J-PARC MR SE Overview

KEK/J-PARC
Masahito Tomizawa

◎ J-PARC SE Scheme and Devices
◎Present Beam Operations
◎Observed High Intensity Phenomena
◎Residual Radioactivity and Dose
◎ESS Trouble and Recovery with Improvements
◎Slow Extraction Efficiency
(◎Future Plans)

Other J-PARC talks in this workshop

Session2 (9th afternoon)
- Loss Collimation (R. Muto)

Session3 (10th morning)
- Feedback and feedforward Spill Control (M. Tomizawa)

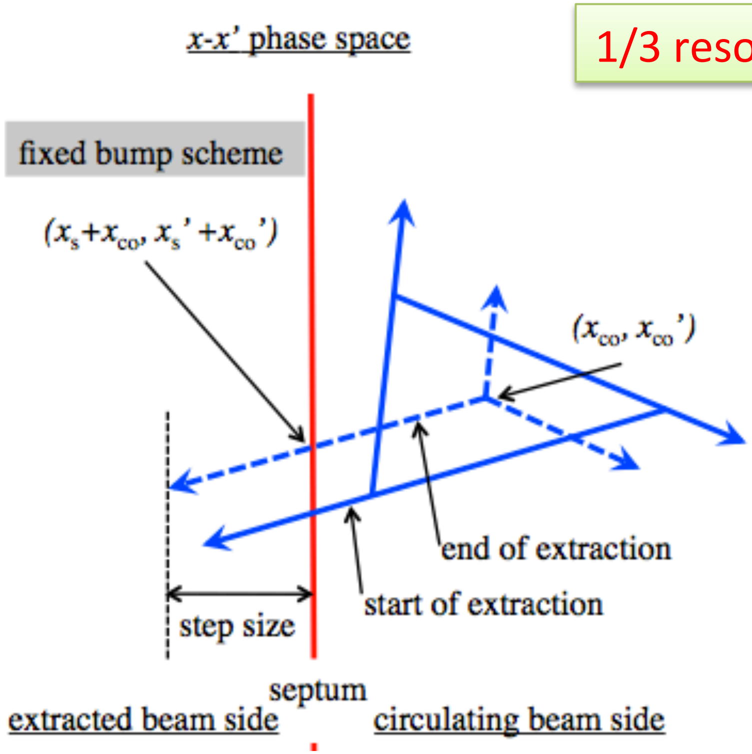
Session4 (10th afternoon)
- Alignment of septa and optimized operational set-up（R. Muto)

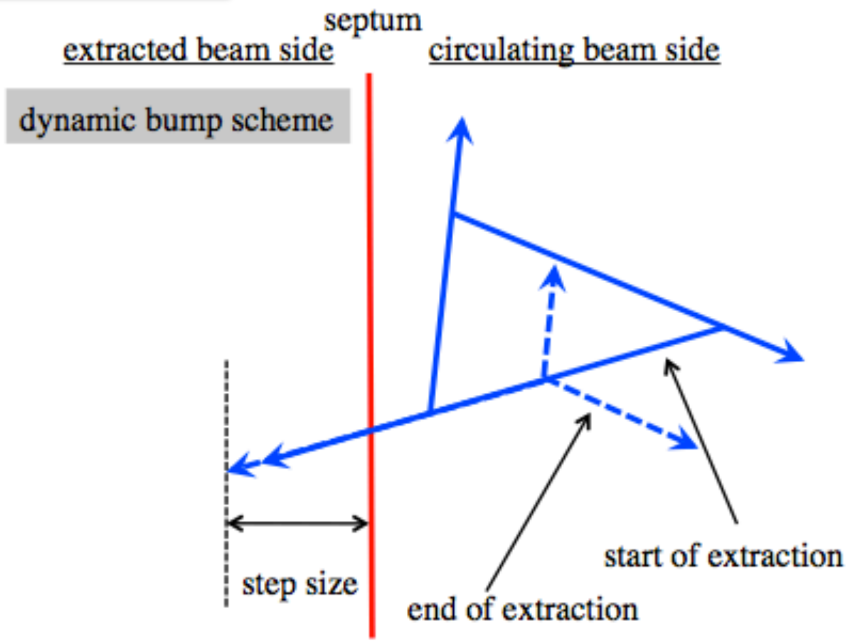
Schemes for Very High Extraction Efficiency (low beam loss)

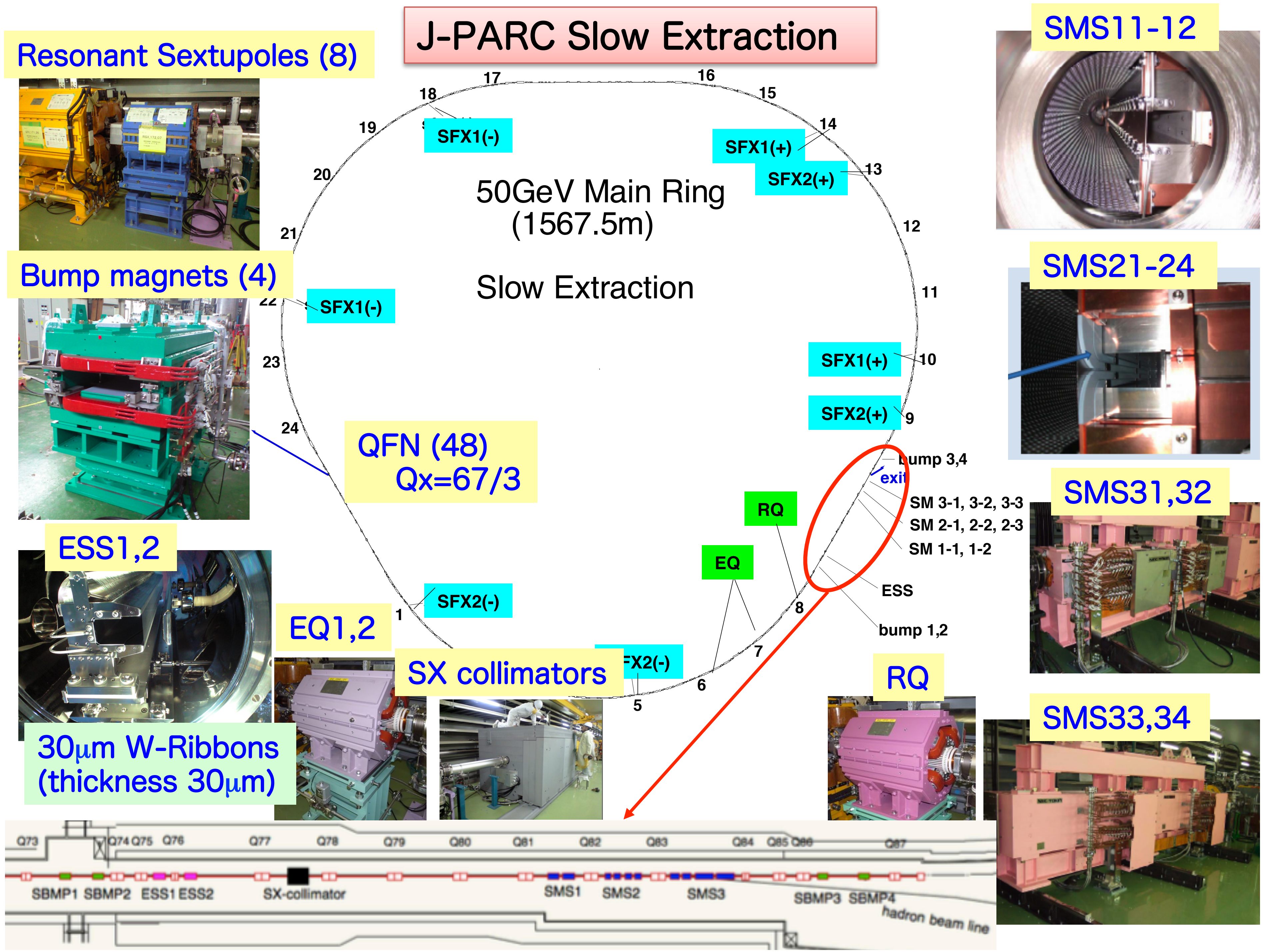
◎Electrostatic Septum (ESS) QF-QF high β (small α) 40m
-> large step size (20mm)

◎dispersion free at ESS + low horizontal chromaticity
-> Separatrix is independent of $\Delta p/p$
depends on tune (constant resonant sextupole)

1/3 resonant extraction

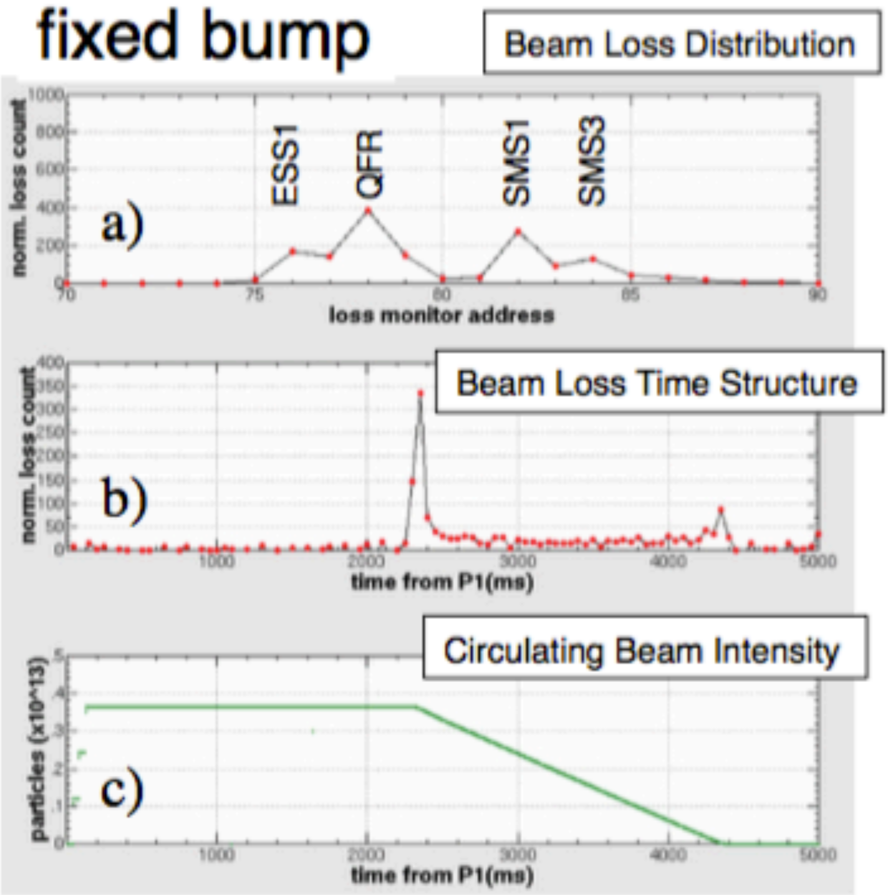




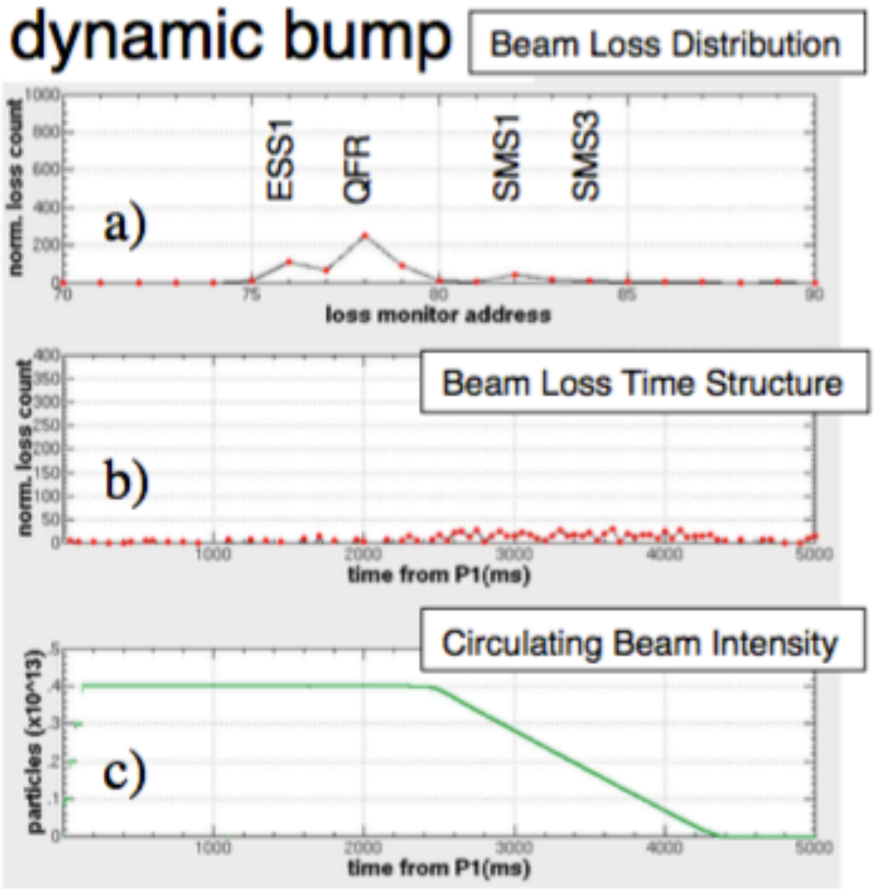

J-PARC Slow Extraction
Resonant Sextupoles (8)
Bump magnets (4)
ESS1,2
30μm W-Ribbons
(thickness 30μm)
EQ1,2
SX collimators
50GeV Main Ring
(1567.5m)
Slow Extraction
QFN (48)
Qx=67/3
SFX1(-)
SFX1(+)
SFX2(+)
SFX2(-)
RQ
EQ
bump 3,4
exit
SM 3-1, 3-2, 3-3
SM 2-1, 2-2, 2-3
SM 1-1, 1-2
ESS
bump 1,2
SMS11-12
SMS21-24
SMS31,32
SMS33,34
Q73 Q74 Q75 Q76 Q77 Q78 Q79 Q80 Q81 Q82 Q83 Q84 Q85 Q86 Q87
SBMP1 SBMP2 ESS1 ESS2 SX-collimator SMS1 SMS2 SMS3 SBMP3 SBMP4
hadron beam line

Fixed Bump and Dynamic Bump

Efficeincy 98.6%



Efficiency 99.5%



Beam loss was reduced to 1/3.4
Efficiency is 99.5%

Beam Intensity dependent phenomena

◎Beam Deceleration during debunch process
by RF cavity impedances
----cured by RF beam loading compensation of feed forward at flat top

◎beam loss at the beginning of acceleration
due to space charge tune shift or transverse instability
--- cured by tune, chromaticity adjust and BxB F.B.

◎Instability during debunch process
- vacuum pressure rise in the whole ring
- electron cloud
- beam loss in debunch and slow process

present cures -> chromaticity, longitudinal dipole oscillation

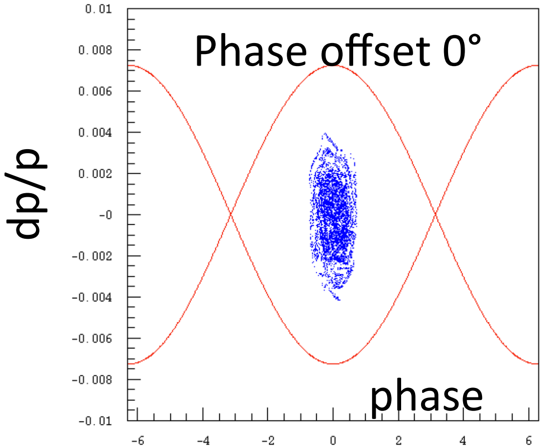
Beam Instability During Debunch Process

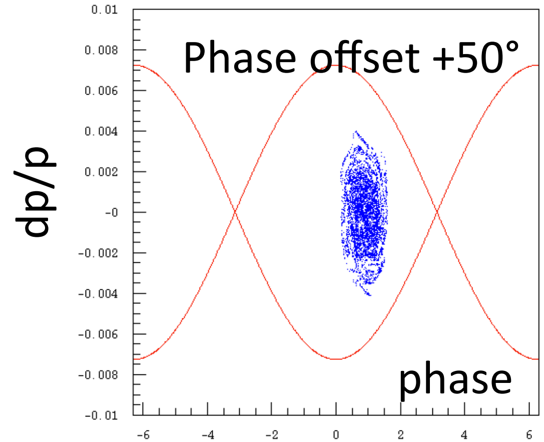
associated with

- Vacuum pressure rise in the whole ring
- Electron cloud
- beam loss increase at slow extraction by factor 2 or more!

