Intrabeam Scattering in the Accumulator

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FNAL, March 28, 2002.

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Heating Mechanisms

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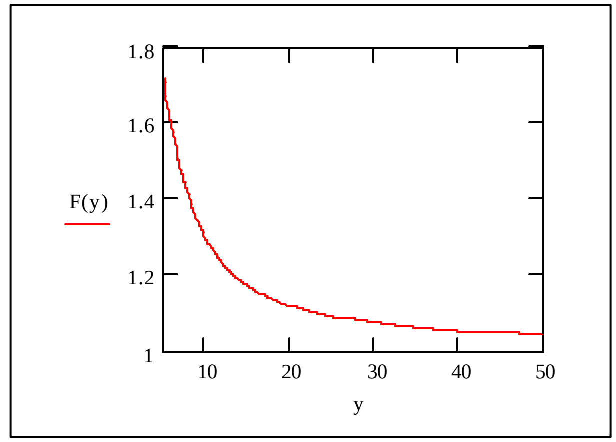
<u>Scattering on the residual gas</u>

<u>Beam lifetime (~500 hour)</u>



- Coulomb scattering (~1000 hour)
- Nuclear absorption (~1000 hour)

$$t_{scat}^{-1} = \frac{2pcr_p^{\;2}}{g^2 b^3}\left(\sum_i n_i Z_i^{\;2}\right)\left(\frac{\overline{b_x}}{e_{mx}} F\left(\frac{e_{mx}}{2e_x}\right) + \frac{\overline{b_y}}{e_{my}} F\left(\frac{e_{my}}{2e_y}\right)\right) + \sum_i n_i s_i cb$$

$$\text{where} \quad \overline{b_{x,y}} = \frac{1}{C}\int b_{x,y}\,ds$$

<u>Emittance growth time</u>

$$\frac{de_{x,y}}{dt} = \frac{2pcr_p^{\;2}}{g^2 b^3}\left(\sum_i n_i Z_i^{\;2}\right)\overline{b_{x,y}}$$

