BNL-104829-2014-TECH

AGS/AD/Tech Note No. 413;BNL-104829-2014-IR

SOME OPTIONS FOR PION and MUON FOCUSING IN THE AGS g-2 and NEUTRINO OSCILLATION EXPERIMENTS (AND POSSIBLE NEW FOCUSING and COOLING SCHEMES FOR A MUON COLLIDER)

A. Hershcovitch

February 1995

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

Accelerator Division
Technical Note

AGS/AD/Tech. Note No. 413

SOME OPTIONS FOR PION and MUON FOCUSING IN THE AGS g-2 and NEUTRINO OSCILLATION EXPERIMENTS (AND POSSIBLE NEW FOCUSING and COOLING SCHEMES FOR A MUON COLLIDER)

A. Hershcovitch

February 27, 1995

Abstract

A preliminary examination of focusing schemes suggests that spark channels and Z pinches deserve a further, more serious consideration for possible use in the AGS g-2 and neutrino oscillation experiments. A Z pinch or a Z channel combined with an intense relativistic electron beam may be a viable cooling scheme for a muon collider. Examination of present-day state of the art indicates that Z pinches may offer the best short-term approach to maximizing initial pion capture. A lens capturing close to 0.3 radians of 3 GeV/c pions can be readily built for the g-2 and neutrino oscillation experiments.

I. INTRODUCTION

In many areas of research involving charged particle beams, various methods of magnetic focusing have been employed to enhance the flux of charged particles from a divergent source such as a production target,[1] or to confine ions emerging from the cross-over region of an ion diode to betatron oscillation for propagation to a small target a few meters away.[2] The method of choice for focusing of high energy charged particles, produced in nanosecond to microsecond bursts, that need to be transported for a distance of a meter or more has been the use of azimuthal magnetic fields that pull the particles radially inward as a consequence of the Lorentz force. These fields are usually generated by currents that are oriented along the desired flight path of the charged projectiles.

Lithium lenses[3,4] and focusing horns[1,5] have been used in high energy physics research, while various spark and Z channels were developed for fusion experiments.[2,6,7,8] Spark and Z channels shall be referred to as plasma lenses in this note, even though in high energy physics research this term was used in reference to lithium lenses and similar lenses in which the lithium was replaced by high pressure gases. In all applications, the purpose of these lenses is to focus and to facilitate propagation of charged particle beams with a minimum of beam absorption and scattering.

Although some features vary from experiment to experiment, there are a number of common requirements for all these lenses:

1. Very large axial currents must be generated and sustained.
2. The lens medium should have as low a density as possible to minimize particle absorption and scattering.
3. Due to large currents and high magnetic fields, the lens must withstand high mechanical and thermal stresses.

4. The lens must survive prolonged exposure to radiation.

Description and comparison of the various lenses, as well as two additional options will be presented in this note.

II. THE VARIOUS LENS OPTIONS

Interest in this type of charged particle focusing is varied and many of the broad number of applications require customized lens configuration. Evaluation of lenses in this note, however, is done based on their applicability to the AGS muon g-2 experiment, the next generation AGS neutrino experiment, and a muon collider.

A. A horn system is a hollow coaxial structure of conductors through which large currents (100s of kA) flow to generate the focusing magnetic fields.[1,5] These conductors must be shaped such that the magnetic field integral increases with radius, thus providing focusing for particles located at radii larger than that of the inner horn inside radius. Requirements on the inner horns are extremely demanding: they have to withstand very large thermal and mechanical stresses, yet, they must be fabricated from light elements to minimize particle losses.

B. A lithium lens consists of a cylindrical conductor (made of lithium) through which a large axial current is induced to generate an azimuthal magnetic field.[3,4] Unsuccessful attempts were made to replace lithium with compressed gases or aluminum. Even though lithium has very low mechanical strength, and it is very reactive chemically, it remains the conductor of choice since it is light (to minimize loss of particles), and conducts electricity well. It must, however, be kept under high pressure in a strong container made of a chemically compatible material like titanium or stainless steel.

