# Present and Future of Neutrino physics

June 5th 2024

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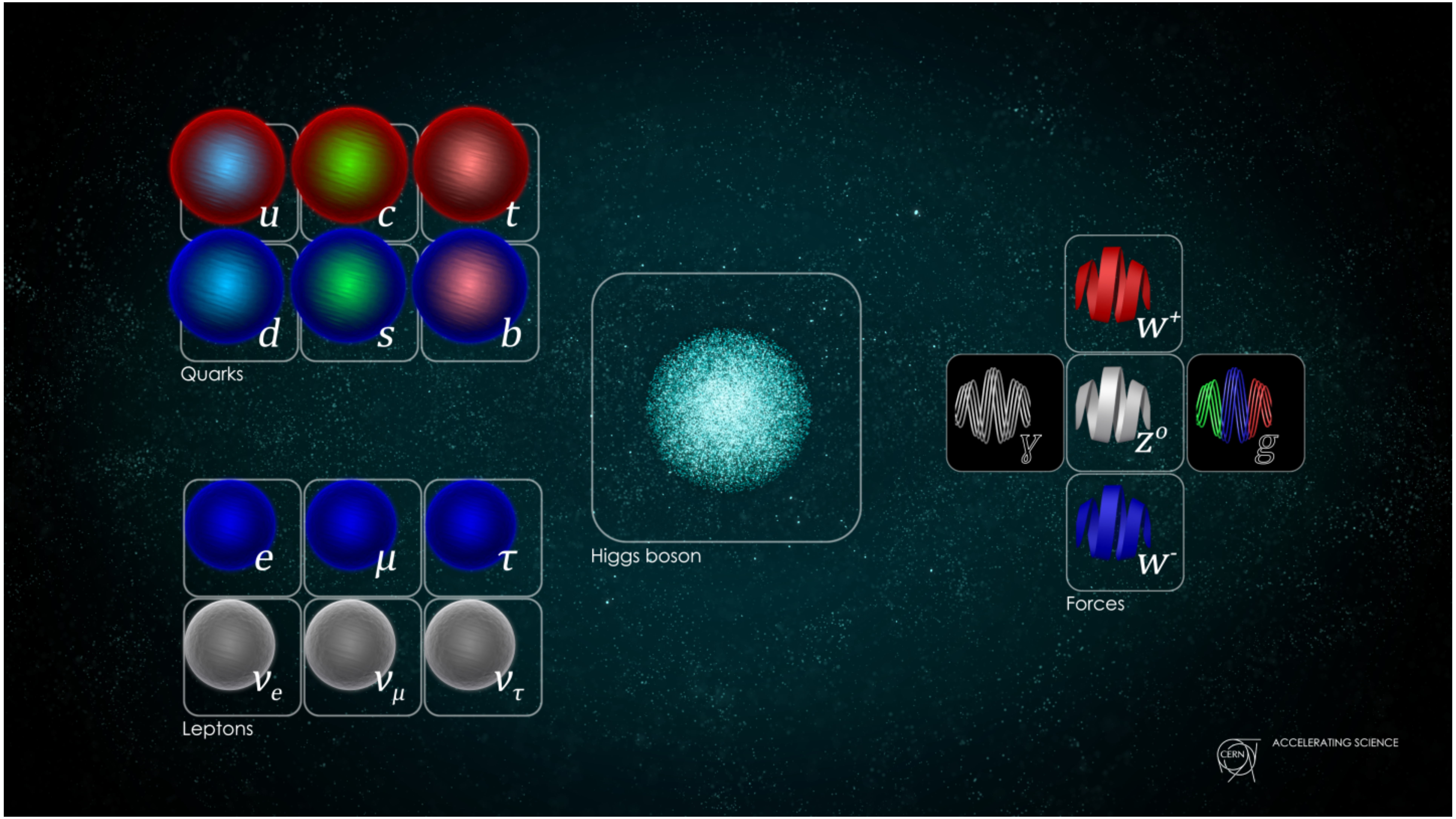
FES Cuautitlán UNAM

XXXVIII Reunión Anual de la División de Partículas y Campos de la Sociedad Mexicana de Física

UNAM
CUAUTITLÁN

DPC-SMF

# Standard model

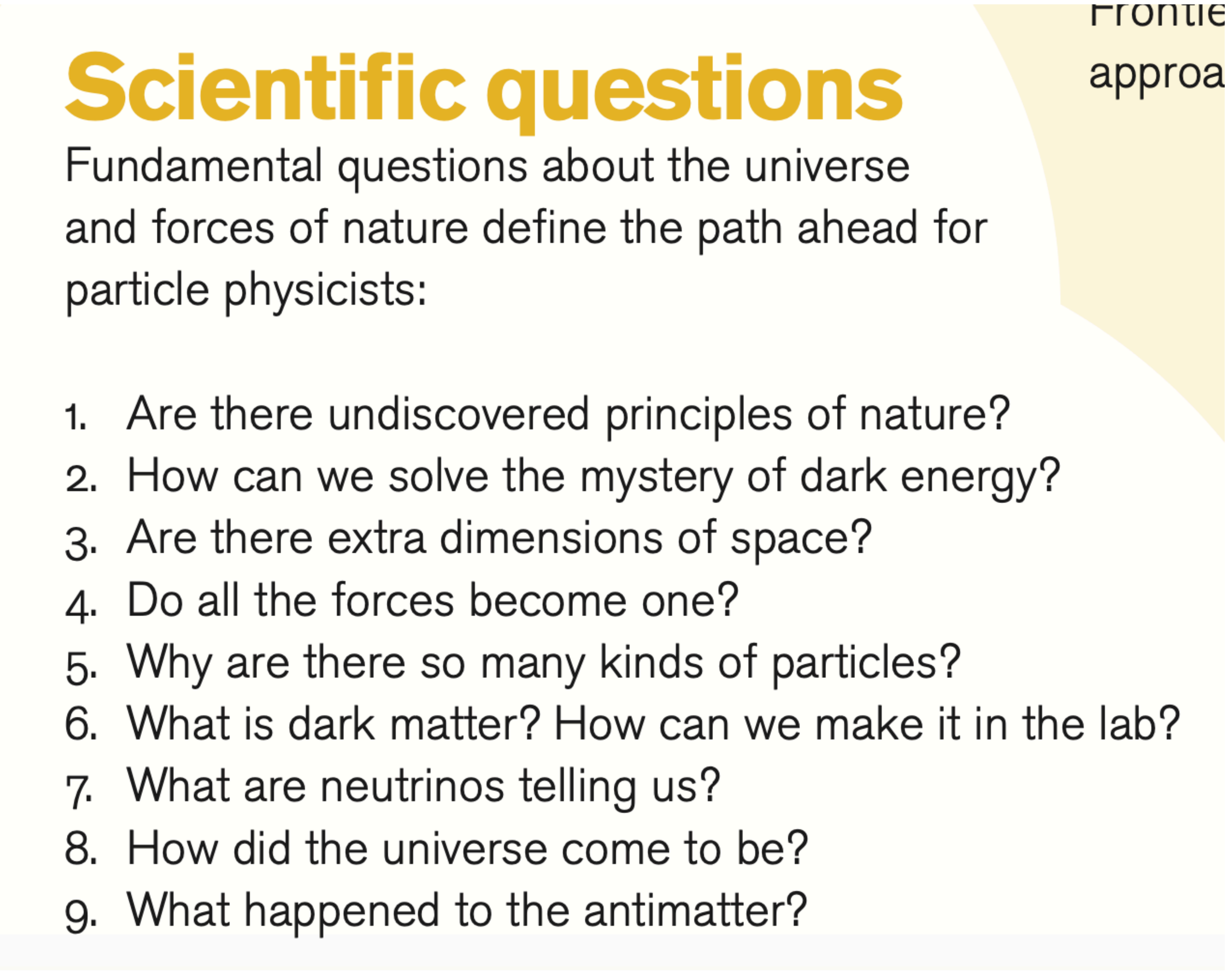


# Then and now

**XXXIV RADPyC**

**2020**

**First Meeting Online**
**Continuity**
**XXXV 2021**
**XXXVI 2022**
**XXXVII 2023 (Cinvestav)**



Frontie
approa

## Scientific questions

Fundamental questions about the universe and forces of nature define the path ahead for particle physicists:

1. Are there undiscovered principles of nature?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter? How can we make it in the lab?
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?

**XXXVIII RADPyC**

**2024**

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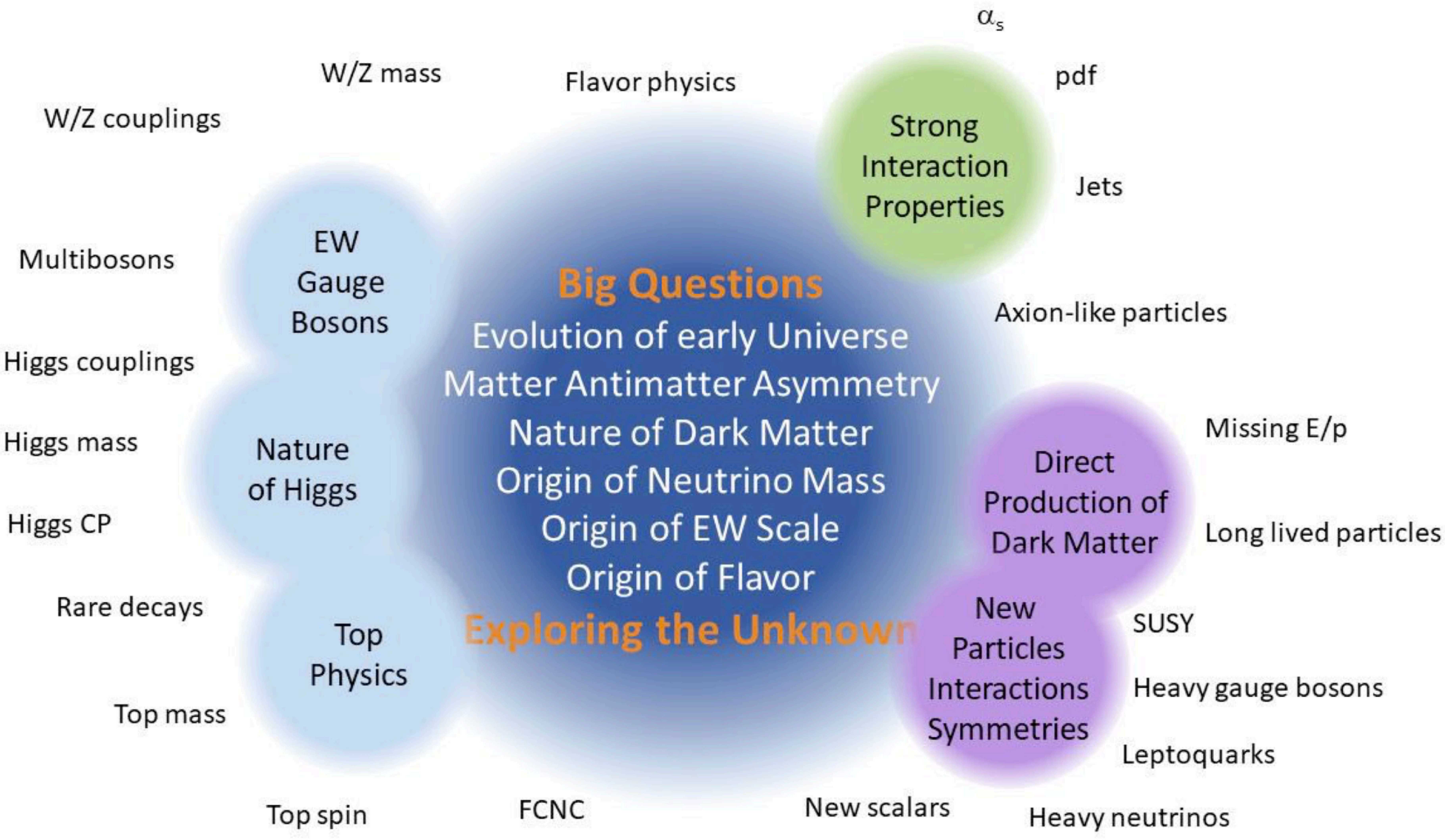
# Big questions



> ***“By the means of Telescopes, there is nothing so far distant but may be represented to our view; and by the help of Microscopes, there is nothing so small as to escape our inquiry; hence there is a new visible World discovered to the understanding. By this means the Heavens are open’d, and a vast number of new Stars, and new Motions, and new Productions appear in them, to which all the ancient Astronomers were utterly Strangers. By this the Earth itself, which lyes so near us, under our feet, shews quite a new thing to us, and in every little particle of its matter, we now behold almost as great a variety of Creatures, as we were able before to reckon up in the whole Universe it self.”***
>
> **Robert Hooke 1665**

Every age confronts its own scientific questions and develops its own tools and techniques to address them. In the 17th century, microscopes and telescopes revealed for the first time aspects of the universe invisible to the naked eye.

# 2013

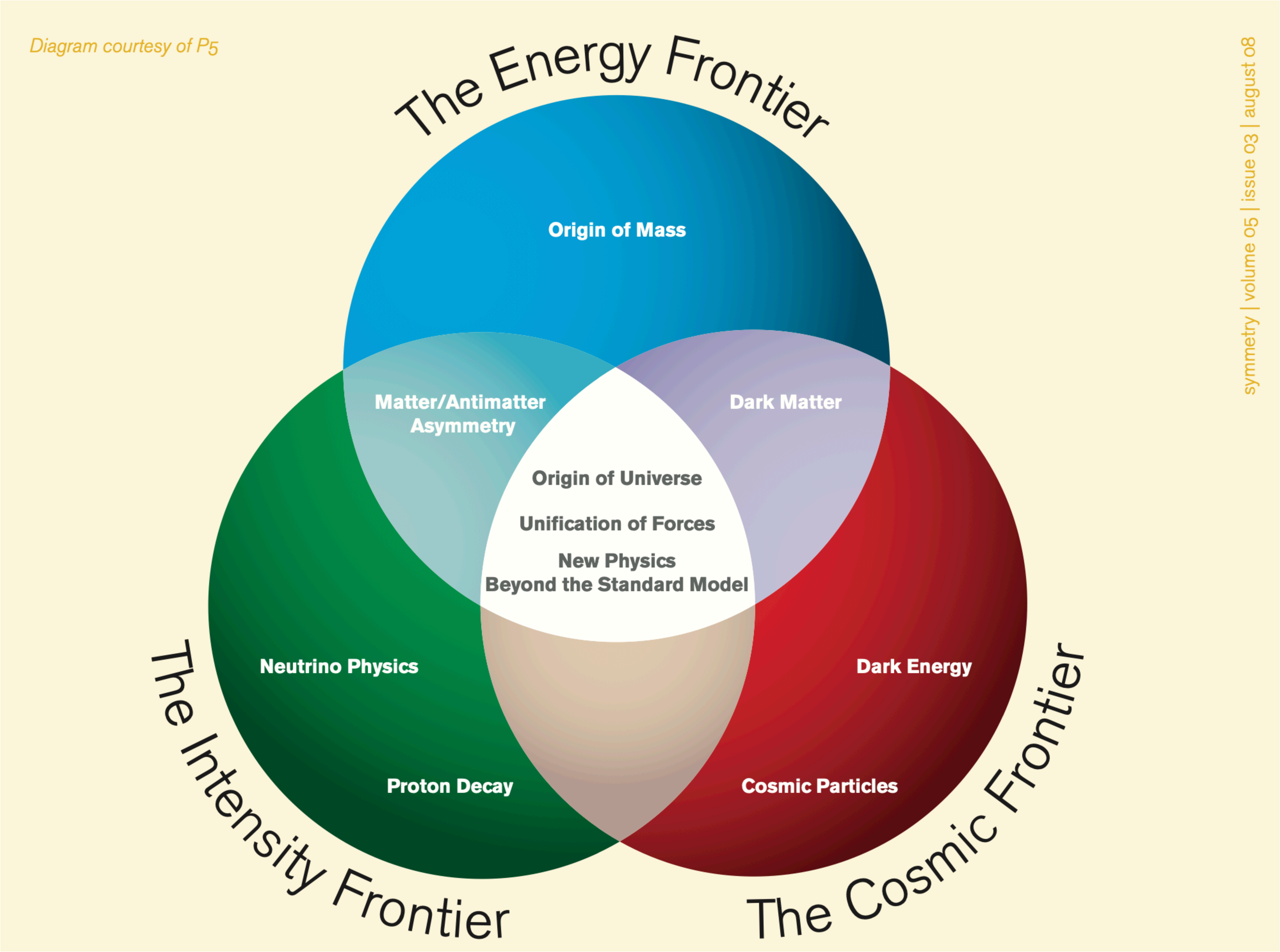


*Diagram courtesy of P5*

symmetry | volume 05 | issue 03 | august 08

# Identified drivers for BSMp in 2013

1. Use the Higgs Boson as a Tool for Discovery,
2. Pursue the Physics Associated with Neutrino Mass,
3. Identify the New Physics of Dark Matter,
4. Understand Cosmic Acceleration: Dark Energy and Inflation,
5. Explore the Unknown: New Particles, Interactions, and Physical Principles.

***The science drivers***

Use the Higgs Boson as a tool for discovery

Pursue physics associated with neutrino mass

Identify the new physics of dark matter

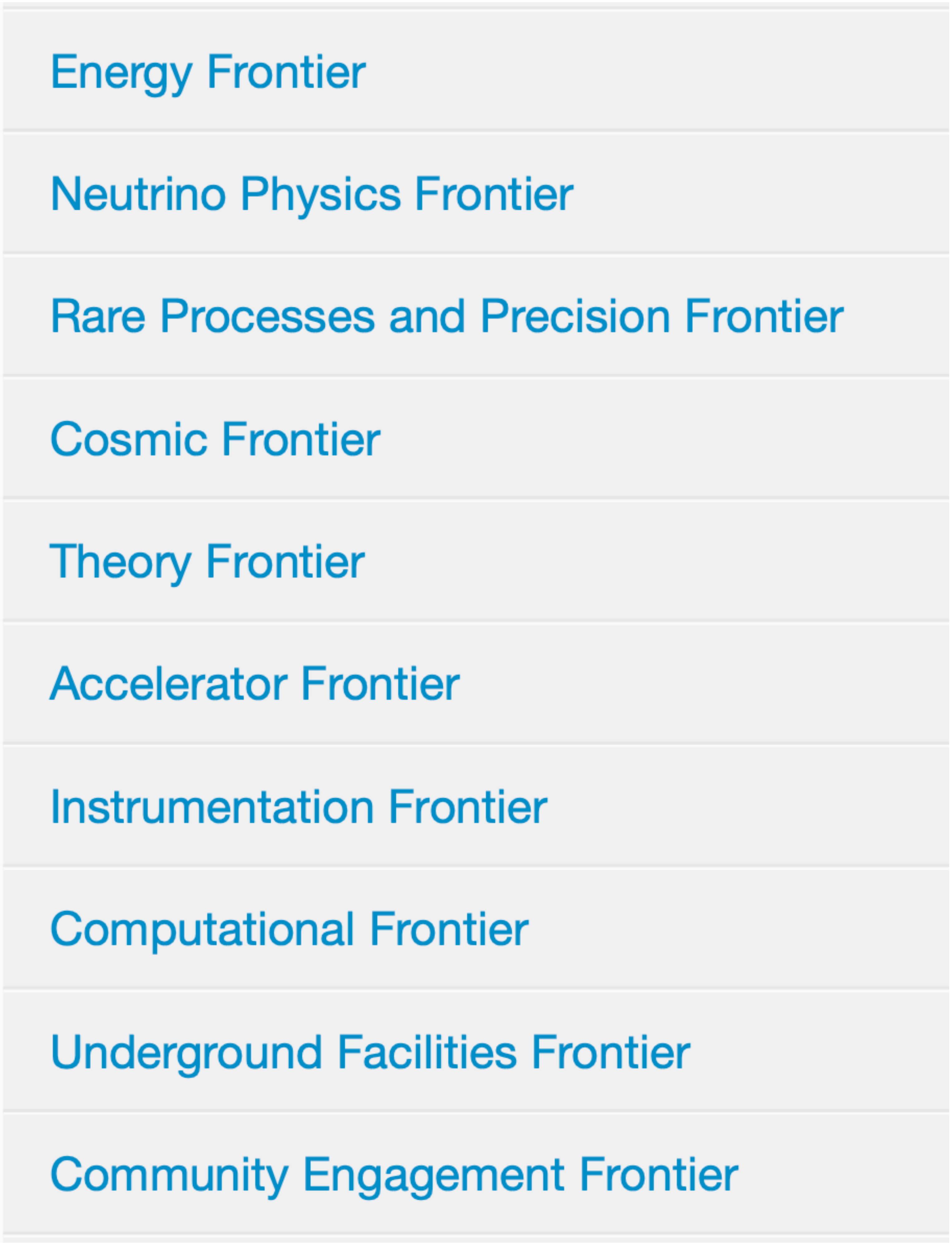
Understand dark energy and inflation

Explore the unknown

# The Snowmass process 2021

**The Snowmass Process is a particle physics community planning exercise sponsored by the Division of Particles and Fields of the American Physical Society.**

PARTICLE PHYSICS
SNOWMASS
COMMUNITY PLANNING



- Energy Frontier
- Neutrino Physics Frontier
- Rare Processes and Precision Frontier
- Cosmic Frontier
- Theory Frontier
- Accelerator Frontier
- Instrumentation Frontier
- Computational Frontier
- Underground Facilities Frontier
- Community Engagement Frontier

# How to snowmass… (Chris Quill) August 2020 (1983, 1988, 2005, 2013)

- Continue to think about what you have heard and done at Snowmass.
- Talk with your particle physics colleagues about what you have seen and heard and done here.
- Arrange seminars to share the experience with all your students and colleagues.
- Talk with your colleagues in other fields of physics and astronomy. Share your enthusiasm!
- Give a colloquium early in the school year about the future of particle physics.
- Talk with your colleagues in other fields about their excitement and aspirations.
- Help your students appreciate the exciting futures all across physics and astronomy.
- You will meet many gifted, articulate, and inspiring colleagues: Invite them to visit your department. Hire them!
- I**n the meantime, work hard, have fun, make yourself a better scientist, and help create a bright future for particle physics.**

# Outline

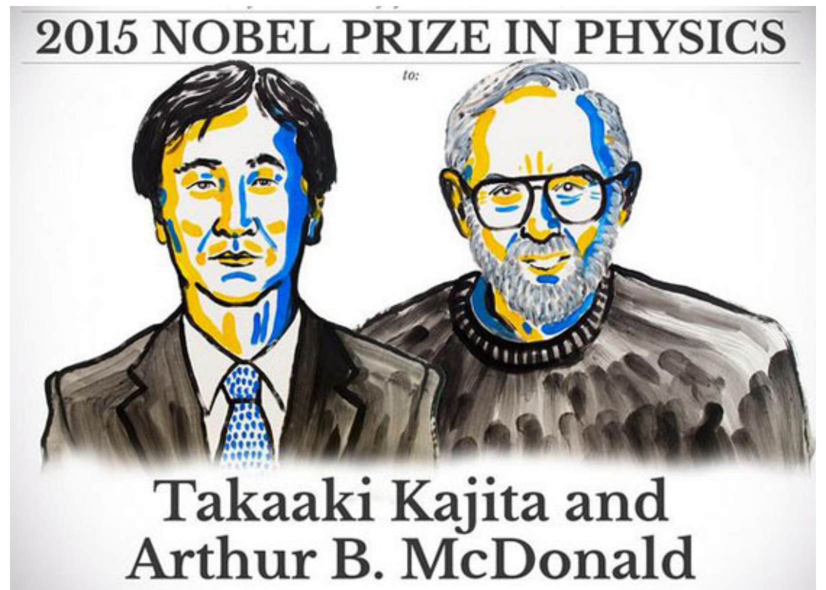
- The 3 neutrino oscillation picture
- Hints for sterile neutrinos
- CEvNS Coherent Elastic Neutrino Nucleus Scattering
- Direct Detection Dark Matter Experiments
- What neutrinos have for us in the road ahead

# Neutrino physics today

- Neutrinos have mass (Noblel Prize 2015)
- Origin of the neutrino mass
- Is there a theory of flavor?
- Neutrino nature: Dirac or Majorana
- 3 Mixing angles and 2 mass splittings from oscillation experiments
- Are there sterile neutrinos?
- What is the mass ordering
- Violation of CP in the Lepton sector

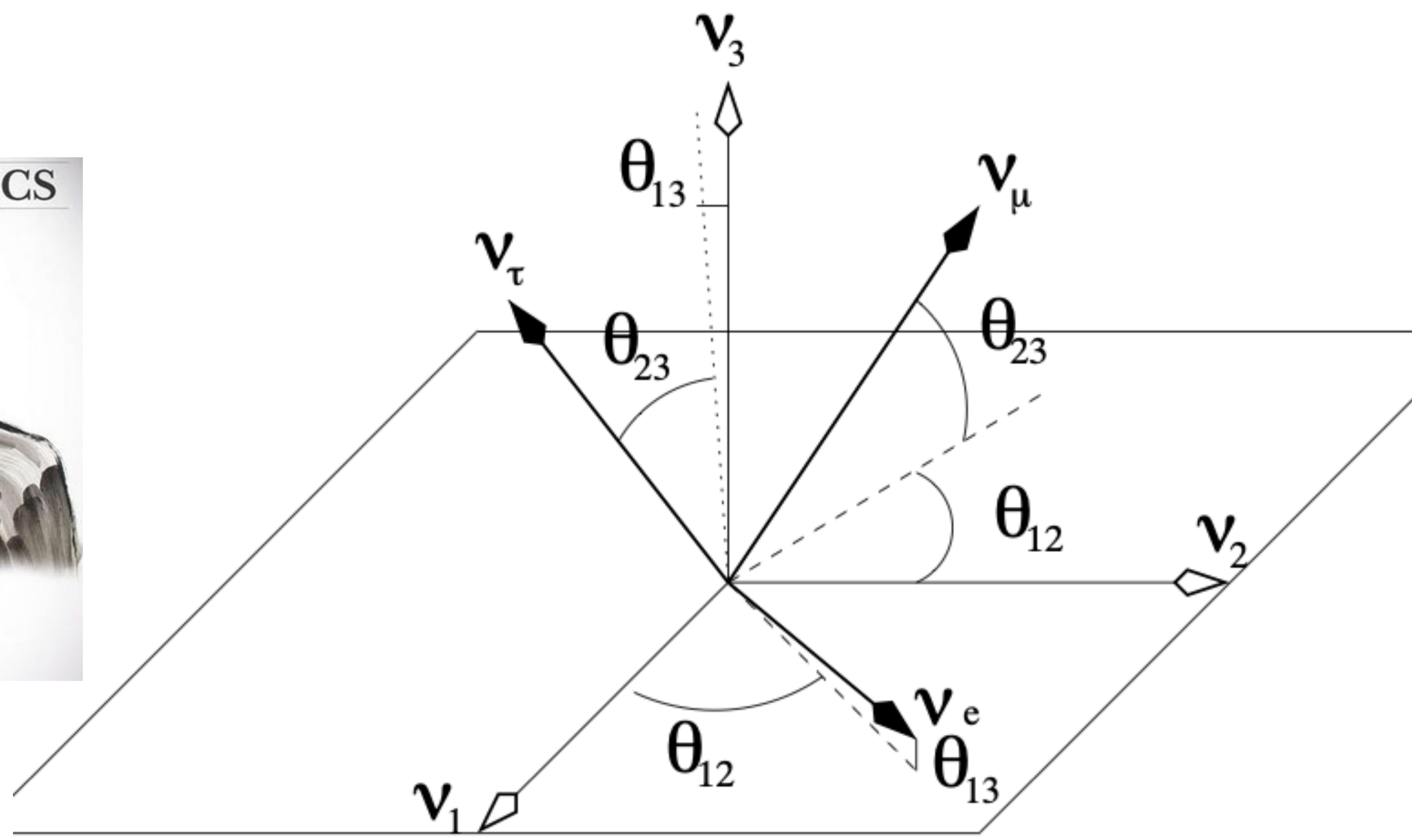
# Neutrino oscillations

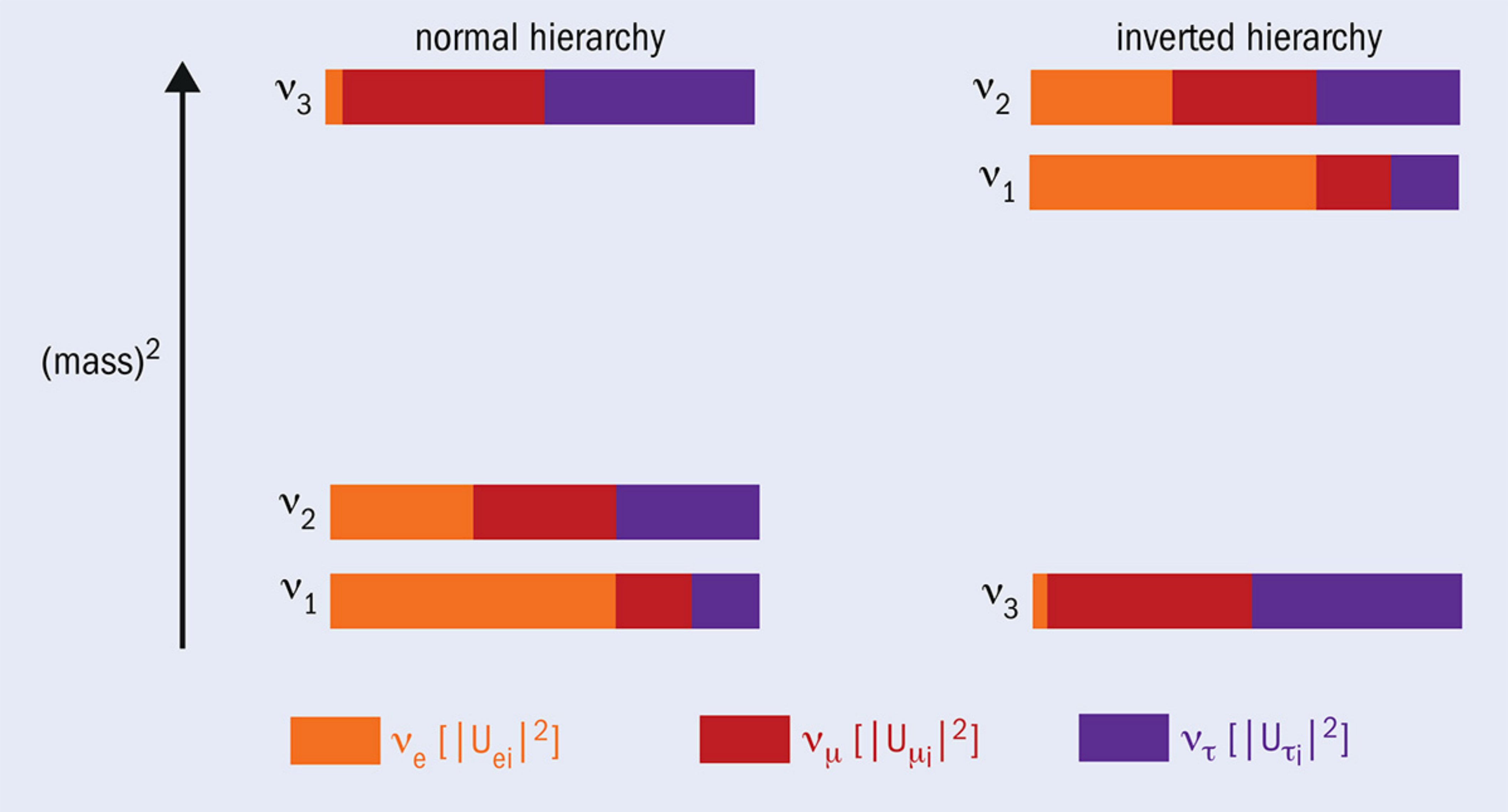
$$U_{MNS} = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{Atmospheric}} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix}}_{\text{Reactor}} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Solar}}$$



2015 NOBEL PRIZE IN PHYSICS

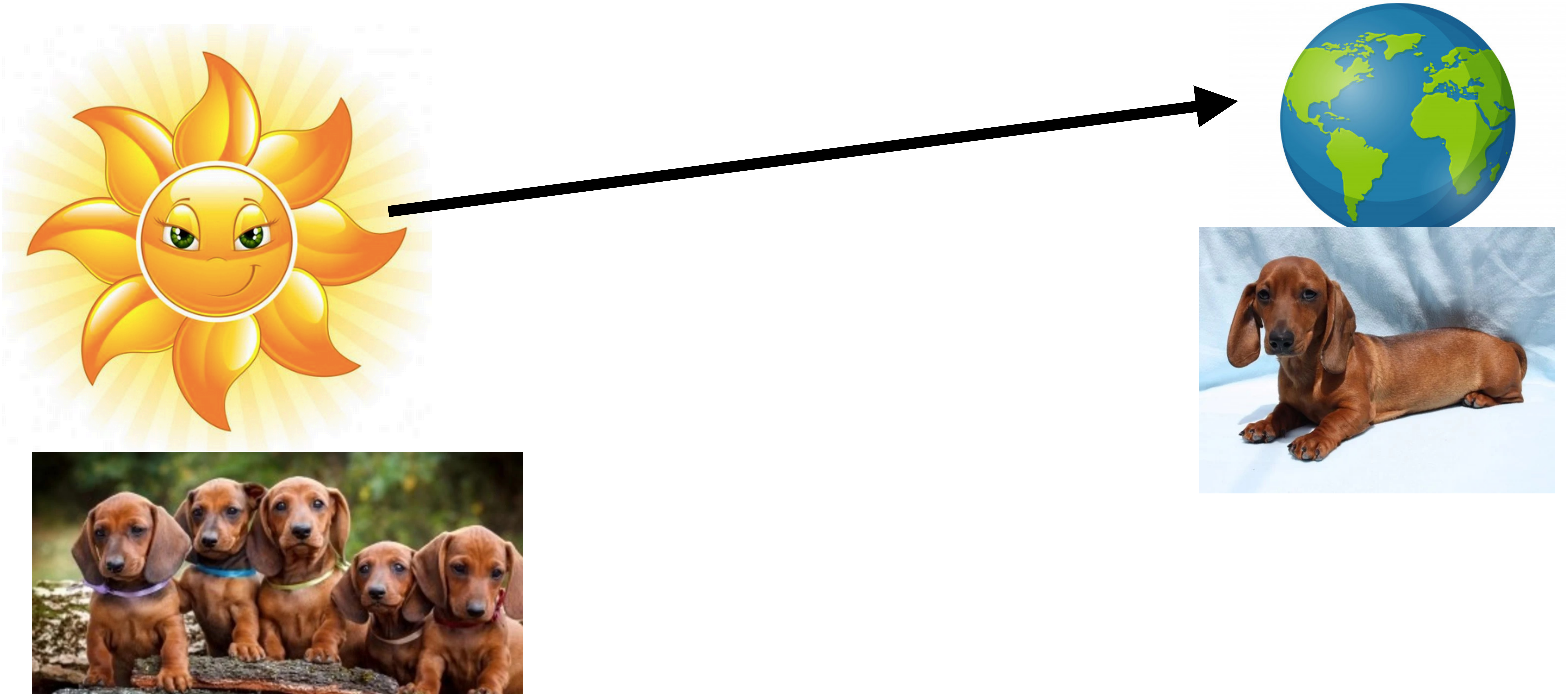
Takaaki Kajita and
Arthur B. McDonald



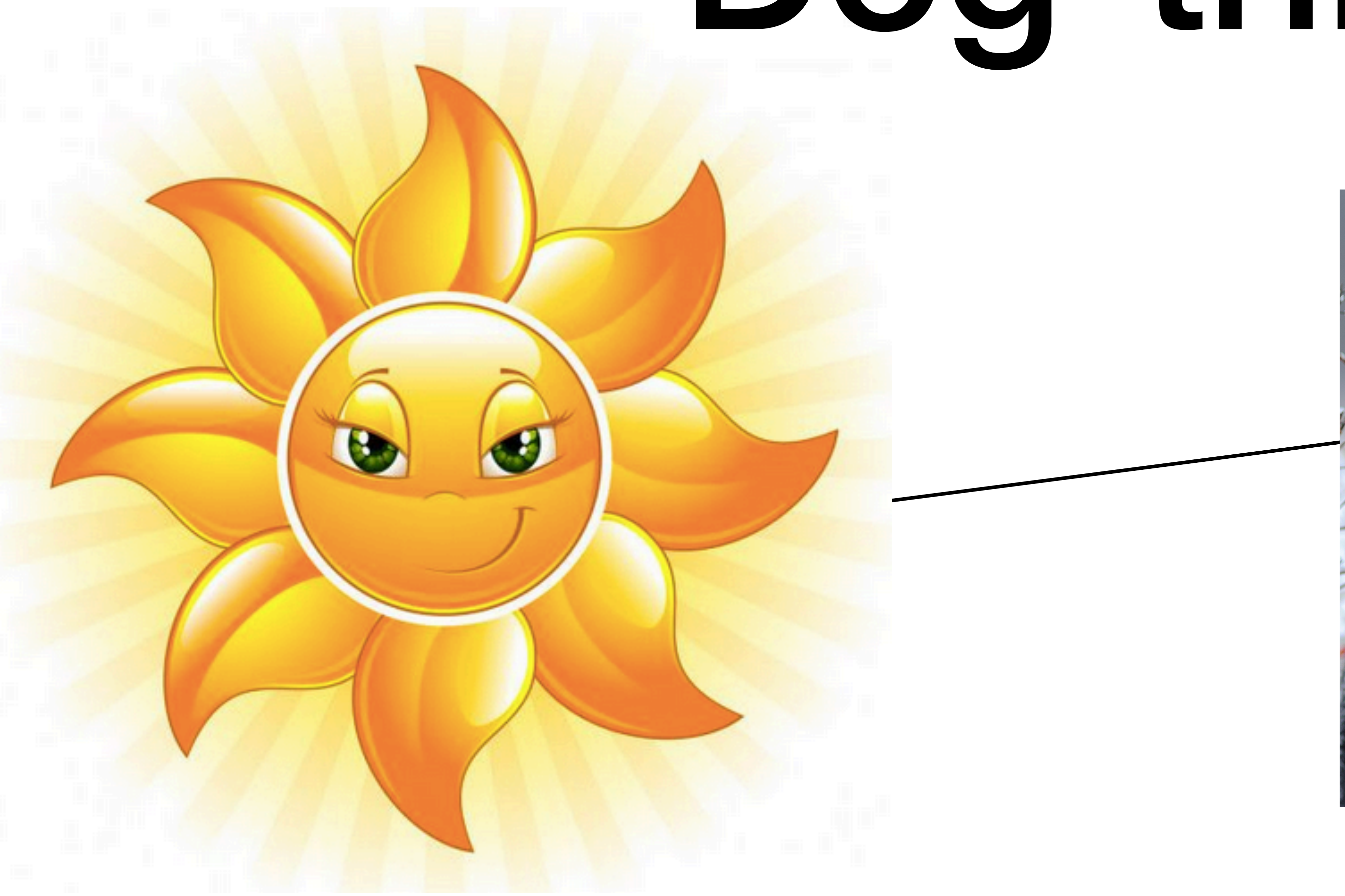


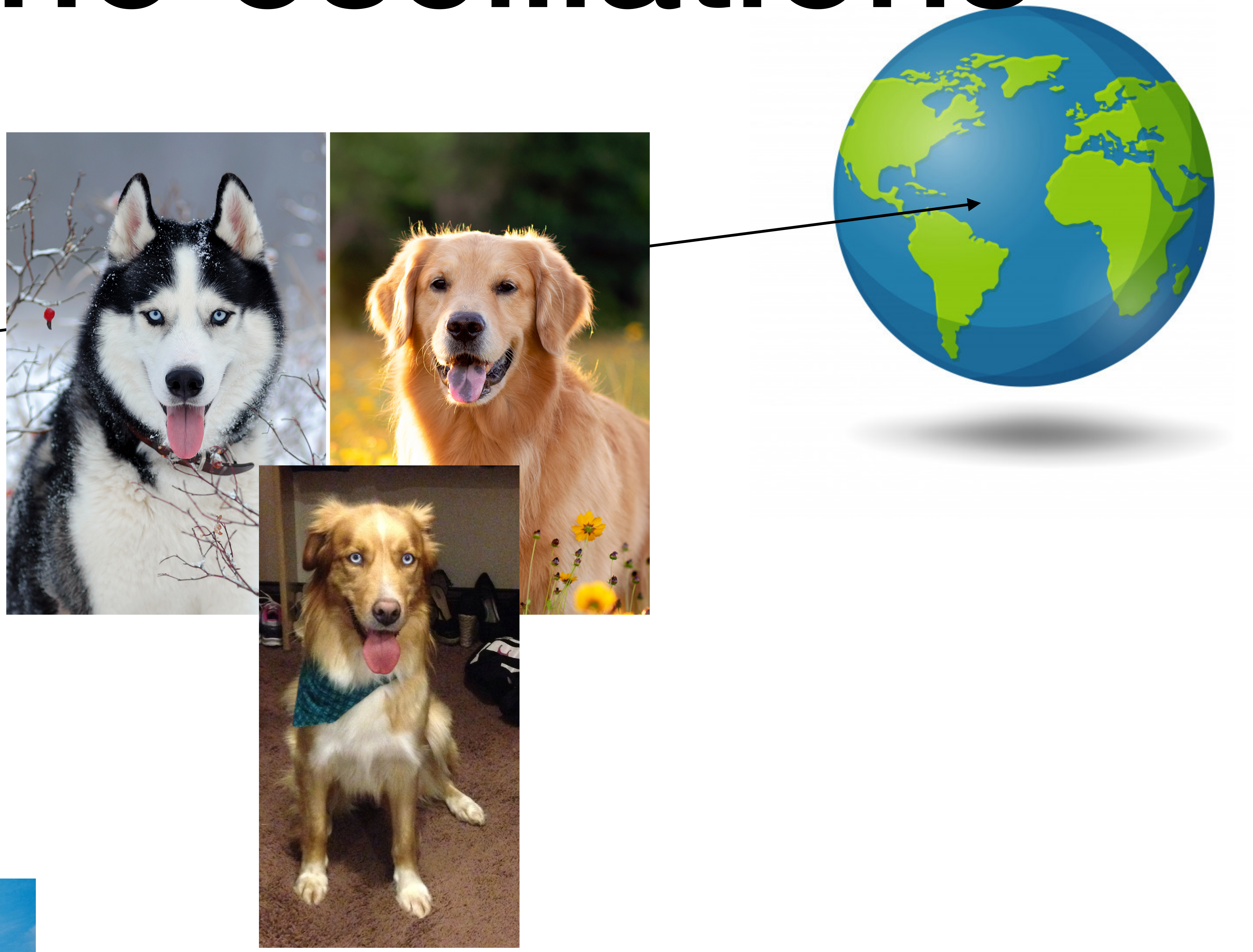
$$P(\overline{\nu}_e \rightarrow \overline{\nu}_e) \cong 1 - \sin^2 \overset{\substack{\textbf{amplitude}\\ \searrow}}{2\theta_{13}} \sin^2 \overset{\substack{\textbf{frequency}\\ \downarrow}}{\frac{\Delta m^2_{32} L}{4E}}$$

