COOL'07
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Lattice Considerations for the Collector and the Accumulator Ring of the FAIR Project

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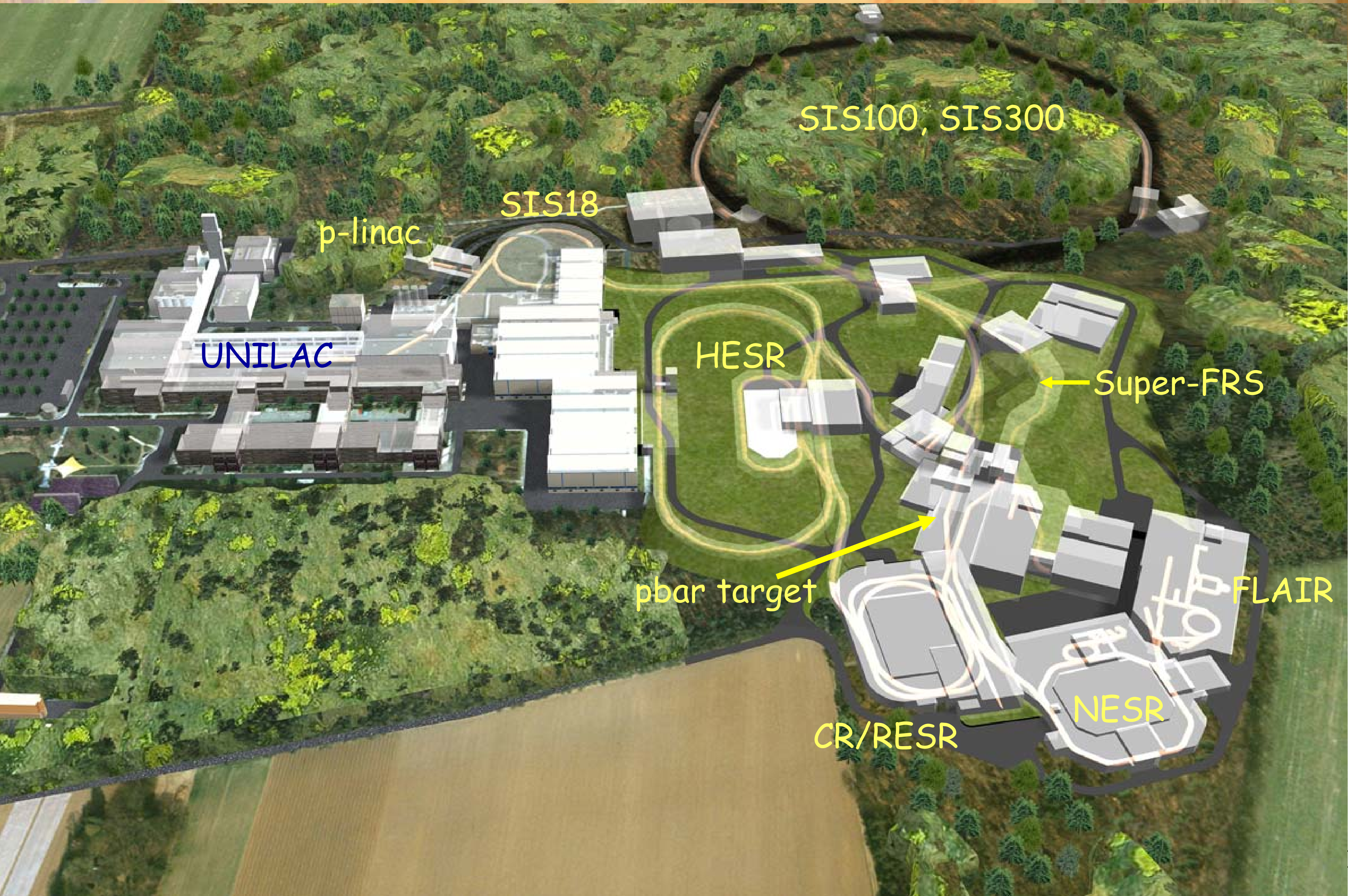
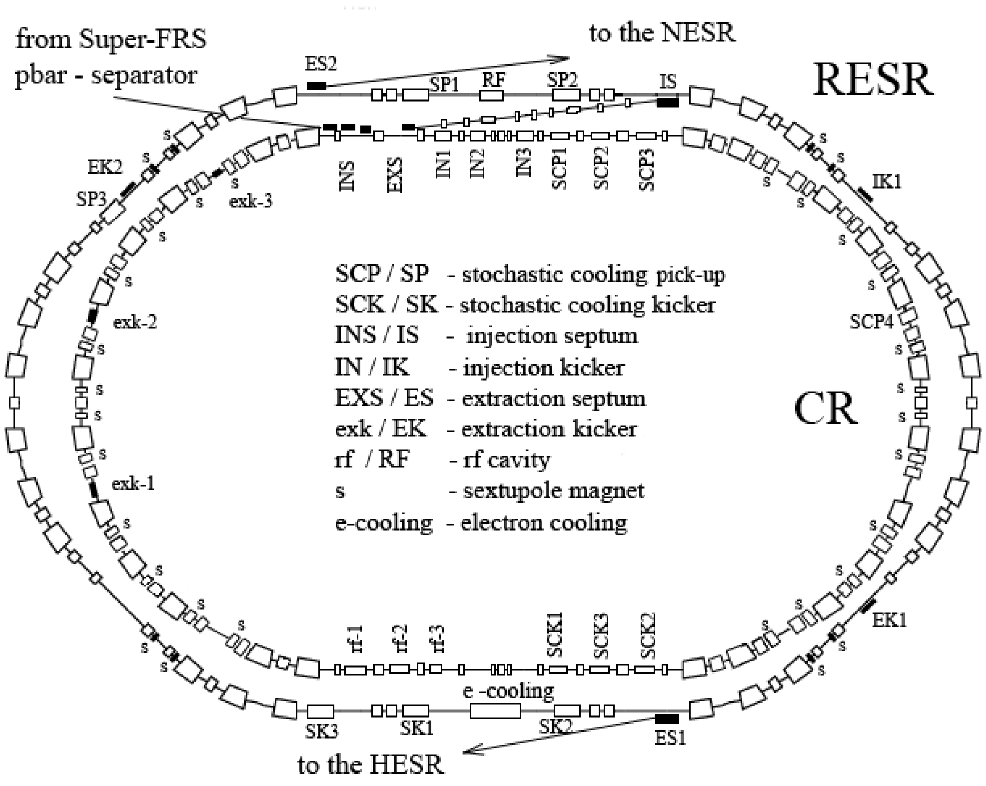
FAIR Facility for RIBs and pbars



Collector and Accumulator Ring



CR – Collector Ring

- fast pre-cooling of the hot ion beams

RESR – Recycled Experimental Storage Ring

- accumulation of antiproton beams
- fast deceleration of rare isotopes

Stochastic cooling technique will be installed in both rings.

