Current Plans for Beam Cooling at FAIR

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with contributions from FZ Jülich

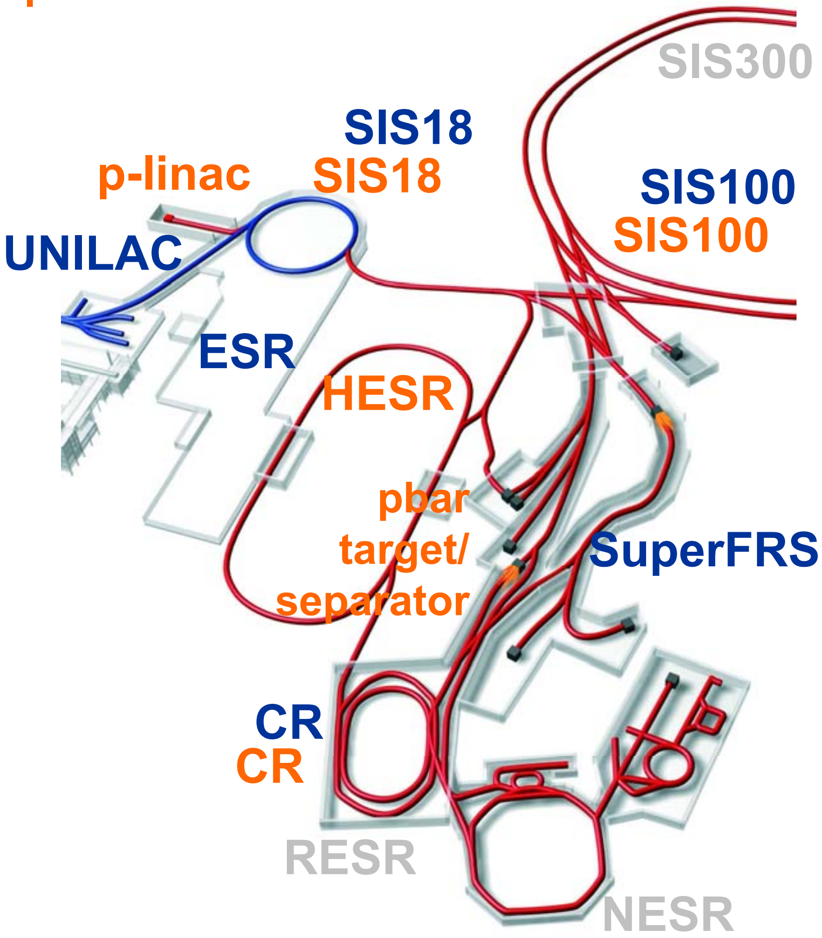
RUPAC 2012, St. Petersburg, Russia

Outline

- Modularized Start Version (MSV) of FAIR
- Collector Ring CR
  - Stochastic Cooling for CR
- High Energy Storage Ring HESR
  - Stochastic Cooling for HESR
  - Electron Cooling for HESR
  - Ion Operation in the HESR
- Experimental Storage Ring ESR at GSI
  - Beam Dynamics Experiments
  - CRYRING @ ESR

Modularized Start Version

Modularized Start Version (MSV)
pbar and RIBs



RESR and NESR will be added

Collector Ring CR

collection and pre-cooling of pbars (RIBs)

isochronous mass measurements of RIBs

High Energy Storage Ring HESR

accumulation and storage of antiprotons

experiments with 0.8-14.1 GeV antiprotons

plans for ion operation added recently

Accumulator Ring RESR

accumulation of up to 10^{11} antiprotons

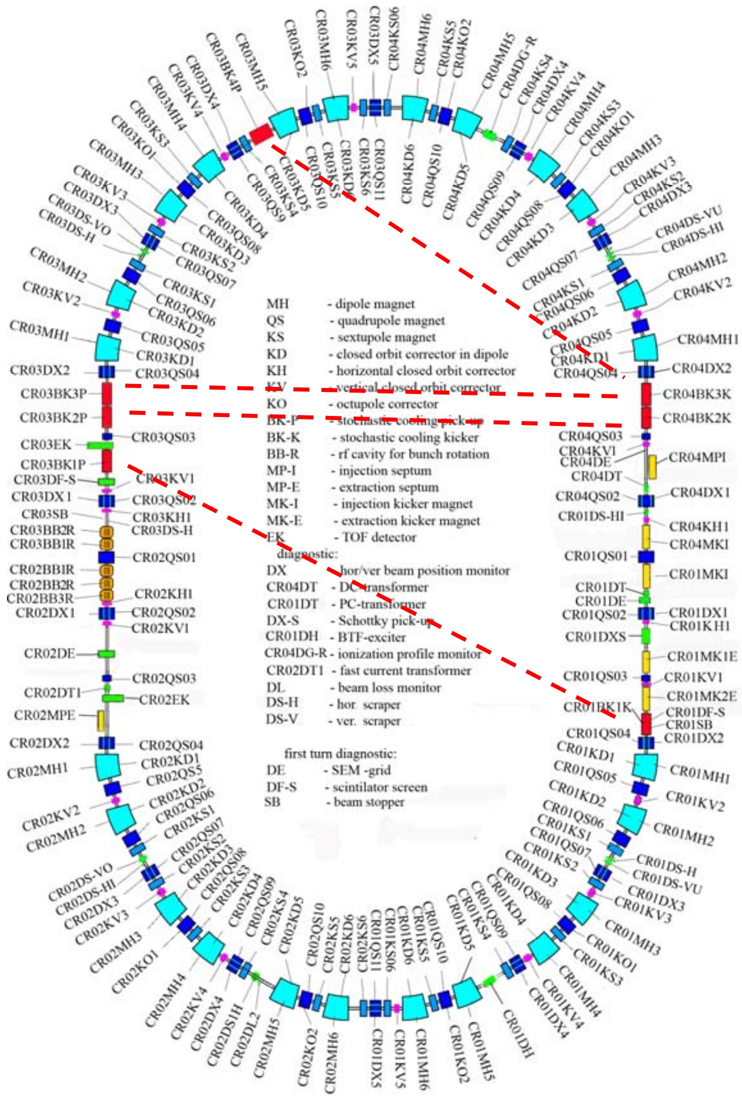
New Experimental Storage Ring NESR

experiments with stable and radioactive ions

deceleration of ions and antiprotons

ESR operation will be continued

The Collector Ring CR



circumference 221.5 m
magnetic bending power 13 Tm
large acceptance $\varepsilon_{x,y}$ = 240 (200) mm mrad
$\Delta p/p = \pm$ 3.0 (1.5) %

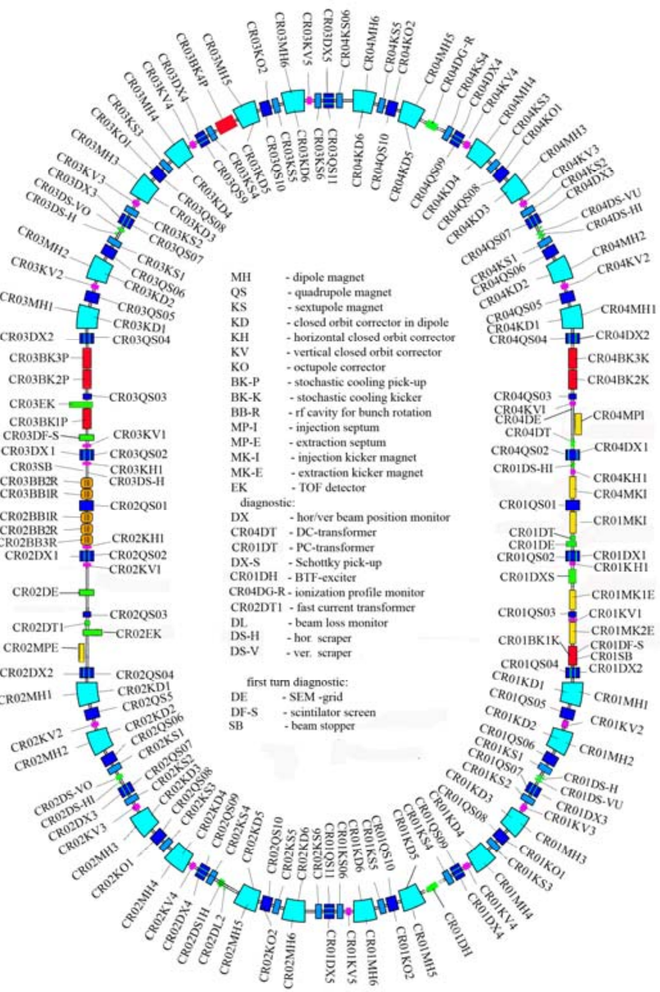
fast stochastic cooling (1-2 GHz) of antiprotons (10 s) and rare isotope beams (1.5 s)

fast bunch rotation at h=1 (U_{rf} =200 kV)
adiabatic debunching
optimized ring lattice (slip factor) for proper mixing
large acceptance magnet system

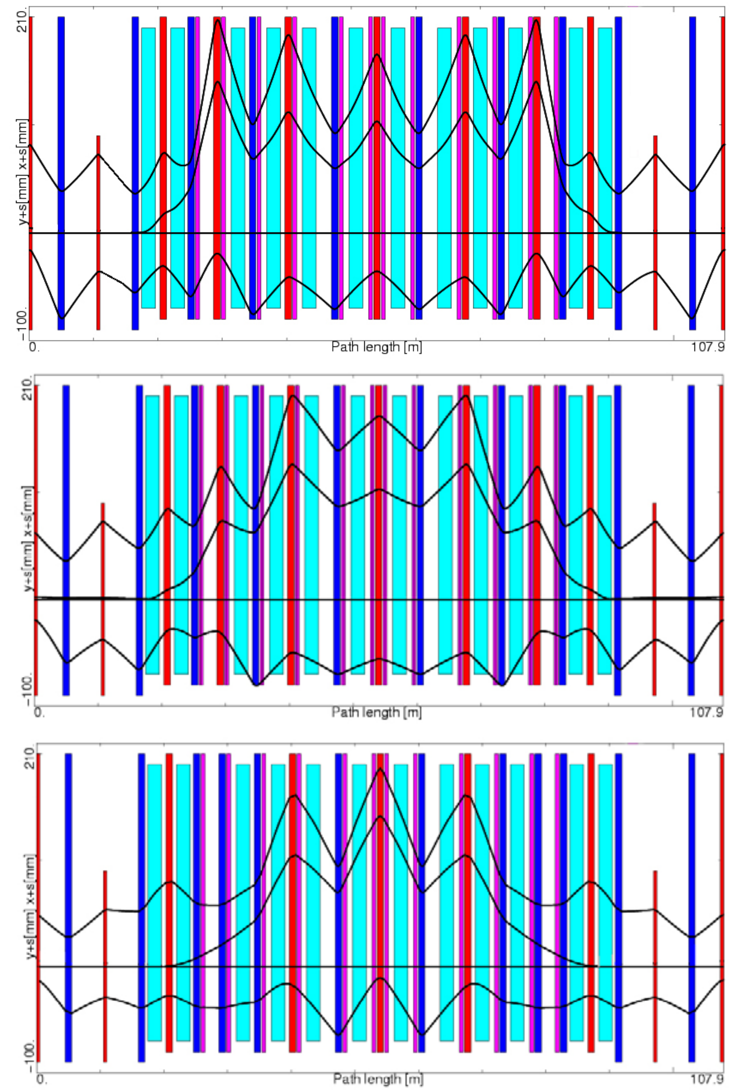
additional feature:
isochronous mass measurements of rare isotope beams

option: upgrade of rf system to 400 kV and stochastic cooling to 1-4 GHz

Ion Optical Modes of the CR



see poster (S. Litvinov)



antiprotons

$Q_x = 4.27$, $Q_y = 4.84$

$\gamma_t = 3.85$

$\eta = -0.011$

$\Delta p/p = \pm 3.0\ \%$

RIBs

$Q_x = 3.19$, $Q_y = 3.71$

$\gamma_t = 2.82$

$\eta = +0.186$

$\Delta p/p = \pm 1.5\ \%$

isochronous

$Q_x = 2.23$, $Q_y = 4.64$

$\gamma_t = 1.67\text{-}1.84$

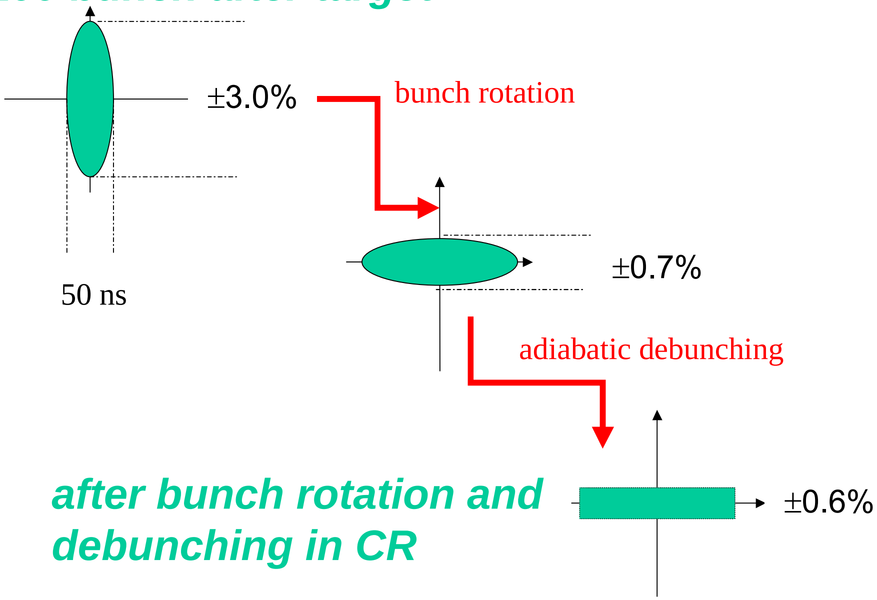
$\eta = 0$

$\Delta p/p = \pm 0.5\ \%$

Fast Bunch Rotation in CR

Fast bunch rotation of SIS100 bunch
to provide optimum initial parameters
for stochastic cooling
total rf voltage 200 kV at h=1 reduces
the momentum spread (± 3.0 → ± 0.7 %)
after passage of production target

