Luminosity for *PAX* project

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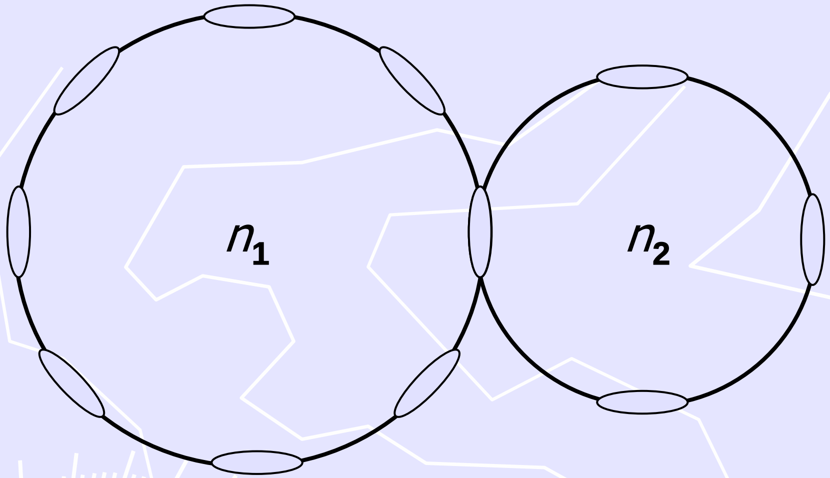
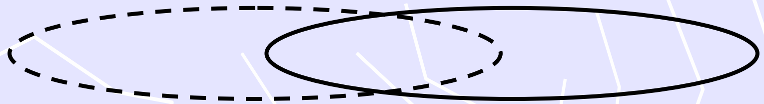
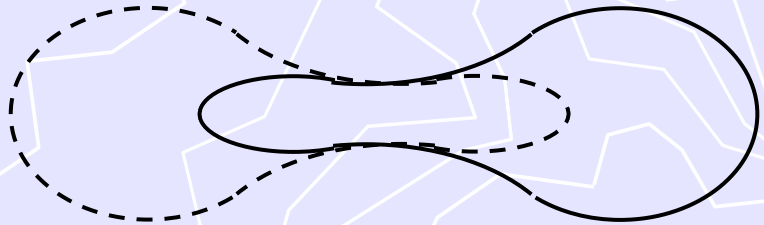
Luminosity for bunch beam



$\beta^* < \sigma_s$



$\beta^* > \sigma_s$ (hourglass effect)

