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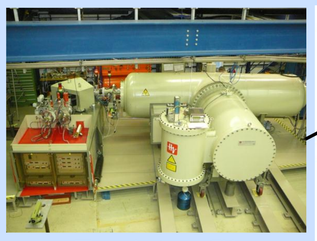
Proton Beam Time Structure of the HZB Cyclotron

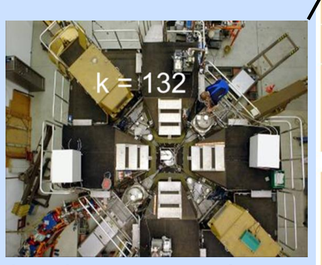
The Facility

Tandetron™:
2 MV tandem accelerator; duoplasmatron ion source; used for therapy since 2011

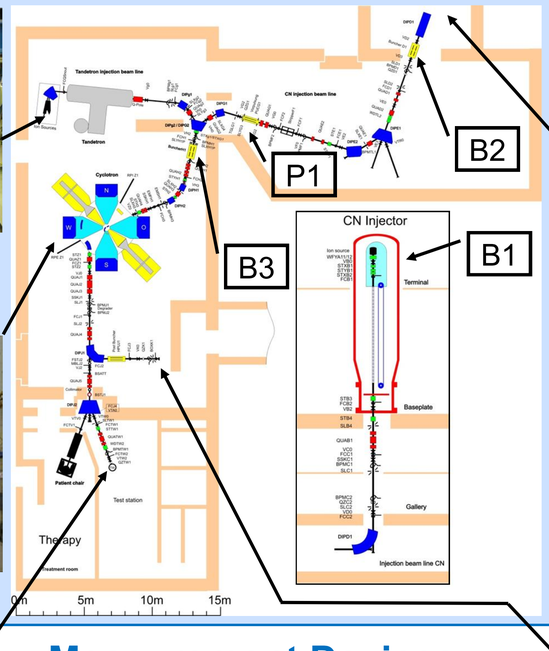
CN:
5.5 MV Van-de-Graaff accelerator with an ECR ion source; very versatile, e.g. used for pulsed beams; accelerates C, H, O and noble gases

Cyclotron:
Isochronous; separated sectors; proton energy up to 72 MeV (light ions 30 MeV/u, heavy ions 6 MeV/u); radio frequency 10-20 MHz; up to 140 kV; acceleration time window of 6° with respect to the radio frequency period


Tandetron™



isochronous cyclotron




CN injector

B1: Buncher 1

B2: Buncher 2

B3: Buncher 3

P1: Pulser

Buncher 1: 60° bunch; max. voltage 1.5 kV
Buncher 2: 6° bunch, max. voltage 60 kV
Buncher 3: 1° bunch, max. voltage 60 kV
(voltage too low for protons)

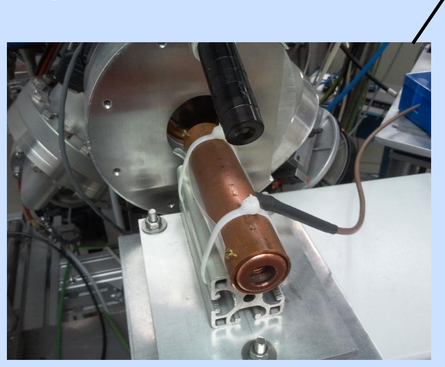
Transmission through the cyclotron:
10 % without bunchers; 50 % with buncher 1+2; 100 % with all three bunchers (only for Z≥2)

Pulser: Similar to a parallel-plate capacitor where –1 kV is applied to one plate to deflect the beam. An external pulser applies –1 kV to the second plate so that the beam can pass through, as long as the external pulse is applied. Max. repetition rate: 150 kHz; min. passage width: 50 ns; pulse-break-ratio: 1/60

