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

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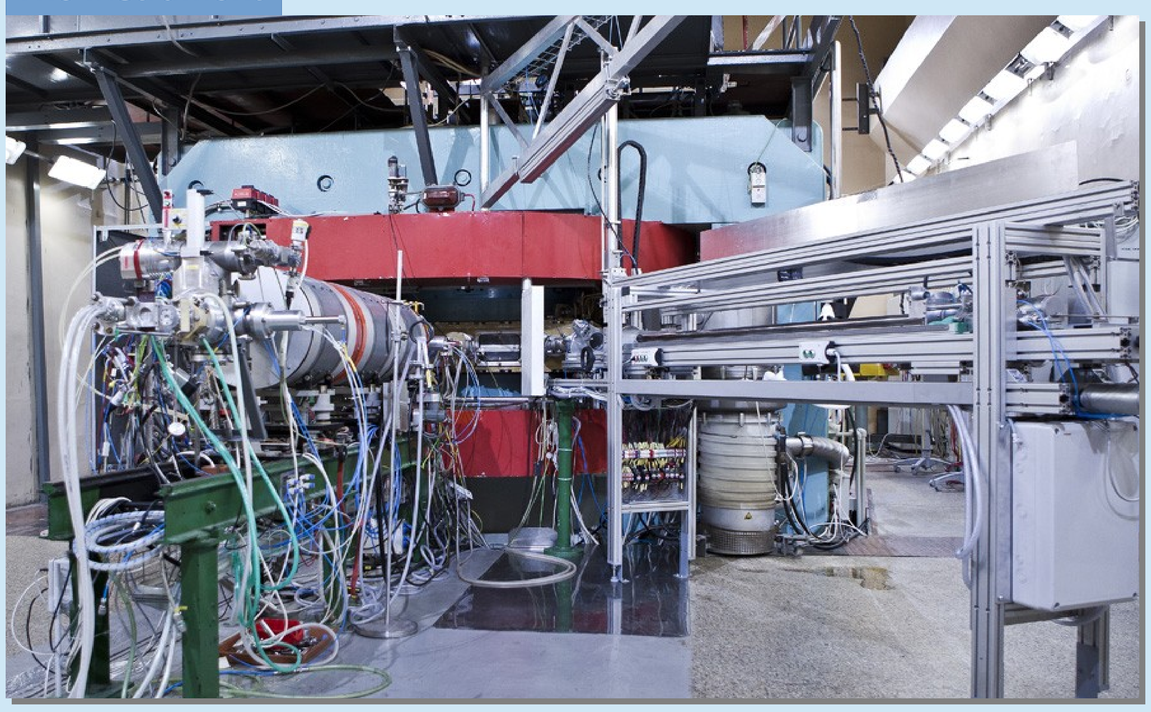
Cyclotron U-120M

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.

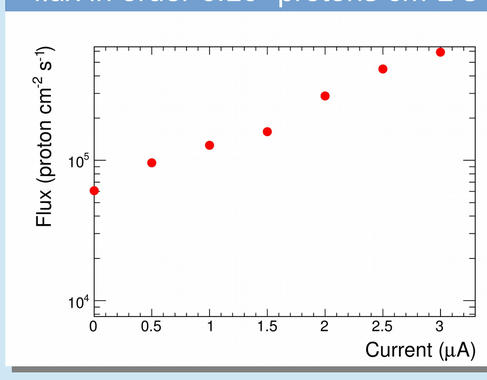
Motivation

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.

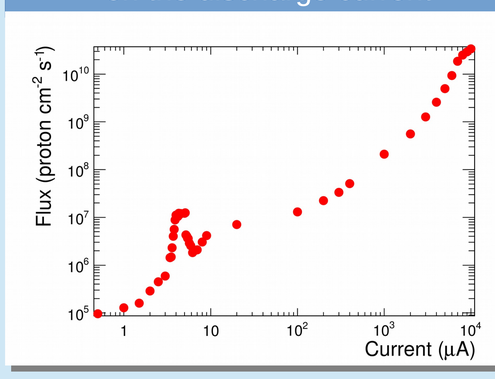
The instrument



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



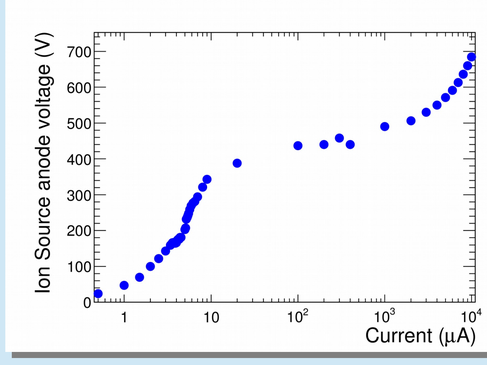
Dependence of the output flux on the discharge current



