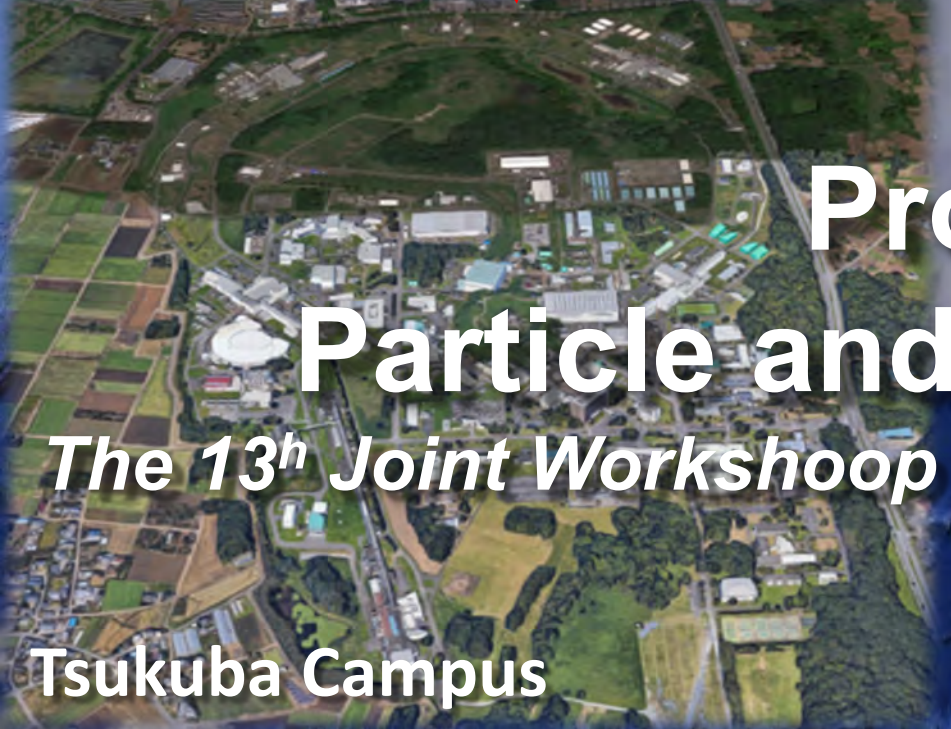


Tokai  
Tsukuba



Tokai Campus



Tsukuba Campus

# Progress Report on Particle and Nuclear Physics

*The 13<sup>th</sup> Joint Workshoop of FKPPN and TYL/FJPPN, May 22-24, 2024*

**Naohito SAITO**

**IPNS**

Institute of  
Particle and  
Nuclear Studies

**IMSS**

Institute of  
Materials  
Structure Science

**QUP**

International Center  
for Quantum Field  
Measurement Systems  
for Studies of Particle  
and Universe

**ACCL**

Accelerator  
Laboratory

**ARL**

Applied Research  
Laboratory

**J-PARC**

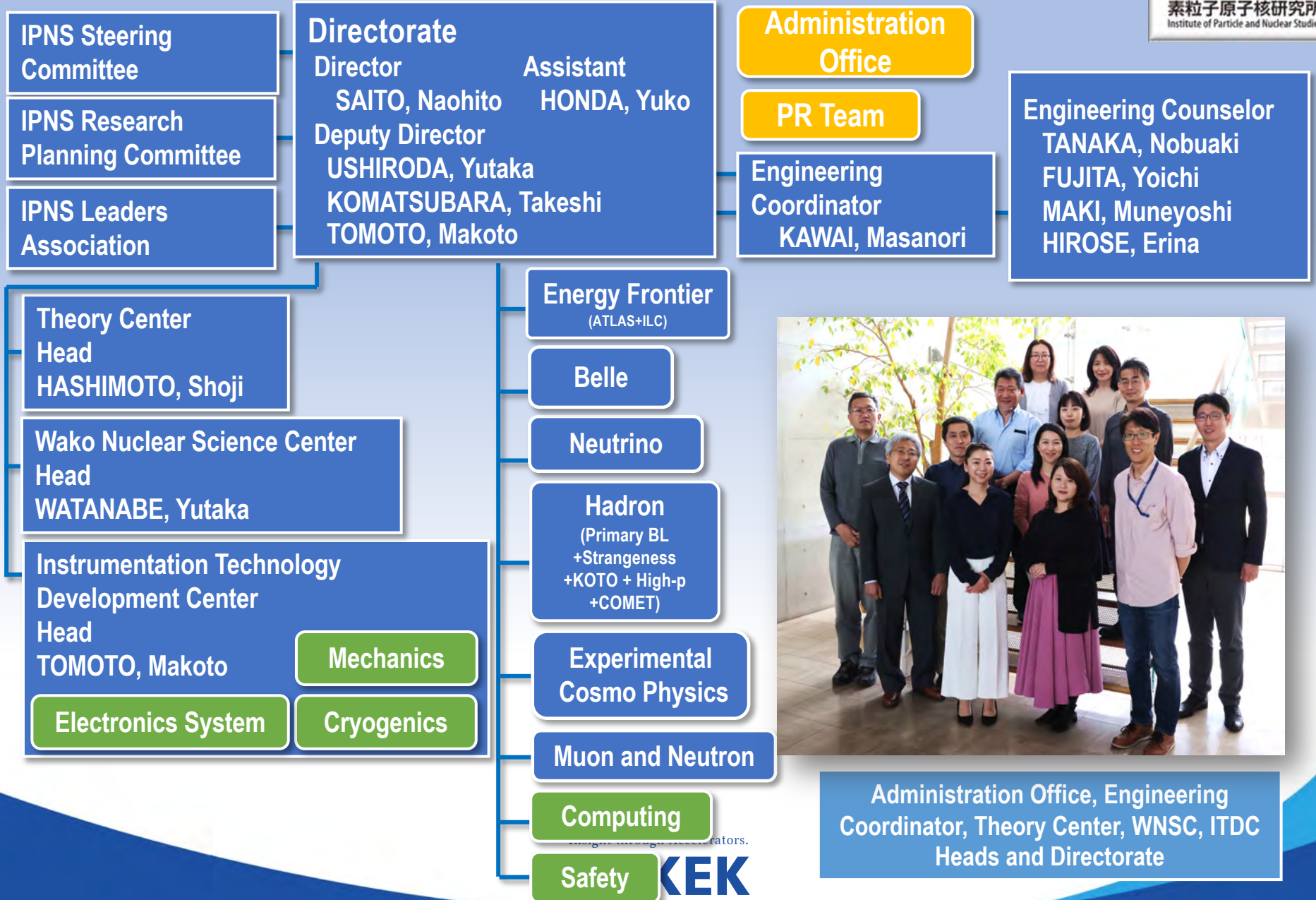
Japan Proton  
Accelerator  
Research  
Complex

Tsukuba Campus



Tokai Campus

# IPNS Organization 2024



Administration Office, Engineering Coordinator, Theory Center, WNSC, ITDC Heads and Directorate

ATLAS実験  
(CERN)

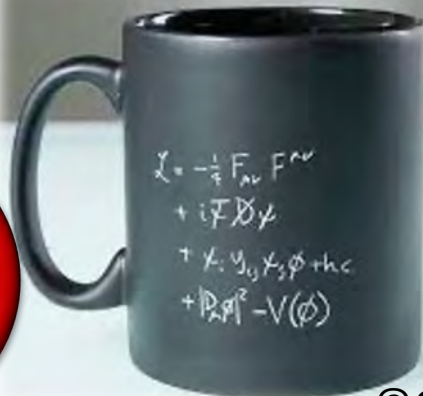
国際リニアコライダー計画  
(将来計画) ILC

KISS実験  
(理研)

エネルギー  
フロンティア  
Energy  
Frontier

理論物理  
Theoretical  
Physics

ハドロン  
核物理  
Hadron  
Nuclear



©CERN

KOTO実験  
(J-PARC)

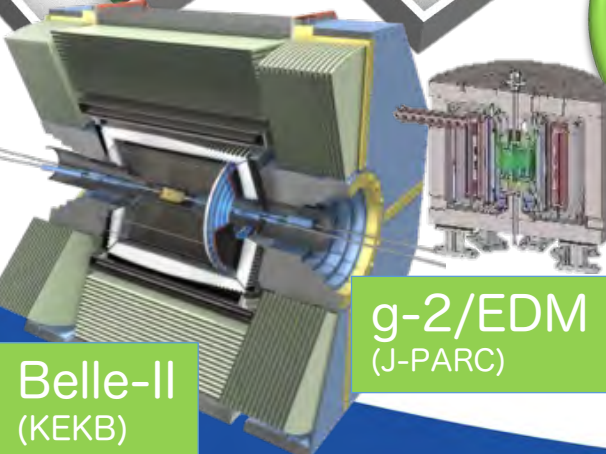
COMET実験  
(J-PARC)

宇宙  
素粒子物理  
Astro-Particle  
Physics

LiteBIRD  
(Space)

ハドロンホール  
(J-PARC) Hadron Hall

フレーバー  
物理  
Flavor  
Physics



g-2/EDM  
(J-PARC)



Super-Kamiokande

UCN  
(TRIUMF)

T2K and Hyper-K  
(J-PARC&神岡)



J-PARC Main Ring  
(KEK-JAEA, Tokai)



## Inter-University Research

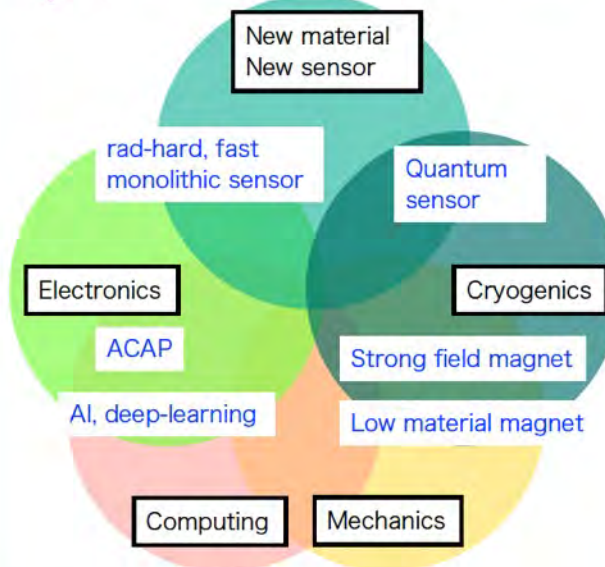
- Extension of inter-university research functions
- More efficient and faster development  
→ International visibility



- Wider users by simpler system for use  
→ Young researchers such as student can easily use  
→ Education

## Cutting Edge Technology Development

- **Common/Core technologies for next generation projects**  
← final application by each project (continue to have support function)
- Some platforms to do R&D
  - works as the interface to the community
- Technology candidates
  - Strong field magnets
  - New material semiconductor (eg. CIGS) for rad-hard
  - BiCMOS technology for high speed
  - Next generation FPGA based readout
  - ...



## Technology Development Platforms

Cryogenics

Mechanics

Sensor

Light sensor

semiconductor  
gas & active  
medium

Electronics

System  
integration

Collider  
Electronics

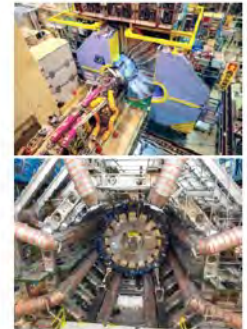
SPADI alliance

Computing

Platform Organization  
flexible, always ready  
to start new one

## Researcher Community

IPNS projects



KEK projects



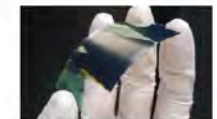
REBCO for HL-LHC

Education



HEP school

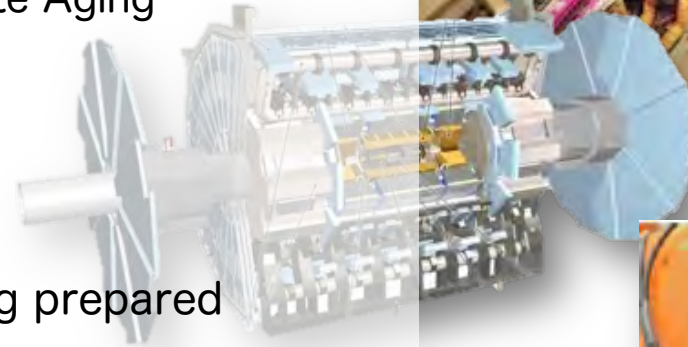
Industry



organic semiconductor

# IPNS Projects current status

- Belle II
  - Continue Run 2 towards higher Lumi after LS1
  - Physics analyses are ongoing; streamline of results
- J-PARC
  - MR resumed; FX achieved  $> 760$  kW ; SX  $> 80$  kW
  - Securing the Beamtime and Mitigate Aging
  - Physics Production
  - Hyper-K construction ongoing
    - IWCD /Beamline upgrades
- ATLAS/LHC
  - Run3 resumed in Spring
  - Detectors and Magnets are being prepared towards HL-LHC
- ITDC
  - Test beamline is being operated
  - R&D platforms are active
- Project Implementation Plan 2022 realization
  - Muon g-2/EDM@J-PARC
    - Annual review is to be held in March
  - Optimization of Hadron Experimental Facility Extension (HEF-ex)
  - LiteBIRD : phase-A@JAXA
    - ISAS – QUP –IPNS meeting



# The Timeline+

subject to change

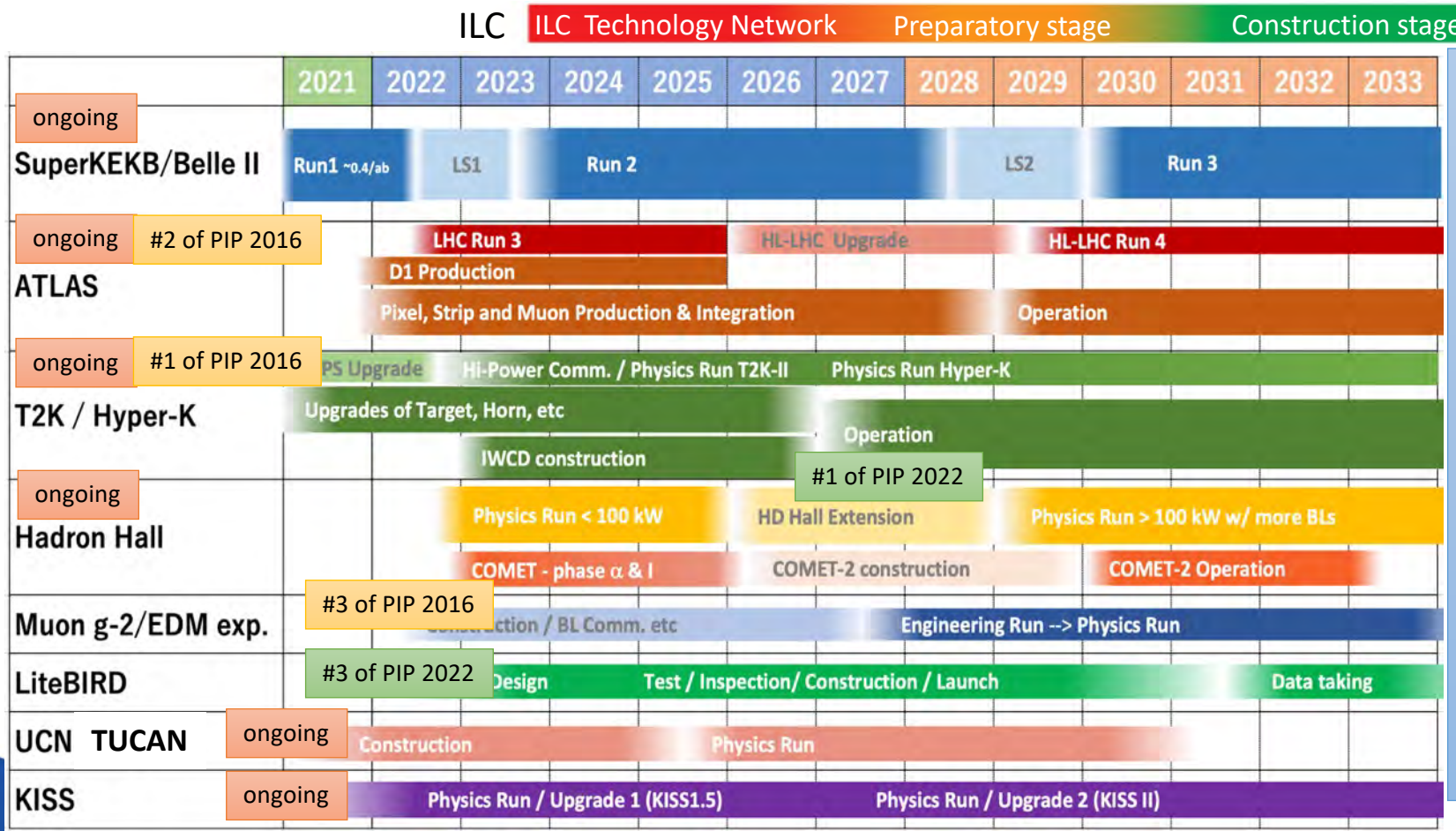
- Aggressive version of intended schedule by IPNS.
- PIP = Project Implementation Plan

## PIP2016

1. Hyper-K /J-PARC upgrades
2. HL-LHC
3. muon g-2/EDM
4. HEF extension

## PIP2022

1. HEF extension
2. HL-LHC++
3. LiteBIRD
4. Muon Microscope



Will start future plan

# IPNS Task Force Meetings

- **B-Factory Promotion Office Meeting (weekly)**
  - Co-chaired by KOSEKI, Tadashi and IPNS director
  - Cf. Dedicated TF for Luminosity Improvement (chaired by DG) started last summer
- **Hadron Promotion TF (bi-weekly)**
  - Chaired by NAKAMURA, Satoshi (U Tokyo)
  - Drive HEF-Ex Planning and Physics production
- **COMET Promotion TF (bi-weekly)**
  - Chaired by AOKI, Masaharu (Osaka U)
  - Encourage communication btwn Facility and Collaboration
- **Neutrino Promotion TF (bi-weekly)**
  - Chaired by NAKADAIRA, Takeshi
  - Discuss facility issues, IWCD, group development, budget etc.
- **Energy Frontier Promotion TF (non-periodic)**
  - Chaired by TOMOTO, Makoto
  - Drive activity related to Energy Frontier i.e. ILC and future colliders
- **Muon g-2/EDM Promotion TF (~monthly)**
  - Chaired by MIBE, Tsutomu
  - Drive activity related to Energy Frontier i.e. ILC and future colliders
- **LiteBIRD Promotion TF (monthly)**
  - Chaired by HASEGAWA, Masaya
  - Drive preparation activities with ISAS/JAXA

