Note on the magnet design and the positron spectrometer simulation for the $\mu \to \mathrm{e} + \gamma$ search at PSI

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1 Introduction

We present some new considerations on the magnet design for the positron spectrometer of the $\mu \to \mathrm{e}+\gamma$ search at PSI. This proposed design minimizes the stray magnetic field in the Xenon calorimeter PMT region. Extensive Monte Carlo simulations were performed to study the implications of the field configuration on the positron tracking, on the drift chamber occupancy and on the angular, spacial and momentum resolutions . The results are compared with the corresponding ones quoted in the proposal [1].

2 The magnet design

We aim at a magnetic field having the nice characteristics presented in the proposal, namely a quick drifting away of the positrons from the wire chamber area and a trajectory transverse radius largely independent of the positron initial direction. At the same time we must respect the constraints of a low stray field in the E.M. calorimeter region and of the smallest amount of material along the photon path to the Xenon calorimeter.

We propose to build a coil whose surface follows the magnetic field lines so that the magnetic field flux is not dispersed outside. This configuration minimizes the field in the calorimeter region.

A coil profile achieving this aim is shown in the (r-z) plane defined by the radial and the beam directions; figure 1b is the new coil profile, figure 1a is the “sandglass shape” of the proposal; the coil of figure 1b is somewhat longer than the one of figure 1a.

