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BEAM FIELDS AND ENERGY DISSIPATION INSIDE THE BE BEAM PIPE OF THE SUPER-B DETECTOR*

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Abstract

We study the bunch field diffusion and energy dissipation in the beam pipe of the Super-B detector, which consists of two coaxial Be thin pipes (half a millimeter). Cooling water will run between these two pipes. Gold and nickel will be sputtered (several microns) onto the beryllium pipe at different sides. The Maxwell equations for the beam fields in these thin layers are solved numerically for the case of infinite pipes. We also calculate the amplitude of the electromagnetic fields outside the beam pipe, which may be noticeable as the beam current can reach 4 A in each beam. Results of simulations are used for the design of this central part of the Super-B detector.

SUPER B INTERACTION REGION

The Super-B project include a new colliding scheme which combine a “large collision angle”, low β*, ultra low emittances and a “*crab waist*” transformation [1]. The IR final focus design has compact doublet quadrupoles that need to be placed very close to the IP. The present IR layout shown in Fig. 1 has been optimized in order to ease the engineering design and provide the best performance in terms of beam stay clear and backgrounds [2].

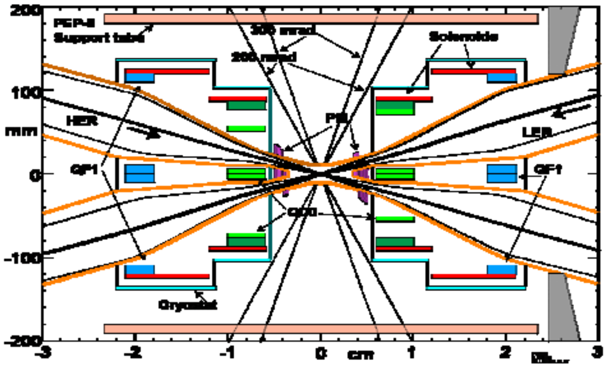

Figure 1: Super B interaction region.

DETECTOR BEAM PIPE

The detector beam pipe is made of Be with a one cm radius. The position and sizes of the Be chamber are shown in Fig. 2. The Be will be coated on the inside with a thin layer of gold several microns thick. We presently plan to water cool this pipe as we expect to have to remove perhaps as much as a kW of power from the beam pipe based on the PEP-II experience. As we design the beam pipes in this area we will be able to perform wake field analysis on the vacuum components which will give us a good estimate of high-order-mode (HOM) power in this region. We expect to have to absorb some amount of HOM power in this area so we will have to include absorbers in the beam pipe design.

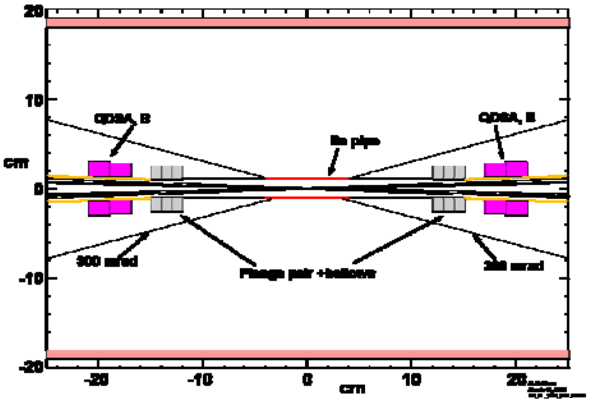

Figure 2: Be beam chamber.

We will study the resistive wall wake field heating for two designs of the Be chamber, described in Table 1 and table 2.

Table 1: IR Be beam chamber. Case I.

	Size	Conductivity 10^6 Ohm^{-1} m^{-1}
Pipe length	25 cm	
Radius to inner surface	10 mm	
1st layer Au	4 µ	48.8
2nd layer Be	0.5 mm	25

Table 2: IR beam chamber. Case II.

	Size	**Conductivity** 10^6 Ohm^{-1} m^{-1}
Pipe length	25 cm	
Radius to inner surface	10 mm	
1st layer Au	4 µ	48.8
2nd layer Be	0.5 mm	25
3 d layer NI	7µ	14.6

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SINGLE BUNCH

To find the power, which is absorbed in the Be chamber we need to know the electromagnetic fields excited by the electron and positron bunches moving in a resistive pipe. We will use a numerical method to solve Maxwell's equations [3]. With this method we can calculate the steady-state solution of the fields for a relativistic bunch. A pipe may have different layers of different materials. We can also calculate the fields, which penetrate through the resistive material inside a Super-B detector. We will do calculations for a 5 mm long bunch, which is the design Super-B value [4].

