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

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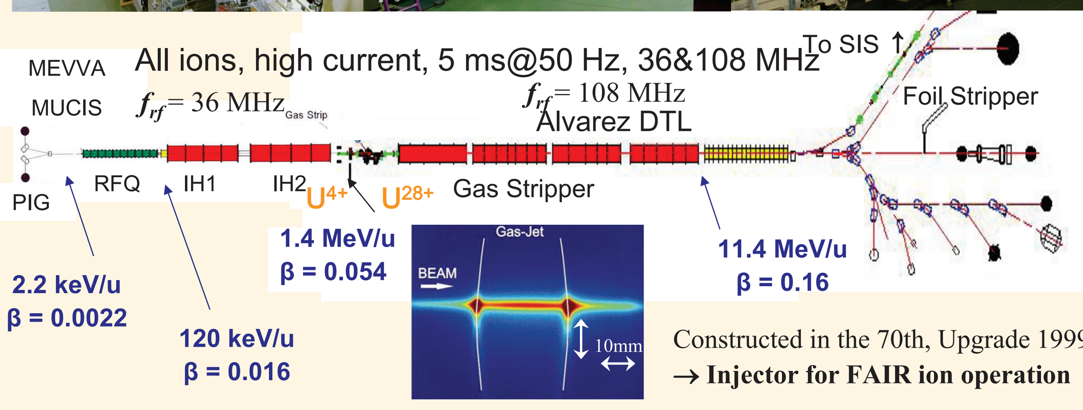
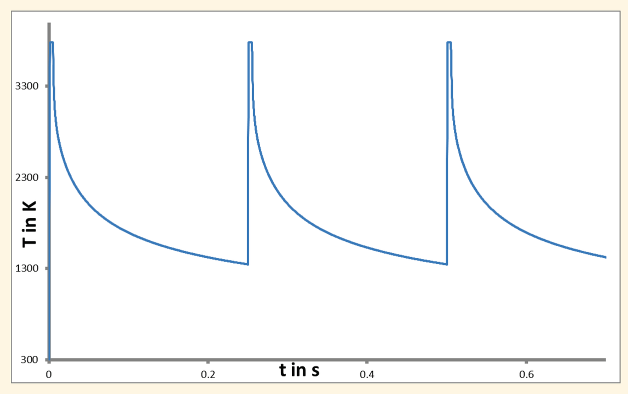
Abstract

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 a detector.
For the applied beam settings this Bunch Shape Monitor is able to obtain longitudinal profiles down to a RMS of 300 ps with a RMS resolution of 25 ps, corresponding to 0.5° @ 36 MHz. The applicability is demonstrated.

The GSI UNILAC Facility

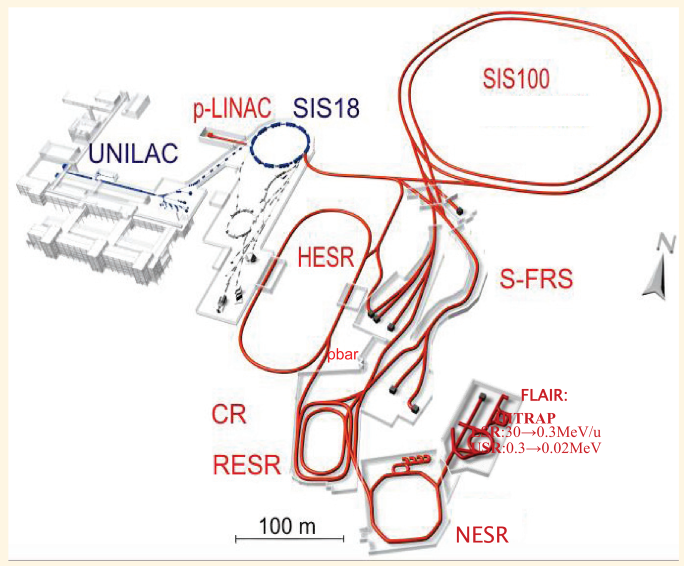




U^{73+} Beam, 5 ms pulse, 5 mA:
- 33 µm carbon wire is suited
- Still T_{max} = 3550 K too high

