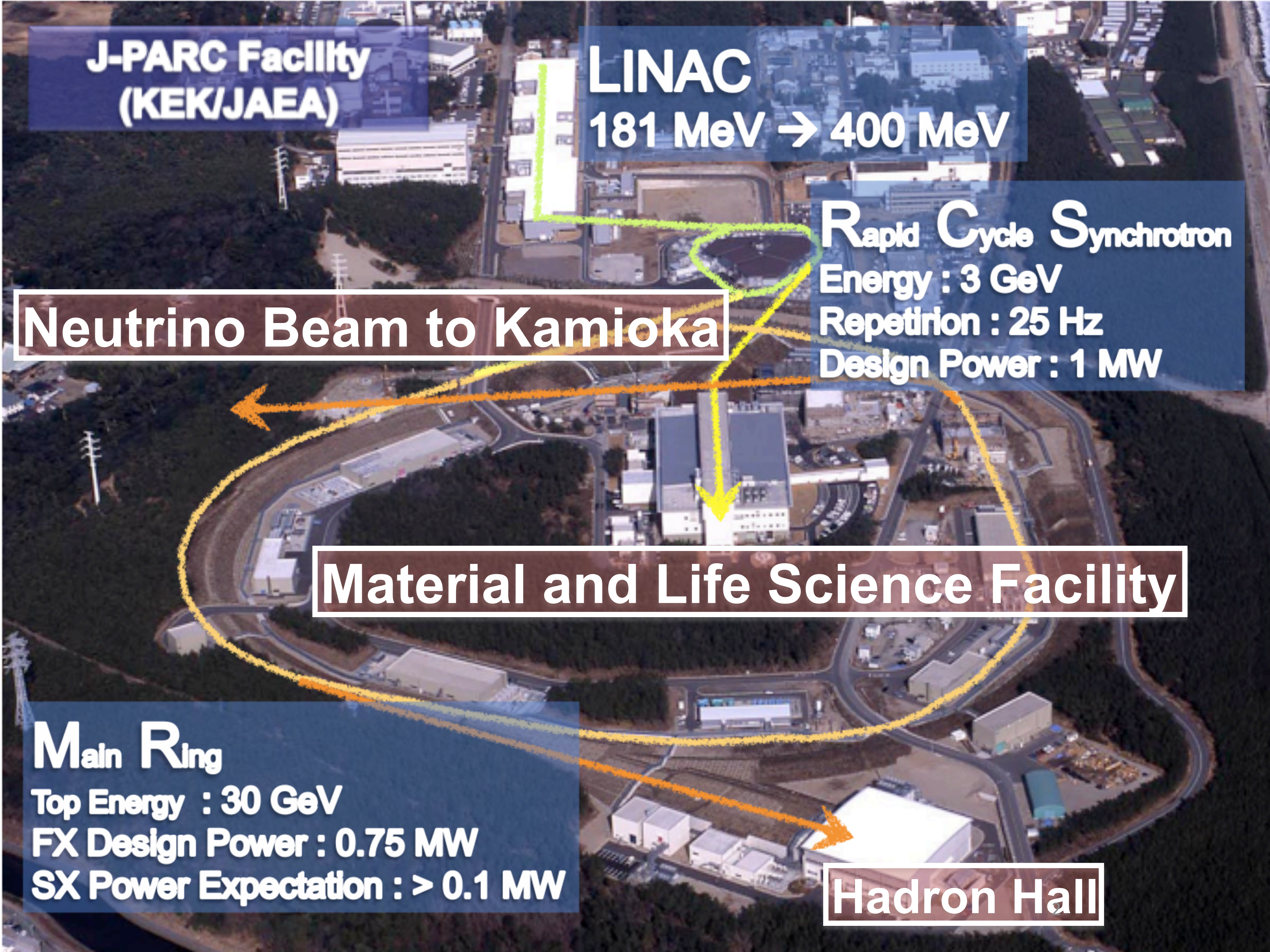
Status of J-PARC and Future Plans

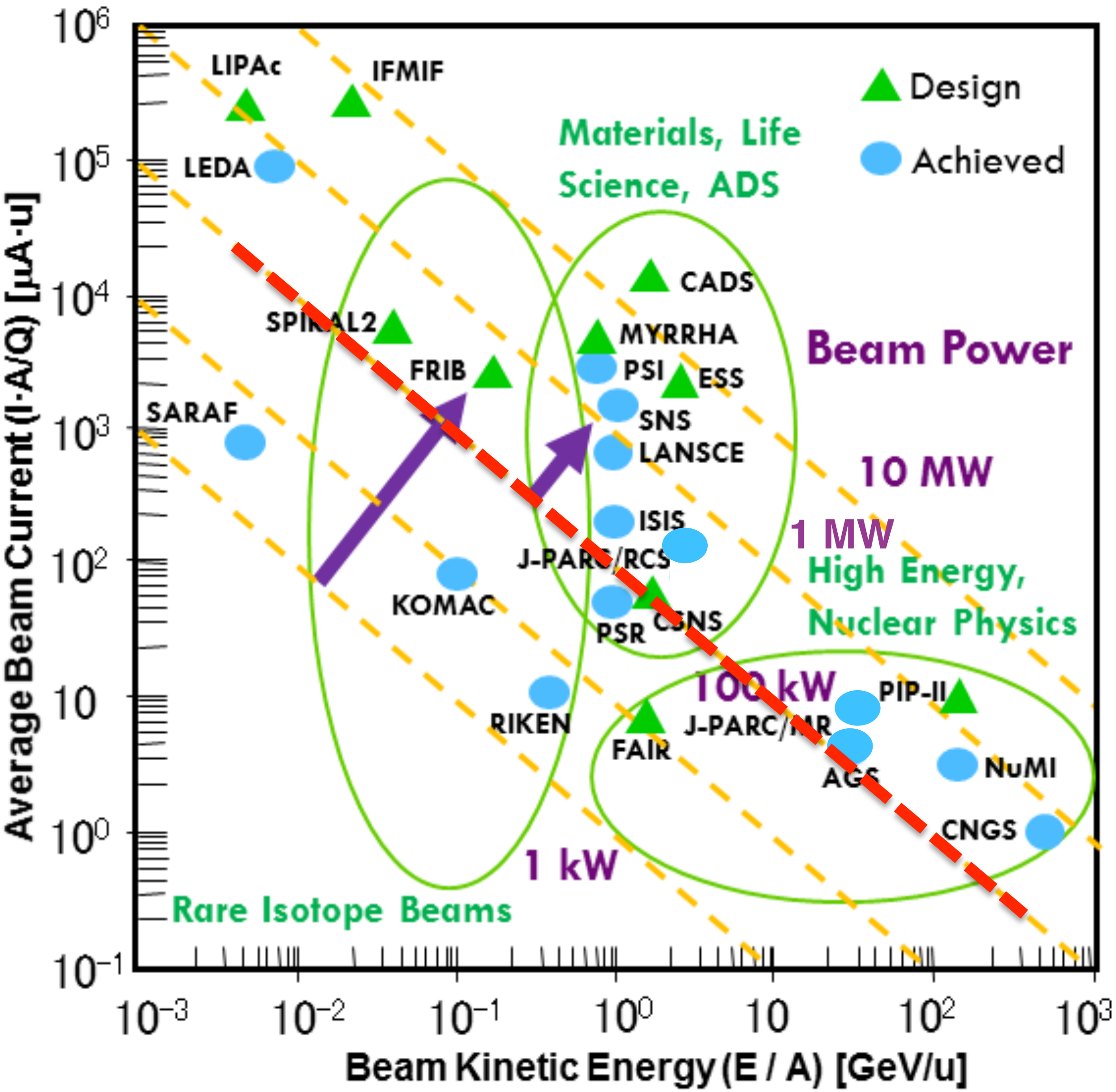
October 28-31, 2015

NNN15, Stonybrook University, NY

Naohito SAITO
J-PARC / KEK
High Energy Accelerator Research Organization (KEK)
Japan Atomic Energy Agency (JAEA)


J-PARC Facility
(KEK/JAEA)
LINAC
181 MeV → 400 MeV
Rapid Cycle Synchrotron
Energy : 3 GeV
Repetirion : 25 Hz
Design Power : 1 MW
Neutrino Beam to Kamioka
Material and Life Science Facility
Main Ring
Top Energy : 30 GeV
FX Design Power : 0.75 MW
SX Power Expectation : > 0.1 MW
Hadron Hall

A Quest for High Intensity



High Intensity

High Statistics

- More Precision
- More Rare Searches
- More Materials

Discovery!

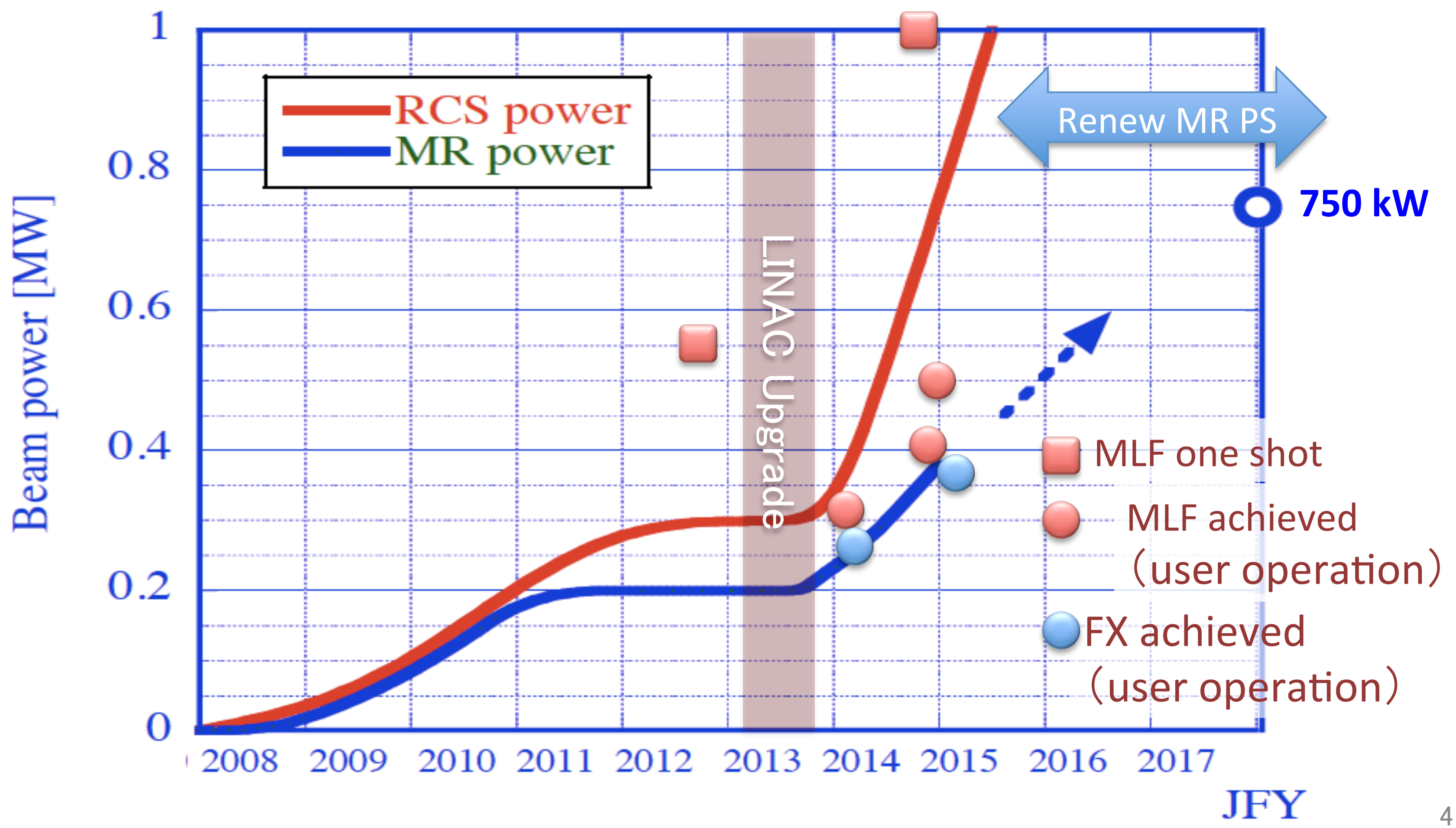
Jie Wei / Y. Yamazaki

Beam Power

RCS ::1 MW achieved in Jan, 2015

Thanks to new working point!

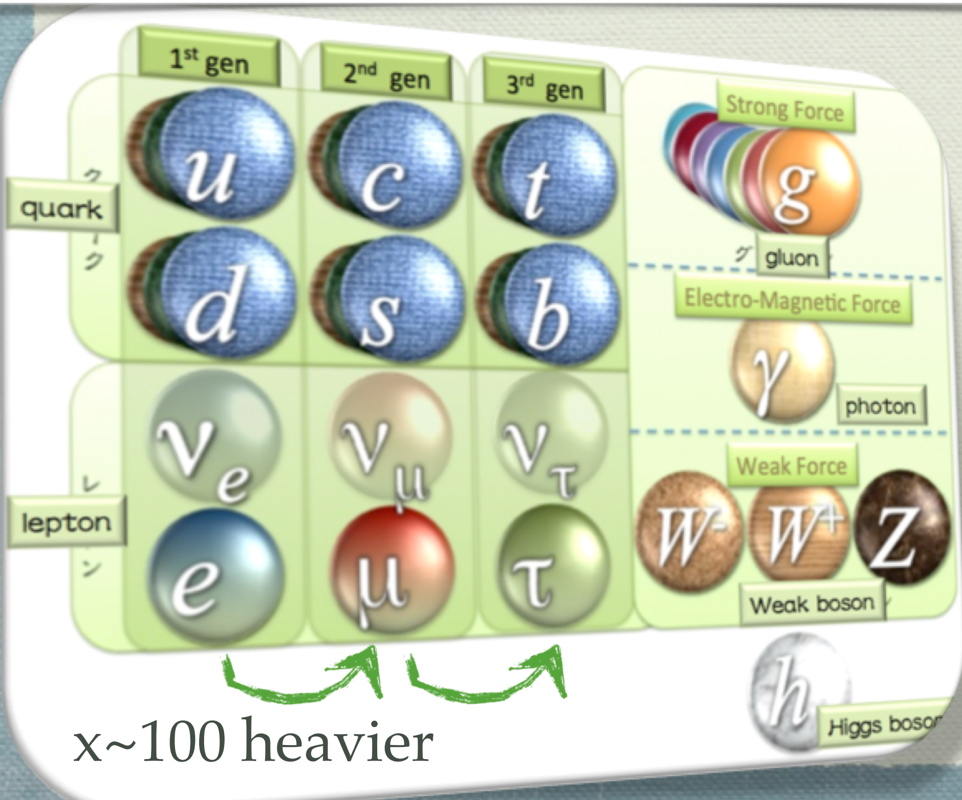
MR ::so far 0.36 MW for FX ; 0.9 MW reachable with new PS



Many Remaining Questions

- Completion of the Standard Model

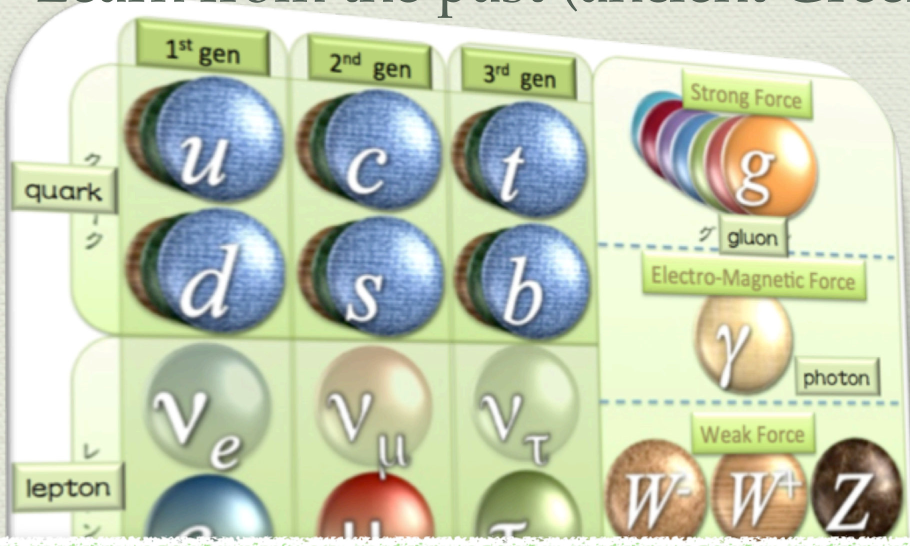
Beginning of New Physics Era



Why 3 generations?
Why CP violates? (particle-anti-particle asymmetry)
Why mass distributed this way?
Baryon number, Lepton number, Lepton flavor violated?
What is Dark Matter, Dark Energy?
How we should understand the gravity?
Why our Universe is matter-dominant?
Is super-symmetry real?

Go Beyond the SM

- Learn from the past (ancient Greek Philosophy) !

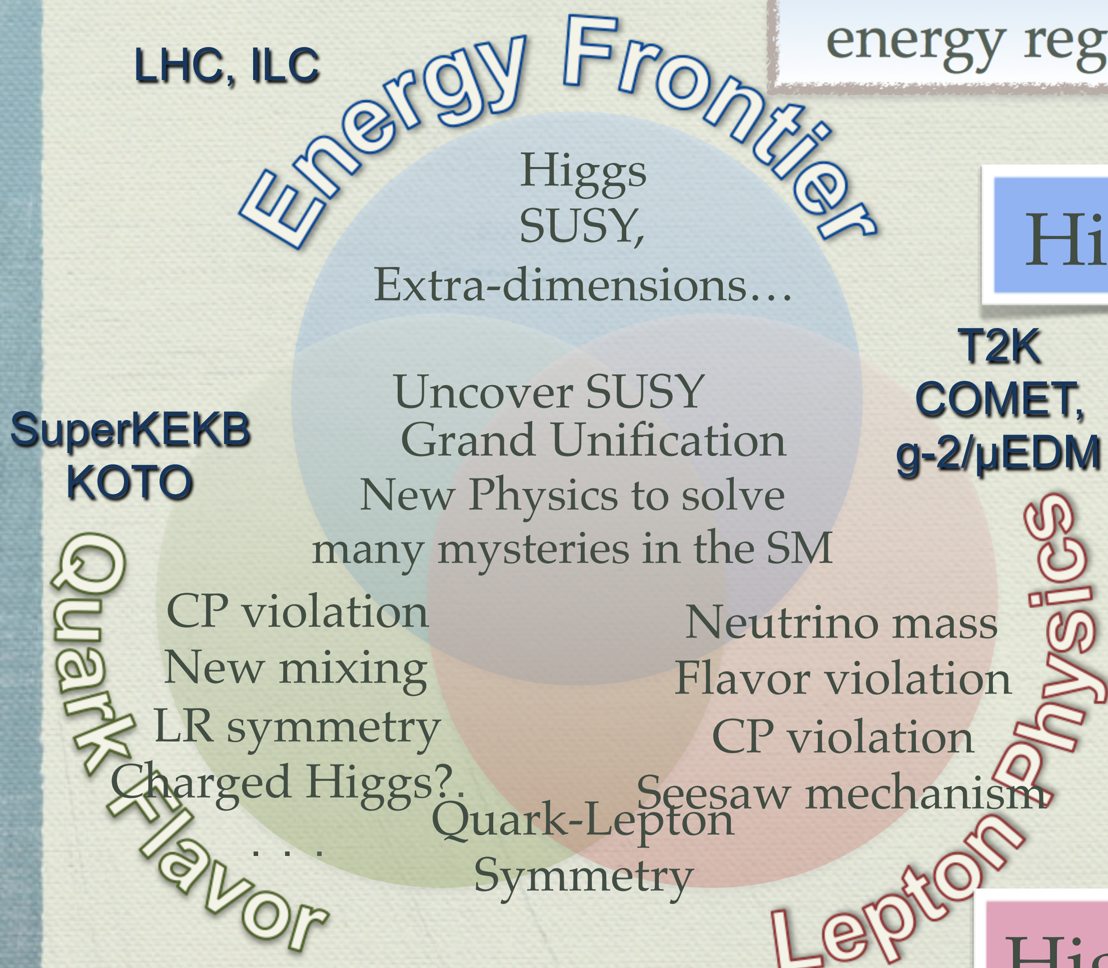


The basic framework is identical; small number of elements interacts thru a number of interaction to produce everything!

