

CERN and KEK cooperation for high intensity beam facility at J-PARC

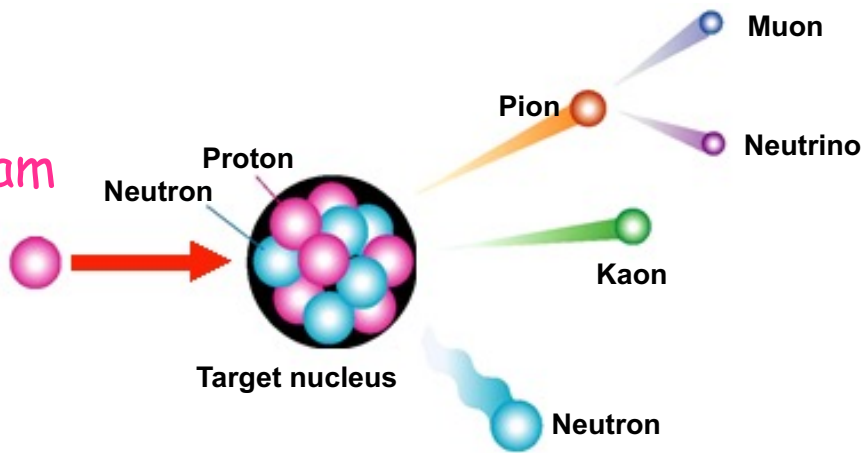
2023/12/7, CERN-KEK committee meeting
K.Sakashita (KEK/J-PARC)

Some slides courtesy of Y.Sugiyama, C.Omori, K.Sato, T.Ishida, R.Muto (KEK/J-PARC)

Various experiments at J-PARC

Intense proton beam

Proton beam
3 GeV, 30 GeV



T2K & HK



Hadron Experiments

COMET

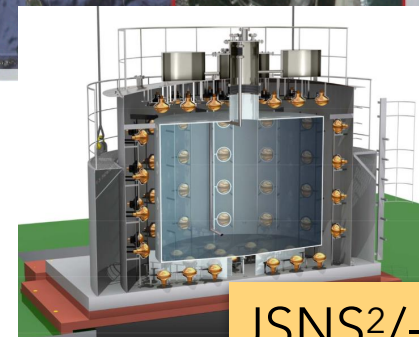
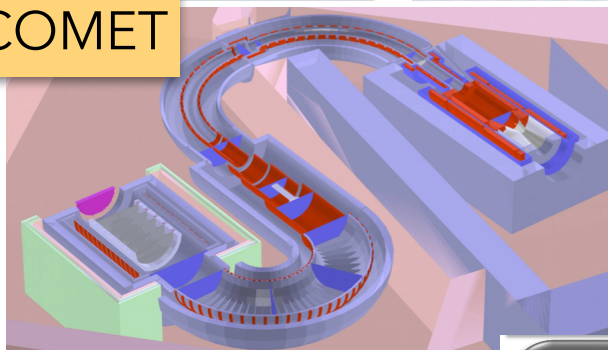
Exploring the mysteries in the process of material formation

高エネルギーの光
中性子 n
陽子 p
K中粒子
シタ粒子 θ^+
中性子

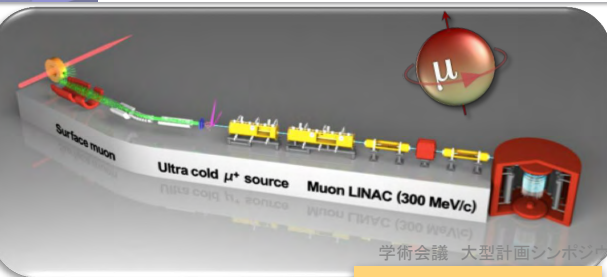
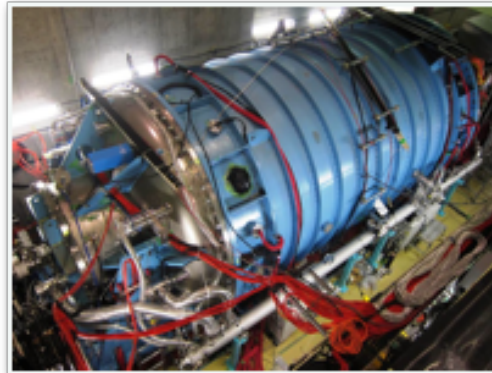
1st gen: u, d, ν_e , e
2nd gen: c, s, ν_μ , μ
3rd gen: t, b, ν_τ , τ

Strong force: g (gluon)
Electro-Magnetic force: γ (photon)
Weak force: W, Z (Weak boson)
Higgs boson

陽子
中性子
 Δ 粒子
sクォーク
dクォーク
uクォーク
ストレンジクォークを含む物質



JSNS2/-II

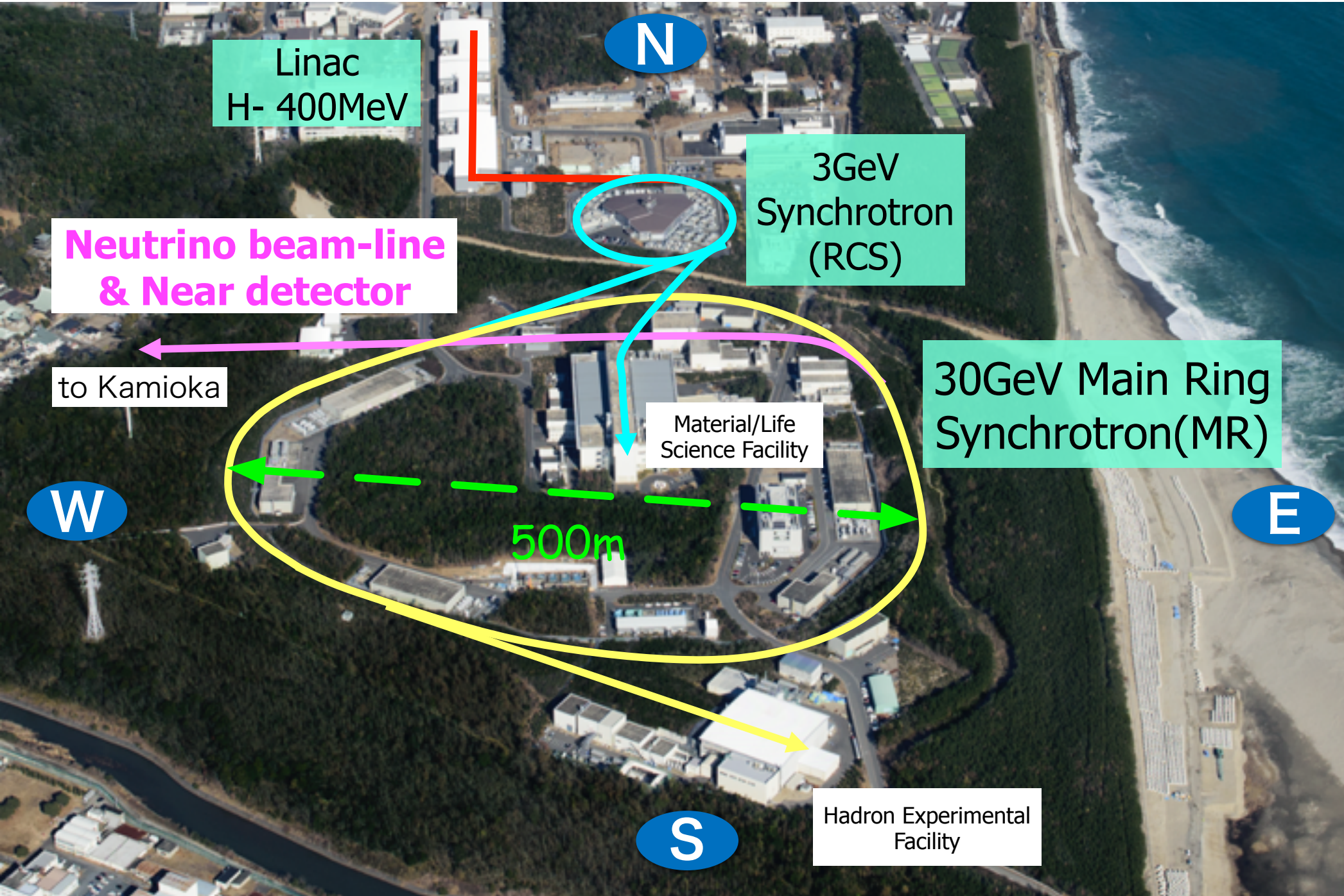


g-2/EDM

KOTO

(this page mainly shows particle/nuclear experiments)

