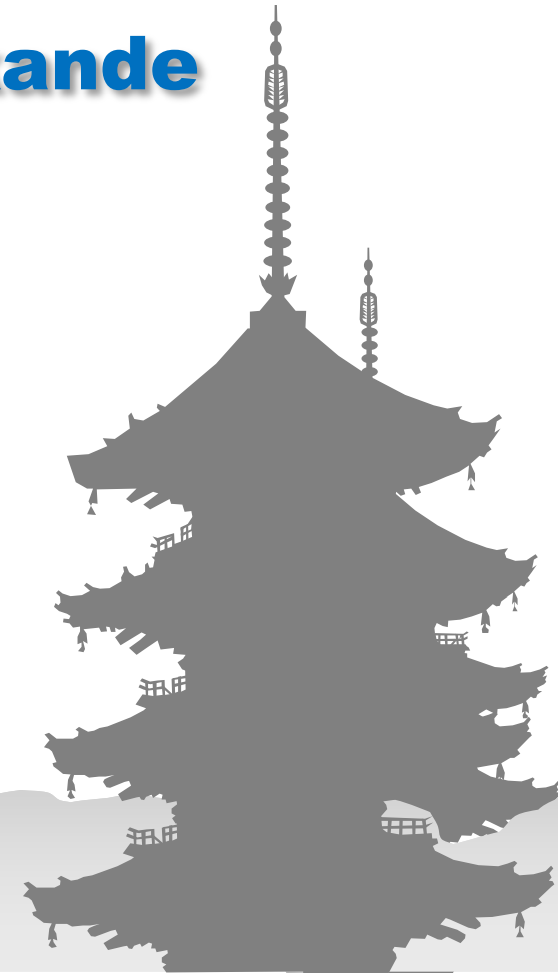


L'après-T2K pour la mesure d'une violation CP leptonique

Le projet Hyper-Kamiokande



Michel Gonin - 27 juin 2013
CS IN2P3



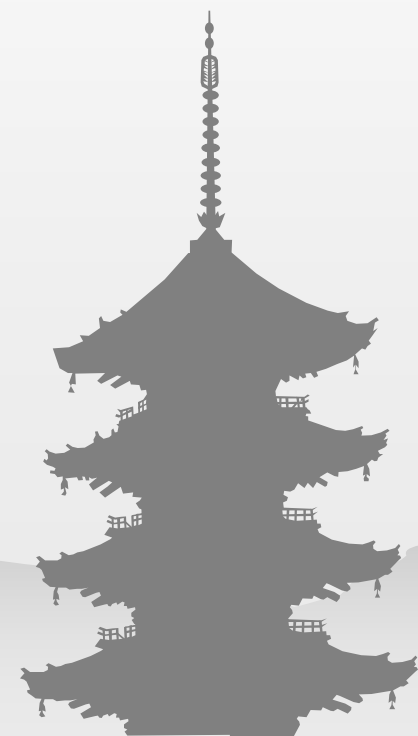
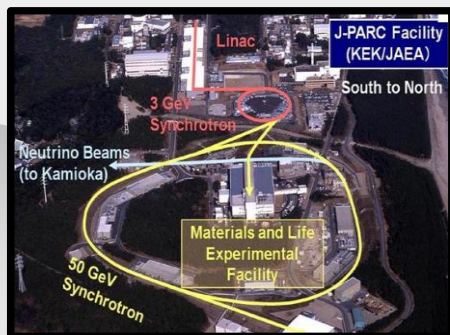
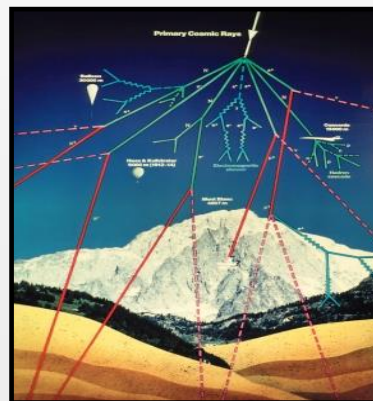
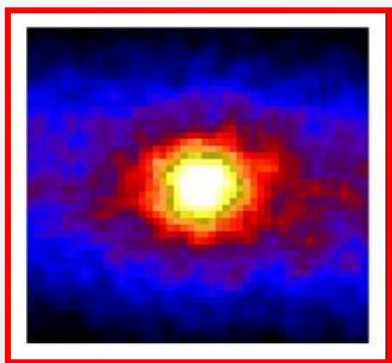
Mesure des angles de mélange

$$\theta_{12} = 33.6^\circ \pm 1.0^\circ$$

$$\theta_{23} = 45^\circ \pm 6^\circ$$

Le futur programme de la physique des neutrinos dépendait fortement de la valeur de θ_{13}

$$\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}$$





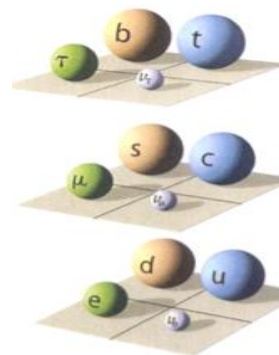
"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature".



♦ états de masse \neq états de saveur

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

♦ 3 générations de particules



♦ 3 angles de mélange, tous différents de zéro



Violation CP $\delta \neq 0$



$$\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}$$

Oscillation quantique sur 300 km

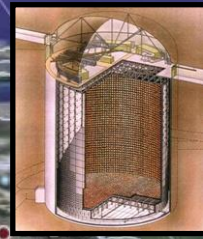
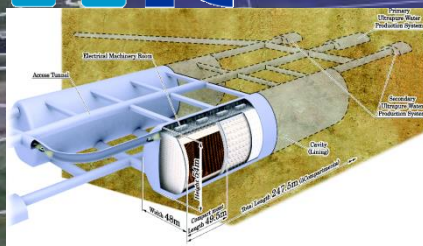
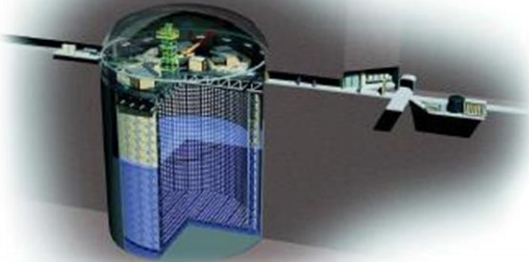


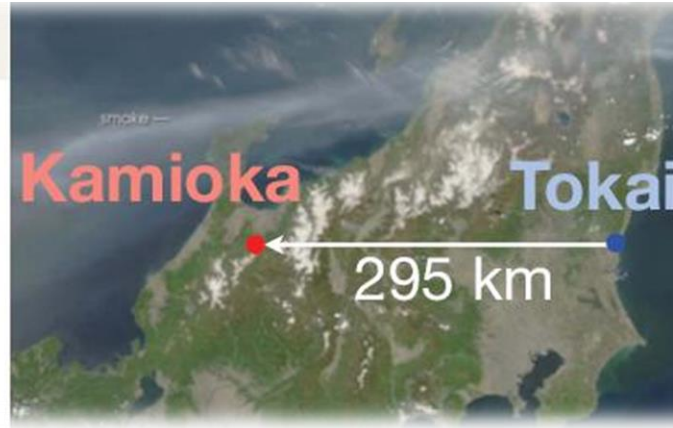
Image NASA
© 2007 Europa Technologies
Image © 2007 TerraMetrics
© 2007 ZENRIN

T2K

Super-K@Kamioka



- Huge far detector

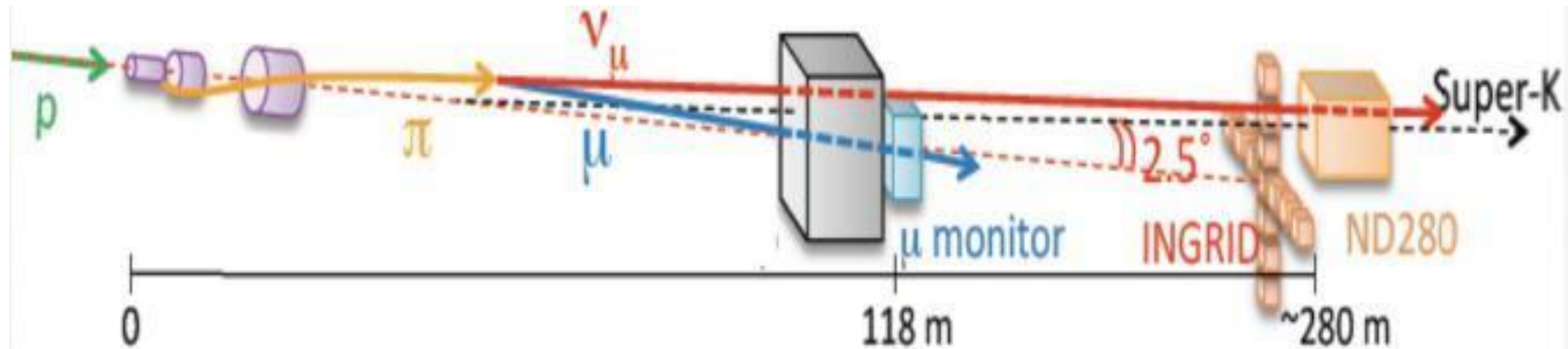


J-PARC Accelerator@Tokai

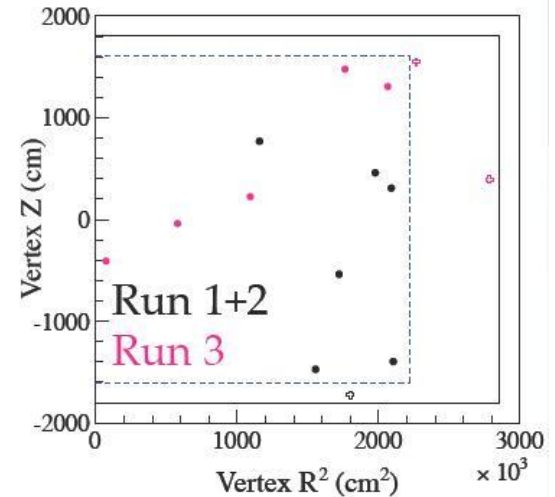
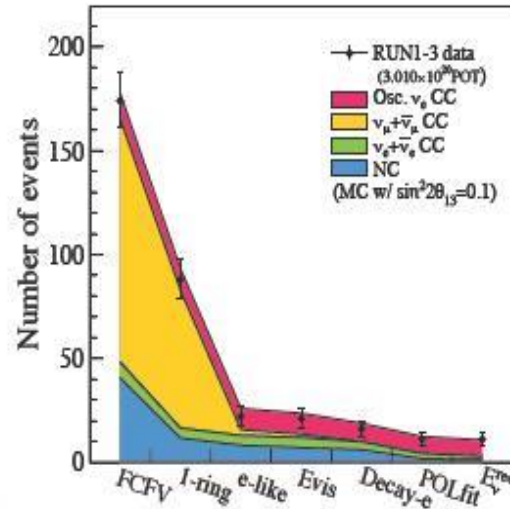
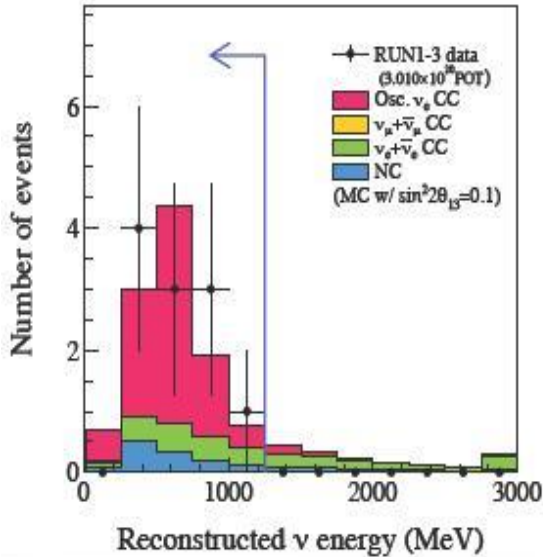


