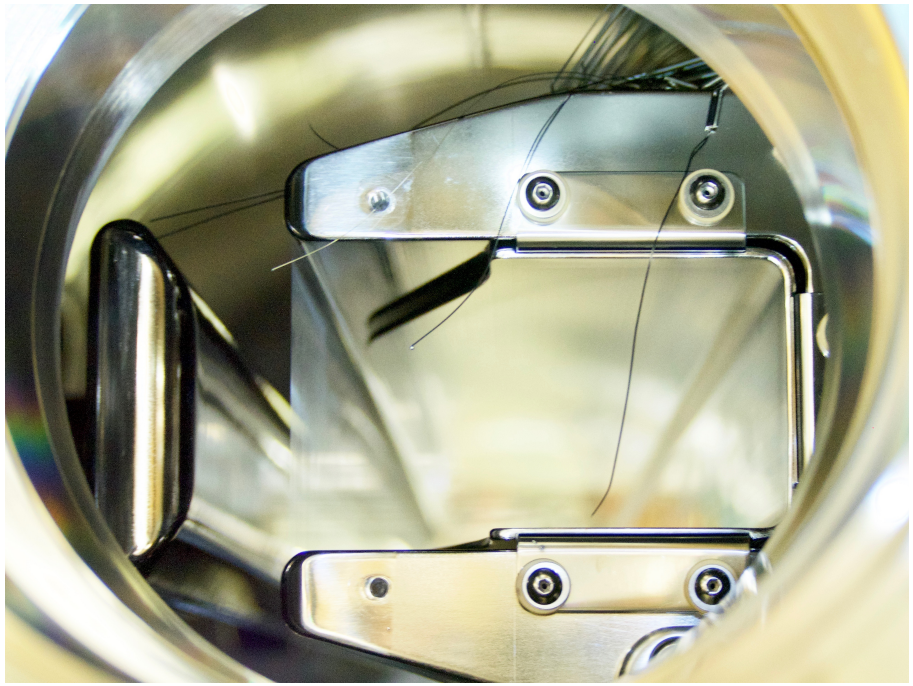
Slow Extraction Status

FNAL meeting
3/12-14/2018
Masahito Tomizawa

◎ESS trouble, SX restart and Ti ESS installation
◎30 GeV SX operation (run78)
◎8 GeV SX tests for COMET experiment
◎Summary

ESS Troubles in RUN74

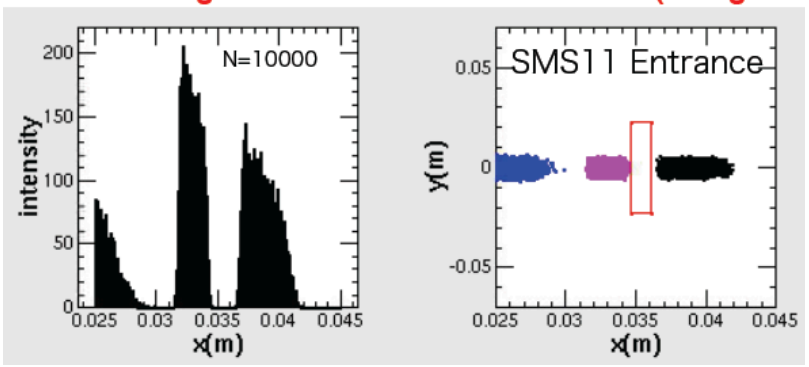
In the check bump orbit in the SX startup,
6 septum ribbons were broken with a large beam loss and vacuum pressure rise
and the one was touched on the electrode of SUS-ESS1 (4/26/2017)



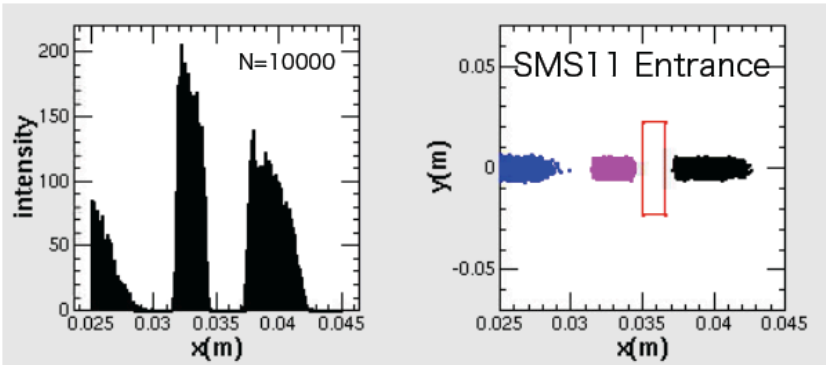
The SUS-ESS1 was uninstalled and a Ti-ESS was transported from Tsukuba campus
while assembling the electrode and installed in the MR.
Dark-current was increased at low voltage of 30-40kV after a spark at 80kV.
A damage of supporting ceramic rods or feedthrough during the transportation has been
suspected.

・Finally, the Ti-ESS1 was uninstalled and the downstream SUS-ESS2 was moved to the ESS1 position to get a higher turn separation @SMS1 (We predicted beam loss @SMS1 was double).

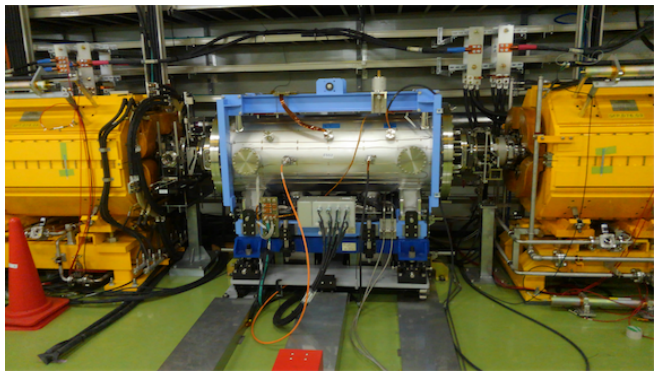
ESS1:Nothing　　ESS2:104.4kV (Design va



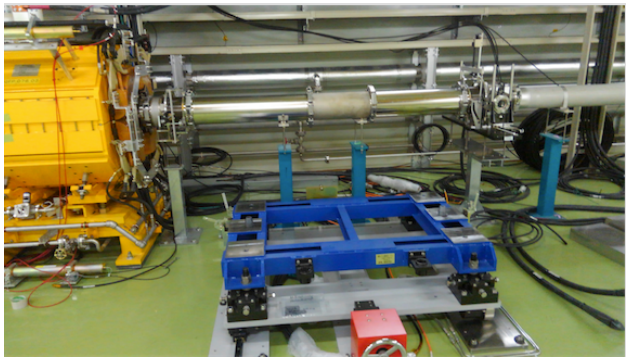
ESS1:104.4kV (Design value)　　ESS2:Nothing



SUS-ESS2 @ESS1 location



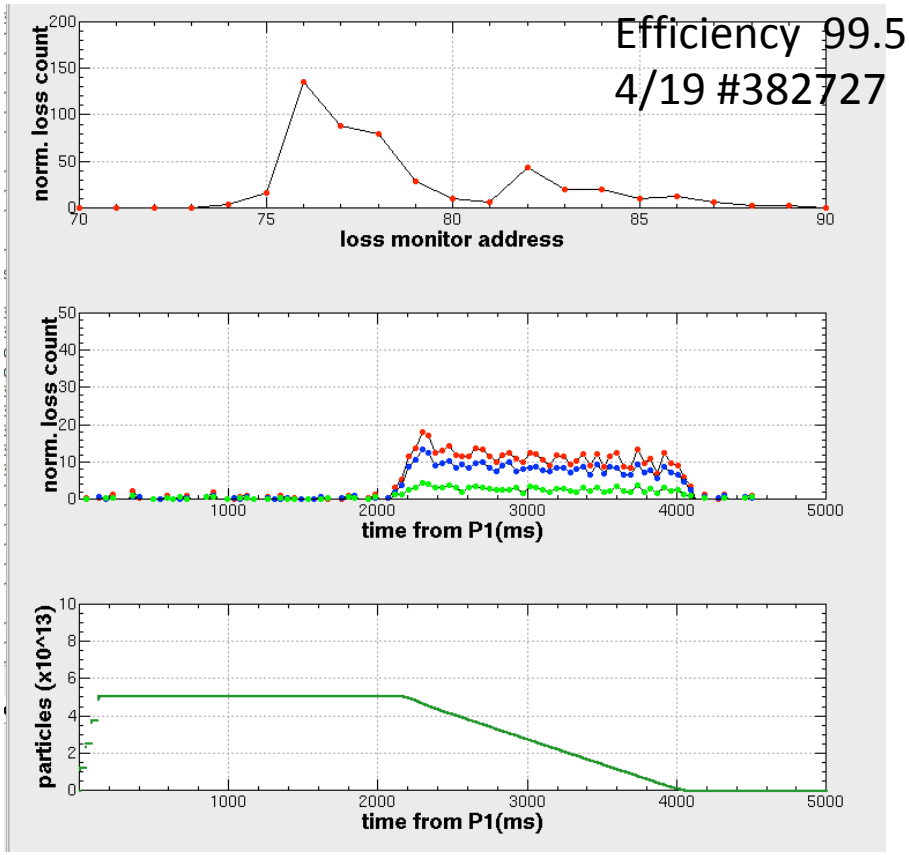
Beam duct @ESS2location



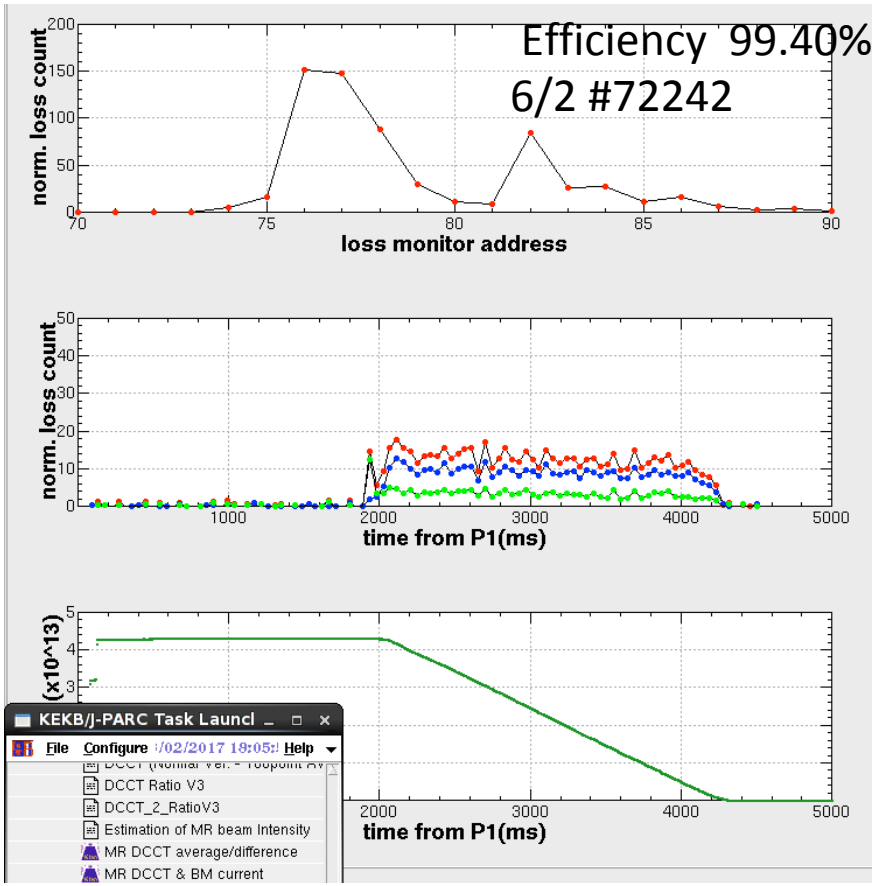
SX Restart after the Trouble (RUN75)

SX run was finally restarted ～1month later from the ESS trouble
Inspection for hadron experimental hall has been passed at 31.2kW (5/31)
Slow beam was supplied to the HD facility at 37.5kW till end of this RUN.
Extraction efficiency was 99.3% @37kW (nominally 99.5%)

ESS1, ESS2
44.4kW
Efficiency 99.56%
4/19 #382727



ESS2 only
37.4kW
Efficiency 99.40%
6/2 #72242



Cause of the ESS trouble (guess)

- The circulating bunched beam oscillated coherently by a transverse beam instability hit the septum ribbons directly, the ribbons were melted and cut
  H-chromaticity was set to slightly positive value on momentum (dangerous!)

