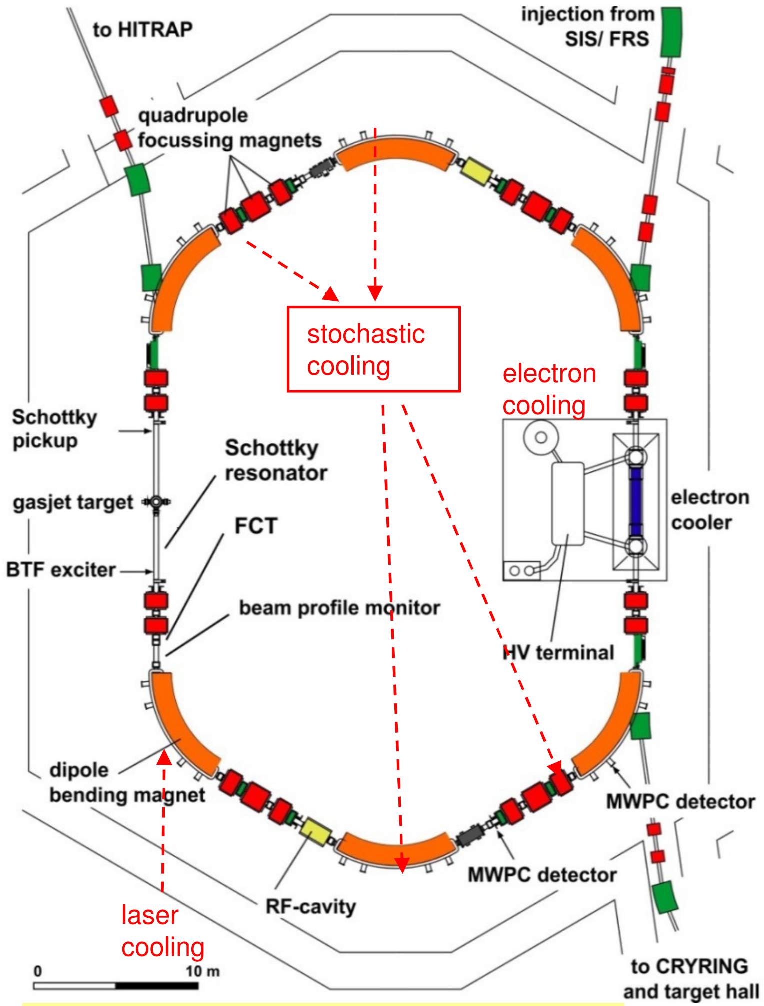
Stochastic Cooling at the ESR

M. Steck
(standing in for F. Nolden)
Storage Rings
GSI Accelerator Operations

The Heavy Ion Storage Ring ESR



circumference 108.36 m
bending power 10 Tm

Stochastic cooling (≥ 400 MeV/u)

Electron cooling (3 - 430 MeV/u)

Laser cooling (C^{3+} 120 MeV/u)

Fast injection (stable ions / RIBs)

Beam accumulation

Internal gas jet target

Deceleration (down to 3 MeV/u)

Fast extraction (HITRAP/CRYRING)

Slow (resonant) extraction

Ultraslow extraction (charge change)

Multi charge state operation

Schottky Mass Spectrometry (SMS) of RIBs

Isochronous mode (TOF detector)

Stochastic Cooling at the ESR

goal:

fast (in seconds) pre-cooling

of hot fragment beams

energy 400 (- 550) MeV/u

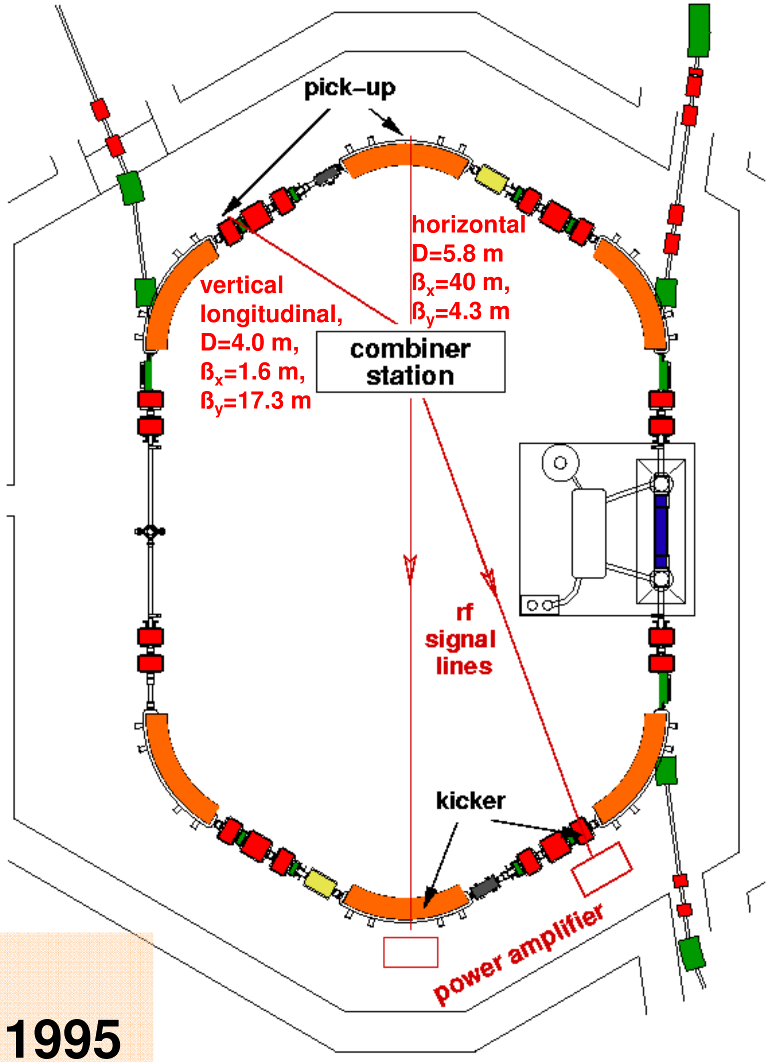
bandwidth 0.8 GHz (range 0.9 - 1.7 GHz)

