DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, January 13, 1993

Note: **IR-1**

INTERACTION REGION VACUUM CHAMBER AND PUMP DESIGN

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In this note we will take a first look at the design of the vacuum system inside the detector, i.e. the length of ± 2.5 m from the interaction point as the cooling and pumping possibilities are rather limited there.

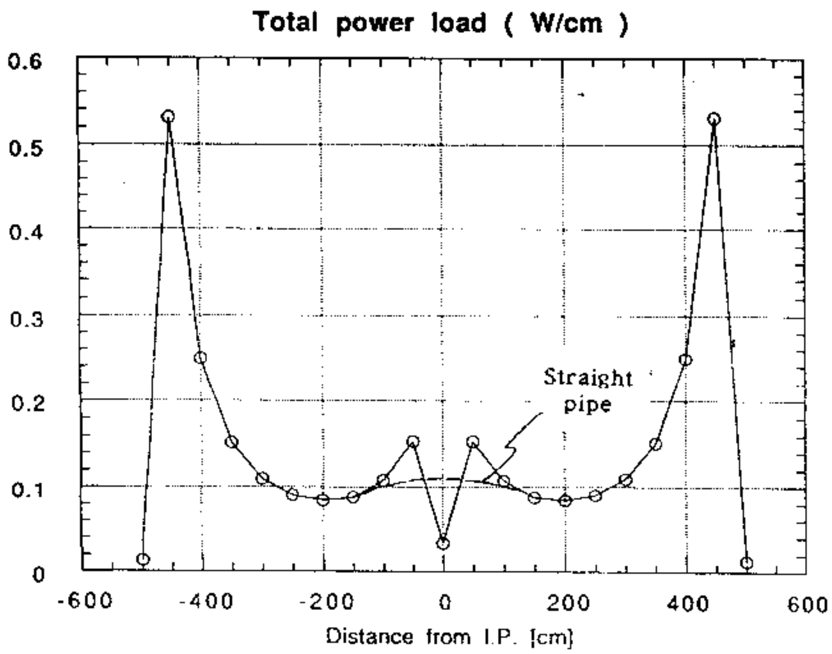
We will assume full current of 5.5 A and 120 bunches. For day 1 operation these values will be lower by about a factor of three.

I. Power Dissipation

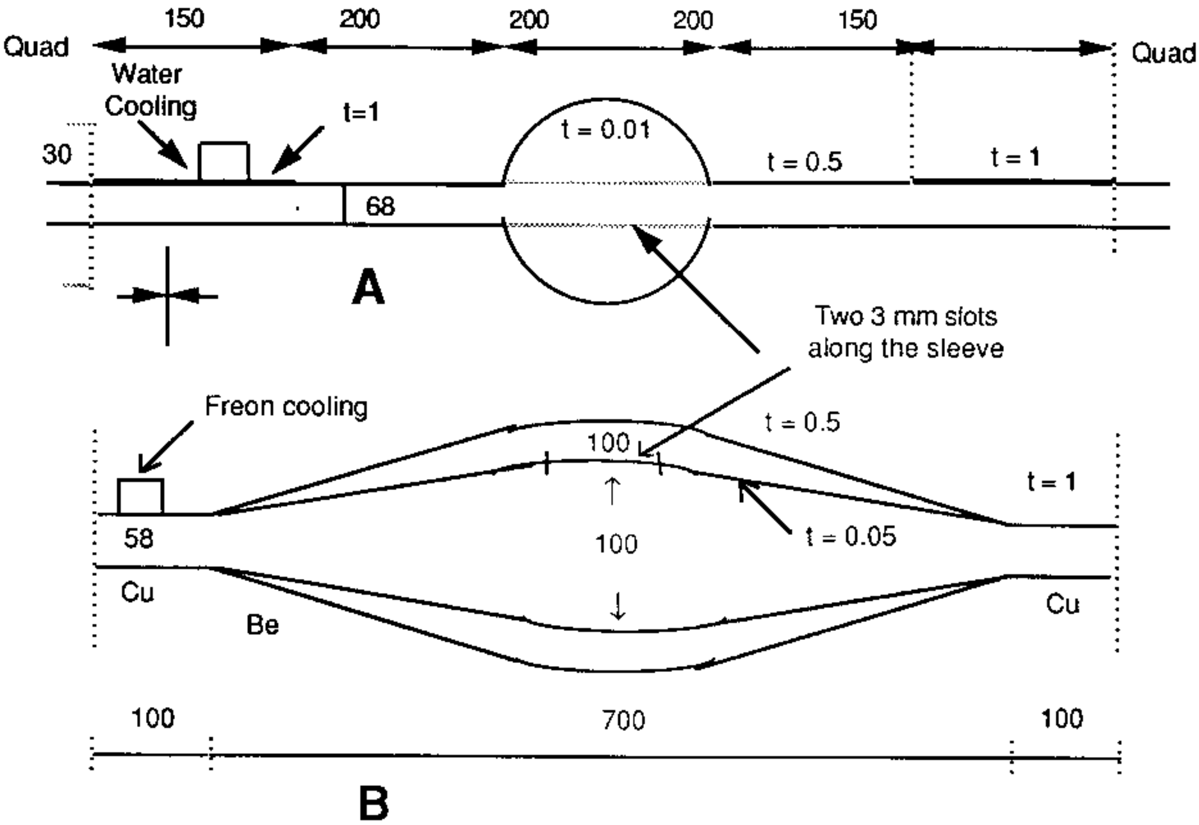
Let us start by calculating the temperature along the beam pipe to see how much heat has to be removed. The two main sources of heat are:

