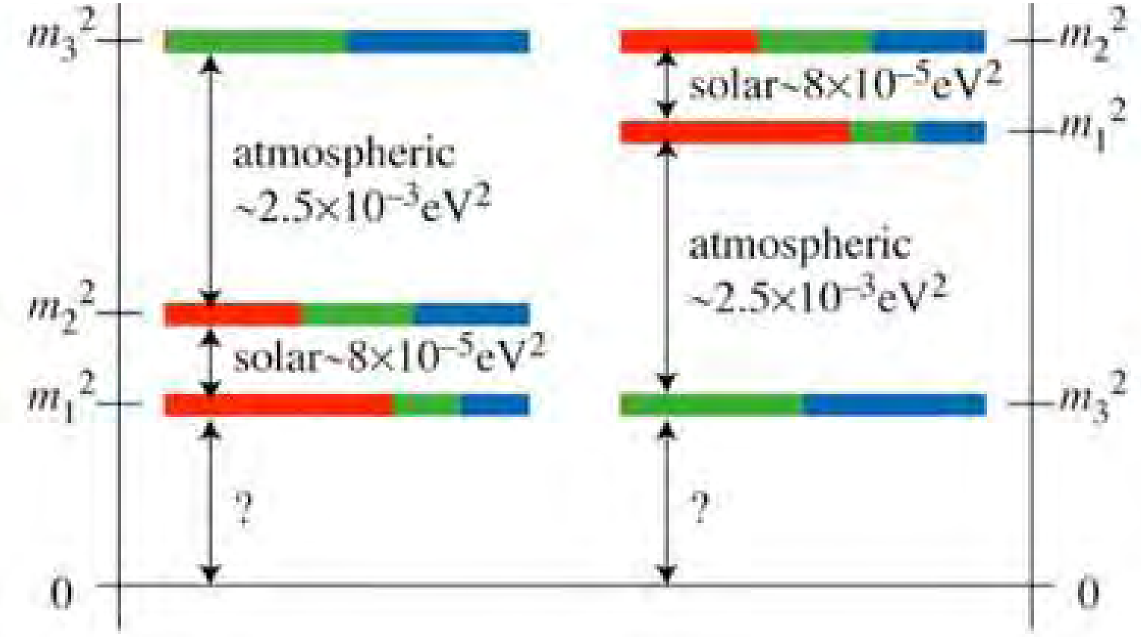
Neutrino-Physics

Status

Achim Stahl, RWTH Aachen

Bad Honnef, November 2012

Open Questions



Spring 2011:

How large is θ_{13} ? → experiments started

Precision measurements (θ_{23} maximal ?) → next gen. oscillations exp.

Absolute mass scale ? → nucl. phys. experiments (KATRIN)

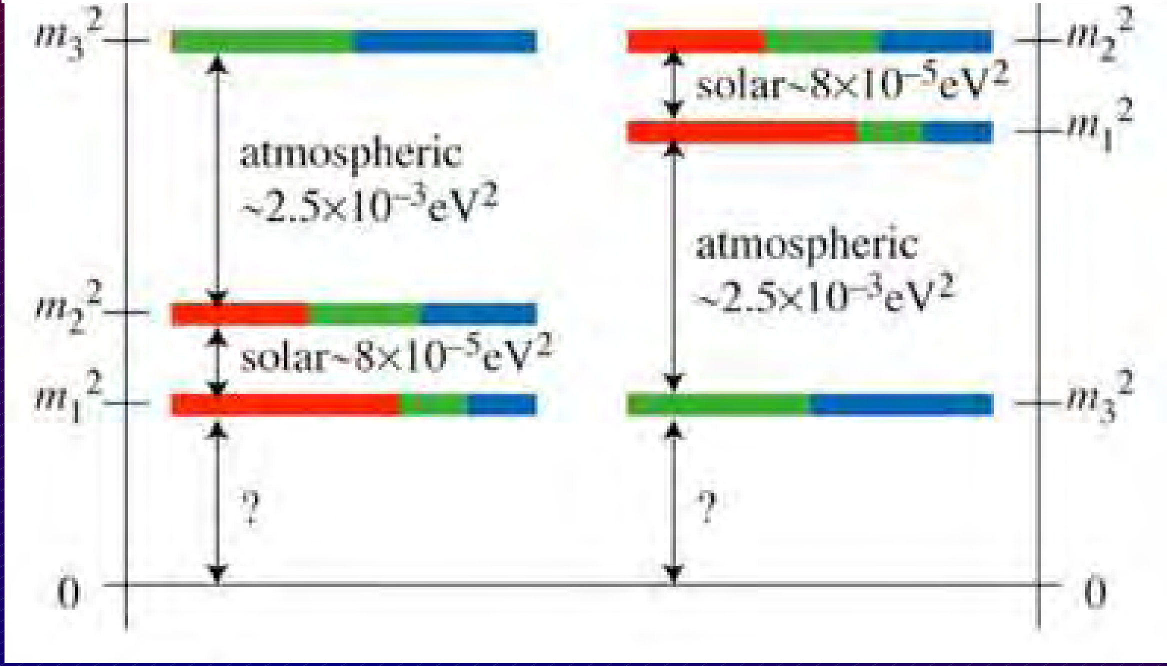
Normal or inverted hierarchie ? → next gen. oscillations exp.

Majorana or dirac neutrinos ? → double beta decay

CP-violation ? → next gen. oscillations exp.

Is the MNS-model correct ?