SIS100 bunch after target



Debuncher rf system ordered

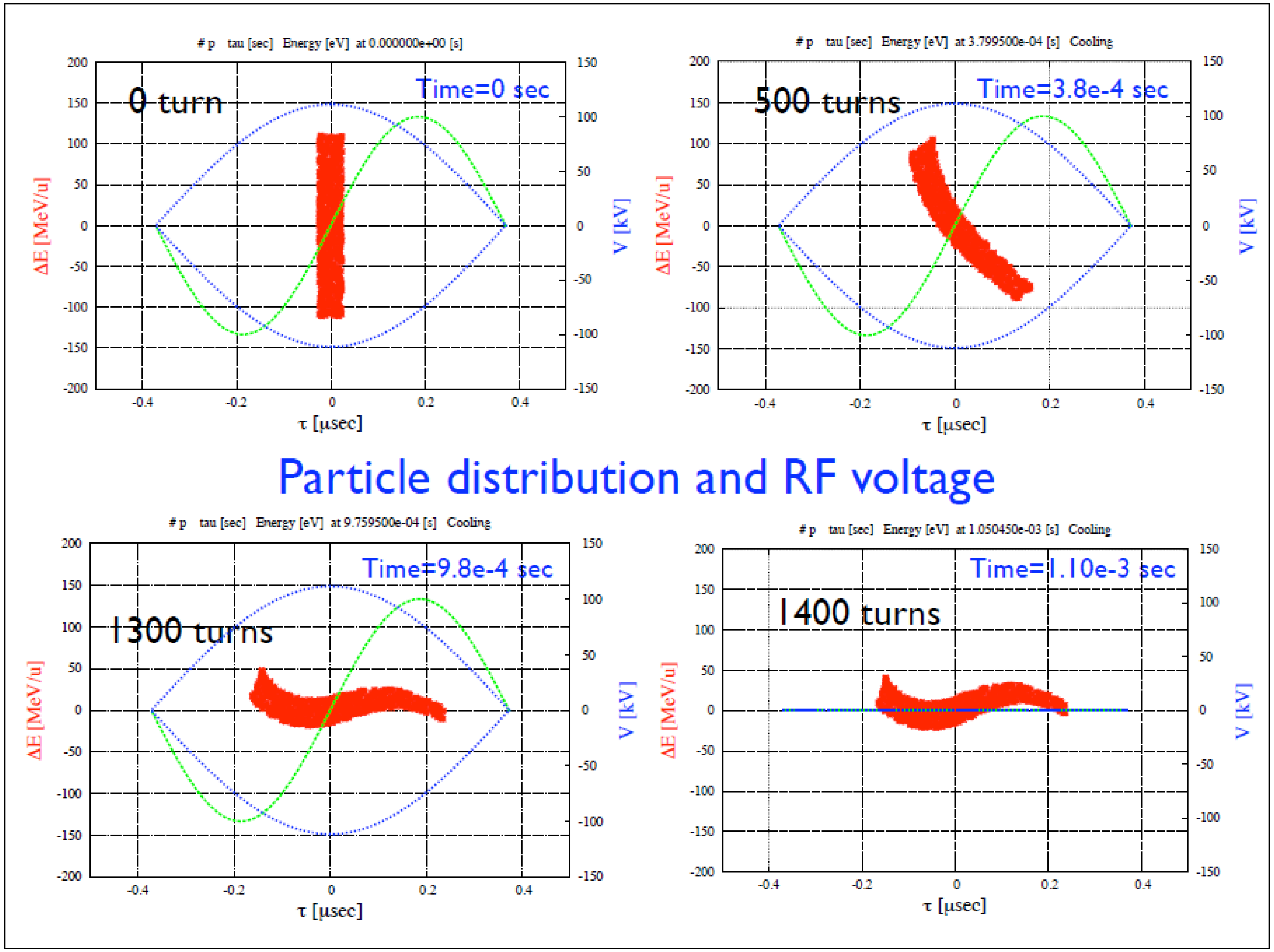
SIS18 bunch compressor cavity prototype for

CR bunch rotation cavity
filled with magnetic alloy

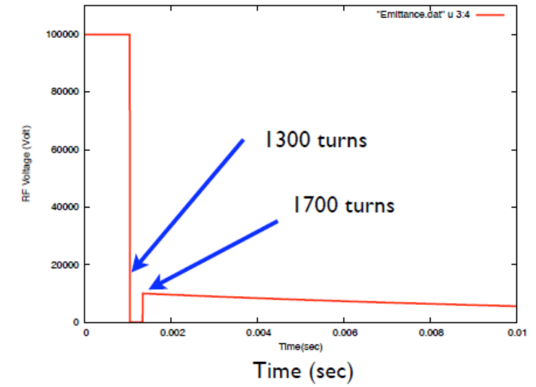
voltage 40 kV
length 1 m
frequency range 1.13 – 1.32 MHz
rotation time 1000 μs (pbars)
600 μs (RIBs)

Simulation of Bunch Rotation

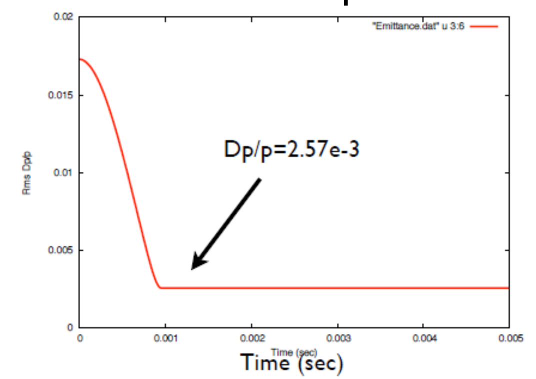
Simulation for 3 GeV antiprotons (50 ns bunch length from SIS100)



rf amplitude



momentum spread

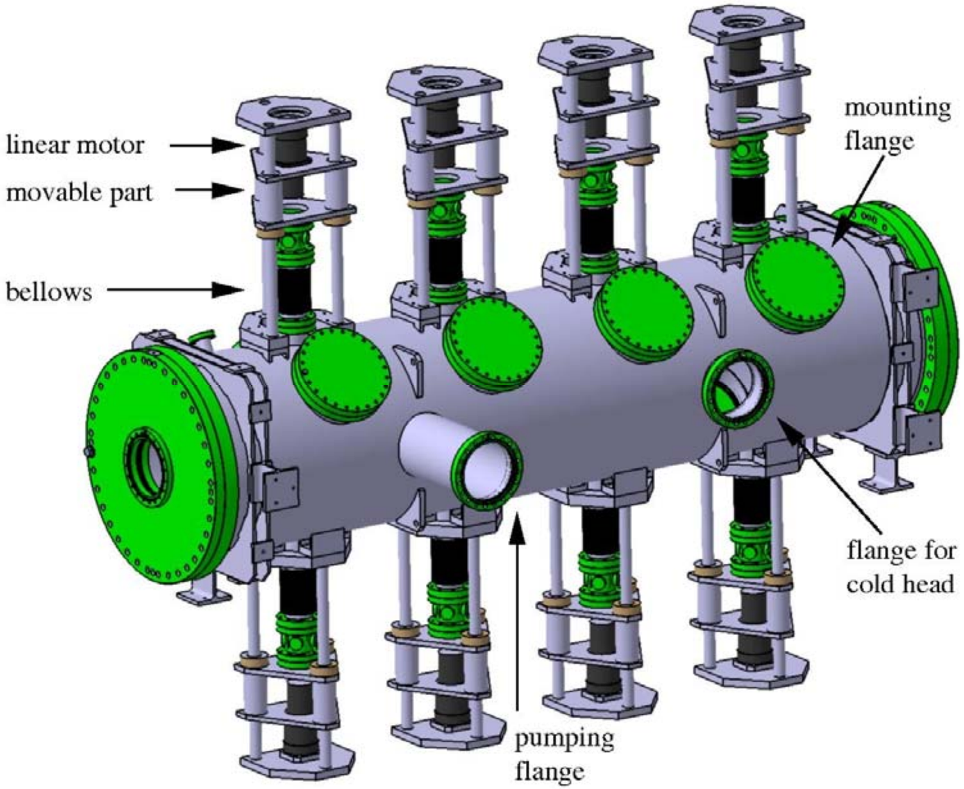


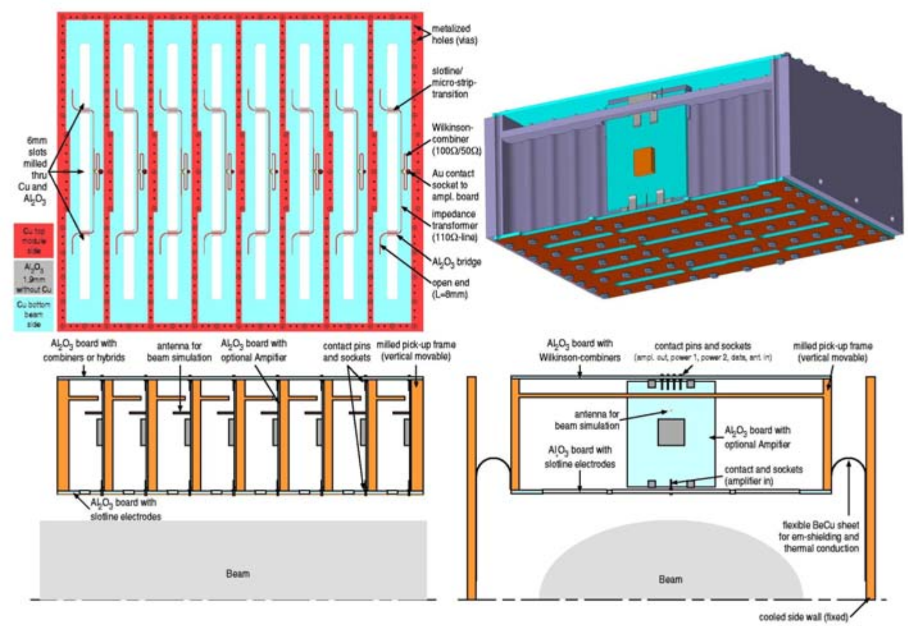
CR Stochastic Cooling

vacuum tank
with actuators for electrode movement including cold heads (20 K) and cooled pre-amplifiers (option)

cooling of rare isotopes ($\beta = 0.83$) and antiprotons ($\beta = 0.97$)

Installed in the vacuum tank: electrodes (and as an option pre-amplifiers) can be cooled to 20 K

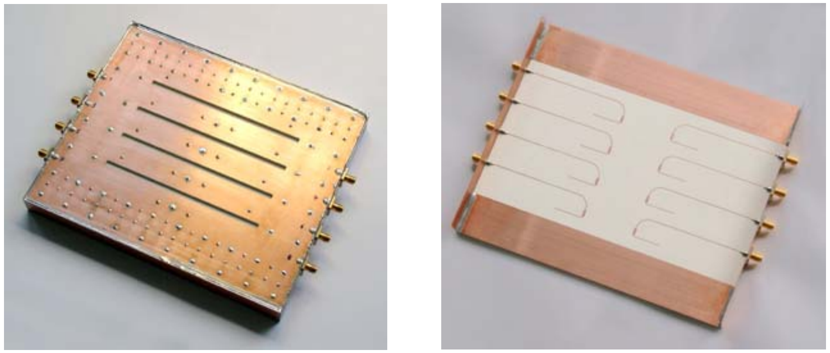




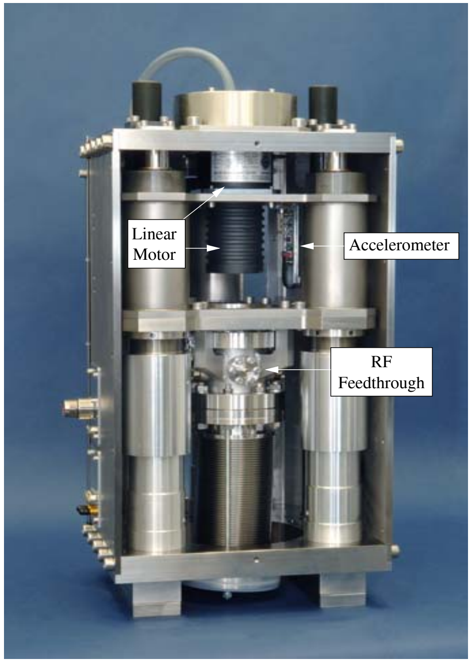
CR Stochastic Cooling Prototypes

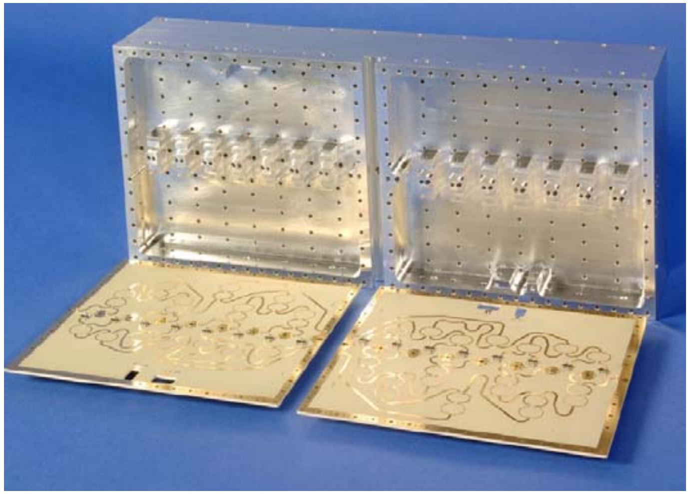
vacuum tank for moving electrodes

Electrode prototype (slot line type)

