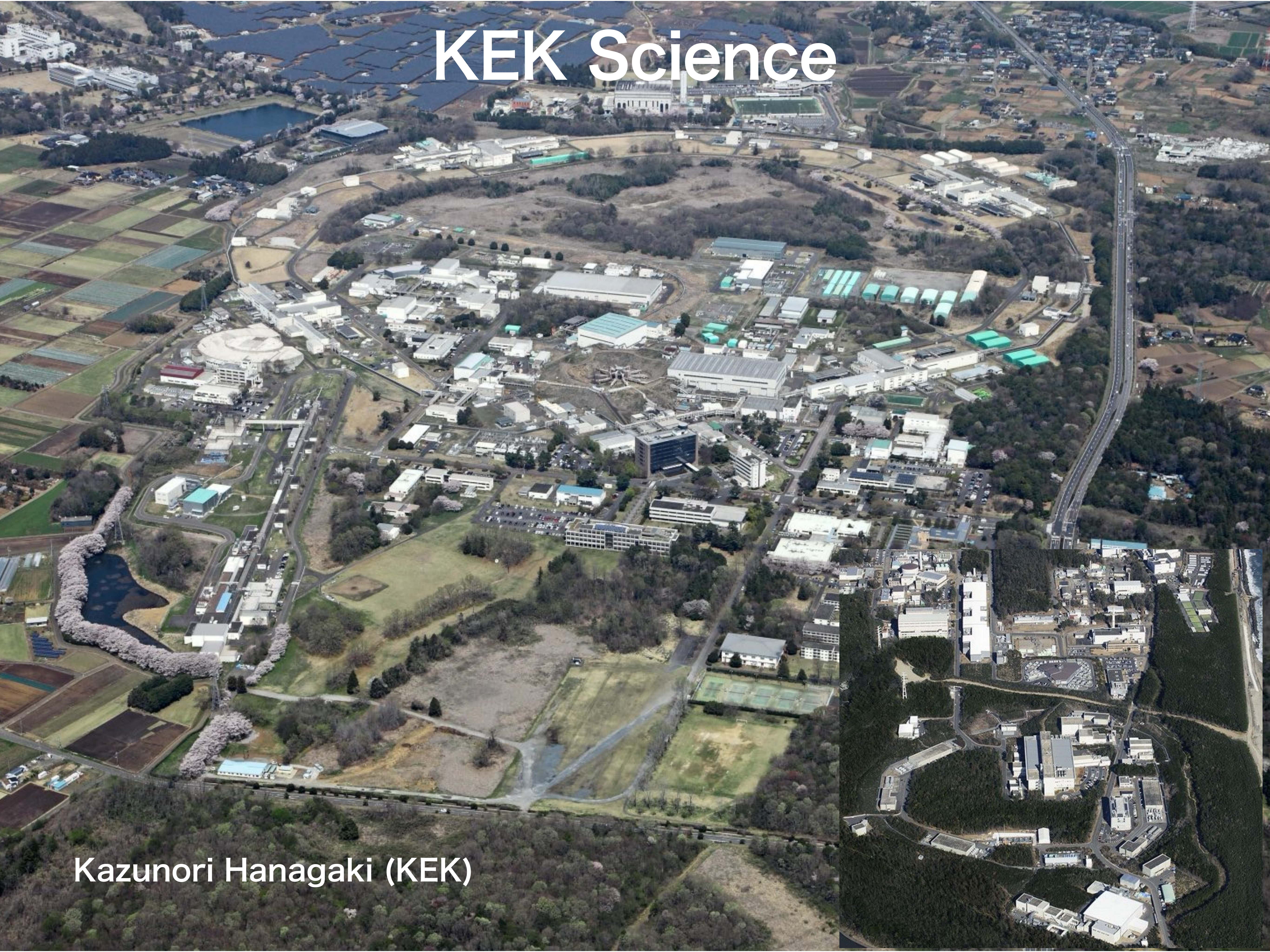
KEK Science



Kazunori Hanagaki (KEK)

Congratulations

Congratulations on the start-up of the wonderful new laboratory.

Thank you so much for inviting me to this memorial event.

Collaboration with HLL/Max Planck/Germany is highly appreciated, which is crucial for our science programs.

Deep apologies from Shoji Asai, KEK Director General, for not being here

KEK Organization

- KEK = High Energy Accelerator Organization
  - was used to be High Energy Laboratory (HEL???)
    高エネルギー研究所：Kou Enerugi Kenkyujo ⇒ KEK

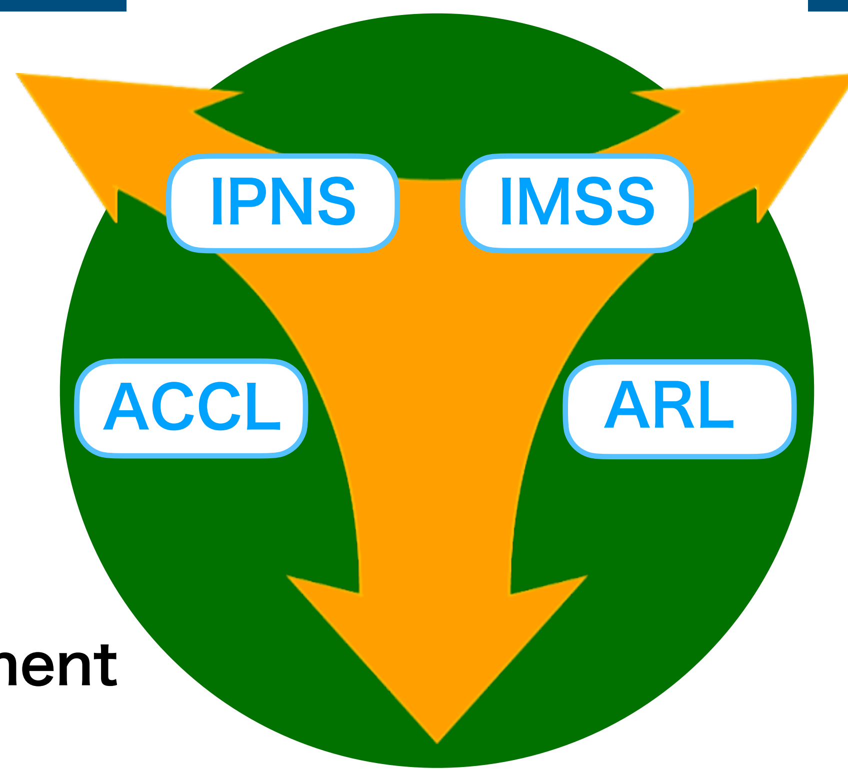
- Two institutes for users from University
  - Institute of Particle and Nuclear Physics
  - Institute of Materials Structure Science
- Two facilities
  - Accelerator Laboratory
  - Applied Research Laboratory
- Two centers
  - QUP
  - J-PARC

Mission of KEK

◉ Mission is to push forward boundary of human knowledge by **<u>accelerator based science</u>**

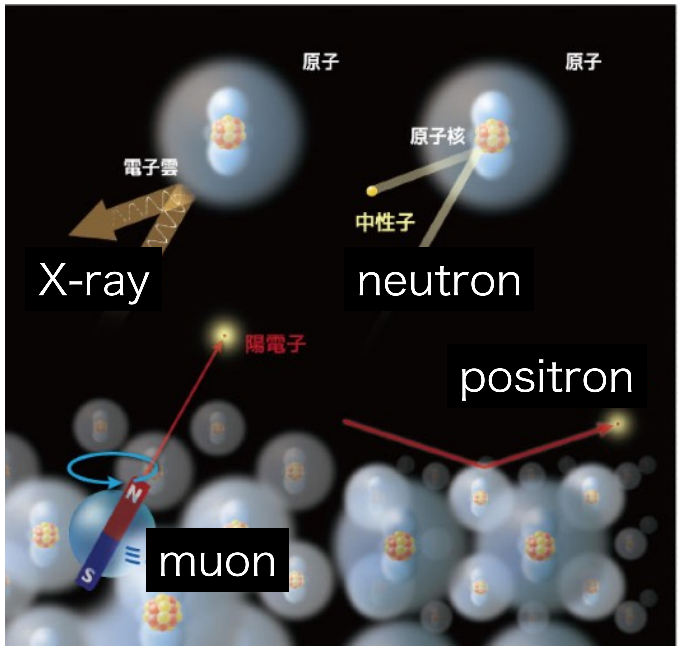
The origin of the Universe

- SuperKEKB/Belle II
- LHC/ATLAS
- T2K/HyperK
- KOTO, COMET
- Nuclear physics
- muon g-2/EDM
- ILC
- Instrumentation development
- theory



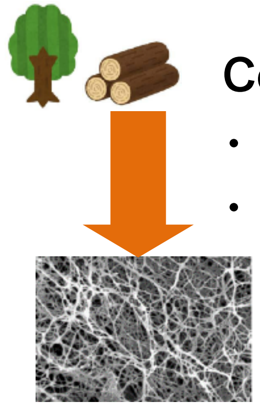
Material and Life Science

Four kinds of quantum beam

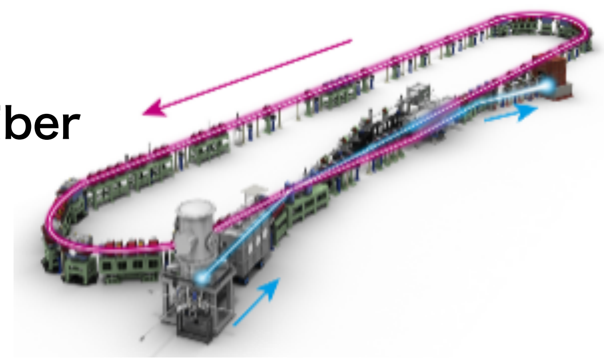


- X-ray and positron at Tsukuba
- Neutron and muon at J-PARC

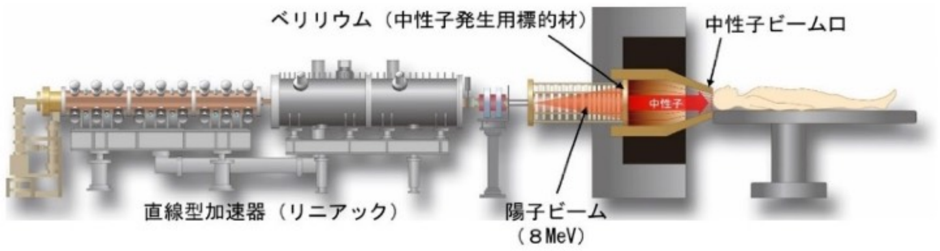
Application of Accelerator



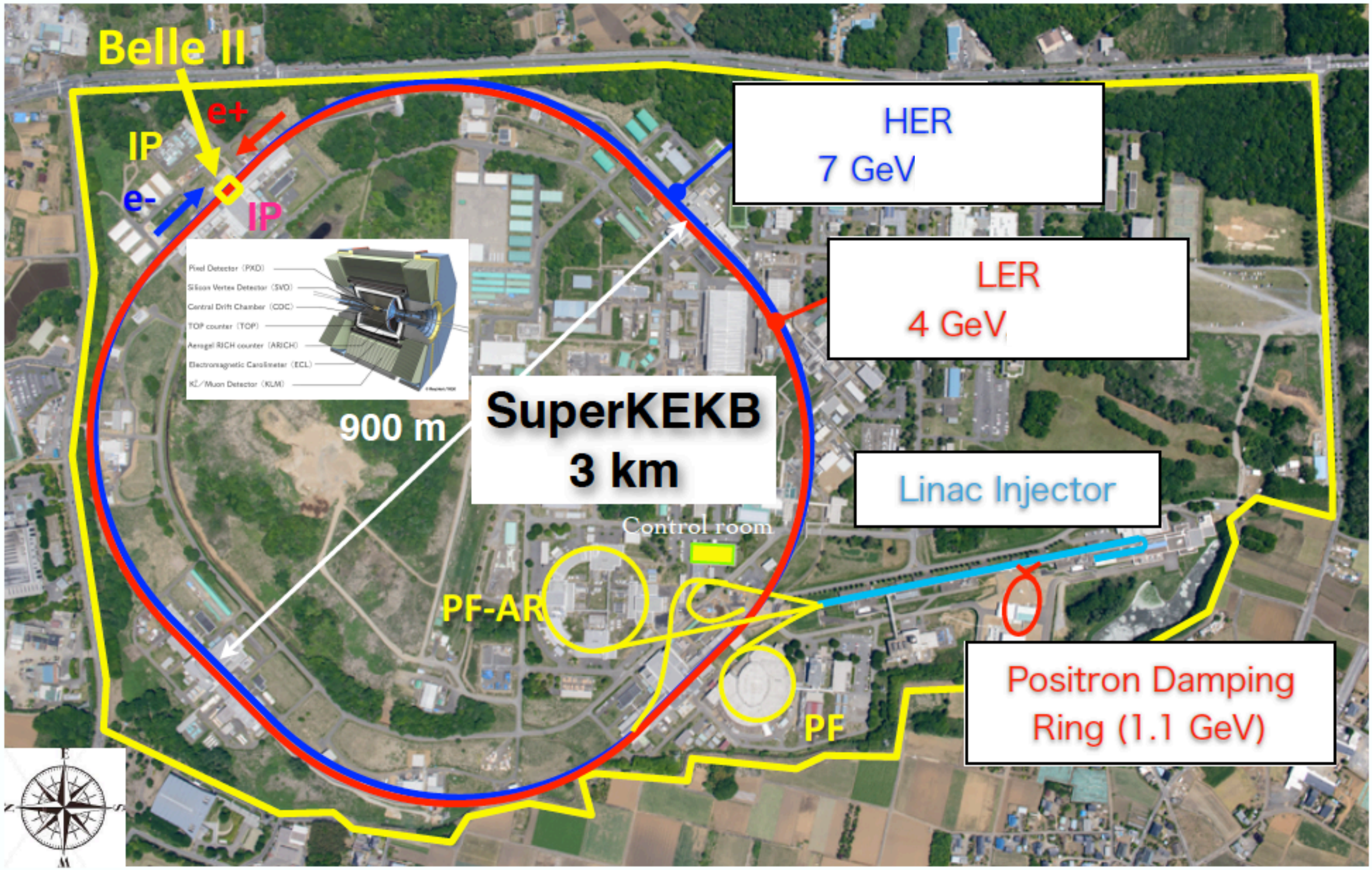
Compact ERL for
- EUV lithography
- Cellulose Nano-fiber



BNCT@J-PARC



Electron/Positron Accelerators in Tsukuba Campus

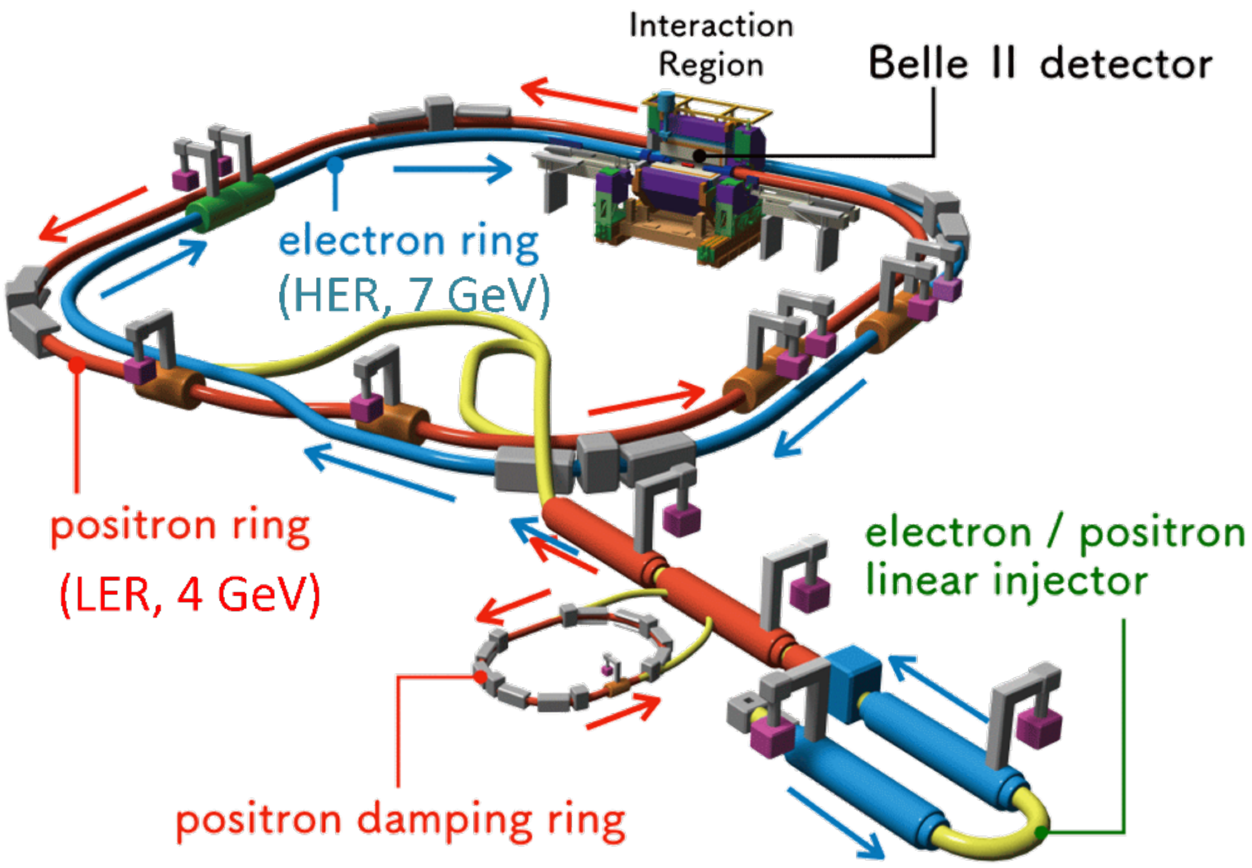


SuperKEKB

Asymmetric energy
to produce B-meson pairs at Υ(4S), and to measure CP violation in B decays (130μm decay length for 1.5ps lifetime)

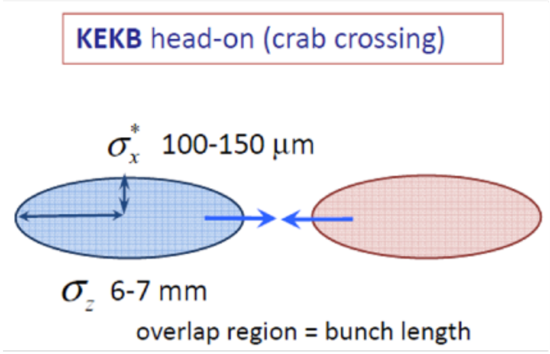
Luminosity world record
***L*=4.7 x 10^34 cm^-2s^-1**
(KEKB record x2.2, PEP-II record x3.9)

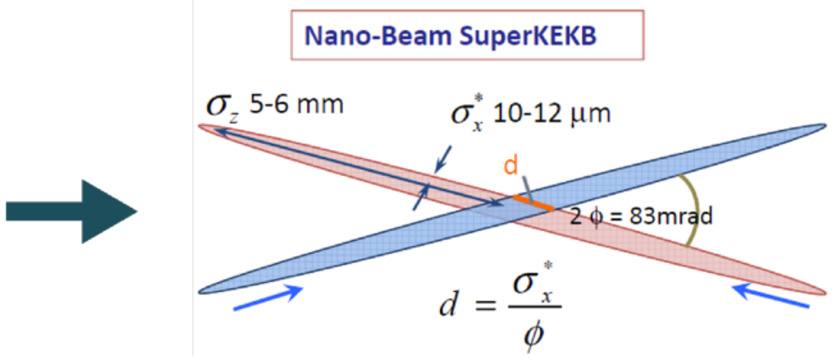
New collider technology standard
Nano-beam scheme
world smallest vertical beam size at the interaction point (200 nm standard deviation)



Powerful injector linac
to compensate the short beam lifetime due to the narrow dynamic aperture

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\frac{R_L}{R_{\xi_y}}$$



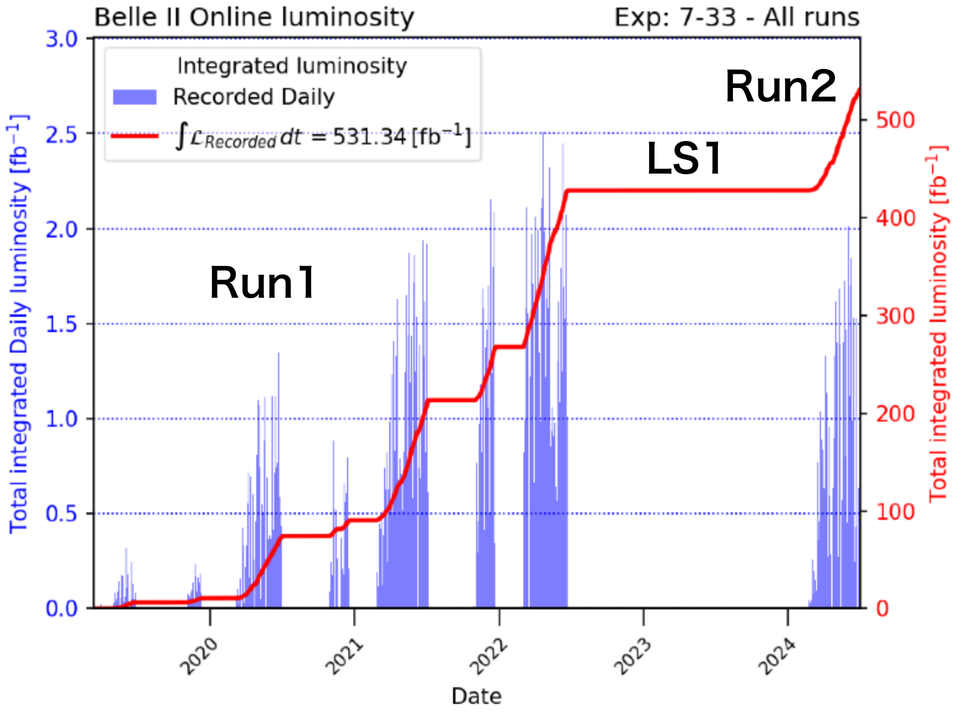


Belle II Detector

Precision decay vertex reconstruction
Twice better resolution than Belle

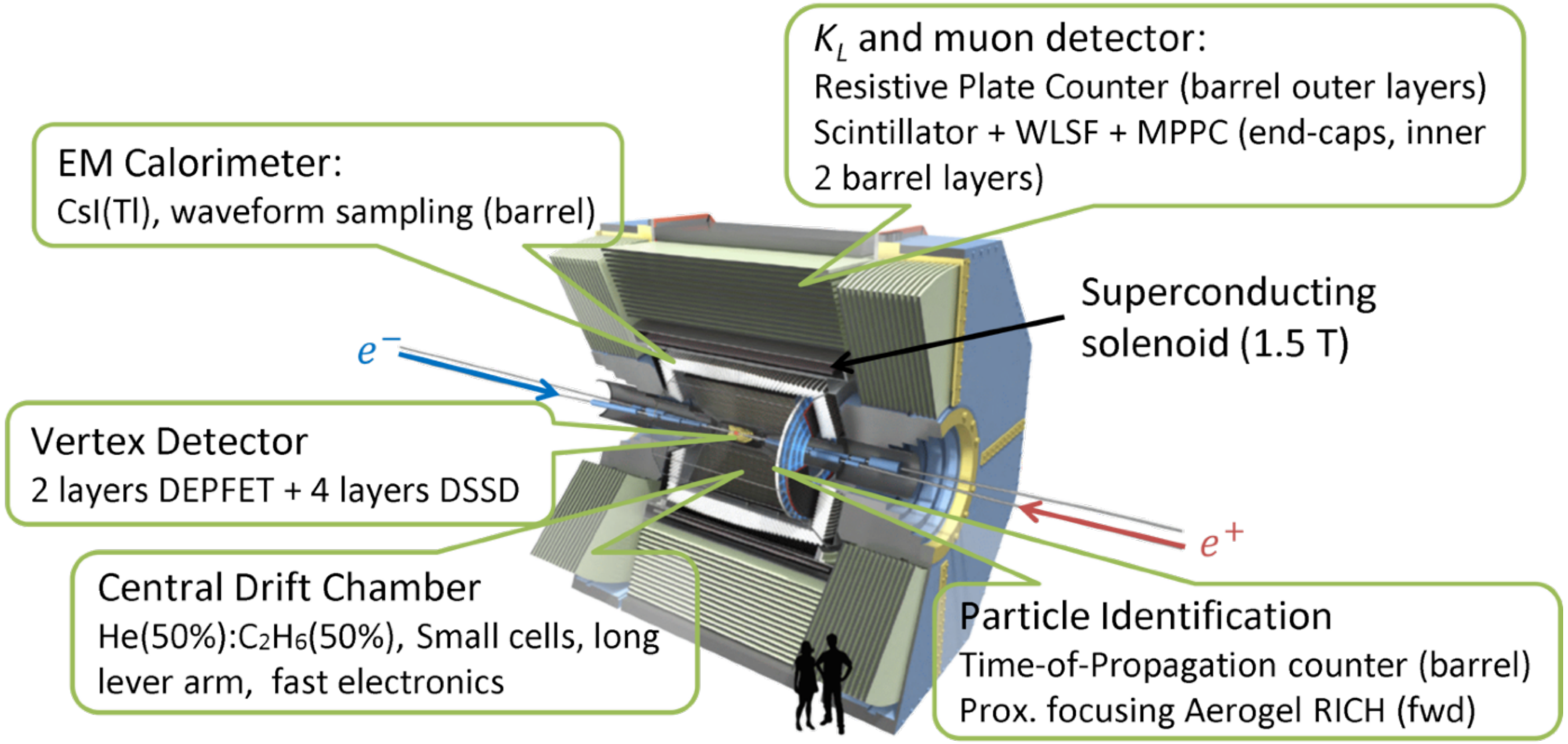
Hermetic detector to infer neutrinos
Charged particles with good identification capabilities
Good photon resolution, capture K-long mesons

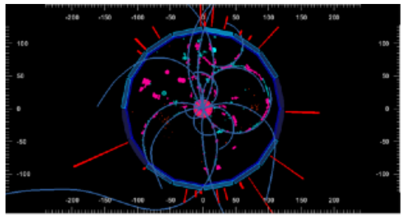
High trigger and reconstruction efficiency
>99% of B decay events are triggered and recorded