C. Spark (or Z) channels are plasma transport channels, characterized by large currents (100s of kA), which have been developed to transport (and focus) intense beams of light ions (with currents of 100s of kA, and energies of a few MeV) over distances of up to 5 meters.[8]

   These channels consists of two annular plates (or rings) placed in a vacuum chamber, as shown in Figure 1. These plates are biased to serve as anode and cathode of the discharge, their spacing determines the channel length. The vacuum chamber is usually filled to a pressure of as low as a few Torr to as high as 40 Torr with either a light or a heavy gas. After an appropriate bias (10s of kV) is applied to the plates and an appropriate gas fill of the vacuum chamber, a discharge can be initiated with either an exploding wire or a laser pulse. This initial discharge preionizes and heats the gas. After the heated gas expands and rarefies on axis, a four-fold reduction in gas density on axis occurs with a corresponding ten-fold reduction in the breakdown voltage. Once breakdown occurs, the hot expanding channel acts as a piston compressing the gas outside the channel. Choice of an appropriate gas fill determines the channel expansion rate that must accommodate the current rise time (which is in turn determined to a large extent by the circuitry).

A large variety of these channels have been made, and an even larger variety is possible.[9] Pulse lengths of 10s of nsec at a repetition rate of 500 Hz - 1 kHz have been generated, as well as three microsecond long pulses at lower repetition rates. Hundreds of kA of discharge currents have been attained. Channel radii from 1 cm to over 10 cm were reported (larger radii are easy to generate, it is next to impossible to generate channels with radii that are below 1 cm, which is desired for inertial confinement fusion). Another feature of these channels, which adds to their versatility, is the ease with which the direction of the discharge current, and hence the focusing magnetic field can be changed (by externally changing the applied bias on the plates). Thus, a single channel can alternately be used to focus positive and negative particles on a shot-to-shot basis.

D. <u>Mega-Ampere electron beams</u>. Any type of axial current generates azimuthal magnetic fields. Electron beam currents that are in the mega-Ampere range have been generated by diodes. Although most of these diodes operate with pulses that are in the nsec range, some diodes have operated with pulse lengths of up to 2 microseconds. More conventional electron guns (some with plasma cathodes) can also be stacked up (or even scaled up) to yield 100s of kA to 1 MA of current. Although in most practical applications (pulse lengths of 100 microseconds or longer), current densities in beam forming gun structures are limited to 100 A/sq.

cm due to voltage breakdown effects, much higher current densities are possible in devices operating with pulse lengths that are sufficiently short (no more than a few microseconds, i.e., shorter than an arc propagation time).

A hybrid system in which an electron beam is launched and is propagated through a plasma channel can be a very attractive option, since it is possible that neither technique may need to be "pushed" to its technological limit to reach resultant axial currents exceeding 1 MA that are 1 meter long. Hollow-beam electron guns may be particularly suitable for such an application due to their larger perveance and enhanced stability in addition to the obvious advantage of their hollow structure.

E. Z pinches. A Z pinch (shown in Figure 2) involves a sudden compression of a low-density plasma by means of a large discharge current that lasts for a few microseconds. It bears some superficial similarity to a spark channel in that a discharge is formed between two end plates (which are solid in Z pinches), but their plasma properties are very different. Its fill pressure is below a milli-Torr. First, a low-density, low-temperature plasma is created by rf or exploding wires. Second, a large voltage is applied to the end plates that drives a very large axial current that compresses the plasma due to an inward acceleration of a surface current shell (just opposite to what occurs in spark channels). At first glance a Z pinch seems to be a poor option due to its minuscule radial dimension, nevertheless, discharge currents of 10 MA over a few centimeters have been reached in a rather expensive system.[10] In a series of experiments with magnetized Z pinches, 2 MA were reached for a length of 0.8 meters with an axial magnetic field of 1.5 Tesla.[11]

III. PION FOCUSING NEEDS VERSUS STATE OF THE ART

Requirements for first focusing lens of the neutrino oscillation experiment (presently considering a horn system) are a 0.2 meter long lens with a current of 2.8 MA pulsed at the AGS cycle for 2.5 microseconds.[12] Similar requirements exist for the g-2 experiment with regard to the current and length combination of the lens, however, there is a preference for shorter pulse lengths (10s of nsec) at a higher repetition rate.[13] An additional, very important requirement, is for the lens to have a diameter of about 10 cm.

State-of-the-art performance for a horn is 300 kA.[12] It can be made with a large enough diameter, which makes it well suited for these experiments. Nevertheless, increasing the current by a factor of over 9 (with a corresponding increase in the force due to the magnetic field and current interacting by a factor of about 90) leads to further technical difficulties of an engineering task that was already very demanding.