Open Questions



Autumn 2012

~~Spring 2011:~~

How large is θ_{13} ? → experiments started done

Precision measurements (θ_{23} maximal ?) → next gen. oscillations exp. almost done

Absolute mass scale ? → nucl. phys. experiments (KATRIN)

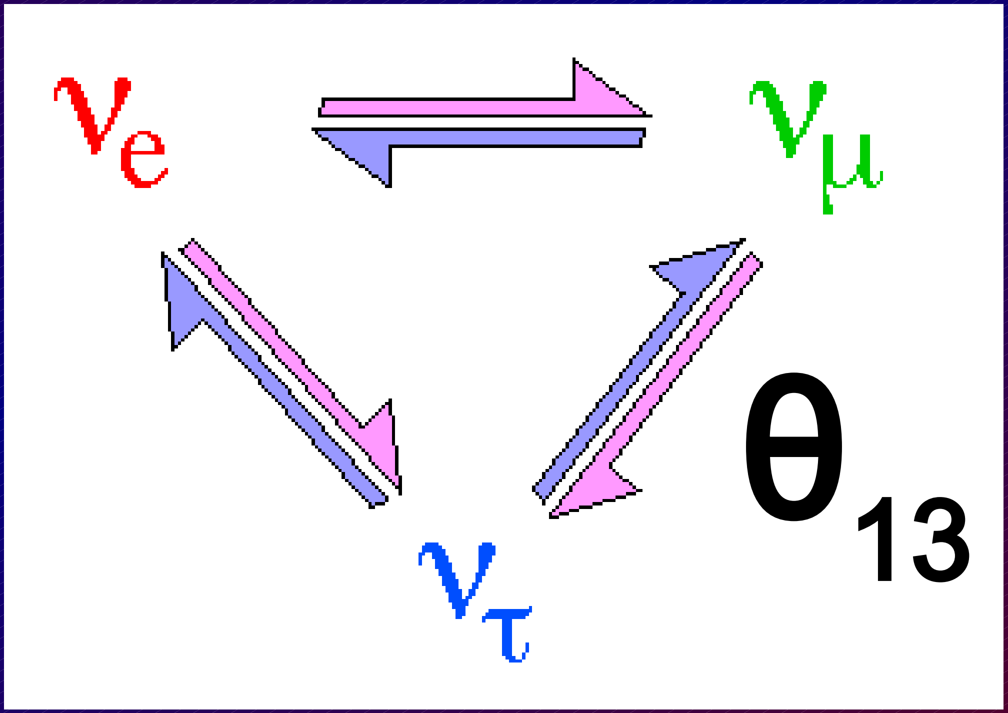
Normal or inverted hierarchie ? → next gen. oscillations exp.

Majorana or dirac neutrinos ? → double beta decay

CP-violation ? → next gen. oscillations exp.

Is the MNS-model correct ? doubts (sterile neutrinos) ?

Neutrino-Oscillations



Neutrino Oscillations

Long Baseline Beams

T2K

RWTH Aachen

MINOS

Appearance

$\nu_\mu \rightarrow \nu_e$

Baseline: 200...2000 km

Depends on: θ_{13}, δ, hierarchy

Reactor Neutrinos

Double Chooz

MPI Heidelberg
RWTH Aachen
TU München
Uni Hamburg
Uni Tübingen

Daya Bay

RENO

Disappearance

$\bar{\nu}_e \rightarrow \bar{\nu}_\mu\ ,\ \bar{\nu}_\tau$

Baseline: 1 km

Depends on: θ_{13}

Neutrino Oscillations

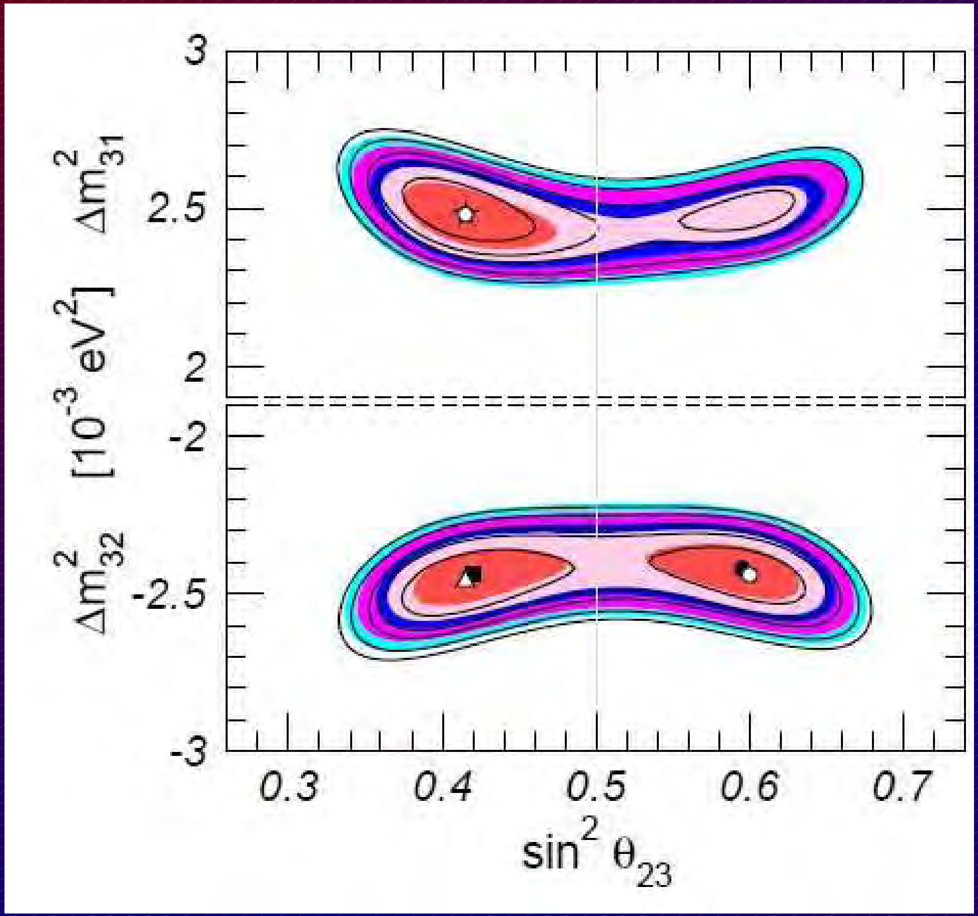
History / θ_{13}

June 2011	T2K	2.5 σ
August 2011	MINOS	1.5 σ
Dec. 2011	DoubleChooz	2.0 σ
April 2012	Daya Bay	5.2 σ
April 2012	Reno	4.9 σ
July 2012	T2K	3.2 σ
August 2012	DoubleChooz	2.9 σ
October 2012	Daya Bay	7.7 σ

