Cooling performances of the Collector Ring

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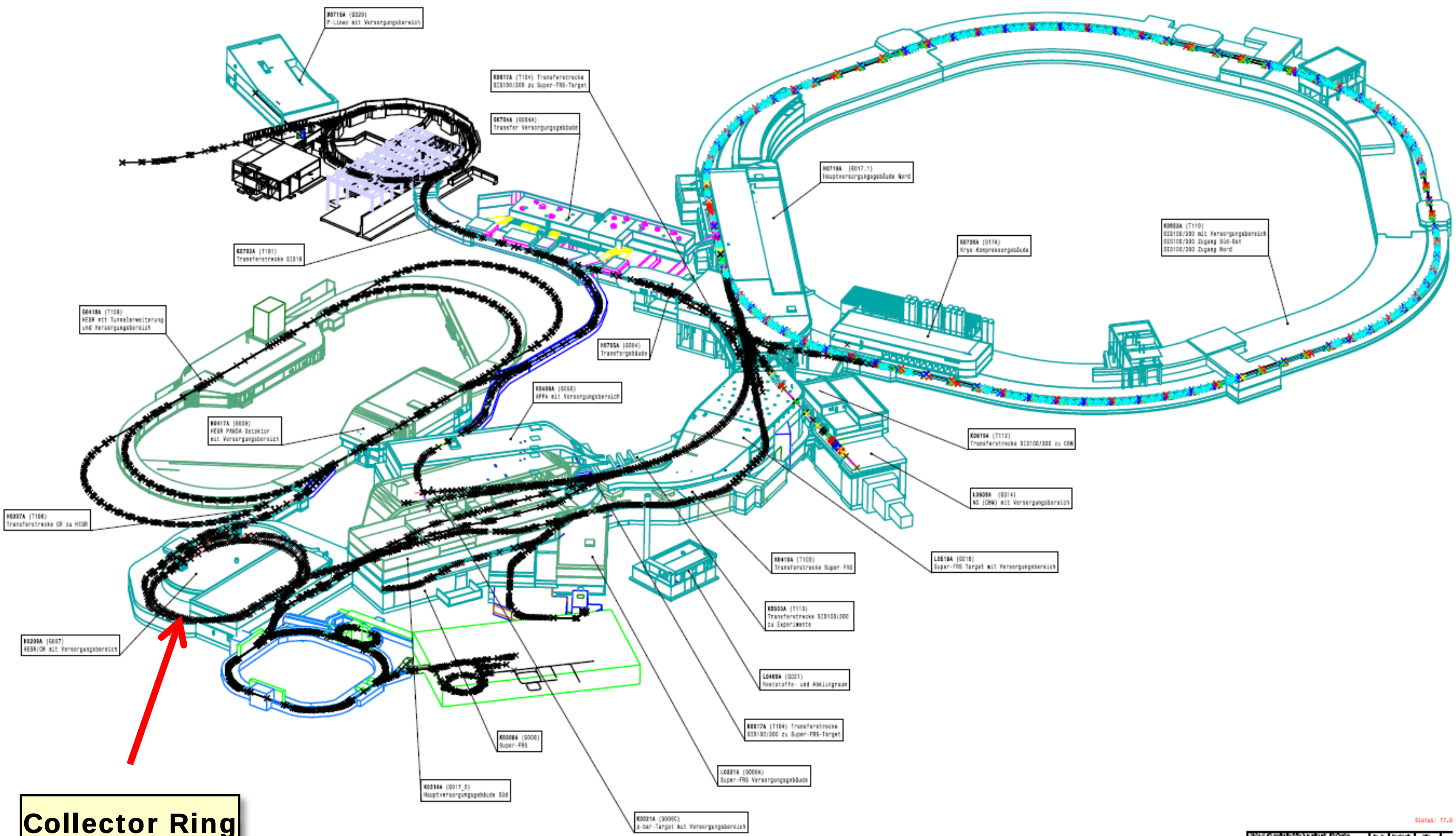
IWAPT at FAIR

November 17th, 2015, BINP (Novosibirsk)

