should the warm BPMs in LHC be coated with a 100 micron copper layer? (question by Gerhard Schneider)

46 BPMs per beam (16 BPMSW, 18 BPMW, 4 BPMWA, 8 BPMWB)

Average beta	Injection	Top
Horizontal beta	109.9 m	328.0 m
Vertical beta	115.1 m	306.5 m

Each BPM is 285 mm long. The inner bore radius *b* is typically 30 mm. The thickness *d* is 10 mm stainless steel. The total length is 13.11 m. I assume a stainless steel conductivity of $\sigma = 1.4 \times 10^6\ \Omega^{-1}\mathrm{m}^{-1}$, which might however increase with temperature, if the beam pipe heats up. Skin depth of copper is 0.7 mm at 8 kHz, and 15 μm at 20 MHz.

1st response by Francesco: a Cu coating is welcome to reduce beam induced ohmic heating and resistive wall impedance at very low frequency (down to ~10 kHz), but a thin coating is not very effective at room temperature, where you need a Cu thickness in the mm range to shield the outer SS.
I have also the following two naive remarks:

- the Cu coating should remain compatible with the BPM functionality,
- the Cu coating may be counter-productive in case of resonant modes with a Q-factor that would be enhanced by such a low resistivity coating.

resistive wall impedance

$$\frac{Z_l}{l} = \frac{1 - i\,\mathrm{sgn}(\omega)}{2\pi b}\sqrt{\frac{|\,\omega\,|\,\rho Z_0}{2c}}$$

CERN formula (L. Vos, E. Metral)

$$\frac{Z_t}{l} = -\frac{2c}{\omega b^2}\frac{Z_l}{l}\frac{i\omega L}{2\pi}\frac{1}{\frac{Z_l}{l} - i\frac{\omega L}{2\pi}}$$

inductive bypass only active in the transverse plane; derivation unclear, independent of chamber thickness

$$\frac{Z_t}{l} = -i\frac{Z_0}{\pi b^2}\frac{1 + \frac{1}{\lambda_1 b}\tanh(\lambda_1 d)}{2 + \left(\frac{1}{\lambda_1 b} + \lambda_1 b\right)\tanh(\lambda_1 d)}$$

$$\lambda_1 = (1 - i\,\mathrm{sgn}(\omega))\sqrt{\frac{\mu_0 \sigma\,|\,\omega\,|}{2}}$$

FNAL formula (Burov, Lebedev)

solution of Maxwell’s equation; chamber thickness enters; Burov/Lebedev’s result agrees with formula in Zotter/Kheifets’ book in some cases and extends it in many others

Burov and Lebedev also give a result for 2-layer chamber, where inner layer, e.g., d=100 micron copper, is surrounded by another material, e.g., by an infinite amount of stainless steel

$$\frac{Z_t}{l} = -i\frac{Z_0}{\pi b^2}\frac{1+\frac{\lambda_2}{\lambda_1}\tanh\left(\lambda_1 d\right)}{1+\lambda_2 b+\left(\frac{\lambda_2}{\lambda_1}+\lambda_1 b\right)\tanh\left(\lambda_1 d\right)}$$

$$\lambda_{1,2} = (1-i\,\mathrm{sgn}(\omega))\sqrt{\frac{\mu_0\sigma_{1,2}\,|\,\omega\,|}{2}}$$

Normalize the beta function to 70 m. Use definition of the transverse effective impedance of LHC Design Report. Effective longitudinal transverse impedance is obtained by integration over the bunch spectrum.

uncoated

L. Vos

(Zlong/n)eff (Ω)	Zeff [8 kHz] (MΩ/m)	Zeff [20 MHz] (MΩ/m)
0.0016 (injection) 0.0011 (top)	0.028-0.056 i (injection) 0.079-0.159 i (top energy)	0.001- 0.001 i (injection) 0.004-0.004 i (top)

factor ~10 difference!