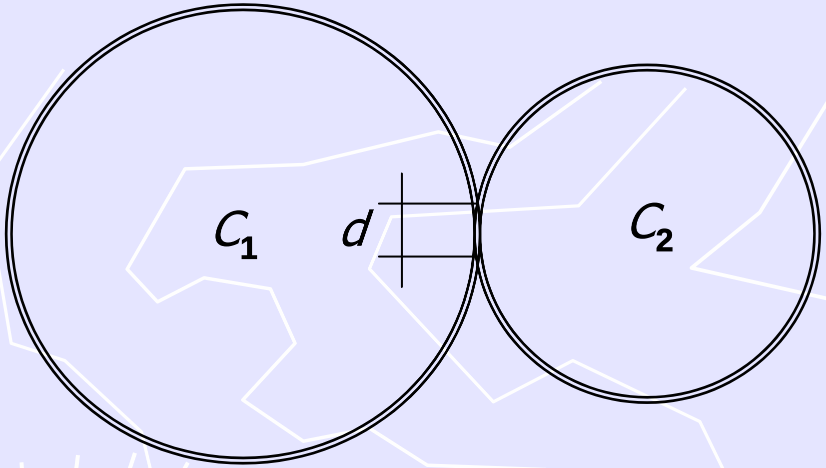


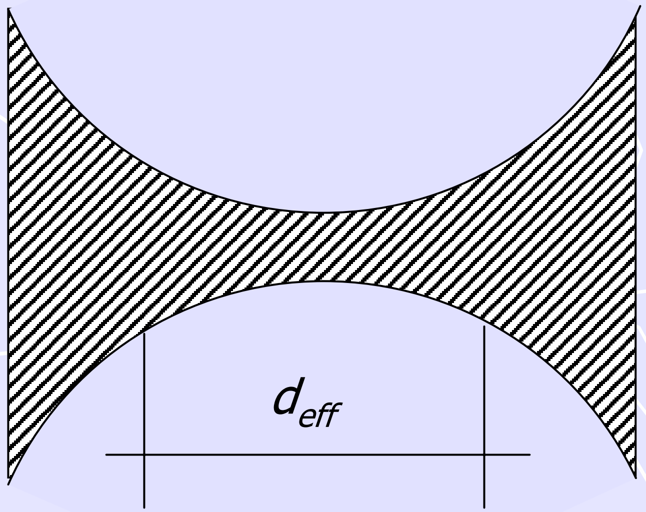
$$L = \frac{N_1 N_2}{2\pi\sqrt{\left(\sigma_{x,1}^2 + \sigma_{x,2}^2\right)\left(\sigma_{y,1}^2 + \sigma_{y,2}^2\right)}} \cdot \frac{f_1}{n_2}$$

N_1 and N_2 – total number of particle, σ – rms beam sizes in collision point, f_1 – revolution frequency in first ring, n_2 – number of bunches in second ring

bunch length less than beta-function at interaction point!

Luminosity for coasting beam





$$L = \frac{N_1 N_2}{2\pi\sqrt{\left(\sigma_{x,1}^2 + \sigma_{x,2}^2\right)\left(\sigma_{y,1}^2 + \sigma_{y,2}^2\right)}} \cdot \frac{f_1 d_{eff}}{C_2}$$

N_1 and N_2 – total number of particle, σ – rms beam sizes in collision point, f_1 – revolution frequency in first ring, C_2 – circumference of second ring, d_{eff} – interaction region

Physical effects defined luminosity

- Intrabeam scattering
- Electron cooling
- Beam-beam effect
- Tune shift
- Particle losses

IBS & ECOOL kicks

IBS kick per one revolution period with Gaussian distribution ξ_{rand}

$$\Delta\theta_j = \frac{\varepsilon_j}{\beta_j}\frac{T_{rev}}{\tau_j}\cdot\xi_{rand} \qquad \frac{1}{\tau} = \frac{N_i r_p^2 c L_C}{8\pi\gamma^4\beta^3\varepsilon_x\varepsilon_y\sigma_s\frac{\Delta P}{P}}\cdot\frac{Z_i^2}{A_i}\cdot I_{lattice}$$

ECOOL kick per one revolution period

$$\Delta\theta_j = \frac{F_j}{m_i c^2\beta^2\gamma} l_{cool} \qquad \vec{F}_{PRF} = \frac{4Z_i^2 e^4 n_e L_C}{m_i}\frac{\vec{V}_i}{\left(V_i^2+\Delta_{e,eff}^2\right)^{3/2}}$$

here index j corresponds to degree of freedoms, $\varepsilon_{x,y}$ – emittances, r_p – proton radius, N_i – ion number, c – light speed, L_C – Coulomb logarithm, Z_i – ion charge state, A_i – atomic number, σ_s – bunch length, $\Delta P/P$ – momentum spread, e – electron charge, $I_{lattice}$ – integral function over lattice structure, m_i – ion mass, l_{cool} – cooler length, V_i – ion relative velocity, Δ_{eff} – electron effective velocity

