Current Plans for Beam Cooling at FAIR

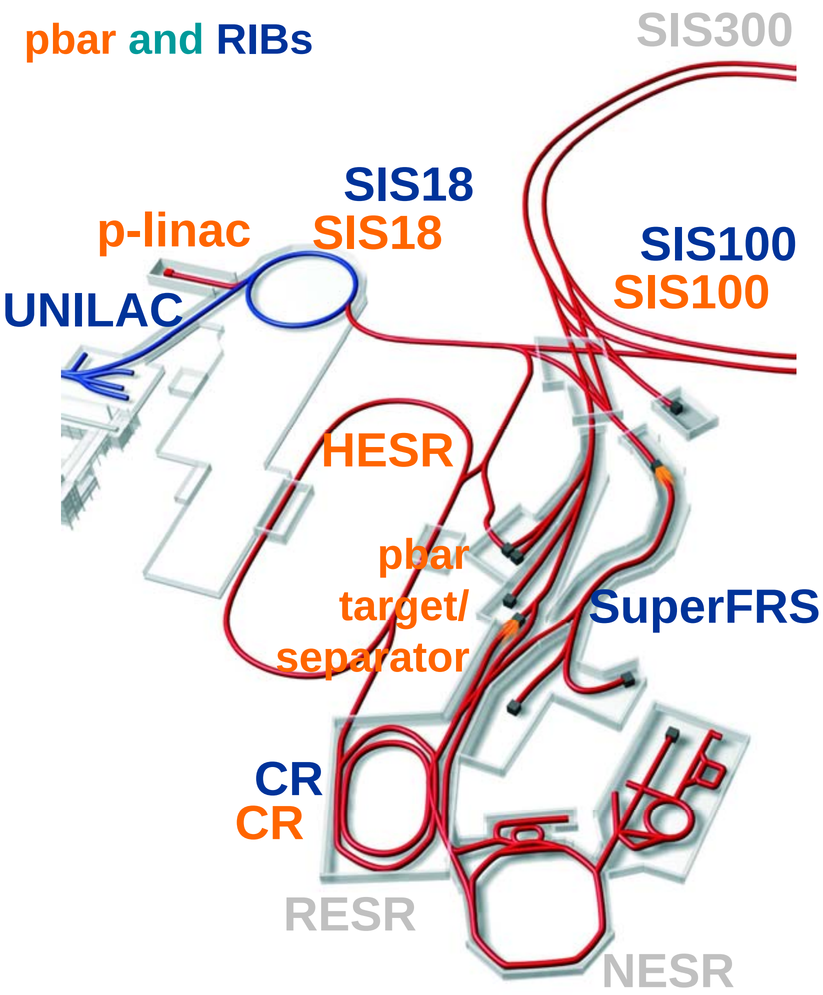
Markus Steck for the FAIR Project Team

with contributions from
GSI and FZJ, Germany

COOL'11, Alushta, Ukraine

Modularized Start Version

modularized start version
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

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 modularized start version (Modules 0-3)

Module 0
SIS100

Module 1
CBM,
APPA

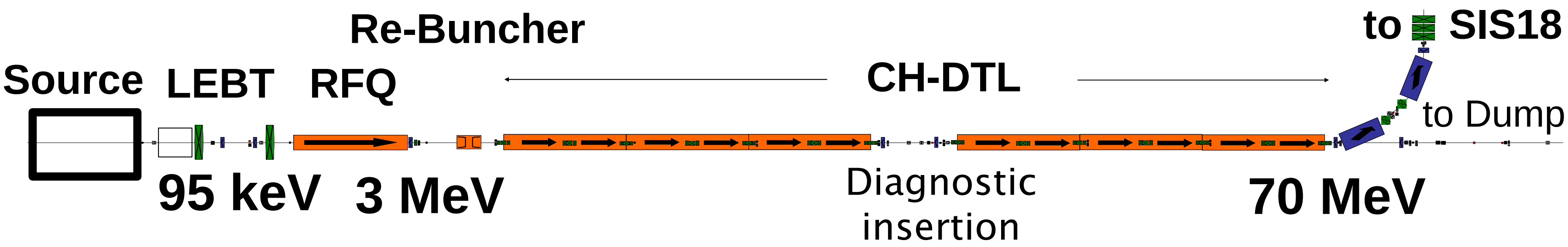
Module 2
Super-FRS

Module 3
Antiproton-target, CR,
p-Linac,
HESR

(module number does not correspond to a priority)

Proton Linac

The new proton linac is needed to fill SIS18 with protons to the space charge limit

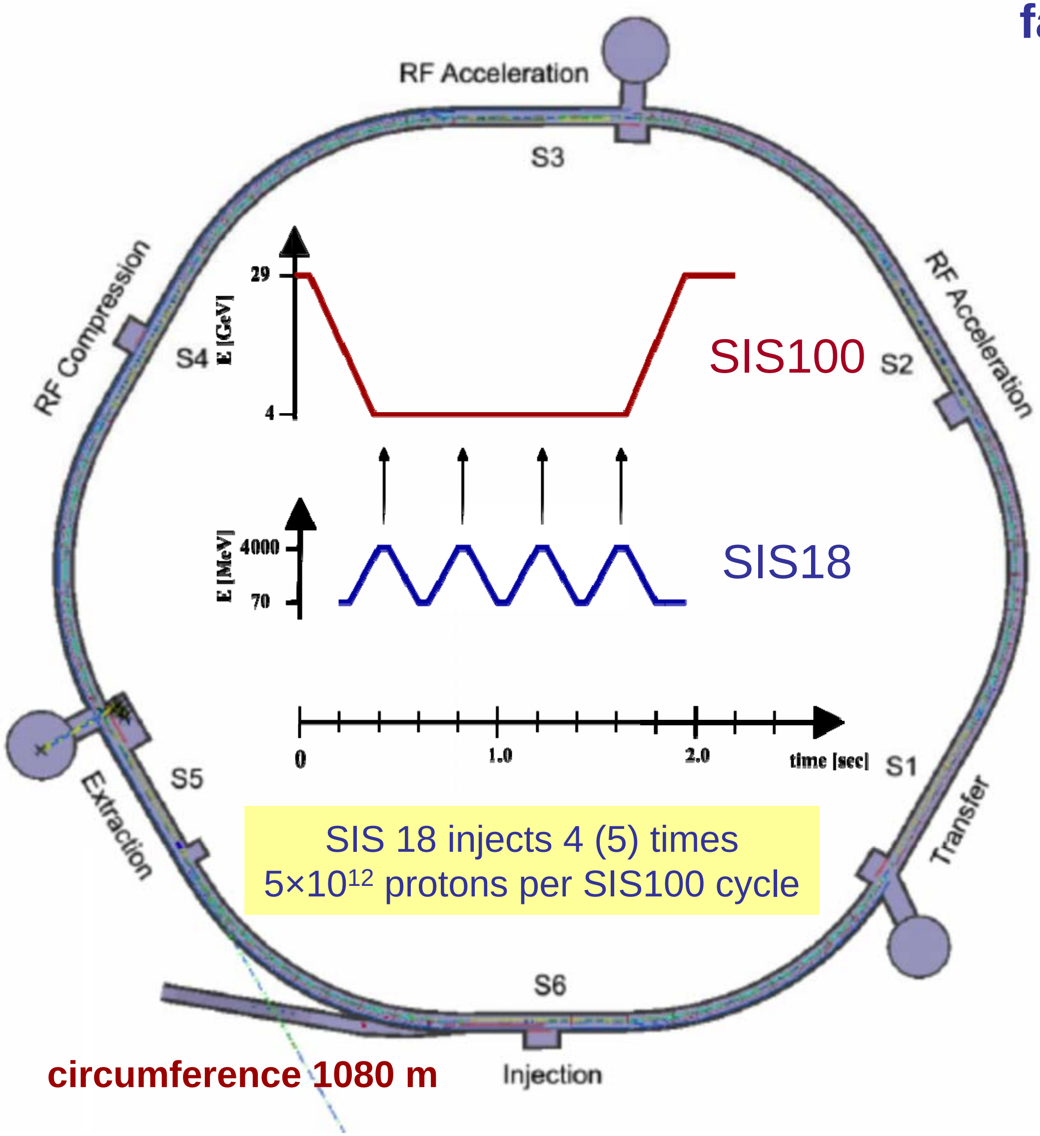


collaboration with: University of Frankfurt
CEA/Saclay, IN2P3, GANIL

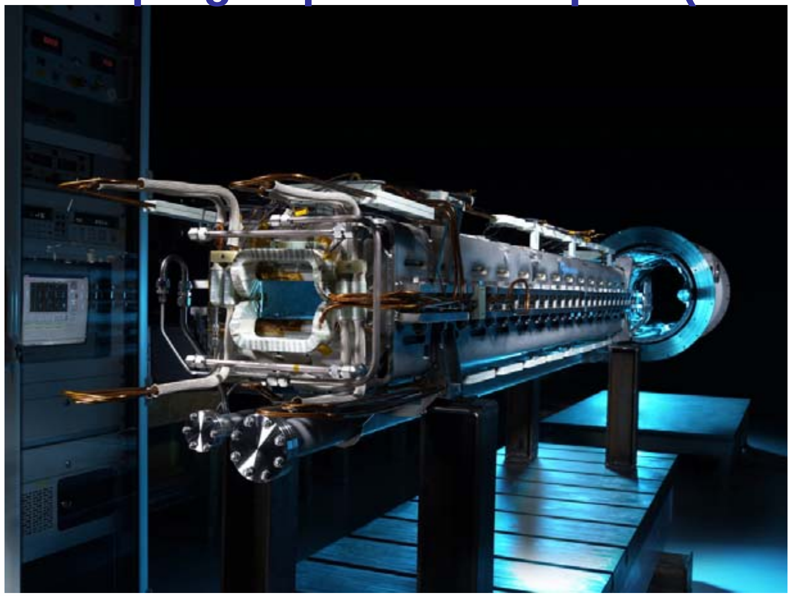
- ECR proton source & LEBT
- RFQ
- 2 re-bunchers
- 2 * 6 accelerating cavities
- 5 MW of beam loading (peak), 720 W (ave.)
- 11 MW of total rf-power (peak), 5 kW (ave.)
- 2 dipoles, 46 quadrupoles, 7 steerers

Energy	70 MeV
Current (oper.)	35 mA
Design current	*70 mA*
Beam pulse length	36 µs
Repetition rate	4 Hz
Rf-frequency	325.224 MHz
Norm. horiz. emit.	2.1 / *4.2* µm
Tot. mom. spread	≤ ± 10^{-3}
Linac length	≈ 35 m

SIS 100



fast ramping super-ferric dipole (4 T/s)



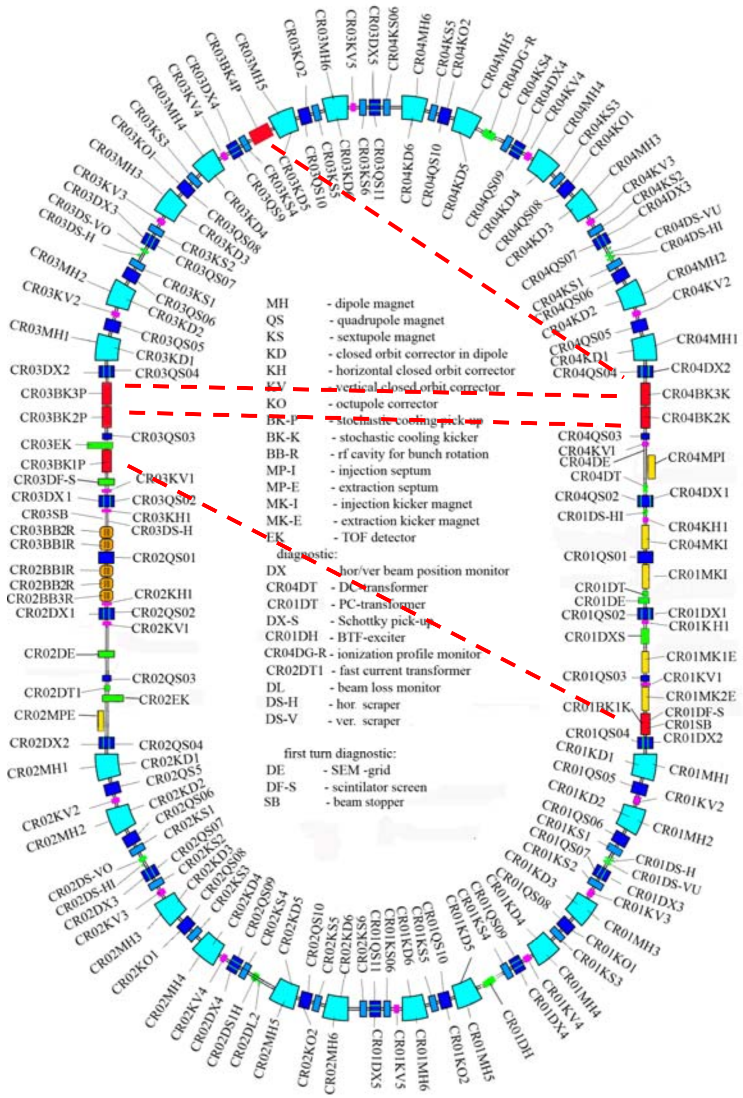
decision for curved dipole
with single layer coil

cooling of vacuum chamber ?

tendering process in preparation

next step: super-ferric quadrupoles

The Collector Ring CR (version 68)



