A proposed experiment for measuring the speed of propagation of the Coulomb force.

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1 Introduction

The electric field at a time t due to an electrical charge moving with velocity $\mathbf{v}$ is given, using the Lienard-Wiechert retarded potentials, by

$$\mathbf{E}(\mathbf{t}) = \mathrm{e}\frac{1-\frac{\mathrm{v}^2}{\mathrm{c}^2}}{(\mathrm{R}(\tau)-\frac{\mathbf{R}(\tau)\cdot\mathbf{v}}{\mathrm{c}})^3}(\mathbf{R}(\tau)-\mathbf{v}\frac{\mathrm{R}(\tau)}{\mathrm{c}})+\frac{\mathrm{e}}{\mathrm{c}^2(\mathrm{R}(\tau)-\frac{\mathbf{R}(\tau)\cdot\mathbf{v}}{\mathrm{c}})^3}\mathbf{R}(\tau)\times[(\mathbf{R}(\tau)-\frac{\mathbf{v}}{\mathrm{c}})\times\dot{\mathbf{v}}] \tag{1}$$

where the vector radius $\mathbf{R}(\tau)$is evaluated at the time $\tau = t - \frac{R(\tau)}{c}$, being t the time when we want to have the field $\mathbf{E}$(t).

It is known [1, 2, 3] that, very surprisingly, the first term, the field obtained for constant velocity, is identical to

$$\mathbf{E}(\mathbf{t}) = \frac{\mathrm{e}\mathbf{R}(\mathbf{t})}{\mathrm{R}(\mathrm{t})^3}\frac{1-\frac{\mathrm{v}^2}{\mathrm{c}^2}}{(1-\frac{\mathrm{v}^2}{\mathrm{c}^2}\sin^2(\theta)^{\frac{3}{2}}} \tag{2}$$

and

$$\mathbf{H} = \frac{1}{\mathrm{c}}\mathbf{v}\times\mathbf{E} \tag{3}$$

where θ is the angle between $\mathbf{v}$ and $\mathbf{R}(\tau)$ (Eqs. 38.8 and 38.9 of [1]) and $\mathbf{R(t)}$ *is the vector radius between the point where the charge is located at the time t and the point P where we want the field, at the same time t*[1].

This can be easily seen by substituting[2] in Eq.1 the expression:

$$\mathbf{R}(\mathbf{t}) = \mathbf{R}(\tau) - \mathbf{v}\frac{\mathrm{R}(\tau)}{\mathrm{c}} \tag{4}$$

As well known, if the particle velocity is not constant, the second term in Eq. 1 in non null and represents an electromagnetic field which propagates, in vacuum, with the speed of light (em wave).

[1]In Landau's words:.....*the distance* $\mathbf{R(t)}$ *at precisely the moment of observation* (see pag.162 in [1]).

[2]For the case of constant velocity $\mathbf{v}$.

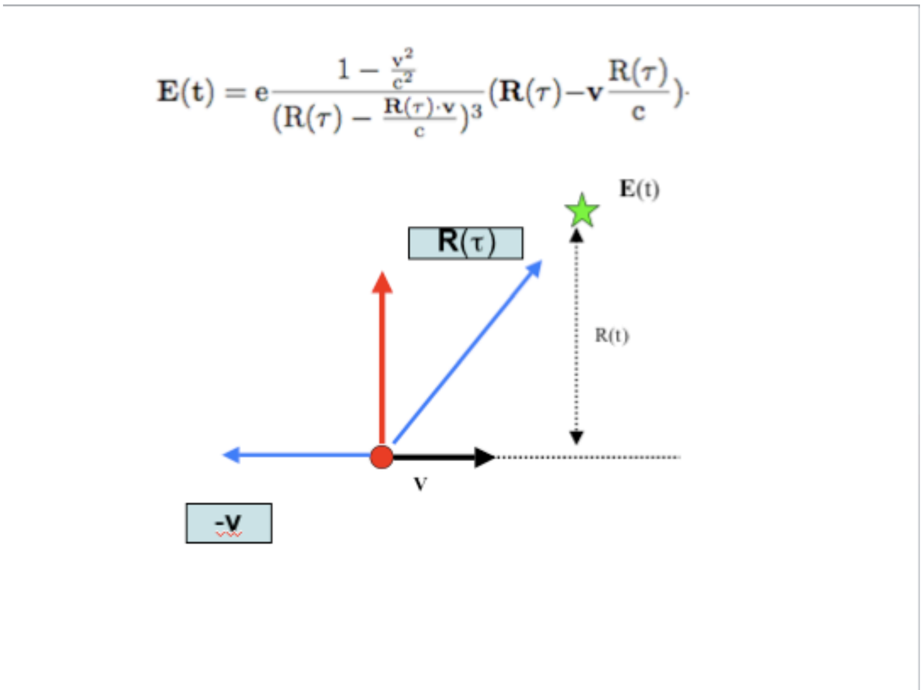

Figure 1: The two components of the electrical field, indicated with the blue color: the first one directed from the retarded position of the charge and the second one directed as **-v**.

