Online monitoring system for the waste beam in the 3-GeV RCS of J-PARC

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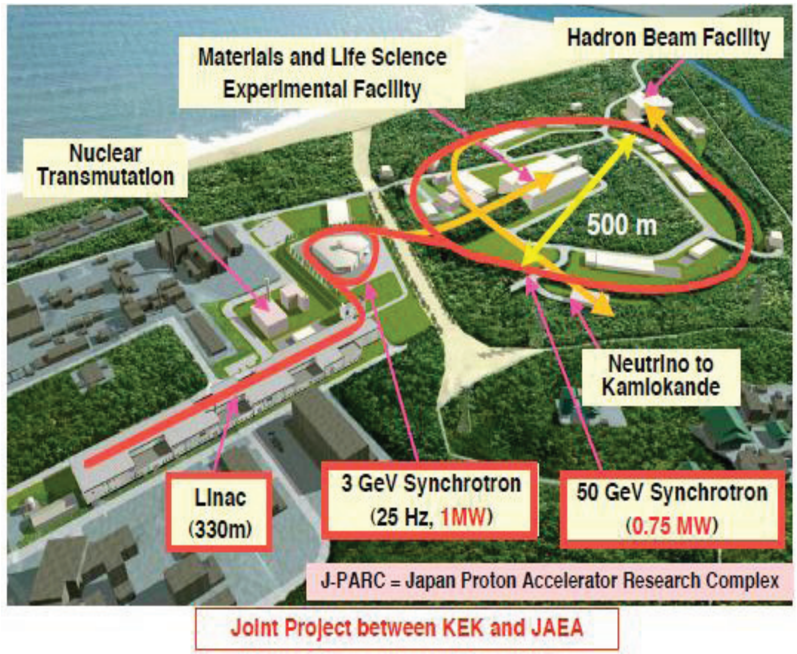
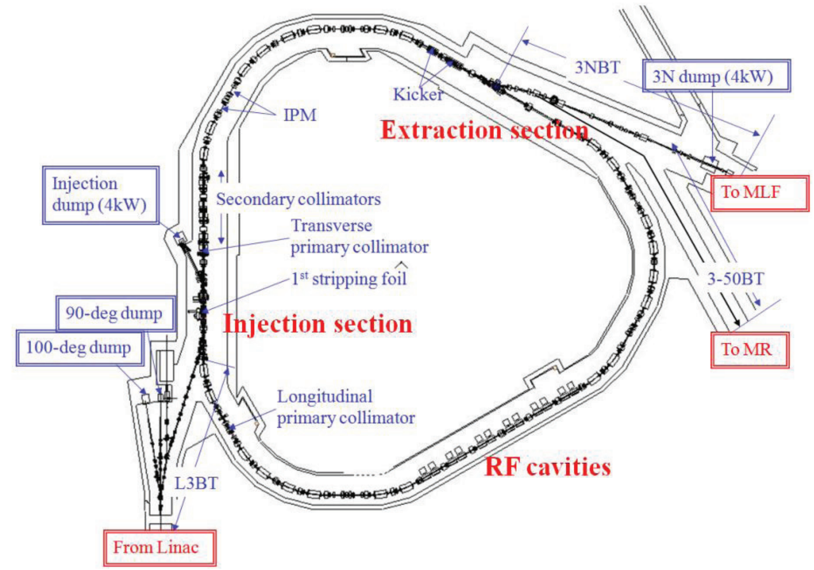
Outline

1. Introduction
2. Overview of the monitoring system
3. Principle and technique
4. Online monitoring data
5. Summary

J-PARC facility and layout of the 3-GeV RCS





Accelerators at J-PARC facility:

- 400 MeV (181 MeV at present) **LINAC**
- 3-GeV Rapid Cycling Synchrotron (**RCS**)
- 50-GeV (30-GeV at present) Main Ring (**MR**)

3-GeV RCS:

3-foid symmetric lattice

*(**uses multi-turn H^- stripping injection**)*

Einj = 400 MeV (181 MeV at present)

Eext= 3 GeV

Repetition: 25 Hz

Beam power (design): 1 MW

→ 8.33 × 10^{13} ppp

Introduction

Online monitoring of the waste beam in RCS is very important because

- Dump capacity is only 4 kW (although realistic waste beam power is 0.4 kW).
- Foil shrinkage, deformation, degradation (such as foil thinning, pinhole formation) etc. due to high temperature rise increased waste beam so as the heat load on the dump.
- A little degradation of the foil is even crucial.
- A sudden foil failure breaks accelerator availability and raises maintenance issues.
- Residual radiation near the dump is also an issue.

→ *We should keep waste beam ~0.4 kW during operation.*

There was several ideas during design stage but unfortunately was hard to adopt mainly due to space, money and even reliability?
Waste beam is only 0.4kW and there exist big noise from nearby inj. systems.
→ *Hard to be confident enough through any conventional way.*

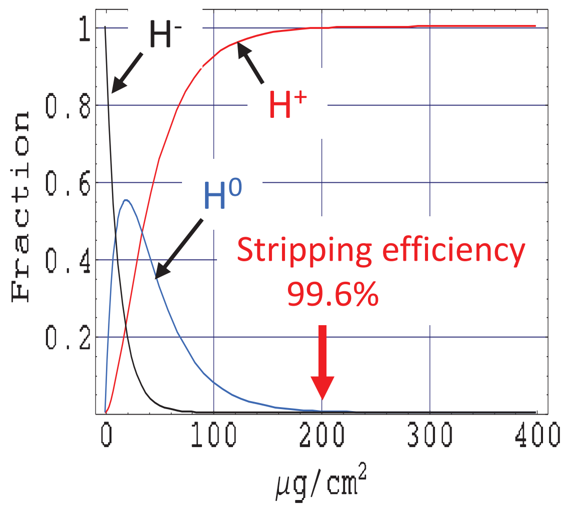
Foil thickness vs. stripping efficiency

Parameter list

Energy (MeV)	400	181
Foil thickness ($\mu g/cm^2$)	290	200
Stripping efficiency (%)	99.7	99.6
Waste beam fraction (%)	0.3	0.4
Inj. beam power (kW)	133	36
Waste beam power (kW)	0.399	0.144
Dump limit (kW)	4	4