531 fb^{-1} recorded
about half of Belle
424 fb^{-1} before LS1

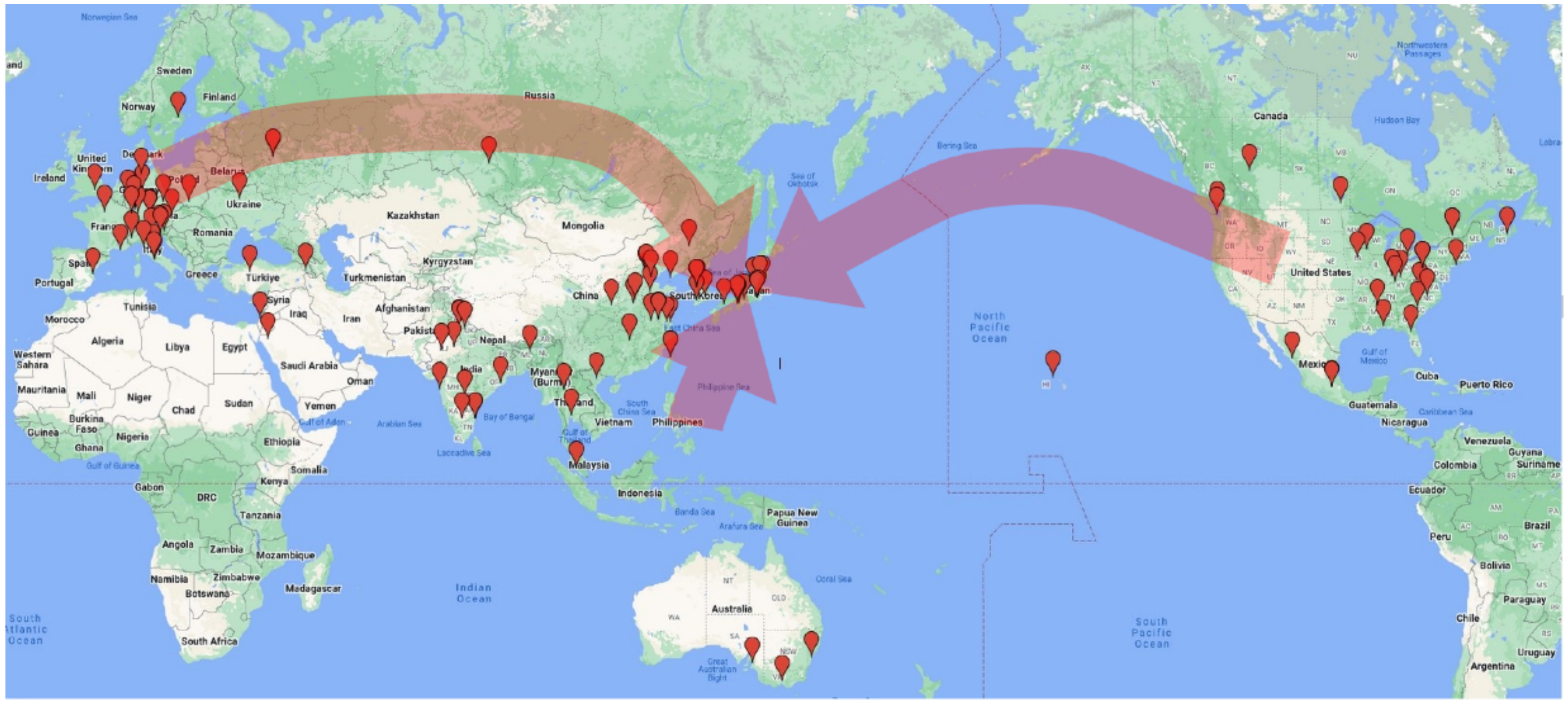
Long shutdown 1 (LS1)
Full pixel detector installation
TOP MCP-PM replacement
Data acquisition upgrade





Live streaming at https://evdisp.belle2.org/

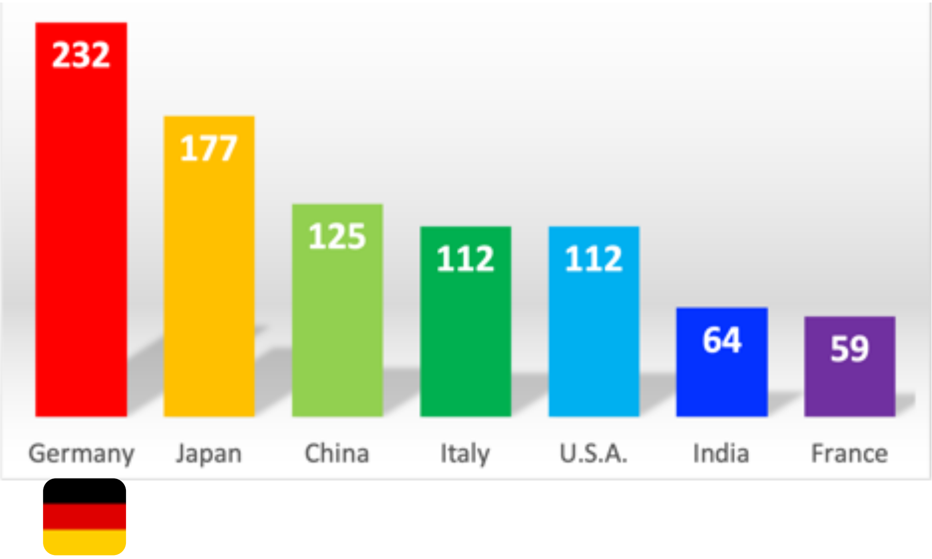
Belle II Collaboration



Hosted and operated
at KEK, Tsukuba,

28 countries/regions, 125 institutes, >1100 members
including 311 staffs, 125 postdocs, 261 PhD students

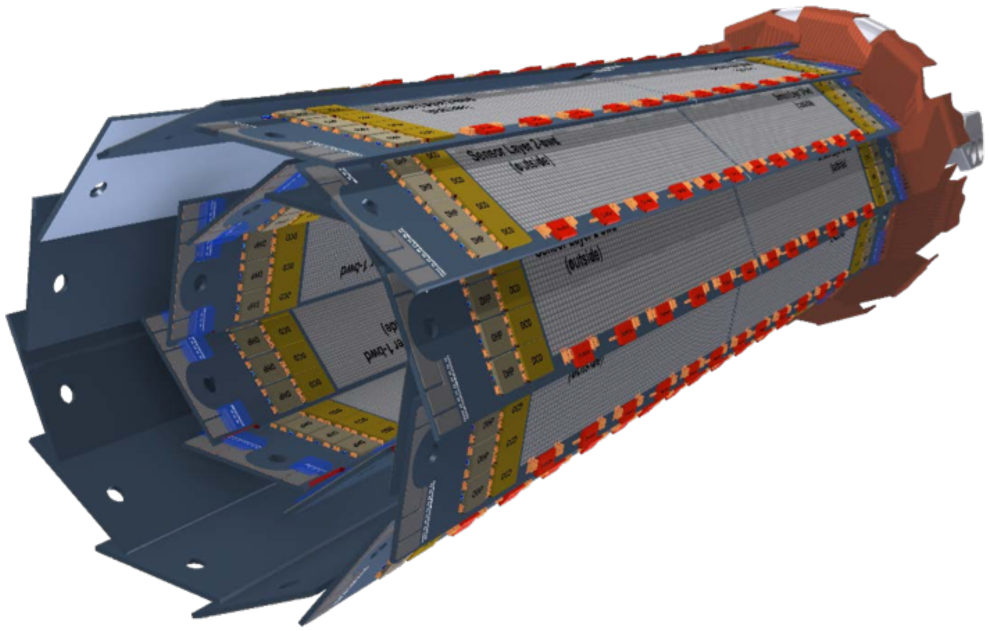
Germany as the largest collaborating country
232 members, even more than Japan (!)
Major organization roles: institutional board chair and next spokesperson



DESY as the information center of Belle II
Providing most of the collaborative tools (documents, mails, wiki, …)

Pixel Detector

Pixel Detector (PXD) based on the DEPFET technology and German efforts



- 20 ladders (40 modules)
- 8M channels in total
- 75μm sensor thickness

Contributions from HLL, MPP and
other institutes mostly in Germany

MPP contributions

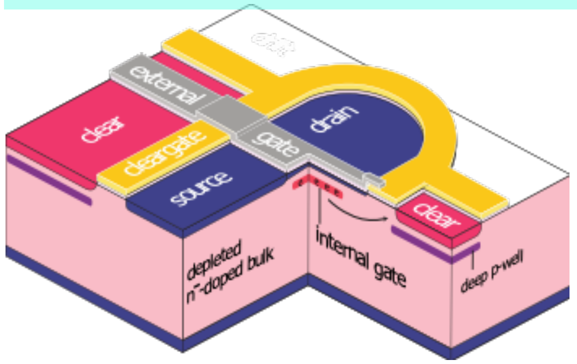
Pixel detector mechanics and assembly

Vertex detector CO_2 cooling system (IBBelle)

Vertex detector installation procedure and tools

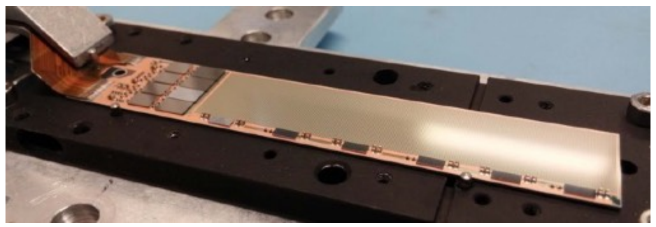
HLL contributions

DEPFET sensor and module production



DEPFET pixel sensor

DEPFET sensor module

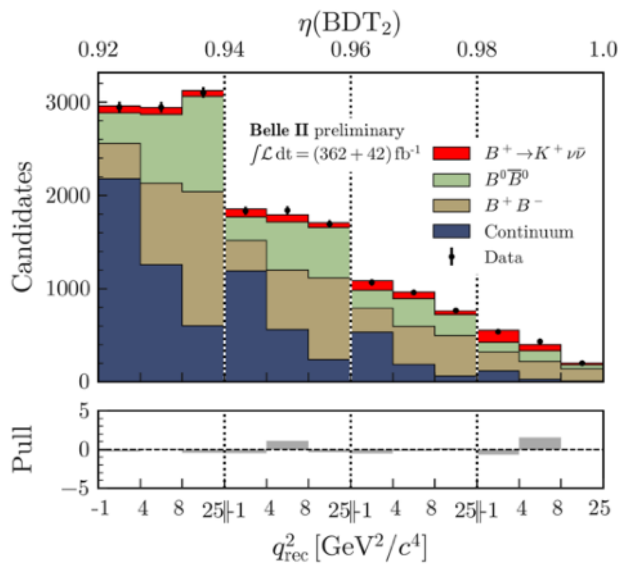


CO_2 cooling system

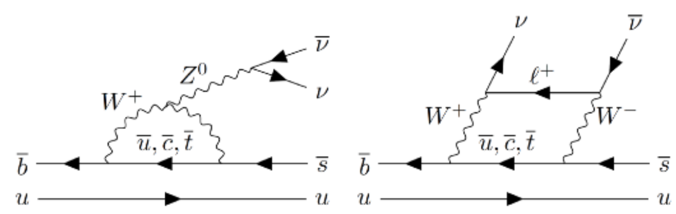
Detector installation into Belle II

Belle II Physics Highlight

Evidence for B→K$\nu\nu$, 2.7σ compatibility with the SM
This measurement is only possible at Belle II



B → K$\nu\nu$ (362fb^{-1})

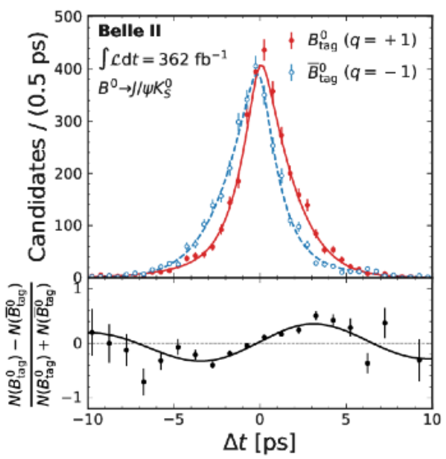


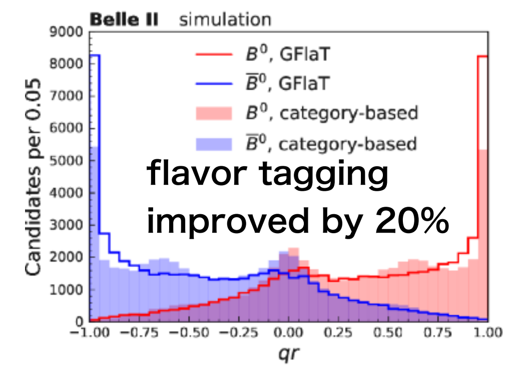
$$\mathcal{B}_{\text{BelleII}} = (2.3 \pm 0.5^{+0.5}_{-0.4}) \times 10^{-5}$$

$$\mathcal{B}_{\text{SM}} = (5.58 \pm 0.37) \times 10^{-6}$$

CP violation as the mainstream program of B-factory with major improvements in detector and analysis

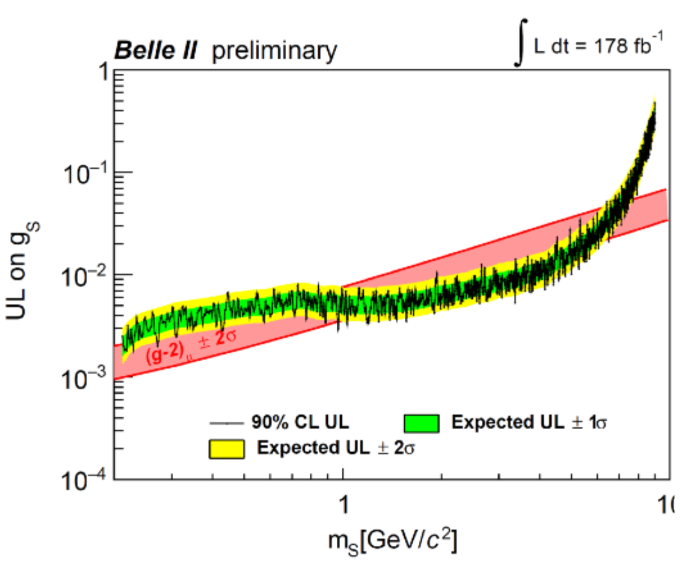
B → J/ψKs (362fb^{-1})



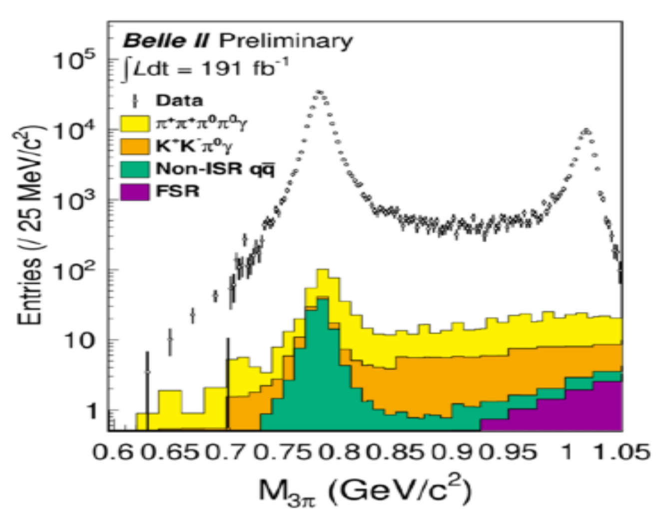


Level-1 trigger designed for dark sector searches and measurement of HVP contribution to muon g-2

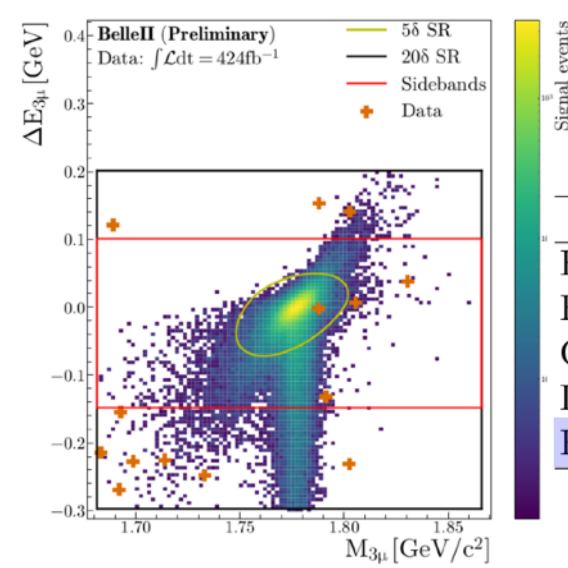
Muon phallic scalar S (178fb^{-1})



σ (e^+e^- → $\pi^+\pi^-\pi^0\gamma$) (191fb^{-1})



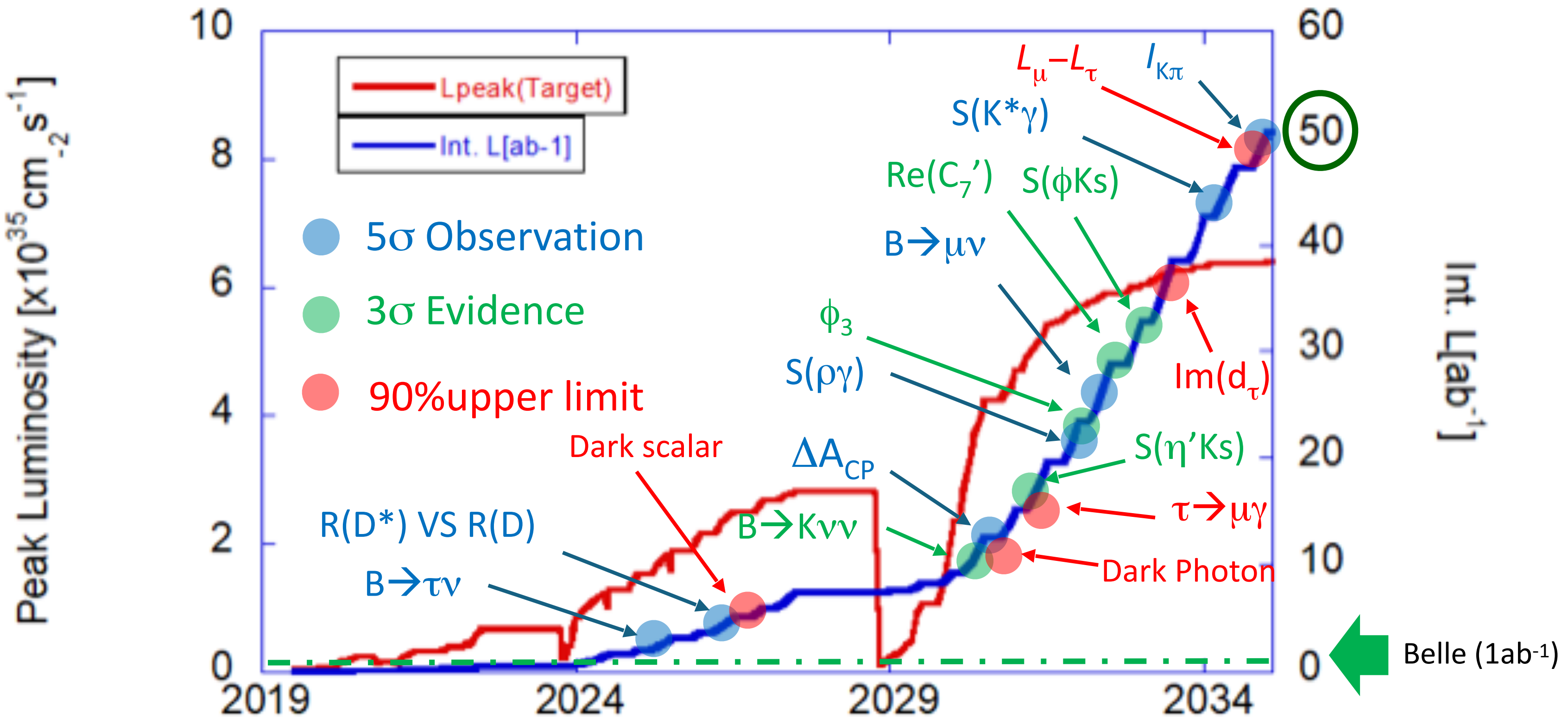
Belle II is the place where world-leading searches for Lepton Flavor Violating τ decay can be performed



τ → $\mu^+\mu^-\mu$ search (424fb^{-1})

	UL at 90% CL on $B(\tau \to 3\mu)$
Belle	2.1×10^{-8} ($\mathcal{L}_{int} = 782\text{fb}^{-1}$)
BaBar	3.3×10^{-8} ($\mathcal{L}_{int} = 468\text{fb}^{-1}$)
CMS	2.9×10^{-8} ($\mathcal{L}_{int} = 131\text{fb}^{-1}$)
LHCb	4.6×10^{-8} ($\mathcal{L}_{int} = 2.0\text{fb}^{-1}$)
Belle II	1.9×10^{-8} ($\mathcal{L}_{int} = 424\text{fb}^{-1}$)

Belle II Prospects



SuperKEKB upgrade in Long Shutdown 2

To overcome the issues on further squeezing the beams and increasing the beam currents

R&D for major redesign of the interaction region is on-going…

To be reviewed

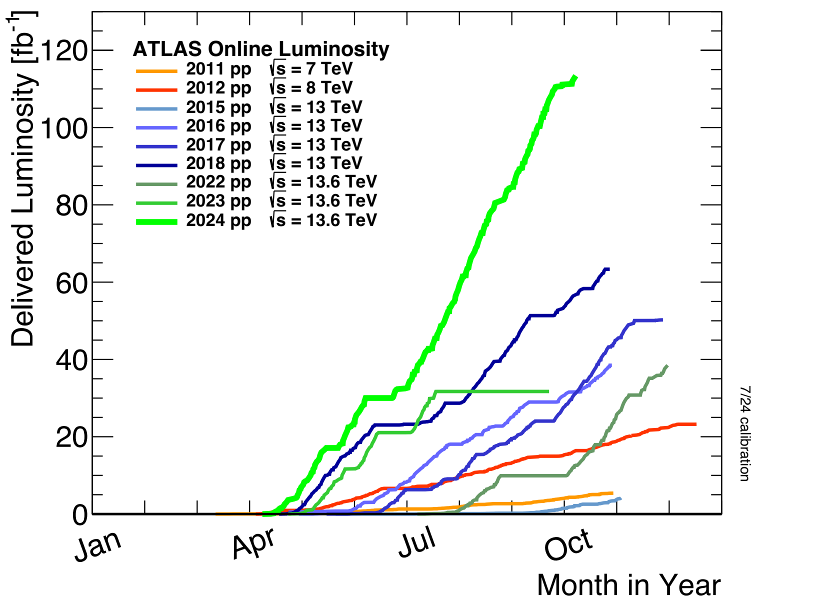
Belle II detector upgrade

To improve detector robustness against future high background rate

To improve measurement performance for better physics sensitivities…

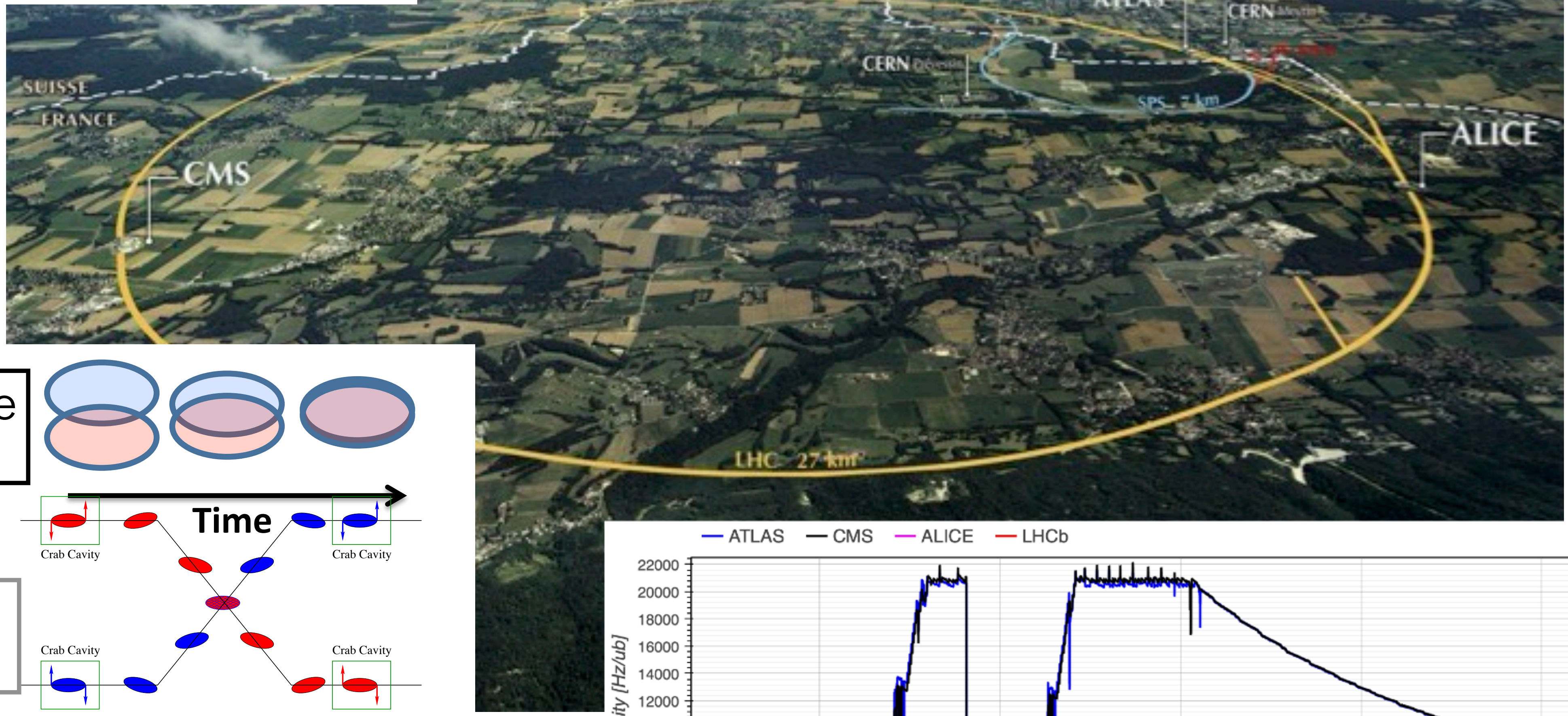
We need your supports !!

