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Advanced uses of a current transformer and a multi-wire profile monitor for online monitoring of the stripper foil degradation in the 3-GeV RCS of J-PARC

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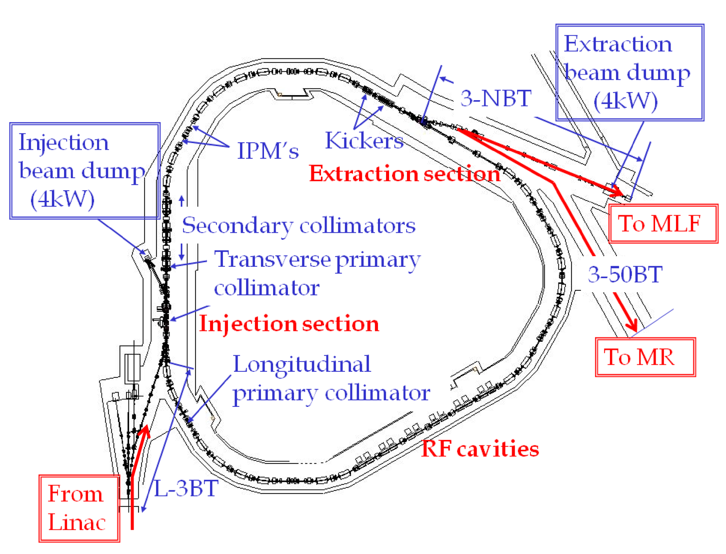
Abstract

We have established an advanced and sophisticated uses of a current transformer and a multi-wire profile monitor for accurate measuring as well as online monitoring of the waste beam so as to know the stripper foil degradation during user operation of the J-PARC 3-GeV RCS. The sensitivity of both monitors are good enough for measuring a change of the foil thickness of 1% or even less. Foil degradation such as, foil thinning and pinhole formation are believed to be the signs of a foil breaking. A sudden foil breaking is not only decreases accelerator availability but also raises maintenance issues. A proper monitoring system of the foil degradation is thus important in order to avoid any such issues by replacing the foil with a new one in the scheduled maintenance day. A foil was used for a continuous last 7 months operation with an extracted beam power of 300 kW (18 kW injected beam). The integrated irradiated particles (only injected H^-) were 8×10^{21} but there was no foil degradation so far. Surprisingly, an increase of the foil thickness of around 10% was observed.

Accelerators at J-PARC facility:

- 400 MeV (181 MeV at present) **LINAC**
- 3-GeV 25 Hz Rapid Cycling Synchrotron (**RCS**)
- 50-GeV (30-GeV at present) Main Ring (**MR**)



Layout of the 3-GeV RCS:
3-foid symmetric lattice
Einj = 400 MeV (181 MeV at present)
Eext= 3 GeV,
Repetition: 25 Hz
Beam power (design): 1 MW (8.33 × 10^{13} ppp)

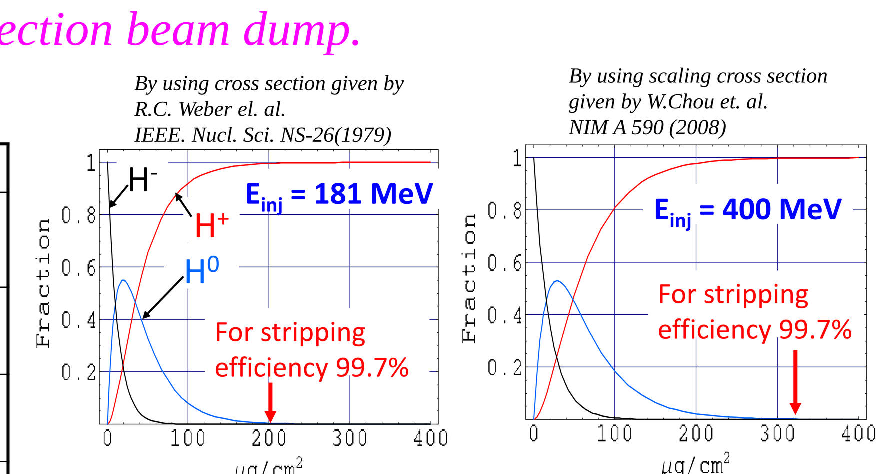
Beam power for user operation at the latest was 300 kW and feasibility of more than 500 kW has also been demonstrated recently.

