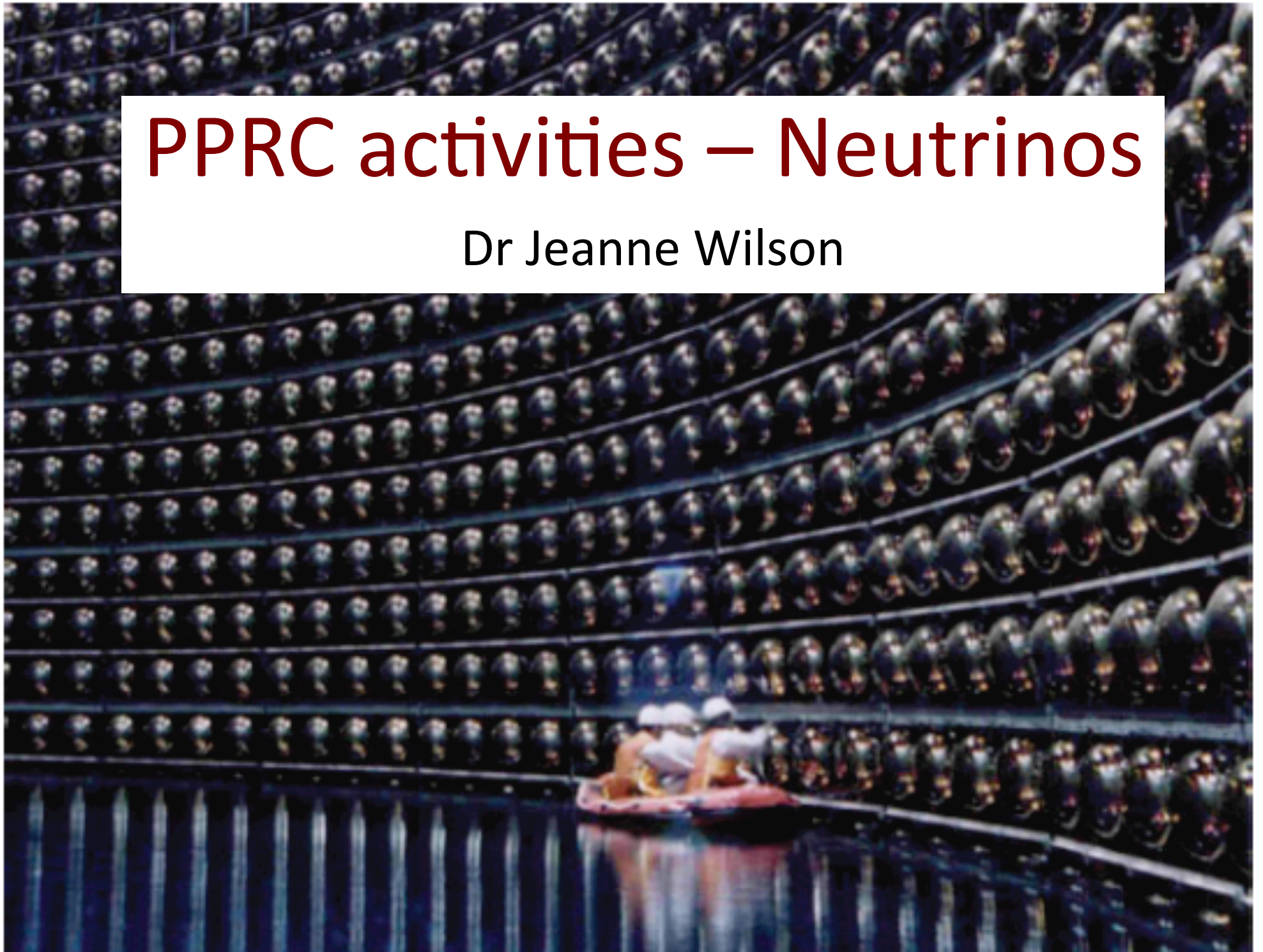


PPRC activities – Neutrinos

Dr Jeanne Wilson



Neutrino Group

- Francesca Di Lodovico
- Jeanne Wilson
- Roberto Sacco
- Ryan Terri
- Ben Still
- Phil Jones
- Ela Poplawska
- Terry Duboyski
- Linda Cremonesi
- Alex Owen
- Fred Gannaway



LBNO

THE STANDARD MODEL

	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	

Neutrinos

- Fundamental particles
- 3 flavours
- Neutral
- Weakly Interacting
- Massless

THE STANDARD MODEL

	Fermions			Bosons	
Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	

Neutrinos

- Fundamental particles
- 3 flavours
- Neutral
- Weakly Interacting
- ~~Massless~~