	Free Fluxes + RSBL	
	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	0.30 ± 0.013	$0.27 \to 0.34$
$\theta_{12}/^\circ$	33.3 ± 0.8	$31 \to 36$
$\sin^2\theta_{23}$	$0.41^{+0.037}_{-0.025} \oplus 0.59^{+0.021}_{-0.022}$	$0.34 \to 0.67$
$\theta_{23}/^\circ$	$40.0^{+2.1}_{-1.5} \oplus 50.4^{+1.2}_{-1.3}$	$36 \to 55$
$\sin^2\theta_{13}$	0.023 ± 0.0023	$0.016 \to 0.030$
$\theta_{13}/^\circ$	$8.6^{+0.44}_{-0.46}$	$7.2 \to 9.5$
$\delta_{\rm CP}/^\circ$	300^{+66}_{-138}	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ {\rm eV}^2}$	7.50 ± 0.185	$7.00 \to 8.09$
$\frac{\Delta m^2_{31}}{10^{-3}\ {\rm eV}^2}$ (N)	$2.47^{+0.069}_{-0.067}$	$2.27 \to 2.69$
$\frac{\Delta m^2_{32}}{10^{-3}\ {\rm eV}^2}$ (I)	$-2.43^{+0.042}_{-0.065}$	$-2.65 \to -2.24$

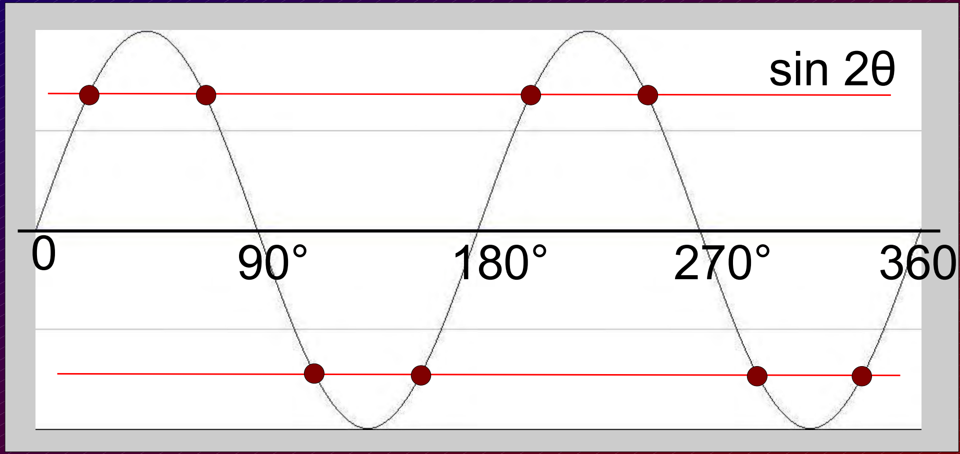
M. C. Gonzalez-Garcia et. al, arXiv 1209.3023

Neutrino Oscillations

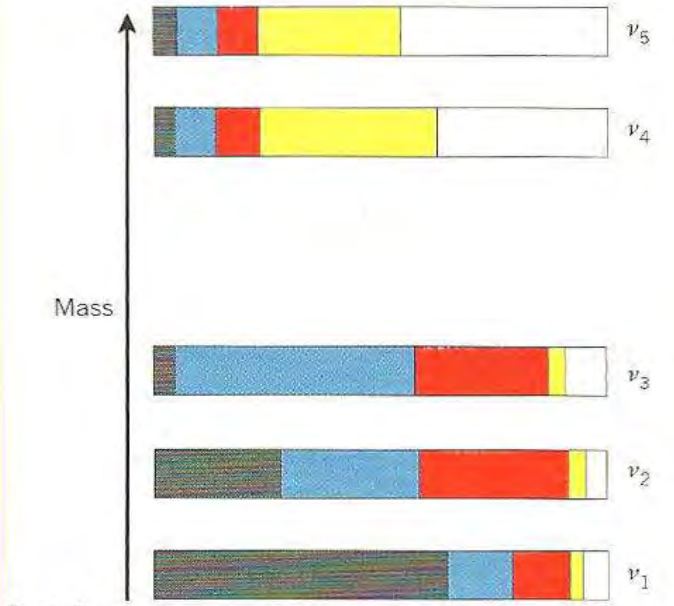


M. C. Gonzalez-Garcia et. al, arXiv 1209.3023

$\theta_{23} \neq 45°$



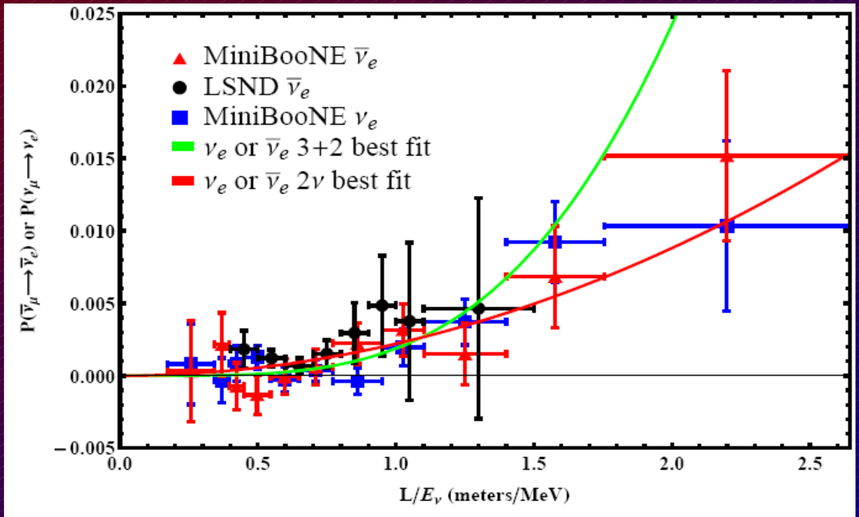
Sterile Neutrinos



Best-fit Neutrino Mixing

Sterile Neutrinos in yellow and white, the rest are active neutrinos.

