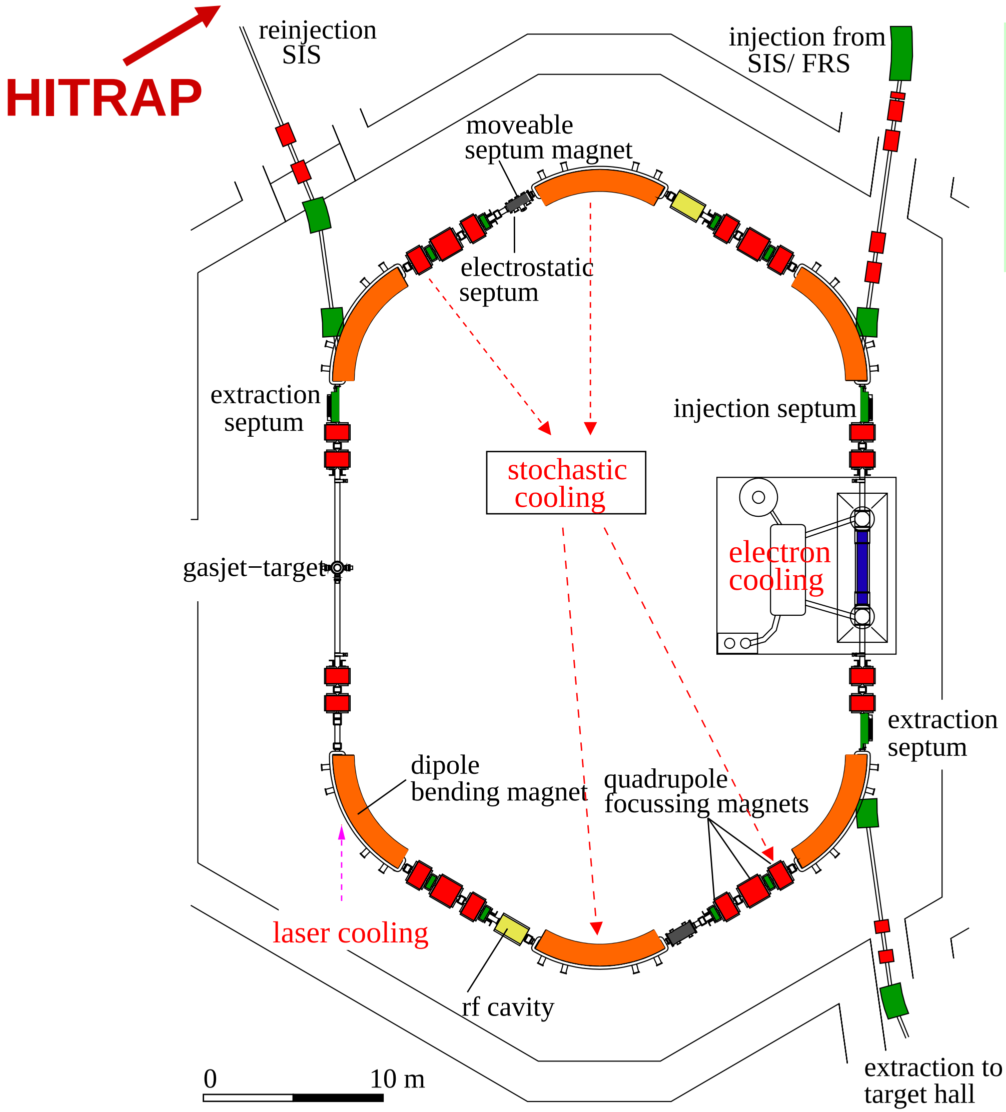
The Heavy Ion Storage Ring ESR



FSR (former ESR) team
K. Beckert, C. Dimopoulou
F. Nolden, U. Popp, M. Steck

main activity:
FAIR storage ring design

ESR:

operation for physics experiments

some machine development towards FAIR

The ESR Electron Cooler

electron beam parameters

energy	1.6 – 250 keV
current	0.001 – 1 A
diameter	50.8 mm
gun perveance	1.95 μP
collection efficiency	> 0.9998
temperature	
transverse	0.1 eV
longitudinal	~ 0.1 meV