Introduction

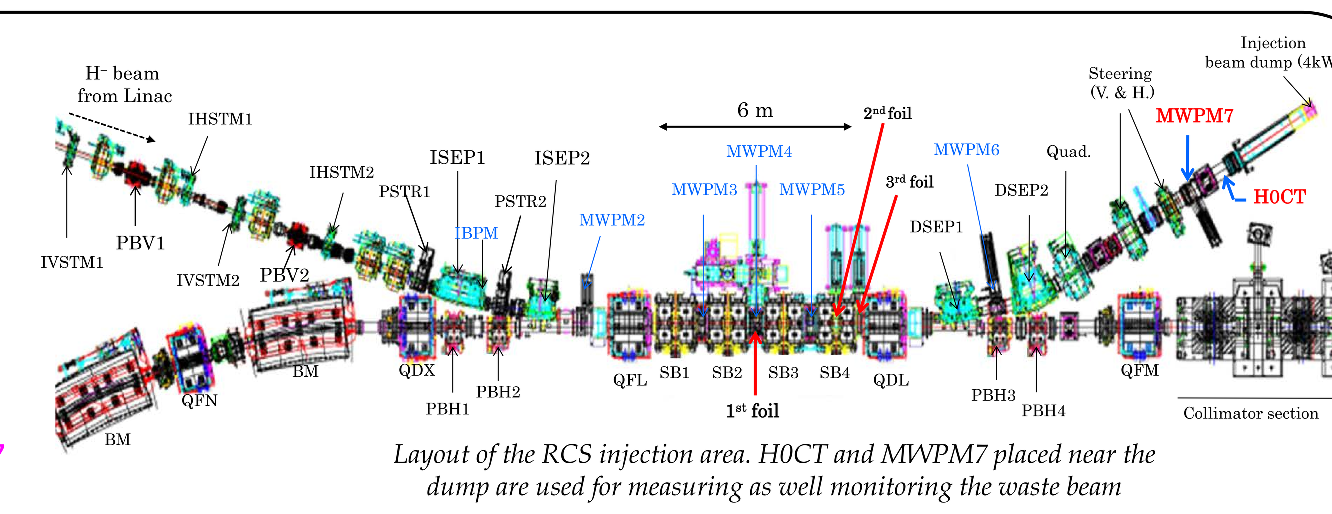
In order to increase circulating beam intensity, multi-turn H^- charge exchange injection is performed. Nearly 99.7% of the H^- beam is stripped to proton beam by using an HBC (*Hybrid type Boron doped Carbon*) stripper foil placed in the middle of chicane bump magnets.
Remaining 0.3% is called waste beam and mainly it is partially stripped H^0, where un-stripped H^- is ideally negligible.
The H^0 and un-stripped H^- (if any) are stripped to H^+ and transported to the injection beam dump.

Foil related parameter list

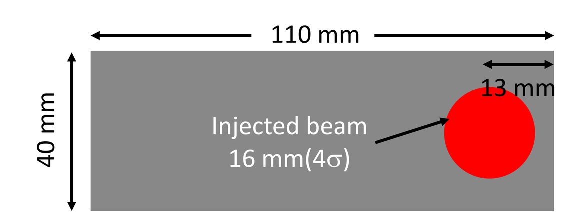
Energy (MeV)	400	181
Foil thickness ($\mu g/cm^2$)	330	200
Stripping efficiency (%)	99.7	99.7
Waste beam fraction (%)	0.3	0.3
Inj. beam power (kW)	133	36
Waste beam power (kW)	0.4	0.11
Dump limit (kW)	4	4



Thicker foil: → stripping efficiency increased.
But foil scattering beam loss also increases.
(Avg. foil hit by circulating beam is 20!)
Thinner foil: → waste beam increased.
Needs larger capacity dump
→ required space and money