$\delta p/p = \pm 0.35\ \%$ → $\delta p/p = \pm 0.01\ \%$

$\varepsilon = 10 \times 10^{-6}$ m → $\varepsilon = 2 \times 10^{-6}$ m

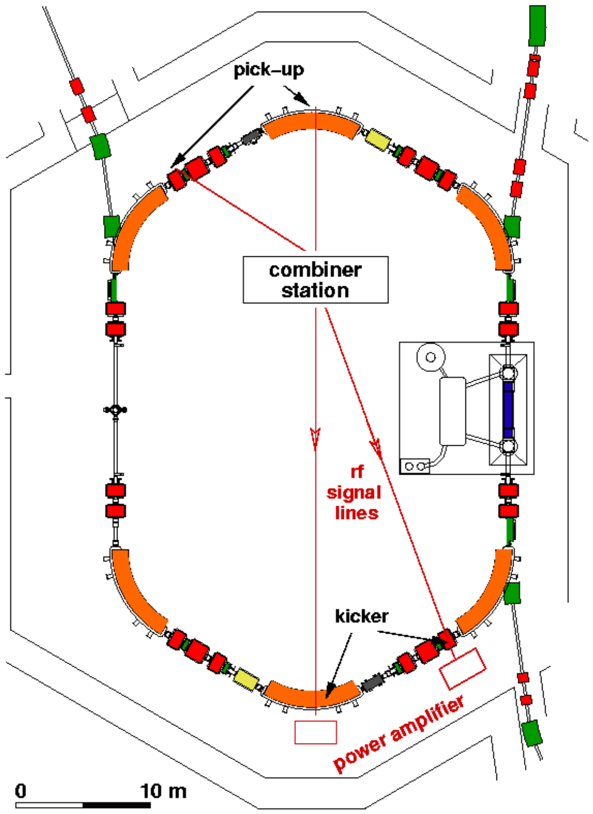
stochastic cooling is performed with

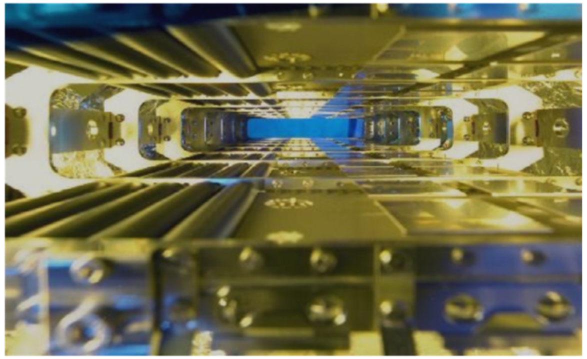
the normal ESR ion optical lattice



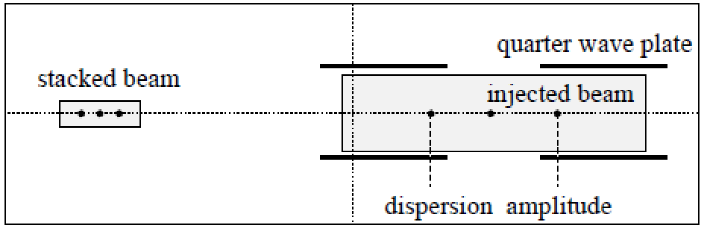
the ESR stochastic cooling system was installed and commissioned in the ESR in 1995

Stochastic Cooling Electrodes

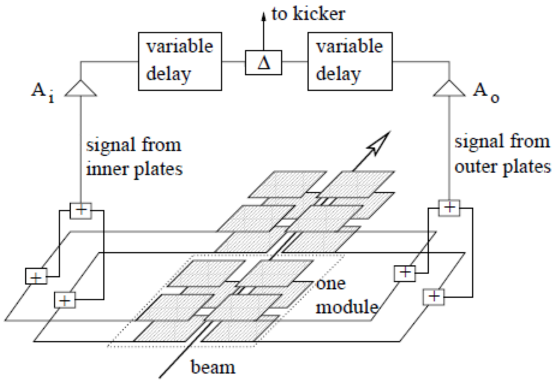




electrodes (pick-ups and kickers) are installed inside magnets because of lack of space



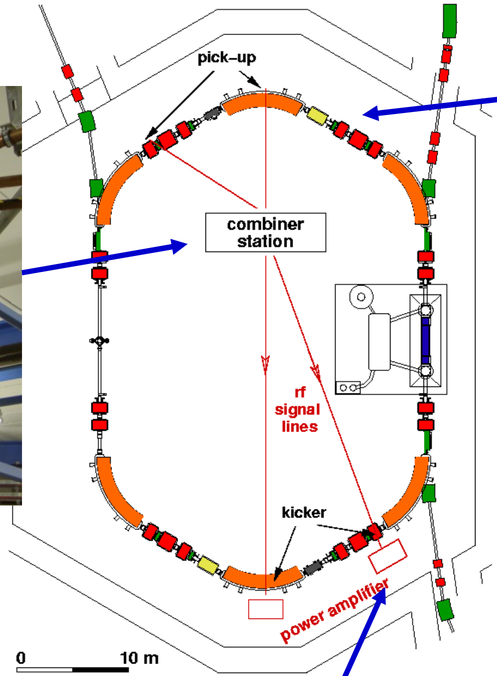
electrodes are installed in sections with large dispersion



the signals of 4x8 superelectrodes (two quarter–wave plates) are combined outside the vacuum
⇒ 32 feedthroughs/station

Stochastic Cooling RF Aspects

combination and
manipulation of the rf signals
from the electrodes

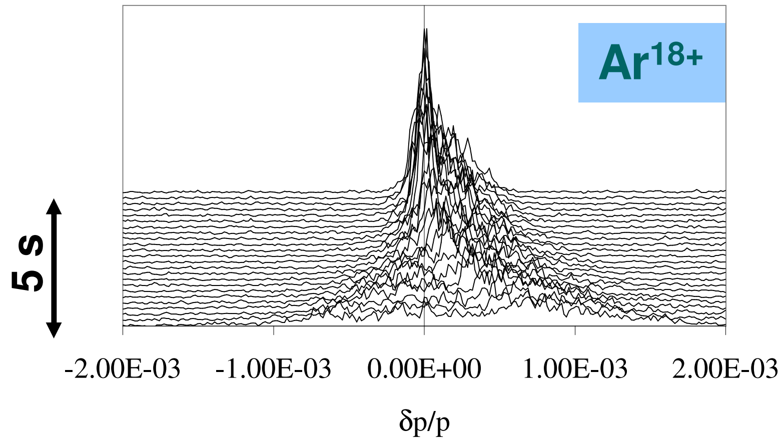


damping material to absorb rf signals
travelling around the ring

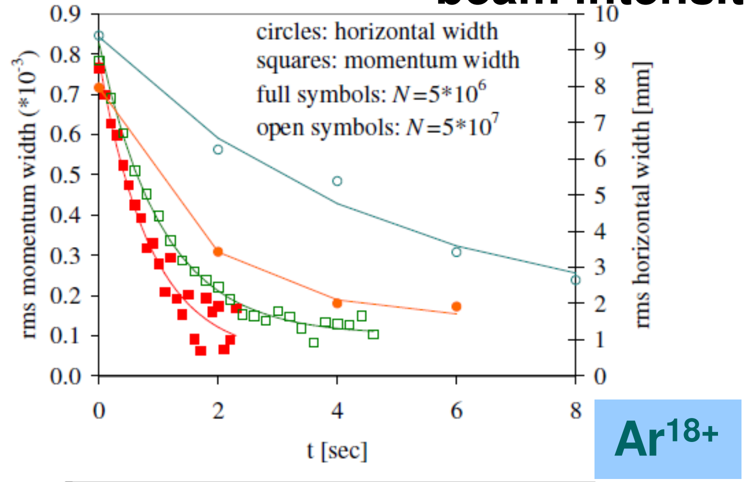
power amplifiers 0.9-1.7 GHz
were chosen due to availability
at the time of the design of the
cooling system,
total installed rf power 2kW

Stochastic Cooling

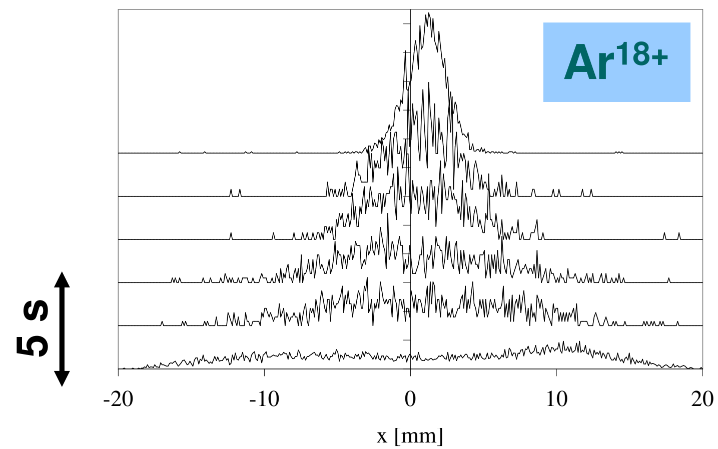
Longitudinal cooling (Schottky noise)

