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PROPOSAL TO BUILD A NEW CONICAL CONVERTER SOLENOID FOR LIL

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The limitations of the converter solenoid presently used in the LIL positron production for LEP are due to its air-core design which prevents to use it at the nominal current of 5 kA. Though its operation at a reduced current of 2.5 kA has permitted a sufficient positron production for the operation of LEP without drawbacks (except minor breakdowns), it is worthwhile to build a prototype conical solenoid based on a new design, for laboratory tests, to be ready to install a new converter when a higher production will be needed for future LEP operations.

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Introduction

The converter producing the positrons in LIL [1] is basically made of a Tungsten target hit by a 200 MeV electron beam, followed by a pulsed solenoid and DC big solenoids where the highly diverging positrons are focused in a quasi-parallel beam fitting the small aperture of the Linac which accelerates them to the EPA ring. The pulsed solenoid SNP25 [2] was similar to the solenoids used for the same purpose in the Desy and Frascati laboratories and is a double air-core (i.e. in vacuum), water cooled, 14 turns copper winding whose support is simply made by the feeder lines welded onto the electrical feedtrough. This coil is fed by a short high current pulse (7 μsec, 2.5 kA) at a pulse rate of 100Hz. The electromagnetic forces initiate vibrations at high current values into this quasily free coil, which can eventually lead to a high voltage breakdown when the adjacent turns of the coil come too close or even a mechanical breakdown when the metal of the coil is softened by long term operations and can then cause a water leak in the vacuum chamber. The use of a reduced current has permitted a sufficient positron production for the LEP operation, this being mainly due to the relatively flat spectrum of positron energies produced in the target and a resulting acceptable positron production yield.

It may nevertheless happen in the future that the positron production becomes the bottleneck in the LEP improvement , and it is worthwhile to study, beside a complete reshuffling of LIL with for instance a displacement of the positron production zone downstream of the Linac and a recirculator beam line, the possible means, by simple and cheap changes in LIL [3] and after a thorough optimization, to raise the positron production yield .

A new design of the converter pulsed solenoid is presented which will allow a minimal change of the setup, as the pulsed power supply and the vacuum box where the coil is sitting will stay the same. The design is basically made by reducing the initial aperture of the coil (this been allowed by the diverging positron beam), and by winding the coils in flat pancakes which may be electrically insulated and mechanically held by plane insulators, this resulting in a shorter length and therefore a stronger optical power for the same current. The whole coil block will be tightly fitted on the vacuum chamber to prevent any deformations and vibrations.

This report gives a summary of the calculations made for this proposal: magnetic field taking into account the exact geometry of the coil and the effect of induced currents in the close target, and positron yield estimates with the available simulation programs. Also several simple formulae of the focal length of a solenoid lens and the angle of collected particles are given to permit simple comparisons with the previous coil. Furthermore the programs used for this study have been developed with the modern software now availabe and are at disposal for any further efficient study.

Geometry of a coil made of flat pancakes

The present solenoid has a very simple geometry: it is a double coil made of a right-handed helix of seven turns, connected at its two ends to a left-handed helix of smaller radius, also of seven turns. The feeding is made by cutting the closed coil in front of the feedthrough location and connecting it to two parallel lines. The addition of an insulator to this coil is a very difficult matter: it is impossible to mould the insulator material inside the coil as this would create large voids due to the diminishing volume of the material when moulded, and it is impossible to machine insulators fitting the complicated geometry of the double solenoid with a sufficient accuracy.

As it is seeked to make a coil as short as possible, it is better to wind the copper wire in flat pancakes: the insulator can then be made by using flat insulator plates. The choice of a insulator material is therefore easier as the polyimides matching the requirements of HV, vacuum and radiation resistance can be found in simple shapes only. A support fixed onto the vacuum chamber will be necessary in the same material to put the whole coil in a stable and accurate location.

The proposed coil is made of two pairs of flat pancakes, each pair has a diverging spiral followed by a converging spiral, each having a constant spacing between adjacent turns. The first pair of pancakes of three turns each, will be connected to a second similar one but beginning on a slightly larger radius and of two turns each, to provide the conical free internal space fitting the diverging positron beam. The connection between spirals will be made with helices. This will result in a total number of fourteen turns which is the same as in the present coil (cf fig.1), so providing an electrical impedance similar to the present one, in order to keep the power supply as it is. This compact geometry may be subject to a further optimization when the final engineering study will be made. Providing the requirement of the power supply is released, it might be possible to consider different geometries yielding higher performances i.e. shorter focal lengthes.