Space charge limits

beam-beam parameter

$$\xi_{x,y} = \frac{Z_1 Z_2 r_p}{4\pi A_1} \frac{(1+\beta_1\beta_2)}{\gamma_1\beta_1} \cdot \frac{\beta^*_{x2,y2}}{\sigma_{x2,y2}(\sigma_{x2,y2}+\sigma_{y2,x2})} \times \begin{cases} \frac{N_2}{n_2} - bunched \\ \frac{N_2 d}{C} - coasting \end{cases} .$$

tune shift

$$\Delta Q_{x,y} = \frac{Z^2 r_p}{2\pi A \beta^2 \gamma^3 \varepsilon_{x,y}\left(1+\sqrt{\varepsilon_{y,x}/\varepsilon_{x,y}}\right)} \times \begin{cases} \frac{N_1 s}{n_1 \sigma_s} - bunched \\ N_1 - coasting \end{cases}$$

β^* – beta function at colliding point, $\varepsilon_{x,y}$ – horizontal and vertical emittances, σ_s – bunch length, *s* – longitudinal separatrix length

Luminosity via space charge

For PAX experiment we assume $Z_1=Z_2=A_1=A_2=1$, $\beta_1\approx\beta_2\approx1$, $\sigma_{x1}=\sigma_{x2}=\sigma_{y2}=\sigma_{y2}$

Luminosity via beam-beam parameter (bunched and coasting beam)

$$L(\xi)=\frac{f_1\gamma_1}{r_p}\cdot\frac{\xi}{\beta^*}N_1$$

Luminosity via tune shift for bunched

$$L_b(\Delta Q)=\frac{f_1\gamma_1}{r_p}\cdot\frac{\Delta Q}{\beta^*}\cdot\frac{n_1\sigma_s}{n_2 s}N_2$$

