Modification of a Classical Penning Ion Source Operating Mode for Sub-Femtoampere Beams at the U-120M Cyclotron

Tomas Matlocha
Nuclear Physics Institute of the CAS, v. v. i. Řež 130, 250 68 Řež, Czech Republic
Czech Technical University in Prague, FNSPE, Břehová 7, 115 19 Praha 1, Czech Republic

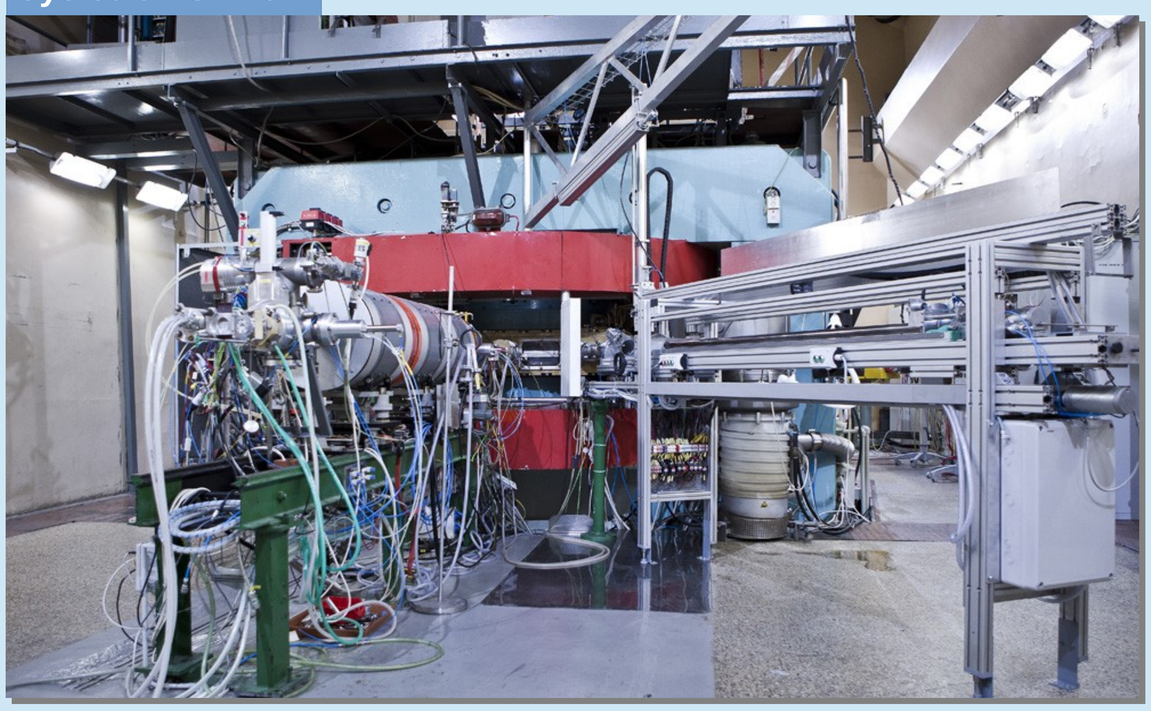
Cyclotron U-120M

The irradiation facility in Rez near Prague is equipped with a four-sector isochronous cyclotron U-120M [1] which allows to accelerate ions with mass to charge ratio up to m/Q=2 up to energies 10 MeV per nucleon. The cyclotron was commissioned in 1977 and is continuously upgraded. The Ion Source (IS) of the cyclotron is an internal Penning type with usual lifetime ~250 beam hours for hydrogen operation, ~60 beam hours for ^{4}He. The maximal recorded lifetime is 700 beam hours.

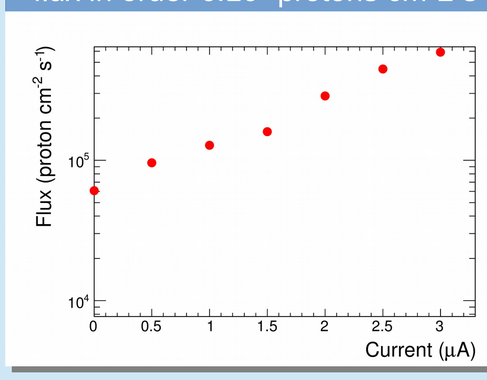
Motivation

Experiments related to radiation hardness tests for newly developed semiconductor detectors need proton fluxes of very low intensities 10^2 –10^9 protons s^{-1} cm^{-2}.
By a cooperation on radiation tests of electronic components for the upgrade of the Inner Tracking System of the ALICE experiment in CERN [2], very efficient method for lowering the beam intensity was developed.