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) %

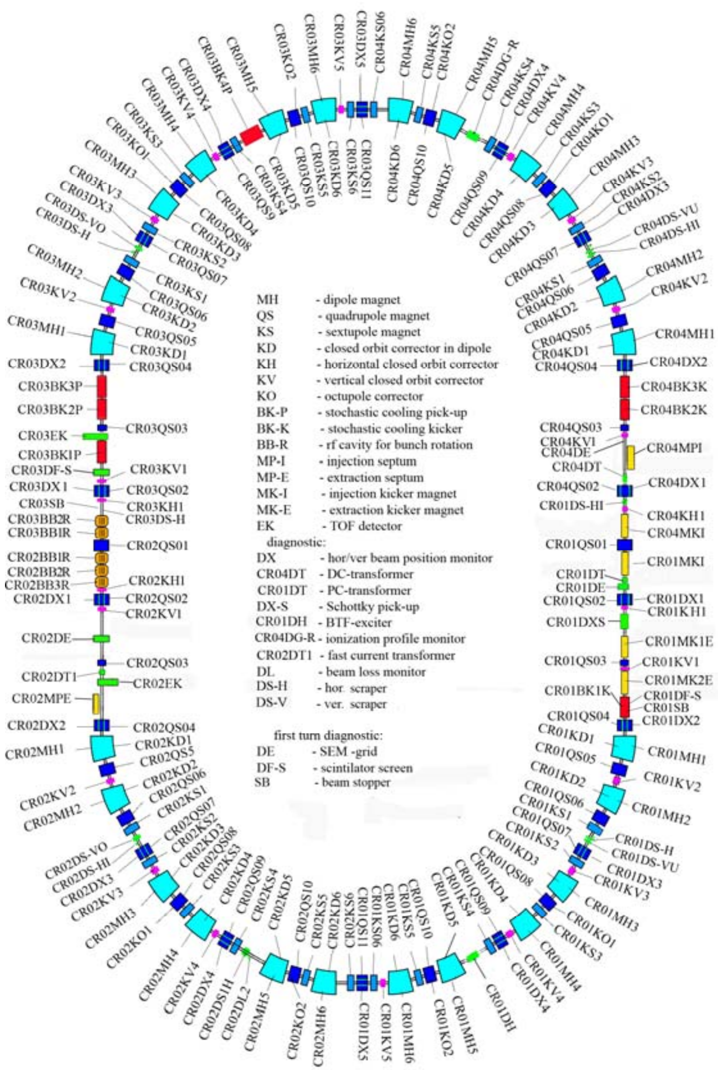
fast stochastic cooling (1-2 GHz) of antiprotons (10 s) and rare isotope beams (1.5 s)

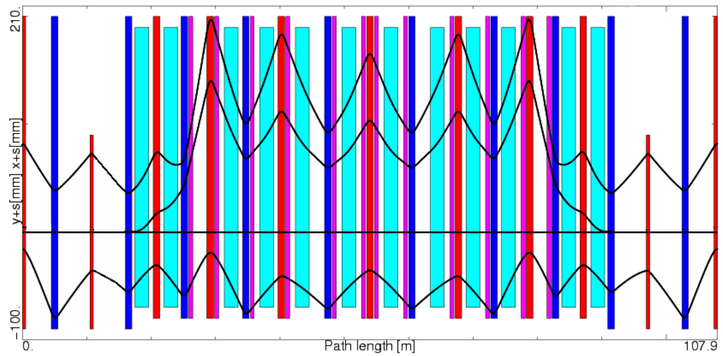
fast bunch rotation at h=1 (U_{rf} =200 kV)
adiabatic debunching
optimized ring lattice (slip factor) for proper mixing
large acceptance magnet system

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





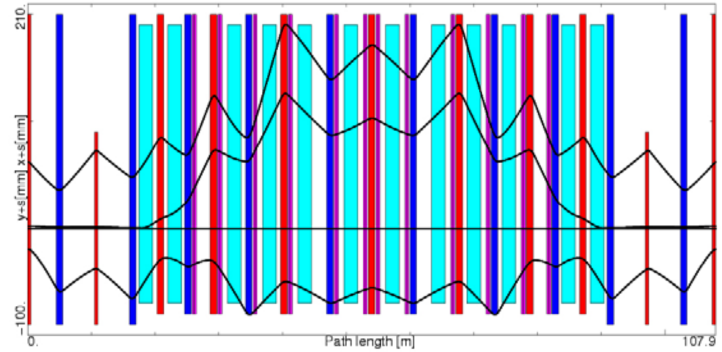
antiprotons

$Q_x = 4.27$, $Q_y = 4.84$

$\gamma_t = 3.85$

$\eta = -0.011$

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



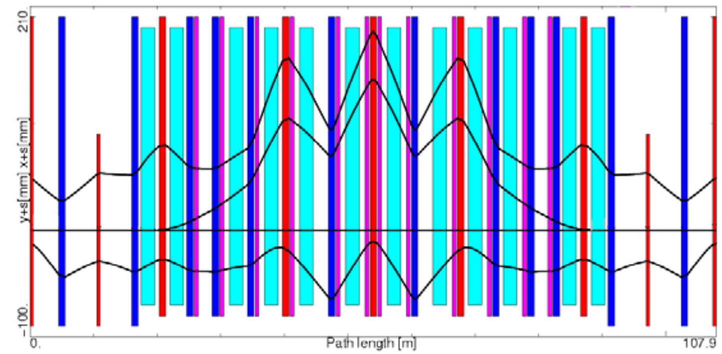
RIBs

$Q_x = 3.19$, $Q_y = 3.71$

$\gamma_t = 2.82$

$\eta = +0.186$

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



isochronous

$Q_x = 2.23$, $Q_y = 4.64$

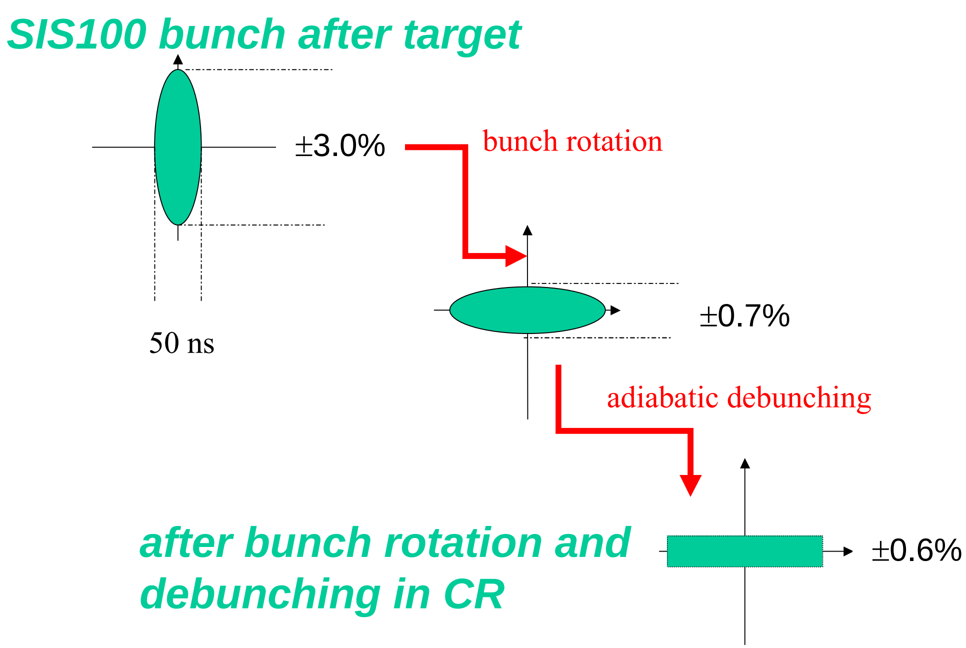
$\gamma_t = 1.67\text{-}1.84$

$\eta = 0$

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

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



SIS18 bunch compressor cavity prototype for

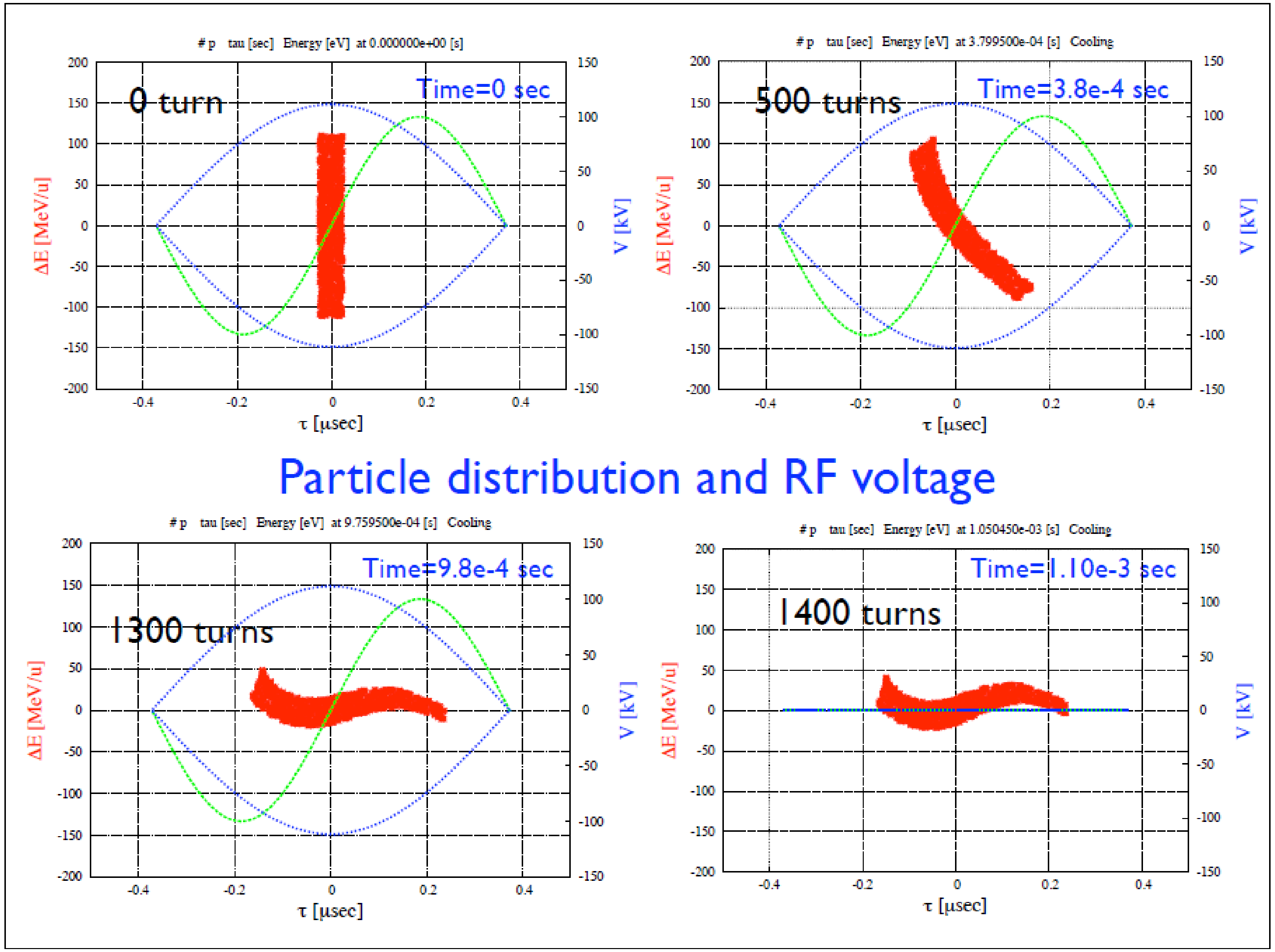
CR bunch rotation cavity
filled with magnetic alloy

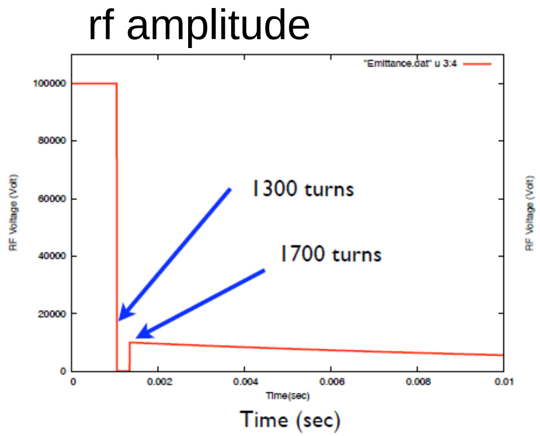
voltage 40 kV
length 1 m
frequency range 1.13 – 1.32 MHz
rotation time 1000 μs (pbars)
600 μs (RIBs)

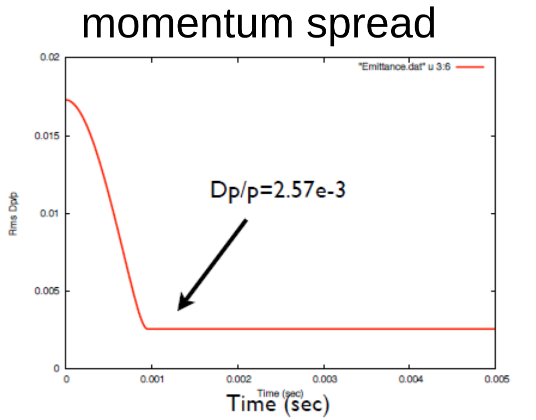
Debuncher rf system order in preparation

