PHIN

Report on 1 GeV Electron Spectrometer

Deliverable 2007-31 (PHIN)

V. Malka, J. Faure, Y. Glinec

Laboratoire d'optique appliquée, CNRS-X-ENSTA, 91761 Palaiseau, France

A. Ben Ismaïl, A. Specka, H. Videau

Laboratoire Leprince Ringuet, CNRS-X, 91128 Palaiseau, France

Abstract

A single shot compact electron spectrometer has been developed in order to measure the electron spectrum that will be produced in future laser plasma accelerator experiments. Electron beams produced in such accelerators have an energy distribution which is composed by a thermal distribution at low energy and by a quasi mono-energetic peak at high energy. For this purpose, this broadband spectrometer has been design in order to give access to the full electron energy distribution.

Contents

1. Introduction

Plasma-based accelerators have been proposed for the next generation of compact accelerators because of the huge electric fields they can support. By focusing light pulses containing a few joules of energy in a few tens of femtoseconds onto gas jets, extremely large electric fields can be generated, reaching the teravolts per metre level. As a result, the length over which electrons extracted from the target can be accelerated to hundreds of MeV is reduced to a few millimetres. The reduction of the size and the cost of laser-plasma accelerators is a promising consequence, but these electron beams also reveal original properties, which make them a wonderful tool for science. By adjusting the interaction parameters, the electron energy distribution can be tuned from a maxwellian-like distribution to a quasi-monoenergetic one. The new properties of these laser-based particle beams are well suited to many applications in different fields, including medicine (radiotherapy), chemistry (ultrafast radiolysis), material science (non-destructive material inspection using radiography) and, of course, for accelerator physics. The purpose of our contribution in the project was the development of these new accelerator techniques and we report here on the design of a compact single shot broadband electron spectrometer at one GeV. This spectrometer is of crucial importance because it provides the full electron energy distribution in a single shot. Thus, it will permit to measure the evolution of the distribution, as a function of the experimental parameters. Such optimisation of the distribution from Maxwell-like to the ideal mono energetic distribution will be performed by changing the laser and plasma parameters.

2. Spectrometer description

The spectrometer is based on a compact 40 cm long permanent magnet and on the use of three phosphor (Kodak lanex screen film) screens that are used to image the spatial and energy distribution of the electron beam. The lanex scintillateur screens are imaged with a high quality Nikon optics onto a high dynamic (16 bit) Andor CCD camera. A schematic view of the spectrometer is illustrated on figure 1.

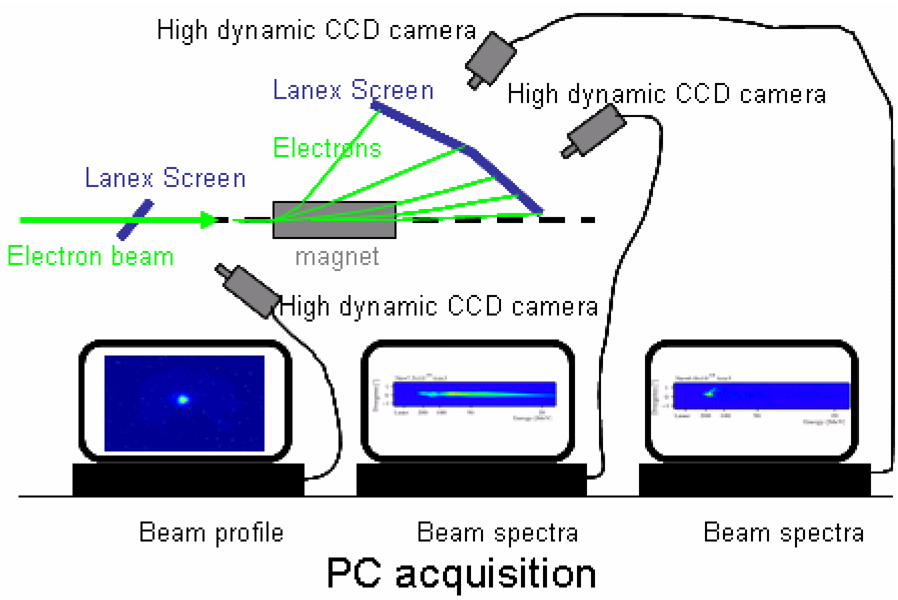

Figure 1 : scheme of principle of the 1 GeV electron spectrometer

The first scintillator screen located on the electron beam axis is used to define precisely the electron position in order to avoid errors on the electron beam energy. The two others scintillator screens are used to cover a wide range of energy. Table 1 gives the characteristics of the scintillator.