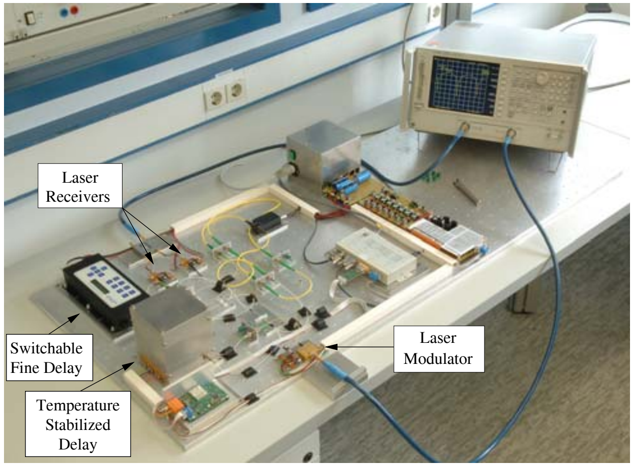


programmable linear actuator



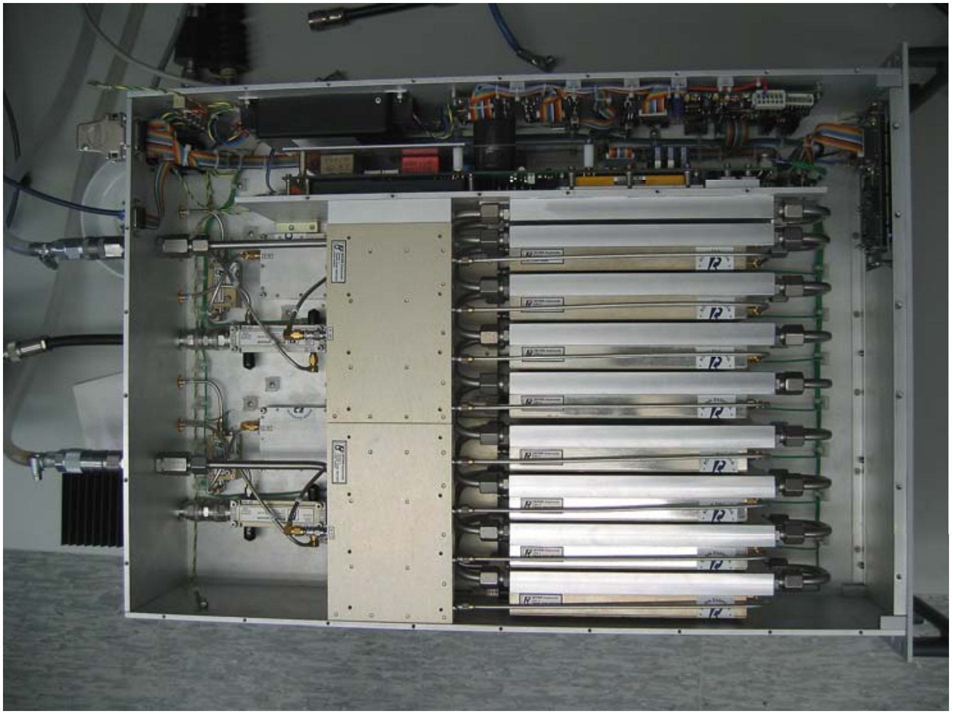


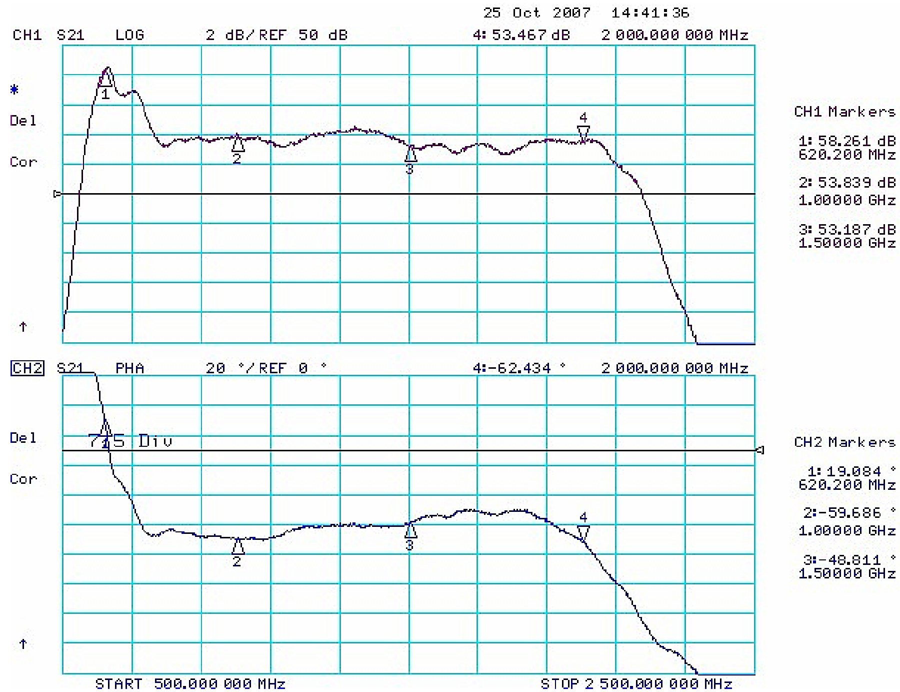
milled module body with combiner board



optical delay line

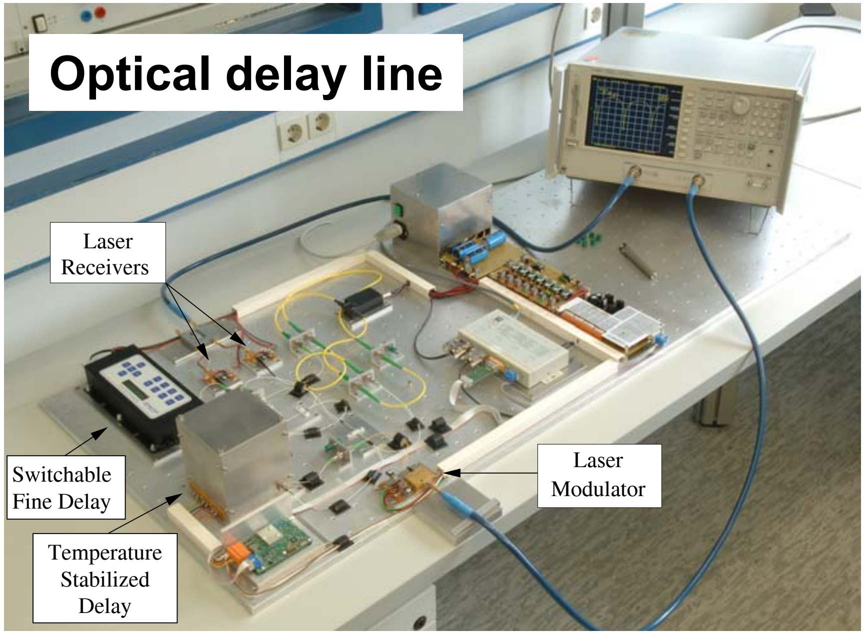
Power Amplifier Prototypes 1-2 GHz



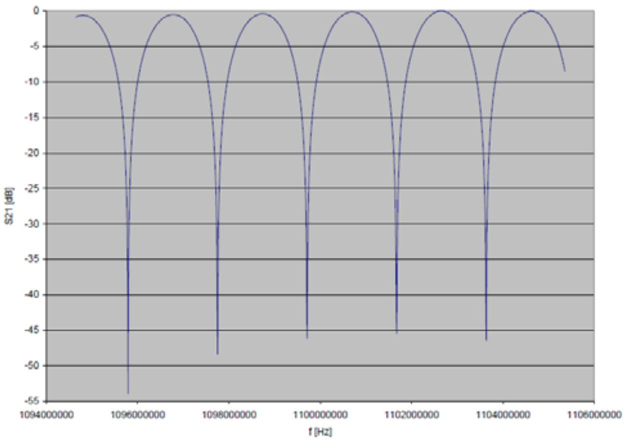


Prototype was tested, but quality is still not according to specifications.

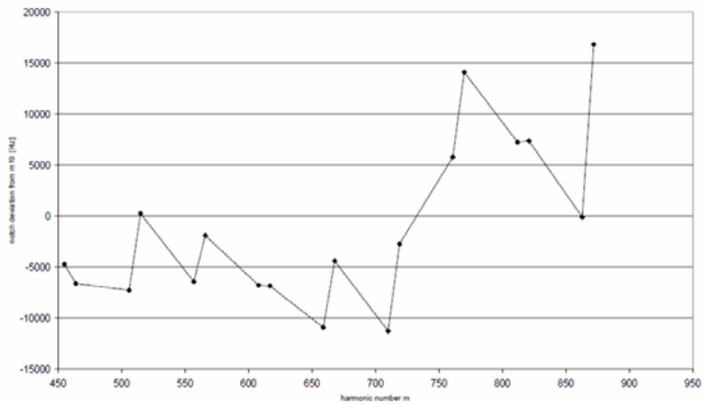
Notch Filter Development



Test set-up of notch filter at ESR



notch depth better 45 dB



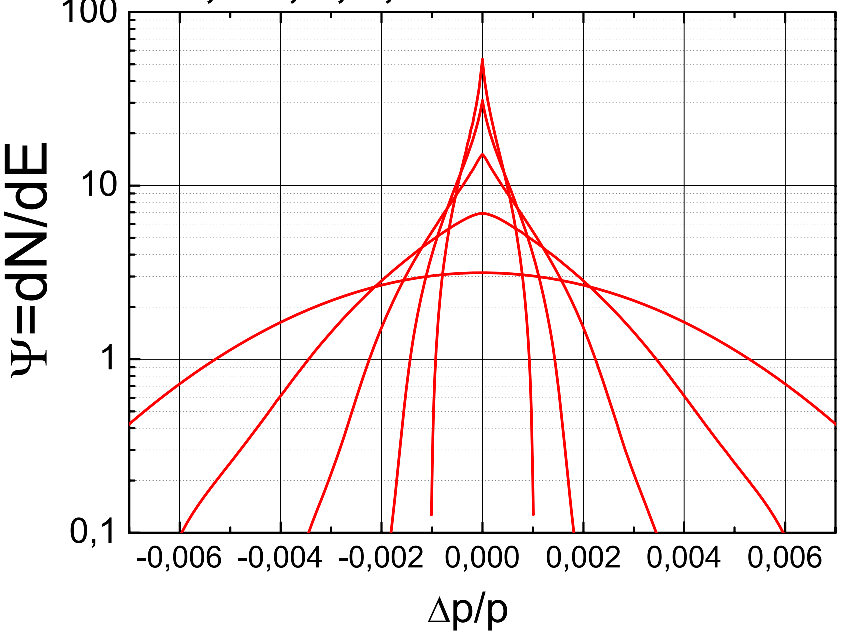
frequency deviation $\leq 5 \times 10^{-5}$

Simulation of Momentum Cooling in CR

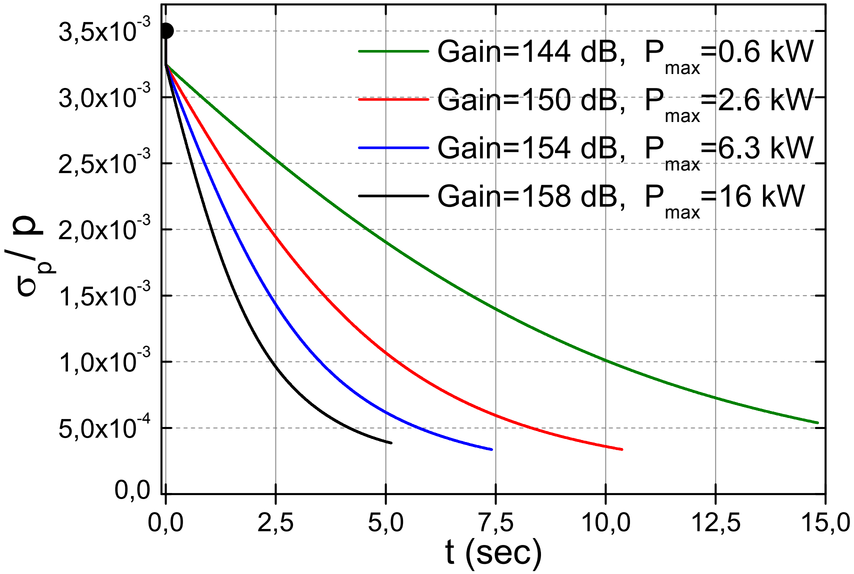
main goal: 10 s cycle time for antiprotons

using the old CERN code cross-checked with T. Katayama

Longitudinal cooling with band 1 – 2 GHz
t=0, 2.5, 5, 7,5 and 10 s



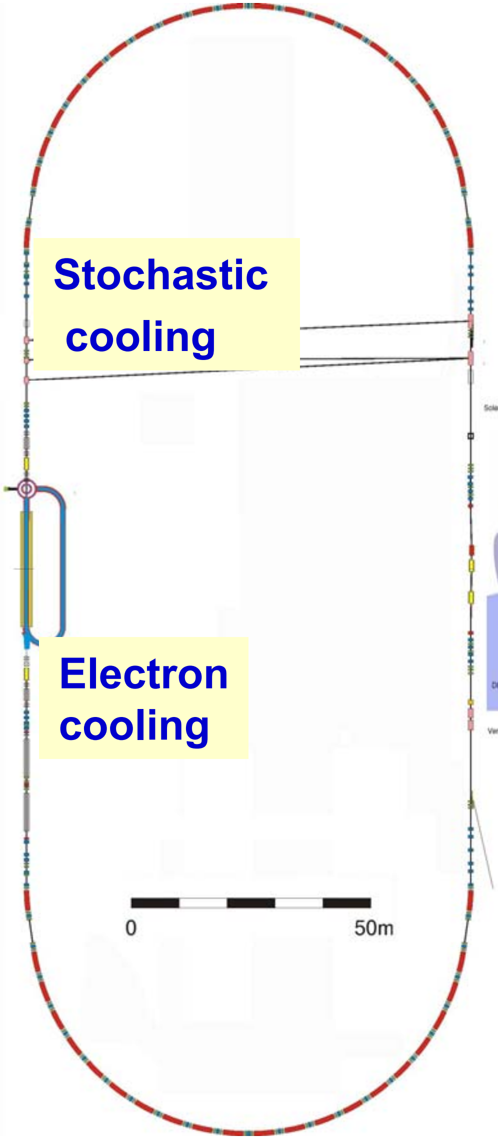
g=150 dB (3.2×10^7); t=10 s



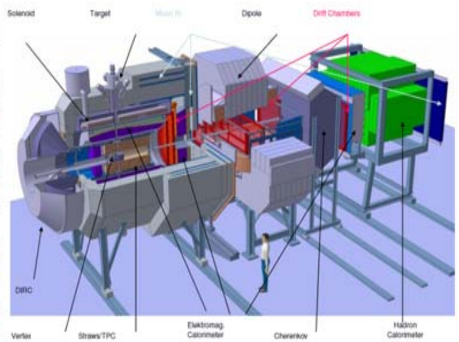
upgrades:
more rf power (presently 8 kW)
cooling with band 2 – 4 GHz

further activities:
simulation of RIB cooling
preparation of specifications

The High Energy Storage Ring HESR



responsibility of FZ Jülich (German in-kind contribution)