Simulation of Bunch Rotation

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





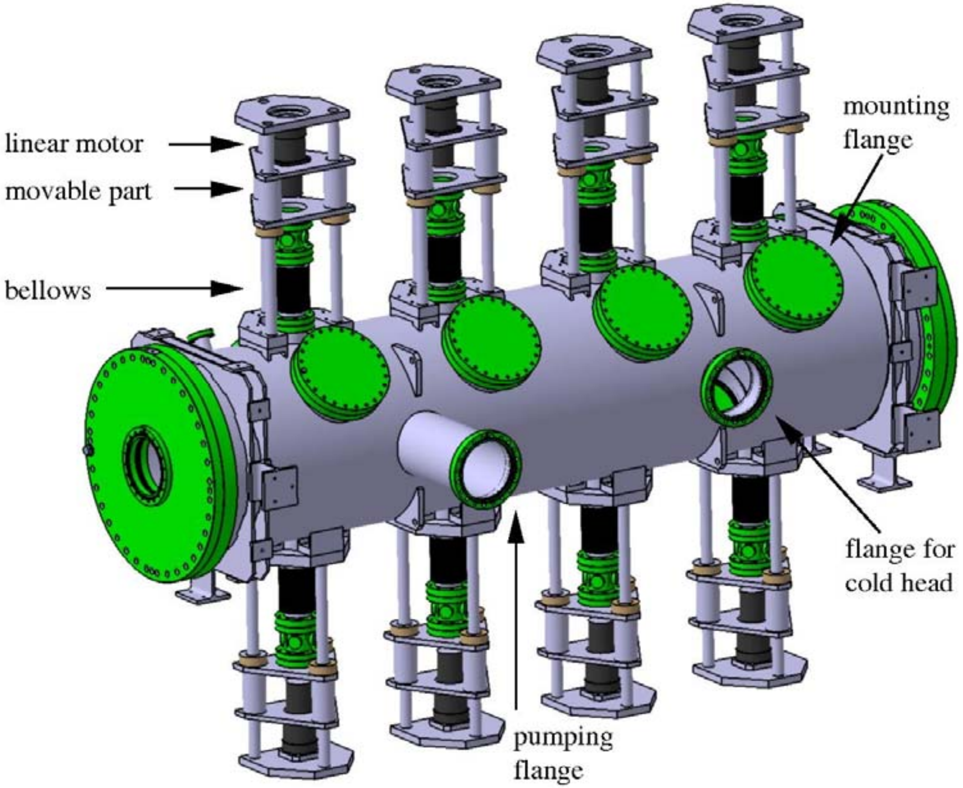


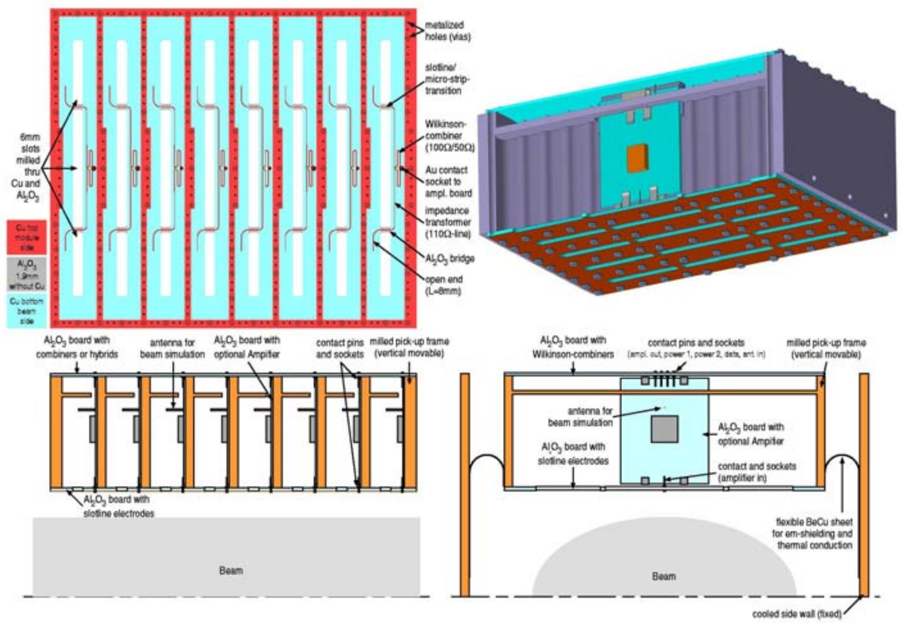
CR Stochastic Cooling

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

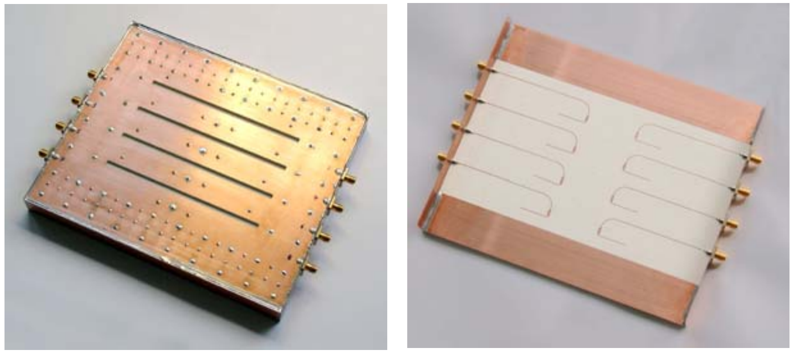


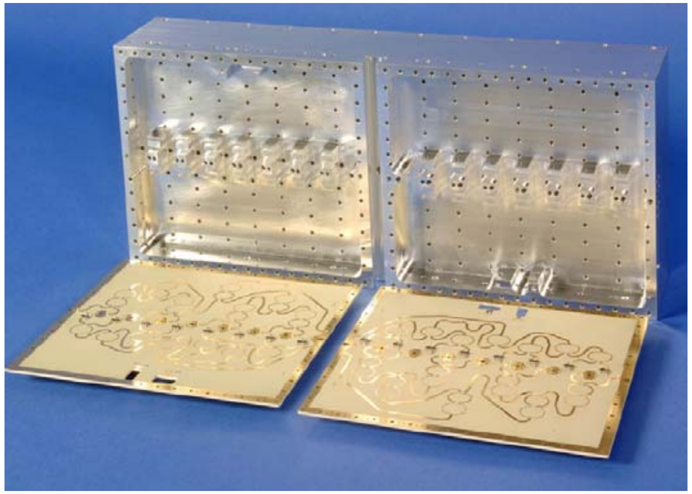


CR Stochastic Cooling Prototypes

vacuum tank for moving electrodes

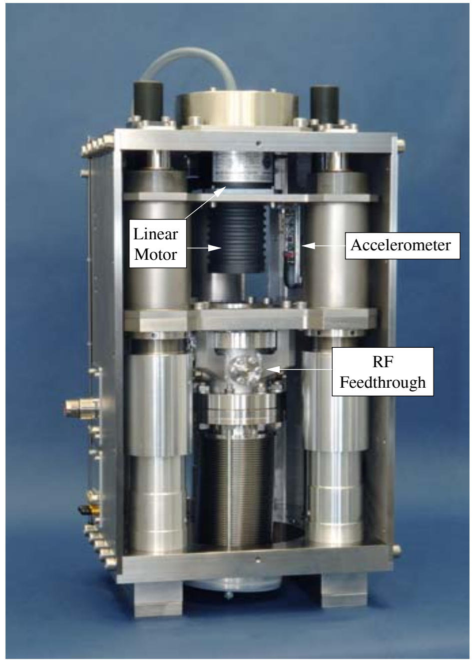
Electrode prototype (slotline type)

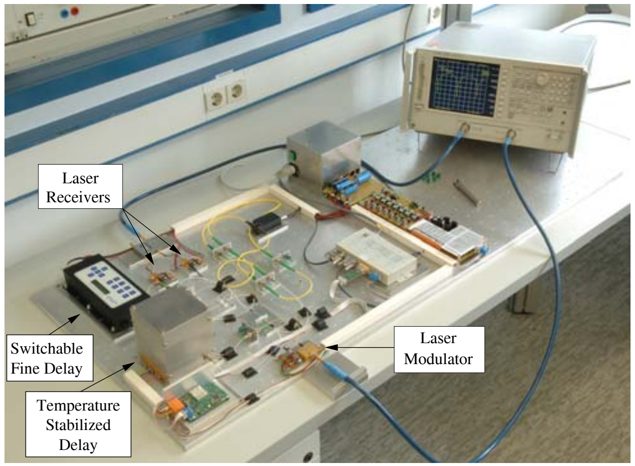




milled module body
with combiner board

**programmable
linear actuator**



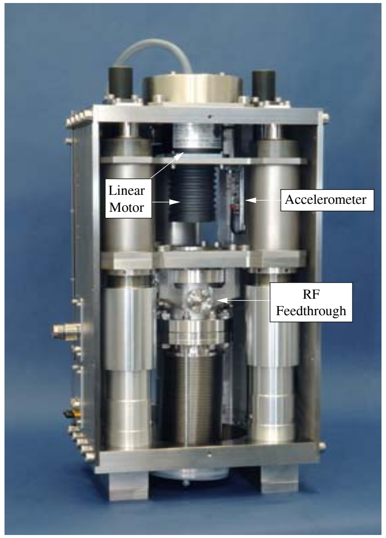


optical delay line

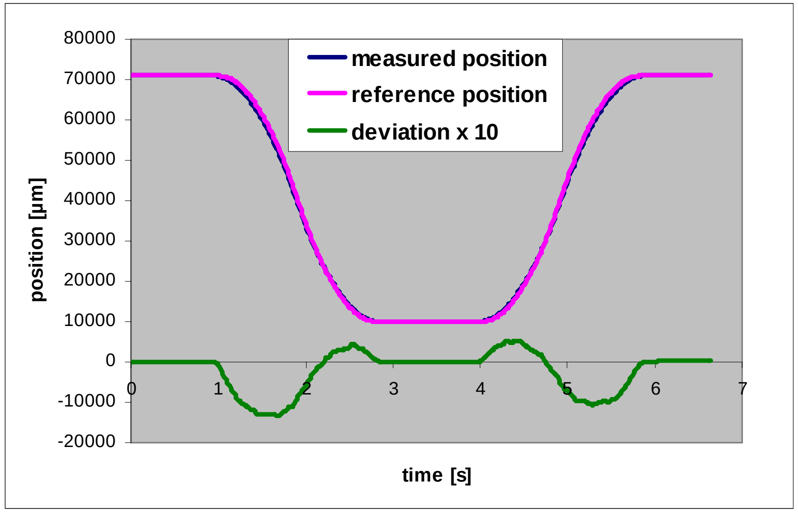
Plunging in Prototype Tank

Programmable linear motors

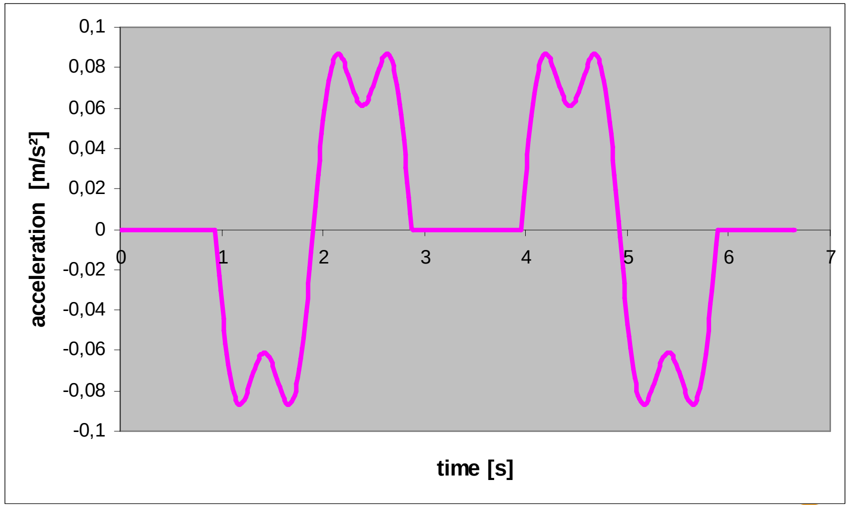
optimization for fast (< 1 s) motion without shocks



position



acceleration



Measurement of Electrode Impedance

$$\sqrt{Z_k(\mathrm{f},\mathrm{y})} \approx \sqrt{Z_k(\mathrm{f_c})} \cdot S(\mathrm{y}) \cdot S(\mathrm{f})$$

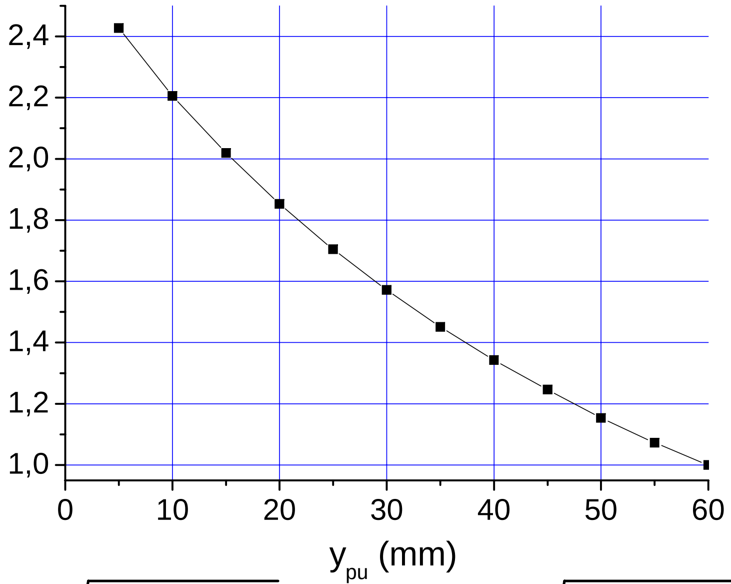
$$\sqrt{Z_{pu}(\mathrm{f},\mathrm{y})} \approx \sqrt{Z_{pu}(\mathrm{f_c})} \cdot S(y) \cdot \mathrm{S(f)}$$

Simplify: $S(y) \approx 1 + \mathrm{slope} \cdot \mathrm{y}$

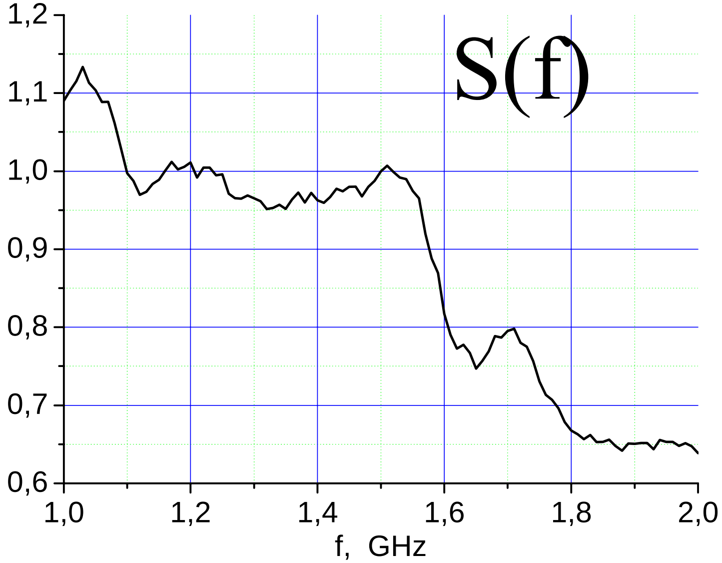
Thorndahl's HFSS simulations absolute values

