New Arrangement of Collimators of J-PARC Main Ring

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Scandic Triangeln Hotel, Malmö, Sweden

Outline

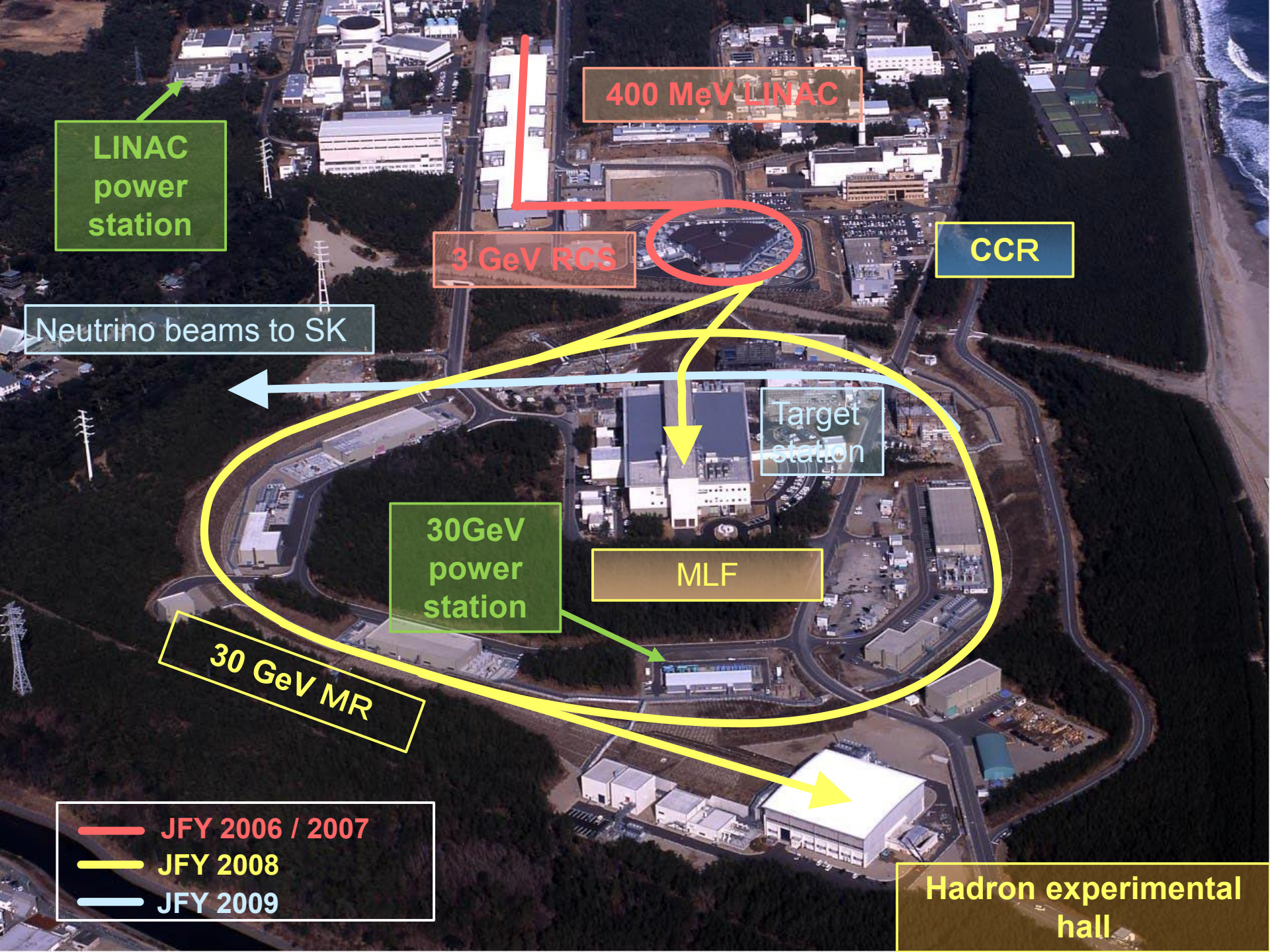
Introduction of J-PARC MR

MR Beam Collimation System

First design:	Scraper-catchers
First update:	Replace of scraper
Second update:	Seven collimators
Third update:	Introducing four-axis collimators
Fourth update:	Requirements and future layout

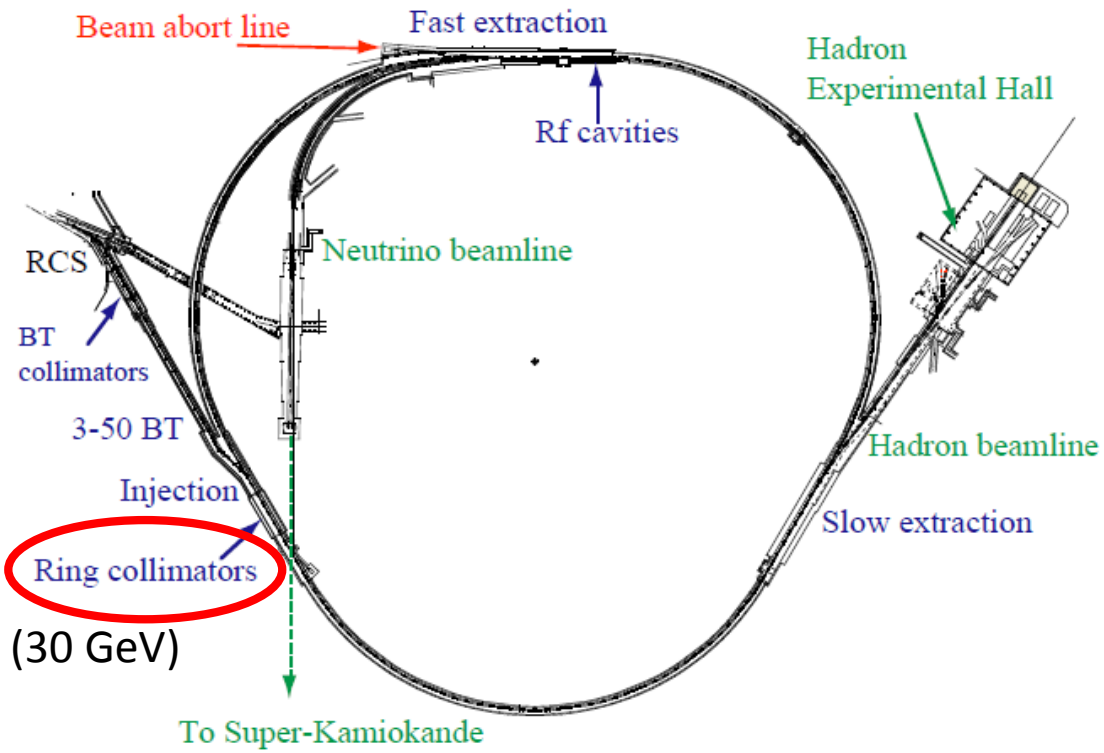
Conclusion

Introduction of J-PARC MR


LINAC power station
400 MeV LINAC
3 GeV RCS
CCR
Neutrino beams to SK
Target station
30GeV power station
MLF
30 GeV MR
JFY 2006 / 2007
JFY 2008
JFY 2009
Hadron experimental hall

Specification of J-PARC Main Ring

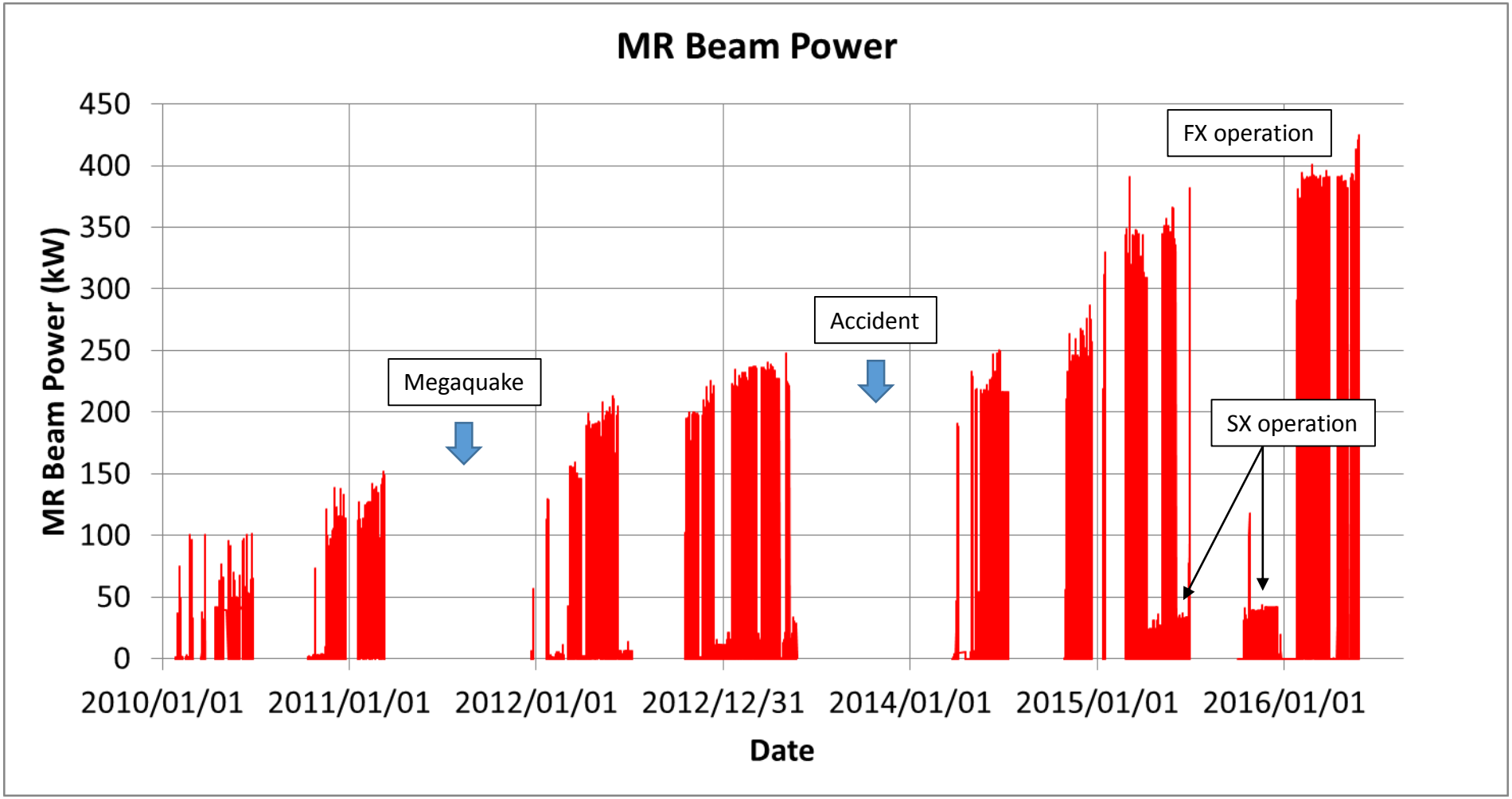
Circumference	1567.5 m
Repetition cycle	2.48 s / 5.58 s
Injection energy	3 GeV
Extraction energy	30 GeV
Superperiodicity	3
harmonic #	9
No of bunches	8
Transition γ	j 31.7
Typical tune	(22.40, 20.75)
Transverse emittance	
At injection	~54 π mm mrad
At extraction	~10 π mm mrad (30 GeV)