Operation after LS1 and ITF

Realistic Facility Design

Endgame plan of Phase-1

IWCD, T2K run, HK construction

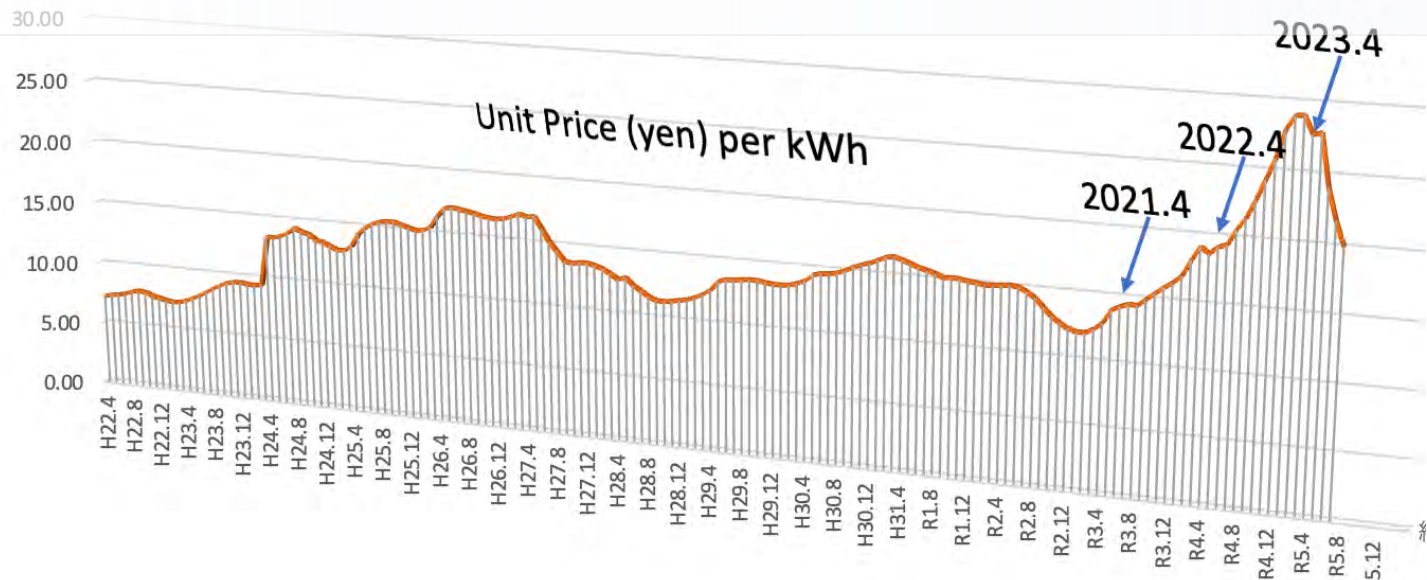
To be resumed ...

To be initiated soon

Transition to Phase-A

# Prospects of Electricity Bill and Beamtime

- Fuel surcharge is trending downwards, with still growing concern due to global instability
- Thanks to a great support by DG and MEXT, we think we can run until the end of CY, and hoping for additional support to run until the end of FY.



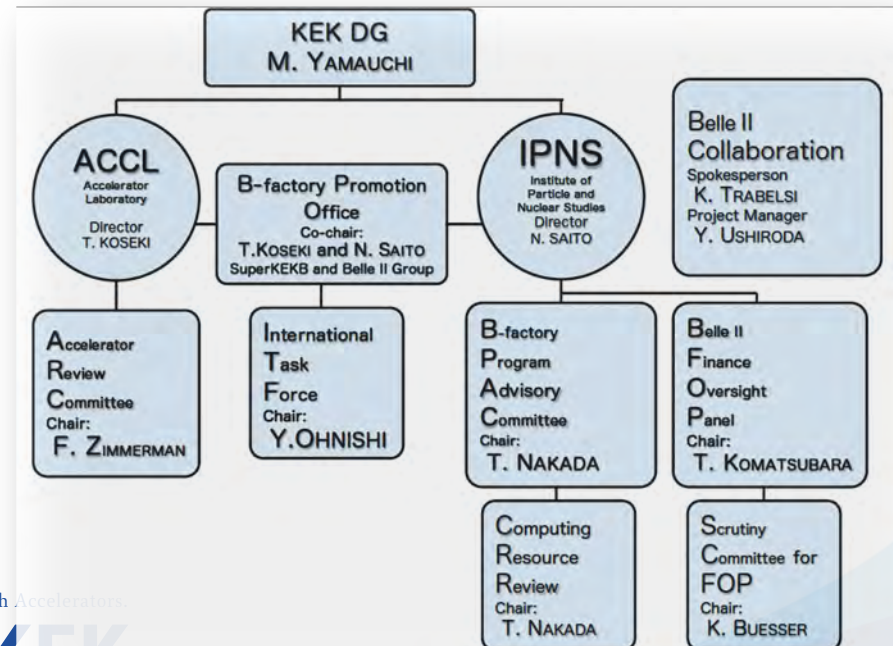
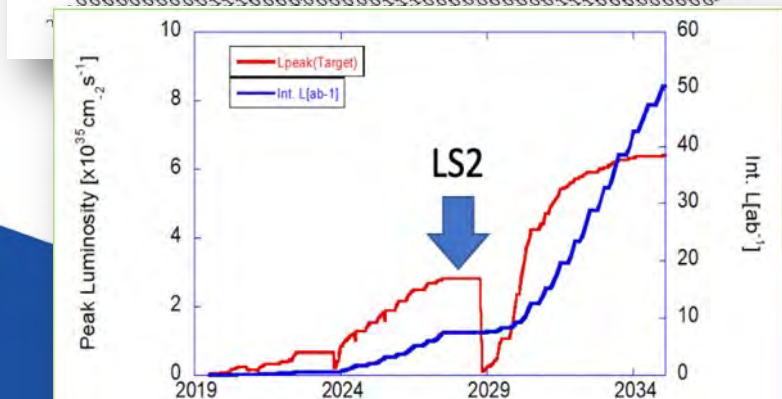
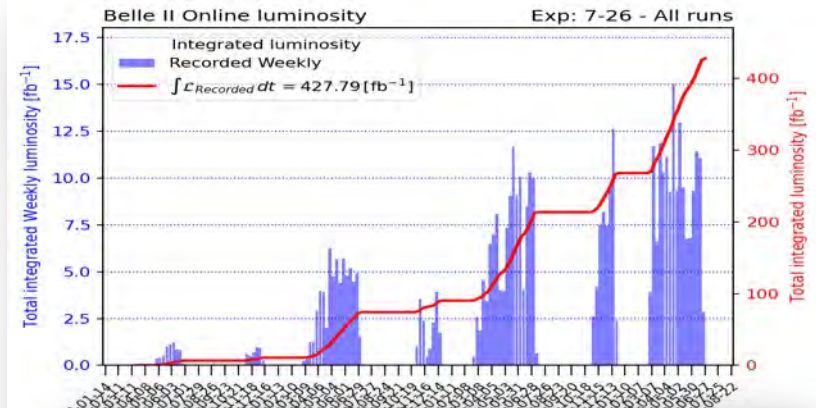
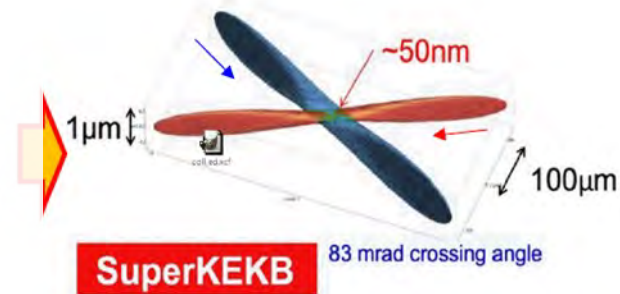
We hope to cover most part of available period in FY 2024.

# Belle II and Belle

# Overview

## Exploration of New Physics with the World Highest Luminosity

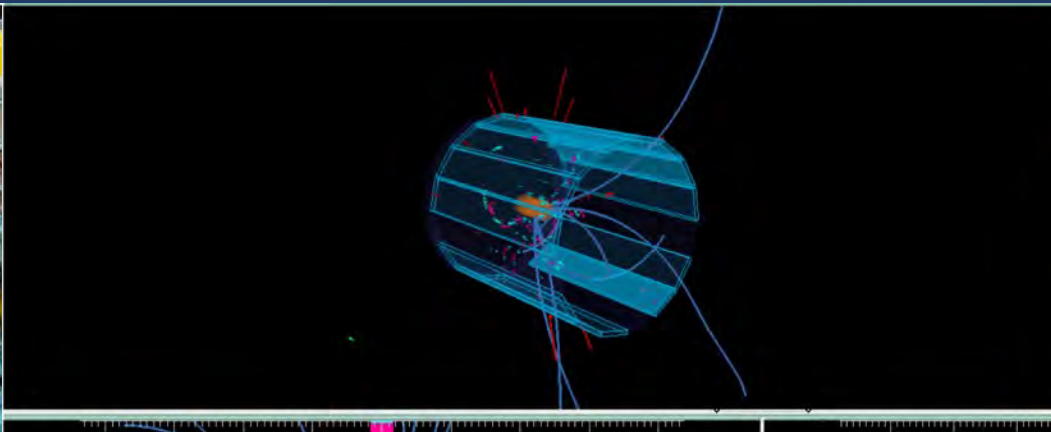
- A Quest for More Luminosity
  - SuperKEKB achieved  $4.7E34\text{cm}^{-2}/\text{s}$  in 2022.
    - KEKBx2.2; PEP-IIx3.8; Still need a factor  $> 10$  improvement
  - Belle II Integrated Luminosity  $428/\text{fb} \sim 41\%$  of Belle's
    - Sensitivities started to exceed Belle thanks to better detector and analysis.
- Near+long term plan is being made with acc group
  - CDR studies for LS2 upgrades and beyond were reviewed at BPAC
    - Still need to form a coherent scenario of an upgrade.



# Belle II and Belle

Run 2 started!

Exploration of New Physics with the World Highest Luminosity



*Belle II*

First Collisions of Run 2  
20<sup>th</sup> February 2024



## What are our goals for 2024 ?

(please a clear and sound message)

YAY!  
Exciting  
times  
ahead.



**Run stably at  $10^{35} / \text{cm}^2 / \text{s}$**

**reach  $150 \text{ fb}^{-1}$  per month**

**exceed  $1 \text{ ab}^{-1}$**

(setting the pace for run 2)

(while doing good physics and working for the upgrade)

... 'This was their finest hour.'

## Exploration of New Physics with the World Highest Luminosity

- Intensive discussions at PHYSICS WEEK (Nov, 2023) - in collaboration with IPNS Theory Center, >100 participants, 20 invited experts/theorists, KEK report being written

### PHYSICS

3:00 PM → 3:20 PM	<b>Physics Overview</b> Speaker: James LIBBY (KEK/IPNS)
3:30 PM → 3:50 PM	<b>Belle/Belle II merger and recent Belle highlights</b> Speaker: Shohei NISHIDA (KEK/IPNS)
4:00 PM → 4:20 PM	<b>Interim report on the Vcb workshop</b> Speaker: Diego TONELLI (INFN Trieste)
4:30 PM → 4:50 PM	<b>Generators working group report</b> Speaker: Swagato BANERJEE (University of Louisville)
9:00 AM → 9:20 AM	<b>EWP summary and plans</b> Speaker: Elisa MANONI (National Institute for Nuclear Physics)
9:30 AM → 9:50 AM	<b>Tau summary and plans</b> Speaker: Laura ZANI (INFN of Roma Tre)

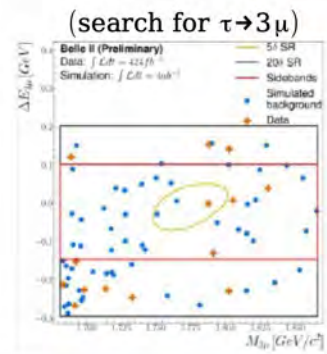
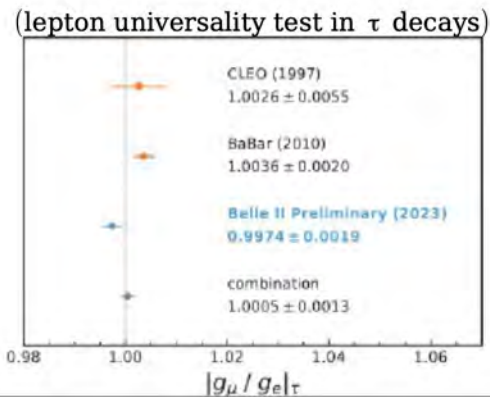
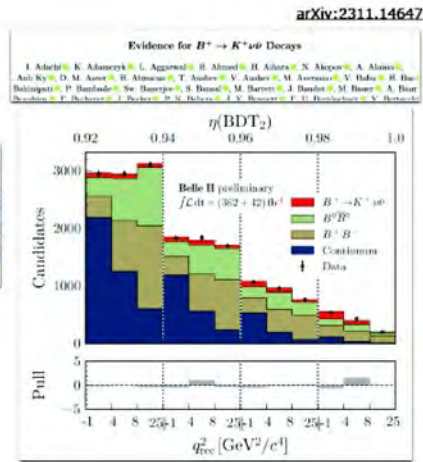



Precision  $|V_{cb}|$  at Belle II  
A reappraisal  
(KEK report in preparation)

All the authors

### Menu

- $b \rightarrow s/d \ell \ell$
- $b \rightarrow s/d \gamma$
- $b \rightarrow d (B^0 \rightarrow \gamma \gamma \text{ analysis})$
- $b \rightarrow s \ell \ell'$
- $b \rightarrow s \tau \tau$
- $b \rightarrow s \tau \ell$
- $b \rightarrow s \nu \nu$
- $b \rightarrow \ell \ell$



## Exploration of New Physics with the World Highest Luminosity

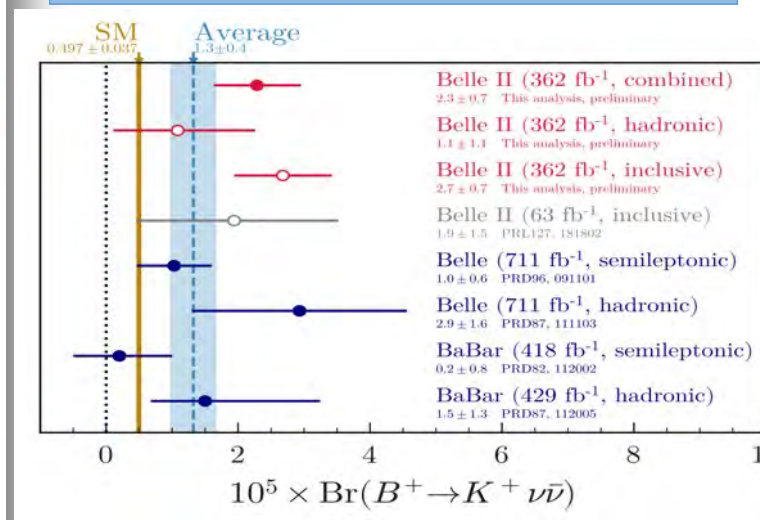
- A streamline of physics production from Belle and Belle II

### Paper acceptance (2) and submitted (6)

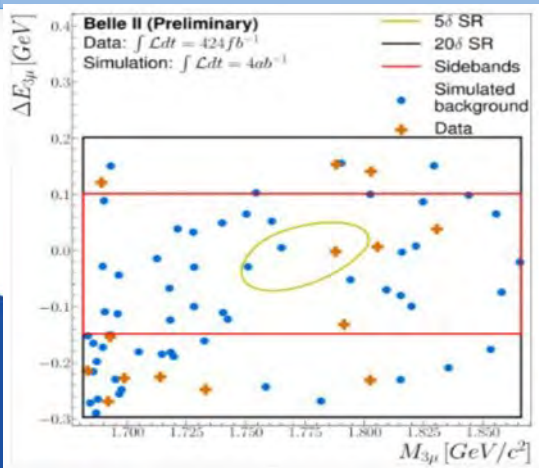
- #18 Evidence for  $B^+ \rightarrow K^+ \nu \bar{\nu}$  decays – comments received from PRD
- #24 Measurement of branching fractions and direct CP asymmetries of  $B \rightarrow K\pi$  and  $B \rightarrow \pi\pi$  decays in 2019-2022 Belle II data- Published PRD
- #26 Search for a long-lived spin-0 mediator in  $b \rightarrow s$  transitions at the Belle II experiment – Published PRD
- #28 Measurement of branching-fraction ratios and CP asymmetries in  $B^\pm \rightarrow D_{CP}^\pm K^\pm$  decays at Belle and Belle II – replied to second round of JHEP comments
- #32 Search for the  $e^+e^- \rightarrow \eta_b(1S)\omega$  and  $e^+e^- \rightarrow \chi_{b0}(1P)\omega$  processes at  $\sqrt{s}=10.745$  GeV – submitted PRD
- #33 A test of lepton flavour universality with a measurement of  $R(D^*)$  using hadronic tagging at the Belle II experiment – submitted PRD
- #37 Study of  $Y(10753)$  decays to  $\pi^+\pi^-Y(nS)$  ( $n=1,2,3$ ) at Belle II – submitted JHEP
- #38 First measurement of  $R(X_{\tau/\ell})$  as an inclusive test of the  $b \rightarrow c\tau\nu$  anomaly – Report from PRL received

All but two of the remaining 10 Spring/Summer 2023 results are through 2<sup>nd</sup> round of collaboration wide review, i.e., submission soon

### Evidence for $B^+ \rightarrow K^+ \nu \bar{\nu}$ decays

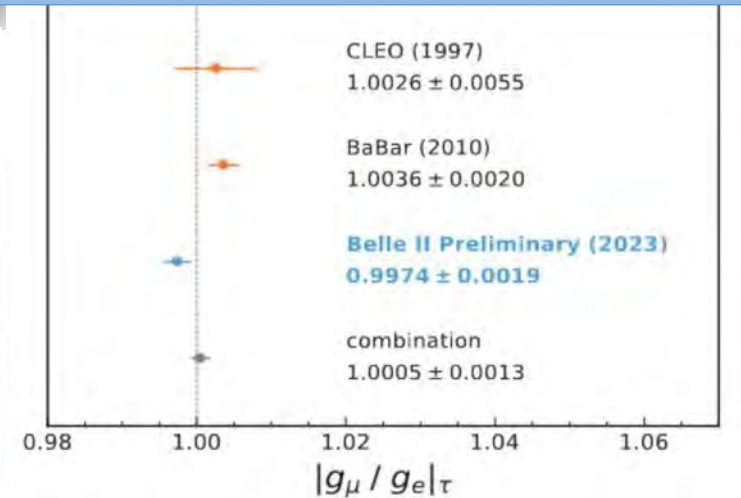


### Search for LFV decays $\tau \rightarrow \mu\mu\mu$



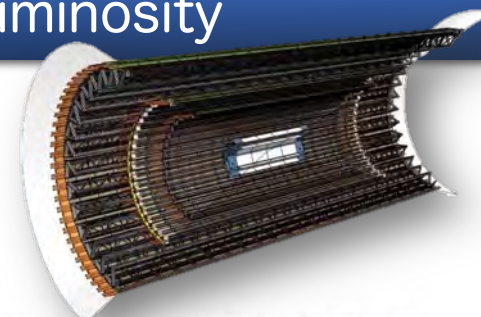
Experiment (Luminosity [fb <sup>-1</sup> ])	$\mathcal{B}_{90}^{\text{UL}}(\tau \rightarrow \mu\mu\mu)$ [10 <sup>-8</sup> ]
Belle (782) <sup>1</sup>	2.1
CMS (131) <sup>2</sup>	2.9
LHCb (3) <sup>3</sup>	4.1
<b>Belle II (424)</b>	<b>1.9</b>

### Test of Lepton Flavor Universality in $\tau$ decays



# Belle II and Belle Upgrades for LS2 and beyond

## Exploration of New Physics with the World Highest Luminosity



- CDR studies was reviewed at BPAC this month
  - More coherent scenario is to be formulated; R&D continues

### Motivations for the upgrade

- Improve detector robustness against backgrounds
- Provide larger safety factors to run at high luminosity
- Increase longer term subdetector radiation resistance
- Develop the technology to cope with different future paths,
  - e.g. if a major interaction region (IR) redesign is required to reach the target luminosity
- Prepare a safety net in case of failure of detector components or accidents
- Keep detector experts engaged and profit from technological advances
- Improve physics performance: get more physics per  $ab^{-1}$ .

