Development of the Beam Diagnostics for the IFMIF Accelerator

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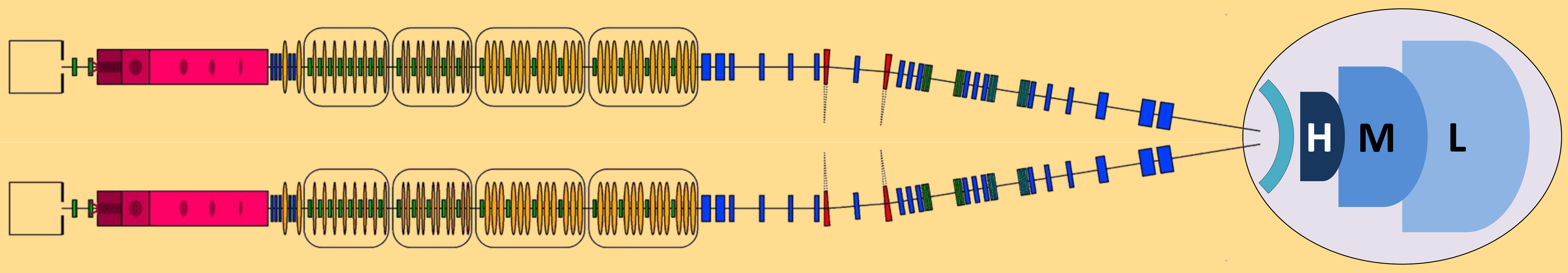
What is IFMIF ?

In times of diminishing fossil fuels, the development of alternative energy sources can be considered as one of the most relevant and urgent topics in research. A promising candidate to bear the brunt of future's energy requirements is fusion. The tremendous neutron flux generated in the fusion core, however, raises unprecedented demands on radiation hard materials which have to be overcome prior to the reactor design.

For this purpose, the *International Fusion Material Irradiation Facility (IFMIF)* will test materials on their radiation hardness. The IFMIF accelerator will thereby serve as high intensity neutron source. It will consist of two separate accelerators that each accelerates a 125 mA *continuous wave (cw)* deuteron beam up to 40 MeV, which corresponds to a total beam power of 10 MW. When the beams are directed on a lithium loop target, it will trigger nuclear reactions generating neutrons that can be used to irradiate test materials.

The development of beam diagnostics for IFMIF, including beam profile monitors, beam loss monitors, micro loss detectors, and ACCTs and DCCTs is subject of the thesis presented in this contribution.

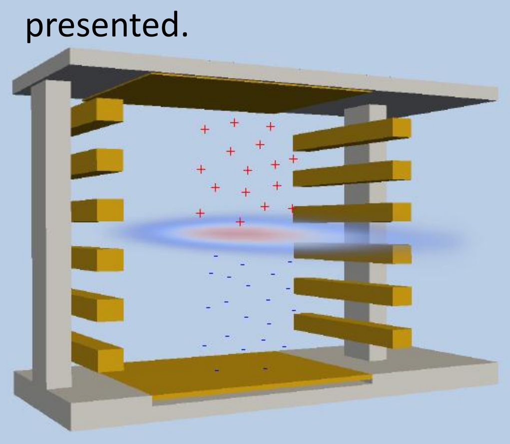


Ionization Beam Profile Monitor

Introduction

When the beam passes through the beam pipe, it will partly ionize the residual gas which is present in any kind of accelerator. Inside the *Ionization beam Profile Monitor (IPM)*, an electric field is applied which is directed perpendicularly to the beam. The ionization products are accelerated by the electric field and drift towards strips where they deposit their charge as illustrated below. By reading the strip current one can reconstruct the actual beam profile.

The latest prototype of the *IPM* was designed based on *Finite element Method (FEM)* simulations to achieve a good electric field homogeneity in the field box. It was tested in two campaigns at GSI in May and November 2010 and at CEA Saclay in December 2010. The results of these tests are presented.