In other words, we have two contributions to the electrical field: the first one of Eq.1 producing a field that one could calculated by considering the propagation of the field with infinite velocity and a second term producing a field that propagates with the speed of light.

The idea that the first term could be attributed to a field propagating with infinite velocity is not, by most of the scientific community, considered valid. According to Feynman [4] the: *influence of the charge comes, in a certain sense, from the retarded position; but because the motion is exactly specified, the retarded position is uniquely given in terms of then present position.* According to Carlip [5]: *This effect does not mean that the electric field propagates instantaneously, rather, the field of a moving charge has a velocity-dependent component that cancels the effect of propagation delay to first order.*

That the field of a moving charge have a velocity-dependent component that cancels the effect of propagation delay is correct as can be seen in the Eq.1 and in fig.1 In our opinion the contribution of the velocity-dependent component does not have a physical meaning, and appears just a mathematical term which compensate the wrong physical assumption of using the retarded potential method for the Coulomb field.

It is also interesting to report the considerations in the text book by Becker [2]: *Il campo di un elettrone in moto qualunque risulta dalla sovrapposizione di due campi, dei quali il primo può interpretarsi come campo elettrostatico che accompagna il moto della particella, mentre il secondo ha il carattere di un'onda elettromagnetica.*

No explanation is given for the *campo elettrostatico che accompagna il moto della particella.* Does this means that the entire coulomb field travels together with the electron, thus without retarded effects inside this field?

2 The force of gravity

There is a strong similarity between the electrical and gravitational forces. From ref. [6] *In the simple Newtonian model, gravity propagates instantaneously: the force exerted by a massive object points directly toward that object's present position. For example, even though the Sun is 500 light seconds from the Earth, Newtonian gravity describes a force on Earth directed towards the Sun's position* **now** *, not its position 500 seconds ago. Putting a light travel delay into Newtonian gravity would make orbits unstable, leading to predictions that clearly contradict Solar System observations.*

The problem of the instability of the solar system planetary orbits, if gravity does not propagates instantaneously, was well known to Newton himself and to Laplace, who calculated an upper limit for the velocity of propagation of gravity of the order of 10^8 times the velocity of light [7](1825, pp 642-645 of translation).

The problem is also considered by Eddington [3] who, however, assumes a velocity of propagation of gravity equal to that of light *because* the same problem occurs in electromagnetism where, *as well known*, the maximum velocity is the velocity of light.

In other words, the problem of propagation of the Coulomb and Newton field exists, but it is often either ignored without a clear explanation.

Hence, the necessity to add experimental data to our knowledge[3].

3 Calculating the Coulomb electrical field

In order to investigate this problem we consider the case treated by Feynman of an electric charge moving with constant velocity. The calculation of the electric field properly done by means of the retarded potential gives, eventually, the two

[3]Per una carica elettrica in moto uniforme il campo puó essere calcolato in due modi: a)mettendosi nel sistema di riferimento in cui la carica è ferma e muovendo il punto in cui si misura il campo. In questo caso chiaramente il risultato è quello espresso dalla Eq. 2. b) Oppure stando fermi con lo strumento di misura e muovendo la carica elettrica. Secondo la relativitá si deve avere lo stesso risultato e così infatti troviamo, ma non possiamo non domandarci: il campo elettrico di Coulomb si muove assieme alla carica ?. Se fosse cosí si avrebbero grosse consequenze quando si dovesse applicare questo al campo gravitazionale delle stelle lontane.

Table 1: The times of the signals in the four sensors for the various models.

model	t_1 ns	t_2 ns	t_3 ns	t_4 ns
e.m.wave	1.69	3.33	3.33	6.67
coulomb with light velocity	1.69	4.53	3.60	9.10
coulomb with infinite velocity	1.69	1.69	3.33	3.33

components

$$E_y = \frac{q}{4\pi\epsilon_o\sqrt{1-v^2}}\frac{y}{[\frac{(x-vt)^2}{1-v^2}+y^2]^{\frac{3}{2}}} \tag{5}$$

$$E_x = \frac{q}{4\pi\epsilon_o\sqrt{1-v^2}}\frac{x-vt}{[\frac{(x-vt)^2}{1-v^2}+y^2]^{\frac{3}{2}}} \tag{6}$$

Fig.2 shows that the calculated field at (x,y) and at the time t is just that obtained considering the position of the charge at the same time t . It is clear that the electric field is central, referred to the present position of the charge. If the charge velocity is near the velocity of light the relativistic effects can be relevant, as illustrated in the fig.3. The relativistic effect enhance the intensity of the field when the charge is nearest and diminish the intensity in the other places. This is clearly shown in the fig.4 referred to the proposed experiment.