J-PARC accelerators at Tokai



CERN & J-PARC cooperation

- Originally started around 2009 on proton LINAC reinforcement
- Agreement document for cooperation among KEK/JAEA/CERN for proton LINAC on 2011 (“arrangement”)
- Amendment No. 1 on 2016 to include beam dynamics studies/RF/LLRF/beam commissioning
- Amendment No. 2 on 2019 to include beam intercepting devices (targets/beam window/collimators/dump), high intensity target facility related items

Common technical challenges for high intensity facility

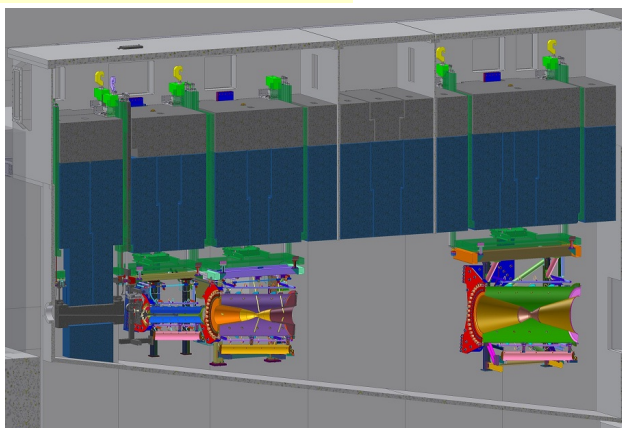
RF(Cavity, Amp)



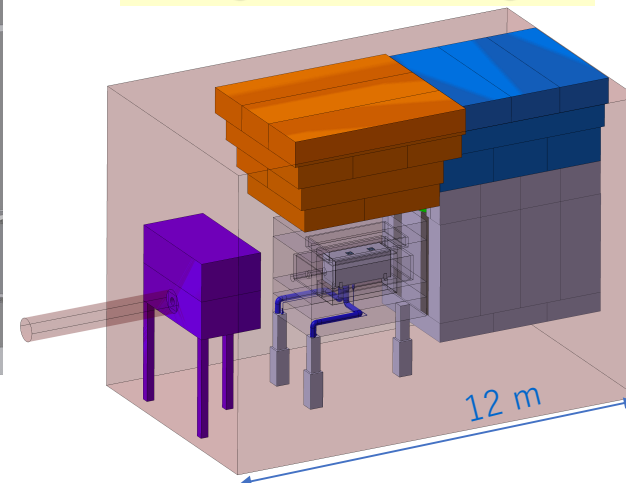
R&D, know-how exchange on radiation safety protection

J-PARC Neutrino Facility Target Station

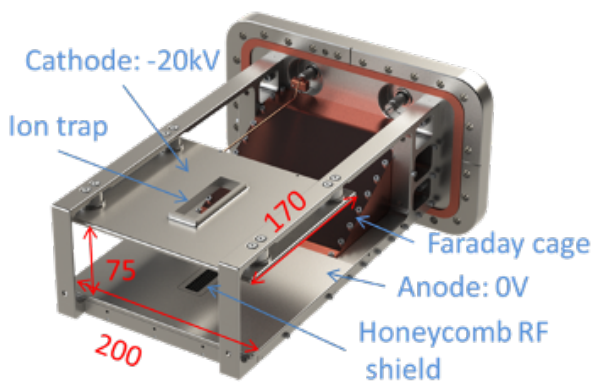
(e.g. Tritium handling in the water, air)



CERN Beam Dump Facility Target Station Design

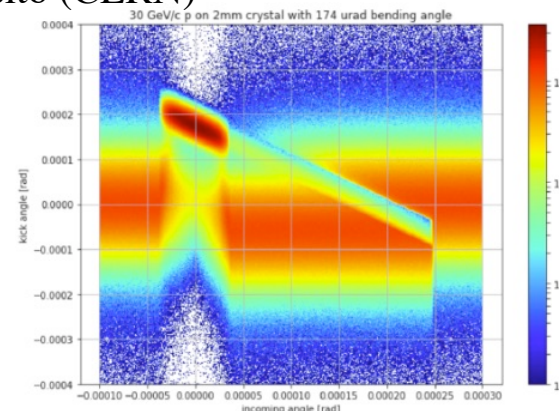
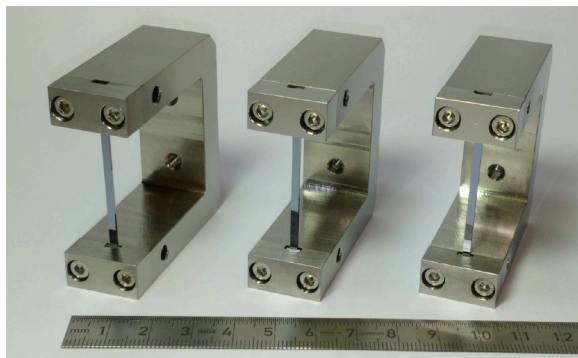


Beam monitors for high intensity beam



Slow extraction

M.A. Fraser, F. M. Velotti, L.S. Esposito (CERN)



Various collaborative research projects in many different fields

Workshop for CERN/JPARC/KEK collaboration on high intensity accelerator/beamline was held on 2019.Oct. @CERN

<https://indico.cern.ch/event/847104/>

- Discussed for beam instrumentation, RF, beam dynamics, slow ex., J-PARC neutrino facility, target, ^3H , Horn, HiRadMat, H2 Low-E, H⁻ source, R2E
- Facility tour



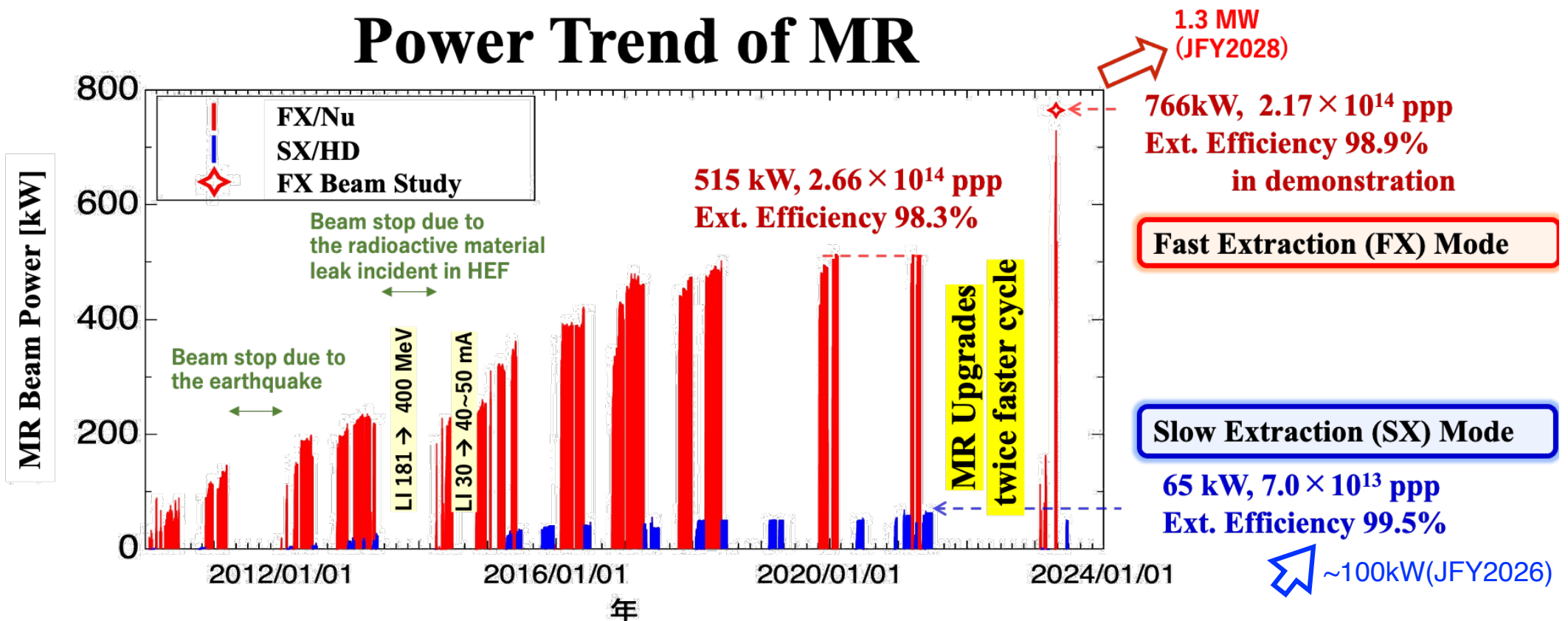
Plan to have next workshop on 2024 at Japan

- Started discussion with S.Gilardoni, M.Calviani (CERN) and J-PARC accelerator/neutrino/hadron facility groups
- **Topics including existing collaborative projects as well as new items** : e.g. various targets and absorbers (COMET, Hadron target facility), He gas conservation etc.