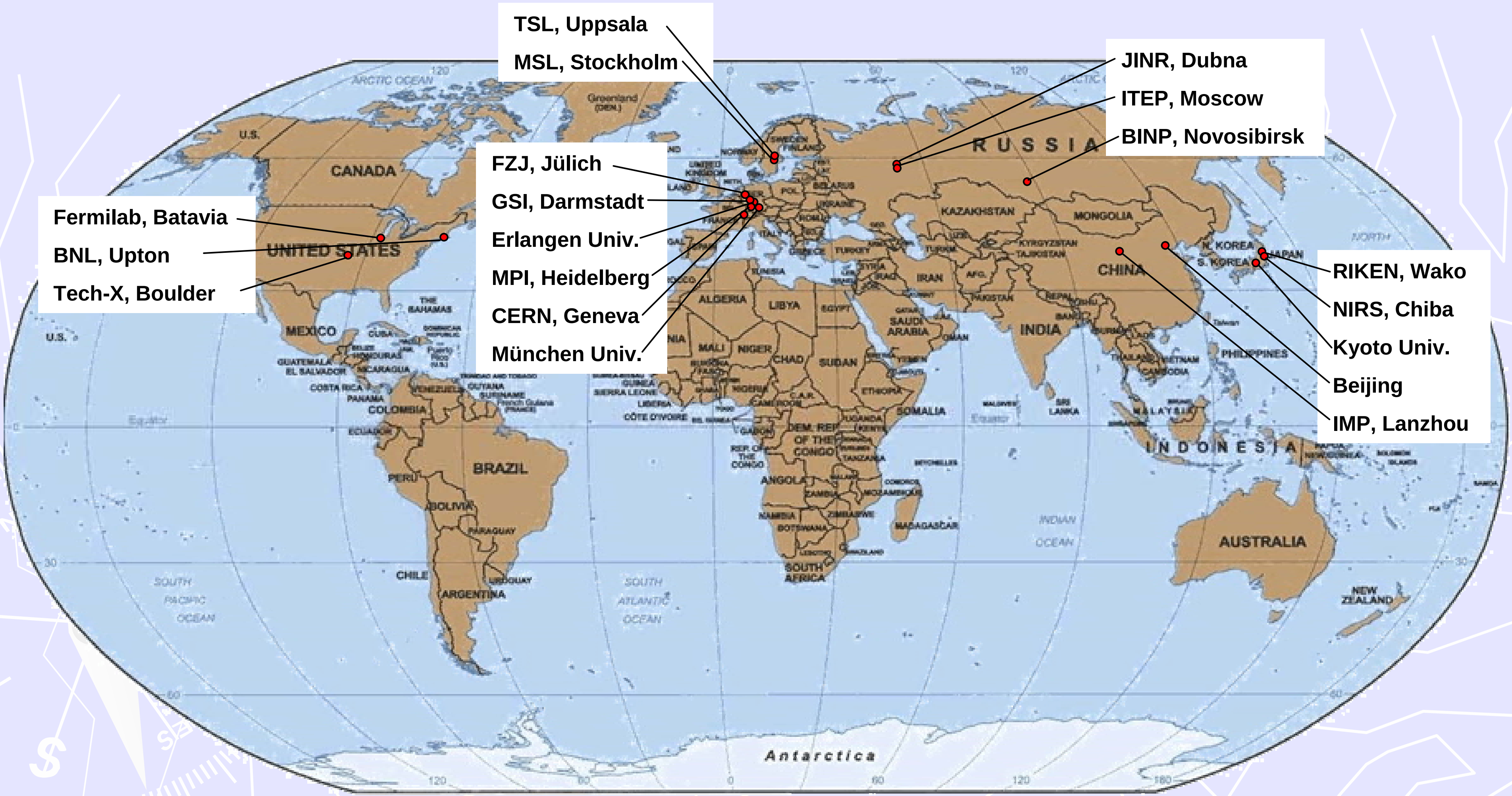
Luminosity via tune shift for coasting

$$L_c(\Delta Q)=\frac{f_1\gamma_1}{r_p}\cdot\frac{\Delta Q}{\beta^*}\cdot\frac{d_1}{C_1}N_2$$

$$\frac{L_b}{L_C}=\frac{n_1\sigma_s}{n_2 s}\cdot\frac{C_1}{d_1}=\frac{10\cdot0.3[\mathrm{m}]}{30\cdot15[\mathrm{m}]}\cdot\frac{150[\mathrm{m}]}{0.5[\mathrm{m}]}=2$$ – for CSR

BETACOOL application over the world

(since 1995)