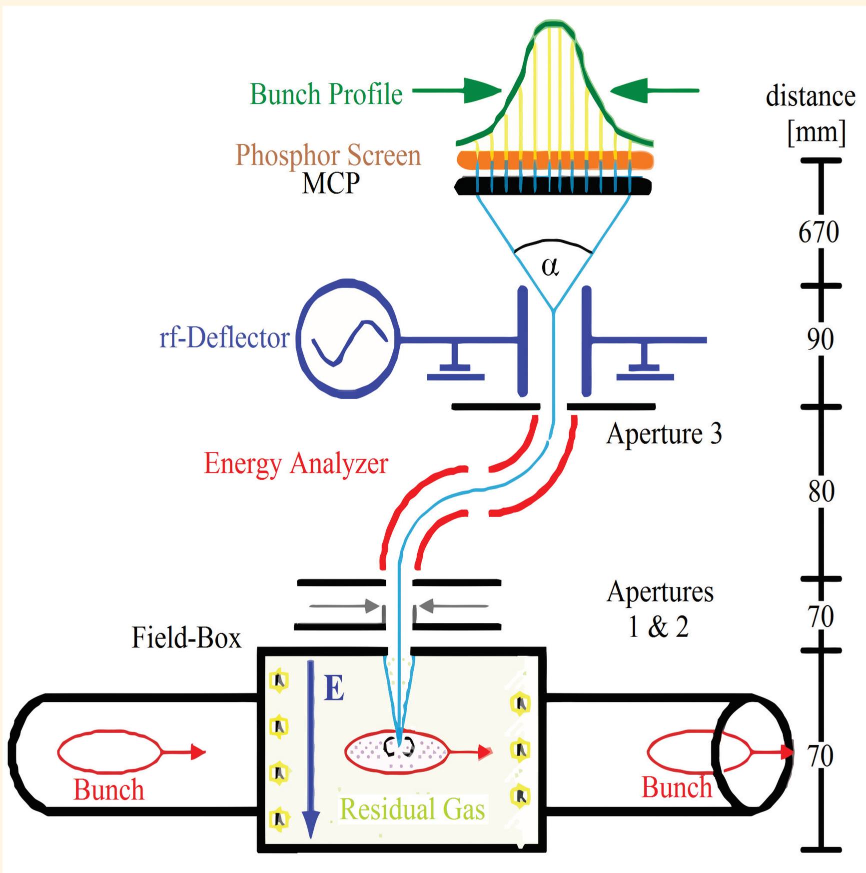
⟹ Non-intercepting design

Typically ion current from 0.1 to 1 mA, depending on isotope.



FAIR physics:
- Rare isotopes beams
- Atomic & mat. physics
- Hadron spectroscopy with anti-protons dedicated proton LINAC

Scheme of the non-intersecting Bunch Shape Monitor

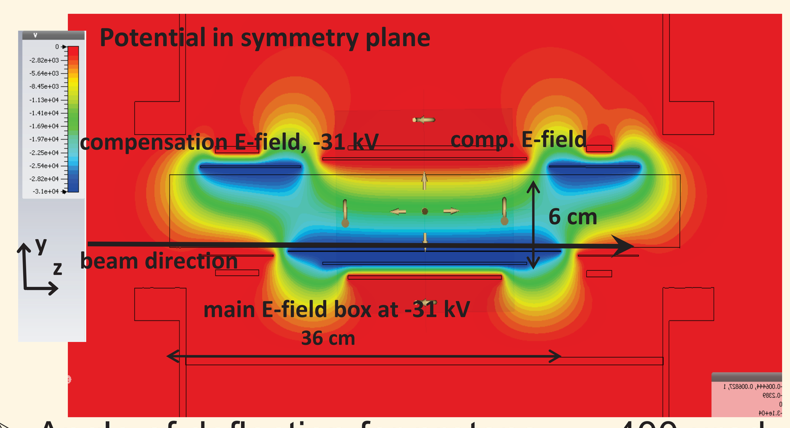


Scheme for non-destructive device:
- Secondary electrons from residual gas
- Acceleration by electric field (like for Ionization Profile Monitor)
- Target localization by apertures and electro-static analyzer (Δy = 0.2 to 2 mm, Δz=0.2 to 1 mm)
- rf-resonator as 'time-to-space' converter λ/4 resonator,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