### Upgrades CDR Table

Table 1.2: Known short and medium-term Belle II subdetector upgrade plans, sorted by time scale. MDI is the Machine-Detector-Interface, while RMBA is Radiation Monitoring and Beam Abort system. Moving from inner to outer radius, the current Belle II sub-detectors are: Silicon Pixel Detector (PXD), Silicon Strip Detector (SVD), forming the Vertex Detector (VXD), Central Drift Chamber (CDC), Time of Propagation Counter (TOP), Aerogel Rich Counter (ARICH), Electromagnetic Calorimeter (ECL), K-Long Muon System (KLM), Trigger and Data acquisition (TRG/DAQ), including the High Level Trigger (HLT).

Subdetector	Function	upgrade activity	time scale
MDI	RMBA	Faster and more performant electronics	medium-term
VXD	Vertex Detector	all-pixels DMAPS CMOS sensors (VIX)	medium-term
CDC	Tracking	upgrade front end electronics	short/medium-term
TOP	PID, barrel	Replace not-life-extended ALD MCP-FMIS Front end electronics upgrade	medium-term medium-term
KLM	$K_L, \rho$ ID	replace 13 barrel layers of legacy RPCs with scintillators upgrade of electronics readout and proportional mode RPC readout timing upgrade for K-long momentum measurement	medium/long-term medium/long-term medium/long-term
Trigger		hardware and firmware improvements	continuous
DAQ		add 1300-1900 cores to HLT	short/medium-term
ARICH	PID, forward	replace HAPD with Silicon PhotoMultipliers replace HAPD with Large Area Picosecond Photodetectors	long-term long-term
ECL	$\gamma, e$ ID	Add pre-shower detector in front of ECL Complement ECL PiN diodes with APDs or SiPM Replace CsI(Tl) with pure CsI crystals	long-term long-term long-term

### Next steps

- CDR
  - We would like to incorporate BPAC input in the next few months
  - Publish to arXiv soon (April ?)
- Use the CDR to
  - Organize and focus the R&D and engineering work
  - Start talking to funding agencies
  - Build/reinforce the groups behind the project
    - For example UK (QMUL) recently joined Belle II with a specific interest on upgrades
- Consolidate the timeline
  - Information from 2024 running
  - First results from the new IR R&D and design
- Prepare the Technical Design Reports
  - Different systems will probably move on different timescales
  - Plan to prepare separate TDRs for systems actually going forward

### P5 recommendations

- Recent P5 recommendations include support for the Belle II upgrade and the SuperKEKB accelerator development
- This bodes well for increasing the support for the upgrade effort and involving more groups

**Recommendation 3:** Create an improved balance between small-, medium-, and large-scale projects to open new scientific opportunities and maximize their results, enhance workforce development, promote creativity, and compete on the world stage.

- In order to achieve this balance across all project sizes we recommend the following:
- Implement a new small-project portfolio at DOE, Advancing Science and Technology through Agile Experiments (ASTAE), across science themes in particle physics with a competitive program and recurring funding opportunity announcements. This program should start with the construction of experiments from the Dark Matter New Initiatives (DMNI) by DOE-HEP (section 6.2).
  - Continue Mid-Scale Research Infrastructure (MSRI) and Major Research Instrumentation (MRI) programs as a critical component of the NSF research and project portfolio.
  - Support DESI-II for cosmic evolution, LHCb upgrade II and Belle II upgrade for quantum imprints, and US contributions to the global Cherenkov Telescope Array (CTA) Observatory for dark matter (sections 4.2, 5.2, and 4.1).
- The Belle II recommendation includes contributions towards the Super-KEKB accelerator.

# Energy Frontier

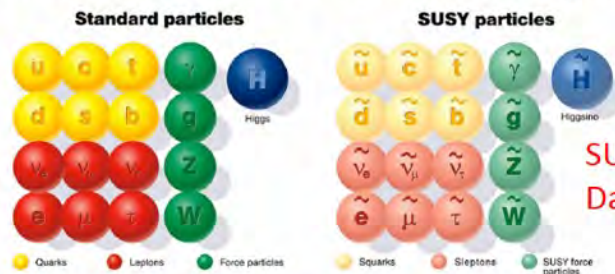
# LHC/ATLAS



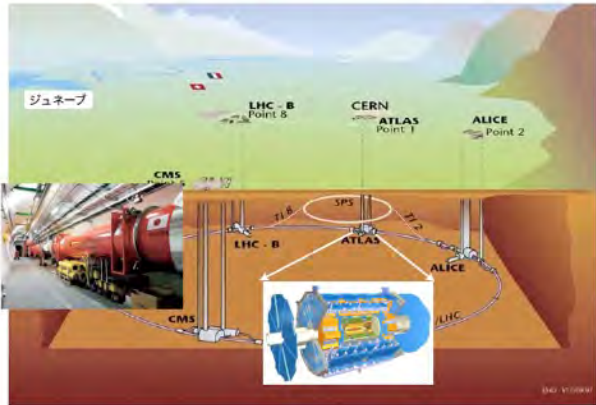
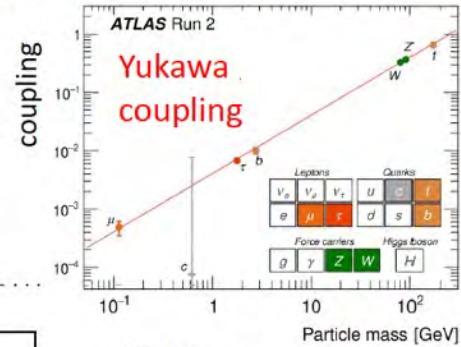
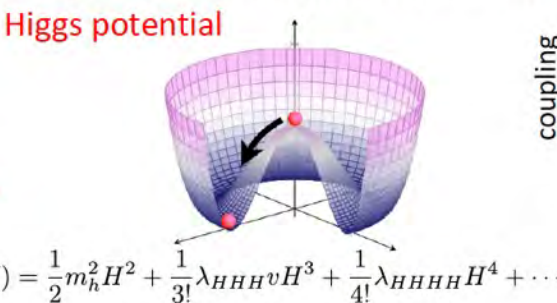
# Energy Frontier

# LHC/ATLAS

- Reveal new physics through;
  - direct searches for the new particles



- precision measurement of the Higgs boson

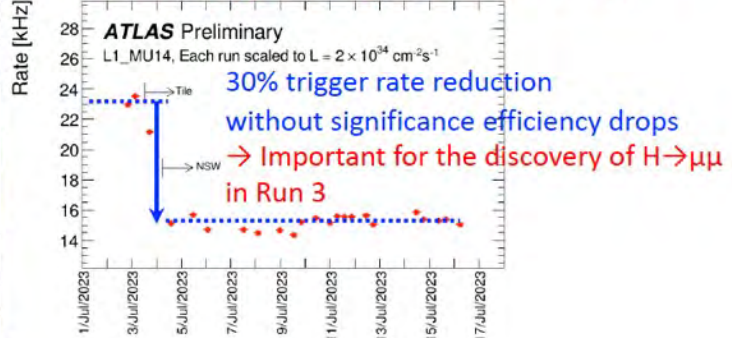
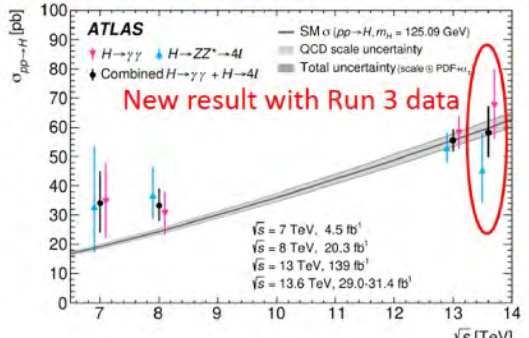


2012 : Discovery of the Higgs boson  
 2015~2018: Run 2 experiment (13 TeV)  
 1,186 papers published (2024/1/1) !  
 2022~2025: Run 3 experiment (13.6 TeV)  
 2026~2028: HL-LHC upgrade  
 2029~ : HL-LHC (14 TeV)

ATLAS:  
 42 countries  
 183 institutions  
 ATLAS-Japan:  
 13 institutions  
 ~150 physicists

Japan plays leading role in the construction and operation of accelerator and detectors as well as physics analysis.

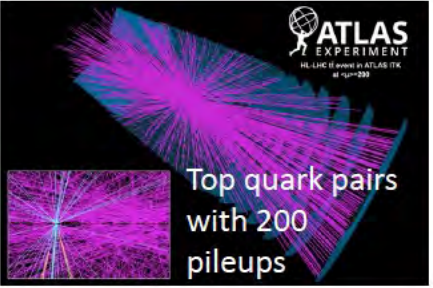
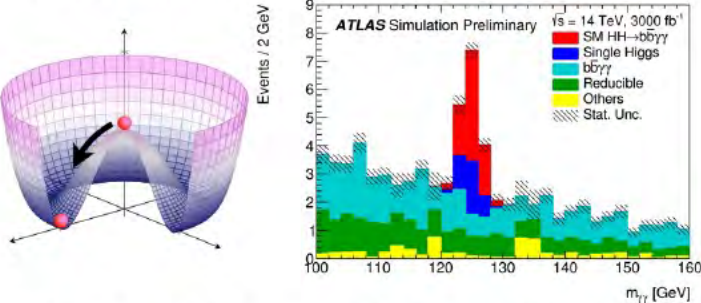
- Run 3 experiment with  $\sqrt{s} = 13.6$  TeV collected  $L=70 \text{ fb}^{-1}$  of proton-proton collision data. One of the major Japanese contribution to Run 3 is introduction of the new muon trigger using New Small Wheel



# Energy Frontier

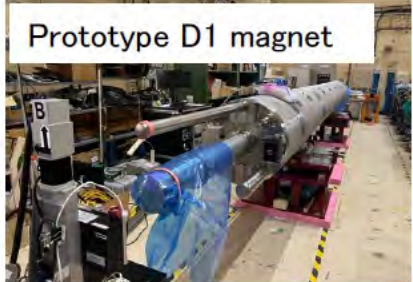
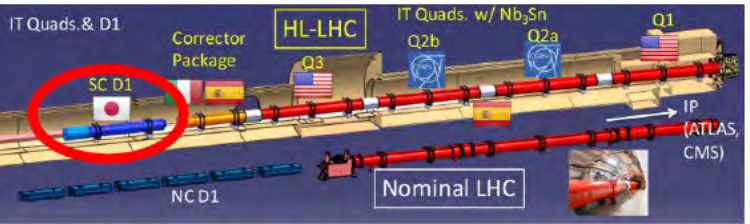
# HL-LHC upgrade

- × 10 data allows as to search for new physics by not only direct searches but also precise measurement of the Higgs couplings.

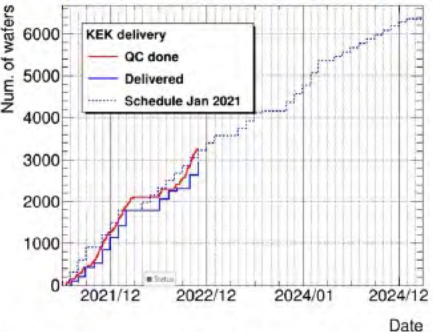


**LHC → HL-LHC: × 10 data**  
**× 10 faster readout**  
**× 10 finer granularity**  
**× 10 radiation hardness**

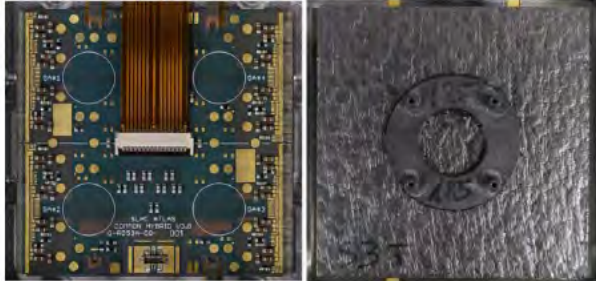
- Seven meters prototype of the beam separation dipole magnet (D1 magnet) completed.
- Production of the real magnet started



- KEK/Japan group plays leading role on upgrades of the inner trackers and muon trigger.



Good progress on silicon strip production



Preproduction Silicon pixel module starts soon



Muon trigger board prototype in good shape

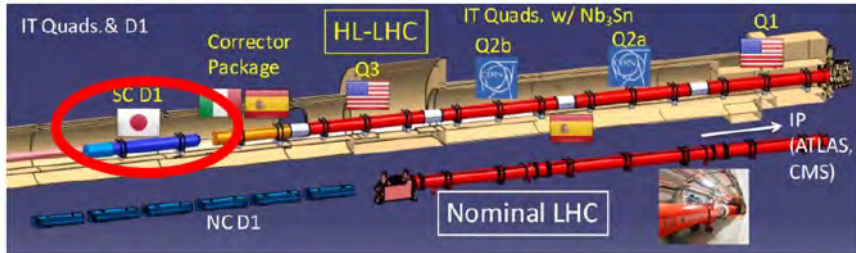
# Energy Frontier

# HL-LHC upgrade

The importance of HL-LHC has been further increased by the achievement of the LHC !

### Challenges of the HL-LHC accelerator

- High field and larger aperture magnets around IP
  - Introduction of the crab cavity
- Japan is charged with the production of six D1 beam separation magnets

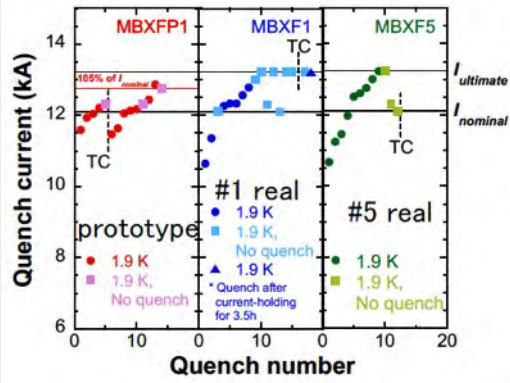


### Challenges of the detector for HL-LHC

- Finer granularity and enhanced radiation tolerance detectors
- Faster and sophisticated trigger/DAQ system

Japan is in charged of the production of

- Silicon pixel modules (25% of outer barrel and endcap)
- Silicon strip sensors (6,350 sensors)
- Endcap muon trigger electronics (all)



Preparation of string tests with prototype at CERN is on going.

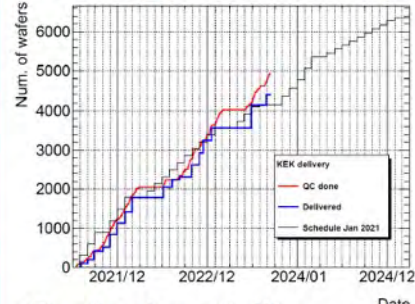
Tests of production magnets are in good shape.

Further Japanese contributions to the HL-LHC accelerator is expected and began.

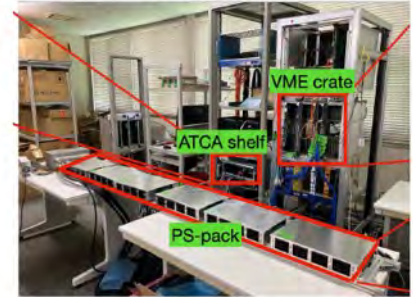
- Power supplies for the quench protection heaters
- RF systems for the crab cavities



Production and QA/QC site for the silicon pixel module are being prepared. Pre-production is on going



Production of silicon strip sensors is in good shape.