Burov/ Lebedev

(Zlong/n)eff (Ω)	Zeff [8 kHz] (MΩ/m)	Zeff [20 MHz] (MΩ/m)
0.00038 (injection) 0.00025 (top)	0.183-0.220 i (injection) 0.517-0.621 I (top energy)	0.004-0.004 i (injection) 0.013-0.013 i (top)

total impedance from design report (sign problem)

(Zlong/n)eff (Ω)	Zeff [8 kHz] (MΩ/m)	Zeff [20 MHz] (MΩ/m)
0.070 0.076	-45-22 i (injection) -91-24 i (top energy)	-3- 9 i (injection) -5-5 i (top)

for longit. impedance I assumed the standard resistive-wall relation $Z_{||}=Z_t\ (\omega\ b^2/(2\ c)$. Resistive-wall contribution from the BPMs is less than 1% of the total.

for a coated chamber ($\sigma=5.9\text{x}10^7\ \Omega^{-1}\text{m}^{-1}$) I find from Burov/Lebedev

(Zlong/n)eff (Ω)	Zeff [8 kHz] (MΩ/m)	Zeff [20 MHz] (MΩ/m)
0.000034 (injection) 0.000028 (top)	0.258+0.288 i (injection) 0.728+0.813 i (top energy)	0.001-0.001 i (injection) 0.002-0.002 i (top)

conclusion on BPMs

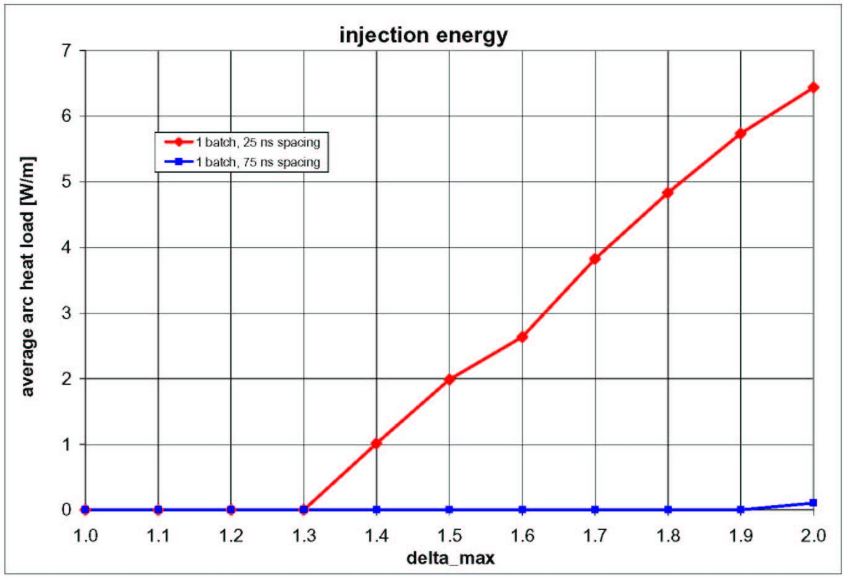
- different formulae give results that differ by a factor 10
- even in the worst case the total impedance for the uncoated BPMs is 1% or less of the total LHC impedance
- Fritz tells me that none of the formulae can be trusted since the real problem is 3-dimensional
- he recommends calculation with HFSS
- nevertheless “2-dim.” estimates should give an upper bound at ~kHz frequencies
- my tentative conclusion is that no coating would be needed