# Dog-trino oscillations



# Dog-trino oscillations





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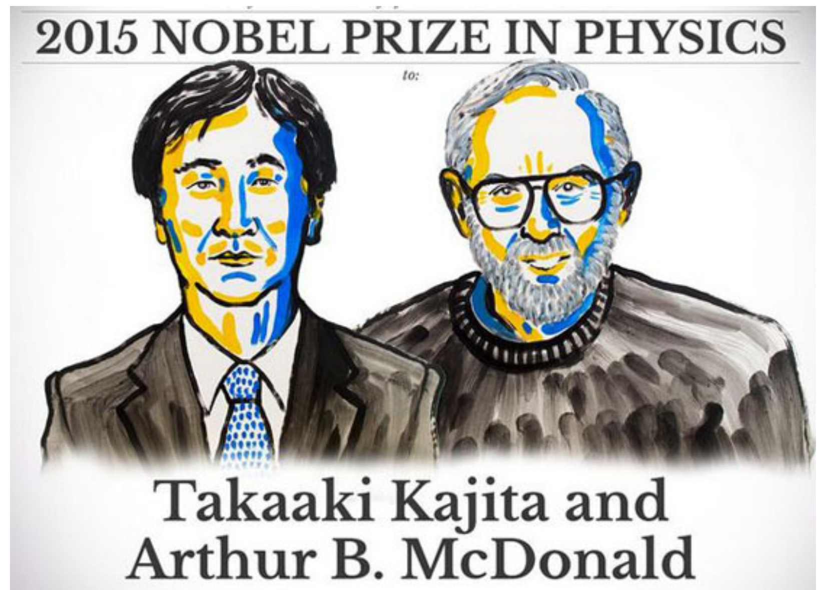

2015 NOBEL PRIZE IN PHYSICS

Takaaki Kajita and
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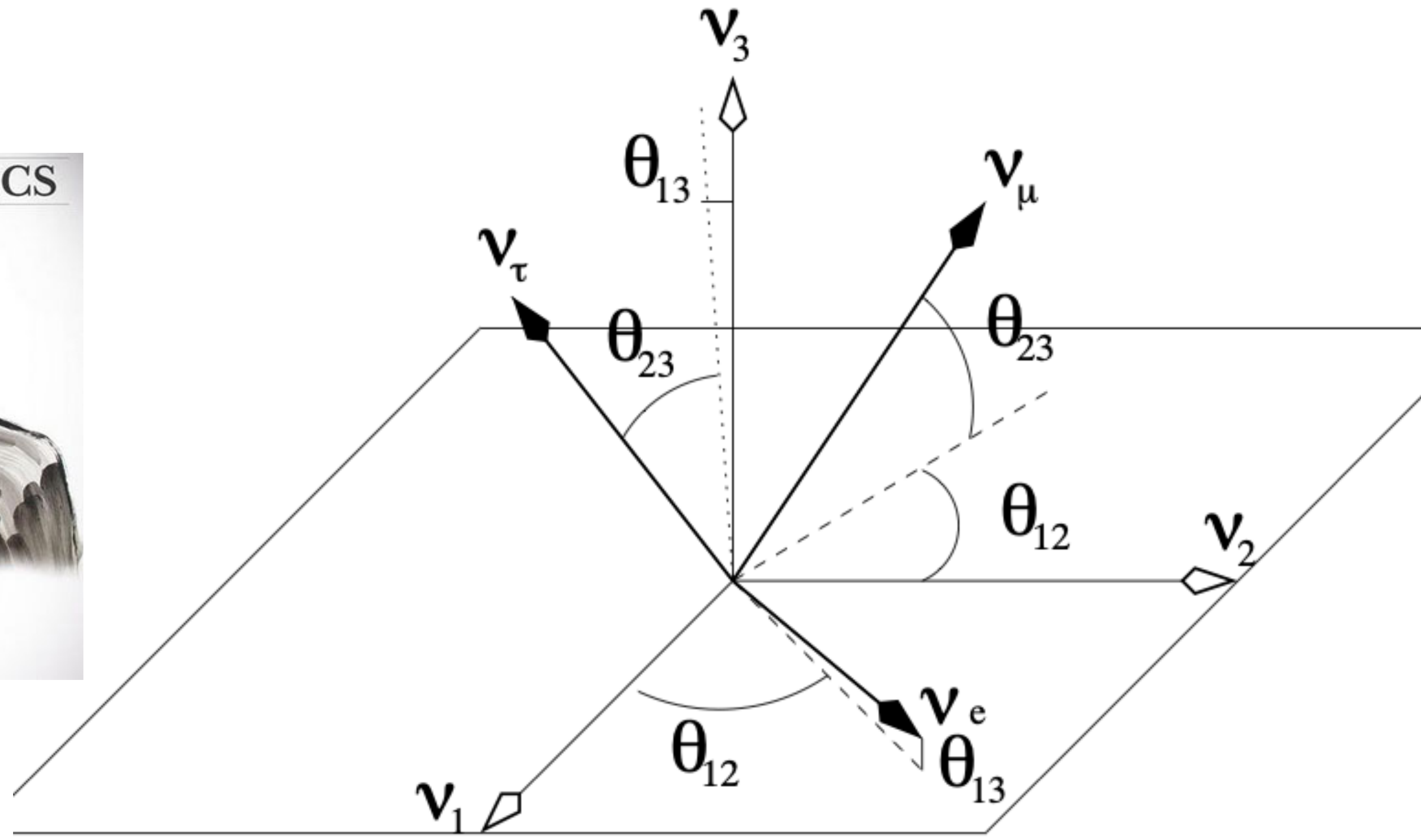
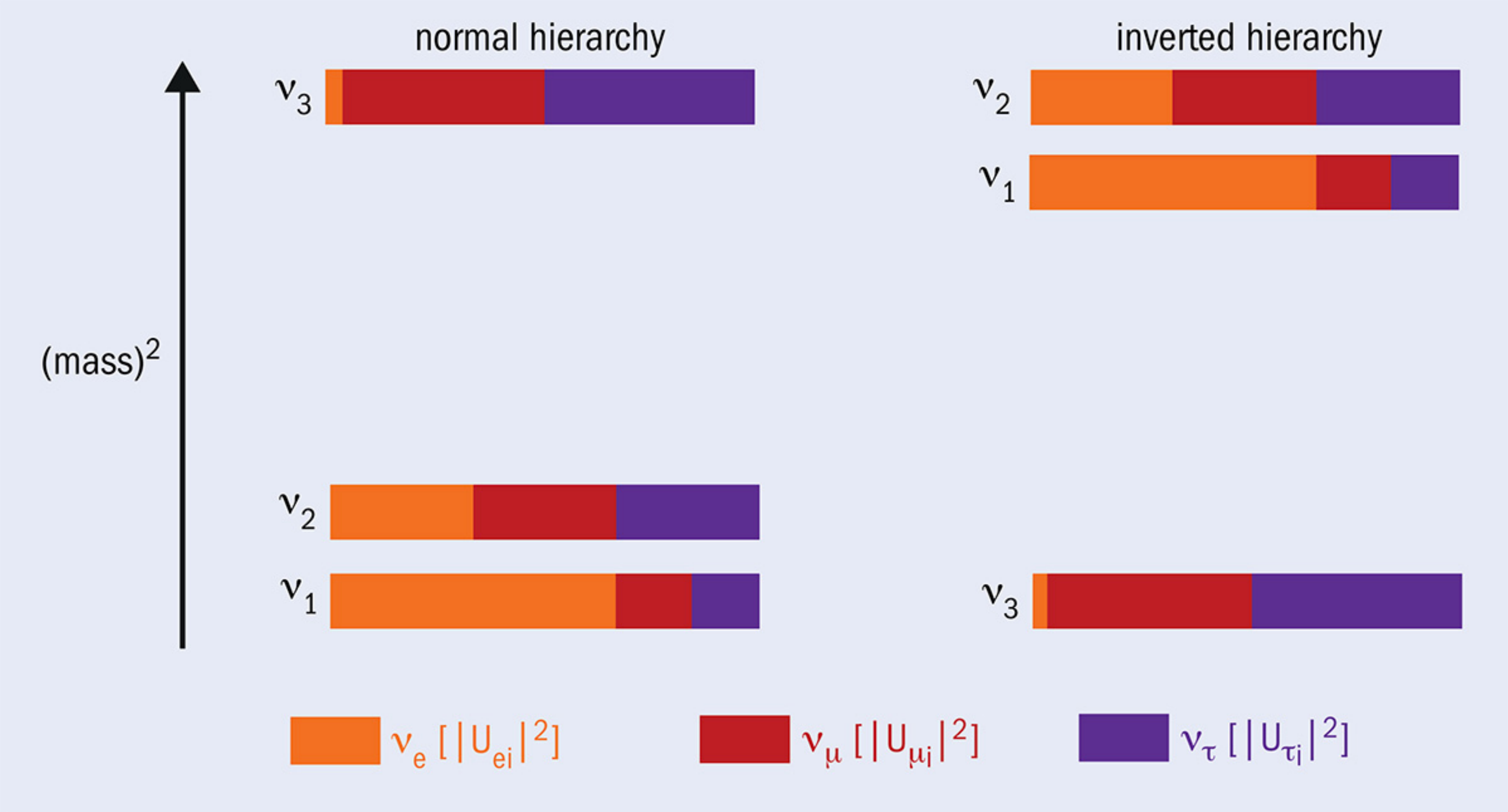
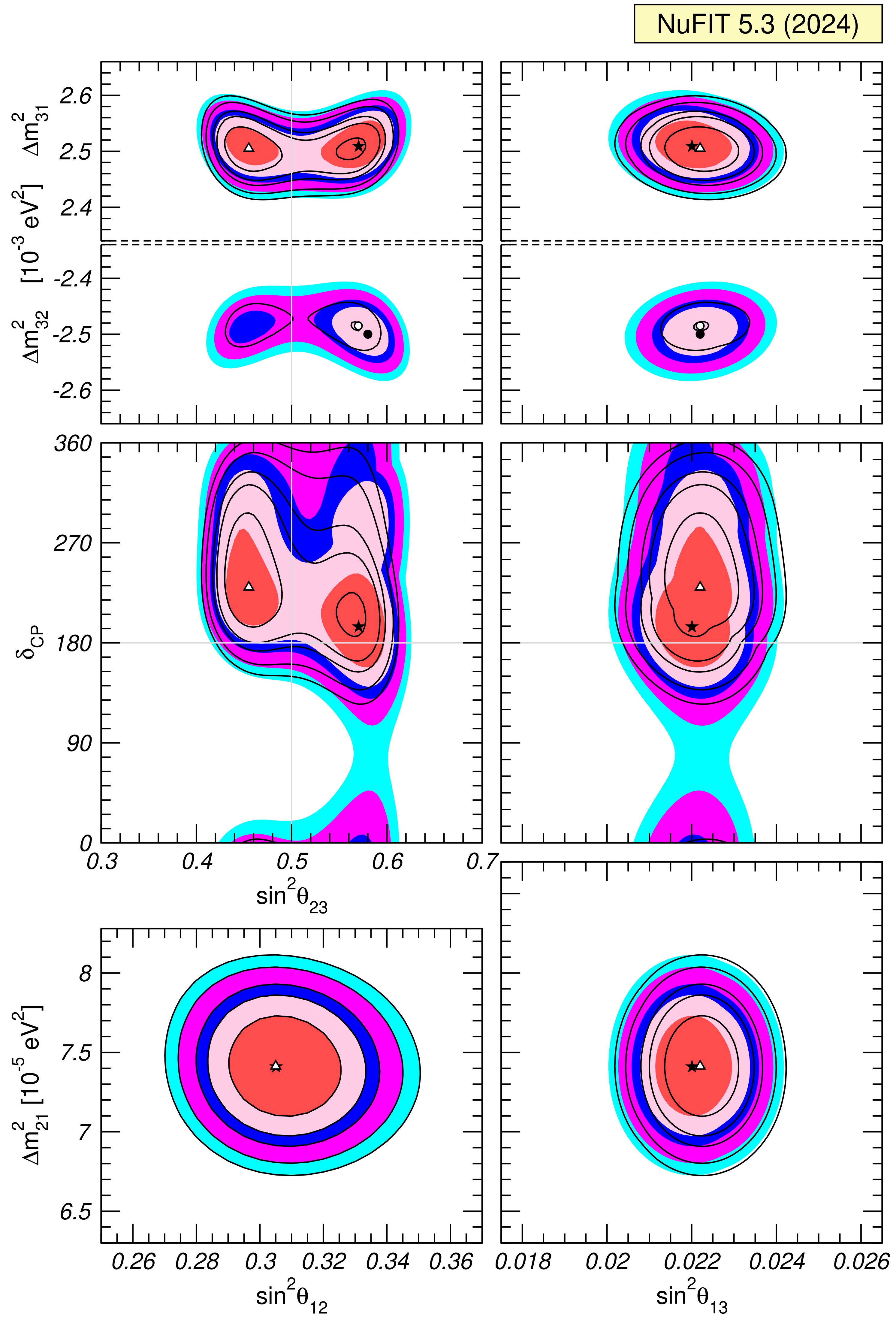
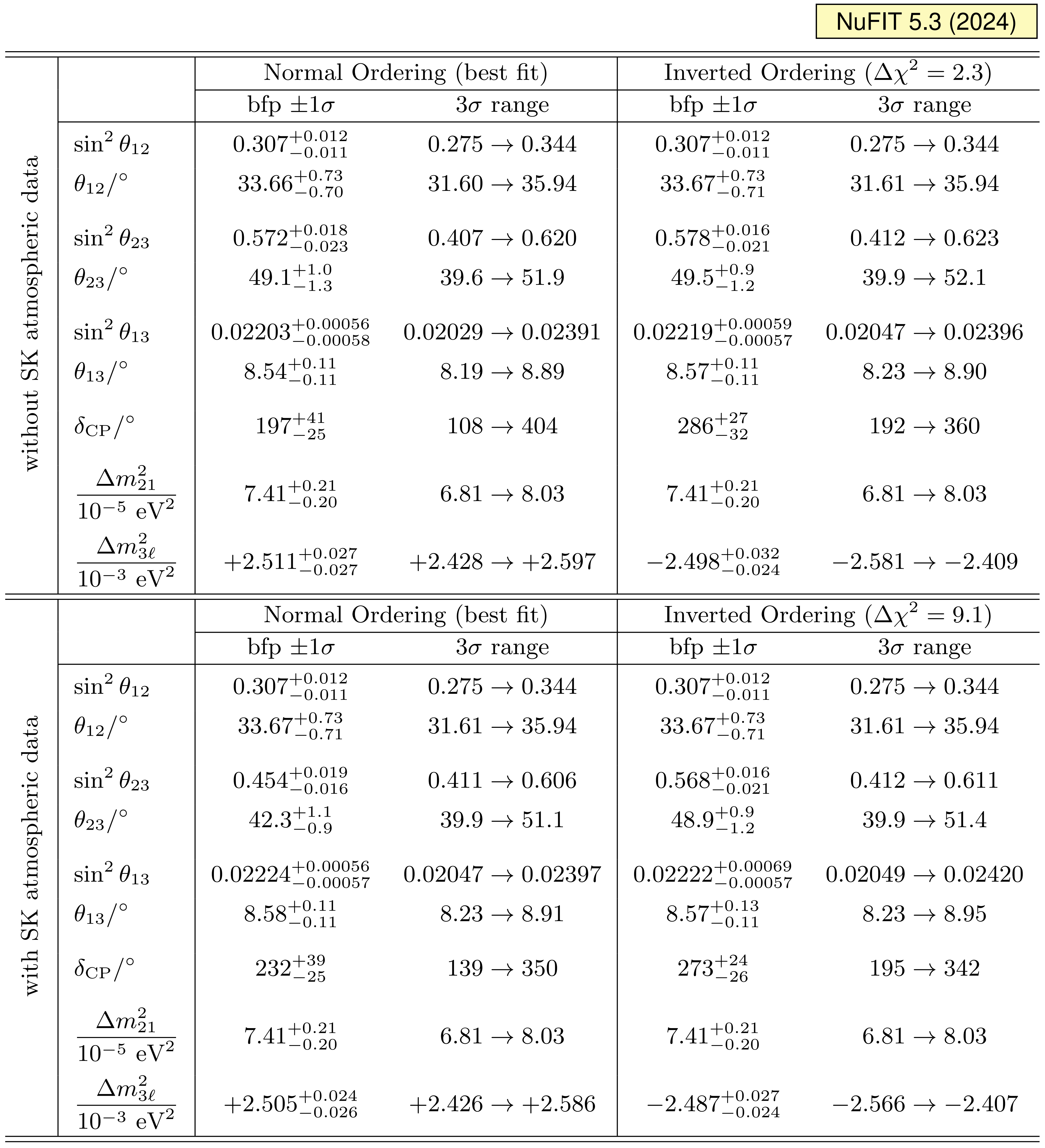




$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \cong 1 - \sin^2 \overset{\text{amplitude}}{2\theta_{13}} \sin^2 \frac{\overset{\text{frequency}}{\Delta m^2_{32}} L}{4E}$$

# Global oscillation parameters fit



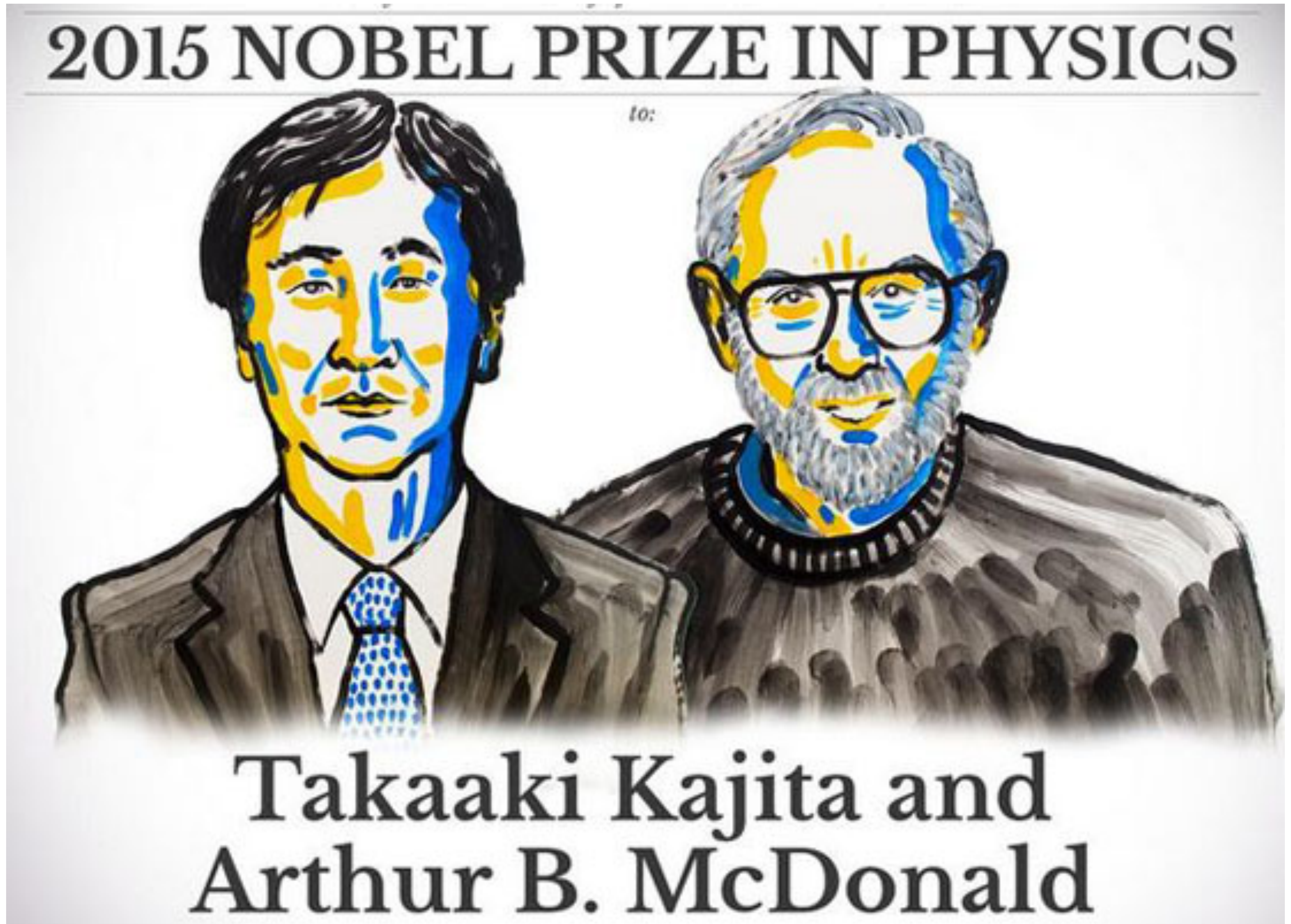


NuFIT 5.3 (2024)

| | | Normal Ordering (best fit) | | Inverted Ordering ($\Delta\chi^2 = 2.3$) | |
|---|---|---|---|---|---|
| | | bfp $\pm1\sigma$ | $3\sigma$ range | bfp $\pm1\sigma$ | $3\sigma$ range |
| without SK atmospheric data | $\sin^2\theta_{12}$ | $0.307^{+0.012}_{-0.011}$ | $0.275 \to 0.344$ | $0.307^{+0.012}_{-0.011}$ | $0.275 \to 0.344$ |
| | $\theta_{12}/^\circ$ | $33.66^{+0.73}_{-0.70}$ | $31.60 \to 35.94$ | $33.67^{+0.73}_{-0.71}$ | $31.61 \to 35.94$ |
| | $\sin^2\theta_{23}$ | $0.572^{+0.018}_{-0.023}$ | $0.407 \to 0.620$ | $0.578^{+0.016}_{-0.021}$ | $0.412 \to 0.623$ |
| | $\theta_{23}/^\circ$ | $49.1^{+1.0}_{-1.3}$ | $39.6 \to 51.9$ | $49.5^{+0.9}_{-1.2}$ | $39.9 \to 52.1$ |
| | $\sin^2\theta_{13}$ | $0.02203^{+0.00056}_{-0.00058}$ | $0.02029 \to 0.02391$ | $0.02219^{+0.00059}_{-0.00057}$ | $0.02047 \to 0.02396$ |
| | $\theta_{13}/^\circ$ | $8.54^{+0.11}_{-0.11}$ | $8.19 \to 8.89$ | $8.57^{+0.11}_{-0.11}$ | $8.23 \to 8.90$ |
| | $\delta_{\rm CP}/^\circ$ | $197^{+41}_{-25}$ | $108 \to 404$ | $286^{+27}_{-32}$ | $192 \to 360$ |
| | $\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$ | $7.41^{+0.21}_{-0.20}$ | $6.81 \to 8.03$ | $7.41^{+0.21}_{-0.20}$ | $6.81 \to 8.03$ |
| | $\frac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$ | $+2.511^{+0.027}_{-0.027}$ | $+2.428 \to +2.597$ | $-2.498^{+0.032}_{-0.024}$ | $-2.581 \to -2.409$ |
| | | Normal Ordering (best fit) | | Inverted Ordering ($\Delta\chi^2 = 9.1$) | |
| | | bfp $\pm1\sigma$ | $3\sigma$ range | bfp $\pm1\sigma$ | $3\sigma$ range |
| with SK atmospheric data | $\sin^2\theta_{12}$ | $0.307^{+0.012}_{-0.011}$ | $0.275 \to 0.344$ | $0.307^{+0.012}_{-0.011}$ | $0.275 \to 0.344$ |
| | $\theta_{12}/^\circ$ | $33.67^{+0.73}_{-0.71}$ | $31.61 \to 35.94$ | $33.67^{+0.73}_{-0.71}$ | $31.61 \to 35.94$ |
| | $\sin^2\theta_{23}$ | $0.454^{+0.019}_{-0.016}$ | $0.411 \to 0.606$ | $0.568^{+0.016}_{-0.021}$ | $0.412 \to 0.611$ |
| | $\theta_{23}/^\circ$ | $42.3^{+1.1}_{-0.9}$ | $39.9 \to 51.1$ | $48.9^{+0.9}_{-1.2}$ | $39.9 \to 51.4$ |
| | $\sin^2\theta_{13}$ | $0.02224^{+0.00056}_{-0.00057}$ | $0.02047 \to 0.02397$ | $0.02222^{+0.00069}_{-0.00057}$ | $0.02049 \to 0.02420$ |
| | $\theta_{13}/^\circ$ | $8.58^{+0.11}_{-0.11}$ | $8.23 \to 8.91$ | $8.57^{+0.13}_{-0.11}$ | $8.23 \to 8.95$ |
| | $\delta_{\rm CP}/^\circ$ | $232^{+39}_{-25}$ | $139 \to 350$ | $273^{+24}_{-26}$ | $195 \to 342$ |
| | $\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$ | $7.41^{+0.21}_{-0.20}$ | $6.81 \to 8.03$ | $7.41^{+0.21}_{-0.20}$ | $6.81 \to 8.03$ |
| | $\frac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$ | $+2.505^{+0.024}_{-0.026}$ | $+2.426 \to +2.586$ | $-2.487^{+0.027}_{-0.024}$ | $-2.566 \to -2.407$ |

JHEP 09 (2020) 178 [arXiv:2007.14792], NuFIT 5.3 (2024), www.nu-fit.org.

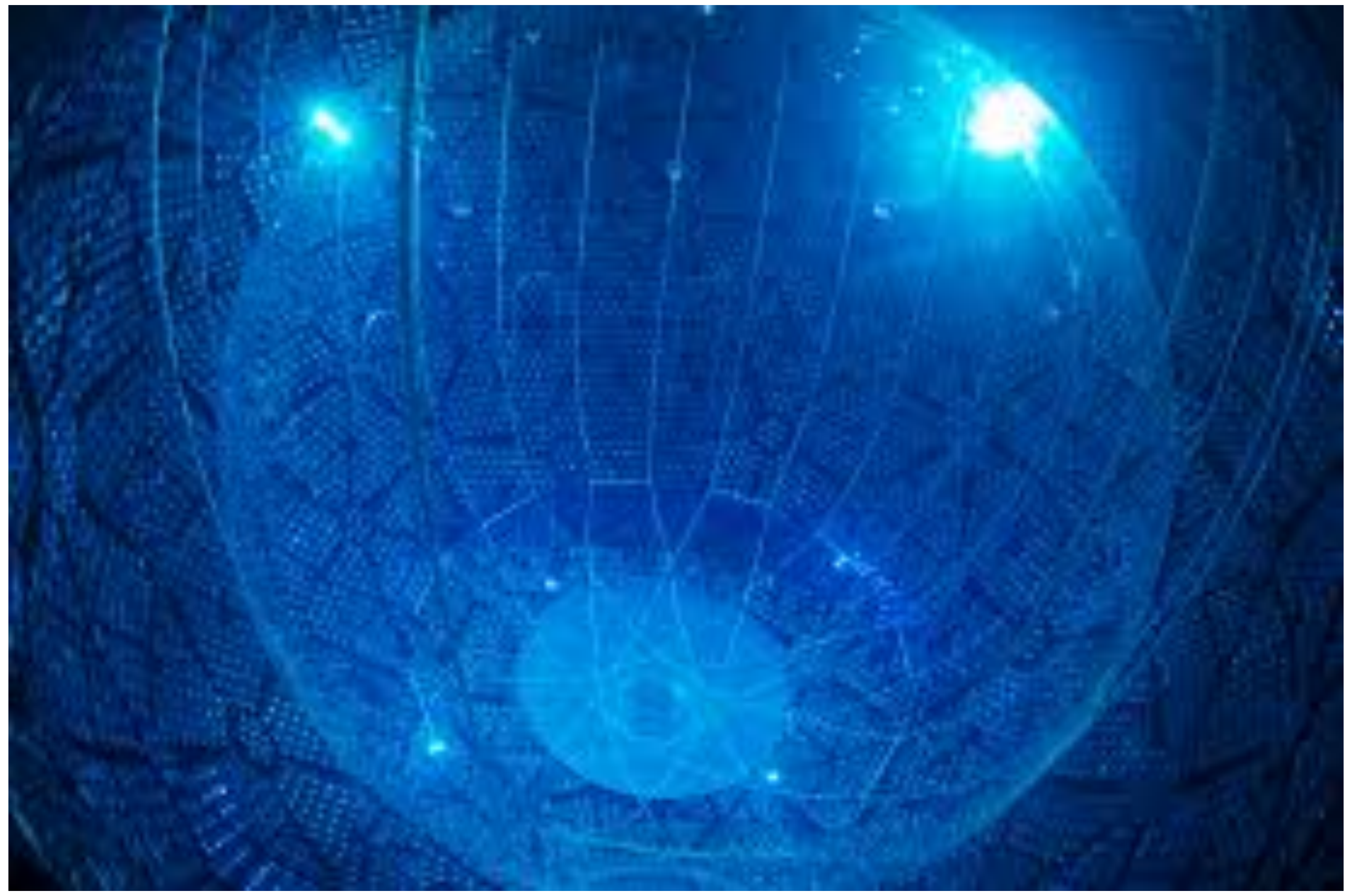
# Nobel 2015, Oscilaciones de neutrinos



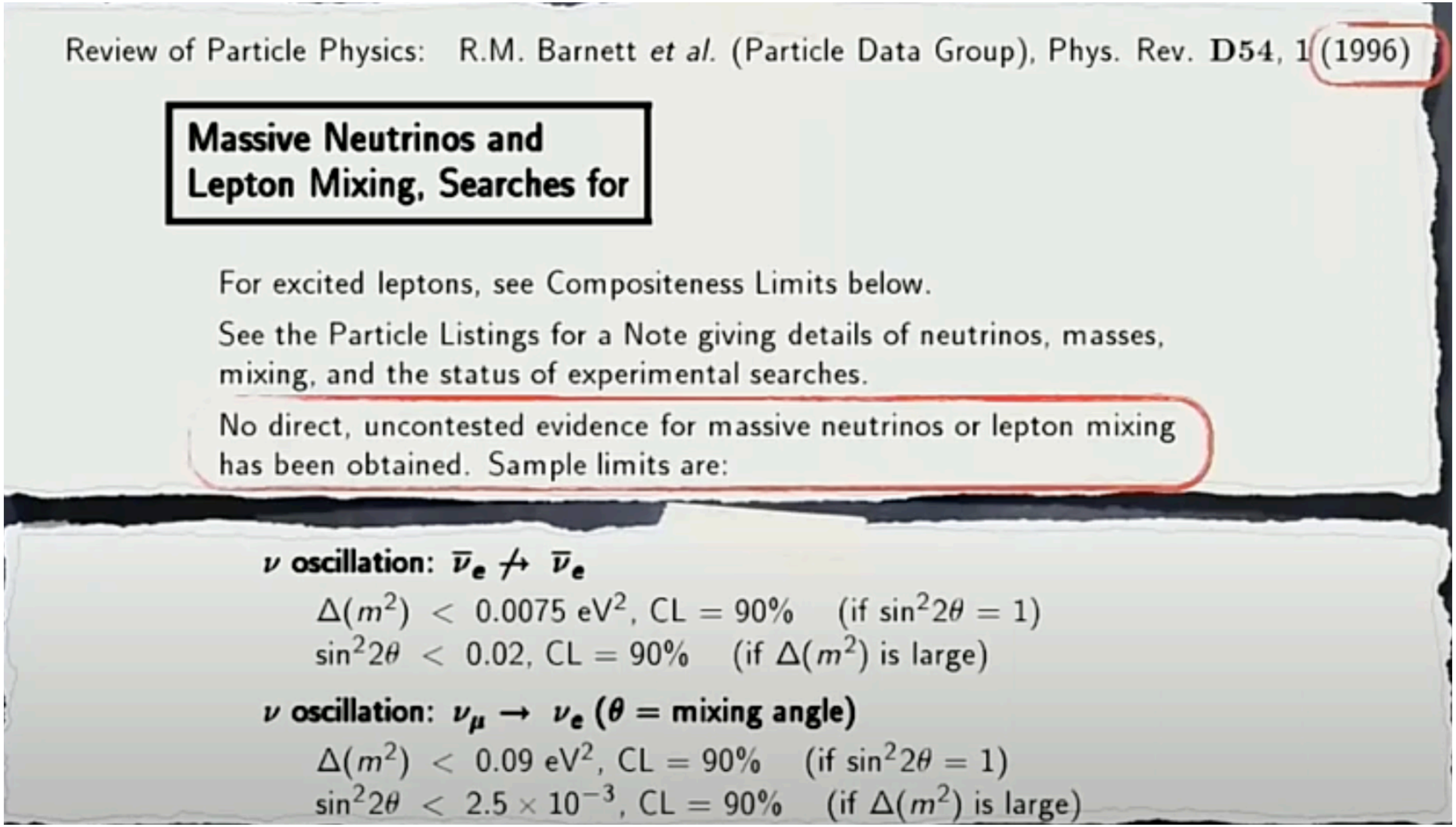
Principia Marsupia
@pmarsupia

El Super Kamiokande, una piscina de 50,000 toneladas de agua ultra-pura donde se midió la oscilación de neutrinos

05:59 - 6 oct 2015



# PDG back in 1996



Review of Particle Physics: R.M. Barnett *et al.* (Particle Data Group), Phys. Rev. **D54**, 1 (1996)

**Massive Neutrinos and Lepton Mixing, Searches for**

For excited leptons, see Compositeness Limits below.

See the Particle Listings for a Note giving details of neutrinos, masses, mixing, and the status of experimental searches.

No direct, uncontested evidence for massive neutrinos or lepton mixing has been obtained. Sample limits are:

**$\nu$ oscillation: $\overline{\nu}_e \not\to \overline{\nu}_e$**

$\Delta(m^2) < 0.0075$ eV$^2$, CL = 90% (if $\sin^2 2\theta = 1$)
$\sin^2 2\theta < 0.02$, CL = 90% (if $\Delta(m^2)$ is large)

**$\nu$ oscillation: $\nu_\mu \to \nu_e$ ($\theta$ = mixing angle)**

$\Delta(m^2) < 0.09$ eV$^2$, CL = 90% (if $\sin^2 2\theta = 1$)
$\sin^2 2\theta < 2.5 \times 10^{-3}$, CL = 90% (if $\Delta(m^2)$ is large)

# Neutrino oscillations evolution

~20 years ago

$\mathcal{O}(1)$

**2 flavor**

Now

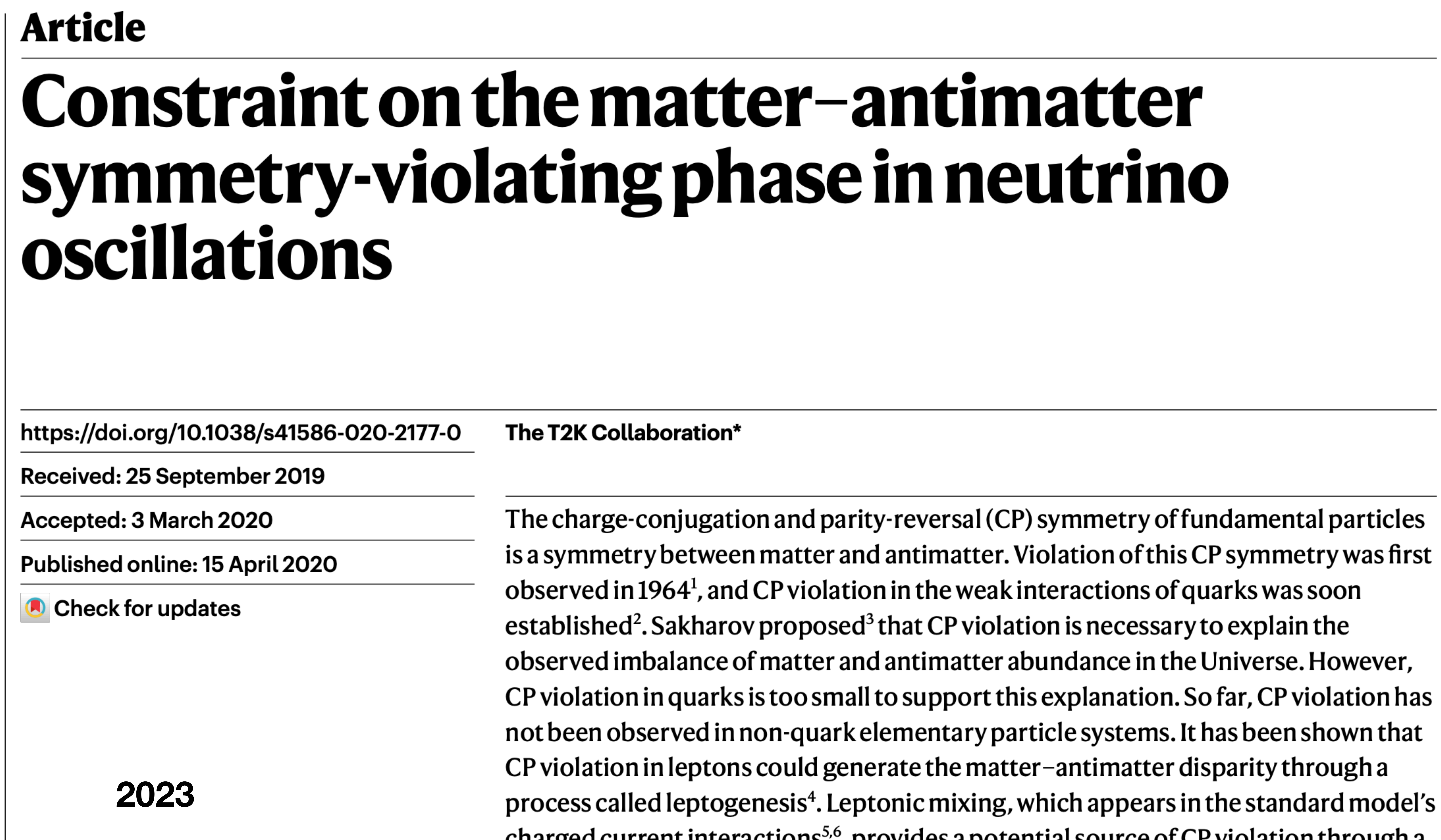
$\mathcal{O}(5\%)$

**3 + ? flavor**

$\mathcal{O}(<1\%)$

Detectors size, sensitivity, better simulation and analysis tools, neutrino sources, etc.

