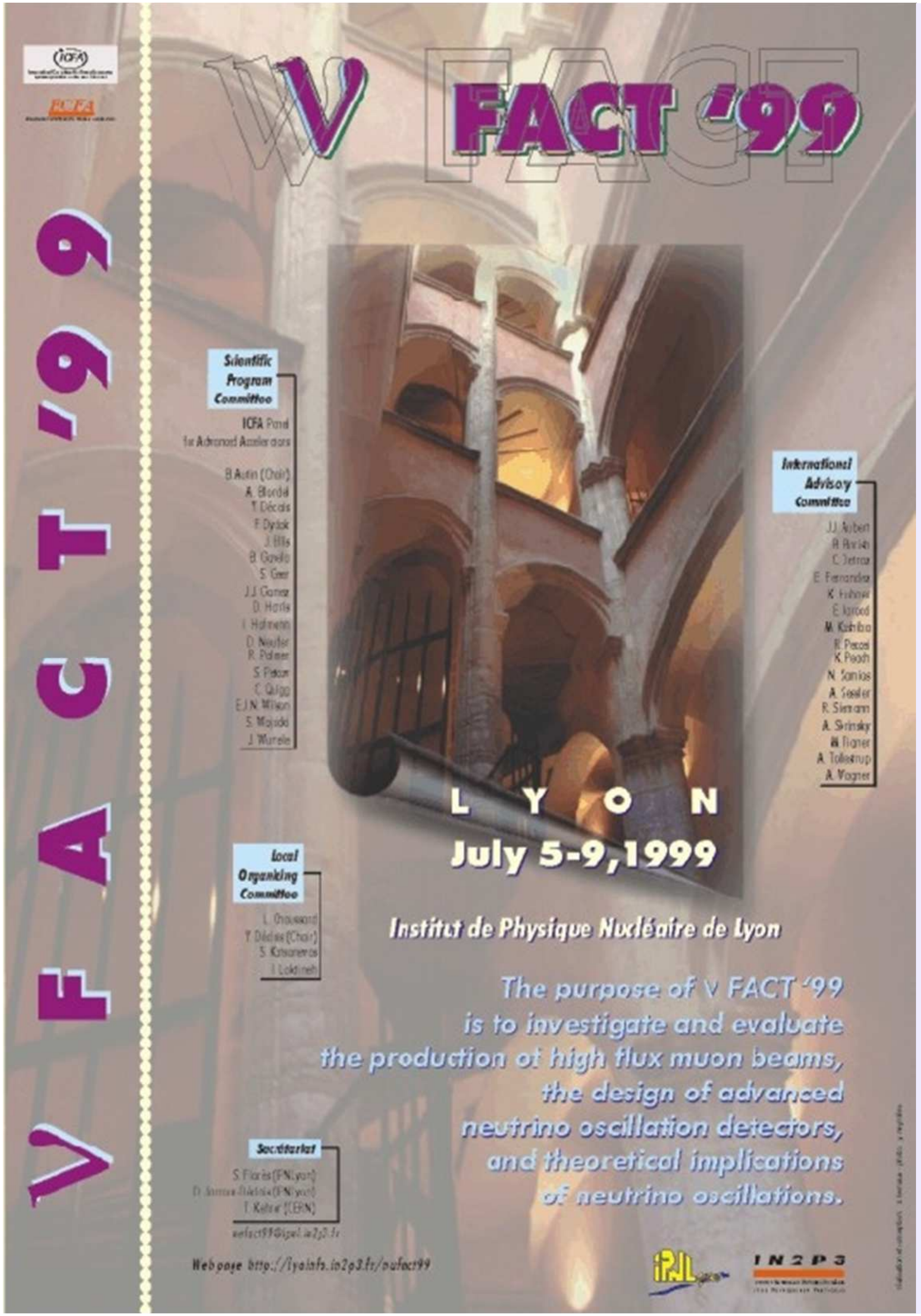
Welcome to the XXVIII (18th) NUFACT Workshop
QUY NHON, Vietnam 22-27 August 2016

Neutrino Physics with Accelerators



The first NUFACT workshop Lyon (1999)

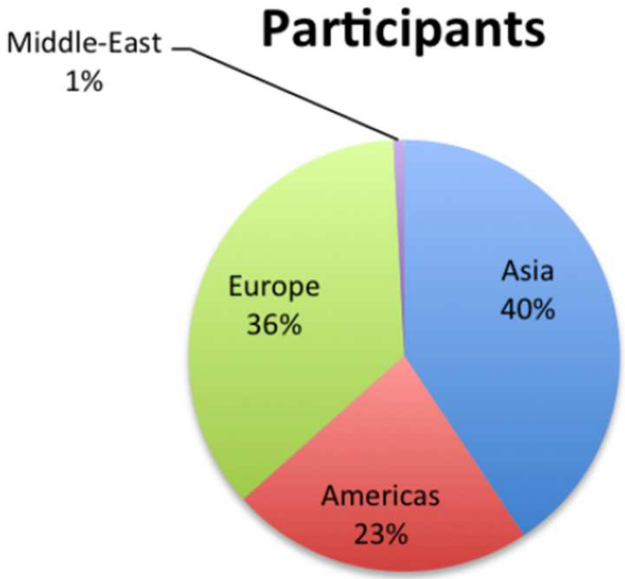
1998: discovery of neutrino oscillations
➔ neutrinos have mass,
accelerator neutrino beams needed