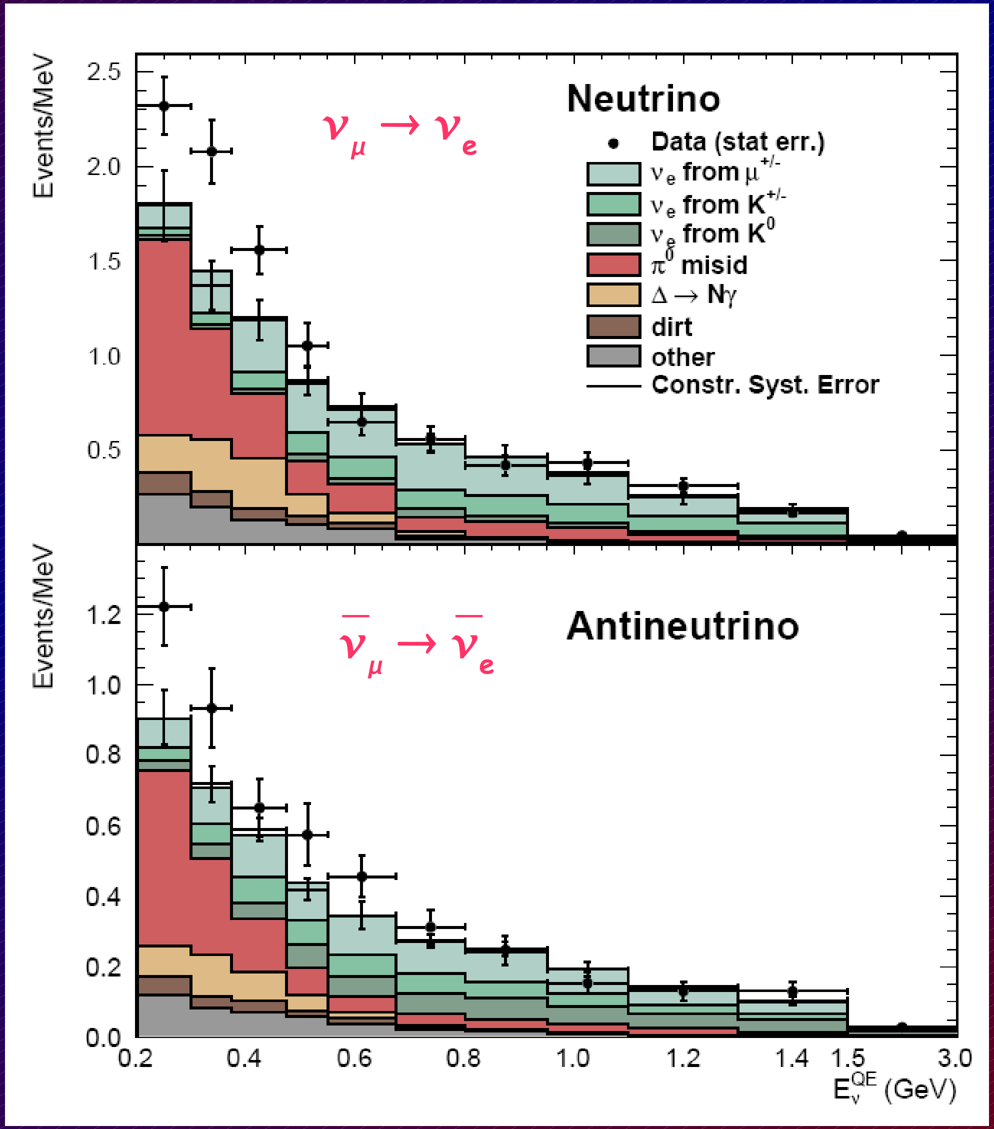
LSND-Effect



Statistcal fluctuation almost excluded

? Systematics ?