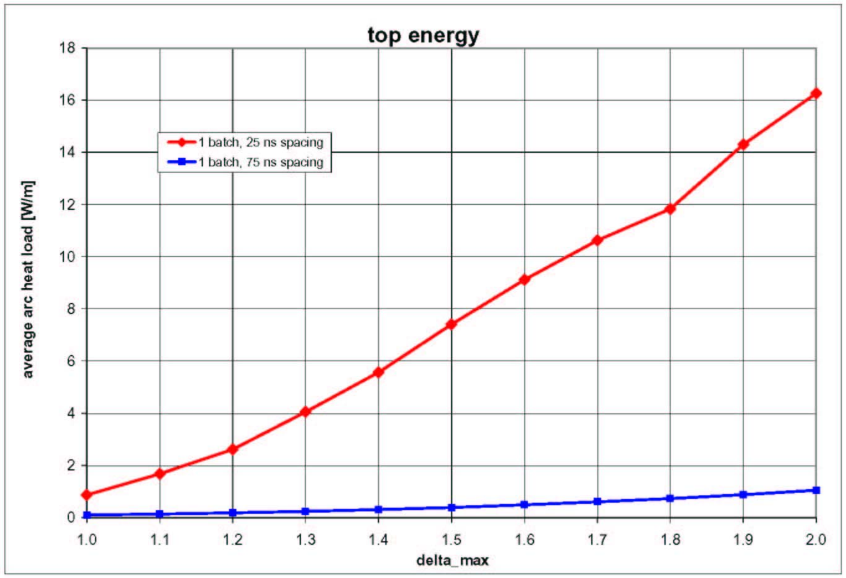
Touschek module in MADX

C. Milardi, F. Schmidt, F. Zimmermann

- implemented general formula from Piwinski (Chao-Tigner handbook)
- implementation facilitated by similarities with IBS module
- new module will give growth rate for each beam-line element
- bunch length and energy spread are at the moment frozen around the ring (not a good approximation for strong rf focusing at DAFNE2)

latest e-cloud predictions for LHC: heat load vs delta_max for nominal bunch population at injection and top energy





e-cloud in DAFNE

- news from Mikhail Zobov:
- Last year DAFNE was substantially changed: modified wigglers, two new interaction regions, some optics modifications etc. Now we can observe a strong horizontal instability which have many features that can be attributed to e-cloud:
- 1) amplitude of horizontal oscillations grows along the train;
- 2) the betatron line is splitted in several lines...
- On the other hand, the same behaviour is observed for the e- ring, but at much higher currents and thresholds. But in case of e-ring, it can be due to the horizontal ion instability like that at KEKB.
- Yet another observation - different tune shifts versus multibunch currents in e- and e+ rings. It seems that in the e+ring there is some additional positive tune shift in both transverse planes...

Mikhail's news cont'd

1. Now we have a possibility to measure betatron amplitudes turn-by-turn on the bunch-by-bunch basis. What you can see is grow-damp measurements: for a very short time we switched off the transverse feedback and look at the amplitudes. In the shown example there were 90 bunches + 30 bunch gap.

2. Tune shift measurements were performed in single bunch and multibunch regimes in October 2002 (for DEAR experiment) and in January 2004 (for FINUDA experiment). Summarizing:

a) Single bunch -- tunes shift is negligible for both rings;