Three dispersion free straight sections of 116 m long:

- Injection and collimation systems
- Slow extraction（SX）
  to Hadron experimental Hall (Rare decay, hyper nucleus…)
- 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 located 300 km west)

Increasing Beam Power in Main Ring

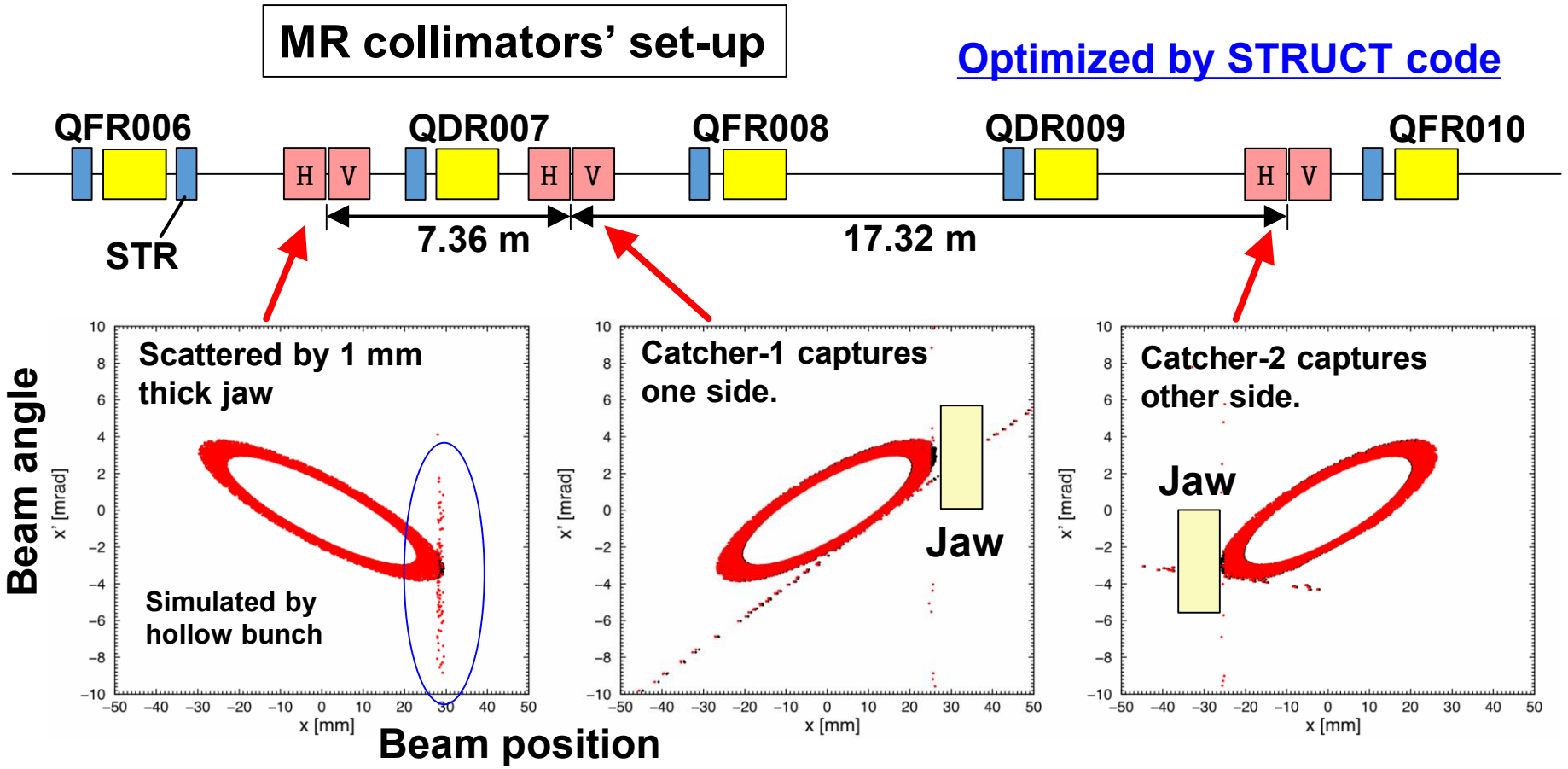


The MR beam power has been increasing. Now we have 2.15e+14 protons per 2.48 s pulse.
It is important to handle and localize beam losses for maintenance and machine protection.

MR Beam Collimation System

First Design

At the beginning: scraper-catchers scheme

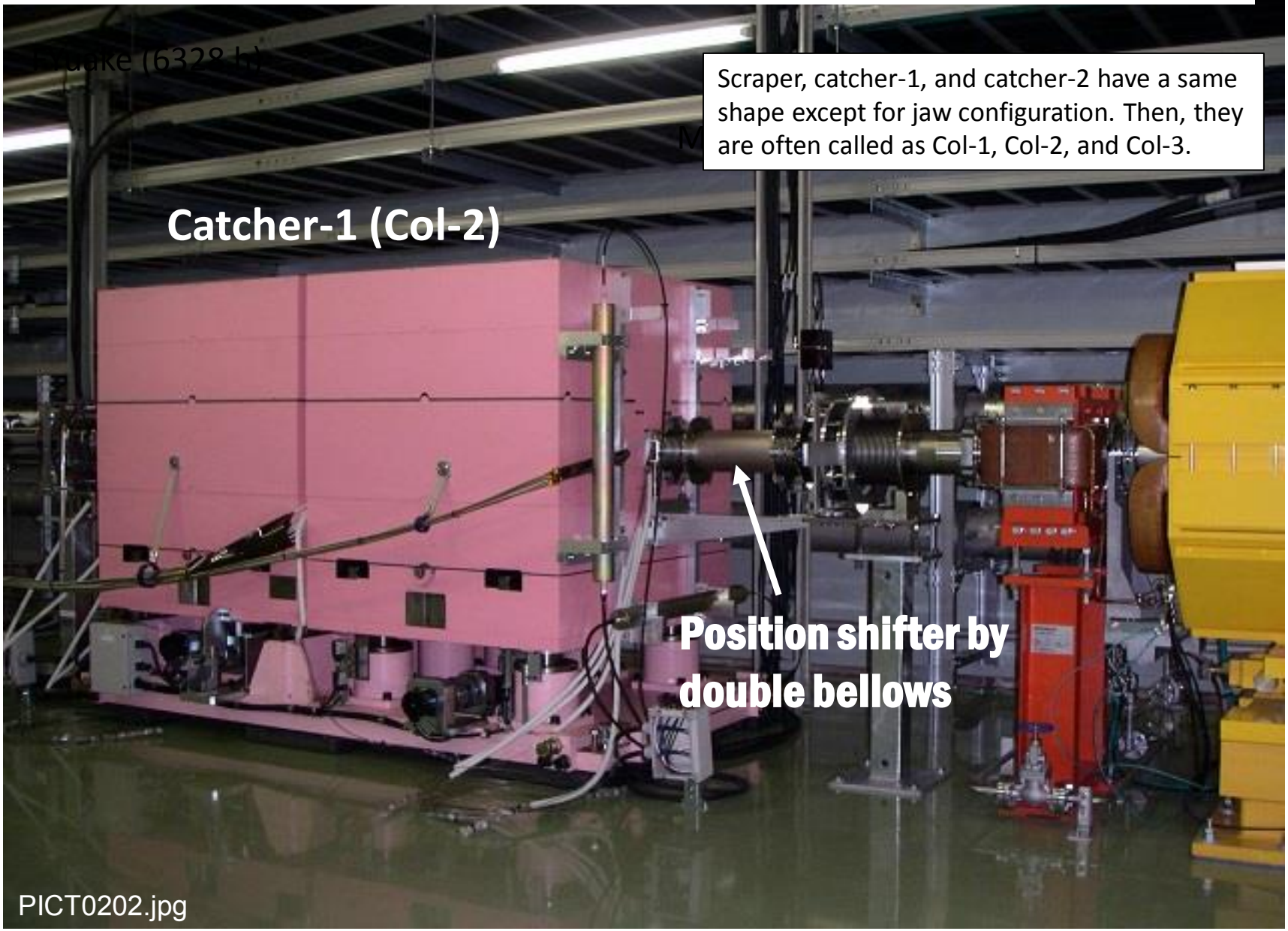


Efficiency of beam loss localization

Assuming 54π beam: >96% in the collimation area

Remarks: the ratio of collimator aperture/physical one should be larger than 1.4, otherwise the efficiency gets small immediately.