# Since 2020 we have…



**Article**

# Constraint on the matter–antimatter symmetry-violating phase in neutrino oscillations

https://doi.org/10.1038/s41586-020-2177-0

Received: 25 September 2019

Accepted: 3 March 2020

The T2K Collaboration*

The charge-conjugation and parity-reversal (CP) symmetry of fundamental particles is a symmetry between matter and antimatter. Violation of this CP symmetry was first observed in 1964[1], and CP violation in the weak interactions of quarks was soon established[2]. Sakharov proposed[3] that CP violation is necessary to explain the observed imbalance of matter and antimatter abundance in the Universe. However, CP violation in quarks is too small to support this explanation. So far, CP violation has not been observed in non-quark elementary particle systems. It has been shown that CP violation in leptons could generate the matter–antimatter disparity through a process called leptogenesis[4]. Leptonic mixing, which appears in the standard model's charged current interactions[5,6], provides a potential source of CP violation through a

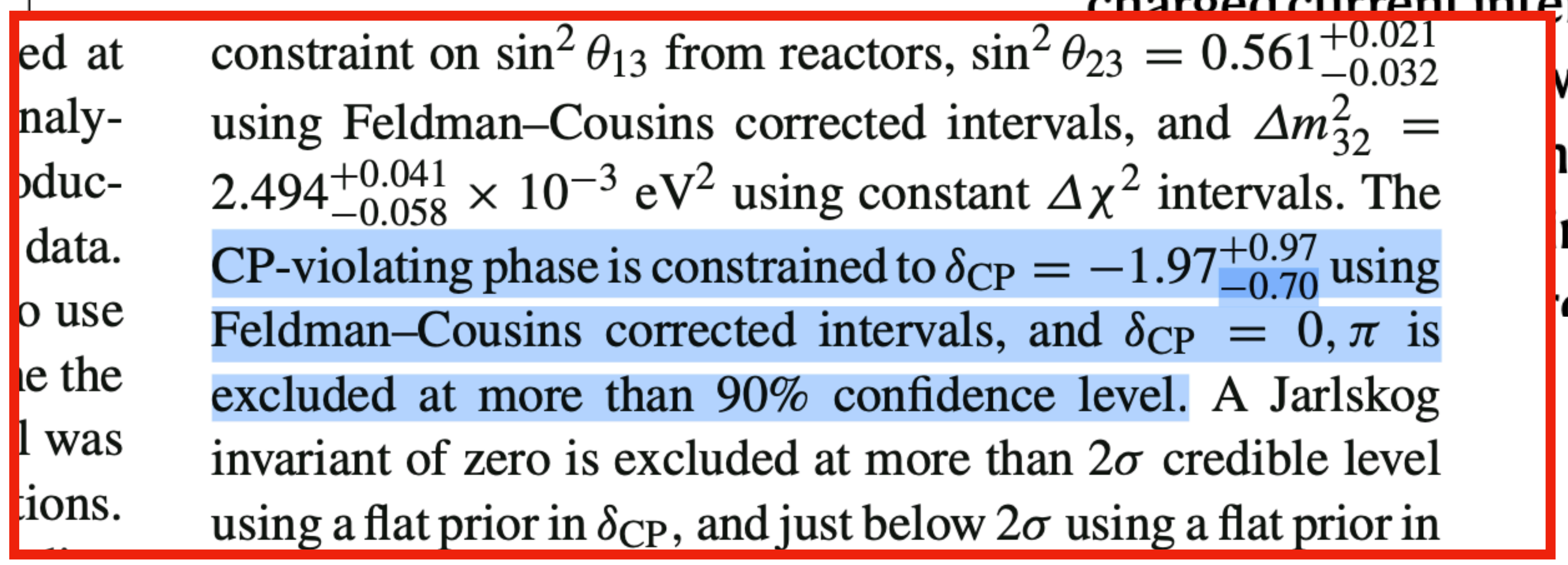
hich is required by some theoretical models of leptogenesis[7–9].

be measured in muon neutrino to electron neutrino oscillations

ng antineutrino oscillations, which are experimentally accessible

oduced beams as established by the Tokai-to-Kamioka (T2K) and

2023



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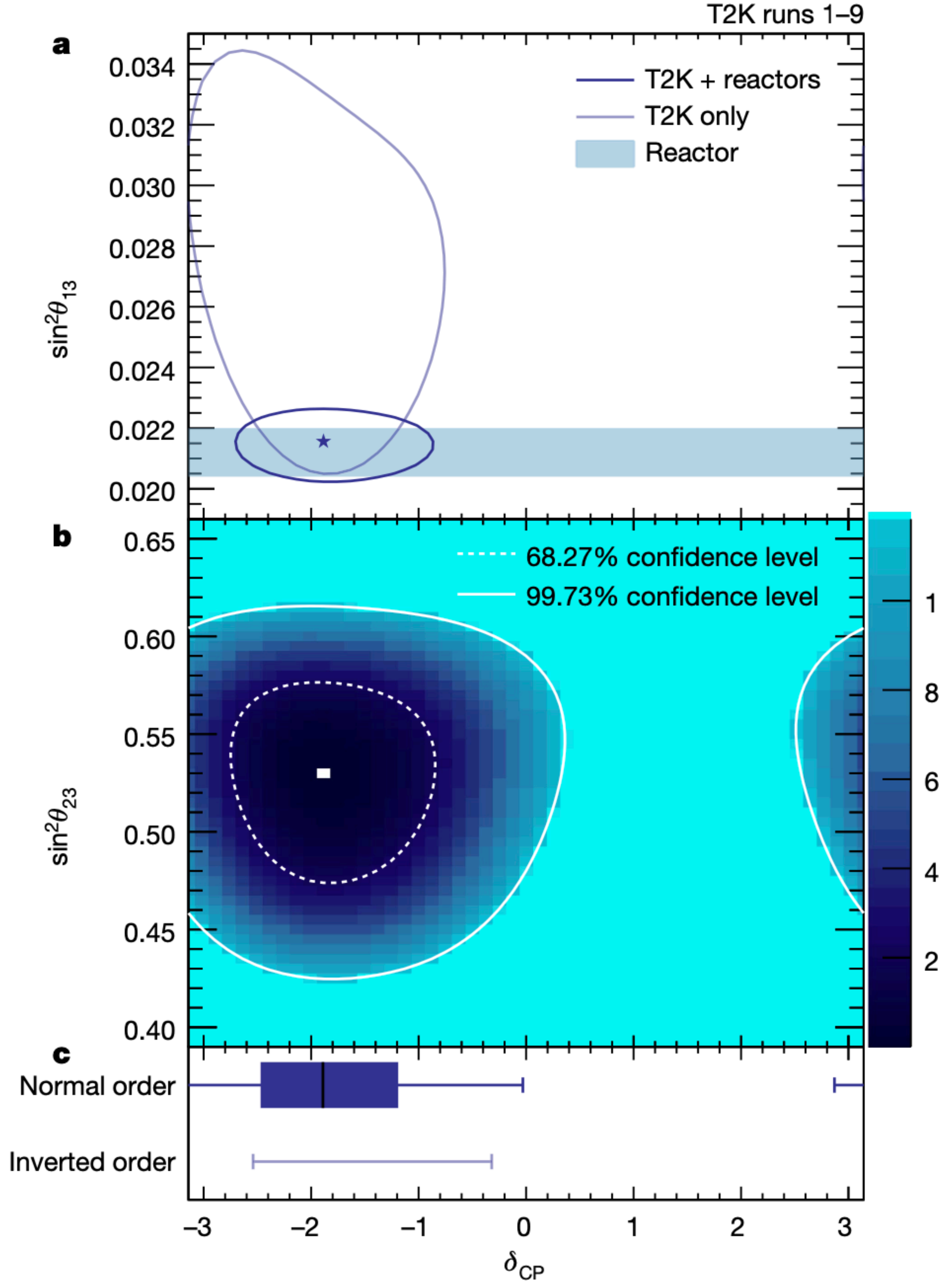
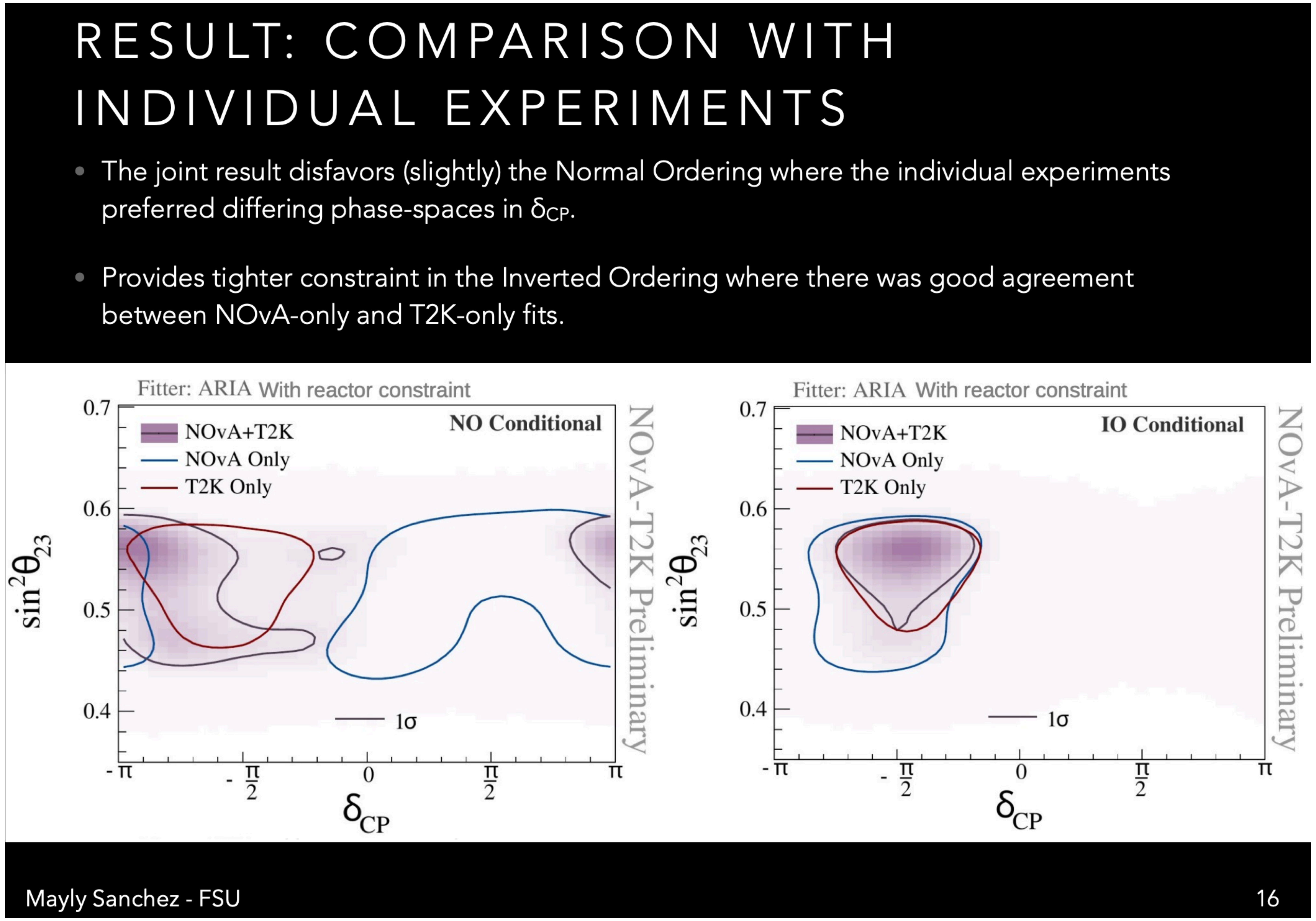
constraint on $\sin^2\theta_{13}$ from reactors, $\sin^2\theta_{23} = 0.561^{+0.021}_{-0.032}$ using Feldman–Cousins corrected intervals, and $\Delta m^2_{32} = 2.494^{+0.041}_{-0.058} \times 10^{-3}\ \mathrm{eV}^2$ using constant $\Delta\chi^2$ intervals. The CP-violating phase is constrained to $\delta_{CP} = -1.97^{+0.97}_{-0.70}$ using Feldman–Cousins corrected intervals, and $\delta_{CP} = 0, \pi$ is excluded at more than 90% confidence level. A Jarlskog invariant of zero is excluded at more than $2\sigma$ credible level using a flat prior in $\delta_{CP}$, and just below $2\sigma$ using a flat prior in



# Leptonic CPv from NOVA and T2K



## RESULT: COMPARISON WITH INDIVIDUAL EXPERIMENTS

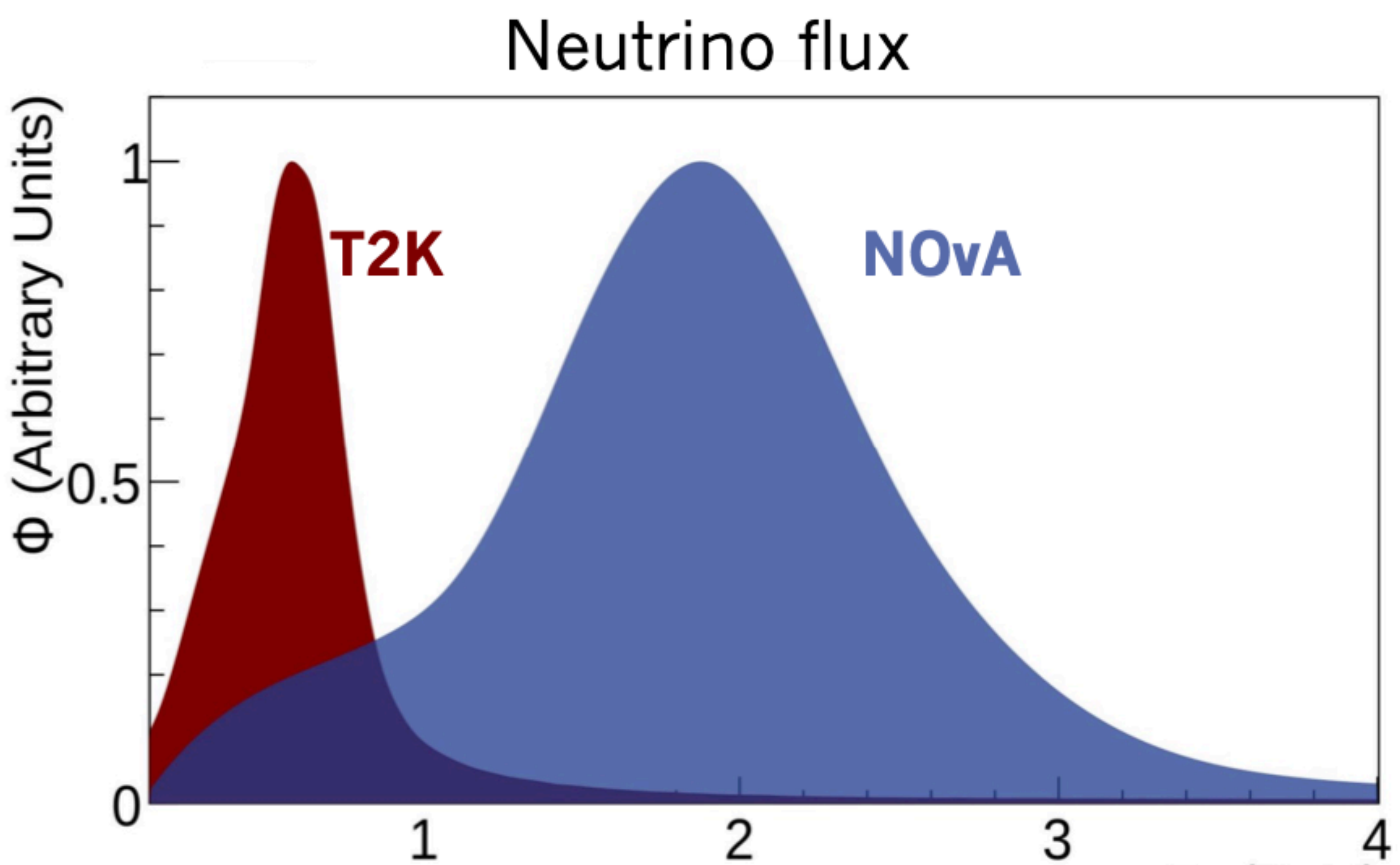
- The joint result disfavors (slightly) the Normal Ordering where the individual experiments preferred differing phase-spaces in $\delta_{CP}$.
- Provides tighter constraint in the Inverted Ordering where there was good agreement between NOvA-only and T2K-only fits.

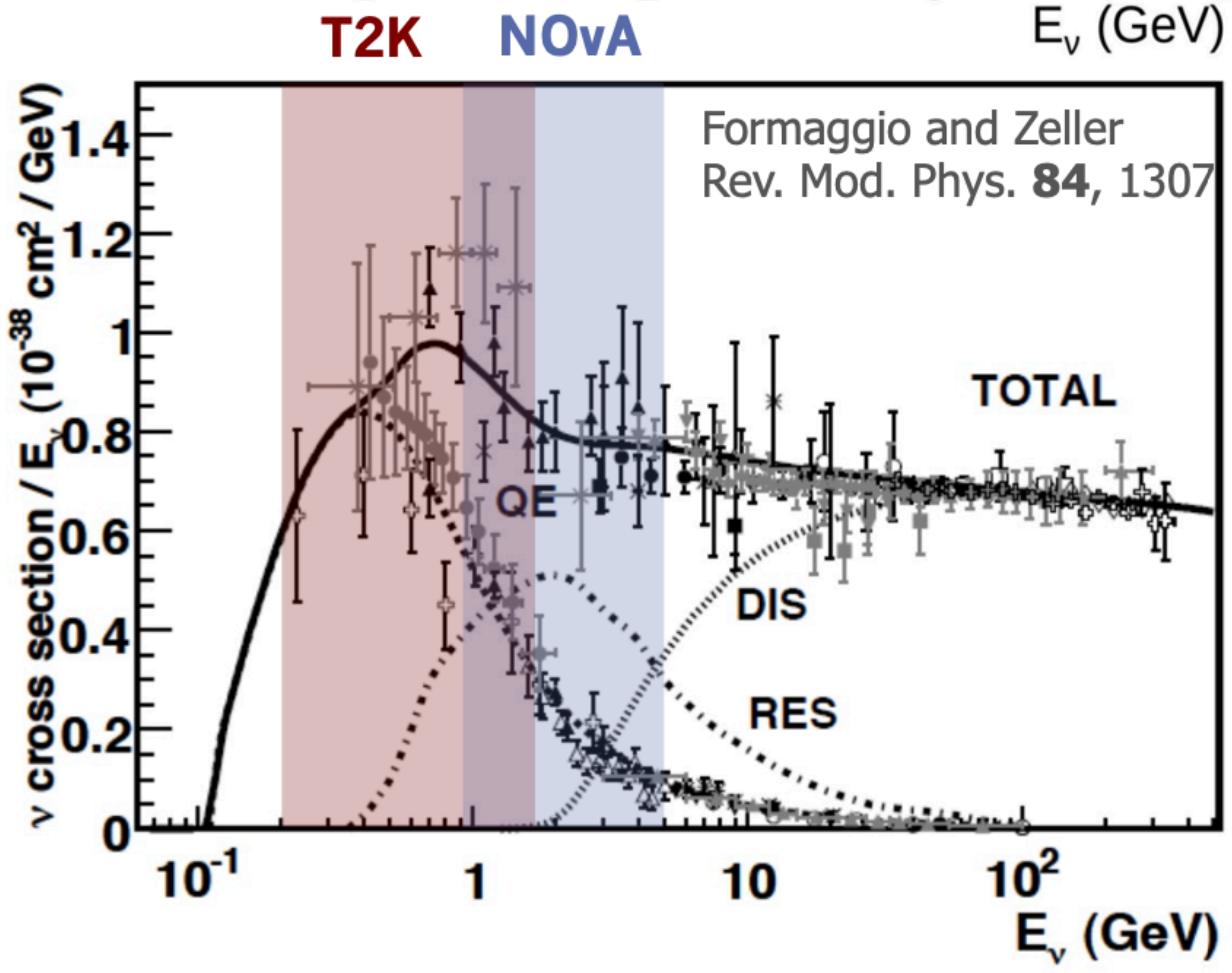
Mayly Sanchez - FSU

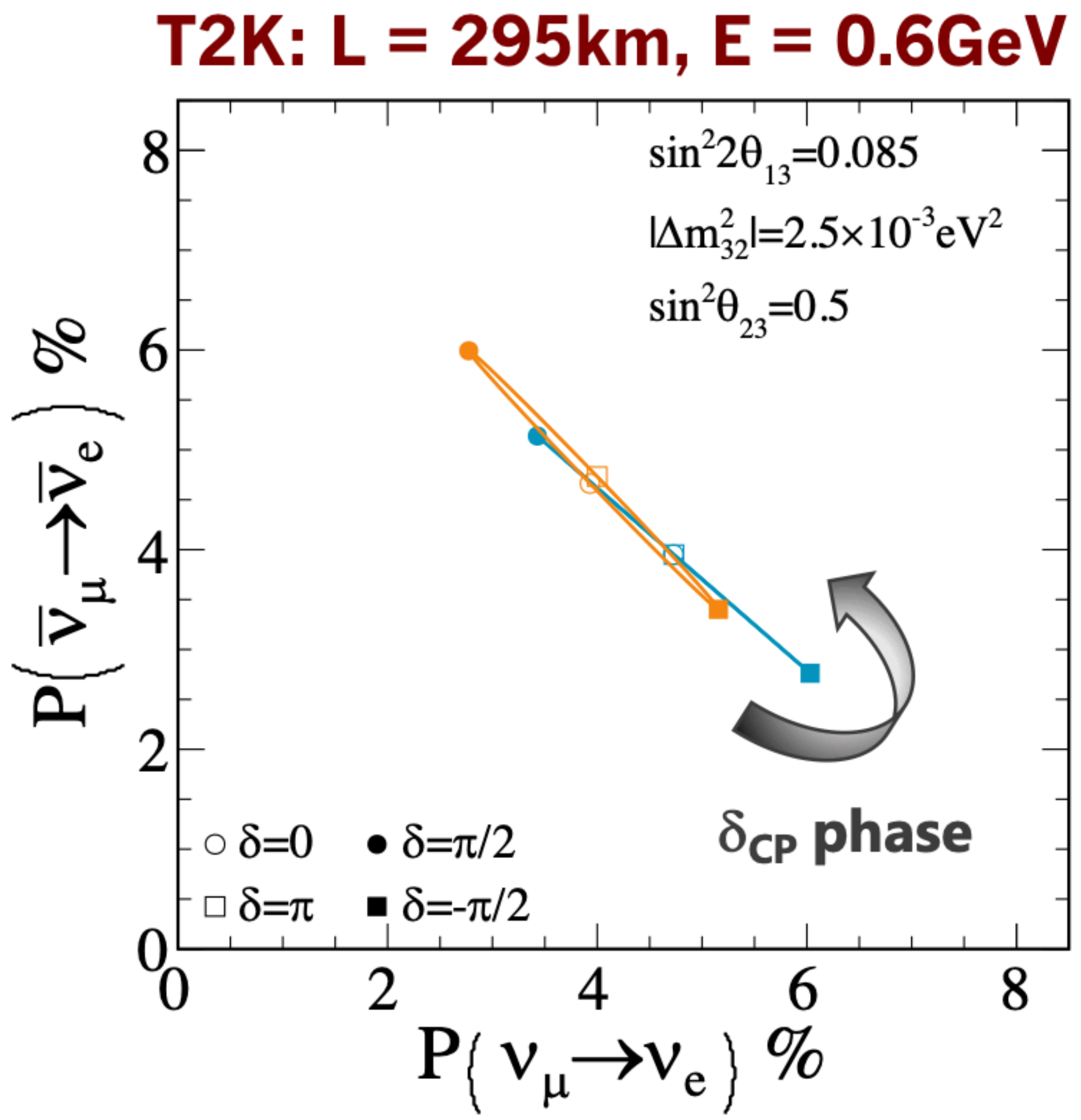
16

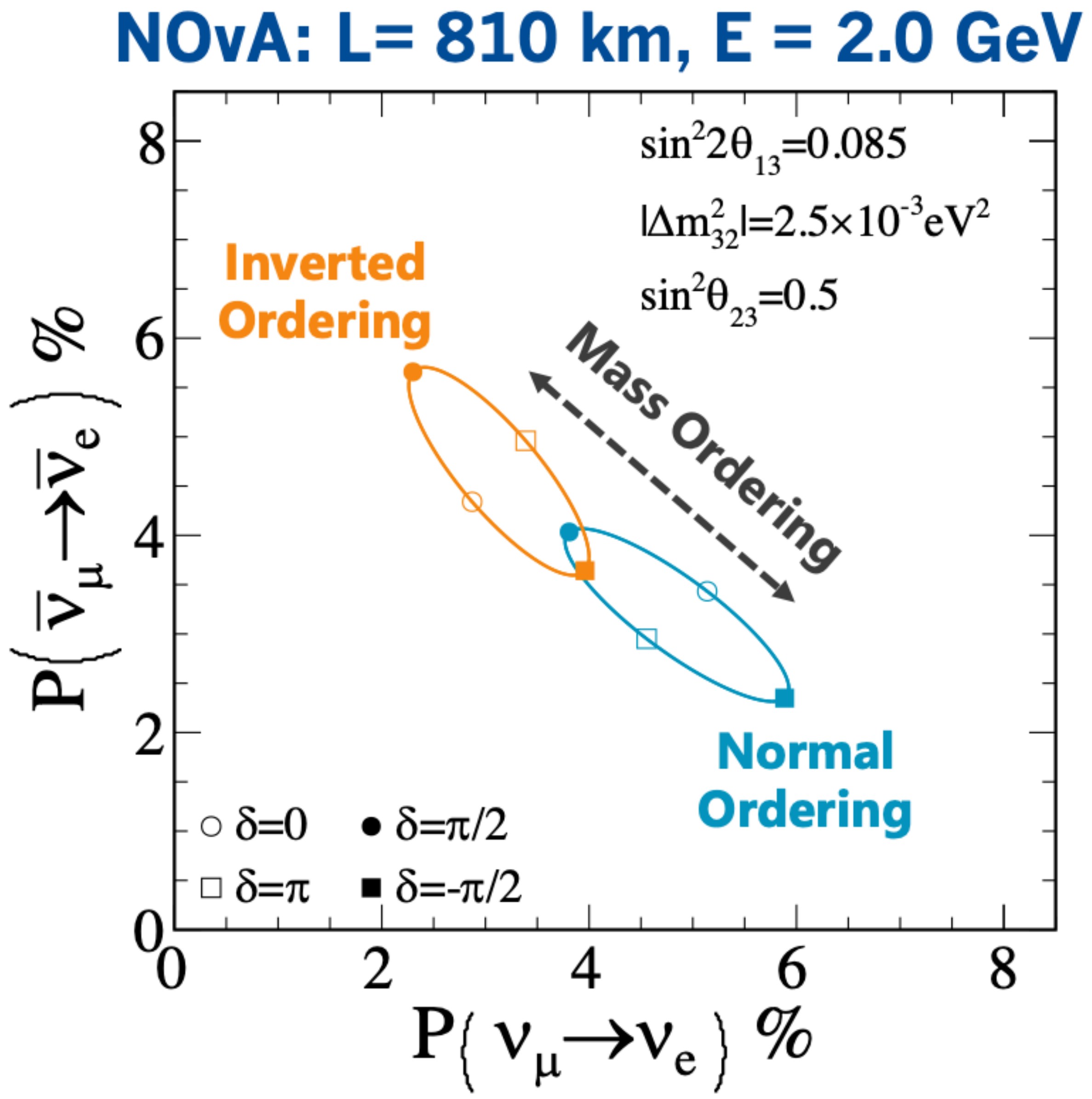
- A strong constraint on | Δm232 |.
- Mass Ordering remains inconclusive. Mild preference for upper octant.
- δCP = π/2 lies outside 3-sigma credible interval for both mass orderings.
- CP conserving values for the Inverted Ordering fall outside the 3-sigma range.

# Nova and T2k on CPv



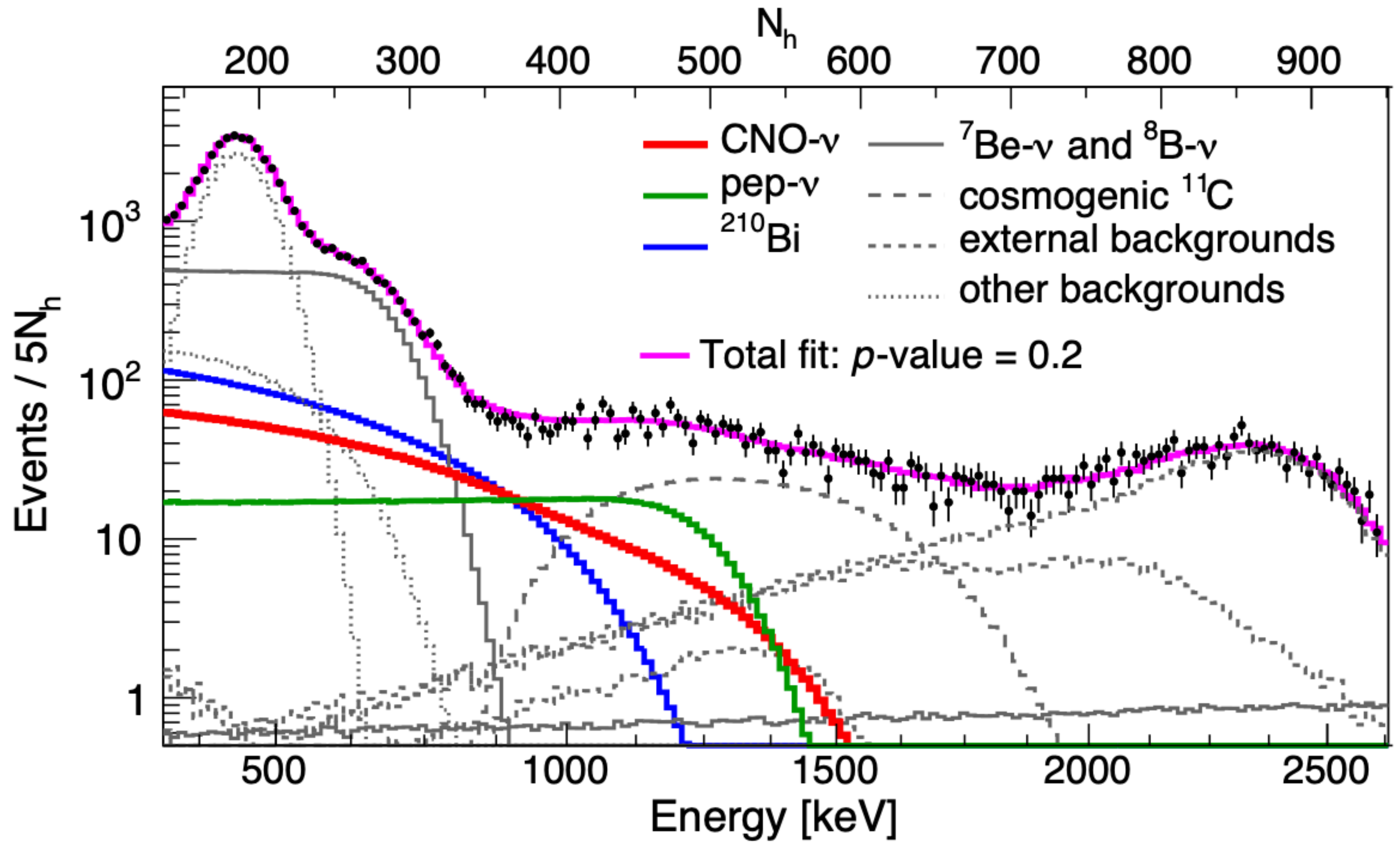






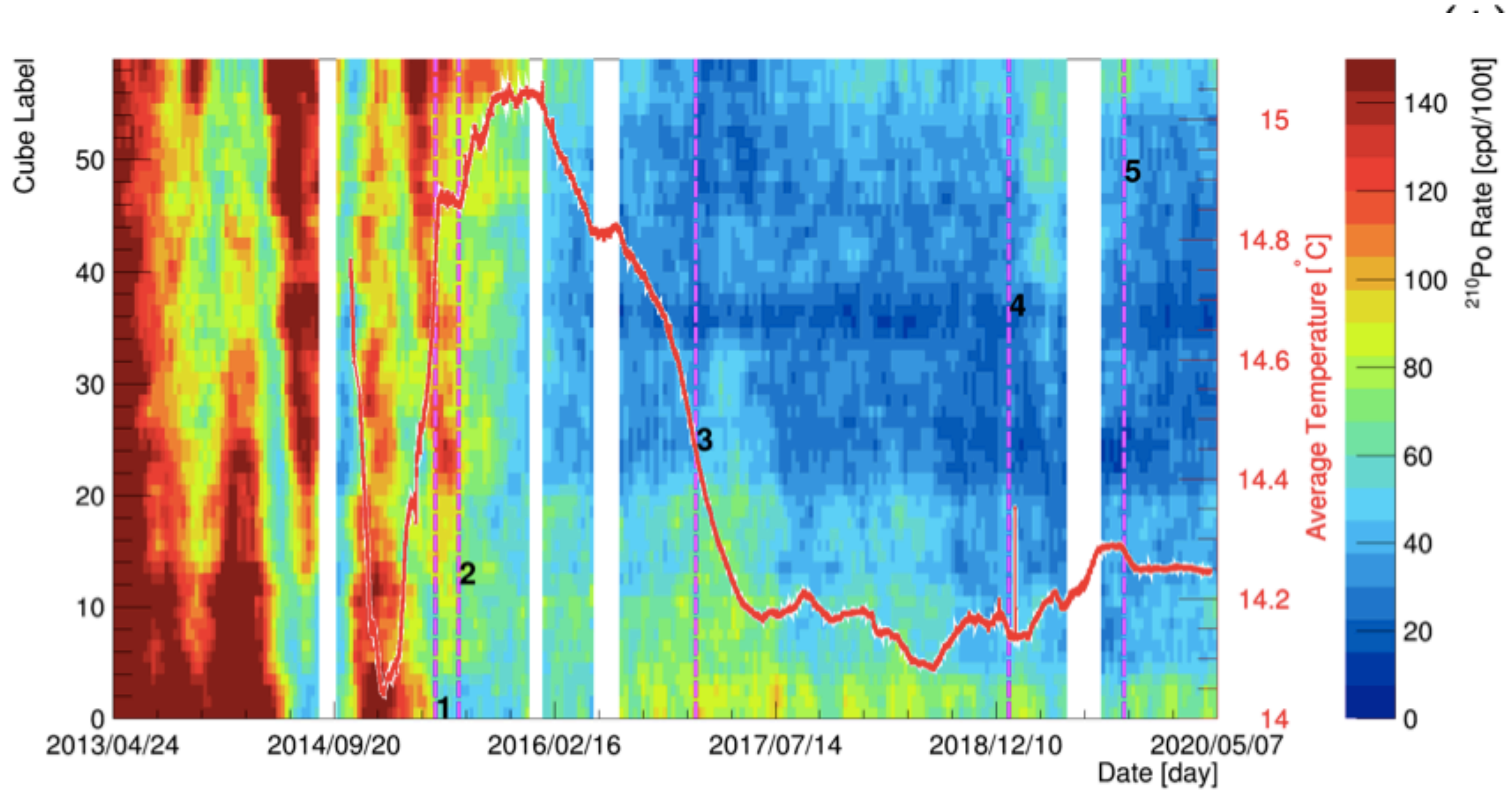
# First Direct Experimental Evidence of CNO neutrinos, Borexino

**Arxiv:2006.15115**



(a)

$$^{210}\mathrm{Pb} \xrightarrow[22.3\,\mathrm{years}]{\beta^-} {}^{210}\mathrm{Bi} \xrightarrow[5\,\mathrm{days}]{\beta^-} {}^{210}\mathrm{Po} \xrightarrow[138.4\,\mathrm{days}]{\alpha} {}^{206}\mathrm{Pb}\,.$$



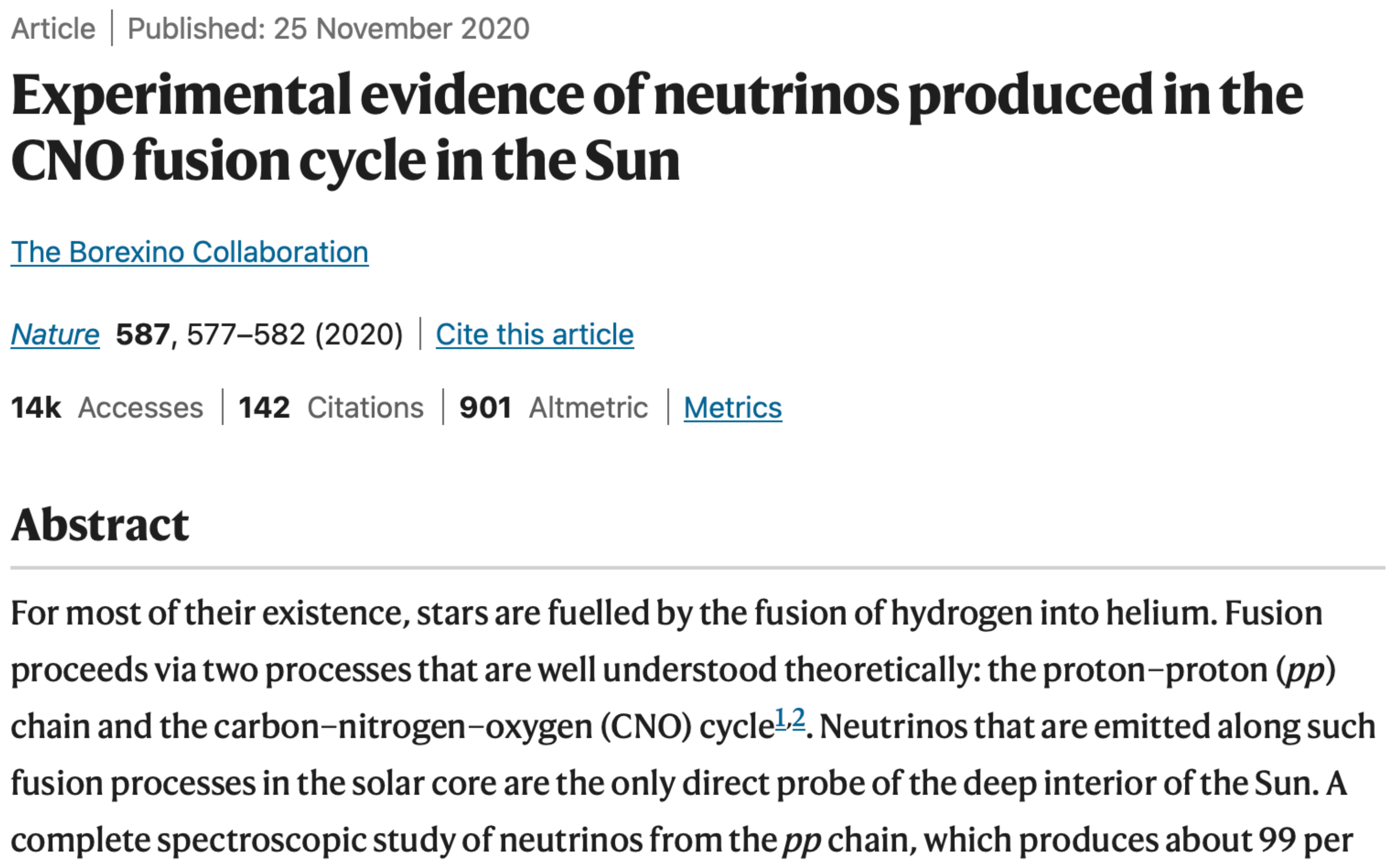
Final syst:
**-0.5 +0.6**
**cpd/100t**

2020 Jun 23

Final CNO result 7.2 (-1.7 +3.0) cpd/100t stat

corresponding to a flux of neutrinos on Earth of 7.0 (−1.9 +2.9)×$10^8$ $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

G. Ranucci - First detection of solar neutrinos from CNO cycle with Borexino



Article | Published: 25 November 2020

**Experimental evidence of neutrinos produced in the CNO fusion cycle in the Sun**

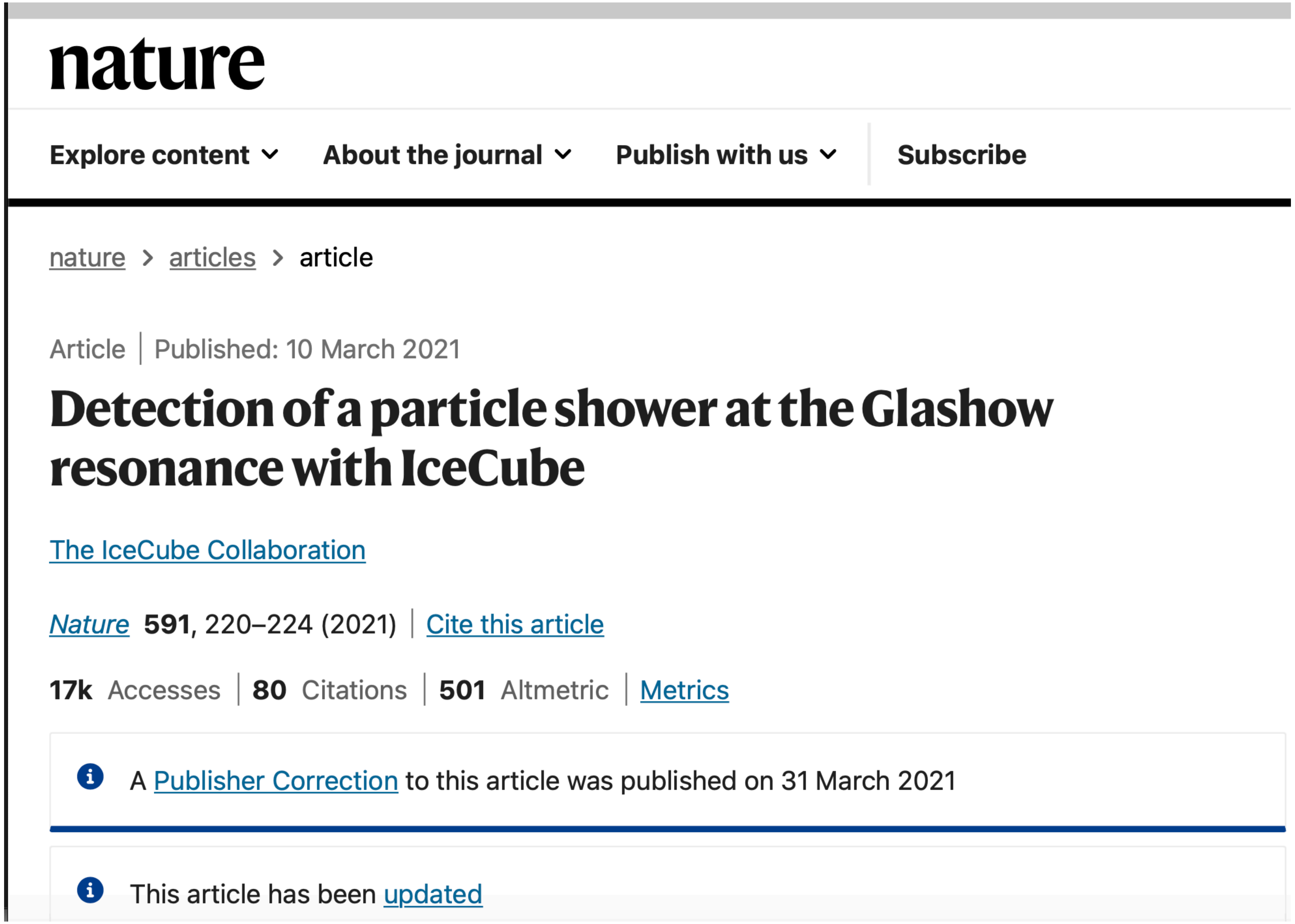
The Borexino Collaboration

*Nature* **587**, 577–582 (2020) | Cite this article

**14k** Accesses | **142** Citations | **901** Altmetric | Metrics

**Abstract**

For most of their existence, stars are fuelled by the fusion of hydrogen into helium. Fusion proceeds via two processes that are well understood theoretically: the proton–proton (*pp*) chain and the carbon–nitrogen–oxygen (CNO) cycle[1,2]. Neutrinos that are emitted along such fusion processes in the solar core are the only direct probe of the deep interior of the Sun. A complete spectroscopic study of neutrinos from the *pp* chain, which produces about 99 per