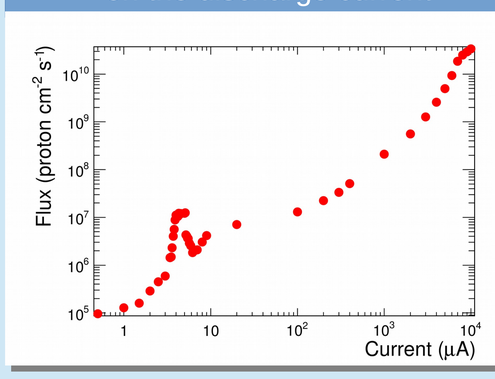
Cyclotron U-120M



Detail for zero IS current - flux in order 6.10^4 protons cm-2 s-1



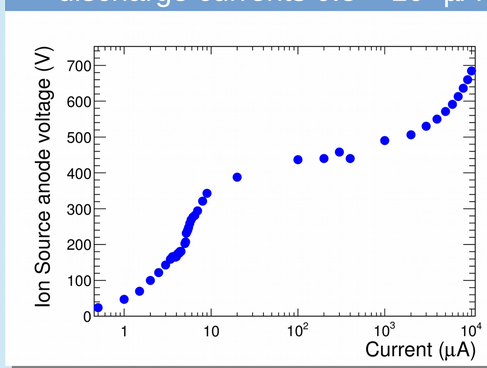
Dependence of the output flux on the discharge current



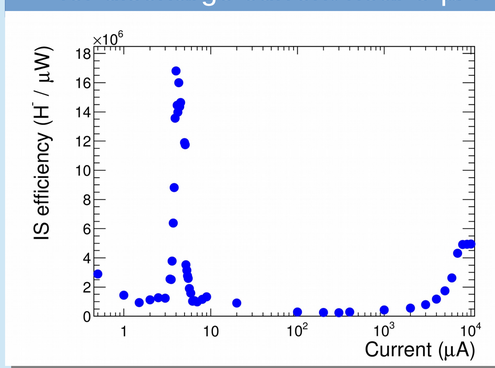
Observations

- Ultra low beam intensities achievable by a combination of IS discharge current regulation with a shift of the IS with respect to the extraction slit on the dee
- No practical limit for the lowest IS discharge current
- Almost linear operation of the IS due a primary ionization effect in central region of the cyclotron
- Effect of the cathodes lifetime reduction due to hydrogen diffusion
- Interesting resonance in negative Hydrogen production yield near ~ 5μA of the discharge current
- Continuous intensity regulation in the range 10^{-1} – 10^{15} protons s^{-1} cm^{-2}
- For intensities above 10^3 protons s^{-1} cm^{-2} the long-term stability is better than 10%

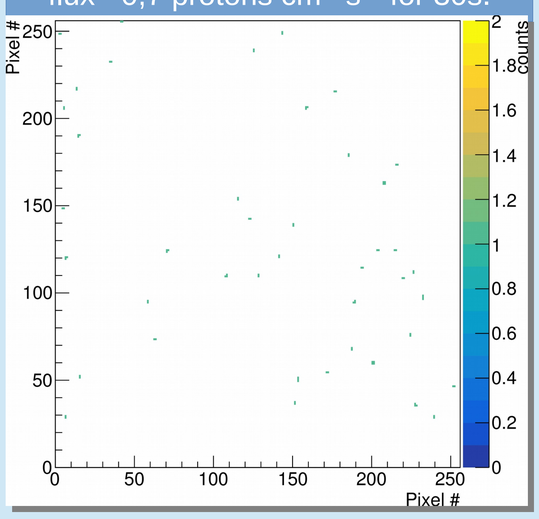
Ion Source IV curve for discharge currents 0.5 – 10^4 μA