- Intense beam
- Near detectors

ν_{μ} beam

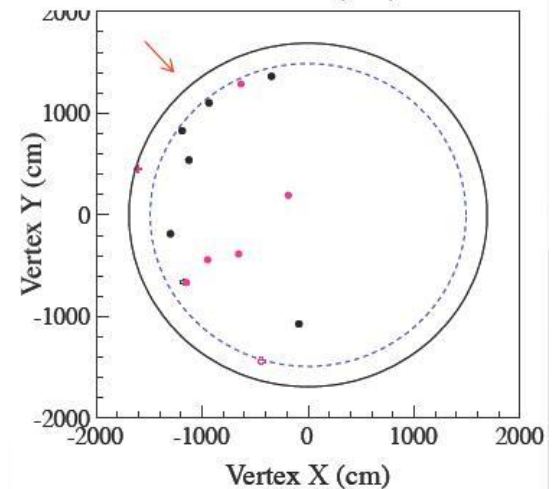


ν_e apparition



11 événements

Event category	The predicted number of events	
	$\sin^2 2\theta_{13} = 0.0$	$\sin^2 2\theta_{13} = 0.1$
Total	3.22	10.71
ν_e signal	0.18	7.79
ν_e background	1.67	1.56
ν_μ background	1.21	1.21
$\bar{\nu}_\mu$ background	0.07	0.07
$\bar{\nu}_e$ background	0.09	0.09



$$\theta_{13} = 9.1^\circ \pm 0.6^\circ$$

3.01 x 10²⁰ POT
6% of data goal

11 événements d'apparition à ~ 3σ

Nouveaux résultats T2K cet été

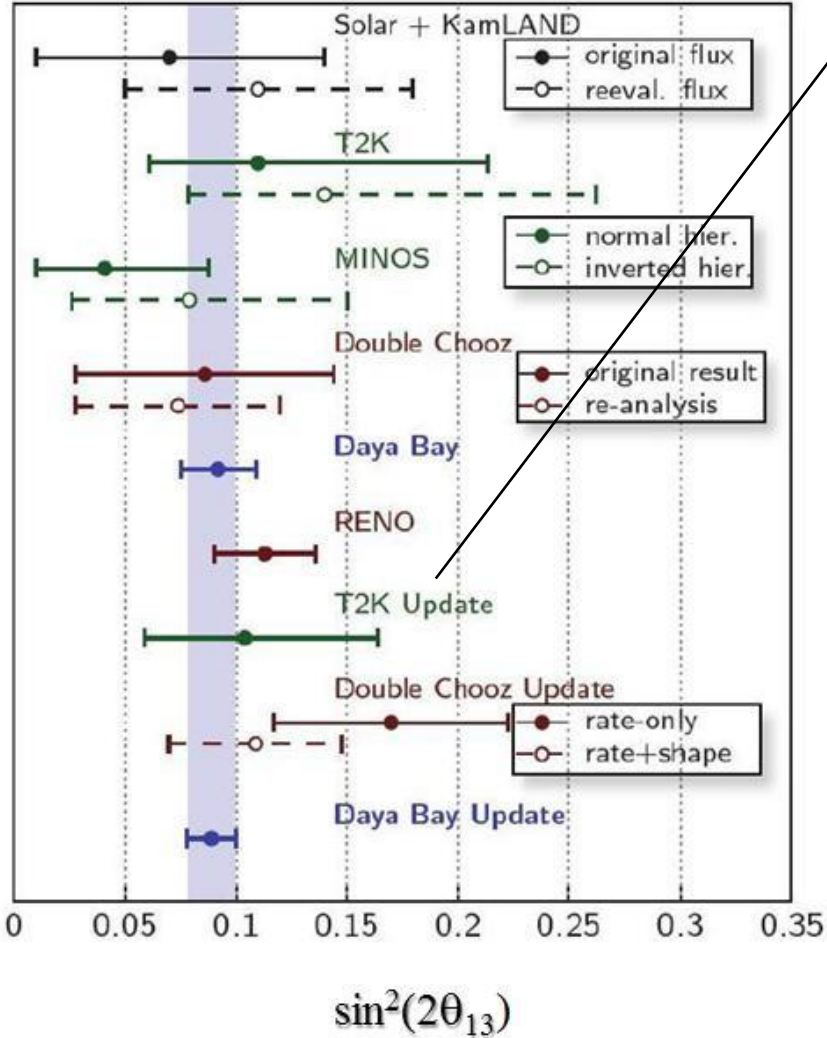
~ 7 x 10²⁰ POT
14% of data goal

~ 26 événements d'apparition ? > 5σ ?

5 x 10²¹ POT
100% of data goal

~ 200 événements d'apparition


Tokai-to-Kamioka (T2K) Long Baseline Neutrino Oscillation Experiment Proposal



	ν_μ CC BG	ν_μ NC BG	beam ν_e BG	ν_e CC signal
Fully-contained, $E_{vis} \geq 100\text{MeV}$	2215	847	184	243
1 ring e-like, no decay-e	12	156	71	187
$0.35 \leq E_\nu^{rec.} \leq 0.85\text{GeV}$	1.8	47	21	146
e/π^0 separations	0.7	9	13	103

Table 1.3: The number of events selected by the ν_e appearance analysis, as predicted by NEUT Monte Carlo for 5×10^{21} POT exposure.

Letter of Intent:
The Hyper-Kamiokande Experiment
— Detector Design and Physics Potential —

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S. Moriyama,^{12,14} M. Nakahata,^{12,14} K. Nakamura,^{2,14} T. Nakaya,^{4,14} S. Nakayama,^{12,14}
K. Nishijima,⁹ Y. Nishimura,¹² Y. Obayashi,^{12,14} K. Okumura,¹³ M. Sakuda,⁷ H. Sekiya,^{12,14}
M. Shiozawa,^{12,14}  A. T. Suzuki,³ Y. Suzuki,^{12,14} A. Takeda,^{12,14} Y. Takeuchi,^{3,14}
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(Hyper-Kamiokande working group)

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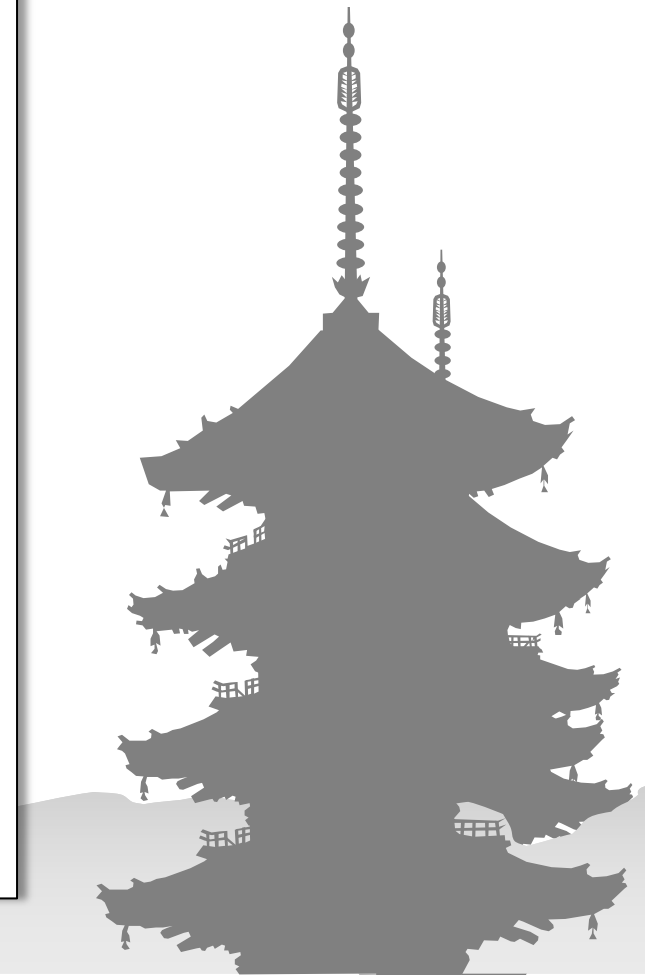
¹¹*University of Tokyo, Earthquake Research Institute, Bunkyo, Tokyo 113-0032, Japan*

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(Dated: September 16, 2011)





3rd Open Meeting for the Hyper-Kamiokande Project

21-22 June 2013

21-22 June 2013





Mesure de θ_{13}

$$P(\nu_\mu \rightarrow \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2 \Delta_{31}$$

$$+ 8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos \delta - S_{12} S_{13} S_{23}) \cdot \cos \Delta_{32} \cdot \sin \Delta_{31} \cdot \sin \Delta_{21}$$

$$- 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin \delta \cdot \sin \Delta_{32} \cdot \sin \Delta_{31} \cdot \sin \Delta_{21}$$

$$+ 4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos \delta) \cdot \sin^2 \Delta_{21}$$

$$- 8C_{13}^2 S_{13}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu} (1 - 2S_{13}^2) \cdot \cos \Delta_{32} \cdot \sin \Delta_{31}$$

$$+ 8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{31}^2} (1 - 2S_{13}^2) \cdot \sin^2 \Delta_{31},$$

$$\Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E_\nu}$$

C=cos S=sin



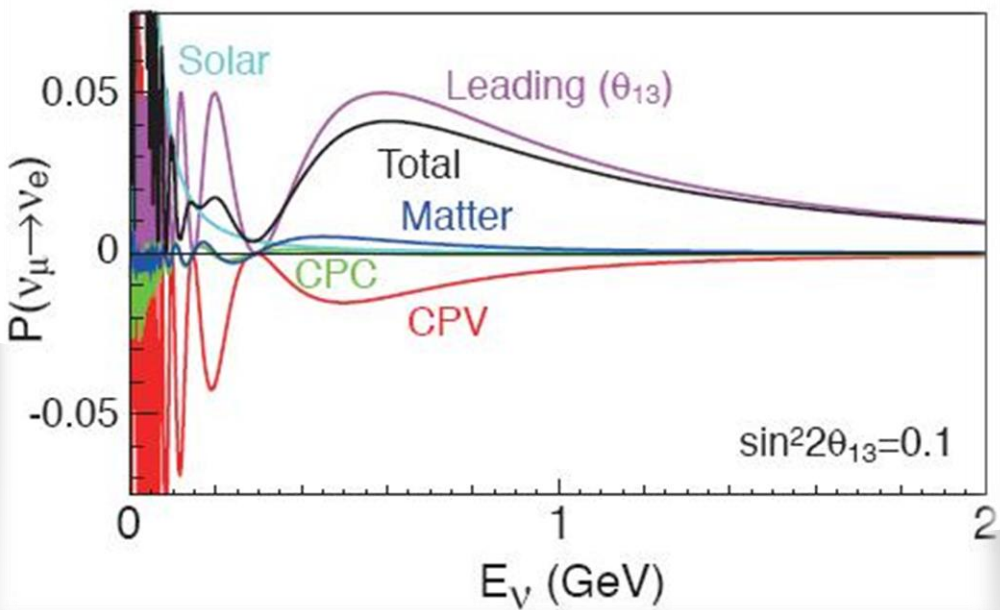
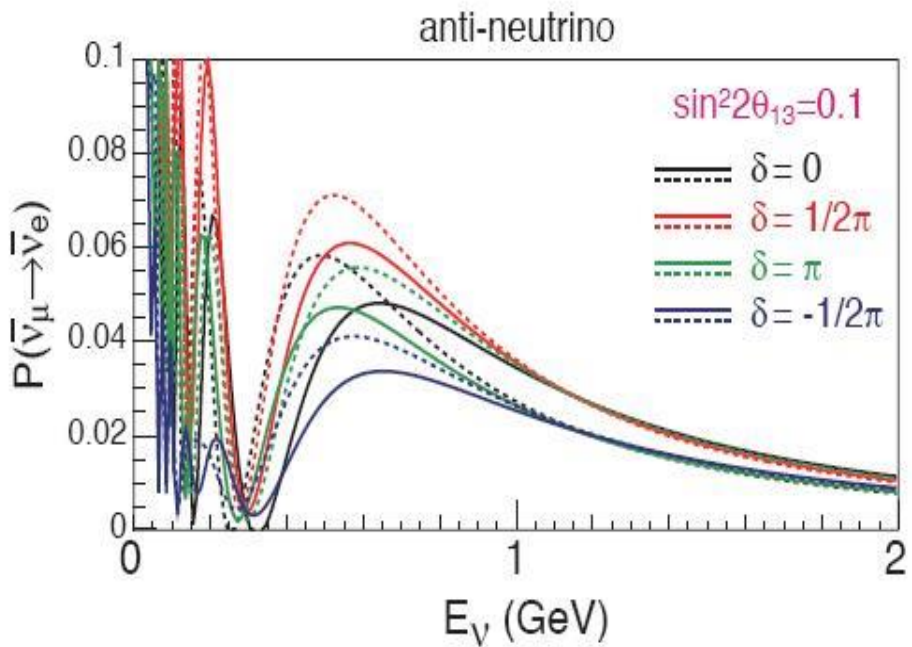
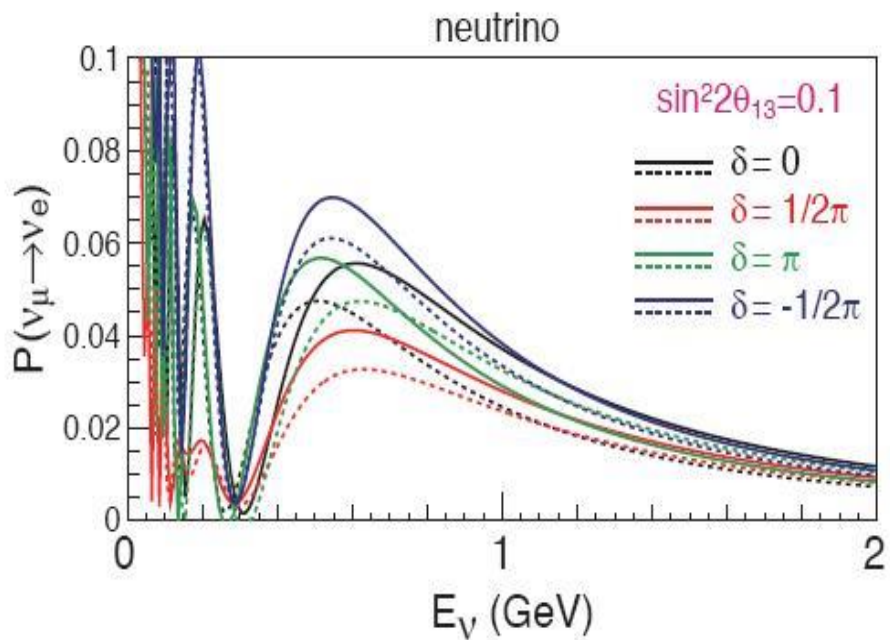
$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \quad \begin{array}{l} a \rightarrow -a \\ \delta \rightarrow -\delta \end{array}$$

