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Physics Potential and Development of a $\mu^+\mu^-$ Collider: The Crystal Collider*

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1 Introduction

The development of new types of colliders is essential to the future of particle physics. In the recent past, the development of the $\bar{p}p$ collider[1] and e^+e^- [2] linear collider as well as hadron colliders using superconductivity magnets has been very important. We believe the $\mu^+\mu^-$ collider may also become of importance in the future[3]. However, it is going to be important to bring the cost of such a machine to reasonable levels. In this paper we discuss the use of bent crystals for μ magnets, channel cooling in crystals, and the possible collision inside a crystal - the quantum collider. In the past we have organized workshop on these colliders at NAPA (92)[3], Sausalito (94)[4] and San Francisco (95).

2 Physics Potential of $\mu^+\mu^-$ Colliders.

The possible usefulness of a $\mu^+\mu^-$ collider is due to the muon mass and fundamentals of lepton-antilepton colliders

i) At low energy (250×250 GeV), the coupling to scalar particles goes like m_μ^2/M_e^2 compared to e^+e^- machines; also the μ^+ and μ^- can be polarized. Thus a $t\bar{t}$/Higgs Boson factory might be developed[3].

ii) At high energy, the μ radiates like $\left(\frac{m_e}{m_\mu}\right)^2$ compared to a e^+e^- machine. Thus circular colliders can be constructed to very high energy to search for SUSY, new leptons etc.[4]

These features are unique to $\mu^+\mu^-$ colliders. The scope of physics goals are illustrated in Fig. 1.

3 How a $\mu^+\mu^-$ Collider Works

We tend to think of μ's as short lived particles, however, a 2 GeV μ will travel 12 Km before it decays. Thus, if it is possible to cool the beam and accelerate it within a fraction of this distance, a $\mu^+\mu^-$ collider might make sense. The essential components of a $\mu^+\mu^-$ collider are

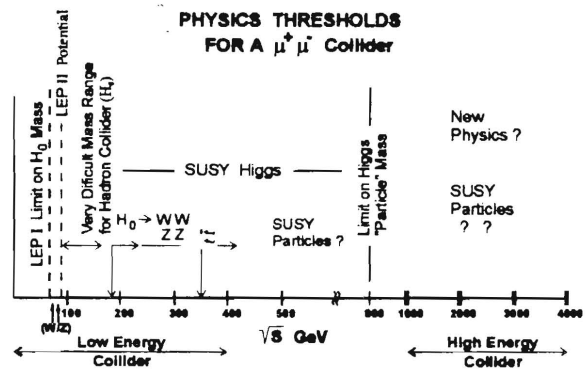

Figure 1: Physics thresholds for a $\mu^+\mu^-$ collider.

given in Table 1 along with the luminosity of a $250\times$ 250 GeV collider from the Sausalito workshop[4].

4 The use of Crystals for $\mu^+\mu^-$ Colliders.

Since μ's are "inert", they can pass through condensed matter systems. This gives new possibilities for cooling, accelerating and colliding μ beams, using the organized magnetic and electric fields inside crystals.

i) **μ cooling.** We have worked out schemes in the past to cool μ's by ionization[3]. This used the random structure of material. However, using crystals, the systematic structure can be used - one example is the μ wiggler[5] where bent crystals (of alternating bend) accelerate the μ to radiate. Another possibility is channel cooling where the μ beam relaxes into the crystal channel[6]. This may be enhanced by acoustic coupling[7].

ii) **μ Acceleration in Crystals[7,8].** It has long been recognized that crystals can supply very high gradients (from 10^5 eV/m to GeV/m - μ beams) and are ideal to use such accelerator due to their inert properties.

iii) **Quantum and Crystal Collider[9,10].** If low emittance μ beams can be obtained, they can be con-

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Table 1: Parameter List for 400 GeV $\mu^+\mu^-$ Collider

Parameter	Value
Collision energy	400 GeV
Energy per beam	200 GeV
Luminosity	$1 \times 10^{31}\text{cm}^{-2}\text{sec}^{-1}$
Source Parameters	
Proton energy	30 GeV
Protons/pulse	$2 \times 3 \times 10^{31}$
Pulse rate	10 Hz
μ (prod./accept.)	0.03
μ survival	0.33
Collider Parameters	
Number of μ/bunch	3×10^{11}
Number of bunches	1
Storage turns	1500 (B = 5T)
Normalized emittance	10^{-4} m-rad
Interaction focus	1 cm
Beam size at interaction	2μm

tained using a series of bent crystals - one can imagine colliding within the channels - thus giving the possibility of quantum collider. Fig. 2 illustrates one such possibility.

5 Cooling Test at TRIUMF

Our team is planing a series of experiments with the well defined μ beams at TRIUMF. The experiment will be performed in three phases. The first phase, called the transmission experiment, will show channeling of muons in a 3 mm long silicon crystal. The second phase will measure the cooling of channeled muons in a long, 4 cm silicon crystal. Finally, the third phase will incorporate acceleration using a laser system.

6 Crystal and Quantum Colliders

We have carried out a conceptual study of a storage ring, composed of crystal bending magnets and cooling cells. Fig. 3 shows some of the properties of this collider[4]. Due to the large energy loss on each turn, it would be necessary to use a high-gradient accelerator method, such as that in crystal acceleration. There is an exciting but very advanced concept, to collide the μ beams inside a crystal in the individual channels[9,10]. This can follow from channel cooling to reduce the emittance of the beams.

There is an enormous gain in luminosity, for example, for 10^5 μ's per channel and 10^3 channels filled, we find a luminosity of 10^{32} cm^{-2} sec^{-1}. However, the total number of μ's per pulse is only 10^8, reducing the required cost and performance of the $\mu^\pm$ source.

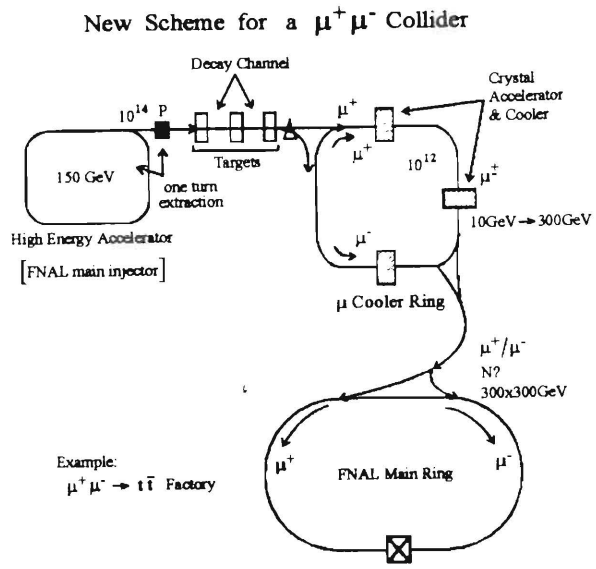

Figure 2: $\mu^+\mu^-$ Crystal Collider

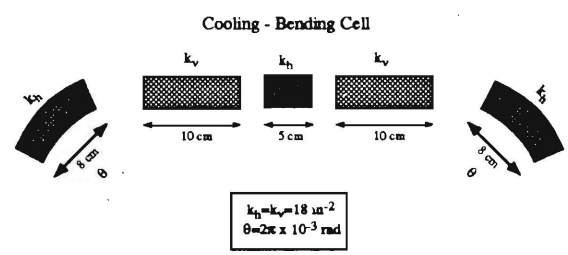

Figure 3: A Cooling-Bending Cell.

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