1) Resistive losses due to the circulating beams which can be determined from Appendix I and,

2) Heating by photons due to synchrotron radiation from all magnets (Fig. 1).



- FIG. 1 -



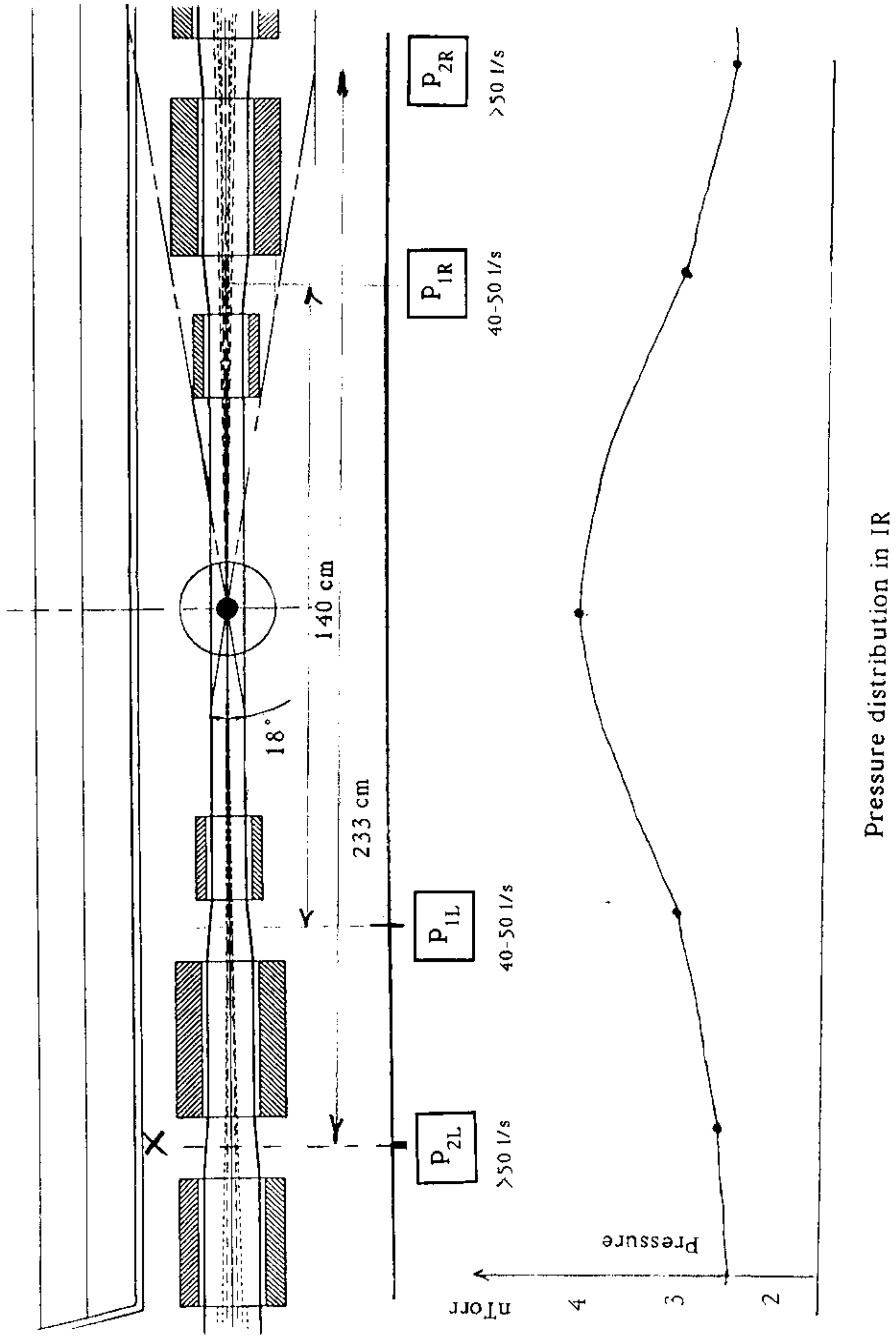
- Fig. 2 -

In Fig. 2 we show two possible boundary solutions. In both cases the temperature difference between the cooling channel and the center ΔT is in the order of 100 °C. The total RF power, dissipated in the 10 µm tube, is ~ 5 W (Appendix IA) and in the 50 µm tube is ~ 10 W (Appendix IB).

