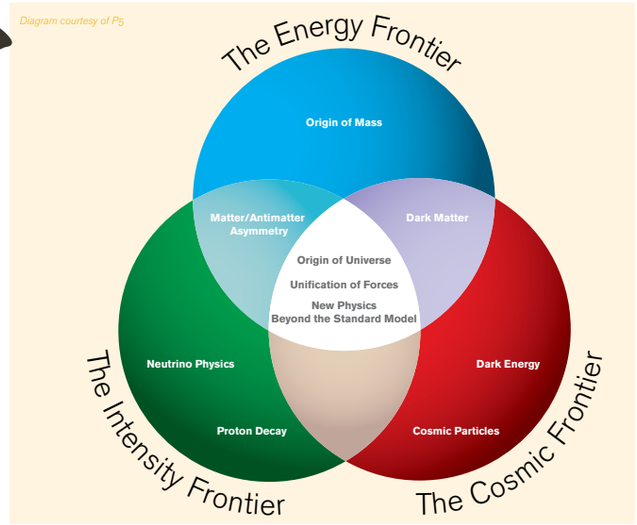
資料

高エネルギーフロンティア



米国P5

質量起源

ニュートリノ質量

物質・反物質
非対称

ニュートリノCPV

暗黒物質

宇宙起源
力の統一
新粒子

ニュートリノ物理

暗黒エネルギー

宇宙背景ニュートリノ
クォーク・レプトン
マヨラナ粒子

ニュートリノ測定器
→陽子崩壊探索

陽子崩壊

宇宙線

大強度フロンティア

宇宙フロンティア

Current θ_{13} measurements

- T2K 0.088+0.049-0.039
  arXiv:1304.0841
- D-Chooz 0.109±0.030±0.025
  PRD86 (2012) 052008
- RENO 0.113±0.013±0.019
  PRL108 (2012) 191802
- Daya Bay 0.089±0.010±0.005
  Chin. Phys. C37 (2013) 011001

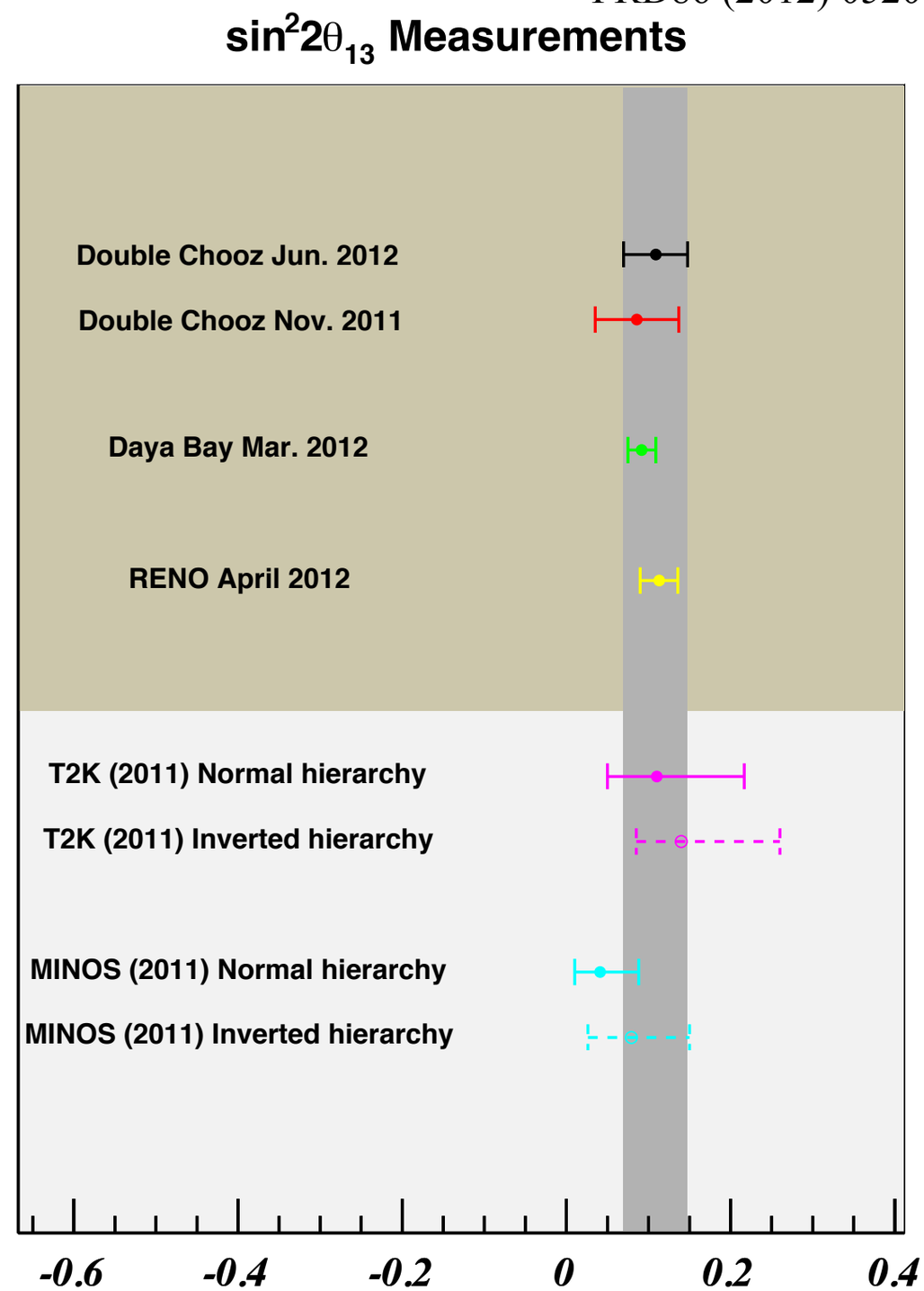
↓

$\theta_{13} \sim 9°$

It was just below the previous limit!