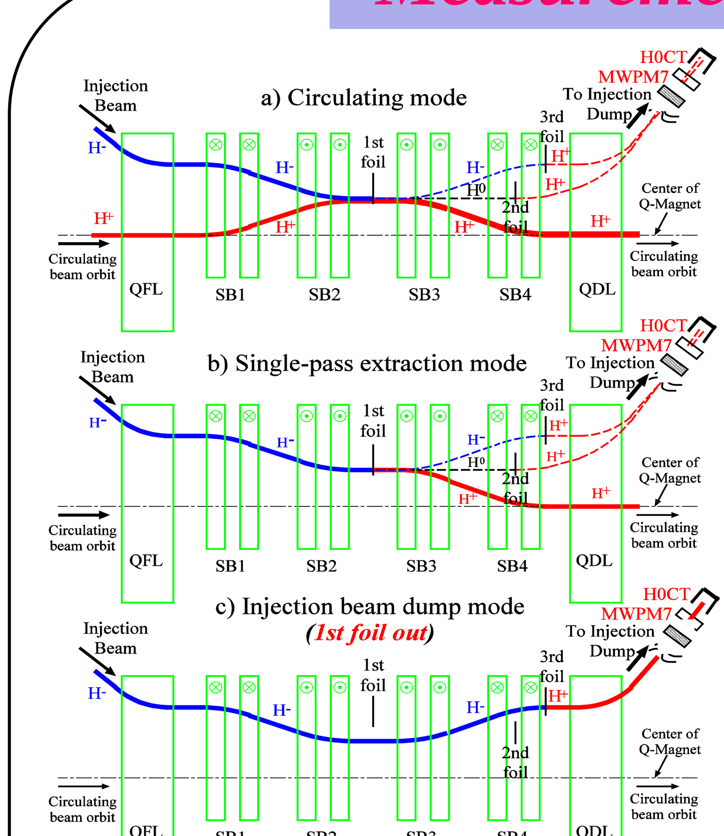
Layout of the RCS injection area. H0CT and MWPM7 placed near the dump are used for measuring as well monitoring the waste beam



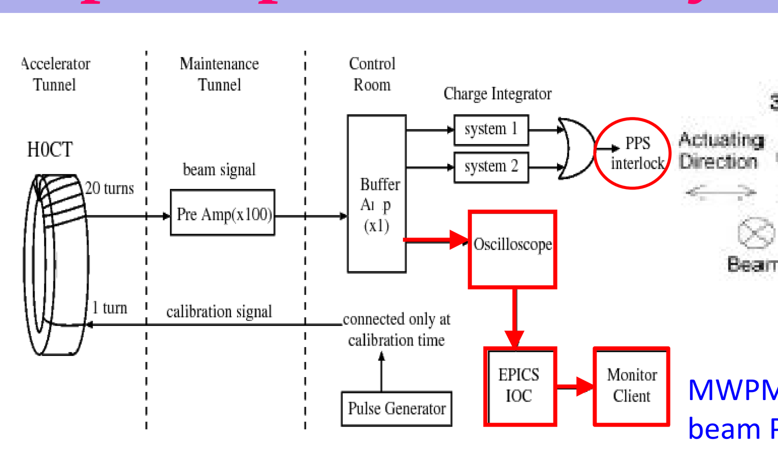
A typical dimension the primary stripper foil used mainly for the beam studies as well as measuring stripping efficiencies for different thicknesses.

Stripper foil lifetime is one big concern in RCS for 1 MW operation. Foil peak temperature at 1 MW operation is estimated to be more than 1100K (at present for 300 kW: ~600K)
A complete breaking is not always a lifetime as foil degradation such as foil thinning and pinhole formation would increase the waste beam so as the heat load on the dump.
A little degradation is even crucial as dump capacity is only 4 kW.
A proper monitoring system of the waste beam is very important. It can also provide useful information for understanding the foil breaking mechanism.

