NEUTRINO HUNTERS AROUND THE WORLD

Zara Bagdasarian

AUGUST 21 2018 I GEORGIAN-GERMAN SCHOOL AND WORKSHOP IN BASIC SCIENCE

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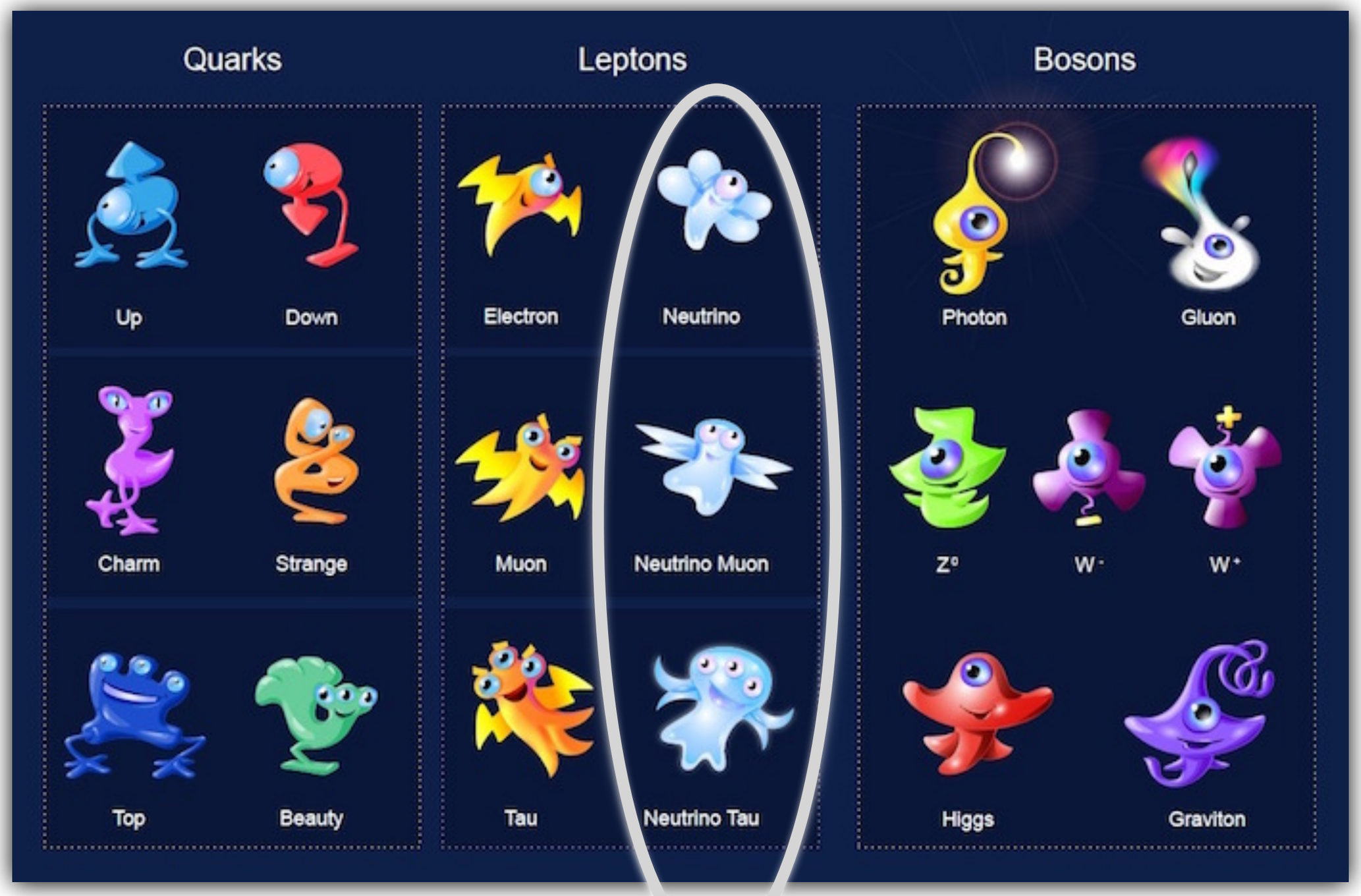
@ZaraBagdasarian

Mitglied der Helmholtz-Gemeinschaft

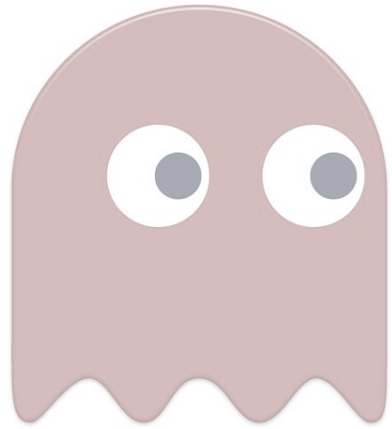
JÜLICH Forschungszentrum

NEUTRINOS IN THE STANDARD MODEL



- And beyond

MEET NEUTRINOS



- No electric charge -> no electro-magnetic interaction
- No color -> no strong interactions
- Weak interaction -> very very small cross sections of interactions with matter

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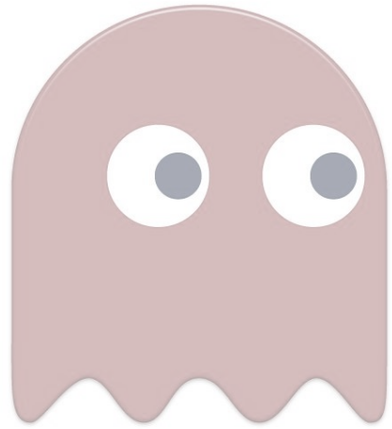

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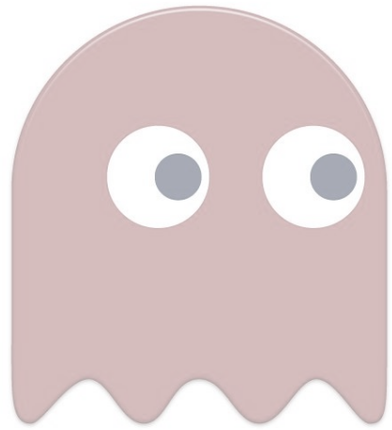

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- Tiny masses (0.04 eV < m < ≈ 1 eV)
- Three flavours
- Changing flavours, aka oscillating

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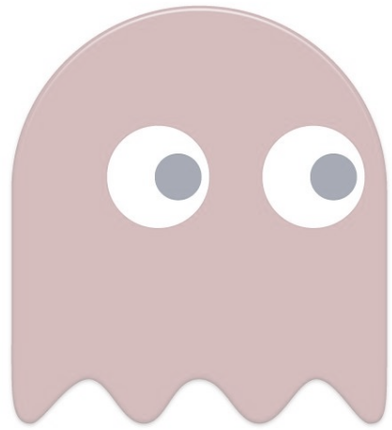

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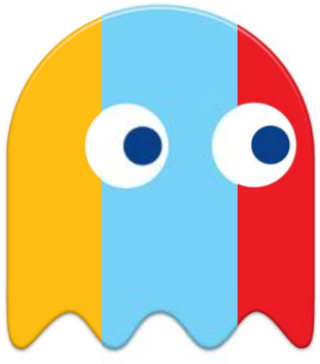

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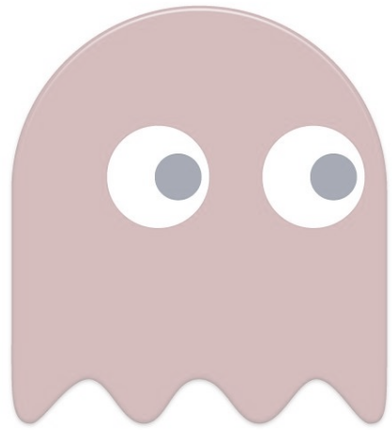

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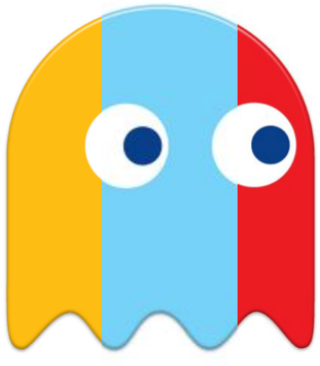
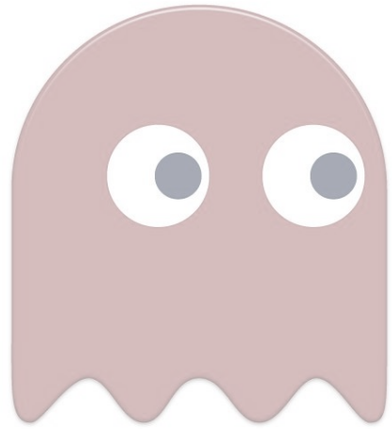


Ghost particles full of mysteries and surprises

MEET NEUTRINOS



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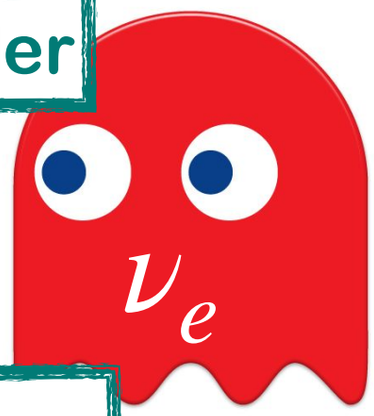
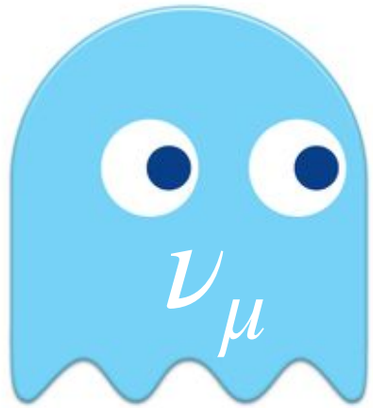
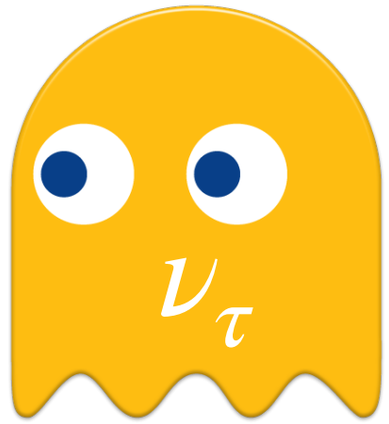
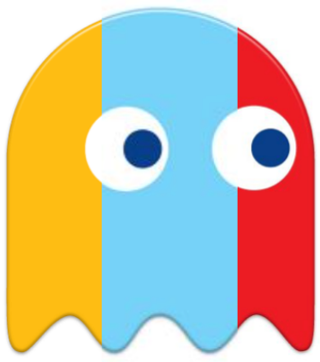
Often referred to as ghost particles

- Tiny masses **exact values and order**
- Three flavours **Or more?**
- Changing flavours, aka oscillating **Exact oscillation parameters**



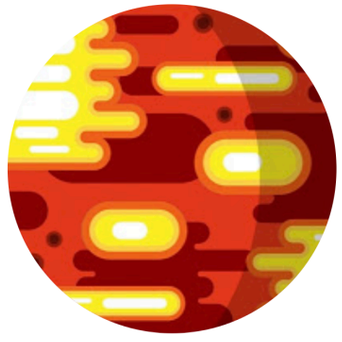


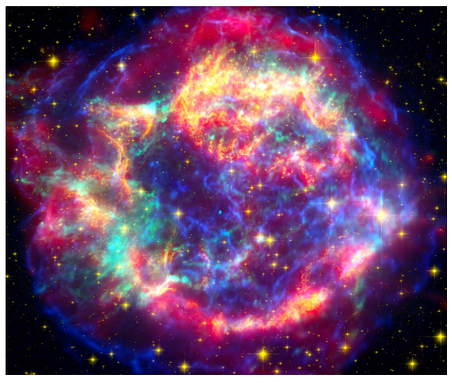
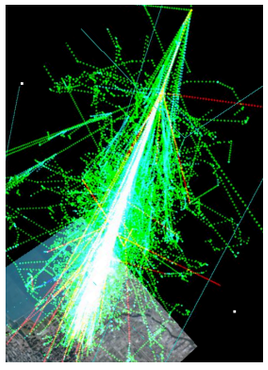




Ghost particles full of mysteries and surprises

NEUTRINO SOURCES

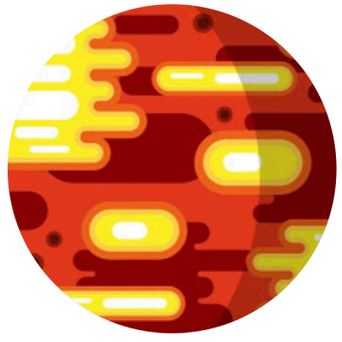



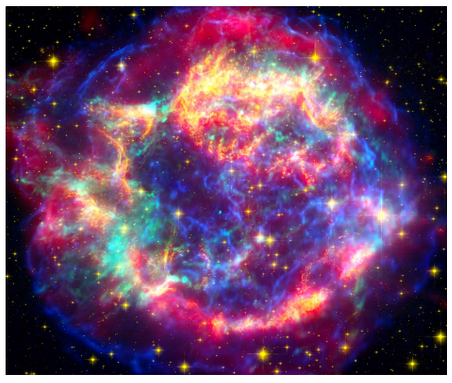
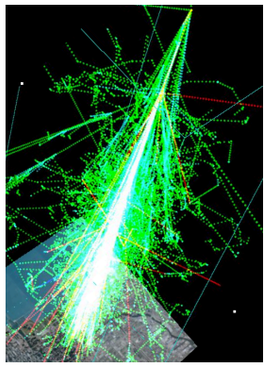
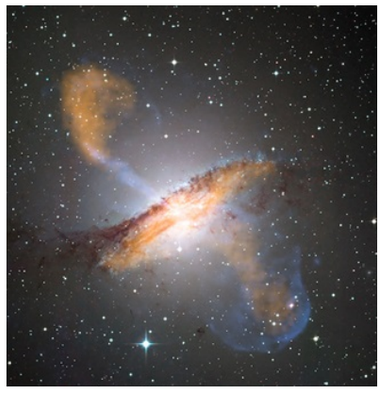

keV MeV GeV TeV

Direct information from the source

Pictures adapted from NASA, Kurzgesagt, the Royal Institution and University of Chicago

NEUTRINO SOURCES

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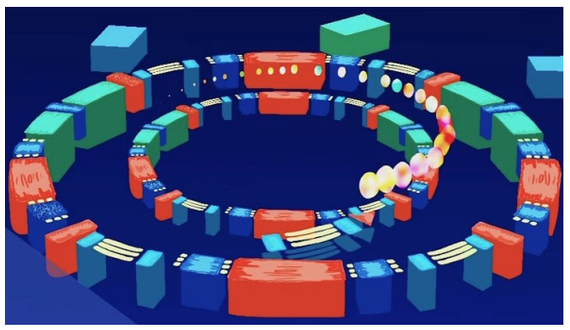
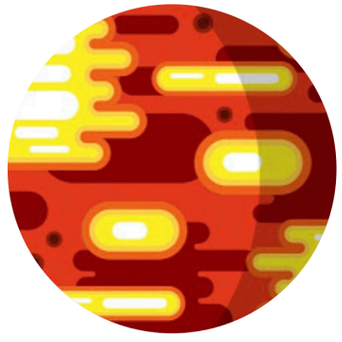


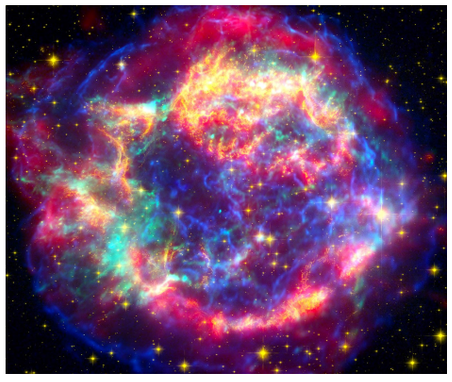
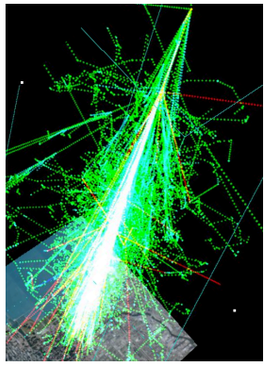
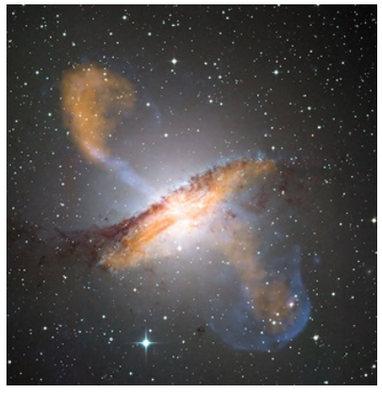
Direct information from the source

Better understanding of neutrino nature

Pictures adapted from NASA, Kurzgesagt, the Royal Institution and University of Chicago

NEUTRINO SOURCES

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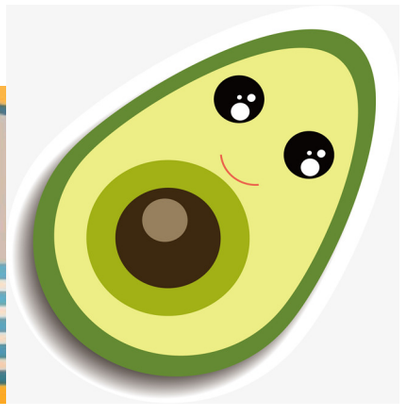
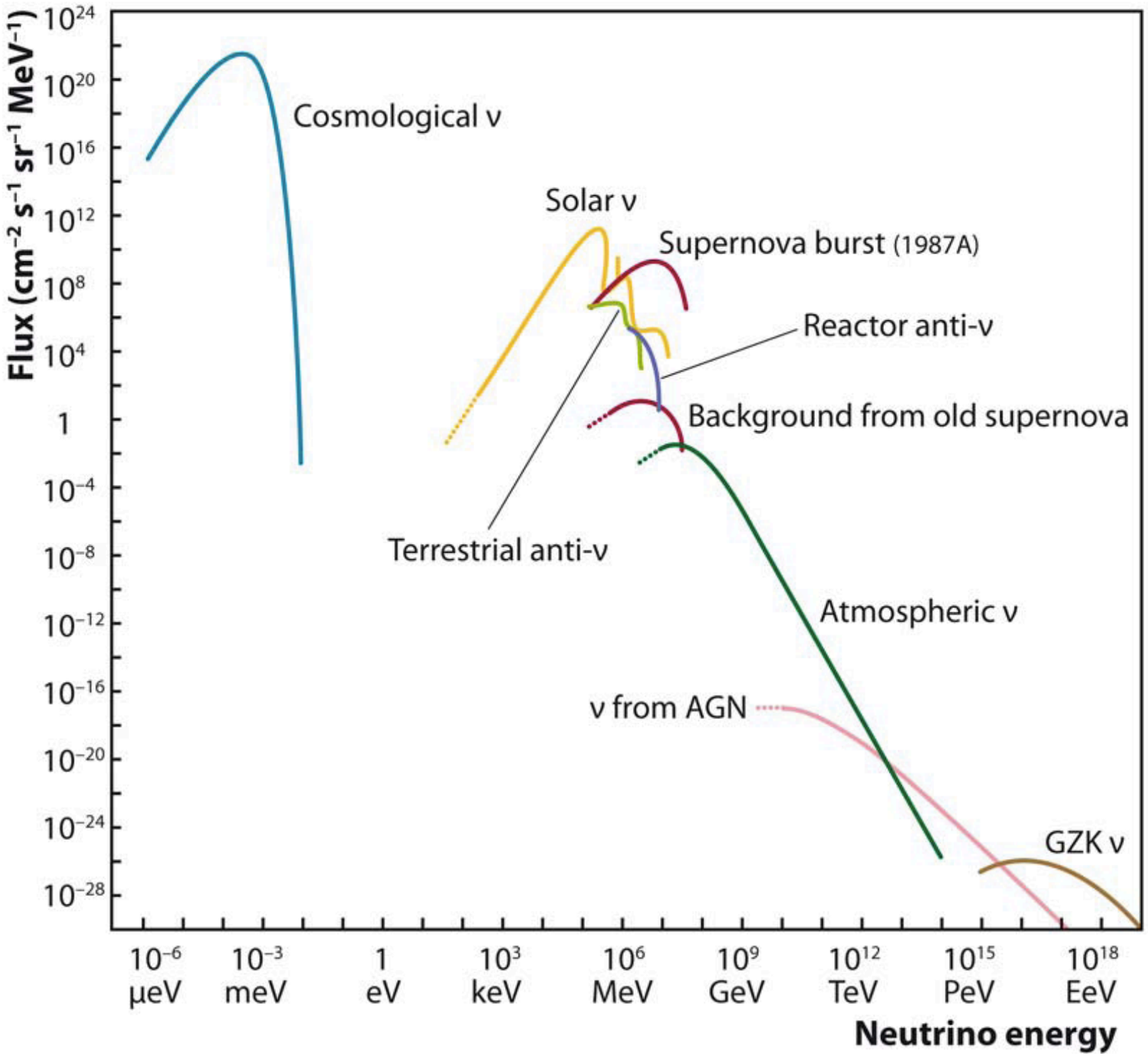


Caution! Cute babies radiating in neutrinos

Pictures adapted from NASA, Kurzgesagt, the Royal Institution and University of Chicago

NEUTRINO SOURCES



A BIT OF HISTORY

Year 1930

Original - Photocopie of PLC 0393

Abschrift/15.12.[illegible] PW

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

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Des. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

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

Source: Perimeter Institue

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Let's call it "neutron"

A BIT OF HISTORY

Year 1930

Year 1932 James Chadwick

Discovered a neutral particle. Calling dips on "neutron"!

