Messages from a theorist

Francesco Vissani, INFN, Laboratori Nazionali del Gran Sasso

RULES OF MODERN RETHORIC

① Orator should make people **laugh**

② Orator should make people **cry**

③ Orator should make people **think**

THIS TALK

My notes before Neutrino 2018

A brief diary of Neutrino 2018

Messages from a theorist

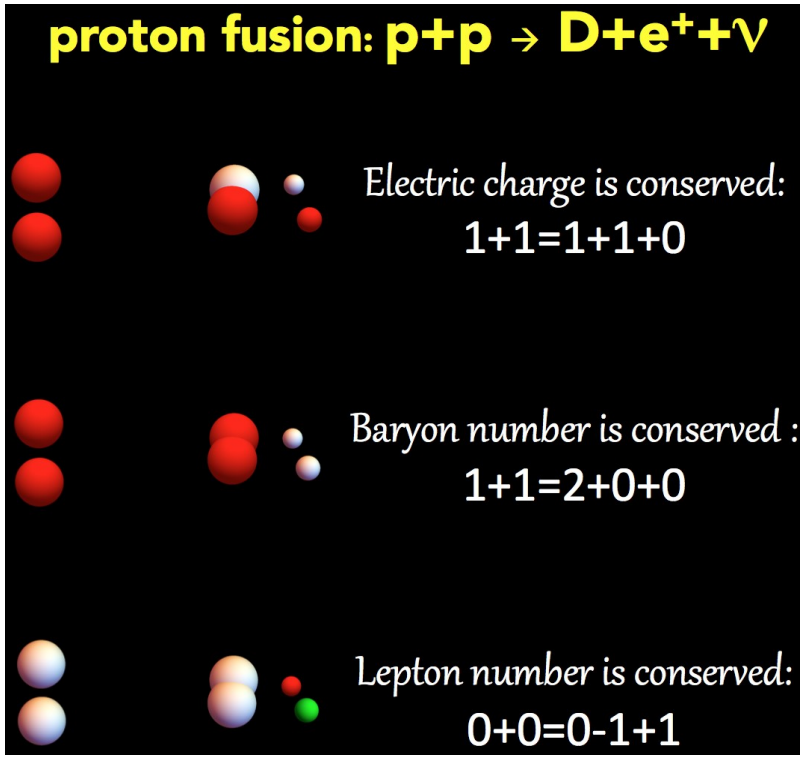
my notes before Neutrino 2018

SOME OF THE MOST IMPORTANT THINGS WE (DO NOT) KNOW AND WHY THEY MATTER: A PERSONAL SELECTION

I.E., MOSTLY, MY LIST OF PREJUDICES

+ ONE POLL

HOW TO RECOUNT THIS TO LEUCIPPUS/DEMOCRITUS?



- You right: Earth, Moon, planets, stars... are made of the same type of matter
- Matter is just what you claim: we saw atoms and their parts, we classified them
- We have even seen `atoms' transforming among them: this is how the Sun shines
- How do we know? We used the smallest part of matter to see center of the Sun

There Is Just One Type of Light Particles

(=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

hem... We Have **One Basic Type** of Matter Particle

(=B+L is not a conserved number in the Standard Model --- leptons and baryons conversions!
Appearance experiments proved that all anomaly free symmetries of SM are violated, except one)

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

Neutrino Mass

(difficult to explain oscillations to the first atomists—easier to modern layman)

- *Mentioned 1933 by Perrin and Fermi - still searched for*
- *Majorana's ≠Dirac's; Racah; Furry & $0\nu\beta\beta$ - still searched for*

- Pontecorvo (1957-1967) points out QM-phenomena analogous to K^0/anti-K^0
- Sakata et al (1962-1963) remarks the connection with ν mass
- MSW (1978-1986) very relevant even if not related directly to ν mass
- From late '60 till SK+SNO' experimental proof of oscillations

Oscillations remain crucial to probe neutrino mass and mixing!
Important role of global analyses within 3ν-theory

Gedankenexperiment

(this I can *almost* explain to our ancient colleagues)

- Since Goldhaber (1958), ultra-rel neutrinos are known to have spin and momentum *anti-aligned*
- We know they have a mass. What happens overtaking them – i.e., inverting the momentum of one mass state?
- Majorana (1937) says: they become antineutrinos

NB to draw this connection, no need to mention SM, lepton number, effective operators, etc.: Just a bit of relativity.

Why This Is So Important

Massive Majorana neutrinos have a major impact on SM:

- ✓ They exist in very reasonable extensions of SM.
- ✓ The only remaining exact global symmetry of SM (for what we know) would be gone, if ν=anti-ν. More dramatic than $p \rightarrow e^+ + \pi^0$
- ✓ In SM, matter or antimatter particle are distinct, e.g., by B-L. Majorana ν would be the only known bridge between matter and antimatter

This can be verified with $0\nu\beta\beta$ if mass is not too small, a process that can be seen as creation of a pair of electrons

Neutrino Astronomy

In *strict sense,* only Kamiokande/SK/SNO did astronomy with $\nu_\odot$.

We are ready to do much more, e.g.:

(1) For a galactic supernova, $\delta\vartheta_{SK}$~degrees, possibly few hrs before the light. Time known with 10 ms accuracy. Synergy with GW detectors

(2) We can identify HE ν-sources, if bright enough. In water, $\delta\vartheta$ improves; solid angle $\pi\times\delta\vartheta^2$ by more than 1 order of magnitude!

Why a km^3 class telescope in Northern hemisphere? 1) to check IceCube 2) to see most of the Galaxy; disk emission, possible DM signal, etc.

High-Energy Neutrinos

Zheleznykh 1957, Markov, Greisen... IceCube 2013-today!

- If due to cosmic ray collision, need sufficient target.
  If pp-collisions, the ν-spectrum should reflect the primary spectrum, e.g., ~E^{-2}.

- If extragalactic, expected to be isotropic.
  Constraints due to observable γ emission below 100 GeV unless opaque source.

*IceCube pointed out a very intense ν emission. Antares not incompatible. Need to see ν_τ signals—**space OPERA**. We want to identify the sources.*

IceCube has two important samples of data "passing μ" and HESE, consistent above 0.2 PeV. Unclear features below.

Supernova Neutrinos

Colgate, White, Arnett, Nadyozhin... SN1987A... eagerly waited for

Simulations difficult, still not definitive

Parameters: intensity, average energy, shape (...?)

Error-bars necessary for interpretation & analyses

- Overall agreement of SN1987A and 'expectations'
- Compact remnant from SN1987A yet unseen

One provocation: should we treat **also** oscillations as a source of error?

$\min[\,\Phi_e^o(E,t)\,,\,\Phi_\mu^o(E,t)\,] < \Phi_e(E,t) < \max[\,\Phi_e^o(E,t)\,,\,\Phi_\mu^o(E,t)\,]$???

Clarifications would be very much welcome, in my view

Solar Neutrinos

Sound and important science with reliable roots: (von Weizsäcker, Bethe), Fowler, Bahcall! Oscillations: from Pontecorvo to MSW.

For pp chain: Precise measurements of fluxes of B, Be (+NC & shape for B) and pp, pep (initial) require to check all SSM inputs – nuclear/plasma/atomic/astro-physics

For CNO cycle: known since 1937, still to be probed. The only flux heavily revised of Bahcall's SSM. Important for metallicity issue. Borexino has a chance; and then?