organized by IN2P3/CERN/US/Japan
supported by ECFA, ICFA

2000 Monterey (California, USA)
2001 Tsukuba (Japan)
2002 London (UK)
2003 Columbia Univ. New York (USA)
2004 Osaka (Japan)
2005 LNF Frascati Rome (Italy)
2006 UC Irvine Los Angeles (USA)
2007 Okayama (Japan)
2008 Valencia (Spain)
2009 Fermilab/IIT Chicago (USA)
2010 Mumbai (India)
2011 CERN/Geneva (Switzerland)
2012 Jefferson Lab/Virgina (USA)
2013 IHEP Beijing (China)
2014 Glasgow (UK)
2015 Rio De Janeiro (Brasil)

yearly meeting 100-200 Physicists

Participants of NUFACT2016 in Quy Nhon, Vietnam

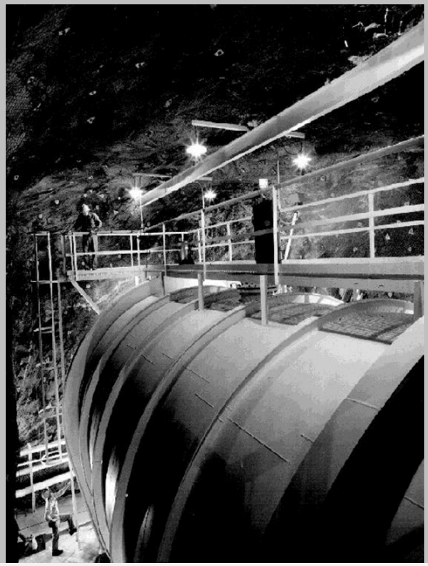


Europe	**44**
Italy	11
Switzerland	11
UK	10
France	5
Spain	3
Germany	2
Poland	1
Sweden	1

Americas	**28**
USA	27
Chile	1

Asia	**50**
Japan	28
P.R. China	10
India	4
Korea	3
Taiwan R.o.C	1
Indonesia	1
Iran	1
Australia	1

Homestake mine detector



first observation of neutrinos from the sun! (1968-2002)

The Nobel Prize in Physics 2002
Raymond Davis Jr., Masatoshi Koshiba, Riccardo Giacconi

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The Nobel Prize in Physics 2002

Raymond Davis Jr.
Prize share: 1/4

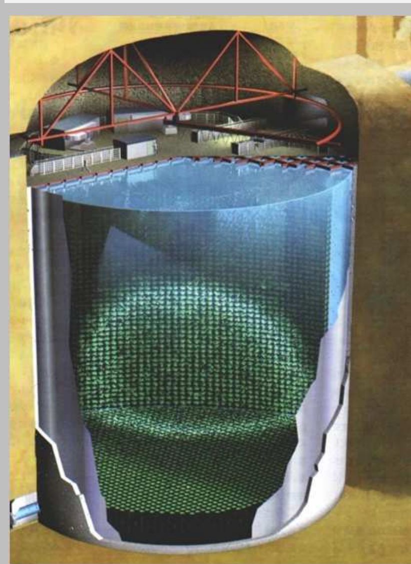
Masatoshi Koshiba
Prize share: 1/4

Riccardo Giacconi
Prize share: 1/2

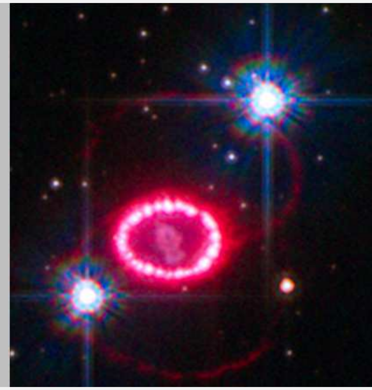
The Nobel Prize in Physics 2002 was divided, one half jointly to Raymond Davis Jr. and Masatoshi Koshiba *"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"* and the other half to Riccardo Giacconi *"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"*.

Ray Davis and Masatoshi Koshiba
detection of cosmic neutrinos
solar neutrinos, atmospheric neutrinos, even supernovae neutrinos!

Kamioka mine detectors



3000 tons (1985-
50000 tons (1996-
500000 tons (2026-?



solar, atmospheric, supernova neutrinos

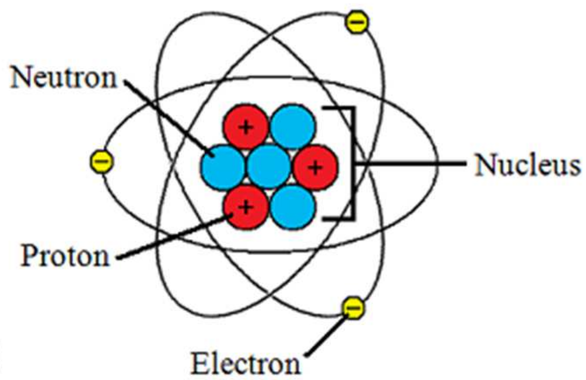
How does the sun work?
A king or a God?

Humans have been asking themselves the question for a long time!
Burning wood, coal, oil?
At the time of the industrial revolution they already calculated that
if it was burning fuel it would take only a few weeks to burn its own mass!
In the mid 20th century it was postulated that the sun was burning by transforming hydrogen into helium (Eddington 1920, Behtke 1938) Nuclear Energy
four hydrogen are heavier than the helium nucleus: (mass→ energy $E= mc^2$)

$$4\,{}^1H \longrightarrow {}^4He + 2e^+ + 2\nu_e$$

But how could one 'see ' this?
The observation of neutrinos from the sun established the validity of the hypothesis.