Let's call it "neutron"

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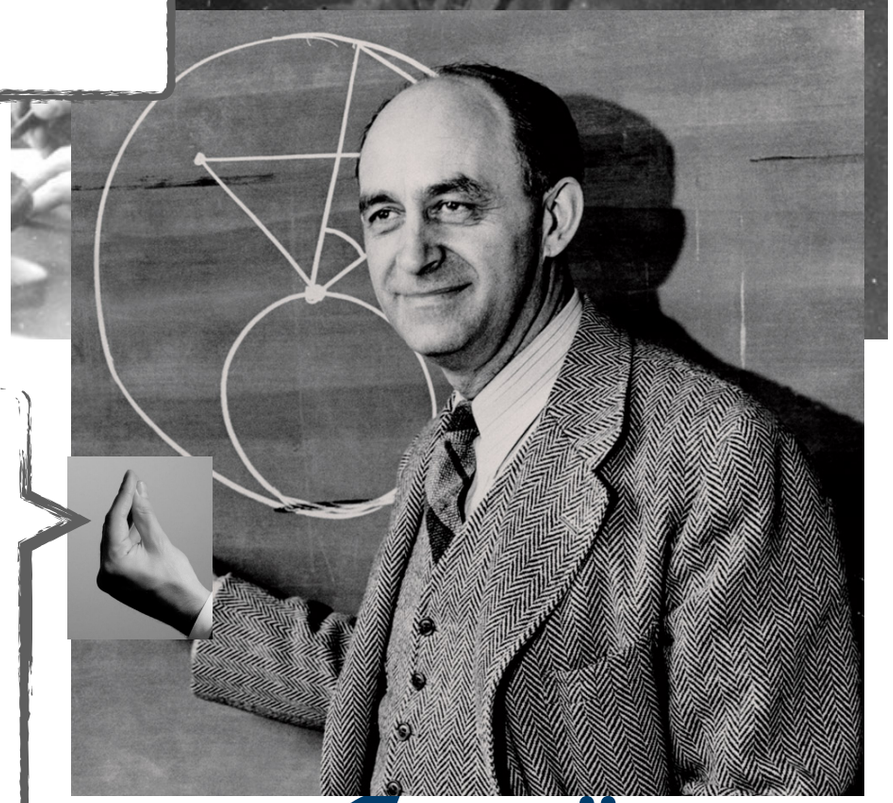
Let's call it "neutron"

Let's call this one "neutrino"



Year 1934

A BIT OF HISTORY

Year 1930

Original - Photocopie of PLC 0393

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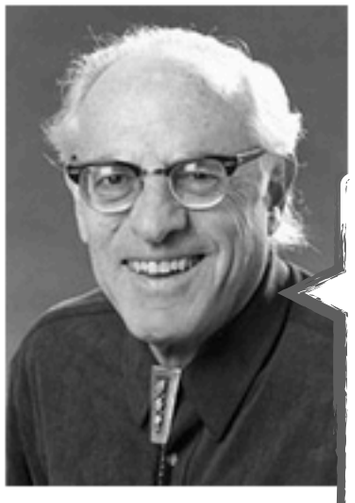
"I have done a terrible thing. I have postulated a particle that cannot be detected"

DETECTION OF THE NEUTRINO

Everybody: "Nobody can do it!"

Cowan and Reines:

Challenge accepted!



Telegram Pauli!

Detecting the Poltergeist

Hanford Team 1953

Year 1956

NEUTRINOS AND NOBEL PRIZES

DETECTION OF THE ~~NEUTRINO~~

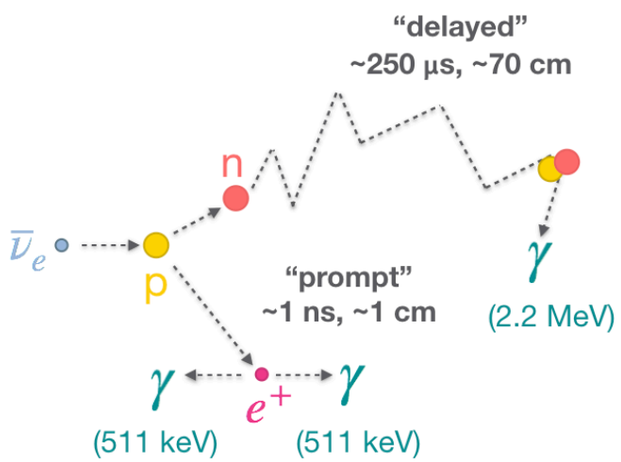
- **Nobel Prize in Physics 1995**

© University of California Regents

Frederick Reines

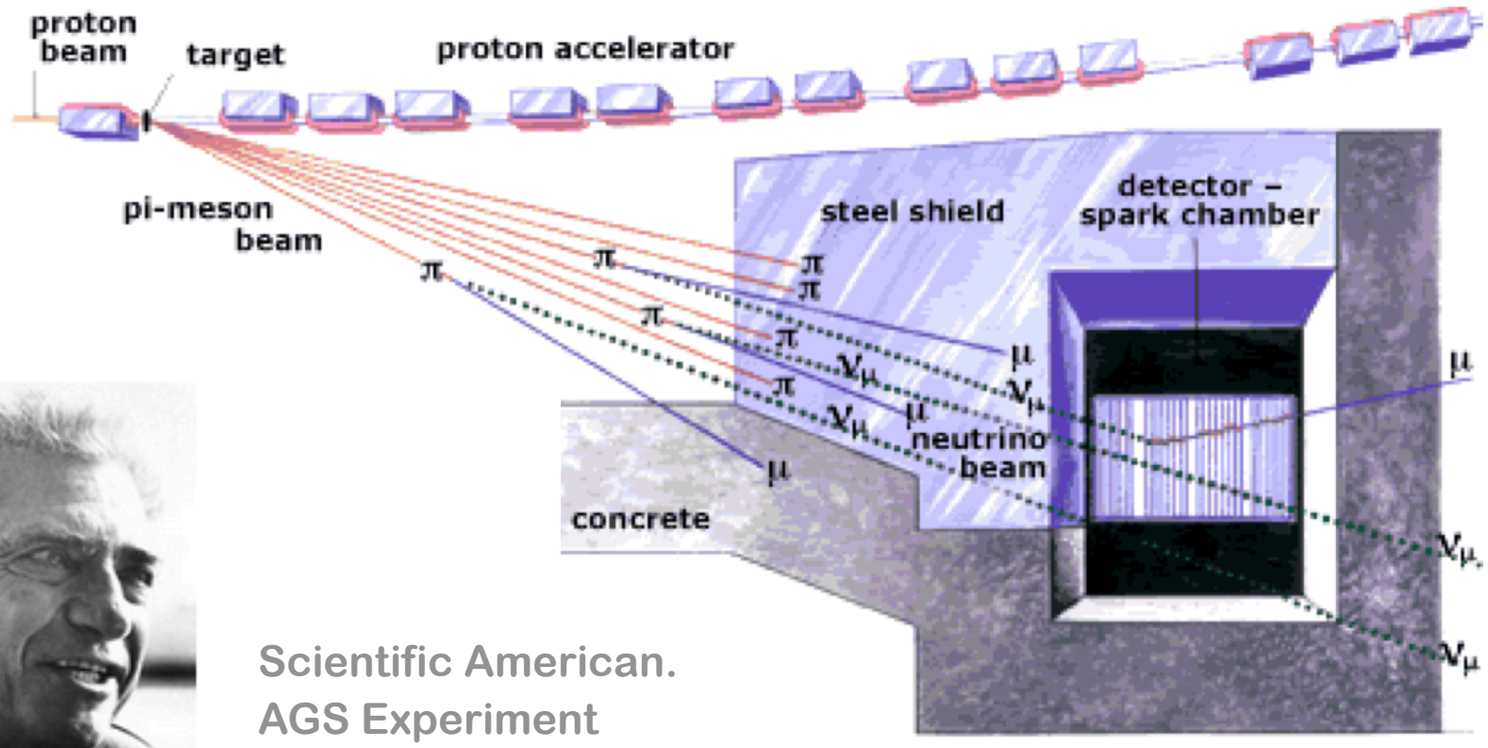
Prize share: 1/2

DETECTION OF THE ANTI-NEUTRINO



DETECTION OF THE MUON NEUTRINO

Beam (tamed) neutrinos
Muon neutrinos ≠ electron neutrinos

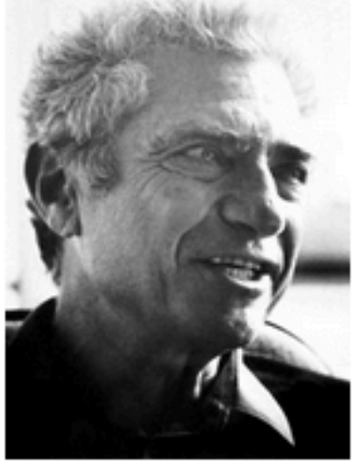


Scientific American.
AGS Experiment

- **Nobel Prize in Physics 1988**

Leon M. Lederman
Prize share: 1/3

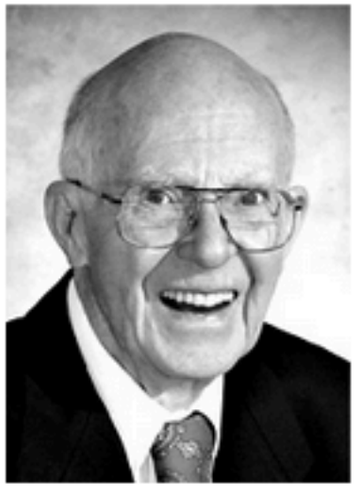
Melvin Schwartz
Prize share: 1/3



Jack Steinberger
Prize share: 1/3

The Nobel Prize in Physics 1988 was awarded jointly to Leon M. Lederman, Melvin Schwartz and Jack Steinberger *"for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino"*.

DETECTION OF THE COSMIC NEUTRINOS



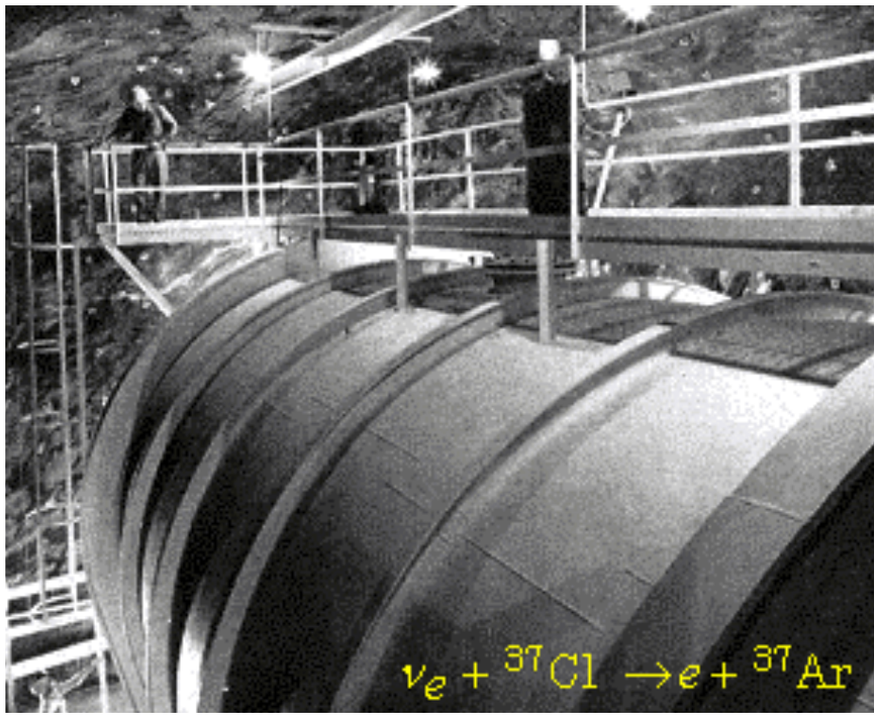
Raymond Davis Jr.
Prize share: 1/4

Masatoshi Koshiba
Prize share: 1/4

- **Nobel Prize in Physics 2002:**

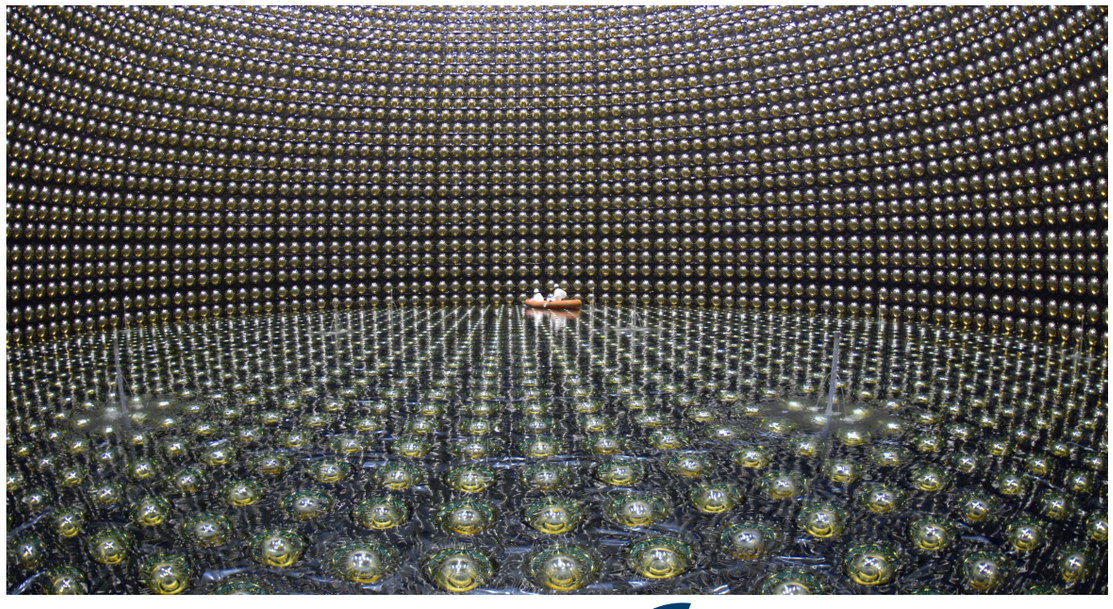
Pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos

Radiochemical detection of solar-ν



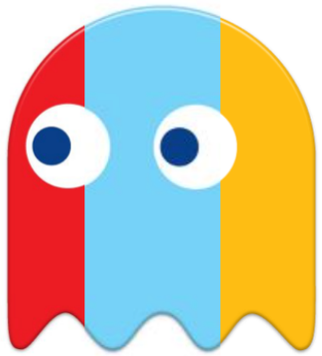
(Homestake)

Water Cherenkov detection of atmospheric -ν



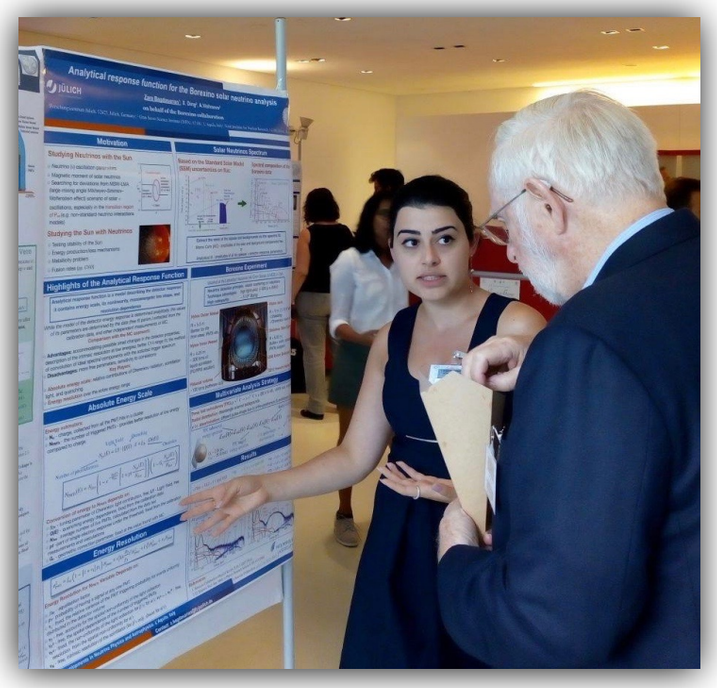
(Super-Kamiokande)

DISCOVERY OF NEUTRINO OSCILLATIONS



- **Nobel Prize in Physics 2015:**
  Discovery of neutrino oscillations

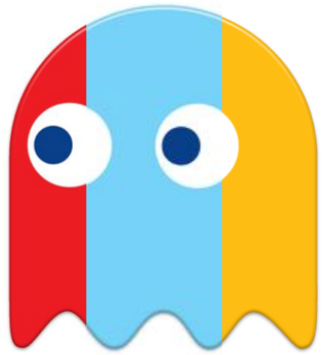
Takaaki Kajita (Super-K)



Arthur McDonald (SNO)