Countermeasures

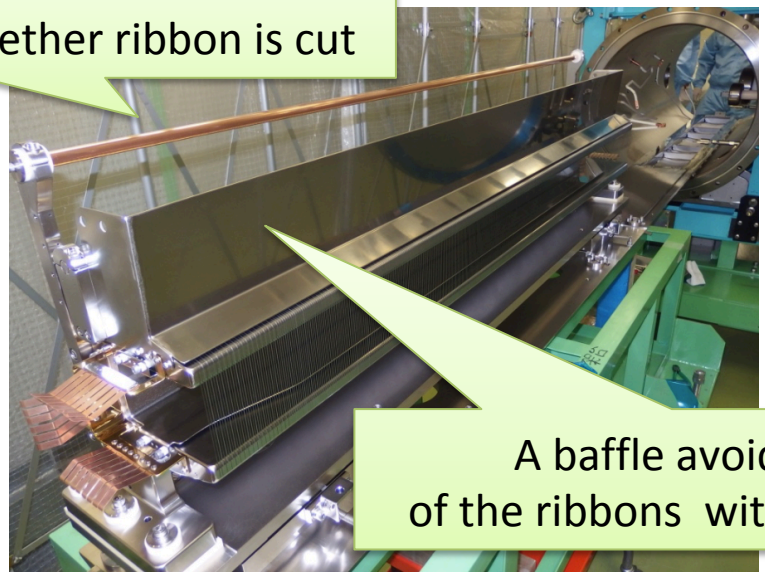
- The chromaticity is carefully set lower (negative) for the bunched beam
- The bump orbit is checked at a low beam intensity
- The bump orbit is quickly set to zero after the orbit checking.

Any similar trouble has not been seen after taking those countermeasures

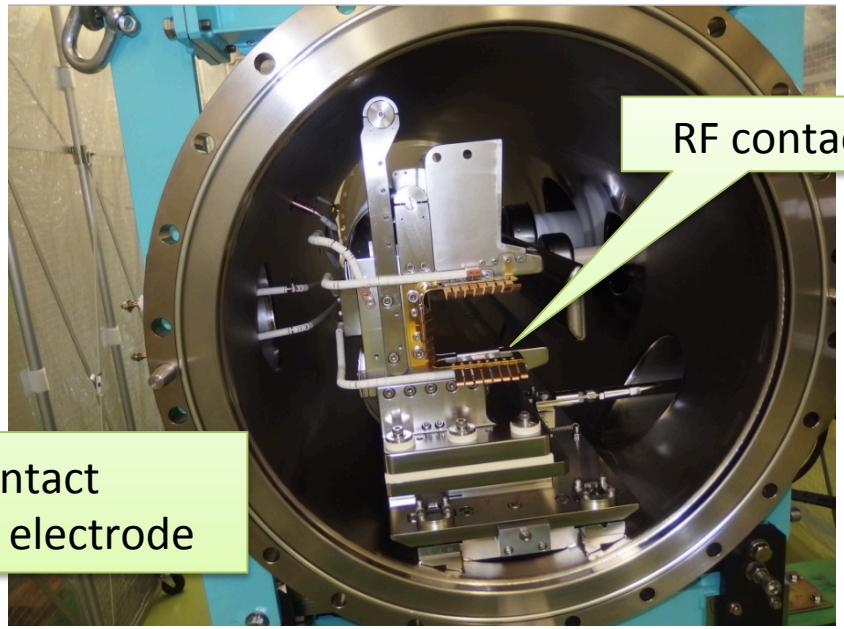
The Ti-ESS1 has been installed in this summer shutdown period