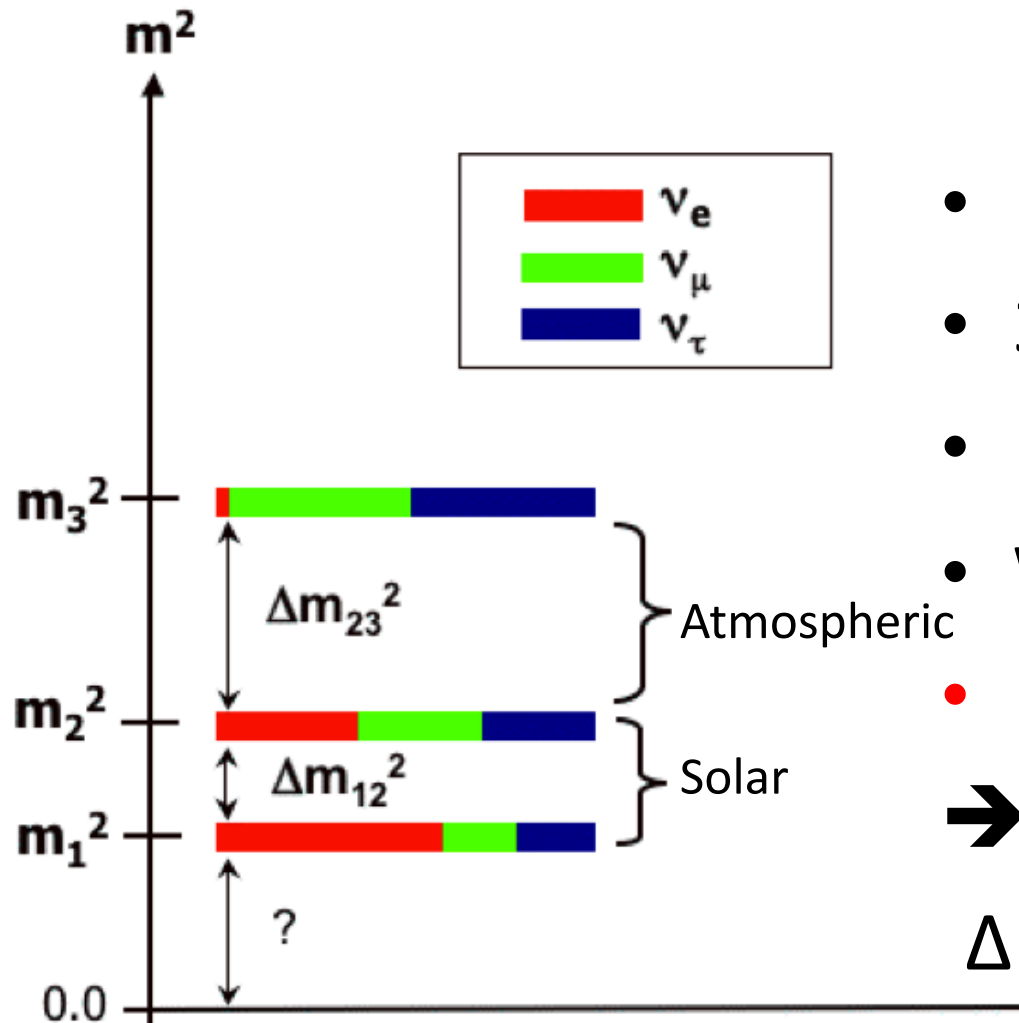
Neutrinos

- Fundamental particles
- 3 flavours
- Neutral
- Weakly Interacting

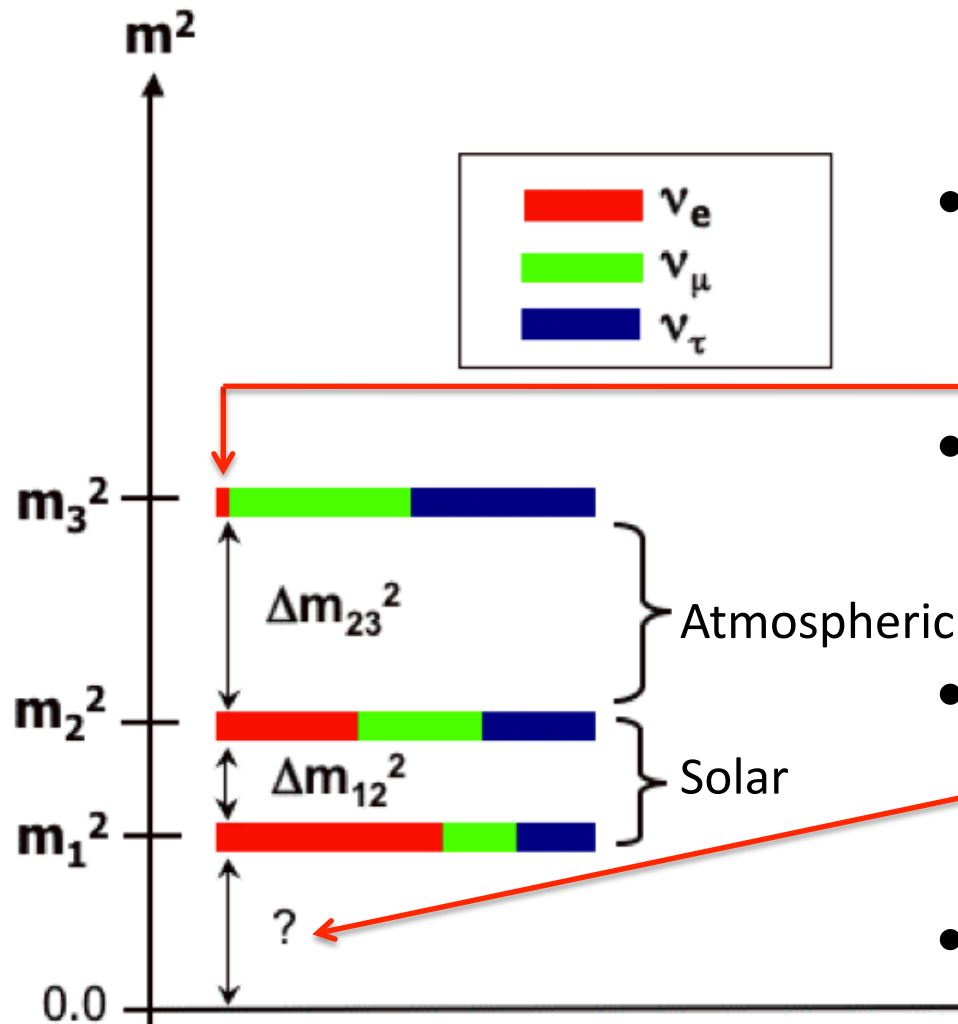
- **Neutrinos oscillate**

➔ Neutrinos have Mass

$$\Delta m_{12}, \Delta m_{13}, \theta_{12}, \theta_{23}, \theta_{13}$$



Neutrinos



- Final mixing angle, θ_{13}
- Leptonic CP violation?
- Absolute mass scale?
- Neutrino nature – Dirac or Majorana?

Neutrinos

Matter Antimatter
Asymmetry of the
Universe

Why are we here?

Final mixing angle, θ_{13}

Leptonic CP violation?