- Very good news for future neutrino programs for CP-δ measurement

PRD86 (2012) 052008



発表時は手短に

3つのニュートリノによる振動

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

Leading

CP violating (flips sign for $\bar{\nu}$)

Solar

Matter effect

Leading

$$\sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right)$$

CPV

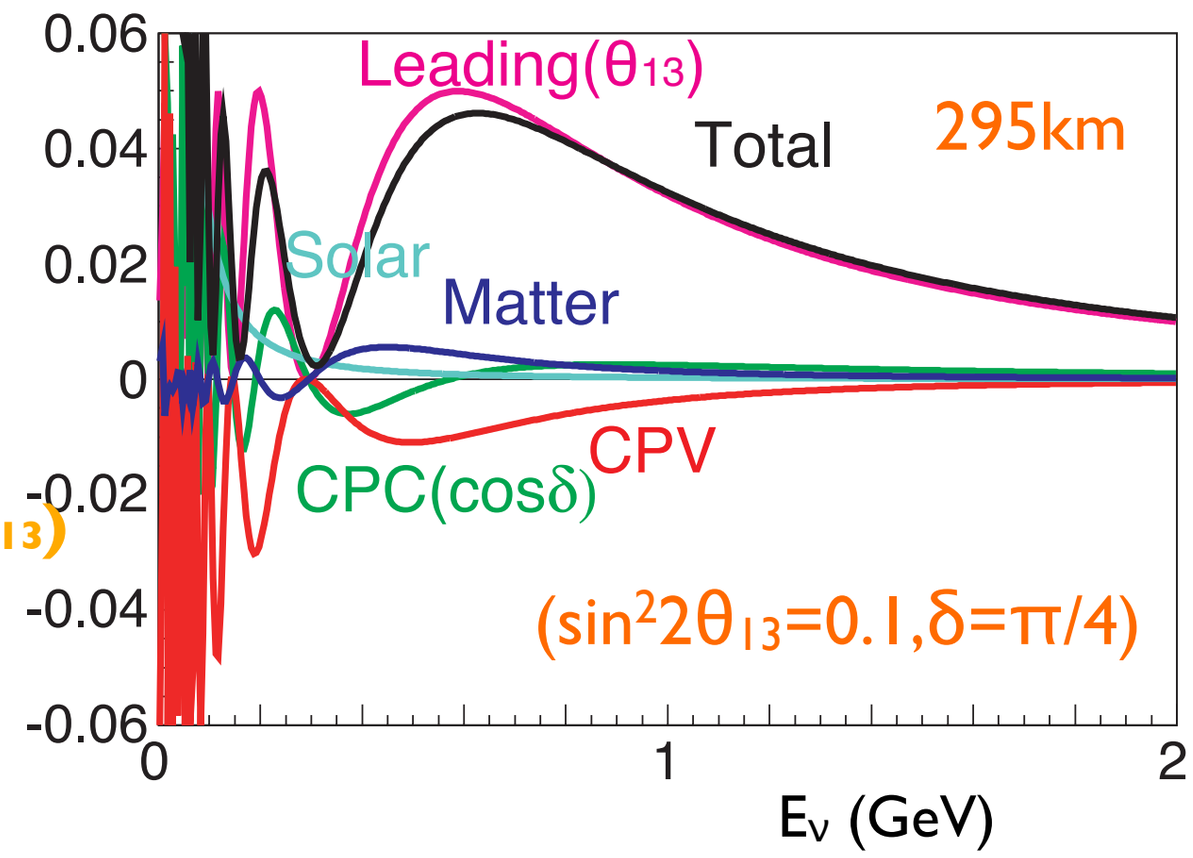
$$\frac{\sin 2\theta_{12}\sin 2\theta_{23}}{2\sin\theta_{13}}\sin^2 2\theta_{13}\sin^2\frac{\Delta m_{31}^2 L}{4E}\sin\frac{\Delta m_{21}^2 L}{4E}\sin\delta$$

~0.03 ~11.8 (6.4 from 1/sinθ13)

$$\sim\frac{\pi}{4}\frac{\Delta m_{21}^2}{\Delta m_{32}^2}\frac{\sin 2\theta_{12}\sin 2\theta_{23}}{\sin^2\theta_{23}\sin\theta_{13}}\frac{E_{1st\,\max}}{E}[leading]\sin\delta$$

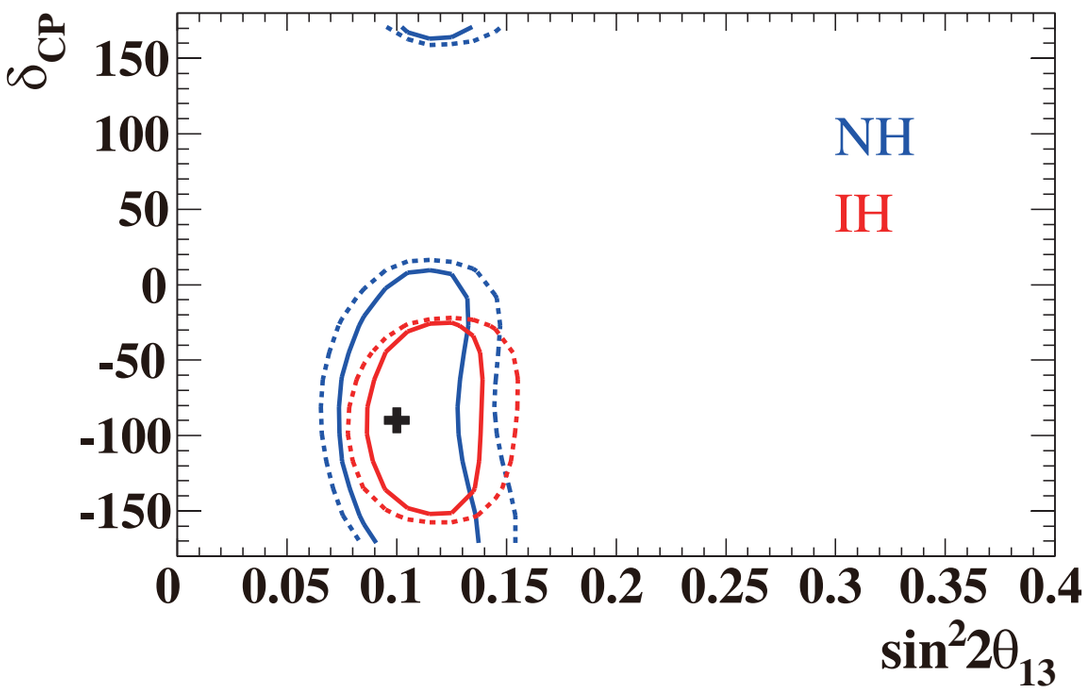
$$\sim 0.27\times[leading]\times\frac{E_{1st\,\max}}{E}\times\sin\delta$$