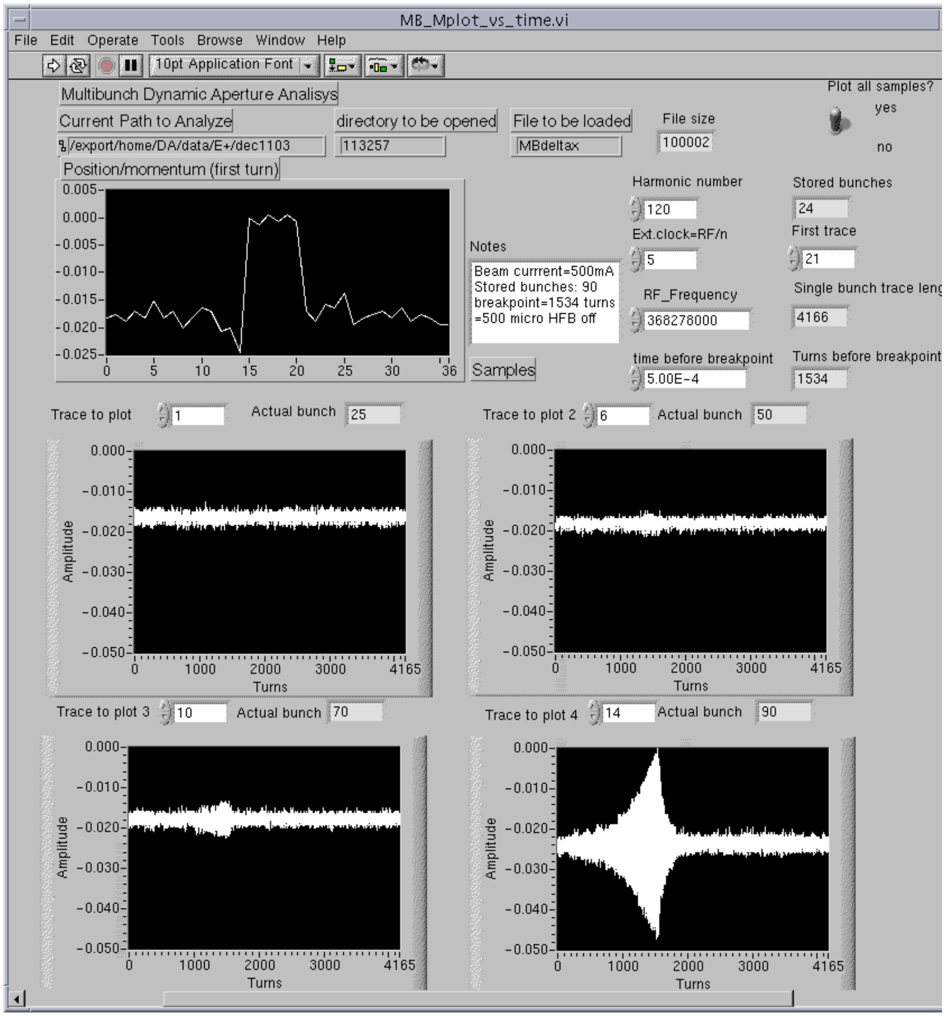
b) Multibunch -- tune shifts have opposite sign slopes and can be calculated analytically for e-ring (strong asymmetry due to wiggler vacuum chamber)

c) In the e+ ring -- the vertical tune shift is almost zero, but the horizontal one is positive and by a factor of 2 higher with respect to the e-ring (Oct. 2002) and almost by a factor of 4 higher now (January). Respectively, the instability threshold is by a factor of 2 lower now.