LHC

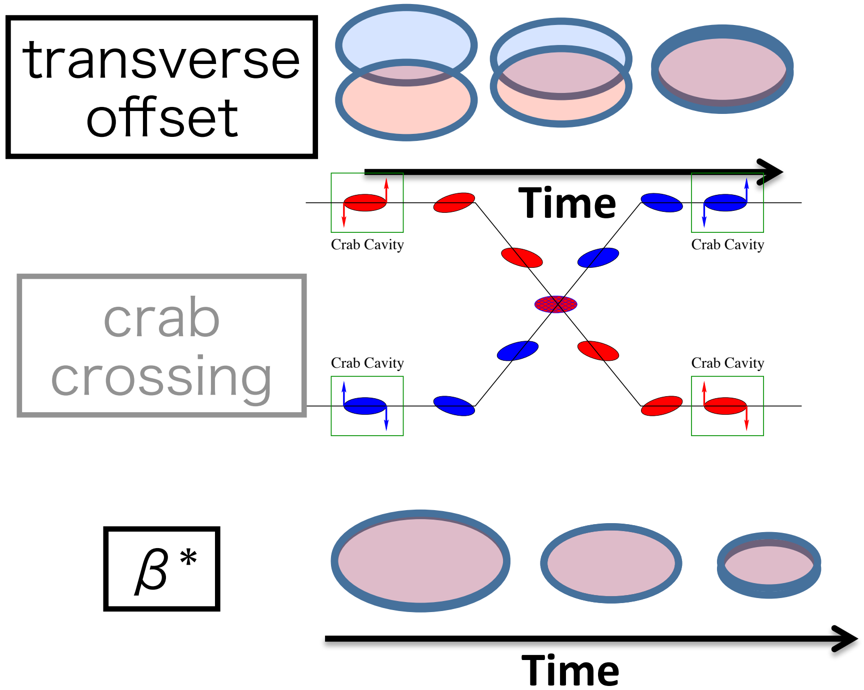


ATLAS Online Luminosity
2011 pp √s = 7 TeV
2012 pp √s = 8 TeV
2015 pp √s = 13 TeV
2016 pp √s = 13 TeV
2017 pp √s = 13 TeV
2018 pp √s = 13 TeV
2022 pp √s = 13.6 TeV
2023 pp √s = 13.6 TeV
2024 pp √s = 13.6 TeV
Delivered Luminosity [fb-1]
Jan
Apr
Jul
Oct
Month in Year
7/24 calibration

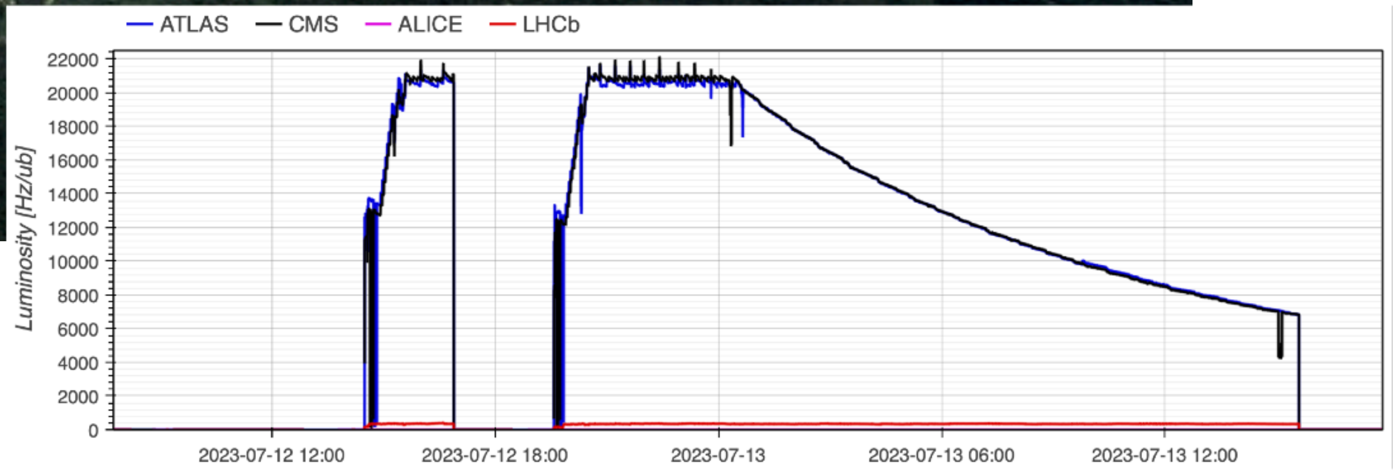
HCLQX
Final Focus Magnet by
KEK and Fermilab



LHCb
ATLAS
CERN
SPS
SUISSE
FRANCE
CMS
ALICE
LHC 27 km



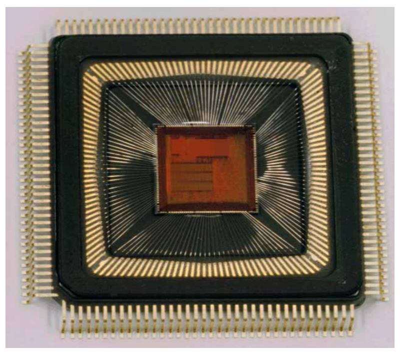
transverse offset
Time
Crab Cavity
crab crossing
β*
Time



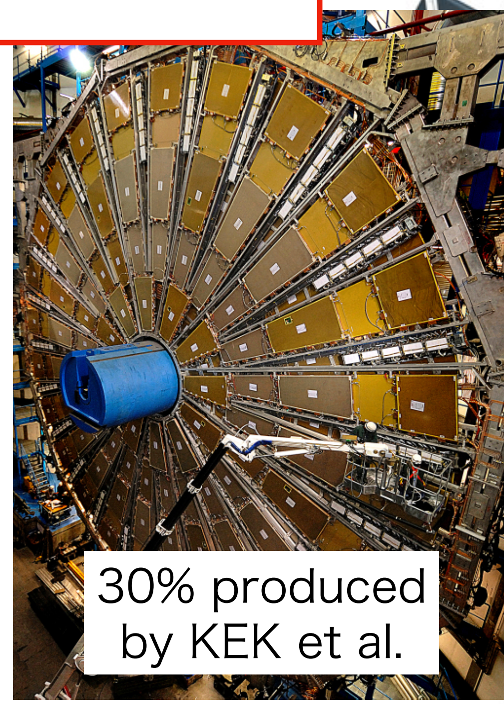
ATLAS
CMS
ALICE
LHCb
Luminosity [Hz/ub]
2023-07-12 12:00
2023-07-12 18:00
2023-07-13
2023-07-13 06:00
2023-07-13 12:00

KEK/Japan Contributions to ATLAS

muon drift tube TDC ASIC: 100%
End cap trigger (TGC)
detector : 30%
electronics : 100%

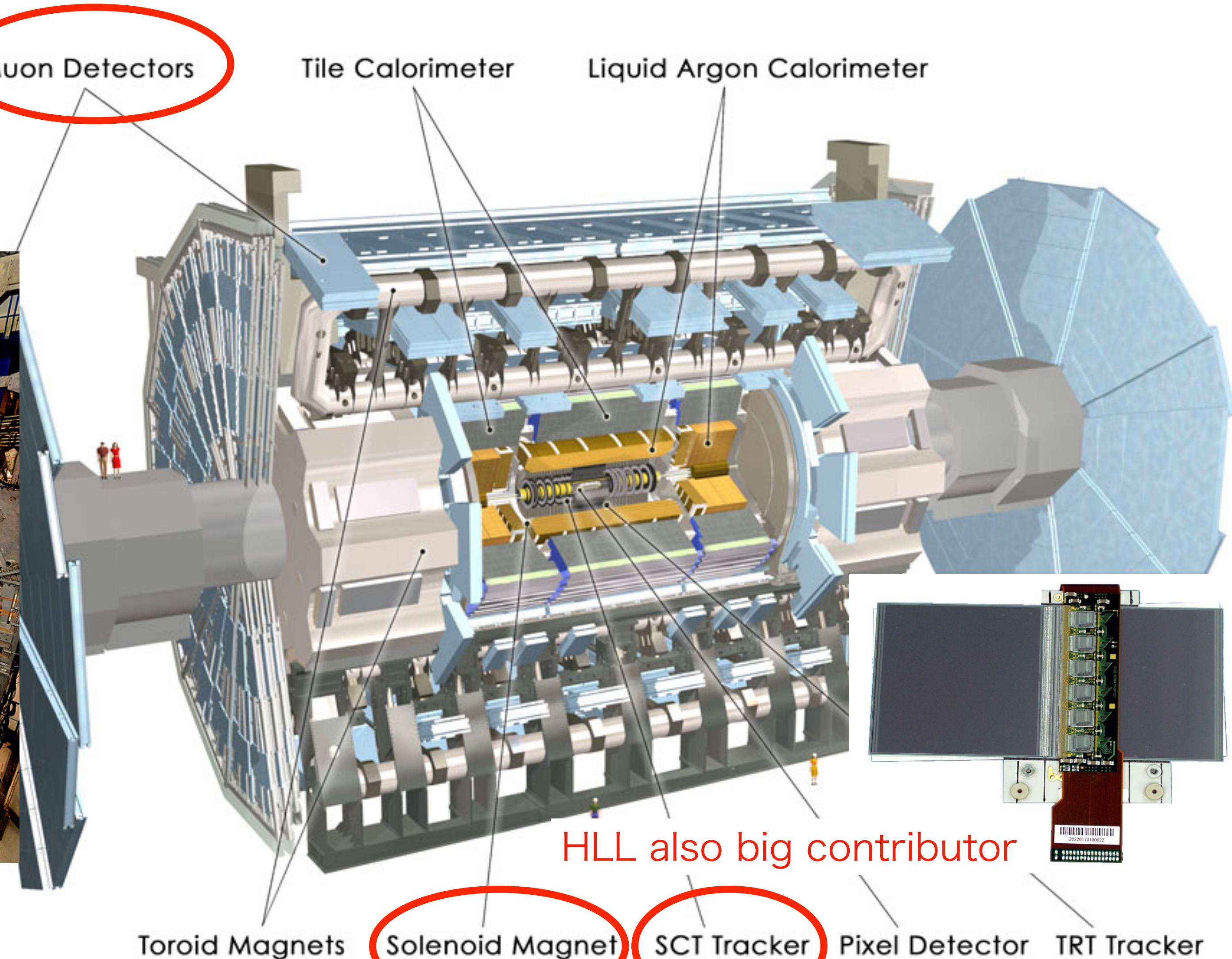


TDC ASIC
20,000 produced



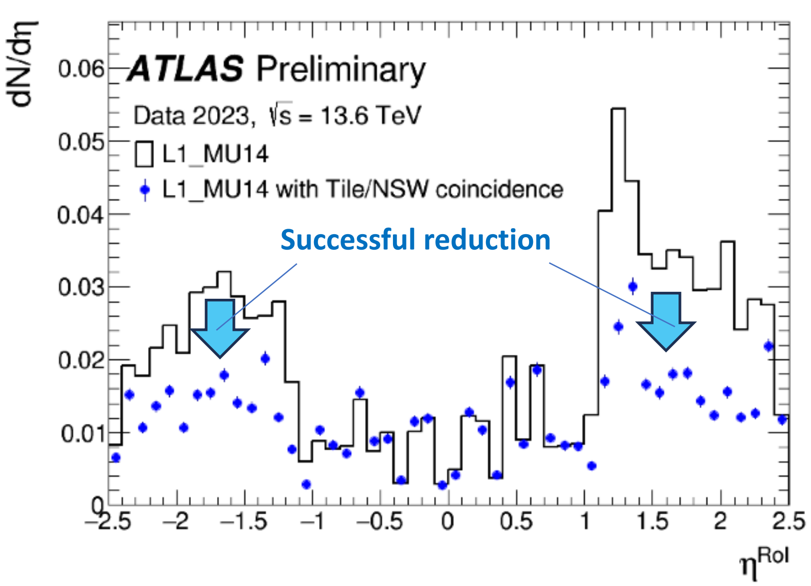
30% produced by KEK et al.

Operation Responsibility
- ~100% for TGC
- 30~40% for SCT

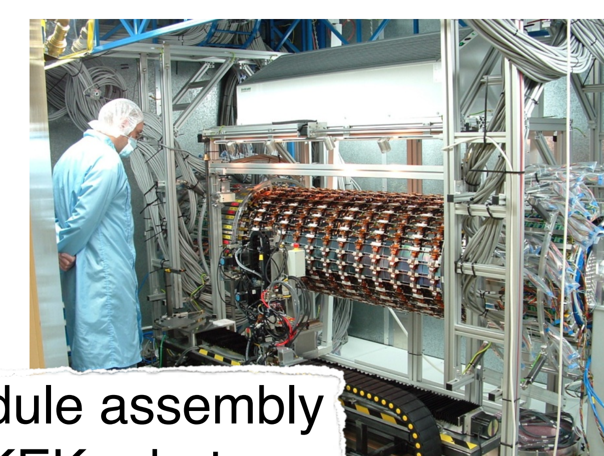


100%

20%



Solenoid at CERN before installation



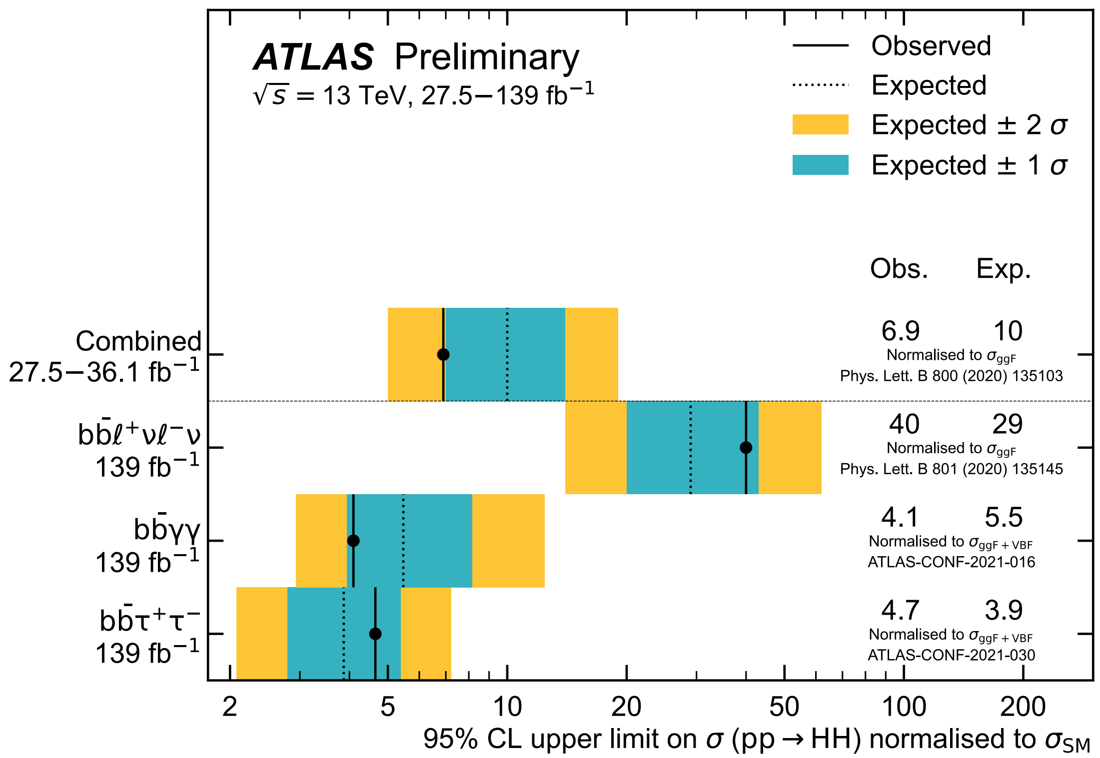
module assembly by KEK robot

ATLAS Physics Highlight

Di-higgs search

$$V(h) = \frac{1}{2}m_h^2 h^2 + \frac{1}{3!}\lambda_{hhh} v h^3 + \frac{1}{4!}\lambda_{hhhh} h^4 + \dots$$

measured target



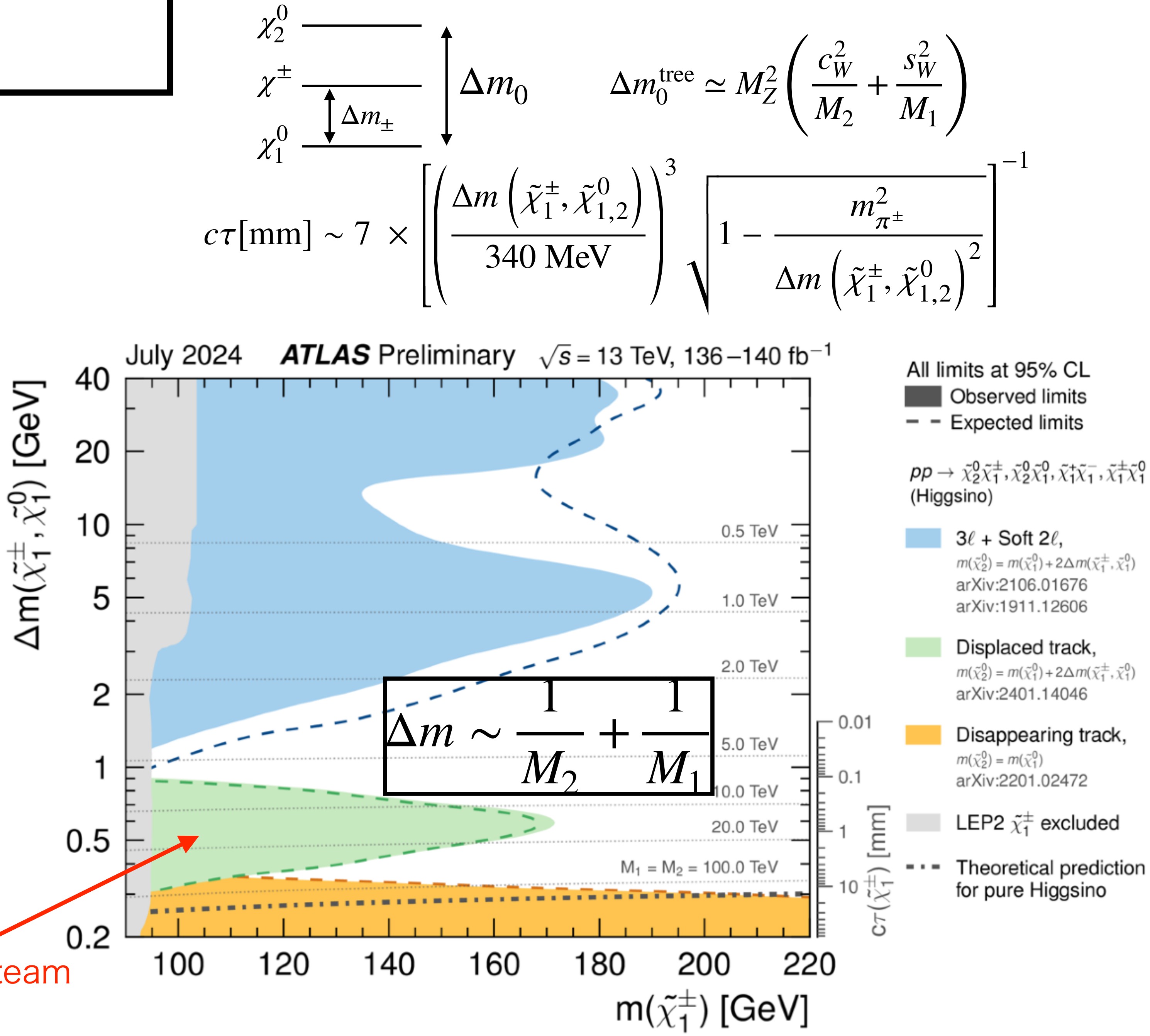
Sensitivities much better than before by Improved analyses
→ we are aiming for further improvements

Electroweakino search

Motivated by
- naturalness
- dark matter

$$\Delta m_0^{\text{tree}} \simeq M_Z^2 \left(\frac{c_W^2}{M_2} + \frac{s_W^2}{M_1} \right)$$

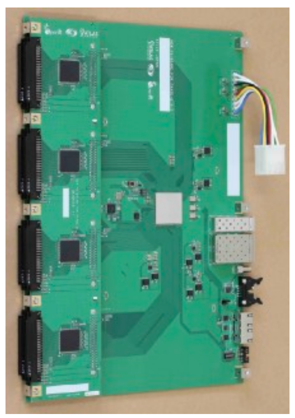
$$c\tau[\text{mm}] \sim 7 \times \left[\left(\frac{\Delta m\left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^0\right)}{340\ \text{MeV}} \right)^3 \sqrt{1 - \frac{m_{\pi^\pm}^2}{\Delta m\left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^0\right)^2}} \right]^{-1}$$

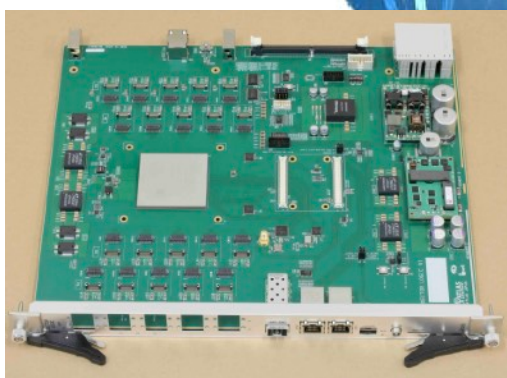


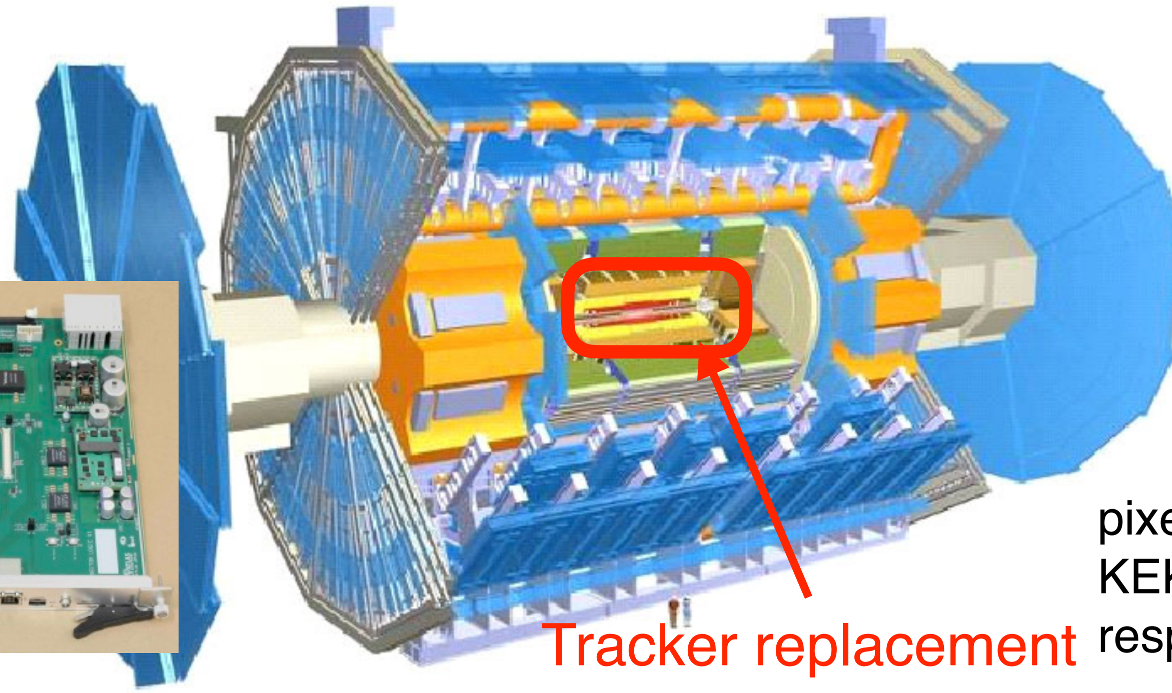
Idea by Japanese team

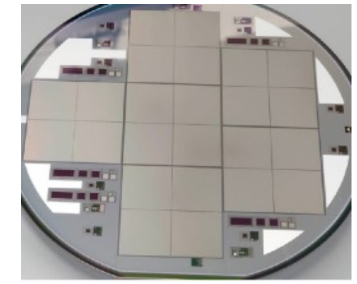
KEK Contributions Towards HL-LHC

Endcap muon trigger electronics replacement

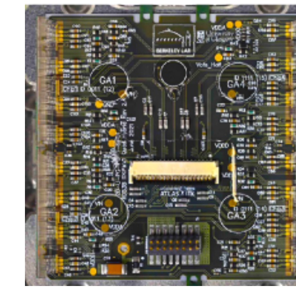


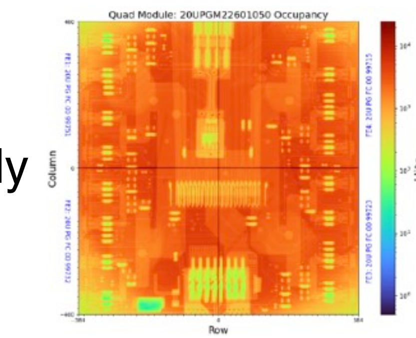






rad-hard n-on-p sensor for pixel and strip

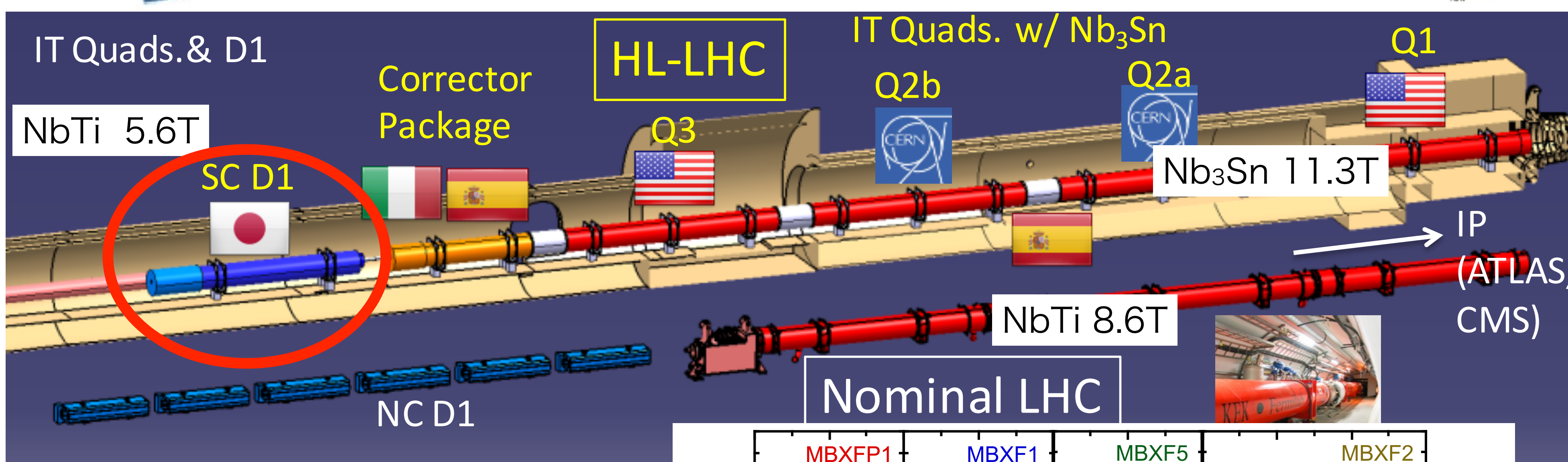


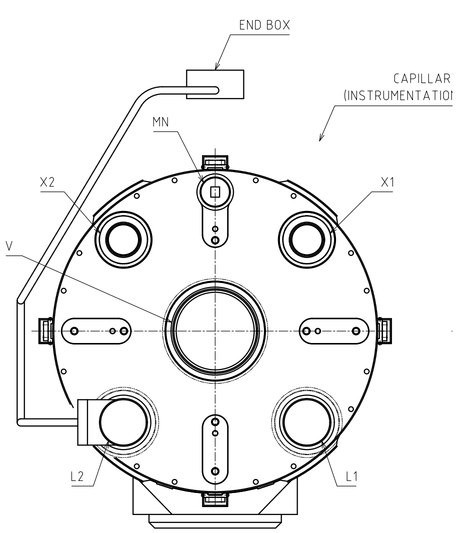


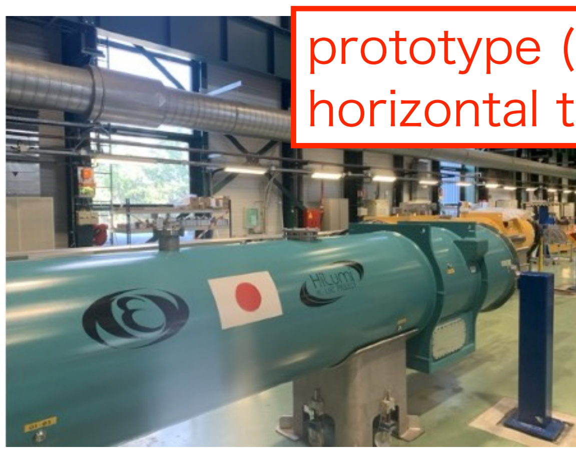
pixel module assembly KEK the largest responsibility