Catcher of First Beam Collimation System

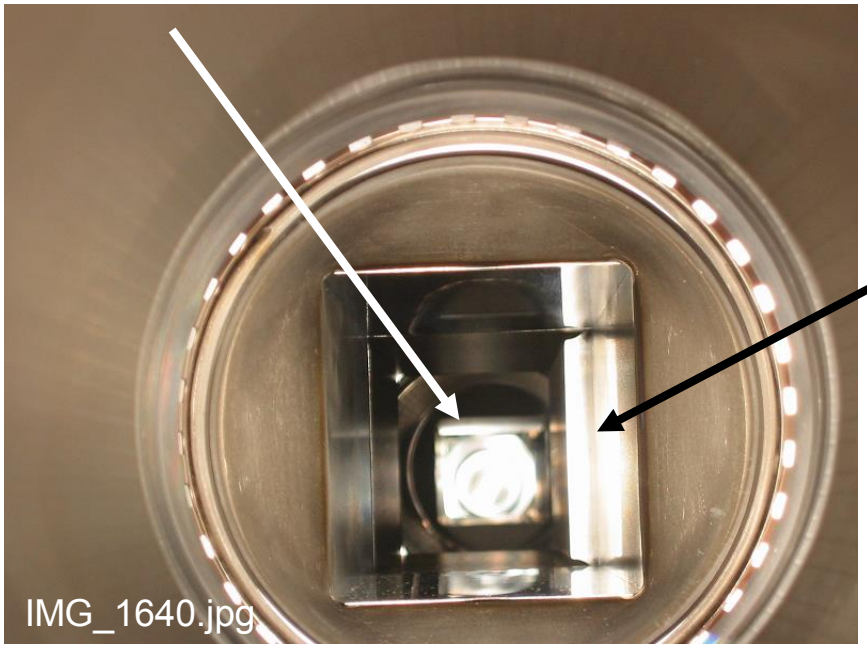


Jaws of catcher-1

Jaws of catcher-2 are prepared on the opposite sides in order to remove the lower side of scattered protons in phase space.

Vertical jaw

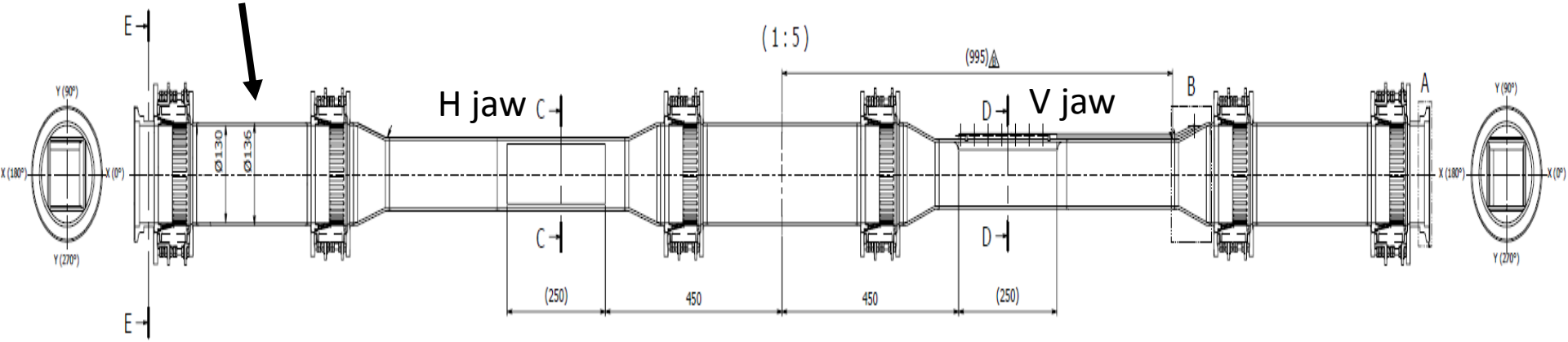
View from upstream



Horizontal jaw

Jaws are made of tantalum

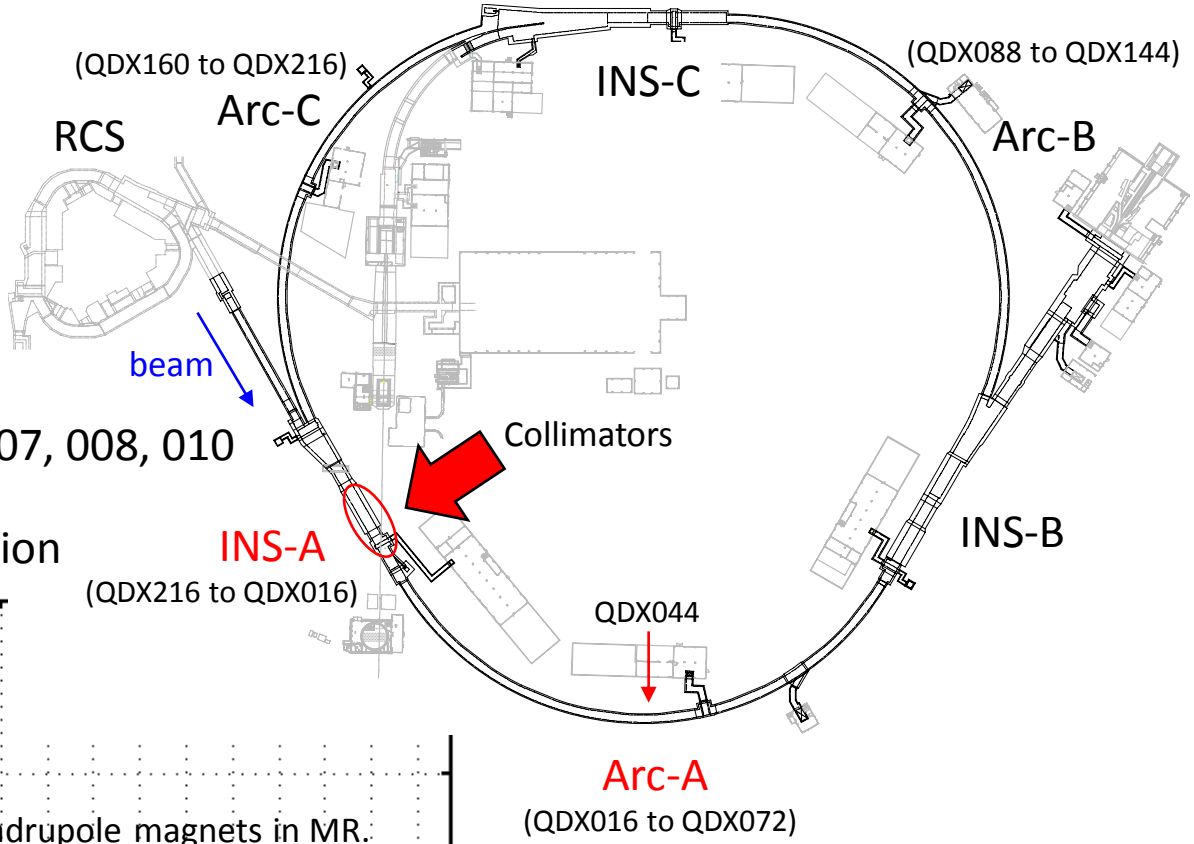
Double bellows bending structure for transverse displacement of jaws



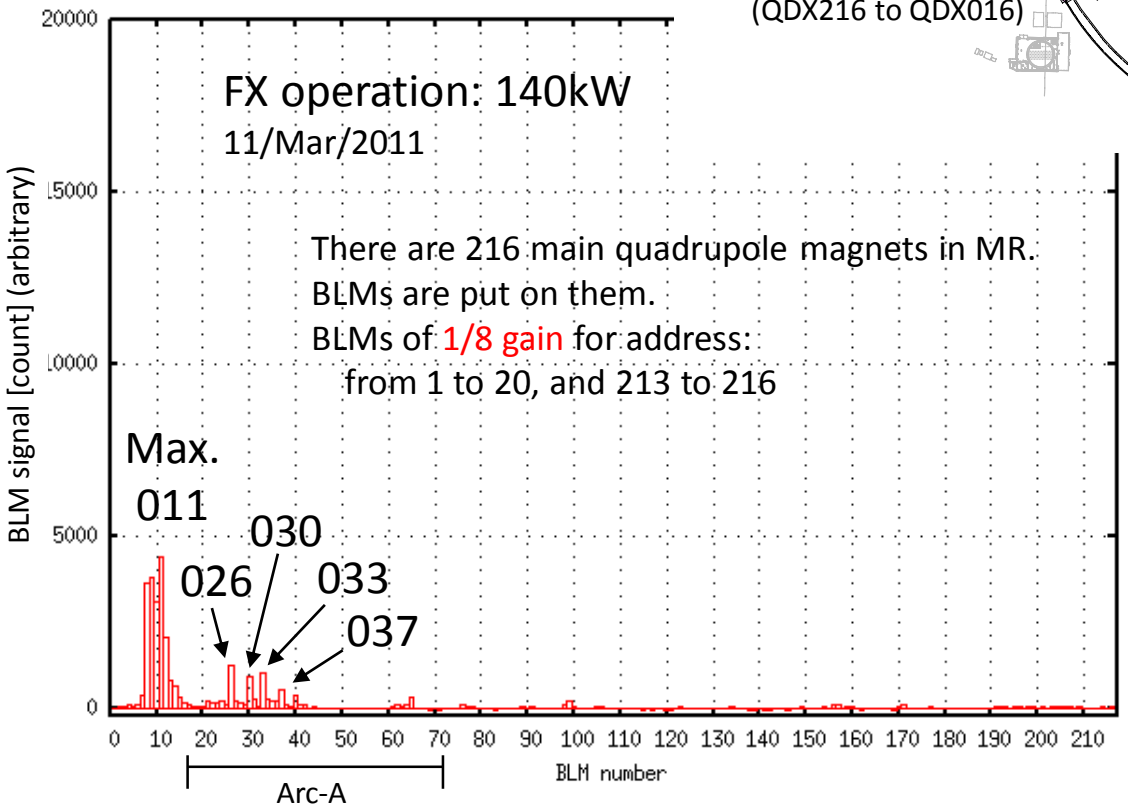
Beam Loss Distribution

(νx, νy) = (22.40, 20.75)

Collimator configuration:
Col-1, Col-2, Col-3 at address: 007, 008, 010



Typical beam loss distribution



There were specific beam loss spots at address: 026, 030, 033, and 037.
The losses at QFX026 and QFX033 came from off-momentum protons because they were dispersion peak points.
The losses at BM030 and BM037 seemed to be leaks from catchers?

First Update

Requirements to the existing Beam Collimation System

- Beam loss capacity was 1 kW for the beam collimation system.
- More beam loss capacity was required for high power beam operation.