MR status and power upgrade plan

- 610kW (FX) and 65kW (SX) stable operation established up to now
- Plan to upgrade beam power to 1.3MW (FX) with RF, beam instrumentation, collimator upgrades

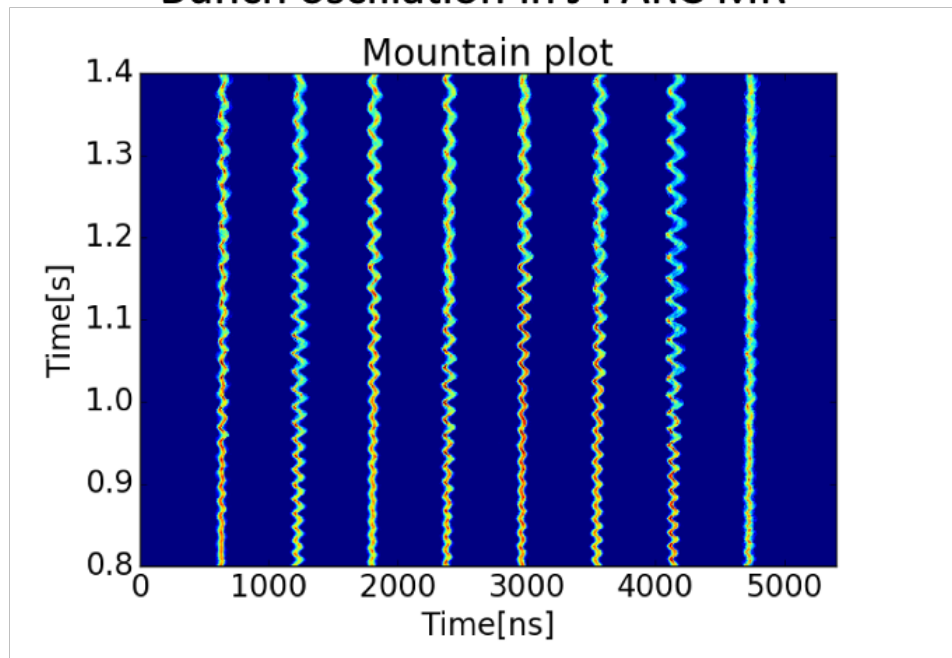
Power Trend of MR



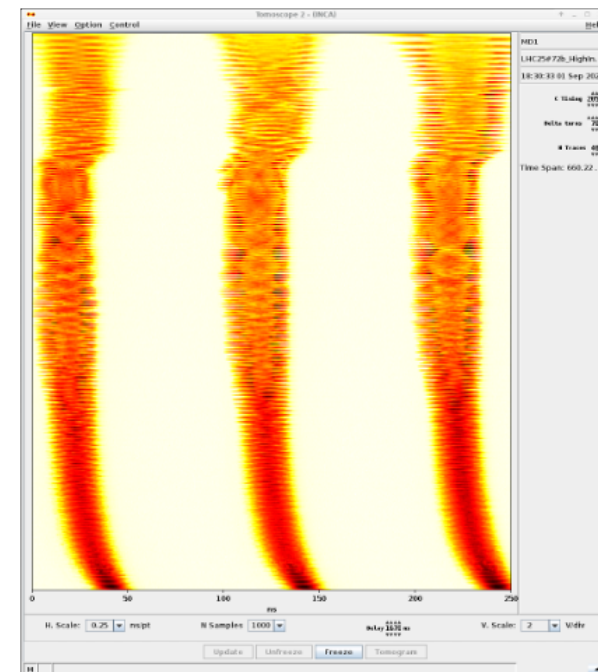
LLRF collaboration between CERN/J-PARC

- CERN PS and J-PARC MR: Proton Synchrotron with same range of energy. (CERN PS: 2~26GeV, J-PARC MR: 3~30GeV)
- Two machine share common issue to achieve high intensity proton acceleration: **Coupled Bunch Instability (CBI)**.
 - Wakefields induced by one bunch affect the next and cause the bunch oscillation.
 - Large bunch oscillation can lead to the loss of beam.

Bunch oscillation in J-PARC MR



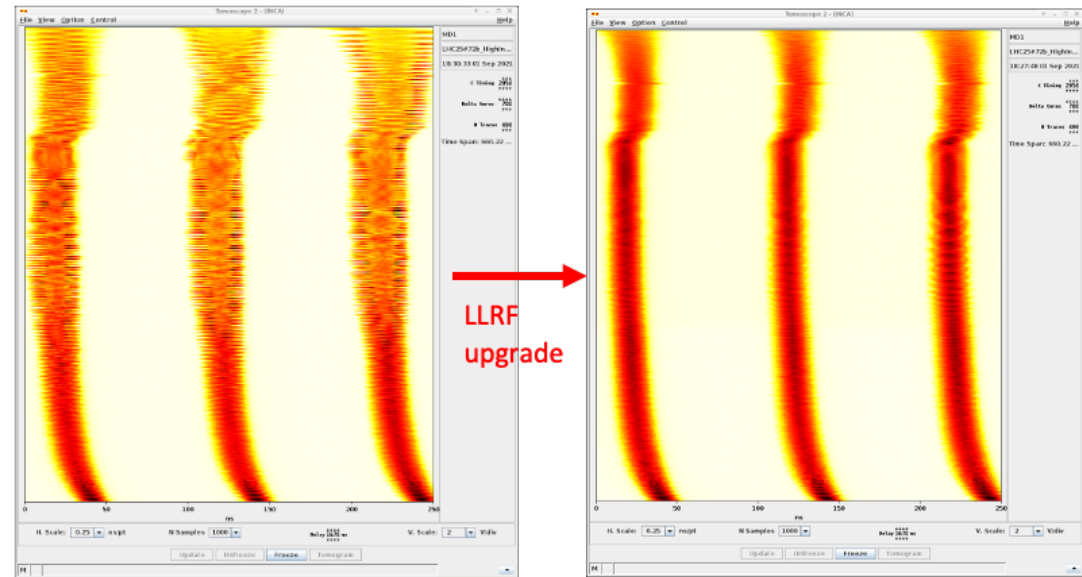
Bunch oscillation in CERN PS



LLRF upgrade for CBI mitigation

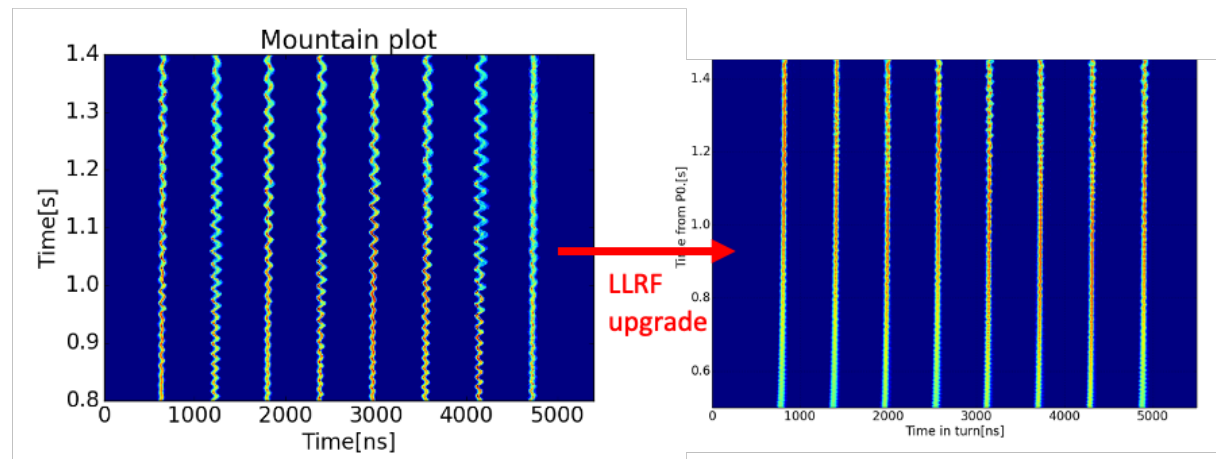
Bunch oscillation in CERN PS

- CERN and J-PARC exchange the ideas and knowledge for CBI mitigation.
 - Helped the design of upgraded LLRF system on each side.
- Dipole oscillation (bunch motion) was successfully suppressed with new LLRF system.
- Quadruple oscillation (amplitude variation) is considered to be the next target for the mitigation.