Article | Published: 10 March 2021

# Detection of a particle shower at the Glashow resonance with IceCube

The IceCube Collaboration

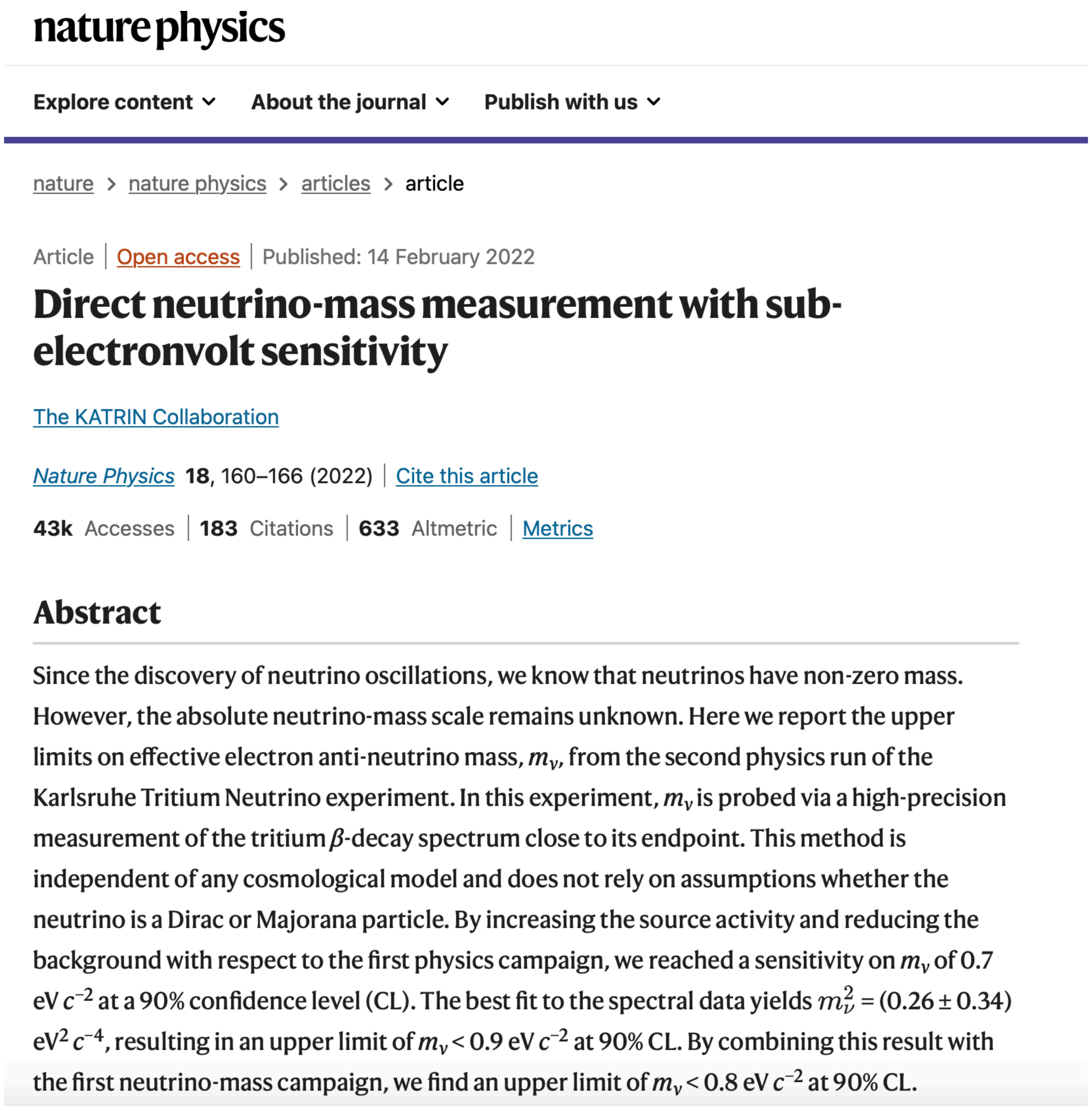
*Nature* **591**, 220–224 (2021) | Cite this article

**17k** Accesses | **80** Citations | **501** Altmetric | Metrics

A Publisher Correction to this article was published on 31 March 2021

This article has been updated

**6.3 PeV**



**nature physics**

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Article | Open access | Published: 14 February 2022

# Direct neutrino-mass measurement with sub-electronvolt sensitivity

The KATRIN Collaboration

*Nature Physics* **18**, 160–166 (2022) | Cite this article

**43k** Accesses | **183** Citations | **633** Altmetric | Metrics

## Abstract

Since the discovery of neutrino oscillations, we know that neutrinos have non-zero mass. However, the absolute neutrino-mass scale remains unknown. Here we report the upper limits on effective electron anti-neutrino mass, $m_\nu$, from the second physics run of the Karlsruhe Tritium Neutrino experiment. In this experiment, $m_\nu$ is probed via a high-precision measurement of the tritium $\beta$-decay spectrum close to its endpoint. This method is independent of any cosmological model and does not rely on assumptions whether the neutrino is a Dirac or Majorana particle. By increasing the source activity and reducing the background with respect to the first physics campaign, we reached a sensitivity on $m_\nu$ of 0.7 eV $c^{-2}$ at a 90% confidence level (CL). The best fit to the spectral data yields $m_\nu^2 = (0.26 \pm 0.34)$ eV$^2$ $c^{-4}$, resulting in an upper limit of $m_\nu < 0.9$ eV $c^{-2}$ at 90% CL. By combining this result with the first neutrino-mass campaign, we find an upper limit of $m_\nu < 0.8$ eV $c^{-2}$ at 90% CL.

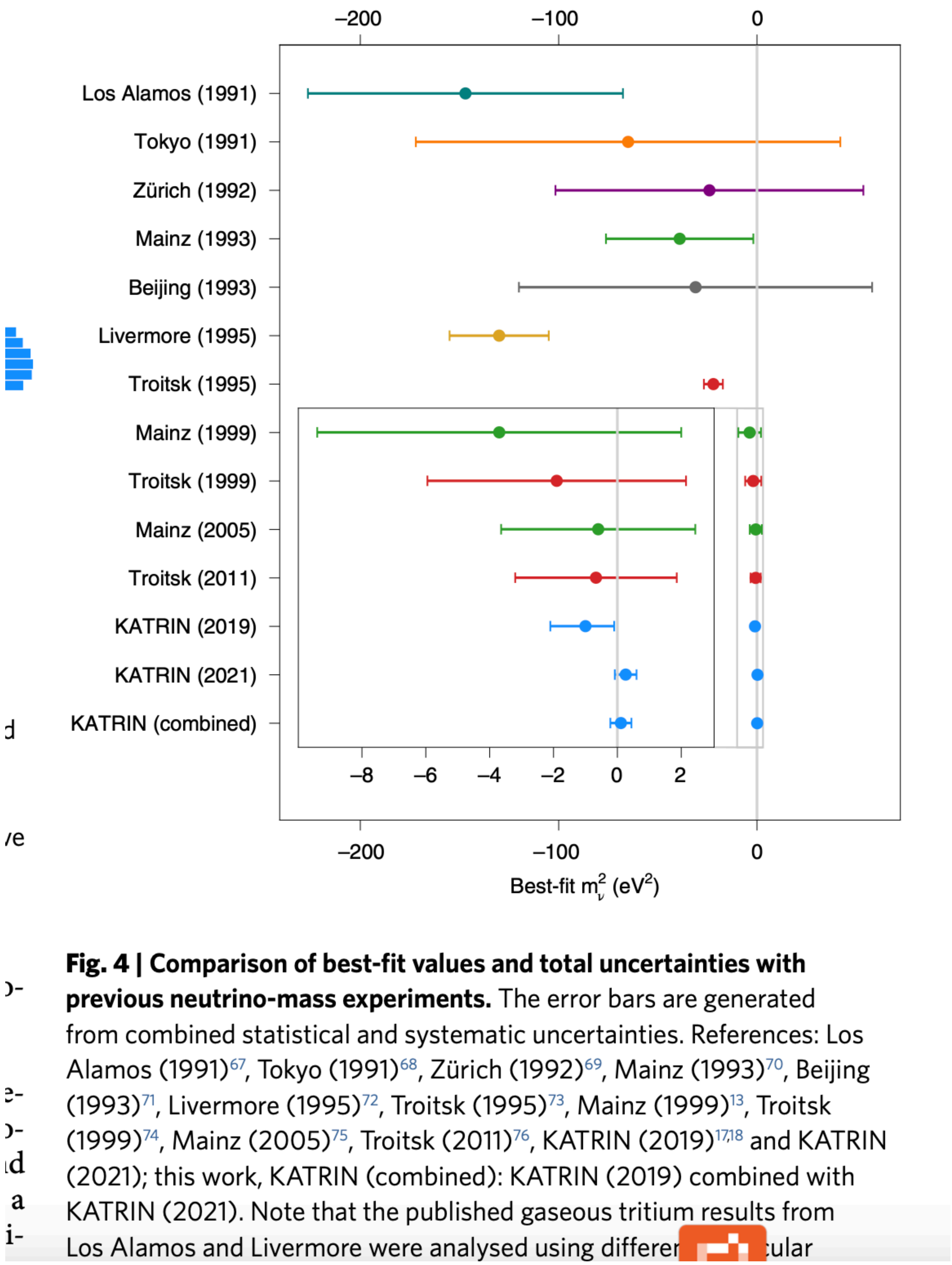
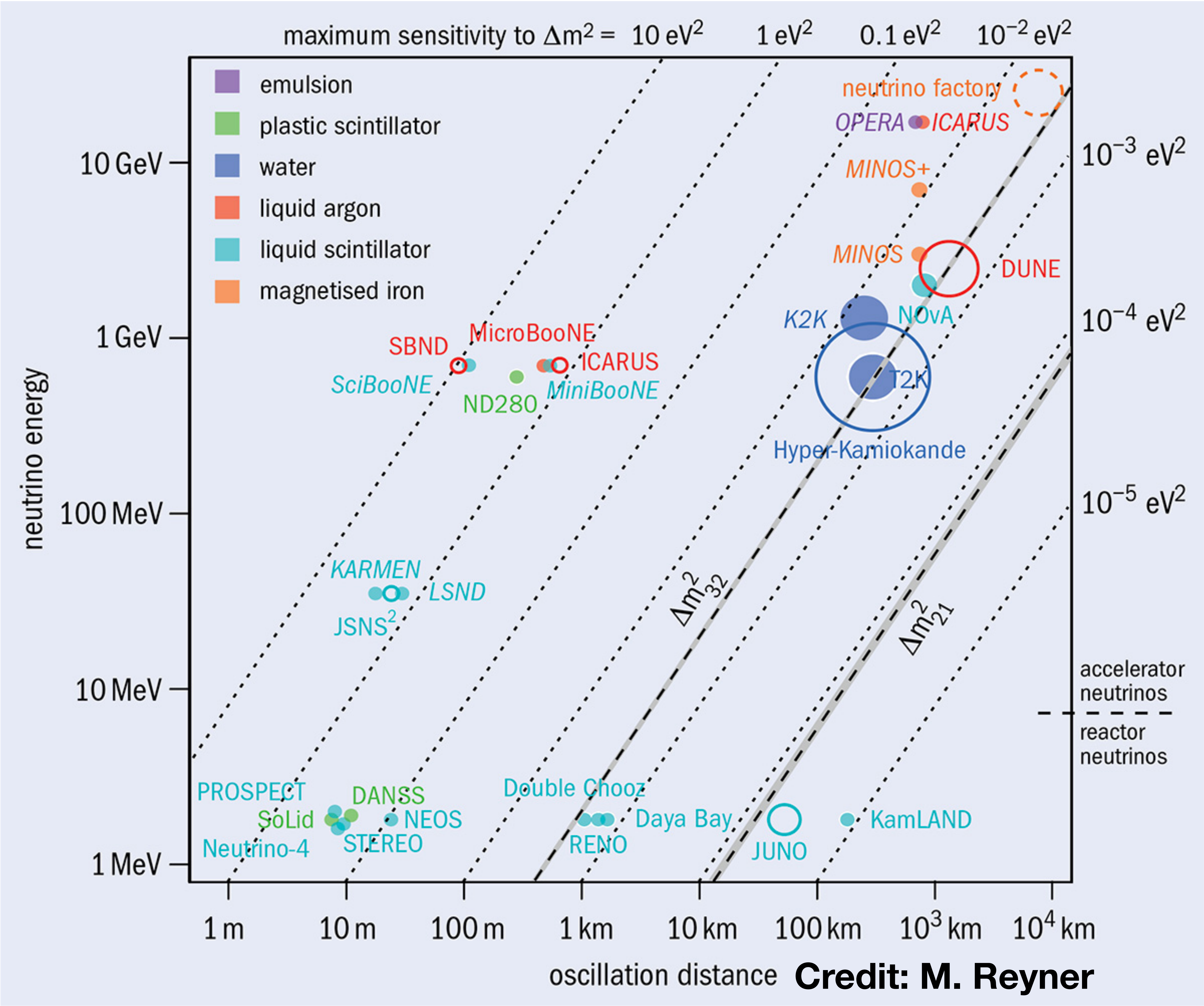


**Fig. 4 | Comparison of best-fit values and total uncertainties with previous neutrino-mass experiments.** The error bars are generated from combined statistical and systematic uncertainties. References: Los Alamos (1991)[67], Tokyo (1991)[68], Zürich (1992)[69], Mainz (1993)[70], Beijing (1993)[71], Livermore (1995)[72], Troitsk (1995)[73], Mainz (1999)[13], Troitsk (1999)[74], Mainz (2005)[75], Troitsk (2011)[76], KATRIN (2019)[17,18] and KATRIN (2021); this work, KATRIN (combined): KATRIN (2019) combined with KATRIN (2021). Note that the published gaseous tritium results from Los Alamos and Livermore were analysed using differe cular

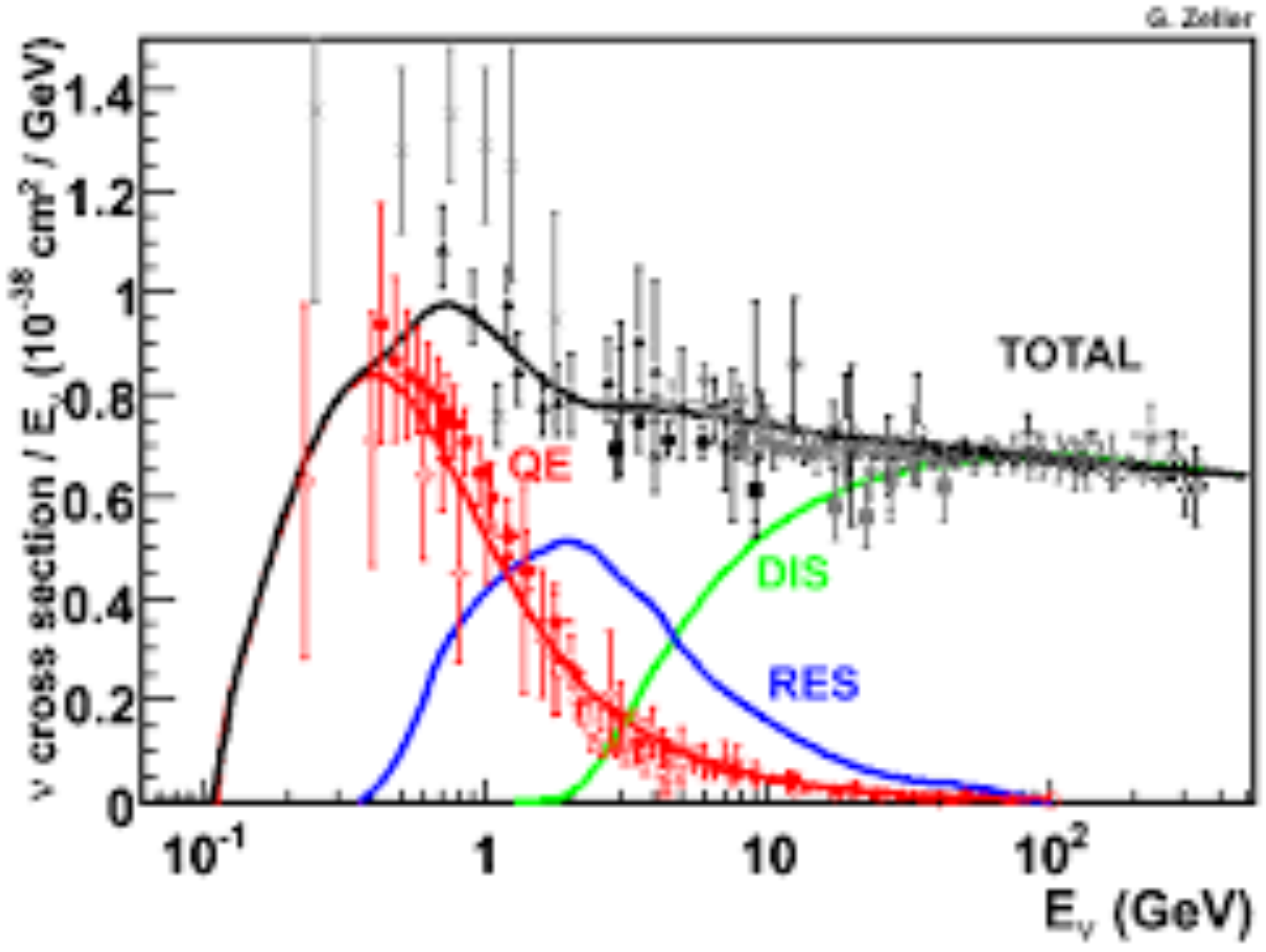
# Transition from a discovery era to a precision era



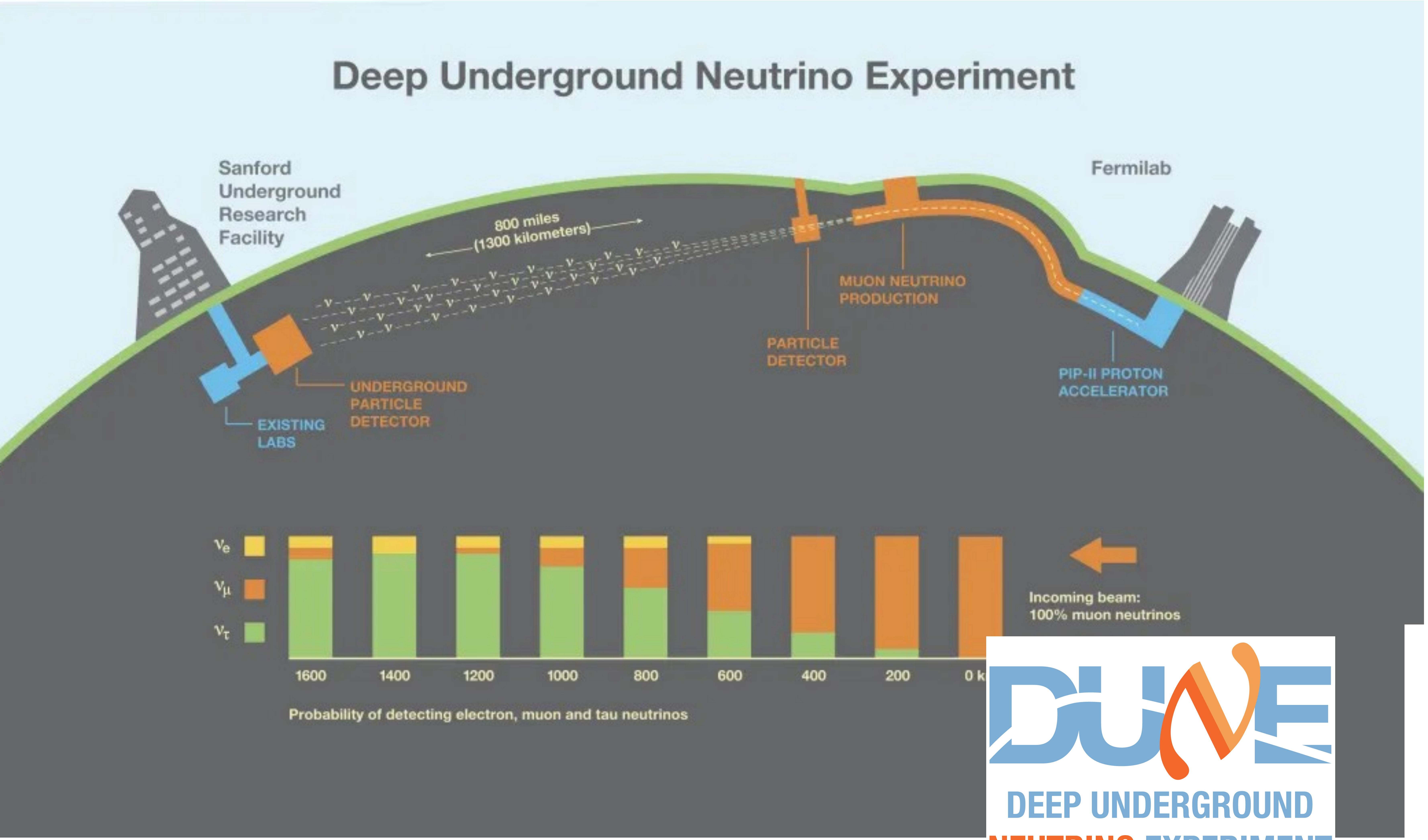
**Credit: M. Reyner**

# Transition from a discovery era to a precision era

- Increased knowledge on nu-N X Sections is required.
- QE, DIS, Minerva experiment measurements, generators and theory improvement
- FF from LQCD



# Deep Underground Neutrino Experiment (DUNE)



DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

**Precision neutrino program**

**New physics potential**

**2028?**
**2031?**

INTERNATIONAL 28/02/2024 a las 06:22pm

**Scientists are building tunnels under South Dakota for a $3 billion experiment that could solve some of the universe's grandest mysteries**

# Unsolved anomalies or Hints for a 4th neutrino

Reactor antineutrino anomaly

**3**

$\bar{\nu}_e \to \bar{\nu}_e$

**Theory driven..**

Galium anomaly

**4**

LSND

**3.8**

$\nu_\mu \to \nu_e$

**Data driven..**

MiniBoone

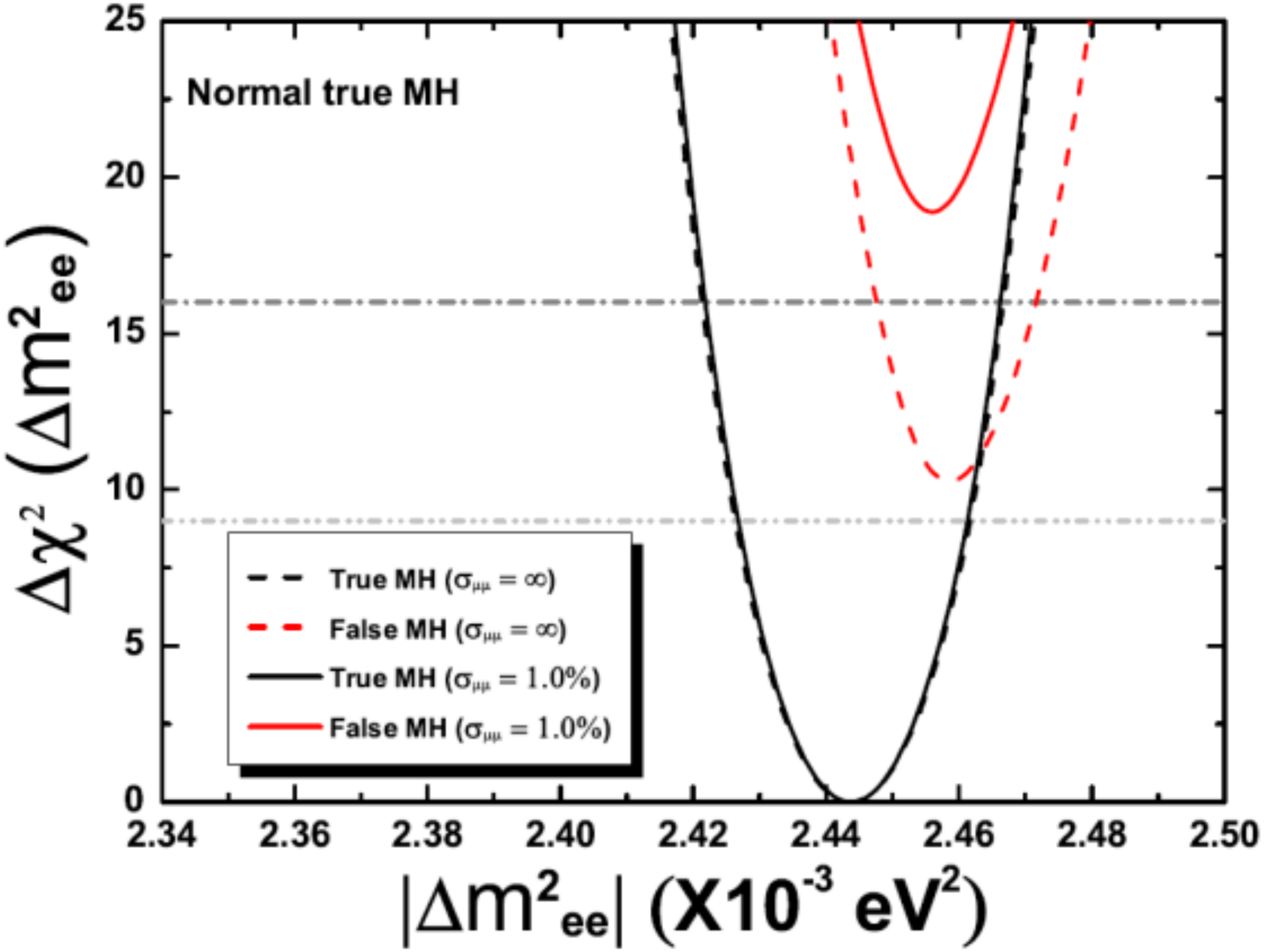
**4.8**

# Sterile neutrinos

- Short Baseline neutrino program +
- Beam dump experiments, high photon flux, ALPs

# JUNO

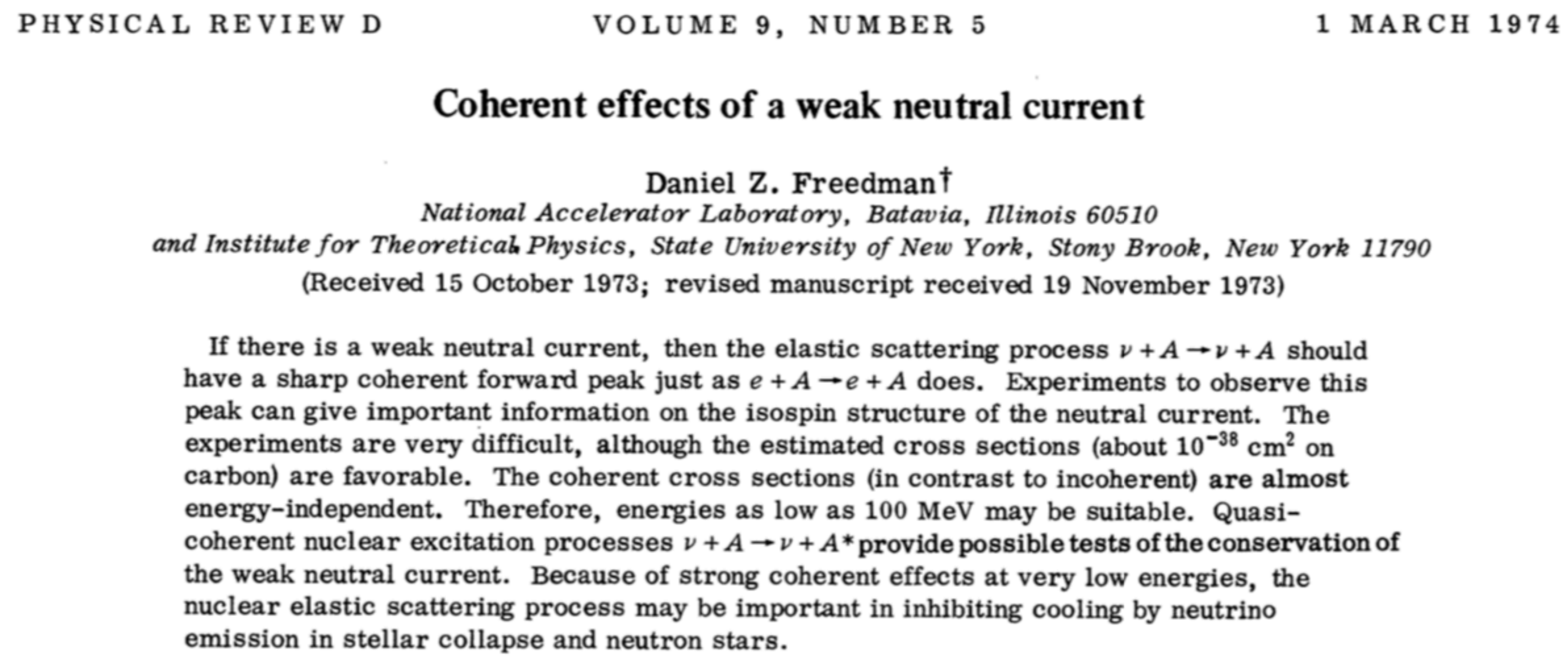
| | Current | JUNO |
|---|---|---|
| $\Delta m^2_{12}$ | ~3% | ~0.6% |
| $\Delta m^2_{23}$ | ~5% | ~0.6% |
| $\sin^2\theta_{12}$ | ~6% | ~0.7% |
| $\sin^2\theta_{23}$ | ~20% | N/A |
| $\sin^2\theta_{13}$ | ~14% → ~4% | ~ 15% |



JUNO
Jiangmen Underground Neutrino Observatory

other scientific possibilities such as supernova neutrinos, geo-neutrinos, solar neutrinos, atmospheric neutrinos, and exotic searches.

# CEνENS

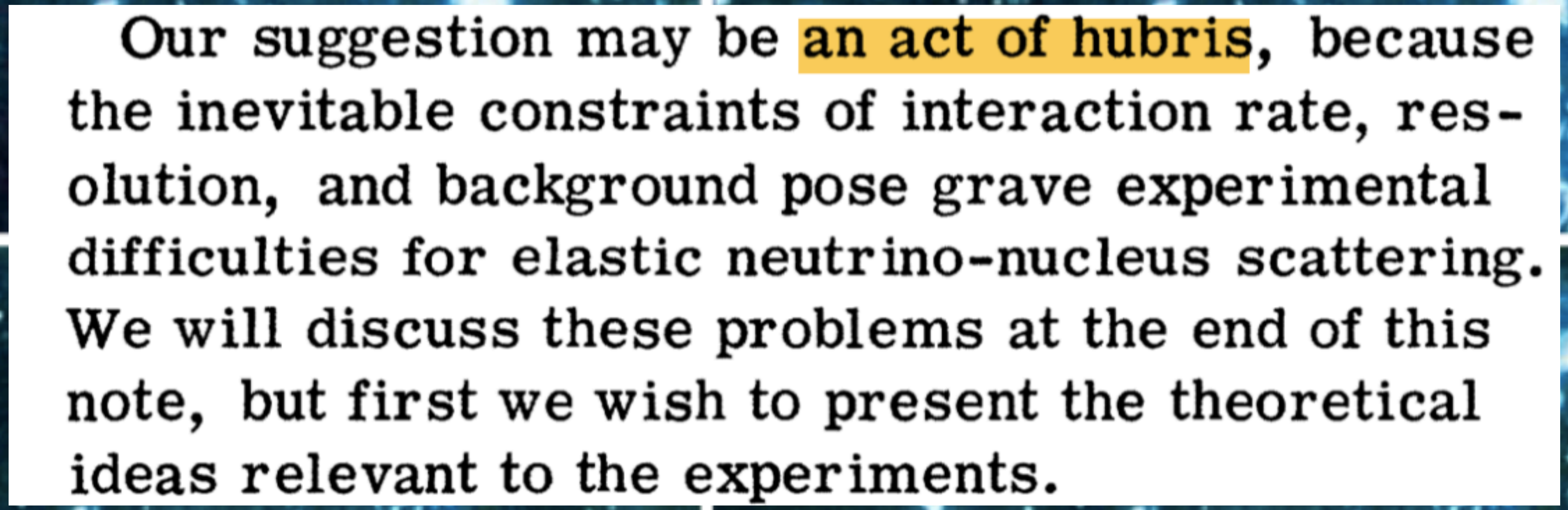

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

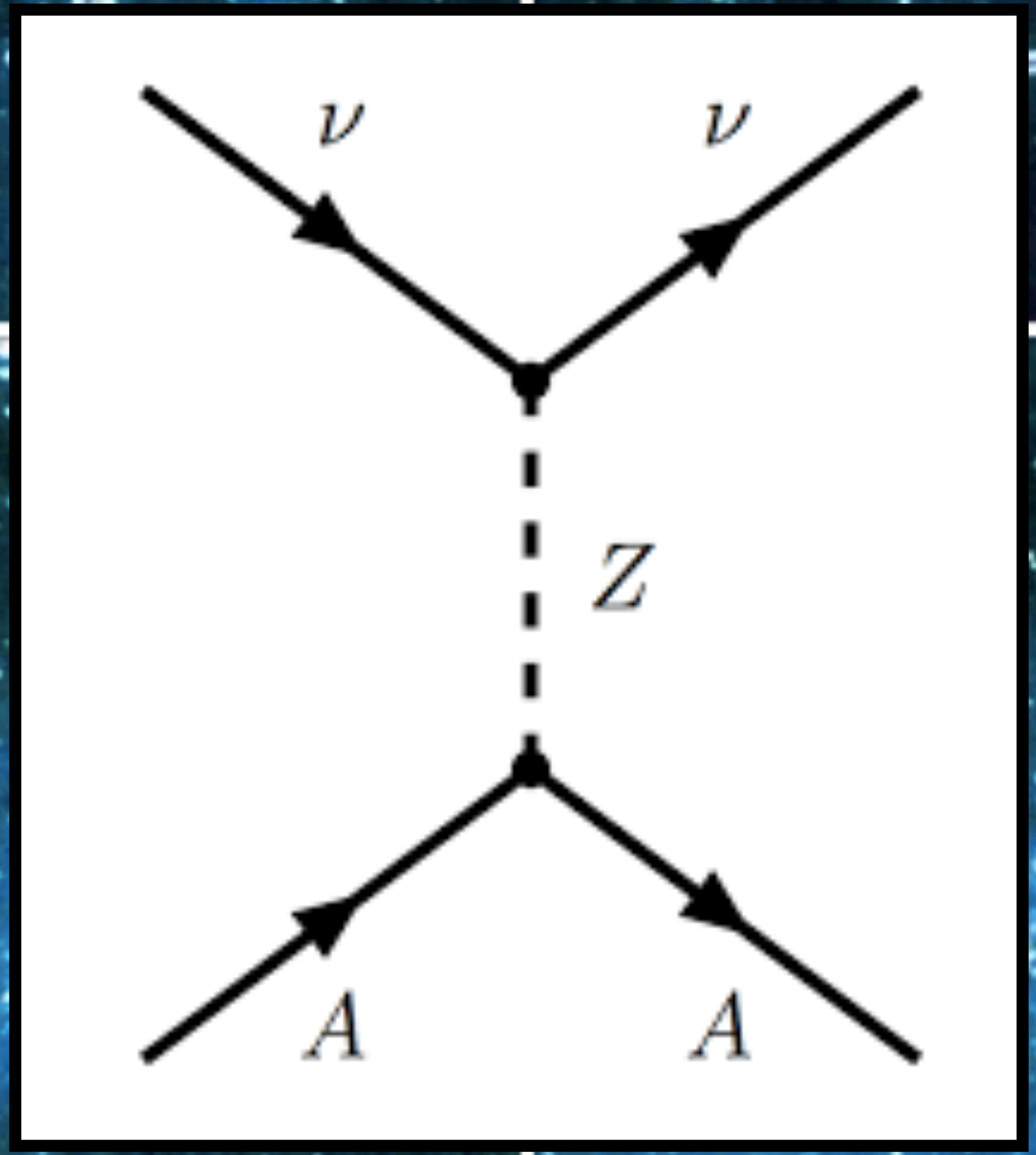
# Coherent effects of a weak neutral current

Daniel Z. Freedman†
*National Accelerator Laboratory, Batavia, Illinois 60510*
*and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790*

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about $10^{-38}$ cm$^2$ on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.


Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.

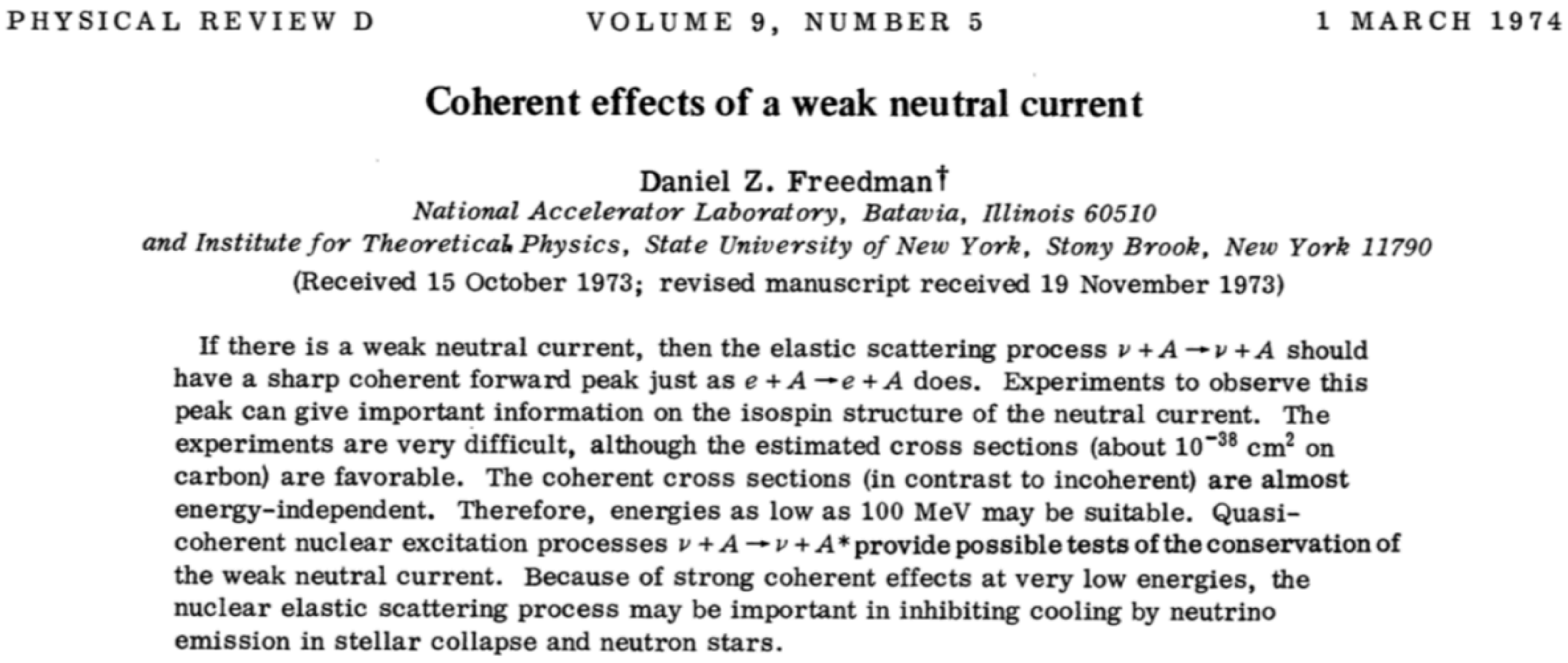


See also:

Freedman, Schramm and Tubbs Ann. Rev. Nucl. Sci. 27 167 (1977)

Gargamelle neutrino experiment. *Phys. Lett. B* 46, 138–140 (1973).