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- It was considered to add one or more beam collimator set as Col-4,5,6 and Col-7,8,9.

⇩

- The main limitation was the boundary condition on the surface of accelerator tunnel.
- The neutron dose must be less than 11 mSv/h in the soil on tunnel surface.

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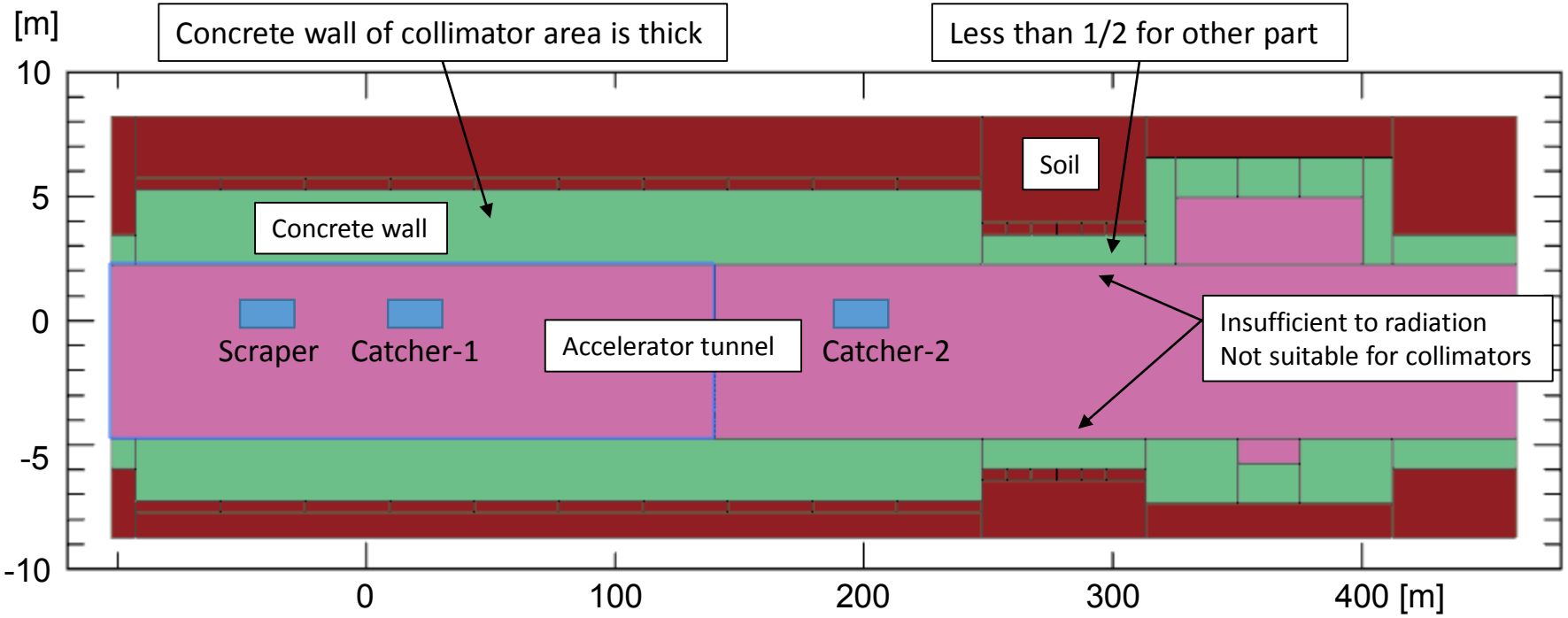
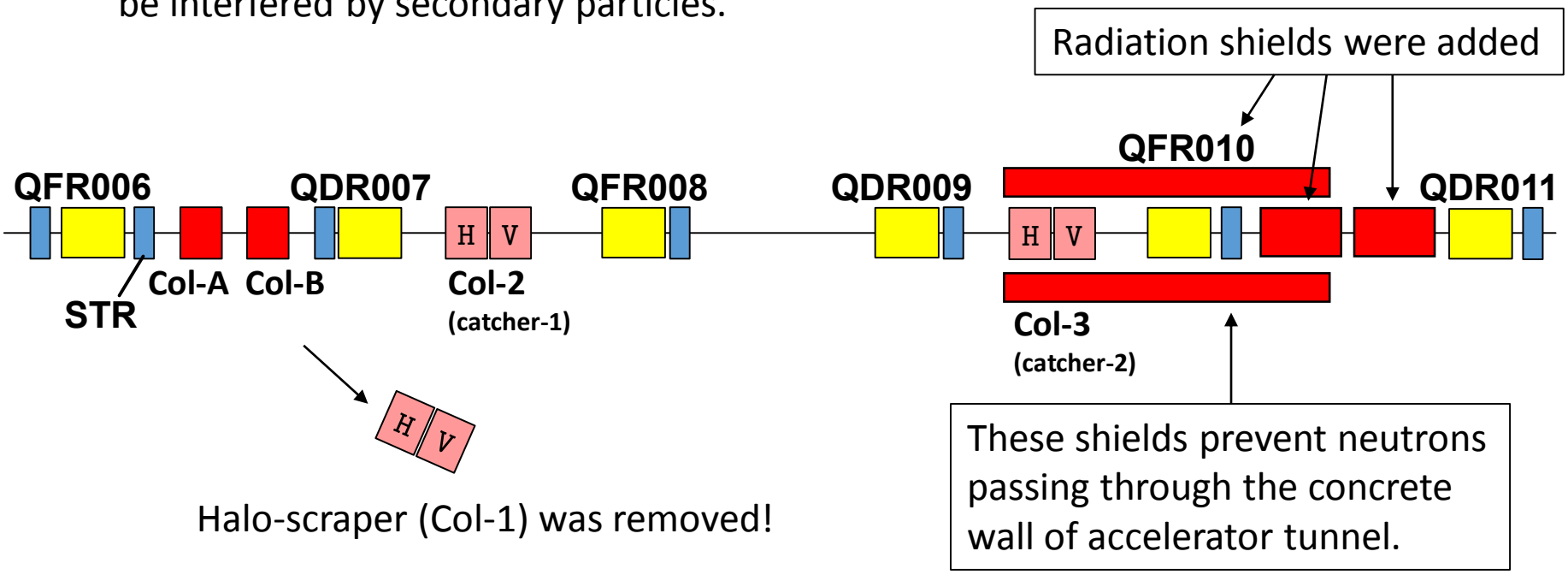
- The available space was restricted, only <u>one more collimator set was installable</u>.
- The beam loss capacity would be limited to 2 kW which was not sufficient.

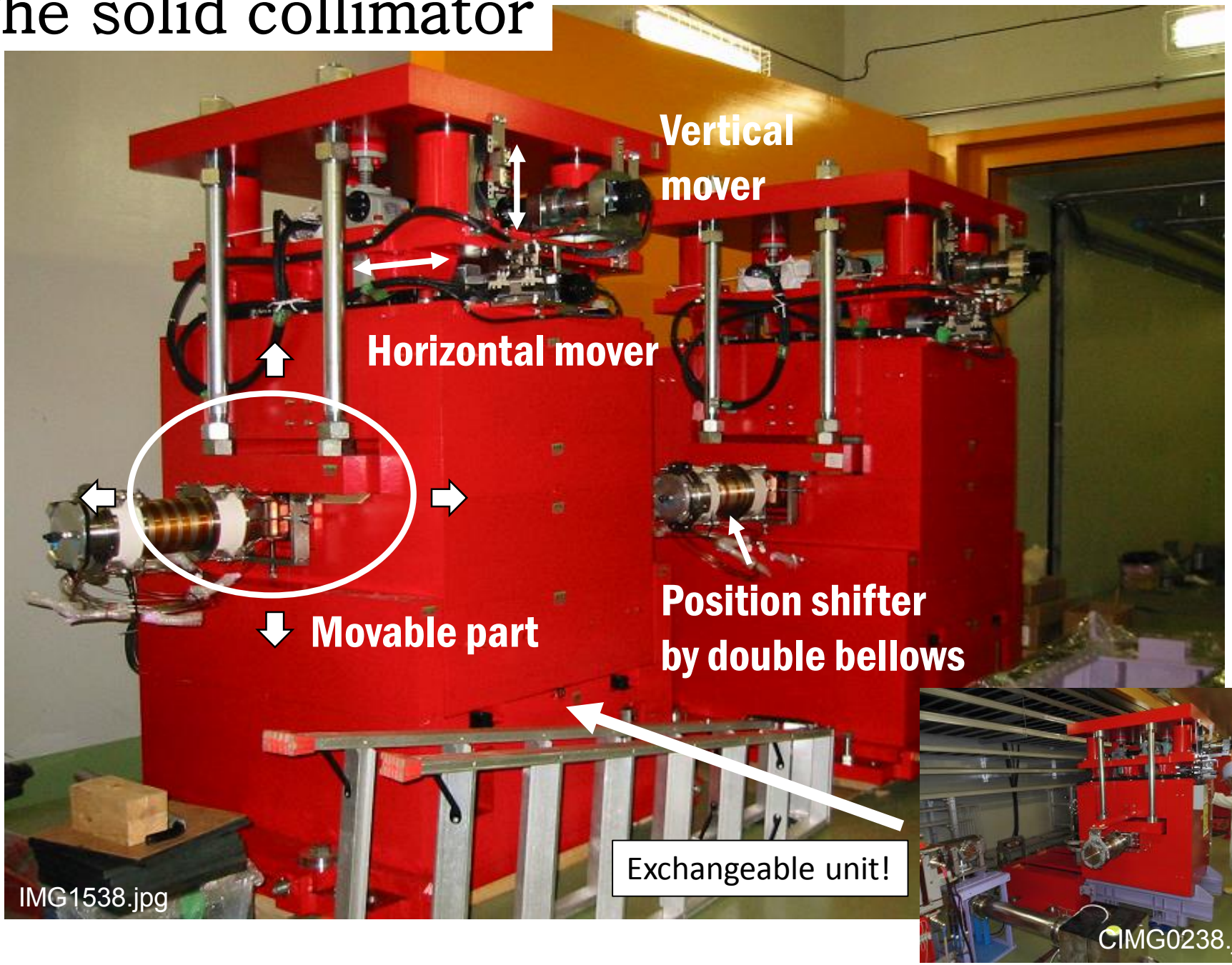


Layout after First update

- We have given-up a scraper-catchers scheme.
- The first update started after the Mega-quake of 3.11 in 2011.
- New radiation shields were installed at addresses 010 and 011 in 2011 to reinforce the shielding power of the accelerator tunnel because the concrete walls are thin for radiation from QFR010.
- Col-A and Col-B which have a long and thick jaw (ordinary in BT) were produced.
- Col-A and Col-B were installed instead of Col-1 (halo-scraper) in 2012.
- Steering magnets at addresses 008, 009, 010, and 011 were moved to behind the quadrupole magnet, because they have a beam position monitor which tended to be interfered by secondary particles.