magnetic field

strength	0.015 – 0.2 T
straightness	1×10^{-4}

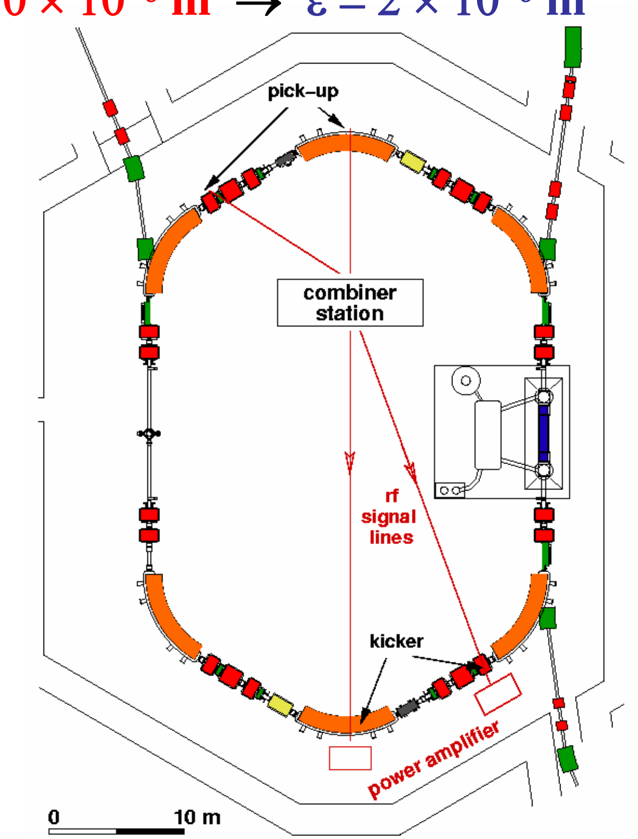
vacuum

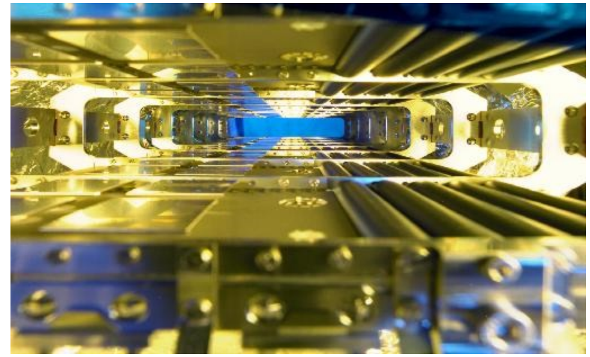
2×10^{-11} mbar

Stochastic Cooling at the ESR

Fast pre-cooling of hot fragment beams

energy 400 (- 550) MeV/u
bandwidth 0.8 GHz (range 0.9-1.7 GHz)
$\delta p/p = \pm 0.35\ \% \rightarrow \delta p/p = \pm 0.01\ \%$
$\varepsilon = 10 \times 10^{-6}\ \mathrm{m} \rightarrow \varepsilon = 2 \times 10^{-6}\ \mathrm{m}$





