Hyper-Kamiokande

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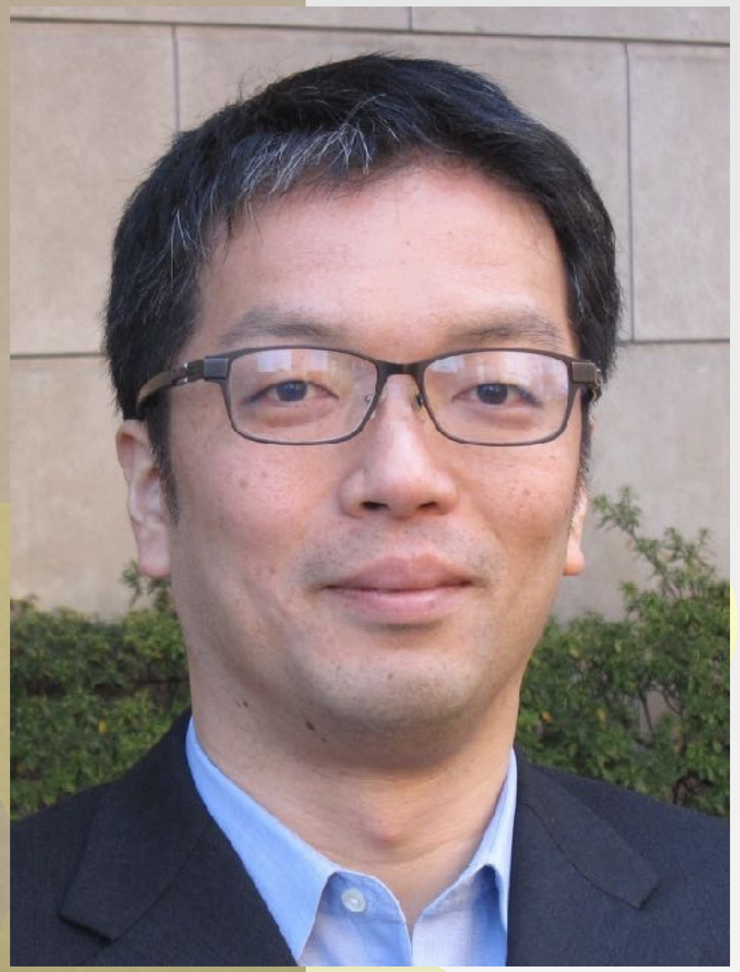
SCHOOL OF SCIENCE, THE UNIVERSITY OF TOKYO



5th International Conference on Particle Physics and Astrophysics

October 9, 2020

Hyper-Kamiokande was approved!

ICRR Latest News

Announcement from UTokyo, KEK, and J-PARC

The Hyper-Kamiokande project is officially approved.

Topics 2020.02.12

東京大学 THE UNIVERSITY OF TOKYO　KEK High Energy Accelerator Research Organization　J-PARC

February 12, 2020
The University of Tokyo
High Energy Accelerator Research Organization (KEK)
Japan Proton Accelerator Research Complex (J-PARC) Center

Hyper-Kamiokande (HK or Hyper-K) project is the world-leading international scientific research project hosted by Japan aiming to elucidate the origin of matter and the Grand Unified Theory of elementaly particles. The project consists of the Hyper-K detector, which has an 8.4 times larger fiducial mass than its predecessor, Super-Kamiokande, equipped with newly developed high-sensitivity photosensors and a high-intensity neutrino beam produced by an upgraded J-PARC accelerator facility.

The supplementary budget for FY2019 which includes the first-year construction budget of 3.5 billion yen for the Hyper-Kamiokande project was approved by the Japanese Diet. The Hyper-K project has officially started. The operations will begin in 2027.

The overall Japanese contribution will include the cavern excavation, construction of the tank (water container) and its structure, half of the photosensors for the inner detector, main part of the water system, Tier 0 offline computing, together with J-PARC accelerator upgrade and construction of a new experimental facility for the near detector complex. International contributions will include the rest of photosensors for the inner detector, sensor covers and light collectors, photosensors for the outer detector, readout electronics, data acquisition system, water system upgrade, detector calibration systems, downstream offline computing system, and the near/intermediate detector complex.

Budget for large scale science projects, MEXT (funding agency)

世界の学術フロンティアを先導する大規模プロジェクトの推進

令和2年度予算額（案）　32,091百万円
（前年度予算額　34,382百万円）
令和元年度補正予算額（案）　4,984百万円

参考　文部科学省

目的
- ○ 最先端の大型研究装置等により人類未踏の研究課題に挑み、**世界の学術研究を先導**。
- ○ 国内外の優れた研究者を結集し、**国際的な研究拠点を形成**するとともに、国内外の研究機関に対し**研究活動の共通基盤を提供**。

- ○ **日本学術会議**において科学的観点から策定した**マスタープラン**を踏まえつつ、専門家等で構成される**文部科学省の審議会**において戦略性・緊急性等を加味し、**ロードマップを策定**。
- ○ ロードマップの中から大規模学術フロンティア促進事業として実施するプロジェクトを選定の上、国立大学法人運営費交付金等の基盤的経費により戦略的・計画的に推進。原則、**10年間の年次計画を策定**し、審議会における**厳格な評価・進捗管理**を実施。
- ○ 現行の13プロジェクトに加え、**ニュートリノ研究の次世代計画である「ハイパーカミオカンデ計画」に新たに着手**。

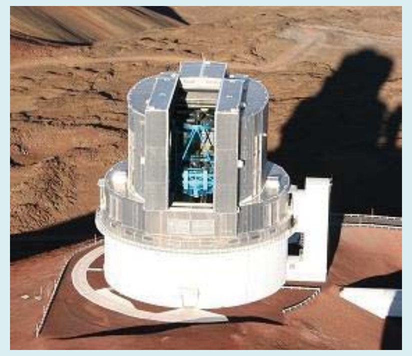
大規模学術フロンティア促進事業等の主な事業

NEW
ハイパーカミオカンデ(HK)計画の推進
〔東京大学宇宙線研究所、高エネルギー加速器研究機構〕

- ○ 日本が切り拓いてきた**ニュートリノ研究の次世代計画**として、**超高感度光検出器**を備えた総重量26万トンの**大型検出器の建設**及び**J-PARCの高度化**により、**ニュートリノの検出性能を著しく向上（スーパーカミオカンデの約10倍の観測性能）**。
- ○ 素粒子物理学の大統一理論の鍵となる未発見の**陽子崩壊探索やCP対称性の破れなどのニュートリノ研究**を通じ、**新たな物理法則の発見、素粒子と宇宙の謎の解明を目指す**。【ロードマップ2017掲載事業】

大型光学赤外線望遠鏡「すばる」の共同利用研究
〔自然科学研究機構国立天文台〕

- ○ **銀河誕生時の宇宙の姿を探り、太陽系外の惑星の謎に迫る**ため、米国ハワイ州マウナケア山頂域（標高約4,200m）に建設された**口径8.2mの「すばる望遠鏡」を運用**し、**大学等の研究者による共同利用観測に供して、世界最先端の天文学研究を推進**する。



新しいステージに向けた学術情報ネットワーク(SINET)整備〔情報・システム研究機構国立情報学研究所〕

- ○ **国内の大学等を高速通信回線ネットワークで結び、共同研究の基盤を提供**。
- ○ 全国900以上の大学や研究機関、約300万人の研究者・学生が活用する**我が国の研究教育活動に必須の学術情報基盤**。

主な成果（学術的価値の創出）

- ○ **ノーベル賞受賞につながる画期的研究成果**
  （受賞歴:H14小柴昌俊氏、H20小林誠氏、益川敏英氏、H27梶田隆章氏）
- ○ **年間約1万人の共同研究者が集結**し、国際共同研究を推進。このうちの**半数以上が外国人研究者、3割程度が若手研究者と割合が高い**。

共同研究者数：10,683人（H29実績）

- ○ 天文分野では、すばる望遠鏡、アルマ望遠鏡の**TOP10%論文割合や国際共著論文割合は、分野全体と比較しても高い**。

天文学・宇宙物理学分野	論文数	Top10%割合	国際共著割合
すばる望遠鏡	644	18.5%	86.3%
アルマ望遠鏡	878	27.3%	89.0%
日本全体	8,938	12.9%	68.0%
世界全体	103,445	9.6%	50.6%

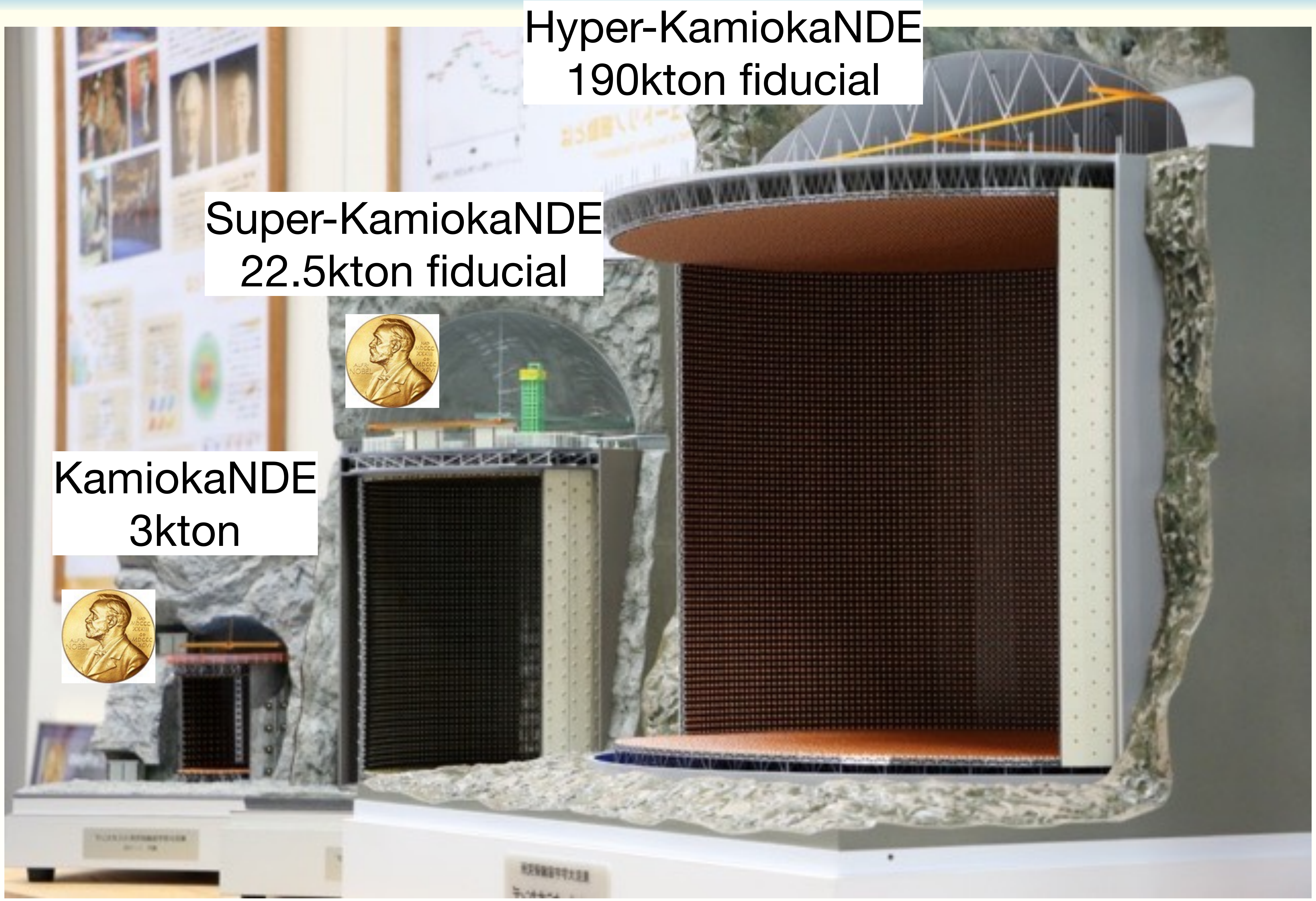
※ 大学共同利用機関法人自然科学研究機構が「InCites」(Web of Science)に基づき、2013-2017の5か年に出版された天文学・宇宙物理学分野の論文(article,review)を分析(2019年7月)。「日本全体」は、著作住所に日本を含む論文を抽出。

＜産業等への波及＞

- ○ 産業界と連携した最先端の研究装置開発により、イノベーションの創出にも貢献
  （事例）・【すばる望遠鏡】超高感度カメラ技術⇒**医療用X線カメラへの応用**
  ・【放射光施設】加齢による毛髪のハリ・コシの低下が毛髪内の亜鉛と関係性を解明⇒亜鉛を毛髪に浸透させる**新しいヘアケア技術の開発・製品化に成功**

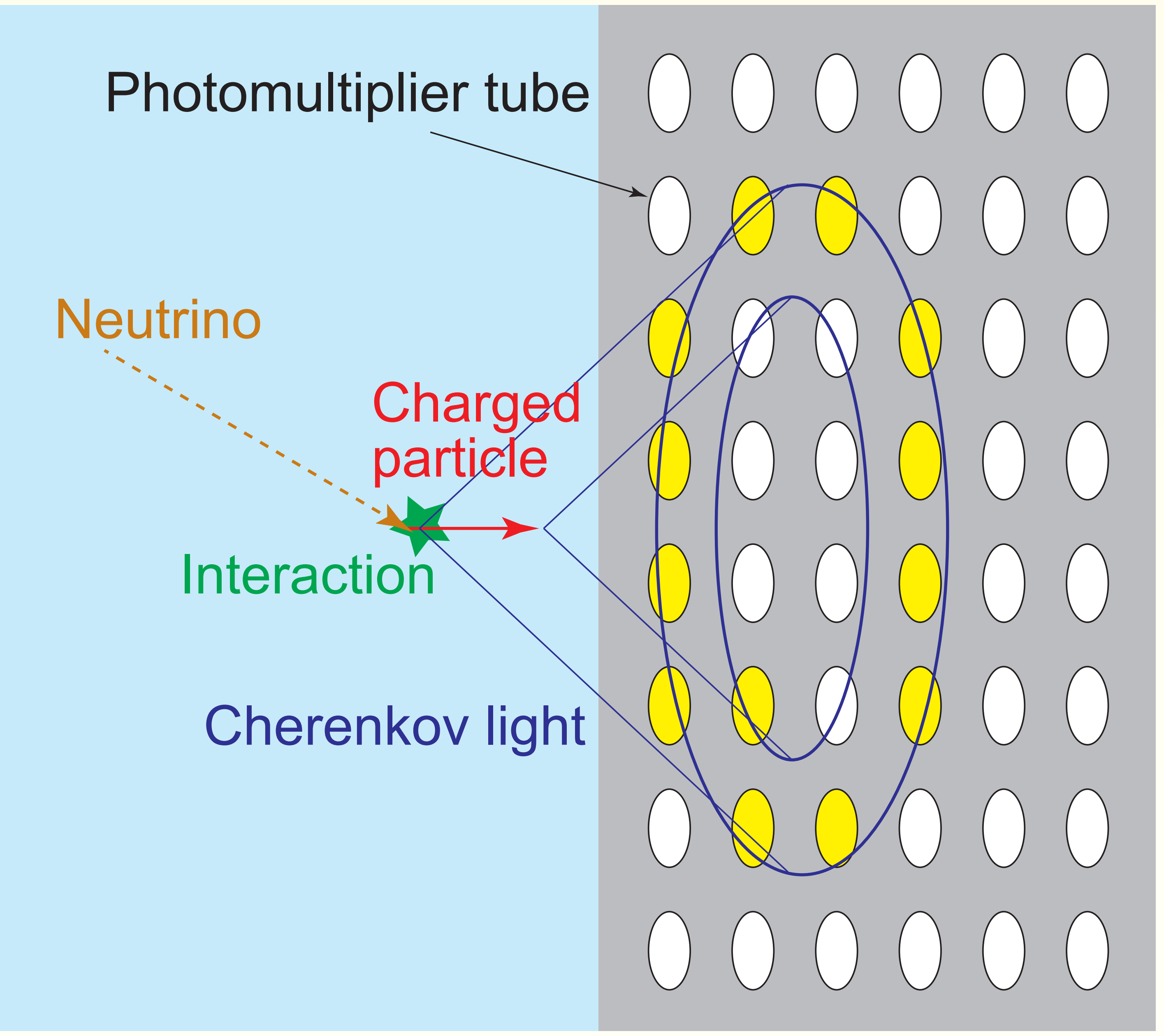
- Construction started from early 2020
- **Start operation from JFY2027**

KamiokaNDE experiments

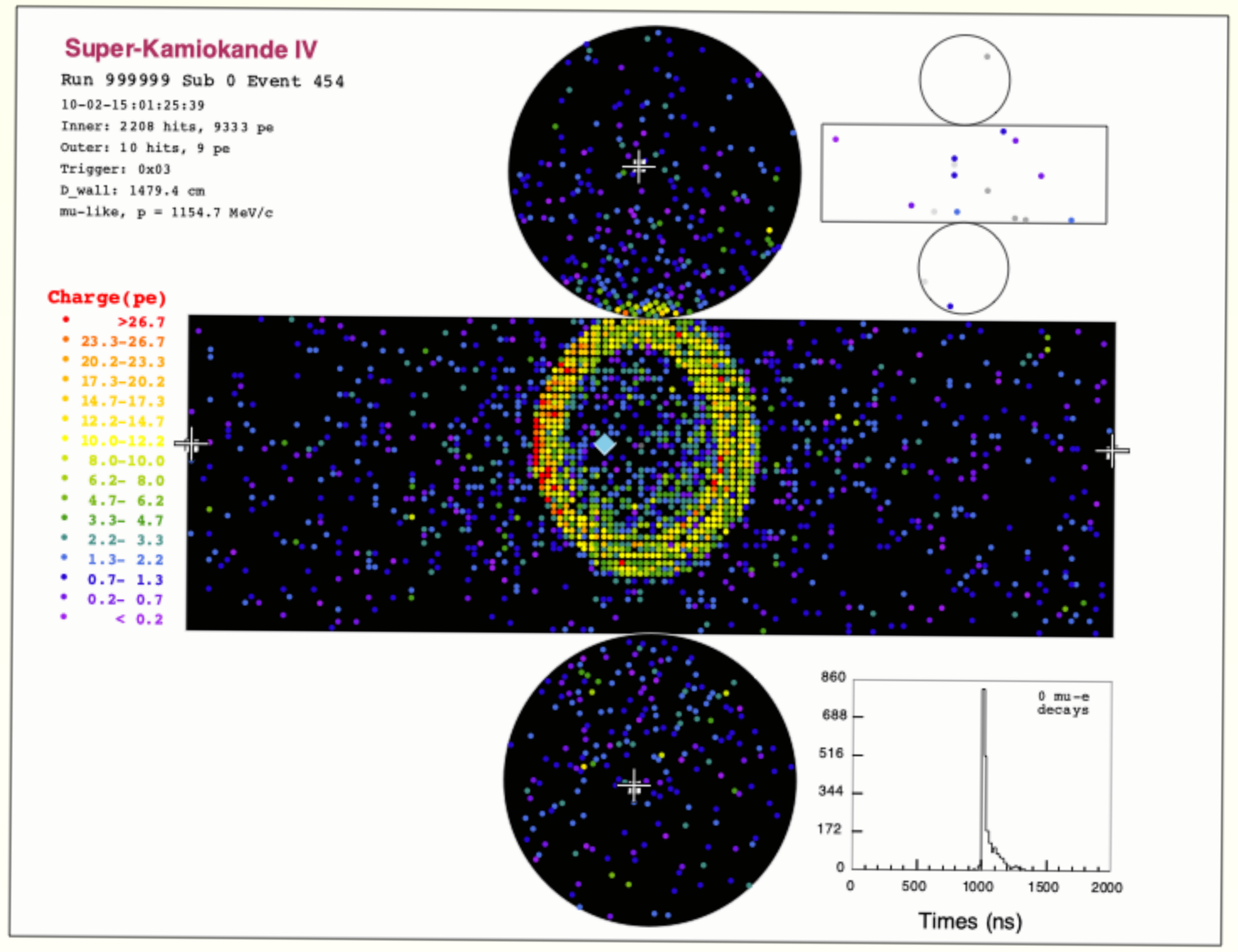


NDE = Nucleon Decay Experiment, or Neutrino Detection Experiment

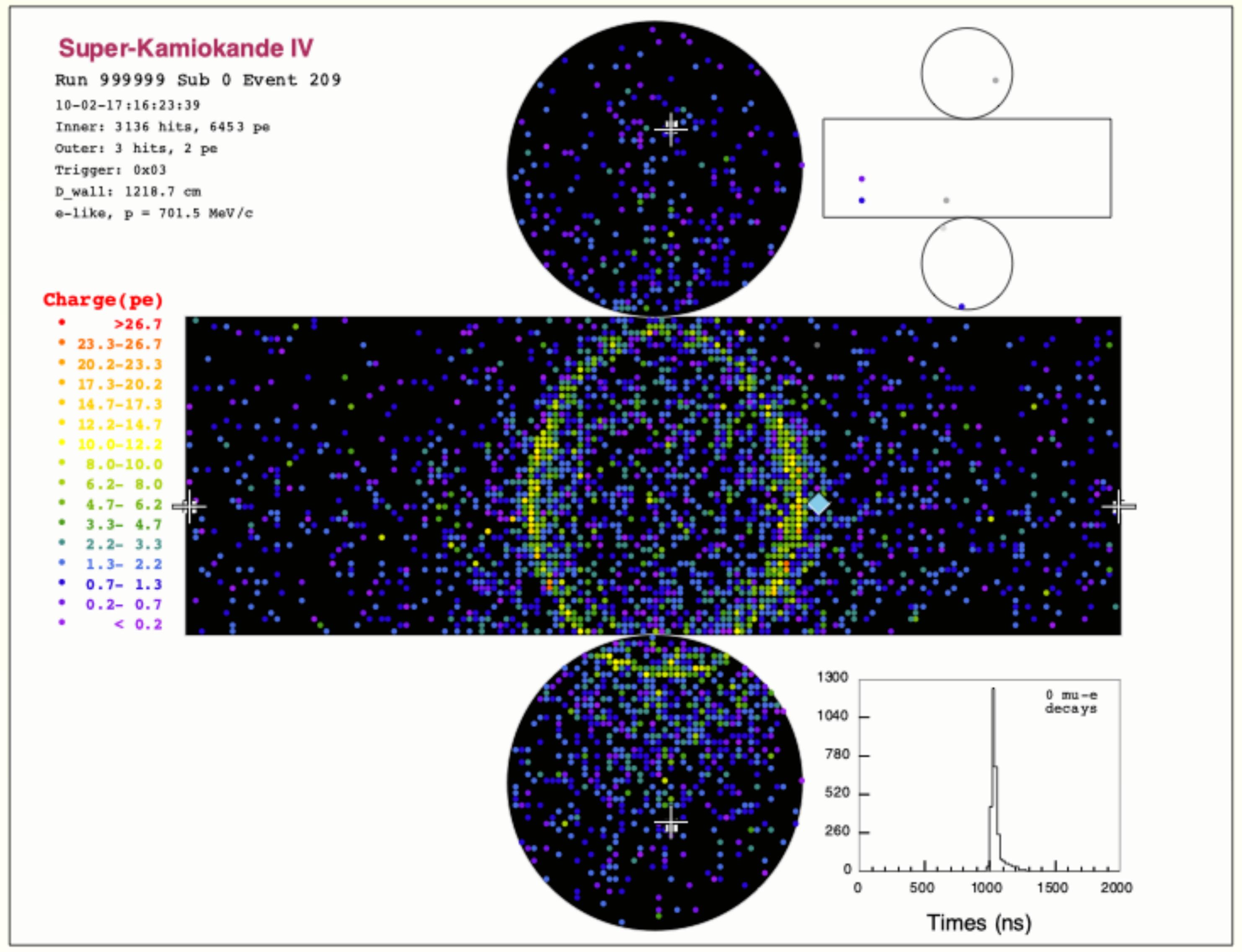
Water Cherenkov detector



μ-like (sharp ring)

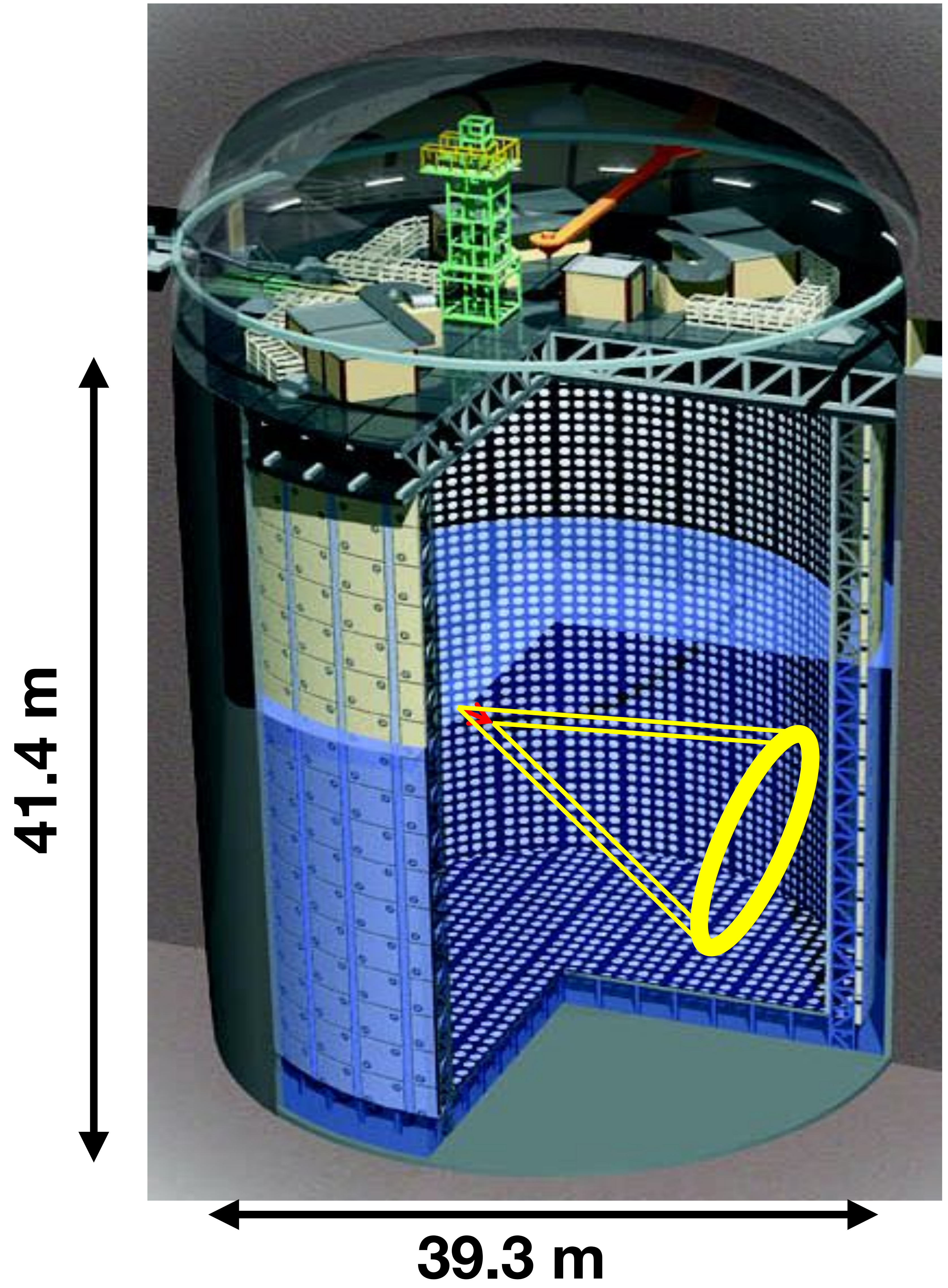


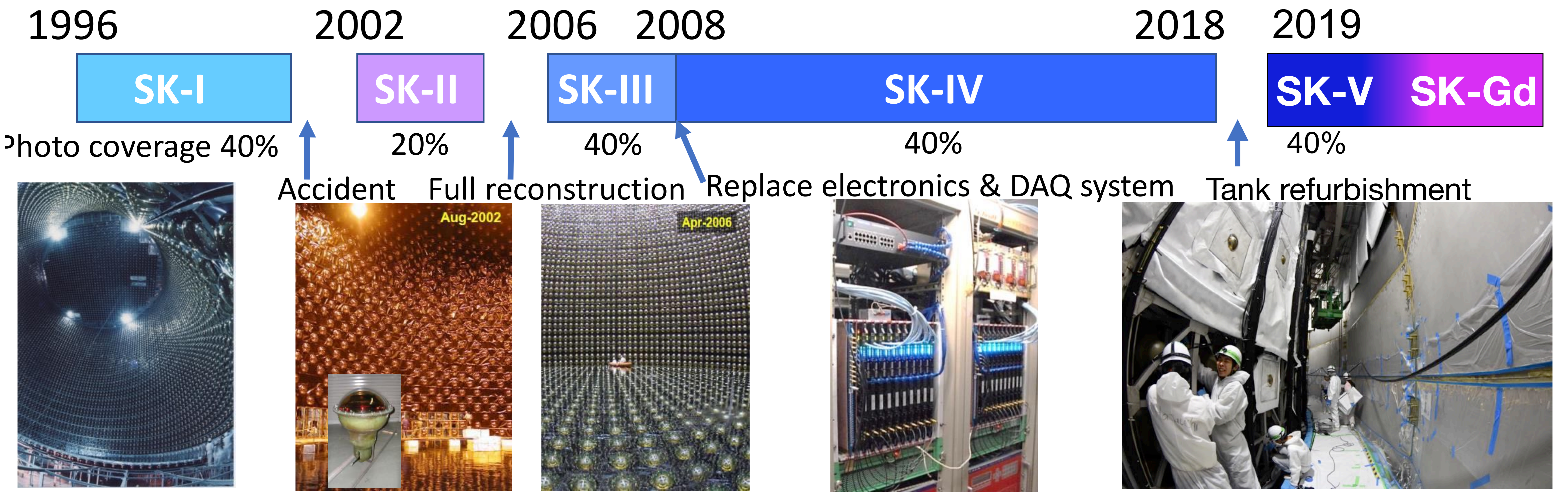
e-like (fuzzy ring)



- Particle detection/reconstruction using Cherenkov rings
  - Measurement of energy, direction, vertex from ring patterns
  - Particle identification (<1% misidentification probability for e/μ)
  - 4π uniform coverage with real time information
  - Wide energy range: ~3MeV to 100GeV-TeV (SK)
- Scalable to larger mass, well established technology

Super-Kamiokande





1998: Discovery of atmospheric ν oscillation

2001: Discovery of solar ν flavor change (with SNO)

2004: Accelerator ν oscillation evidence by K2K

2011: Discovery of ν_e appearance by T2K

2012: ν_τ appearance in atmospheric ν

2014: Indication of day/night effect in solar ν

World-leading discoveries over >20 years

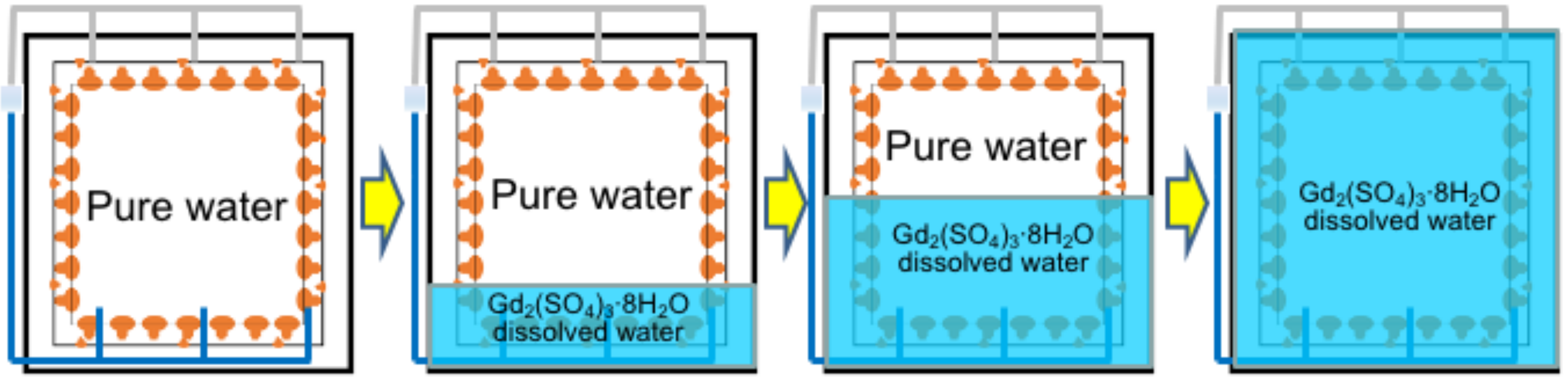
…and, <u>still evolving</u>!

