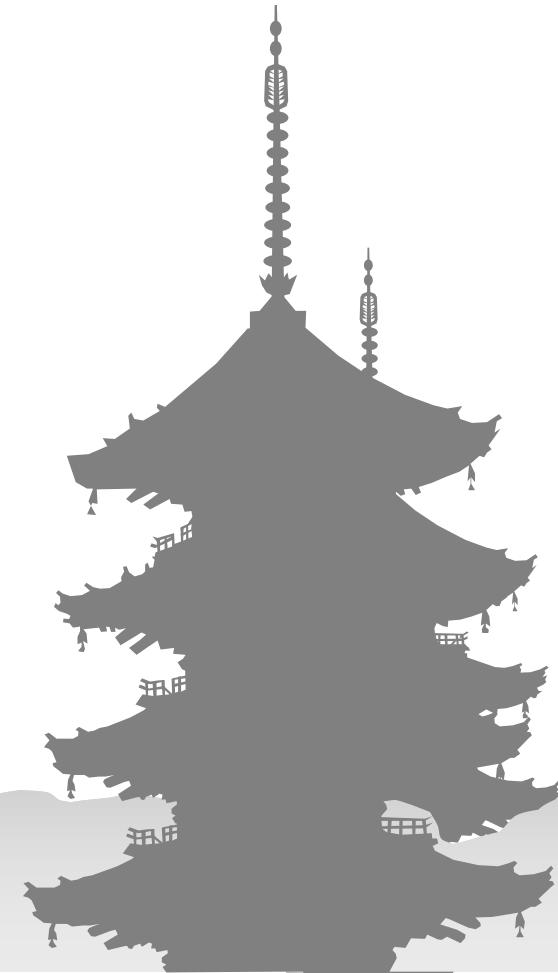


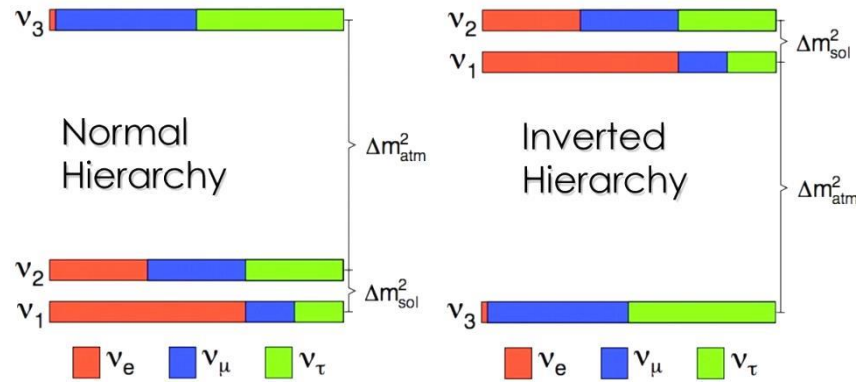
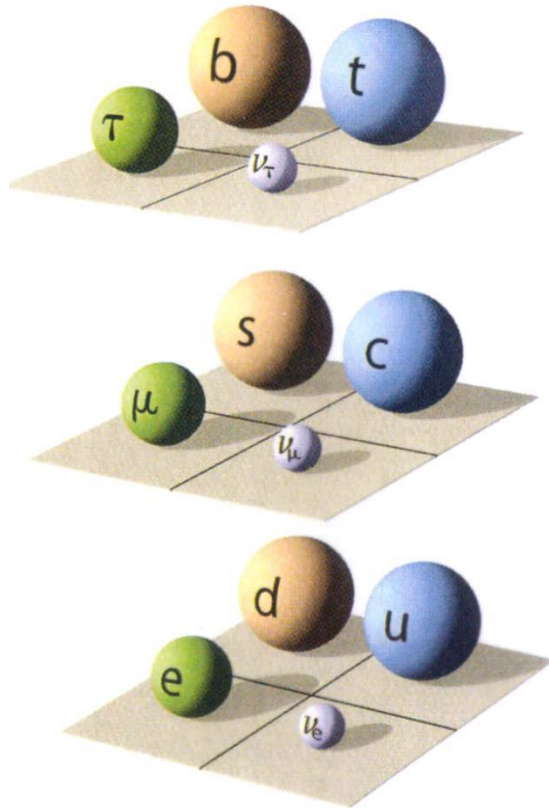
Les neutrinos au LLR et notre projet de participation à l'expérience Super-K

- Le contexte physique (très rapide)
- Nos expériences en cours
 - T2K
 - WAGASCI
 - JUNO
- Nos perspectives
 - Extended T2K
 - Hyper - Kamiokande
 - **Super - Kamiokande (basse énergie)**

MICHEL GONIN



Les oscillations des neutrinos

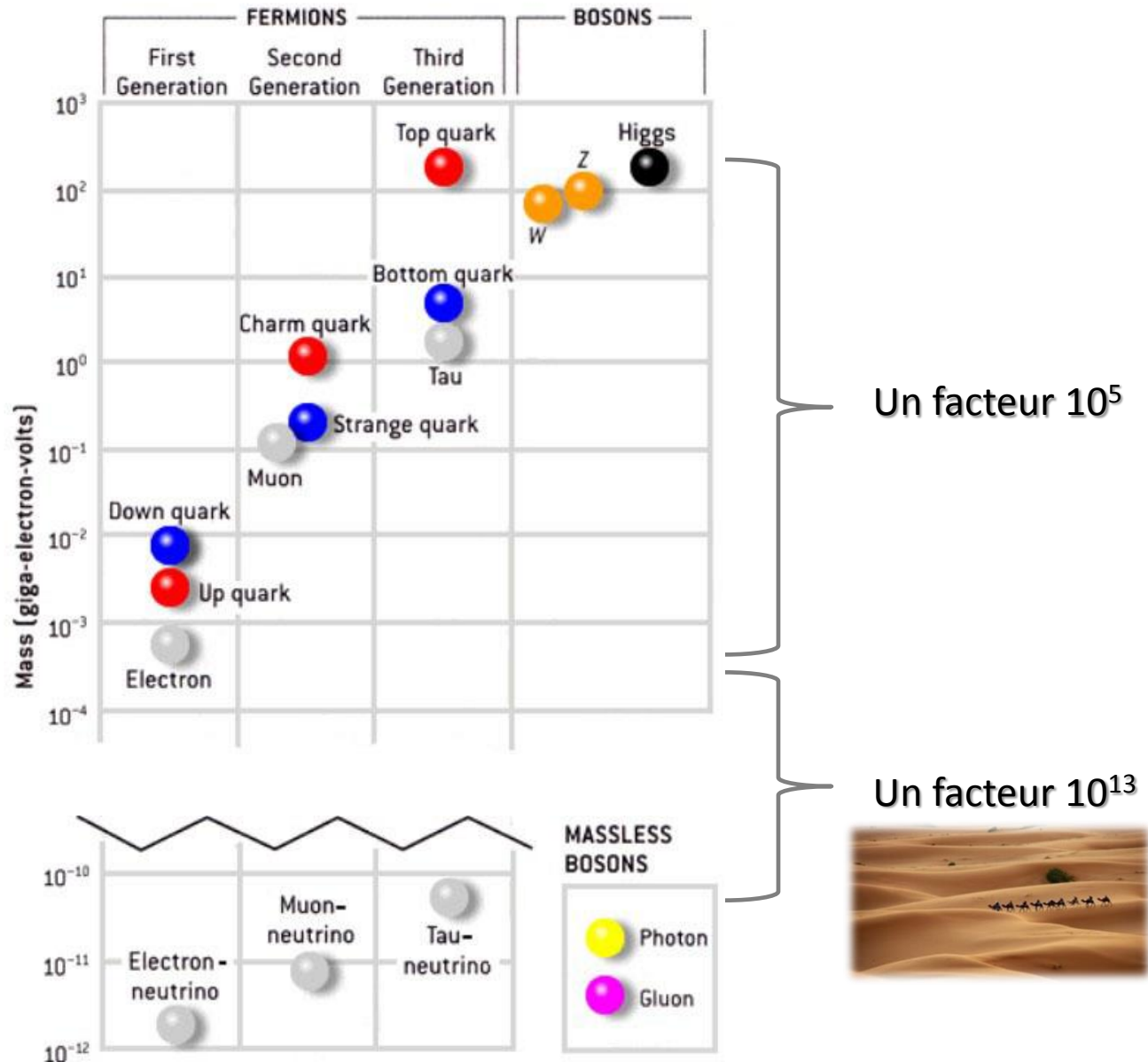


T2K

$$\begin{aligned}
 P(\nu_\mu \rightarrow \nu_e) = & 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2} (1 - 2S_{13}^2) \right) \\
 & + 8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos \delta - S_{12} S_{13} S_{23}) \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E} \\
 & - 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin \delta \sin \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E} \\
 & + 4S_{12}^2 C_{13}^2 \{ C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos \delta \} \sin^2 \frac{\Delta m_{21}^2 L}{4E} \\
 & - 8C_{13}^2 S_{13}^2 S_{23}^2 \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \frac{aL}{4E} (1 - 2S_{13}^2)
 \end{aligned}$$

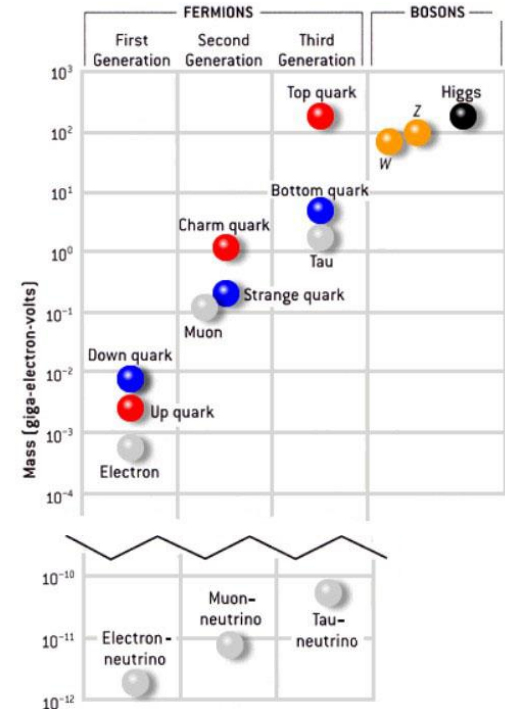
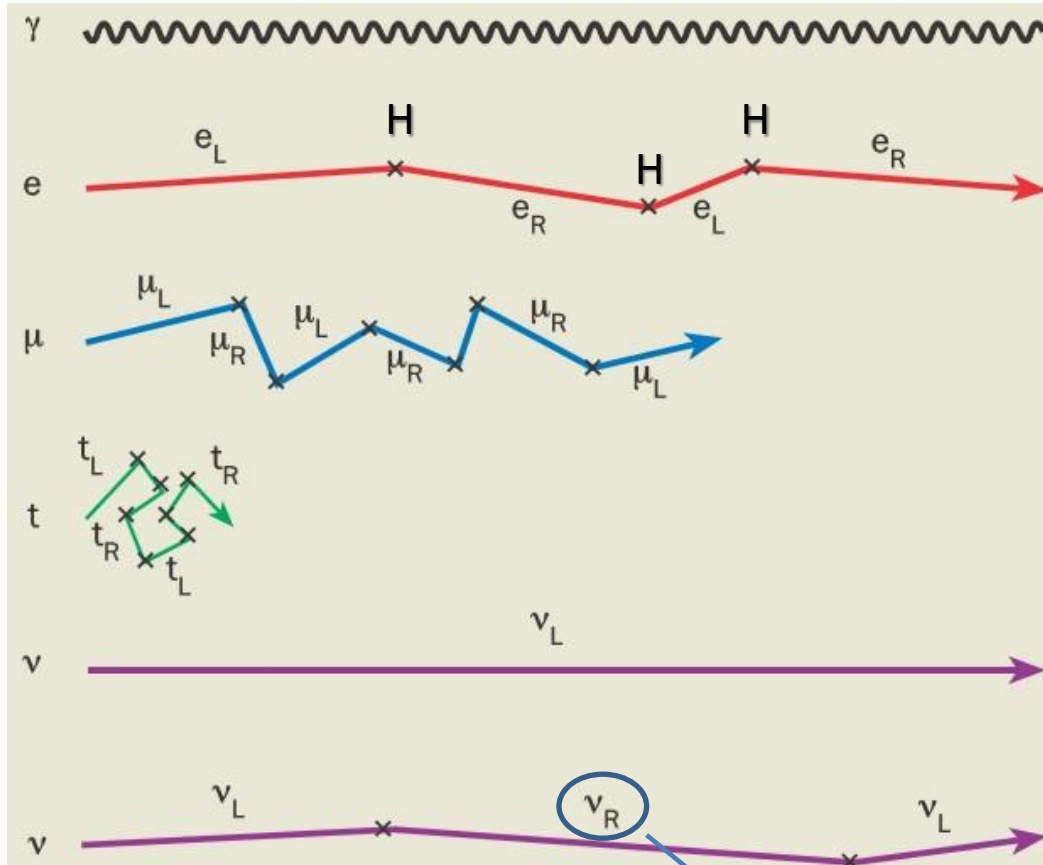
Vers une physique au-delà du modèle standard

Hiéarchie de masse des particules élémentaires



Hiérarchie de masse des particules élémentaires

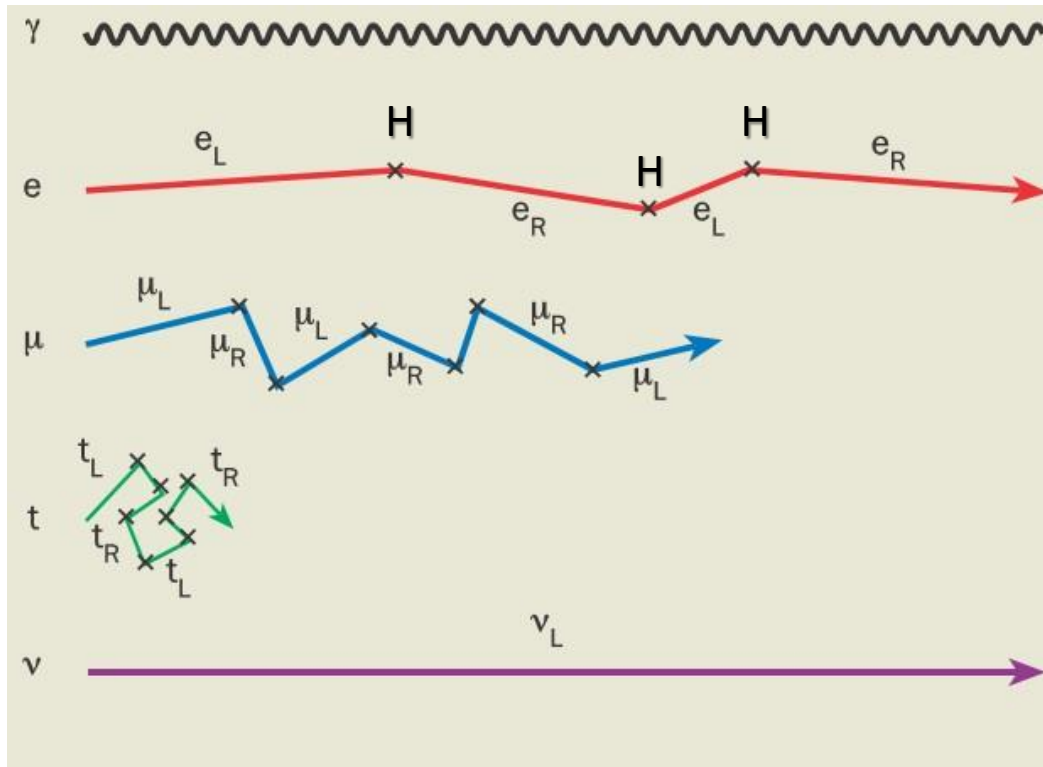
Mécanisme de Higgs



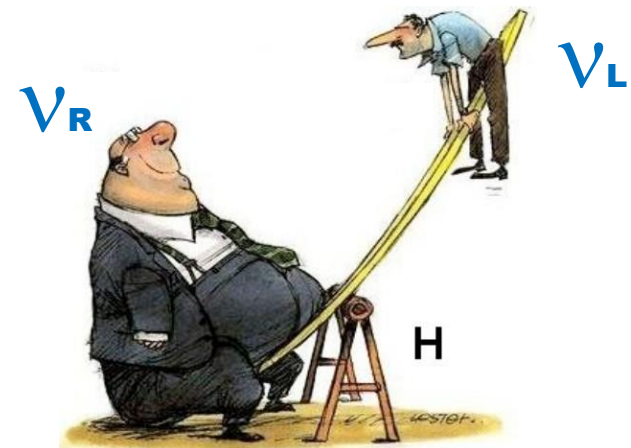
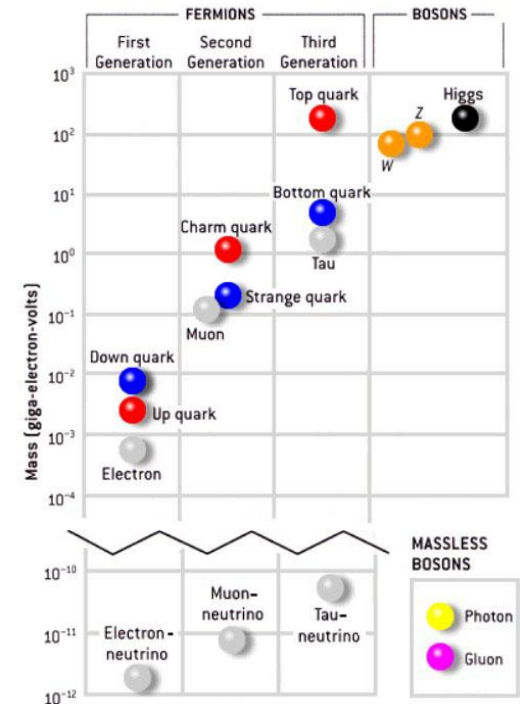
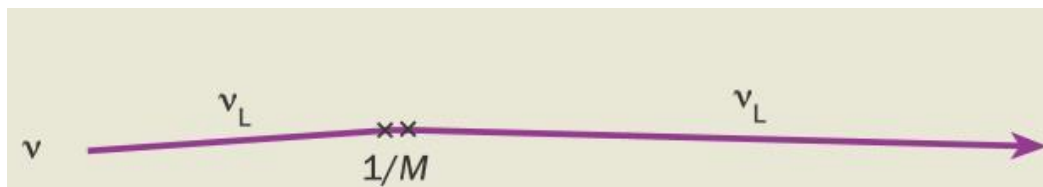
On invente ainsi une particule qui n'interagit (vraiment) avec rien