PANDA experiment

Storage of antiprotons

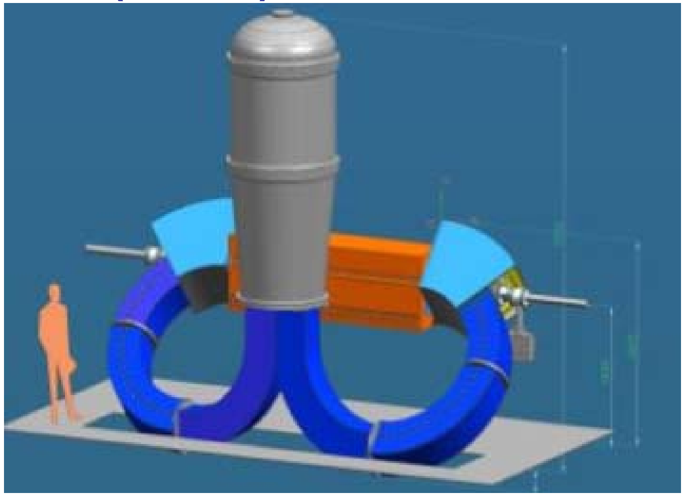
HESR Parameters

- circumference 574 m
- momentum (energy) range 1.5 to 15 GeV/c (0.8-14.1 GeV)
- injection of antiprotons from CR accumulation with barrier bucket and stochastic cooling (later accumulation in RESR)
- maximum dipole field: 1.7 T
- dipole field at injection: 0.4 T
- dipole field ramp: 0.025 T/s
- acceleration rate 0.2 (GeV/c)/s
- internal experiment PANDA: dipole field ramp: 0.015 T/s internal hydrogen target
- option: high energy electron cooling

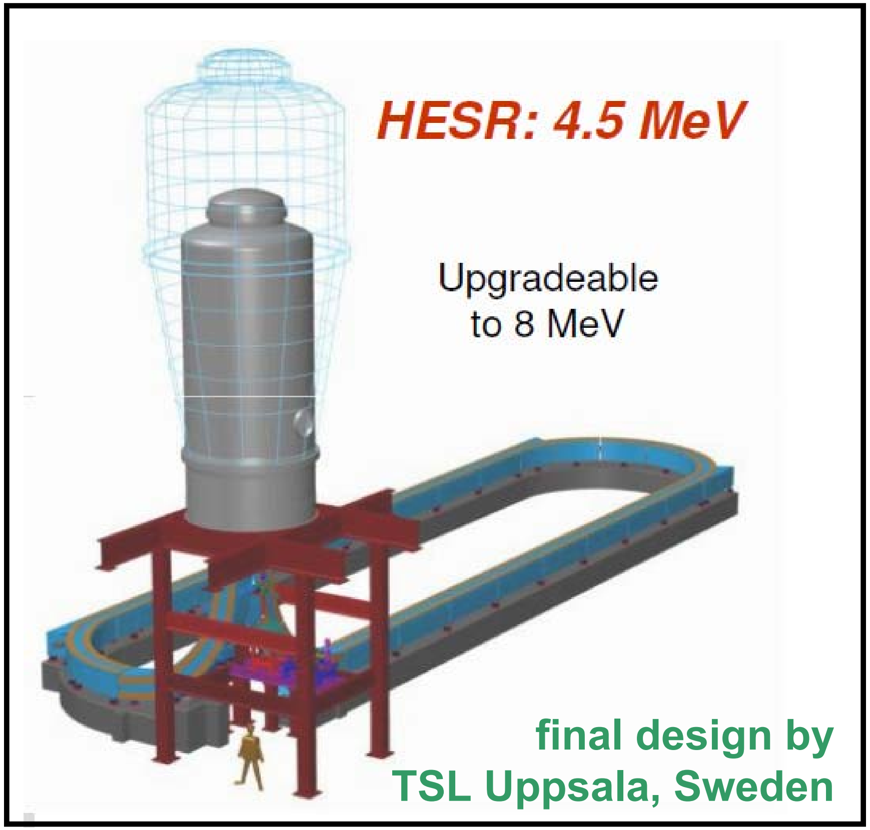
JÜLICH FORSCHUNGSZENTRUM

HESR Cooling Systems

COSY (HESR) 2 MeV Electron Cooling

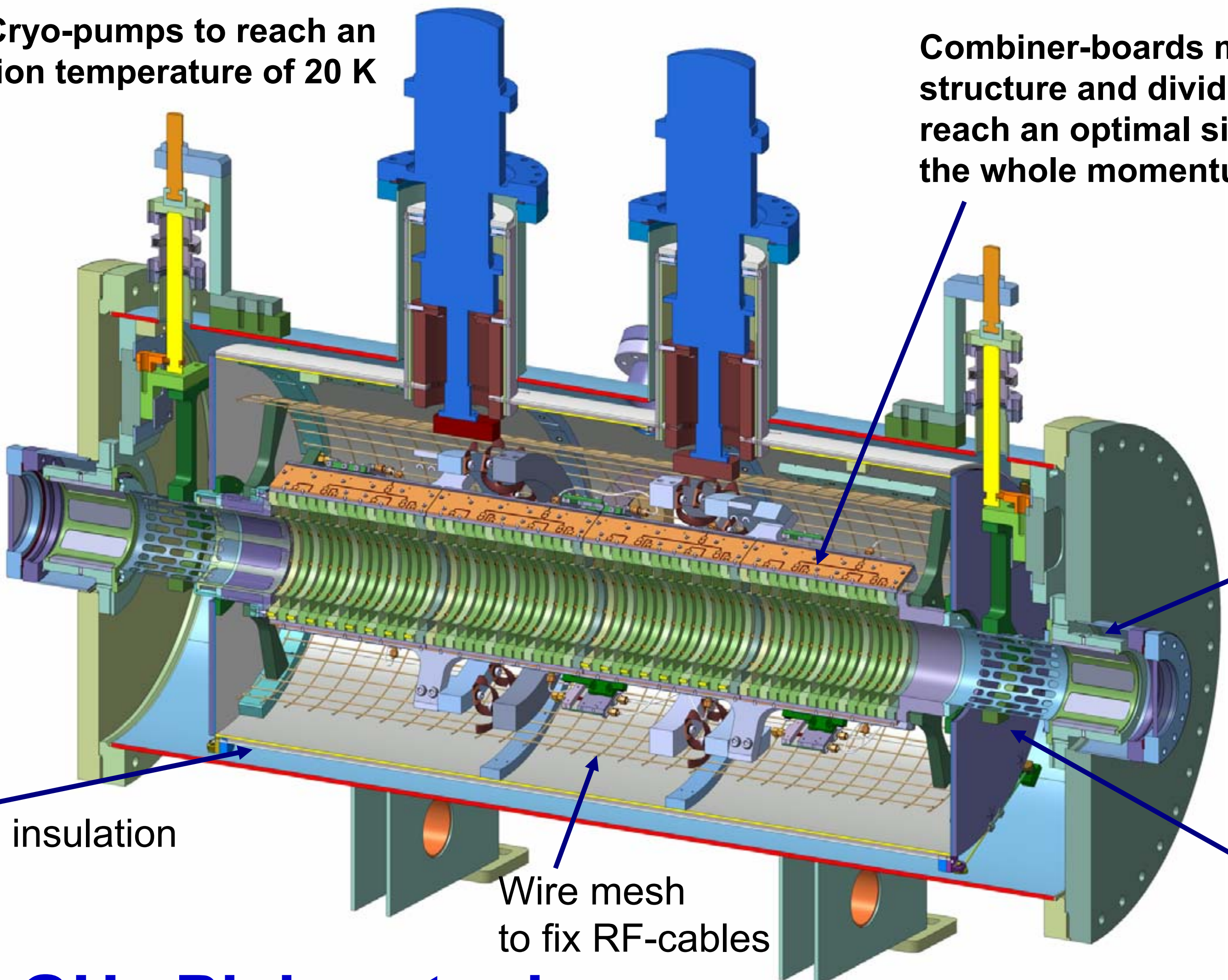


Ultimate HESR Electron Cooling



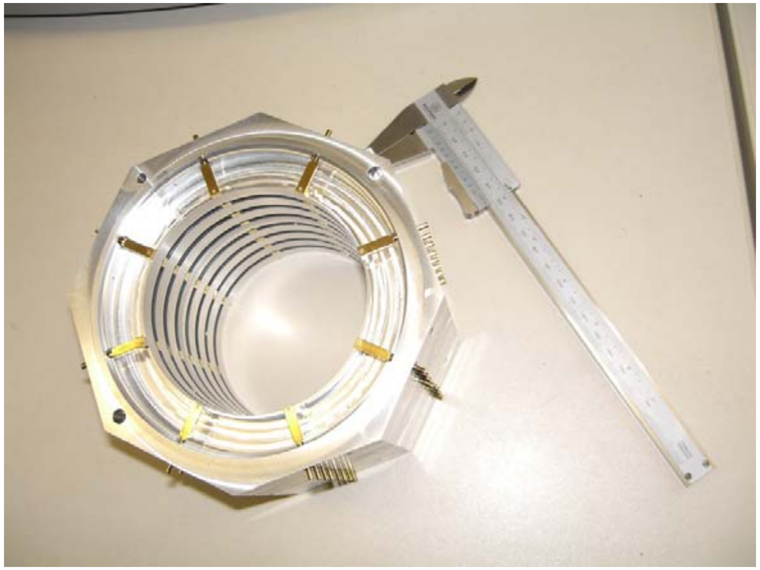
stochastic cooling

HESR Stochastic Cooling



2-4 GHz Pickup-tank

Pickup Structures for the HESR Stochastic Cooling System

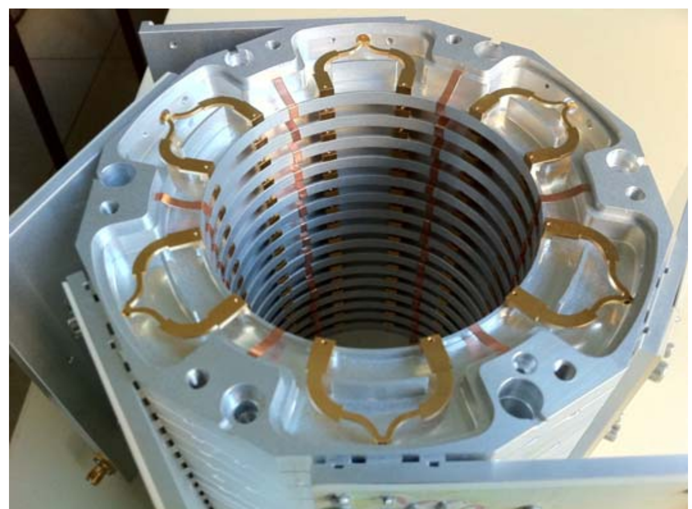


2-4 GHz slot ring couplers:

- Self-supporting and robust structure with 8 50Ω strip line electrodes
- No plunging system
- One structure for all three cooling planes
- Structure tested in small cryogenic test-tank with real COSY beam. The measured sensitivity was higher than the plunging COSY-lambda/4 structures

4-6 GHz slot ring couplers:

- Same aperture (90mm)
- 12 electrodes already formed as 2:1 combiner within the structure
- Sensitivity significantly lower but tolerable because 4-6 GHz system will be used for longitudinal cooling only
- Additional modes still a problem