Preparation work for upgrade in 2018-19

SK-Gd has started!

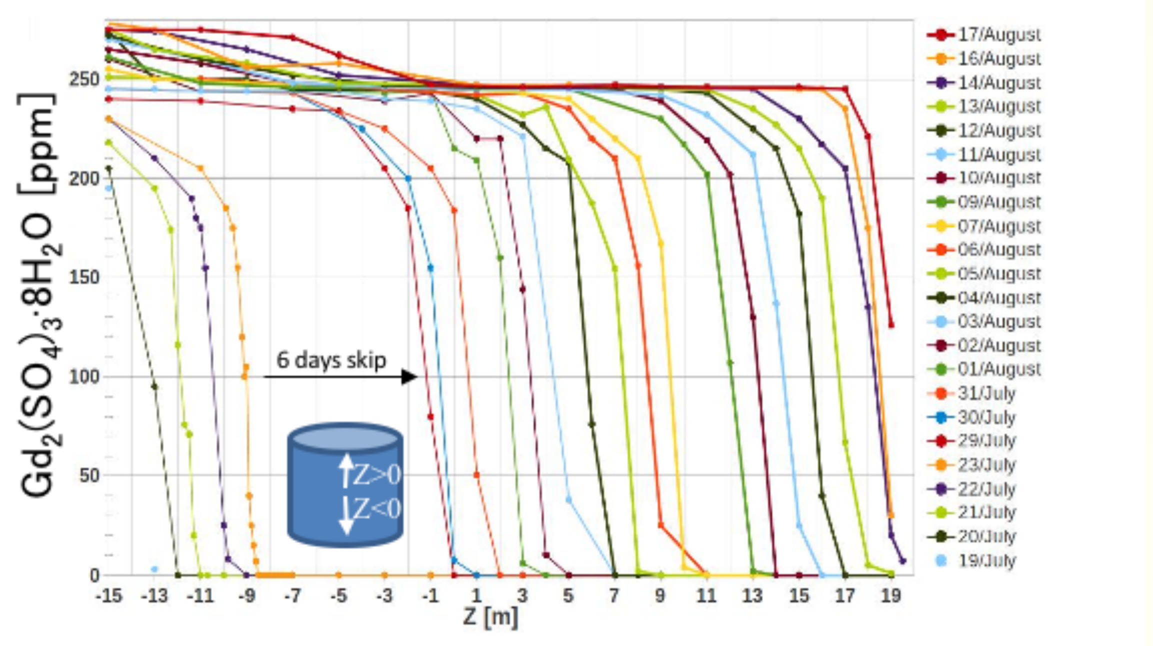
New water system
for Gd-doped water

Introduced Gd-doped water from bottom



making 0.3°C temperature difference

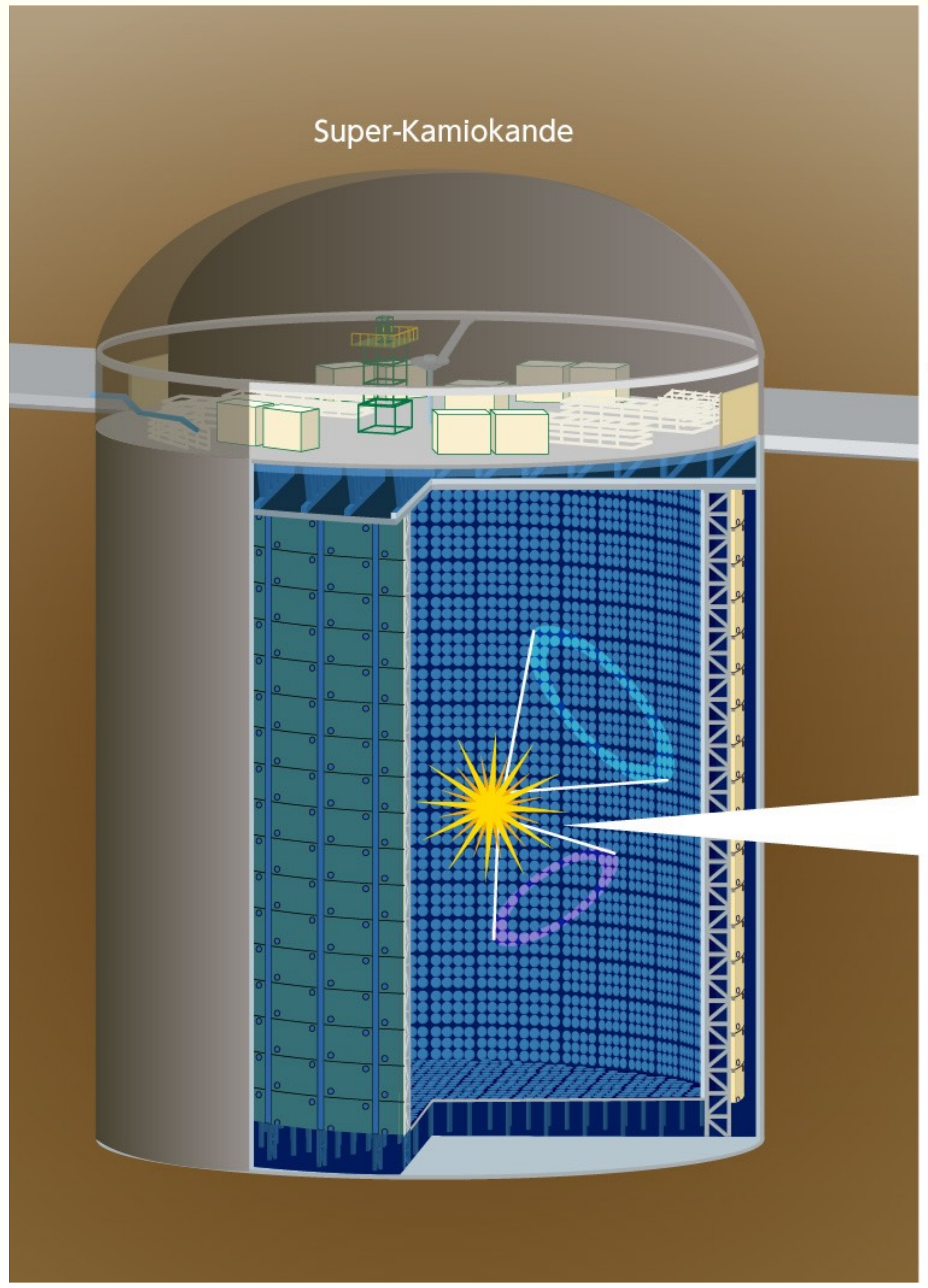
July 14-August 17, 2020



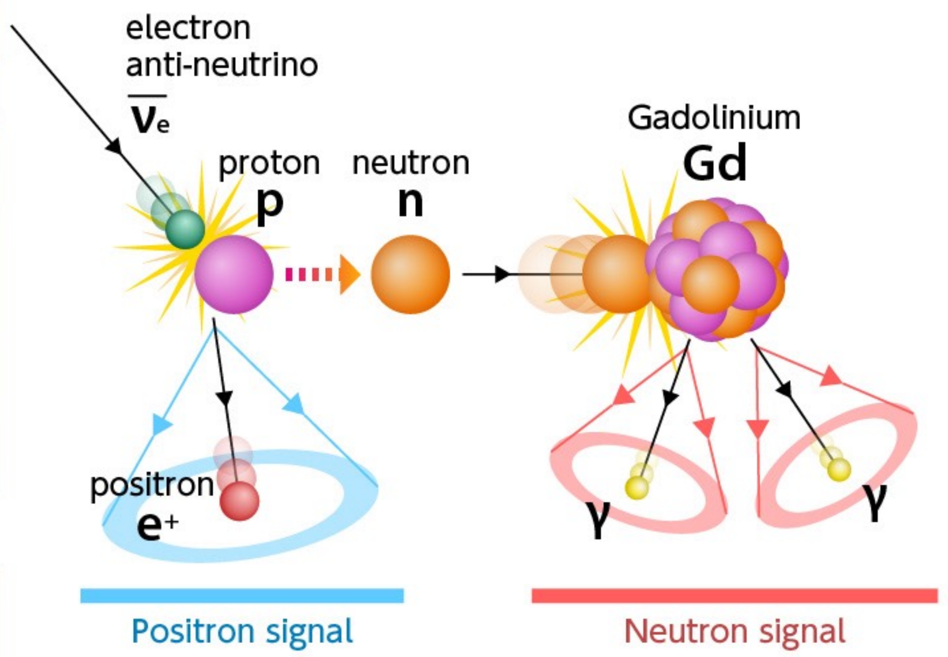
Rich physics program by much improved neutron tagging

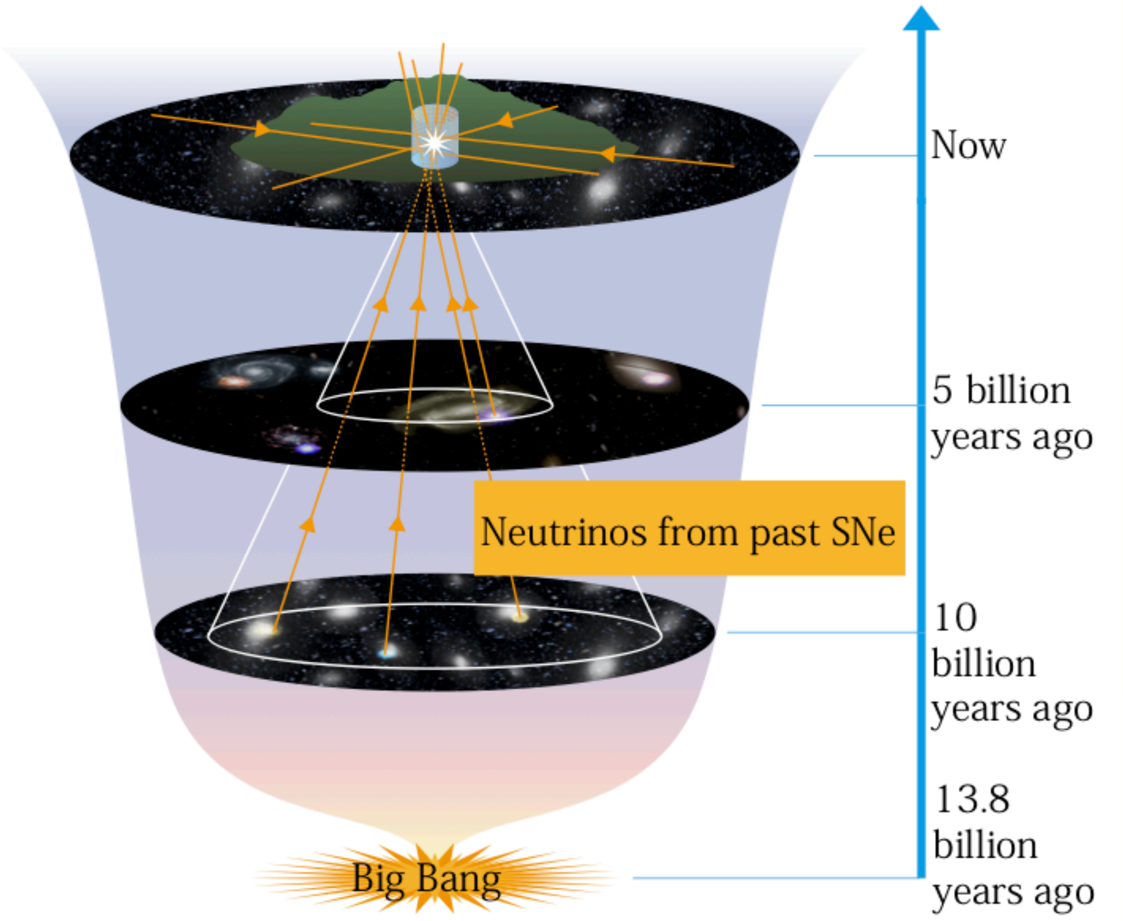
$Gd_2(SO_4)_3 \cdot 8H_2O$

13 ton was dissolved
(0.01% Gd,
50% n-capture eff.)



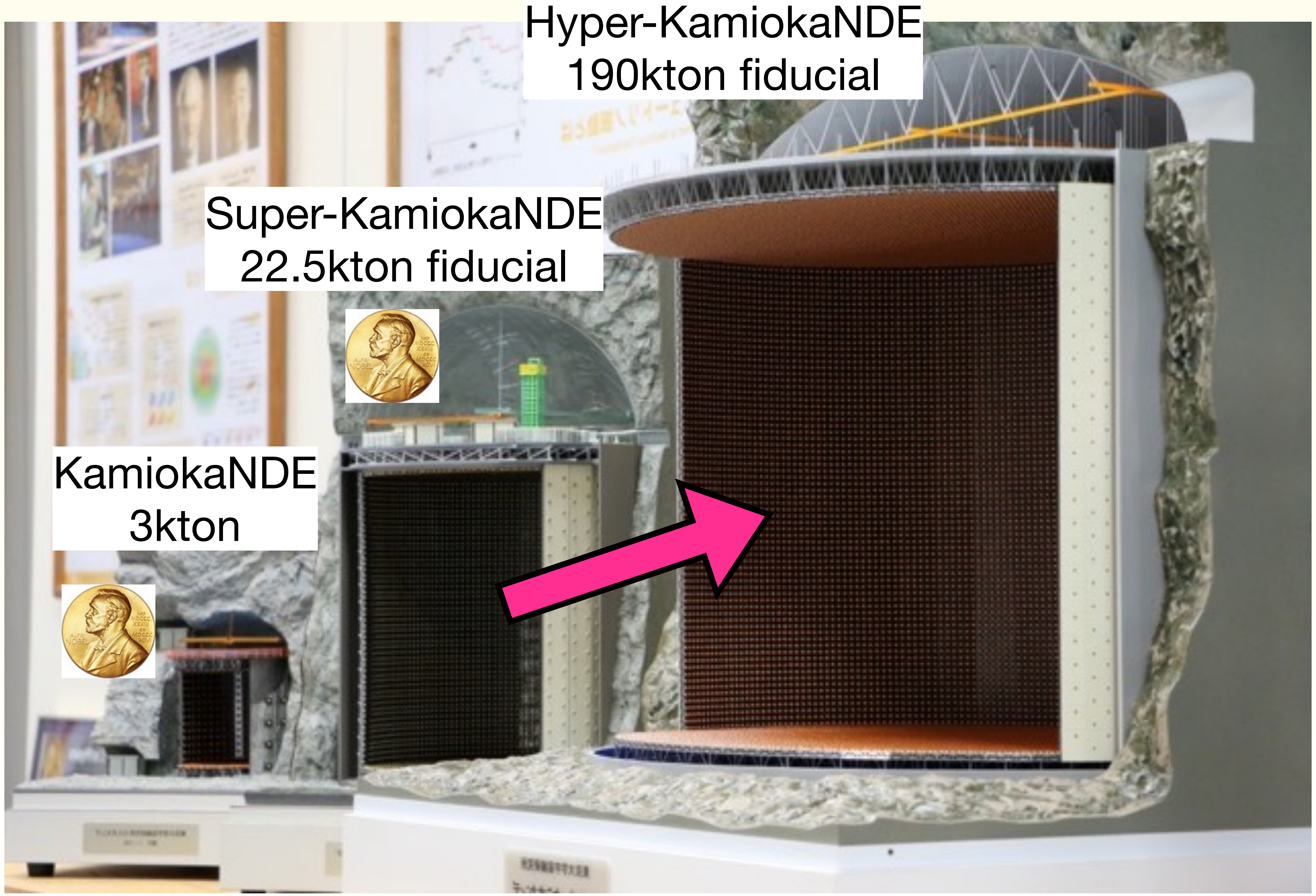
ex. Observation of relic supernova neutrinos



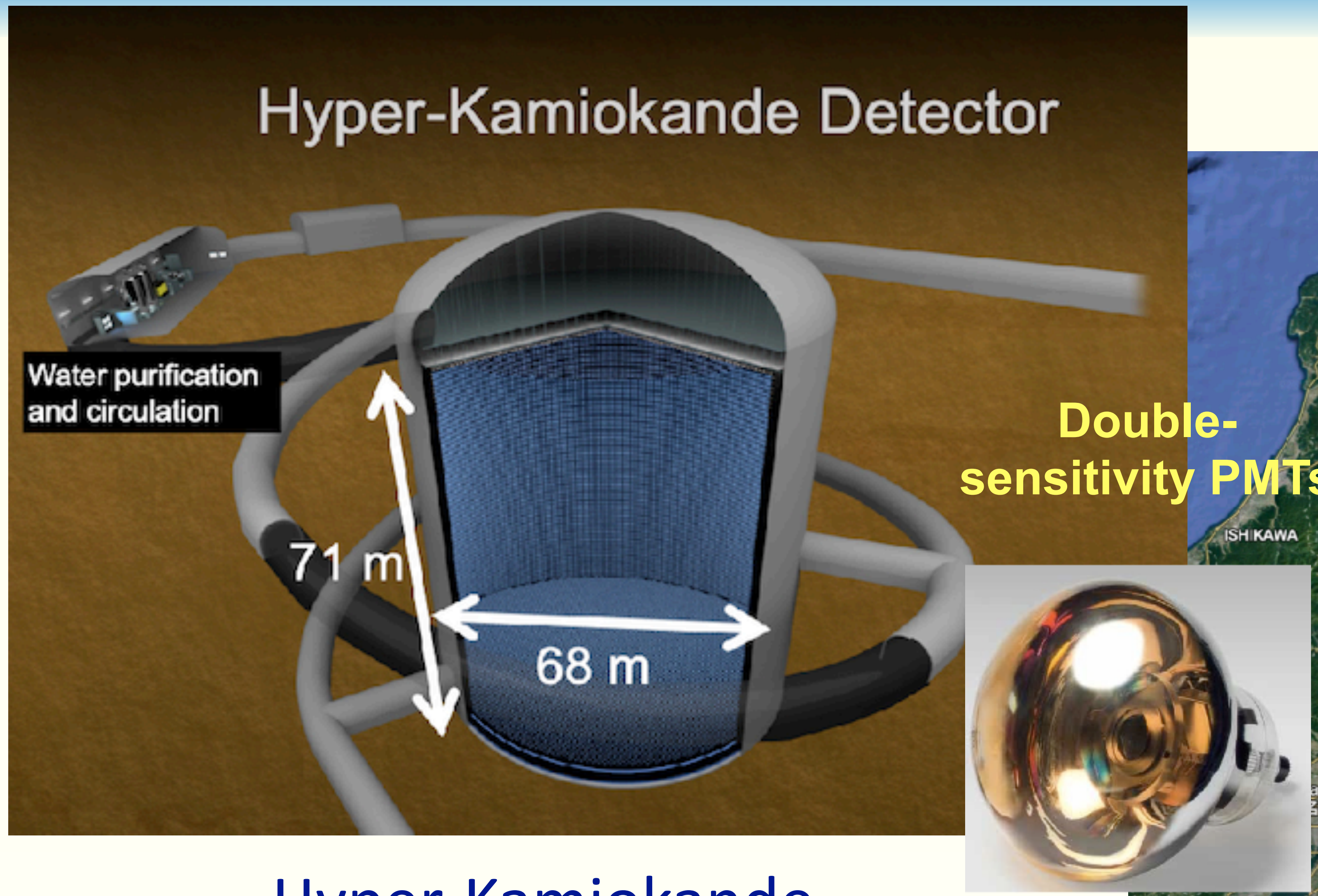


Extends capability even after >20 years of operation
Great potential of water Cherenkov detector

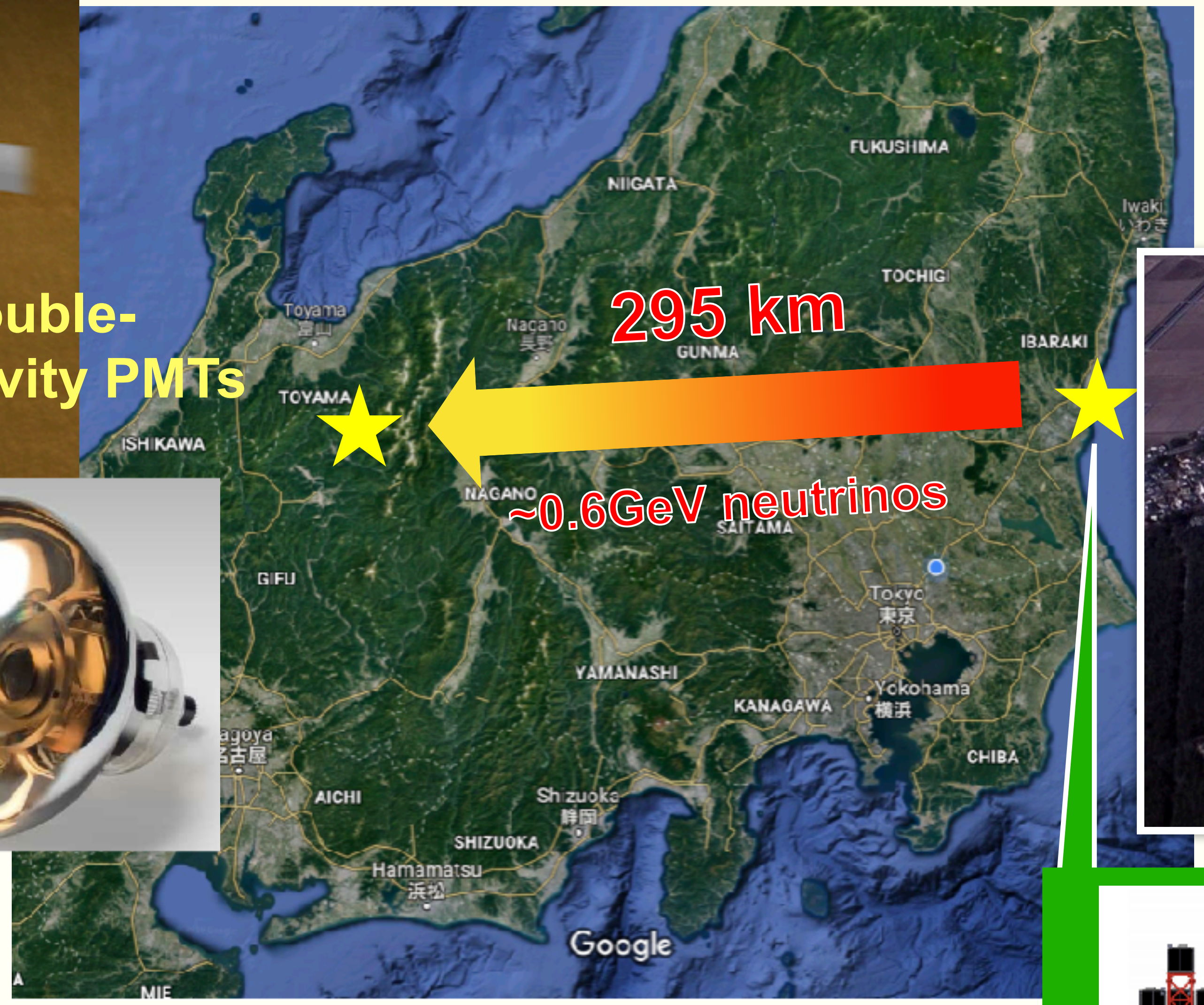
From Super-K to Hyper-K



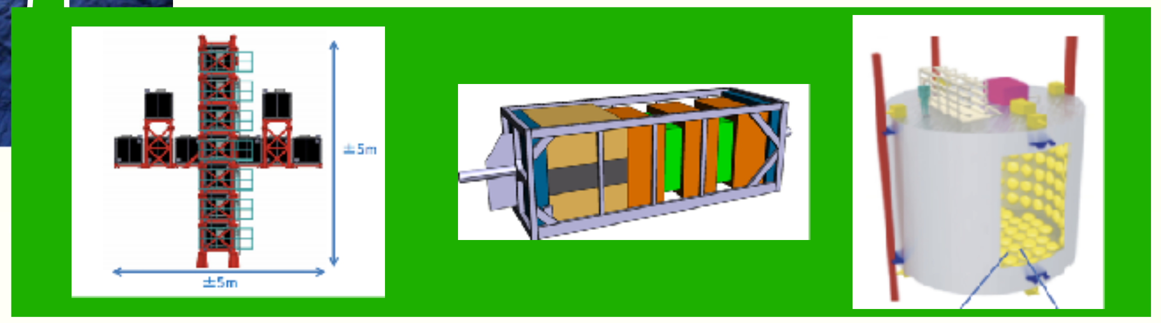
Hyper-Kamiokande Project



Hyper-Kamiokande
(hosted by The University of Tokyo)



High power proton beams
J-PARC
(hosted by KEK)