Present cure: Force longitudinal dipole oscillation by a RF phase offset at injection

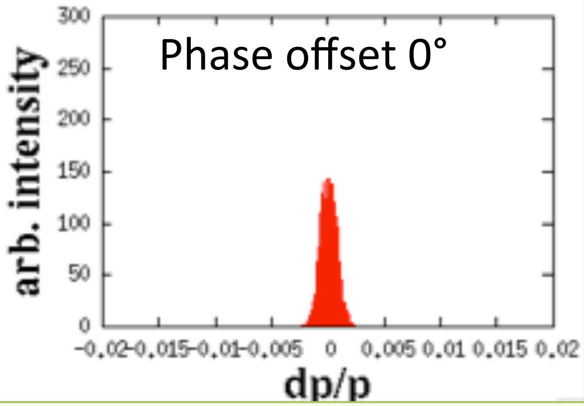
160kV
Injection

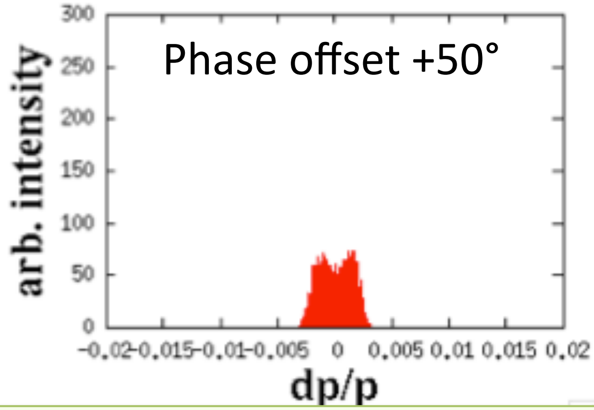




Dipole oscillatior
Smear

256kV
Flat top
Before debunch





The cure is essential to achieve the present and a higher beam power

Present User Operation Performances (41-44.5kW)

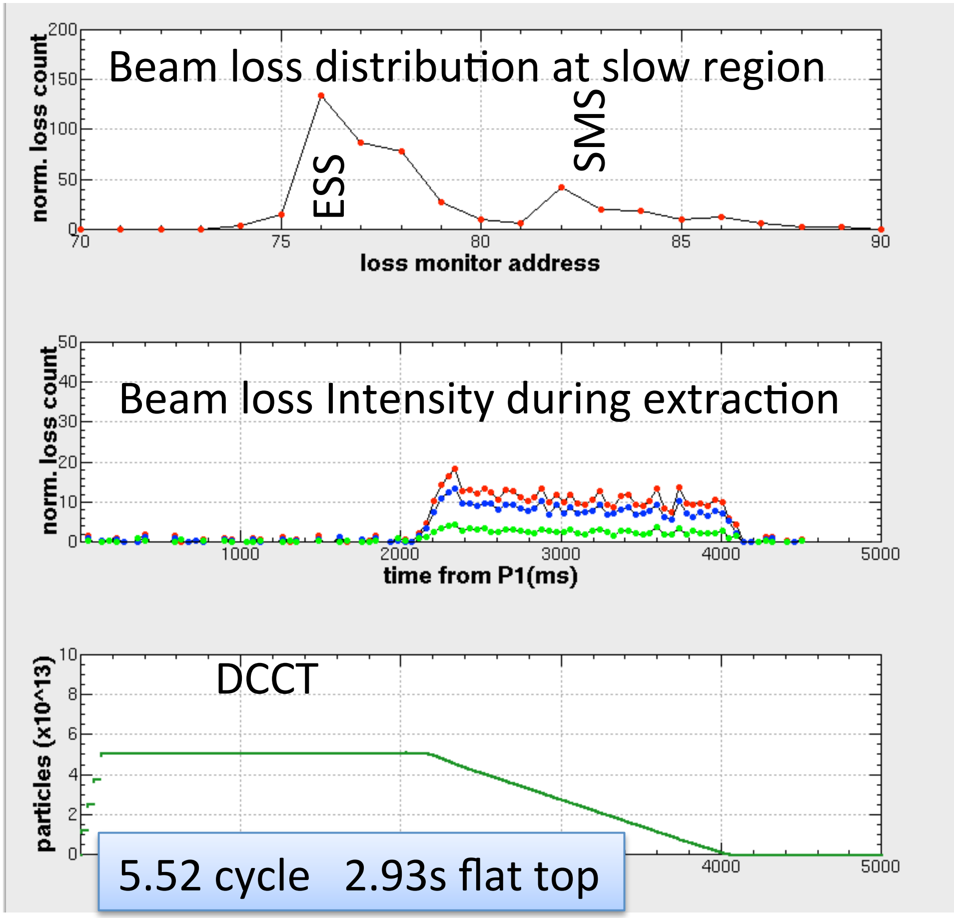
- RF phase offset injection +50deg.
- Dynamic bump
- ESS1（rotation）,ESS2(parallel、rotation) position tuning
- SMS1(parallel） position tuning

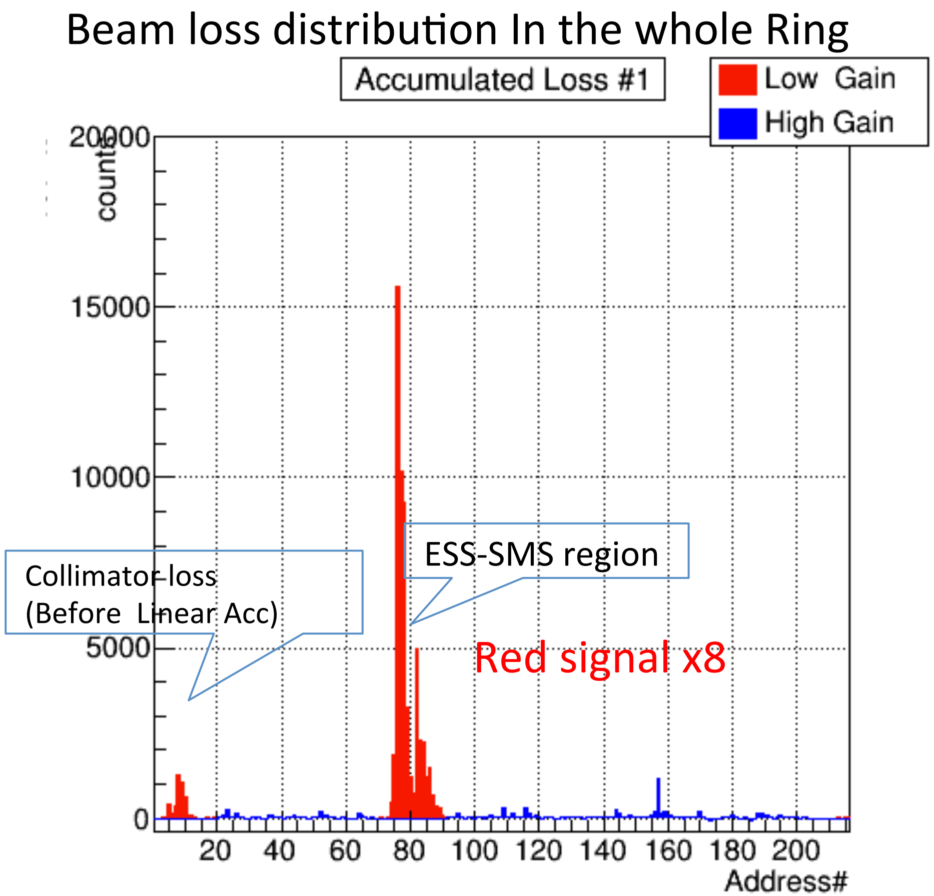
#383139 (RUN74)

Beam Power 44.5kW

PPP 5.1x10^13

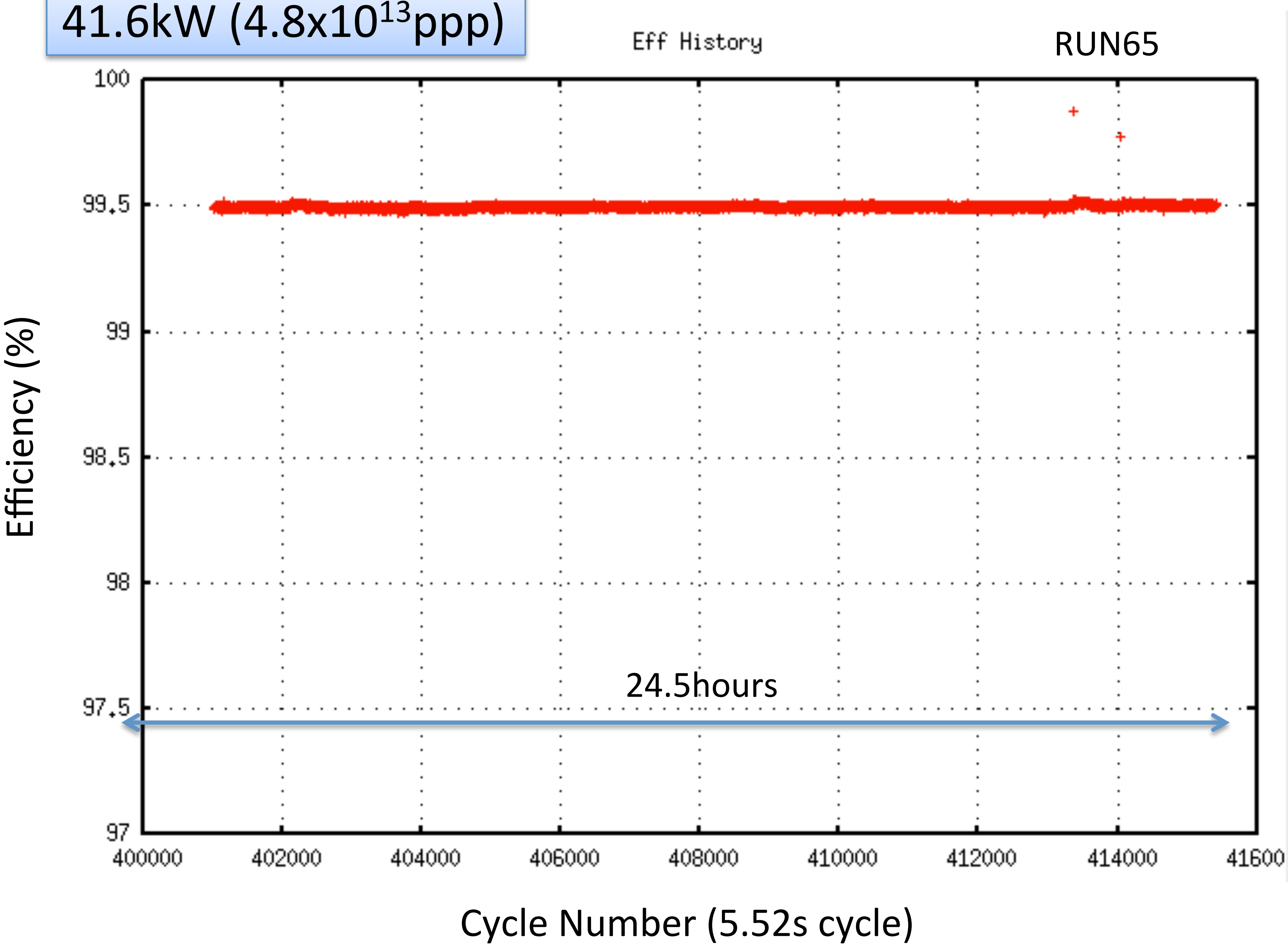
Efficiency 99.6%





Stability of Extraction Efficiency

41.6kW ($4.8x10^{13}$ppp)



50.8 kW beam has been successfully slow-extracted

(6/30 SX Study, one shot mode, HD target defocus mode)

5.84x10[13] ppp
Efficiency 99.53%
Duty 55.3%
Spill Length 2.12s

Thinning 24/32
Chopping 280 ns

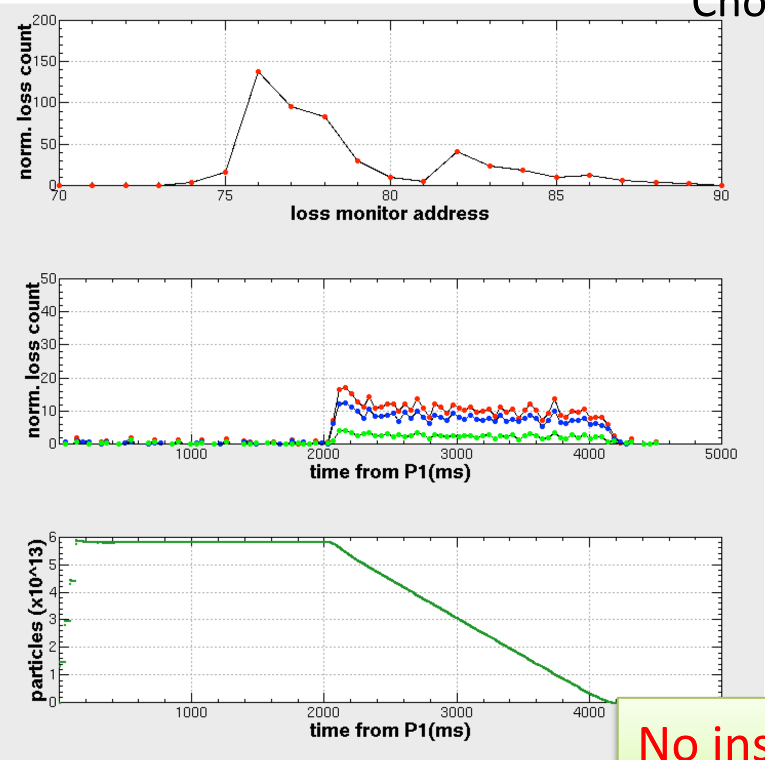
Offset   +50deg from Center

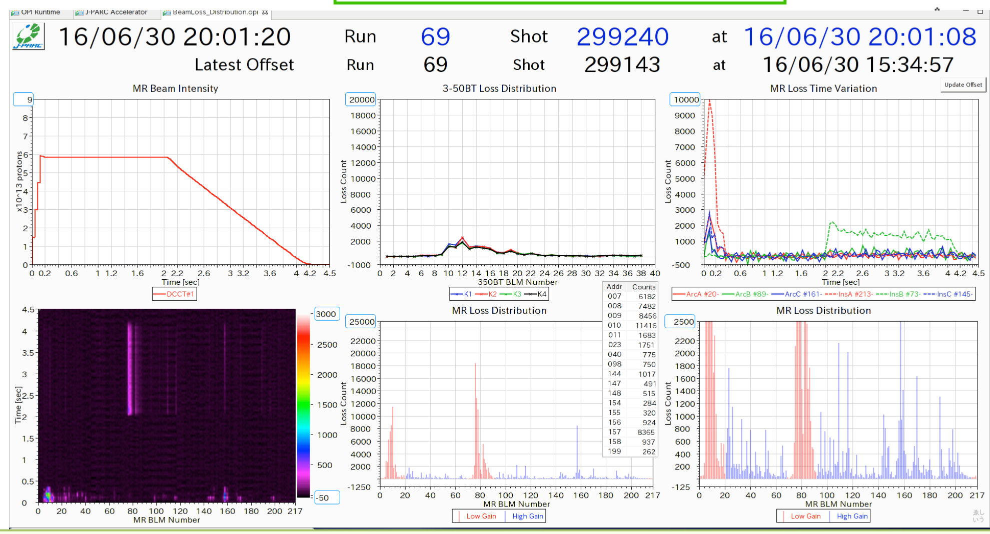
MR@K2/RCS	1.994		Beam loss[ppp]
K3/K2	1.496	K1loss	3.66e+09
P2/K2	1.973	K2loss	3.66e+09
P2/K3	1.319	K3loss	1.32e+11
BE/K2	1.957	K4loss	0.00e+00
BE/P2	0.992		

	Beam loss[Watt]	
INJ(K1+K2+K3+K4)	12	1.40e+11
P2 --> +90ms	62	5.76e+11
P2+90ms --> +120ms	16	1.48e+11
P2+100ms ---> EXT		4.29e+28

19

MR Power   50.78 kW



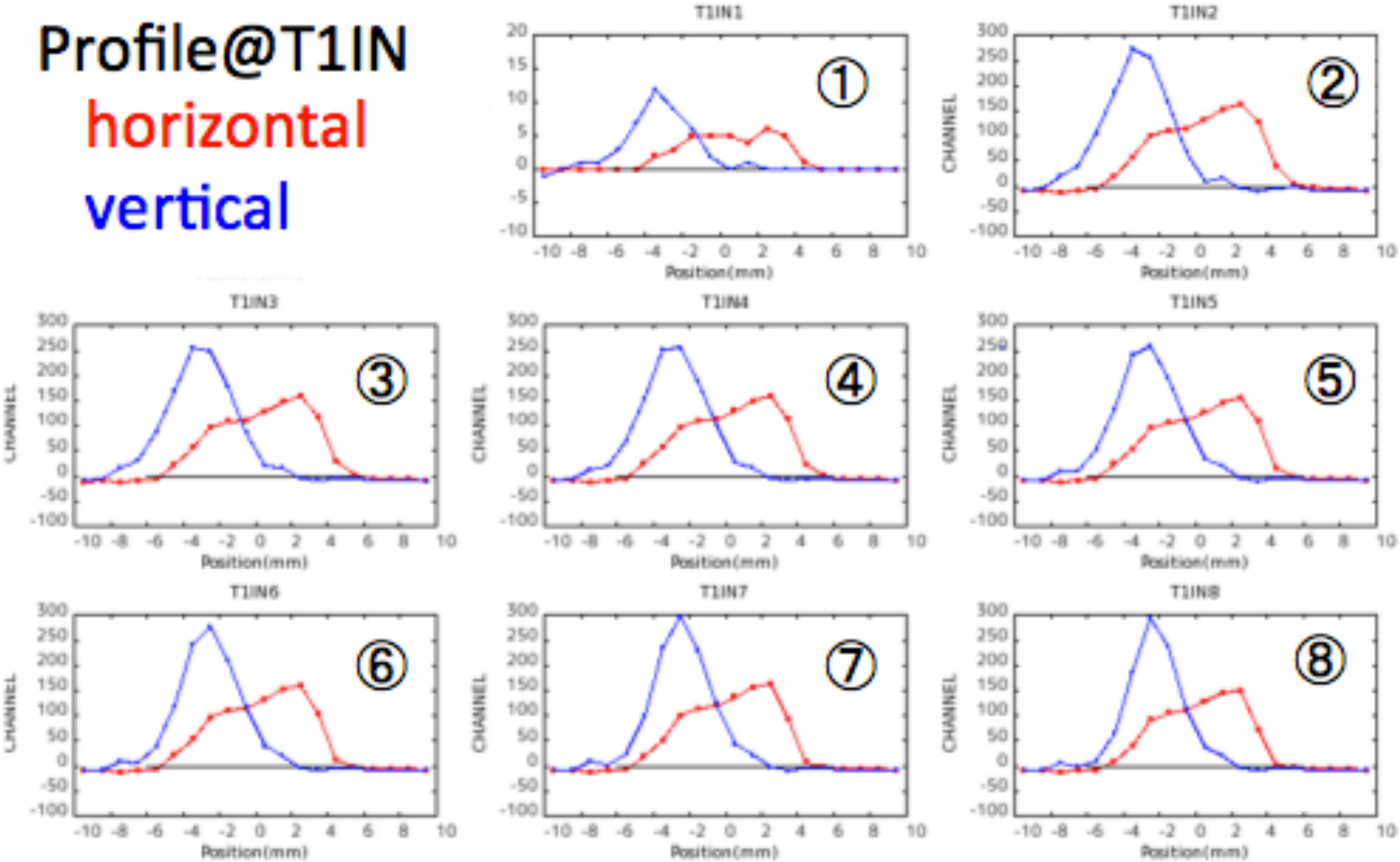


No instability occurred at 66.3 kW (60° offset) not SX

Beam Position at Target during Extraction

2016/06/17 10:50:41 #shot=166088

Profile@T1IN
horizontal
vertical



Dispersion Dx=0.58m Dy=-0.37m @ T1IN

Beam spot does not move (Dynamic bump, Achromatic Extraction)

SE Beam Stop System

We can stop SE beam for the machine or beam loss trip to protect the devices (target,ESS,SMS,,,) within 1ms.