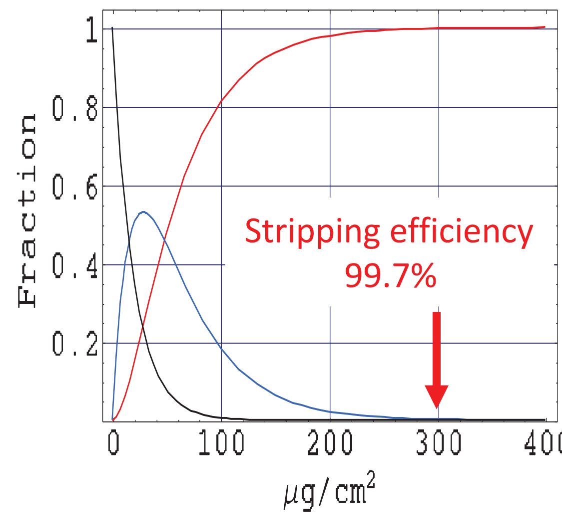
R.C. Webber el. al.
IEEE. Nucl. Sci. NS-26(1979)

E_{inj} = 181 MeV



W.Chou et. al.
NIM A 590 (2008)

E_{inj} = 400 MeV

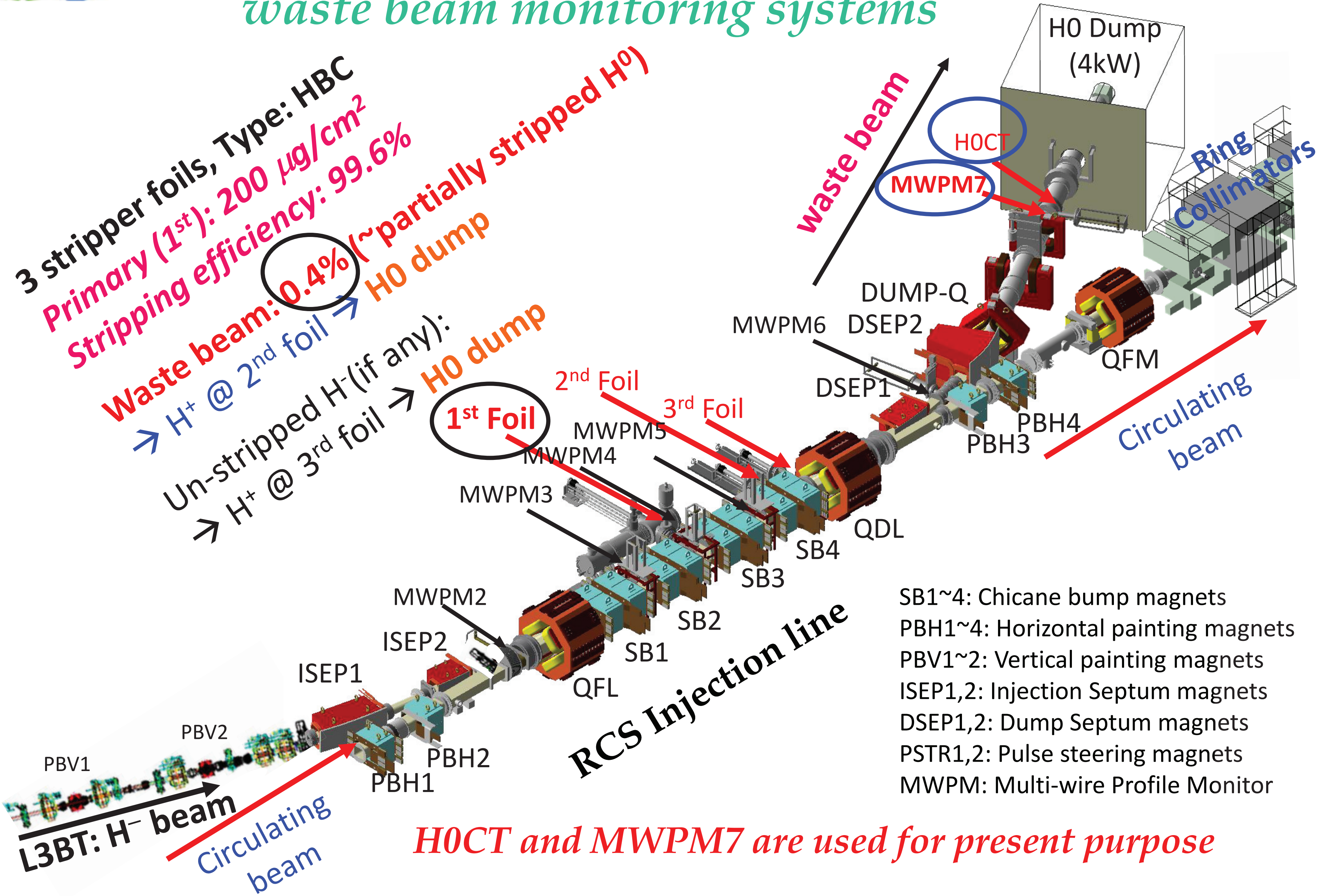


Thicker foil → increases stripping efficiency
but it increases foil scattering beam loss too.

