Transition energy variation in antiproton mode of CR

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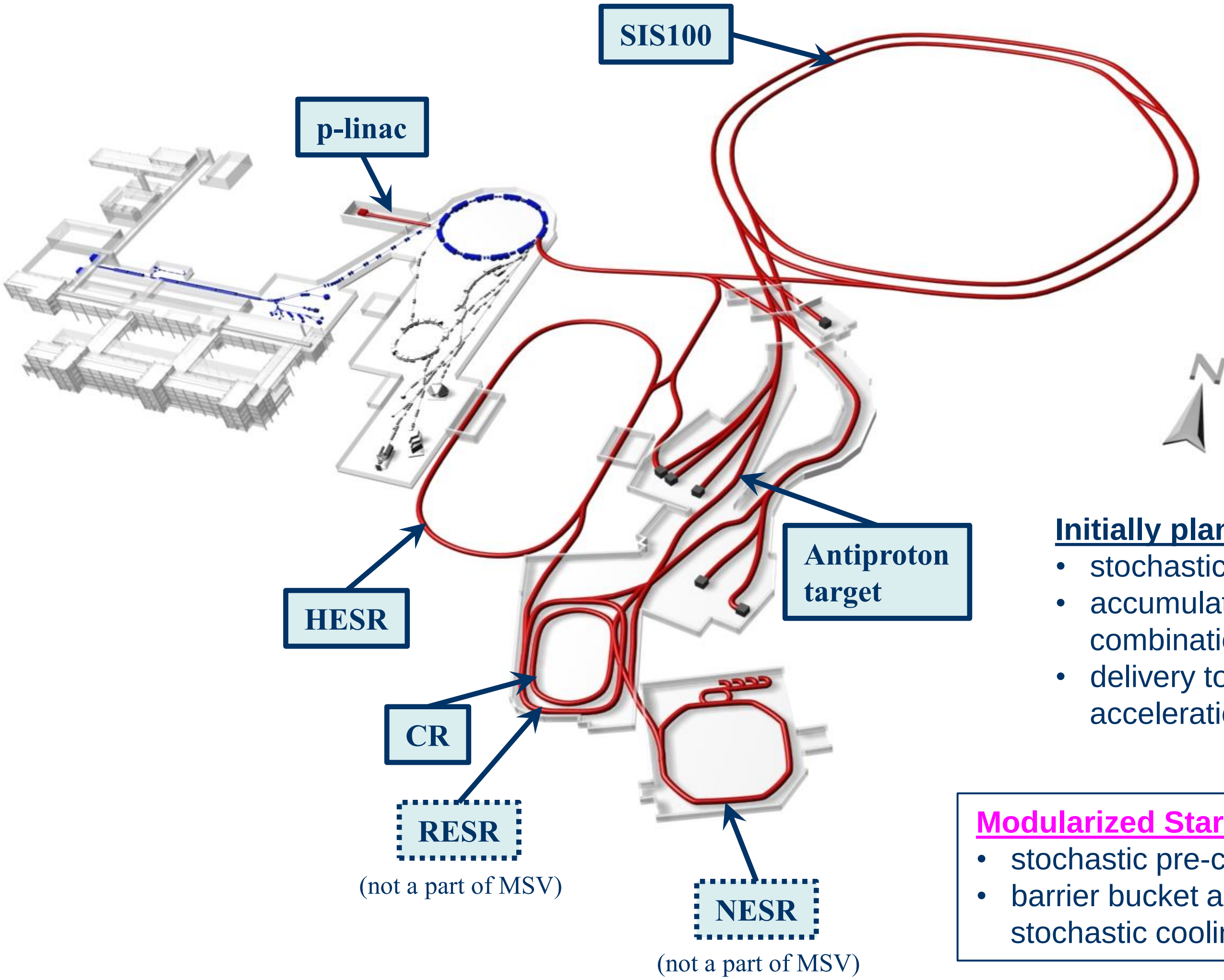
BINP-FAIR-GSI 6th workshop, GSI
2 December 2014

Antiprotons at FAIR



Initially planned scenario for pbars:

- stochastic pre-cooling in CR
- accumulation by longitudinal stacking in combination with stochastic cooling in RESR
- delivery to HESR or NESR for acceleration/deceleration and experiments

Modularized Start Version (MSV) of FAIR:

- stochastic pre-cooling in CR
- barrier bucket accumulation with stochastic cooling in HESR

Beam parameters

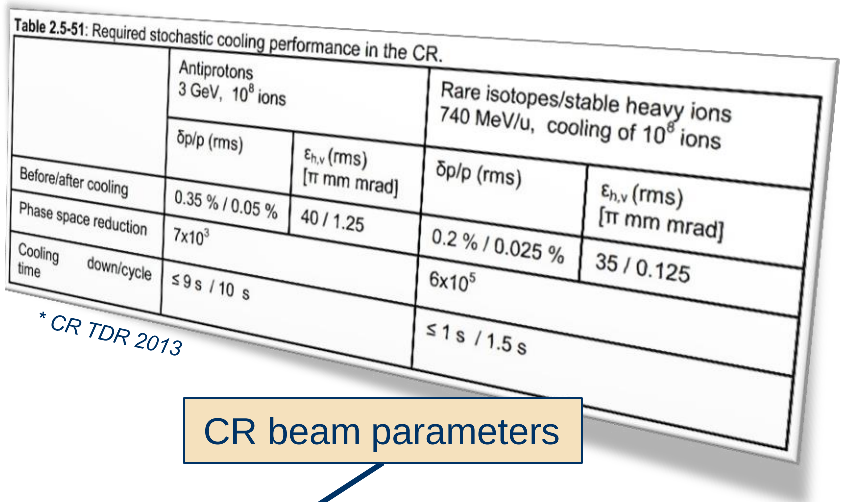


Table 2.5-51: Required stochastic cooling performance in the CR.