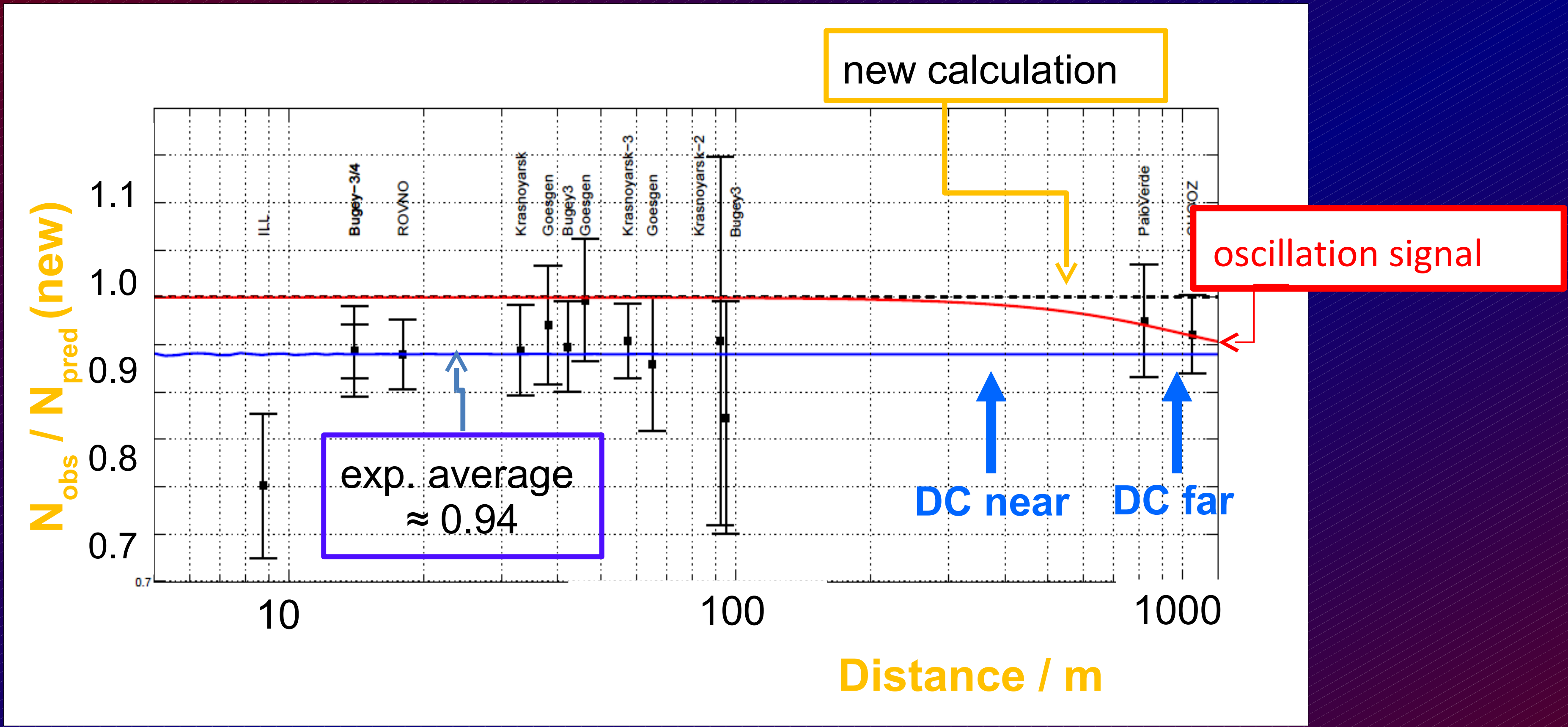
New SciBooNE results show less effect



MiniBooNE

Reactor Neutrino Anomaly ?

New calculation of neutrino flux from reactors

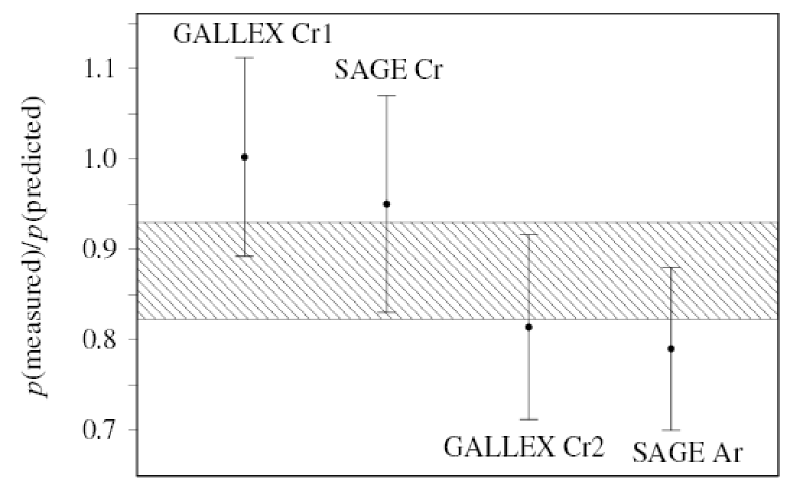


T. A. Mueller *et al.*, arXiv:1101.2663 [hep-ex].

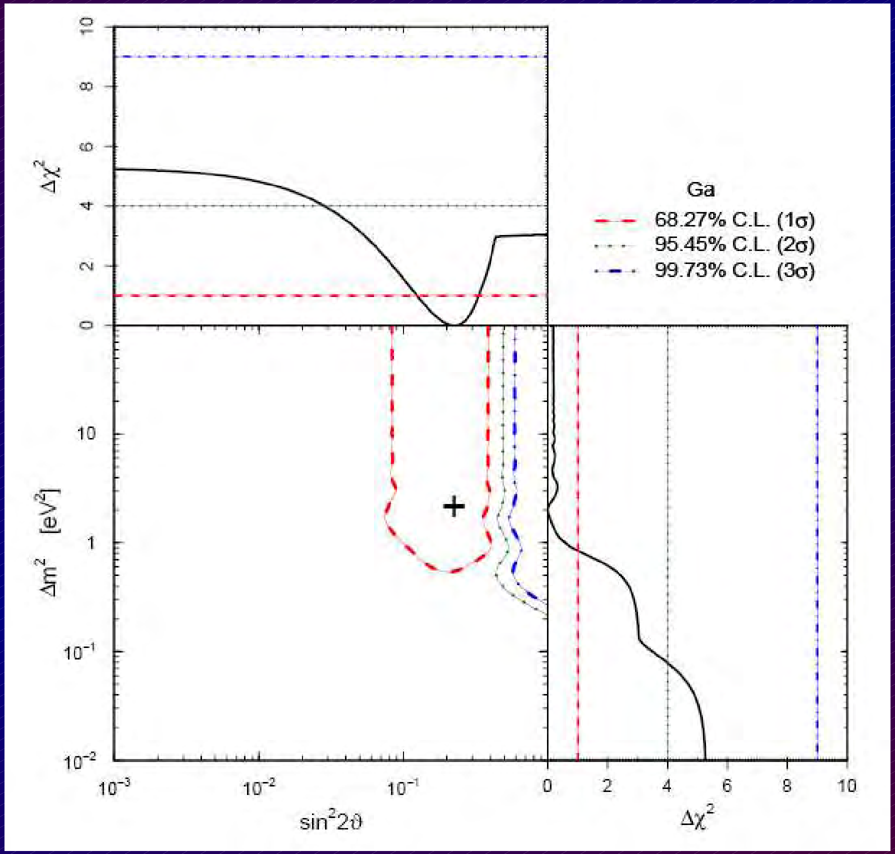
G. Mention *et al.*, arXiv:1101.2755 [hep-ex].