QA/QC system for the muon trigger are being prepared

# Energy Frontier

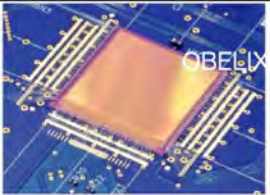
# future frontier experiments

- Promote R&D of the detector system for future Higgs factory experiment while playing leading role in ongoing projects.
  - Solid state detectors for future experiments
    - ✓ Monolithic CMOS sensors
    - ✓ Pico-second timing resolution sensors (SiGe BICMOS, LGAD)
    - ✓ New material (CIGS)
  - Electronics for future experiments
  - AI/Machine Learning for energy frontier experiments
  - High field detector/accelerator magnet
  - Simulation framework for Higgs factory



**MAPS**

- Cheap
- Radiation tolerance :  $2 \times 10^{15}$



In collaboration with Belle

**Monolithic CMOS**  
 $\mu\text{m}$  spatial resolution

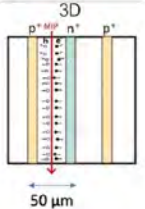
**LGAD**

- timing res. : < 30 ps



**3D**

- timing res. : < 50 ps
- Radiation tolerance :  $2 \times 10^{16}$



**SiGe BiCMOS**

- timing res. : < 20 ps (without gain layer)
- Radiation tolerance :  $1 \times 10^{16}$

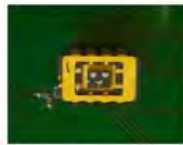
<https://arxiv.org/abs/2310.19398>



In collaboration with U. Geneve UNIVERSITÉ DE GENÈVE

**CIGS:**  
Cu(In, Ga)Se<sub>2</sub>

- Recovery from radiation damage



**New material**  
radhard?

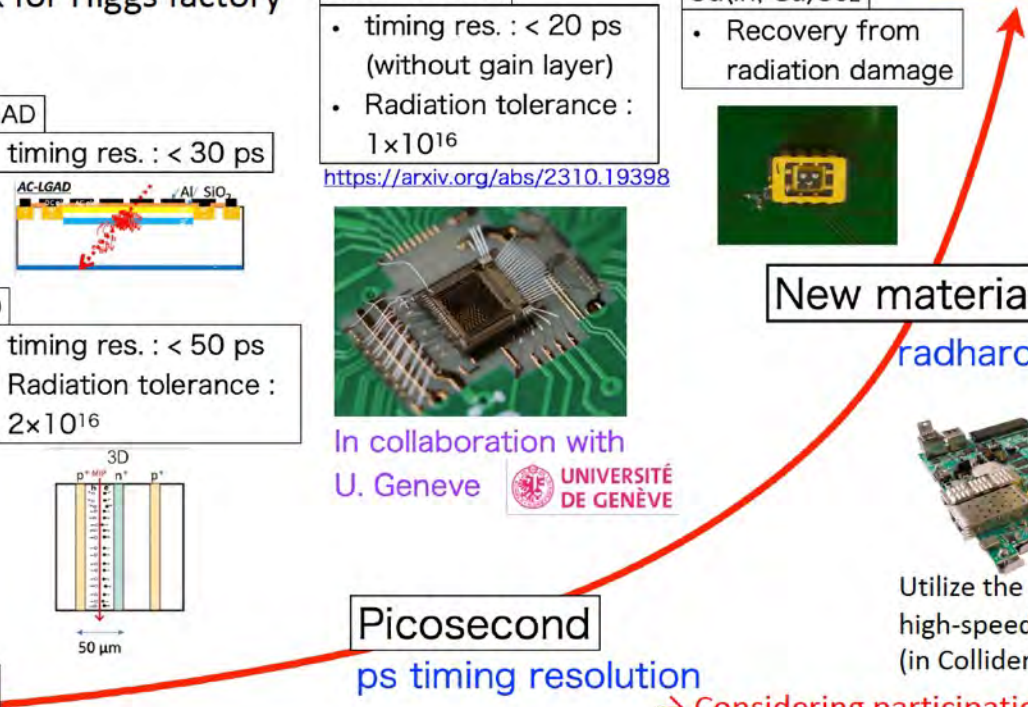


Xilinx VCK190  
Utilize the high-end FPGA and high-speed transceiver (in Collider Electronics Forum)

**Picosecond**  
ps timing resolution

→ Considering participation in the oversea detector R&D projects such as ECFA-DRD.

**Future**



# Particle and Nuclear physics at J-PARC

**Super Kamiokande**

**T2K**

**J-PARC**

295km

**Neutrino Experiment : T2K**  
~ Mixing Angle, CP phase, and Mass Hierarchy ~

**3GeV RCS**

**FX beam**

**CPV in Charged Lepton?**

Surface muon

Ultra cold  $\mu^+$  source

Muon LINAC (300 MeV/c)

**$g_{\mu-2}/\mu$ EDM**

クォーク	第一世代	第二世代	第三世代	強い力 グルーオン 電磁力 光子 弱い力 W <sup>-</sup> W <sup>+</sup> Z ウィークボゾン
	u	c	t	
	d	s	b	
レプトン	$\nu_e$	$\nu_{\mu}$	$\nu_{\tau}$	
	e	$\mu$	$\tau$	

**new particle  $\nu_s$ ?**

**MLF**

**KOTO**

$K_L \rightarrow \pi^0 \nu \bar{\nu}$

CPV beyond CKM

**Hyper-nuclear physics**

**Strangeness in Nuclei**

**Role of strange quark in extreme high density matter?**

**Neutron star**

**Hadron Experiments**  
~ CP beyond CKM; Mass modification ~

Hadron properties in Nuclear Matter

**Hadron Hall**

105MeV

**Flavor&CPV in charged lepton?**  
Search for  $\mu \rightarrow e$  conversion

**COMET (Hadron Hall)**

# Finally J-PARC is up and running!

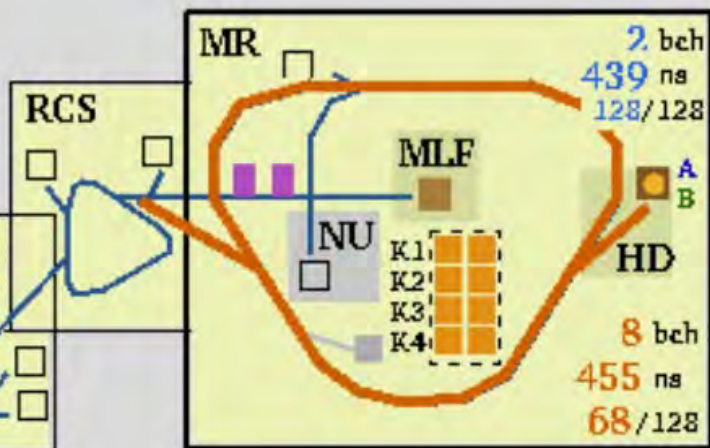
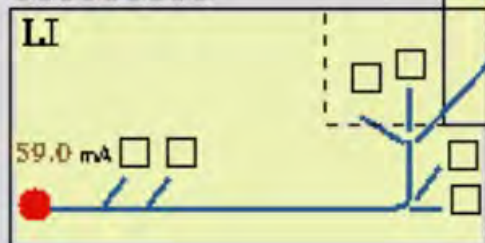
- FX > 750 kW, SX > 80 kW, and MLF~950 kW achieved!

## Beam Destinations of Accel. Run 91

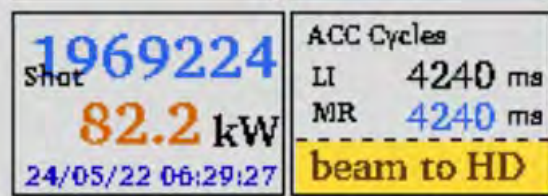
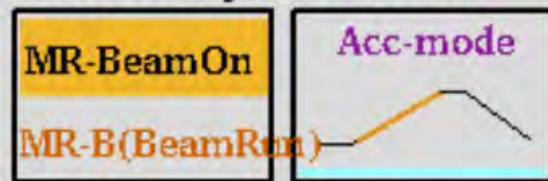
24/05/22 06:29:28

Ver.2.15 (Jan.2024)

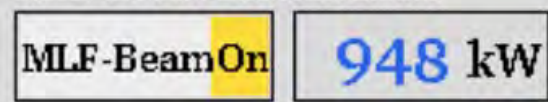
LI MacroPulse  
MLF 500 us  
MR 200 us



### MR Beam Cycle and Mode



### MLF Beam Information

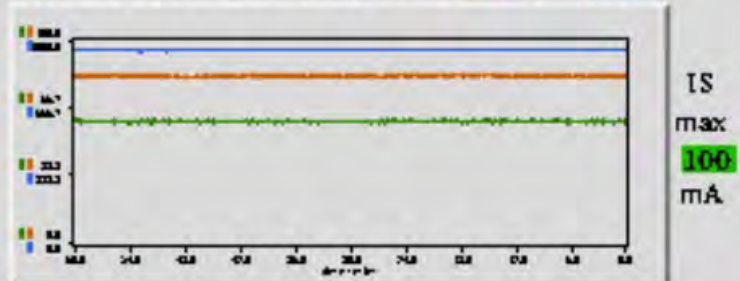


LI	
LI BD 90deg	
LI BD 100deg	
LI BD 30deg	
LI BD 0deg	
LI MEBT1	
LI LEBT	

RCS	
3NBTD AC	
3NBTD DC	
RCS H0 Dmp	
MLF	
MLF TGT	

MR	
MR ExtAbt	
MR InjDmp	
NU	
NU(N TGT)	
HD	
HD(K TGT)	

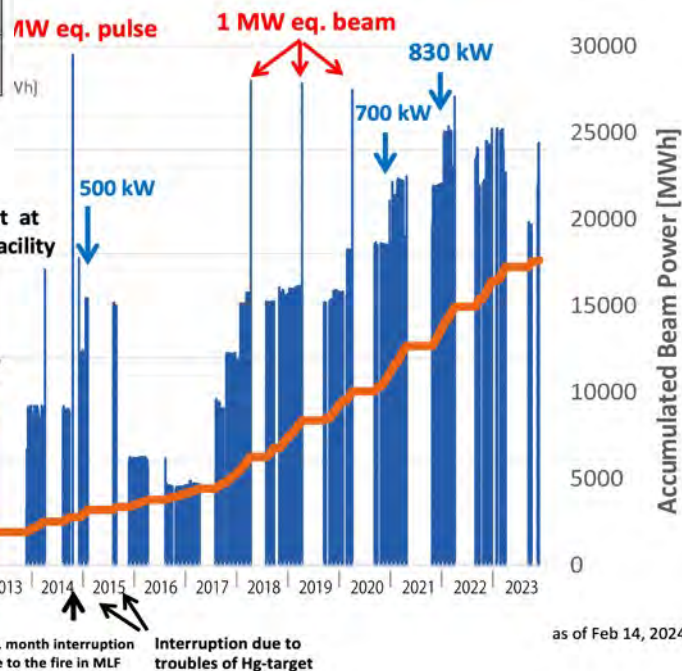
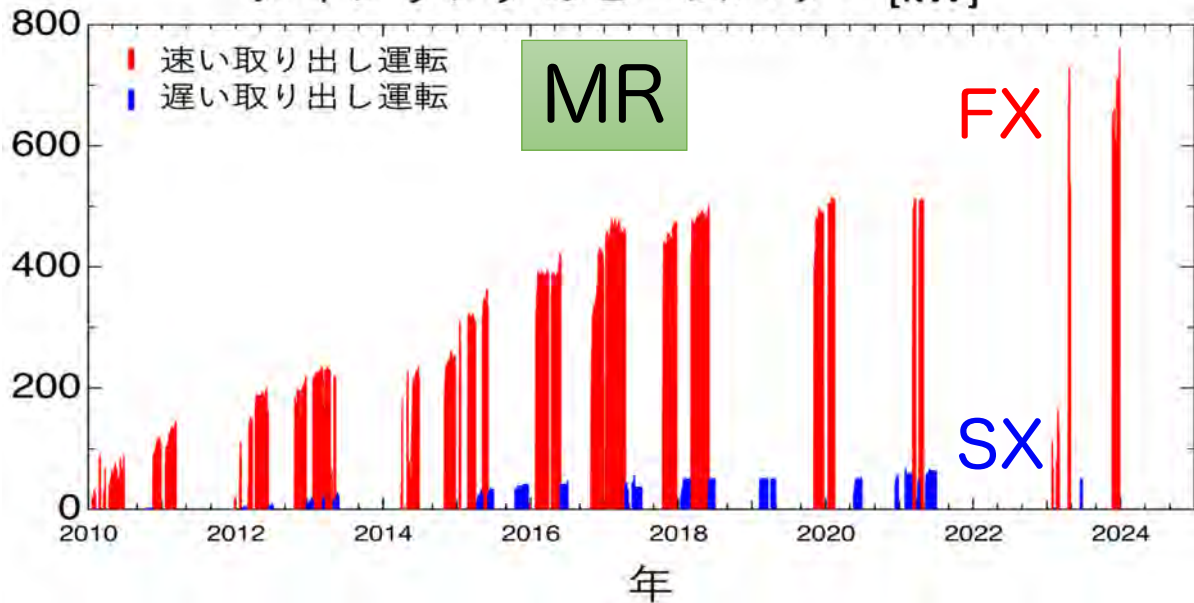
### Power Trend (1 hour) <MLF 1MW/MR 100kW>



# J-PARC Beam Power History

- > 760 kW is achieved for MR-FX. MR-SX is resuming.

メインリングのビームパワー [kW]



Cf.  
Sterile Neutrino is utilizing full beam at MLF. (Mercury target)  
Muon program is using ~10% of the beam. (Carbon target)

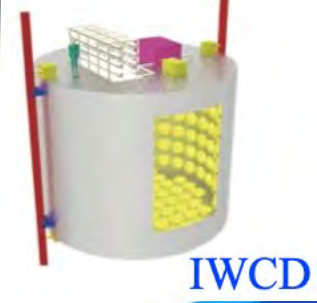
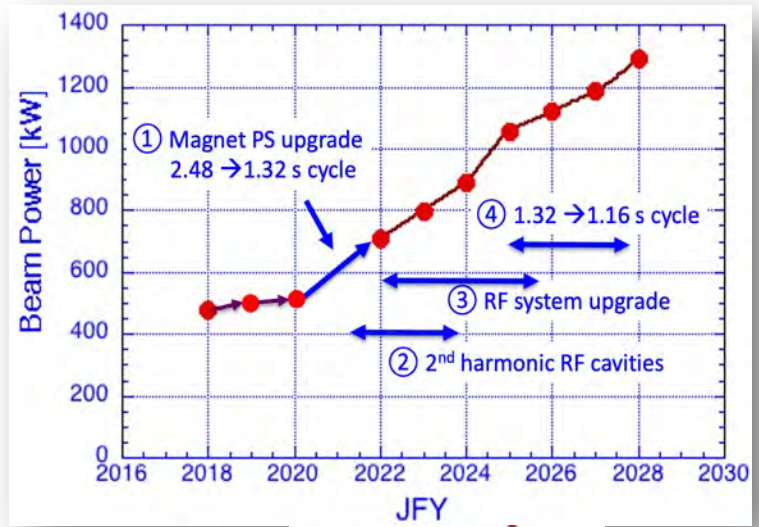
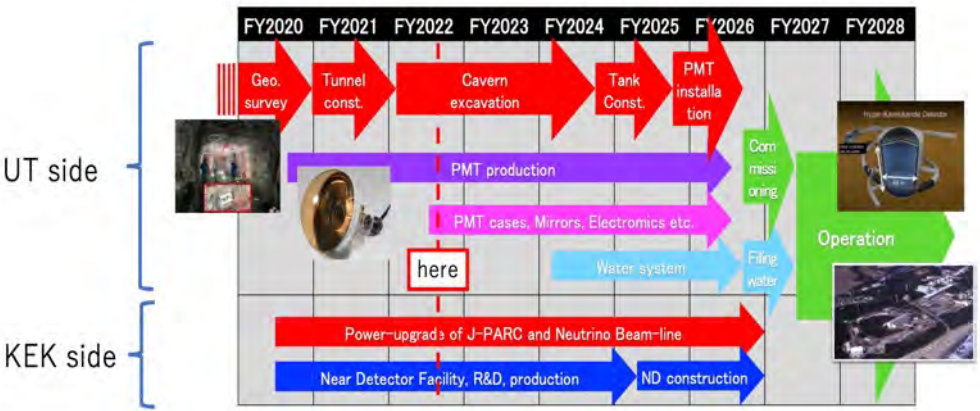
# Neutrino

## Establish CPV in neutrino sector and explore BSM



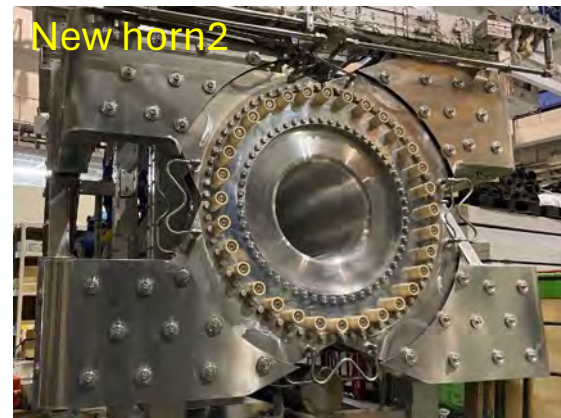
- ### Ongoing upgrades
1. Power upgrade of J-PARC MR
  2. Upgrade of Neutrino BL
  3. Upgrade of Near-Mid Detector
    - a) ND280 upgrades by T2K
    - b) Construction of IWCD

### Exploration of CPV with T2K-II, Hyper-K



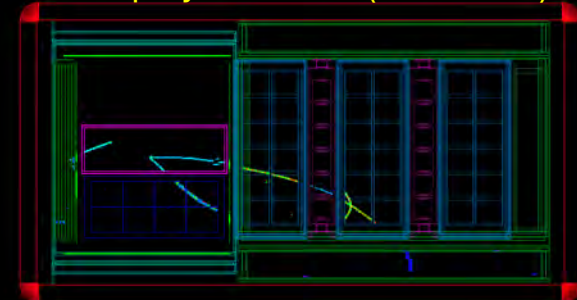
# T2K enters a new phase

- J-PARC MR and neutrino beamline has been upgraded toward 1.3MW
  - New Power supply for short rep. installed and in operation
  - Reinforcement of RF is in progress by 2027
  - Neutrino beamline upgrade (e.g. horn, target) conducted. New horn PS enable to increase the current from 250kA to 320kA (+10% v)
  - 710kW continuous beam operation is achieved without any crucial troubles
- T2K off-axis detector upgrade is on-going
  - New sub-detectors(SuperFGD, HA-TPC, TOF) are partially installed in 2023 and successfully detect neutrino events !
  - Complete upgrade and take beam data with full configuration by summer 2024



Run number : 19179 | SubRun number : 8 | Event number : 191051 | Spill : 4818 | Time : Thu 2023-12-21 00:21:27 JST | Partition : 81 | Trigger : Beam End

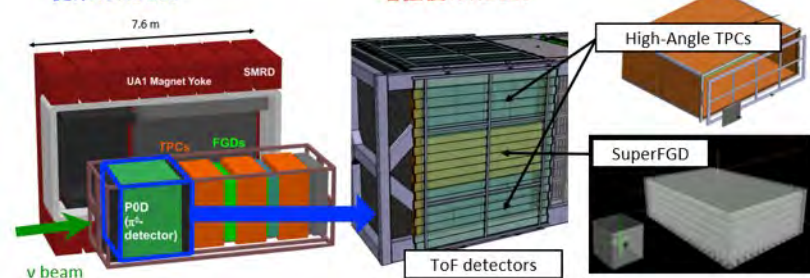
Event display of ND280 (2023 Dec.)



