HEPAP Accelerator R&D sub-panel meeting at BNL
Aug. 26, 2014

# The intensity frontier at KEK and J-PARC

## - Status, future plans and related R&D's -

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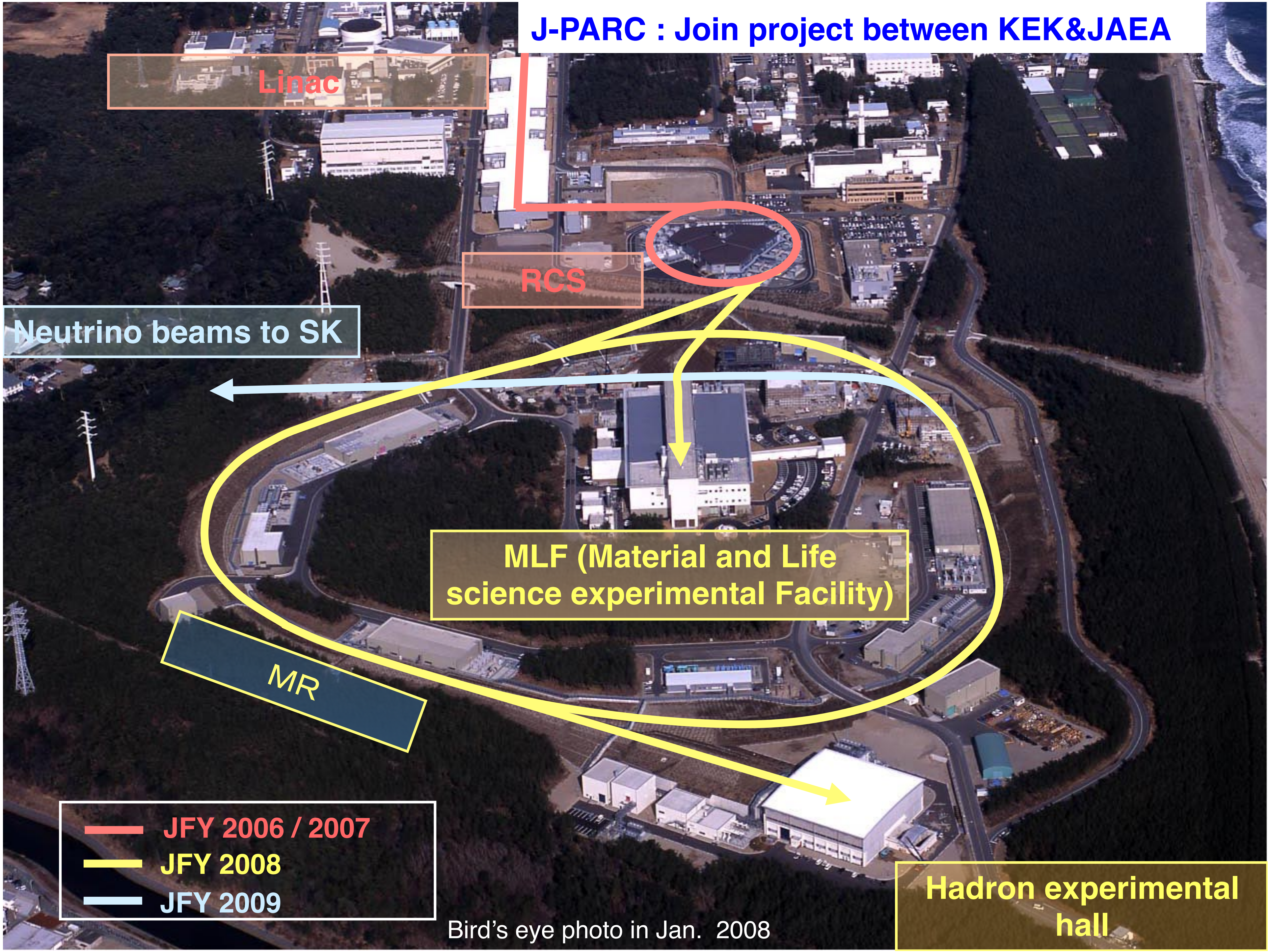
# Contents

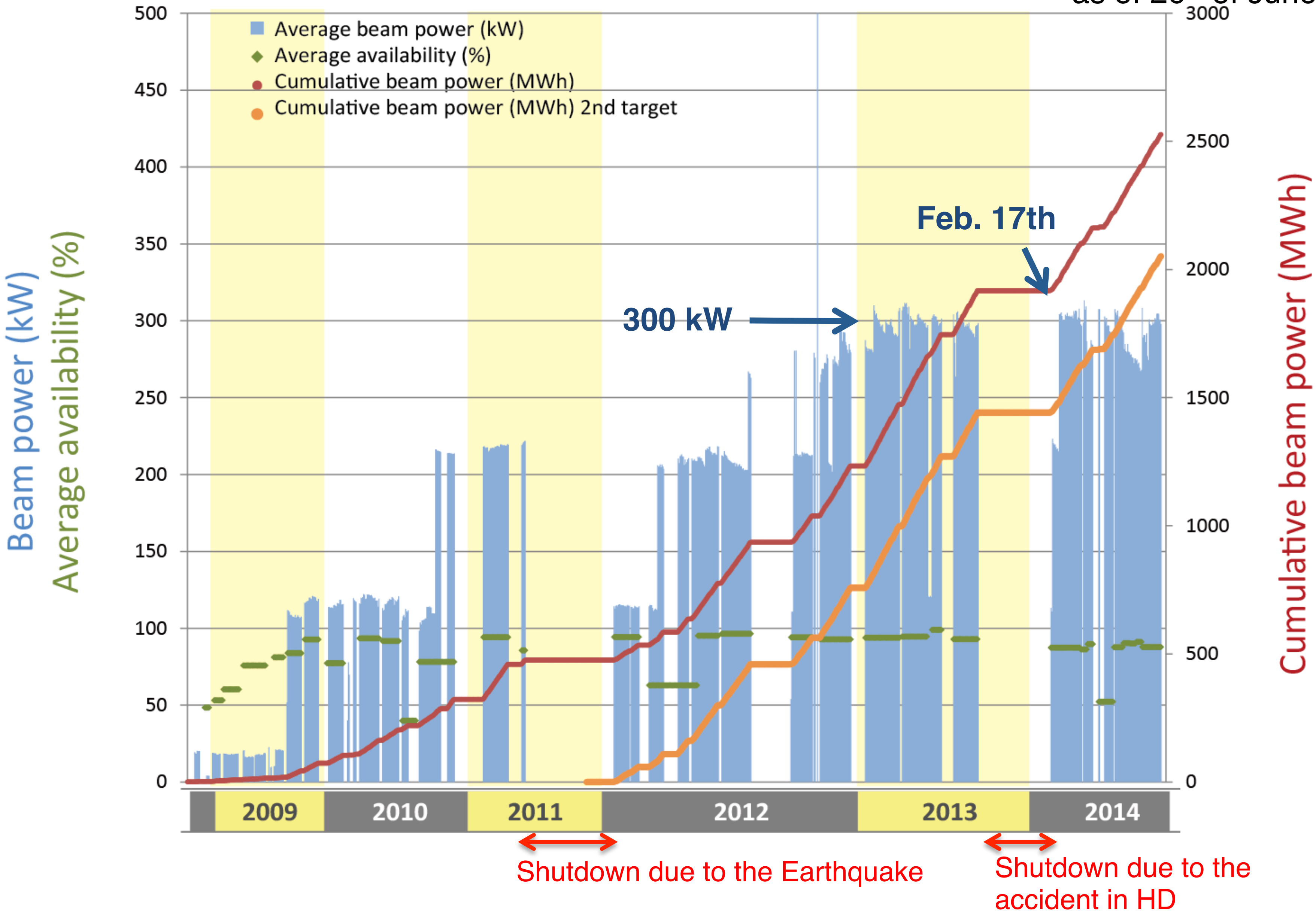
# J-PARC


J-PARC : Join project between KEK&JAEA
Linac
RCS
Neutrino beams to SK
MLF (Material and Life science experimental Facility)
MR
JFY 2006 / 2007
JFY 2008
JFY 2009
Bird's eye photo in Jan.  2008
Hadron experimental hall

# Status of accelerator operation and achievements

# History of beam delivery to the MLF

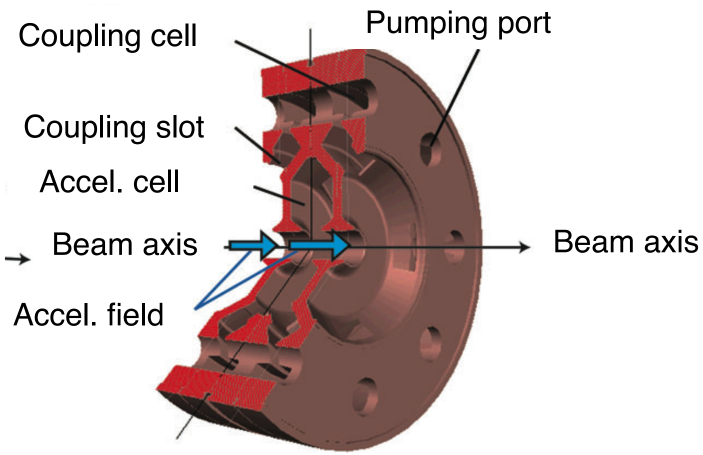
* as of 26th of June 2014



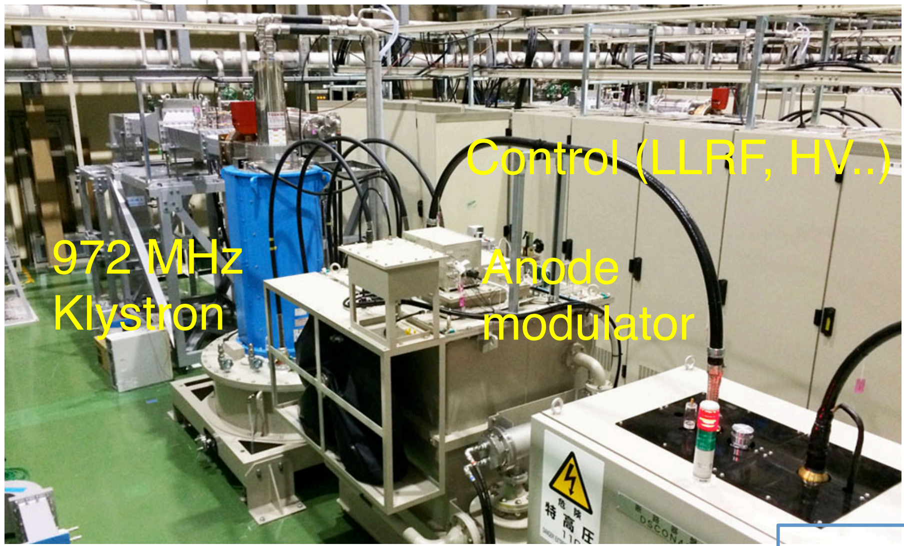

After the 9-month shutdown due to the accident in the HD hall, beam operation resumed in Feb. 2014.

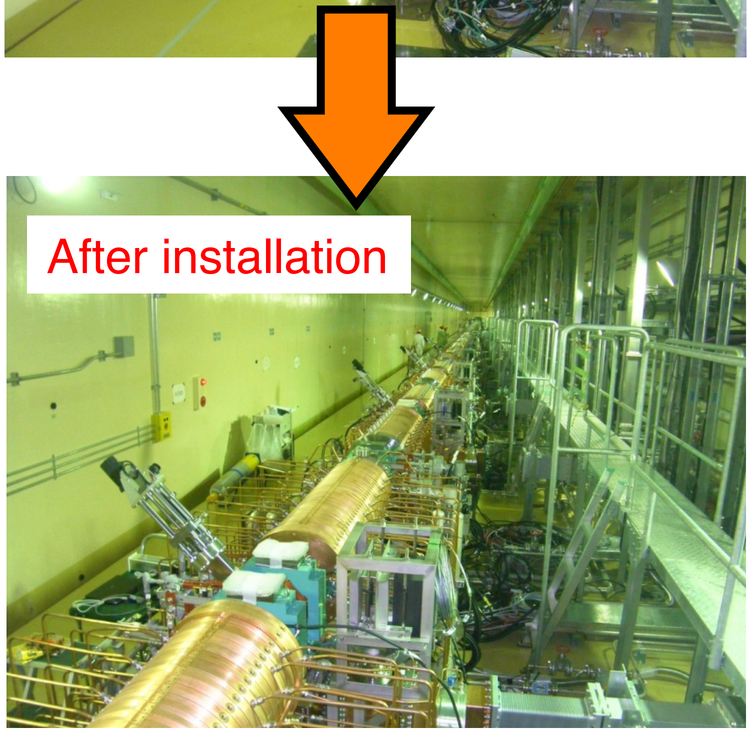
# Energy upgrade of linac : 181 to 400 MeV

The ACS (Annular-ring Coupled Structure linac) system
- Frequency : 972 MHz
 - 21 accelerating modules
 - 4 debuncher modeules





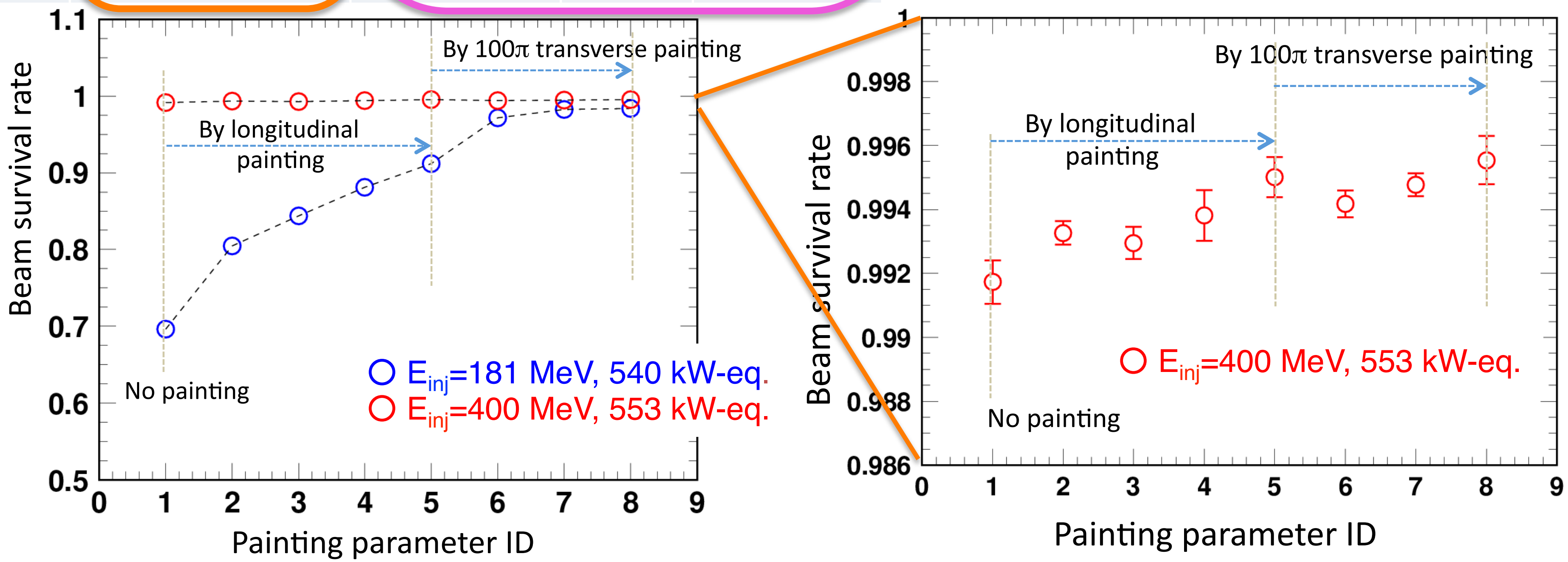



400-MeV acceleration was achieved on Jan. 17, 2014.

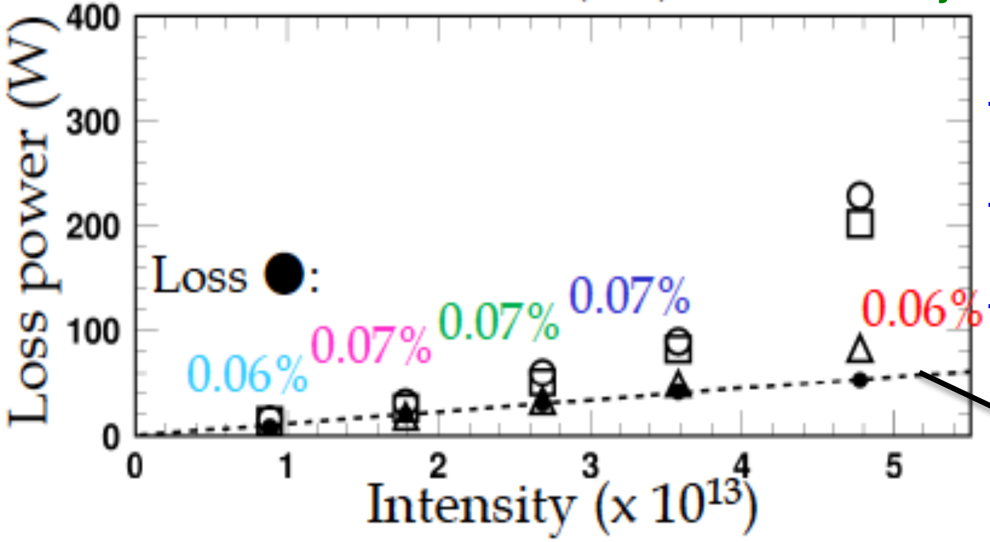
# Painting parameter dependence of beam loss

| ID | Trans.-paint ($\pi$ mm mrad) | RF $V_2/V_1$ (%) | $\phi_2$ (deg) | dp/p (%) |
|---|---|---|---|---|
| 1 | - | - | - | - |
| 2 | 100 | - | - | - |
| 3 | - | 80 | -100 | -0.0 |
| 4 | - | 80 | -100 | -0.1 |
| 5 | - | 80 | -100 | -0.2 |
| 6 | 100 | 80 | -100 | -0.0 |
| 7 | 100 | 80 | -100 | -0.1 |
| 8 | 100 | 80 | -100 | -0.2 |



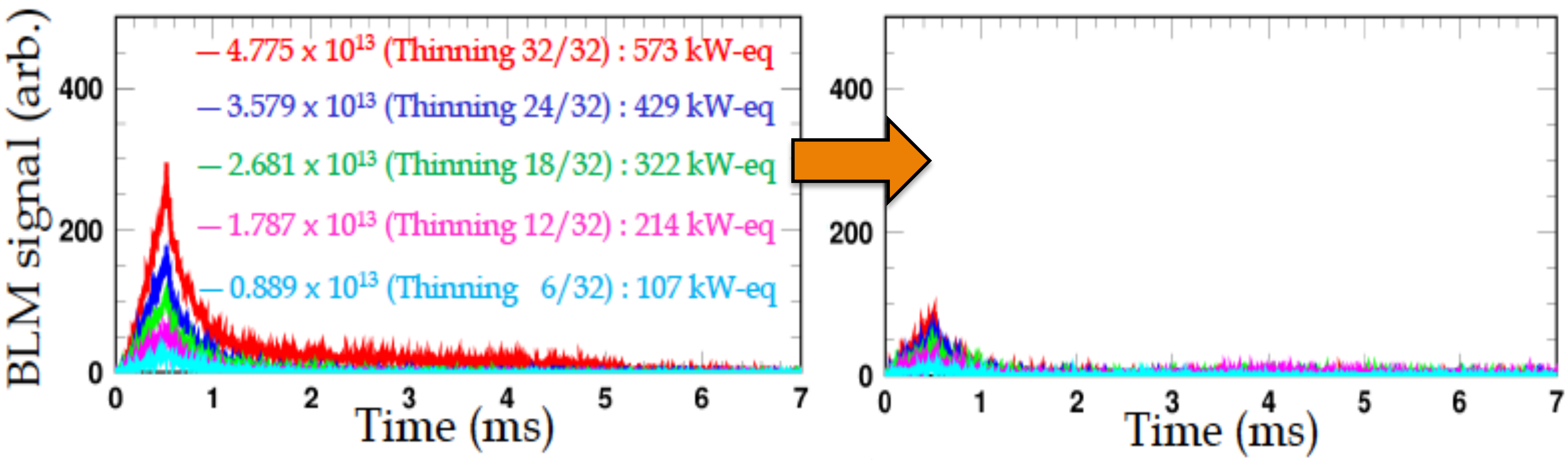
# Minimization of beam loss

Results of beam study in the end of June, 2014.




- Momemtum spread of the injection beam
  dp/p : 0.106 % → 0.066 % : ○→□
- Mismatch correction of the Twiss parameters of the injection beam :□→△
- Operating point
  (νx, νy)=(6.45,6.42) →(6.38, 6.42):△→●

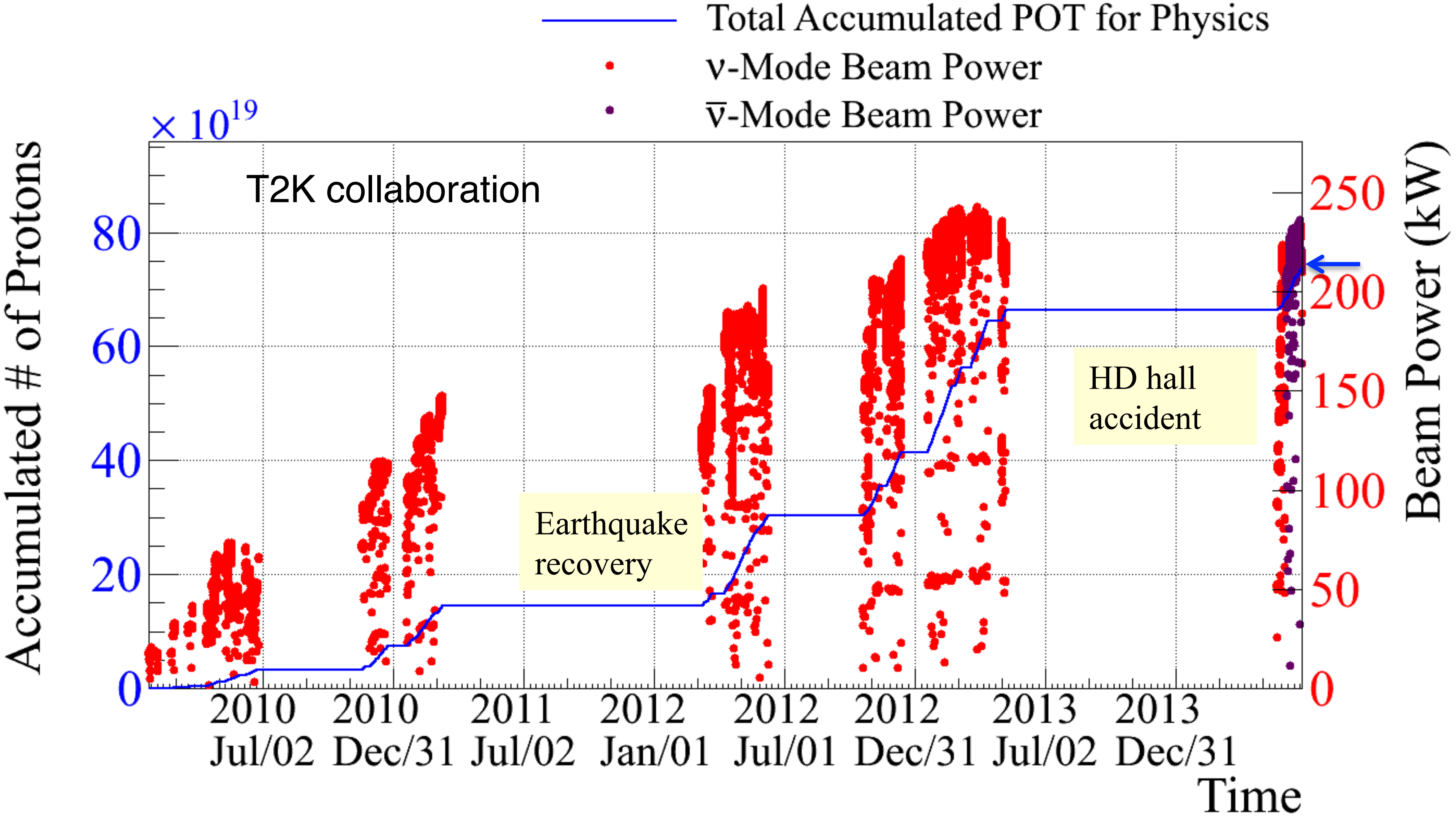
Beam loss due to the foil scattering




Beam loss of the RCS is well understood and minimized.