	Antiprotons 3 GeV, 10^8 ions		Rare isotopes/stable heavy ions 740 MeV/u, cooling of 10^8 ions	
	δp/p (rms)	$\varepsilon_{h,v}$ (rms) [π mm mrad]	δp/p (rms)	$\varepsilon_{h,v}$ (rms) [π mm mrad]
Before/after cooling	0.35 % / 0.05 %	40 / 1.25	0.2 % / 0.025 %	35 / 0.125
Phase space reduction	7×10^3		6×10^5	
Cooling down/cycle time	≤ 9 s / 10 s		≤ 1 s / 1.5 s	

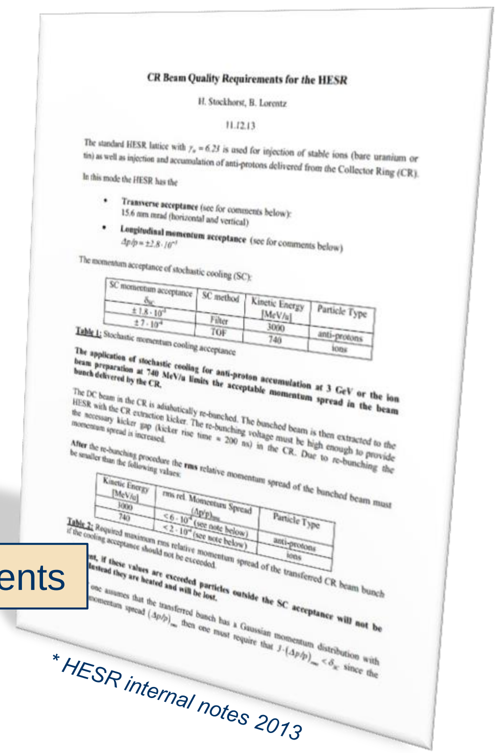
* CR TDR 2013

CR beam parameters

	δp/p (rms)
Momentum spread after cooling in CR	5×10^{-4}
Momentum acceptance of stochastic cooling system in HESR*	6×10^{-4}

** assuming 99% of particles within a given distribution*

HESR requirements



CR Beam Quality Requirements for the HESR

H. Stockhorst, B. Lorentz

11.12.13

The standard HESR lattice with $\gamma_{tr} = 6.23$ is used for injection of stable ions (bare uranium or tin) as well as injection and accumulation of anti-protons delivered from the Collector Ring (CR).

In this mode the HESR has the

- **Transverse acceptance** (see for comments below): 15.6 mm mrad (horizontal and vertical)
- **Longitudinal momentum acceptance** (see for comments below) $\Delta p/p = \pm 2.8\cdot10^{-3}$

The momentum acceptance of stochastic cooling (SC):

SC momentum acceptance δ_{SC}	SC method	Kinetic Energy [MeV/u]	Particle Type
$\pm 1.8\cdot10^{-3}$	Filter	3000	anti-protons
$\pm 7\cdot10^{-4}$	TOF	740	ions

Table 1: Stochastic momentum cooling acceptance

The application of stochastic cooling for anti-proton accumulation at 3 GeV or the ion beam preparation at 740 MeV/u limits the acceptable momentum spread in the beam bunch delivered by the CR.

The DC beam in the CR is adiabatically re-bunched. The bunched beam is then extracted to the HESR with the CR extraction kicker. The re-bunching voltage must be high enough to provide the necessary kicker gap (kicker rise time ≈ 200 ns) in the CR. Due to re-bunching the momentum spread is increased.

After the re-bunching procedure the **rms** relative momentum spread of the bunched beam must be smaller than the following values:

Kinetic Energy [MeV/u]	rms rel. Momentum Spread $(\Delta p/p)_{rms}$	Particle Type
3000	$< 6\cdot10^{-4}$ (see note below)	anti-protons
740	$< 2\cdot10^{-4}$ (see note below)	ions

Table 2: Required maximum rms relative momentum spread of the transferred CR beam bunch if the cooling acceptance should not be exceeded.