Thinner foil → increases the waste beam

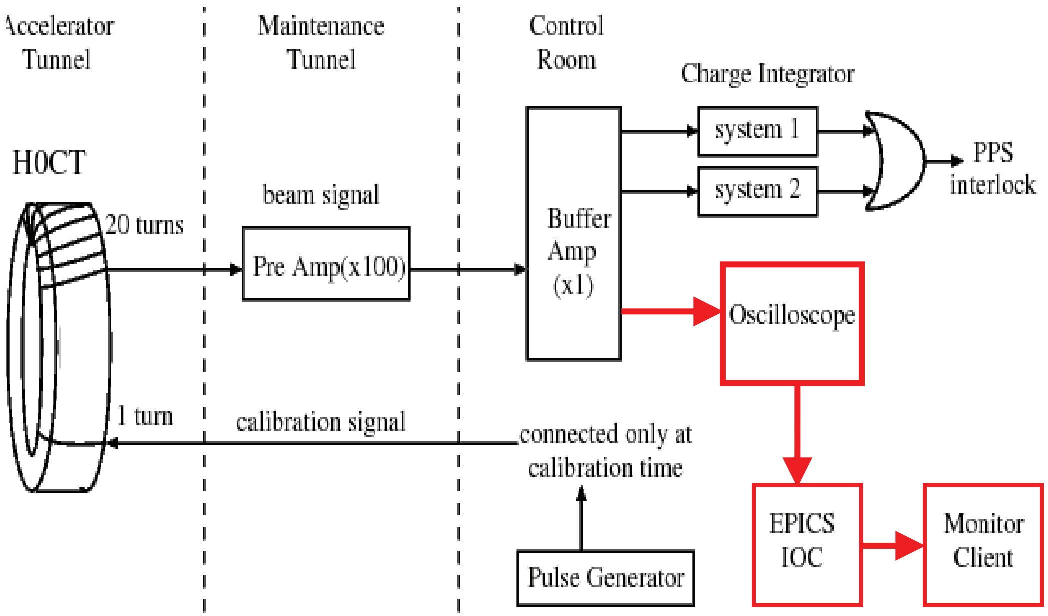
- Needs larger dump → require space and money
- H^0 excited state loss also increases

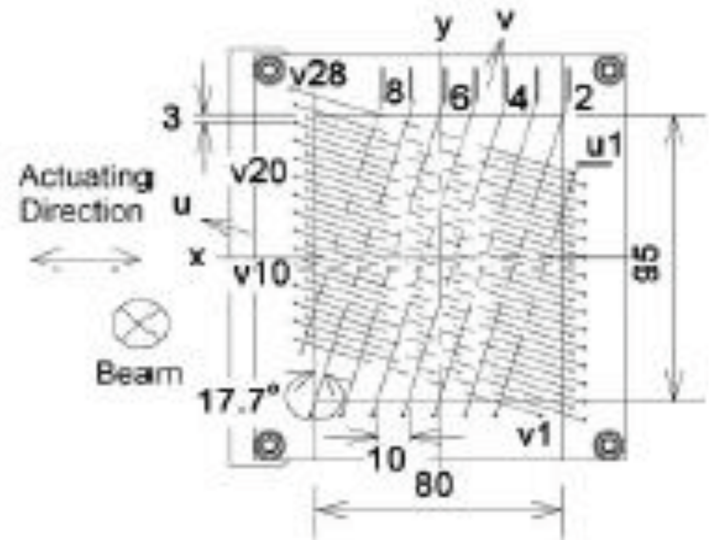
RCS injection area and waste beam monitoring systems



H0CT and MWPM7 are used for present purpose

Monitor configurations





H0CT and data taking logic:

(Used as a PPS interlock system through upper part logic at present).

For online monitoring of the waste beam, we fed buffered signal to an oscilloscope and is controlled by an OPI.

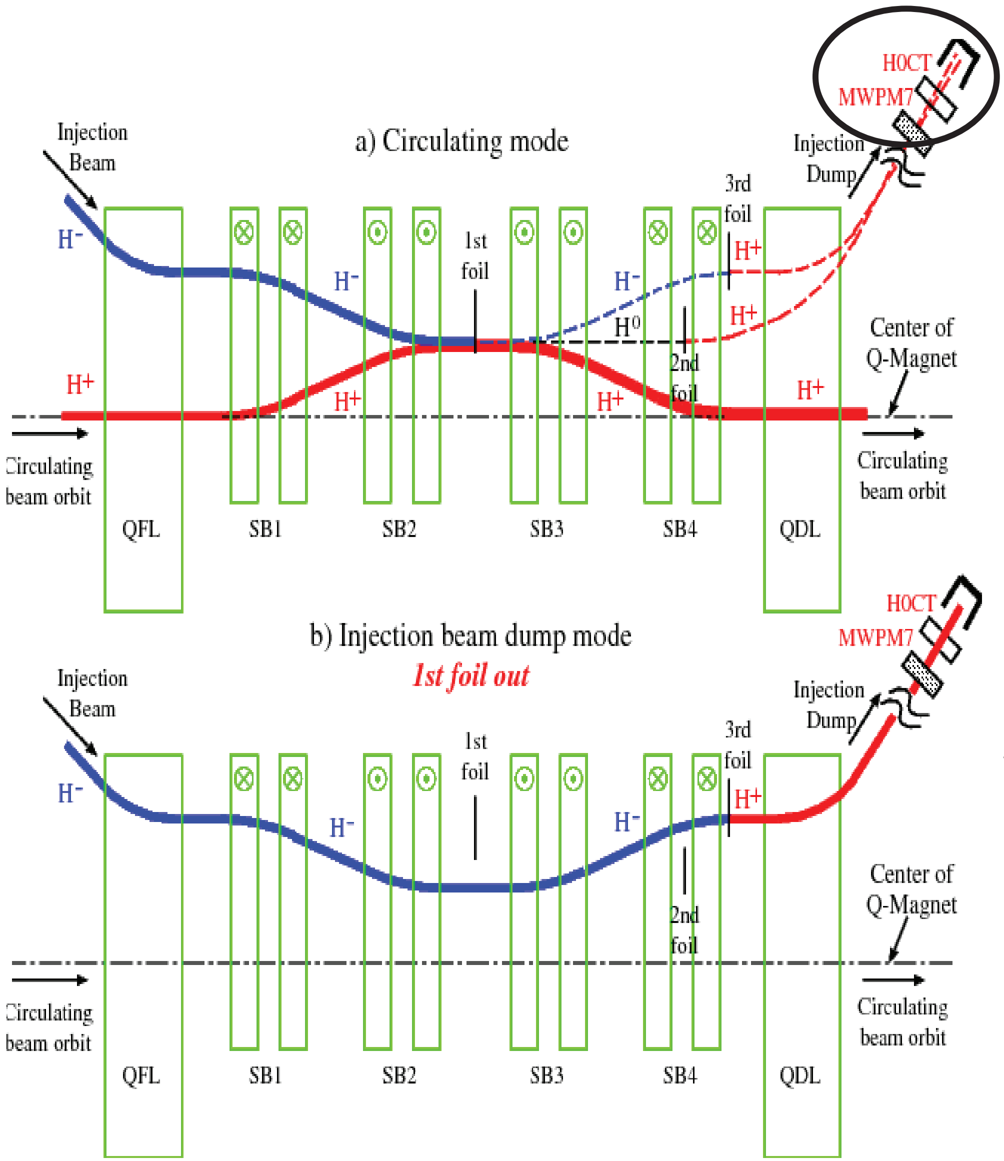
1024 avg. @ 25 Hz opr. → 40 s for one data point