Measurement Devices

Pick-Up

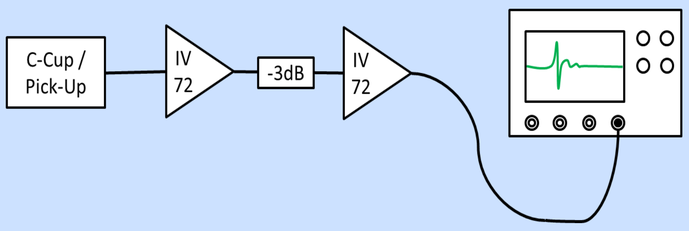

Pick-Up tube


Pick-Up tube with shielding in front of the nozzle

The Pick-Up is a device for contactless measurements of the proton beam concerning time structure and intensity. It is a 5 cm long tube of copper with a diameter of 1.3 cm. The in and out coming proton bunch generates a typical swing-through signal. The tube is more sensitive to reflections as the Coaxial Cup, as it was not possible to adjust the Pick-Up to 50 Ω impedance. An additional shielding is necessary to avoid stray pick-ups. The shielding tube is 12 cm long. Our prototype is shown in the pictures above.

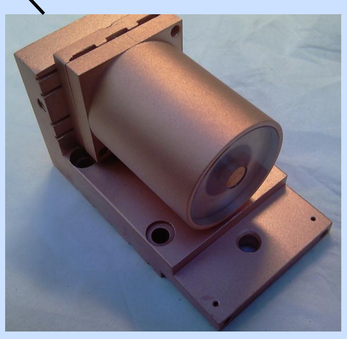
Signal Processing

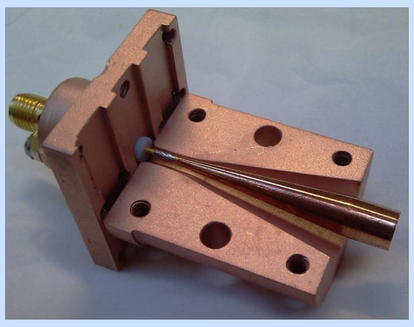
The signal generated by the Coaxial Cup or the Pick-Up is carried to the amplifiers „IV 72“. Each has an amplification of 30 dB and with the attenuator (to avoid oscillations) the overall amplification is 57 dB or $0.5 \cdot 10^6$.
The readout of the amplified signal is done by the oscilloscope WavePro 725Zi from LeCroy™, which has 2.5 GHz and a max. sample rate of 40 GS/s.



signal processing set-up

Coaxial Cup

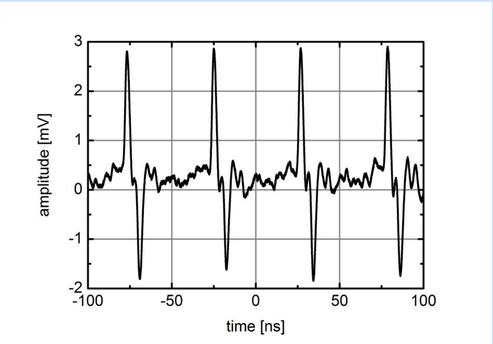

exterior view of the Coaxial Cup


interior view of the Coaxial Cup

The Coaxial Cup is a beam interrupting device for the measurement of the intensity and time structure of the beam. In principle it is a cylindrical copper target surrounded by a copper cup. But this particular cup is, in order to avoid reflections, adjusted to 50 Ω impedance; from a diameter of 1.2 mm at the SMA plug up to 6 mm at the beam side of the copper bolt. The dielectric is acrylic glass at the front and vacuum behind. In addition the whole cup is placed in an aluminum shielding.