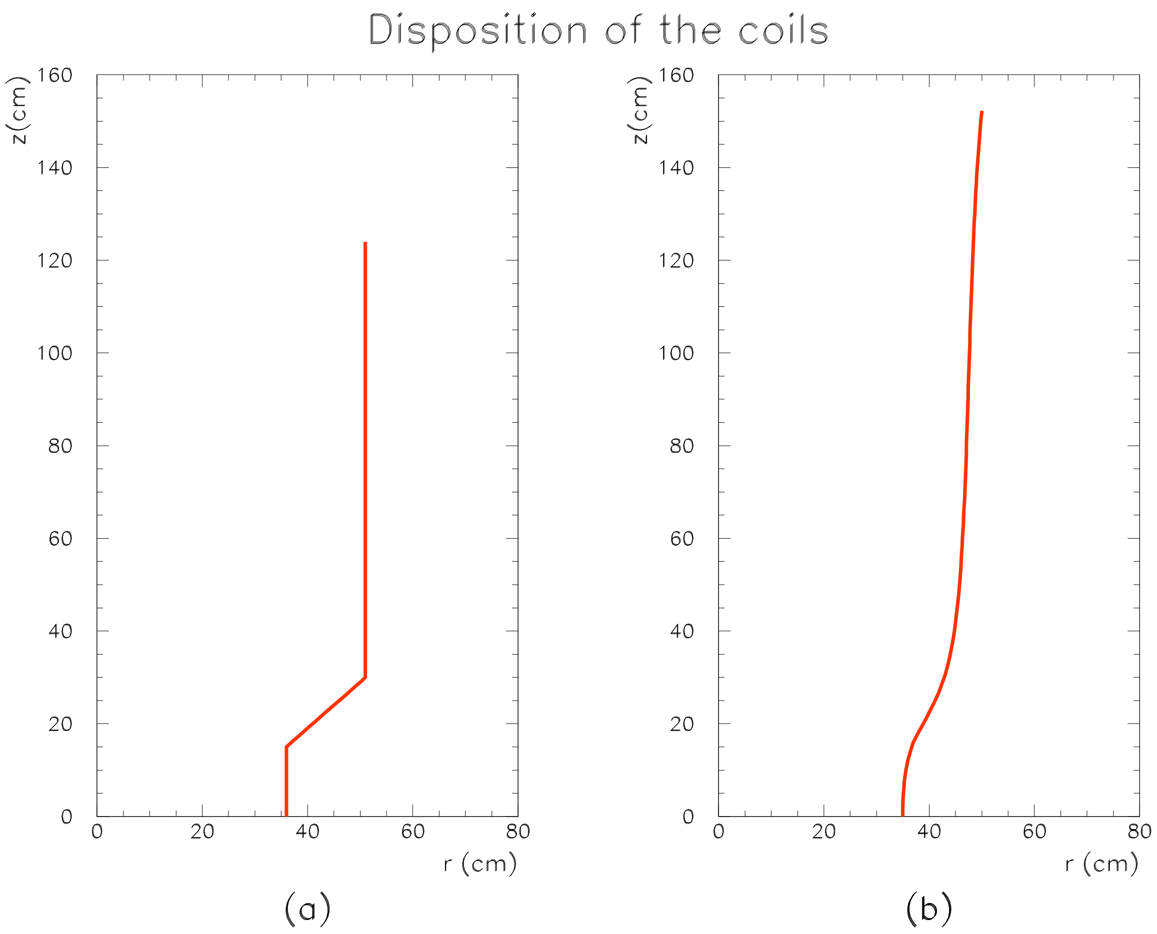

Figure 1: Coils profiles: a) Proposal b) This note

The current density in the coil must be a function of z. To the first order, it is proportional to the z–component of the magnetic field along the symmetry axis. The required field is reached by means of an iterative procedure.

Figure 2b shows B_z along the z–axis; it is again compared with that of the proposal.

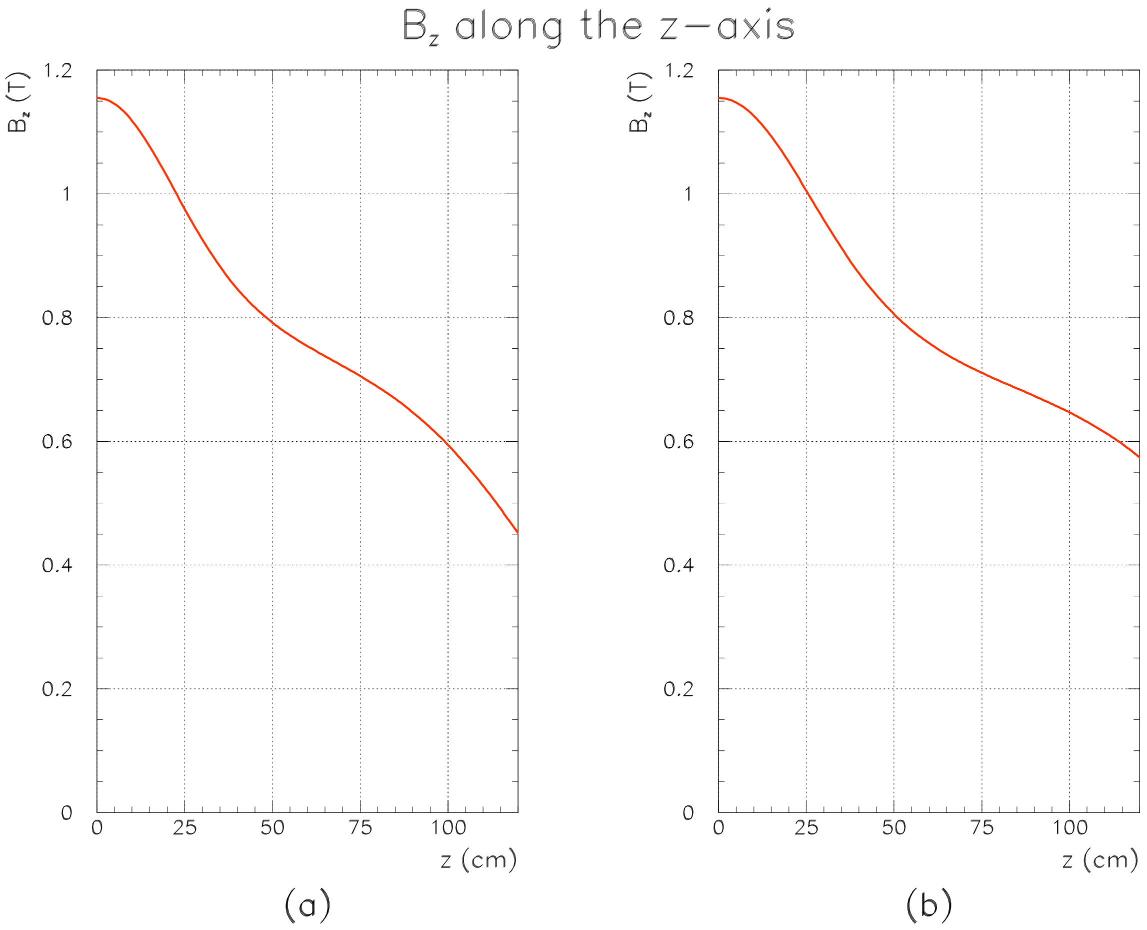

Figure 2: B_z as a function of z: a) Proposal b) This note

The field intensity in the r–z plane is shown in figure 3 for the two cases.

