Quantitative monitoring of the stripper foil degradation in the 3-GeV RCS of J-PARC

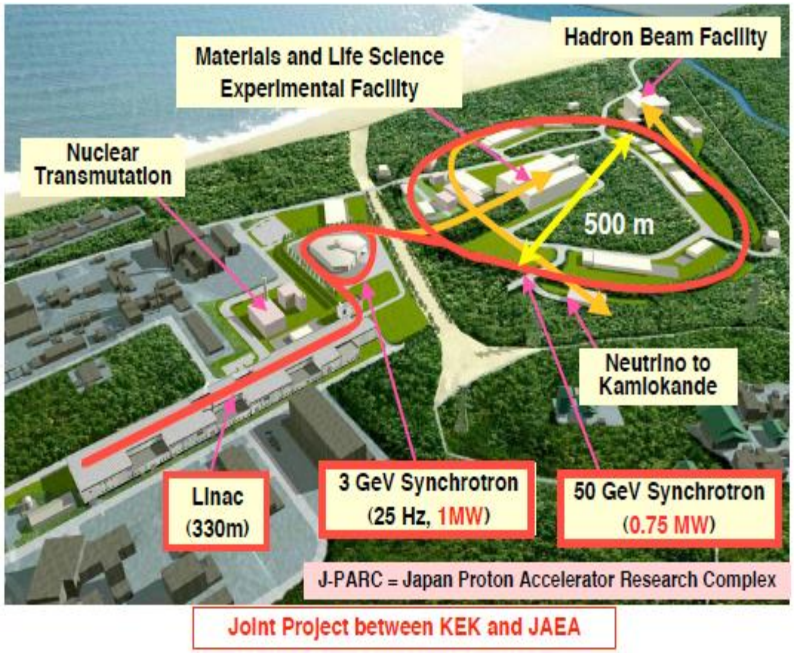
Pranab K. Saha

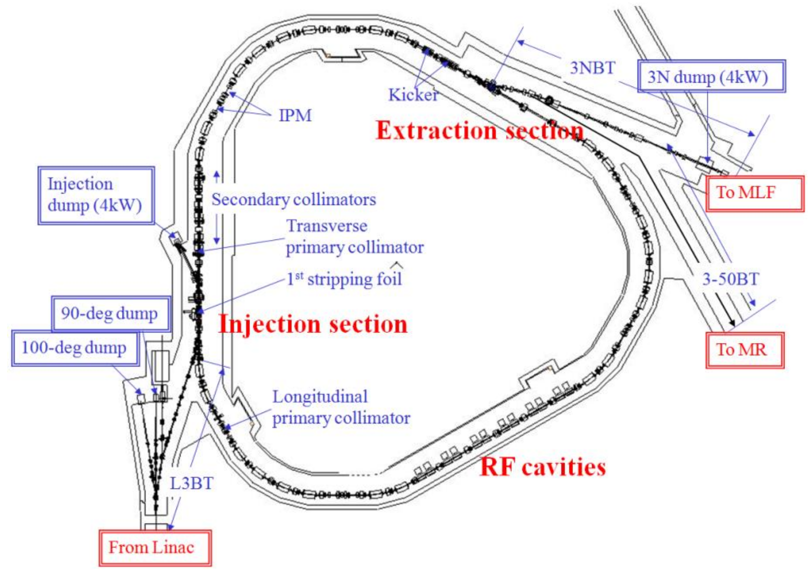
Japan Proton Accelerator Research Complex (J-PARC)

INTDS 2012, Mainz, Germany

August 19-24, 2012.

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 at present)
Eext= 3 GeV
Repetition: 25 Hz
Beam power (design): 1 MW
→ 8.33×10^{13} ppp

Outline

1. Introduction
2. RCS injection system and stripper foil related issues
3. overview of the foil properties
4. Principle and technique of the present monitoring system
5. Experimental results and discussion
6. Summary

1. Introduction

A stripper foil with longer lifetime is required for RCS 1 MW operation.
A sudden foil failure breaks the accelerator availability as well as raised maintenance issues.

There are many reasons behind foil breaking:
High temperature rise of both instant and average, thermal buckling, shrinkage due to mechanical stress,
carbon buildup, foil degradation (such as foil thinning, pinhole formation), etc.