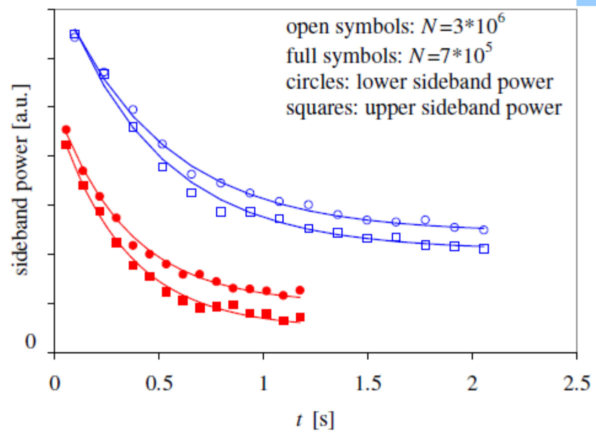


Cooling time dependent on beam intensity



Transverse cooling (beam profile monitor)

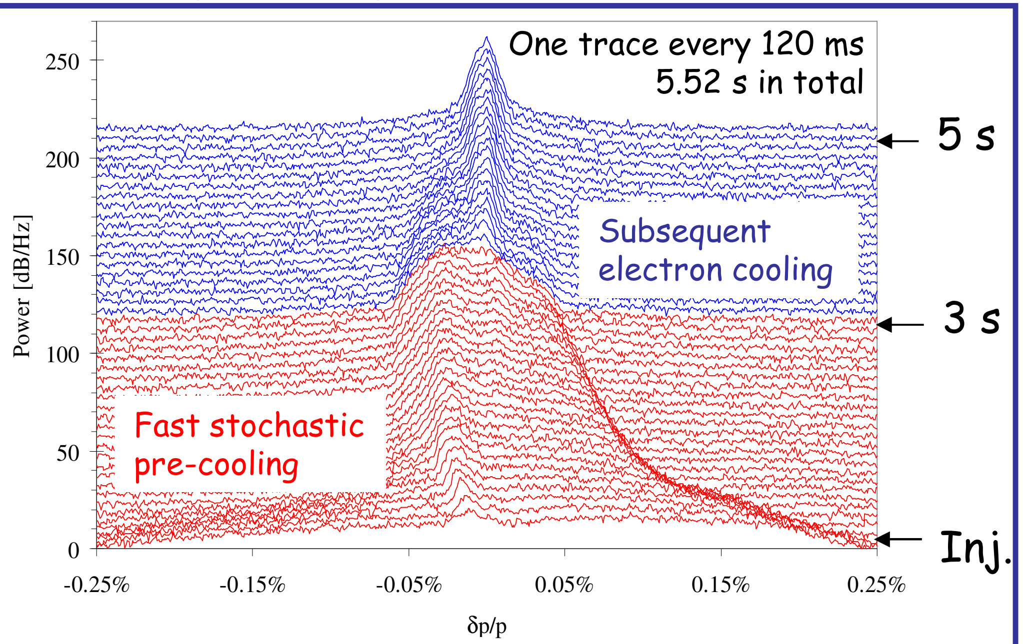




cooling time for U^{92+} (N=10^6):
longit., vert.: 0.5 s, horiz.: 2.5 s

Combination of Stochastic and Electron Cooling

stochastic pre-cooling + **final electron cooling**
immediately after injection

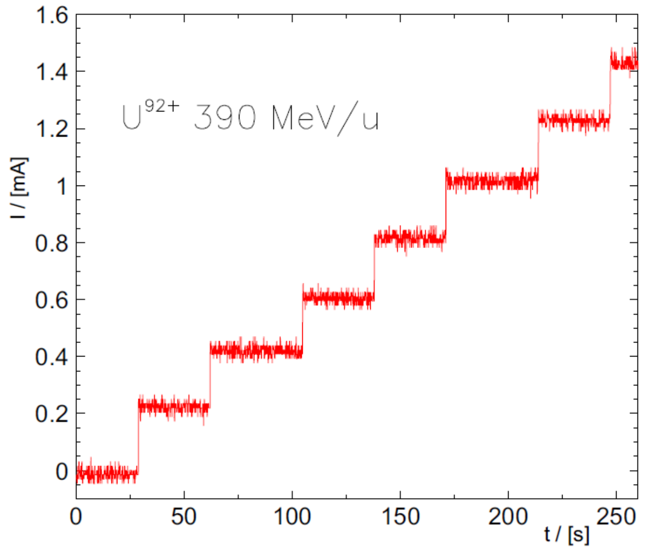


Primary Uranium beam
heated in thick target

Stochastic pre-cooling reduces the total cooling time to a few seconds, electron cooling only takes 10 - 60 s