Item	Materiel	Density (g/cm^3)	Thickness (cm)
Laser shielding	aluminium	2.7	0.01
Kodak lanex fine screen			
Protective coating	Cellulose acetate	1.32	0.001
Plastic subtrate	Poly (ethylene terephtate)	1.38	0.0178
scintillator	Gd_2O_2S+urethane binder	4.25	0.0084
Protective coating	Cellulose acetate	1.32	0.0005

Table 1 : composition of the phosphor screen

The emission of the phosphor screen has been calibrated using a RF accelerator (ELYSE, Université d'Orsay) for electrons between 3 and 10 MeV (see reference: *"Absolute calibration for a broadrange single-shot electron spectrometer";* Y. Glinec, J. Faure, A. Guemnie-tafo, V. Malka, H. Monar, J.-P. Larbre, V. de Waele, J. L. Marinier and M. Mostofavi; Rev. Sci. Inst. **77**, 103301 (2006))

2. 1 Magnet parameters

The magnet has been commissioned by TE2M. The magnetic circuit has been designed in order to provide a homogeneous magnetic field. Simulations of the circuit are shown on figure 2. On figure 3 we show the front view of the magnet.

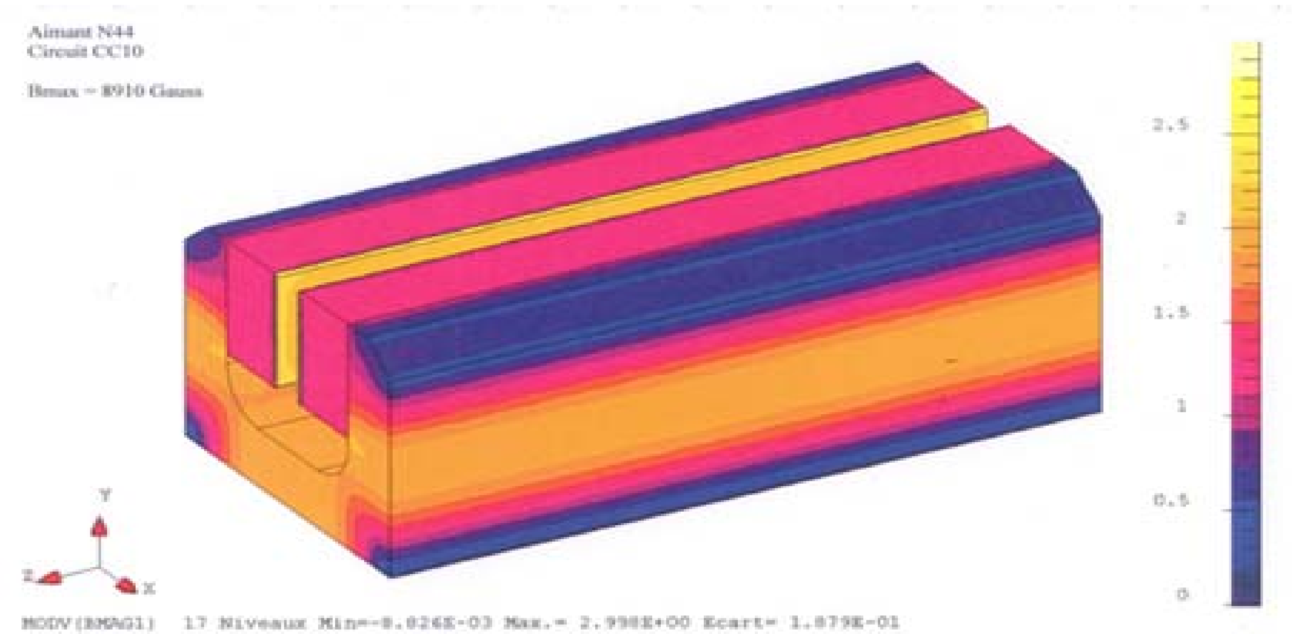

Figure 2 : Circuit magnet

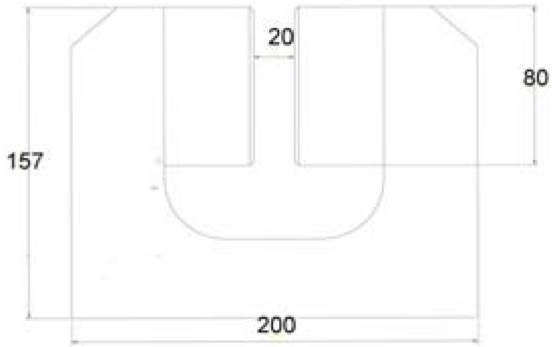

Figure 3 : Front view of the magnet

Nominal magnetic field	B_m	0.9 T
Magnet Length	L_m	40 cm
Magnet Width	l_m	8 cm
Magnet shift	δl_m	4 cm
Magnet Lanex length	D_l	55 cm
Source Magnet length	D_s	10 cm

Table 2 : 40 cm magnet dimensions

2. 2 Magnet field simulations

The magnetic field has been simulated into the magnet in both the longitudinal and transverse dimensions. These simulations are shown in figure 4.

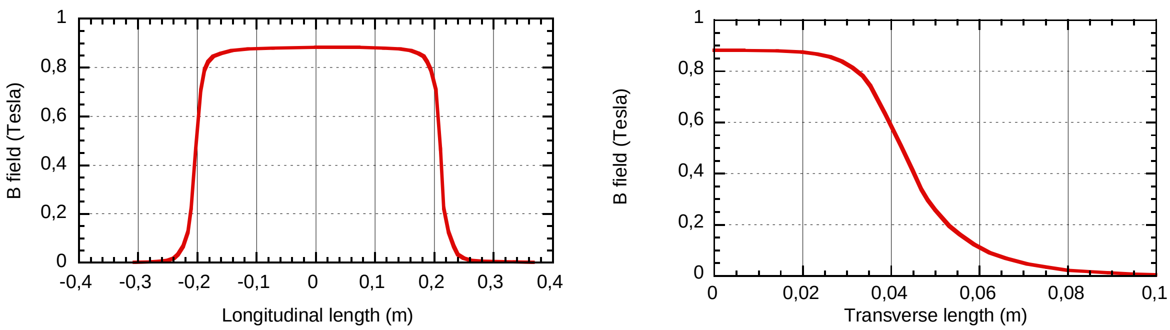

Figure 4 : B field values along the longitudinal (left) and transverse coordinate (rigth).