Grand Unified Theories

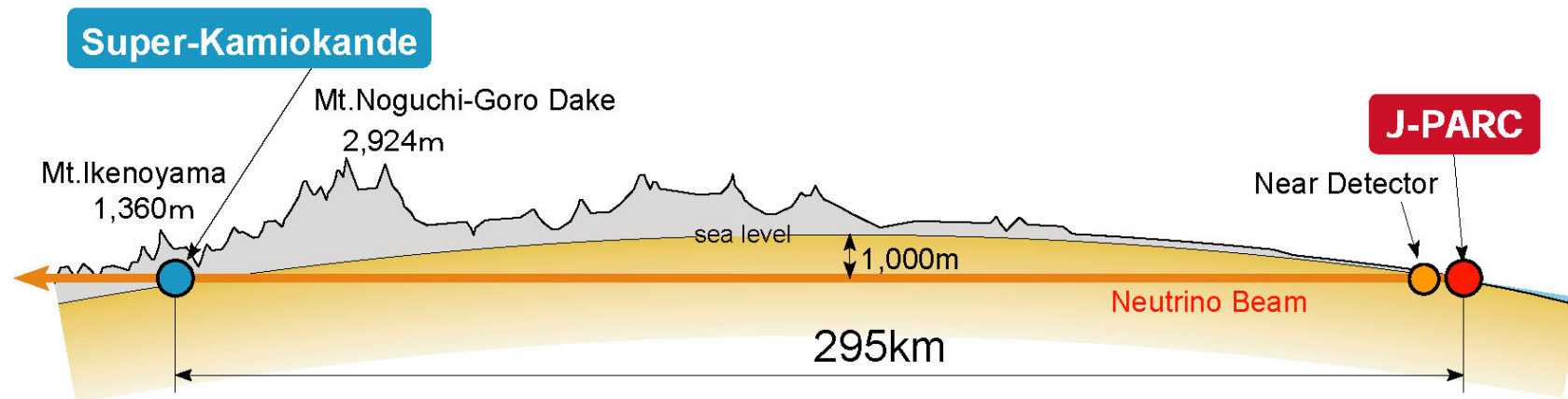
Full understanding of the
forces of nature

Absolute mass scale?

Neutrino nature –
Dirac or Majorana?

Messengers from inaccessible places

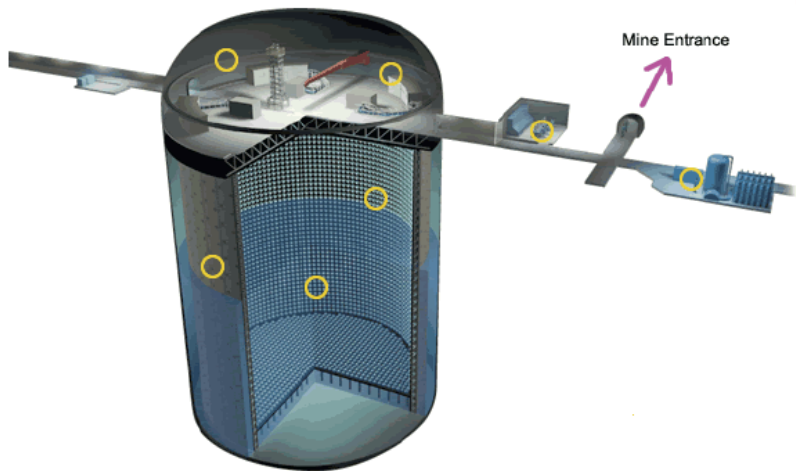
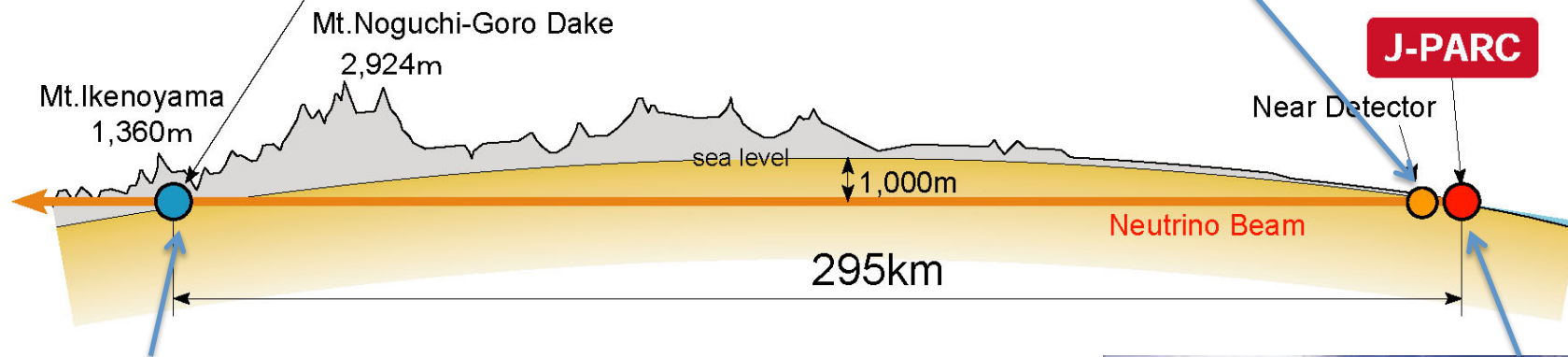
How does the Sun shine?



- Appearance: $\nu_{\mu} \rightarrow \nu_e$ 1st measurement of θ_{13}
- ν_{μ} Disappearance: 2-3 mixing parameters (Δm_{23}^2)