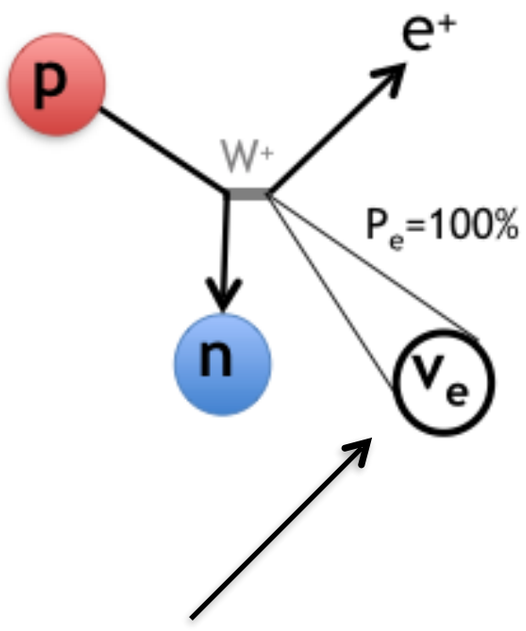
Credit: Lindau Nobel Laureate Meeting

NEUTRINO OSCILLATIONS



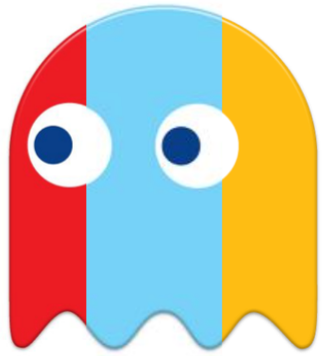
ν production

e.g. β⁺-decay



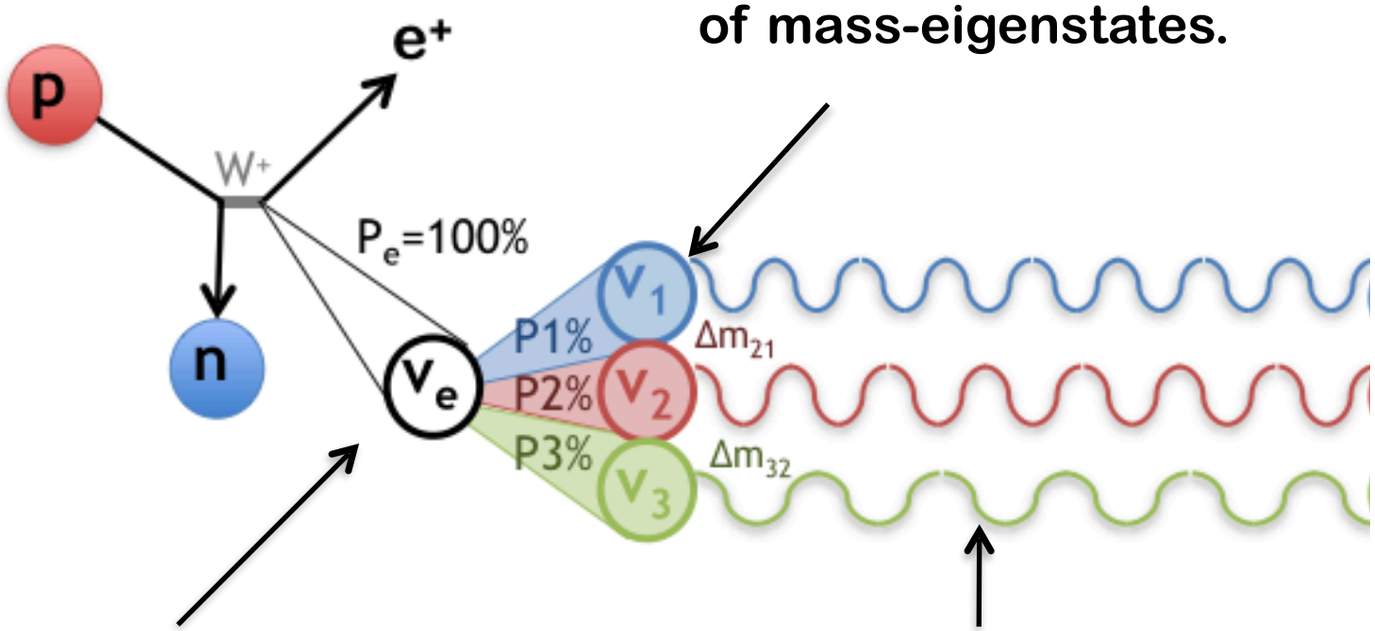
Weak interaction creates neutrino in flavor eigenstate.

NEUTRINO OSCILLATIONS



ν production

e.g. β^+-decay



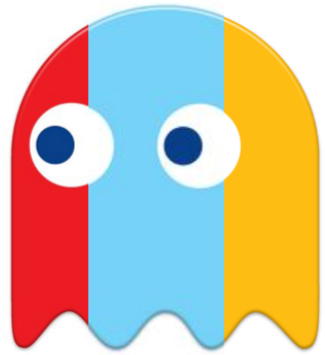
Weak interaction creates neutrino in flavor eigenstate.

ν propagation

as coherent superposition of mass-eigenstates.

Different masses create a phase difference over time.

NEUTRINO OSCILLATIONS



ν production

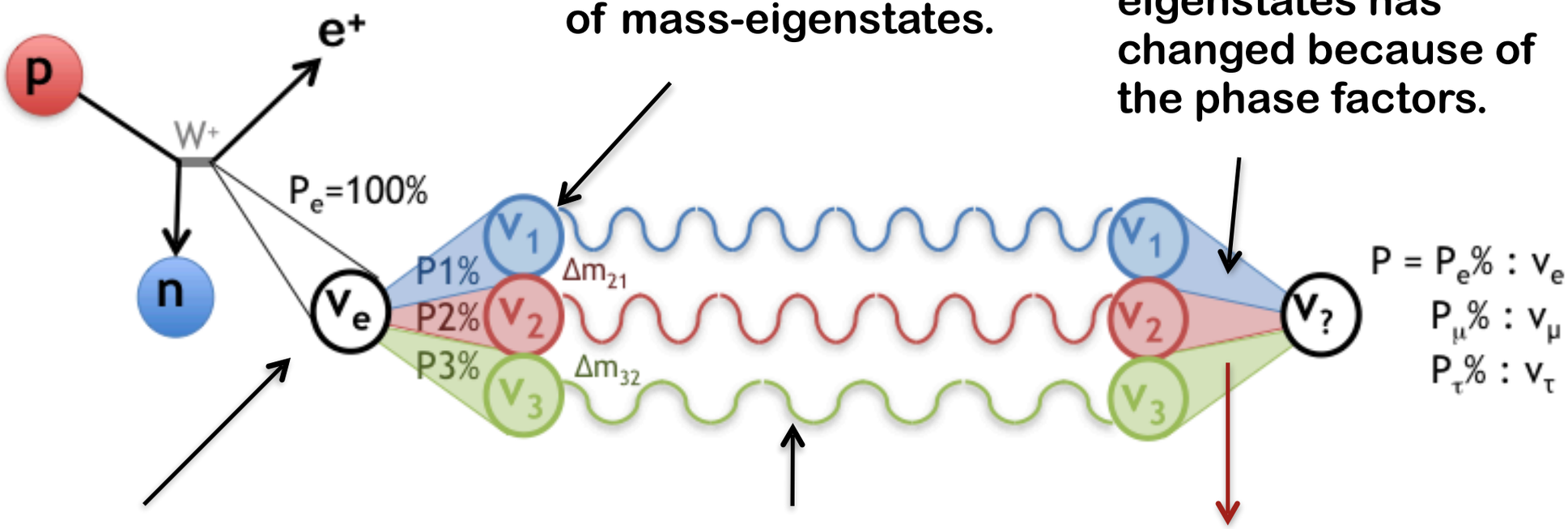
e.g. β^+-decay

ν propagation

as coherent superposition of mass-eigenstates.

ν detection

as flavor eigenstate: superposition of mass eigenstates has changed because of the phase factors.



Weak interaction creates neutrino in flavor eigenstate.

Different masses create a phase difference over time.

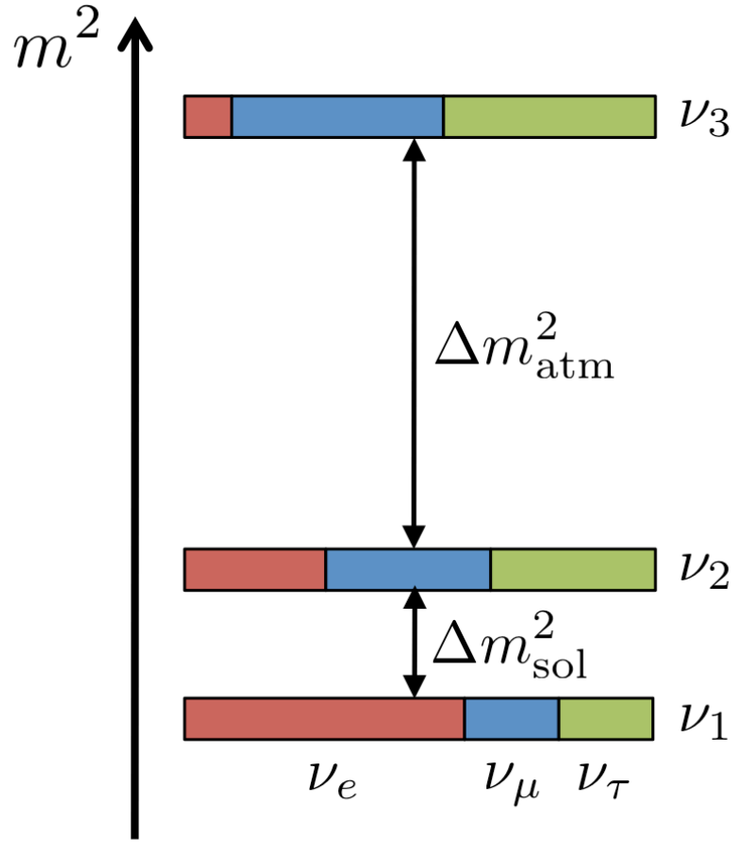
Finite probability to detect a different neutrino flavor!

$$P(\nu_e \rightarrow \nu_e) = 1 - sin^2 2\theta_{12} sin^2 \frac{1.27 \Delta m^2_{12} L}{E}$$

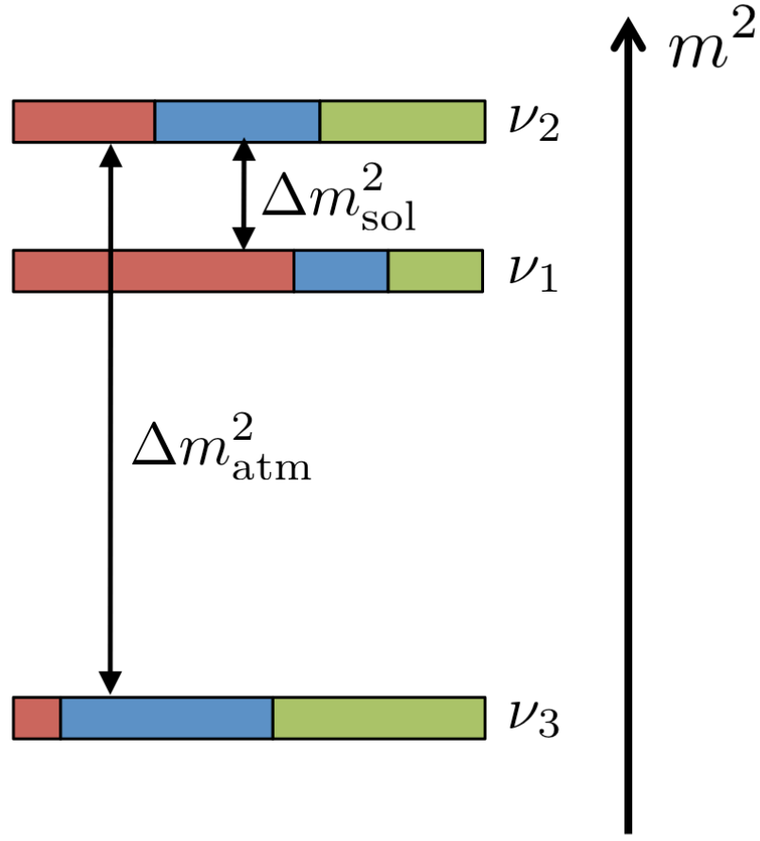
IT'S ALL ABOUT THAT MASS

Mass ordering

Normal Ordering (NO)



Inverse Ordering (IO)

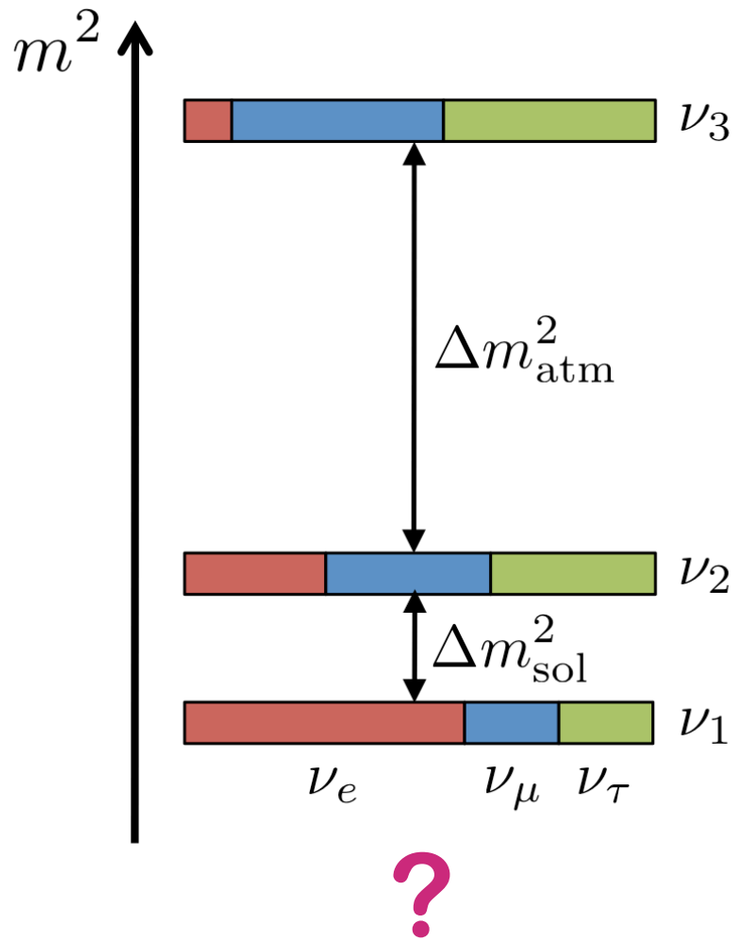


IT'S ALL ABOUT THAT MASS

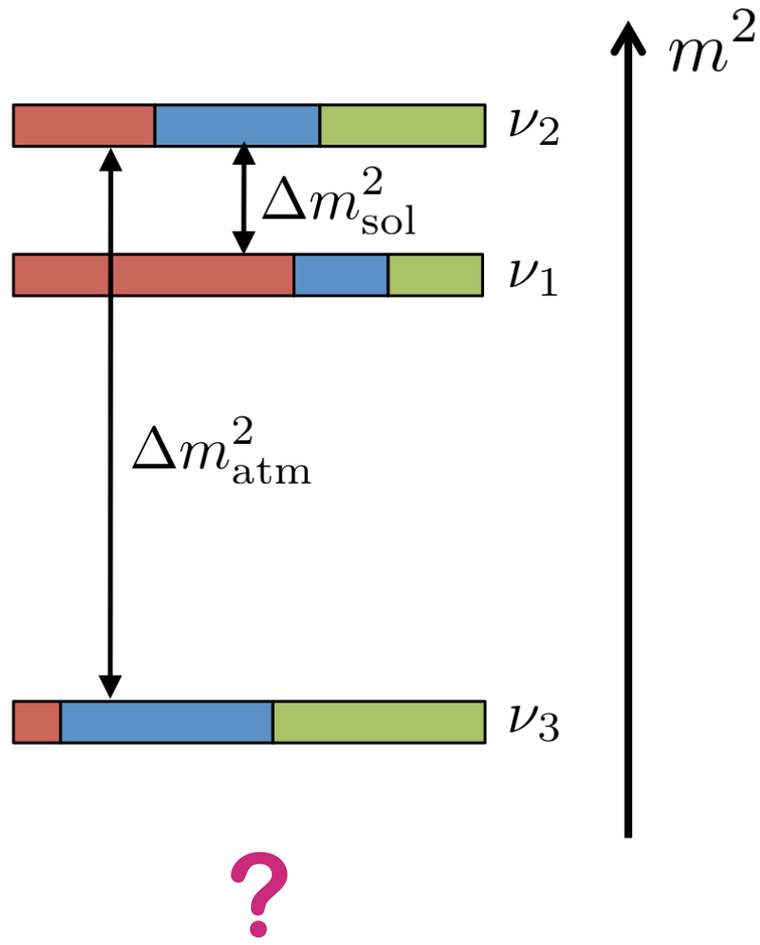
Mass ordering

Absolute Mass

Normal Ordering (NO)

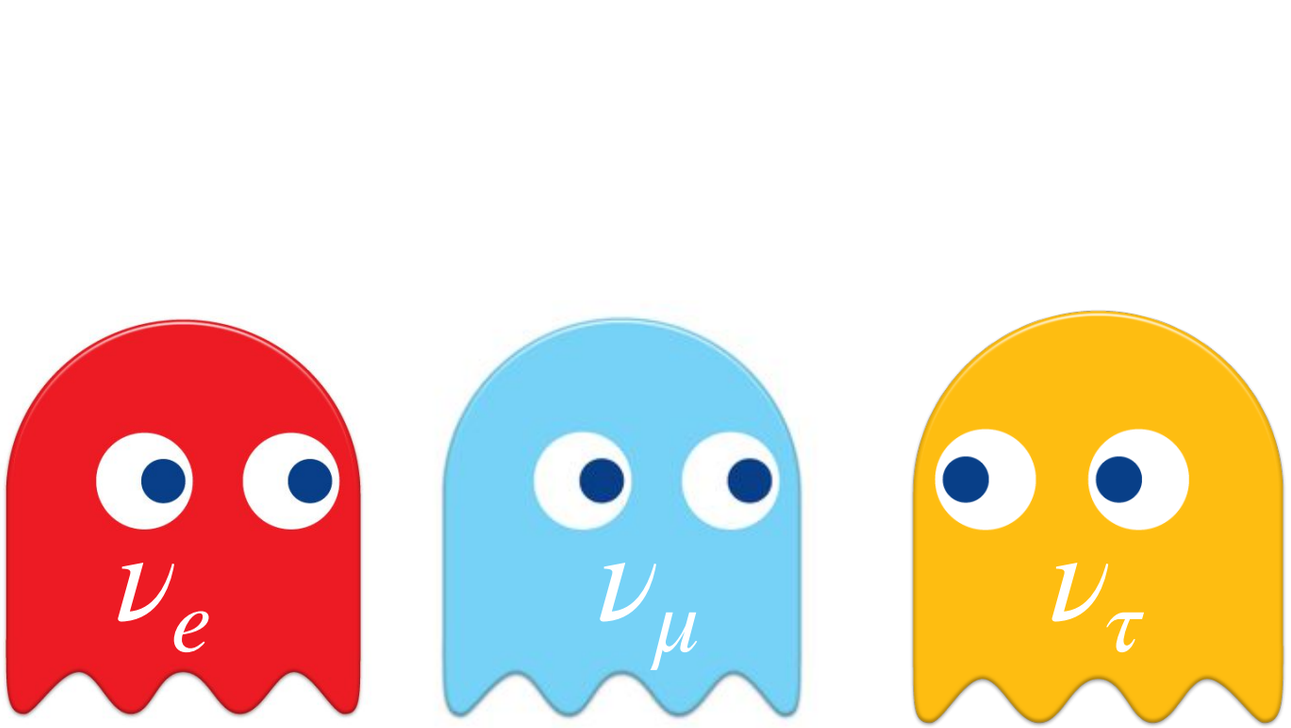


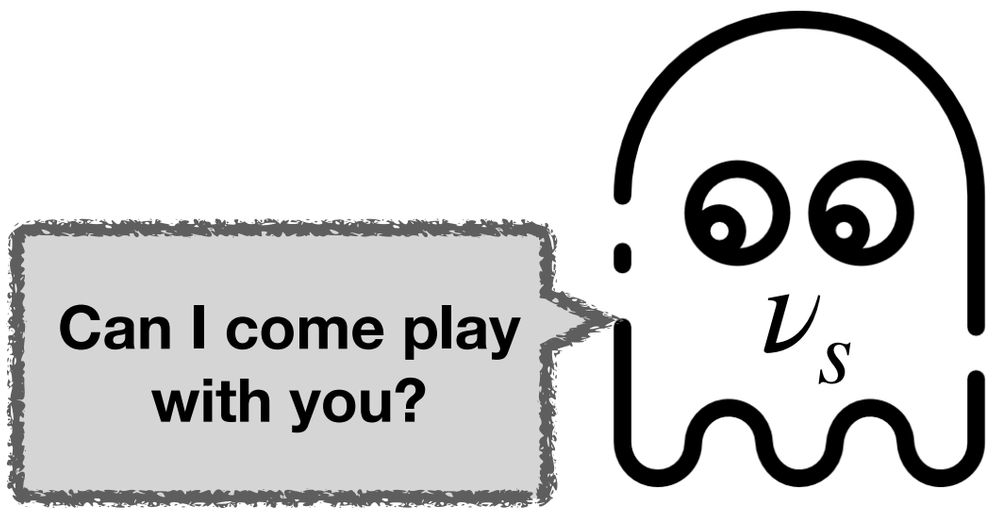
Inverse Ordering (IO)



MORE THAN THREE?

$$P(\overline{\nu}_e \rightarrow \overline{\nu}_e) = 1 - sin^2 2\theta_{14} sin^2 \frac{1.27 \Delta m^2_{14} L}{E}$$





DIRAC OR MAJORANA

$$\nu \neq \bar{\nu}$$

Dirac

vs.

$$\nu = \bar{\nu}$$

Majorana

Mechanism for matter-antimatter asymmetry in the universe?