The support rods and feedthrough were replaced to new ones

An Isolated rod detects whether ribbon is cut

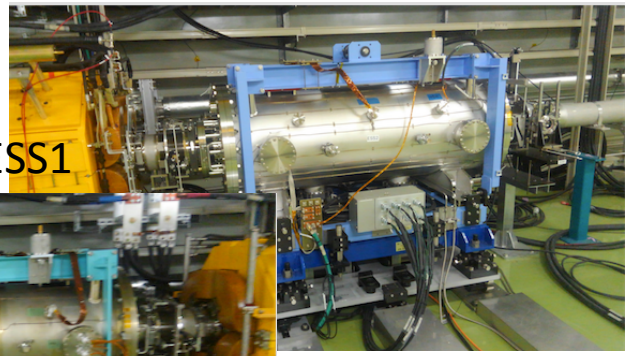


A baffle avoids contact of the ribbons with the electrode

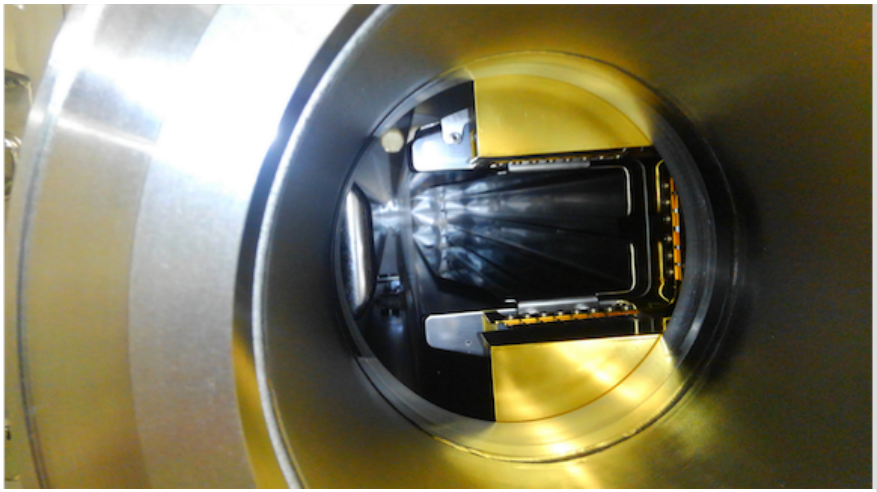


RF contact

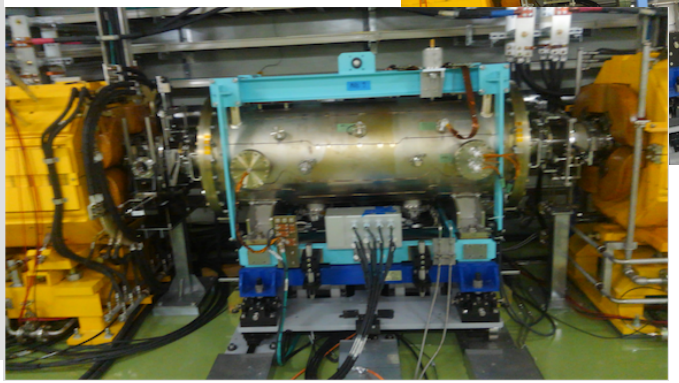
SUS-ESS2 reinstalled @ESS2



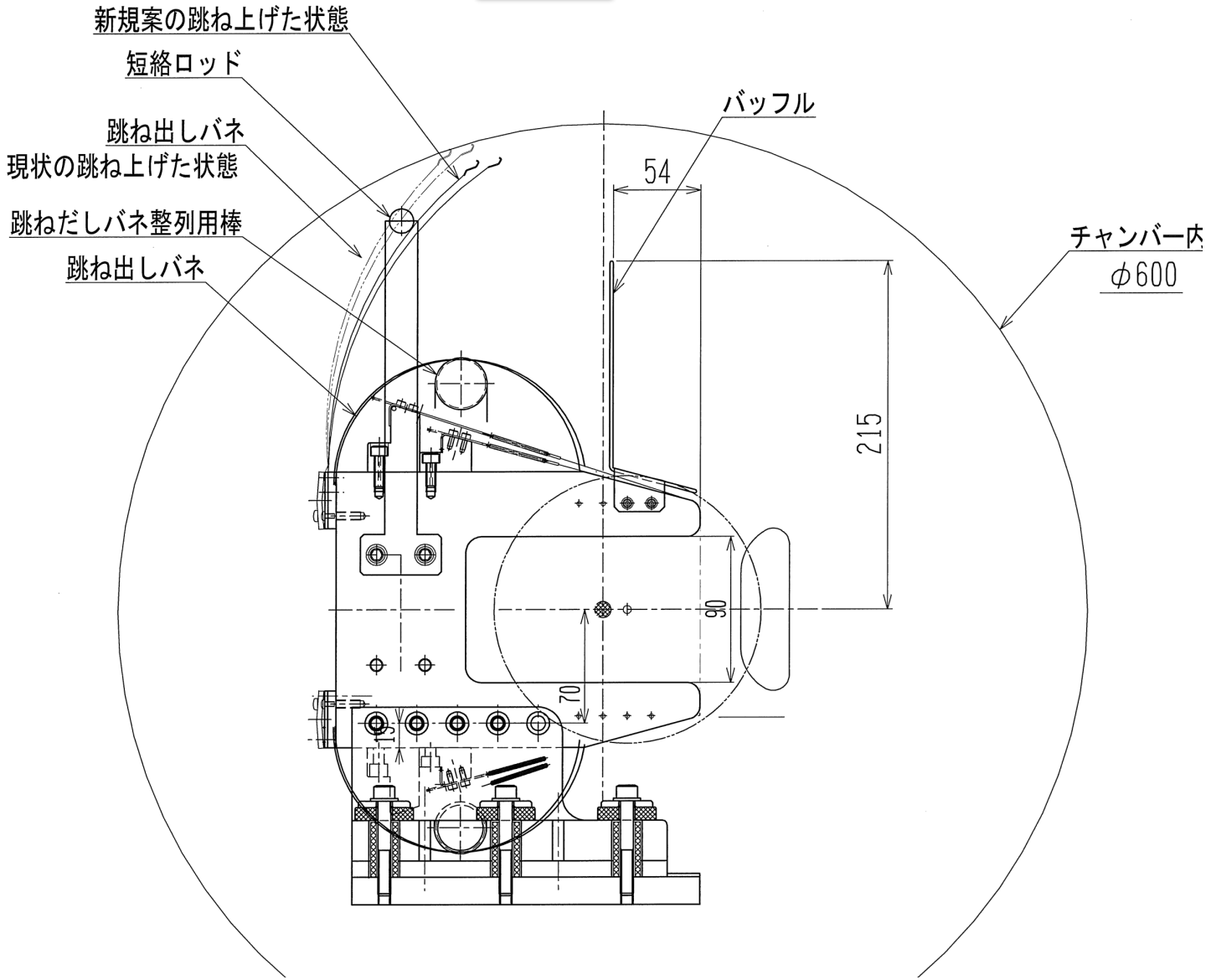
View from beam duct



Ti-ESS installed @ESS1

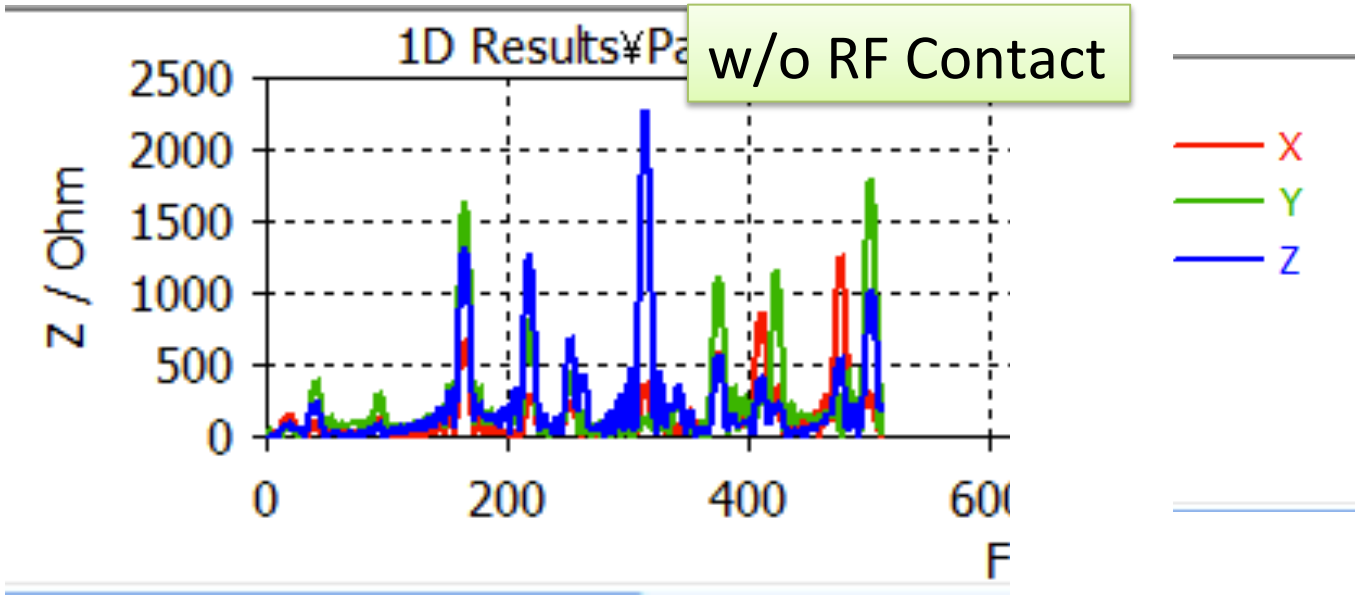


ESS

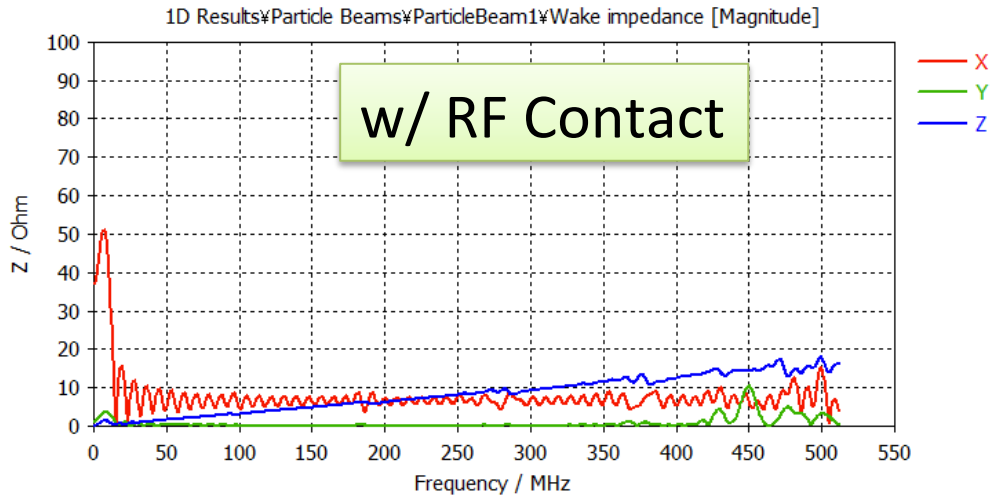

新規案の跳ね上げた状態
短絡ロッド
跳ね出しバネ
現状の跳ね上げた状態
跳ねだしバネ整列用棒
跳ね出しバネ
バッフル
54
チャンバー内
φ600
215
90
70
15
100

ESS Impedance Reduction by RF contact (CST Studio)

ESS_tomizawa_031.cst

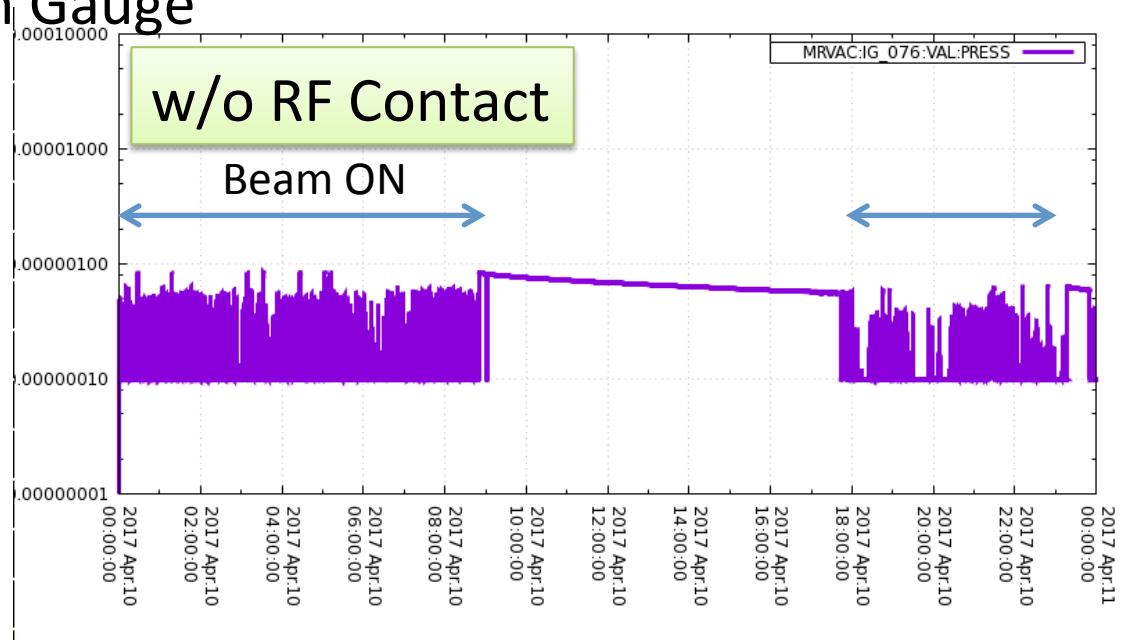


ESS_tomizawa_070.cst

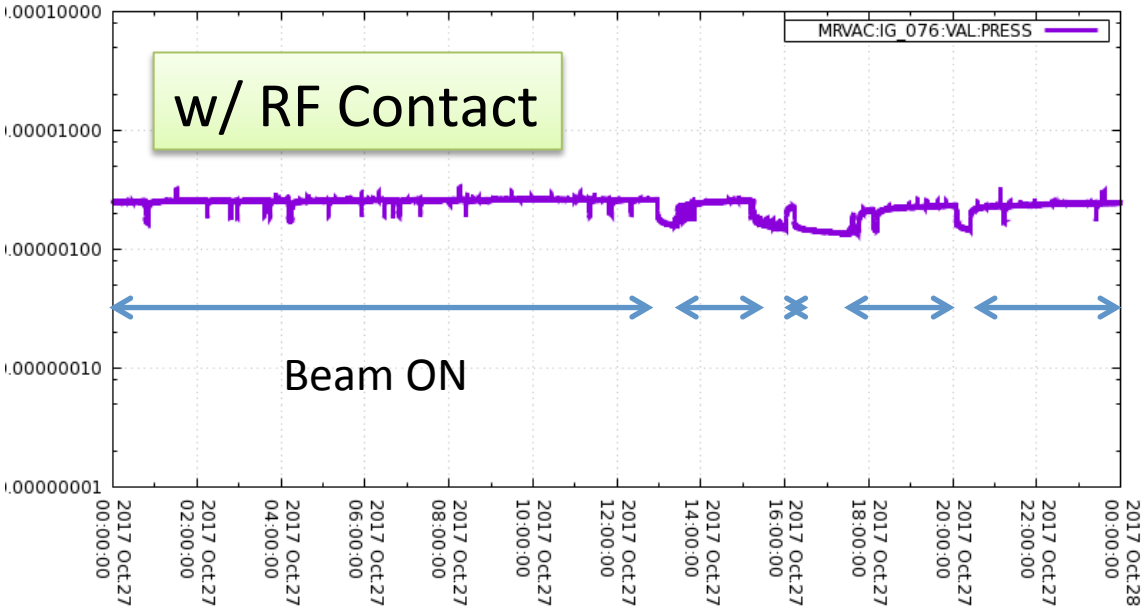


ESS1 Vacuum Ion Gauge

2017/4/10
460kW Nu RUN



2017/10/27
440kW Nu RUN



30 GeV Slow Extraction (RUN78)

New titanium ESS (improved type) has been installed at ESS1 position, stainless ESS has been returned at ESS2 position in last summer shutdown.

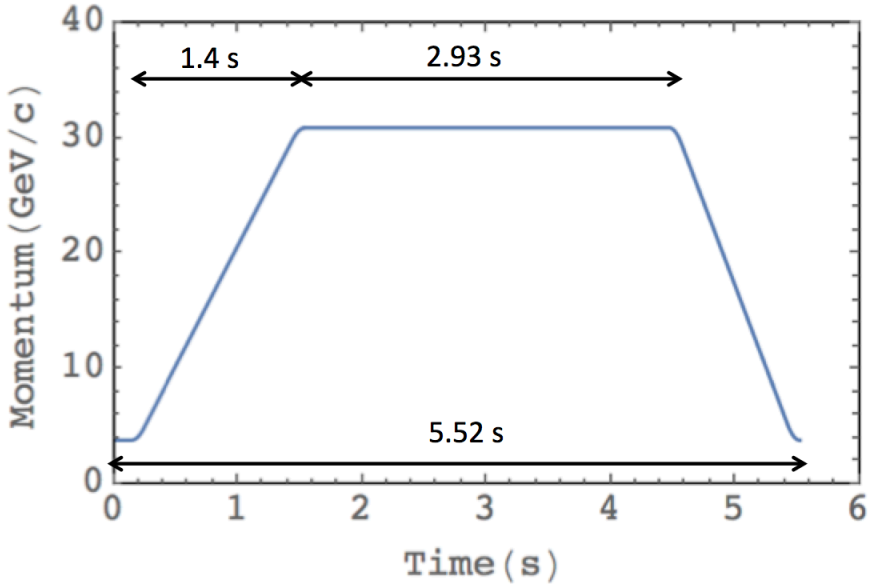
- Beam power for user run started from 10kW
  Vacuum pressure rise by debunched slow extraction was observed at ESS1
  ESS1 voltage was set to 70kV (ESS2 is 104.4kV). Any beam loss increase has not been observed.