# Beam delivery to the T2K experiment

* as of 26th of June 2014



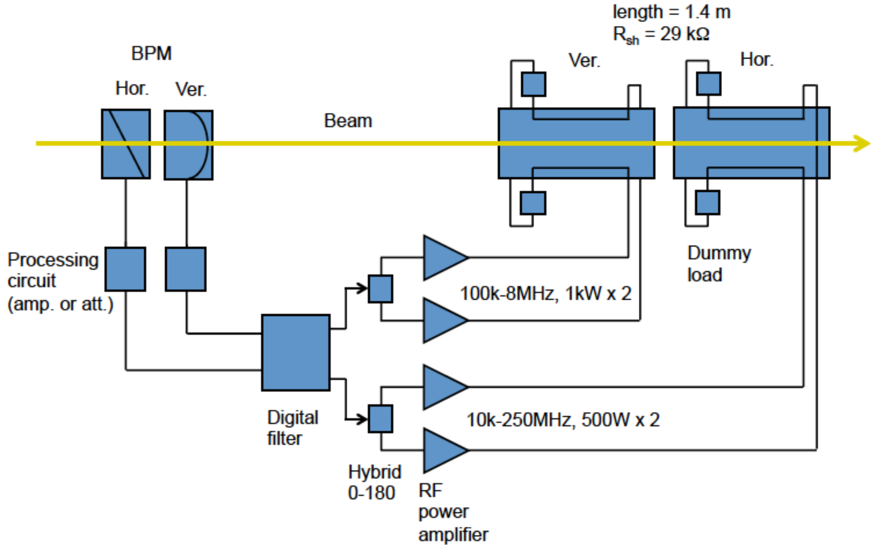

The max. delivered beam power ~ 240 kW ($1.24 \times 10^{14}$ ppp)

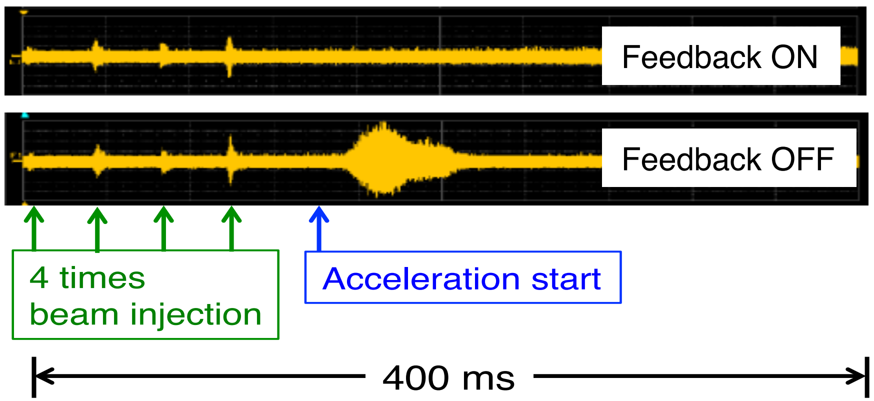
Accumulated number of proton ~$7.5 \times 10^{20}$ POT.

# Feedback system for suppression of beam instability

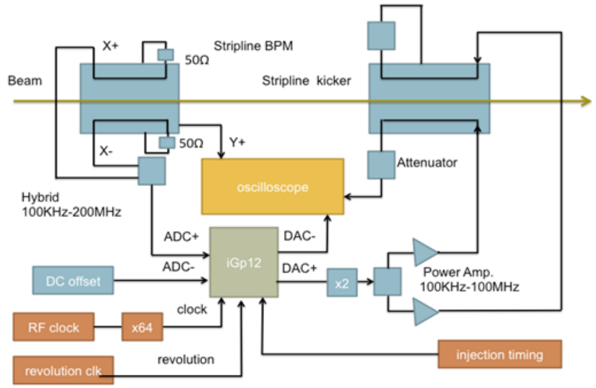
Transverse instabilities are observed at the injection and the beginning of acceleration at the MR.
The instabilities are suppressed by the bunch feedback systems.

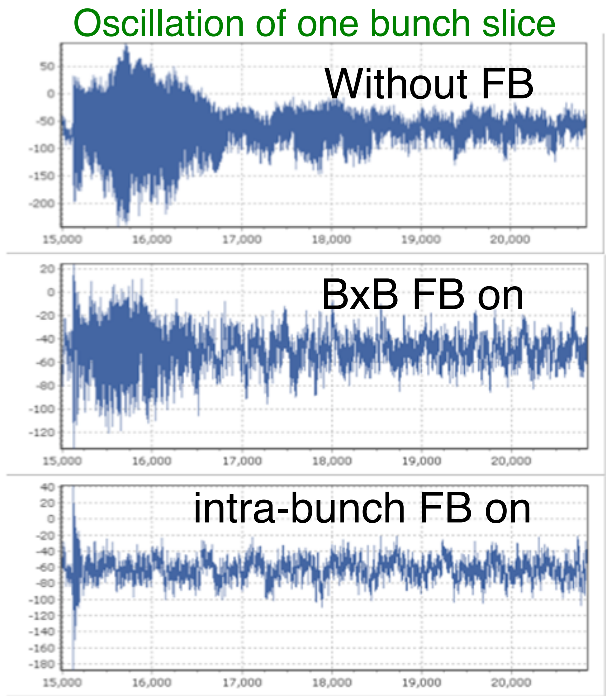
## BxB FB (narrow-band FB) since 2012

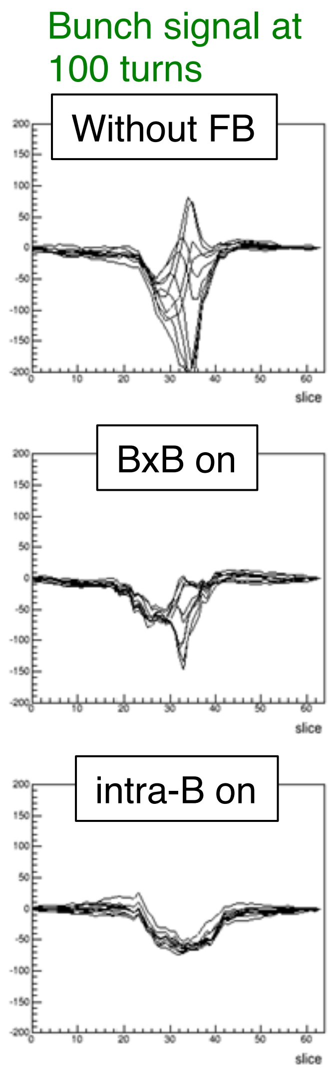



## Intra-bunch FB (wide-band FB) since 2014



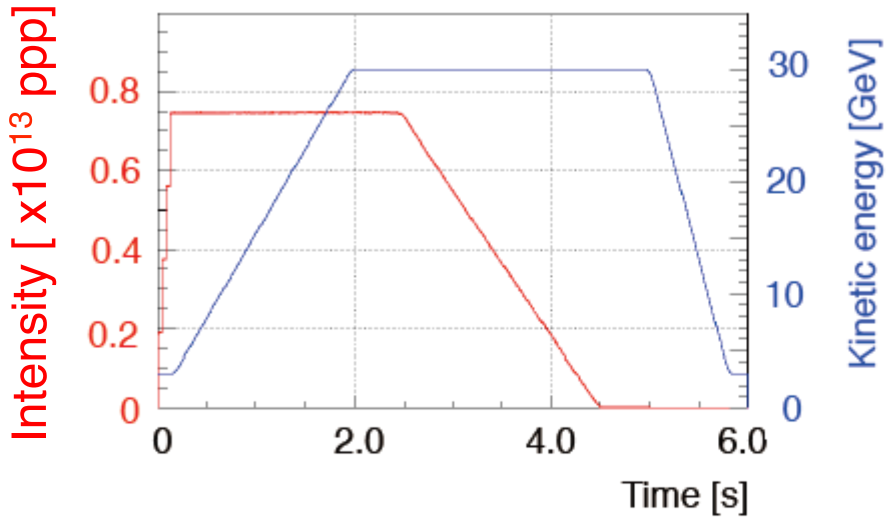



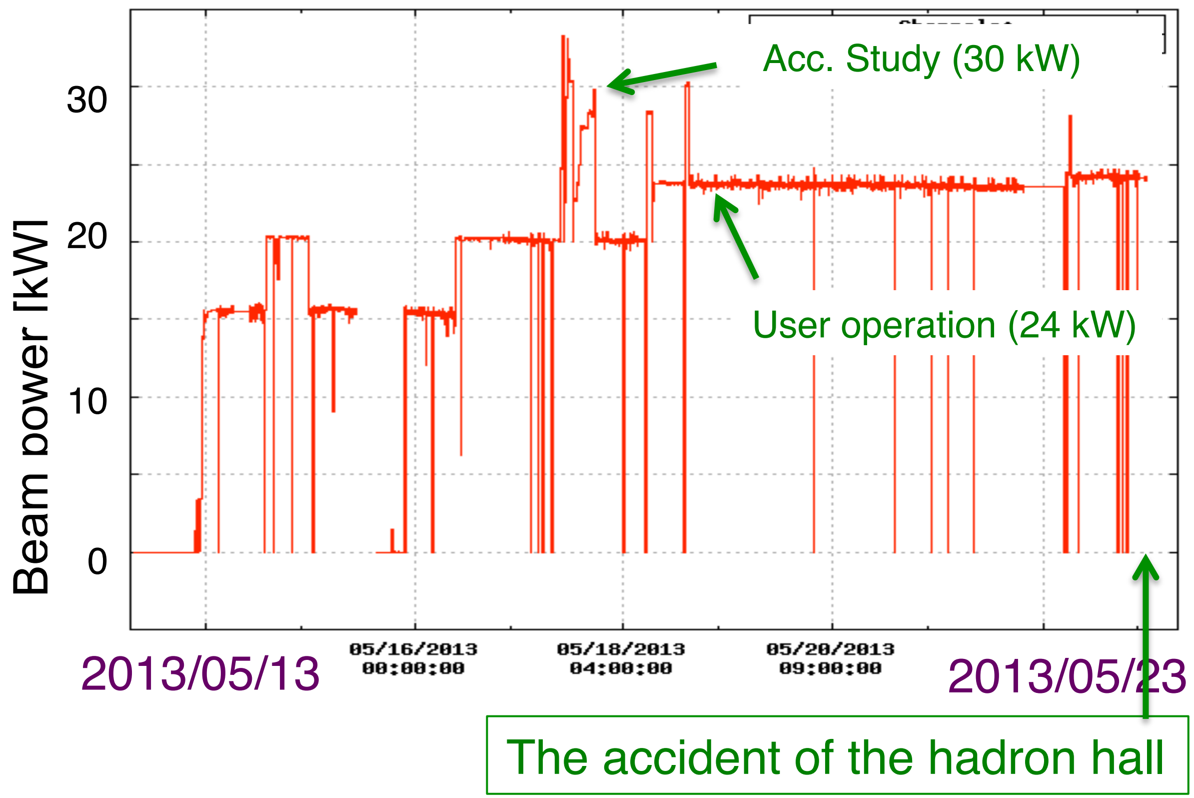
# Slow Extraction

- Third-integer resonance extraction
  ( $\nu x = 67/3$ )

- Extraction efficiency ~ 99.5 %
  with the “dynamic bump” system
  ( -> Next slide)

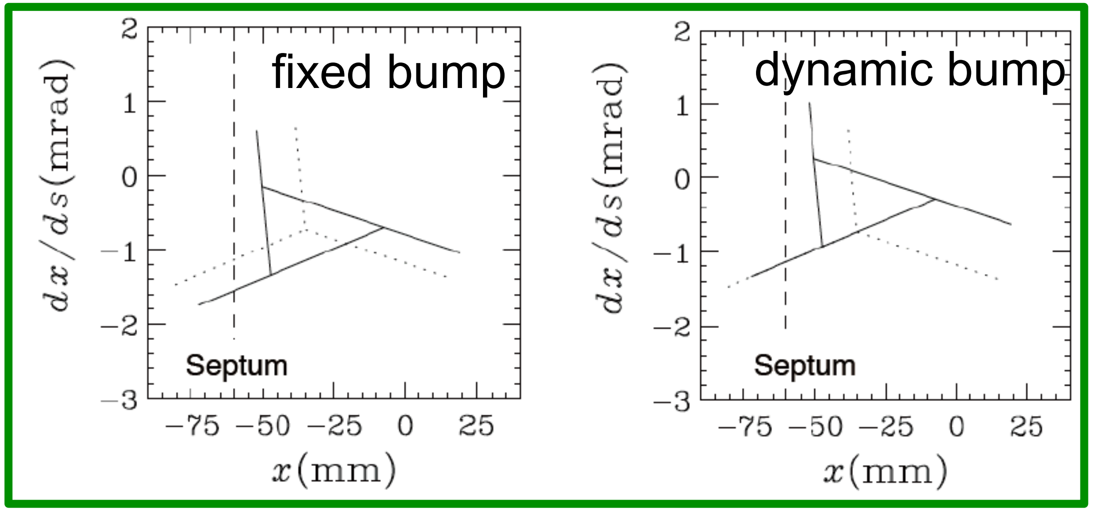
- Beam power
  ~ 15 kW ( until April 2013)
  ~ 24 kW ( from May 18, 2013)



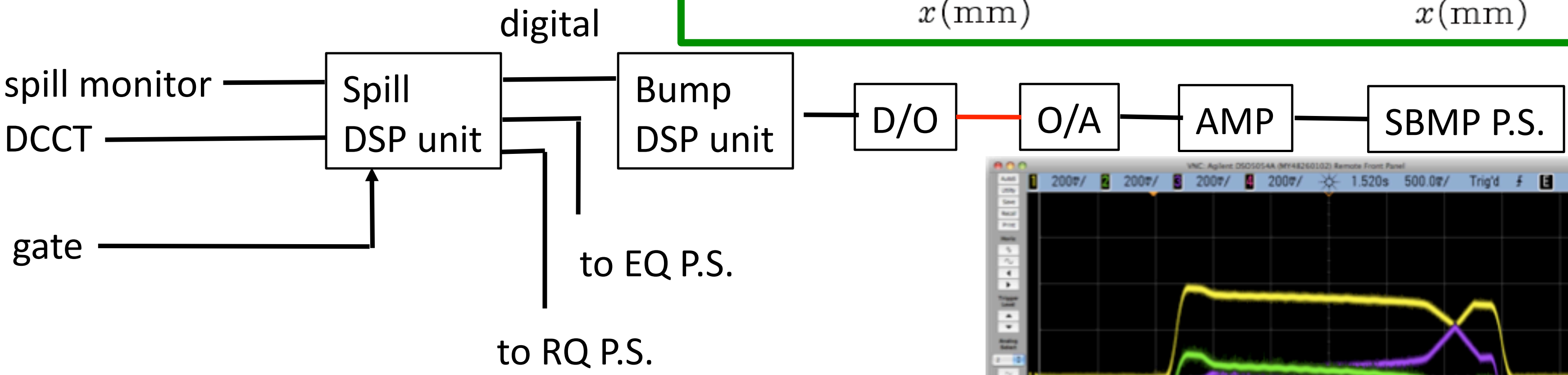



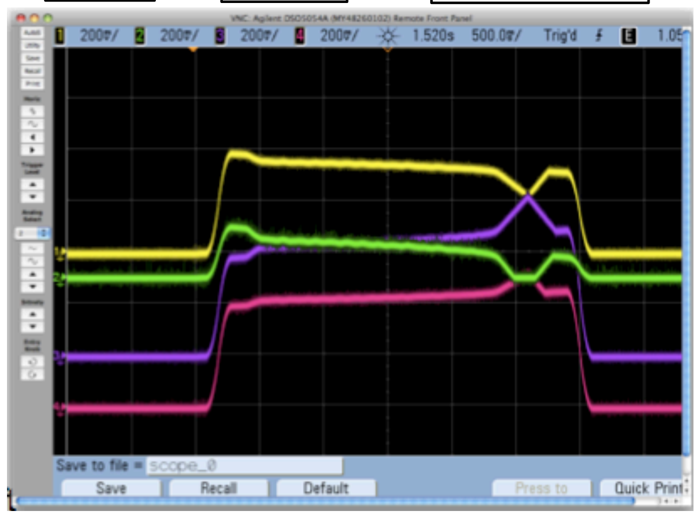
# Slow extraction with dynamic bump system

Separatrices at the ESS for the fixed and dynamic bump schemes.




Dynamic-bump system : The center of the separatrix is adjusted to fix the beam angle at the ESS septum during the extraction. It can reduce the impact rate of the beam on the septum.



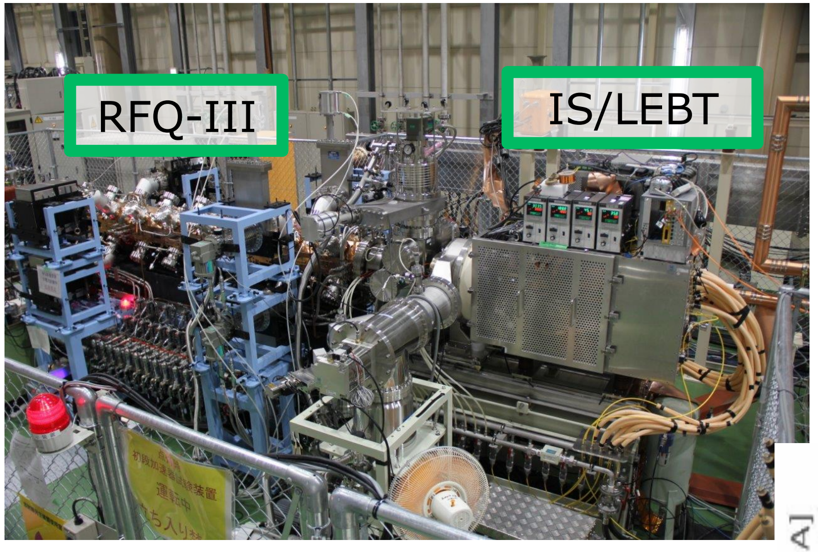




The DSP calculates the setting currents for four bump magnets.

Current patterns of the bump magnets

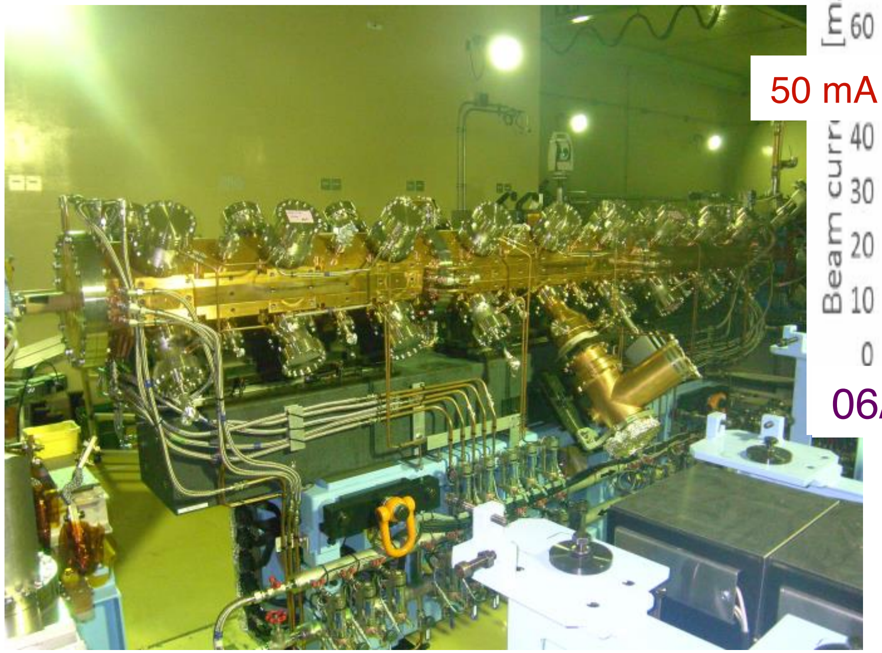
# Status of new front-end system for peak current upgrade

An newly developed rf-driven $H^-$ ion source and new RFQ for the peak current of 50 mA were tested in a test bench. Long-term continuous operation of 50 mA for one month was successfully demonstrated .





Long-term continuous operation in the test bench

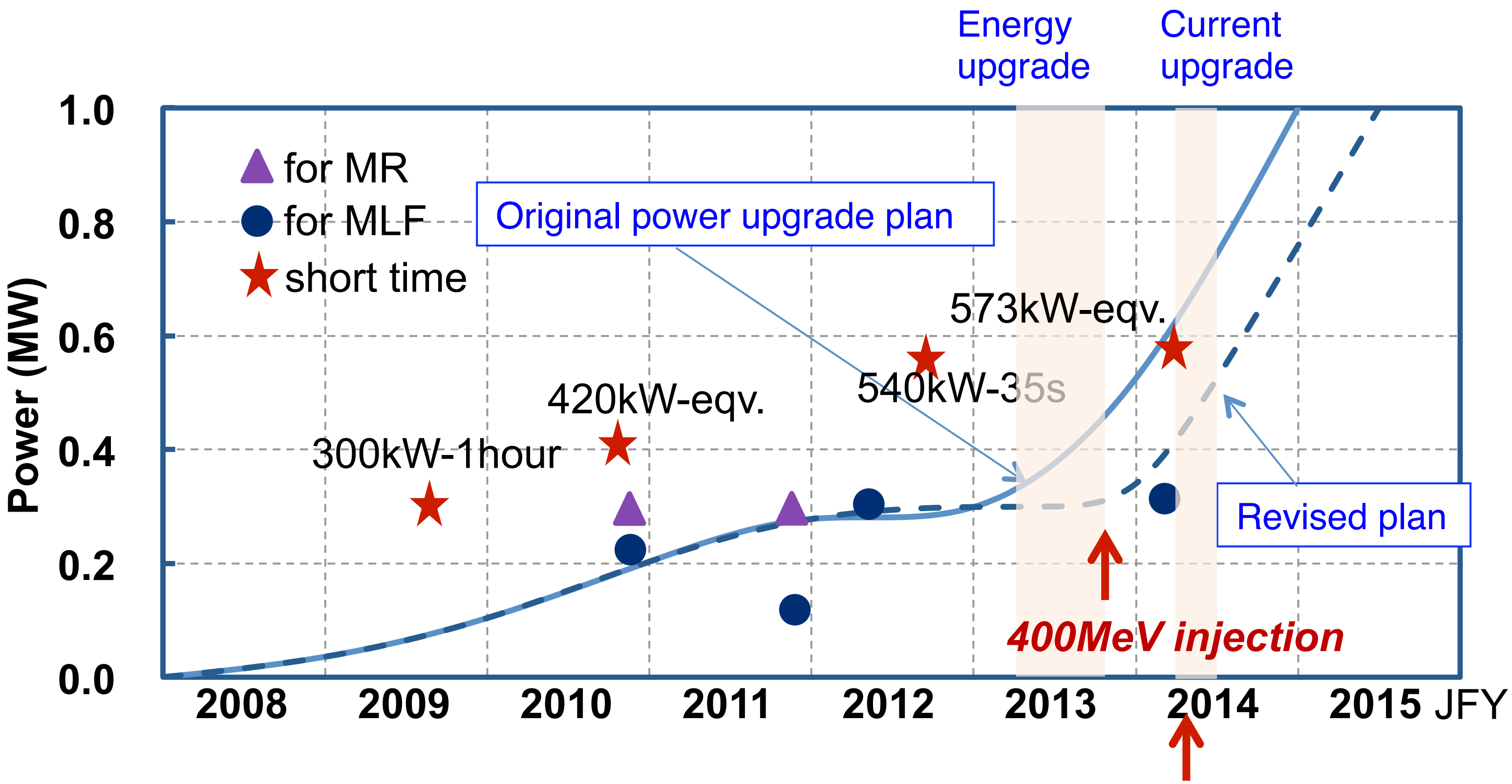



The front-end system installed in the linac tunnel in August, 2014.