$Z_k(\mathrm{f_c}) = 45\,\Omega$ at y_{PU}= ±60 mm

$Z_k(\mathrm{f_c}) = 151\,\Omega$ at y_{PU}= ±20 mm



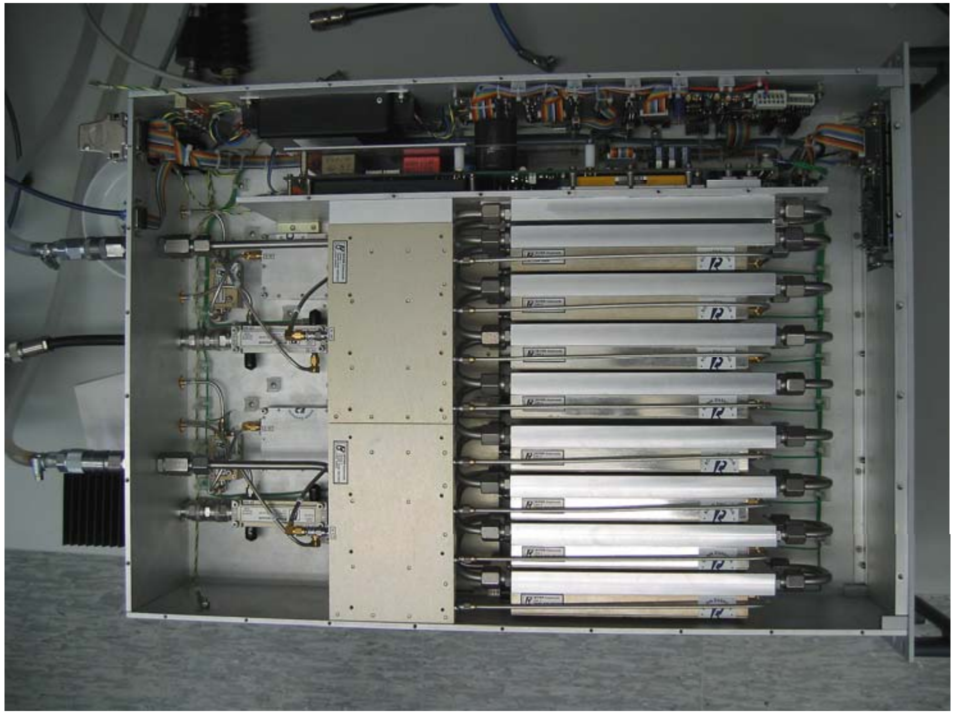
Relative measurement on prototype PU

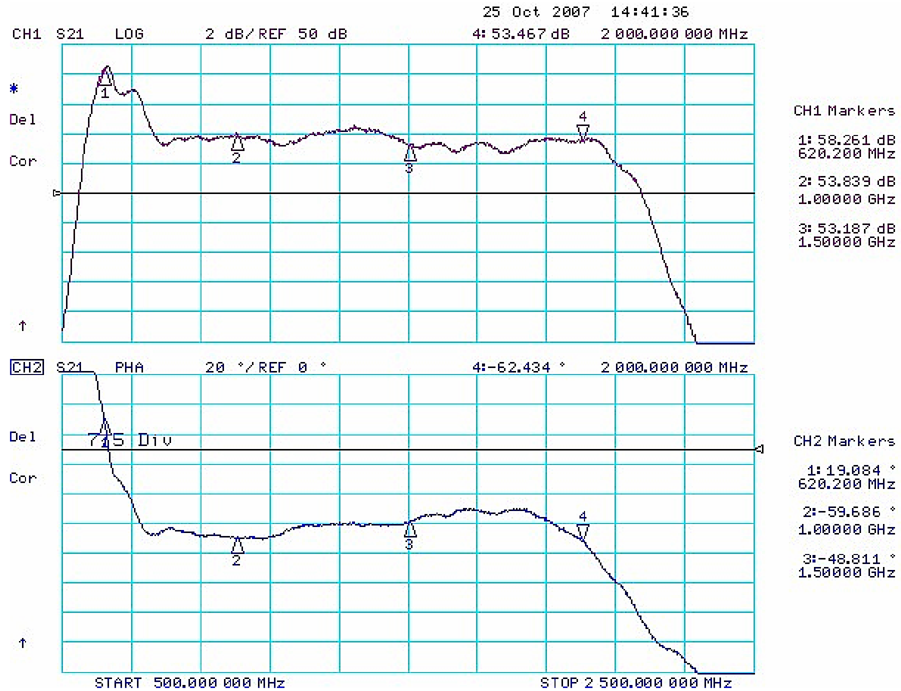


$$\sqrt{Z_{pu}(\mathrm{f_c})} \cdot \mathrm{slope} \rightarrow \sqrt{Z_{pu}(\mathrm{f_c})} \cdot \mathrm{slope} \cdot \mathrm{plung}(t)$$

Factor of 1.8 in sensitivity, 3.4 in Z_{pu} from y_{PU}=±60 mm→ y_{PU}=±20 mm

Power Amplifier Prototypes 1-2 GHz

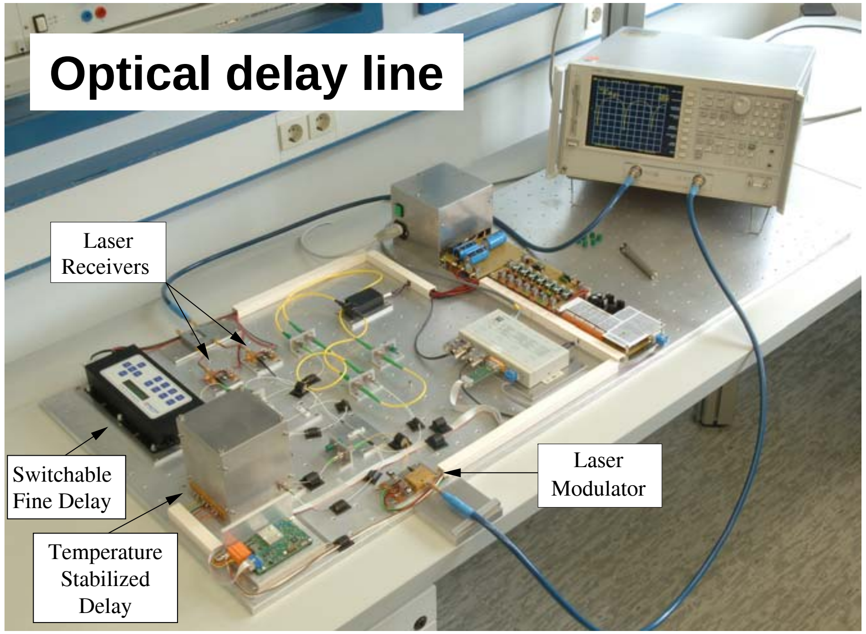




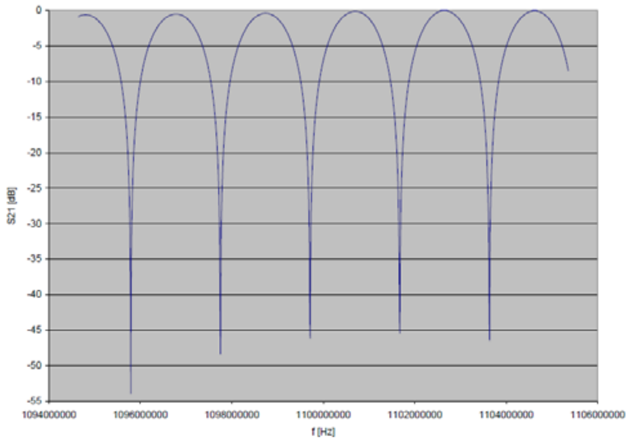
Prototype was tested, but quality is still not satisfying.

Further development is needed, if further funding is available.

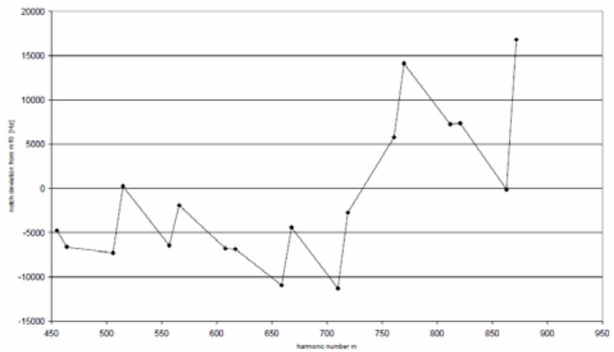
Notch Filter Development



Test of notch filter at ESR is prepared



notch depth better 45 dB

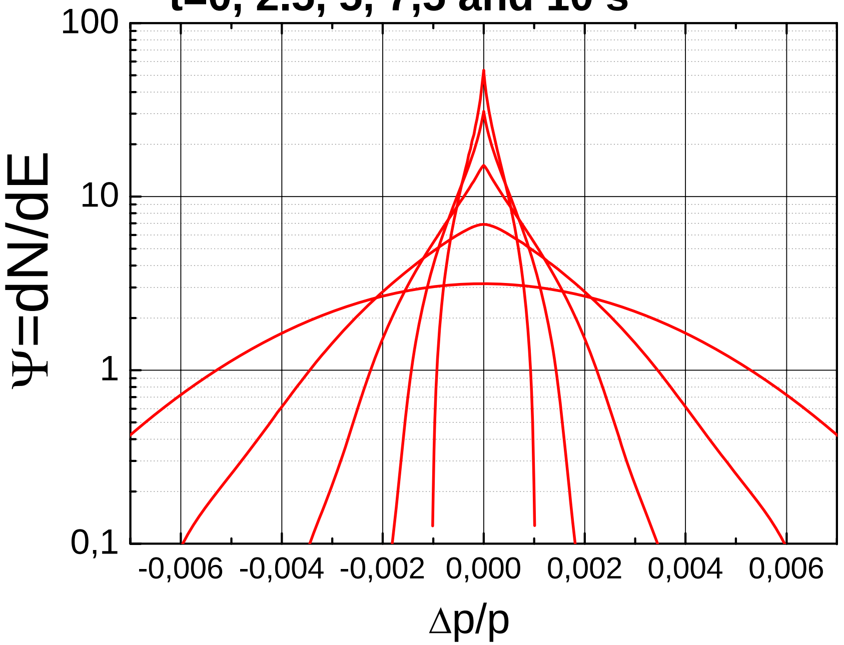


frequency deviation $\leq 5 \times 10^{-5}$

Simulation of Momentum Cooling in CR

main goal: 10 s cycle time

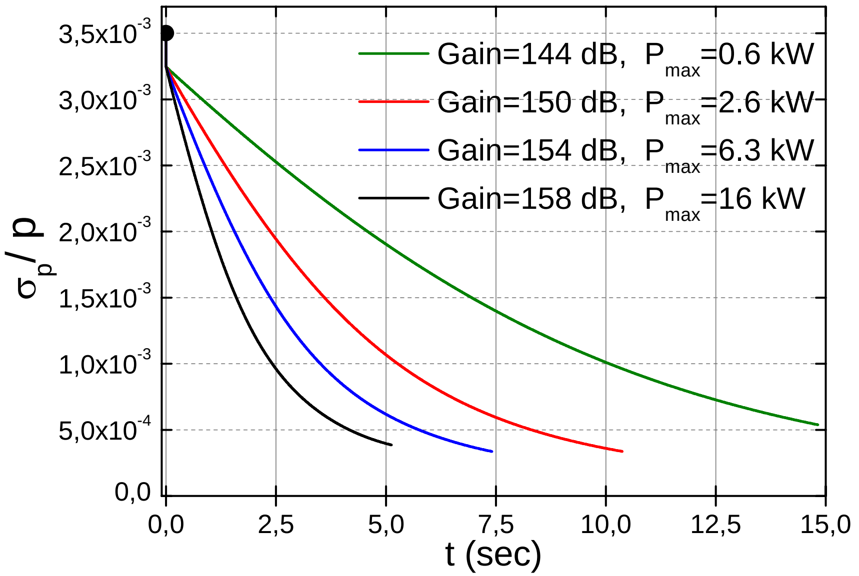
Longitudinal cooling of antiprotons with band 1 – 2 GHz
t=0, 2.5, 5, 7,5 and 10 s



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

more details in C. Dimopoulou´s talk

g=150 dB (3.2×10^{7}); t=10 s



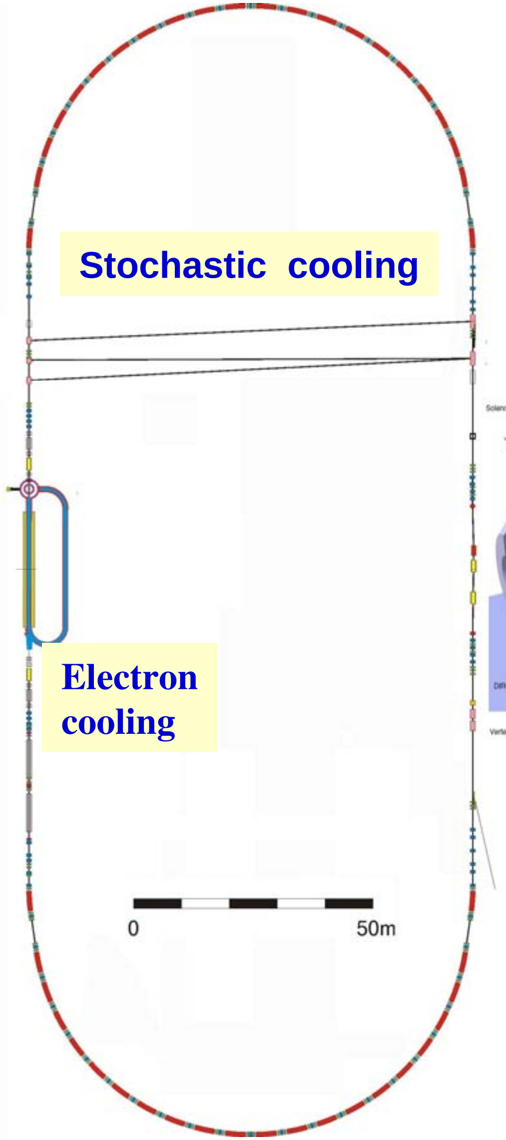
upgrades:

more rf power (presently 4.8 kW)
cooling with band 2 – 4 GHz

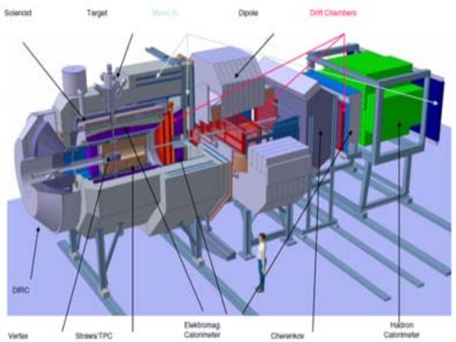
Present activities:

preparation of component specifications

The High Energy Storage Ring HESR



responsibility of FZ Jülich (German in-kind contribution)