Our view is limited by what we can see, touch, and feel !

We need to extend our "sense" ; micro scope / ultra-sensitive devices

“Microscope” = Accelerator

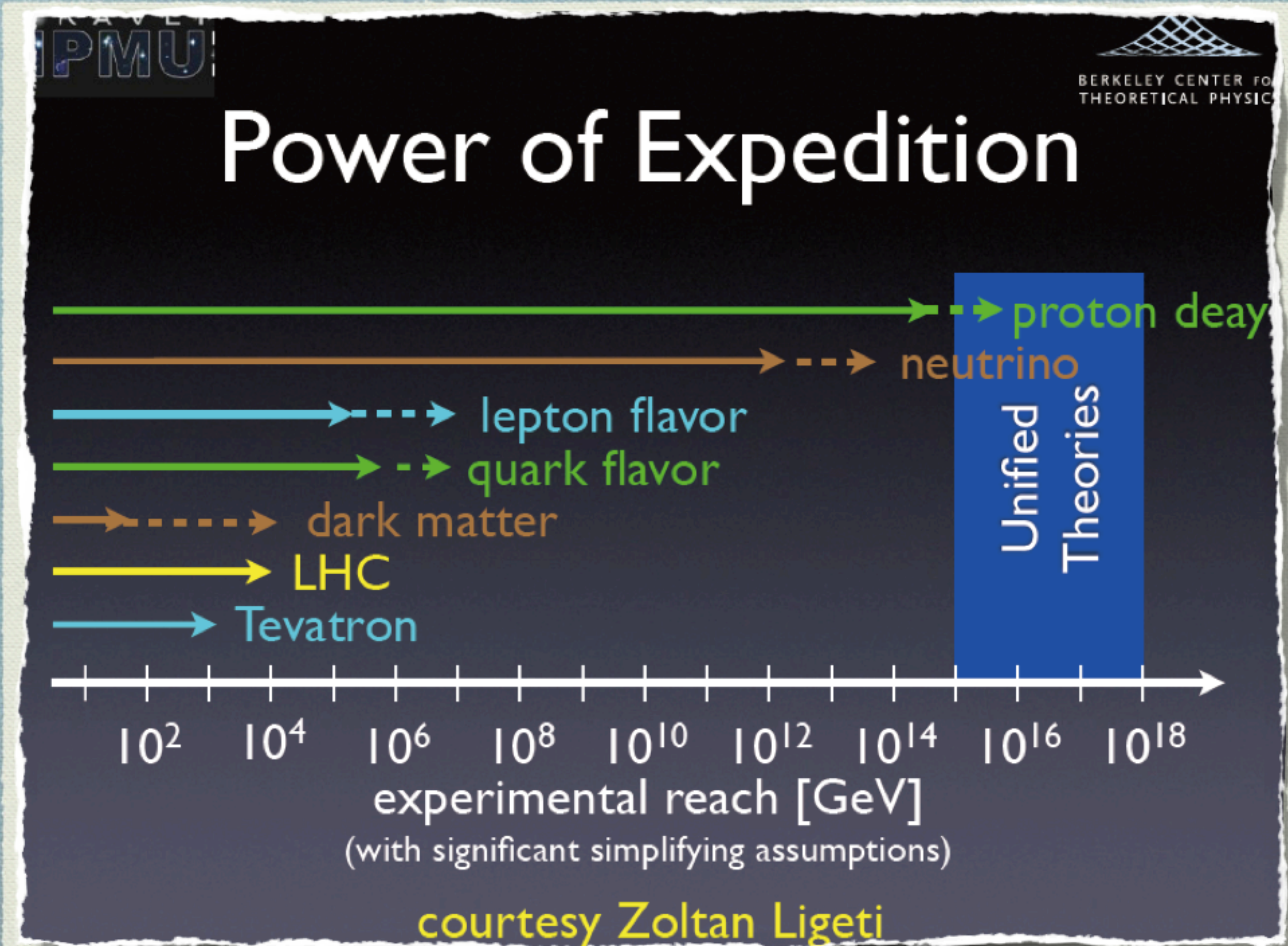


High Energy Frontier?
new phenomena in the unprecedented energy region may provide an answer?

High Energy Accelerator

Any other way?
ultra-precision measurement may provide a hint for New Physics?

High Intensity Accelerator



a slide by Hitoshi Murayama

Origin of Matter :

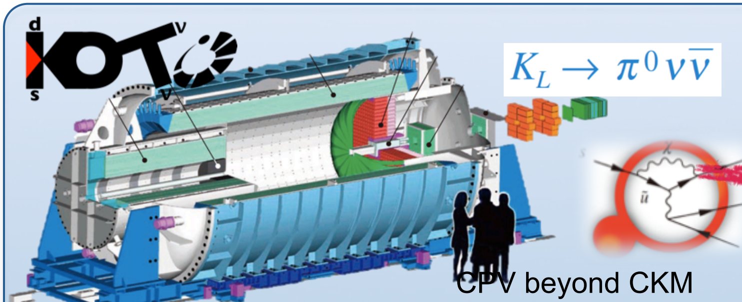
Explored with High Intensity Proton Driver = J-PARC

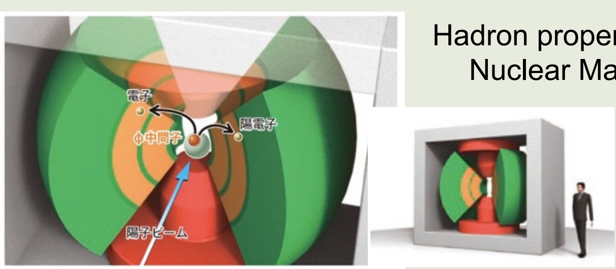
Neutrino Experiment : T2K

～Mixing Angle, CP phase, and Mass Hierarchy ～

Hadron Experiments

～CP beyond CKM; Mass modification～



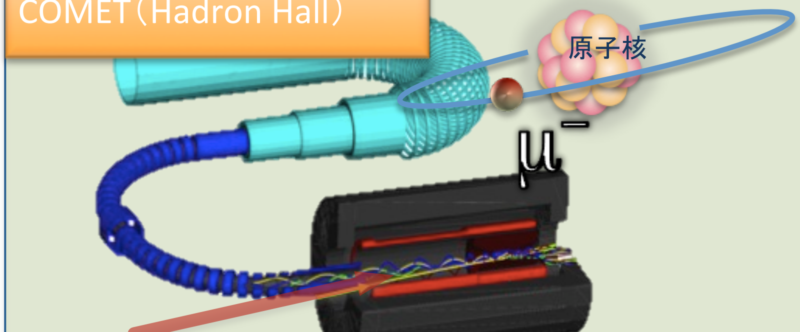


Hadron properties in Nuclear Matter

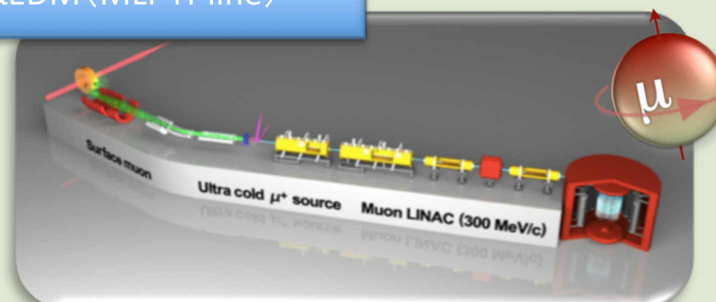
Muon Fundamental Physics

～Flavor and CP are violated in the charged Leton sector?～

COMET（Hadron Hall）



g-2/μEDM（MLF H-line）



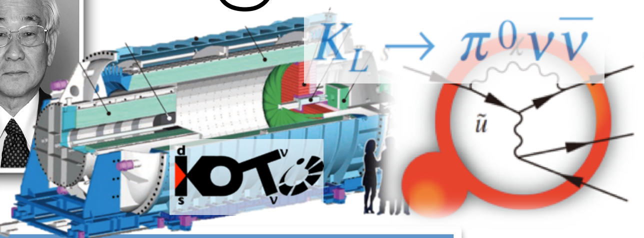
Origin of Matter

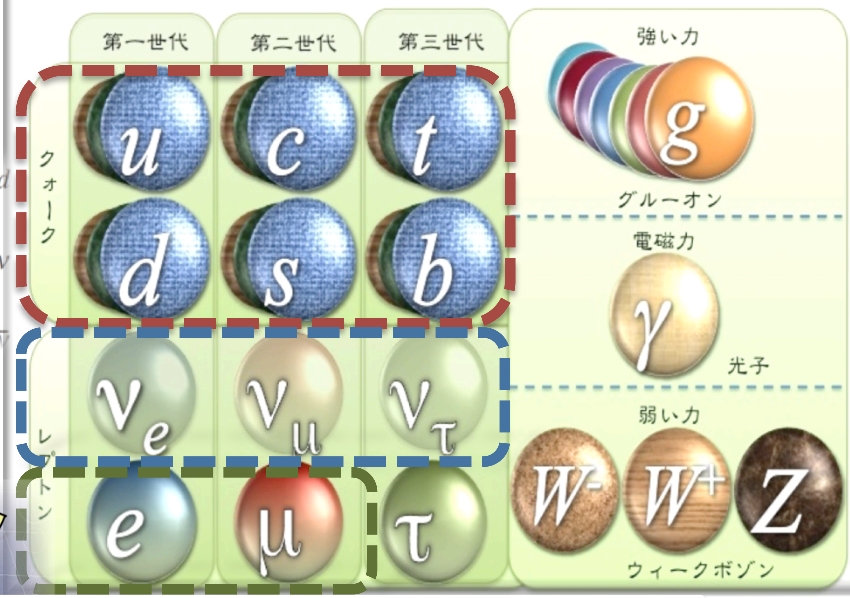
- Search for Physics Beyond SM in Quark and Lepton sectors
- Deeper understanding of Strong Int.

Particle–Nuclear Physics explored at J-PARC

Search for CPV beyond CKM theory

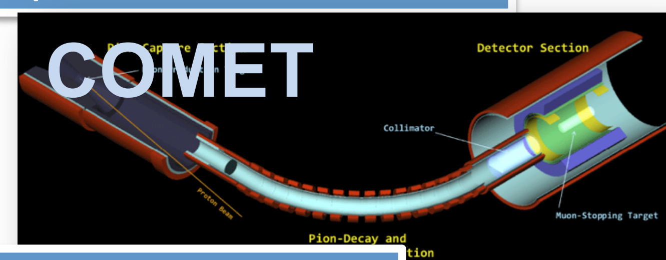
KOTO@Hadron Hall





Neutrino Mixing thru PMNS matrix

Charged Lepton Flavor violated?

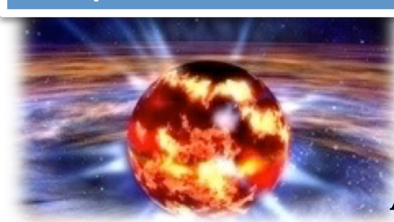


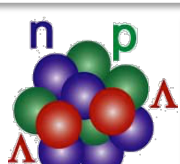
T2K Exp.

CPV in neutrino sector?

Explore role of strangeness in neutron stars

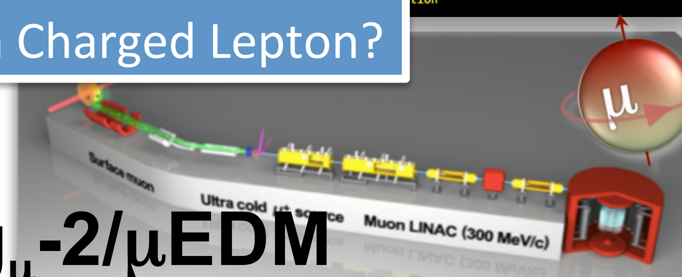
CPV in Charged Lepton?





ΛΛ-Hyper Nuclei

Strange quark may play an important roles in an extreme high density matter, aka neutron star.



g_μ-2/μEDM

Multi-Probe Platform for

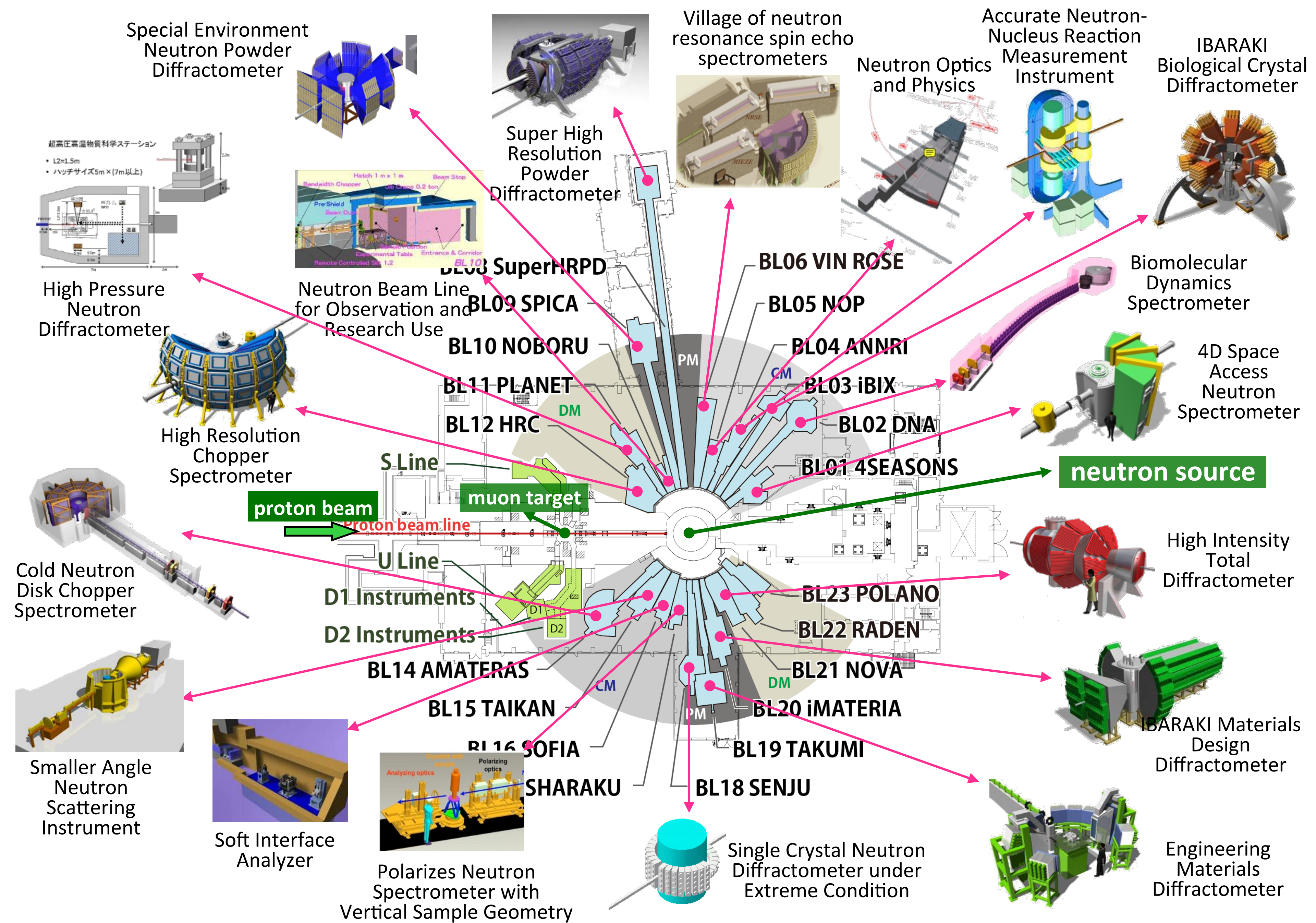
Material and Life Science

With Synergetic Use of Neutron, Muon, Photon and Positron

Neutron・Muon
(J-PARC)

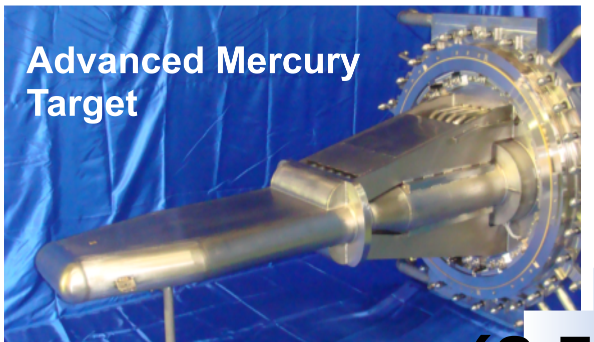
Photon・Positron
(KEK, Spring-8)

Neutron Instruments in MLF

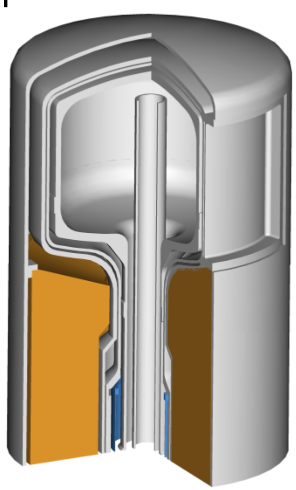


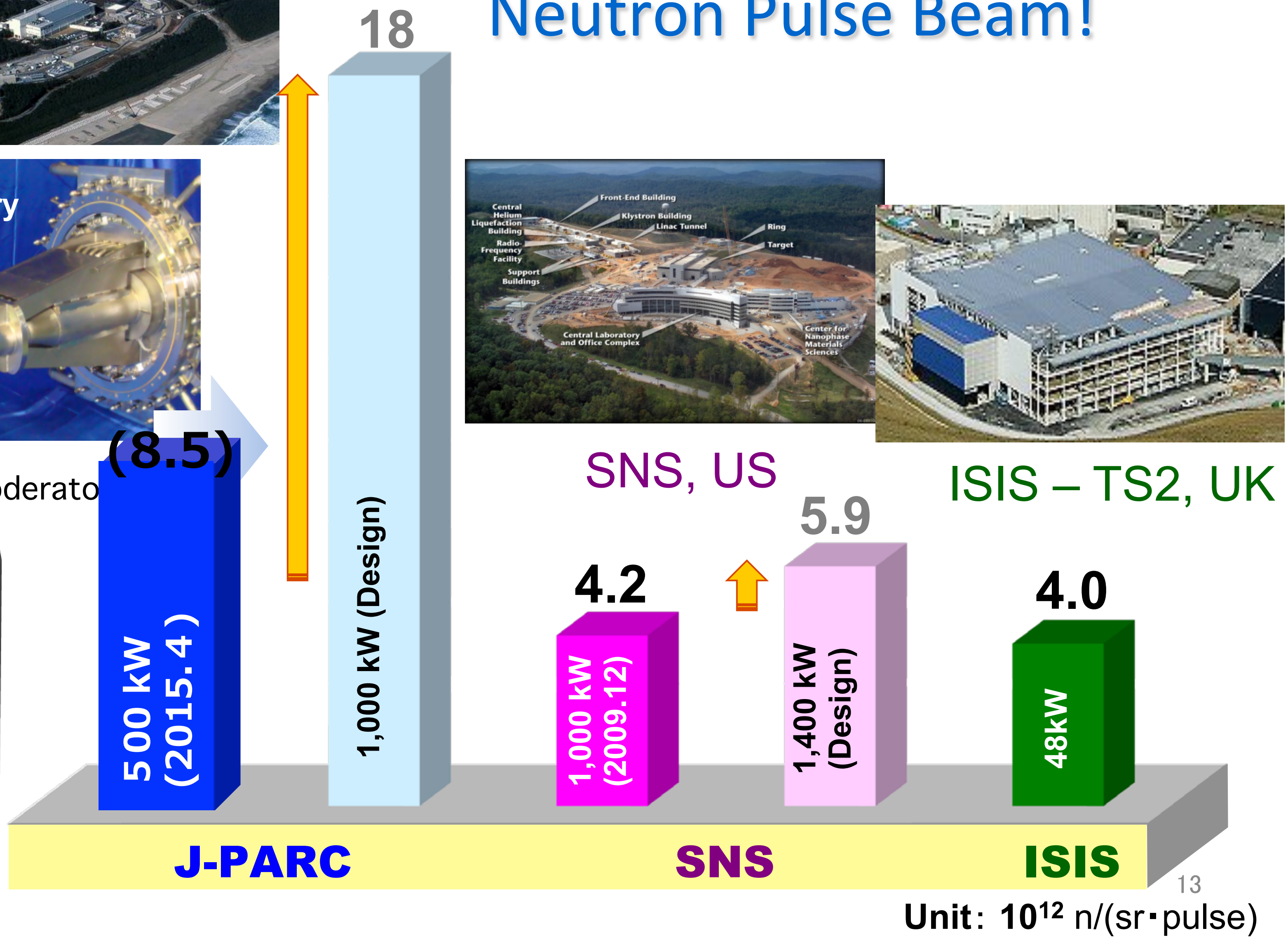
Material and Life Science Facility（MLF）

World Highest Intensity of Neutron Pulse Beam!



