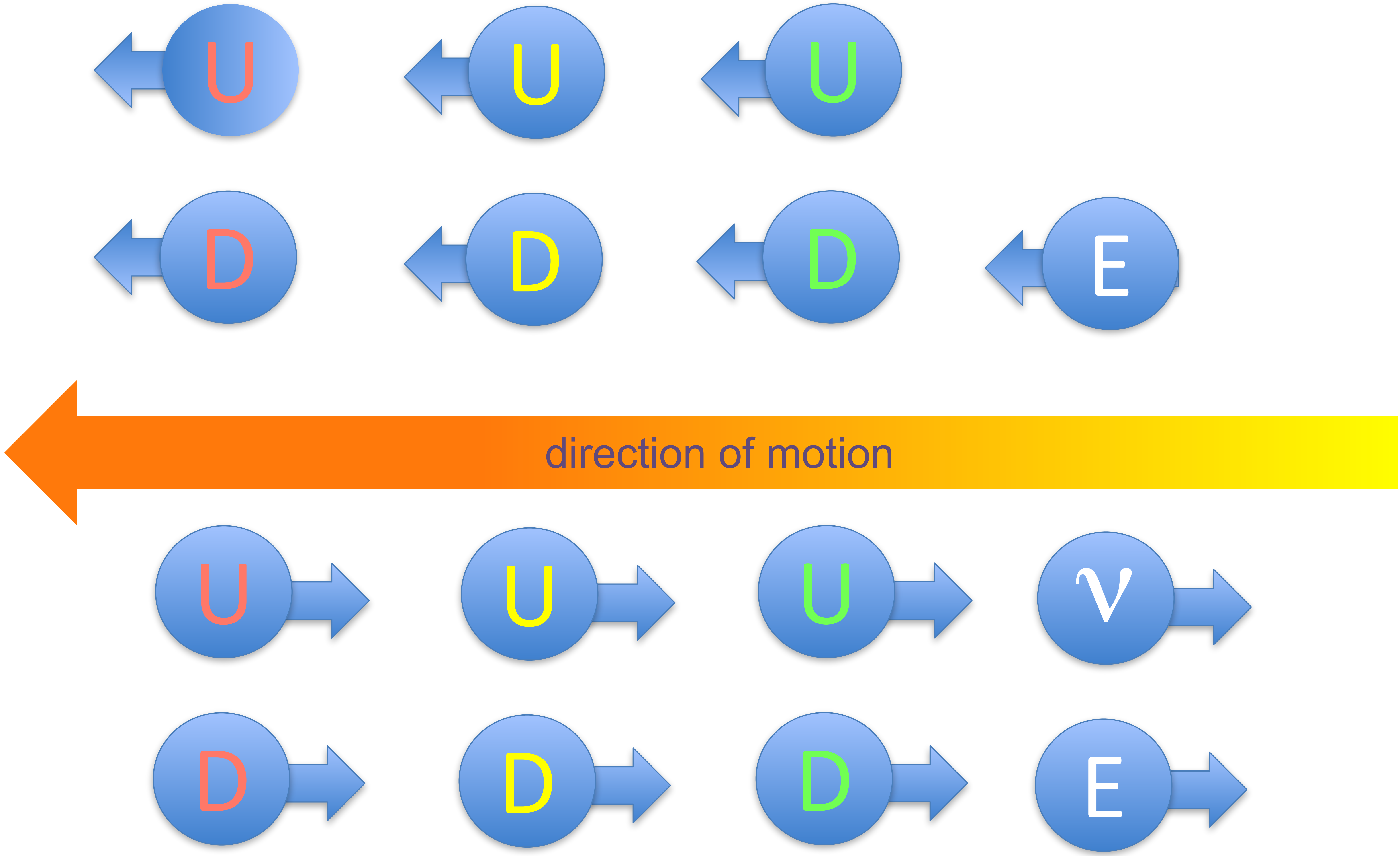
questions & remarks

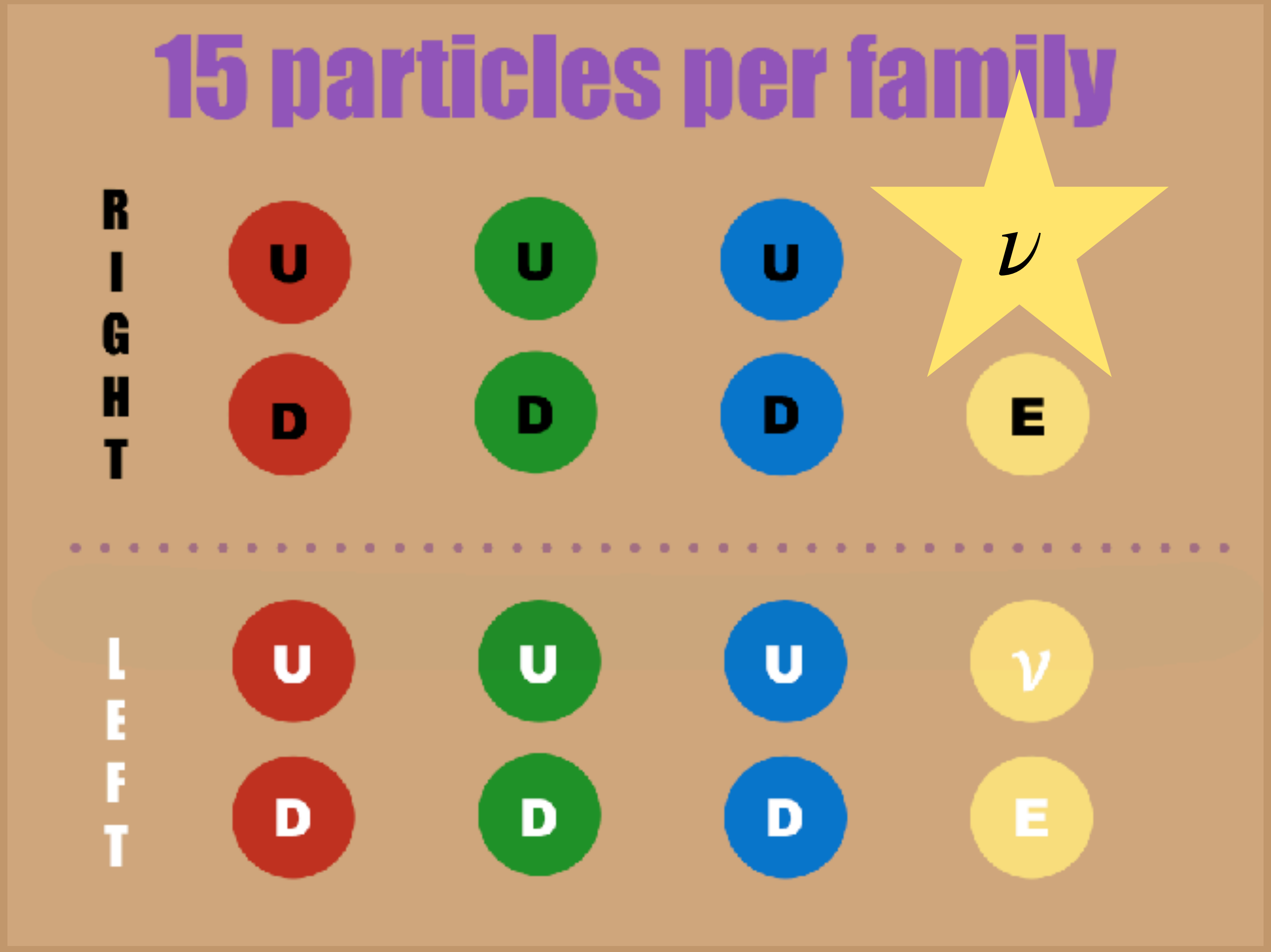
promising directions, uncertainties, and risks of missteps