The longitudinal field inside a pipe for case I is shown in Fig. 3 together with the bunch shape

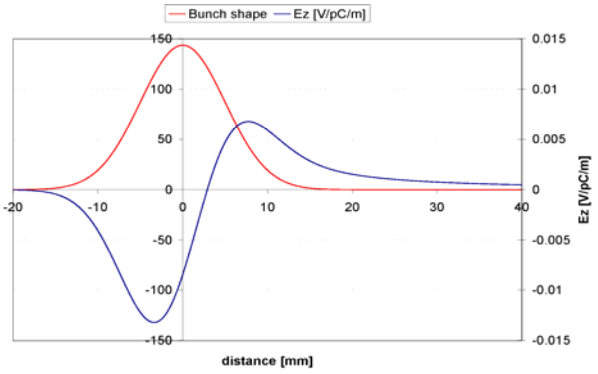

Figure 3: Longitudinal electric field of a 5mm long bunch moving inside the Be pipe for the case 1. Red line shows bunch shape.

The longitudinal field for the case II differs very little from case 1. Power, which is absorbed in the Be pipe can be calculated by the formula

$$P_{pipe} = k\tau\left(I_{LER}^2 + I_{HER}^2\right)l$$

Where k is a single bunch loss factor per unit length, τ is the bunch spacing (time interval between bunches), *I* is the total electron (LER) or positron current (HER) and *l* is the pipe length. Loss factors for case I and II are shown in Table 3. There are several possibilities for different electron and positron currents at Super-B. Base line currents are 1892 mA for HER and 2447 mA for LER with a bunch spacing of 4.2 ns [4]. In the high current regime the currents are higher: 3094 mA for HER and 4000 mA for LER but the bunch spacing is two times smaller 2.1 ns and the absorbed power is not much higher. This power is shown in the table 3.

Table 3: Loss factor and power.

	Loss factor V/pC/m	Absorbed power
Case 1	$5.07 \cdot 10^{-3}$	68 W
Case 2	$5.56 \cdot 10^{-3}$	76 W

Additionally to this resistive power there will be some absorption of the wake fields generated at the intersection of the LER and HER beam pipes. The power from these fields is of the order of several kilowatts [5], but they will be absorbed at a large area.

PENETRATING FIELDS

The thickness of the Be chamber is very small and we can suspect that some fraction of the bunch fields can penetrate the pipe and can be seen by the detector. Calculations for a single bunch show that this penetrating part is small. Fig. 4 shows the time profile of the field induced by a bunch on the inner side (pancake thin red line on the left) and on the outer side (dark red line) of the Be chamber. Note that the plot scales for the inner and outer field are different. What is interesting is that the time delay is very large: it is 1.5 µs.

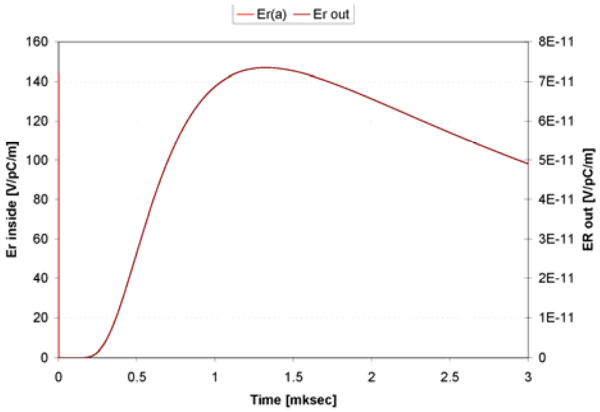

Figure 4: Field induced by a bunch on the inner side (pancake thin red line) and on the outer side (dark red line) of the Be chamber.

We can estimate this time delay using the solution of a diffusion equation

$$\frac{\partial E}{\partial t} \approx \frac{c}{Z_0\sigma}\frac{\partial^2 E}{\partial x^2}$$

For the δ-function initial conditions

$$E_{in}(t=0) = \delta(x)$$

the solution is

$$E(x,t) = \sqrt{\left(\frac{Z_0\sigma}{4\pi ct}\right)}\exp\left(-\frac{Z_0\sigma}{4ct}x^2\right)$$

From here we can estimate the diffusion time

$$t_d \sim \frac{Z_0\sigma}{4c}d^2$$

For the parameters of the Be pipe this formula gives a diffusion time of 2 µs, which is very close to the time delay. As the time delay is very long in comparison with the bunch spacing the many bunch case will contribute to the field outside of the Be pipe.