# CEvENS Coherent Elastic Neutrino Nucleus Scattering



PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

## Coherent effects of a weak neutral current

Daniel Z. Freedman†
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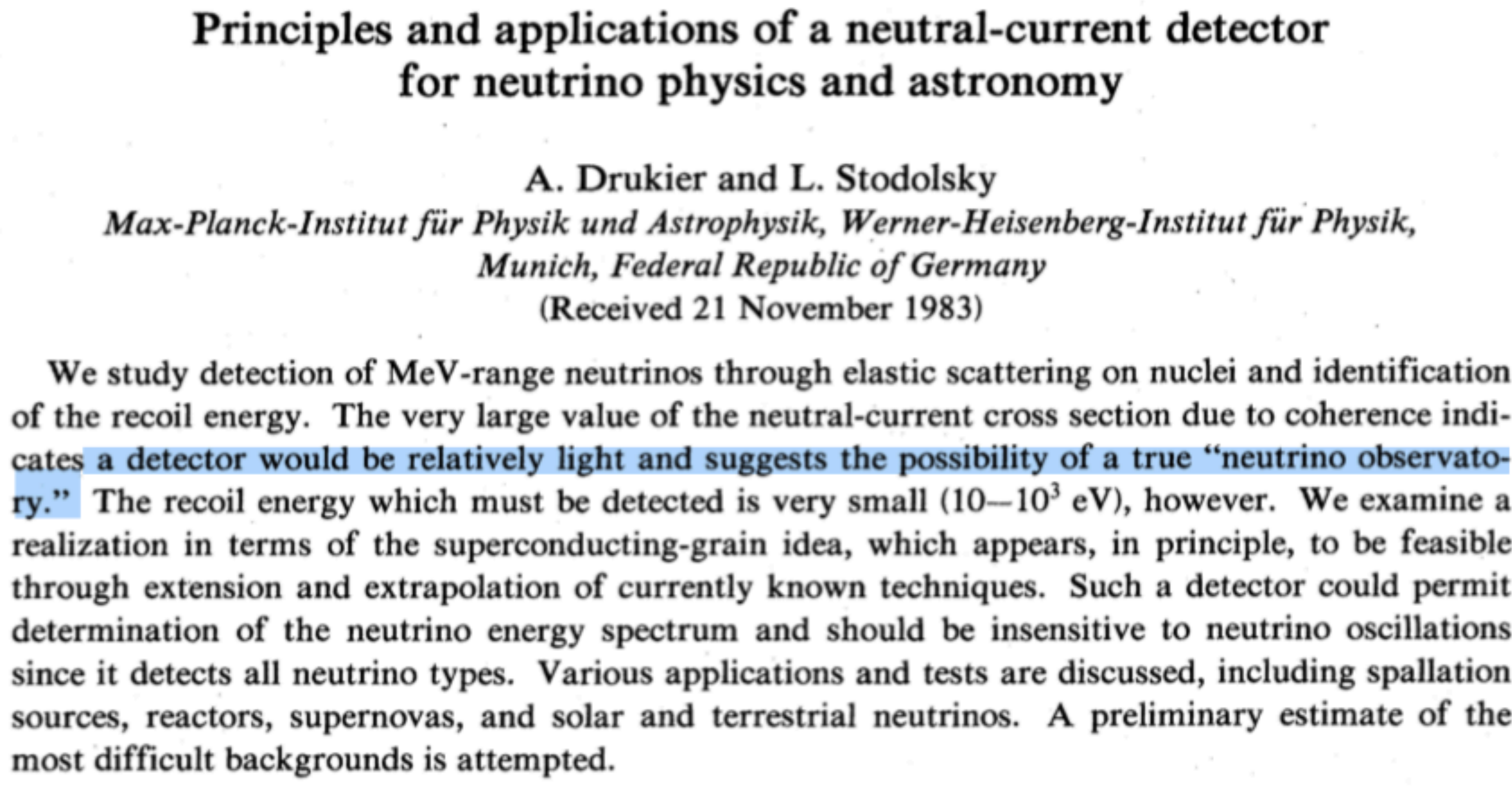
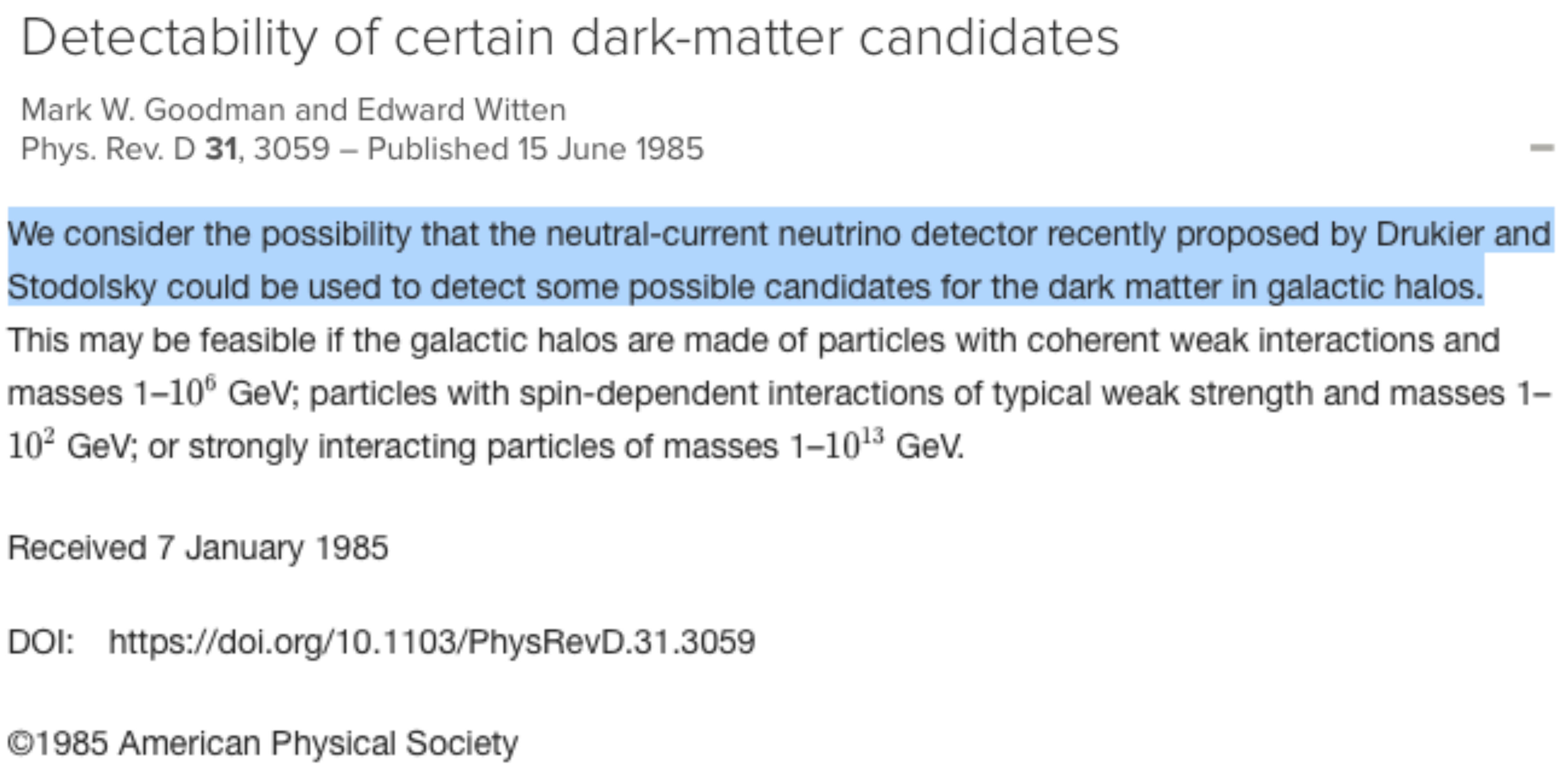


## Principles and applications of a neutral-current detector for neutrino physics and astronomy

A. Drukier and L. Stodolsky
*Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany*

(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small (10—$10^3$ eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted.



## Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten

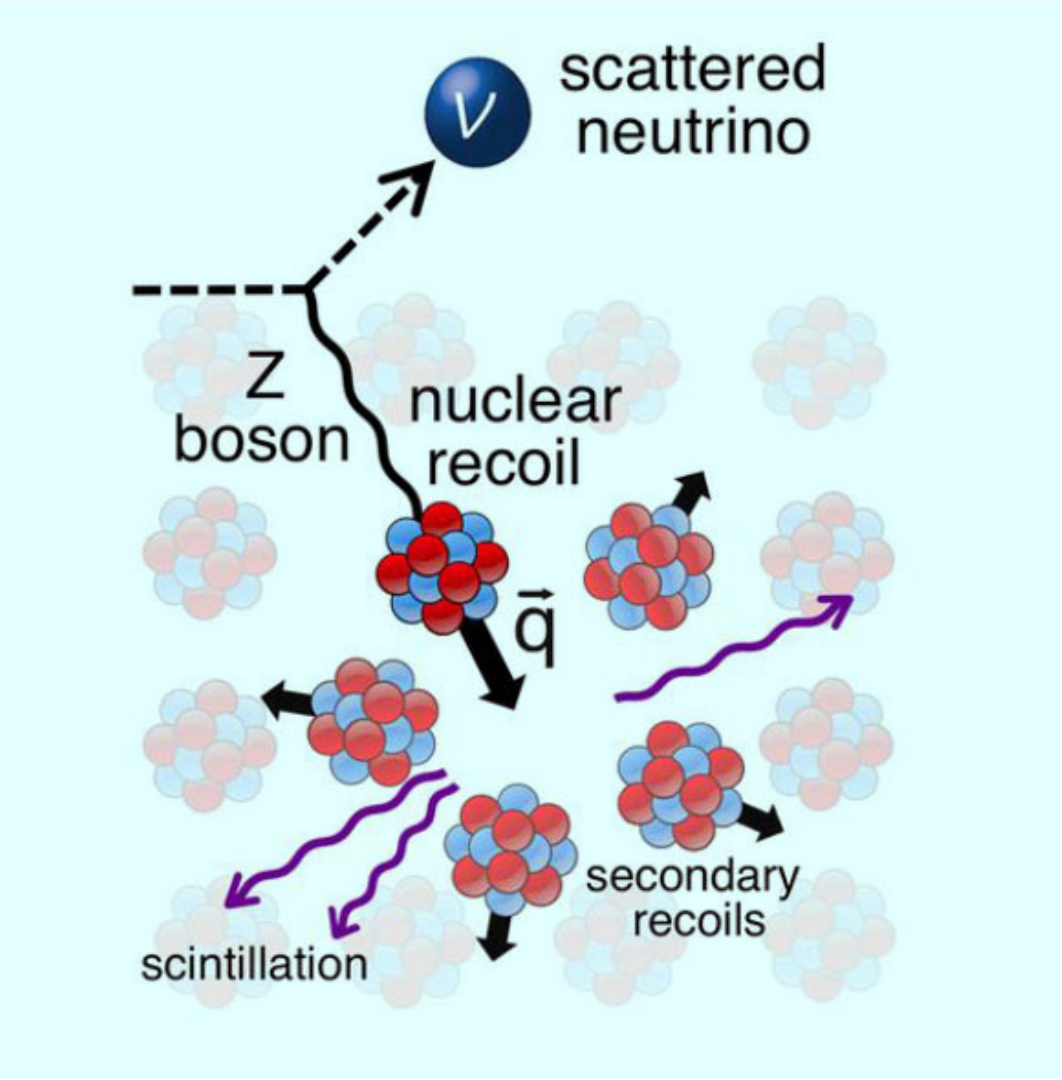
Phys. Rev. D **31**, 3059 – Published 15 June 1985

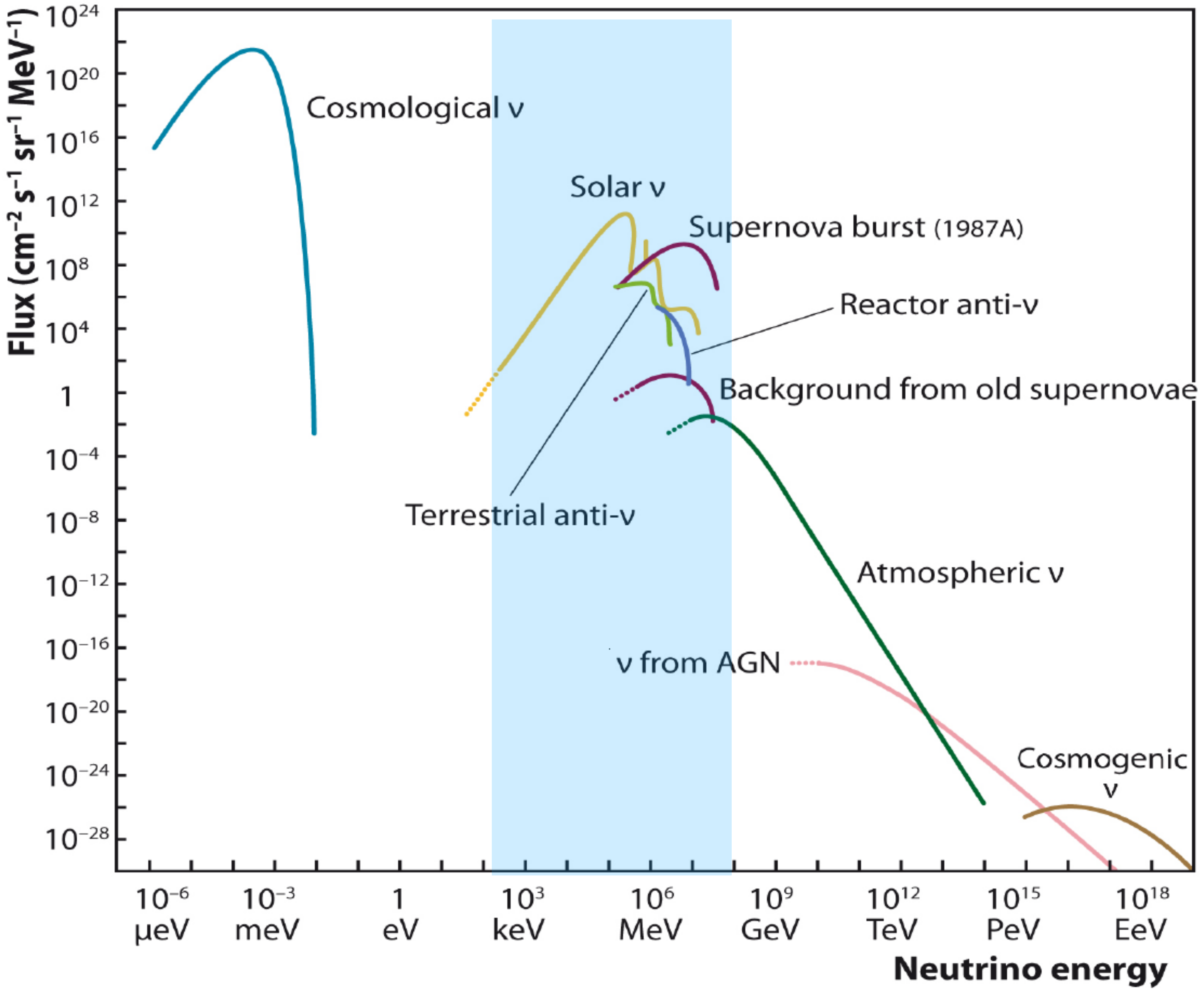
We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses 1–$10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses 1–$10^2$ GeV; or strongly interacting particles of masses 1–$10^{13}$ GeV.

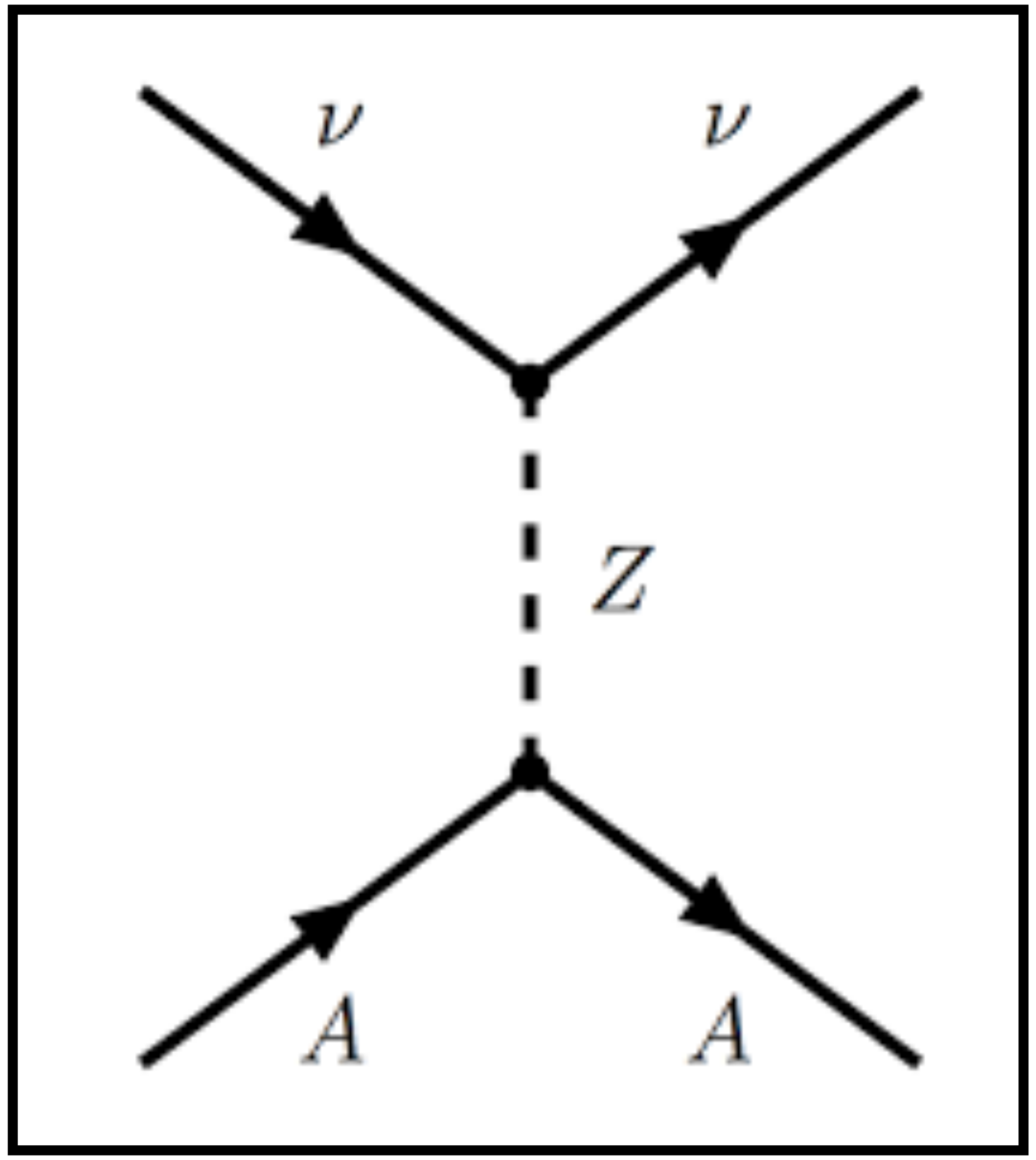
Received 7 January 1985

DOI: https://doi.org/10.1103/PhysRevD.31.3059

# CEvENS - NC SM Interaction







# CEvENS cross section

Barranco, J. *et al.* JHEP 0512 (2005) 021

$$\mathcal{L}^{NC}_{\nu Hadron} = -\frac{G_F}{\sqrt{2}} \sum_{q=u,d} \left[\bar{\nu}_e \gamma^\mu (1-\gamma^5)\nu_e\right] \left(f^{qL}\left[\bar{q}\gamma_\mu(1-\gamma^5)q\right] + f^{qR}\left[\bar{q}\gamma_\mu(1+\gamma^5)q\right]\right)$$

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left\{(G_V+G_A)^2 + (G_V-G_A)^2\left(1-\frac{T}{E_\nu}\right)^2 - (G_V^2-G_A^2)\frac{MT}{E_\nu^2}\right\}$$

$$G_V = \left[(g_V^p)\,Z + (g_V^n)\,N\right] F_{nucl}^V(Q^2)\,,$$

$$G_A = \left[(g_A^p)\,(Z_+ - Z_-) + (g_A^n)\,(N_+ - N_-)\right] F_{nucl}^A(Q^2)\,.$$

$$T_{max} = \frac{2E_\nu^2}{M + 2E_\nu}$$

# Cross Section

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} \left\{ 2 - \frac{2T}{E_\nu} + \left(\frac{T}{E_\nu}\right)^2 - \frac{MT}{E_\nu^2} \right\} [g_V^p Z + g_V^n N]^2 [F_{nucl}^V(Q^2)]^2$$

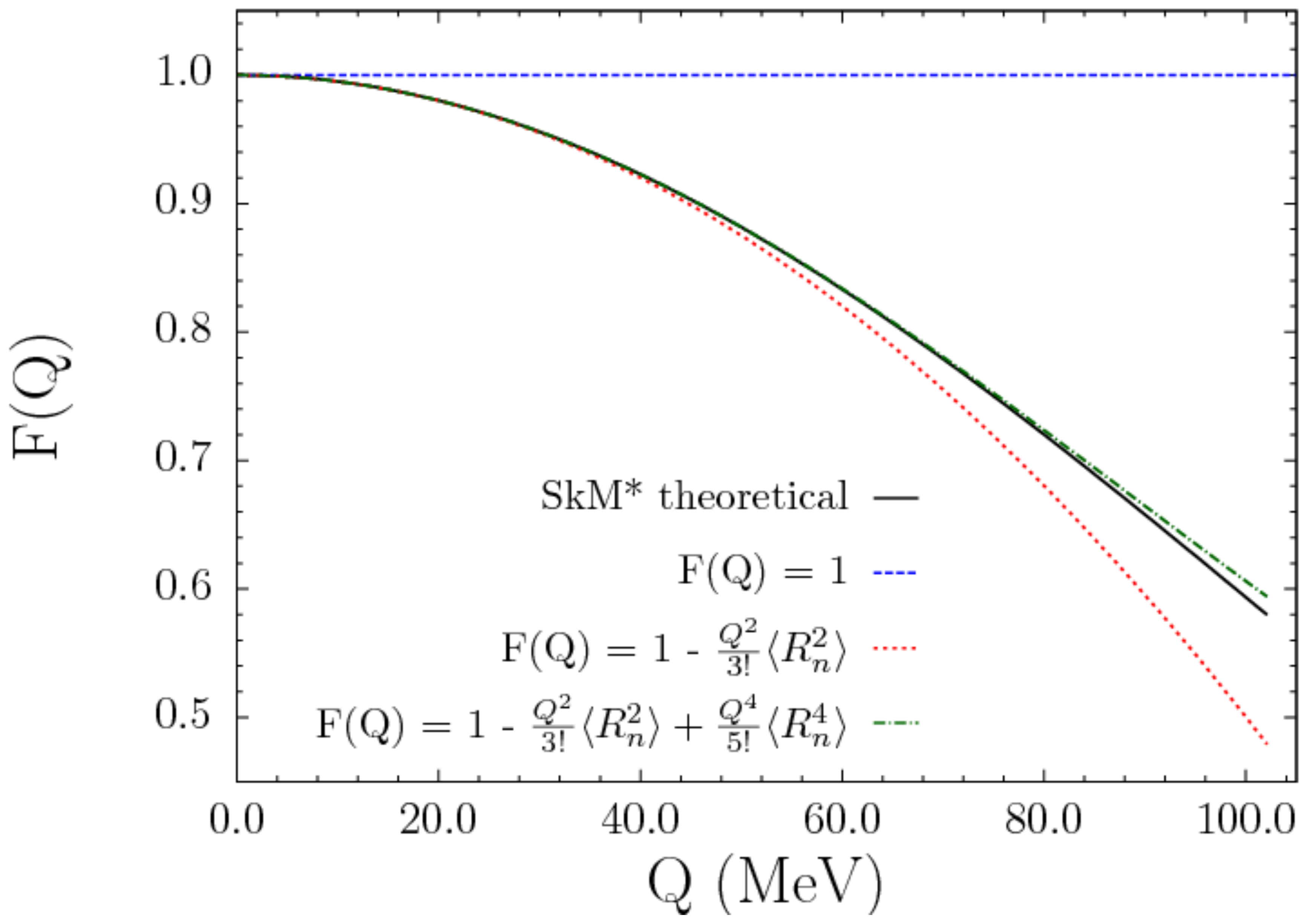
$$g_V^p = \rho_{\nu N}^{NC} \left( \frac{1}{2} - 2\hat{\kappa}_{\nu N} \hat{s}_Z^2 \right) + 2\lambda^{uL} + 2\lambda^{uR} + \lambda^{dL} + \lambda^{dR},$$

$$g_V^n = -\frac{1}{2}\rho_{\nu N}^{NC} + \lambda^{uL} + \lambda^{uR} + 2\lambda^{dL} + 2\lambda^{dR}.$$

$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

$$\frac{d\sigma}{dT} \propto N^2$$

**K. Patton et al**
**Phys.Rev. C86 (2012) 024612**



# Sensitivity to the weak charge and N² dependence

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$

$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

$$\frac{d\sigma}{dT} \propto N^2$$

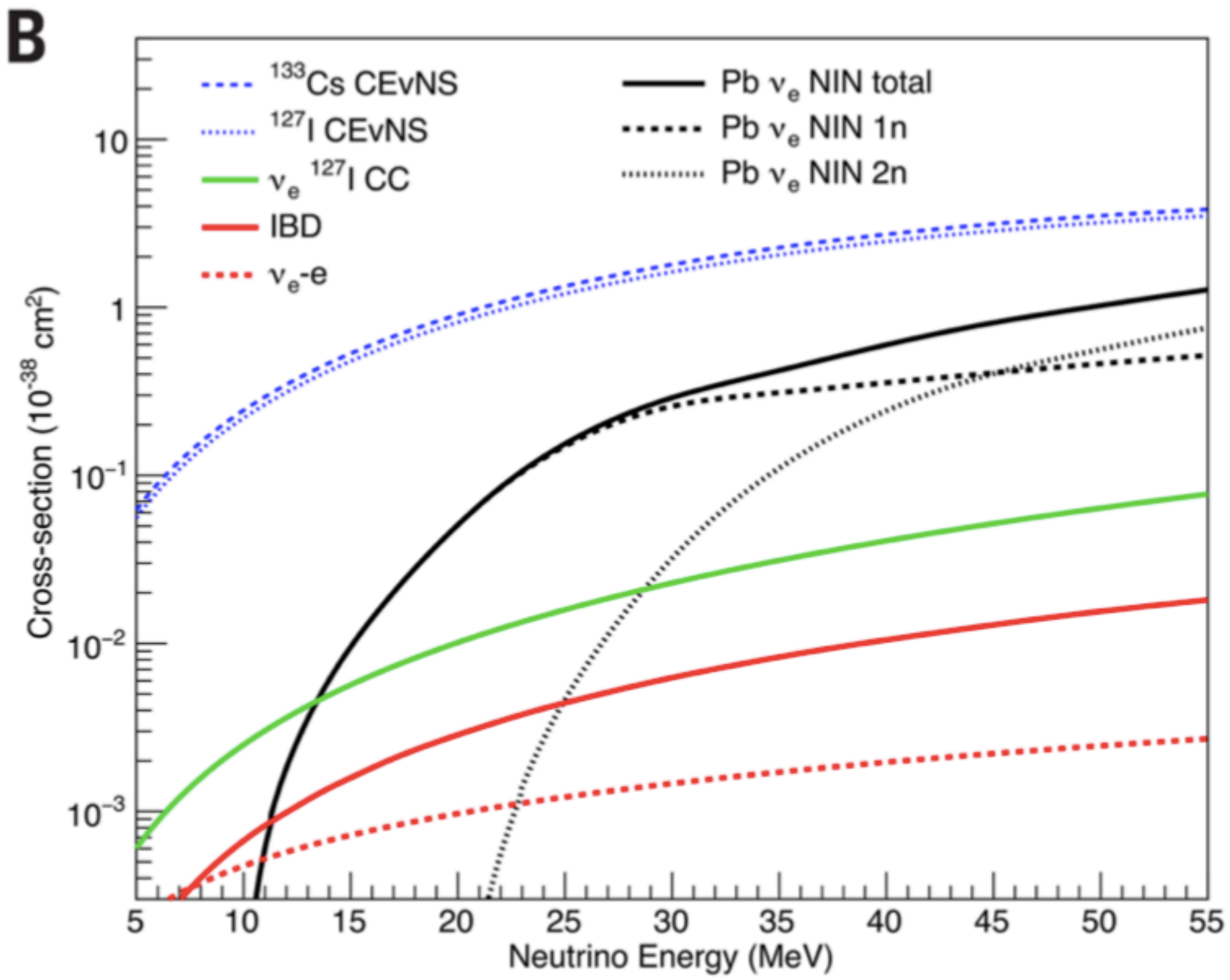
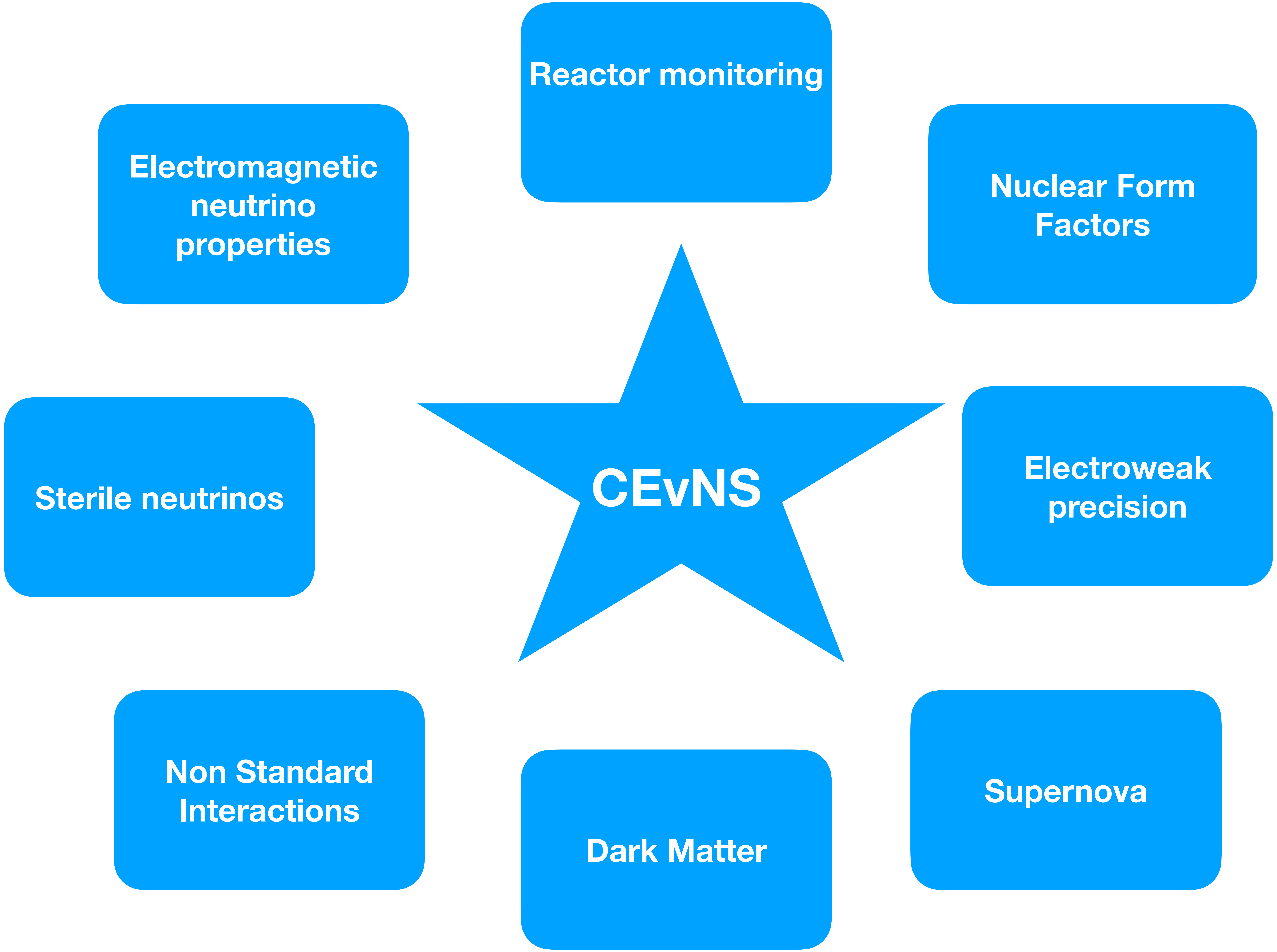


Image credit: COHERENT Collaboration.



CEvNS

Reactor monitoring

Electromagnetic neutrino properties

Nuclear Form Factors

Sterile neutrinos

Electroweak precision

Non Standard Interactions

Dark Matter

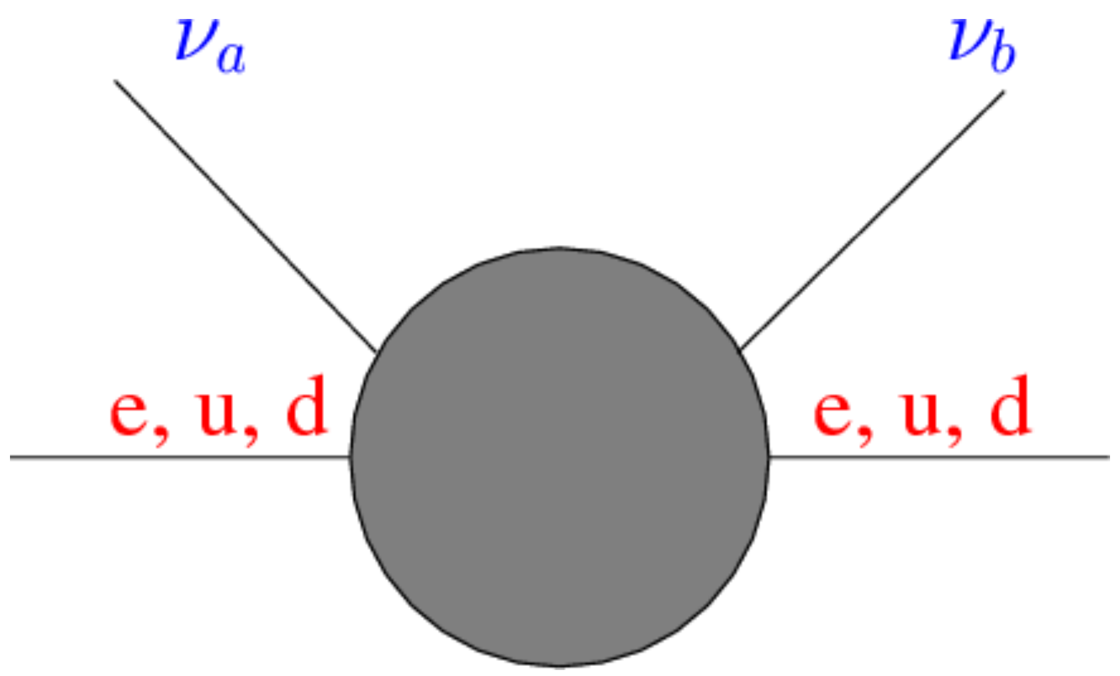
Supernova

# Non Standard neutrino interactions (NSI)

Barranco, J. *et al.* JHEP 0512 (2005) 021

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left\{(G_V+G_A)^2 + (G_V-G_A)^2\left(1-\frac{T}{E_\nu}\right)^2 - \left(G_V^2-G_A^2\right)\frac{MT}{E_\nu^2}\right\}$$

$$\begin{aligned} G_V &= \left[\left(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}\right) Z + \left(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV}\right) N\right] F_{nucl}^V(Q^2)\,, \\ G_A &= \left[\left(g_A^p + 2\varepsilon_{ee}^{uA} + \varepsilon_{ee}^{dA}\right)(Z_+ - Z_-) + \left(g_A^n + \varepsilon_{ee}^{uA} + 2\varepsilon_{ee}^{dA}\right)(N_+ - N_-)\right] F_{nucl}^A(Q^2)\,. \end{aligned}$$

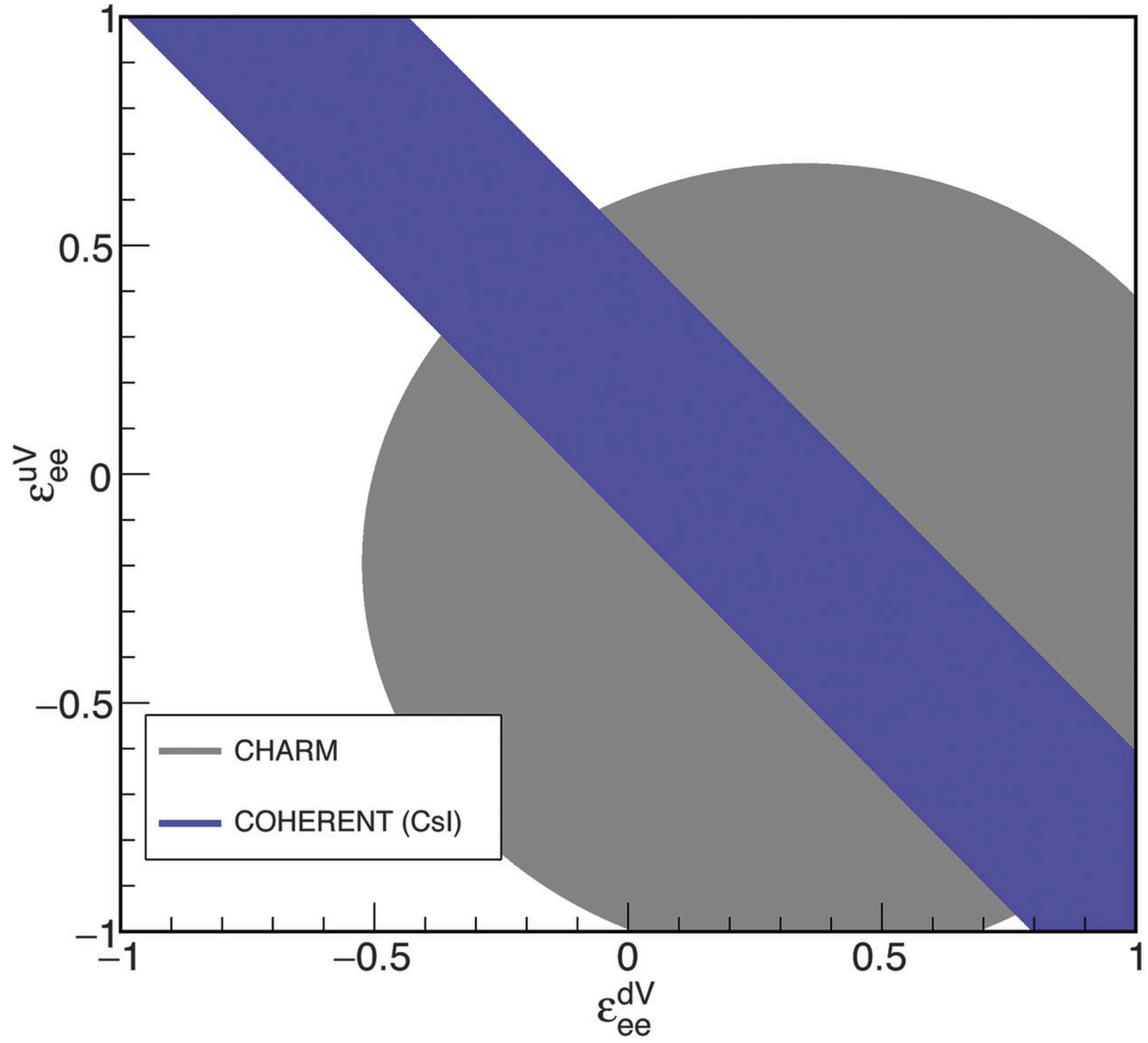


J.W.F. Valle Conf.Proc.
C0908171 (2009) 363-375

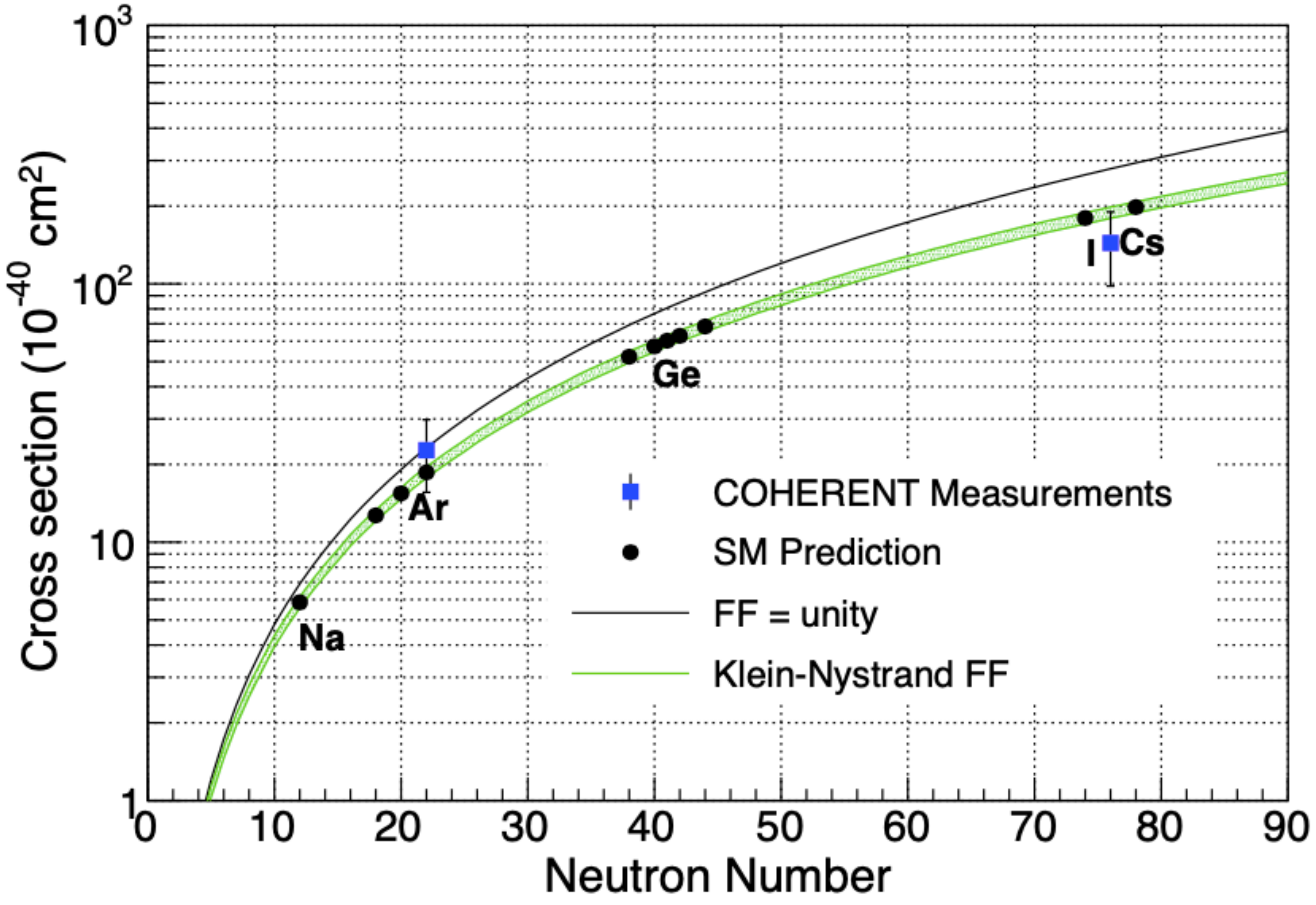
**Y. Farzan, M. Tortola, Front. Phys. 6 10 (2018)**
**Miranda, H. Nunokawa NJP 17 095002 (2015)**
**T. Ohlsson, Rept. Prog. Phys 76 044201 (2013)**