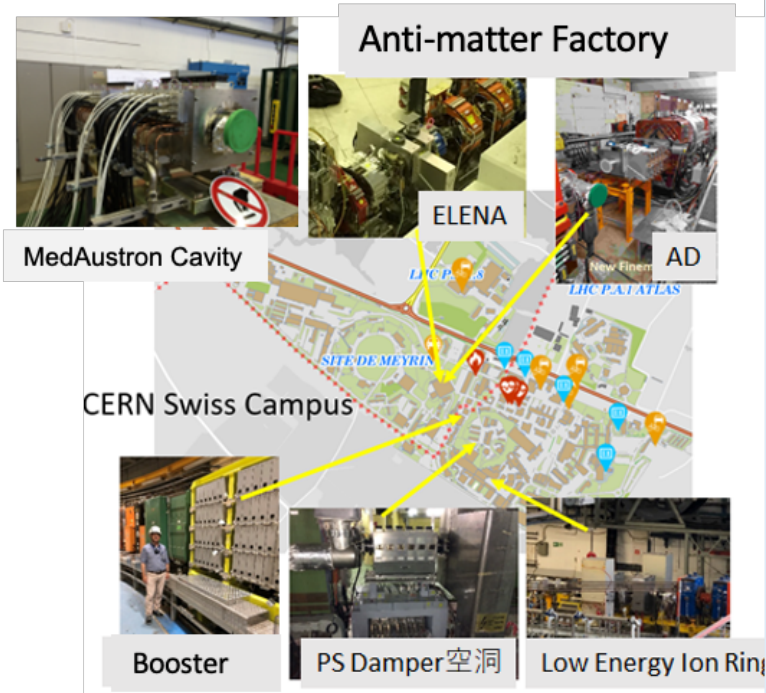


Courtesy of
CERN PS RF group

Bunch oscillation in J-PARC MR



20-years collaboration on RF



- **Wideband cavity technology using Magnetic alloy, Finemet, loaded cavity**

- PS Booster
 - Replacements of all ferrite cavity systems to MA cavities
- PS
 - Installation of a wideband damper cavity system for longitudinal coupled bunch instability (CBI)
 - Damper system is also used as a barrier RF for SPS users
- Anti-proton (AD and ELENA)
 - Deceleration of anti-proton to 100 keV
- Low Energy Ion Ring
 - Acceleration of Lead ion beam

In addition, contribution to Med-Austron RF system

- 40 MHz cavity R&D (On-going)

- **Robust solid-state Amplifiers**

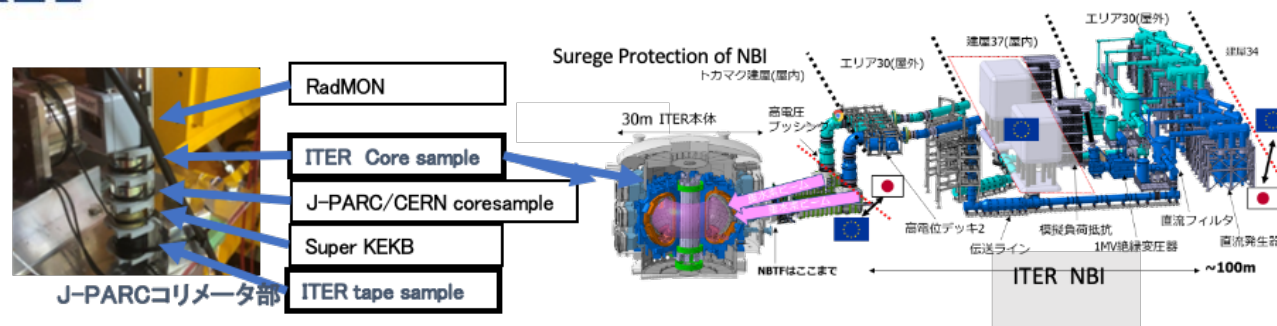
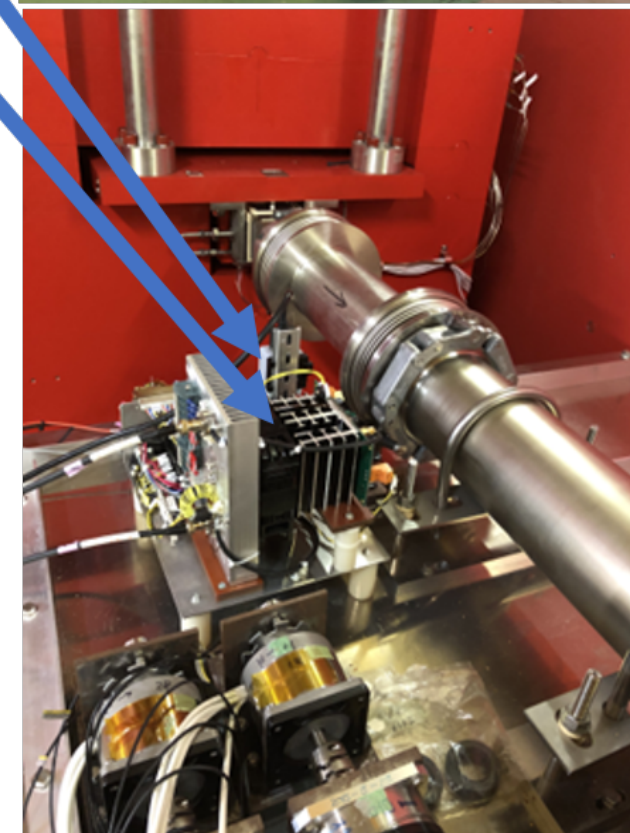
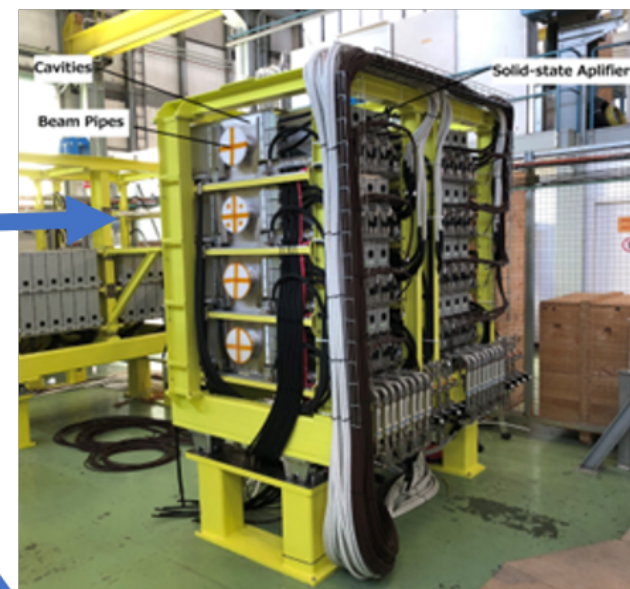
- CERN technology has been used for 150 AMP units in RCS and MR
- 20kW amplifier for RCS upgrade



Radiation test (2013~)

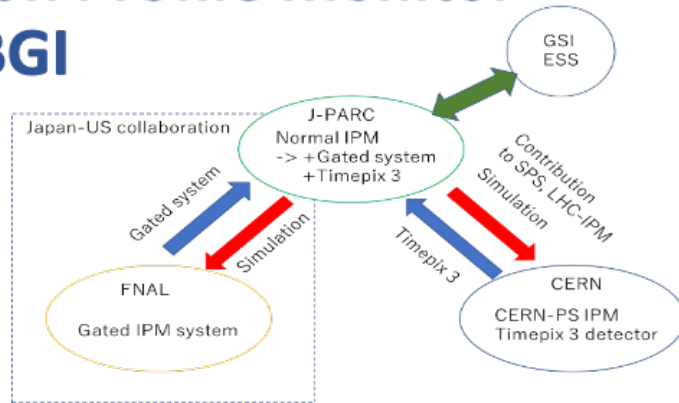
For developments of Rad-hard solid-state amplifier for LIU