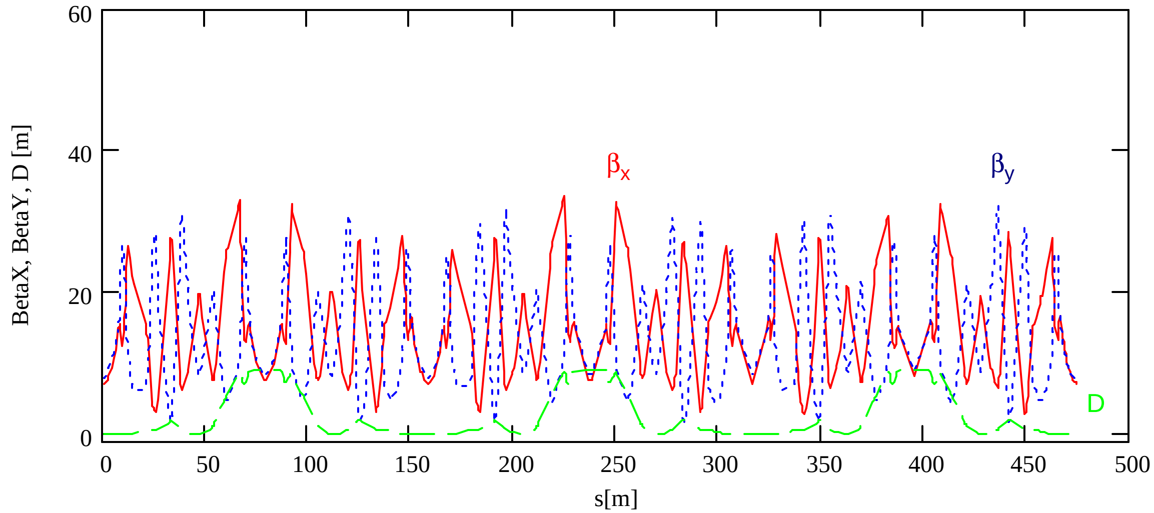
For the beam life time of 460 hour -

$$\frac{de_x}{dt} = 0.249 \text{ mm mrad/hour}$$

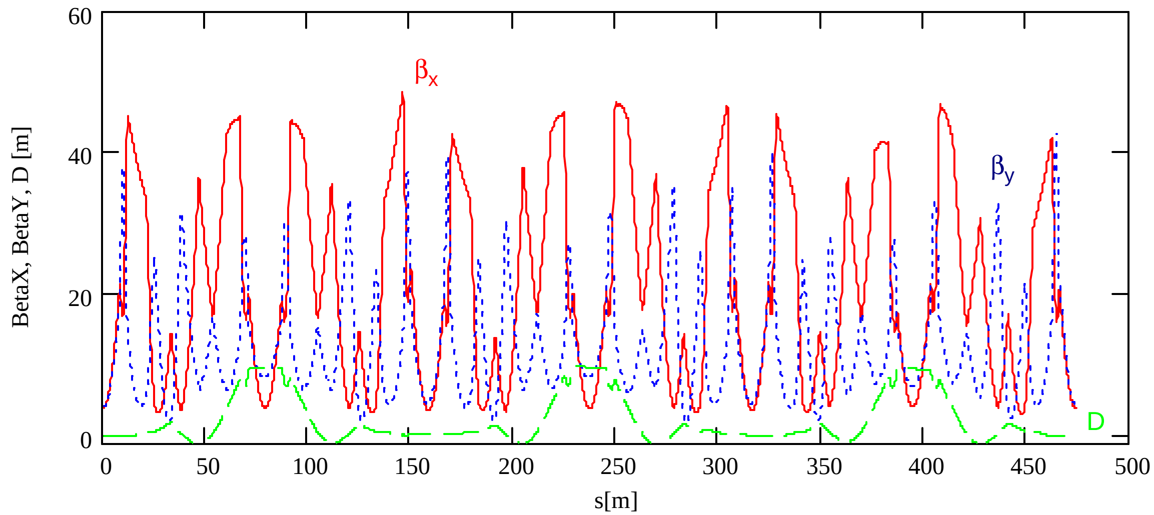
$$\frac{de_y}{dt} = 0.148 \text{ mm mrad/hour}$$

Measured minimum vertical emittance growth time coincides well with the calculations
The horizontal one is usually above predictions and grows fast with beam current

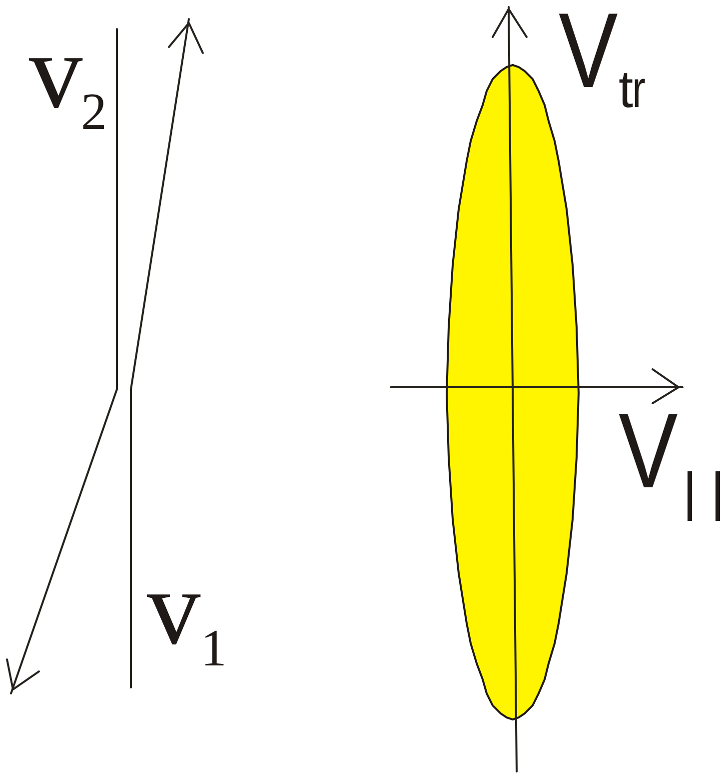
Twiss parameters for the old and new accumulator lattices



