Hyper-Kamiokande

次世代核子崩壊・ニュートリノ検出器

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塩澤　真人

ニュートリノ混合

$$(\nu_e, \nu_\mu, \nu_\tau)^T = U(\nu_1, \nu_2, \nu_3)^T$$

*U*はMaki-Nakagawa-Sakata混合角

レプトン

$$|U_{\mathrm{MNS}}| = \begin{pmatrix} 0.834 & 0.788 & 0-0.2 \\ 0.439-0.557 & 0.479-0.701 & 0.707 \\ 0.439-0.557 & 0.479-0.701 & 0.707 \end{pmatrix}$$

エラーはsinθ_{13}とδ起源のみ表示。エラーなし項の測定エラーは5－15%。

$$(d', s', b')^T = V(d, s, b)^T$$

クォーク

$$|V_{\mathrm{CKM}}| = \begin{pmatrix} 0.97419 & 0.2257 & 0.00359 \\ 0.2256 & 0.97334 & 0.0415 \\ 0.00874 & 0.0407 & 0.999133 \end{pmatrix}$$

測定エラーは<1%。最大で5%。

$|U_{MNS}|$は非対角成分も非常に大きい。←→$|V_{CKM}|$~I なぜか？
ニュートリノはまだ未測定のパラメータも存在する。$\theta_{13}, \delta, \alpha 1, \alpha 2$
微小質量の起源？質量階層性？

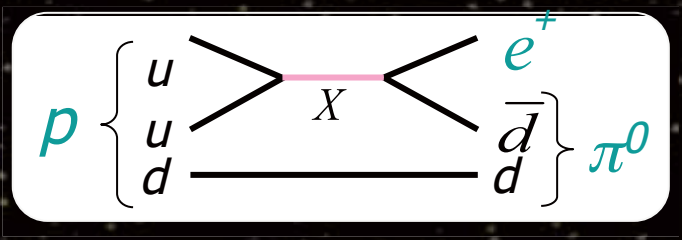
- クォーク＋レプトン両方同時説明する必要あり
- 超高エネルギーの物理の存在（ニュートリノ質量の起源？）

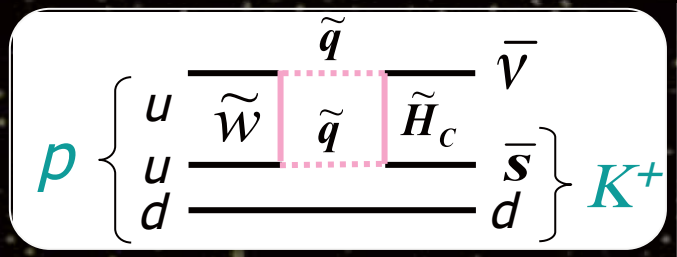
➡ 大統一理論（GUT）へ

3つの相互作用の統一、クォーク･レプトンの統一
大きなゲージ対称性、SU(5), SO(10), E6… with SUSY?

多くの間接的な（実験的･理論的）示唆はあるが、確定的な証拠はない。
モデルの詳細を決めまでにいたらず。

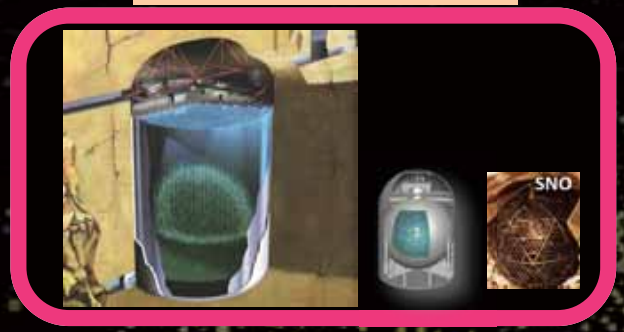
陽子崩壊探索はGUTの直接的な検証
- GUTモデルの排除
- 発見 → GUTの存在の証拠、モデルの詳細情報を引き出す