Beam seperation Dipole D1 for HL-LHC

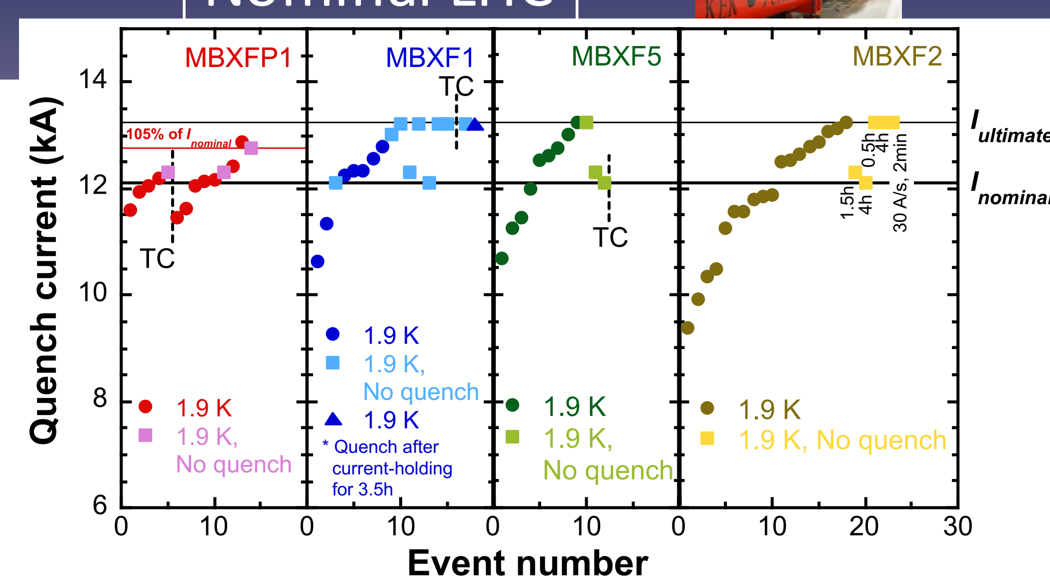
D1	Aperture	B
LHC	63mm	1.3T
HL-LHC	150mm	5.6T



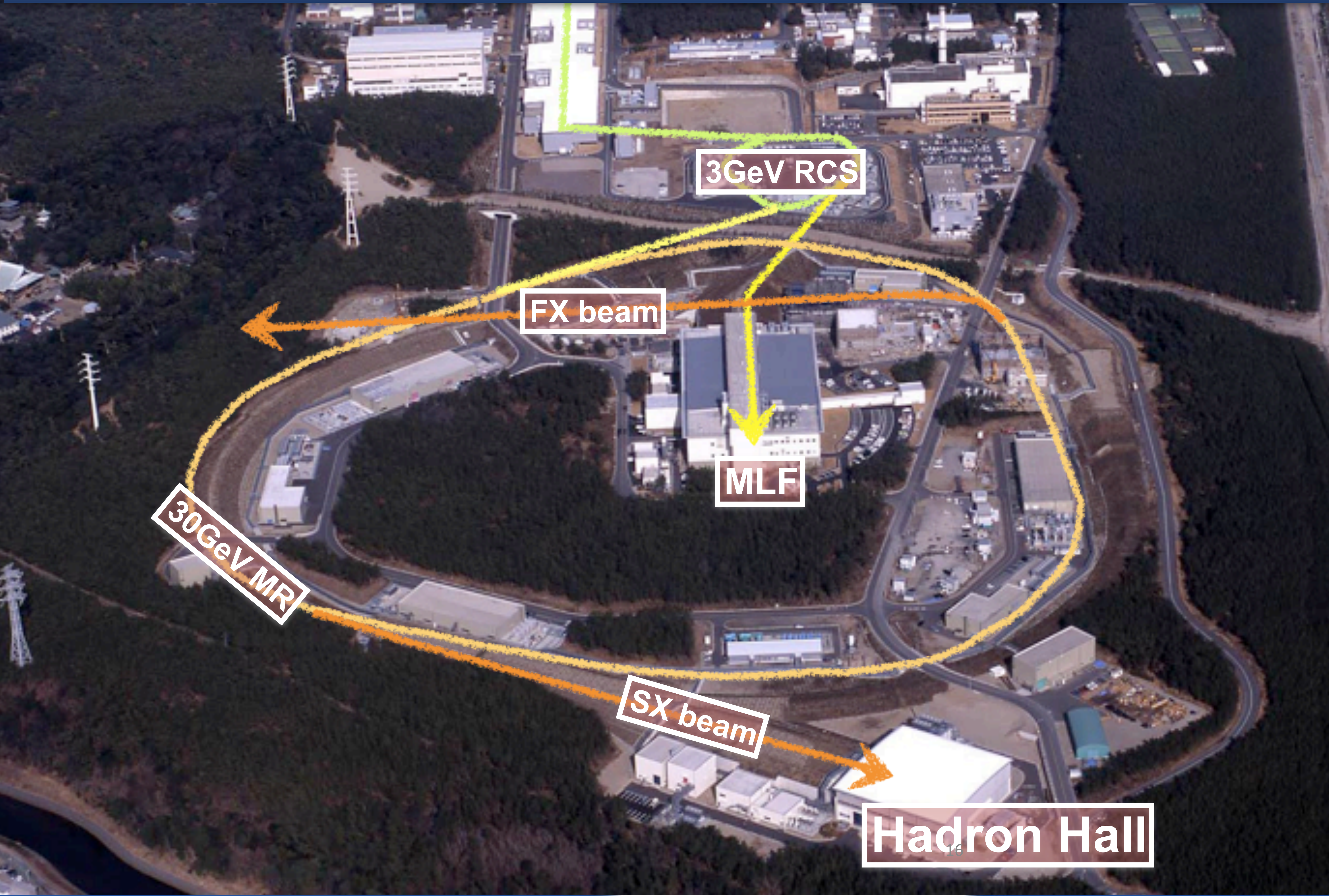




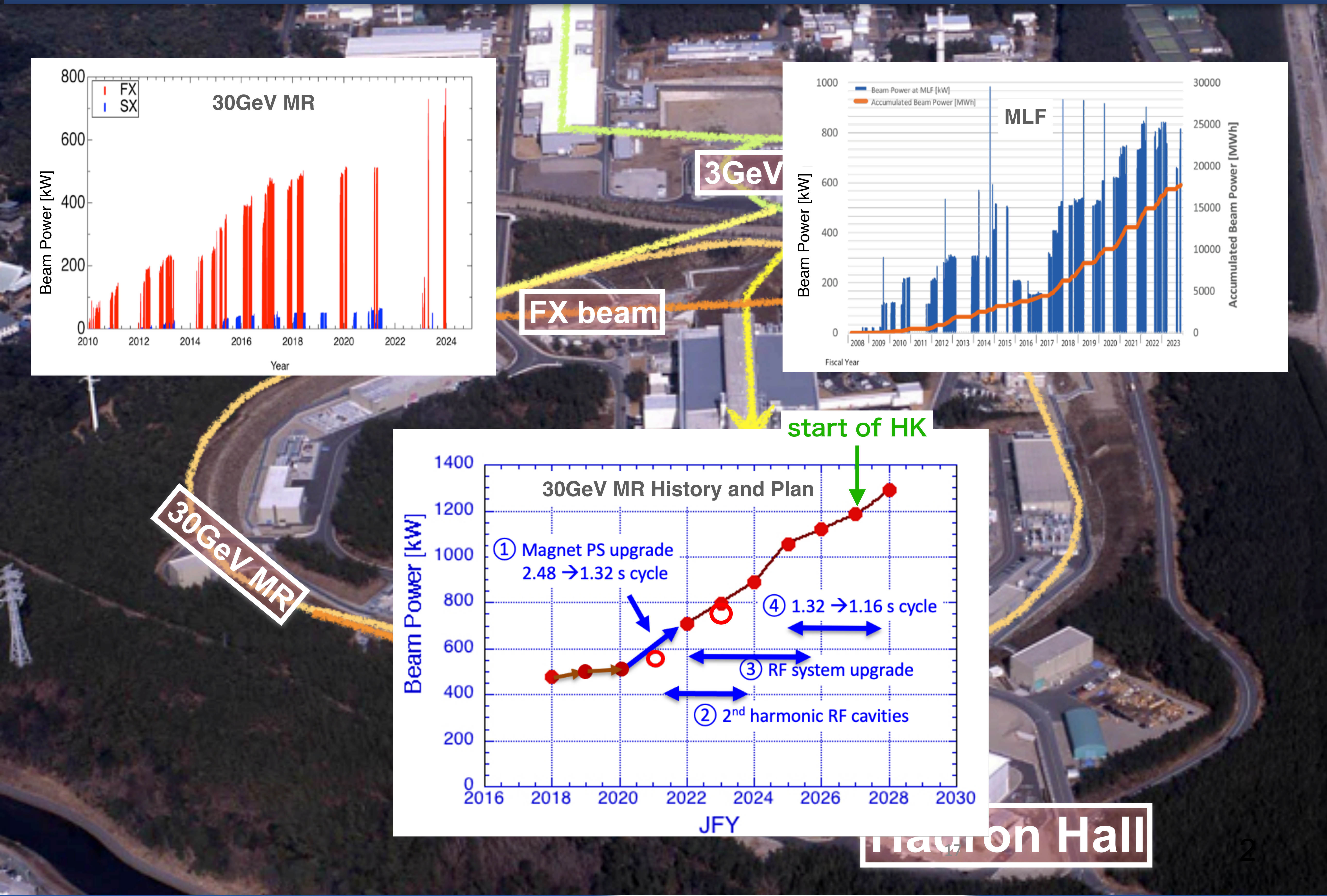
prototype (MBXFP1) horizontal test at CERN



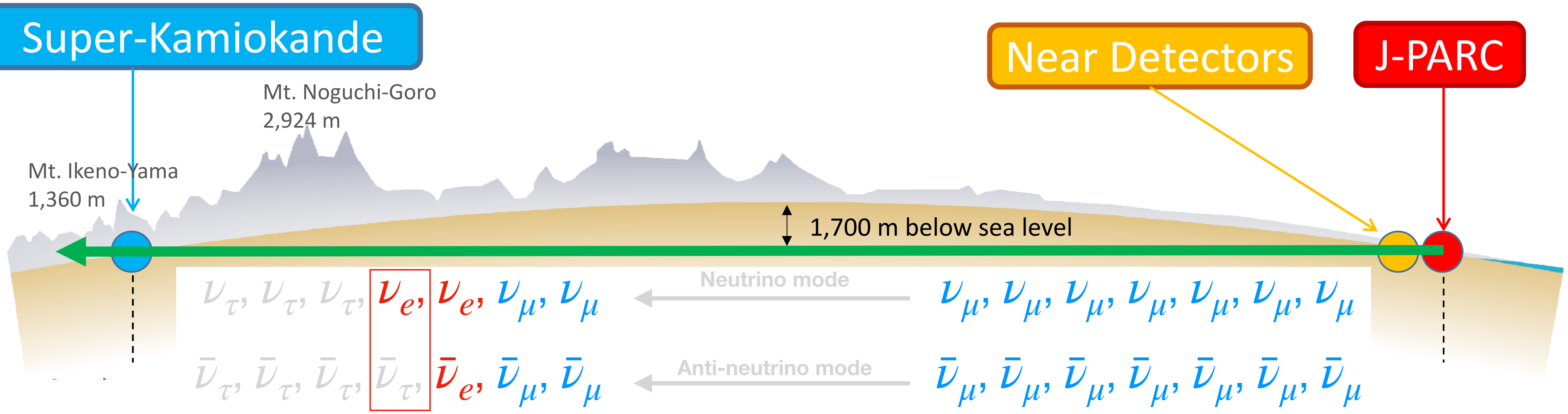
Particle and Nuclear physics at J-PARC



Particle and Nuclear physics at J-PARC



T2K



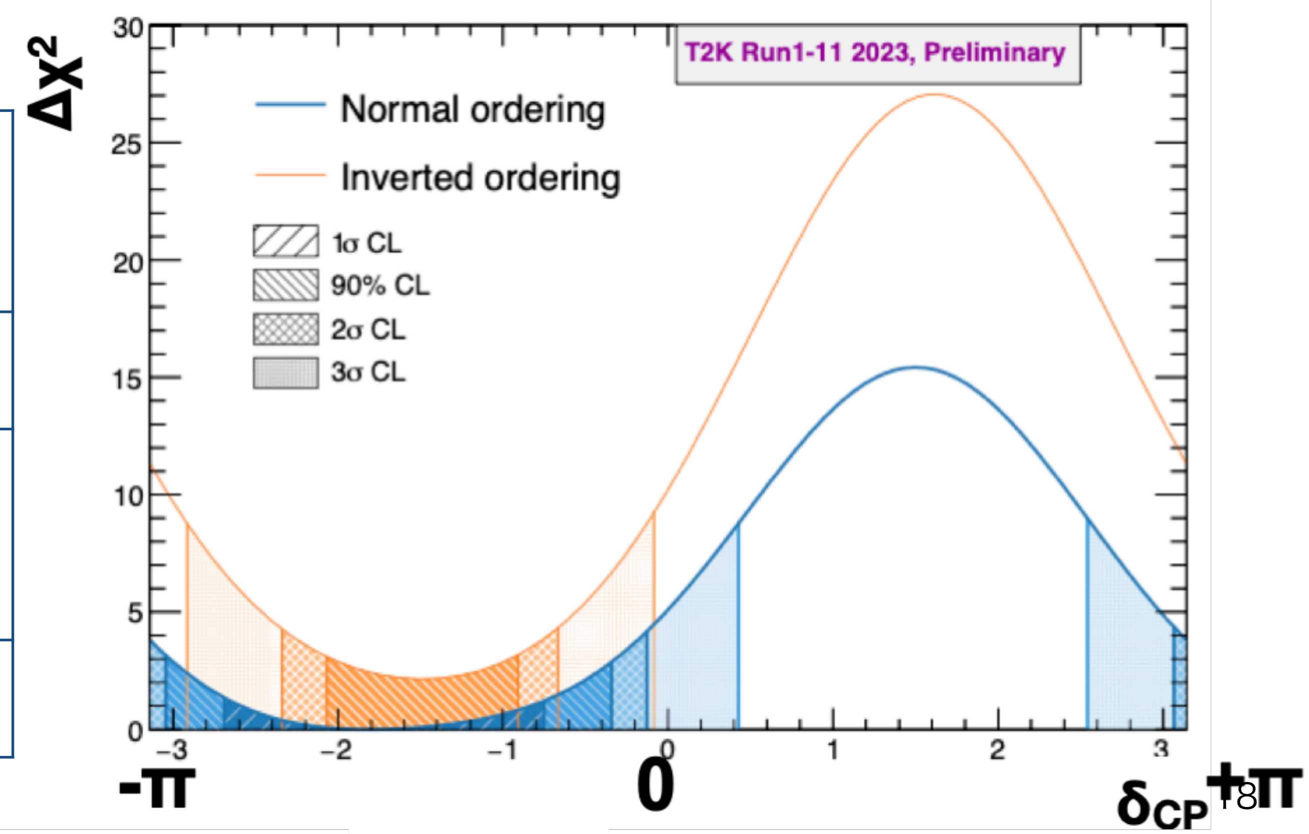
New results shown at the Neutrino2024 conference

of ν_e appearance events

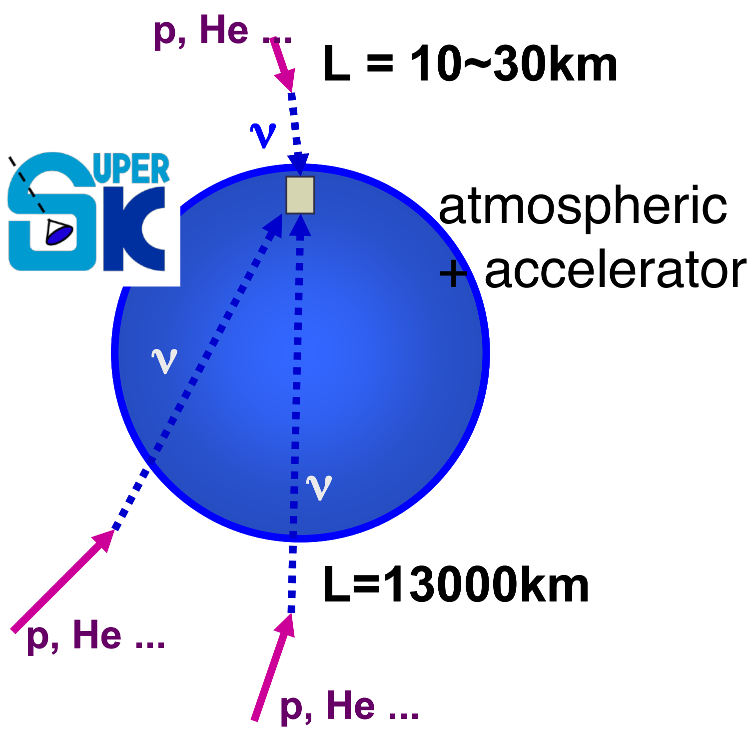
	MC for each δ_{CP}				Data
	$-\pi/2$	0	$\pi/2$	π	
ν-mode 1Re	113.2	95.5	78.3	96.0	**102**
ν-mode 1Re+d.e.	10.0	8.8	7.2	8.4	**15**
$\bar{\nu}$-mode 1Re	17.6	20.0	22.2	19.7	**16**

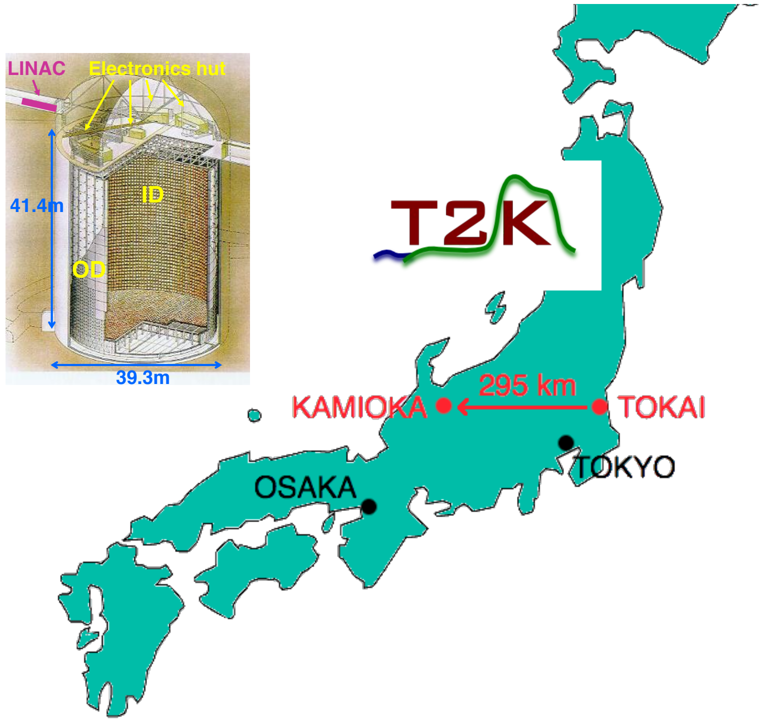
First constraint on lepton CP asymmetry has been obtained

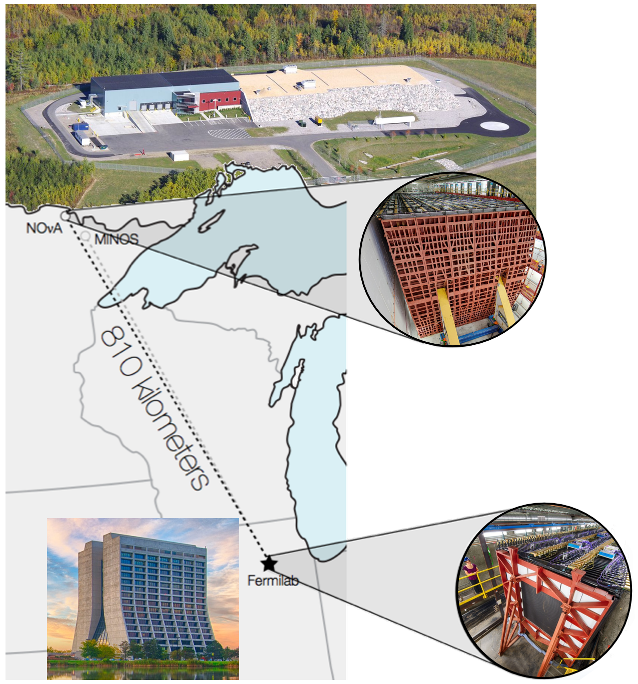
CP conservation is excluded at 90% C.L.