$$\begin{aligned} P(\nu_\mu \rightarrow \nu_e) = & 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2 \Delta_{31} \\ & + 8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos \delta - S_{12} S_{13} S_{23}) \cdot \cos \Delta_{32} \cdot \sin \Delta_{31} \cdot \sin \Delta_{21} \\ & - 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin \delta \cdot \sin \Delta_{32} \cdot \sin \Delta_{31} \cdot \sin \Delta_{21} \\ & + 4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos \delta) \cdot \sin^2 \Delta_{21} \\ & - 8C_{13}^2 S_{13}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu} (1 - 2S_{13}^2) \cdot \cos \Delta_{32} \cdot \sin \Delta_{31} \\ & + 8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{31}^2} (1 - 2S_{13}^2) \cdot \sin^2 \Delta_{31}, \end{aligned}$$

$$\Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E_\nu}$$

C=cos S=sin

Measure CPV



T2K



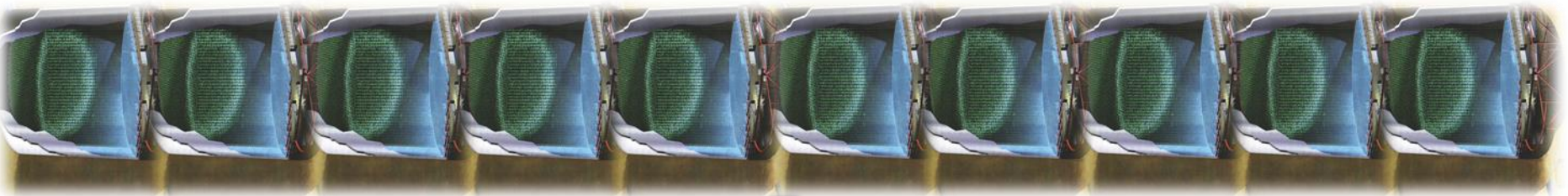
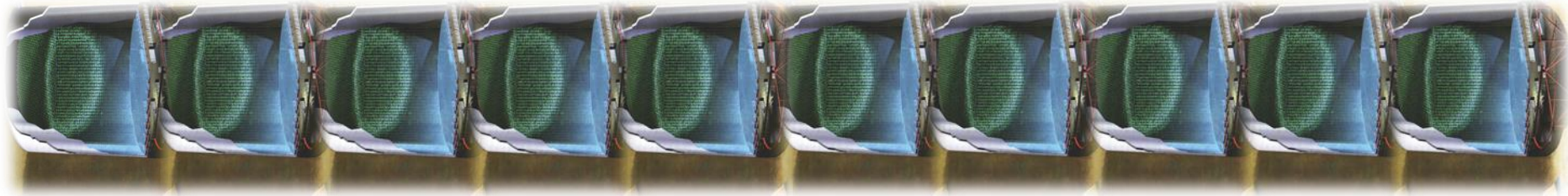
T2H