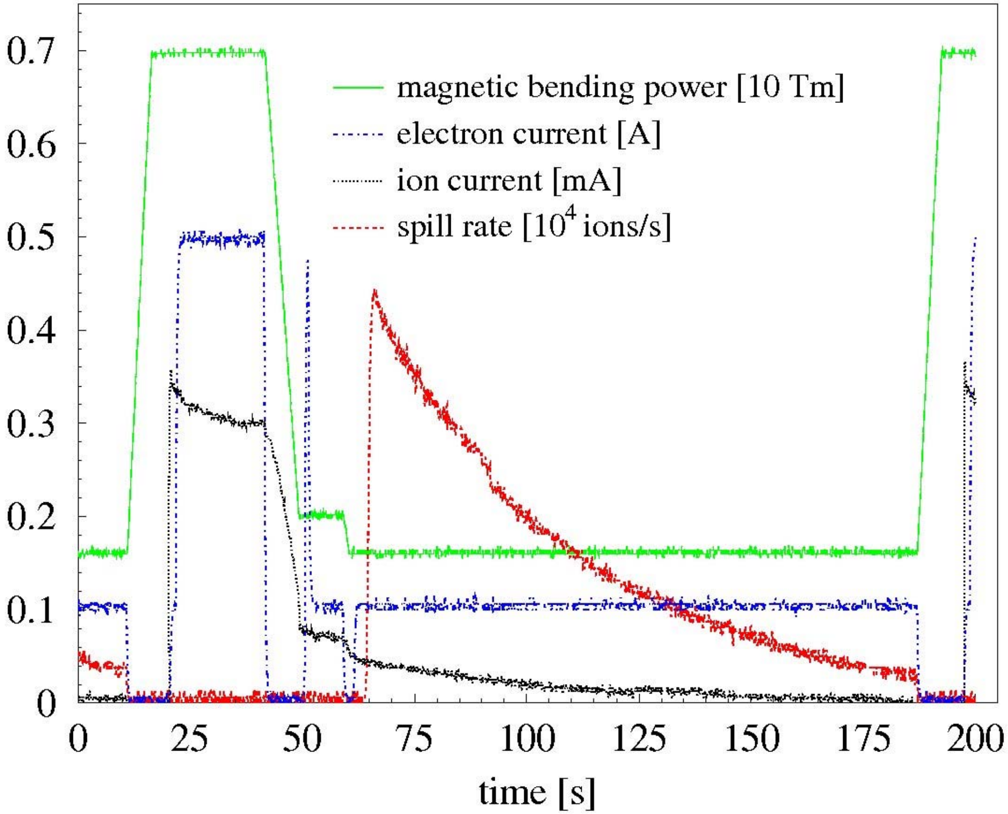
electrodes installed inside magnets

combination of signals from electrodes

power amplifiers for generation of correction kicks

Typical Deceleration Cycle

U^{92+} 300 → 30 → 20 MeV/u

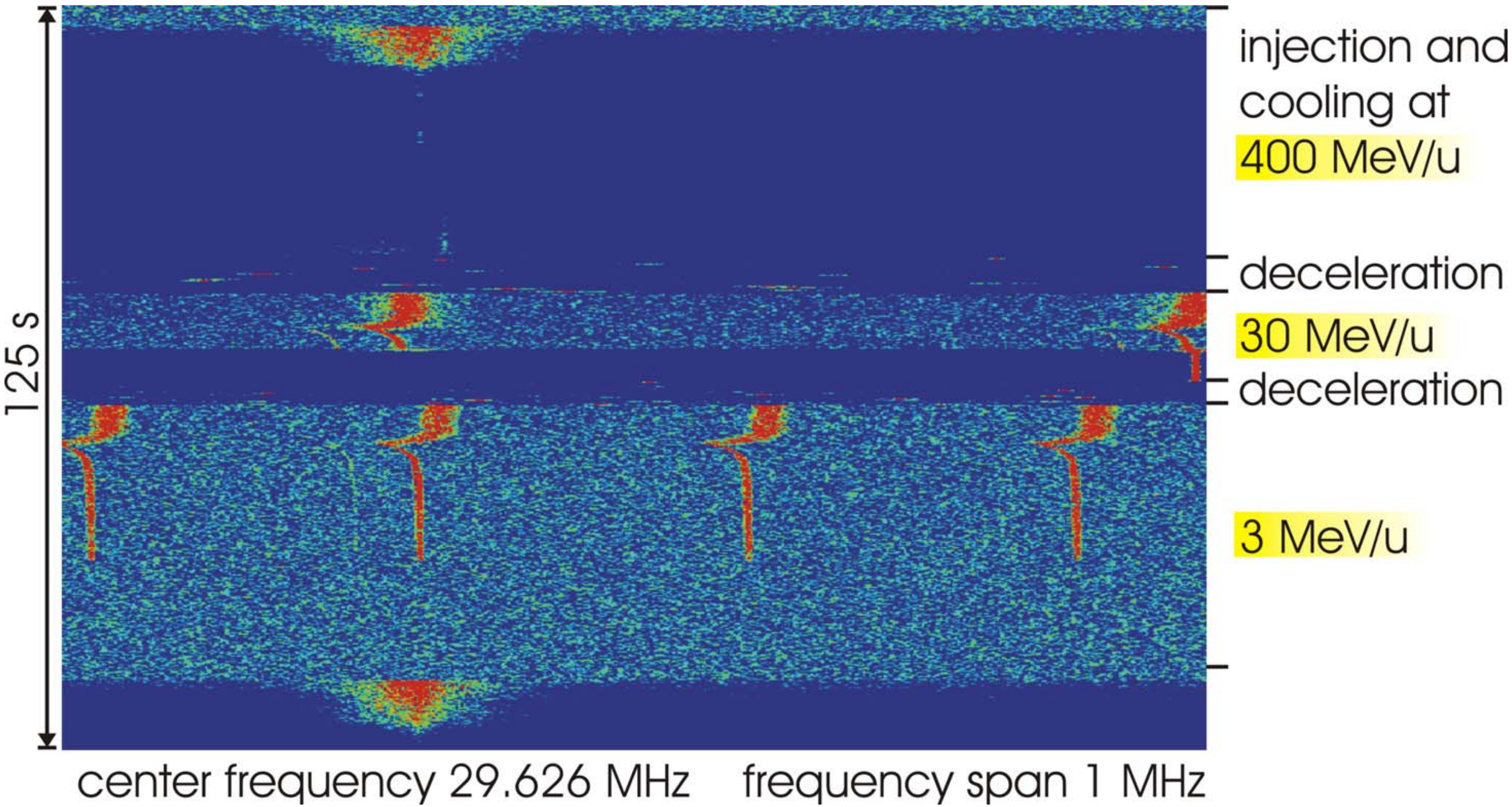