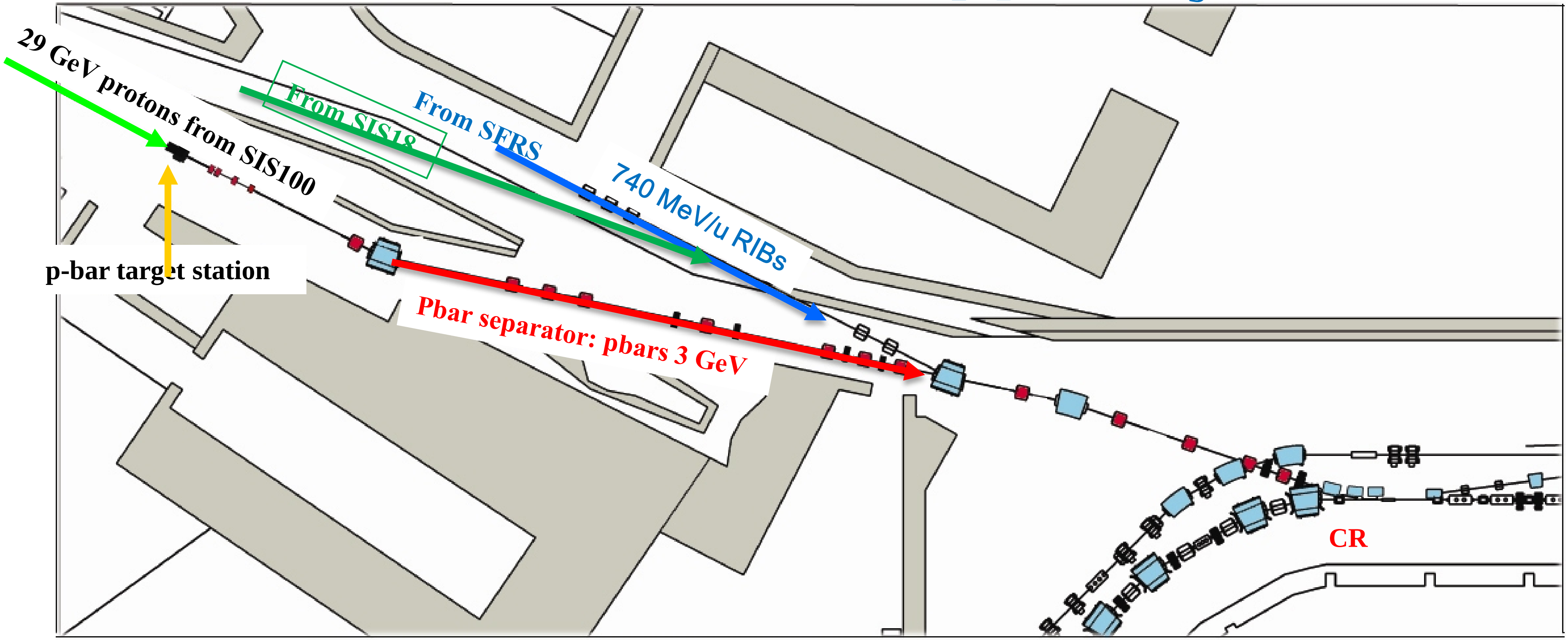
FAIR layout of accelerators



Collector Ring

Beams for the CR

RIBs from SFRS: 200 π mm mrad; $\Delta p/p=3\%$; $t_b=50$ ns

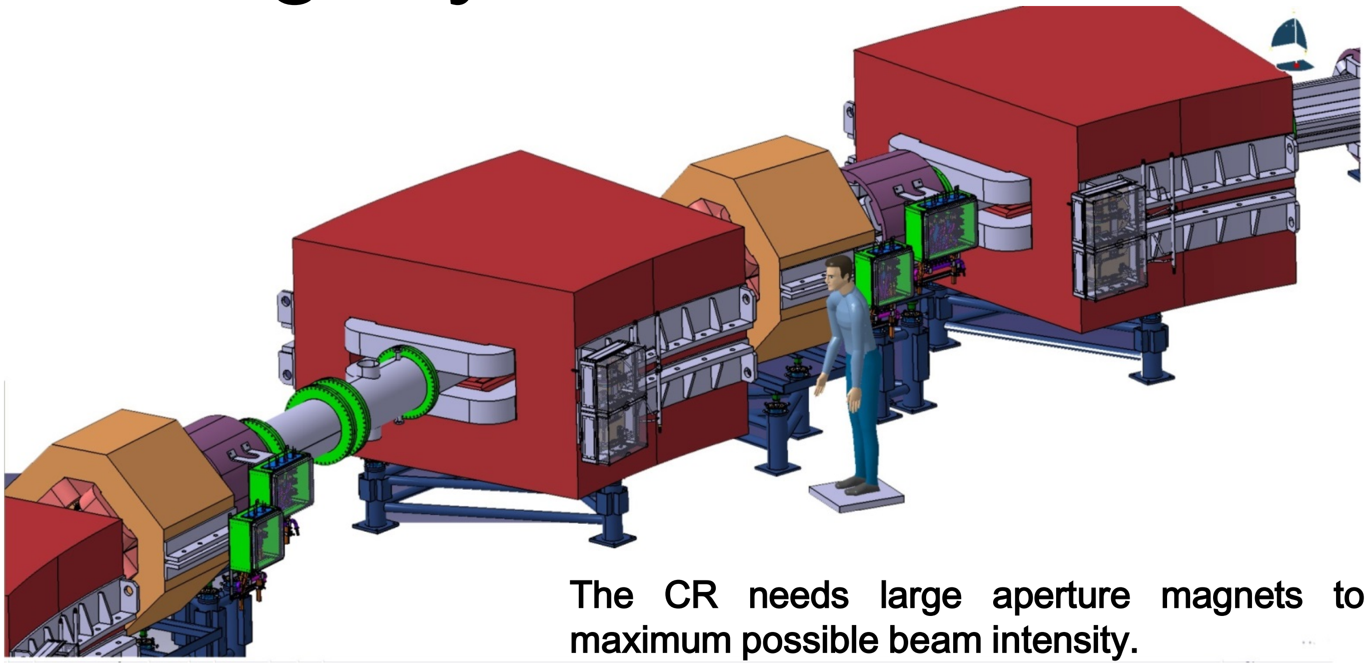


Antiprotons from pbar-sep.: 240 π mm*mrad; $\Delta p/p=6\%$; $t_b=50$ ns

Ions from SIS18: 50 π mm mrad, $\Delta p/p=10^{-3}$; $t_b=100$ ns

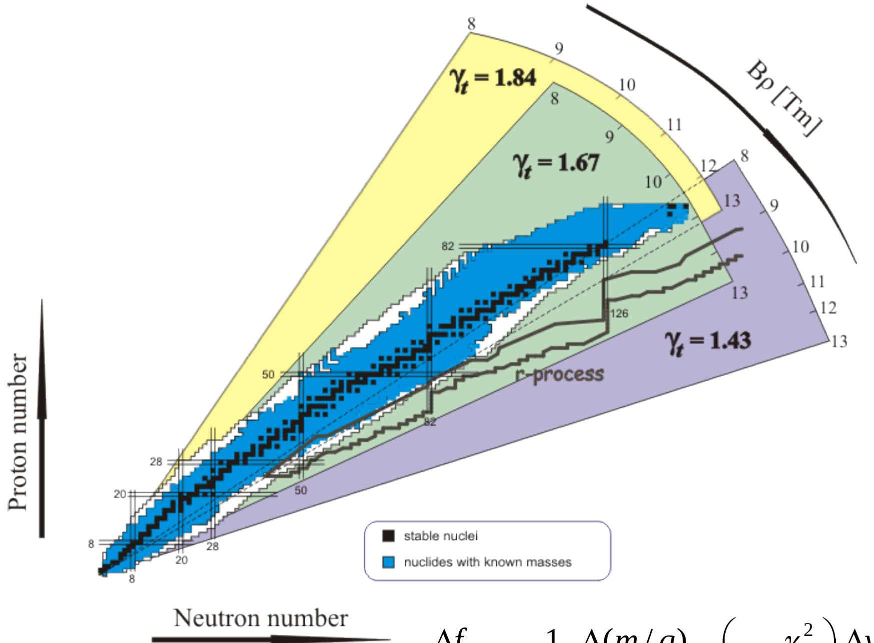
The main task of the CR

Fast pre-cooling of the hot ion beams coming from separators at the maximum magnetic rigidity of BR=13 Tm.

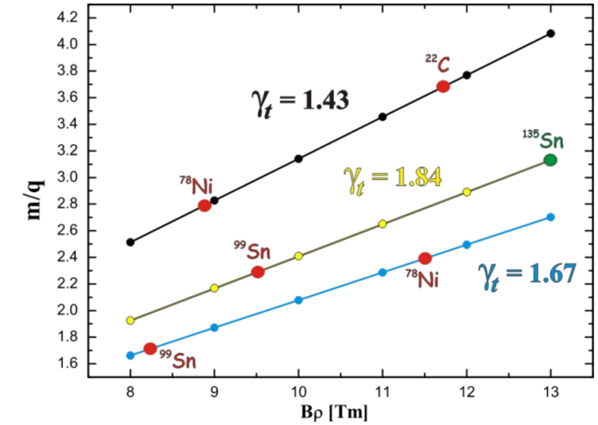


The CR needs large aperture magnets to collect the maximum possible beam intensity.

Mass measurements in the CR



1. $\gamma_t = \gamma = 1.84$ (E = 782.5 MeV/u)
2. $\gamma_t = \gamma = 1.67$ (E = 624.1 MeV/u)
3. $\gamma_t = \gamma = 1.43$ (E = 400.5 MeV/u)



$$\frac{\Delta f}{f} = -\frac{1}{\gamma_{tr}^2}\frac{\Delta(m/q)}{m/q} + \left(1-\frac{\gamma^2}{\gamma_{tr}^2}\right)\frac{\Delta v}{v} + \left(\frac{\delta f}{f}\right)_{error}$$

Isochronous mode ($\gamma_{tr} = \gamma$) is required for fast mass measurements.
Methods: TOF, Schottky spectroscopy

