Test of a non-invasive Bunch Shape Monitor at GSI high Current LINAC

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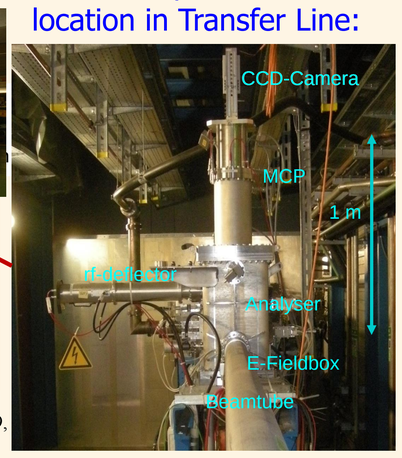
Abstract

At the heavy ion LINAC at GSI, a non-invasive Bunch Shape Monitor has been tested with several different ion beams at 11.4 MeV/u.
The monitors principle is based on the analysis of secondary electrons liberated from the residual gas by the beam impact. These electrons are accelerated, filtered by a electrostatic energy analyzer and deflected by an rf-deflector, acting as a time-to-space converter. A MCP–phosphor combination acts as the detector.
For the applied beam settings this Bunch Shape Monitor is able to obtain longitudinal profiles down to a width of 440 ps with a resolution of 135 ps, corresponding to 2° @ 36 MHz. The applicability is demonstrated.

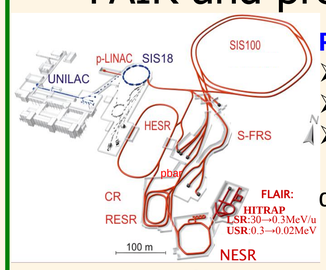
The GSI UNILAC Facility

Bunch Shape Monitor location in Transfer Line:



Beam current at monitor location: typically 0.1 to 1 mA depending on isotope.

FAIR and proton-LINAC

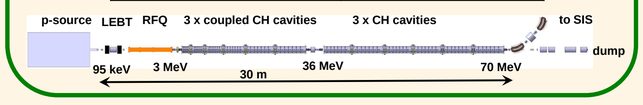


FAIR physics:
- rare isotopes beams
- atomic & mat. physics
- hadron spectroscopy with anti-protons

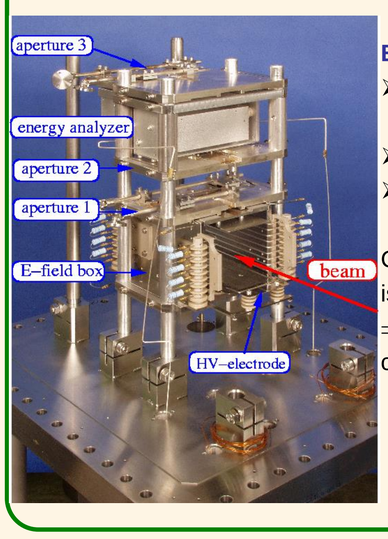
dedicated proton LINAC

Proton LINAC beam parameter:

Beam energy	70 MeV
Beam current	*70* mA
Beam pulse length	36 µs
Repetition rate	4 Hz
Rf-frequency	325.224 MHz
Tot. mom. spread	≤ ± 10^{-3}