	Old	New
β_x[m]	15.3	20.9
β_y[m]	13.4	12.5



Intrabeam scattering theory



If in the beam frame the longitudinal momentum spread is much less than the transverse one the IBS formulas can be significantly simplified

<u>The IBS growth rate for longitudinal degree of freedom</u>

- IBS transfers the energy from the transverse degrees of freedom to the longitudinal one and the growth rate can be approximated by the following formula

$$\frac{d}{dt}\left(q_{\|}{}^{2}\right) \equiv \frac{d}{dt}\left(\frac{\overline{p_{\|}{}^{2}}}{p}\right) = \sqrt{\frac{p}{2}}\,\frac{e^{4} N_{i} L_{C}}{m_{p}{}^{2} c^{3} g_{i}{}^{3} b_{i}{}^{3} C}\left\langle \frac{\Xi_{\|}\left(q_{x}, q_{y}\right)}{s_{x} s_{y} \sqrt{q_{x}{}^{2} + q_{y}{}^{2}}} \right\rangle_{s} \quad ,$$

where averaging is performed along the beam orbit,

$$\Xi_{\|}(x, y) \approx 1 + \frac{\sqrt{2}}{p} \ln\left(\frac{x^{2} + y^{2}}{2xy}\right) - 0.055\left(\frac{x^{2} - y^{2}}{x^{2} + y^{2}}\right)^{2},$$

$s_{x} = \sqrt{e_{x} b_{y} + D^{2} q_{\|}{}^{2}}$, $s_{y} = \sqrt{e_{y} b_{y}}$, $q_{x} = \sqrt{e_{x}/b_{x}}$ and $q_{y} = \sqrt{e_{y}/b_{y}}$

- are the beam sizes and angular spreads along the ring, and
- L_c - is the Coulomb logarithm.

The IBS growth rate for transverse degree of freedom

- The heating of the longitudinal degree of freedom causes cooling for both transverse degrees of freedom;
- Additional mechanism heats the horizontal degree of freedom
  - At regions with non-zero dispersion, changes in longitudinal momentum change the particles reference orbits, which additionally excites the horizontal betatron motion,

$$\frac{d\varepsilon_x}{dt} = \frac{1}{2}\left\langle A_x \frac{d\theta_{\parallel}^{\ 2}}{dt} \right\rangle_s \qquad ,$$

where $\quad A_x = \dfrac{D^2 + \left(D'\beta_x + \alpha_x D\right)^2}{\beta_x}$

Coefficient ½ is related to the fact that the beam is unbunched

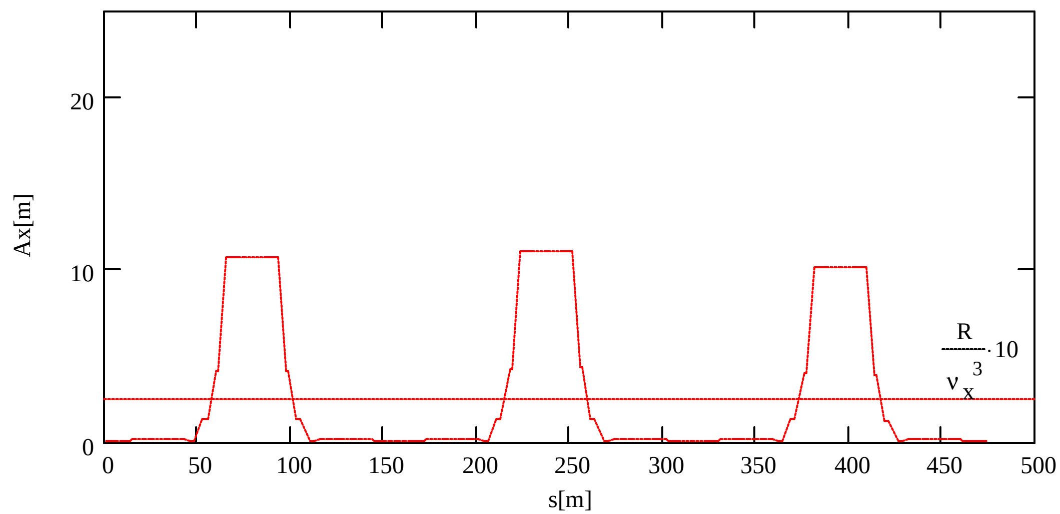
- Finally, one can write for the emittance growth rates