Stochastic Cooling

transverse cooling rate $$\frac{1}{\tau} = \frac{W}{2N}\left[2gB - g^2(M+U)\right]$$

undesired mixing $$B = \cos\left(m_c k \eta_{pk} \frac{\delta p}{p}\right)$$

$$M = \left(m_c \eta_{kp} \frac{\delta p}{p}\right)^{-1}$$ desired mixing

$$\eta = \left|\frac{1}{\gamma^2} - \alpha_p\right|$$

$$\alpha_p = \frac{1}{\gamma_{tr}^2} = \frac{1}{C}\oint \frac{D(s)}{\rho} ds$$

$\alpha_p = 1/\gamma^2_{tr}$

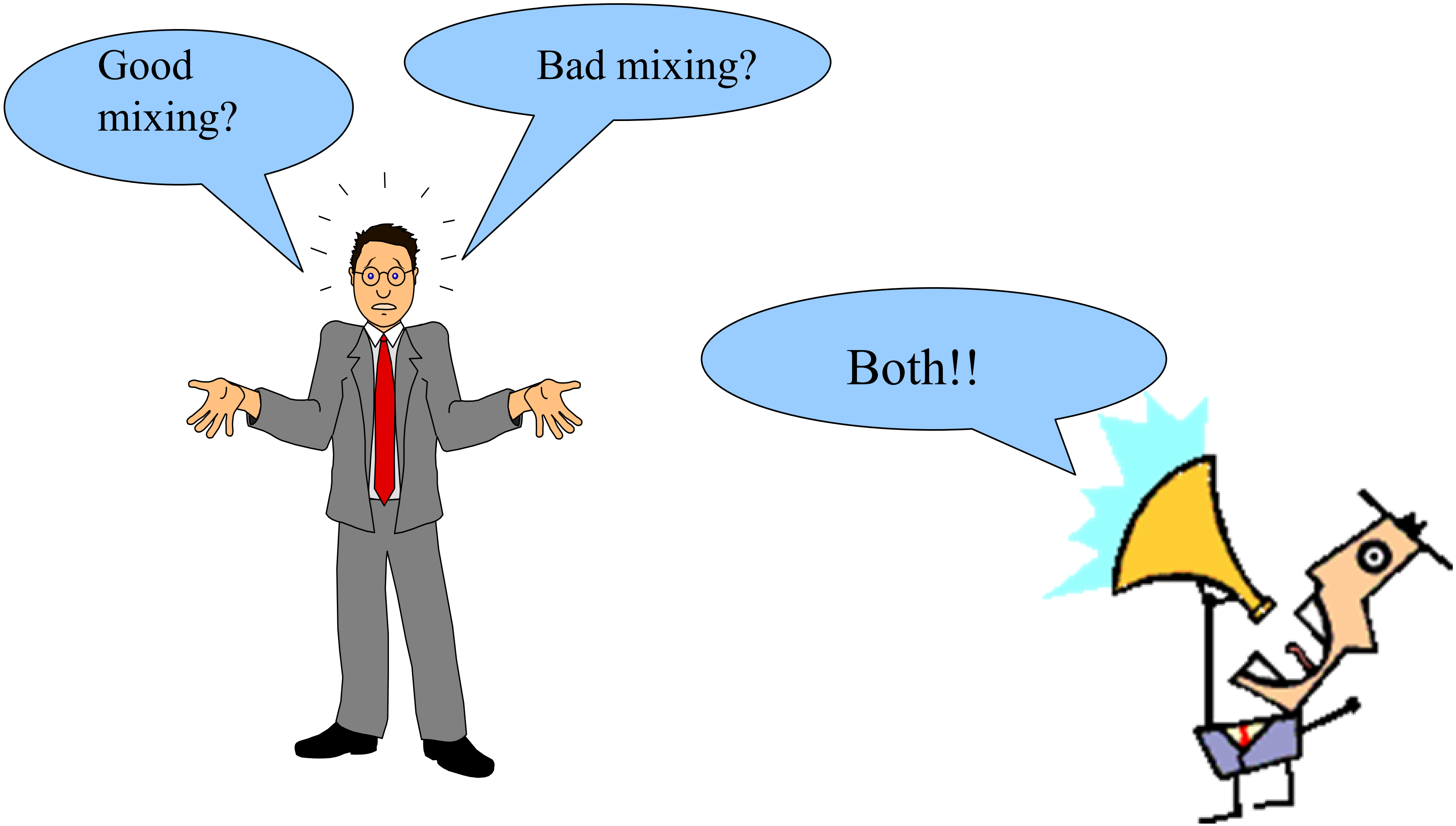
D(s) - dispersion function of the ring

γ - Lorentz factor

$\gamma_{tr} \approx \gamma$ for bad mixing

γ_{tr} >> or << γ for good mixing

The mixing dilemma



Ring layout for stochastic cooling

Split ring :

- one arc with local $\gamma_{tr} \approx \gamma$
- another arc with:

  a) high local $\gamma_{tr} \gg \gamma$

  b) very low local $\gamma_{tr} \ll \gamma$

  (There is idea to have even imaginary γ_{tr} (Senichev's lattice of the HESR). But the ring lattice must follow certain additional requirements (arc. periodicity, number dipoles, phase advance, high dispersion?

  Advantages: high dynamic aperture after chromaticity correction, good mixing , flexibility to get optimal γ_{tr} with respect to the S.C. and optical ring properties, increasing the micro-wave stability threshold).