Hiérarchie de masse des particules élémentaires

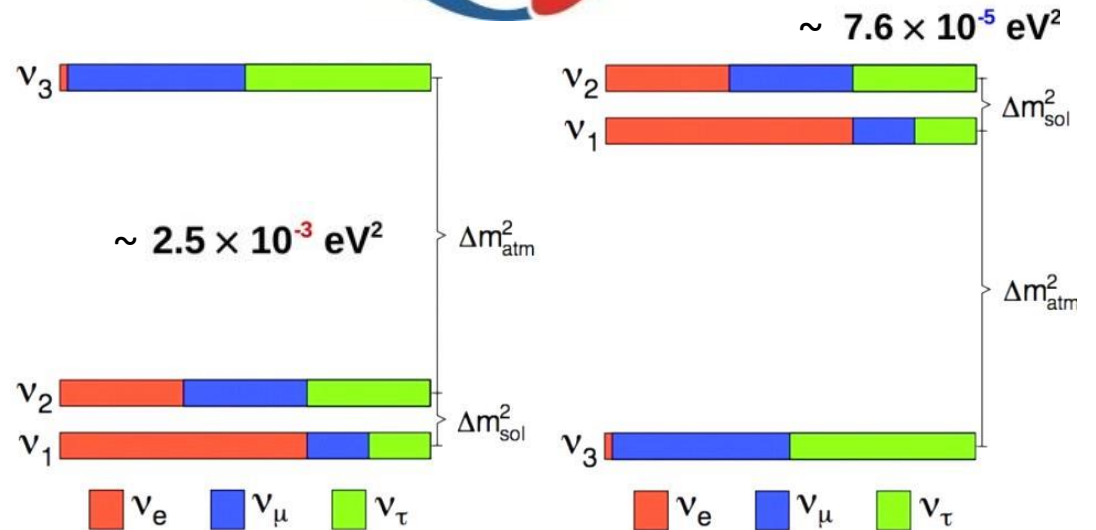
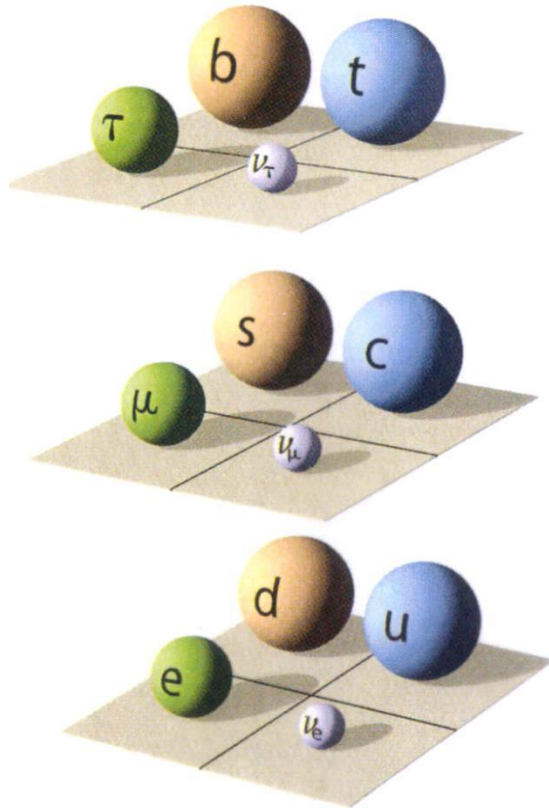
Mécanisme de la « balançoire »



Neutrinos de Majorana



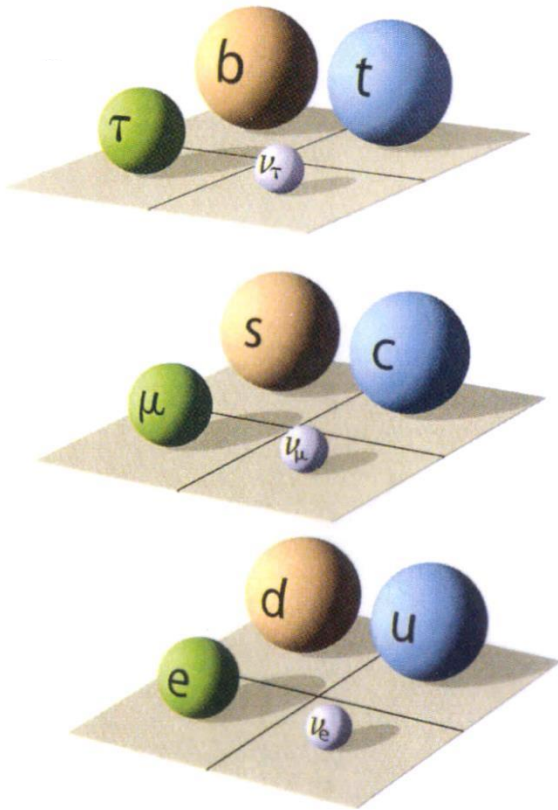
Ordre pour les masses des neutrinos



$$\begin{aligned}
 m_1 &= m_{\min} \\
 m_2 &= \sqrt{m_{\min}^2 + \Delta m_{\text{sol}}^2} \\
 m_3 &= \sqrt{m_{\min}^2 + \Delta m_{\text{A}}^2}
 \end{aligned}$$

$$\begin{aligned}
 m_3 &= m_{\min} \\
 m_1 &= \sqrt{m_{\min}^2 + \Delta m_{\text{A}}^2 - \Delta m_{\text{sol}}^2} \\
 m_2 &= \sqrt{m_{\min}^2 + \Delta m_{\text{A}}^2}
 \end{aligned}$$

Matrices de mélanges



Réduction progressive des incertitudes pour les leptons

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

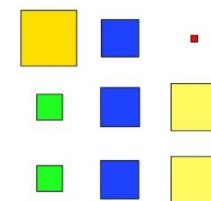
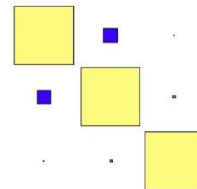
Quark "Mixing"

mixing parameters	best fit	3σ range
θ_{23}^q	2.36°	2.25° - 2.48°
θ_{12}^q	12.88°	12.75° - 13.01°
θ_{13}^q	0.21°	0.17° - 0.25°

Lepton "Mixing"

mixing parameters	best fit	3σ range
θ_{23}^e	45°	35.5° - 53.5°
θ_{12}^e	34°	31.5° - 37.6°
θ_{13}^e	9°	8.5-9.5°

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$





"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature".

Une violation de la symétrie matière – antimatière n'est possible que si nous avons :

- des états propres de masses \neq états propre de saveurs
- 3 familles de fermions
- 3 angles de mélange tous non nuls
- **une matrice de mélange complexe**

Mesure de la violation CP

T2K-II

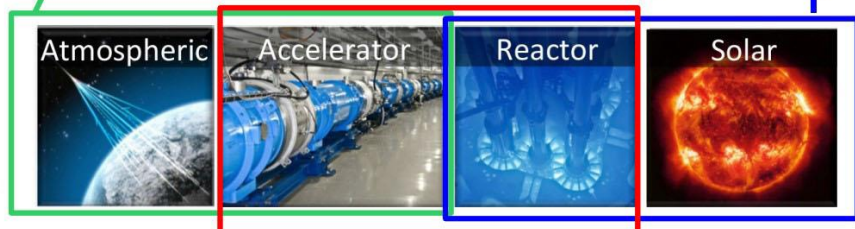


Hyper Kamiokande
@HyperKamiokande

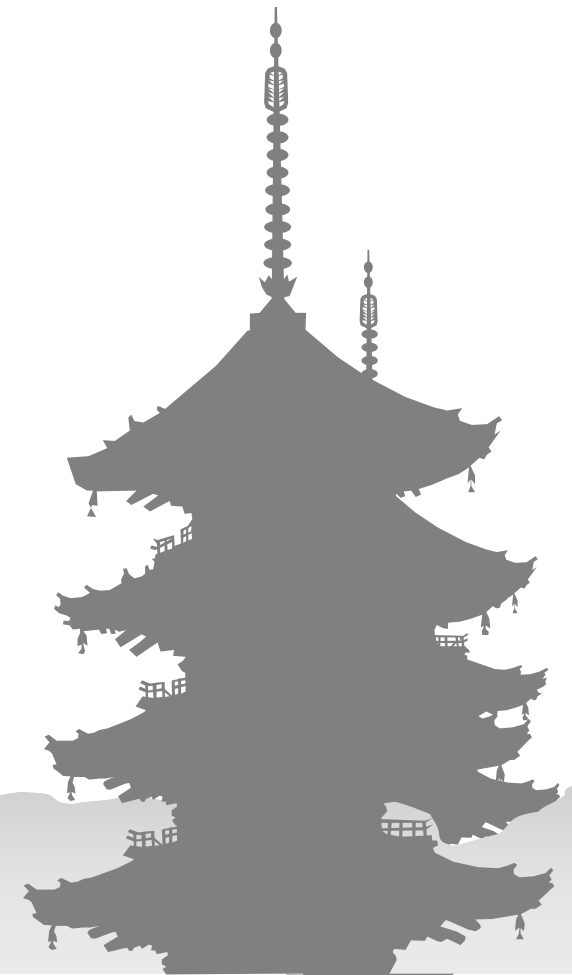
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13} e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$c_{xy} = \cos\theta_{xy}$$

$$s_{xy} = \sin\theta_{xy}$$



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 - **Super - Kamiokande (basse énergie)**



Le groupe Neutrinos du LLR



Olivier Drapier DR
Michel Gonin DR
Margherita Buizza Avanzini CR

Qinhua HUANG Thésard



Olivier Drapier DR
Michel Gonin DR
Margherita Buizza Avanzini CR
Thomas Mueller CR

James Imber Post doc

Matthieu Licciardi Thésard
Olivier Volcy Thésard



Michel Gonin DR
Thomas Mueller CR

James Imber Post doc

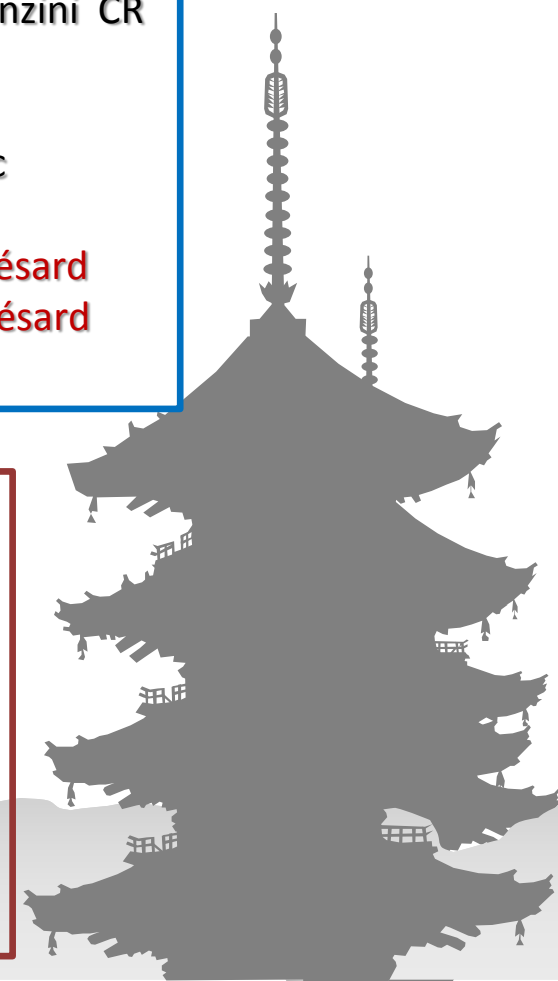
Proto collaboration



Hyper Kamiokande
@HyperKamiokande

Olivier Drapier DR
Michel Gonin DR
Margherita Buizza Avanzini CR
Thomas Mueller CR

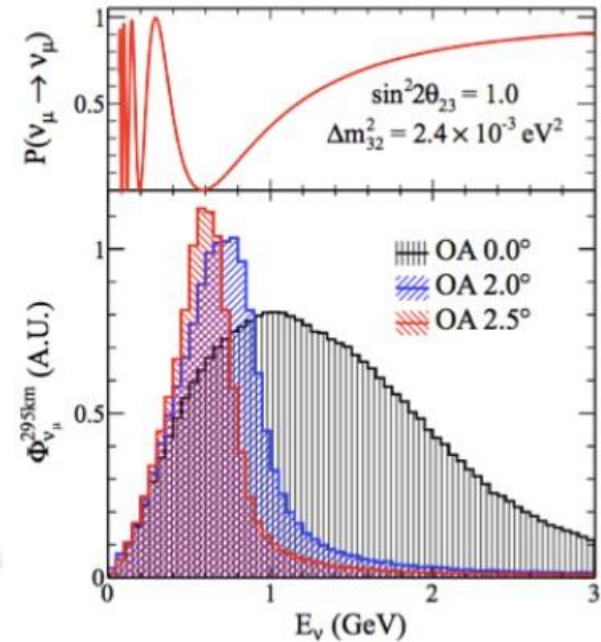
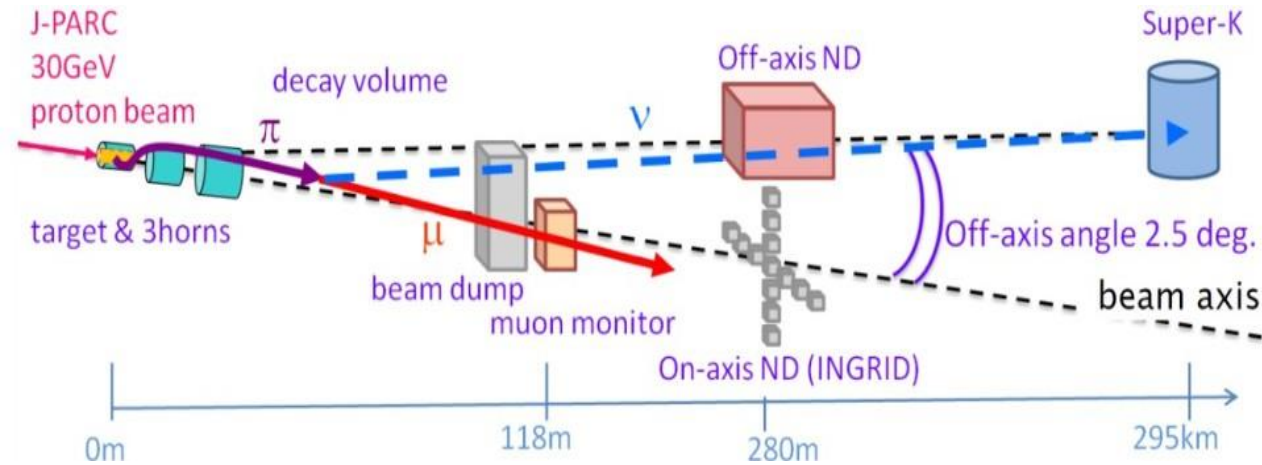
James Imber Post doc



Nos expériences en cours



T2K

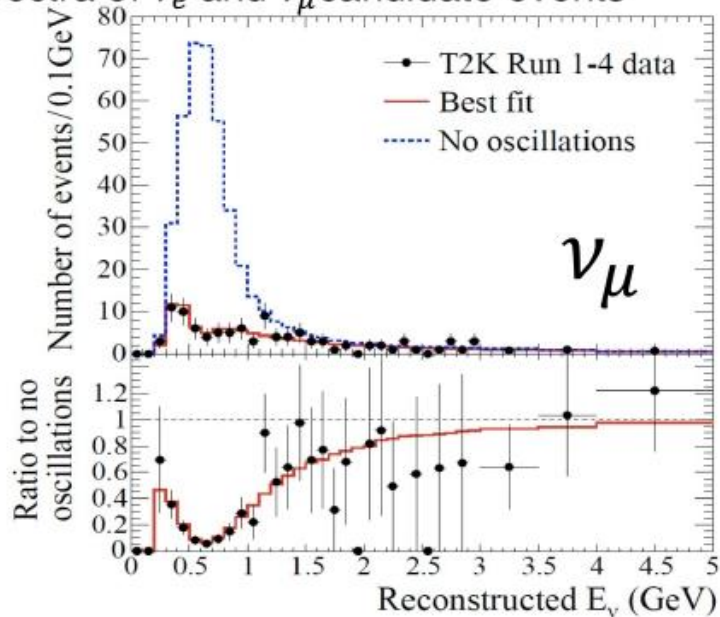
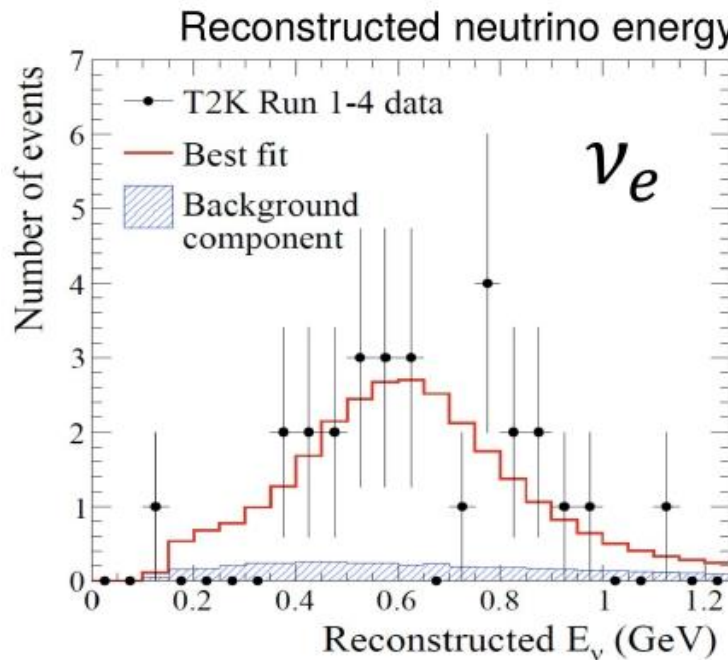
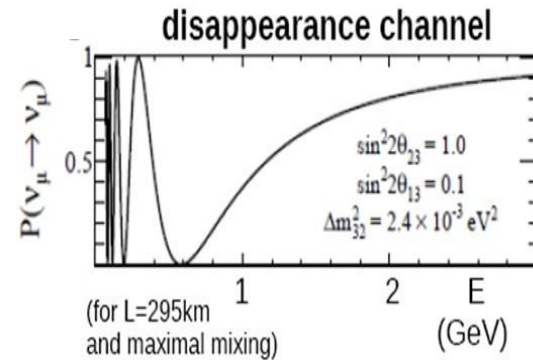