ultra-slow beam extraction by charge changing
lowest energy with slow extraction: 12 MeV/u

<u>supercycle</u>

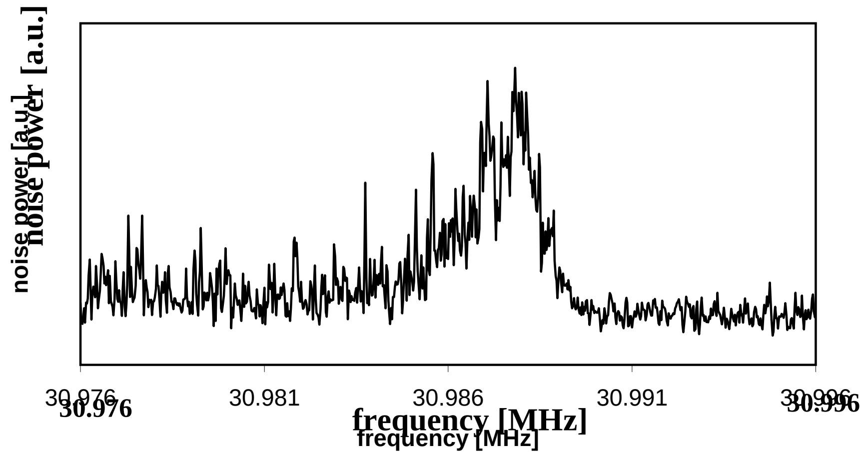
- **Injection**
- **Cooling**
- **Centering**
- **Deceleration**
- **Cooling (change of harmonic)**
- **Deceleration**
- **Cooling**
- **Extraction**
- **Reset**