- Neutrino Oscillations ?
- L < 10m → $\Delta m^2 \approx 1\ eV^2$

Gallium Anomaly ?



$$R \equiv \frac{\mathrm{p(measured)}}{\mathrm{p(predicted)}} = 0.88 \pm 0.05 (1\sigma)$$



Cosmological Evidence ?

Big Bang Nucleosynthesis

N_{eff} 3.8 … 3.9   error 0.2 … 0.5

Large Scale Structure

N_{eff} 3.8 … 4.8   error 0.4 … 0.8

r-Process in Super Novae

sterile ν might explain n-rich environment in which heavy nuclei form.

Sterile Neutrino Projects

Sage-2	$\nu_e \to \nu_e$	Source (^{51}Cr), int.	Radiochemical	RUS, Baksan	likely; ~ 2015
Lens	$\nu_e \to \nu_e$	Source (^{51}Cr), int.	In-loaded scint.	US, Virg.Tech.	paper, proposal ?
SNO+	$\nu_e \to \nu_e$	Source (^{51}Cr), ext.	liquid scintillator	CA, SNOLab	under discussion
SOX	$\nu_e \to \nu_e$ $\bar{\nu}_e \to \bar{\nu}_e$	Source (^{51}Cr), ext. Source (^{144}Ce), int.	liquid scint. (Gd) (BOREXINO)	I, Gran Sasso	likely; 2015 likely; 2017
Ricochet	$\nu_e \to \nu_e$	Source (^{37}Ar), ext.	bolometers	US	prototyping
CeLAND	$\bar{\nu}_e \to \bar{\nu}_e$	Source (^{144}Ce), int	liquid scint.	J, KAMLAND	likely; 2015
DayaBay	$\bar{\nu}_e \to \bar{\nu}_e$	Source (^{144}Ce), ext	liquid. scint (Gd)	China	paper;
KATRIN	$\bar{\nu}_e \to \bar{\nu}_e$	Source (^{3}H)	spectrometer	G, Karlsruhe	comissioning; start 2014
NUCIFER	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 7m	liquid. sint. (Gd)	F, Paris	comissioning; ~ 2015
STEREO	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 10m	liquid. scint. (Gd)	F, Grenoble	
SCRAAM	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 24/12m	liquid. scint. (Gd)	US, California	studies ongoing, proposal
SONGS	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 24 m	liquid. scint. (Gd)	US, California	running
POSEIDON	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 7 & 10m	liquid. scint. (Gd)	RUS, PIK react.	
DANSS	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 14m	TASD	RUS	prototyping
Mumm, NIST	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 4-11m	?	US	proposal
Nu4	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor, 6-12m	liquid. scint. (Gd)	RUS	
HANARO	$\bar{\nu}_e \to \bar{\nu}_e$	Reactor,	liq. scint. (Gd/^{7}Li)	S-Korea	
IsoDAR	$\bar{\nu}_e \to \bar{\nu}_e$	^{8}Li decay-at-rest	liq. scint. (Gd?)	unknown	paper, R&D
OscSNS	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_e \to \nu_e$	π-decay-at-rest	liq. scint. (Gd?)	US, OakRidge	paper
CLEAR	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_e \to \nu_e$	π-decay-at-rest	liq. scint.	?	?
DAR-SK	$\bar{\nu}_\mu \to \bar{\nu}_e$	π-decay-at-rest	Gd-loaded water	J, SuperK	
DEAδALUS	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_e \to \nu_e$	π-decay-at-rest	liq. scint.	SF, LENA	paper, >2020
MicroBOoNE	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_\mu \to \nu_e$	π-decay-in-flight	liq. scint., 200m	US FermiLab	under construction
KDAR	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_e \to \nu_e$	K-decay-at-rest	LAr, 2kt		paper
LAr1	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_\mu \to \nu_e$	π-decay-in-flight	LAr 1kt, 700m	US FermiLab	idea, studies ongoing
νSTORM	many	μ-decay-in-flight	MID, 1.3 kt, 2km	US FermiLab	idea (low E νfactory)
NESSiE	$\bar{\nu}_\mu \to \bar{\nu}_e$, $\nu_\mu \to \nu_e$	π-decay-in-flight	LAr, 150+600 kg	CH, CERN	proposal