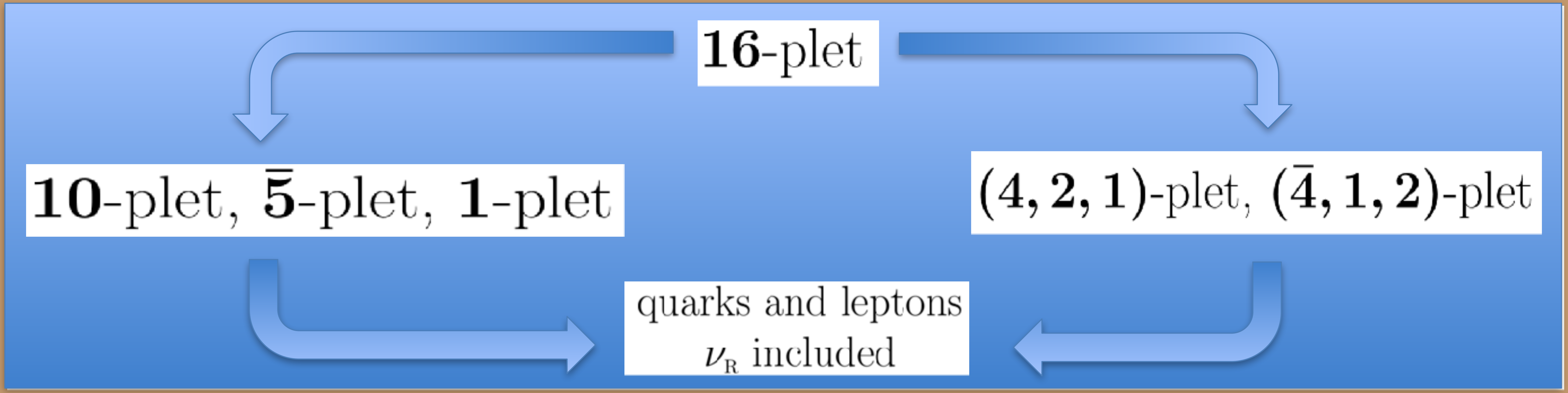
particle physics

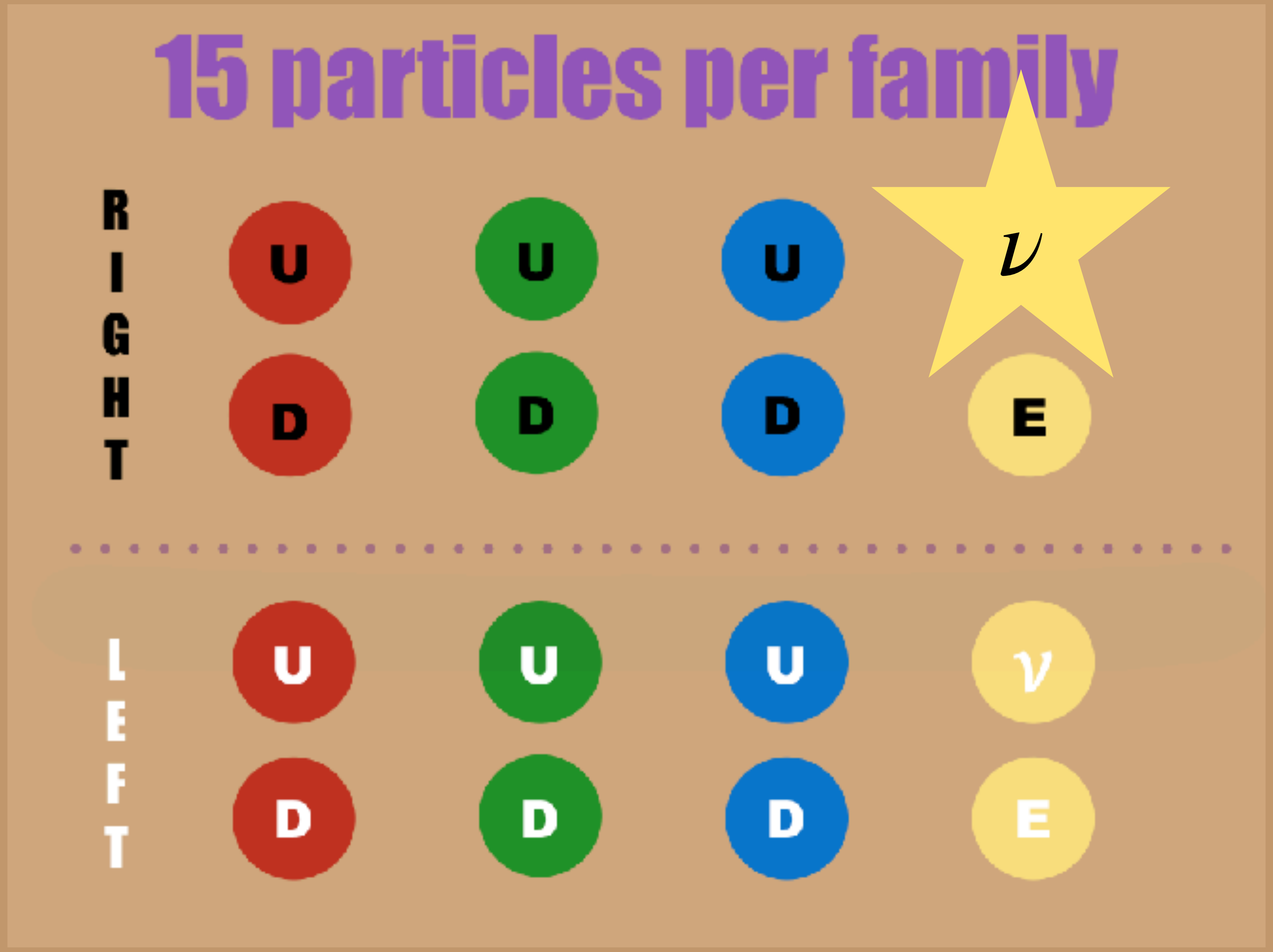
- Why *certain particles* in a family? What is *behind* neutrino masses? Why replication of families?
- Can the principles of ***gauge theory*** still help us move forward?
- Is there any further light state?
- Is there a connection of neutrino masses and ***proton decay?***
- Are *fermions masses* connected among them?

what's in a family




15 particles per family
RIGHT
LEFT
U
D
E
ν


16-plet
10-plet, $\bar{5}$-plet, 1-plet
(4, 2, 1)-plet, ($\bar{4}$, 1, 2)-plet
quarks and leptons
ν_R included