Deceleration of U^{92+} from 400 to 3 MeV/u

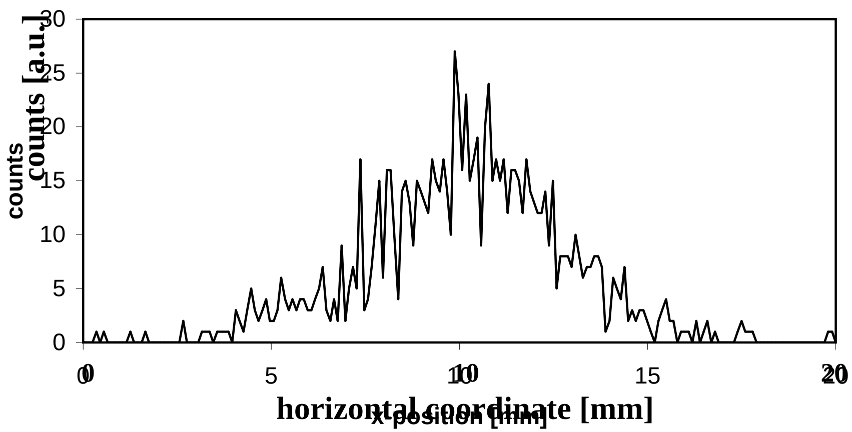


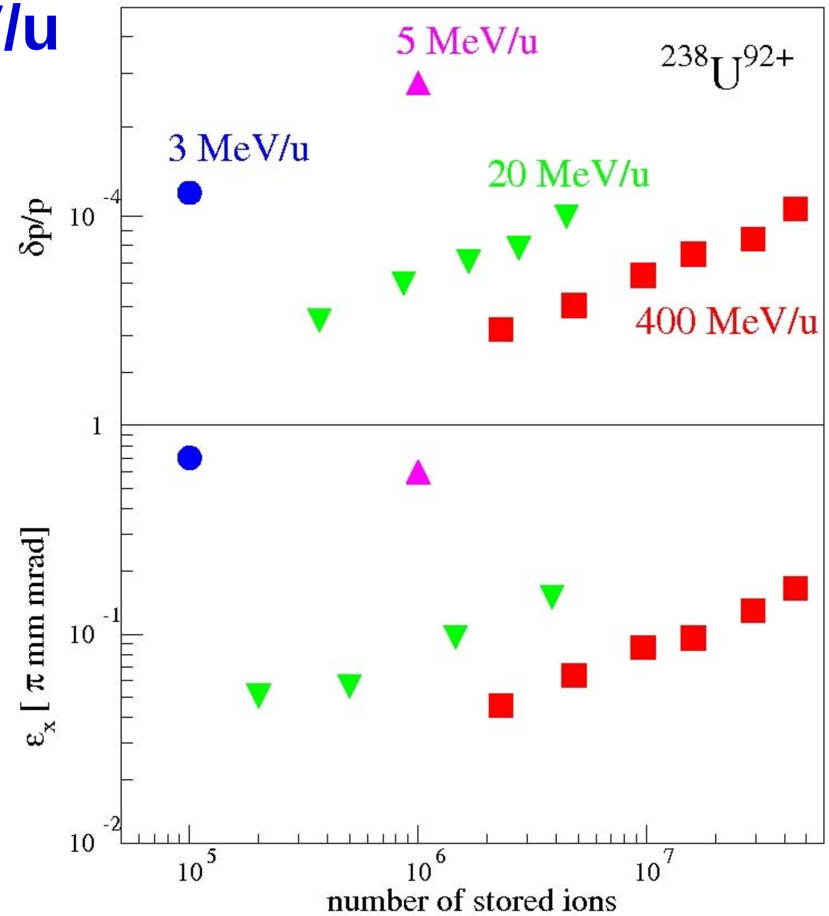
Parameters of U^{92+} at Low Energy

Schottky spectrum U^{92+} 3 MeV/u

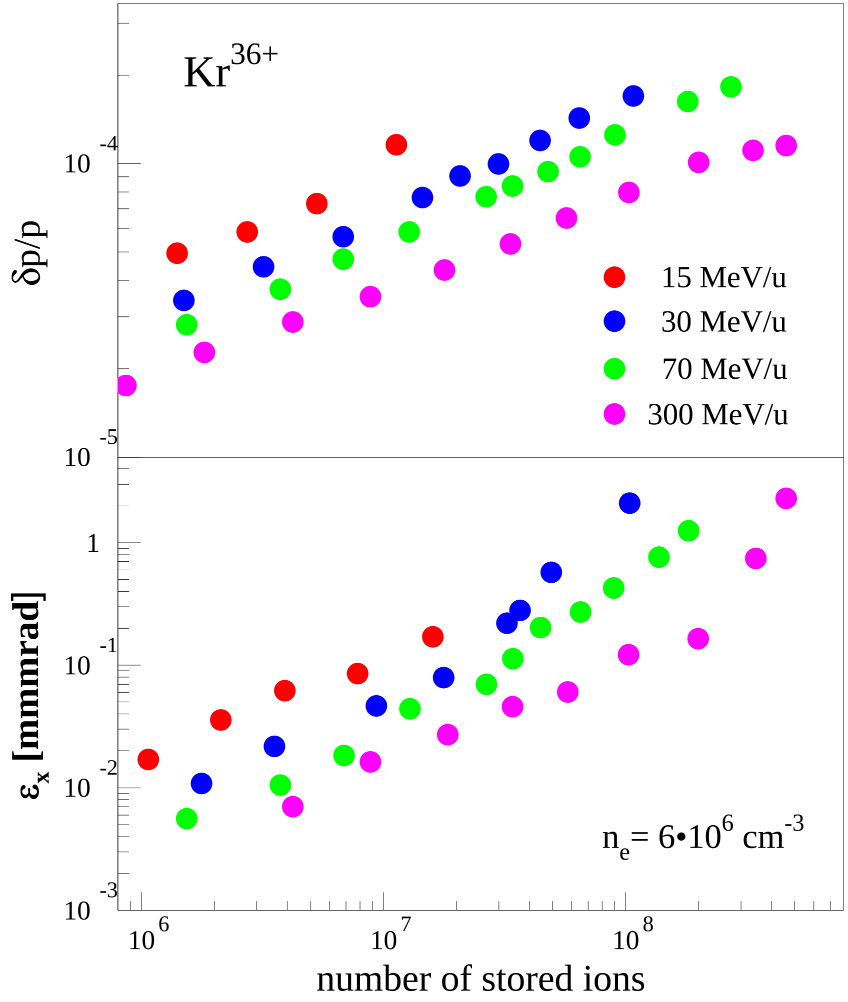


beam profile





Energy Dependence of Beam Parameters