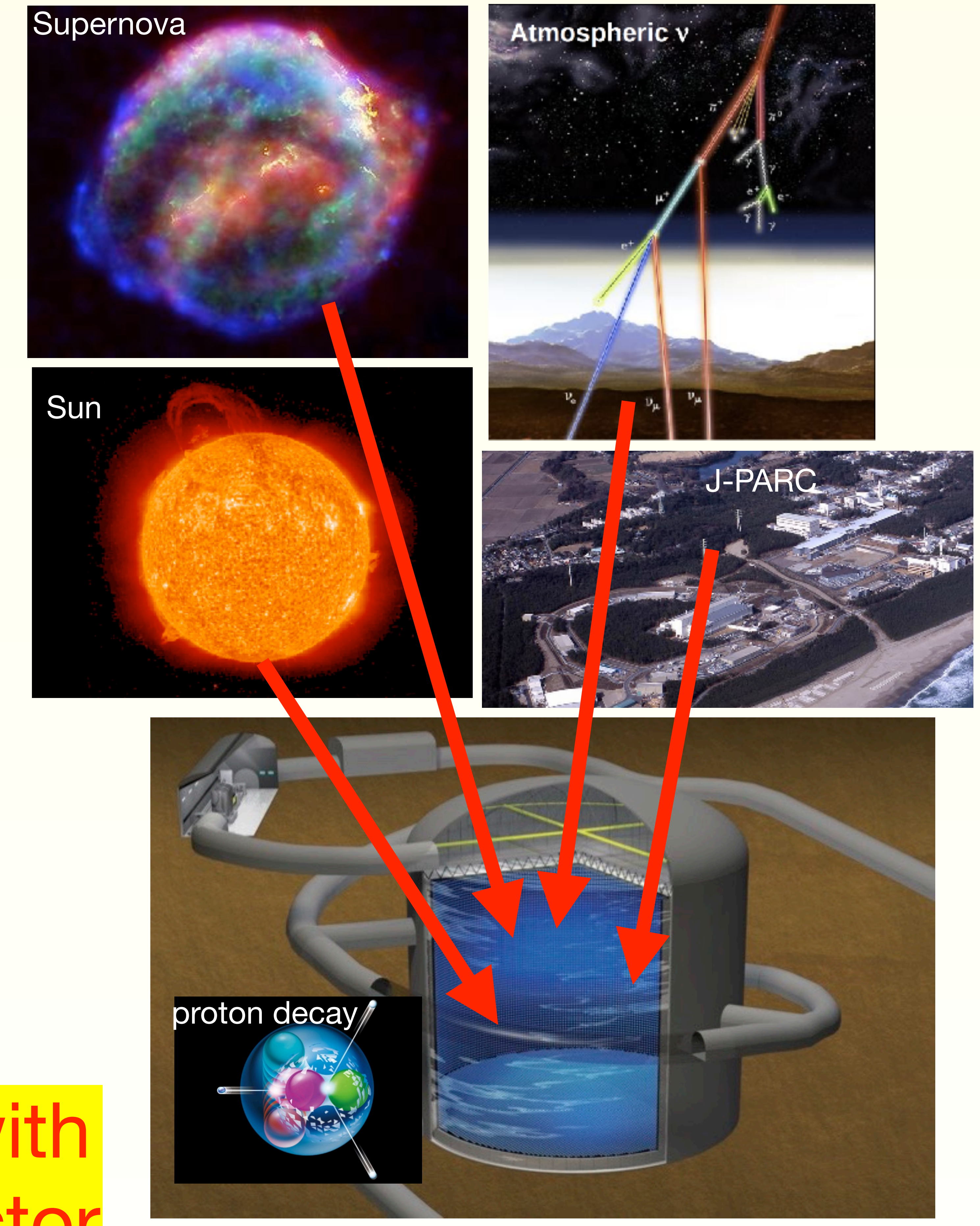


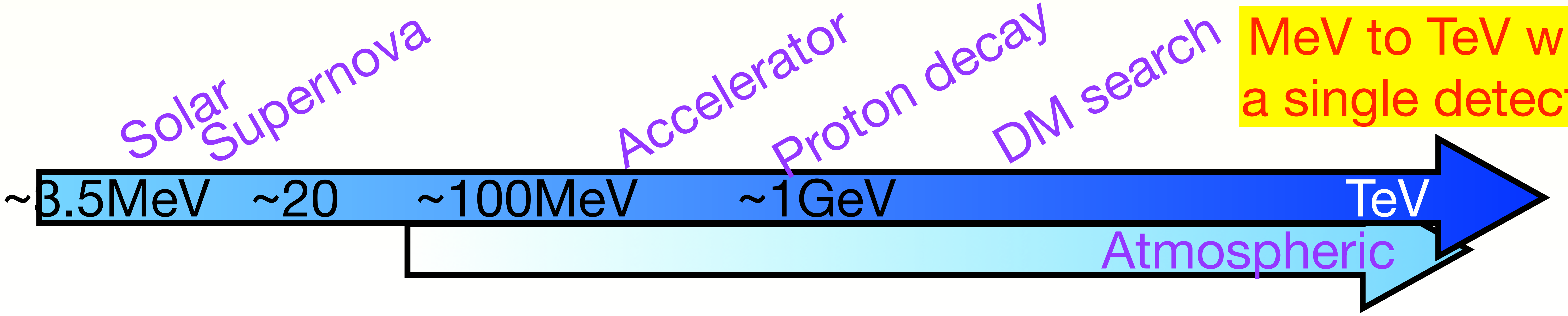
1. Hyper-K detector to be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and to be instrumented with **double-sensitivity PMTs**.
2. J-PARC neutrino beam to be **upgraded from 0.5 to 1.3 Mega Watt**
   - **x8** Natural Neutrino Rate and **x20** Accelerator Neutrino Rate
3. New and upgraded near detectors to control systematic errors

<u>Long baseline experiment and non-accelerator physics in a single project</u>

Broad science program with Hyper-K

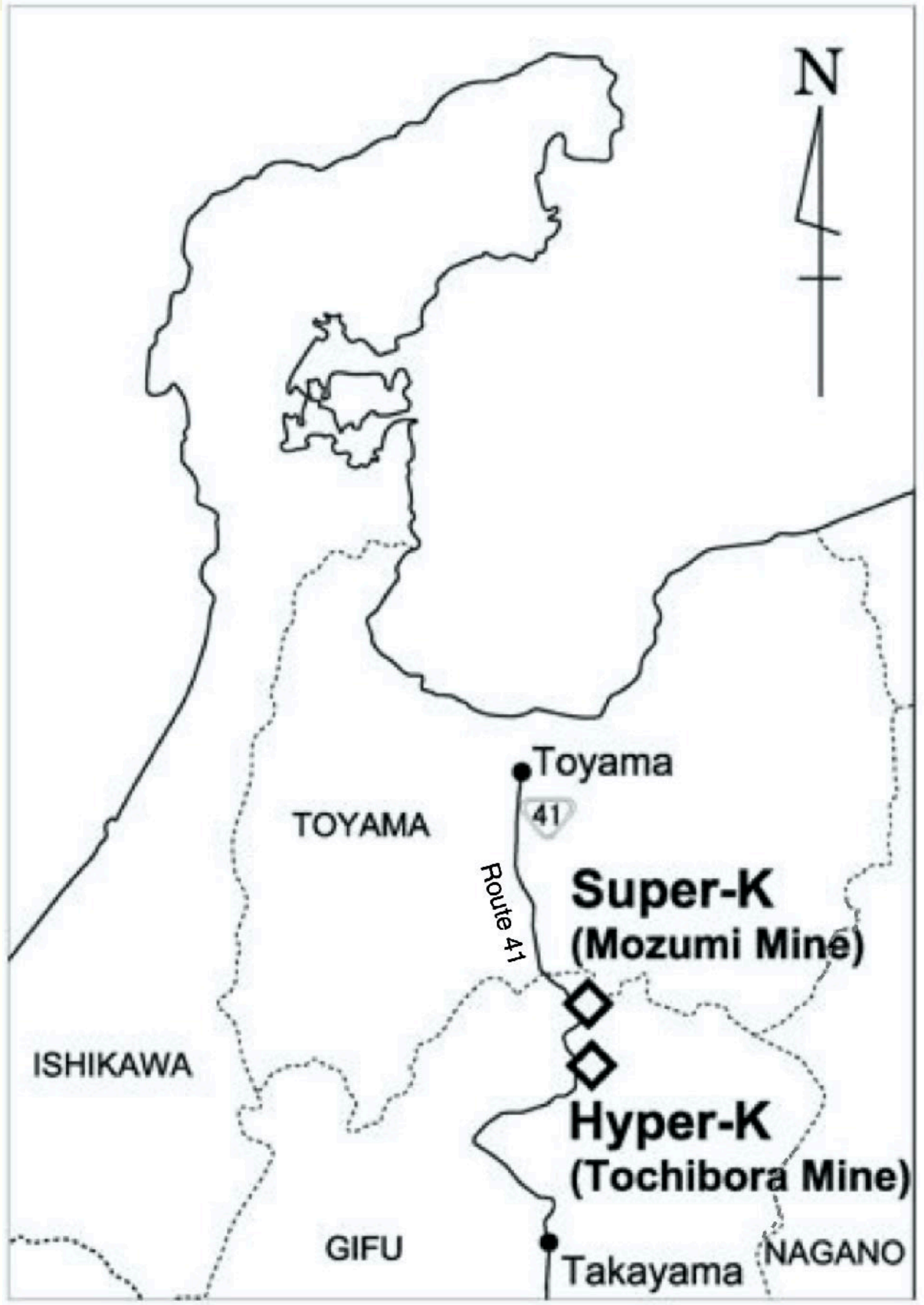
- Neutrino oscillation physics
  - Comprehensive study with beam and atmospheric neutrinos
- Search for nucleon decay
  - Possible discovery with ~×10 better sensitivity than Super-K
- Neutrino astrophysics
  - Precision measurements of solar ν
  - High statistics measurements of SN burst ν
  - Detection and study of relic SN neutrinos
- Geophysics (neutrino oscillography of interior of the Earth)
- Maybe more (unexpected!?)

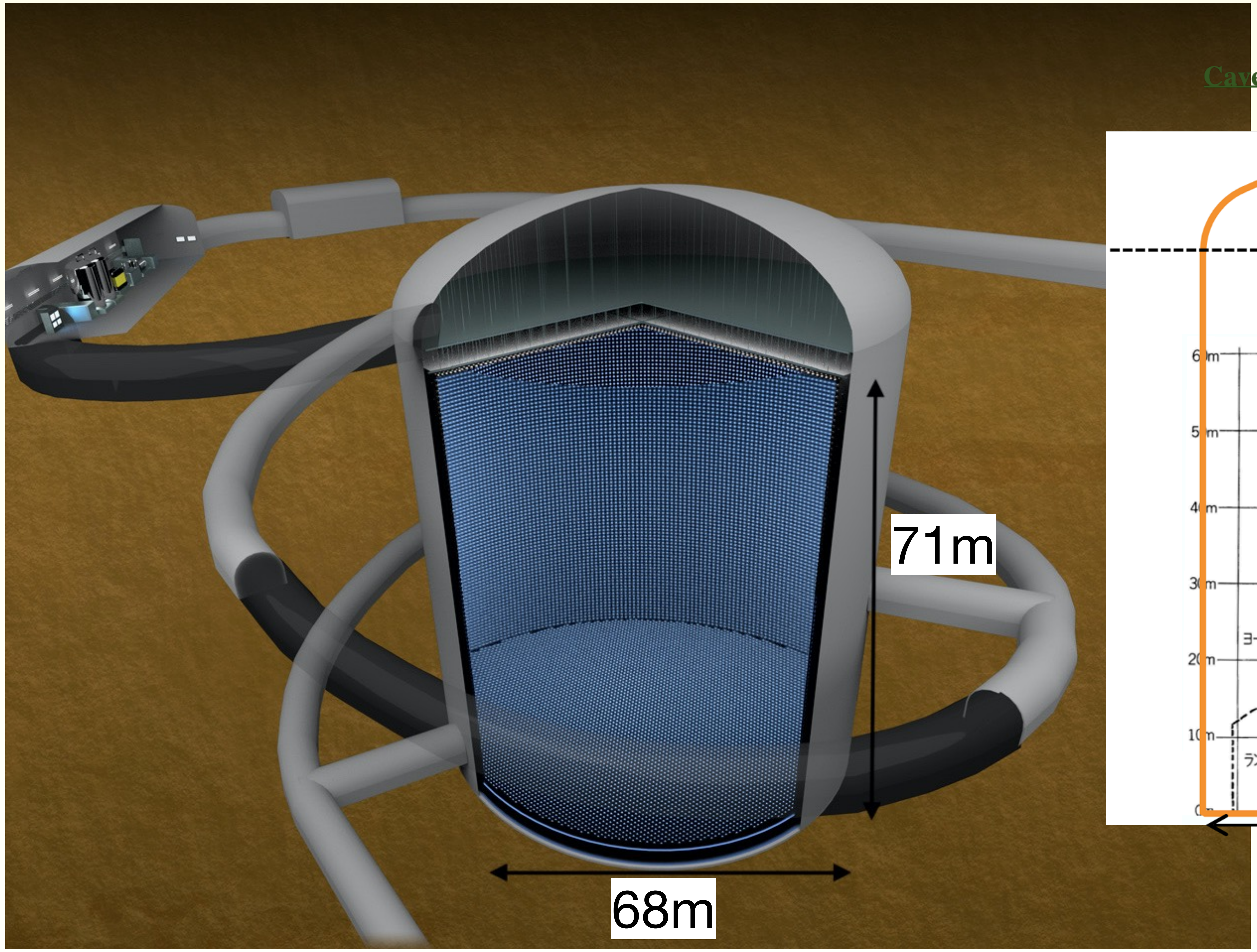


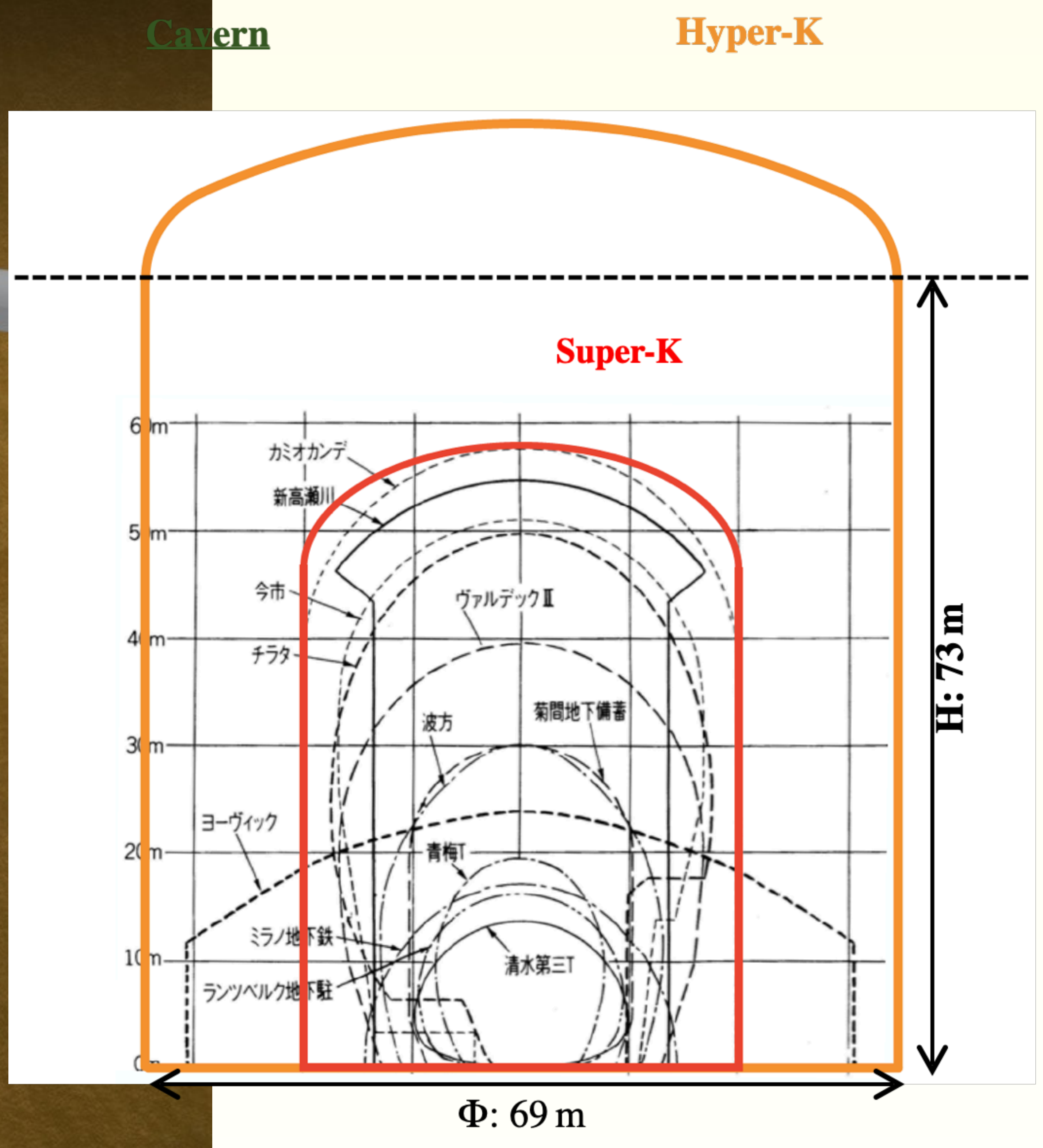


MeV to TeV with a single detector

The Hyper-Kamiokande detector







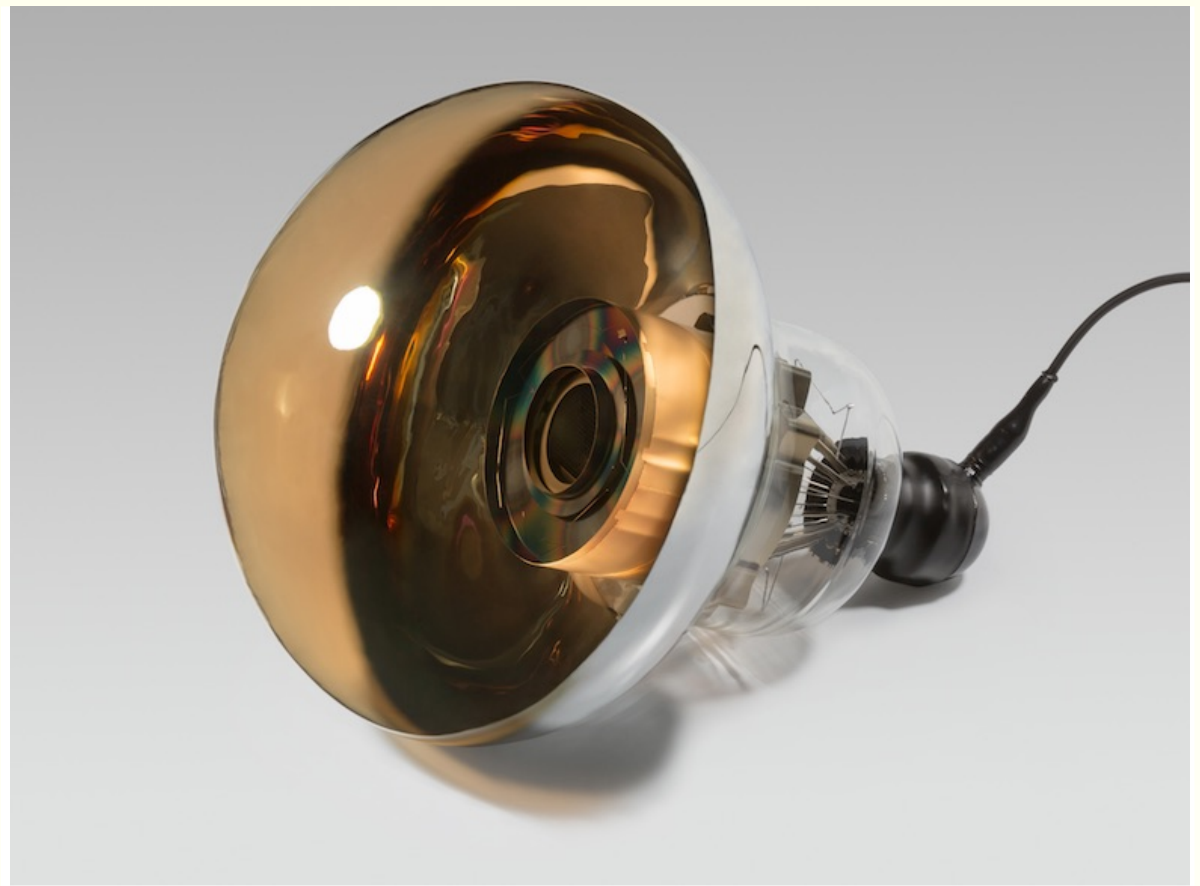
~8km south of Super-Kamiokande

260kton total water mass
190kton fiducial mass

NOT just a larger version

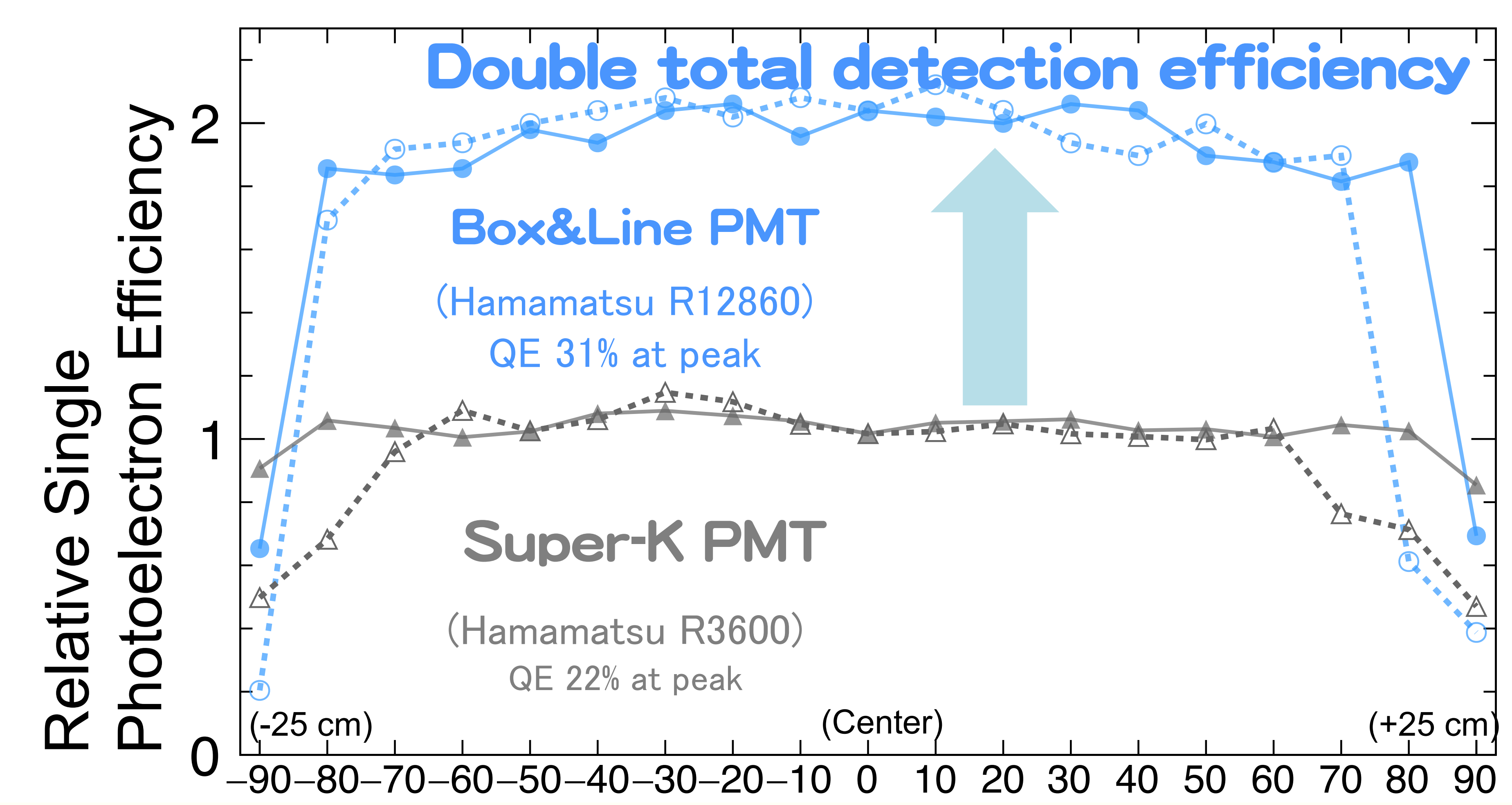
(Performance in SK tank, 1.7e7 gain)

Hamamatsu R12860

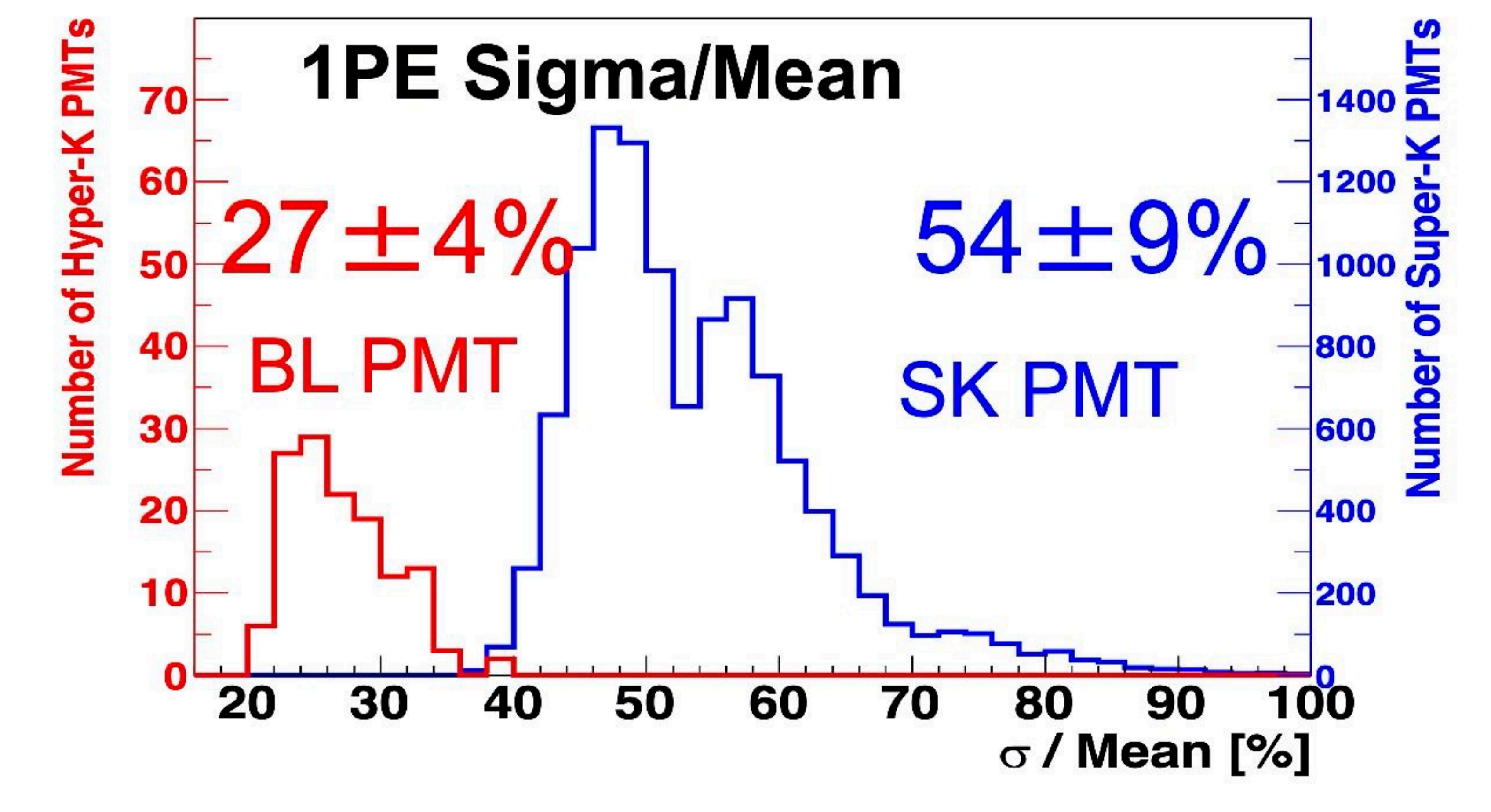


Newly developed for HK

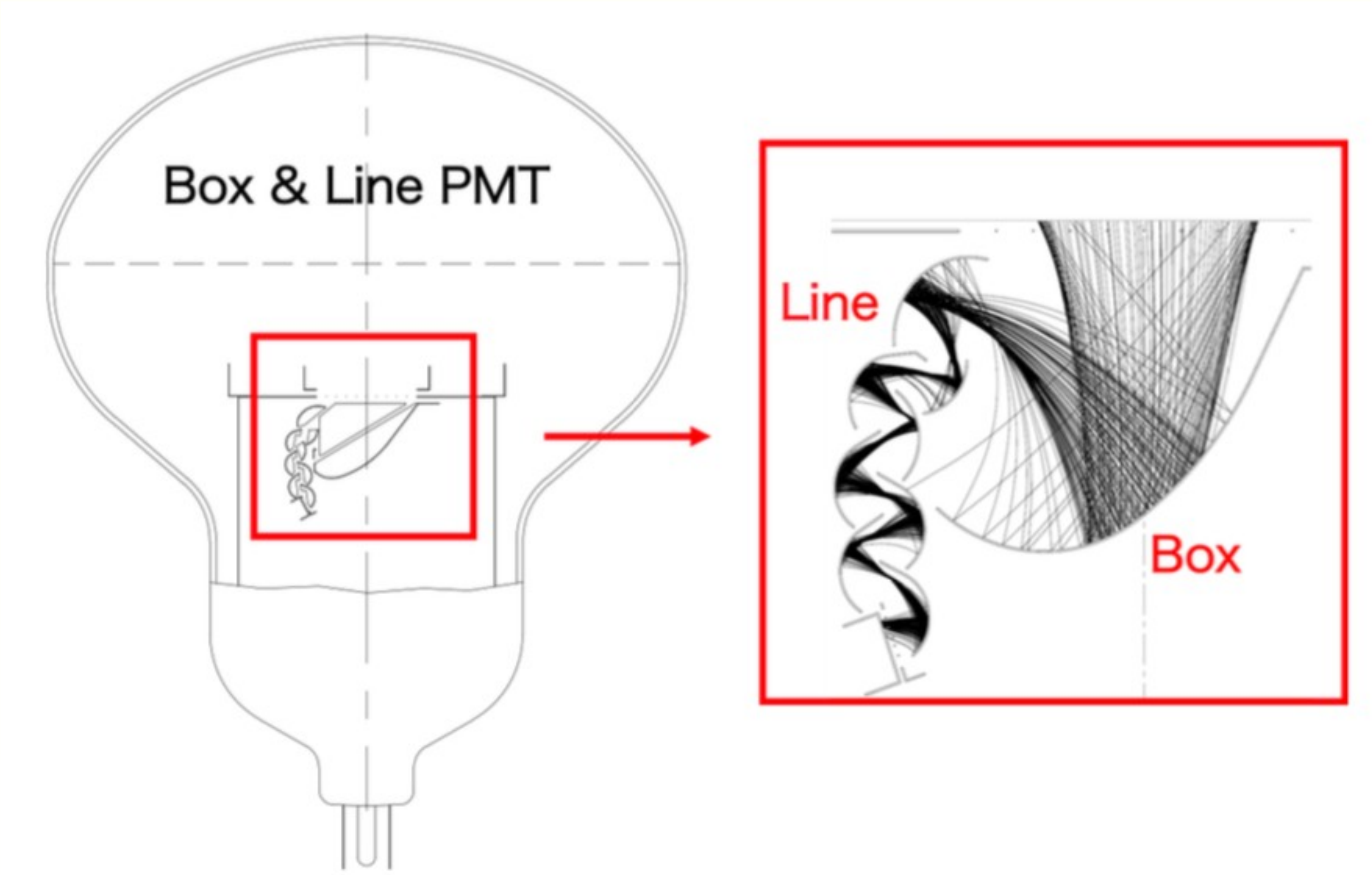
×2 better photodetection efficiency (QE×CE)