従来のND280

増強後のND280

Installed new sub-detectors



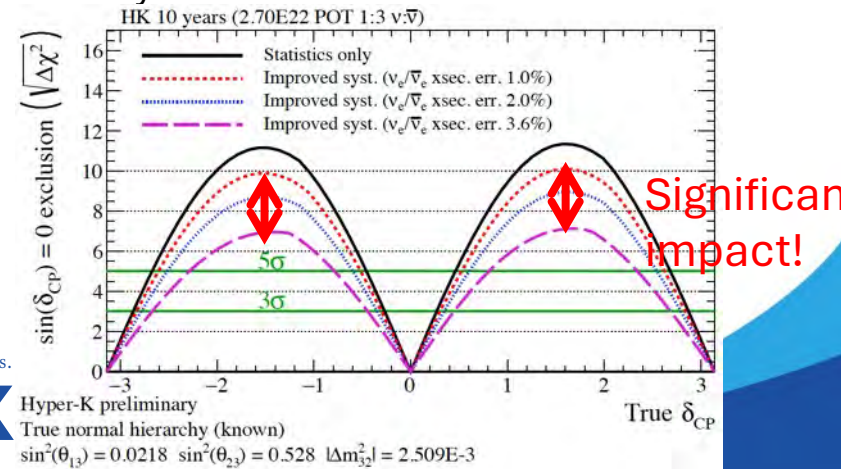
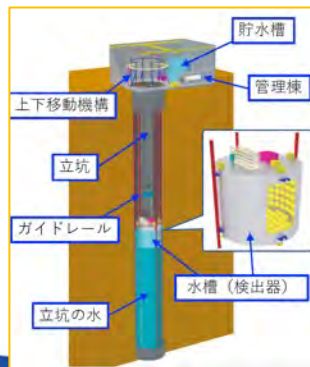
# Construction of Hyper-K detectors in progress

- Far detector construction
  - Civil construction is on-going as scheduled
    - Doom part of main cavern is completed in 2023
  - Engineering design for Tank, PMT support structure, water system is completed, and ready to contract of construction
  - Mass-production of 50cm PMT is going well

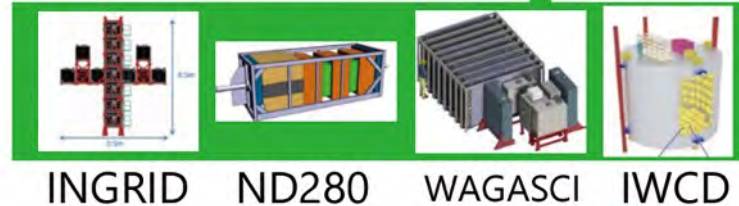
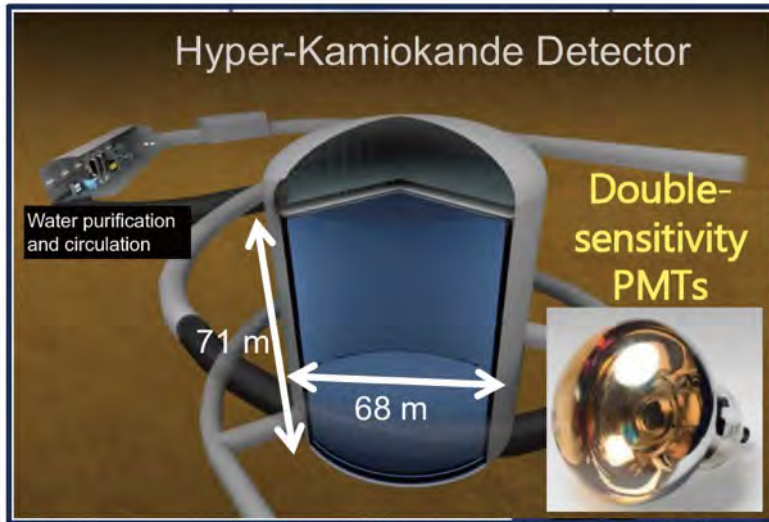


2023 Oct.: Doom part of the main cavern ( $\phi = 69\text{m}$ ,  $H = 21\text{m}$ )

- A new near detector, Intermediate Water Cherenkov Detector (IWCD)
  - Same detection principal as far detector for required systematic error reduction
  - Agreement to use the site with the land owner is established in summer 2023
  - Detailed design in JFY2024, and the facility construction in JFY2025-2026



# Hyper-K Project



1. Hyper-K detector will be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and will be instrumented with **double-sensitivity PMTs**.
2. J-PARC neutrino beam will 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

# HK Project Advisory Committee

established by UT-ICRR and KEK-IPNS



Director of UT-ICRR

Director of KEK-IPNS



Advice, Recommendation



HK Project Advisory Committee  
 Chairperson +  
 10 regular + some (\*) expert members



~3 times/year

- 10<sup>th</sup> Mtg: 6-8 Dec, 2023
- 9<sup>th</sup> Mtg: 8-10 Jul, 2023
- 8<sup>th</sup> Mtg: 11-13 Apr, 2023
- 7<sup>th</sup> Mtg: 7-12 Nov, 2022
- ...
- 1<sup>st</sup> Mtg: 12-19 Sep, 2020

(\*) 2 persons in the current HKPAC

Cavern & Tank sub-committee  
 Chairperson +  
 6 expert members



HK Project

1-2 times/year

- 5<sup>th</sup> Mtg: 16 Oct, 2023
- 4<sup>th</sup> Mtg: 17 Oct, 2022
- 3<sup>rd</sup> Mtg: 27 May, 2022
- 2<sup>nd</sup> Mtg: 27 Dec, 2021
- 1<sup>st</sup> Mtg: 11 Feb, 2021

Beamline sub-committee  
 Chairperson +  
 7 expert members



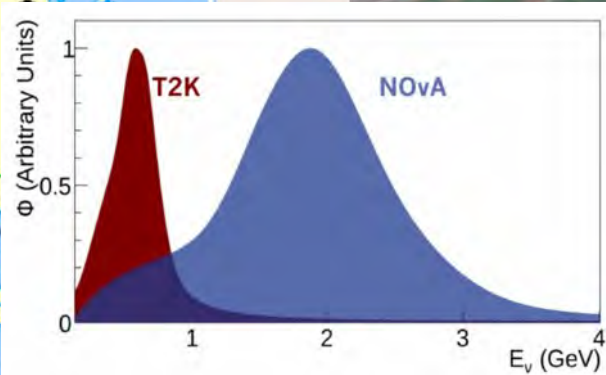
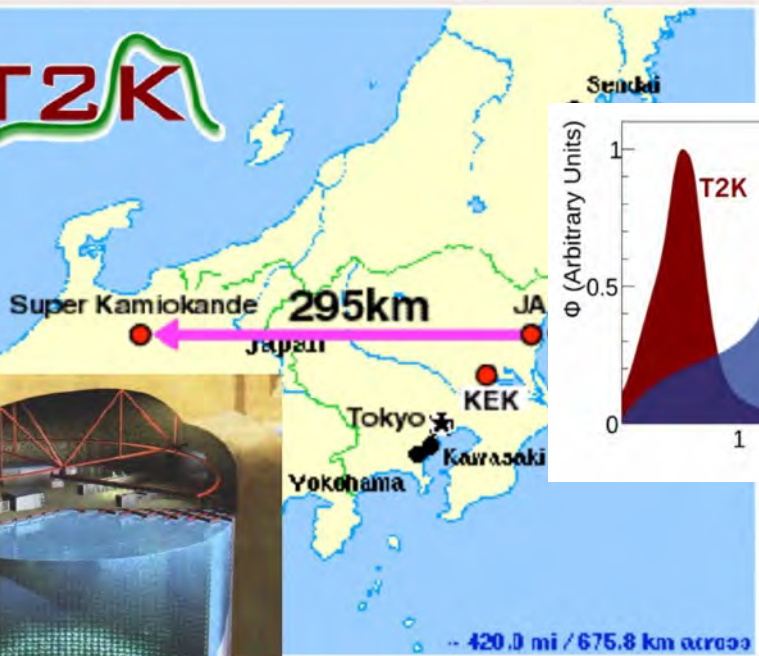
1-2 times/year

- 1<sup>st</sup> Mtg: 1-2 Nov, 2023

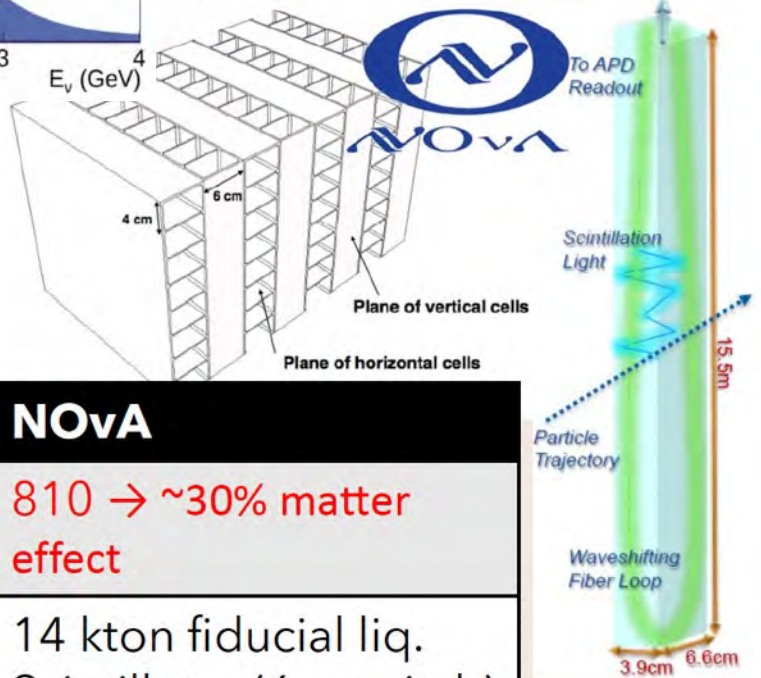


# Joint Analysis T2K and NOVA

**T2K**

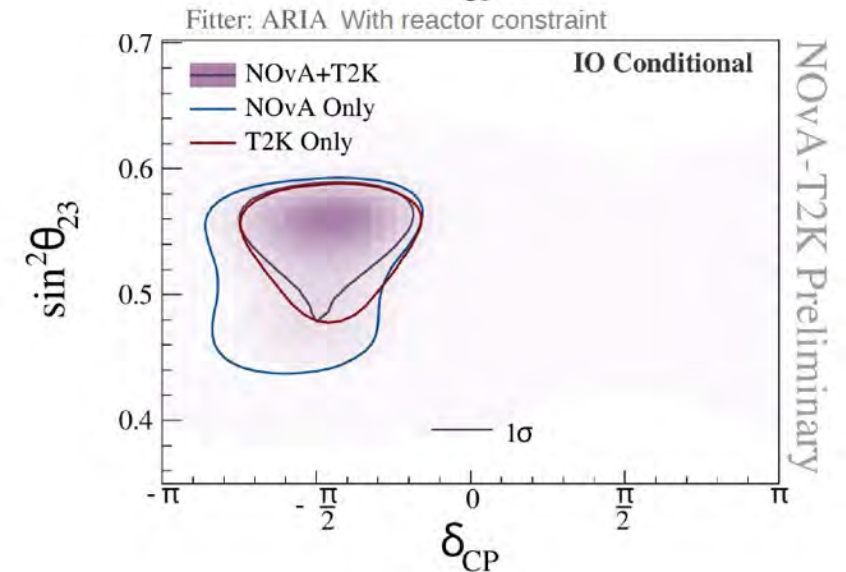
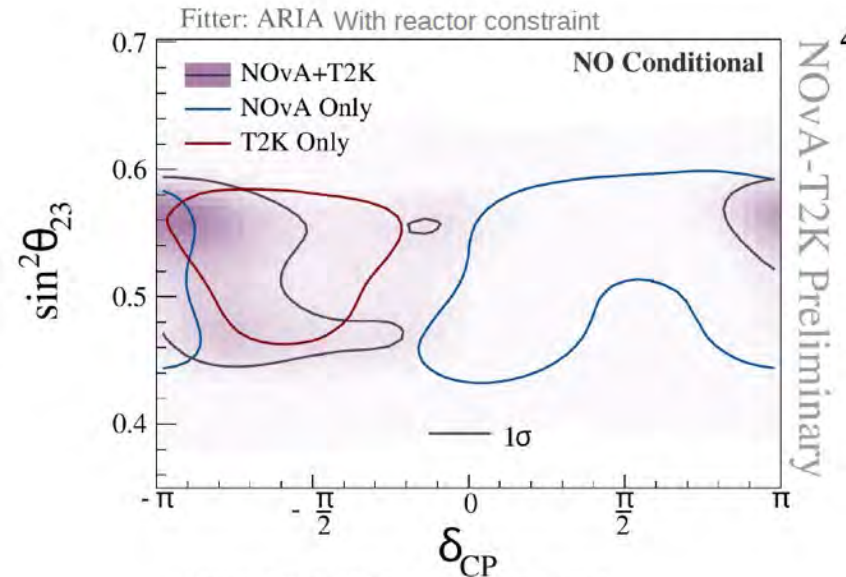
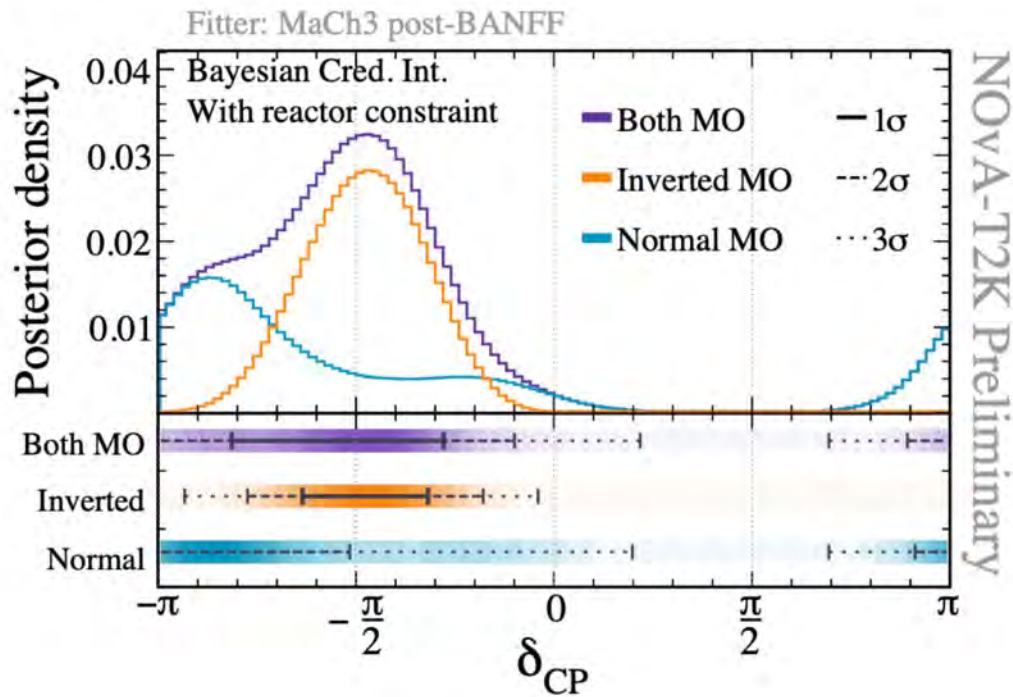


**NOvA Far Detector**



	<b>T2K</b>	<b>NOvA</b>
$L(\text{km})$	295 $\rightarrow$ ~10% matter effect	810 $\rightarrow$ ~30% matter effect
detector	Super-K (22.5+ fid. V water Cherenkov)	14 kton fiducial liq. Scintillator (6cm pitch)
period	2009~	2014~

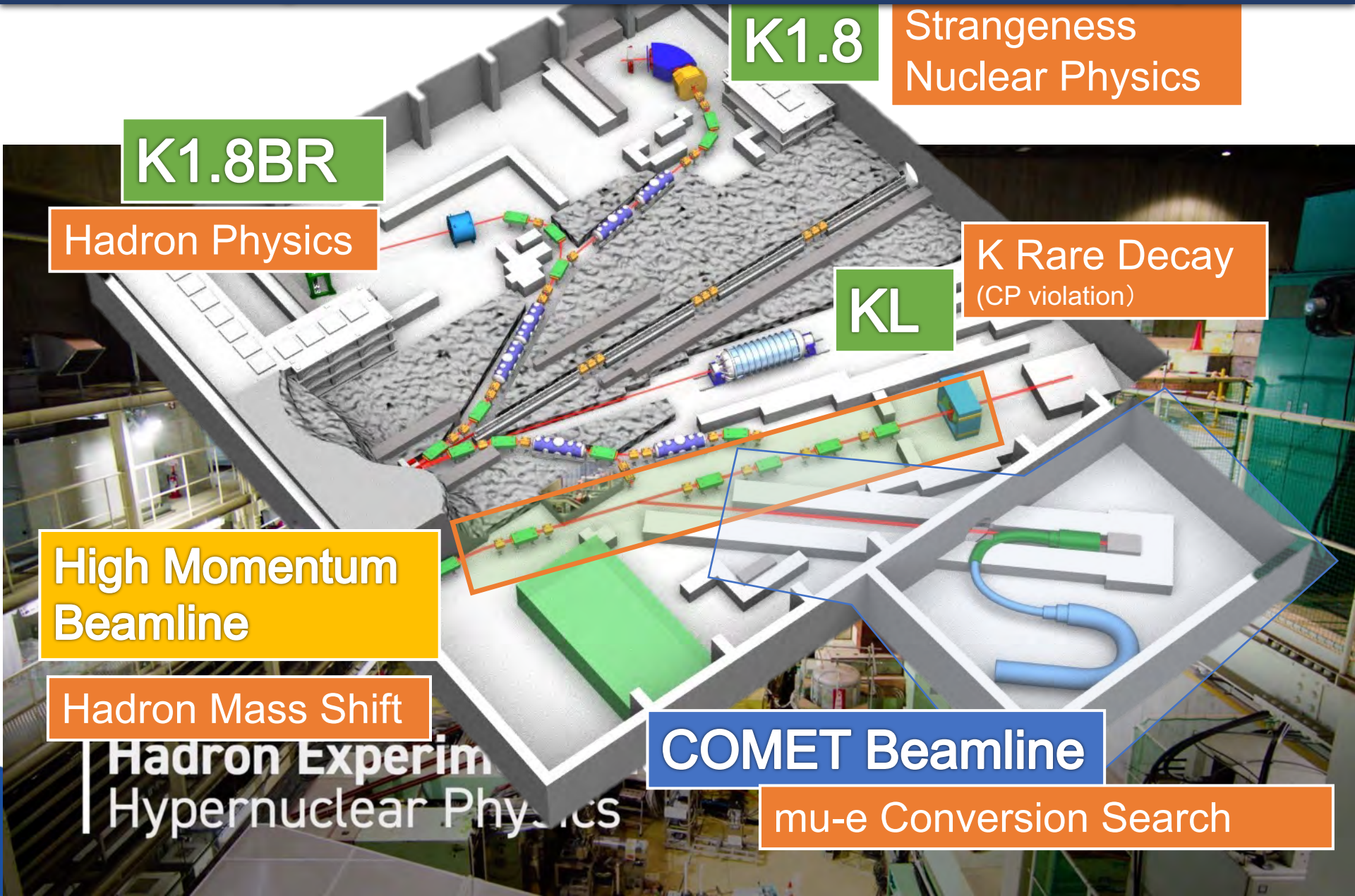
# Joint Analysis T2K and NOVA



- The joint analysis shows no strong preference for either mass ordering.
- $\delta_{CP} = \pi/2$  lies outside the  $3\sigma$  credible interval for both mass orderings.
- All CP conserving-values for the Inverted Ordering fall outside the  $3\sigma$  CI.
- But the Normal ordering permits a wide range of permissible  $\delta_{CP}$  values.

