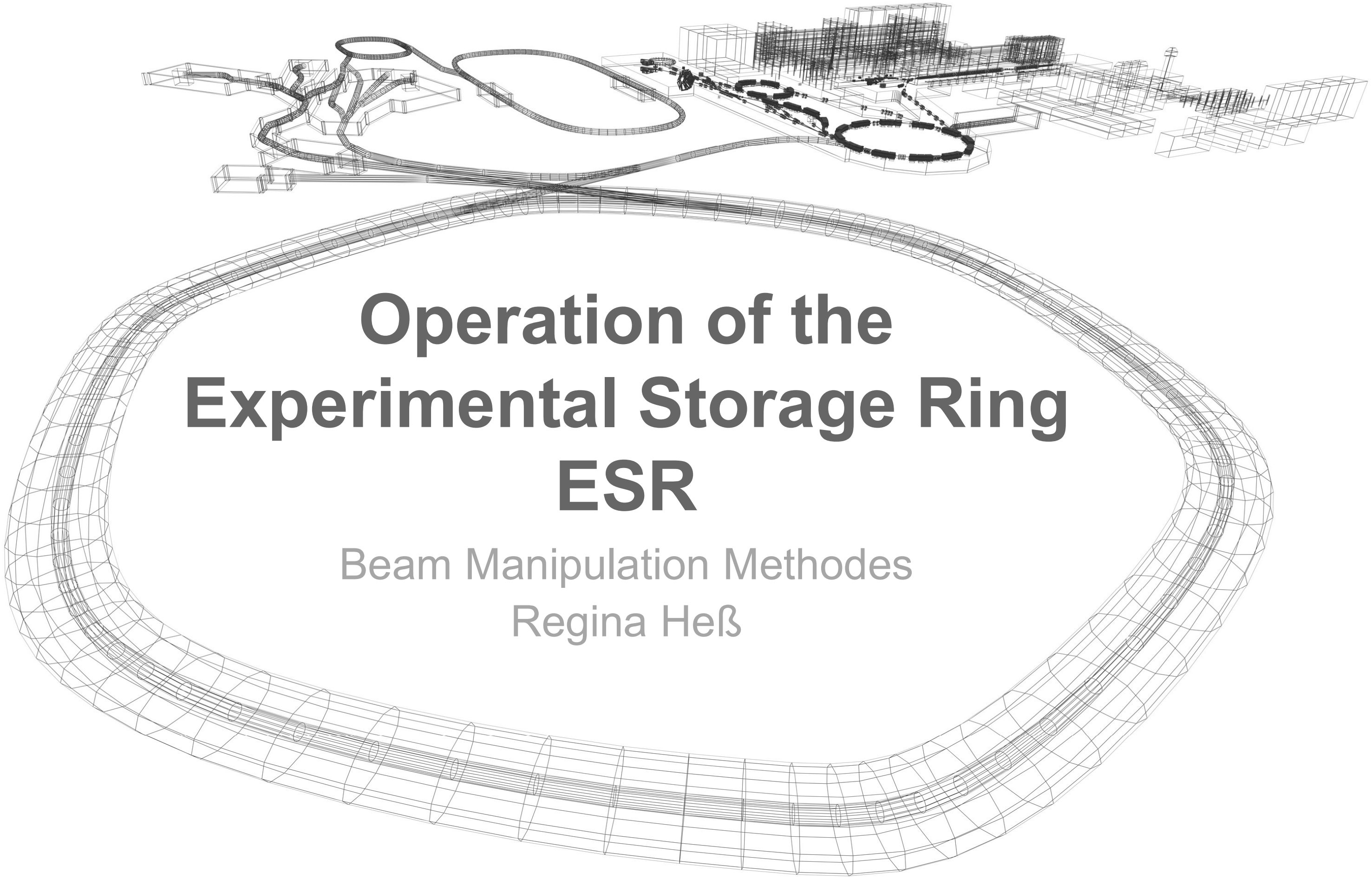


Operation of the Experimental Storage Ring ESR

Beam Manipulation Methodes

Regina Heß

GSI accelerator facility

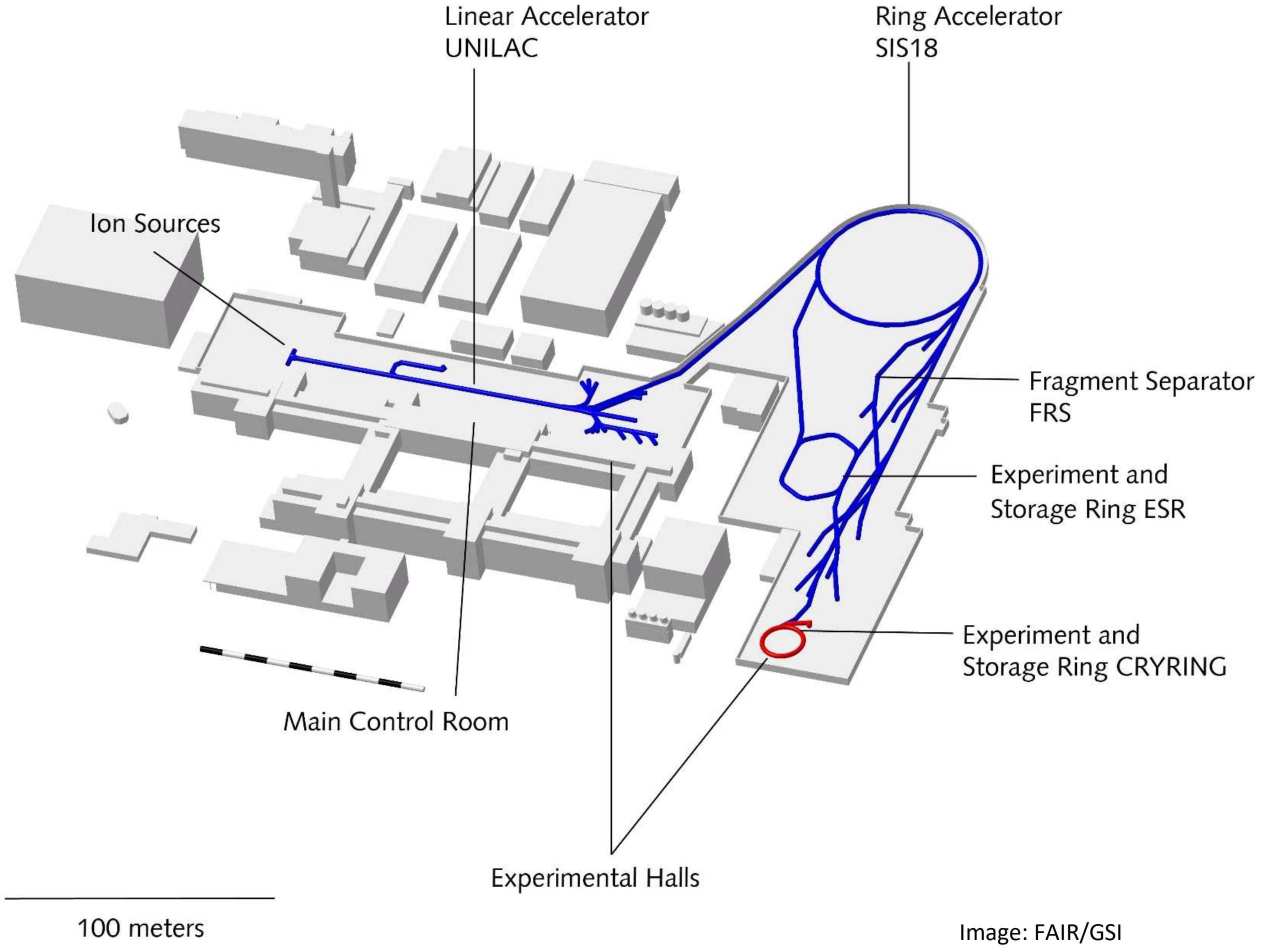


Image: FAIR/GSI

UNILAC

- 3 ion sources @ 2 injectors
- 11.4 MeV/u → 15% speed of light

SIS18

- 18 Tm, 90-98% speed of light
- 4.5 GeV (protons), 1GeV/u (Uranium)

FRS (Fragment Separator)

- production and separation of rare isotopes

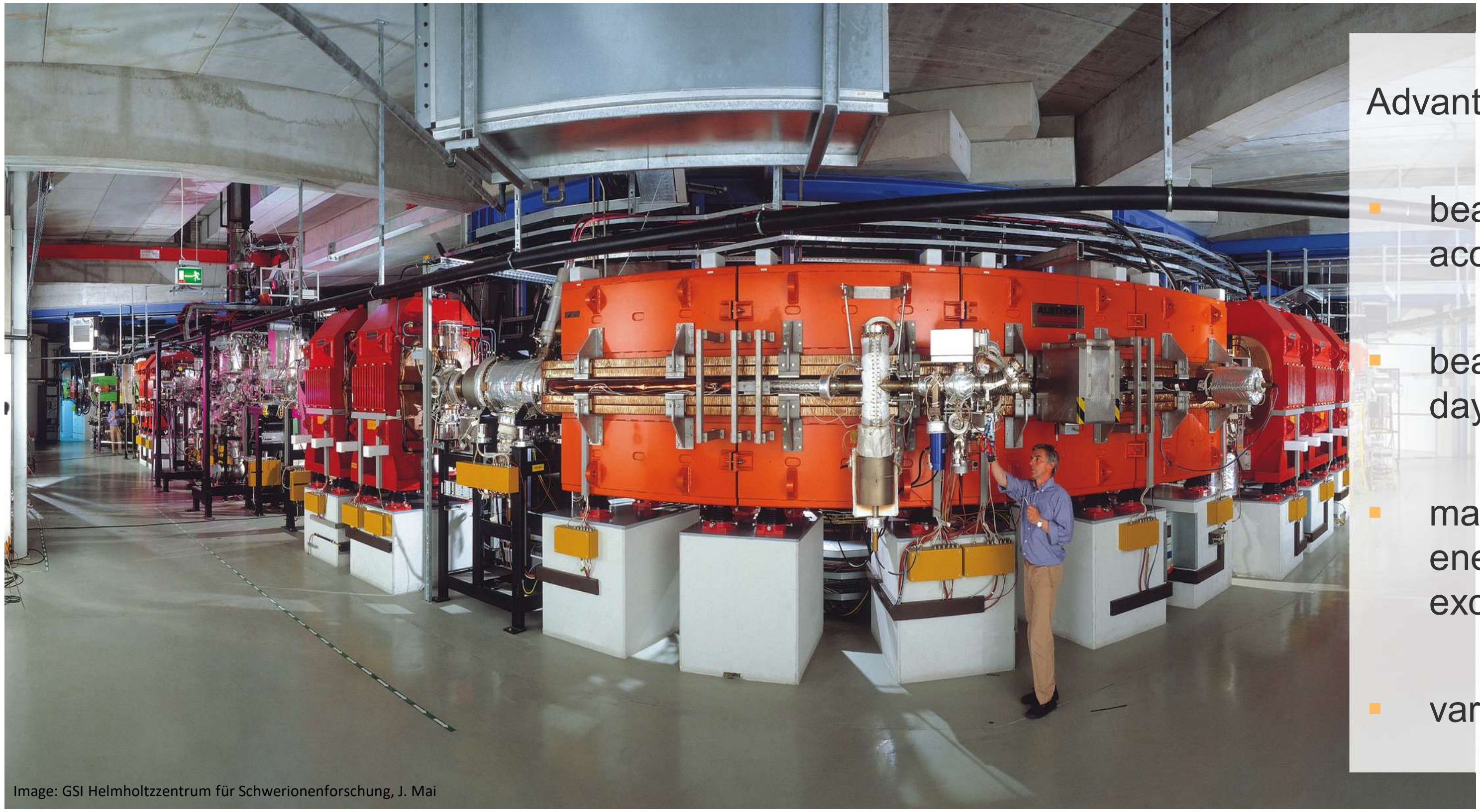
ESR (Experimental Storage Ring)

CRYRING (low energy storage ring)

HITRAP (decelerator & ion trap)

PHELIX (Petawatt High Energy Laser)

Experimental Storage Ring ESR



Advantage of a storage ring:

- beam is stored and does not need the accelerator chain continuously
- beam is used for a long time (seconds up to days)
- manipulations can be observed (cooling, energy change, charge exchange, excitation,…)
- various experimental installations possible