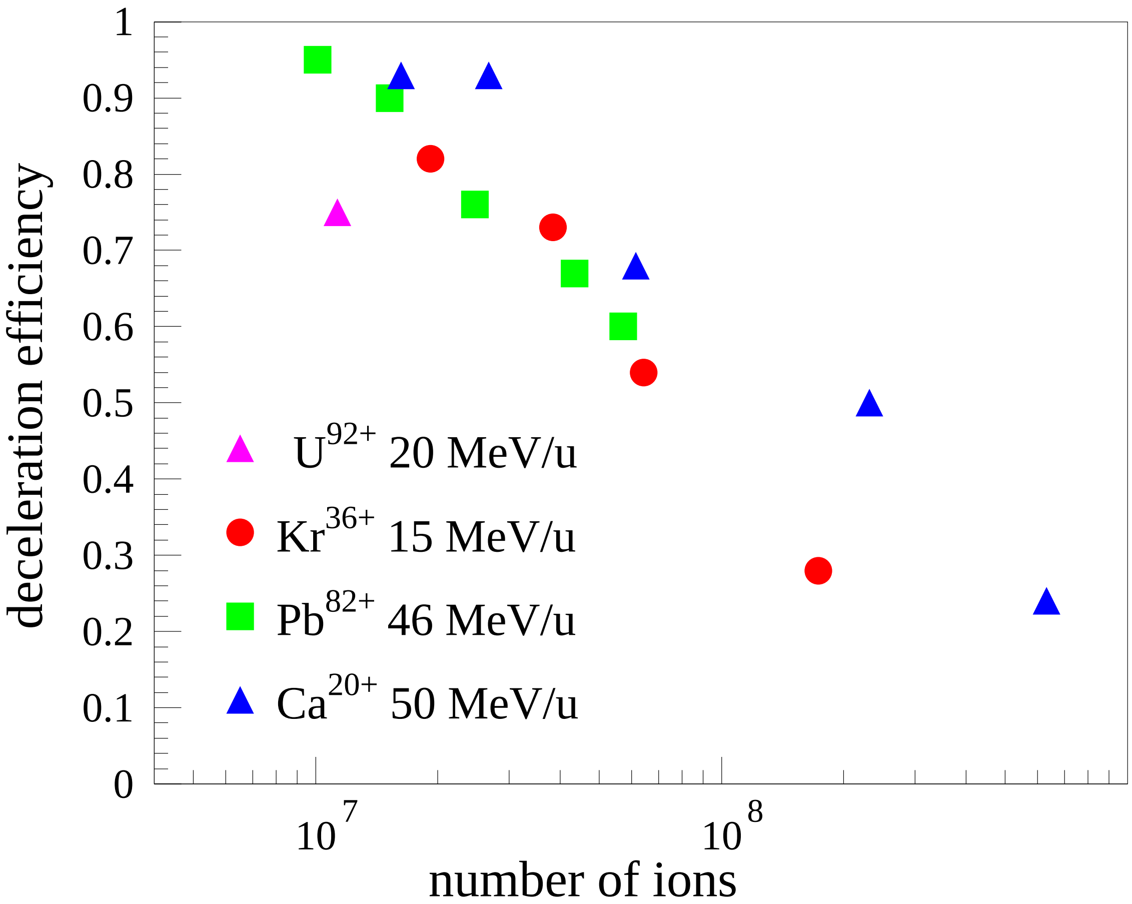


For constant cooling rate the equilibrium beam parameters increase with decreasing beam momentum

equilibrium: $\tau_{IBS}^{-1} = \tau_{cool}^{-1}$

$$\tau_{IBS}^{-1} \propto ((\beta\gamma)^3 \varepsilon_x \varepsilon_y \delta p/p)^{-1}$$