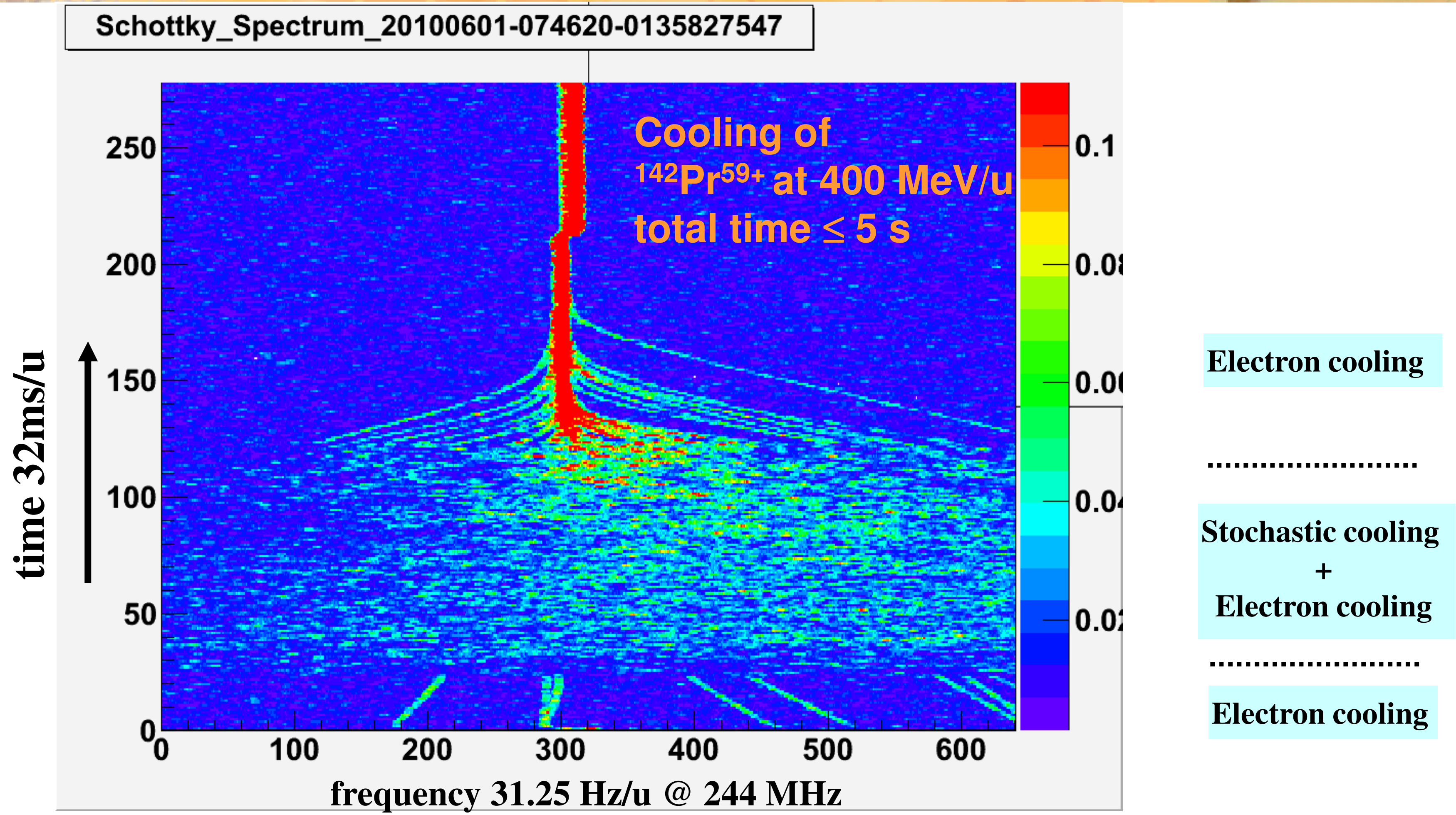
Accumulation of secondary beams

1) s.c. on injection orbit
2) rf stacking
3) electron cooling of stack



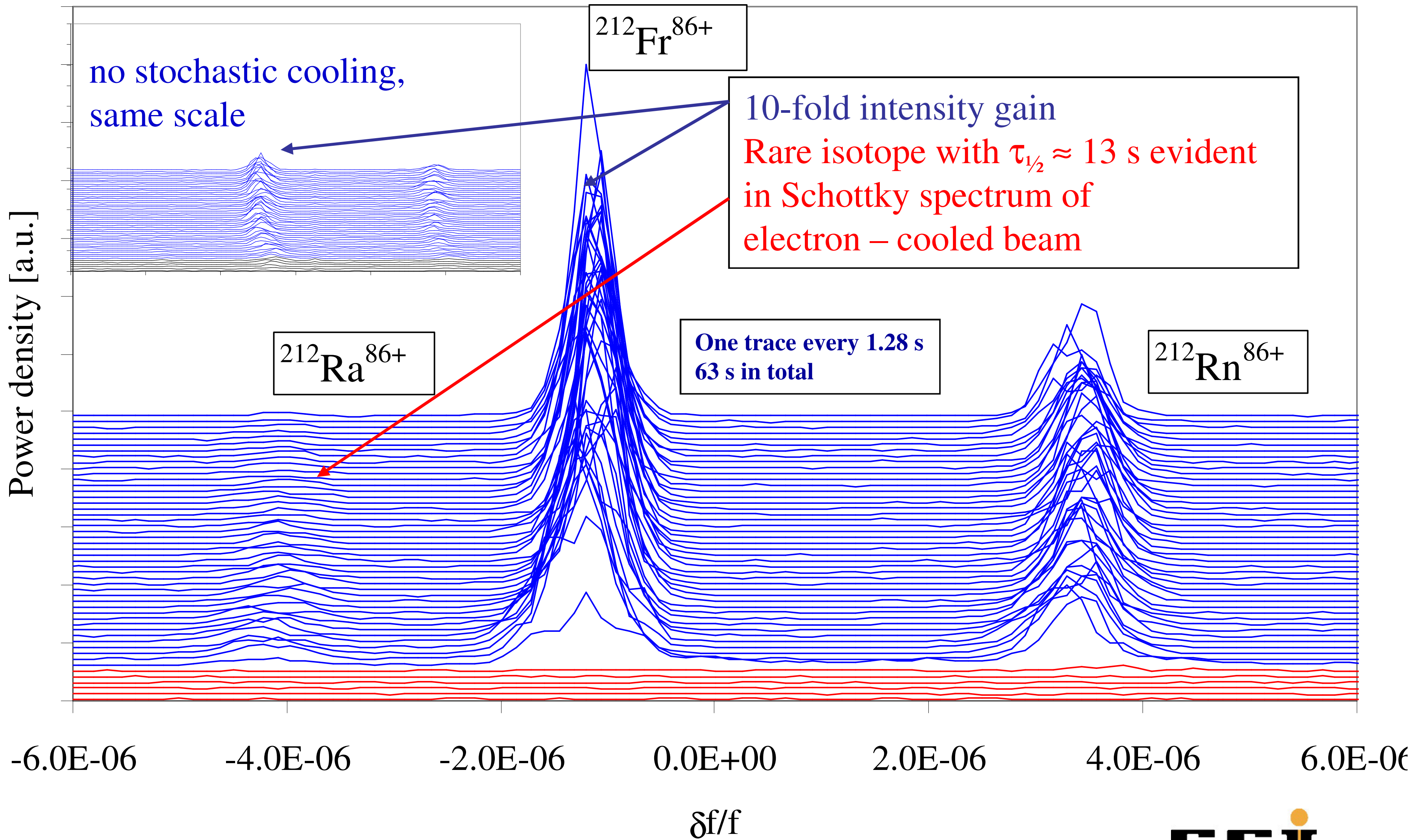
Intensity increase for secondary beams

Cooling of Very Few Injected Ions

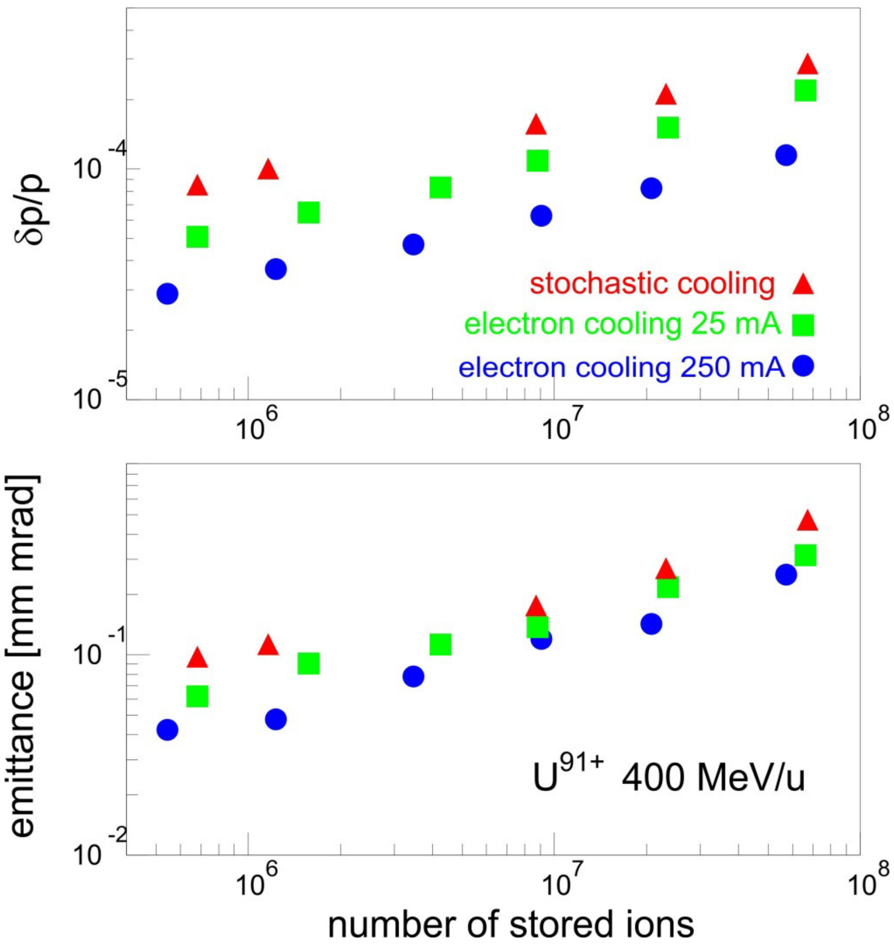


in experiments with very few (down to single) stored ions stochastic cooling efficiently served as pre-cooling for electron cooling reducing the total cooling time

Intensity Gain of Rare Isotope Beams due to Stochastic Pre-Cooling



Equilibrium Beam Parameters of the Cooled Beam in the ESR



limited by intrabeam scattering

Electron cooling results in smaller momentum spread and smaller emittance.