MWPM7 wire configuration:

U:15 (pitch 20 mm),V:48 (pitch 4 mm)
Scan direction: X

For profile:
100 shots @ 1 Hz
Scan Δx= 0.2mm/s

Measurement principle



1. H0CT

Measure the waste beam as a whole.

Waste beam= H0CT signal in mode (a)/(b)

2. A multi-wire profile monitor (MWPM7)

Measure H^0 and H^-(if any) separately .

H^0 and H^- beam position differs by 80 mm!

→ No overlap (measure simultaneously).

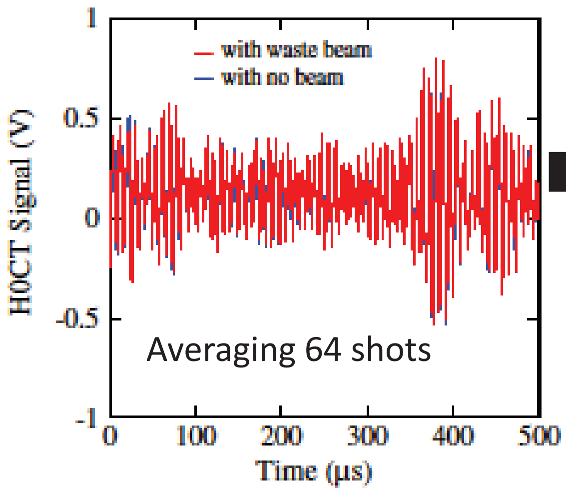
H^0 fraction = H^0 yield (a) /Total yield (b)

H^- fraction = H^- yield (a) /Total yield (b)

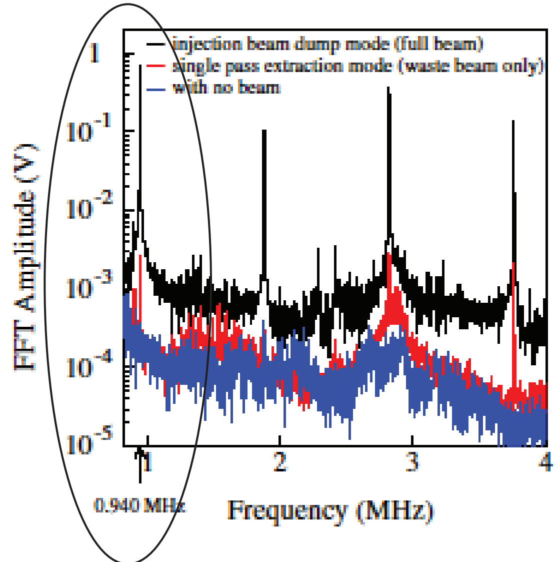
Where, a and b denote operation modes.

- **An increase of the H^0 fraction**
  → ***Foil thickness reduction.***
- **An increase of the H^- fraction**
  → ***Pinhole formation.***