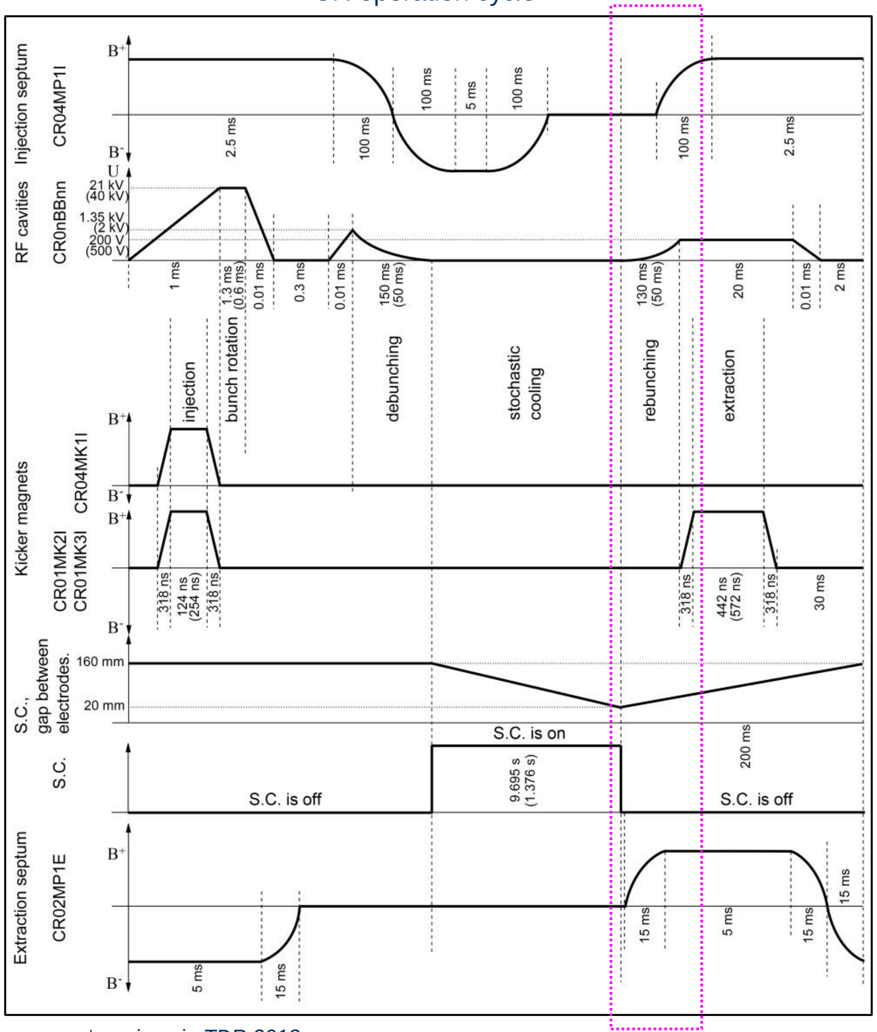
...nt, if these values are exceeded particles outside the SC acceptance will not be ... Instead they are heated and will be lost.

... one assumes that the transferred bunch has a Gaussian momentum distribution with ... momentum spread $(\Delta p/p)_{rms}$ then one must require that $3\cdot(\Delta p/p)_{rms} < \delta_{SC}$ since the

* HESR internal notes 2013

... after rebunching

CR operation cycle



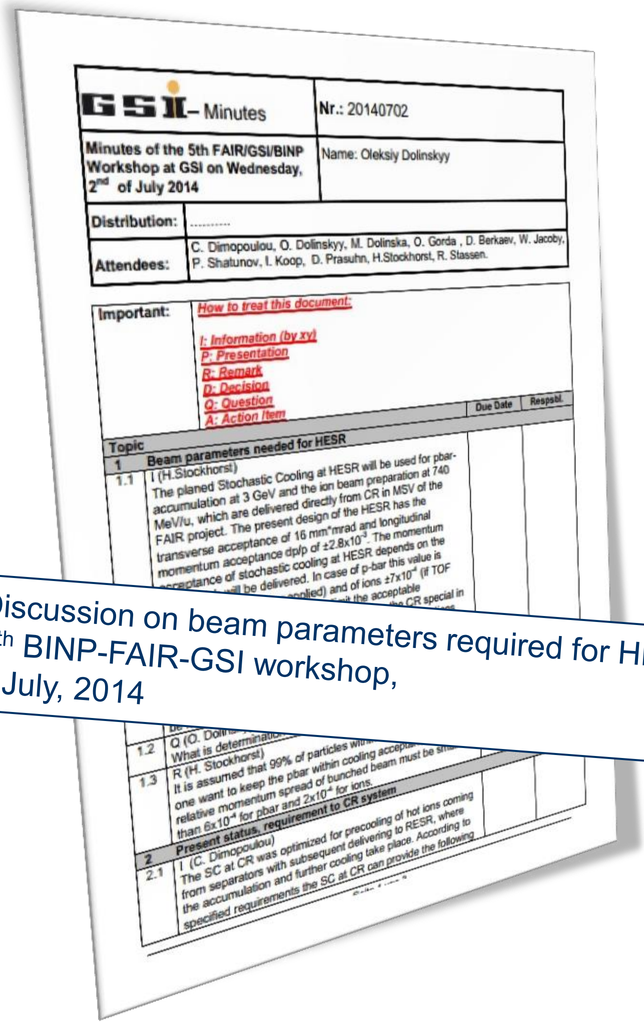
*as given in TDR 2013

- Cooling → rebunching → extraction to HESR.
- During the rebunching the momentum spread is increased by a factor of 2 (?).
- Numerical simulations by Jülich colleagues (for beam parameters given in TDR 2013) :

About 30% of pbars are out of acceptance of HESR stochastic cooling system, and will be lost due to heating.