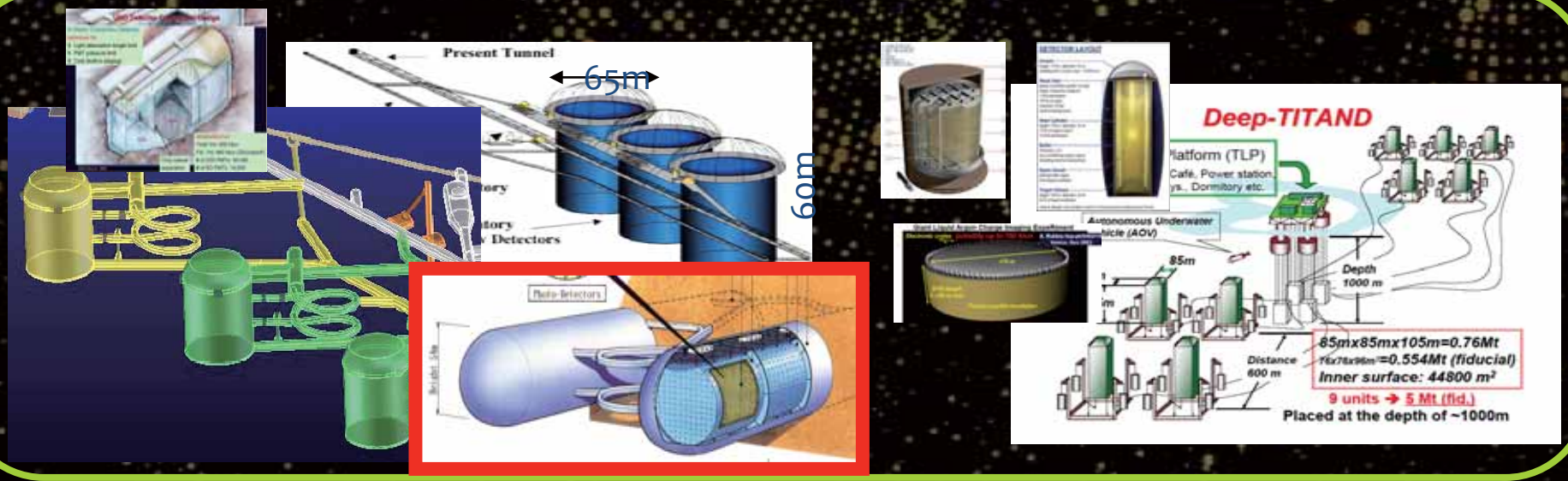


次世代検出器

RUNNING
Super-K 50kton



FUTURE (20??~)
- ~ 1Mton WC
- ~100kton LAr, Liq.scinti
- ~5Mton WC

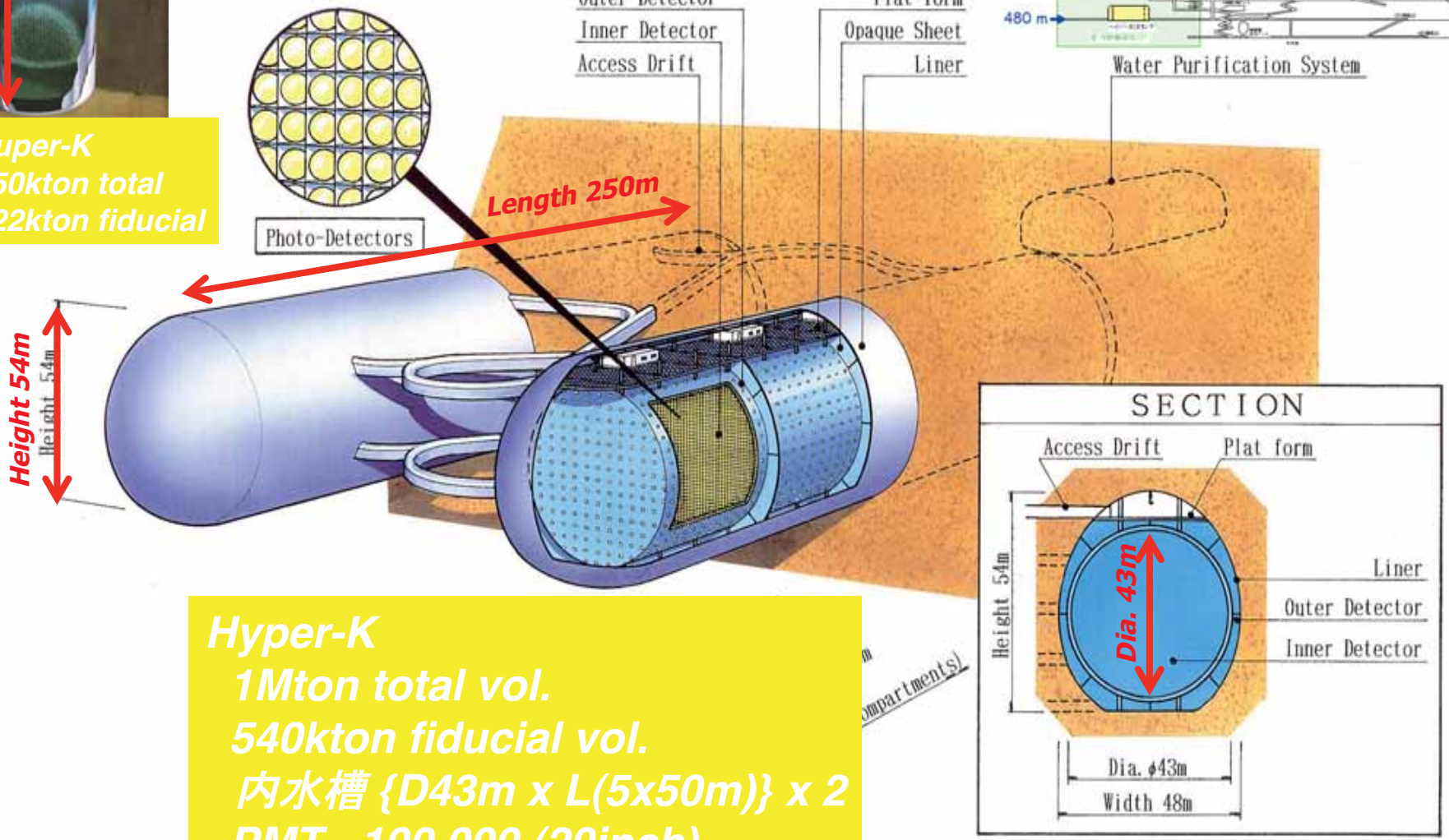


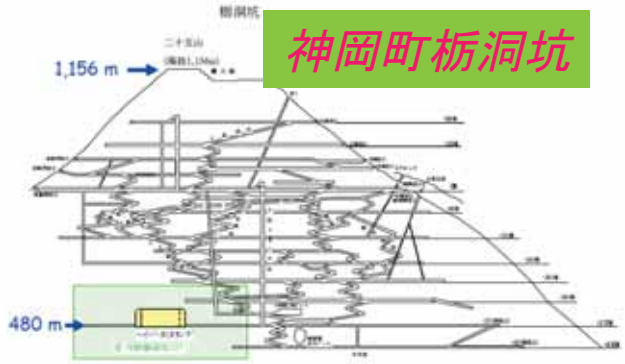
DUSEL(US) received design funding $31M from NSF('09) and DOE('10).
国際競争が始まっている。日本も早急に進める。