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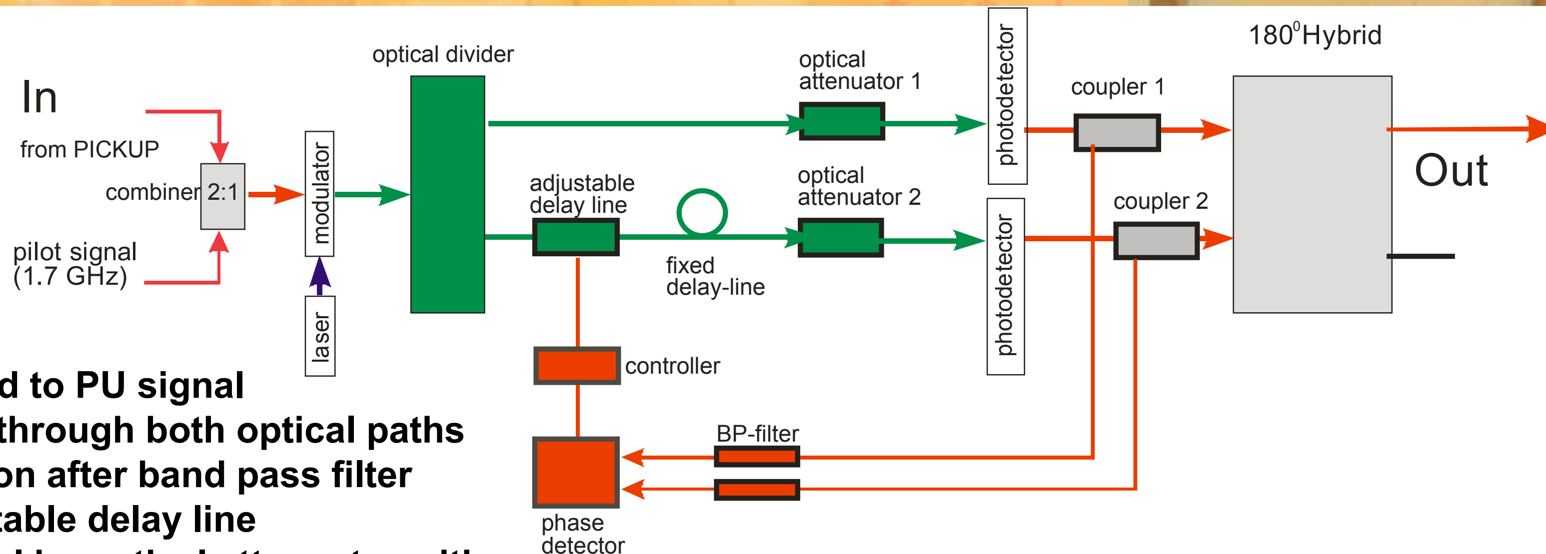
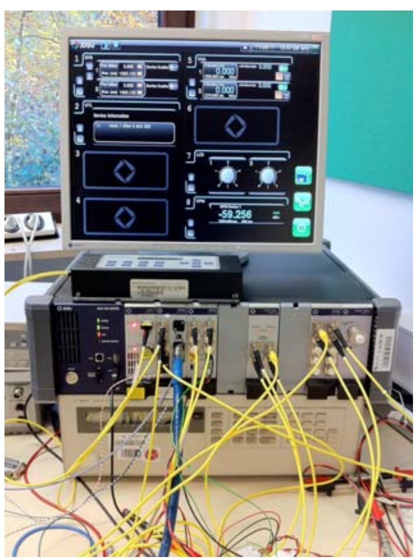
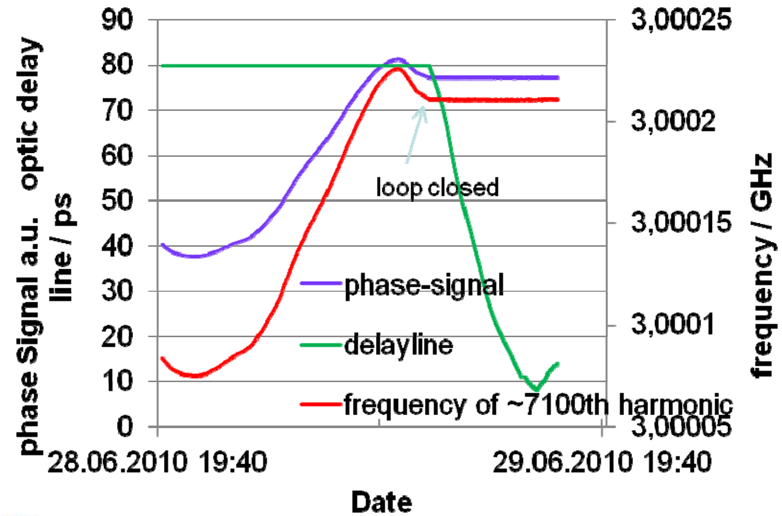
Active Control of Optical Notch Filter



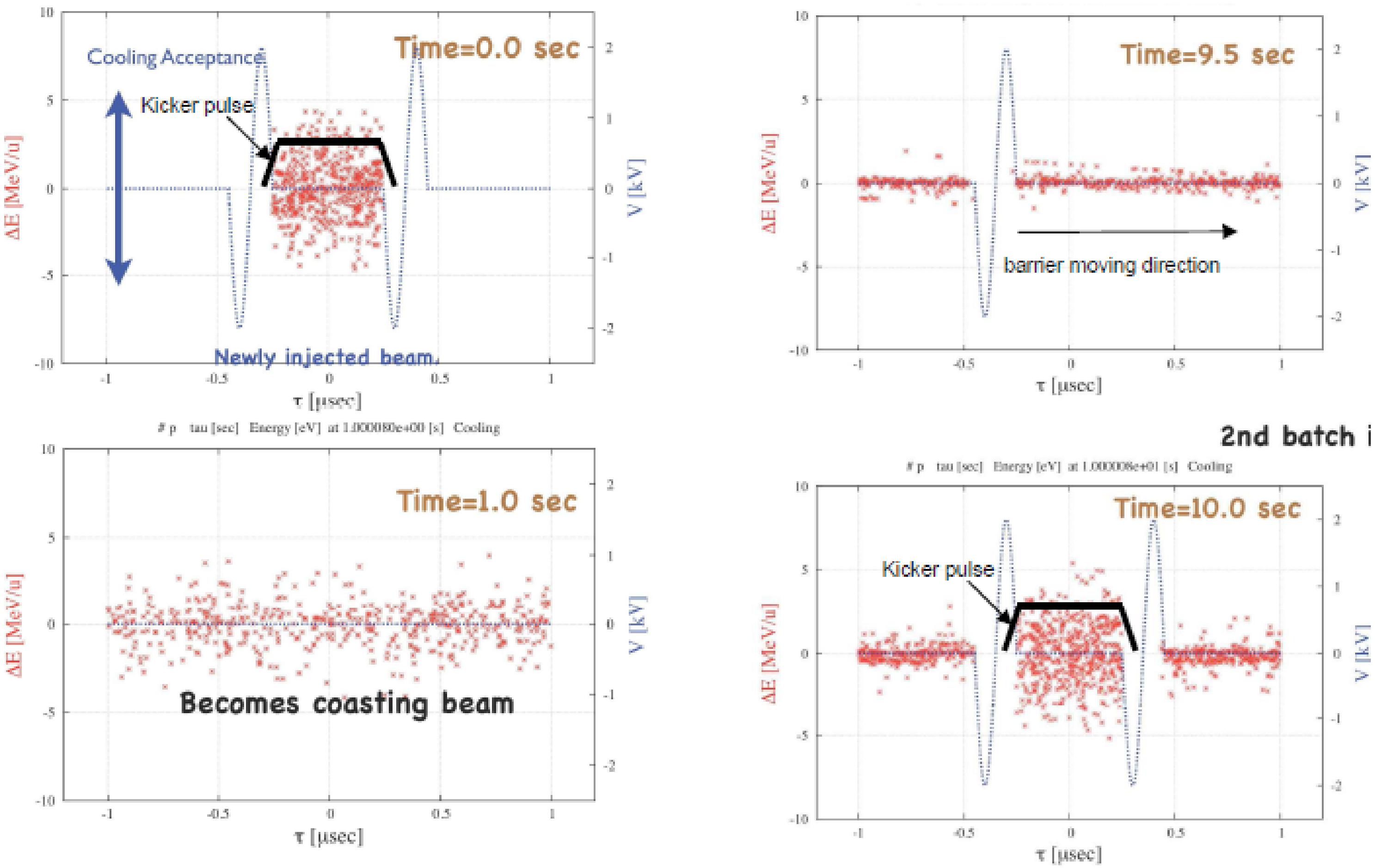
- Pilot signal added to PU signal
- parallel transfer through both optical paths
- Phase comparison after band pass filter
- Control of adjustable delay line
- Amplitude control by optical attenuator with included power meters





Accumulation in the HESR

idea: accumulate pre-cooled antiprotons from CR
by combination of barrier buckets and stochastic cooling



T. Katayama

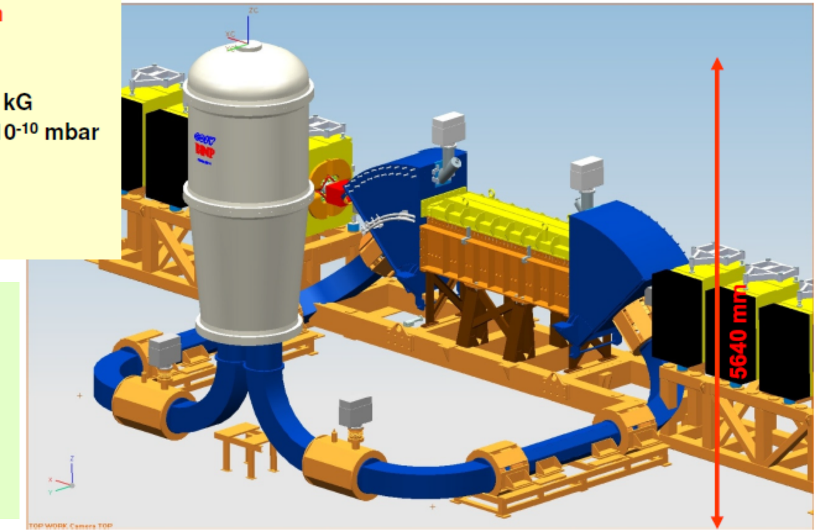
Electron Cooling in the HESR

The COSY (HESR) 2 MeV Electron Cooler

Technical Design – Layout BINP

Basic Parameters and Requirements

Energy Range:	0.025 ... 2 MeV
High Voltage Stability	$< 10^{-4}$
Electron Current	0.1 ... 3 A
Electron Beam Diameter	10 ... 30 mm
Cooling section length	2.694 m
Toroid Radius	1.00 m
Variable magnetic field (cooling section solenoid)	0.5 ... 2 kG
Vacuum at Cooler	10^{-9} ... 10^{-10} mbar
Available Overall Length	6.390 m
Maximum Height	5.7 m
COSY beam Axis above Ground	1.8 m



presentation
V.V. Parkhomchuk
J. Dietrich

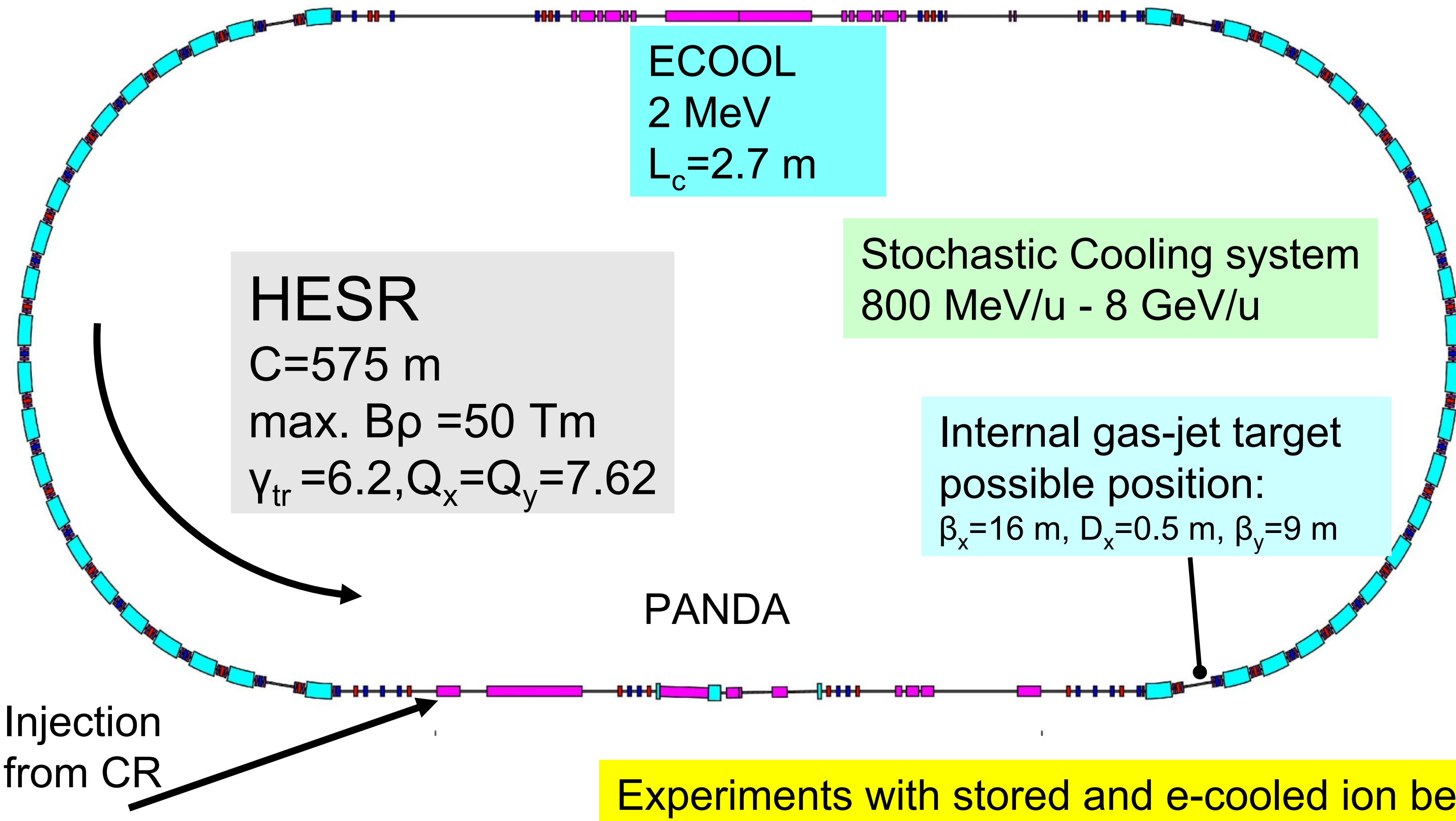
presently: final commissioning at BINP Novosibirsk
afterwards: transfer to FZJ and installation in COSY

Antiproton Cooling:
at injection energy and below: 0.8 – 3 GeV

Ion and RIB Cooling:
In the energy range 0.2 – 3.5 GeV/u
injection at 0.74 GeV/u

applications:
- **compensation of target heating and intrabeam scattering**
- **accumulation of ions**

Operation of the HESR with Ions



3 GeV antiprotons,
740 MeV/u ions

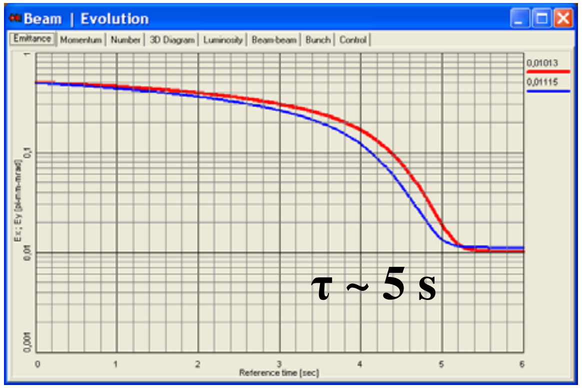
Experiments with stored and e-cooled ion beams
Kinetic energy range: 200 MeV/u – 3 GeV/u
Reference ions: $^{238}U^{92+}$ and $^{132}Sn^{50+}$