Experimental Storage Ring ESR

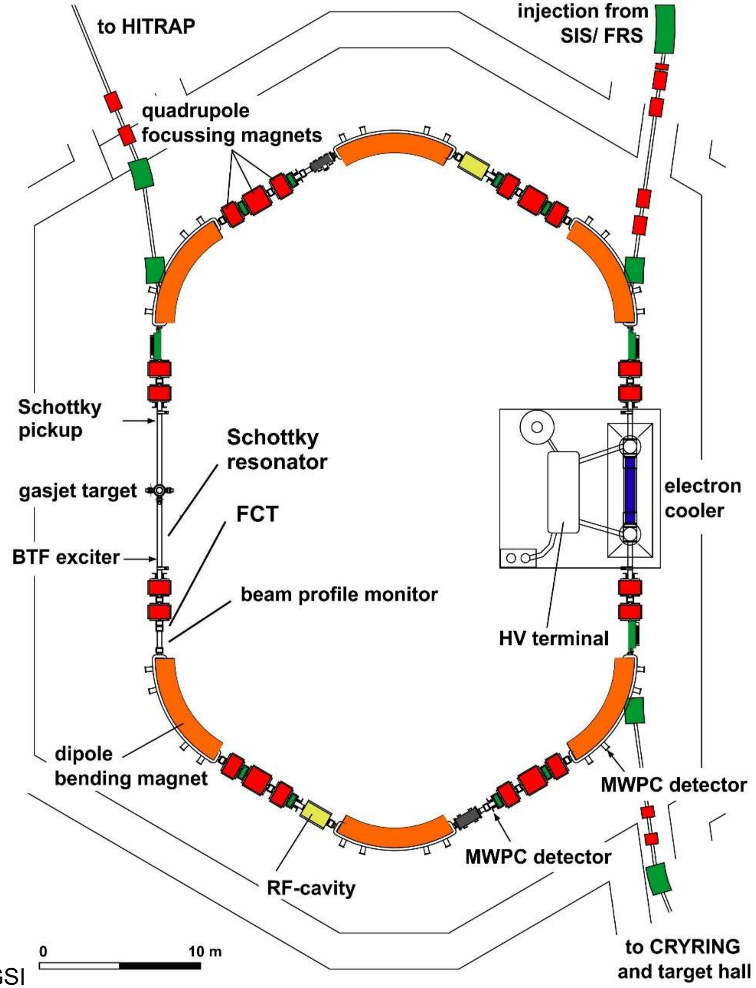
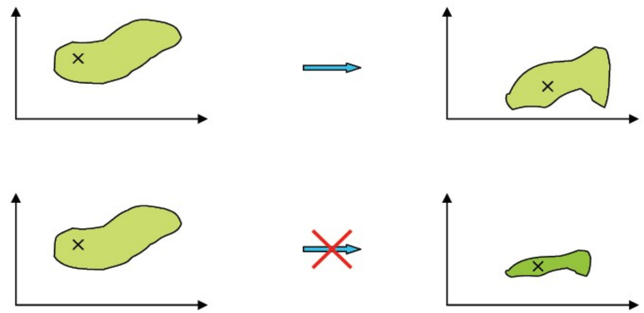


Image: FAIR/GSI

Technical details of the ESR	
Circumference	108.36 m
Maximum bending power	10 Tm
Energy range	4 MeV/u – 400 MeV/u
Ions	Z = 1 – 92 (Protons – Uranium)
RF	2 rf cavities
Beam cooling	Electron cooling Stochastic cooling
Vacuum	Operational 10-11 mbar
Beam diagnostics	12 position monitors dc transformer 2D beam profile monitor broad band Schottky monitor resonant Schottky monitor
Extraction	2 extraction points
Experimental equipment	internal gas jet target movable detector pockets laser beam windows

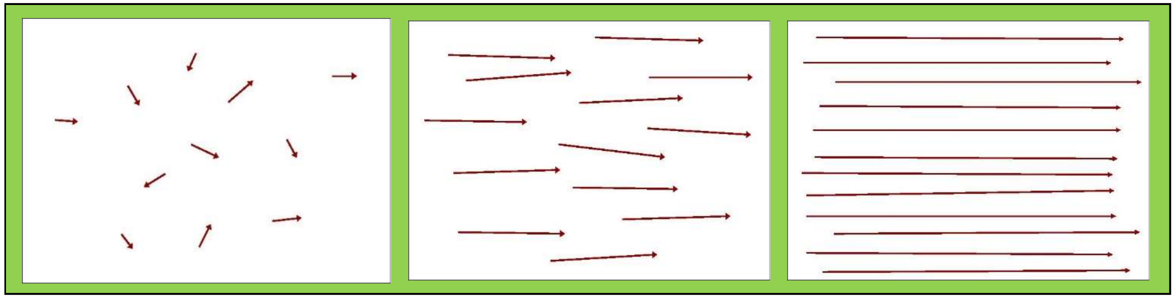
Challenges for beam storage

Liouville‘s theorem: The phase space distribution function is constant along the trajectories of the system



A beam in phase-space is like an incompressible liquid.

Beam temperature



at rest (source)　　low energy　　high energy

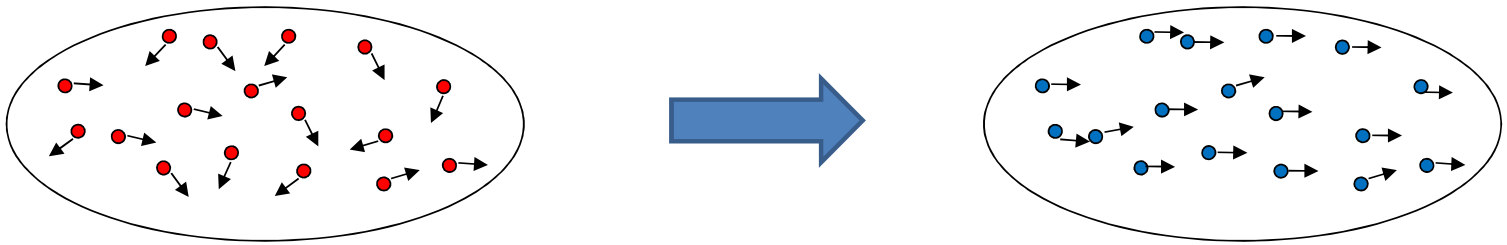
In a standard accelerator the beam temperature is not reduced. (The average motion after acceleration is superimposed to the thermal motion)

Many processes can heat up the beam (intrabeam scattering, targets, residual gas)

Stored beams: Cool before using!

hot beam

cold beam



chaotic movement of ions in the beam,

high intrinsic energy

defined movement, all ions in the beam move with the same nominal velocity, low intrinsic energy