- **Possible mitigations?**

Possible improvements



Discussion on beam parameters required for HESR,
5th BINP-FAIR-GSI workshop,
2 July, 2014

- Reduce the rise time of the kicker magnets from 318 ns (CR TDR 2013) to 200 ns or even less?
- Consider plunging of pick-up electrodes in simulations. Check whether cooling in longitudinal space could be improved?
- Applying of combined TOF and Notch filter methods for stochastic cooling of antiprotons in HESR.
- **Improve the cooling efficiency in CR by a variation of the mixing parameter (or the transition energy) during the cooling process.**

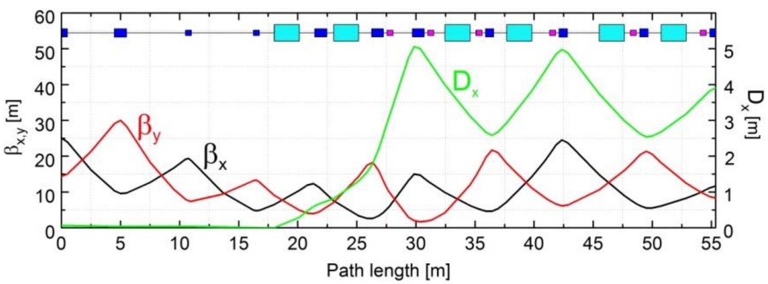
GSI and BINP optics

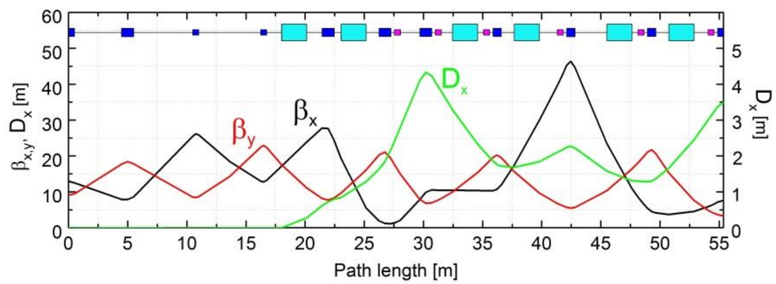
GSI

Parameter	Value
Lorentz γ	4.20
Transition γ_{tr}	3.85
Momentum compaction η	-0.011
Betatron tunes Q_x/Q_y	4.09/4.34

BINP

Parameter	Value
Lorentz γ	4.20
Transition γ_{tr}	4.84
Momentum compaction η	0.013
Betatron tunes Q_x/Q_y	4.18/3.23





- Variation of transition energy in the range of **$3.85 \geq \gamma_{tr} \geq 3.35$** corresponding to the momentum compaction **$-0.011 \geq \eta \geq -0.03$**

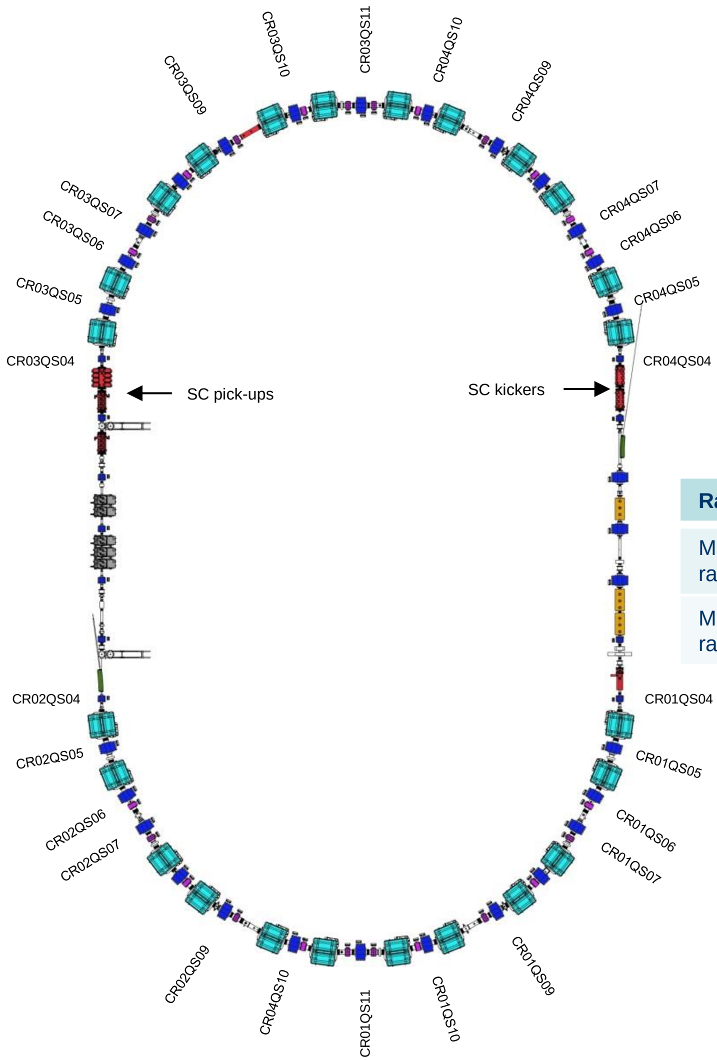
- Variation of transition energy in the range of **$4.84 \leq \gamma_{tr} \leq 6.2$** corresponding to the momentum compaction **$0.013 \leq \eta \leq 0.03$**

$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2} \quad \text{with} \quad \frac{1}{\gamma_{tr}^2} = \frac{1}{C}\int_0^C \frac{D_x(s)}{\rho(s)} ds, C \ - \text{ring circumference}$$

- Average dispersion D_x has to be increased.