# Medium-term plan

- JFY2013-2017 -

# RCS power upgrade plan




User operation of the 1-MW beam power will start in JFY2015.

# Mid-term plan of MR

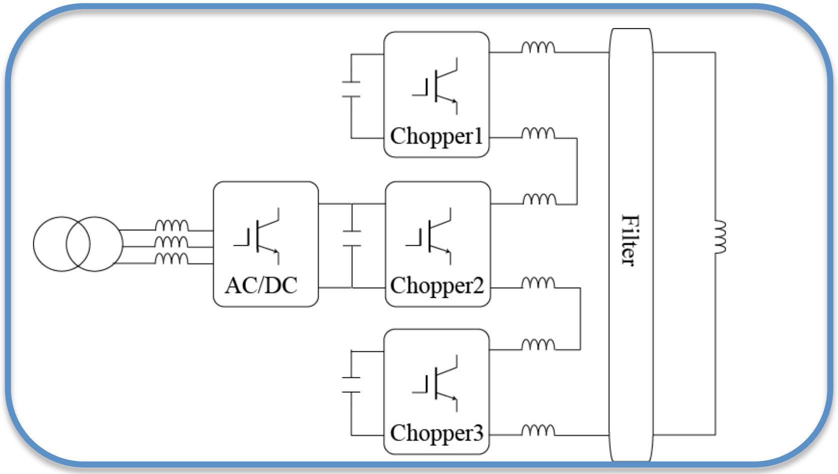
FX: The high repetition rate scheme is adopted to achieve the design beam intensity, 750 kW. Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.

SX: Parts of stainless steel ducts are replaced with titanium ducts to reduce residual radiation dose. The beam power will be gradually increased toward 100 kW watching the residual activity.

| JFY | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| | | | Li. energy upgrade | Li. current upgrade | | | |
| FX power [kW] (study/trial)<br>SX power [kW] (study/trial) | 150<br>3 (10) | 200<br>10 (20) | 200 - 240<br>25 (30) | 200 –300 (400)<br>20-50 | → | → | 750<br>100 |
| Cycle time of main magnet PS<br>New magnet PS for high rep. | 3.04 s<br>R&D → | 2.56 s<br>R&D → | 2.48 s<br>R&D → | R&D → | Manufacture installation/test → | Manufacture installation/test → | 1.3 s<br>→ |
| Present RF system<br>New high gradient rf system | Install. #7,8<br>R&D → | Install. #9<br>R&D → | R&D → / Manufacture installation/test → | Manufacture installation/test → | Manufacture installation/test → | → | → |
| Ring collimators | Additional shields | Add.collimators and shields (2kW) | Add.collimators (3.5kW) | | | | |
| Injection system<br>FX system | Inj. kicker | Kicker PS improvement, Septa manufacture /test →<br>Kicker PS improvement, LF septum, HF septa manufacture /test → | → | → | → | → | → |
| SX collimator / Local shields | SX collimator | | | | Local shields → | Local shields → | Local shields → |
| Ti ducts and SX devices with Ti chamber | | SX septum endplate | Beam ducts | Beam ducts ESS | | | |

# New power supplies for 1 Hz operation

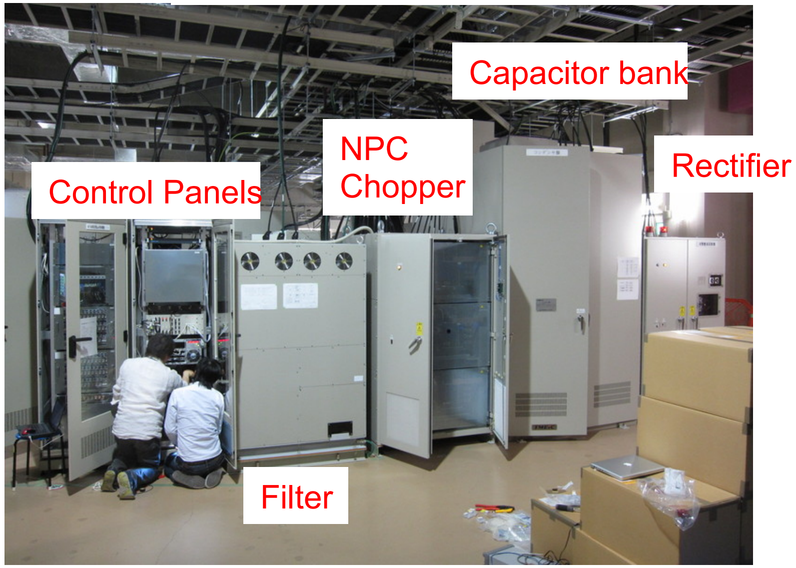
***Large scale PS for bending magnets and quad. magnets in arc setions***

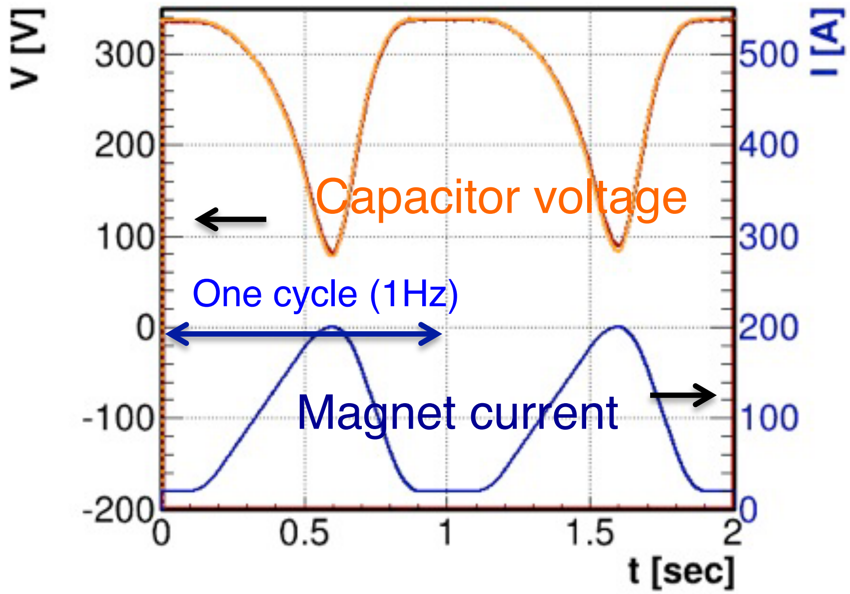



Two large converters and large capacitance for energy recovery, symmetric power module circuit

R&D is now in progress.
The total PS system will be tested in JFY2014

A mini-prototype model test using the real bending magnet and capacitors.

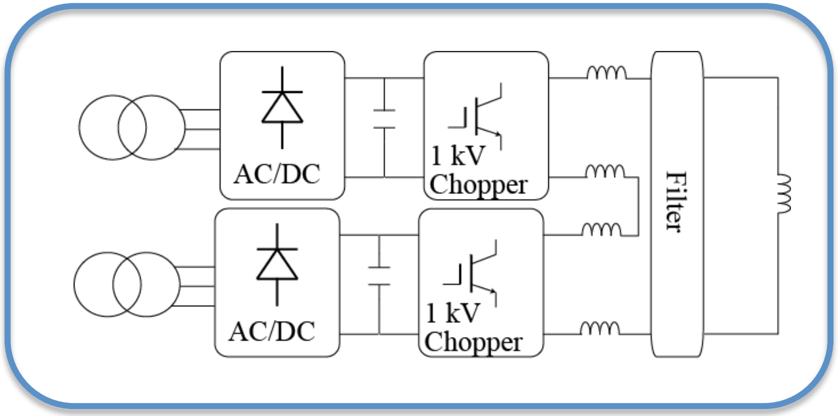



**Mass production will start in JFY2015 if the budget request is approved by the government.**

# R&D of new power supplies for 1 Hz operation (cont'd)

***Small scale PS for Quad. Magnets in straight section and sextupole magnets***

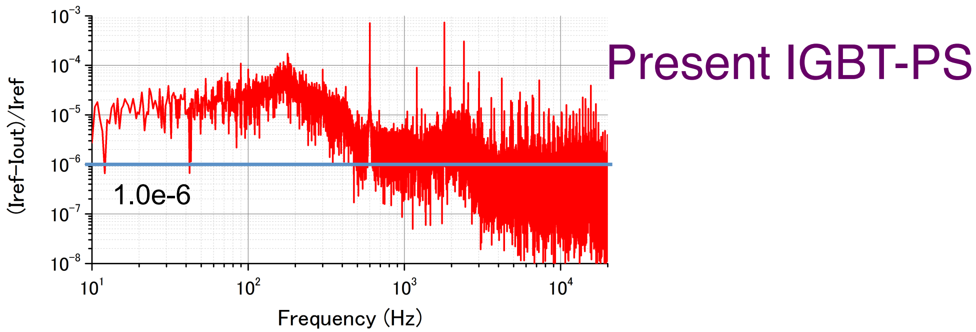


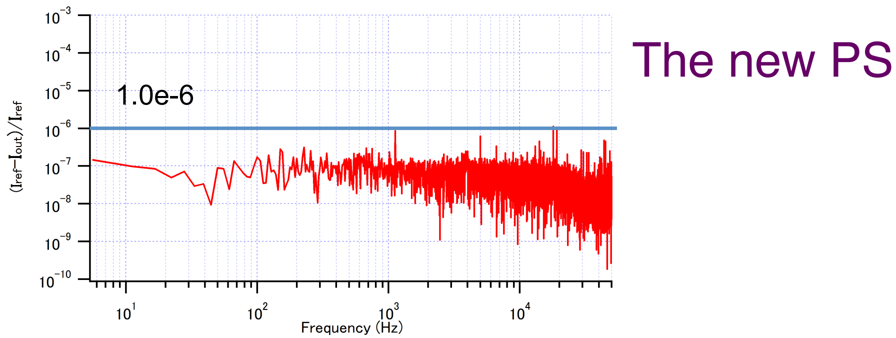

Diode rectifiers, two 1kV choppers are connected in series, symmetric power module circuit

It is possible to build with the combination of existing products.

The model PS system was tested using the real sextupole magnet network.

Current ripple at 30 GeV

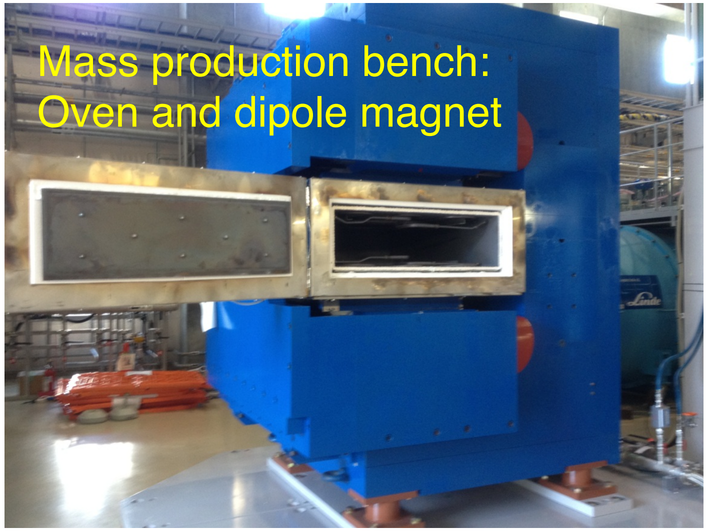


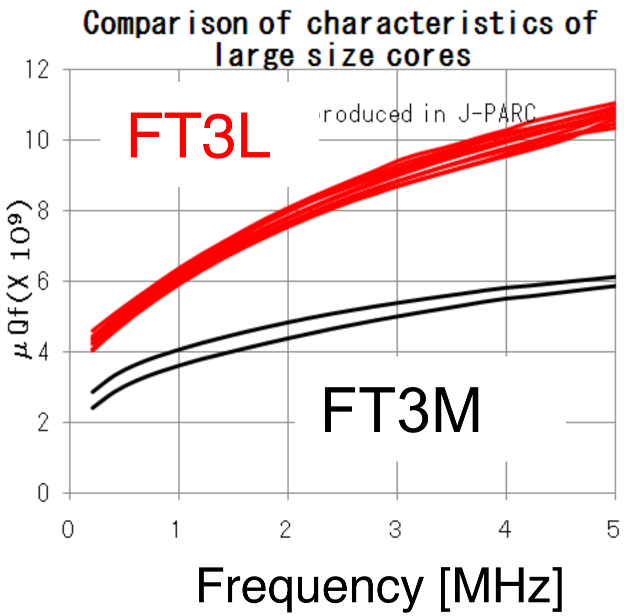




**Mass production will start in JFY2015 if the budget request is approved by the government.**

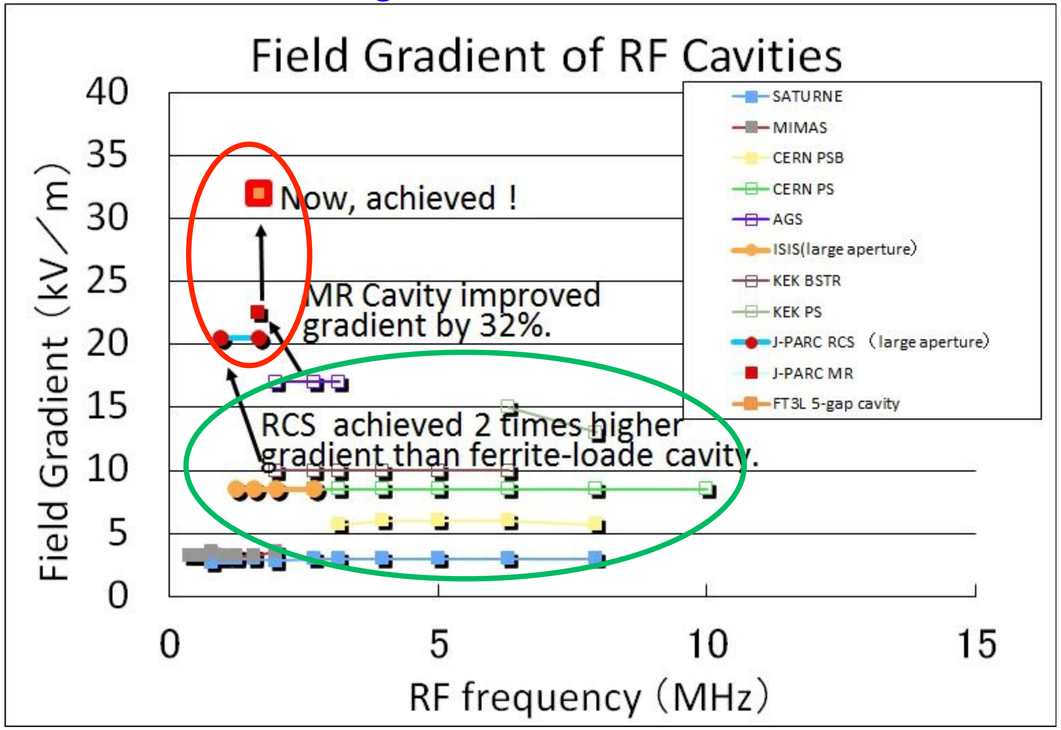
# High impedance rf system

A new type of the magnetic alloy (MA) core, FT3L(made by Hitachi Metal), is adopted to increase shunt impedance of the rf cavity. The core is processed by annealing with magnetic field.



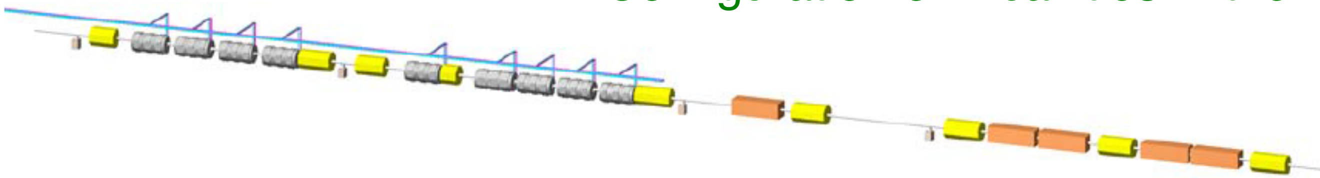

Comparison of field gradient of rf cavities for hadron rings.




Performance of cavities depends on core materials: ferrite and MA.
J-PARC already achieved very high field gradient.

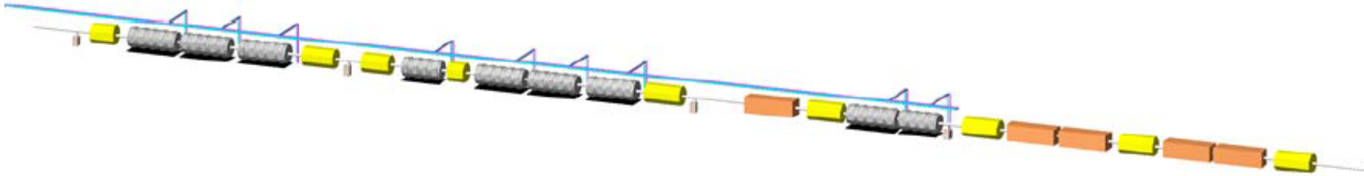
# High impedance rf system (cont'd)

Configuration of rf cavities in the MR



Current situation : 3gap X 9 = 27 gaps

Total rf voltage ~ 270 kV



After replacement : 4gap X 2 + 5gap X 7 = 43 gaps

Total rf voltage ~ 560kV

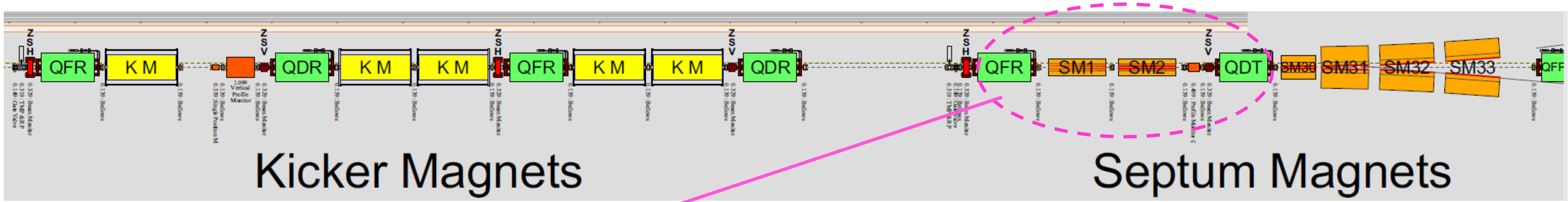
A second harmonic cavity is also installed in the injection straight section.

1st 5-cell FT3L cavity under 80 kV high power test

Budget for the new rf cavities is mostly secured by supplementary budgets in JFY2011 and 2012.
All the cavities will be ready to install in JFY2015.

The developed FT3L cores are adopted to the PSB for LHC injector upgrade .

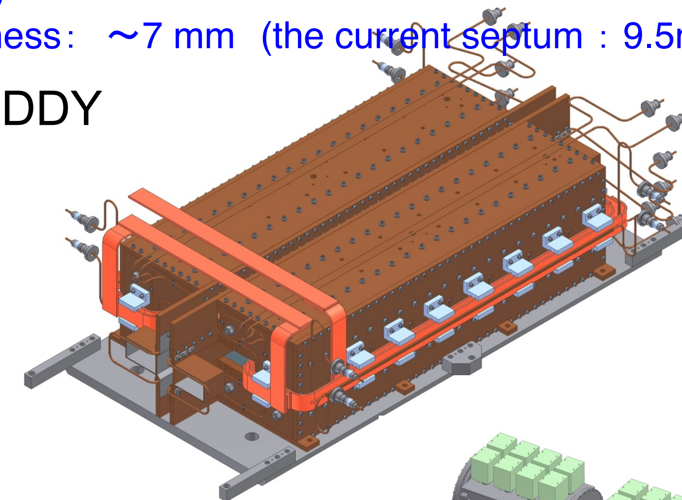
# New low field FX septum: Eddy current type

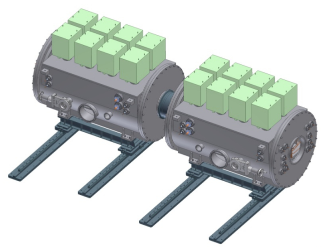



Current FX low field septum

Eddy current type septum is adopted to the new system
- Small Power Consumption (possible at low cooling capacity)
- Small Leakage Field: ~$10^{-4}$ ( the current type septum : $10^{-3}$ )
- Stable (low vibration)
- Thin Septum Thickness: ~7 mm (the current septum : 9.5mm)

New FX EDDY





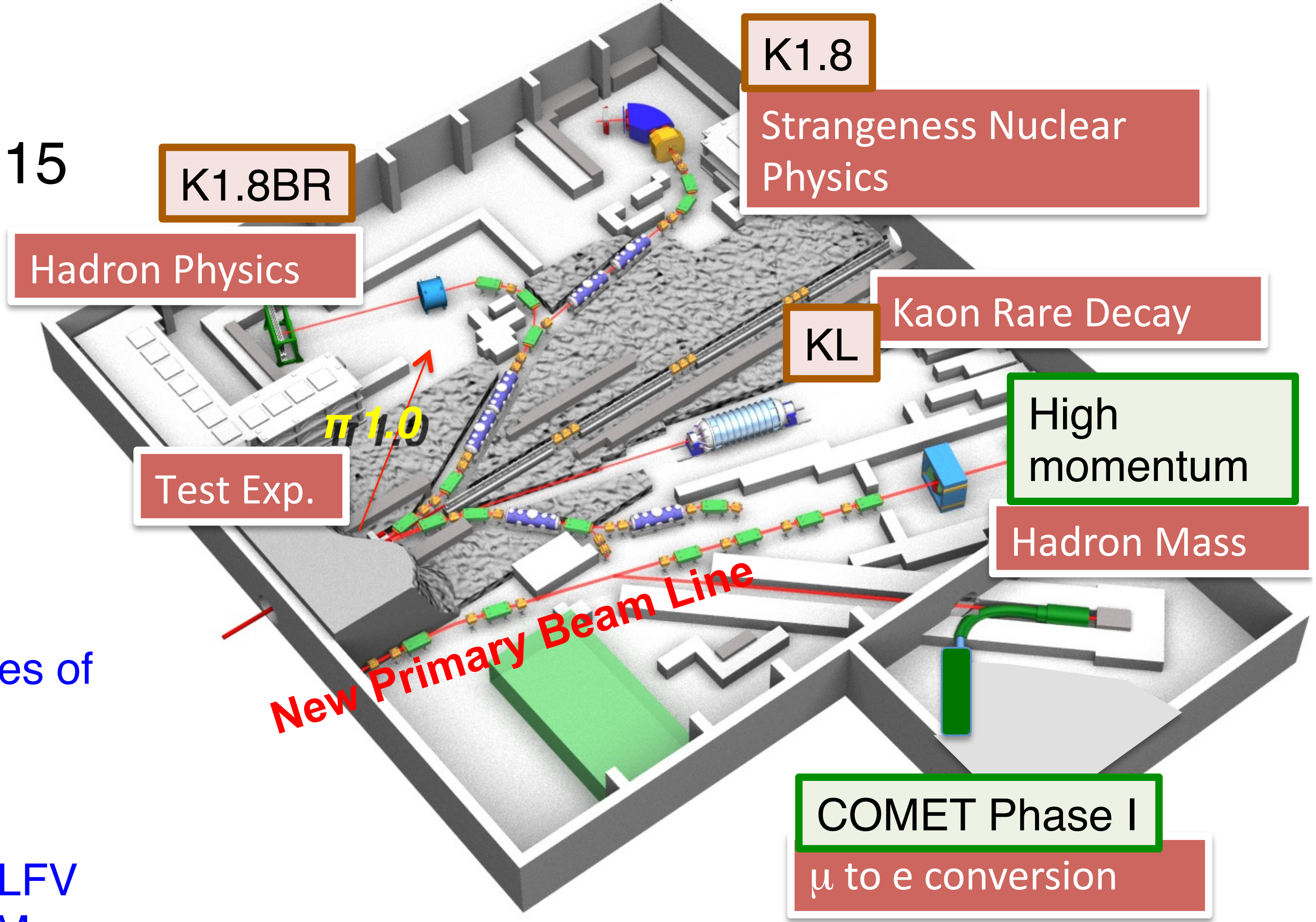
| | New FX Eddy model | Current FX low Field |
|---|---|---|
| # of magnets | Nu 2 + Abort 2 | Nu 4 + Abort 4 |
| # of coil turns | 2 | 4 |
| Pole Length | 1.5 m | 0.875 m |
| Septum Thickness | 7 mm | 9.5 mm |
| Current / Voltage | 11 kA / 3 kV | 3250 A / 144 V |
| BL (Tm) | 0.3 × 1.5 × 2 = 0.90 | 0.224 × 4 = 0.90 |
| Aperture (H×V) | 150 ×80 mm | 80 ×70 mm |
| Inductance | 36μH (2magnets series) | 27 × 8 = 216 μH |
| Pulse or Pattern | 0.7 ms half sine (3rd order) | Pattern |
| Leakage Field | ~ $10^{-4}$ | ~ $10^{-3}$ |

The magnet has been manufactured. It will be installed in the 2015 summer shutdown.