Measurement technique



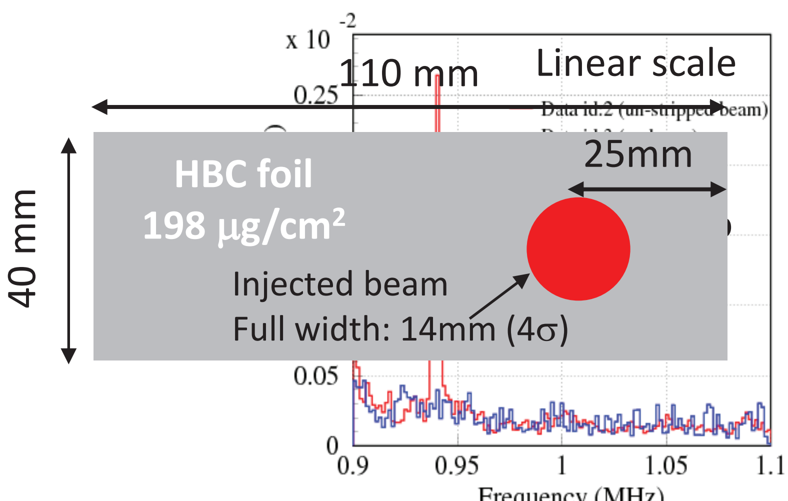
FFT

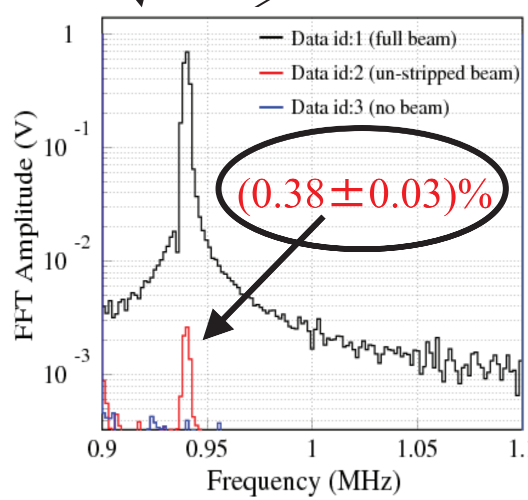


Typical waste beam signal measured by a CT

Very identical w/ beam and w/ no beam

→ Hard to extract real information





e pulse &

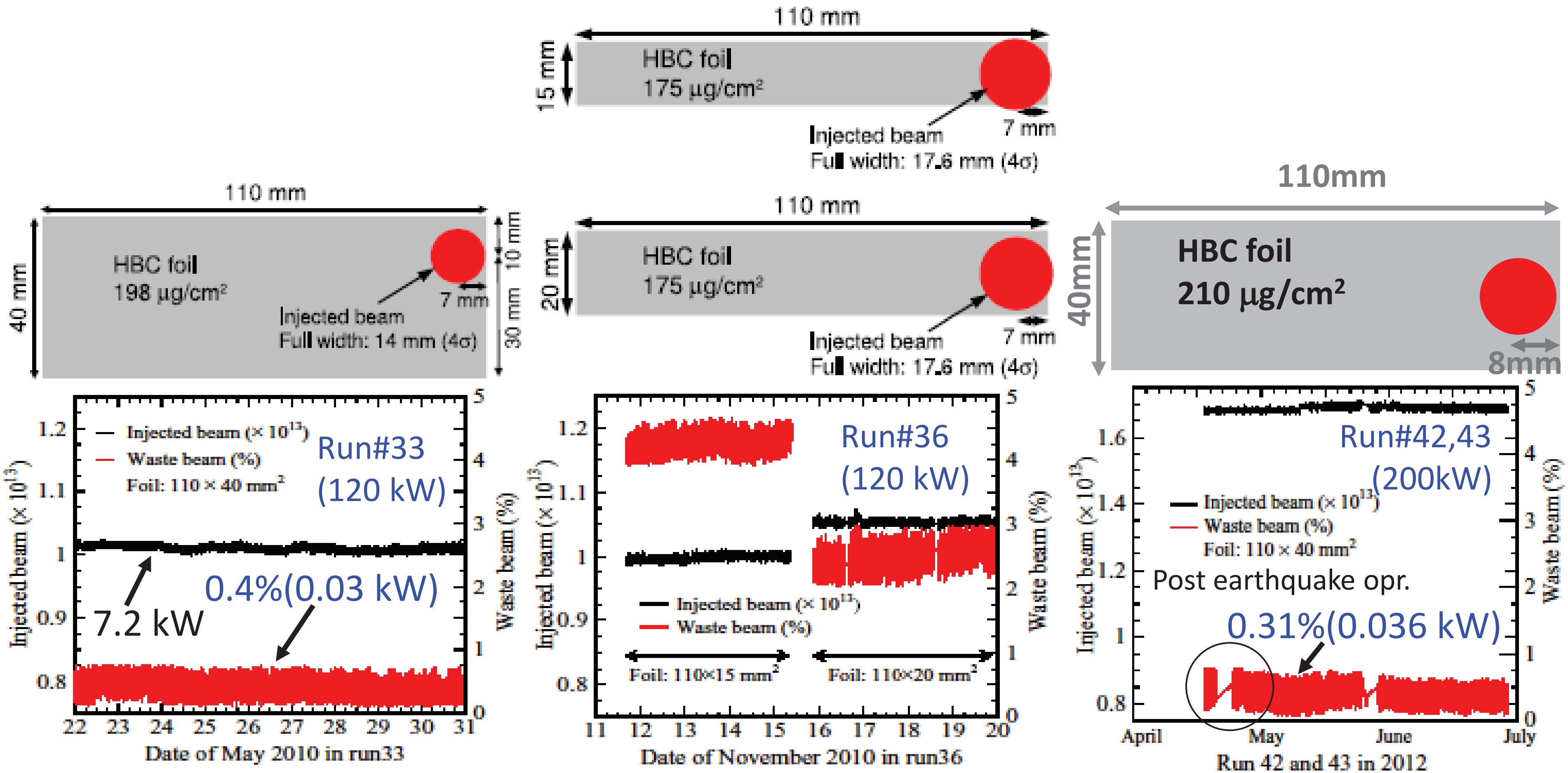
d

P.K. Saha et. al.
PRST-AB 14, 072801 (2011)