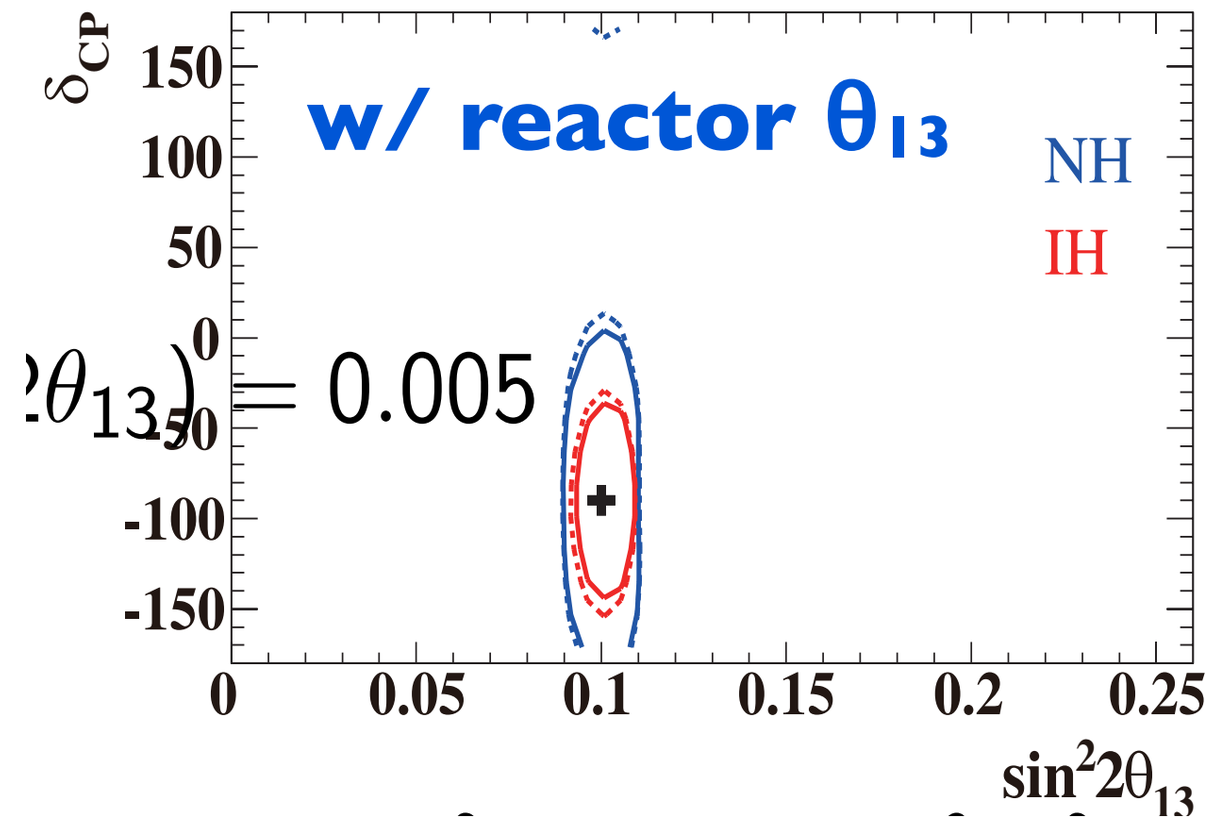
27%



T2K の δ_{CP} に対する予想感度

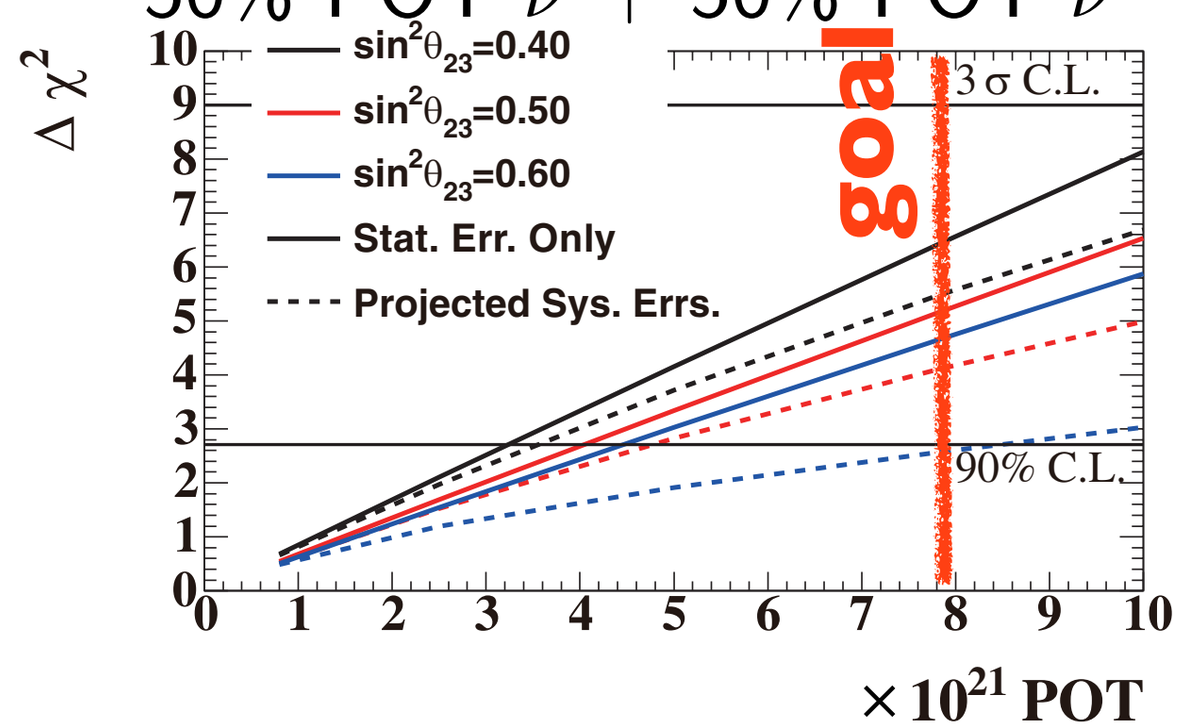
3.9×10^{21} POT both $\nu + \bar{\nu}$