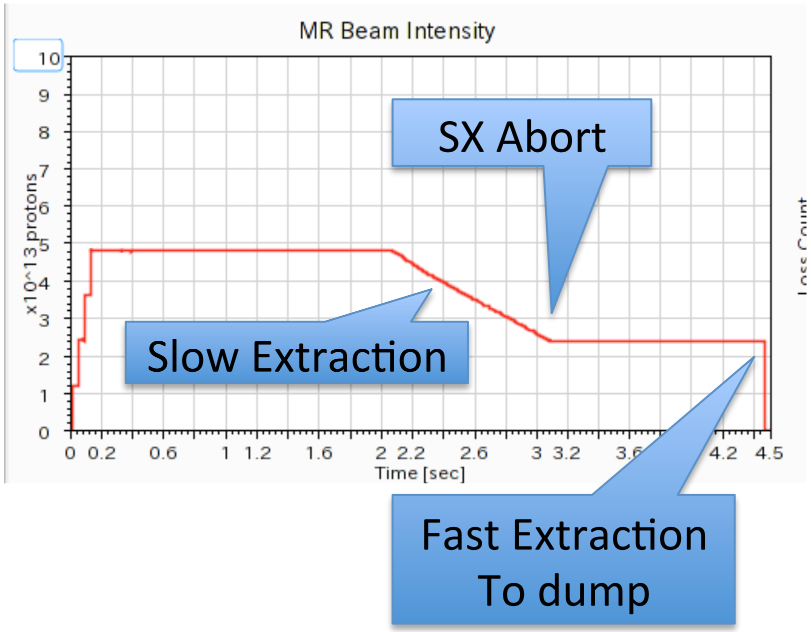
The beam is dumped at the end of flat top.

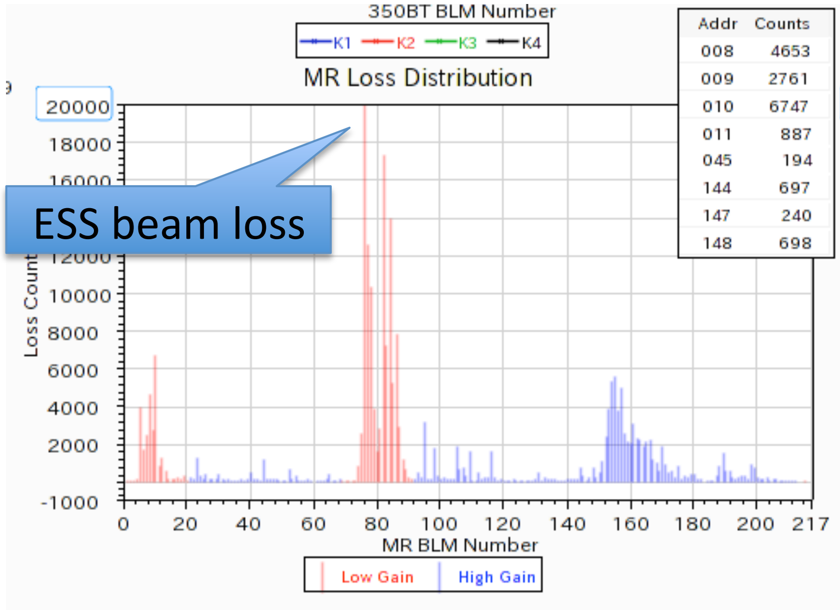
This system is indispensable for present high intensity runs

SX Beam Study BLM76 (ESS1) beam loss count increase

2015/11/25 12:07 run65 #109878

Present MR can not abort beam at any timing





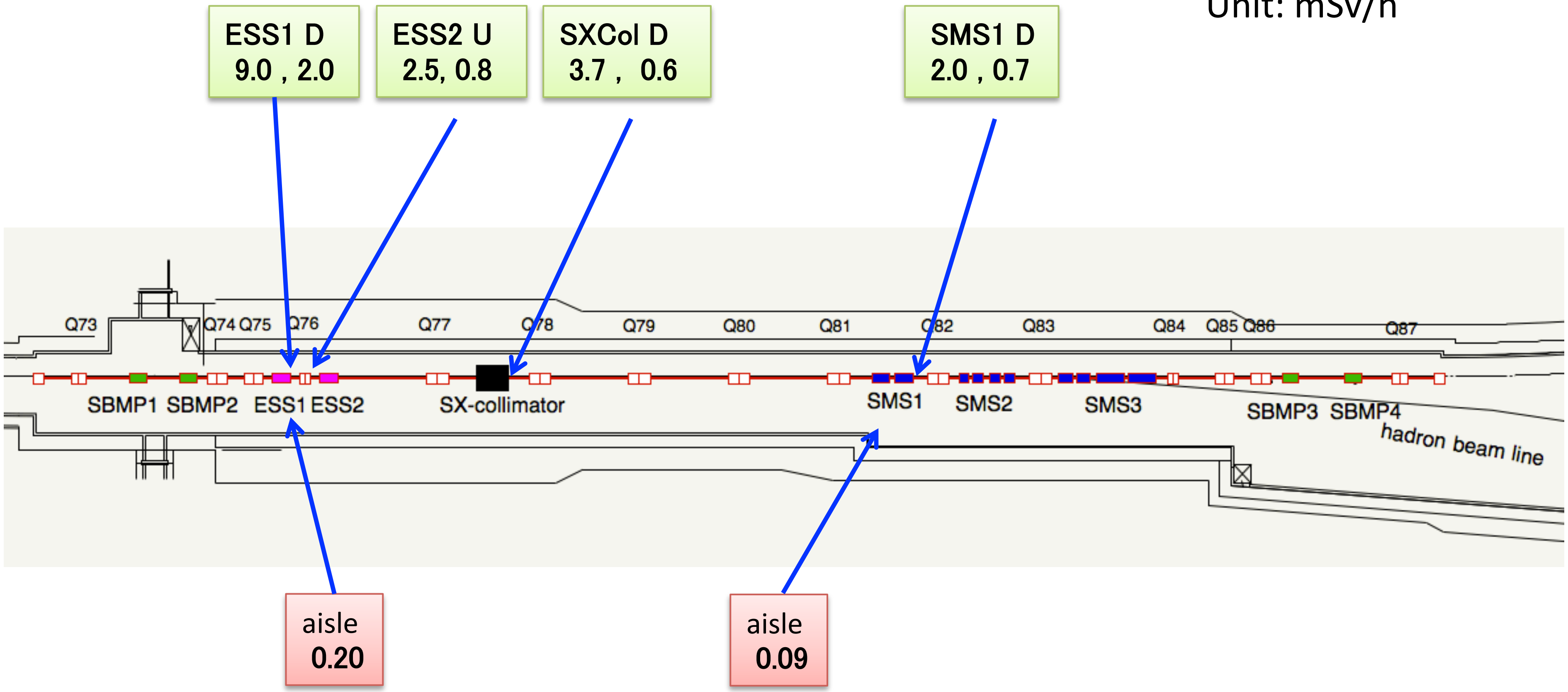
Residual Radioactivity

2016 6/15

Residual dose distribution at 4 hours cooling time
after 41kW SX beam irradiation

on contact, 30cm

Unit: mSv/h



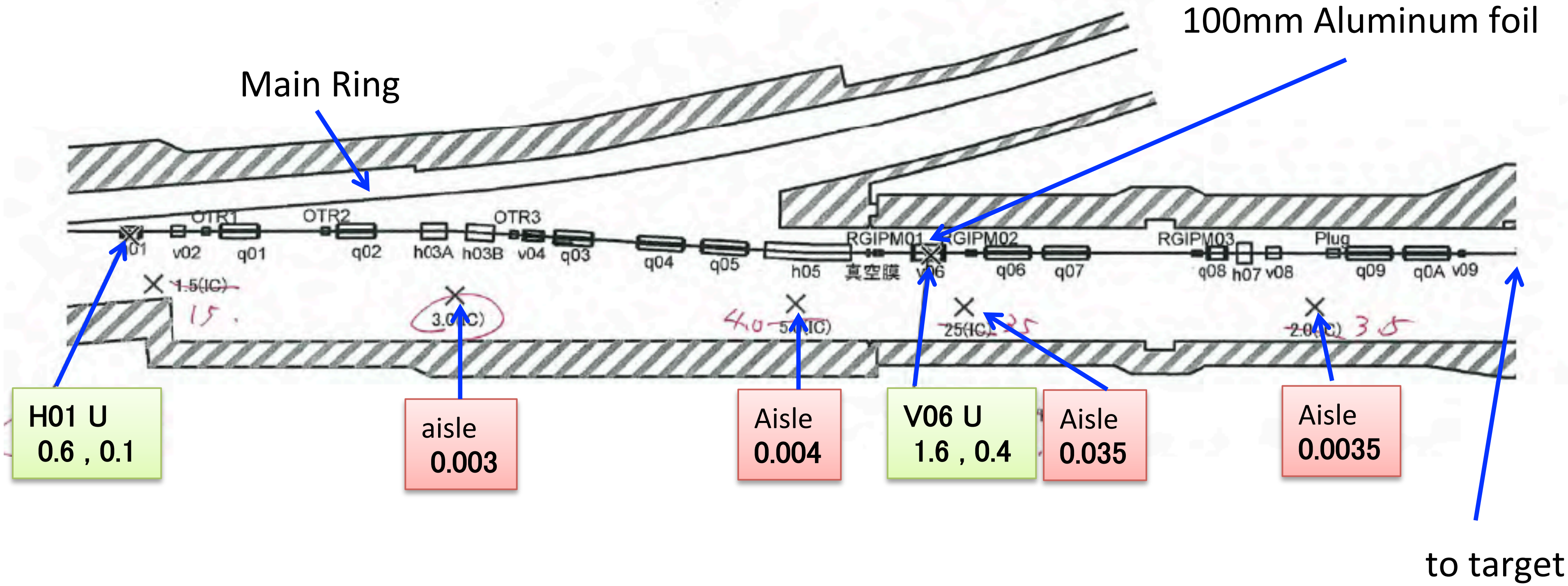
Residual Radioactivity (HD beam line)

Residual dose distribution at 4 hours cooling time
after 41kW SX beam irradiation

2016 6/15

on contact, 30cm

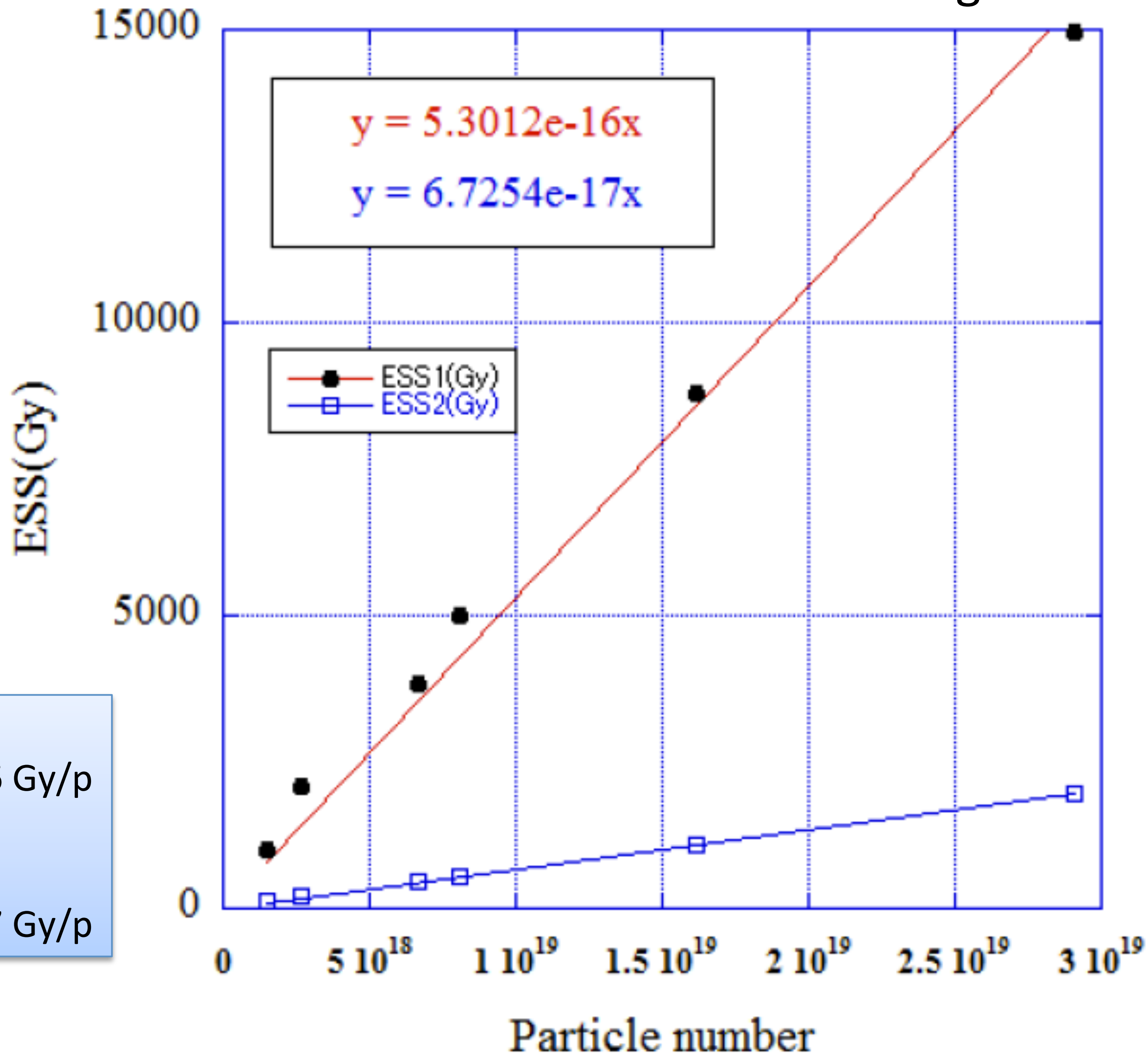
Unit: mSv/h



2017.1.27 Arakaki

Alanine dosemeter

Measured Dose on ESS feedthrough duct

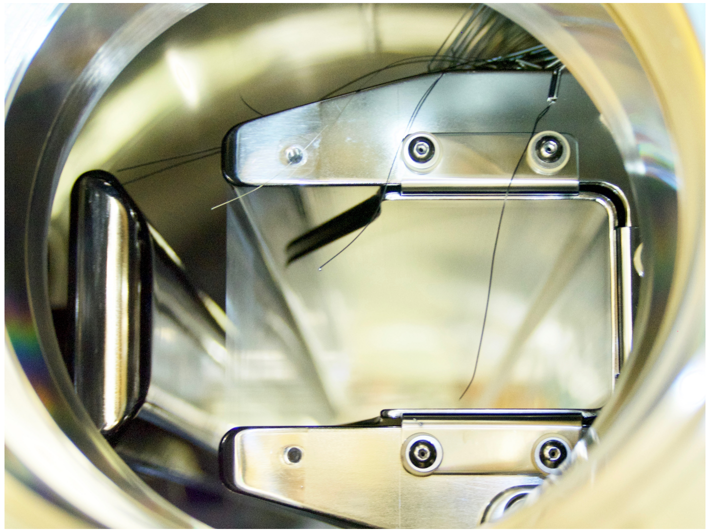


ESS1
5.3x10-16 Gy/p

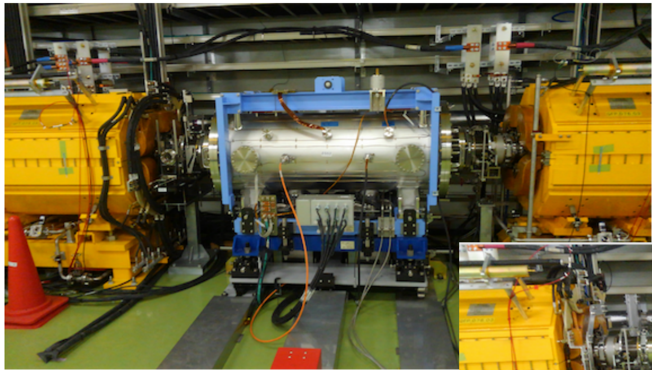
ESS2
6.7x10-17 Gy/p

Ribbons were cut and touched on the electrode of SUS-ESS1 (2017.4.26)

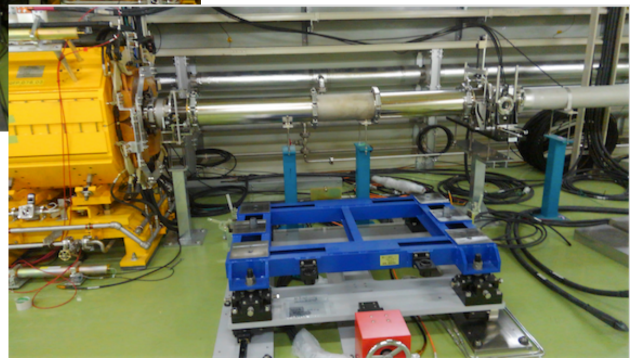
- This trouble is estimated to be caused by a transverse beam instability during the bump orbit check (5-10kW)
- H-chromaticity was set to a slight positive value (dangerous!)