Peak performance of a lithium lens was 750 kA,[14] but typical top performance is at the 500 kA level. The radius of a lithium lens is 1 cm or smaller. Therefore, the magnetic field at a distance of about 10 cm from the lens axis (where it is most important for focusing) is an order of magnitude lower than at the lens radius. Thus, for this particular application, a lithium lens is not very attractive.

Currents of 10 MA have been generated in Z pinches for lengths of a few centimeters. But, the discharge collapses to a very small diameter. It is possible, in principle, to almost prevent the pinching effect with a large axial magnetic field, which together with a stabilizing wall will allow for longer discharges with even larger current, in addition to the larger radii. However, no such research was done for close to 40 years, since the main objective of a pinch is to heat and compress a plasma for the purpose of attaining thermonuclear fusion.

Spark (or Z) channels were developed to transport and focus light ion beams into small DT pellets and drive fusion microexplosions. Hence, these channels were optimized for light ion inertial confinement fusion. Currents of up to 200 kA were achieved (sufficient for focusing 1 MeV carbon ions in less than 0.4 meter). The longest channel generated was 5 meters long.[8] This channel was 10 centimeters in radius, it had a current of 50 kA (more than what is needed to focus any conceivable light ion beam for fusion). A possible scheme that could satisfy the focusing needs of both the neutrino oscillation experiment and the g-2 experiment is presented in the next section. In this scheme, five 50 cm long 250 kA spark channels with gradually increasing radii are used. Z channels are versatile with regard to repetition rates and pulse lengths that could meet the needs of both the g-2 and the neutrino oscillation experiments.

An alternative approach to meeting the needs of both the g-2 and the neutrino oscillation experiments is to utilize a wall-stabilized Z pinch with an axial magnetic field. Parameters reached in such a discharge 40 years ago indicate that using this type of a Z pinch will enhance the capture of pions to levels that are significantly greater than what is expected from other lenses.

Maximizing the capture of 2 GeV/c pions is crucial for the muon collider.[15] A scheme utilizing state-of-the-art Z pinch is presented in the following section.

Particles focused in a spark channel or a Z pinch lens travel in what is essentially vacuum, hence there is indeed negligible absorption and scattering of pions or muons.

IV. NOVEL LENSES FOR PION CAPTURING AND FOCUSING

Two pion focusing lenses, one based on spark channels and the other based on Z pinches, are described next. Both schemes are based on achieved parameters or on a reasonable extension of parameters already reached. Evaluation of capture requirements for the most energetic and divergent pion is used to estimate the acceptance angle. Capture criterion for this pion is for its trajectory to become parallel to the lens axis. G. Danby's formula for bending in a magnetic field is used

$$p\ x\ \sin(\theta) = (BxL)/1313.22 \tag{1}$$

where p is particle momentum in GeV/c, B is magnetic field in kG, and length L in inches.

The magnetic field is determined from Ampere's Law

$$\oint B \cdot dl = \mu_o I$$

which in this case, the uniform current distribution can be solved for the magnetic field to be,

$$B = (\mu_o J/2) \cdot r \tag{2}$$

where $J = I/\pi r^2$, i.e., $B \propto r$. Also from Ampere's Law, the magnetic field at a radial distance r from the axis is,

$$B = 0.2 \cdot I/r \tag{3}$$

where the units for B, I, and r are Gauss, Amperes, and centimeters, respectively.

A. Applications for the g-2 and Neutrino Oscillation Experiments

Figure 3 is a schematic of a pion focusing arrangement that could be suitable for either the neutrino oscillation experiment or the g-2 experiment. It comprises five stacked laser initiated spark channels with successively increasing radii. The current in each 50 cm long channel is 250 kA. Since an acceptance (half angle) of 0.1 radians is needed,[12,13] a channel radius of 5 cm is chosen for the first channel (a self-consistent solution would result in a somewhat smaller radius and yield and stronger pion bending).

Computing the average magnetic field encountered by a 3 GeV/c pion entering the channel on axis at an angle of 0.1 radians from Equations 2 and 3, yields an average field of 5 kG. Using this field in Equation 1 and solving for the bending angle results in $\theta = 0.025$ radians. Thus, this pion enters the second channel at $r \leq 5$ cm with the divergent angle reduced to 0.075 radians. From this angle, the radius of this channel can be calculated to be $r \leq 5 + 50 \tan(0.75) = 8.75$ cm.