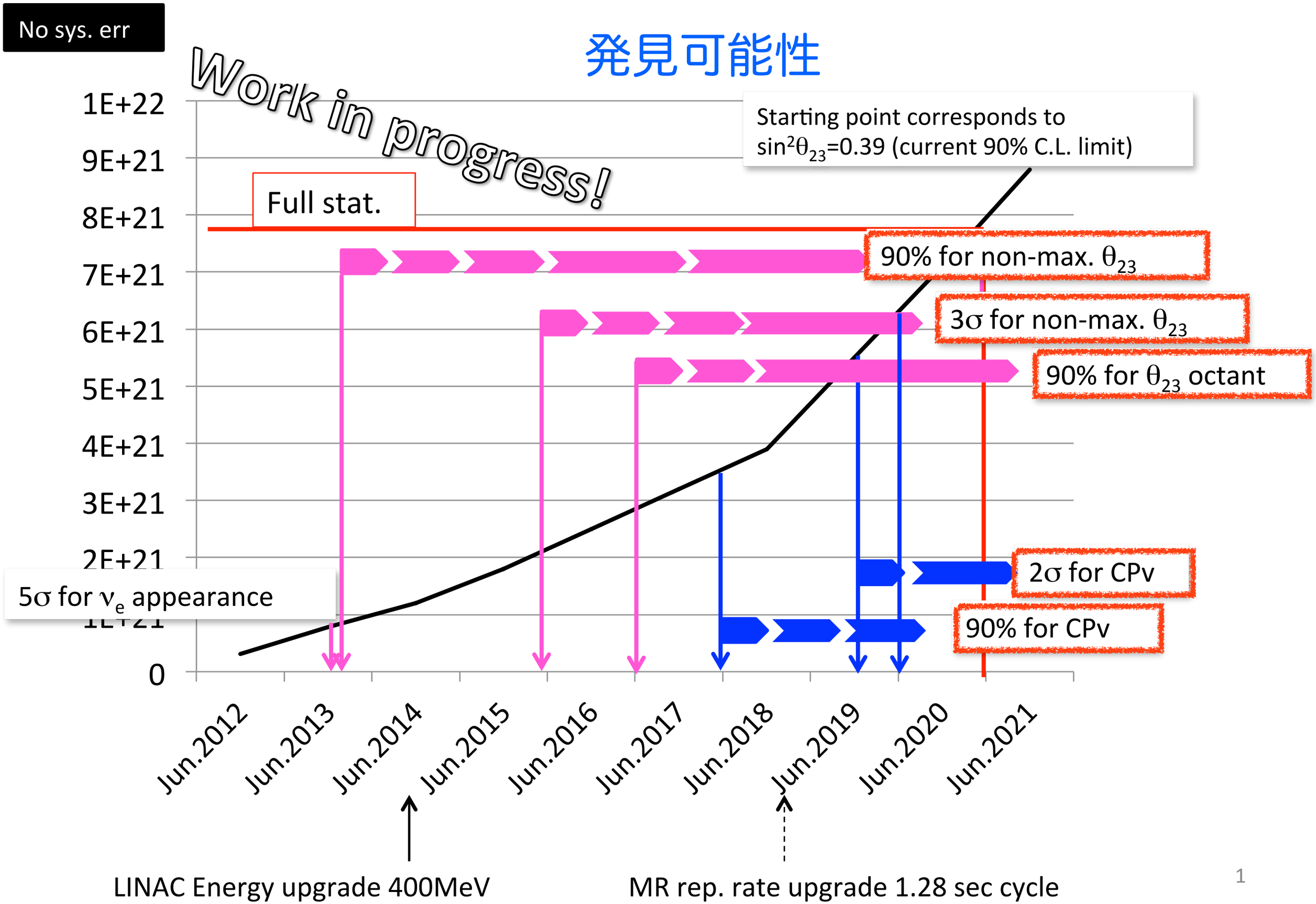


$\sin^2\theta_{13}$=0.1, δ_{CP}=-90°, $\sin^2\theta_{23}$=0.5, Δm^2_{32}=2.4E^{-3}eV^2