SUS-ESS2 @ESS1

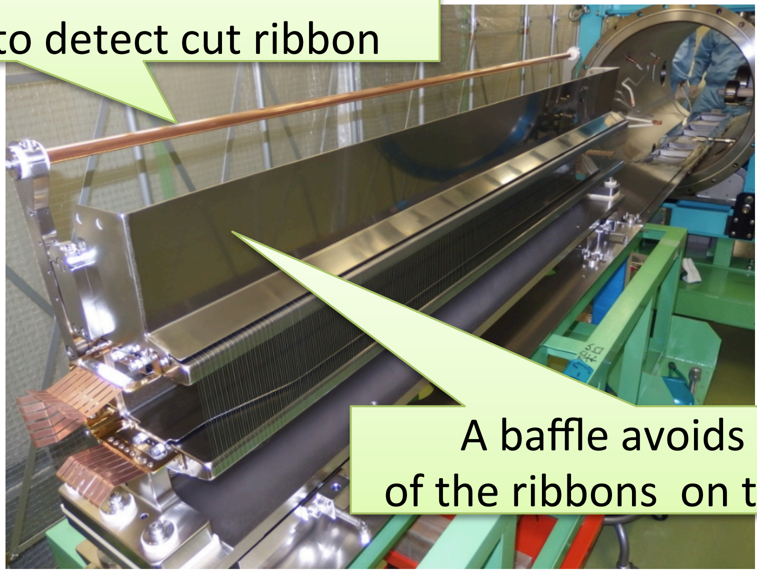


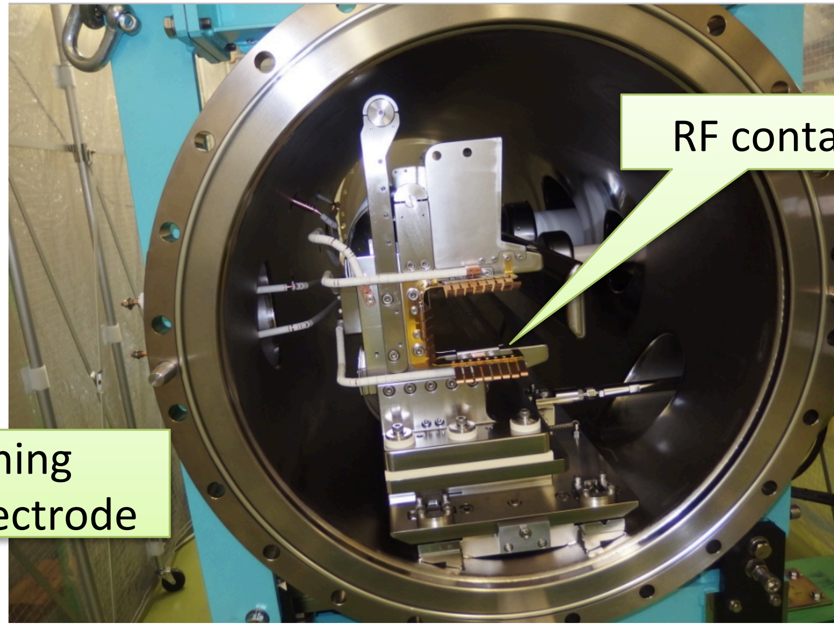
Beam duct @ESS2



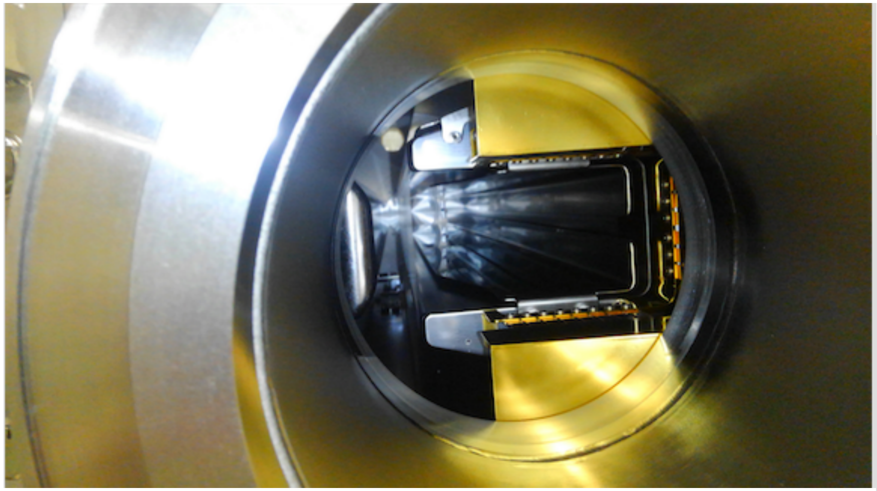
- Finally, the troubled SUS-ESS1 was uninstalled and downstream SUS-ESS2 was moved to the ESS1 position to get a higher turn separation @SMS1
Extraction efficiency was 99.5 -> 99.3% @37kW
(loss @SMS1 was double).

Ti-ESS1 has been installed in this summer shutdown period

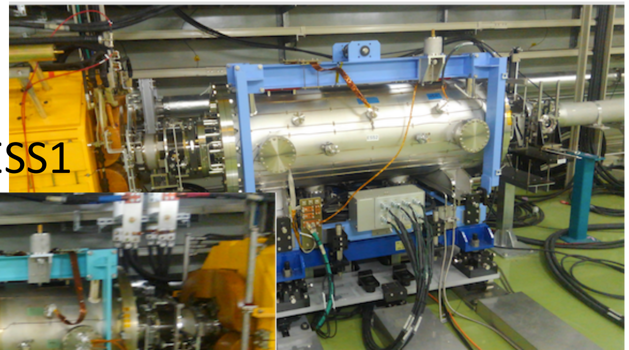




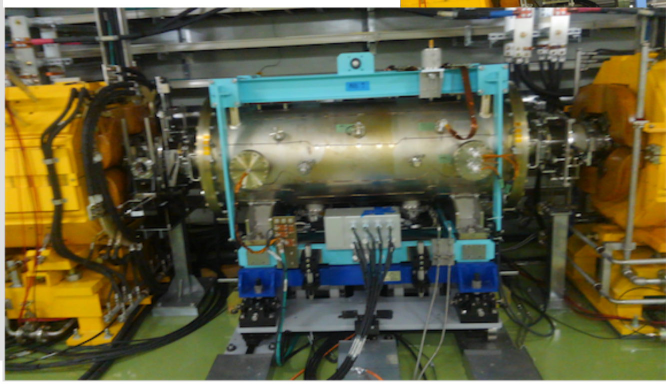
View from beam duct



SUS-ESS2 reinstalled @ESS2

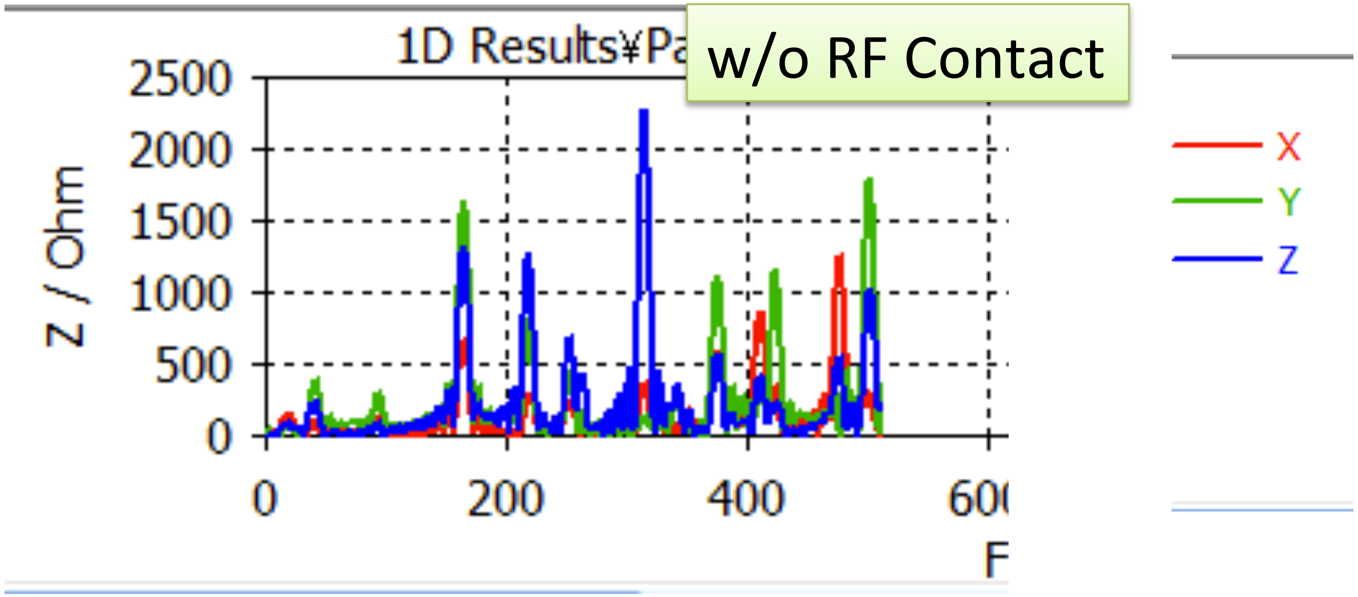


Ti-ESS installed @ESS1

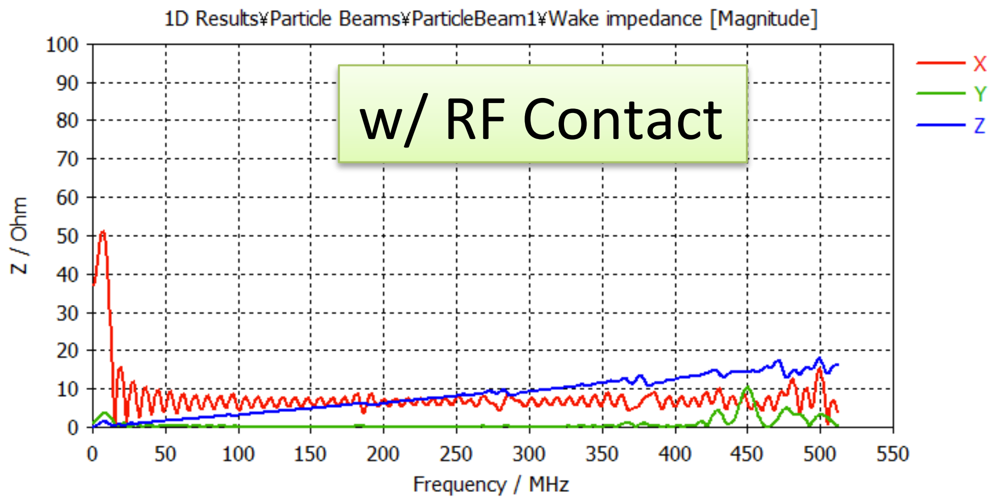


ESS Impedance Reduction by RF contact (CST Studio)