Symmetric ring: one has to find optimal γ_{tr} to have effective stochastic cooling (see talk given by F. Nolden)

Collector Ring: CR

The CR must be operated at static magnetic field corresponding to BR=13 Tm

1. Cooling of secondary beams of radioactive ions (RI)

Initial RI beam
$\varepsilon_{\perp}$=200 mm mrad
$\Delta p/p$=3 %

From Super-FRS → CR (1 sec) → to the RESR

Final RI beam
$\varepsilon_{\perp} \leq 0.5$ mm mrad
$\Delta p/p \leq 0.05$ %

2. Cooling of antiproton beams (Pbar)

Initial antiproton beam
$\varepsilon_{\perp}$ =240 mm mrad
$\Delta p/p$=6 %

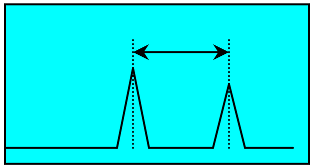
From antiproton separator → CR (5 sec) → to the RESR

Final Pbar parameters
$\varepsilon_{\perp} \leq 5$ mm mrad
$\Delta p/p \leq 0.1$ %

3. Mass spectrometer of radioactive ions RI (TOF)

RI beam
$\varepsilon_{\perp}$ =100 mm mrad
$\Delta p/p$=1 %

From Super-FRS → CR (few turns)

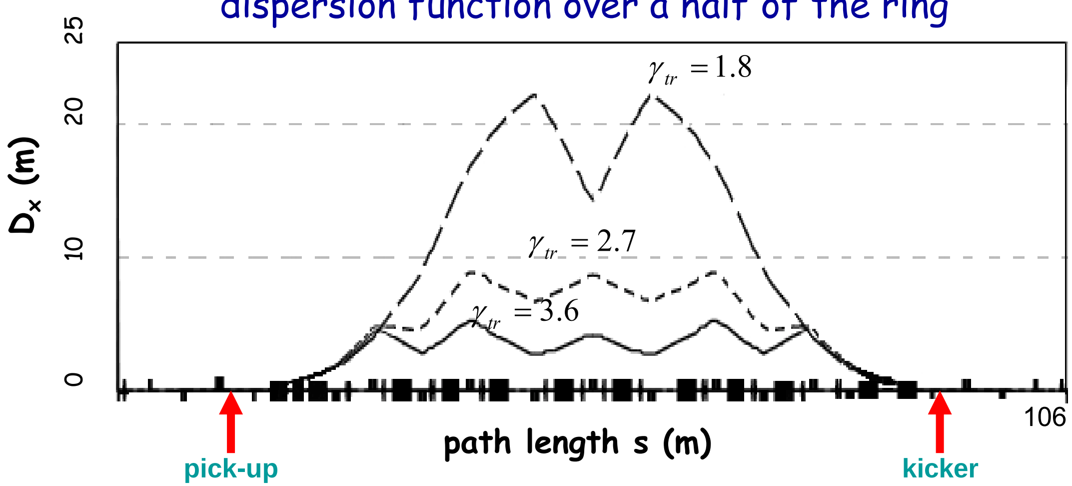


$$\frac{\Delta m}{m} = \gamma_{tr}^{2} \frac{\Delta f}{f}$$

CR: Requirements to the ring optic

* Three operation mode require three different ion optics of the ring
* Phase advance between pick-ups and kickers for stochastic cooling must be quantum number $\Delta\mu \approx \pi(2n+1)/2$
* One has to control phase advances between inj./extr. devices
* Chromatic correction in all mode operation
* The dispersion free straight sections in all mode operation
* One needs 12 quadrupole and 7 sextupole families in order to have flexibility in optic variation and chromatic correction.

dispersion function over a half of the ring



Three mode operation

(optimal γ_{tr} for symmetric ring)

Isochronous mode (γ_{tr} =1.8, γ=1.8)

Rib mode (γ_{tr} =2.7, γ=1.8)

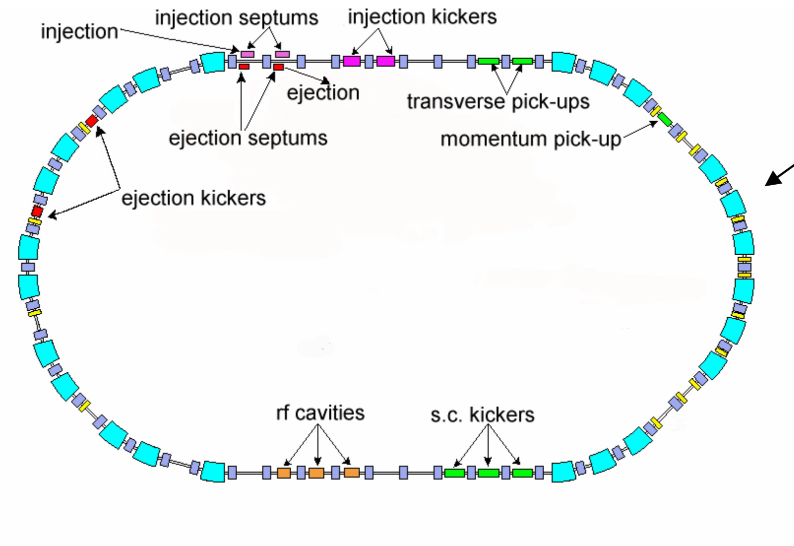
Pbar mode (γ_{tr}=3.6, γ=4.2)