We remark that this is just one possible magnetic field configuration. If further studies point to a different optimization of the field configuration, this could be easily obtained too.

An iron yoke composed by two ring end-plates connected by two side-plates is being studied. By adequate sizing this yoke it is possible to reduce the stray field in the region of the E.M. calorimeter down to values $\lesssim 10\,\mathrm{G}$. The photon production due to the positrons interaction in the iron end-plates must be carefully evaluated and steps taken in order to minimize the

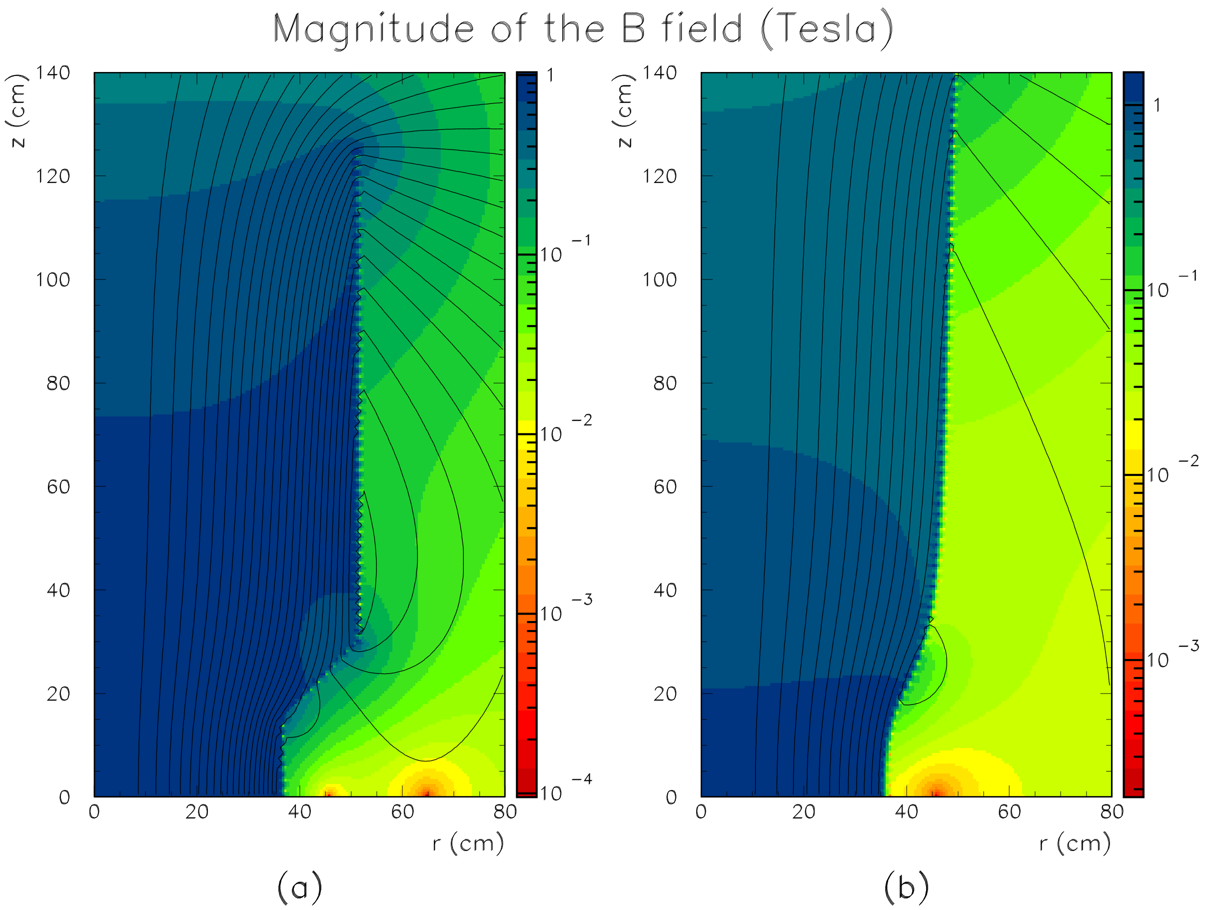

Figure 3: Field intensity and lines: a) Proposal b) This note

corresponding background.

