Status of the ESR And Future Options

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for the Storage Ring Division

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Outline

1) New – Old ESR

2) Slow (Resonant) Extraction

3) Deceleration for HITRAP

4) Barrier Bucket Accumulation

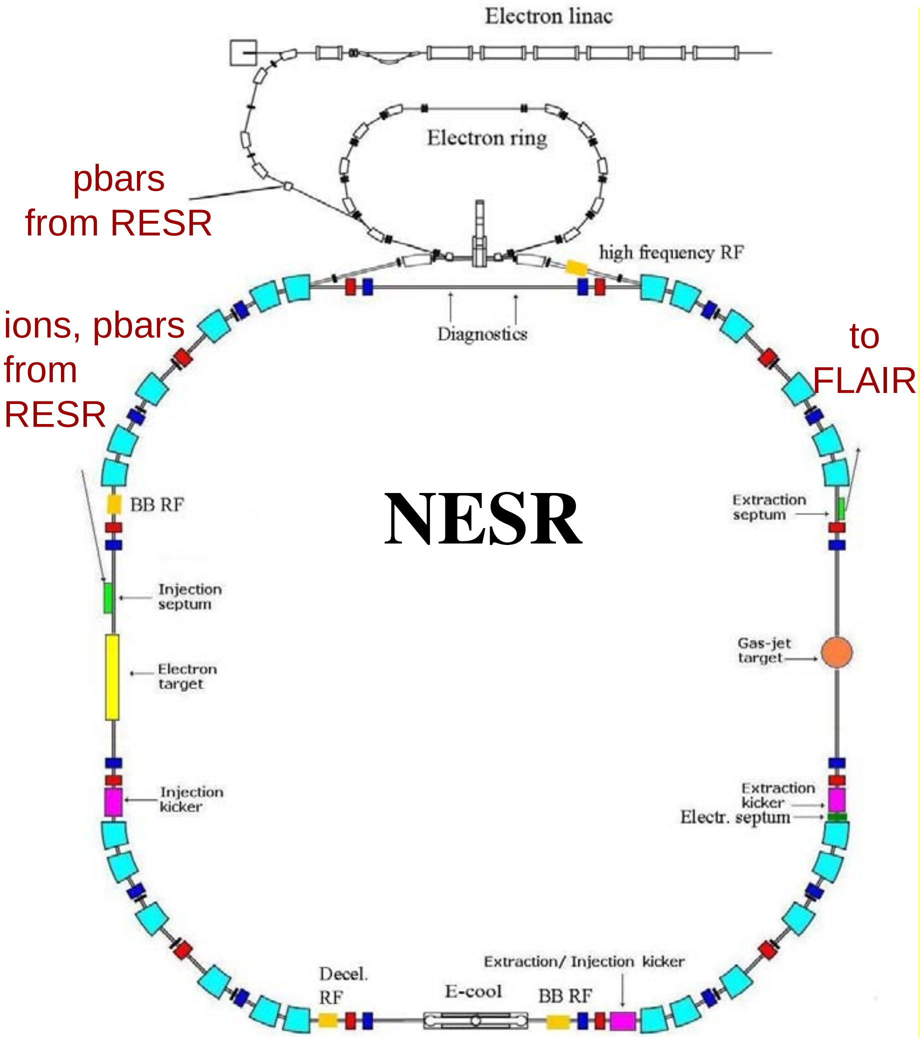
5) RIB Preparation with Scrapers

6) New Schottky Resonator

7) New Two-dimensional Beam Profile Monitor

8) Outlook

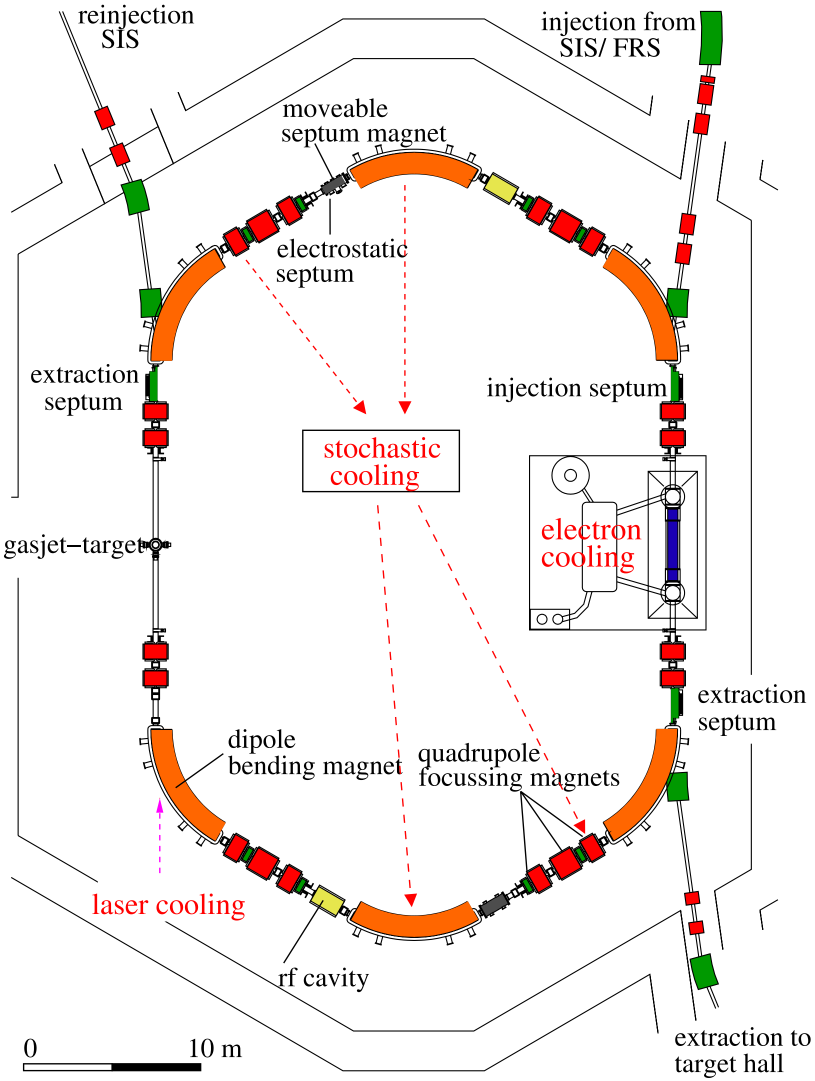
The New Experimental Storage Ring



- Electron cooling of ions and antiprotons
- Fast deceleration of ions to 4 MeV/u
  and antiprotons to 30 MeV
- Fast extraction (1 turn)
- Slow (resonance) extraction
- Ultraslow (charge changing) extraction
- Longitudinal accumulation of RIBs
- Electron-Ion collisions (bypass mode)
- Antiproton-ion collisions
- Internal target
- Electron target
- High precision mass measurements

HELMHOLTZ GEMEINSCHAFT

The Old ESR



Fast injection (stable ions / RIBs)

Stochastic cooling (≥ 400 MeV/u)

Electron cooling (3 - 430 MeV/u)

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

Internal gas jet target

Acceleration/deceleration (down to 3 MeV/u)

Fast extraction (reinjection to SIS / HITRAP)

Slow (resonant) extraction

Ultraslow extraction (charge change)

Beam accumulation

Multi charge state operation

Schottky mass spectrometry

Isochronous mode (TOF detector)

Differences NESR - ESR

NESR:

Operation with antiprotons (only deceleration for FLAIR)

Electron Target

Collider (ion-electron, ion-antiproton)

High Intensity RIBs

Stochastic Pre-Cooling and Isochronous Mode in CR

ESR:

Stochastic cooling

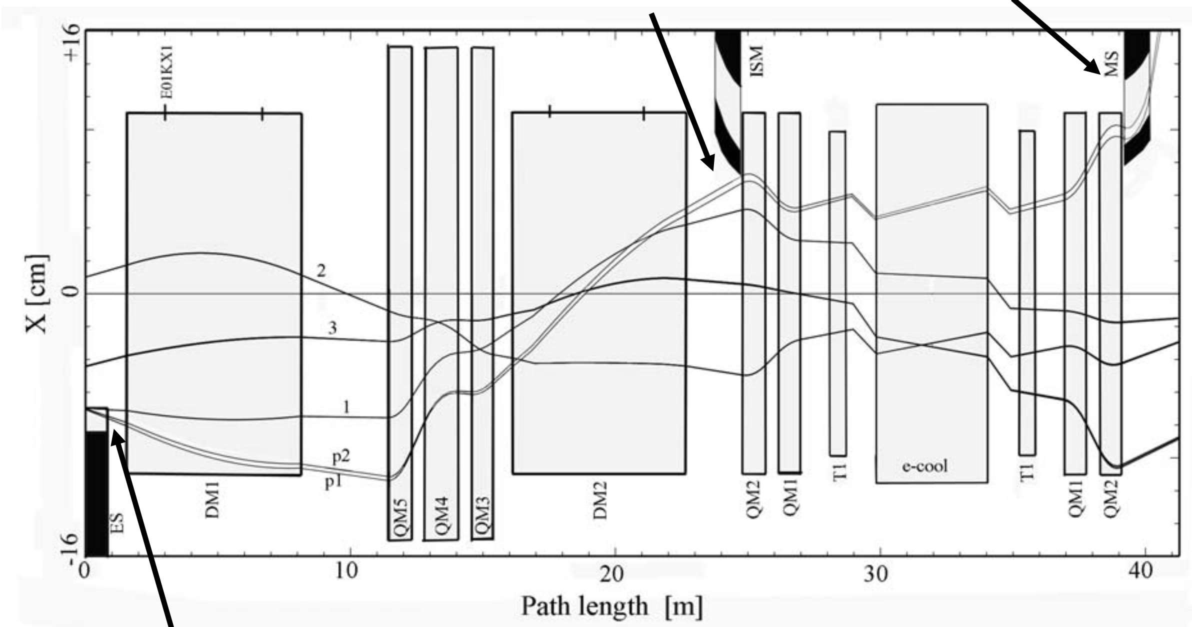
Isochronous mode

Slow (Resonant) Extraction from ESR

test with Ar^{18+} 100 MeV/u

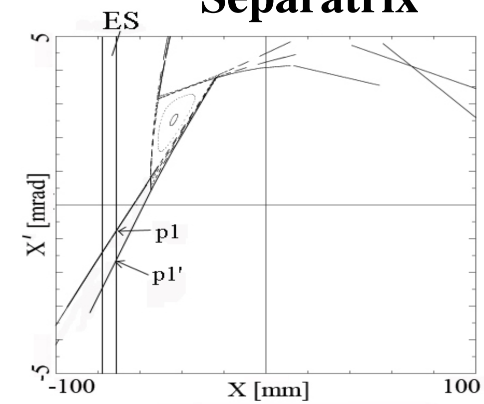
must pass injection septum

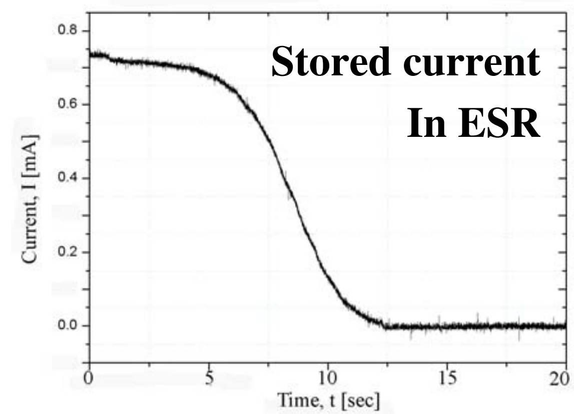
extraction septum



Kick in electrostatic septum

Separatrix





Beam profile on fluorescent screen (every 1 second)

Beam center was moving during extraction

Slow (Resonant) Extraction from ESR

So far tested at high energy → basic parameters are known

Deceleration and extraction at low energy still have to demonstrated

precise control of orbit and tune (flexibility of control system)

considerable development time needed

Further transport to target (diagnostics)

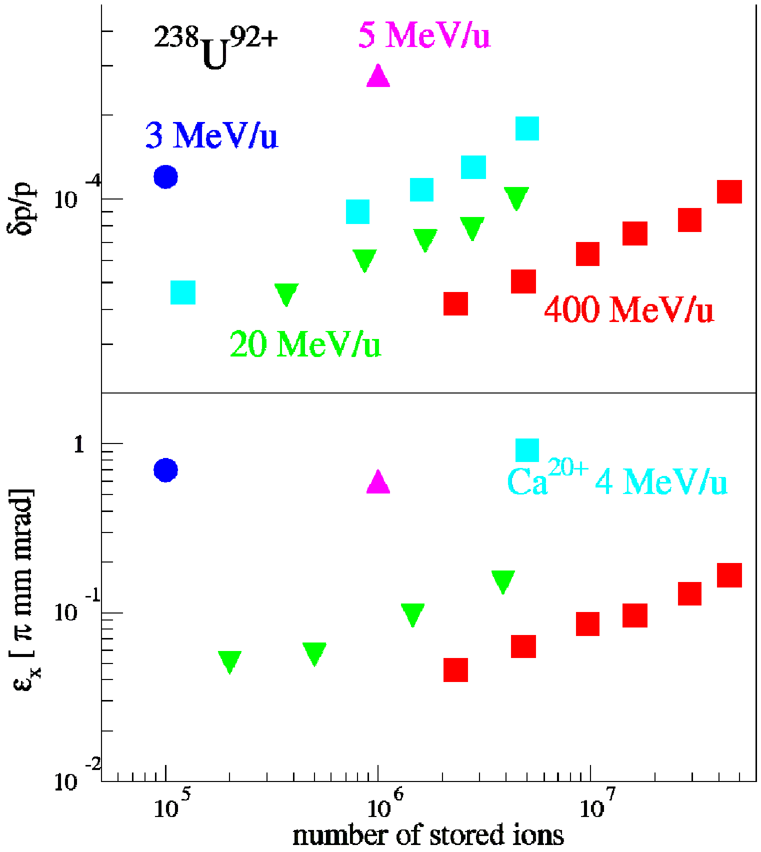
Control of macro and micro spill (time) structure

Extraction time ≤ 15 seconds

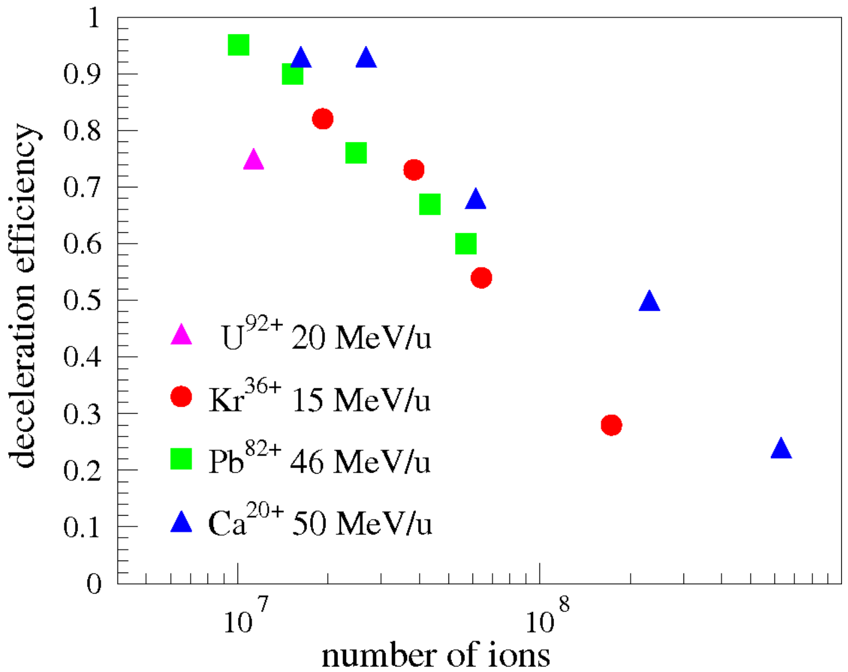
Cycle time will be about 1 minute (as for HITRAP)

Properties of Decelerated Beams

Equilibrium Beam Parameters after Electron Cooling



Losses increase with stored particle number



Some 10^7 decelerated ions at 4 MeV/u are realistic

Space Charge Limit

Space charge limit due to incoherent tune shift

$$\Delta Q_x = \frac{r_p Z^2 N g}{\pi A \beta^2 \gamma^3 B (\epsilon_x + \sqrt{\epsilon_x \epsilon_y Q_x / Q_y})}$$

$$\Delta Q_x \simeq \frac{r_p Z^2 N}{2\pi A \beta^2 \gamma^3 B \epsilon_x}, \quad g = 1, \epsilon_x = \epsilon_y, Q_x = Q_y$$

at 4 MeV/u, for ΔQ_x=0.1 and ε_x = 1 mm mrad:

Coasting (B=1):
- **Ne^{10+}: 1.8 × 10^8**
- **Kr^{36+}: 5.8 × 10^7**
- **U^{92+}: 2.5 × 10^7**

Bunched (≤ 1µs, B=1/5):
- **Ne^{10+}: 4 × 10^7**
- **Kr^{36+}: 1 × 10^7**
- **U^{92+}: 5 × 10^6**

For bunched beam the intensity limit is reduced by the bunching factor. This was recently observed experimentally when the beam was bunched with h=1 before extraction.