The advantage of the 2B solution is twofold: no synchrotron radiation is incident on the 70 cm length of Be tube but is absorbed right at the cooling coil which is obviously preferred.

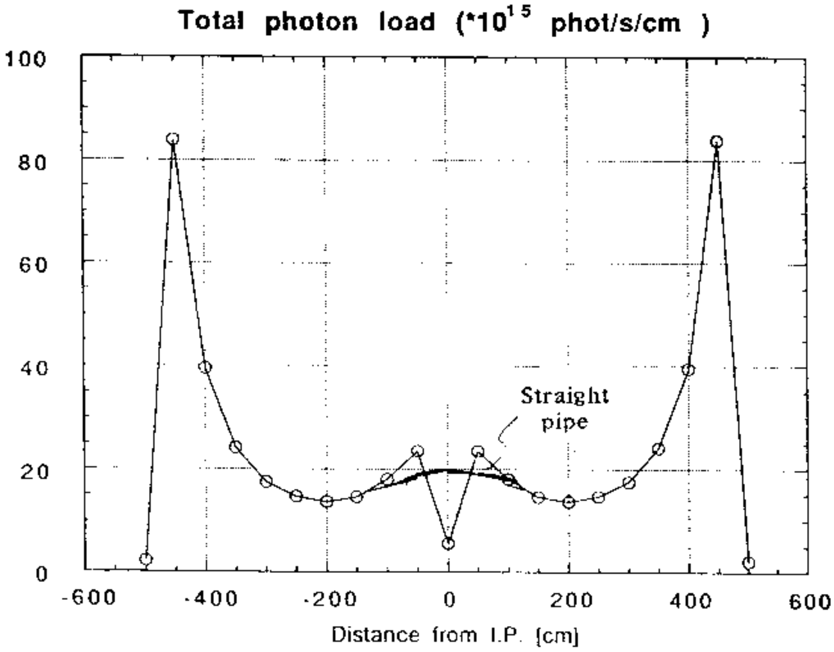
The remaining beam tube in the detector is made of Cu rather than stainless to reduce RF heating by a factor of 6.4 and to increase heat conductivity by a factor of 25. Only a moderate amount of cooling (<100 W) to remove the RF and photon heat is now required.