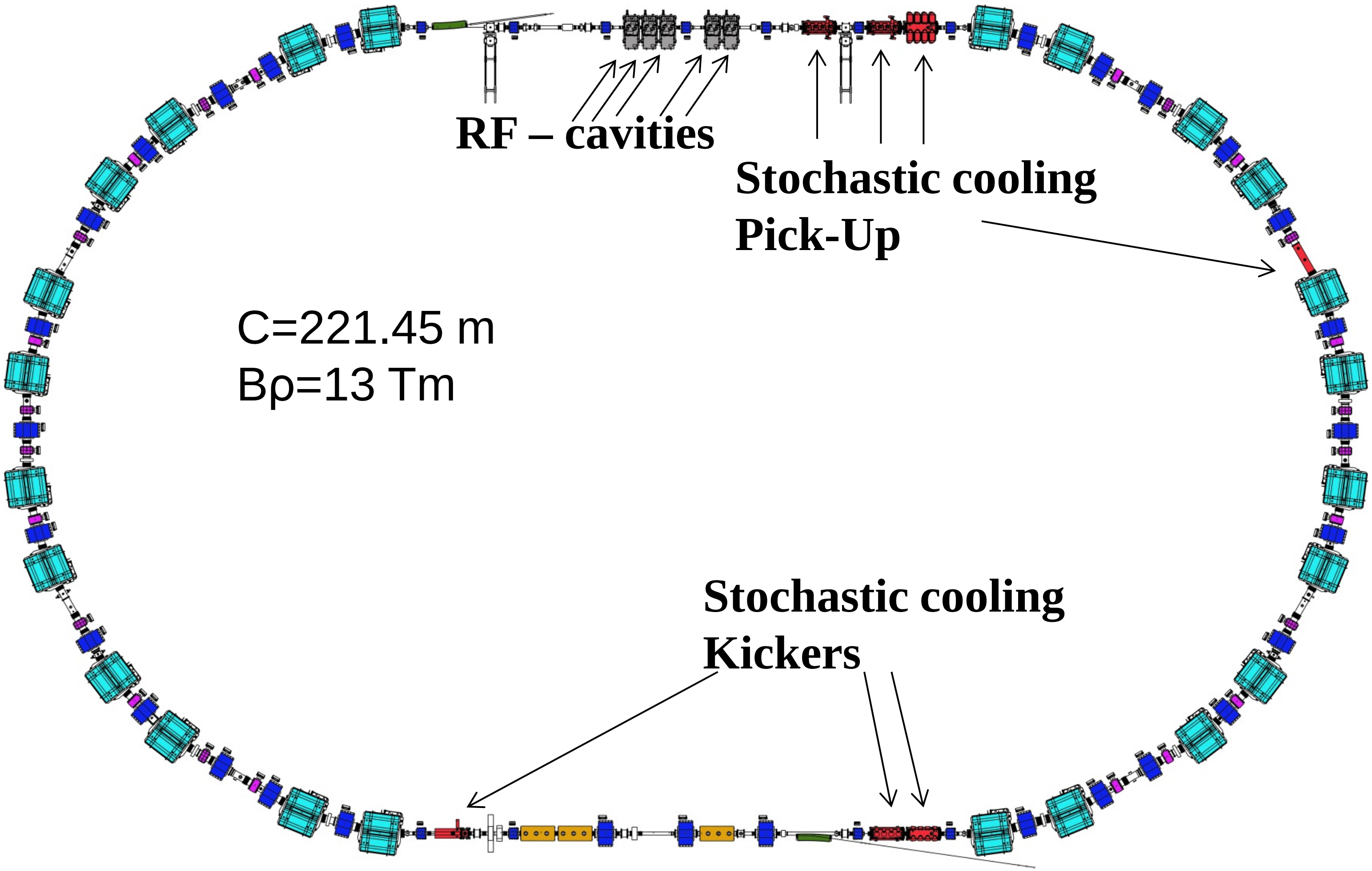
RIBs from SFRS: 100 π mm*mrad; Δp/p=1%; t_b=50 ns

Layout of the CR

The CR layout is optimized to have optimal Stochastic Cooling (SC) system for both antiproton and rare isotope beams.

The specific ring parameters have been adjusted specially for SC system.
(gamma-tr, phase advances, beta-functions, dispersion, position in ring).

Layout of the CR

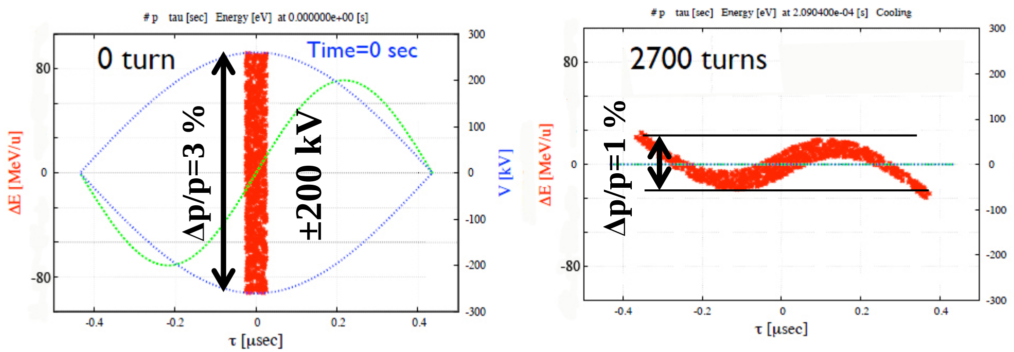


The CR operation cycle

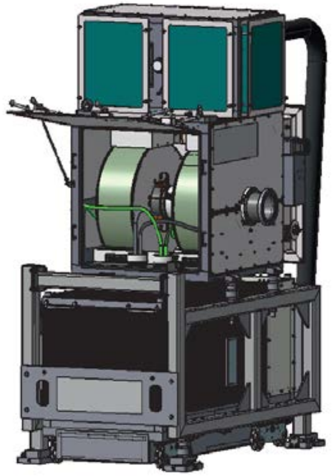
- Injection using full aperture kicker magnets
- RF bunch rotation + de-bunching
- Stochastic cooling
- RF re-bunching
- Extraction to the HESR

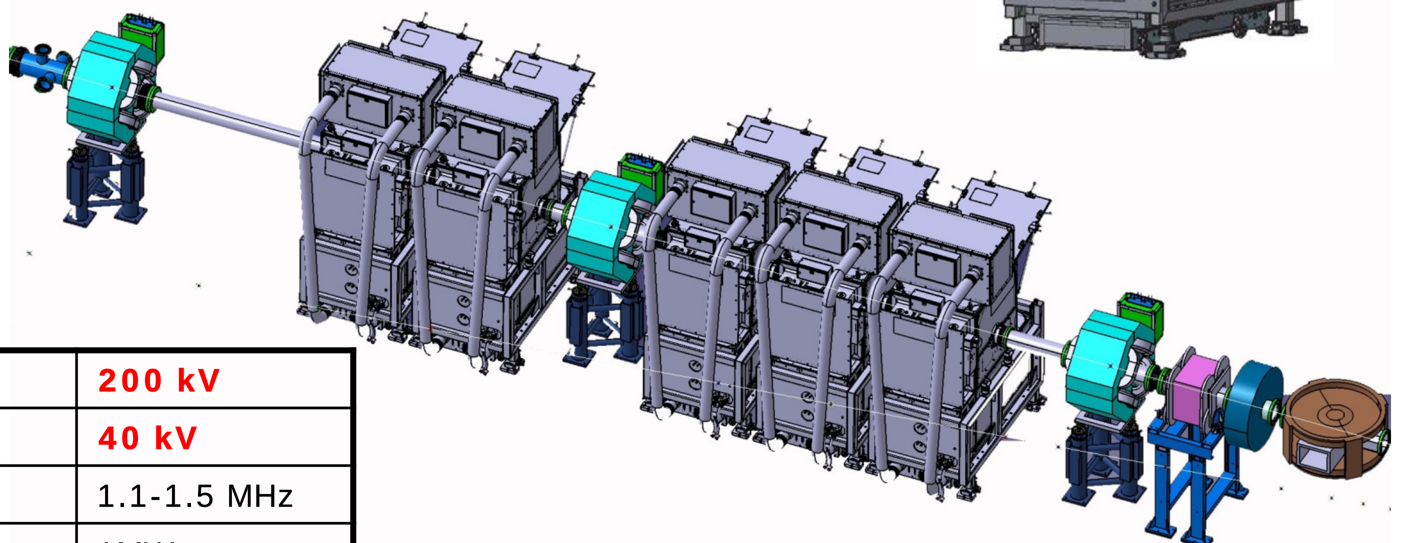
No accelaration, no decelerations.
Operation at the constant Bρ=13 Tm.