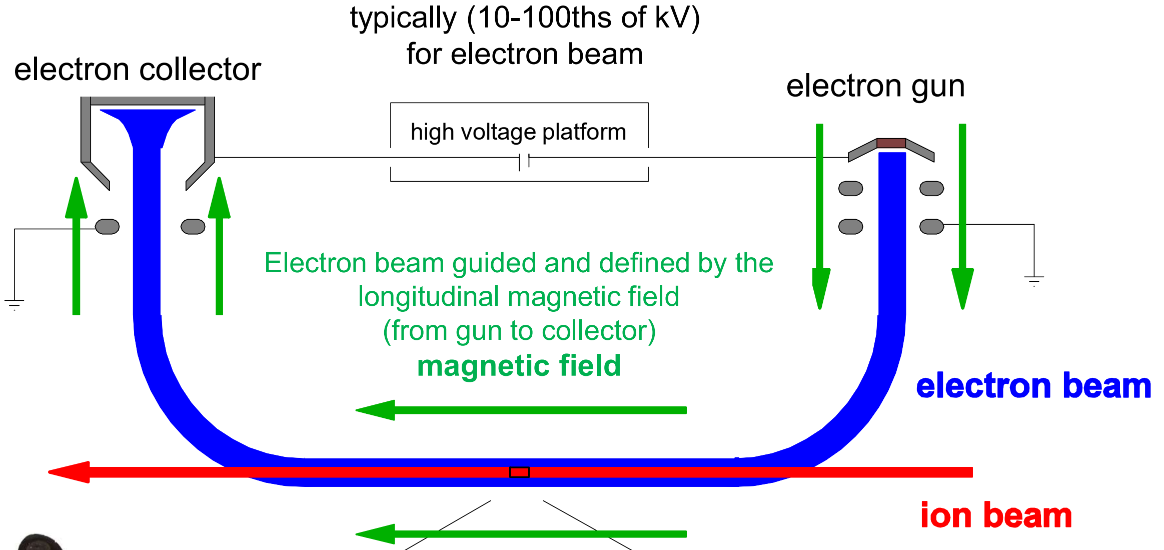
Solution: Beam cooling

→ Friction to remove inner energy from the beam: **electron cooling** (G. Budker 1966)

→ Electromagnetic-force on beam samples: **stochastic cooling** (S. van der Meer 1972, Noble prize in 1984)

→ realisation is difficult in both cases

Electron cooling



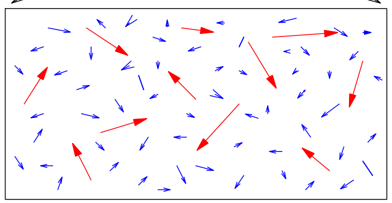


Image: M. Steck

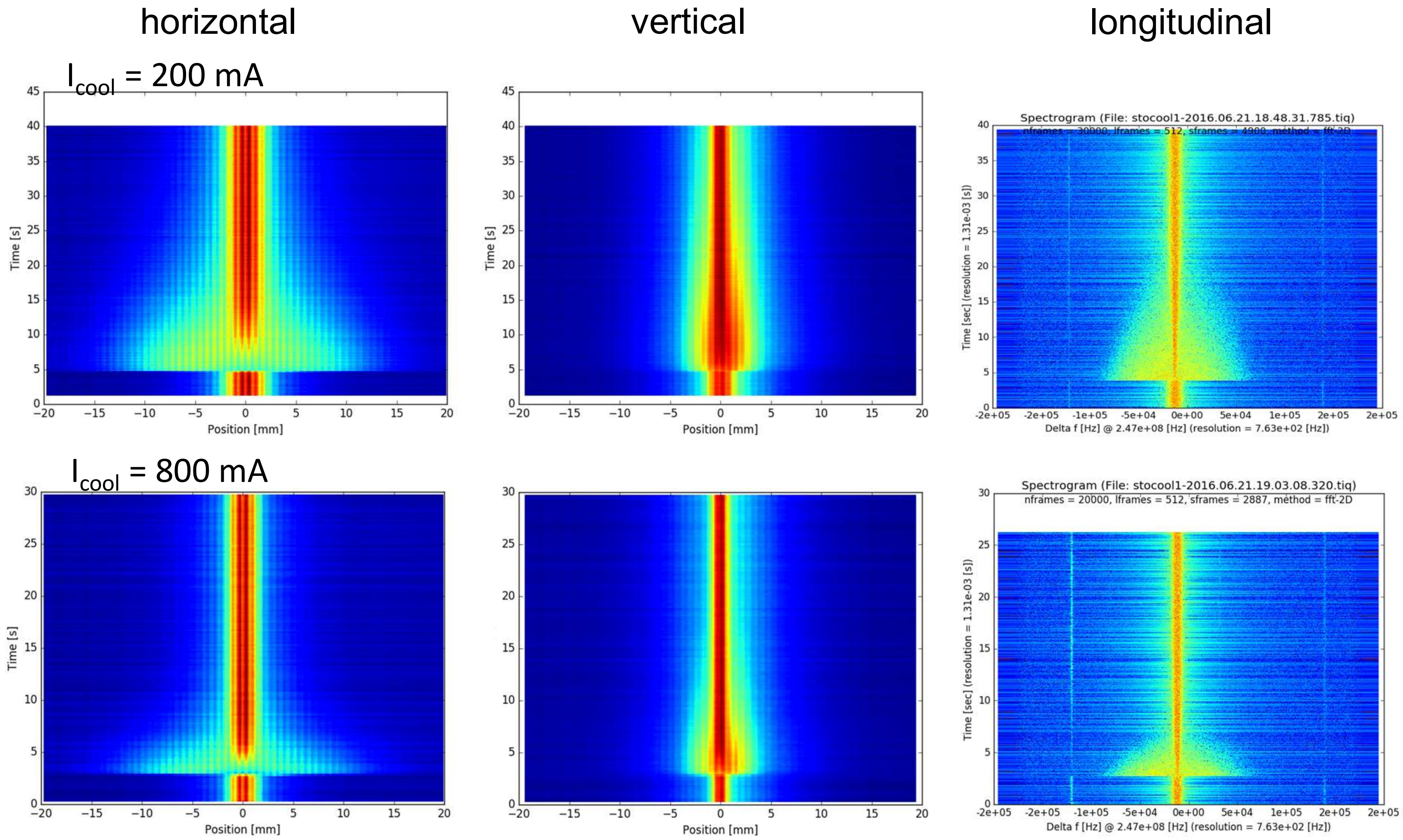
in the reference frame of the beam:
cold electrons interacting with hot ions

momentum transfer by Coulomb collisions

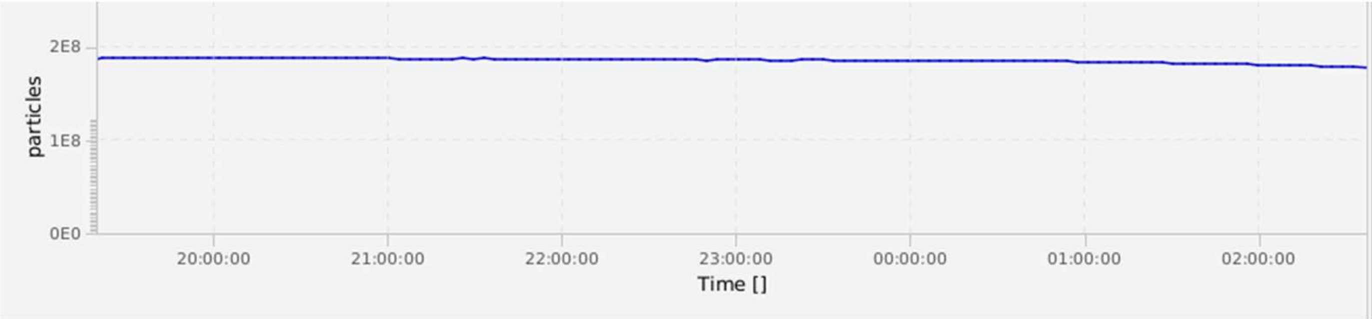
Image: GSI/FAIR

Ions and electrons must have the same nominal velocity v_0

Cooling after Injection (ESR)