×2 better charge resolution



Box&Line dynode

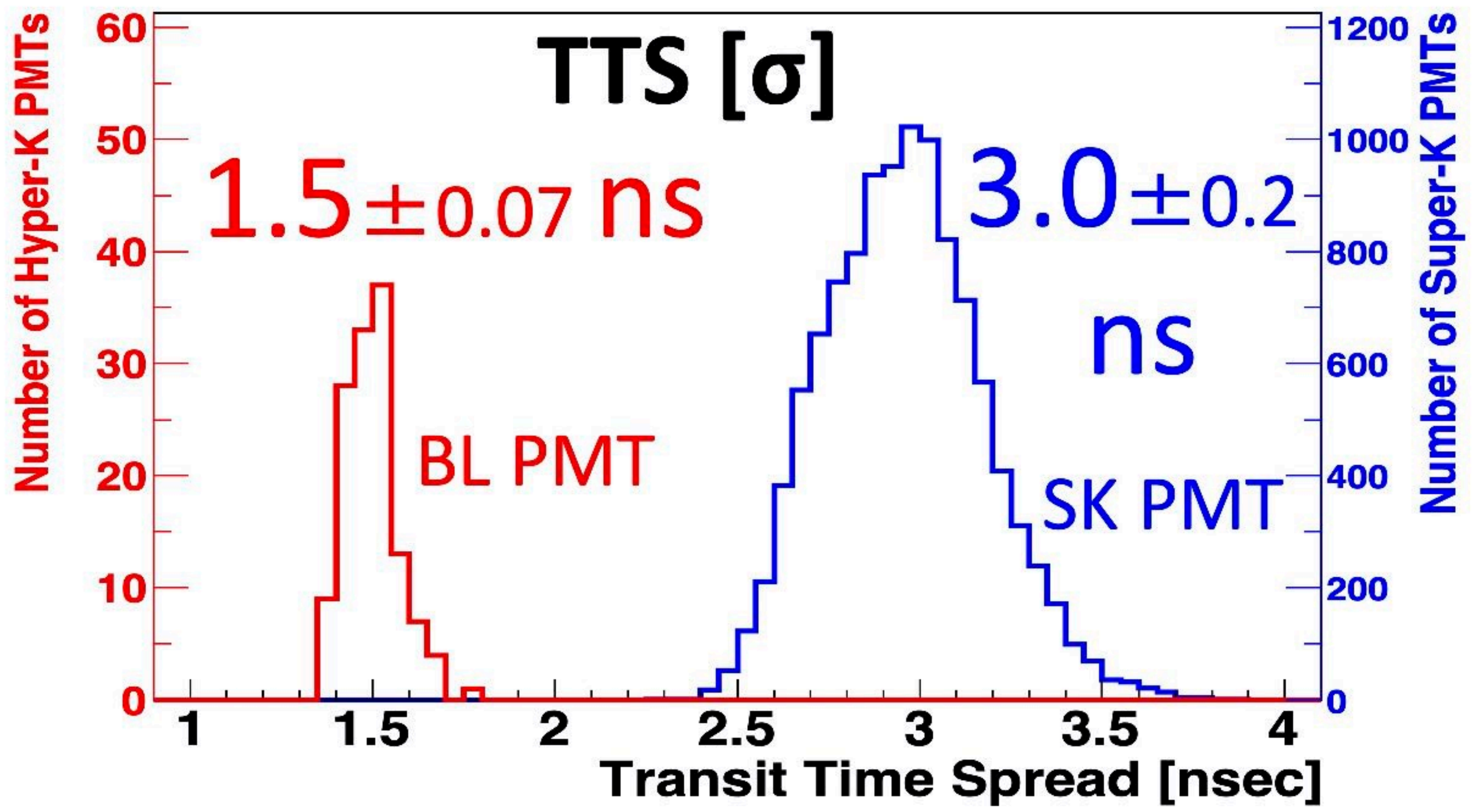


×2 better pressure tolerance
→ enable taller tank, design optimization

All PMTs will be tested >0.85MPa

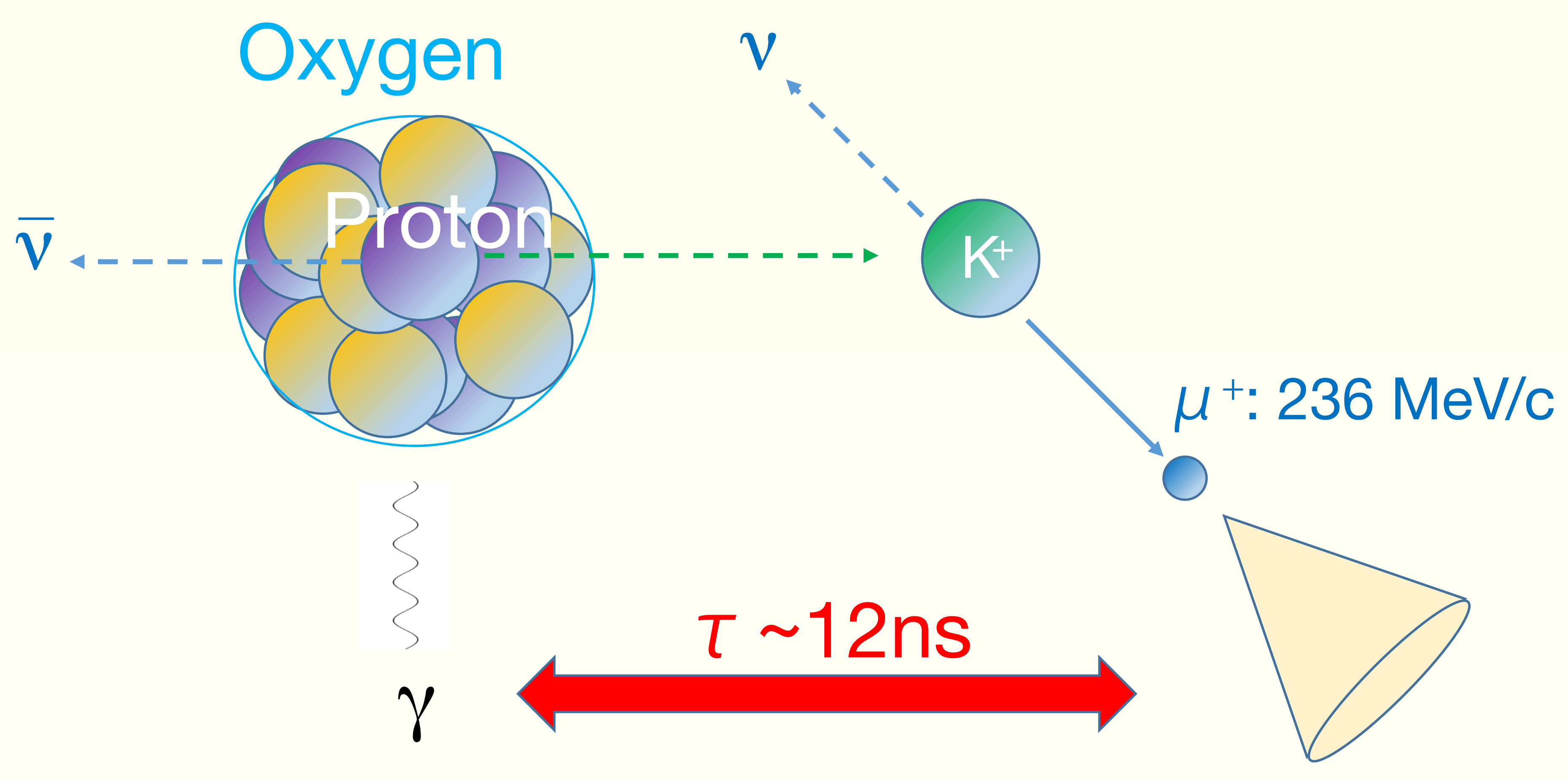
Low dark rate (4kHz) and RI

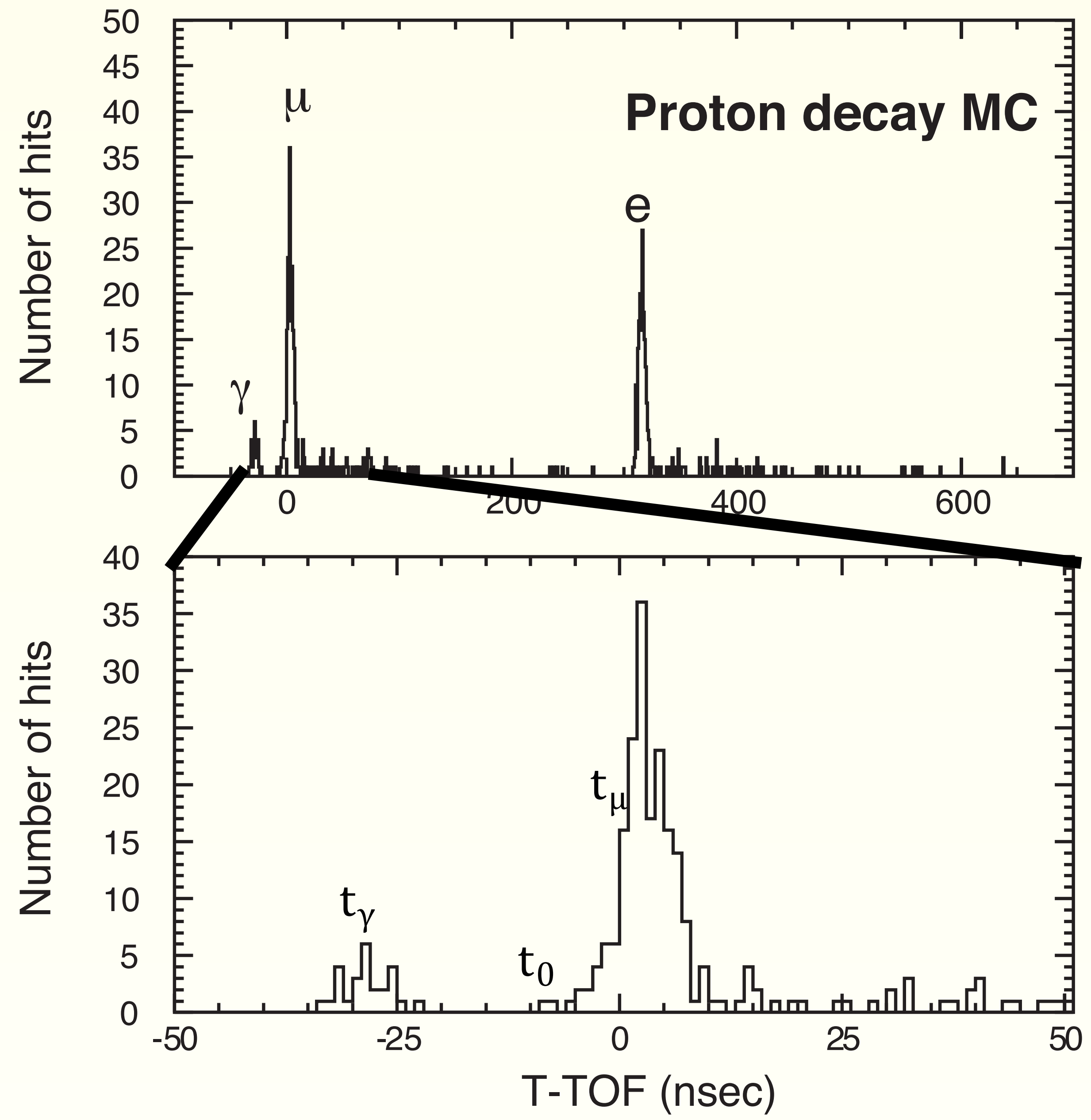
×2 better timing resolution



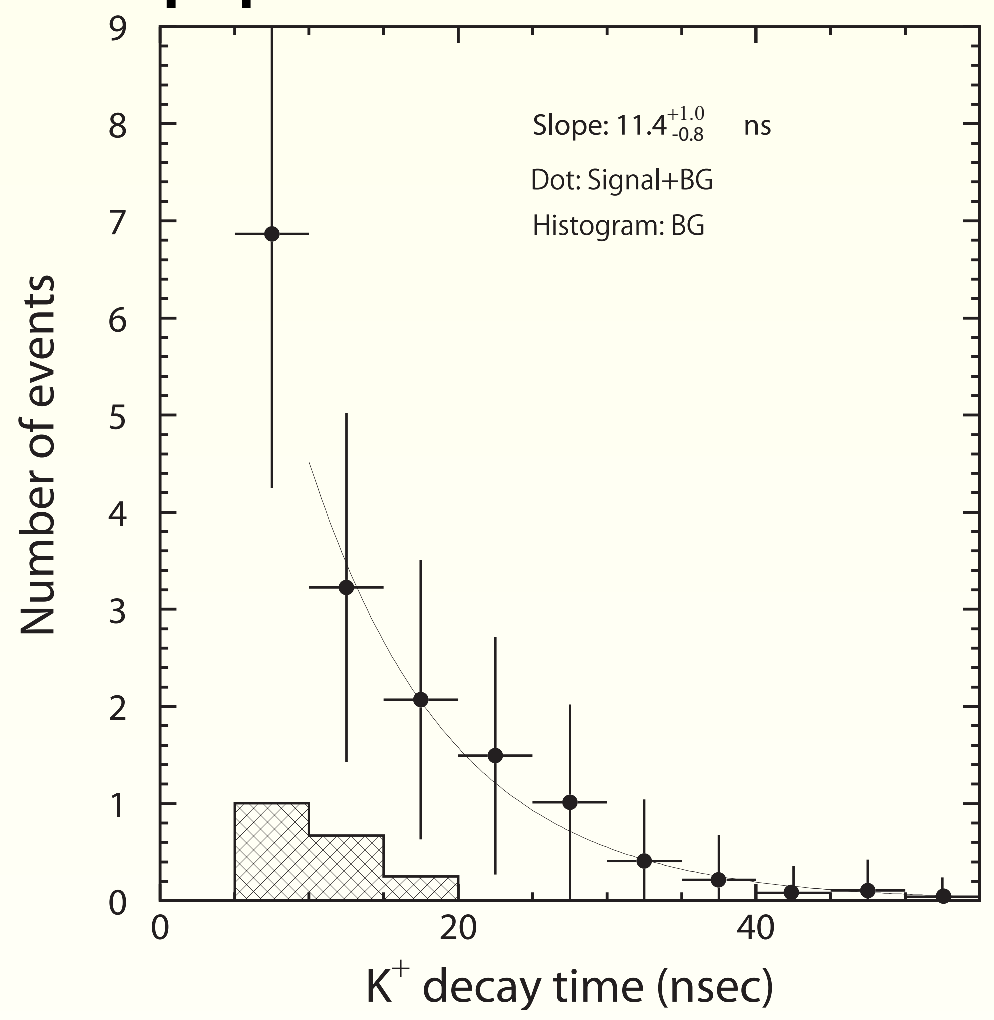
Improvement by the new PMT

Example: $p \to \bar{\nu} K^+$, $K^+ \to \mu^+ \nu$





γ-μ time difference

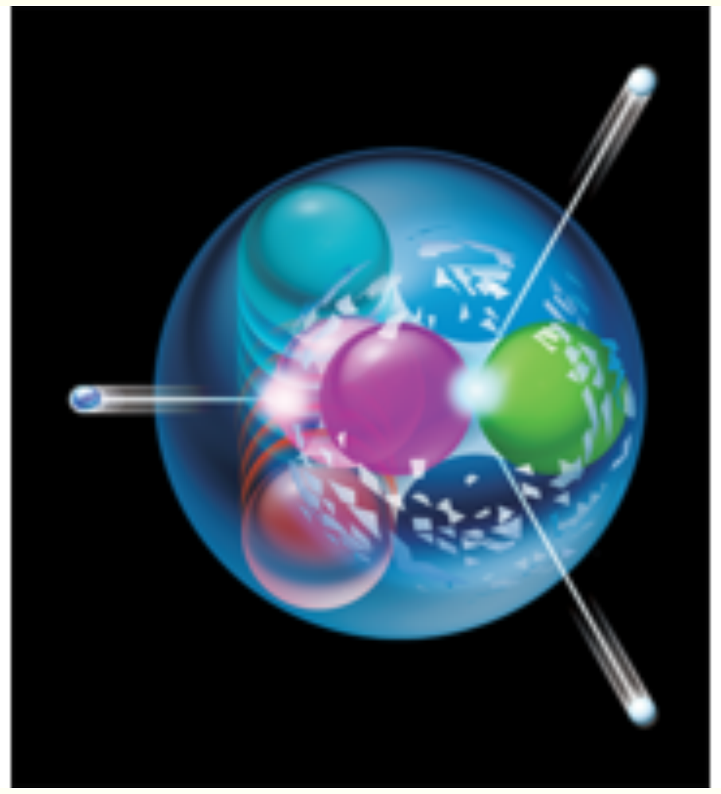


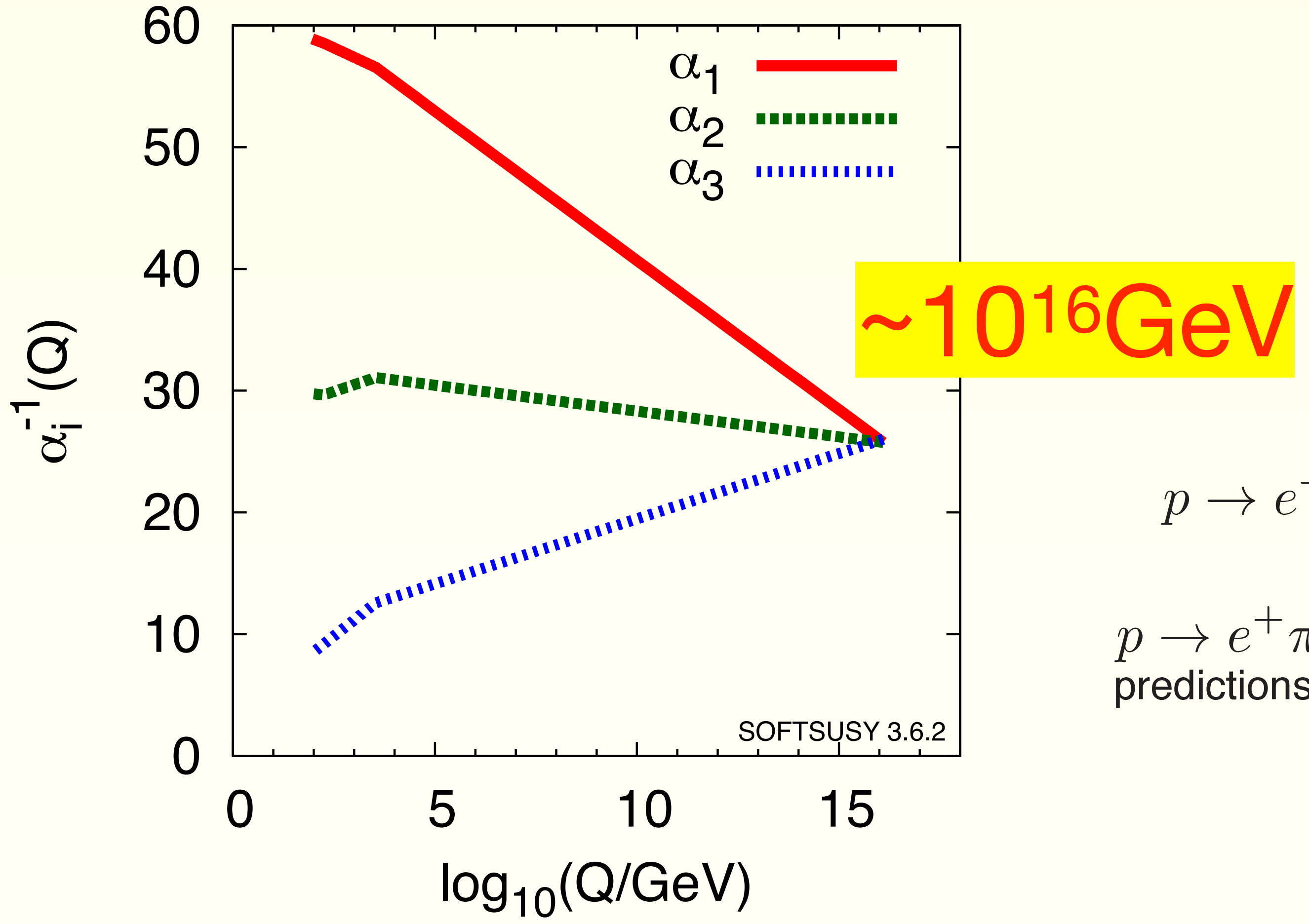
- K^+ (340MeV/c) is below Cherenkov threshold
- $K^+ \to \mu^+ \nu$ (64%) : 236MeV/c μ^+ can be detected (with decay-e)
- Suppress background by tagging a 6MeV γ from nuclear de-excitation
  - γ and μ signal separated by τ_{K+}~12ns
  - Better separation with better timing resolution

→ better efficiency (SK4: 9.1% → HK: 12.7%)

Finding evidence of GUT

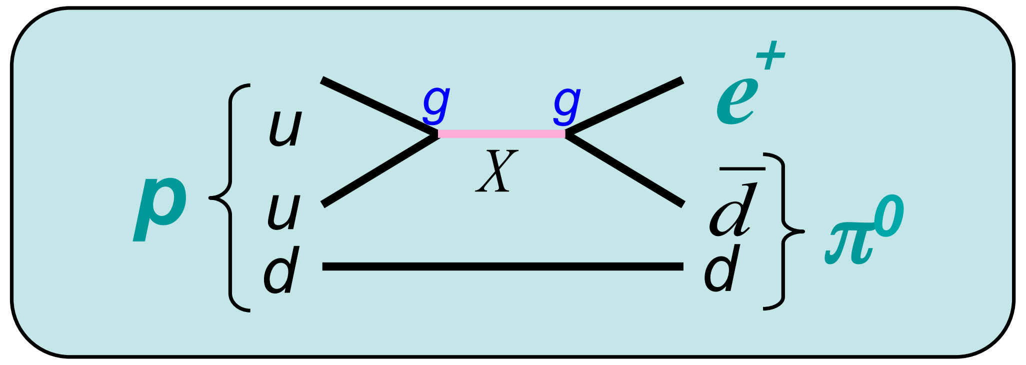
Nucleon decay!





Two modes as benchmark

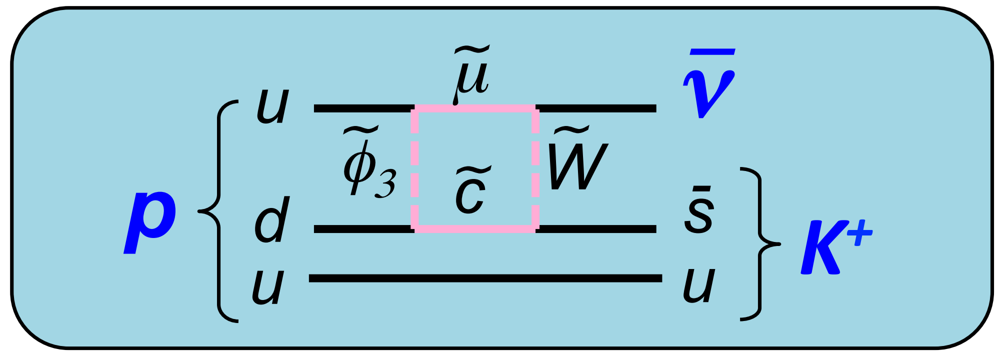
Mediated by gauge bosons



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

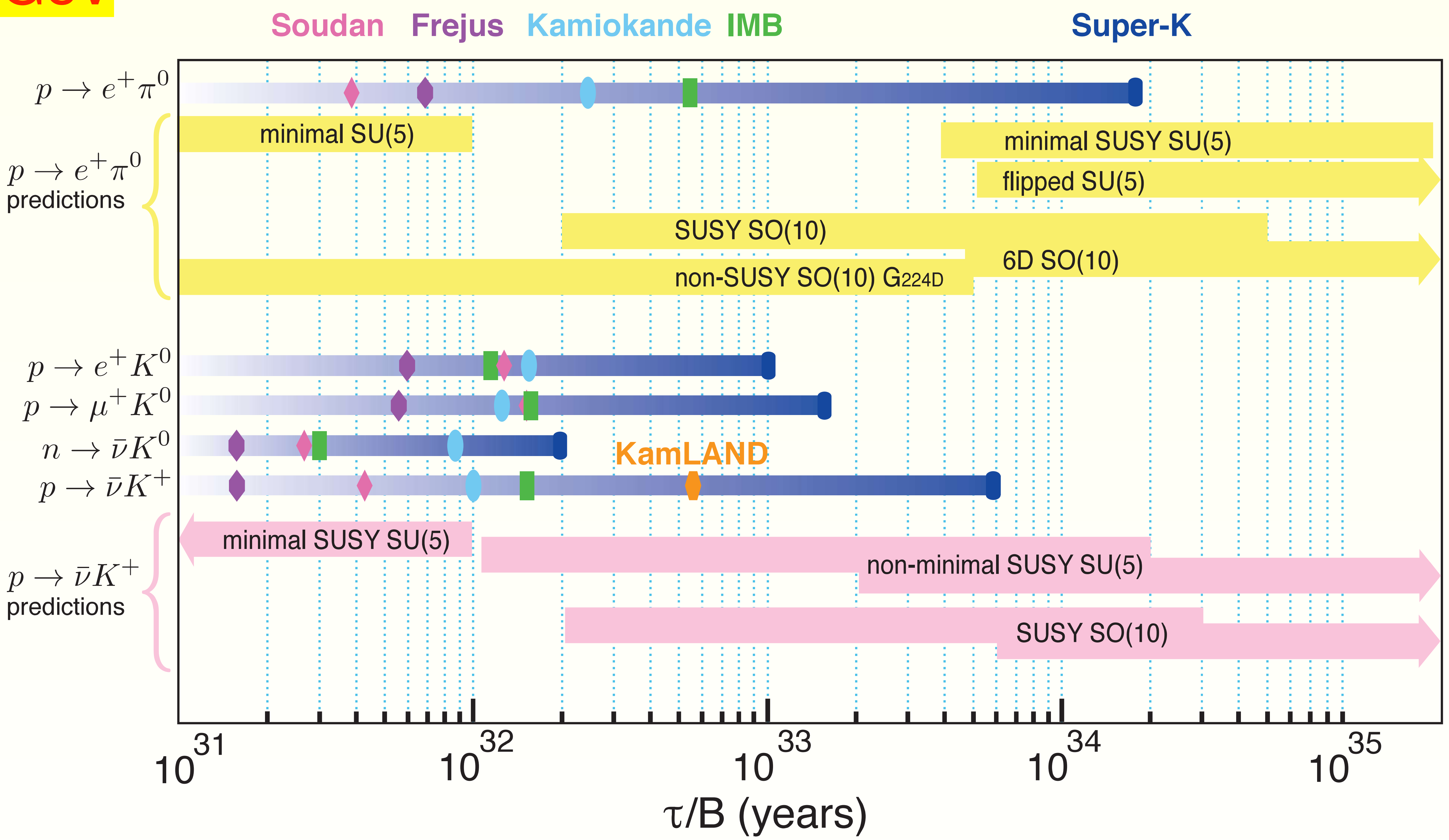
$$\Gamma(p \to e^+\pi^0) \sim \frac{g^4 m_p^5}{M_X^4}$$