Beam Losses During Deceleration



Losses increase with intensity of stored ion beam

Causes:
- **adiabatic emittance growth**
- **imperfections of components**
- **intrabeam scattering**

number of decelerated particles $\leq 10^8$

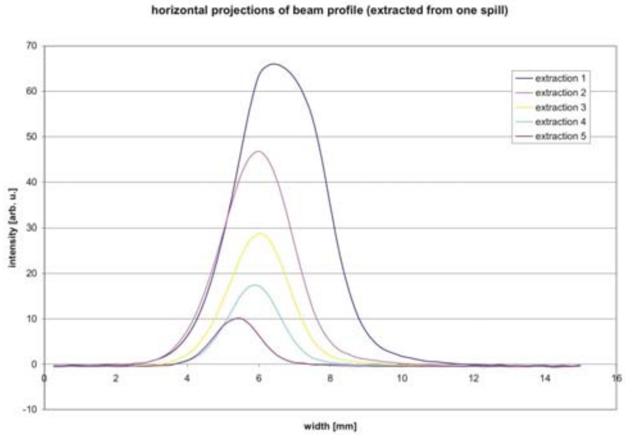
Profile of Fast Extracted Beam

Ca^{20+} 4.2 MeV/u cooled with I_{el}= 20 mA

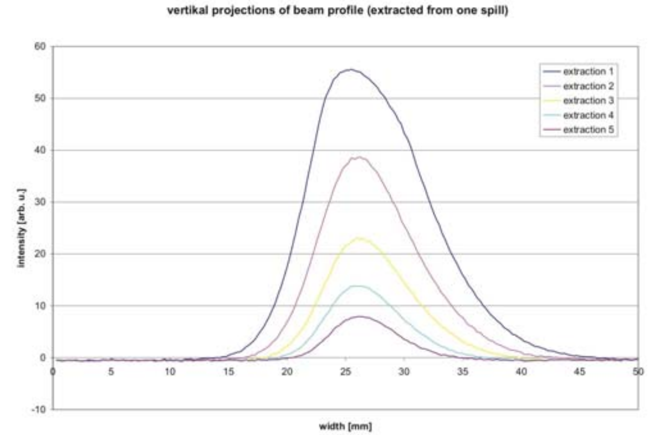
revolution time 3.8 μs

kicker pulse 3 μs

horizontal profile

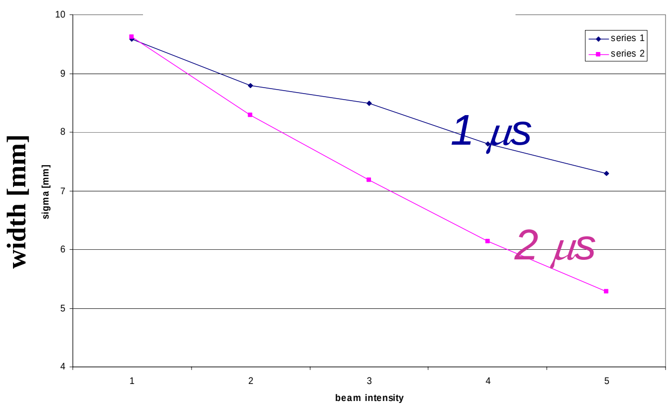


vertical profile

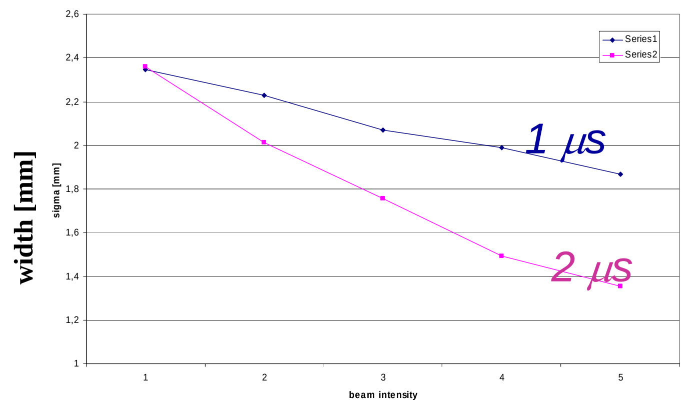


reduced kicker flat top 1, 2 μs

horizontal width



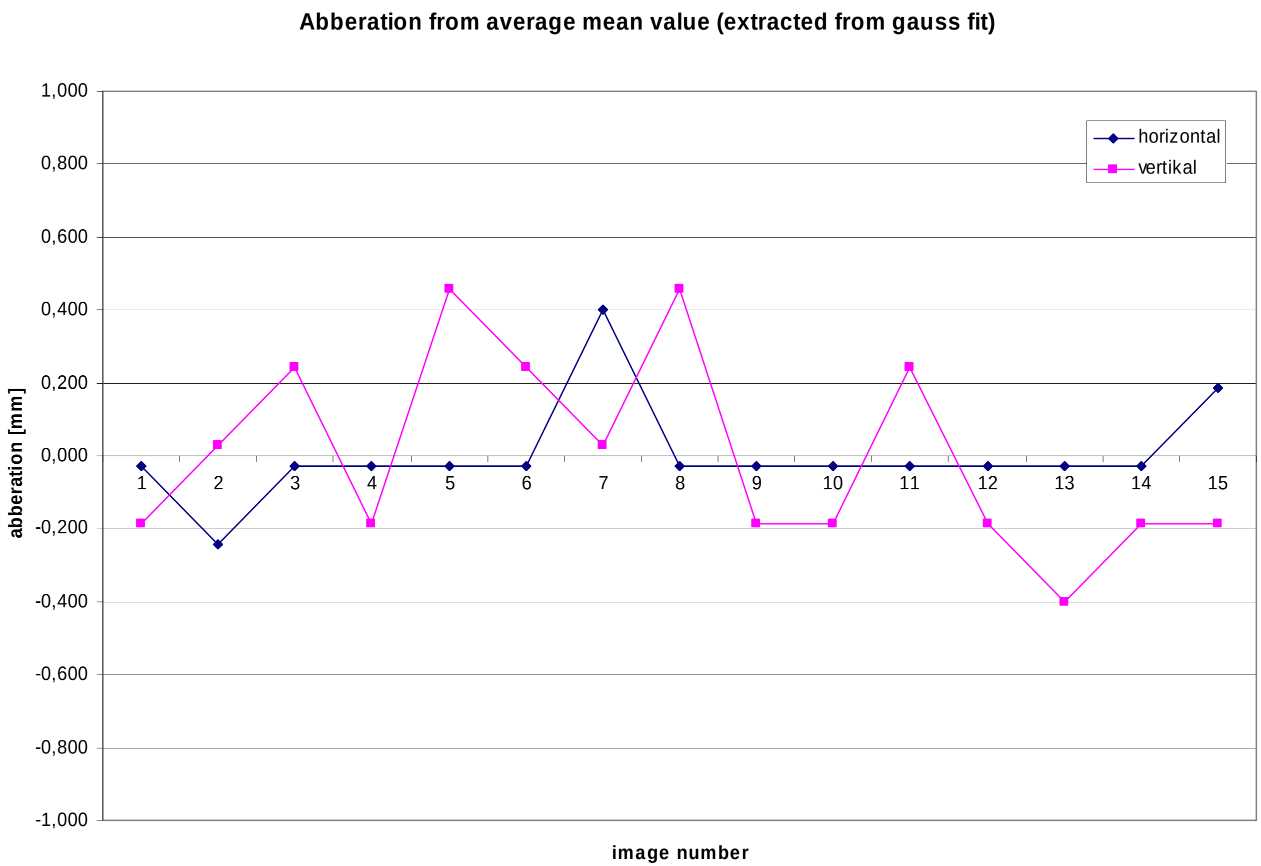
vertical width



momentum spread of coasting beam $\delta p/p = 2\times10^{-4}$ (5×10^{6}), $\delta p/p \propto N^{0.3}$

estimated emittance $\varepsilon_{x,y}$= 0.2 μm (N = 5×10^{6}) , $\varepsilon \propto N^{0.5}$