Physics Potentials

リングイメージング水チェレンコフ検出器

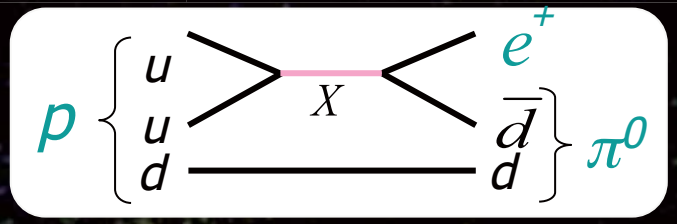
Super-K
50kton total
22kton fiducial

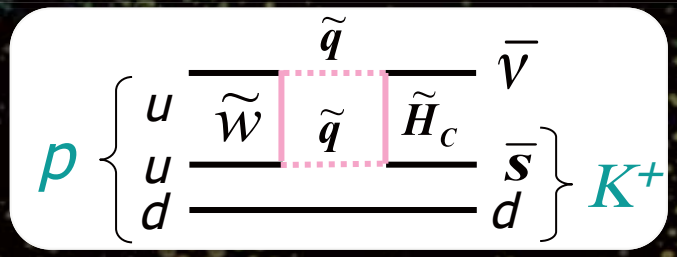




Hyper-K
1Mton total vol.
540kton fiducial vol.
内水槽 {D43m x L(5x50m)} x 2
PMT ~100,000 (20inch)
(センサーの被覆率20%)

proton decay
- explore quark/lepton unification -



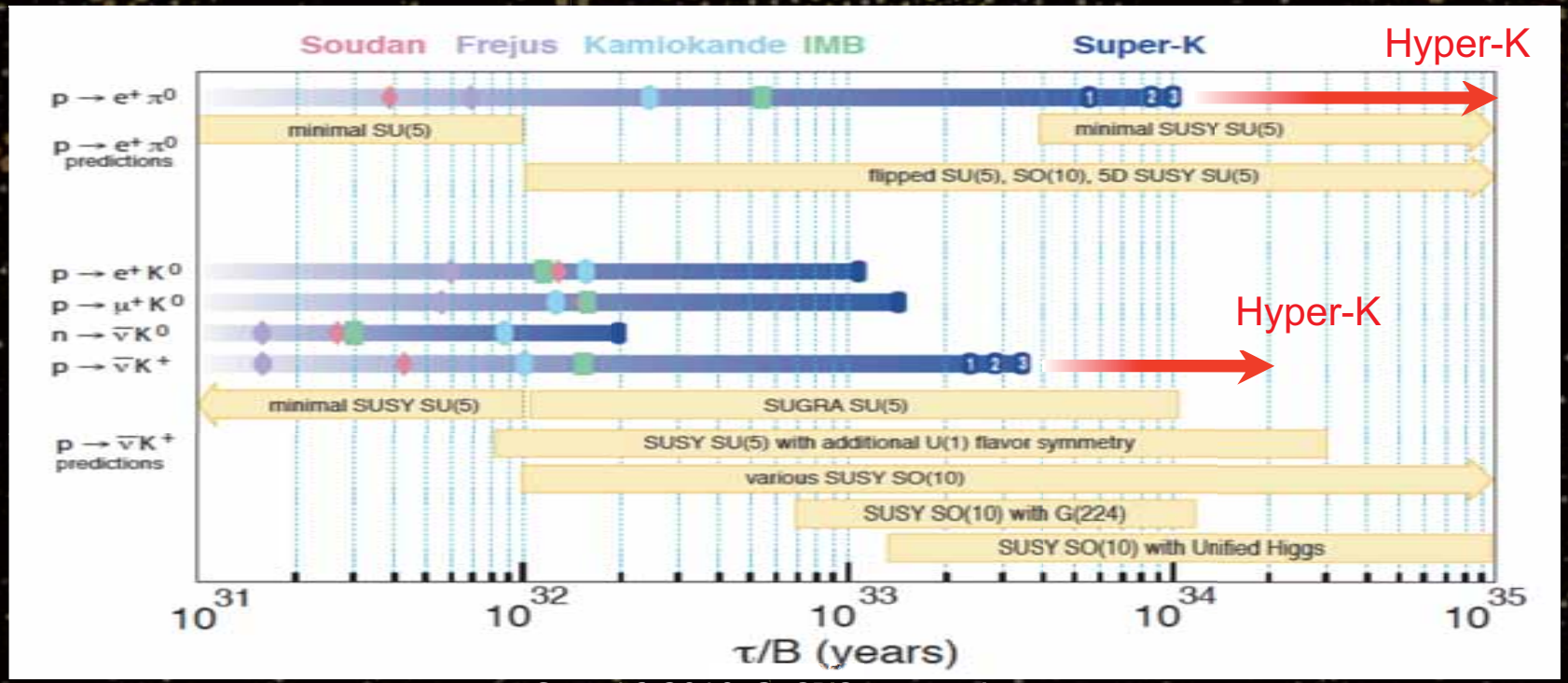


$p \rightarrow e^+\pi^0$

- 1.0 x 10^{34} years (Super-K I+II+II @ 90% C.L.)
  - → *1 x 10^{35} years (0.54Mton x 10yrs @ 90% CL)*

$p \rightarrow \nu K^+$

- 3.3 x 10^{33} years (Super-K I+II+III @ 90%C.L.)
  - → *2 x 10^{34} years (0.54 Mton x 10yrs @ 90% CL)*