SK-T2K and NOvA-T2K Joint Analysis

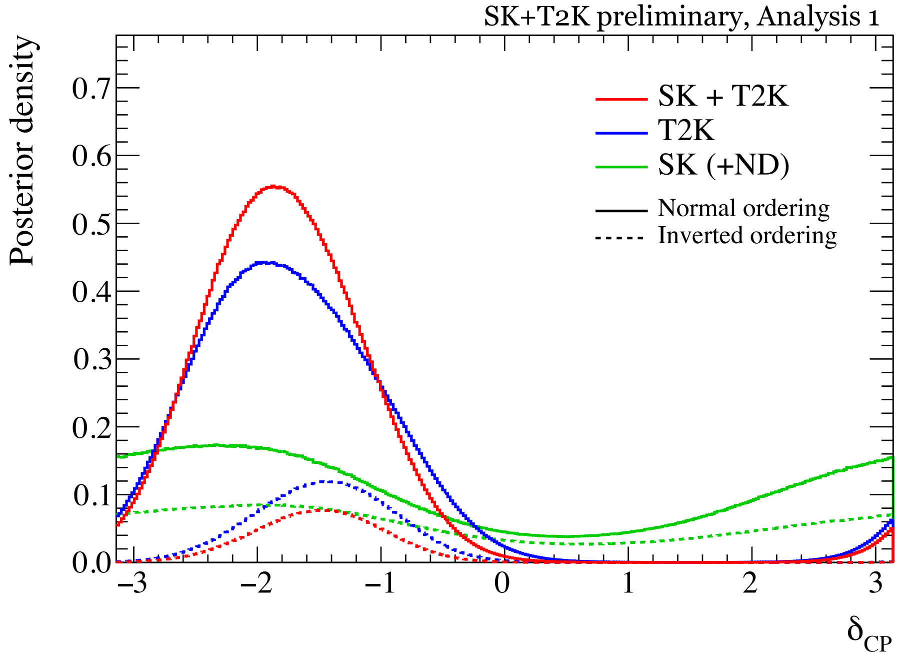


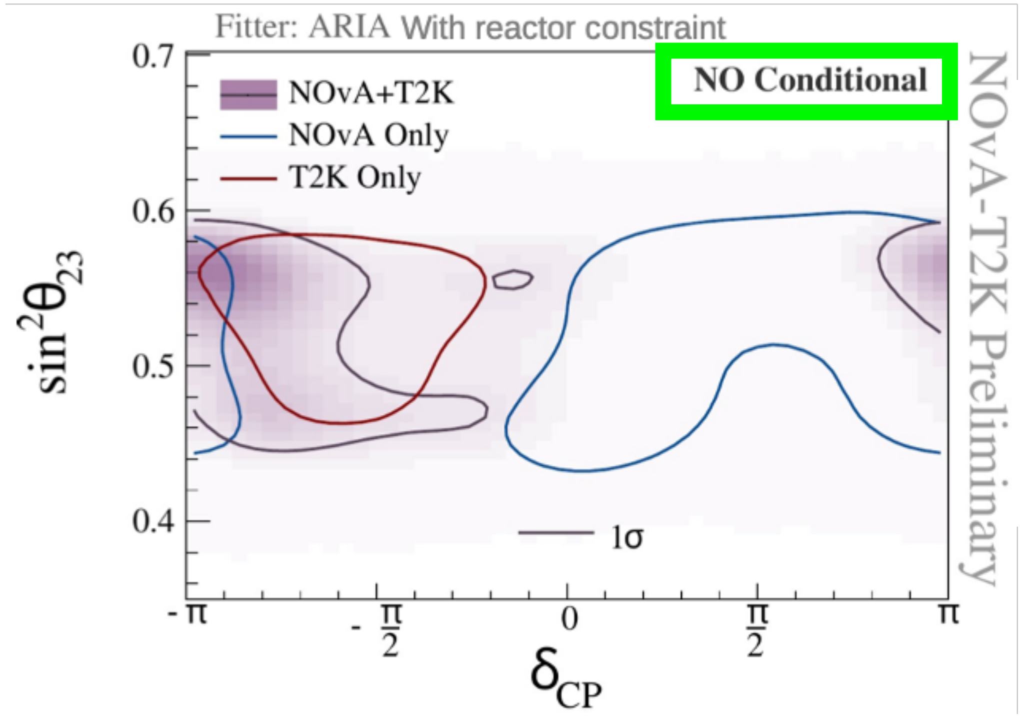




Slide from A. Himmel, Neutrino 2020

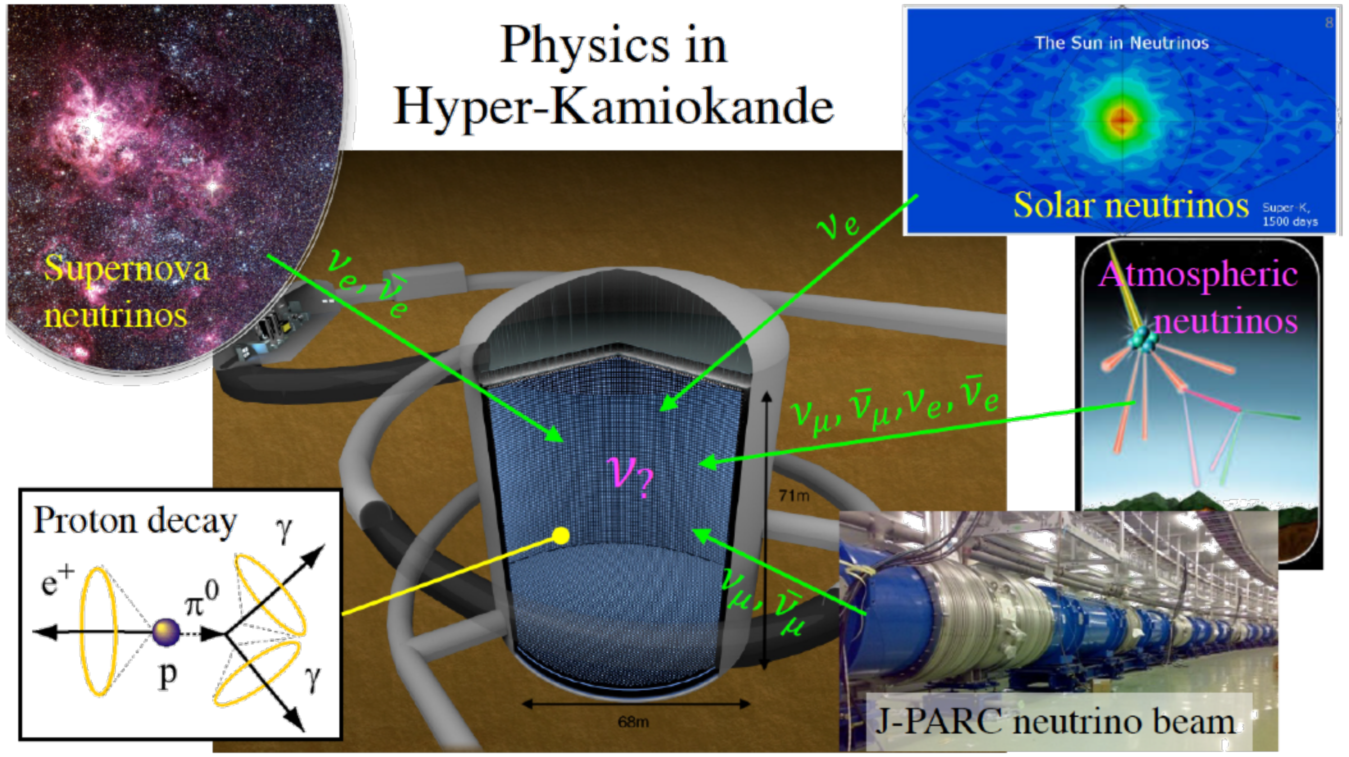
- Two joint oscillation analysis conducted : SK+T2K and NOvA+T2K
  - Different energies, baselines can resolve the degeneracies between oscillation parameters



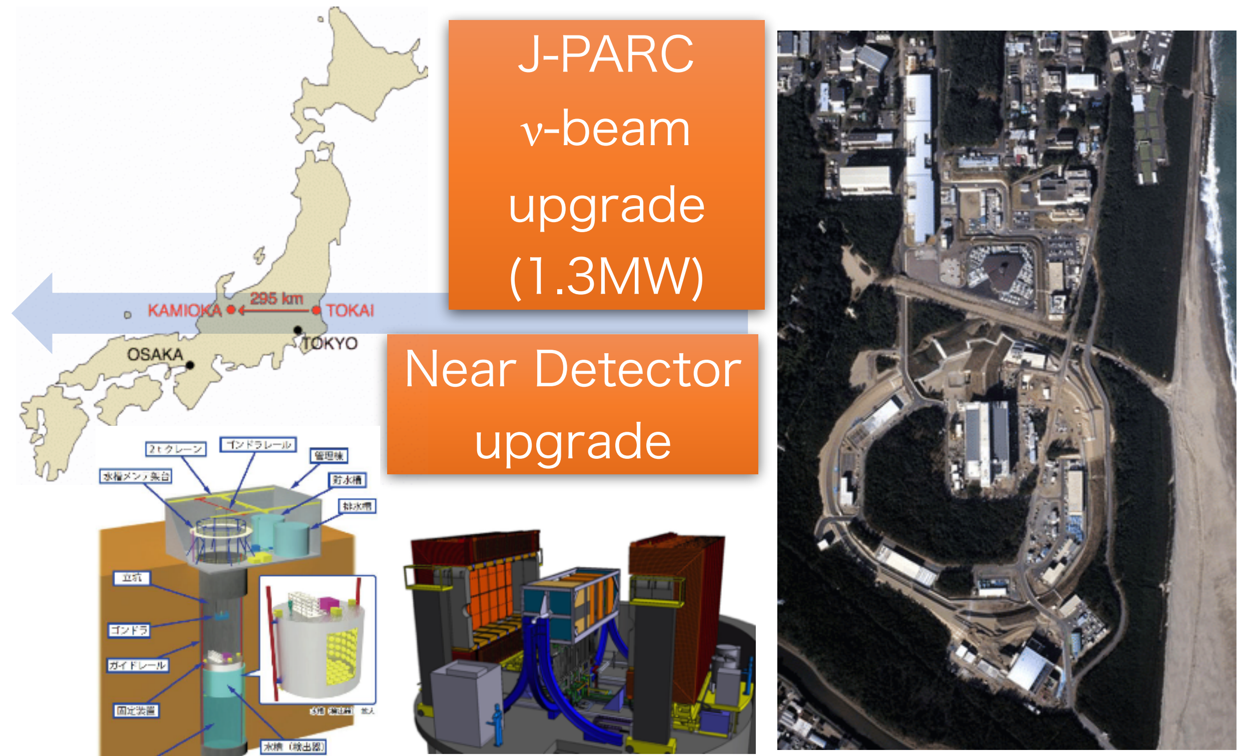


	T2K	NOvA
Baseline	295km	810km
Peak neutrino energy	0.6 GeV	2 GeV
CP effect	32%	22%
Matter effect	9%	29%

Hyper-K Overview



New Huge Water Cherenkov Detector
(Fiducial mass = 190kt)



Civil construction at Kamioka and PMT mass production is in progress.

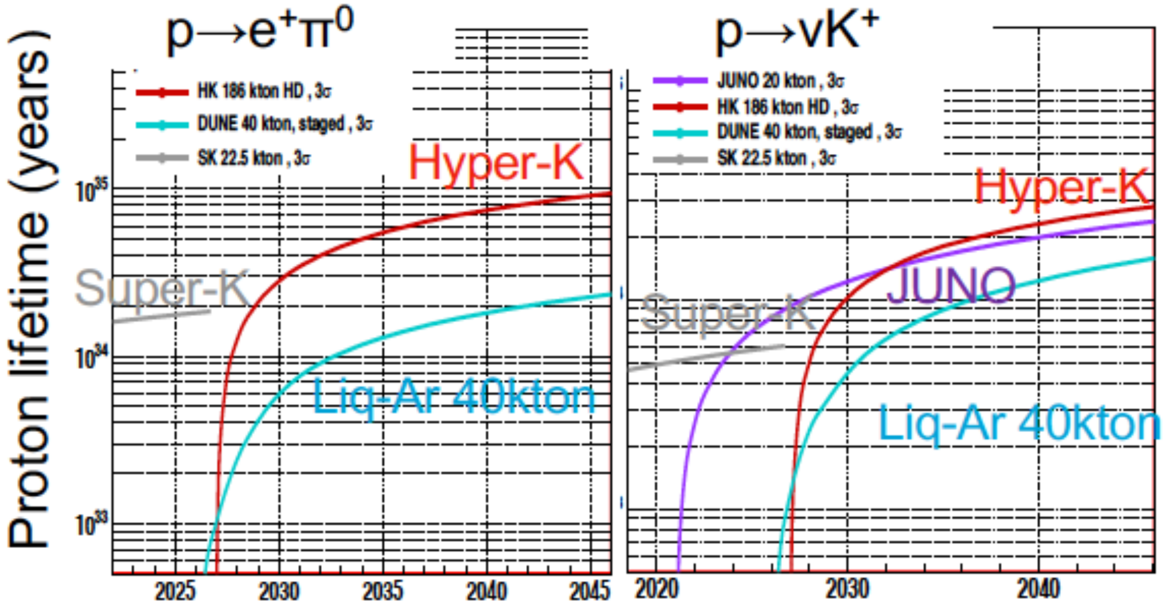
Hyper-K Expectation

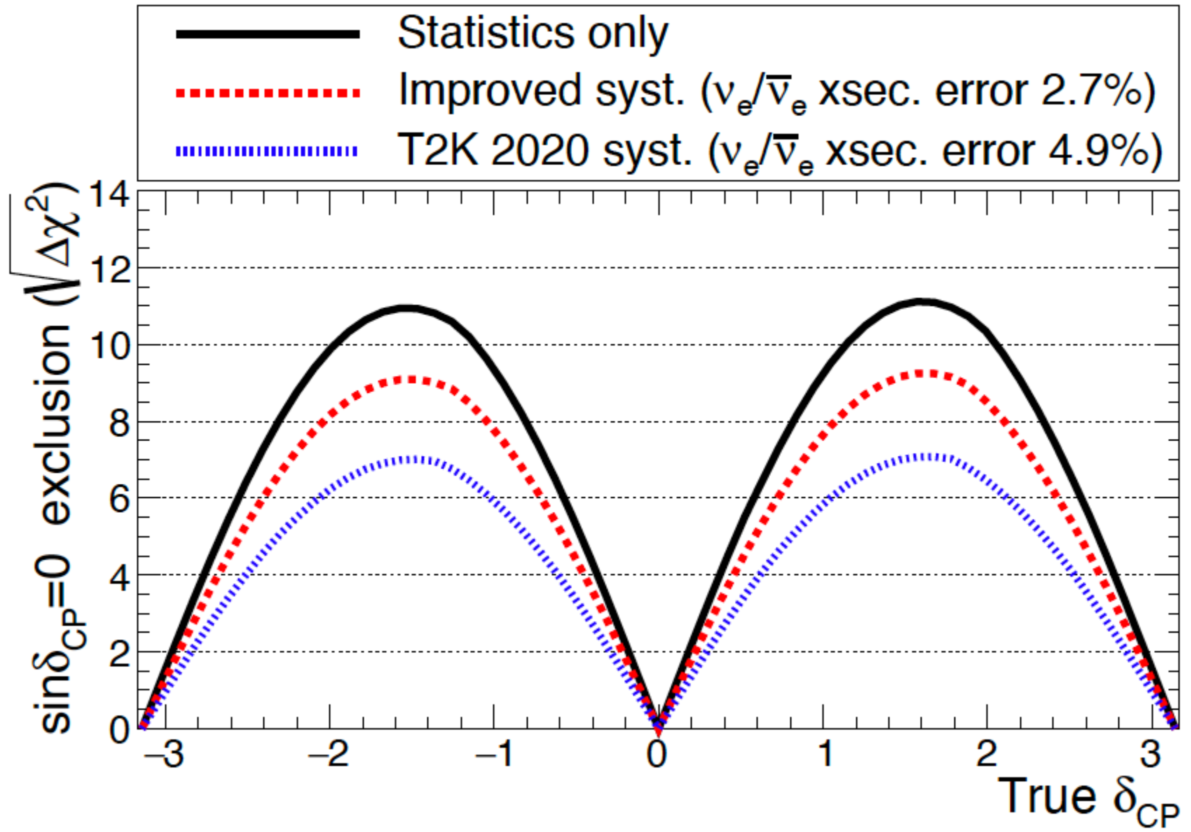
- **Proton decay search**
  → Direct probe for GUT
  - 3σ discovery potential up to $\tau_p \sim 10^{35}$ years

- High statistics samples:
  ~2300 $\nu_\mu \rightarrow \nu_e$
  ~1900 $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  are expected in 10 years
  : Max. 27% effect by CPV (standard 3-flavor model)

➔ Discovery (>5σ) potential for ~60% of parameter space

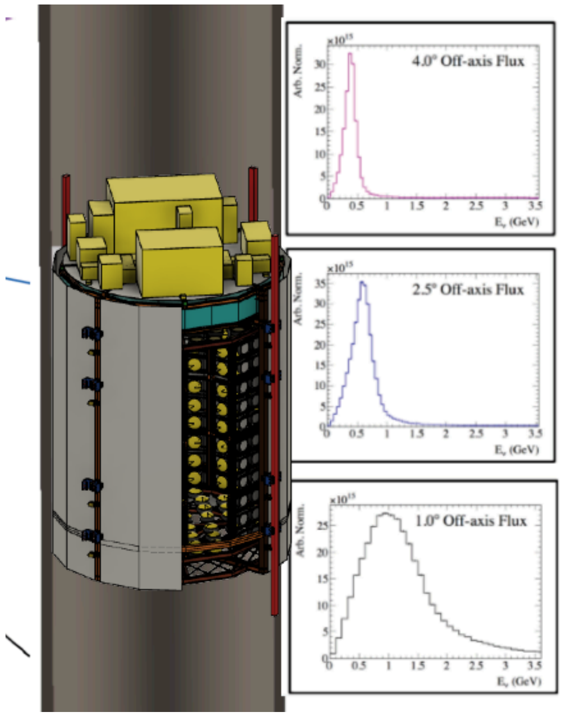
➔ Measure the size of CPV effect with good precision

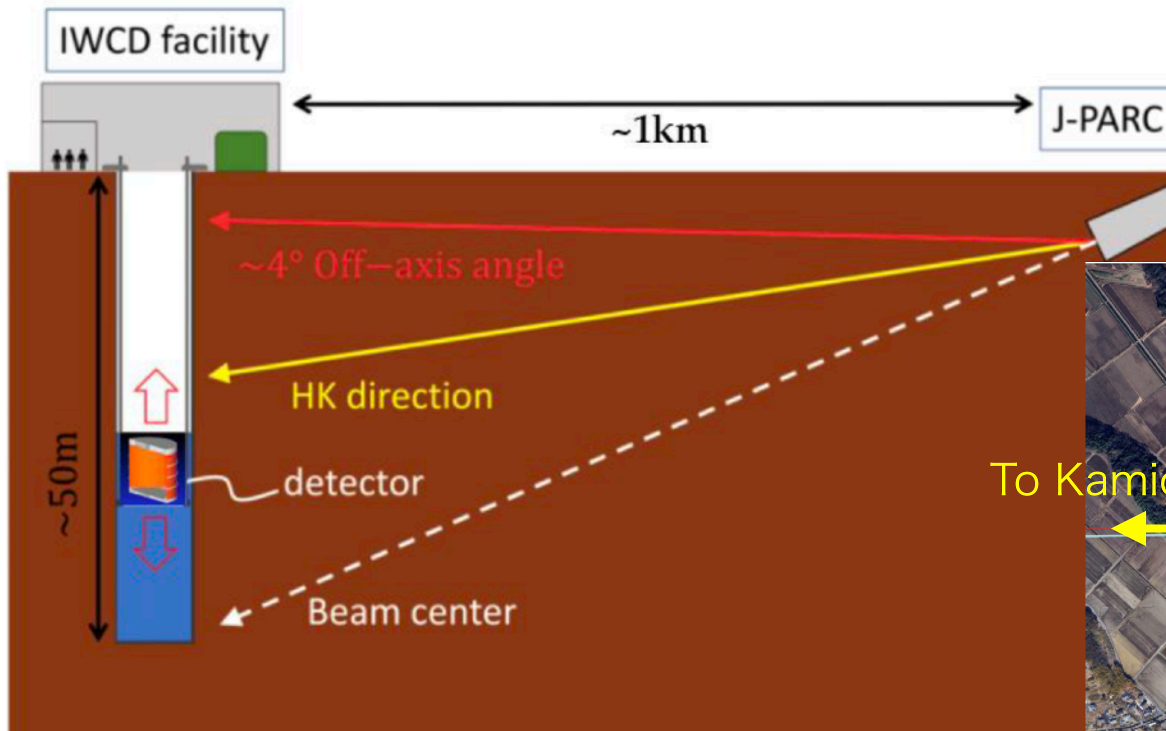


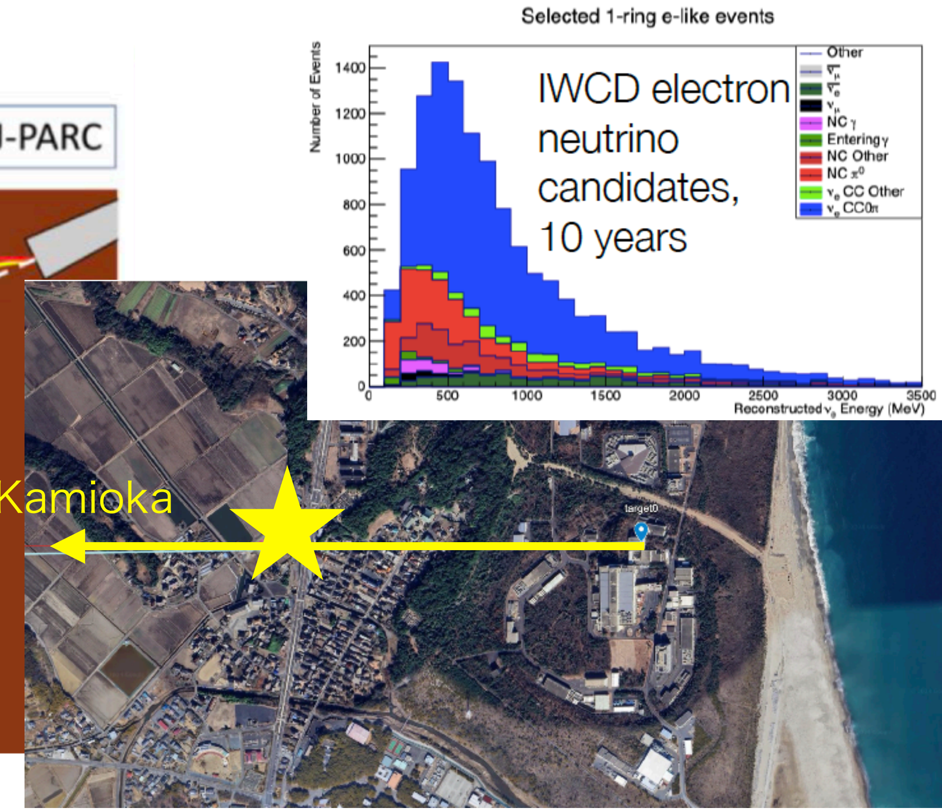


Hyper-K preliminary
True normal ordering (known), 10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)
$\sin^2\theta_{13}=0.0218\pm0.0007$, $\sin^2\theta_{23}=0.528$, $\Delta m^2_{32}=2.509\times10^{-3}\,\mathrm{eV}^2/c^4$

Intermediate Water Cherenkov Detector (IWCD)







- Novel **Movable** Water Cherenkov Detector (ϕ~9m × H~12m) using mPMT
  - Key to achieve the 2.7% systematic uncertainty on $R \equiv \left[\frac{\sigma(\nu_e)/\sigma(\nu_\mu)}{\sigma(\bar{\nu}_e)/\sigma(\bar{\nu}_\mu)}\right]$
- Progress in securing the detector site
  - Civil construction from JFY 2025~.
  - Detailed facility design based-on the geological survey is in progress.

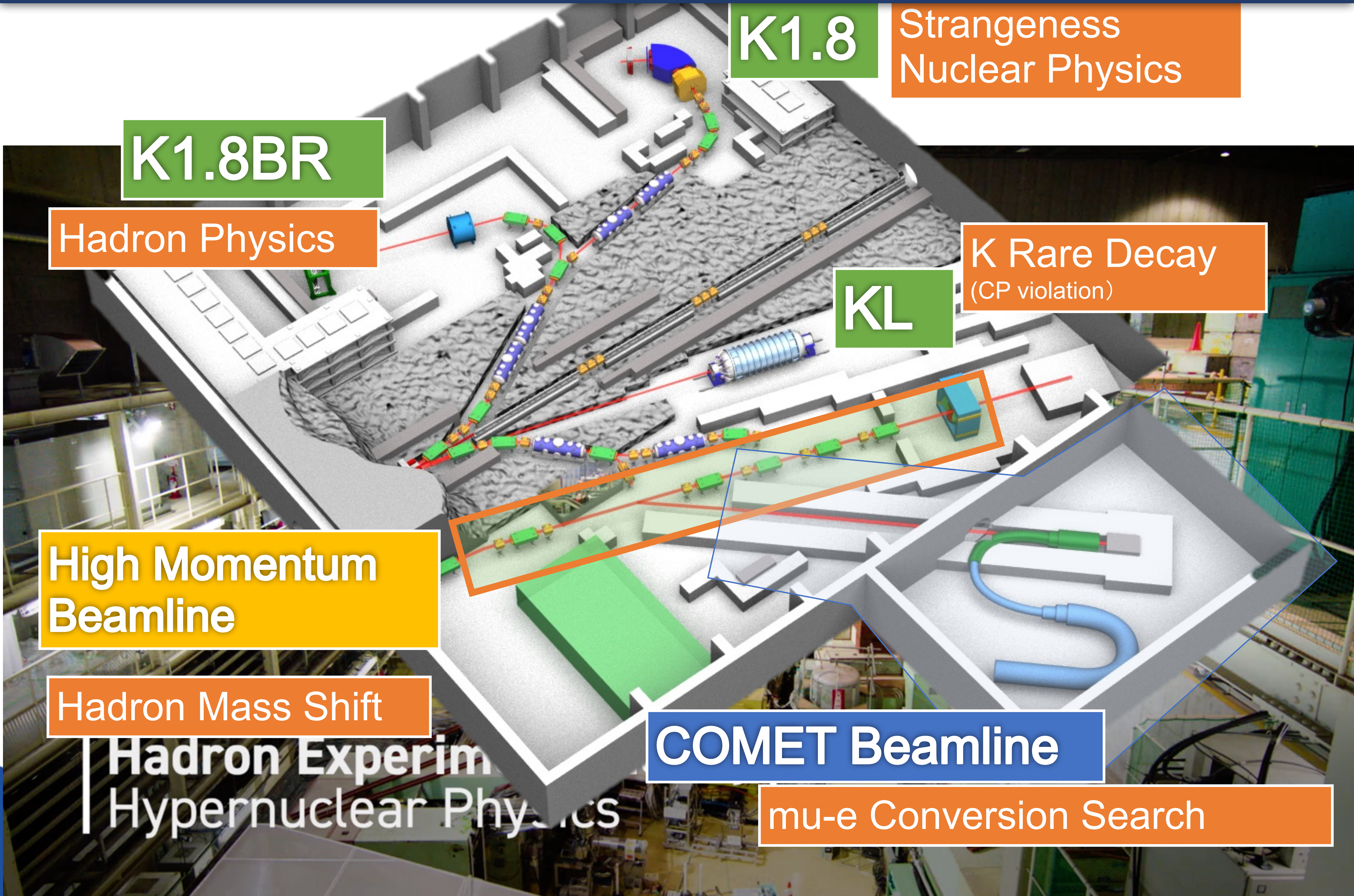
mPMT

Your contributions are highly welcome

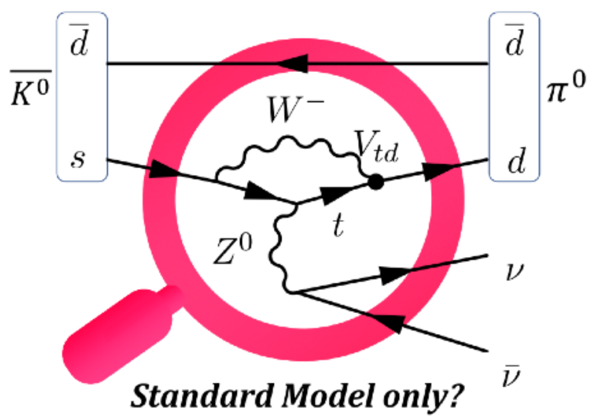
cf. Large contribution by Aachen and Mainz on T2K near detector