# Experiments at Hadron Hall

New primary beam line / facility are now being constructed.

~2015




**2 years Project with 35MD**

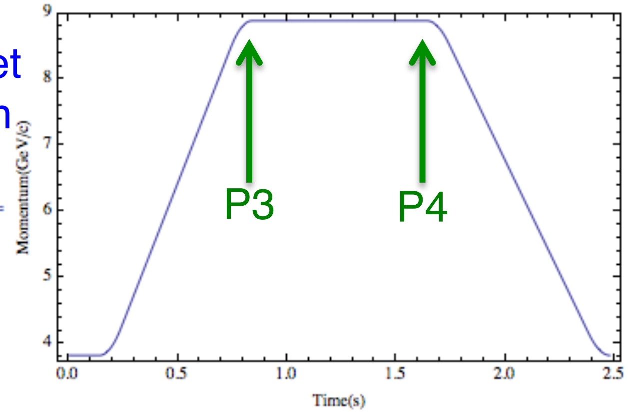
•Hi-mom BL for studies of hadron properties in nuclear matter.

•Search for charged LFV process to probe BSM. (First phase of the COMET experiment)

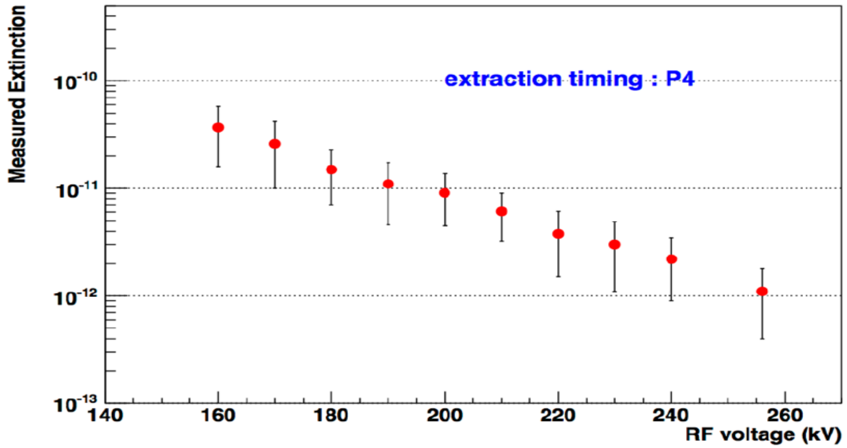
Slide by Hadron group

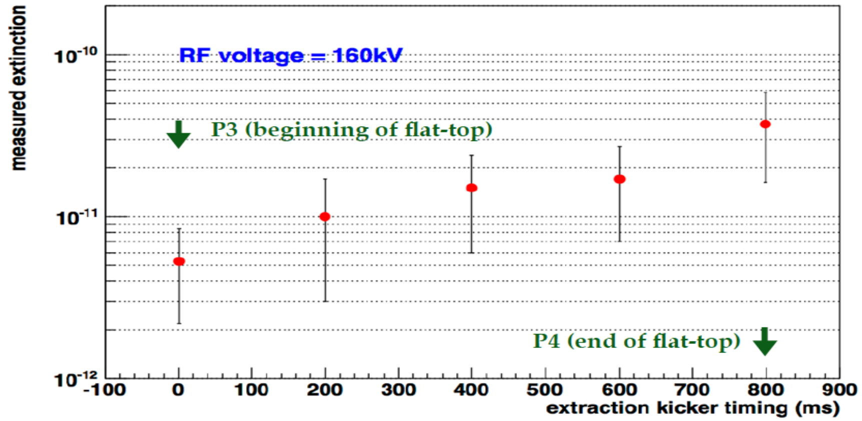
# Study of 8-GeV operation for the COMET phase-I

Magnet pattern

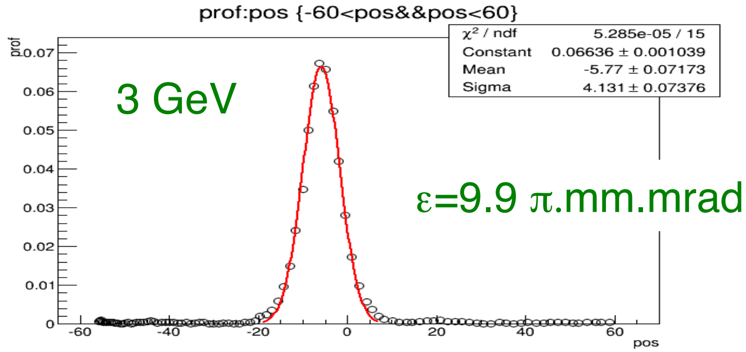


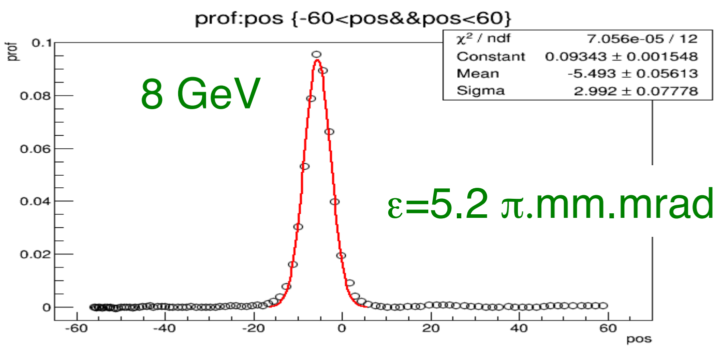

Extinction measurement of FX beam for the single bunch operation. Injection kicker timing was shifted to sweep out protons in the front bucket of the main bunch.




H. profile for 1.64x10$^{12}$ ppb (3.2 kW-eq.)



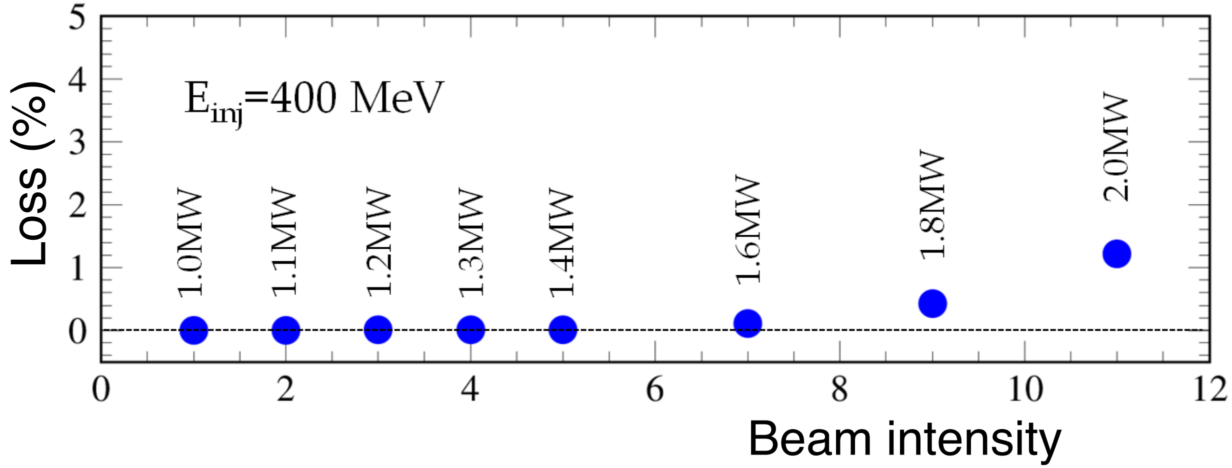




Extinction generated by the processes other than the SX can be much smaller than the experimental requirement.

# Long-term plan

# Feasibility of the RCS

Injection beam parameters:
Energy : 400 MeV
Peak current : 50 mA~100 mA
Pulse length: 0.5 ms
Chopper-beam on duty : 0.53




| RCS intensity | Loss | Loss power at 25 Hz |
|---|---|---|
| 1.0 MW | ~0.3% | 400 W |
| 1.1 MW | ~0.3% | 440W |
| 1.2 MW | ~0.3% | 480 W |
| 1.3 MW | ~0.3% | 520 W |
| 1.4 MW | ~0.3% | 560 W |
| 1.6 MW | ~0.5% | 1067 W |
| 1.8 MW | ~0.7% | 1680 W |
| 2.0 MW | ~1.5% | 4000 W |

RCS collimator limit ~4 kW
→ RCS has a feasibility to operate 2 MW

- Linac 100 mA/0.5 ms (50 mA/1.0 ms) operation is required.
  R&D of ion source / long pulse operation of linac
- The rf system should be replaced to compensate a heavy beam loading.
- The collimator capability should be upgraded to get a margin for the beam loss.
- Activation downstream of the charge exchange foils should be reduced.

….

# Future proton driver for long-baseline neutrino experiment

The maximum beam intensity is limited by the physical aperture of the MR.

The scenarios for achieving much larger beam power than the design specification for neutrino experiment are now discussed.

1. Booster ring for the MR (emittance damping ring)

    The BR with an extraction energy ~ 8 GeV, is constructed between the RCS and the MR

2. New proton linac for neutrino beam production

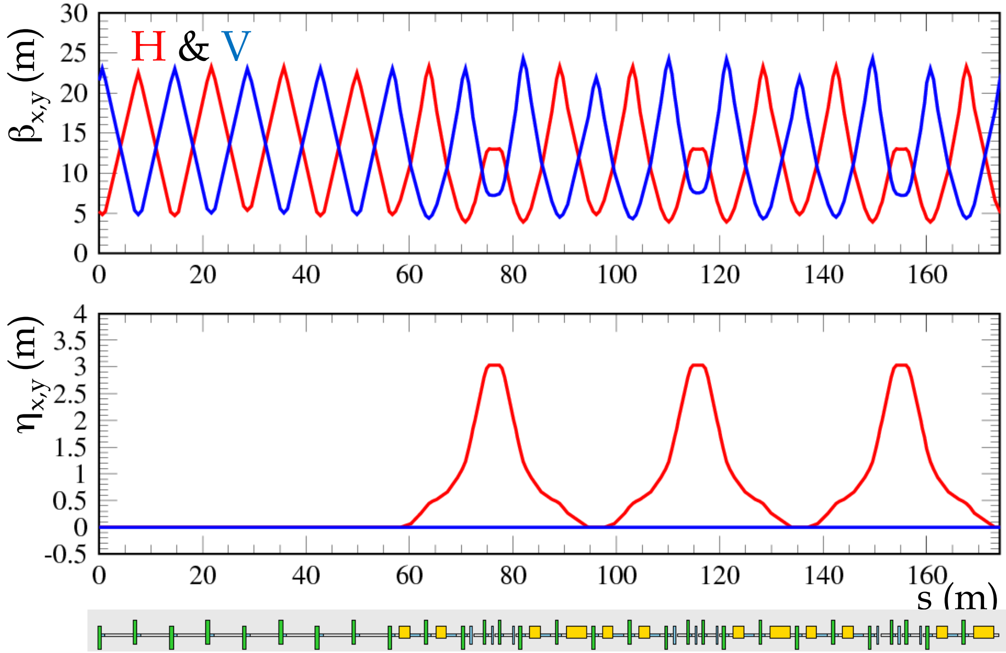
    ( Construction site may not be the Tokai campus)

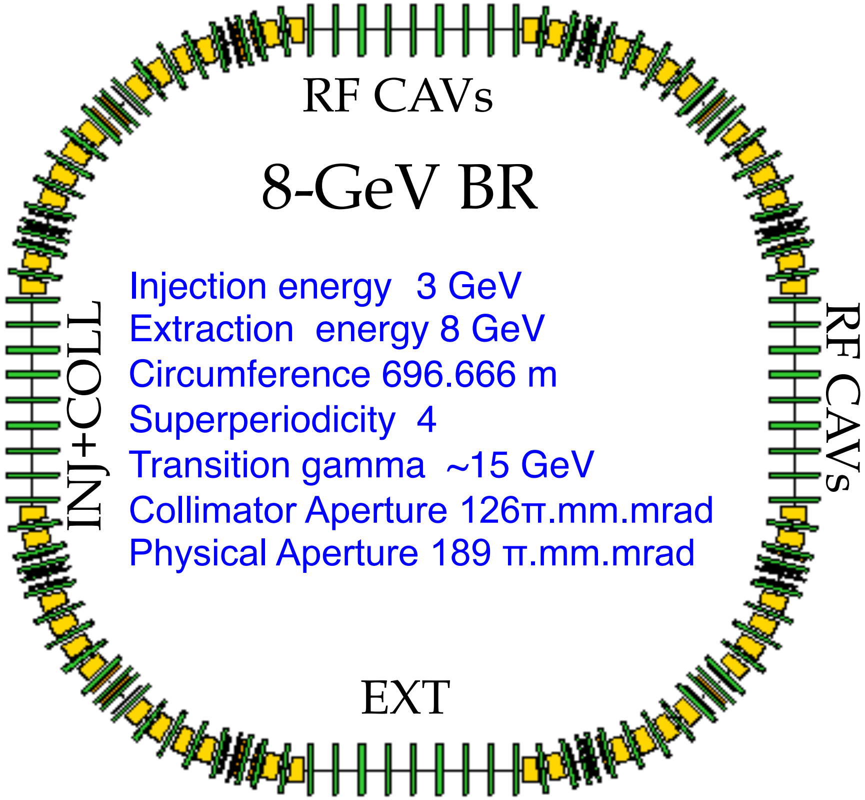
    - Linac with an beam energy > 9 GeV
    - The MR is operated only for the SX users

R&D's for upgrade of the neutrino beam line (target, DC horn…) are key issues.

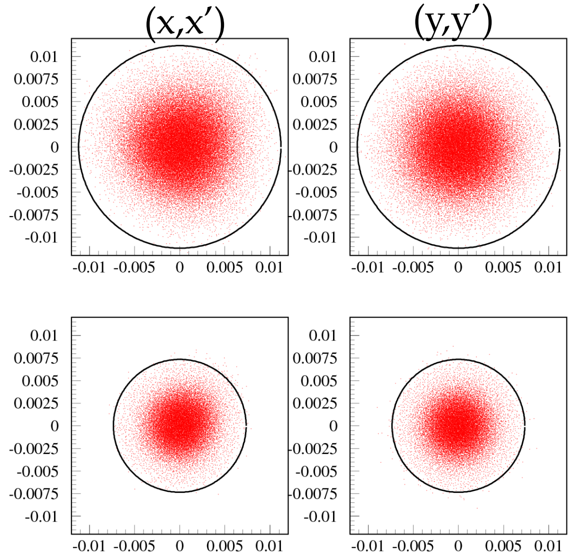
# The 8-GeV booster ring

## Beta & Dispersion for 1-superperiod




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

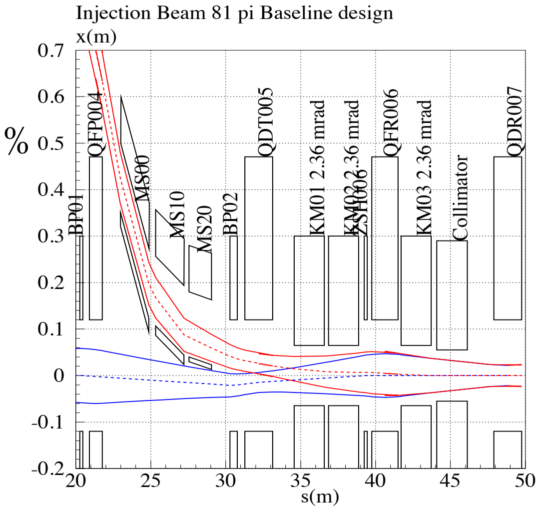



@ 3GeV

ε>125.5π ~0.04%

@ 8GeV

ε>54π ~0.06%

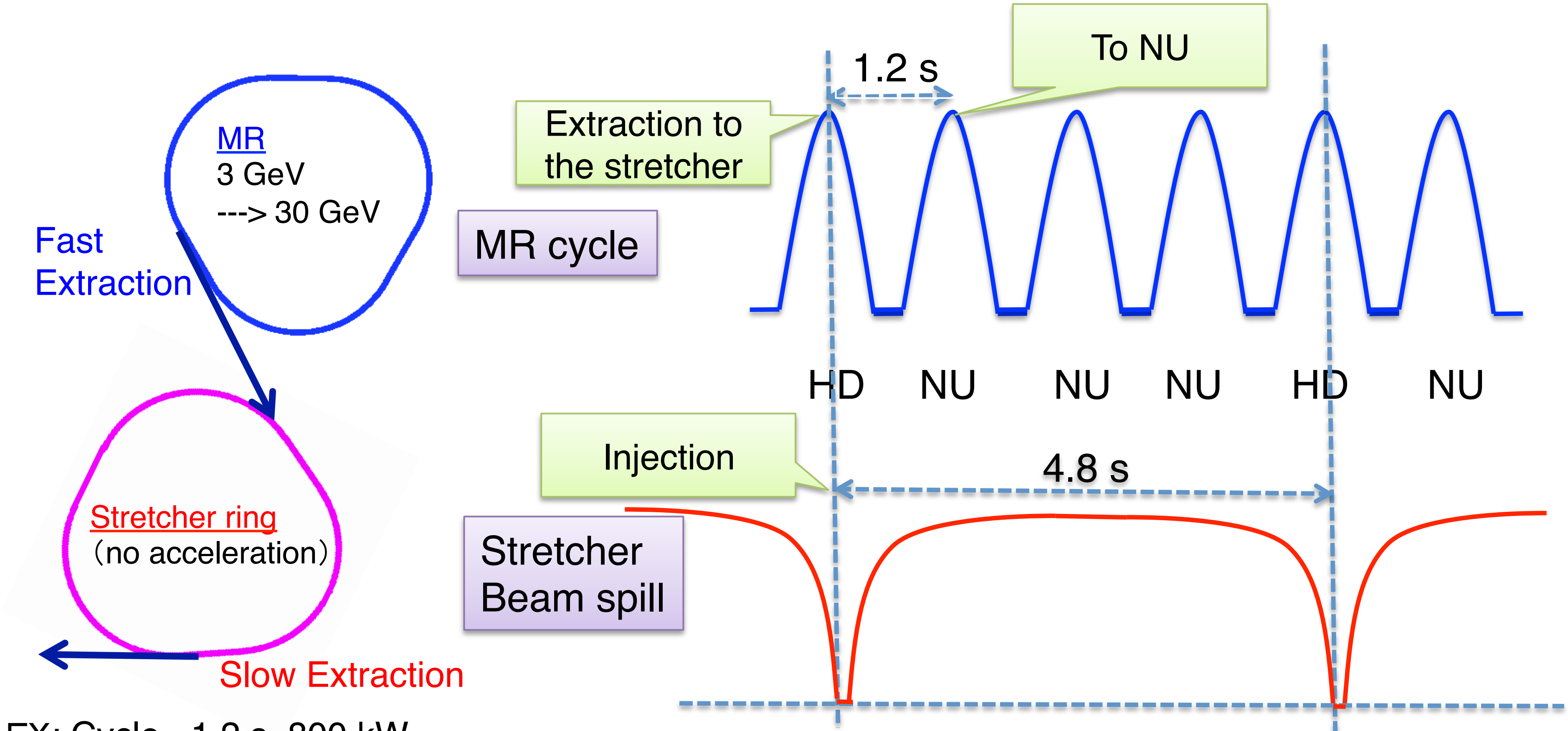



8 GeV injection in the MR using new septa&kickers

RCS : 1.6 MW
MR > 2.6 MW

RCS : 2 MW
MR > 3.2 MW

# Stretcher ring for increasing operation time of HD users




FX: Cycle= 1.2 s, 800 kW
SX: Cycle= 4.8 s (flat-top 3.6 s)
Circumference of the stretcher is same as the MR

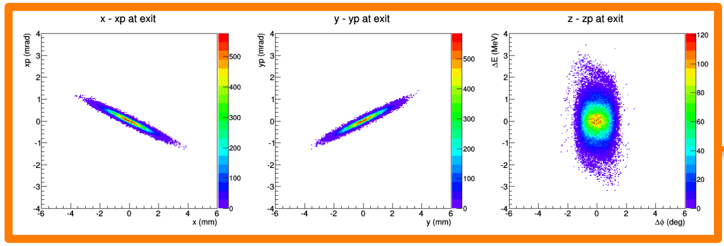
Integrated beam power for 200 days/year;
- NU : 800kW x 3/4 x 200 days =600kW x 200 days
- HD : 800kW x 1/4 x 200 days =200kW x 200 days