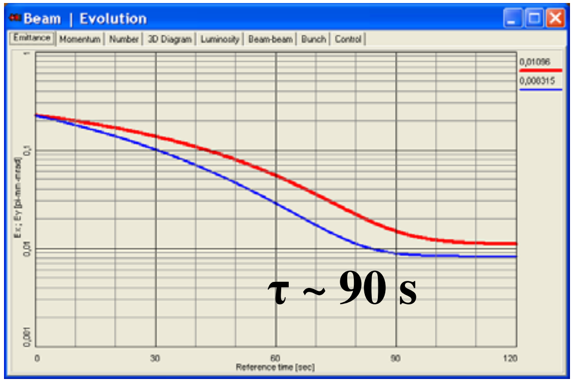
BETACOOL Simulations of Electron Cooling in the HESR

BETACOOL-simulation of cooling U^{92+} from CR

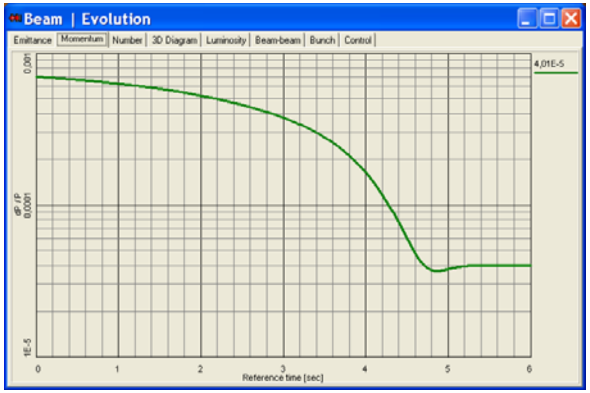
740 MeV/u I_e=0.5 A | **3 GeV/u I_e=1.0 A**

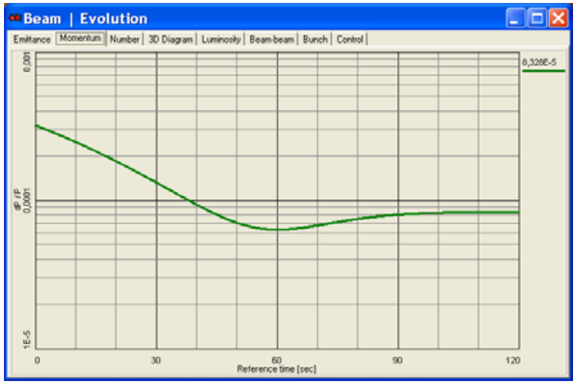
Transverse emittance





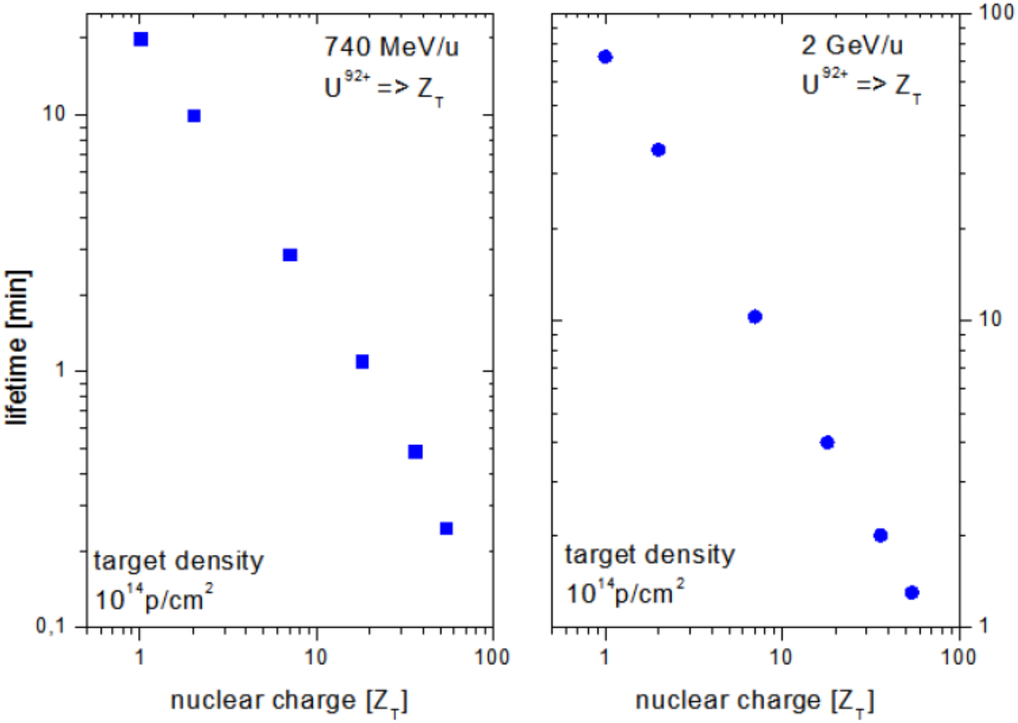
Momentum spread

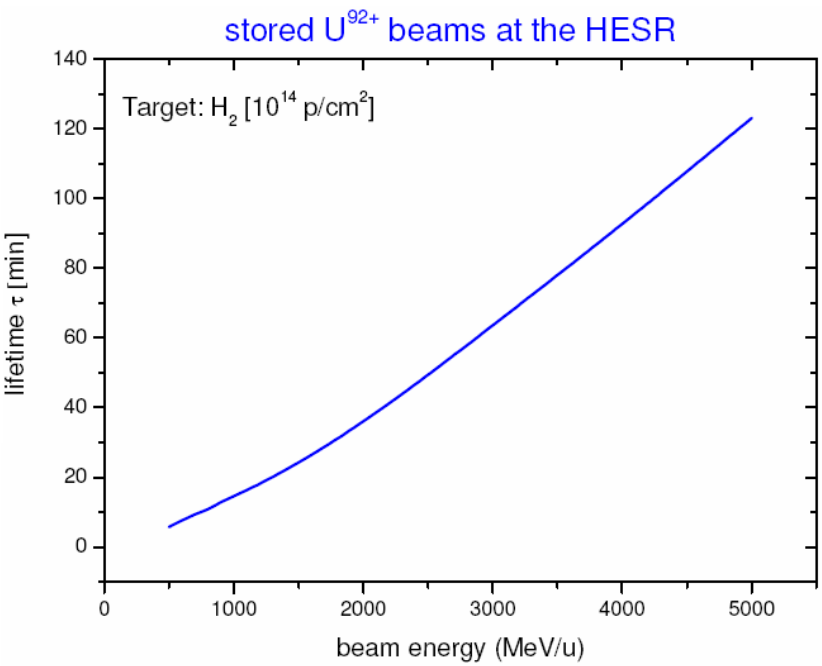




Lifetime of Ions in the HESR

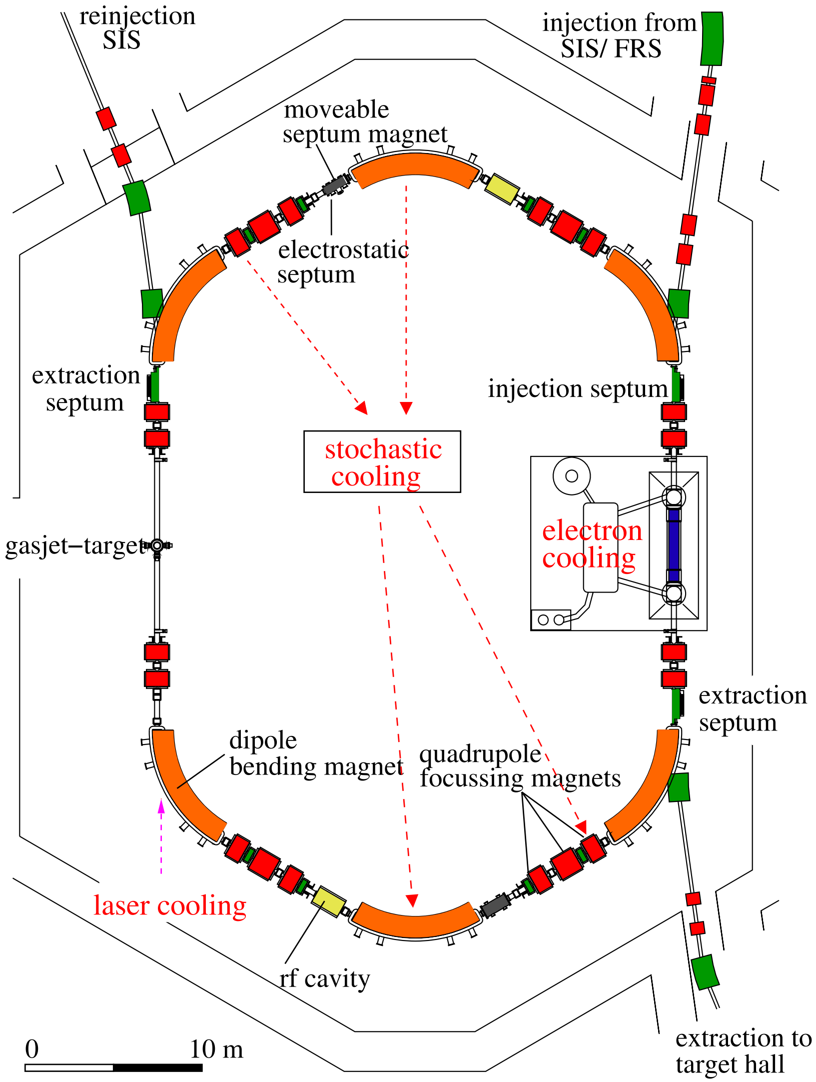
assuming vacuum without bakeout of vacuum system, p ~ 1 × 10^{-9} mbar and operation of an internal target (target heating compensated by cooling)





even without bakeout of the vacuum system beam lifetimes of several minutes will allow experiments with stored ions

The Existing ESR



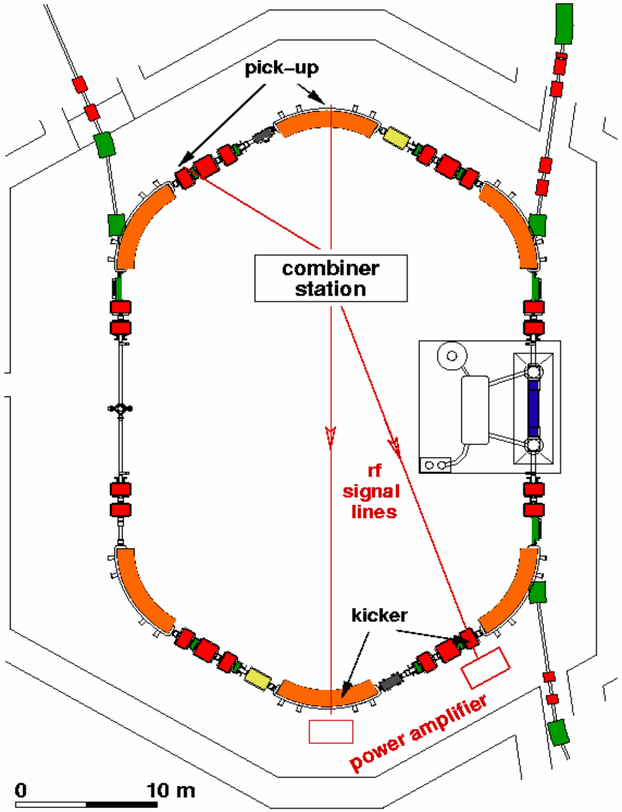
- Fast injection (stable ions / RIBs)
- Stochastic cooling (≥ 400 MeV/u)
- Electron cooling (3 - 430 MeV/u)
- Laser cooling (C^{3+} 120 MeV/u)
- Internal gas jet target
- Acceleration/deceleration (down to 3 MeV/u)
- Fast extraction (reinjection to SIS / HITRAP)
- Slow (resonant) extraction
- Ultraslow extraction (charge change)
- Beam accumulation
- Multi charge state operation
- Schottky mass spectrometry
- Isochronous mode (TOF detector)

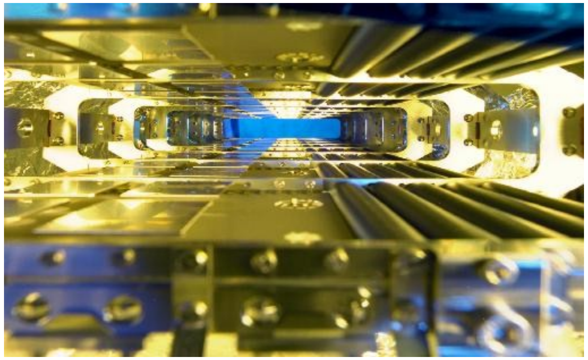
The ESR will be a valuable test bed to develop techniques for FAIR

Stochastic Cooling in the ESR

fast pre-cooling of hot fragment beams

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





electrodes installed inside magnets

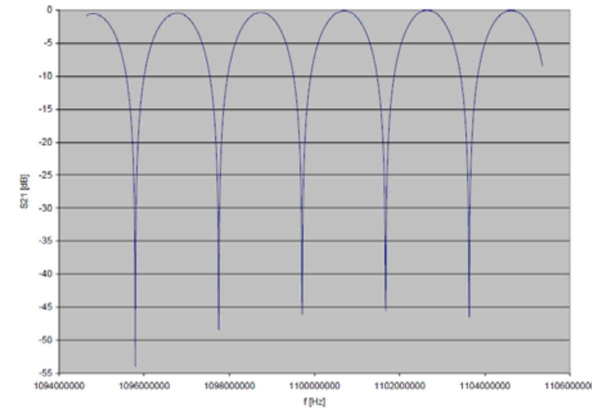
combination of signals from electrodes

power amplifiers for generation of correction kicks

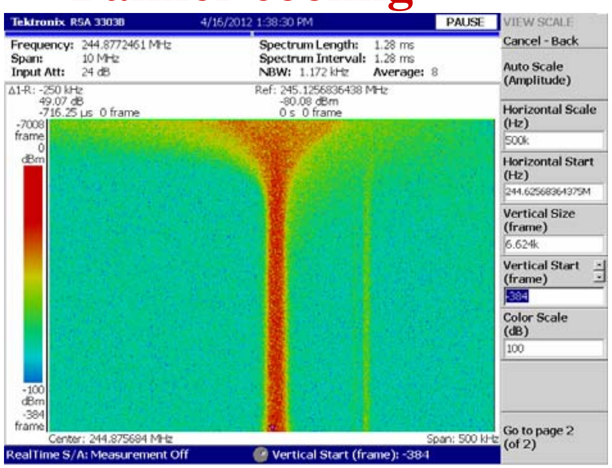
Test of Notch Filter Cooling at the ESR

Optical delay line installed in the ESR for tests of TOF and notch filter cooling