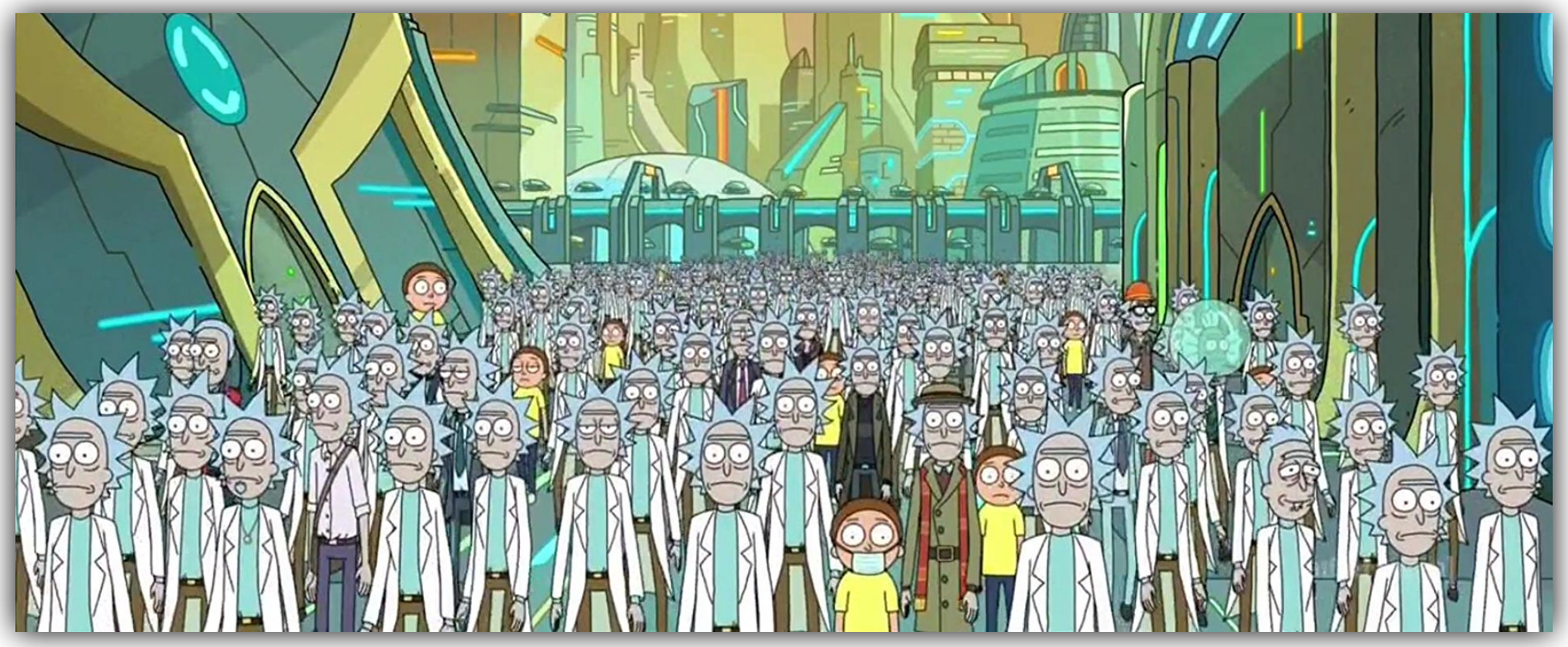
WHO ARE THE NEUTRINO HUNTERS?

- A lonely grey-haired crazy scientist?

Source: Rick and Morty

WHO ARE THE NEUTRINO HUNTERS?

- A lonely grey-haired crazy scientist?
- Maybe crazy, but not alone, and not only grey-haired



Source: Rick and Morty

WHO ARE THE NEUTRINO HUNTERS?

Recent photo from the biggest neutrino conference (Heildelberg, Germany)

Source: https://www.mpi-hd.mpg.de/nu2018/

WHO ARE THE NEUTRINO HUNTERS?

Recent photo from the biggest neutrino conference (Heildelberg, Germany)

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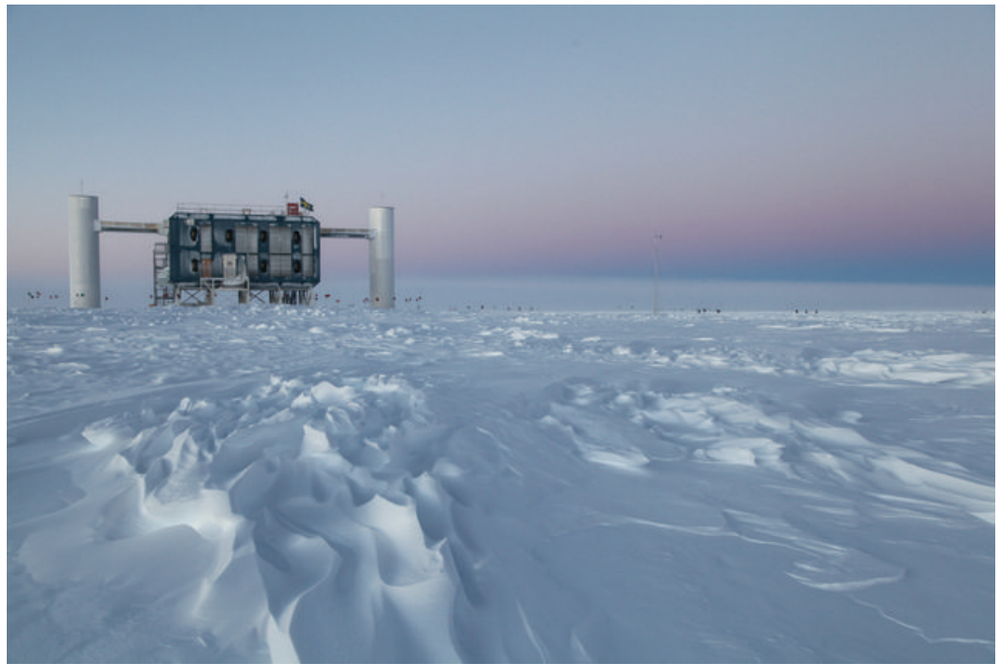
WHAT ARE NEUTRINO HUNTERS DOING?

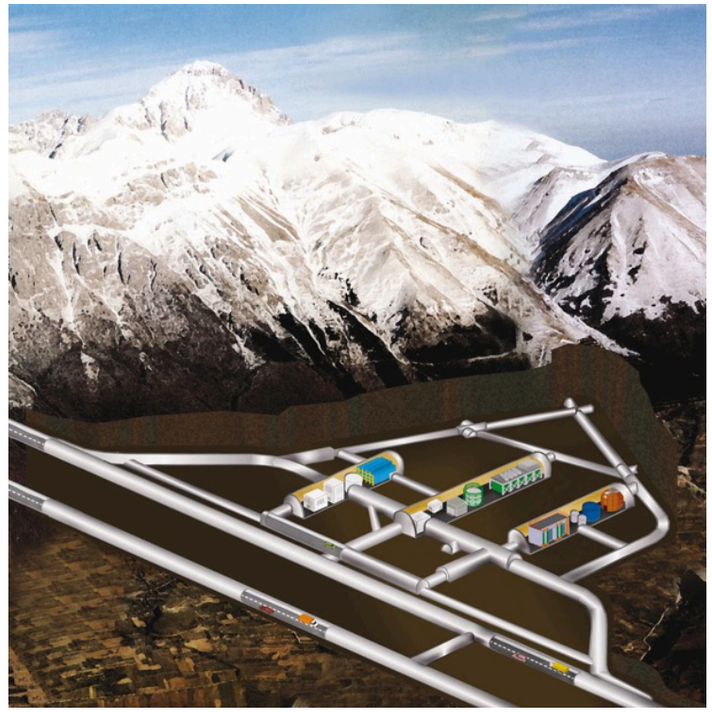
Build the laboratories

- In the mines
- In the mountains
- In the ice

Credit:SNOLAB



Credit: IceCube/NSF



Credit: Laboratori Nazionali del Gran Sasso

WHAT ARE NEUTRINO HUNTERS DOING?

Build the laboratories

- In the mines
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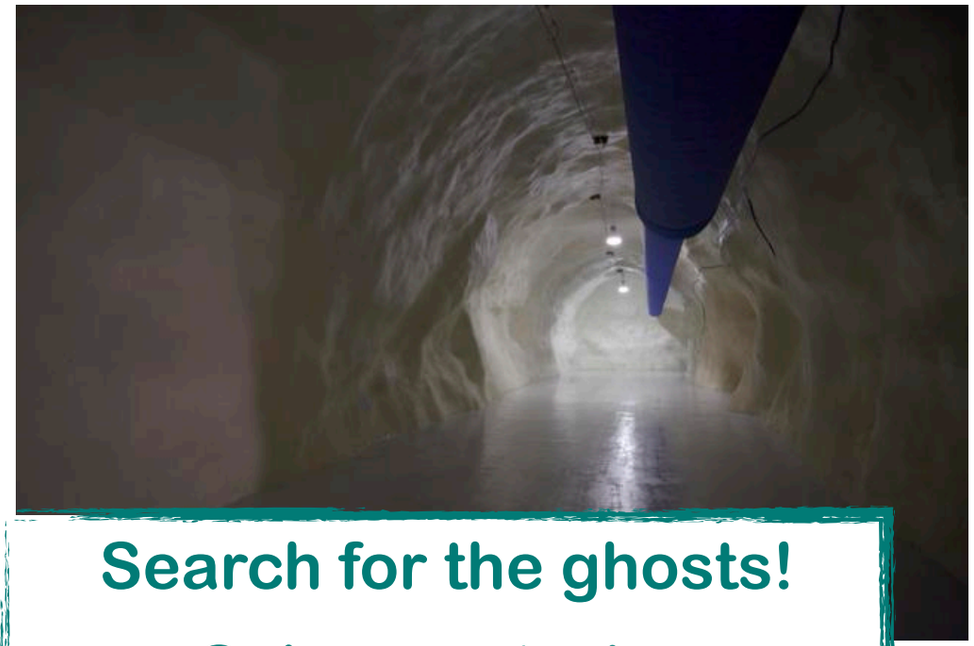
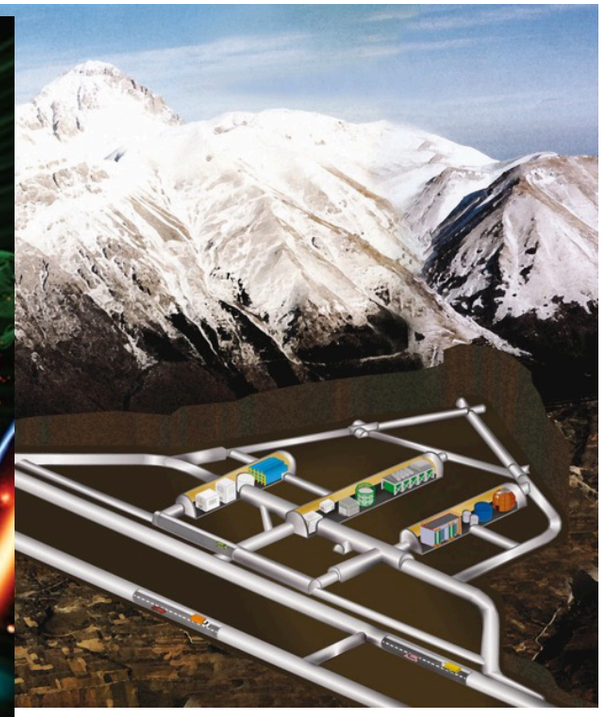


Search for the ghosts!

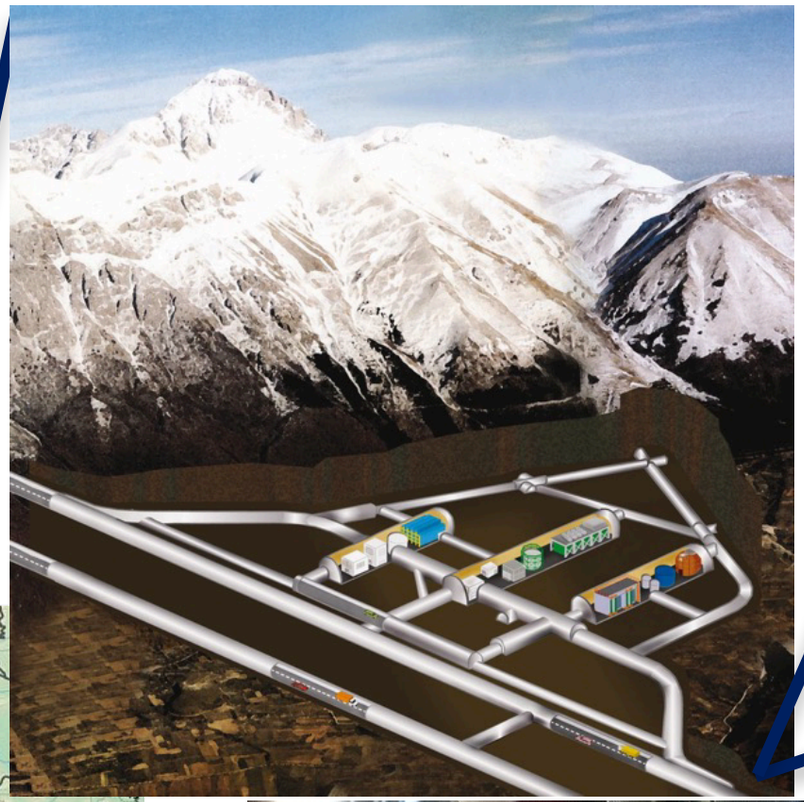
Solve mysteries

Credit: IceCube/NSF

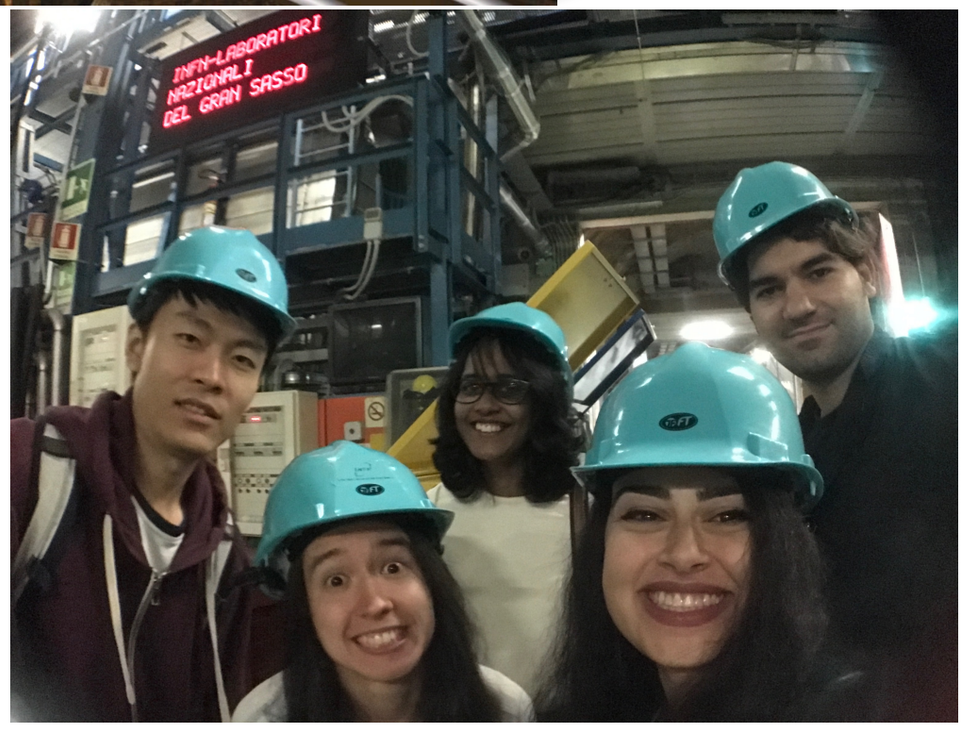


Laboratori Nazionali del Gran Sasso

LABORATORI NAZIONALI DEL GRAN SASSO (LNGS)