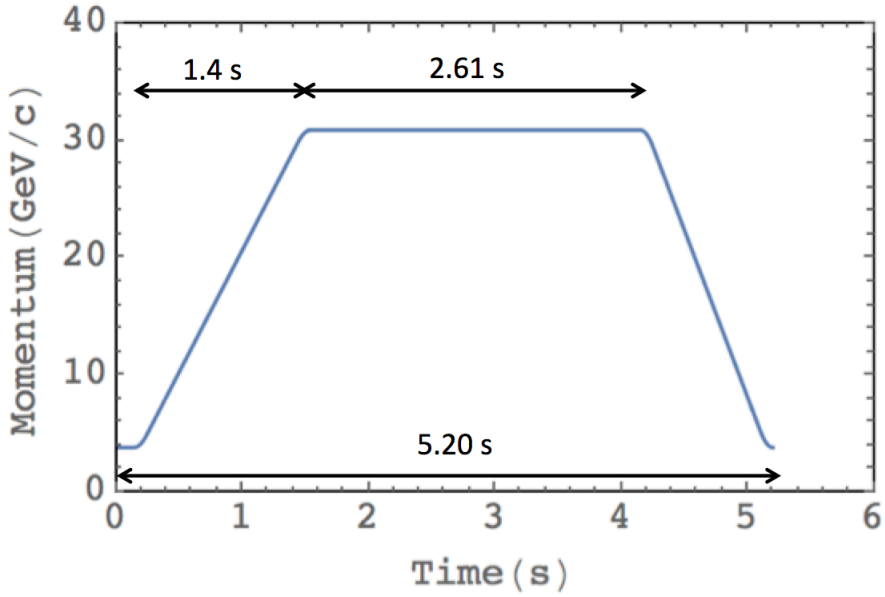
- MR rep. rate has been changed from 5.52s to 5.20s after the first 8GeV test (1/25).
  Beam power was increased from 31.5 kW to 33.52 kW

- Beam power was recovered to 45kW (RUN74) on 1/26.

- User operation above 50kW has been achieved (1/30～2/26)
  major milestone

5.52 s cycle → 5.20 s cycle





Smoothly switched!

Flat top shorten by 0.32 s, spill length is kept at 2s

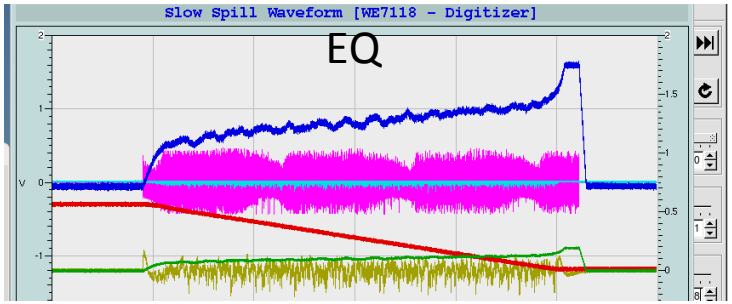
30 GeV Slow Extraction

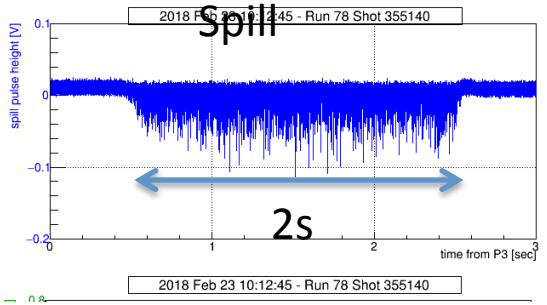
Shot 355150
51.09 kW

Rep. rate 5.20 s
flat top is 2.61 s

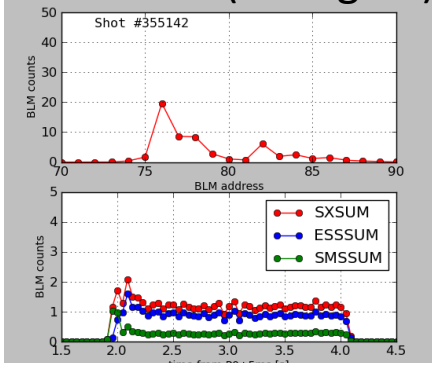
2/23 10:13

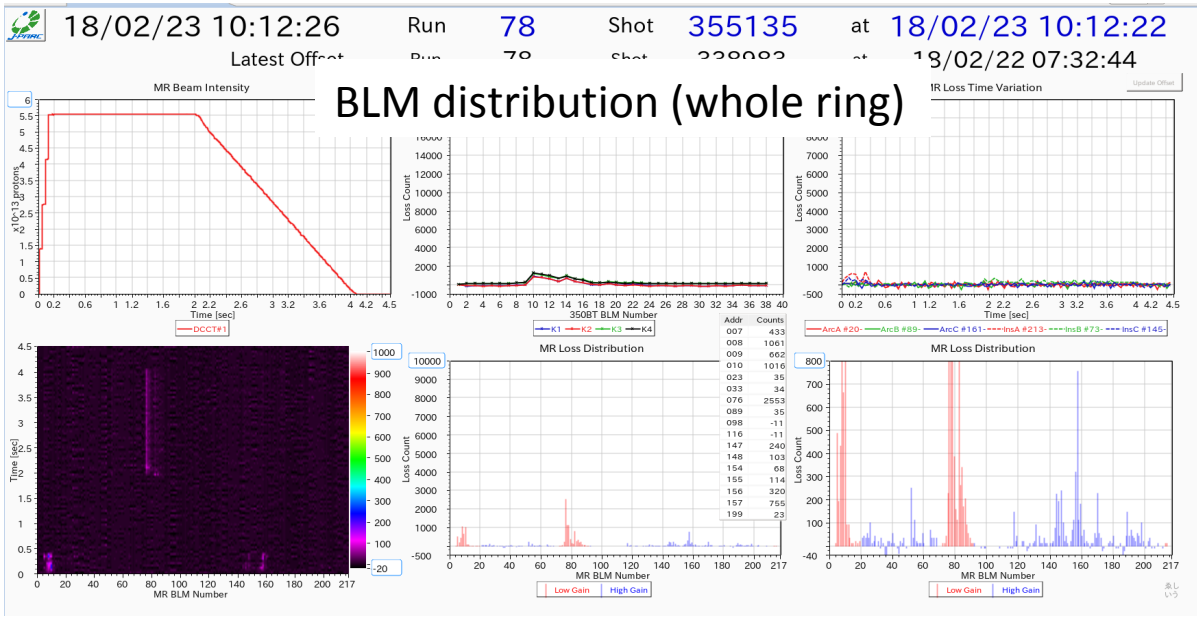
Efficiency 99.52%
Spill Duty 48%
Spill length 2.05s



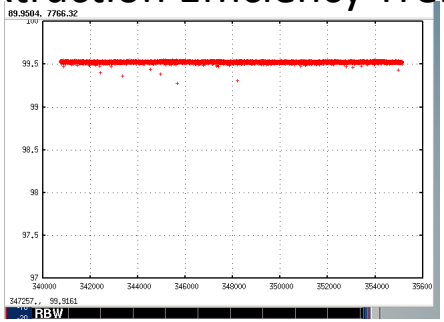


Beam Loss (SX region)