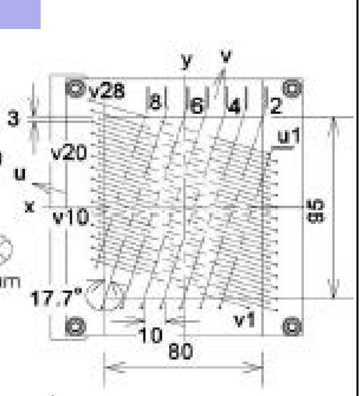
Measurement principle and Validity



RCS Operation/study modes

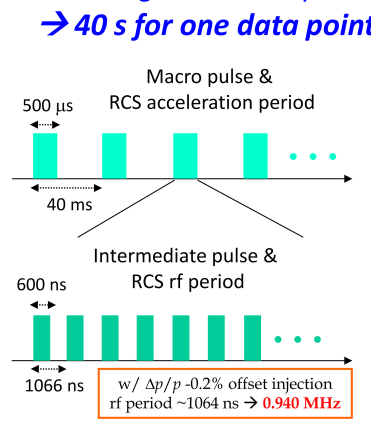


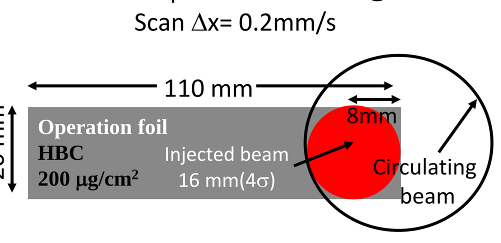
H0CT is current transformer originally used as a PPS interlock system.
For online monitoring of the waste beam, we fed buffered signal to an oscilloscope and is controlled by an OPI.
1024 avg. @ 25 Hz opr.
→ 40 s for one data point



MWPM7 is a scan type beam Profile monitor used only during beam studies

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



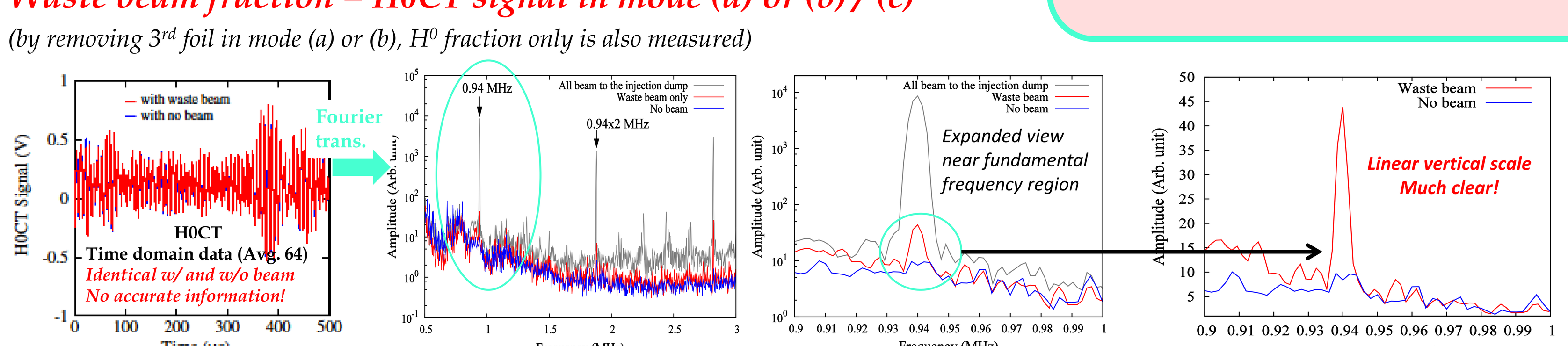


- **An increase of the H^0 fraction**
  → ***Foil thickness reduction.***
- **An increase of the H^- fraction**
  → ***Pinhole formation.***

H0CT P.K, Saha et. al., PRST –AB 14 (2011) 072801

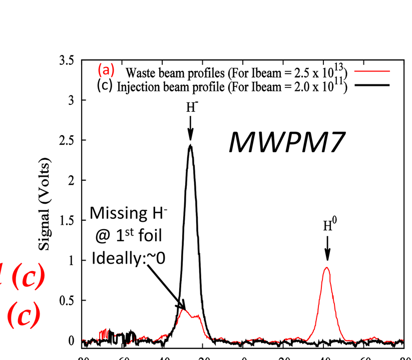
Fourier transform of the time domain data and picking up amplitude of the power spectrum corresponding to the frequency of the intermediate pulses.