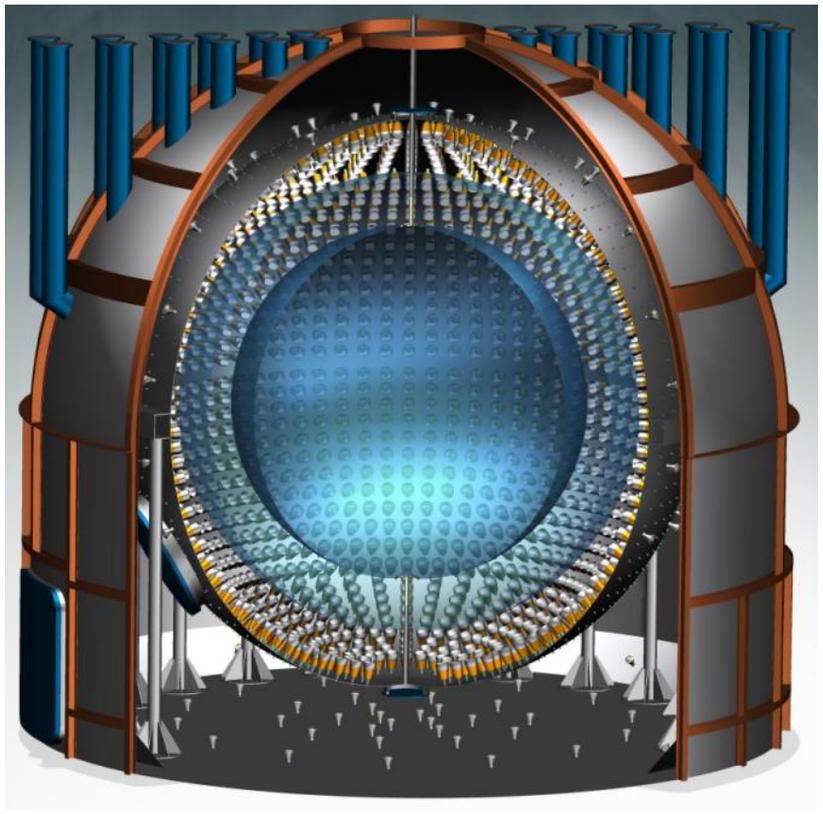


Credit: Laboratori Nazionali del Gran Sasso



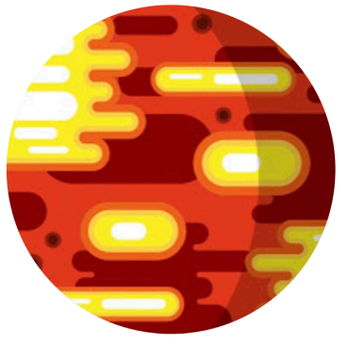
Credit: Zara Bagdasarian

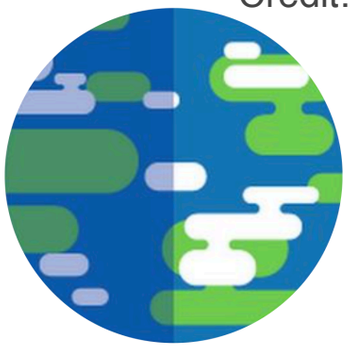
BOREXINO @ LNGS



physicsworld TOP 10 BREAKTHROUGH 2014

Credit: Borexino



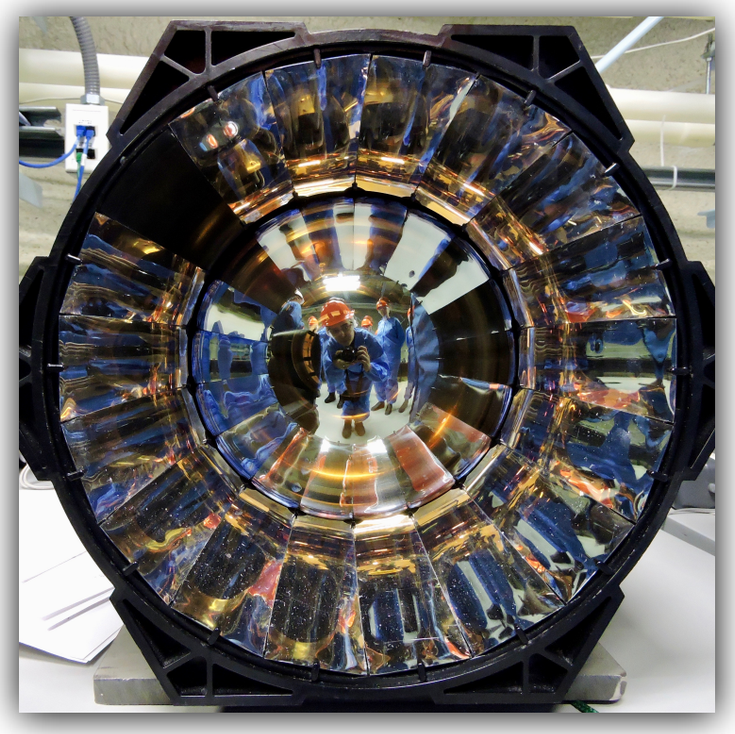


The most radiopure spot in the world

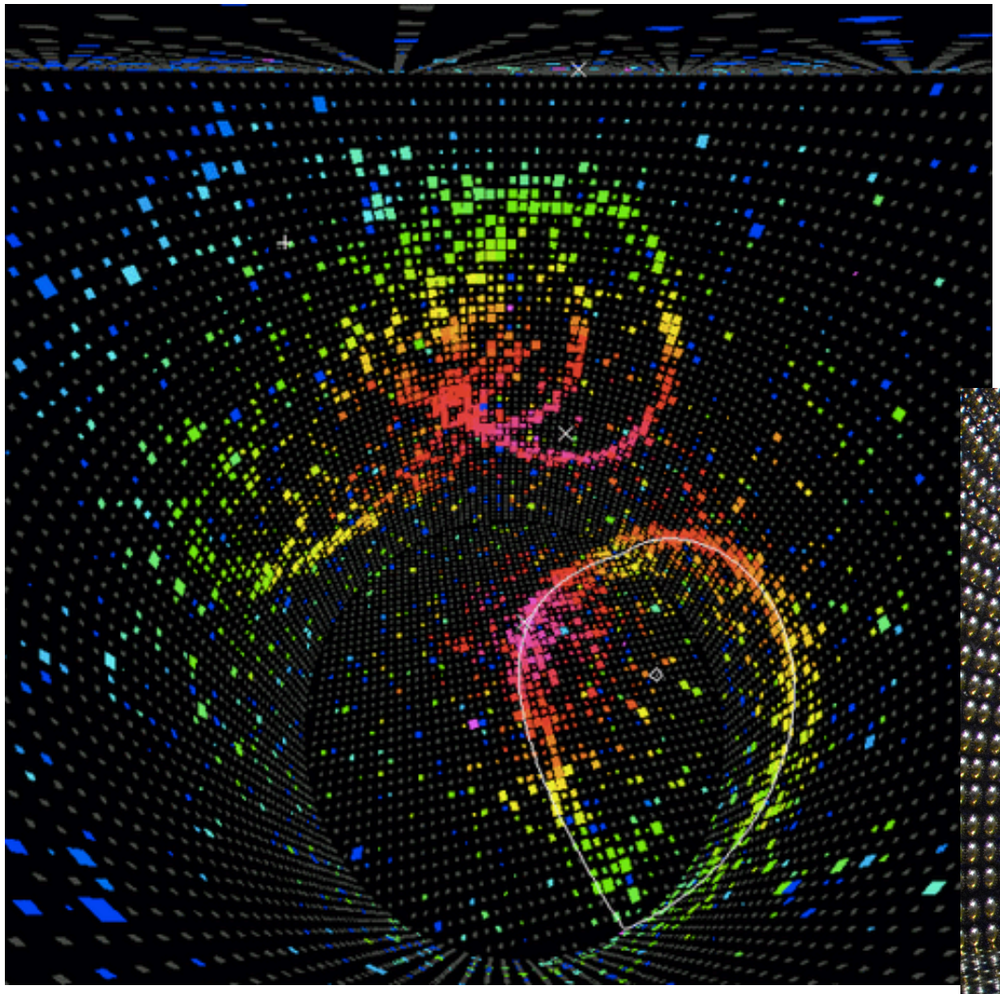
SUDBURY NATIONAL OBSERVATORY

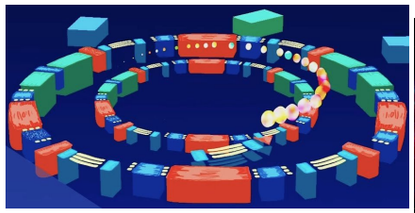
- 2 km down the mine
- Solved solar neutrino problem

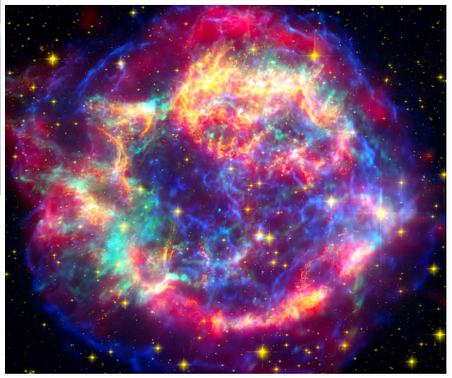
Credit: Zara Bagdasarian

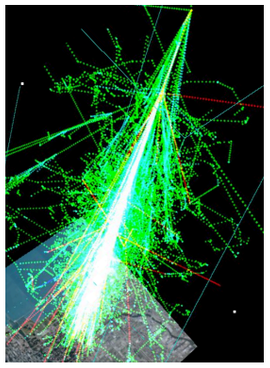


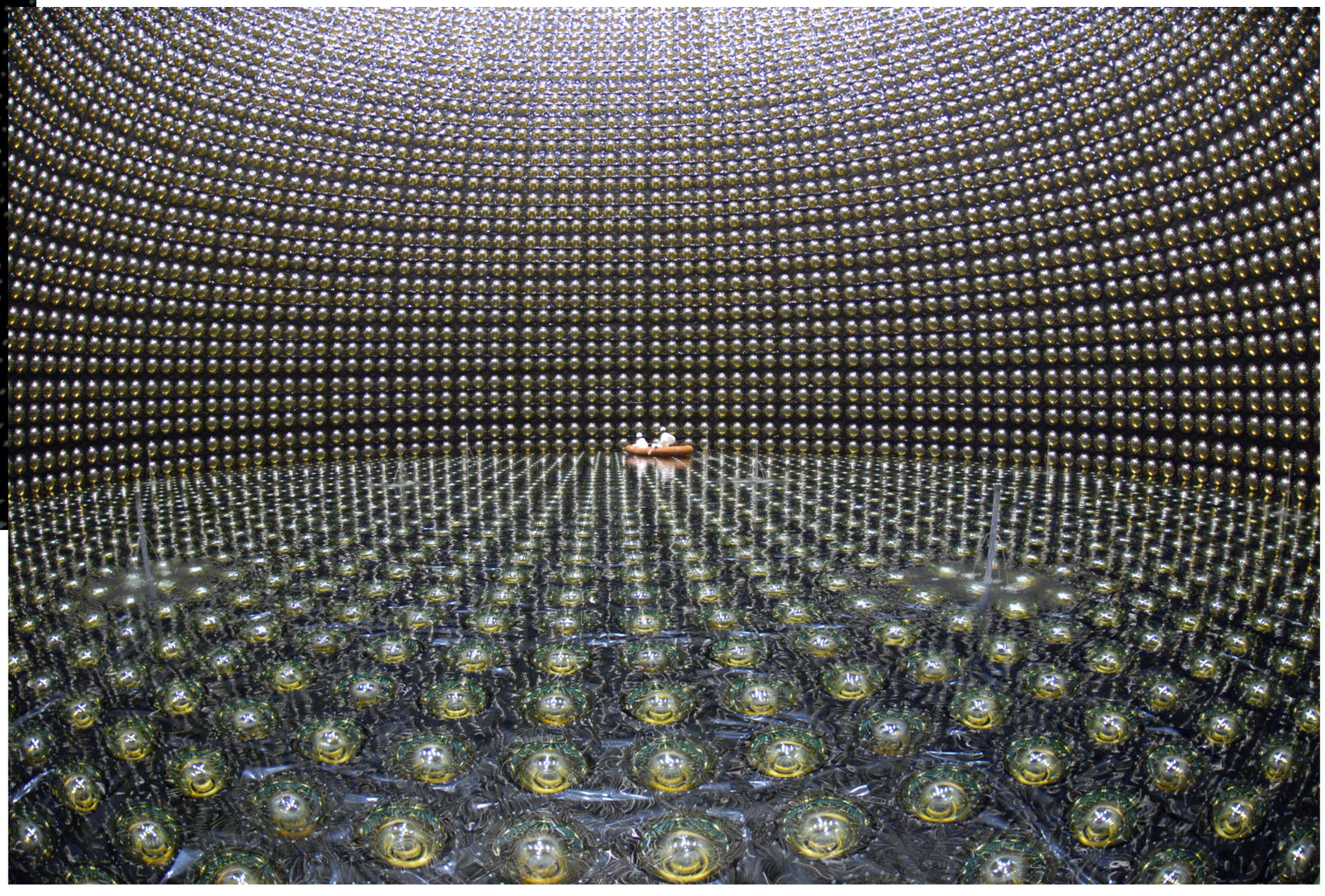
SUPER-KAMIOKANDE









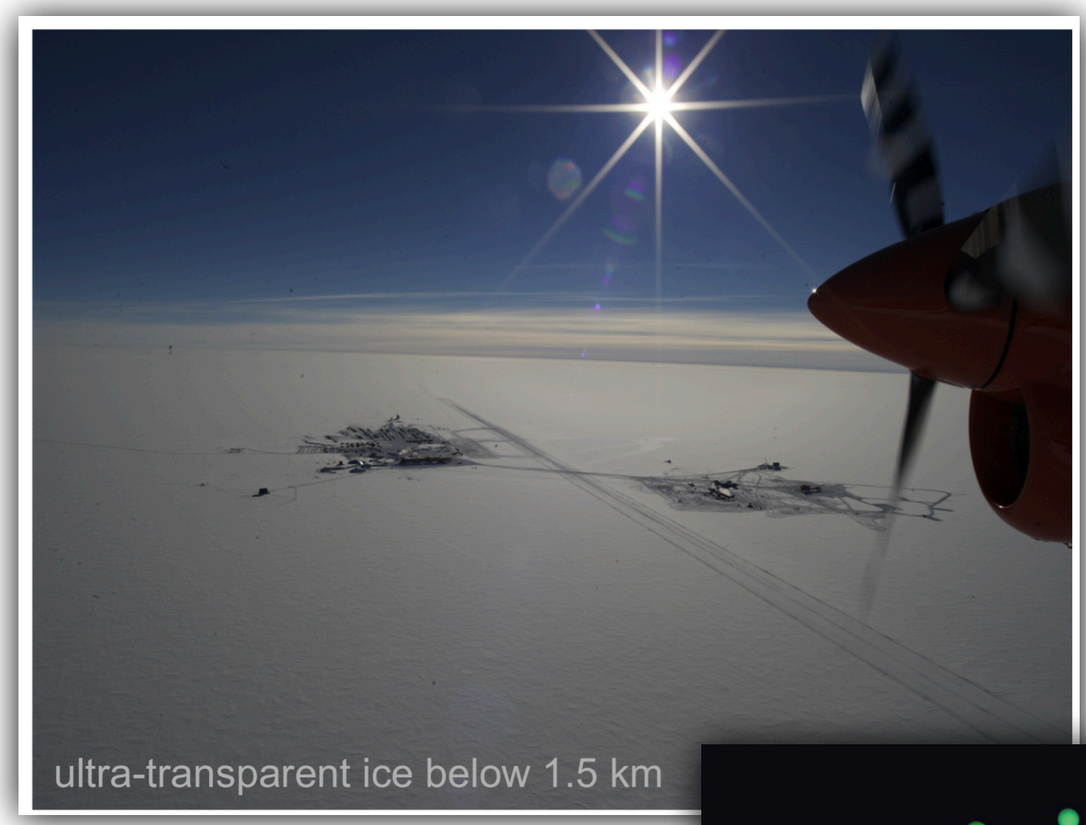


a massive tank containing 50,000 tonnes of ultra pure water:
over 33 Olympic sized swimming pools!