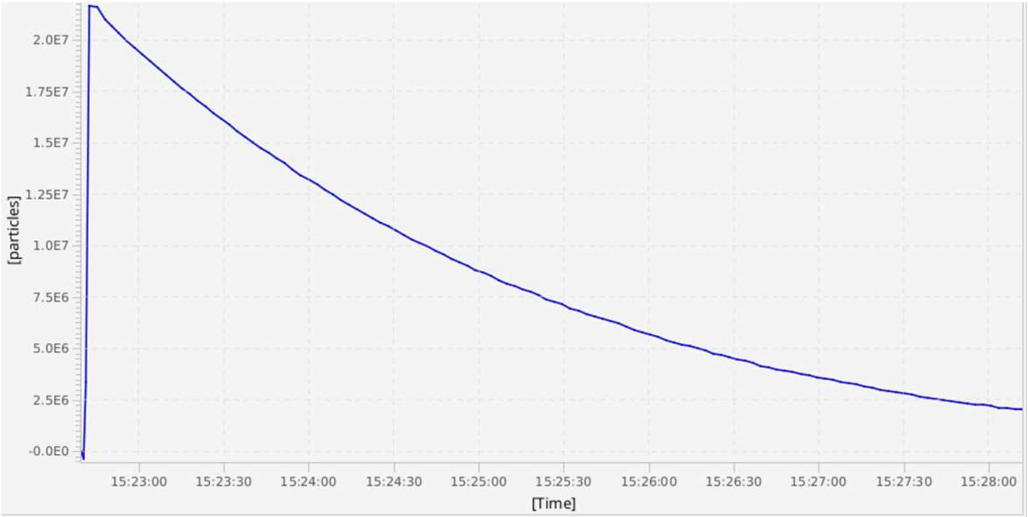


Lifetimes of cooled beams

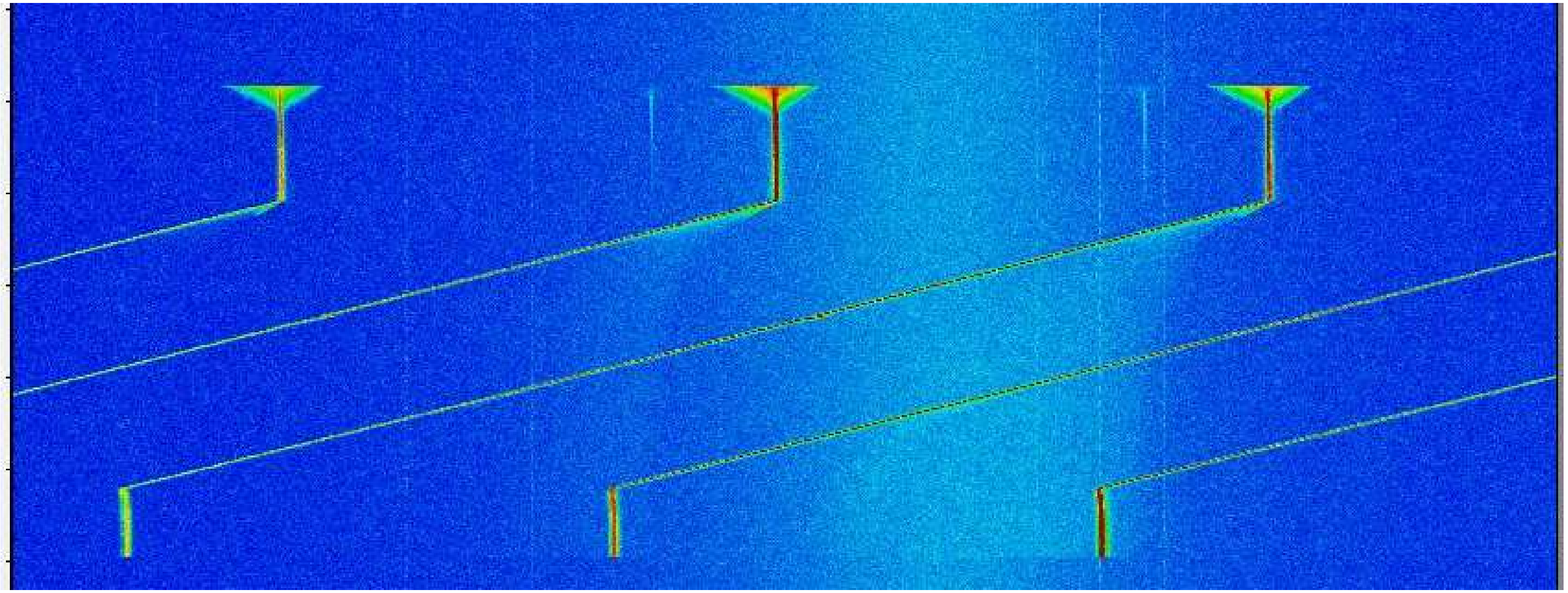


Long term measurement of a C^{6+} beam @ 400 MeV/u stored in the ESR.
In the early morning hours the electron cooler broke down.

U^{90+} beam @ 190 MeV/u, the lifetime of the beam is limited by interaction processes.