T2K

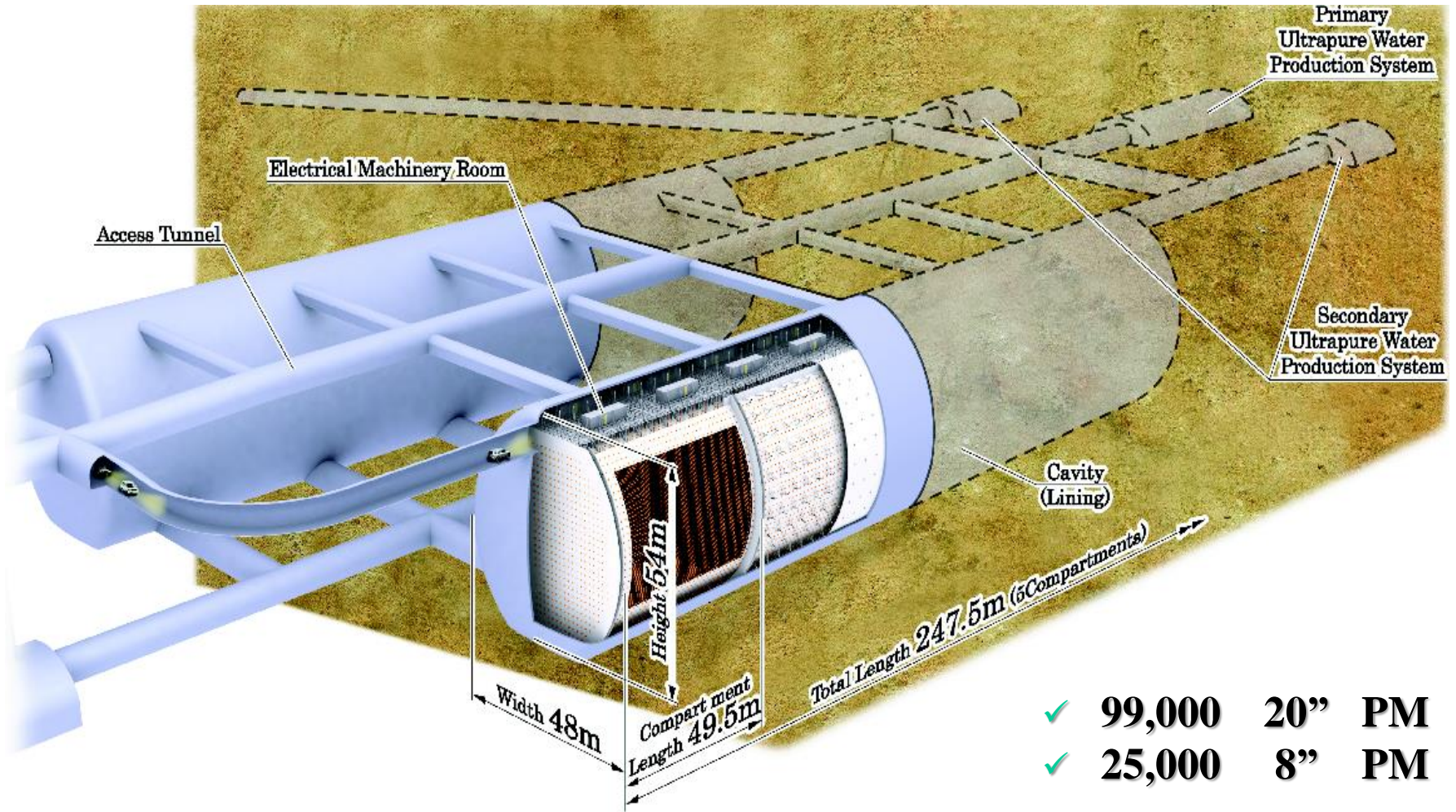


T2H



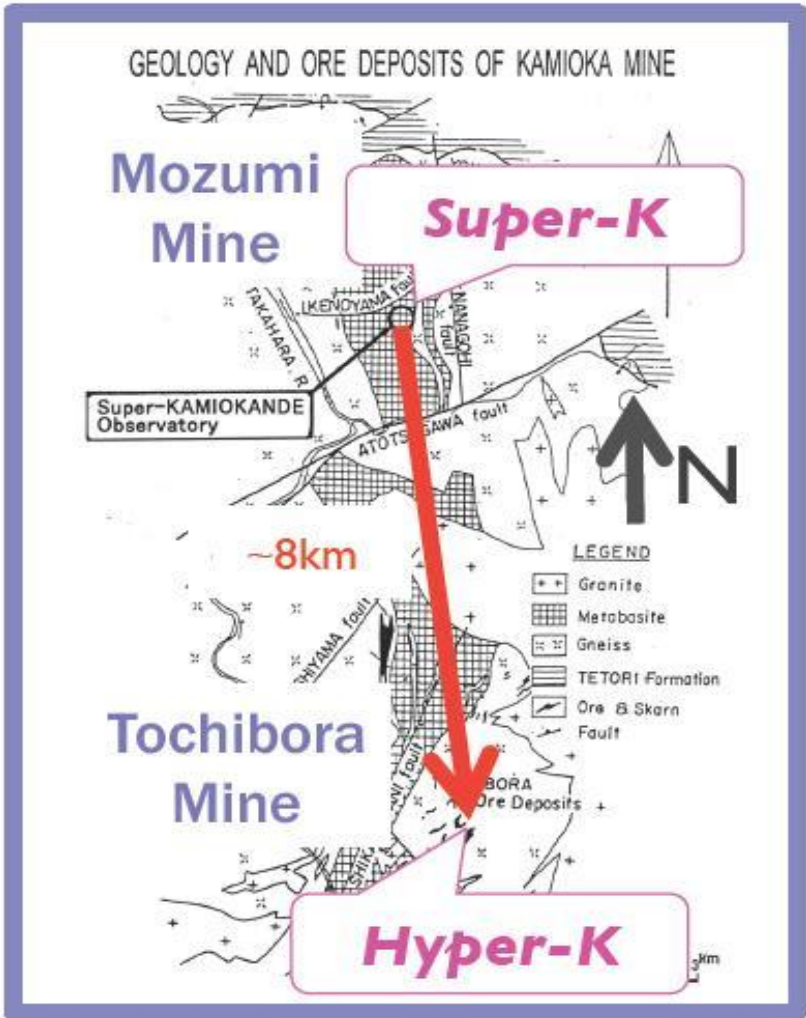
20 Super-Kamiokande

Le projet Hyper-Kamiokande



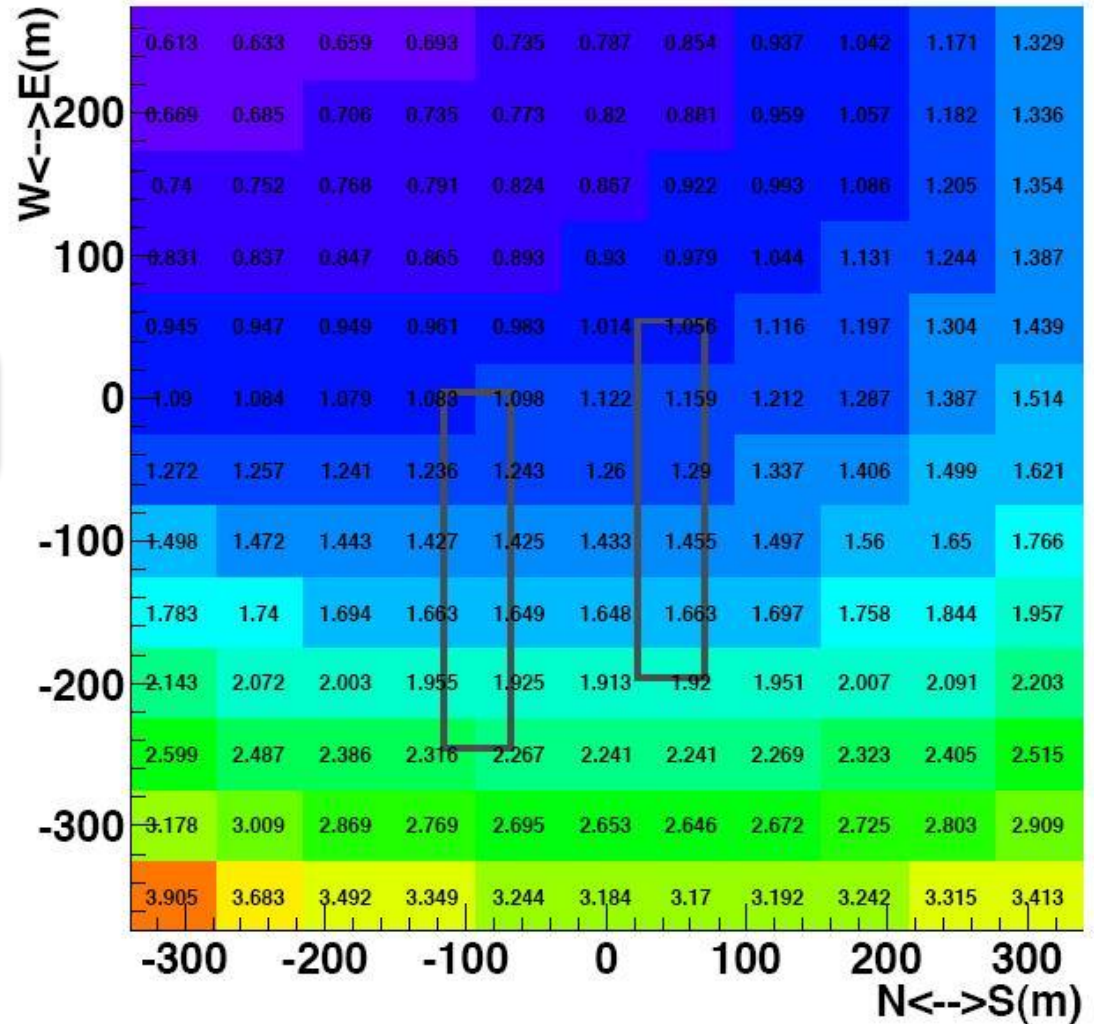
Détecteur Tcherenkov à eau d'une méga tonne

Le projet Hyper-Kamiokande



Bruit de fond cosmique (muons)

Alt= 508.0m

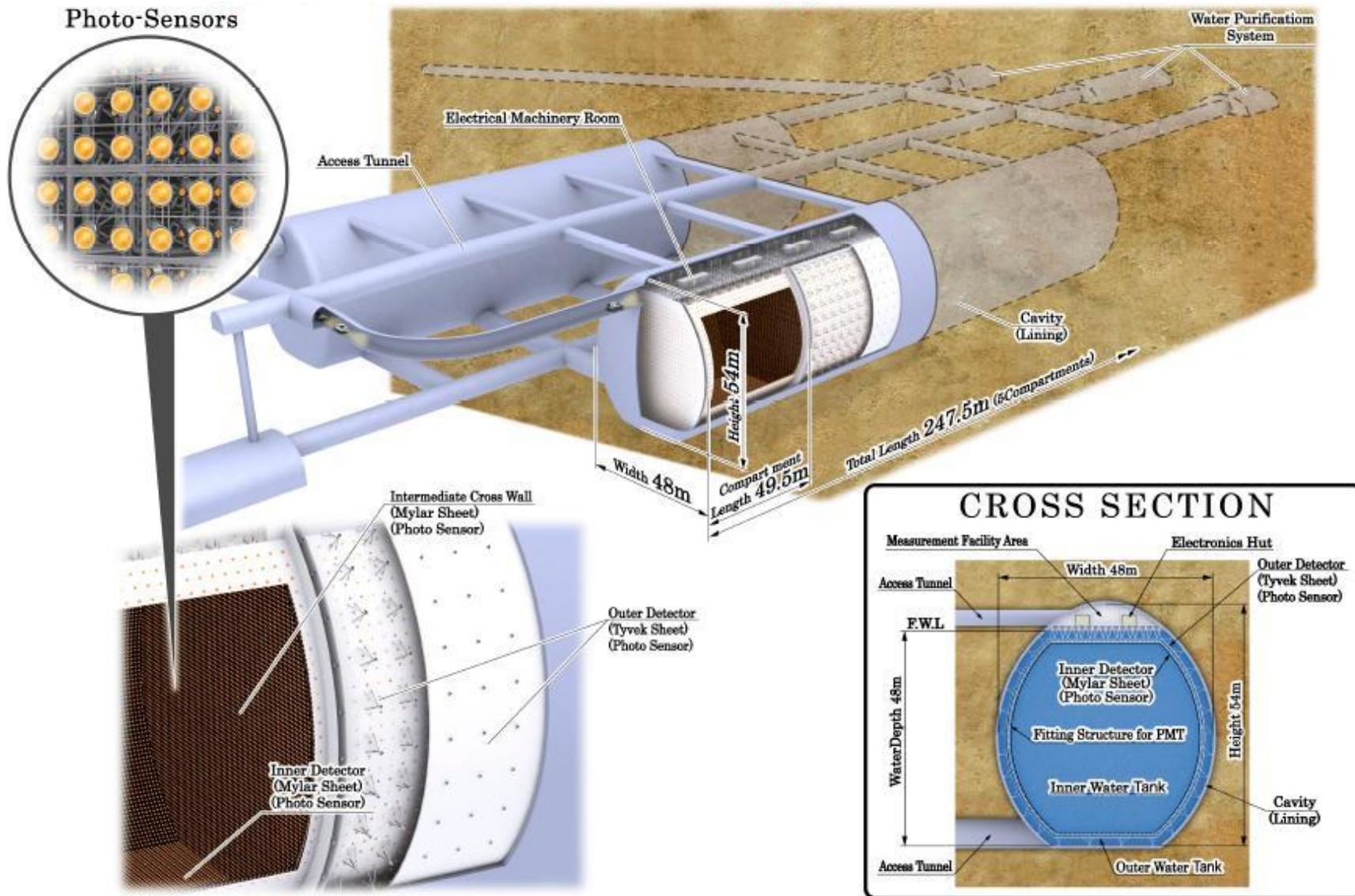


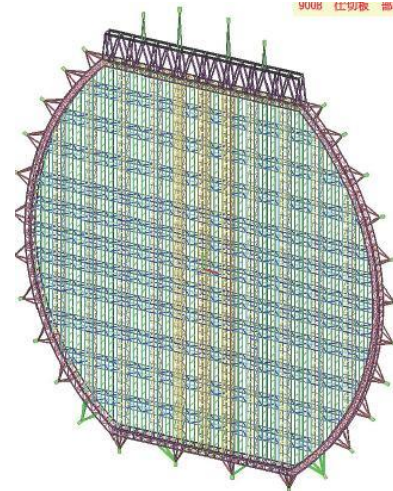
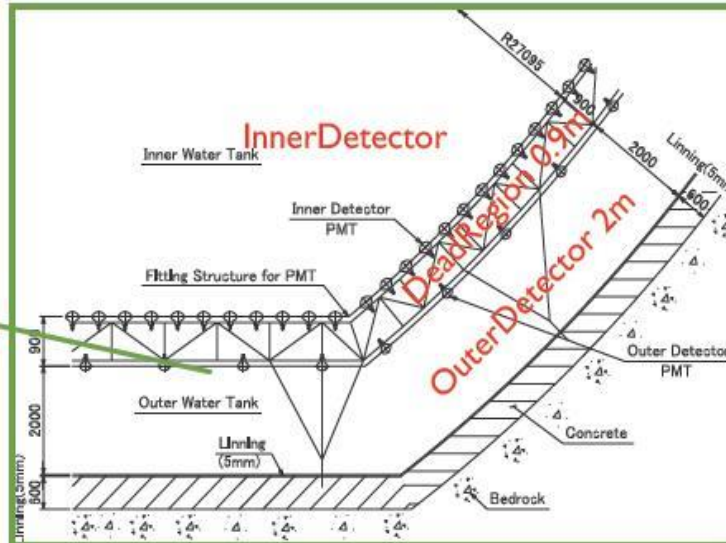
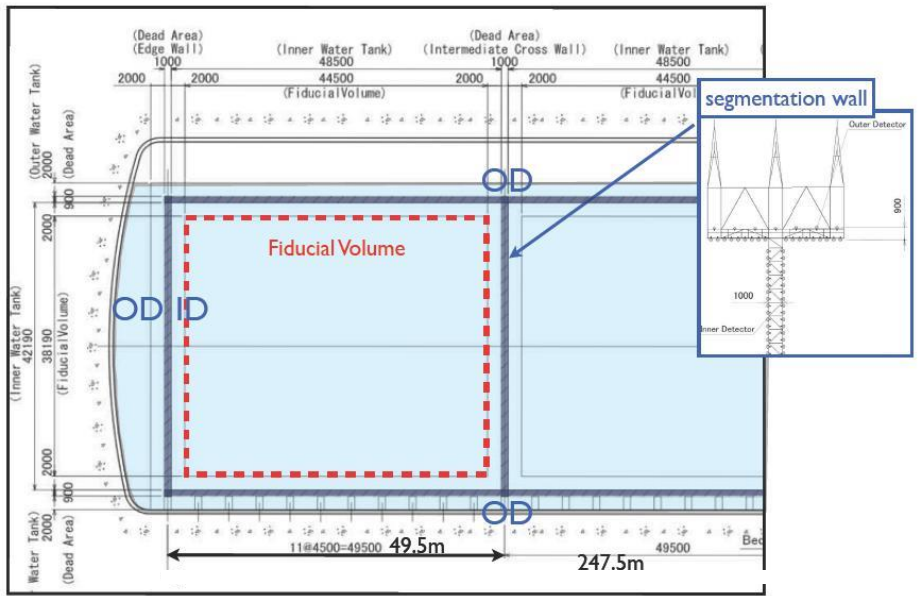
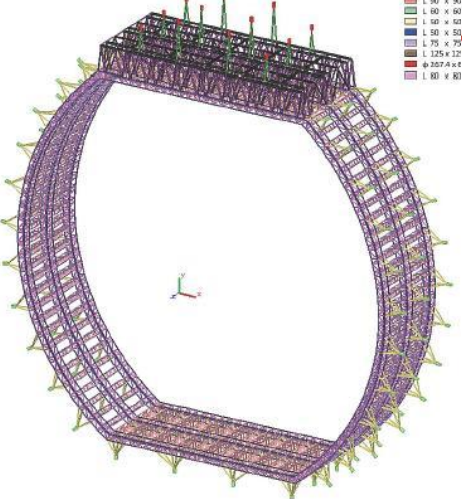
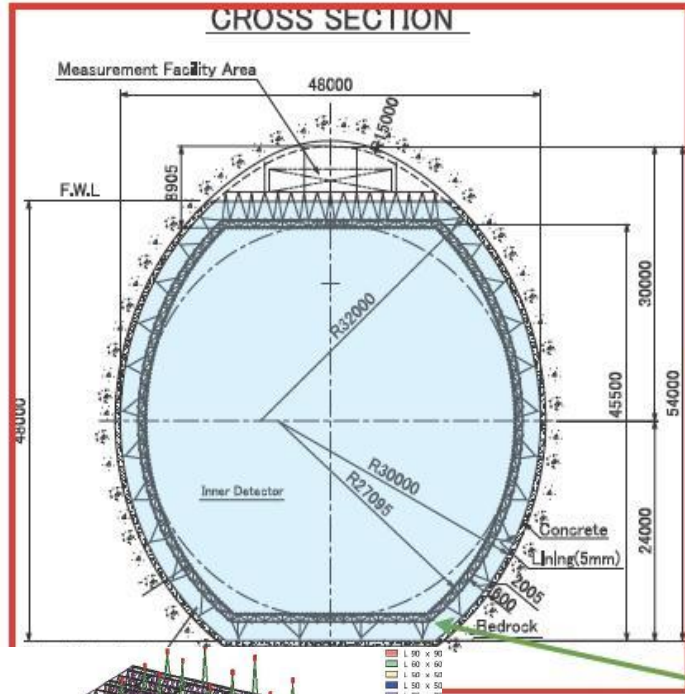
$\sim 1-2 \cdot 10^{-6} \text{ sec}^{-1} \text{ cm}^{-2}$