Hi-performance Moderato

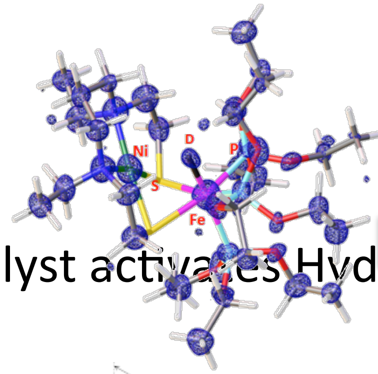




SNS, US

ISIS – TS2, UK

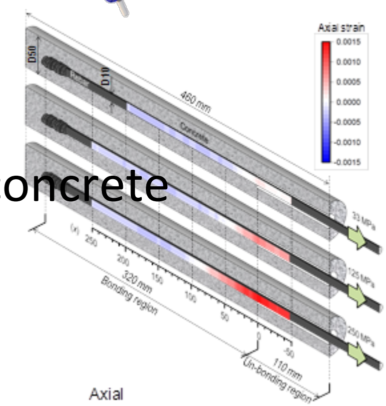
Examples of Industrial Use at MLF



- Battery for Vehicles

  Elucidate a mechanism of Ni-Fe Catalyst activates Hydroge

  ⇒ Development Battery w/o Pt



- For buildings with more strength

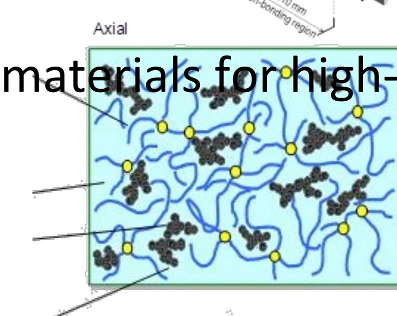
  Inspect internal structure of reinforced concrete

  ⇒ for more solid concrete

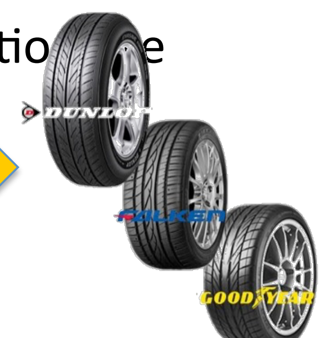
- For high-function tire

  Investigate the microscopic structure of materials for high-functio e

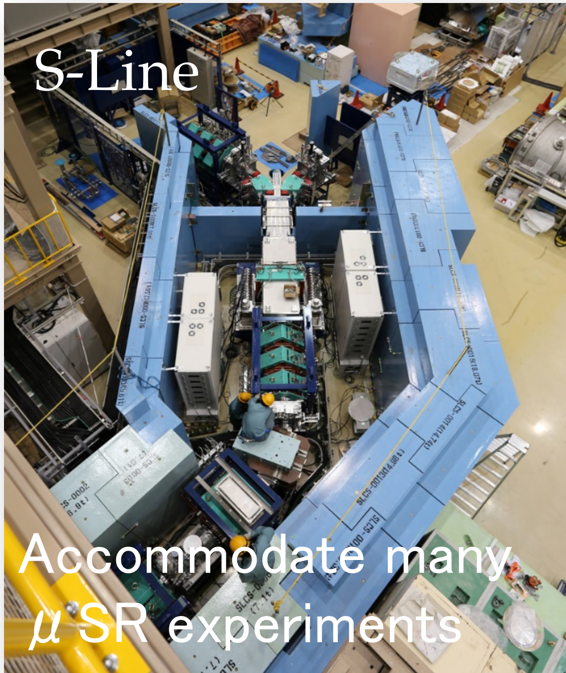
  ⇒ for higher performance tire

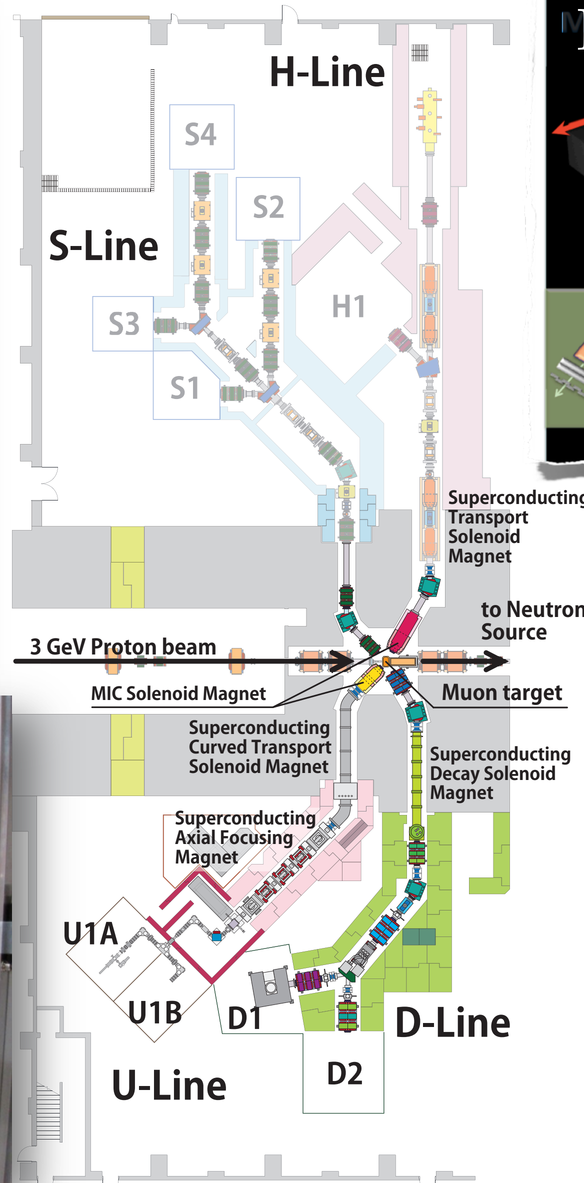


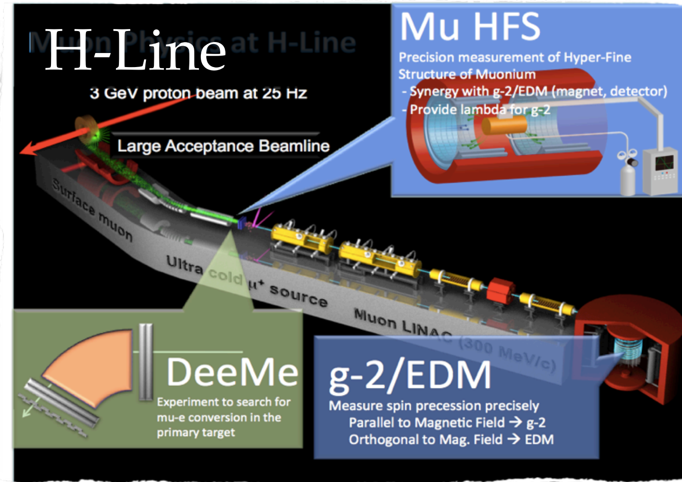
Microstructure of rubber



Muon Facility MUSE @ MLF



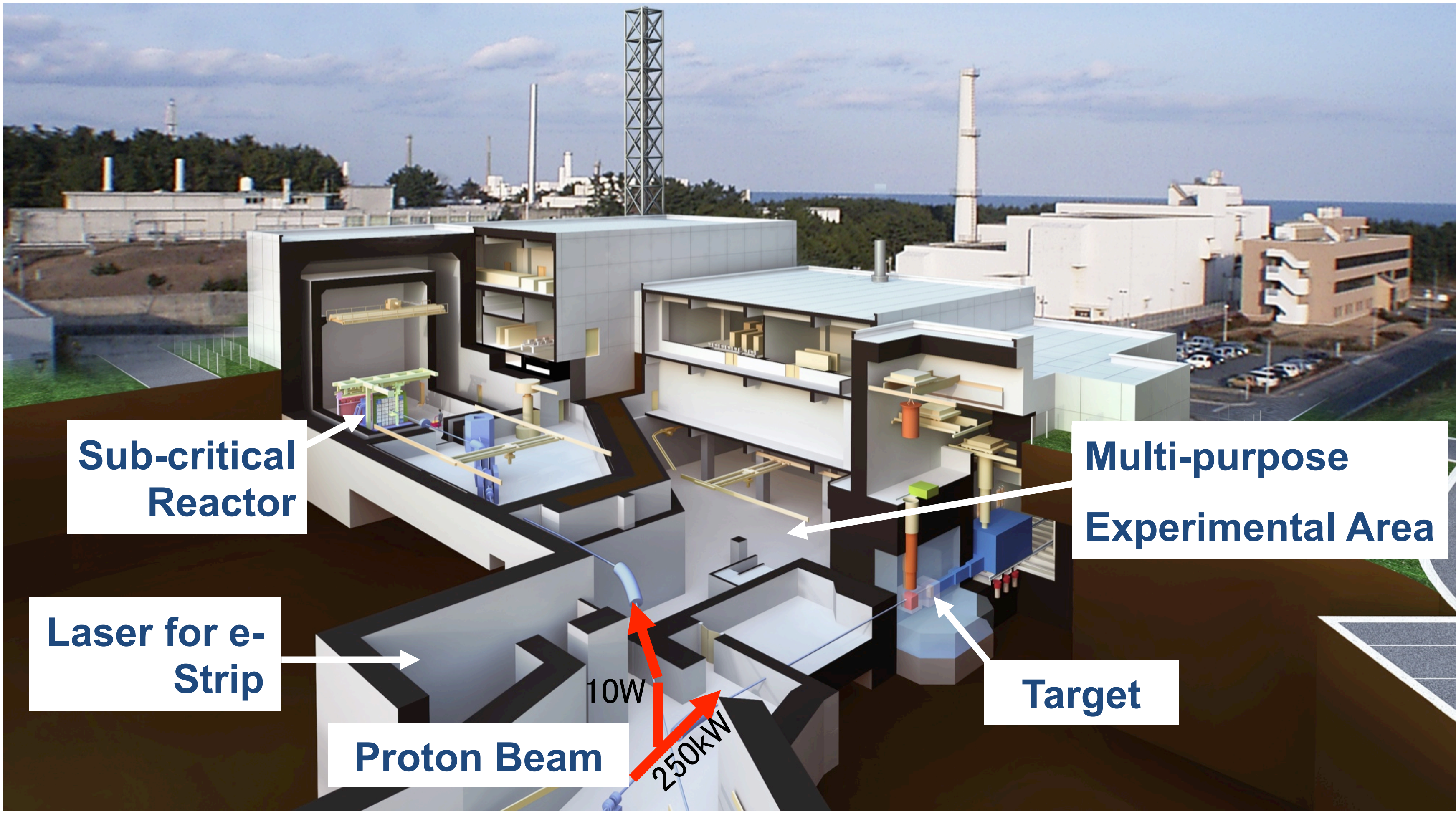




Fundamental Science with a large scale international coll.

ADS Test Facility for Nuclear Transmutation

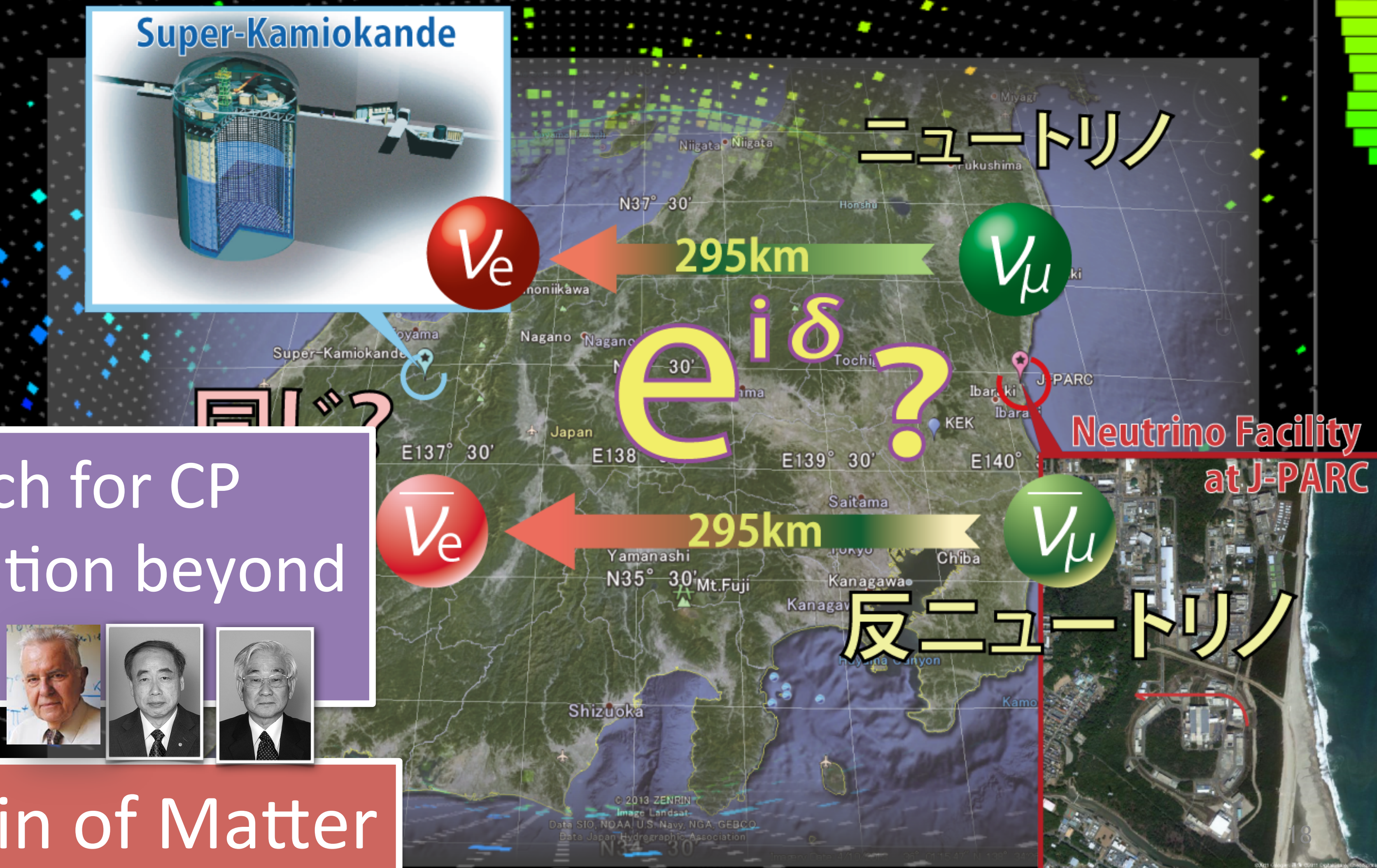
TDR being developed for construction start in JFY 2018



Neutrino Program

Goal of T2K

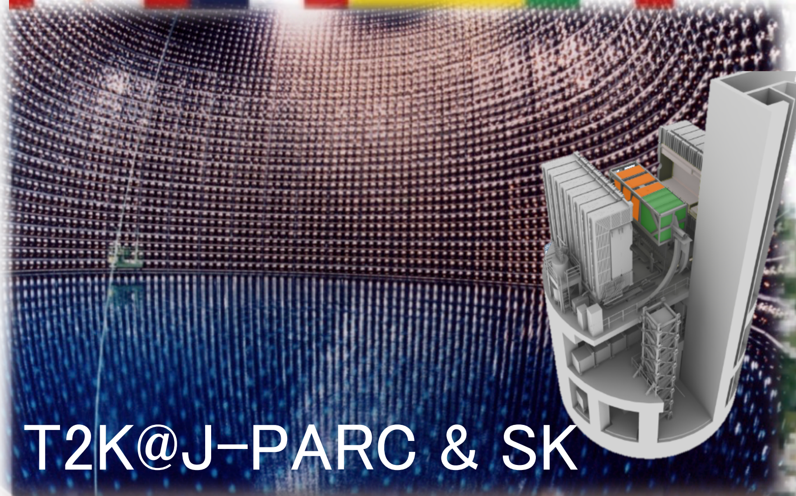
Neutrino and anti-neutrino behave same?



Search for CP Violation beyond CKM

Origin of Matter

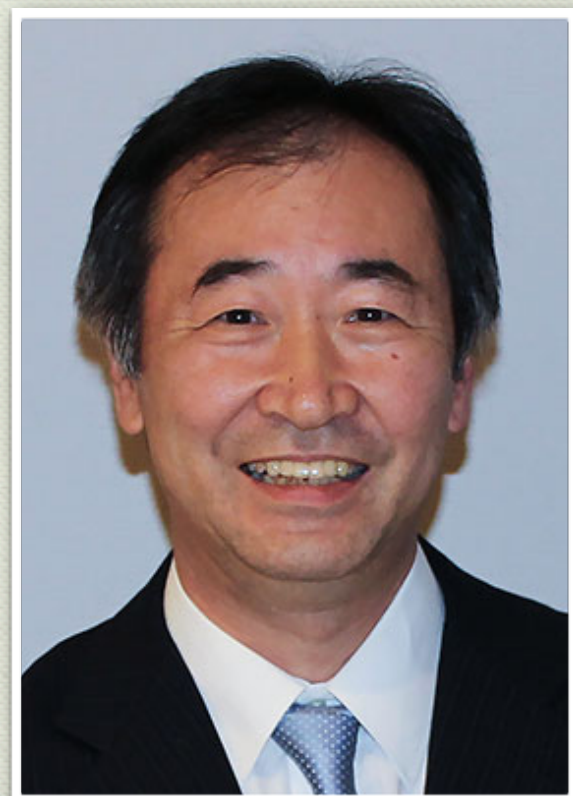
T2K Collaboration



Nishina Memorial Prize 2014
Prof. Nakaya
Prof. Kobayashi

6th Yoji Totsuka Prize
Prof. Nakaya
Prof. Kobayashi
Prof. Shiozawa

Congratulations!