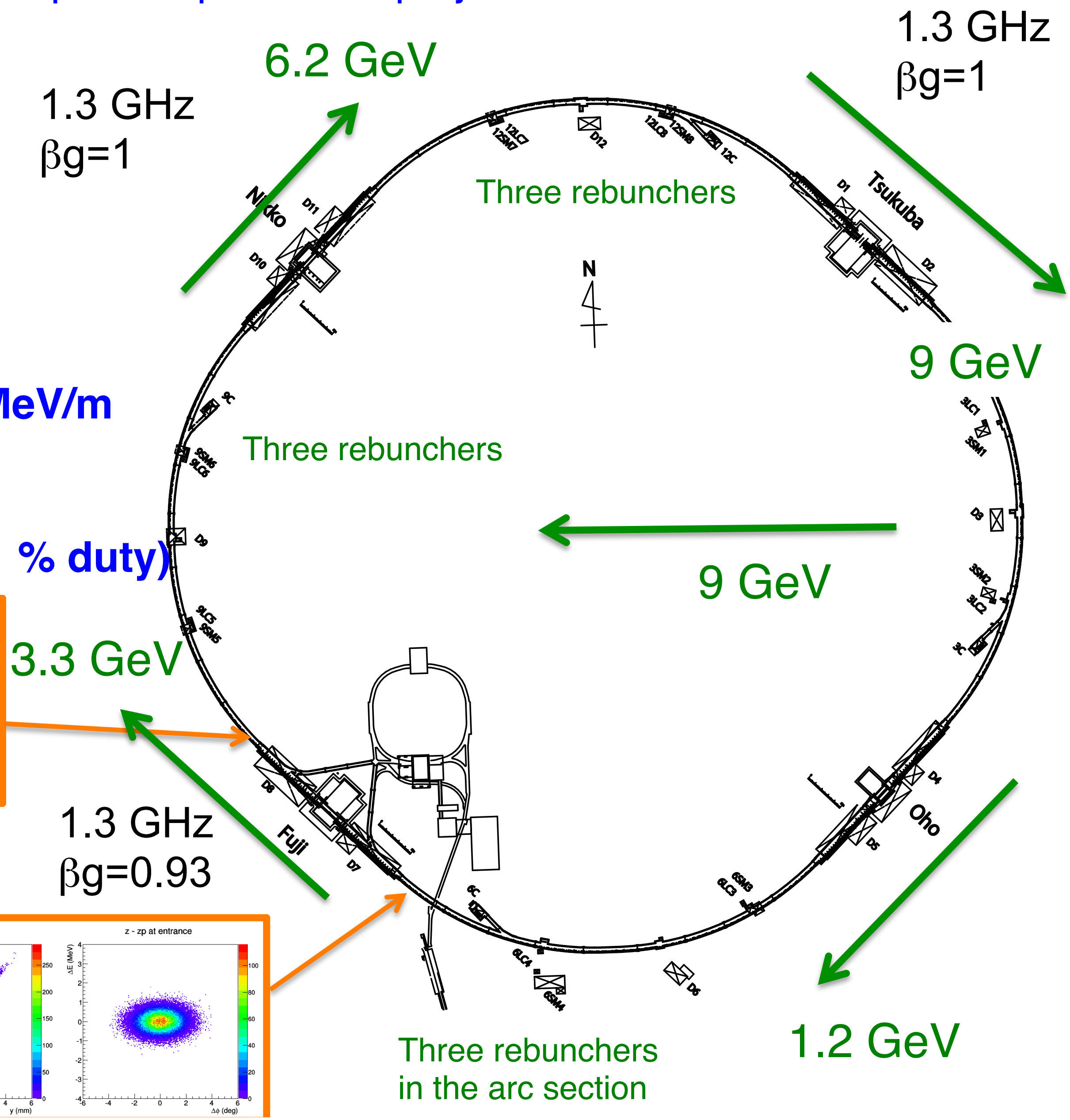
# Linac based proton driver in KEKB tunnel

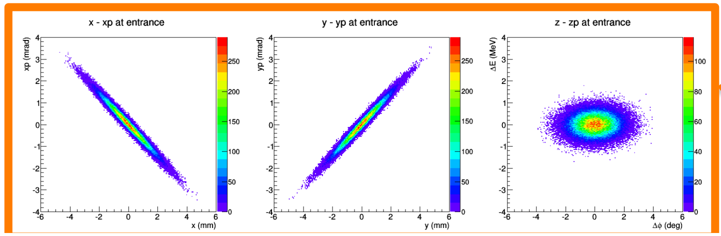
We start discussion as one of the post-Super KEKB project.
KEKB tunnel:
Circumference ~3 km
LS section 200 m x 4

**Proton linac:**
**E = 9 GeV**
**1.3 GHz, 9 cell (ILC)**
**E0= 30 MV/m**
**Real estate grad.  10.9, 14.9 MeV/m**

**Beam power  > 9 MW**
**(9GeV x 0.1 A x 1 % duty)**



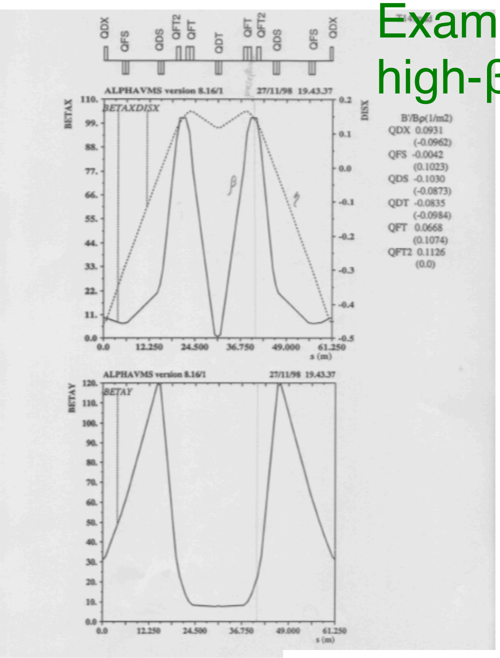
# Slow extraction with beam power >> 100 kW

Feasibility study for low-loss SX system
to reduce beam loss on the ESS section is started.

- High β insertion
  - β > several 100m @ESS
  - Q-PS separated in the SX straight section
  - Add extra Qs in the SX
  - Larger-bore Qs in SX

- Low-Z material for ESS ribbon
  - carbon-wire
  - carbon-nanotube
  - Beryllium,Titanium, …..

- Combination of low-z scatterer and ESS scheme
  - Scatterer made of low-Z material is installed upstream of the ESS to reduce beam loss at the ESS.



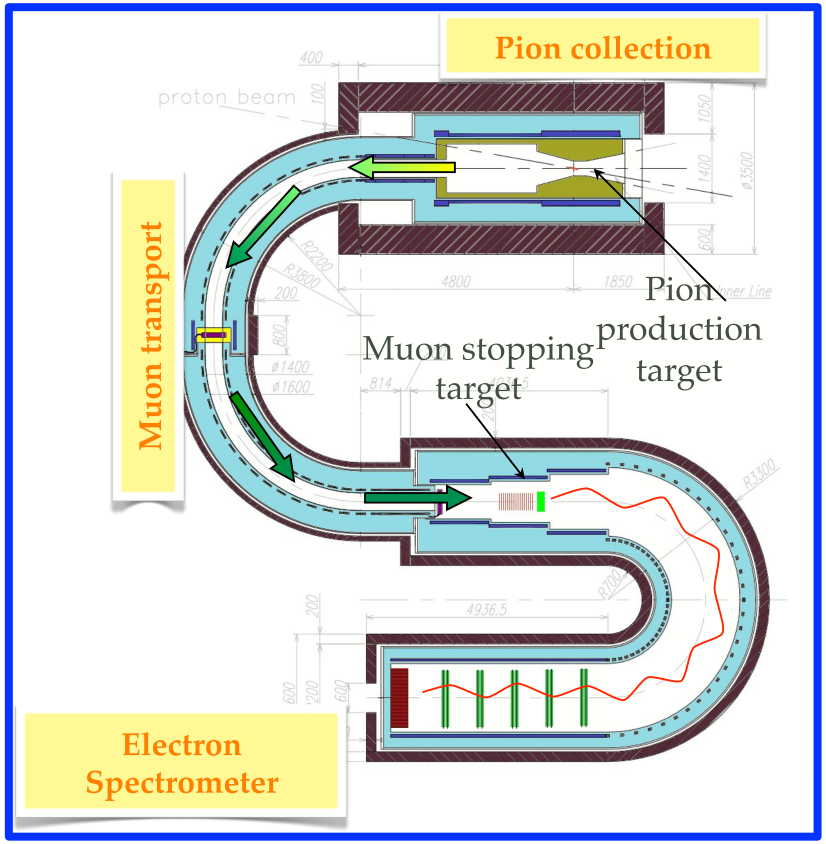

Examples of high-β optics

High voltage test of carbon wire ribbon

# COMET (I $<10^{-14}$; II $< 10^{-16}$)

Search for muon to electron conversion
Adopted staging approach
Phase-I: $10^{-14}$ (funded)
Phase-II: $10^{-16}$

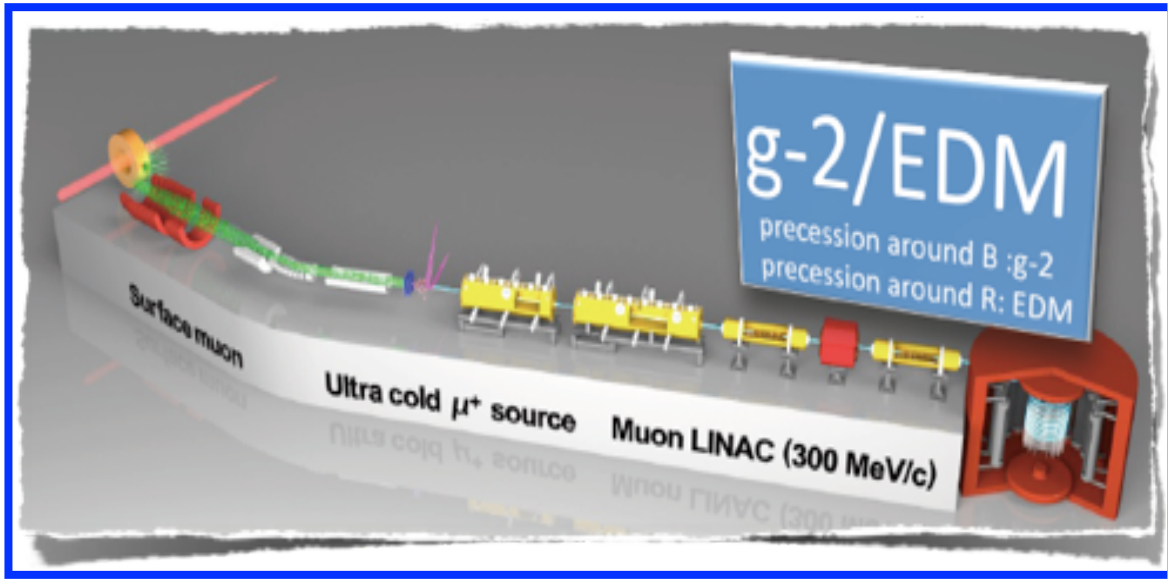
- 32 m SC solenoid magnet
- Beam extinction $< 10^{-9}$



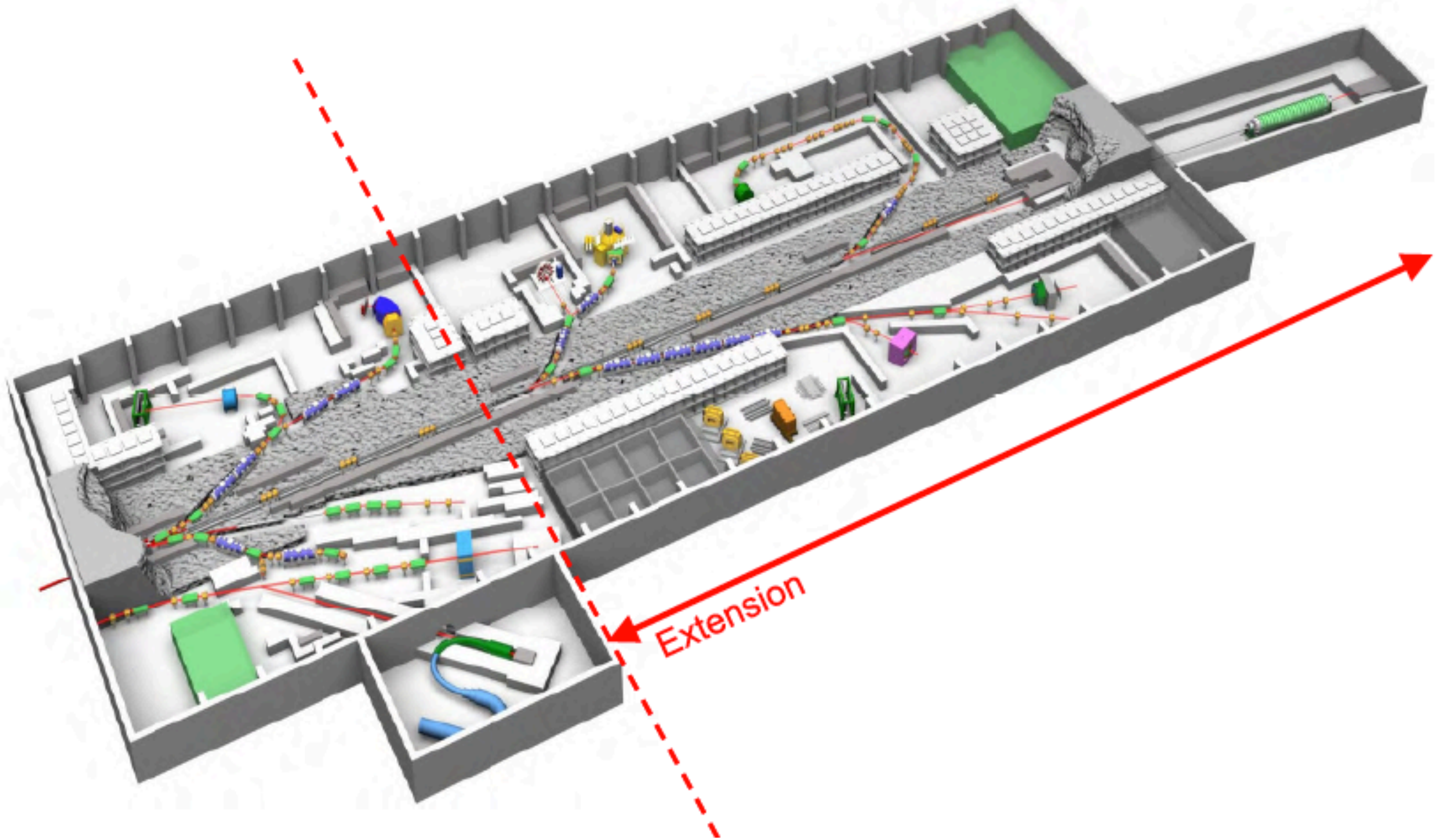

# g-2/EDM (0.1ppm/$10^{-21}$ e cm)
at MUSE in the MLF

- Ultra-Cold Muon Beam
  RFQ,IH,disk-loaded
- Ultra-Precision Magnetic Field
  3T, 1 ppm

g-2 and EDM SIMULTANEOUSLY !!

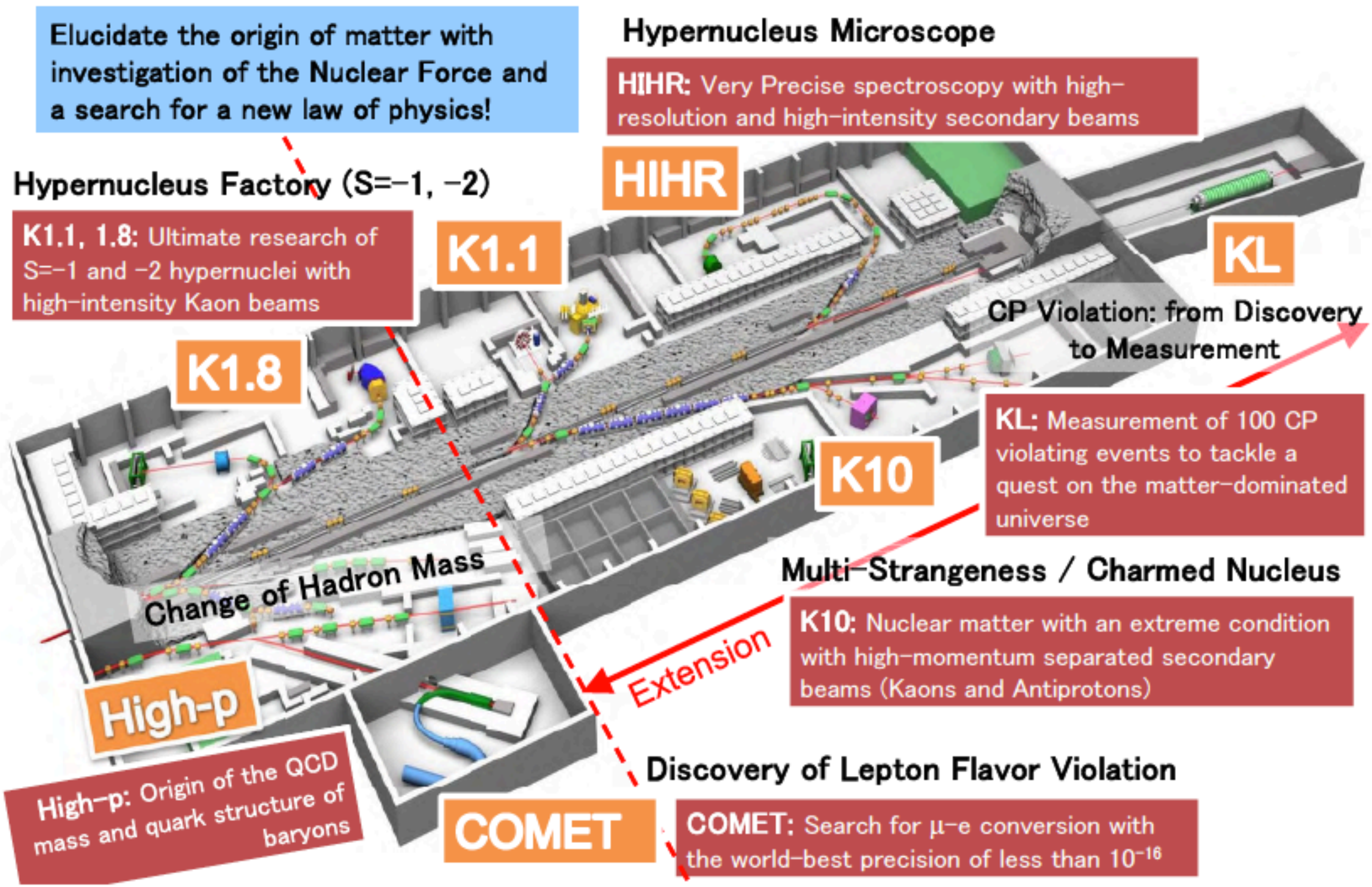


# Extension of the HD hall




Slide by Hadron group

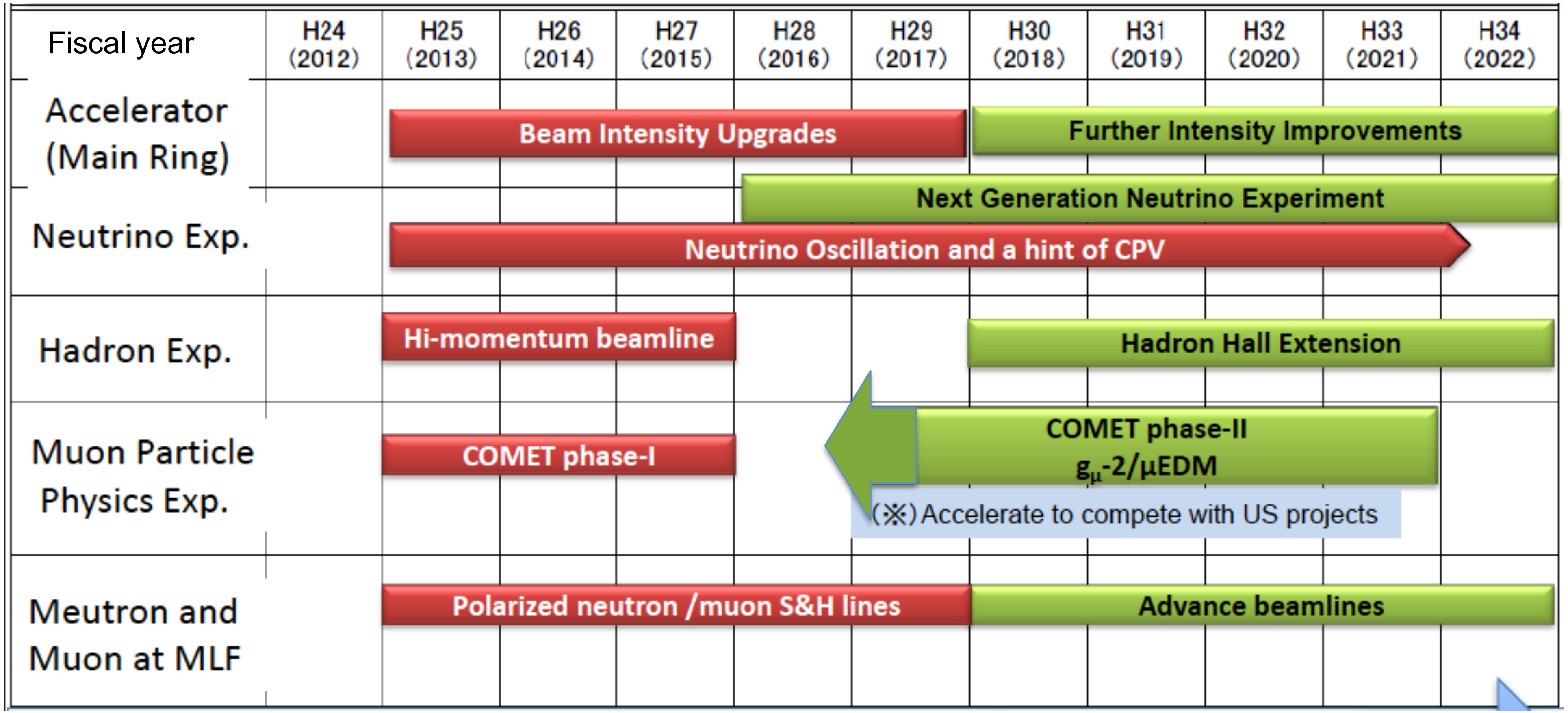
# Extension of the HD hall (cont'd)




Slide by Hadron group

# Long-term plan of particle/nuclear physics at J-PARC

"Elucidation of the origin of matter with an upgrade of J-PARC experimental facility" submitted to science council of Japan.