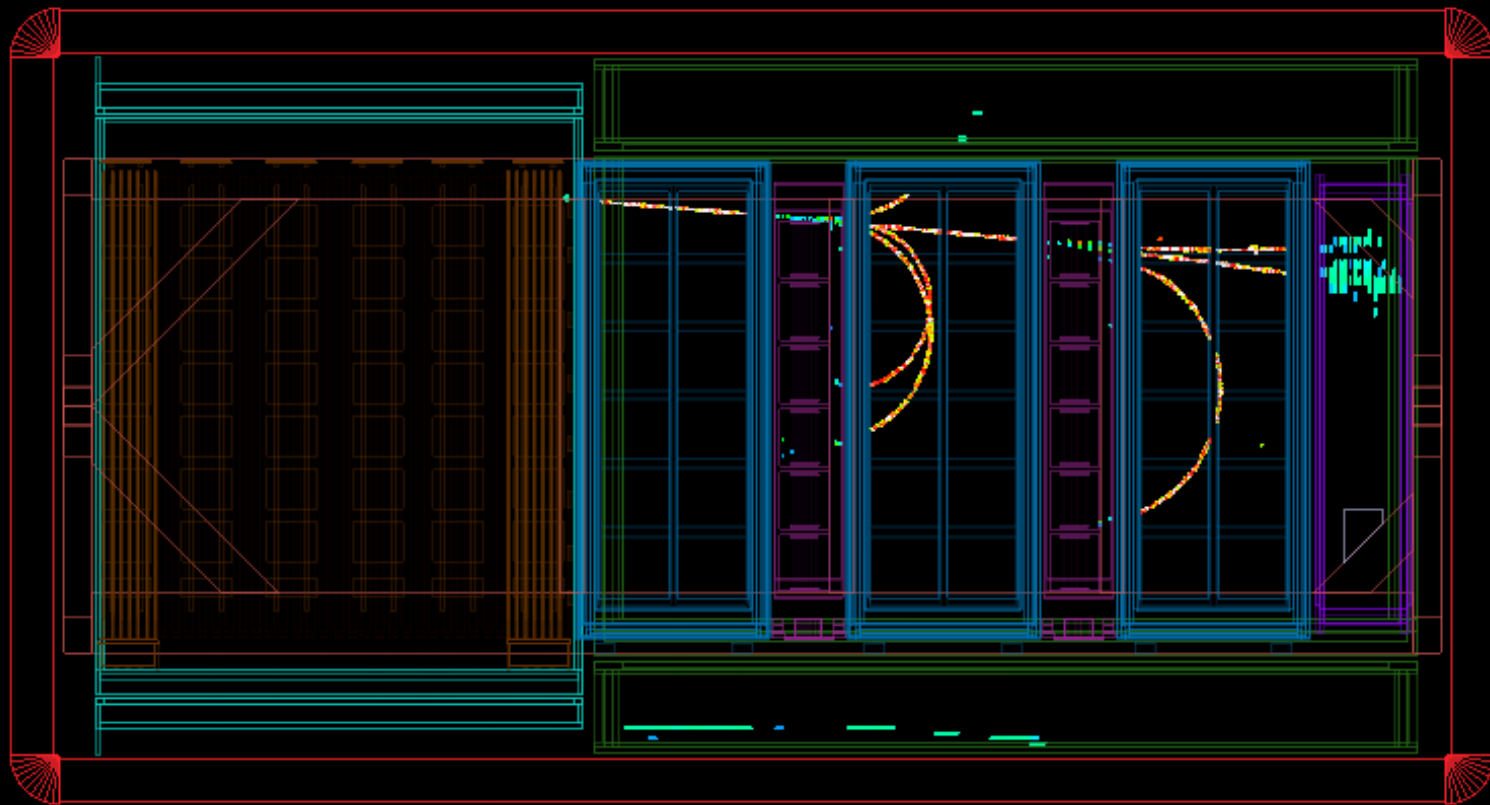


Super-Kamiokande



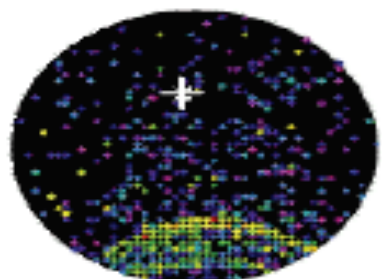
T2K beam back on – first ν in ND280!

Event number : 27404 | Run number : 8115 | Spill : 51004 | Time : Mon 2012-01-23 06:04:28 JST | Trigger: Beam Spill

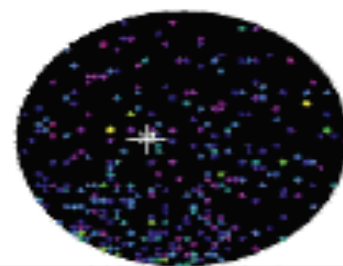
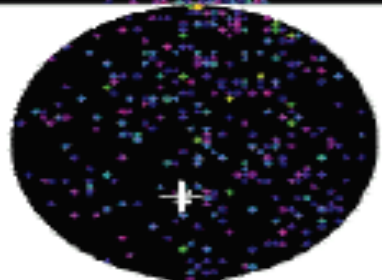
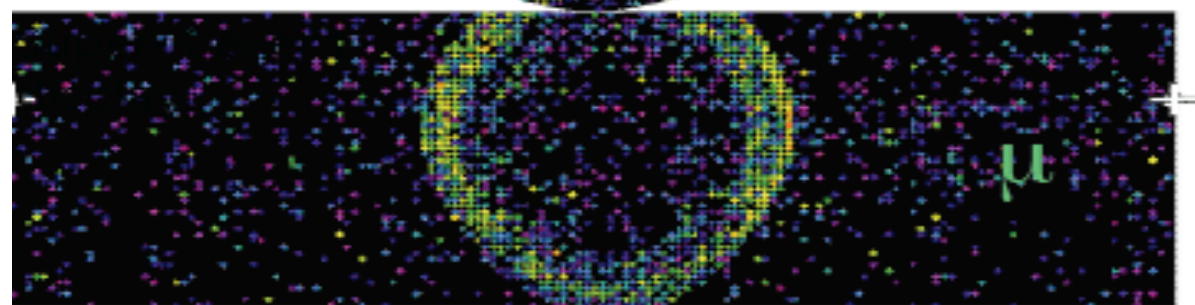


Super K real time event display

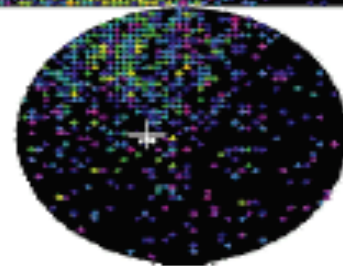
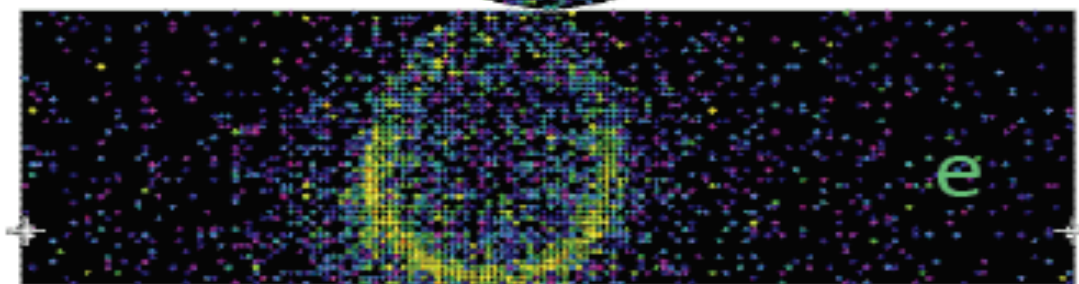
- <http://www-sk.icrr.u-tokyo.ac.jp/realtimemonitor/>