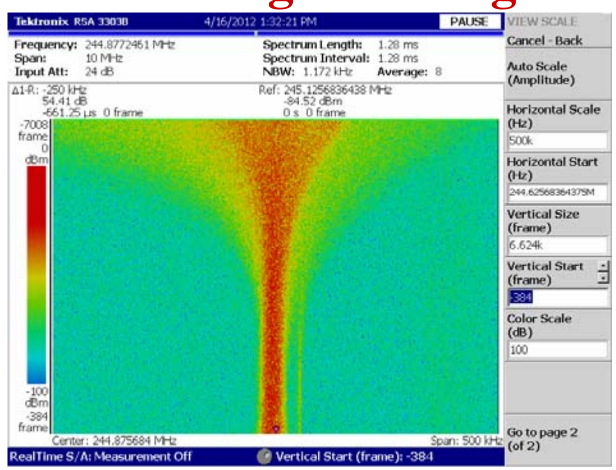
using existing electrodes designed for Palmer cooling



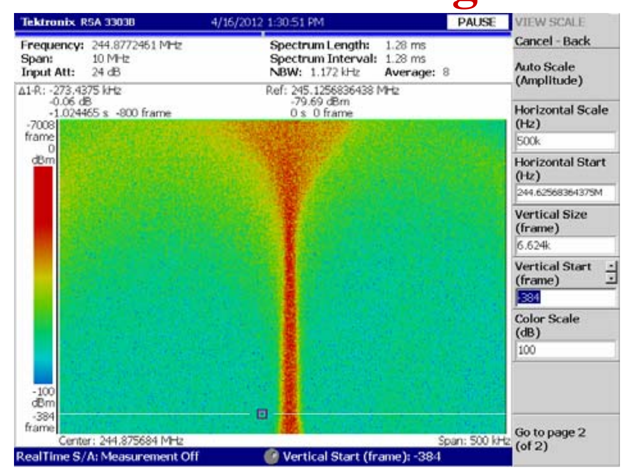
Palmer cooling



Time-of-Flight cooling



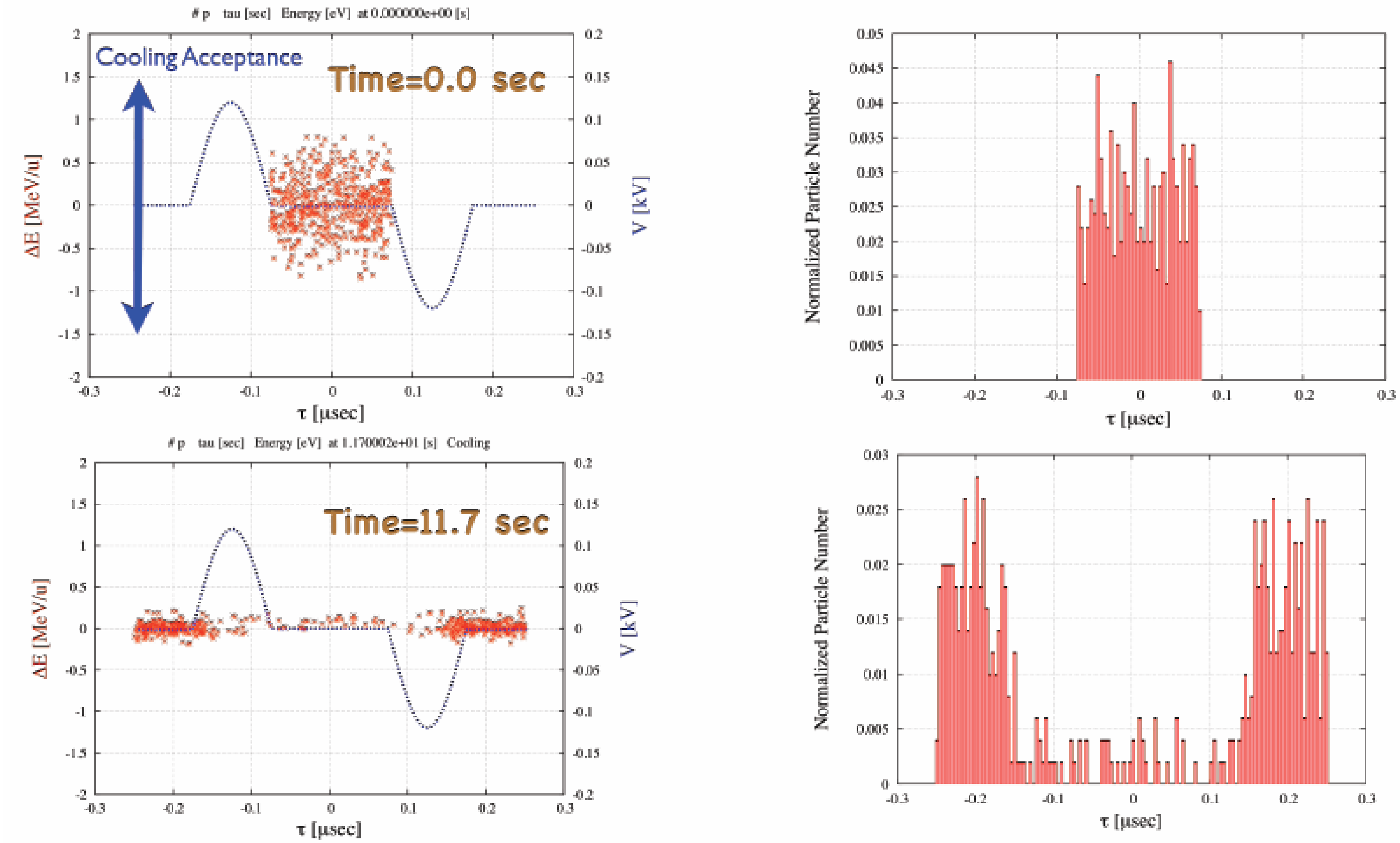
Notch filter cooling



Ar^{18+} 400 MeV/u

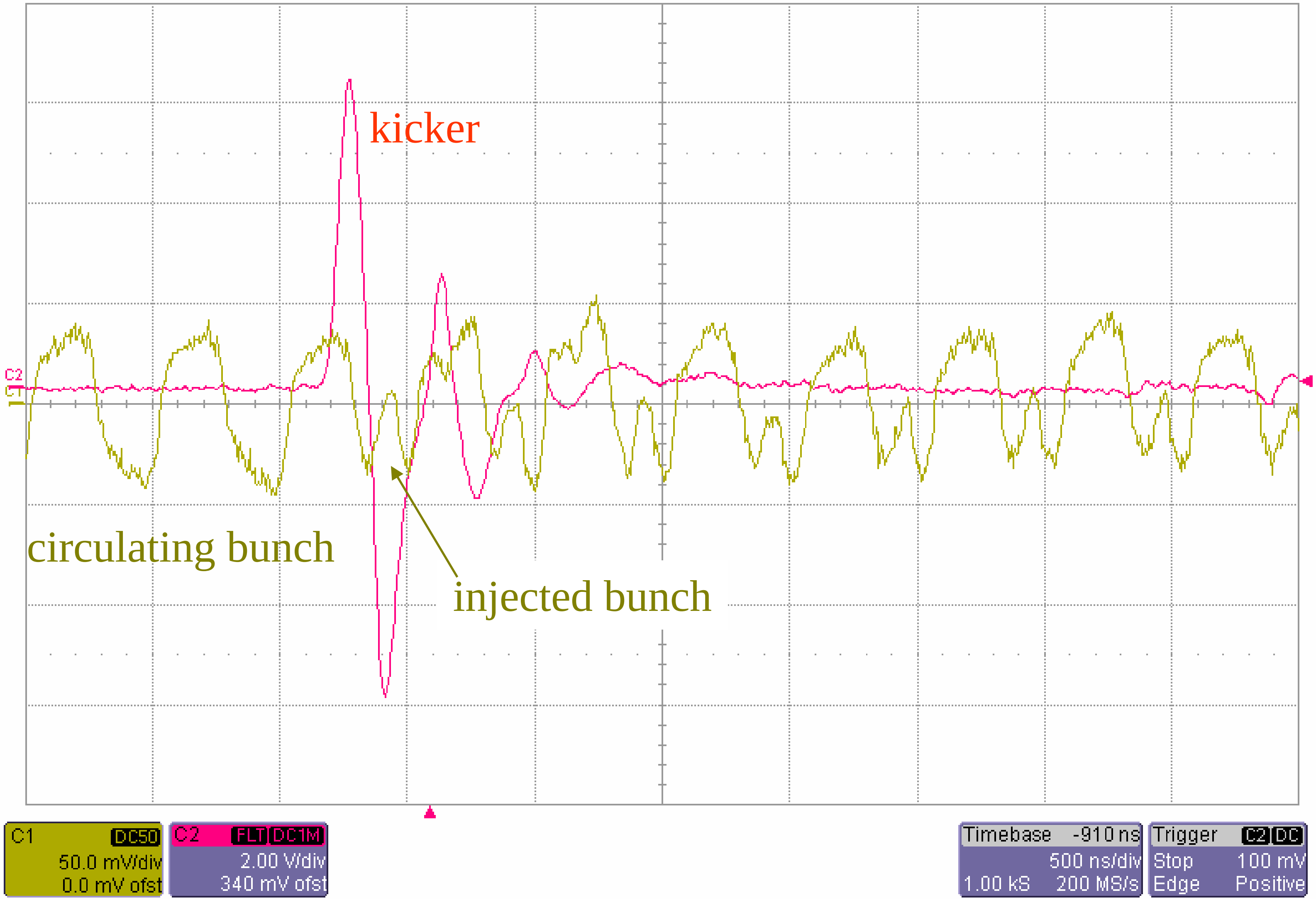
Proof-of-Principle Experiment in the ESR