Challenges and design criteria for RF cavities



Bunch rotation of ions





Total voltage (5 RF stations)	**200 kV**
Peak voltage per cavity	**40 kV**
Frequency range	1.1-1.5 MHz
Peak power per RF station	1MW

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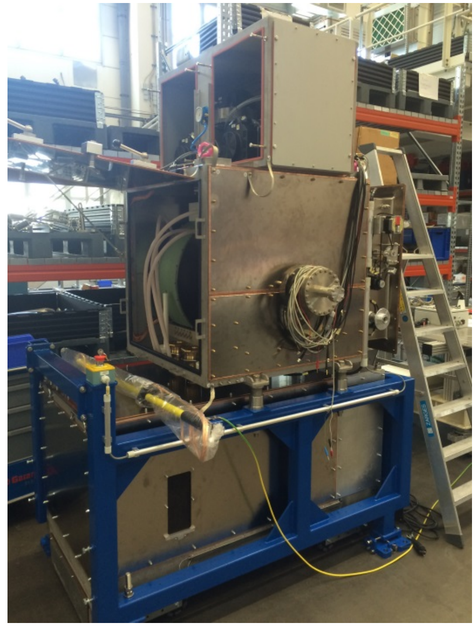
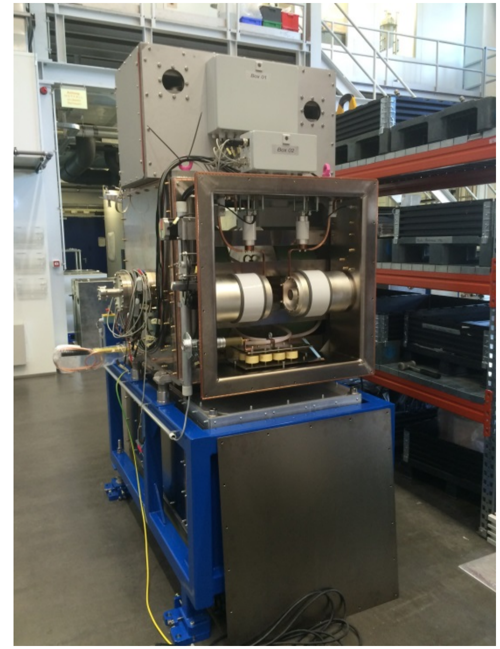
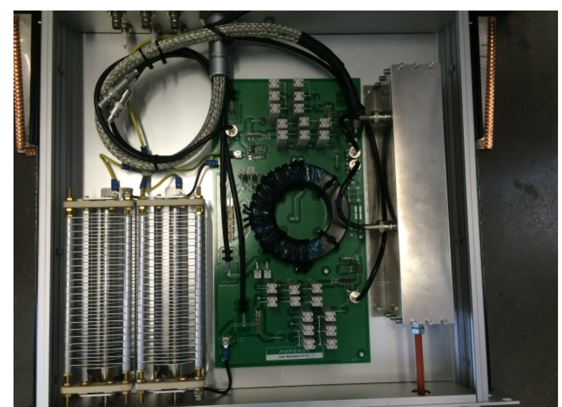
First of Series debuncher at GSI







Challenges and design criteria for Stochastic Cooling

From the CERN/Fermilab experience→ Cooling of pbars is very demanding!
From the ESR/GSI experience→ Very fast cooling of hot RIBs is challenging!

Main issue for antiprotons: increase ratio

$$\frac{\text{Schottky signal } (\propto Q^2)}{\text{thermal noise}}$$

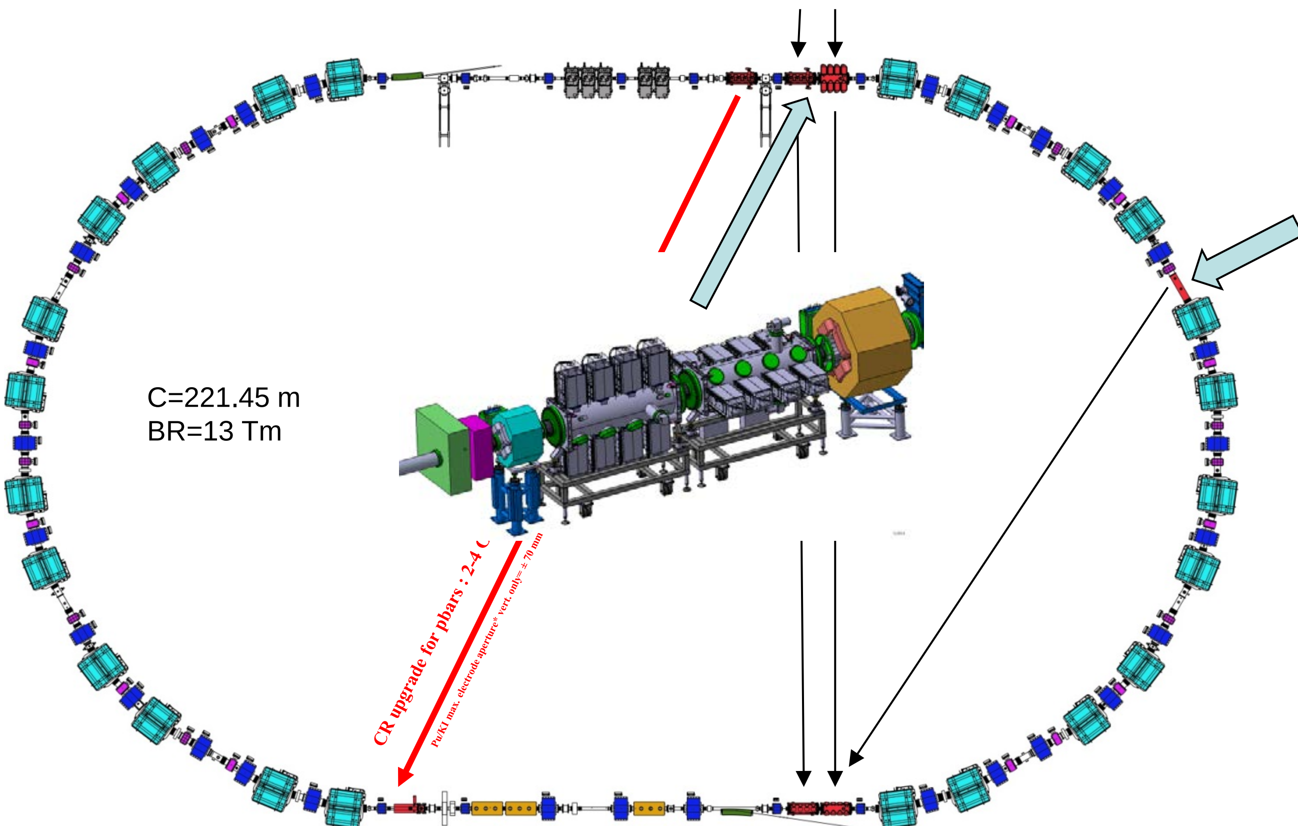
Main issue for rare isotopes: undesired mixing (from PU to K)

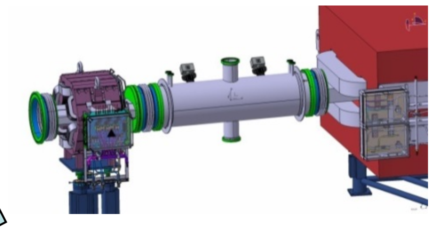
- **Pick-up electrodes cooled at 20-30K**
- **Plungeable pick-up electrodes i.e. moving closer to the beam during cooling**
- **Notch filter longitudinal cooling for noise suppression around revolution harmonics**

- **Pre-cooling (1st stage) with Palmer method**
- **Cooling (2nd stage) with the notch filter**

CR Stochastic Cooling System

Filter cooling PU (1-2 GHz)





Palmer cooling PU (1-2 GHz)

$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2}$$

η=+/-0.011 (pbars 1-2 GHz)
η=-0.011 (pbars 1-2 & 2-4 GHz)
η=+0.18 (RIBs)