Sharp edge



Fuzzy ring

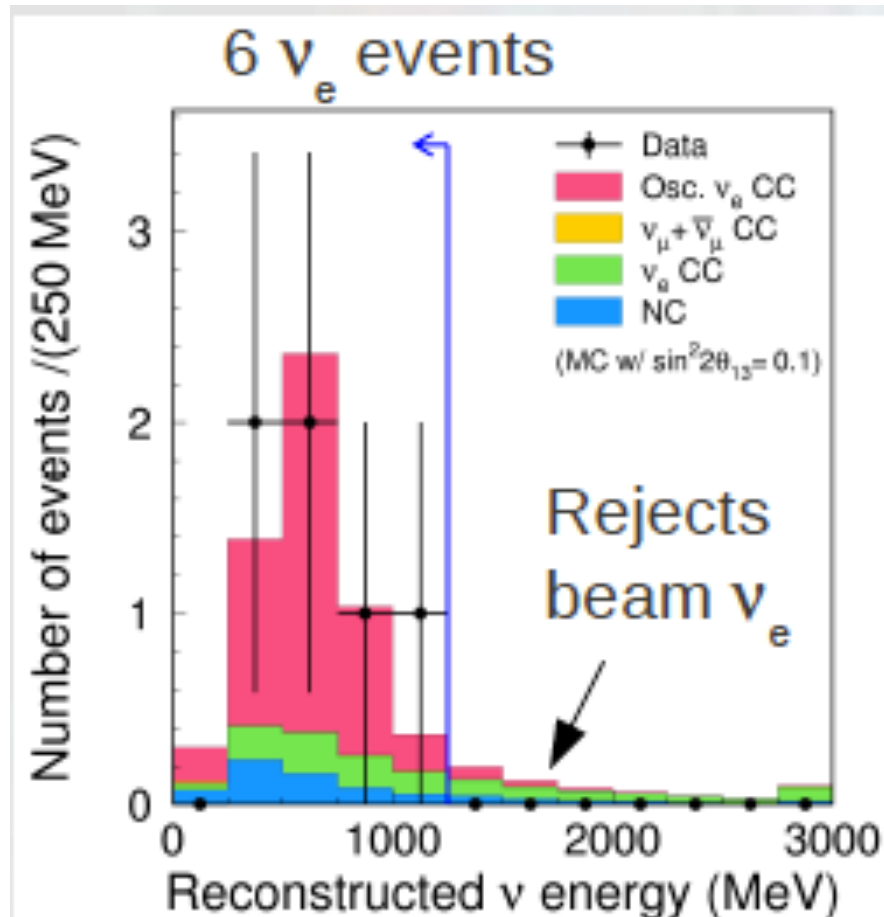


T2K Results: Appearance

... so far

Observed 6 events in SuperK

Expected 1.5 ± 0.3 events for $\sin^2 2\theta_{13}=0$



Consistent with no oscillation at 0.7% (2.5 σ significance)

Normal hierarchy, $\delta=0$:

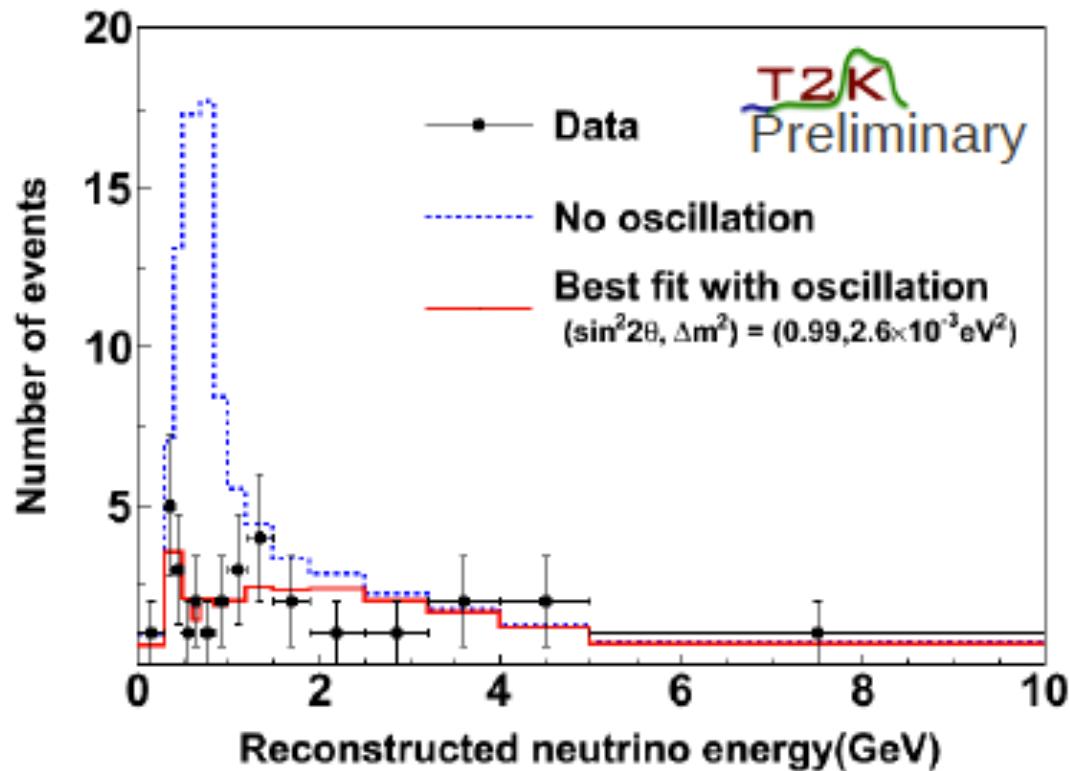
- Best fit: $\sin^2(2\theta_{13})=0.11$
- $0.03 < \sin^2(2\theta_{13}) < 0.28$ @90% C.L.

Phys. Rev. Lett. 107, 041801 (2011)
arXiv:1106.2822v1 [hep-ex]

T2K Results: Disappearance

... so far

Observed 31 fully contained ν_μ events at SuperK
Expected 104 ± 14 for no oscillation scenario



Best fit:

- $\sin^2(2\theta_{23}) = 0.98$
- $\Delta m^2_{32} = 2.65 \times 10^{-3} \text{eV}^2$
(90% CL)

[arXiv:1201.1386v1](https://arxiv.org/abs/1201.1386v1)

Neutrinos

Matter Antimatter
Asymmetry of the
Universe

Why are we here?

Final mixing angle, θ_{13}

Leptonic CP violation?