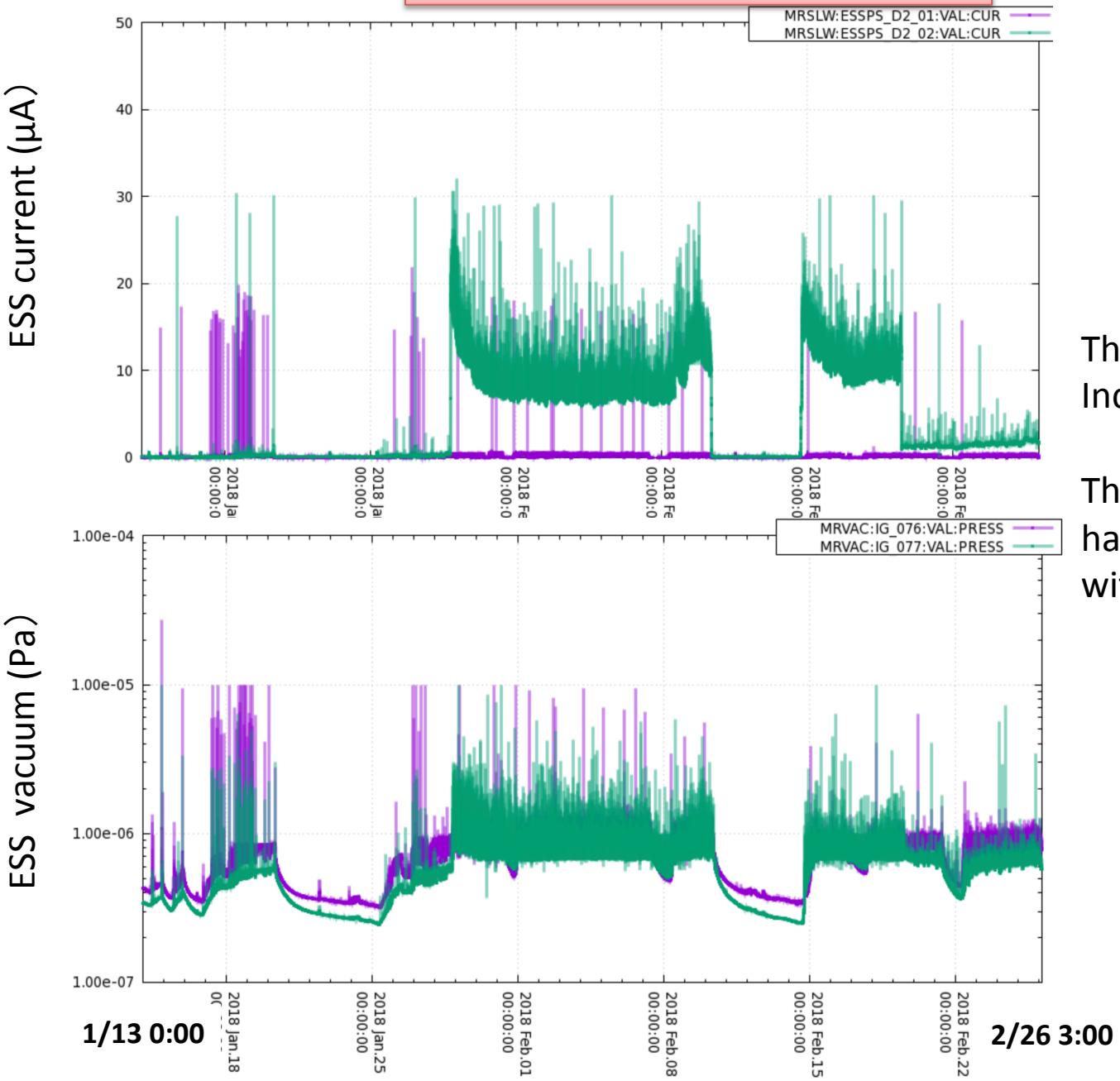




Extraction Efficiency Trend



RUN78 ESS performances



Purple: ESS1 70kV
Green: ESS2 104.4kV

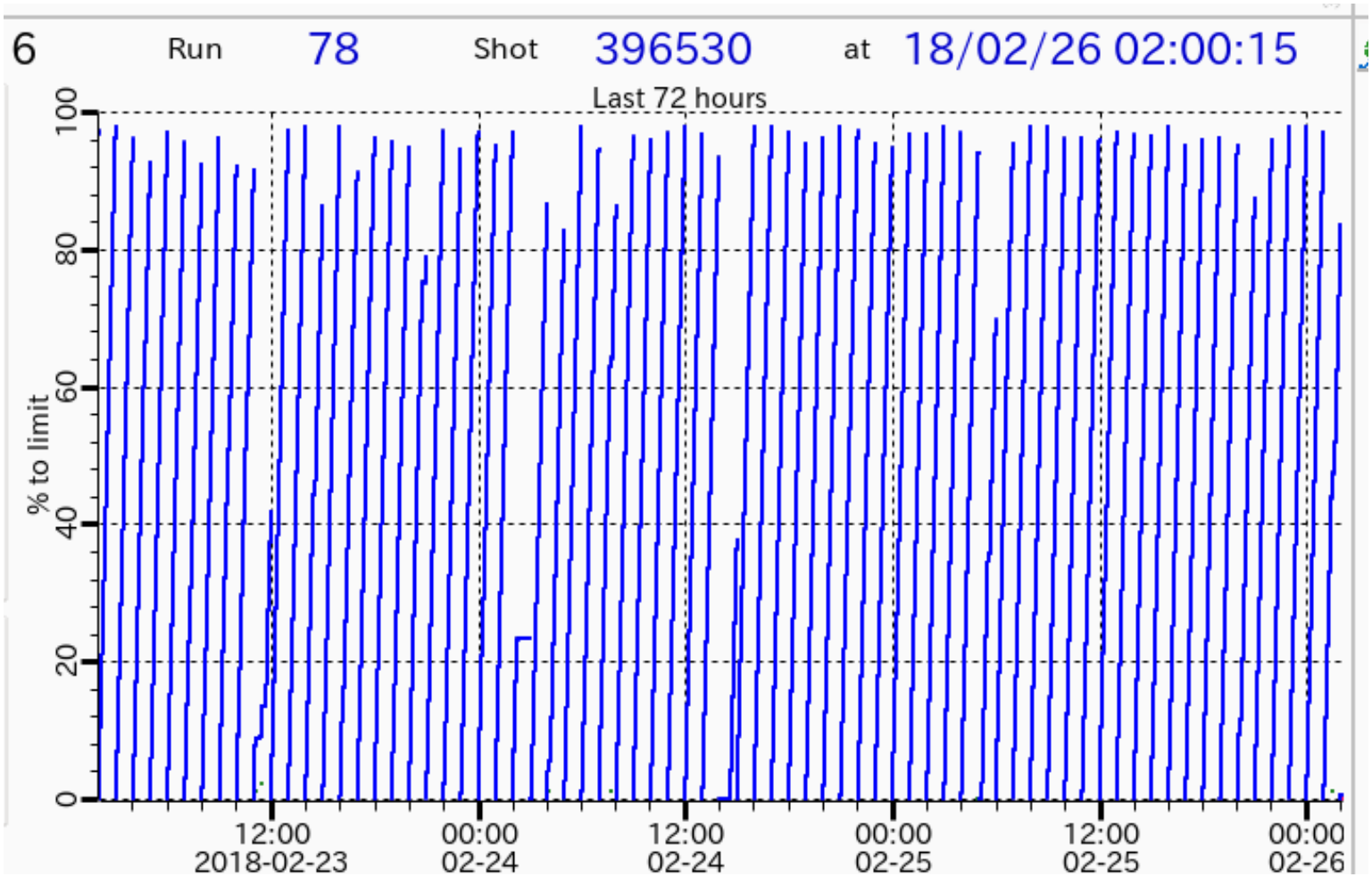
The dark current of ESS2
Increased -> decreased

The freqency of discharge
has been decreased
with operation.

MR Beam intensity normalized at PPS limit for RUN78 SX operation

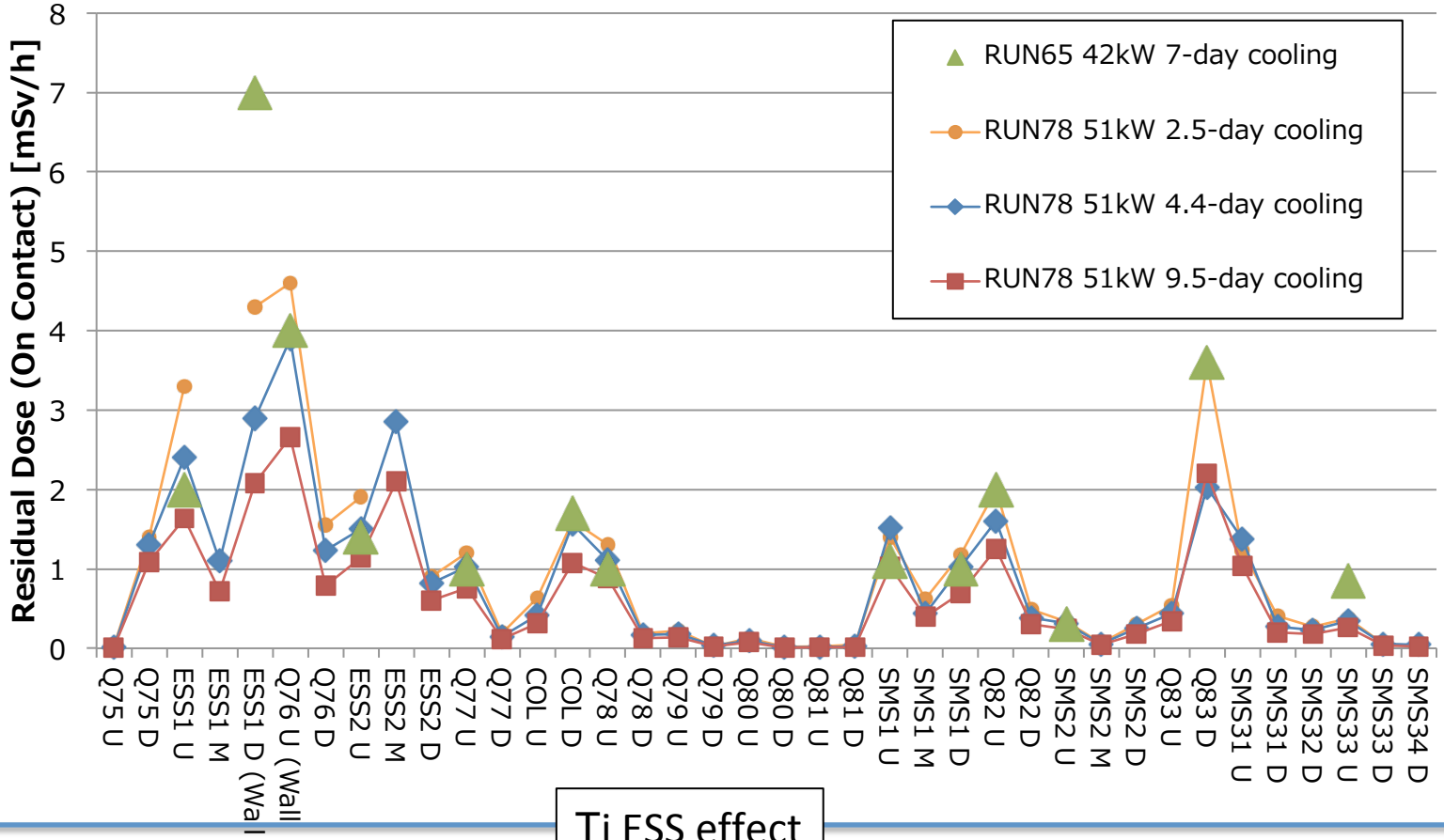
Lifted administrative beam power limit 53.4 kW x1h
PPS beam power limit 52.3kW x 1h (2% less)
MPS beam power limit 51.8kW x 1h (3% less)

Beam intensity for PPS Limit (per hour)



Last 3 days

Measured Residual Dose (on contact) RUN78-51kW and RUN65-42kW



Ti ESS effect

Run78 ESS chamber center

ESS1M/ESS2M=1.1/2.85=0.39　4.4days cooling

ESS1M/ESS2M=0.715/2.1=0.34　9.5days cooling

2015.5.13 ～2year cooling

ESS1M/ESS2=0.488/0.101=4.8

RUN78 51kW　7days cooling (Interpolated)

ESS1 up　1.91mSv/h

ESS1 down　2.39mSv/h

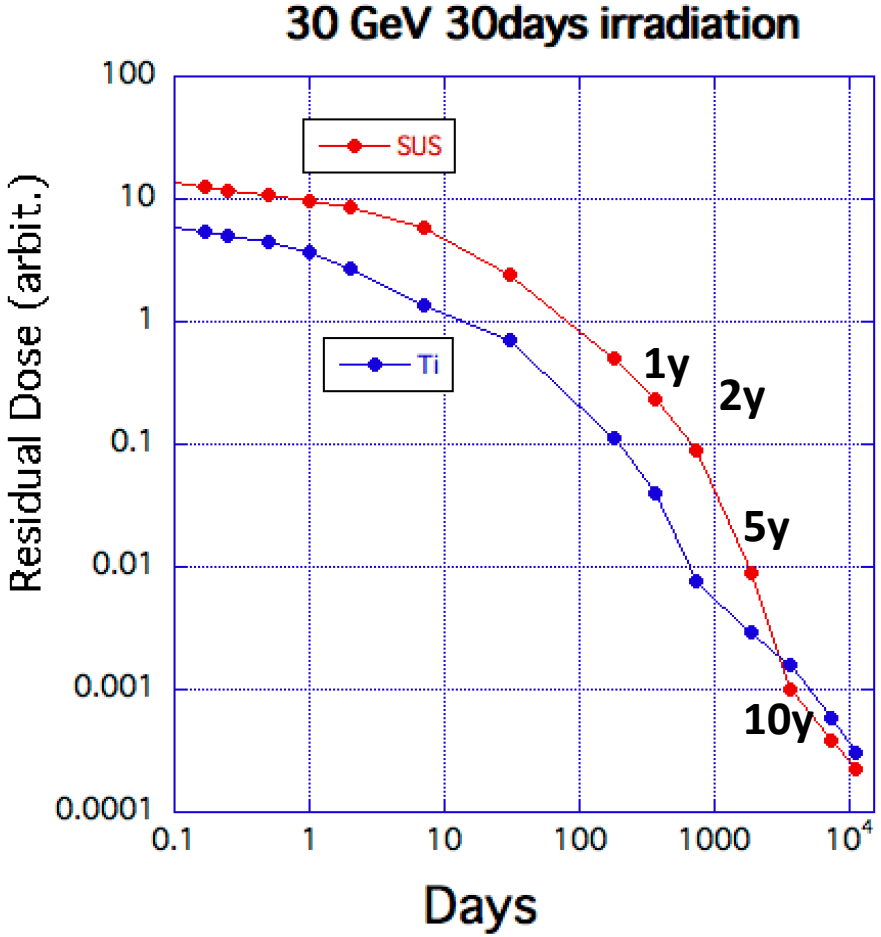
RUN65 42kW　7days cooling (Measured)