In this second channel, the average magnetic field computed from Equations 2 and 3 for $5 \leq r \leq 8.75$ is 4.5 kG. Now from Equation 1, $\theta = 0.0225$ radians. Therefore, in the third channel, the pion enters at $r \leq 8.75$ cm with an angle of 0.0525 radians. Hence, $r \leq 8.75 + 50 \tan(0.0525) = 11.375$ cm and the average magnetic field for $8.75 \leq r \leq 11.375$ is 3.9 kG. At this field, Equation 1 yields a bending angle of about 0.02 radians. Thus, the pion enters the fourth channel at $r \leq 11.375$ cm with an angle of about 0.0325 radians. Therefore, repeating the previous procedure yields a channel radius of 13 cm and an average magnetic field of 3.6 kG. Using this field in Equation 1, results in a bending angle of 0.081 radians, thus entering the last channel at an angle of 0.0145 radians. Repeating these calculations yield a channel with a radius of 13.75 cm and an average magnetic field "seen" by the pion of 3.45 kG resulting in a bending angle of 0.017, which is greater than the divergence angle, i.e., the pion is captured (its orbit actually turns at L = 17 cm).

The preceding scheme is not an optimal lens configuration. The choice of only five channels was made to ease calculations and demonstrate the principle. It is clear that a system of spark channels that is as tapered as possible (i.e., many short channels with successively increasing radii) would yield better results.

An alternative scheme is to use a wall-stabilized Z pinch with a magnetic field. Such a discharge reached the following parameters 40 years ago [11]: a 0.8 meter long discharge with a current of 2 MA for a duration of 250 μsec was achieved. The axial magnetic field was 1.5 Tesla and the discharge radius was about 6 cm.

From Equations (3) and (2), the average poloidal field acting on a pion in such a discharge is 33.33 kG. Using Equation (1), with these discharge parameters and solving for θ yields $\theta = 0.263$ radians. Thus, using such a discharge as a lens for either the g-2 or neutrino oscillation experiment would yield an acceptance angle of at least 0.263 radians (the axial magnetic field enhances the acceptance). Tapering the discharge can further enhance pion focusing for these experiments.

B. Z Pinches as Focusing Lens for the Muon Collider

For the muon collider, a state-of-the-art Z pinch with a current of 10 MA is considered. From Equation 3, the azimuthal magnetic field at a distance of 1 cm from the axis is 2000 kG. For such an average magnetic field acting for only one inch on a 2 GeV/c pion, Equation 1 yields a bending angle of 0.84 radians, i.e., it is reasonable to conclude that this may be close to the capture angle for 2 GeV pions entering the Z pinch on its axis.

Next, a preliminary computation for the focusing capability of a lens based on a series of 10 MA Z pinches is presented. A computation was performed with a computer code that was developed by J. Gallardo and R. Palmer to evaluate a lens system consisting of a 1 meter long tapered lens followed by a series of cylindrical lenses for a total length of 200 meters (length needed for pions to decay into muons). The tapered section starts with a radius of 8 cm that increases to 15 cm (which is the radius of the straight section). The focusing magnetic field was generated by a series of Z pinches stabilized by a small axial magnetic field (with insignificant effect on focusing). The production target was bombarded by 10 GeV protons yielding pions with energies of 1.2 GeV $\pm$ 0.98 GeV, which later decay into 0.8 GeV $\pm$ 0.73 GeV muons. The muon-to-proton ratio for this system of lenses, based on calculations using this code, is

$$\mu/p = 0.38\,.$$

This represents a 50% enhancement in muon capture when compared to two other scenarios that utilize similar configurations. For example, lithium lenses yielded $\mu/\mathrm{p} = 0.23$. With further optimization, the yield from this system of Z pinches can be increased, and a large part of the 200 m (following capture) can be made of a solenoidal magnetic field.

V. ELECTRON COOLING EFFECTS

A low thermal spread electron beam moving at the same velocity with a hotter charged particle beam will have a cooling effect on that beam. Spark channels, Z pinches, or hybrid systems can be designed to have electrons moving at the same velocity as pions and muons during the discharge. Pions and muons focused into such a spark channel will be cooled by the electrons.

At first glance, this idea does not seem very feasible since pions and muons are not trapped; consequently, cooling must be on a time scale much shorter than a second (which is typical for electron beam coolers). However, if the parameters from LEAR are scaled up, this idea seems more interesting.