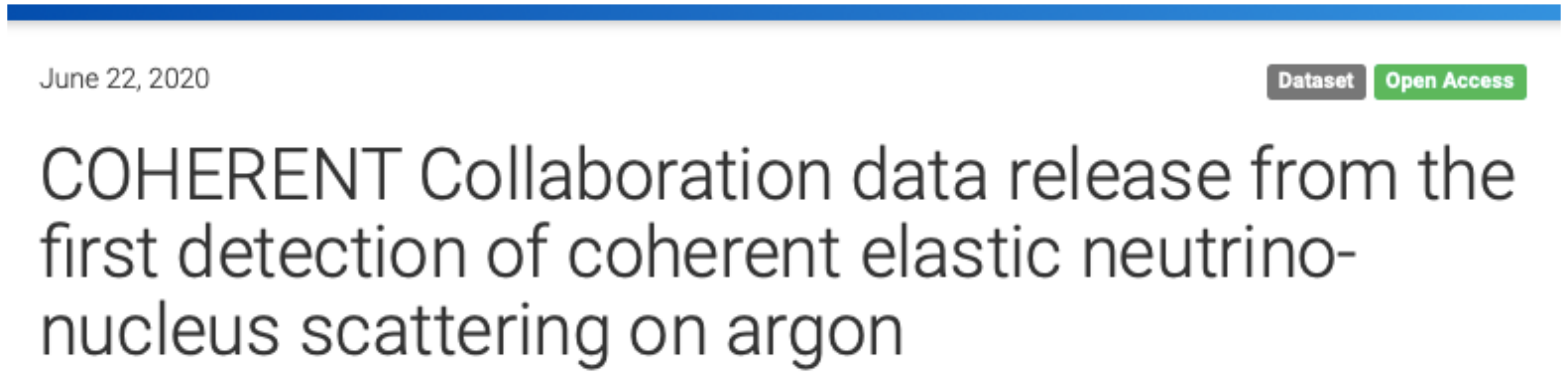
# COHERENT Collaboration
# First detected in SNS neutrinos 2017

Breakthrough of the year, smallest neutrino detector ever build



# News from COHERENT in 2020




June 22, 2020

Dataset Open Access

COHERENT Collaboration data release from the first detection of coherent elastic neutrino-nucleus scattering on argon

10.1103/PhysRevD.100.115020

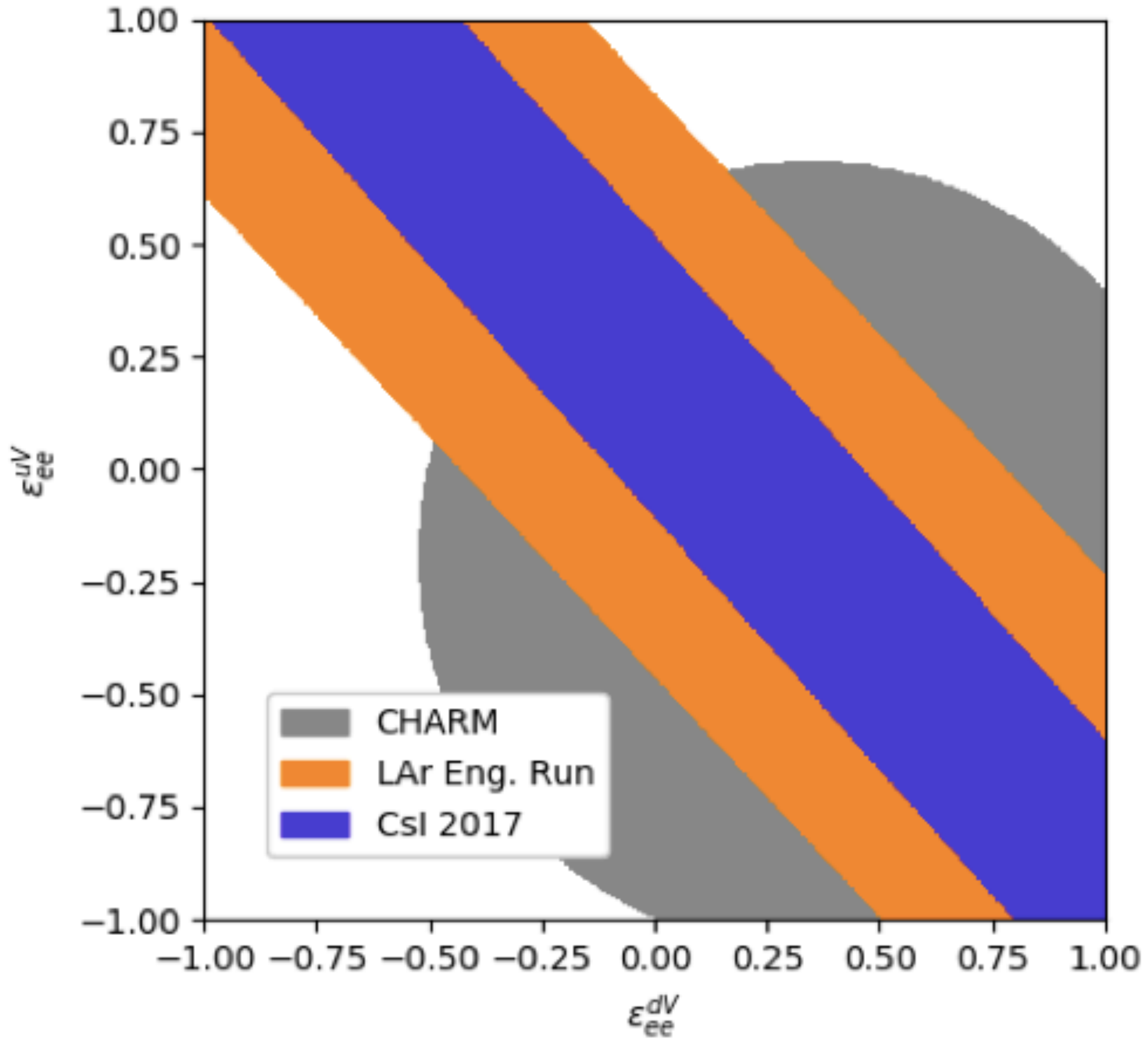
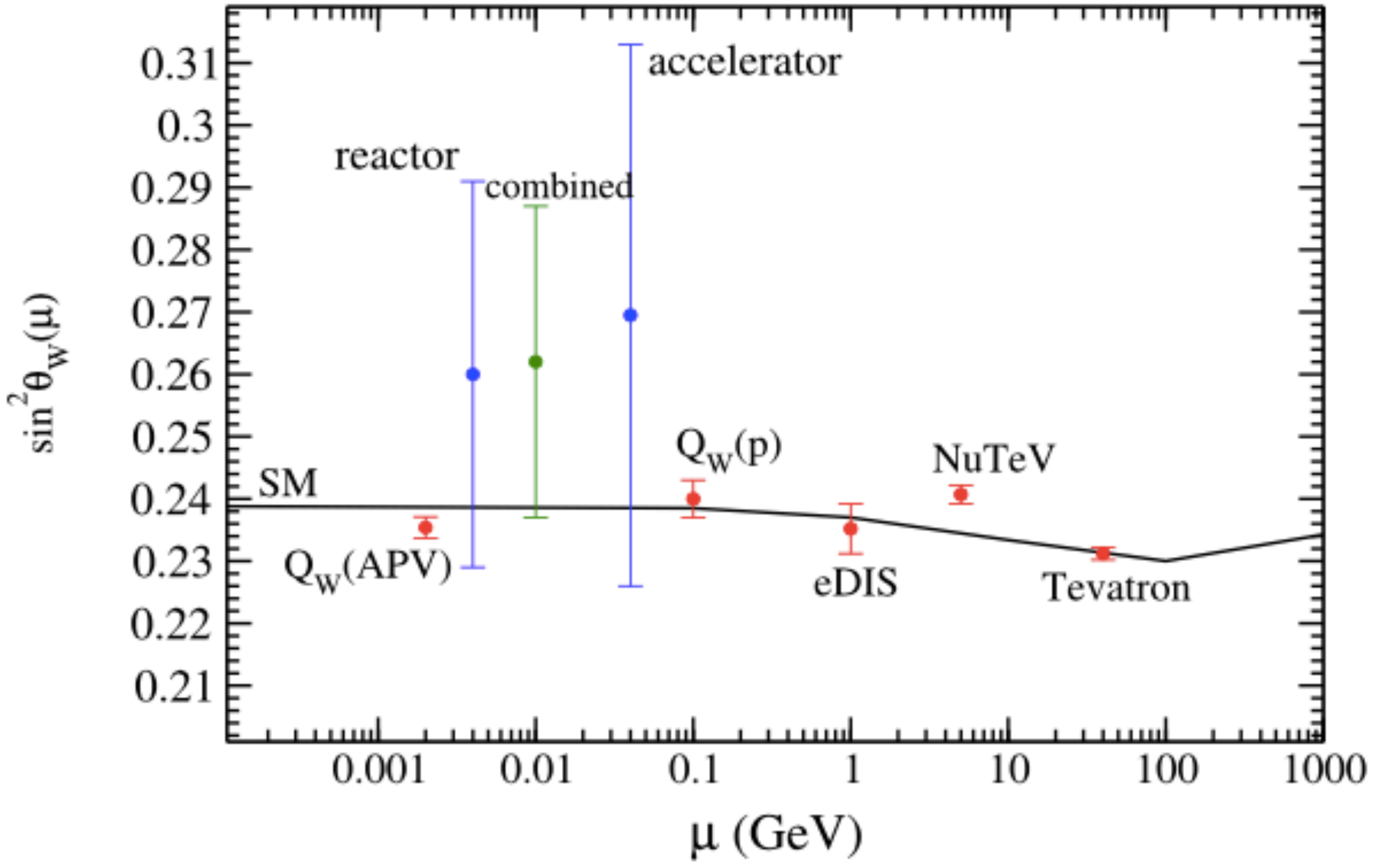


FIG. 10. 90 % CL on NSI parameters $\epsilon_{ee}^{uV}$ and $\epsilon_{ee}^{dV}$ from this CENNS-10 engineering run. The earlier CsI[Na] result [18] is confirmed and much of the pre-COHERENT phase space allowed by CHARM [49] is ruled out.

# Reactor neutrino experiments in the quest for CEVNS

# Sensitivity(reactor CEVNS) to Weak Mixing Angle

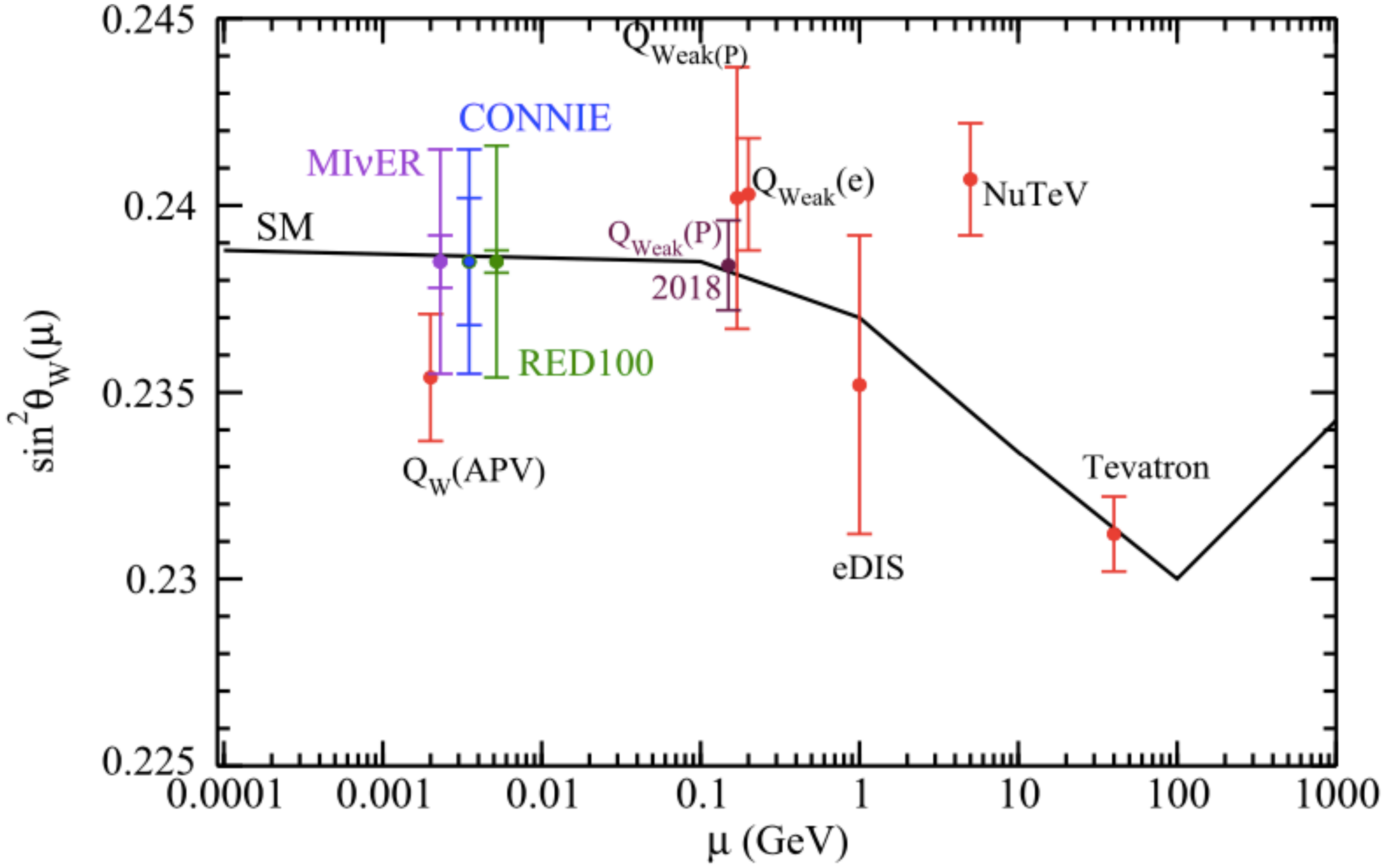
Physics Letters B 761 (2016) 450–455



The weak mixing angle from low energy neutrino measurements: A global update

B.C. Cañas [a], E.A. Garcés [b], O.G. Miranda [a,*], M. Tórtola [c], J.W.F. Valle [c]

Physics Letters B 784 (2018) 159–162

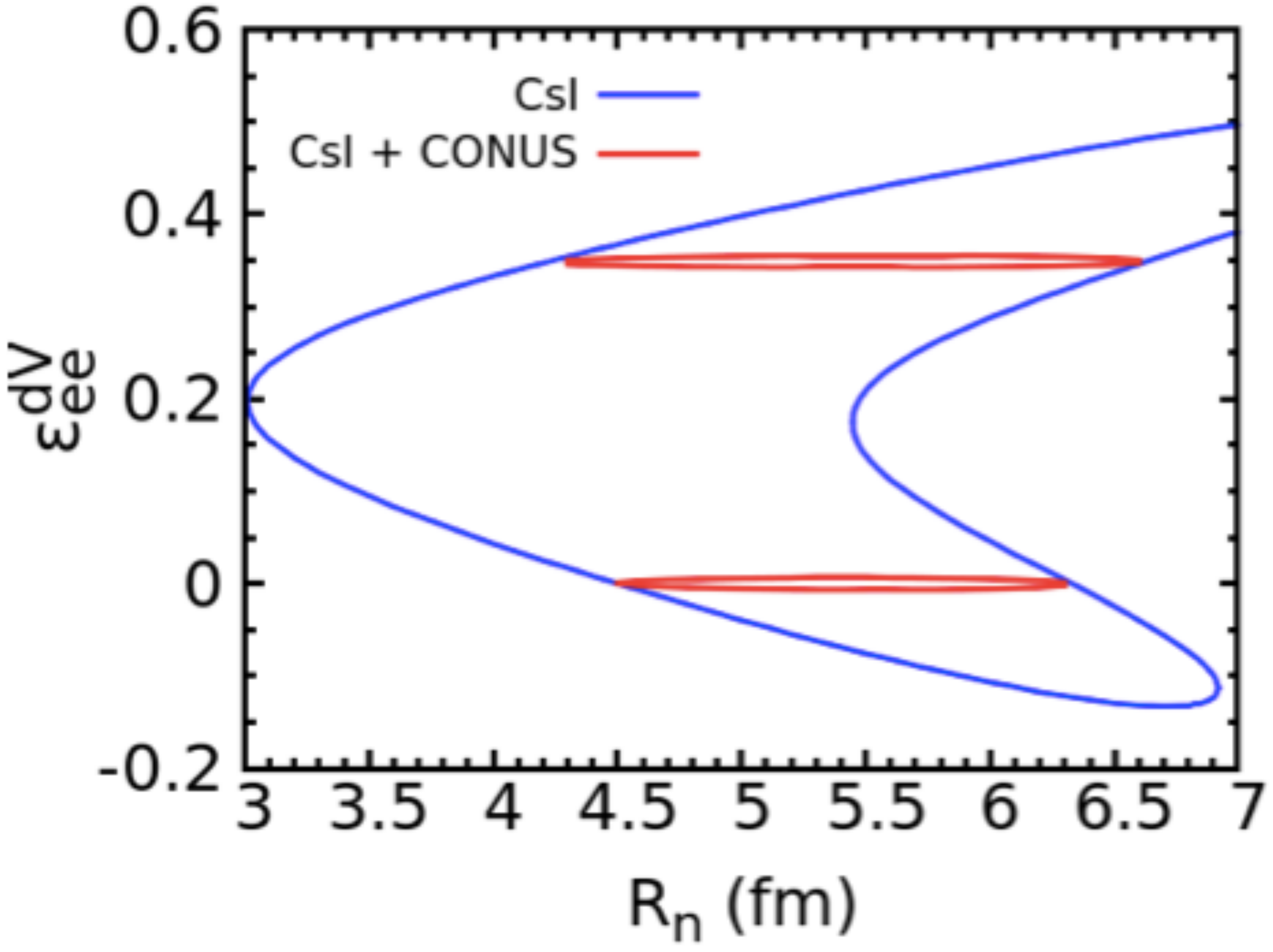


Future perspectives for a weak mixing angle measurement in coherent elastic neutrino nucleus scattering experiments

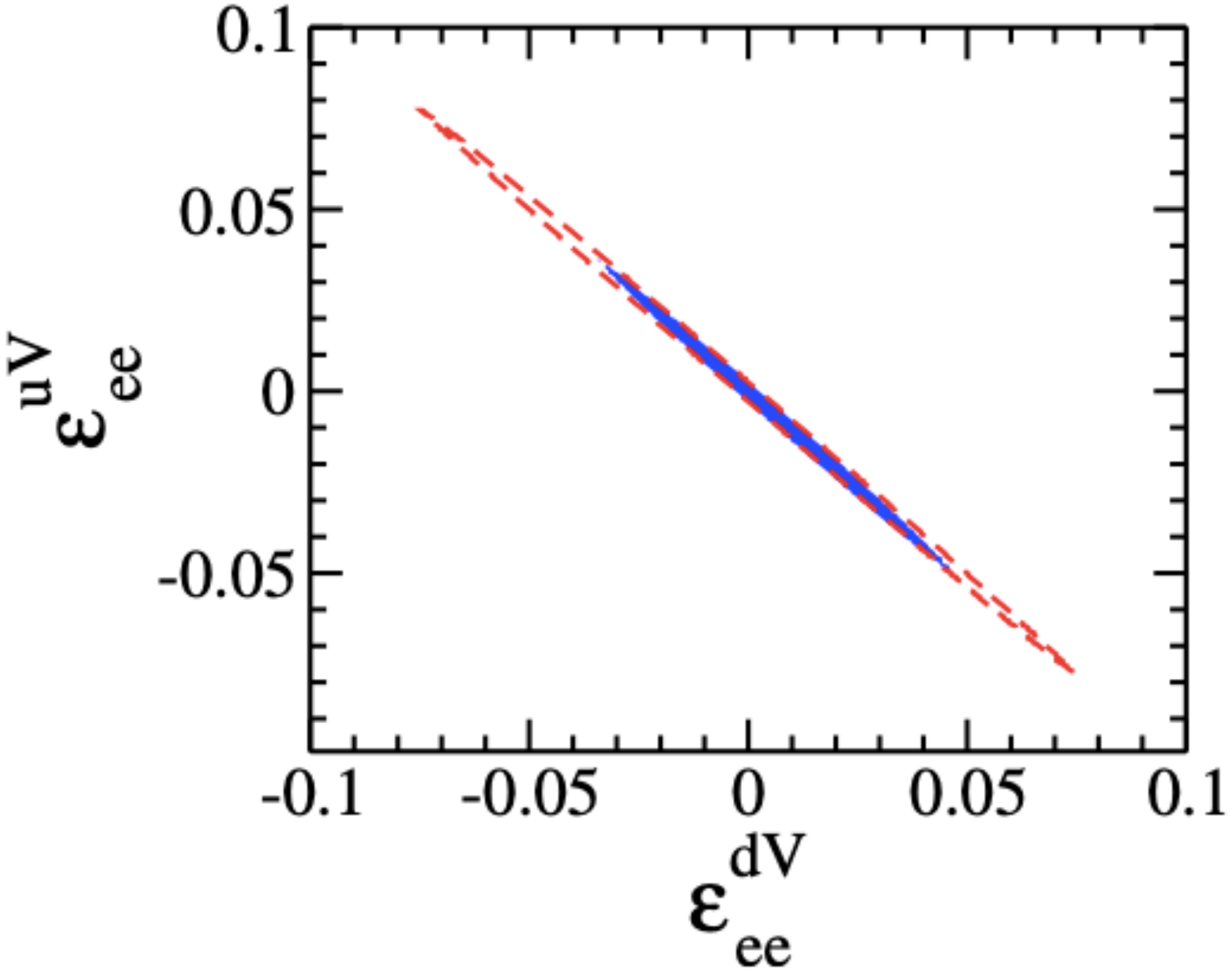
B.C. Cañas [a,b], E.A. Garcés [a], O.G. Miranda [a,*], A. Parada [c]

# Non standard interactions

B.C. Canas, E.A. Garces, O.G. Miranda, A. Parada, G. Sanchez Garcia
Published in: *Phys.Rev.D* 101 (2020) 3, 035012



**Expected: Connie + Covus**



# Sterile neutrinos

Physics Letters B 776 (2018) 451–456

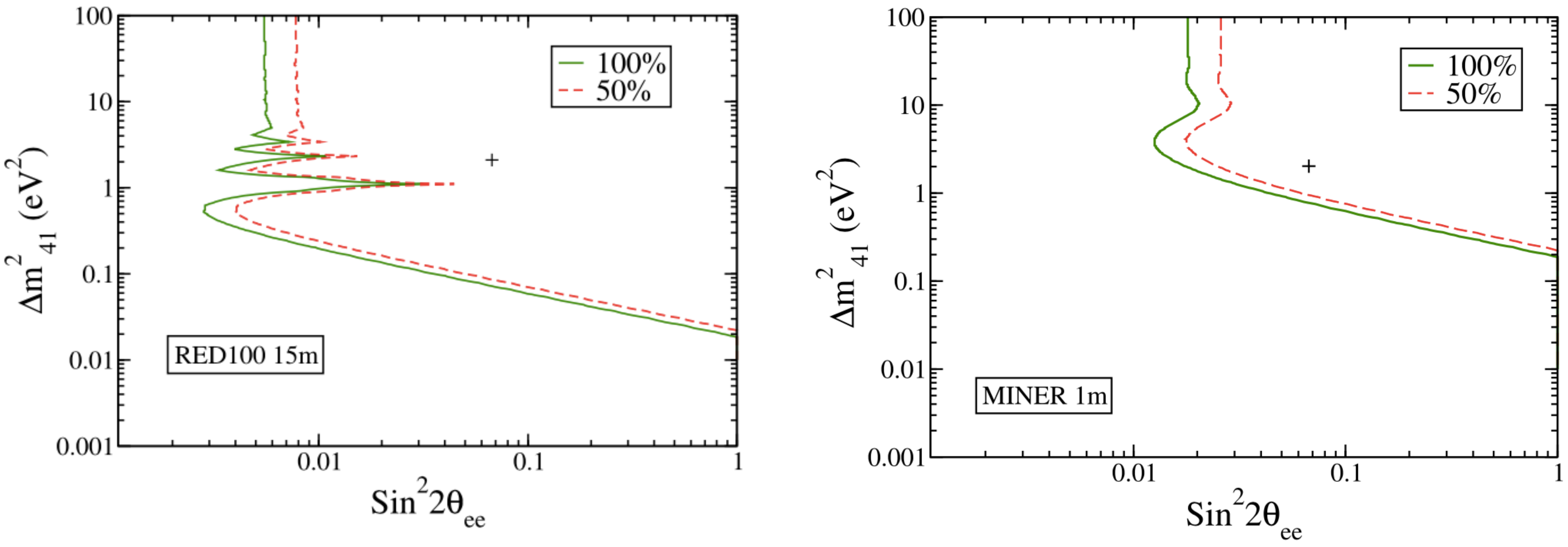
The reactor antineutrino anomaly and low energy threshold neutrino experiments

B.C. Cañas [a,b], E.A. Garcés [a], O.G. Miranda [a,*], A. Parada [b]

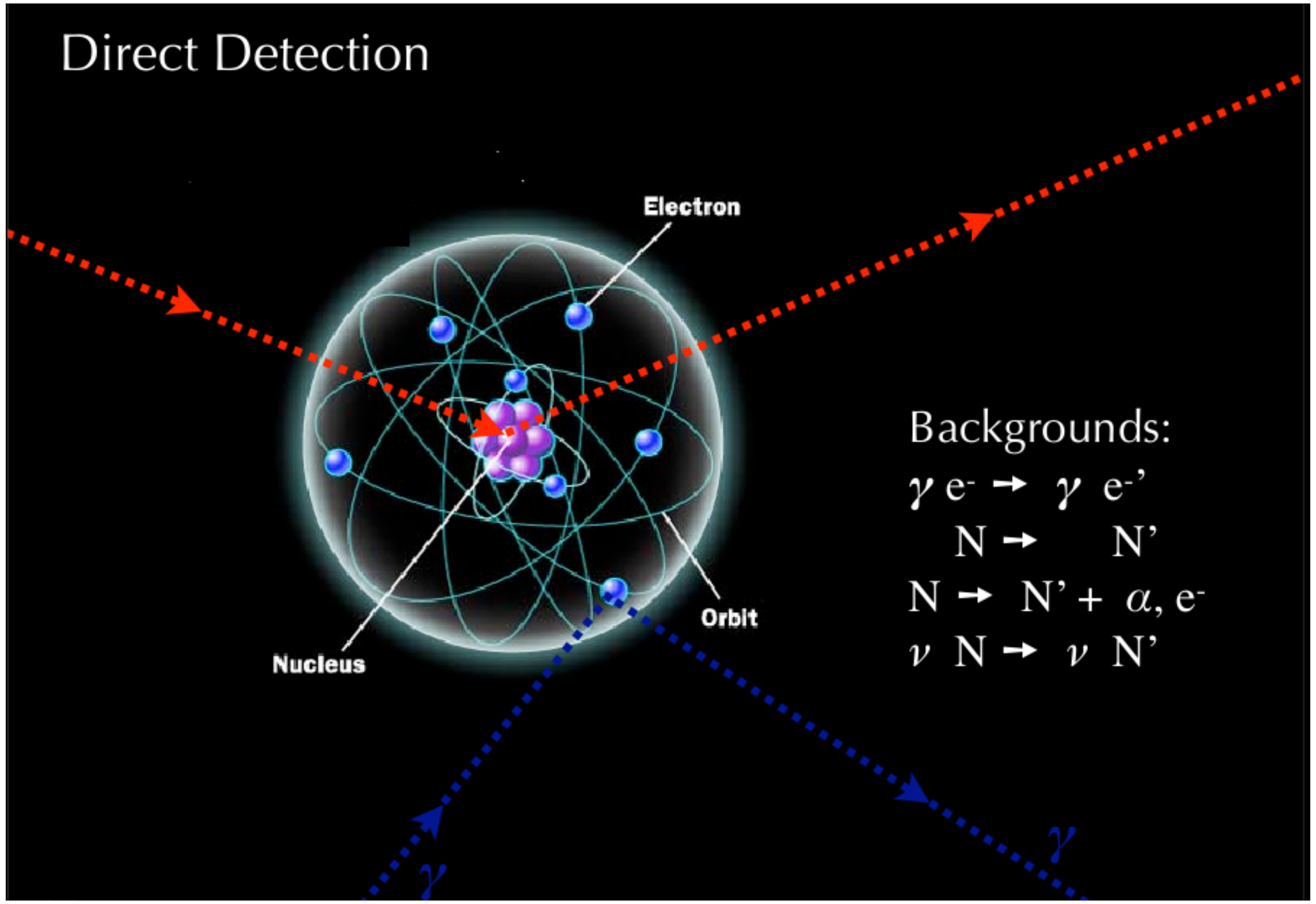
[a] Departamento de Física, Centro de Investigación y de Estudios Avanzados del IPN, Apdo. Postal 14-740, 07000 Ciudad de México, Mexico

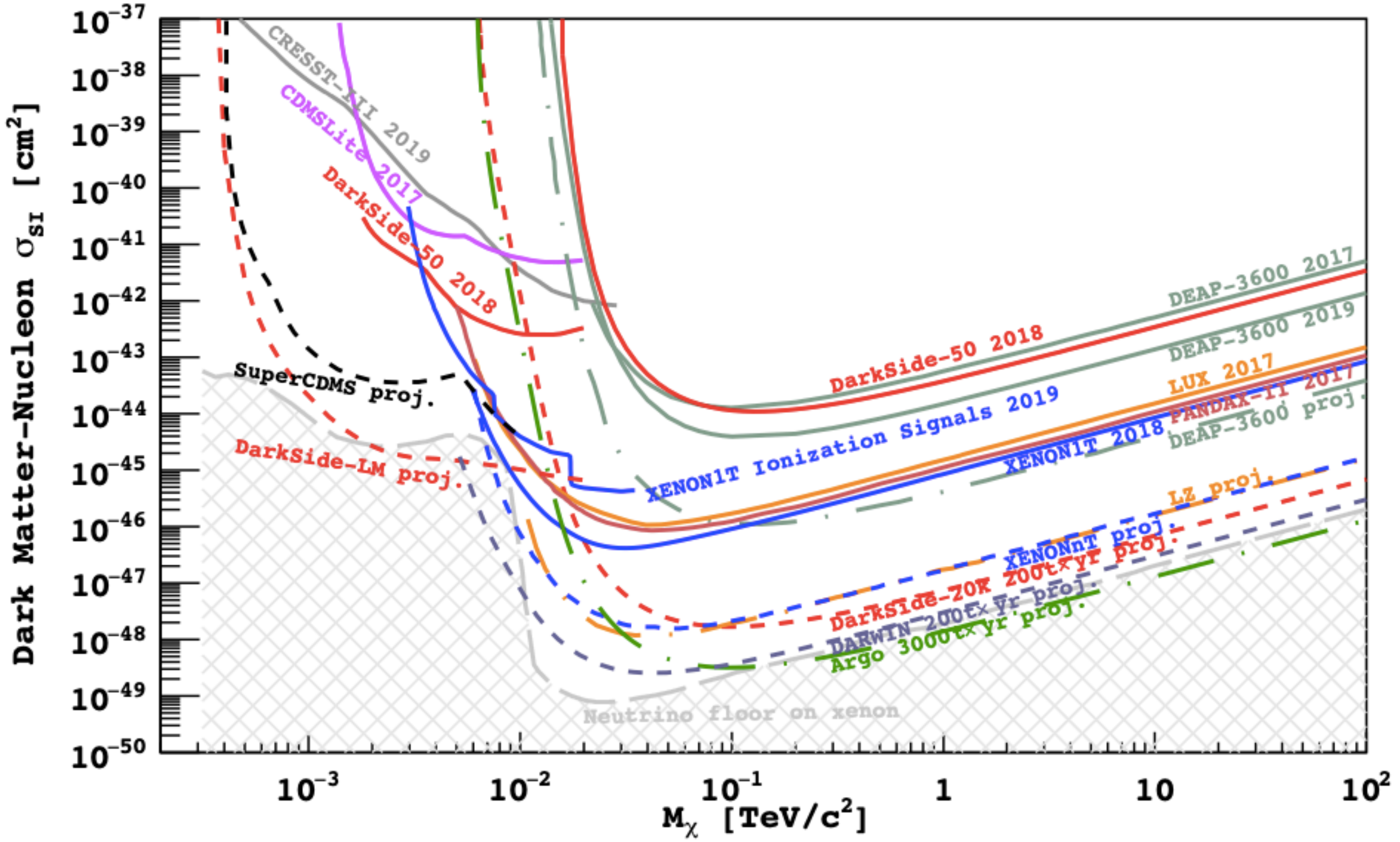
[b] Universidad Santiago de Cali, Campus Pampalinda, Calle 5 No. 6200, 760001, Santiago de Cali, Colombia

**Sensitivity in Xe, Ge, could exclude BFP**



# Direct Detection Dark Matter Experiments





# Isospin violating scenarios

### Violación de isoespín y supresión a la sección eficaz

**Violación del isoespín.**

Se considera violación de isoespín cuando la razón de los acoplamientos $f_n/f_p \neq 1$.

$$\sigma_p = \frac{4\mu_p^2}{\pi} f_p^2 \tag{11}$$

$$\sigma_N^Z = \sigma_p \frac{\sum_i \eta_i \mu_{A_i}^2 [Z + (A_i - Z) f_n/f_p]^2}{\sum_i \eta_i \mu_{A_i}^2 A_i^2} \tag{12}$$

**Máxima supresión.**

Factor de supresión a la sensibilidad:

$$F_Z = \frac{\sigma_p}{\sigma_N^Z} \tag{13}$$

- Xe $\sim$ -0.7
- Ar $\sim$ -0.82
- Ge $\sim$ -0.99
- Si $\sim$ -0.79
- $C_3F_8 \sim$ -0.92

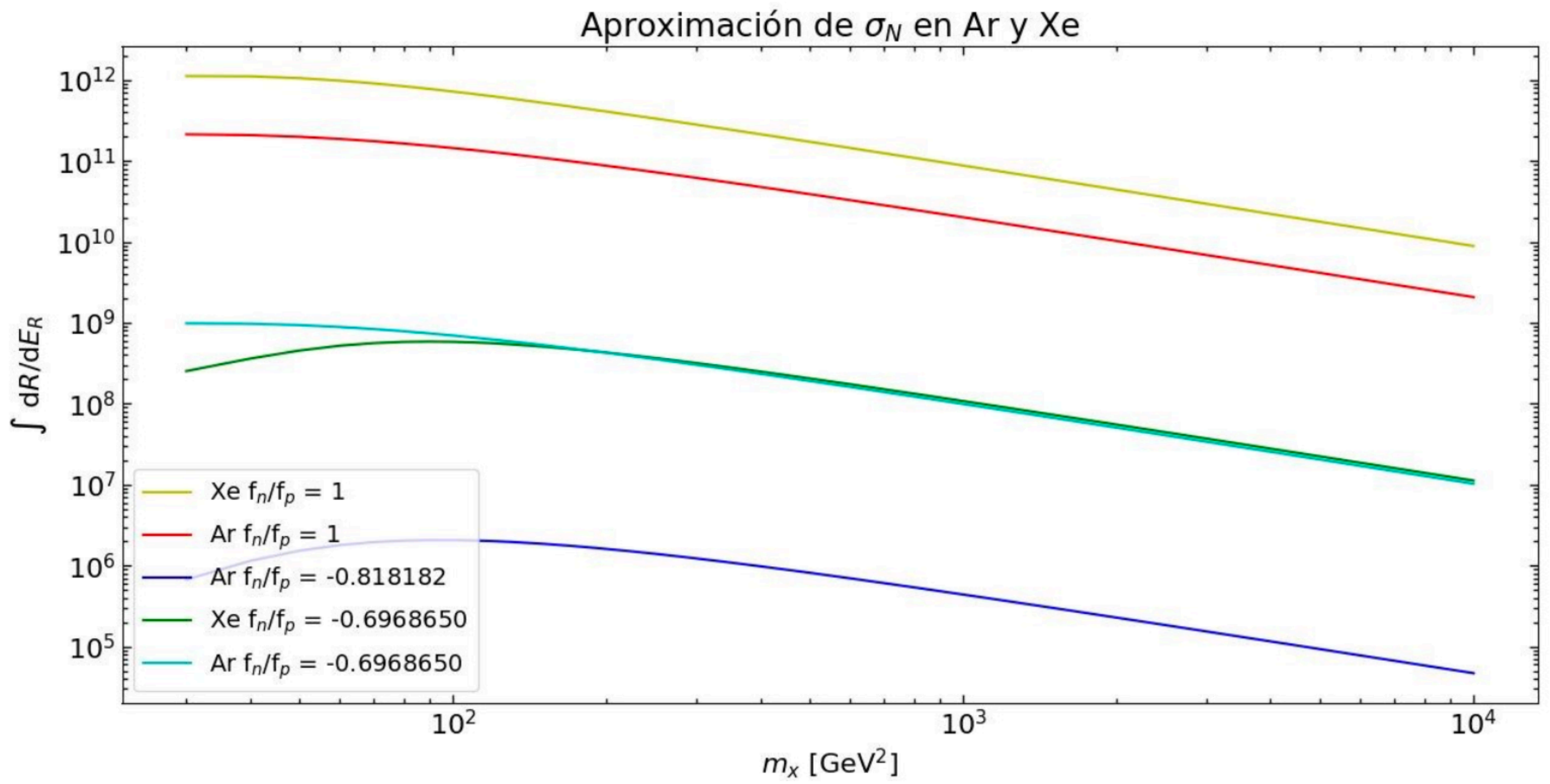


Figura 15: Aproximación al comportamiento de curvas de exclusión para el argón y el xenón considerando en interacciones SI, en los casos isoescalar, $F_Z$ máximo para ambos objetivos y argofílico.