Hadron Experimental Facility

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

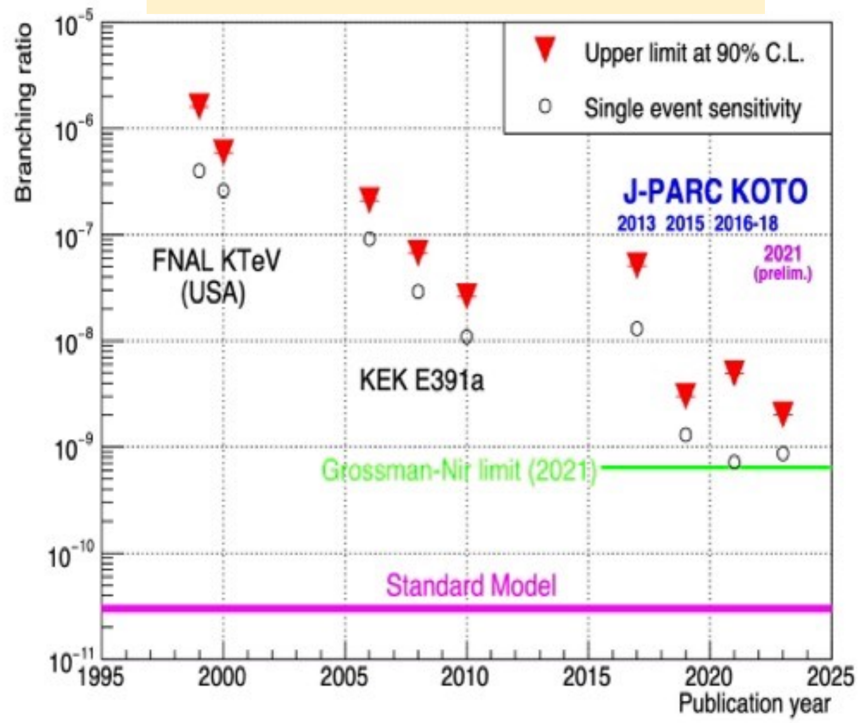


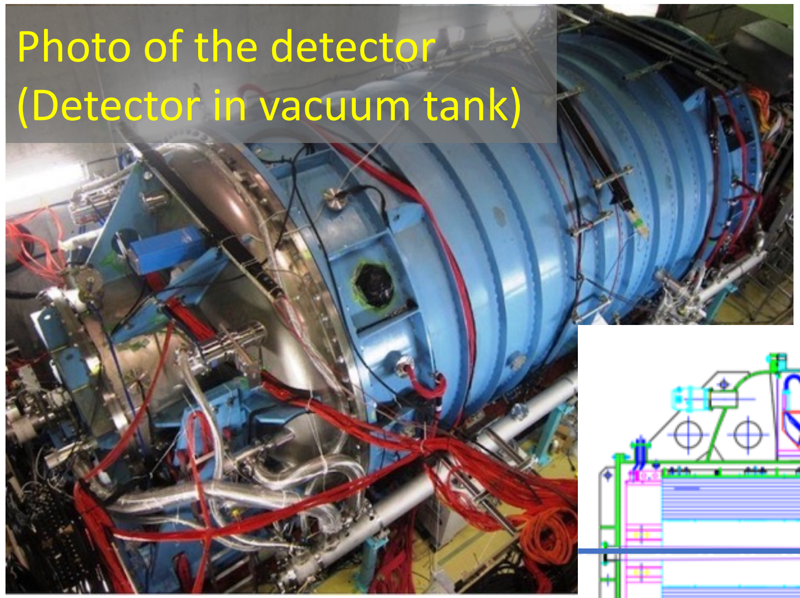
KOTO : $K_L \to \pi^0 \nu \bar{\nu}$ search at J-PARC



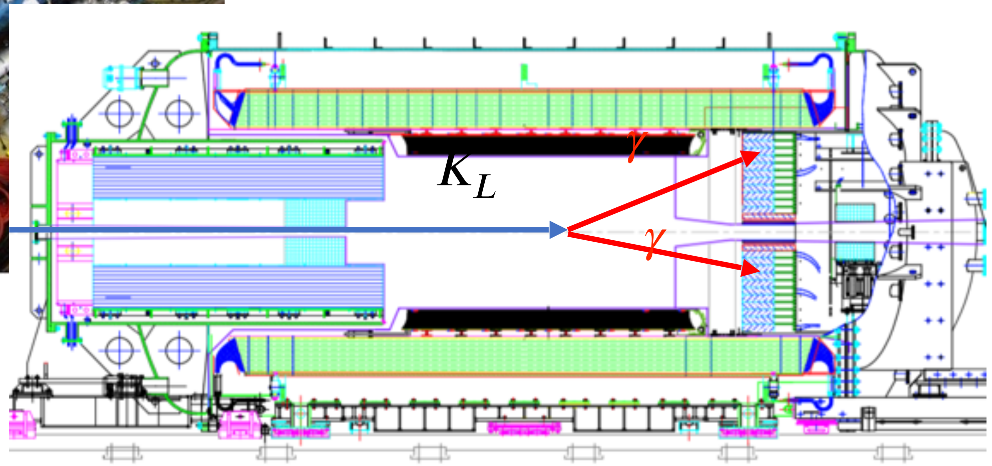
- CP-violating rare decay
- Predicted B.R.(SM)=3x10^{-11}
- Not yet observed
- Good probe to search for New physics beyond SM

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





Event signature
- 2γ from π^0 decay
- Nothing else ($\nu, \bar{\nu}$ undetected)

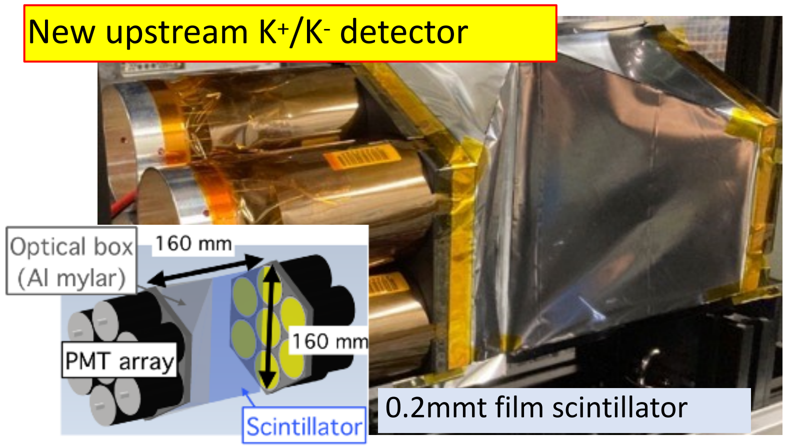


Highlights in FY2023

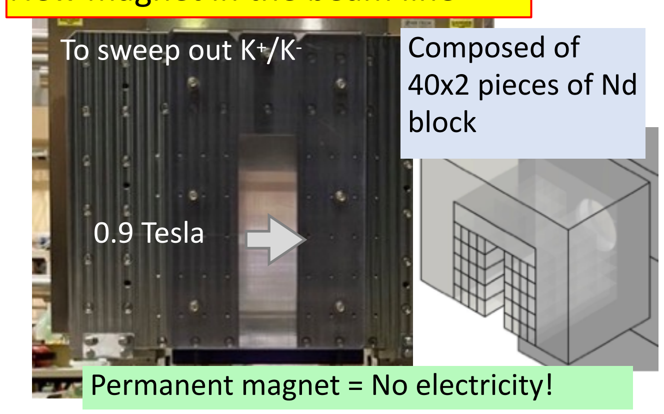
➢ The analysis of data taken in 2021 provided a new world-best upper limit B.R.<2.0x10^{-9} (preliminary).

➢ Upgrades of the beamline, detector, and DAQ system
- For better understanding and further reduction of background events

New upstream K+/K- detector

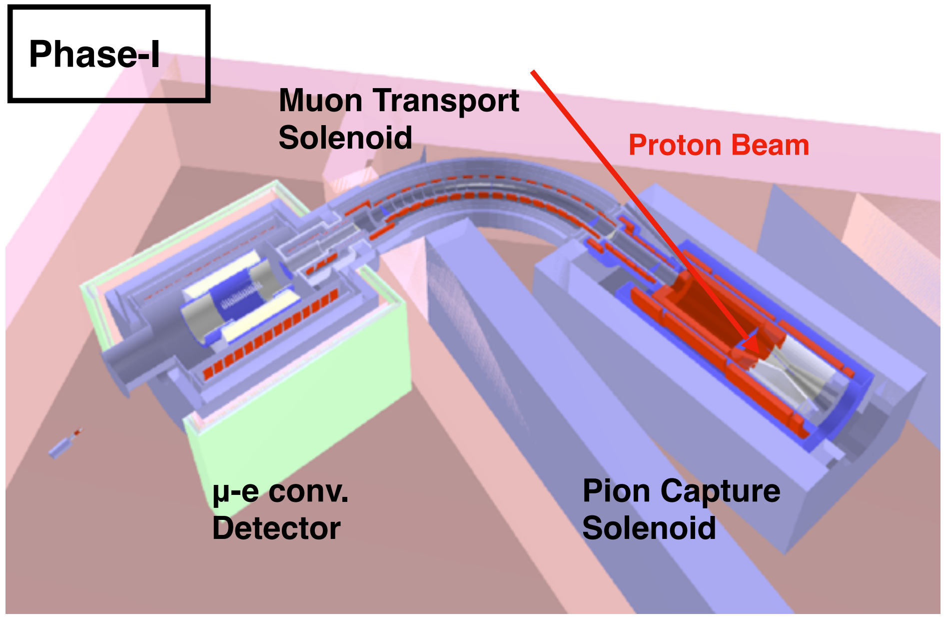


New magnet in the beam line



COMET : μ-e Conversion Search at J-PARC

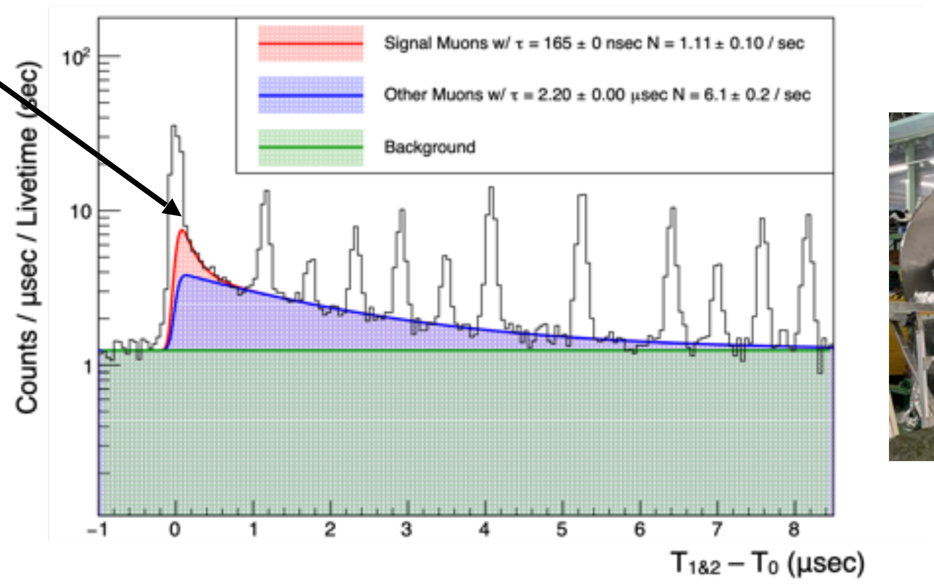
- cLFV decay
- No Standard Model BG
- Excellent probe to search for New physics beyond SM
- Key to understand the origin of neutrino mass
- Staging approach
  - Phase I S.E.S. < 10^{-14}
  - Phase II S.E.S. < 10^{-16}



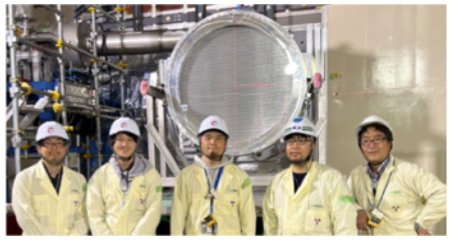
<u>Highlights in FY2023</u>

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

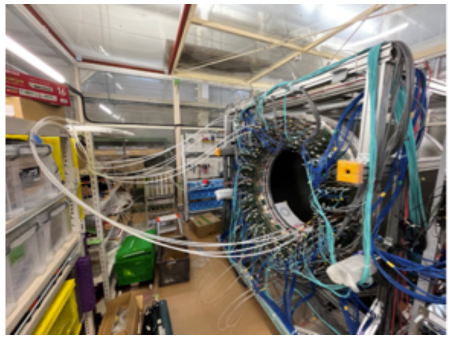
Engineering Run Primary Beamline



Straw-tube tracker



PCS construction



CDC in conditioning

Nuclear Physics at Hadron Hall

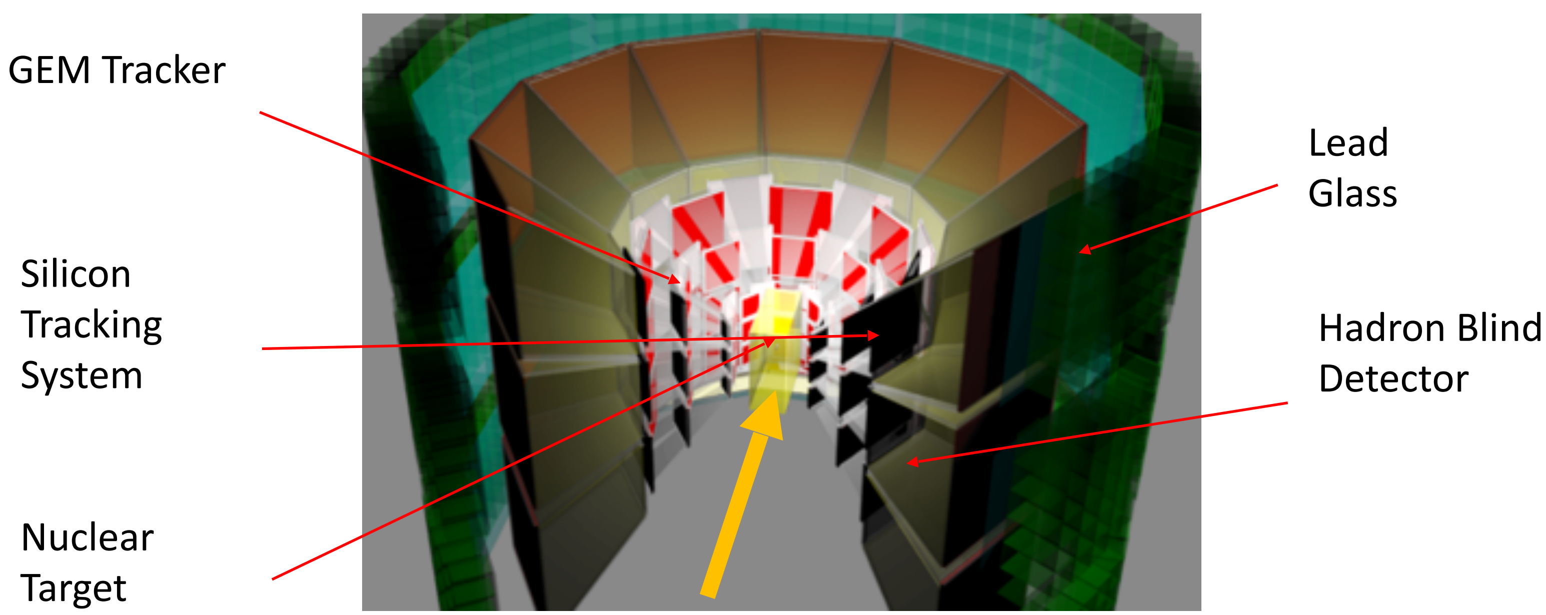
Many experiments are either on-going or planned under supervision of PAC

- Measurements of mass spectra changes of vector mesons (ρ, ω, ϕ) to study <u>QCD matter</u>
  - p+A → ρ, ω, ϕ + X

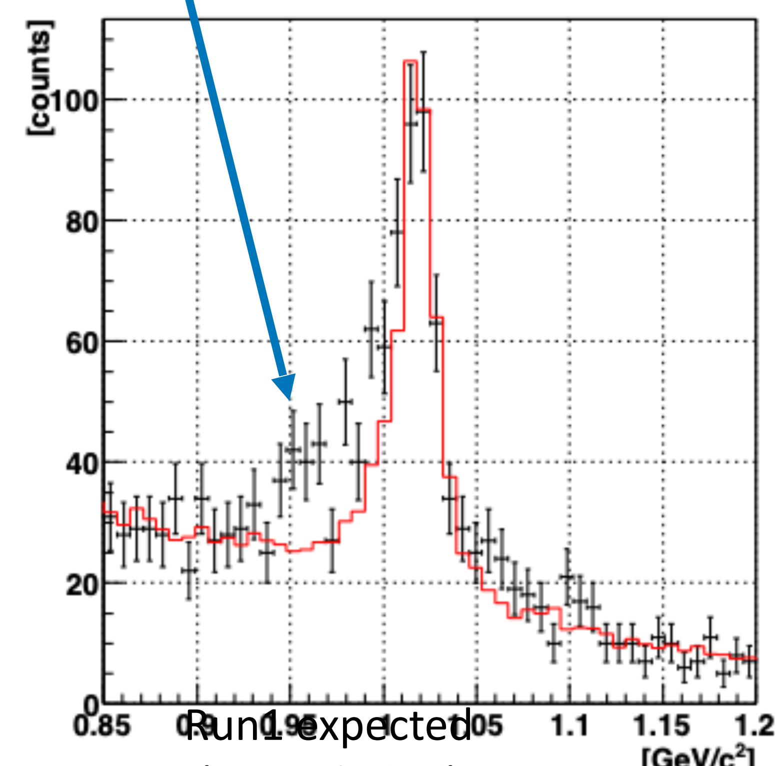
high momentum beam line

Generate vector mesons <u>using primary proton beam</u> and
Detect <u>electron-positron pairs</u> decayed from vector mesons

Mass modifications of ϕ meson due to QCD matter effects



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



Run1 expected (BG included)

Muon g-2/EDM at MLF

We are looking for collaborators for this new experiment

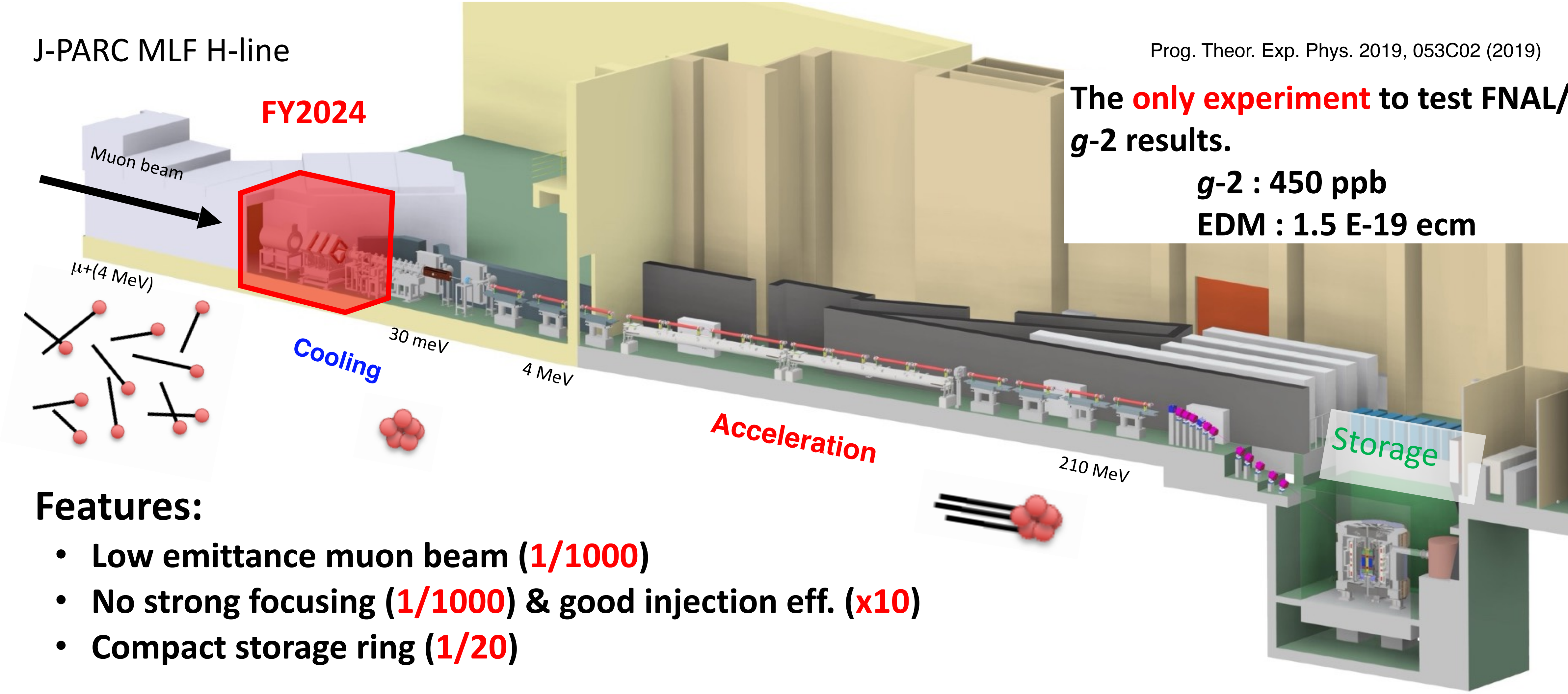
J-PARC MLF H-line

Prog. Theor. Exp. Phys. 2019, 053C02 (2019)

The only experiment to test FNAL/BNL *g*-2 results.

***g*-2 : 450 ppb**

EDM : 1.5 E-19 ecm

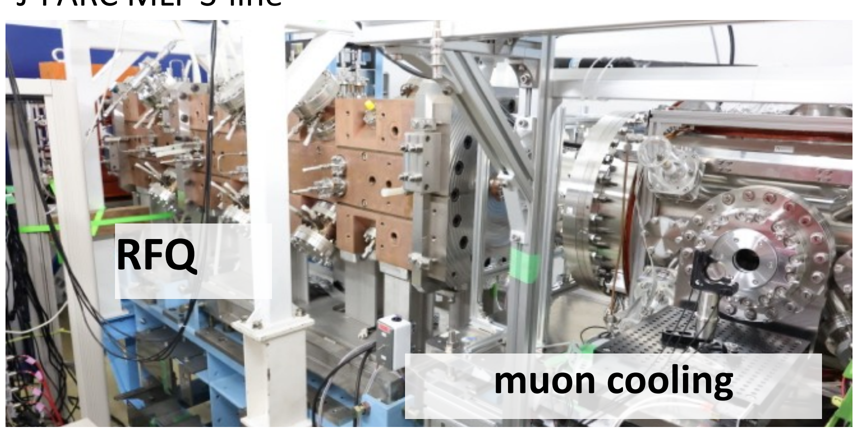


Features:

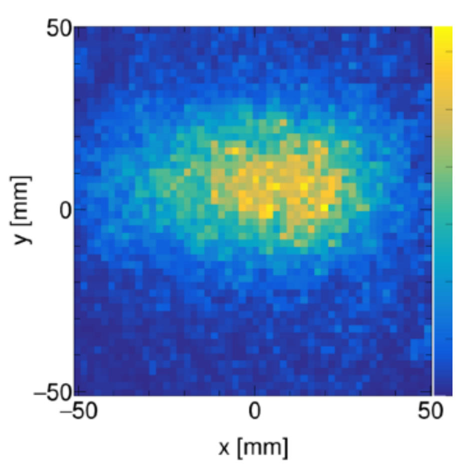
- **Low emittance muon beam (1/1000)**
- **No strong focusing (1/1000) & good injection eff. (x10)**
- **Compact storage ring (1/20)**

Acceleration of positive muon to 100 keV (Apr. 2024)

J-PARC MLF S-line

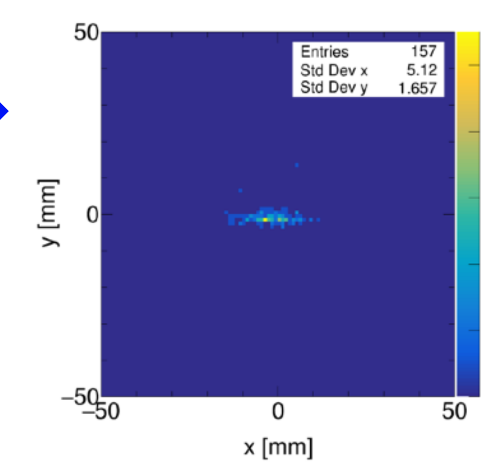


before cooling



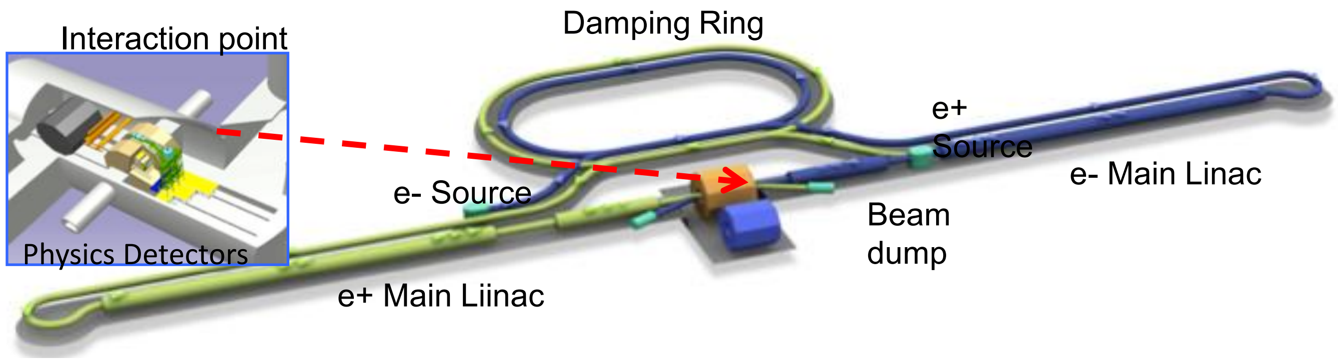
Emittance reduction by more than a factor of 100

after cooling & accel.