Using calculations from H. Poth's CERN report,[16] a 1 Ampere electron beam will cool antiprotons in 0.03 seconds if exposed continuously to the electron beam (since they are subjected to the cooling effects of the electrons for only 1/50 of their orbit, cooling occurs in 1.5 seconds). Theoretically, the thermal equilibration time is given by

$$\tau = 5.56x10^{18} \frac{(m_h T_c + m_c T_h)^{3/2}}{(m_c m_h)^{1/2} Z_h^2 Z_c^2 \lambda n_c} \text{ sec} \tag{4}$$

(eV, cgs units)

where subscripts c and h refer to cold and hot particles, respectively. It is clear from Equation 4 that equilibration time is proportional to the density of the lower temperature particles and for electron beams with equal cross section (and velocity), the electron density is proportional to the current.

To scale up from LEAR, consider a 3 meter long 1 MA hybrid electron beam spark channel. The transit time of a pion or a muon through that distance is 10 nsec; therefore, to compensate for this, shorter cooling period, the electron current (density) must be raised, 1 MA to make up six orders of magnitude. An additional gain is made by the fact that electrons equilibrate faster with lighter particles (pions and muons here versus antiprotons in LEAR). Since the energy equipartion time is proportional to the square root of the mass ratio, cooling time is reduced by a factor of 2.6 for pions and about 3 for muons. Thus, the cooling properties of such a hybrid electron beam spark channel for pions and muons and the electron cooler for antiprotons are not too far apart. Furthermore, these hybrid channels can be stacked.

However, Equation 4 shows a very strong temperature dependence. Those pions and muons whose temperature is not too far off the electron temperature can indeed be cooled in such a hybrid channel. At LEAR, electron cooling of 308.6 MeV/c antiprotons with an initial momentum spread of 2 x 10^{-3} was performed.[17] To cool 2 GeV/c pions or muons with a thermal spread of about 200 MeV, cooler parameters need to be increased by close to four orders of magnitude. This can be accomplished by increasing the total current to 10 MA and by stacking channels of hybrid systems to a total length of about 3 km. Such a cooler is not very feasible due to its cost.

However, if pions are initially cooled by other means, electron cooling can be used as a final stage cooler. Consider a muon beam that was cooled and slowed down to a momentum P = 300 MeV/c and a momentum spread of

$$\frac{\Delta P}{P} = 4\% .$$

To calculate the cooling time, H. Poth's formula is used

$$\tau = \frac{\sigma_\mu^3 + \Delta_e^3}{6\pi Z^2 R_e R_\mu n_e L_c} \tag{5}$$

where L_c is the Coulomb logarithm, R is the classical radius, σ_μ and Δ_e are velocity spreads of muons and electrons, respectively (MKS units).

For the electron velocity to match that of 300 MeV/c muons, 0.516 MeV electron are needed. Therefore, a 10 MA electron beam in a Z pinch or a spark channel with a 1 cm radius (to match the radius of the muon beam) will have a density

$$n_e = 4.77 \ x \ 10^{15} \ electrons/cm^3 .$$

And, we choose for the electrons to have a thermal spread of 3.48 keV to match the velocity spread of the muons (and L_c = 15).

Using Equation (5) to calculate the cooling time, yields 6.48 x 10^{-9} sec. Hence, since 300 MeV/c muons travel a distance of 1.68 meters during this time (their velocity is 2.6 x 10^8 m/sec), a cooling channel of 1.68 meters is needed. At the end of this cooling channel, $\Delta P/P$ = 2.86 x 10^{-3}. An additional stage with much colder electrons T_e = 0.1 eV can be added. In this stage, cooling occurs according to Equation (5) in 2.16 nsec (in a 10 MA channel). At this current, a cooling channel length of 56 cm is needed (or the current can be reduced in a longer channel) and ΔP/P can be reduced to

$$\frac{\Delta P}{P} = 1.53 \; x \; 10^{-5} \; .$$

These preliminary calculations indicate that two channels, containing 10 MA 516 keV electron beams, with a total length of 2.24 meters can be a very effective final cooling stage for the muons and reduce their momentum spread by more than three orders of magnitude.