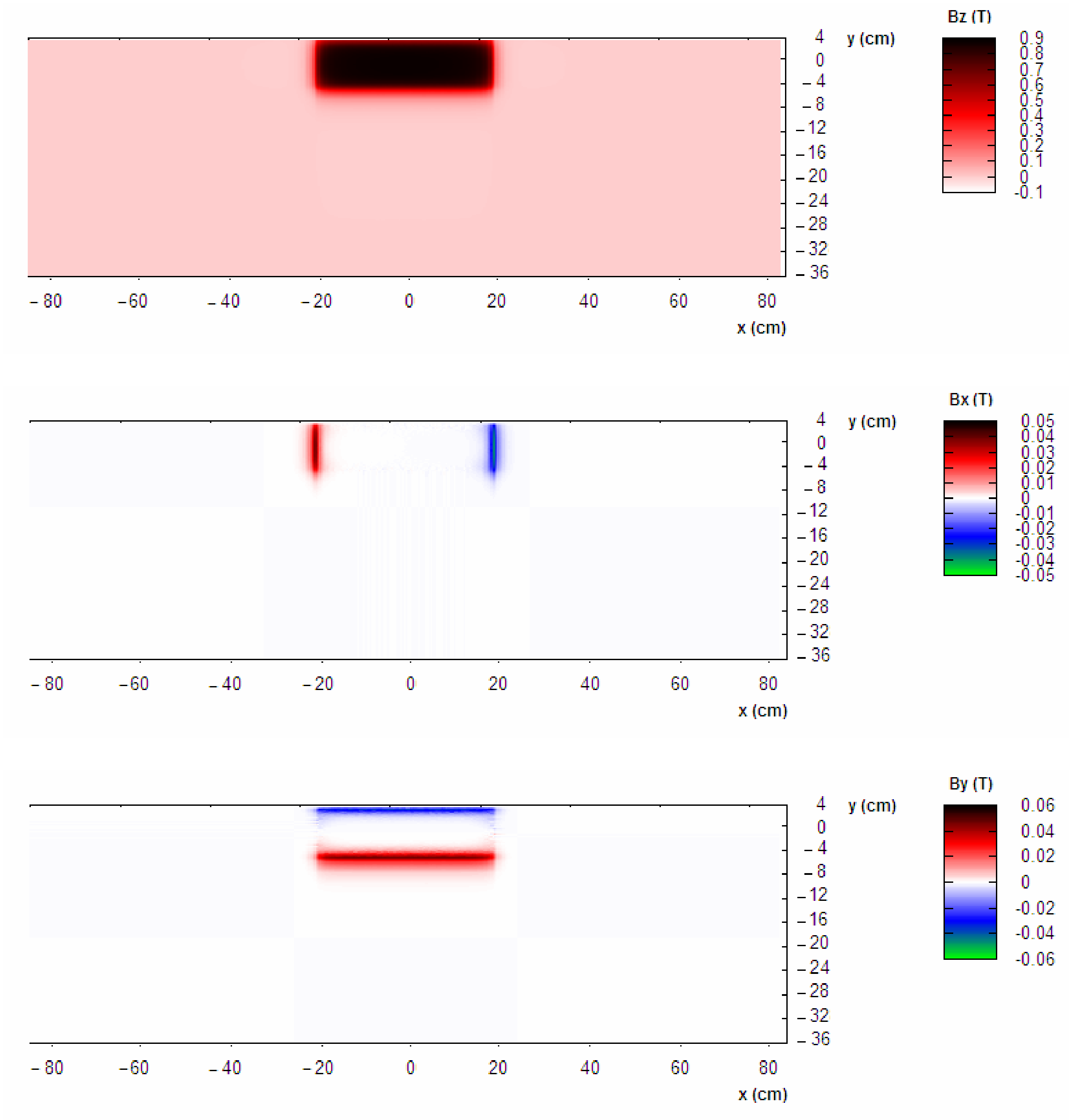

Figure 5 : Measurements of the 3D distributions of the magnetic field.

2. 3 Magnetic field measurements

The magnet has been delivered and tested at LOA using a gaussmeter. Resutls of the measurements are shown on figure 5. The experimental values have been found in good agreement with the simulated ones.

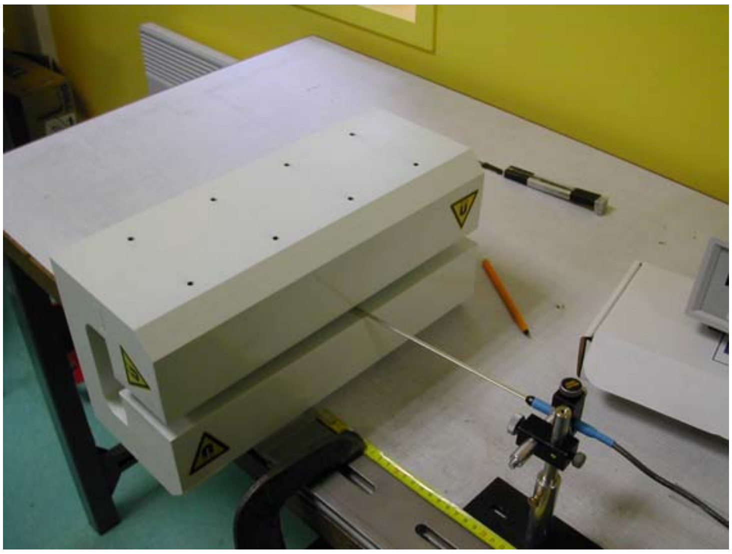

Figure 6 : Experimental set up for the measurement of the magnetic field