$$\frac{d\varepsilon_{x,y}}{dt} = \frac{\sqrt{2\pi}\, e^4 N_i L_C}{8 m_p^{\ 2} c^3 \gamma_i^{\ 3} \beta_i^{\ 3} C} \left\langle \frac{1}{\sigma_x \sigma_y \sqrt{\theta_x^{\ 2} + \theta_y^{\ 2}}} \begin{bmatrix} 2A_x \Xi_{\parallel}\left(\theta_x, \theta_y\right) - \dfrac{\beta_x}{\gamma_i^{\ 2}} \Xi_{\perp}\left(\theta_x, \theta_y\right) \\ -\dfrac{\beta_y}{\gamma_i^{\ 2}} \Xi_{\perp}\left(\theta_y, \theta_x\right) \end{bmatrix} \right\rangle_s \quad .$$

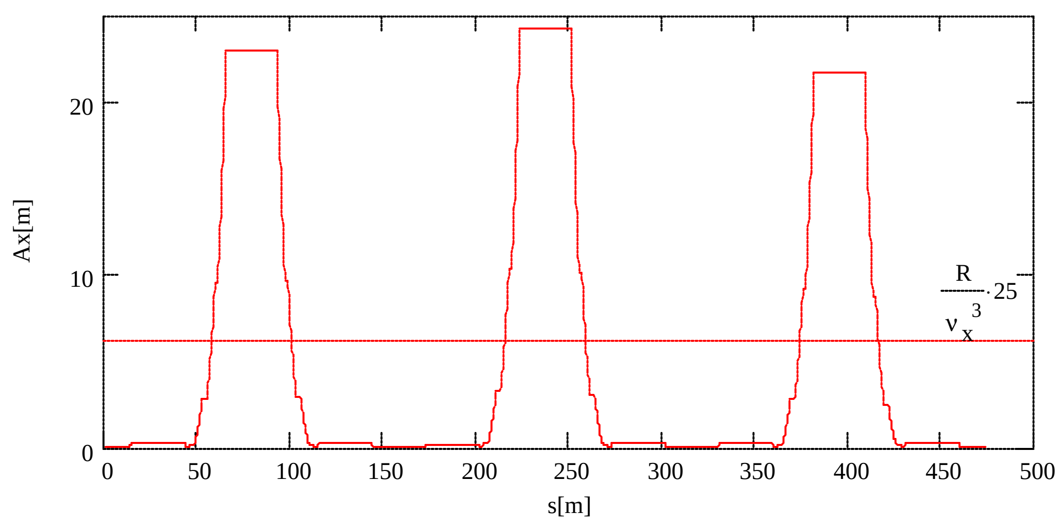
where

$$\Xi_{\perp}(x, y) \approx 1 + \frac{2\sqrt{2}}{\pi} \ln\left(\frac{\sqrt{3x^2 + y^2}}{2y^2} x \right) + \frac{0.5429 \ln(y/x)}{\sqrt{1 + \ln^2\left(y/x\right)}} \qquad .$$

Comparison of the old and new accumulator lattices from the horizontal emittance growth rate due to IBS