ILC Technology Network (ITN)

By KEK and IDT (set up under ICFA) initiative, ITN is set up so that ILC related accelerator technology is further developed



Parameters	Value
Beam Energy	125 + 125 GeV
Luminosity	1.35 / 2.7 x 10^{34} cm^2/s
Beam rep. rate	5 Hz
Pulse duration	0.73 / 0.961 ms
# bunch / pulse	1312 / 2625
Beam Current	5.8 / 8.8 mA
Beam size (y) at FF	**7.7** nm
SRF Field gradient	< 31.5 > MV/m (+/-20%) $Q_0 = 1x10^{10}$
#SRF 9-cell cavities (CM)	~ 8,000 (~ 900)
AC-plug Power	111 / 138 MW

Not only for the **ILC** but also for **various application**

- Creating particles — ***Sources***
  - polarized elections / positrons
- High quality beams — ***Damping ring***
  - Low emittance beams
    - Small beam size (small beam spread)
    - Parallel beam (small momentum spread)
- Acceleration — ***Main linac***
  - superconducting radio frequency (SRF)
- Getting them collided — ***Final focus***
  - nano-meter beams
- Go to ***Beam dumps***

SRF

e-, e+ Sources

Nano-Beam

WPP	1	Cavity production
WPP	2	CM design
WPP	3	Crab cavity
WPP	4	E- source
WPP	6	Undulator target
WPP	7	Undulator focusing
WPP	8	E-driven target
WPP	9	E-driven focusing
WPP	10	E-driven capture
WPP	11	Target replacement
WPP	12	DR System design
WPP	14	DR Injection/extraction
WPP	15	Final focus
WPP	16	Final doublet
WPP	17	Main dump

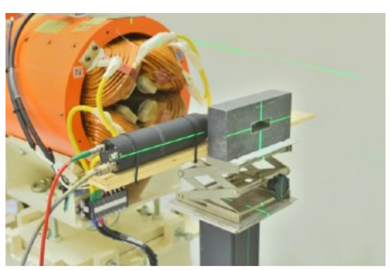
Instrumentation Technology Development (ITDC)

Instrumentation Technology Development Center

International Hub for instrumentation development
Promotion of Innovation and Young researches

Inter-University Research

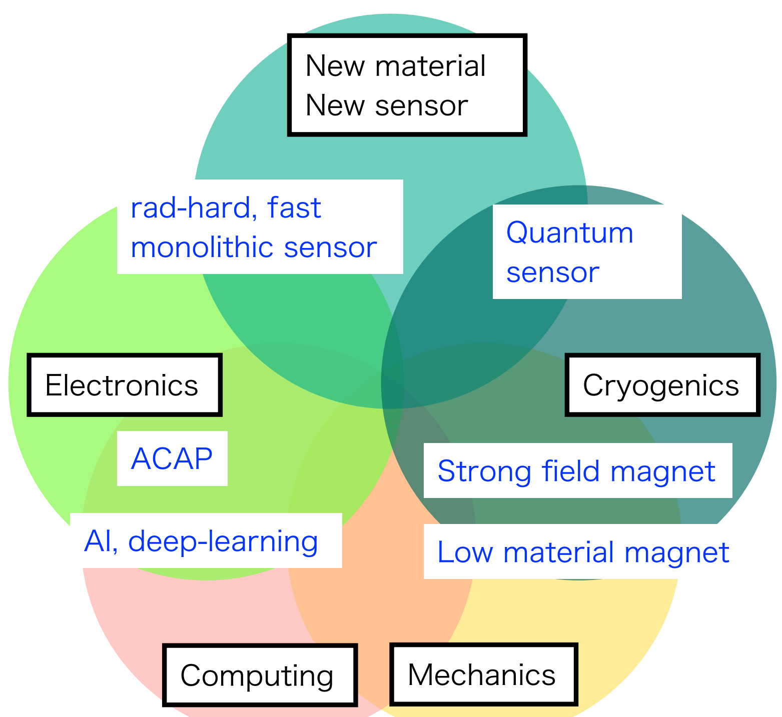
- **Extension of inter-university research functions**
- More efficient and faster development



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

Cutting Edge Technology Development

- **Continue to support IPNS project in both development and operation**
- **Support bottom-up research : some R&D platforms**
  - works also as the interface to the community
- **Common/Core technologies for next generation projects led by ITDC**
  - **Cryogenics and superconducting technology**
  - **Monolithic semiconductor pixel sensor**



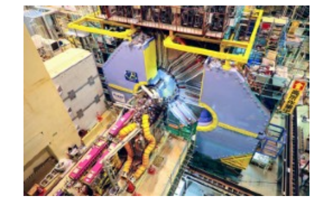
Technology Development Platforms

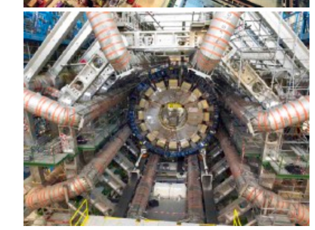
- Cryogenics
- Mechanics
- Sensor
  - Light sensor
  - semiconductor
  - gas & active medium
- Electronics
  - System integration
  - Collider Electronics
  - SPADI alliance
- Computing

Platform Organization flexible, always ready to start new one

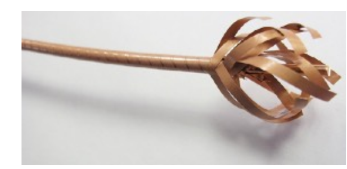
Researcher Community

IPNS projects





KEK projects

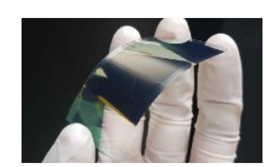


REBCO for HL-LHC

Education

HEP school

Industry



organic semiconductor

Example : Cryogenics and Magnet

Cryogenics Technology Development for below 1K

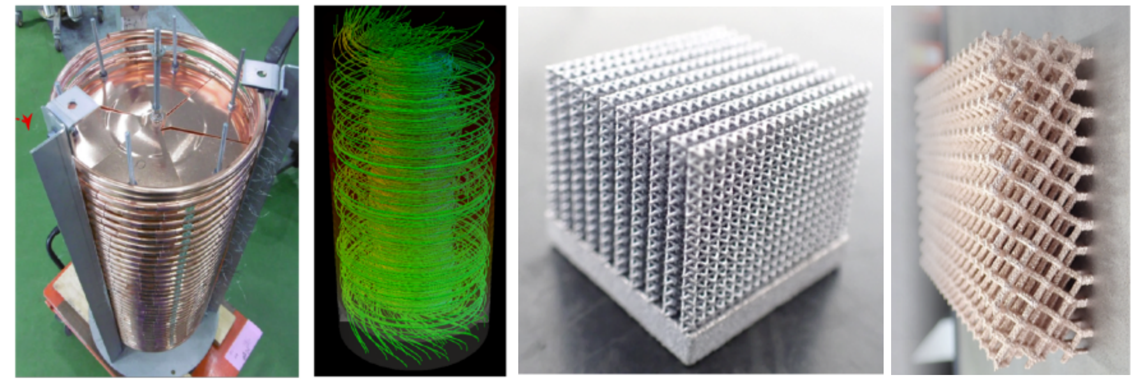
He^3 Refrigerator, Enlarge capacity of dilution refrigerator

Goal

HEX development

P1. 2mW@100mK

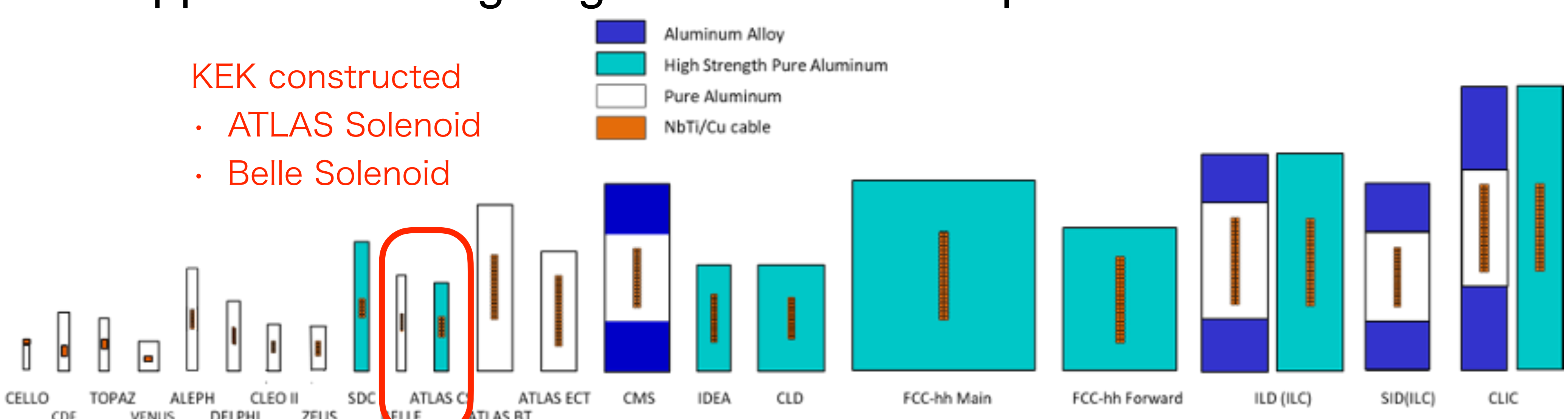
P2. Distributing technology



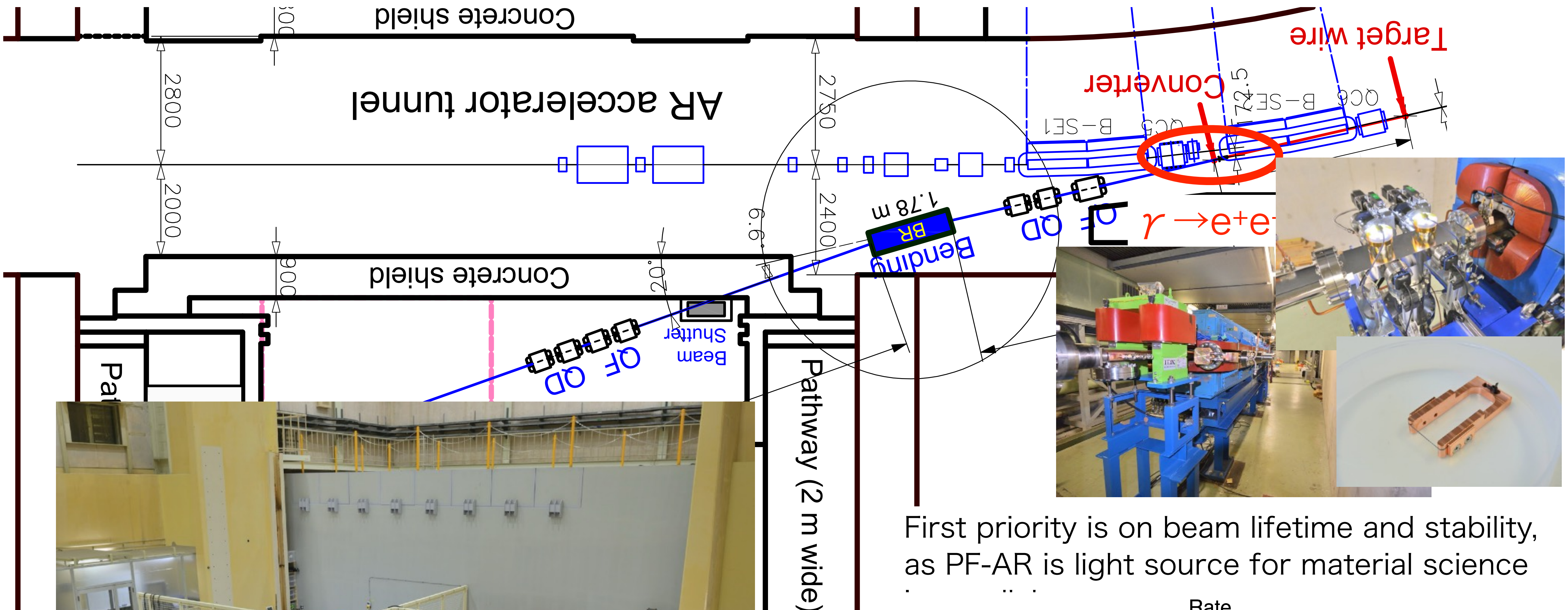
Magnet Development

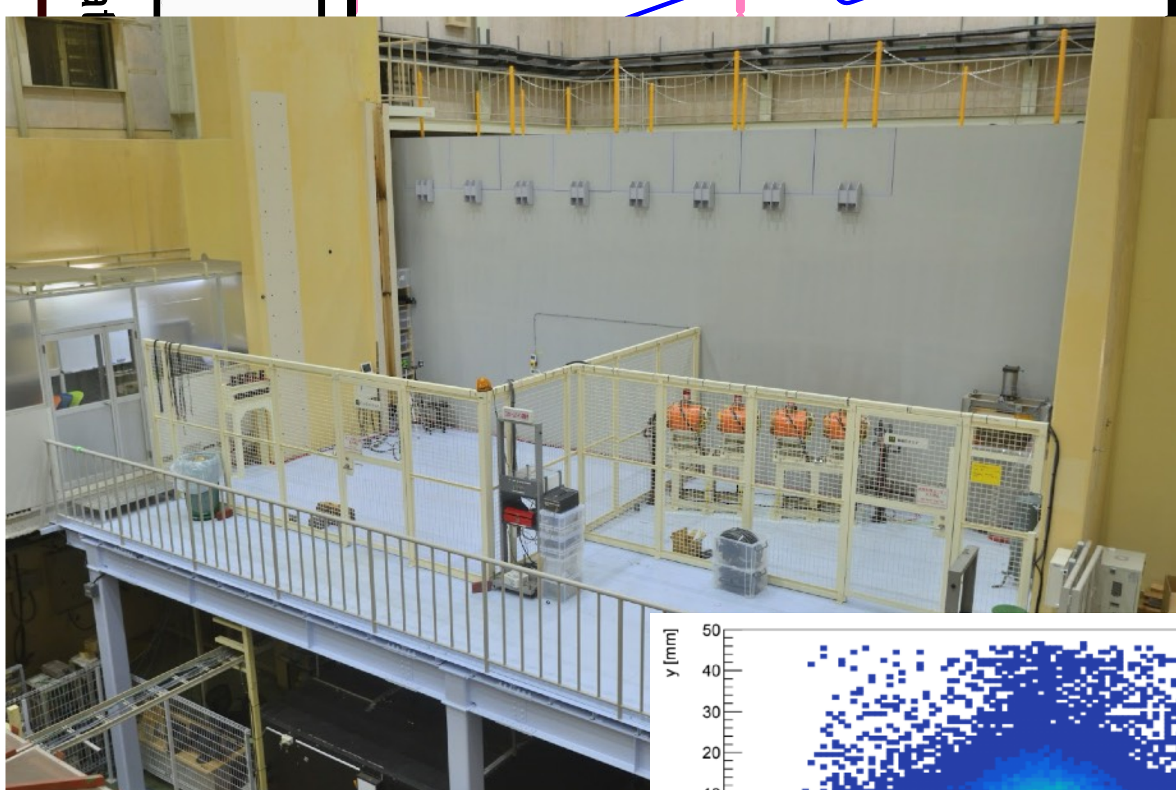
- Al stabilized superconductor is critical to construct detector solenoid due to its transparency to particles
- Lack of industrial provider will cause serious trouble in next generation projects
- Started cooperative work with CERN to revive and further develop technology
  - We have expertise with strong industrial partnership
- Can be applied to cutting-edge new material superconductor instead of NbTi

KEK constructed
- ATLAS Solenoid
- Belle Solenoid

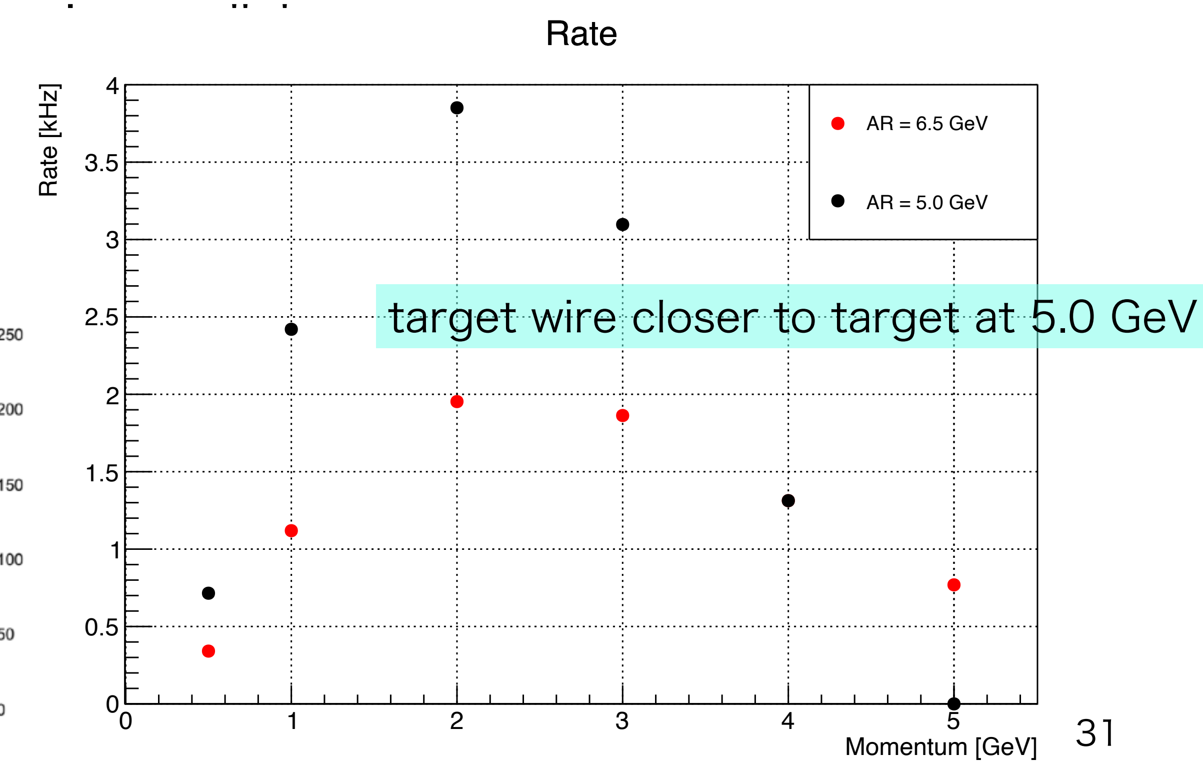


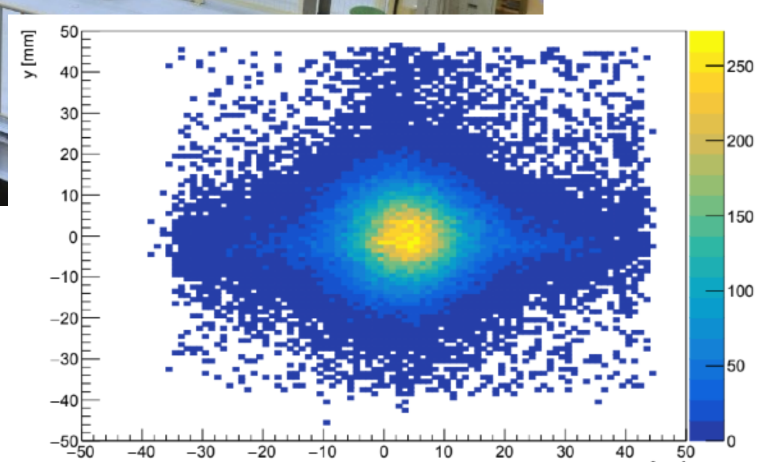
Test Beam Line at PF-AR





First priority is on beam lifetime and stability, as PF-AR is light source for material science





Optimization of optics is still on-going for higher rate and smaller beam size

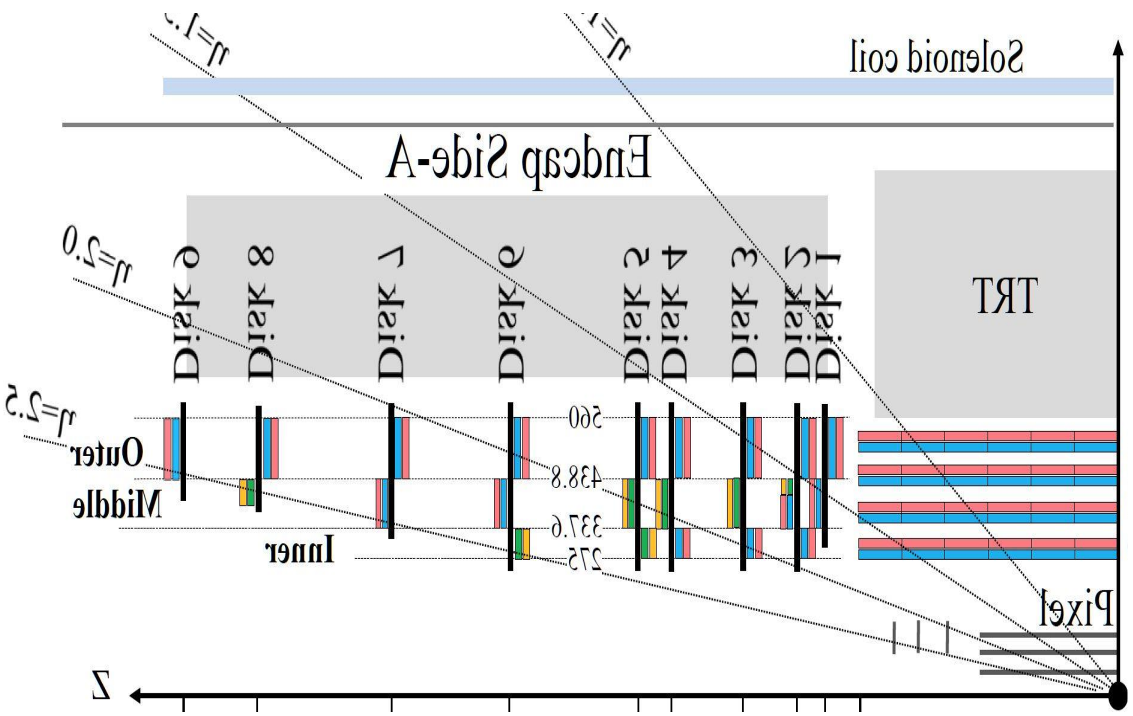
Summary

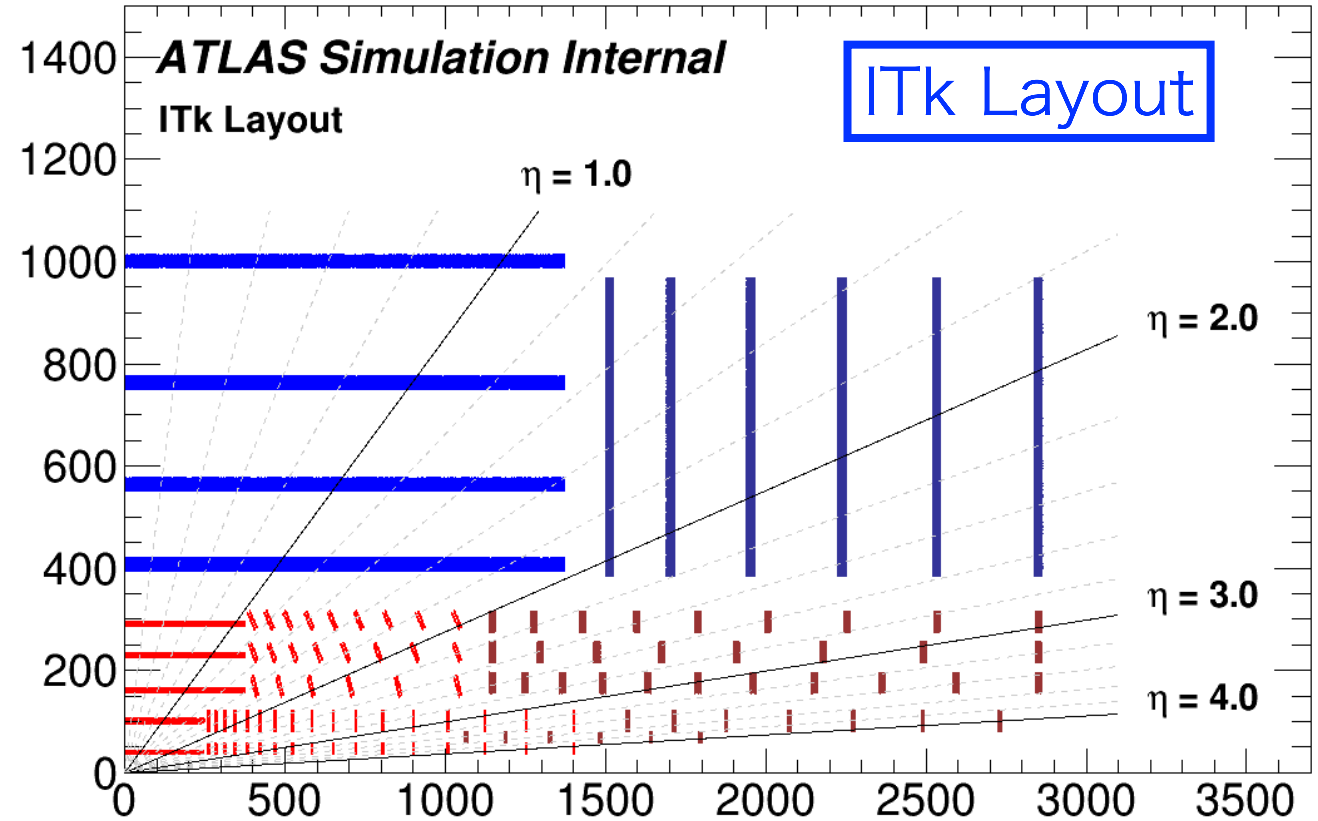
- Wide variety of Science
  - Focus only on particle/nuclear physics in today's talk
- KEK mission consists of three pillars
  - Particle/nuclear physics, material and life science, application of accelerator technology
- Collaboration with HLL/Max Planck and German institutes is crucially important for KEK science
  - We (not only me but also Shoji Asai) are looking forward further and deeper collaboration with you

Backup

Silicon Tracker (ITk)

Current Layout





- ❖ Totally new detector
- ❖ Area
  - ▸ Pixel 2.7m² → 13.5m²
  - ▸ Strip 62m² → 165m²
- ❖ The number of channels
  - ▸ Pixel 90M → >5G
  - ▸ Strip 6M → 60M

◉ Finer

- Pixel size
  $50\times400\,\mu m^2 \rightarrow 50\times50\,\mu m^2$
- Strip length
  20cm → 2.4cm (shortest)

⇒ faster data transfer

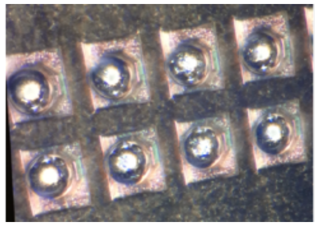
◉ Radiation harder

- Innermost 1×10^{15} n_{eq}/cm^2 → 2×10^{16} n_{eq}/cm^2

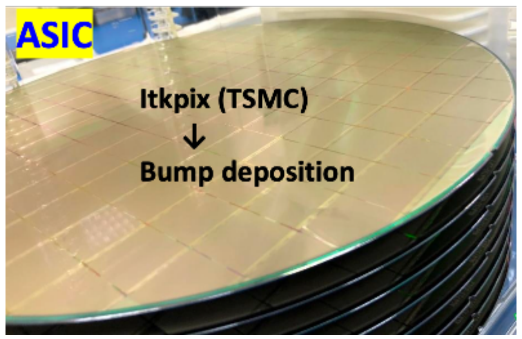
Pixel Module Production Flow

Japan will make ~2,800 modules
→ 7 modules / day in production

Bumps



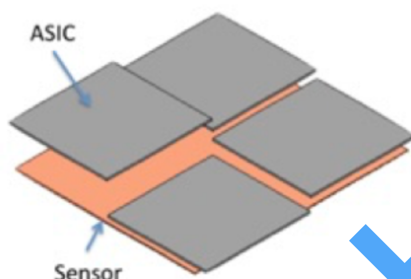
ASIC



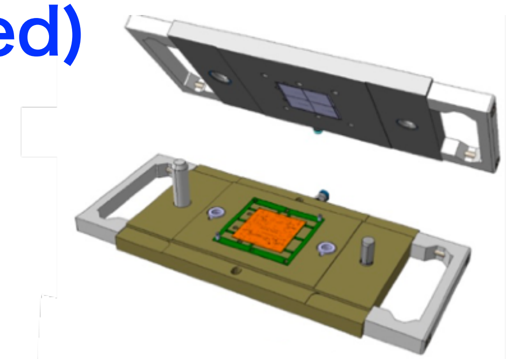
"Hybridization"