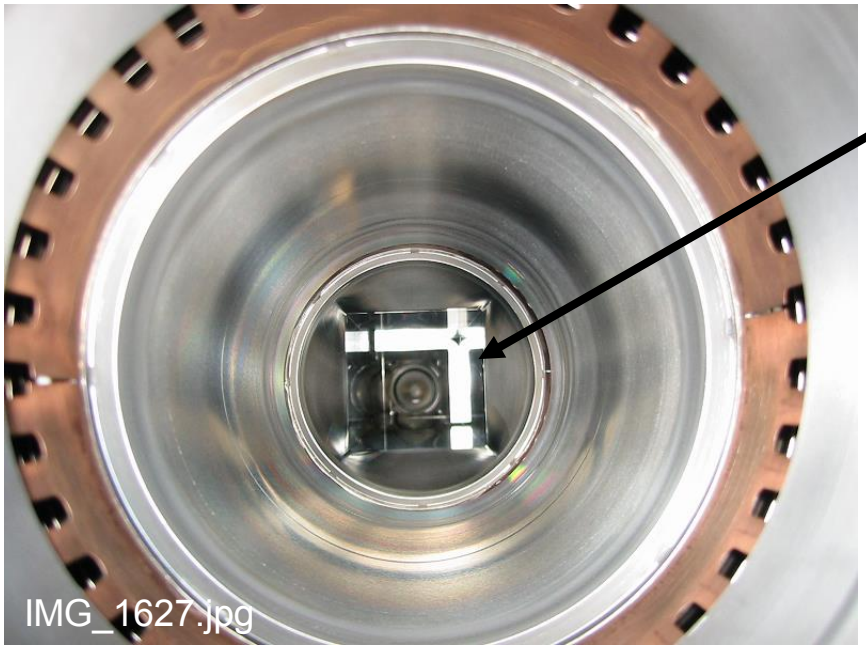


The solid collimator



Jaw of solid collimator

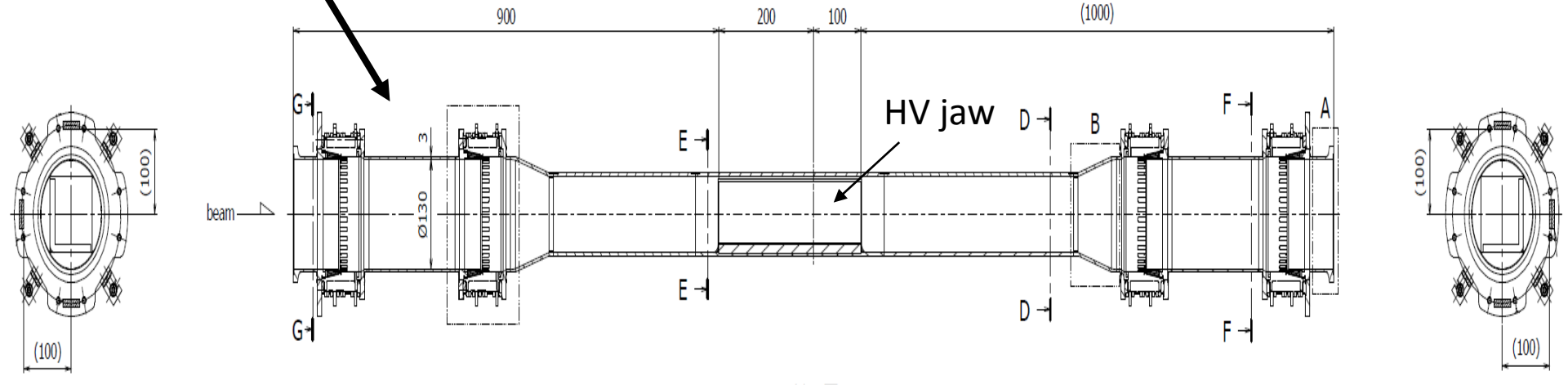
View from upstream



L-letter type jaw

used with 180 degrees turned here

Double bellows bending structure for transverse displacement of a jaw



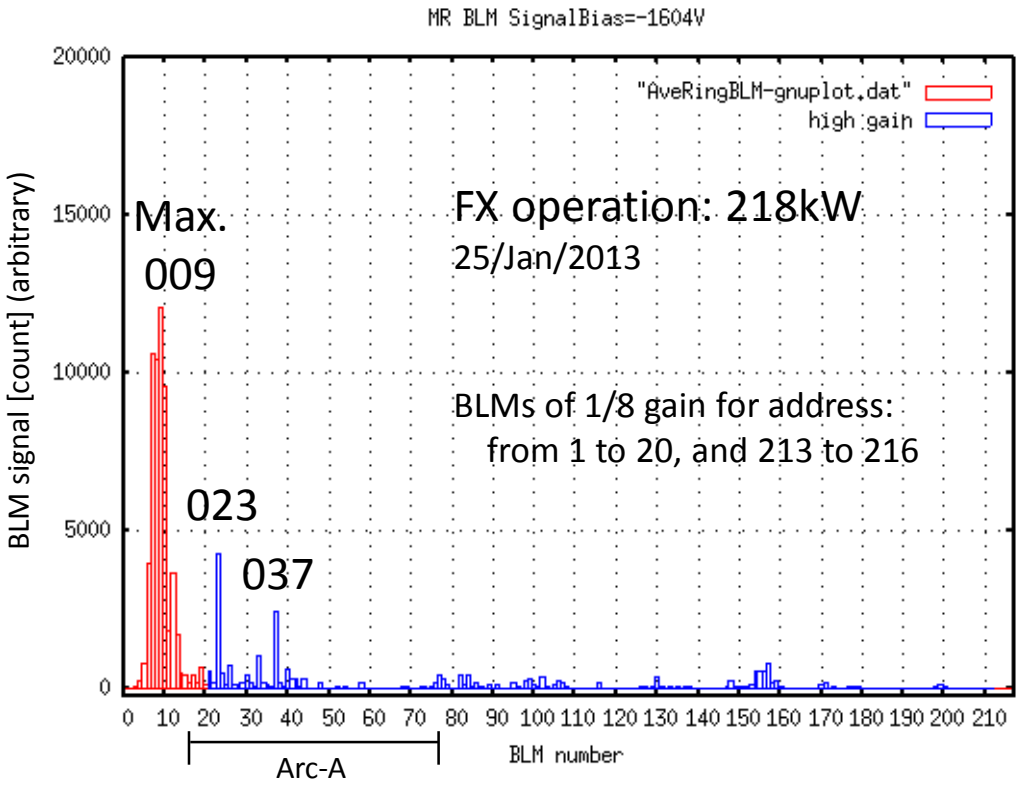

First update in Sep. 2012
Scraper was replaced by two collimators.
Col-A
Col-B
Col-2
Col-3
IMG2569.jpg

Beam Loss Distribution after the First Update

(νx, νy) = (22.40, 20.75)

Collimator configuration:
Col-A, Col-B, Col-2, Col-3

Typical beam loss distribution



Results of first update

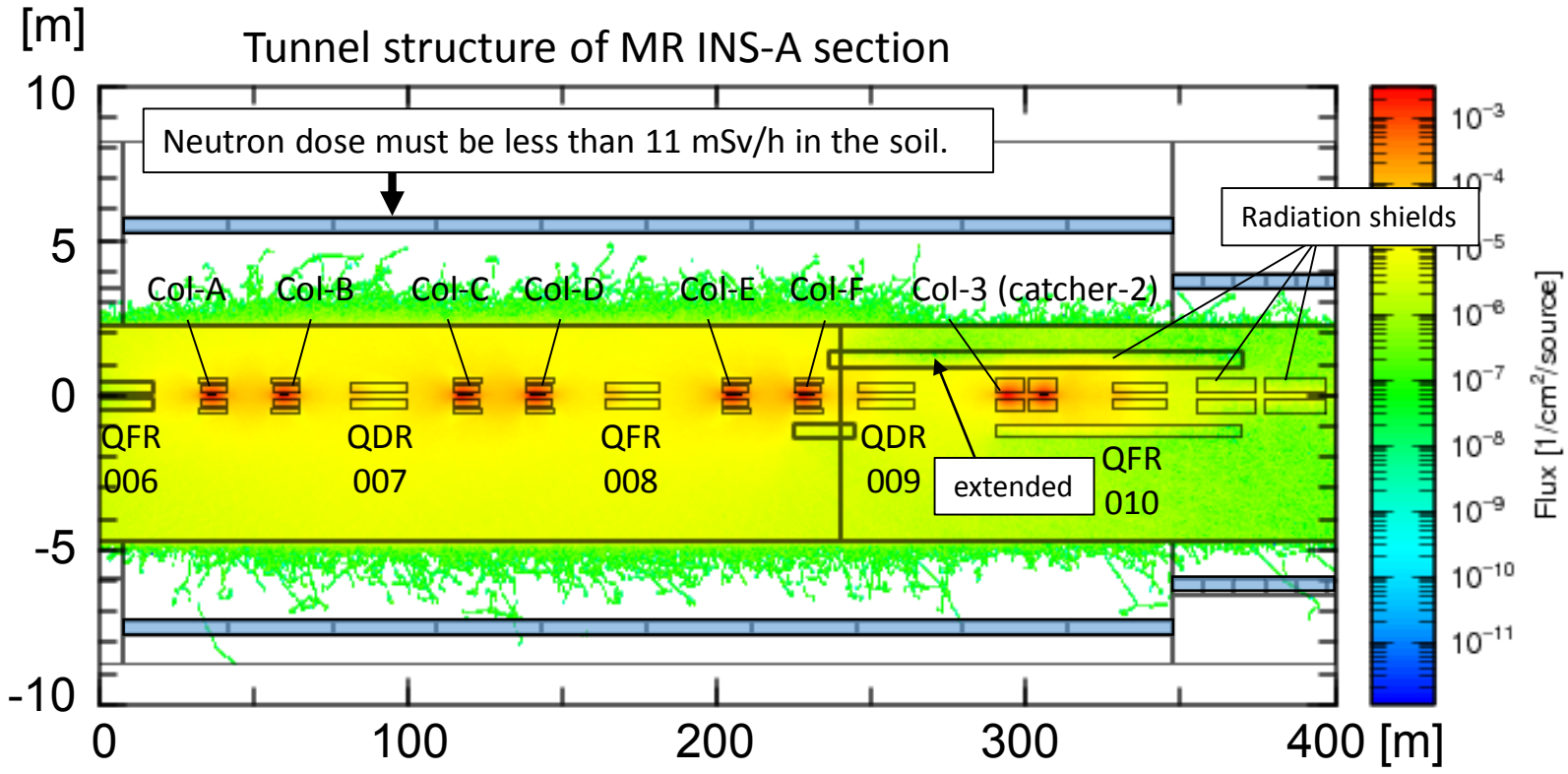
- The specific beam loss spots are at address: 023, (033), and 037.
- The beam loss at address 023 newly appeared in this configuration. Protons scattered by some collimator jaws seemed to make this signal.
- Beam loss at QFX033 was due to the dispersion peak.
- Beam loss at BM037 remained.
- The maximum beam loss point changed from address 011 to 009 or 010 because of radiation shield installed in 2011.
- The residual radiation dose at QFN017 increased though the beam loss signal was not remarkable. This was a side effect of scheme change.