Waste beam fraction = H0CT signal in mode (a) or (b) / (c)
(by removing 3rd foil in mode (a) or (b), H^0 fraction only is also measured)



MWPM7

Measure H^0 and H^- waste beam simultaneously.
No overlap (profile center separated by 70 mm)
Analysis is done based on integrated yield for each corresponding profile
H^0 fraction = H^0 yield in mode (a) or (b) / total yield (c)
H^- fraction = H^- yield in mode (a) or (b) / total yield (c)
H^+ fraction = 1 – (H^0 + H^-)

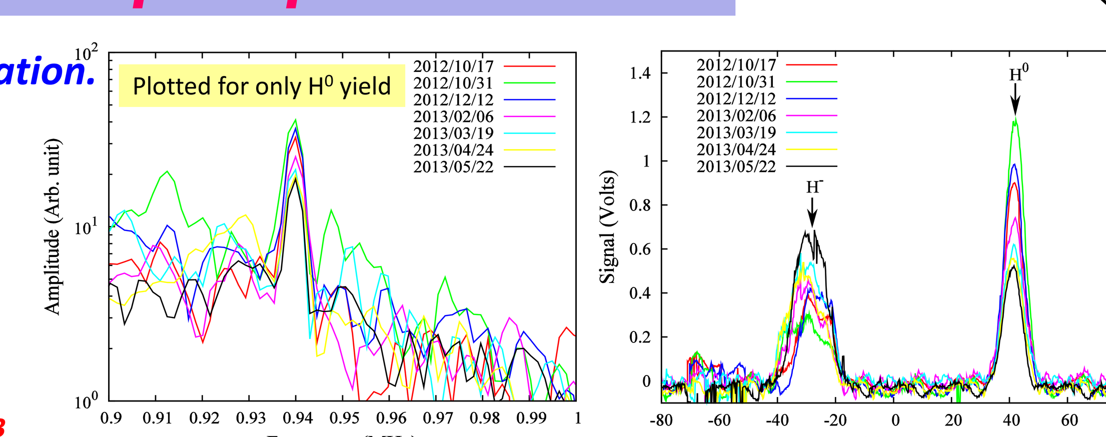


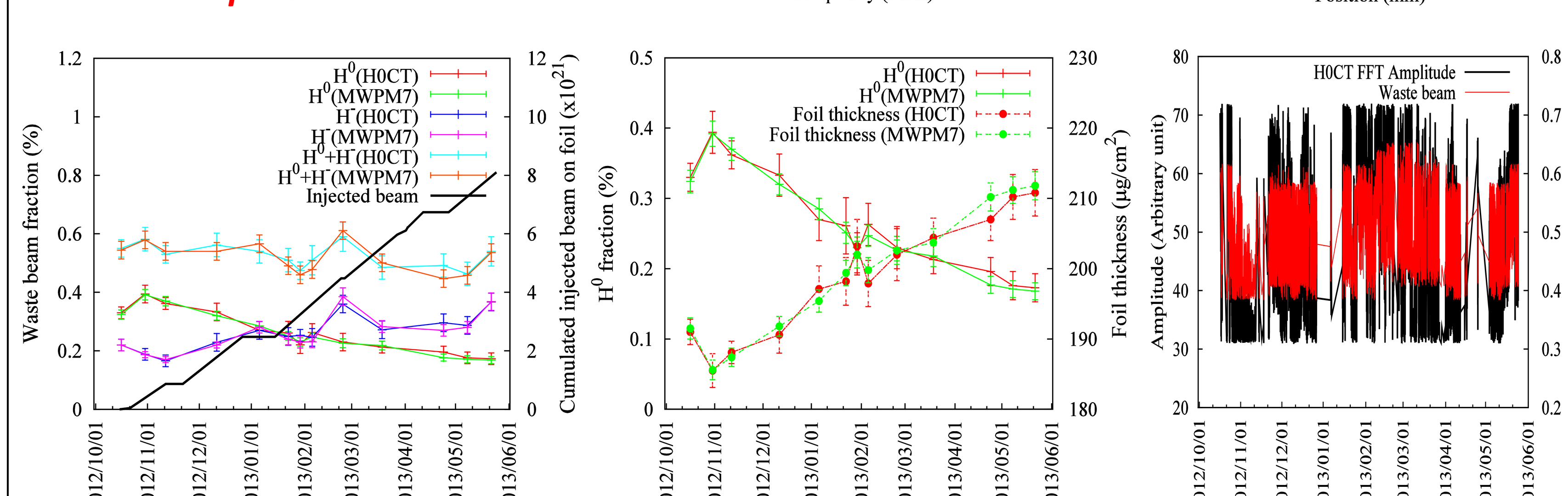
H^0 fraction:
H0CT: 0.33 ± 0.02%
MWPM7: 0.32 ± 0.01%