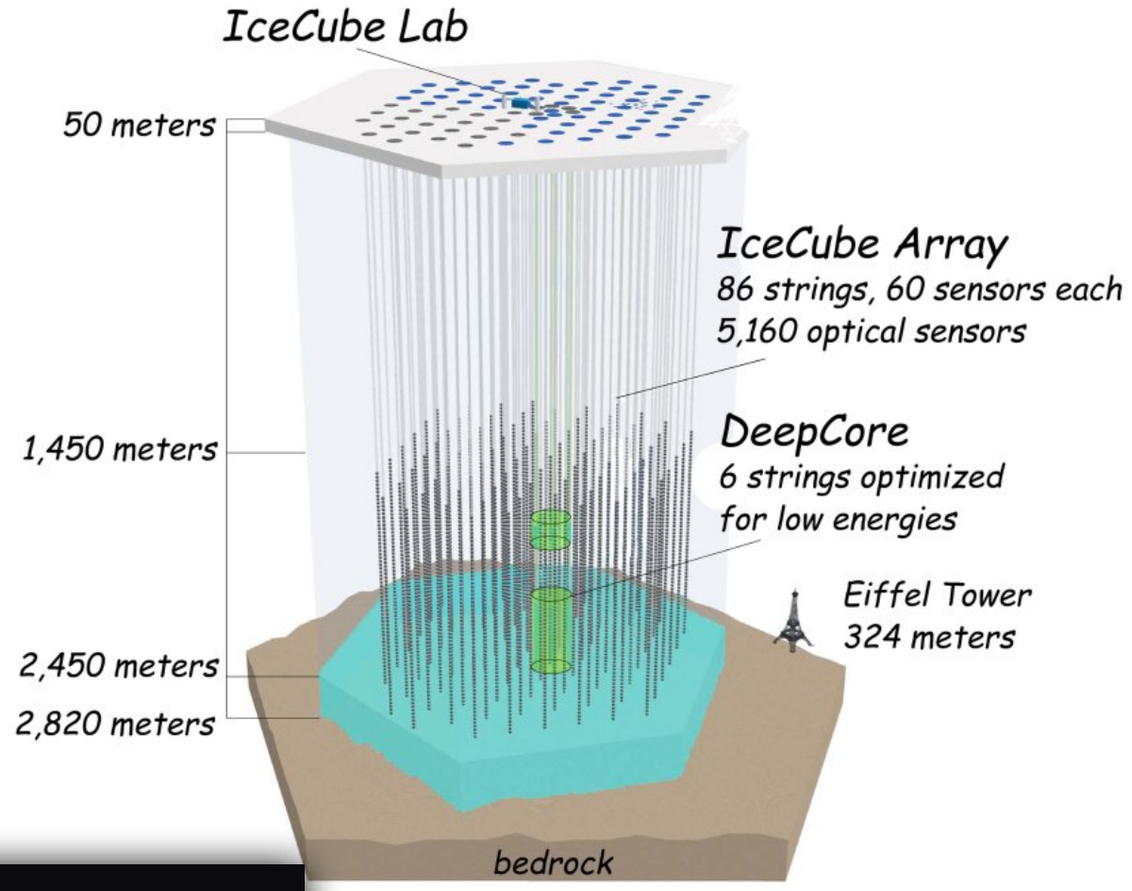
Future: from Super to Hyper

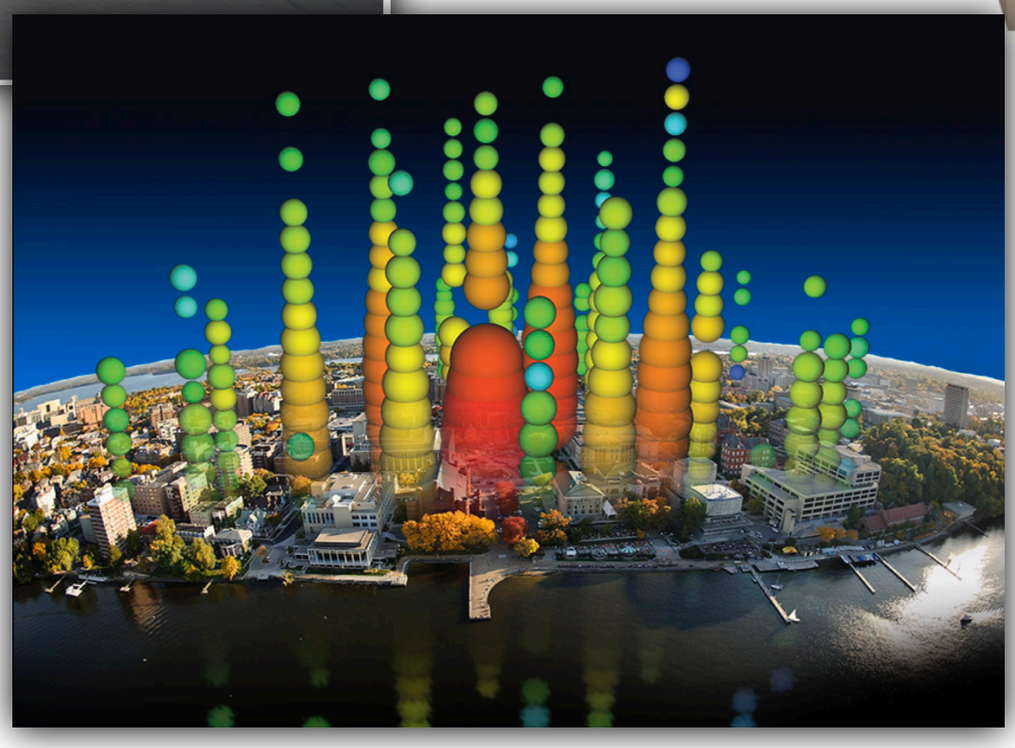
Credit: Super-Kamiokande

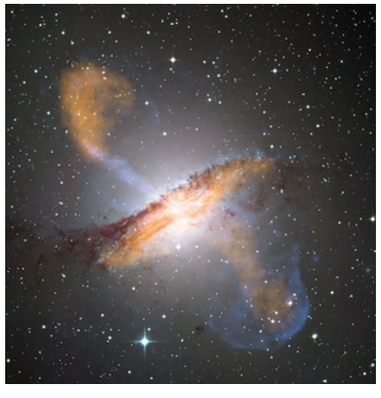
ICE CUBE

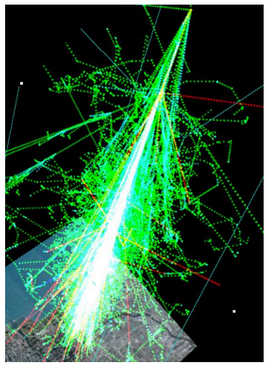


Credit: IceCube



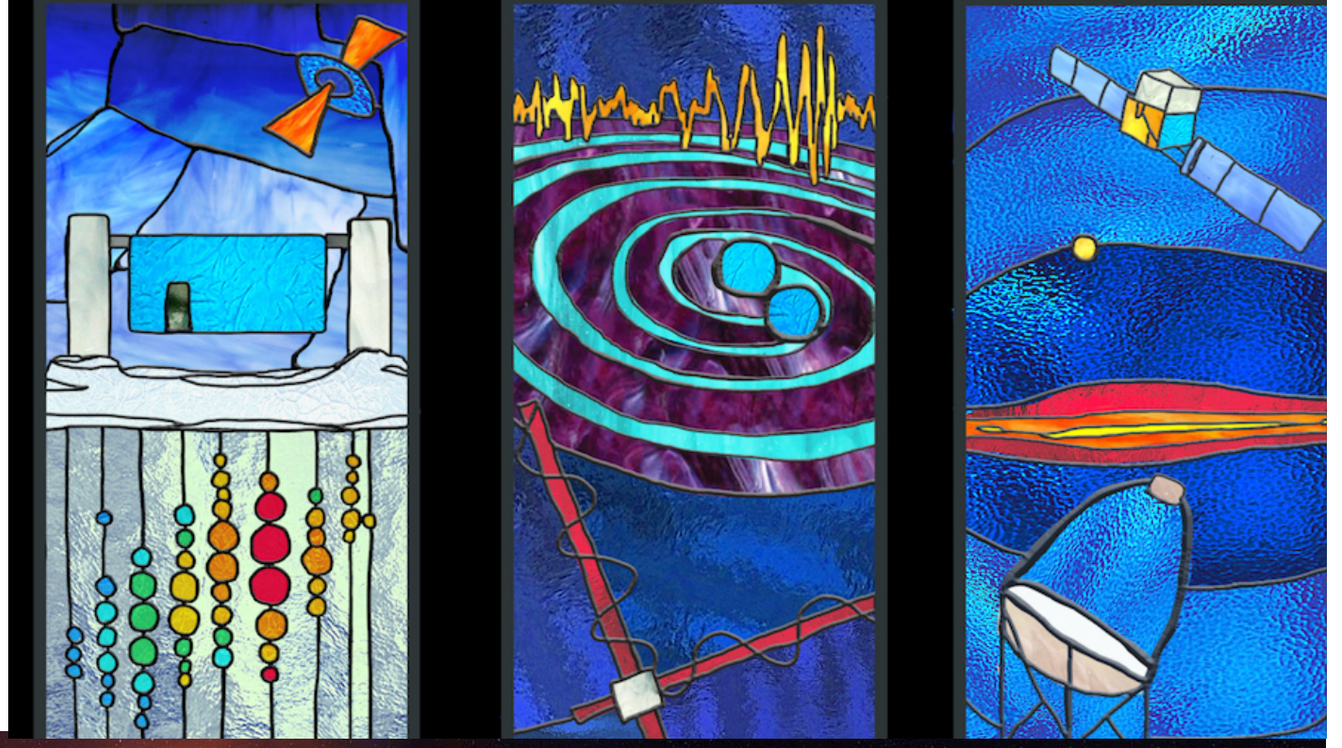




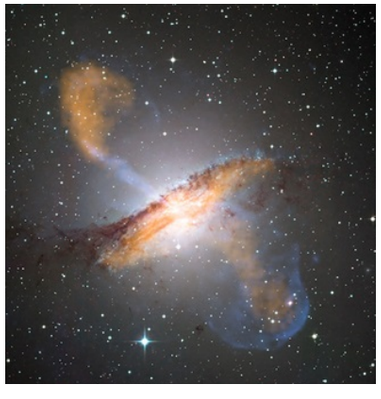


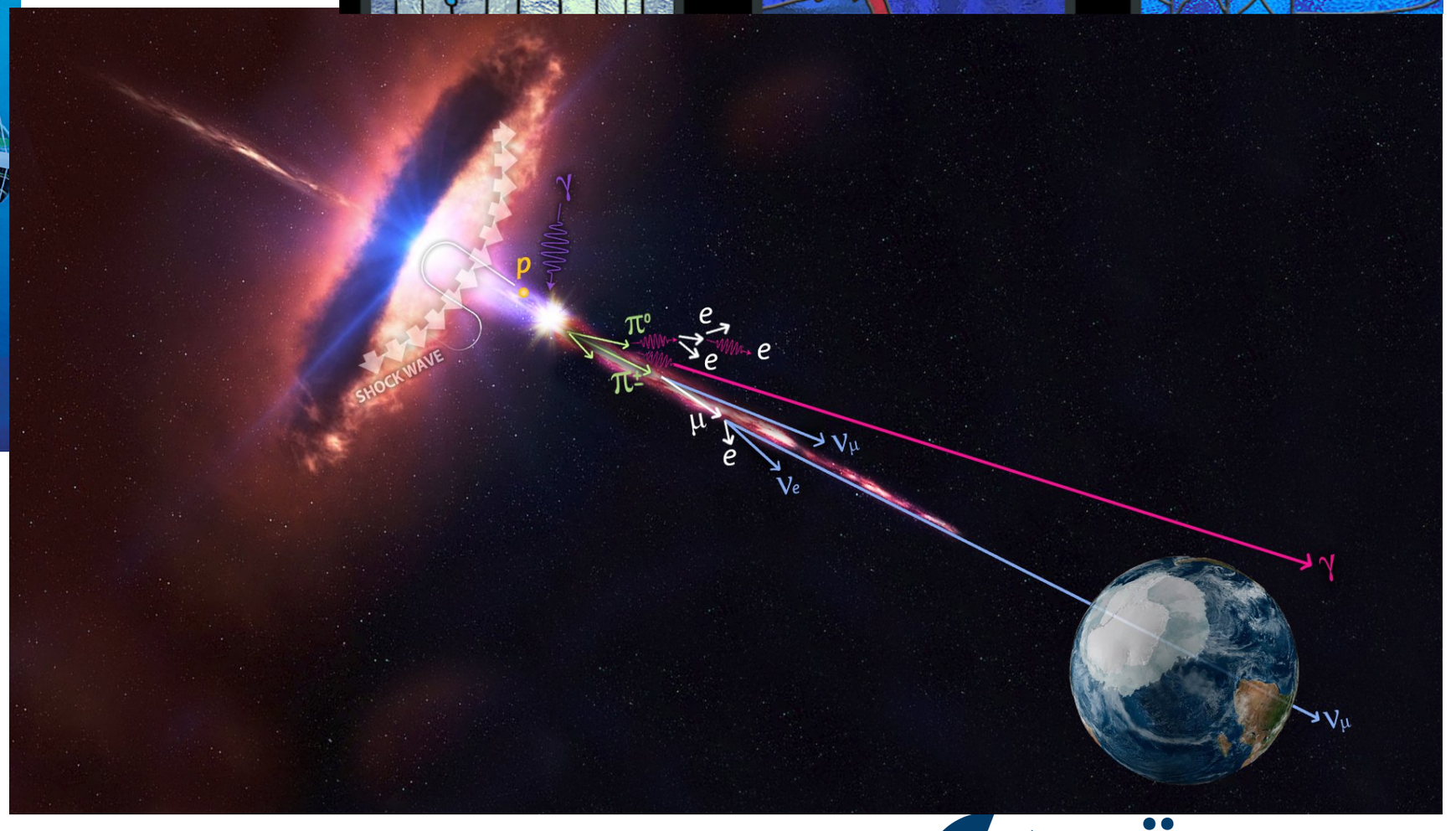
ICE CUBE

Credit: IceCube/Science



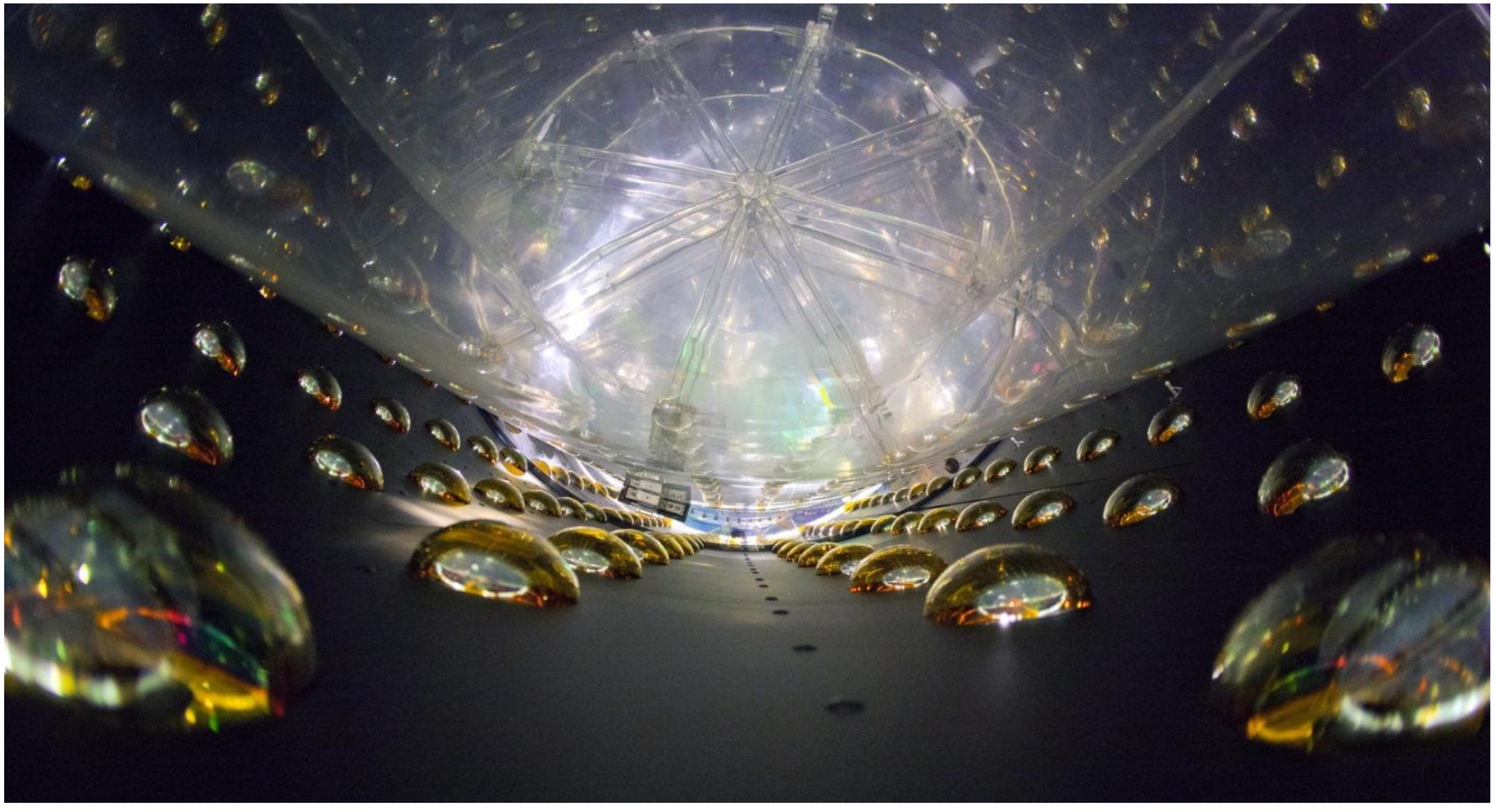
Credit: IceCube





DAYA BAY

- Reactor antineutrinos: record 4 million antineutrinos dataset



Credit: Daya Bay

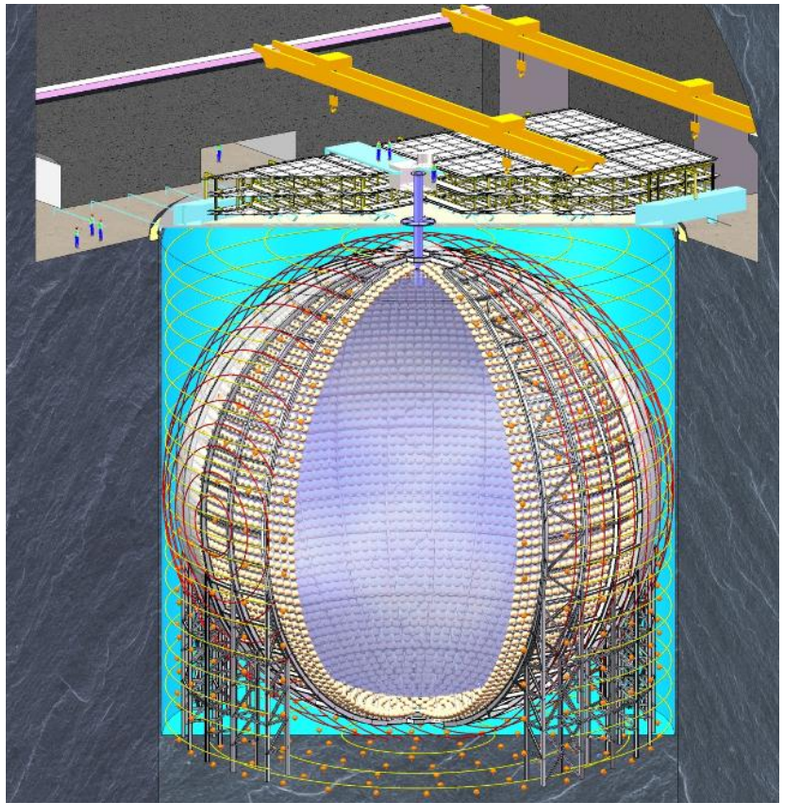
$sin^2 2\theta_{13} = 0.0856$

$\Delta m^2_{ee} = 2.52 \times 10^{-3} eV^2$

precision of 3.4% and 2.8%

ANTINEUTRINOS FROM REACTORS

Credit: RENO



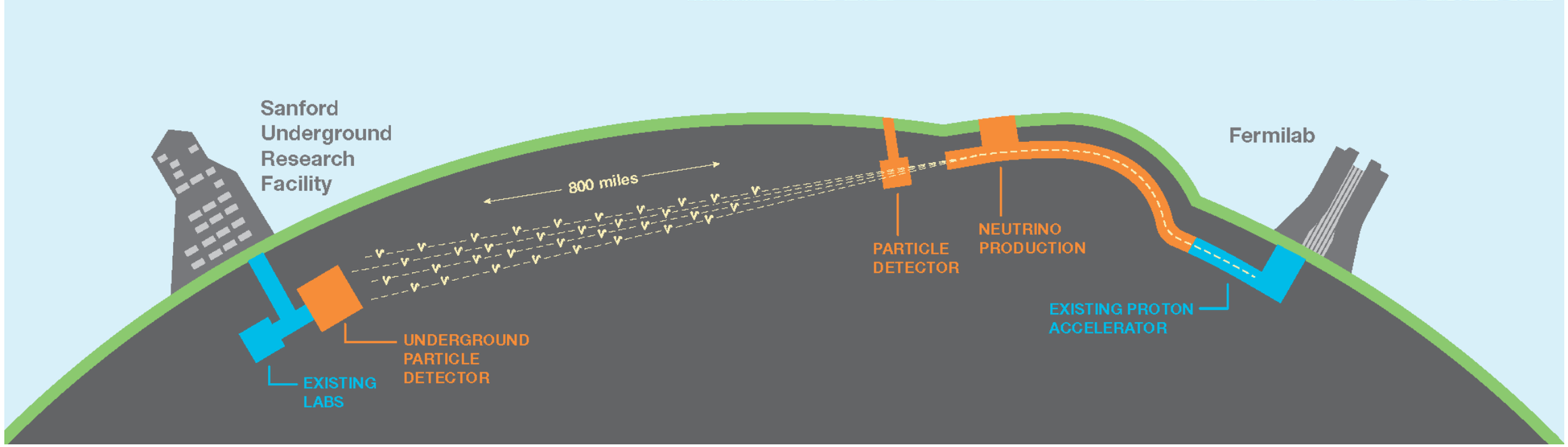
Credit:JUNO Collaboration

Credit: Double Chooz

- Other reactor experiments:
  - DOUBLE CHOOZ (France)
  - RENO (Korea)
  - JUNO (China) (upcoming)

NEUTRINOS FROM MAN-MADE BEAMS

- MINOS (USA)
- NOvA(USA)
- T2K (Japan)
- DUNE (USA) (future)

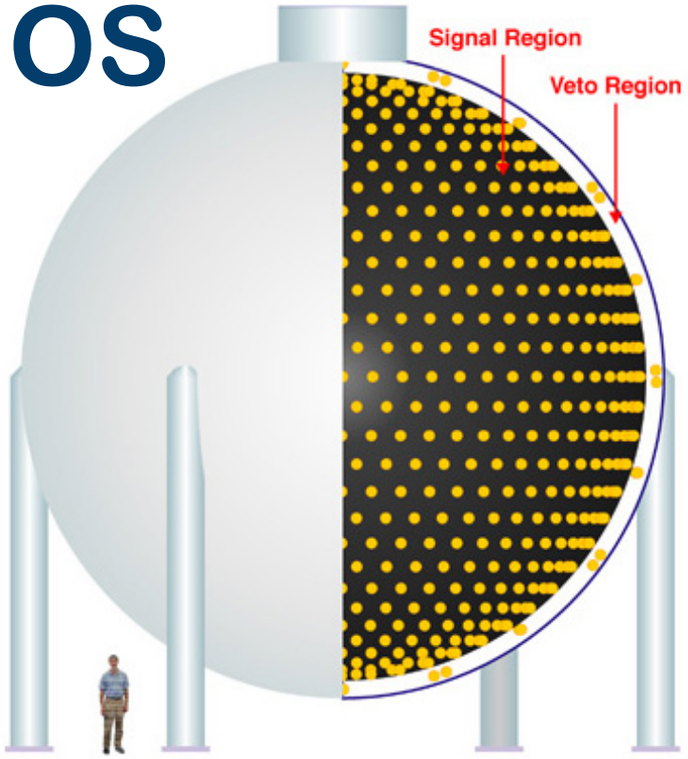


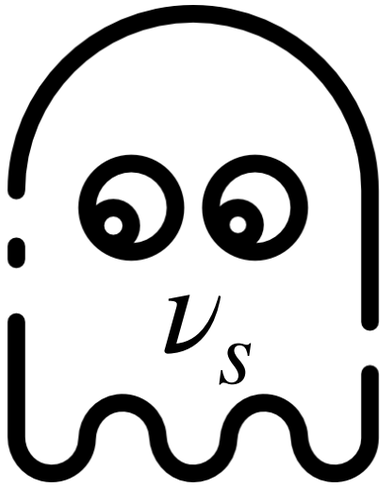
CP-violation: differences between neutrinos and antineutrinos