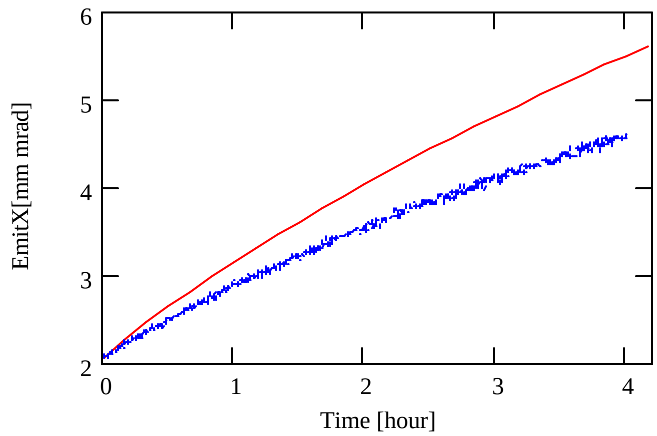
Old lattice

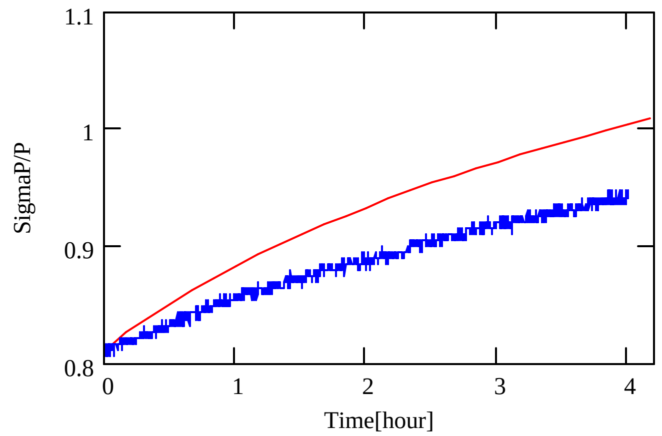


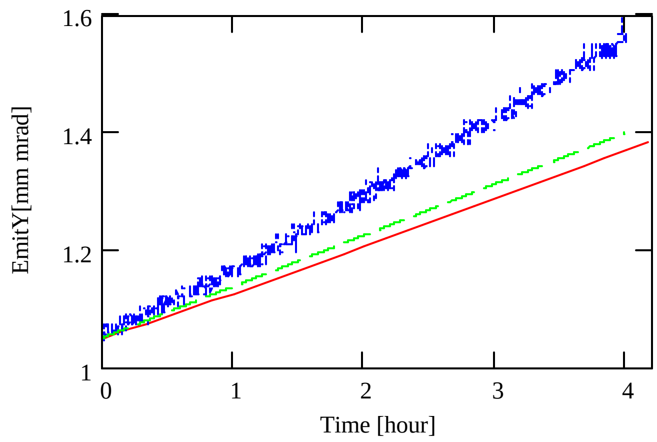
New lattice

- Both lattices are not designed to have small IBS
- New lattice amplifies IBS by more than factor of two in comparison with the old one

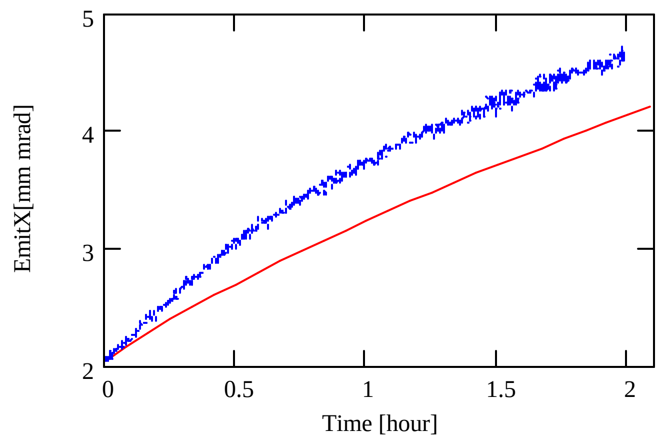
IBS calculations and comparison with experimental data