SUSY mediated



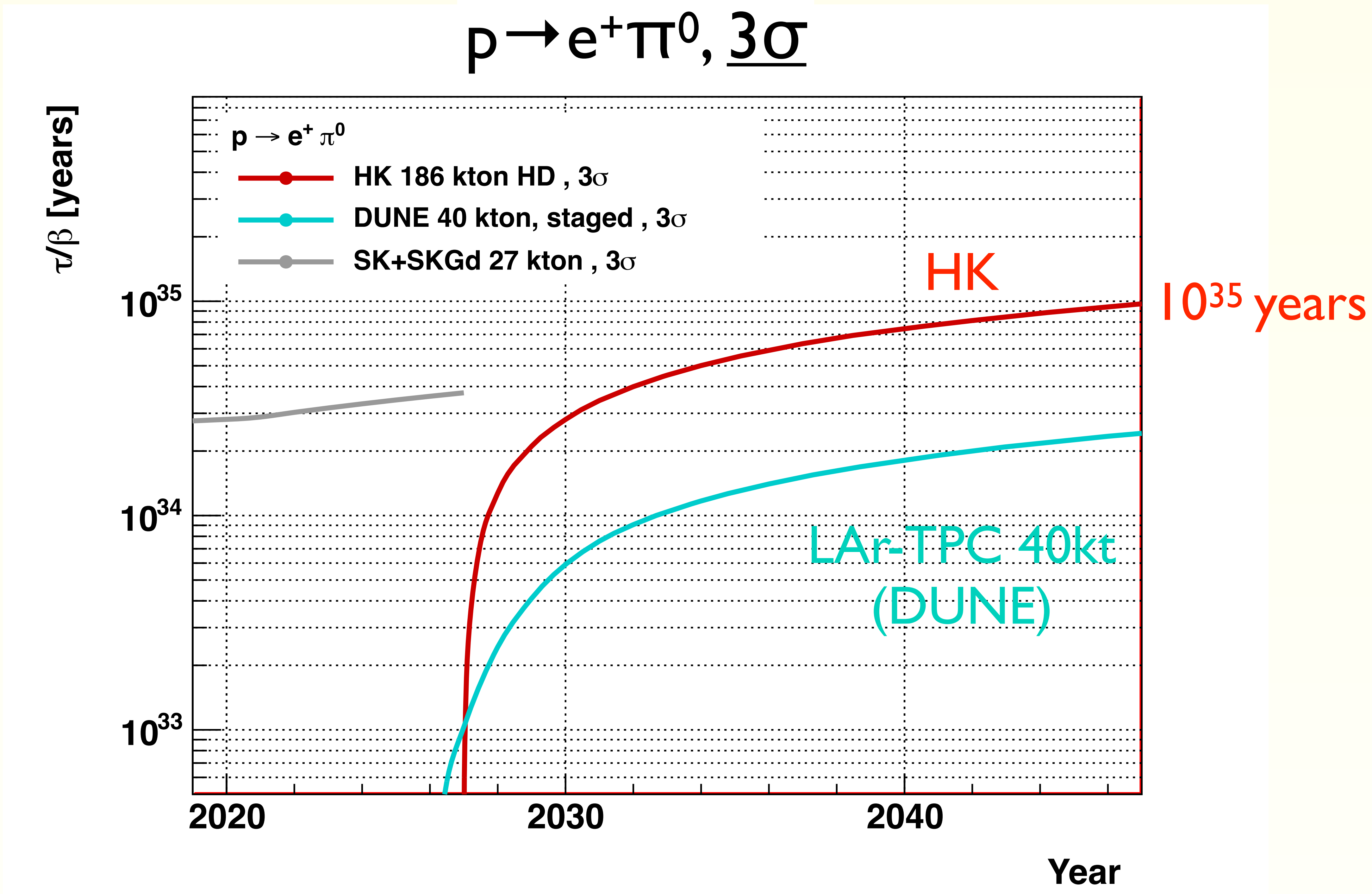
$p \to \nu K^+$

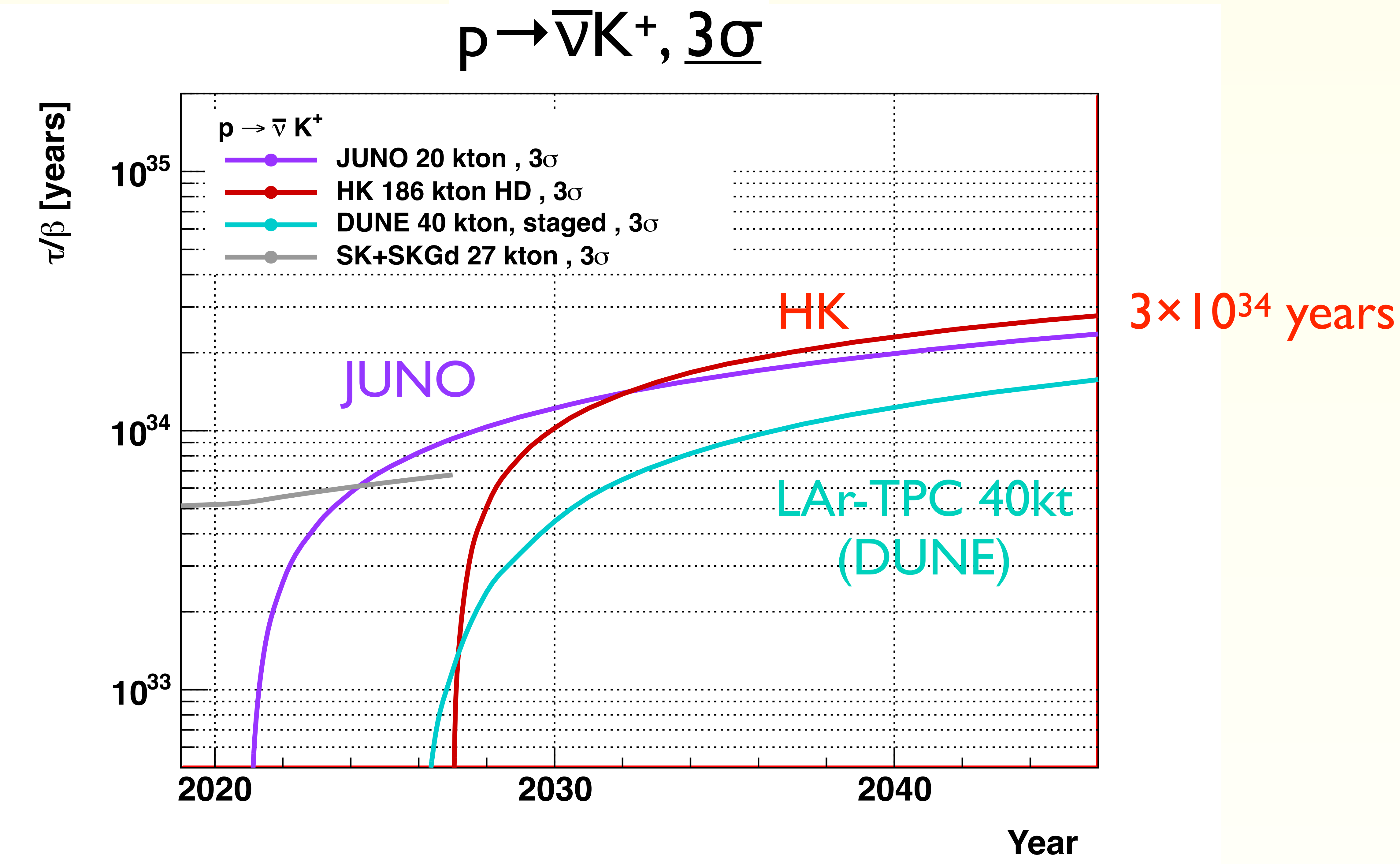
$$\Gamma(p \to \bar{\nu}K^+) \sim \frac{\tan^2\beta \times m_p^5}{M_{\tilde{q}}^2 \times M_3^2}$$



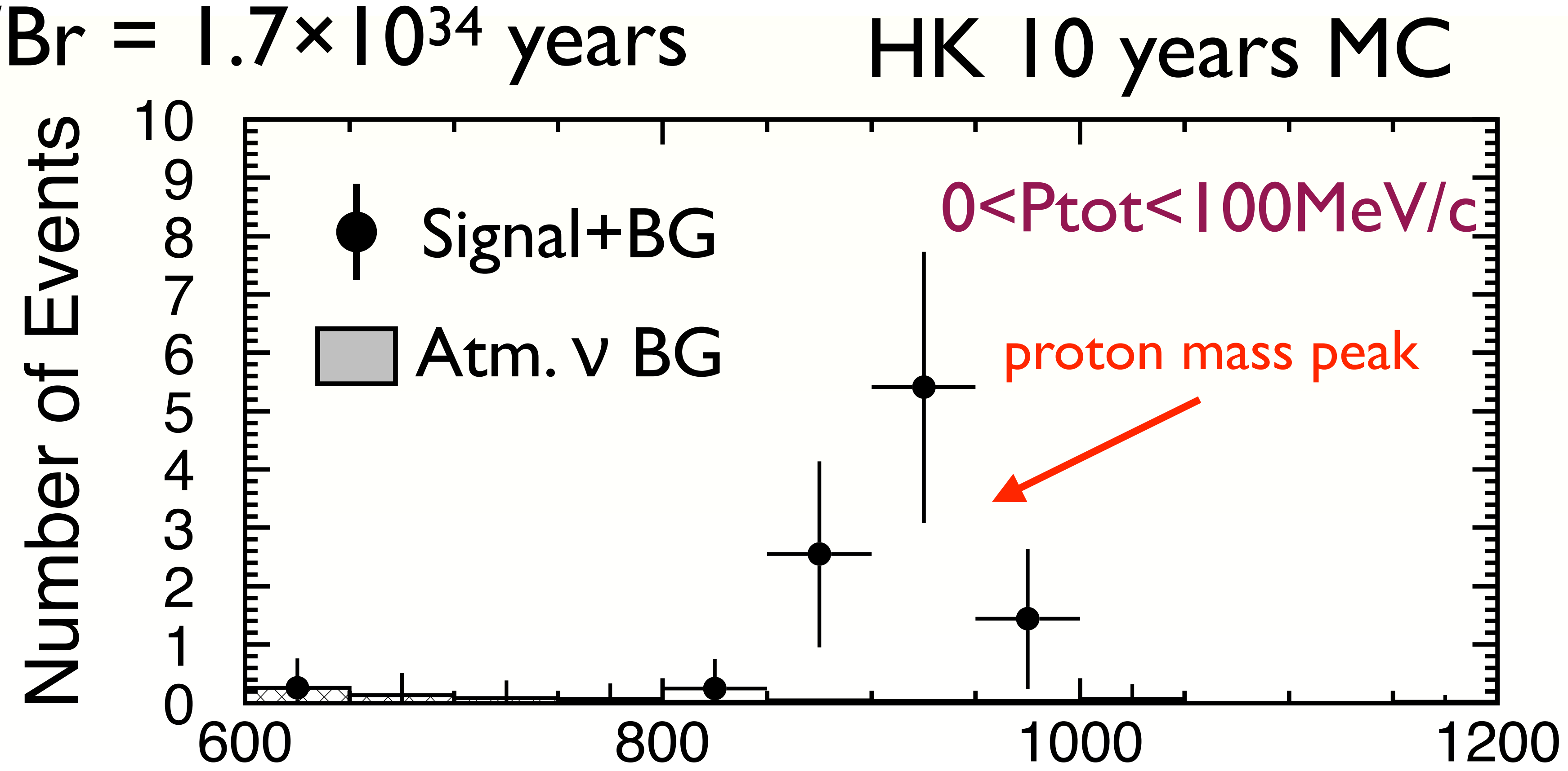
Of course, other possible modes are also important

Sensitivity to proton decay





For $\tau_p/Br = 1.7\times10^{34}$ years



Assumptions

HK: $\mu^+\nu$ (eff. 12.7%) and $\pi^+\pi^0$ (eff. 10.8%)

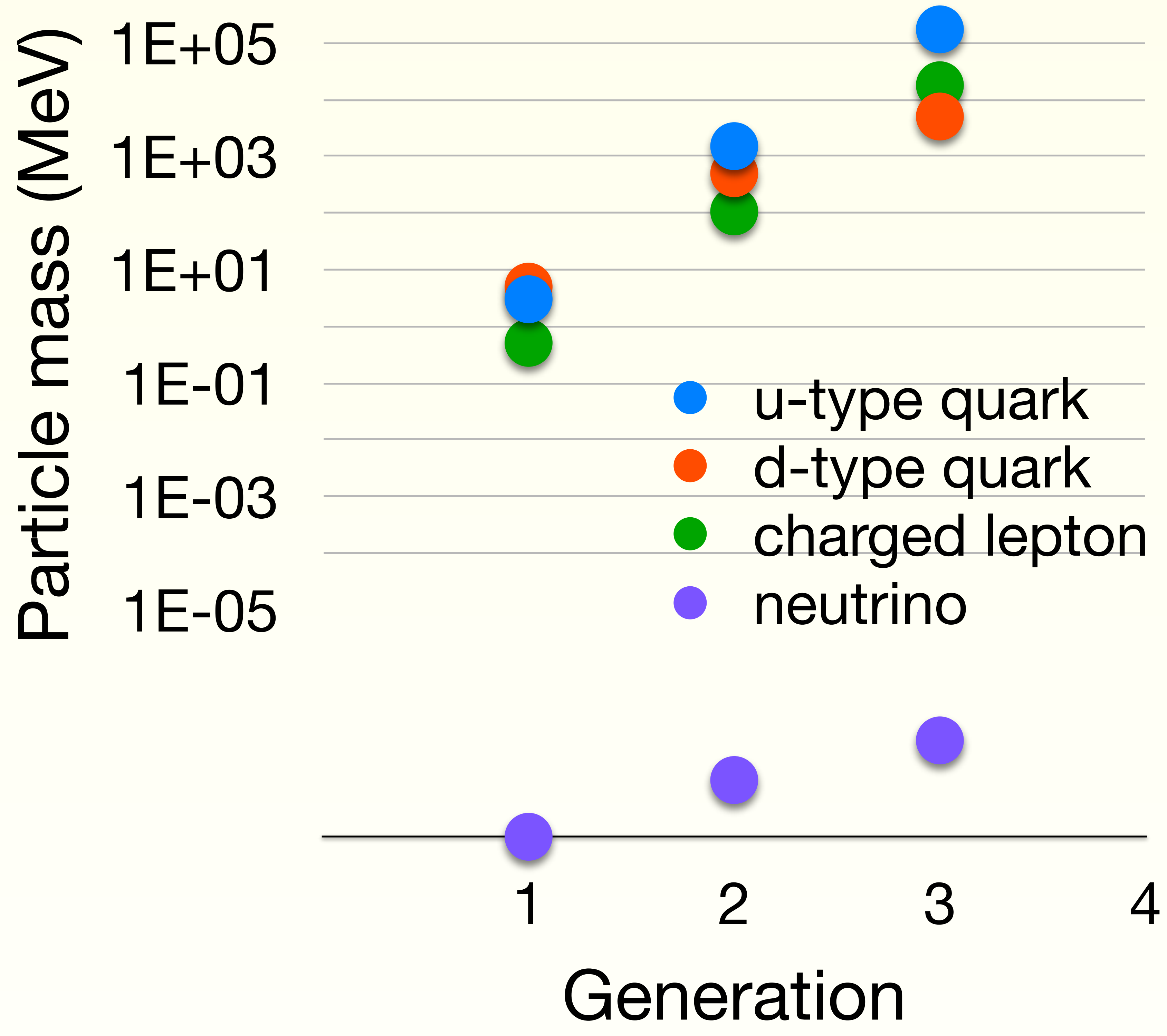
DUNE: TDR (arXiv:2002.03005)
30% efficiency, 1ev/Mt/year

JUNO: arXiv:1507.05613
65% efficiency, 0.05ev/20kt/year

Neutrino oscillation measurements

We learned a lot about neutrinos through **neutrino oscillation**, but many questions emerged and remains

- Origin of **tiny mass**
  - Why mass is much smaller than other fermions?
- **Large mixing** parameters
  - Why so different from quarks?
  - Symmetry behind the pattern?
- **Mass hierarchy (ordering)**
  - Which is the heaviest?
- **CP** violation
  - Is it violated just as in quarks?
  - Or new source exists?
- Extra neutrino **families**?

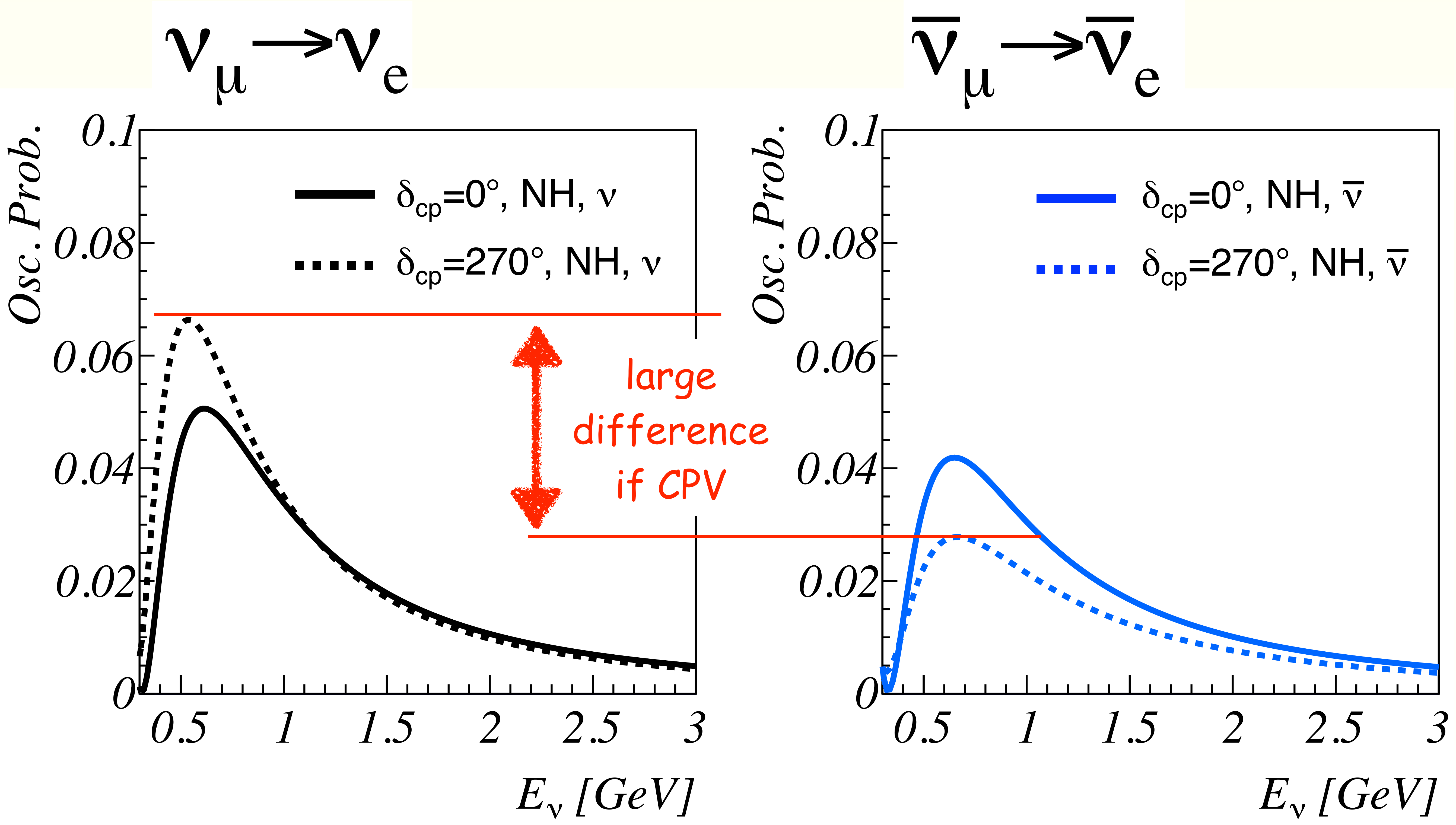


Properties of neutrino are considered to be connected with fundamental questions

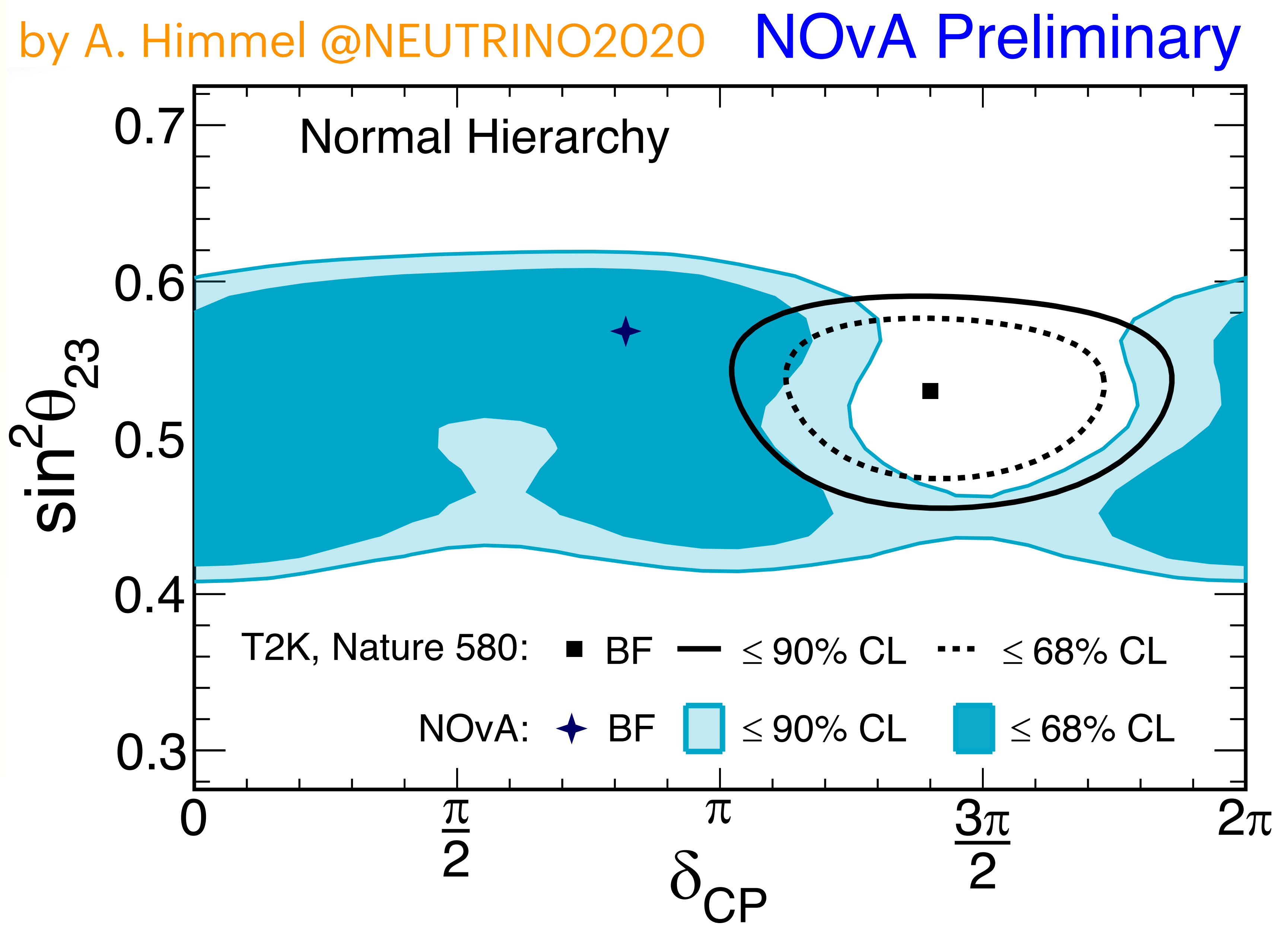
- Source of baryon asymmetry of Universe?
- Very high scale physics? (seesaw?)
- Origin of generations?

CP asymmetry measurement

- Comparison of $P(\nu_\mu \to \nu_e)$ vs. $P(\bar{\nu}_\mu \to \bar{\nu}_e)$
- T2K reports a hint of CP asymmetry, but some tension with NOvA
  - Number of candidate $(\nu_e+\bar{\nu}_e)$ events ~100 for both experiments
  - Plan to collect more data as well as combined analysis



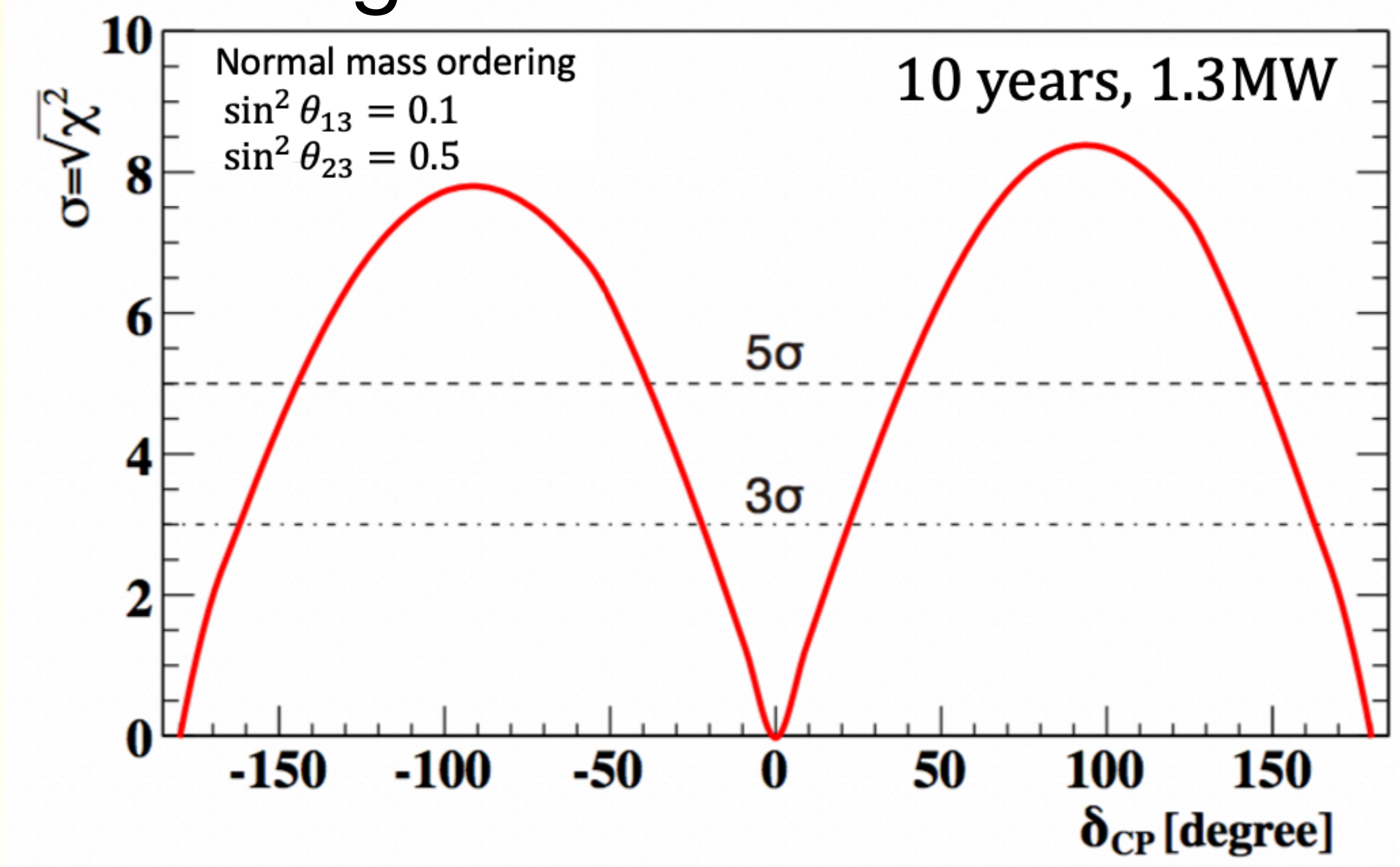
(See talk by T.Nakaya)