ESS_tomizawa_031.cst

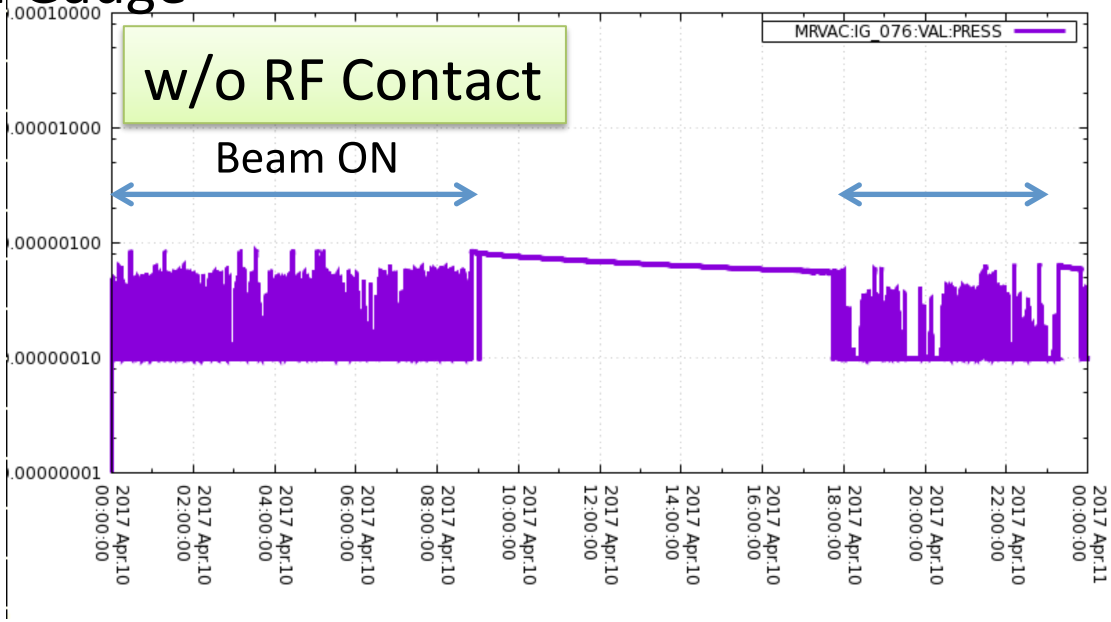


ESS_tomizawa_070.cst

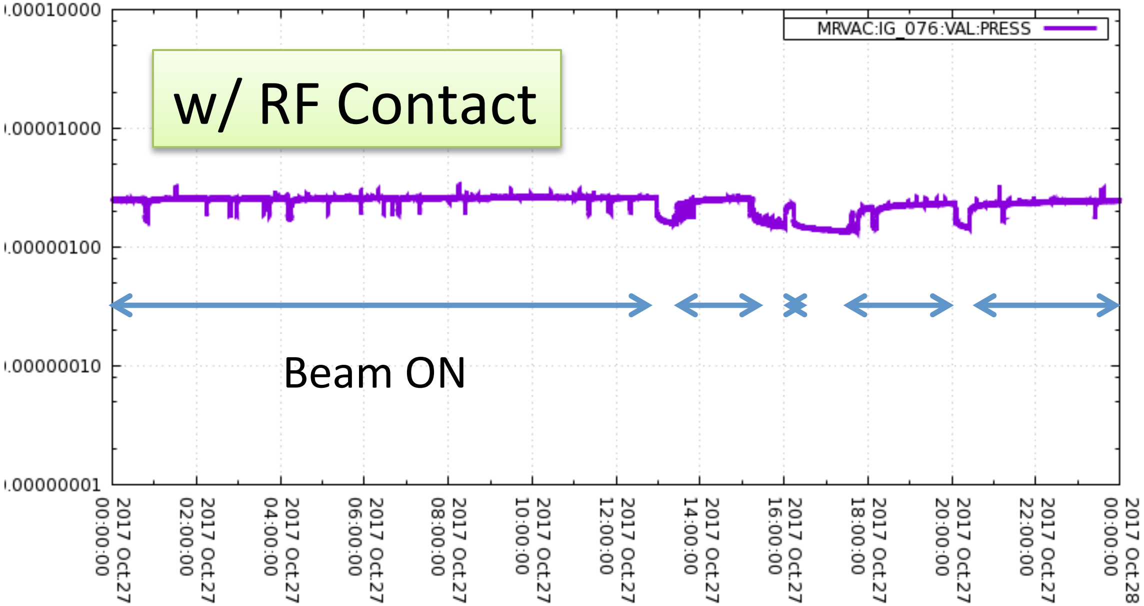


ESS1 Vacuum Ion Gauge

2017/4/10
460kW Nu RUN



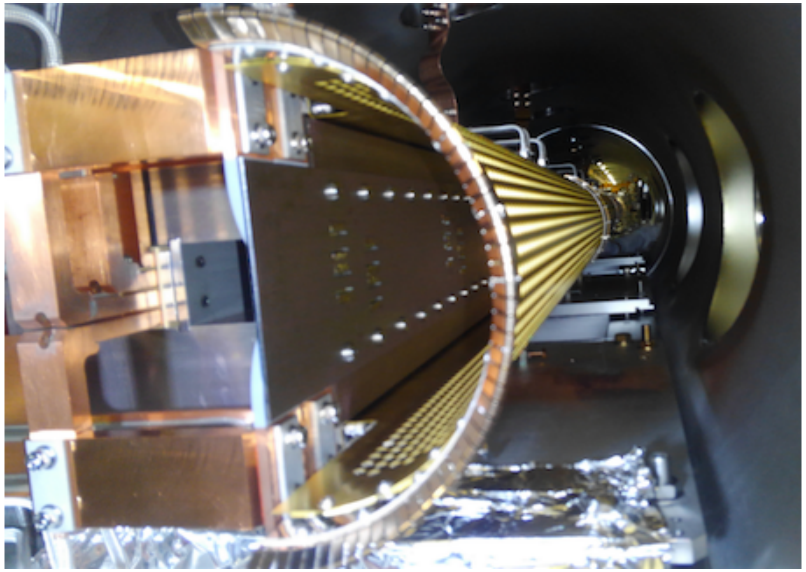
2017/10/27
440kW Nu RUN

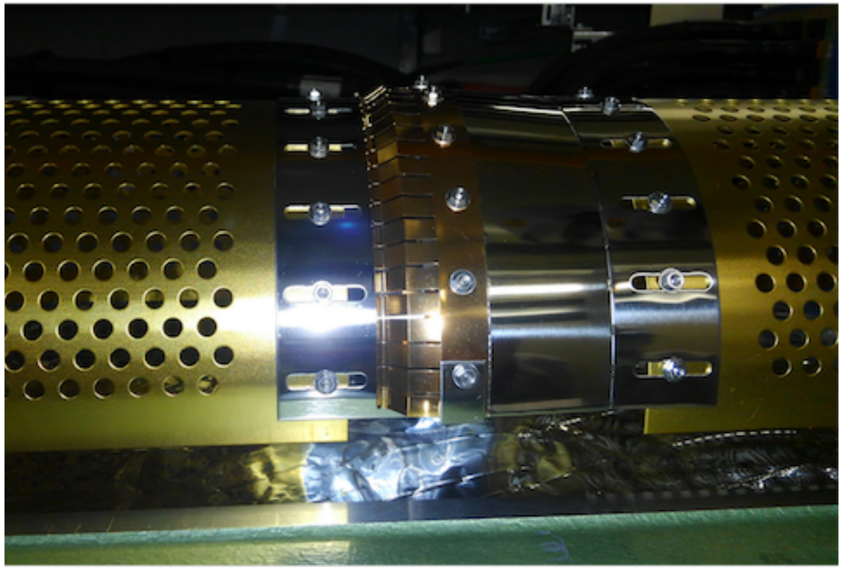


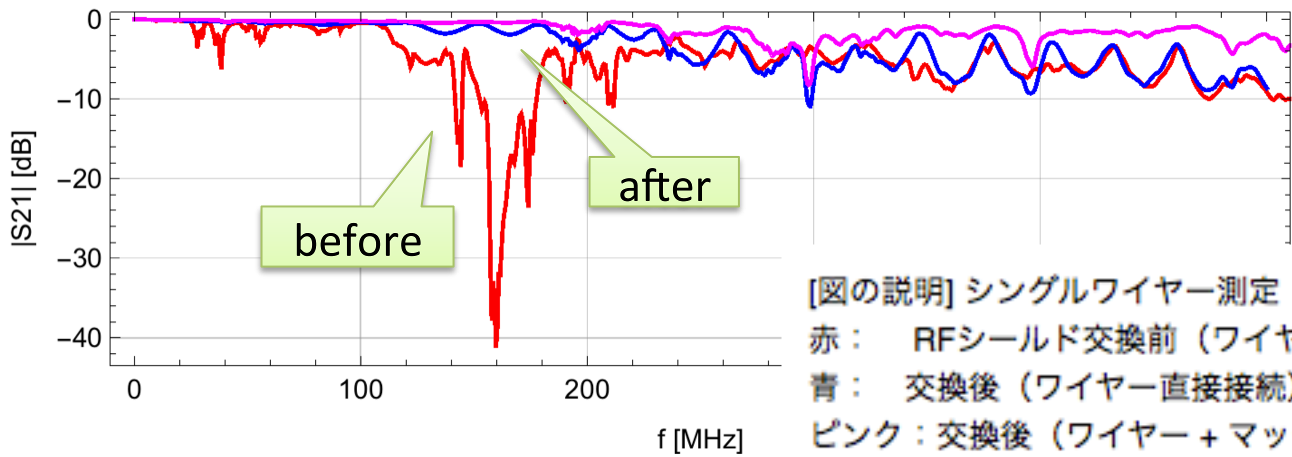
Low and Medium Field Magnetic Septa RF shields

Low field MS: 2015
Mid. field MS: 2016 9/21-9/30

TiN coated magnetic shield







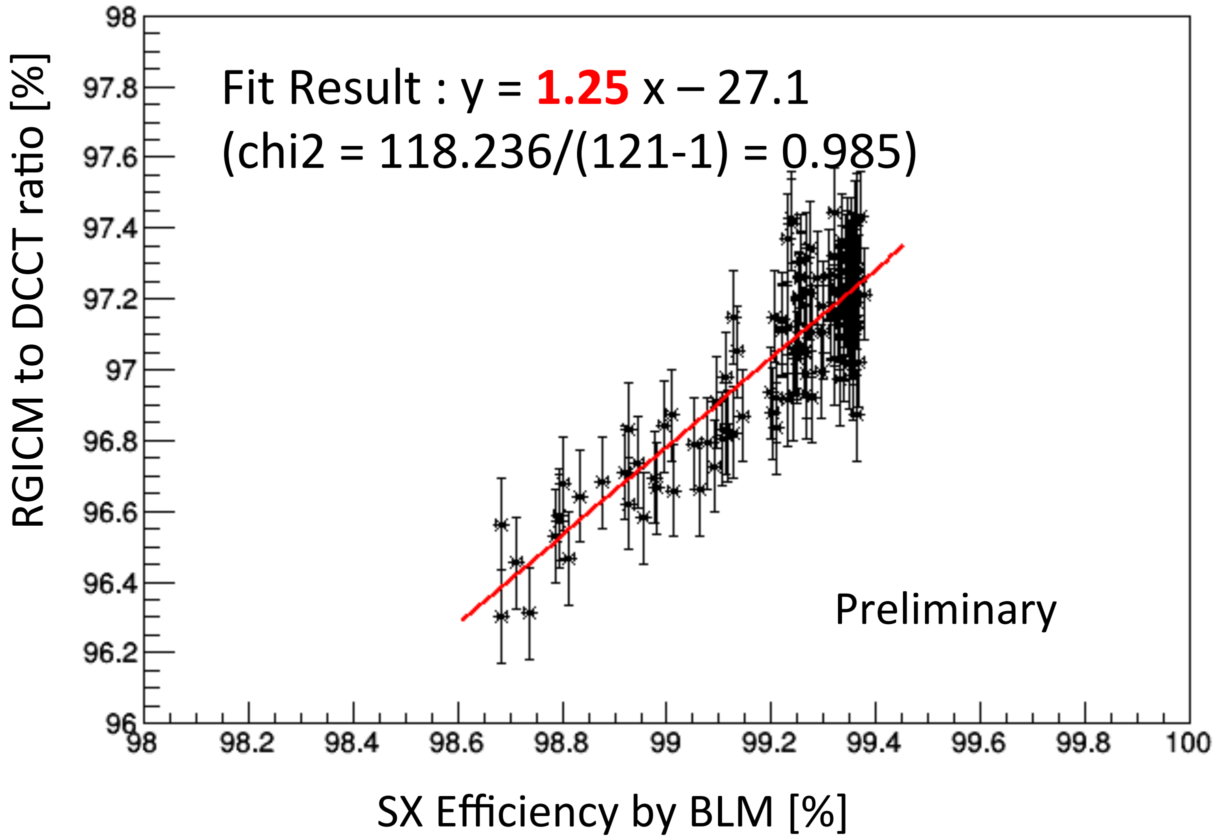
by Toyama, Kuboki

[図の説明] シングルワイヤー測定（longitudinal impedance ZL 評価用）
赤：　RFシールド交換前（ワイヤー直接接続）
青：　交換後（ワイヤー直接接続）
ピンク：交換後（ワイヤー + マッチング抵抗 361Ω 接続）

Slow Extraction Efficiency

◎Derived from BLM signals, calibrated with DCCT signals
for the beam loss produced by local bumps

◎Extracted Beam intensity at Beam loss in the ring (AGS -> SPS)



The beam loss (calculated using BLM outputs)
could be underestimated by a factor of ~1.25 (e.g. 99.5% → 99.4%)
(assuming that the linearity of the RGICM is not so bad)

Summary

・41-44.5kW (5.1x10^13 ppp) beam has been stably delivered
at 99.5% efficiency for user run
We has succeeded a 50.8kW (5.1x10^13 ppp) SE test

・We guess observed transverse instability during debunch
is triggered by longitudinal instability
The beam instability during debunch has been suppressed by
RF phase offset injection, Qx' tuning,

・Beam position shift at target during extraction is negligible small

・The troubled SS ESS1 has been replaced by Ti ESS with a baffle and a isolation rod

・ Impedance has been improved by RF contacts in Ti-ESS1 and SMS1 and SMS2.

・Extraction efficiency derived by AGS way roughly agrees with that of our way.

・Present residual radioactivity is still tolerable from the J-PARC dose limit.
～1mSv/y (limit 7mSv/y) (ALALA)

Future Plans

◎New project and proposal

- COMET (μ-e conversion search) phase I (3kW), phase II (56 kW), 8GeV 1MHz, extinction < 10-9
- S.C. stretcher ring (under design and proposing , The S.C. magnets R&D will be soon submitted to KEK Multi-national Partnership Project)

◎ >100kW SE (with upgrade production target)

- higher rep rate by replacing BM,QM power supplies for Neutrino (～2019)
- moderate increases of PPP

◎Instability suppression

- phase jump before debunch (soon tested)
- VHF cavity (under design, phase modulation, noise)
- transverse beam feedback during SE (under discussion)

◎toward Higher extraction efficiency

- resonant sextupole strength 75% (step size 15mm) -> 85% (step size 20mm)
- Scatterer/diffusers (under design study)
- low-Z septum ESS (CNT) Grants-in-Aid for Scientific Research 2017-2019
- multipoles (K. Brown et. al)
- high βx lattice at ESS (under discussion)
- mass less septum as pre-ESS (under discussion)

◎ Protection devices upstream septa (e.g. SPS)

100 kW SE Scenario

◯Upgrade production target

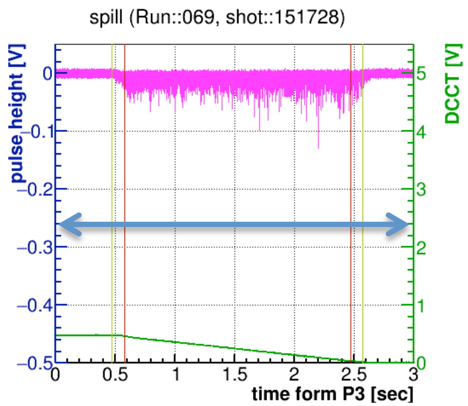
◯ Cure of Instability during debunch is most critical part.
However we have already succeeded to suppress the instability at 66.3kW (rep. 5.52s) by the longitudinal dipole oscillation (not SX). We expect SX also goes well

◯ The beam loss at the beginning of the acceleration (66.3kW) can be reduced by tune, optics correction, chromaticity, skew Q and BxB feedback (enough study time)
4.4% loss at 66.3kW (no tuned) -> 1.5% loss (to 1/3) 68 kW

◯ Higher Rep. Rate

- High Rep. in 2019
  Rep. 2.48s -> 1.3 s (NU)
- flat top 2.93s -> 2.43 s (not to shorten spill length)
  Rep. 1.3 + 2.43 =3.73 s (SX)
  5.52/3.73 *68 kW -> 100 kW