Results

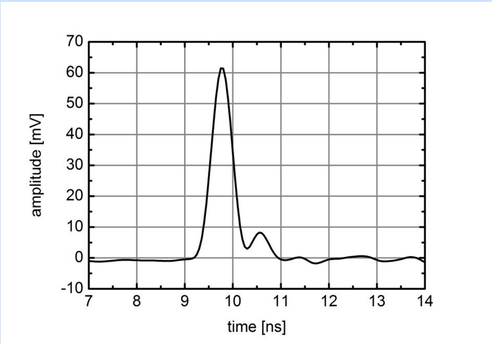
Quasi DC



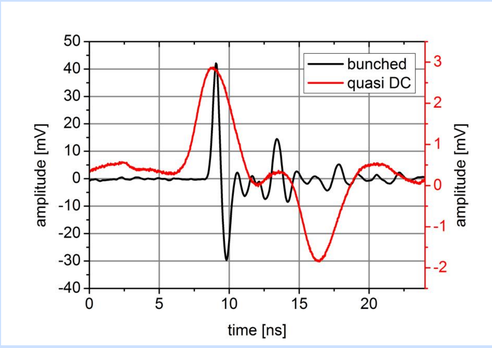
substructure of the quasi DC proton beam, 68 MeV, measured with the Pick-Up

The picture above shows an unbunched 40 nA proton beam with a substructure (nanobunches) due to its acceleration with the cyclotron. It is measured with the Pick-Up and therefore you can see the typical swing-through. Due to the cyclotron frequency the distance between two nanobunches is approx. 50 ns. This substructure is the reason why this beam current is called quasi DC instead of just DC.

Single Bunch



single proton bunch, 68 MeV, measured with the Coaxial Cup



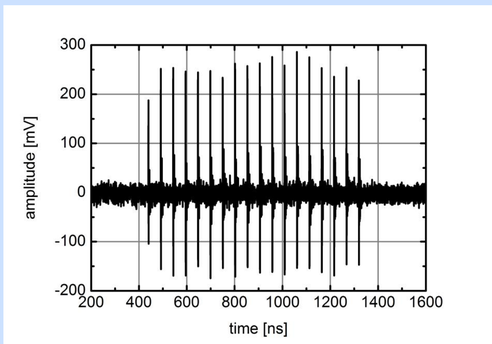
single proton bunch, 68 MeV, measured with the Pick-Up in comparison with a quasi DC beam

Single Bunch: The two graphs on the left show a bunched single proton pulse (with the same beam parameters). The Coaxial Cup (CC) measured signal is shown on the upper graph. The lower one shows the signal measured by the Pick-Up (PU) in comparison with the quasi DC signal from the graph in the very left. The PU signal shows very well the bunching effect concerning time sharpness. Further swings in the PU graph are reflections. The reflections in the CC graph are lower and the amplitude is a bit higher, due to the higher sensitivity of the CC. But it is unclear, where the second peak comes from. However, it is excluded that this second peak shows protons.

What we offer:
- Pulse length: single pulses, pulse packets up to some µs or quasi DC beam
- Proton currents from fA up to µA depending on the pulse structure
- Due to the low repetition rate and pulse-break-ratio of the pulser (150 kHz, 1/60), a new pulser is under construction.

What you can do with that:
- Dosimetry with pulsed radiation (protons and neutrons)
- Verification of dosimeters
- What else comes to your mind...

Pulse Packet



proton pulse packet, 68 MeV, measured with Pick-Up

The picture above shows a pulse packet made of 18 bunched proton pulses. It is approx. 900 ns long and it is measured with the Pick-Up. The variations of each peak intensity can, for instance, be attributed to fluctuations in the ion source current or variations due to the rotating belt in the CN injector. Furthermore, fluctuations in the whole bunching process can cause such peak variations.

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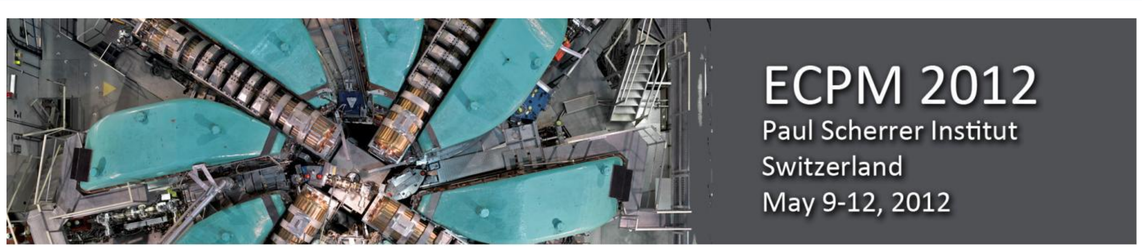

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