Foil thickness
(by using 181 MeV scaling cross section of 200 MeV data)
H0CT: 191 ± 1.8 $\mu g/cm^2$
MWPM7: 192 ± 1.5 $\mu g/cm^2$

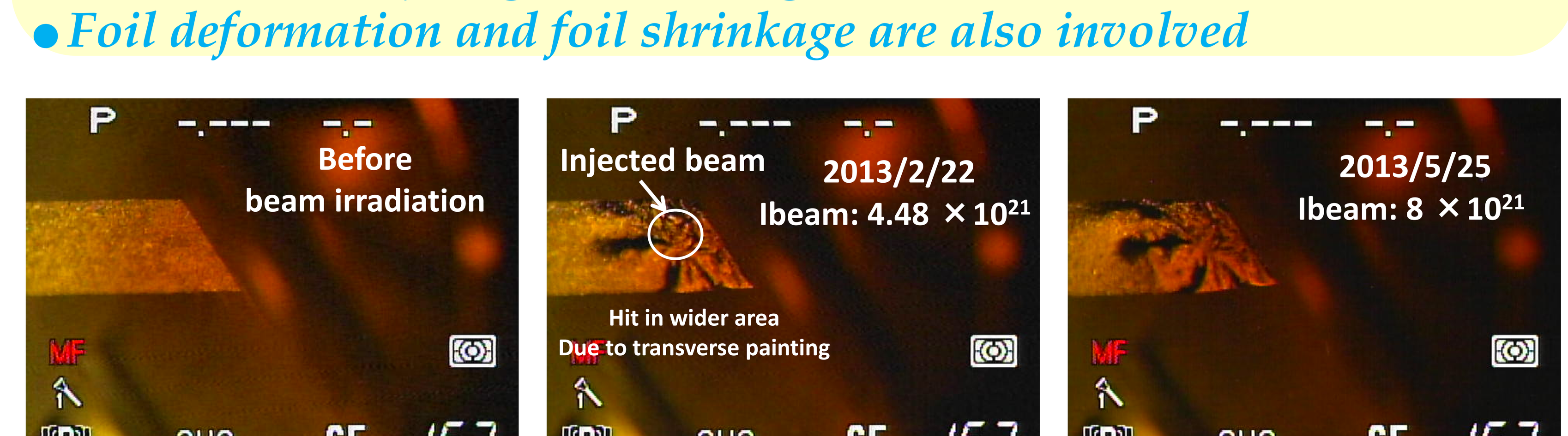
Online trend of the foil thickness

For a continious 7 months operation.
Extracted beam power: 300 kW
(injected beam power: 18 kW)
2.5×10^{13} ppp
Total integrated inj. particles,
(Ibeam) : 8×10^{21}
Avg. foil hit of circulating beam: ~20;
→ Total hit particles: 1.6 × 10^{23}





In addition to the H0CT data taken online, waste beam was in detail measured almost every maintenance day
Clear reduction of the H^0 yield obtained by both H0CT and MWPM7
Foil thickness increased by 10%! 191 $\mu g/cm^2$ → 210 $\mu g/cm^2$
- ***Carbon build-up might be one big reason*** *(foil temperature:~600K at present)*
- ***Foil deformation and foil shrinkage are also involved***



Summary

An accurate measurement of even a small fraction of the waste beam has been successfully done. Online monitoring of the waste beam and recognizing any change of the foil thickness during RCS operation has also been demonstrated. An HBC foil used for a continuous 7 months operation did not show any foil degradation but a linear increase of the thickness as much as 10% from it's initial value has been measured. More repeated and further longer time range experimental data might be necessary for detail explaining the present data.