But who are the neutrinos?



All matter around us is made of atoms,
themselves made of only three constituants:
electrons, protons and neutrons. (observed 1897-1930)

Neutrons and protons are made of quarks and they interact strongly.
Electrons do not interact strongly but they have electric charge.
Protons Neutrons and electrons are confined in atoms

There is a fourth particle called neutrino which is similar to electrons (observed 1956)

-- has no charge
-- interacts very very little (goes through light year of water before interacting)
→very hard to detect!
-- is not confined in matter
-- can reach us directly from inside the sun, supernovae and other cosmic sources
or even from inside nuclear reactors (a good messenger/spy!)
-- very strangely is always spinning clockwise (→ this can happen if no mass)

Elementary particles we are made of

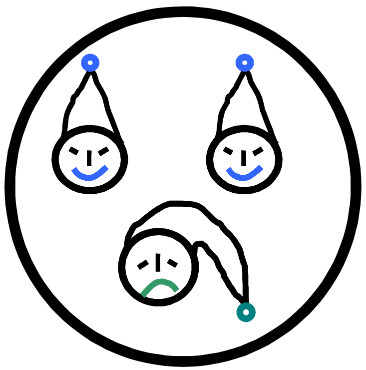
10^{-10} m   Atom = nucleus + electrons

10^{-15} m   Nucleus = protons+neutrons

$<10^{-18}$ m protons and neutrons = 3 quarks

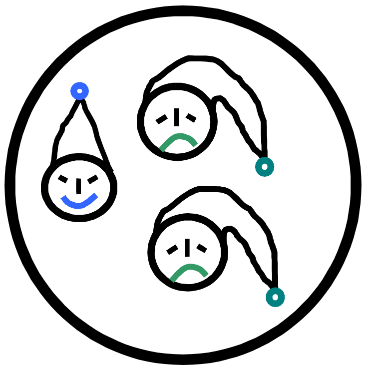
Quarks are always in treesome (or couple with antiquark)

Proton=
2 up + 1 down

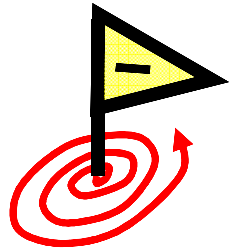


Charge= 1

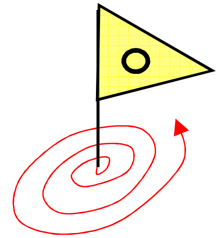
Neutron=
1 up + 2 down



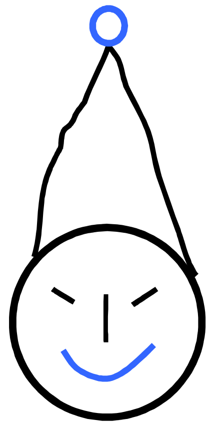
Charge= 0



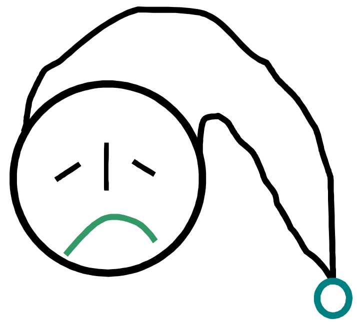
Electron
charge -1



Neutrino
charge 0



Quark up
charge 2/3



Quark down
charge -1/3

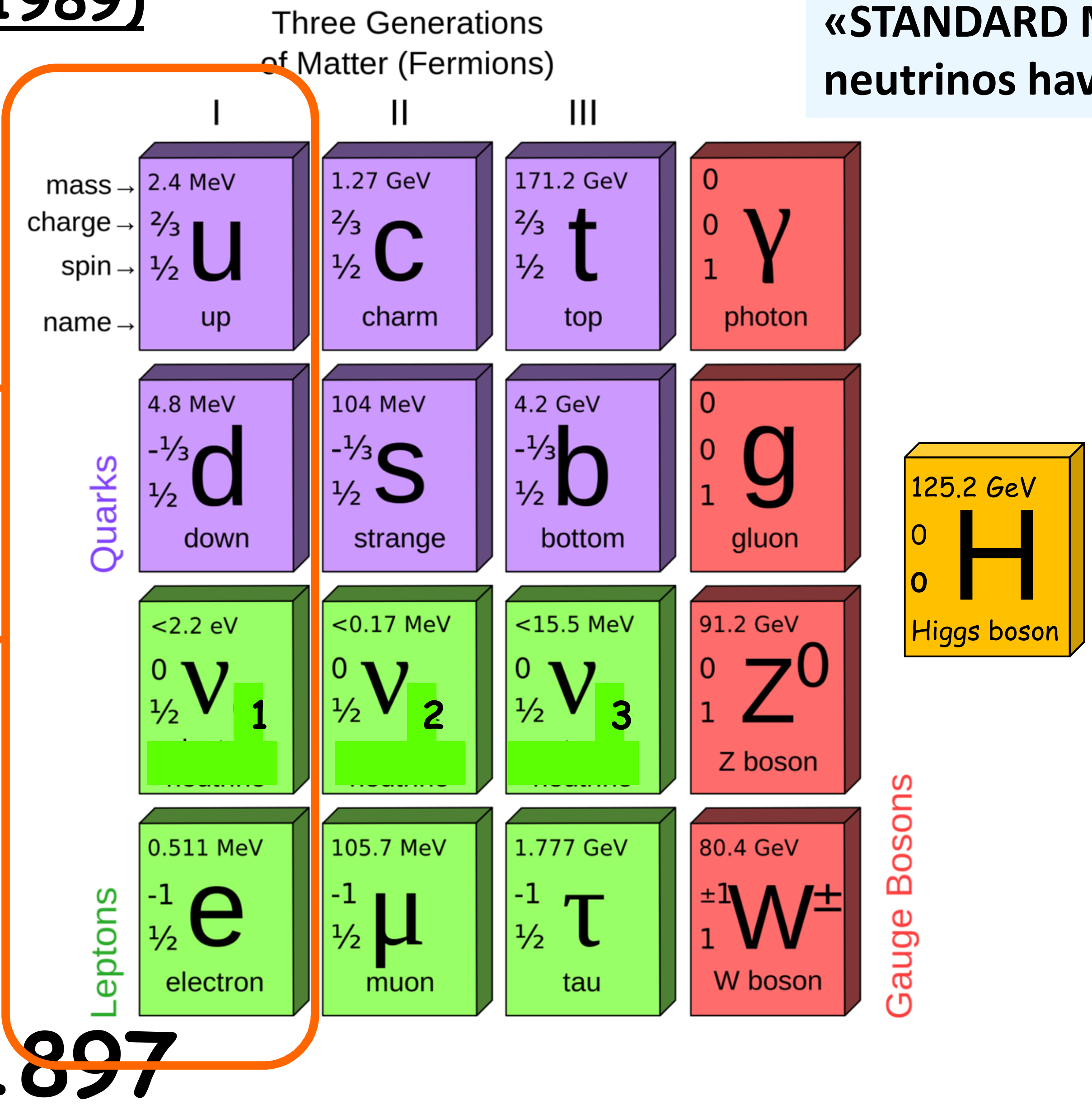
The sum of charges is zero!