Faisceaux de neutrinos muons

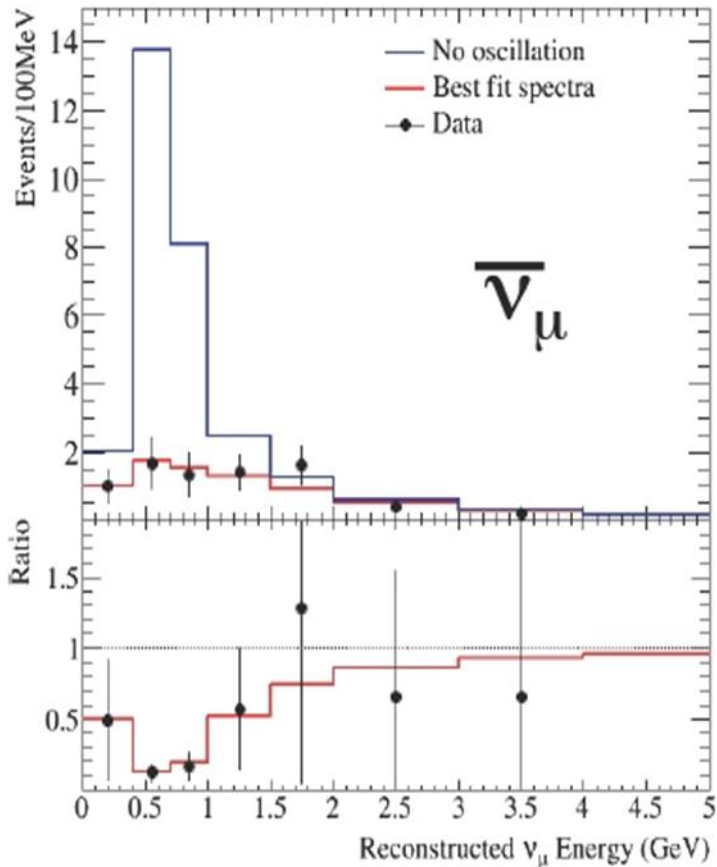
Nos expériences en cours

T2K

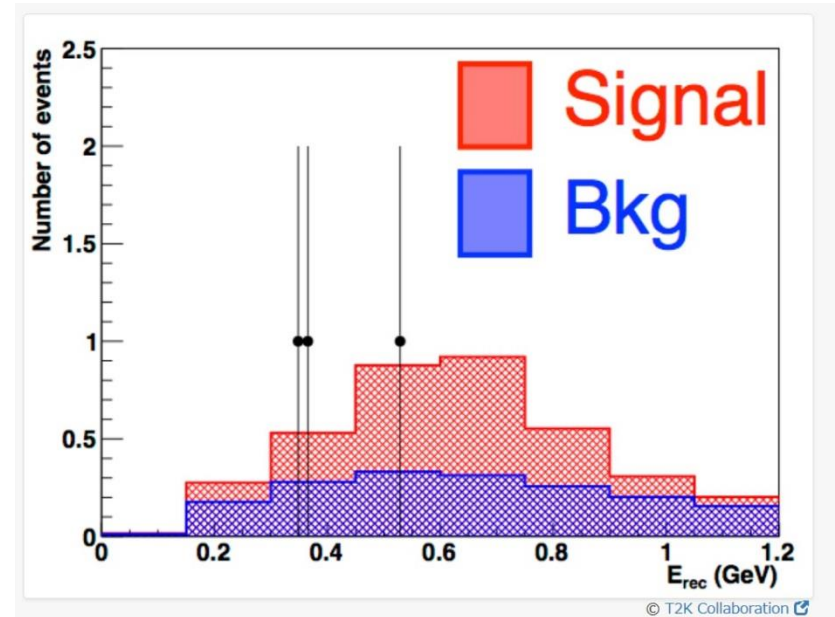
**Découverte en 2013
de l'apparition de saveur**



Prise de données antineutrinos



T2K



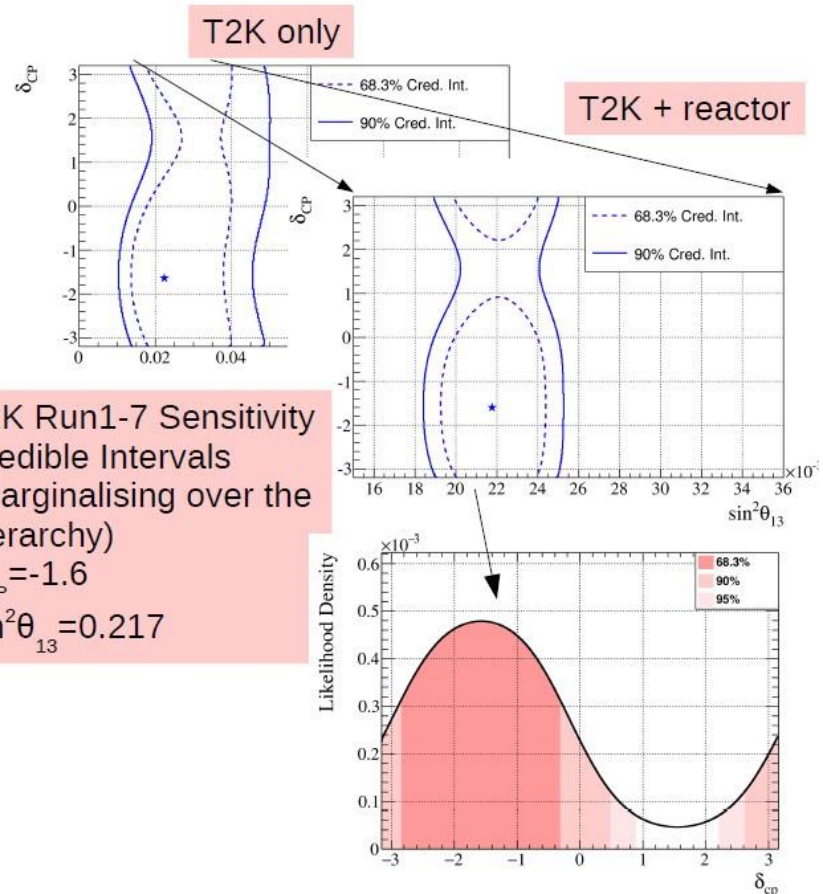
34 events observed
103.6 expected (w/o osc.)

Contributions du LLR



T2K Run1-7 Oscillation Analysis

- Run7 increased antineutrino mode POT by 86%
- First appearance + disappearance analysis using both neutrino + antineutrino data
- New results produced for Neutrino2016 using updated dataset (further updates for ICHEP2016 in preparation)

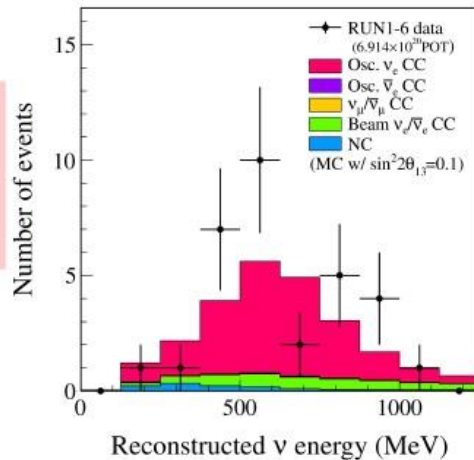




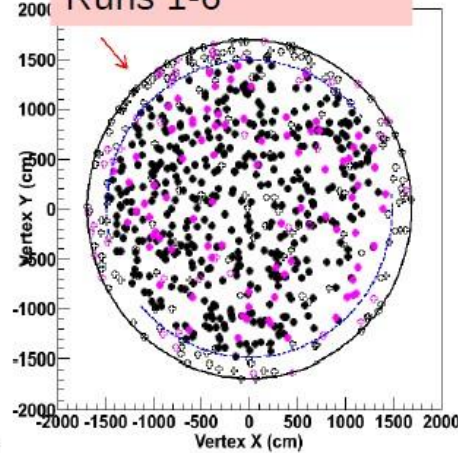
T2K-SK Data Quality & Reduction

- Semi-realtime event monitoring
- Detector stability
- Event timing/GPS monitoring
- Event Rate
- Vertex distribution
- Non-beam background
- Final sample production/validation
- Run7 data sets prepared for Neutrino2016 and ICHEP2016

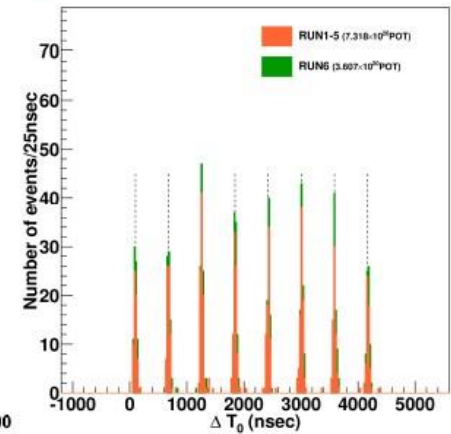
Neutrino e-like events
Runs 1-6



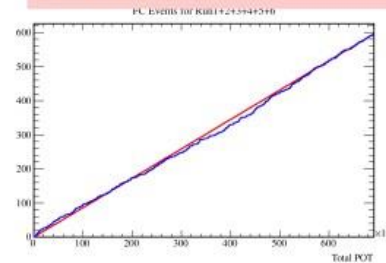
Neutrino FC events
Runs 1-6



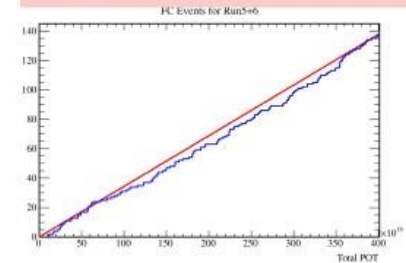
All FC events Runs 1-6



Neutrino FC events
Runs 1-6



Antineutrino FC events
Runs 5-6



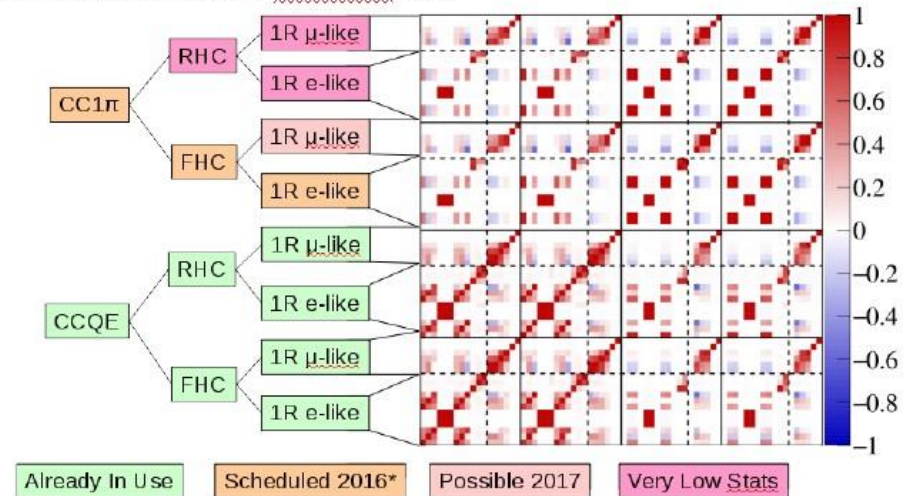
FC = Fully Contained (no outer detector veto)



T2K-SK Detector Systematic Uncertainties

- Updated detector uncertainties for the summer 2016 oscillation analyses.
- Added uncertainties for new samples
- Uncertainties will be updated again following adoption of event selection exclusively using new reconstruction algorithm

FHC – Forward Horn Current = “neutrino beam”
RHC – Reverse Horn Current = “antineutrino beam”



*Will include improvements to reduce the size of the error

Evaluation des erreurs systématiques liées aux bruits de fond π^0 pour l'apparition des ν_e à Super-Kamiokande



- Les événements incluant un π^0 mal reconstruit sont la **source d'erreur systématique dominante** pour l'apparition des ν_e au niveau du détecteur SK

- Pas d'échantillon de contrôle disponible
- **création d'un échantillon** dit "hybride" mêlant données électrons et γ obtenus par MC (NC π^0 , NC π^0 +other, ν_μ CC π^0 +other)

- Evaluation des erreurs systématiques** associés à ces événements "hybrides"
- utilisé dans toutes les publications concernant l'apparition des ν_e (PRL 107&112, PRD 88&91)

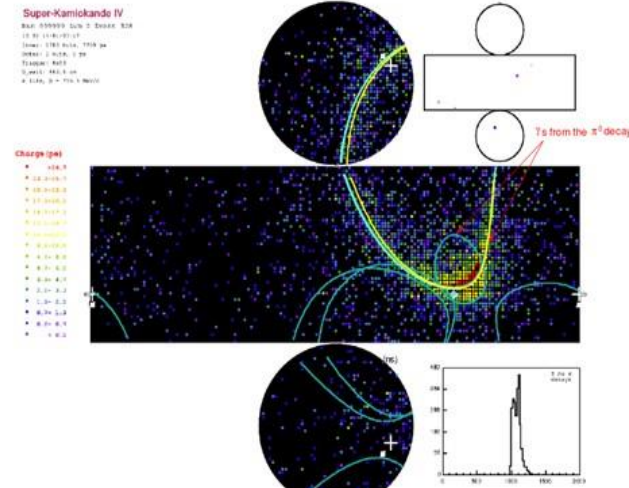
- Développement et optimisation des **algorithmes de détection** des événements incluant un π^0 POI fit et fitQun

Final state	Signal ν_e	BG all
ν_e CC 1e	4.101 (96.8)	0.950 (51.3)
ν_e CC other	0.137 (3.2)	0.101 (5.4)
ν_μ CC	0.000 (0.0)	0.032 (1.7)
ν_μ CC π^0 other	0.000 (0.0)	0.012 (0.6)
NC $1\pi^0$	0.000 (0.0)	0.567 (30.6)
NC π^0 other	0.000 (0.0)	0.081 (4.4)
NC 1γ	0.000 (0.0)	0.040 (2.1)
NC $1\pi^\pm$	0.000 (0.0)	0.039 (2.1)
NC other	0.000 (0.0)	0.032 (1.8)

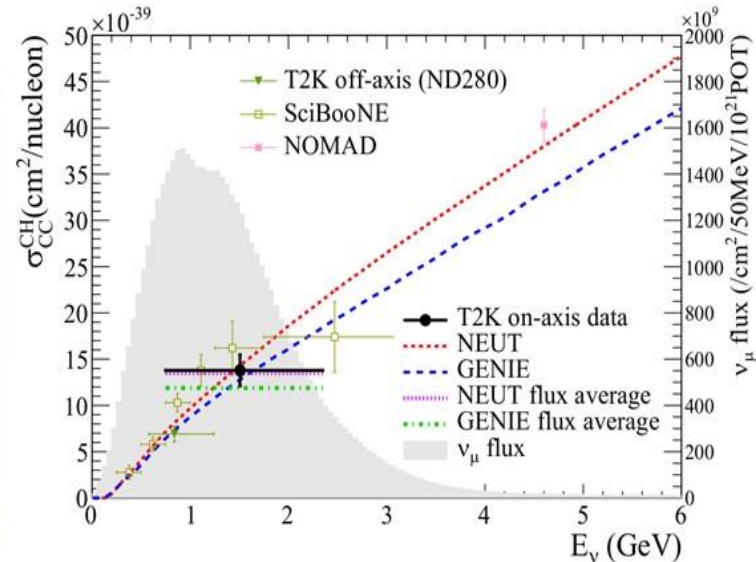
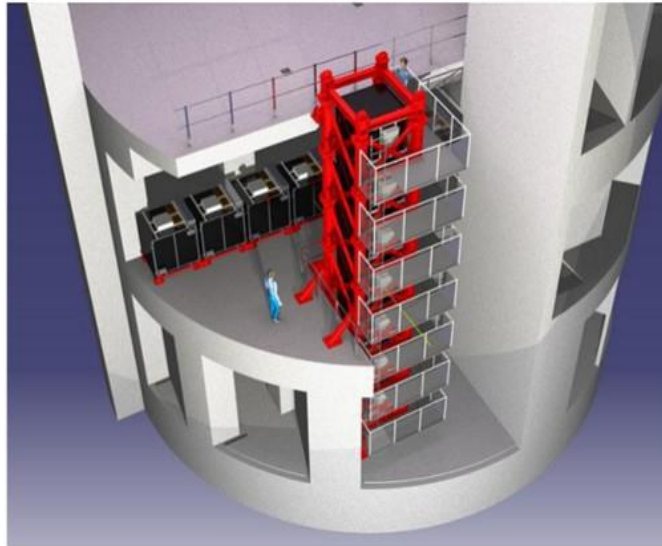
Expected events and fractions of ν_e selected events
Run1+Run2 (1.431×10^{20} POT), beam flux 10dv3.1



JP



Mesure des sections efficaces par courant chargé des neutrinos avec les détecteurs INGRID et Module Proton

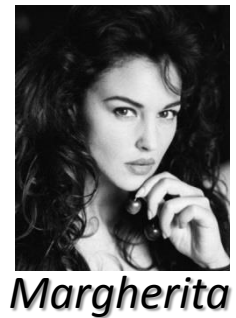


Christophe



Phuong

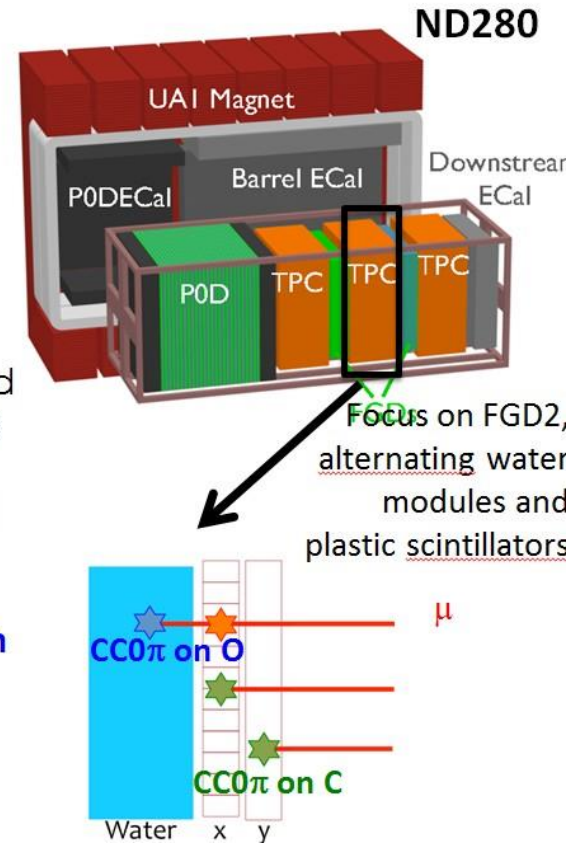
- Amélioration de la [simulation Monte-Carlo](#) des détecteurs et des algorithmes de reconstruction
- Participation à l'exploitation des données



T2K/ND280: Oxygen/Carbon $CC0\pi$ cross section analysis

Uncertainties on neutrino cross sections are the major sources of systematics in T2K oscillation analysis. This is true also for future experiments as HyperKamiokande and Dune. We try to exploit T2K near detector data to improve our knowledge of neutrino x-sec (INGRID, ND280 + Wagasci)

Neutrino interactions in water are reconstructed as having a first hit in x layers: in FGD2, X layers will contain a majority of neutrino-Oxygen interaction events. By separating «X» and «Y» events we can simultaneously extract the **Oxygen only and the Oxygen/Carbon ratio cross sections** through a **likelihood fit approach** in p_μ and $\cos\theta_\mu$ bins. Presently blind analysis on MC data: event selection, statistics and systematics evaluations,...