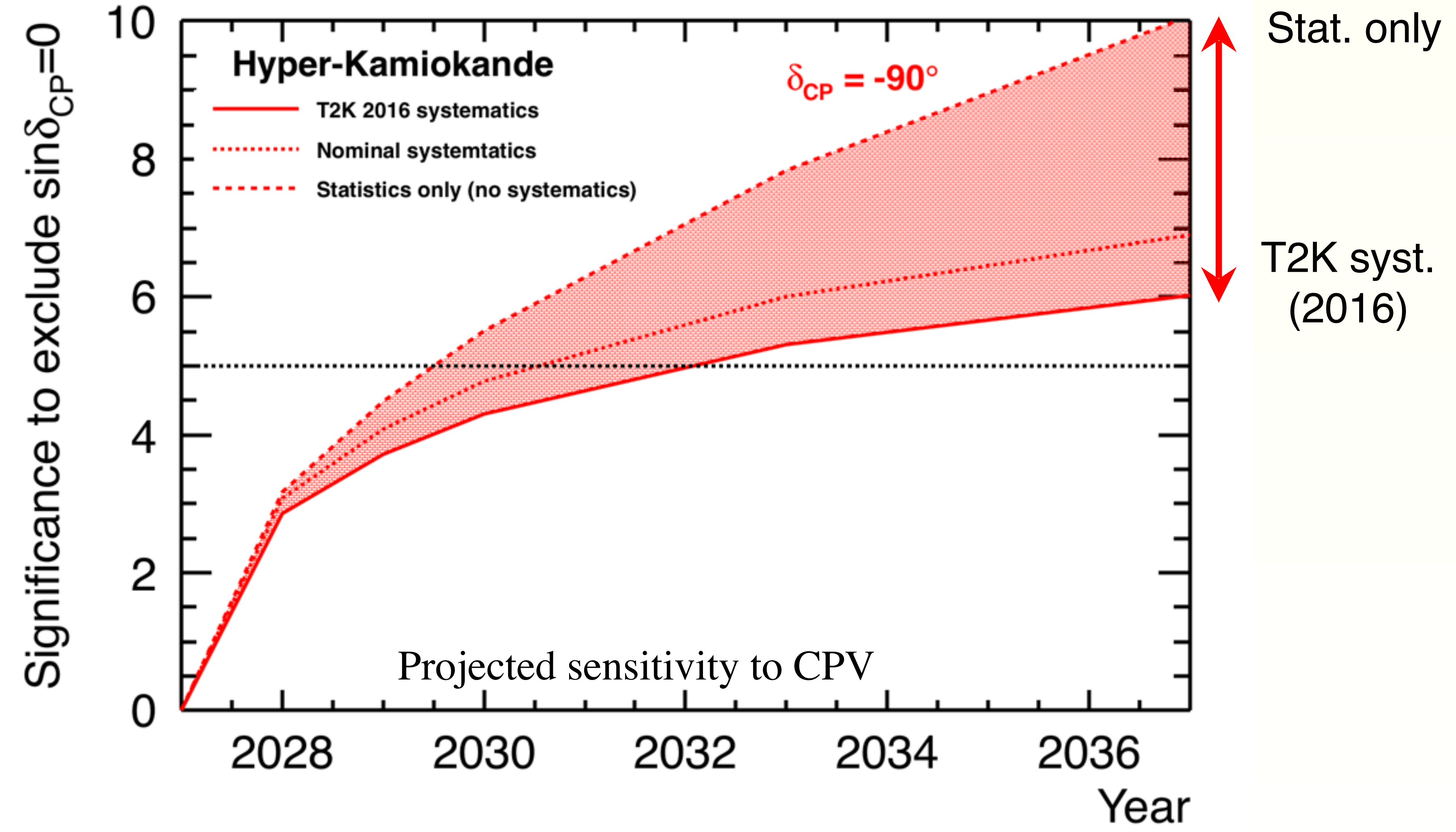


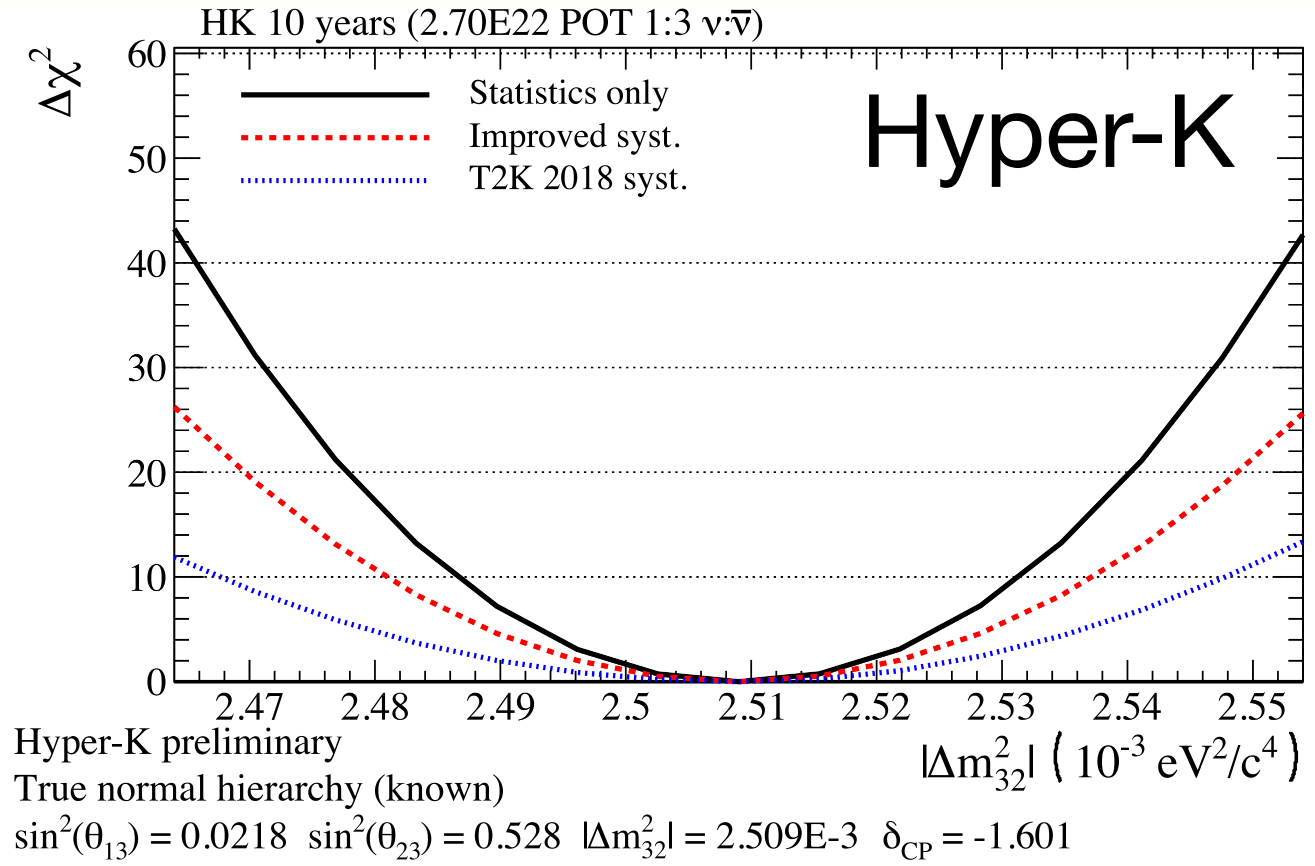
Neutrino oscillation measurements in HK

- Expect **~2000** candidate events for each of ν_e and $\bar{\nu}_e$
  - Definite measurement of CP asymmetry
- ~10,000 events for $\nu_\mu/\bar{\nu}_\mu$
- Precision measurements of oscillation parameters
- Consistency check with other measurements
  - θ_{13} from reactor experiments
  - Δm^2 from reactor experiments
    - Another way to determine mass ordering
  - Different baseline/energy with NOvA and DUNE

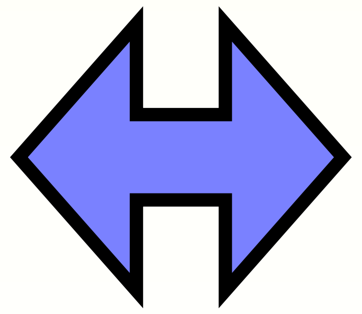
Significance of CPV



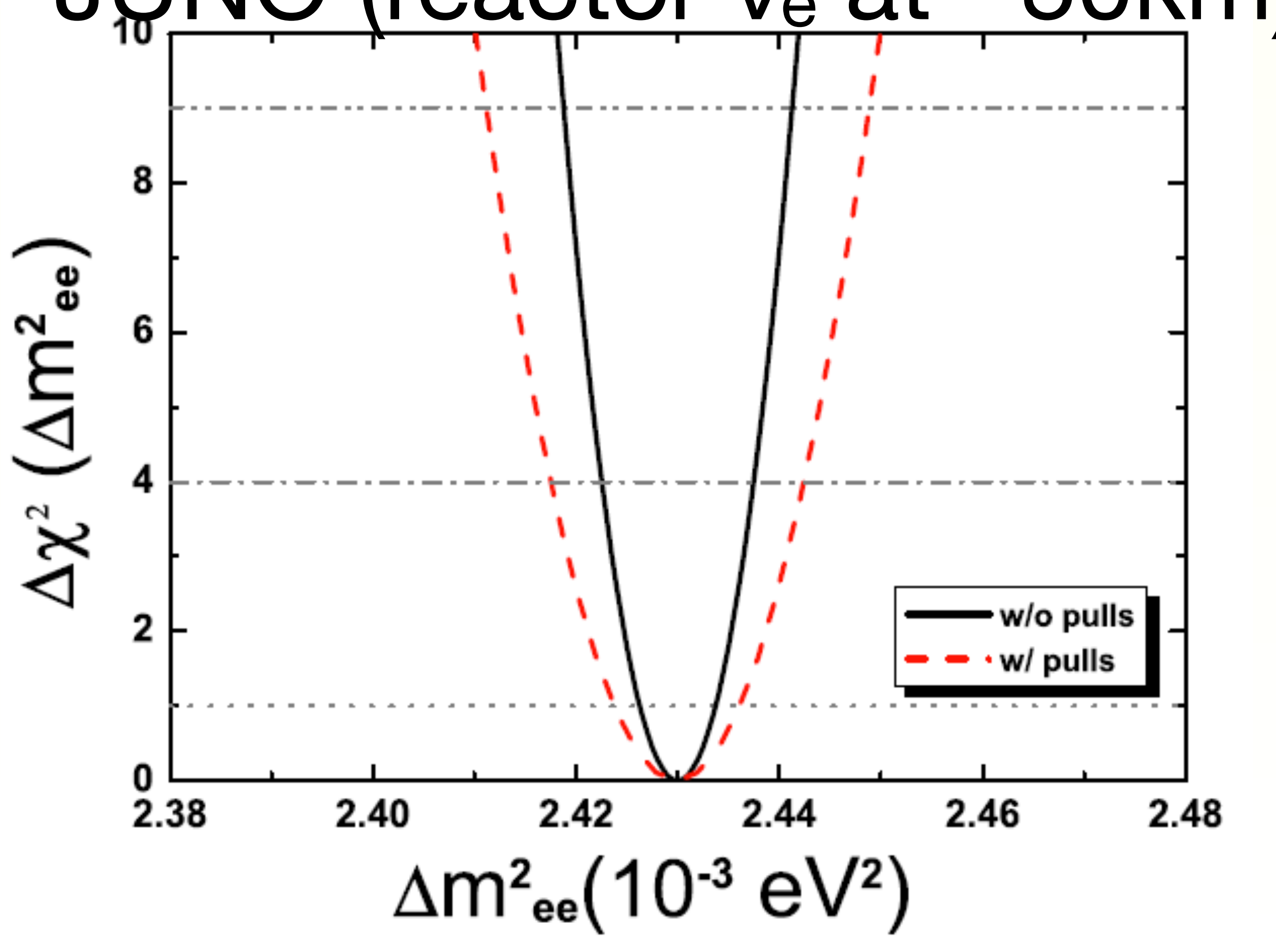




Δm^2



JUNO (reactor $\bar{\nu}_e$ at ~50km)

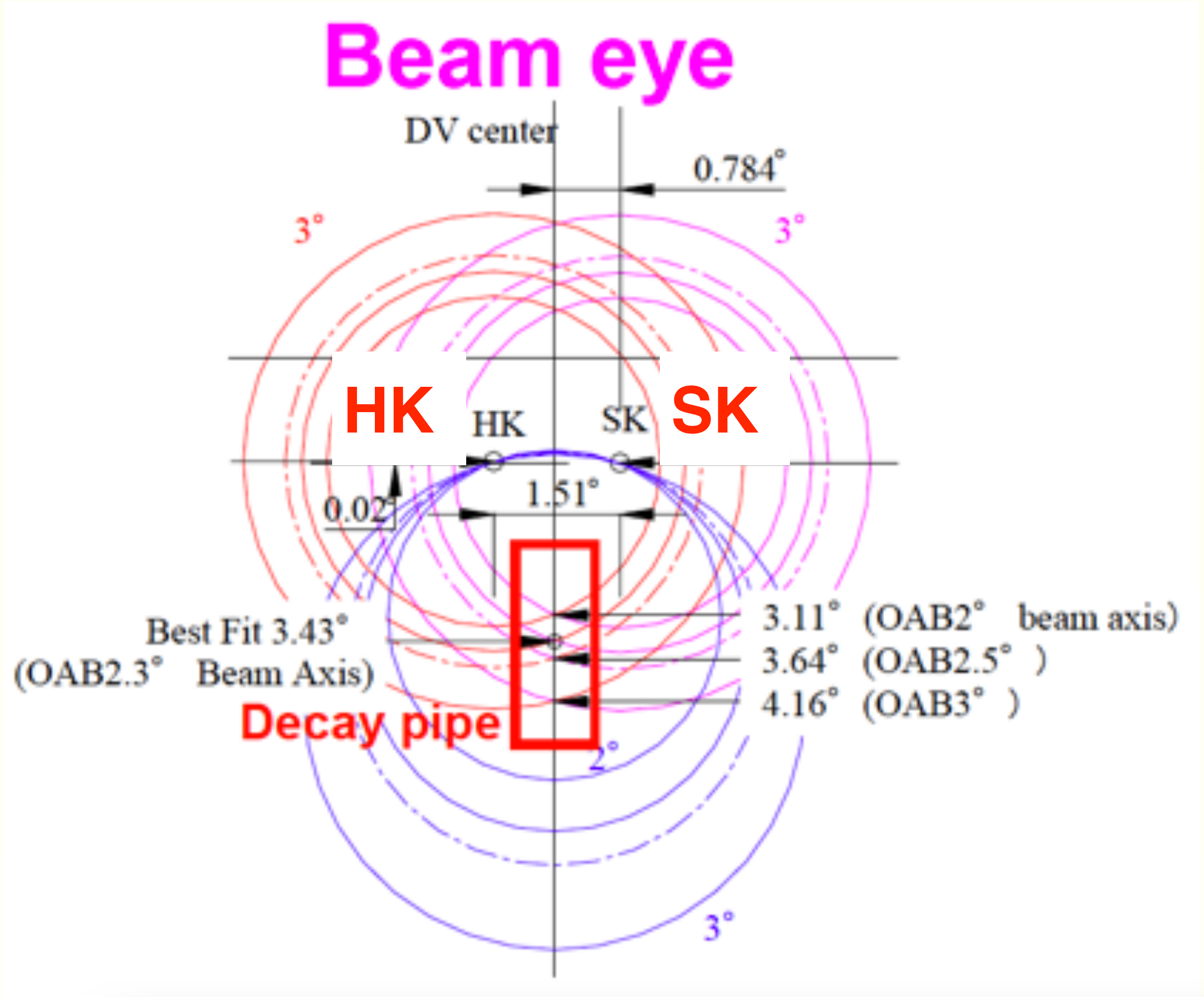


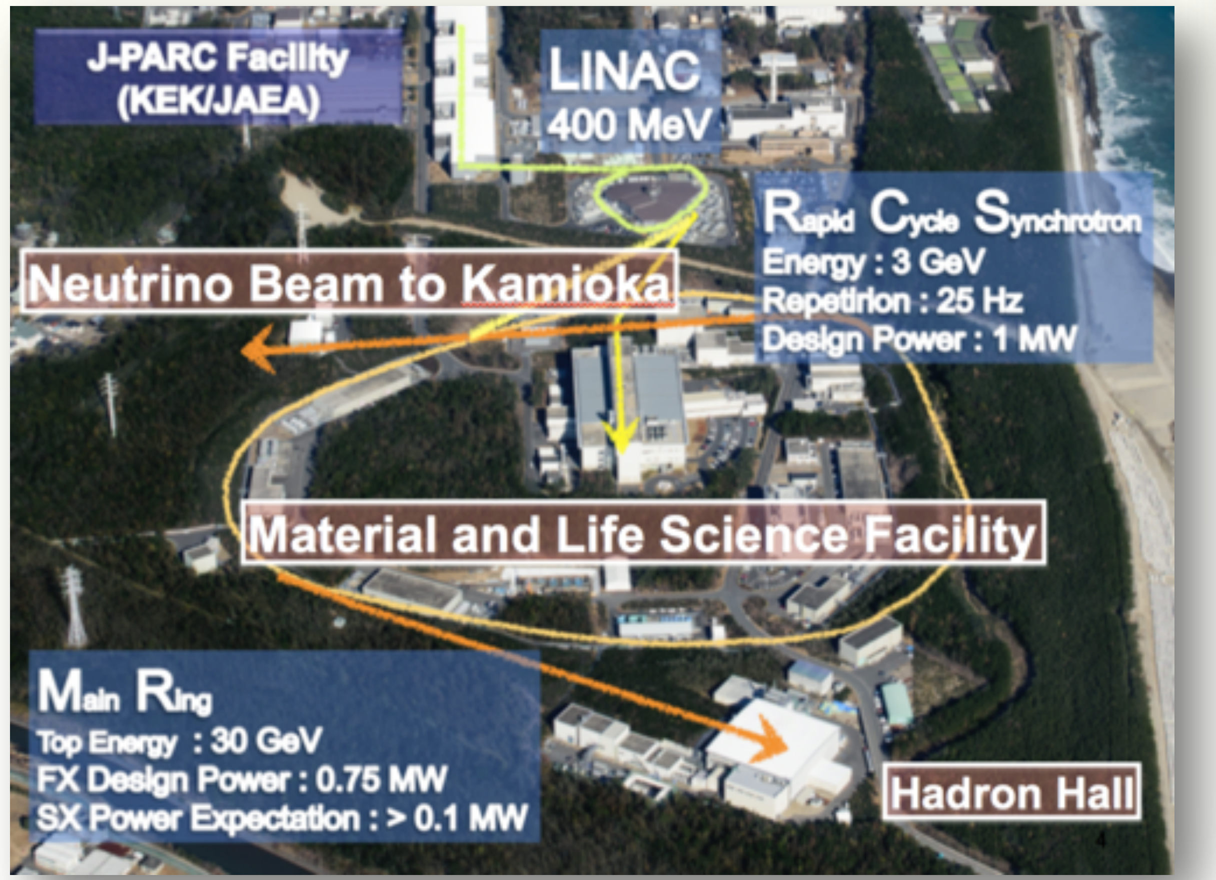
Important to control systematic uncertainties in addition to statistics

J-PARC power upgrade

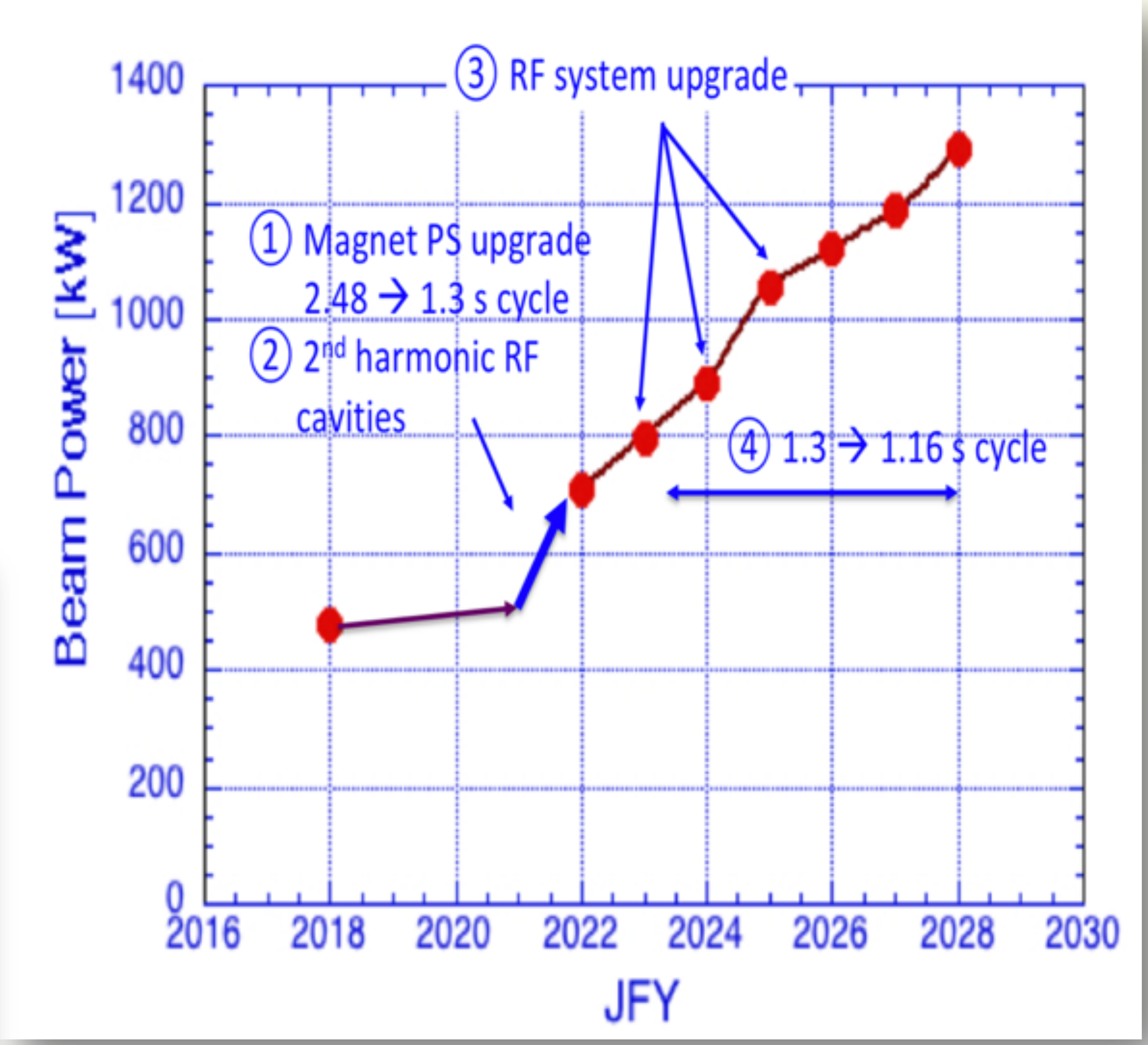
- **Shorter cycle**
  - 2.48s → 1.32s → 1.16s
  - New power supply
  - High gradient RF cavity
  - Collimator improvement
  - Rapid cycle pulse magnet for injection/extraction
- **More protons / pulse**
  - Improve RF Power
  - More RF Systems
  - Stabilize the beam with feedback
- **Beamline upgrade** to handle high power beam
- Together with operation for T2K

J-PARC beamline designed to realize the same off-axis angle for SK and HK



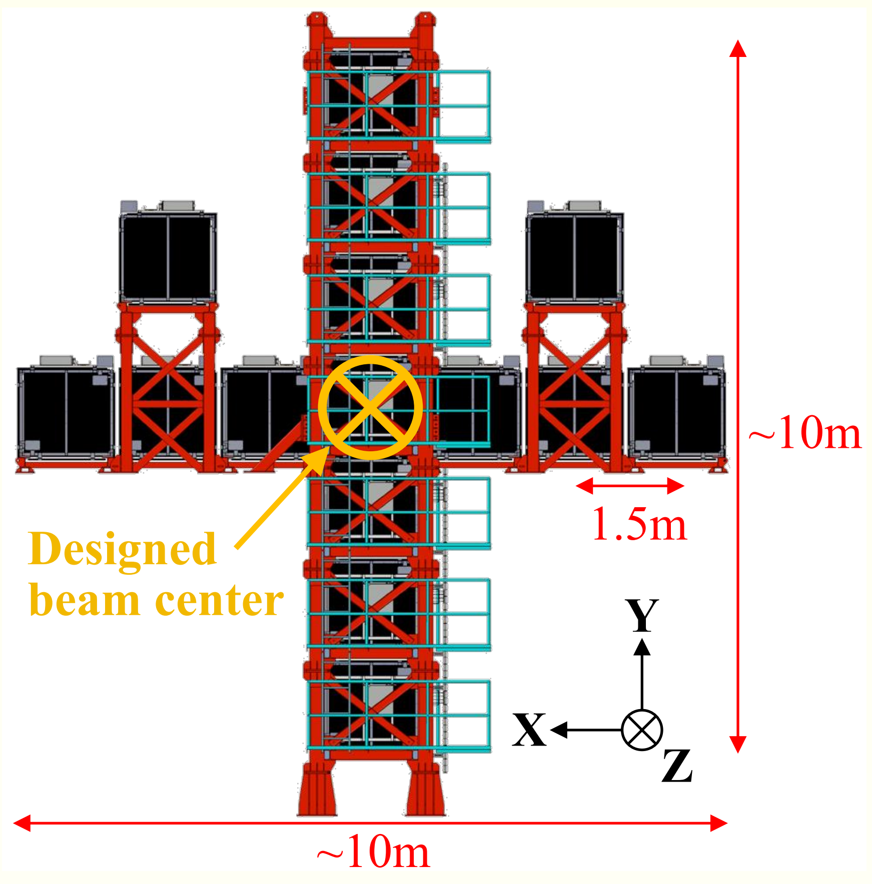


Power upgrade plan
500kW → 750kW → 1.3MW



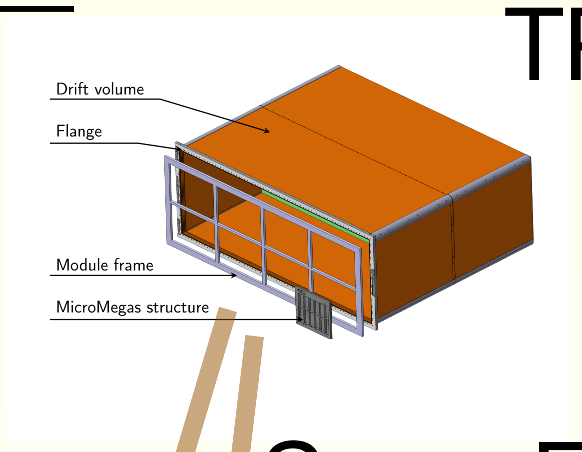
Near and intermediate detectors

Near detector complex

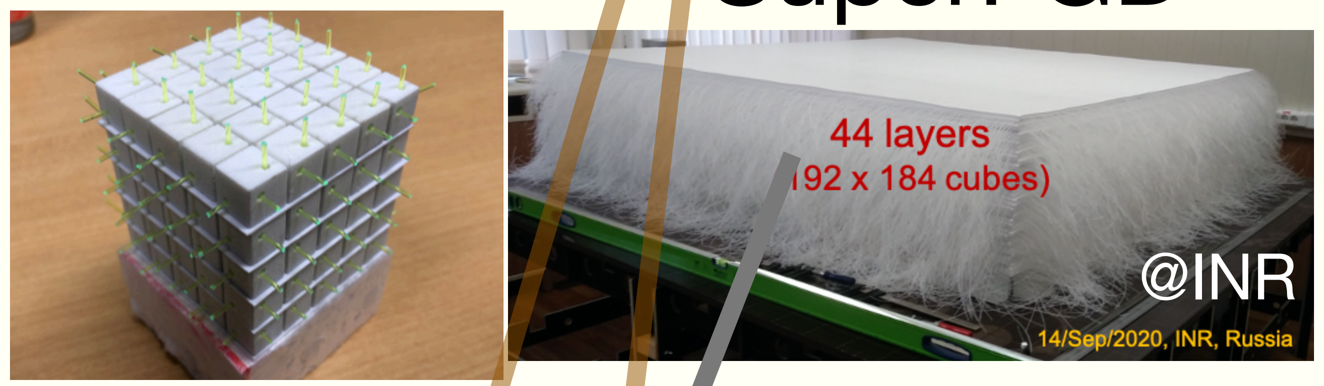


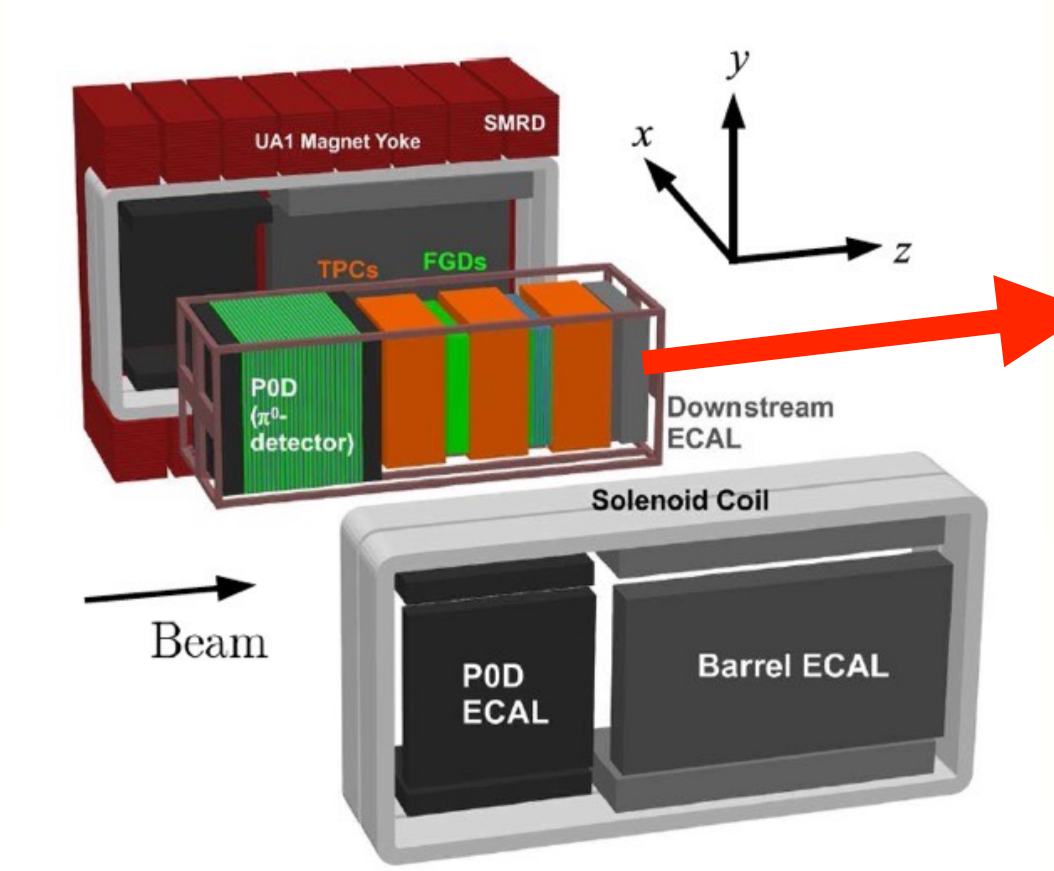
INGRID on-axis detector

TPCs

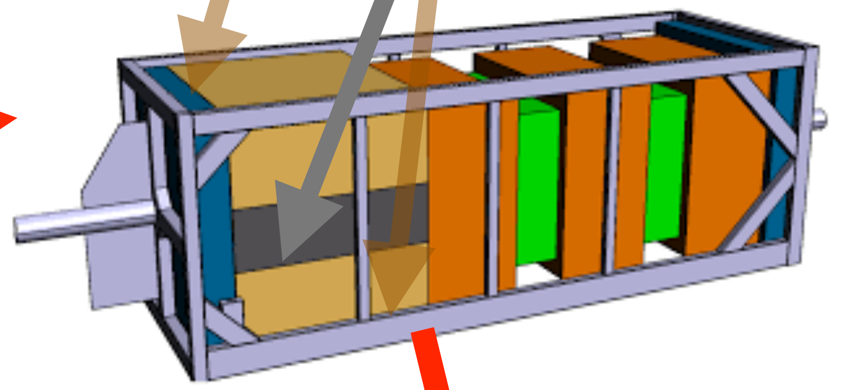


SuperFGD





Upgrade for T2K (2022)