# Hadron Experimental Facility

Explore the origin of matter with nuclear, hadron, and flavor physics



K1.8

Strangeness  
Nuclear Physics

K1.8BR

Hadron Physics

K Rare Decay  
(CP violation)

KL

High Momentum  
Beamline

Hadron Mass Shift

Hadron Experiment  
Hypernuclear Physics

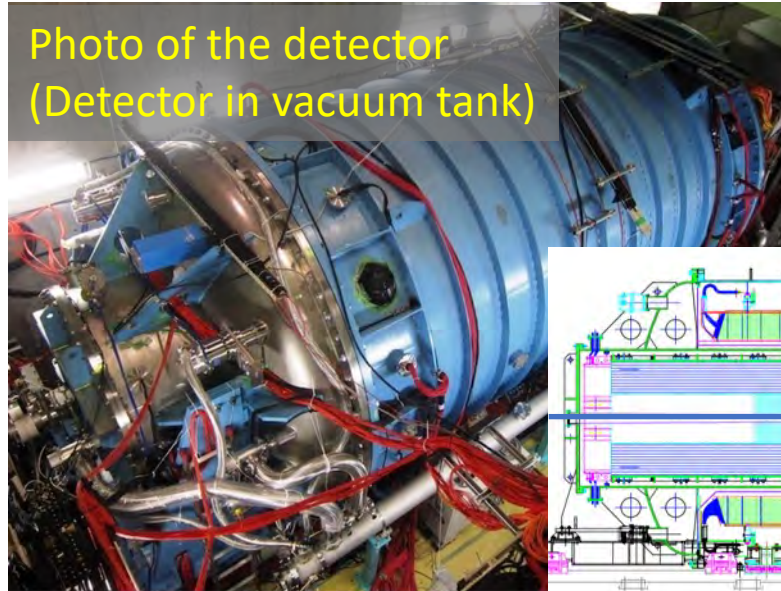
COMET Beamline

$\mu$ -e Conversion Search

# KOTO: $K_L \rightarrow \pi^0 \nu \bar{\nu}$ search at J-PARC

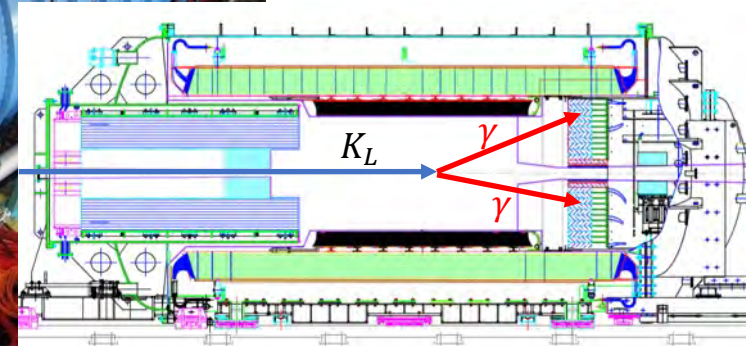
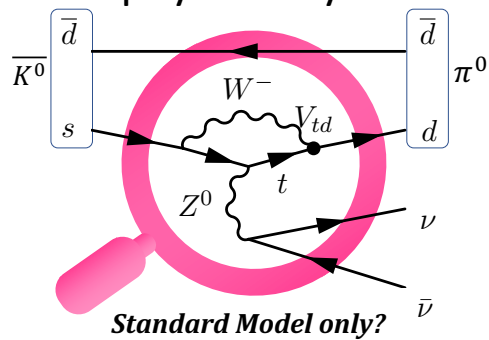
- CP-violating rare decay
- Predicted B.R.(SM) =  $3 \times 10^{-11}$
- Not yet observed
- Good probe to search for New physics beyond SM

Photo of the detector (Detector in vacuum tank)



Event signature

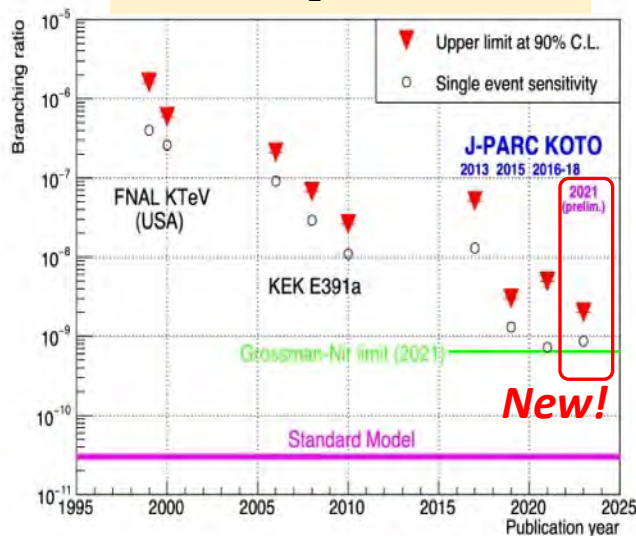
- $2\gamma$  from  $\pi^0$  decay
- Nothing else ( $\nu, \bar{\nu}$  undetected)



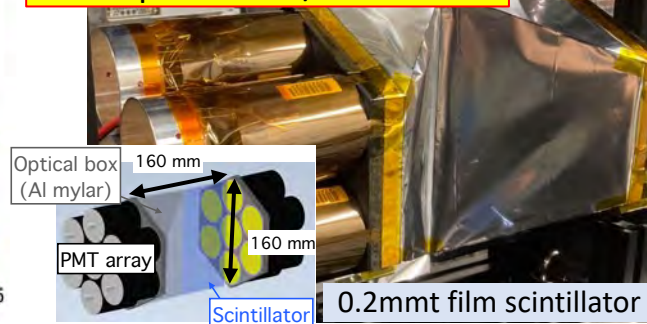
## Highlights in FY2023

- The analysis of data taken in 2021 provided a **new world-best upper limit** B.R.  $< 2.0 \times 10^{-9}$  (preliminary).
- Upgrades of the beamline, detector, and DAQ system
  - For better understanding and further reduction of background events

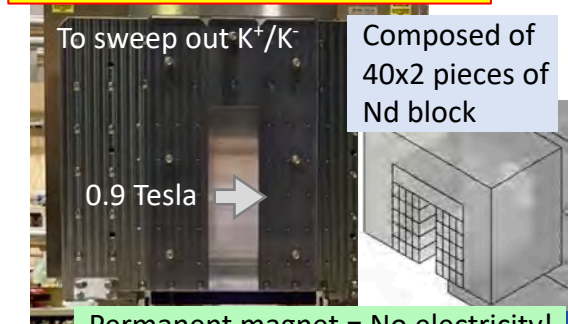
History of  $K_L \rightarrow \pi^0 \nu \bar{\nu}$  search



New upstream  $K^+/K^-$  detector



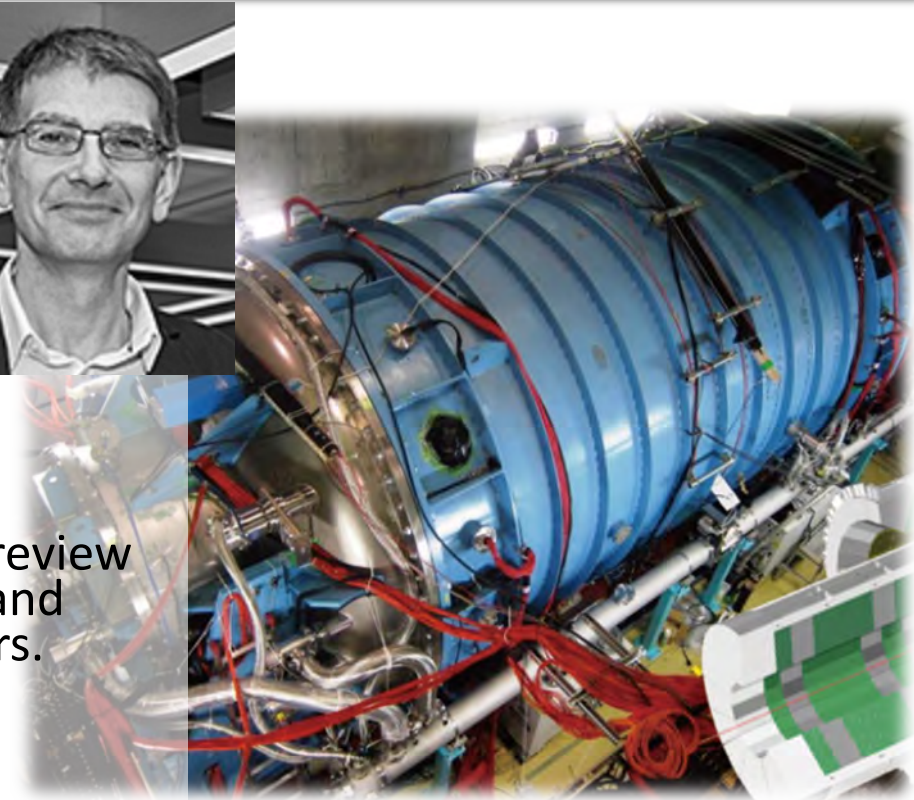
New magnet in the beam line



# KOTO Review

February 14 and 16, 2023

- A review team is formed.
  - Augusto Ceccucci (chair)
  - Cristina Lazzeroni (from this PAC)
  - Gino Isidori
  - NAKAYA, Tsuyoshi
  - Sasha Glazov
- Placed under J-PARC PAC.
- Mandate:
  - Assess the current achievements and review its capability of background rejection and reach of the experiment incoming years.
    - GN-limit and SM level.
- The report:

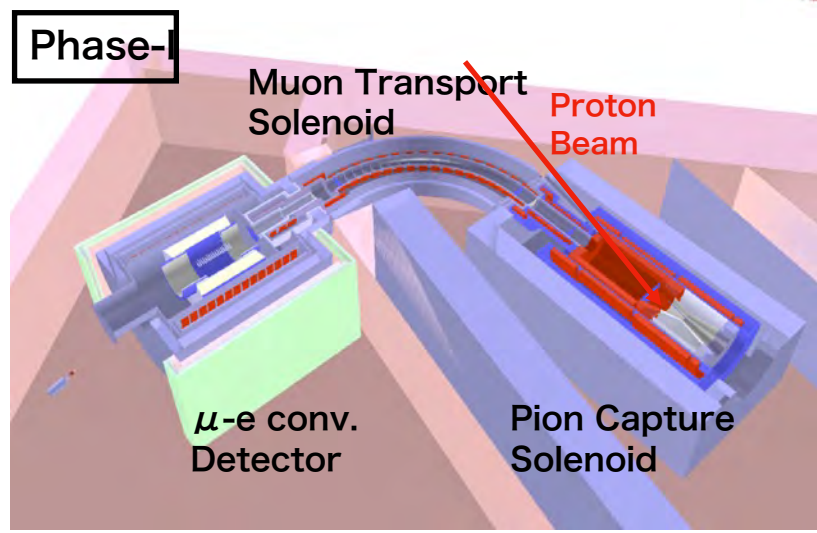


Overall, the panel felt that KOTO has made significant progress and that, under somehow optimistic hypotheses, a significant physics goal can be achieved by extending data taking during the next years as long as steady progress in the background suppression is reported.

The review did not address the prospects for KOTO II in detail. However, the panel would like to stress that KOTO II would be a major new endeavor requiring many new groups and new investments. It can become a flagship program for J-PARC but without credible and timely guidance from the KOTO results it might be difficult to attract funds and new collaborators

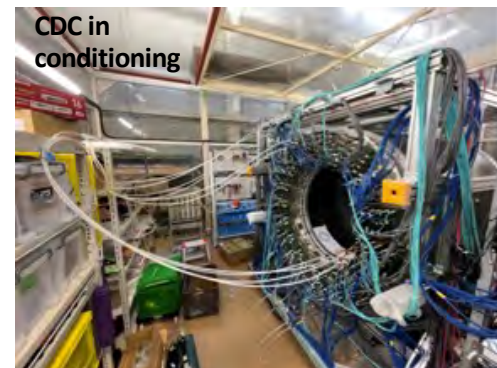
# COMET: $\mu$ -e conversion search at J-PARC

- cLFV decay
- No Standard Model BG
- Excellent probe to search for New physics beyond SM
- Key to understand the origin of neutrino mass
- Staging approach
  - Phase I S.E.S.  $< 10^{-14}$
  - Phase II S.E.S.  $< 10^{-16}$

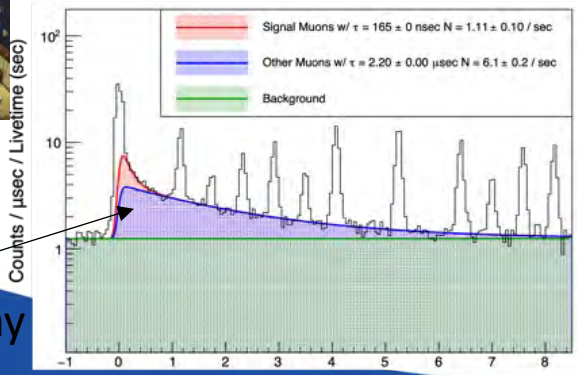


## Highlights in FY2023

- First-time beamline operation in Engineering Run. Observation of muons transported through the Muon Transport Solenoid (MTS)
- Construction of the Pion Capture Solenoid (PCS)
- Detector commissioning on-site



Engineering Run Primary Beamline



Muon Decay

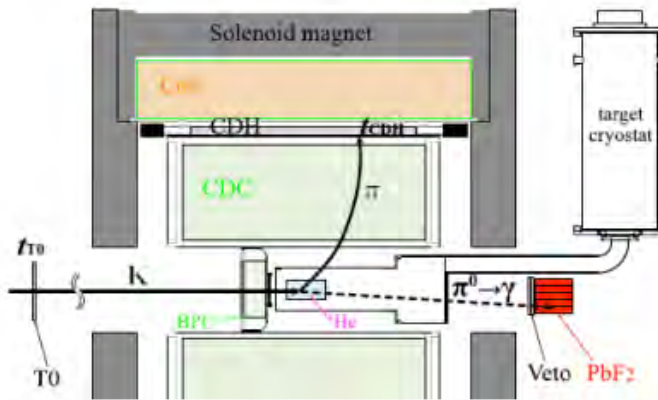
$T_{1\&2} - T_0$  (usec)

# Precise lifetime measurement of ${}^4_{\Lambda}\text{H}$ hypernucleus using in-flight ${}^4\text{He}(\text{K}^-, \pi^0) {}^4_{\Lambda}\text{H}$ reaction (E73/T77@K1.8BR)

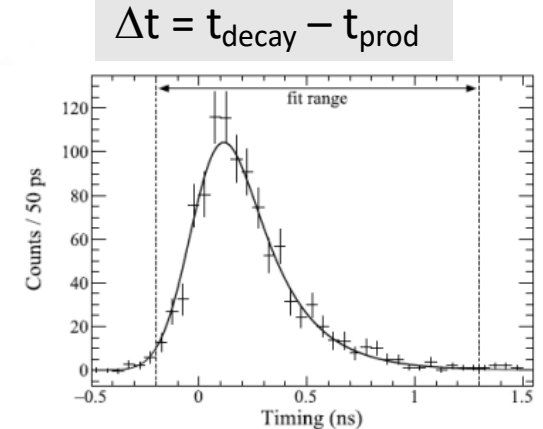
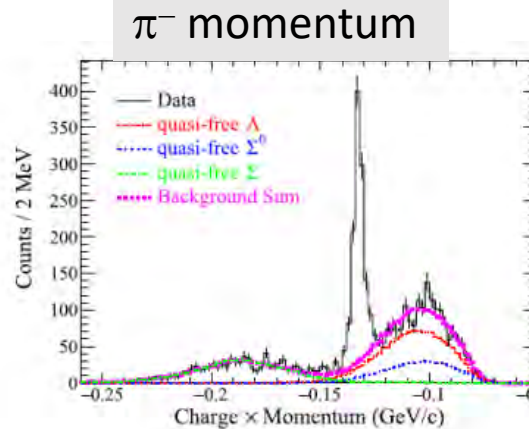
Phys. Lett. B 845, 138128 (2023)

Improved data on  ${}^4_{\Lambda}\text{H}$  lifetime was obtained in the feasibility study of  ${}^3_{\Lambda}\text{H}$  lifetime measurement.

## Data-taking June 2022



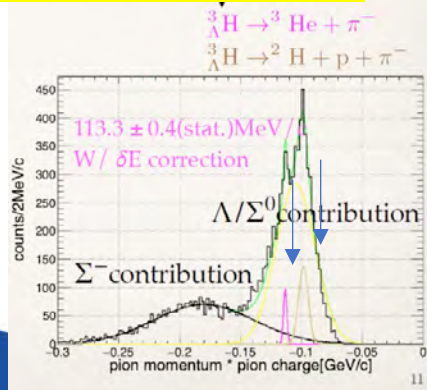
$\pi^0$  is tagged by  $\gamma$   
(monochromatic)  $\pi^-$  from weak decay is measured with CDS.



$\tau = 206 \pm 8(\text{stat.}) \pm 12(\text{syst.}) \text{ ps}$

Previous data: NPA639, 251c (1998)  
 $194_{-26}^{+24} \text{ ps}$

## Pilot data on ${}^3_{\Lambda}\text{H}$ using Liq.- ${}^3\text{He}$ (taken May 2021)



Method and  ${}^3_{\Lambda}\text{He}$  yield were confirmed to be fine.