4 The proposed experiment

We propose to use the electrons produced by the linear accelerator of DAΦNE.

The DAΦNE Beam Test Facility (BTF) is a beam transfer line optimized for the production of a defined number of electrons or positrons, in a wide range of multiplicities and down to single-electron mode, in the energy range between 50 and 800 MeV. The typical pulse duration is 1ns or 10 ns and the maximum repetition rate is 50 Hz.

We propose to measure the electrical field as function of time in the predetermined locations shown in the fig.5.

These locations have been chosen considering that we have three possibilities:

• The signals observed by the sensors are due to electromagnetic waves emitted when the electrical charges exit from the linear accelerator.

• The signals are due to the coulomb field which travels with the velocity of light

• The signals are due to the coulomb field which propagates with infinite velocity.

For electrons exiting the accelerators at time zero the four sensors shown in the fig.5 observe signals at the times indicated in the Table 1.

From preliminary tests we have verified that with the available instrumentation signals due the electron beam is observed with SNR greater than one order of magnitude and that it is possible to measure a time difference between two sensors of the order of 0.2 ns.

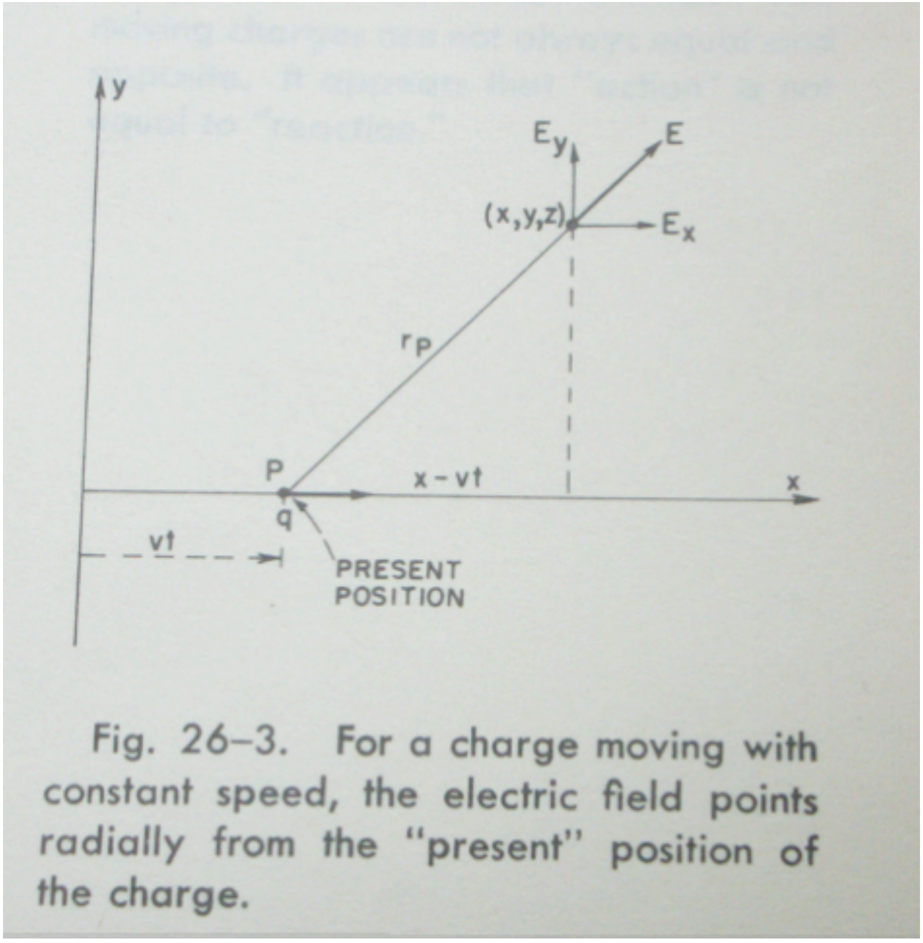

Figure 2: The field is calculated at the point with coordinates (x,y) at the time t. The charge begins its motion at x=y=0 in the **x** direction.