Cooler voltage defines beam energy



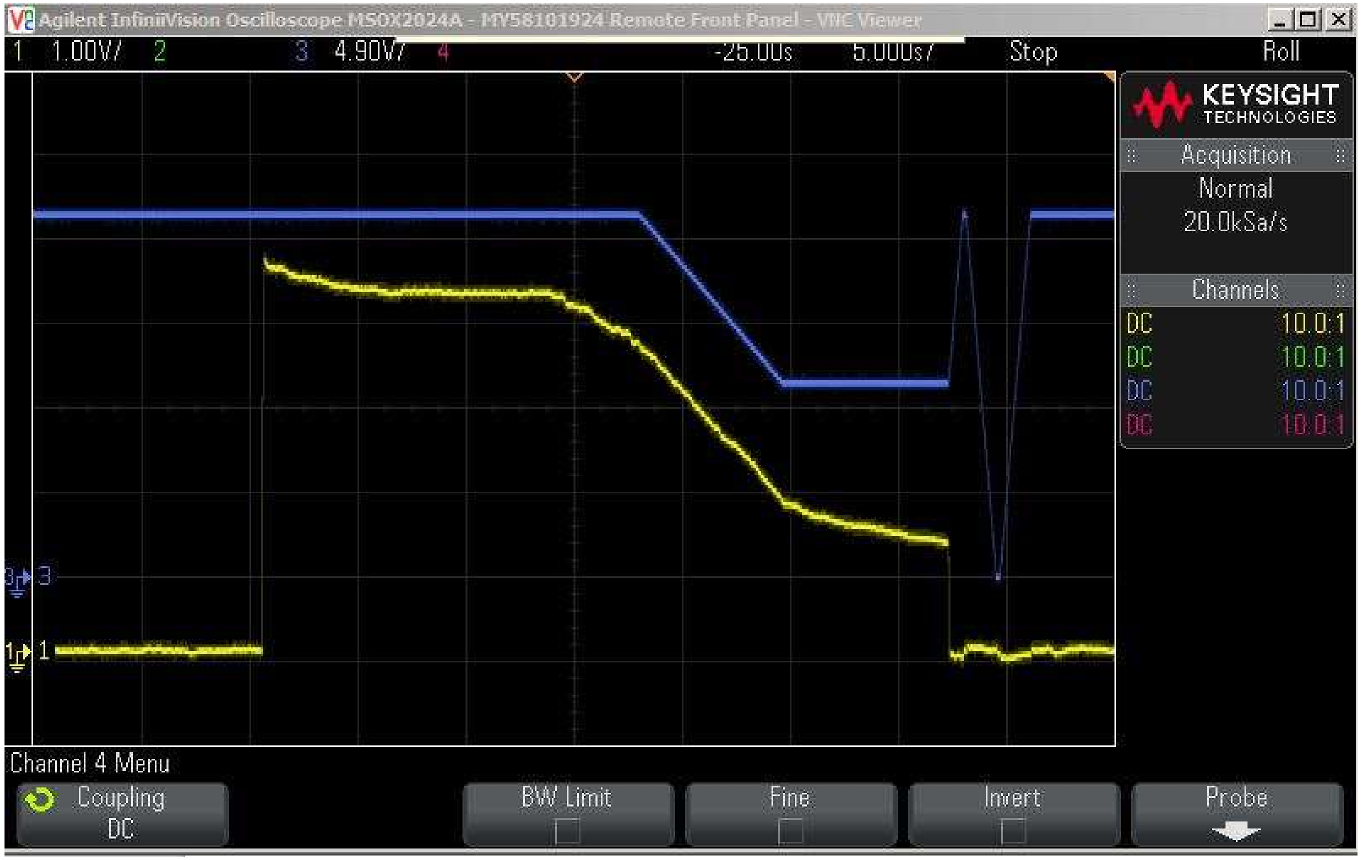
The ion beam energy was reduced by 3.6 % by ramping the electron energy by the same amount within 10 seconds, i.e. Delta E = 4.3 MeV/u

I(electron) = 400mA   Delta U = -2400V , Ion beam: Fe^{25+} @ 120 MeV/u , constant dipole field

Deceleration

- time reversed process of acceleration
- the coasting beam in the ring has to be bunched
- energy matching between RF and electron cooling
- RF and magnetic field have to be changed simultanuously to keep the ion beam on the orbit
- during the deceleration process the emittance of the beam grows -> energy matched cooling is needed at the end of the ramp

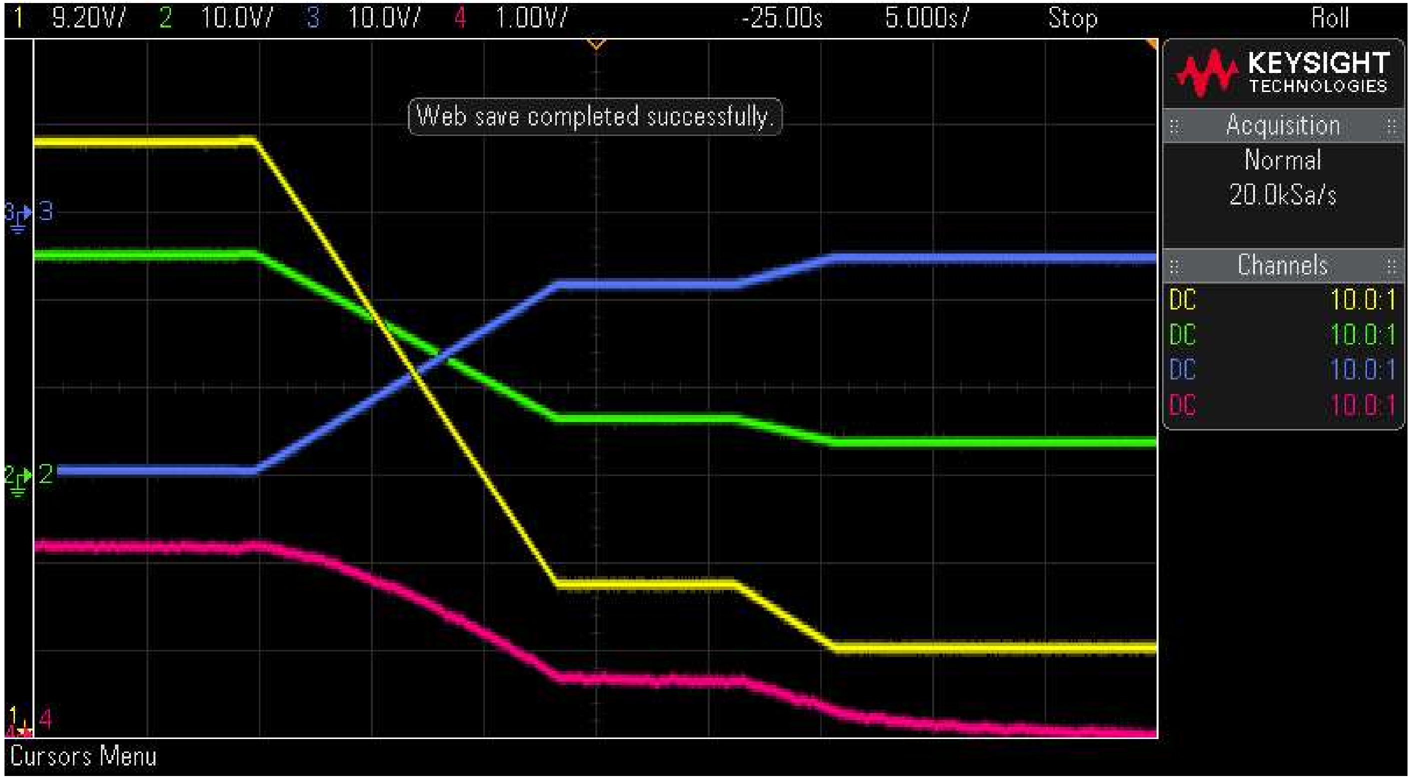
Example: Deceleration of Ar^{18+}



blue: dipole field
yellow: ion current

The beam is injected, cooled, bunched and decelerated from 70 to 20 MeV/u, followed by electron cooling at the lower energy.