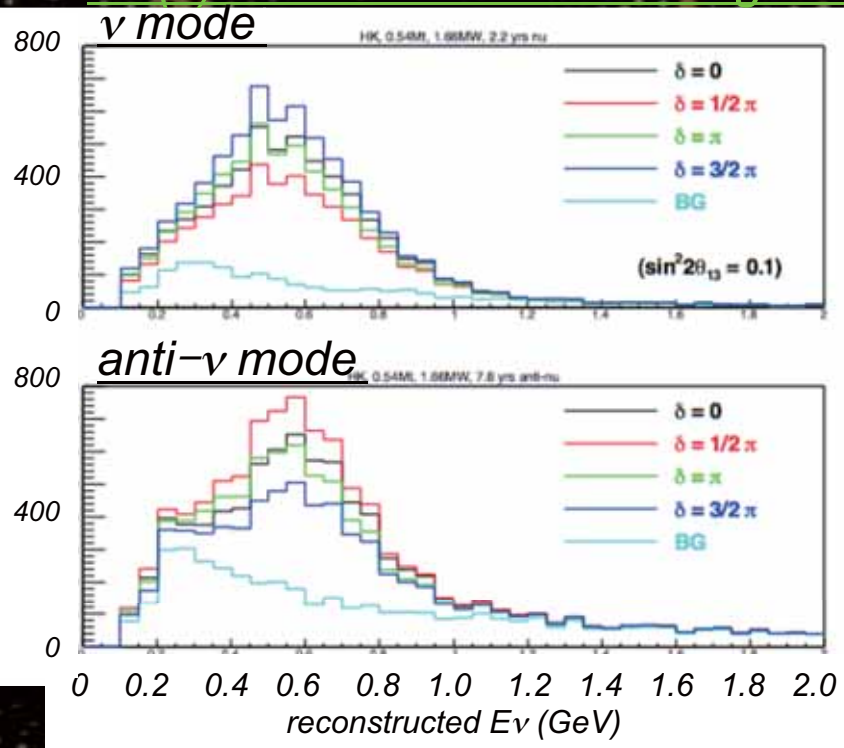


CP measurement

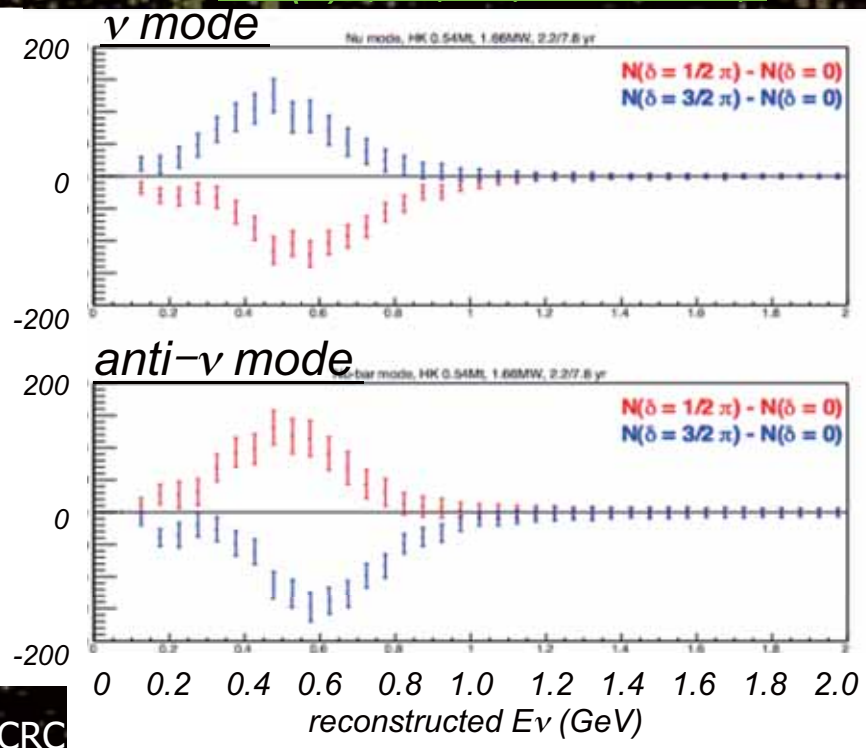
- *T2K (JPARC-SK) has been started data taking, reactor experiments in a few months ~ years*
- *discovery of ν_e appearance (nonzero θ_{13})*
  → open door to CP phase measurement !
  (turning point in a few years?)

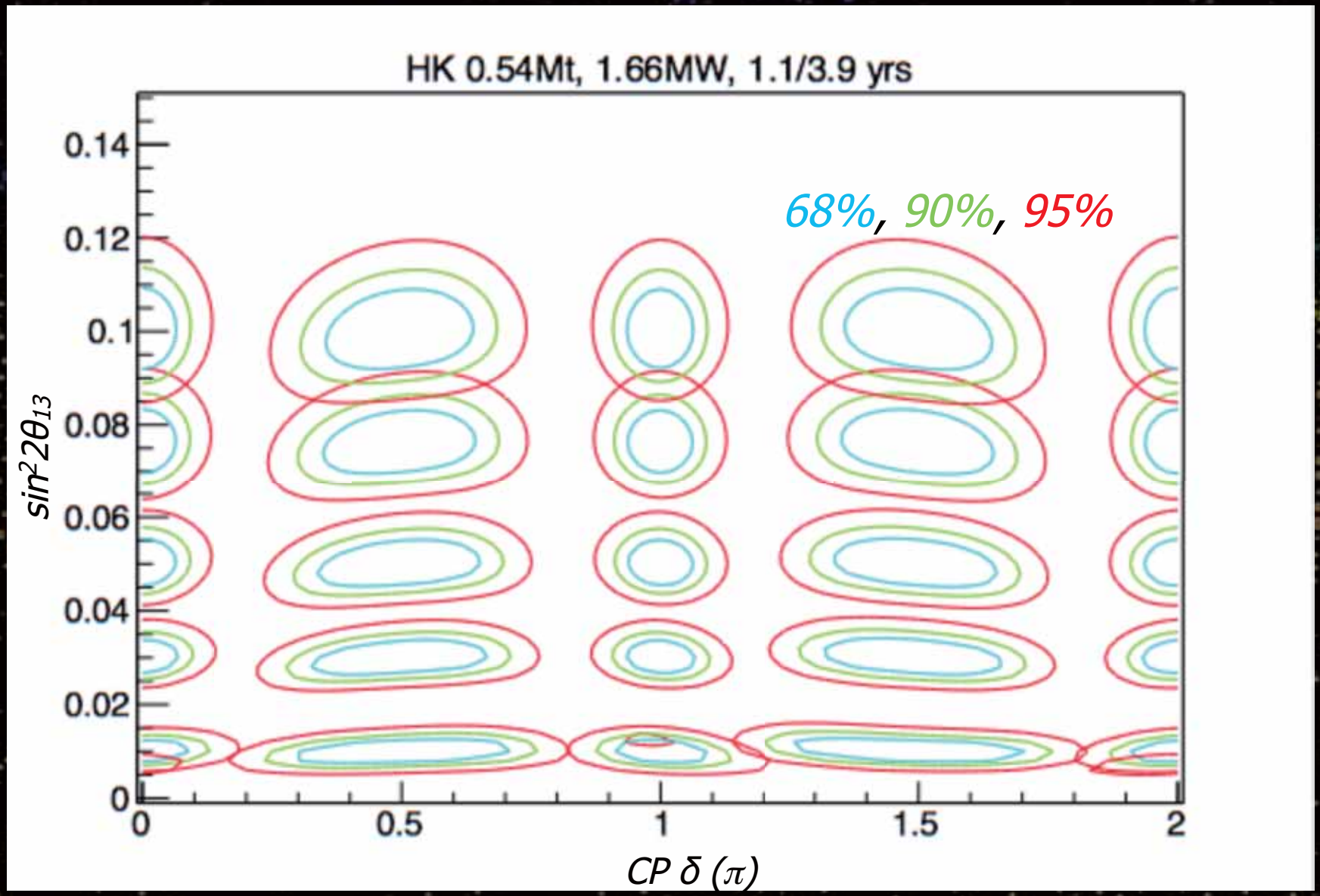
item	parameters
ν beam	Quasi-monochromatic beam (off-axis 2.5 degree, Eν=~0.6GeV) Upgraded to 1.66MW
Far ν detector	0.54Megaton
Data taking period	5 yrs (1.1 yrs ν mode + 3.9 yrs anti-ν mode) – 10yrs *1 yrs = 10^7 sec
Electron selection	Single-Ring, Pe>100MeV/c, no decay-e, Mπ0<100MeV/c^2, $\cos\theta_\mu$ < 0.9
systematic errors (reference)	5% for νe signal, NC BG, beam νe (anti-νe), ν mode/anti-ν mode normalization
ν parameters	$\sin^2\theta_{23}$=0.5, Δm^2_{23}=2.4x10^{-3}eV^2(normal hierarchy), $\sin^2\theta_{12}$=0.32, Δm^2_{12}=7.6x10^{-5} eV^2