In cooling μ^-, the magnetic field generated by the co-moving electrons focuses μ^-. But, such a magnetic field defocuses μ^+. To cool μ^+ particles, no net axial current should exist in a channel. One possibility is to shoot the 10 MA electron beam through a 10 MA Z pinch such that the two currents cancel each other. Confinement can then be provided by a multiple magnetic field. For a Z pinch with parameters achieved earlier [10], the confining magnetic field can be calculated from $B^2/2\mu_o$ = nkT to be 6.34 Tesla. In such a channel scattering by the Z pinch particles can be shown not to be a problem, since electron-electron scattering time is 320 nsec, while electron-muon scattering time is 3.6 msec, both of which are much longer than the total cooling time of 8.48 nsec.

This configuration is expected to be stable for the time scale of interest (nsec) to muon colliders. Although such a velocity space configuration is potentially micro-unstable, the resulting instabilities, if they occur, will have growth rates that are slower than the cooling time. This configuration resembles that of reverse field pinches, which are more stable than conventional Z pinches (since a number of macroinstabilities have a slower growth rate).

VI. CONCLUSIONS

Spark channels or a Z pinch can, in principle, meet the pion focusing needs of both the neutrino oscillation experiment and the g-2 experiment. One proposed scheme utilizes 250 kA spark channels that exceed the 200 kA already achieved. No effort was made to reach higher current values since 50-75 kA channels were found to be well suited for fusion. It is reasonable to assume that 250 kA can be reached; however, lower current values can be compensated for with longer or additional channels. A 2 MA Z pinch with a tapered configuration can extend the acceptance angle for pions to 0.3 radians. Without tapering, a Z pinch, with parameters that were reached 40 years ago, can serve both the neutrino oscillation experiment and the g-2 experiment as a lens with an acceptance angle of 0.263 radian, i.e., a substantial enhancement over what is being presently considered. Thirty years ago, a very modest version of such a lens was used in an AGS experiment.[18] This lens performed well until a ceramic liner broke and was not replaced since the experiment was close to its conclusion.[19]

Multi-Mega-Ampere Z pinches deserve a further, more serious consideration for possible use as first lens in a muon collider. State-of-the-art Z pinches have reached 10 MA. Extending a Z pinch type discharge length and radius with wall and axial magnetic field stabilization is possible. This will result in larger current as well. Consequently, pursuing this approach can result in a formidable pion capturing and focusing lens.

A hybrid system of electron beams and spark channels, or electron beams with Z pinches, is an interesting idea to pursue, as a final stage cooler for the muon collider. The scheme proposed for cooling positive muon involves a more complex configuration, which is also worth pursuing.

VII. REFERENCES

[1] M. Giesch, et al., NIM 20, 58 (1963).

[2] C.L. Olson, J. Fusion Energy 1, 309 (1982).

[3] G. Dugan, et al., IEEE Trans. Nucl. Sci. NS-30, 4, 3660 (1983).

[4] A. Ijspeert and P. Sievers, CERN SPS/86-18 (ABT).

[5] A. Carroll, et al., Proceedings of IEEE Particle Accelerator Conf. 1987, p. 1731.

[6] J. Olsen, D. Johnson, and R. Leeper, Appl. Phys. Lett. 36, 808 (1980).

[7] J. Olsen and R. Leeper, J. Appl. Phys. 53, 3397 (1982).

[8] P. Ottinger, et al., Proceedings of IEEE, 80, 1010 (1992).

[9] C.L. Olson, private communication, 1994.

[10] A series of papers (by Golovin, et al., Komelkov, et al., and Andrianov, et al.), presented at the second U.N. Conf. on Peaceful Uses of Atomic Energy, Vol. 31 and 32, Geneva, 1958.

[11] Work by McDaniel, et al., D.L. Cook, private communication, 1994; Rahman, Wessel, and Rostoker, reported current levels of 5 MA in PRL 74, 714 (1995).

[12] A. Carroll, private communication, 1994.

[13] G. Bunce, private communication, 1994.

[14] C. Hojvat, private communication, 1994.

[15] J. Gallardo, private communication, 1994.

[16] H. Poth, CERN-EP/90-04.

[17] H. Poth, et al., NIM A287, 328 (1990).

[18] E.B. Forsyth, L. Lederman, and J. Sunderland, IEEE Trans. Nucl. Sci., p. 872 (June, 1965).