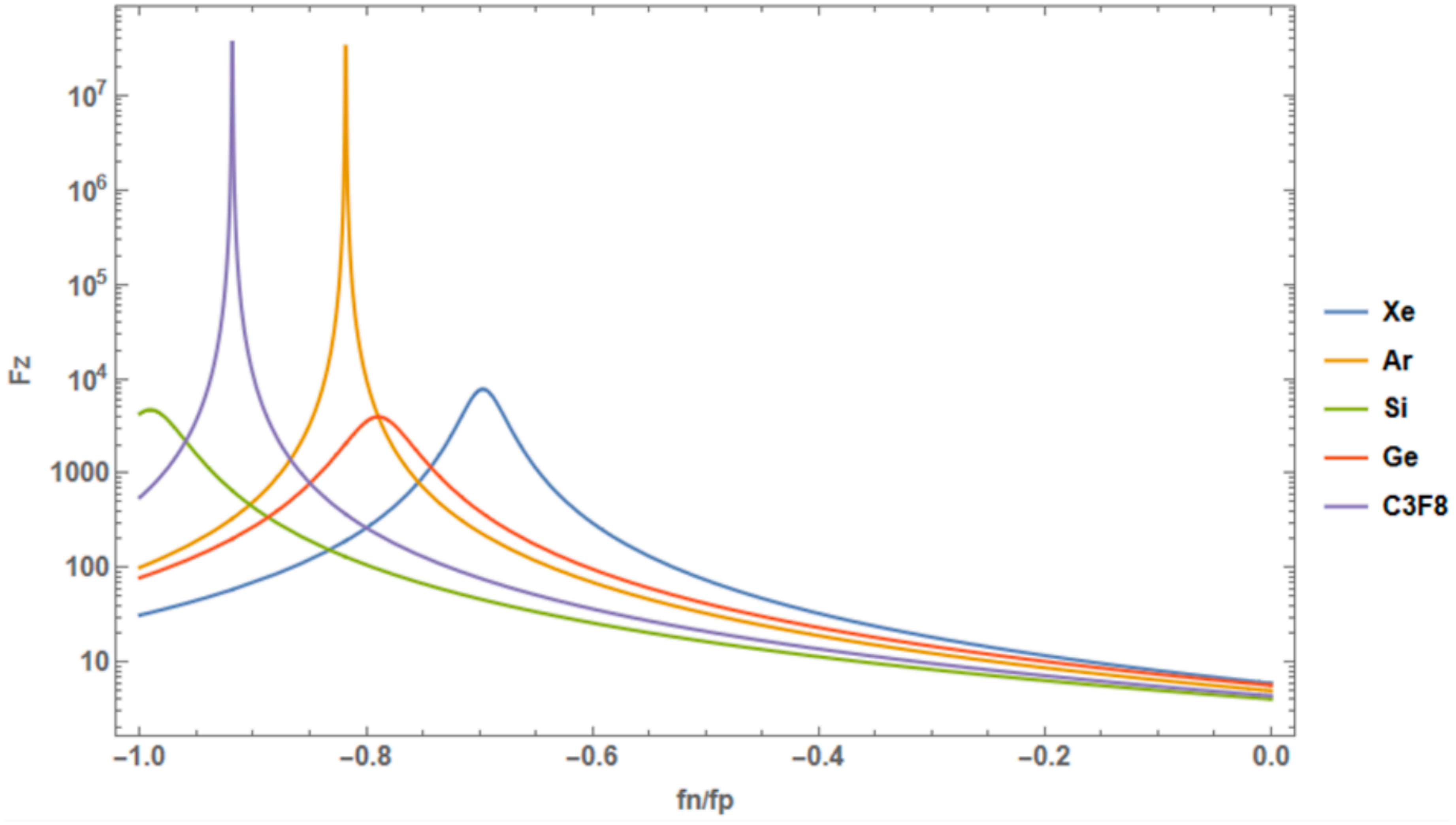
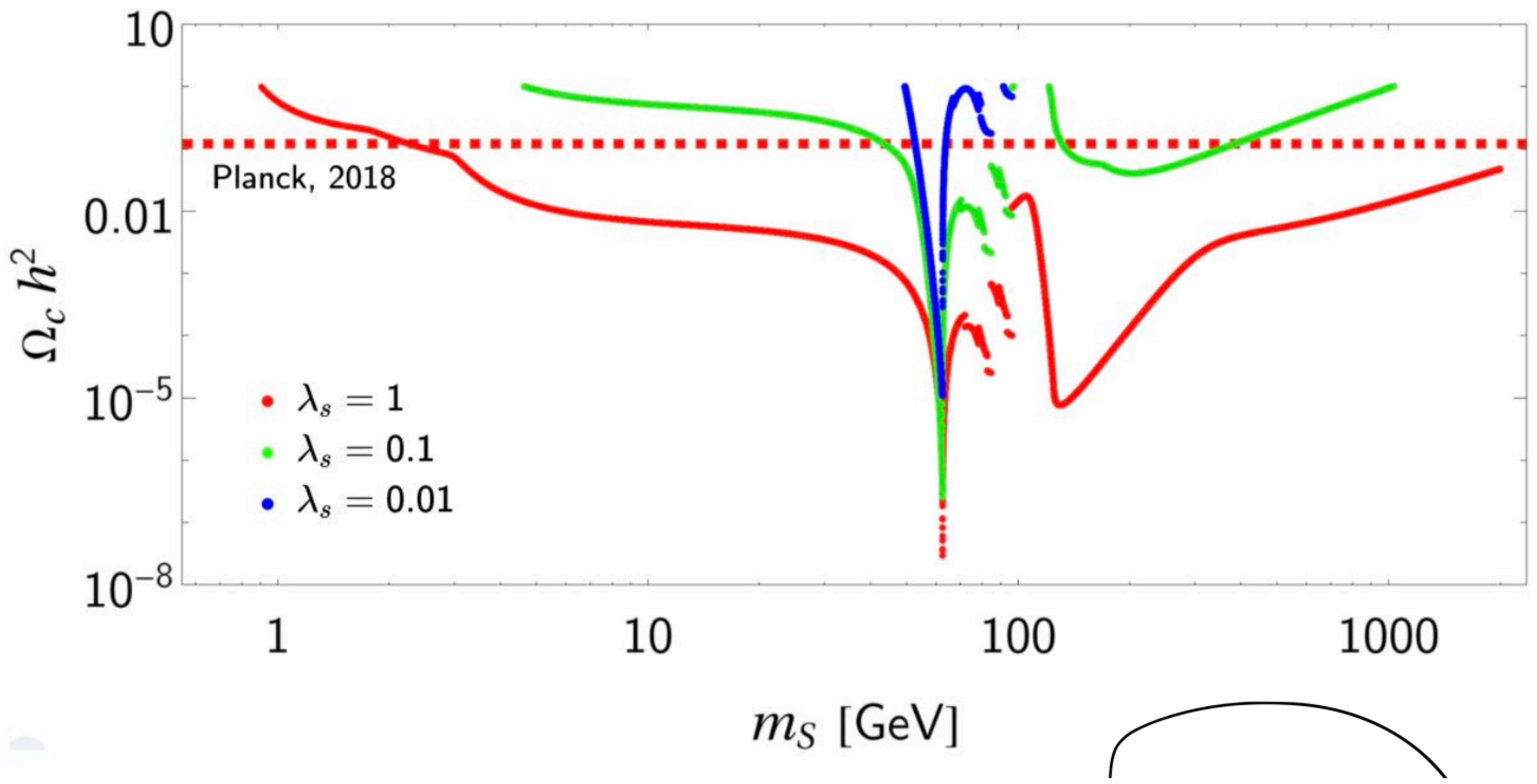
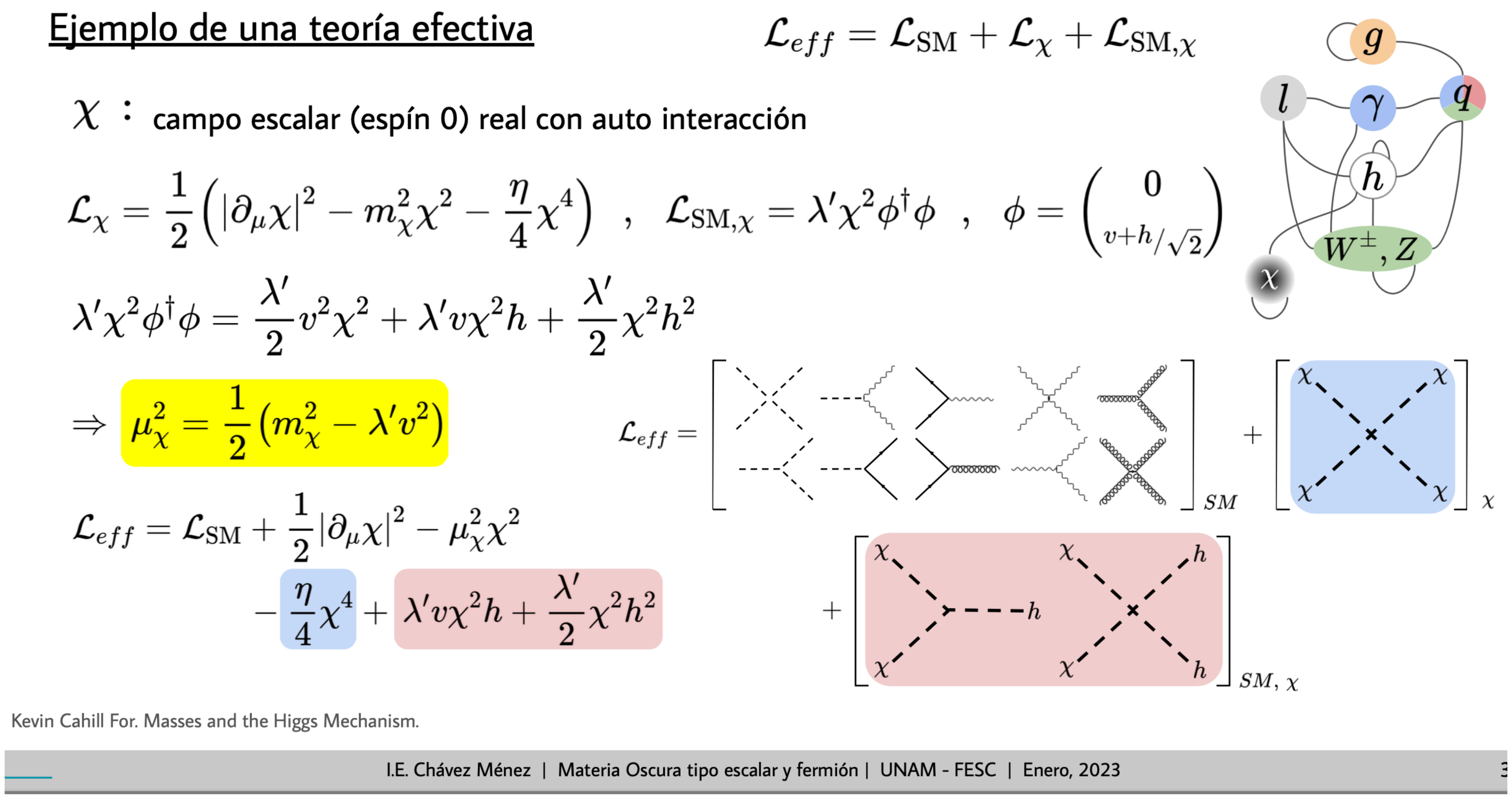


Figura 8: Relación de $F_Z$ respecto a la razón de los acoplamientos $f_n/f_p$, los máximos indican la máxima supresión a la sensibilidad de la sección eficaz.

**Tesis: Fernando Damian Sanchez Ferto.**

# BSM





## Ejemplo de una teoría efectiva

$$\mathcal{L}_{eff} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_\chi + \mathcal{L}_{\mathrm{SM},\chi}$$

$\chi$ : campo escalar (espín 0) real con auto interacción

$$\mathcal{L}_\chi = \frac{1}{2}\left(|\partial_\mu\chi|^2 - m_\chi^2\chi^2 - \frac{\eta}{4}\chi^4\right) \quad , \quad \mathcal{L}_{\mathrm{SM},\chi} = \lambda'\chi^2\phi^\dagger\phi \quad , \quad \phi = \begin{pmatrix} 0 \\ {}^{v+h}/_{\sqrt{2}} \end{pmatrix}$$

$$\lambda'\chi^2\phi^\dagger\phi = \frac{\lambda'}{2}v^2\chi^2 + \lambda' v\chi^2 h + \frac{\lambda'}{2}\chi^2 h^2$$

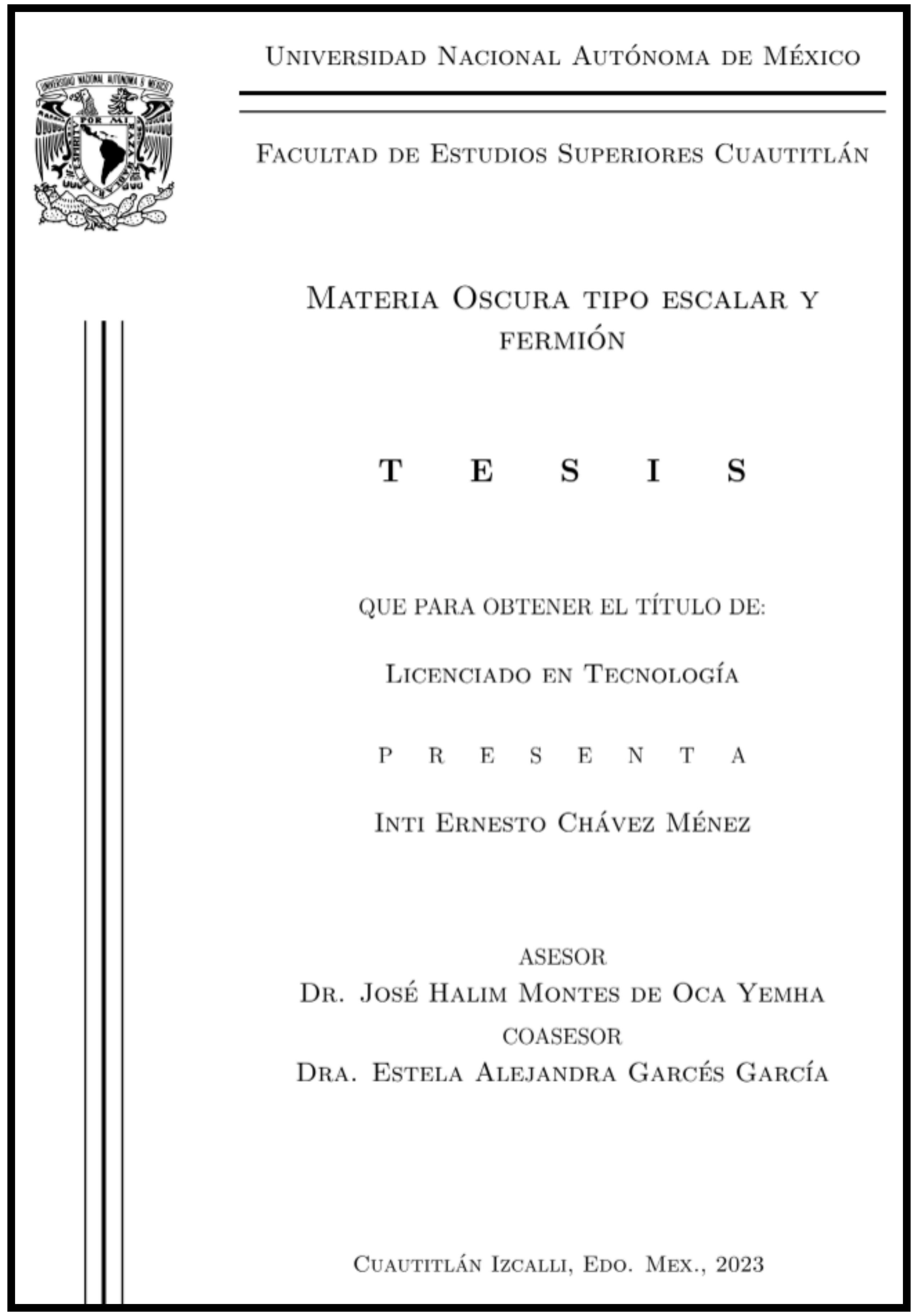
$$\Rightarrow \mu_\chi^2 = \frac{1}{2}\left(m_\chi^2 - \lambda' v^2\right)$$

$$\mathcal{L}_{eff} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{2}|\partial_\mu\chi|^2 - \mu_\chi^2\chi^2 - \frac{\eta}{4}\chi^4 + \lambda' v\chi^2 h + \frac{\lambda'}{2}\chi^2 h^2$$

$$\mathcal{L}_{eff} = \Big[\ \cdots\ \Big]_{SM} + \Big[\ \cdots\ \Big]_{\chi} + \Big[\ \cdots\ \Big]_{SM,\,\chi}$$

Kevin Cahill For. Masses and the Higgs Mechanism.

I.E. Chávez Ménez | Materia Oscura tipo escalar y fermión | UNAM - FESC | Enero, 2023



Universidad Nacional Autónoma de México

Facultad de Estudios Superiores Cuautitlán

Materia Oscura tipo escalar y fermión

TESIS

que para obtener el título de:

Licenciado en Tecnología

PRESENTA

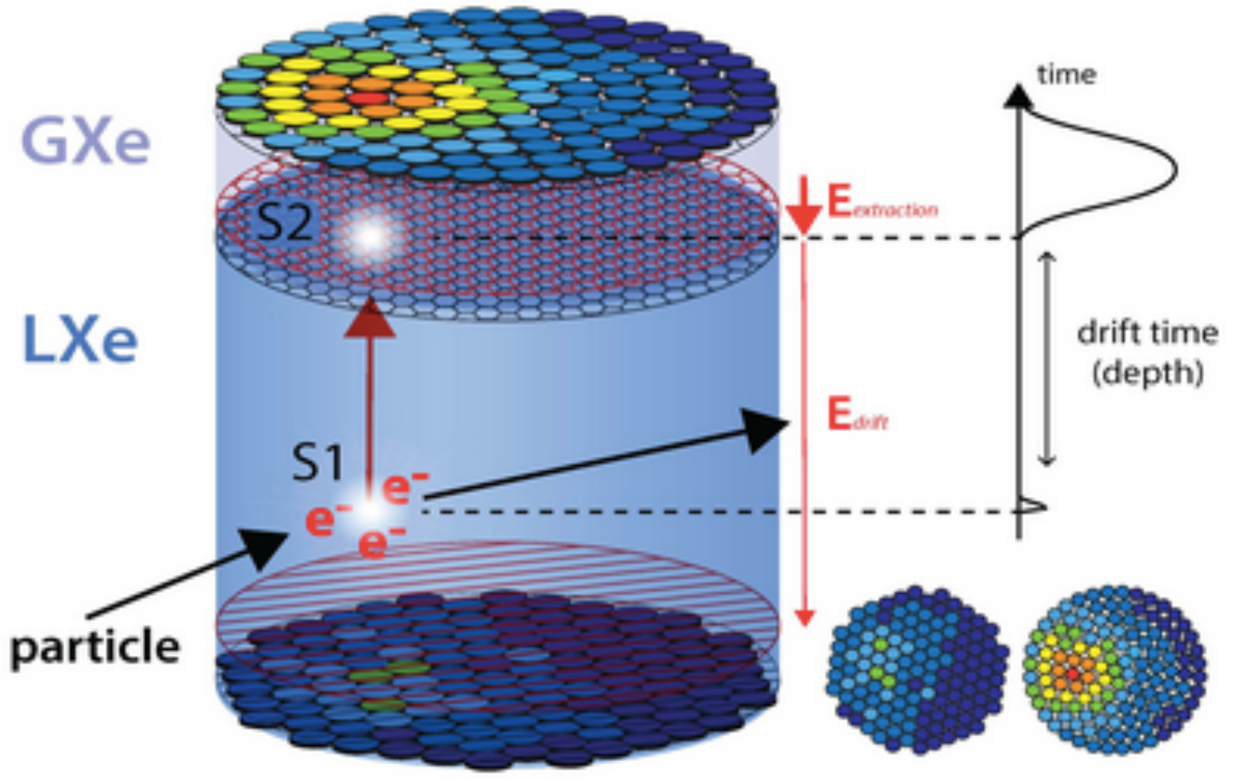
Inti Ernesto Chávez Ménez

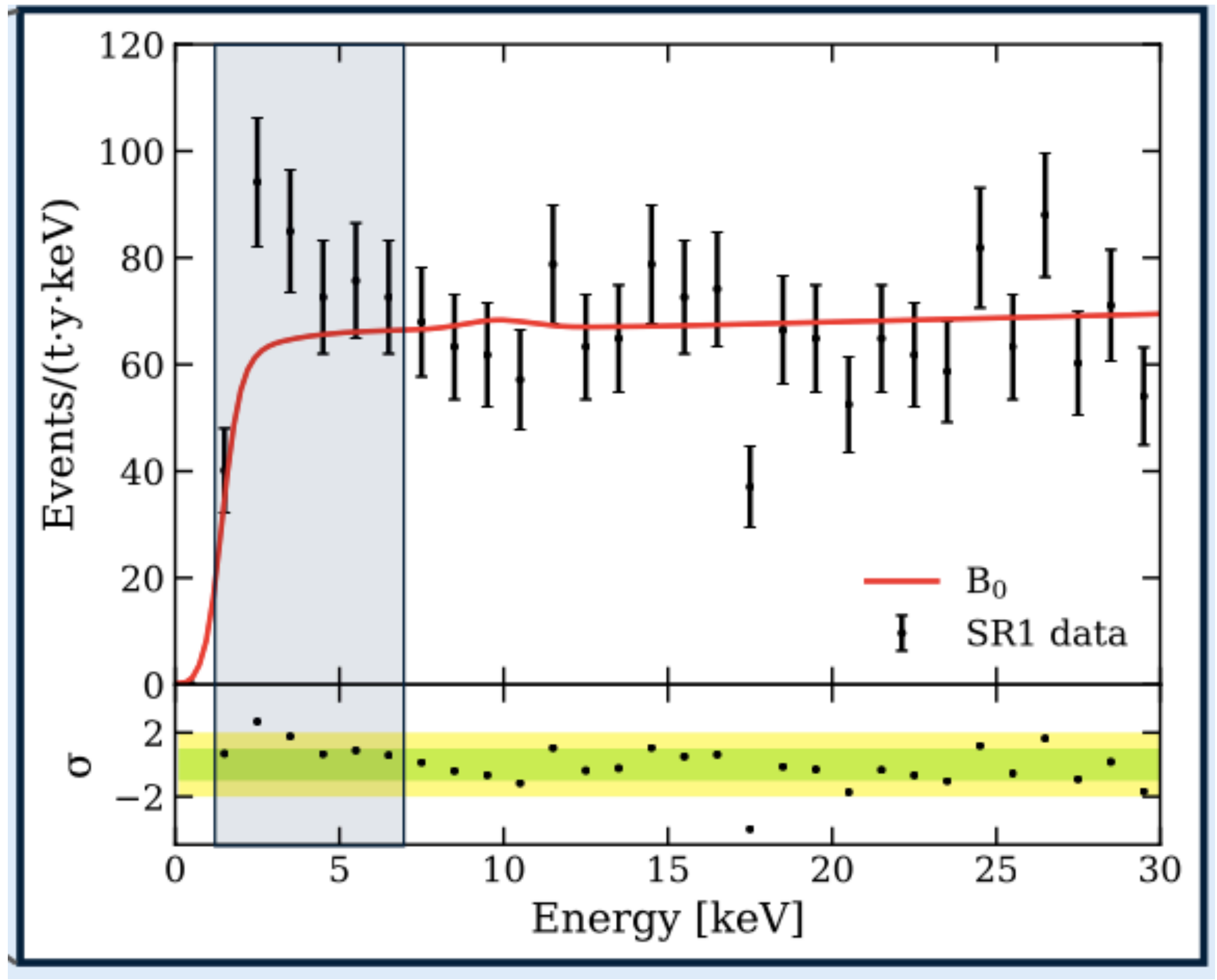
ASESOR
Dr. José Halim Montes de Oca Yemha
COASESOR
Dra. Estela Alejandra Garcés García

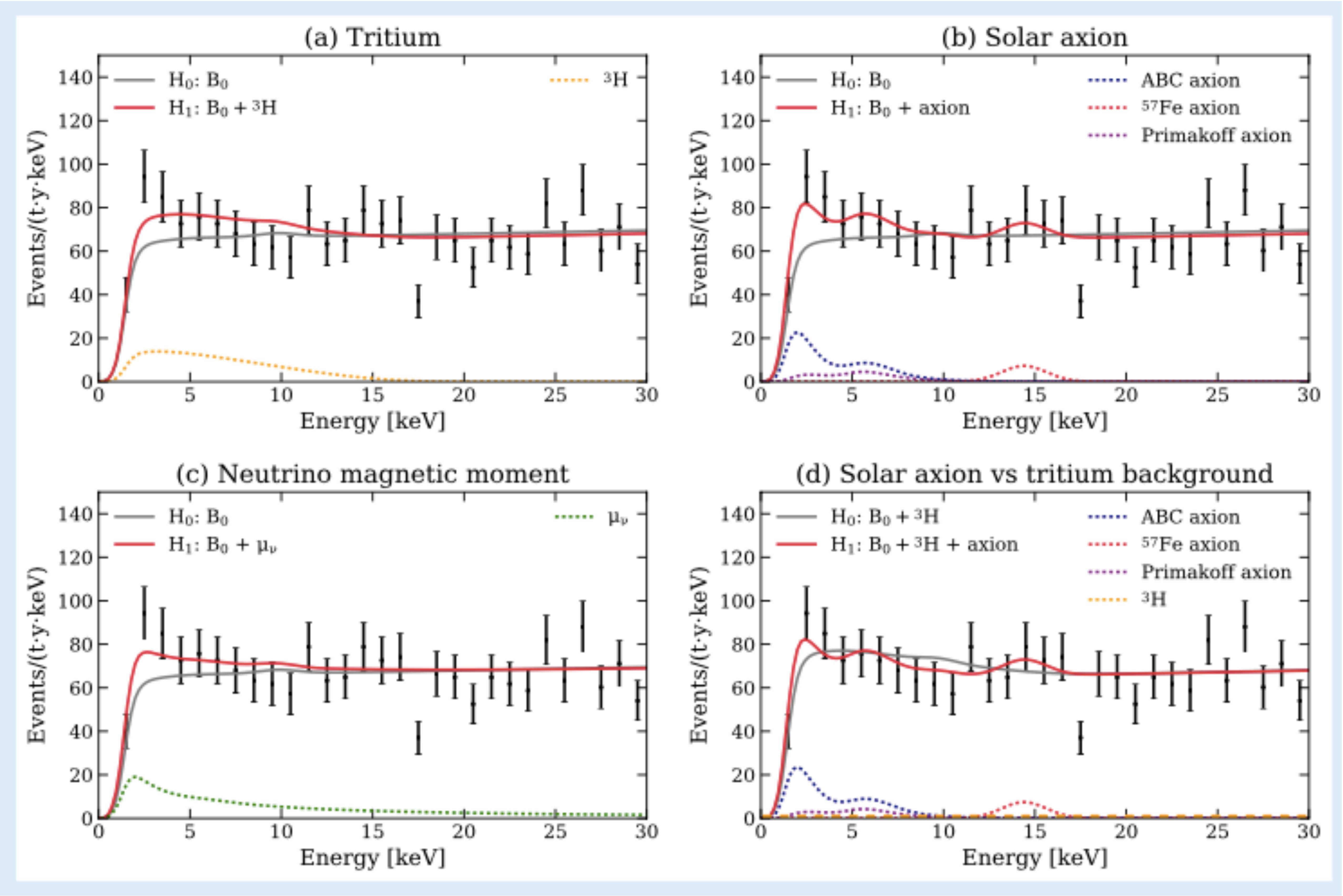
Cuautitlán Izcalli, Edo. Mex., 2023

# XENON1T Electron recoil data

ArXiv:2006.09721



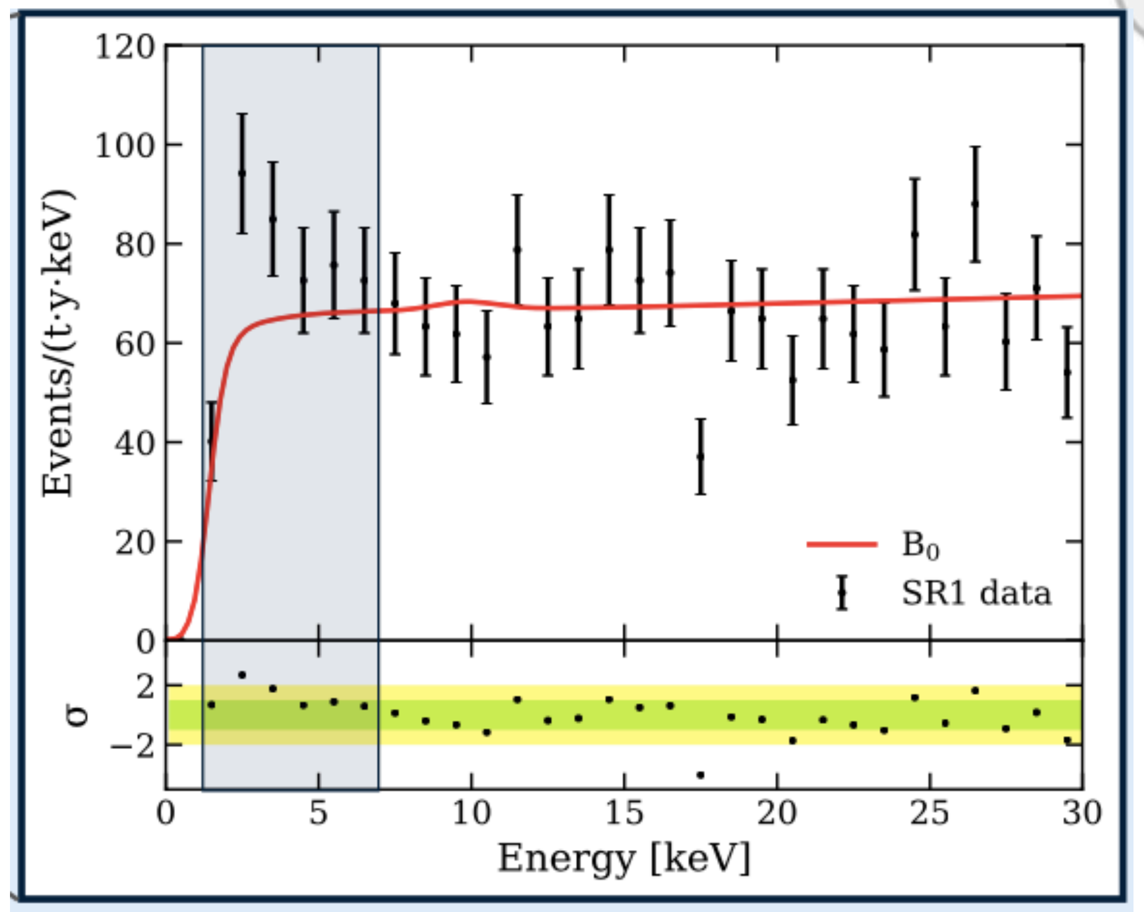


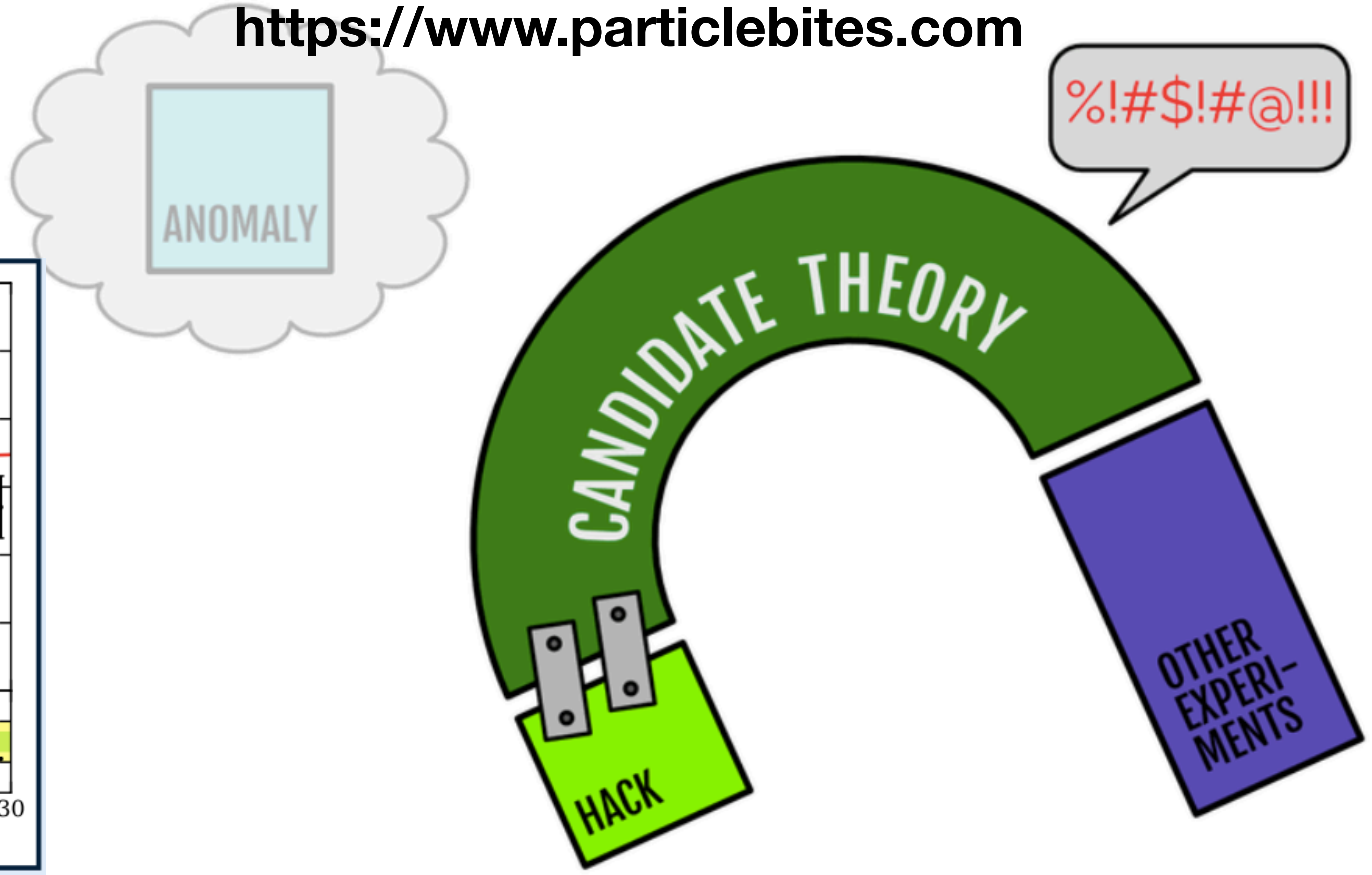


Axions: Discrepancy with astrophysical constraints from stellar cooling *(arXiv:2003.01100)*

# Some anomalies tend to go away

- Tritium backgrounds
- Neutrino Magnetic Moment
- Neutrino NSI
- Vector or scalar mediators
- Neutrino self interactions
- Mirror dark matter
- U(1) , U(1)_{B-L}, Z’
- SU(2)$_H$ horizontal symmetry
- and many more……….





https://www.particlebites.com

*Sometimes anomalies go away and the models built to explain them don’t hold together.*

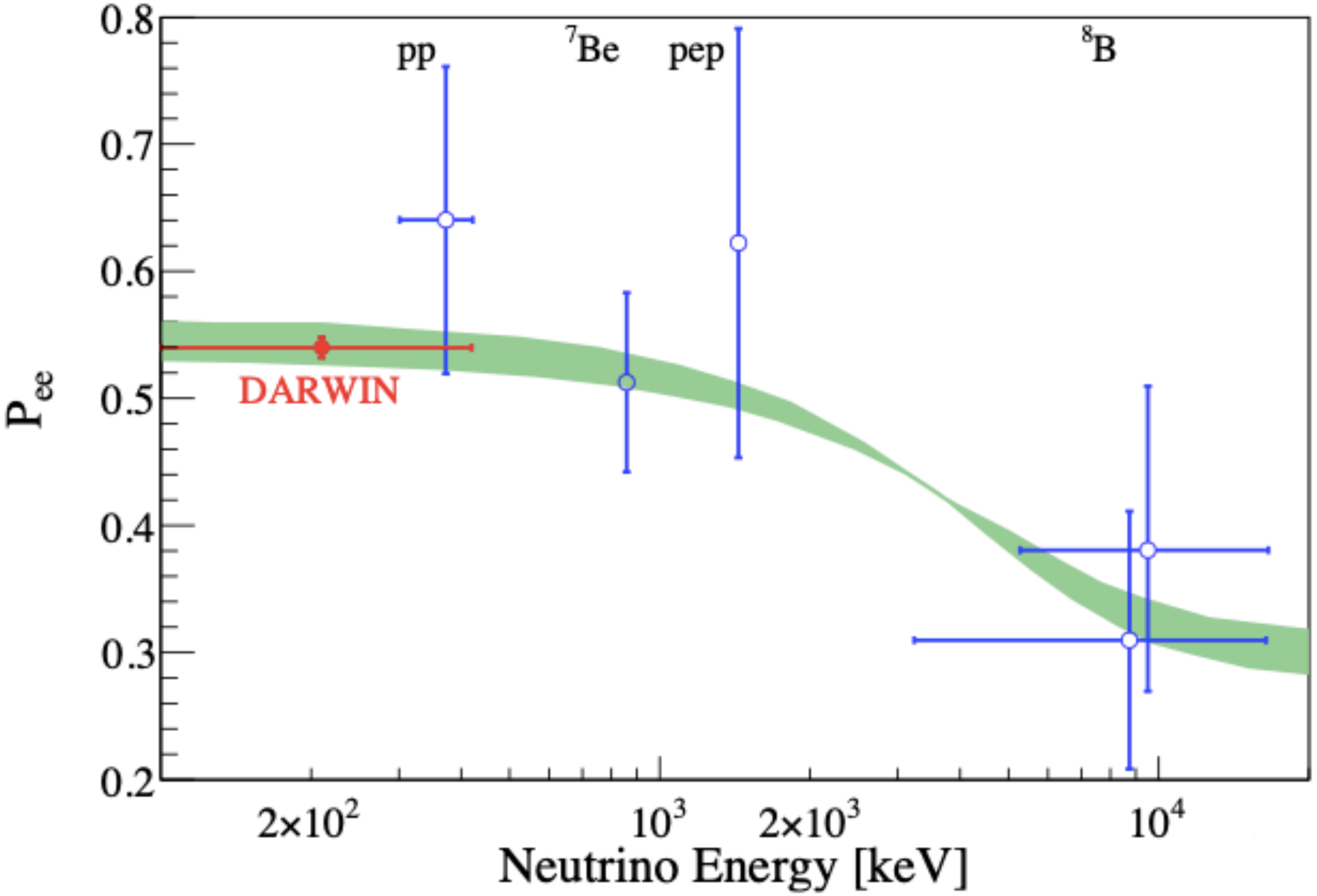
# BSM neutrino physics

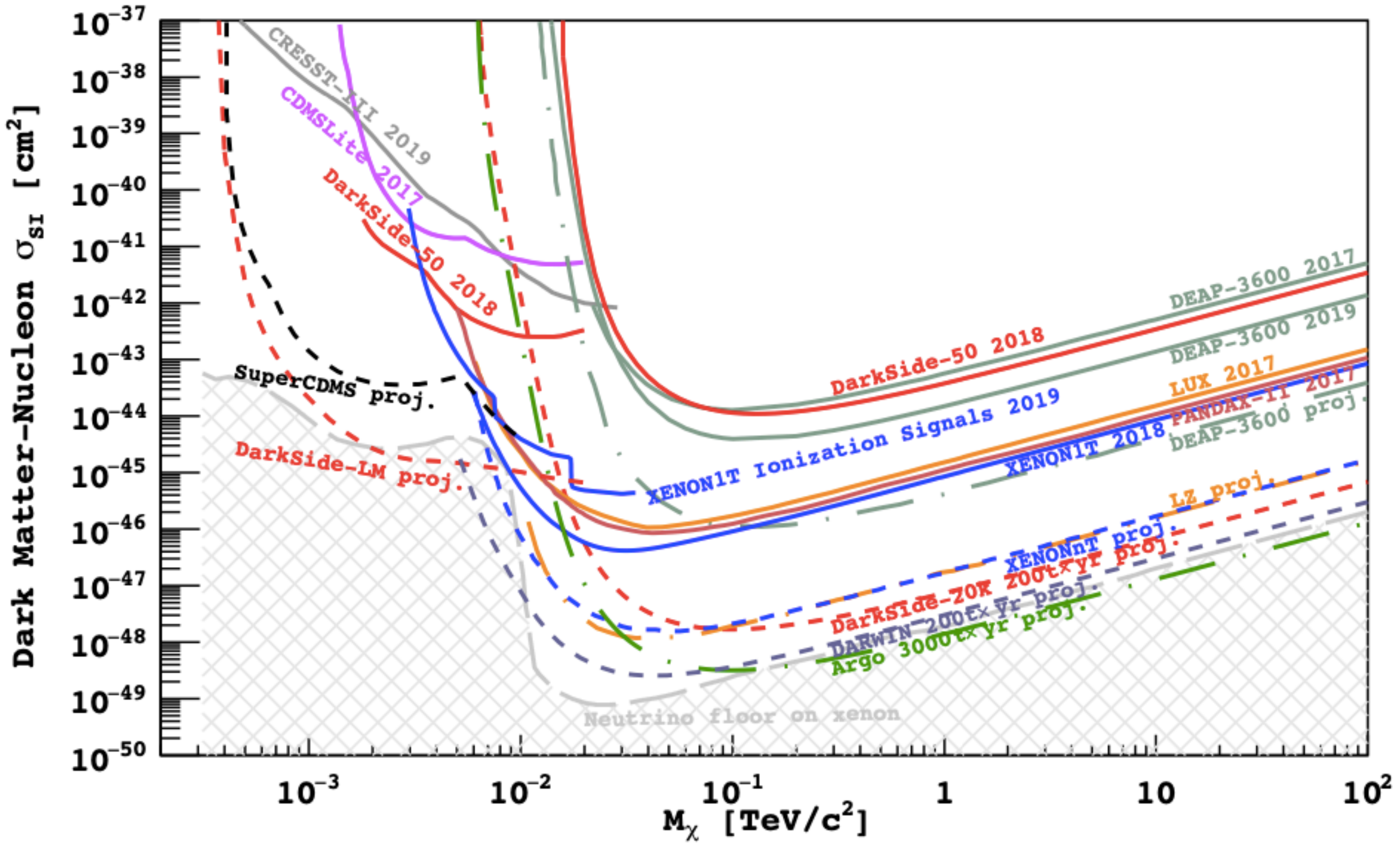
- Oscillation parameter precision input for Flavor models
- Neutrino near detectors for beam dump type experiments
- New physics searches in existing and upcoming data
- Many opportunities for model building and phenomenological tests

# Neutrino physics potential of future DD DM

- Neutrino - electron scattering of solar neutrinos
- Coherent Elastic Neutrino Nucleus Scattering
- Neutrinoless double beta decay
- Sterile neutrino searches in the beta decay spectrum
- Potential to observe Geoneutrinos
- Will benefit of the progress made by xsections experiments (Minerva, Nova, T2K, Coherent.)