15 particles per family
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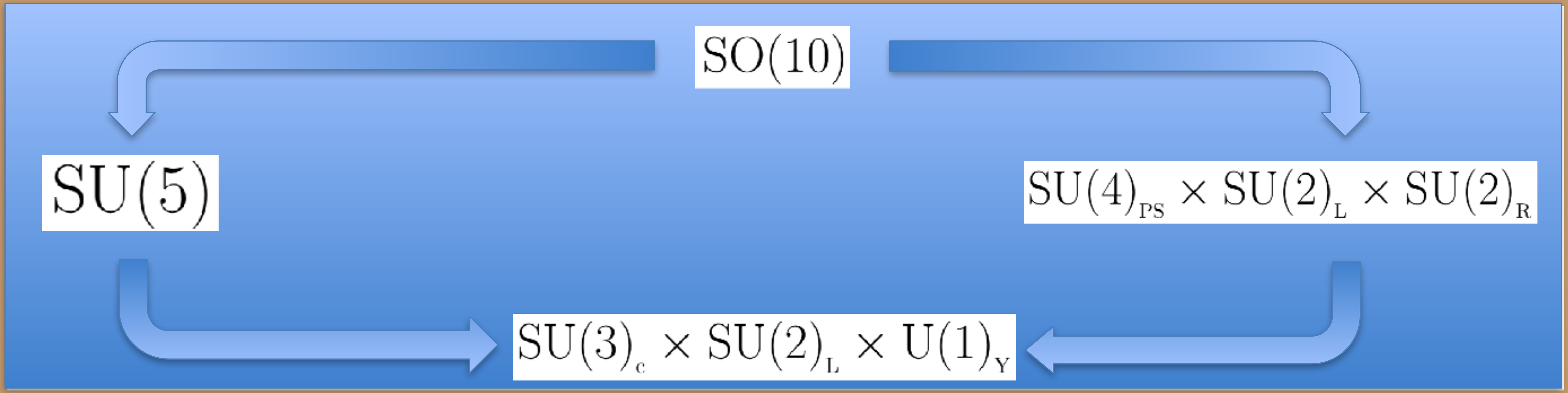
SO(10)
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SU(3)_c × SU(2)_L × U(1)_Y

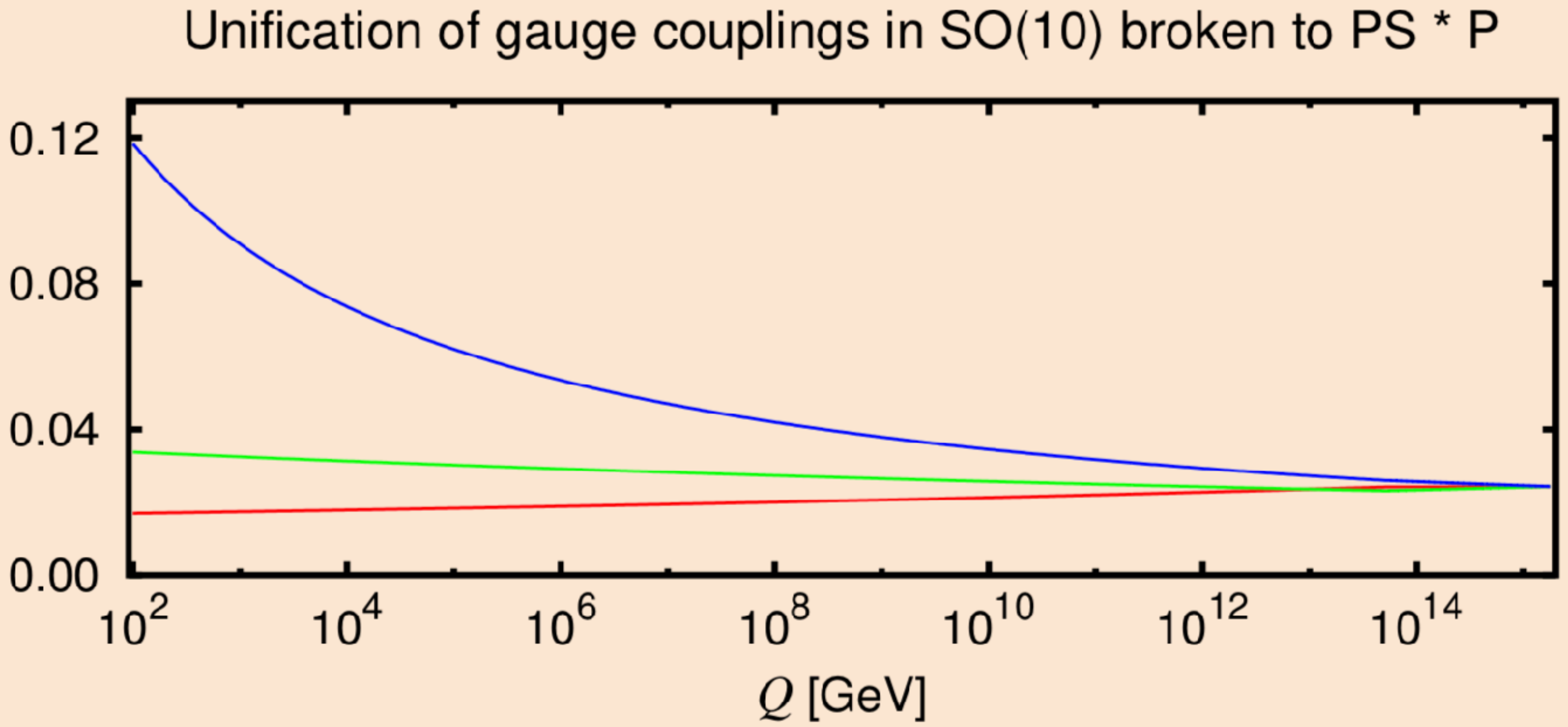


Figure 2: Evolution of the gauge coupling constants in a GUT model with intermediate scale. Here, $M_{\text{interm.}} \approx 5 \times 10^{13}$ GeV.

cosmology

- In view of the indeterminacy $\mathscr{H} \rightarrow \mathscr{H} + \rho_\Lambda$, why $\rho_\Lambda \equiv 0$?
- Why $\Omega_\Lambda \sim \Omega_{DM} \sim \Omega_{atoms}$?
- Inflation requires $\Lambda(t)$; *time dependence* today?
- Dealing with *reliable principles* or *empirical procedures?*