- Booster RF amplifier using Silicon VMOS-type MOSFET
 - Single event effects were observed for LDMOS-type
 - MR collimator area has been used for irradiation test of amplifier
- Usage of CERN RADMON to measure TID and neutron flux
- On-going test of solid-state amplifier using GaN devices for improvement of feedback amplifier of PS 10 MHz RF system
- Irradiation tests/Measurements of other devices using RADMON:
 - MA cores for accelerator uses, Glue, Rad-hard CID camera
 - Disaster prevention system for accelerator tunnels
 - MA core for ITER NBI (see below)
 - Measurements of single event effects in T2K target building
 - Single event measurements of 3NBT beam line

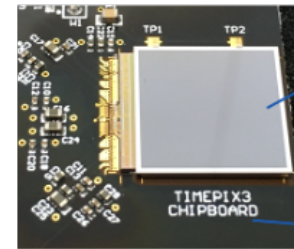


Beam monitor : on-going collaboration

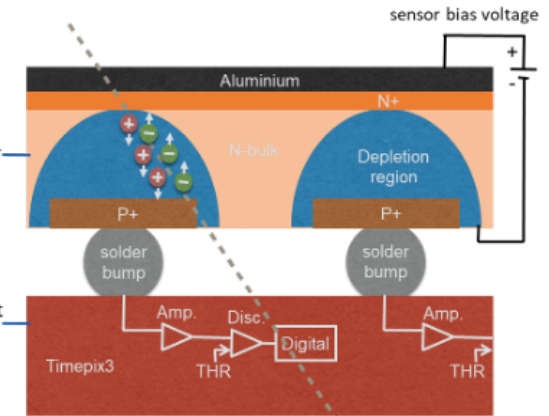
• Ionization Profile Monitor (IPM)=BGI



• Fast Beam loss monitor (Timepix3 base)

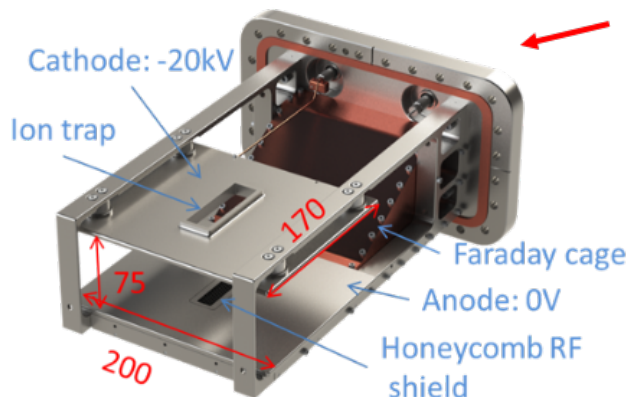


Si multi-pixel detector
256 × 256 pixels
55um in size



13th March 2019

J-PARC Seminar
Courtesy by J. Storey



J-PARC - CERN collab. on CPS-IPM

An ion trap structure was developed and installed in the CERN PS IPM. Gave a radical solution of the influence of secondary electrons.

Many concerns of IPM for high intensity beams

- Profile distortion by the **strong beam space charge field**
 $E \sim \text{a few MV/m} \Rightarrow$ Accuracy limitation?
- Profile distortion simulation \Rightarrow Sim. code dev.
- Detector issue
MCP (J-PARC, FNAL)
New detector! : Timepix3 Si sensor (CERN)
- HV Gated system (FNAL, J-PARC)
Realized at FNAL firstly and the transferred to J-PARC

In 2019, J. Storey (CERN) stayed at J-PARC to discuss the appl. of Timepix3

J-PARC is interested in its appl. as **BLM**.

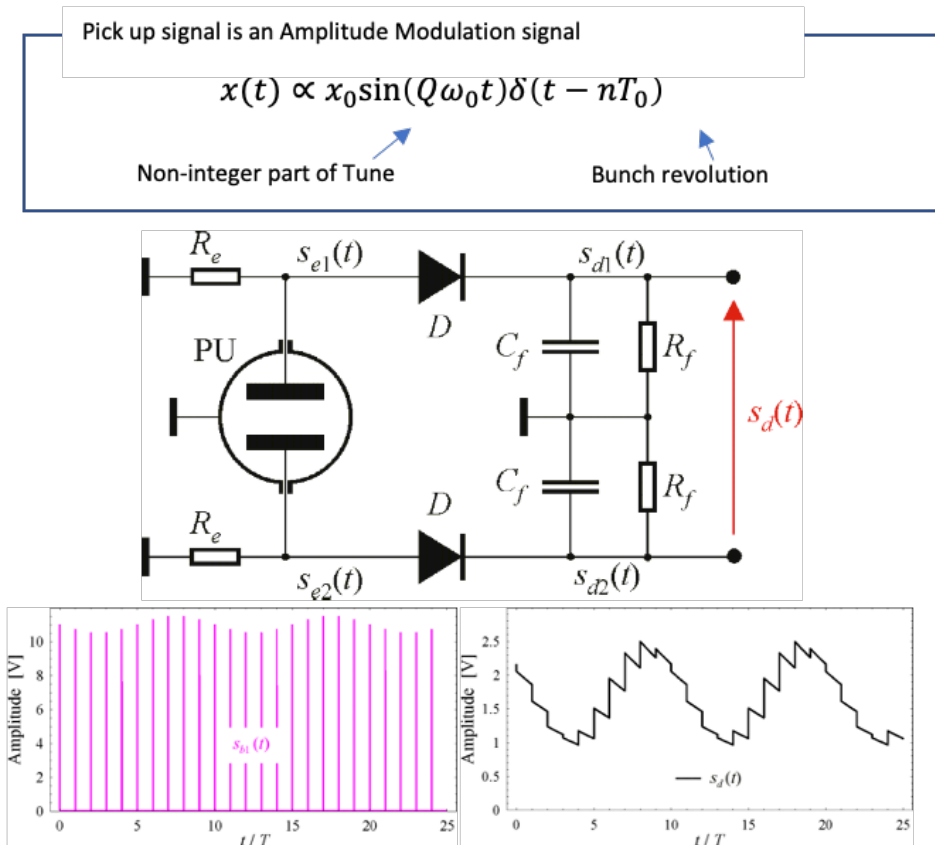
Multipixel 55um size Si sensor, on-chip digital sampling, rad-hard system

- Collision angle determination -> Loss point
Particle tracking in Si
Point to point coincidence between two Timepix3 detectors
- Energy deposit determination -> Particle ID
Fast Neutron detection using converter
Charged K, π , μ : as a MID particle

KEK is not a part of Timepix3 consortium \Rightarrow Support from CERN for the intro. of Timepix3 would be essential, for **purchasing** and development

Upgrade plan: Tune measurement by BBQ

CERN BBQ system



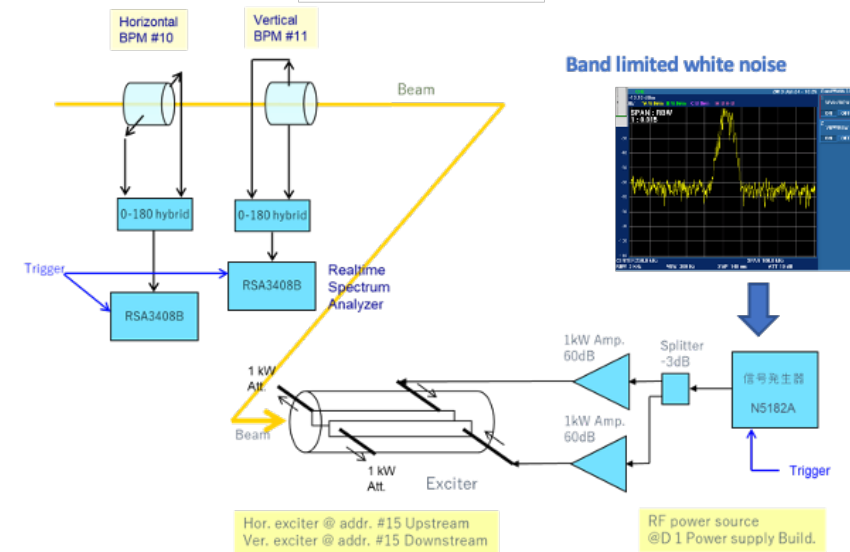
From presentation file by M. Gasior, R. Jones, DIPAC2005

Tune monitoring during stable beam operation

Concerns

- Design of diode detection system
- Pickup signal <200Vpp
- Usage in the tunnel -> Tolerance for radiation

J-PARC Tune Meter system



BPM Δ signal -> Spectrum analyzer

Need kick to **excite beam oscillation** = Differ from a real beam condition and a beam loss

Realtime monitoring without beam excitation will be required for J-PARC MR to upgrade beam power to 1.3 MW

Two possible candidates for J-PARC BBQ

- A **BBQ system based on analog system equivalent to CERN's BBQ**
Basic design is now on going and **need technical support from CERN**
- **Digital-based BBQ with a new BPM DAQ system under development**
New Daq will be ready by 2025, and BBQ system will be implemented as a part of its feature.