Cross section measurements	Target	Reported in	Detector
ν_{μ} CC inclusive	CH	PRD 87, 092003 (2013)	ND280, Tracker
ν_{μ} CCQE	CH	Accepted by PRD	ND280, Tracker
ν_e CC inclusive	CH	PRL 113, 241803 (2014)	ND280, Tracker
ν_{μ} NC π^0	CH/Water	Publication in progress	ND280, POD
ν_{μ} NC elastic	Water	PRD 90, 072012 (2014)	SK
ν_{μ} CC inclusive	CH/Fe	PRD 90, 052010 (2014)	INGRID
ν_{μ} CCQE	CH	PRD 91, 112002 (2015)	INGRID + PM
ν_{μ} CC coherent	CH	Publication in progress	INGRID + PM
ν_{μ} CC coherent	CH	Publication in progress	ND280, Tracker
ν_{μ} CC π^+	Water	Publication in progress	ND280, Tracker
ν_{μ} CC 0π	CH	Publication in progress	ND280, Tracker



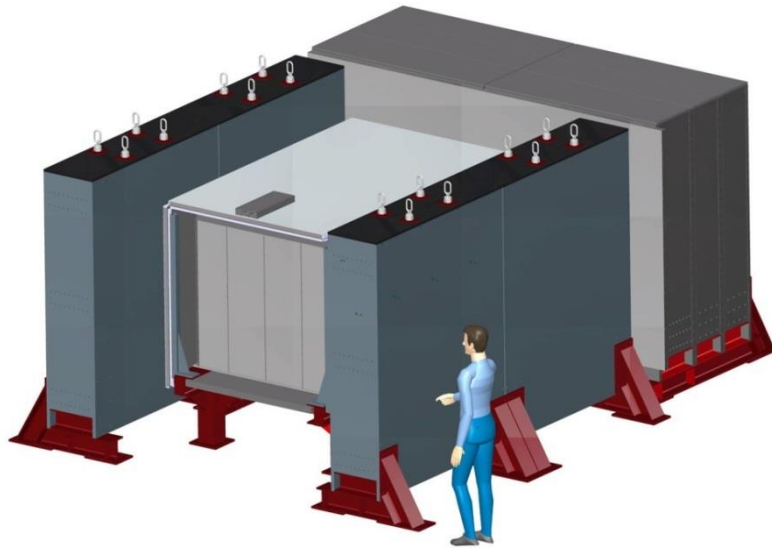
Benjamin

WAGASCI

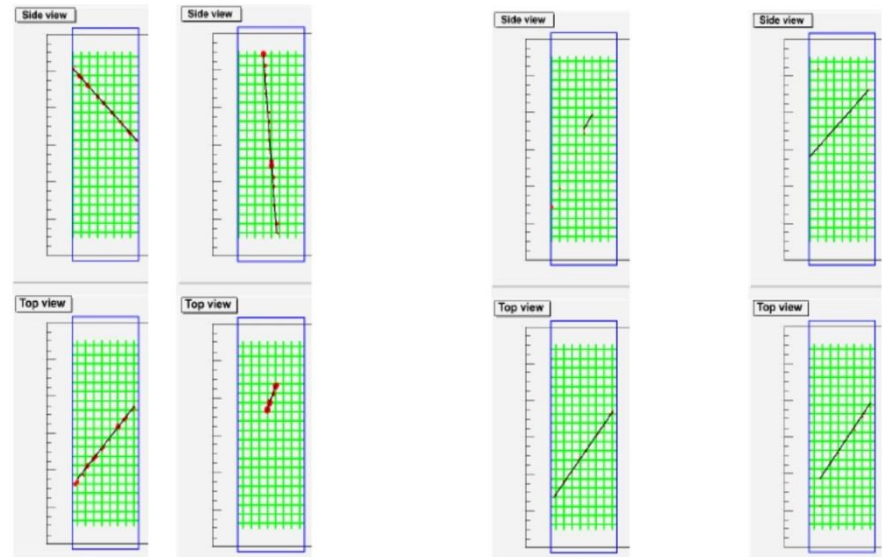
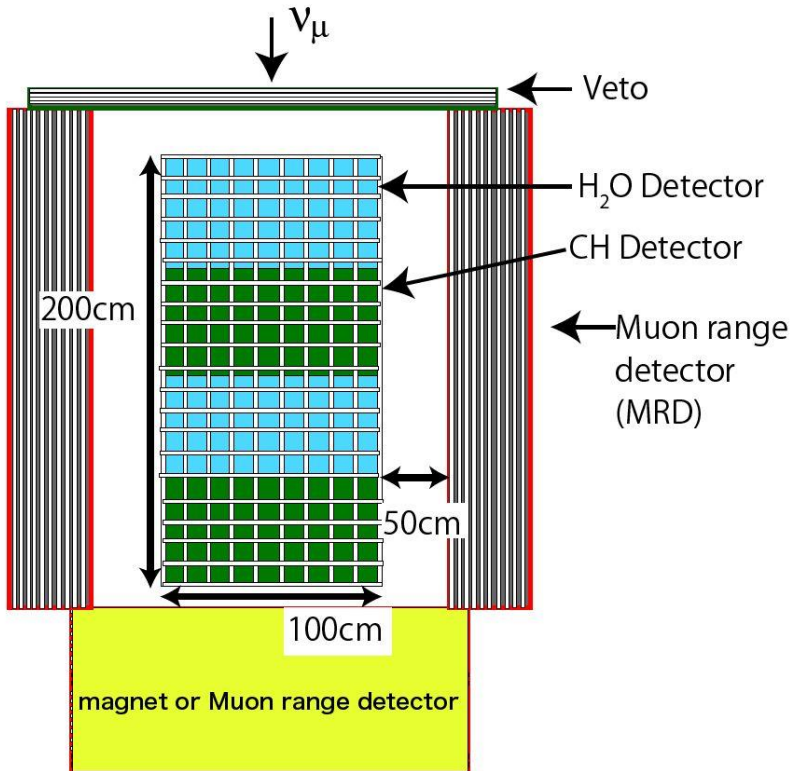
Matthieu



Note : 48 K€ de l'X pour WAGASCI



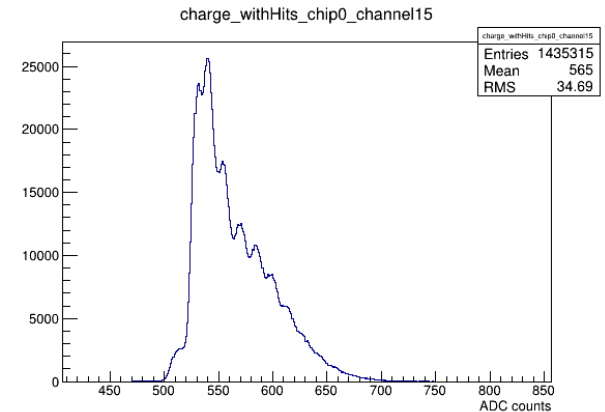
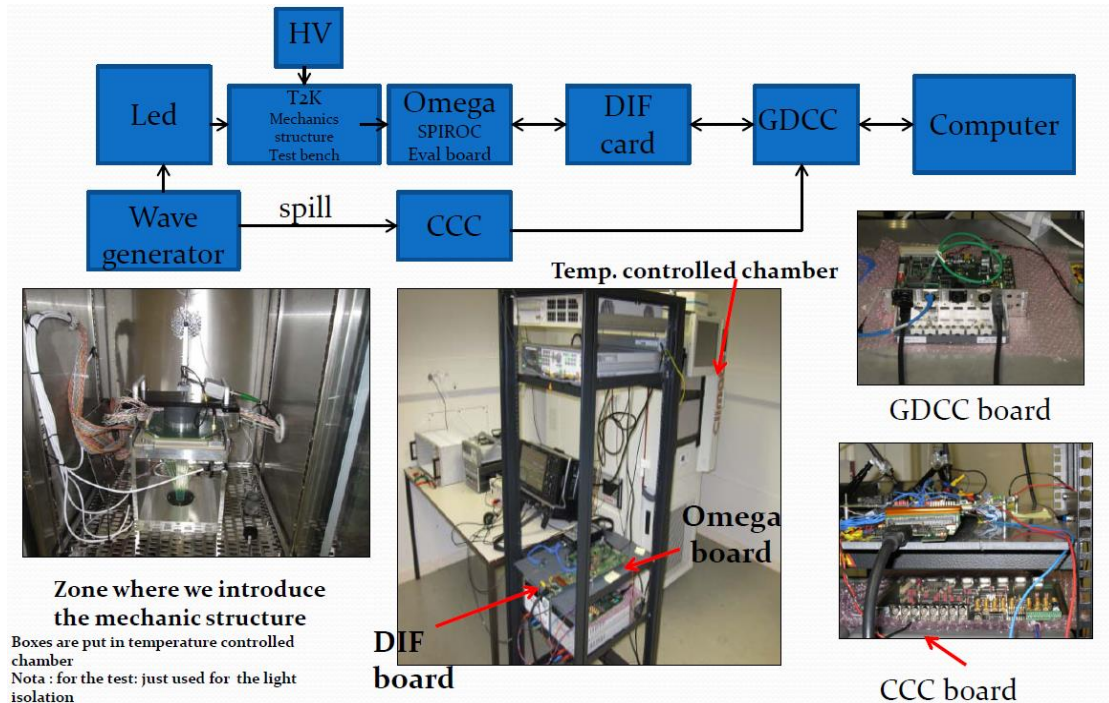
WAGASCI



Contributions du LLR



Conception mécanique (A. Bonnemaïson & O. Ferrreira) Conception et production de la DAQ (F. Gastaldi)



Nos expériences en cours

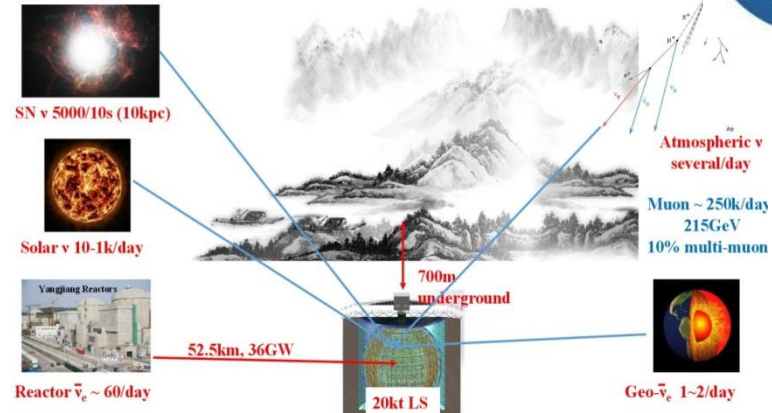
Location of JUNO

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

Overburden ~ 700 m by 2020: 26.6 GW



Neutrino rates

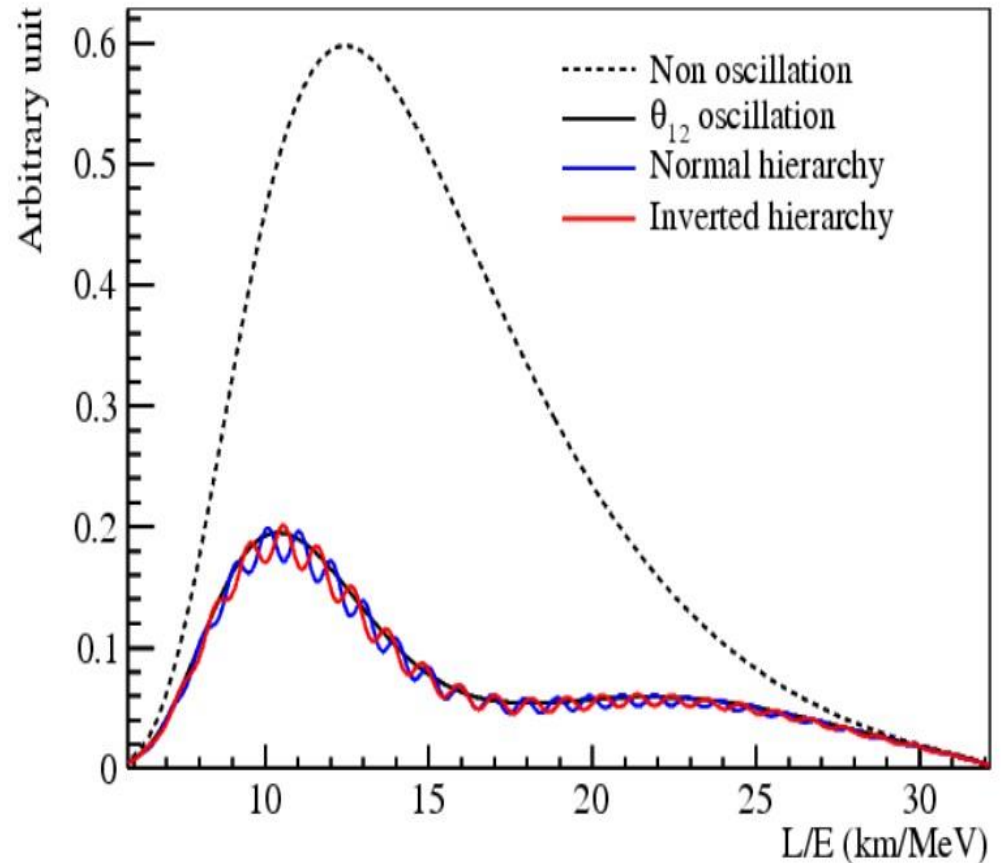
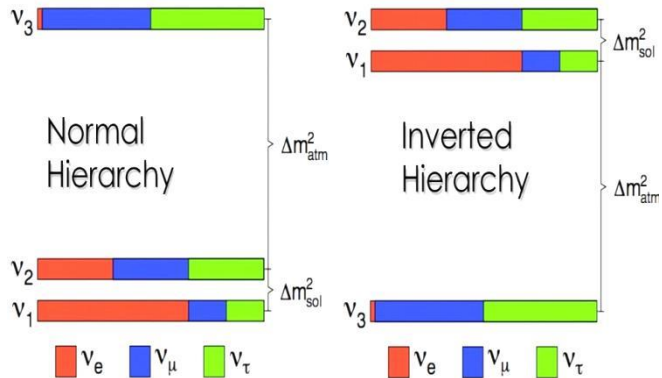


Calendrier

- ◆ Préparation: 2013-2014
 - ⇒ état actuel: sondage sur site fini
 - ⇒ design de l'ingénierie civile en cours
- ◆ CDR, proposal et MoU: 2015
- ◆ Construction du site: 2015-2017
 - ◆ cérémonie le 10 janvier 2015
- ◆ R&D détecteur: 2013-2016
- ◆ Construction des composants du détecteur: 2016-2017
- ◆ Production des PMT: 2016-2019
- ◆ Assemblage et installation du détecteur: 2018-2019
- ◆ Remplissage du détecteur et prise de données: 2020



Nos expériences en cours

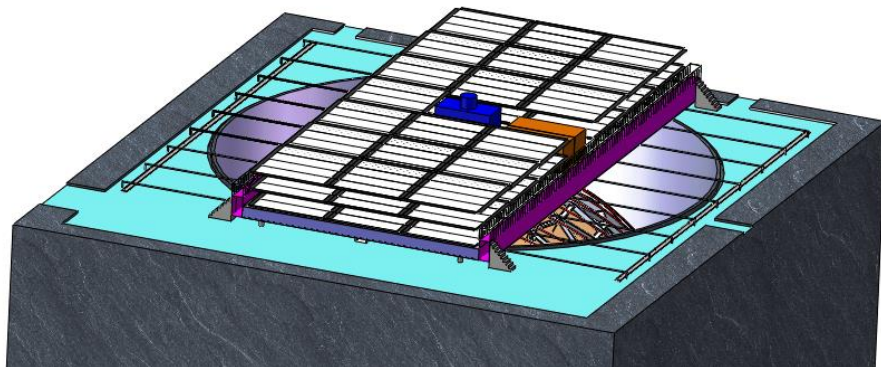
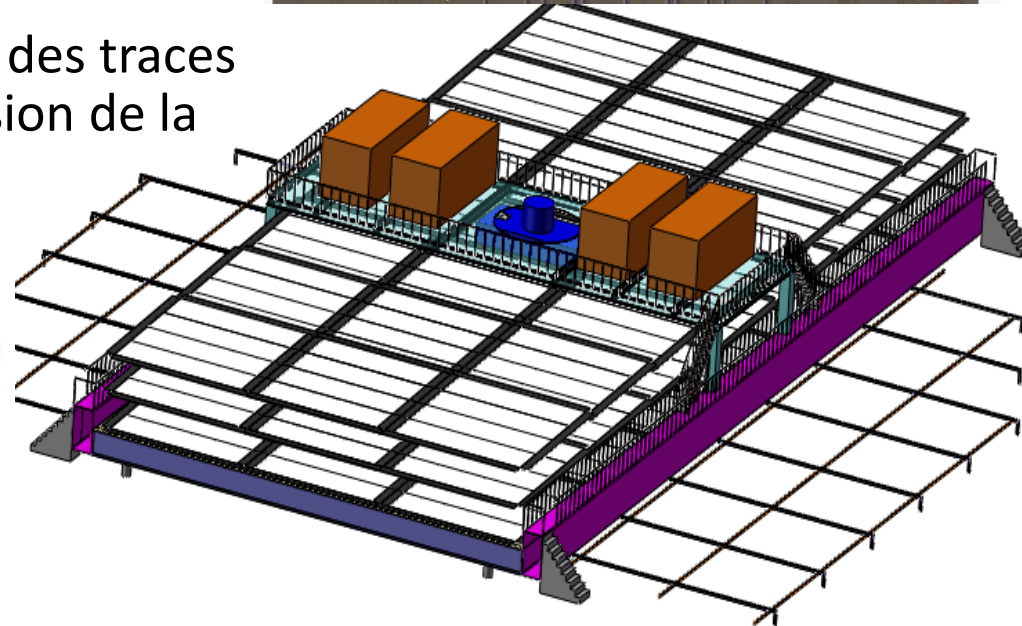
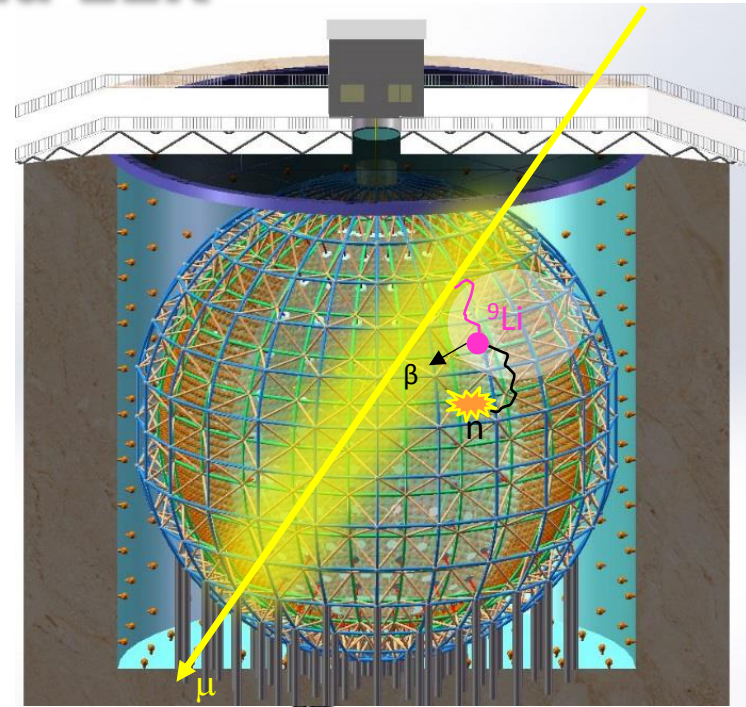


Objectif : détermination de l'ordre pour les masses des neutrinos



Contributions du LLR

- Important bruit de fond cosmogénique
 - ${}^9\text{Li}$ et ${}^8\text{He}$ créés par μ -spallation de ${}^{12}\text{C}$
 - $\tau \approx 0.1 - 0.2 \text{ s}$, decay $\beta + n$, miment ν (IBD)
 - Par jour : ≈ 2 candidats / ≈ 40 IBD
- Veto μ impossible sur tout le détecteur :
 - Taux de μ cosmiques : $\approx 4 \text{ Hz}$
 - Temps de veto : $\approx 1 \text{ s}$
- Solution : veto d'un tube ($\approx 1 \text{ m}$) autour des μ
 - Reconstruction des μ par
 - Détecteur veto (cherenkov à eau)
 - Détecteur central
- **Top Tracker** : échantillonnage des traces de muons pour améliorer la précision de la reconstruction des muons





Top Tracker de JUNO : OPERA Target Tracker

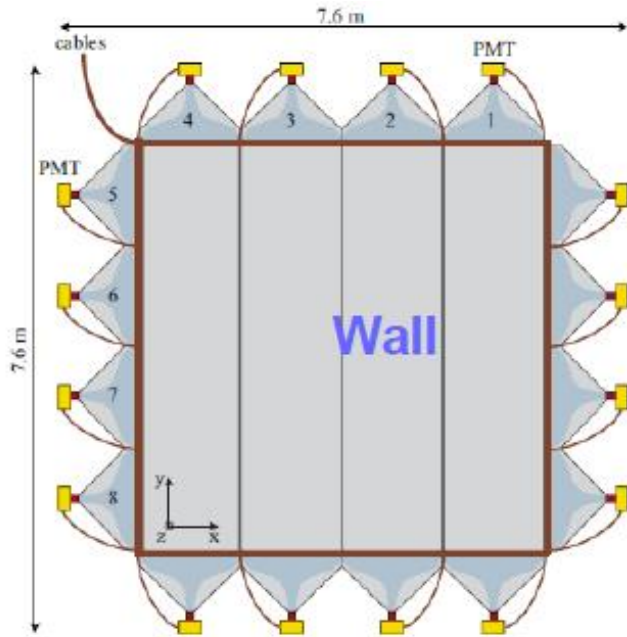
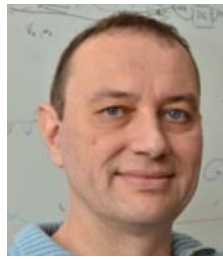


Fig. 3. Schematic view of a plastic scintillator strip wall.