Comparé à SK :
 $\sim 0.1 - 0.2 \cdot 10^{-6} \text{ sec}^{-1} \text{ cm}^{-2}$



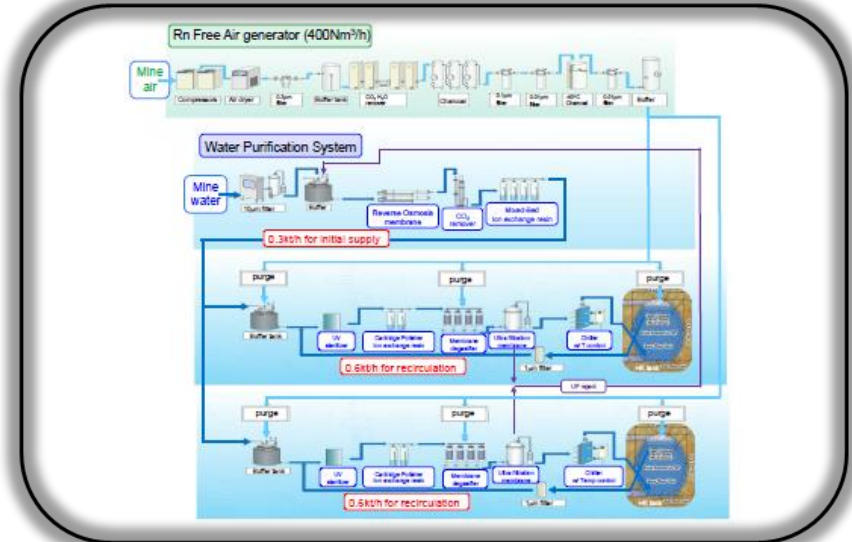
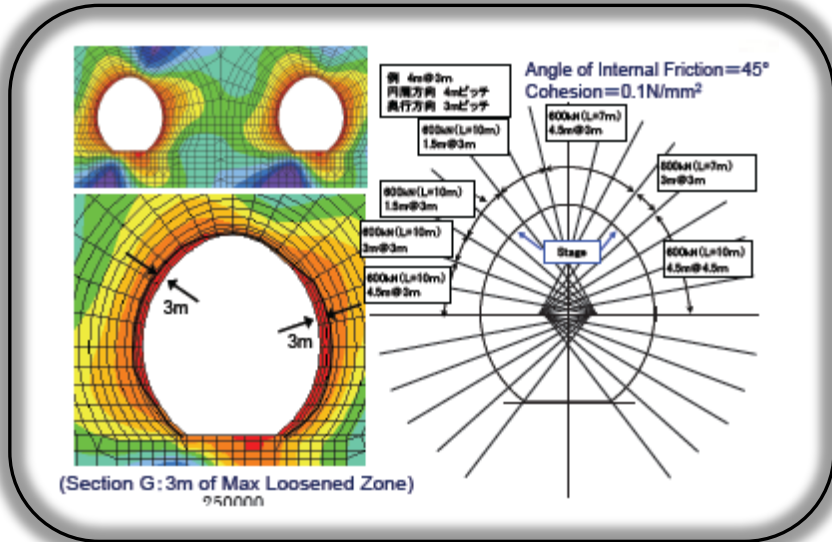
Le projet Hyper-Kamiokande





2 ans pour les travaux

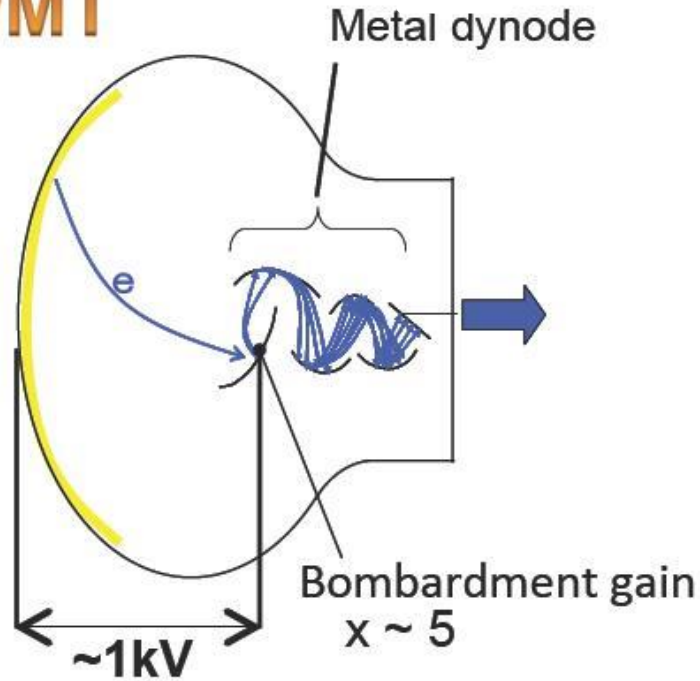
Objectif principal : réduction des coûts



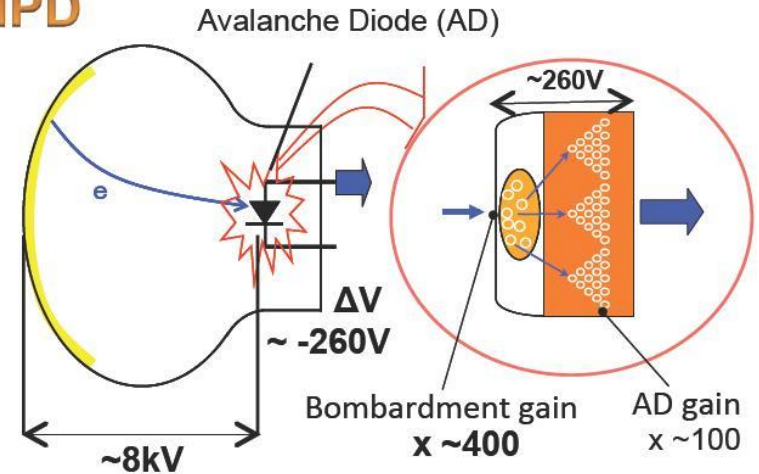
Objectif principal : réduction des coûts

Hybrid Photo-Detector (HPD)

PMT



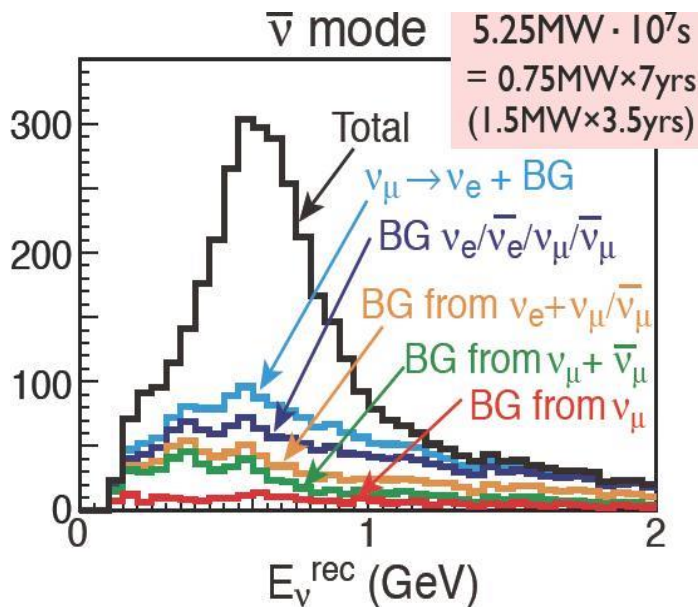
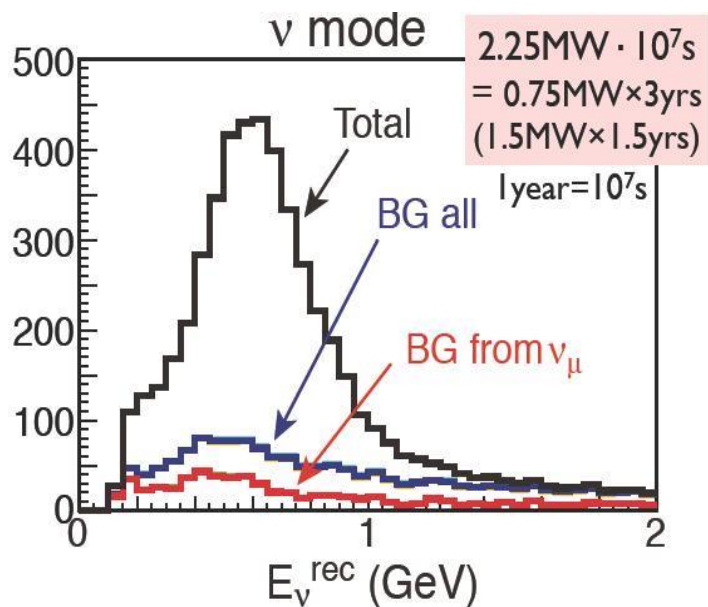
HPD