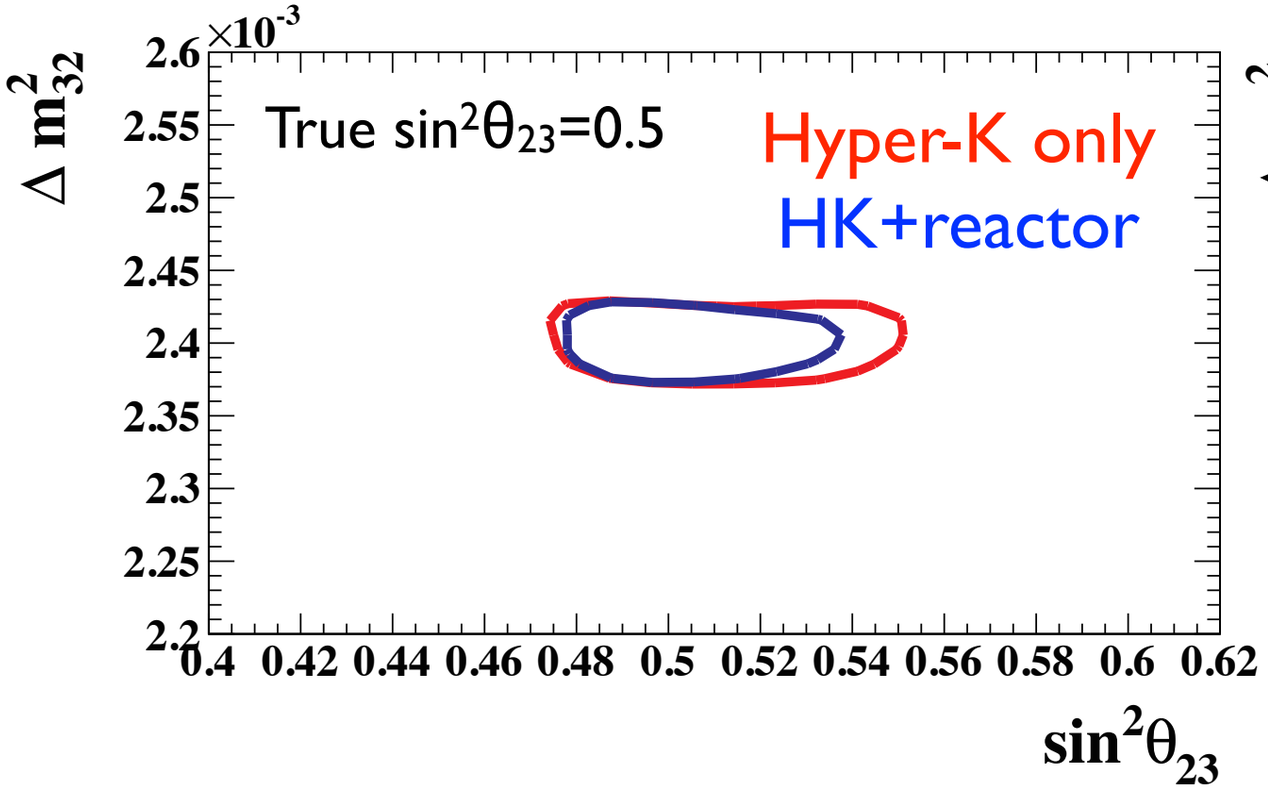
50% POT ν + 50% POT $\bar{\nu}$

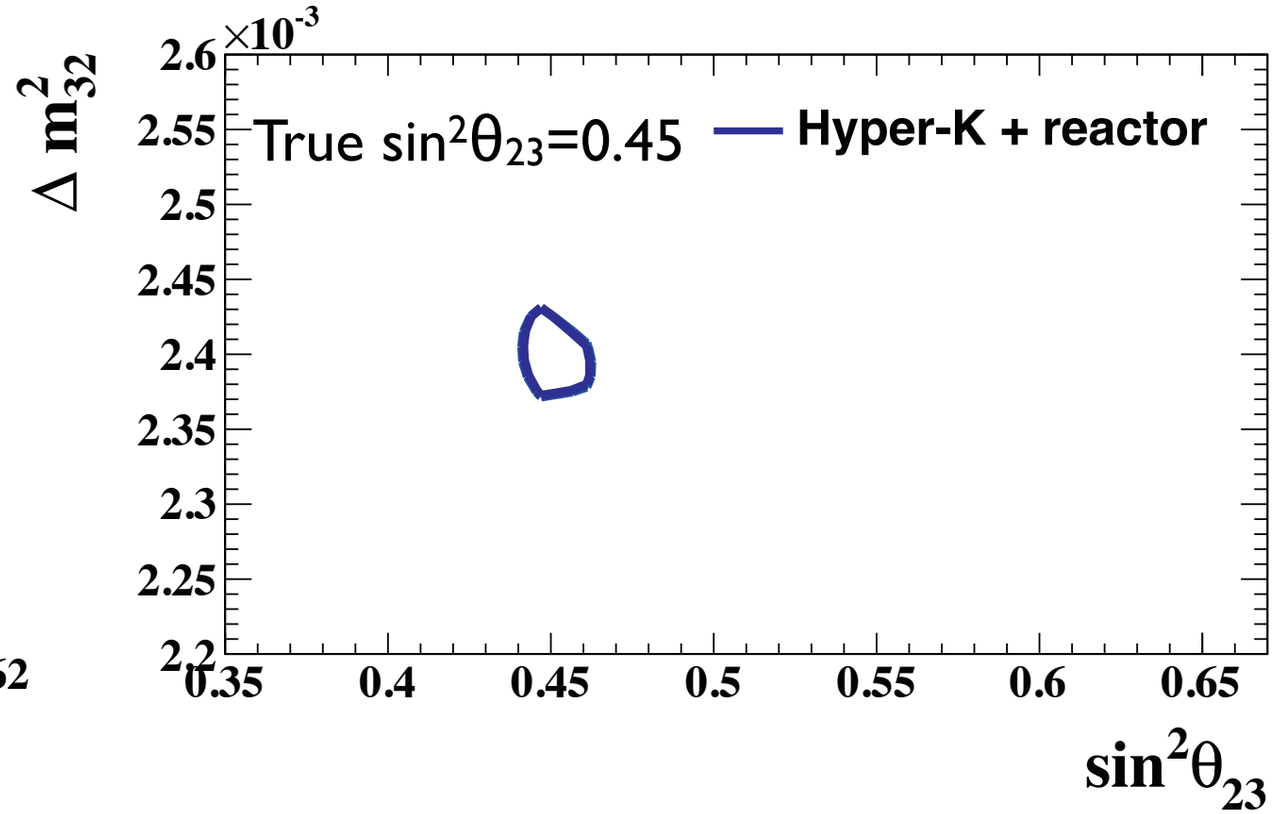


- 状況によれば, CPの破れに2〜3σの感度で迫る.


No sys. err
発見可能性
Work in progress!
1E+22
9E+21
8E+21
7E+21
6E+21
5E+21
4E+21
3E+21
2E+21
0
Starting point corresponds to
sin²θ23=0.39 (current 90% C.L. limit)
Full stat.
90% for non-max. θ23
3σ for non-max. θ23
90% for θ23 octant
2σ for CPv
90% for CPv
5σ for νe appearance
Jun.2012
Jun.2013
Jun.2014
Jun.2015
Jun.2016
Jun.2017
Jun.2018
Jun.2019
Jun.2020
Jun.2021
LINAC Energy upgrade 400MeV
MR rep. rate upgrade 1.28 sec cycle