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., $m_{\beta\beta}\approx_{\surd}\Delta m^{2}_{\odot}$ and $\Sigma_{cosm}\approx_{\surd}\Delta m_{atm}$

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%]

a brief diary of Neutrino 2018

JUNE 4-9; WITH A BIT OF EMPHASIS ON A FEW POINTS THAT I FOUND PARTICULARLY IMPRESSIVE (AND LACK OF EMPHASIS ON THINGS I DID NOT UNDERSTAND ENOUGH)

FINALLY, 3 AWARDS - NOT FOR SPEAKERS, OF COURSE

JUNE 4 (ACCELERATORS, DETECTORS)

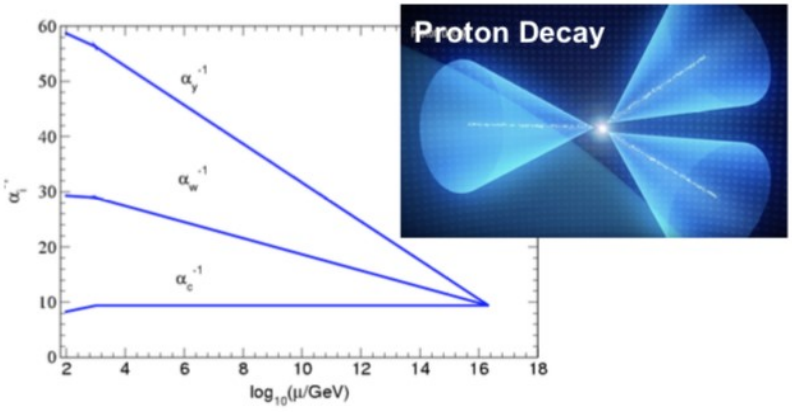
- 3σ evidence for NH within 3ν-theory. Is ν_s just a "mirage"?

- T2K and NOvA results wunderbar, espe. ν_e appearance
- Less space for ν_s after MINOS (+)
- Proton-decay & supernova-ν mentioned by Hyper-K, DUNE, etc
  interest in geoneutrinos as well
- Beautiful near future detectors & ideas to proceed further

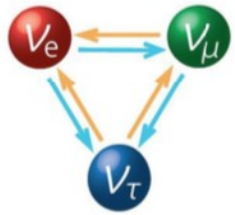
- Hadron dynamics is not just QCD. Need specific efforts

Goals of Hyper-K Physics

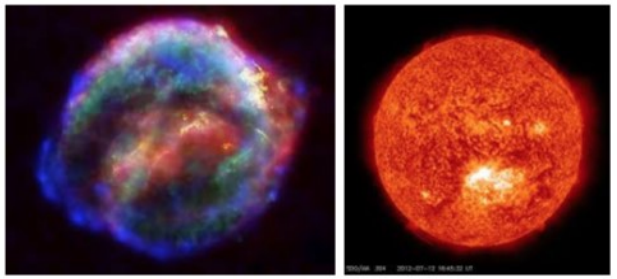
1. Nucleon Decay Searches



2. Explore full picture of neutrino oscillation including δ_{CP} and Mass hierarchy



3. Neutrino astronomy and astrophysics



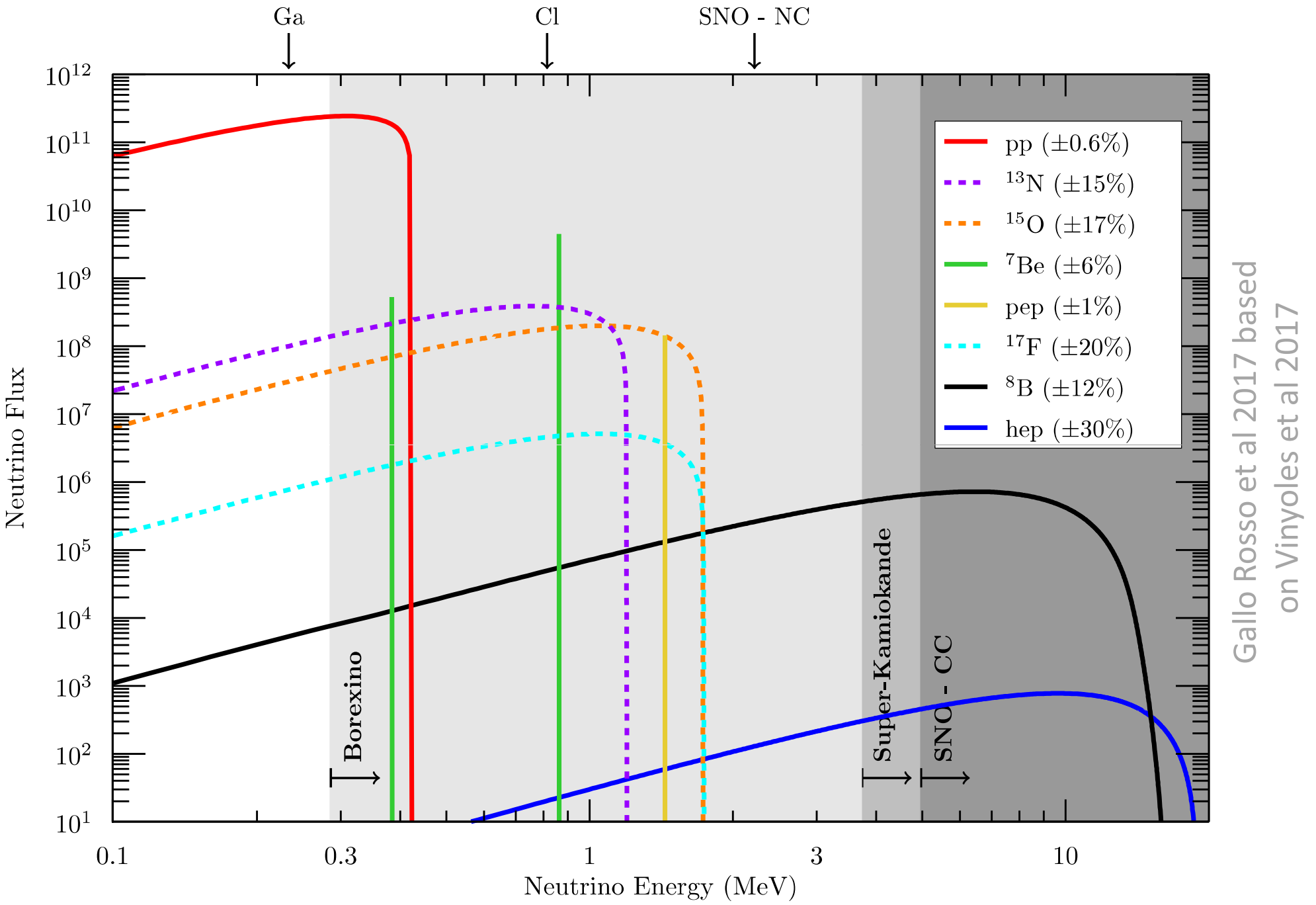
from Masato Shiozawa's talk

JUNE 5 (REACTORS, ATMOSPHERIC, SOLAR NEUTRINOS)

- Error bar estimation for reactor neutrinos, not an easy task
- Daya Bay, Double Chooz, Reno: lot of improvements, 3ν is still *O.K.*
- JUNO getting ready also with the help of Daya Bay

- NH favored by Super-K (atm) that is still progressing; τs seen, also in Deep-Core

- NSI analysis in Super-K (sol) from ^{8}B shape. Ready for Gd
- Borexino observes ^{7}Be, pep, pp, bounds CNO: hopes of measurement!
- Solar neutrinos still very appealing. Modeling might surprise us, need g-modes


Ga
Cl
SNO - NC
Neutrino Flux
Neutrino Energy (MeV)
pp (±0.6%)
^{13}N (±15%)
^{15}O (±17%)
^{7}Be (±6%)
pep (±1%)
^{17}F (±20%)
^{8}B (±12%)
hep (±30%)
Borexino
Super-Kamiokande
SNO - CC
Gallo Rosso et al 2017 based on Vinyoles et al 2017