There are three families of quarks and three families of neutrinos (1989)

«STANDARD MODEL»
neutrinos have no mass

the particles we are made of

'first family'



2012

Ray Davis observed neutrinos from the sun convincingly since 1968… how come it took so long to get the Nobel prize in 2002?

He only saw one third of what the theory expected!

The *«solar neutrino puzzle»*

There was soon an other neutrino puzzle with the observation of anomalies in neutrinos generated in the atmosphere by cosmic rays

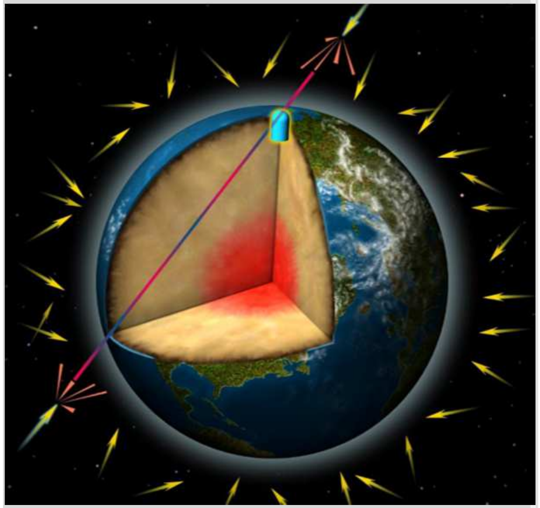
These puzzles were solved in 1998—2002 by the observation that neutrinos can transform from one family to another → disappearance!

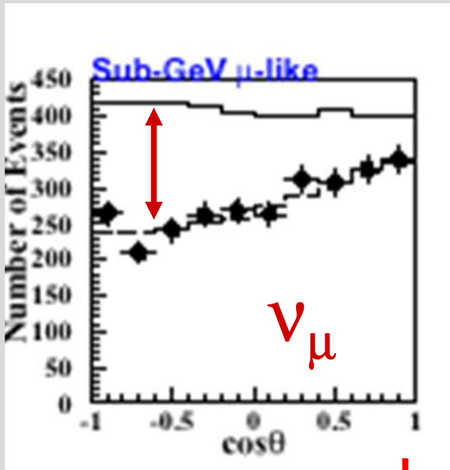
This implies that *neutrinos have mass*

quantum phenomenon of Neutrino Oscillations.

NB We are used to quantum mechanics phenomena taking place in atoms (1 billionieth of meter)
but here it works on millions of kilometers!

Kamioka mine detectors





from under

from above

The Nobel Prize in Physics 2015
Takaaki Kajita, Arthur B. McDonald

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The Nobel Prize in Physics 2015

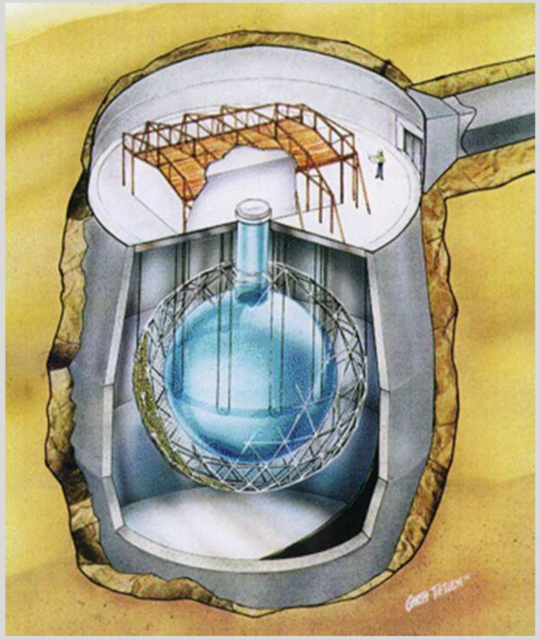
Photo © Takaaki Kajita
Takaaki Kajita
Prize share: 1/2