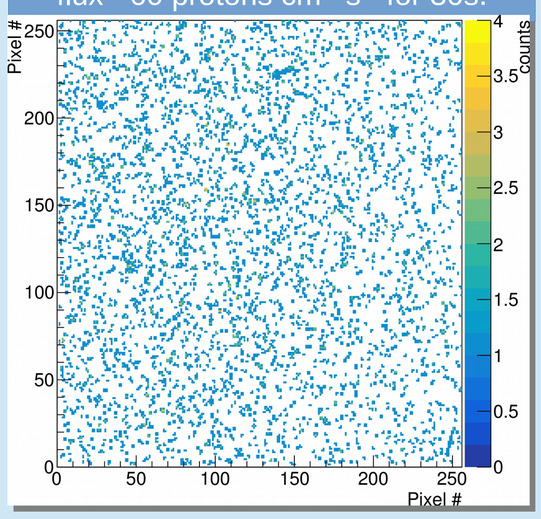
Efficiency peak in H- production for discharge current near 5 μA



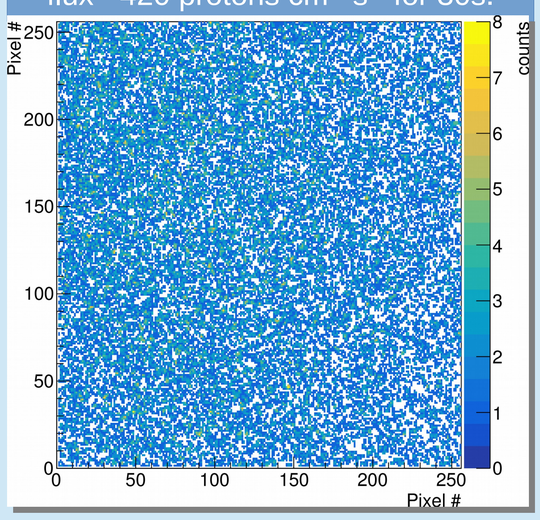
Ion Source OFF
flux ~0,7 protons cm-2 s-1 for 30s.



IS discharge current 60 μA
flux ~60 protons cm-2 s-1 for 30s.



IS discharge current 200 μA
flux ~420 protons cm-2 s-1 for 30s.



Measurement setup

Beam flux monitoring & regulation

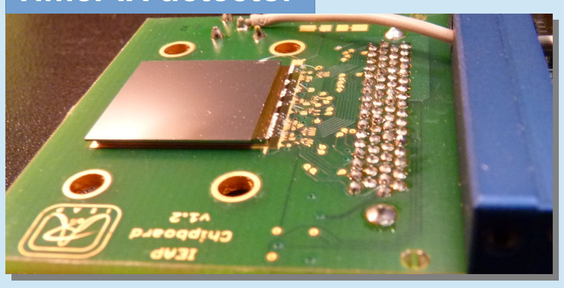
The low intensity proton beam current is monitored [3] with an ionization chamber Farmer 30010 from PTW-Freiburg [4] connected to a UNIDOS E Universal Dosemeter. Fluxes below 10^3 protons s^{-1} cm^{-2} are monitored with a Timepix device [5].

Main beam intensity regulation techniques at U-120M:
- lowering the arc current in the ion source
- reducing the duty cycle
- shifting the horizontal position of the ion source with respect to the extraction slit
- increasing the gas pressure in the IS and worsening the accelerator vacuum
- collimating extracted beam on a vertical input slit of the beamline

Ion types and intensities at U-120M	H^- / H^+	D^- / D^+	$^4He^{2+}$ / $^3He^{2+}$
Intensity of internal beam [μA]	– / 200	– / 100	40 / 20
Intensity of external beam [μA]	50 / 5	35 / 5	5 / 2
Energy [MeV]	6 – 37	11 – 20	4 – 40 / 3 – 55

Cathodes after ~80 beam hours

TimePIX detector



References

1)Center of Accelerators and Nuclear Analytical Methods, Nuclear Physics Institute of the CAS http://canam.ujf.cas.cz/.
2)B. Abelev (The ALICE Collaboration) , Upgrade of the ALICE Experiment: Letter Of Intent, J. Phys. G: Nucl. Part. Phys. 41, 087001, 2014.
3)F. Krizek et al. , Cyclotron based irradiation setup for ALICE inner silicon tracker upgrade – Preprint, Nuclear Inst. and Methods in Physics Research, A, NIMA-D-17-00930, 2017.
4)PTW Freiburg, Germany: http://www.ptw.de/.
5)X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos, W. Wong , Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements, Nucl. Instrum. Methods Phys. Res. A 581 (2007) 485.