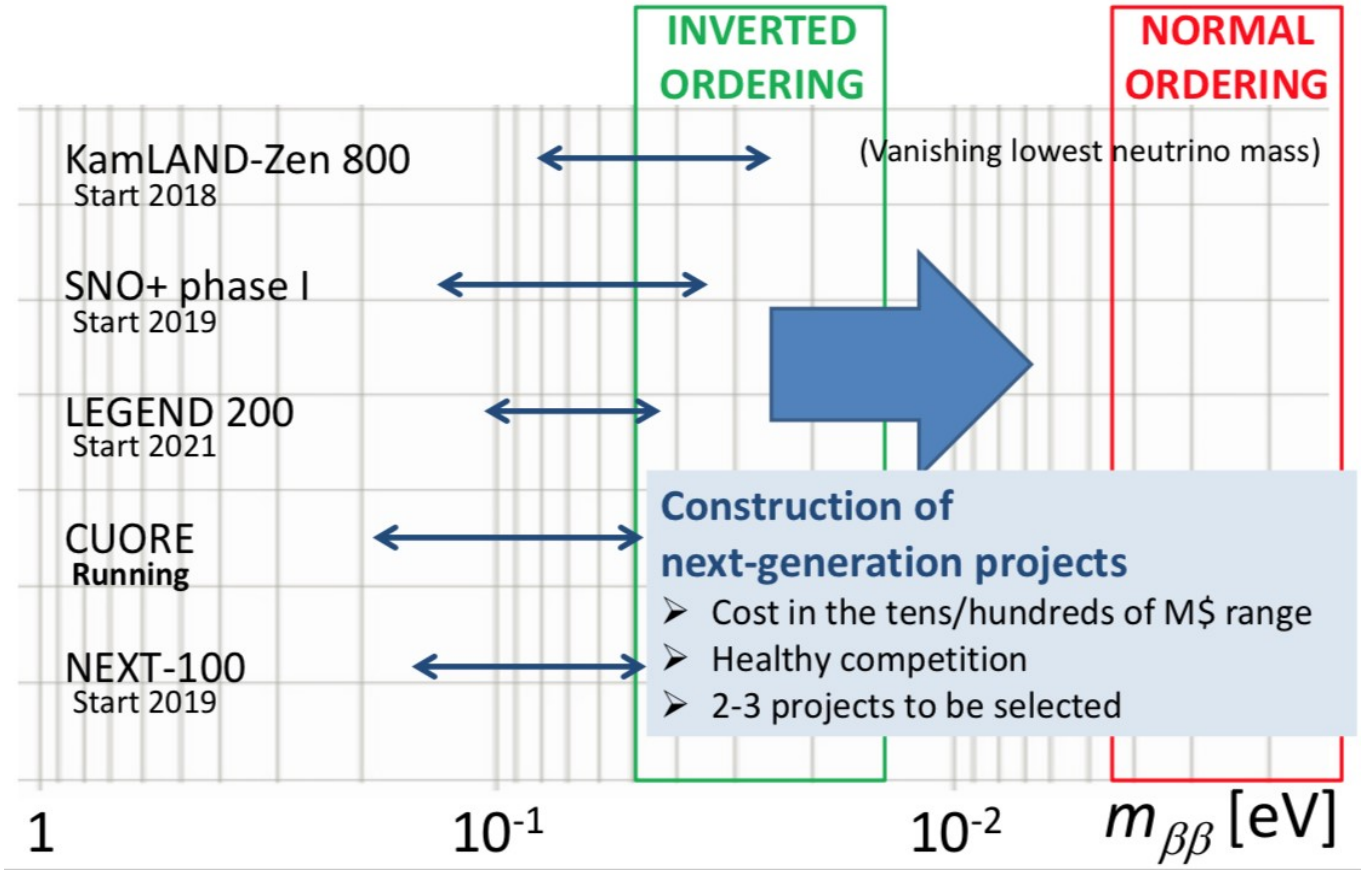
JUNE 5-6 (THEORY, NEUTRINOLESS DOUBLE BETA DECAY)

- Global analyses consistent within 3ν model. Future (2025) exps
- Ideas for the model of neutrino mass [theory? naturalness?]

- EXO, Kamland-Zen, Gerda-II, Majorana, Cuore: impressive progresses. Debate: *no bkgr vs large mass* won by both parties
- All experiments presented convincing ways to proceed further and there are many more good ideas to reach 10^{28} yr (!!!)
- Quenching is an unsolved issue. Nuclear physics uncertainties are significant but not precisely assessed

Possible scenario in 2024

Considering running or well advanced projects (for results, funding and infrastructures)

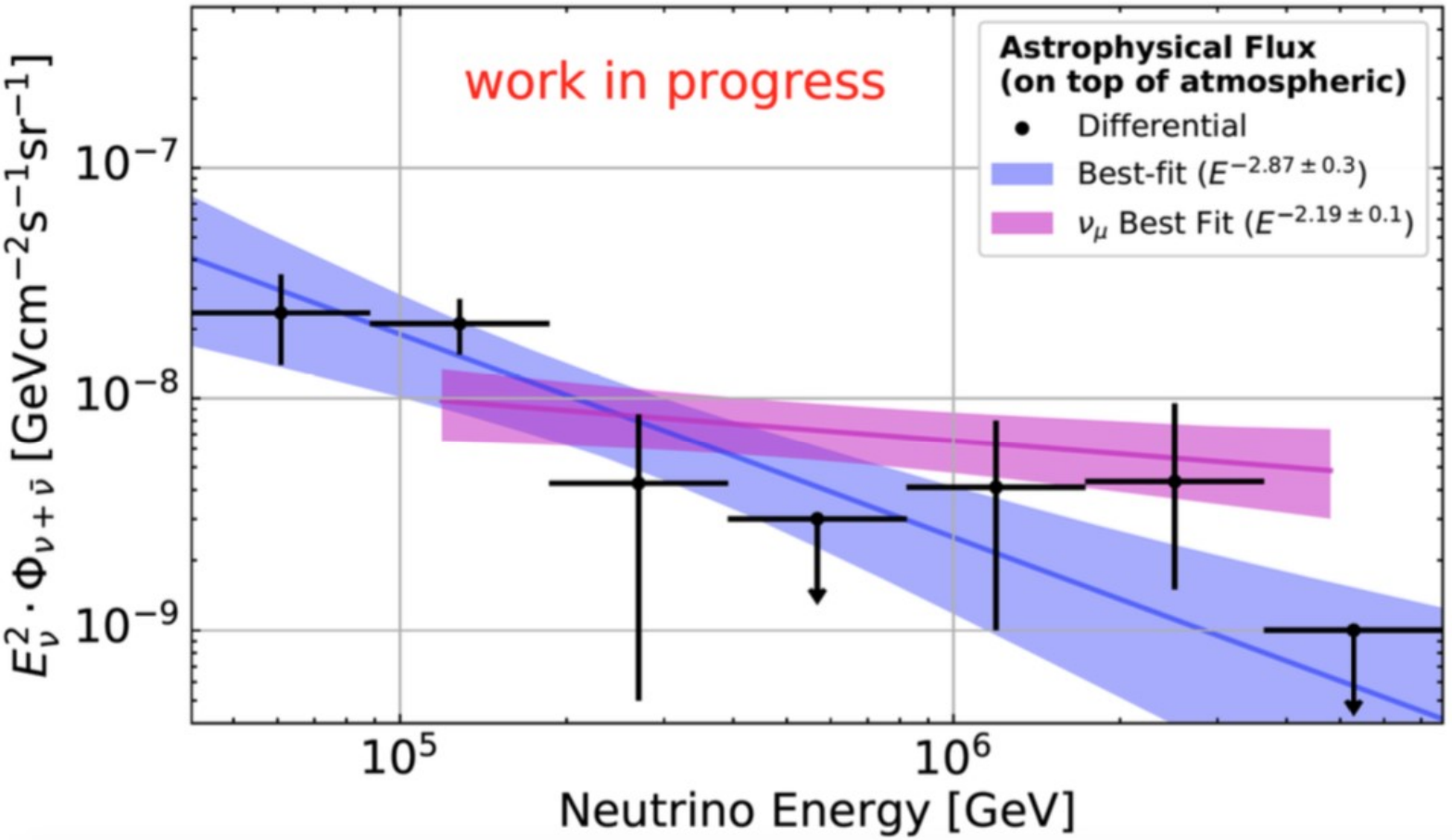


from Andrea Giuliani's talk

JUNE 6 (HIGH-ENERGY ASTRONOMY)