Ne(δ) = selected electron signal



Ne(δ) (Ne(δ=0) subtracted)

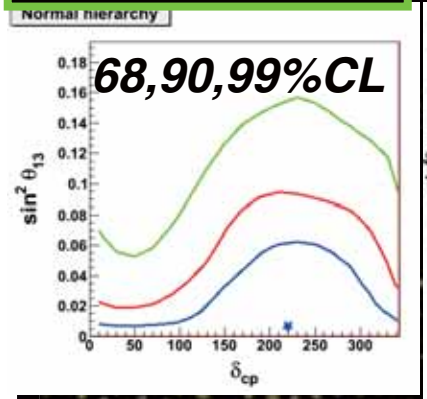



HK 0.54Mt, 1.66MW, 1.1/3.9 yrs
68%, 90%, 95%
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
$\sin^2 2\theta_{13}$
0
0.5
1
1.5
2
CP δ (π)

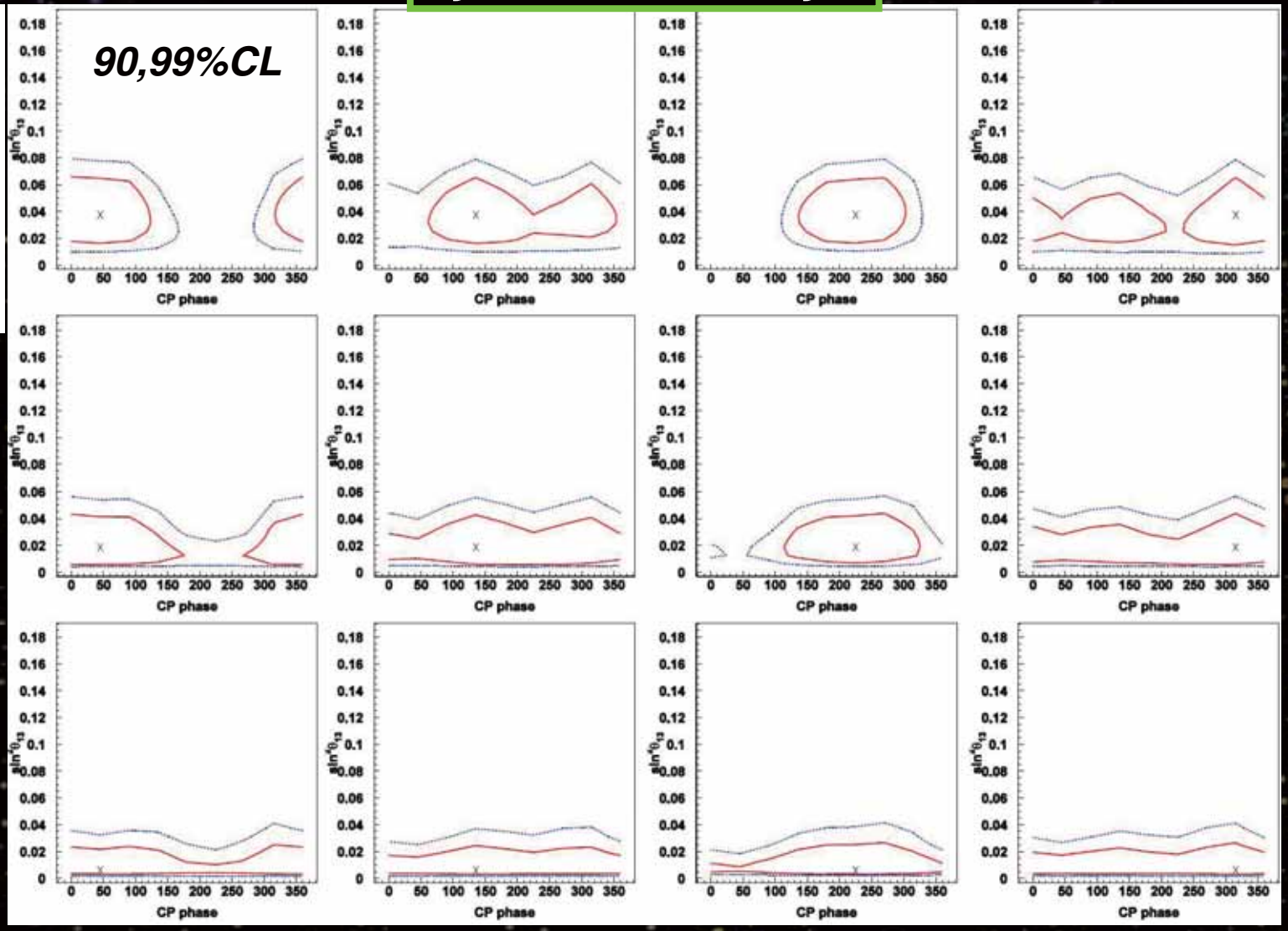
CP phase with atmospheric ν

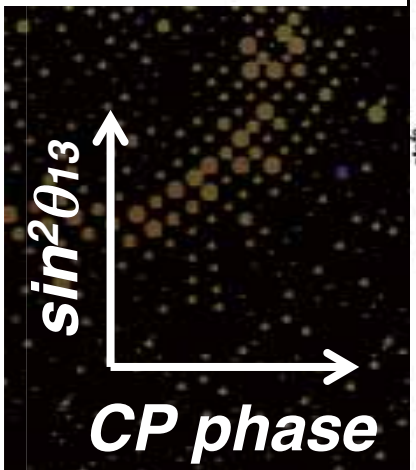
$s^2 2\theta_{12}=0.825$
$s^2\theta_{23}=0.5$
$s^2\theta_{13}=0.00\sim0.04$
$\delta cp=0^o\sim360^o$
$\Delta m^2_{12}=8.3e\text{-}5$
$\Delta m^2_{23}=2.5e\text{-}3$

Super-K data



4yrs HK sensitivity





atmospheric ν could provide supplemental info. if θ13 is large.

Other Physics targets

- Nucleon Decay Searches
  - Direct test of quark-lepton unification
- *Far Detector in future LBLE*
  - *CP phase measurement in Lepton sector*
- Precise Measurement of atmospheric neutrinos