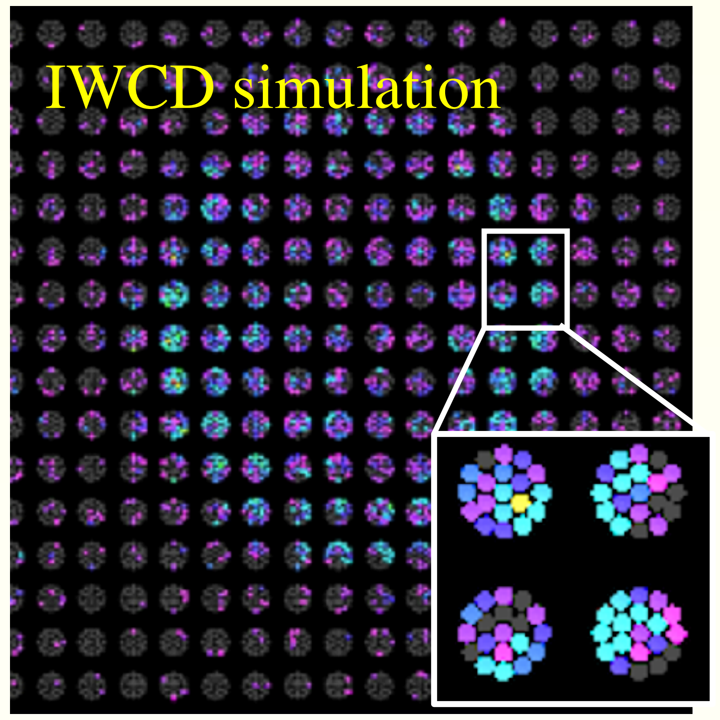


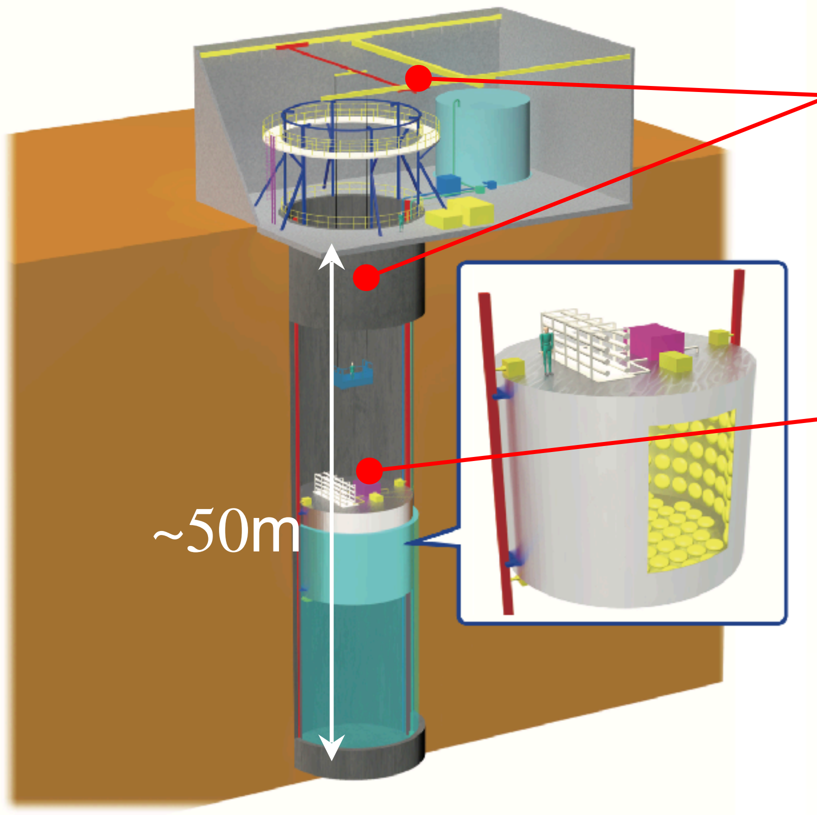
ND280 off-axis detector

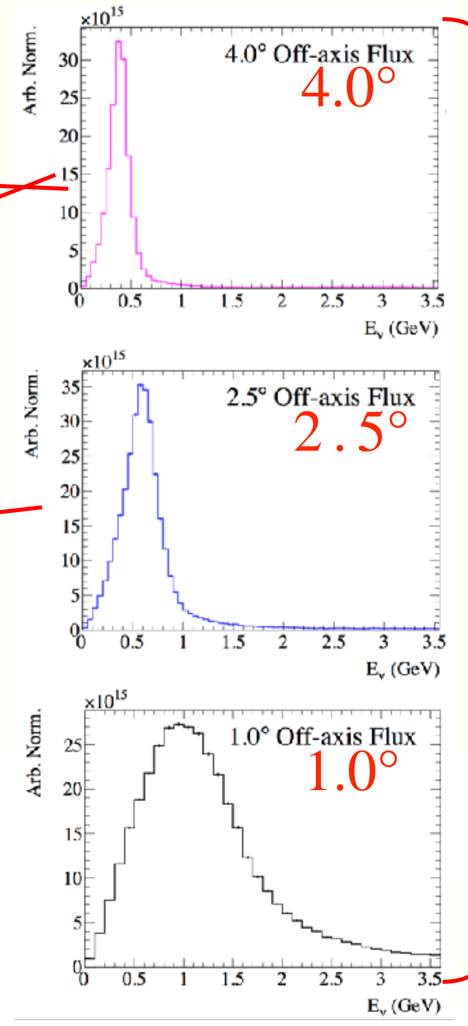
Further upgrade for HK (to be discussed)

Intermediate Water Cherenkov Detector (IWCD)

- 1kton scale water Cherenkov detector at ~1km baseline
- Detector can move vertically → measurement at different off-axis angles



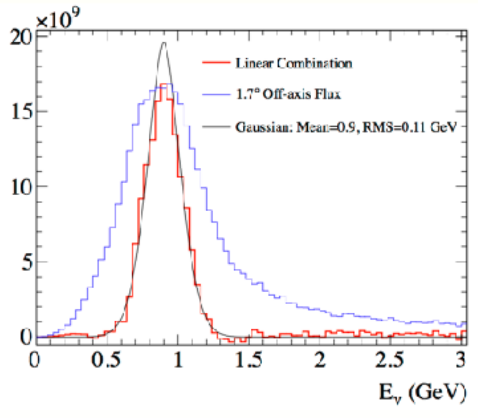




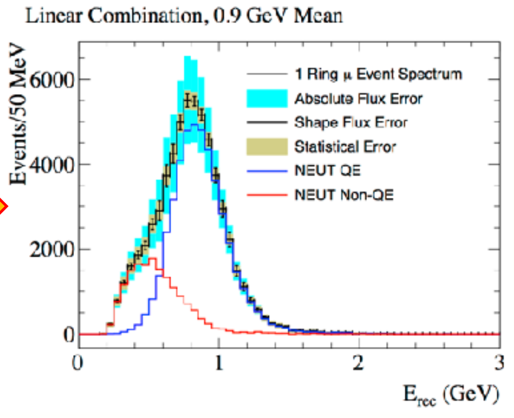
Physics target

- ν-int. measurement by off-axis scanning
- ν_e cross section (3-5% for $\sigma(\nu_e)/\sigma(\nu_\mu)$, $\bar{\sigma}(\nu_e)/\bar{\sigma}(\nu_\mu)$)
- NC and intrinsic ν_e BG measurement (3-4%)
- Neutron multiplicity with Gd loading

Linear sum to make monochromatic energy

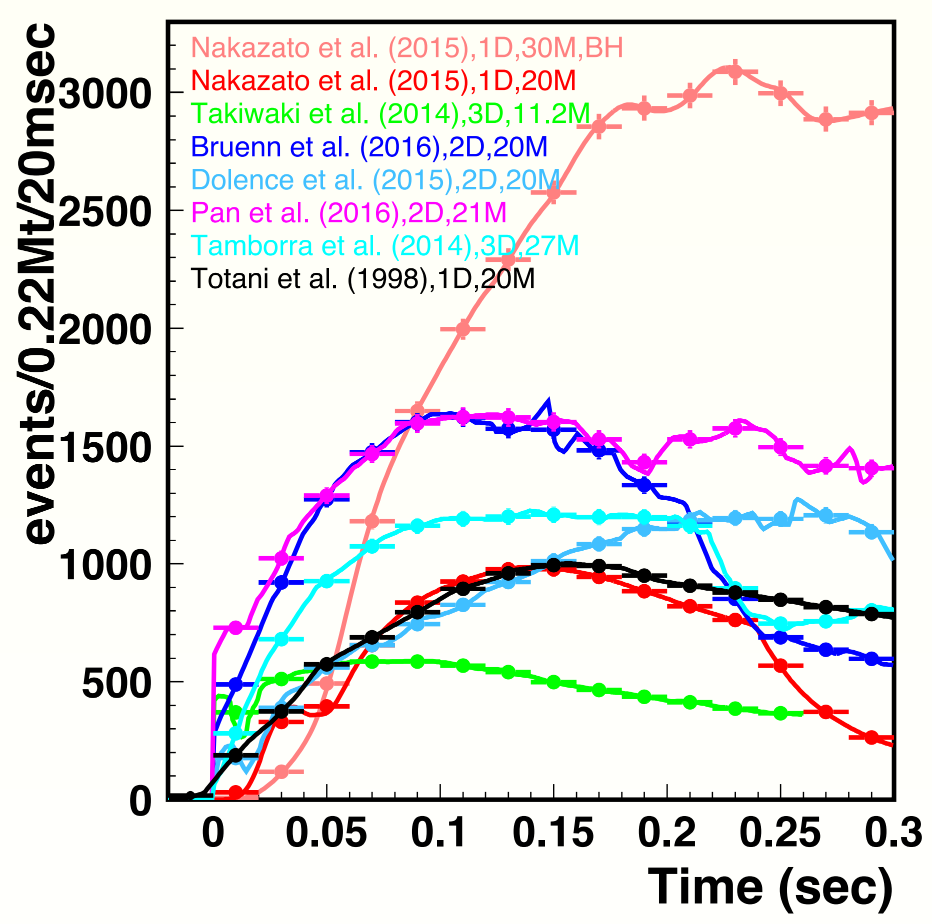


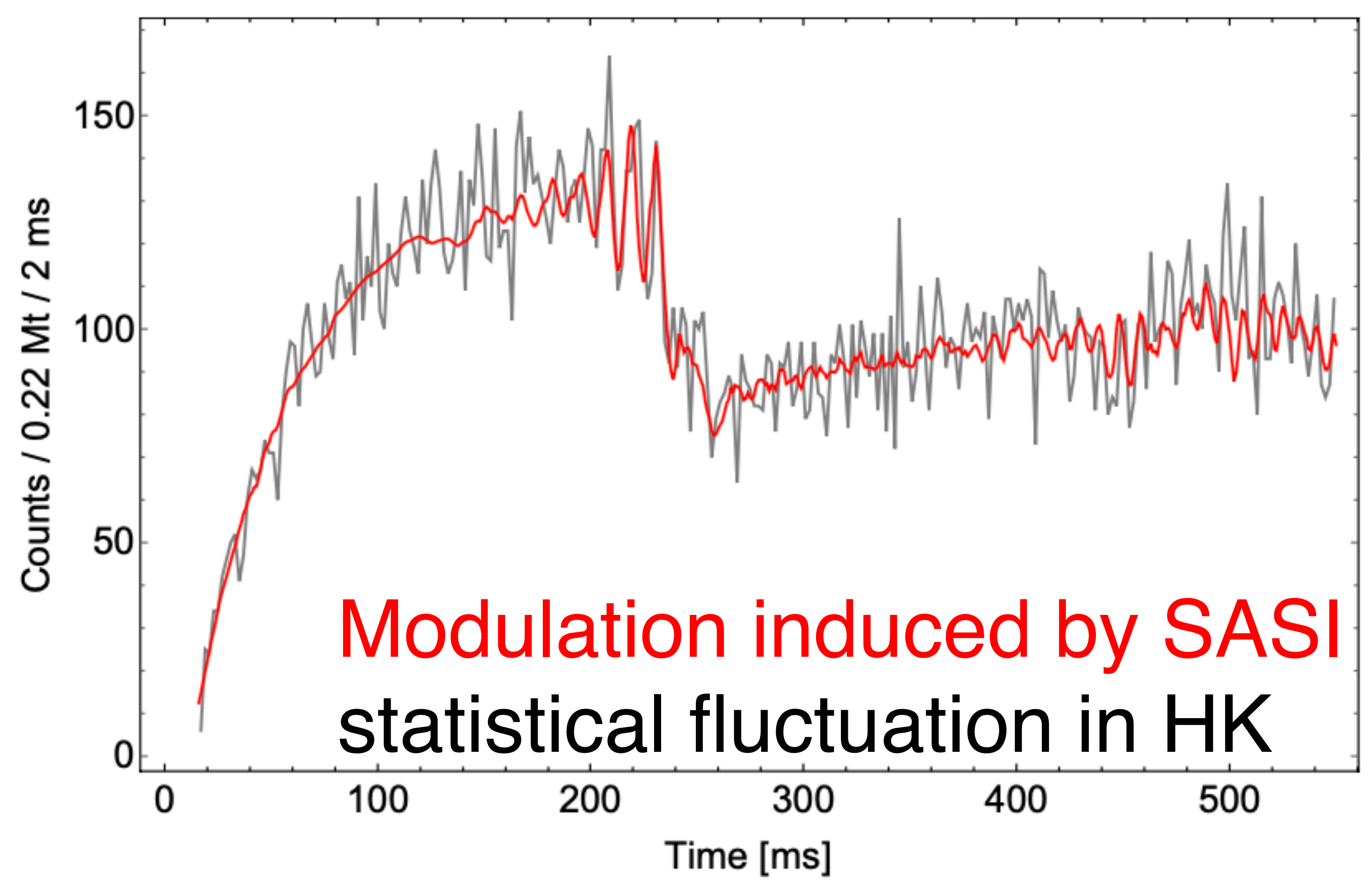
Reconstruction

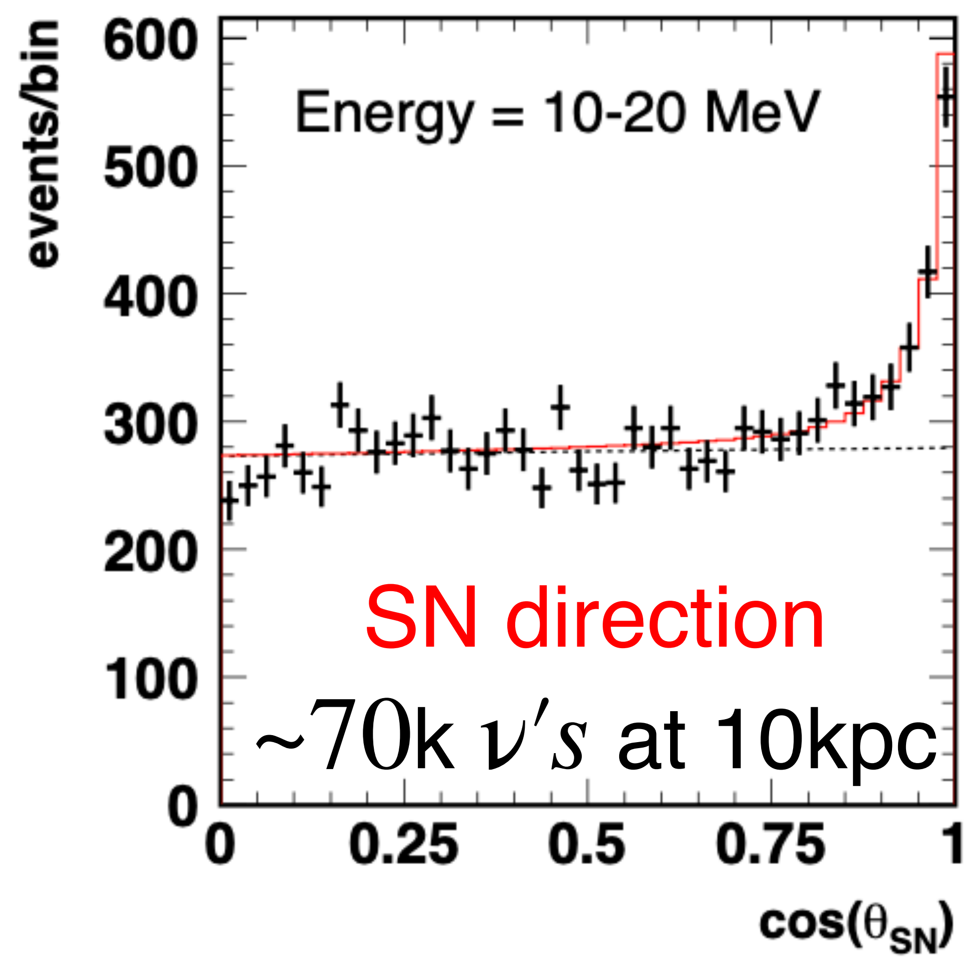


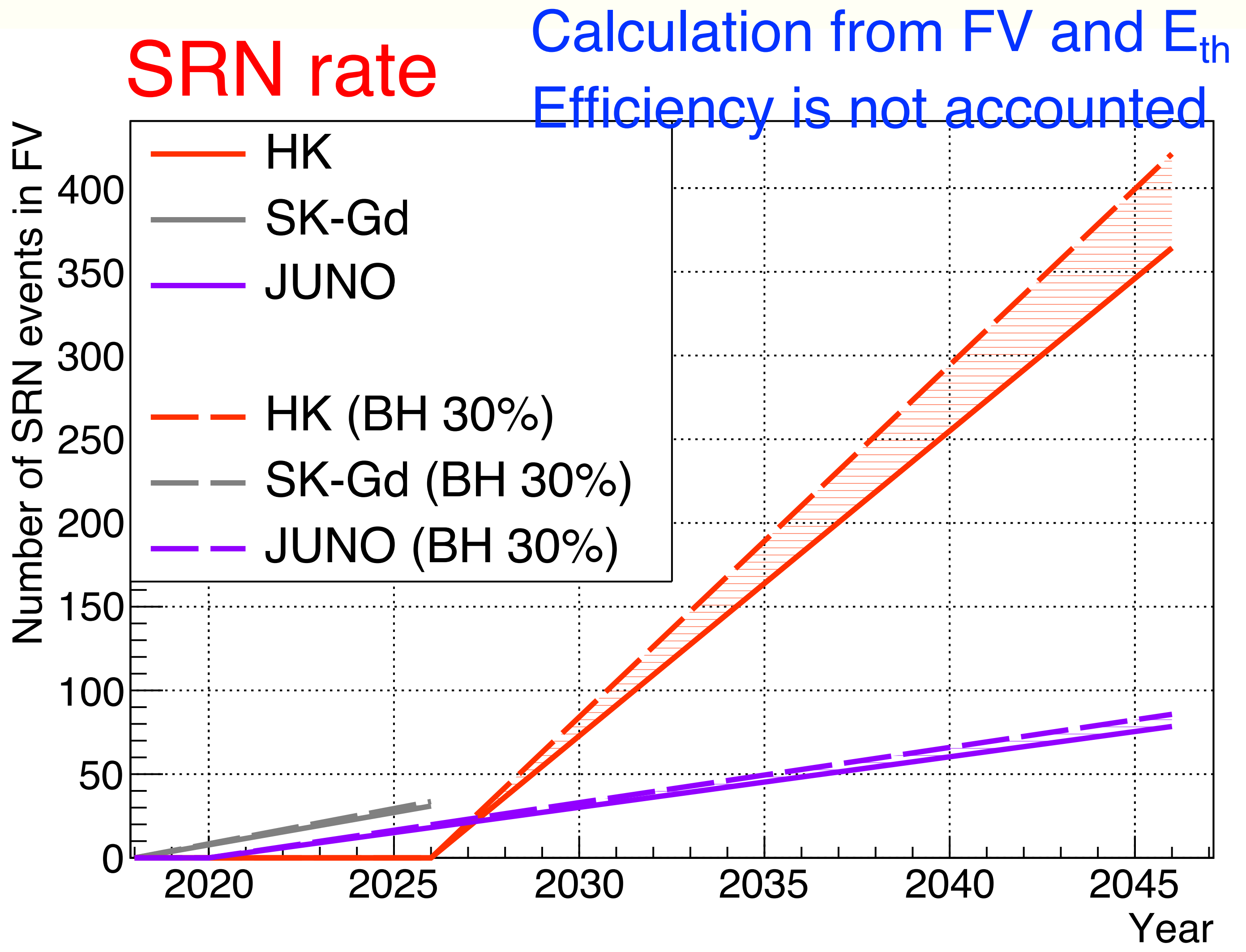
Neutrino astrophysics

- Observation of a few to 10 MeV neutrinos with time, energy and direction information
  - Unique role in multi-messenger observation
- Solar neutrinos: up-turn at vacuum-MSW transition, Day/Night asymmetry, hep neutrino observation
- Supernova burst neutrino: explosion mechanism, BH/NS formation, alert with ~1° pointing
- Supernova Relic Neutrino (SRN): stellar collapse, nucleosynthesis and history of the universe



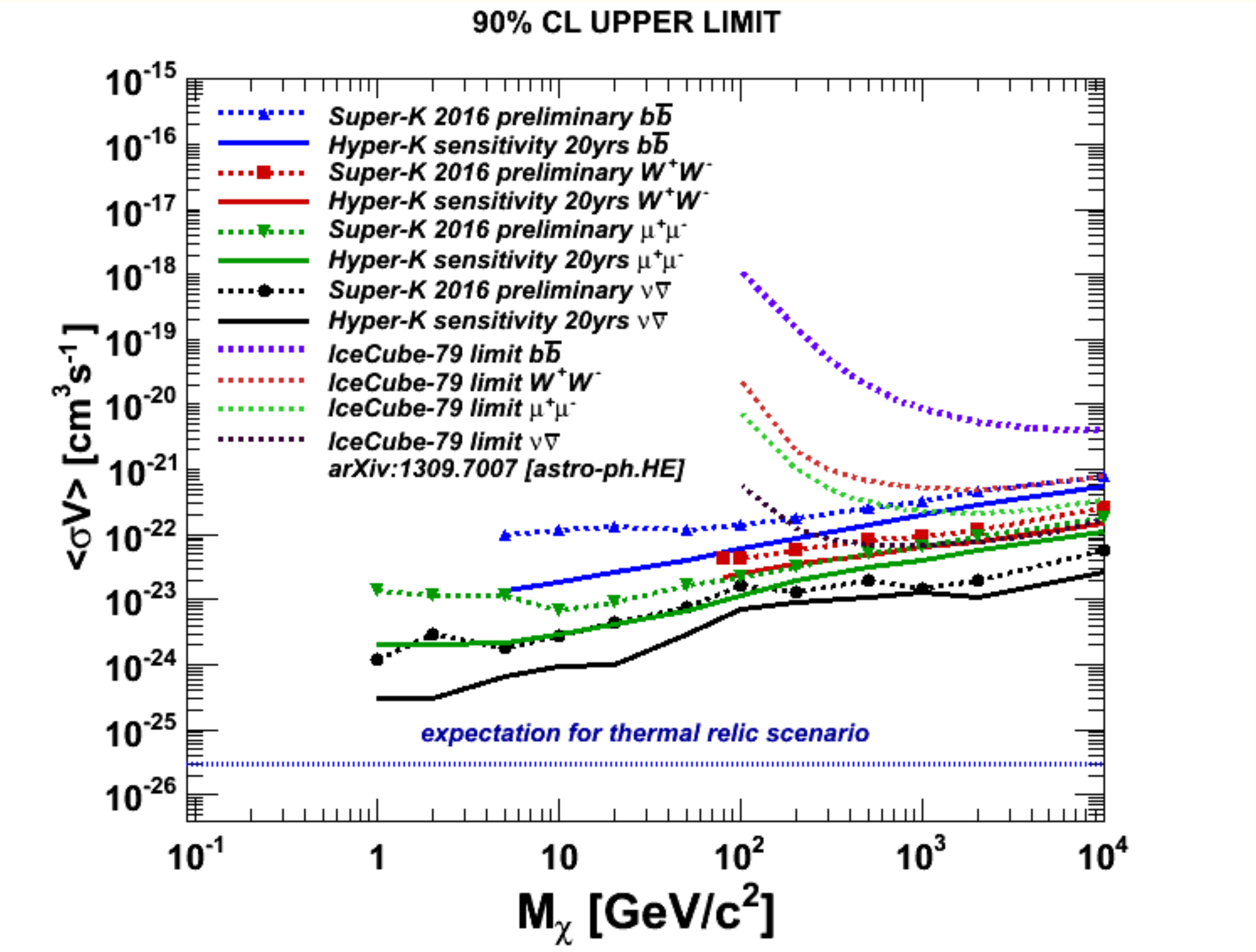




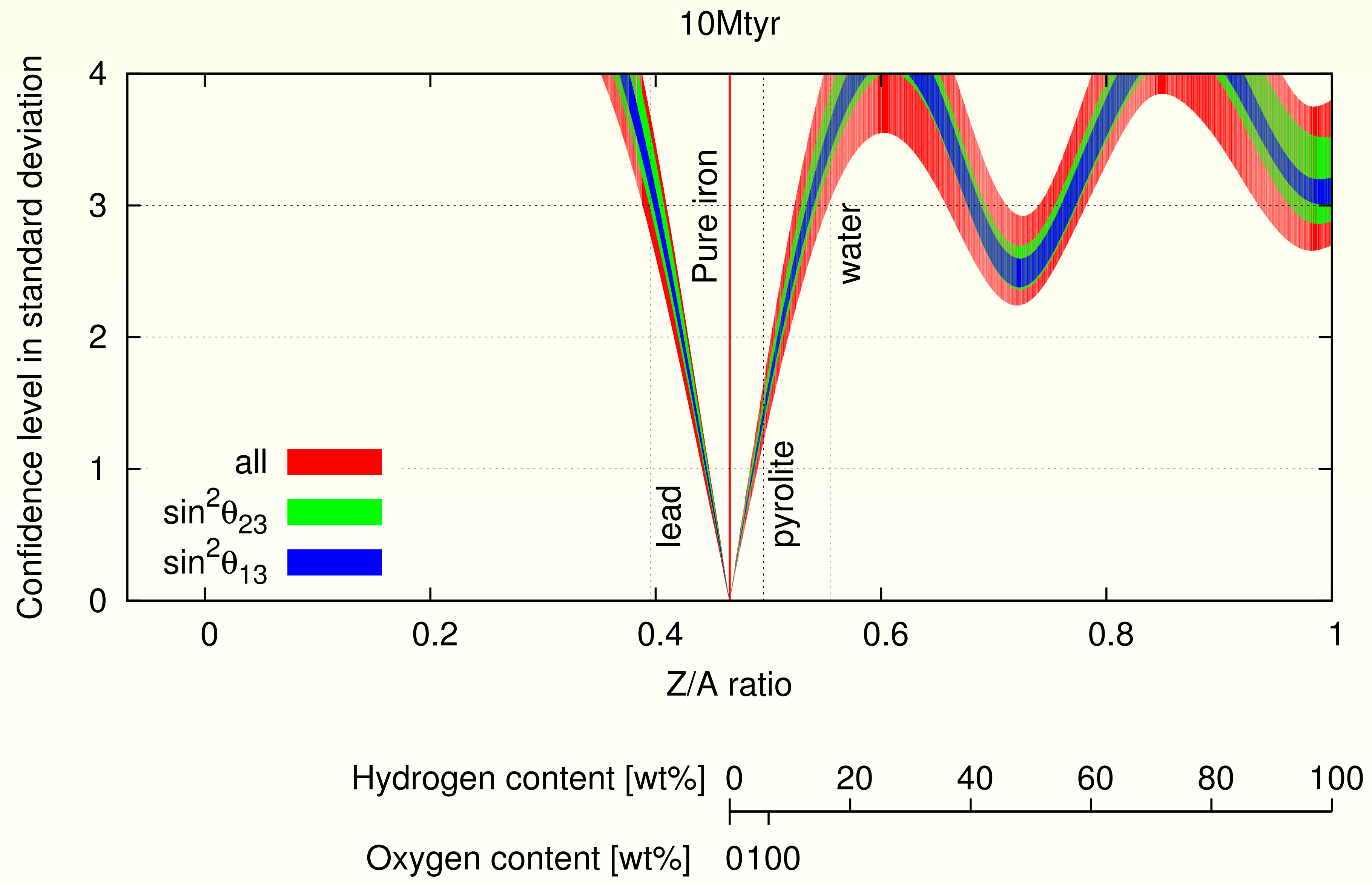


More science topics

Indirect dark matter search



Neutrino oscillogram of Earth's core



Constraints on the proton to nucleon ratio of the Earth's outer core for a 10 Mton year exposure of Hyper-K