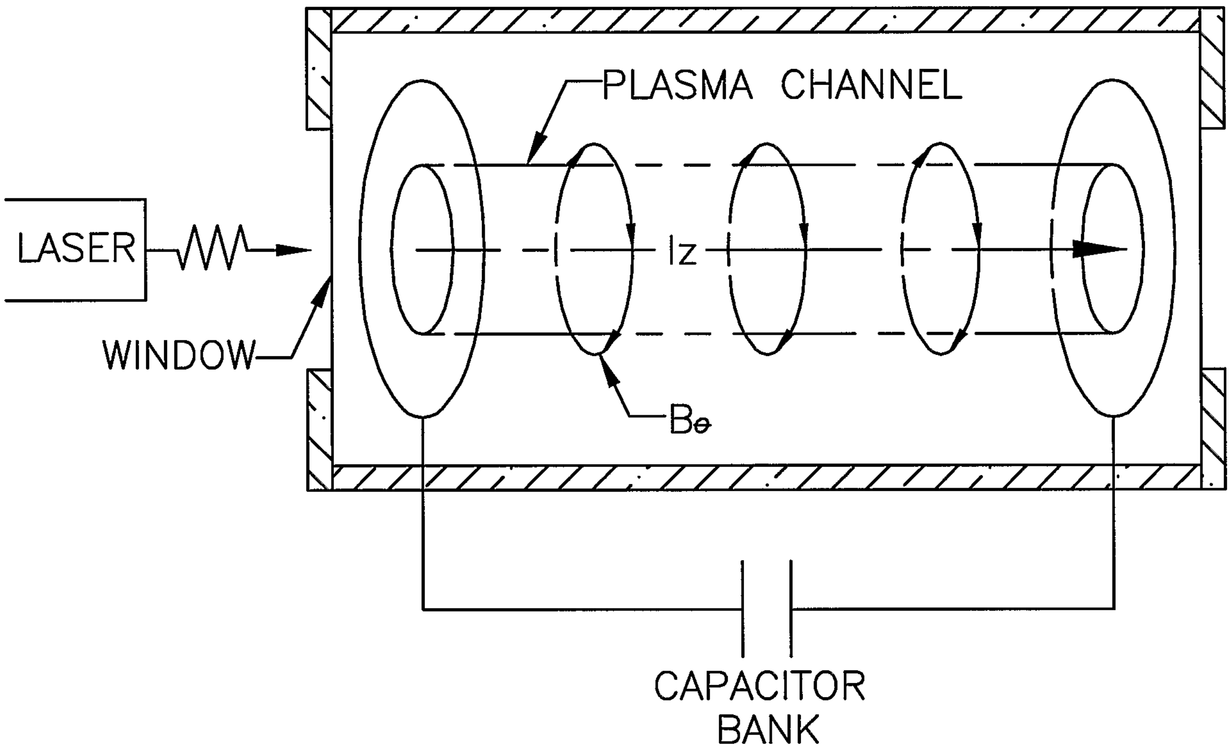
[19] E.B. Forsyth, private communication, 1995.

Figure Captions

Figure 1. Schematic of a laser initiated spark channel.