Photo: K. MacFarlane. Queen's University /SNOLAB
Arthur B. McDonald
Prize share: 1/2

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*

The discovery of neutrino oscillations shows that neutrinos have mass

Sudbury Neutrino Observatory



1000 ton of heavy water D_20
12 m diam. 9456 PMTs

Determine that all neutrinos reach the earth but only 1/3 remain the same family as were produced in the sun

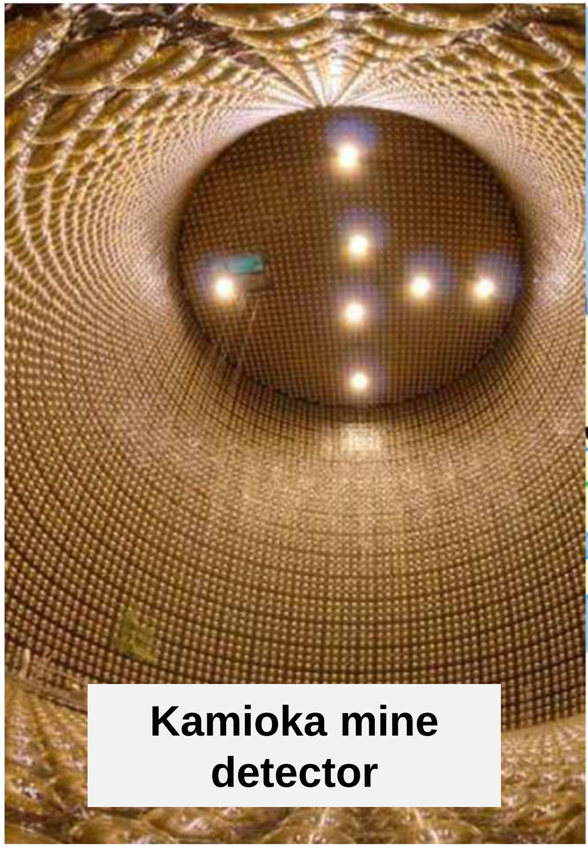
neutrinos of second «family» change family over the distance of crossing the earth

Since 1998, many things happened:

-- The Higgs boson was discovered at CERN! (2012)
-- Several neutrino experiments using accelerators and nuclear reactors have confirmed the oscillation phenomena
-- and discovered new ones

direct observation of change of family : $\nu_\mu \rightarrow \nu_e$ (2013), $\nu_\mu \rightarrow \nu_\tau$ (2015)

-- and open many new questions and opportunities
-- Very large international projects are being launched.



Kamioka mine detector

Tokai to Kamioka experiment T2K: sending neutrinos 295 km away.

~500 members, 61 Institutions, 12 countries

Canada
TRIUMF
Univ. Alberta
Univ. Brit. Columbia
Univ. Regina
Univ. Toronto
Univ. Victoria
York Univ.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany
Univ. Aachen

Italy
INFN, Univ. Rome
INFN, Univ. Naples
INFN, Univ. Padua
INFN, Univ. Bari

Japan
ICRR Kamioka
ICRR RCCN
KEK
Kobe Univ.
Kyoto Univ.
Miyagi Univ. of Educ.
Osaka City Univ.
Univ. Tokyo

Poland
Soltan Inst., Warsaw
Niewodniczanski Inst., Cracow
Technical Univ. Warsaw
Univ. Silesia, Katowice
Univ. Warsaw
Univ. Wrocław