jection

940 MHz

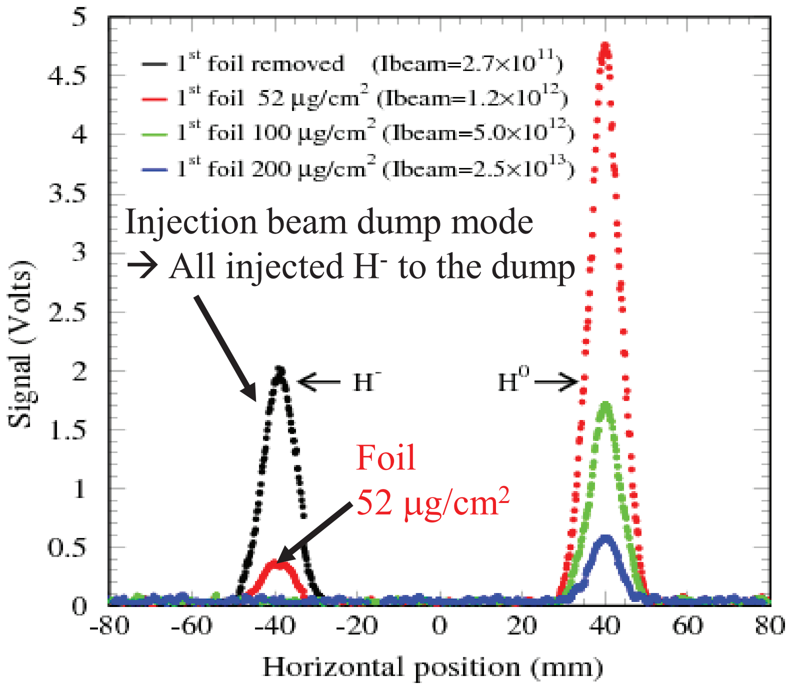
Online monitoring with H0CT

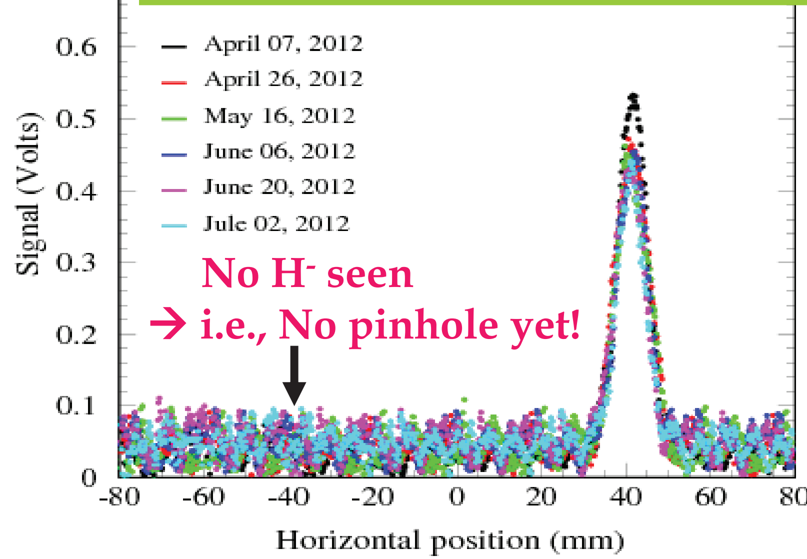


We could monitor even only a 0.03 kW (4 ×10¹⁰ ppp) of the waste beam!

Measurement by MWPM7 in Run42,43

4 months operation: **foil: 210 μg/cm²**
Ibeam : 2.7 × 10²¹
◎Almost No change of the H⁰ yield!
◎No H⁻ seen!





Beam profiles measured by the MWPM7. Data with 1st foil removal (black) is used to normalize the waste beam so as to get the waste beam fraction.

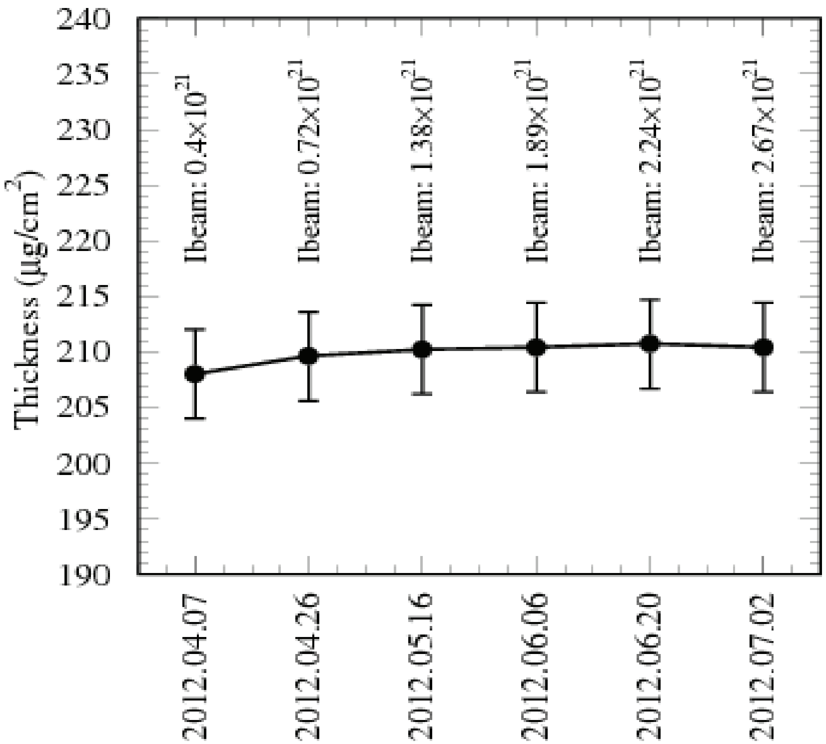
Measurement of the waste beam during RCS operation:

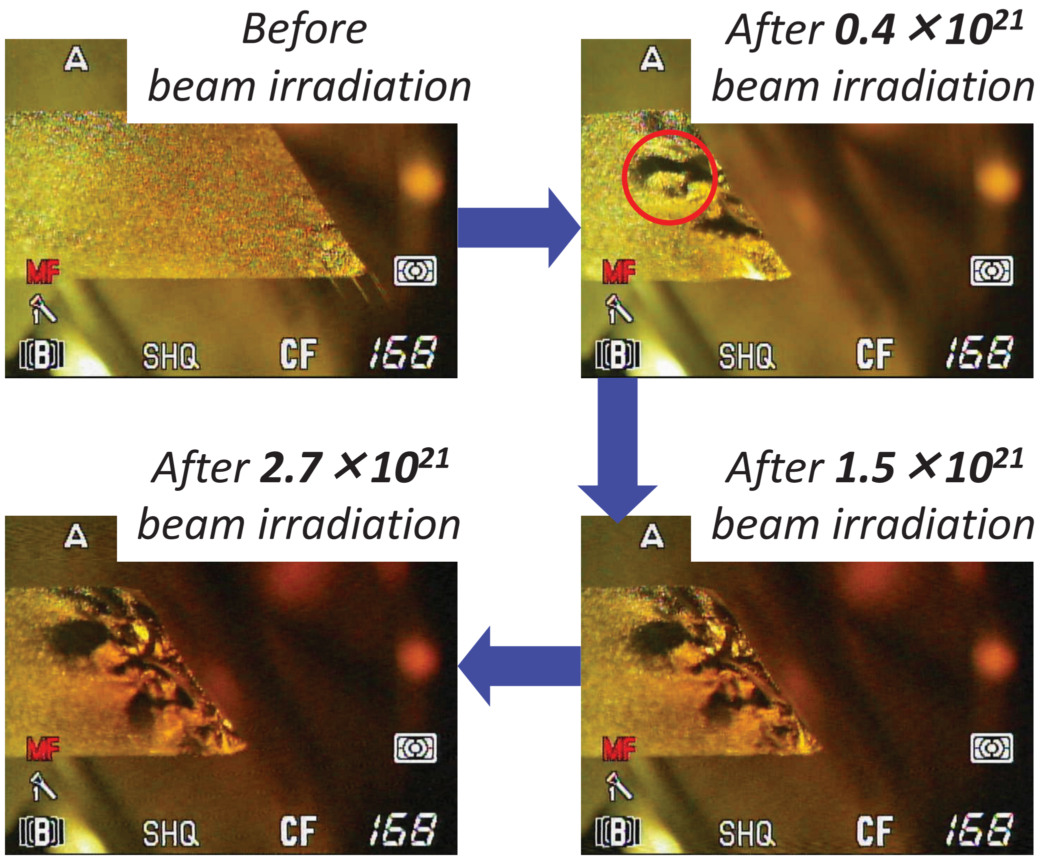
H^0 fraction in the 1st measurement:

0.31 ±0.035% → 208±4 μg/cm²

→ Consistent with expectation (210 μg/cm²)!!

Foil thickness trend





Measurement error: ±2% in thickness

- ***No observable foil degradation so far!***
- ***Thickness increases a little (~1%) in the beginning.***

→ *But smaller than the measurement error.*

May not only due to deformation, shrinkage of the foil?

(~8 deg. tilted → 1% increase in thickness)

→ Further data might provide better understanding.

Foil keep deforming but no degradation yet!

RCS 1st stripper foil magazine and operation scenario

At present, 6 foils are installed for operation. The rest are with different thickness for the study.

A total of 15 foils can be installed at a time.

For 1 MW operation:

1 foil should work for 15 days

(15 days x 15 = 6.5 months)

In order to replace the whole magazine in scheduled timing. (twice a year)

Experimental understanding of the lifetime:

◎Determine a proper replacement timing.

◎Ensure the best use.

◎Avoid sudden failure related troubles.

Summary

We have established efficient techniques for measuring waste beam with good accuracy.

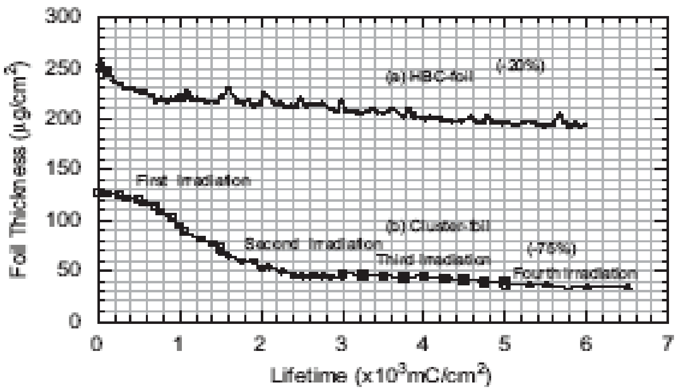
The FFT analysis of the raw signal made us possible for measuring as well as online monitoring of the waste beam of only 0.4%.

It is also very useful for adjusting foil related injection parameters in the RCS beam studies.

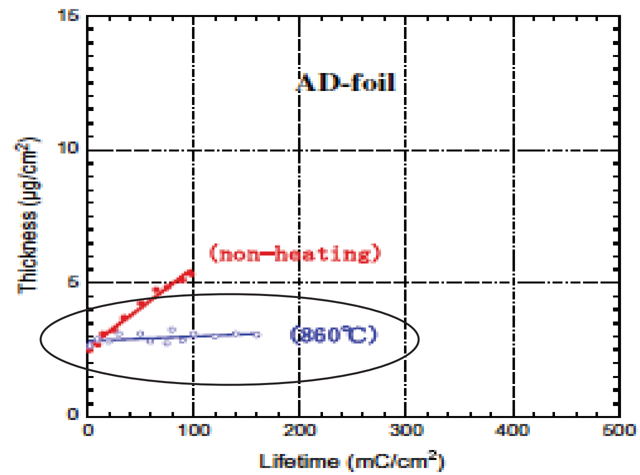
In addition, separate measurement of the H^0 and H^- charge fraction by MWPM is very interesting to know the detail of the foil degradation.

One can avoid not only a sudden foil breaking but it may provide ingredients to explore deep understanding of the foil breaking mechanism.

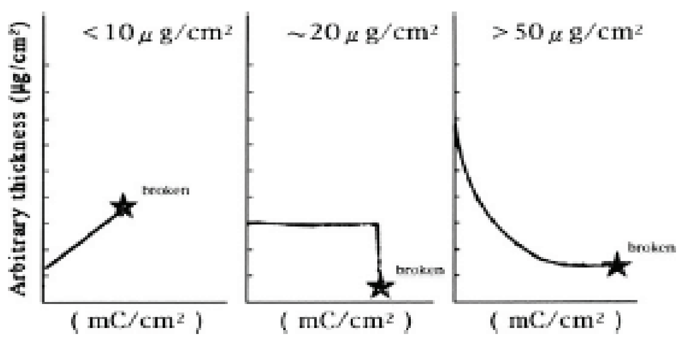
Stripper foil properties: Brief overview



I. Sugai et. al.
NIM A 613 (2010)
NIM B 269 (2011)



Thick foils: Foil thinning due to radiation is a general phenomenon



Thin foils: Foil thickening is not a surprise!
Carbon buildup, foil shrinkage foil deformation might be the reasons.
Suppression of carbon buildup by foil heating is one new progress towards making longer lifetime foil.