Open question: Which one is the dominant factor?
Significant progress have been achieved in foil manufacturing these days.
But the lifetime may strongly depends on use?
(i.e., foil type & thickness, type of accelerator, beam power and so on.)
■***Measurement by beam might be the direct way of determining the lifetime.***

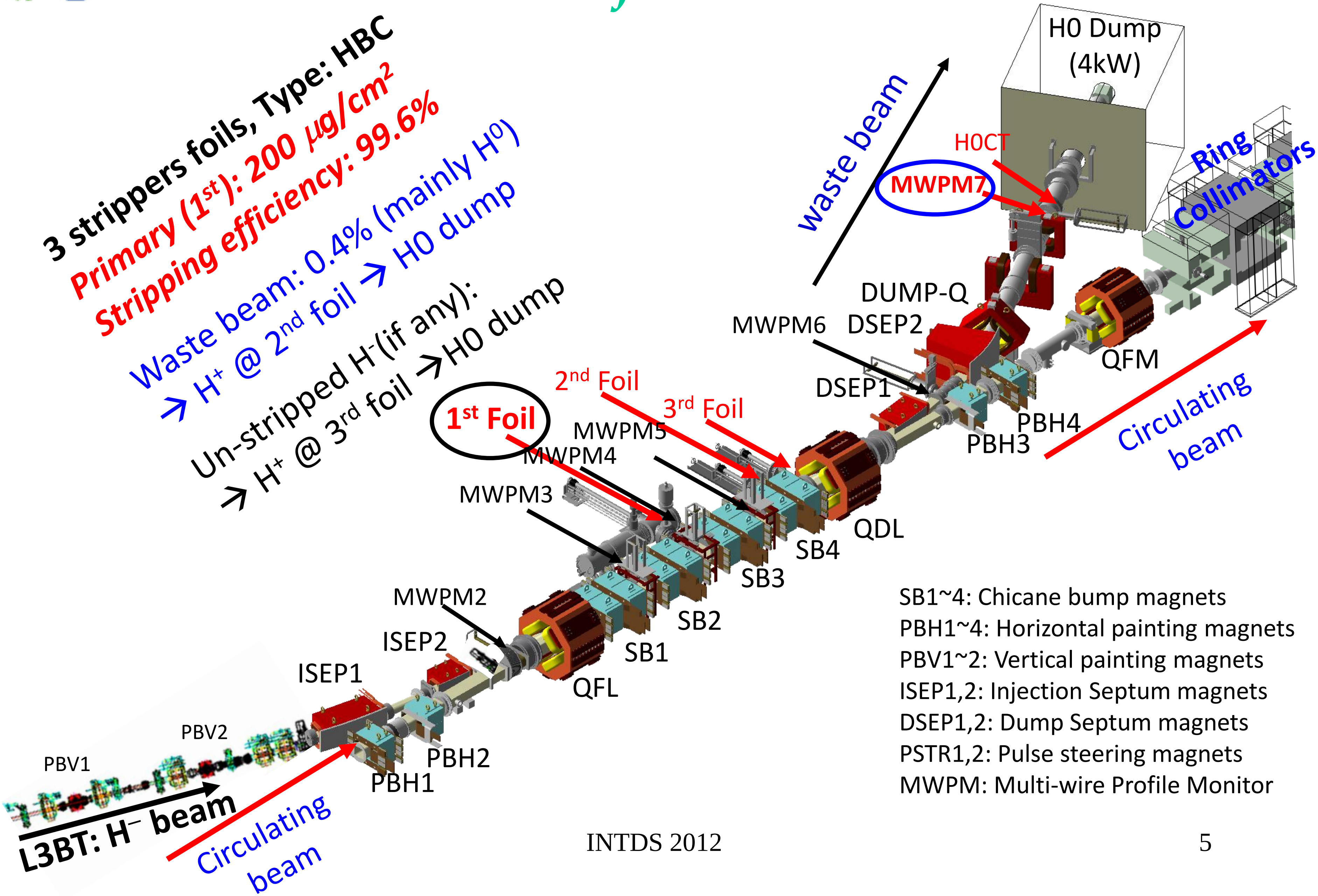
→ Present study aims for an efficient online monitoring of the foil degradation (lifetime).
→ Deep understanding of the foil braking mechanism through systematic studies.