  - δ, θ_{13}, mass hierarchy ($\sin^2\theta_{13} >\sim 0.01$)
  - $\theta_{23}<\pi/4$ or $\theta_{23}=\pi/4$ or $\theta_{23}>\pi/4$
- *Supernova Neutrinos*
  - mass hierarchy as well as explosion mechanism
- *High statistical observation of Solar Neutrinos*

Feasibility study of large cavern

これまでのsite study

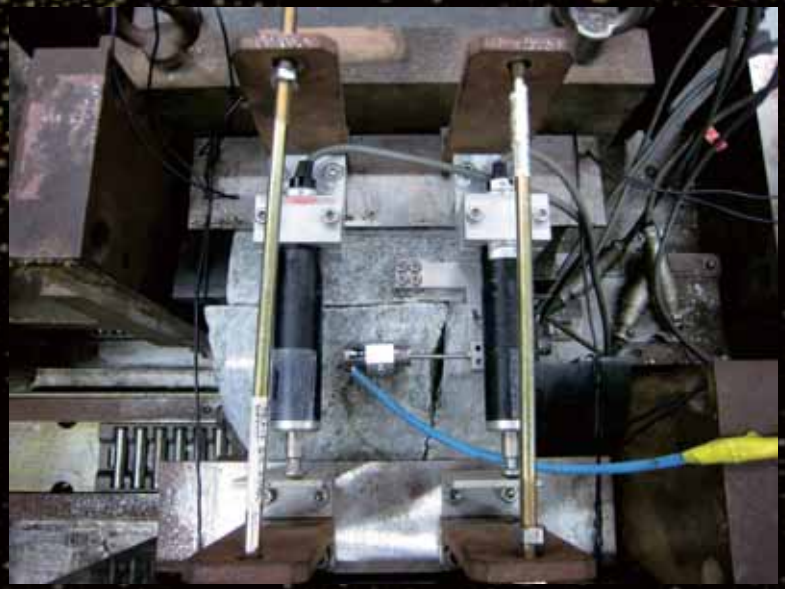
- ✓ *site selection (Tochibora mine, +410~480m s.l.)*

- ✓ *geological sketching – very sound intact mass in excellent condition*
- ✓ *core boring – geological map, joint orientation survey*
- ✓ *rock sampling – mechanical property of rock mass and joint*
- ✓ *initial state of stress in the rock mass*

- ✓ *conceptual cavern design and layout (two 250m tunnels with 100m spacing)*
- ✓ *FEM analysis of the cavern*

- ✓ *clean natural water supply*

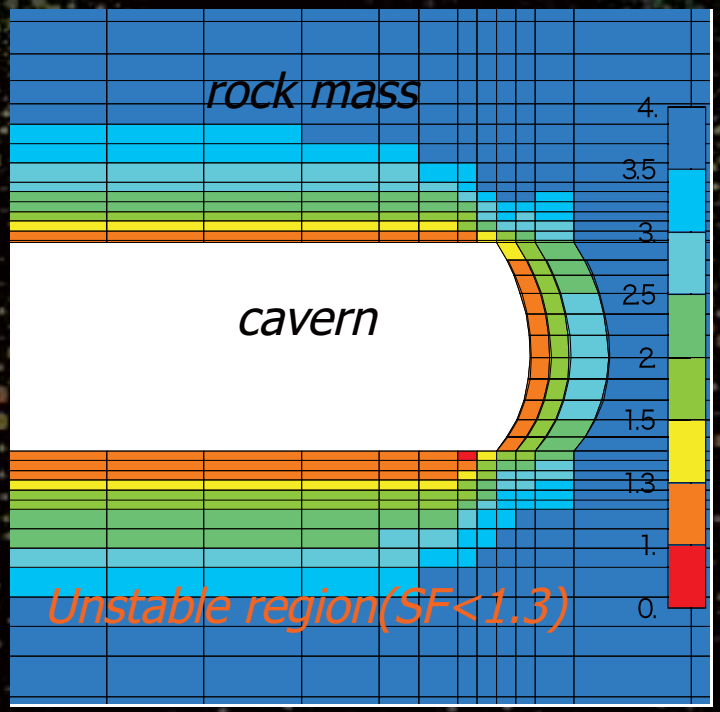
mechanical properties and joint orientation measure