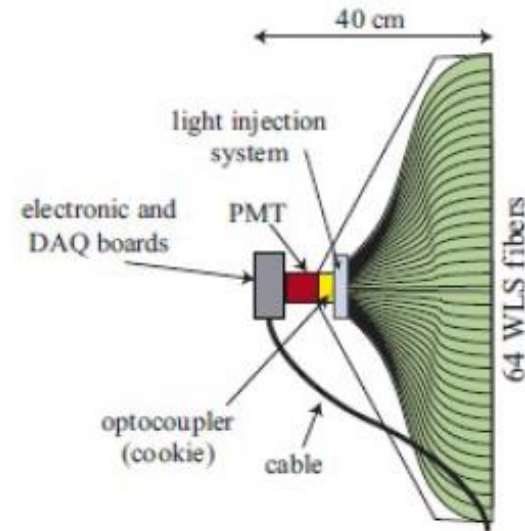
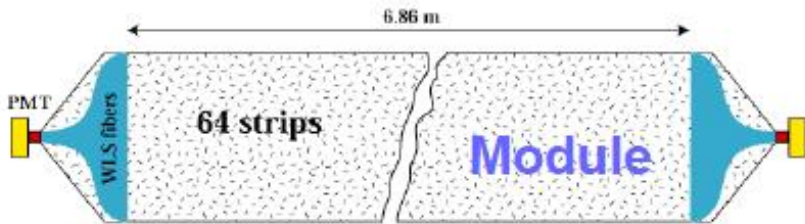
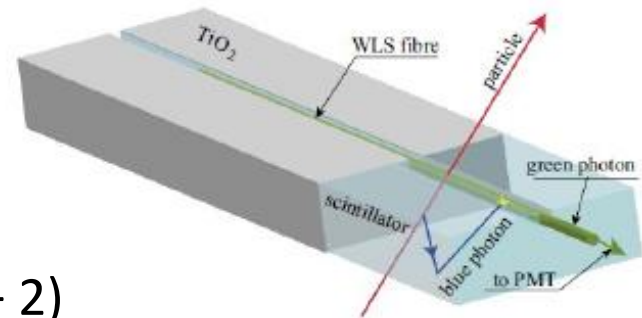


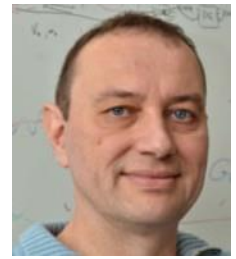
Fig. 2. Schematic view of an end-cap of a scintillator strip module.



- 62 « Murs » répartis en 3 couches ($3 \times 20 + 2$)
 - Chaque mur : 16 « modules » ($4X + 4Y$)
 - Chaque module a 64 canaux
 - Lus par 2 PMTs multi-anodes (H7546)
- 63488 canaux au total



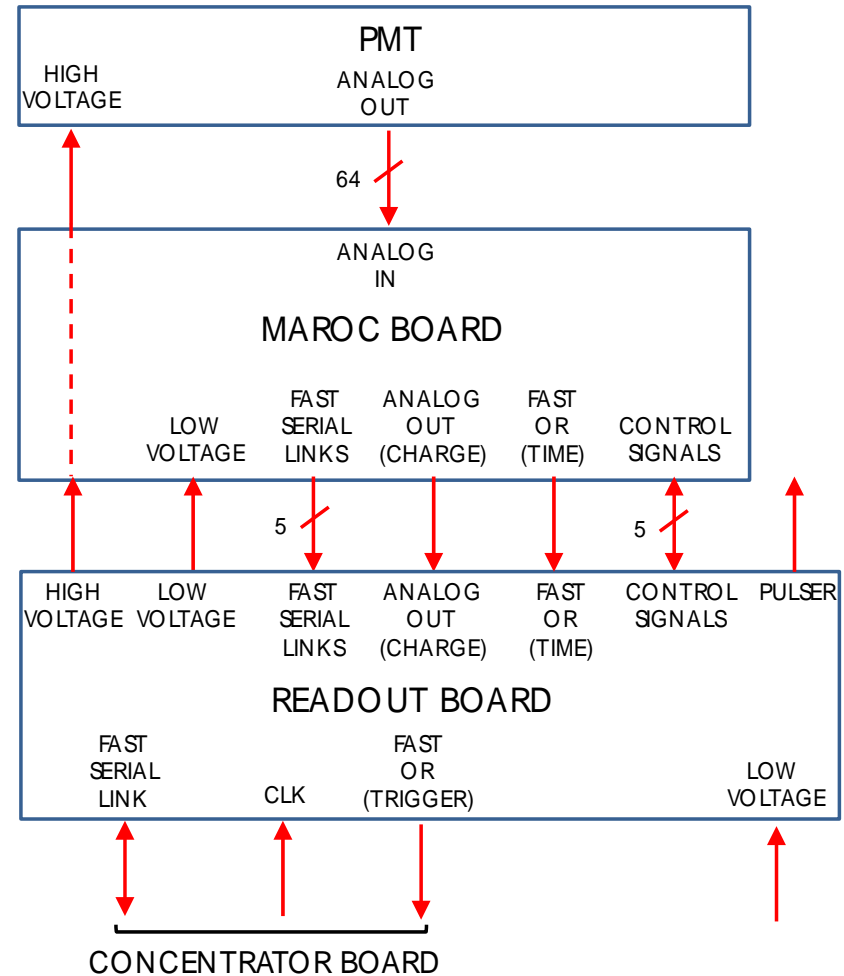
Électronique du Top Tracker de JUNO



- Bruit de fond cosmique (μ) ~ 4 Hz total mais
- Radioactivité ambiante importante
 - Pas de béton sur les parois

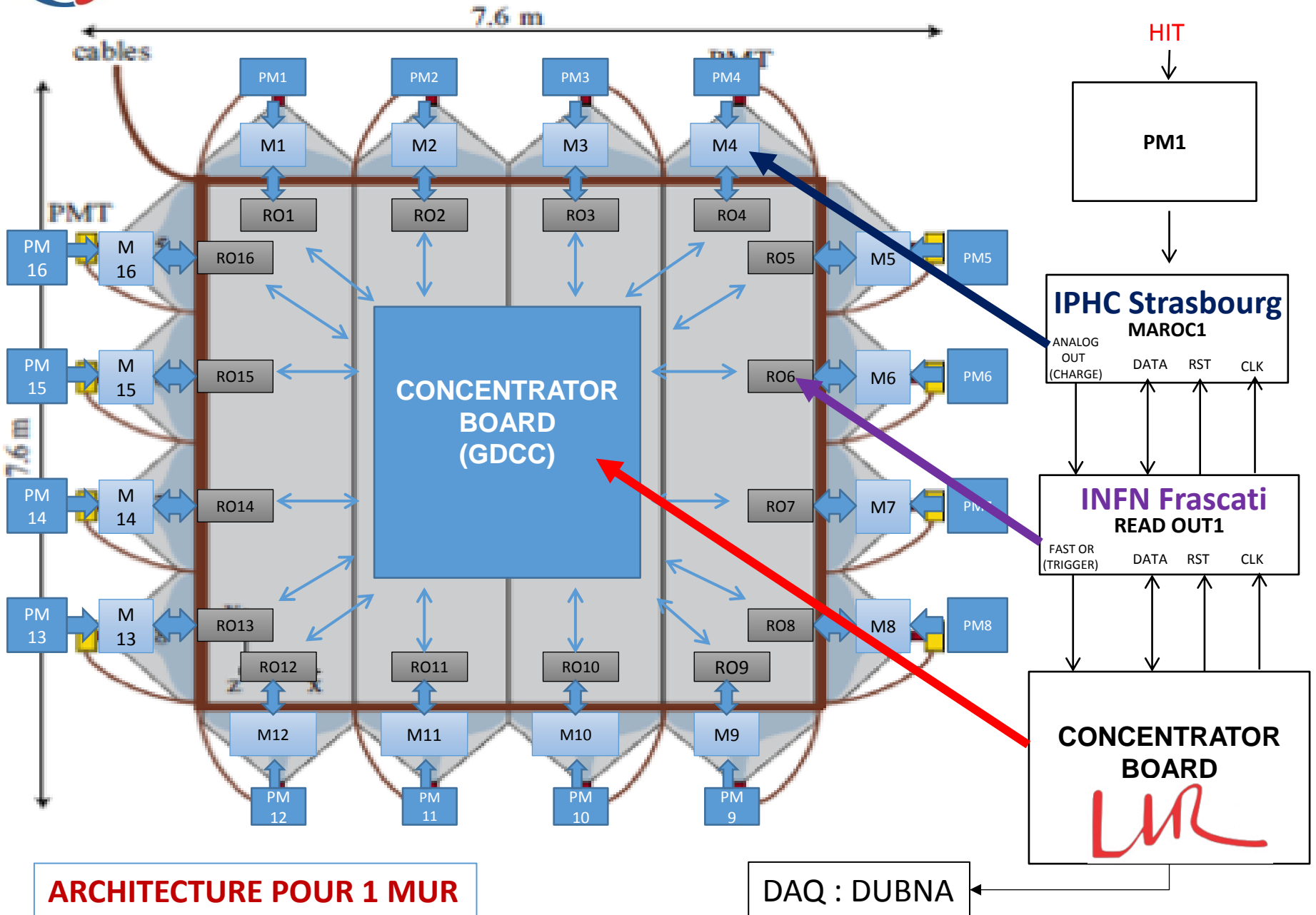
	0.3 p.e. OR	1 p.e. OR
Rate (Hz/m ²)	7400	4990
Rate (Hz/PMT)	50781	34640

- Bruit de fond de radioactivité ambiante : 35 KHz / PMT
 - Trop élevé pour le chip MAROC
 - Coincidences X.Y : 8 KHz : OK
- TRIGGER LVL1 coïncidence X.Y
 - « intelligente » (géométrie plausible ou pas selon signaux aux 2 extrémités de la fibre)
 - FPGA dans une carte « concentrateur »



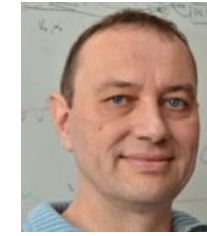


Carte GDCC développée pour CALICE au

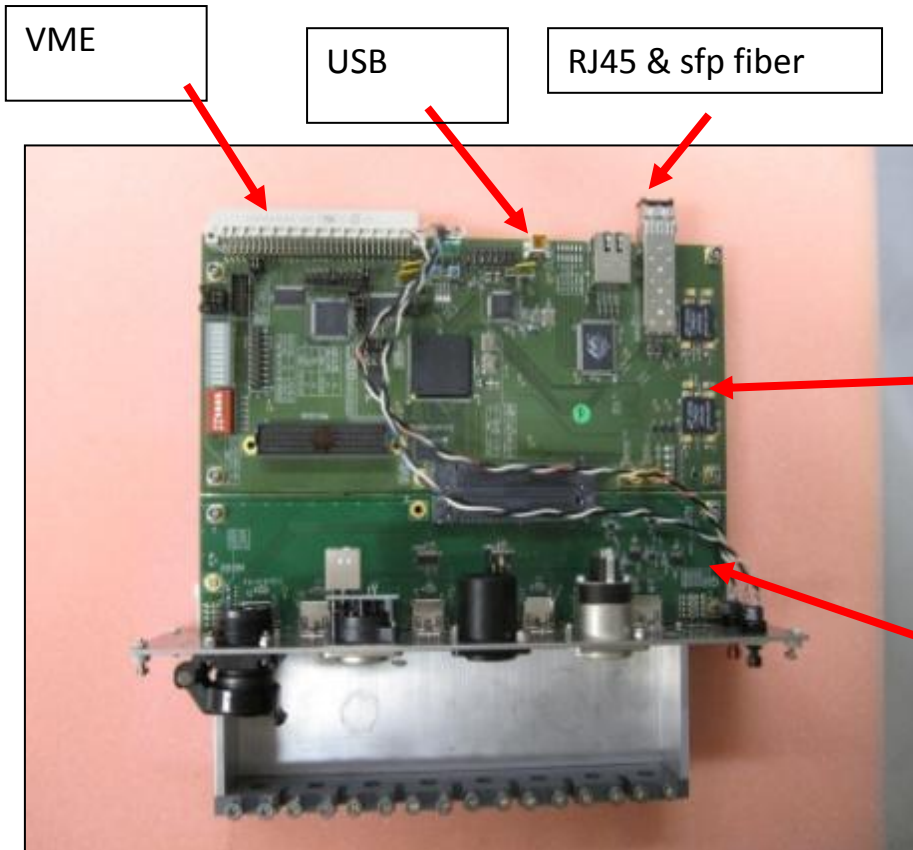




La carte GDCC



- Format : VME 6U (connecteur J1 pour tensions)
- 1/3 mezzanine avec connections vers cartes Read-out
- 2/3 carte mère avec Xilinx Spartan XC6SLX75 + Marvell
- USB pour debug



7 x DIFs HDMI

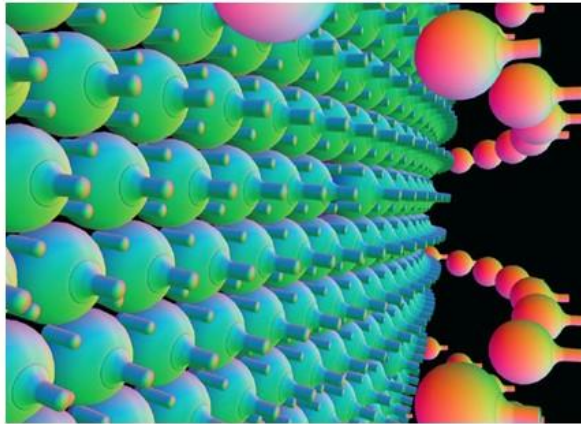
CCC HDMI

- **Adaptation principale : MEZZANINE pour 16 connections**
- **Révision du routage de la carte mère**
- **Upgrade du FPGA pour performances et approvisionnement**

Contributions du LLR (APC)



Margherita

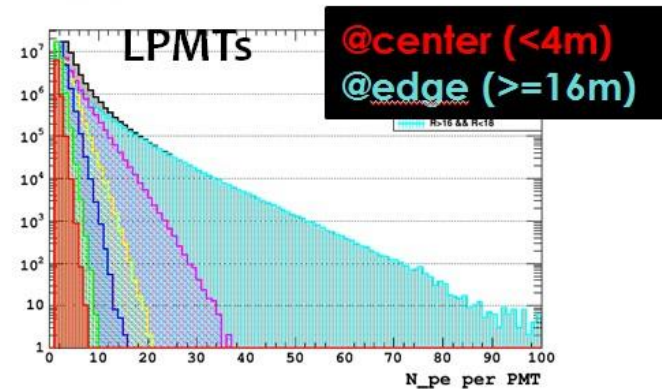


JUNO light read-out system:

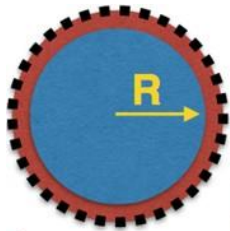
1. ~17k 20-inch PMTs (LPMTs)
2. and ~34k 3-inch PMTs (SPMTs)

SPMT physics concept was approved by JUNO collaboration in July 2015. The project design was approved in January 2016

The dynamic range for LPMT is very different between events @detector center and @edge, while SPMTs work in photon counting regime for all events

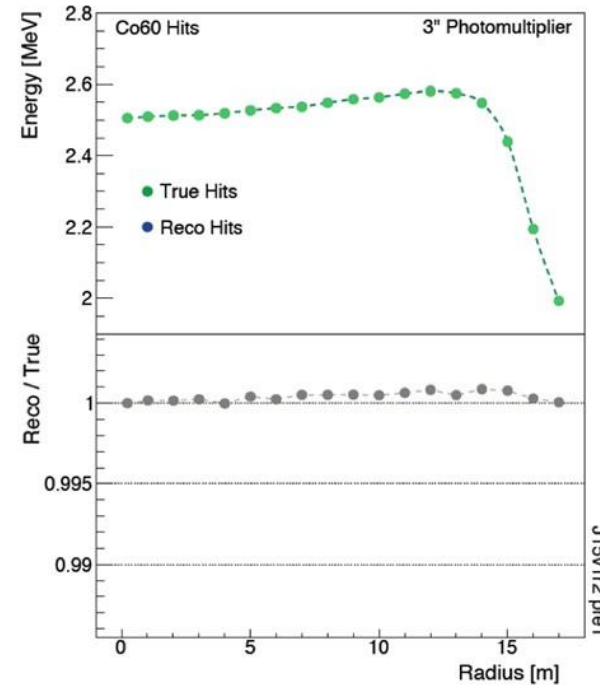
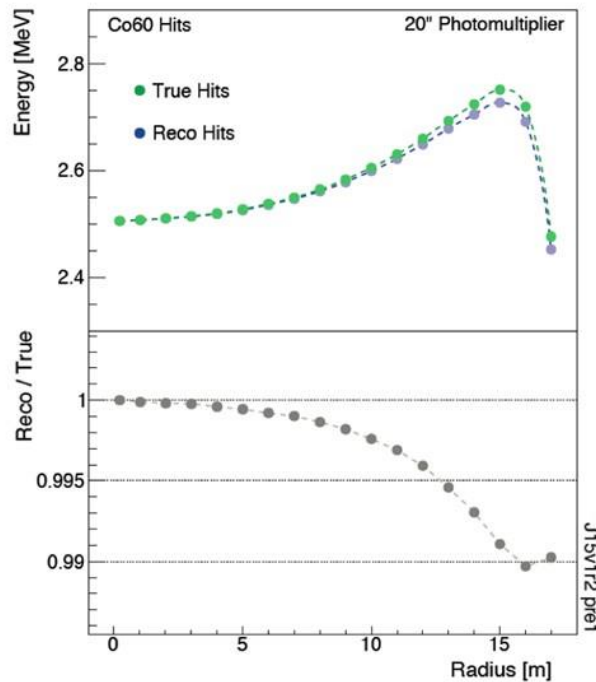


- 1st goal: use SPMT to calibrate the LPMT energy response, reduce systematics and improve energy resolution
- 2nd goal: natural extension to high energy physics (as muon reconstruction)
- 3rd goal: supernova neutrinos
- 4th goal: oscillation analysis with SPMT system only



Double Calorimetry

Non-linearity (single channel) → **Non-uniformity** (position dependent) → **Spoils resolution** (full detector)



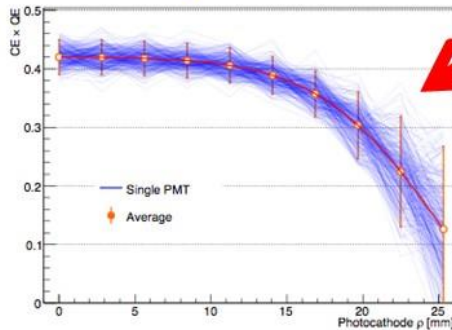
The reconstructed energy with SPMT represents the truth while with LPMT is biased.