	PMT (20")	HPD (8")
HV	~1kV	~8kV
Gain	~10 ⁷	~10 ⁴ ~ 10 ⁵

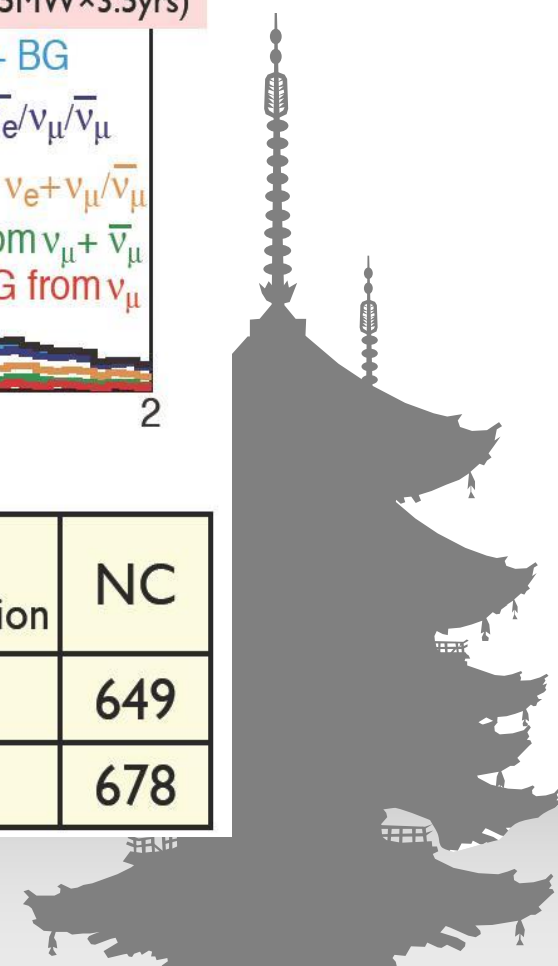
Performances et sensibilités

10 ans de prise de données à 700 KW



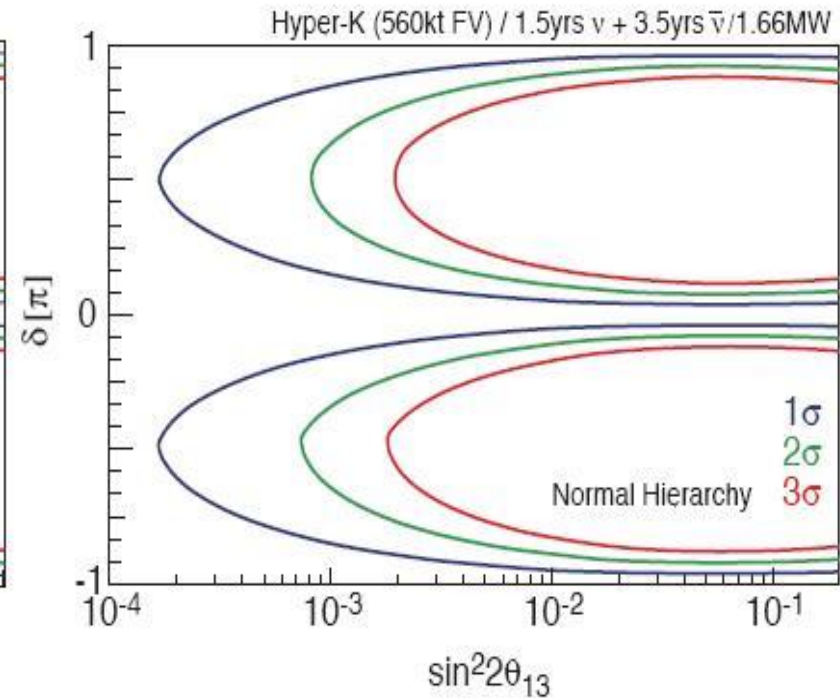
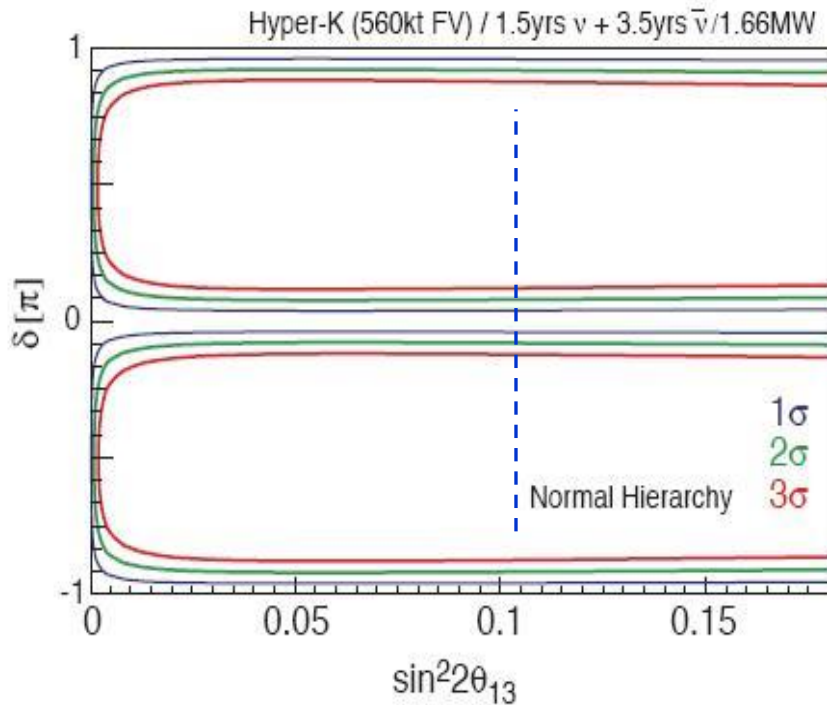
	Signal ($\nu_{\mu} \rightarrow \nu_e$ CC)	Wrong sign appearance	$\nu_{\mu}/\bar{\nu}_{\mu}$ CC	$\nu_e/\bar{\nu}_e$ contamination	NC
ν ($2.25\text{MW} \cdot 10^7\text{s}$)	3,560	46	35	880	649
$\bar{\nu}$ ($5.25\text{MW} \cdot 10^7\text{s}$)	1,959	380	23	878	678

HM normale et $\delta = 0$



Découverte d'une violation CP

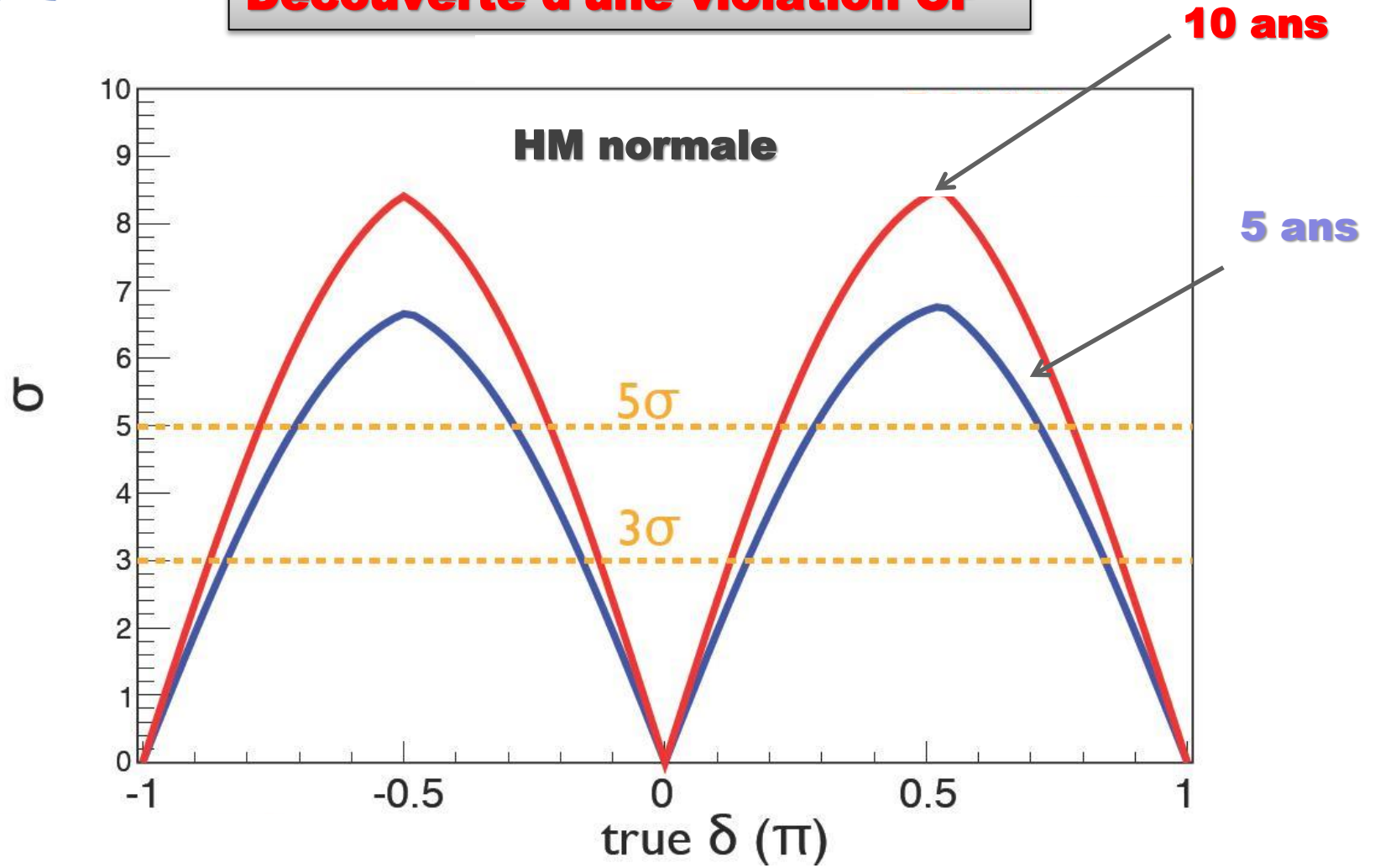
10 ans de prise de données à 700 KW



Exclusion de $\delta = 0$ à 74% (pour 3 σ)

Performances et sensibilités

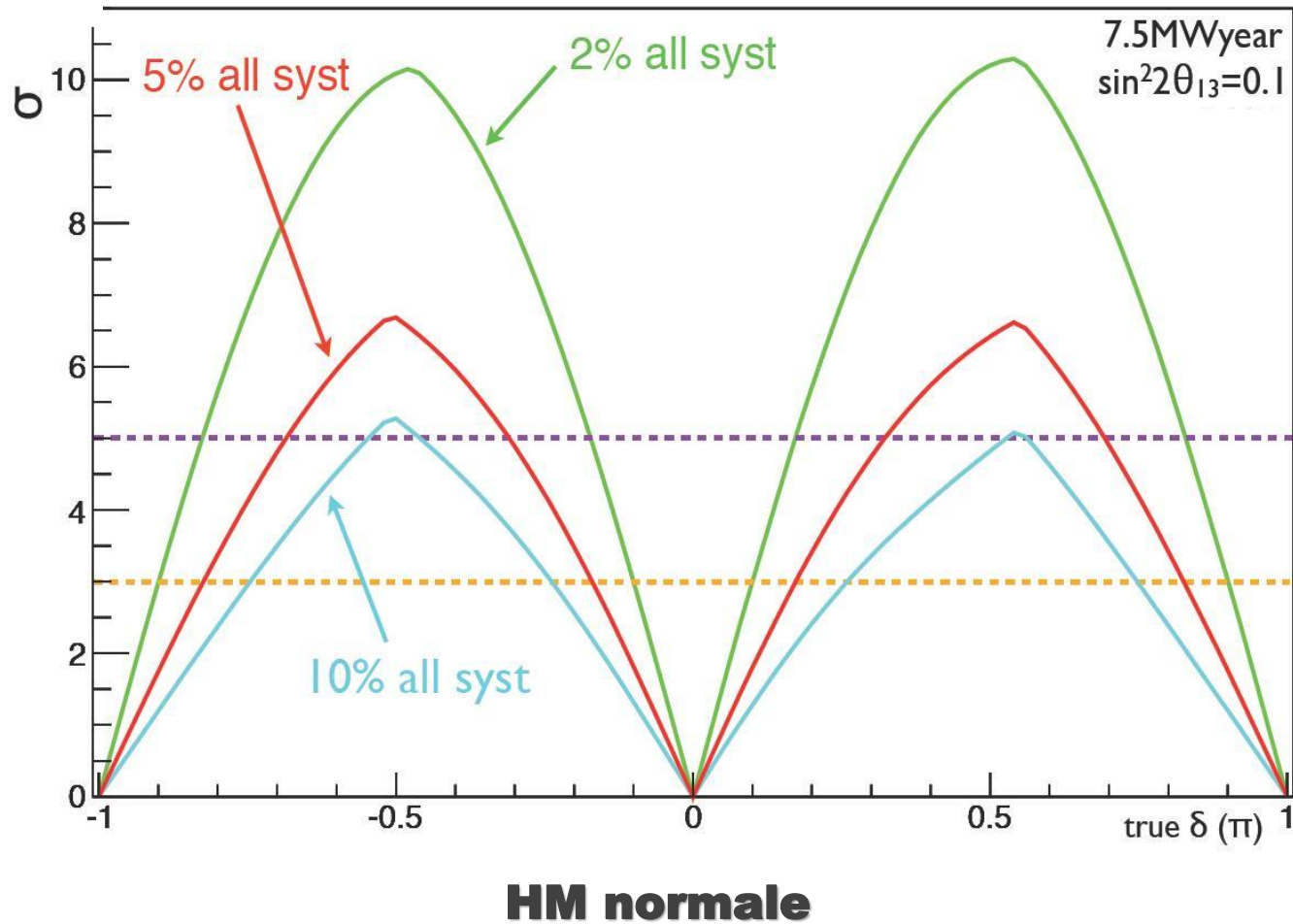
Découverte d'une violation CP



Exclusion de $\delta = 0$ à 74% (3σ) et 55% (5σ)