Second Update

Straight Forward


Second update in Jan. 2014
Catcher-2 was removed, four collimators were installed.
Col-A
Col-B
Col-C
Col-D
Col-E
Col-F
Col-3
IMG2785.jpg

Beam Loss Capacity of MR Tunnel



- Beam loss capacity was confirmed to satisfy the boundary condition with up to eight beam loss sources with seven collimators by PHITS code.
- Neutron dose must be less than 11 mSv/h outside of the accelerator tunnel.
- Beam loss power of each source is assumed to be 500 W with a margin.
- The total beam loss capacity of more than 3.5 kW was achieved.

Reset to October 2012

- The newly installed collimators were called as Col-C, Col-D, Col-E, and Col-F.
- The material of jaw changed from tantalum to tungsten for these.
- The total beam loss capacity increased to 3.5 kW with seven collimators.

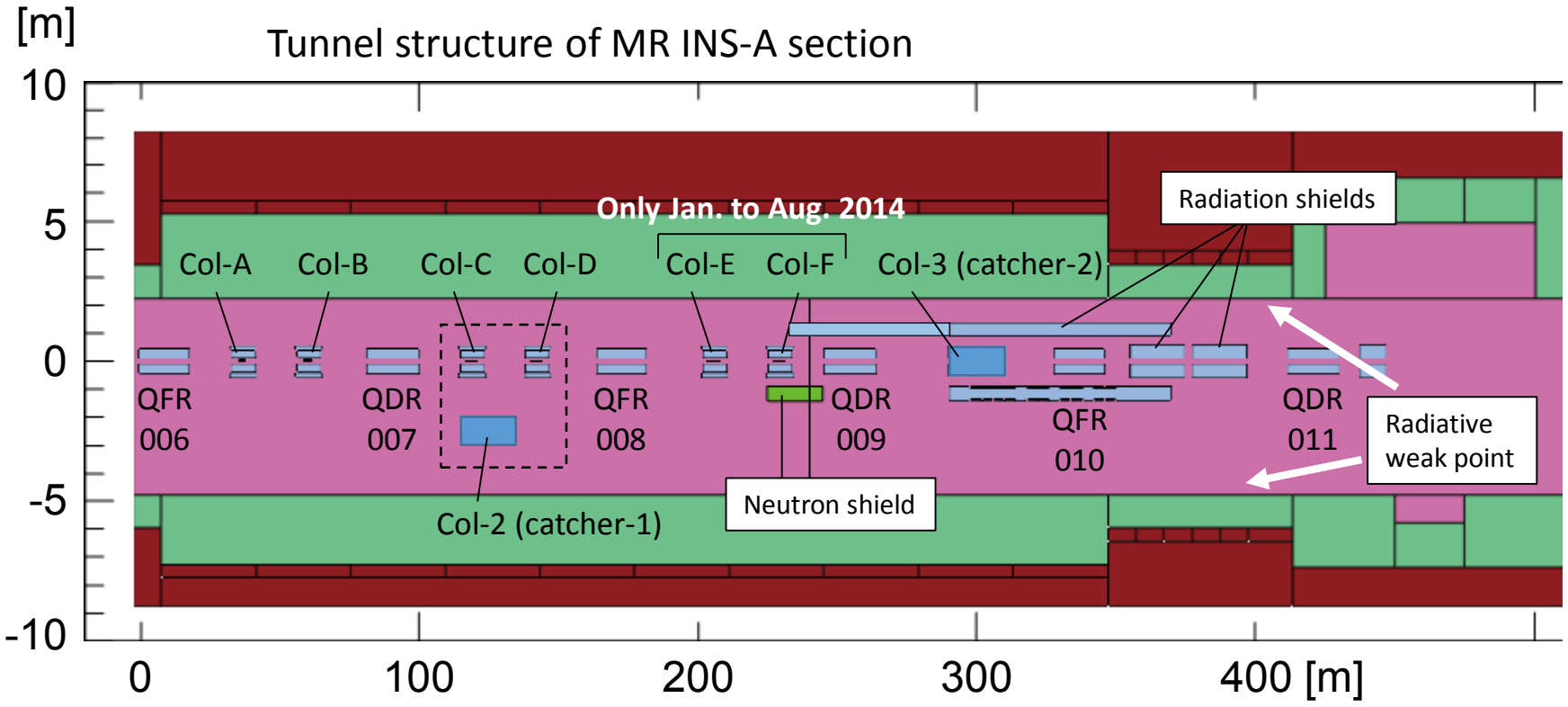
- The parasitic beam losses caused by collimator jaws were investigated and it was found that the beam loss tend to occur especially at addresses 023, 030, 037, and 044 where the lattice had a same structure BMnnn + QDXnnn. Beam loss was occurred in bending magnets.
- The fundamental beam responses with seven collimators were studied in April and May.

- However, we've got a leak on vacuum chamber during summer shutdown.
- It was a serious problem: vacuum leak occurred on similar place (weld) for two of four collimator ducts produced in 2013. Maybe there was a "failure" on manufacturing process.
- The second update was cancelled. Col-C, D, E, F were removed from the beam line, and catcher-1 was reinstalled to the original position, that is, the beam collimation system returned to the configuration in October 2012.

Third Update

New Device

Collimator Configuration after 2014

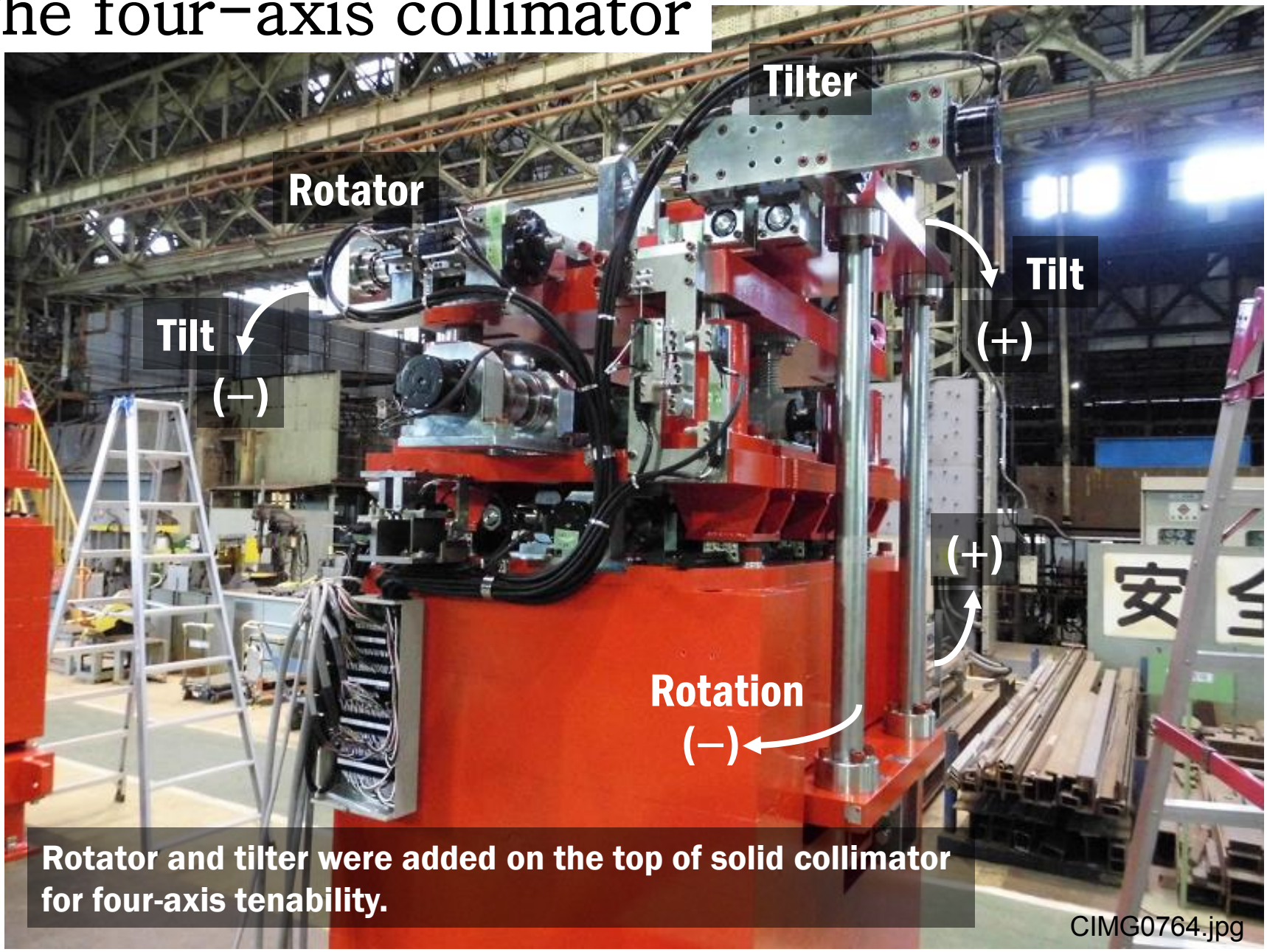


History of the collimator layout with the schematic view of accelerator tunnel.

