Some Comments on the Early History of the $\mu^+\mu^-$ Concept and the High Intensity μ Storage Ring

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It is always difficult to pin down the origin of a good idea in particle physics. Take the case of the $p\bar{p}$ collider. The concept of a colliding $p\bar{p}$ was discussed a few years after the discovery of the anti-proton but a realistic collider could not be considered until ~1976[1] when electron and stochastic cooling had been invented.

The $\mu^+\mu^-$ collider story will likely be the same. There are two aspects of the development:

1. High Energy $\mu^\pm$ Storage Ring
2. Collection and Cooling of $\mu^\pm$ and Concept of the $\mu^+\mu^-$ Collider.

There is a long history to (1). For example, the various μ(g-2) experiments store the μ's for a short time. One of the earliest concepts of a high energy μ storage ring for a μ-p collider seems to have started with Rochester[2]. A more detailed discussion of a μ storage ring - this time to produce specific neutrino beams - was proposed by Cline and Neuffer in 1980 (see following paper reproduced here)[3].

The development of μ ionization cooling is also an old idea (two other early papers on this are reproduced here: Neuffer[4]; Parkhomchuk & Skrinsky[5]). We have obtained some information concerning even earlier discussions at Novosibirsk from Skrinsky. We provide those extracted statements here. We also provide reference to the early work by Neuffer on $\mu^+\mu^-$ colliders[6].

REFERENCES:

1. C. Rubbia, P. McIntyre and D. Cline, Proc. of 1976 Aachen Neutrino Conf., (Eds, H. Faissner, H. Reithler and P. Zerwas)(Vieway Braunschweig), (1977) 683.
2. A. Melissinos, private communication. He and others at Rochester proposed a μp collider in the 60's.
3. D. Cline and D. Neuffer, AIP Conf. Proc. no. 68 pt 2, (1980) 846.
4. D. Neuffer, Proc. 12th Int. Conf. on High Energy Accelerators, (Eds. F. T. Cole and R. Donaldson), (1983) 481.
5. A. N. Skrinsky and V. V. Parkhomchuk, Sov. J. Part. Nucl. 12(3) (1981) 223.
6. D. Neuffer, Part. Accel. 14 (1983) 75; D. Neuffer, in: Adv. Accel. Concepts [AIP Conf. Proc. 156 (1987) 201.

Extracts:

The First INP Publications on Muon Colliders

From the Budker's talk at the International Accelerator Conference, Erevan, 1969:

"On the other hand, of obvious interest are the lepton collisions at energies of a few hundred GeV (in the center of mass system). For this, the most convenient particles are mu-mesons. One can consider two variants:

1. The mu-mesons injected into a storage ring make some certain number of turns during their lifetime independent on energy: 400 turns in a 20 kG field and 4000 turns in a field of 200 kG. Using accelerators of very high intensity as the injectors of mu-mesons one can attempt to realize my-meson collisions in a special accelerator. The small cross-section of the event and low factor of conversion for protons into mu-mesons with a low spread of energy and angles make this problem very complex even with the presence of a proton accelerator at very high energy.
2. Another method currently under development in Novosibirsk suggests the long time storing of a very large number of protons of rather low energy (25 GeV), slamming them into a target, obtaining a large number of mu-mesons of both signs of low energy and in a good phase volume, and their further acceleration in a special coreless pulsed accelerator up to high energies in the range where the reactions with mu-meson interactions are being studied. Because of an increase in the mu-meson lifetimes with an increase in energy, the acceleration can be performed practically with no loss."

From the Budker's talk at the International High Energy Physics Conference, Kiev, 1970:

"Therefore we are seriously considering the somewhat exotic but quite real project of mu-meson accelerators and mu-meson colliding beams. The relativistic effects enable one to accelerate mu-mesons in cyclic accelerators with practically no loss at a sufficiently high growth rate of the magnetic filed. Therefore, for mu-meson accelerators with fixed targets and colliding beams, we plan to use the short-focus ironless magnets developed at INP. The magnets accurately form fields due to their thin skin current distribution. For obtaining a large current of mu-mesons, which is very important for colliding beams, we expect to use the proton accelerator VAPP as well as the whole megagauss focusing instrumentation being developed at the VAPP-NAP installation for focusing of antiprotons.

In order to decrease the phase volume of mu-mesons from the decay of pi-mesons generated prior to their entrance into the storage ring we expect to build an intermediate pulsed storage ring with a field of 200 kG with the damping of the mu-meson beam due to the energy losses on a target installed inside the ring.

At present, two stages are under consideration: the installation of a 12-15 m radius ring with an energy of 7-100 GeV and the installation of a 160 m radius ring at 1000 GeV. It should be noted, that these installations can be used both as the proton and antiproton accelerators up to these energies and as the installations with the proton-anti-proton colliding beams. The low duty factor of the pulse accelerators is practically entirely compensated for by the high particle current and this gives them experimental possibilities compatible with the iron magnet at the corresponding energy. Their much lower cost makes their construction feasible for small laboratory having reasonably low funds such as the Novosibirsk Institute of Nuclear Physics. One should note, that the possibility of using these accelerators for protons provides us with the decisiveness to start their construction. Though we hope to get a lot of experimental data with the mu-meson colliding beams, it does not exclude the possibility that it might be an installation of a single experiments, namely, the discovery of the form-factor at the lepton interactions. If the cross-section of the weak interaction stops to grow with energy, the installation's luminosity is not sufficient for any observation. Whatever interesting result could it be, however, this does not justify the decisiveness for such a complex project."

Morges Seminar 1971 - Intersecting Storage Rings at Novosibirsk A.N. Skrinsky

$\mu^+\mu^-$ Possibilities

These experiments at hundreds GeV energy region will be available, only when several very difficult things will be discovered:

1. To have a very large number of protons with 10 GeV energy in rather short bunches. It is necessary to have about 10^{14} or even 10^{15} protons in about 10 sec in several meters long bunch.
2. To produce with maximum efficiency muons with 1 GeV or less energy, using nuclear cascade, strong focusing in the target and in pion decay channel. It seems possible to have 0.1 or even more useful muon per proton.
3. To cool muons in special 100 kilogauss pulsed storage ring, using ionization energy losses. If the targets are in places with very small β-function, the finishing emittance of muon beam should be small enough to be injected into the main muon accelerator with small aperture and to be well compressed in interaction points.
4. To accelerate muons rapidly in some accelerators. If the muons are accelerated to their rest energy in a time, several times less than their life time at rest, most of the muons will be accelerated up to the required energy. It is possible to use a linear accelerator, or to use a synchrotron with more than a 100 kilogauss and magnetic field with a short rise time. In the last case, the accelerator will be at the same time the colliding beams ring. In the ring with such a magnetic field it is possible to have several thousands of useful turns of muon beams.

If all of these conditions are satisfied, it seems to be possible to have an average luminosity $10^{31} cm^{-2} sec^{-1}$ and may be a bit more, which should be sufficient.

Accelerator and Detector Prospects of Elementary Particle Physics - A.N. Skrinsky

Institute of Nuclear Physics of the Siberian Division of the Academy of Sciences of the USSR, Novosibirsk, Usp. Fiz. Nauk 138, I-43 (September 1982)

This review treats the progressive changes in the filed of physics and technology of accelerators, and in part, of detectors, which have exerted and will in the near future exert a fundamental influence on the development of elementary-particle physics. In particular, it discusses the possibilities of generation of beams of elementary particles and the prospects of performing experiments with colliding beams involving the development of methods of cooling charged-particle beams, designing superconducting systems, and developing Superlinacs.

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