2. RCS injection area

3 strippers foils, Type: HBC
Primary (1st): 200 μg/cm²
Stripping efficiency: 99.6%

Waste beam: 0.4% (mainly H0)
→ H+ @ 2nd foil → H0 dump

Un-stripped H-(if any):
→ H+ @ 3rd foil →H0 dump



SB1~4: Chicane bump magnets
PBH1~4: Horizontal painting magnets
PBV1~2: Vertical painting magnets
ISEP1,2: Injection Septum magnets
DSEP1,2: Dump Septum magnets
PSTR1,2: Pulse steering magnets
MWPM: Multi-wire Profile Monitor

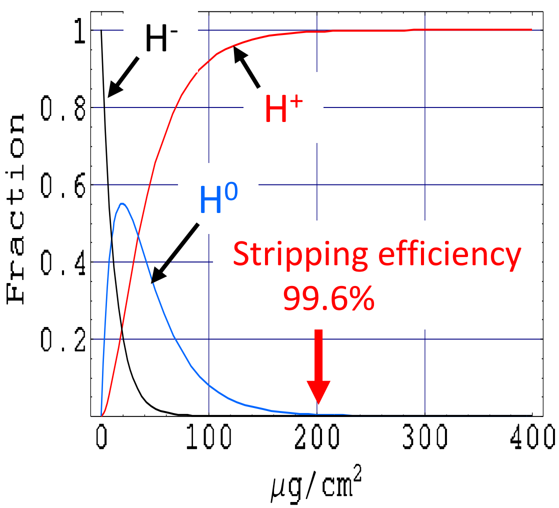
2. Foil thickness vs. Stripping efficiency

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

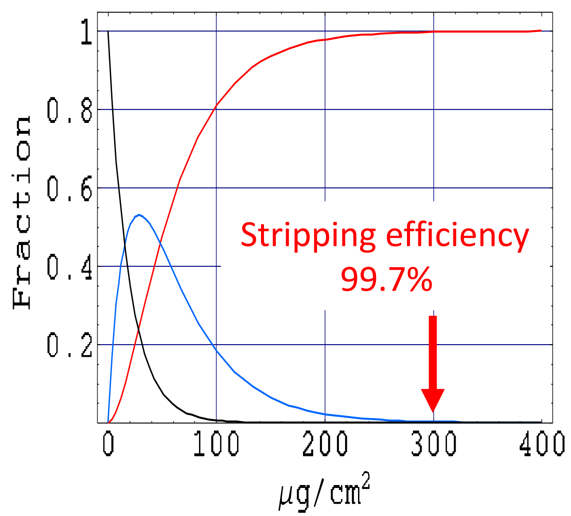
R.C. Weber el. al.
IEEE. Nucl. Sci. NS-26(1979)

E_{inj} = 181 MeV



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

E_{inj} = 400 MeV

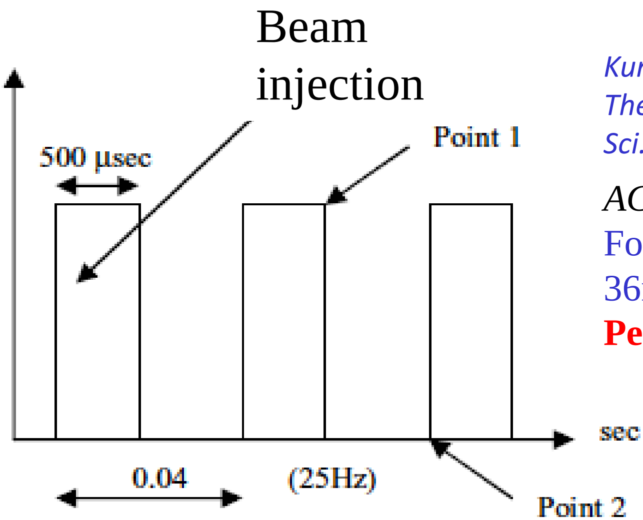


Thicker foil → increases stripping efficiency
but it increases foil scattering beam loss too.