RaDIATE Collaboration Activities



- **RaDIATE (Radiation Damage In Accelerator Target Environment)** international collaboration is organizing high-intensity proton irradiation experiment at **BNL-BLIP** facility
 - ◆ **Test specimens** provided by participating accelerator labs.
 - ◆ **Post-Irradiation Examination (PIE)** being conducted at participating reactor/fusion energy research institutions with hot-cell facilities
- Collaboration is also conducting an in-beam thermal shock destructive inspection at CERN's **HiRadMat facility**
 - ◆ Including irradiated/damaged specimens at BLIP (BeGrid2)
 - ◆ Beam exposure completed in 2018, shipment / PIE in preparation

HiRadMat Experiments (HRMT35 & HRMT48) at CERN



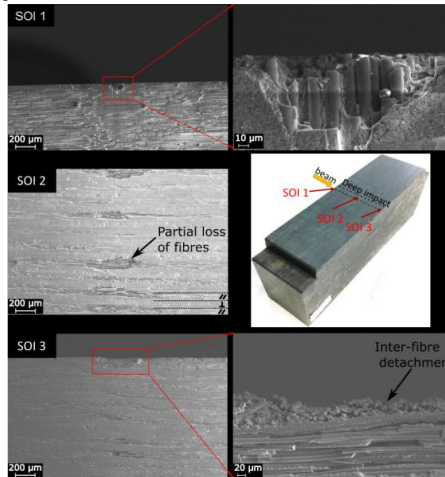
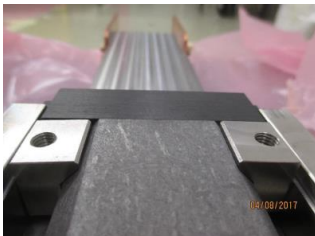
NITE SiC/SiC

- Specimen was supplied by Muroran Institute of Technologies.
- Included in HRMT35 for Target Dump Internal, Coated low-Z absorbing material
- Different beam impact depths, beam angles
- Thermal analysis of composite material through Tsai-Wu criterion

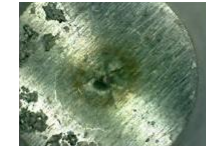
Superficial damage for all impacts and had craters at the entrance and exit faces for deep and grazing impacts, coherent with analysis.

POT: 3.5×10^{13}
 Beam size: 0.3 mm \times 0.3 mm
 288 bunches,
 pulse duration 7.2 ms

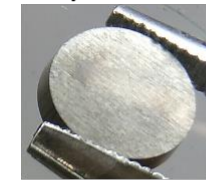
dT=2100°C J. Maestre et al.



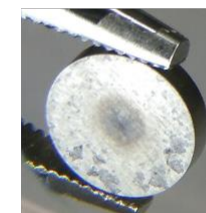
C. T. Martin et al.



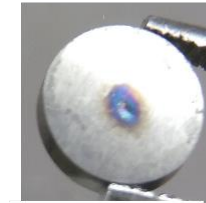
hot rolled W-recrystallized



W-TiC-with GSMM



W-TiC-without GSMM



Hot rolled W

TFGR W-TiC

- Included in HRMT48 for AD-target design, Ir, Ta, TFGR,,,
- No noticeable damage
- Promising response

POT: $3.2 \times 10^{13} \sim 1.12 \times 10^{14}$
 Beam size: 1mm \times 1 mm
 50 pulses, pulse duration 25 ns
 dT=700°C,
 Tensile stress: 1 GPa