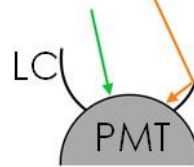
Margherita

Light Concentrators

Example of Detection Efficiency for a 20'' PMT



Collection Efficiency decreases + PMT-to-PMT spread



Originally proposed to mask the photocathode edge and to transmit light towards the center (better performing) of the photocathode.

Simulation studies performed in collaboration with APC, INFN and IHEP.

Proposed to the collaboration in January 2016.

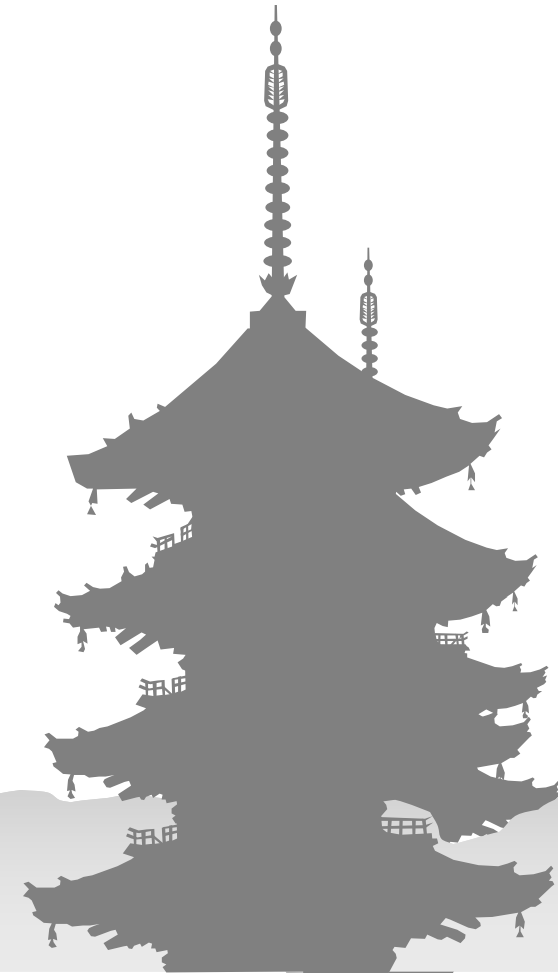
Presently LCs are an option for:

1. Occulting the PMT edge, where the CE decreases
2. More uniform light collection across the detector
3. Recovering (good) light if the number of PMTs is to be reduced (clearance between PMTs still to be defined)



Prototyping under study in China

- Le contexte physique (très rapide)
- Nos expériences en cours
 - T2K
 - WAGASCI
 - JUNO
- Nos perspectives
 - Extended T2K
 - Hyper - Kamiokande
 - **Super - Kamiokande (basse énergie)**



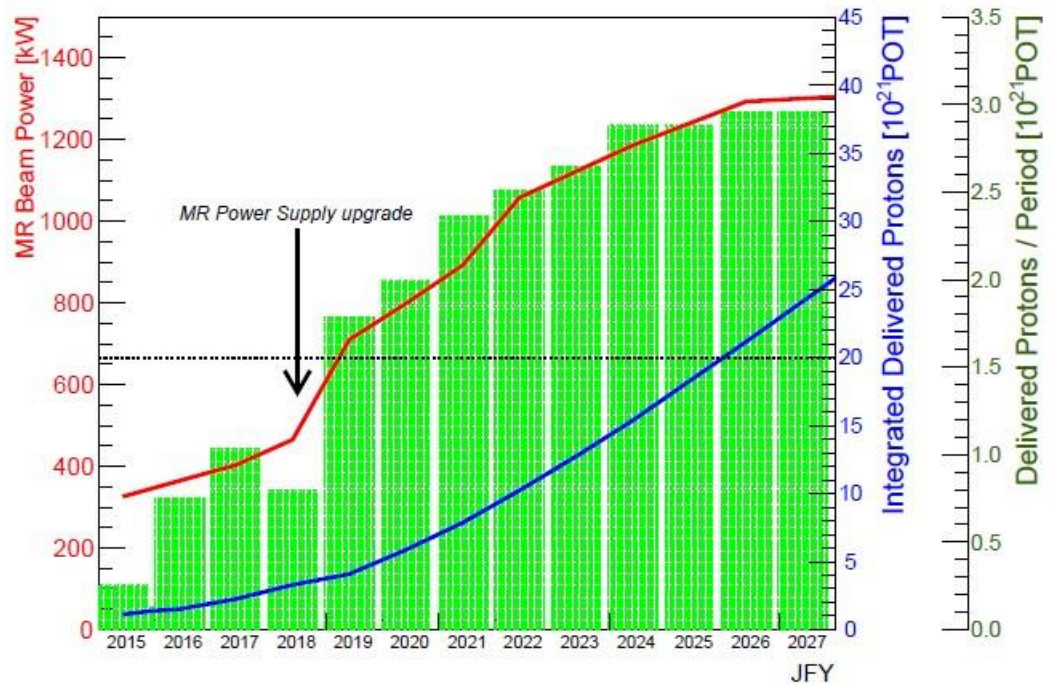
Extended T2K

Proposal for an Extended Run of T2K to 20×10^{21} POT

K. Abe,⁴⁵ H. Aihara,^{44,19} J. Amey,¹³ C. Andreopoulos,^{43,23} M. Antonova,¹⁸ S. Aoki,²⁰
 D. Autiero,²⁵ S. Ban,²¹ F.C.T. Barbato,¹⁵ M. Barbi,³⁶ G.J. Barker,⁵² G. Barr,³²
 P. Bartet-Friburg,³³ M. Batkiewicz,⁹ V. Berardi,¹⁴ S. Bhadra,⁵⁶ J. Bian,² S. Bienstock,³³
 A. Blondel,⁸ S. Bolognesi,³ S. Bordini,¹¹ S.B. Boyd,⁵² D. Brailsford,²² A. Bravar,⁸
 C. Bronner,¹⁹ M. Buizza Avanzini,⁷ J. Calcutt,²⁶ R.G. Calland,¹⁹ D. Calvet,³
 T. Campbell,⁶ S. Cao,²¹ S.L. Cartwright,⁴¹ R. Castillo,¹¹ M.G. Catanesi,¹⁴ A. Cervera,¹²
 D. Cherdack,⁵ N. Chikuma,⁴⁴ G. Christodoulou,²³ A. Clifton,⁵ J. Coleman,²³
 G. Collazuol,¹⁶ D. Coplowe,³² L. Cremonesi,³⁵ A. Cudd,²⁶ A. Dabrowska,⁹ A. Delbart,³
 G. De Rosa,¹⁵ T. Dealtry,²² P.F. Denner,⁵² S.R. Dennis,²³ C. Densham,⁴³ D. Dewhurst,³²
 F. Di Lodovico,³⁶ S. Dolan,³² O. Drapier,⁷ K.E. Duffy,³² J. Dumarchez,³³ M. Dunkman,²⁶
 M. Dziewiecki,⁵¹ S. Emery-Schrenk,³ P. Fernandez,⁴⁰ T. Feusels,⁵⁷ A.J. Finch,²²
 G.A. Fiorentini,⁵⁶ M. Friend,¹⁰ Y. Fujii,¹⁰ D. Fukuda,³⁰ Y. Fukuda,²⁷ V. Galymov,²⁵
 A. Garcia,¹¹ C. Giganti,³³ F. Gizzarelli,³ M. Gonin,⁷ N. Grant,⁵² D.R. Hadley,⁵²
 L. Haegel,⁸ M.D. Haigh,⁵² D. Hansen,³⁴ J. Harada,³¹ M. Hartz,^{19,49} T. Hasegawa,¹⁰
 N.C. Hastings,³⁶ T. Hayashino,²¹ Y. Hayato,^{45,19} T. Hiraki,²¹ A. Hiramoto,²¹ S. Hirota,²¹
 M. Hogan,⁵ J. Holeczek,⁴² F. Hosomi,⁴⁴ K. Huang,²¹ A.K. Ichikawa,²¹ M. Ikeda,⁴⁵
 J. Imber,⁷ J. Insler,²⁴ R.A. Intonti,¹⁴ T. Ishida,¹⁰ T. Ishii,¹⁰ E. Iwai,¹⁰ K. Iwamoto,³⁷
 A. Izmaylov,^{12,18} B. Jamieson,⁵⁴ M. Jiang,²¹ S. Johnson,⁴ J.H. Jo,²⁹ P. Jonsson,¹³
 C.K. Jung,²⁹ M. Kabirnezhad,²⁸ A.C. Kaboth,^{38,43} T. Kajita,⁴⁶ H. Kakuno,⁴⁷
 J. Kameda,⁴⁵ T. Katori,³⁵ E. Kearns,^{1,19} M. Khatabullin,¹⁸ A. Khotiantsev,¹⁸ H. Kim,³¹
 S. King,³⁵ J. Kiesel,⁴² A. Knight,⁵² A. Knox,²² T. Kobayashi,¹⁰ L. Koch,³⁹ T. Koga,⁴⁴
 A. Konaka,⁴⁹ K. Kondo,²¹ L.L. Kormos,²² A. Korzenev,⁸ Y. Koshio,³⁰ K. Kowalik,²⁸

Abstract

Recent measurements at T2K indicate that CP violation in neutrino mixing may be observed in the future by long-baseline neutrino oscillation experiments. We propose an extension to the currently approved T2K running from 7.8×10^{21} protons-on-target to 20×10^{21} protons-on-target, aiming at initial observation of CP violation with 3σ or higher significance for the case of maximum CP violation. The program also contains a measurement of mixing parameters, θ_{23} and Δm_{32}^2 , with a precision of 1.7° or better and 1%, respectively. With accelerator and beamline upgrades, as well as analysis improvements, this program would occur before the next generation of long-baseline neutrino oscillation experiments that are expected to start operation in 2026.



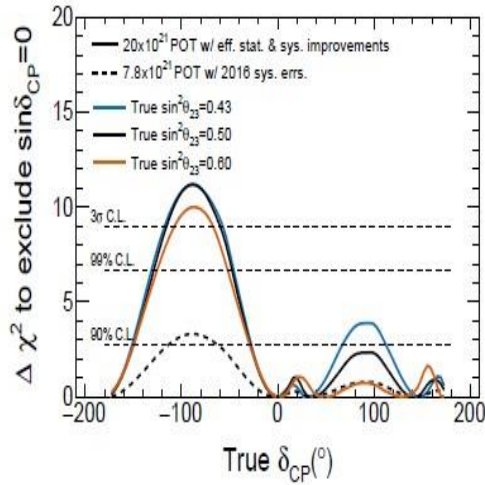
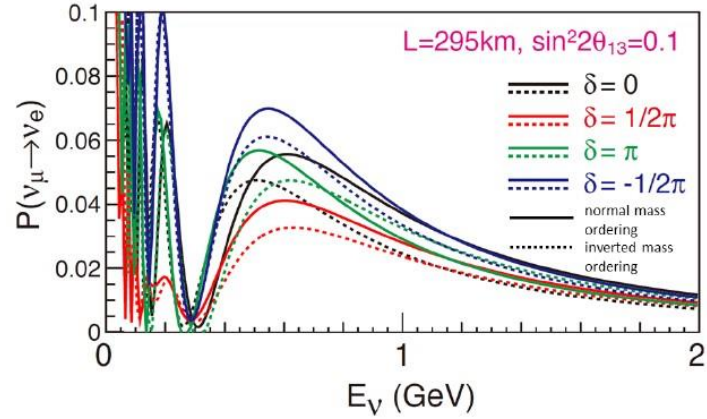
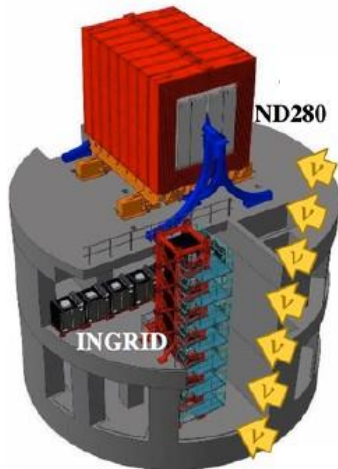
Extended T2K

TABLE I: Number of events expected to be observed at the far detector for 10×10^{21} POT ν - + 10×10^{21} POT $\bar{\nu}$ -mode with a 50% statistical improvement.

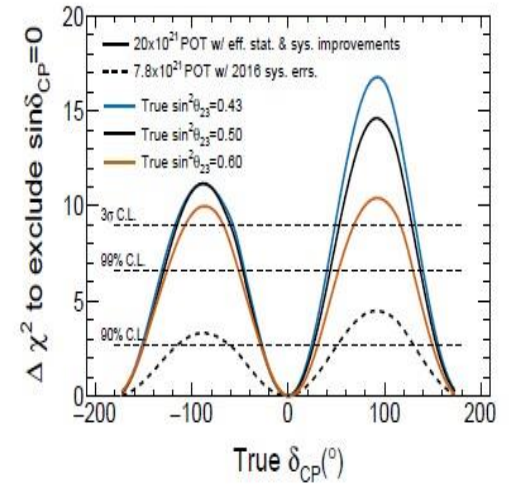
Assumed relevant oscillation parameters are: $\sin^2 2\theta_{13} = 0.085$, $\sin^2 \theta_{23} = 0.5$, $\Delta m_{32}^2 = 2.5 \times 10^{-3} \text{ eV}^2$, and normal mass hierarchy (NH).

	True δ_{CP}	Total	Signal	Signal	Beam CC	Beam CC	NC
			$\nu_\mu \rightarrow \nu_e$	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	
ν -mode	0	467.6	356.3	4.0	73.3	1.8	32.3
ν_e sample	$-\pi/2$	558.7	448.6	2.8	73.3	1.8	32.3
$\bar{\nu}$ -mode	0	133.9	16.7	73.6	29.2	0.4	14.1
$\bar{\nu}_e$ sample	$-\pi/2$	115.8	19.8	52.3	29.2	0.4	14.1

	Total	Beam CC	Beam CC	Beam CC	$\nu_\mu \rightarrow \nu_e +$	NC
		ν_μ	$\bar{\nu}_\mu$	$\nu_e + \bar{\nu}_e$	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	
ν -mode ν_μ sample	2735.0	2393.0	158.2	1.6	7.2	175.0
$\bar{\nu}$ -mode $\bar{\nu}_\mu$ sample	1283.5	507.8	707.9	0.6	1.0	66.2



(a) Assuming the MH is unknown.



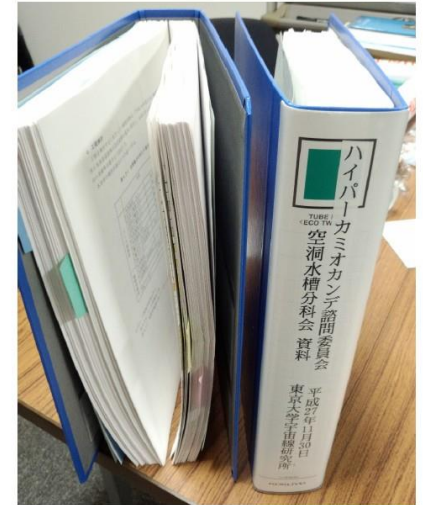
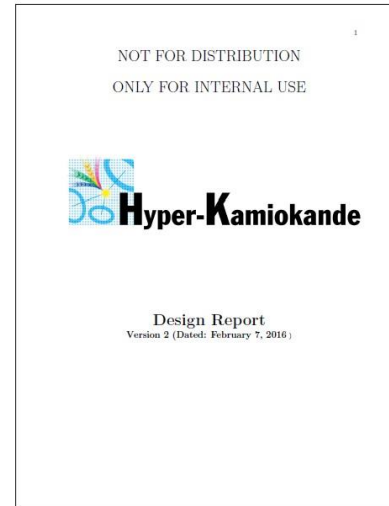
(b) Assuming the MH is known – measured by an outside experiment.

Hyper-K proto-collaboration

Inaugural Symposium@Kashiwanoha, January 2015



- **International Hyper-K group has been established**
 - International interests to the project
 - ~250 members, ~70% from abroad
- MoU between UTokyo/ICRR and KEK/IPNS
- Int. Hyper-K Advisory Committee has been launched.



Hyper Kamiokande
@HyperKamiokande

Vous avez retweeté

Hyper Kamiokande @HyperKamiokande · 1 juin Voir la traduction

"J-PARC upgrade for HK is the highest priority", KEK Project Implementation Plan, N. Saito, kds.kek.jp/indico/event/2...

KEK Project Implementation Plan Review

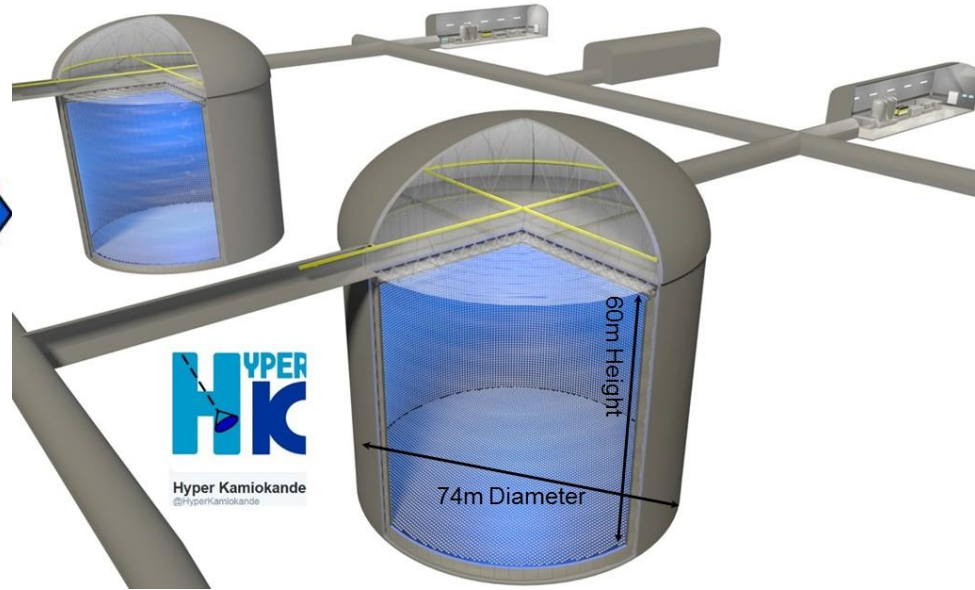
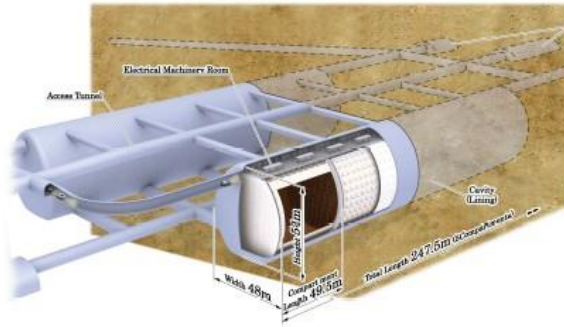
- Priority of new projects to be promoted with a major budget request was discussed.