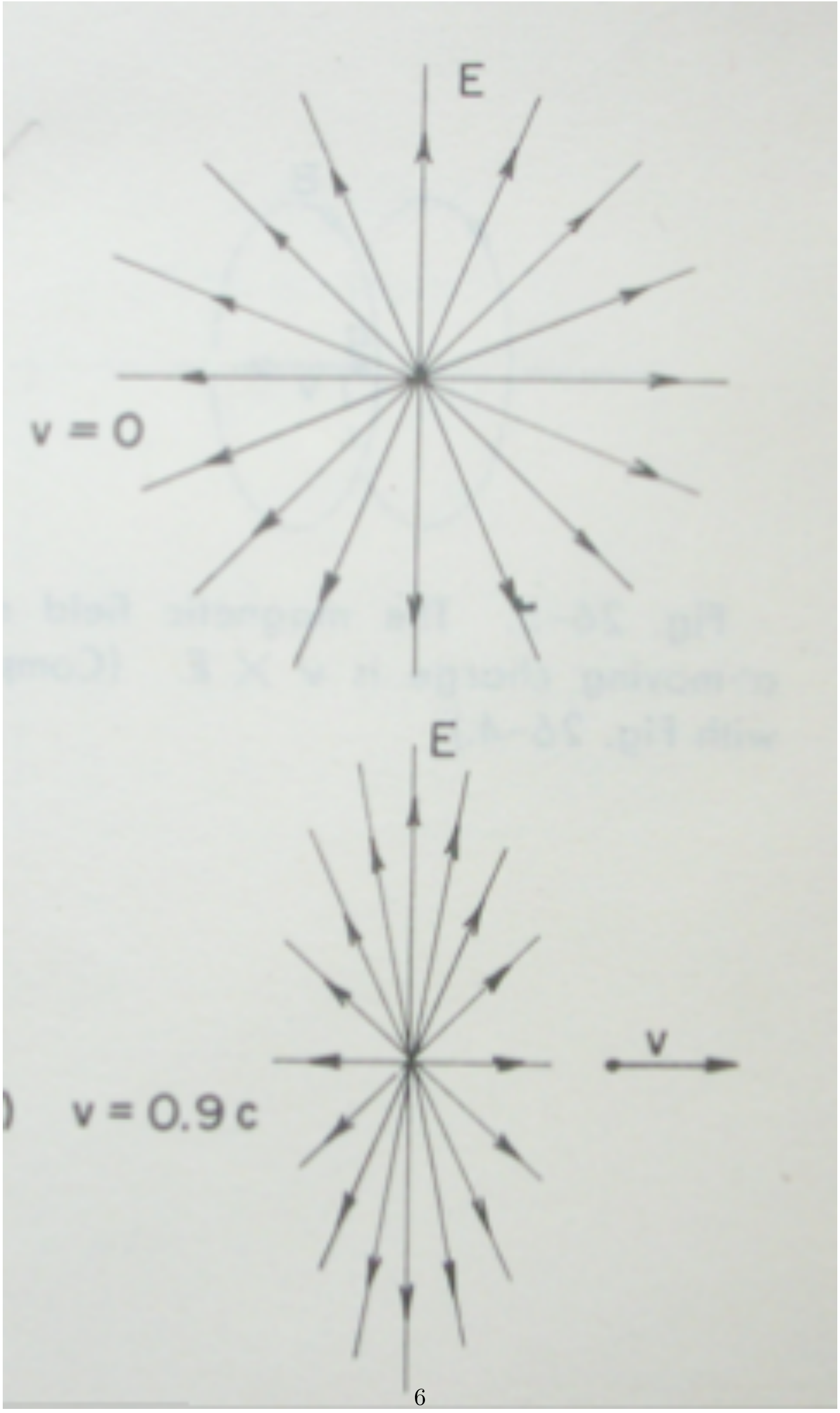

Figure 3: In the upper graph the electric field lines of force in the reference system where the charge is at rest; in the lower graph the lines of force where the charge is moving with velocity $v = 0.9c$.