- IceCube: HESE is $E_\nu^{-2.87\pm0.3}$ + announcements: correlation with BLlac; revised positions; 2 ν_τ and 1 Glashow resonance candidates
- List of promising theoretical sources of IceCube neutrinos, constraints from diffuse γ's below 100 GeV (IGB)
- Antares, GVD, upgrade of IceCube and KM3NeT – checks of present IceCube, exploring the ν-sky
- Various ways to probe the ν-sky above 10 PeV, ongoing tests

High-Energy Starting Events (HESE) – 7.5 yr



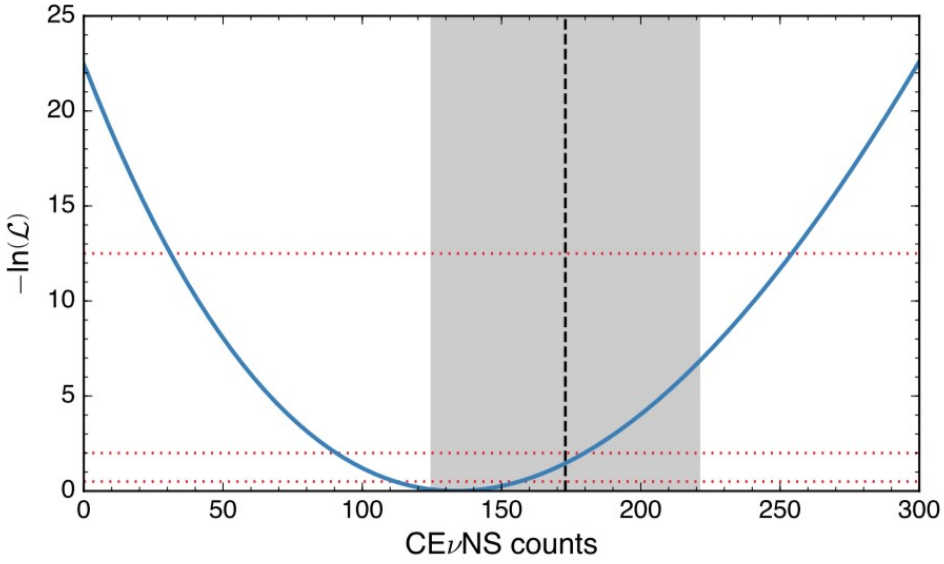
Poster #175. Wandkowsky et al. (IceCube)

from Ignacio Taboada's talk

JUNE 7 (COHERENT SCATTERING, DIRECT MASS SEARCH)

- COHERENT measurement of NC-νA scattering with π-at-rest beam
- CONUS first results using reactor beam.
- Many options to proceed/to use it; many implications, including NSI tests

- Katrin: The ultimate endpoint experiment is ready to start and to deliver the promised 0.2 eV/c^2 sensitivity
- ECHo/HOLMES: calorimetric measurements using EC. Toward 10 eV/c^2
- Project-8: possibly the future of this field.



INVITATION

OFFICIAL KATRIN INAUGURATION

KIT and the international KATRIN Collaboration are pleased to invite you to the official inauguration of the experiment on

June 11, 2018

marking the start of the long-term data taking to measure the absolute mass scale of neutrinos with unprecedented sensitivity.

The afternoon symposium will highlight the important role of neutrinos in particle physics and cosmology and review important milestones of the experiment up to now.

Starts 11 Jun 2018, 10:00
Ends 11 Jun 2018, 18:30
Europe/Berlin

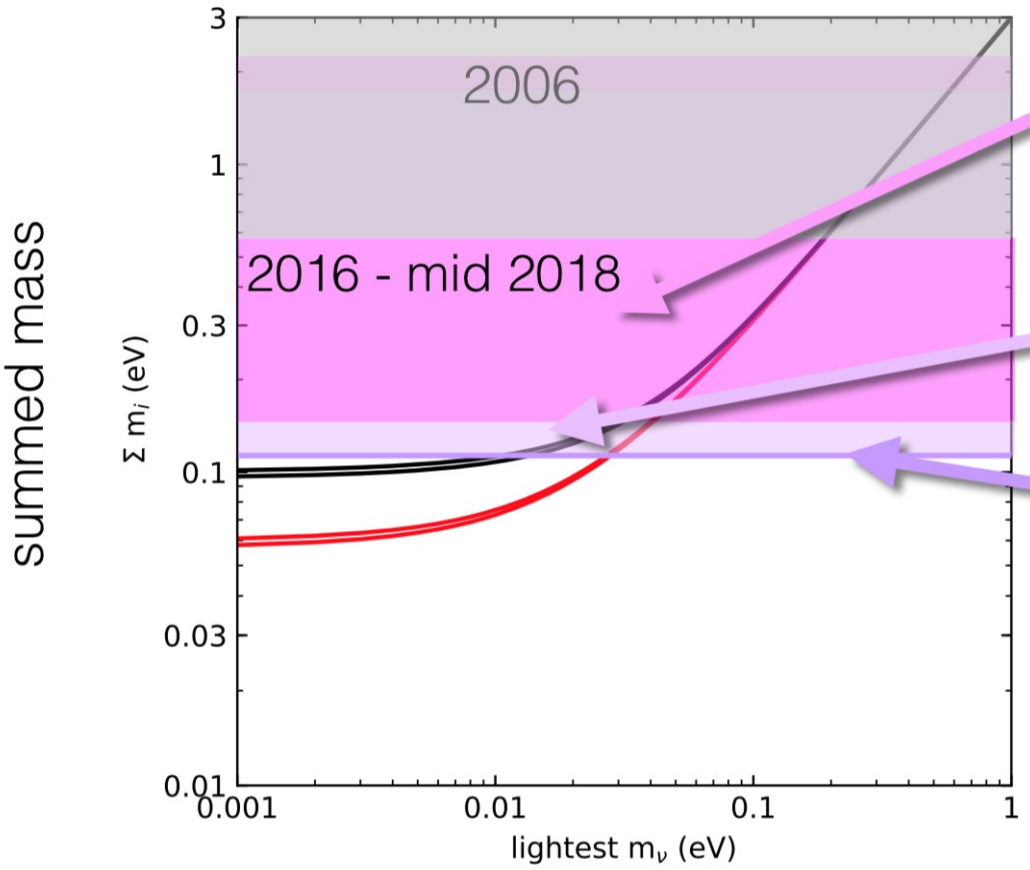
FTU
Main lecture hall

KIT, Campus North
Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen

JUNE 8 (THEORY AND COSMOLOGY)

- Mass scale of RH ν and possibilities to observe it at LHC
- Meaning and tests of lepton numbers L_e L_μ L_τ. Extended gauge symmetries. B-L gauge symmetry?
- Observed anomalies in hadronic flavors
- Non-standard neutrino interactions and ν oscillations
- Constrained baryogenesis-via-leptogenesis mechanisms
- Observational cosmology, $\Sigma m_\nu < .12(.6) meV$ & $N_\nu \approx 3$ (also BBN)