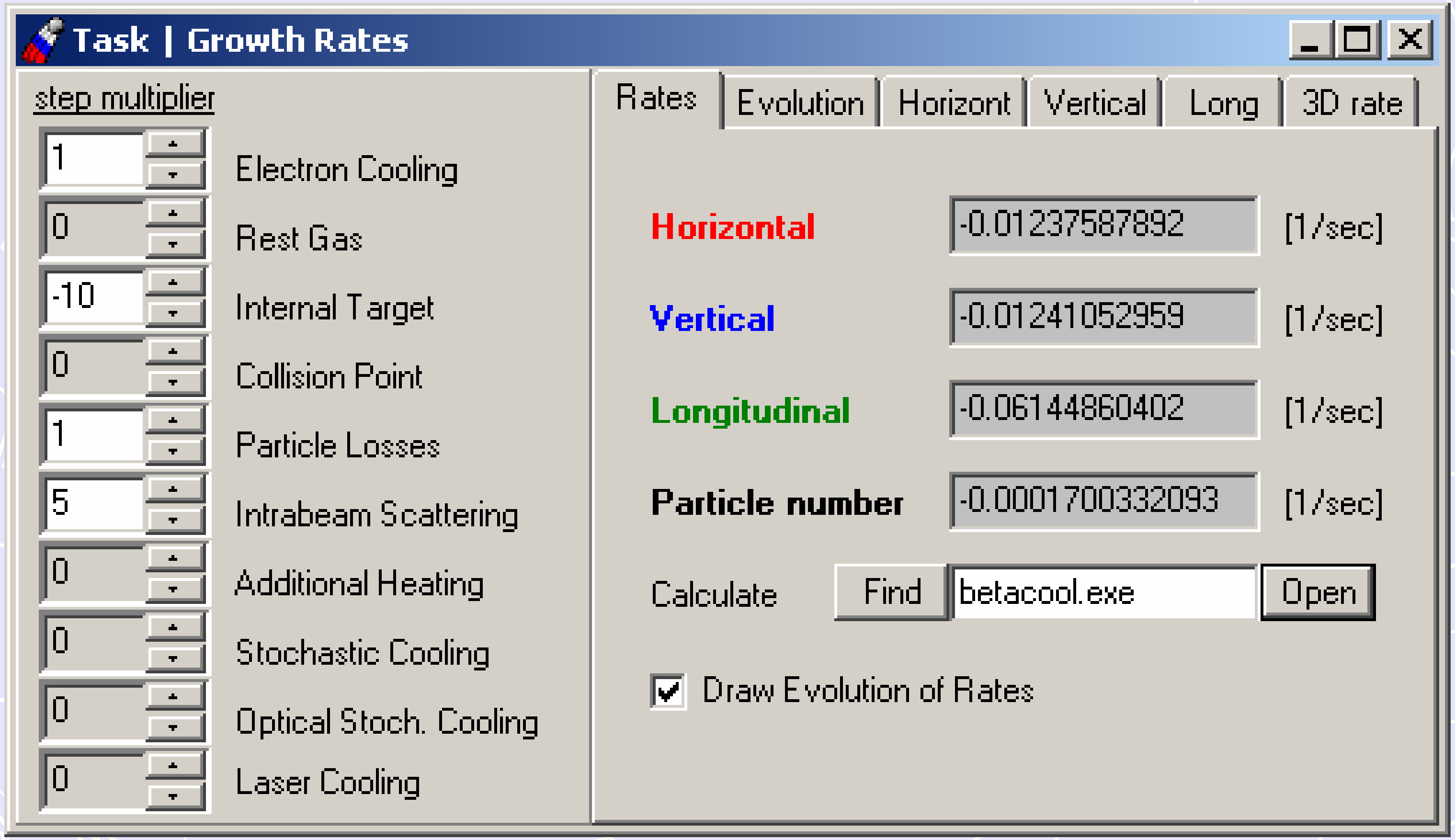


http://lepta.jinr.ru/betacool.htm

BETACOOL assumptions

- General goal of the BETACOOL program is to simulate long term processes (in comparison with the ion revolution period) leading to variation of the ion distribution function in 6 dimensional phase space.
- The ion beam motion inside a storage ring is supposed to be stable and it is treated in linear approximation.
  Ion beam is presented by array of model particles
- Simplest model of the ring – only lattice functions in the location of the effects are necessary.
- Each effect calculates a kick of the ion momentum components and changes the particle number
- One integration step equals some revolution turns

Physical Effects involved in BETACOOL code

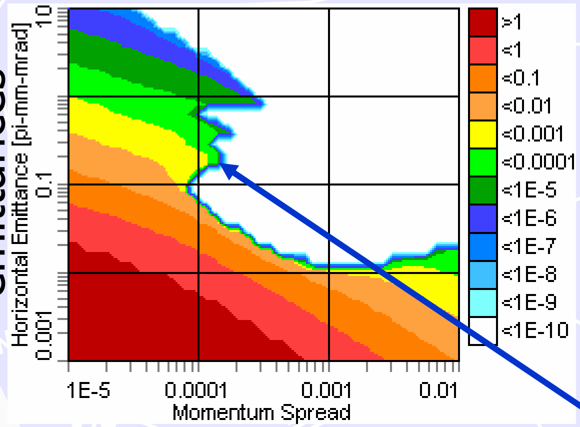


3D Diagrams for HESR

heating and cooling growth rates

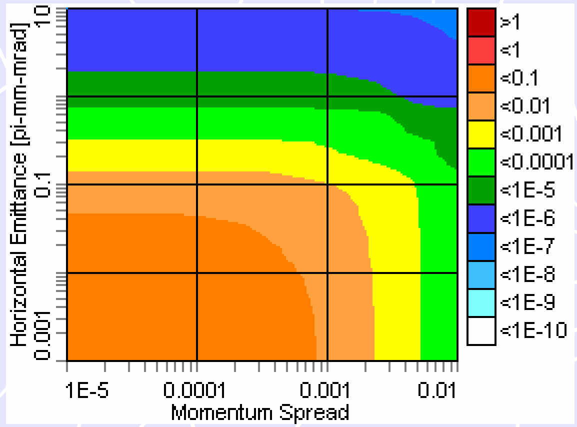
IBS
(positive)

emittances



momentum spread

ECOOL
(negative)