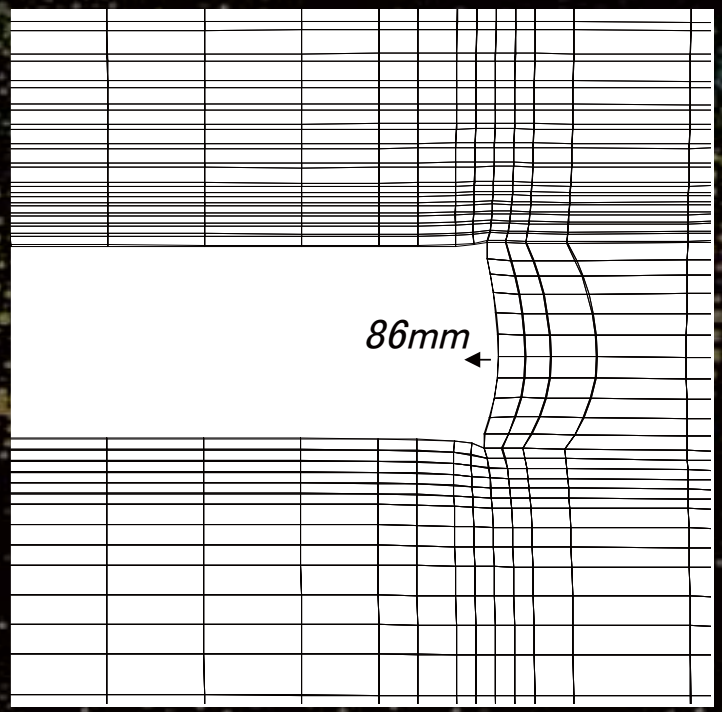
F.E.M. analysis of cavern

initial stress ratio $K_0 = \sigma_{horizontal}/\sigma_{vertical}$ =1.5 (conservative condition)