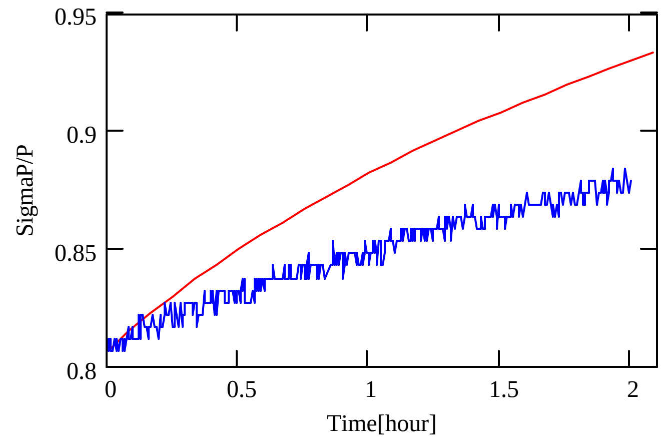


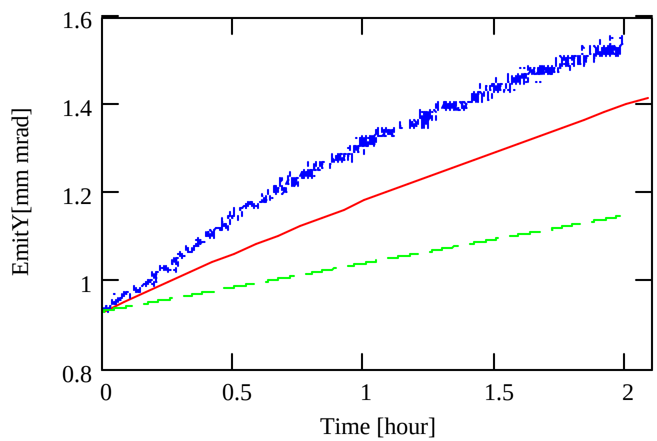




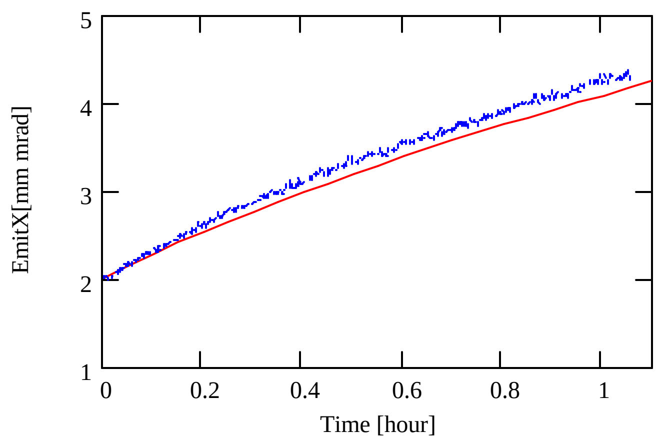
Protons	
Beam current [mA]	48.2
Lifetime [hour]	800
Coupling (X to Y)	0