τ_{hor}^{-1}

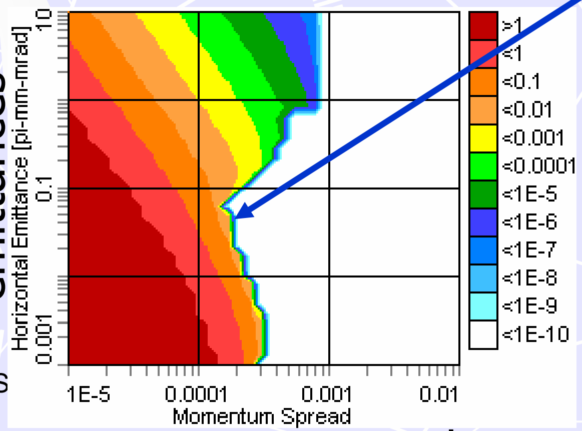
transverse component

Equilibrium between IBS and ECOOL

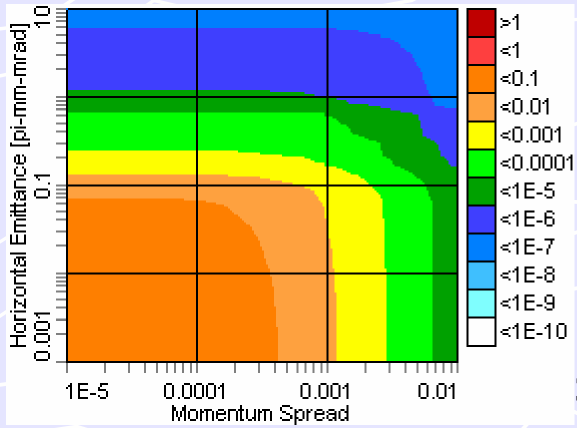
τ_{lon}^{-1}

longitudinal component

emittances



momentum spread



RMS Dynamics for HESR

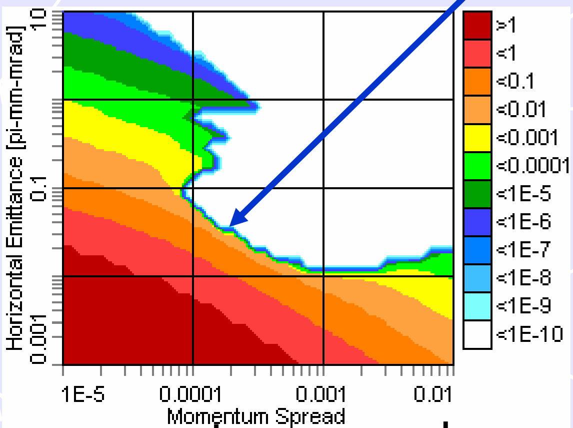
(ECOOL+IBS)

