Intra-beam scattering

A. Fabich, CERN

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http://cern.ch/beta-beam

Outline

- Definitions
- The beta-beam case: RCS, PS, SPS and decay ring
  - Comparison of different models
  - Long-term evolution; equilibrium
  - Critical cases
- Summary

IBS definitions

- Emittance growth

$$\epsilon_{long,hor,ver}(t_0) = \epsilon_{long,hor,ver}(0)\; e^{\int_0^{t_0} \frac{1}{\tau_{long,hor,ver}(t)}\, dt}$$

- Growth time

$$\frac{1}{\tau_{long,hor,ver}} \propto A_0 \int e^{-Dz} \ln\left(1 + C^4 z^2\right) \begin{pmatrix} n_b\,(1 - d^2)\, g_1 \\ a^2 g_2 + (d^2 + \tilde{d}^2)\, g_1 \\ b^2 g_3 \end{pmatrix} d\theta\, d\phi\, dz$$

- Assumes Gaussian distributions of the three phase spaces.

$$A_0 \propto N \frac{Z^4}{A^2} \frac{1}{\epsilon_x^* \epsilon_y^* \sigma_p \sigma_s \beta \gamma^2}$$

- Injection and ^{18}Ne operation is more demanding.

A. Piwinski, Intra-beam scattering, proc 9th Conf. on High Energy Accelerators, 1974, p. 405
J. Bjorken, S. Mtingwa, Intrabeam Scattering, Particle Accelerators 1983 13, pp 115-143
J. Wei, "Evolution of hadron beams under Intra-beam scattering", PAC1993

Beta-beam cases

- Investigated machines:
  - RCS, PS, SPS, decay ring
    only at injection

- Ions: ^{6}He, ^{18}Ne

^{6}He

	RCS	PS	SPS	DECAY
N_b	9.264×10^{11}	8.981×10^{11}	7.667×10^{11}	4.829×10^{12}
$l_{full,bunch}$ [m]	189.7	23.94	5.984	2.992
sigt [m]	63.	8.0	2.0	0.63
sigE/E [mrad]	0.13	0.30	0.36	1.3

^{18}Ne

	RCS	PS	SPS	DECAY
N_b	2.726×10^{11}	2.692×10^{11}	2.564×10^{11}	3.708×10^{12}
$l_{full,bunch}$ [m]	189.7	23.94	5.984	2.992
sigt [m]	63.	8.0	2.0	0.55
sigE/E [mrad]	0.17	0.20	0.16	1.5

- IBS codes (and simplified models):
  - MAD8 and MAD-X (differ on the per-mille level)
  - Wei approximation (thanks to J. Jowett)

~~Discrepancy~~ Wei↔Mad

Different to the last report, the difference in the results of the two reports is acceptable.

- Ratio= τ_{Wei} / τ_{Mad}

6He

RCS	PS	SPS	DECAY
0.86	0.86	0.93	0.98
0.37	1.2	0.91	2.3
0.43	0.36	0.21	0.11

18Ne

RCS	PS	SPS	DECAY
0.78	0.78	0.83	0.89
0.34	1.0	0.44	2.1
0.36	0.46	0.43	0.097

- Wei is more pessimistic.

Growth times

- ^{6}He

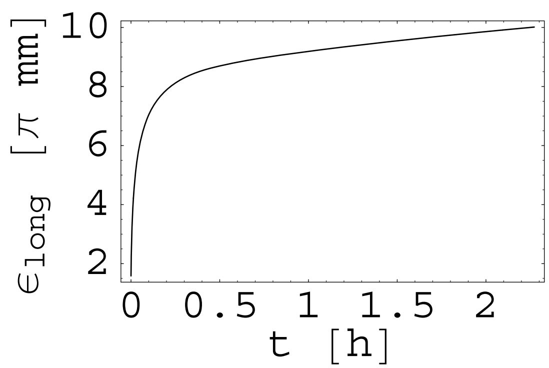
	RCS	PS	SPS	DECAY
τ_{long}[s]	9	102	16464	36600
τ_{hor}[s]	-5778	-3548	-1004676	29974
τ_{ver}[s]	-3856	-4017	-1216324	-3660078

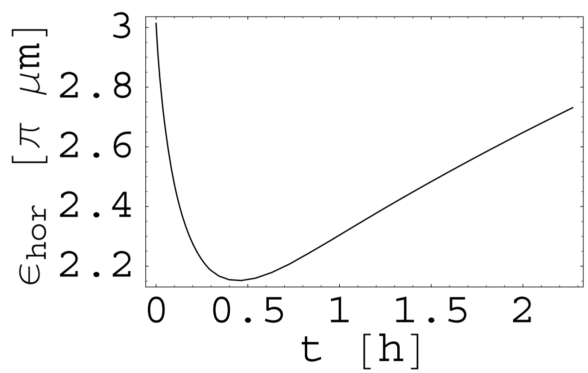
- ^{18}Ne

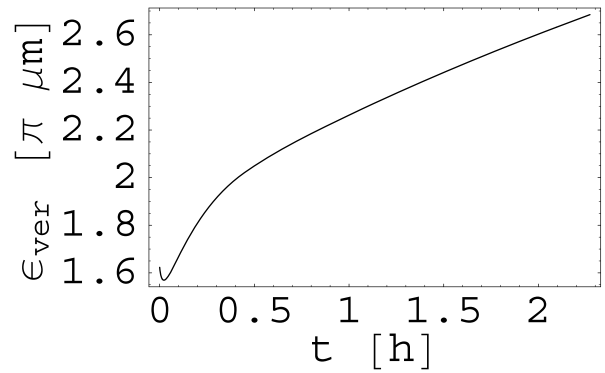
	RCS	PS	SPS	DECAY
τ_{long}[s]	1	3	23	759
τ_{hor}[s]	-313	-520	-67442	621
τ_{ver}[s]	-220	-367	-9044	-75871