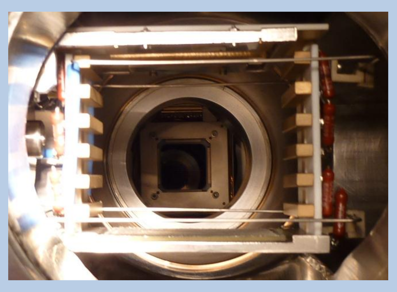
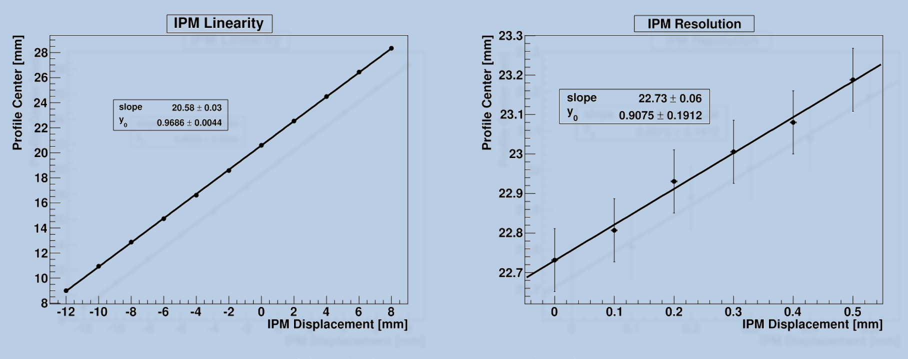


Photo of the IPM

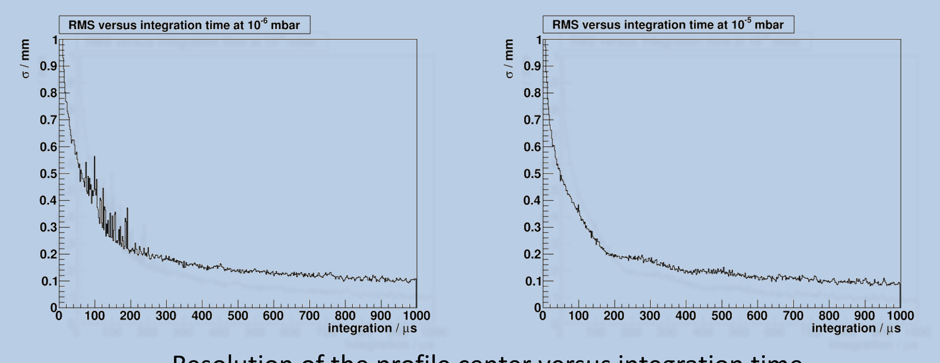
Electric Field Homogeneity

In case of electric field inhomogeneities, acquired profiles will be distorted as the ionization current will be deformed by the horizontal field components. To check the field homogeneity the IPM was moved perpendicularly to the beam and the profile center was plotted versus the IPM displacement, given below.



Profile shift versus IPM displacement

A linear fit was performed indicating a slope of 0.969 ± 0.004 which is in good agreement with the expected unitary slope. The same way, the position resolution for the profile center can be estimated. It can be concluded that the IPM can well resolve beam shifts down to 100 µm.