Thinner foil → increase the waste beam

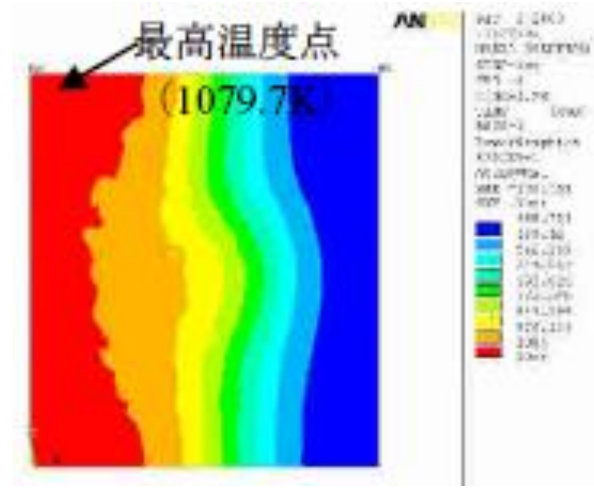
- Needs larger dump → require space and money
- H0 excited state loss also increases

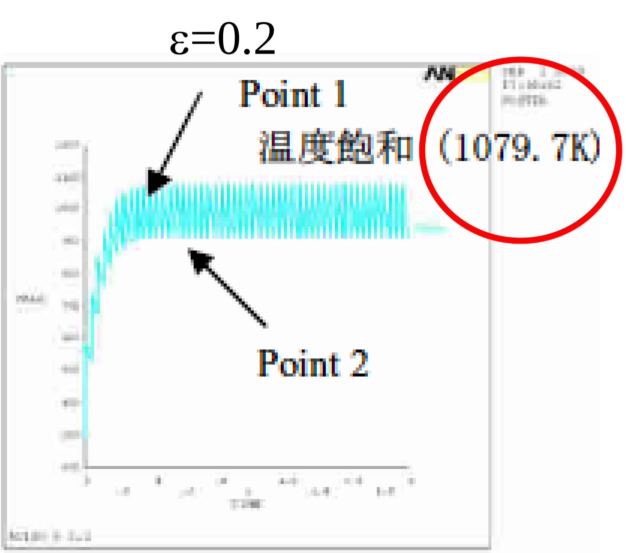
2. Foil temperature at 1 MW operation

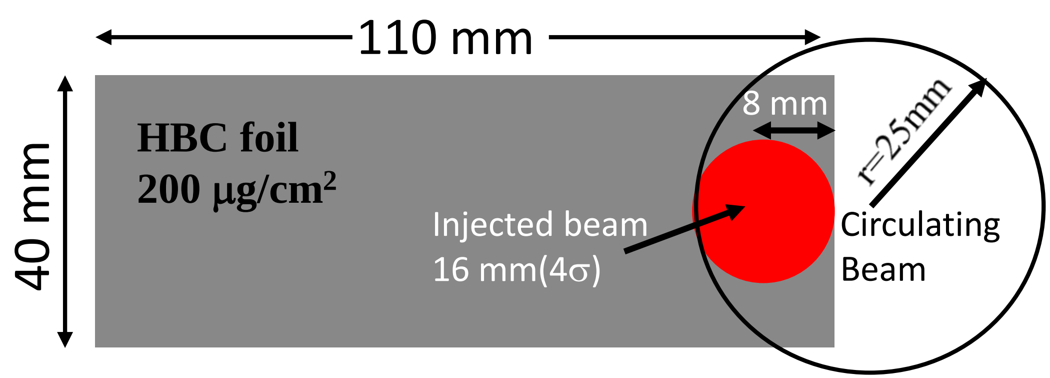


Kuramochi et.al.
The 14th Symposium on Acc.
Sci. and Tech., Tsukuba, Japan 2003

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



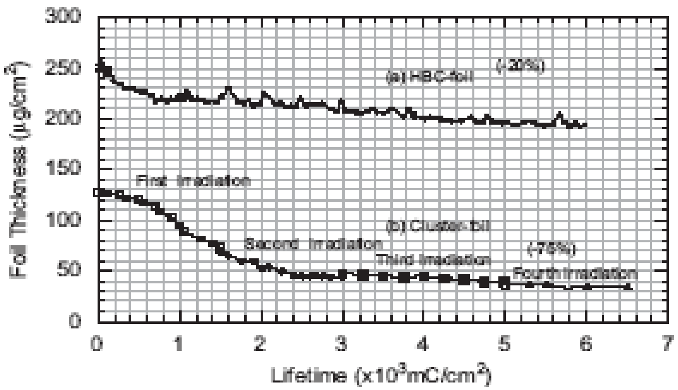




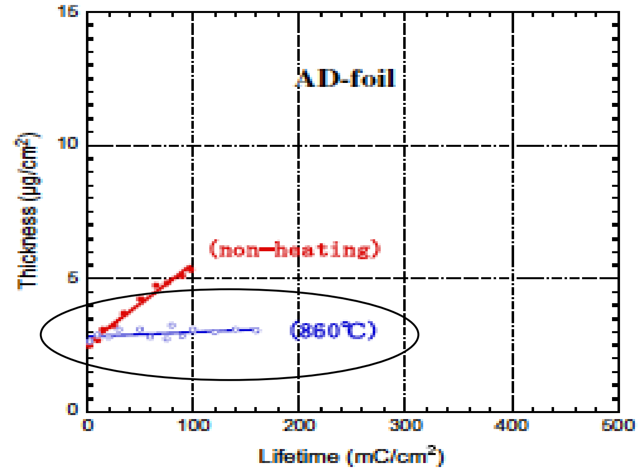
At present for the RCS operation:
Beam power: ~300 kW
Foil: HBC w/ larger dimension:
(100 μg/cm² x 2 foils are sandwiched)
→ Expected peak temperature: ~650K

3. Stripper foil properties: General overview

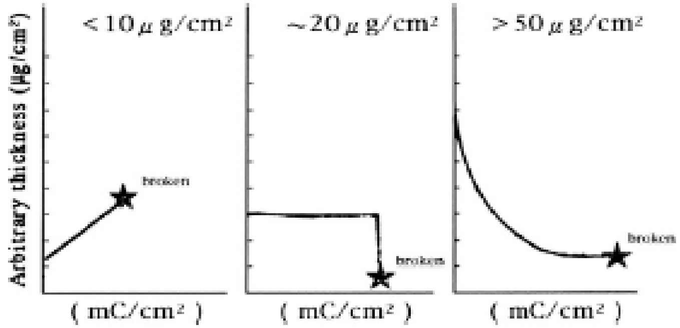
Based on research and development by I. Sugai group in KEK



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



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



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

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.