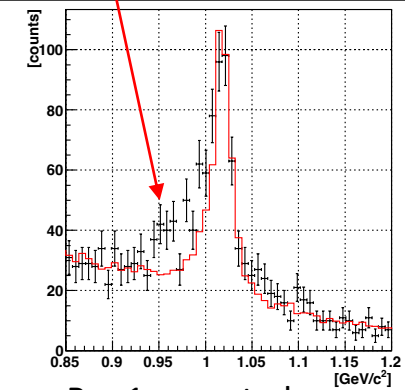
In the coming E73 physics run (FY2024),  ${}^3_{\Lambda}\text{H}$  lifetime will be measured to obtain conclusive result against the **hypertriton ( ${}^3_{\Lambda}\text{H}$ ) puzzle** (much shorter lifetime than that of free  $\Lambda$  was obtained in several heavy ion collision experiments in spite of very loosely bound system).

# J-PARC E16 experiment

- Measurements of mass spectra changes of vector mesons ( $\rho$ ,  $\omega$ ,  $\phi$ ) to study QCD matter
  - $p+A \rightarrow \rho, \omega, \phi + X$
  - $\rightarrow e^+e^-$

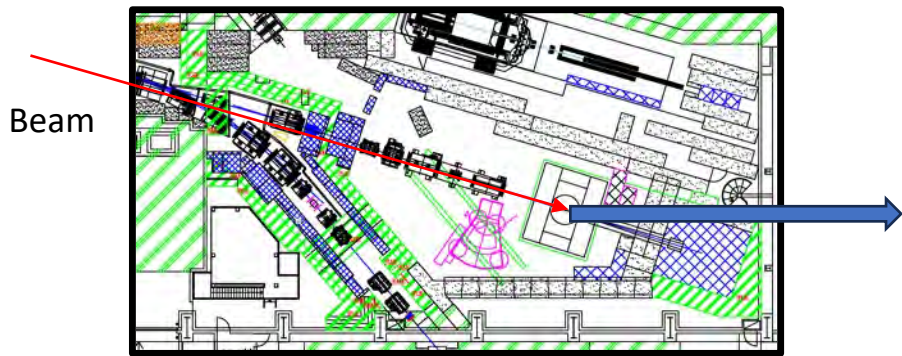
Generate vector mesons using primary proton beam and Detect electron-positron pairs decayed from vector mesons

Mass modifications of  $\phi$  meson due to QCD matter effects

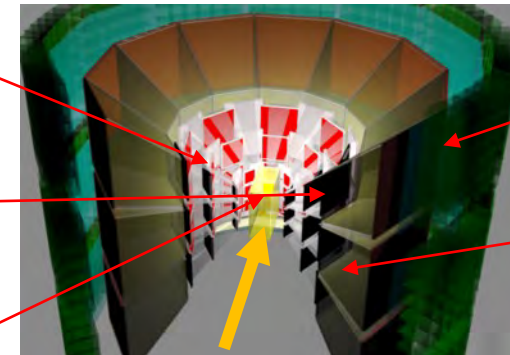


Run1 expected (BG included)

## Hadron Hall



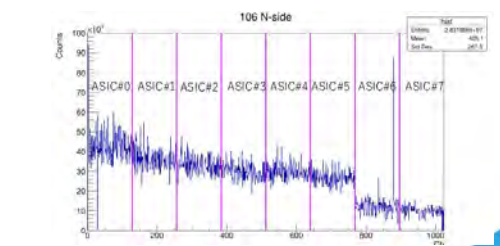
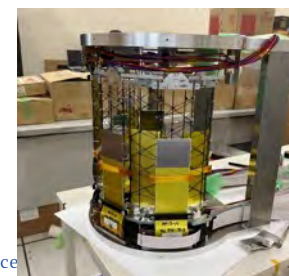
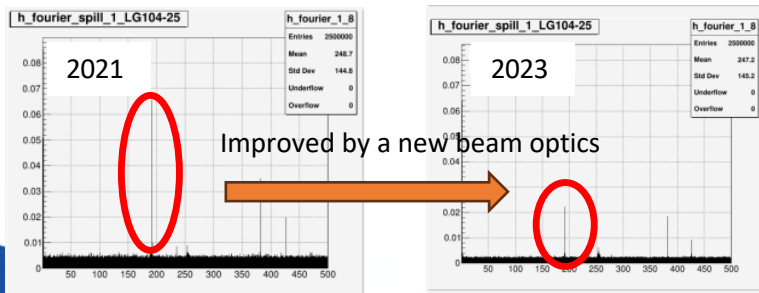
- GEM Tracker
- Silicon Tracking System
- Nuclear Target



- Lead Glass
- Hadron Blind Detector

30 GeV Primary Proton Beam  $10^{10}$  per spill

## Beam Study in 2021 and 2023



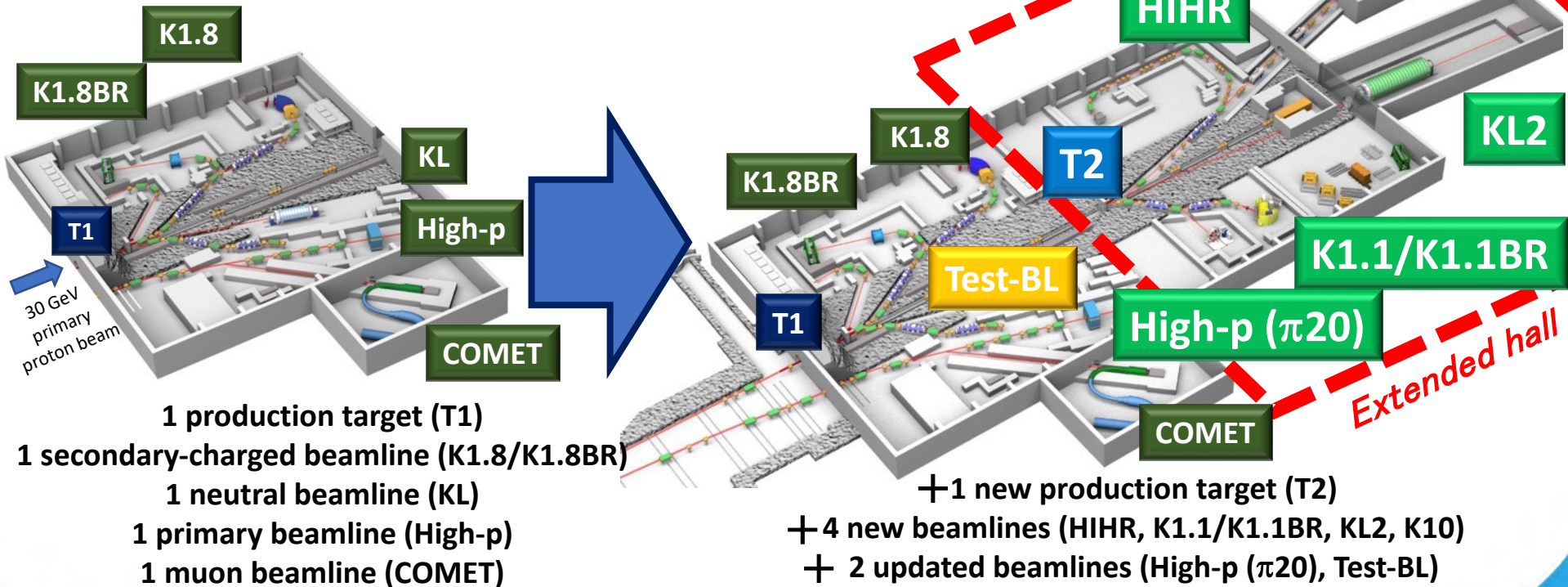
Hit profile of new silicon obtained in 2023

# Hadron Experimental Facility extension (HEF-ex) Project

Expand research programs at the Hadron Experimental Facility to explore **Origin & Evolution of Matter** more deeply

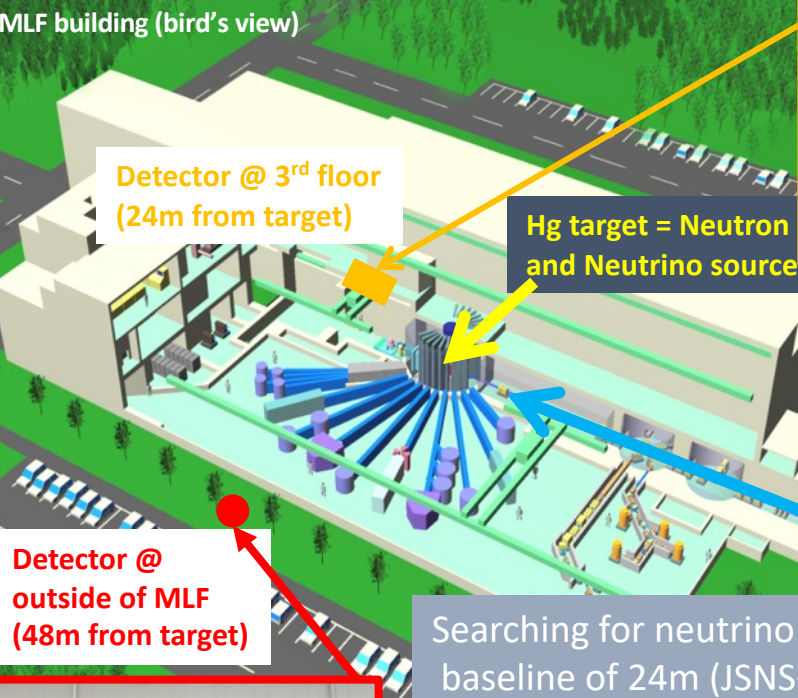
Present HEF (2009~)

Extended HEF



Revision is ongoing!

# JSNS<sup>2</sup>(-II) experiment : Search for sterile neutrinos



(JSNS<sup>2</sup>)  
 17t GdLS fiducial (target) detector (4.6m dia. x 4.0m height, 120 10" PMTs)

## (JSNS<sup>2</sup>) : 1MW x 3 years

- The long physics runs (2021-2023)
  - In total, ~15 months.
  - normal  $\nu$  created at the target are seen.
  - Sterile  $\nu$  analyses are on-going

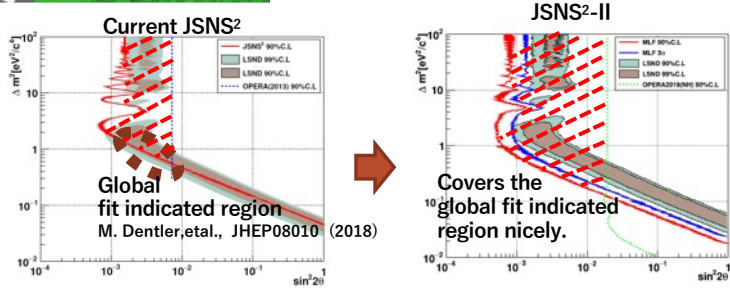
• **New run began from 2023/12/7**

## (JSNS<sup>2</sup>-II) : 1MW x 5 years

- 2<sup>nd</sup> phase of the experiment
  - new far detector : 32 tons fiducial in 48m baseline.
  - Improved the sensitivity, especially in low  $\Delta m^2$  region.
  - Stage-2 approval was granted.
  - **Detector construction : on-going**



(JSNS<sup>2</sup>-II: New detector)  
 32t GdLS fiducial  
 (6.2m dia. x 6.2m (h)  
 ~230 10" PMTs)

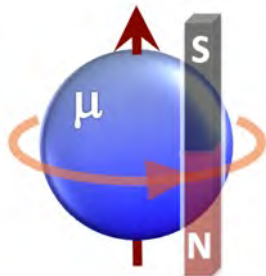


# J-PARC muon $g-2$ /EDM experiment

$g-2$

Anomalous magnetic moment

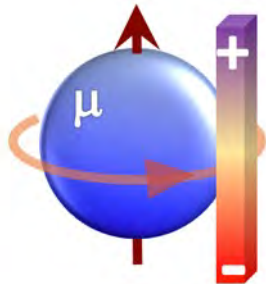
450 ppb



EDM

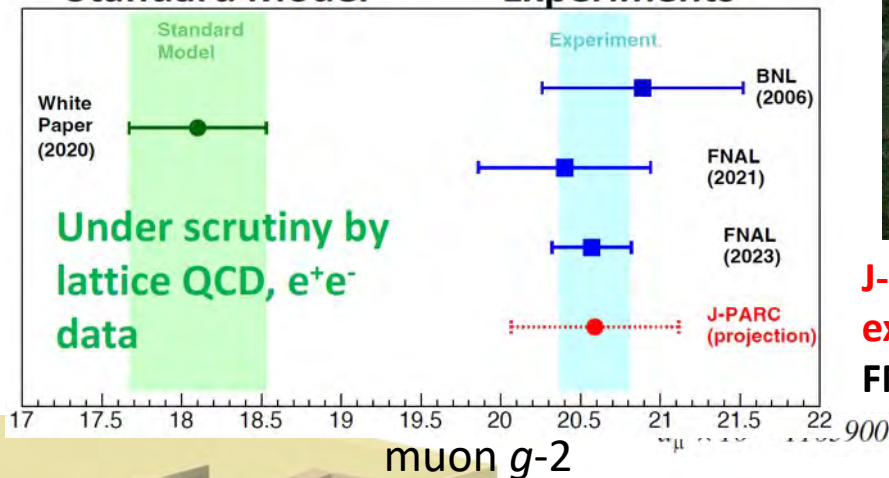
Electric Dipole Moment

1.5 E-19 ecm



Standard Model

Experiments



**J-PARC is the only experiment to check FNAL/BNL results.**

Constructed

To be constructed in 2024

Aiming for data taking from 2028  
**Construction budget start in JFY2024**

$\mu^+(4 \text{ MeV})$

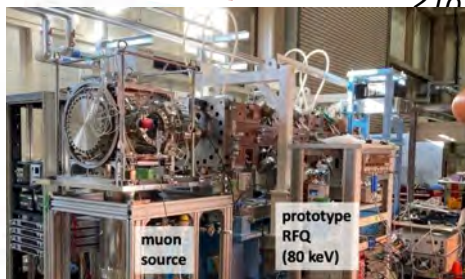
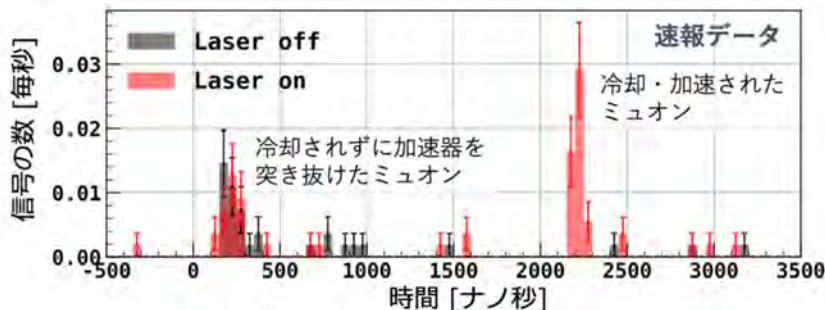


Cooling 25 meV 4 MeV

Acceleration

210 MeV

Storage



# Muon g-2/EDM Progress Review

- Mission

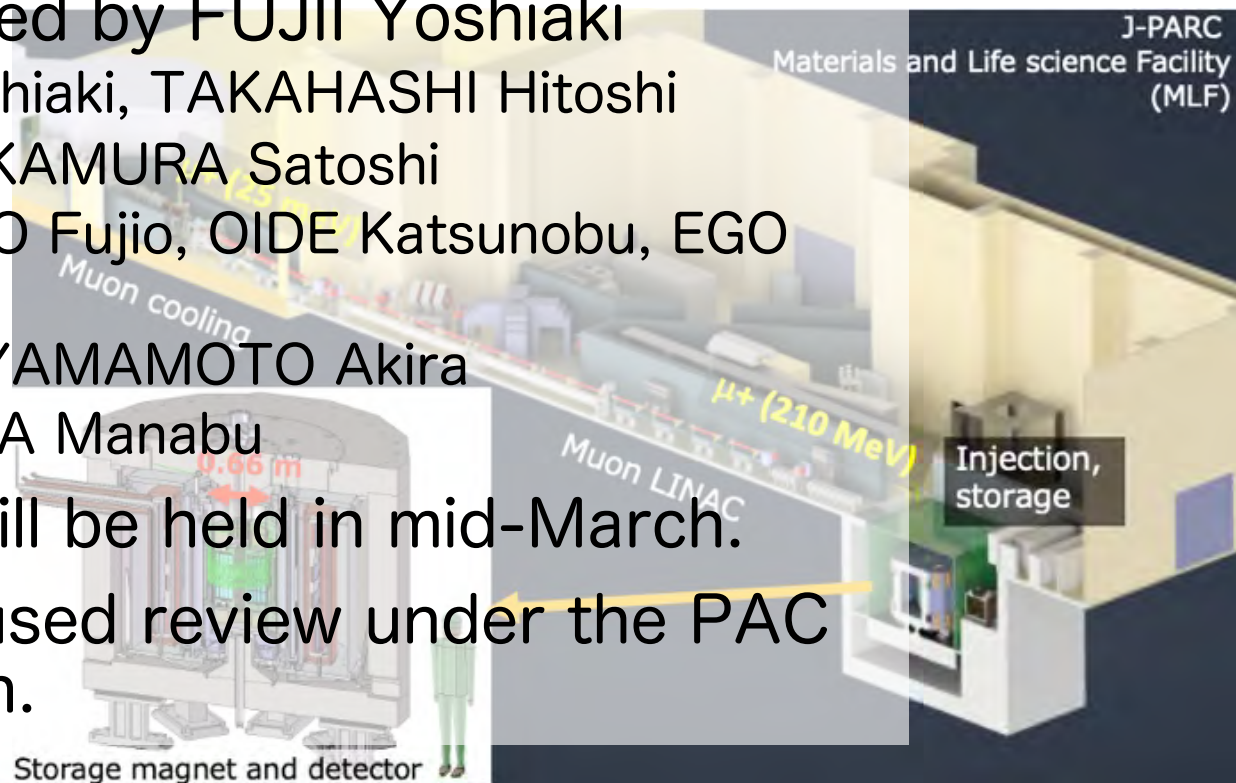
- Assess the progress in the design, R&D, and construction/preparation of the experiment to realize the experiment timely
- (follow-up of the focused review under PAC )

- Review team chaired by FUJII Yoshiaki

- Facility : FUJII Yoshiaki, TAKAHASHI Hitoshi
- Muon Source: NAKAMURA Satoshi
- Accelerator: NAITO Fujio, OIDE Katsunobu, EGO Hiroyasu
- Storage Magnet: YAMAMOTO Akira
- Detector: TOGAWA Manabu

- The 2<sup>nd</sup> meeting will be held in mid-March.

- Reconvene of focused review under the PAC is under discussion.