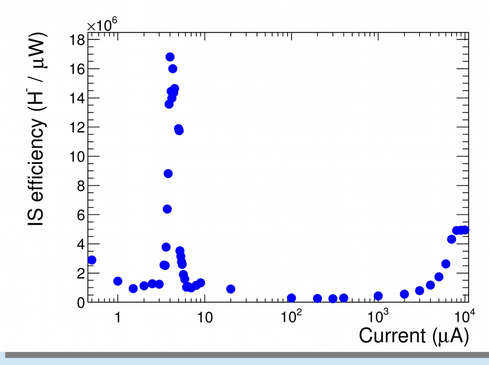
Observations

- 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 the 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%

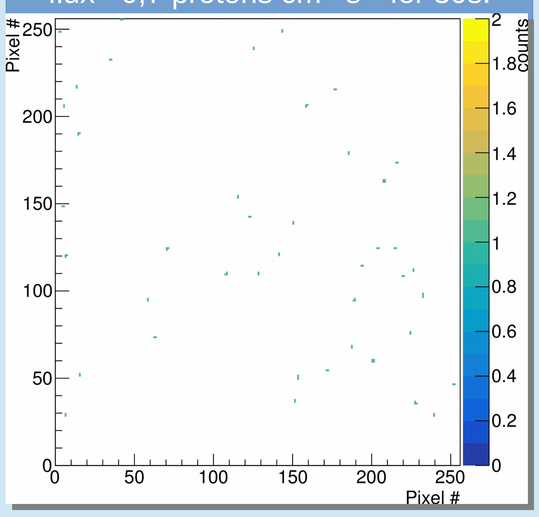
Ion Source IV curve for discharge currents 0.5 – 10^4 μA



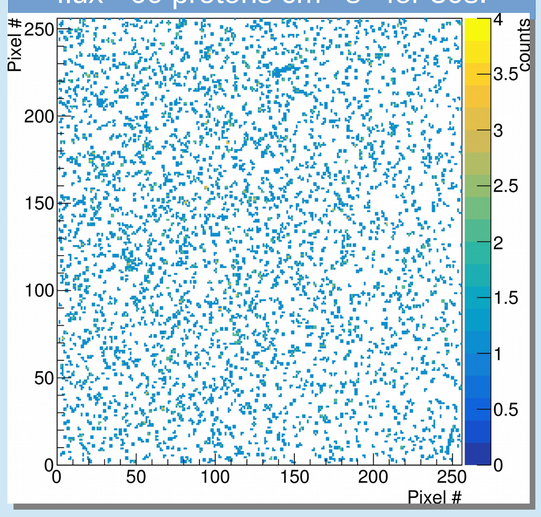
Efficiency peak in H^- production for discharge current near 5 μA



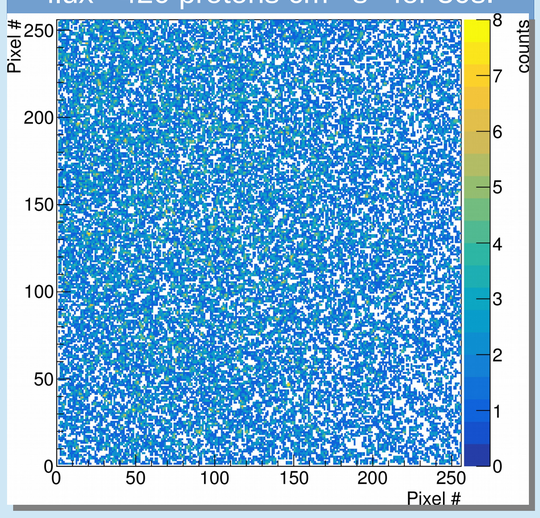
Ion Source OFF
flux ~0,7 protons cm-2 s-1 for 30s.



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

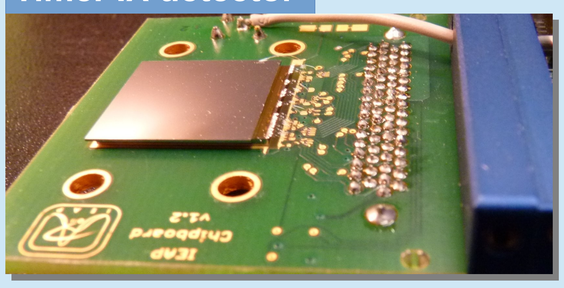
The low intensity proton beam current is monitored [3] with an ionization chamber Farmer 30010 from PTW-Freiburg [4] connected to a UNIDOS E Universal Dosemeter. Fluxes below 10^3 protons s^{-1} cm^{-2} are monitored with a Timepix device [5].

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.