Needless to say much work needs to be done in this area.



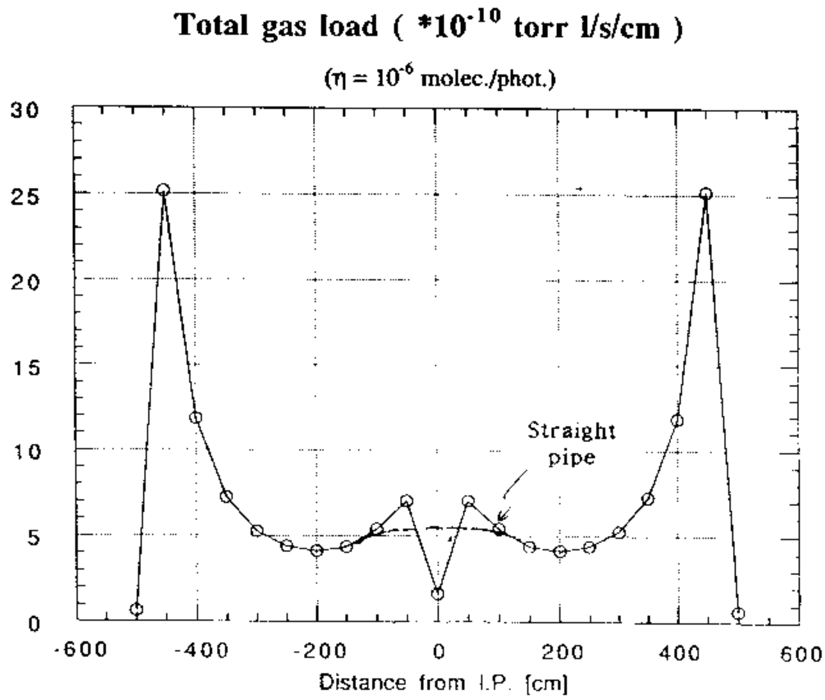
P_{2R}
>50 l/s
P_{1R}
40-50 l/s
140 cm
18°
233 cm
P_{1L}
40-50 l/s
P_{2L}
>50 l/s
Pressure
nTorr
4
3
2
Pressure distribution in IR

- FIG. 3 -



Total photon load (*10^15 phot/s/cm)
100
80
60
40
20
0
-600
-400
-200
0
200
400
600
Distance from I.P. [cm]
Straight pipe

- FIG. 4 -



Total gas load (*10^-10 torr l/s/cm)
(η = 10^-6 molec./phot.)
30
25
20
15
10
5
0
-600
-400
-200
0
200
400
600
Distance from I.P. [cm]
Straight pipe

- FIG. 5 -

II. Gas load and Pumping

In Fig. 3 we calculate the pressure distribution in the interaction region using all 4 possible locations for pumps. We assume distributed ion pumps (DIPs) using the existing solenoidal field. High capacity NEG pumps could also be used. Both pumps need to be studied to decide which type would be better suited.

Extrapolating from BNL plate DIP_s [Ref. 1] we may, if we are lucky, achieve an effective pumping speed S of 40 l/s and 50 l/s for P_{1L}, P_{1R} and P_{2L}, P_{2R}, respectively (Fig. 3), since they have to operate in low 10^{-10} Torr range.

The pressure distribution computed in Fig. 3 is based on Figs 4 and 5 using photons above 10 eV, $\eta = 1 \cdot 10^{-6}$ and thermal outgassing of hot Beryllium of $1 \cdot 10^{-11}$ Torr l s^{-1}. The pressure obtained is an order of magnitude higher than desired and illustrates the main problem, i.e. not enough space for pumps in the entire 10 m Interaction Region.