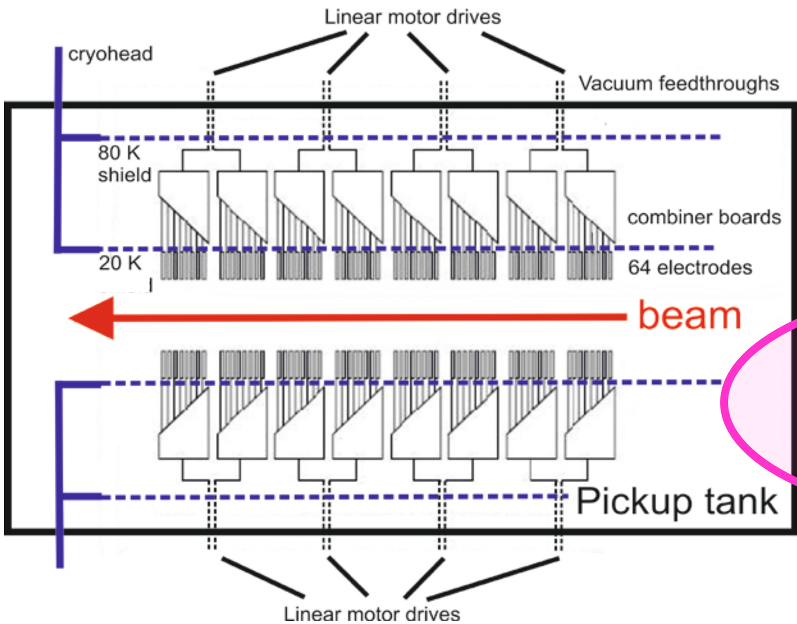
Kickers (1-2 GHz)

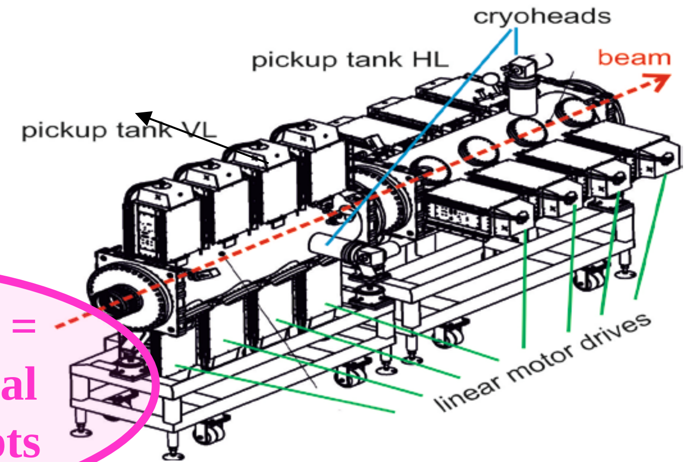
***: w.r.t. beam axis**

max. electrode aperture*
h/v= ± 70 mm

The CR is designed to have required η parameter both for antiprotons and RIBs. Optics and positions of PU and KI are designed for the required dispersion & phase advances between all pairs of PU-KI. The size of all beams must be smaller than the specified internal apertures of the electrodes at PU/KI.

Slotline PU vacuum tanks: cryogenic + plunging challenges



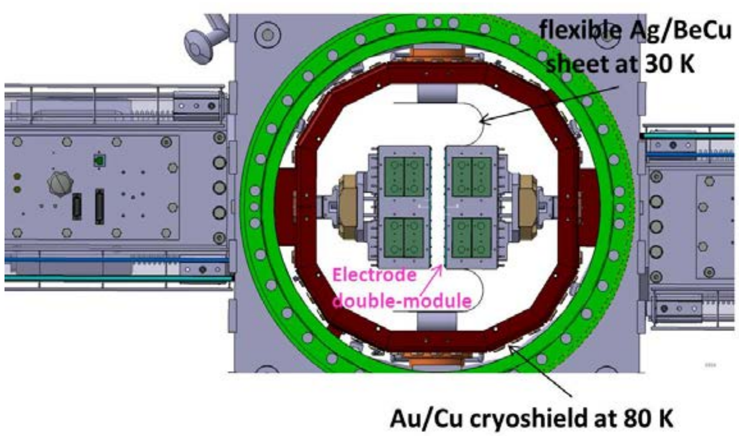


Highest priority = testing the critical technical concepts

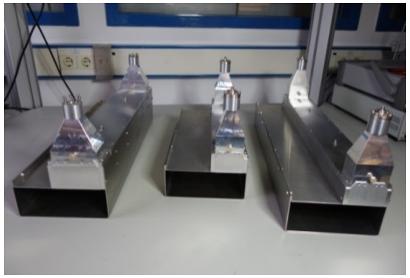
robust, programmable, water-cooled linear motor drive units for synchronous movement of the electrode double-modules

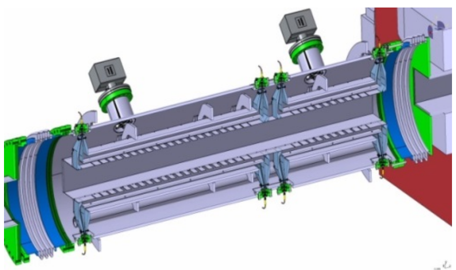
electrode modules sliding along flexible Ag/BeCu sheets cooled by cryoheads at 20-30 K

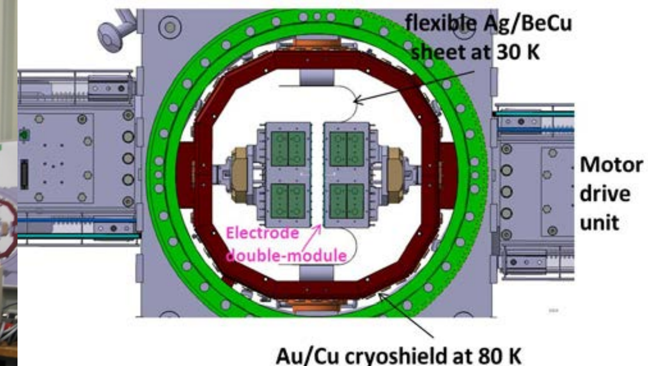
intermediate gold-plated cryoshield at 80 K