With rf amplitude 100 V (h=1) the bunching factor was B ≈ 1/20

⇒ Precise control of rf amplitude down to small values

Deceleration to 4 MeV/u for HITRAP

Ni^{28+} 400 → 30 → 4 MeV/u

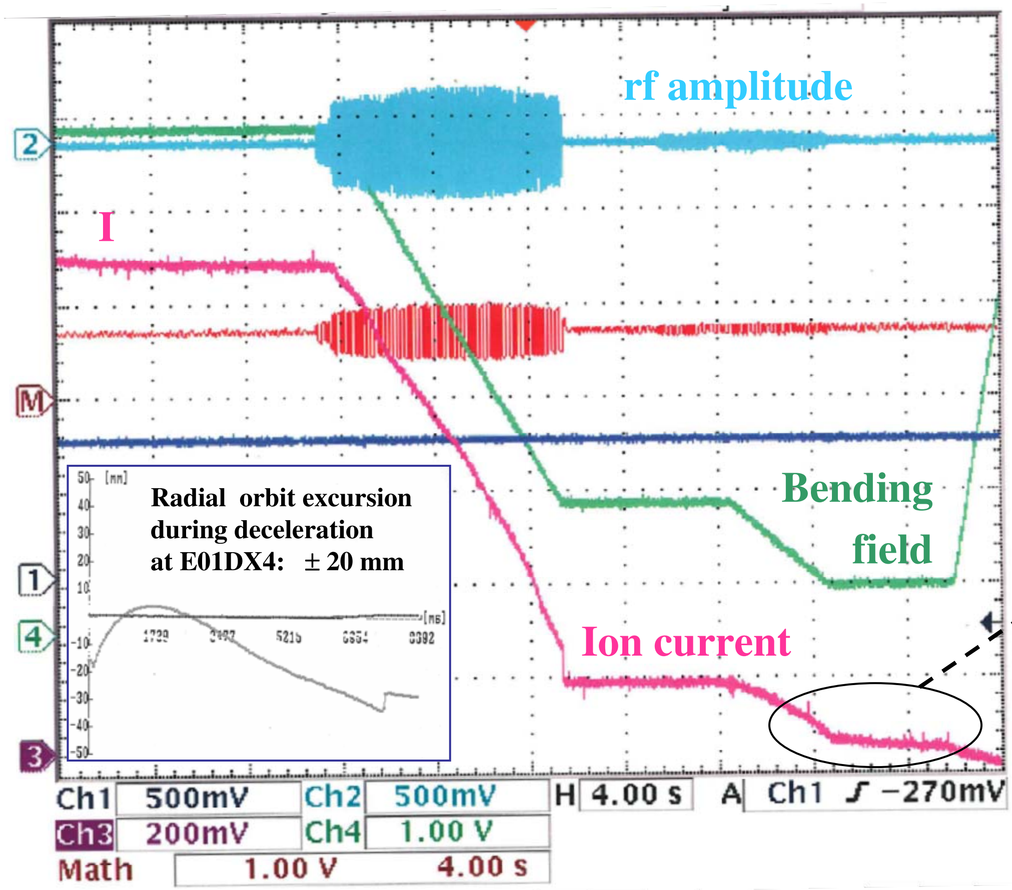
1100 μA → 180 μA → 25 μA

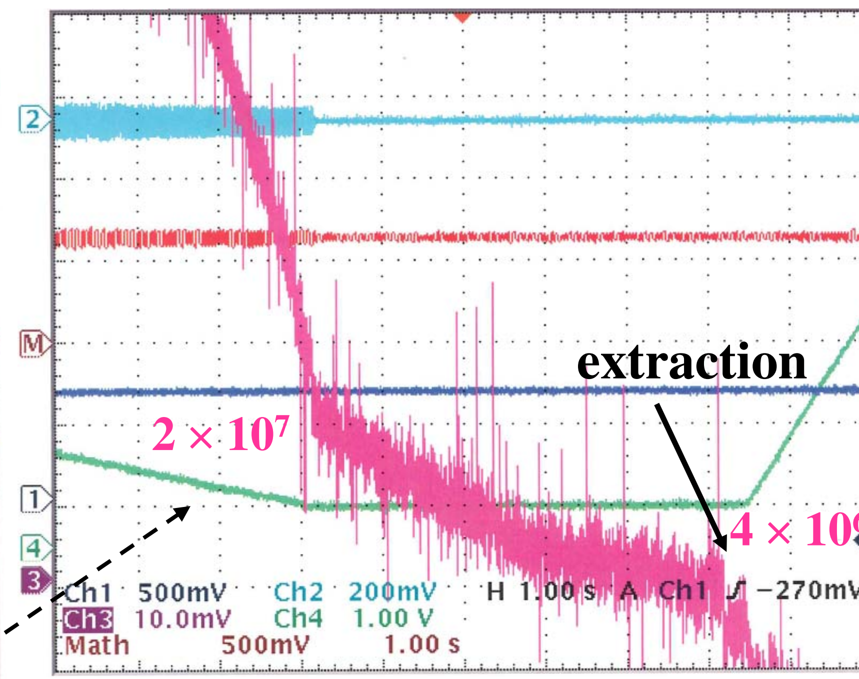
45 %   37 %

cycle time
45 s

Main losses:

- End of ramp
- Storage and cooling at low energy



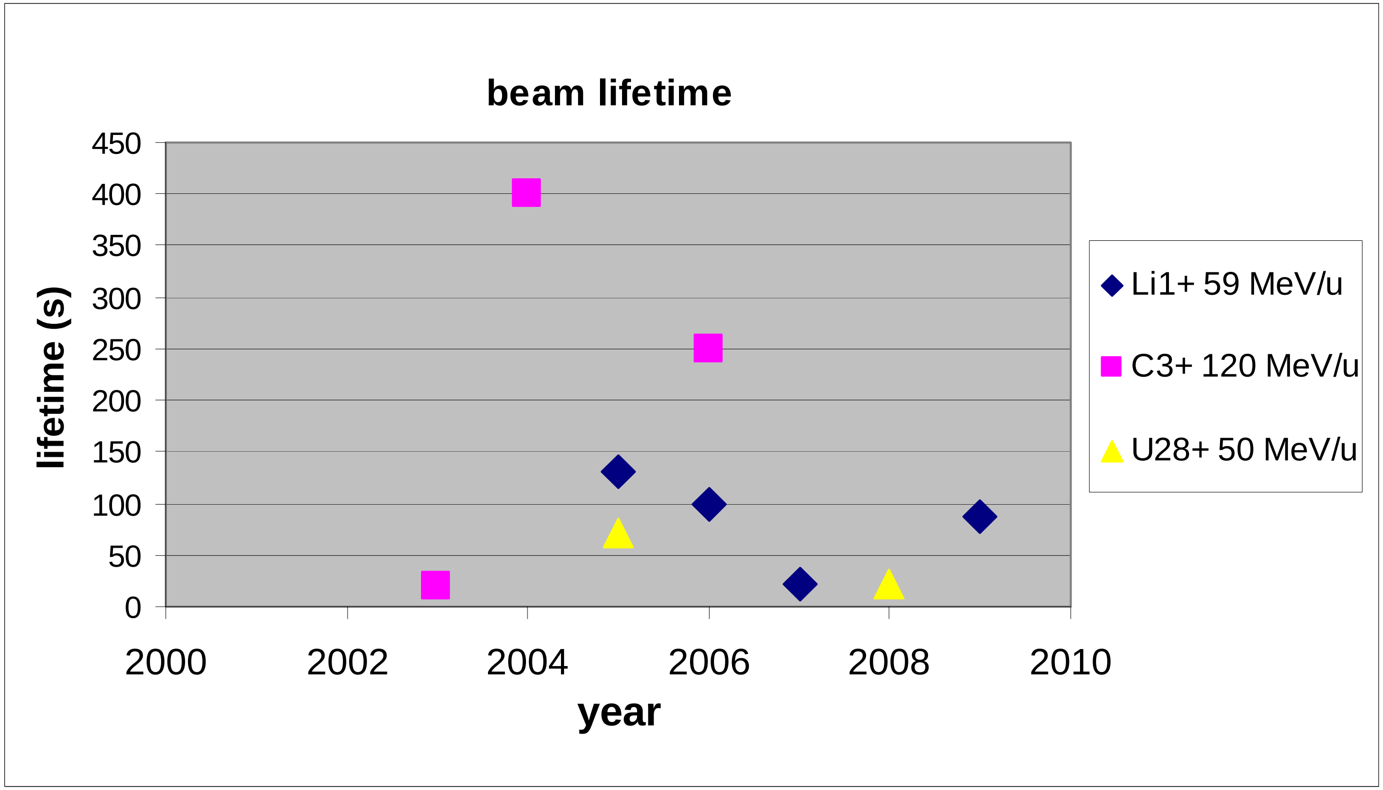


beam half life (vacuum dominated):

30 MeV/u: $T_{1/2}$ ≈ 480 s

4 MeV/u: $T_{1/2}$ ≈ 2 s

Low Energy Beams – Vacuum



Beam lifetime of bare ions at 4 MeV/u

5/07 **Ni^{28+}: ~ 5 s**

8/07 **Ne^{10+}: < 1 s**

8/08 **Au^{79+}: ~ 1.7 s**

2/09 **Ni^{28+}: ~ 2.5 s**

4/09 **Xe^{54+}: ~ 3 s**

Vacuum is very critical for HITRAP

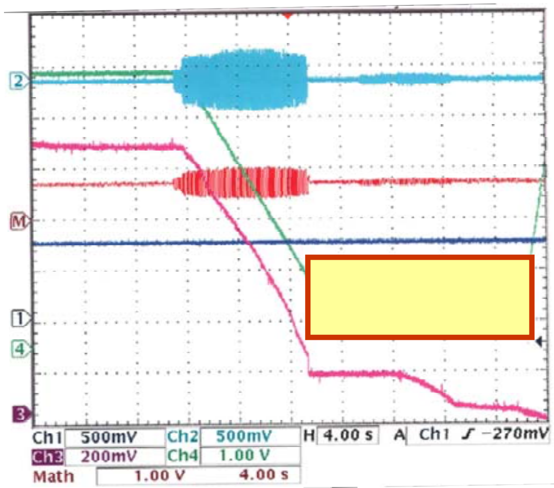
Injection at 30 MeV/u of charge states produced at 11.4 MeV/u helps but: operation with bare highly charged ions will be more difficult

Reduction of Cycle Time

A reduction of the cycle time (starting at 400 MeV/u) requires more flexibility of the control system ⇒ new controls software
It will also need significant machine development time and manpower

An alternative attempt to transport a 4 MeV/u from UNILAC failed (problems: ion optics, stability of power converters, ESR acceptance)