Measurement of Δm^2_{32}, θ_{23}





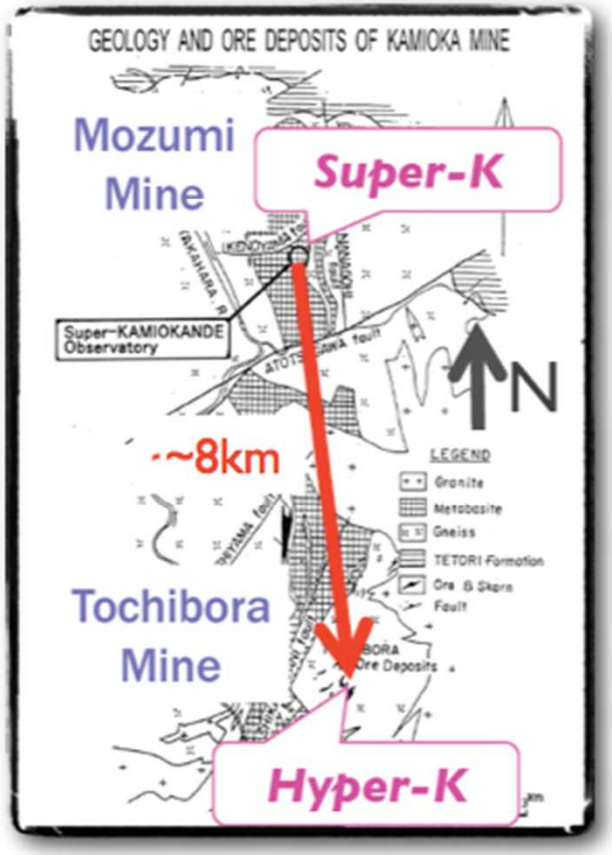
Expected 1σ uncertainty

True $\sin^2\theta_{23}$	0.45		0.50		0.55	
Parameter	Δm^2_{32}	$\sin^2\theta_{23}$	Δm^2_{23}	$\sin^2\theta_{23}$	Δm^2_{32}	$\sin^2\theta_{23}$
Normal hierarchy	1.4×10^{-5} eV^2	0.006	1.4×10^{-5} eV^2	0.015	1.5×10^{-5} eV^2	0.009
Inverted hierarchy	1.5×10^{-5} eV^2	0.006	1.4×10^{-5} eV^2	0.015	1.5×10^{-5} eV^2	0.009

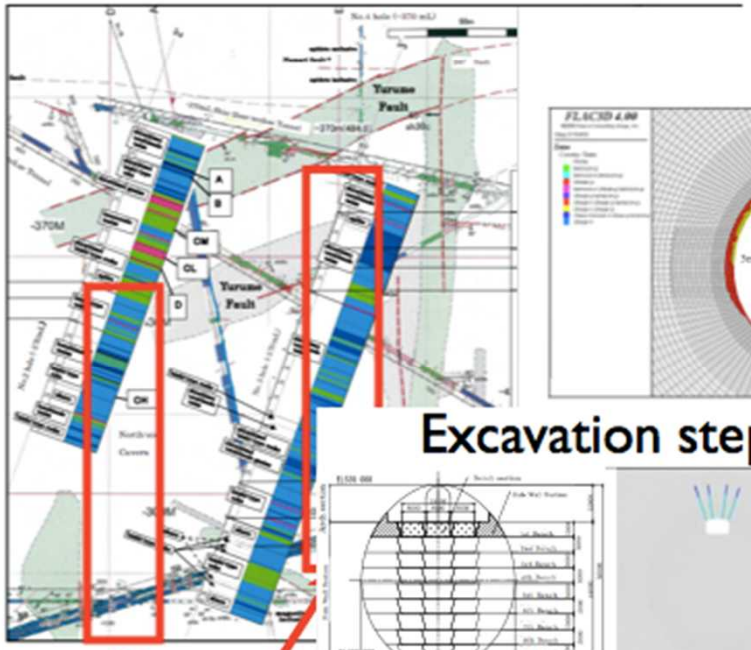
cf. T2K 2014 result: $\Delta m^2_{32}=2.51\pm0.10\times10^{-3}$eV^2, $\sin^2\theta_{23}=0.514\pm0.055$