KEK-PIP Advisory Committee Meeting
from Sunday, 22 May 2016 at 08:00 to Monday, 23 May 2016 at KEK Tsukuba (TBA)

Description	Advisory Committee Members
Project to be prioritized:	COMET II
Priority of new projects to be promoted with a major budget request was discussed.	J-PARC upgrade for Hyper Kamiokande
	Hadron Hall Extension
	H-line and g-2/EDM
	LHC and ATLAS
	Super Computer
	RNB
	Separate prioritization
	Light Source

PIP review concluded that "J-PARC upgrade for HK is the highest priority".

Nouveau design (et coût)

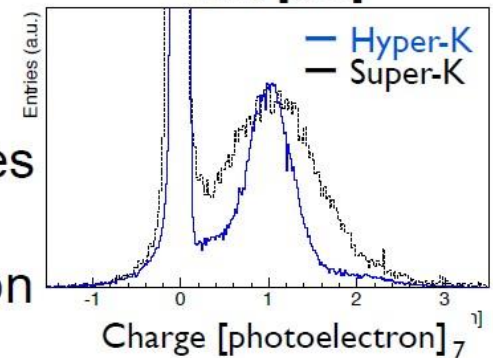
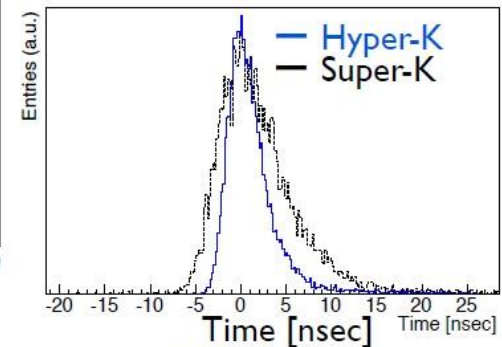
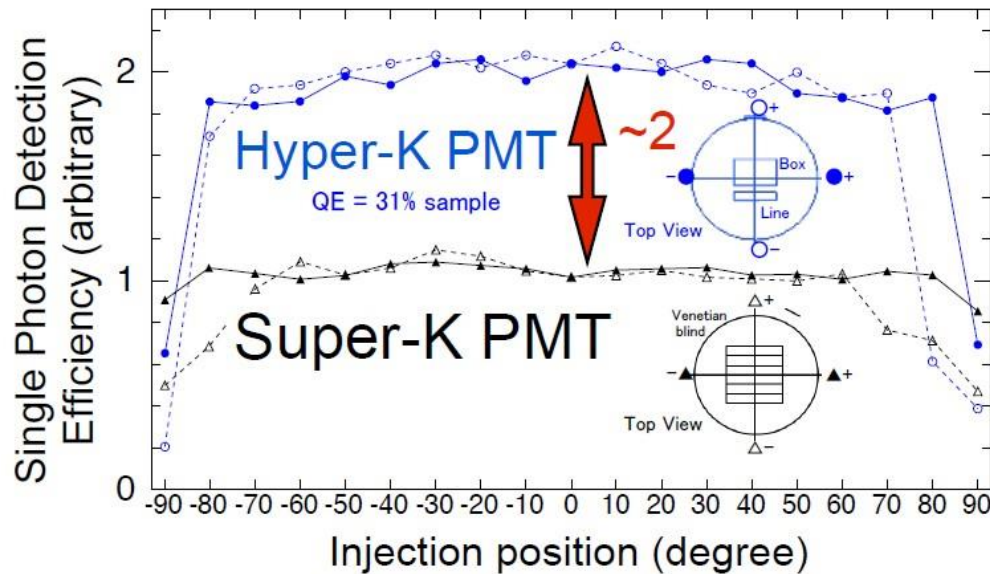


- Vertical tank a la SK
- **2 Tanks with staging**

1Tank

- Cylindrical Tank: 60m(H)×74m(D)
- Volume: Total 260 kton
- Fiducial volume(FV): 190 kton
 - ~10 x SK FV
 - ~ 5 x DUNE
 - ~ 1/3 x original HK design
- PMT coverage 40%, 40,000 ID-PMT, 6,700 OD-PMT

New 50cm Φ PMT

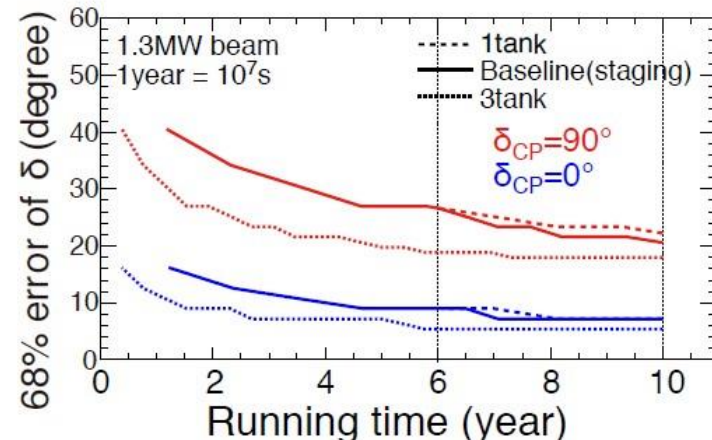
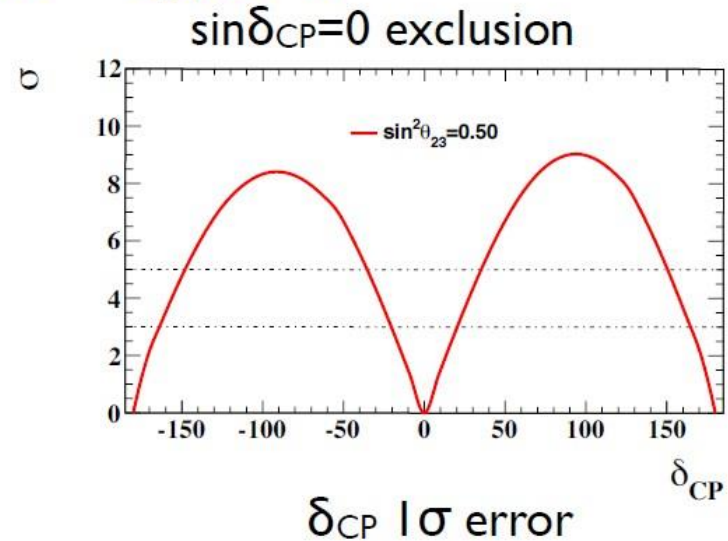


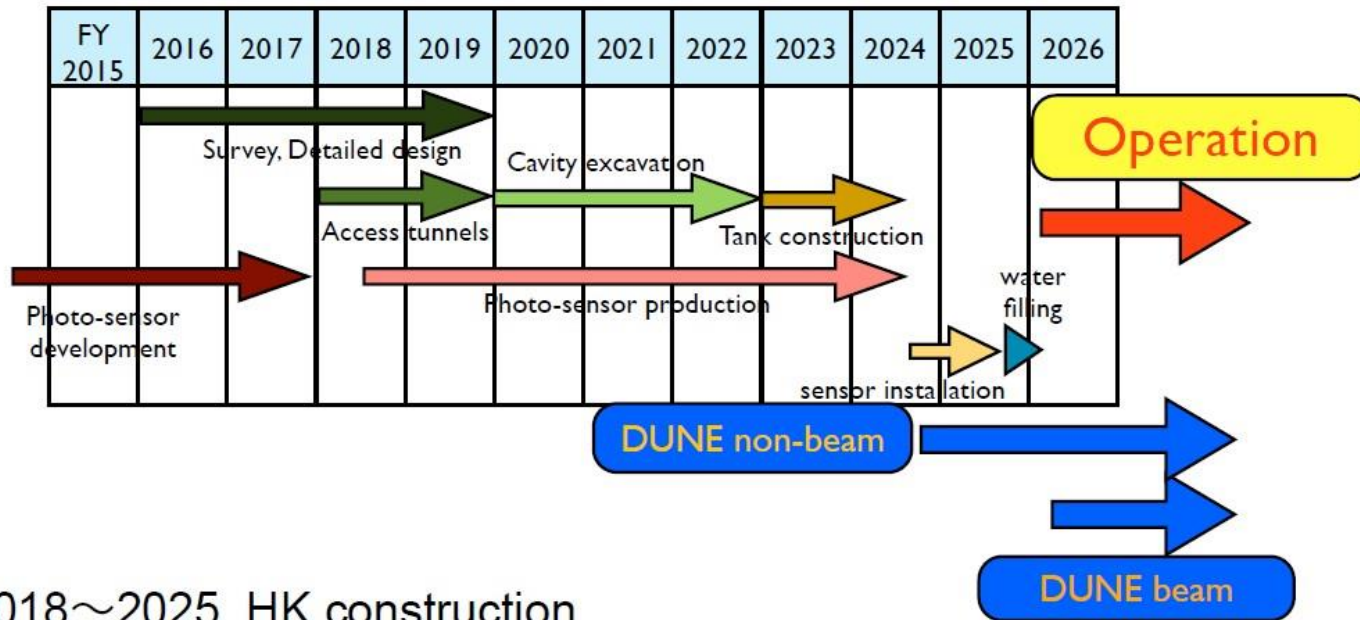
- Efficiency $\times 2$, Timing resolution $\times 1/2$
- Pressure tolerance $\times 2$ ($>100\text{m}$)
- The impact is large to physics sensitivities and detector design optimization
 - enhance $p \rightarrow \nu K^+$ signal, solar ν , neutron signature of $np \rightarrow d + \gamma (2.2\text{MeV})$

CPV sensitivity

J-PARC ν beam + Hyper-K

- Exclusion of $\sin\delta_{\text{CP}}=0$
 - 8σ for $\delta=-90^\circ$ (T2K best fit)
 - 80% coverage of δ parameter space for CPV discovery w/ $>3\sigma$
- δ_{CP} precision measurement
 - 20° for $\delta=-90^\circ$
 - 7° for $\delta=0^\circ$





- 2018~2025 HK construction
- 2026~ CPV study
Atm · Solar · Supernova v study, Proton decay searches

(Note) In the physics potential study, assumed are start of 2nd tank operation 6 years after the start of 1st tank.

Le prix Nobel 2015

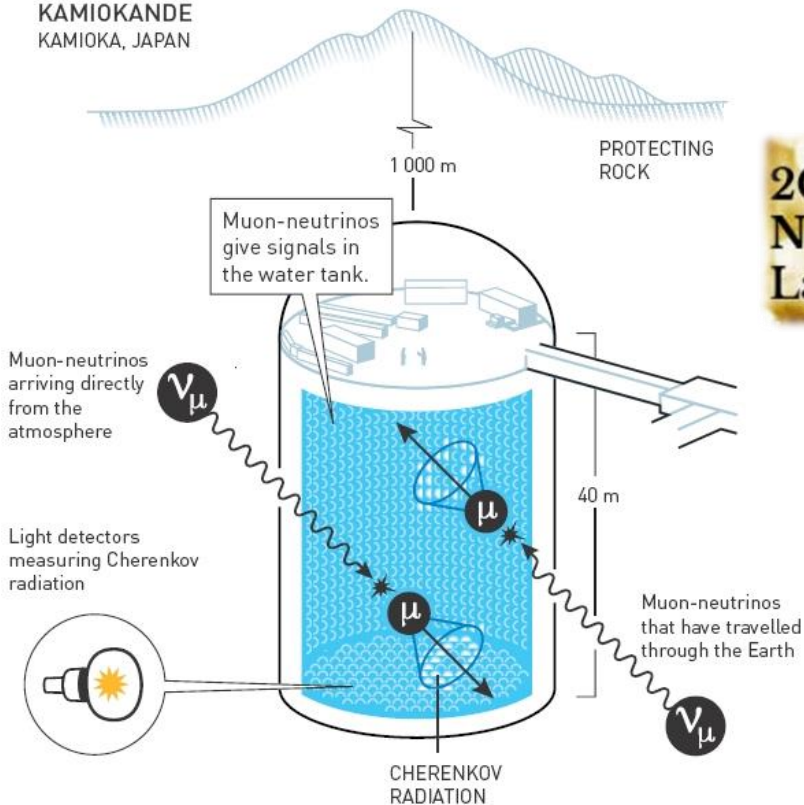


Torn between identities – tau-, electron- or myon-neutrino?

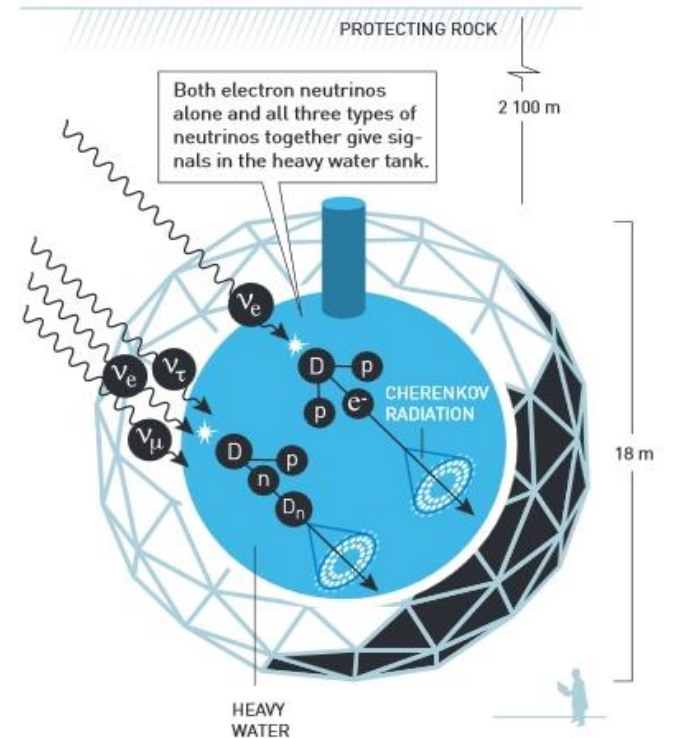
Super-Kamiokande

SNO

SUPER-KAMIOKANDE
KAMIOKA, JAPAN

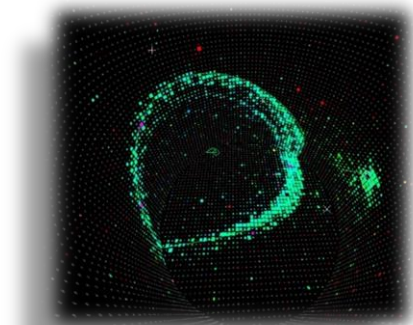
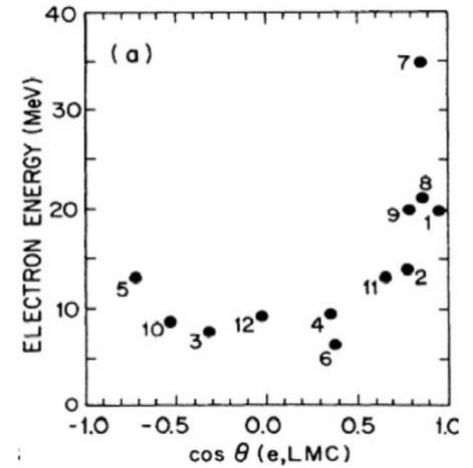
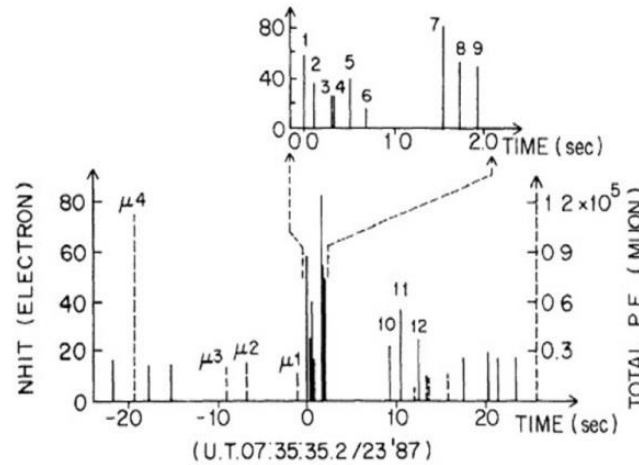
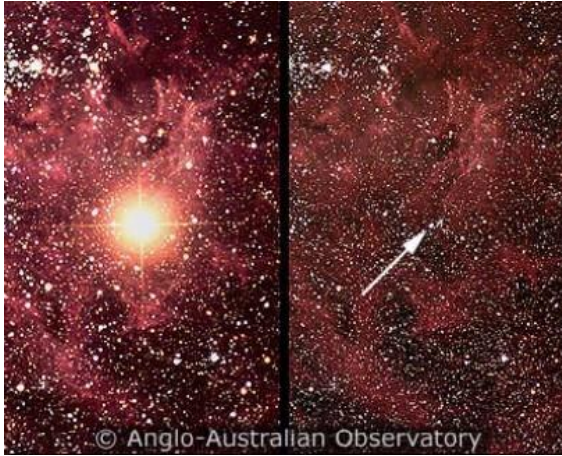


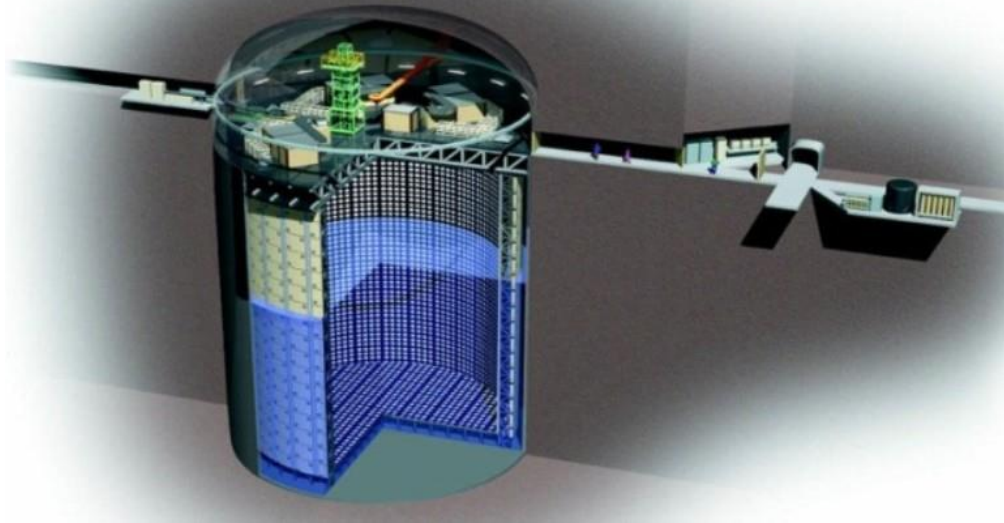
SUDBURY NEUTRINO OBSERVATORY (SNO)
ONTARIO, CANADA



Explosion de la supernova SN 1987A

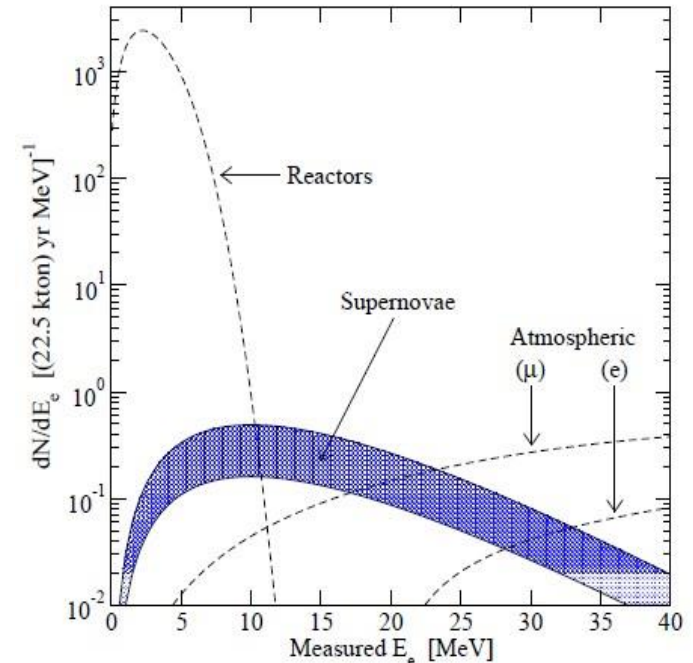
Prix Nobel 2002 (Kamiokande) pour la détection de 11 neutrinos émis





La collaboration Super-Kamiokande (SK) a décidé très récemment de rajouter du **gadolinium** (Gd) dans sa cuve d'eau pour élargir son domaine de recherche à la cosmologie. L'objectif de ce projet sera d'identifier *les antineutrinos de basse énergie* grâce à la capture des neutrons produits par l'interaction faible des antineutrinos électrons avec l'eau.