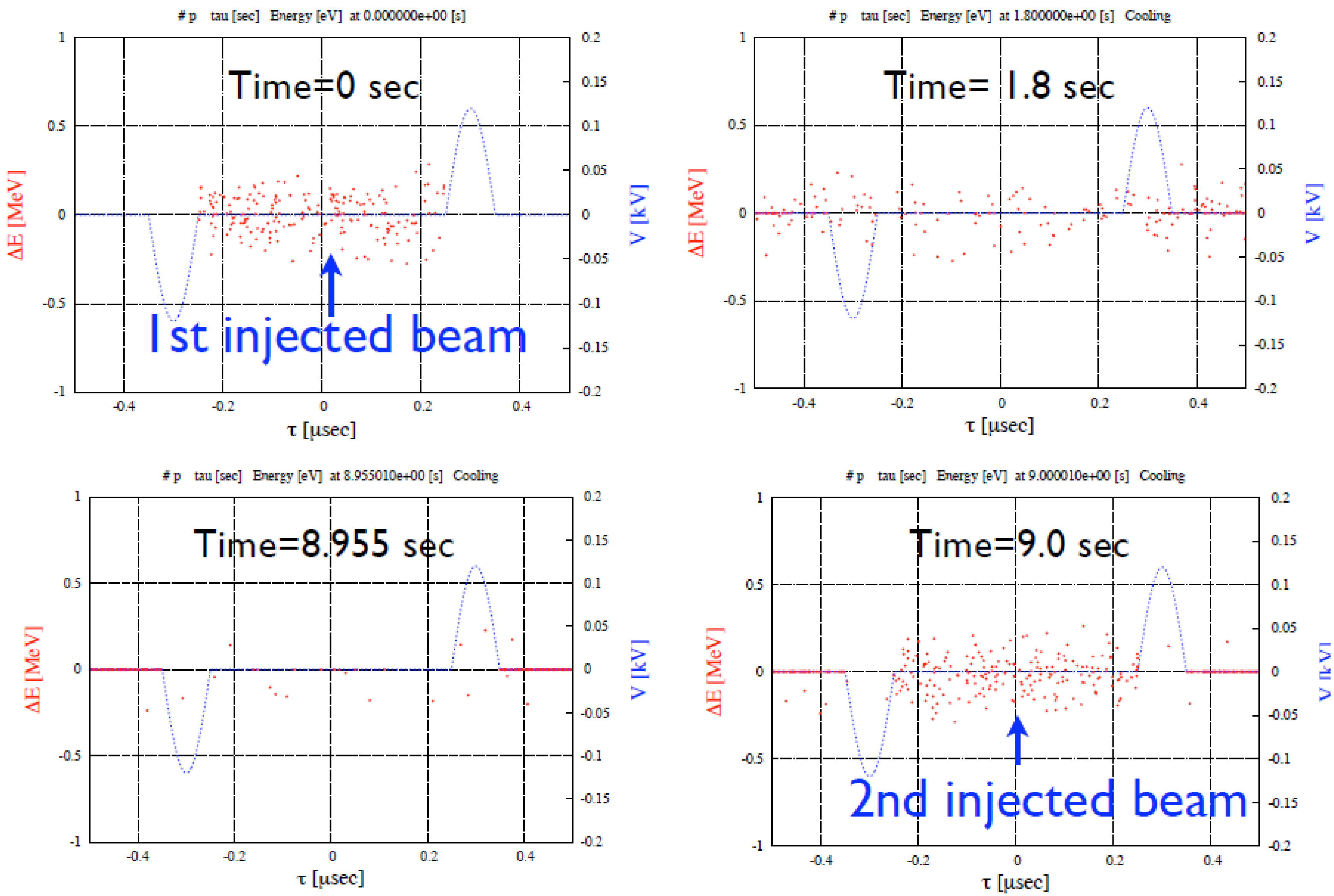
Recently we started to inject beams at 30 MeV/u (energy of intermediate cooling) with the SIS charge state (produced at 11.4 MeV/u)



Reduction of cycle time by a factor of ~ 3

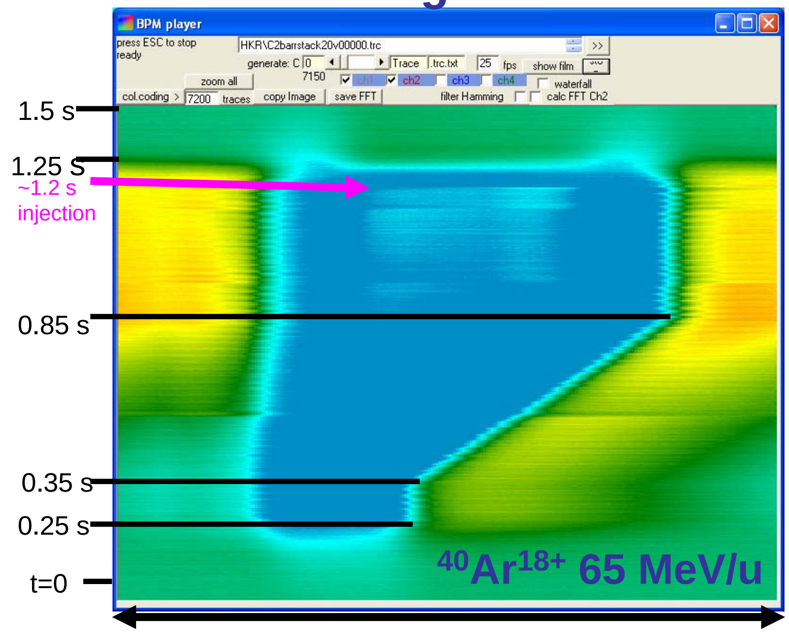
(only useful for commissioning)

Accumulation with Barrier Buckets



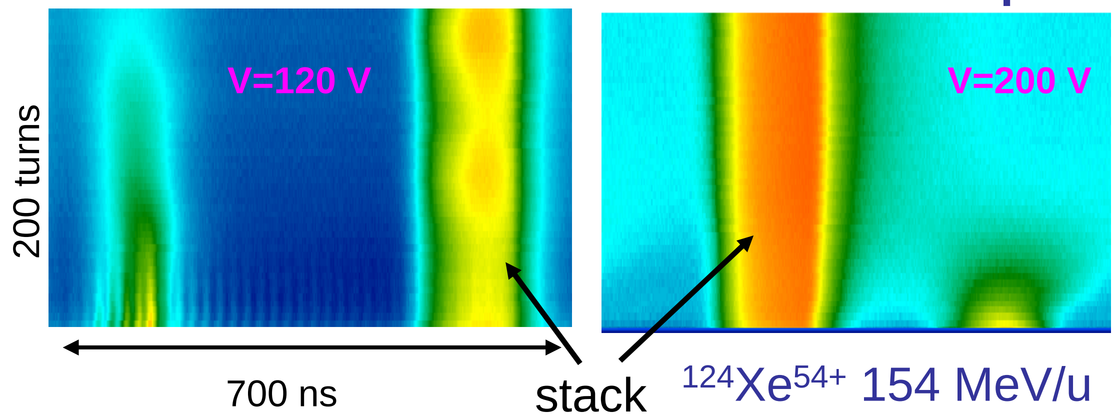
Proof of Principle in the ESR

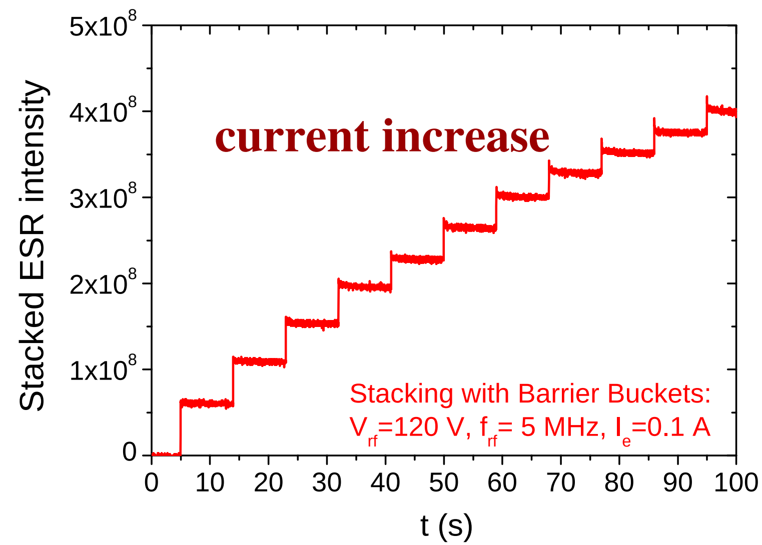
moving barrier



fixed barrier

h=1 unstable fixed point





all three schemes successfully tested:

cooling times close to expectations

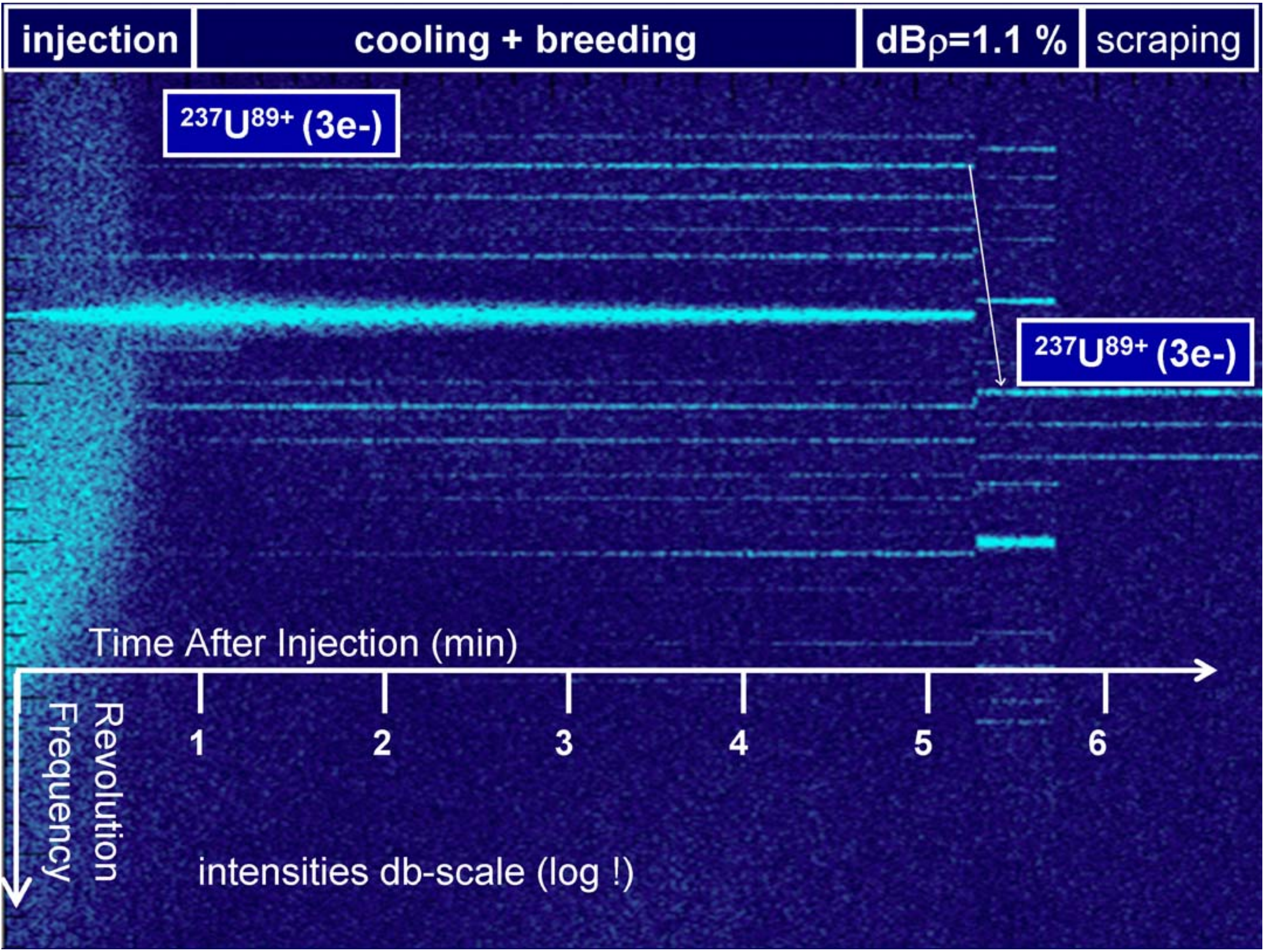
efficient accumulation

high quality timing and kicker pulses required

Intensity limits: rf voltage and instabilities

For regular use in the ESR a dedicated rf system has to be developed

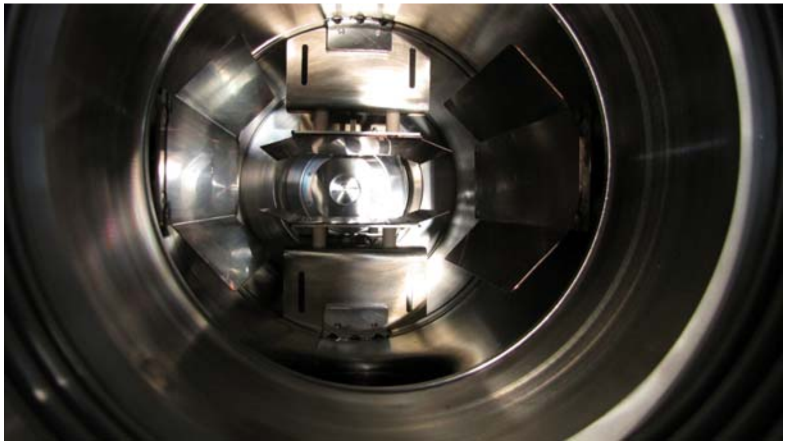
RIB Preparation in the ESR

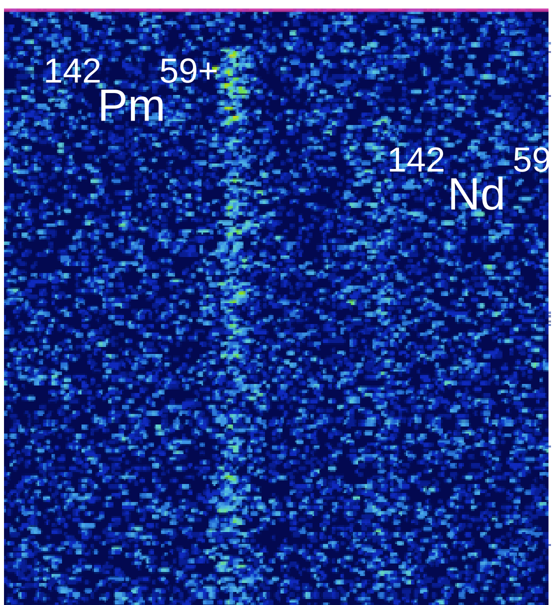


- **Production target in TE-line**
- **Magnetic separation**
- **Cooling**
- **Breeding ($U^{90+} \rightarrow U^{89+}$)**
- **Orbit adjustment**
- **Scraping**

⇒ almost isotopically pure RI beam

New Schottky Resonator

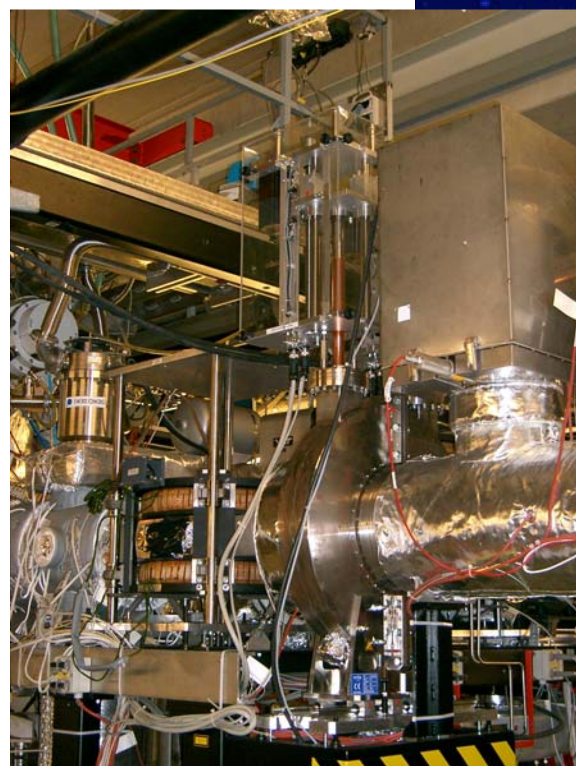


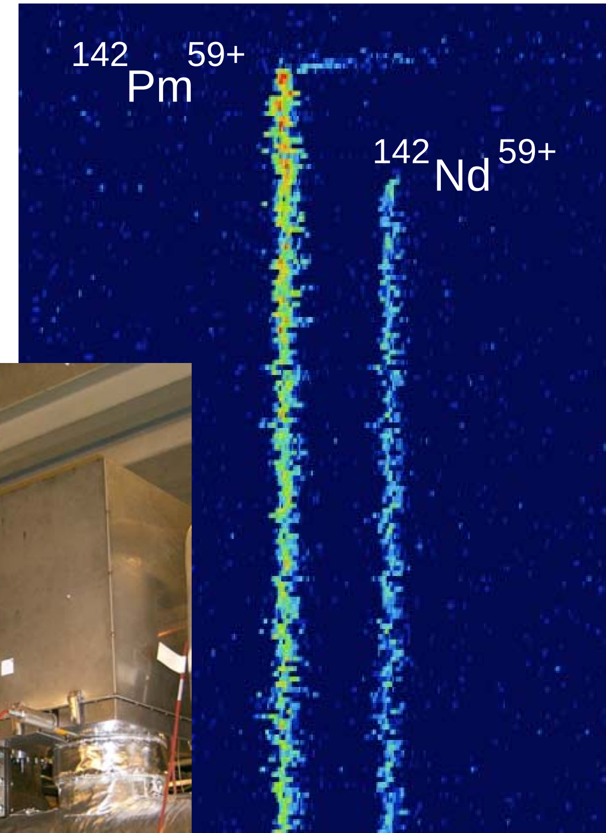


Old Schottky pickup

Resonant circuit at 30th harmonic

First decays
Y Litvinov
17.04.2010

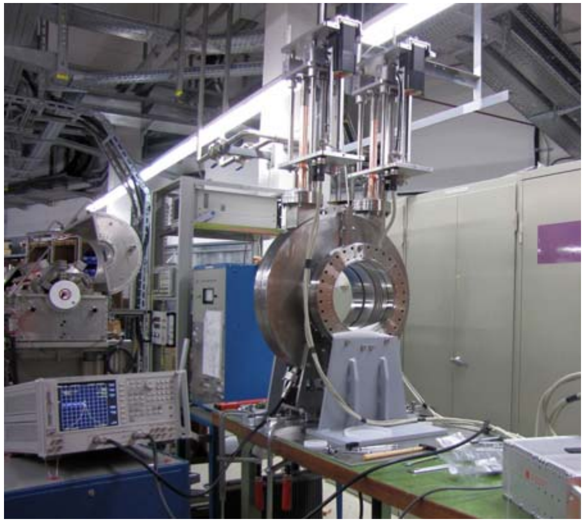




New resonator Cavity (2010)