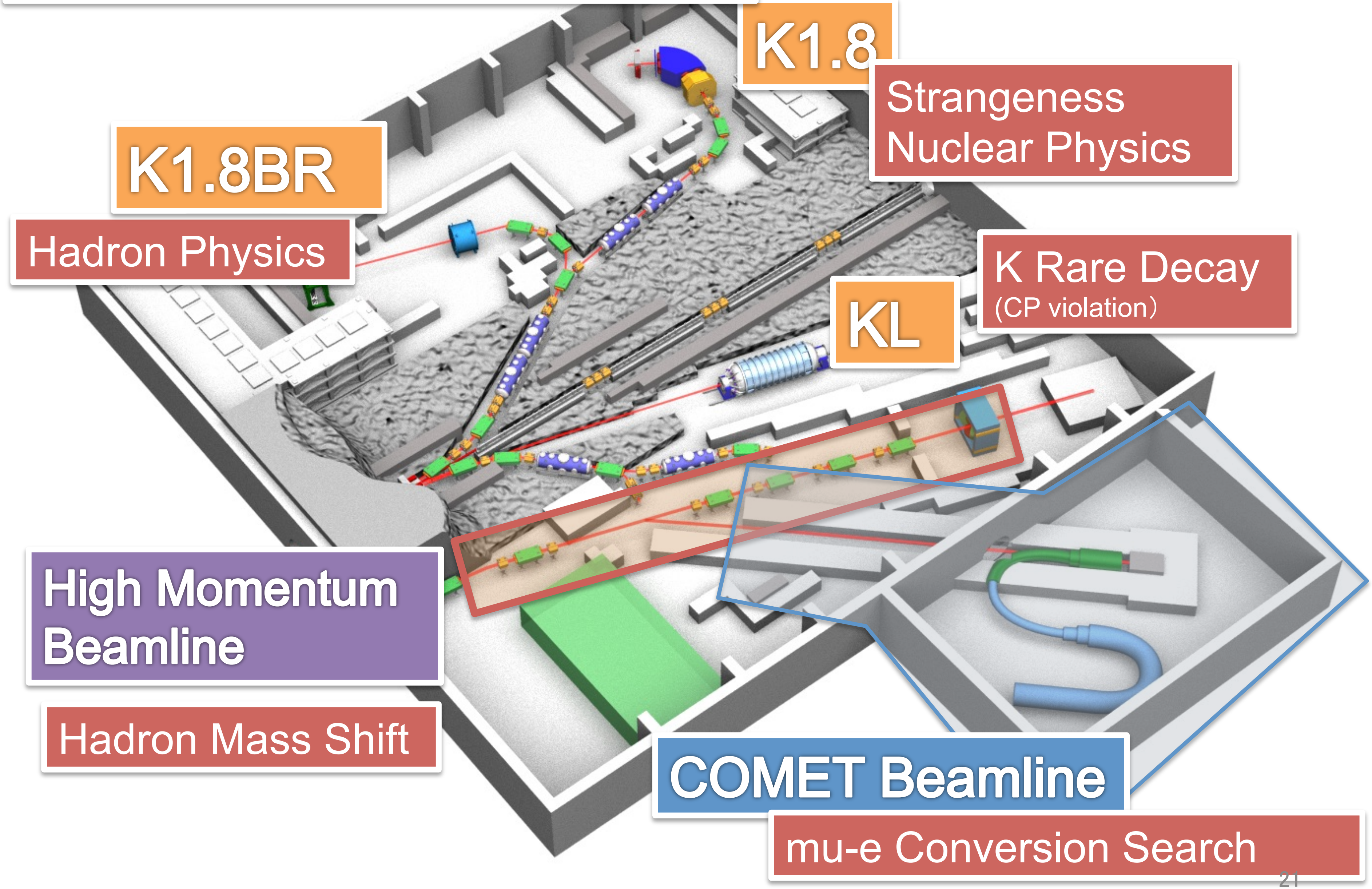
Prof. Takaaki KAJITA

Prof. Arthur B. McDonald

- For Discovery of Neutrino Oscillation

Pictures from Nobelprize.org

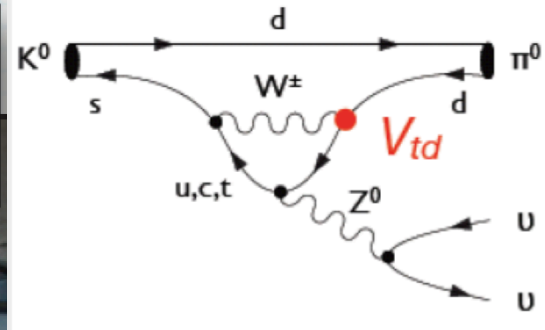
Hadron Hall in 2016

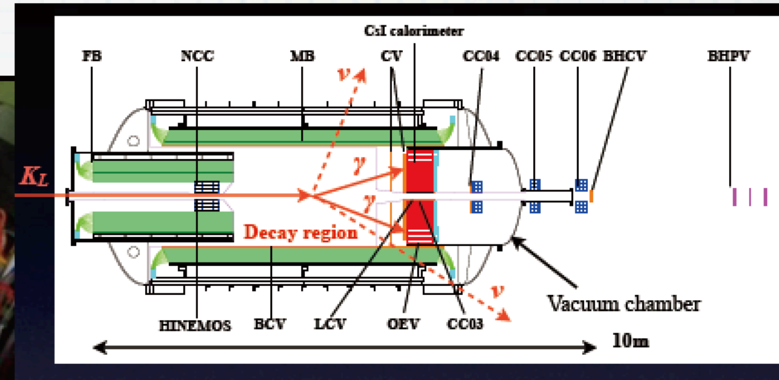


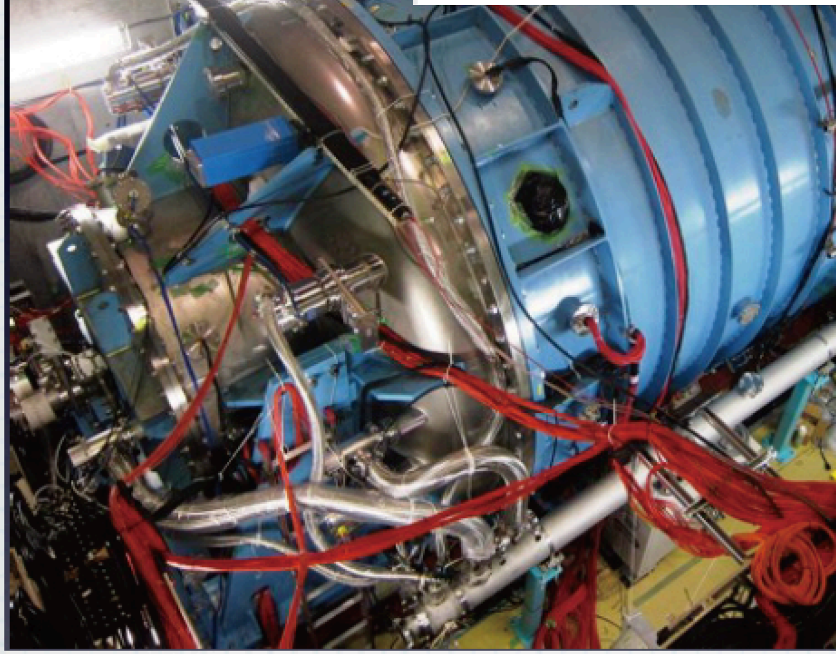
Kaon program

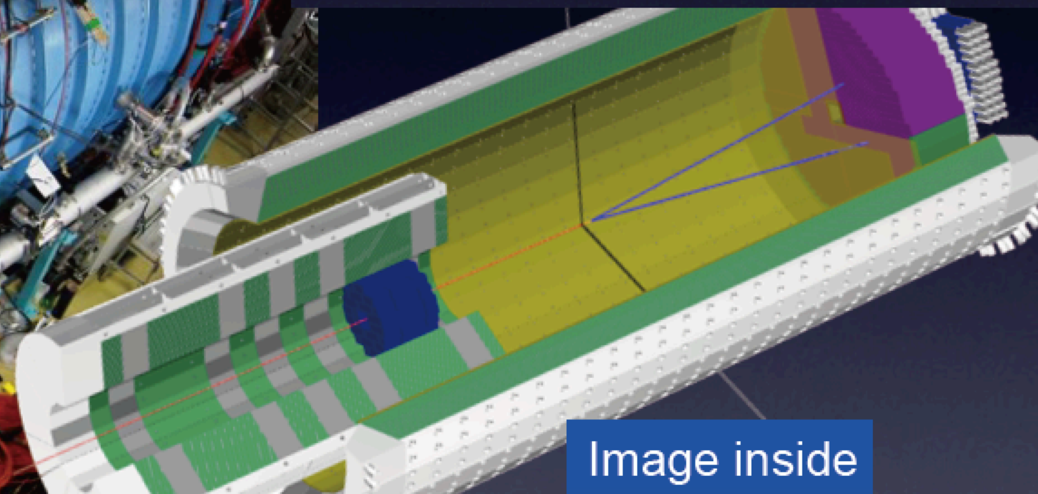
KOTO : Study on $K_L \rightarrow \pi^0 \nu\nu$

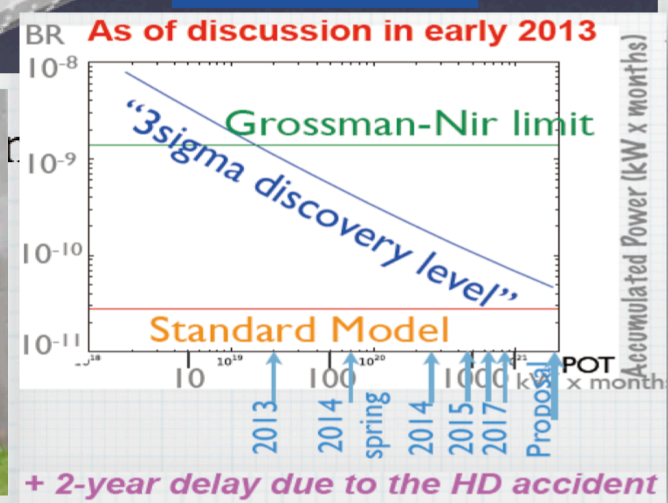
Slide by T. Nomura











Slide by T. Nomura

Kaon program

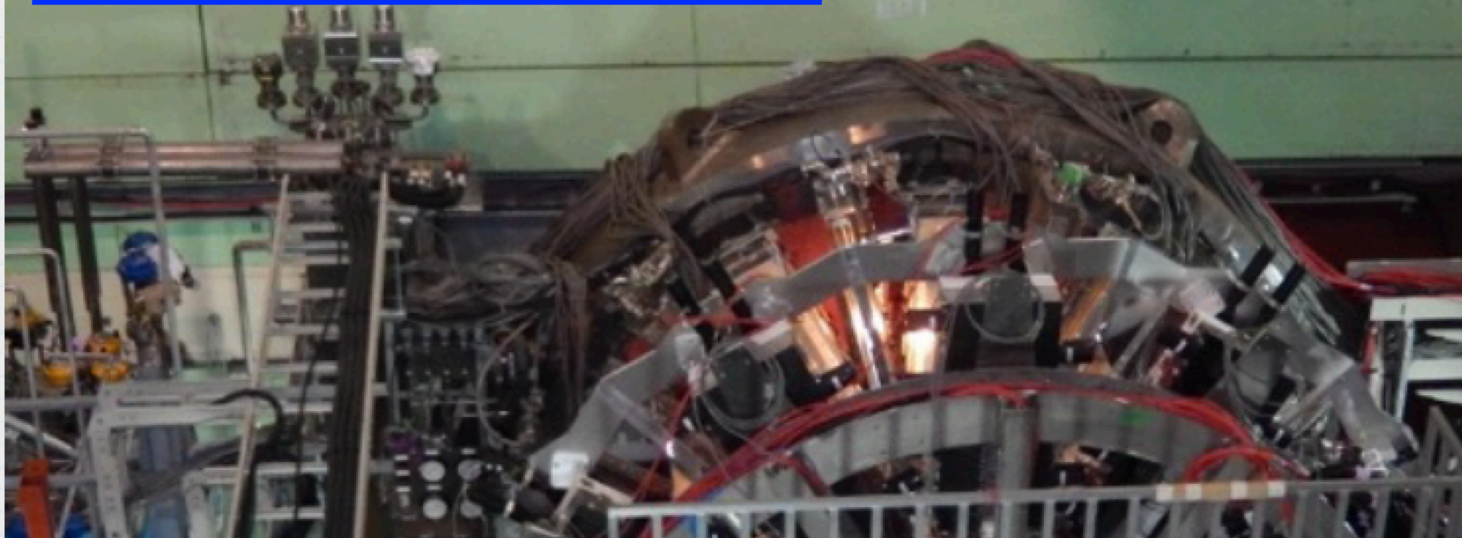
E36: Lepton universality in K^+ decay

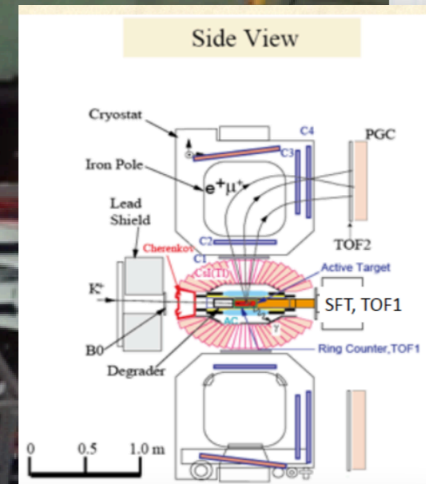
Slide by T. Nomura

Photo of K1.1BR experimental area

Slide by T. Nomura

E36



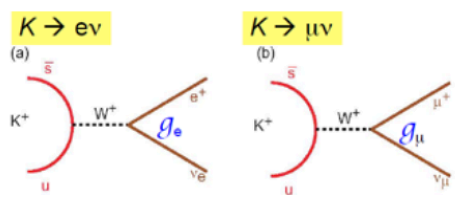


Lepton universality in K_{l2} decay

- Precise measurement of decay width ratio

$$R_K^{exp} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)}$$

$g_e = g_\mu$?



$$\Gamma(K_{l2}) = g_l^2\,(G^2/8\pi)\, f_K^2 m_K m_l^2 \{1-(m_l^2/m_K^2)\}^2$$

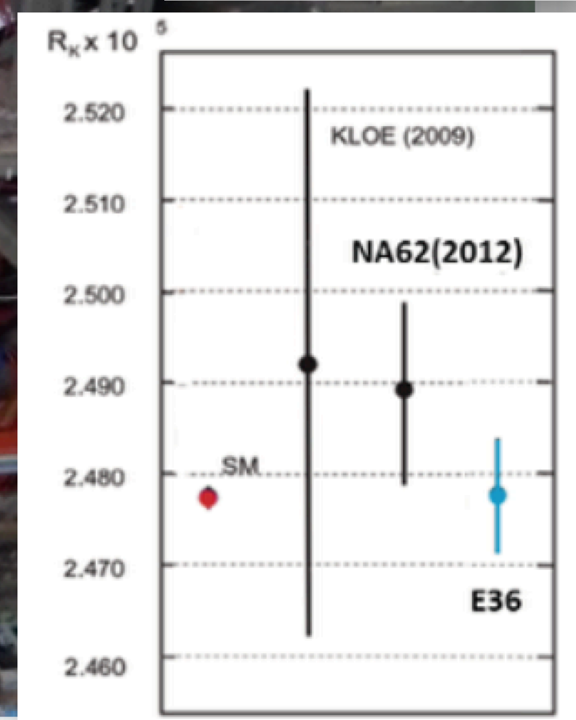
- In the ratio of the $\Gamma(Ke2)$ to the $\Gamma(K\mu2)$, the hadronic form factors are cancel out and R_K^{SM} is highly precise.

$$R_K^{SM} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r)$$

$R_K^{SM}=(2.477\pm0.001)\times10^{-5}$

SM uncertainty is $\Delta R_K/R_K \sim 0.04\%$

- Deviation of the experimental R_K from the SM prediction indicates lepton universality violation, which arises from New Physics



Muon Program

Search for μ→e conversion

COMET @ HEF

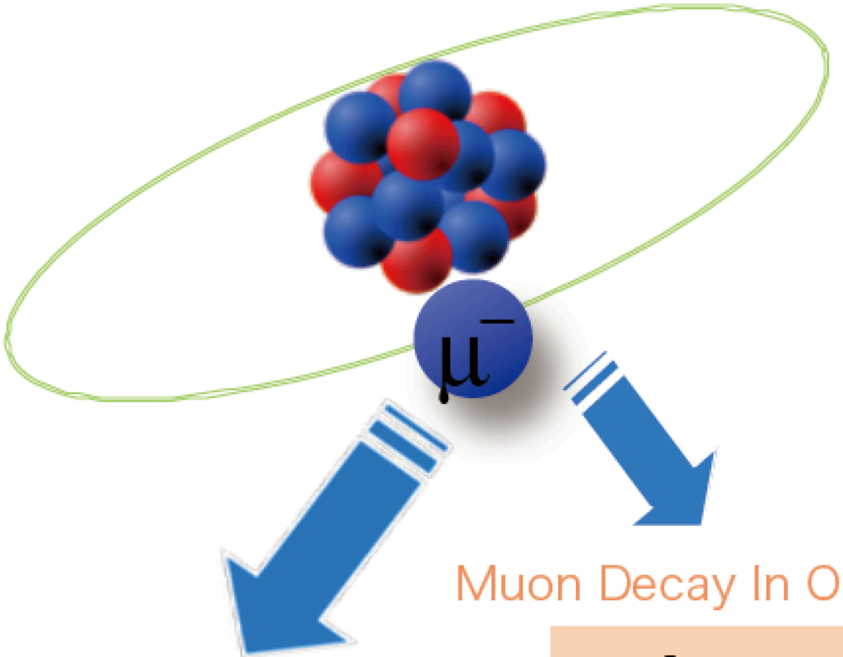
and

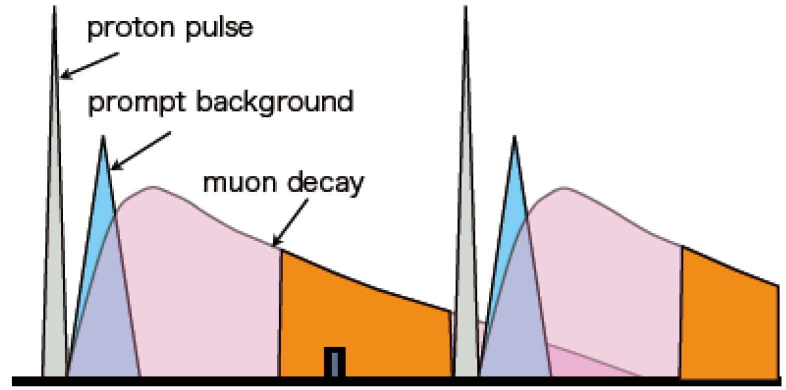
DeeMe @ MLF H-line

Slide by T. Nomura

COMET

$\mu \to e$ search using pulsed muon beam





$\pi^- + (A,Z) \to (A,Z-1)^*$, $(A,Z-1)^* \to \gamma + (A,Z-1)$, $\gamma \to e^+ e^-$