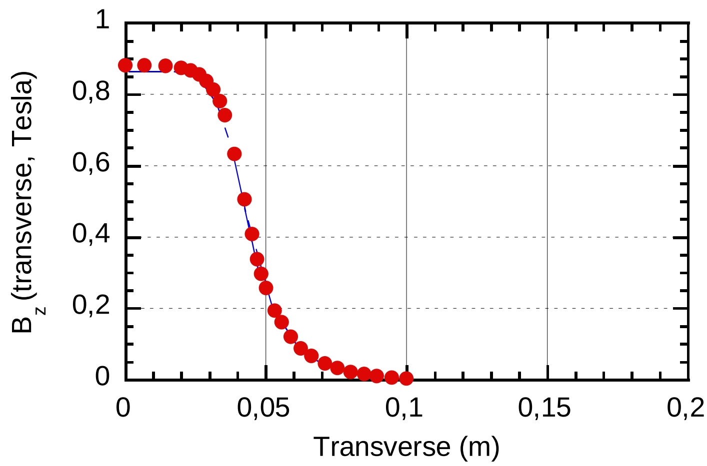

Figure 7 : Experimental results (red dots) and simulation (blue line)

3. Dispersion

The computations of the energy resolution and the beam deviation was performed with different localisations of the scintillator screen and with the magnet placed at 78 cm behind the point source. The positions of the point source, the magnet and the scintillator screen are showed in figure 8.