Cette nouvelle technique doit améliorer considérablement, environ d'un facteur mille, la sensibilité du détecteur SK pour la détection du **Fond Diffus des Neutrinos de Supernovas** (DSNB) émis lors des explosions de supernovas.



~ 5-6 evts/an

Notre projet : rejoindre la collaboration SK pour la physique « basse énergie » dès la fin de l'année.

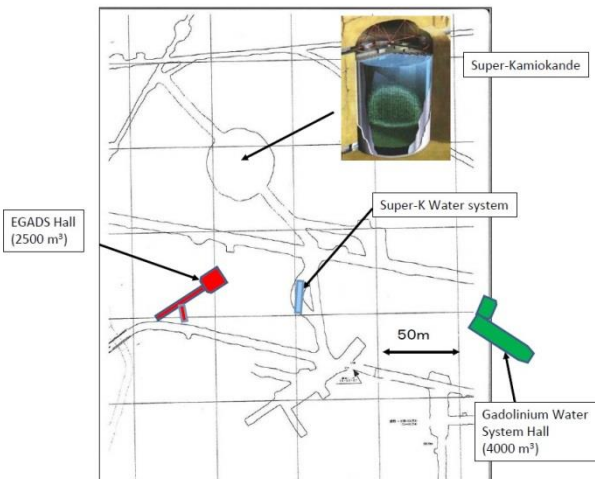
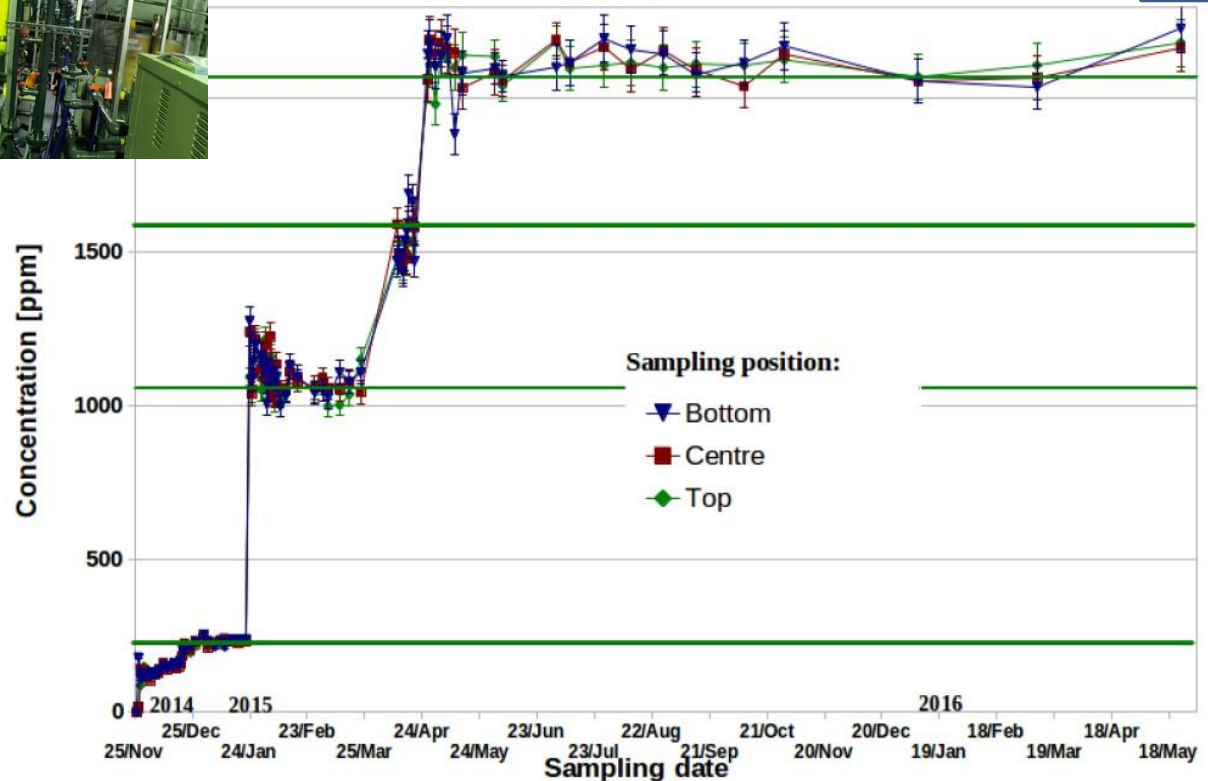


After gadolinium loading was completed on April 24th, 2015, the EGADS water filtration systems have continuously recirculated the 0.2% $Gd_2(SO_4)_3$ water in the 200-ton tank.

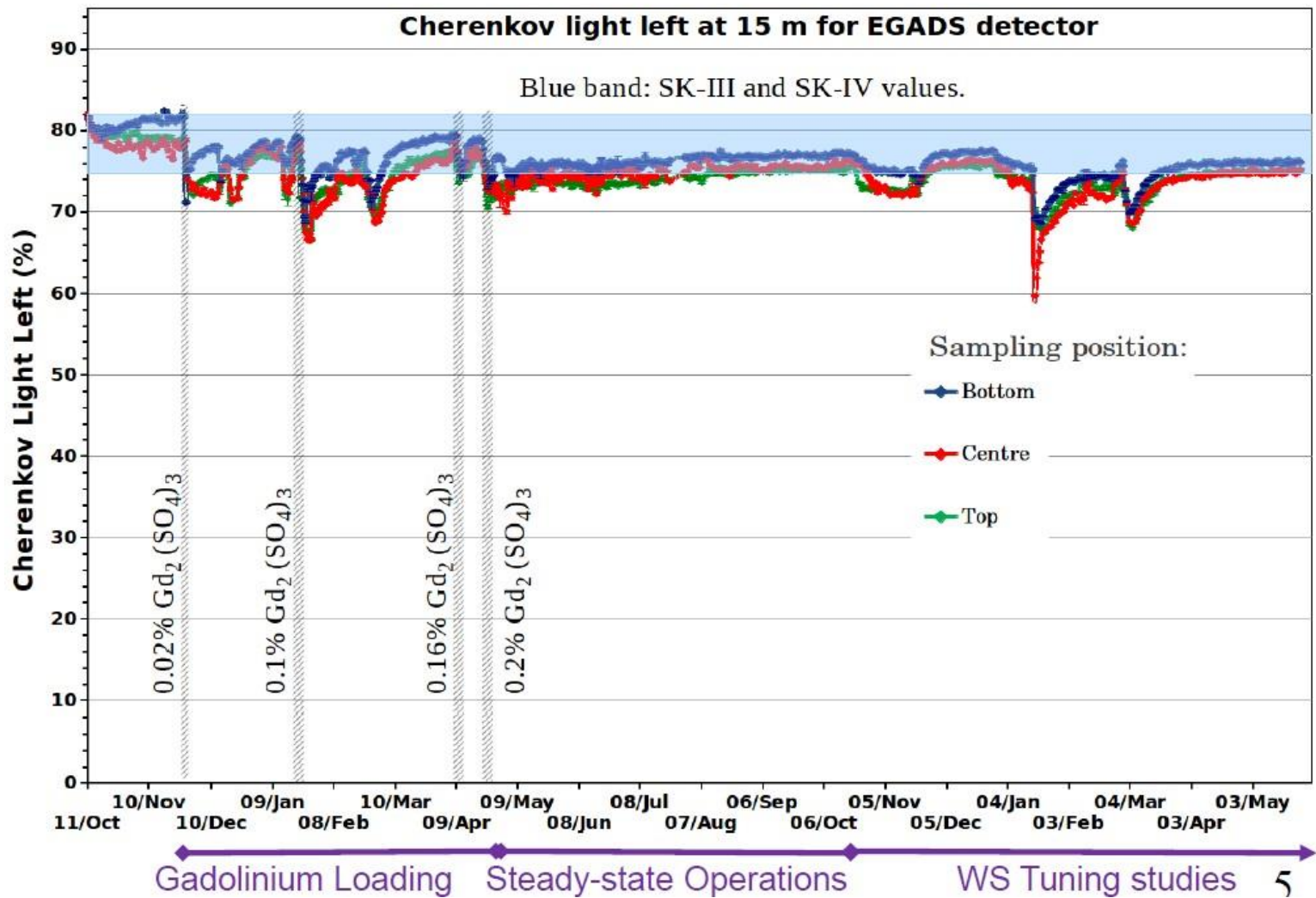
Water system operation has been exceptionally stable.



EGADS $Gd_2(SO_4)_3 + x \cdot H_2O$ concentration



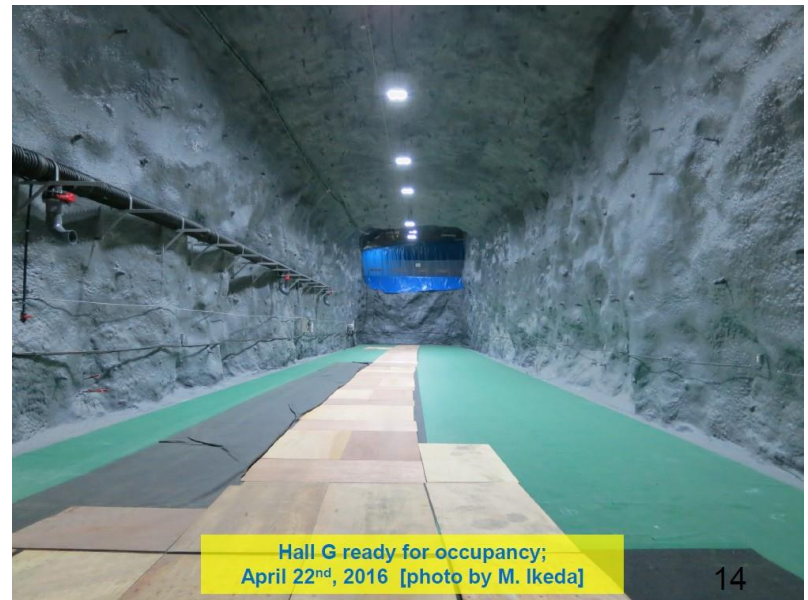
Our Gd-capable water system really is lossless (>99.99%) – the fully-loaded EGADS tank has been turned over 250 times so far.





New gadolinium water system hall ("Hall G");
September 10st, 2015 [photo by M. Nakahata]

13



Hall G ready for occupancy;
April 22nd, 2016 [photo by M. Ikeda]

14

Next topic: reduction of introduced background

Intrinsic radioisotopes in $Gd_2(SO_4)_3$ could add low energy background in 8B solar ν region of spectrum

- BG reduction → Purification of 100 tons of $Gd_2(SO_4)_3$

Typical $Gd_2(SO_4)_3$ on the market

Chain	Main sub-chain isotope	Radioactive concentration (mBq/kg)
^{238}U	^{238}U	50
	^{226}Ra	5
^{232}Th	^{228}Ra	10
	^{228}Th	100
^{235}U	^{235}U	32
	$^{227}Ac/^{227}Th$	300

For DSNB

Expected signal ~ 5 events/year/FV

- ^{238}U Spontaneous Fission:
 $\sim 5.5 [\gamma(E_\gamma > 10.5 \text{ MeV}) + 1n] / \text{year} / \text{FV}$

1 order reduction

For solar neutrino

Current BG ~ 200 events/day/FV

- $U(n) \sim 320$ events/day/ FV
- $Th/Ra (\beta, \gamma) \sim 3 \times 10^5$ events/day/ FV

1 order reduction

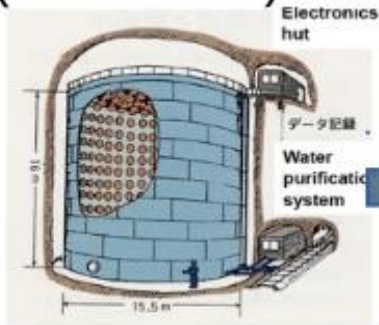
3 orders reduction



2025 →



Kamiokande
(1983-1996)



3kton

Super-Kamiokande
(1996-)



50kton

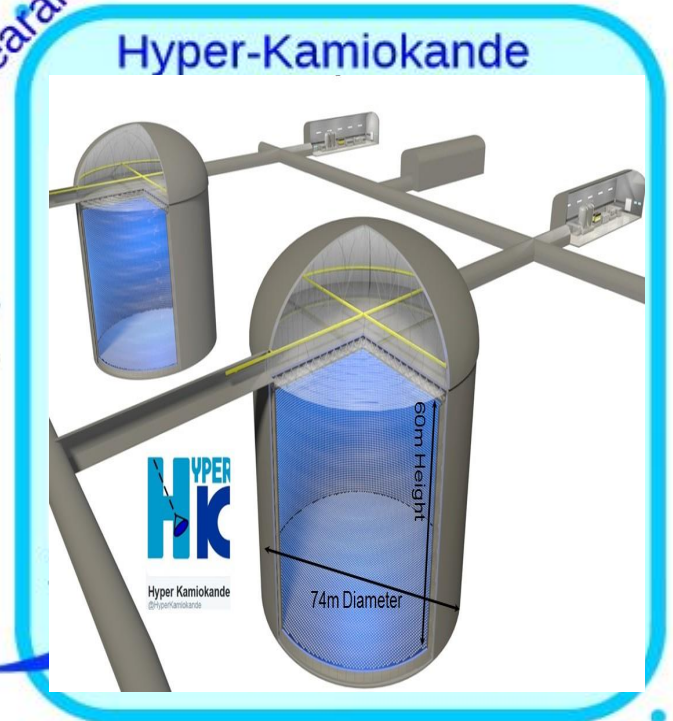
Discovery of neutrino oscillation (1998)
Observation of electron neutrino appearance (w/ beam, T2K, 2013)

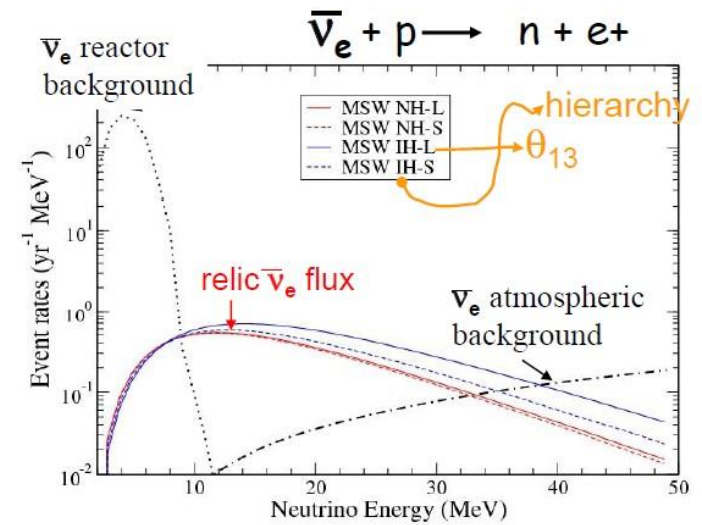
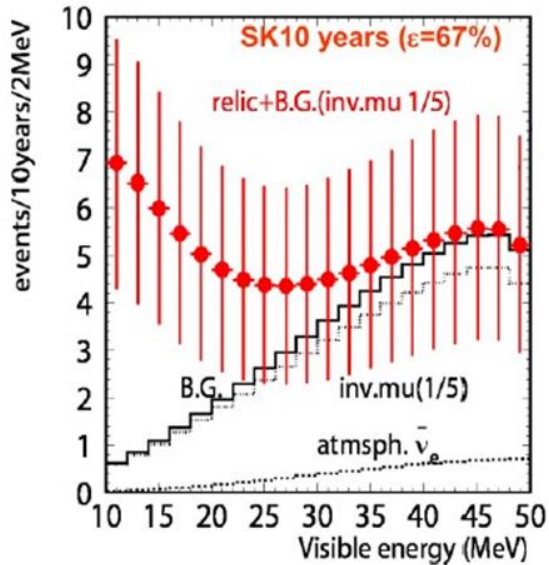
x17

x20

(x25 fiducial mass)

Hyper-Kamiokande





Calendrier SK – Gd

Juin 2016 : Participation du LLR très encouragée par l'IN2P3

Novembre 2016 : Réponse de la collaboration SK

2018 : Vidange complète de SK

2019 – 2020 : première prises de données

~ 2028 fin des prises de données SK



T2K, WAGASCI, JUNO, T2K-II. Un programme de physique neutrinos « oscillations » cohérent. Potentiel de découverte très important

Super- Kamiokande. Ouverture vers une nouvelle physique pour nous. Programme très ambitieux (technologiquement) avec là aussi un potentiel de découverte très important

Hyper- Kamiokande. Sans doute le prochain projet à moyen terme. Physique de « précision ». Coût raisonnable & technologie connue.

Besoin de renforcer le groupe, CR2 ou CR1.

Déjà un des groupes neutrinos le plus important de l'IN2P3 (3 thésards par exemple, unique en France) mais cela n'est pas suffisant !