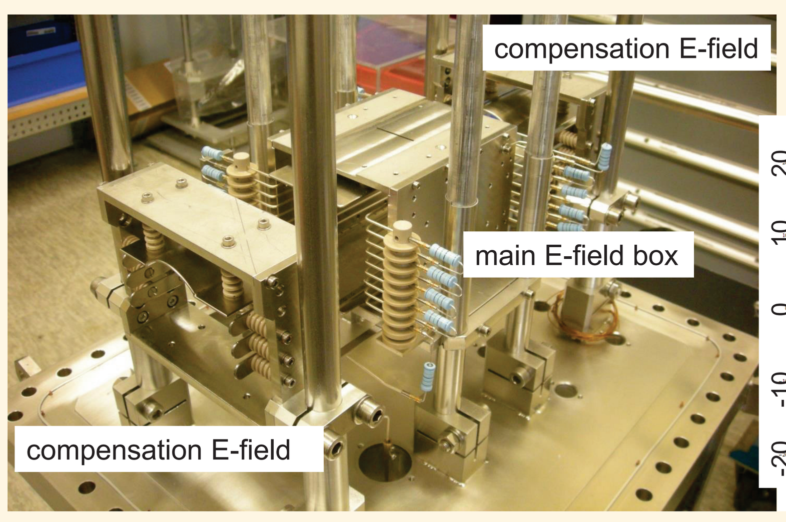
Field-Box Design

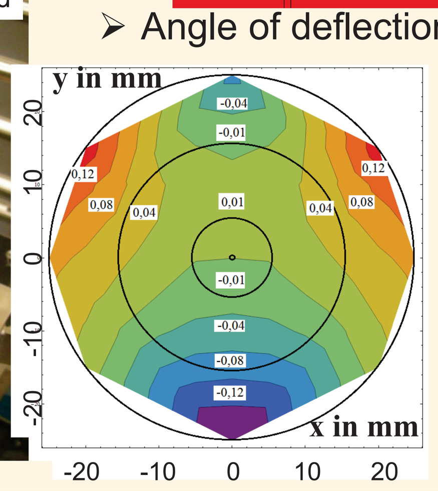
Compensation of beam deflection:
- E-field for box: 30 kV/ 70mm = 4.2 kV/mm
- Short intersection length with reversed field
- compact design realized

⟹ **Beam based tests proved functionality**



- Angle of deflection for protons $\alpha \approx 400$ µrad





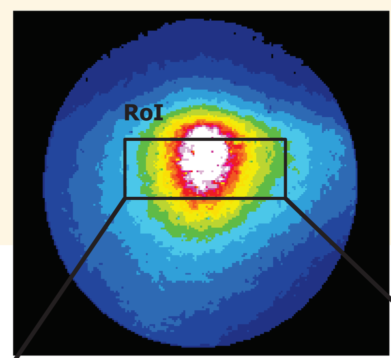
Compensation f based on CST code:

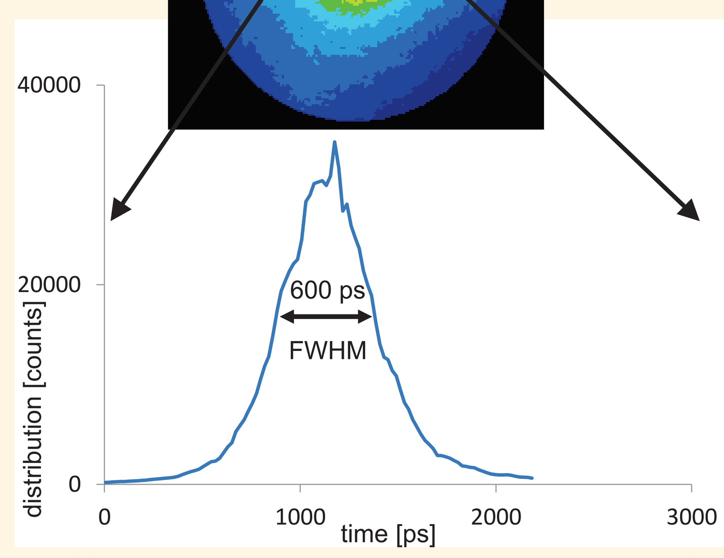
$$f = \frac{\int E_y(compensate) \cdot dz}{\int E_y(un-compensate) \cdot dz}$$

- 4 µrad left within ∅ 20 mm
- 48 µrad left within ∅ 50 mm

Typical Results and their Discussion

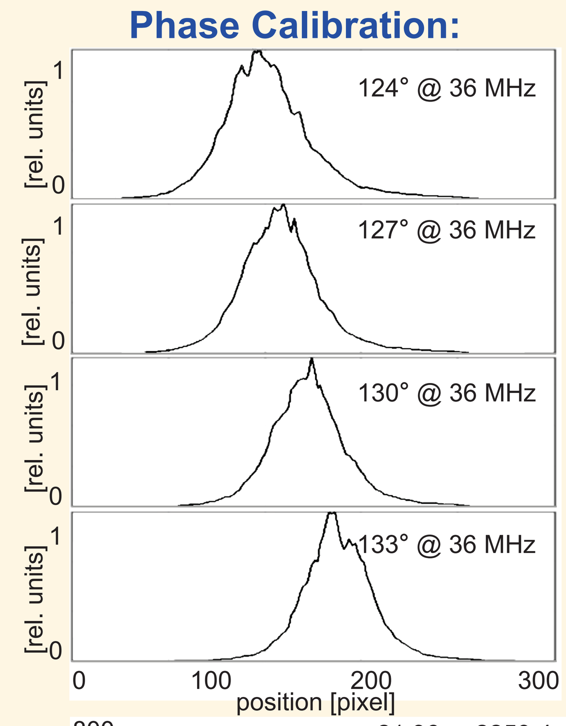
Profile Measurement:

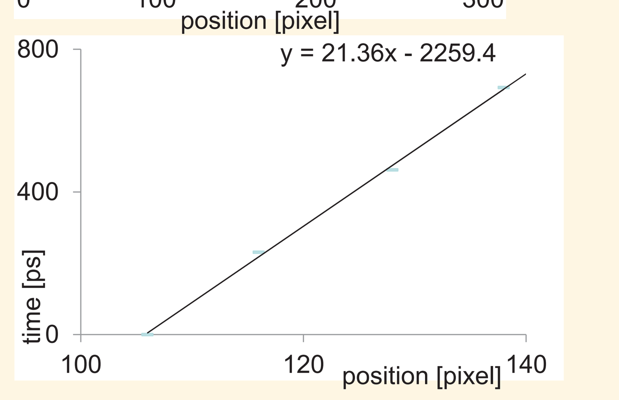




- Ni^{28+}, I = 900 µA, t_p = 180 µs, P = $5 \cdot 10^{-6}$ mbar, 16 averages,
- RMS 290 ps ⟹ FWHM 681 ps
- FWHM read-off = 600 ps
- Phase calibration: 21 ps/px

Phase Calibration:



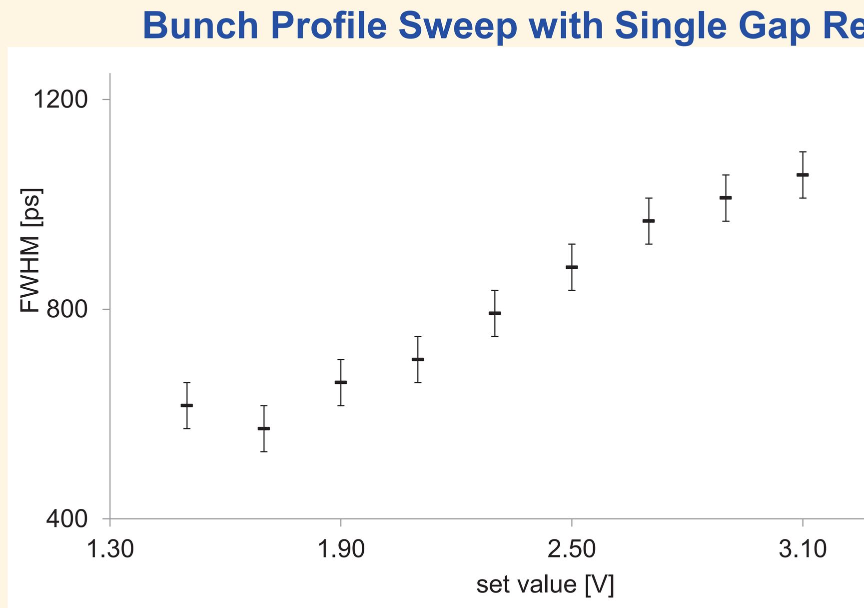


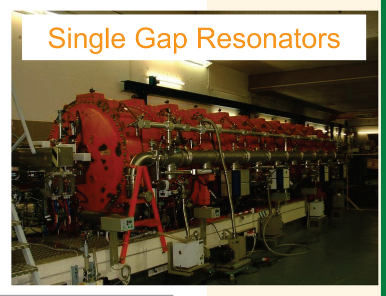
Demonstration of Usability

Bunch Profile Sweep with Single Gap Resonator

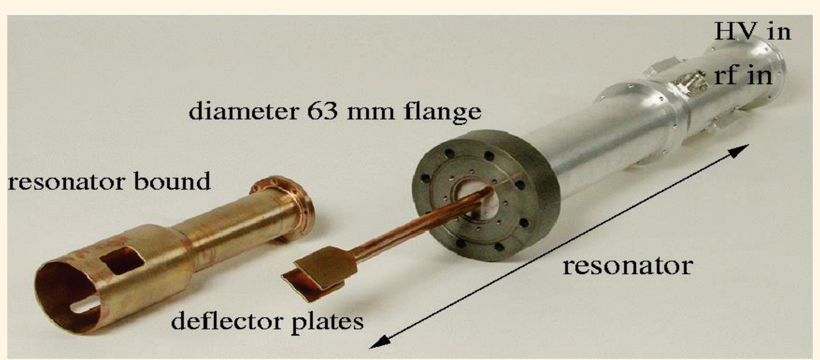
- N^{7+}, I = 5 mA, t_p = 220 µs, P = $1 \cdot 10^{-5}$ mbar
- Phase calibration: 195 ps/mm
- FWHM 570 ps -1150 ps
- 64 averages per Profile
- Focus passes through BSM

⟹ **BSM is sensitive for Bunch Profile sweep**





RF-Deflector



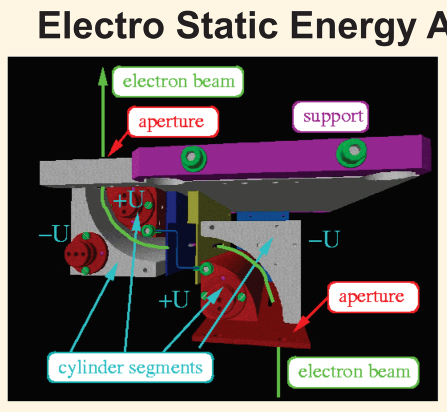
The rf-deflector produced by INR Troitzk:

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

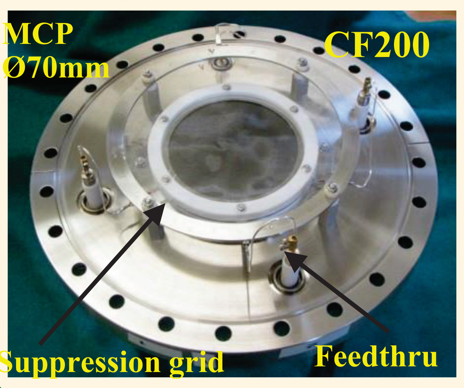
Electro Static Energy Analyzer



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 Detector



MCP-phosphor module:

Drift from rf-deflector: 670 mm corresp. to α_{max} = 3°

MCP: Hamamatsu Ø 77 mm

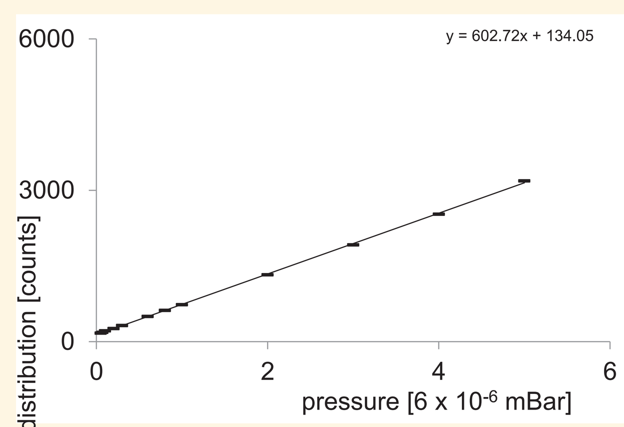
Phosphor: P20

CCD: PCO SensiCam VGA 12 bit, cooled to -10° C digital interface

MCP Detector Background

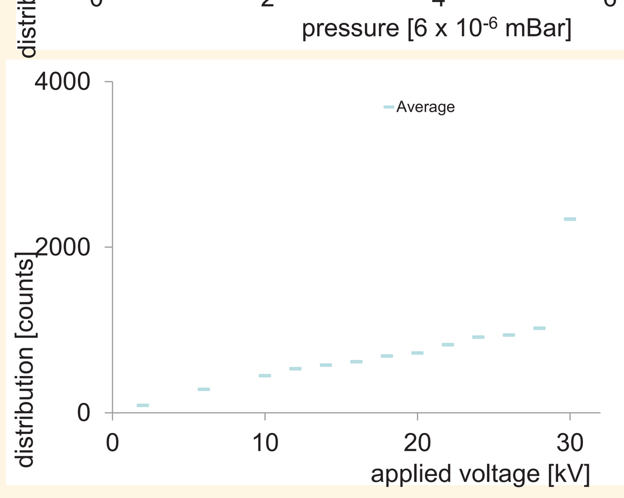
Pressure induced Background:
- N^{7+}, I = 900 µA, t_p = 180 µs
- 20.5 keV, 1600 V MCP,
- 16 averages
- Apertures are closed
- Plot shows linear behaviour

⟹ **Background strongly depending on the pressure**



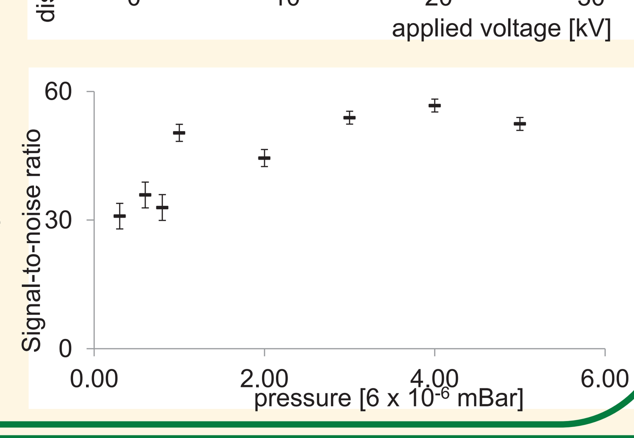
Field Box induced Background:
- N^{7+}, I = 900 µA, t_p = 180 µs
- 1 x 10^{-6} mBar, 1600 V MCP
- 8 averages
- Apertures are closed
- At 30 kV a threshold occurs