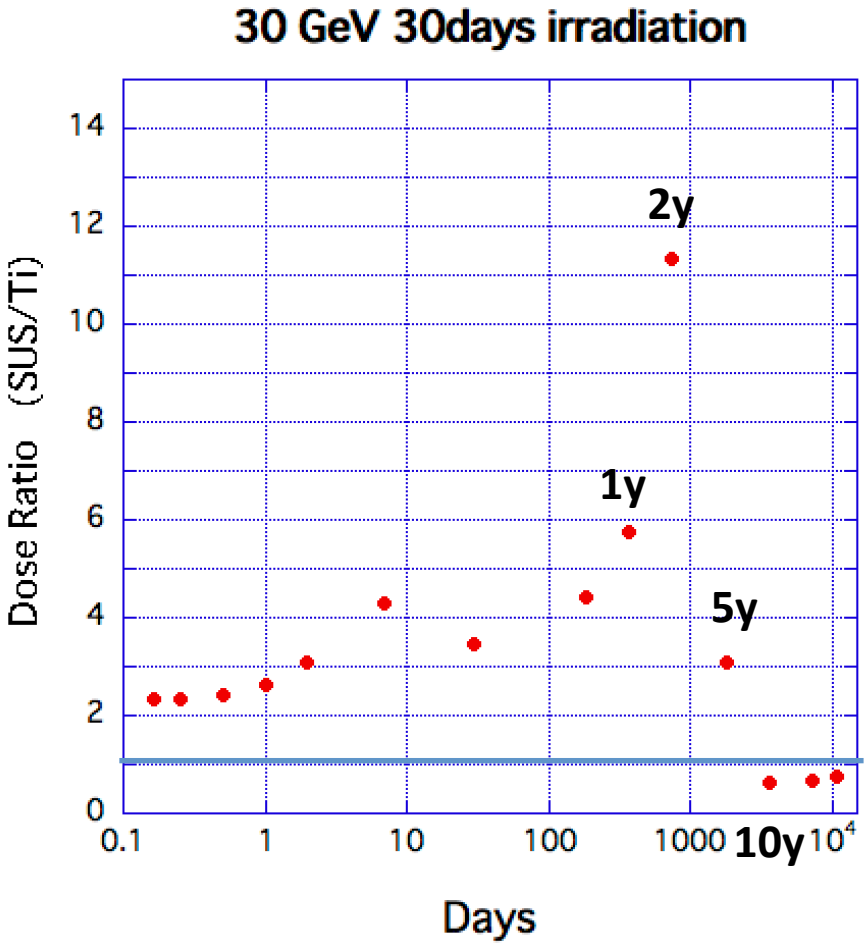
ESS1 up　2mSv/h

ESS1 down　7mSv/h

Residual Dose Comparison Between Ti and SUS

MARS simulation for ESS1 downstream end-plate

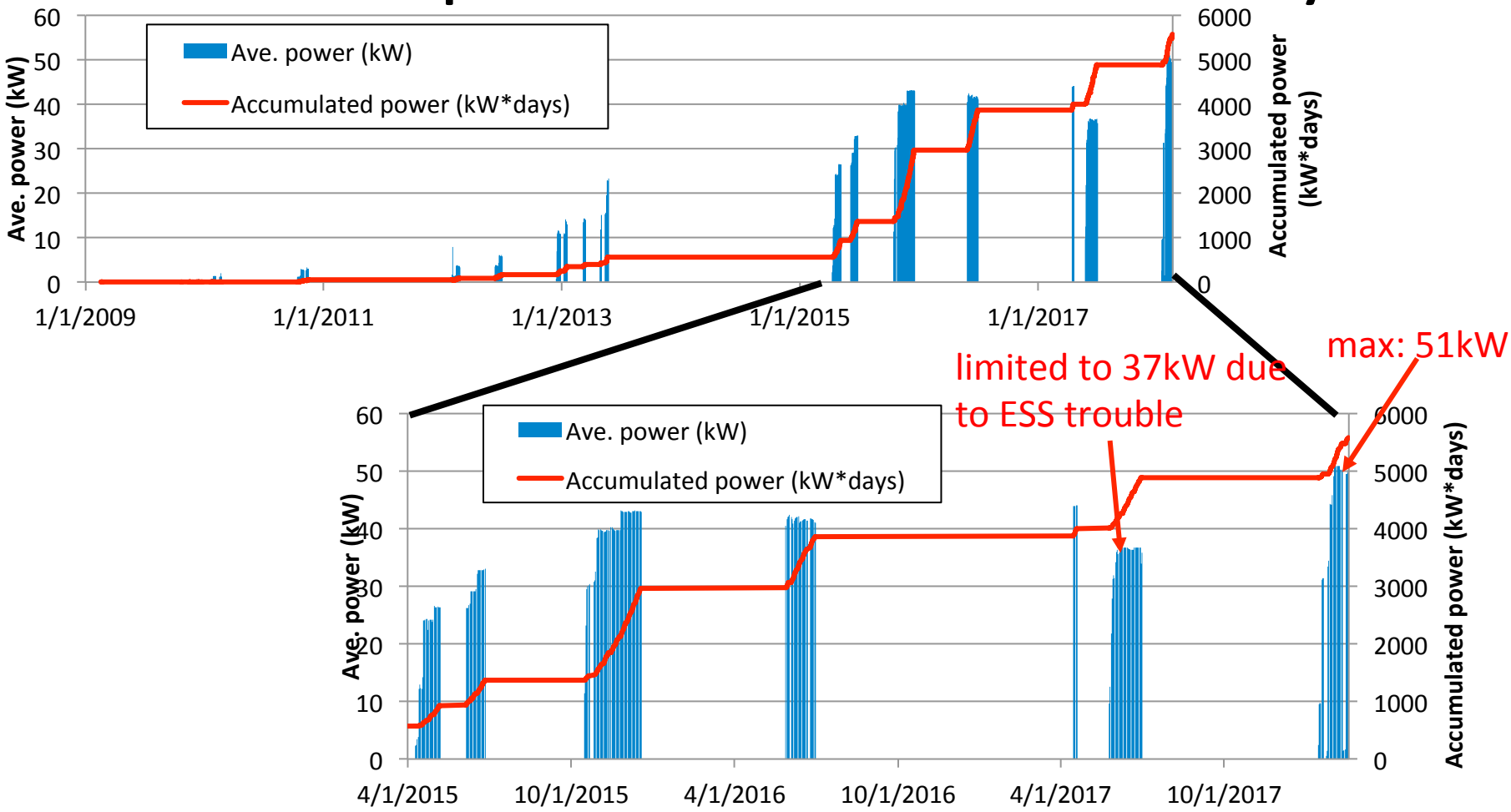




Maintenance work is practically done after 10days to 100 days cooling,
Ti is advantageous than SUS.

After 10 years cooling, SUS becomes better, but both residual doses are very small,
the difference can be negligible.

Development of Beam Intensity



Accumulated beam time and intensity for HD

※spill: # of beam shots to HD

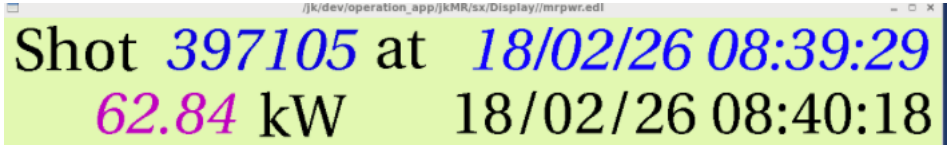
Before accident (Feb, 2009 – May, 2013): 1.26×10^6 spills, 560 kW*days

JFY2015 run (Apr, 2015 – Dec, 2015): 1.05×10^6 spills, 2338 kW*days

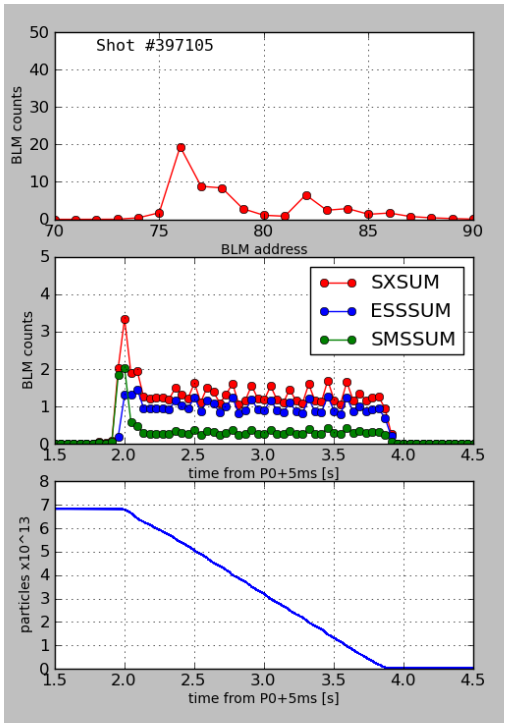
JFY2016 run (May, 2016 – Jun, 2016): 0.33×10^6 spills, 875 kW*days

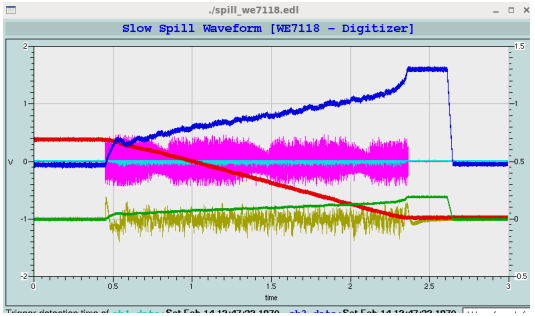
JFY2017 run (Apr, 2017 – Feb, 2018): 0.83×10^6 spills, 2038 kW*days

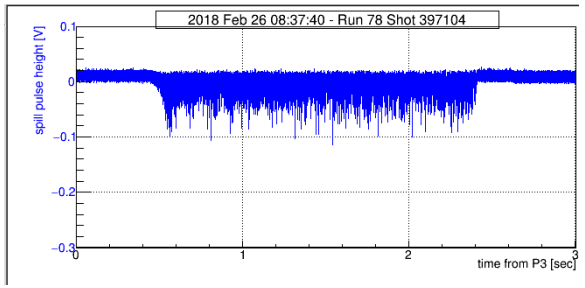
Higher Power SX Demonstration (2 shots)

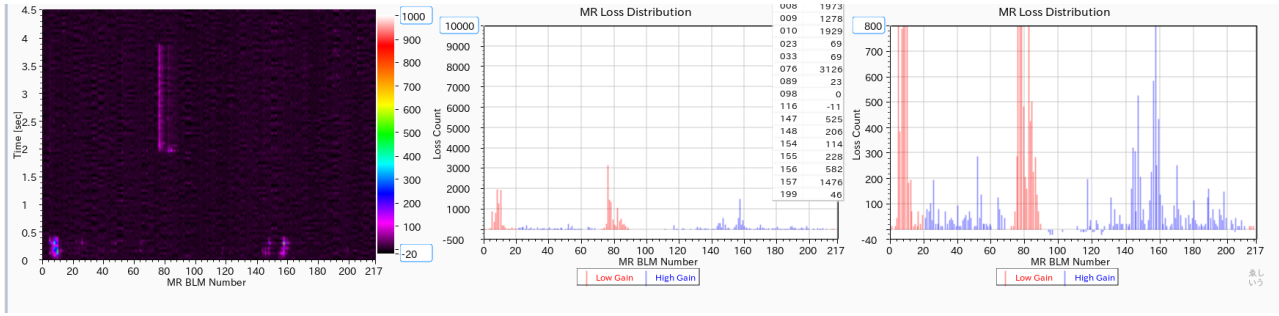


Beam power 62.8kW (rep. 5.2s)
6.8x10^13 ppp
Efficiency 99.47%
Spill Duty 56%
Spill length 1.82s
RF phase offset 50deg (45deg)