Russia
INR

S. Korea
N. Univ. Chonnam
Univ. Dongshin
Univ. Sejong
N. Univ. Seoul
Univ. Sungkyunkwan

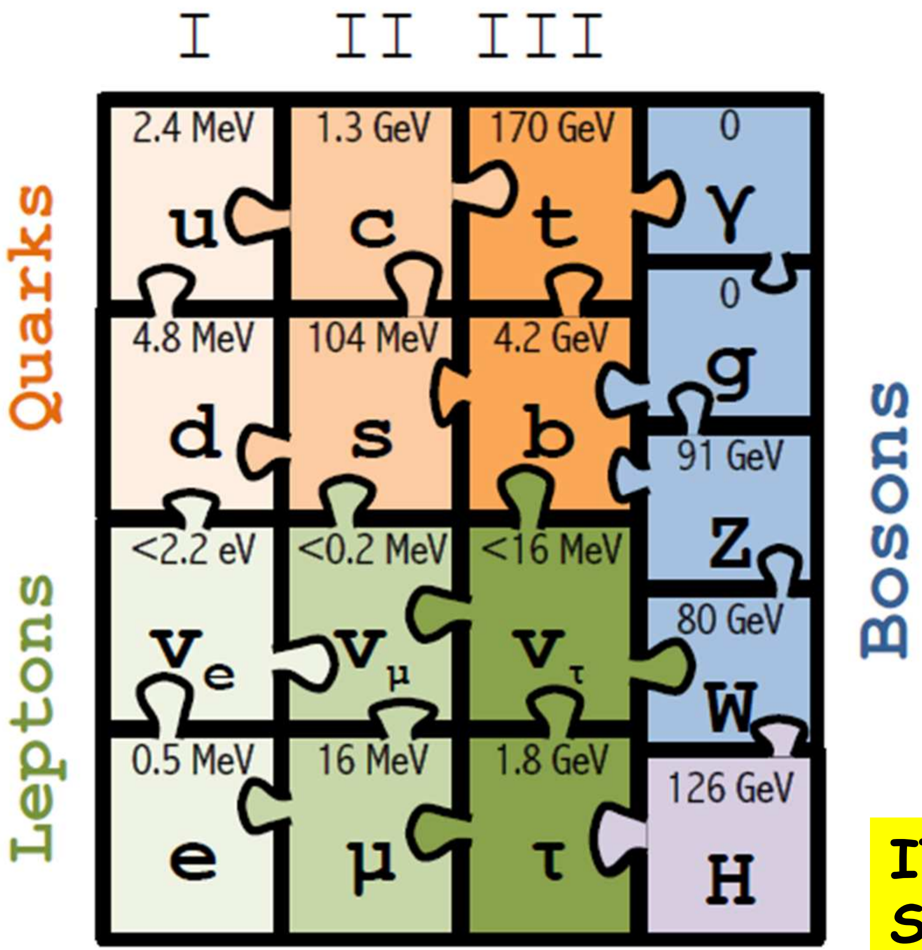
Spain
IFIC, Valencia
Univ. A. Barcelona

Switzerland
Univ. Bern
Univ. Geneva
ETH Zurich

United Kingdom
Imperial C. London
Queen Mary Univ. L.
Lancaster Univ.
Liverpool Univ.
Oxford Univ.
Sheffield Univ.
Warwick Univ.
STFC/RAL
STFC/Daresbury

USA
Boston Univ.
BNL
Colorado St. Univ.
Duke Univ.
Louisiana St. Univ.
SUNY-Stony Brook
U. C. Irvine
Univ. Colorado
Univ. Pittsburgh
Univ. Rochester
Univ. Washington

The Higgs boson was discovered at CERN! (2012)



(c) Sfyrla

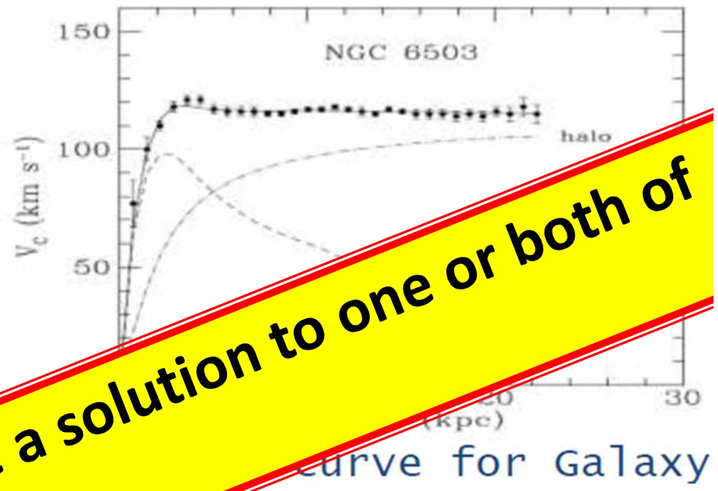
IT LOOKS LIKE THE STANDARD MODEL IS COMPLETE.....

BUT:

We cannot explain:

Dark matter

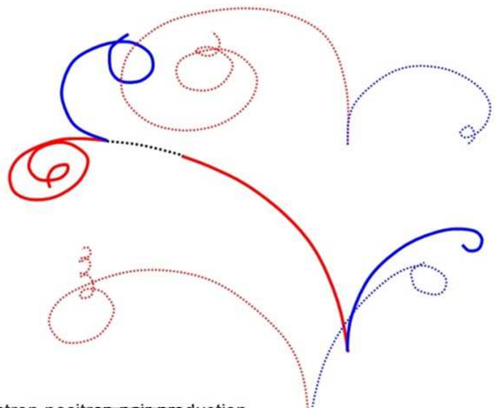
Standard Model particles constitute only 5% of the energy in the Universe



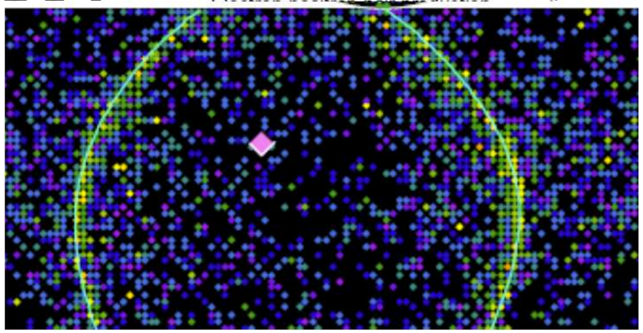
The fact that neutrinos have mass might provide a solution to one or both of these puzzles!

Were is antim

However far w tter in the Universe,
but in o ys transform energy into
ti-particles.