Prompt timing

Other sources

μ^- decay-in-flight, e^- scattering, neutron streaming

Muon Decay In Orbit

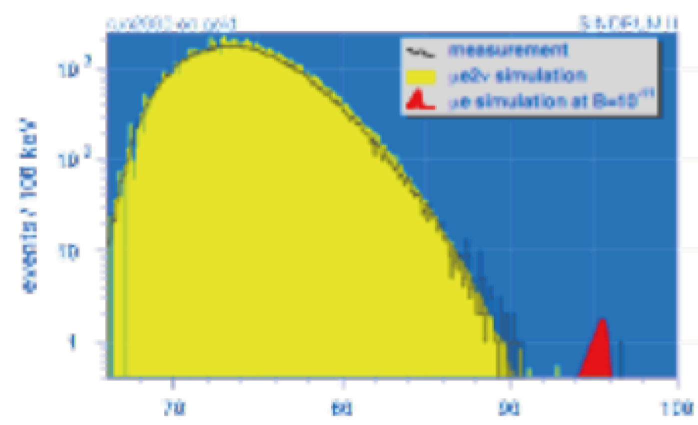
$\mu^- \to e^- \nu \bar{\nu}$

$$R_{ext} = \frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}$$

nuclear muon capture

$\mu^- + (A, Z) \to \nu_\mu + (A, Z-1)$

SINDRUM II BR[$\mu^- + Au \to e^- + Au$] < 7×10^{-13}



μ-e conversion

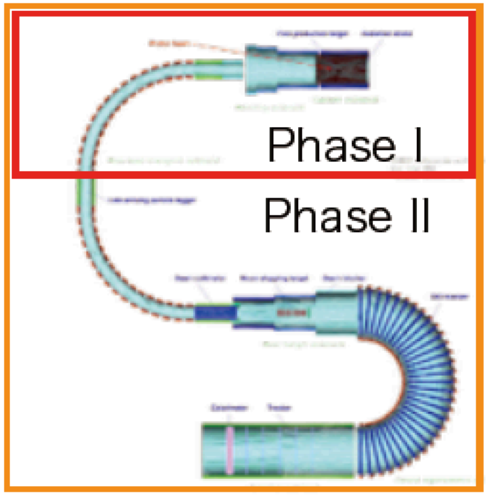
$\mu^- + (A, Z) \to e^- + (A, Z)$

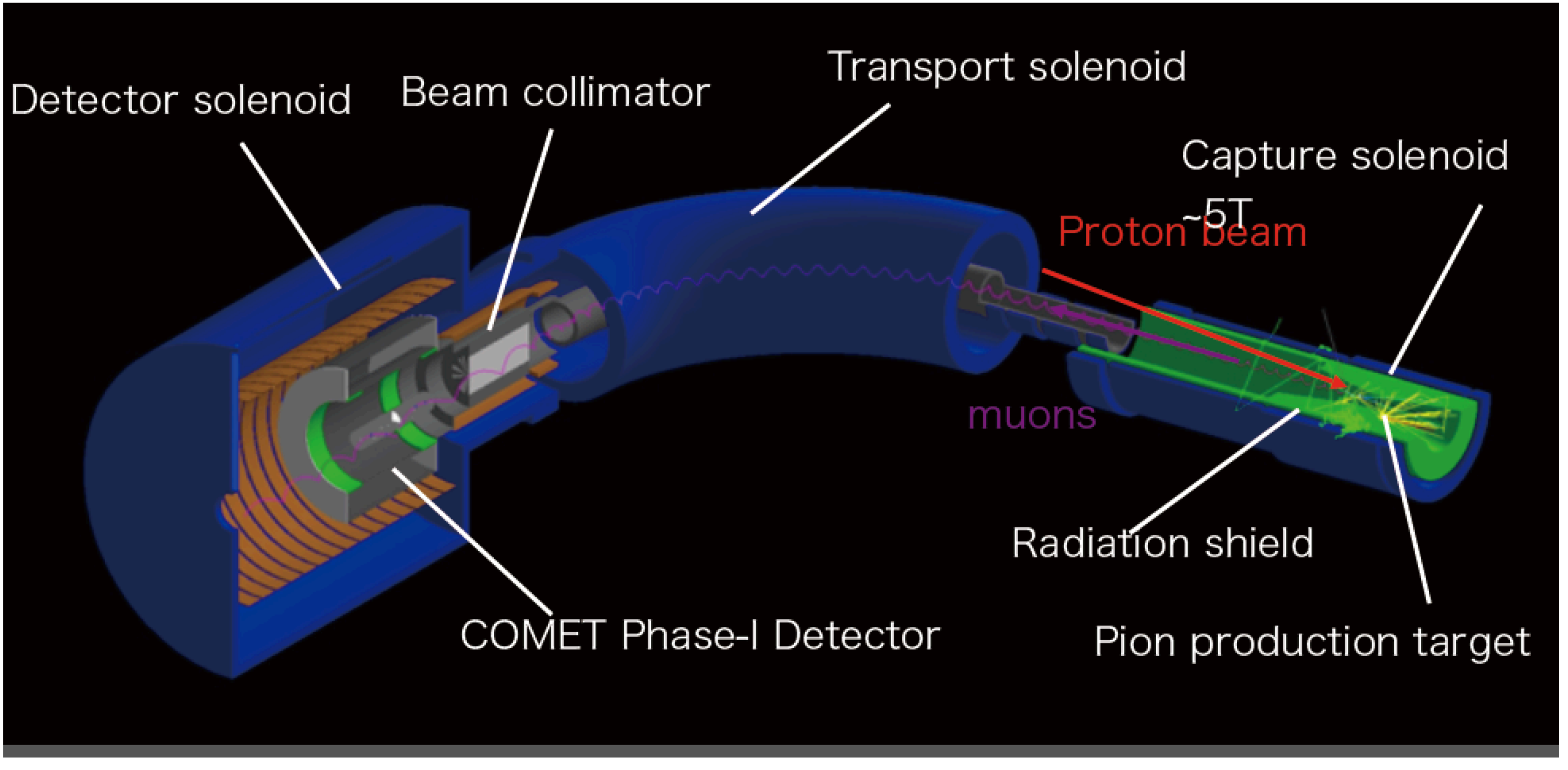
- $E_{\mu e(Al)} \sim m_\mu - B_{\mu} = 105\,\text{MeV}$

  –B_μ: binding energy of the 1s muonic atom

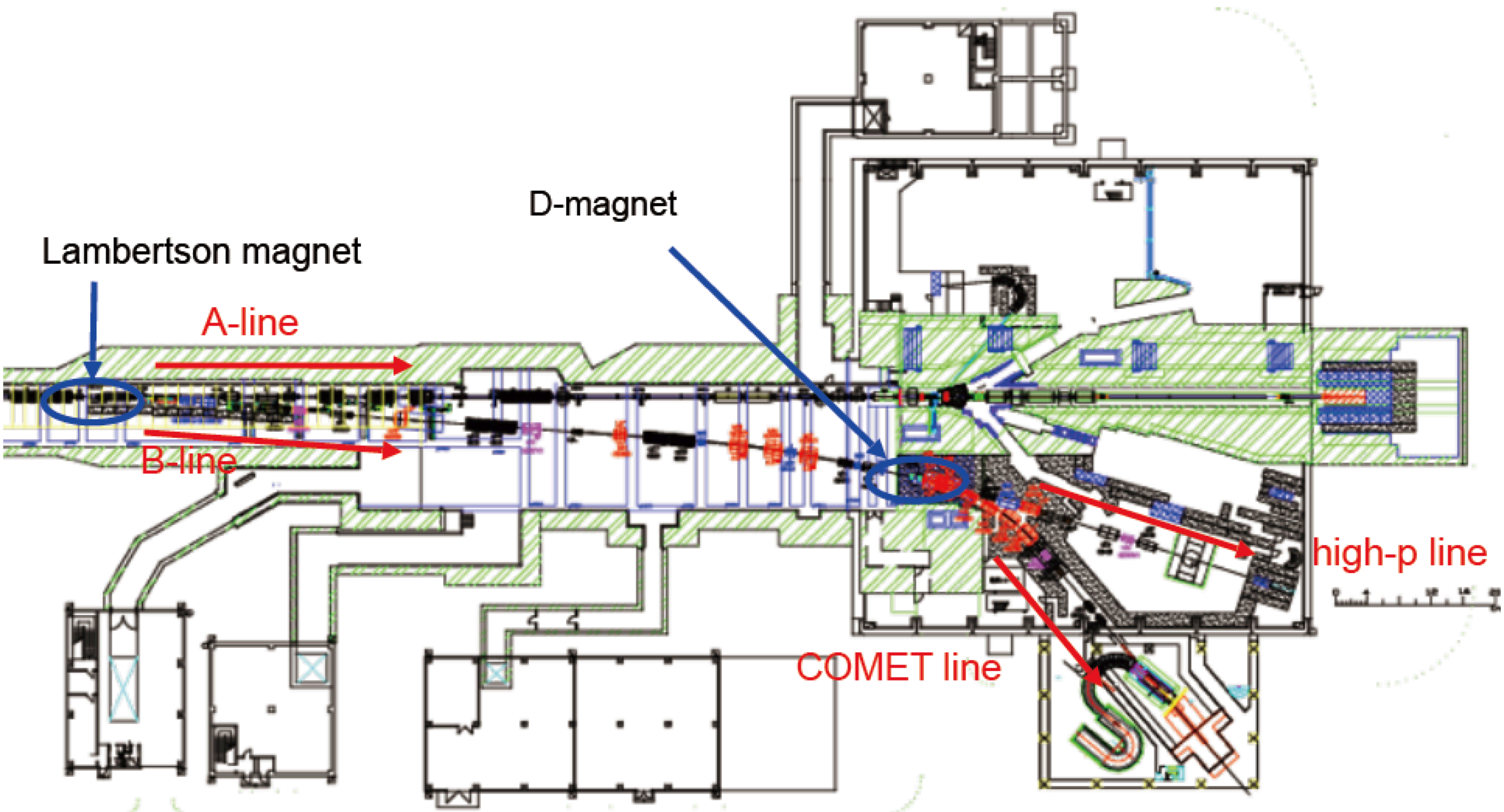
COMET Phase I

- Phase I
  - Beam background study and achieving an intermediate sensitivity of $<10^{-14}$
    - 8GeV, ~3.2kW, ~90 days of DAQ
- Phase II
  - 8GeV, ~56 kW, 1 year DAQ to achieve the COMET final goal of $< 10^{-16}$ sensitivity





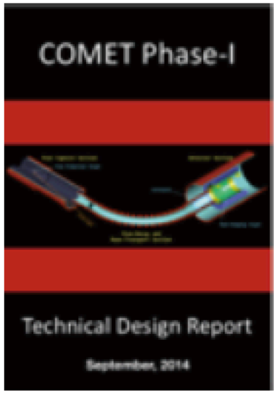
COMET Hall & Beamline



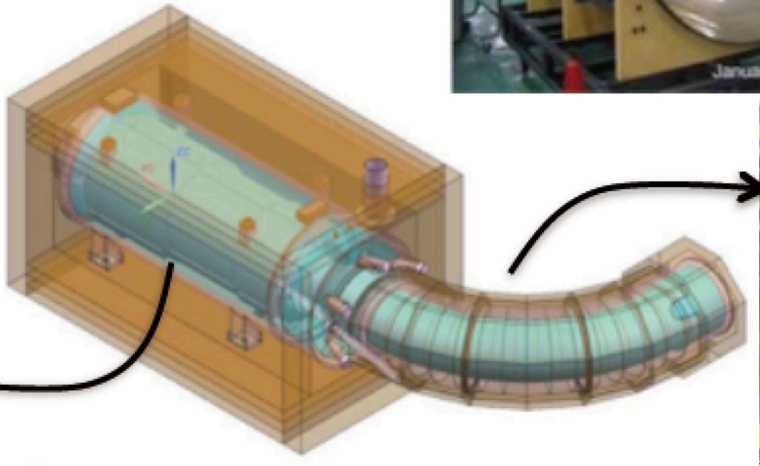
Branch for COMET and high-p is realized by normal dipole magnets.
(No simultaneous operation of COMET and other hadron-hall experiments)

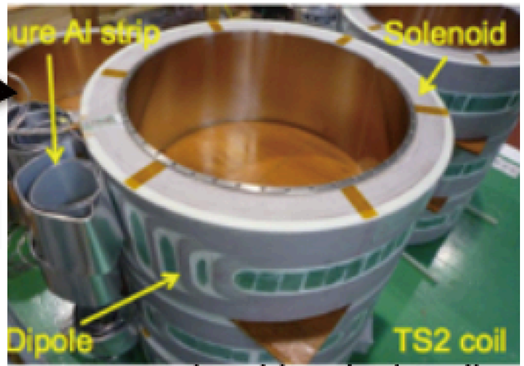
COMET Status

- Construction of Hadron South Exp. Building (completed in JFY 2014)
- Construction of new primary beam line
  - Strong support by the hadron beam line group
- Construction of pion/muon capture (in progress) & transport solenoid magnets (completed in JFY2014)
  - High field / high radiation tolerance
- Development and construction of detectors, Radiation tolerance test of detector components (in progress)
- Submission of Technical Design Report to J-PARC PAC (in Oct. 2014)



Capture Solenoid Coil Winding

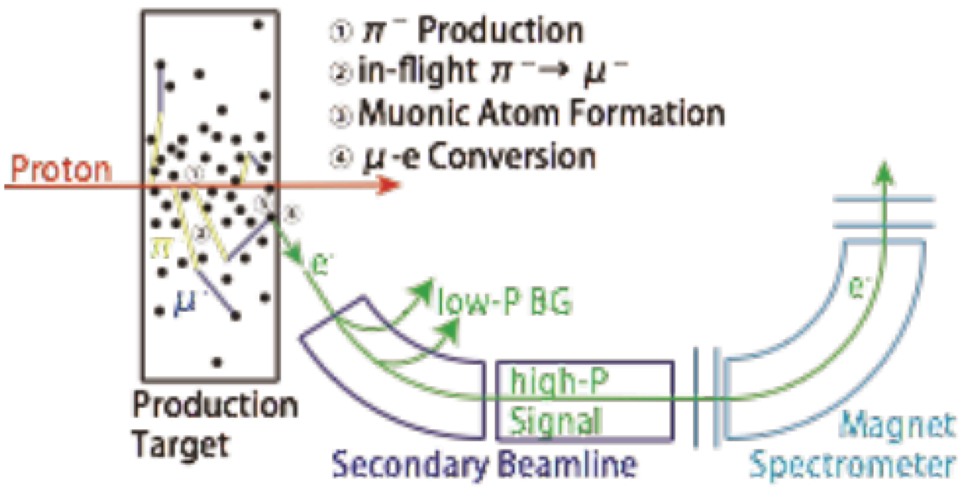




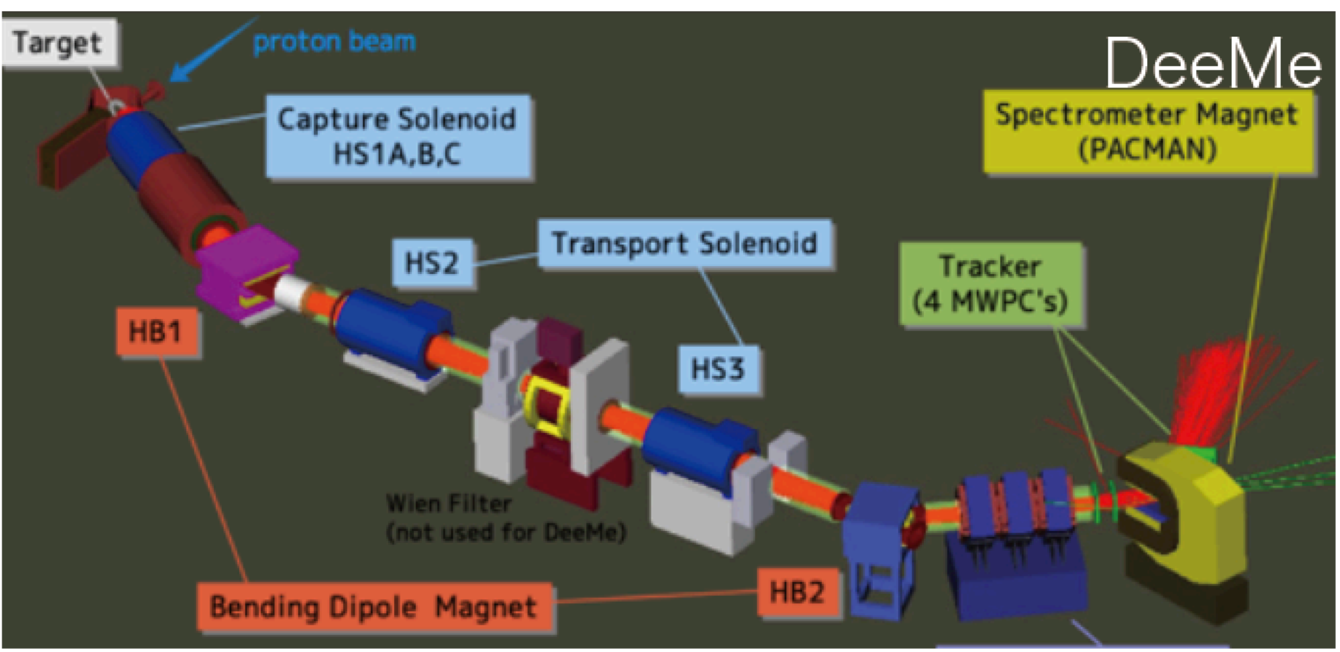
Transport solenoid + Dipole coils

COMET is moving forward!

DeeMe: Search for μ-e Conversion



- **IMSS/Muon PAC: Stage-2 Approved**
- **J-PARC/RCS**: High-Power High-Purity Pulsed Proton Beam.
- **Production Target as μ-stopping target**.
- **H-Line/MLF**: Large-Acceptance Beam line.
- **State-of-the-Art MWPC** Technology
- **S.E.S. — BR~5 x 10^{-15}**
  (8 x 10^7 sec of data taking with SiC target)
- Start the physics run with graphite target
  - S.E.S. — 1 x 10^{-13} (2 x 10^7 sec)
- Aiming to start the engineering run in **2015**.



Magnet leased from TRIUMF is waiting for the installation at MLF

Muon Program

Muon g-2/EDM measurement

@ MLF H-line

Slide by T. Nomura

muon g-2/EDM measurements

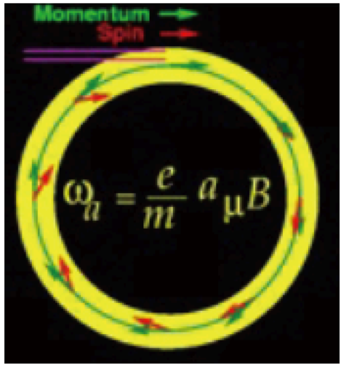
Anomalous magnetic moment (g-2)

$a_\mu = (g-2)/2 \quad = 11\,659\,208.9\,(6.3) \times 10^{-10}$ (BNL E821 exp) **0.5 ppm**

$11\,659\,182.8\,(4.9) \times 10^{-10}$ (standard model)

Δa_μ = Exp - SM = $26.1\,(8.0) \times 10^{-10}$ **3σ anomaly**

In uniform magnetic field, muon spin rotates ahead of momentum due to $g\text{-}2 \neq 0$



general form of spin precession vector:

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

BNL E821 approach
$\gamma=30$ ($P=3$ GeV/c)

J-PARC approach
$E = 0$ at any γ

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

Continuation at FNAL with 0.1ppm precision

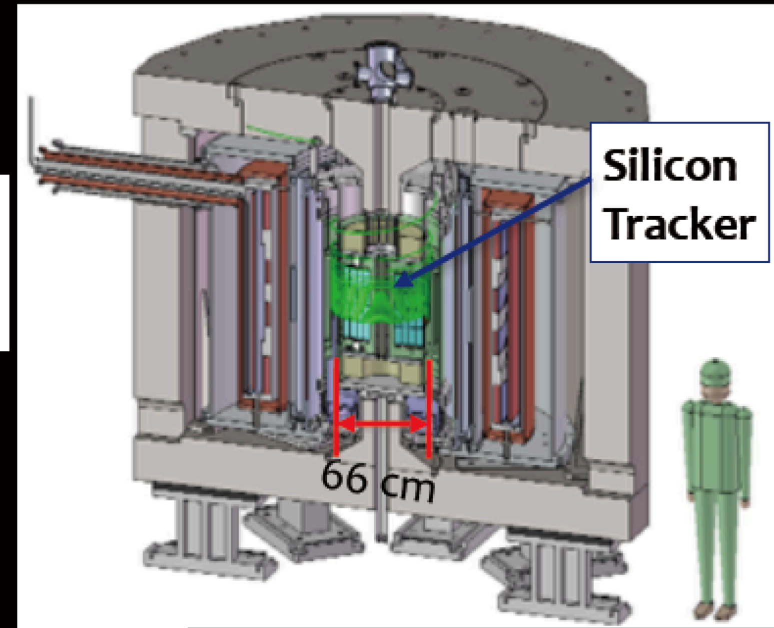
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta} \times \vec{B}\right)\right]$$

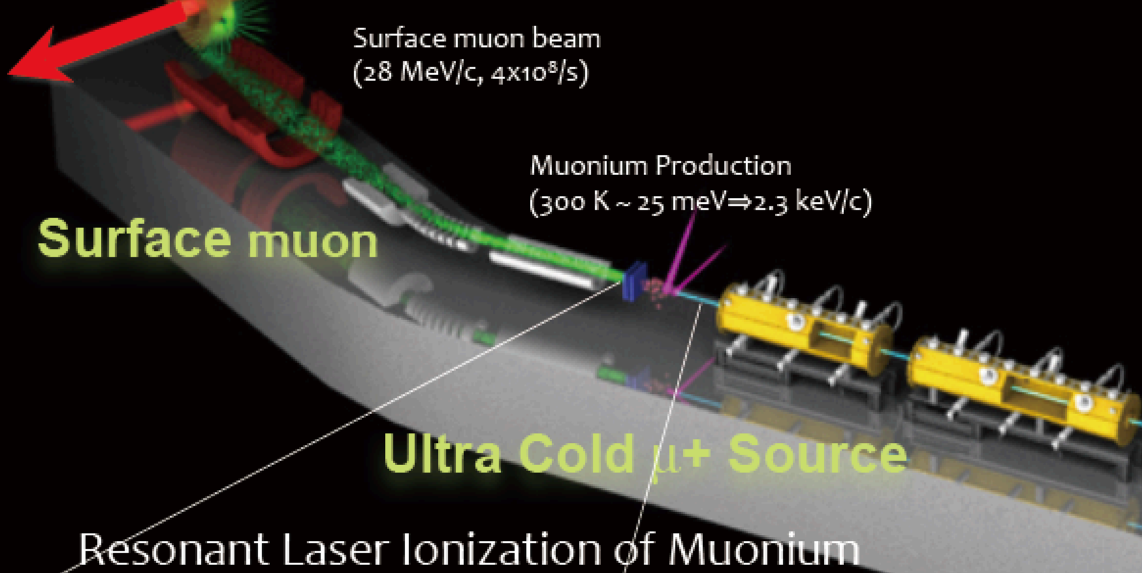
Proposed at J-PARC with 0.1ppm precision