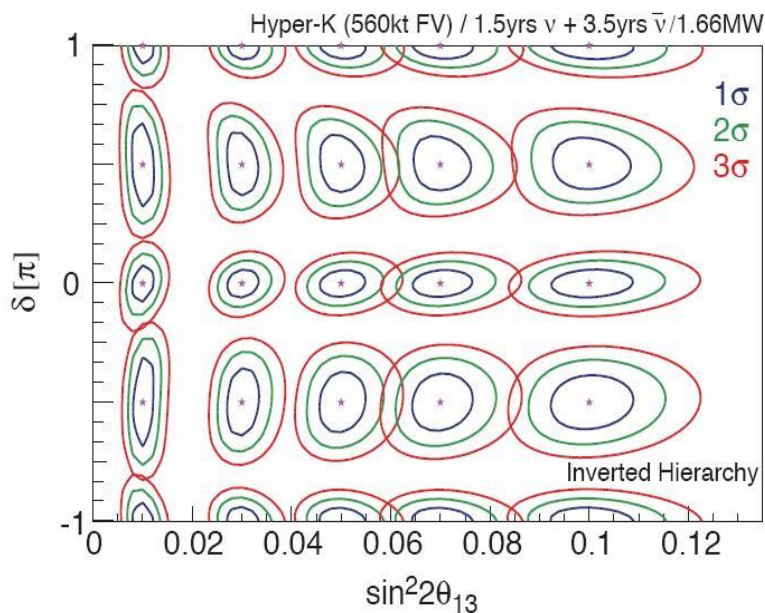
Performances et sensibilités

Découverte d'une violation CP

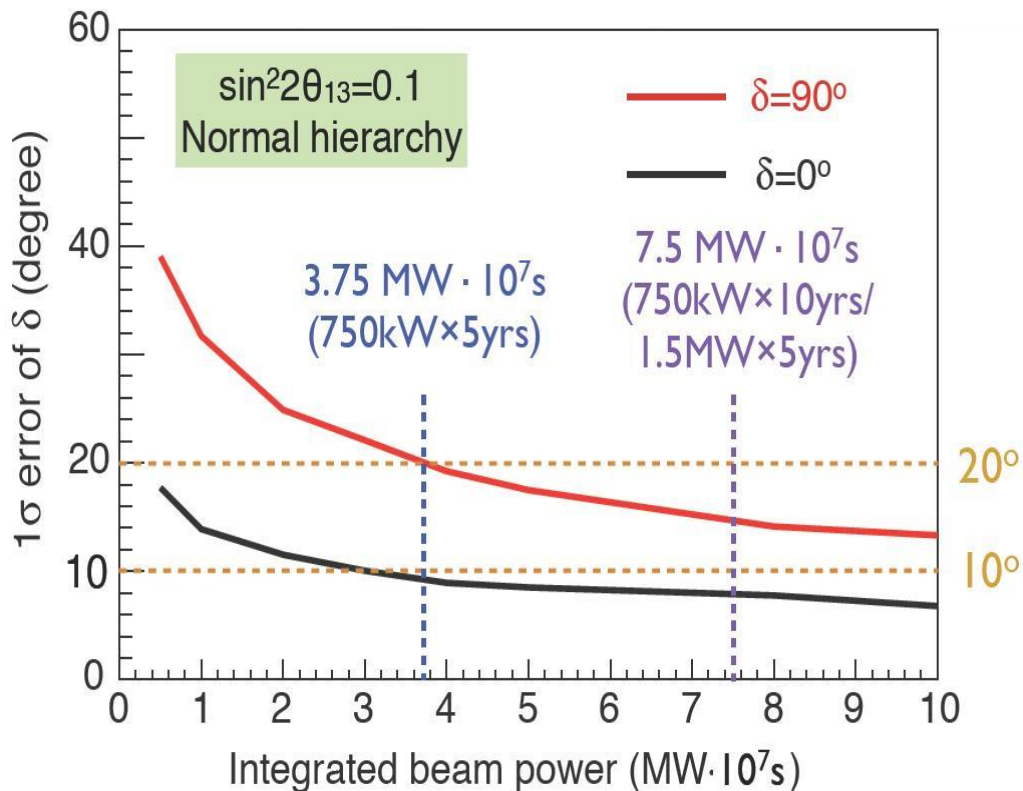


Influence des erreurs systématiques de HK

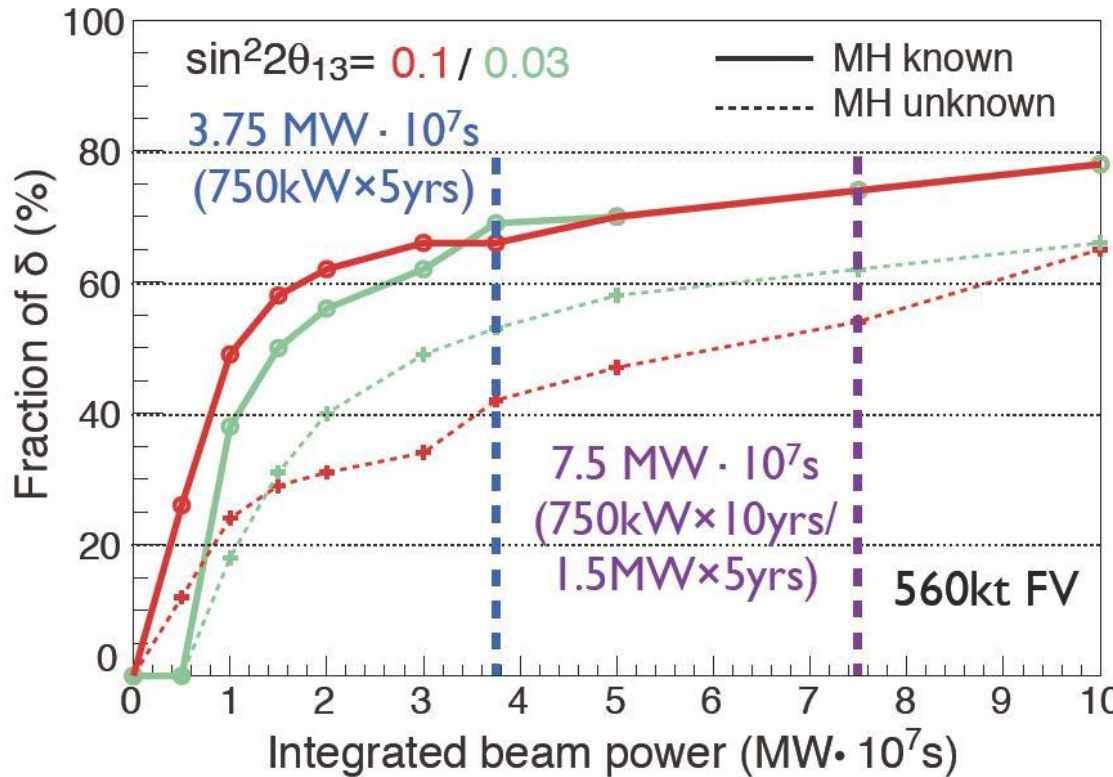
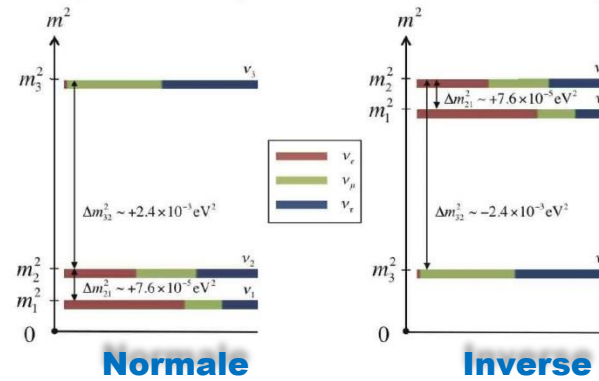
Mesure de la phase CP δ



Une erreur de $\sim 18^\circ$ pour une violation CP maximale



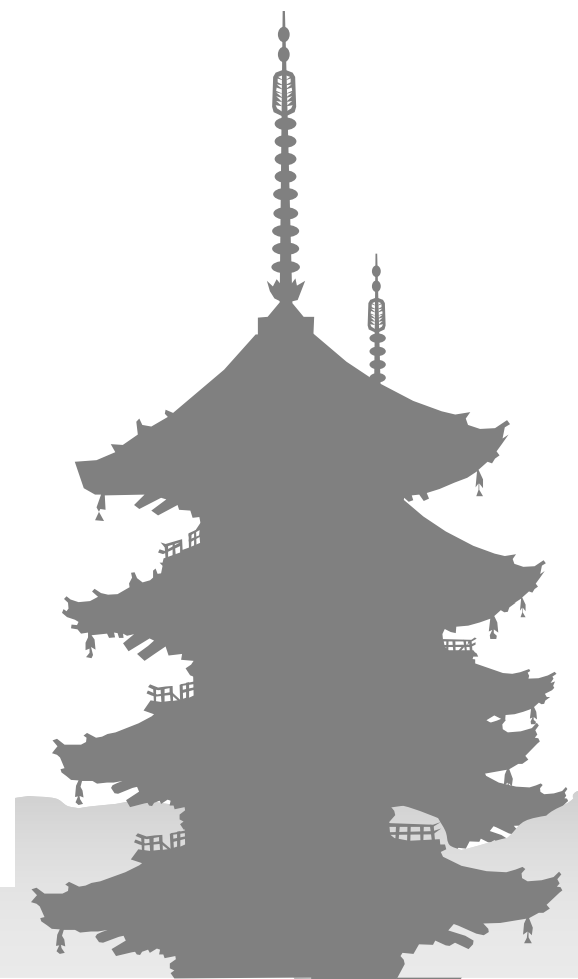
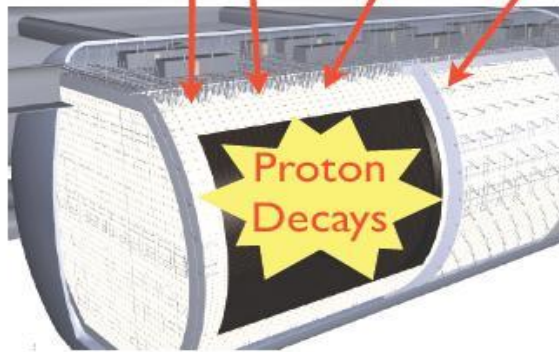
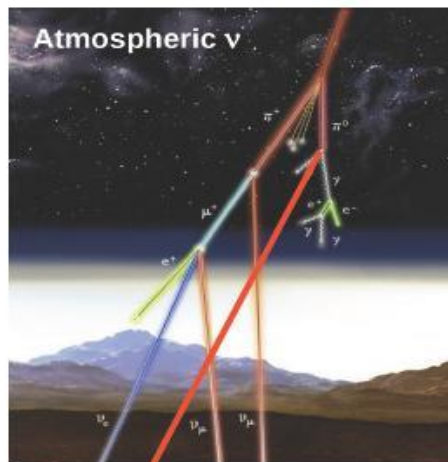
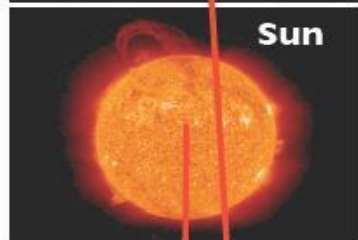
Performances et sensibilités



$$\sin^2 2\theta_{13} = 0.1$$

Integ. power (MW × 10 ⁷ s)	Mass hierarchy	
	known	unknown
3.75	69%	42%
7.5	74%	54%