Magnetic Fields on axis

The magnetic fields are commonly calculated only on axis by simple means and then the radial field components are estimated by a simple derivation. It is obvious that this method, valid when the paraxial gaussian conditions of optics are present, can deliver very approximate or even erroneous results when the trajectories are not close to the optical axis. This is the case for positrons production because here the aperture of the lens has to be filled by trajectories in orded to capture the maximum number of positrons and the magnetic fields have to be known with a sufficient accuracy even close to the conductors.
We first begin by the axial field on axis from which some elementary but interesting optical properties can be deduced. This field will be calculated by applying the Biot-Savart law which delivers the fields by an integration over the path of the conductor:

$$\vec{B} = \frac{\mu_0 I}{4\pi} \int_{conductor} \frac{d\vec{l} \times \vec{r}}{r^3}$$

dl being an element of the conductor and r being the vector from the current point to the field point. Therafter each field component can be obtained as a function of the parameters defining the geometry of the coil i.e. the distance of the coil to the origin, the radii, the number of turns,and the length. All details of the calculation are given in a Mathcad[R] program, cf[4][6].

It turns out that the coil is fed by a so short pulse current that the fields can't penetrate the target and its support made of a good conductor. This effect can be taken into account by considering a mirror plane at the target location in which all axial field component vanish. This is obtained by adding a mirror coil (putting the opposite signs in front of the relevant parameters of the field component functions). The effect of the mirror coil is to sharpen the field rise on the target side (cf Fig.2). The short length of the coil brings a total field variation (above the value of field due to DC solenoids), in about half the length of that of the previous coil, or in other words the field variation will be steeper by a factor two.

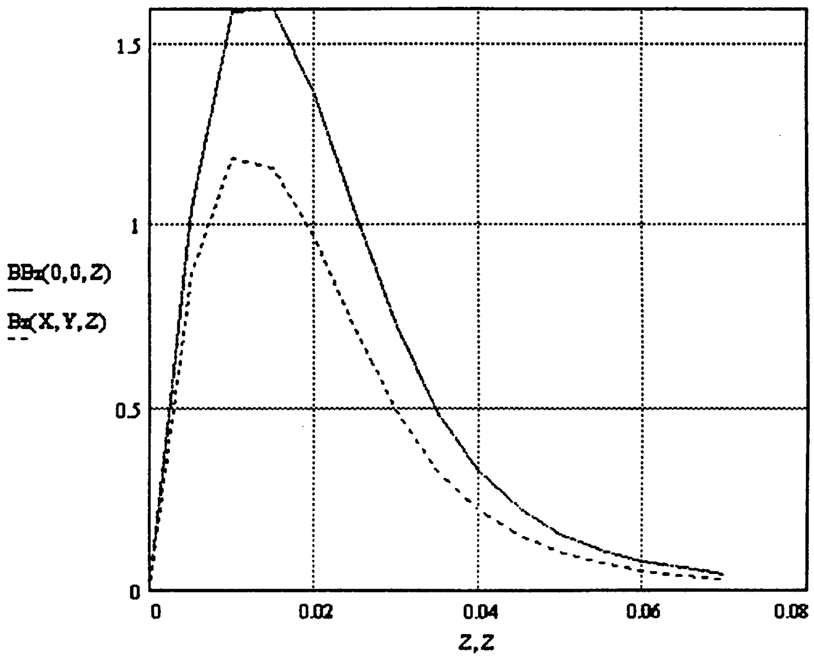

Fig.2.Axial magnetic field (Bz is for spirals only, BBz for spirals and helices)

3D Fields

Traditionally the magnetic fields calculations end up in curves and tables for further use by interpolation method. For the converter problem it is better to build functions delivering exact field values at the point of interest (e.g. along a trajectory) cf [4] (SPI prog.), this mainly because the exact fields are 3D, and the corresponding results tables would be enormous. Here some examples are given along a line parallel to the axis.