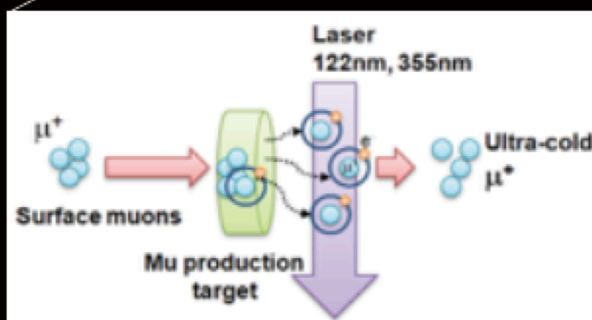
New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam

$\Delta(g\text{-}2) = 0.1\text{ppm}$

EDM ～ 10-21 e・cm





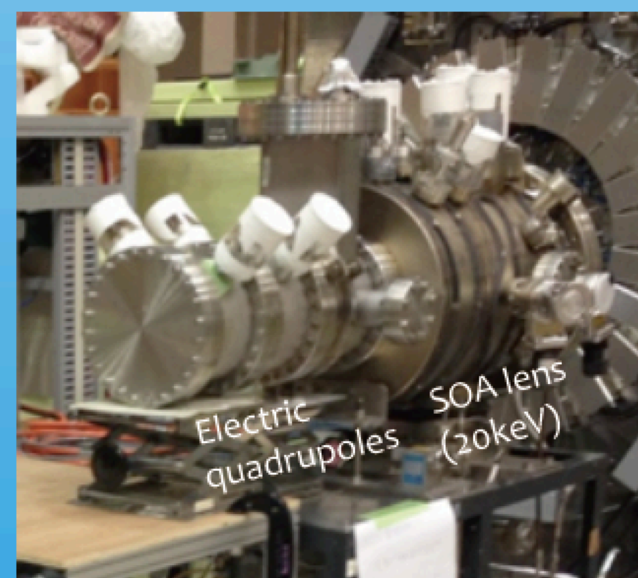


1. Ultra-cold μ^+ beam is injected to storage magnet.
2. Pulse kicker stops muons in storage area
3. Positron tracker measures e+ from $\mu^+ \rightarrow e^+\nu\nu$ decay for the period of 33μs（5 x lifetime）

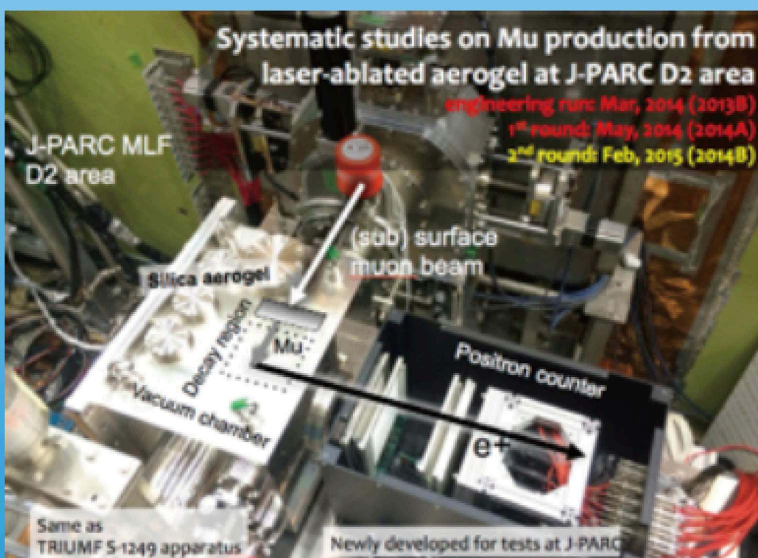
E34: R&D highlights

Muon acceleration test

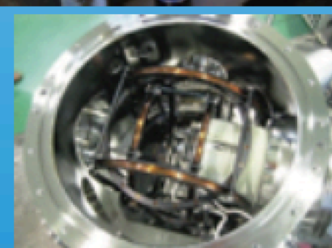
Beamline components were imported from RIKEN-RAL. Now being assembled at MLF.



Ultra-slow muon production



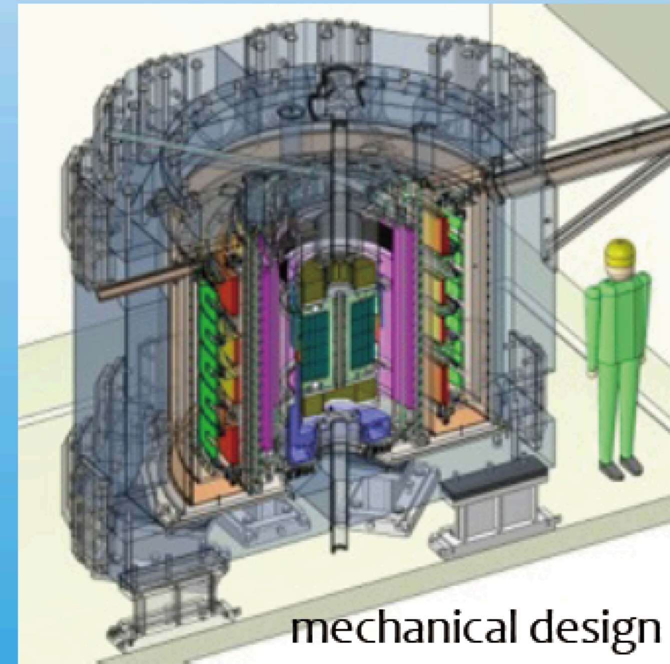
Optimization of Mu production target
(Feb. beam time was canceled)



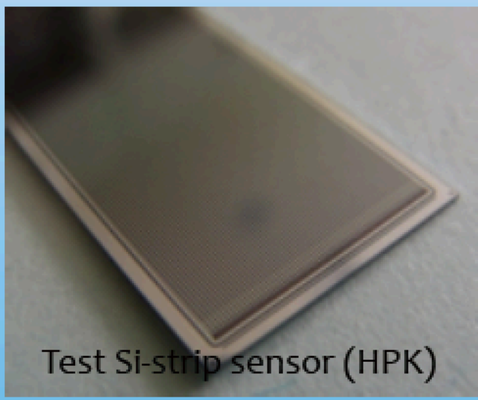
Laser-ionization chamber (RIKEN-RAL)

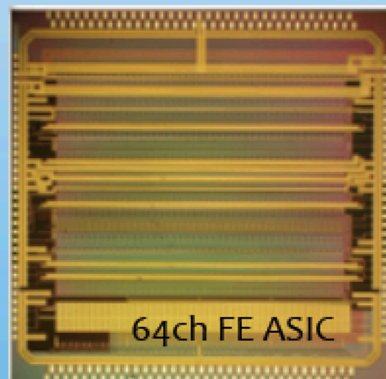
E34: R&D highlights

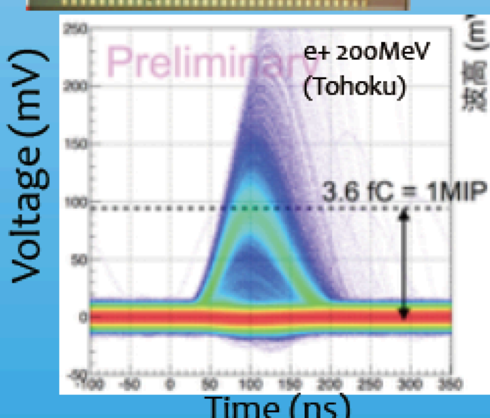
Muon storage magnet



Positron tracking detector

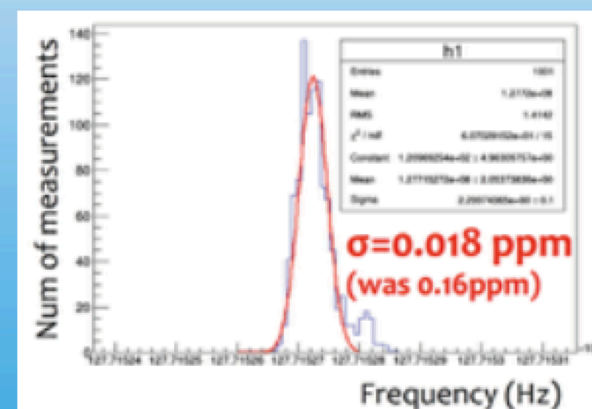






A Silicon-strip sensor and ASIC prototype was assembled and evaluated with with e+ (Tohoku) and μ+→e+ (J-PARC). S/N > 15.