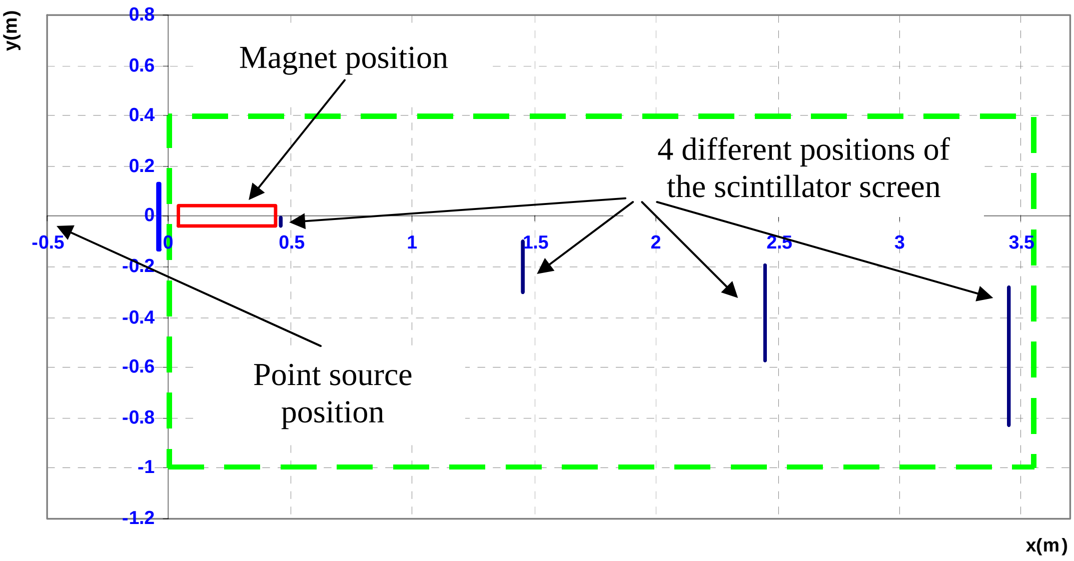

Figure 8 : Positions of the point source, the magnet and the scintillator screen.

The 3D numeric description of the magnetic field (figure 5) and a cloud in cell scheme were used in order to simulate the beam dynamics including the focusing and the aberration effects of the magnet field. The electron bunch was illustrated by a set of macro-particles (figure 9). The magnetic forces were applied to these particles via the step by step ‘‘Runge-Kutta 4’’ scheme [1].