CR: Split ring

Arc with a strong focusing

(Local γ_{tr} = 5.9 > γ = $(1.8)_{RIB,}$

γ = $(4.2)_{pbar}$



Arc with a weak focusing

(Local γ_{tr} = $(2.3)_{RIB}$

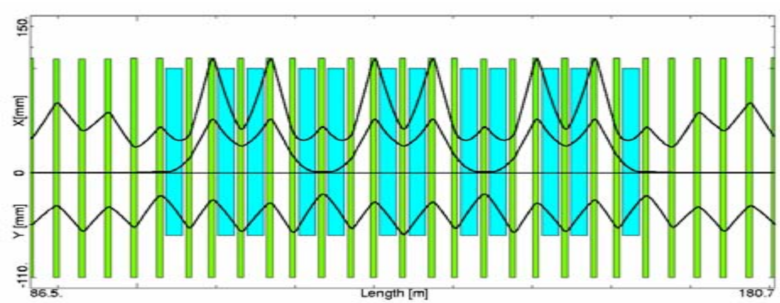
γ =$(1.8)_{RIB}$

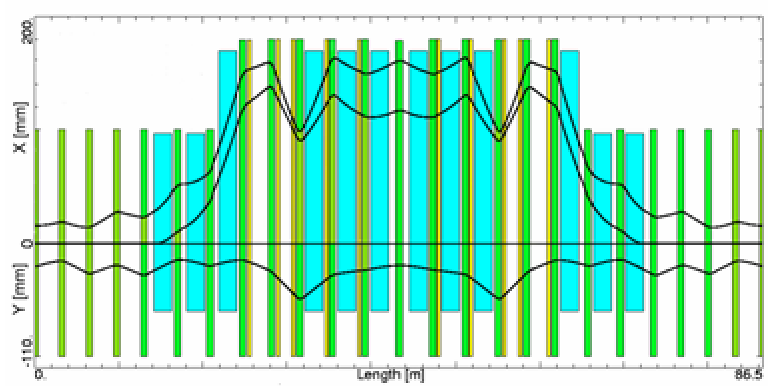
γ_{tr}= $(3.93)_{pbar}$

γ =$(4.20)_{pbar}$

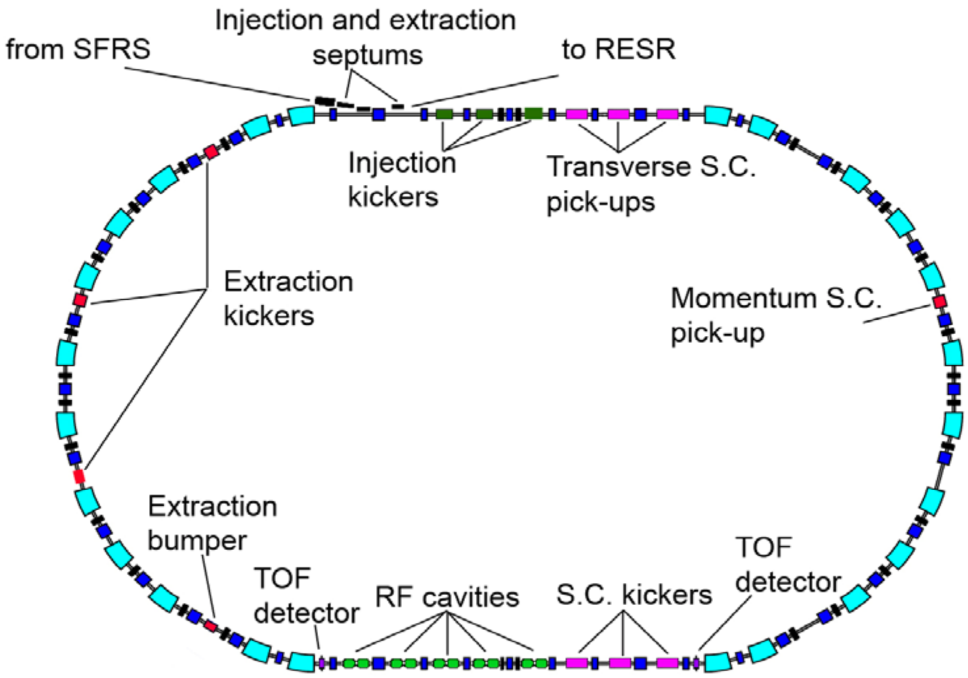
Large average dispersion function

Low average dispersion function





CR: Symmetric ring



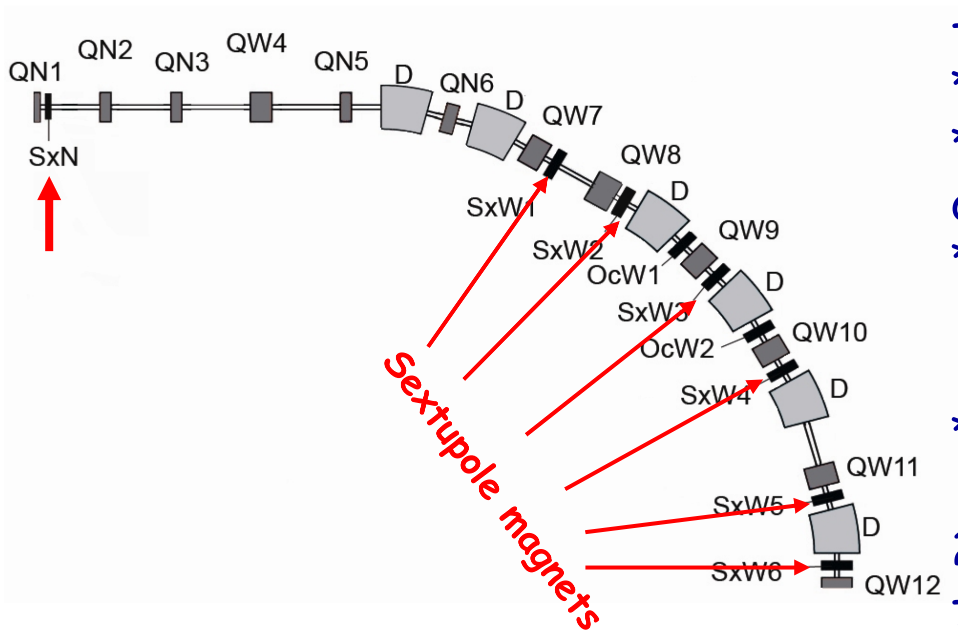
Optimal gamma-tr

$\gamma_{tr} = 3.6$ *for pbar optic, where* $\gamma = (4.2)_{pbar,}$

$\gamma_{tr} = 2.7$ *for RIB optic,* $\gamma = (1.8)_{RIB}$

$\gamma_{tr} = 1.8$ *for Isochronous mode,* $\gamma = (1.8)$

CR: Chromatic correction



7 independently powered sextupole families are needed for

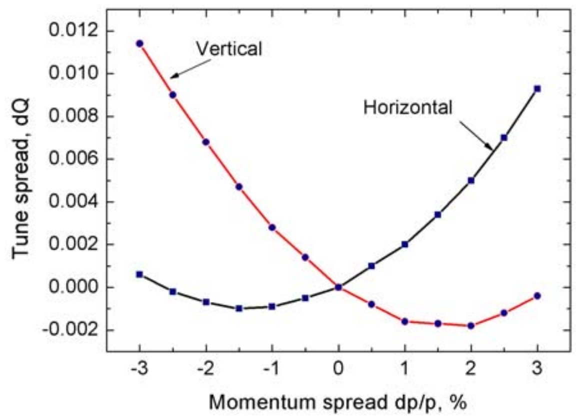
* Chromaticity correction
* Control of the dispersion function over full momentum range (-3% +3%)
* Control chromaticity (as low as possible over full momentum range (-3% +3%)
* Avoiding synchrobetatron coupling