incomplete list

Sterile Neutrino Searches

Several Proposals to test
short range oscillations

CERN proposal
Carlo Rubbia

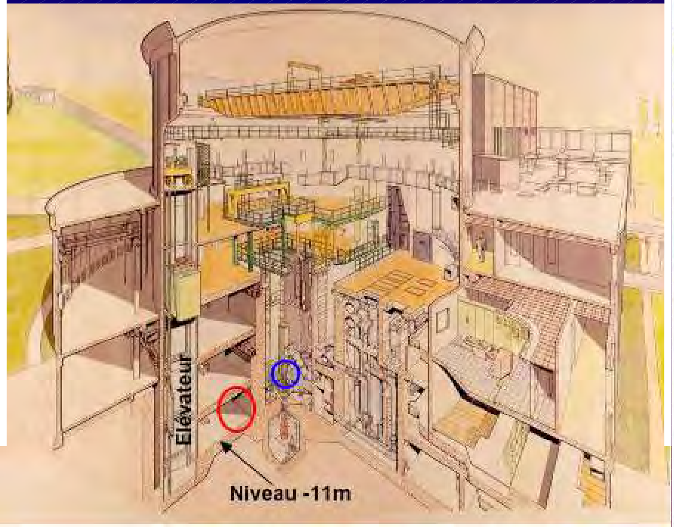
higher E

SPS wide band beam
to ICARUS @ CERN

NUCIFER
small detector for
non-proliferation

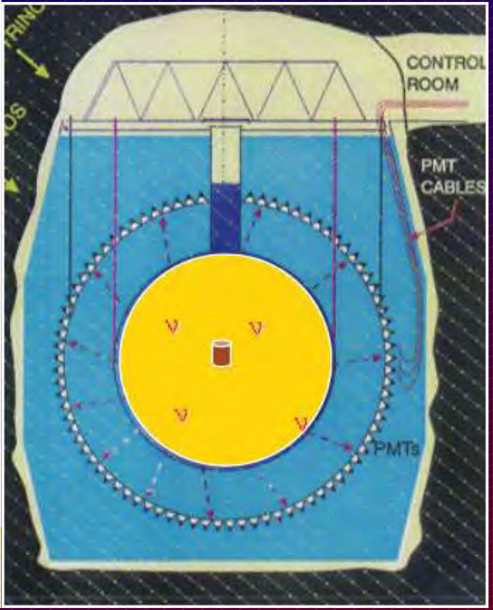
smaller L

sketch NUCIFER@OSIRIS



BOREXINO
KAMLAND
SNO+ (or others)
Radioactive source inside
large ν-detector

smaller L



^{37}Ar
SNO+

Non-KET Neutrinos

KATRIN	absolute mass	Start-up now
BOREXINO	solar neutrinos	excellent new results
Double-Beta	majorana masses	several experiments in preparation
IceCube	astro-neutrinos	now fully in operation
…	…	…

Sorry! No time to discuss

Neutrino Strategy

European Strategy
for Particle Physics

DayaBay II	reactor 60km	20 kt LS	3 σ in 6 years	R&D on E-reso. my guess 2020	Karsten Heegner	
ICAL@INO	atmos.	50 kt MID (RPCs)	2.7 σ in 10 years	2027	Sandhya Choubey	
HyperK	atmos.	1 Mt Water Cerenkov	3 σ in 5 years 4 σ in 10 years	2027/28 2033/34	Sandhya Choubey	LoI submitted
T2HK	LBL accel. 295 km	1 Mt Water Cerenkov	0..3 σ in 10 years	2028	Masashi Yokoyama	
PINGU	atmos.	Ice (South pole)	3...11 σ in 5 years	feasibility study ongoing.	Sandhya Choubey Poster	Systematics ?
MINOS+	LBL accel. 735 km	MID 5.4 kt	no claim on mass hierarchy	---	speaker on question	
GLADE	LBL accel. 810 km	LAr 5 kt	In combination with NOνA and T2K $\leq 2\ \sigma$	Letter-of-Intent	André Rubbia, Poster	
NOνA	LBL AshRiver 810 km	TASD 14 kt	0...3 σ in 6 years depending on δ	2020	Ryan Patterson	under construction starts 2014
LBNE	LBL Homestake LBL Soudan LBL AshRiver	LAr 10 kt LAr 15 kt LAr 30 kt	1.5...7 σ in 10 y 0...3 σ in 10 y 0.5...5σ in 10 y	2030	Bob Swoboda	range gives dependence on δ
GLACIER	LBL accel. 2300 km	LAr 20 kt	> 5σ in a few y.	2025 + number of years to the decision	André Rubbia	
LENA	LBL accel. 2300 km	Liq. Scint. 50 kt	5 σ in 10 years	2028 + number of years to the decision	Lothar Oberauer	
ν-factory	LBL accel. ? km	LAr ? kt	$\gg 5\ \sigma$	?		

The information is collected from talks given at the NEUTRINO2012 conference in Kyoto in June 2012.
The following transparencies are extracted from the corresponding talks (speakers listed in the 6th column).

Neutrino Strategy

1. Long Baseline Neutrino Observatory LBNO
   Beam CERN to Pyhäsalmi, Lab, 2 far det., near det.

2. Short Baseline Beam @ CERN
   Sterile Neutrino Search (ICARUS + NESSIE)

3. R&D for Neutrino Factory

Neutrinos: Globalisation

Medium Term (goal → mass hierarchy
→ first shot at CP; 3σ in 50...70%):