Oct. 2018, HRMT43

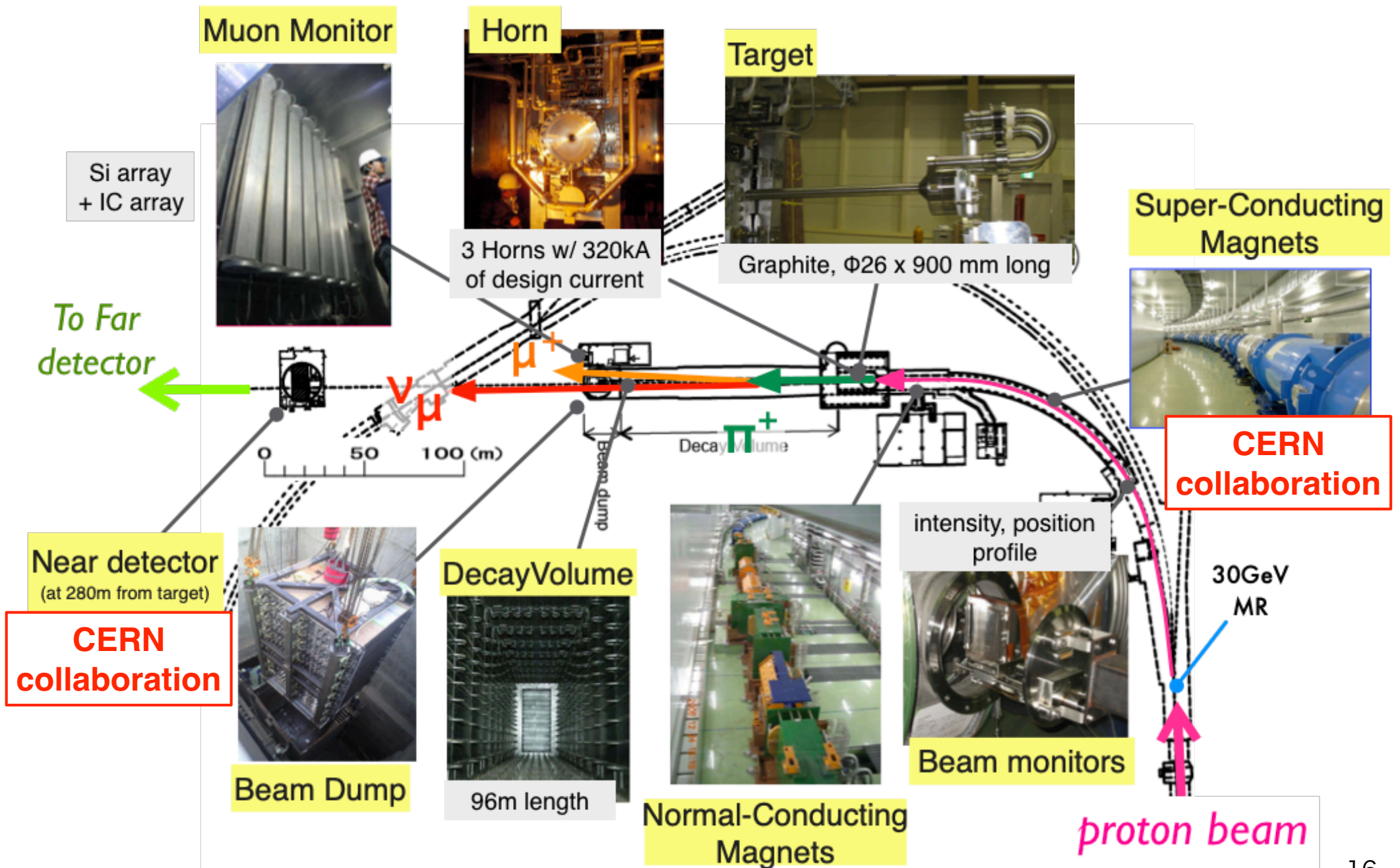


Nov. 2022, HRMT60



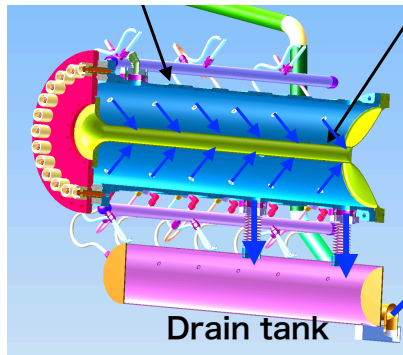
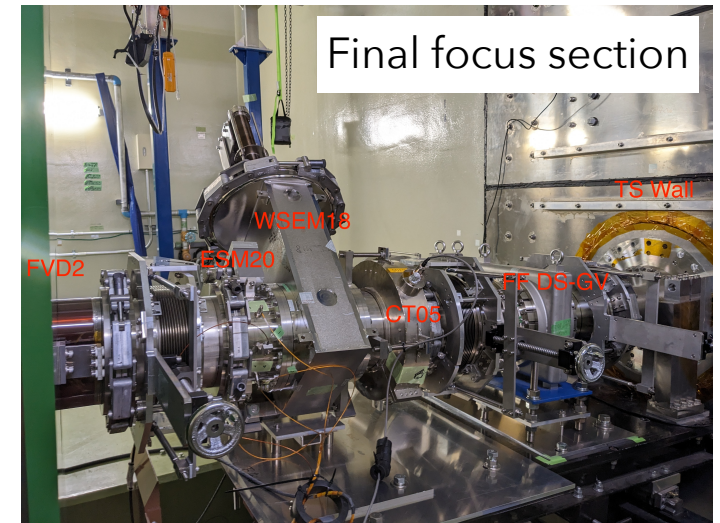
[related information : HPTW23 successfully took place and that the next event will take place at CERN in 2026]

J-PARC neutrino beamline facility



Potential new collaborative research projects related to neutrino beam facility

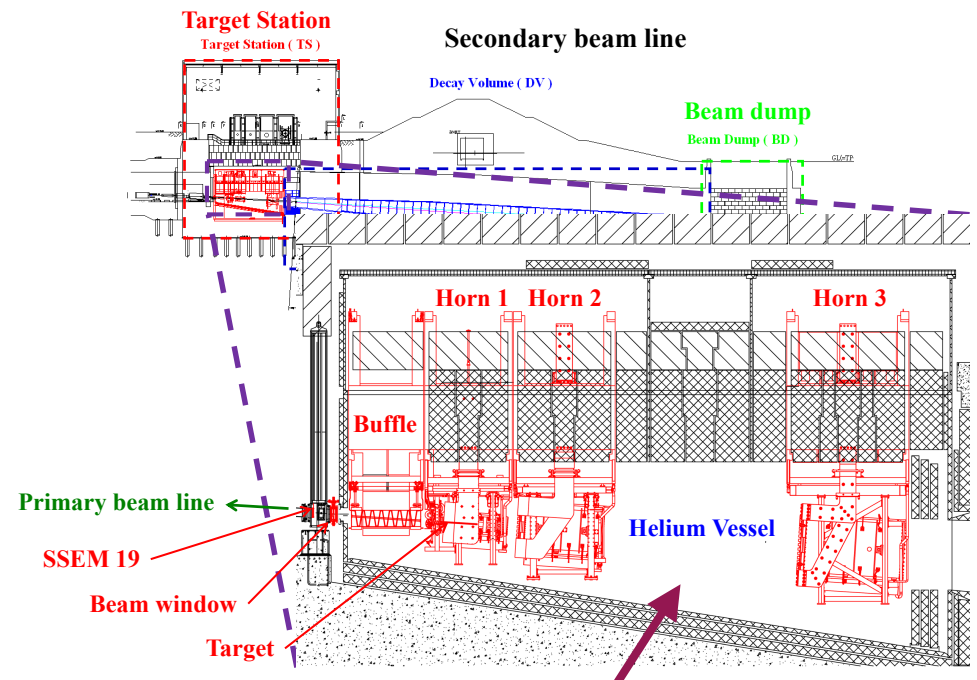
- ▶ Remote maintenance scheme for the final focusing section of the primary proton line
- ▶ Horn magnet design and operation
- ▶ R&D to understand ^3H (Tritium) production and knowledge sharing on ^3H treatment
- ▶ Helium gas conservation system
- ▶ Radiation effects on electronics
- ▶ Beam monitor



Horn cooling water → activated by ^3H

↑

Decay volume cooling water

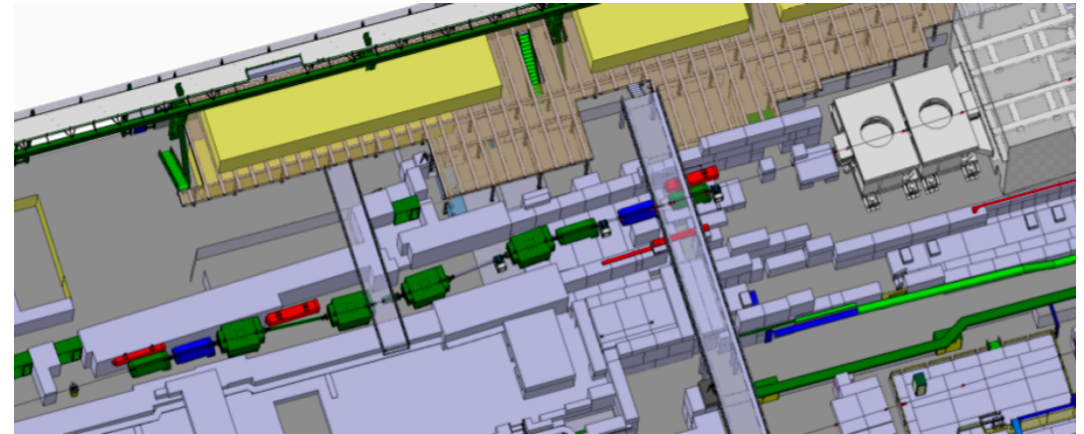


1500m³ of He gas

Hadron production measurements



- Thanks to NA61/SHINE (@CERN) experiment, T2K flux prediction w/ $\sim 5\%$ uncertainty was successfully achieved
- Proposed a new low-energy (2-13 GeV/c) beamline @H2 line**
 - important for J-PARC neutrino experiments (T2K/HK, JSNS²) and atmospheric ν

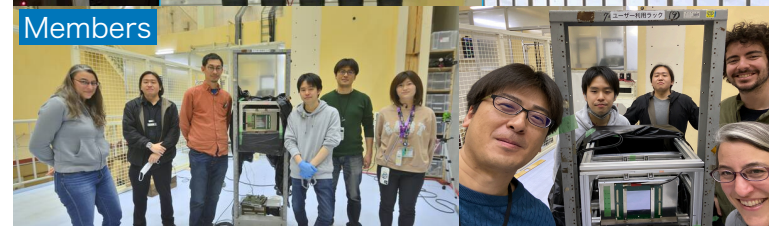
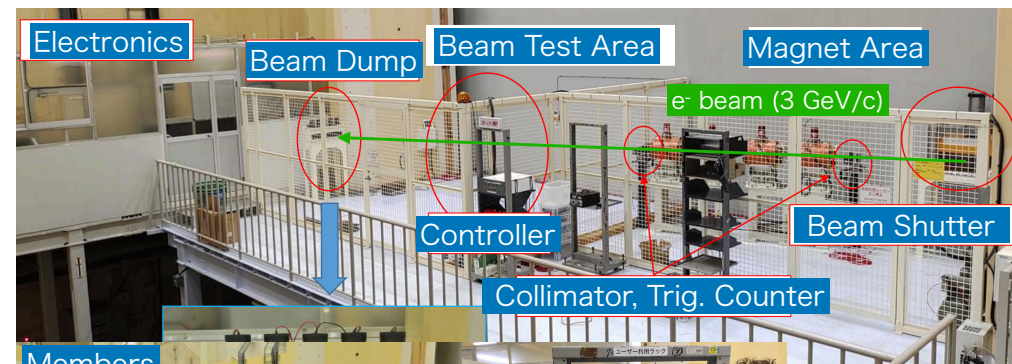


Collaboration with N.Charitonidis (CERN)

Engineering Change Request, Memorandum to SPSC was submitted (2023)

Design of new low-E beamline \rightarrow Ph.D thesis of C.A. Mussolini (Oxford/CERN, 2023)