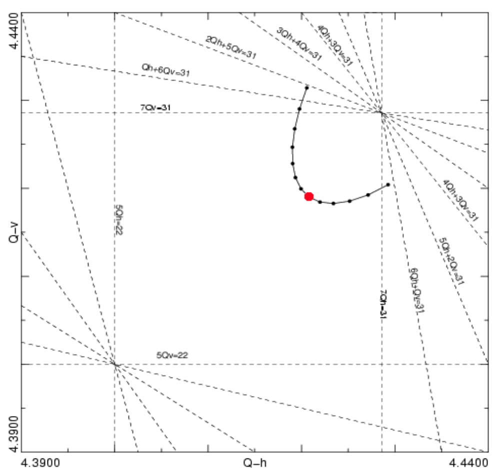
2 families of the octupole correctors for minimizing of the fringe field influence in the isochronous mode operation

CR: Chromatic correction

Antiproton mode

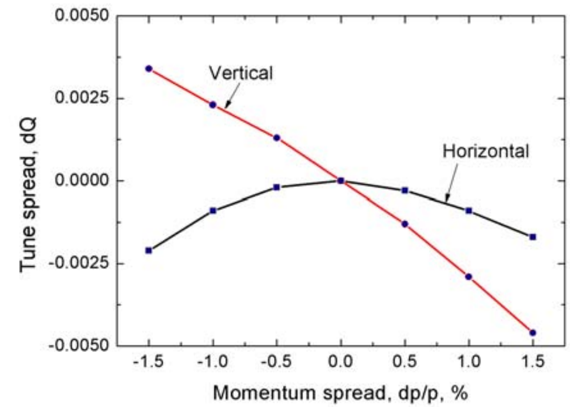
$\Delta Q_{h,v} \approx 0.014$

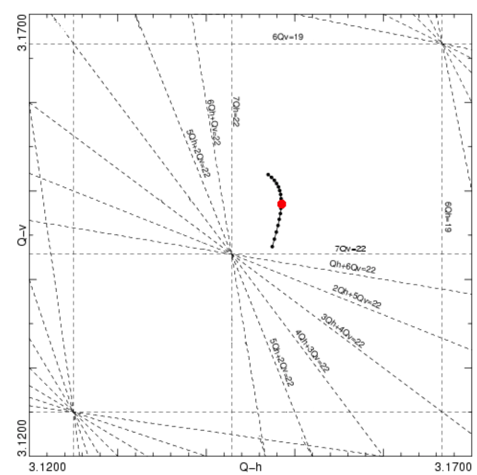




Radioactive Ion mode

$\Delta Q_{h,v} \approx 0.009$

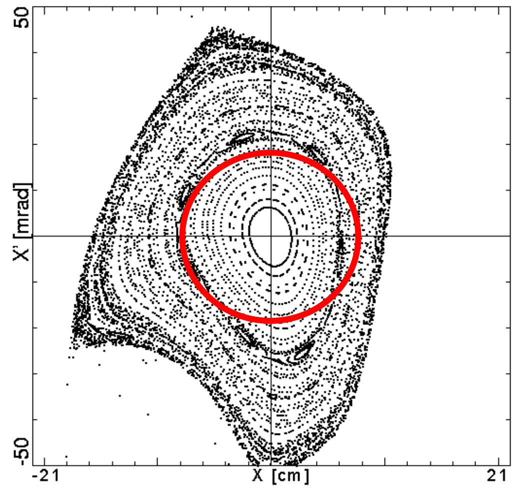


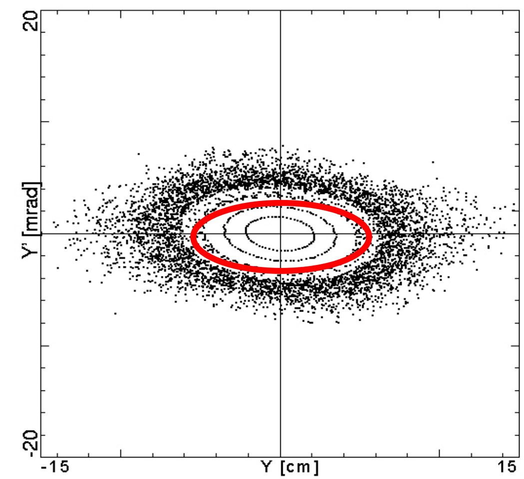


CR: Dynamic aperture with only chromaticity sextupoles

Split ring:

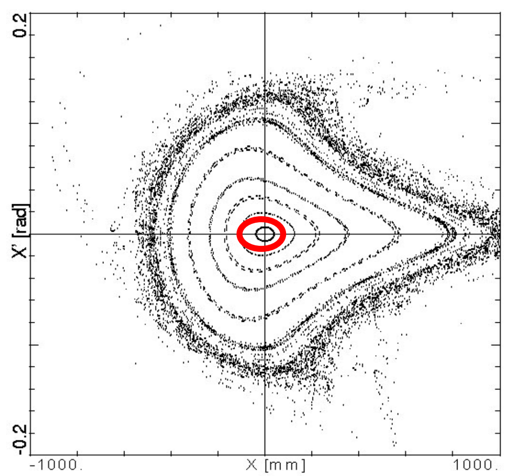
RIB optic

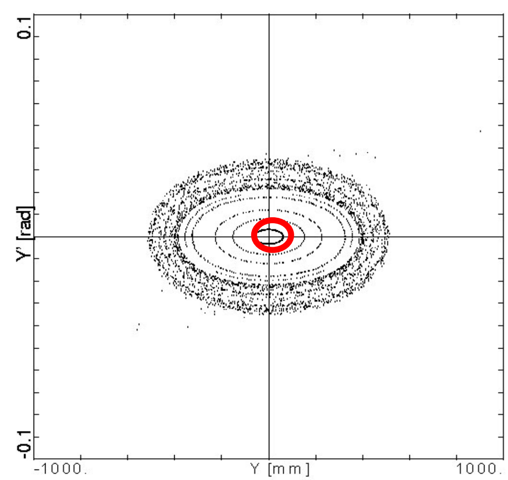




Symmetric ring:

RIB optic

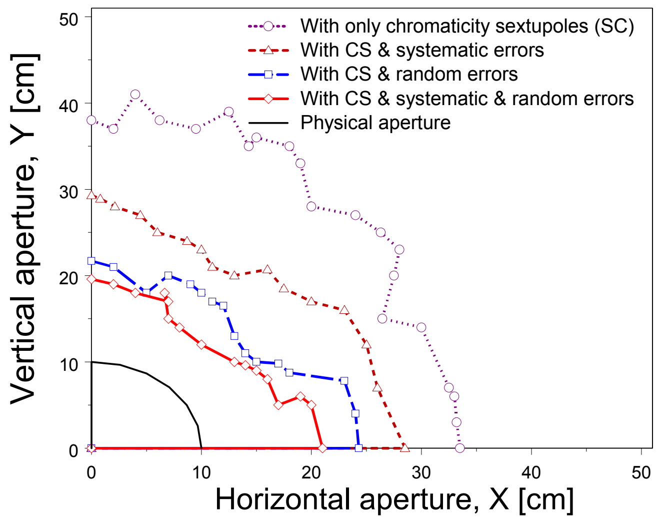




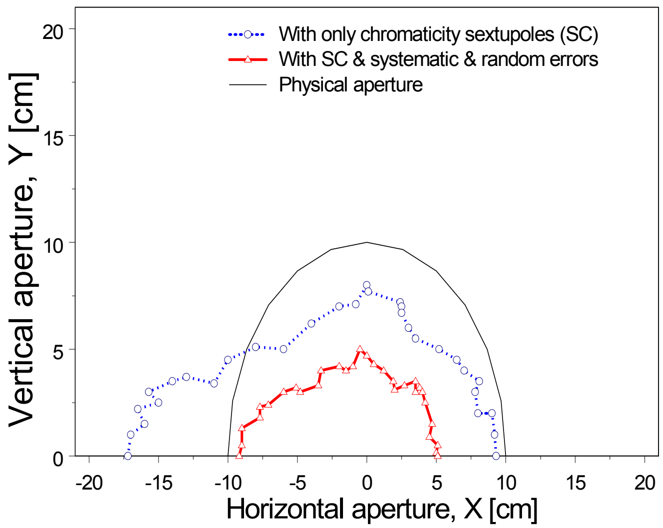
CR: Dynamic aperture

Dynamic aperture with field imper. up 9th order : MAD simulation (Turns=1000)

CR optic for RIB's (Δp/p=0)



Symmetric ring



Split ring

A. Dolinskii, P. Beller , M. K.Beckert, B. Franzke, F. Nolden M. Steck , Optimized lattice for the Collector Ring (CR), **NIMA 532 (2004) 483**

CR: Dynamic aperture

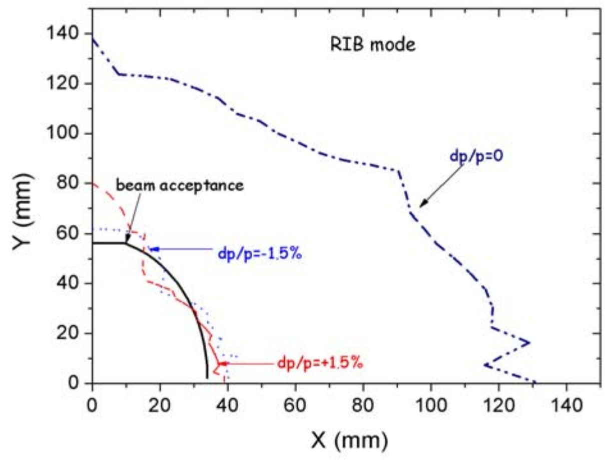
Particle tracking: 1000 turns

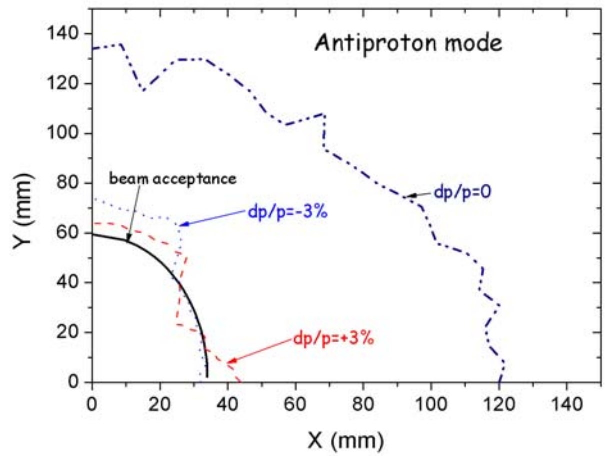
Dynamic aperture with field imperfection up 9th order

Fringe field effect of quadrupole magnets is included

The relative multipole errors of the CR magnets, unit x 10^{-4}

	Dipole (r=70 mm)	Quadrupole (r=200 mm)
1	10^4	0
2	0.0334	10^4
3	-3.553	0
4	-0.1302	-0.203
5	-0.854	0
6	0.1322	-1.482
7	0.0197	0
8	-0.0839	-0.0095
9	-0.04224	0
10	0.1171	0.752