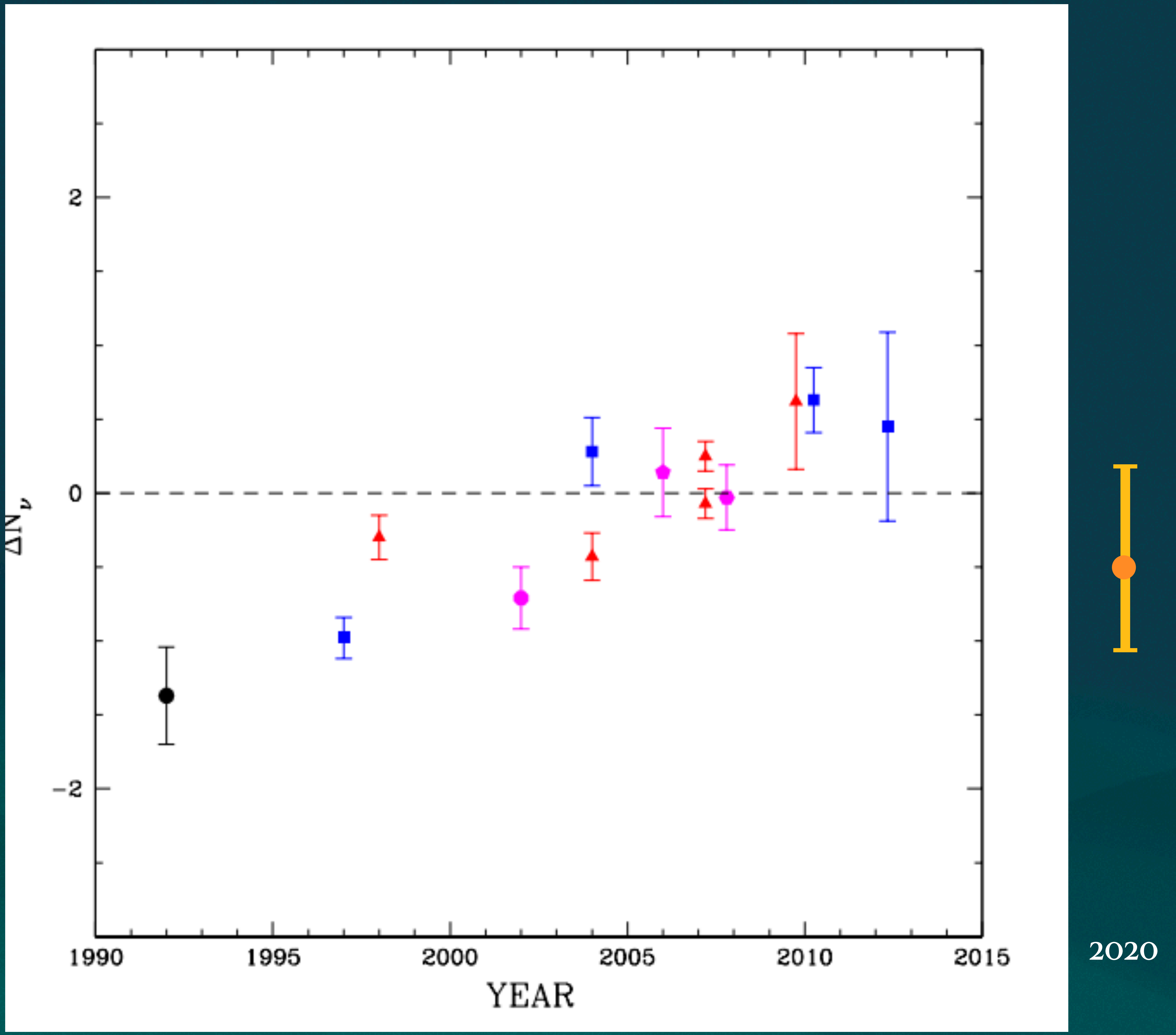
BBN & Number of Neutrinos

- *Steigman 12* depicts the change in number of neutrinos from BBN theory
- Today , thanks to *LUNA 2020* , we have

$$N_\nu = 2.8 \pm 0.3$$

in line with the findings at $z \sim 0\!-\!\text{few}$

- Errors grew with time; input values of ^{4}He is still crucial (*Pisanti et al 21*)
- Bound on ***any types*** of neutrinos



- not too much room for an **additional** neutrino;
- it would be a dream to **detect big-bang neutrinos directly**;
- one expects some **leptonic asymmetry** stored in big-bang neutrinos, but so little as to be almost impossible to probe;
- (how does **dark matter** fit into this picture?)

neutrino applications

Neutrinos helped to construct SM and to go beyond it

- They have many interesting **applications**: we shouldn't forget this
- A brief detour on **history** (next two pages) illustrates this well
- While this is not necessarily **"fundamental physics"**, it may help us to avoid the risks of a dangerous "fundamentalist" attitude.

neutrinos & exploration of the cosmos

is a rather successful enterprise that began a century ago

von Weiszacker; Bethe **1938;39** *Model of the Sun*

Gamow, Schoenberg **1940** *Stars & neutrinos*

Pontecorvo **1946** *Solar neutrinos detection*

B2FH **1956** *^{7}Be & ^{8}B neutrinos*

Bahcall **1964-...** *Standard solar model*

Pontecorvo; Sakata et al **1957-67** *Oscillations*

Davies et al **1969** *First detection*

Bellini et al **2023** *Complete observational test*

Gamow, Schoenberg **1941** *Neutrinos & supernovae*

Colgate White; Arnett **1966** *First calculations*

Kamiokande, IMB, Baksan **1987** *First detection*

Gamow **1946** *Idea of BBN*

$\alpha\beta\gamma$ **1948** *BBN Details of BBN*

Hayashi **1950** *BBN & neutrinos*

Peebles; Wagoner **1966; 1967** *Calculations*

Smith, Kawano, Malaney **1993** *Computer program*

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Observation of an ultra-high-energy cosmic neutrino with KM3NeT

The KM3NeT Collaboration

Nature **638**, 376–382 (2025) | Cite this article

Abstract

The detection of cosmic neutrinos with energies above a teraelectronvolt (TeV) offers a unique exploration into astrophysical phenomena[1,2,3]. Electrically neutral and interacting only by means of the weak interaction, neutrinos are not deflected by magnetic fields and are rarely absorbed by interstellar matter: their direction indicates that their cosmic origin might be from the farthest reaches of the Universe. High-energy neutrinos can be produced when ultra-relativistic cosmic-ray protons or nuclei interact with other matter or photons, and their observation could be a signature of these processes. Here we report an exceptionally high-energy event observed by KM3NeT, the deep-sea neutrino telescope in the Mediterranean Sea[4], which we associate with a cosmic neutrino detection. We detect a muon with an

summary

- Global analyses showed that the quality of some putative acquisitions was *less than believed;* and when ΛCDM is reconsidered ***the inference on m_ν is impacted***.

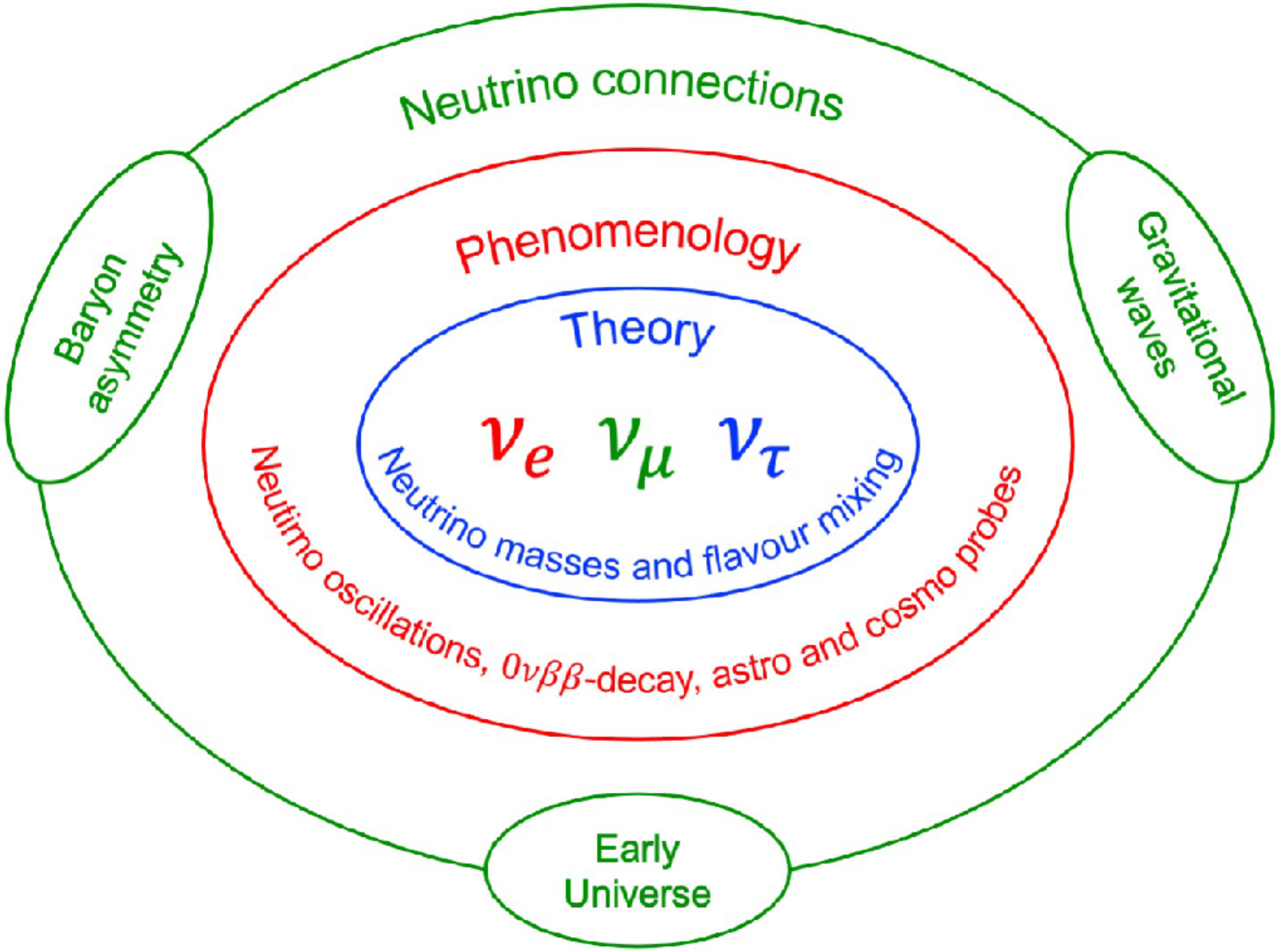
- Current situation suggests that one should measure one's steps well and not be in a hurry to abandon the partial and slowly evolving ***indications from theory***.