95%CL upper bounds on $\Sigma_i m_i$ for 7 parameters



CMB only: Planck,
w/o high-l polarisation and lensing…
$\Sigma_i m_i < 590$ to 140 meV (95%CL)

CMB + conservative LSS :

- Planck 2016 {TT+SIMLow+lensing} + BAO:
  $\Sigma_i m_i <$ **170 meV** (95%CL)
- Planck 2016 {TTTEEE+SIMLow} + BAO:
  $\Sigma_i m_i <$ **120 meV** (95%CL)
- Planck 2015 + Lyman-α:
  $\Sigma_i m_i <$ **120 meV** (95%CL)

[Planck col.] 1605.02985; Cuesta et al. 2016;
Palanque-Delabrouille et al. 1506.05976;
Vagnozzi et al. 1701.08172;
PDG "Neutrino Cosmology" [JL & Verde]

… harder to avoid bounds with simple cosmological model extensions

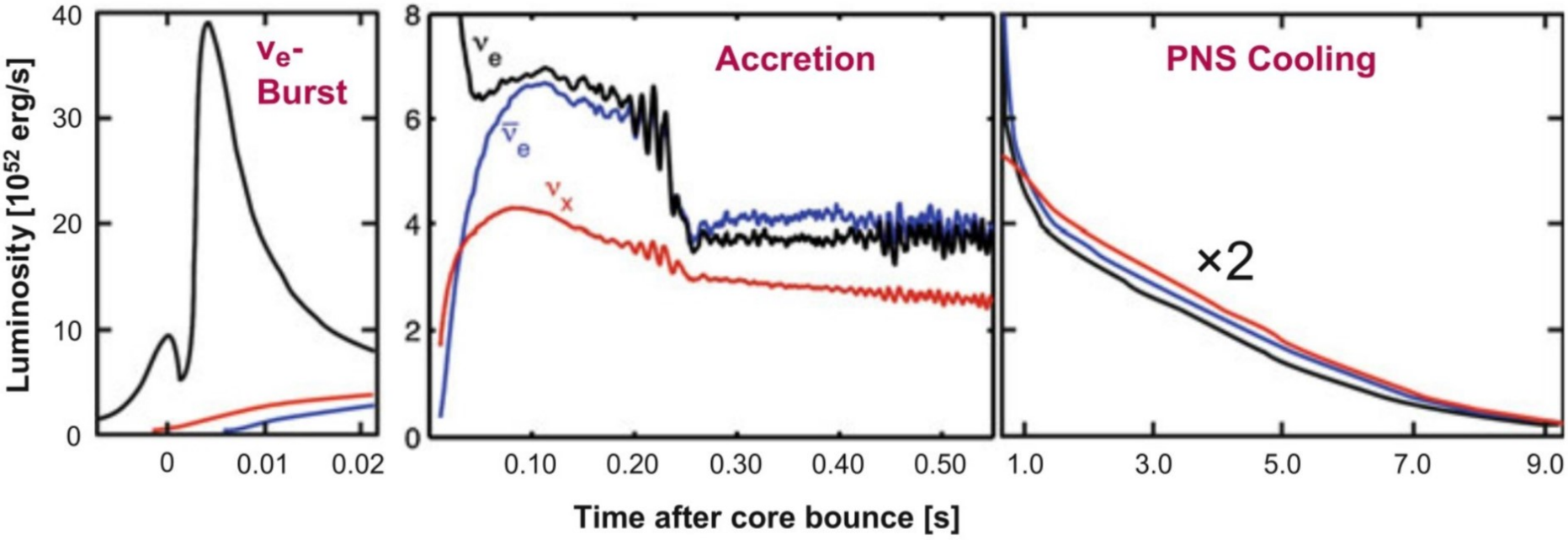
from Julien Lesgourgues's talk

JUNE 8 (STERILE NEUTRINOS)

- DANSS: excludes Gallium anomaly; potential ν_s candidate
- NEOS and Stereo: bound, no support to reactor anomaly
- Prospect, Solid, microBoone: future search and prospects
- MiniBoone: strong anomaly at low energy, 6.1 σ with LSND
- ν_s anomaly has anomalous features, changes with time. 3+1 (+n) model is predictive: points to inconsistency of global evidence

JUNE 9 (SUPERNOVAE, NS MERGERS, NEUTRINOS & DARK MATTER)

- 'Small' mass stars explode in 3D; for 'large' ones, physics being explored. Expected modulation of (anti-ν_e) signal
- Oscillations in SN still being clarified. Many physics chances from a true event
- The new science of NS mergers. GW and light seen HE-ν searched. Observable NS properties and nucleo-synthesis in r-processes.
- keV neutral fermions alive as a dark matter candidate - the 3.5 keV line!
- DM might show up unexpectedly; WIMP-det. is also ν-det. (if big and clean)



from Thoms Janka's talk

(alternative) Awards

- FOR GENUINELY CANDID COMMENT/QUESTION:
  - **CK Jung:** "*It does not seem a real theory of mass*"
  - **S Petcov:** "*Do you mean we do not understand g_A?*"

- MOST STYLISH CHAIRPERSON:
  - **T Kirsten:** *(to Borexino) "Old cow still gives good milk"*
  - **E Akhmedov:** *10 talks in 20 smooth min, w/o showing off*

- BEST ORGANIZER:
  - **G Drexlin:** *for scientific/social program, atmosphere…*
  - **M Lindner:** *…and also organization, location, food…*

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messages from a theorist

ON THE RELATIONSHIP BETWEEN THEORY AND EXPERIMENTS; ON THE RELATIONSHIP OF NEUTRINO PHYSICS AND OTHER SCIENCES.

REMARKS, QUESTIONS AND A PROPOSAL

ON RELATIONSHIP BETWEEN THEORY AND EXPERIMENTS

- In this moment, when the field is changing, with an increased role of bigger experiments, maybe it is a good idea to pause and think a bit

- One reason why neutrino physics is in good shape is the continuous comparison between theory and experiments. This is needed to provide motivations, assessment, even confrontation, in the hope eventually to make good science

- An important simple principle: science first. Theory and experiments are just tools, to accomplish this goal – science

- Publishing one theoretical paper more – or making experiments just to do one experiment more – is not the same thing

THEORY AND EXPERIMENTS TOGETHER SINCE THE START

Observed β-ray spectra & nuclear spin disagree with theory that nuclei are collections of p and e, fixed by charge and isotopic mass

- Pauli 1930 hypothesizes neutrinos in nucleus. This explains measured nuclear spin *and* β-ray (=electron) spectra
- Fermi 1933, *who knew about neutrons*, proposed a new QFT where the nuclear charge does change
- From this theory, implications worked out: EC (Wick), IBD (Bethe, Peierls) $2\nu\beta\beta$ (Goppert-Meyer) etc
- It took time, but all these have been then observed

NEUTRINO PHYSICS AND RELATED SCIENCES (A FEW KEY EXAMPLES)

Particle physics aspects are usually emphasized in our discussions. However, at low energies, crucial theoretical and experimental aspects of ν-science need extensive nuclear physics expertise, not QCD in its full glory - and limitations.

There are many lively links with astrophysics, besides those emerged with the studies of $\nu_{\odot}$ and ν_{SN} and they are increasingly more evident.

Cosmology progressed greatly and yields a limit on absolute masses, number (and type!) of ν-species that we need to understand at best.