(a) Safety Factor

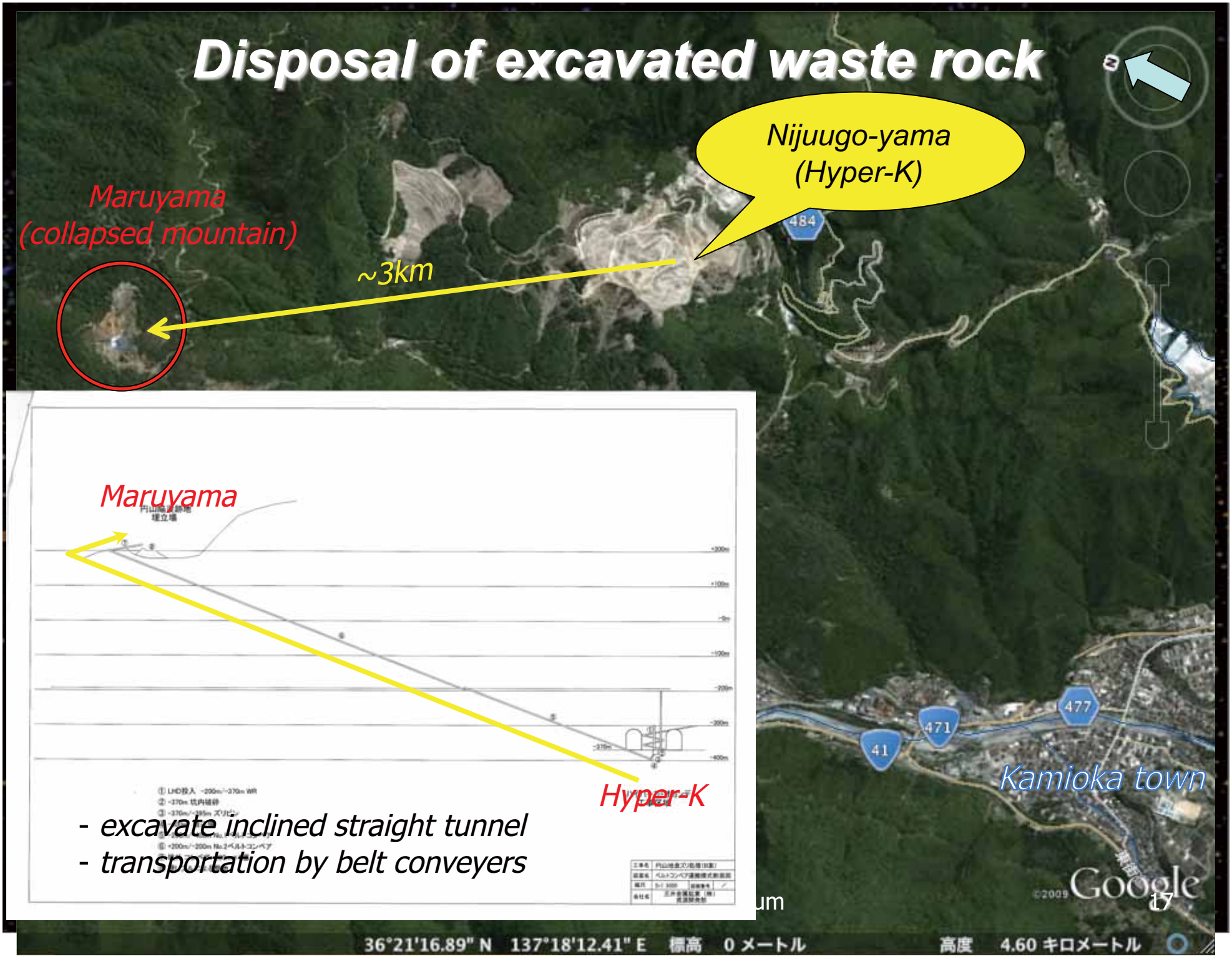


(b) Displacement



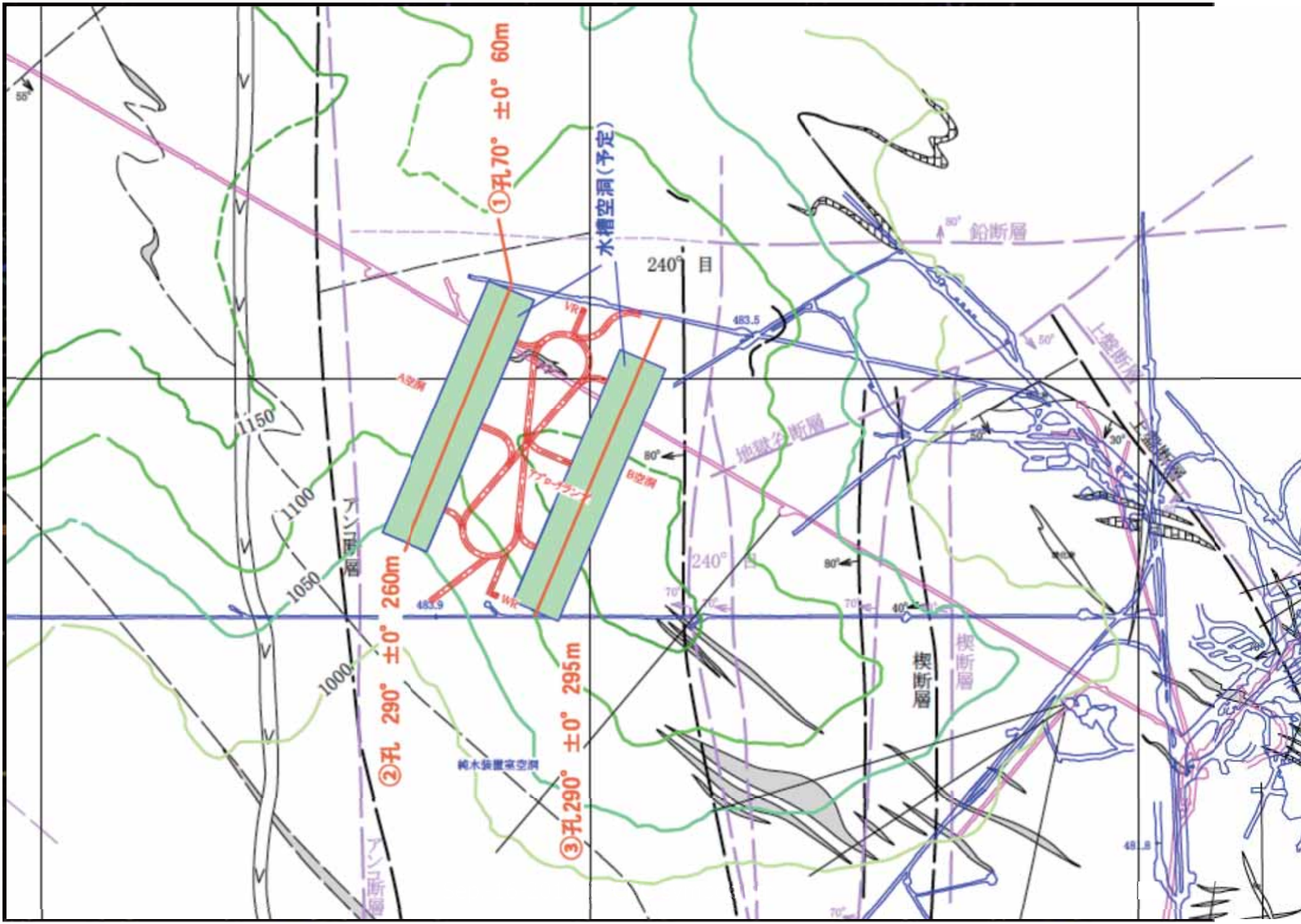
Unstable region Depth<5m and is tolerable.

Disposal of excavated waste rock



今年度の予定

- 建設にGOをかけられる状態にする。
  - 場所、深さ（水が出ない最深の場所）、水槽方向、ずり廃棄、工法、工期、コスト
    - *サイト全体の地質調査開始（10月～）*
  - 水槽デザイン（壁、構造、センサー取り付け、工期、コスト）
  - センサー（必要最小限の数を決定、生産期間とコスト）
  - 物理解析の感度study
- 外部に発信
  - 日本で国際会議(December 13-16, Toyama, Workshop on Next Generation Nucleon Decay and Neutrino Detectors)
- レポートにまとめる。


①孔70° ±0° 60m
水槽空洞(予定)
240° 目
鉛断層
483.5
上盤断層
地塁状断層
A空洞
B空洞
アプローチランプ
VR
WR
1150
1100
1050
1000
アン山断層
483.9
②孔 290° ±0° 260m
③孔290° ±0° 295m
純水貯蔵容空洞
楔断層
楔断層
アン山断層
55°
80°
50°
30°
40°
70°

ハイパーカミオカンデまとめ

- ✓ 物理
  - ✓ クオーク・レプトン性質やその統一の解明
  - ✓ 広い物理トピック、発見の可能性
- ✓ Feasibility
  - ✓ これまでは良好な結果
  - ✓ 工期や費用の見積もりを進めている(一年以内)