- I feel we should invest in exploring *credible and principled theories*; at worst it will help us maximize significance of future experimental & observational findings.

- And in parallel with ***exploring the nature of neutrinos***, it's worth keeping in mind how important it is to keep ***exploring nature with neutrinos***.

Thanks!

N2N: a research initiative with Davide, Giulia, Silvia, Arsenii, et al



direct search of big-bang neutrinos

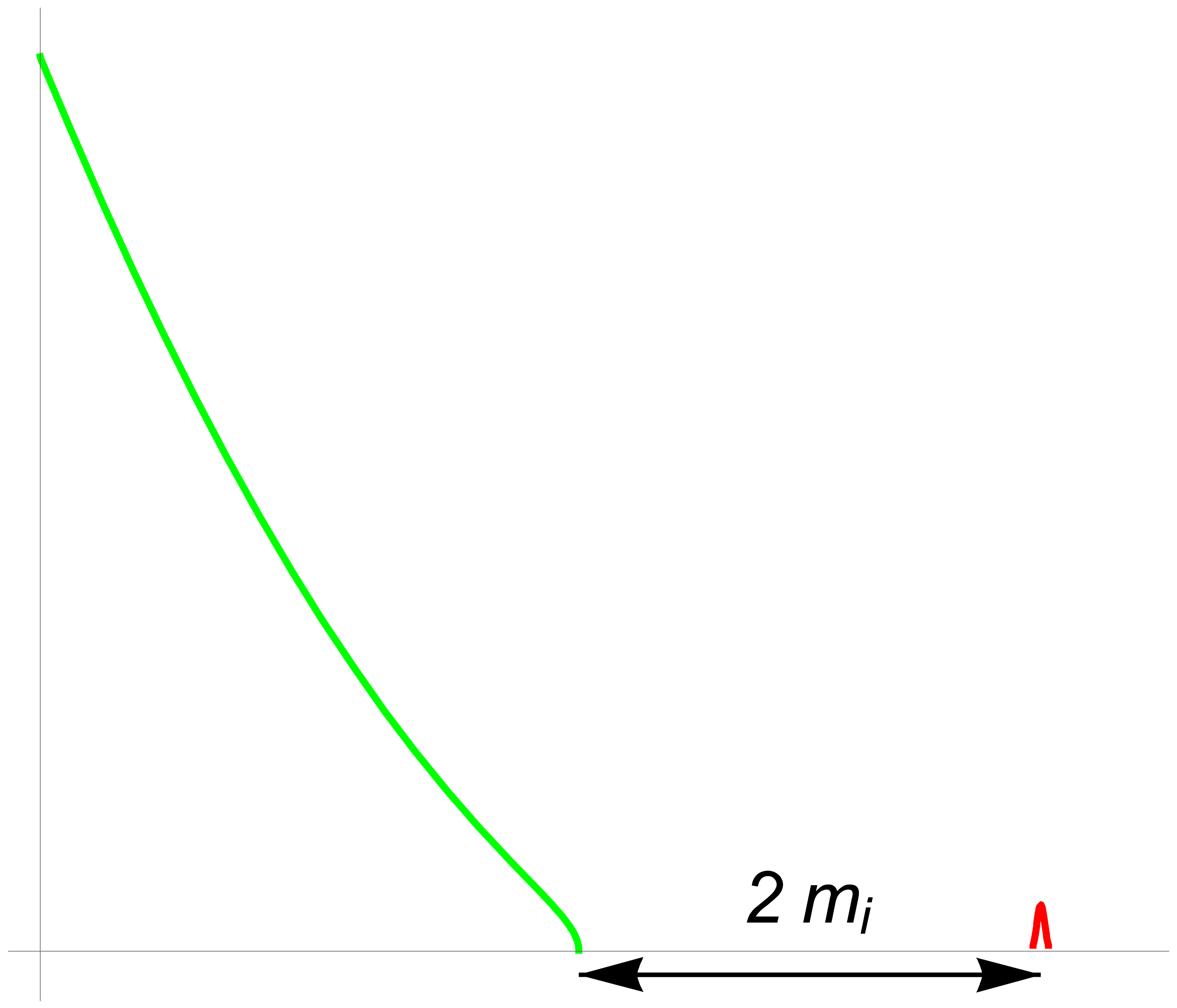
big-bang neutrinos produce 3 **neutrino-capture** lines for a radioactive target