Site and Cavern

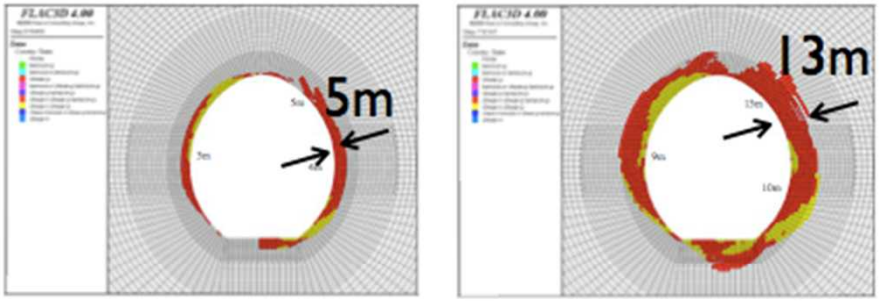
Candidate site:
~8km south of SK



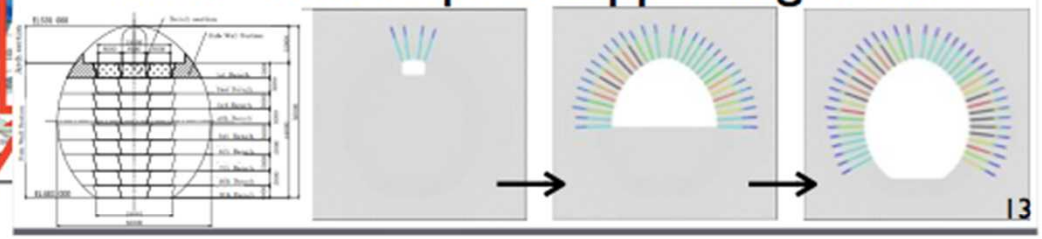
Rock mass characterization



Cavern stability



Excavation steps & supporting method

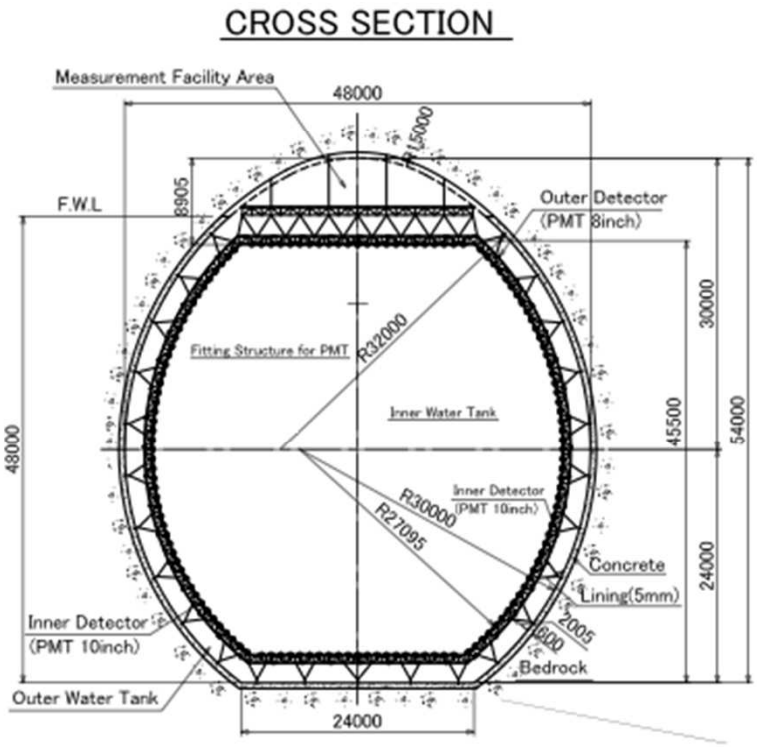


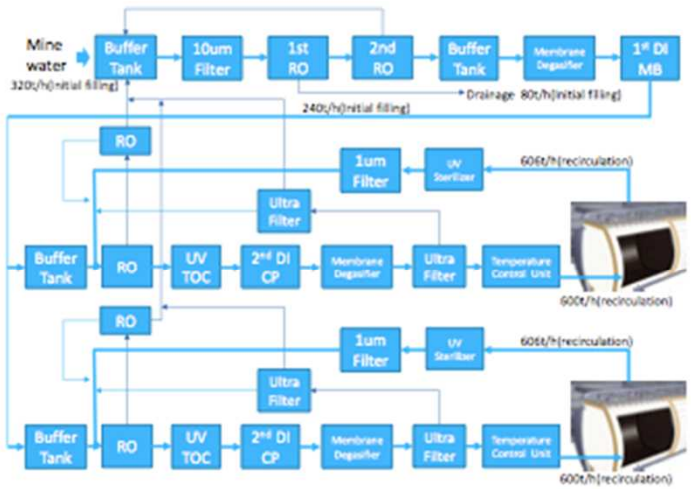
HK tank location

Cavity design studied based on the in-situ measurements of rock quality and stress

HK caverns can be constructed with existing technology

Detector design





- Baseline design established
  - Construction possible with current technology
- Some R&D for enhancing the capability and reduction of the cost
  - New photo-sensor development
  - Possible new near detectors

Selected as one of 27 top projects in Japanese Master Plan for Large Scale Research Projects by Science Council of Japan (Feb. 2014)