Grand Unified Theories

Full understanding of the
forces of nature

Absolute mass scale?

Neutrino nature –
Dirac or Majorana?

Messengers from inaccessible places

How does the Sun shine?

SNO+

First solar pep flux measurement.
Test of neutrino oscillation models and new physics

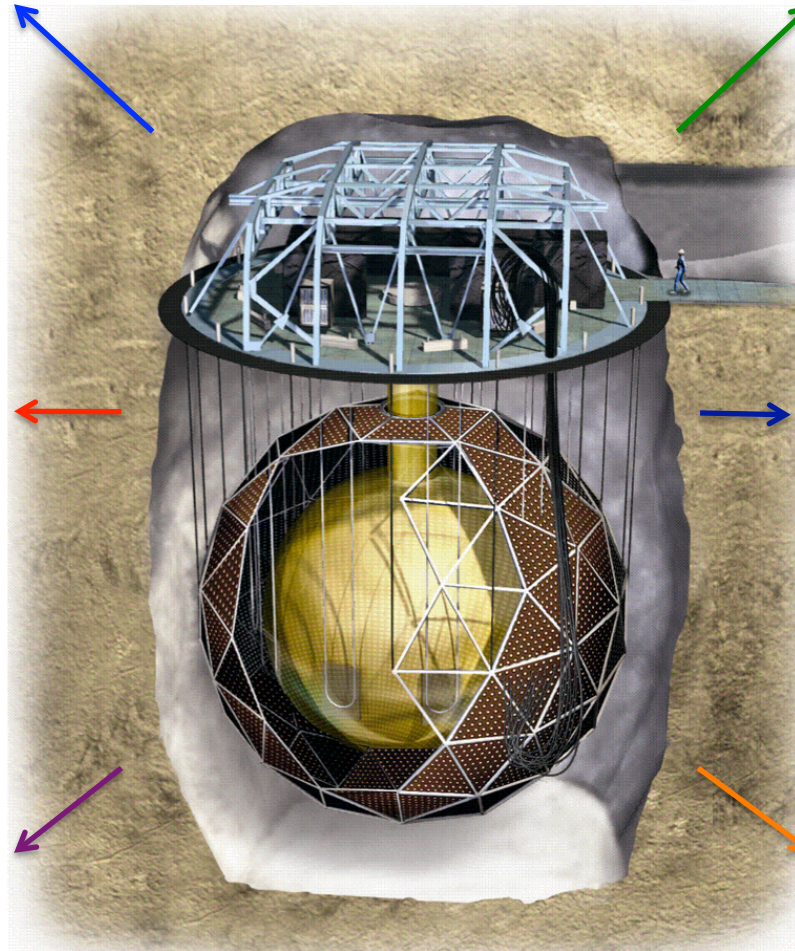
Search for Neutrino-less double beta decay.
Probe neutrino nature and mass.

First solar CNO flux measurement.
Understanding of solar models

Inputs to $2\nu\beta\beta$ models and theory

Unique environment for other low energy physics:
reactor neutrinos,
geo-neutrinos,
supernova detection

Advancing detector technology:
LAB scintillator
Calibration techniques
Purification methods

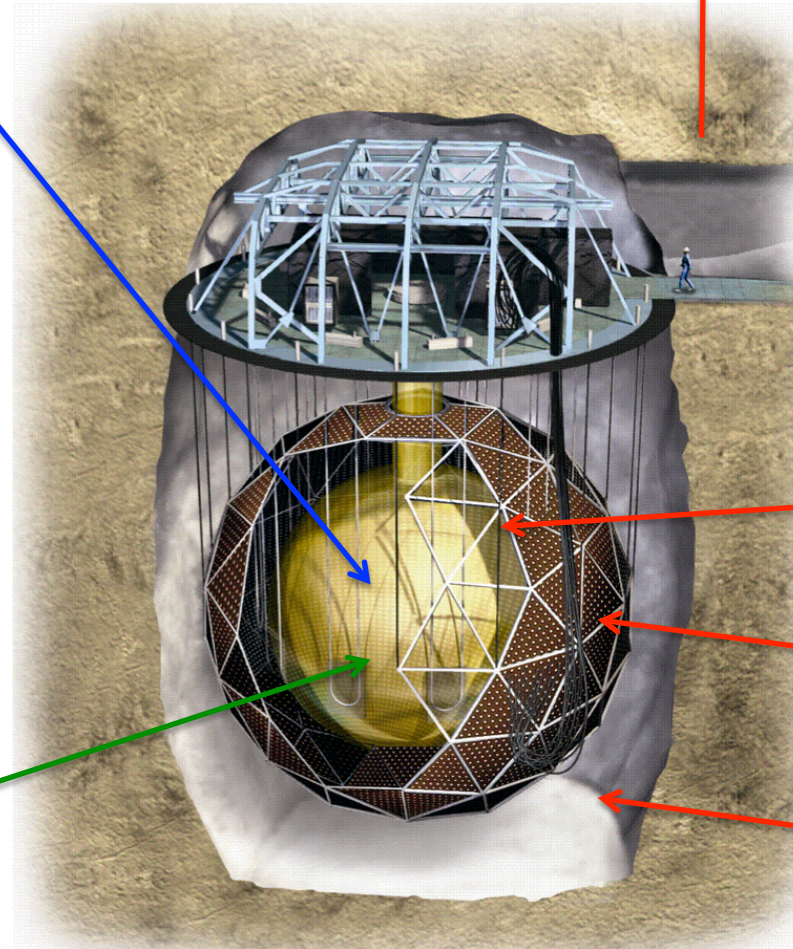


SNO+

2km underground, 6000 mwe
Ultra-low CR μ background
No ^{11}C

780 tonnes linear alkyl benzene (LAB) liquid scintillator
Low energy threshold for solar measurements

$\sim 50\text{kg } ^{150}\text{Nd}$ loaded into the LAB
 $0\nu\beta\beta$ measurement