Additional foil heating reduces carbon buildup.
(1) No thickening (2) longer lifetime

How about with HBC foil and for 300 kW operation in RCS today?

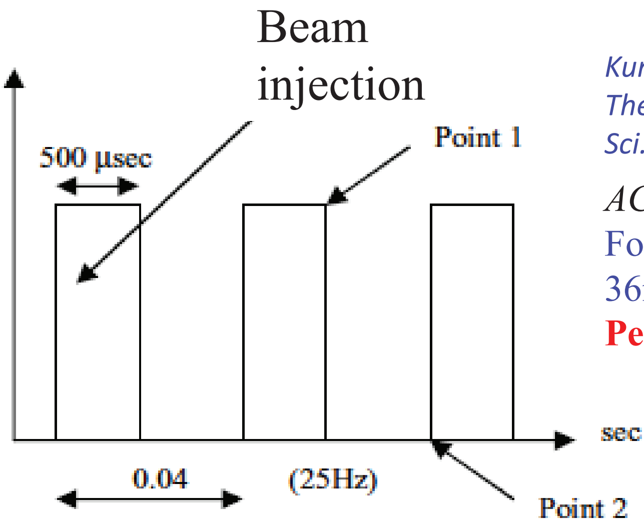
Expected foil temperature: only ~ 650K

- Possibility of Carbon buildup?
- Foil shrinkage? yes
- Foil deformation? yes

→ **Foil thickening in the beginning?**

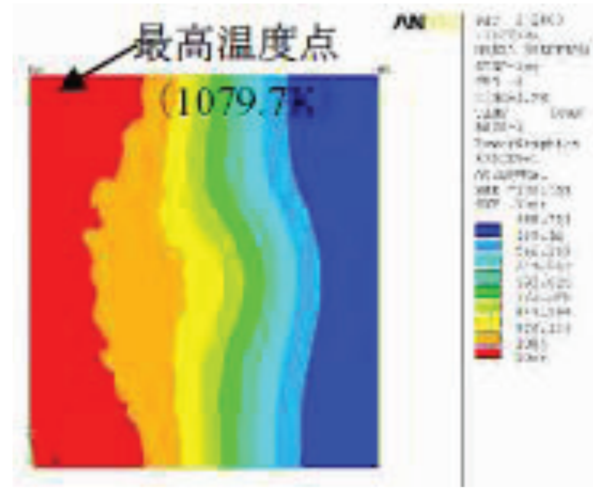
We can measure!

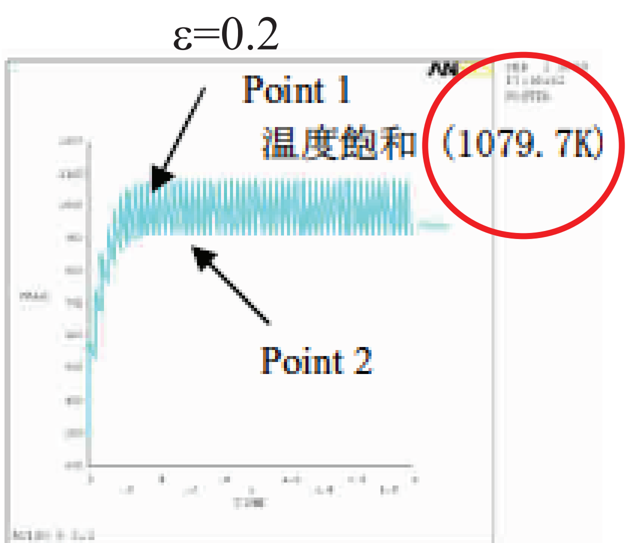
Foil temperature at 1 MW operation

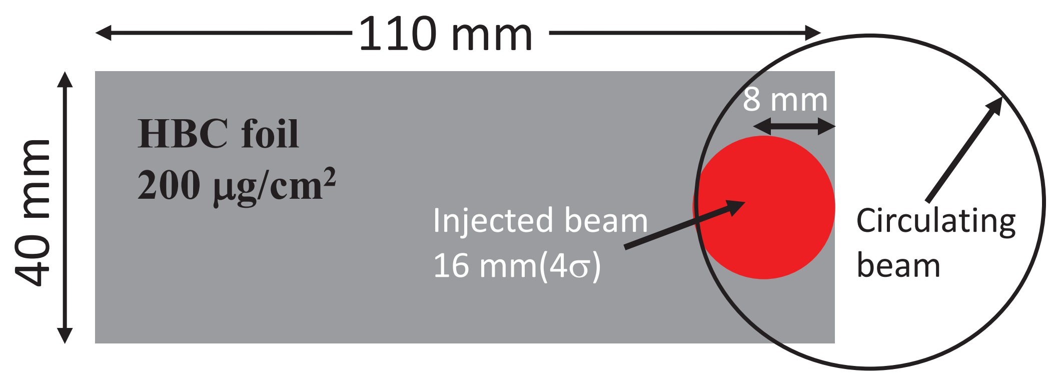


Kuramochi et.al.
The 14th Symposium on Acc.
Sci. and Tech., Tsukuba, Japan 2003

ACCSIM + ANSYS
Foil dimension:
36mm × 32mm × 1.5μm
Peak temperature: 1079 K







At present for the RCS operation:
Beam power: ~300 kW
Foil: HBC w/ larger dimension:
(100 μg/cm² x 2 foils are sandwiched)
→ Expected peak temperature: ~650K