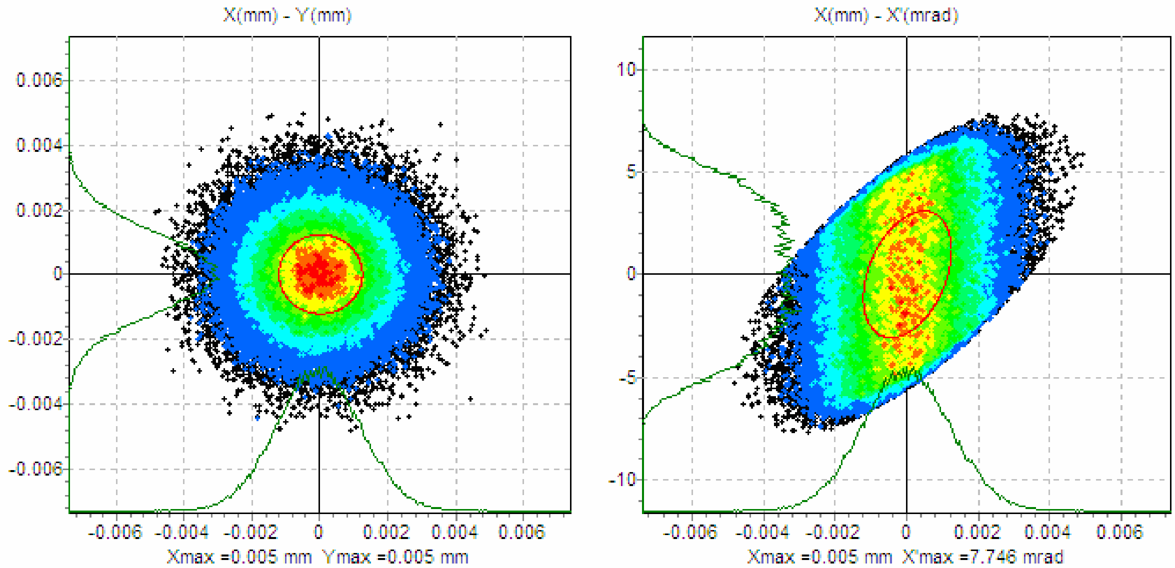

Figure 9 : The initial transverse bunch parameters. The rms normalized emittance and angular dispersion are respectively: ε_{rms} = 2 mm mrad and r'_{rms} = 3 mrad. Distributions plotted with PLOTWIN code [2].

Simulations were performed with different cases of electron energies. We computed the resulting position and RMS transverse size for each case. The deduced values of energy resolution are reported on figure 10 for the four positions of the scintillator screen.

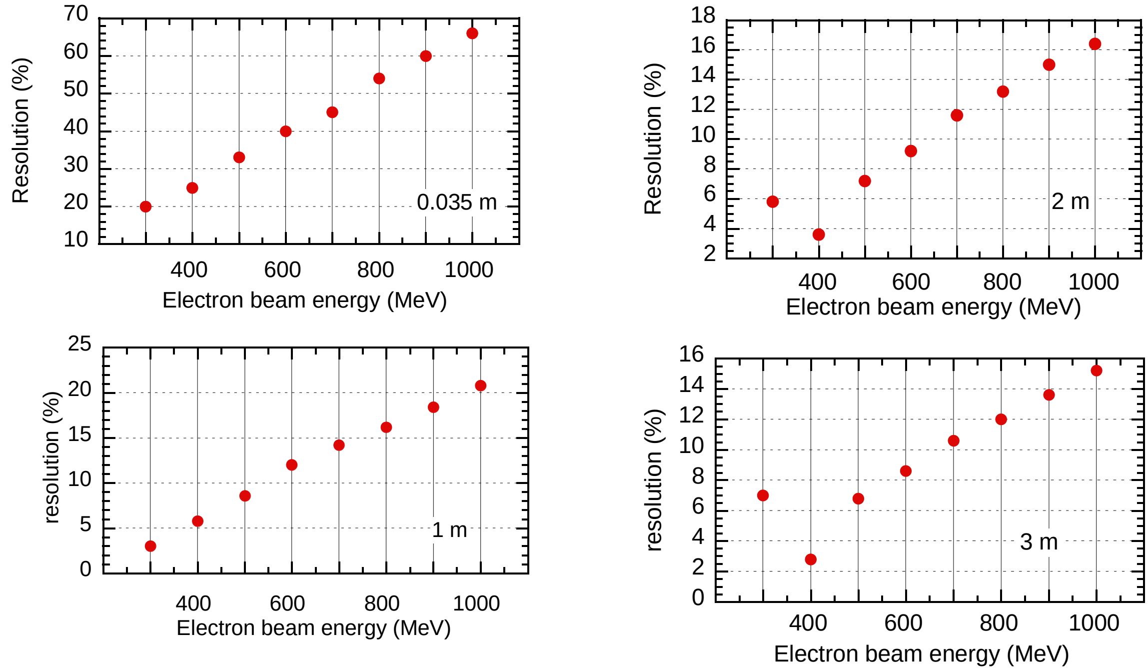

Figure 10 : Resolution for different location of the scintillator screen.

4. Conclusion of the work

A 1 GeV electron spectrometer including magnet and detectors has been designed, build and tested. The spectrometer will be used in future experiments in order to measure in a single shot the full electron distribution. Future works with the same magnet will be performed in the near future in order to increase the energy resolution by tilting the magnet or by using quadrupoles.

Acknowledgements

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395)

Bibiography:

[1] W.H. Press et al, *Numerical Recipes in Fortran (second edition)*, (Cambridge University Press, New York, 1992), p.859, 704, 833.

[2] R. Duperrier, N. Pichoff, and D. Uriot, in Proceedings of the International Conference on Computational Science (ICCS 02) (Springer-Verlag, London, 2002), Part III, pp. 411–418.