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

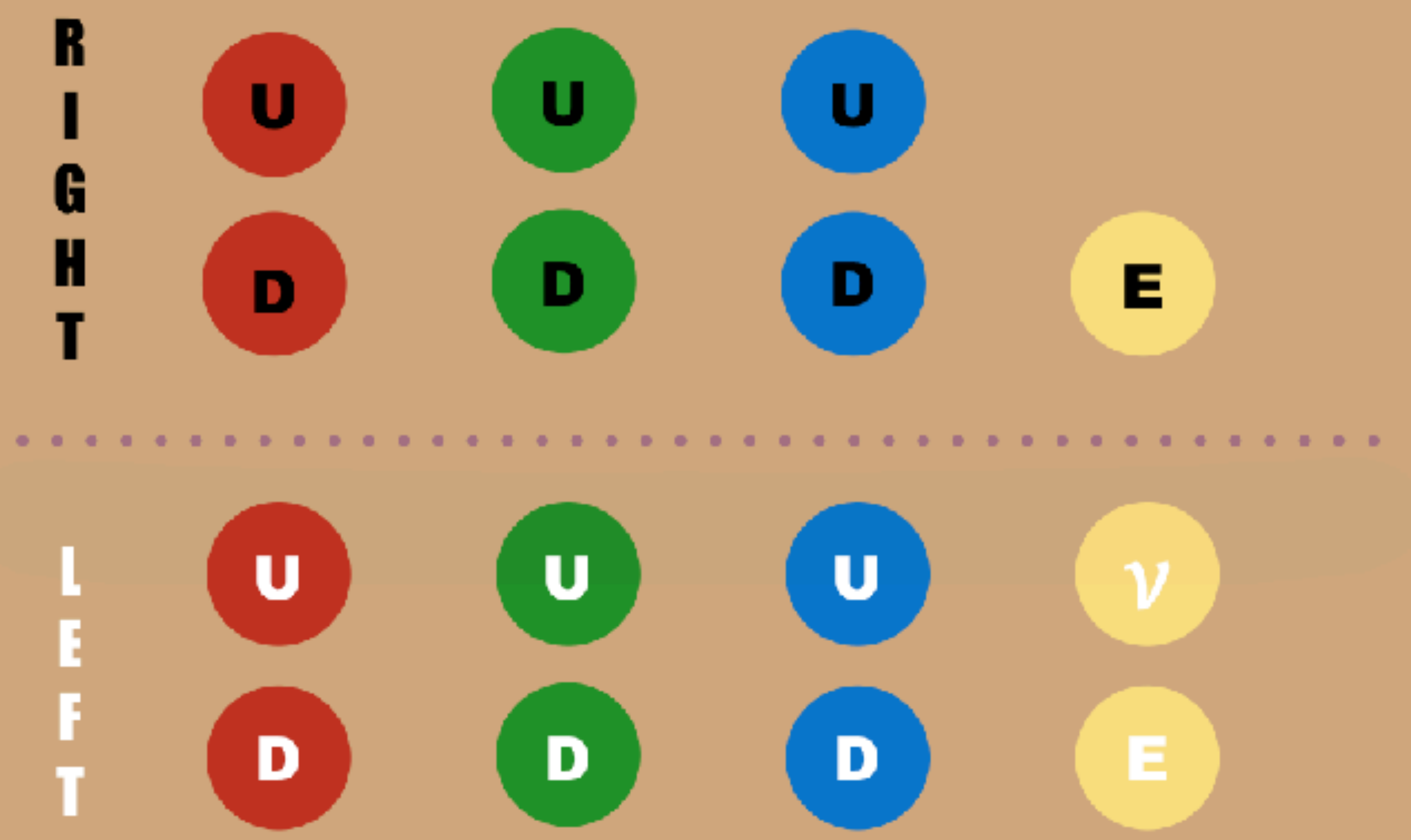
lightest neutrino gives the most intense line for normal hierarchy