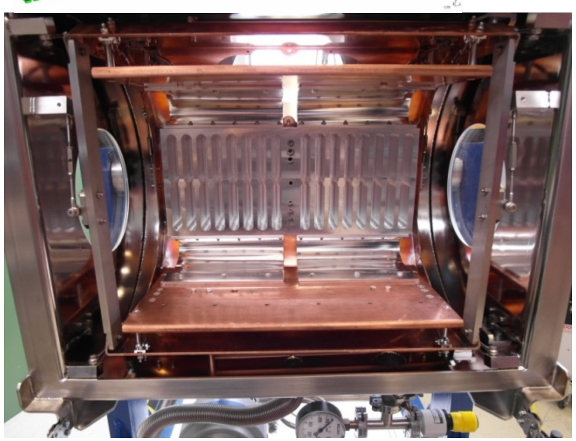


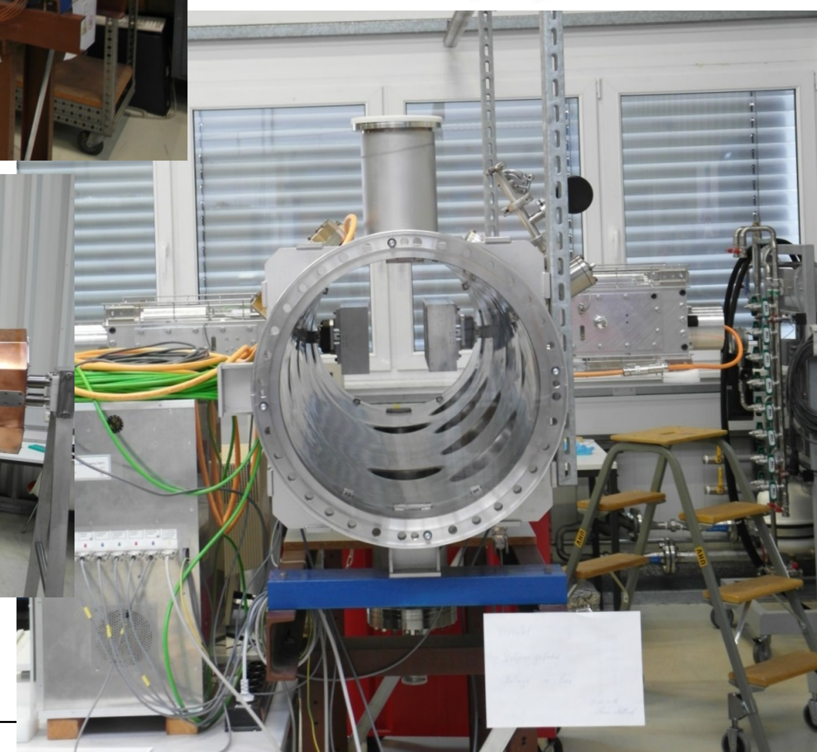
Stochastic cooling for CR at GSI











Cooling process study

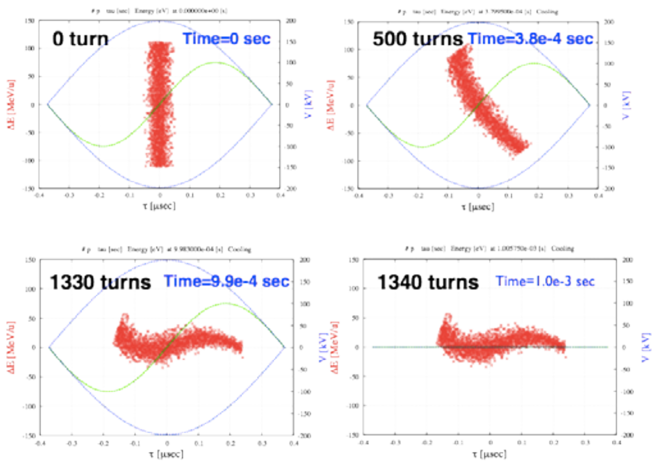
After CR optics optimization for antiproton
(from η=-0.011 to η=+0.011)
the Cooling Process is recalculated, where three processes are considered in a chain:

1. **RF bunch rotation + de-bunching**
2. **Stochastic cooling**
3. **RF re-bunching**

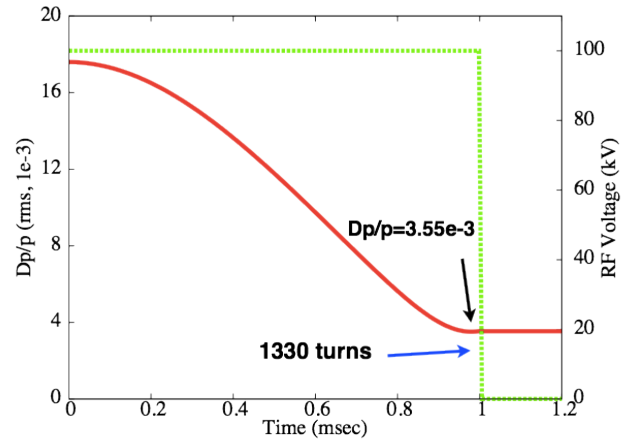
1.bunch manipulation (rotation + re-bunching)

antiproton beam

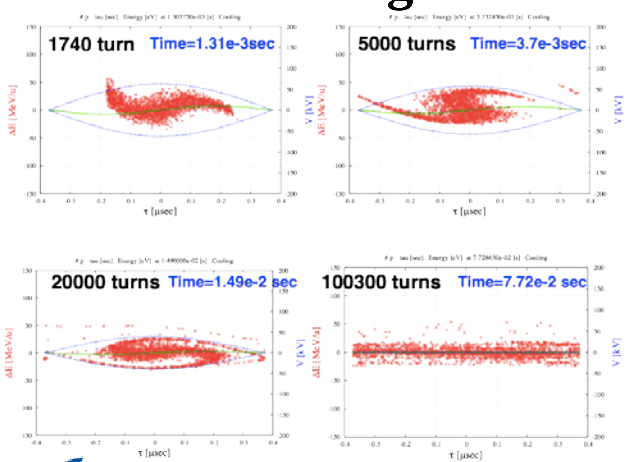
bunch rotation



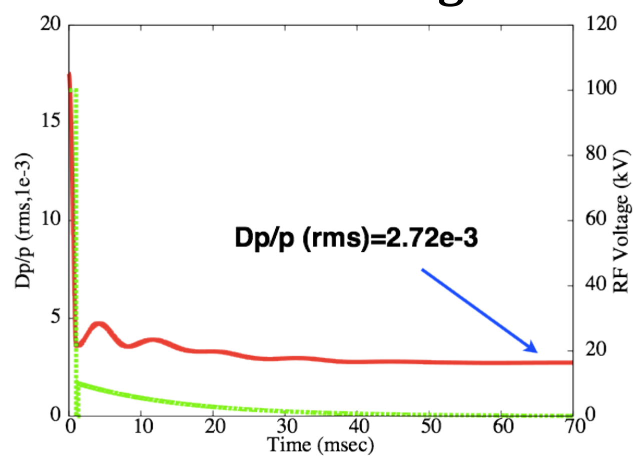
bunch rotation



de-bunching



de-bunching



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Simulations of T.Katayma (2015)

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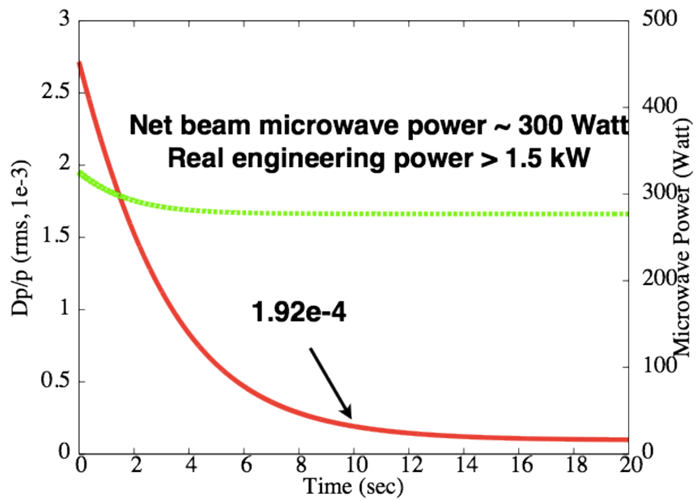
2.Stochastic cooling

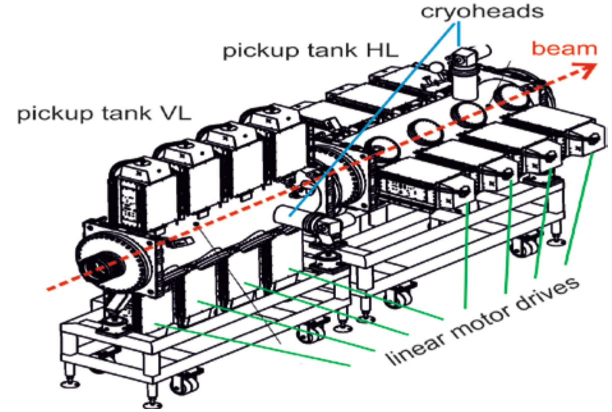
momentum spread evolution



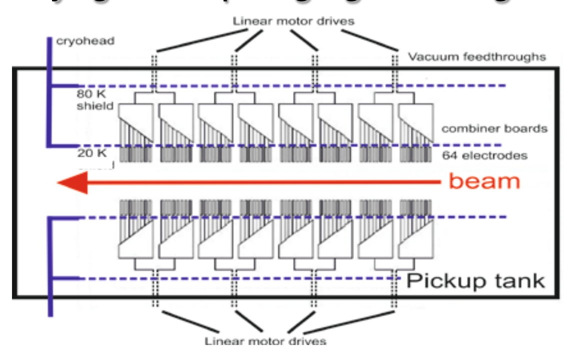
Number of PU and kicker electrodes: 128
PU & kicker vertical gap: 120 mm
Kicker & PU shunt impedance : 45/11.25 Ohm
Band: 1-2 GHz
Gain : 144, 147 and 150 dB