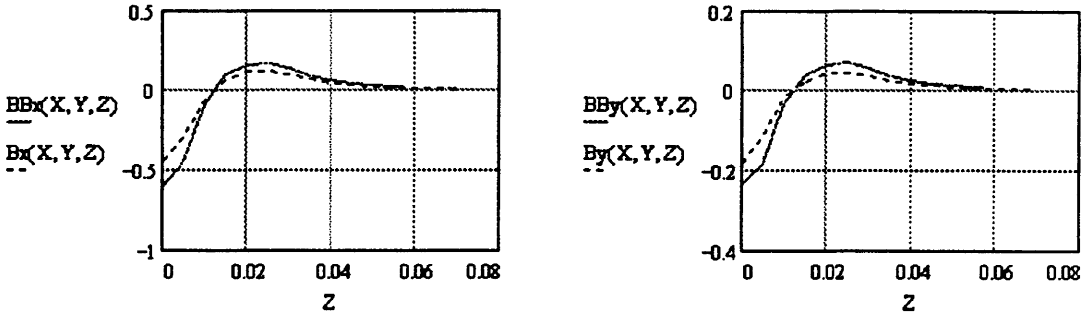

Fig.3, Radial field components for x=0.05, y=0.002, (BBx, BBy total fields)

Positron yield estimates:

The production yield improvement is difficult to assess not only because the basic assumptions made in the programs are simplified but also because a full optimization algorithm with all variables doesn't exist (it may happen that raising a parameter can decrease the yield for a given set of the other parameters, but do the contrary for a different set of these parameters!).

1)a simple argument:

The converter solenoid's role is to collect the diverging trajectories of the positrons into a parallel beam matching the small aperture of the Linac. The optics of magnetic lenses is essentially understood as follows: it is the radial field which generates a helical motion of the particles around axes parallel to the beam axis. Then the axial field coupled with the azimuthal component of the velocity creates the needed focusing force towards the axis. The study is commonly made by considering a plane turning around the axis and the classical optical parameters can then be deduced. Here the focal length f is the relevant parameter and is given by integration of the axial field squared. For our purpose the focal length permits by a straightforward geometrical construction to deduce the maximum collected angle θ:

$$\theta = \frac{r}{f} \qquad \text{with} \qquad \frac{1}{f} = \frac{1}{(2\cdot B\rho)^2}\cdot\int_0^\infty B^2\, dz$$

r being the exit radius. Therefore any shorter lens (delivering the same maximum field) will collect larger angles, providing the source is displaced to the right point and all other optical parameters are matched. The goal of the proposed lens is to reduce the focal length by a factor two or more, this being obtained because of the different shape and a higher current, and then to be able to collect a double angle. This will be possible by raising the current to 3.1 kA in the new coil instead of 2.5 kA in the present one. The programs developed in [4] allow to calculate the trajectories in the 3D fields really produced by the proposed lens and to assess the results of this elementary approach.

2)elementary method for the yield estimate:

The Convert series of programs of [4] summarize a semi-analytical method used early in the LEP project, based on an empirical angular distribution of positron production, cf [1], which can be used for a yield estimate by calculating the increase of collected positrons due to a larger angle. For that we double the angle in the G function of Convert2: we get a number of positrons np of 0.021 (per electron) instead of 0.009 (with a DC solenoids field of 0.3 T). Taking into account that the acceptance is limited (the acceptance radius reflected backwards to the target exit becomes half if the corresponding angle is doubled), we only get a np of 0.017. These results are higher if the DC solenoids field is raised to 0.35 T: np is then 0.025, and 0.020 for a limited acceptance.

3)Monte-Carlo simulation:
The Compost code written in C [5] takes a position and an angle at target exit from a statistical distribution given by the Geant program and performs the tracking of the trajectory down to the end of the Linac; repeating that process numerous times and counting the rare particles matching a chosen set of conditions and rejecting all the others it can estimate the positron production yields. This program can only take approximately into account the exact shape of the proposed conical coil and the exact 3D fields which are really present, but fortunately it has the distance from the target to the coil as a free parameter. By a trial and error method a better yield can progressively be obtained: with 5 kA in the conical coil and 700 A in the DC solenoids, the number of accepted positrons is 0.023 (0.015 in 2% momentum window), and becomes 0.027 (0.017 in 2% momentum window) for a DC solenoids current of 810 A. For the sake of comparison the present solenoid gives 0.013 (0.008 in 2%) with a current of 2.5 kA.

Fabrication and tests planning:
The first step is to make a mechanical design of the conical coil with its insulator and support, then a prototype can be built for tests in the positron test zone, under vacuum and with water cooling. This will permit to assess the maximum operational current and therefore the definitive calculated gain in yield. Therafter a beam test can be made with a fine optimization involving all parameters, within the present limits of the hardware.