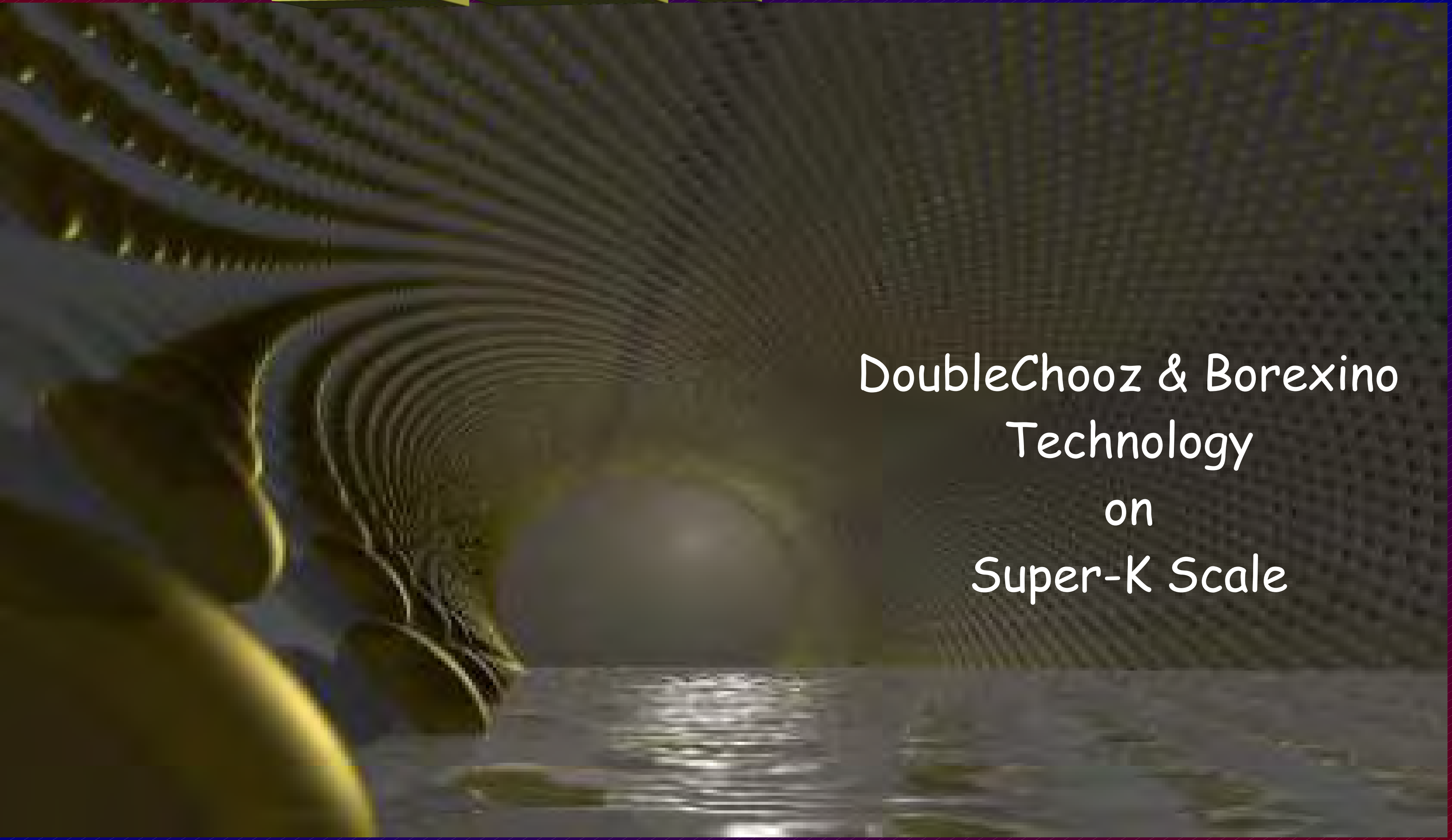
Japan:	T2K, T2HK	(minor astro-program)
US:	LBNE	(no astro-program)
Europe:	LBNO	(full complementarity)

Longterm (goal → CP-violation):
Neutrino Factory

What is the optimal baseline (at fixed detector mass and beam power) ?
mass hierarchy: broad maximum between 500km and several 1000 km.
CP-violation: essentially flat from 200 km on.

LBNE ~ 800km, T2K 295 km, C2PY 2300 km
Interest on a second beam to Pyäsalmi from Russia

LENA



LENA: Detector

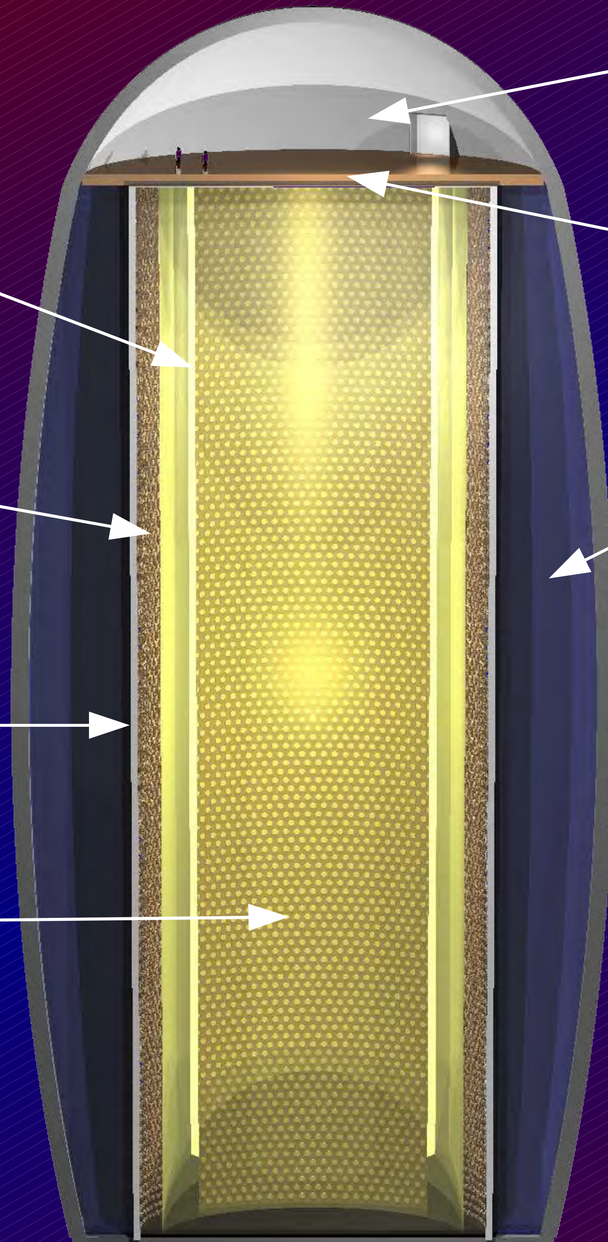
Liquid Scintillator
ca. 50kt LAB

Inner Nylon Vessel
radius: 13m

Buffer Region
inactive, Δr = 2m
ca. 20kt LAB

Steel Tank
r = 15m, h = 100m

50,000 8‘‘-PMTs
Winston cones
optical coverage: 30%



Electronics Hall
dome of 15m height

Top Muon Veto
scintillator panels/RPCs
vertical muon tracking

Water Cherenkov Veto
3000 PMTs, Δr > 2m
fast neutron shield
inclined muons

Egg-Shaped Cavern
about 105 m3

Rock Overburden
at least 4000 mwe

Physics Summary

- Proton Decay
- Galactic Supernova Burst
- Diffuse Supernova Neutrino Background
- Long baseline neutrino oscillations
- Solar Neutrinos
- Geo neutrinos
- Atmospheric neutrinos
- Dark Matter indirect search
- Neutrino oscillometry (sterile neutrinos)

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