# Super KEKB

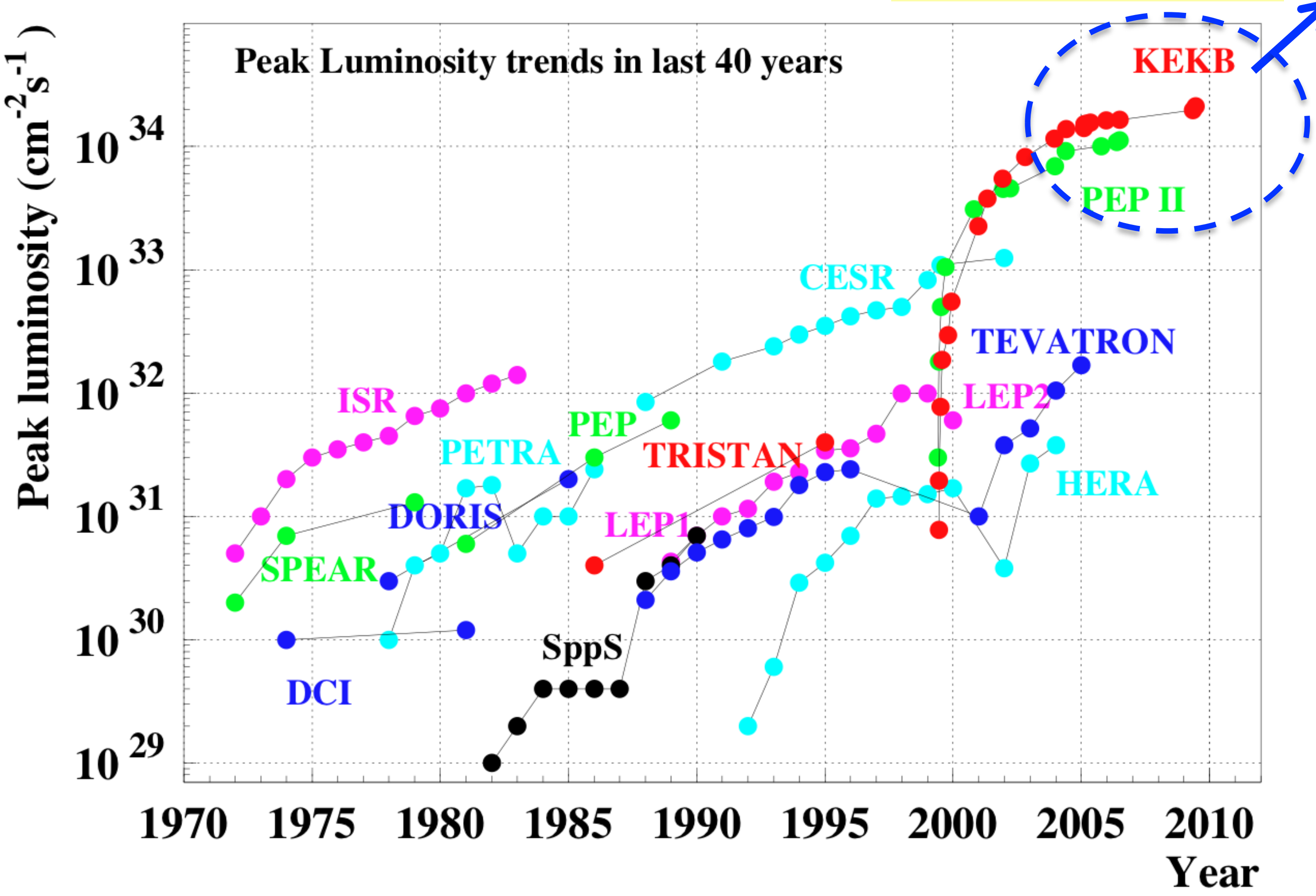
# *KEKB to SuperKEKB*

KEKB: 1998 – 2010

Peak luminosity 2.1 x $10^{34}$ $cm^{-2}s^{-1}$

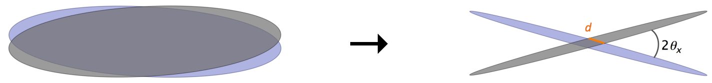
**SuperKEKB**

Design luminosity
8 x $10^{35}$ $cm^{-2}s^{-1}$



# SuperKEKB

- Increase the luminosity by 40 times based on "Nano-Beam" scheme



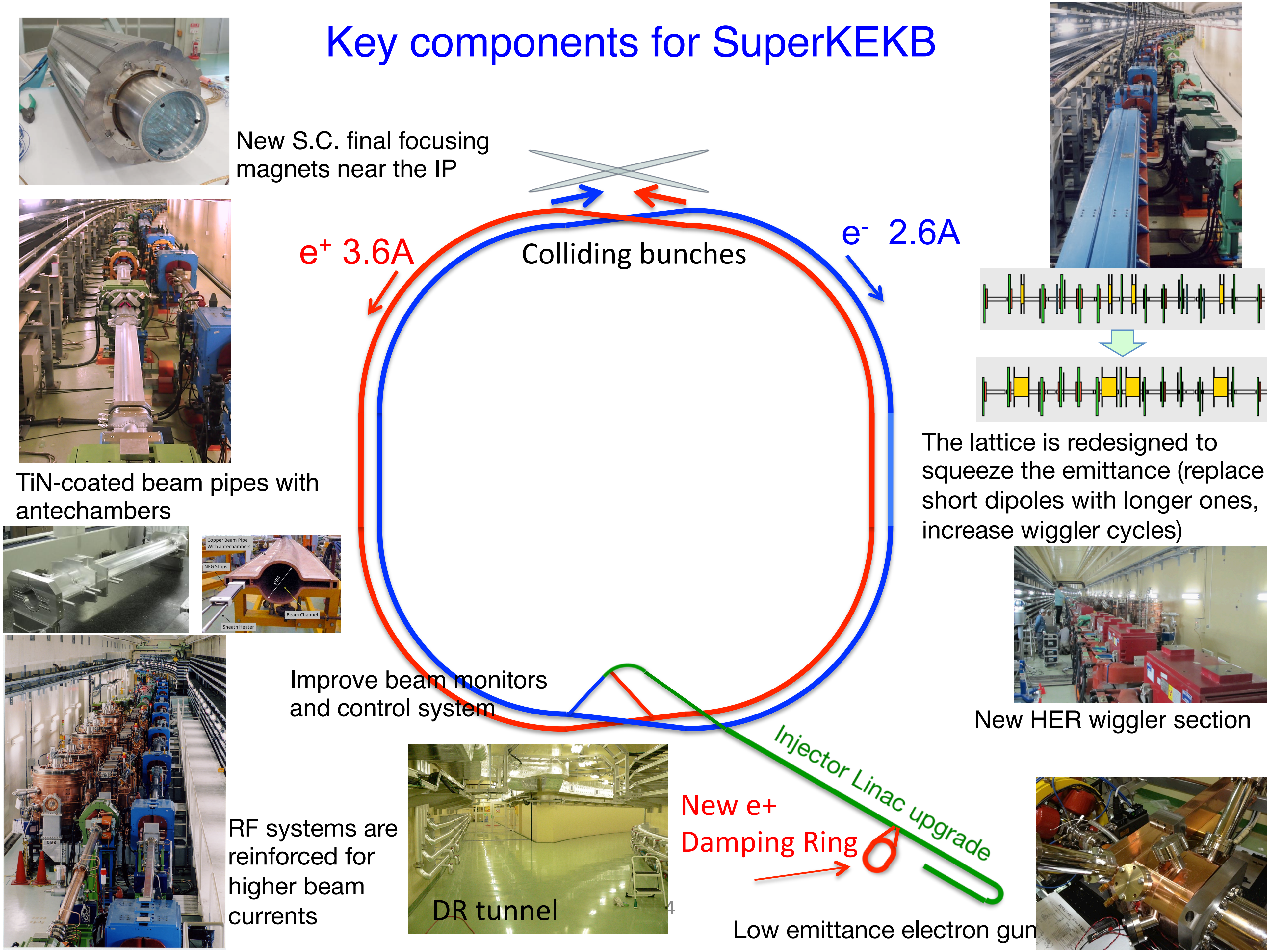

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

| | KEKB | | SuperKEKB | Luminosity Gain |
| --- | --- | --- | --- | --- |
| Vertical β function at IP : | 5.9 | → | 0.27/0.30 mm | (× 20) |
| Beam current : | 1.7/1.4 | → | 3.6/2.6 A | (× 2) |
| Vertical beam-beam parameter : | 0.09 | → | 0.09 | (× 1) |

- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
HER : Lower emittance and lower SR power

# Key components for SuperKEKB



# Commissioning phases

- Phase 1
  - No QCS, No Belle II solenoid
  - Basic machine tuning
  - Low emittance tuning
  - Vacuum scrubbing
    - Belle II people request enough vacuum scrubbing in this stage (before Belle II roll in).
    - At least one month at beam currents of 0.5~1A /ring.
  - DR commissioning starts before Phase 2.
- Phase 2
  - with QCS and Belle II (w/o Vertex detectors)
  - Low beta optics tuning
  - Small x-y coupling optics tuning
  - Beam collision tuning
  - Belle II background study
  - Target luminosity at this stage is $1 \times 10^{34}$ $cm^{-2}s^{-1}$
- Phase 3
  - Physics run (Vertex detectors installed)
  - Increase beam currents
  - Beam tuning continued to increase luminosity

# Construction status

# Vacuum system

- Fabrication

  Most of MR vacuum components which required for Phase 1 were already ordered, and will be completed soon.

- Baking and TiN coating

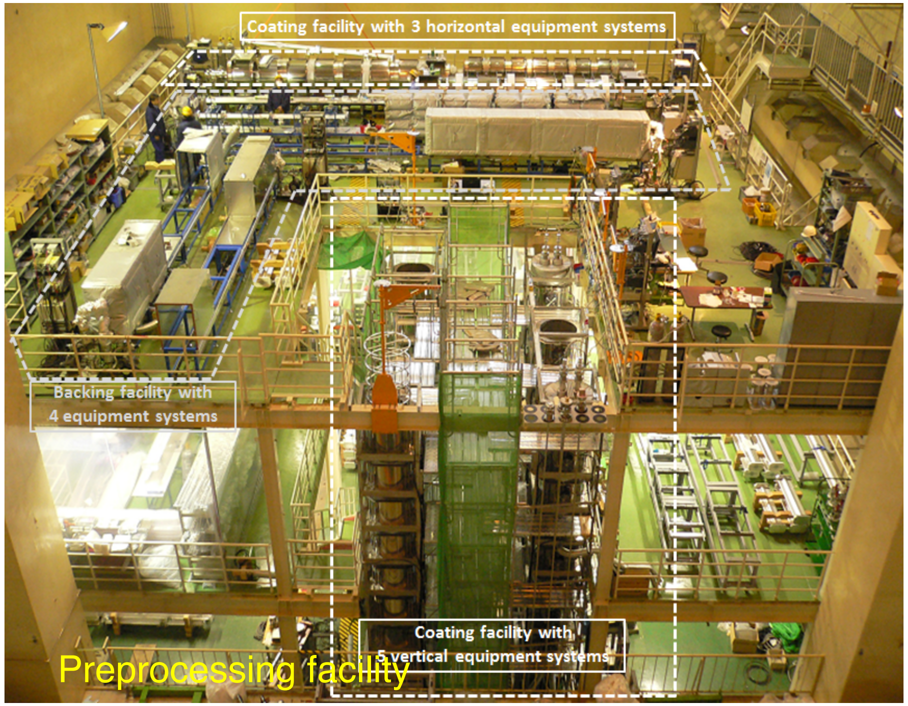
  More than 850 beam pipes have been TiN-coated using a facility in KEK site.

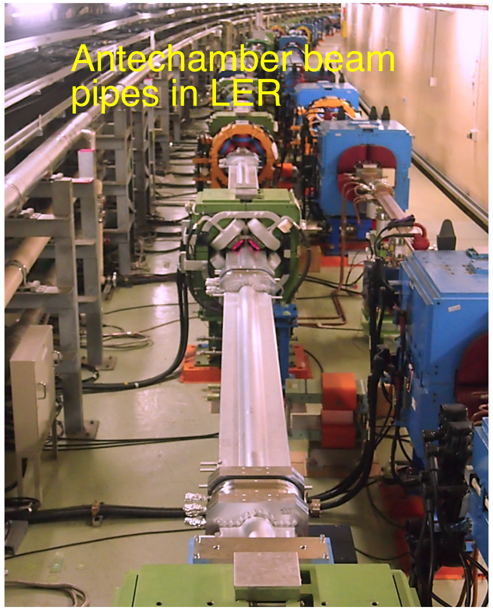
  Output: 10 ~ 15 beam pipes per week.

  Goal is about 1000 beam pipes.

- Installation

  Beam pipes and bellows started in JFY2013.

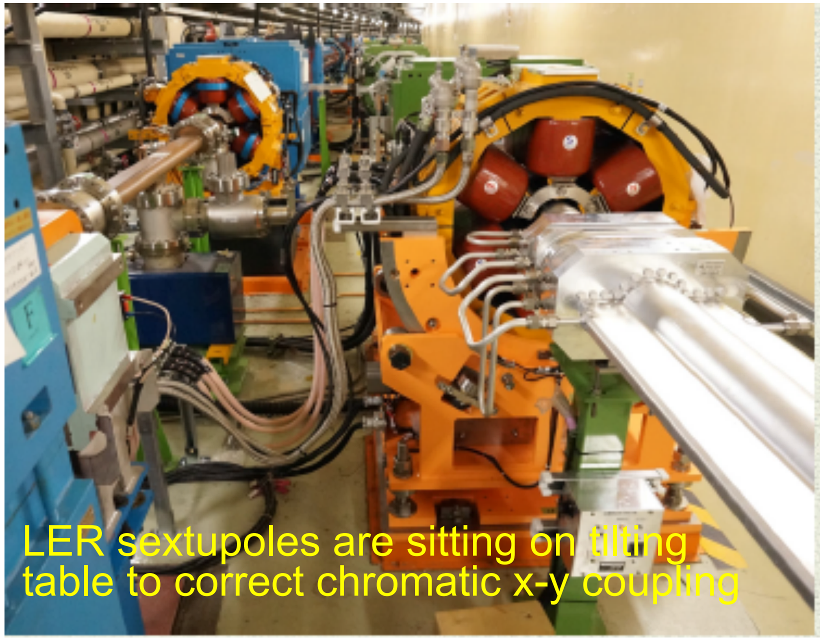




# Magnet System

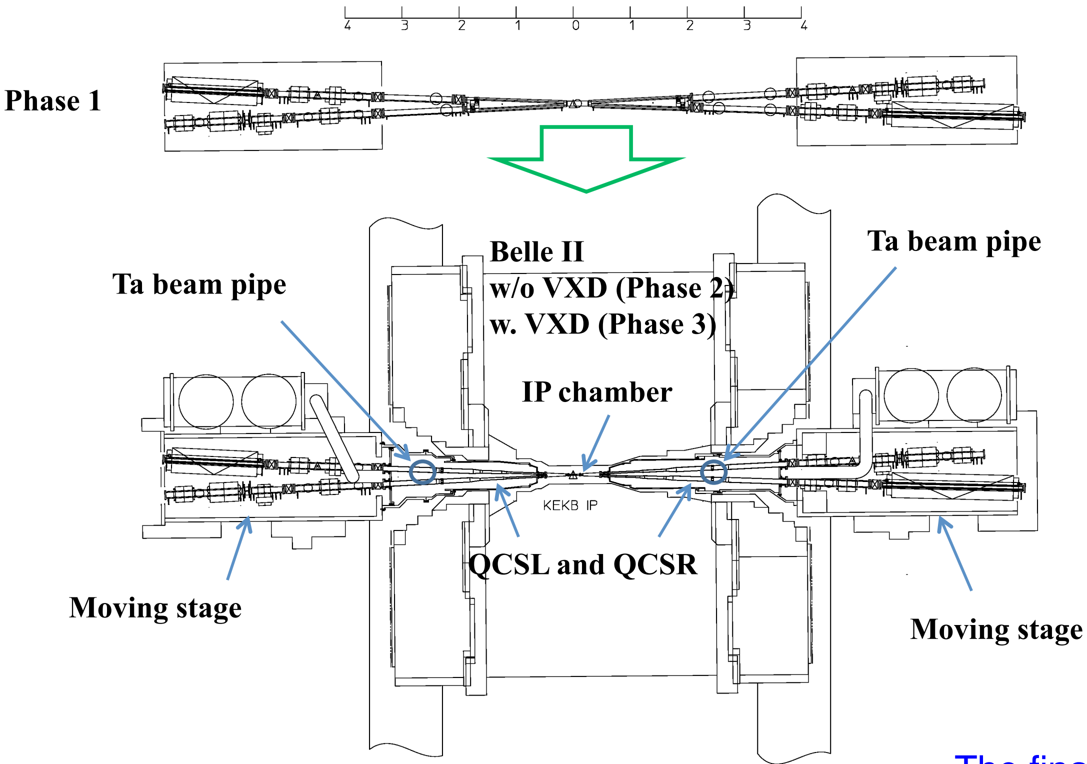
- Fabrication
  - Production of more than 500 new magnets has been completed.
- Field measurements
  - Most of new magnets already done.
- Installation and alignment.
  - 100 LER bending magnets have been replaced with new 4m length magnets.
  - Rearrangement of LER wiggler sections and new HER wiggler section is completed.
- Power supplies.
  - Production, install, and startup of MW class, 100kW class, and small class power supplies for magnets ongoing.
  - Cabling and piping of cooling water ongoing.

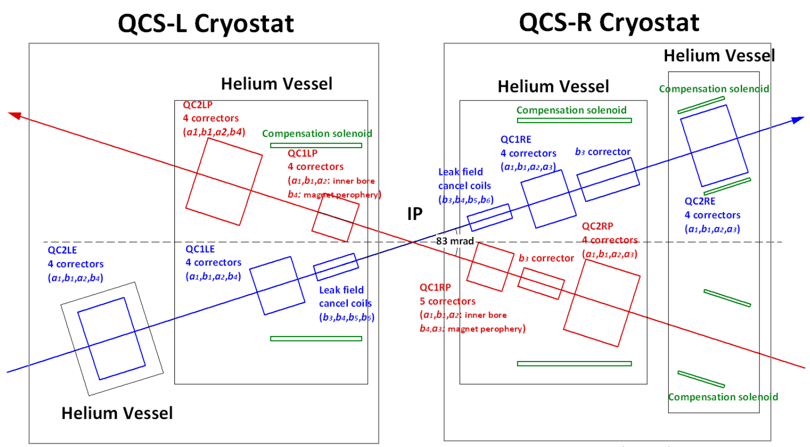


LER sextupoles are sitting on tilting table to correct chromatic x-y coupling

HER wiggler section and LER ARES cavities

# IR section



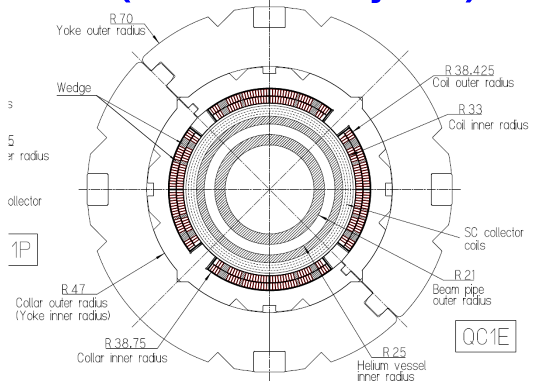




Target luminosity = 8 ×10$^{35}$ cm$^{-2}$ s$^{-1}$
Beam size at IP: e- = 62 nm, e+= 46nm

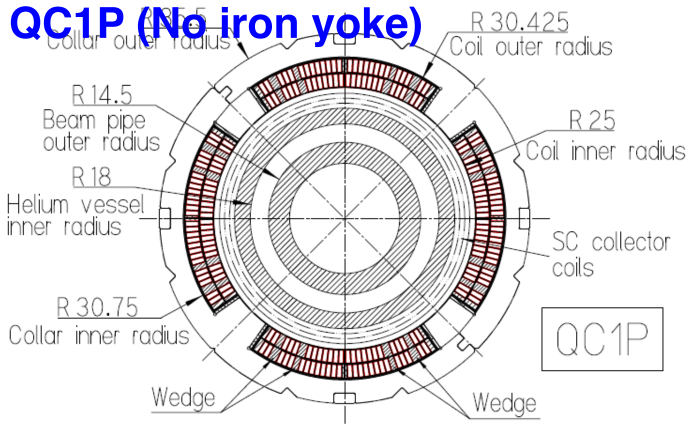
S.C. quadrupole: 8
S.C. solenoid: 4
S.C. corrector: 43

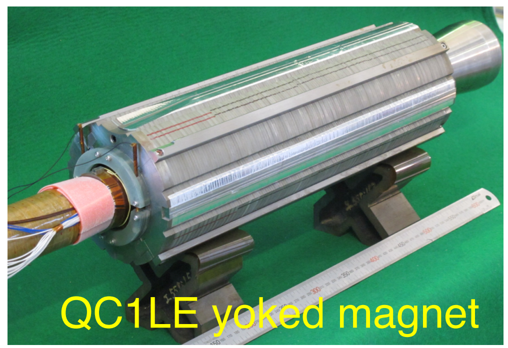
The final focus quadrupole magnets, QC1P and QC1E, were designed and constructed.