Conclusion
It is possible and advisable to build a new pulsed solenoid of conical aperture fitting well the diverging positron beam produced in the LIL converter and having a better mechanical design than the presently used solenoid. The new proposed coil will also allow a sizeable gain in the positron production yield of more than 50%, worthwhile for the future operations of LEP.

Acknowledgments
I am thankful to H.Braun to have made available the Compost program, to J.-C. Godot for useful discussions about the technical problems of coil windings and to L.Rinolfi for having drawn my attention to relevant internal notes of the LPI group.

References:
[1]K.Hübner, Positron Production for Particle Accelerators, CERN/PS/88-19 (LP), April 1988.

[2]R.Bertolotto, Source de positrons du LIL, Convertisseur e^--->e, Note PS/LP 89-06, 20.3.89.

[3]H.Braun, L.Rinolfi, Proposal for an improvement of positron capture at LIL, PS/LP Note 92-18, July 1992.

[4]J.-C.Schnuriger, A Collection of Accelerator Algorithms for the Personal Computer, Part II, PS/AR Note 94-18, 6th July 1994.

[5]H.Braun, private communication.

6]Mathcad is a registered trademark of MathSoft, Inc.

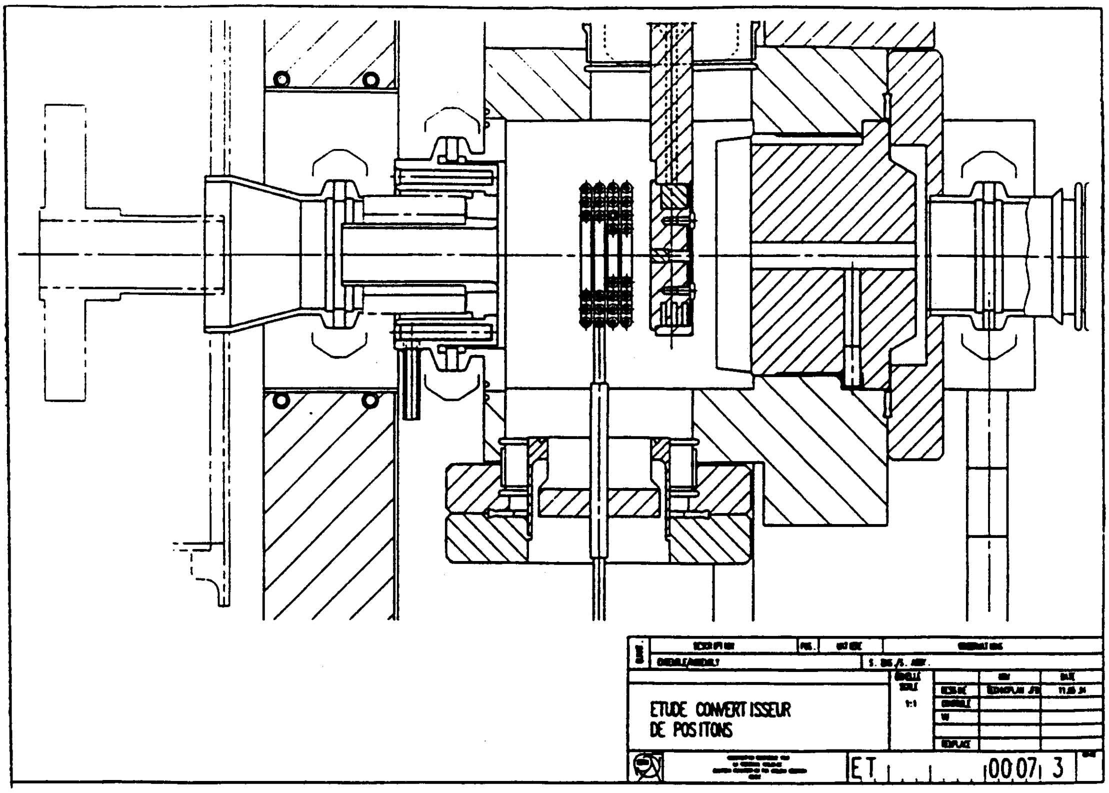

Fig.1. General view of the proposed conical coil for the LIL converter, in the vacuum chamber. The target is on the right of the coil. Please take note that neither the insulator of the coil nor its mechanical support are drawn.