3D Diagrams

Equilibrium point

Beam evolution

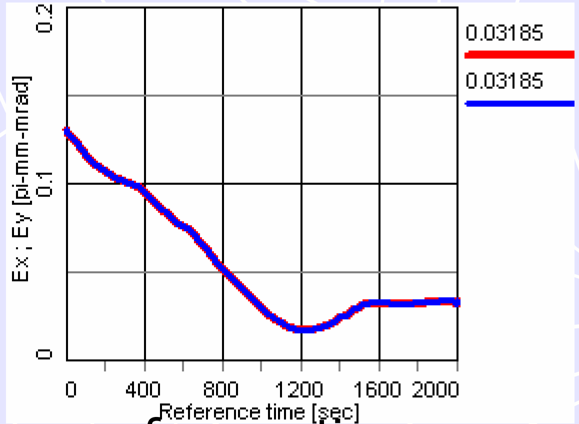
emittances



momentum spread

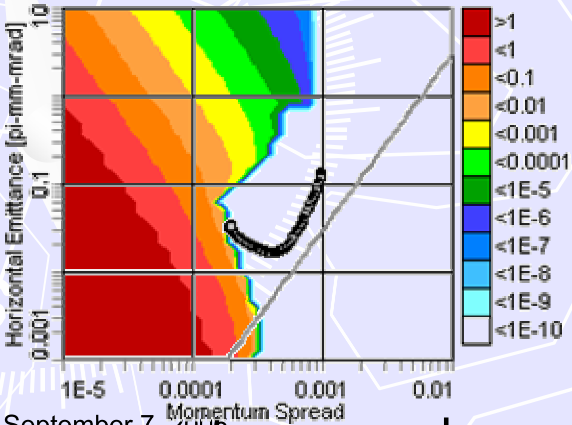
transverse

emittances



reference time

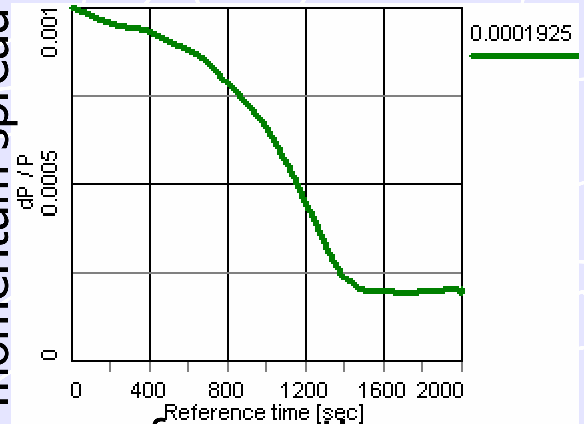
emittances



momentum spread

longitudinal

momentum spread



reference time

	bunched		coasting	
	CSR	HESR	CSR	HESR
Particles	antiproton	proton	antiproton	proton
Momentum [GeV/c]	3,65	15	3,65	15
Length of interaction point [cm]	---	---	50	50
Number of bunches	10	30	---	---
Total number of particles	5×10^{11}	$2,4\times10^{12}$	5×10^{11}	1×10^{13}
Beta function at IP [m]	0,3	1	0,1	0,1
Electron cooler length [m]	10	30	10	30
Electron beam current [A]	1	1	1	1
Cooling time [sec]	~300	~1000	~250	~1500
Transverse emittance [mm mrad]	0,5	0,08	0,05	0,05
Momentum spread, $\Delta P/P$	$2,7\times10^{-4}$	3×10^{-4}	1×10^{-4}	2×10^{-4}
Bunch length [cm]	28	31	---	---
Beam-beam parameter, ξ	0,01	0,0025	0,006	2×10^{-4}
Tune shift, ΔQ	0,05	0,02	0,02	0,006
Total life time [hours]	~1500	~300	~1500	~300
Peak luminosity [cm^{-2} sec^{-1}]	5×10^{30}		$1,2\times10^{31}$	

Maximum Luminosity

Luminosity	CSR	HESR
L (ξ=0.03), $cm^{-2}s^{-1}$	1.5×10^{31}	5×10^{31}
L (ΔQ=0.1), $cm^{-2}s^{-1}$	1×10^{31}	2.5×10^{31}

Ways to increase luminosity

- ▶ Design of lattice structure
  - decrease beta-function at interaction point
  - decrease intrabeam scattering
- ▶ Optimization of cooling process
  - beta-function at electron cooler
  - combination electron and stochastic cooling
- ▶ Space charge limits
  - achieve maximum brilliance
  - increase the energy of experiment