## QC1E (Permendur yoke)




## QC1P (No iron yoke)



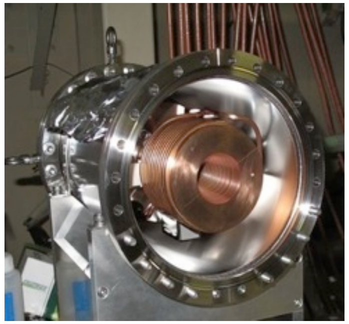



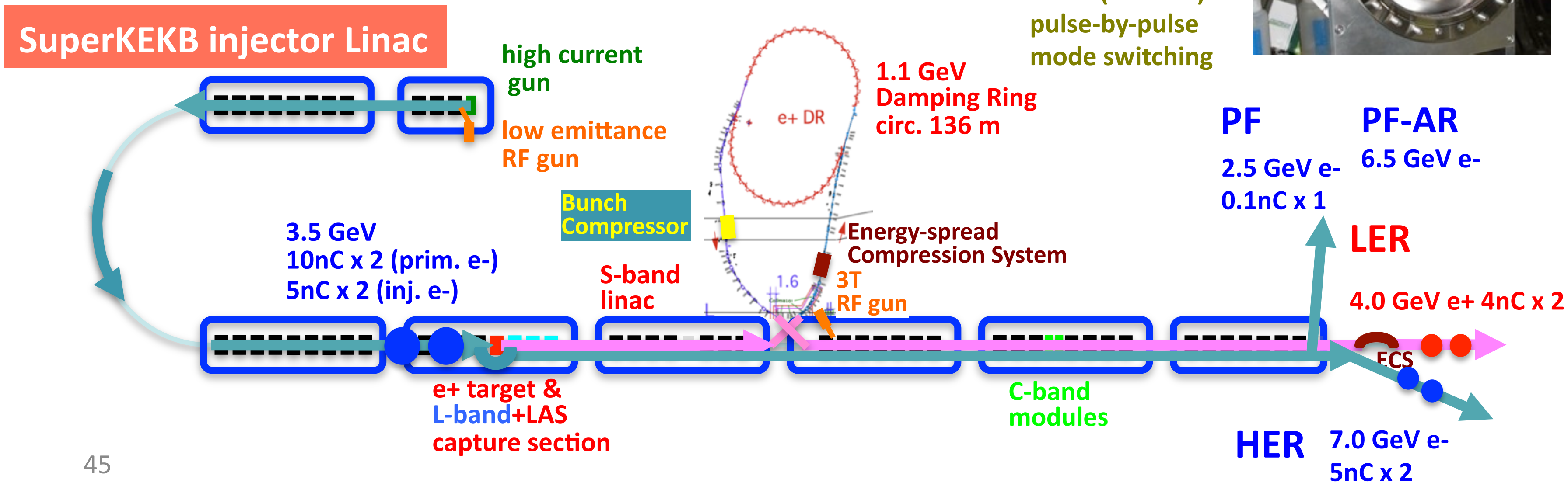
# Linac Upgrade for SuperKEKB

- Lower-emittance Injection Beam
  - To meet nano-beam scheme in the ring
  - Positron with a damping ring, Electron with a photo-cathode RF gun
  - Emittance preservation by alignment and beam instrumentation
- Higher Injection Beam Current
  - To meet larger stored beam current and shorter beam lifetime in the ring
  - 4~8-times larger bunch current for electron and positron
  - Reconstruction of positron capture section and electron gun
- Quasi-simultaneous injections into 4 storage rings
  - SuperKEKB $e^-/e^+$ rings, and light sources of PF and PF-AR
  - Improvements to beam instrumentation, low-level RF, controls, timing, etc

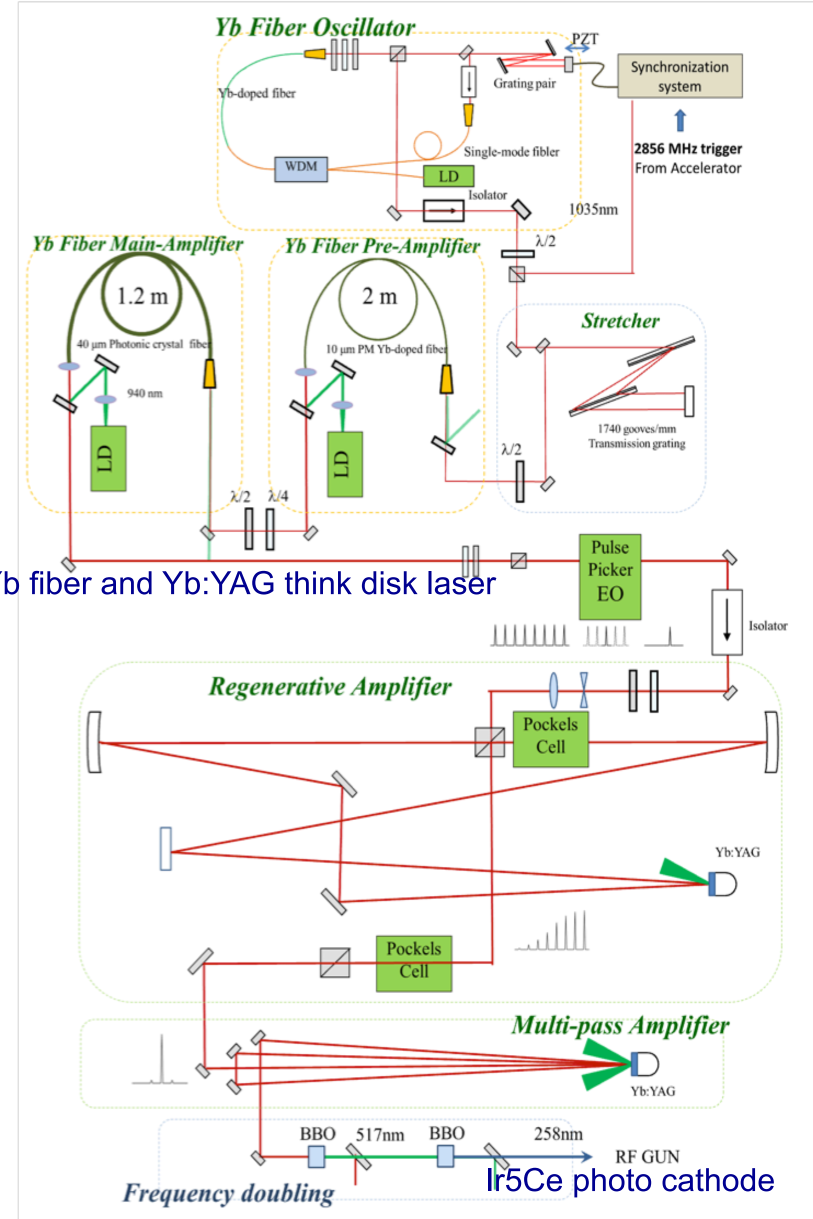
$Ir_5Ce$ photo-cathode

Flux Concentrator



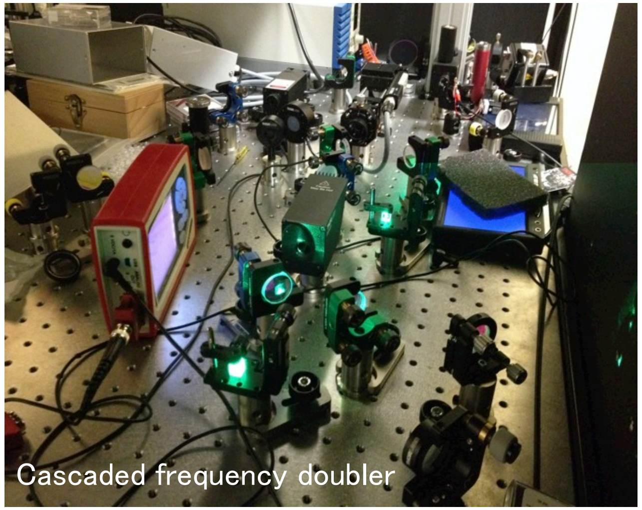


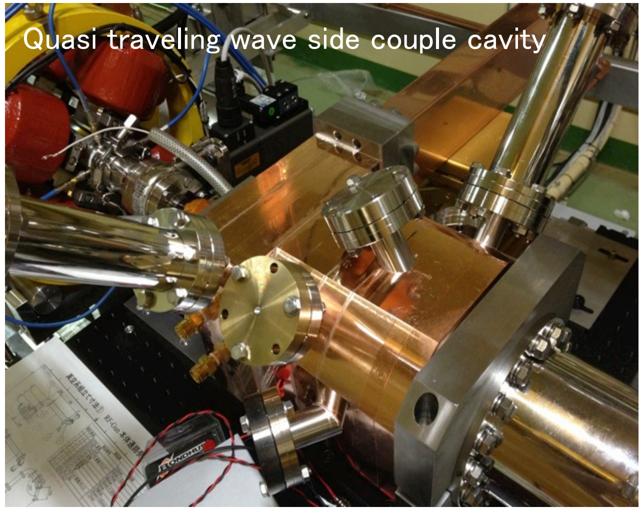
# Photo-cathode RF-gun Development




Yb fiber and Yb:YAG think disk laser

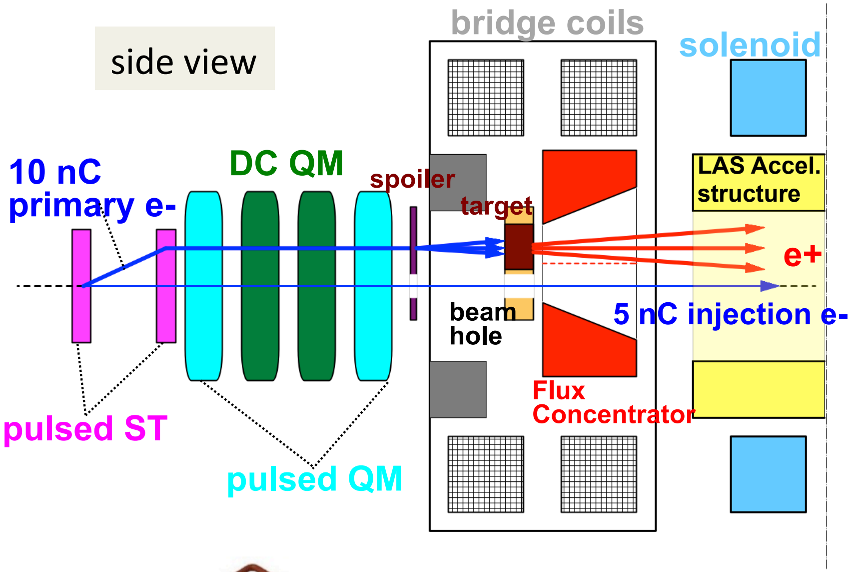
Ir5Ce photo cathode


Cascaded frequency doubler

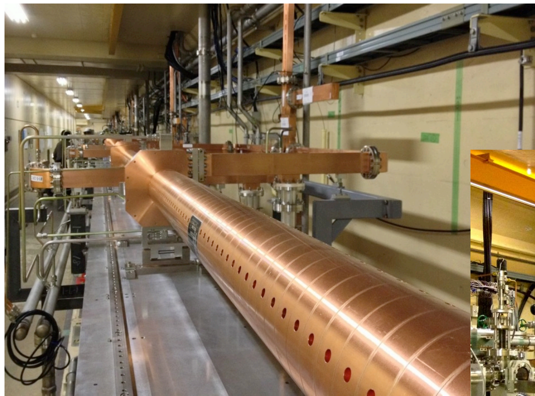

Quasi traveling wave side couple cavity

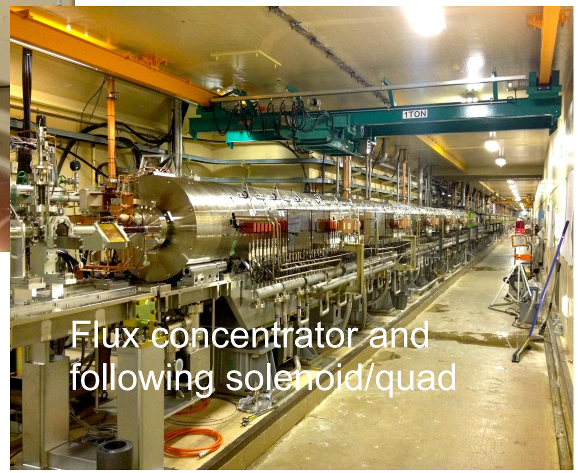
- 5.6 nC / bunch was confirmed
- Next step:
  50-Hz beam generation & Radiation control

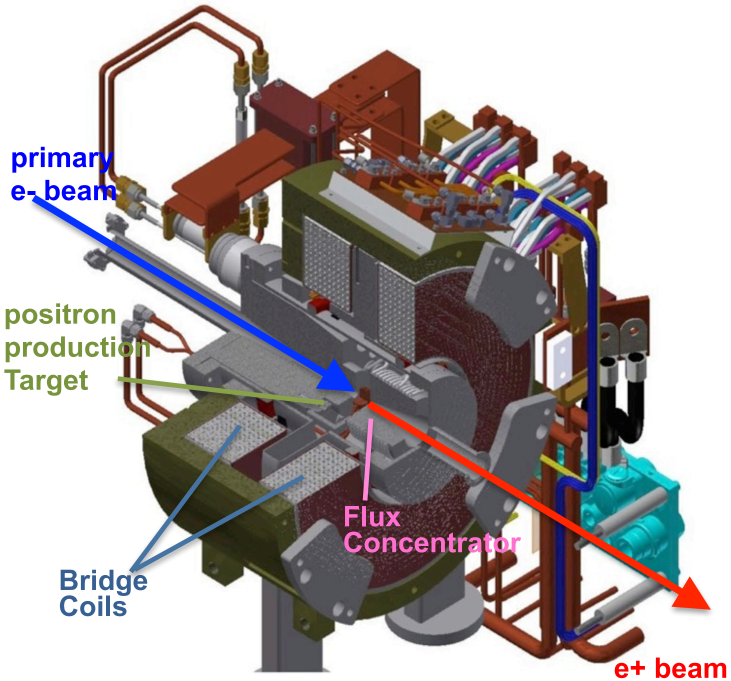
# Positron generation




Positron capturing with flux concentrator (FC)
and large aperture s-band structure (LAS)
Deceleration field to reduce satellite bunches
Pinhole beside target for electron beam
Protection system with beam spoilers





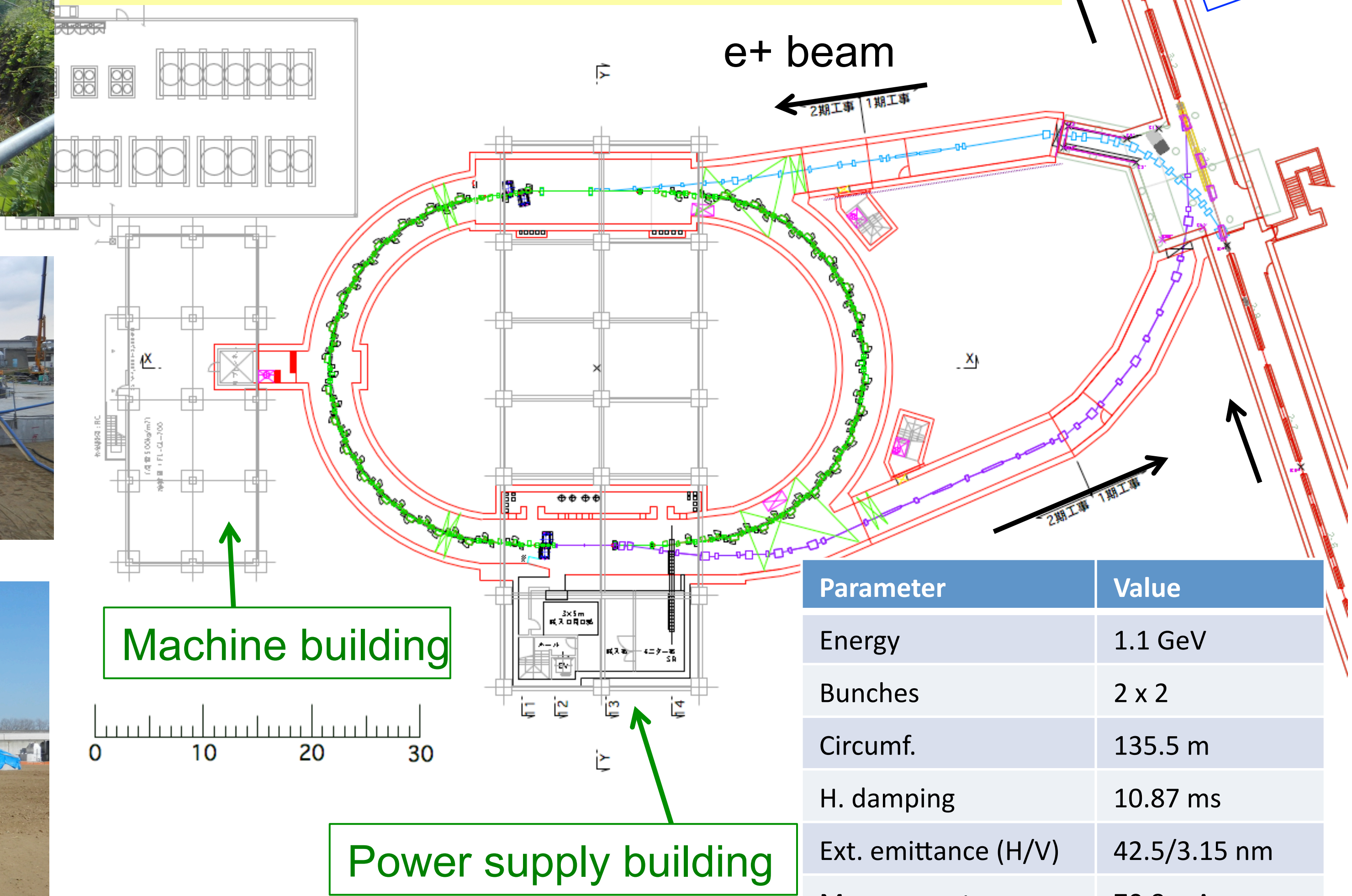

Beam test started with low magnetic field,
low primary beam current in June 2014.
Generated positron ~0.1nC was transferred to
the entrance of damping ring.
With higher magnetic and electric field, 4-nC
positron will be generated.

# New Damping Ring for positrons

DR tunnel construction




- Construction of the DR tunnel and buildings has been completed.
- Installation will start in JFY2014.
- DR commissioning will start before Phase 2 commissioning.




| Parameter | Value |
|---|---|
| Energy | 1.1 GeV |
| Bunches | 2 x 2 |
| Circumf. | 135.5 m |
| H. damping | 10.87 ms |
| Ext. emittance (H/V) | 42.5/3.15 nm |
| Max. current | 70.8 mA |

# Summary

J-PARC :

- Achieved beam power in user operation is :
  300 kW for MLF users, 240 kW and 24 kW for the T2K and hadron hall users, respectively.

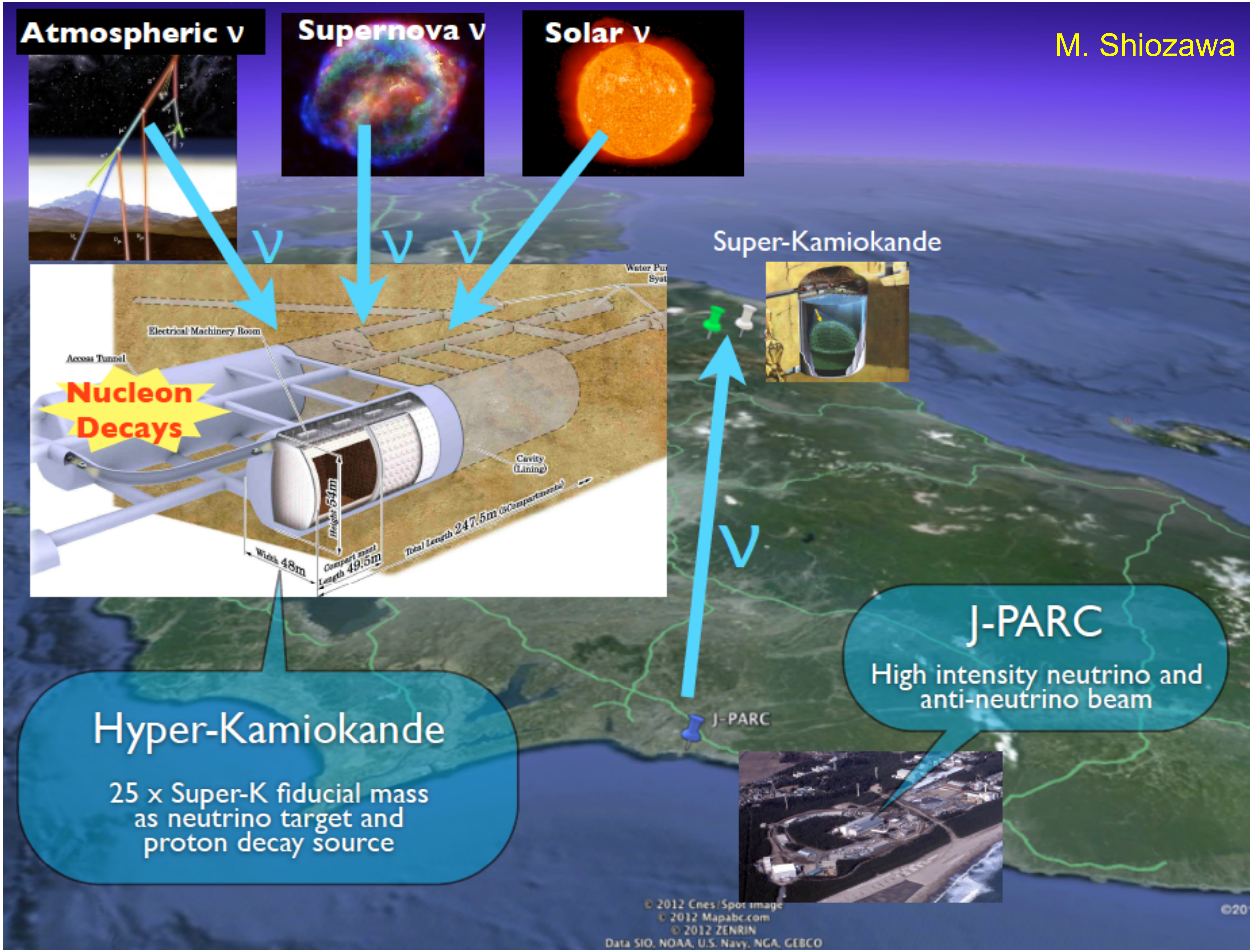
- The RCS will deliver the design beam power of 1 MW by middle of 2015.
- Goal of the 5 year mid-term plan is the design power of 750 kW for the FX, and 100 kW for the SX in 2017. The 750-kW beam is achieved by high rep. rate of 1 Hz with 30 GeV.
- R&D's of magnet power supply and high impedance rf cavity are now well in progress.

- Some scenarios to achieve beam power beyond current design for neutrino experiment are now under discussion; the 8 GeV booster, 9 GeV linac, etc.
- Increasing time availability of the slow extraction mode is one of the key issues for the future upgrade plan.

SuperKEKB:

- The construction of SuperKEKB has reached the final stage.
- The first beam will come in 2015.