Performances et sensibilités



Performances et sensibilités

Nucleon Decay Searches

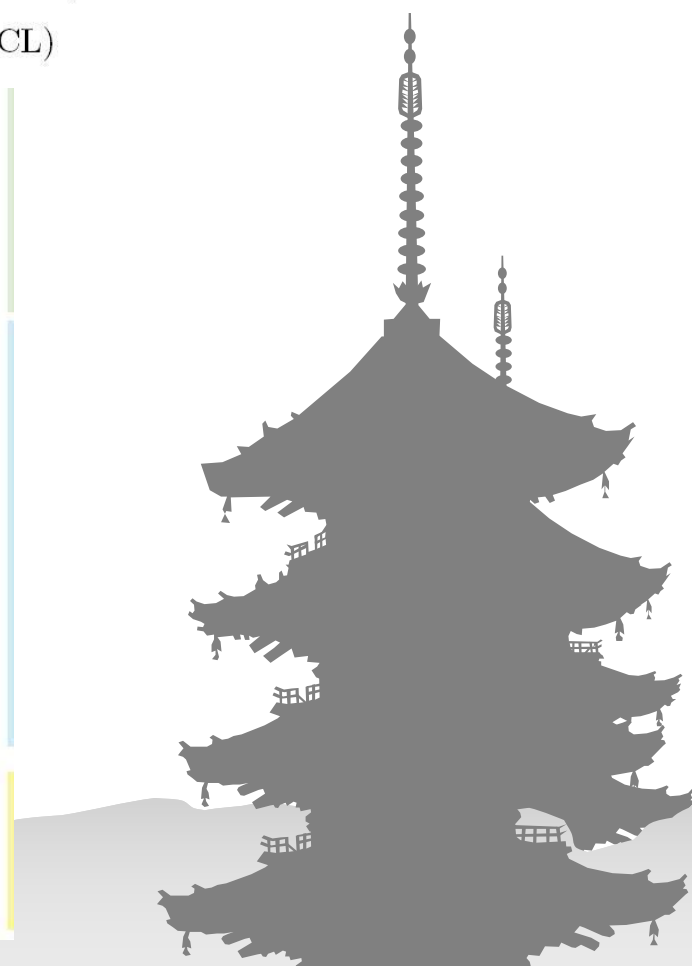
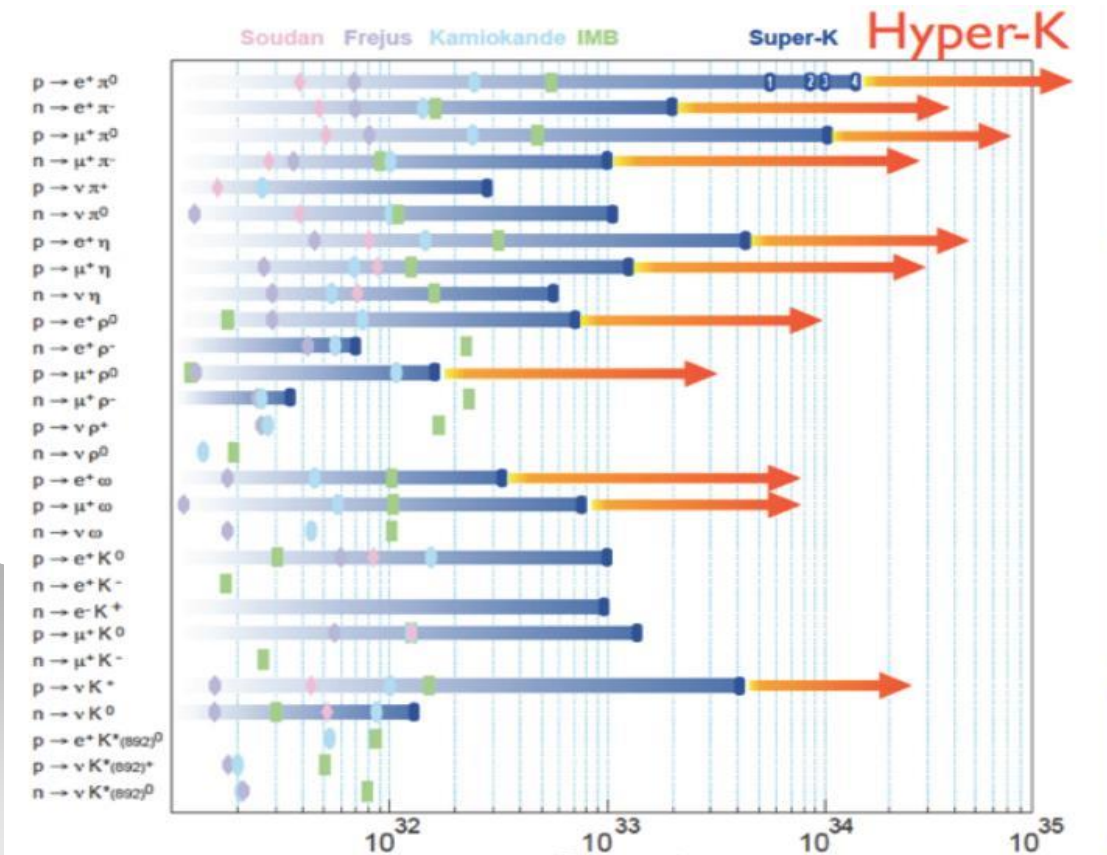
$p \rightarrow e^+ + \pi^0$ 1.3×10^{35} yrs (90% CL)

5.7×10^{34} yrs (3σ CL)

$p \rightarrow \bar{\nu} + K^+$ 2.5×10^{34} yrs (90% CL)

1.0×10^{34} yrs (3σ CL)

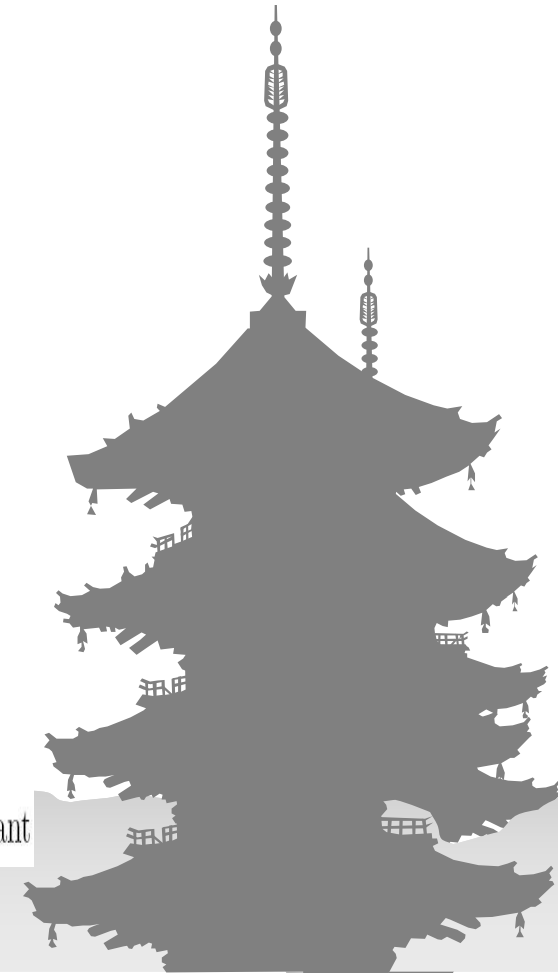
10 years data



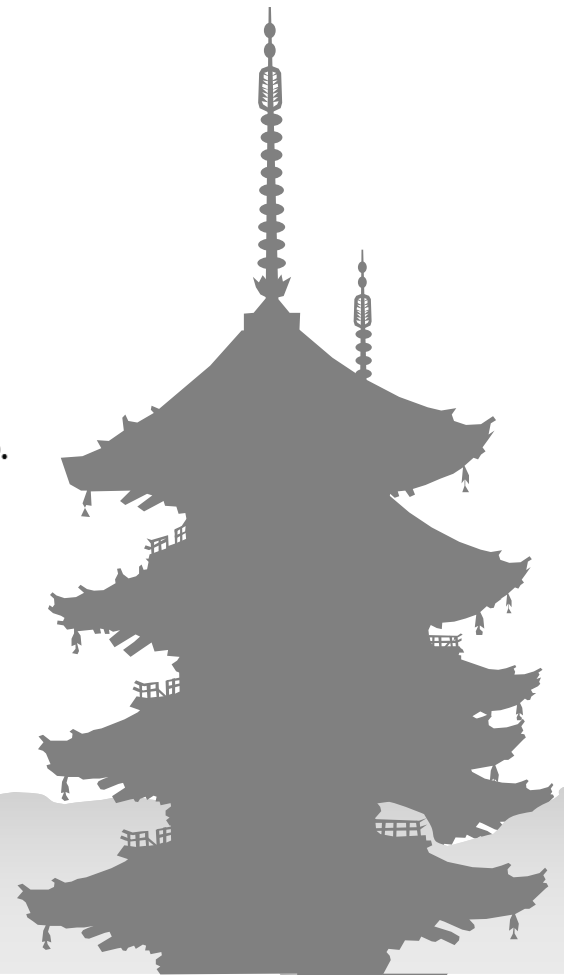
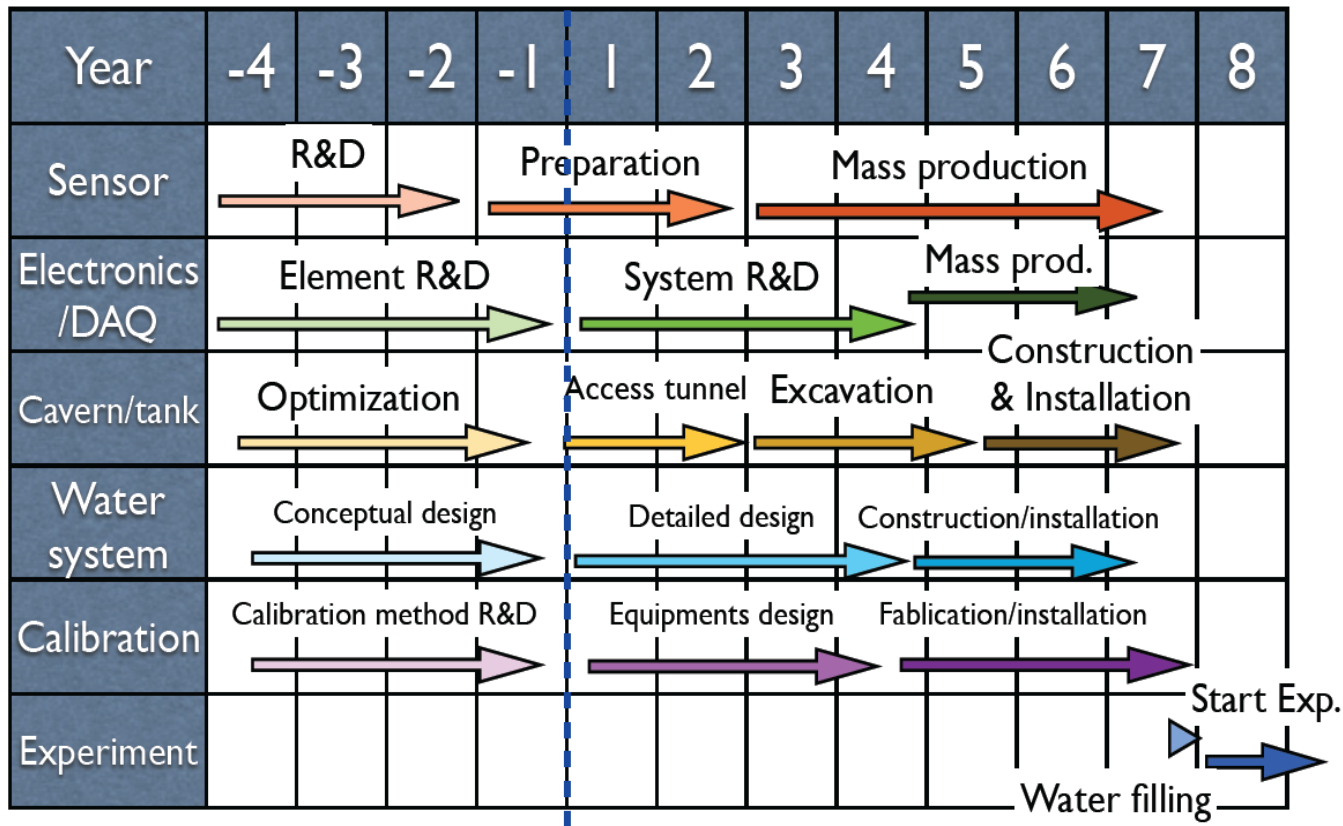


Astrophysical objects

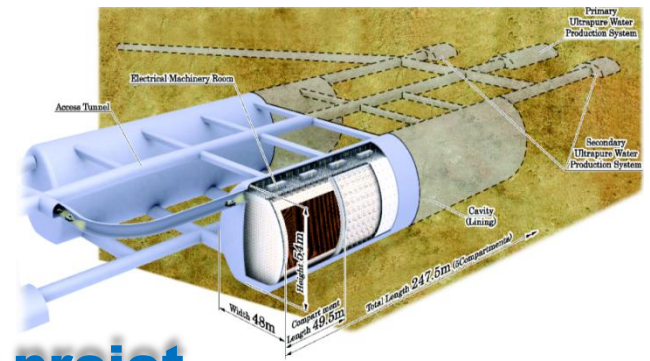
- Supernova burst ν
 - 170,000~260,000 ν 's @ Galactic center (10 kpc)
 - 30~50 ν 's @ M31 (Andromeda galaxy)
- Supernova relic ν
 - 830 ν 's / 10 years
- WIMP annihilation at Sun
 - 5 years observation
 - $\sigma_{SD} = 10^{-39} \text{cm}^2$ @ $M_{\text{WIMP}} = 10 \text{ GeV}$, $\chi\chi \rightarrow b\bar{b}$ dominant
 - $\sigma_{SD} = 10^{-40} \text{cm}^2$ @ $M_{\text{WIMP}} = 100 \text{ GeV}$, $\chi\chi \rightarrow W^+W^-$ dominant



Calendrier



Conclusions



- Fort intérêt du groupe du LLR dans ce projet
- **Suite logique de notre participation dans T2K**
- Les résultats récents sur theta13 ouvrent une voie royale aux projets MT
- HY utilisera une technologie connue de détection
- R&D pour réduire les coûts
- Un projet soutenu par le Japon
- **Un potentiel de découverte fondamentale très important**
- **Un détecteur unique pour des études au-delà du modèle standard**

Proposition de notre groupe de participer à l'écriture du TDR. Rejoindre éventuellement la collaboration SK (missions HK+SK : 20 Keuros/an)