The magnetic forces acting on the coil (shown in Fig.4b) are perpendicular to its surface (except at the edges) since the field lines were required to be parallel to it.

Profiting of the curved shape of the coil and of the limited size of the region crossed by photons within the angular acceptance we are very confident that the total thickness crossed by a photon travelling from the target to the E.M. calorimeter can be kept under $2.7\,\mathrm{g/cm^2}$.

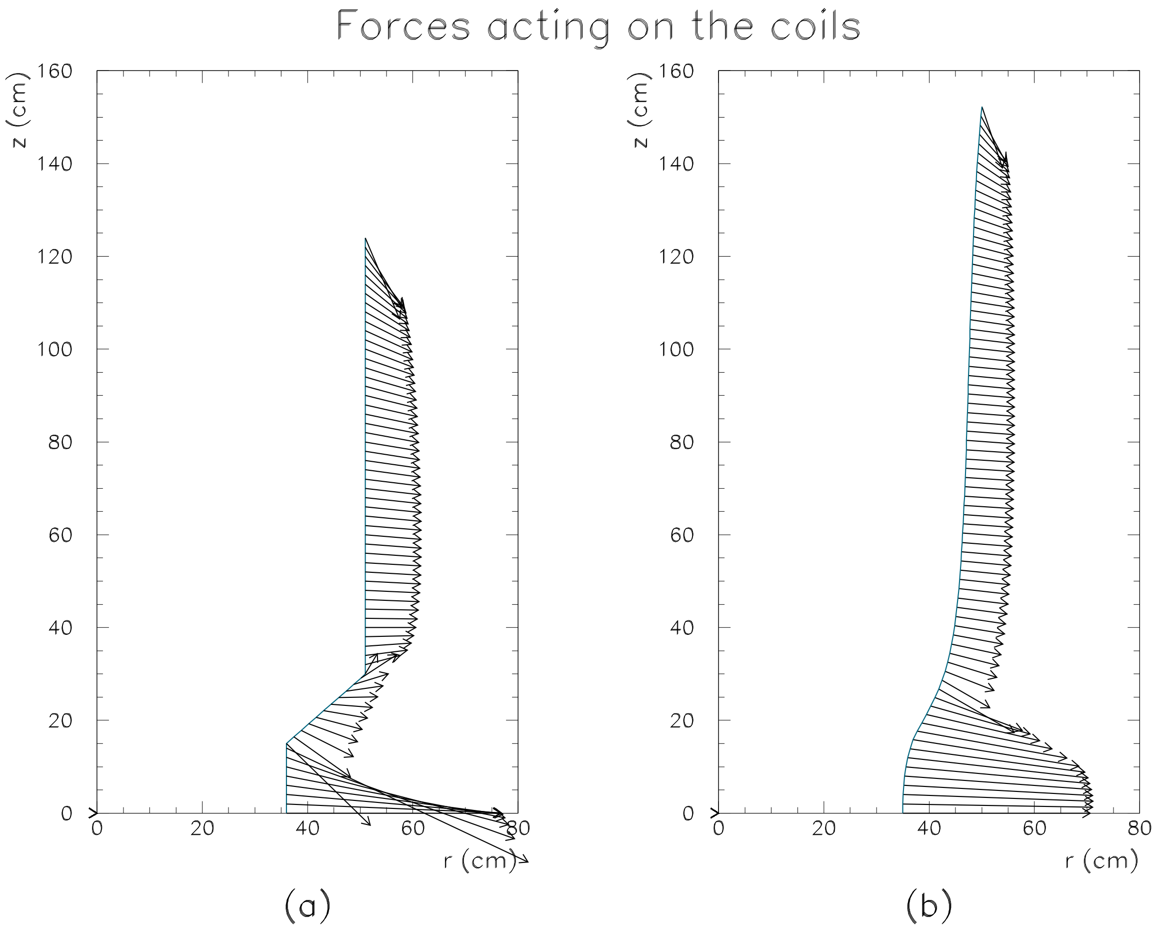

Figure 4: Magnetic forces acting on the coils: a) Proposal b) This note

3 The positron spectrometer

The effect of the modified field on the positron trajectories was studied by the Monte Carlo method. The results are shown in the following sections.