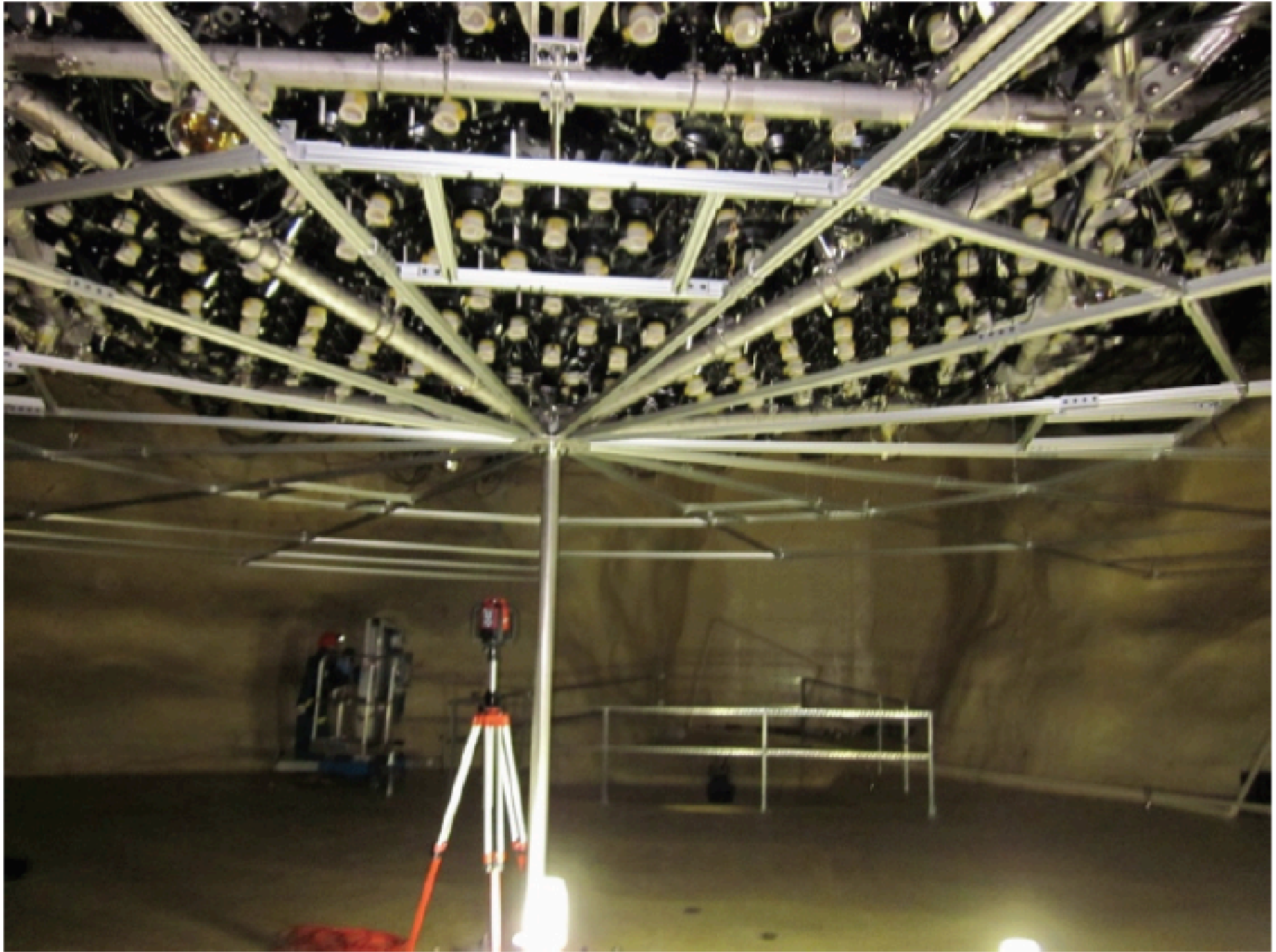


12m diameter acrylic vessel (AV)

~ 9000 PMTs

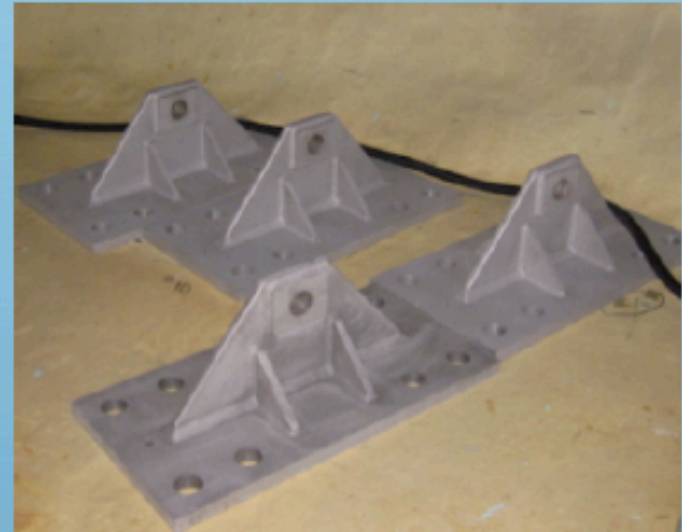
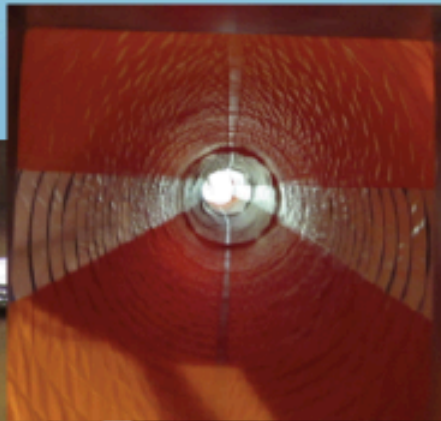
~ 7 ktonne H_2O shielding

- Located in Canada
- Inherits from the successful SNO experiment
- Currently performing structural modifications to SNO+



February 15th 2011

access tube



*drilling to install anchors for the
hold-down net*



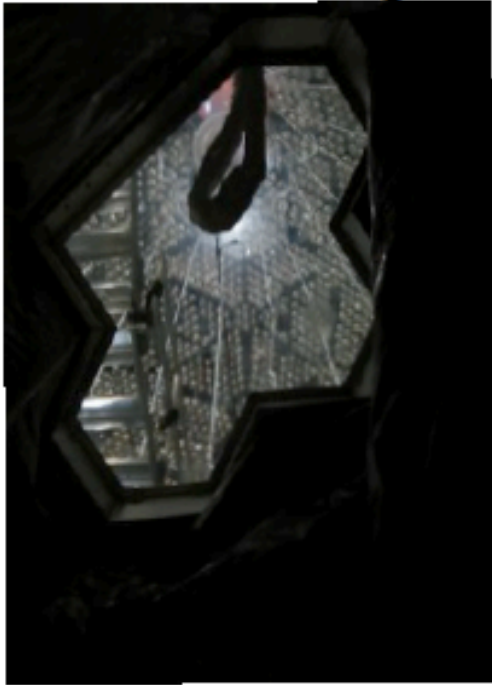
*in the SNO+ cavity, under the
umbrella*