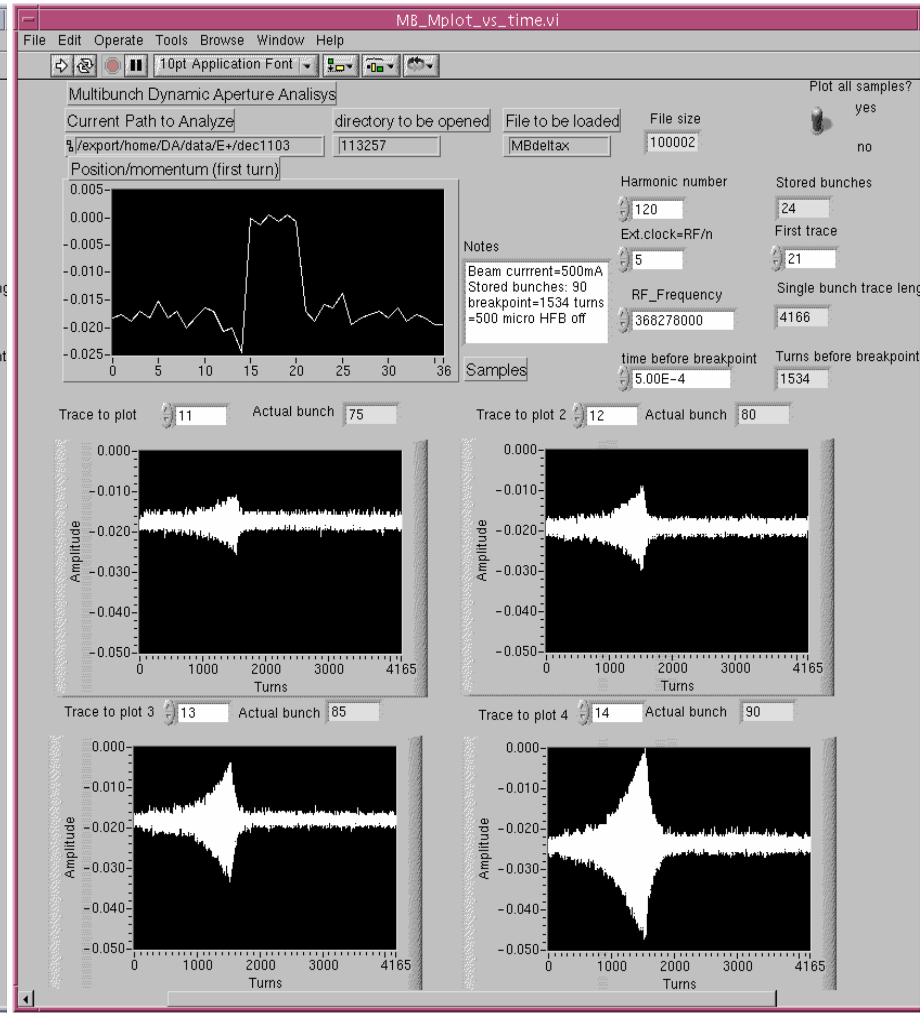
Cure: certainly, beam-beam. Yet another strange thing - the instability threshold grows from 500 mA to 1A by changind the RF frequence by -10 kHz (dispersive orbit?, impedance? Energy?)
(the orbit changes by 3 mm at maximum inside the wiggler vacuum chambers having sizes 13 x 2 cm. No (slight) tune changes, no chromaticity changes. No nonlinearity changes - we have measured the decoherence at different RF frequencies).

90 consecutive bunches + 20 bucket gap

Bunches 25, 50, 70, 90



Bunches at the train end:75, 80, 85,90



Tune Shifts of Bunch Trains due to Resistive Walls without Circular Symmetry

PRSTAB,5,111001 (2002)
(Chao, Heifets, Zotter)

DAΦNE, Oct. 2002

$$\frac{dQ_{x,y}}{dI} = \pm\left(\frac{\pi}{48Q_{x,y}}\right)\left(\frac{Z_0}{E/e}\right)\left(\frac{R}{b}\right)^2\left(\frac{L}{C}\right)\left\{1+\frac{b^2}{d^2}\right\}$$

b - horizontal vacuum chamber size;