- Average dispersion D_x has to be decreased.

γ_{tr} variation (GSI optics)

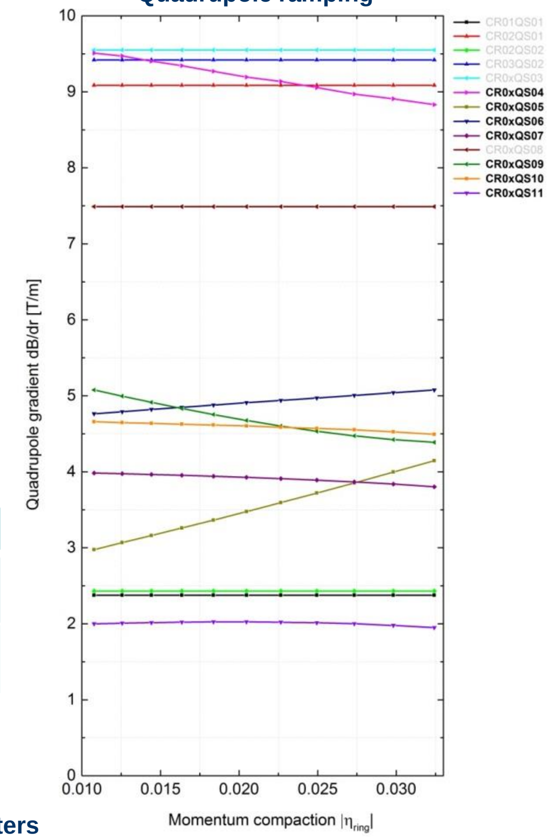


- 7 families of quads are used.
- Phase advance $\Delta\mu = \pi/2$ between SC pick-ups and kickers is controlled during ramping.
- Betatron tunes Qx,Qy are constant during ramping to avoid cross of resonances.
- Dispersion Dx=0 in the straight sections is adjusted during ramping.

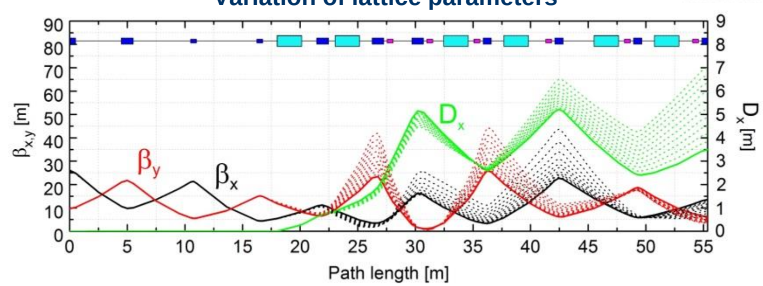
Required ramp rate:

Ramping time	10 s	8 s	5 s	3 s
Max. gradient rate, T/m/s, WQ	0.12	0.15	0.24	0.4
Max. gradient rate, T/m/s, NQ	0.07	0.09	0.14	0.23