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

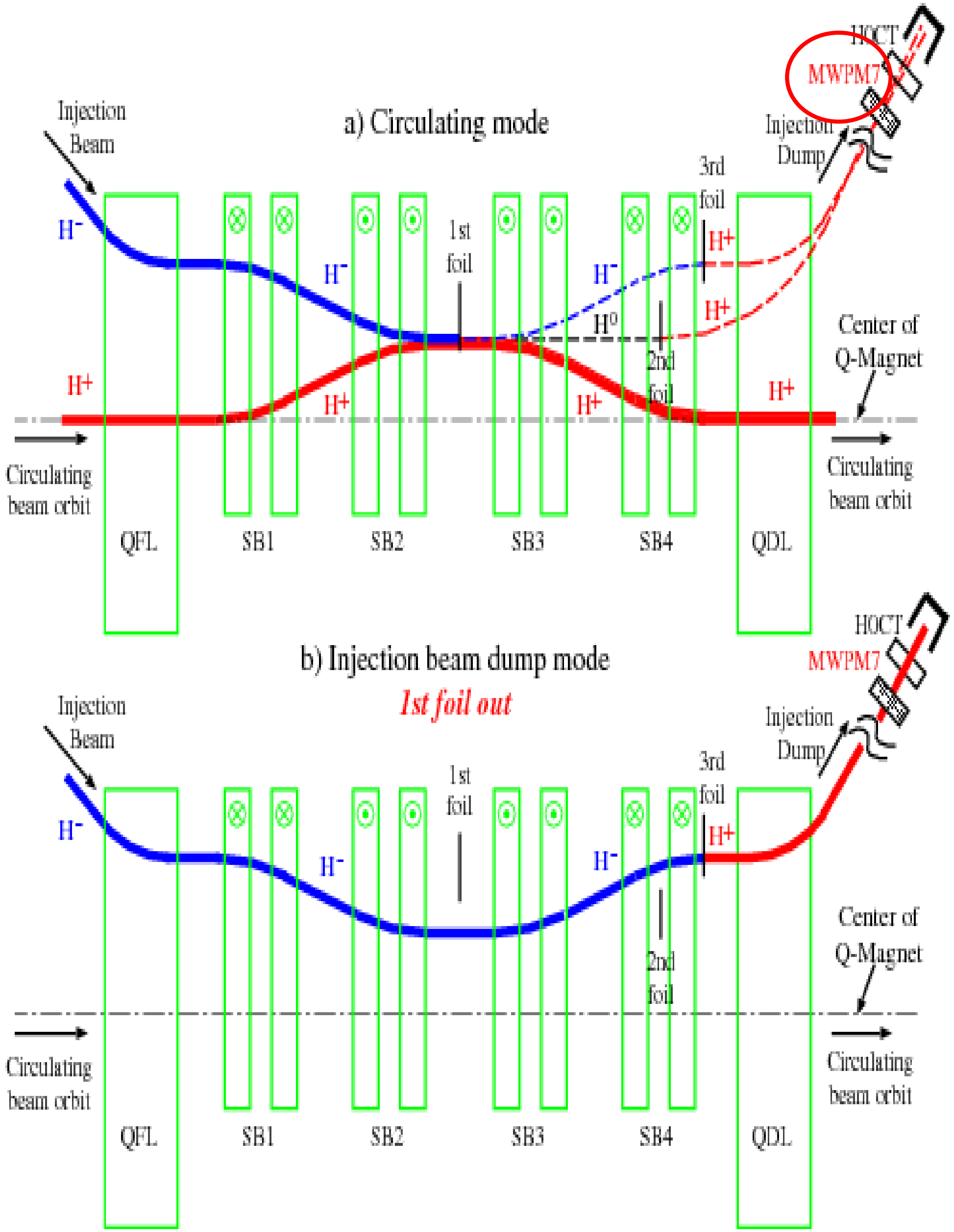
Expected foil temperature: only ~ 650K

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

→ Foil thickening in the beginning?

We can measure!

4. Experimental principle



A multi-wire profile monitor (MWPM7).

Measure H^0 and H^-(if any) waste beams simultaneously.

H^- and H^0 beam position differs by 80 mm!
→ No overlap

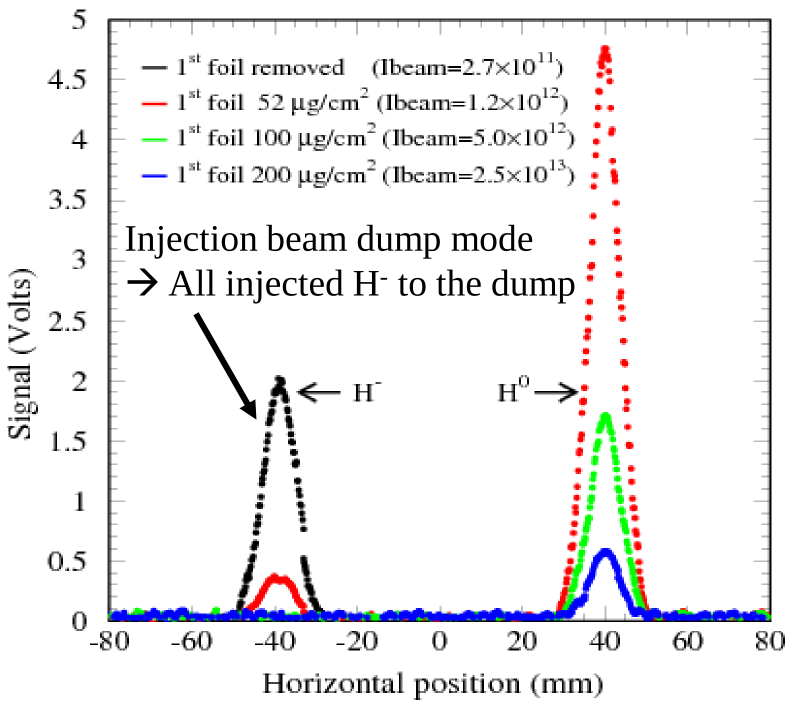
H^0 fraction = H^0 yield (a) /Total yield (b)
H^- fraction = H^- yield (a) /Total yield (b)
Where, a and b denote operation modes.