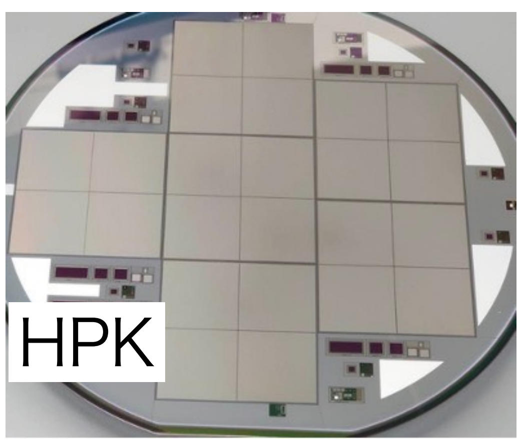
4 groups in parallel
Japanese group product best quality
(two are not qualified)

Bare Module



Assembly tool

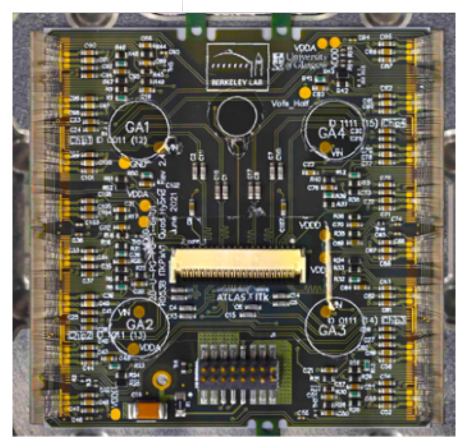




Sensor

Production finished

Flex PCB

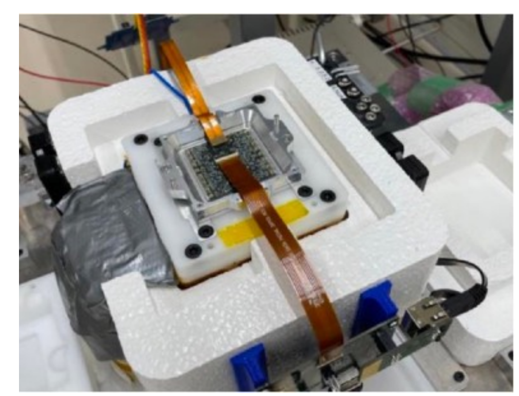


"Assembly"

Module

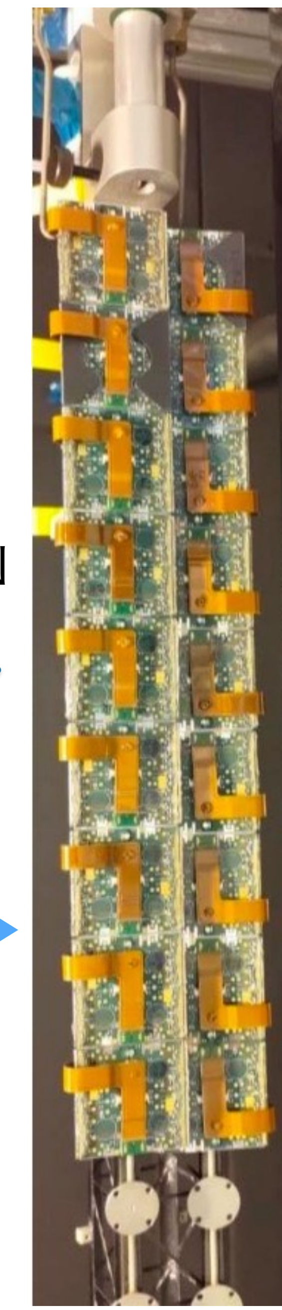
About to start production
Japanese group top runner

transport to CERN



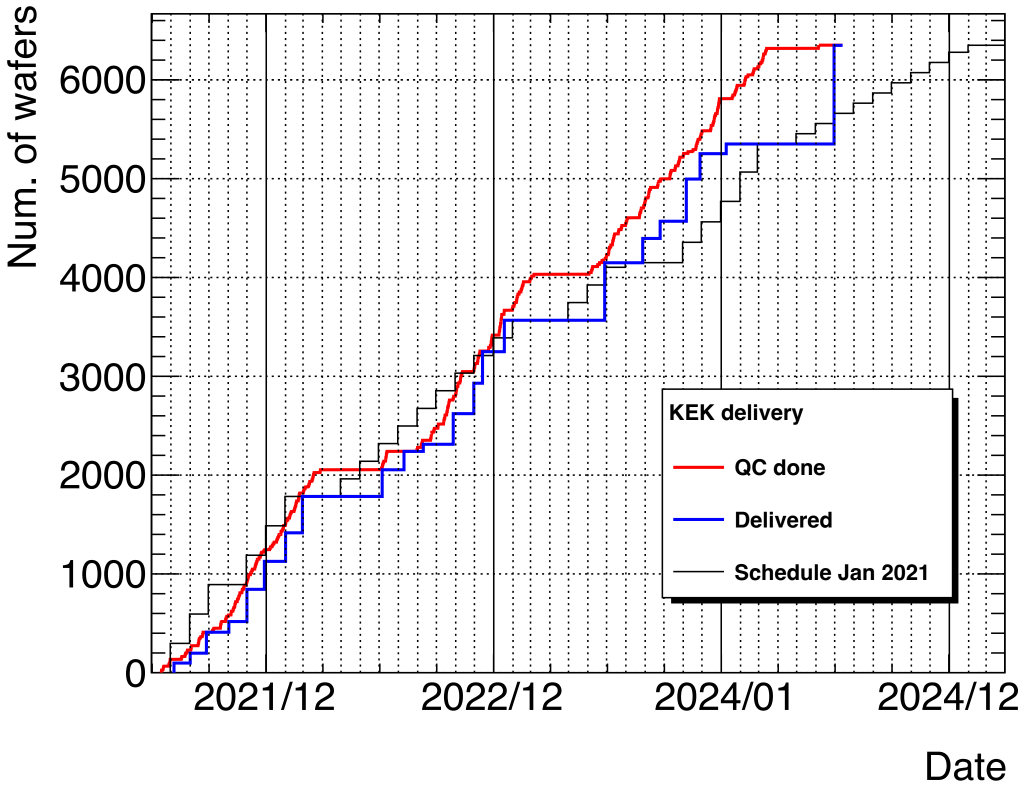
Testing

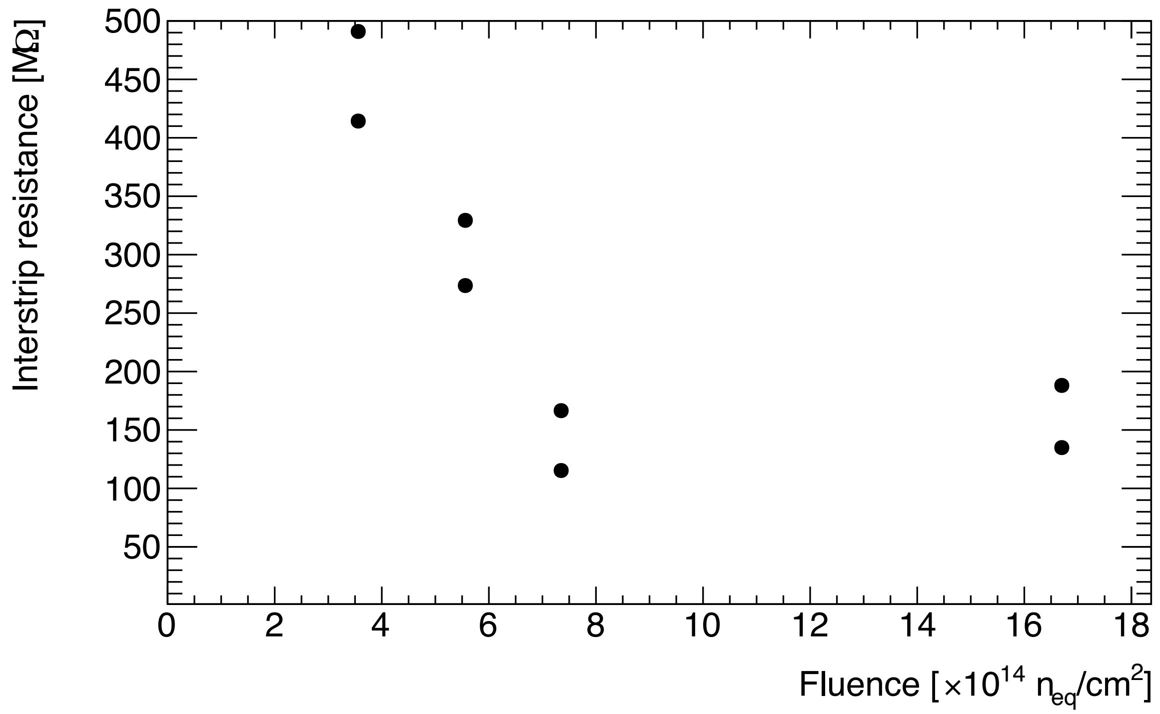
Loading to Support

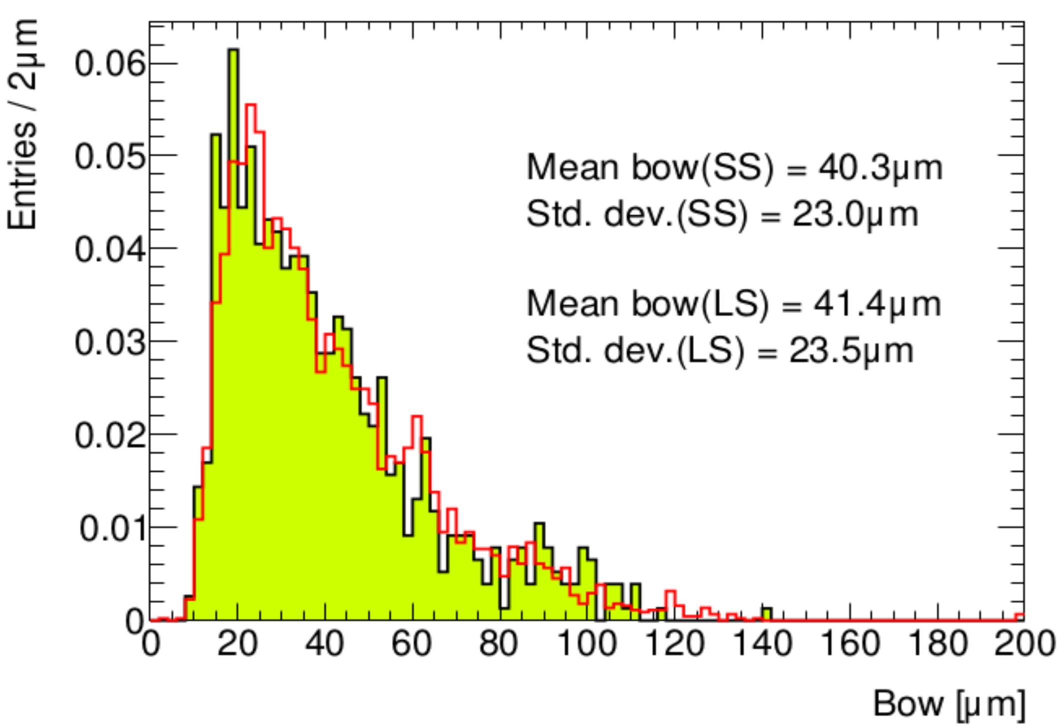


Silicon Strip Sensor

- Japanese responsibility is to provide a half of barrel sensors
- Production of Japanese share finished
  - 6350 sensors
- Testing results show all sensor satisfy
  - bow < 200 μm
  - deficit strip < 0.1%
- Irradiation at CYRIC, Tohoku U for QA





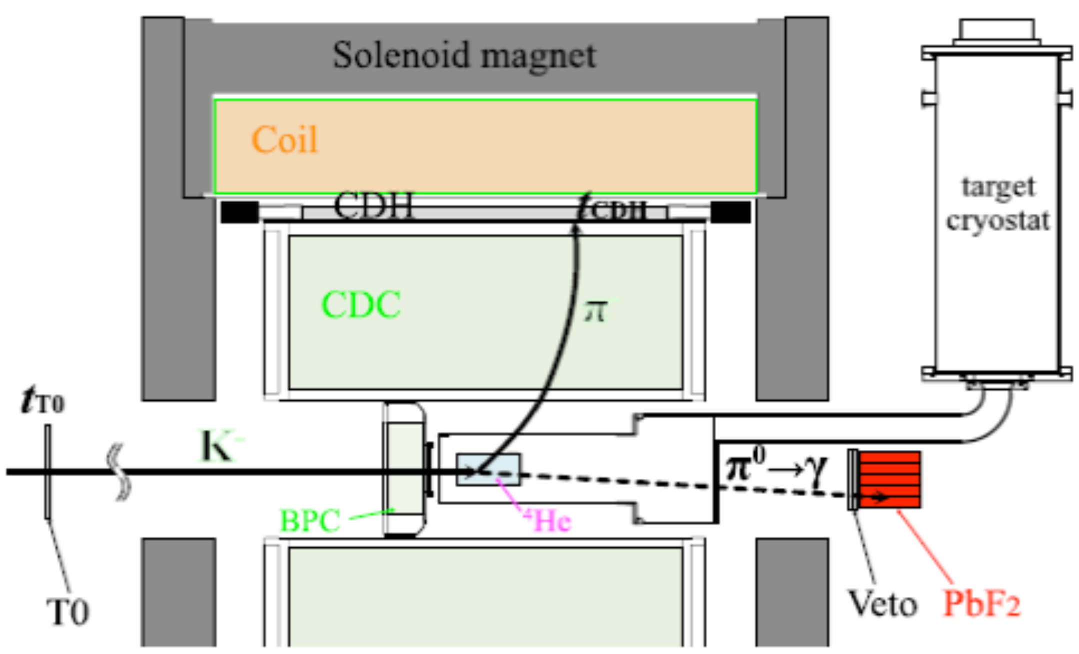


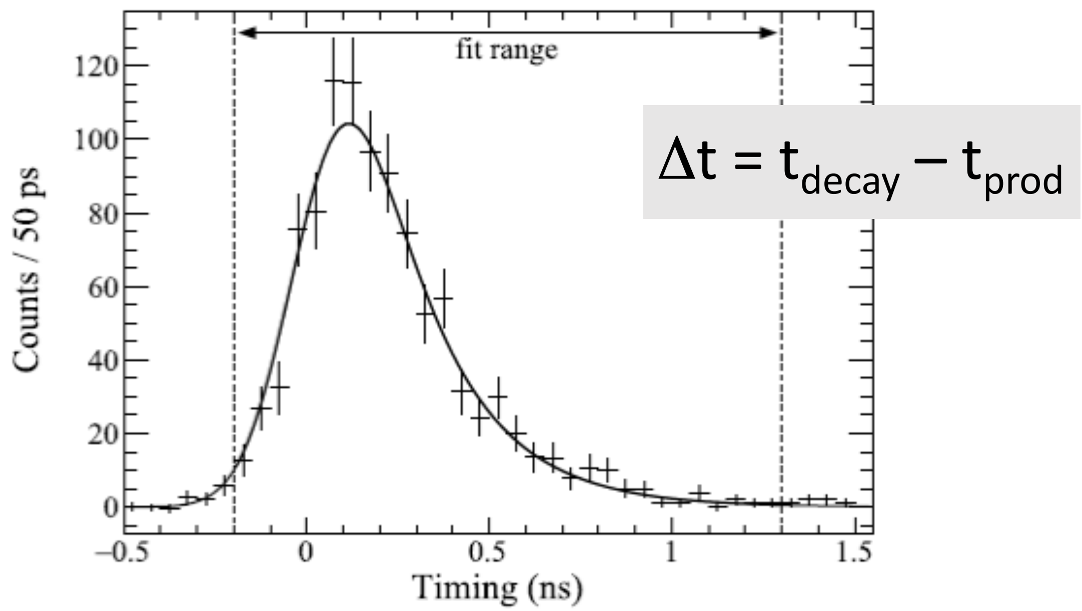
Nuclear Physics at Hadron Hall

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

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

π^0 is tagged by γ
(monochromatic) π^- from weak decay is measured with CDS.



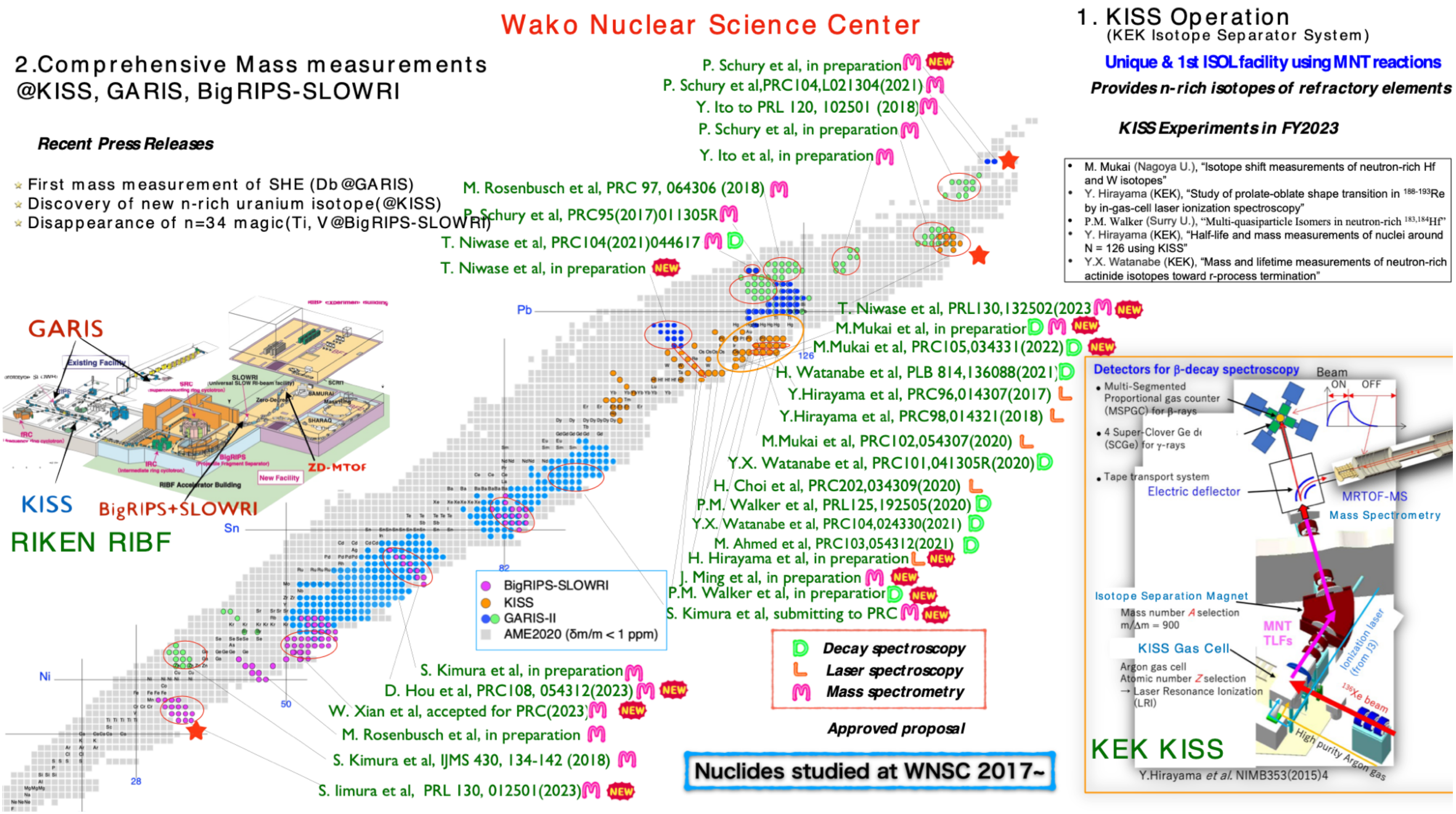


τ=206±8(stat.)±12(syst.) ps

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

Nuclear Physics at Wako Campus

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



Muon g-2/EDM measurement

Muon g-2/EDM can be obtained by measuring the muon spin precession in a uniform B-field.

- We can reconstruct time dependent spin information by decayed positron energy and momentum.

g-2 **EDM**

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

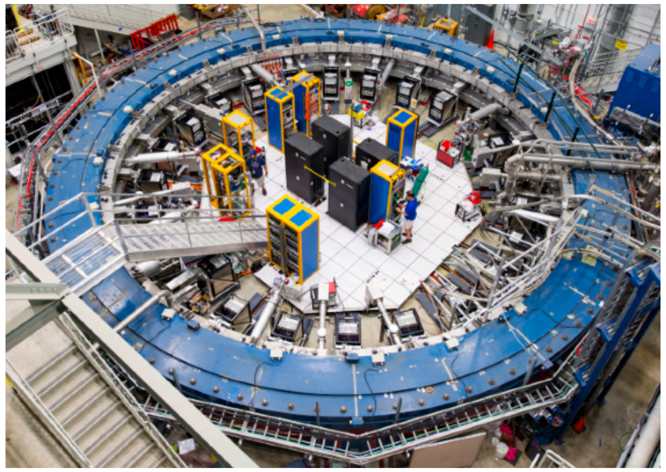
$\vec{\omega} = \vec{\omega_a} + \vec{\omega_\eta}$

<u>BNL/FNAL experiment</u>

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

= 0

- To focus muons in the storage volume, electric field is necessary.
- Magic gamma is selected to cancel out 2nd term.
  - p = 3.1 GeV/c
  - muon orbit : ϕ = 14 m (B = 1.45 T)

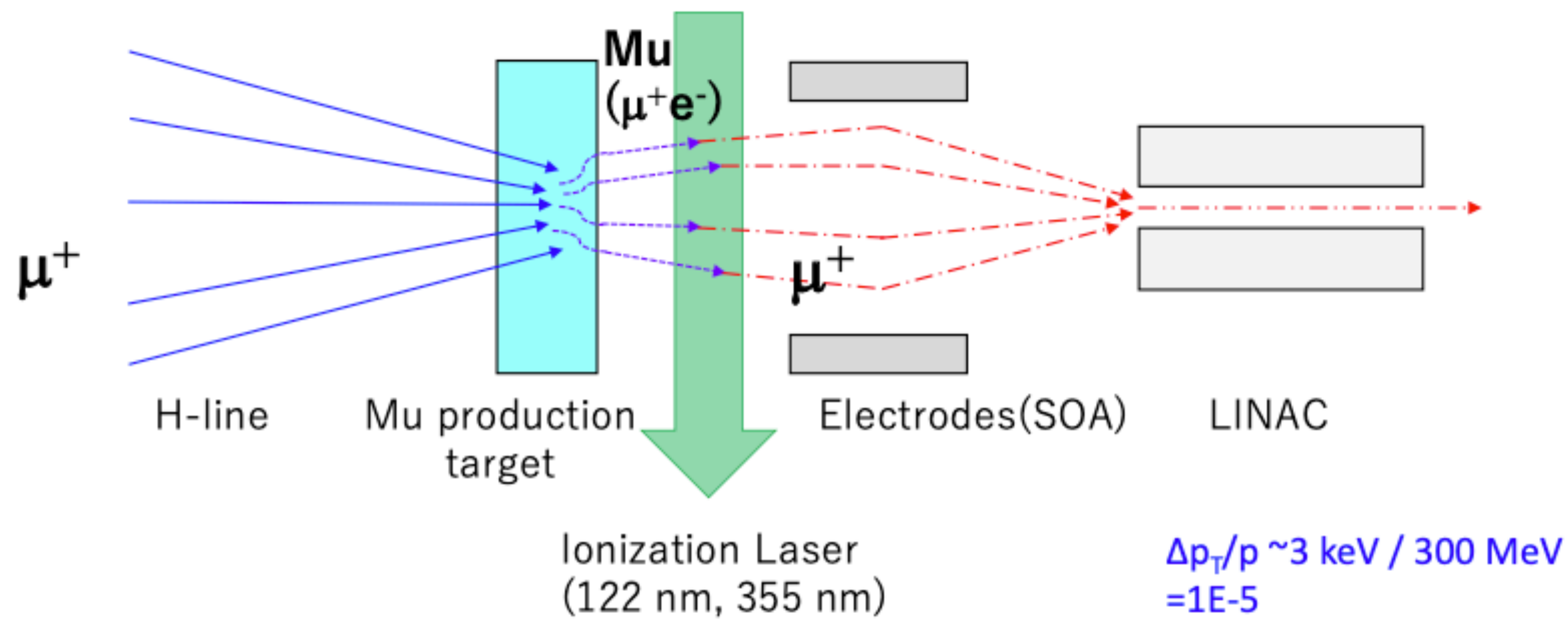


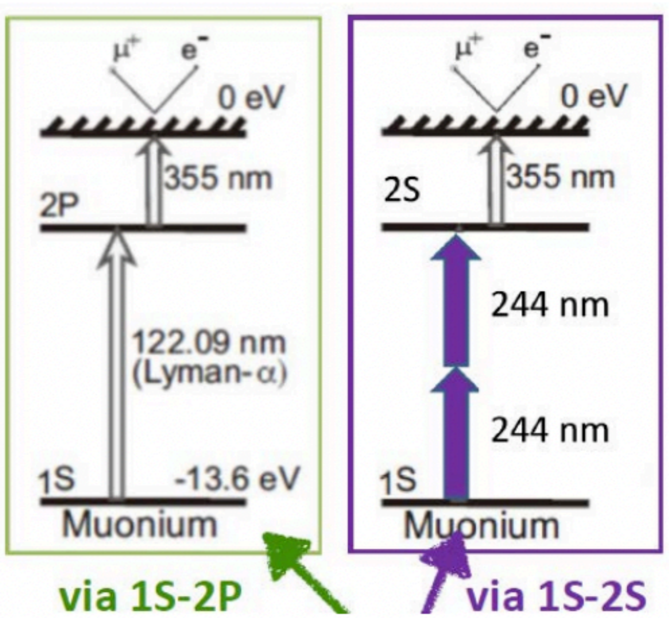
Muon cooling

Cool surface muons before reacceleration

- Silica aerogel target : Stop surface muons, and thermal muoniums are emitted.
- Laser ablated aerogel for muonium production target.

	surface muon	thermal muon	accelerated muon
E	3.4 MeV	30 meV	212 MeV
p	27 MeV/c	2.3 keV/c	300 MeV/c
Δ p/p	0.05	0.4	4×10^{-4}





Thermal muonium ionization by laser.

- Two scheme under consideration.
- 1S-2P excitation by 122 nm or 1S-2S excitation by 244 nm