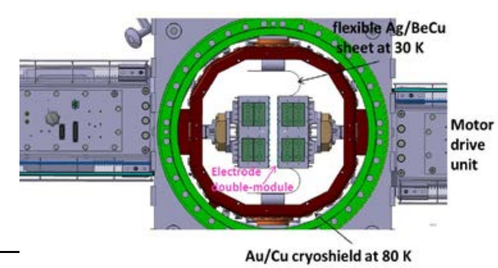
Ring parameter: η = 0.011

Slotline PU vacuum tanks



cryogenic + plunging challenges





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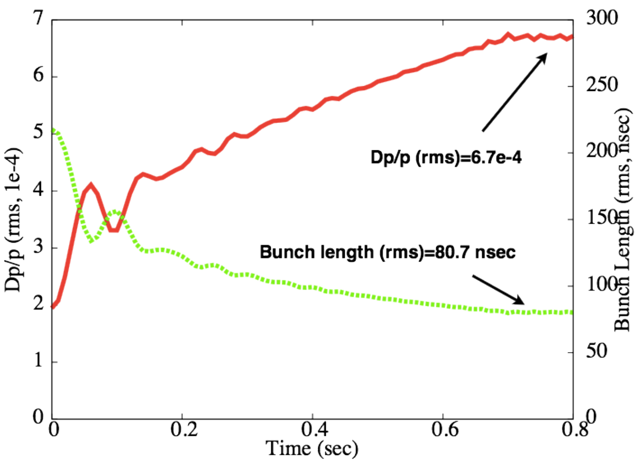
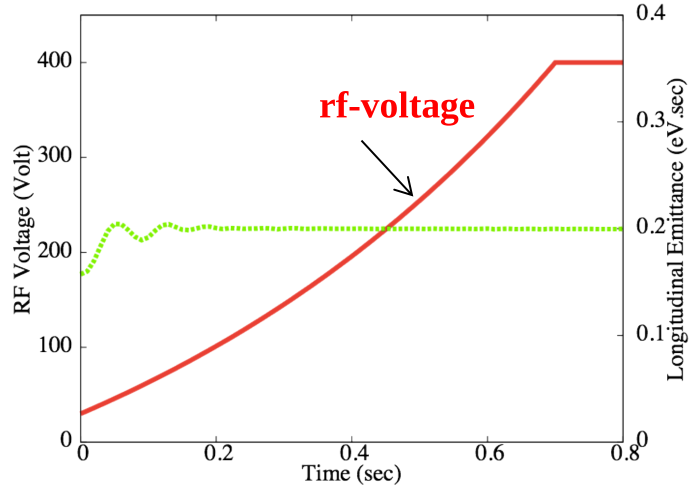
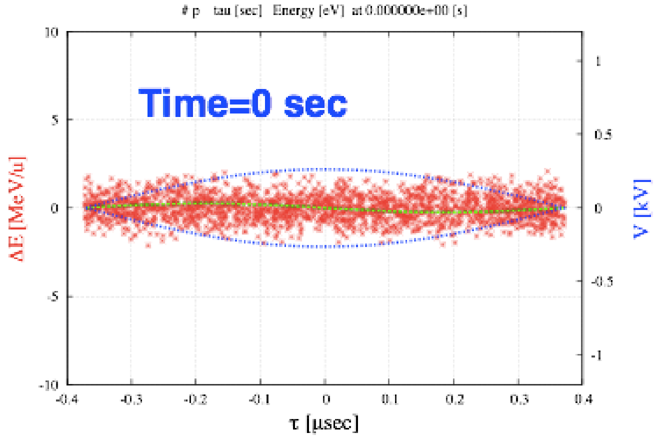
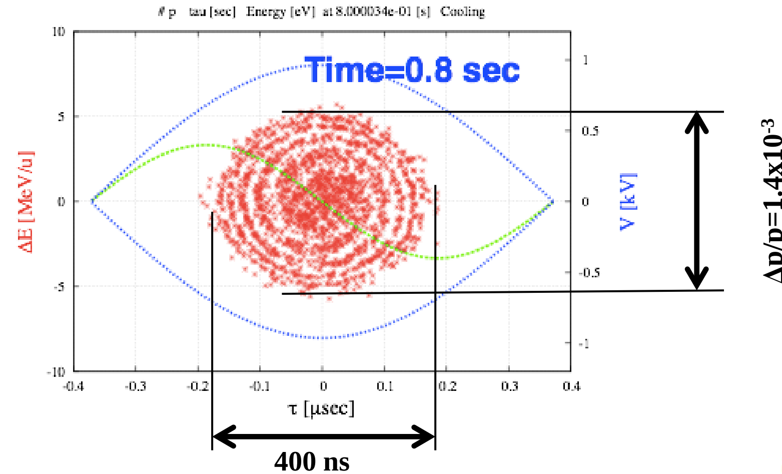
3. re-bunching process









Simulations of T.Katayma (2015)

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Performance of beam cooling in the CR

	10^8 Antiprotons E=3 GeV		10^8 Heavy ions E=740 MeV/u	
	δp/p (rms)	$\varepsilon_{h,v}$ (rms) [π mm mrad]	δp/p (rms)	$\varepsilon_{h,v}$ (rms) [π mm mrad]
At injection	**1.75 %**	**40**	**0.6 %**	**35**
After bunch manipulations	**0.27 %**	**40**	**0.2 %**	**35**
After cooling	**0.05 %**	**1.25**	**0.025 %**	**0.125**
After re-bunching (at extraction)	**0.1 % (TDR)** **0.07% ?**	**1.25**	**0.05 %**	**0.125**
Cycle time	**10 s**		**1.5 s**	

Matching to the HESR

The HESR Stochastic cooling acceptance: $\Delta p/p$ (rms) < 6 x 10^{-4} .
For CR optics with eta =-0.011 (TDR): $\Delta p/p$ (rms) = 10 x 10^{-4}
Due to this mismatching pbars can be lost by 30 %
For new CR p-bar optics with eta=+0.011 $\Delta p/p$ (rms) = 7 x 10^{-4}

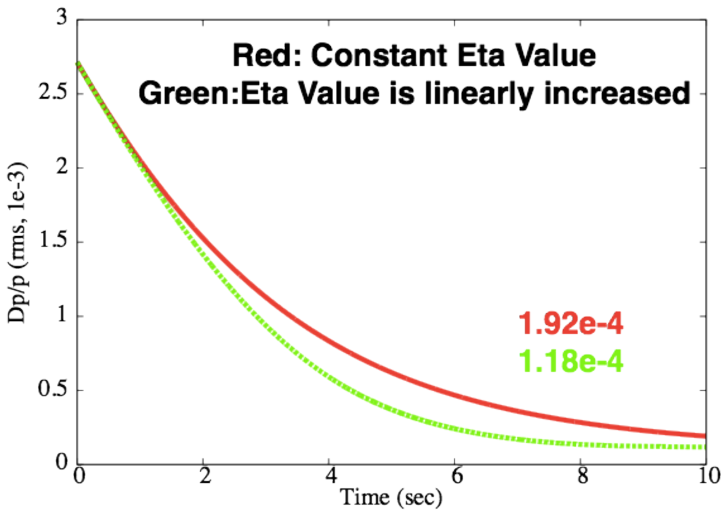
There are 2 ideas how to improve cooling performance of the CR

1. **Optics variation during cooling process. The eta-parameter is increased by a factor of 3, that helps SC to have better mixing condition. $\Delta p/p$ can be reduced by a factor of 2.**
2. **The $\Delta p/p$ of injected beam in the HESR could be further reduced, roughly by a factor of 2 through the de-bunching process with use of barrier bucket cavity system in the HESR.**

Takeshi Katayama has made preliminary studies of both ideas.