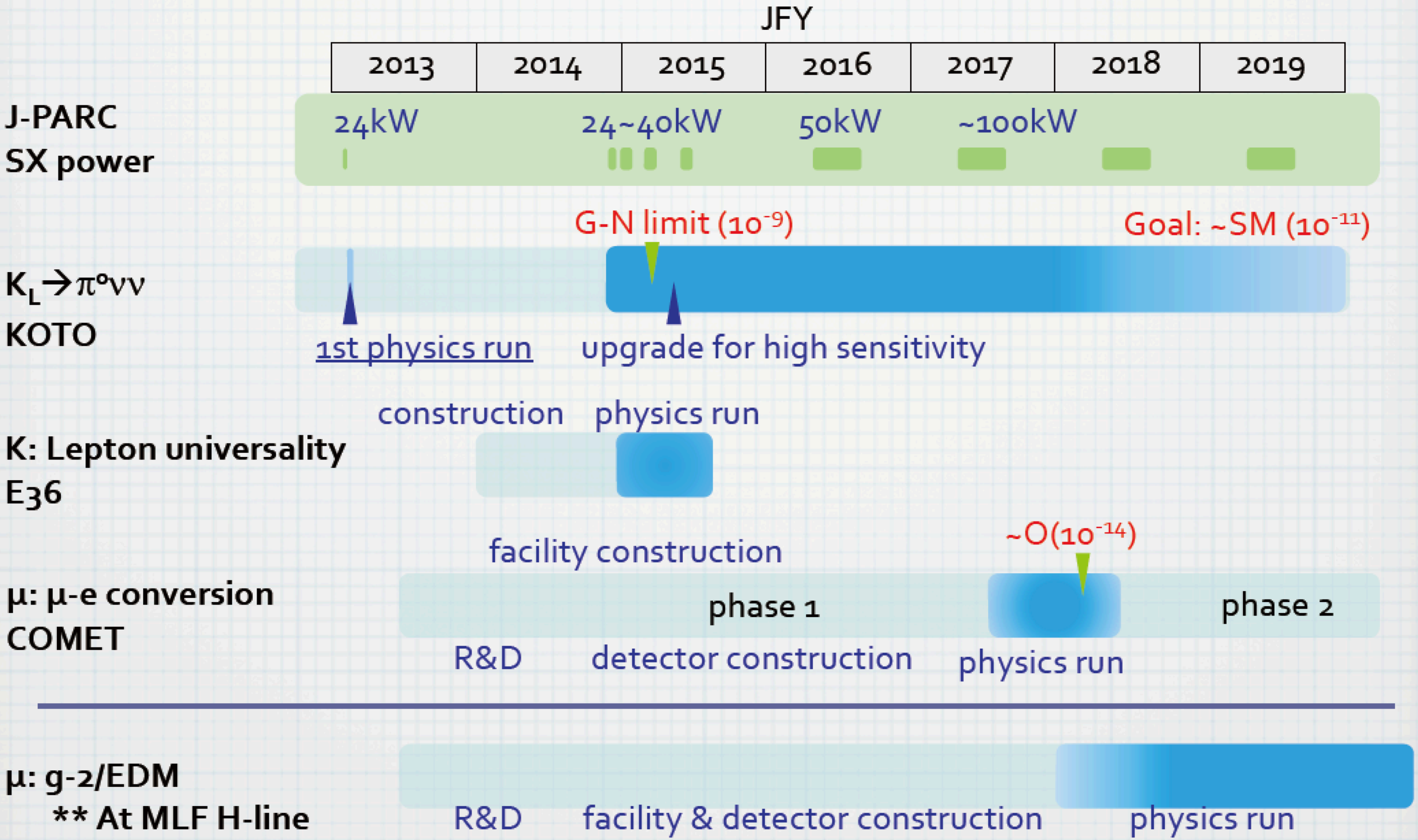
Precision B-field measurement



Signal spectrum under 3T MRI

TDR in preparation for stage-2

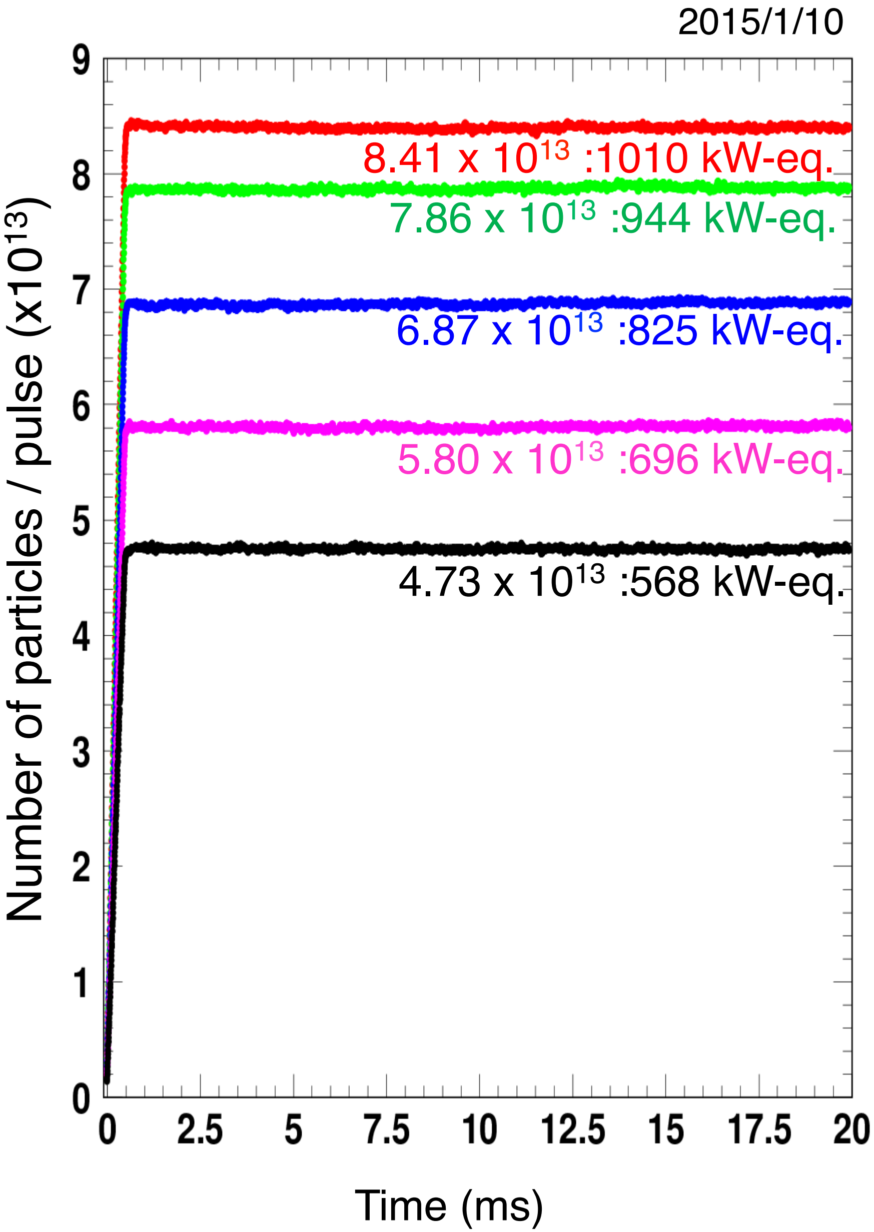
(Rough) scope in time domain



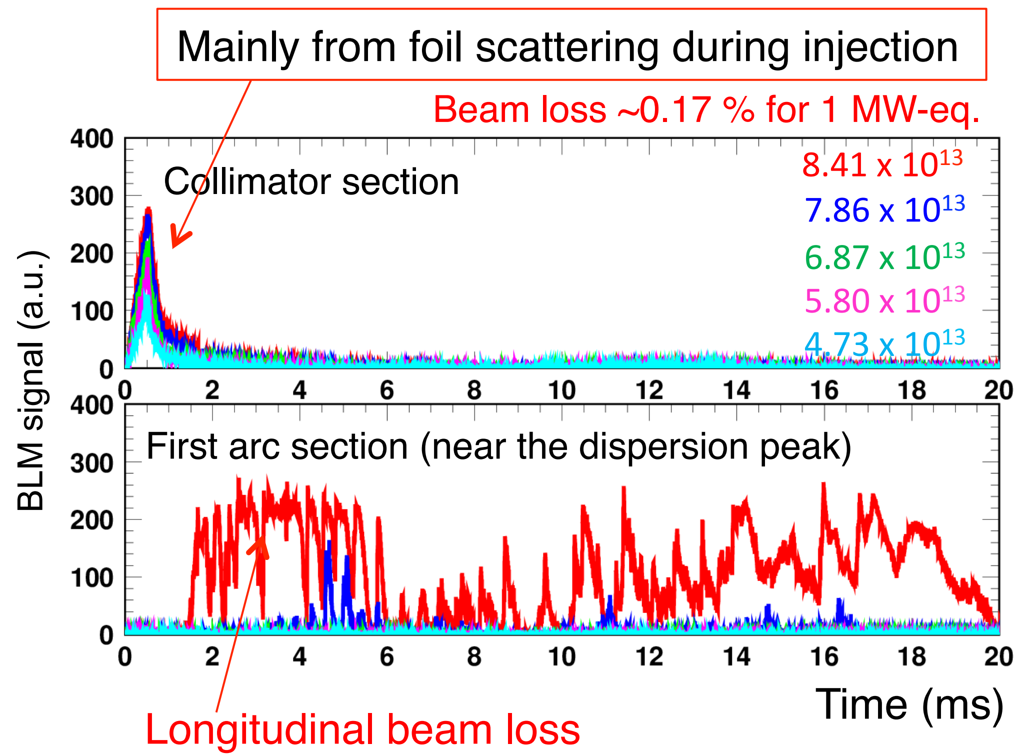
Slide by T. Nomura

Accelerator Improvements at J-PARC

Demonstration of 1 MW-eq. beam@RCS



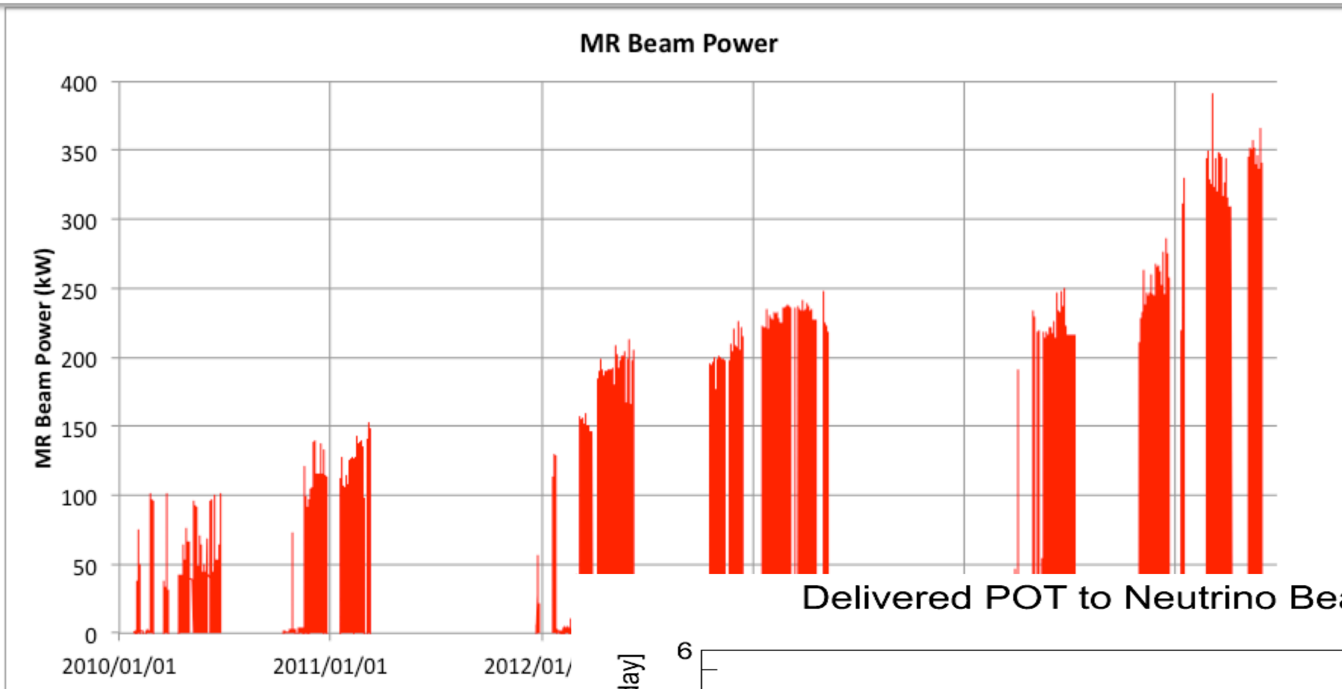
BLM signals @ collimator & arc sections



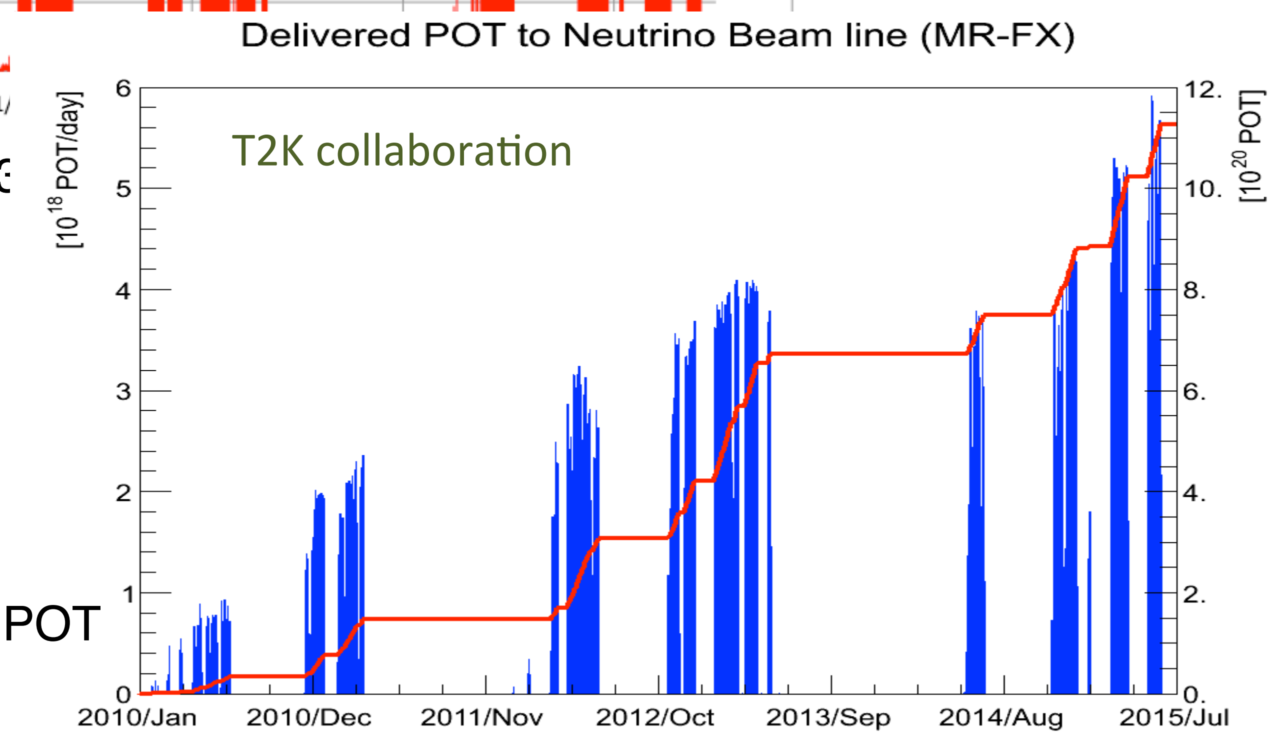
The anode power supplies of the rf power amplifiers were reinforced in the 2015 summer shutdown periods.

→ On Oct. 12, 2015, stable beam acceleration of 1 MW-eq beam was confirmed without the longitudinal losses.

History of MR beam power



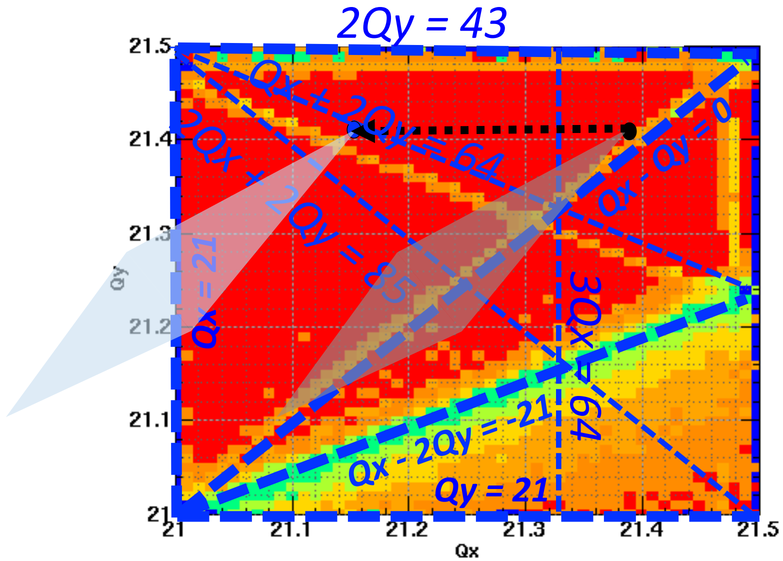
Delivered beam power is 3

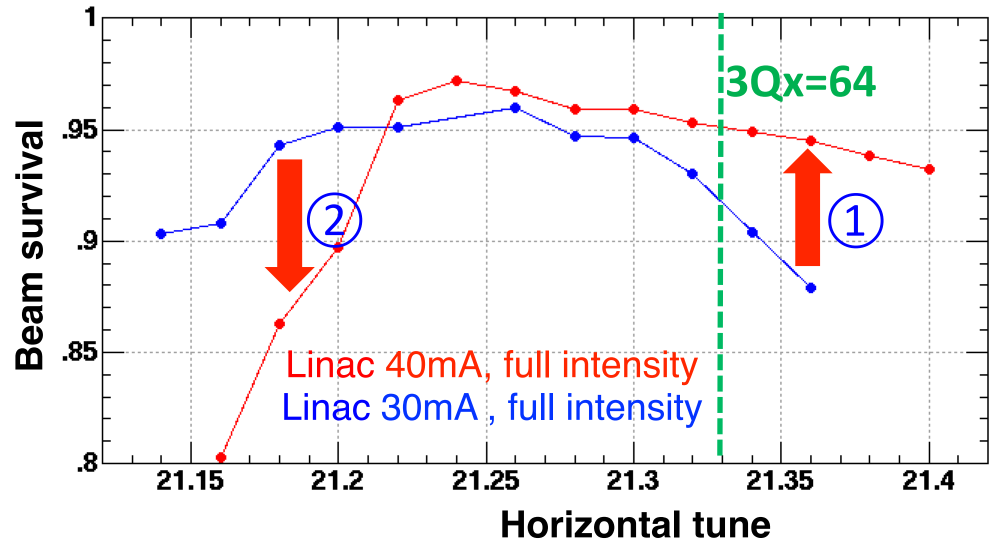


Total number is > 1.1×10^{21} POT as of June 3.

High Intensity beam study at MR

Horizontal tune survey at 3 GeV

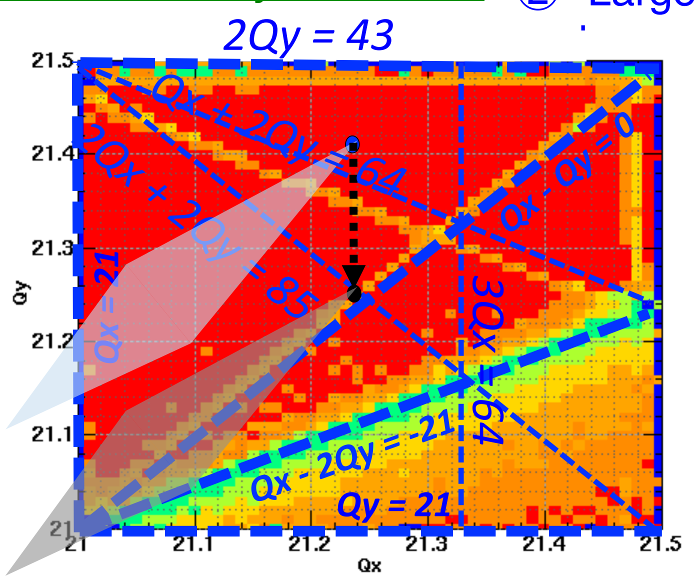


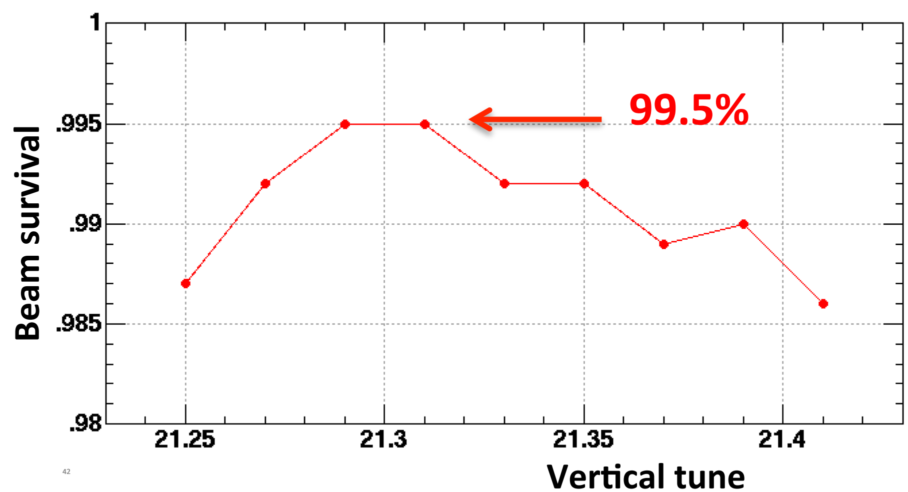


① 3[rd] Integer resonance correction (3Qx=64) by Trim-Sext.

② Larger tune spread and crossing integer resonance (Qx=21)

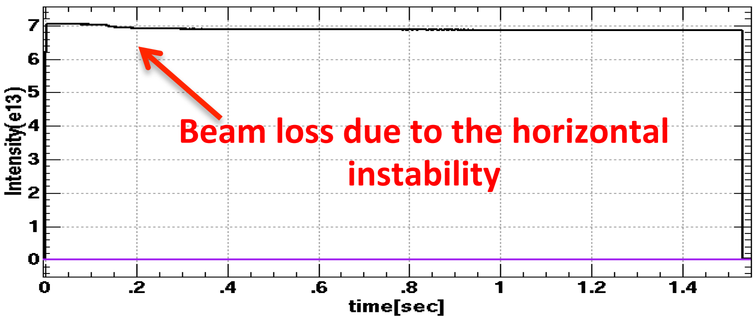
Vertical tune survey at 3 GeV





High Intensity beam study at MR (cont'd)

High power trial with two bunches



Extracted beam : 3.41e13 ppb
6.82e13 ppp (132 kW eq. ,2 bunches)

	Beam loss[Watt]	
INJ(K1+K2+K3+K4)	144	7.43e+11
P2 --> +90ms	241	1.00e+12
P2+90ms --> +120ms	31	1.30e+11
P2+100ms ---> EXT		1.83e+11

Total beam loss ~ 420 W

Near future tunable knobs to reduce the beam loss:
Injection kicker, BxB feed-back,
2nd harmonic cavity, VHF cavity, etc.

	Bunch number	repetition period (sec)	Beam power (kW)	Beam loss (kW)	Notes
1	2	2.48	132	0.42	measurement
2	8	2.48	529	1.7	estimation
3	8	1.3	1009	3.2	estimation

The MR has capability to reach 1MW with the high repetition rate operation.

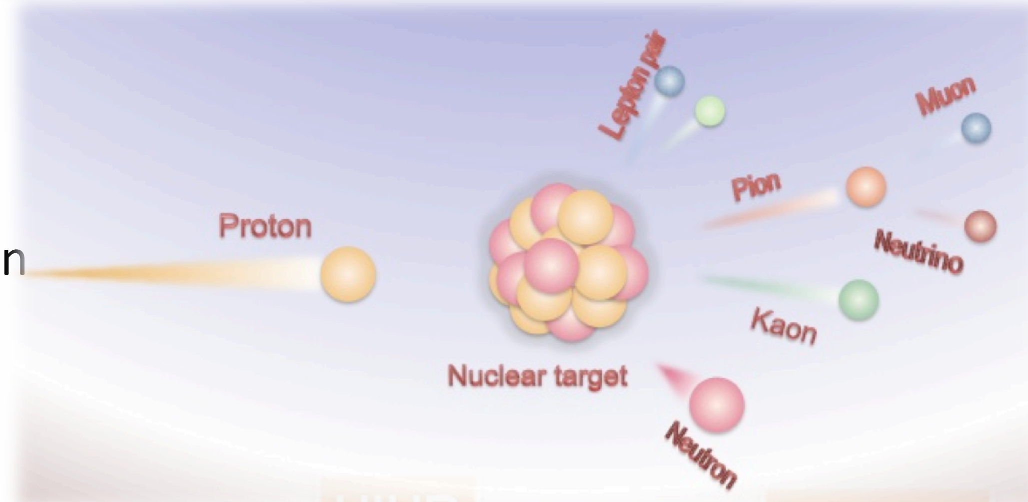
Future Plan at J-PARC

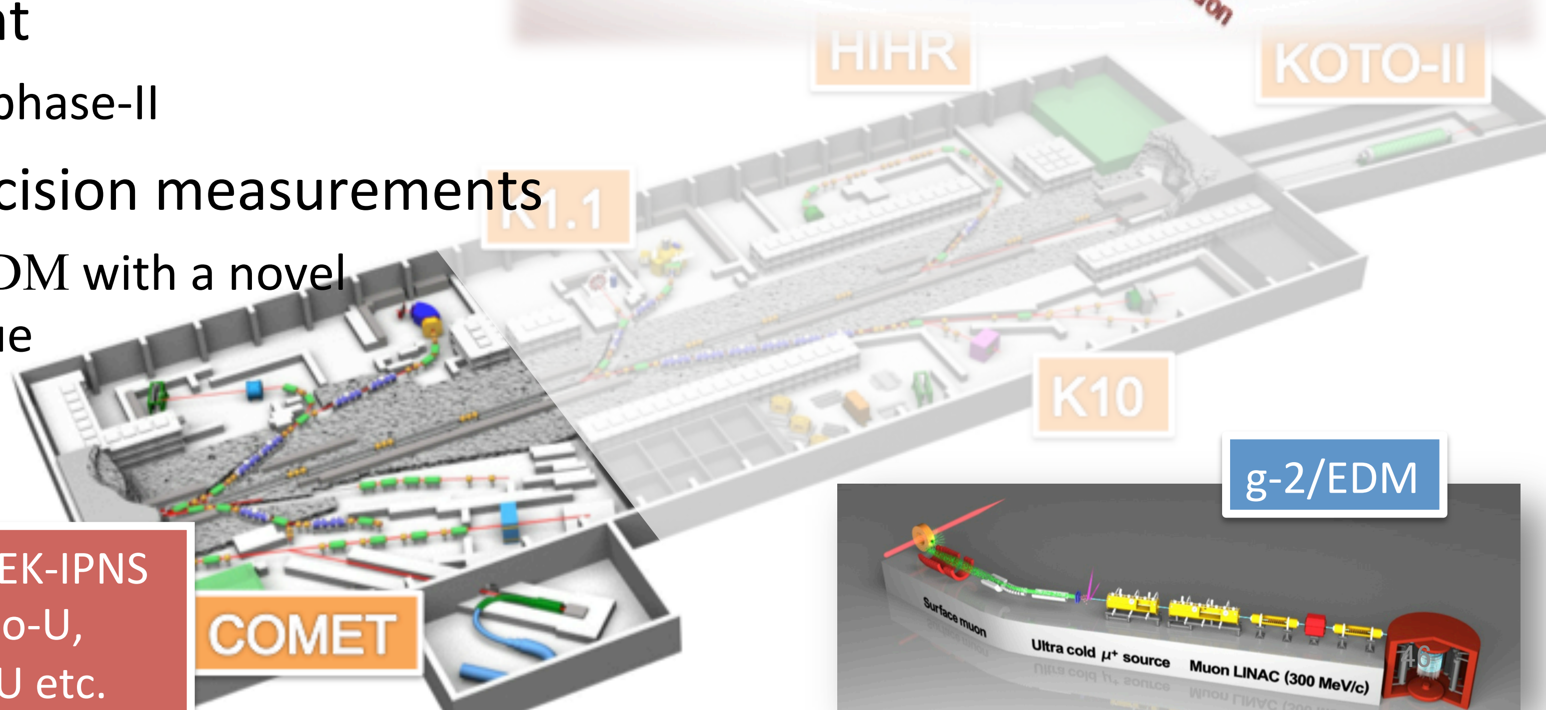
Master Plan of Science Council of Japan for "Large Scale Research Project"

- J-PARC upgrades and Hyper-K are selected as 27 important projects among 209 proposals under Japan Science Council !