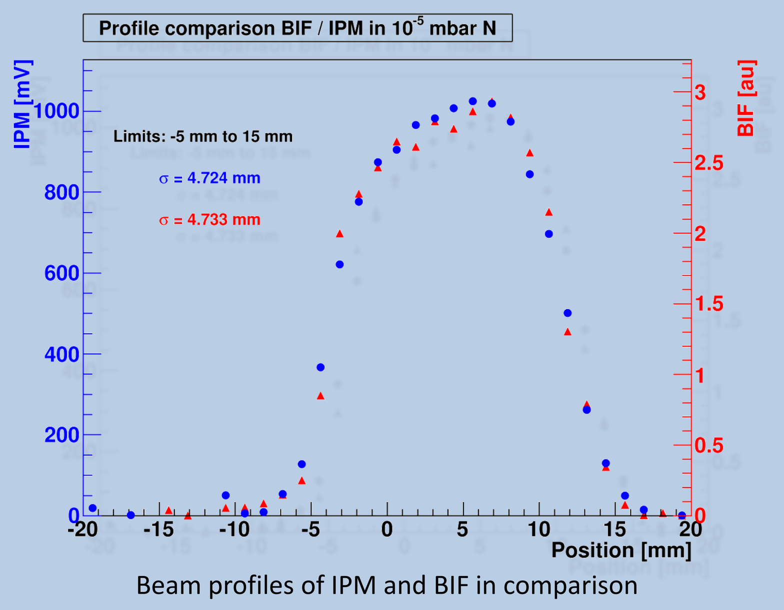


Resolution of the profile center versus integration time

A given data set of profile measurements of 2 µs duration was used to determine the time dependency of the spatial resolution. At first, the center of the beam profile was calculated for each reading and their standard deviation was calculated. Then, the number of readings was successively increased to simulate longer integration times. Above, the derived standard deviations of the profile center are given at 10^{-6} and 10^{-5} mbar residual gas pressure. A plateau of about 100 µm is reached after a few hundred µs depending of the residual gas pressure which is in good agreement with the previous claim to be able resolve beam shifts down to 100 µm.

BIF Comparison

Despite the good resolution of the profile center achieved, there are mechanisms that lead to profile distortions without effecting the beam position, e.g. beam space charge or intrinsic particle velocities. To account for such effects, the IPM has been compared with a *Beam Induced Fluorescence (BIF)* Monitor from GSI. Profiles have been taken for different residual gases at various pressures and extraction voltages. As example, the profiles from IPM and BIF in nitrogen gas at 10^{-5} mbar are given below.

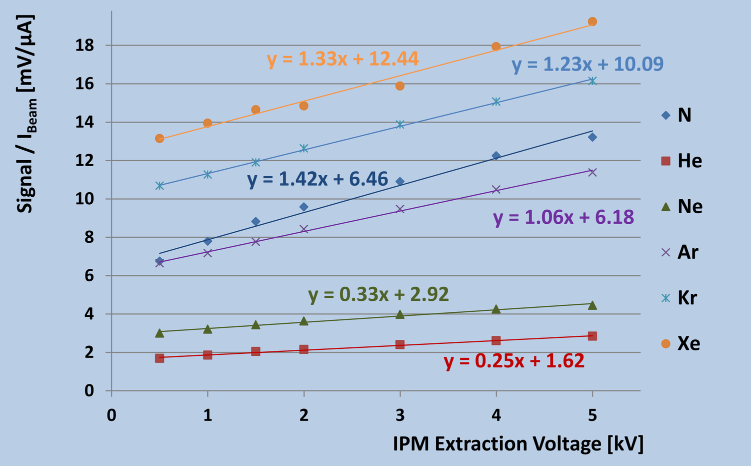


Beam profiles of IPM and BIF in comparison

The profile shape matches nicely for all residual gases and the calculated standard deviations in the beam region match better than 5 %.

Signal Amplification Effect

The IPM output signal rises linearly with the applied extraction voltage. It was seen that the slope depends on the residual gas pressure type. It was therefore assumed that ions release secondary electrons from the strip surface which increases the effective signal with higher ion energies.



IPM output signal versus extraction voltage

The integral profile signal for various extraction voltage has been calculated and is plotted above. A linear fit has been performed to determine the secondary electron yield. For a better comparison with literature values, the electron yield was normalized and preliminary results are given in the table below.

	Magnuson	Carlston	Zalm	Baragiola	IPM
He	---	---	---	1.47	1.48
Ne	1.14	0.97	1.13	---	1.05
Ar	0.95	1.06	0.94	1.06	1.16
Kr	0.91	0.97	0.94	0.94	0.79
Xe	0.64	0.64	0.61	---	0.61

Scaled secondary electron yields compared with literature data [1,2,3,4,5]

The ratio of the secondary electron yields of the different gases are in good agreement with literature values.

1. **Zalm, P.C. and Beckers, L.J.** *"Ion-induced secondary electron emission from copper and zinc"*, 1985, Journal of Surface Science, Vol. 152, pp. 135-141
2. **Magnuson, et al.** *"Electron ejection from metals due to 1- to 10-keV noble gas ion bombardment. I. Polycrystalline Materials"*, 1963, Physical Review, Vol. 129, pp. 2403-2409
3. **Carlston, et al.** *"Electron ejection form single crystals due to 1- to 10-keV noble gas ion bombardment"*, 1965, Physical Review, Vol. 139, pp. A729-A736
4. **Baragiola, et al.** *"Electron emission from clean metal surfaces induced by low-energy light ions"*, 1979, Physical Review B, Vol. 19, pp. 121-129
5. **Baragiola, et al.** *"Ion-induced electron emission from clean metals"*, 1979, Journal of Surface Science, Vol. 90, pp. 240-255

Beam Loss Monitor

Ionization Chambers

It is planned to use *Ionization Chambers (IC)* similar to the ones used at the *LHC (Large Hadron Collider)* as beam loss monitors. A photo of such an IC during without casing is given below.