1. Col-2 was replaced by Col-C, D, and Col-E, F were installed in January 2014.
2. Col-2 returned removing Col-C, D, and Col-E, F were removed in September 2014.
3. Col-2 was replaced again by new Col-C, D in September 2015.

New Col-C, Col-D are more functional. (four-axis collimator)

The four-axis collimator



Rotator and tilter were added on the top of solid collimator for four-axis tenability.

CIMG0764.jpg

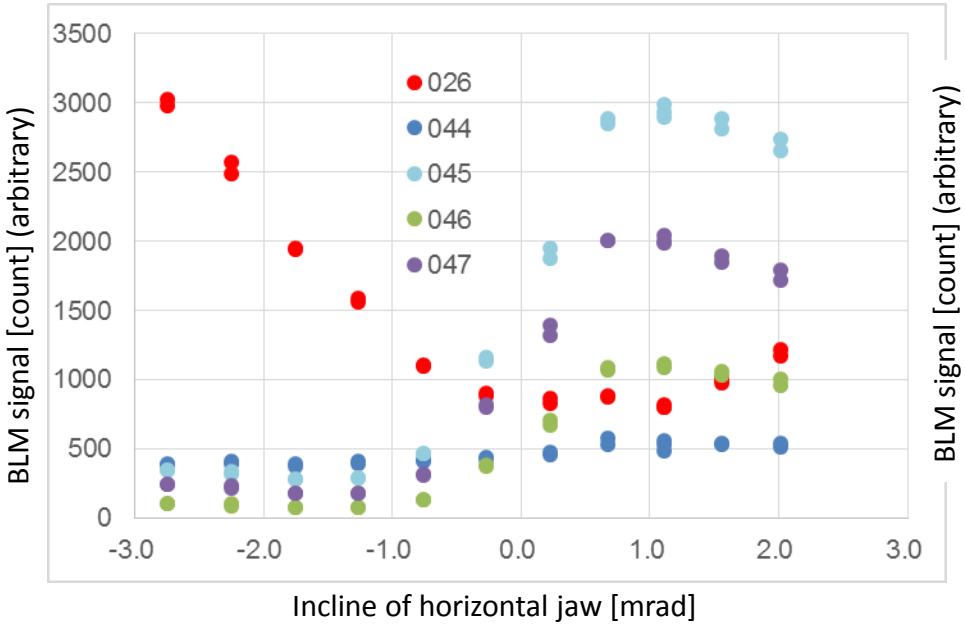

Third update in Sep. 2015
Catcher-2 was removed again, two four-axis collimators were installed.
Col-A
Col-B
Col-C
Col-D
Col-3
CIMG0957.jpg

Effect of Inclined jaw

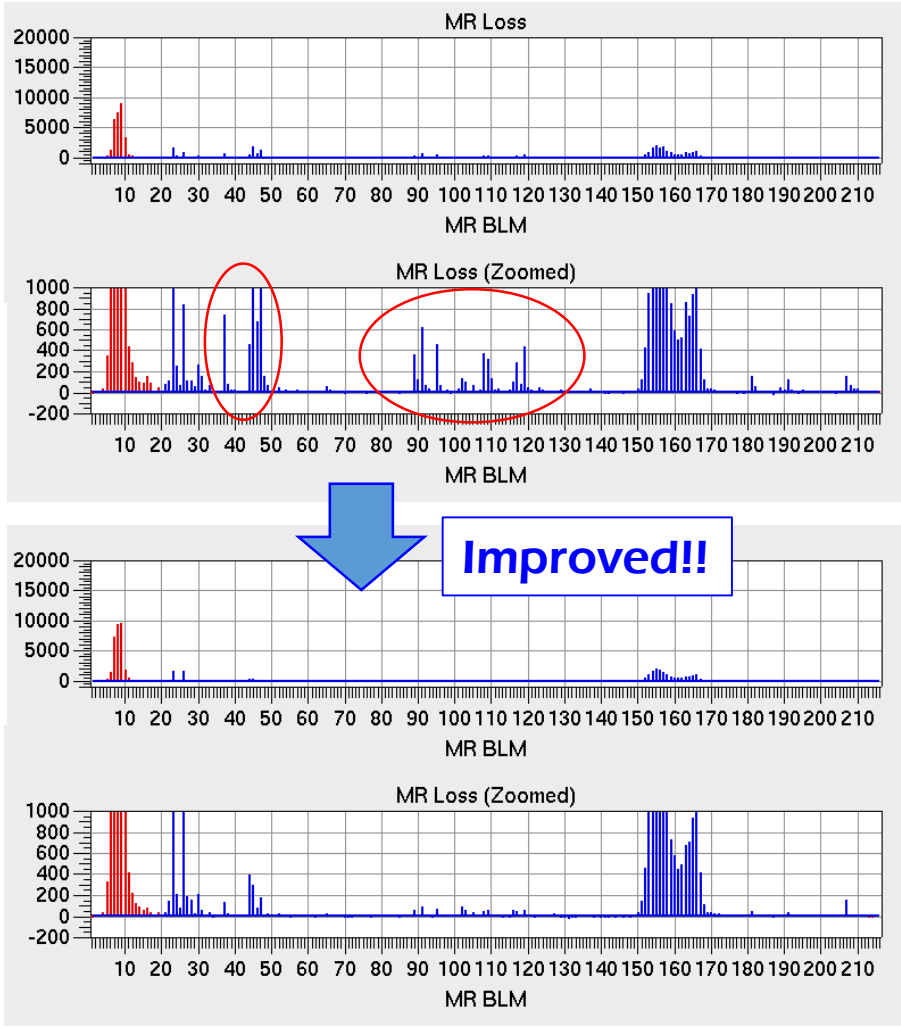
Col-CH insertion: +11.918 mm

No tuning #417073
Optimized #417088

Beam loss was minimized
except add.23 and 26.

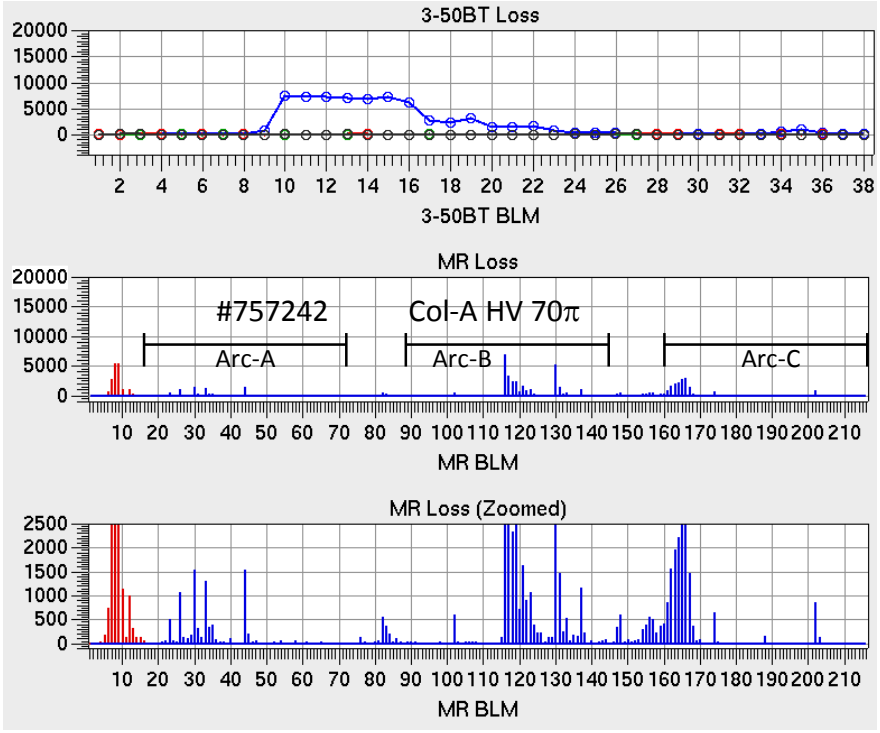


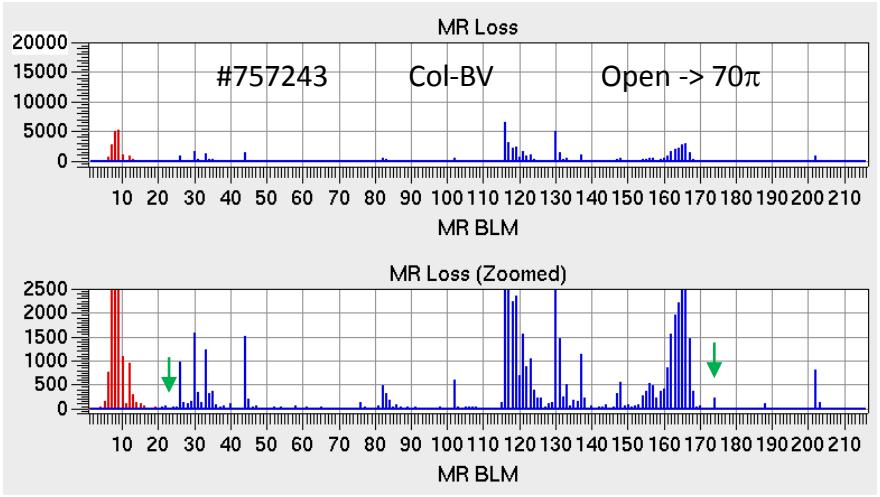
Col-C theta(horizontal)



From "Four-axis_test_20151224.pptx"