# Wako Nuclear Science Center

- The center has been leading comprehensive studies of rare isotopes with KISS and other devices at RIBF

## Wako Nuclear Science Center

### 1. KISS Operation (KEK Isotope Separator System)

Unique & 1st ISOL facility using MNT reactions

Provides n-rich isotopes of refractory elements

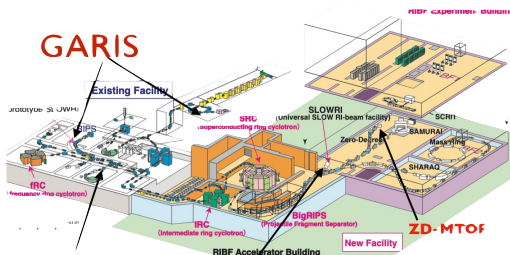
#### KISS Experiments in FY2023

- M. Mukai (Nagoya U.), "Isotope shift measurements of neutron-rich Hf and W isotopes"
- Y. Hirayama (KEK), "Study of prolate-oblate shape transition in  $^{188-193}\text{Re}$  by in-gas-cell laser ionization spectroscopy"
- P.M. Walker (Surry U.), "Multi-quasiparticle Isomers in neutron-rich  $^{183,184}\text{Hf}$ "
- Y. Hirayama (KEK), "Half-life and mass measurements of nuclei around  $N = 126$  using KISS"
- Y.X. Watanabe (KEK), "Mass and lifetime measurements of neutron-rich actinide isotopes toward r-process termination"

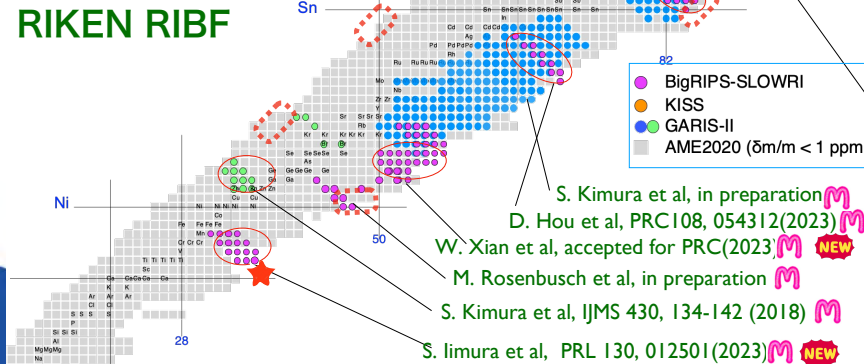
### 2. Comprehensive Mass measurements @KISS, GARIS, BigRIPS-SLOWRI

#### Recent Press Releases

- First mass measurement of SHE (Db@GARIS)
- Discovery of new n-rich uranium isotope (@KISS)
- Disappearance of  $n=34$  magic (Ti, V@BigRIPS-SLOWRI)



KISS BigRIPS+SLOWRI  
RIKEN RIBF



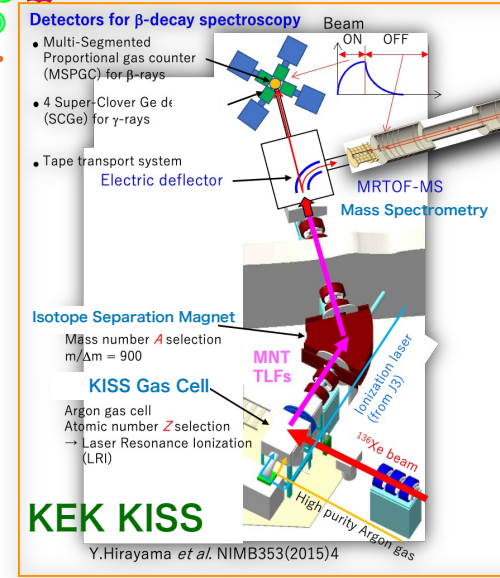
- M. Rosenbusch et al, PRC 97, 064306 (2018) M
- P. Schury et al, PRC95(2017)011305R M
- T. Niwase et al, PRC104(2021)044617 M D
- T. Niwase et al, in preparation NEW

- P. Schury et al, in preparation M NEW
- P. Schury et al, PRC104,L021304(2021) M
- Y. Ito to PRL 120, 102501 (2018) M
- P. Schury et al, in preparation M
- Y. Ito et al, in preparation M

- T. Niwase et al, PRL130, 132502(2023) M NEW
- M. Mukai et al, in preparation D M NEW
- M. Mukai et al, PRC105,034331(2022) D NEW
- H. Watanabe et al, PLB 814, 136088(2021) D
- Y. Hirayama et al, PRC96,014307(2017) L
- Y. Hirayama et al, PRC98,014321(2018) L
- M. Mukai et al, PRC102,054307(2020) L
- Y.X. Watanabe et al, PRC101,041305R(2020) D
- H. Choi et al, PRC202,034309(2020) L
- P.M. Walker et al, PRL125,192505(2020) D
- Y.X. Watanabe et al, PRC104,024330(2021) D
- M. Ahmed et al, PRC103,054312(2021) D
- H. Hirayama et al, in preparation L NEW
- J. Ming et al, in preparation M NEW
- P.M. Walker et al, in preparation D NEW
- S. Kimura et al, submitting to PRC M NEW

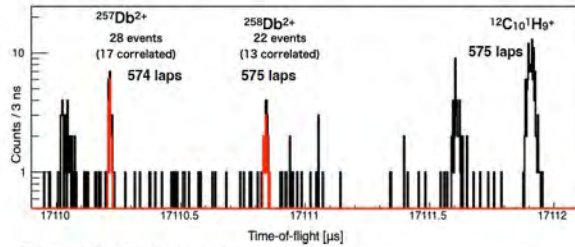
- D Decay spectroscopy
- L Laser spectroscopy
- M Mass spectrometry
- Approved proposal

Nuclides studied at WNSC 2017~

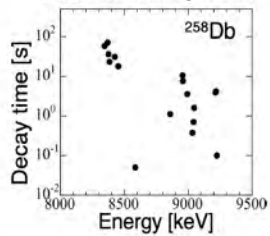


# Wako Nuclear Science Center

## Mass spectrometry of Superheavy Elements



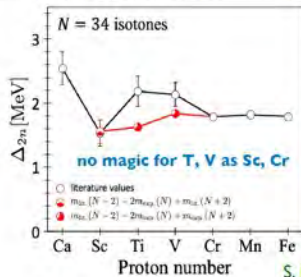
### Correlated $\alpha$ -decay events



Following Db-257, the mass of Db-258 has been measured. More events are being stored aiming at identifying decay orders via correlation measurement with alpha-decay.

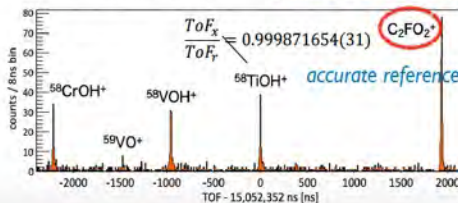
P. Schury et al, PRC104,L021304(2021) & in preparation

## Disappearance of N=34 magic number for Ti, V

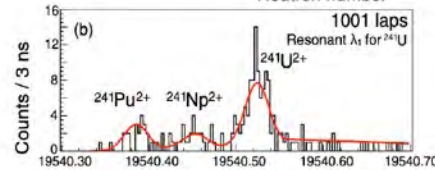
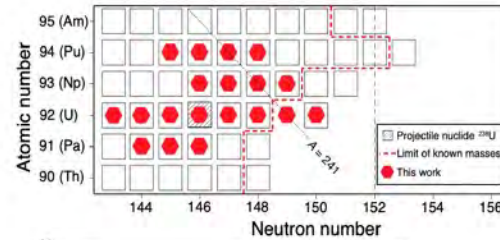


Previously observed magic number N=34 in Ti, V isotopes was denied in accurate mass measurements of Ti-58 and V-59 with the ZD-MRTOF device.

S. Iimura et al, PRL 130, 012501(2023)



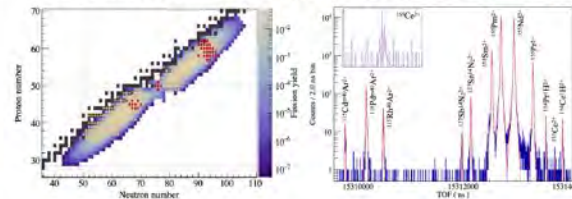
## Discovery of new n-rich uranium isotope produced by MNT reaction



The production of n-rich uranium isotopes is currently possible only using multi-nucleon transfer reactions (MNT). KISS is the only ISOL facility in the world using MNT, and the first Y + Pt experiment successfully discovered new n-rich isotopes. This discovery was accompanied by precise ( $\delta M=50$  keV) mass measurement, an experiment that is a step beyond mere existence confirmation.

T. Niwase et al, PRL130,132502(2023)

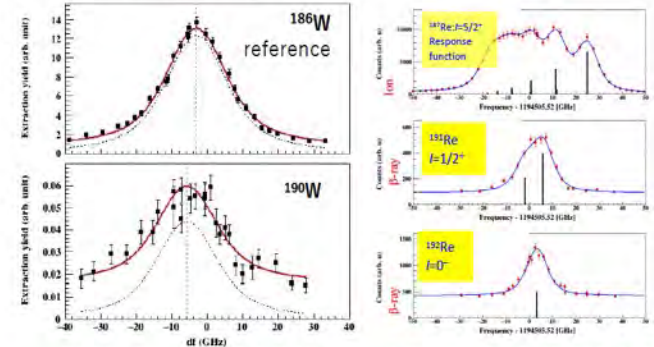
## Mass measurements of fission fragments of <sup>252</sup>Cf



Mass measurements of more than 300 nuclides are in progress using the Cf-252 source. Simultaneous measurement of isobaric and molecularized ions enables highly accurate measurements. Since isotopes of different nuclear spins of various elements can always be obtained with equal intensity ratios, new atomic physics research can be performed.

S. Kimura et al, in preparation

## Laser spectroscopy of n-rich refractory elements at KISS

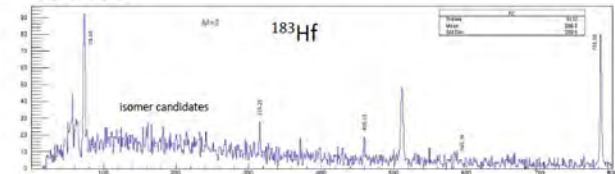


M. Mukai et al, NP2112-RR72-03

Y. Hirayama et al, NP2212-RR77-01

KISS is an element-selective isotope separator using resonant ionization, and its resonant laser wavelengths can be used to measure the charge radius, nuclear spin, and nuclear moment of nuclei. In particular, the KISS is the sole facility for neutron-rich isotopes of refractory elements.

## beta-gamma spectroscopy of n-rich refractory elements



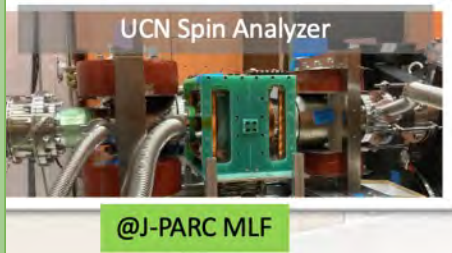
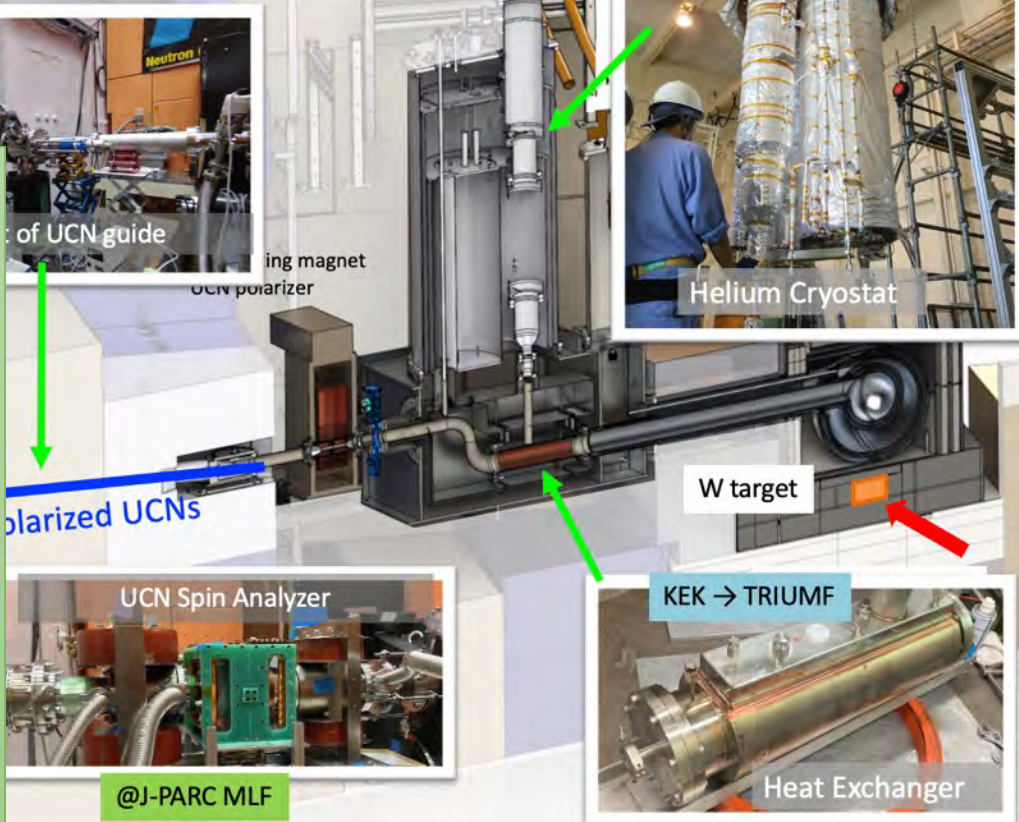
Nuclear isomer studies by  $\beta \gamma$  spectroscopy of neutron-rich isotopes of refractory elements, which can only be obtained at KISS, are in progress. Following Ta-187 (P.M. Walker et al., PRL125,192505(2020)), the Hf-183 experiment was carried out.

P. Walker, Z. Podolyak et al, NP2012-RR67-01

## Development in Japan

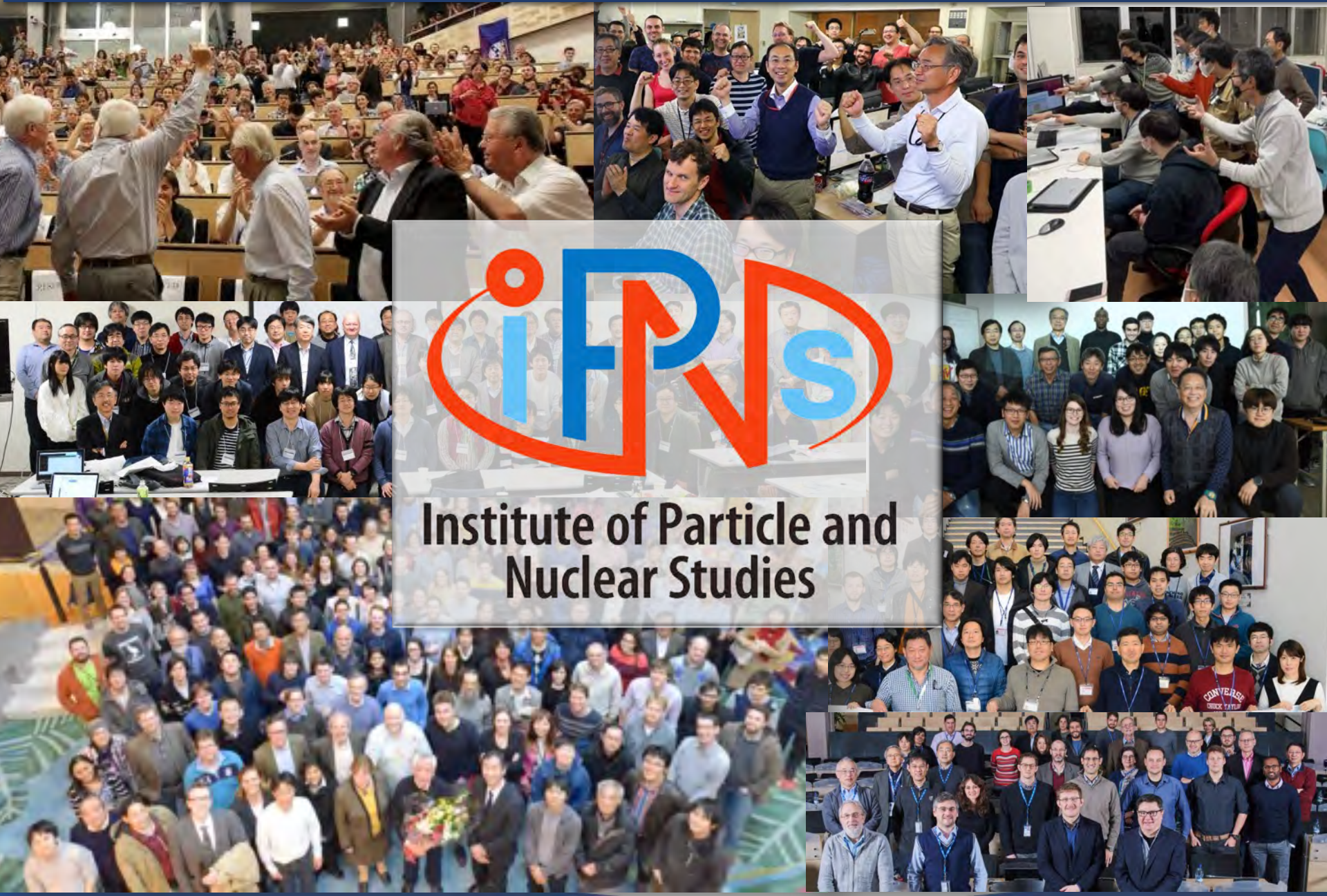


nEDM Spin



- 2019 Prototype UCN source operated
  - 5E4 UCN/shot at 0.5 kW
  - 3E5 UCN/shot at 5 kW
  - stable operation for ~ one month
- 2020 UCN source upgraded
  - proton power 20 kW
  - <sup>3</sup>He Cryostat from KEK (10W@0.8K)
- 2023
  - LD<sub>2</sub> moderator construction
  - <sup>3</sup>He Cryostat Commissioning
- 2024 Expectation
  - 2E7 UCN/shot
  - 6,400 UCN/cm<sup>3</sup> at source
  - 250 polarized UCN/cm<sup>3</sup> at EDM cell
- 2025 Engineering and Physics Run will start

# Let's Share More Excitements!



**Institute of Particle and  
Nuclear Studies**