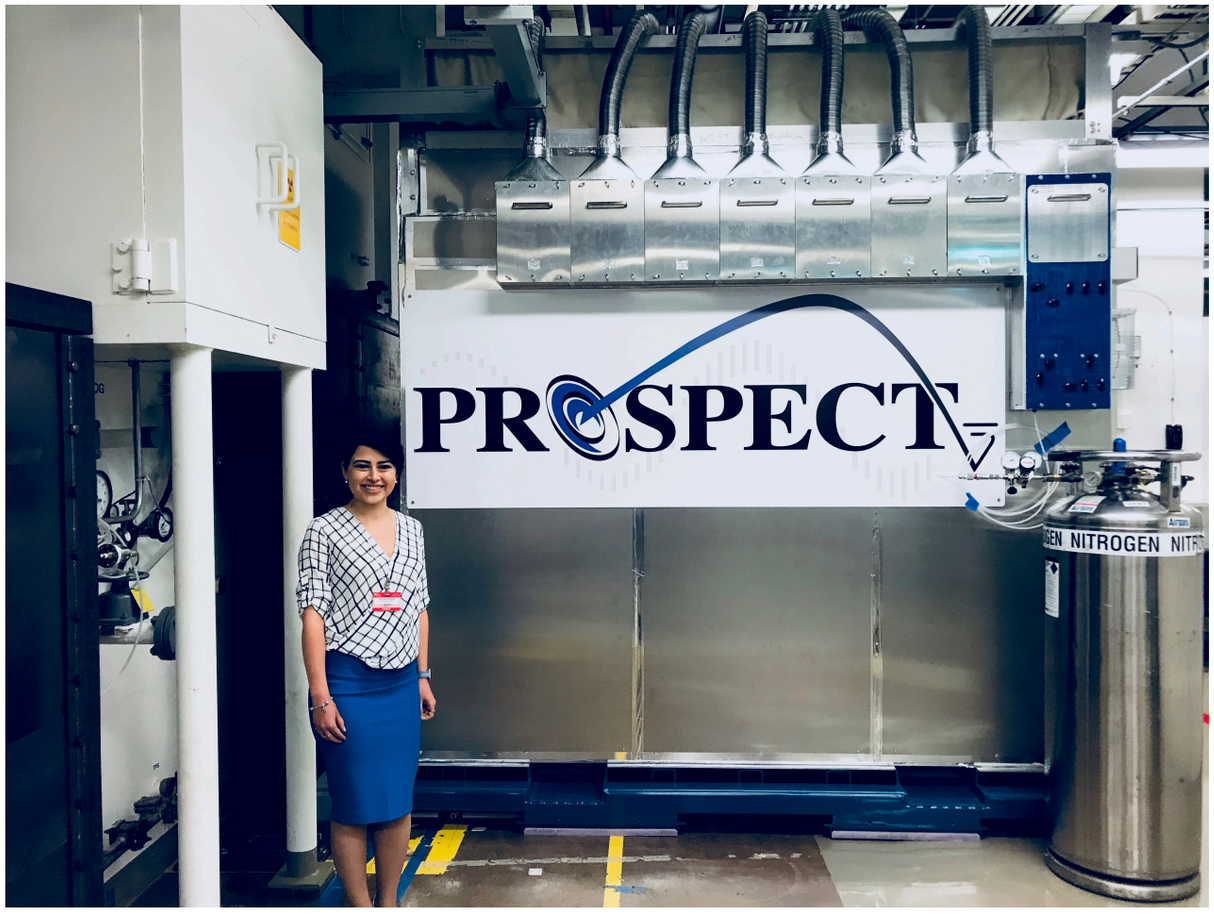
Credit: DUNE Collaboration

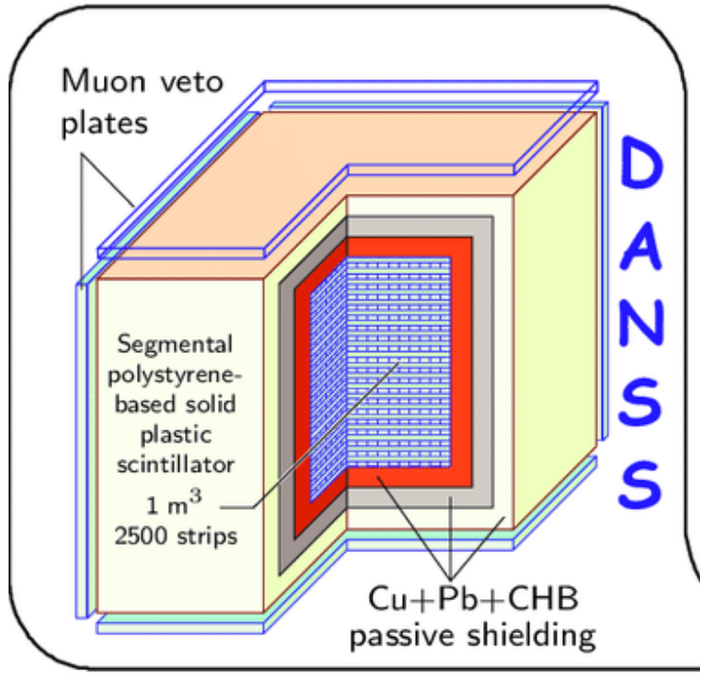
SEARCH FOR STERILE NEUTRINOS

- MiniBooNE (USA) (recently in the news)
- DANSS (Russia)
- NEOS (Korea)
- PROSPECT (USA)



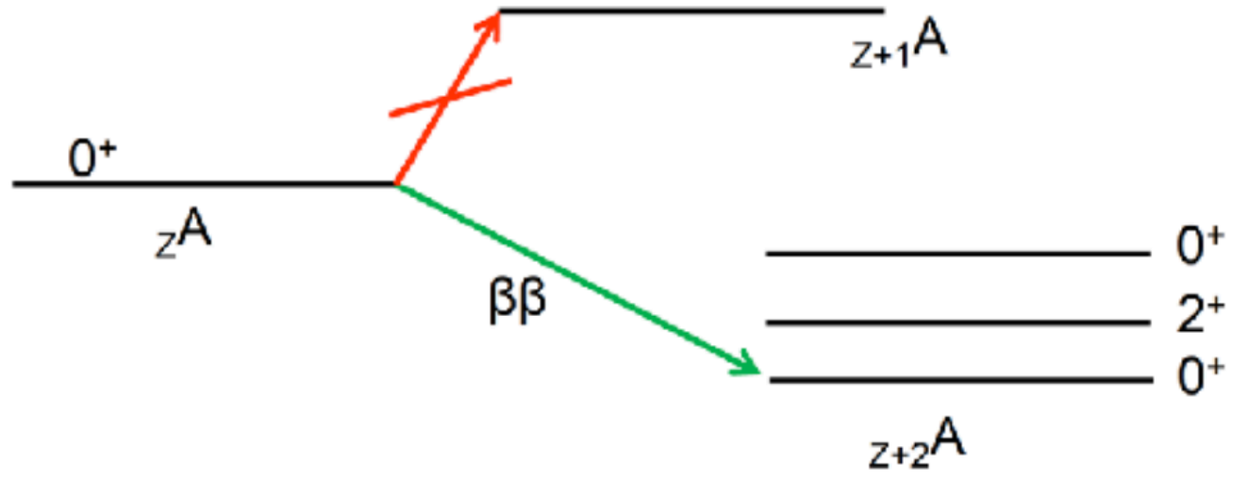


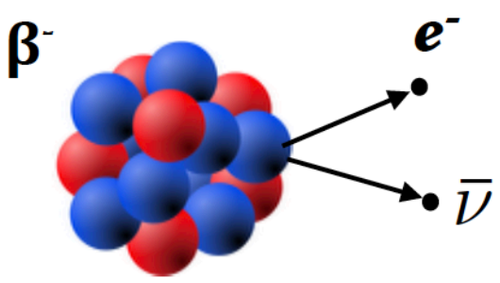


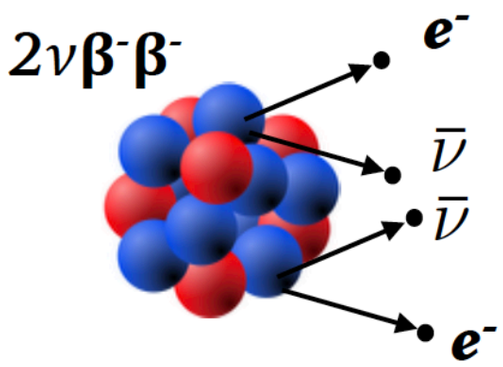


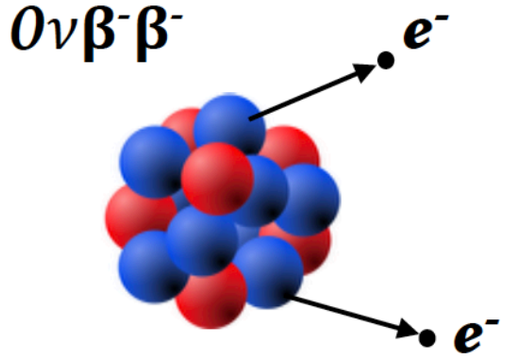
SEARCHES FOR $0\nu\beta\beta$ DECAY

Elements for which normal beta decay is suppressed:
Germanium, Xenon, Tellurium







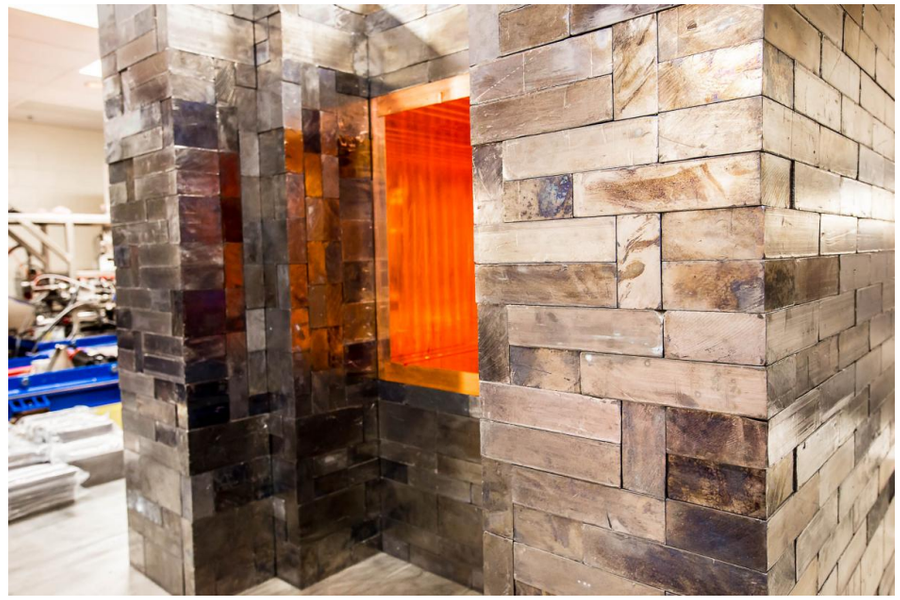


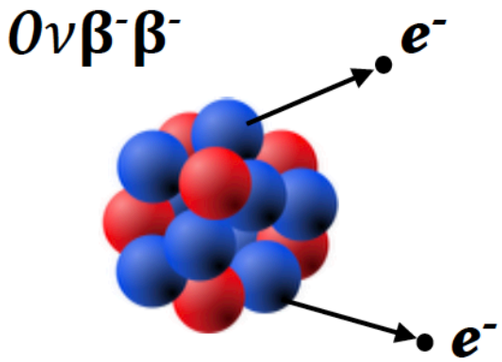
Processes within the Standard Model

Neutrinos are their own antiparticles
Lepton number is not conserved

SEARCHES FOR $0\nu\beta\beta$ DECAY

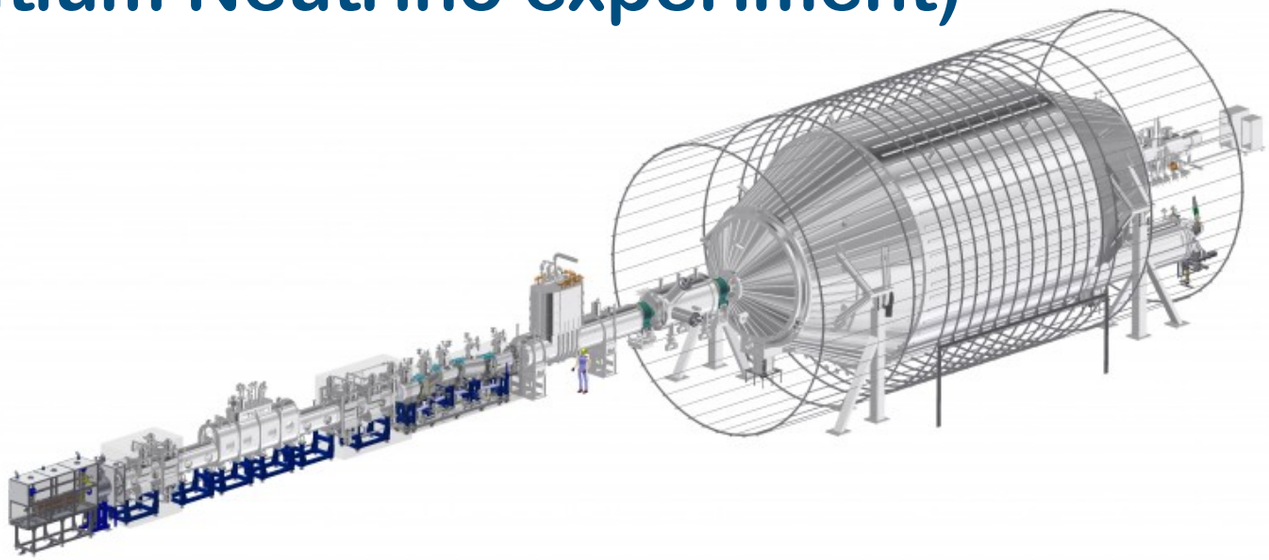
- GERDA (Italy) $m_{\beta\beta} < (110, 260)$ meV
- MAJORANA DEMONSTRATOR (USA)
- CUORE (Italy)





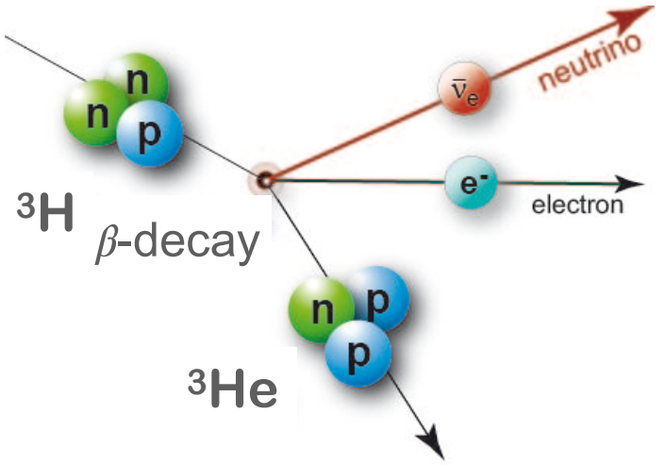
- EXO (USA)
- KAMLand- Zen (Japan)

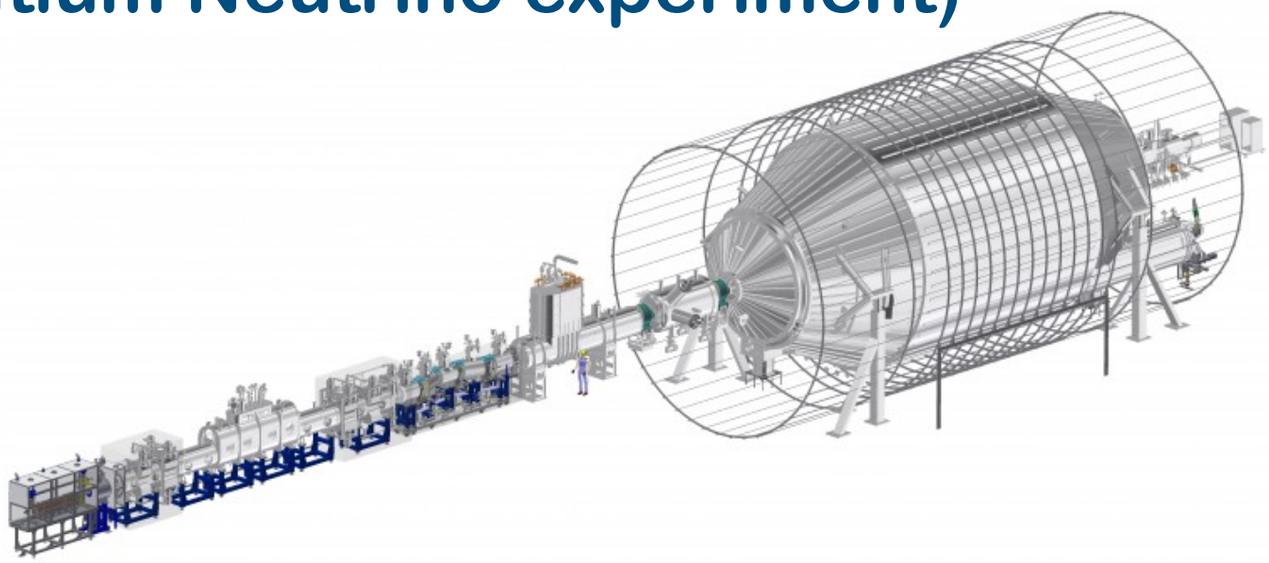
KATRIN (the KArlsruhe TRItium Neutrino experiment)