PANDA experiment

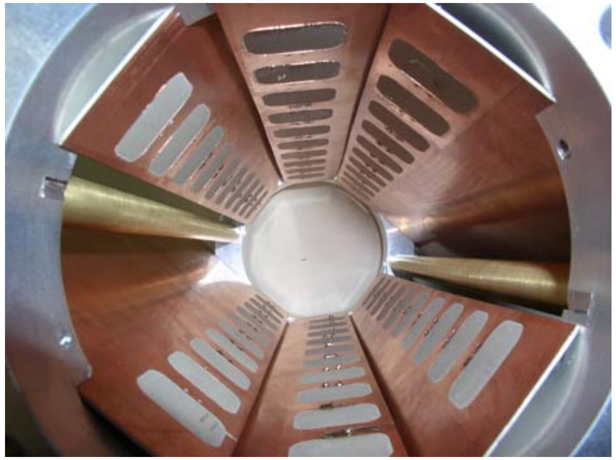
Storage of antiprotons

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

Cooling in the HESR

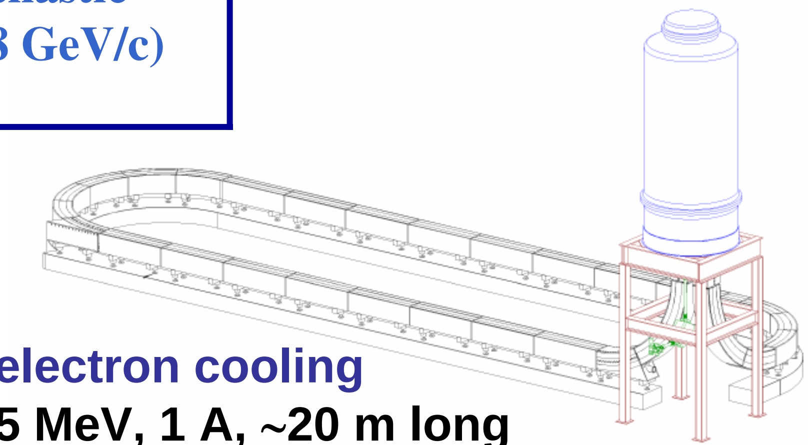
Effective target thickness (pellets):	4×10^{15} cm^{-2}	
Beam radius at target (rms):	0.3 mm	
Mode	**High Resolution**	**High Luminosity**
Momentum range	1.5 - 8.9 GeV/c	1.5 – 15 GeV/c
Antiproton number	10^{10}	10^{11}
Peak luminosity	2×10^{31} cm^{-2}s^{-1}	2×10^{32} cm^{-2}s^{-1}
Momentum spread	$\Delta p/p \leq 4\times10^{-5}$	$\Delta p/p = 1\times10^{-4}$
Beam cooling	Electron ($\leq$ 8.9 GeV/c)	Stochastic ($\geq$ 3.8 GeV/c)



stochastic cooling
printed loop coupler, 2-4 GHz

Both modes are not available in the Modularized Start Version

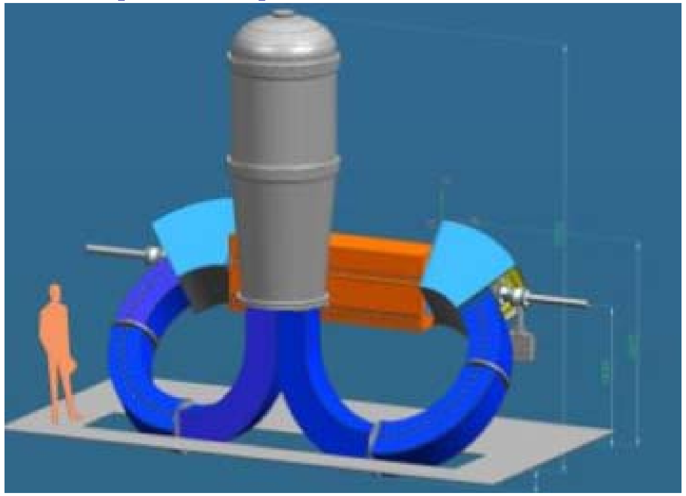
more details in D. Prasuhn´s talk



electron cooling
5 MeV, 1 A, ~20 m long

HESR Cooling Systems

COSY (HESR) 2 MeV Electron Cooling



more details in talk by J. Dietrich and V. Reva and on poster 15 by R. Stassen

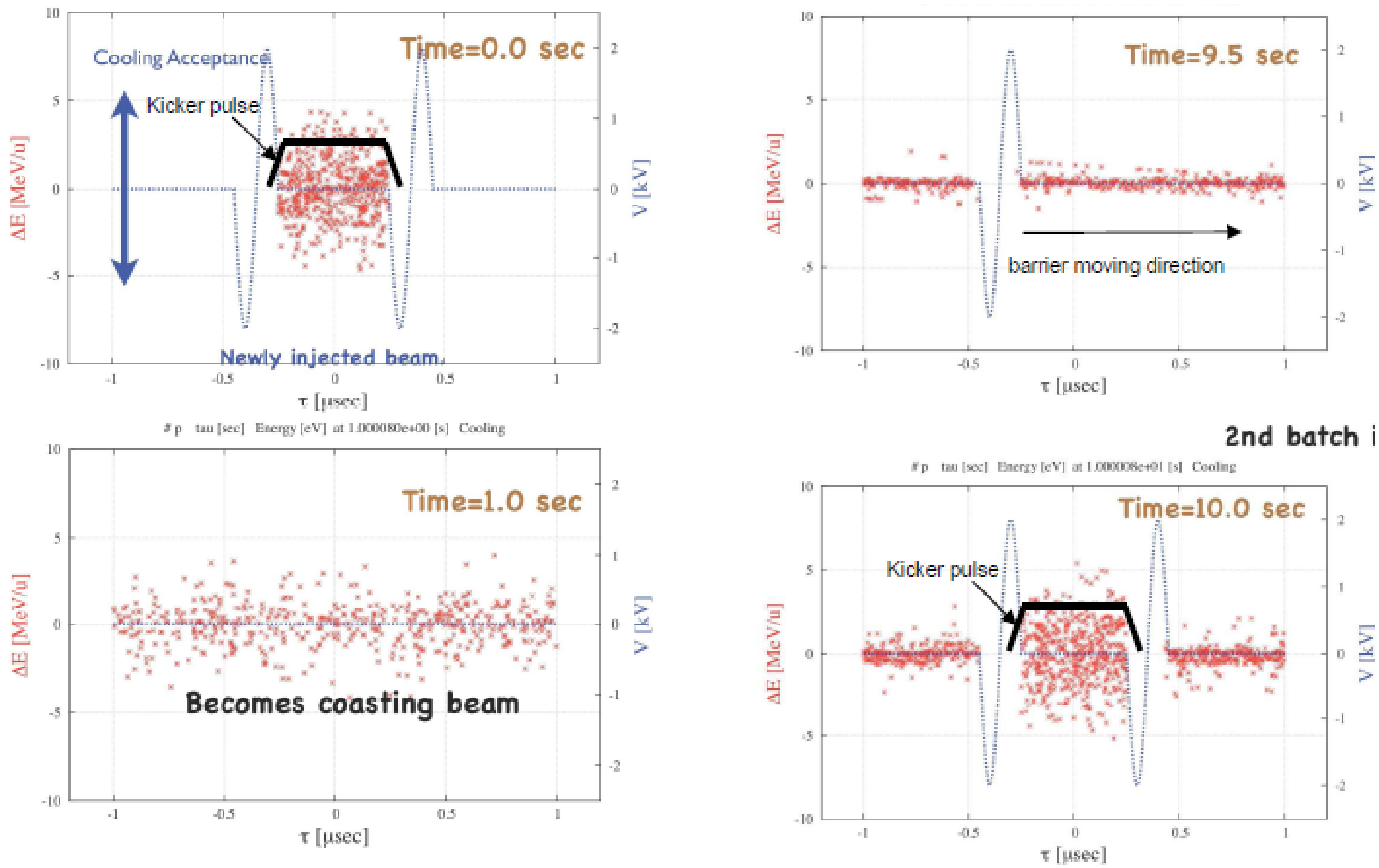
Ultimate HESR Electron Cooling

final design by TSL Uppsala, Sweden

stochastic cooling **printed loop coupler, 2-4 GHz**

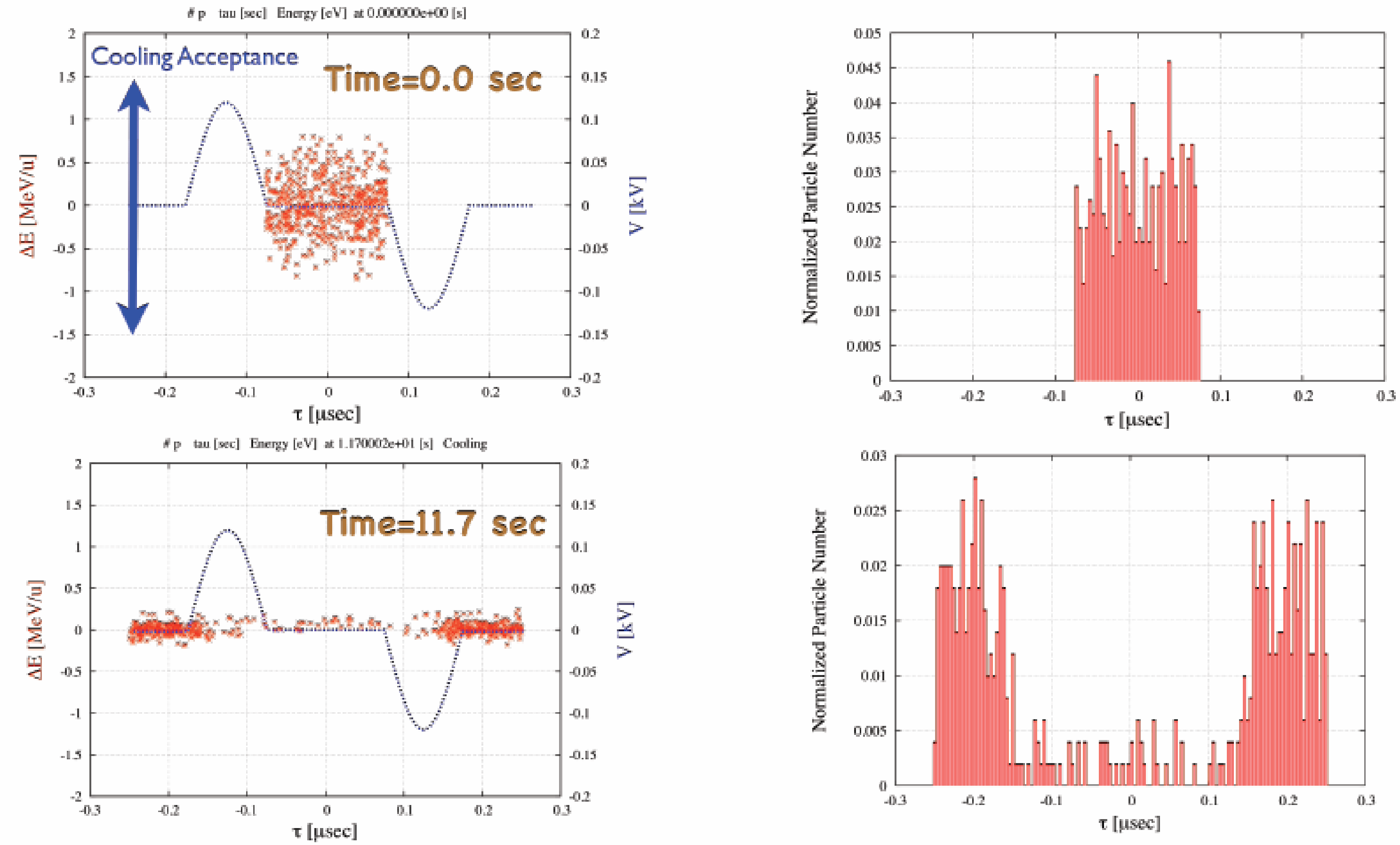
Accumulation in the HESR

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



Proof-of-Principle Experiment in the ESR

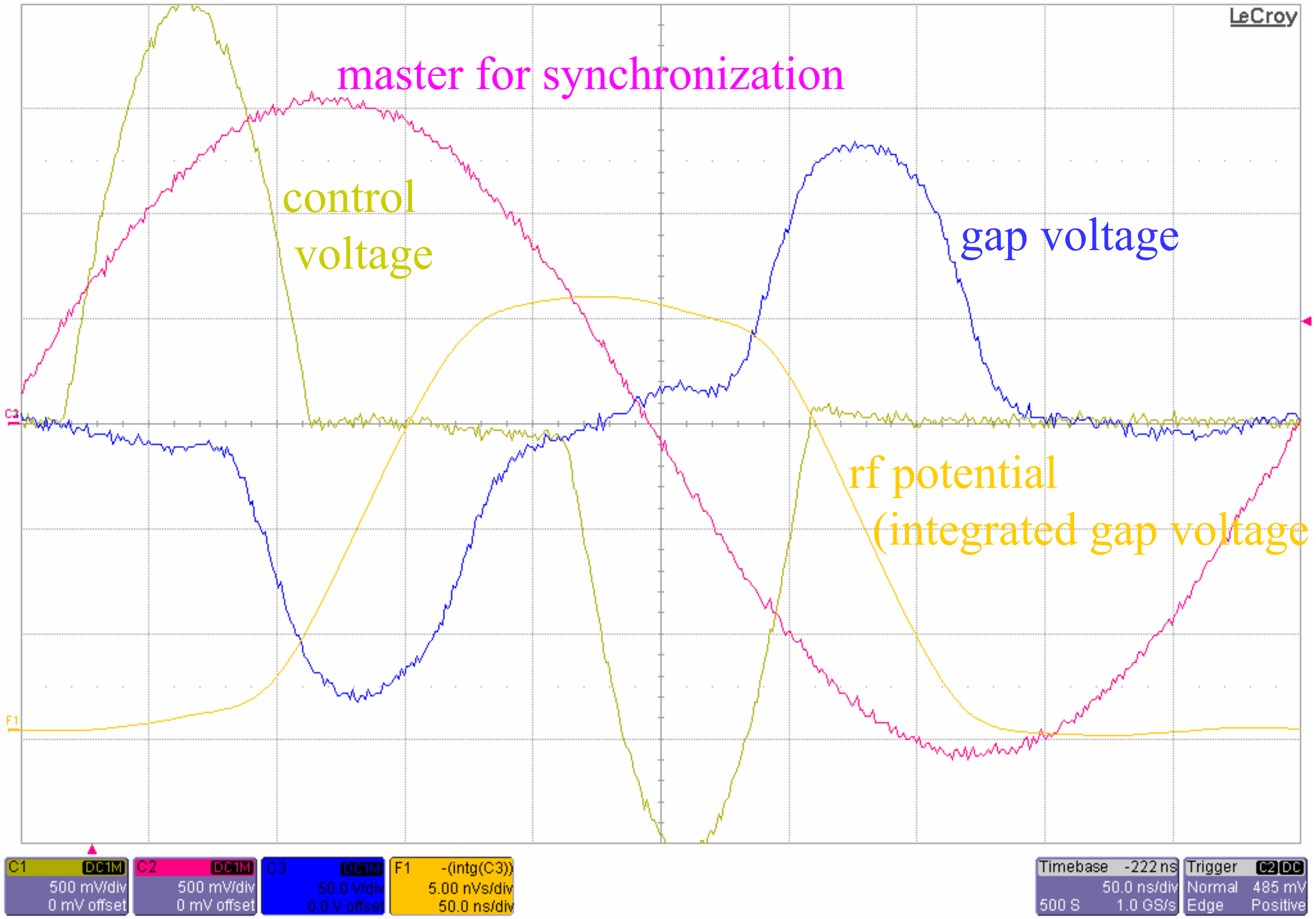
using a single bunch of Ar^{18+} at 400 MeV/u from SIS