CONCLUSIVE THEORETICAL REMARKS

- Principled theoretical models are precious – e.g., 3ν or also 3+1
- A theoretical assessment of newly investigated issues is always useful/needed. E.g., status of understanding of proton decay and of (relic) supernova, important for HK, DUNE, JUNO..., is not the same.
- We should estimate theoretical uncertainties, whenever possible: e.g., for reactor fluxes, ν_{SN}, or for ββ - apropos, "quenching" of g_A is not a theory
- *Ab initio* nuclear models may lead to progress-e.g., for ν-xsec or for ονββ
- Should we worry of "naturalness"? It does not help with Λ_{cosm} after all
- Astrophysical/cosmological investigation of ν properties have a great potential, we should welcome synergy or critical attitudes-not biased ones

SOME QUESTIONS

- Do we understand $\nu_\odot$ (the Sun) enough? Is MSW proved? What about Ga-xsec?
- How often core collapse events occur in the Milky Way?
- Are we ready for future supernova ν – or are we stuck in theoretical doubts?
- Do we understand sufficiently ν interactions in astrophysical conditions?
- Are events seen by IceCube really isotropic distributed? (through-going-μ below 200 TeV?)
- What do we aim to learn from E_ν>10 PeV? What is the composition of UHECR?
- Alternative ways to see Majorana neutrinos? Chances to probe other properties?
- Is there a chance to see relic (BBN) neutrinos?
- On which principles should we possibly build a theory of fermion masses?

It would be nice to collect remarks and questions, in particular those arisen at/after this conference. Maybe organizers could consider the idea to arrange something like that. I cannot imagine a better summary to offer to our future colleagues.

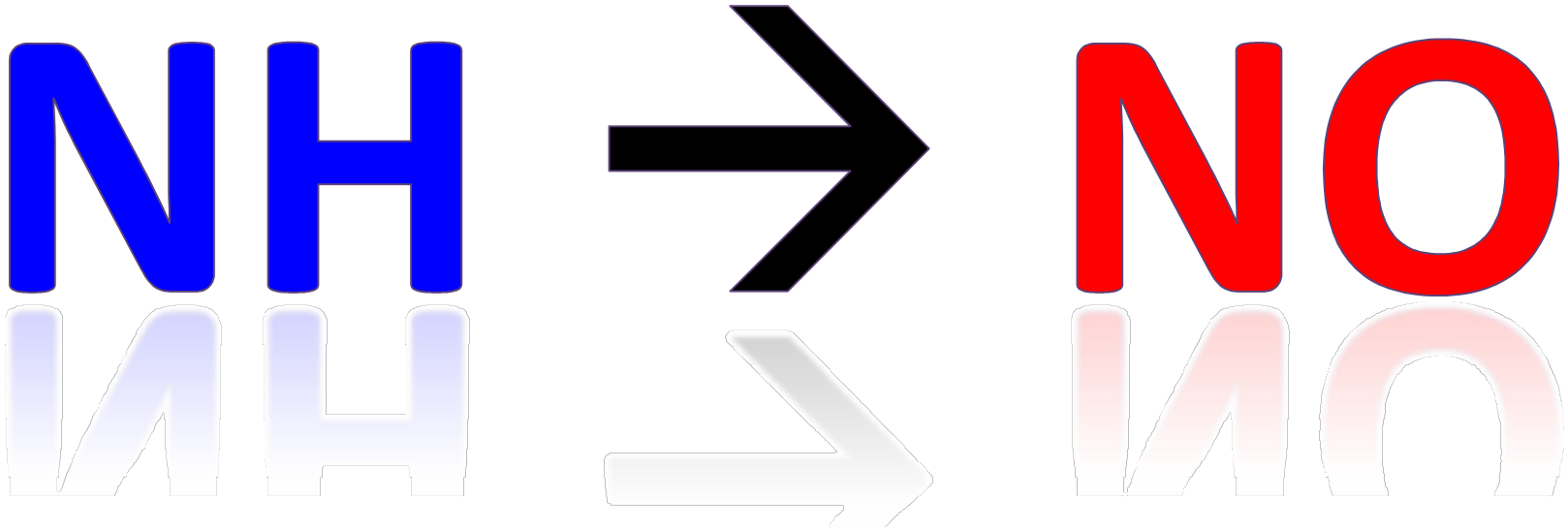
Otherwise, if you like the idea and you write me, it will be my pleasure and honor to discuss these remarks and questions, and use the next pages to keep track of them.