Operation at (νx, νy) = (21.35, 21.43) part 1

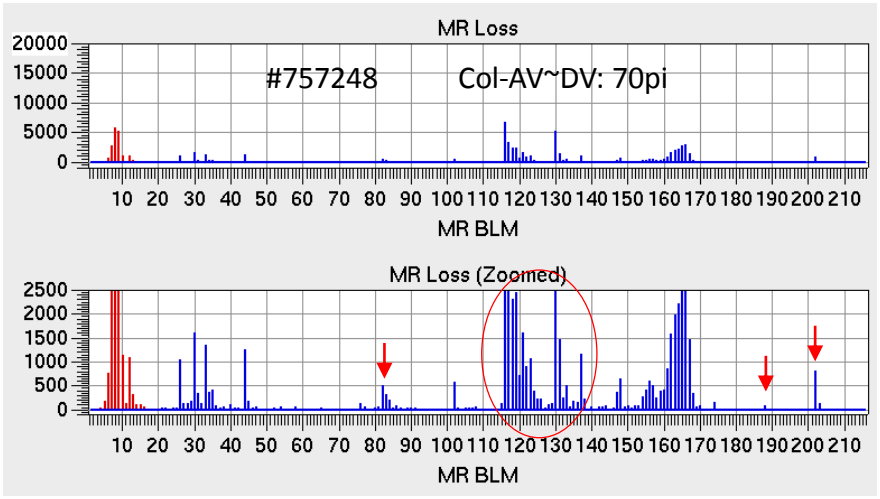


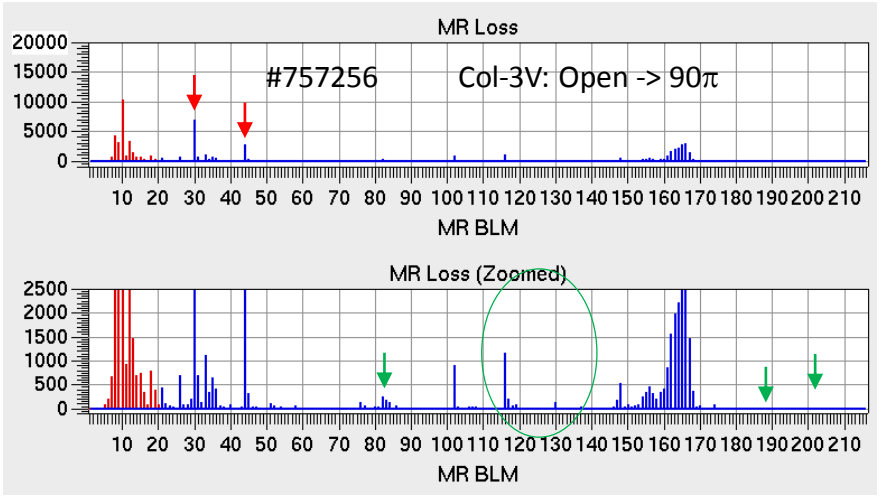


Results of the third update

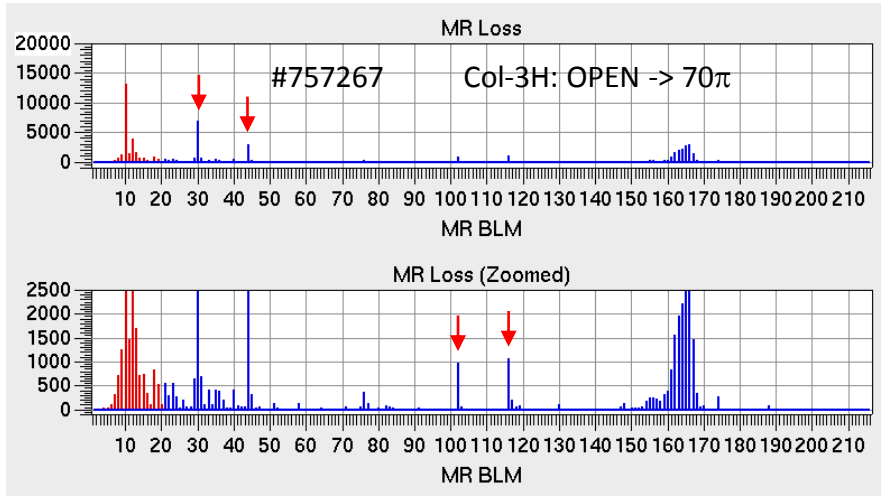
- Since May 2016, we have changed the operating point from (νx, νy) = (22.40, 20.75) to (21.35, 21.43) for the FX operation toward the higher beam power beyond 400 kW.
- The responses of each collimator jaw were investigated. At the beginning, Col-AH and Col-AV were set to the aperture of 70π mm mrad. Here, we call the horizontal jaw of Col-A as Col-AH, the vertical jaw of Col-A as Col-AV, in same way for other collimators here-after.
- The specific beam loss spots are addresses 023, 026, 030, 033, 044, 082-084, 102, 116-124, 130, 131, 137, 147, 148, 174, and 202.
- Because the signals from addresses 154 to 168 are the beam loss at the extraction and reflections from the beam dump, we can ignore them.
- The reason why beam losses in Arc-B and after (from 102 to 202) survive is not well known.
- **The beam loss at address 023 could be eliminated by using Col-BV.** It is a good thing of this operating point because it was difficult on the previous tune.
- Col-CV and Col-DV was inserted but we didn't get remarkable response on the distribution.

Operation at (nx, ny) = (21.35, 21.43) part 2





BLM signal [count] (arbitrary)



BLM signal [count] (arbitrary)

- **The beam losses from addresses 082 to 203 could be eliminated by using Col-3V.** It was a large effect!

- After the same method was repeated in horizontal plane, the parasitic beam loss spots survived at addresses 030, 044, 102, and 116 (final state with five collimators).
- The beam losses at addresses 030, and 116 can be reduced by inserting Col-3V more, however, beam losses at addresses 044, 102, around 018, and around 036 increase.
- Though the **Col-3V** should be a key device, **we cannot use it effectively**, because it makes significant parasitic beam losses in the following section especially in Arc-A.
- For the user-run of 416 kW FX operation, all the collimators were retuned and the Col-3H and Col-3V were eased.

Fourth Update

Future Plan

Re-arrangement of Collimators

Requirements for next update

- Though the roll of Col-3 is important, the side effect producing parasitic beam losses is a large problem.

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  It should be replaced by a four-axis collimator.

- As Col-A and Col-B don't have a incline mechanism, they release scattered protons in the lower reaches. It is good that they remain at the upper-most stream part of beam collimation system.

  ⇩

  In order to catch the leak protons from Col-A and Col-B by the following collimators, the jaw polarity of Col-C or Col-D should be turned to the opposite side.

- The old catchers should be used before address 009. It is possible to install a catcher and a four-axis collimator in one cell. When we reuse a catcher, the side effect should be considered carefully because the leakage of scattered protons seems to be large.

  ⇩

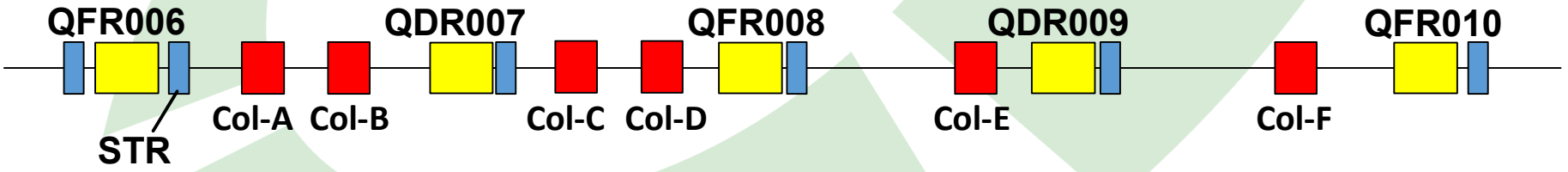
  It is good not to use a catcher if the beam loss capacity of collimation system was secured sufficiently.

Conclusion

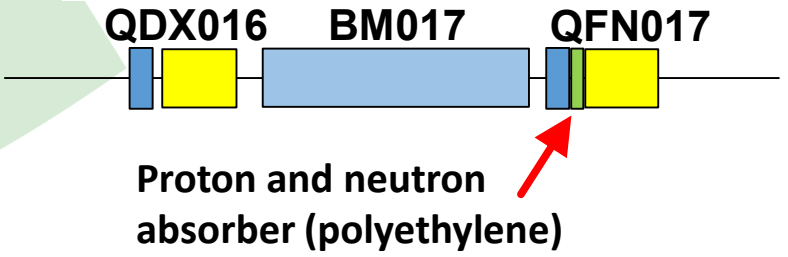
Summary of the fourth update plan

- Col-3 will be removed.
- Col-C will be moved to the address 010 instead of Col-3. It will be called as Col-F.
- New Col-C which has a jaw in opposite side will be installed.
- New Col-E will be installed at upstream of QDR009.
- Proton and Neutron absorber will be prepared between BM017 and QFN017 in order to protect QFN017.

Next Layout of MR Beam Collimation System



At least 3 kW capable beam collimation system with six short collimators



References

Sorry, some materials are written in Japanese.

[1] Y. Yamazaki et.al "Accelerator Technical Design Report for J-PARC", http://hadron.kek.jp/~accelerator/TDA/tdr2003/index2.html.
[2] S. Igarashi, MOAM6P60, Proc. of HB2016, Malmö, Swe-den, Jul. 2016, in these proceedings.
[3] M. J. Shirakata et al., THPS035, Proc. of IPAC2011, San Sebastián, Spain, Sep. 2011, pp. 3496-3498.
[4] J. Takano et al., WEPS018, Proc. of PASJ9, Osaka Univ., Japan, Aug. 2012, pp. 394-396.
[5] A. Drozhdin, N. Mokhov, "The STRUCT Program User's Reference Manual", FNAL, Dec. 1999.
[6] T. Sato, K. Niita, N. Matsuda, S. Hashimoto, Y. Iwamoto, S. Noda, T. Ogawa, H. Iwase, H. Nakashima, T. Fukahori, K. Okumura, T. Kai, S. Chiba, T. Furuta and L. Sihver, Particle and Heavy Ion Transport Code System PHITS, Version 2.52, J. Nucl. Sci. Technol. 50:9, 913-923 (2013)
[7] M. J. Shirakata et al., WEP016, Proc. of PASJ12, Tsuruga, Fukui, Japan, Aug. 2015, pp. 441-443.