3.1 Field and detector simulation

A detailed simulation of the positron spectrometer was obtained by the use of the CERN GEANT package (3.21 version)[2]. The detector, according to the proposal prescriptions, consists of:

- Muon Target: a stopping target of 100μm thick mylar, placed at the detector centre with a slant angle of 22^o with respect to the beam axis (the target region being filled with Helium);

- Chamber System: 17 drift chamber sectors, of trapezoidal shape, radially aligned at 10^o intervals in azimuthal angle. Each chamber is made of two 7.5 cm–wide gas layers (an equal mixture of Helium and Ethane) separated by three 10μm-thick Kapton foils;

- Timing Counters: two plastic scintillator arrays, placed on both sides of the chamber system, with $210^o < \phi < 330^o$ and $27 < |z| < 125$ cm.

Radial and axial field components are evaluated for the new and the proposal field configurations by exact computation of elliptical integrals. Figure 5 shows that the positron bending radius is independent of its emission angle, as required.

3.2 Drift chamber occupancy

Fig. 6 shows the hit rate per unit surface, for Michel positrons, as a function of radius, in the case of a muon decay rate of $10^8\,\mathrm{s}^{-1}$. The chamber occupancy turns out to be similar to that obtained with the proposal field, but the results shown in the proposal (black dots in fig. 6) do not agree with our computation.

3.3 Momentum determination

The positron tracking is based on a minimization procedure using MINUIT[3]. For each set of the five fit parameters (3 momentum components + 2 decay coordinates) the positron track is accurately traced in the non-uniform field by means of the fourth-order Runge-Kutta formulae[4]. A χ^2 is built with the