⟹ **X-rays responsible for background**

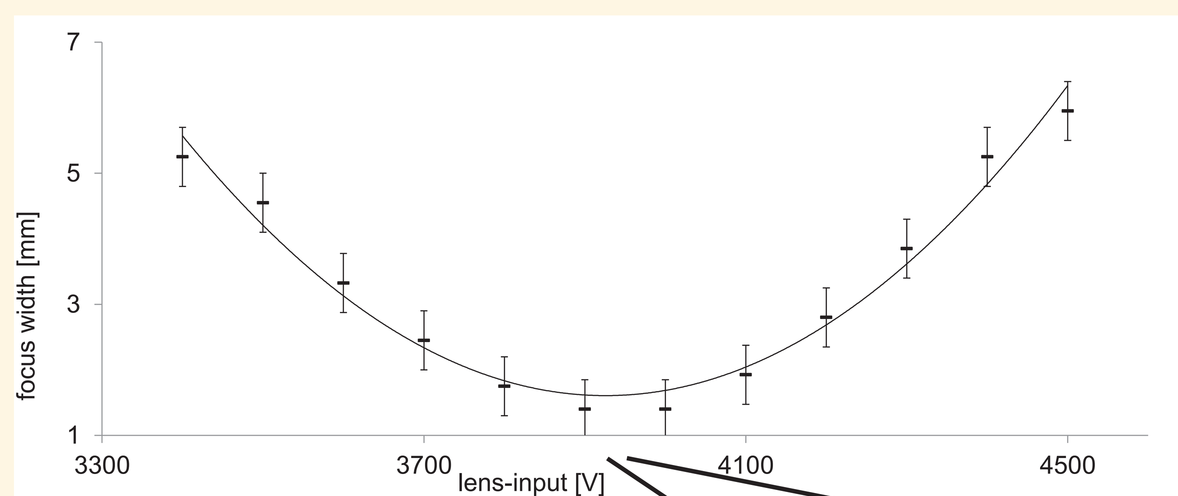


Signal-to-noise ratio:
- N^{7+}, I = 900 µA, t_p = 180 µs
- 1800 V MCP, 8 averages
- SNR gets better with higher pressure

⟹ **Signal-to-noise ratio sufficient for profile measurements**



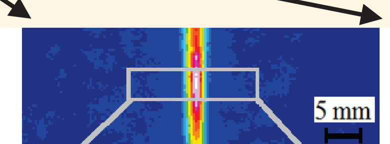
Focus Width determines Resolution

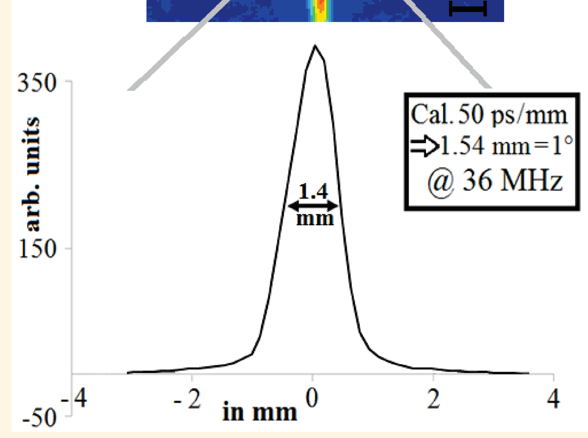


Aperture Adjustment

- N^{7+}, I = 900 µA, t_p = 180 µs
- Apertures set to 0.5 mm open
- 11.5 keV, 7 ×10^{-7} mBar, 1500 V MCP
- Optimum easy achievable
- Up to 0.1 mm setting possible but intensity will go to zero

⟹ **RMS 0.6 mm focus leads to 25 ps total resolution**





Summary and Outlook

- Monitor design: adaption of 'Feschenko Monitor' to non-invasive device
- Realization and successful beam-based test has been executed
- Determination of resolution → sufficient for application, monitor can be used at UNILAC
- Resolution can be matched to bunch length by rf power adaption
- Background is significantly decreased, present background, if the ion beam is well aligned, is due to x-ray radiation

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