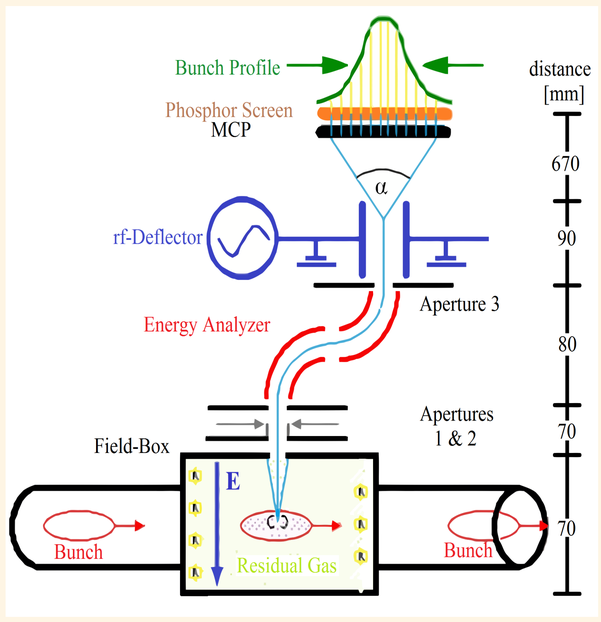
Electric Field Box



E-field box:
- U_{max} = 30 kV ⇔ 4.3 kV/cm
- Length 160 mm
- Aperture 70 x 70 mm

Care: Beam deflection is significant
⇒ installation of compensation foreseen

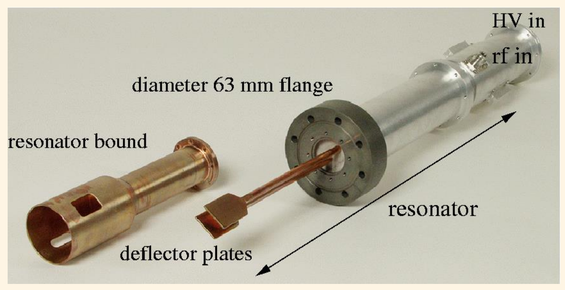
Scheme of the non-intersecting Bunch Shape Monitor



High current heavy ions: Large energy deposition within a range of ≈ 30 µm
⇒ non-intersecting device preferred.

Scheme for non-destructive device:
- Secondary electrons from residual gas
- Acceleration by electric field (like for Ionization Profile Monitor)
- Target localization by apertures and electro-static analyzer (Δy = 0.2 to 2 mm, Δz=0.2 to 1 mm)
- rf-resonator as 'time-to-space' converter λ/4 resonator, Q_0≈300, P_{in}=50 W max.
- Readout by MCP + Phosphor + CCD
- Measurement within several macro-pulses

rf-Deflector

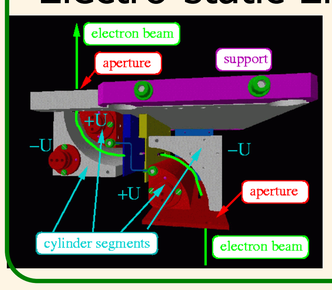


The rf-deflector produced by INR Troitzk:
Parallel wire λ/4-resonator:

f_0	36 MHz	108 MHz
length	800 mm	800 mm
P_{max}	100 W	30 W
Q_0	290	370
t_{max}	6 ms	6 ms
α_{max}	3^0	3^0

Additional action:
- Common U_Σ up to 7 kV acting as einzel lens
- Different U_Δ up to 1 kV acting as steerer

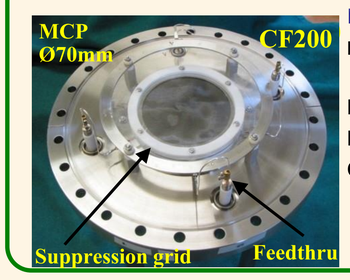
Electro-static Energy Analyzer



Energy analyzer for source volume restriction:
- Radius ρ=30 mm,
- 90^0 bending, ±5.5 kV
- point-to-point focusing
- Remote controlled aperture: 0.1 to 2 mm

e.g. for ±0.25mm & ±0.5mm
⇒ ±0.2 mm vert. prolongation (comparable to wire)

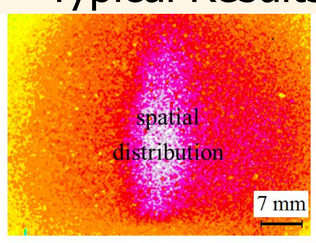
MCP Electron Detector



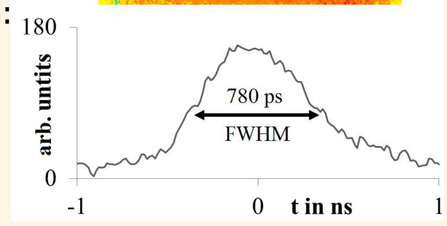
MCP-phosphor module:
Drift from rf-deflector: 670 mm corresp. to $\alpha_{max}=3^o$
MCP: Hamamatsu Ø 77 mm
Phosphor: P20
CCD: PCO SensiCam VGA 12 bit, cooled to -10° C digital interface

Typical Results and its Discussion

MCP image:



Projection:



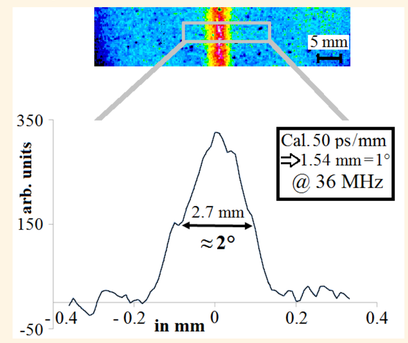
Results:
- bunch shape clearly detectable
- large background contribution [explanation still pending]
- improvements concerning background reduction under way

Beam parameter:
- U^{28+} , current I = 200 µA
- macro pules lengtht = 180 µs
- gas pressure p = 5 ·10^{-6} mbar
- averages of 64 macro pulses