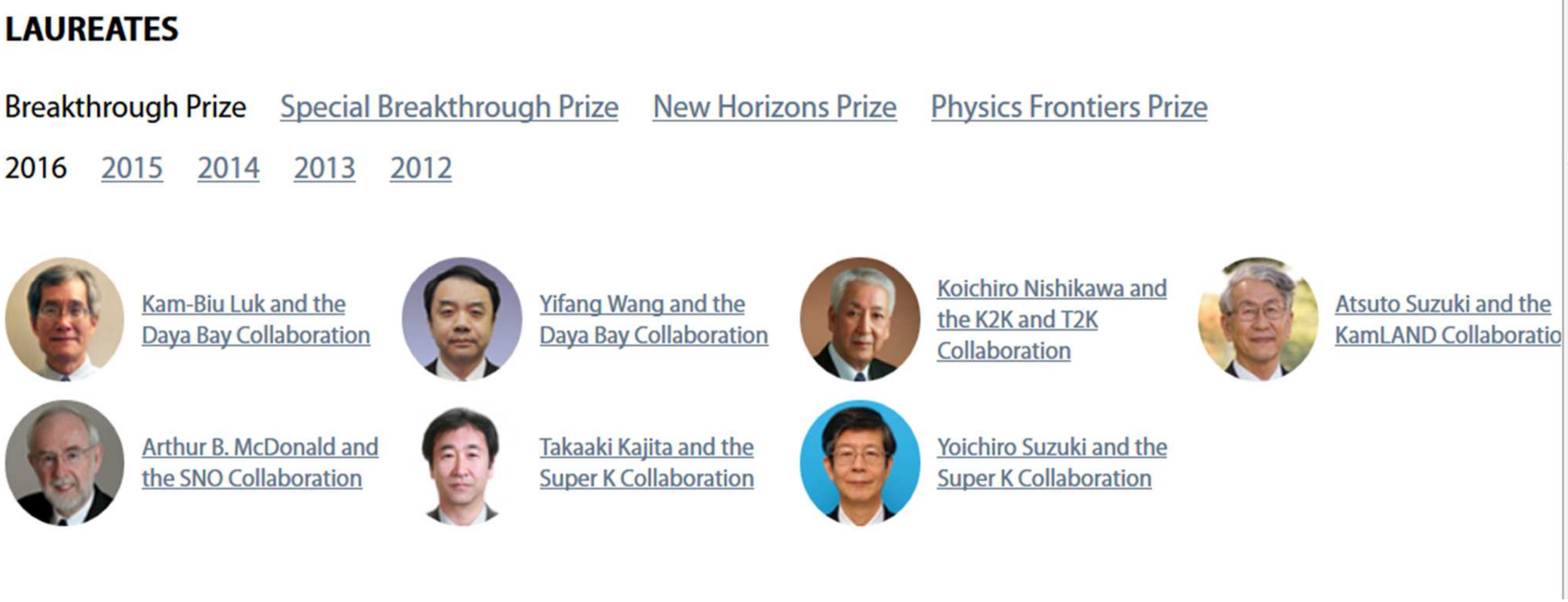


t makes neutrino masses?



Not a unique solution in the SM --
Higgs gives mass?
→ right handed neutrinos? Heavy?
→ How to detect them?
→ One of the questions we discuss at NUFACT