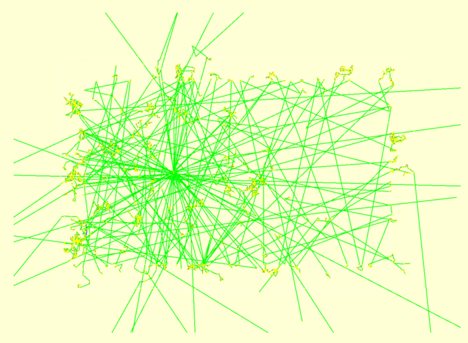
As the ICs will be mounted outside the beam pipe, they have to be calibrated on neutrons and γ as these are the only particles able to escape the beam pipe.

A calibration for γ of 1.25 MeV was performed at *CoCase (Cobalt Casemate)* at CEA Saclay. The neutron response of the detector has been tested by accelerator generated neutrons of 3 MeV and 14.7 MeV at CEA Valduc. Both measurements are in good agreement with CERN simulations.

Photo of an LHC IC without casing

Due to the high sensitivity requirements of the beam loss monitors it is desirable to somehow increase the IC sensitivity. Geant4 simulations are currently in progress to evaluate options to increase the IC sensitivity in the neutron and γ range expected at IFMIF.

Measurement at CoCase

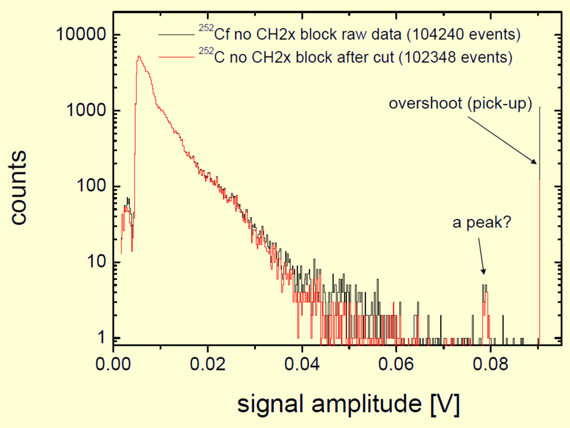


Geant4 simulation of CEA Valduc Vault

CVD Diamond Detectors

For hands-on maintenance requirements, losses must be well less than 1 W/m, i.e. 10^{-6} of the beam power. To tune the accelerator accordingly, even lowest losses, so-called µ-losses, have to be measured on the level of the sc-linac.

For this aim, it is foreseen to place *Chemical Vapour deposition (CVD)* diamond detectors inside the cryostat to detect even lowest losses. First tests with a ^{252}Cf source indicate that diamond detectors can operate at cryogenic temperatures.



Diamond output signal from a ^{252}Cf source

Michal Pomorski, CEA Saclay

However, due to a contamination with decay products, the ^{252}Cf source cannot be used to calibrate the detector on neutrons. Additional calibrations on their neutron response will be performed at an accelerator driven neutron source.

Conclusion

The beam profile monitor has been tested in detail at GSI for low and intermediate beam currents in pulsed mode and for high currents in cw mode at CEA Saclay. Tests indicate a very good electric field homogeneity which results in a high position resolution for the beam center. Since we had to renounce a magnetic field guidance due to the lack of space available, the successful comparison with the BIF monitor was of utmost importance to prove the reliability of the profiler. Measurements in different residual gases have finally supported the theory of secondary an electron emission from the read-out strips.

For the beam loss monitoring, two detectors are foreseen, LHC ICs and diamond detectors inside the cryostat. Calibrations for neutrons and γ are performed or ongoing.

Acknowledgement

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