A decrease in ΔP is realized by preventing the photons from hitting the Be tube (Fig. 2B). In addition the gas conductance is also increased. IP pressure of less than $1 \cdot 10^{-9}$ will thus be achieved in "Day One" operation with 2A. But the entire straight section has to be worked on to achieve the desired pressure in 10^{-10} Torr range at full current.

Substantial gains must be realized in radiation shielding and in providing more space for more pumps. Since low 10^{-10} Torr range is desired, other options like TSPs and NEGs should be investigated if solenoidal DIPs have too low pumping speed.

Acknowledgment

I would like again to thank Pina for her making the drawing, correcting my mistakes and all the help given generously and cheerfully. I don't know how my notes could be written without her.

References

[1] T.S. Chou, J. Vac. Sci. Technol. 5(6) 3446 (1987).

APPENDIX IA

Losses in the I.R.

1) *Resistive losses in Be:*

$$\frac{dp}{dz} = 0.204 \, \frac{W}{\text{m x pair of bunches}}$$

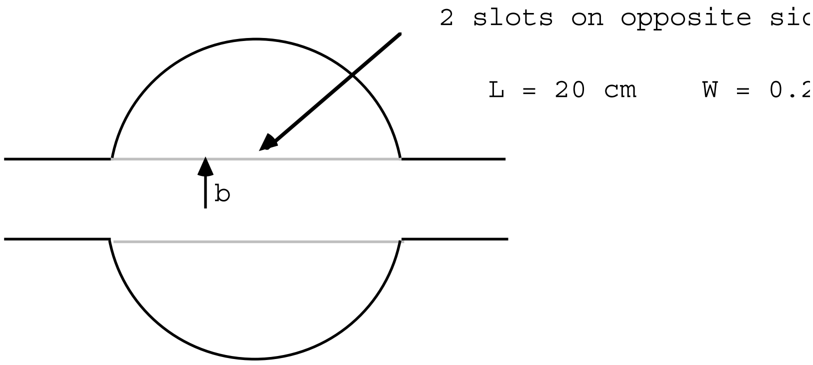
In this case: σ = 3 cm; radius of beam pipe b = 3.4 cm.
Losses scale as $\sigma^{-3/2}$; $\sqrt{\rho}$; $\frac{1}{b}$.
$\rho = 4.57 \cdot 10^{-6}\ \Omega$ cm.

2) *RF losses:*

a) because of 2 tapers (on the both sides):

$$P = 0.4 \, \frac{W}{\text{pair of bunches}} \text{ (dissipated not in the IR)}$$

b) because of slots in the IR



$$\Delta P = 0.00106 \, \frac{W}{\text{pair of bunches}}$$

The increase in dissipated power, ΔP, is therefore negligible.

APPENDIX IB

RF Losses

$$\frac{P}{\text{bunch}} = \langle I_o\rangle^2 K_e T_o$$

$\langle I_o\rangle$ average current = 0.044 A

T_o revolution period = $\frac{2\pi R}{c} = \frac{97.69}{3\ 10^{-8}} = 32.564\ 10^{-8}$

K_e loss factor given by TBCI code

$$K_e = 3.924\ 10^7\ \frac{v}{c}$$

$$\frac{P}{\text{bunch}} = (0.044)^2 \cdot 3.924\ 10^7 \cdot 32.564\ 10^{-8} = 0.02474\ \text{W}$$

$$\frac{RF}{P_{total}} = \frac{P}{\text{bunch}} \cdot 240 = 5.93\ \text{W};$$

$$P = P^{RF} = P_{resistive} \approx 6 = 4\ \text{W} = 10\ \text{W}.$$

APPENDIX 1

Losses in the I.R.