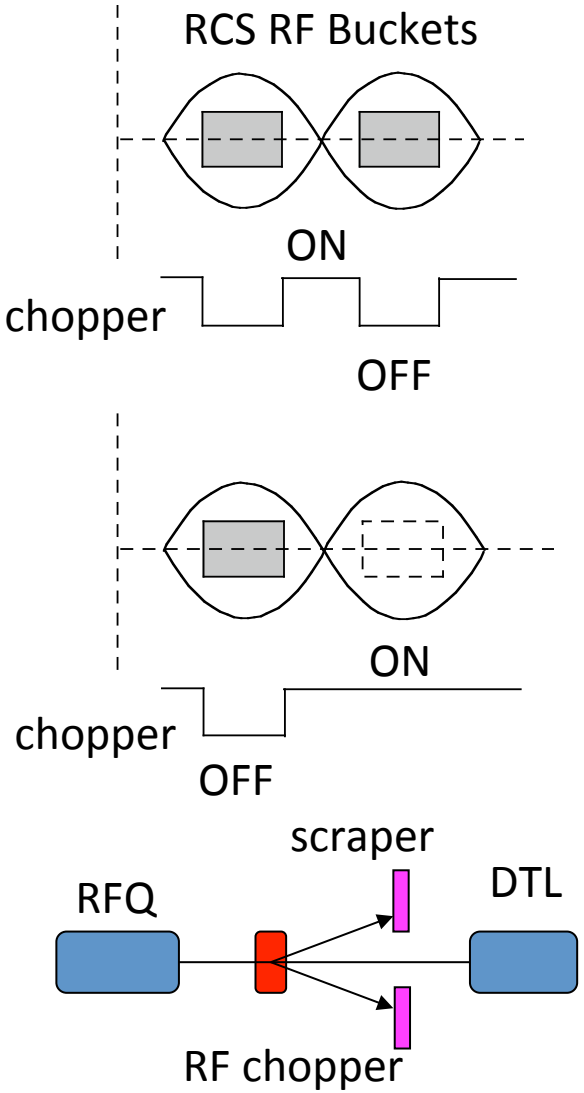






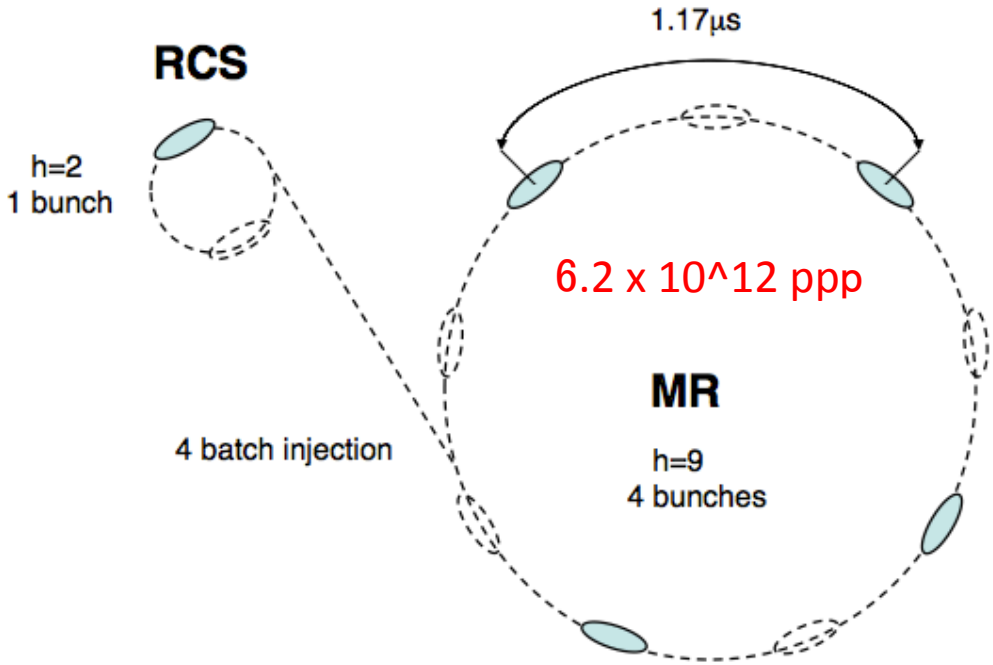


8GeV 1MHz-Pulsed Beam Scheme for COMET



1.6 x 10^12 ppb

2.48s cycle for physics run (3.2kW)
5.20s cycle in this test (1.5kW)

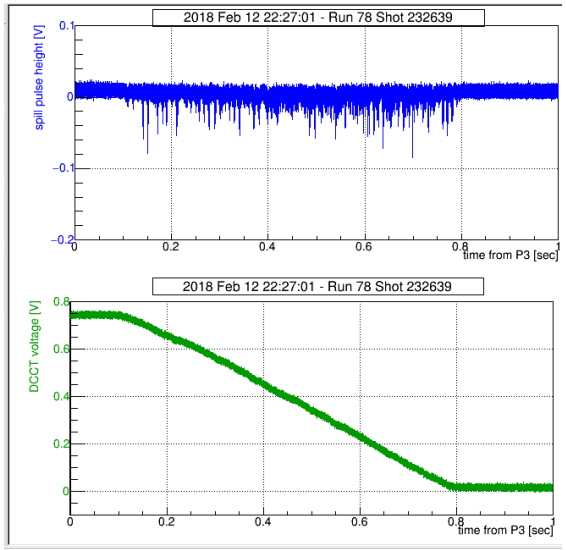


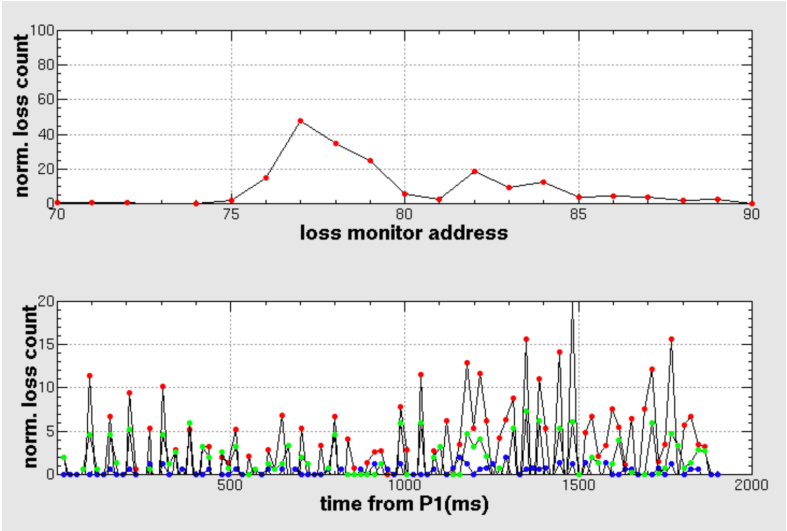
Bunched Slow Extraction at 8 GeV
(option: 3 bunches in h=9)

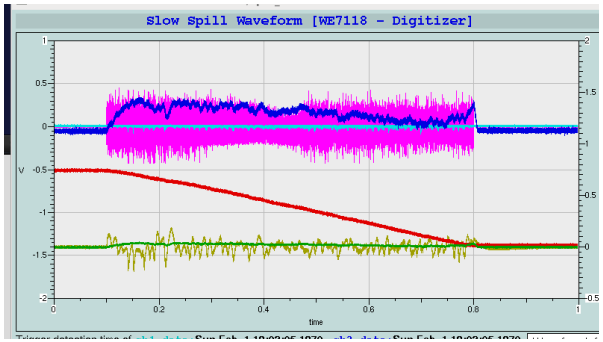
8 GeV Slow Extraction

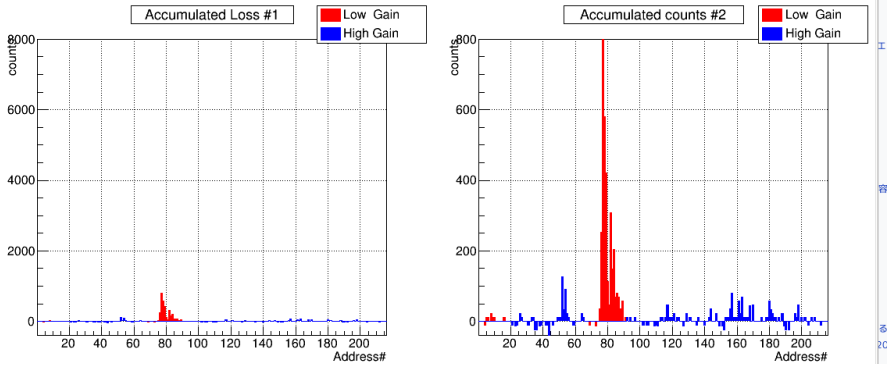
(2/12 ～22:30)

7.3x10^12 ppp (4bunches) w kicker delay, 5.20s cycle
Average beam power 1.8kW
Efficiency 97.3% (could be improved by further beam-based alignment for the ESSs and SMSs)
Duty factor 16% (w/o Transverse RF)
Spill length 0.65s

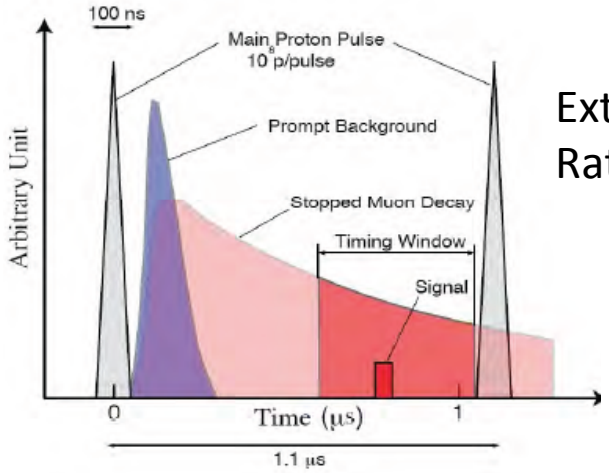






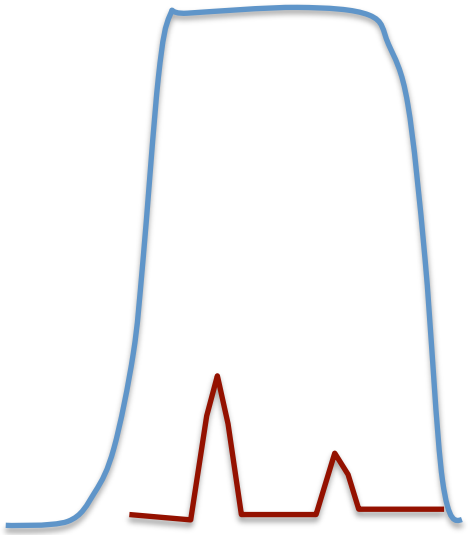


Extinction Improvement



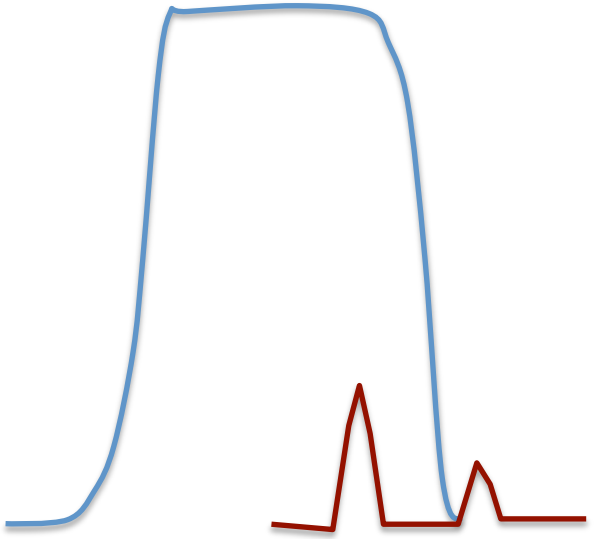
Extinction:
Ratio of beam in between and main pulse beam

Ordinary injection kicker wave timing



Initial extinction O(10^{-6})