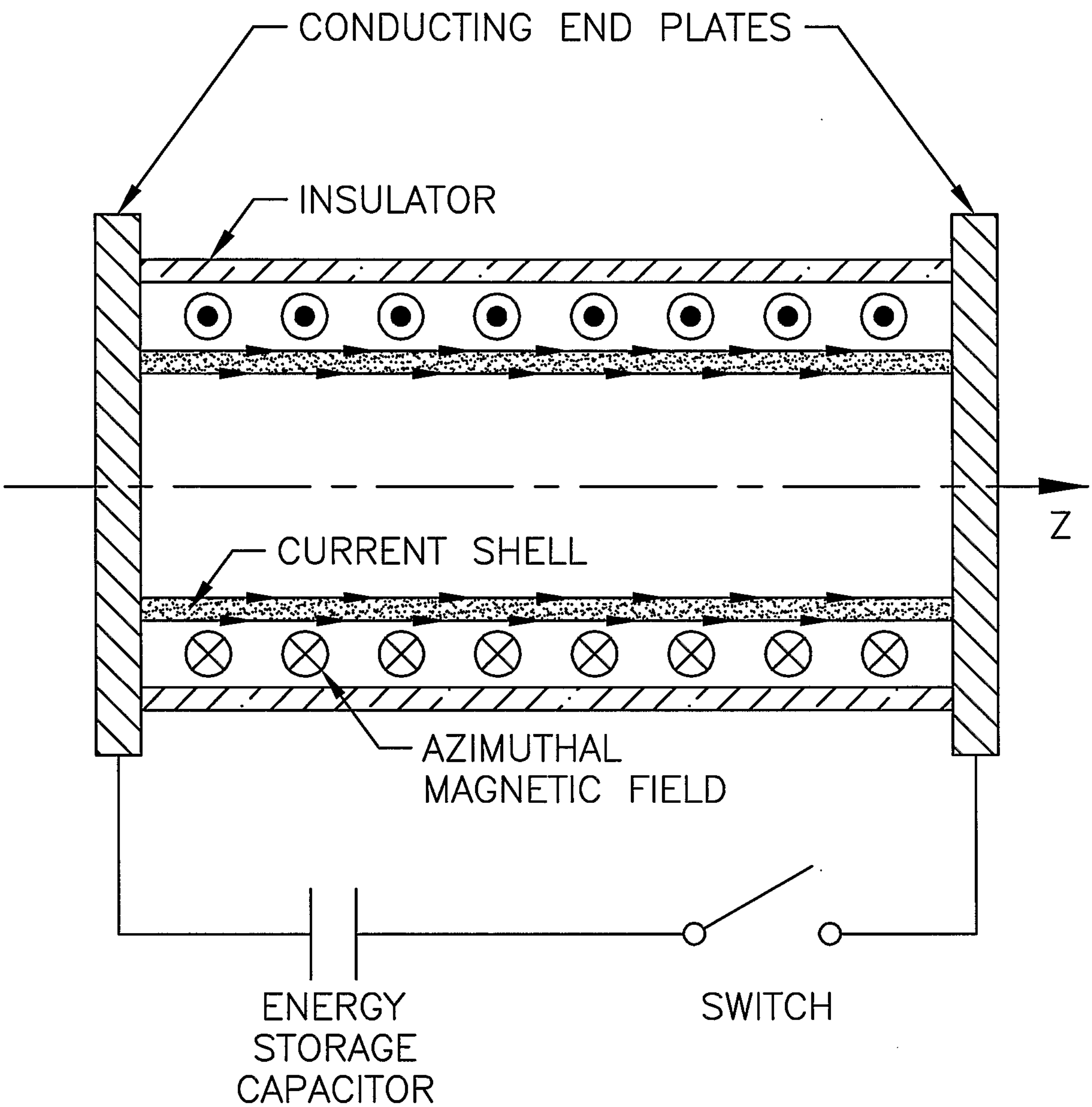
Figure 2. Schematic of a Z pinch.

Figure 3. Diagram of a possible pion focusing scheme for the g-2 and neutrino oscillation experiments.



SPARK CHANNEL

FIGURE 1



Z PINCH

FIGURE 2

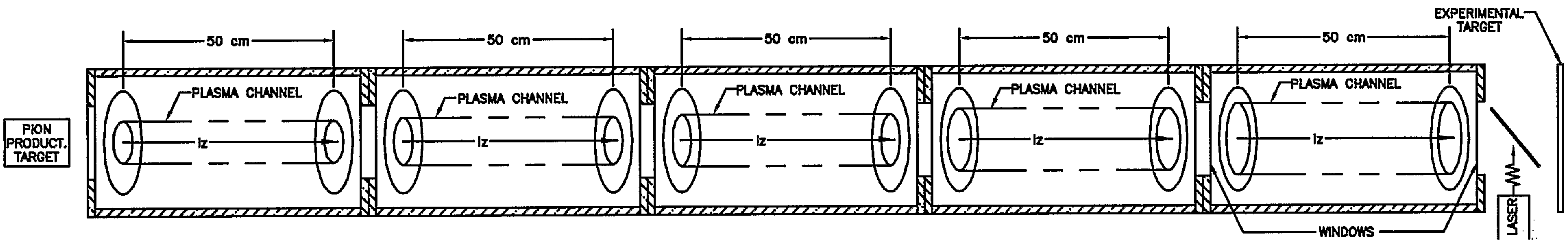

PION PRODUCT. TARGET
50 cm
50 cm
50 cm
50 cm
50 cm
PLASMA CHANNEL
PLASMA CHANNEL
PLASMA CHANNEL
PLASMA CHANNEL
PLASMA CHANNEL
Iz
Iz
Iz
Iz
Iz
EXPERIMENTAL TARGET
WINDOWS
LASER

FIGURE 3