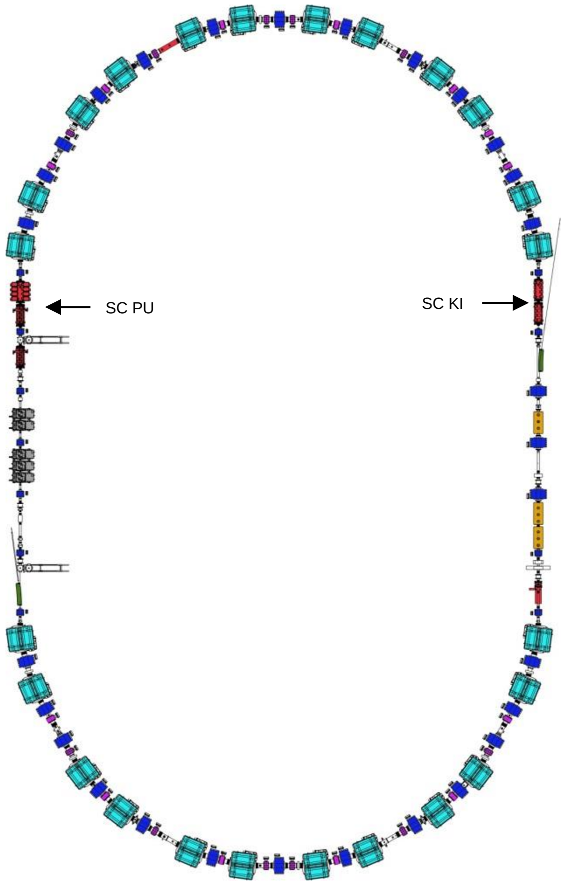
Quadrupole ramping

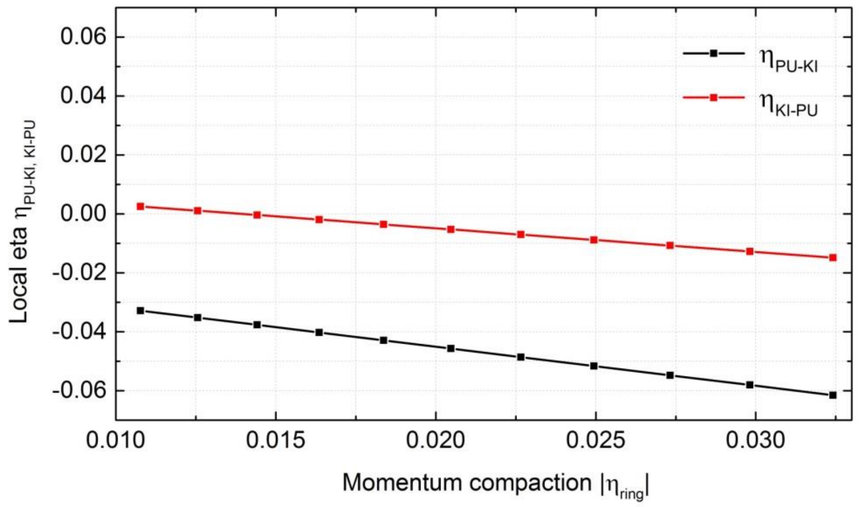


Variation of lattice parameters

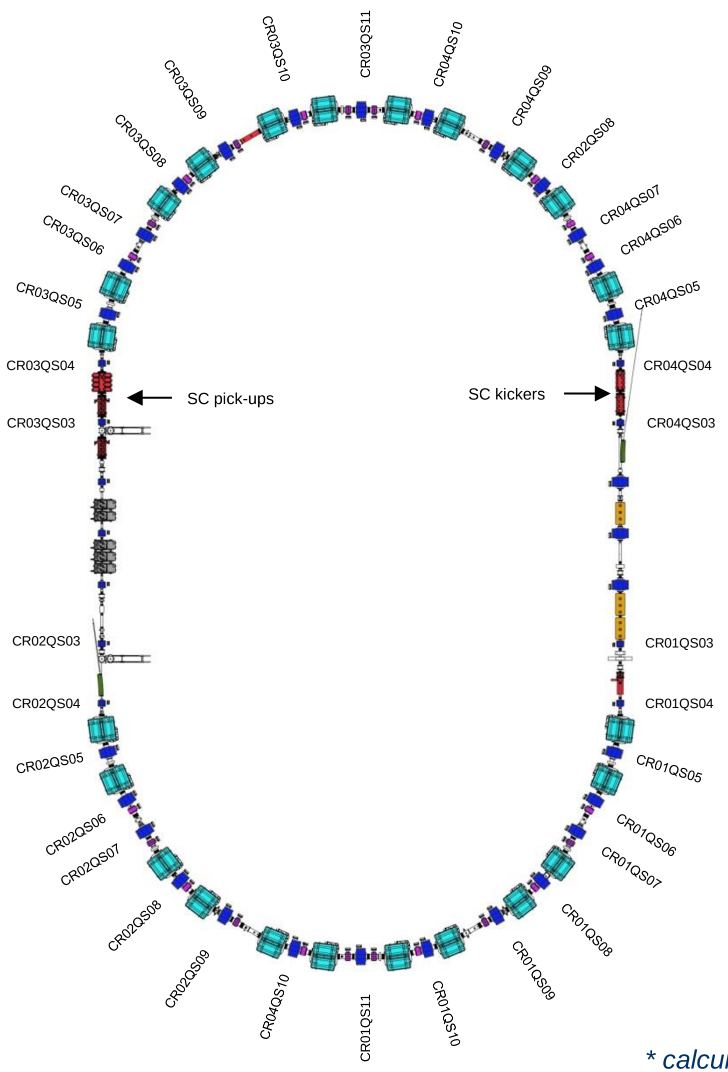


Local η variation (GSI optics)



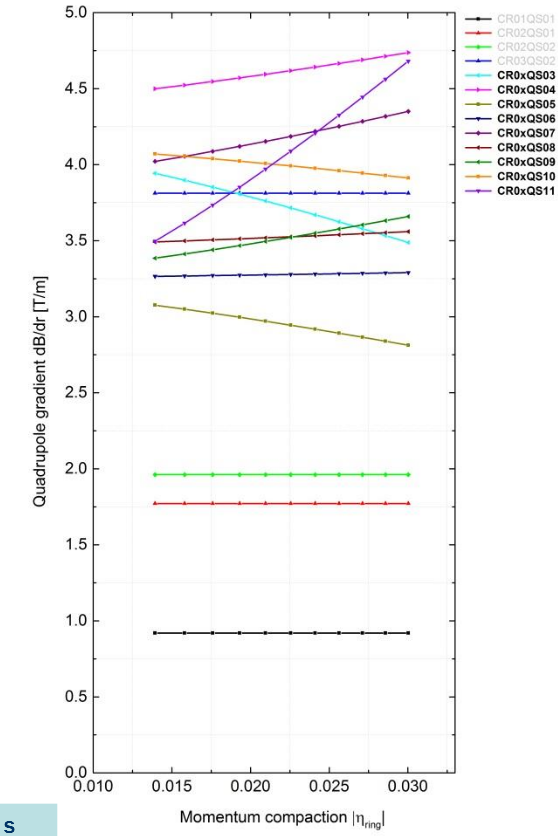


γ_{tr} variation (BINP optics)



- 9 families of quads are used.
- Phase advance $\Delta\mu = \pi/2$ between SC pick-ups and kickers is controlled during ramping.
- Betatron tunes Qx,Qy are constant during ramping to avoid cross of resonances.
- Dispersion Dx=0 in the straight sections is adjusted during ramping.