Example: Deceleration of Bi^{83+}

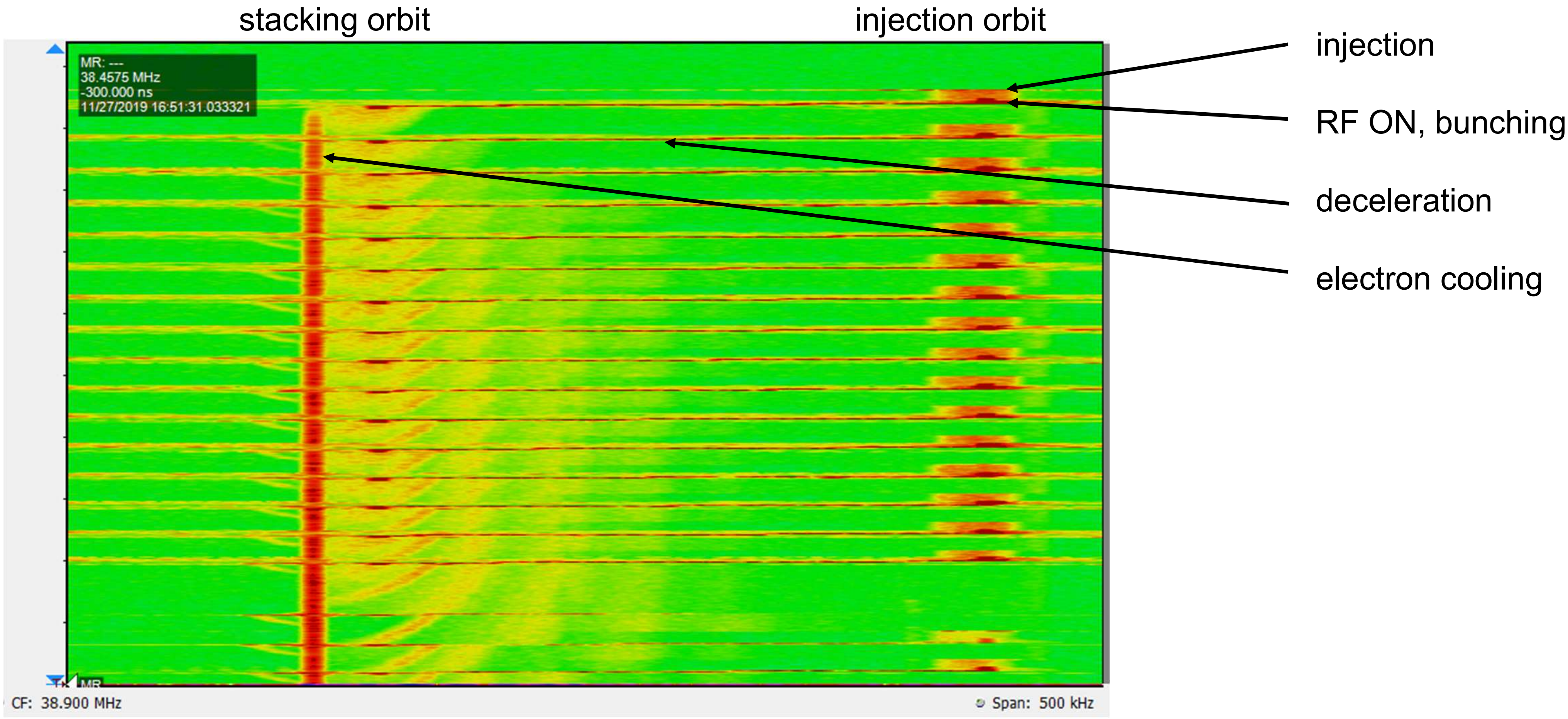


yellow: dipole
blue/green: quadrupoles

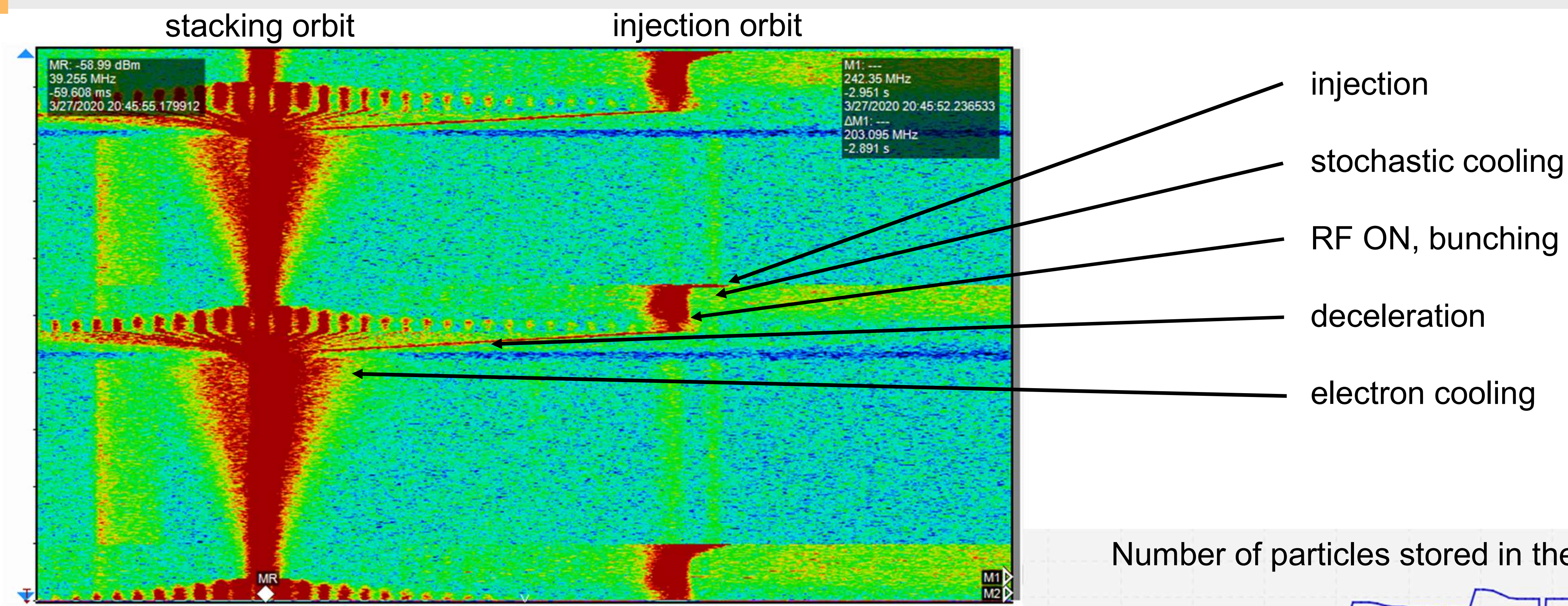
red: ion current

First, the beam is injected, cooled, bunched and decelerated from 400 to 30 MeV/u, then cooled at 30 MeV/u and further decelerated down to 10 MeV/u.