Shifted injection kicker wave timing

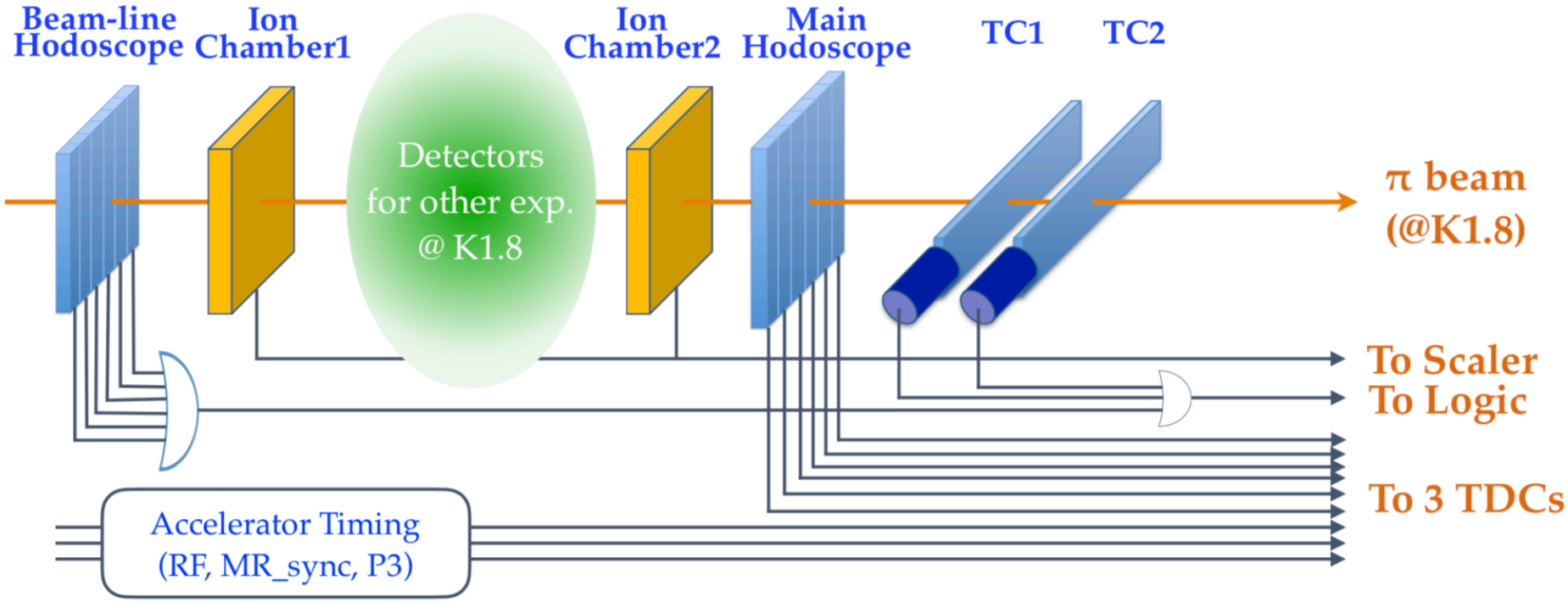


Improved extinction

By COMET-G

Extinction measurement @ Bunched-SX -1-

- By Counting the # of secondary particles @ K1.8 secondary beam line of HD
- Very Simple Measurement (Particle Counting by plastic scintillation counters)
  - **Hodoscope and Ion Chamber count the # of all secondary particles**
  - **With help of beam-line hodoscope and trigger counters to ID beam particles**
- But need a special read out to handle a huge dynamic range
  - 3 dedicated TDC systems are prepared

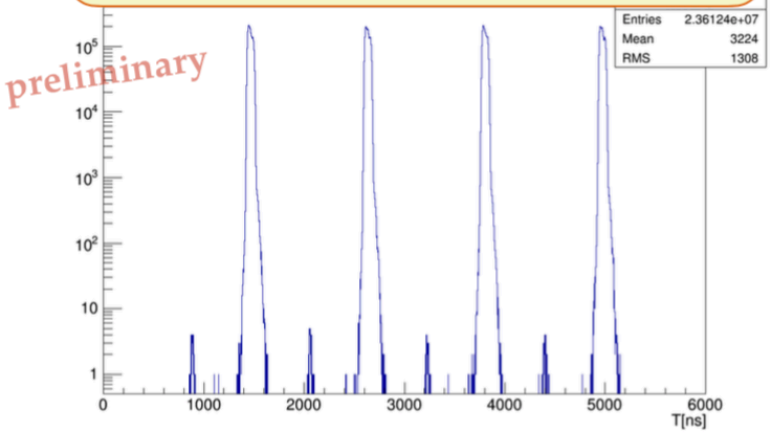


By H. Nishiguchi

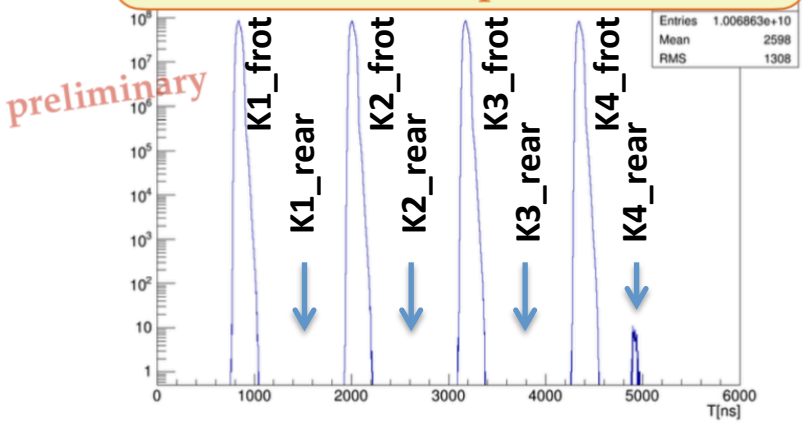
Extinction measurement @ Bunched-SX -4-

- Three TDCs show very similar results, but careful check is ongoing.
- Very preliminary result with a part of obtained data is shown here.

w/o kicker shift = initial extinction



w/ kicker shift = improved extinction



- Obtained initial extinction = 8.0×10^{-6}
- Consistent with 3 TDCs
- Consistent with the result by FX

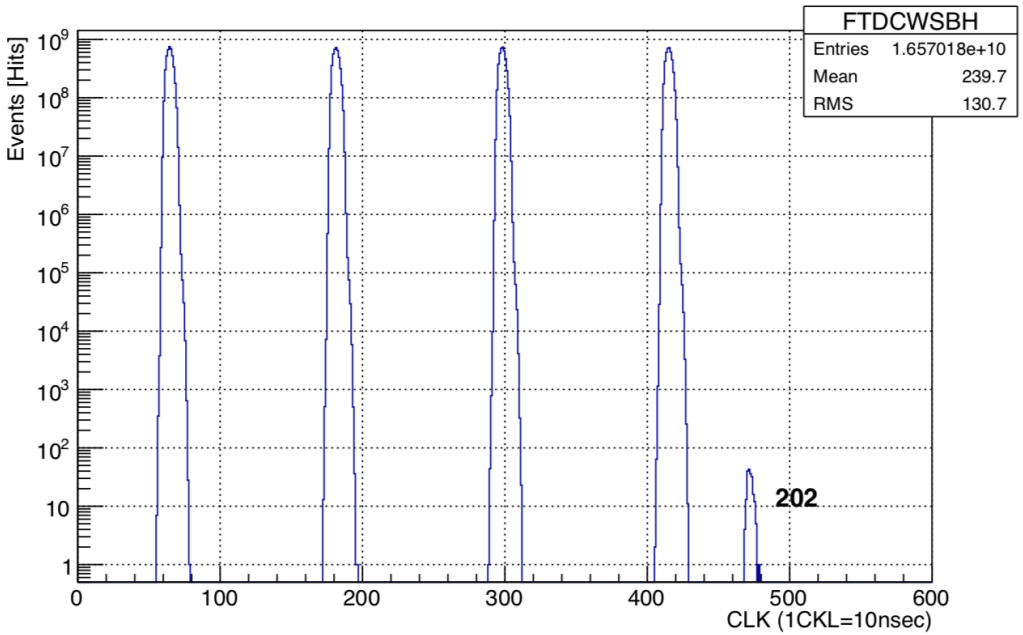
mTDC

- Obtained improved extinction = 1.7×10^{-8}
- Proton leakage is appeared in **K4_rear only** within very early extraction timing (<0.1sec)
- No leakage is appeared in other region
- By rejecting <0.1sec events, upper limit of extinction is obtained: **$<9.9 \times 10^{-11}$**
- **Good enough for COMET !!**
- **Need further studies on K4_rear leakage**

Preliminary

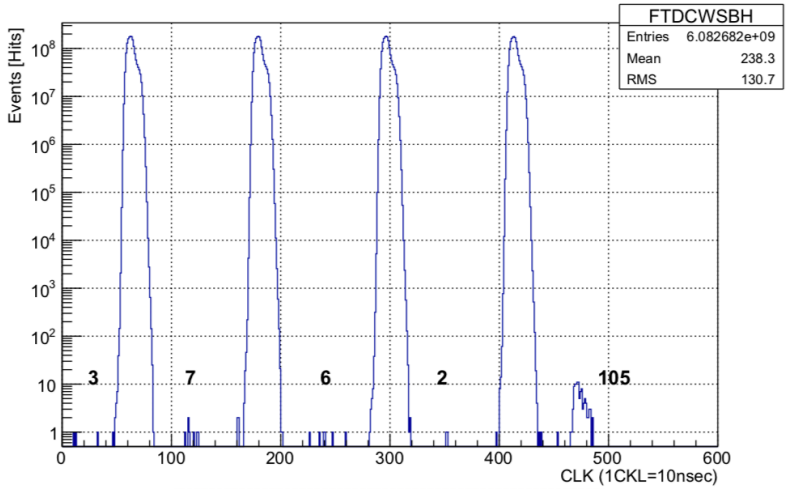
Result from H-TDC

By H. Nishiguchi



Obtained beam timing structure (all data)

- No leakage was observed for all data with "kicker shift" run (1.7E10 proton equivalent)
- 202 protons are observed in K4_rear only, corresponding to an extinction factor of 1.2E-8
- Excluding this 202 protons by masking <100 msec event, extinction UL of < 6.0E-11 is obtained



Lower RF voltage (30kV)

- In order to have a look at a behavior of proton leakage, RF voltage was lowered down to 30kV.
- Distribution of leaked proton in K4_rear was widen according to the lower RF, *ie*. it is confirmed that this leak is really coming from the proton bunch in MR.
- Also some leaked proton was observed even in K1,2,3 due to the lower bucket height of RF.

The mechanism of in the leakage is under discussion and further beam study will be planned

Summary

- The ESS1 troubles occurred in RUN74
- Slow beam operation restarted by moving the ESS2 at the ESS1 location
- The revised Titanium ESS has been installed and the ESS2 moved at ESS2 location in the summer shutdown period.

- In RUN78, 30 GeV beam power for user operation has achieved above 50 kW.
- ～63kW slow extraction has been successfully demonstrated

- We have succeeded in 8 GeV slow extraction in the beam test for COMET phase I experiment
- Preliminary extinction for slow extracted beam shows a very promising result.

Mid-term plan of MR

FX: The higher repetition rate scheme : Period 2.48 s —> 1.30 s for 750 kW.
(= shorter repetition period) —> 1.16 s for 1.3 MW
SX: Mitigation of the residual activity for 100kW

JFY	2017	2018	2019	2020	2021	2022	2023	2024
Event	New buildings		HD target		Long shutdown			
FX power [kW]	475	>480	>480	>480		>700	800	900
SX power [kW]	50	50	50	70		> 80	> 80	> 80
Cycle time of main magnet PS New magnet PS	2.48 s	2.48 s	2.48s	2.48s		1.32 s	<1.32s	<1.32s
High gradient rf system 2nd harmonic rf system		Mass production installation/test						
Ring collimators	Add.collimators (2 kW)	Manufacture, installation/test			Add.colli. (3.5kW)			
Injection system FX system	Kicker PS improvement, Septa manufacture /test Kicker PS improvement, FX septa manufacture /test							
SX collimator / Local shields						Local shields		
Ti ducts and SX devices with Ti chamber	Ti-ESS-1	(Ti-ESS-2)						