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



mainly to demonstrate the method and benchmark codes, limited by ESR hardware

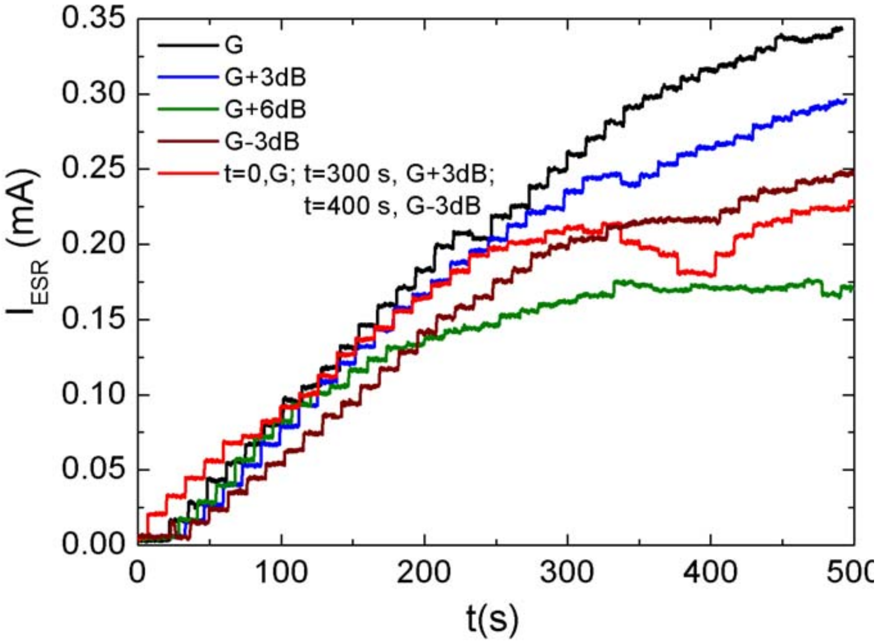
Bunch Signal from Beam Position Pick-up

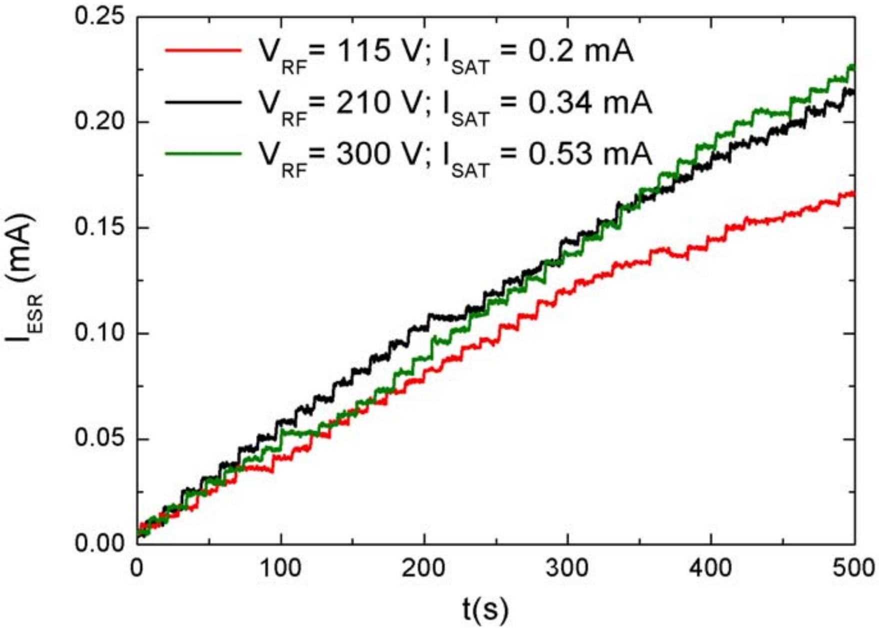


PoP-Experiment ESR

Stacking by combination of rf and stochastic cooling

with good efficiency and reliability





rf h=1 stacking on unstable fixed point

stacking with fixed barriers

stacking with moving barriers unsuccessful due to limited rf amplitude

simulations in talk by T. Katayama

Deceleration to 4 MeV/u for HITRAP

Ni^{28+} 400 → 30 → 4 MeV/u

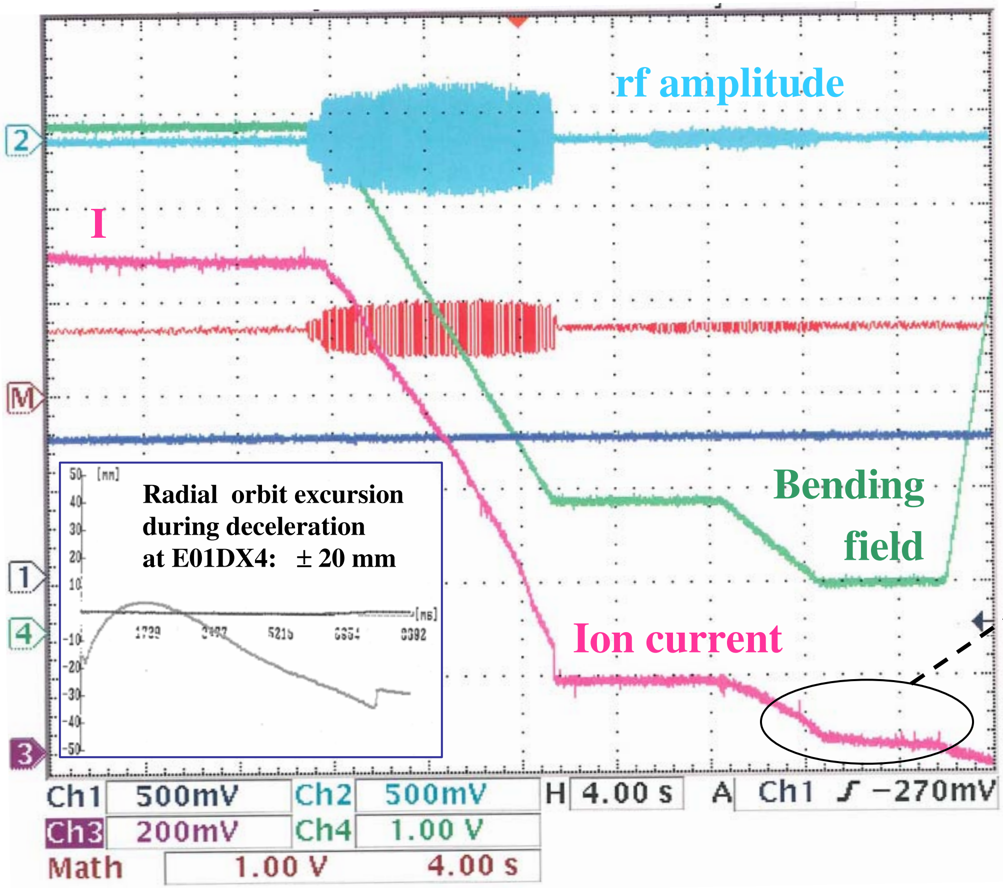
1100 μA → 180 μA → 25 μA

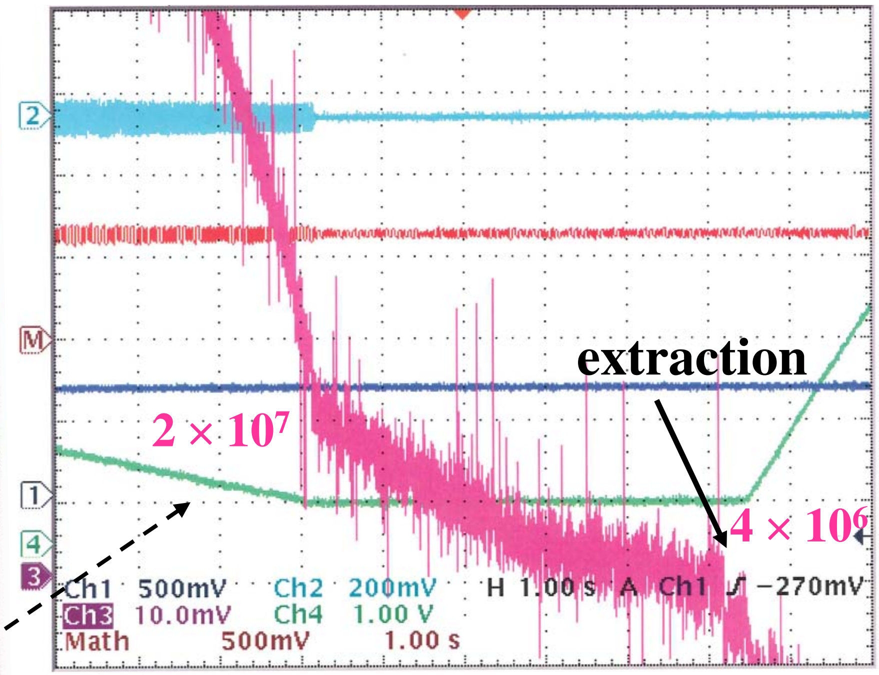
45 %   37 %

cycle time 45 s

Main losses:

- End of ramp (hysteresis, eddy currents)
- Storage and cooling at low energy



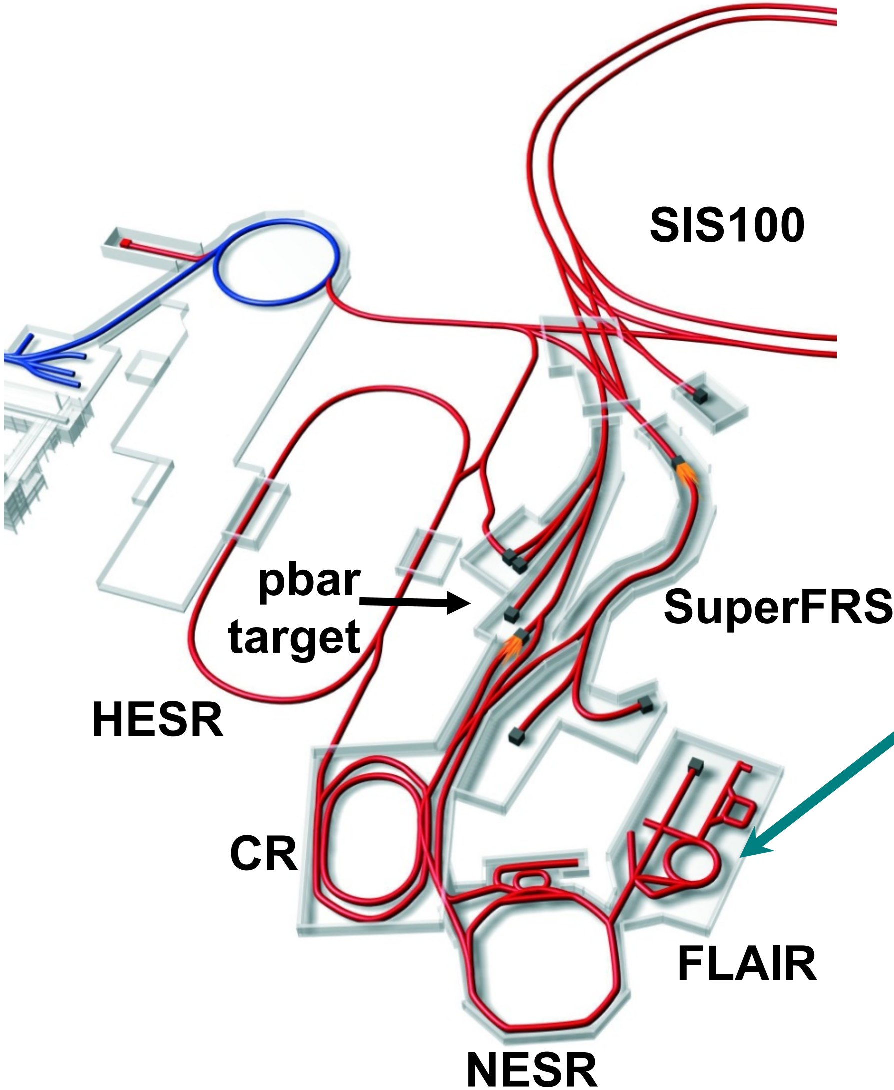


beam half life (vacuum dominated):

30 MeV/u: $T_{1/2} \approx 480$ s

4 MeV/u: $T_{1/2} \approx 2$ s

CRYRING as Low Energy Storage Ring



Stockholm University

FLAIR

offered as a Swedish in-kind contribution to FAIR of value 2 M€

$C = 51.6$ m

$B\rho_{max} = 1.44$ Tm

$dB_{dip}/dt = 7$ T/s

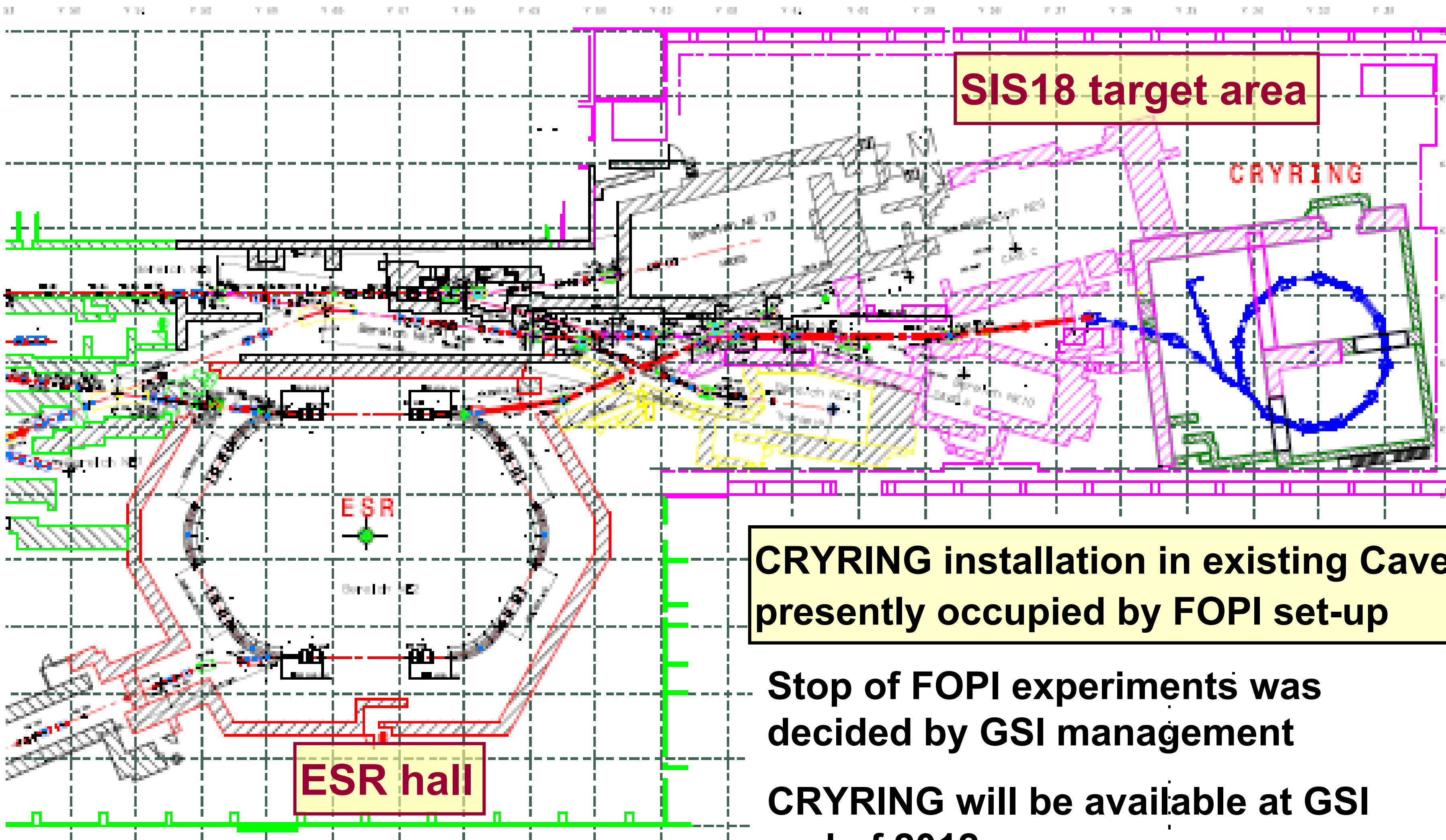
goal:

provide decelerated (secondary) beams

1) antiprotons of 300 keV – 30 MeV

2) highly charged ions and RIBS
   energies 40 keV/u – 4 MeV/u

CRYRING@ESR



CRYRING installation in existing Cave B presently occupied by FOPI set-up

Stop of FOPI experiments was decided by GSI management

CRYRING will be available at GSI end of 2012

Use of CRYRING@ESR

Experiments with decelerated ions and RIBS from the ESR

in-ring experiments

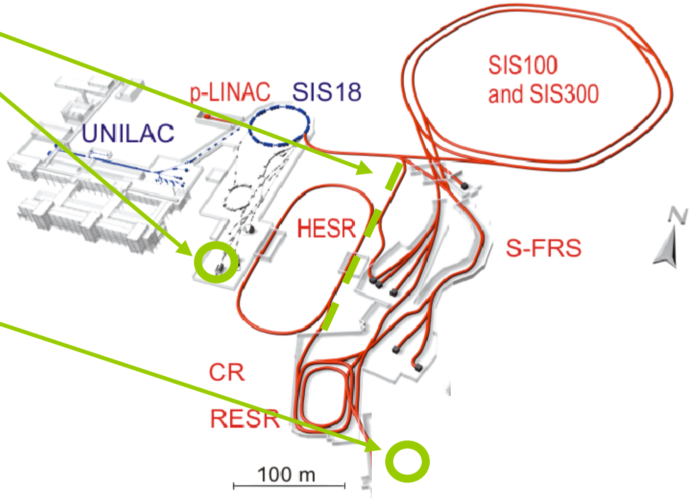
slow (fixed target) and fast extraction (traps)

Stand alone operation with beam injected from ion source + RFQ

accelerator developments for FAIR (diagnostics, new control system)

options in future:

- **transfer secondary beams (antiprotons, RIBs from SuperFRS) from CR/RESR to ESR and CRYRING**
- **move CRYRING behind RESR sharing antiprotons with HESR**



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