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

Barrier Bucket rf Voltage

Rf voltage provided by modified ESR acceleration cavity



50 Ω load

parallel to gap

⇒ gap voltage limited to 120 V

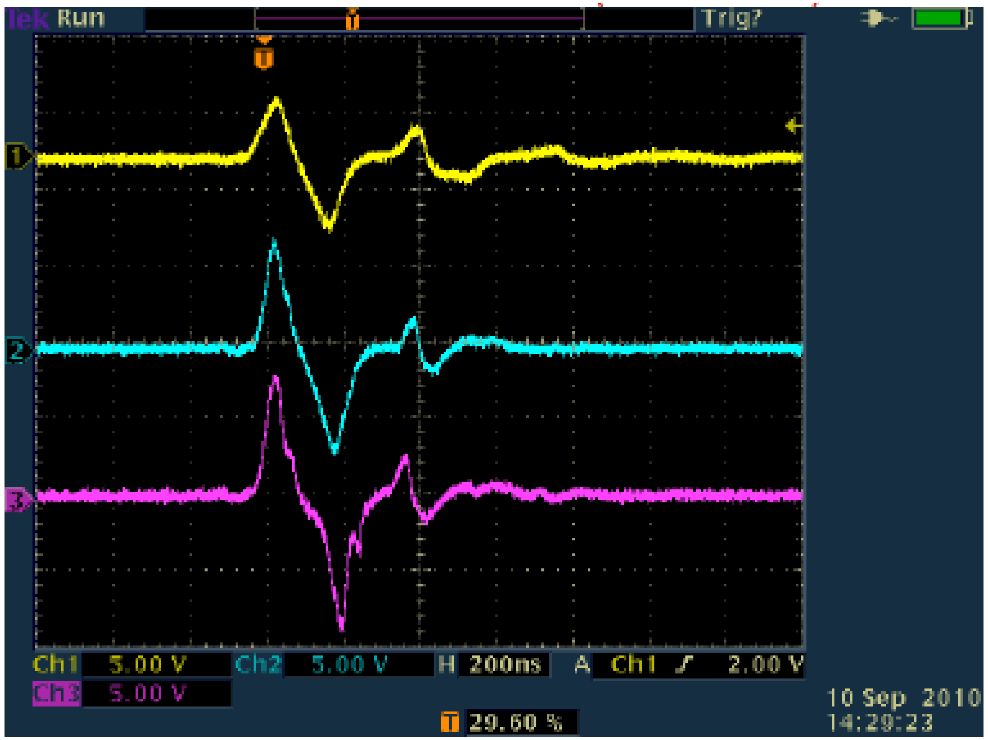
non-perfect waveform

ESR Injection Kicker

Measured Kicker Magnet field

(derivative)

Seite 1 von 1



for PoP-Experiment:

unusually short kicker pulse required

flat top ≈ 50 ns

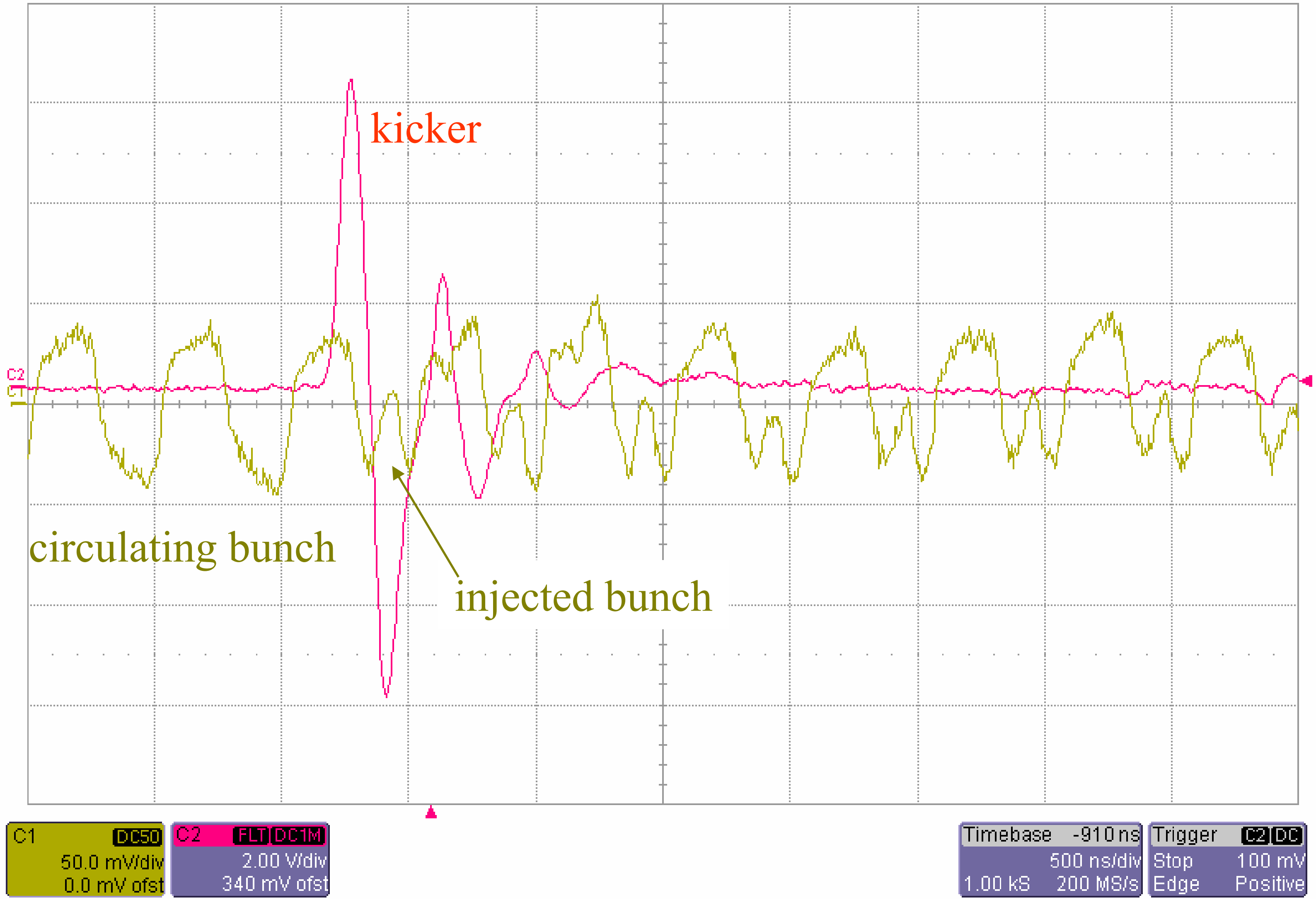
(normal operation ≥ 500 ns)

precise timing and synchronization of 3 modules

300 nsec

kicker flat top ≈ 50 ns

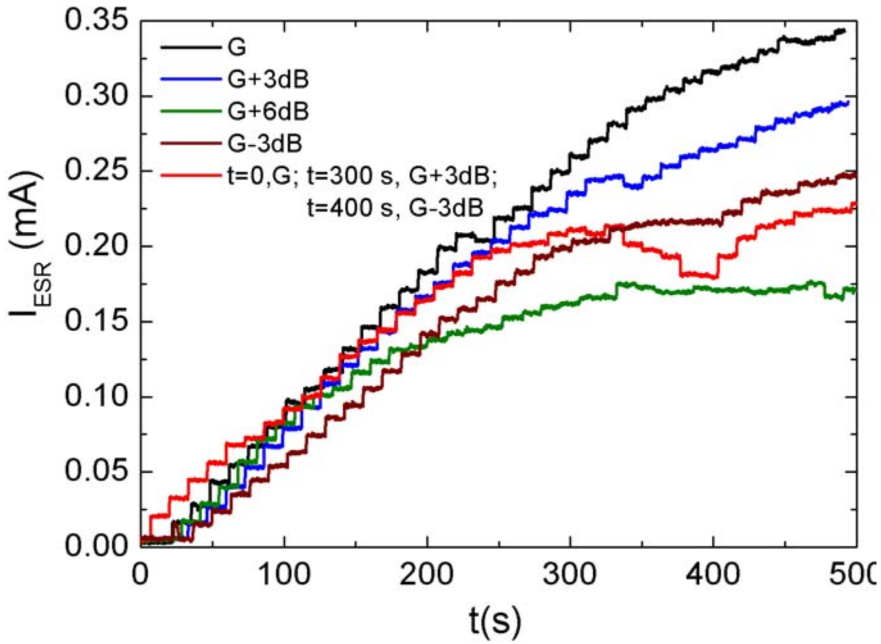
Bunch Signal from Beam Position Pick-up

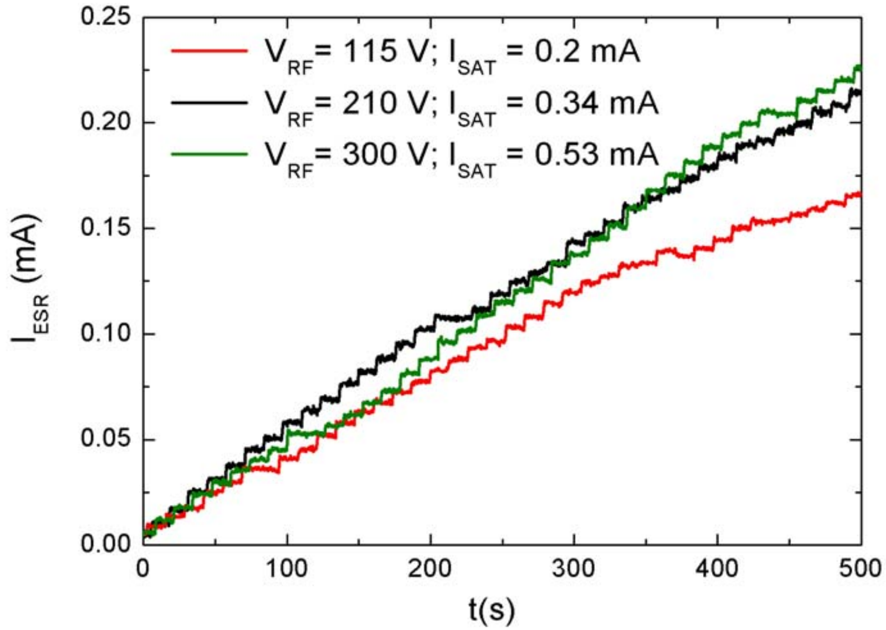


PoP-Experiment ESR

Stacking by combination of rf and stochastic cooling

with good efficiency and reliability





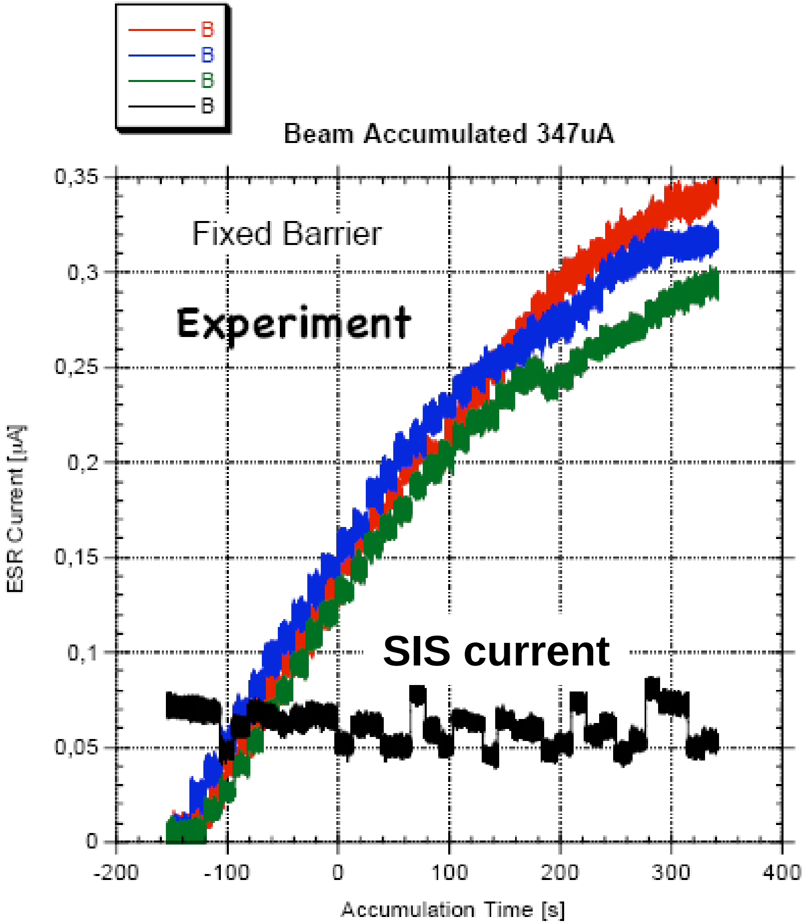
rf h=1 stacking on unstable fixed point | **stacking with fixed barriers**

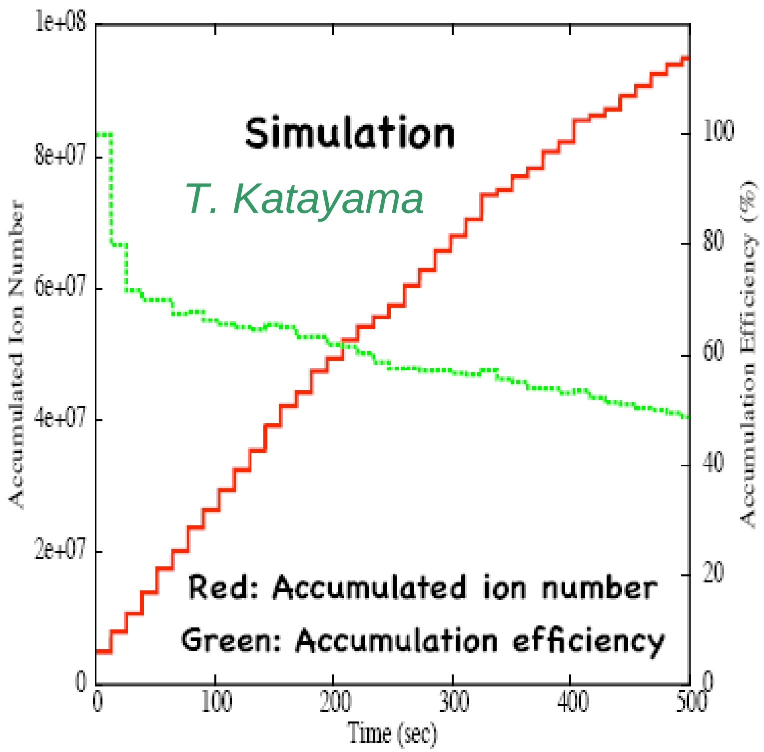
for more details see poster 20

stacking with moving barriers unsuccessful due to limited rf amplitude

Comparison Experiment-Simulation

Fixed barrier bucket at ESR POP experiment





for more details see poster 19

PoP-Experiment Collaboration

Celebration of Success of POP Experiment
2010 September 9th, at ESR Control Room

collaboration members from:

CERN

FZJ

GSI

JINR Dubna

After the Modularized Start Version

Funding of the MSV is confirmed by the partner countries.