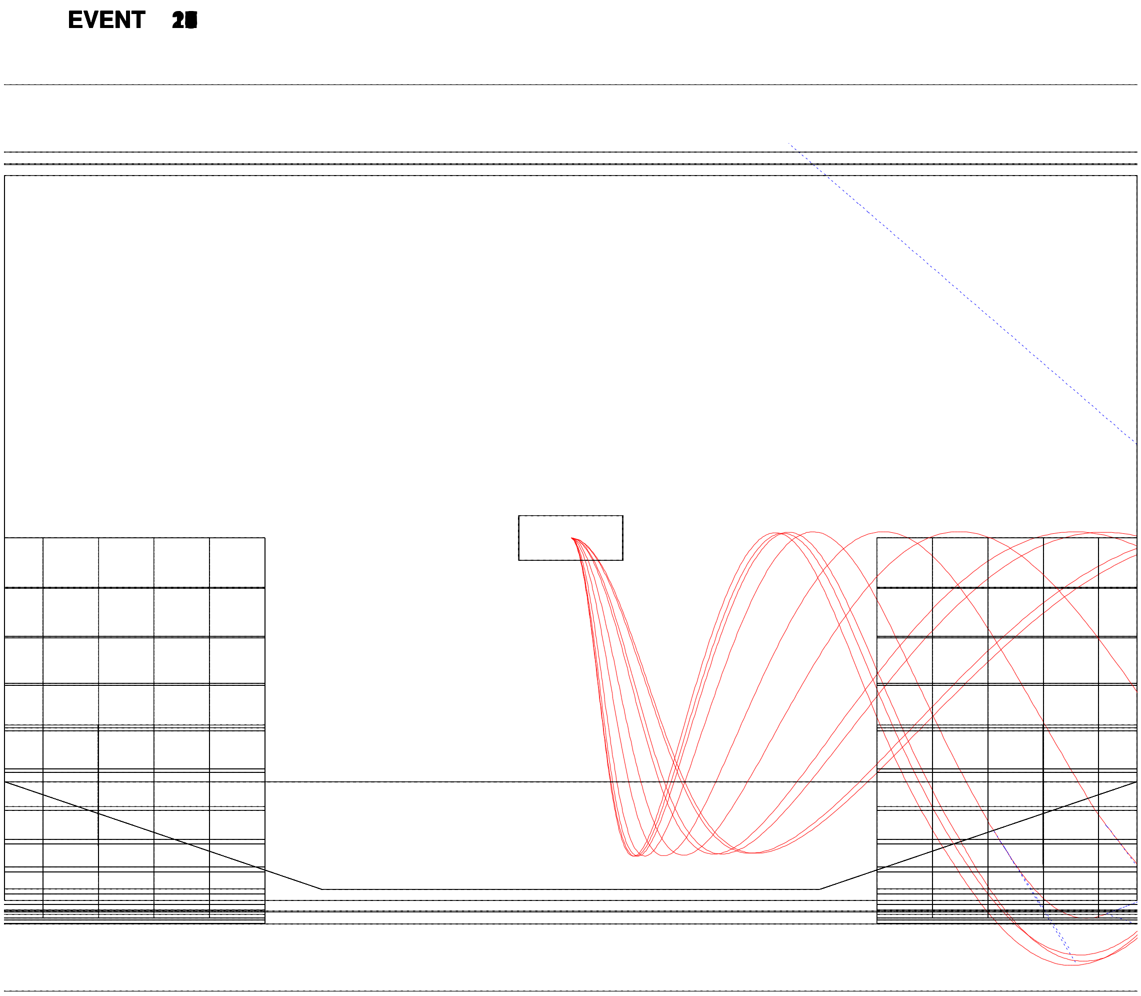

Figure 5: Positron trajectories in the modified magnet design

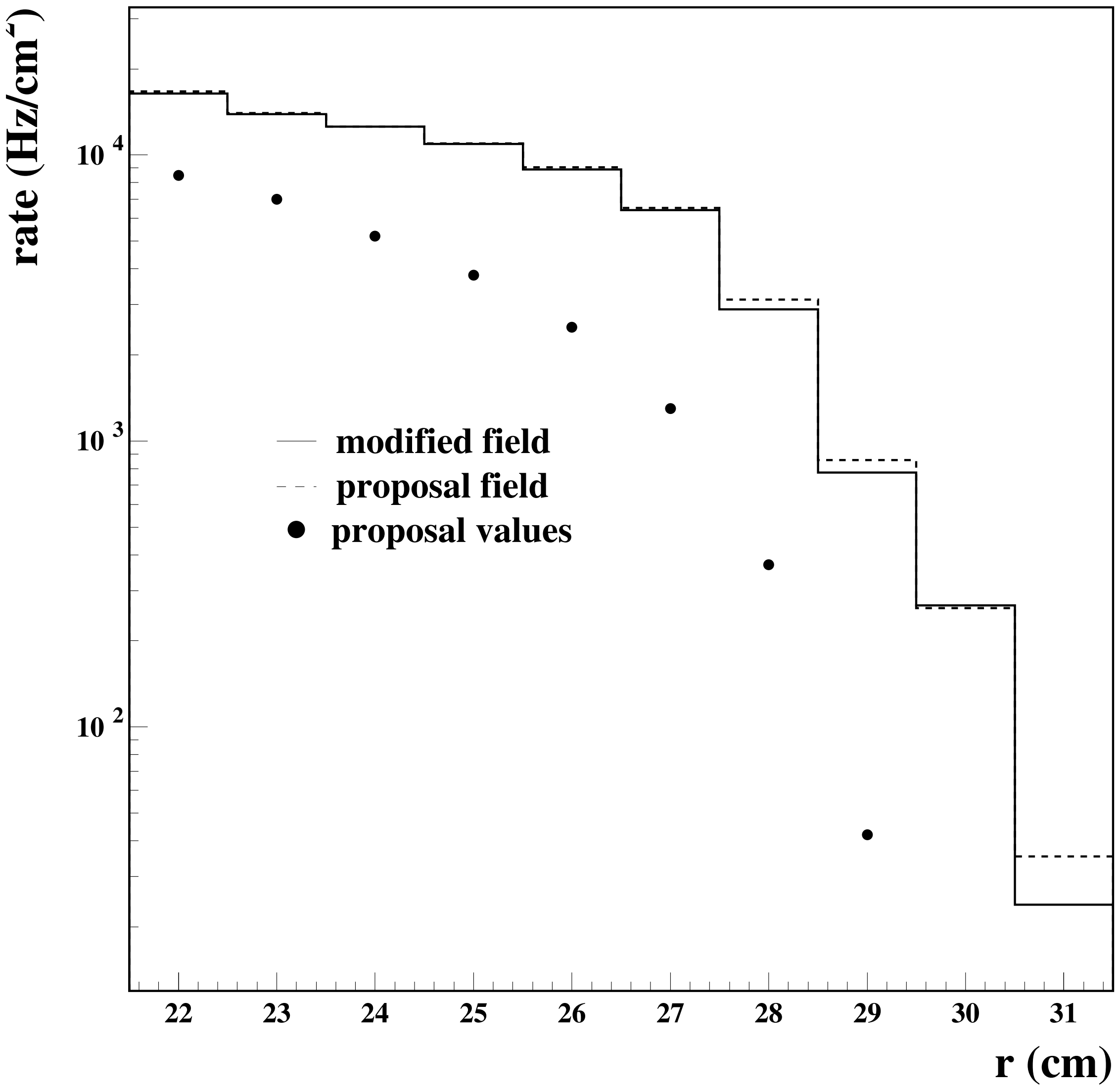

Figure 6: Hit rate of Michel positrons as a function of radius for a muon decay rate of $1 \times 10^8\,\mathrm{s}^{-1}$.

differences of the "measured" hits and the "trajectory" hits. The "measured" hits are the ones produced by the Monte Carlo simulation, which keeps into account all physical effects like the multiple scattering, etc. The "trajectory" hits are the intercepts of the trajectory with the chambers, after the tracking procedure; the error on the position of each point is obtained by composing the one due to the intrinsic chamber accuracy with the one associated with the tracking (about one half of the previous one). We assumed full chamber efficiency.

The parameters of the fit are listed in Tab. 1. The resolutions on each fit parameter, for both field configurations, were obtained for positrons from $\mu \to \mathrm{e} + \gamma$ decays emitted within the angular acceptance ($0.08 < |\cos\theta| < 0.35$, $-60^o < \phi < 60^o$) and corresponding to a "good-fit event sample" ($\chi^2 < 10$, which introduces a 15% inefficiency); they are also listed in the table. The results are compared with the ones of the proposal. It turns out that the

Table 1: Resolution values (FWHM) obtained by positron reconstruction on both field configurations. The values quoted in the proposal are also listed for comparison.

Fit parameters	Modif. field	Proposal field	Proposal values
$\lvert\vec{p}\rvert$(MeV/c)	0.48 (0.9%)	0.47 (0.9%)	0.37 (0.7%)
azimuthal angle (mrad)	16	17	9
zenith angle (mrad)	11	12	
$\delta\Theta^*$ (mrad)	11	12	
x_0 (mm)	1.2	1.3	
y_0 (mm)	3.3	3.3	