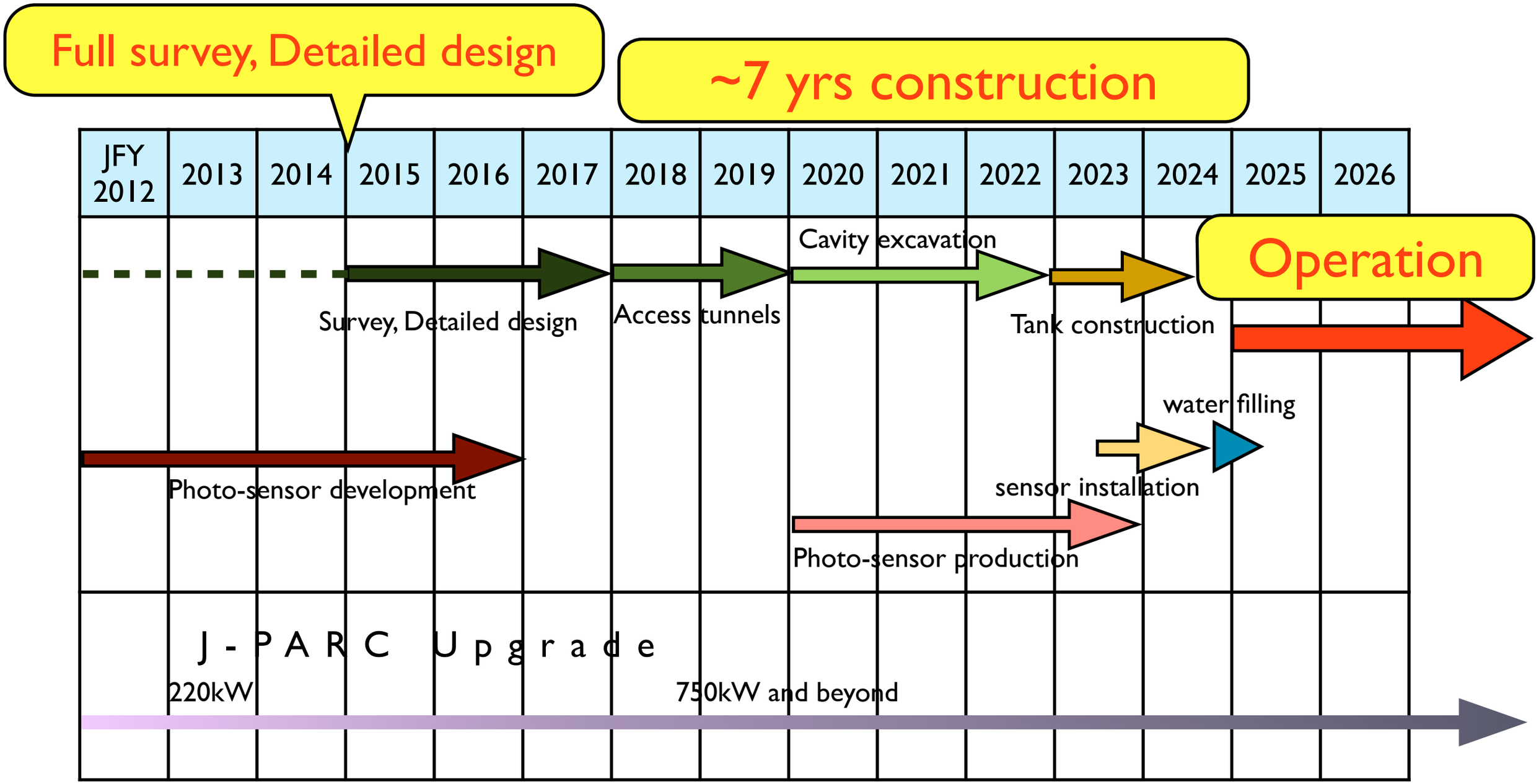
提　言

第 22 期学術の大型研究計画に関する
マスタープラン
（マスタープラン 2014）

平成２６年（２０１４年）２月２８日
日　本　学　術　会　議
科学者委員会
学術の大型研究計画検討分科会

No.	Scien-tific Field No.	Project Name	Project Summary	Scientific Significance	Social Value	Project Duration	Financial Requirement (1billion yen)	Implementing Institution, or Affiliation of Proposer
85	23-2	Nucleon decay and neutrino oscillation experiment with an advanced large detector	The project aims to construct a one million ton-scale water Cherenkov detector, Hyper-Kamiokande, to succeed Super-Kamiokande and to perform world-leading neutrino and nucleon decay research in conjunction with the J-PARC accelerator facility.	The project will explore CP violation (matter-antimatter asymmetry) in neutrinos in order to help understand the evolution of the universe. Additionally, with the world's best nucleon decay searches it also aims to establish the unification of elementary particles and their forces.	Addressing profound questions concerning the elementary structure and evolution of the universe appeals directly to the inherent intellectual curiosity mankind harbors for comprehension of its origins and future. Additionally, dramatic advances in neutrino research with a world-leading project in Japan represent society's dreams for a rich program in basic science.	2015 to 2038	Total:1,880 Construction of Hyper-Kamiokande 800, Operating cost of Hyper-Kamiokande 450, Operating cost of J-PARC 600, Neutrino monitor 30	Lead by the Institute for Cosmic Ray Research, University of Tokyo and the High Energy Accelerator Research Organization. Participation from domestic and foreign universities and research institutions is anticipated.

Notional Timeline



- 2015 Full survey, Detailed design (3 years)
- 2018 Excavation start (7 years)
- 2025 Start operation

想定外（Surprise!）

- 相対論の破綻（ローレンツ不変性の破れ）
- 新しい相互作用の発見
  - 5次元以上の世界のヒント
- 宇宙背景ニュートリノ発見
- 新しいタイプのニュートリノ発見
- ニュートリノ質量の測定

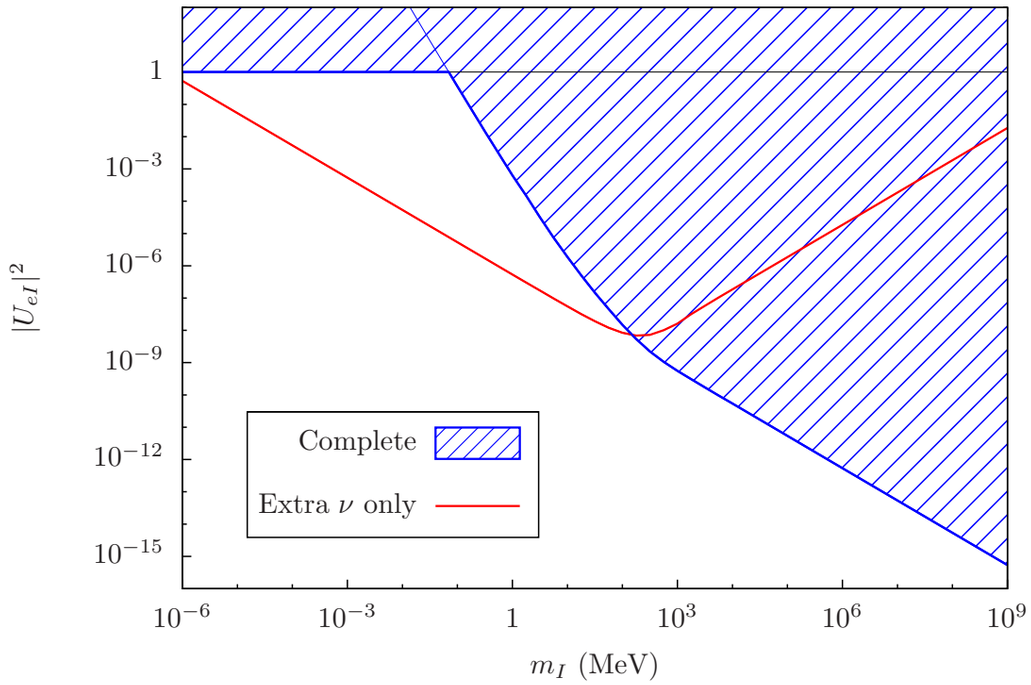
- 世界の最先端を走る日本のニュートリノ科学
- だからこそ、予期せぬ発見に出会う可能性大。

（注）2011年　ニュートリノが光速を超えた。。。

ニュートリノはまだまだ分かっていない！

What could we still observe?

- Decompose $y = \frac{1}{v} U_\nu \sqrt{m_\nu^{\rm diag}} \mathcal{R} \sqrt{M_M}$
  $\Rightarrow$ **oscillation experiments** constrain some parameters
- **absolute mass scale**: $\#\ \nu_R$-flavours $\geq \#$ non-zero m_i
- **lepton flavour violation**
  - if lepton number is approx. conserved, m_ν is protected by symmetry
    Wyler/Wolfenstein, Mohapatra/Valle, Branco/Grimus/Lavoura,. . .
  - $\mu \to e\gamma$ may be observable Smirnov/Kersten, Abada/Biggio/Bonnet/Gavela/Hambye, Gavela/Hambye/D.Hernandez/ P.Hernandez, Blanchet/Hambye/Josse-Michaux
- **neutrinoless double β-decay** constrains
  $m_{ee} \sim -\sum_I M_I (U_\nu)^2_{eI}$



Blennow/Fernandez-Martinez/Lopez-Pavon/Menendez 1005.3240