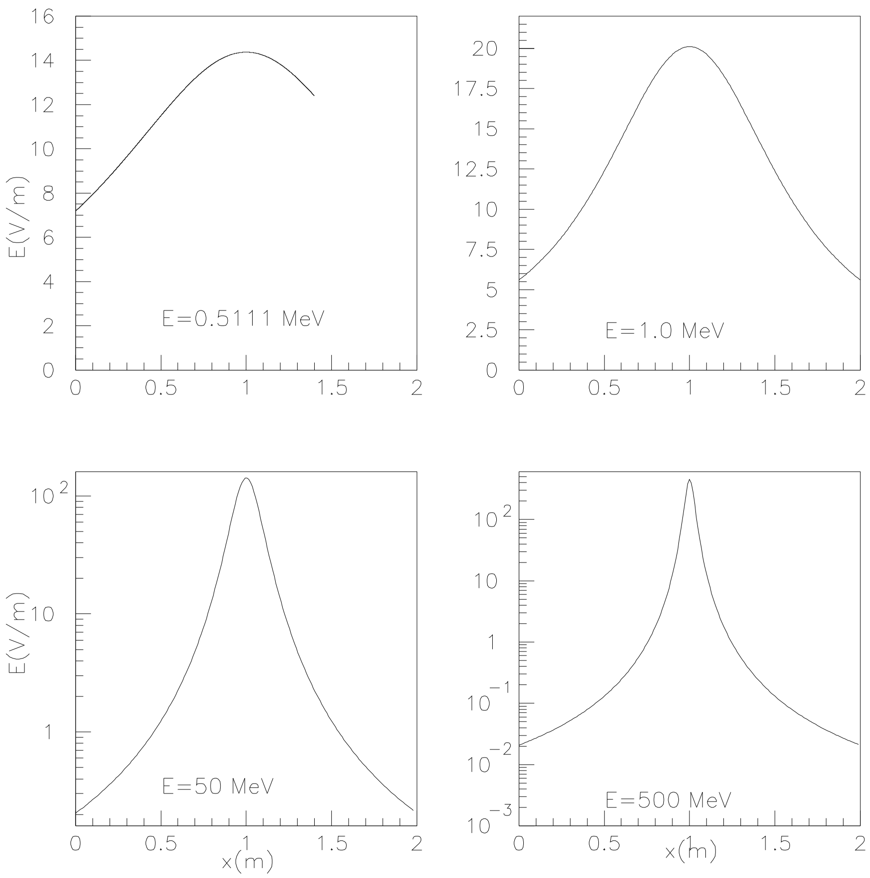

Figure 4: The expected electric field, at x=y=1 m, versus the position of the charge= 10^{10} electronic charges, for various total energies.

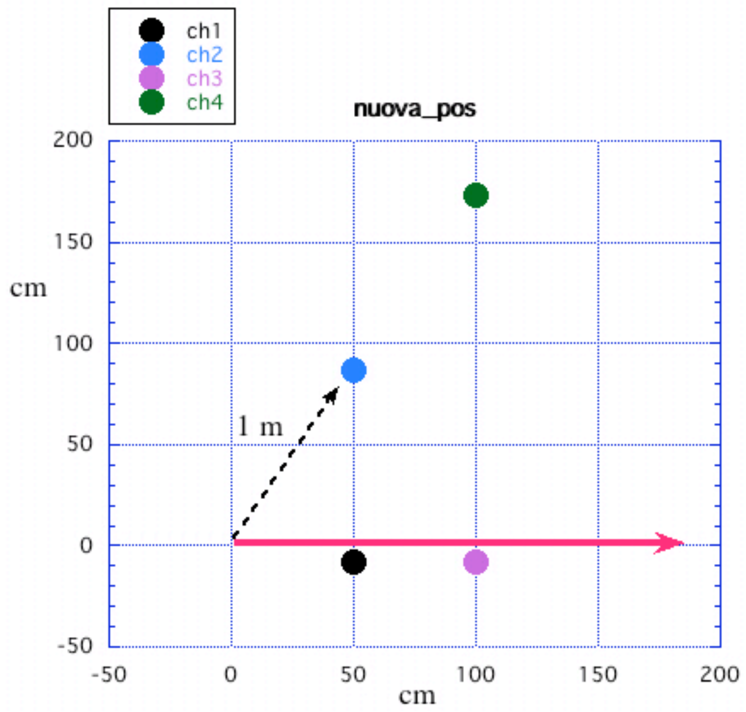

Figure 5: The position of the four sensors. The red arrow indicates the electron beam.

References

[1] L.D.Landau and E.M.Lifshitz *The classical theory of fields,* pag.162, Pergamon Press, Oxford (1971)

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[4] R. Feynman, R.B. Leighton, M.L. Sands, *The Feynman Lectures on Physics*Addison-Wesley, Redwood City, vol. II, Chapter 21 (1989)

[5] S.Carlip *Physics Letters A***267** , 81-87 (2000)

[6] http://www.math.ucr.edu/home/baez/physics/Relativity/GR/grav_speed.html

[7] Laplace, P., Mechanique Celeste, volumes published from 1799-1825, English translation reprinted by Chelsea Publ., New York (1966).