1. Resistive losses in the RF shielding.

Resistive wall impedance per unit length of a round beam pipe with a radius b made of a material with resistivity ρ is given by :

$$Z'_{RW} = \begin{cases} \dfrac{1 - j}{2\pi b}\sqrt{\rho \dfrac{Z_0 \omega}{2c}} & \text{if } s > \delta_s \\ \dfrac{\rho}{s}\dfrac{1}{2\pi b} & \text{if } s < \delta_s \end{cases} \tag{1}$$

where s is thickness of the beam pipe wall and δ_S is a skin-depth.

Then we can define a loss factor per unit length as:

$$k'_{RW} = \frac{1}{\pi}\int_0^{\infty} \mathrm{Re}\{Z'_{RW}\}\, e^{-(\omega\sigma/c)^2}\, d\omega \tag{2}$$

or using (1):

$$k'_{RW} = \frac{c}{2\pi^2 b\sigma}\left\{\frac{\rho}{s}\int_0^{\omega^*\sigma/c} e^{-x^2} dx + \sqrt{\frac{\mu_0 \rho c}{2\sigma}}\int_{\omega^*\sigma/c}^{\infty} \sqrt{x}\, e^{-x^2} dx\right\} \tag{3}$$

where σ is rms bunch length; ω^* is a frequency at which the skin-depth is equal to thickness of the beam pipe wall:

$$\omega^* = \frac{2\rho c}{Z_0 s^2} \tag{4}$$

Dissipated power per unit length of the beam pipe is given by:

$$\frac{dP}{dz} = \frac{(eN)^2 k'_{RW} n_b}{T_0} \tag{5}$$

where T_0 is revolution period, n_b is number of bunches.

To avoid RF radiation special Be screen of 10 μm thickness was proposed. Its radius is equal to the beam pipe radius b=3.4 cm and the length is about L = 20 cm, allowing to shield spherical part of the vacuum chamber in the IR .

For 10 μm of Be $\omega^* = 0.727$ GHz and $\omega^*\sigma/c = 0.0727$ (at $\sigma = 3$cm).

The first term in (3) is equal to $4.95*10^6$ V/C*m. As far as $\omega^*\sigma/c$ is small we can replace the lower limit of the integral in the second term by 0 and get:

$$k_{RW}^{secondterm} = \frac{c}{4\pi^2 b \sigma^{3/2}} \sqrt{\frac{Z_0 \rho}{2}}\, \Gamma(3/4) \tag{6}$$

where $\Gamma(x)$ is a gamma-function.

For out set of parameters $k_{RW} = 1.6*10^8$ V/C*m and resistive losses per unit length:

$$\frac{dP}{dz} = 0.204 \frac{W}{m*\text{pair of bunches}} \tag{7}$$

Total resistive loss in the Be shielding is P=4.8 W (L=20 cm, nb=120 in each beam).

It is worthwhile to note that resistive losses scale as $\sigma^{-3/2}$, $\rho^{1/2}$, b^{-1}.

2. RF radiation due to pumping slots.

For the pumping purposes two slots of the 2 mm width along the Be shielding are needed.

The real part of the impedance introduced by a slot is (S. S. Kurennoy, CERN SL/91-29 (AP)):

$$\mathrm{Re}\,\{Z(\omega)\} = \frac{Z_0}{3072\,\pi} \left(\frac{w\,\omega}{c}\right)^4 \frac{l^2}{b^2} \tag{8}$$

where w and l are the width and length of the slot, correspondingly.

The loss factor which corresponds to the impedance is given by:

$$k_l = \frac{Z_0}{3072\,\pi^2} \frac{l^2\,w^4\,c}{b^2\,\sigma^5} \frac{\Gamma(5/2)}{2} \tag{9}$$

and the radiated RF power is:

$$P = \frac{(eN)^2\,k_l\,n_b}{T_0} \tag{10}$$

For given slots the loss factor is equal to $8.5*10^3$ V/C and RF radiated power $1.3*10^{-3}$ W. We should expect even smaller losses than those predicted by (8-10) when the length of a slot is much longer the the width of it. Numerical calculation show that the longitudinal loss factor practically does not depend on the slot length for long slots.

So we can neglect RF losses in comparison with resistive losses in Be shielding.