124th harmonic

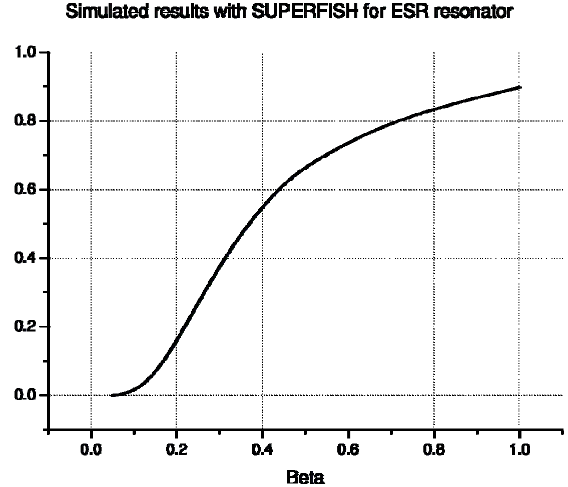
New Schottky Resonator

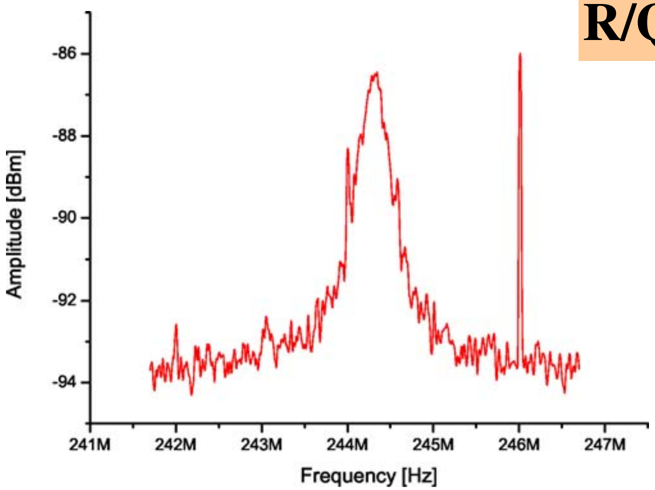


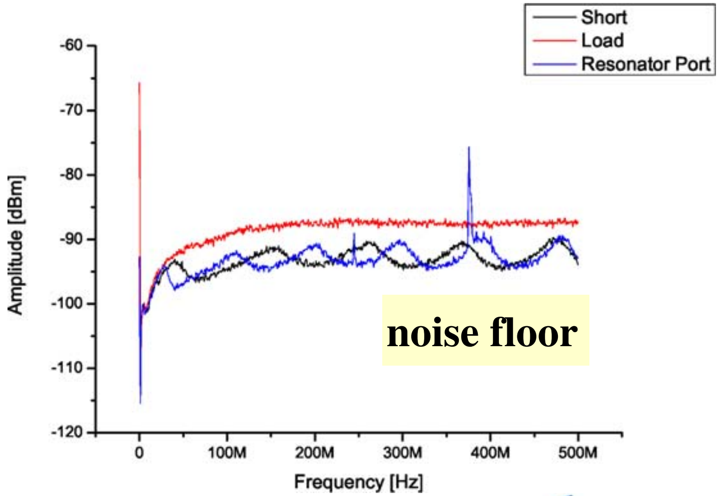
pill box type cavity
resonant frequency variable
by slow tuners

Frequency	244 ± 2.5 MHz
Quality factor (unloaded)	1130
Quality factor calc.	1940/3837
R/Q exper.	50.7 Ω
R/Q theor.	50.3/43.1 Ω

Transit time factor
(sensitivity vs velocity)







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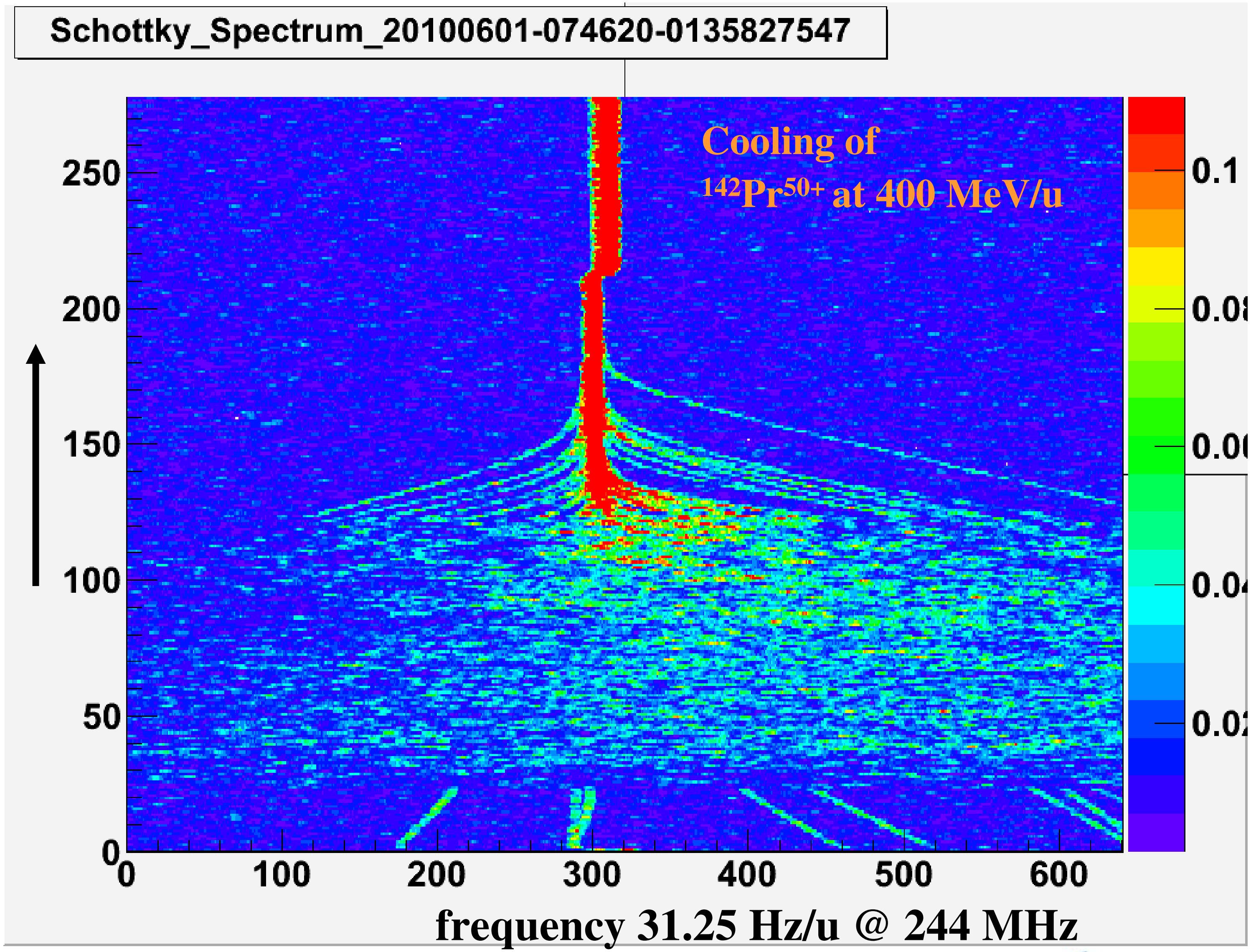
New Schottky Resonator