Stochastic cooling with variable CR optics

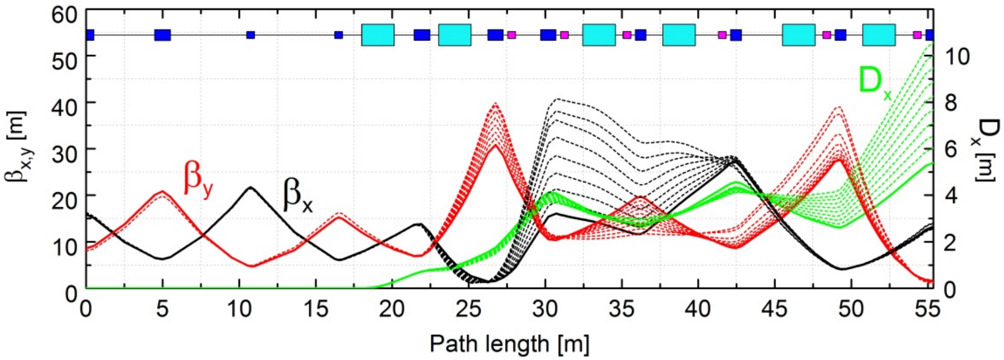
momentum spread evolution



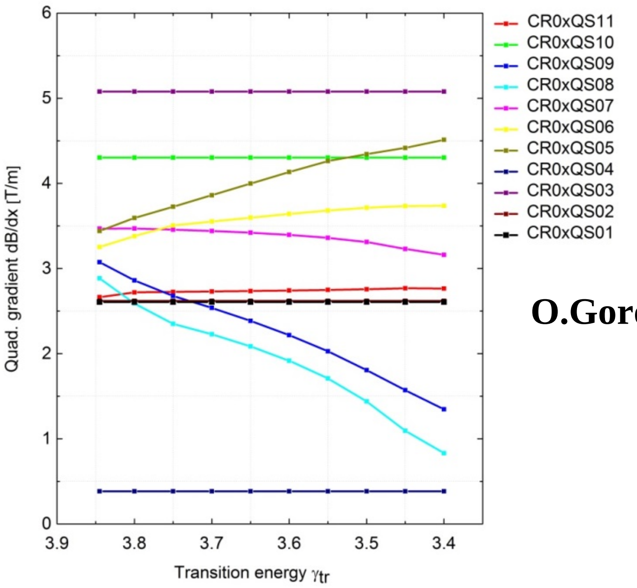
T.Katayama's simulations

Required ramping rate of quadrupoles dB/dt=0.35 T/s

η variation from 0.014 to 0.033



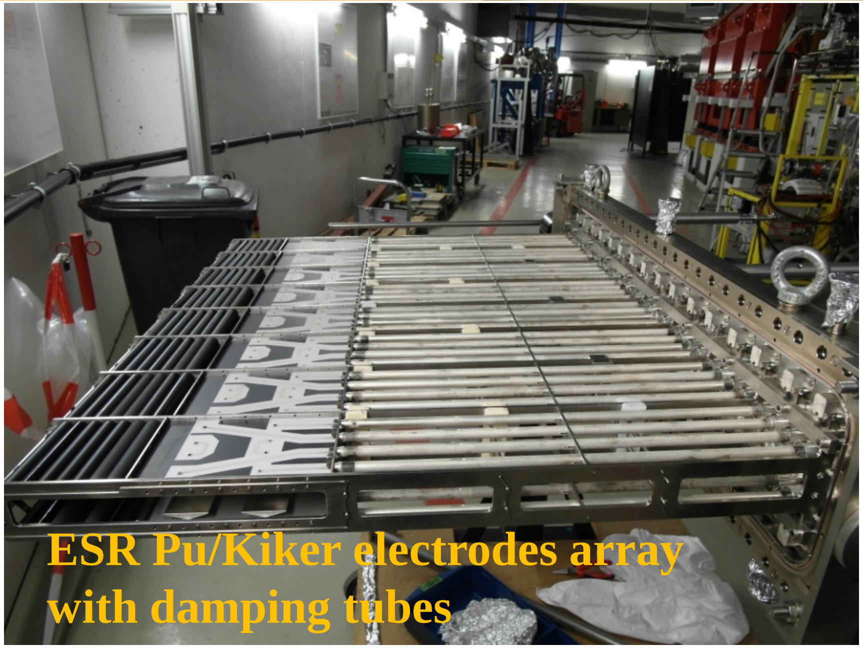
quadrupole ramping



O.Gorda's simulations

Microwave mode damping

ESR quadrupole chamber with damping tubes for microwave modes



ESR Pu/Kiker electrodes array with damping tubes

Around the ring (Experience ESR): ceramic tubes with resistive coating distributed in 12 positions around the ring inside vacuum chambers to damp unwanted microwave modes.

→ keep in mind when designing CR magnets/chambers!

→ choice by testing during stoch. cooling commissioning in CR

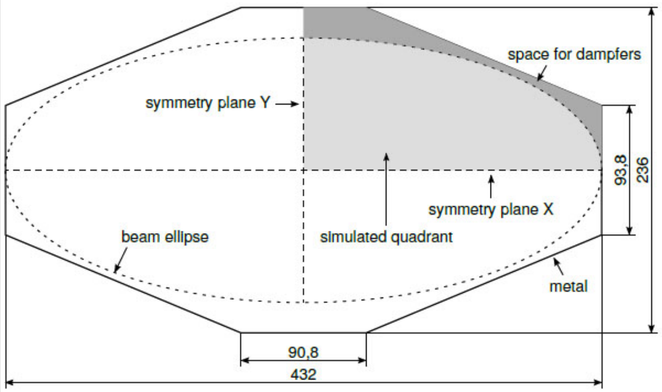
At PU/KI: must include ferrites, resistive coated tubes or other lossy material in the tank/electrode concept (tests, RF simulations).

Palmer PU (CERN and GSI experience): need electrode box full with ferrite

Large apertures→more modes→need moredamping

Microwave mode damping material necessary for stochastic cooling

Damping Material in a Modified Sextupole Chamber

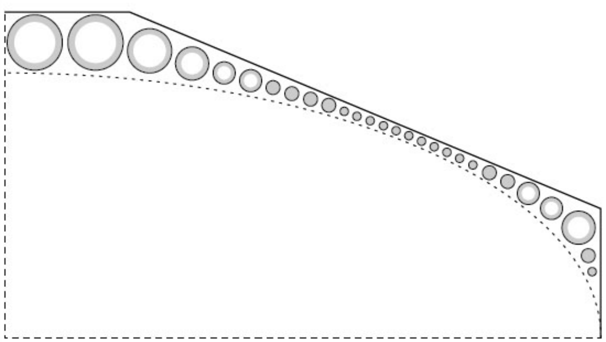


modification of sextupole chamber

- 44 mm increased height
- width and angle unchanged
- may still fit into sextupole or quadrupole magnets

→ usage of larger ⌀20 mm damping tubes possible

→ lower cut-off frequencies, more propagable modes up to 2,3 GHz: 12 TM modes, 16 TE modes



third try: four times 20 alumina rods and tubes from ⌀3 mm to ⌀20 mm with resistive coating on the outside

- optimisation for sheet resistance is not ready yet
- very preliminary results: sufficient, but no reserves

→ a little bit more free space will be necessary

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PSP 2.5.10 CR Stochastic Cooling
Version 11.11.2015 (preliminary)

Summary

- The CR is designed for fast cooling of hot secondary beams coming from separators
- The beam cooling in the longitudinal phase space is performed by two steps: 1. RF bunch rotation; 2. Stochastic Cooling
- The beam cooling in the transverse phase space is performed only by Stochastic Cooling
- The CR operates as a cooler at the static regime at Bρ=13 Tm.
- The cooling cycle of: heavy ions – 1.5 s; antiprotons – 10 s.
- At Extraction from the CR: the Δp/p (rms): of pbars = 0.07 – 0.1 %
  of heavy ions = 0.05 %
- The Δp/p matching to the HESR requires Δp/p < 0.06 %. There are ideas how to improve cooling performances of the CR, which are under considerations.
- Stochastic cooling CANNOT work without microwave mode damping in the CR. Large CR apertures, many modes need strong damping.