$*$ $\delta\Theta$ is computed as the half-aperture of the cone containing 76% of the positrons along the known photon direction.

resolution on each variable does not depend on the particular magnetic field chosen. However, the angular resolution on the positron direction appears to be about 1.5 times worse than the value quoted in the proposal.

3.4 Timing counters

We studied the correlation of the positron impact time (relative to the time of the muon decay) on the scintillation counters versus the z–coordinate for positron from $\mu \to \mathrm{e} + \gamma$ decay in the accepted angular range. The beam spot size ($\sigma_x = \sigma_y = 0.5\,\mathrm{cm}$) introduces a spread on the impact position of $\sigma_z \approx 1.2\,\mathrm{cm}$, which is twice as large as the one due to multiple scattering.

As shown in Fig. 7a), this correlation is quite similar to that appearing in the proposal in the case of a point-like target. The extended target case (Figs. 7b,c) corresponds to a weaker correlation.

4 Conclusions

This note contains some new considerations on a magnet fulfilling the requirements imposed by a $\mu \to \mathrm{e} + \gamma$ experiment aiming at a sensitivity of $BR = 10^{-14}$. If the responsibility of the magnet were assigned to our group, we would be able to complete its technical design by this summer. A smaller size prototype should be built within one year in order to test the mechanical properties of the proposed set-up.

A careful study of the spectrometer, based on a full Montecarlo simulation, gives values for the resolutions which are somewhat different from the ones quoted in the proposal.

Acknowledgements

We warmly thank Mr G. Pozzo for the very useful discussion we recently had at CERN.