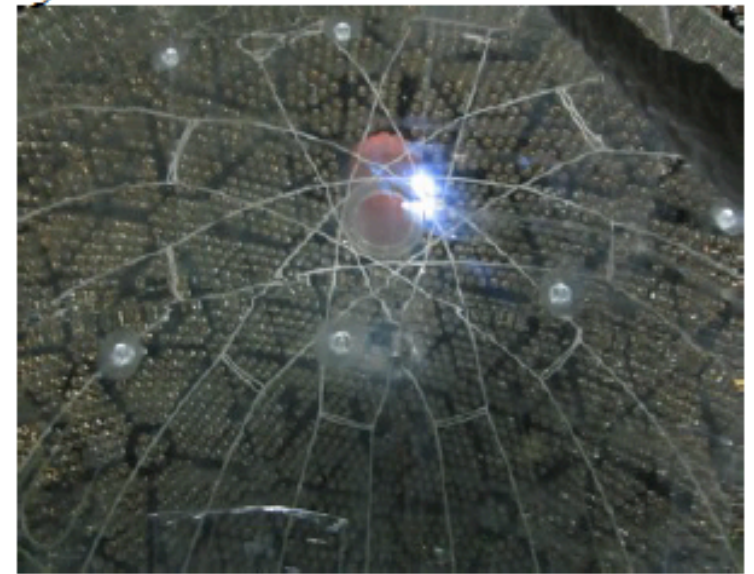




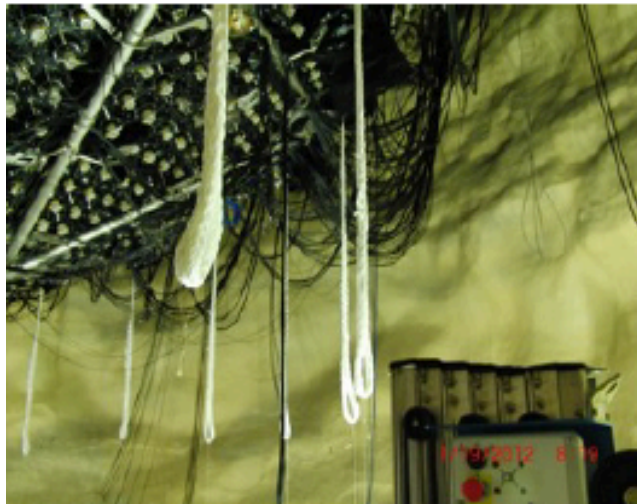
From cavity floor, eye passing through cookie cutter



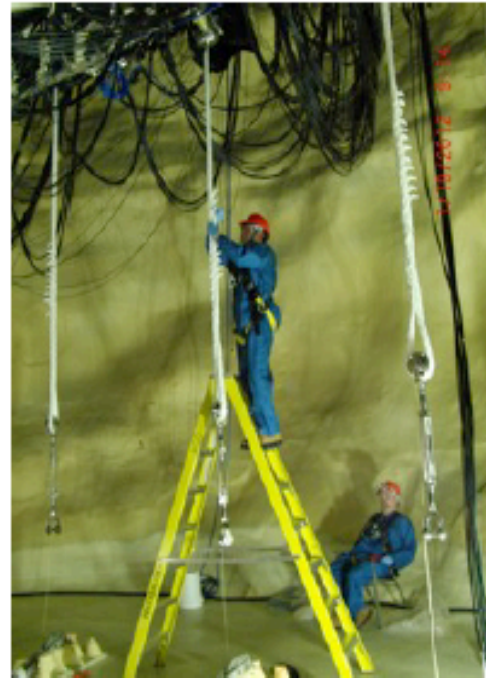
From GENIE lift, rope legs on opposite side passing through PSUP



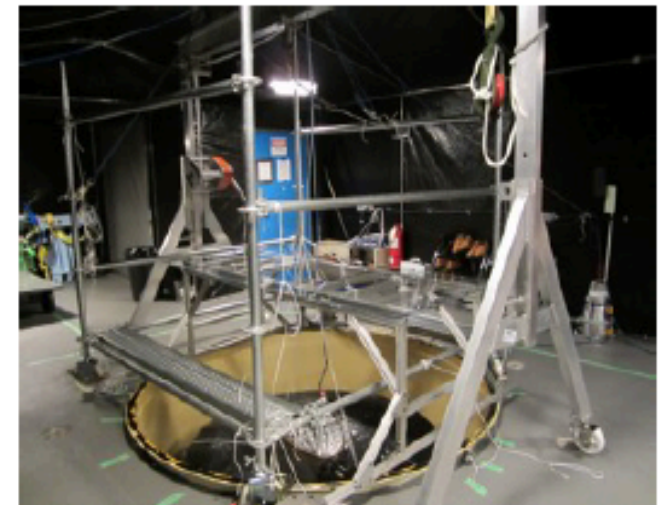
From GENIE lift, through AV up: rope net in place



From cavity floor, eyes hanging



From cavity floor, attach turn buckles as weights



DCR, empty table - just cleaning up and covering hole left to do

LAGUNA-LBNO far sites

Focus on a subset of sites based on LAGUNA findings and prospects for LBL from CERN

- ▶ CERN-Fréjus is a short baseline. It offers good synergy for enhanced physics reach with β -beam at $\gamma=100$
- ▶ CERN-Pyhäsalmi is the longest baseline. It offers good synergy for enhanced physics reach with a NF
- ▶ [CERN-Umbria has an existing beam but is considered at lower priority (missing near detector, limited power upgrade scenarios)]
- ▶ Other LAGUNA sites can serve as alternative and/or backup options.



Summary

- Exciting times ahead for neutrino physics
 - Can **T2K** confirm hints on $\theta_{13} > 0$ later this year?
 - Can leptonic CP violation explain “**why are we here**”?
 - Precision oscillation measurements at **T2K** and **SNO+**
 - Will we see **neutrinoless double beta decay** in **SNO+**
 - Neutrino nature and mass inputs to a **Grand Unified Theory**



Lots of challenges...