The 0.3s cut was tested



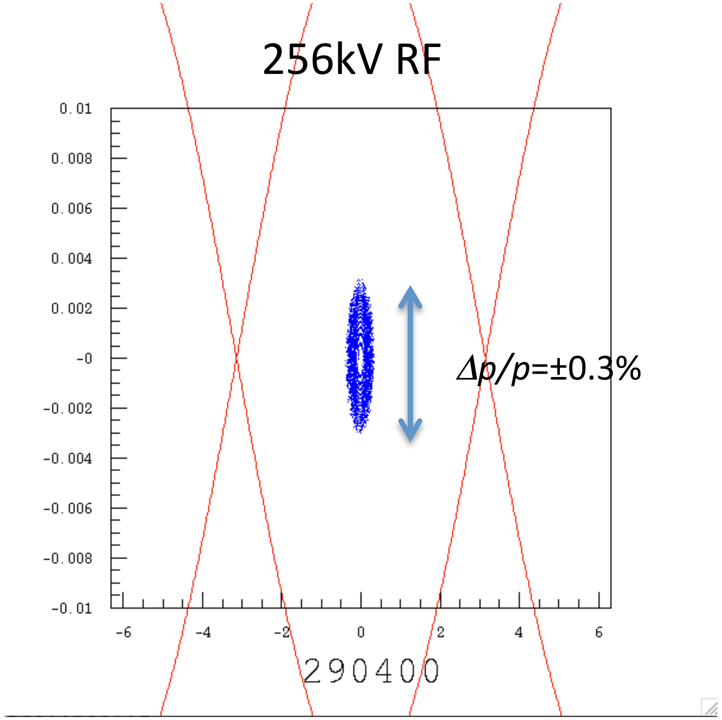
pulse height of spill

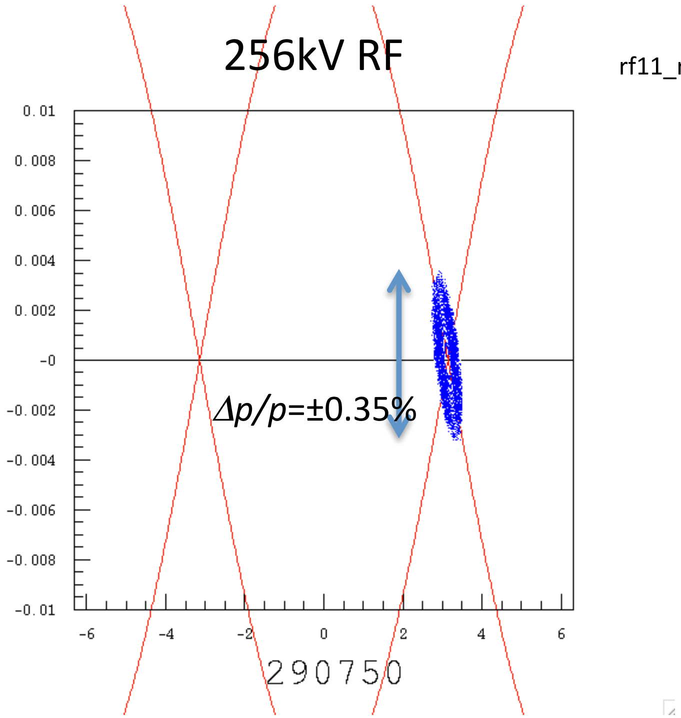
◯ Residual radioactivity

- Titanium ESS
- Local shield
- Titanium ducts

Suppression Schemes of the instability during debunch

◎debunch after RF phase jump at flat top





rf11_rf6_010_26.com

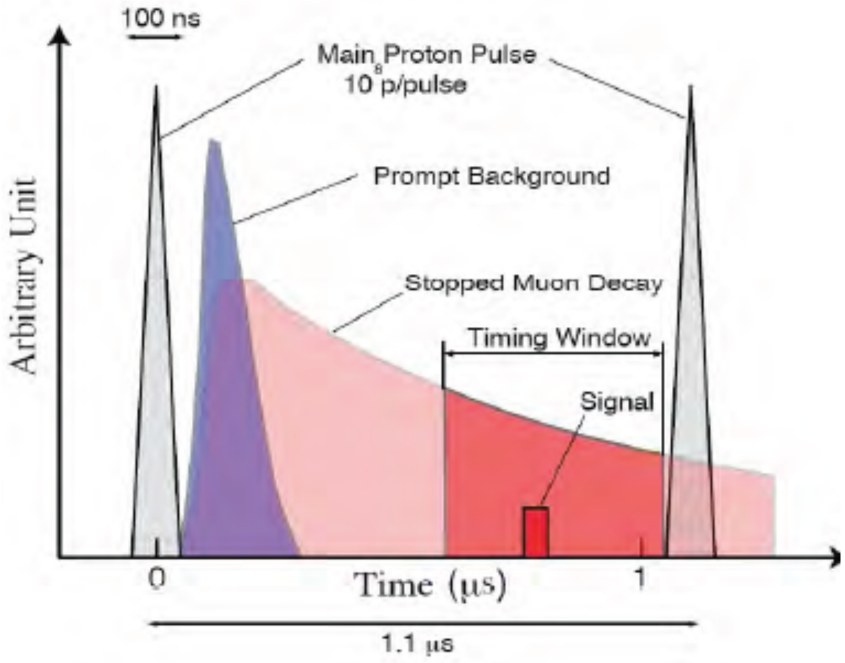
Combination with RF phase offset

◎ 100-200MHz VHF cavities uniform and enlarge longitudinal emittance

COMET Experiment

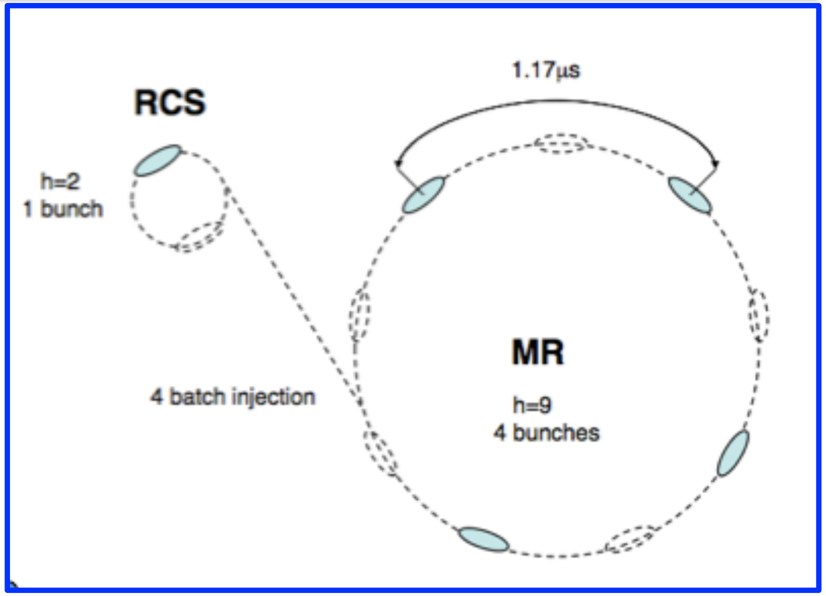
(COherent Muon to Electron Transition)

8GeV 1MHz pulsed beam



RCS 1 bunch acceleration

3 or 4 bunches are injected and SE in MR



◎8 GeV SE adiabatic dumping is small

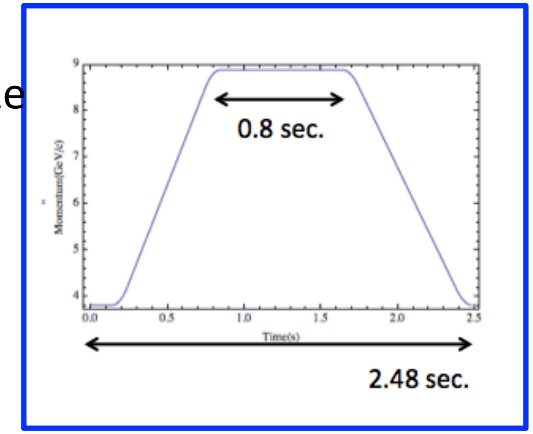
Aperture of magnetic septa

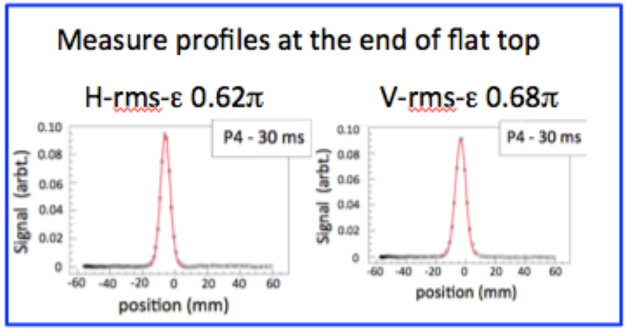
◎Beam intensity ratio between pulses: Extinction < 10^{-9}

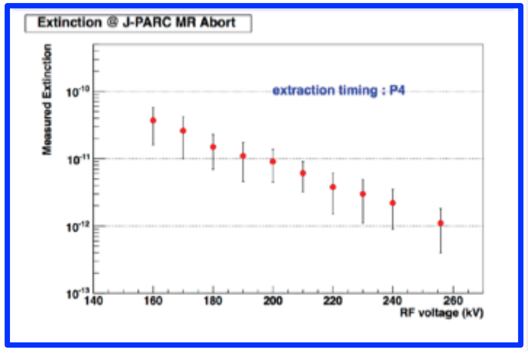
COMET Phase I

Beam power 3.2kW

The beam with a small beam size
Is produced in the RCS
(painting in a small area
at the injection)







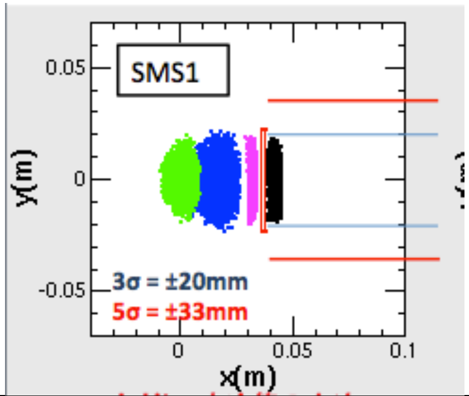
same as a typical 30 GeV beam size

8GeV SE test and extinction measurement
will be scheduled in the next SE RUN

COMET Phase II

Beam power 56kW

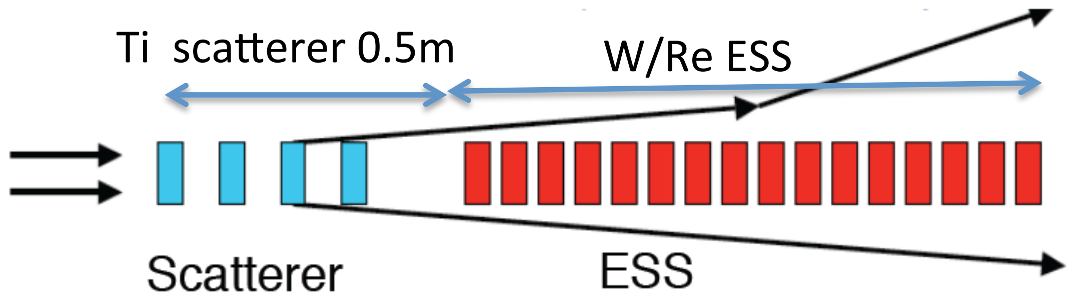
Magnetic Septa will be
replaced to larger aperture ones
and their P.S. will be built
SMS1 V-gap 55mm -> 76mm
3104A -> 4300A



Scatterers/diffusers

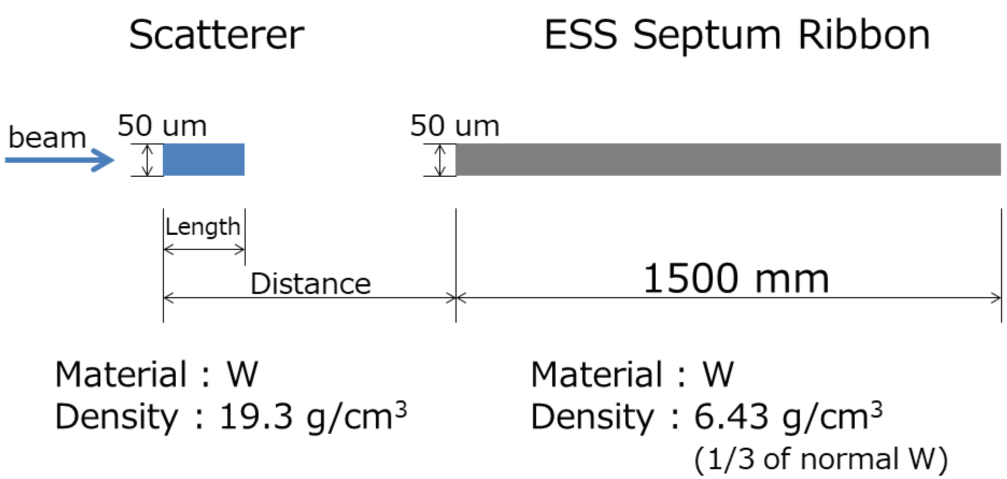
- multiple scattering（diffuse beam）
- Reaction（beam loss）

(Some schemes are under study)



1.5m long, 3mm pitch W ->
0.5m long, 9mm pitch Ti + 1m long, 3mm pitch W
residual dose at ESS downstream duct is reduced by 50% (MARS simulation)

By M. Tomizawa



1mm ribbon width
Distance 350mm
Loss reduced by 36%
(MARS)

By R. Muto

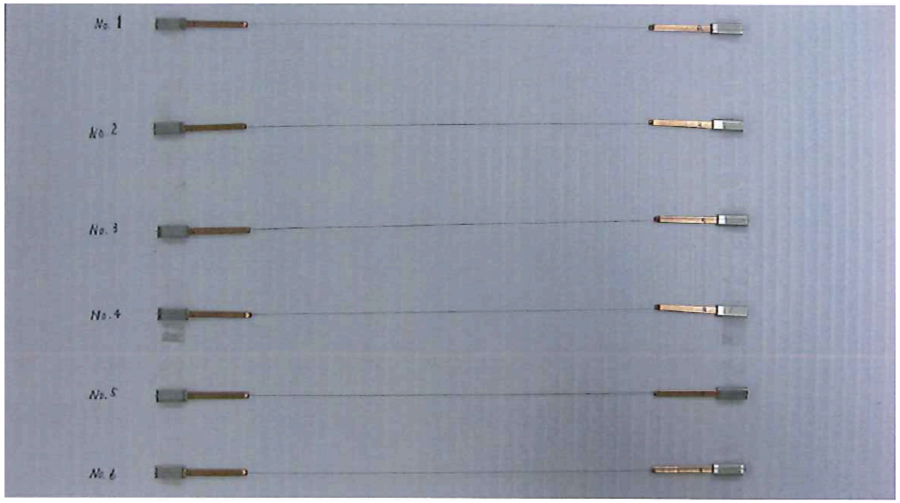
Low-Z septum materials

CNT
- wires

ϕ30-90μm
  90μm 2.3N (361MPa)
- Ribbons
  1mm width 30μm thick 400mm long
  6N (200MPa)
- A high voltage test by a short yoke model will be planned

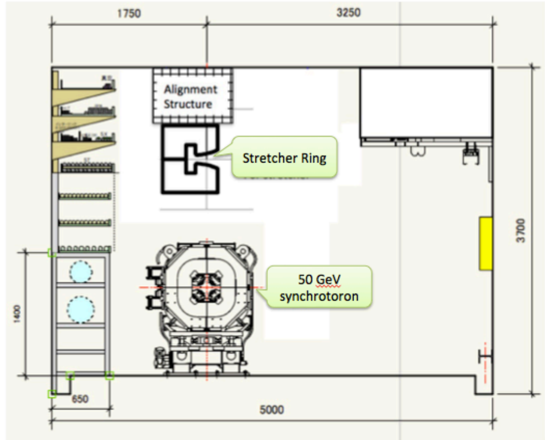
Grants-in-Aid for Scientific Research 2017-2019

Φ90μm CNT



SX-Stretcher Design Study

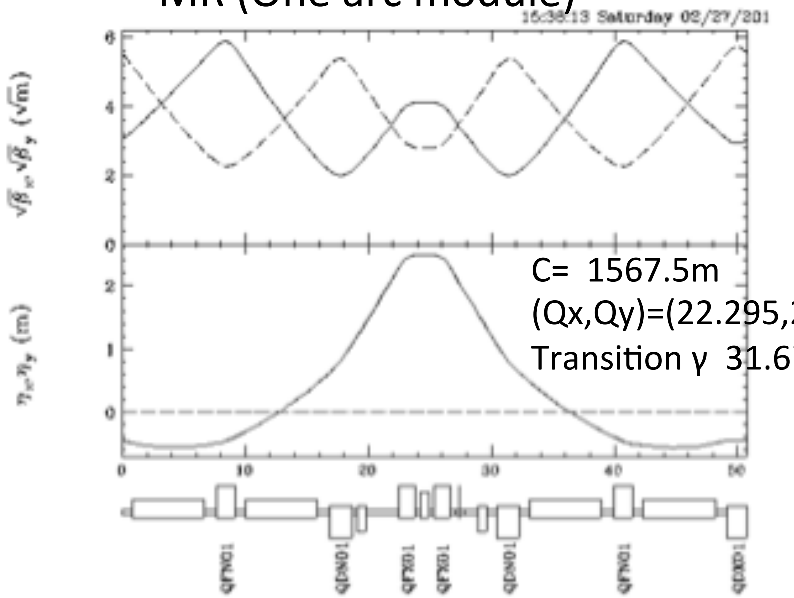
Collaboration with TRIUMF A.Konaka
KEK Low Temp. Center T. Ogitsu G



Neutrino RUN and SX RUN compete for beam time
A SX stretcher has a great advantage.
During slow extraction (2-3s),
beam can be delivered to Neutrino.

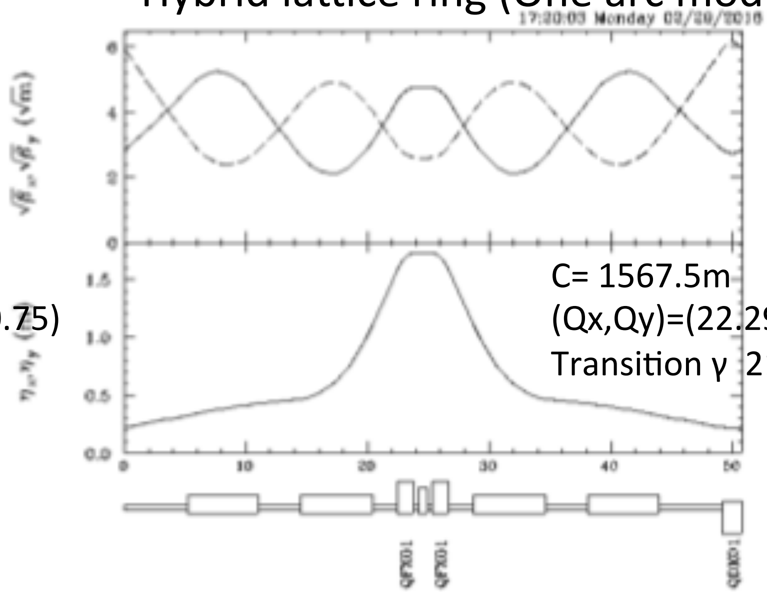
Base line design
Hybrid: SC-quadrupole magnets
and combined function transmission line superferric magnets

MR (One arc module)