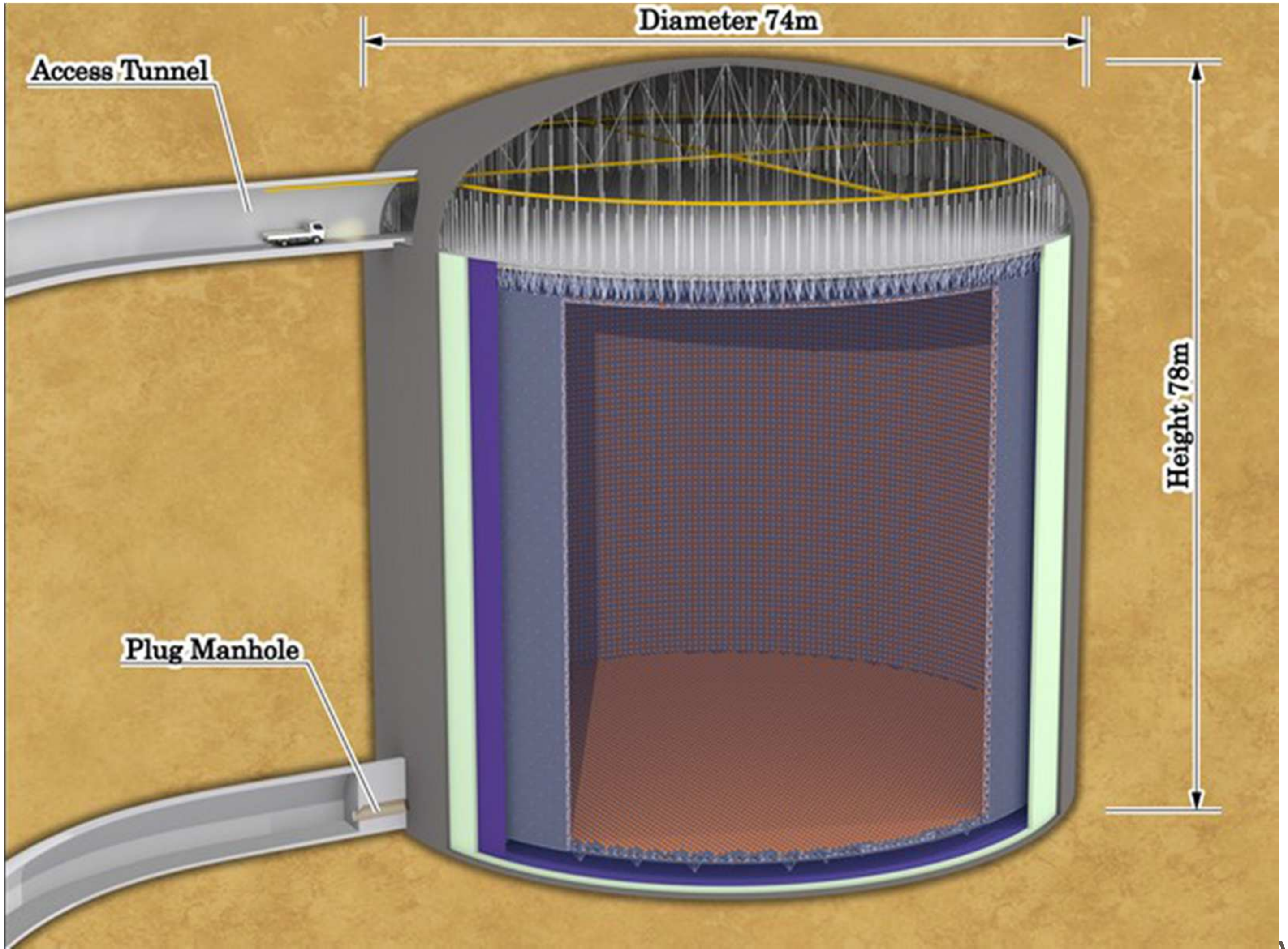
Breakthrough prize



The prize, presented by the Breakthrough Prize Foundation, was awarded "for the fundamental discovery of neutrino oscillations, revealing a new frontier beyond, and possibly far beyond, the standard model of particle physics".

CP violation and the existence of heavy right-handed neutrinos are expected, and will provide an intense reseach program for many years to come. Neutrinos are leading candidates to explain the dominance of matter over anti-matter in the Universe, and constitute good dark matter candidates.

HyperKamiokande: 2 tanks of 300 ktons

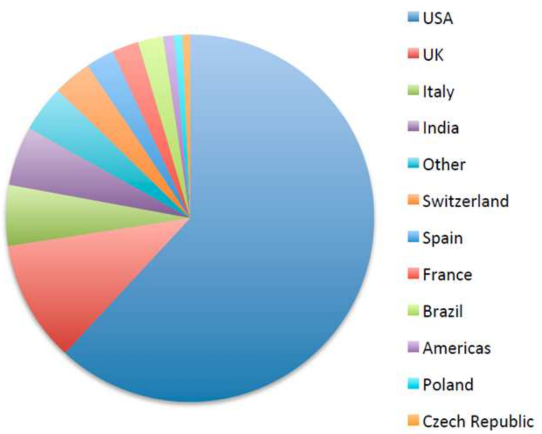


The DUNE Collaboration

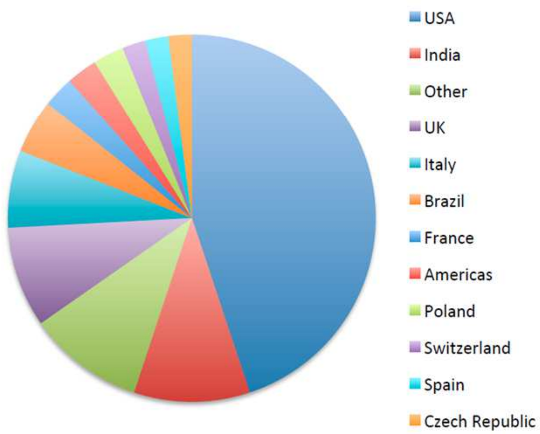
complementary to HyperK

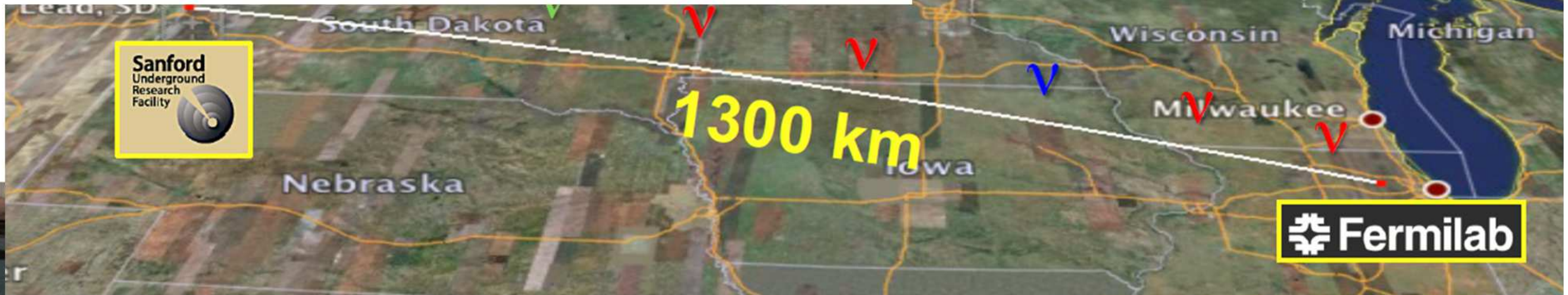
As of today: (Feb 2016) from

790 Collaborators



144 Institutes





Conclusions

Neutrinos have been more difficult to study than the other building blocks of the Universe. There is still a lot we dont know about them.

Great progress was made and neutrinos are today at the limit of the unknown

neutrinos have mass and might contains the solution of other unexplained questions: dark matter, matter-antimatter asymmetry of the Universe.

The news of the creation of a neutrino physics group at Quy Nhon is exciting!

NUFACT workshops have been a place of choice where questions were raised, followed up and often answered in this quest,
by discussions between physicists involved in theory, experiments and accelerators.
<u>This is in the spirit of the Rencontres du Vietnam</u>

THANK you for hosting the NUFACT16 workshop!