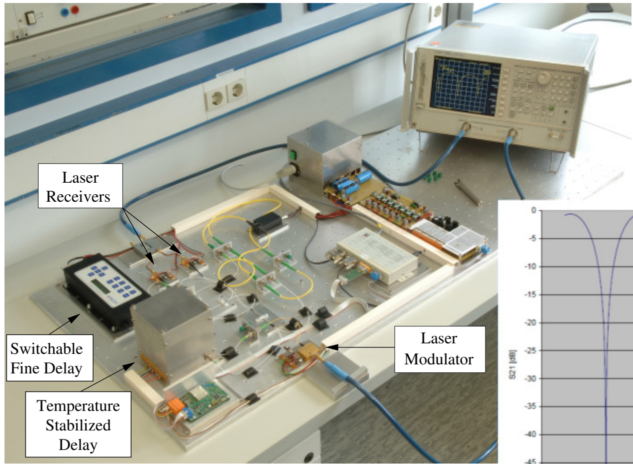
The equilibrium is a balance between the cooling rate and the heating rate by intrabeam scattering.

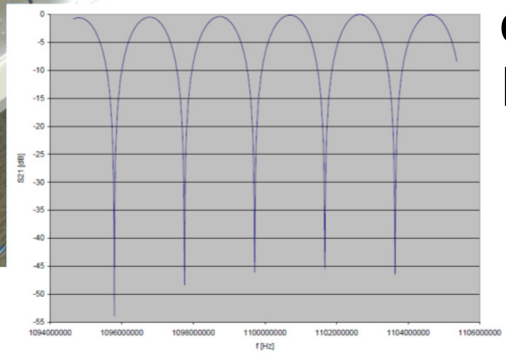
<u>calculated IBS-heating/cooling rate [s^{-1}]</u>

	longit.	transv.
stoch. cool.	0.9 - 2.2	0.5 - 1.3
el. cool. [25 mA]	2.0 - 6.0	1.4 - 3.3
el. cool. [250 mA]	18 - 58	7 - 10

electron cooling is more powerful in producing cold beams, it provides higher cooling rate for cold beams

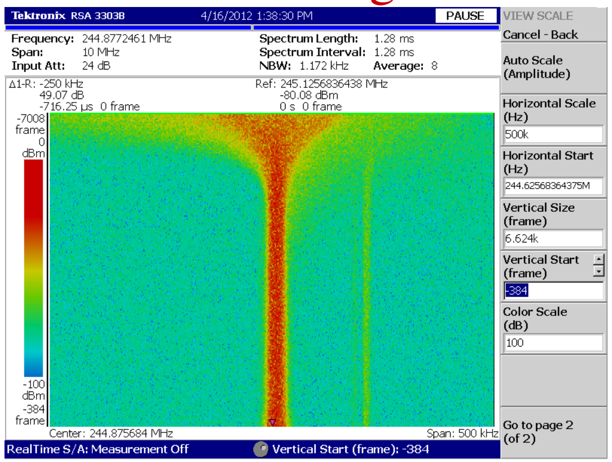
Test of Notch Filter Cooling at the ESR



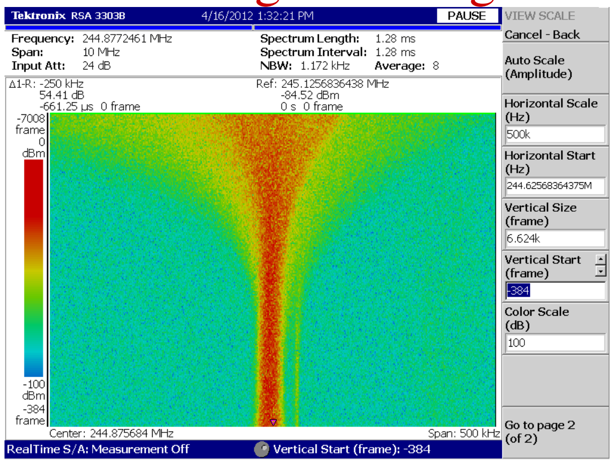


Optical delay line installed in the ESR for tests of TOF and notch filter cooling using existing electrodes designed for Palmer cooling