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

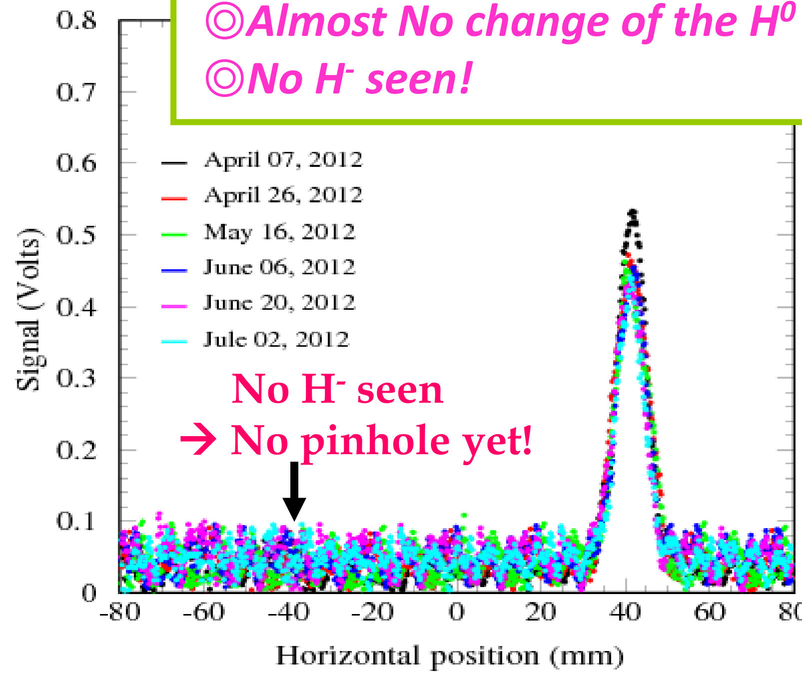
Same monitor → self consistent!

5. Experimental results

4 months operation:
Beam irradiation: 2.7×10^{21}
◎Almost No change of the H^0 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.



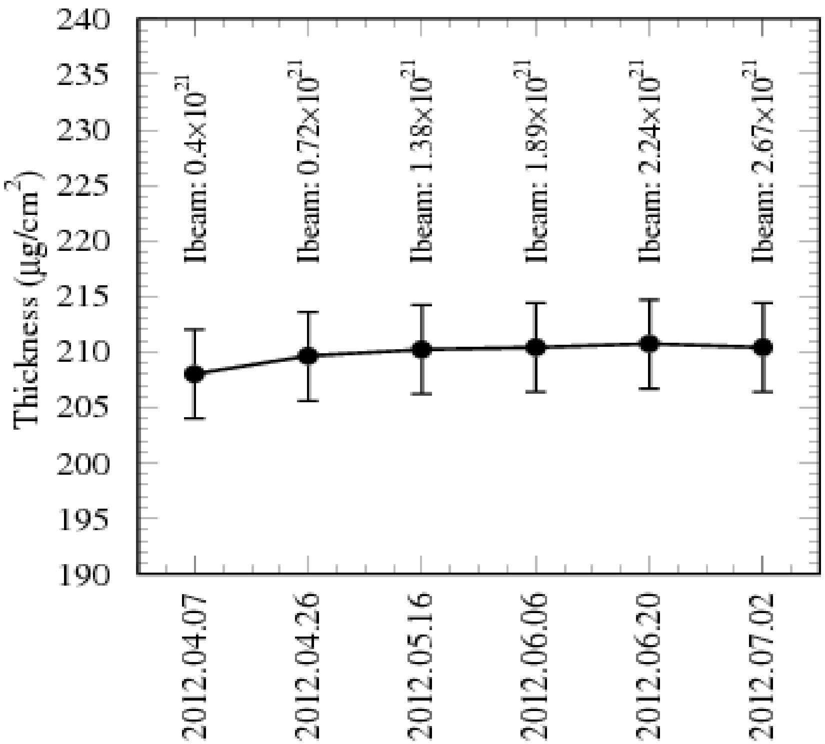
Measurement of the waste beam during RCS operation:

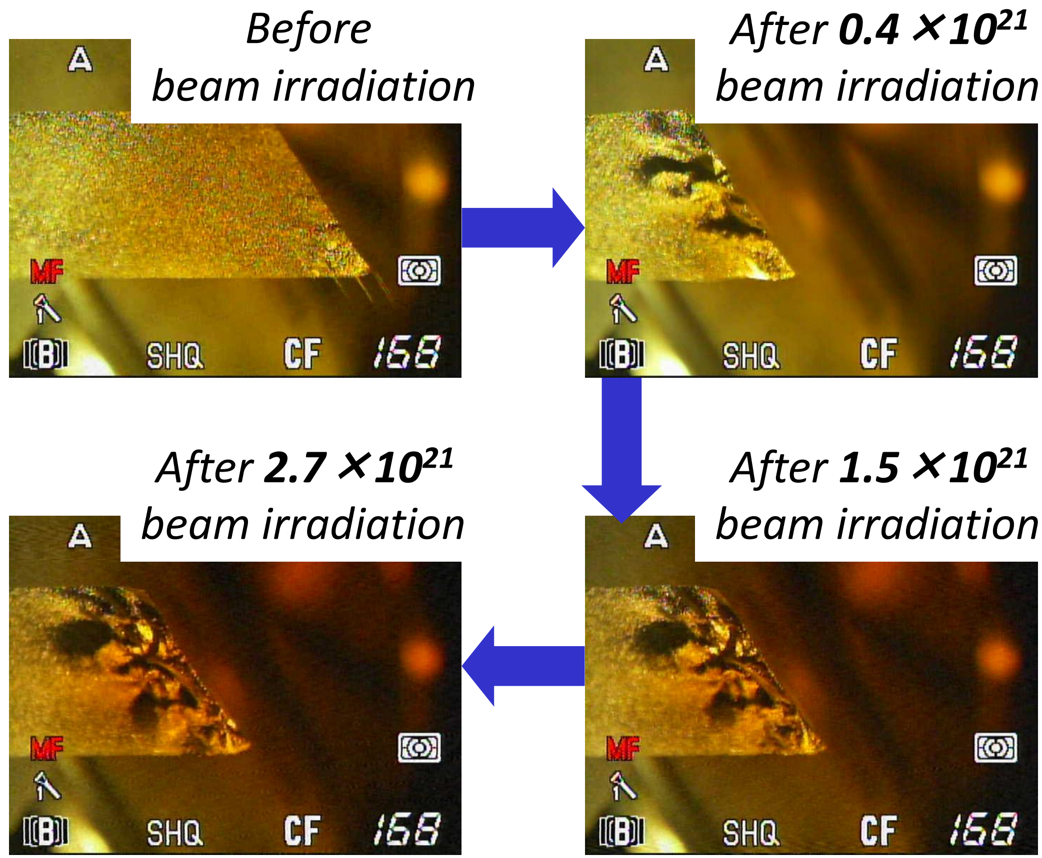
H^0 fraction in the 1st measurement:

0.31 ±0.035% → 208±4 μg/cm²

→ Consistent with expectation !!

5. 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)

→ Needs more data to investigate more precisely.

Foil keep deforming but no degradation yet!

RCS 1st stripper foil magazine

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 uses.
◎Avoid sudden failure related troubles.

6. Summary

We have established a self consistent method to measure the foil degradation so as to determine the real lifetime in a high intensity proton machine like RCS.

An HBC foil of 200 $\mu g/cm^2$ is using for the last 4 months (~2.7×10^{21} injected H^-) with 200 kW operation, but there has no observable foil degradation yet.

An little increase of the thickness in the beginning would be interesting through investigating more precisely.

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