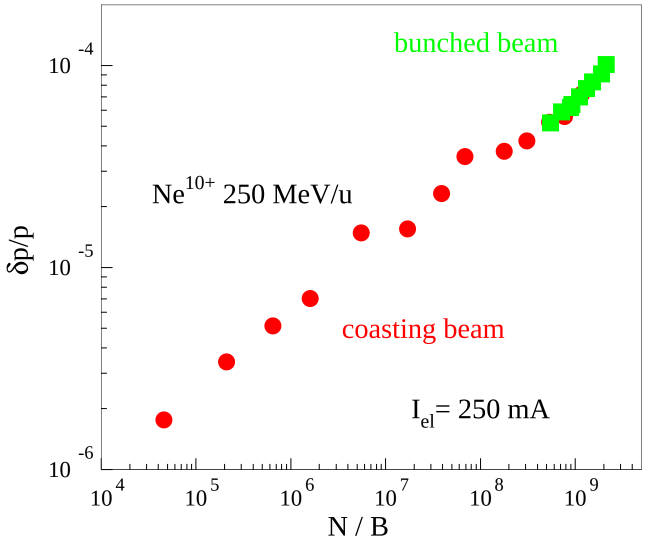
Stability of Extracted Beam

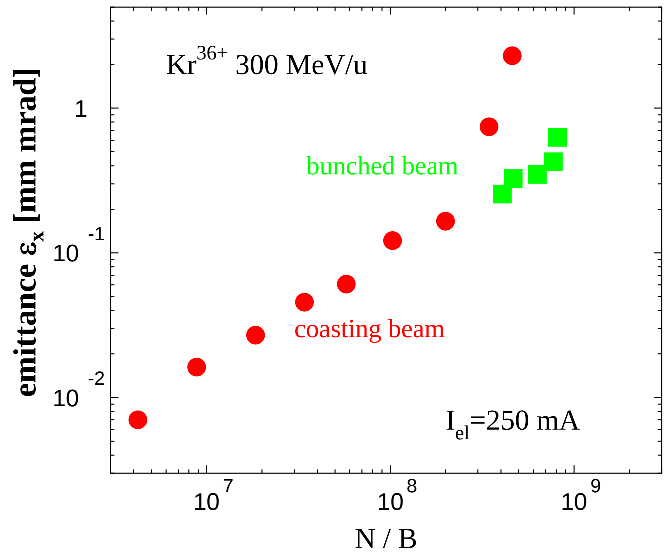


position of extracted beam stable to better than ± 0.5 mm

Parameters of Bunched Beams

comparison coasting beam - bunched beam
as a function of the line density



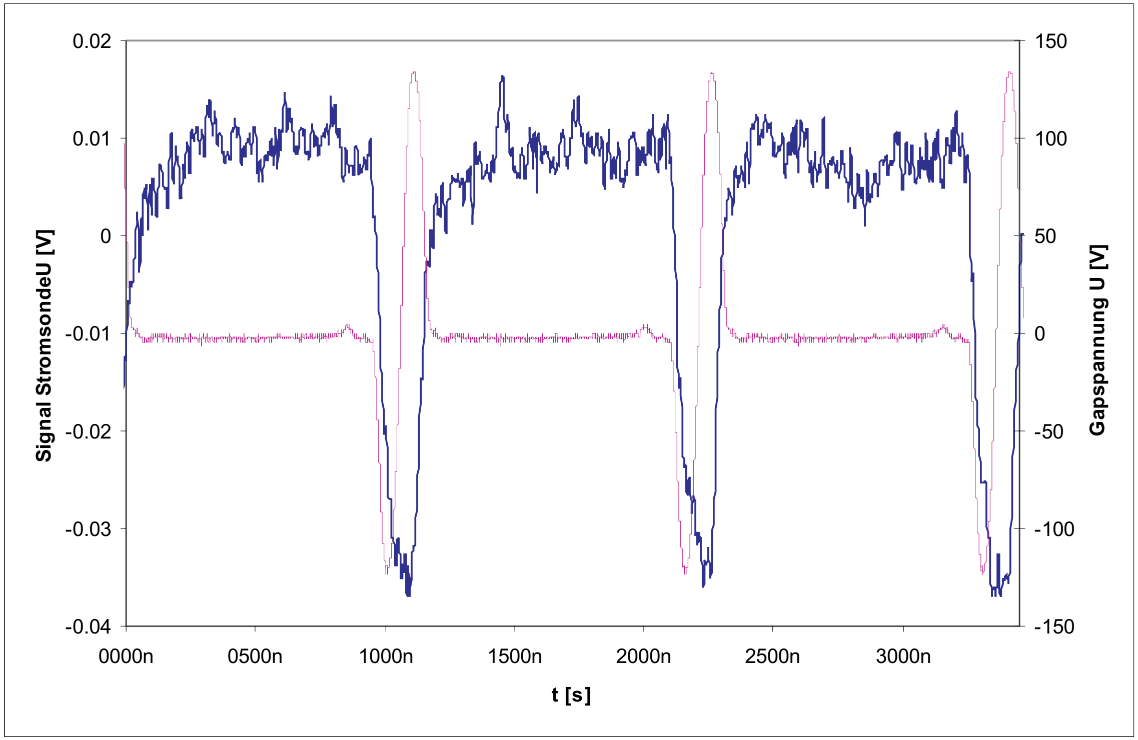


bunched beams show the same IBS dominated beam parameters as coasting beams

for HITRAP: with a bunching factor B=0.25 emittance and momentum spread will increase by a factor of about 2.

Test of Barrier Bucket Generation

Kr^{36+} 50 MeV/u *G. Schreiber, P. Hülsmann*



Barrier buckets tests for the FAIR project
- **beam transfer**
- **beam accumulation (secondary beams)**

modification of ESR cavity (broadband)
allows operation at h=1 with rf amplitude 170 V

alternative: capacitive load to lower eigenfrequency to 250 kHz

Potential ESR Upgrades for HITRAP

- Compress decelerated beam to less than 1 microsecond (B=0.25)
- Optimize beam transport to HITRAP (focussing, position, stability)
- Optimize beam diagnostics
- Accelerate deceleration:

  reduce cycle time:

  present deceleration cycle time of about 60 sec.
  cooling time 15, 5, 10 sec
  deceleration 10 + 5 sec
  injection, extraction, ramping up 10 s

  measures:

  stochastic cooling after injection
  ($\rightarrow$ faster cooling, reduced ramping of cooler)

  faster ramping (ramp rate 0.5 T/s was demonstrated)

but: time consuming developments