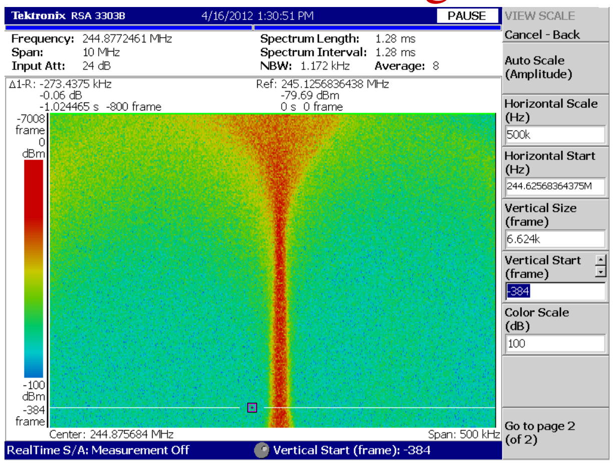
Palmer cooling



Time-of-Flight cooling

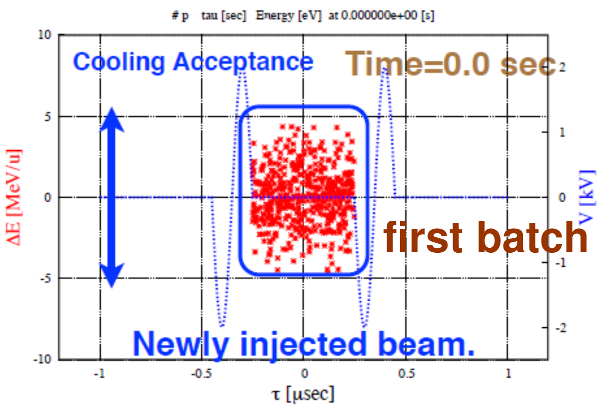


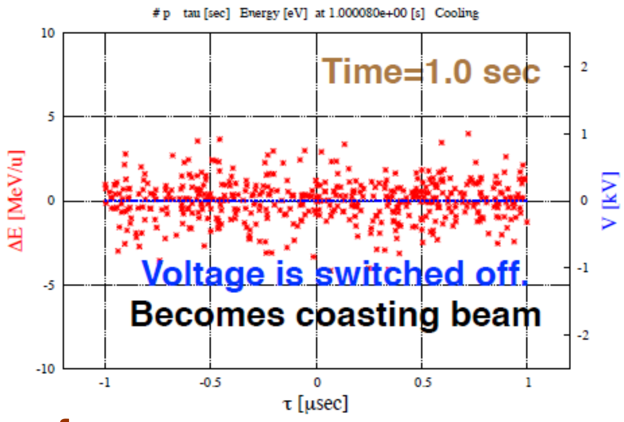
Notch filter cooling

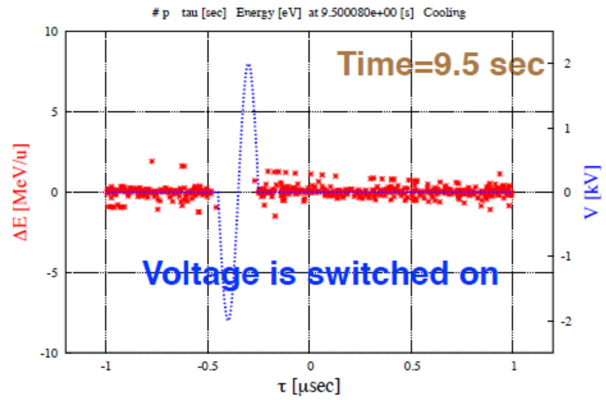


Ar^{18+} 400 MeV/u

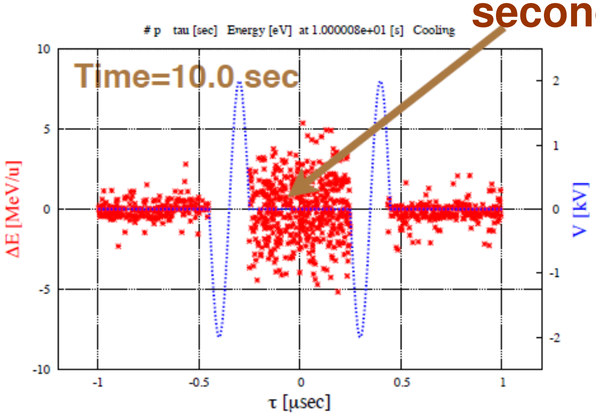
Barrier Bucket Accumulation in the HESR

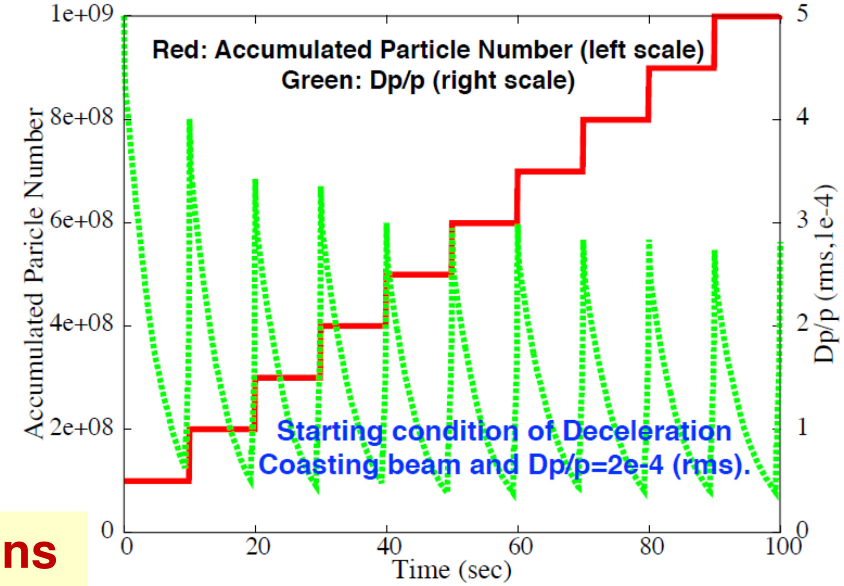






injection of second batch



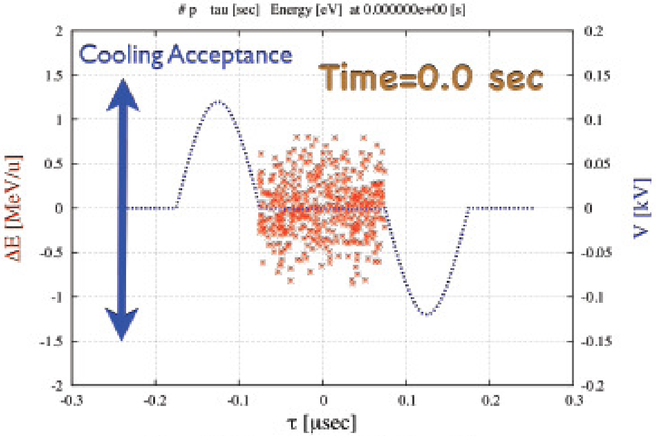


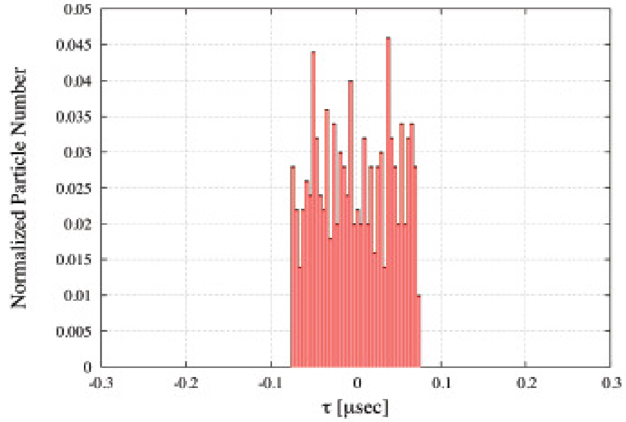
accumulation (in 1000 s) of 1 × 10^{10} antiprotons

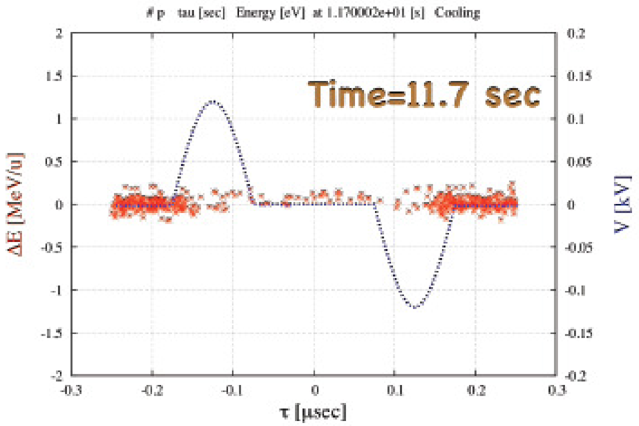
simulation by T. Katayama

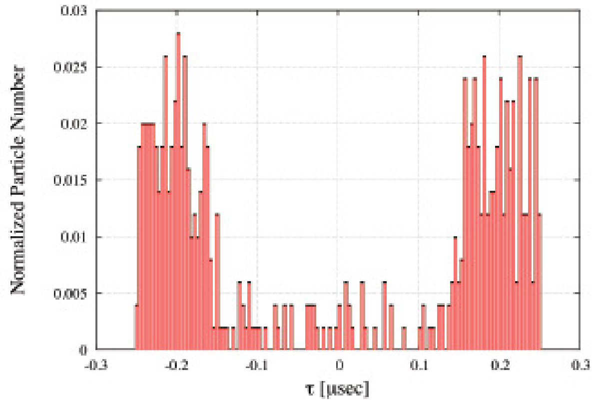
Beam Accumulation with Stochastic Cooling Proof-of-Principle Experiment in the ESR