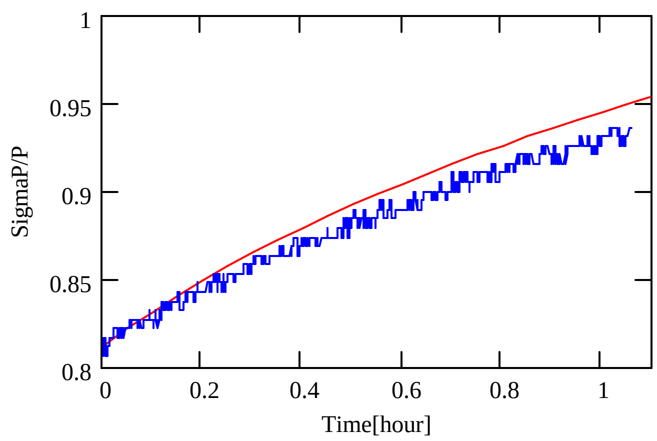


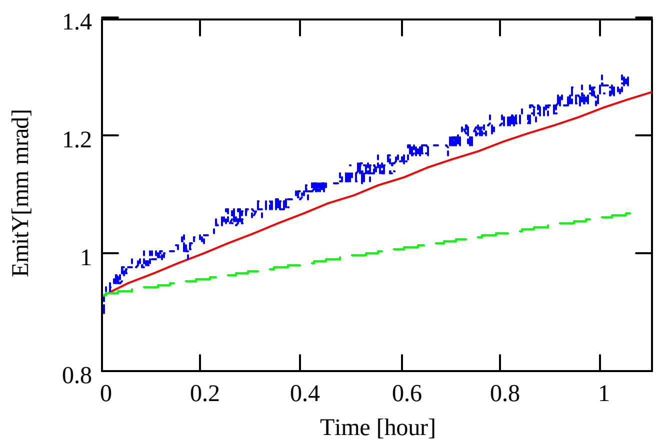




Antiprotons	
Beam current [mA]	50.8
Lifetime [hour]	650
Coupling (X to Y)	0.13



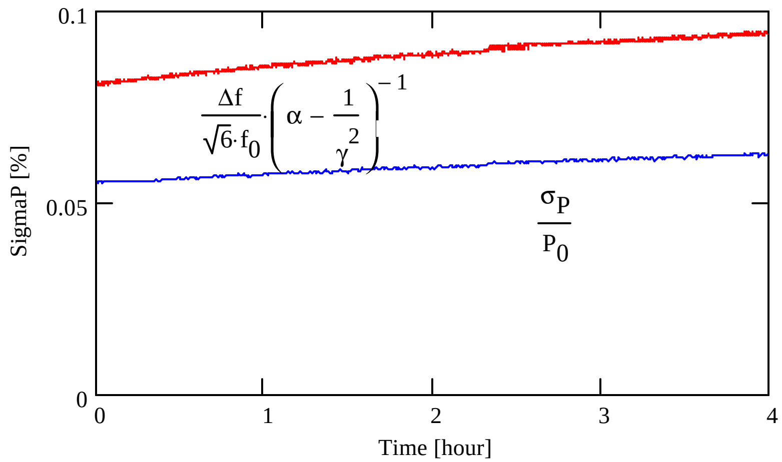


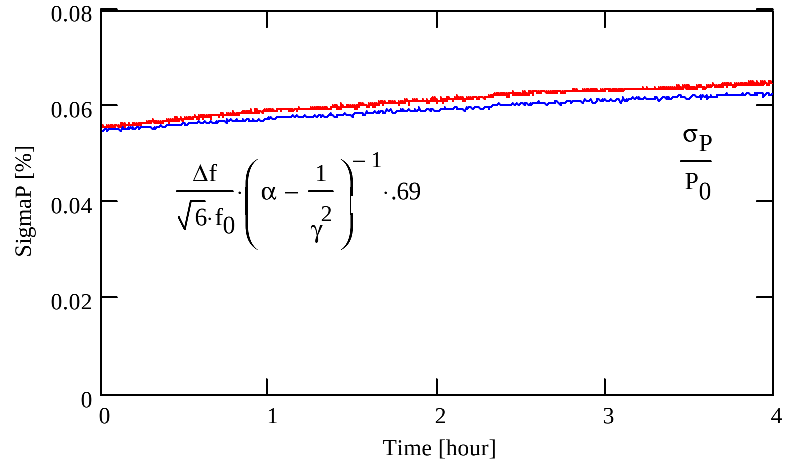


Antiprotons	
Beam current [mA]	105.3
Lifetime [hour]	550
Coupling (X to Y)	0.1

Accuracy of the measurements

- Momentum spreads reported by A:SIGMAP and A:FRWDTH is different by ~40% and the are not proportional to each other in the both cases of proton and antiproton beam
  - Non-gaussian beam





- 79 and 300 MHz emittance monitors report the same numbers for antiproton beam but different numbers for the proton beam
  - Directionality of the emittance monitor
- More detailed work and better calibration of diagnostics is required to figure out exact contribution of IBS into beam heating

Conclusions

1. **IBS is the main contributor to heating of horizontal degree of freedom**
2. **Lattice upgrade of the accumulator amplified the IBS by about factor of two**
3. **If we believe that the IBS is the only heating mechanism for horizontal degree of freedom than cooling upgrade will bring more moderate gain in the horizontal emittance than expected**

$$e \propto \left(\frac{G_{new}}{G_{old}} \right)^{2/5} \approx 3^{2/5} \approx 1.5$$

4. **Redesign of the accumulator optics potentially can return the lost factor of 2. We will study possible optics improvements. The gain can be as high as**

$$e \propto \left(\frac{A_{old}}{A_{new}} \right)^{2/5} \approx 2^{2/5} \approx 1.3$$