Accumulation of ^{18}Ne in the PS

- Time transient model

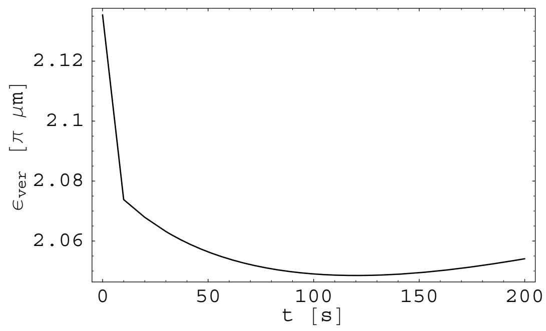


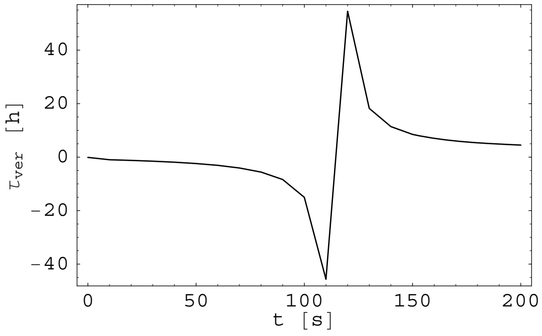




The sensitivity on the input parameters is “linear”.

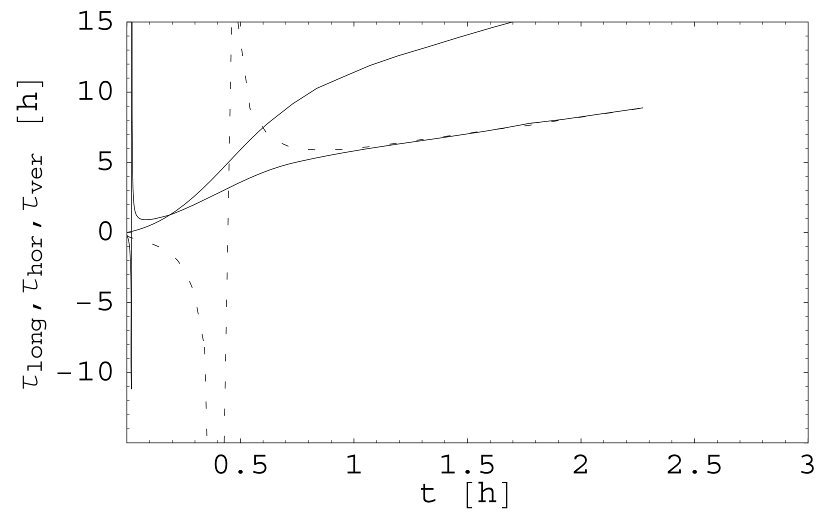
- Sign change for growth time:

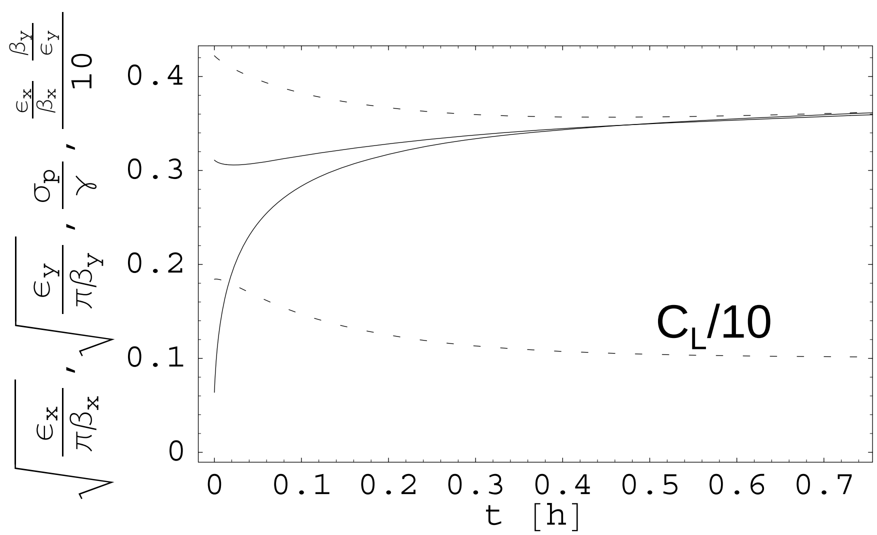




Emittance growth–“equilibrium”

Mad-Simulation
for 18Ne in the
PS at injection





$$\sqrt{\frac{\epsilon_x}{\pi \beta_x}} \approx \sqrt{\frac{\epsilon_y}{\pi \beta_y}} \approx \frac{\sigma_p}{\gamma}$$

e.g. see Piwinski CAS 1991

Growth times – critical case(s)

Results obtained with Mad-8

- ^{6}He

	RCS	PS	SPS	DECAY
τ_{long}[s]	9	102	16464	36600
τ_{hor}[s]	-5778	-3548	-1004676	29974
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- ^{18}Ne

	RCS	PS	SPS	DECAY
τ_{long}[s]	1	3	23	759
τ_{hor}[s]	-313	-520	-67442	621
τ_{ver}[s]	-220	-367	-9044	-75871
t_{accel} [s]	0.05	1	0.8	~100

Summary

- Different models in acceptable agreement.
- Sensitivity of growth times “linear” with input parameters.
- ^{18}Ne in the PS at injection is the critical case.
  - Compare t=3s with maximum 2 s accumulation time.
  - Blow-up of up to 30% expected (without RF).

  Assuming emittances given for 11 Tm at PS injection.