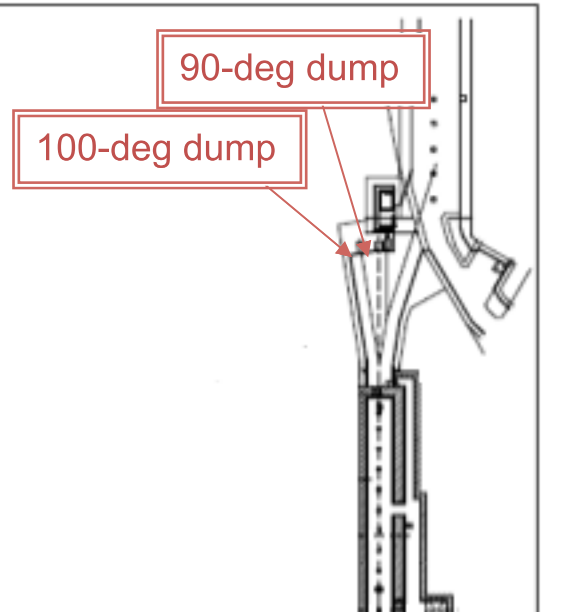
# Backup

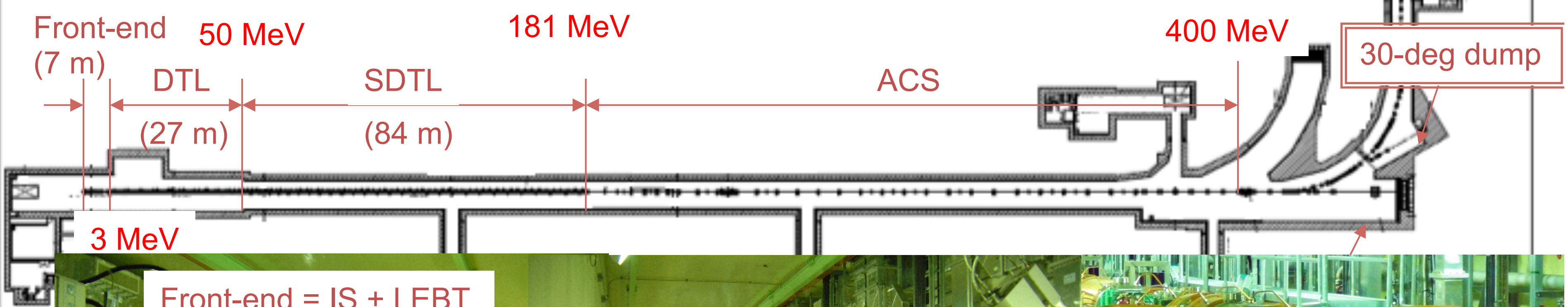


Atmospheric ν
Supernova ν
Solar ν
M. Shiozawa
ν
ν
ν
Super-Kamiokande
Electrical Machinery Room
Access Tunnel
Nucleon Decays
Cavity (Lining)
Total Length 247.5m (5Compartments)
Height 54m
Width 48m
Compartment Length 49.5m
ν
J-PARC
High intensity neutrino and anti-neutrino beam
J-PARC
Hyper-Kamiokande
25 x Super-K fiducial mass as neutrino target and proton decay source
© 2012 Cnes/Spot Image
© 2012 Mapabc.com
© 2012 ZENRIN
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

# Linac

- **Particle:** **$H^-$**
- **Energy:** **181 MeV (~ May 2013)**
  **400 MeV (Jan. 2014~) by installing ACS**
- **Peak current:** **30 mA at present**
  **50 mA by replacing front-end in 2014**
- **Repetition:** **25 Hz**
- **Pulse width:** **0.5 msec**

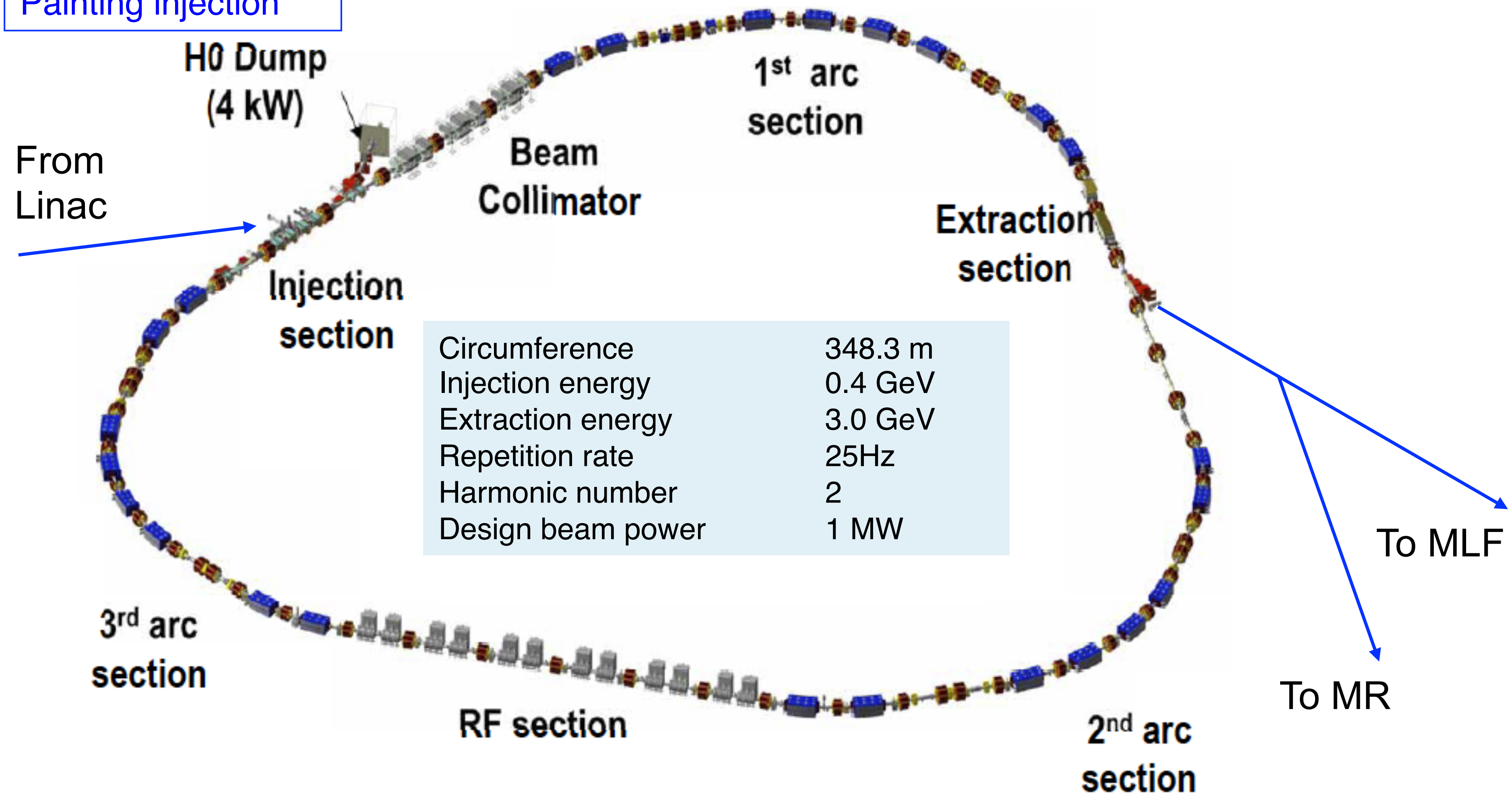



# RCS (Rapid Cycling Synchrotron)

Two purposes of the RCS:
- Proton driver for neutron/muon production in MLF
- Booster of the MR injection

Charge-exchange & Painting injection

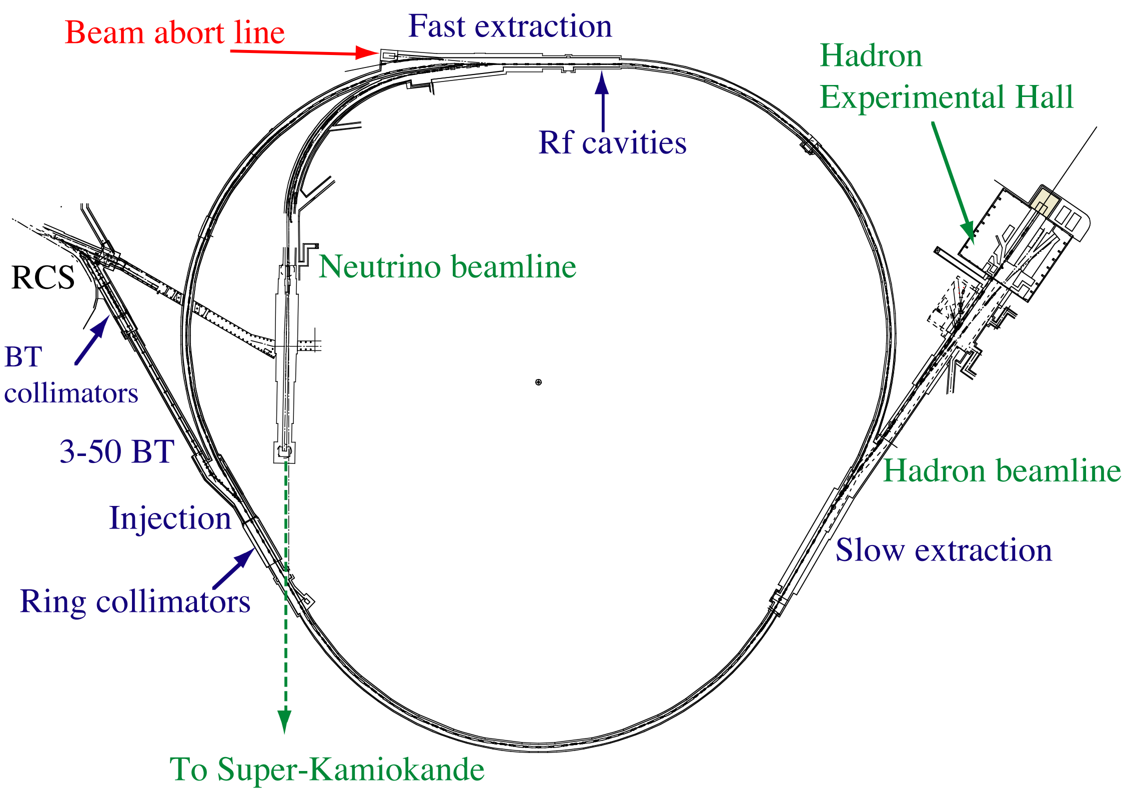



| | |
|---|---|
| Circumference | 348.3 m |
| Injection energy | 0.4 GeV |
| Extraction energy | 3.0 GeV |
| Repetition rate | 25Hz |
| Harmonic number | 2 |
| Design beam power | 1 MW |

# Main parameters of MR

| | |
|---|---|
| Circumference | 1567.5 m |
| Cycle time | 6 s for SX |
| | 2.48 s for FX |
| Injection energy | 3 GeV |
| Extraction energy | 30 GeV |
| Superperiodicity | 3 |
| h | 9 |
| Number of bunches | 8 |
| Rf frequency | 1.67 - 1.72 MHz |
| Transition $\gamma$ | j 31.7 (typical) |

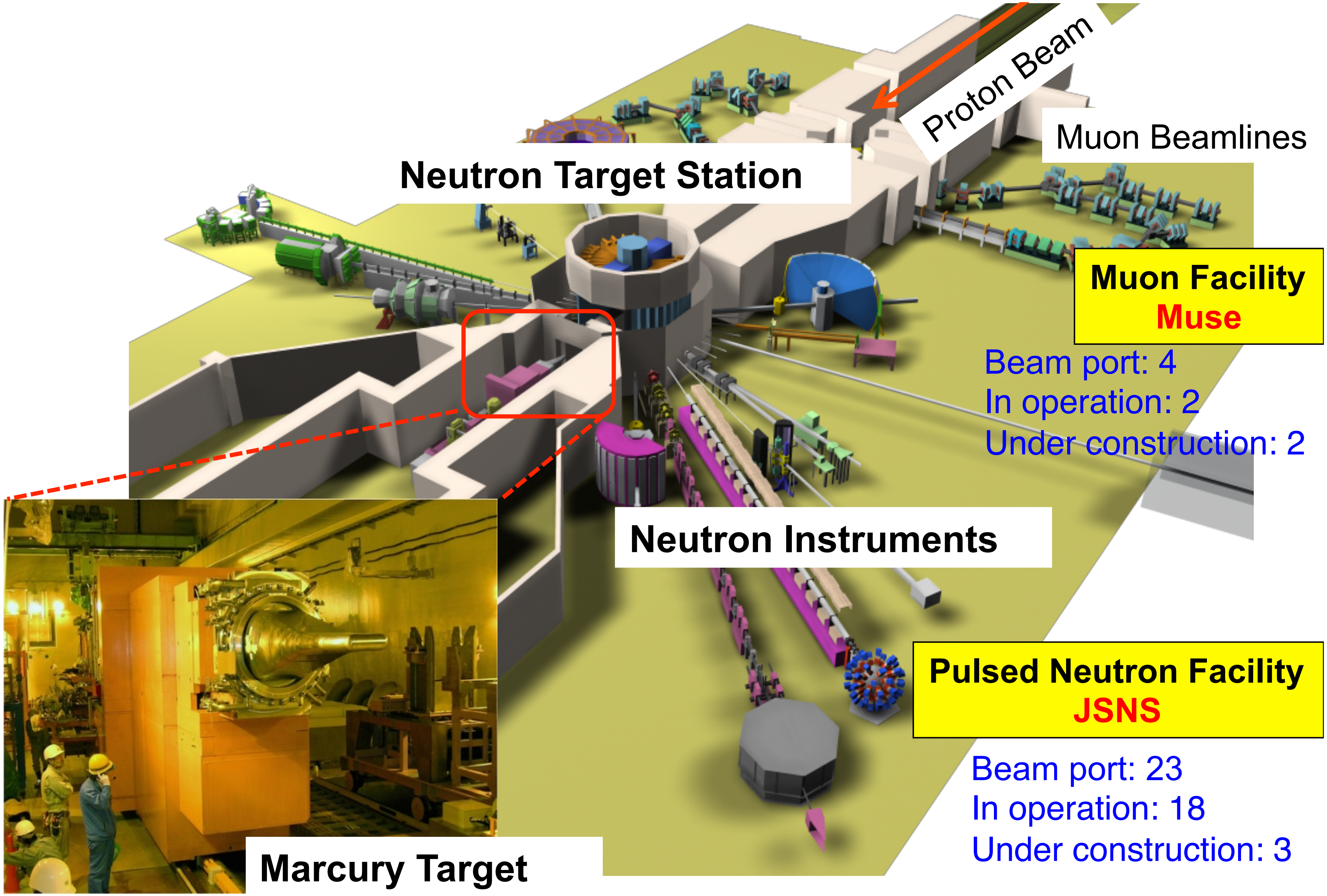
| | |
|---|---|
| Physical Aperture | |
| 3-50 BT Collimator | 54-65 π.mm.mrad |
| 3-50 BT physical ap. | > 120 π.mm.mrad |
| Ring Collimator | 54-65 π.mm.mrad |
| Ring physical ap. | > 81 π.mm.mrad |




**Three dispersion free straight sections of 116-m long:**

- Injection and collimator systems
- Slow extraction (SX)
  to Hadron experimental Hall
- MA loaded rf cavities and Fast extraction(FX) (beam is extracted inside/outside of the ring)
  outside: Beam abort line
  inside: Neutrino beamline ( intense ν beam is send to SK)

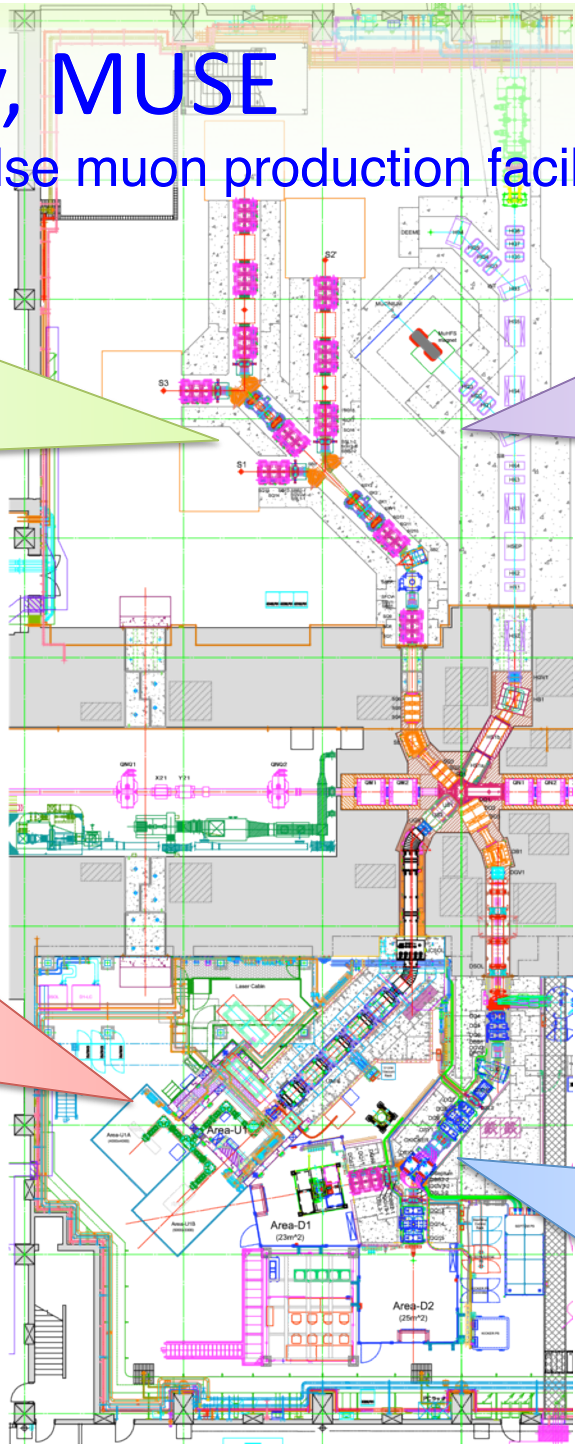
# Materials & Life Science Experimental Facility (MLF) with Neutron and Muon Beams



# Muon facility, MUSE

Slide by MUSE group

## The world highest pulse muon production facility




**S-line** μ⁺

Slow beam (4 MeV), dedicated to bulk μSR ultralow tem-perature/ high magnetic field/ pulsed excitations. (S1:2014~)

**H-line** μ±

Slow (4 MeV) ~ fast (50 MeV) beam, for particle physics (g-2, EDM), atomic physics ("precision frontier")

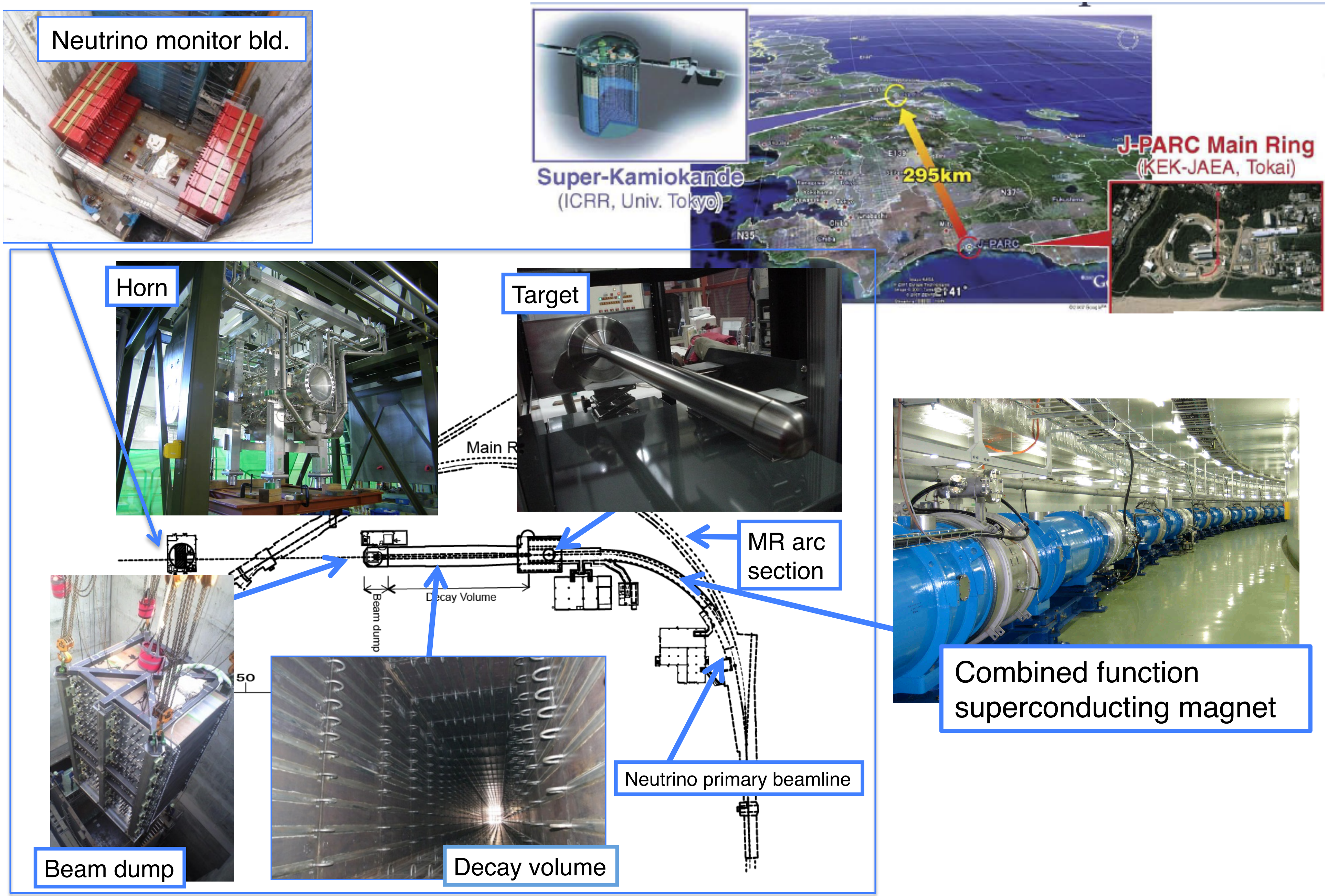
**U-line** μ⁺

Ultra slow beam (0.1~ 30 keV), near-surface, sub-micron scale condensed matter physics, chemistry, etc. (2014~)

**D-line** μ±

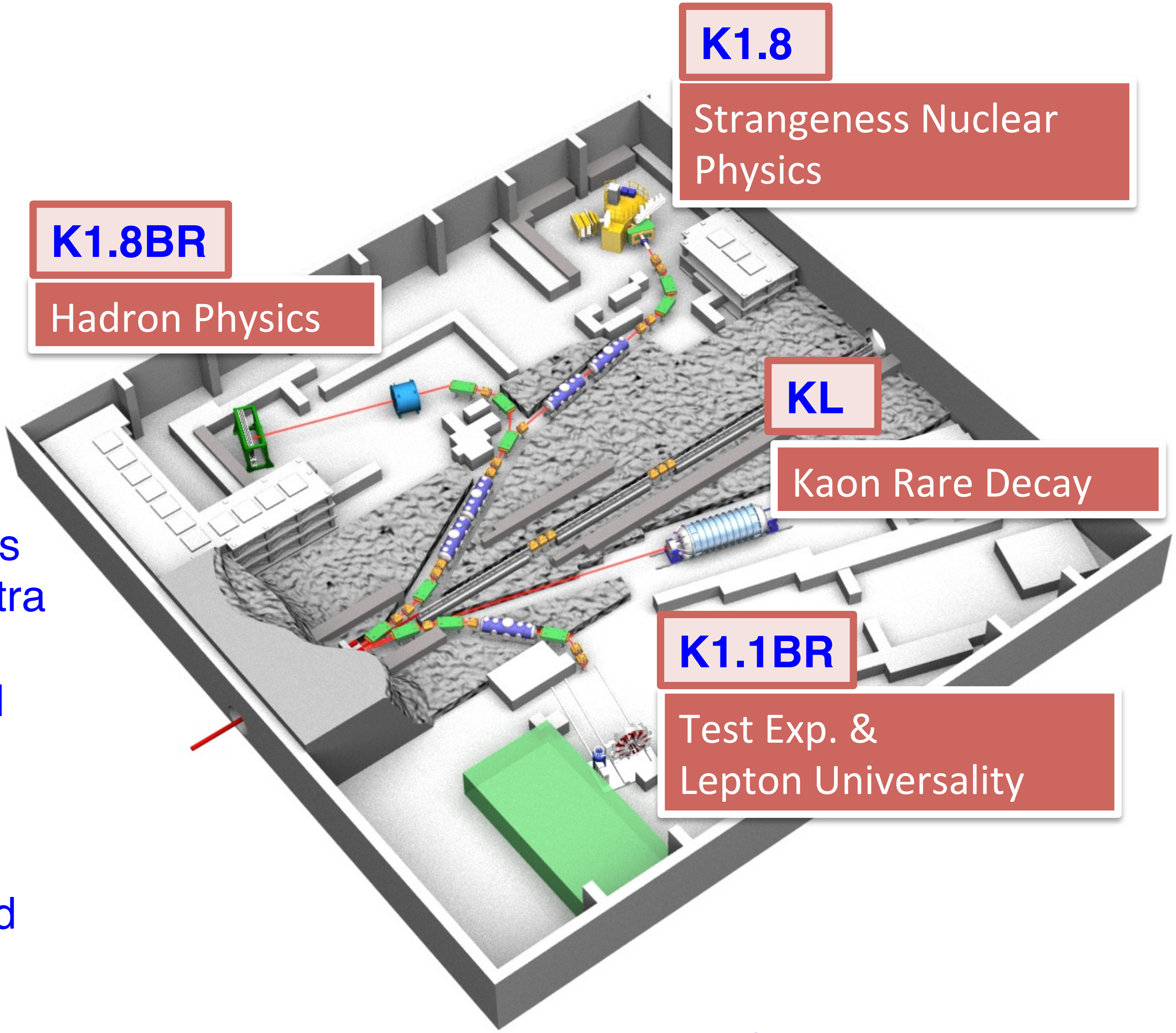
Slow (4 MeV) ~ fast (50 MeV), general-purpose beamline with 2 exp. areas. (2009~)

# Neutrino Beamline and T2K experiment



# Experiments at Hadron Hall

Experiments at Hadron Hall utilize primary beam and secondary beams including Pion, Kaon and Muon.




- Explore nuclear physics with strangeness for ultra high-density nuclear-matter and generalized nuclear force
- Search for rare Kaon decays for CPV beyond CKM

Slide by Hadron group