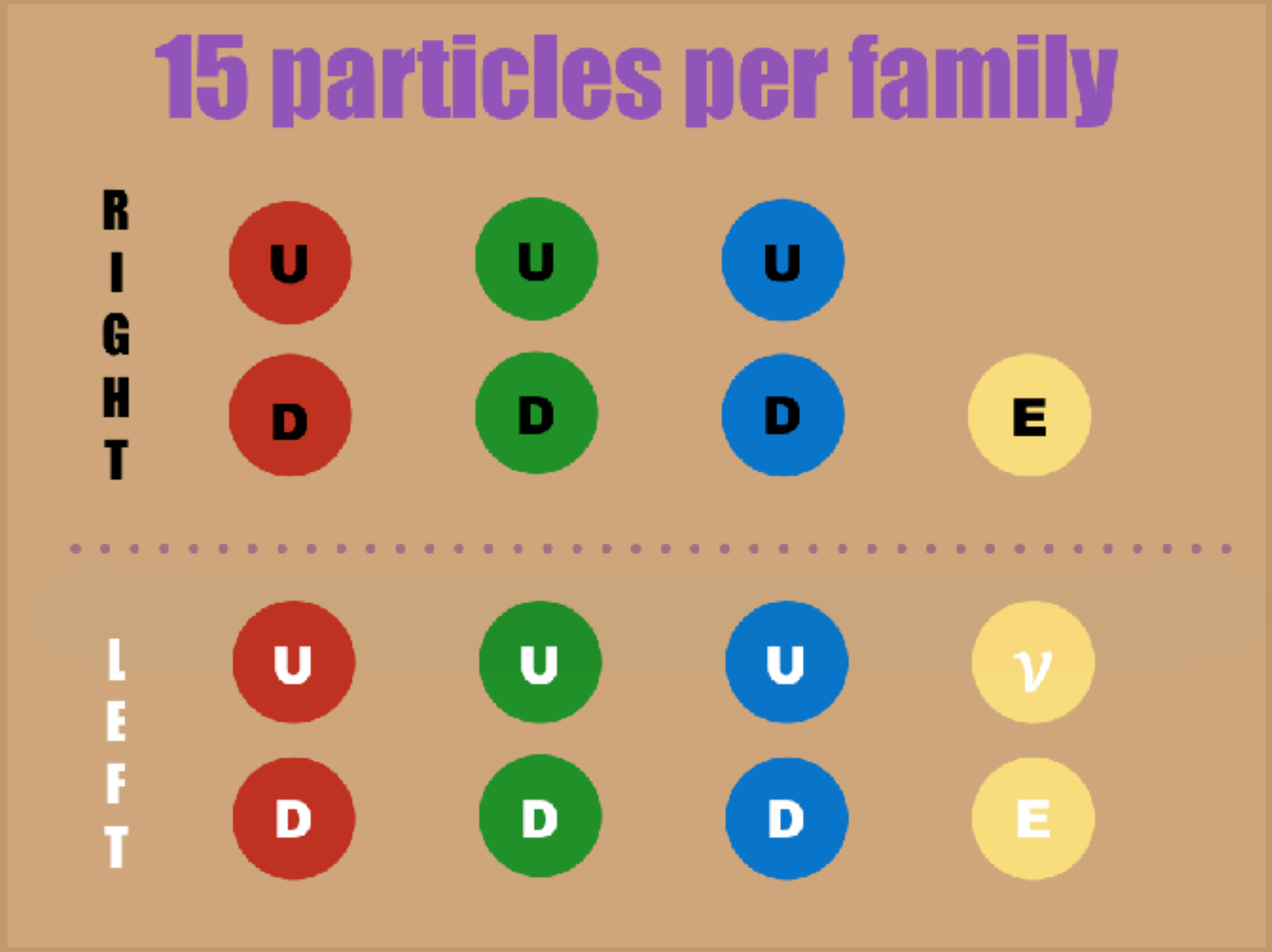
Needs

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

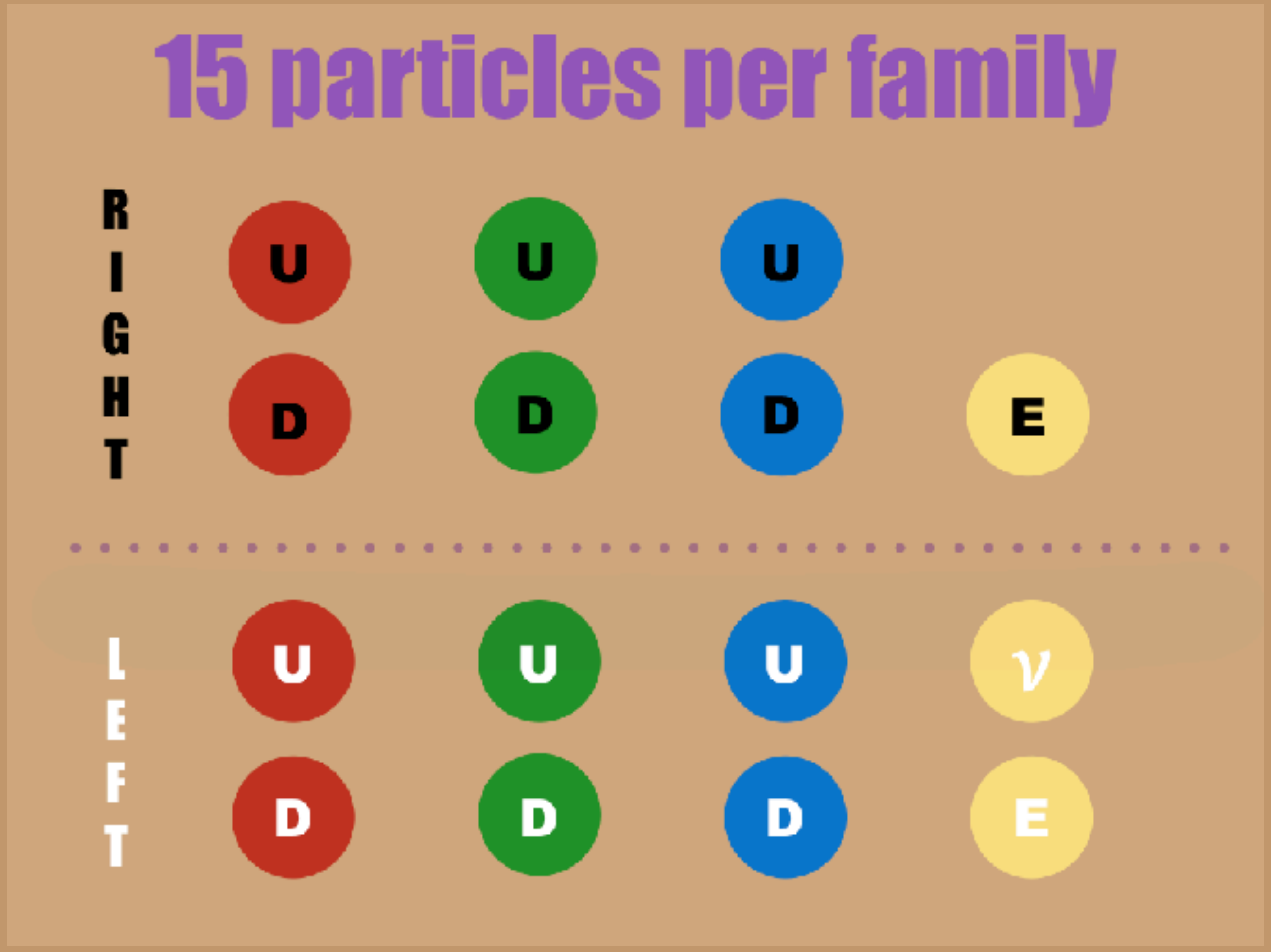


15 particles per family





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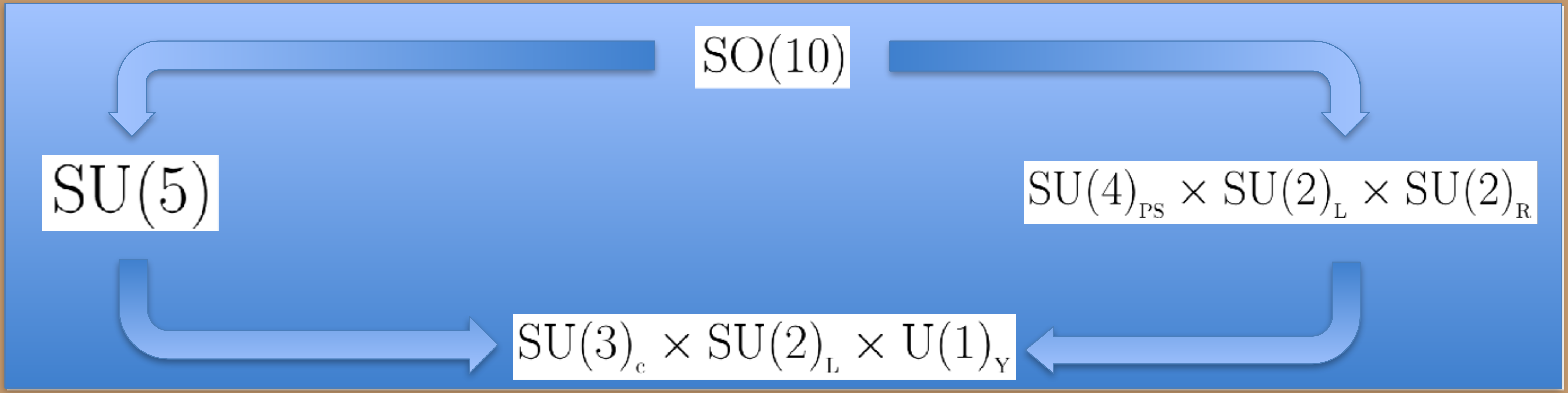
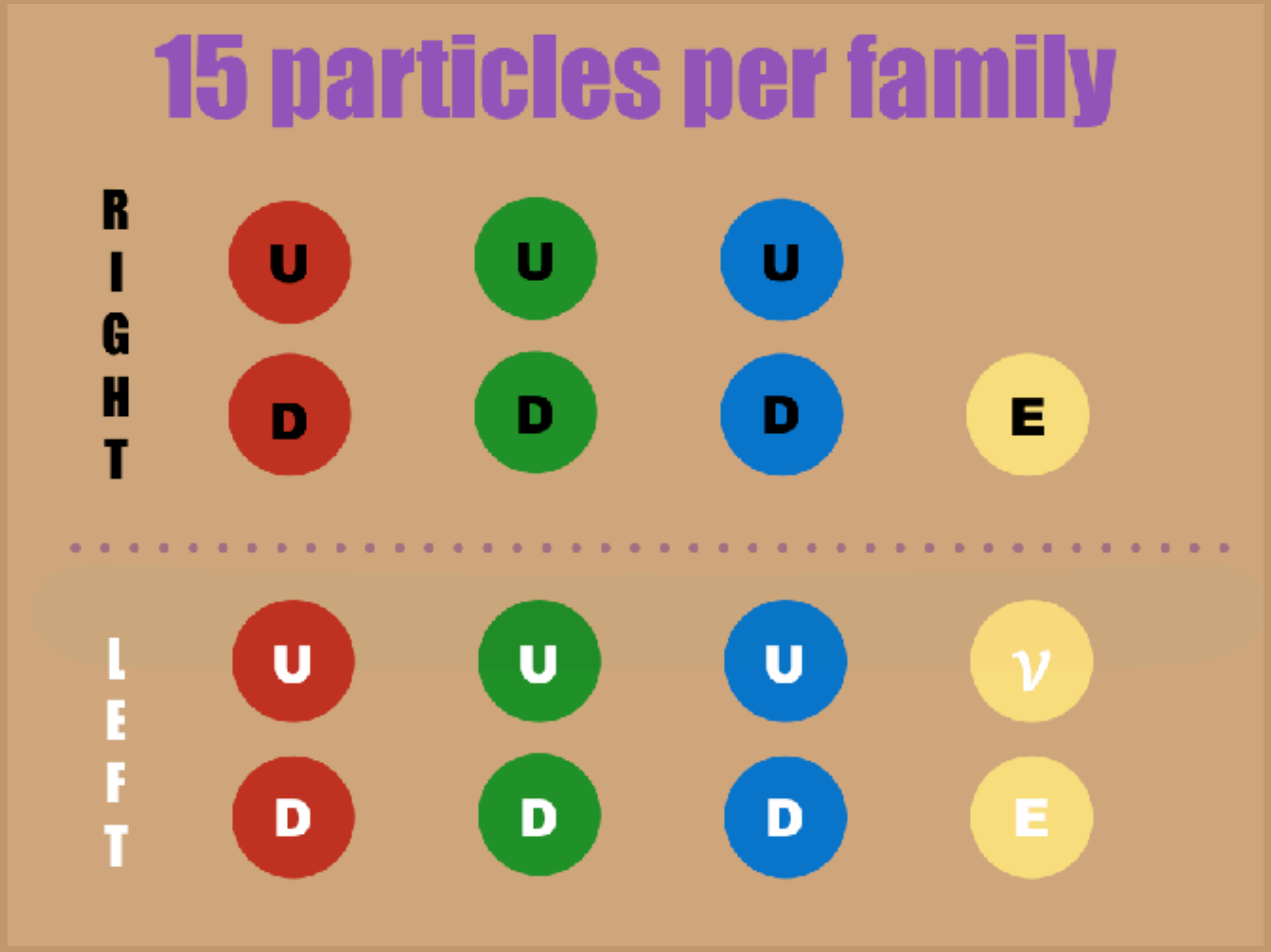