Quadrupole ramping

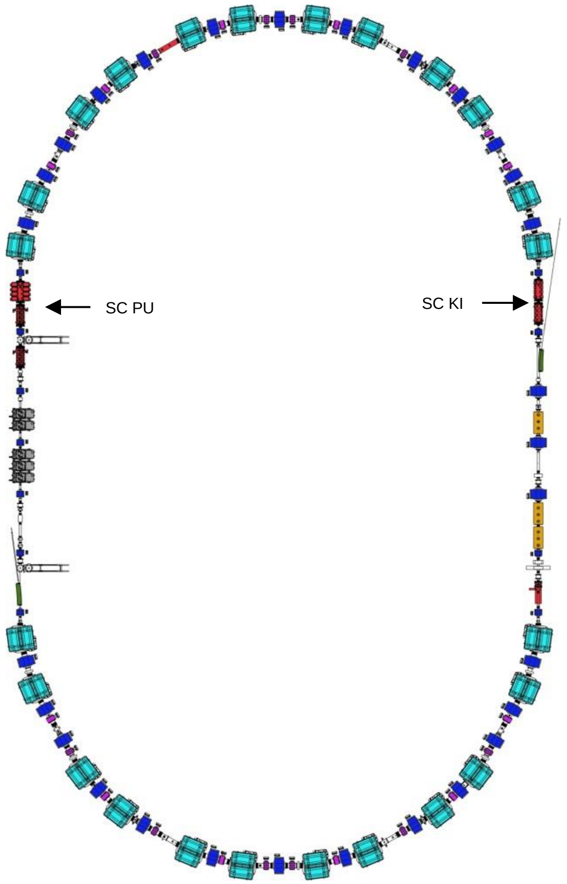


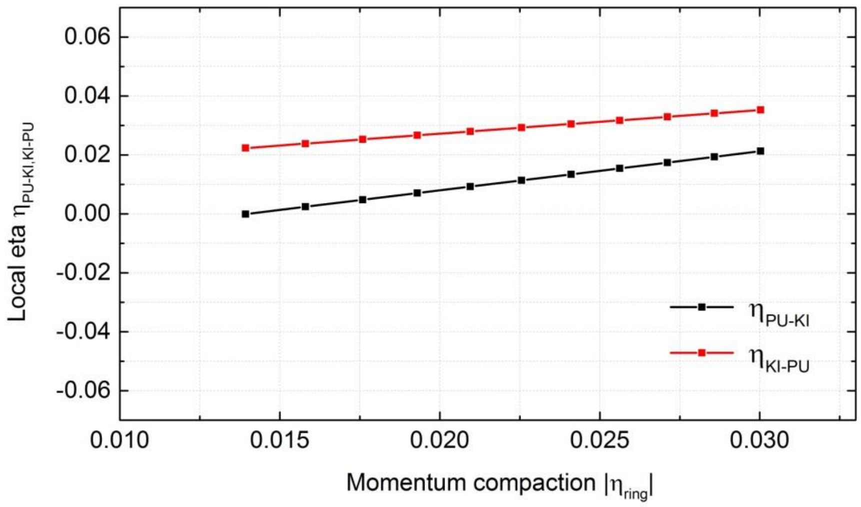
Required ramp rate:

Ramping time	10 s	8 s	5 s	3 s
Max. gradient rate, T/m/s, WQ	0.12	0.15	0.24	0.4
Max. gradient rate, T/m/s, NQ	0.04	0.05	0.08	0.13

** calculations by S. Litvinov*

Local η variation (BINP optics)