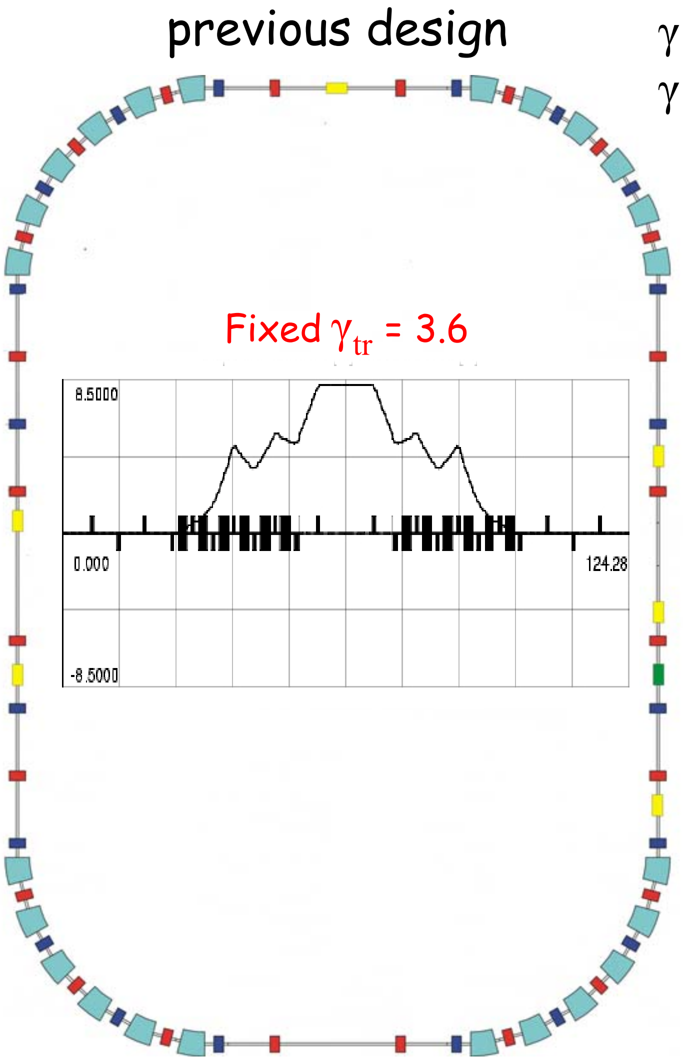


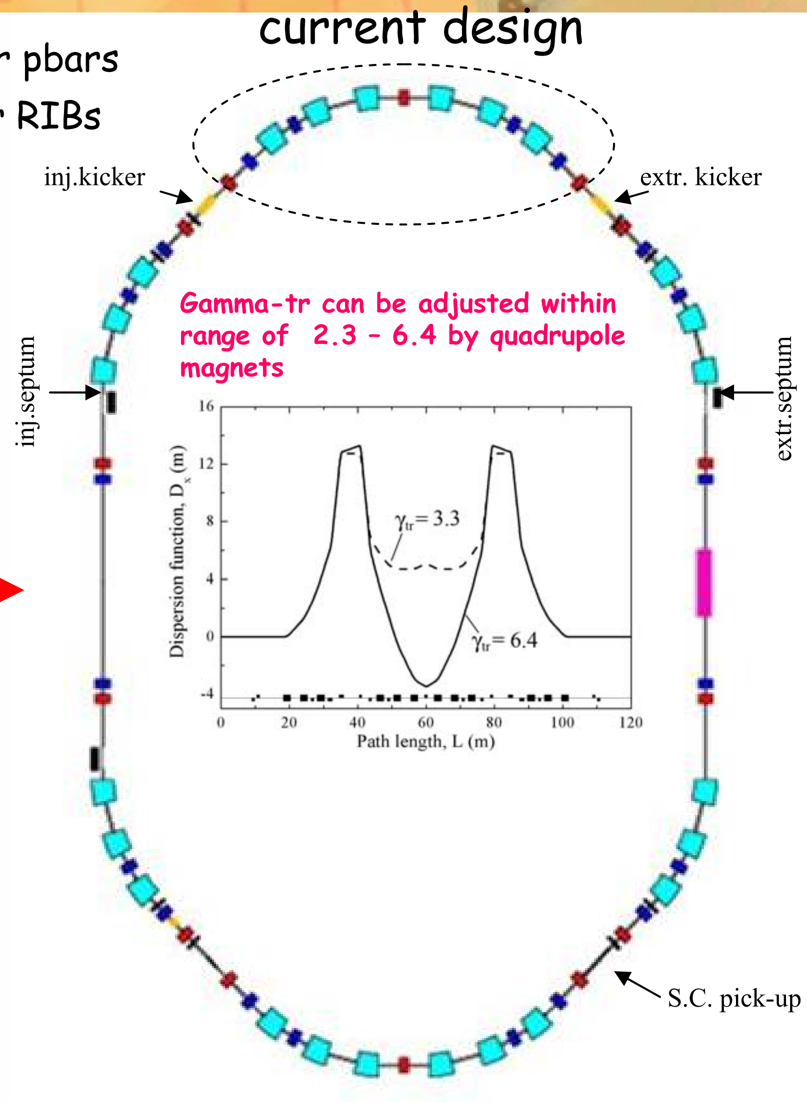


RESR lattice

γ = 4.2 for pbars

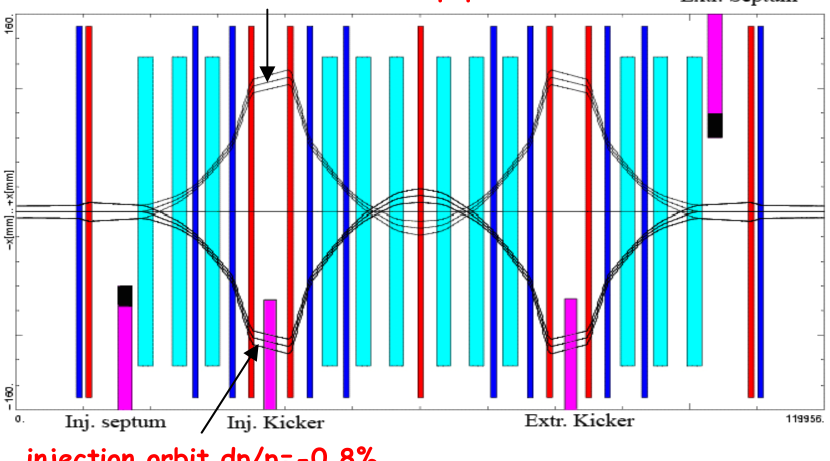
γ = 1.8 for RIBs



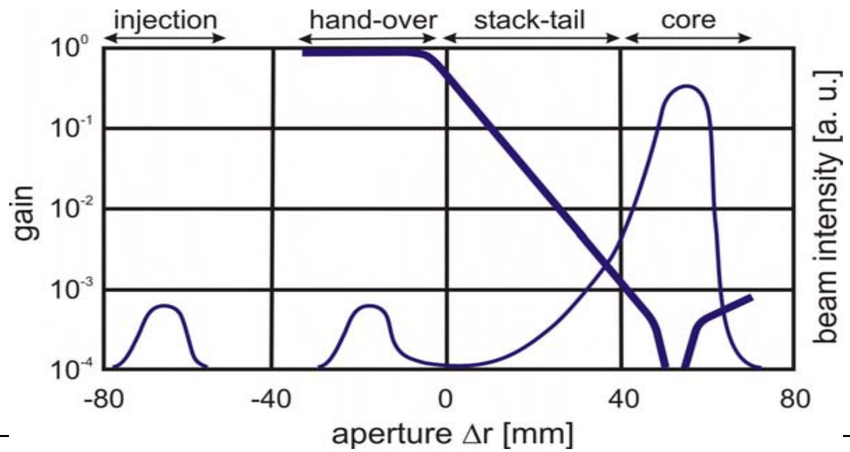


RESR
Stochastic Cooling, Accumulation Scheme

- **Two transverse cooling systems (horizontal, vertical)**
- **Three longitudinal systems (hand-over system, stack-tail system, stack-core system)**

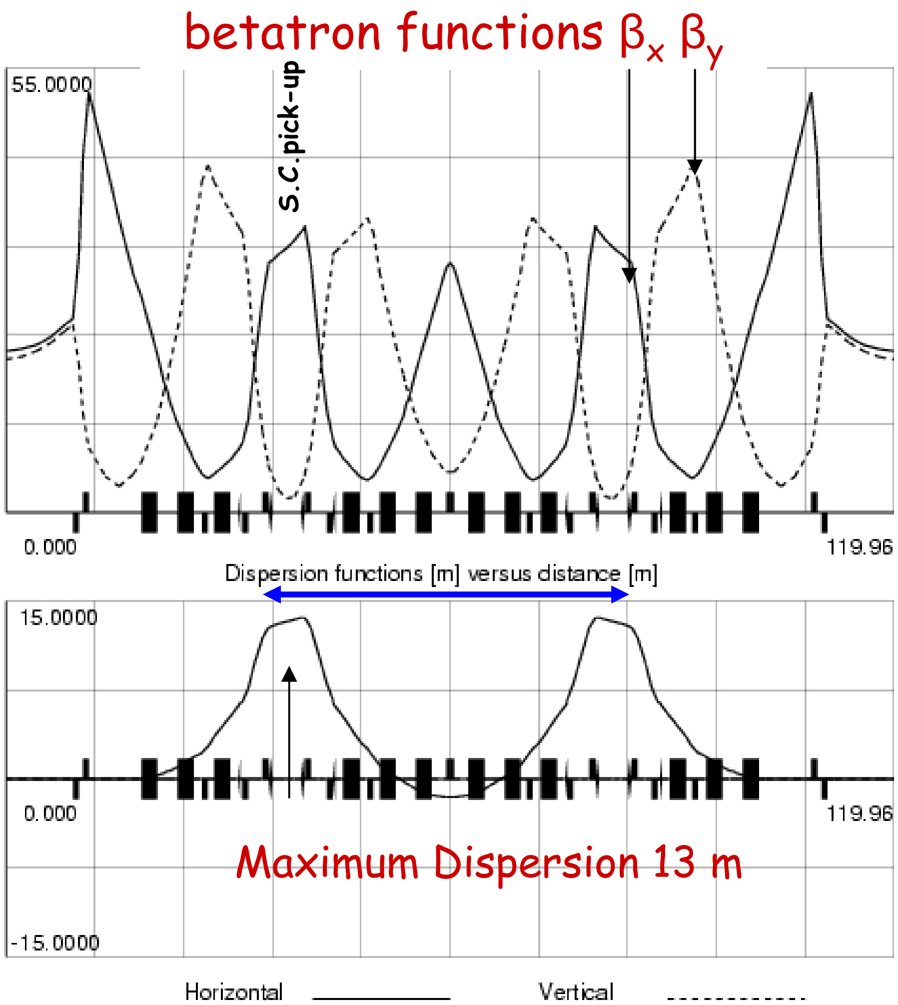


Accumulation rate 3.5 x 10^{10} h^{-1}
Accumulation time 3.5 h
Number of particles 10^{11}



Pick-up gain profile (Palmer) and distribution function

RESR: Lattice functions



- The lattice enables a flexible choice of the γ_{tr} from 2.3 up to 6.4 by quadrupoles adjustment, while betatron tunes remain unchanged.
- This feature gives possibility even to ramp quadrupoles during cooling in order to have an optimal value of γ_{tr} depending on the momentum width.
- Straight sections with a large dispersion and small vertical beta-function
- Good properties with respect to the injection/extraction procedures
- Deceleration of RIBs or antiprotons is simplified due to injection always below transition energy.
- In this layout one can implement also a split-ring optic

RESR: Beam Parameters

Antiproton beam (pre-cooled in the CR)

Injection energy	3 GeV
Momentum spread (2σ)	< ±0.1 %
Horizontal emittance (2σ)	< 5 mm mrad
Vertical emittance (2σ)	< 5 mm mrad

Accumulation rate 3.5 x 10^{10} h^{-1}
Accumulation time 3.5 h
Number of particles 10^{11}

RIB Parameters (pre-cooled in the CR)

Injection energy [MeV/u]	740 MeV/u
Extraction energy	100 – 740 MeV/u
Horizontal emittance (2σ)	< 0.5 mm mrad
Vertical emittance (2σ)	< 0.5 mm mrad
Momentum spread (2σ)	< ±0.05 %

Deceleration ramp rate - 1 T/s