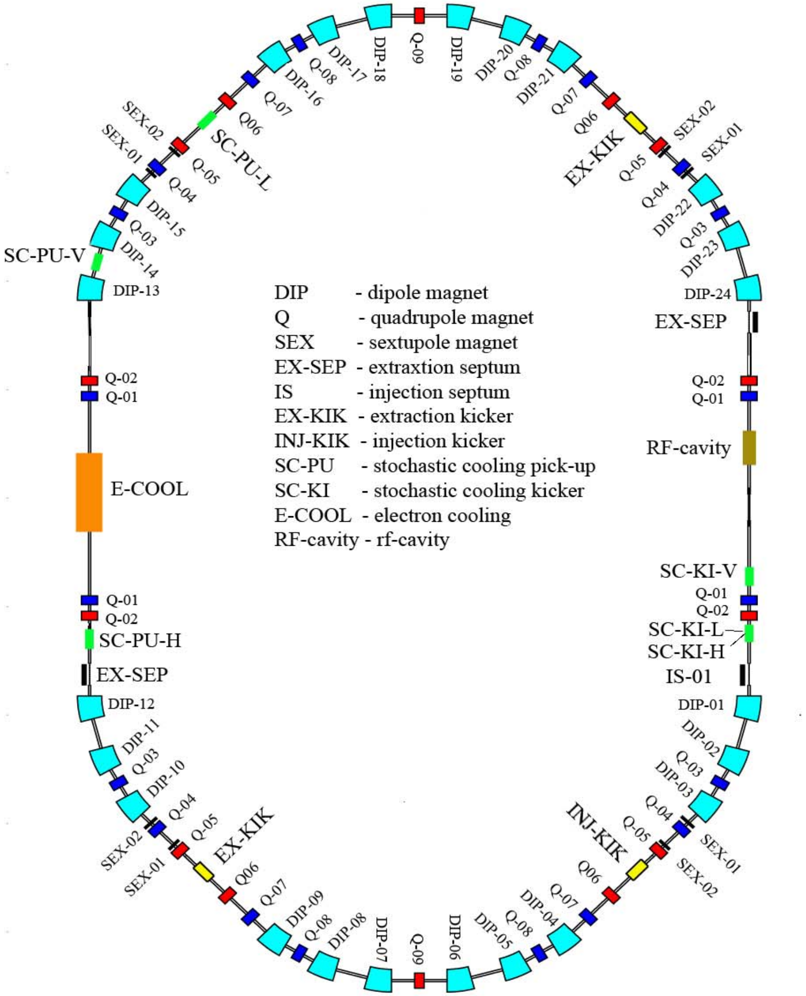
Missing subprojects: SIS300, RESR, NESR (with e-ion collider & FLAIR)

All planning is supposing to extend the facility to the full FAIR project.

However, this requires additional funding,
either by larger contributions of the present partners
or by new partners who will join in the future.

Although the further modules were defined,
there is at present no priority list.

The Accumulator Ring RESR



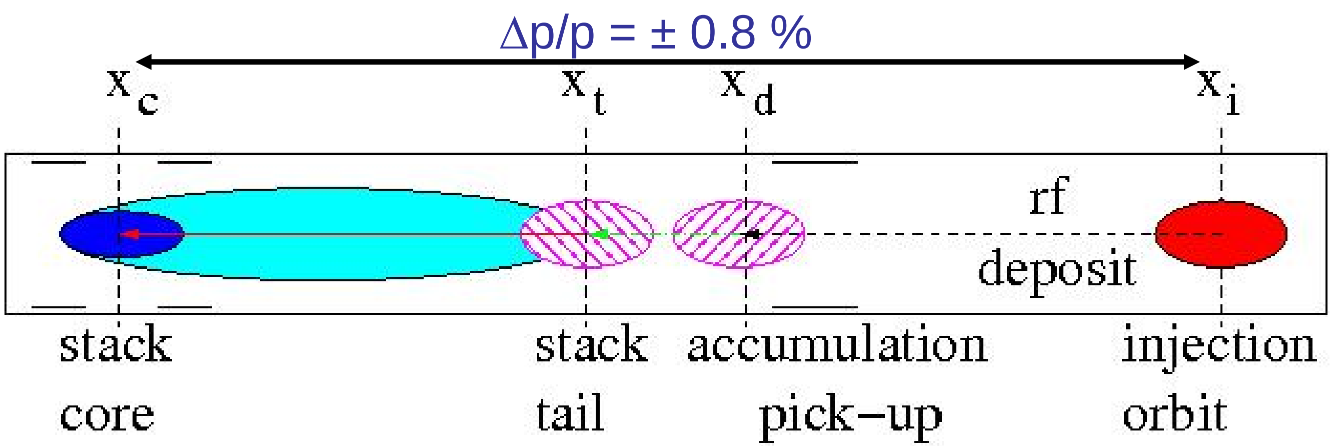
circumference	**246 m**
magnetic bending power	**13 Tm**
tunes Q_x/Q_y	**3.12/4.11**
momentum acceptance	**±1.0 %**
transverse accept. h/v	**25 mm mrad**
transition energy	**3.3 - 6.4**

accumulation of antiprotons by a combination of rf and stochastic cooling

repetition rate determined by CR: (10 (5) s)$^{-1}$
max. accumulation rate 3.5 (7)×10^{10}/h
max. stack intensity ~1 × 10^{11}
with some reserve in accumulation rate and intensity limitation

ring lattice optimized for accumulation with flexibility in choice of transition energy

Antiproton Accumulation in RESR



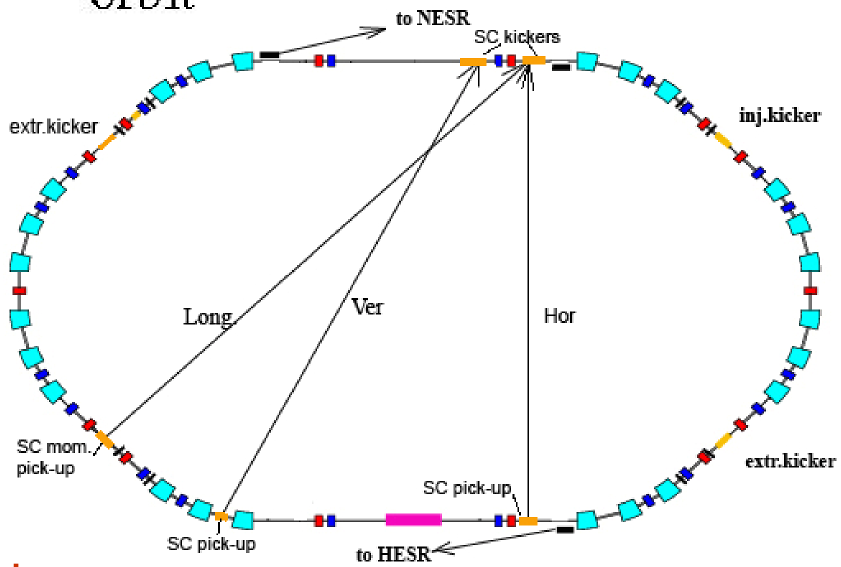
in collaboration with
D. Möhl, L Thorndahl (CERN)
T. Katayama

core cooling 2-4 GHz

longitudinal
horizontal
vertical

tail cooling 1-2 GHz

longitudinal



injection of 1×10^8 antiprotons every 10 s

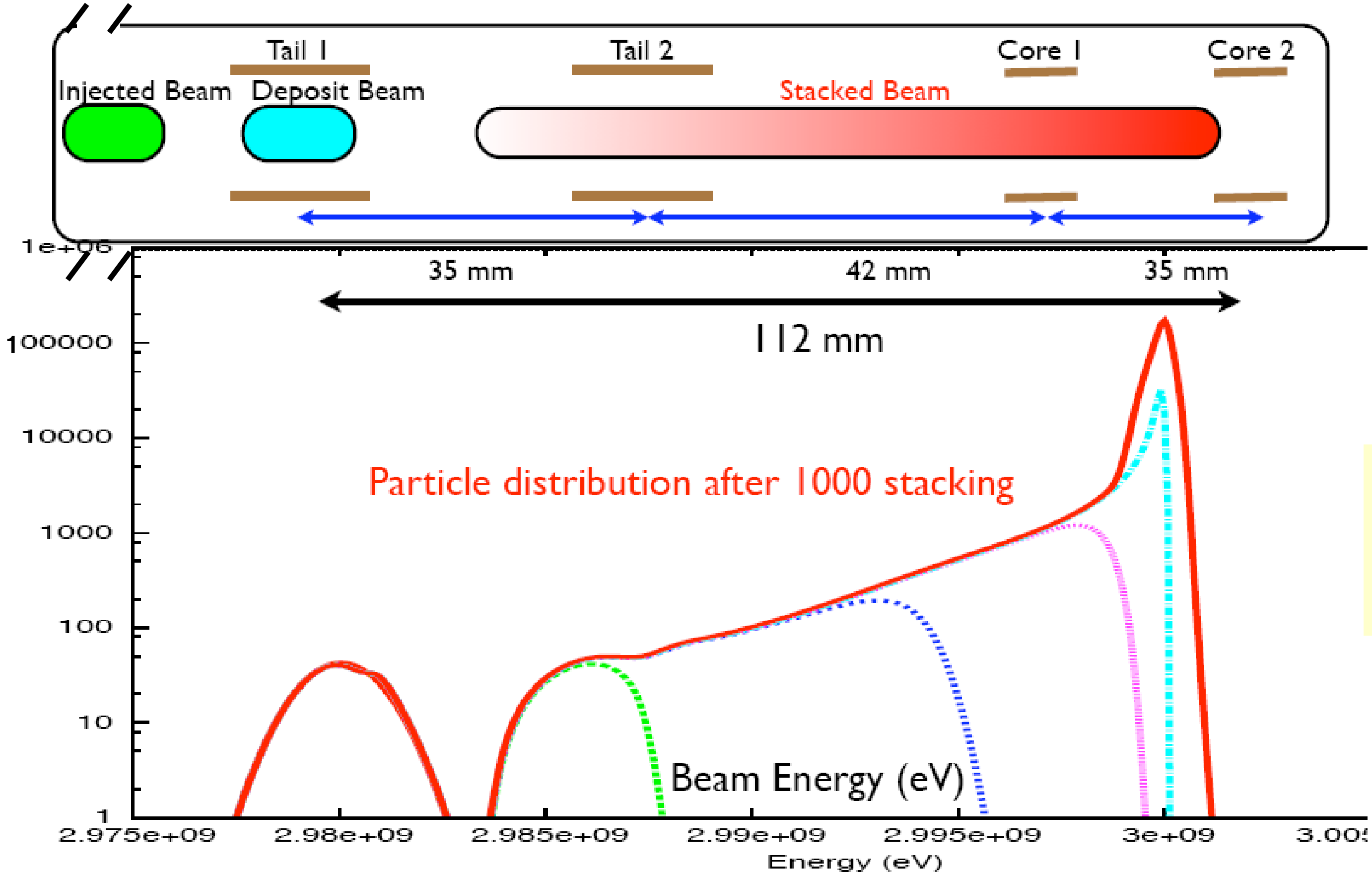
pre-cooling in CR provides
$\delta p/p = 1\times10^{-3}$, $\varepsilon_{x,y}$= 5 mm mrad

maximum RESR stack intensity: 1×10^{11} antiprotons

pre-cooling after injection considered as an upgrade option

Accumulation System for RESR

Longitudinal stochastic cooling system: tail and core cooling



electrodes: loop couplers or Faltin-type

an adjustable antiproton number will be captured from the core for extraction

RESR Scenario

Installation in common (existing) tunnel with CR

Support large antiproton intensities for HESR (towards design luminosity)

Share antiprotons between HESR and NESR (low energy antiprotons)

Open questions:

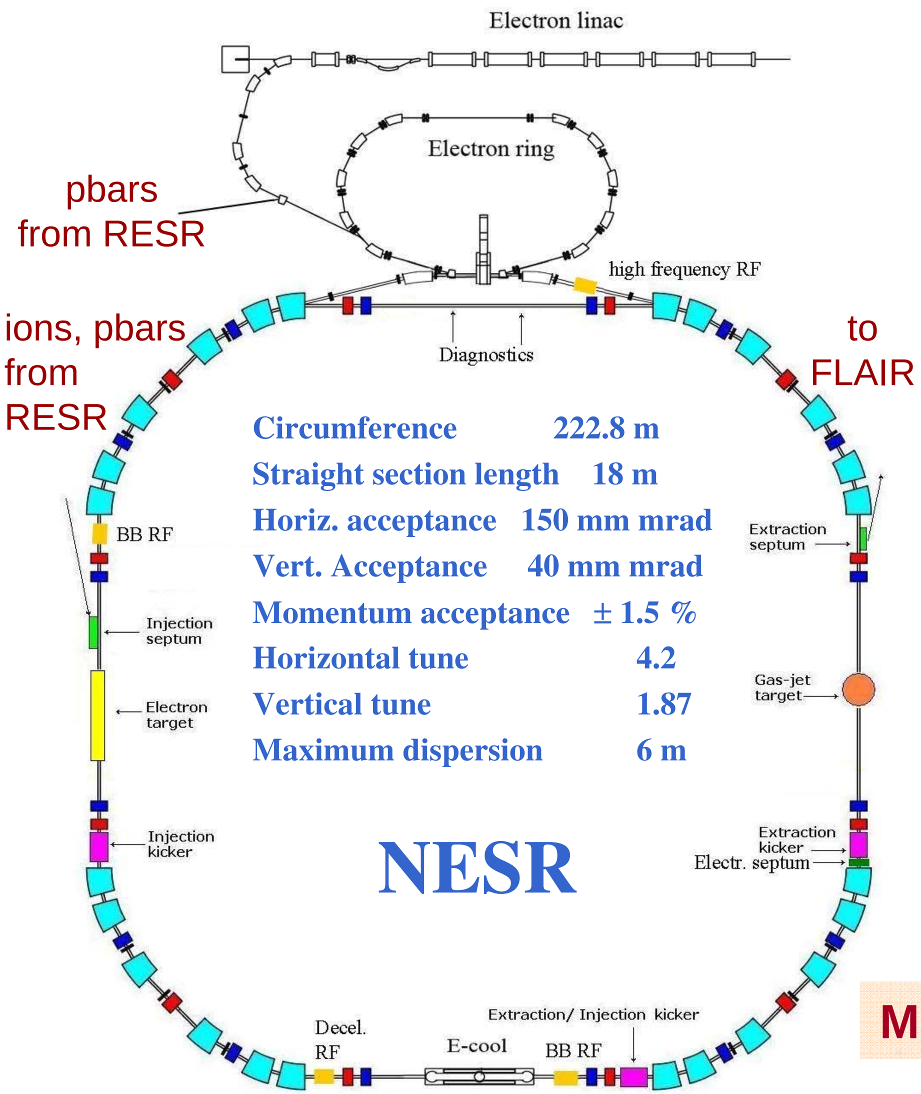
Will the RESR be a dedicated accumulator?

- **use for internal experiments with ions/rare isotopes**

Is recuperation of ESR components feasible/possible?

- **ESR operation will be continued for undetermined period of time**

The New Experimental Storage Ring NESR

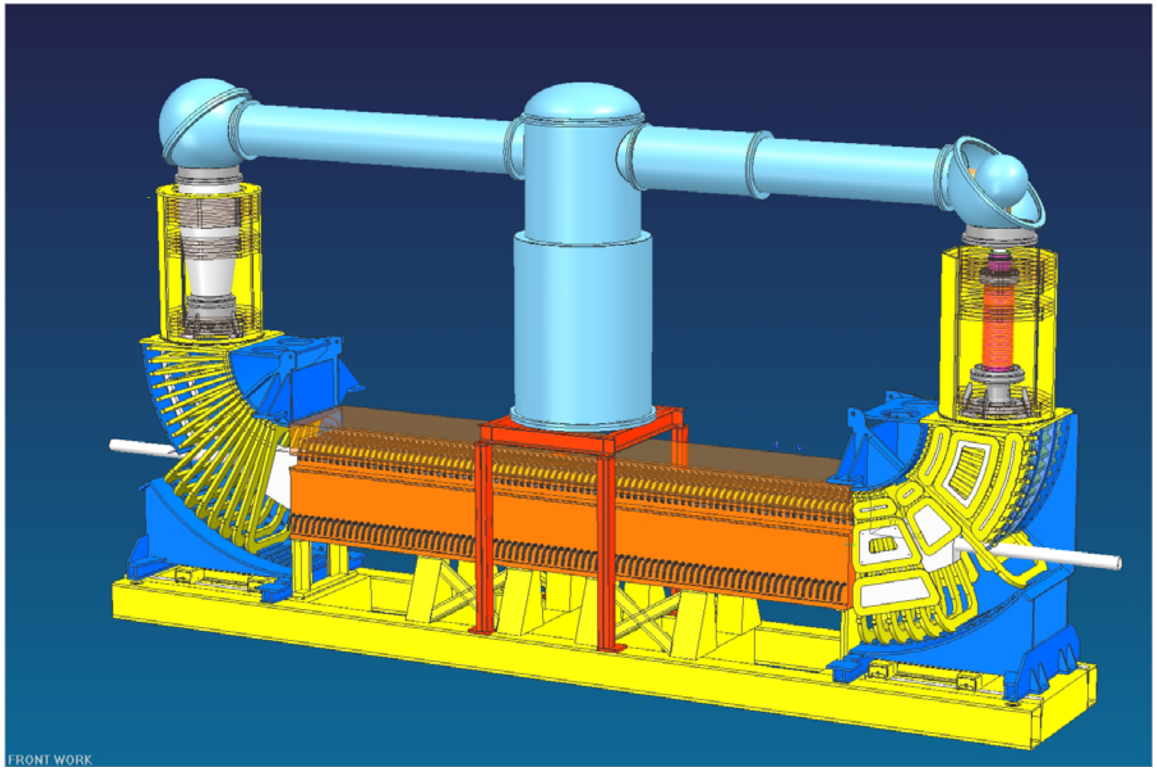


- Electron cooling of ions and antiprotons
- Fast deceleration of ions to 4 MeV/u
  and antiprotons to 30 MeV
- Fast extraction (1 turn)
- Slow (resonance) extraction
- Ultraslow (charge changing) extraction
- Longitudinal accumulation of RIBs
- Electron-Ion collisions
- Antiproton-ion collisions
- Internal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

Money for accelerator and buildings needed

NESR Electron Cooler

design by BINP, Novosibirsk



Electron Cooler Parameters

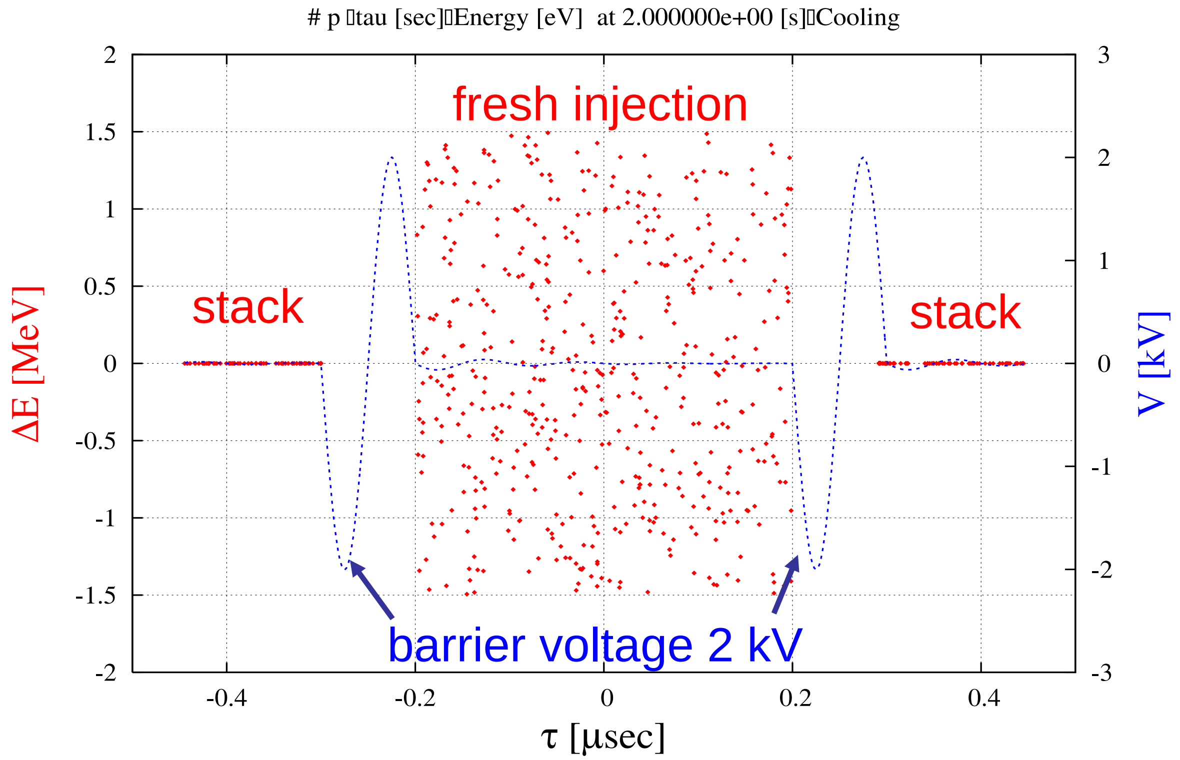
energy	2 - 450 keV
max. current	2 A
beam radius	2.5-14 mm
magnetic field	
gun	up to 0.4 T
cool. sect.	up to 0.2 T
straightness	2×10^{-5}
vacuum	$\leq 10^{-11}$ mbar

Issues:
- high voltage up to 500 kV
- fast ramping, up to 250 kV/s
- magnetic field quality

Accumulation of RIBs in NESR

basic idea: confine stored beam to a fraction of the circumference, inject into gap
apply strong electron cooling to merge the two beam components

⇒ fast increase of intensity (for low intensity RIBs)



$^{132}Sn^{50+}$

E_k = 740 MeV/u

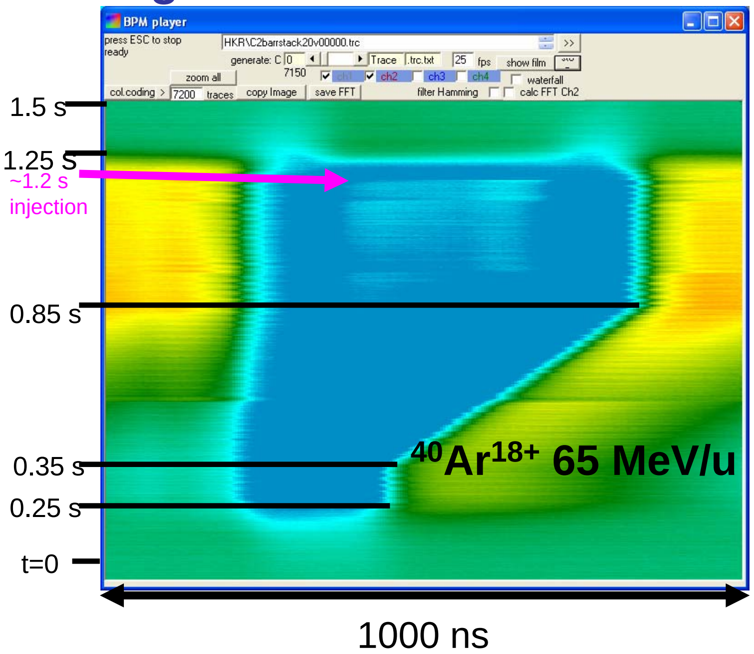
simulation of longitudinal stacking with barrier buckets

revolution time 0.9 μs

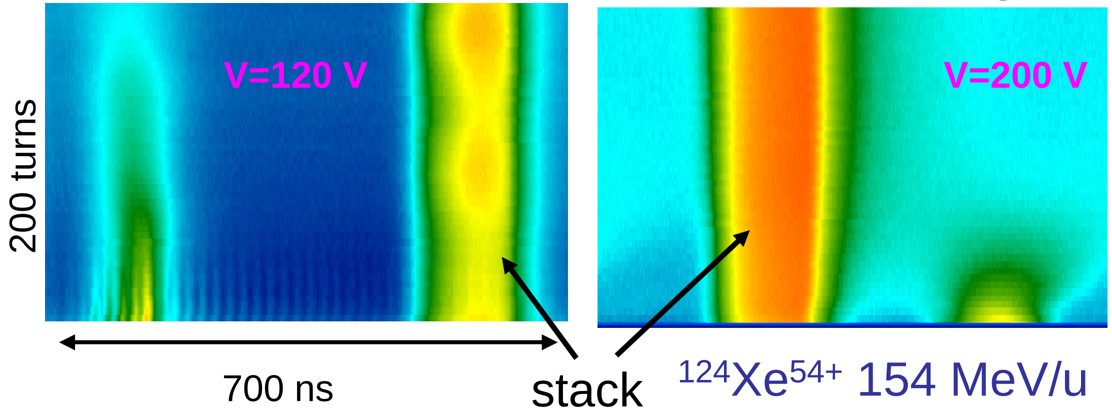
Proof of Principle in the ESR

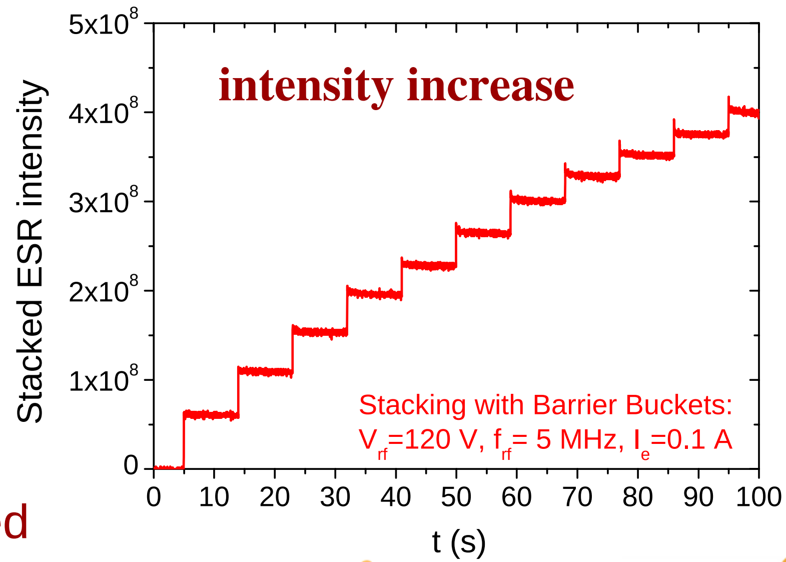
by combination of rf and electron cooling

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

Next Steps towards FAIR

Internal Organization of the project

- **FAIR company (accelerator, experiments, buildings)**
- **GSI accelerator department (project structure)**

GSI and FZJ application for full project money from German funding agencies

building permit by German authorities
($\Rightarrow$ permission to cut trees, hopefully this winter)

Thanks

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the organizers of COOL´11

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