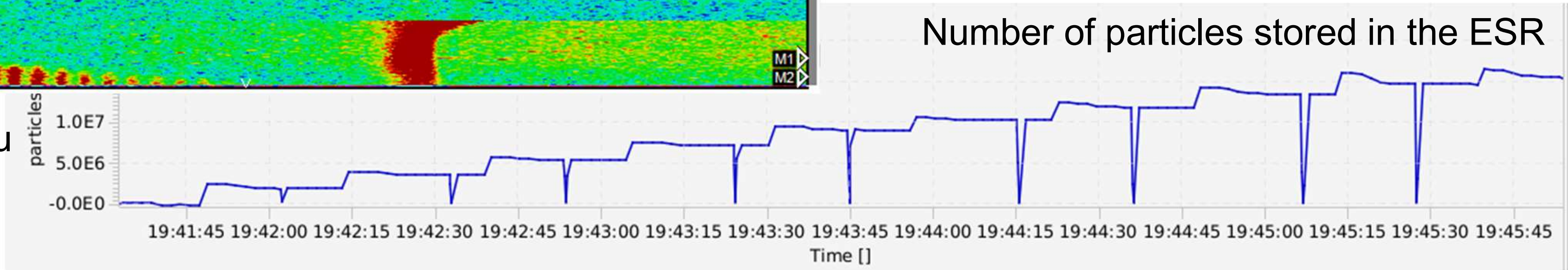
Stacking Methods 1



Stacking Methods 2

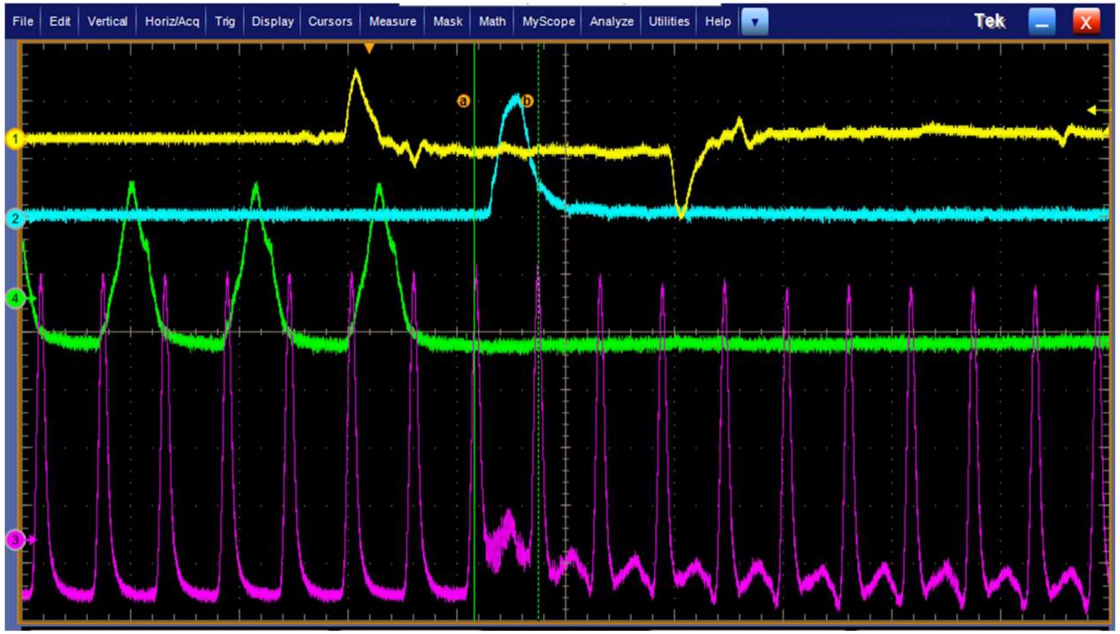


Pb^{81+} @ 400 MeV/u



Stacking Methods 3

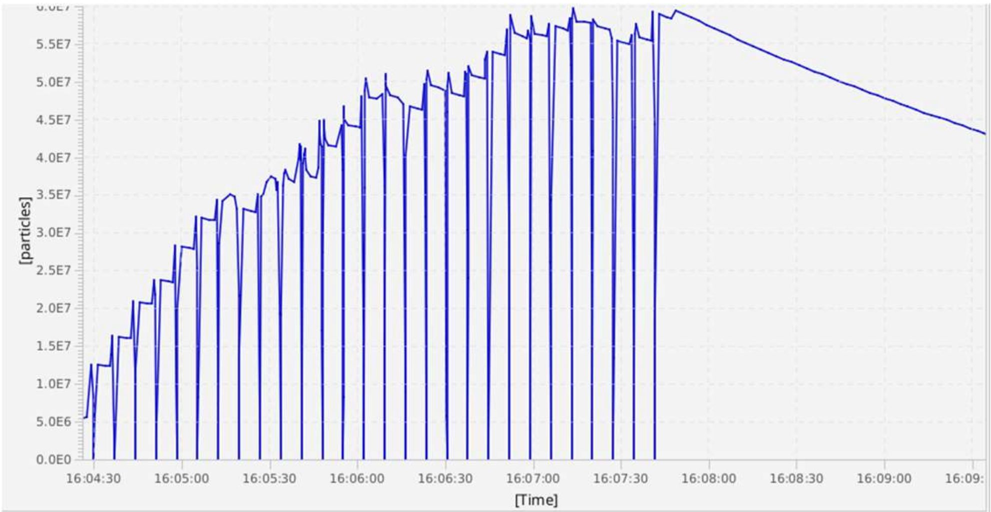
very first try and test in 2022 with the new B2B (bunch to bucket) system (D. Beck)



green: beam in the SIS18; purple: beam in the ESR

I. the beam is stored and cooled in the ESR
II. the next bunch is injected in between the already circulating bunch
III. the injected beam is cooled into the bucket

Accumulated particles in the ESR



Thanks to…

the ESR – team (S. Litvinov, B. Lorentz, M. Steck)

my colleagues from the cooler department, beam diagnostics and control system

you for listening