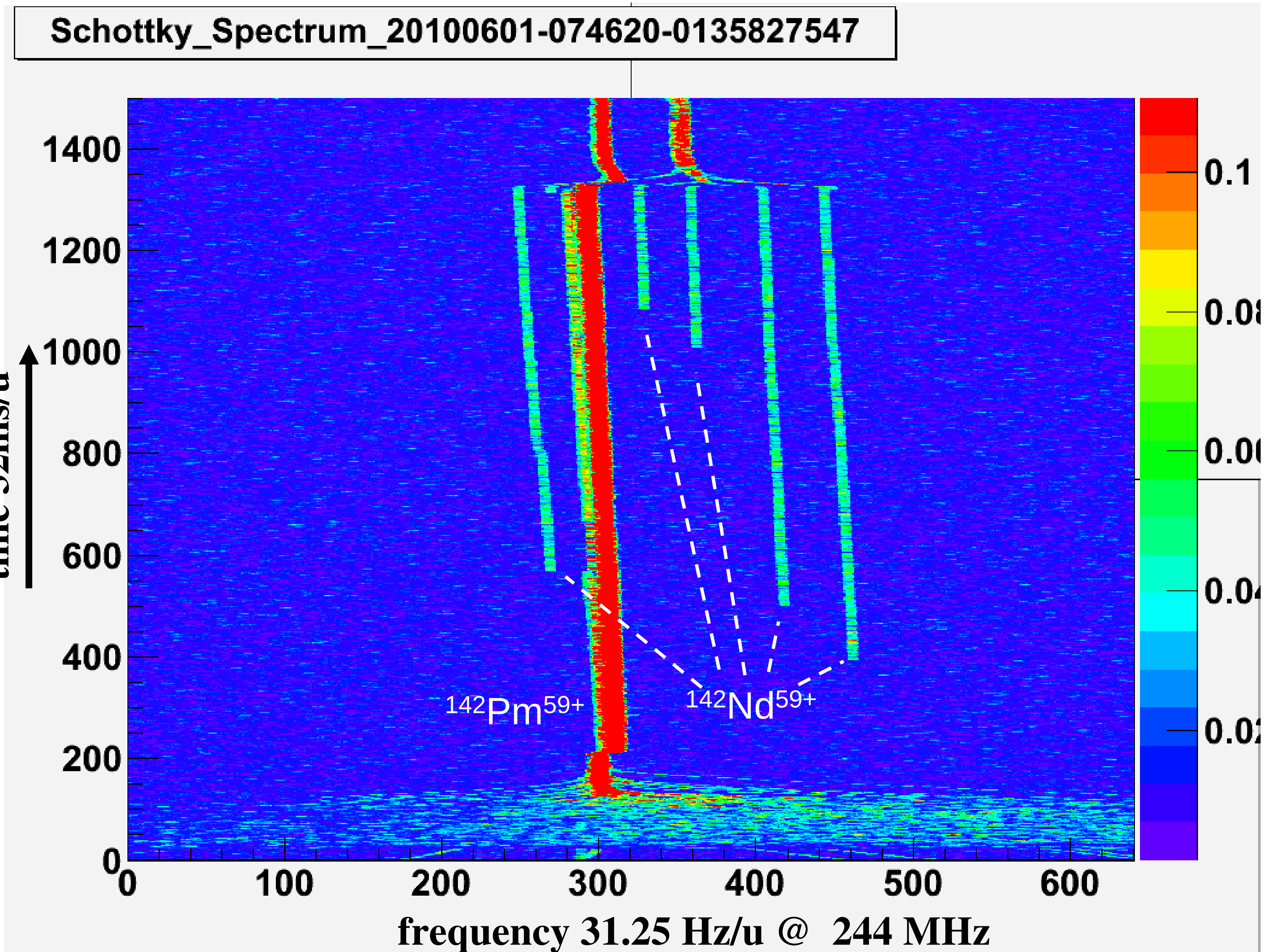


Electron cooling

Stochastic cooling
+
Electron cooling

Electron cooling

New Schottky Resonator



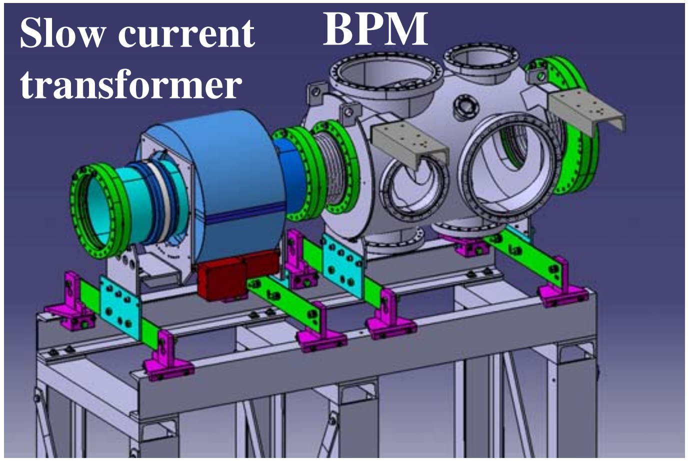
Electron cooling

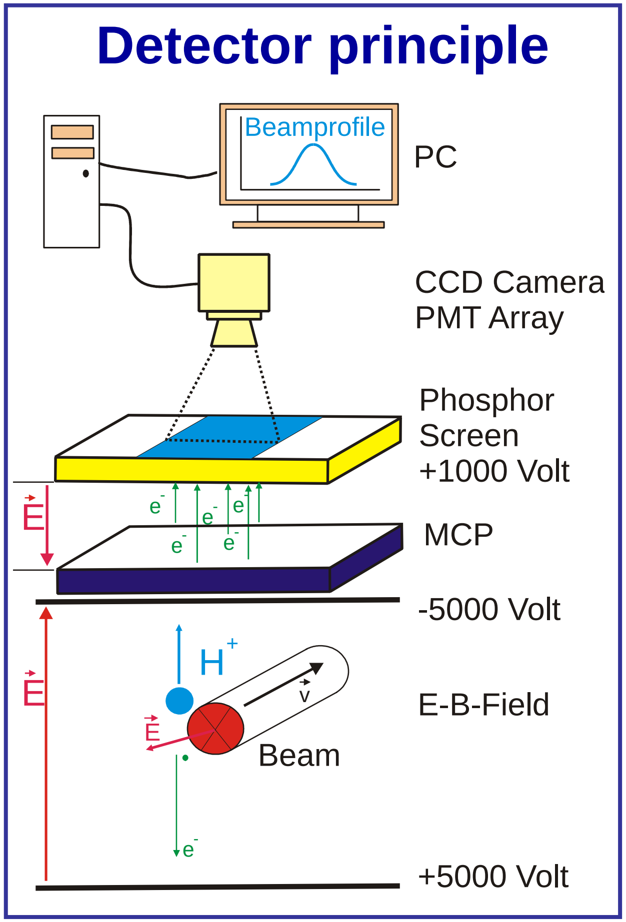
no cooling

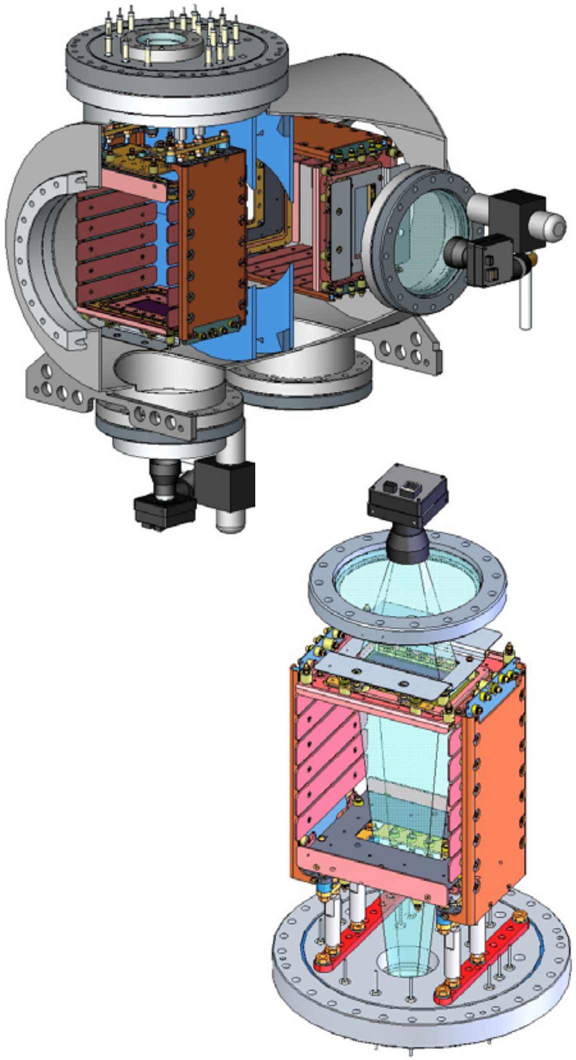
Electron cooling

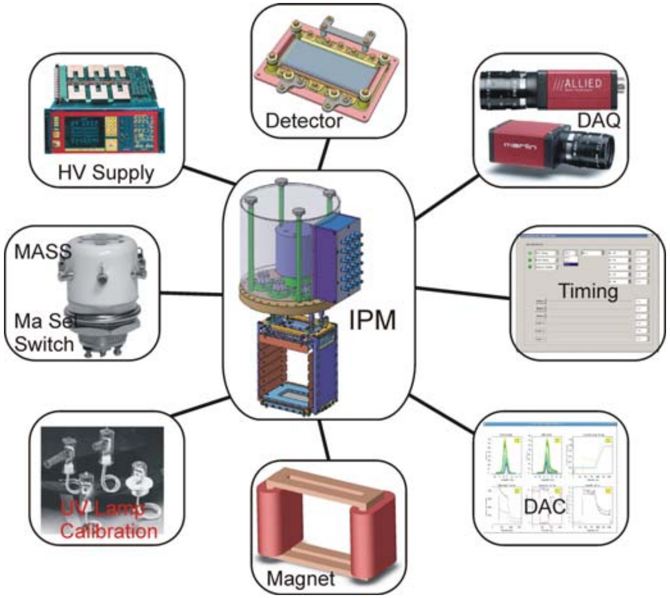
Stochastic cooling

New Beam Profile Monitor



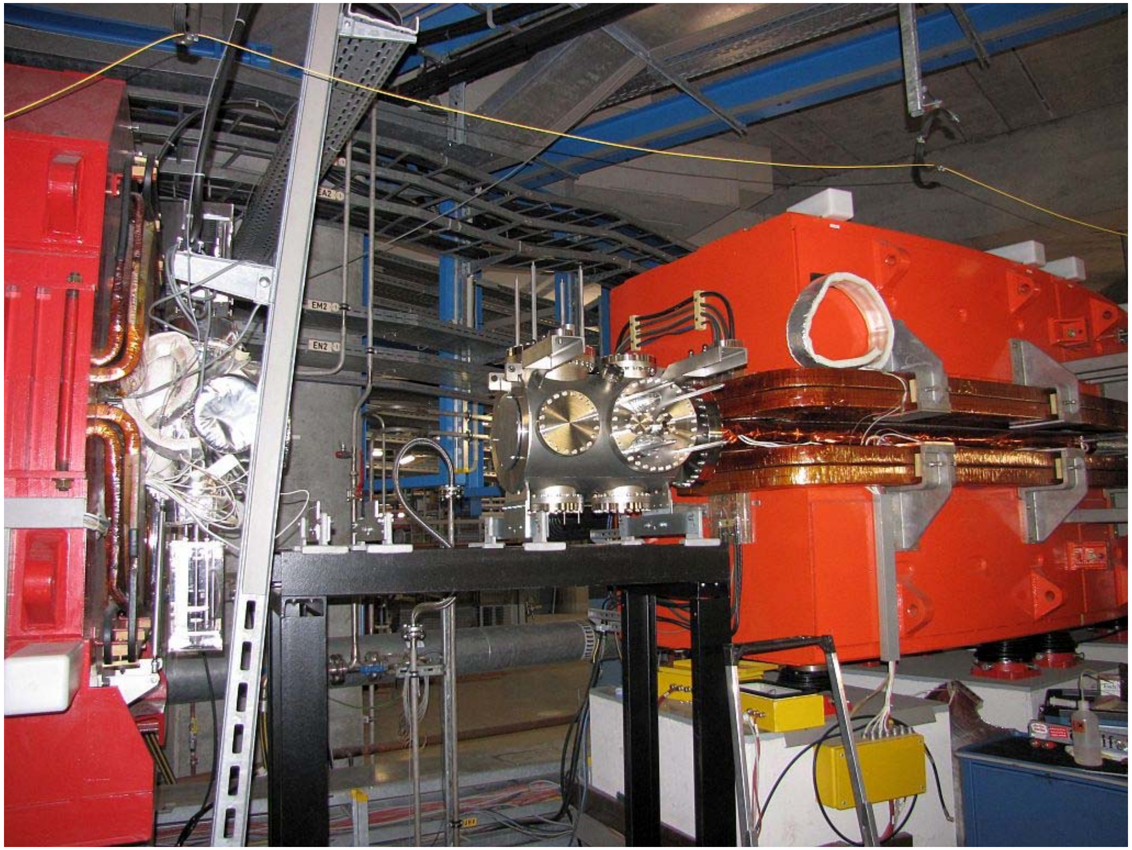






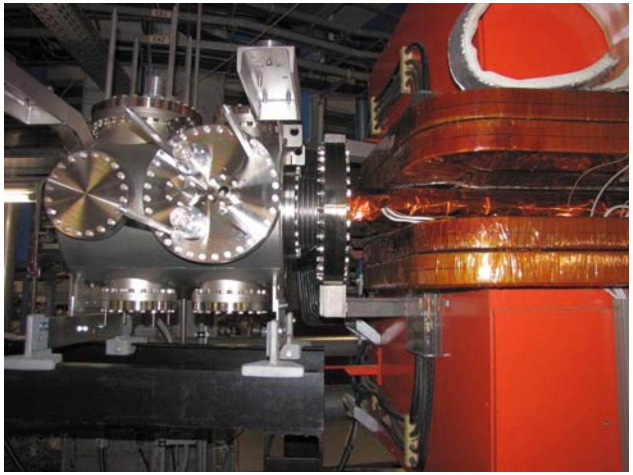
- **Two planes**
- **Fast measurement (ms)**
- **Improved resolution**

New Beam Profile Monitor



Installation in the ESR replacing old Q-kicker
(next to current slow transformer)

view from ring outside



view from ring inside

Potential Improvements of ESR Operation

Studies of beam dynamics at low energy (hopefully with new BPM)

Reduction of deceleration cycle time

larger flexibility of control system, faster cooling

Storage of ions at lowest energies (< 10 MeV/u)

machine studies, vacuum

Mode with small dispersion at target

machine studies, larger flexibility of control system

Fast accumulation by barrier buckets