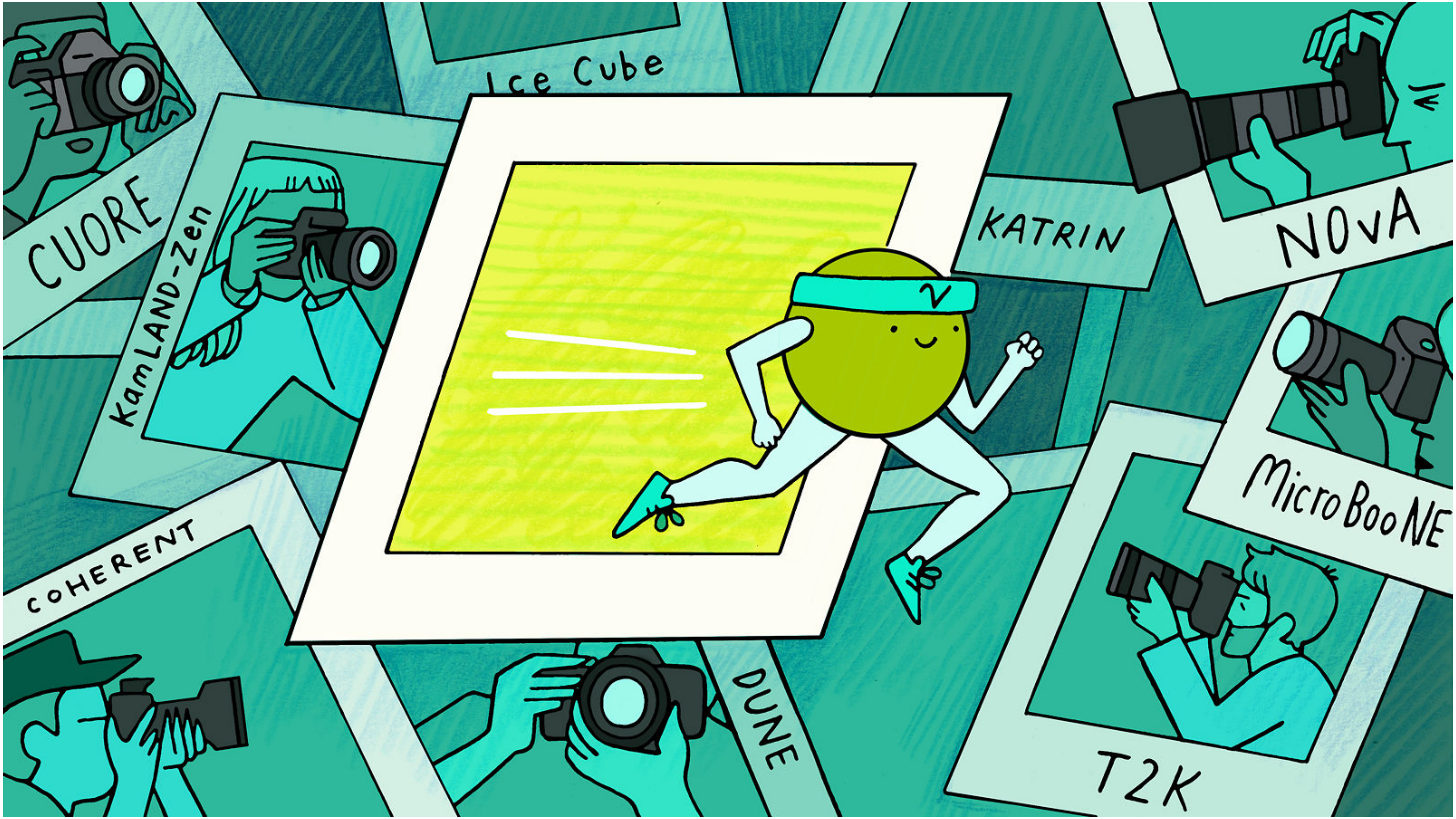
# Future DD DM experiments





# Summary

- Future accelerator and reactor Long Baseline experiments, joining a growing ensemble of experiments, the 3nu paradigm.
- Current and future reactor and accelerator-neutrino experiments will provide an indispensable input for understanding neutrino physics.
- CEvNS Coherent Elastic Neutrino Nucleus Scattering, from theoretical predictions to first observation, to studying new interactions.
- Dark Matter detectors might become the neutrino observatories of the future.


Ice Cube
CUORE
KamLAND-Zen
KATRIN
NOvA
ν
MicroBooNE
COHERENT
DUNE
T2K

# XXXIV Reunión Anual de la División de Partículas y Campos de la SMF

9-10 July 2020
Mexico City
Mexico/General timezone

# Reactor antineutrino anomaly

G. MENTION *et al.* PHYSICAL REVIEW D **83,** 073006 (2011)

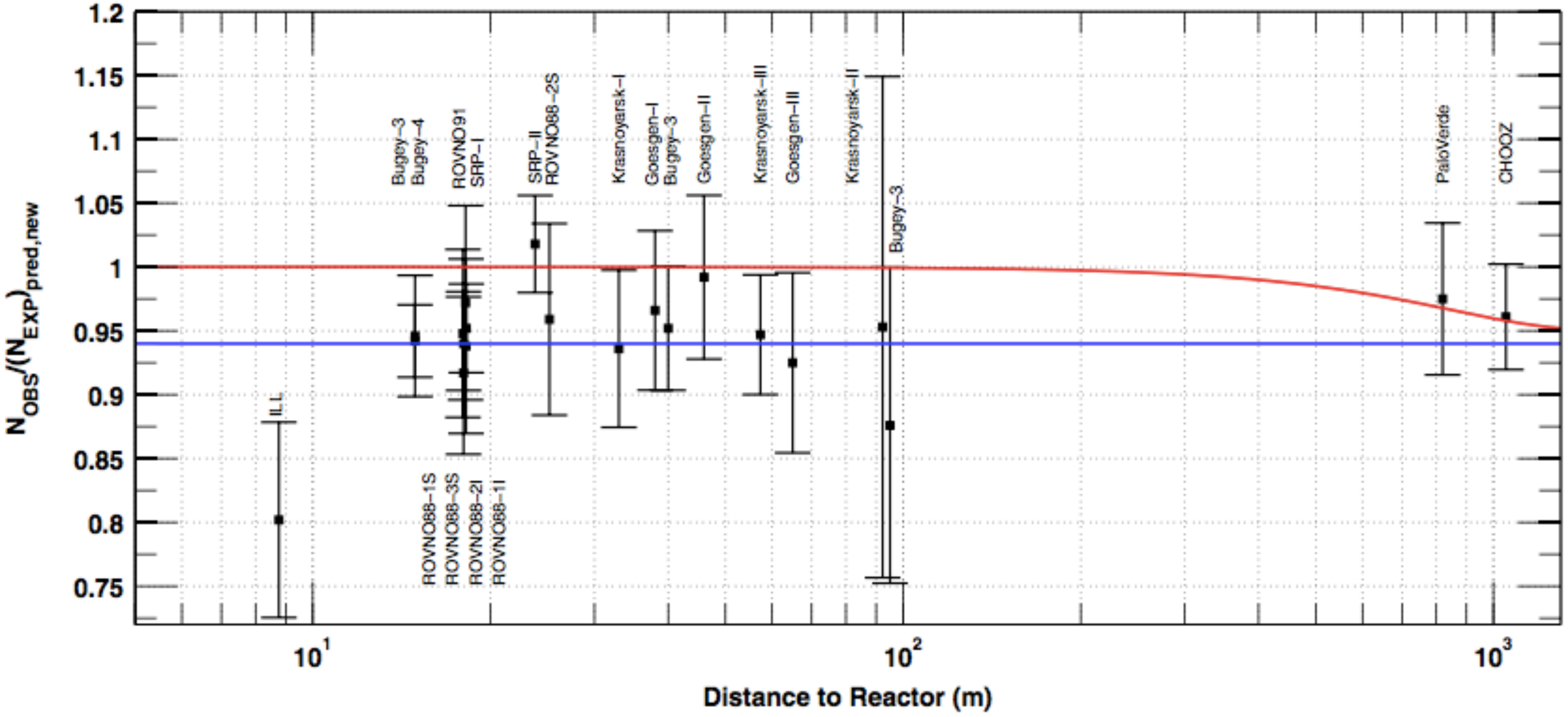
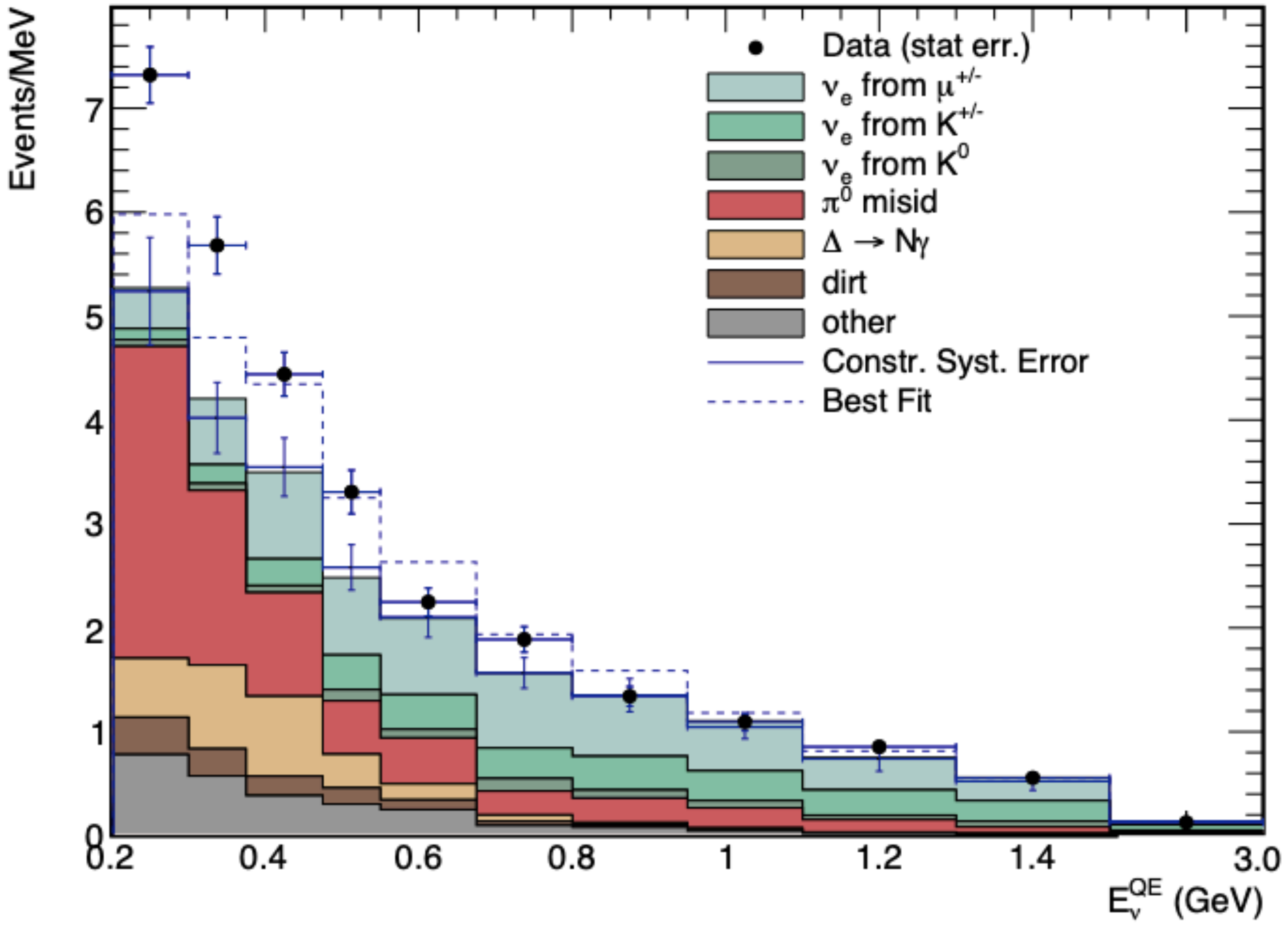
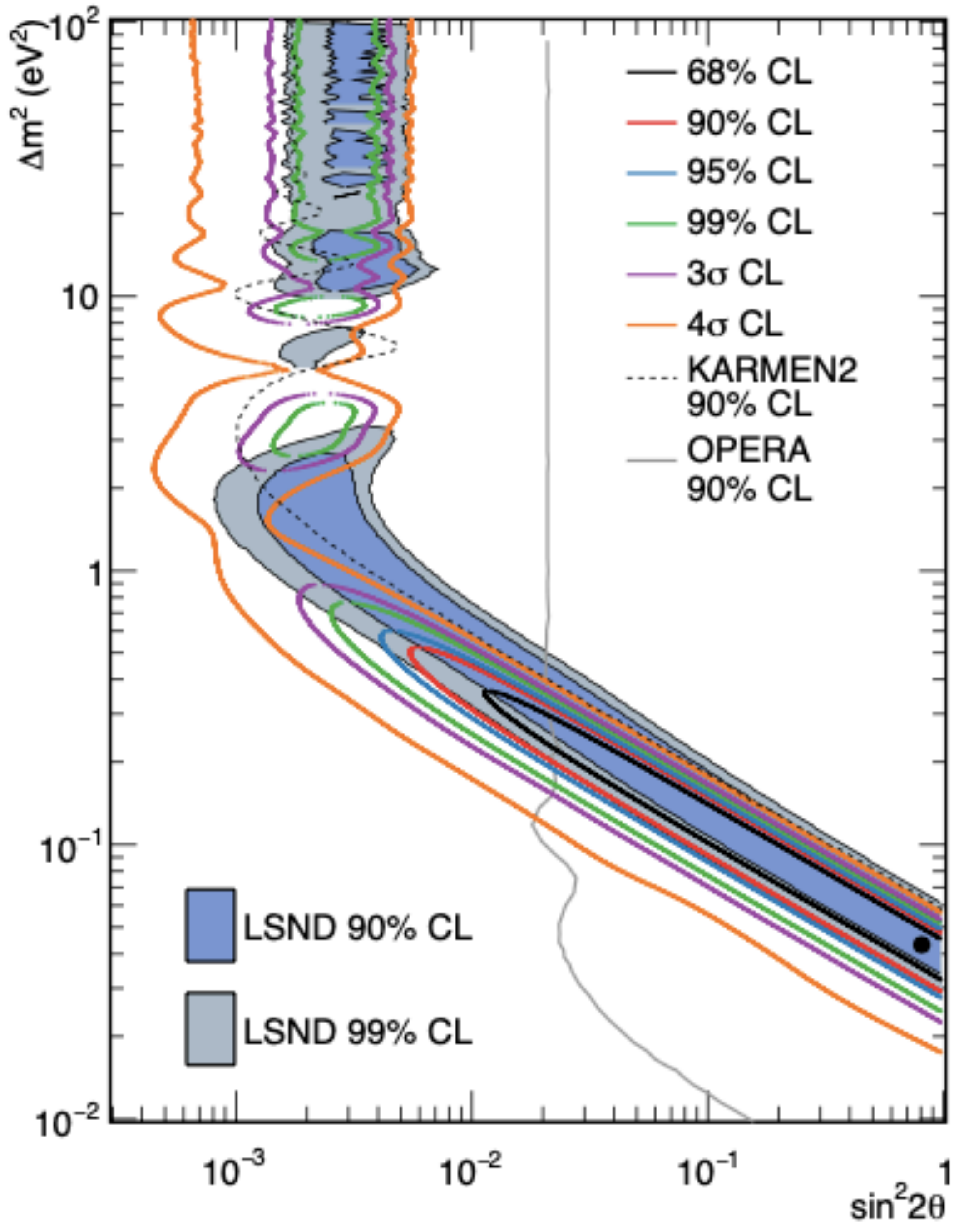
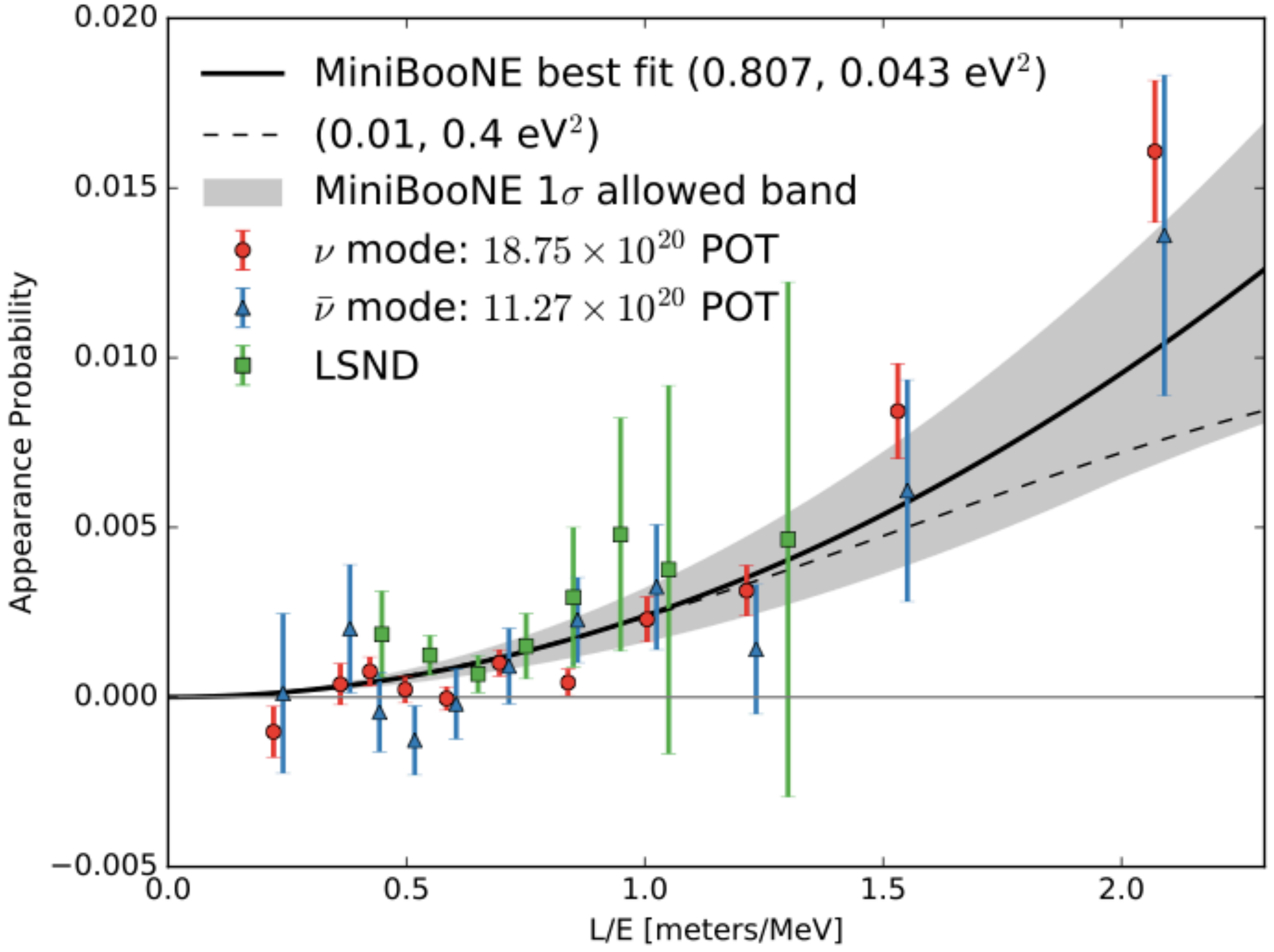


FIG. 5 (color online). Illustration of the short baseline reactor antineutrino anomaly. The experimental results are compared to the prediction without oscillation, taking into account the new antineutrino spectra, the corrections of the neutron mean lifetime, and the off-equilibrium effects. Published experimental errors and antineutrino spectra errors are added in quadrature. The mean averaged ratio including possible correlations is $0.943 \pm 0.023$. The red line shows a possible three-active neutrino mixing solution, with $\sin^2(2\theta_{13}) = 0.06$. The blue line displays a solution including a new neutrino mass state, such as $|\Delta m^2_{\mathrm{new,R}}| \gg 1\ \mathrm{eV}^2$ and $\sin^2(2\theta_{\mathrm{new,R}}) = 0.12$ (for illustration purpose only).

# MiniBoone (After neutrino 2020)

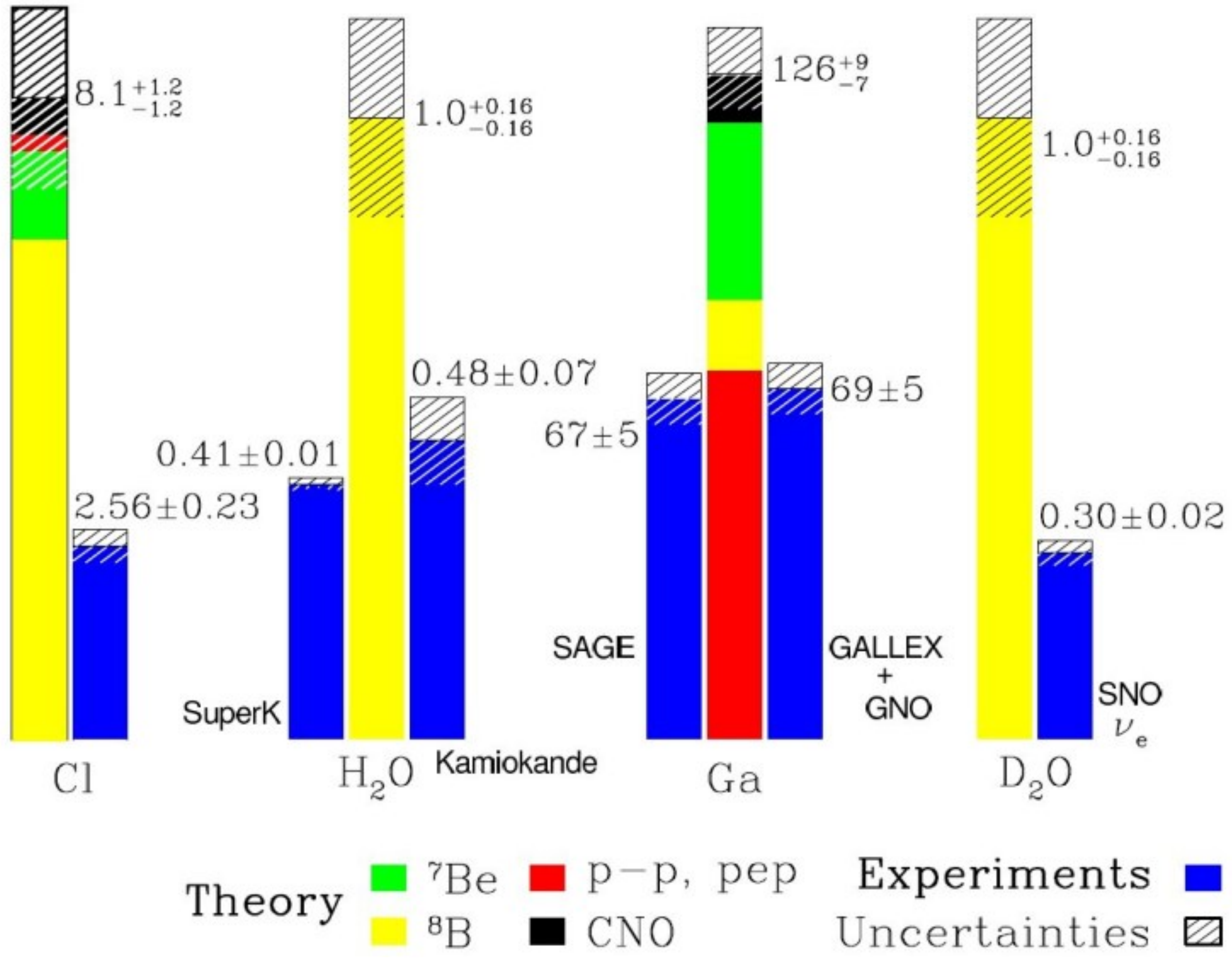






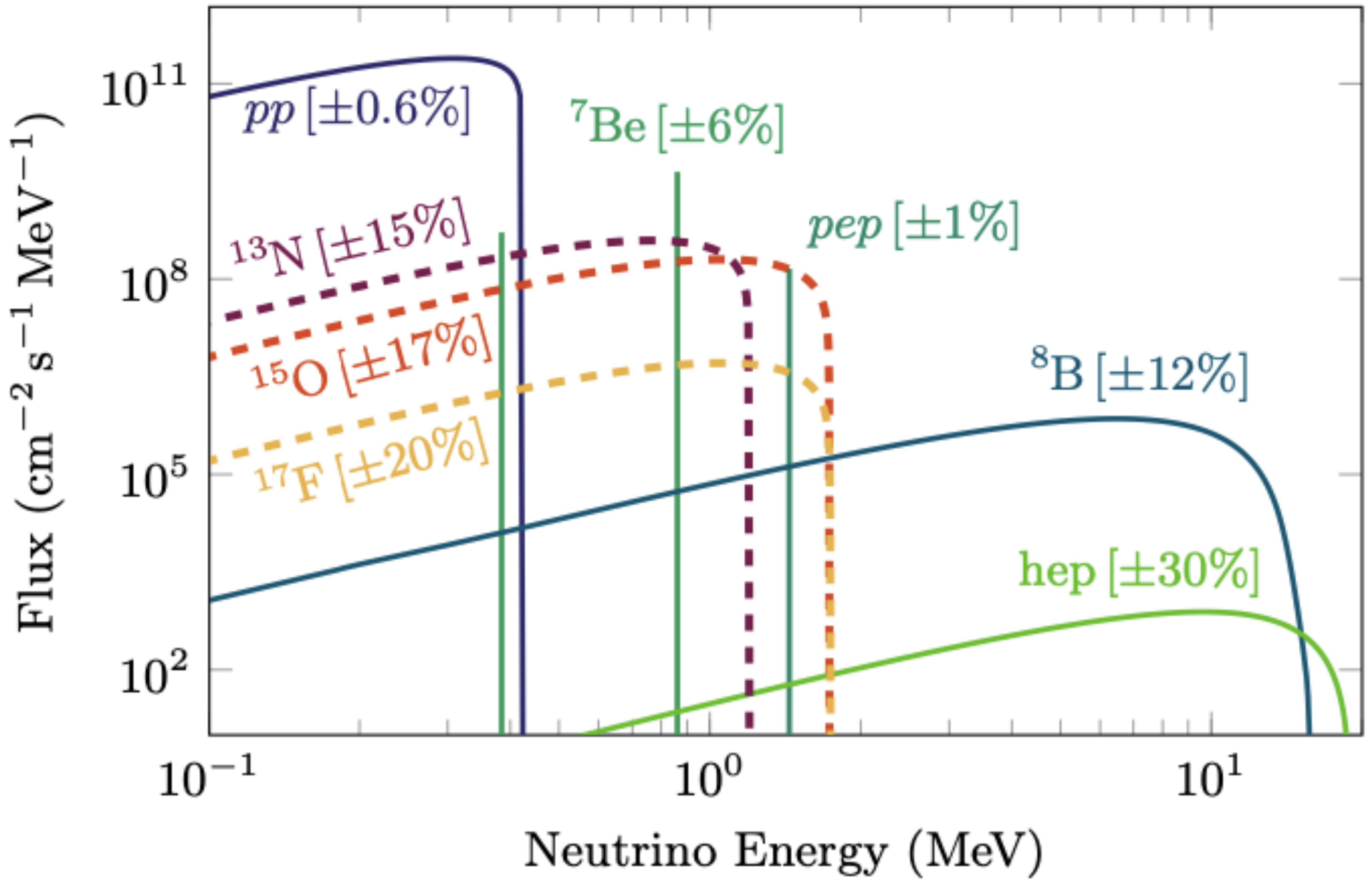
**ArXiv:2006.16883**

# Neutrinos from the sun



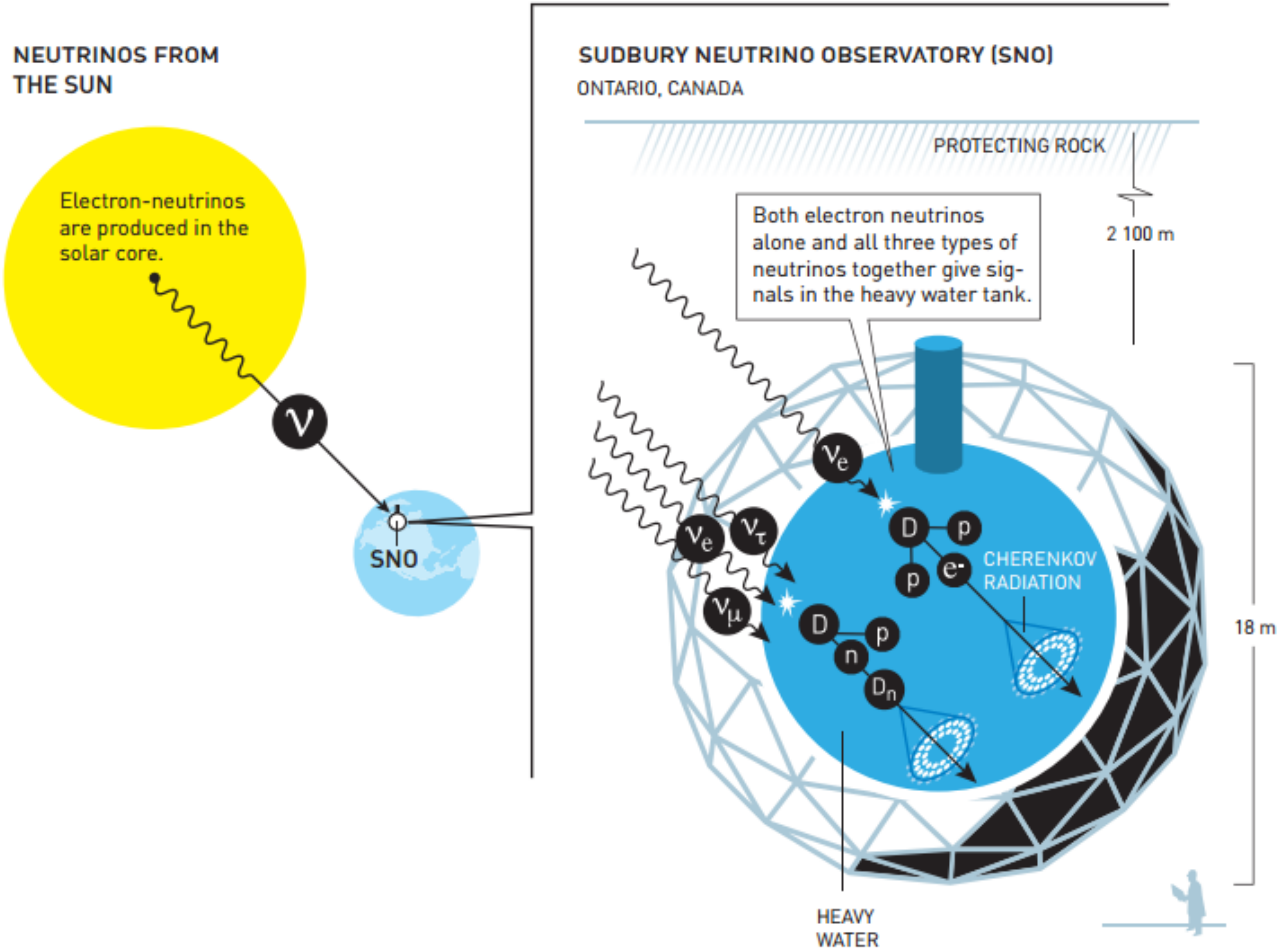
**J, Bahcall 2004**

1. Astrophys. J. 835, 2, 202 (2017)



*If I had not lived through the solar neutrino saga, I would not have believed it was possible. John N. Bahcall*

# Experimento SNO
# Sudbury Neutrino Observatory



# TRINO: A Neutrino Experiment in México

Investigador responsable: EVJ (IFUNAM)

TRIGA MARK III @ 3m

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

**AV 100kg Scintillator 0.2% Gd**
**SiPMs**
**To be upgraded to 500kg**

3 Postdocs and 5 graduate students (4 PhD)

# CONNIE Light vector mediator searches

(A. Aguilar-Arevalo et. al. *JHEP* 04 (2020) 054 )

**USING DATA!**

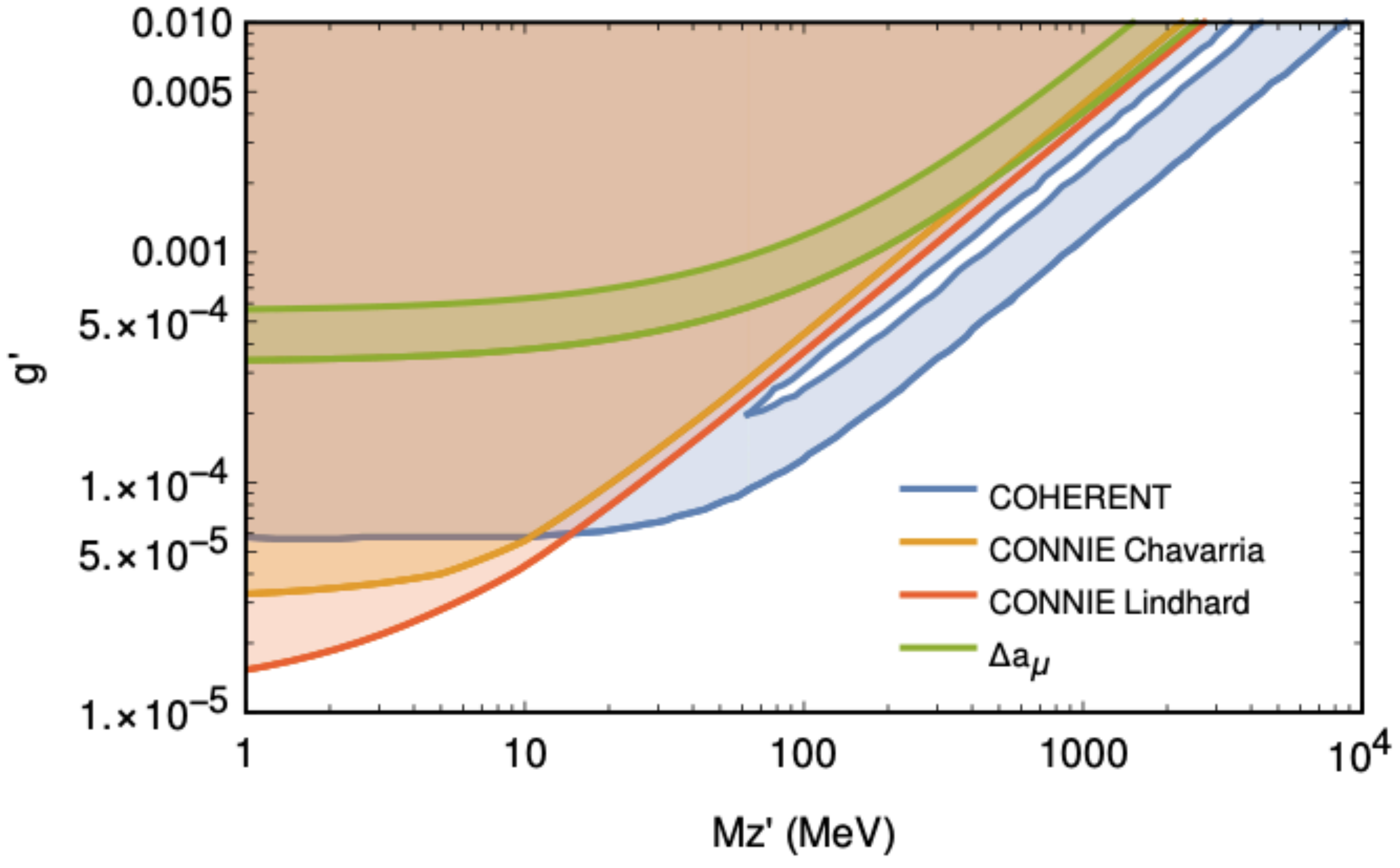


**Figure 2.** Exclusion region in the $(M_{Z'}, g')$ plane from the CONNIE results assuming quenching given by the fit to the measurements in Ref. [25] (orange) and the expressions in Ref. [26] (red). The COHERENT limit curve [5] (blue) and the $2\sigma$ allowed region to explain the anomalous magnetic moment of the muon ($\Delta a_\mu = 268 \pm 63 \times 10^{-11}$) [27, 28] (green) are shown for reference.

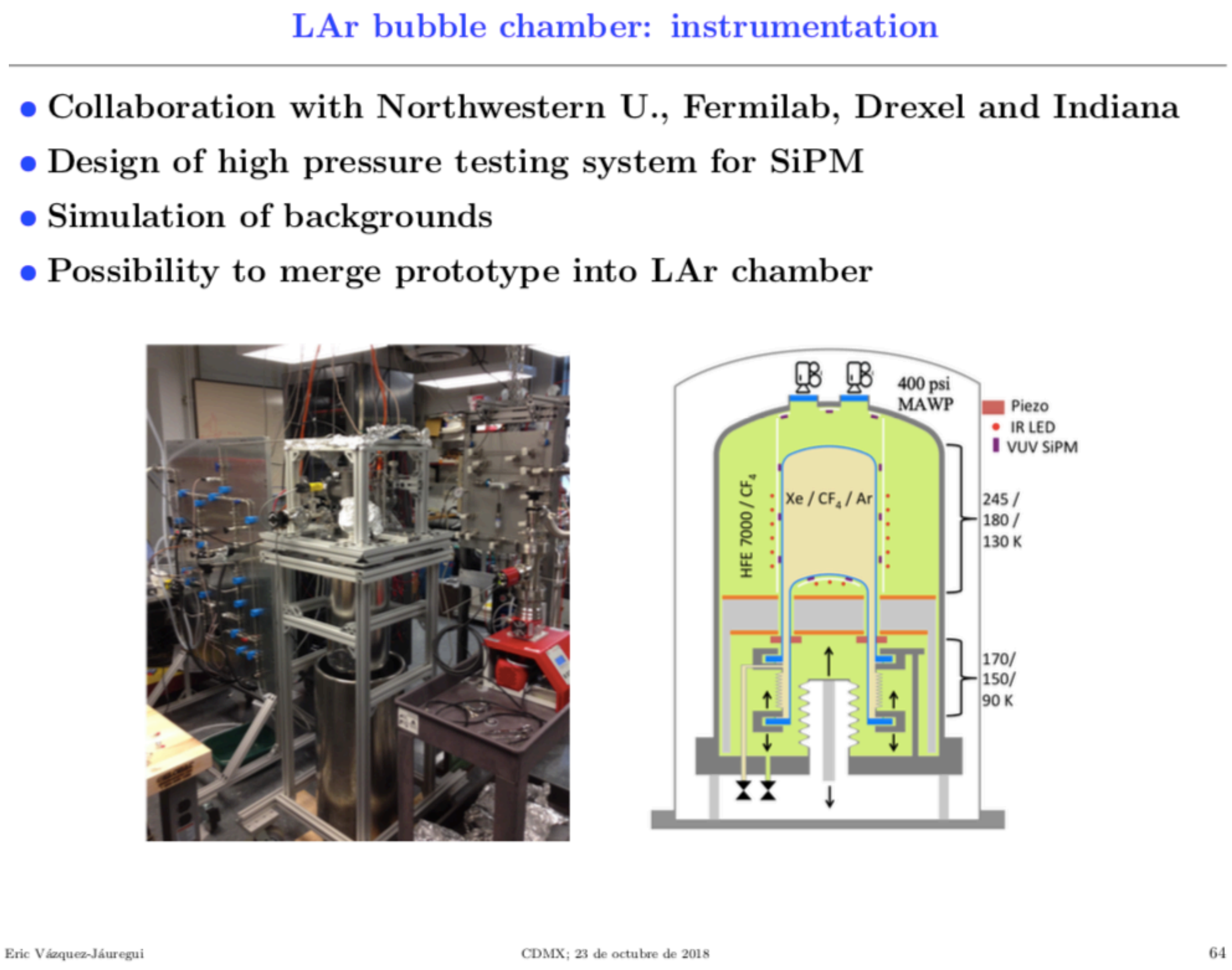
$$\frac{d\sigma_{LM}}{dE_R}(E_{\bar{\nu}_e}) = \left(\frac{Q_{LM}}{Q_W}\right)^2 \frac{d\sigma_{SM}}{dE_R}(E_{\bar{\nu}_e}) \ ,$$

$$Q_{LM} = Q_W - f_{LM}(E_R)\,(N+Z) \ ,$$

$$f_{LM}\left(E_R\right) = \frac{3g'^2}{\sqrt{2}G_F\left(2ME_R + M_{Z'}^2\right)} \ .$$

# SBC Scintillating Bubble Chamber

Instituto de Física
UNAM



## LAr bubble chamber: instrumentation

- Collaboration with Northwestern U., Fermilab, Drexel and Indiana
- Design of high pressure testing system for SiPM
- Simulation of backgrounds
- Possibility to merge prototype into LAr chamber

Eric Vázquez-Jáuregui CDMX; 23 de octubre de 2018 64

**Scintillating Bubble Chamber Collaboration**
@SBCcollab

We build bubble chambers that also scintillate. It's pretty cool. Cryogenic, technically.
~WIMPS & Neutrinos ~

Joined March 2020

**11** Following **18** Followers

Followed by McDonald Institute, SNOLAB, and Pietro Giampa