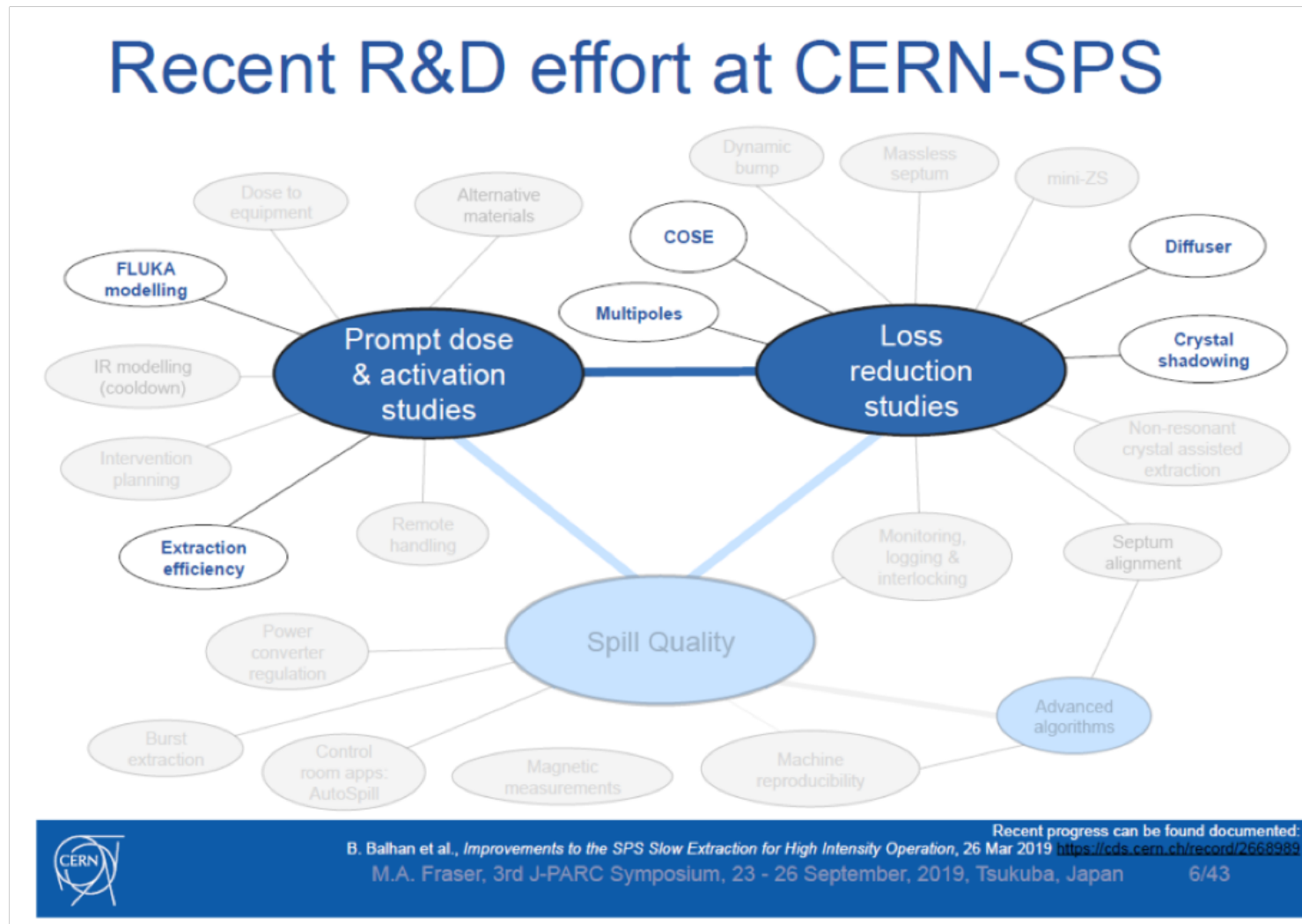
- Beam test for a silicon-based beam profile monitor for low-E beamline (contribution from Japan) was conducted at KEK AR-TBL



K. Sakashita
Y. Nagai
M. Friend
Y. Hino
C. Mussolini
S. Nishimori
T. Tada

Collaboration on Slow Extraction from Proton Synchrotron

CERN SPS and J-PARC MR have many common challenges in **slow extraction**



Slide from the presentation by Mathew Fraser (CERN) at the J-PARC Symposium 2019

Collaboration on Slow Extraction from Proton Synchrotron

2017 Francesco M. Velotti (CERN SPS) stayed at J-PARC for a week and exchanged information on the various topics of slow extraction, especially the beam loss reduction

2017 Slow Extraction Workshop (CERN)

M. Tomizawa, Y. Arakaki and R. Muto participated

2019 J-PARC Symposium (Tsukuba, Japan)

We invited Mathew Fraser (CERN SPS) for the presentation on the beam loss reduction improvements at the CERN SPS

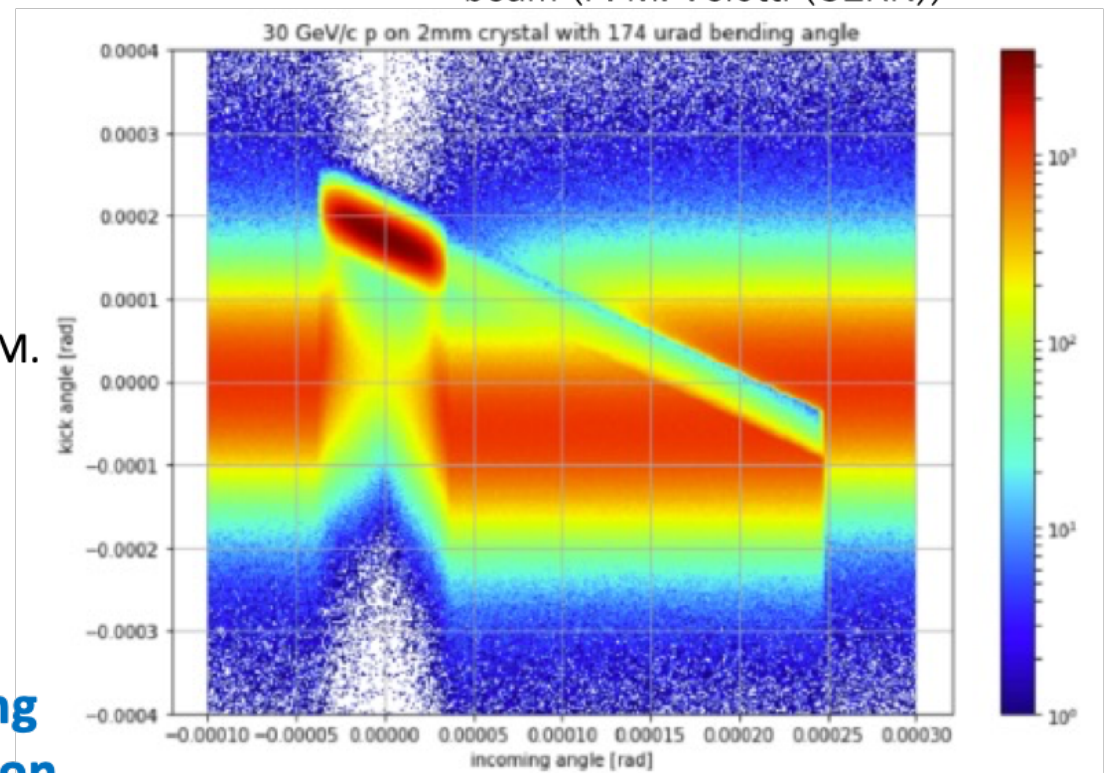
2019 Simulation studies of the crystal shadowing for J-PARC Main Ring by Francesco M. Velotti, Mathew Fraser, and Brennan Goddard (CERN)

2022 Slow Extraction Workshop (KEK, online)

Many CERN researchers participated

We would like to continue exchanging information on various slow extraction challenges.

Simulation studies for crystal shadowing for 30 GeV proton beam (F. M. Velotti (CERN))



Summary

- There are various collaborative research projects between CERN and J-PARC, in many different fields
- Discussions have also begun on new items
 - There are also several potential items which not shown today (e.g. Power Converter, Hadron target facility etc.)
 - This talk was focused on J-PARC related items but there are also items for electron accelerator (e.g. non-linear collimator, positron sources etc.)
- Plan to have a workshop on CERN / JPARC / KEK collaboration for high intensity beam facility on 2024 at Japan