Many thanks

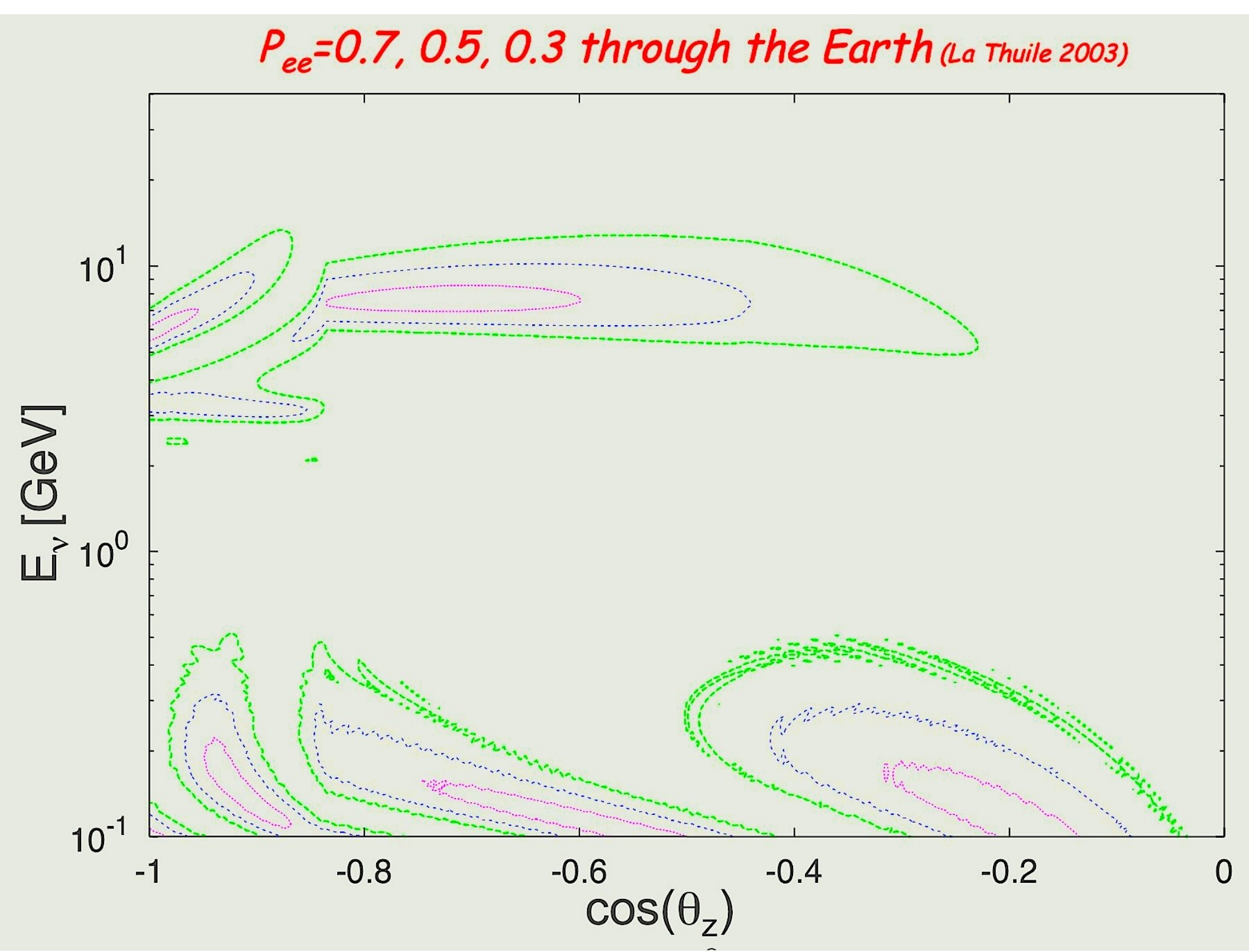
supporting material

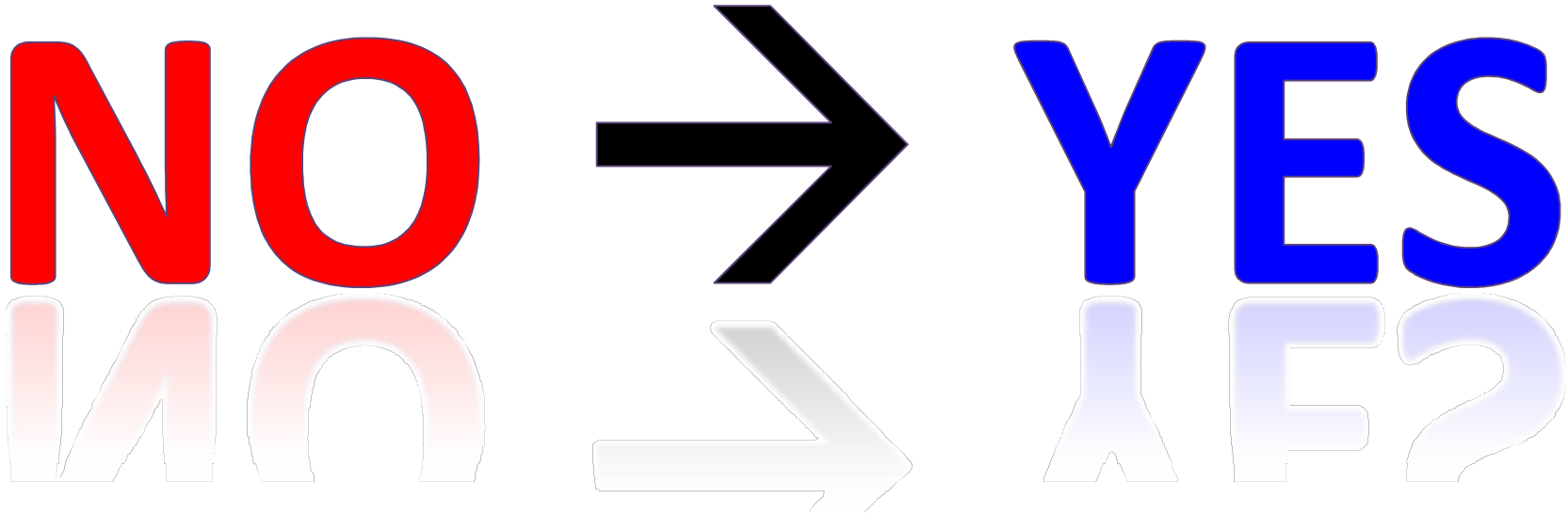
(JOKES INCLUDED)

SHOULD WE CHANGE CURRENT ACRONYMS? HOW TO EXPLAIN OSCILLATIONS TO LEUCIPPUS AND DEMOCRITUS; THE POINT OF MAJORANA NEUTRINOS ILLUSTRATED; A GLOBAL ANALYSIS OF 2004 ON STERILE NEUTRINO; A COUPLE OF SERIOUS SLIDES (AT LAST!); ETC



Normal hierarchy → Normal ordering


P_{ee}=0.7, 0.5, 0.3 through the Earth (La Thuile 2003)
10^1
10^0
10^{-1}
E_ν [GeV]
-1
-0.8
-0.6
-0.4
-0.2
0
$\cos(\theta_z)$



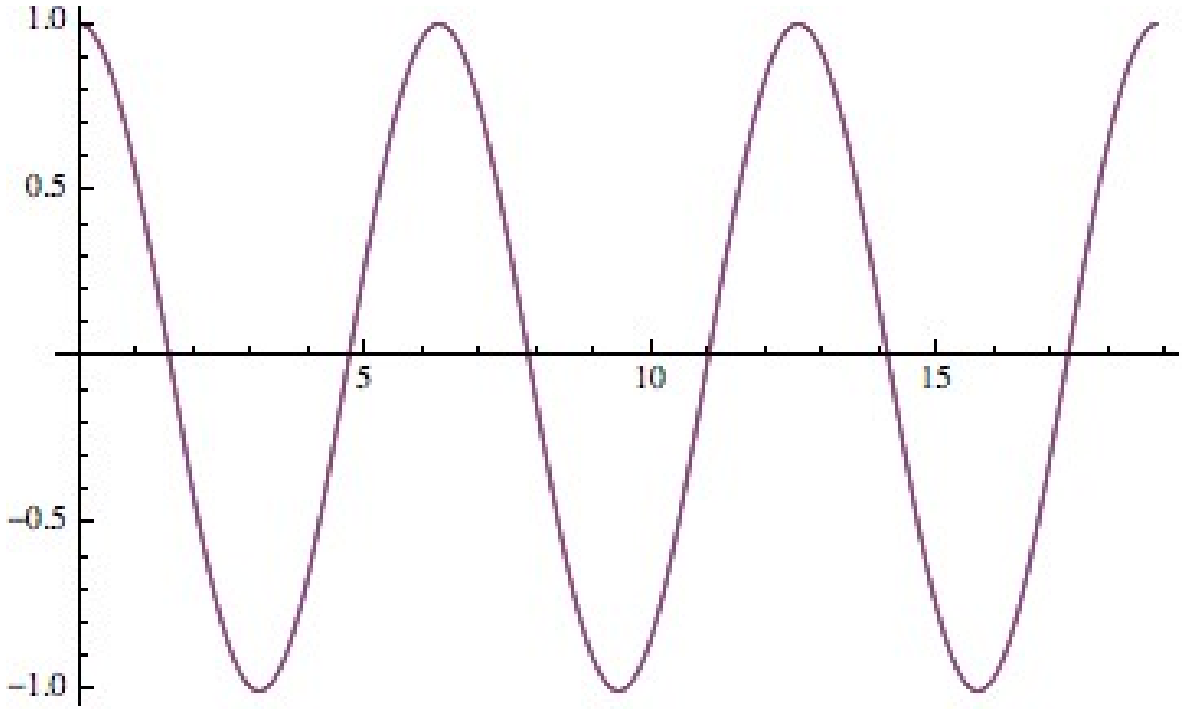
Normal ordering → Yearningly Expected Spectrum

An attempt to explain neutrino oscillations to Leucippus

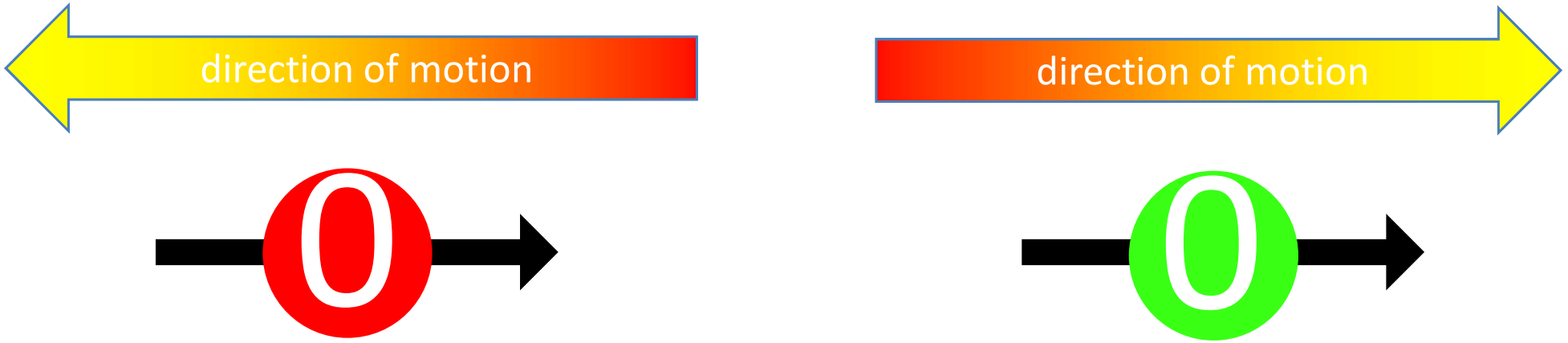
Well, we need at least a bit of wave mechanics, if not the full understanding of quantum mechanics…