SO(10)
SU(5)
$SU(4)_{PS} \times SU(2)_L \times SU(2)_R$
$SU(3)_c \times SU(2)_L \times U(1)_Y$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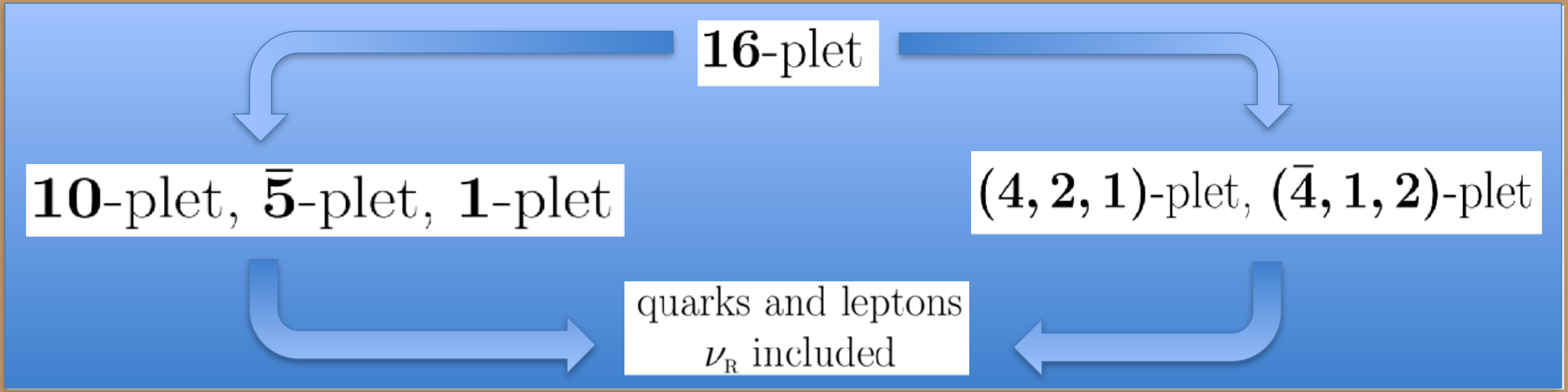
16-plet
10-plet, $\bar{5}$-plet, 1-plet
(4, 2, 1)-plet, ($\bar{4}$, 1, 2)-plet
quarks and leptons
ν_R included

Theory (?) of Neutrino Masses

- How can we hit a theory of neutrinos mass w/o a theory of fermion masses? It is not forbidden to try, but...
- with mixings, all possible errors have been made in the past: ϑ_{12} small ; $\vartheta_{13} \approx 0$; $\vartheta_{23} < 45^o$; $\delta_{CP} \approx 0$.
- maybe, it's time to make new ~~errors~~ attempts on the masses now, e.g.,

$$m_{\beta\beta} \approx \sqrt{\Delta m^2_{sol}} \text{ and } \Sigma_{cosm} \approx \sqrt{\Delta m^2_{atm}}$$

presented at neutrino 2018

MY POLL:

Do you feel we have chances to come across the theory of neutrino mass before Neutrino 2020?

- ➢ No [67.081%]
- ➢ Not my job, I work on deep learning [7.208%]
- ➢ Please read my next paper [25.711%]

Messages from a theorist

Francesco Vissani, INFN, Laboratori Nazionali del Gran Sasso

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Resource type

Presentation

Publisher

Zenodo

Conference

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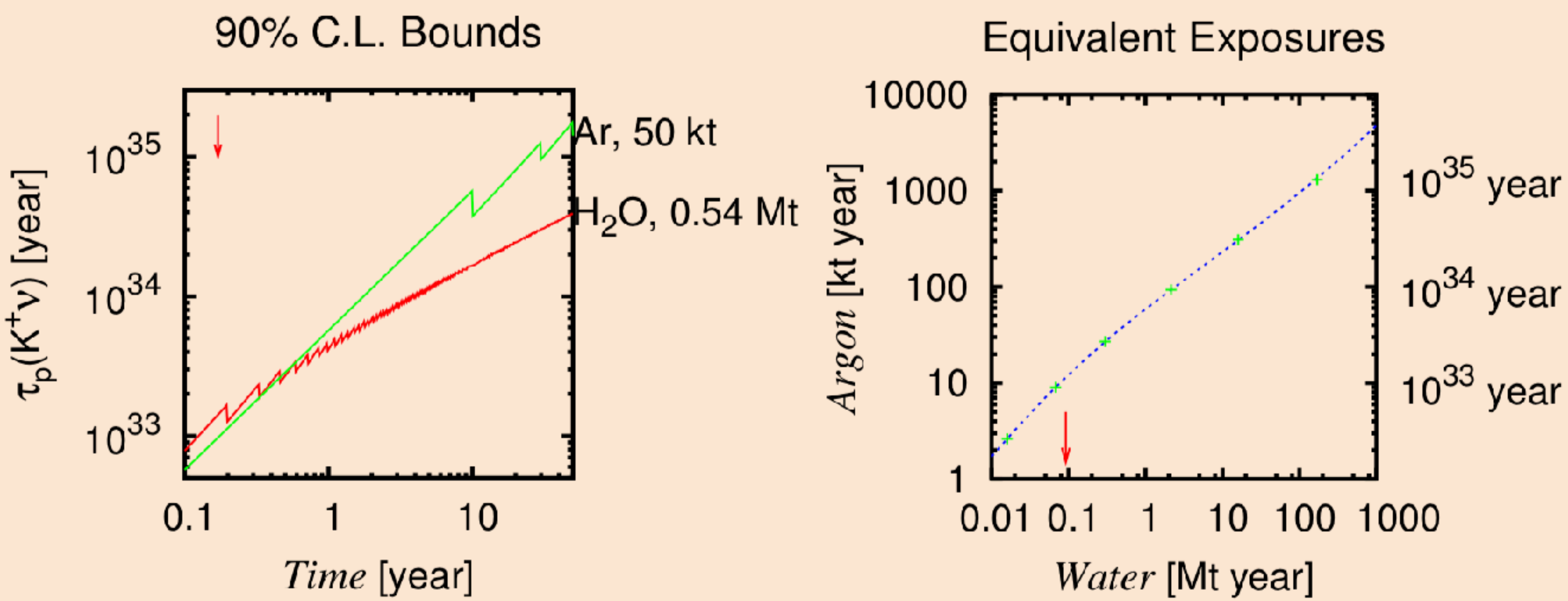

Figure 1: Sensitivity to $p \to K\bar{\nu}$; syst. not included. Water, $\epsilon = 14.6\%$ and $b = 14/(\text{Mton y})$ (2 methods, summed); Argon, $\epsilon = 97\%$ and $b = 1/(\text{Mton y})$. Impact of stat. fluctuations ≈ 2.

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.