References

[1] T. Mori *et al.*, *Search for* $\mu \to \mathrm{e} + \gamma$ *down to* 10^{-14} *branching ratio*, proposal to PSI (1999)

[2] GEANT Reference Manual, vers. 3.21 (1993)

[3] F. James, MINUIT Reference Manual, vers. 94.1 (1994)

[4] W. H. Press *et al.*, *Numerical Recipes*, Cambridge University Press

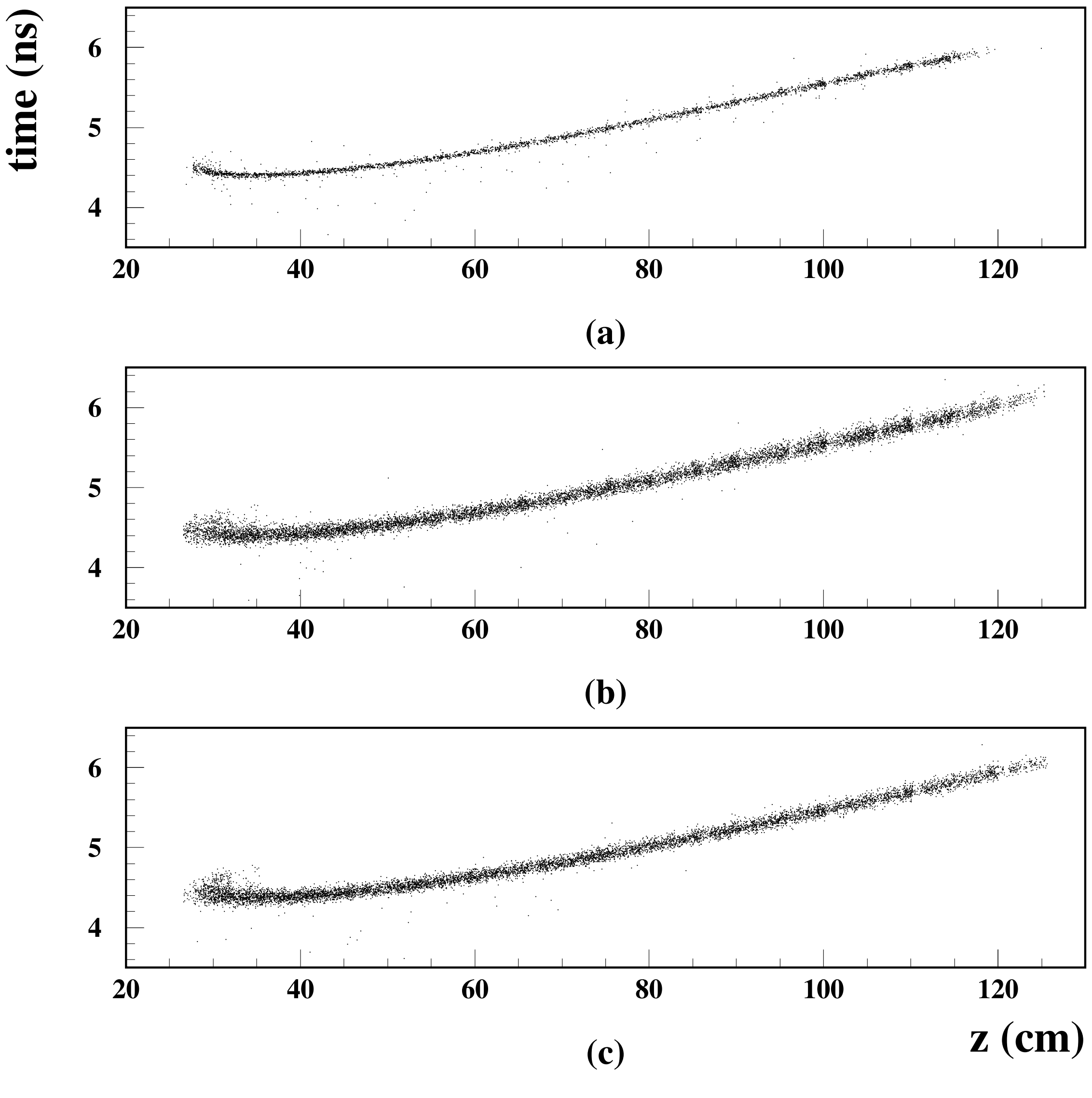

Figure 7: Correlation between impact time and z-coordinate: a) Proposal field, point-like target b) Proposal field, extended target c) Modified field, extended target.