It will be not that easy to convince him that any particle is also a wave, but one can try…

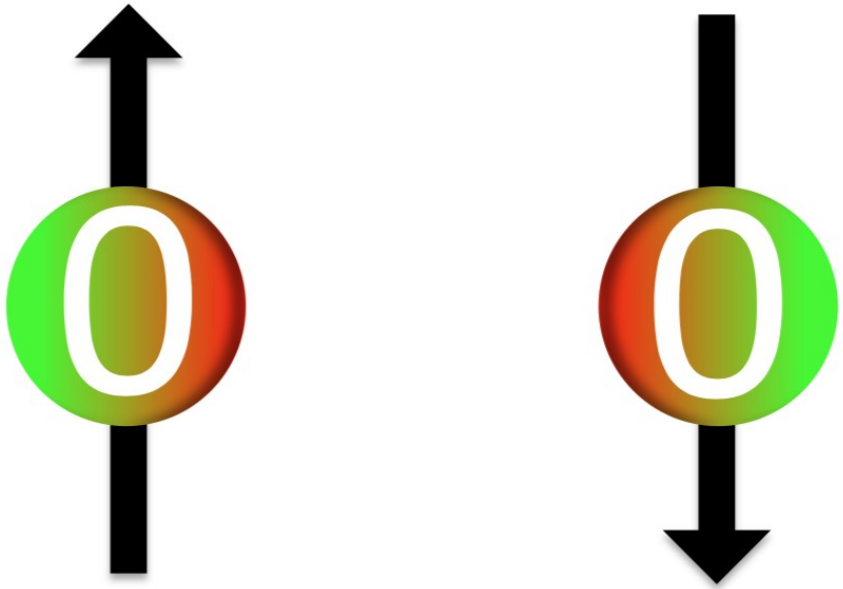
Then, I would say that “a neutrino is produced as a mixture of 2 waves with different mass; since they move with different velocity, neutrinos change nature when they propagate”



Usually we see ultrarelativistic (anti) neutrinos



If we could stop them, we would see the spin states



Available online at www.sciencedirect.com
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Nuclear Physics B 708 (2005) 215–267
NUCLEAR PHYSICS B
ELSEVIER

Probing oscillations into sterile neutrinos with cosmology, astrophysics and experiments

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

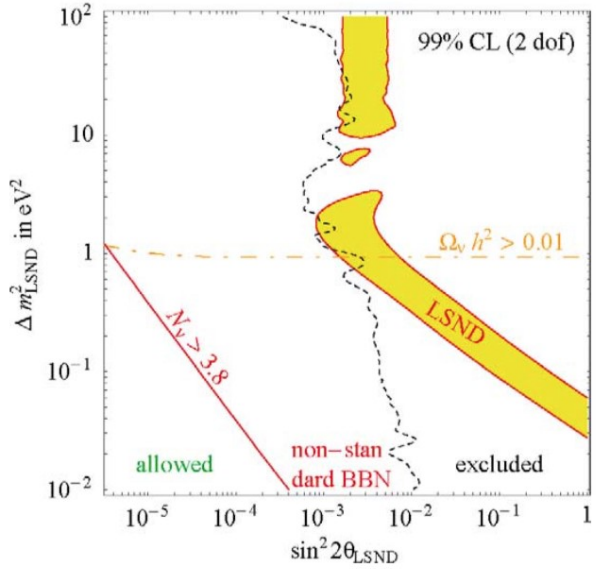


Fig. 13. The LSND anomaly interpreted as oscillations of $3+1$ neutrinos. Shaded region: suggested at 99% C.L. by LSND. Black dotted line: 99% C.L. global constraint from other neutrino experiments (mainly Karmen, Bugey, SK, CDHS). Continuos red line: $N_\nu = 3.8$ thermalized neutrinos. Dot-dashed orange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

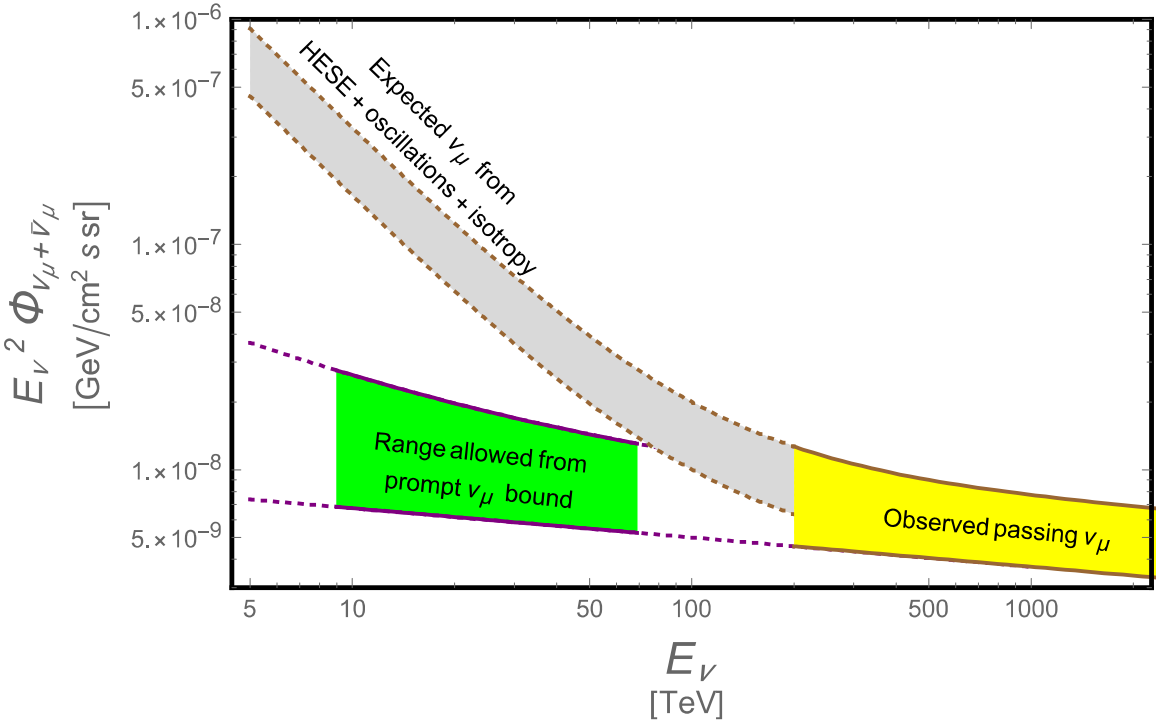
TESTING HESE WITH MUONS BELOW 0.2 PEV

If the HESE flux is isotropic it should be also in the Northern sky

If neutrino oscillate on cosmic scales, electron tau and muon neutrinos are almost the same

Expectation: there are muon neutrinos from Northern sky also below 0.2 PeV

Remark: IceCube searched in this dataset for atmospheric prompt neutrinos, w/o success



Palladino et al 2017

The scientific method

- Begins with facts / observations / evidences
- Continues with hypotheses / assumptions / principles / bases / foundations
- Proceeds with theorems / demonstrations / expectations / implications / predictions
- Ends with correspondence to reality / tests / experiments / i.e., back to facts

It’s just OK to go fishing….

… as long as we know whether we want to fish herrings or whales and we behave consequently - just as Sanpei does