Elucidation of Origin of Matter with J-PARC Upgrades

- Hadron Hall Extension
  - A Search for CPV beyond CKM with Kaon rare decay KOTO-II
  - Strangeness Nuclear and Hadron Physics
- Muon to electron conversion experiment
  - COMET phase-II
- Muon precision measurements
  - g_{μ}-2/μEDM with a novel technique



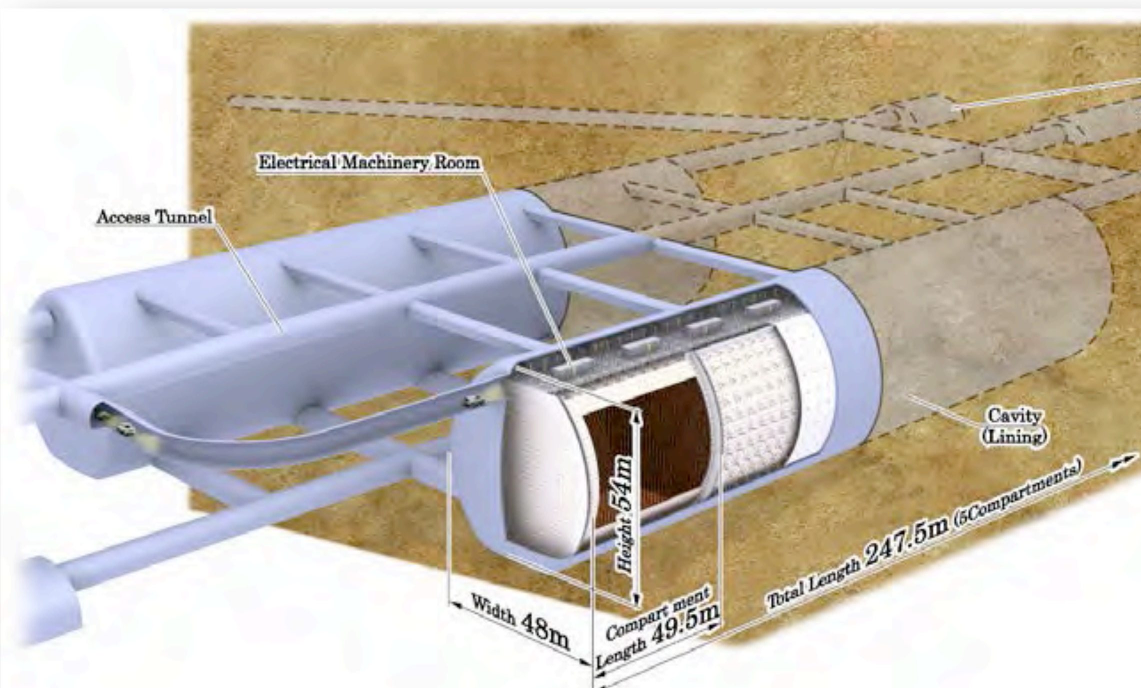


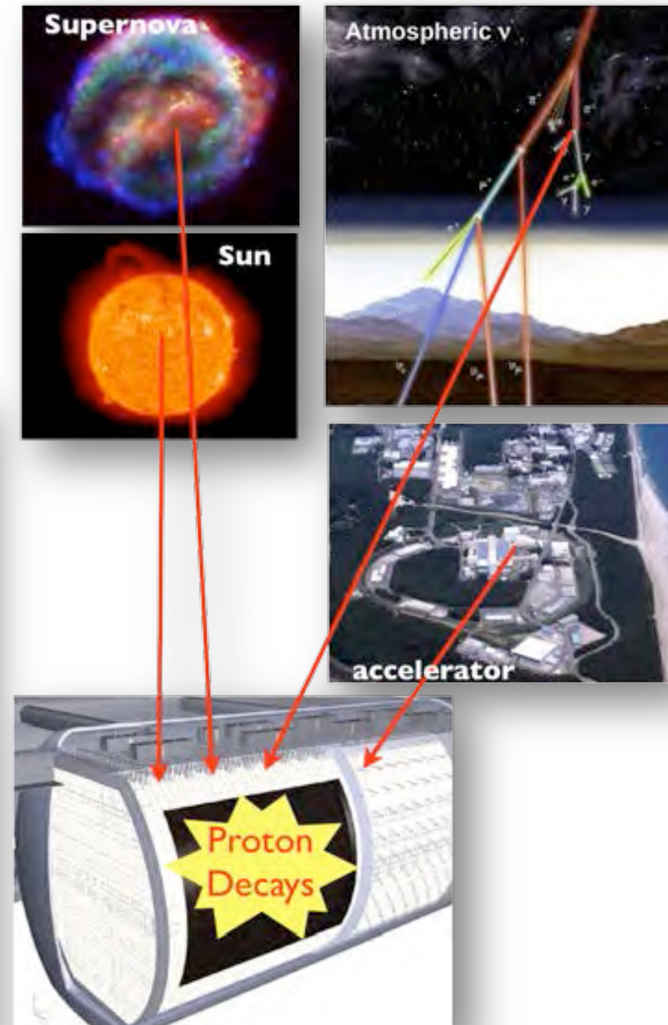
Collaboration of KEK-IPNS and U.Tokyo, Kyoto-U, Tohoku-U, Osaka-U etc.

Nucleon decay and neutrino oscillation experiment with

A Large Advanced Detector

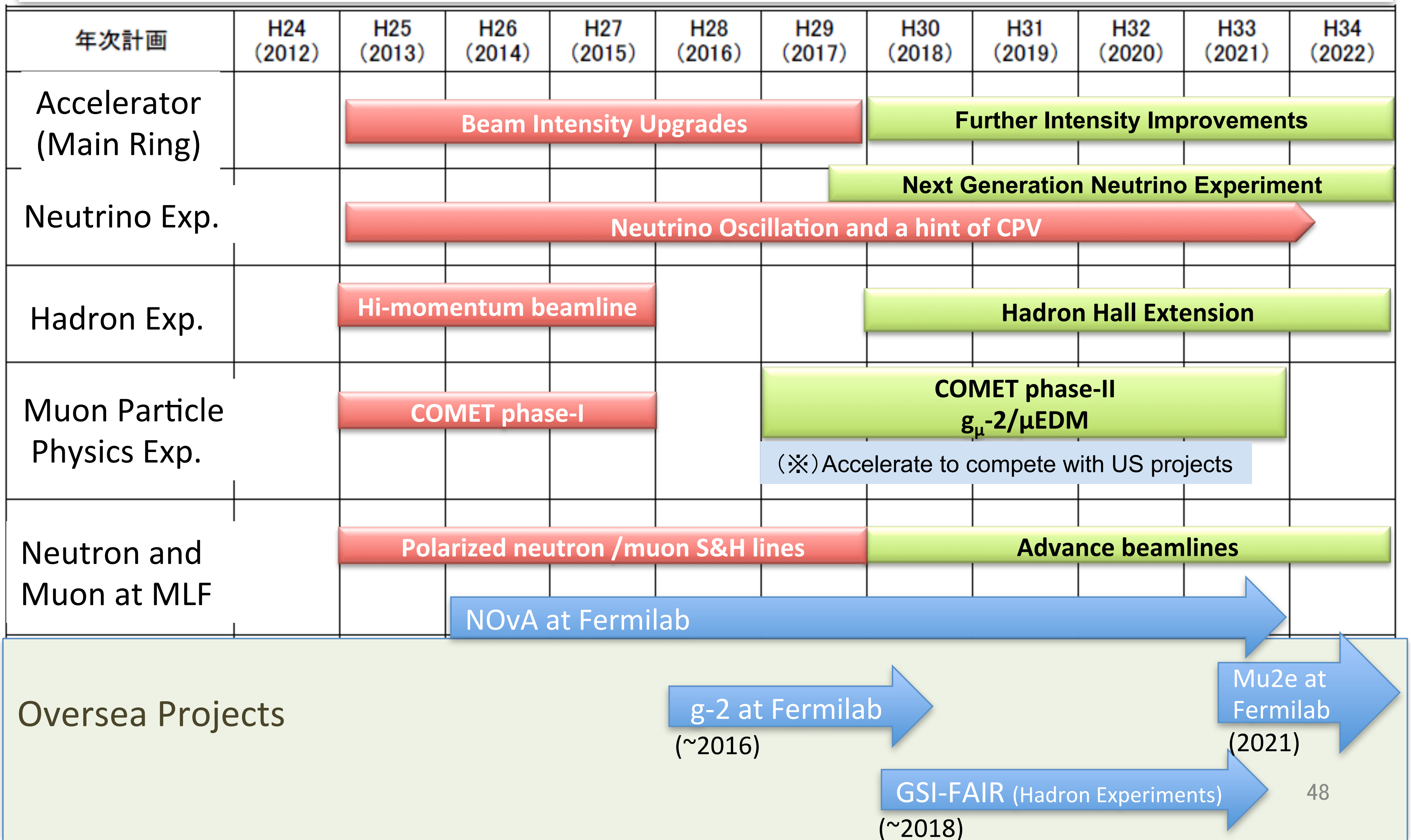
- 1 Mt class water-cherenkov detector, together with J-PARC High Intensity Proton Beam!





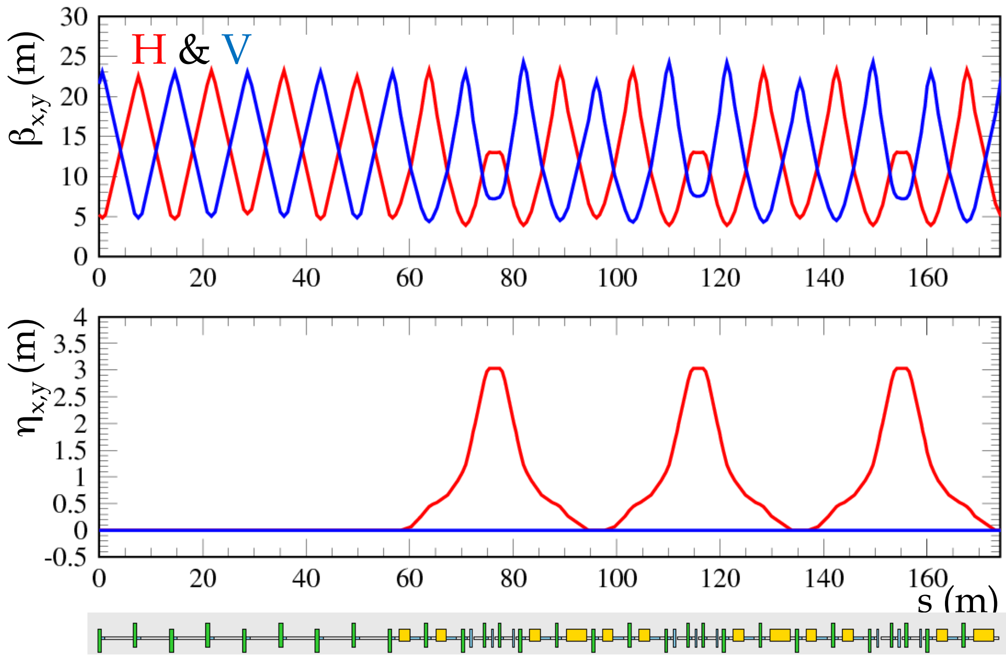
Elucidation of the origin of matter with an upgrade of J-PARC

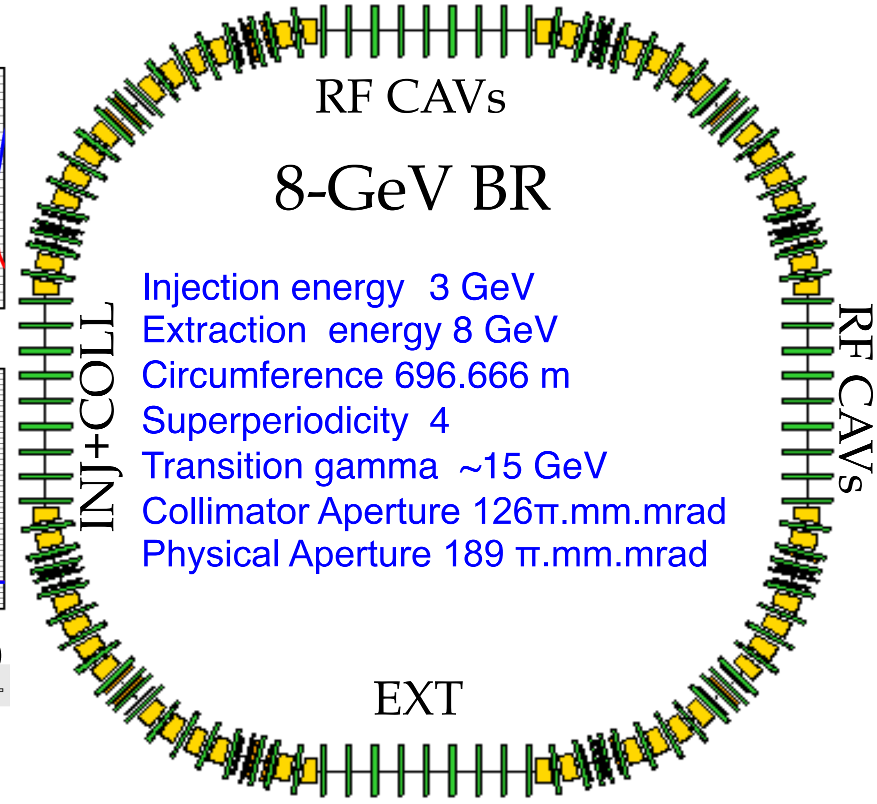
Intended Schedule (JFY2017-)



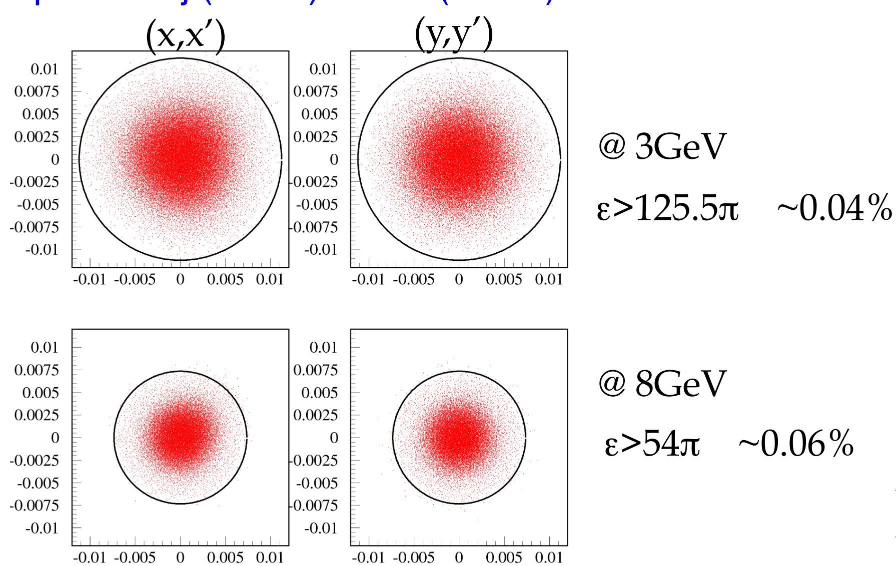
The 8-GeV booster ring

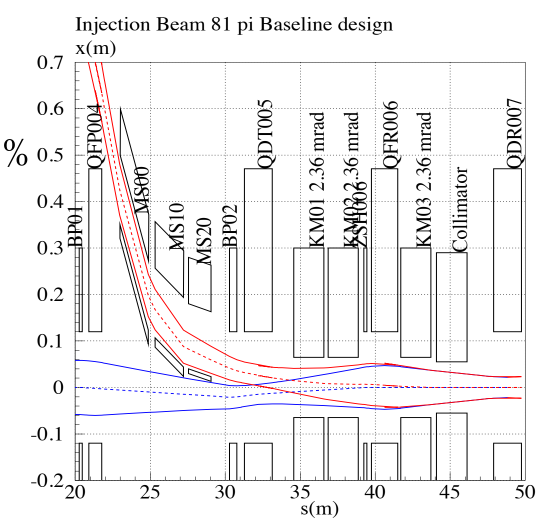
Beta & Dispersion for 1-superperiod





Phase plot @ inj.(3GeV) & extr.(8GeV)





8 GeV injection in the MR using new septa&kickers

RCS : 1.4 MW
MR > 2.2 MW

RCS : 2 MW
MR > 3.2 MW

The proton driver in the KEKB Tunnel

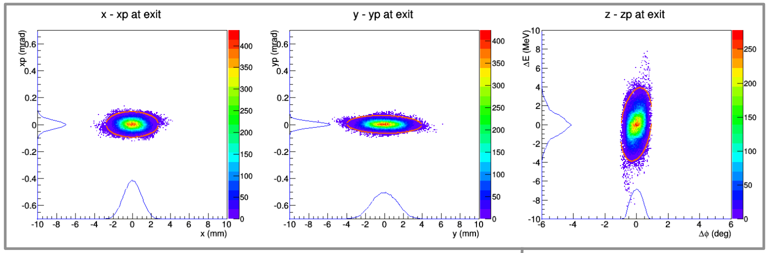
- Outline of acceleration :
  - 1.2 GeV in 1st straight.
  - 3.3 GeV in 2nd straight.
  - +2.9 GeV in 3rd and 4th straight.

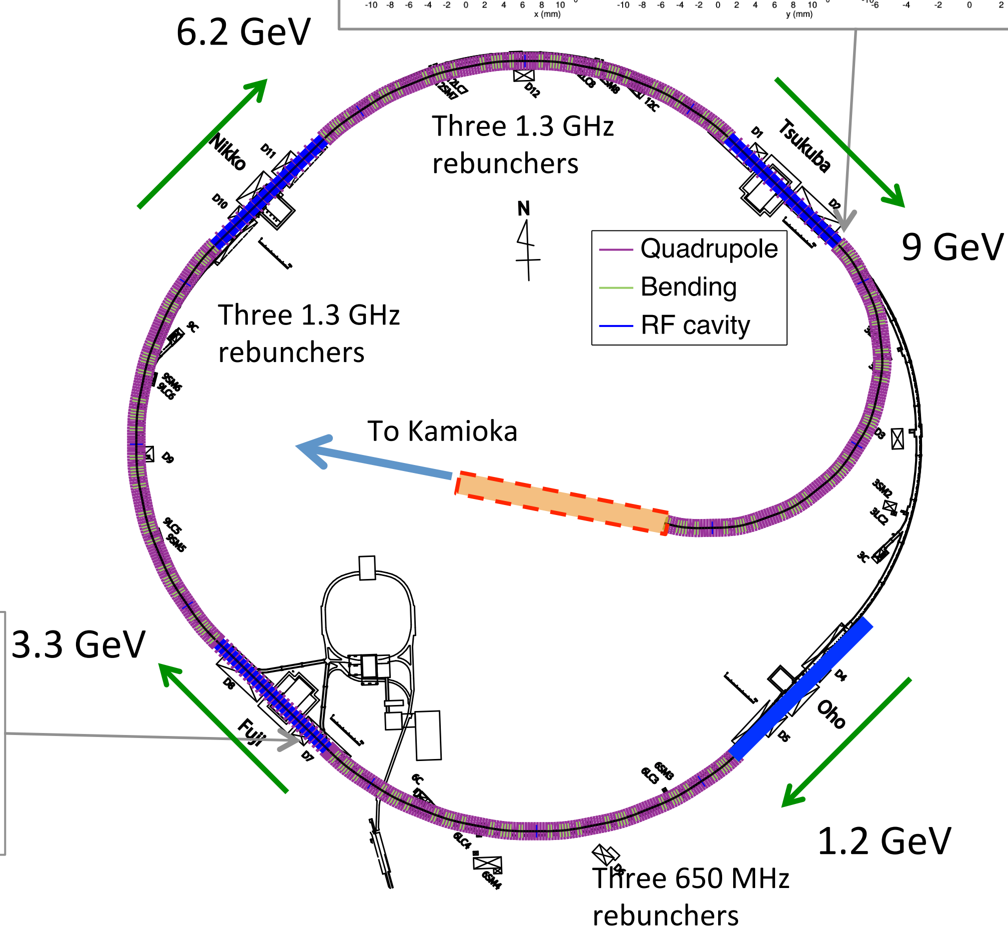
    3.3 + 2.9 x 2 = 9.0 GeV

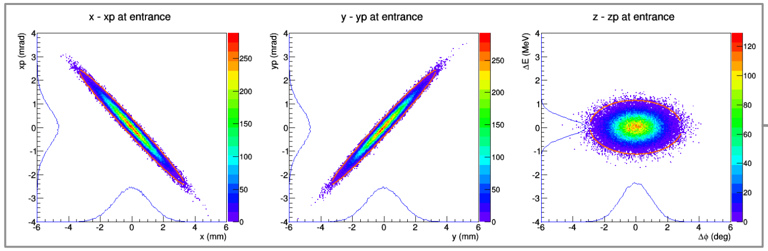
- Peak current : 100 mA (pulse)
- Beam duty : 1 %

- Beam power :

9000 MeV x 0.1 A x 1 % = **9 MW**







R&Ds are necessary : Higher gradient SC cavities, High power target, Horn…

- Muon particle physics with high intensity beam

J-PARC: Next 5 Years

- Achieve Design Intensity
- More Science Outputs
- Explore Intensity Frontier

Accelerator

- RCS:1 MW achieved
- MR 0.75 MW → 1.3 MW
- Explore Multi-MW Possibility

Neutrino

- Established non-zero θ_{13}
- Constrain CPV. Hierachy?
- Prepare next gen. of Exp.

ADS (Acc. Driven System)

Staged R&D approach from ADS Target Test Facility to Transmutation Exp. Facility

Hadron

- Restarted Physics Production
: Hyper-nucl/hadron physics, K-rare decays
- Complete new beam line for COMET/Hi-p BL and 1st results

MLF

Stability and Intensity

- Neutron : Diverse Material and Life Science
- Muon : Produce outputs from D and U lines / New beam lines to extend Muon Science Frontier (g-2/EDM/HFS/DeeMe)

Summary

- J-PARC is a multi-purpose facility with the high-intensity proton driver
  - Particle and Nuclear physics
  - Material and Life Science
  - R&D for nuclear transmutation
- High power scenario is refined based on REAL DATA : MR 0.75 MW → 1.3 MW
- Multi-MW proposals are being developed
- We invite YOUNG scientists to share more excitements!

Including Young at Heart!