Resolution Determination

- electrons originated from bottom HV grid as liberated by the residual gas **ion** impact
- acceleration within E-field box
- focusing by rf-deflector dc-voltage acting as einzel lens
- depending on aperture's setting (here maximal open)

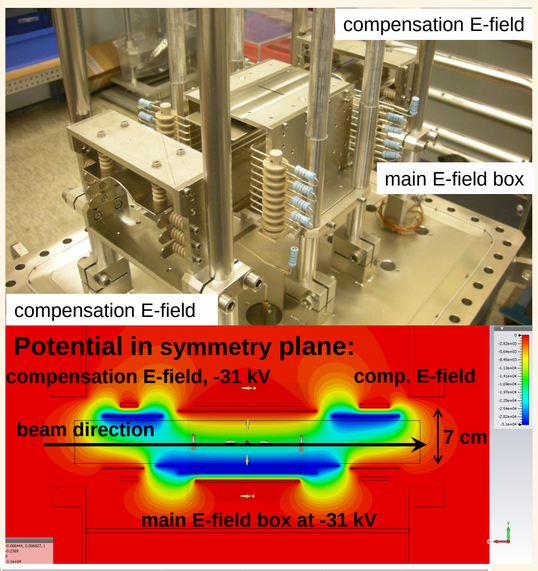
⇒ electron optics leads to 2.7 mm on ∅ 77 mm MCP

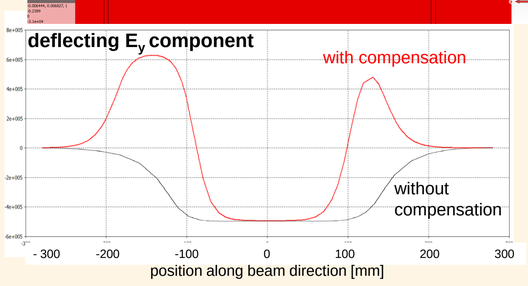


Static Compensation Field

Compensation of E-field beam deflection:
- E-field for box: 30kV/ 70mm = 4.2 kV/mm
- short intersection length with reversed field

⇒ compact design realized

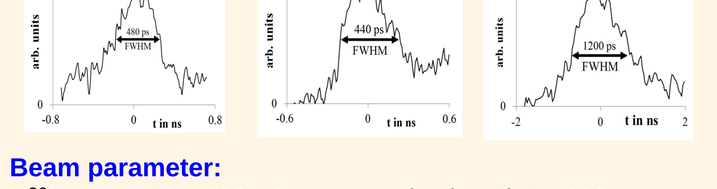




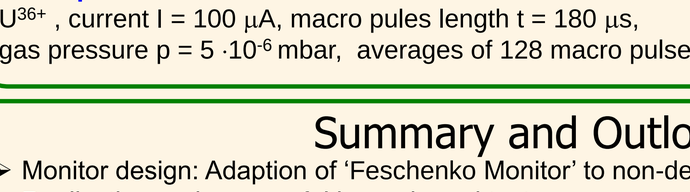
Result for compensation of beam deflection:
- 99 % within ∅ 8 mm
- 90 % within ∅ 20 mm compared to single E-field

Demonstration of Usability

MCP images:



Projections:



Beam parameter:
U^{36+} , current I = 100 µA, macro pules length t = 180 µs,
gas pressure p = 5 ·10^{-6} mbar, averages of 128 macro pulses

Change of beam's bunch length by buncher cavity upstream of monitor location:
- clear image of bunches at MCP
- variation of rf deflector power
- projections show bunch shape
- variation of beam parameters detectable

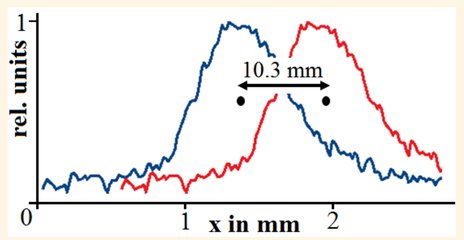
⇒ functionality proven

Problems:
- large background
  reason not understood
  ⇒ further experiments required
- structure in background
  caused by field of MCP HV leads
  ⇒ mechanical shield foreseen

Calibration Measurement

Variation of rf phase by electronic phase shifter, set value accuracy ≈0.3 °

Results depends on chosen rf-power :
Example: set value 6.6° @ 36 MHz ⇔ 514 ps
Result: 10.3 mm offset leads to 50 ps / mm



Summary and Outlook

- Monitor design: Adaption of 'Feschenko Monitor' to non-destructive device
- Realization and successful beam-based test
- Determination of resolution → sufficient for application, monitor can be used at UNILAC
- Resolution can be matched to bunch length by rf power adaption
- Background not completely explained, but improvements done, beam-based test in Feb. 2014

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