dedicated rf system

Resonant extraction

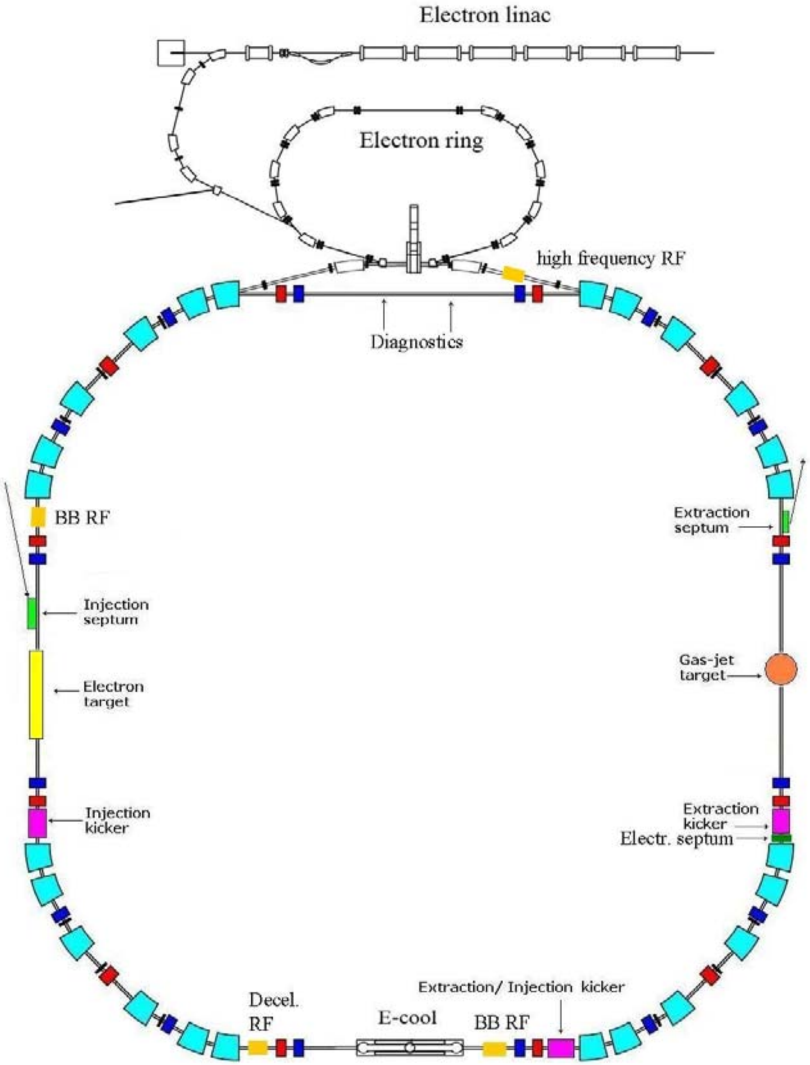
machine studies

Studies of the influence and properties of the new Schottky resonator

Development of single ion detection

design of rf structures with higher sensitivity

Parameters of the NESR



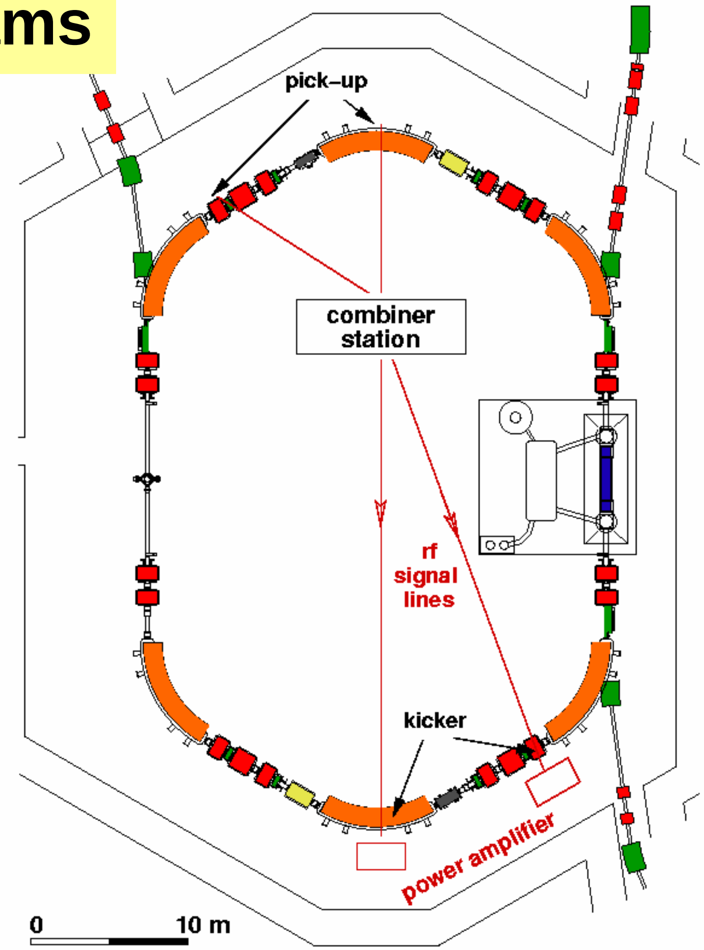
Circumference [m]	222.8
Straight section length [m]	18
Horizontal acceptance [mm mrad]	150
Vertical acceptance [mm mrad]	40
Momentum acceptance [%]	± 1.5
Max. momentum deviation [%]	± 2.5
Horizontal tune	4.2
Vertical tune	1.87
Transition energy	4.59
Maximum dispersion [m]	6.8
Horizontal chromaticity	5.9

Stochastic Cooling at the ESR

Fast pre-cooling of hot fragment beams

energy 400(-550) MeV/u
bandwidth 0.8 GHz (0.9-1.7 GHz)
total rf power 2 kW

$\delta p/p = \pm 0.35\ \% \rightarrow \delta p/p = \pm 0.01\ \%$
$\varepsilon = 10 \times 10^{-6}\ \text{m} \rightarrow \varepsilon = 2 \times 10^{-6}\ \text{m}$



In quadrupole magnets:
pick-ups and kickers for vertical and longitudinal cooling (Palmer method)

In dipole magnets: →
pick-ups and kickers for horizontal cooling