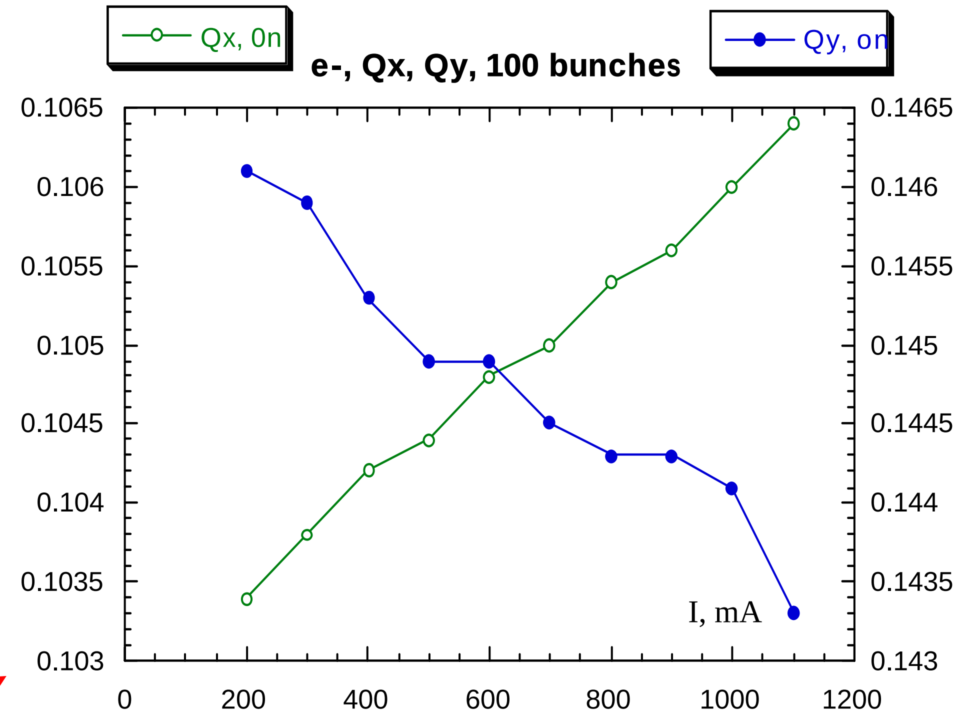
d - vertical vacuum chamber size;

L – vacuum chamber length;

R – machine radius;

Z_0 – 376 Ω;

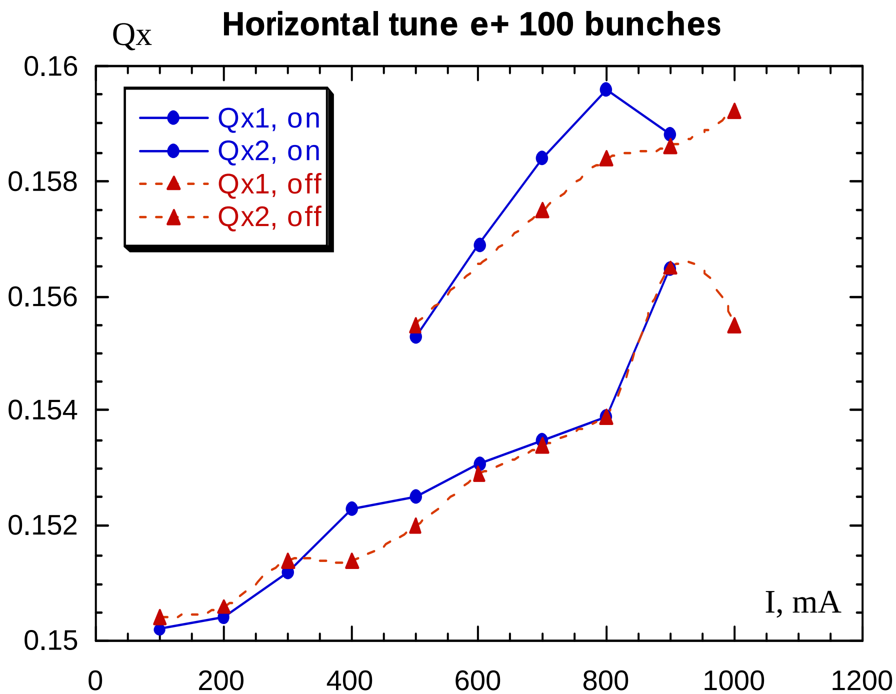
$$\frac{dQ_{x,y}}{dI} = \pm 0.0024/A$$



Good agreement with experimental data!!

Tune Shift Measurements in e+ Ring

(important not only for the instability, but also for beam-beam collisions !)



Factor of instability threshold increase

Δf, kHz	Qx (SB)	Qx 500 mA	ΔQx
0	0.1124	0.1217	0.0093
-10	0.1129	0.1180	0.0051

DAΦNE, Oct. 2002

DAΦNE, 21/01/2004