MULTI BUNCH REGIME

The outside signal increases a thousand times in the multi bunch regime. Fig. 5 shows how the outside signal build up with the number of bunches for the case I.

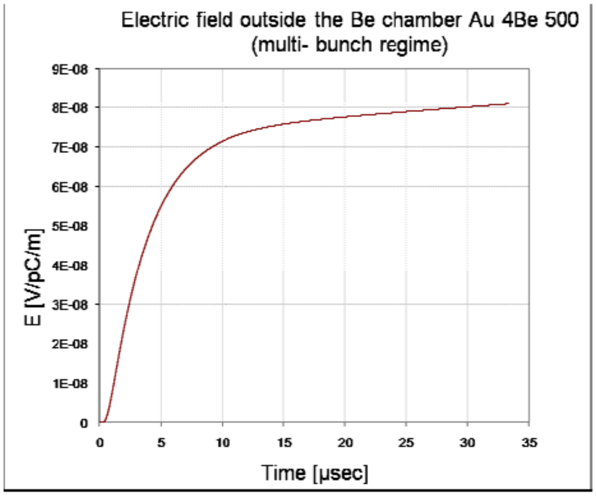

Figure 5: Field on the outer side of the Be chamber in multi bunch regime for the case I.

The outside field for case II is shown in Fig. 6. It needs approximately 20-30 µs to reach a steady state. This time is several times more than the revolution period. If there is a gap in the beam current, than we can have a modulation of the outside fields. To understand the level of these fields we will calculate the equivalent current on the outer surface of the pipe. For our two cases here this current is of order of 1-2 µA.

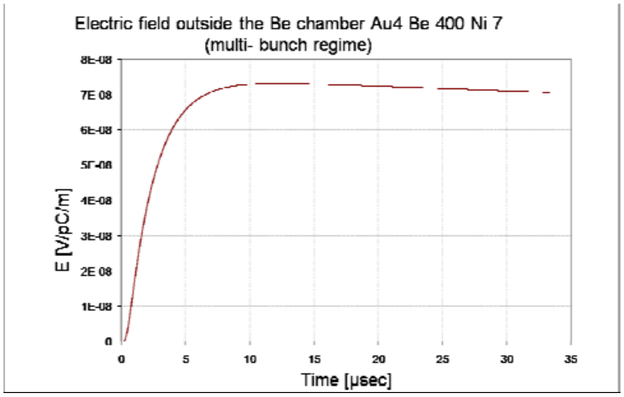

Figure 6: Field on the outer side of the Be chamber in multi bunch regime for the case II.

COLLISION IMAGE CURRENTS

Let's analyse the image currents in the interaction region. The sum of electron and positron current is

$$I(t,z)=\sum_n I_b^{LER}\delta(z+nc\tau-ct)+I_b^{HER}\delta(z-nc\tau+ct)$$

Collision position correspond to z=0. Fourier transform gives

$$I(\omega)=\sum_n I_b^{LER}e^{i(\omega z/c+\omega\tau n)}+I_b^{HER}e^{i(-\omega z/c+\omega\tau n)}$$

If LER and HER bunch currents are equal then

$$I(\omega)=2I_b\cos\frac{\omega z}{c}\sum_n e^{i\omega\tau n}=I_b\frac{\cos\frac{\omega z}{c}}{\sin\frac{\omega\tau}{2}}ie^{-\frac{i\omega\tau}{2}}$$

So the image reaches extreme values at the collision point z=0 and at the other places were

$$z_m=\pi\frac{c}{\omega}m$$

A resonant condition gives frequencies

$$\frac{\omega\tau}{2}=\pi k \qquad \omega_k=\frac{2\pi}{\tau}k \qquad z_{mk}=\frac{c\tau}{2}\frac{m}{k}$$

These frequencies are limited by the bunch length. The skin depth is

$$\delta_k=\sqrt{\frac{c\tau}{\pi k Z_0\sigma}}$$

For beryllium for the minimum frequency (k=1) skin depth is 6.5 µ.

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