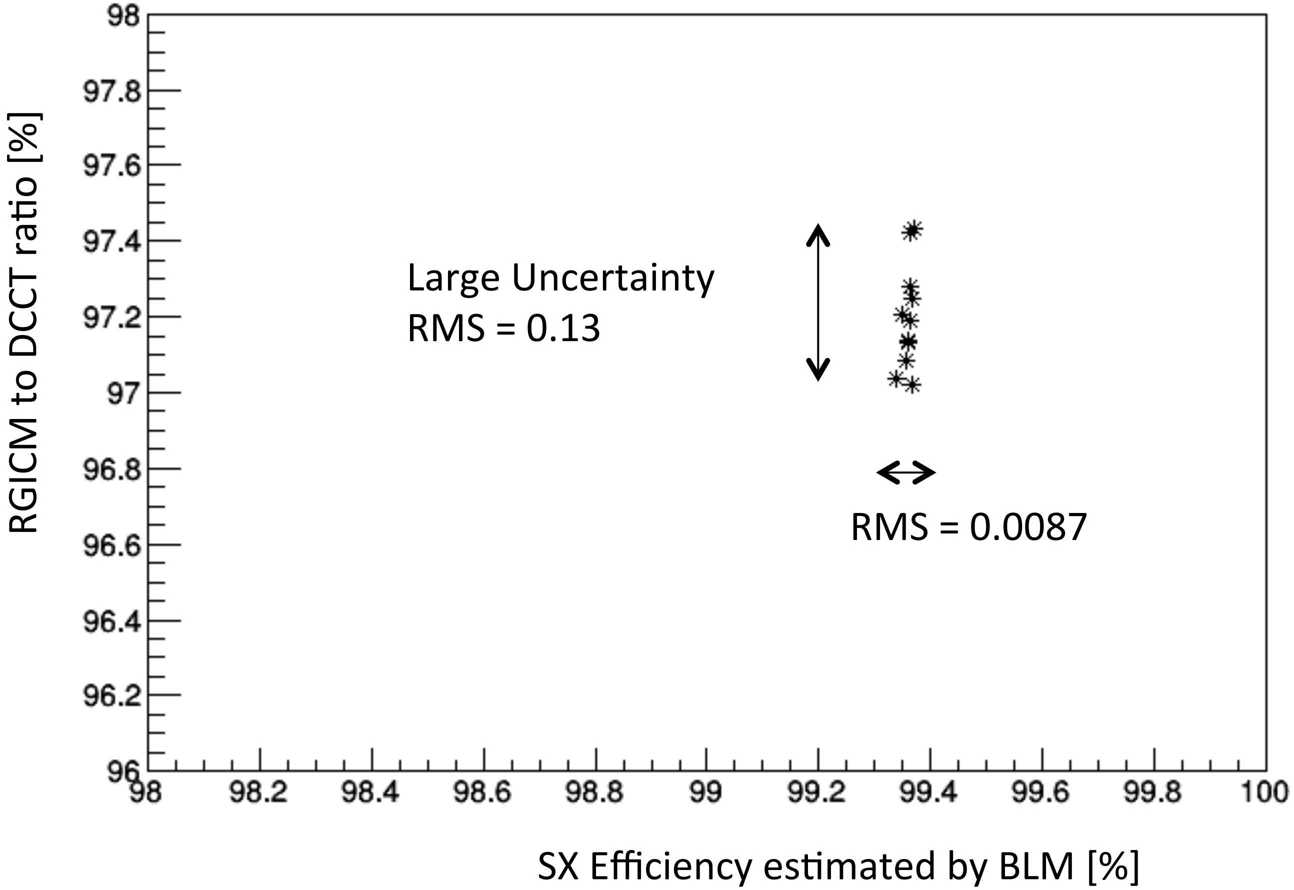
C= 1567.5m
(Qx,Qy)=(22.295,20.75)
Transition γ 31.6i

Hybrid lattice ring (One arc module)



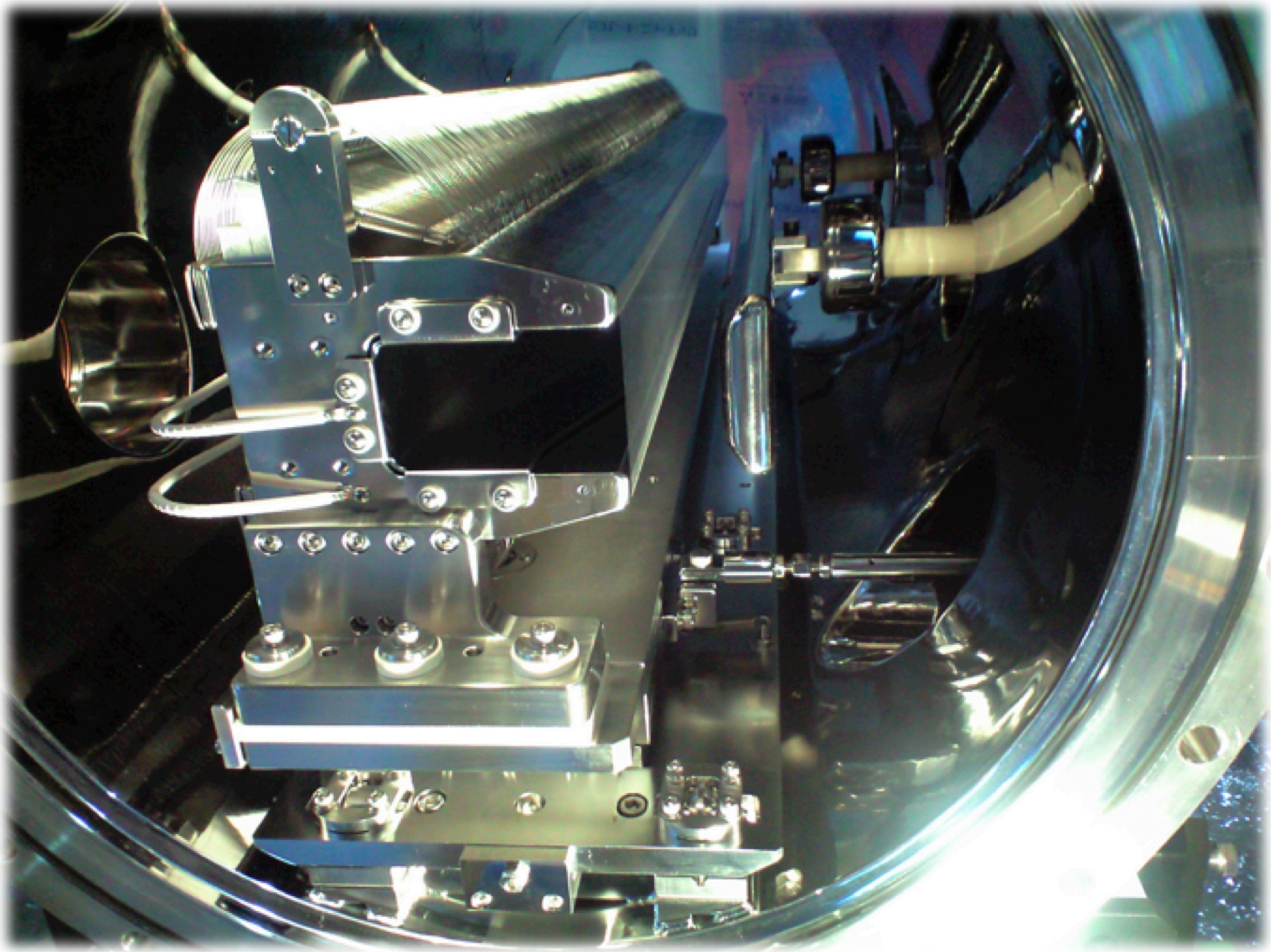
C= 1567.5m
(Qx,Qy)=(22.295,20.75)
Transition γ 21.7

Uncertainties of RGICM and BLM



11 shots with same accelerator condition (RUN75 #398578~88)
RGICM outputs have larger uncertainty than BLM

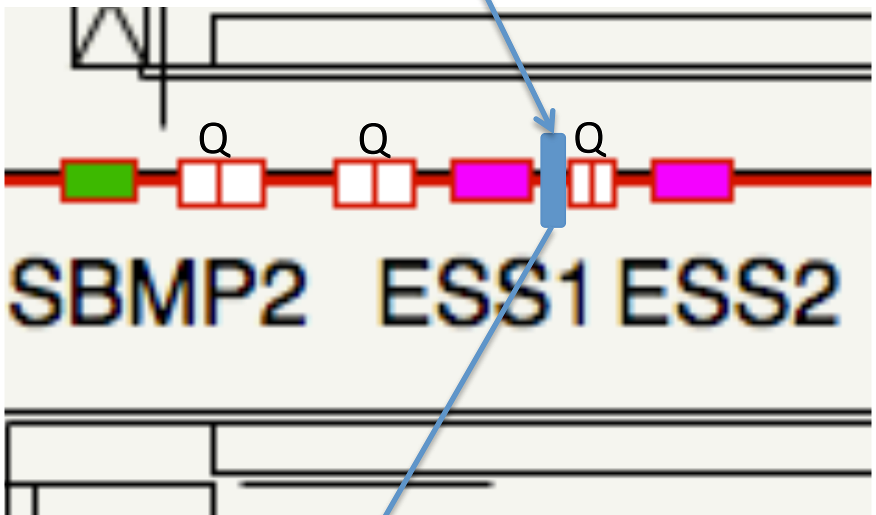
ElectroStatic Septa (ESS1,2)

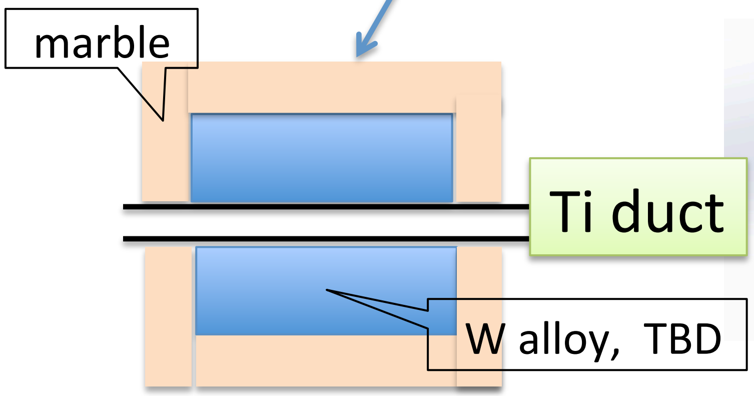


Toward 100kW SX

Local shield (under design)

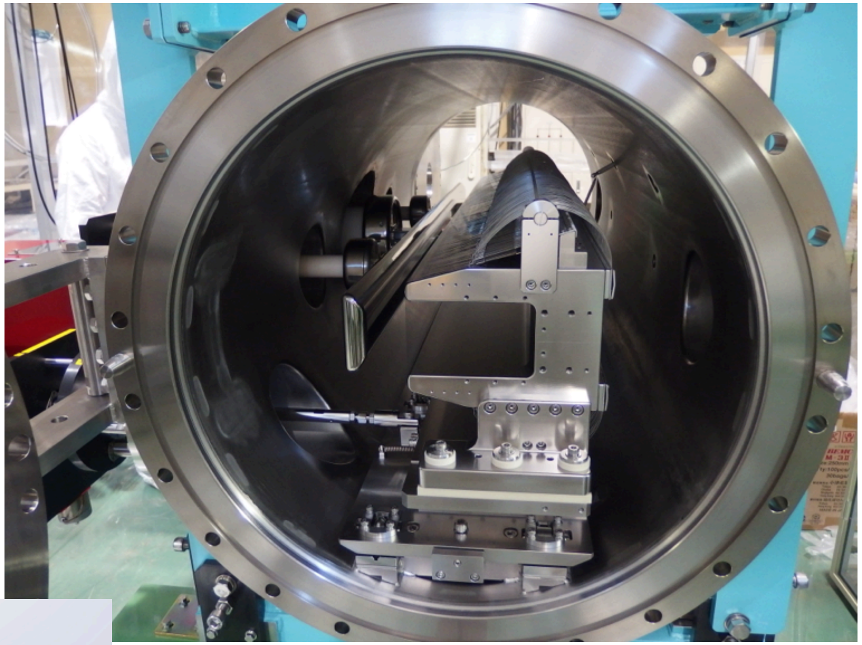
Protects Q-mag. from a high radiation

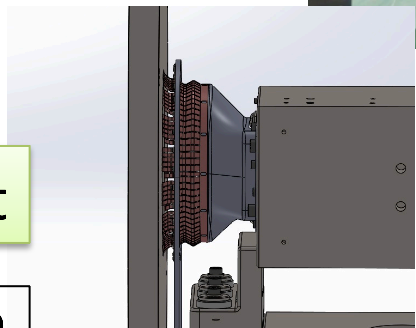




Titanium ESS

Residual dose is 1/5 of present SUS304
at 30day irradiation 7day cooling (MARS)

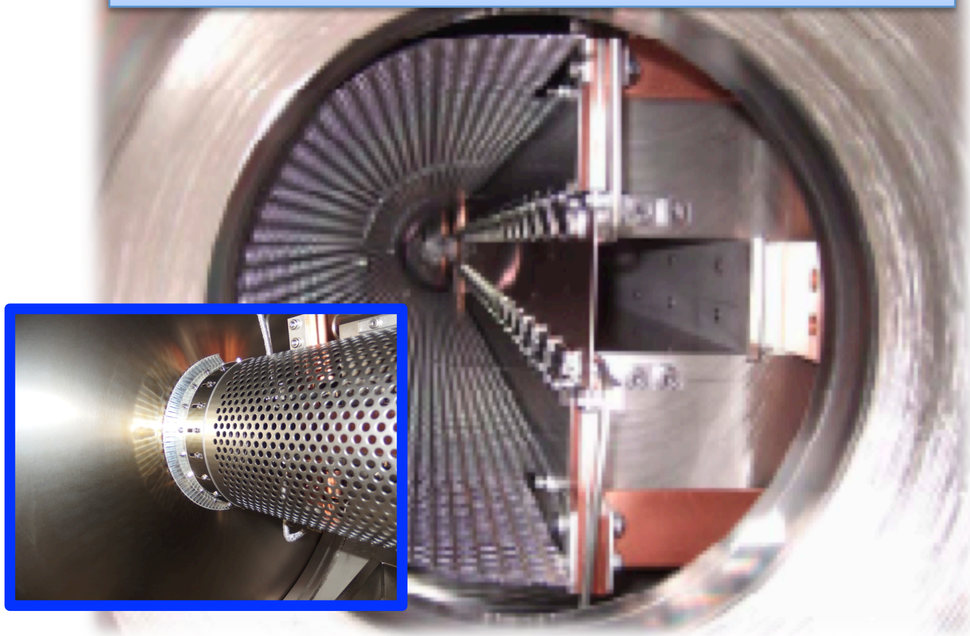




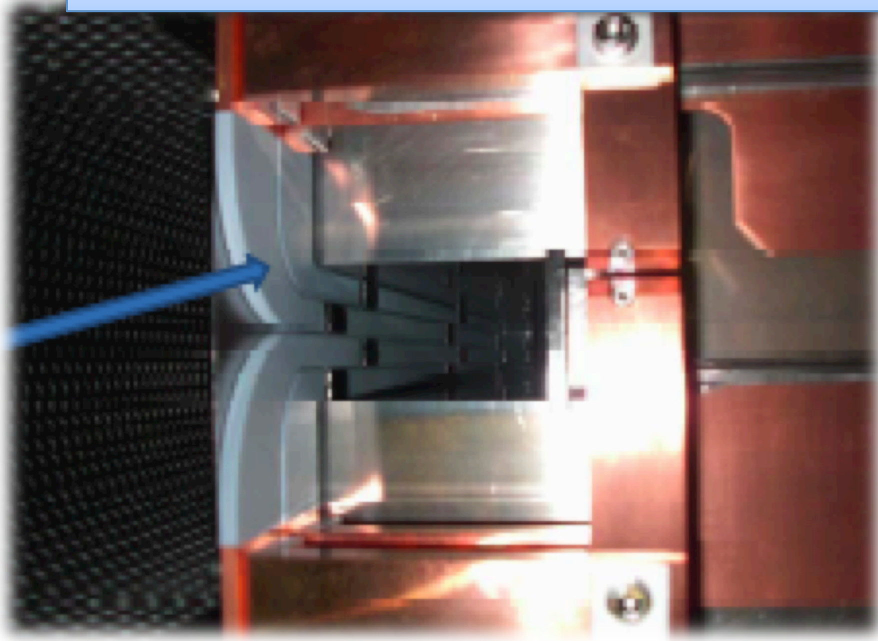
140 kV achieved (offline test)
(operating voltage 104.4kV)

An RF shield will be implemented

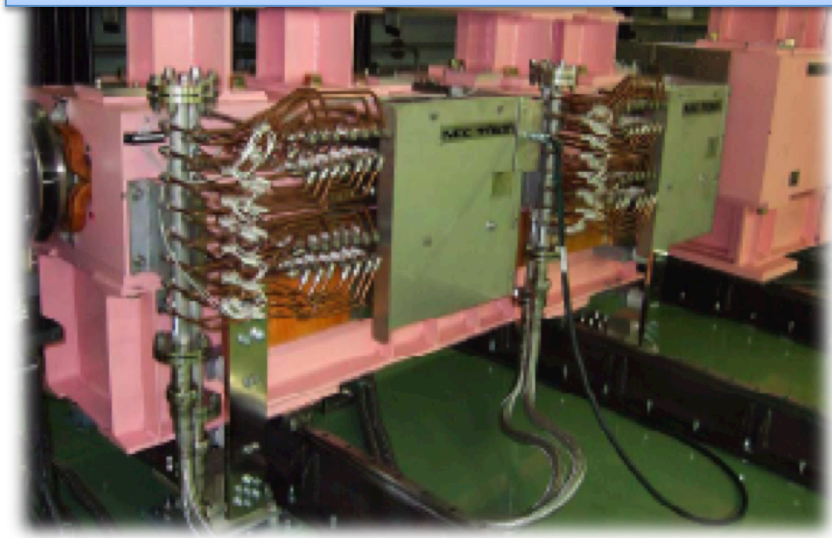
Low field magnetic septa (SMS11,12)