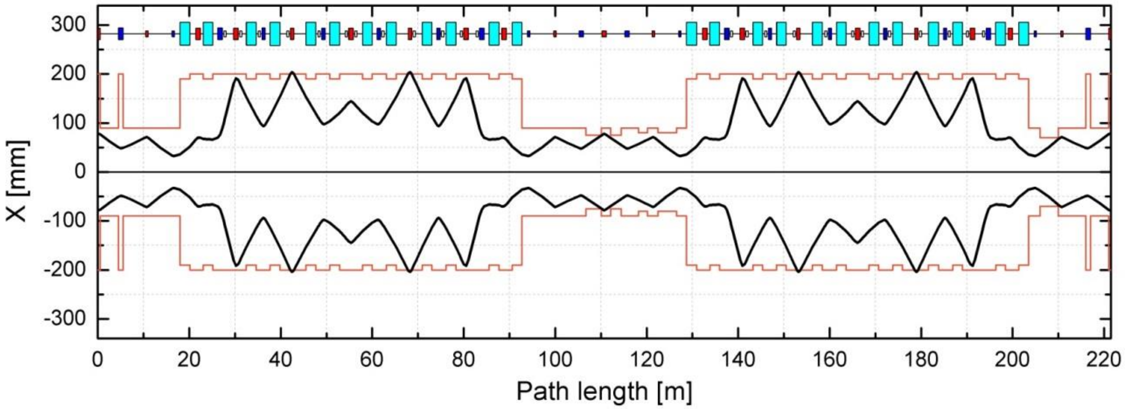


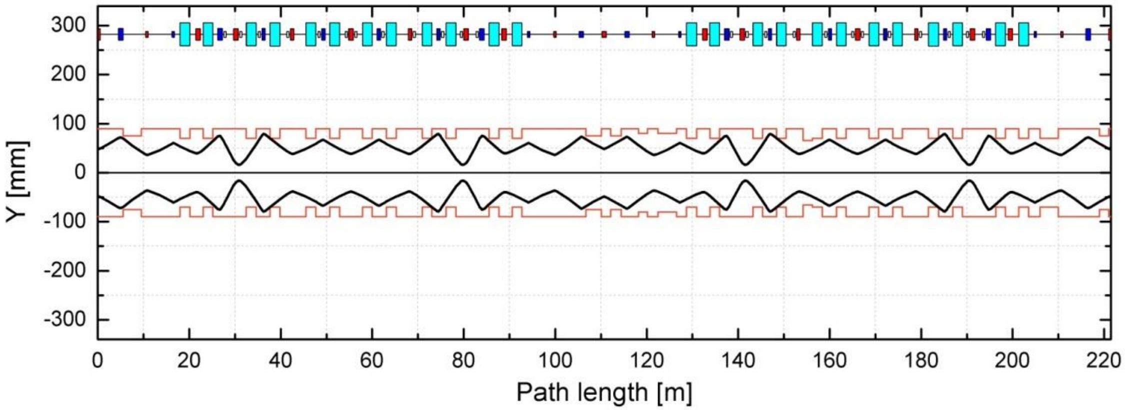
** calculations by S. Litvinov*

Short summary

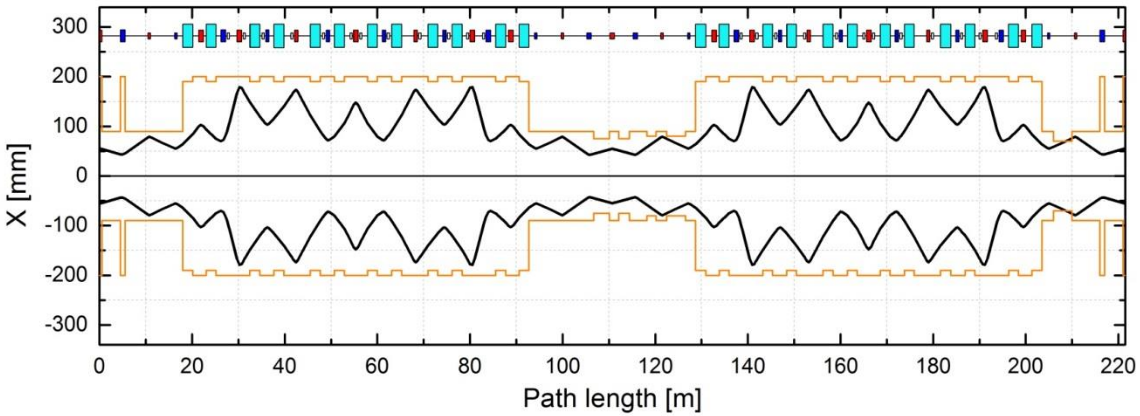
- Momentum compaction can be varied in range of $0.011 \le |\eta| \le 0.33$ in both GSI and BINP pbar-optics.
- Control parameters during ramping:
  - phase advance between SC PU and KI,
  - betatron tunes,
  - dispersion in the straight sections.
- Quadrupole current limits have to be taken into account.
- Calculations for latest ion-optics.

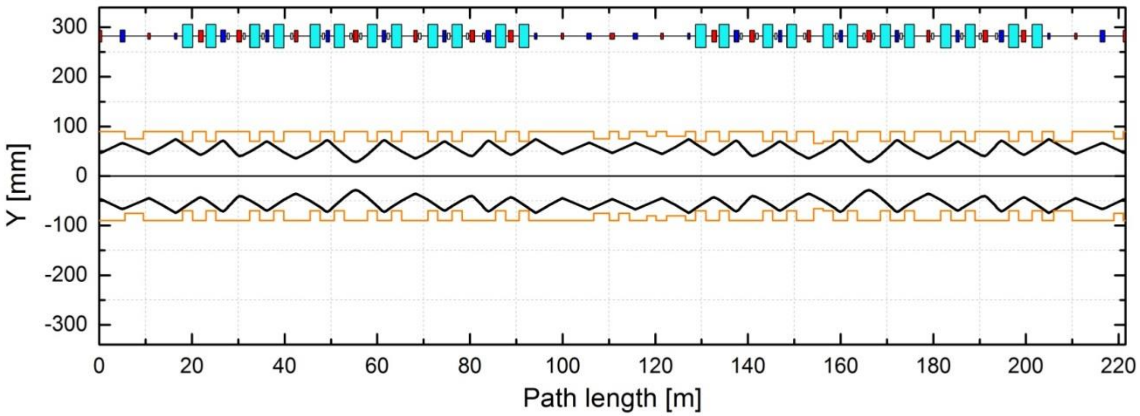
Beam envelopes (GSI)





Beam envelopes (BINP)





Local eta variation