Project status

Construction has started

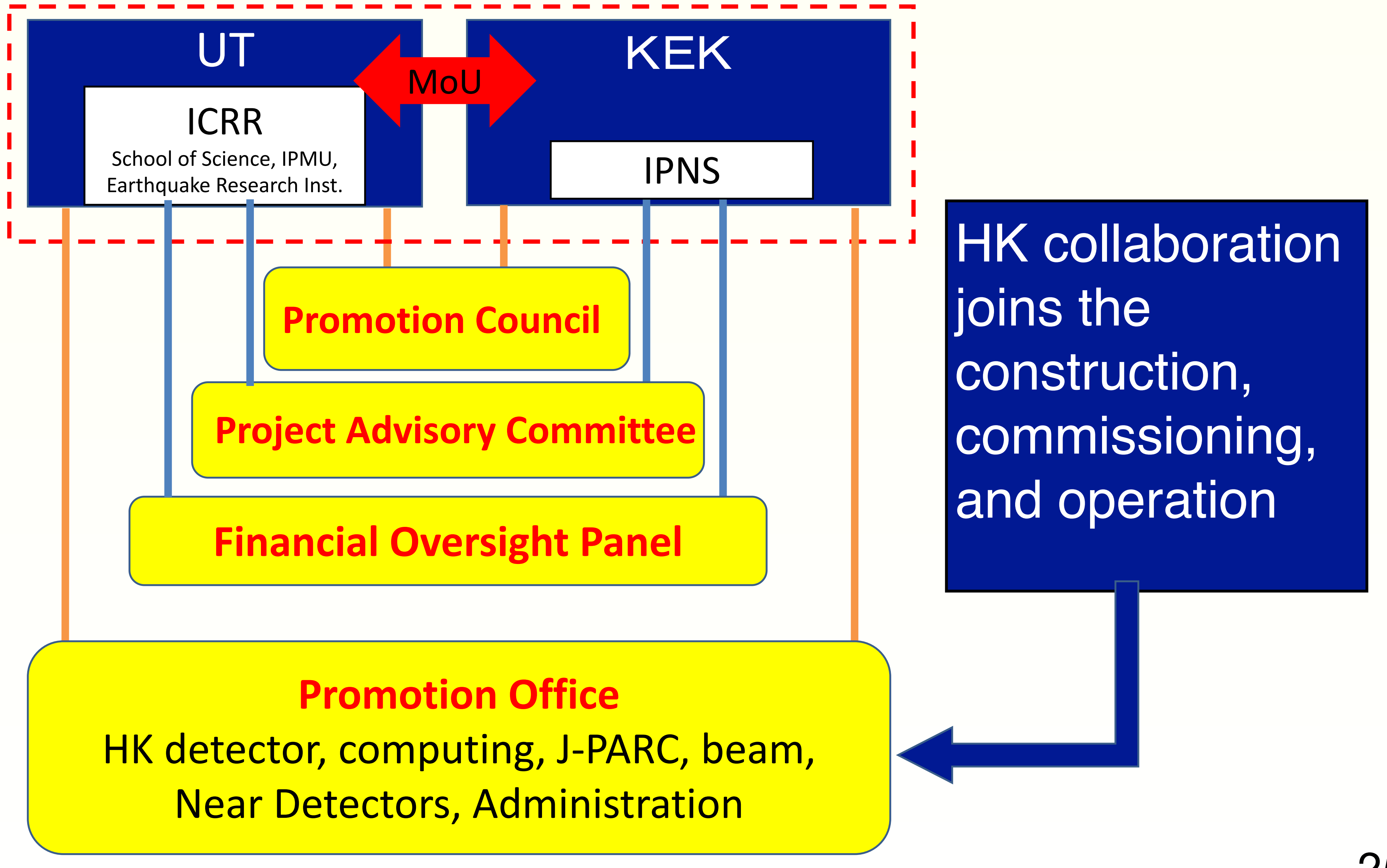
- Detailed geological survey
- Preparation of entrance of the access tunnel
- Detailed design of tunnel and cavern
- Production of PMT starts
- Power upgrade of J-PARC accelerator and neutrino beamline
- Investigation of near and intermediate detectors

Around center of HK tank-top

New Power supply for J-PARC MR

Hosts and organization

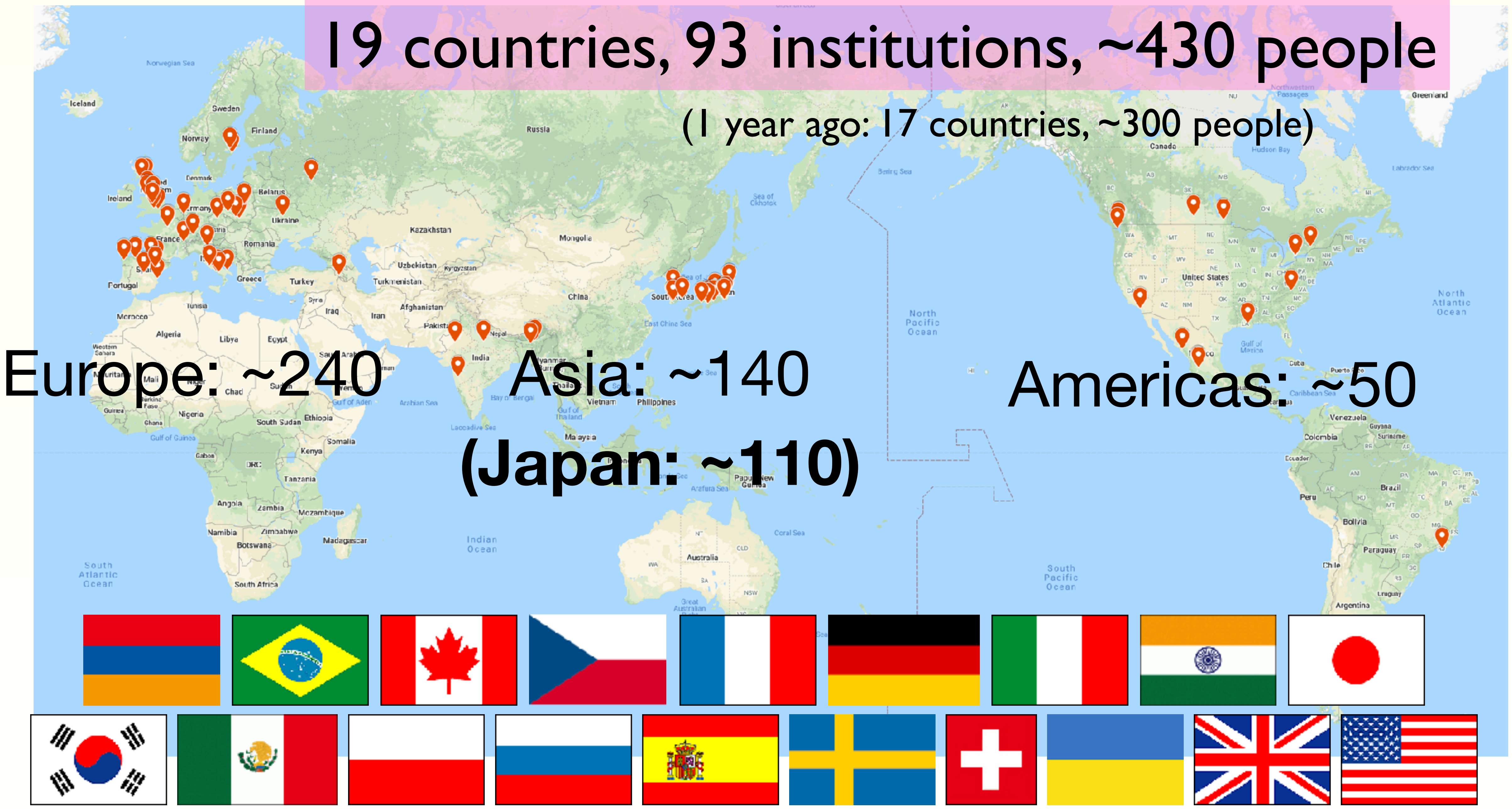
- Host institutions：The Univ. of Tokyo and KEK
- Signed a MoU to promote the HK project (May 2020).
  - UT launched Next-generation Neutrino Science Organization (NNSO) (Oct. 2017).
- Project management organization is defied
- First meeting of Project Advisory Committee (PAC) was just held in September 2020
  - Chair: Toshinori Mori (ICEPP)
  - 10 members (8 from outside Japan)
- Other organizations are also being formed



Hyper-Kamiokande Collaboration

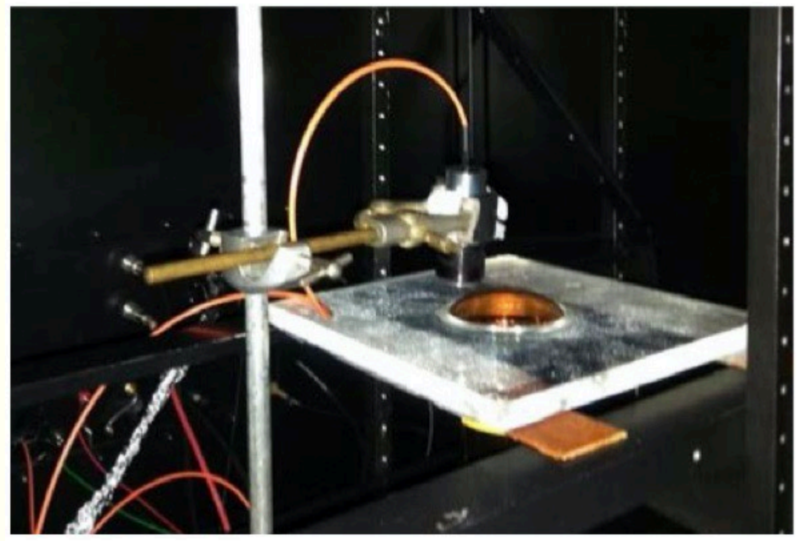
- Transition from "proto-collaboration" to the full collaboration
  - Collaboration Agreement
  - Formed Institutional Board and selected Chair (Emilio Radicioni, INFN)
  - Election of Spokespersons, Executive Board, … this year
  - Definition of Construction Working Group and leaders

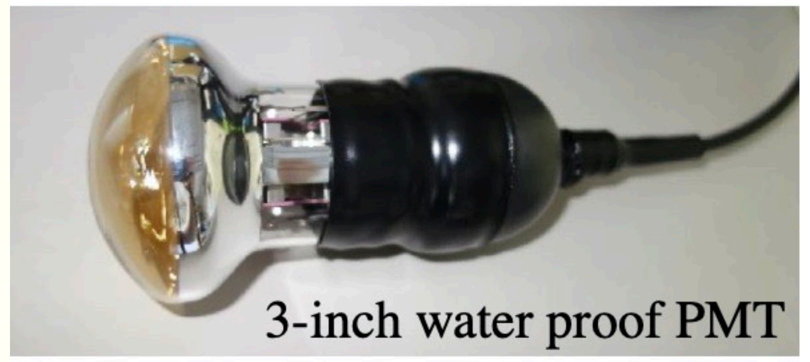
The last "Proto-Collaboration" Meeting, Feb. 2020



International effort for HK construction

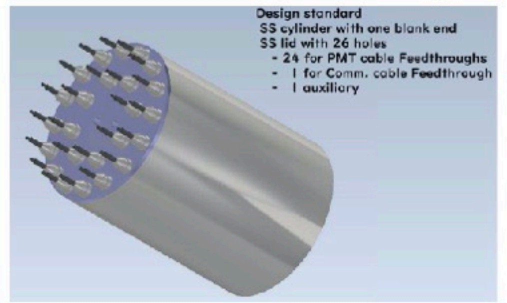
Outer detector:
PMT + WLS plate (UK)



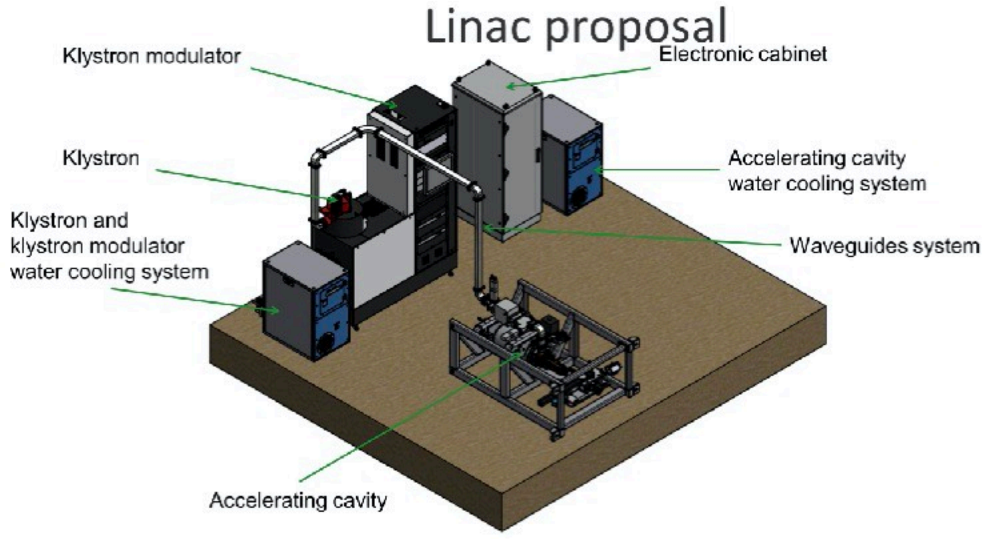

3-inch water proof PMT

ID mockup at ICRR

Underwater electronics:
Case design and feedthrough

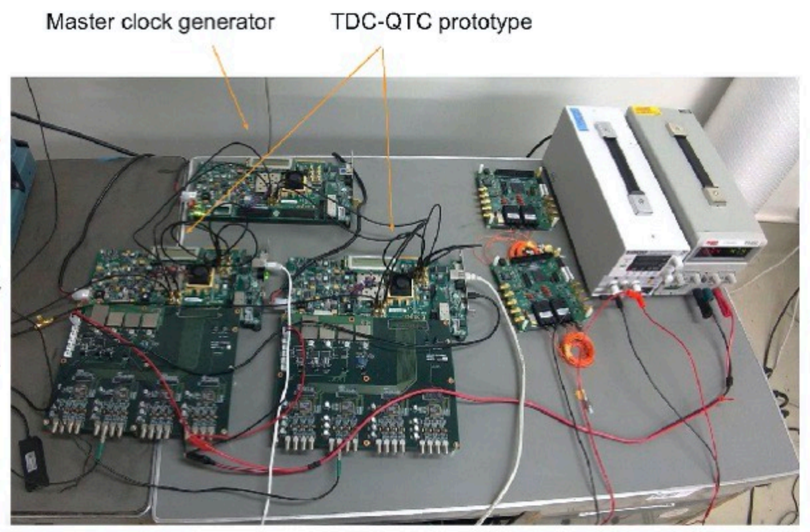


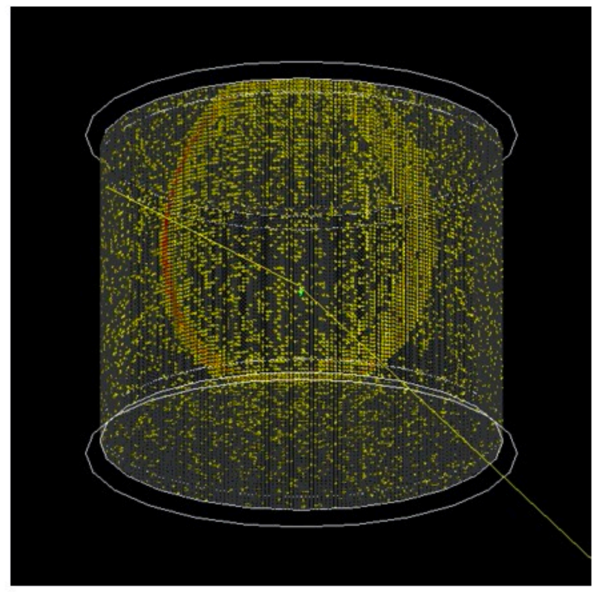
Linac for calibration
Developed in Poland



PMT cover
in Spain

Sync and clock system
test bench at TokyoTech

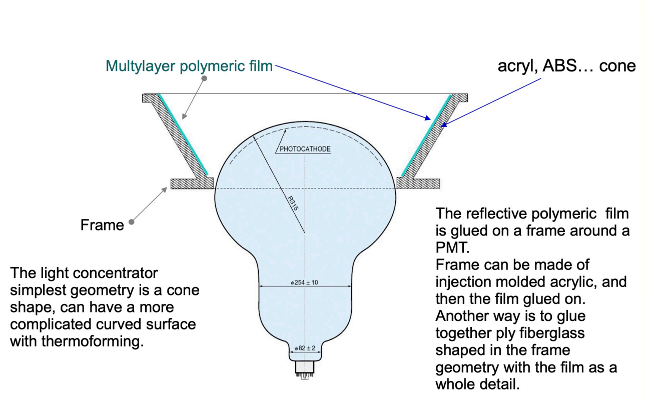




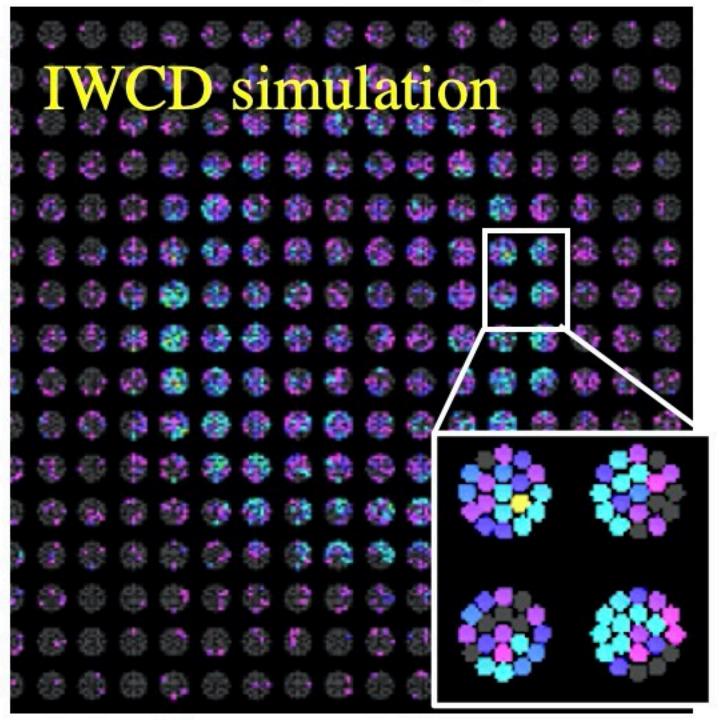
Dedicated software
Simulation and reconstruction

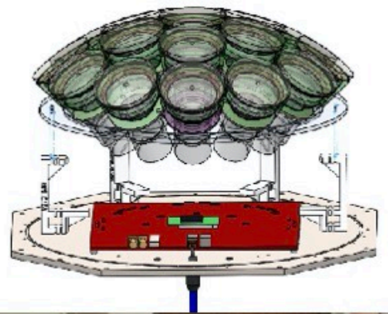
Light collector R&D
(Russia & Japan)

Conception of the light concentrator



Multi-PMT module:
(ref. KM3NeT)
High resolution Cherenkov ring imaging essential for IWCD
Consider to use for part of HK






Prototype at TRIUMF

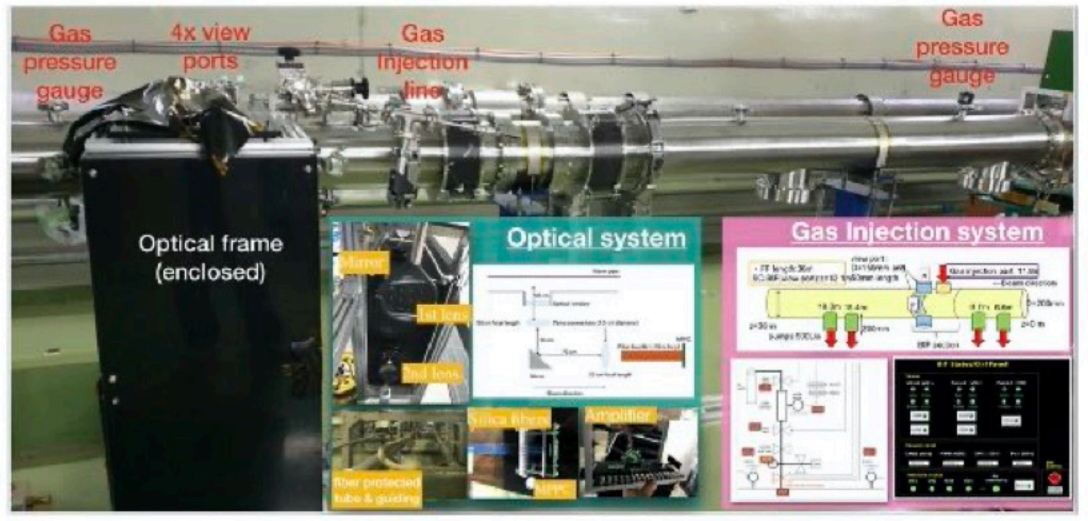

Electronics at INFN

20-inch MCP PMT:
Test in dark room

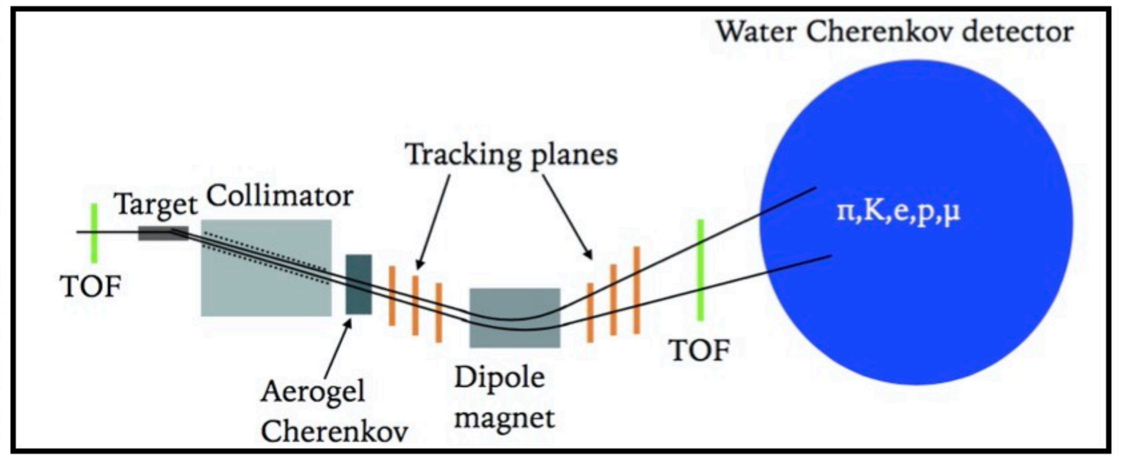

mPMT in Memphyno water tank in France


Box&Line PMT in Super-K

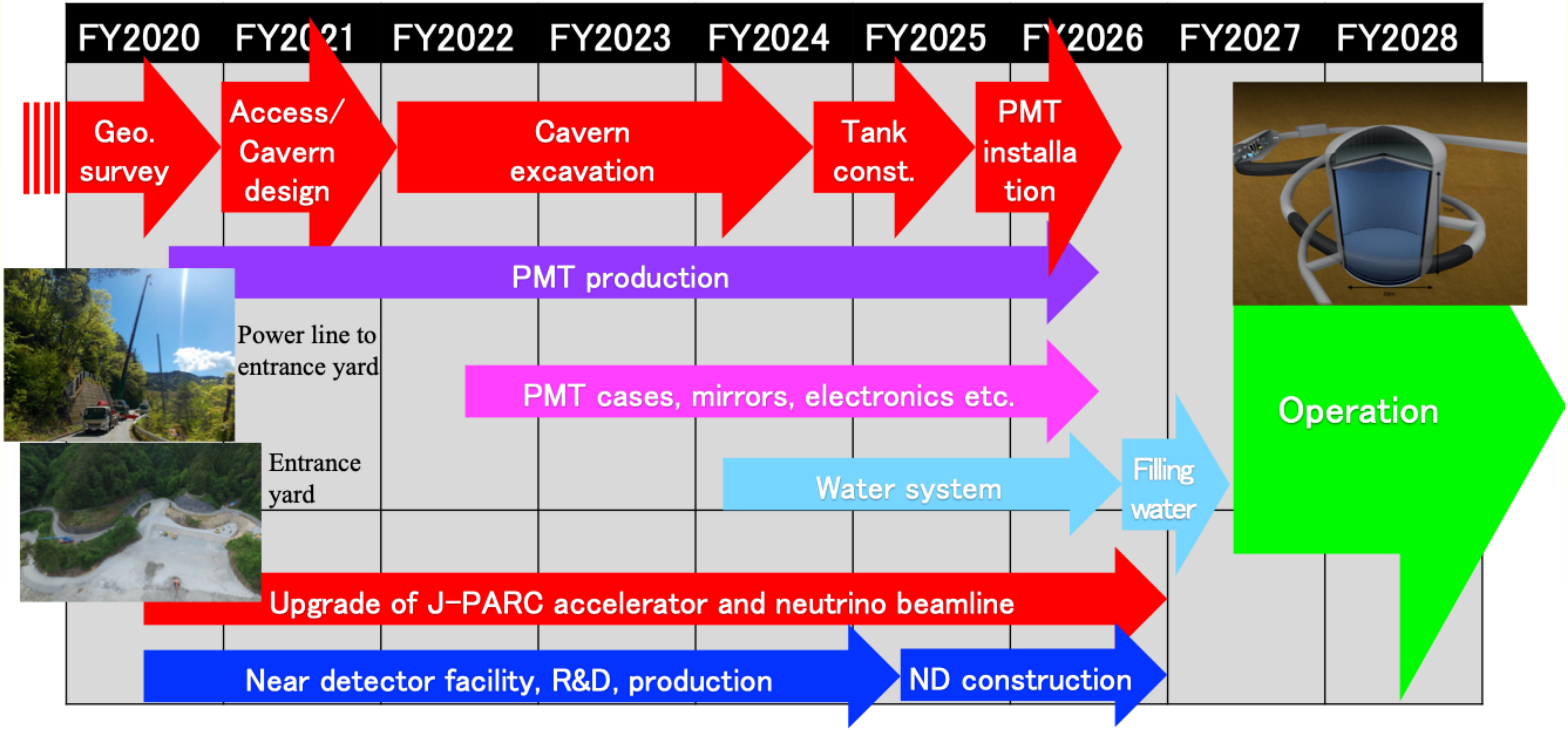
New beam monitor



WC test experiment at CERN



Project timeline



Conclusions

- Hyper-Kamiokande is the next generation water Cherenkov detector with a very broad science capability
  - Based on the success of Kamiokande and Super-Kamiokande
  - Proton decay (>10^{35} years), neutrino oscillation, neutrino astrophysics, ...
- Project was **approved** in 2020 and **construction has started**
- International collaboration is working together for the **start of experiment in 2027**