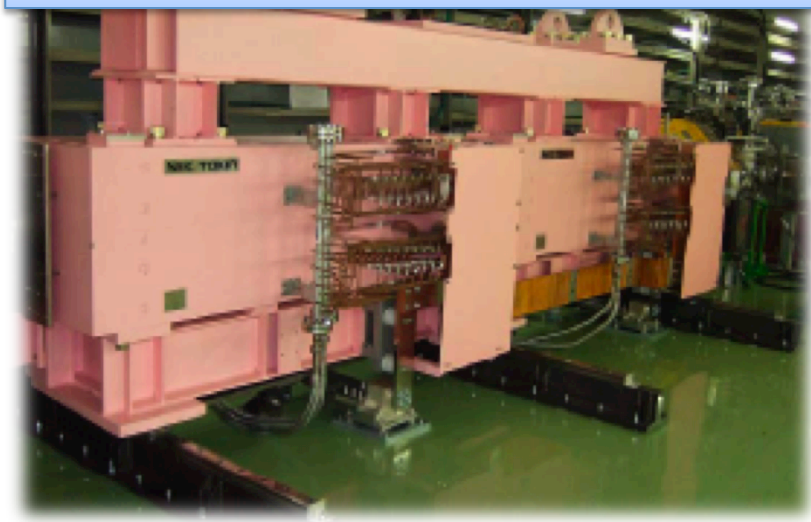
Mid field magnetic septa (SMS21-24)



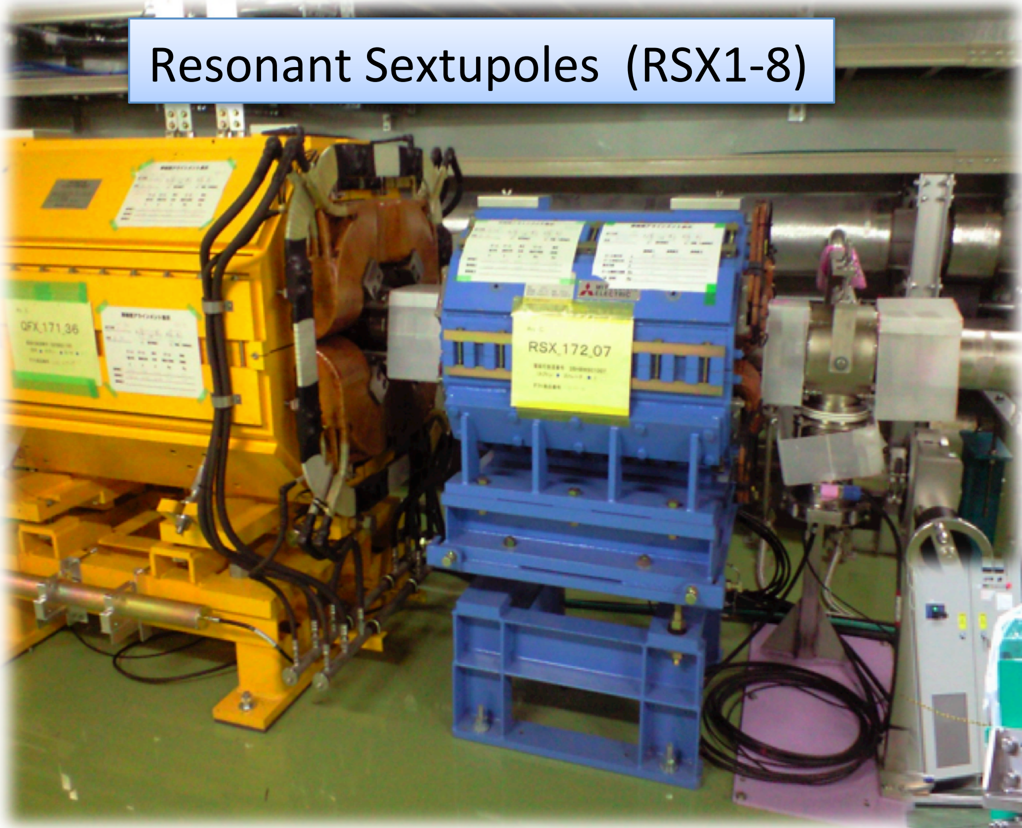
High field magnetic septa (SMS31,32)



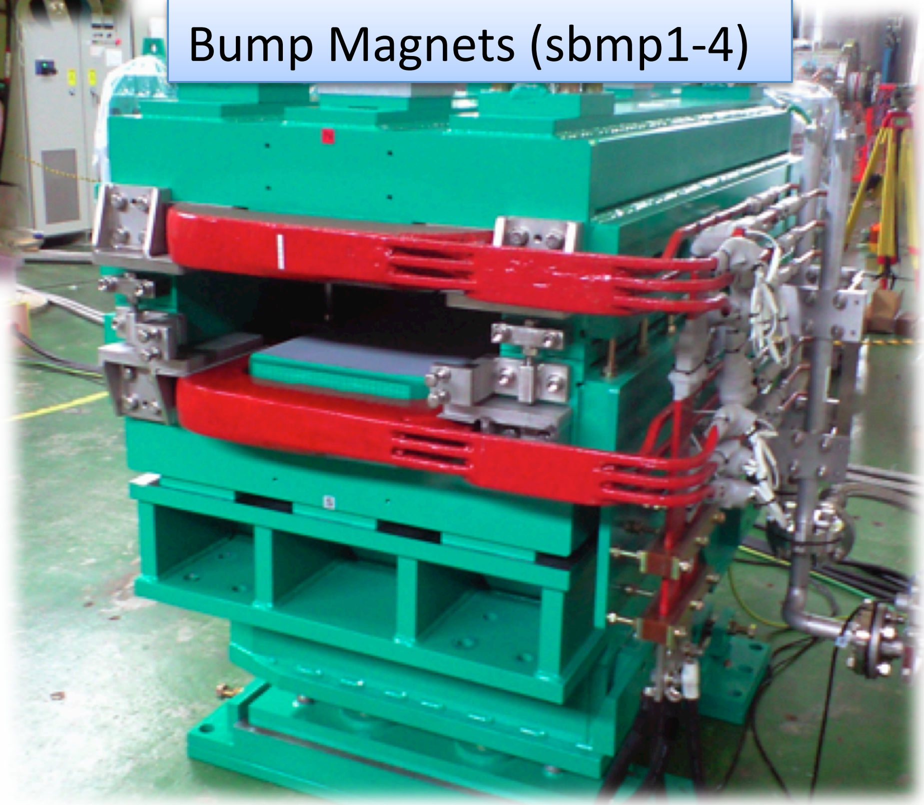
High field magnetic septa (SMS33,34)



Resonant Sextupoles (RSX1-8)

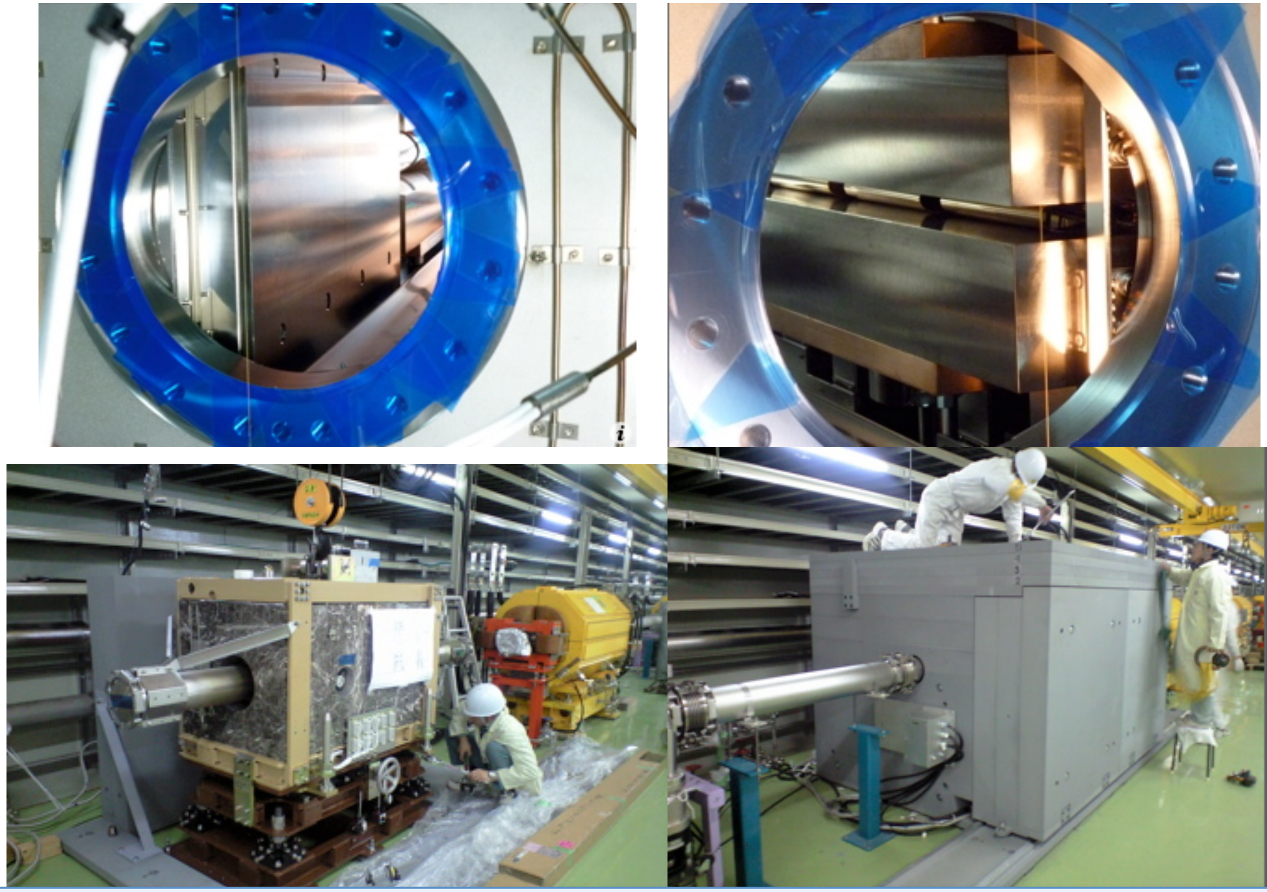


Bump Magnets (sbmp1-4)



Slow Collimators

scrape beam hallo produced by hitting on the ESS ribbons



residual radioactivity improvement by SX collimator
900μSv/h -> 150μSv/h @downstream quadrupole duct (on contact, 4hr. cooling)

J-PARC Slow Extraction Brief History

- First Slow Beam Jan., 2009
- East Japan Earth Quake March, 2011
- Slow Beam Operation resumed in Jan. 2012
- Radiation leakage incident at the experimental hall in May, 2013
- Slow Beam Operation resumed in April, 2015

  SX-RUN

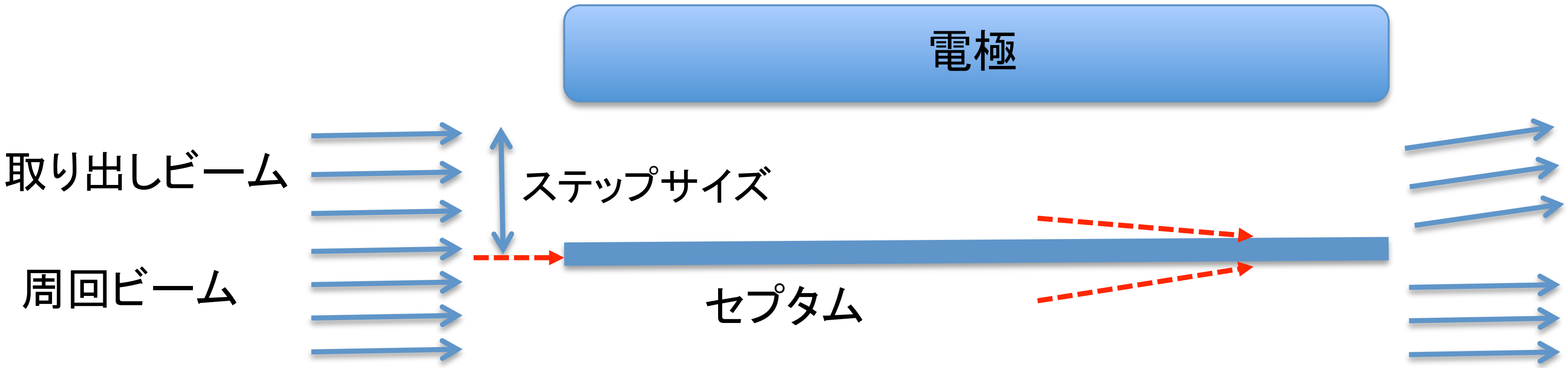
  2015 4/24-5/7、6/4-6/26、10/15-12/18、

  2016 5/27-(6/29)

大強度陽子加速器の遅いビーム取り出しの課題

・遅い取り出しプロセスにおけるビームロスの低減
　　メンテナンス時の被曝低減、周辺機器の保護
・取り出しビーム強度の時間構造の一様性
　　実験検出器からの要請

遅い取り出しのビームロス (ESS)

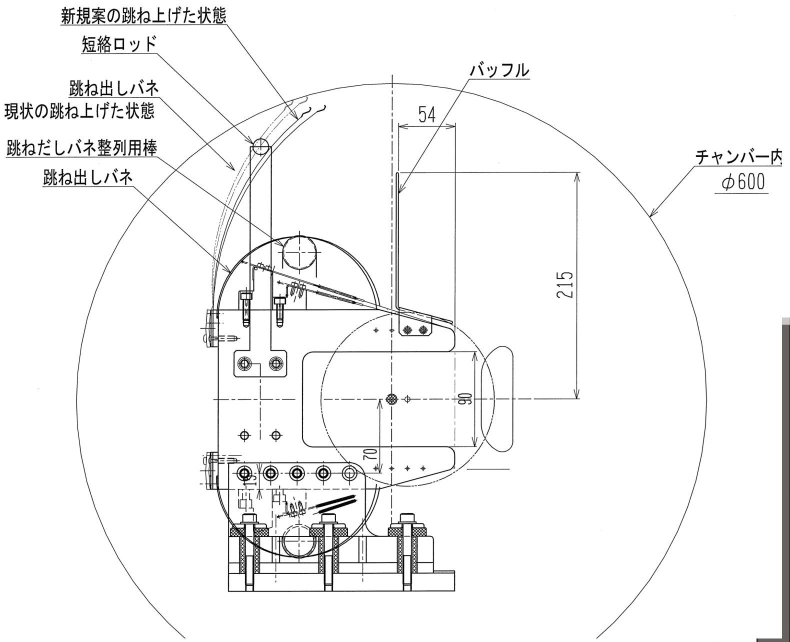


・静電セプタム位置での水平方向ビームサイズを大きくする
（他の場所ではロスしない）
・セプタムの厚さを薄くする
・ビームの角度の広がりを小さくする

ESS

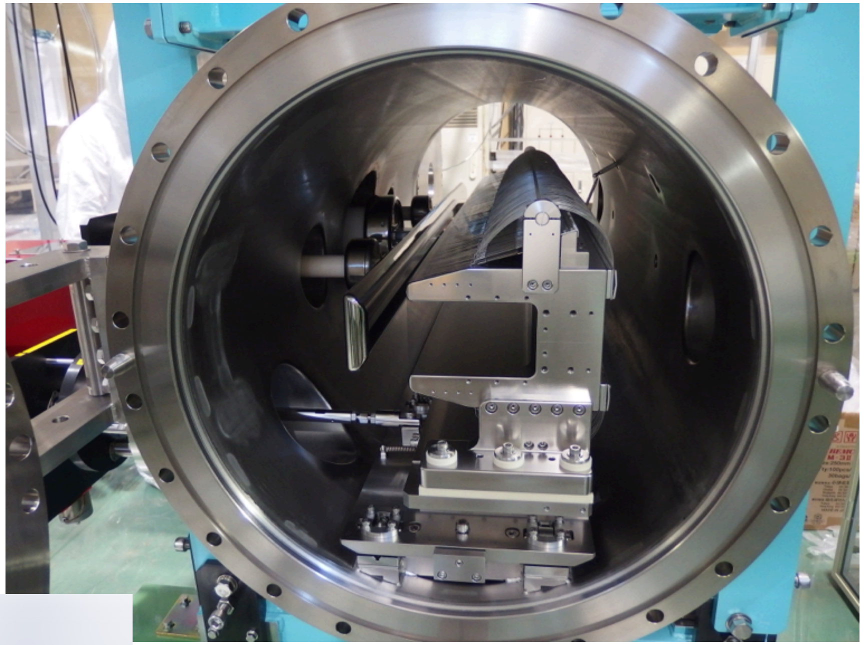
2017.4.
(ビーム不安定性によるビームコアがリボンを直撃）
SUS ESSのリボン切断し電極にショート
試験中のチタンESSをKEKから移設
放電後40kV 暗電流増加
-> SUS ESS１台運転で利用運転(37kW)

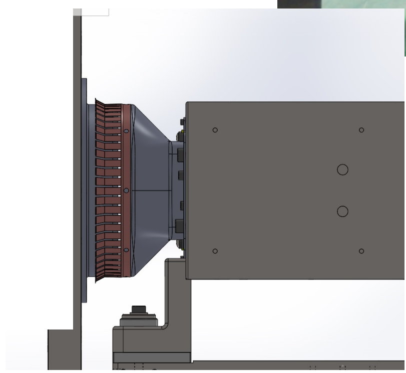
・ビーム不安定性に注意した運転
・万が一の切断時にショート回避対策



チタンESS

残留線量は SUS304の数分の１ (1/5)
30day 照射 7day 冷却 (MARS)





・電極ロッド、電極交換
115 kV (offline test)
(operating voltage 104.4kV)
・An RF shieldを導入（wake対策）

今夏インストール予定