method proposed for antiproton accumulation in the HESR



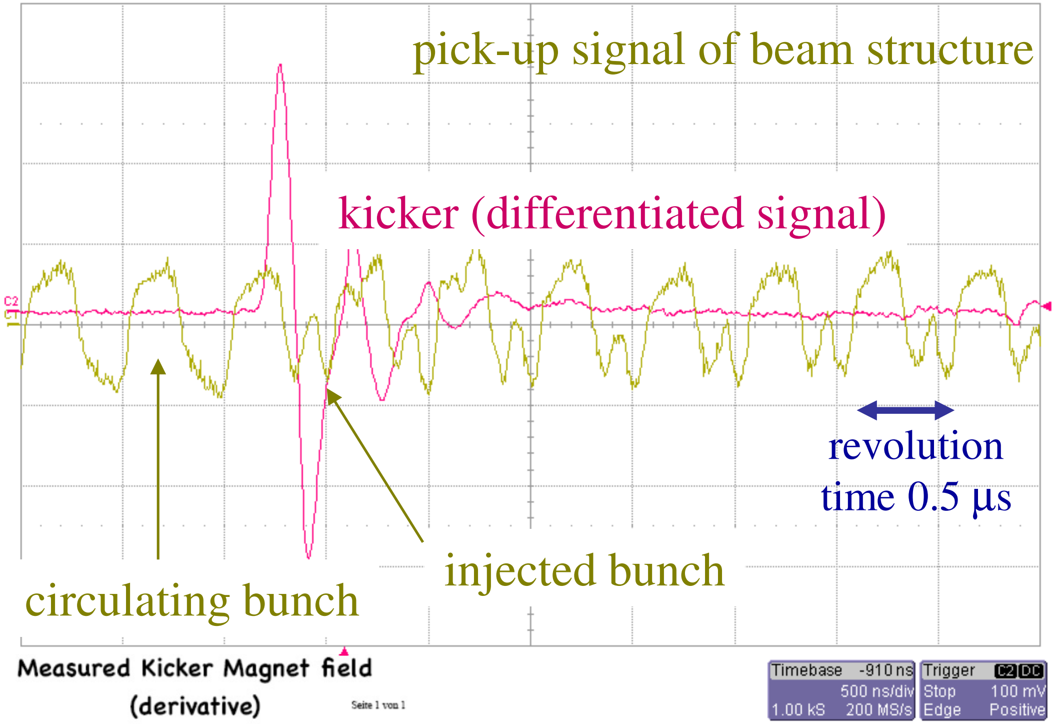




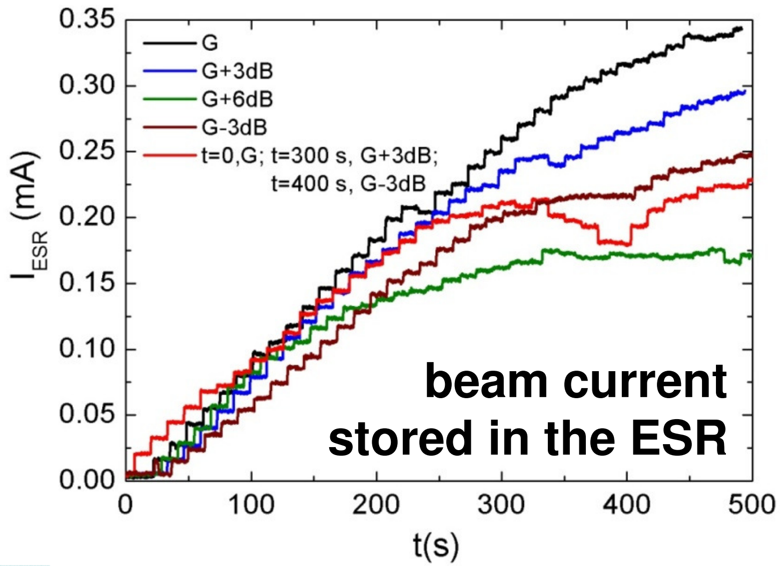


simulation
by T. Katayama

Proof of Principle Experiment at ESR
Longitudinal Accumulation with Stochastic Cooling

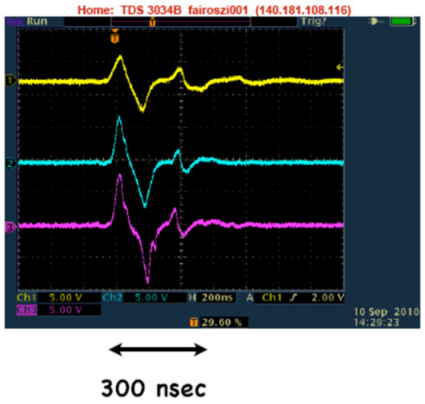


using a single bunch of Ar^{18+} at 400 MeV/u from SIS



Measured Kicker Magnet field
(derivative)

Seite 1 von 1



precise (ns) timing of injection kicker required

kicker pulse length 50-200 ns is very demanding

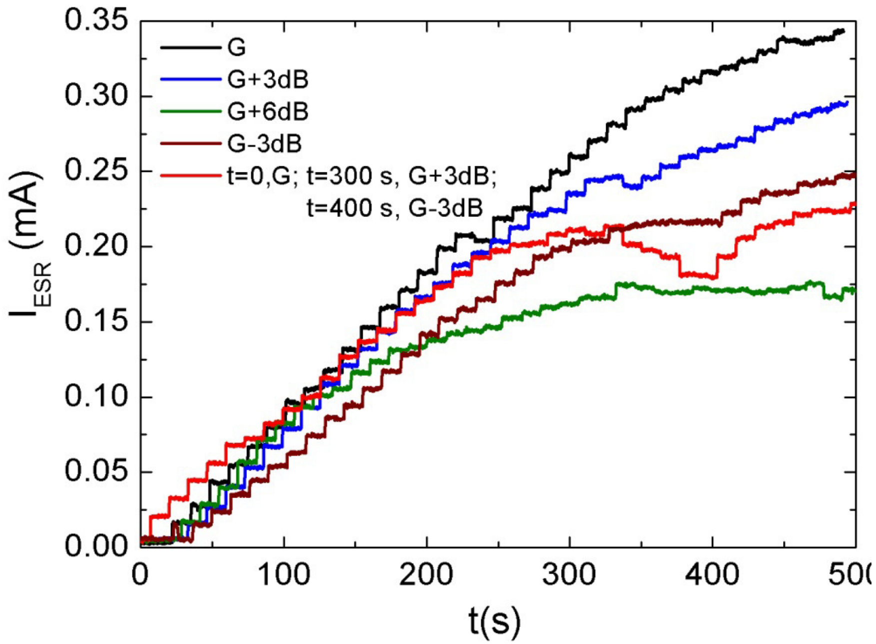
(rf h=1 stacking on unstable fixed point accumulated with application of stochastic cooling)

PoP-Experiment ESR

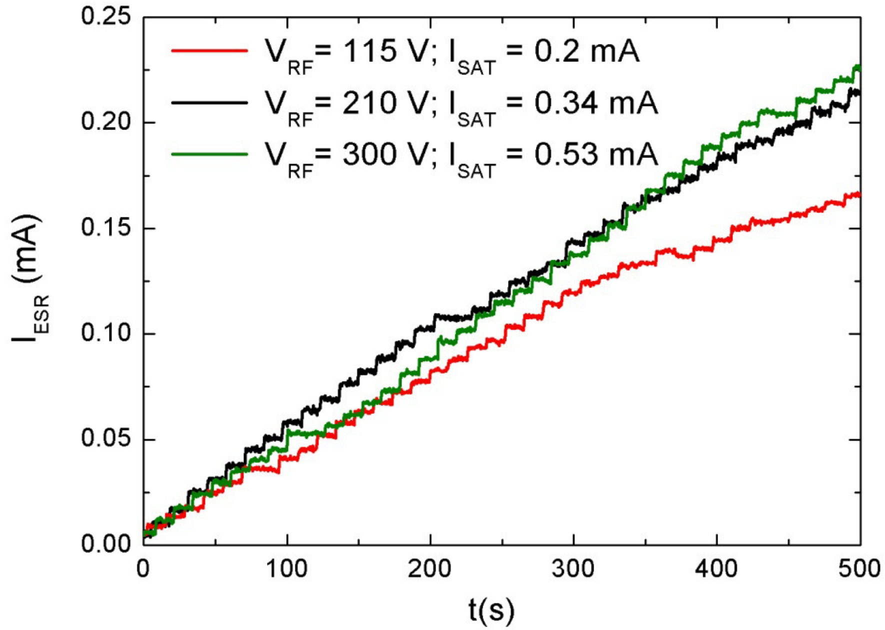
Stacking by combination of rf and stochastic cooling