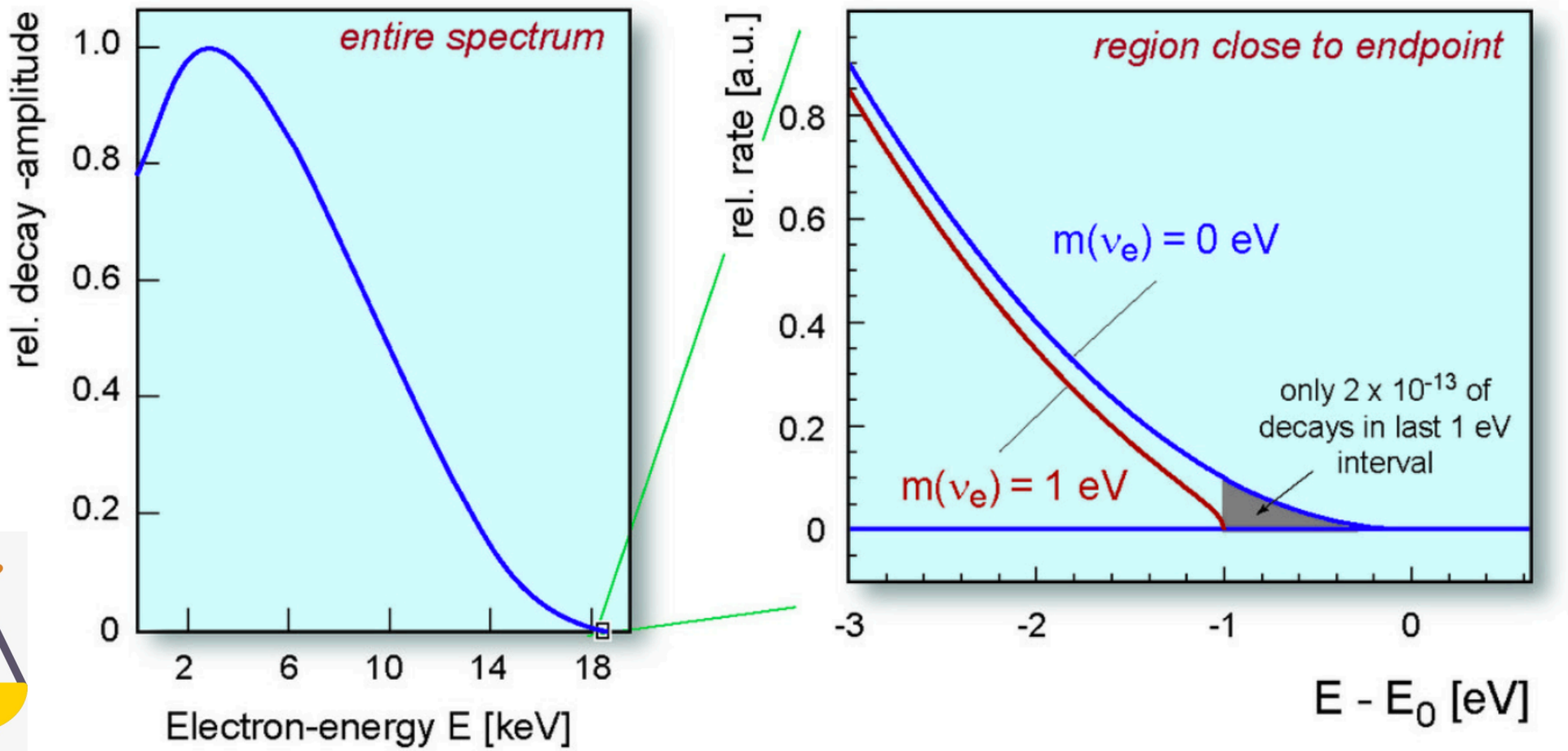


Goal: Absolute mass scale of neutrinos

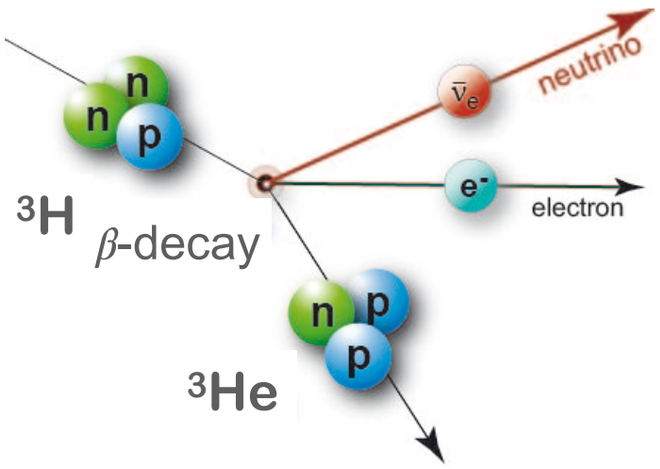
KATRIN (the KArlsruhe TRItium Neutrino experiment)

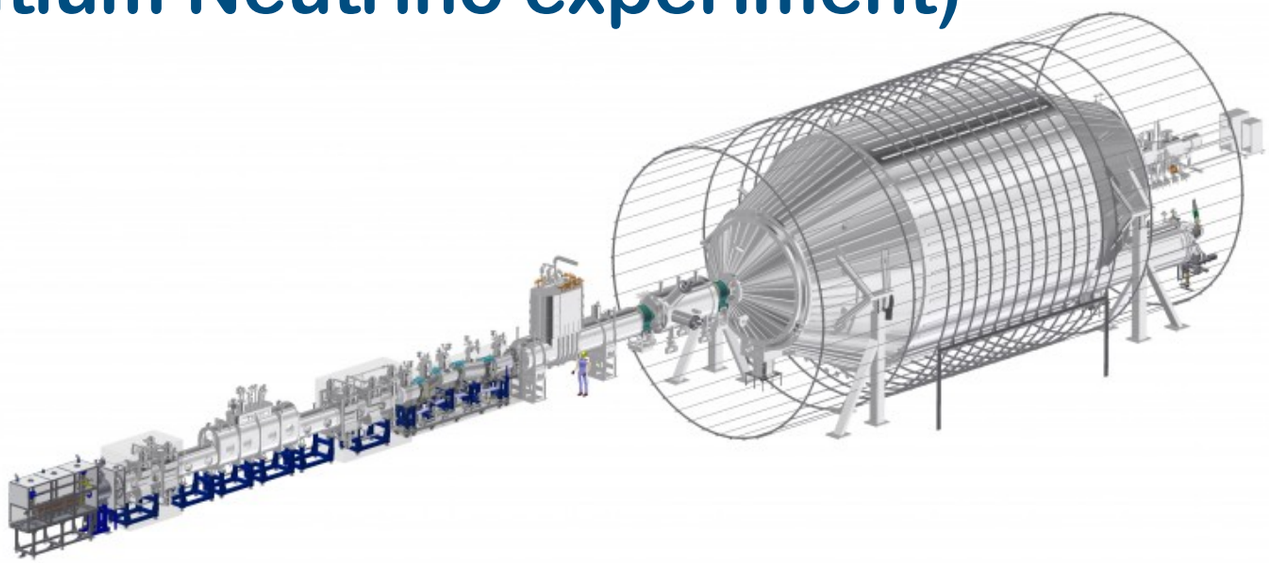


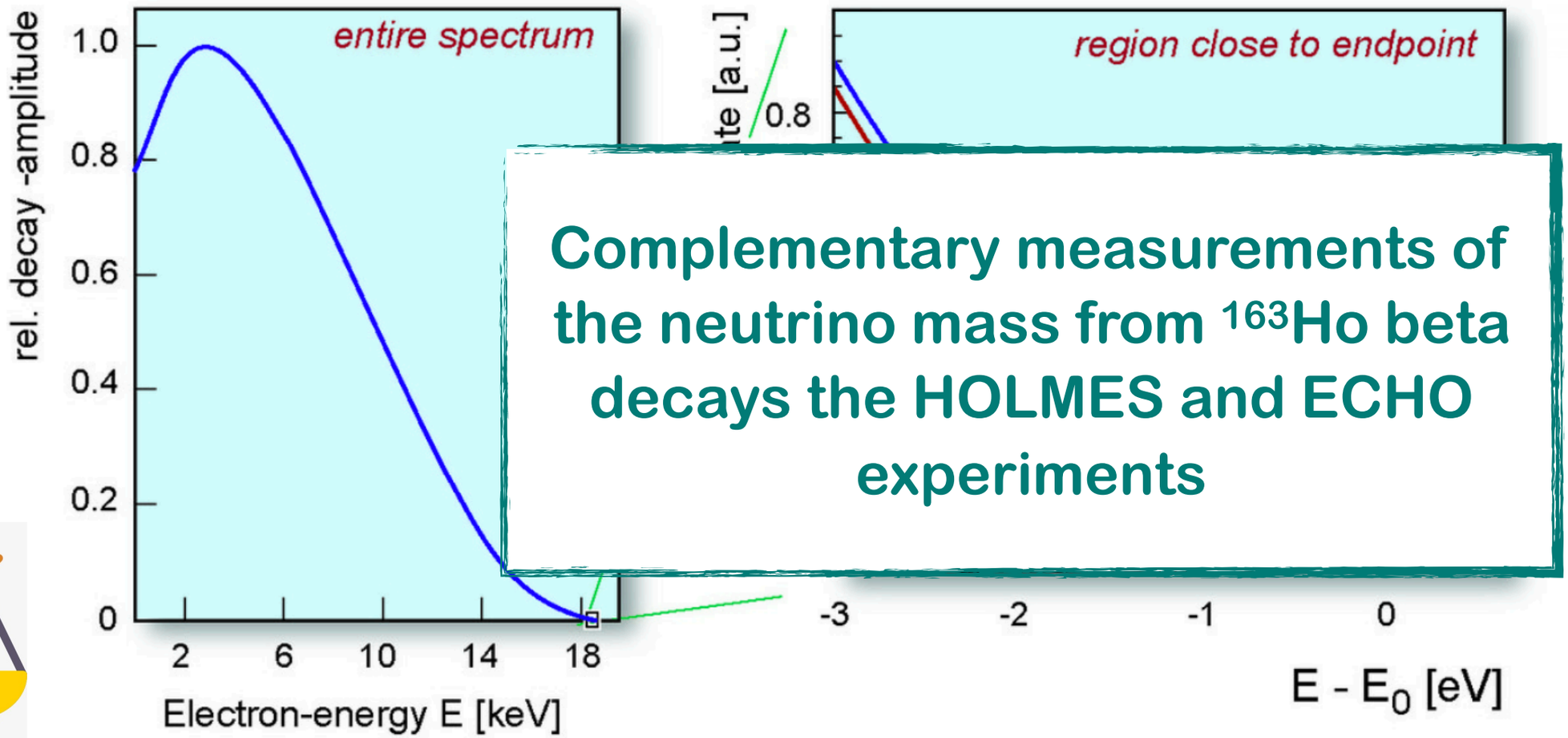




KATRIN (the KArlsruhe TRItium Neutrino experiment)



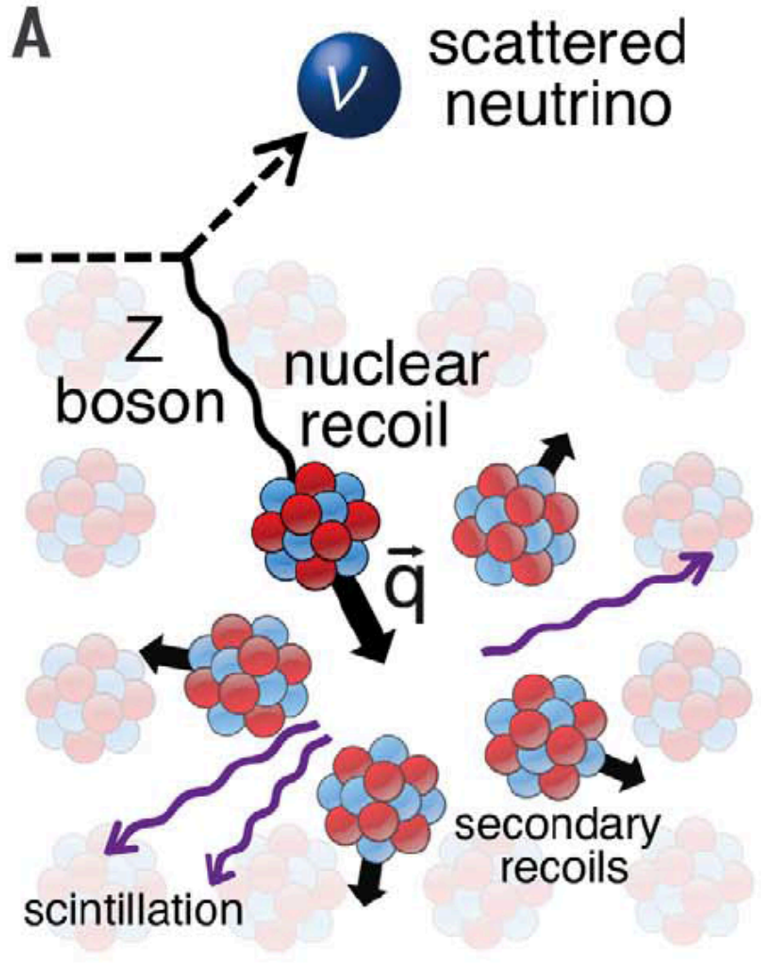




Complementary measurements of the neutrino mass from ^{163}Ho beta decays the HOLMES and ECHO experiments

NOT ALL ABOUT THE SIZE

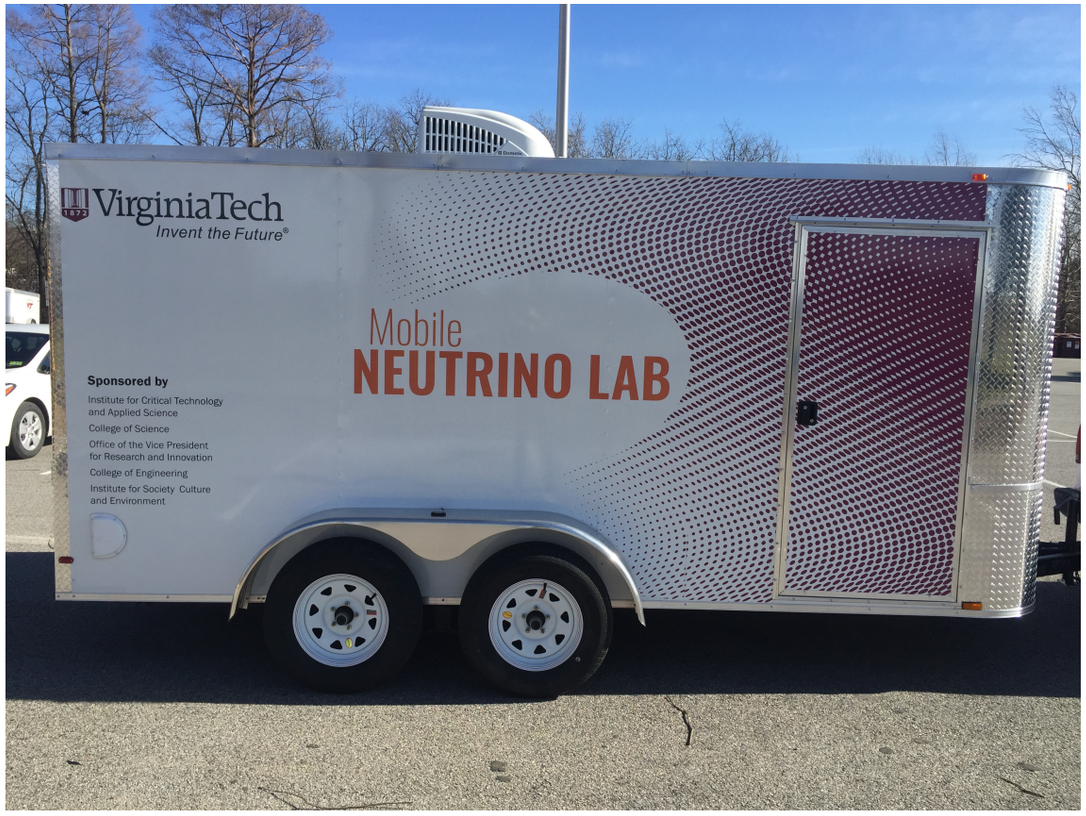
COHERENT



First observation of coherent elastic neutrino-nucleus scattering (2017):

Large cross-section -> small detector size

PORTABLE NEUTRINO DETECTORS?



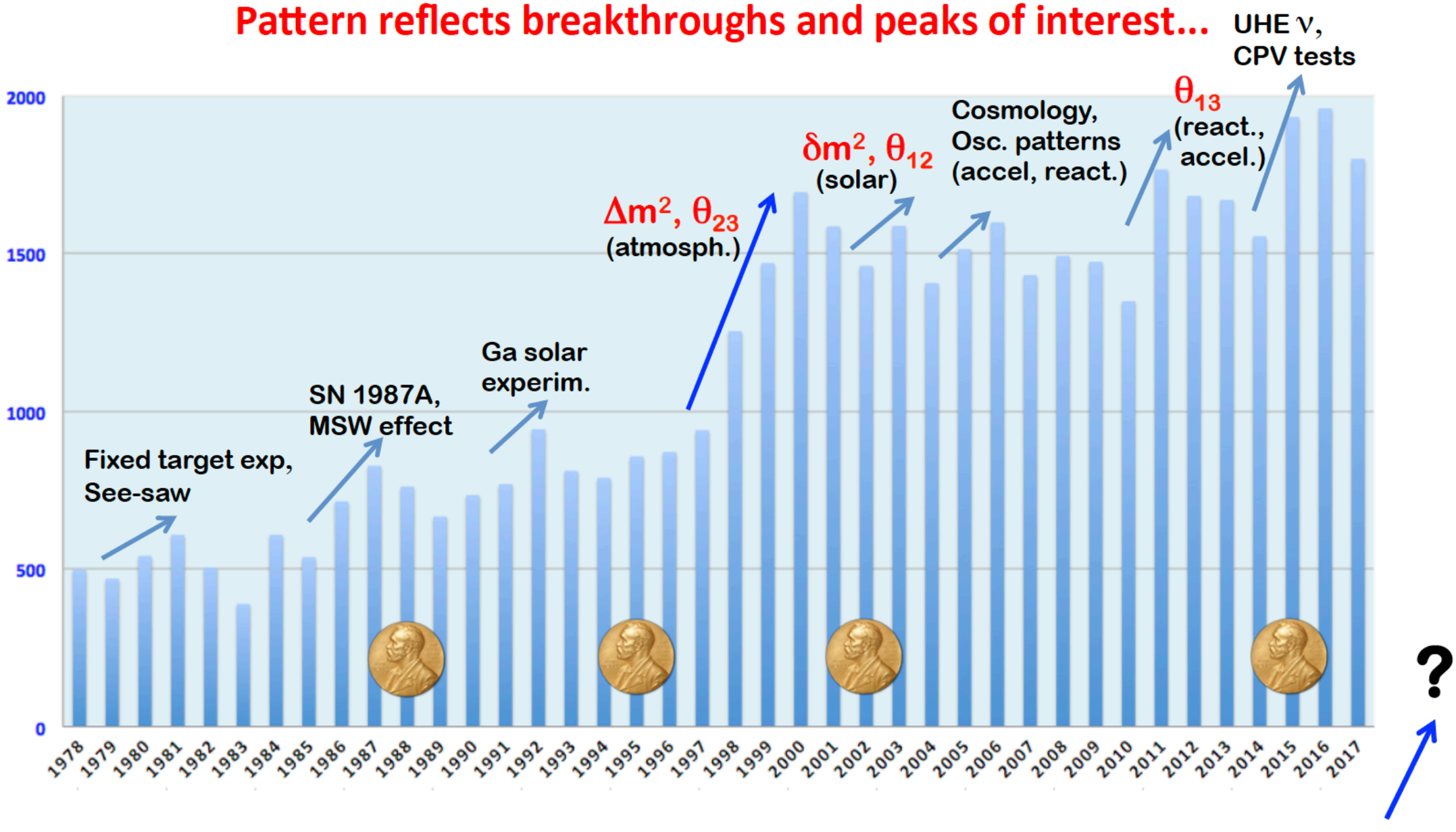
Why not drive to the nuclear reactors?

MiniCHANDLER - portable neutrino lab

STATE OF NEUTRINO PHYSICS FIELD

N. of #neutrino# preprints per year (1978-2018) from INSPIRE

Pattern reflects breakthroughs and peaks of interest...



Credit: Eligio Lisi doi:10.5281/zenodo.1286744

SUMMARY

- Huge progress in the last decades
- Still wide range of open questions
- Wide range of experiments:
  - Long-baseline beam experiments -> oscillations parameters
  - Spectrometers and cosmology -> the absolute mass measurement
  - Clean experiments -> solar neutrinos and neutrino less double beta decay
- Exciting future full of experiments

THANKS FOR YOUR ATTENTION

QUESTIONS ARE WELCOME