with good efficiency and reliability

Ar^{18+} 400 MeV/u



rf h=1 stacking on unstable fixed point

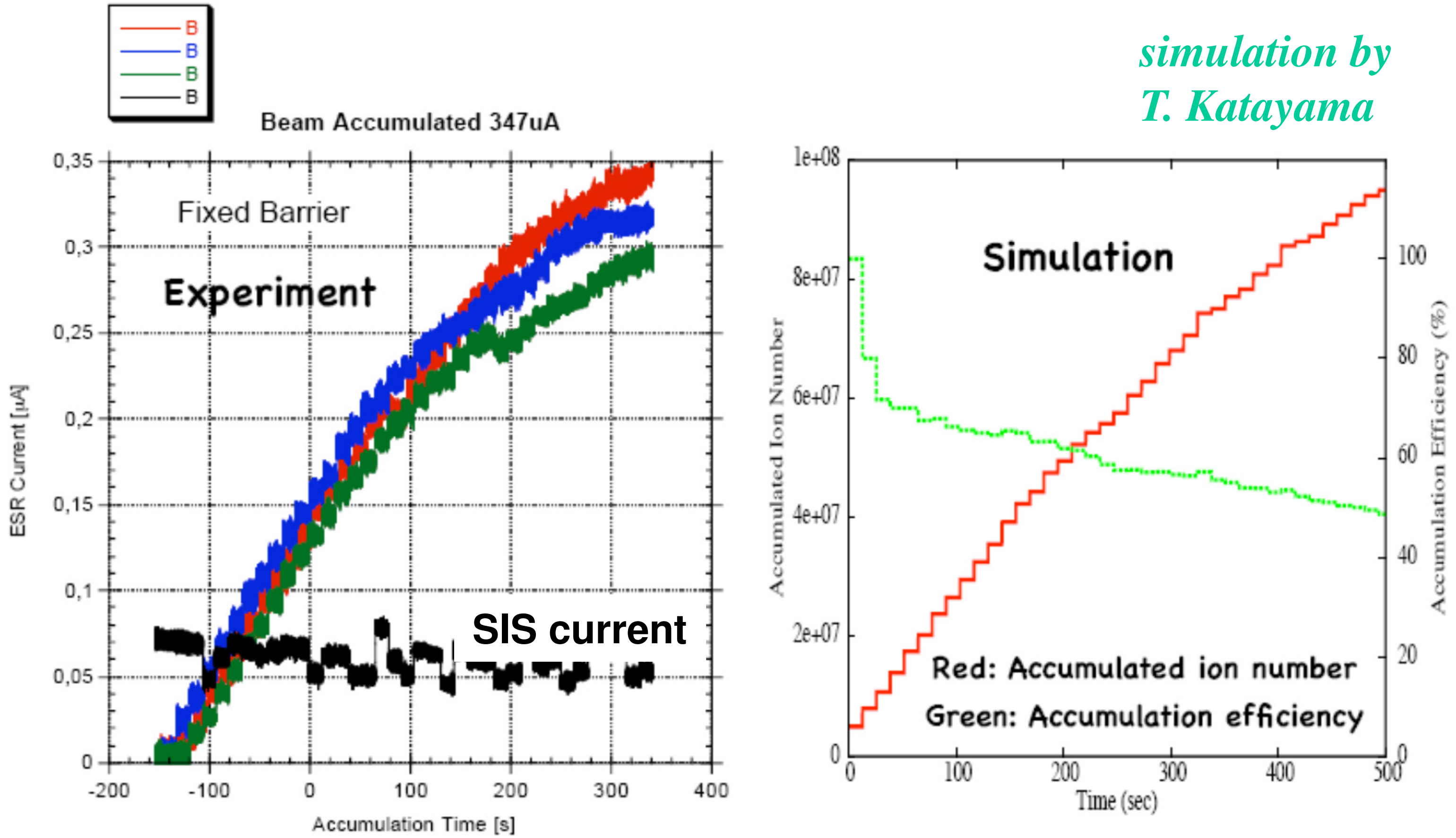


stacking with fixed barriers

stacking with moving barriers unsuccessful due to limited rf amplitude

Comparison PoP-Experiment - Simulation

Fixed barrier bucket at ESR POP experiment



PoP experiment mainly to demonstrate the method and benchmark codes, limited by ESR hardware (no dedicated barrier bucket rf system)

Experience with Stochastic Cooling at the ESR

Stochastic cooling always 3-D at fixed energy 400 MeV/u, protons to U^{92+}

cooling from single ions up to 10^8 U^{91+} ions

pre-cooling for final electron cooling on injection orbit

rf stacking with stochastic cooling on injection orbit and electron cooling on inner (stack) orbit

stacking with barrier buckets and stochastic cooling on injection orbit

Stochastic cooling at injection energy within deceleration cycle

only one experiment used the beam with continuous stochastic cooling (DR of U^{91+})

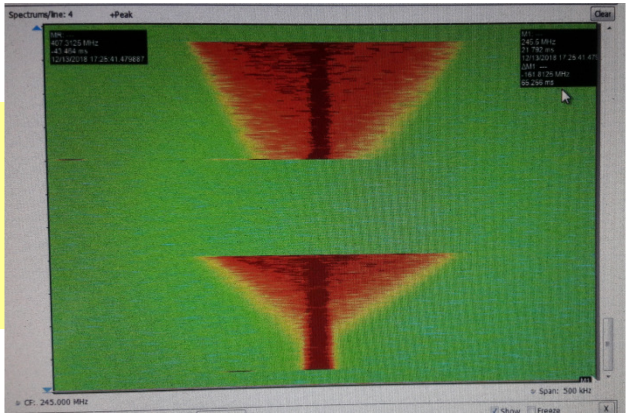
Tuning of stochastic cooling system based on the use of electron cooled beams

Main tuning diagnostics method was Schottky noise detection of analog signals (longitudinal and transverse)

ESR Re-Commissioning

- The old control system is stopped and not available any more
- The ESR needs to be re-commissioned with the new control system
- Various tools (e.g. tune and orbit correction) have to be implemented
- Stochastic cooling has to be performed in the frame of the new control system

first beam storage and electron cooling with the ring operated by LSA control system, December 17, 2018, after a two and a half years‘ shutdown

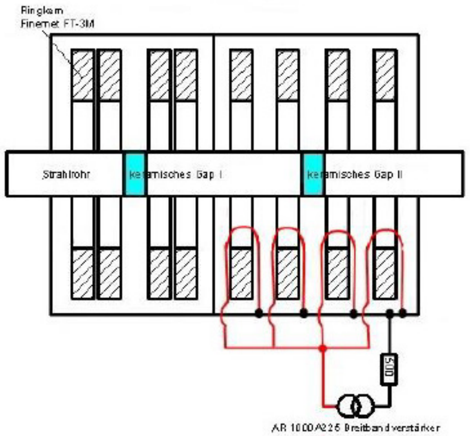


Future stochastic cooling at the ESR:

- Integrate stochastic cooling operation into new control system
- Establish a routine deceleration cycle with initial stochastic cooling
- Move analog to digital signal acquisition and processing
- Extension of stochastic cooling to higher energy

New ESR Barrier Bucket Cavity

1) accumulation in combination with cooling
2) bunching of the beam for fast extraction at low energy



Technical Parameters

frequency 0.25 - 5 MHz
maximum voltage 1 kV
rf power (at 5 MHz) 850 W
air cooling
two gaps
eight magnetic alloy rings