A PRELIMINARY DESIGN OF THE PS COLLIDER

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abstract

A preliminary design of the heavy ion collider (PS-Collider), which has been recently proposed at KEK PS, is described. The PS-Collider(PSC) aims to accelerates and collides various ions from proton(polarized) to gold at the energy of 5-7GeV/u with a luminosity of 10^{25}cm^{-2} s^{-1} to create high nuclear density matter($\rho \approx 10\rho_0$) and high energy spin physics.

1. Introduction

One of the recent very important issues in high energy nuclear physics is to discover new states of hadron/quark matter such as quark-gluon plasma. From the recent experiments with high energy heavy ions at BNL and CERN, it seems obvious that colliding nuclei would almost stop at the beam energy of as high as 40 GeV/u(in the fixed target mode) or 4GeV/u (in the collider mode).In heavy ion collisions at this energy range, if two colliding nuclei completely stop, expected nucleon density reaches at the level as high as $\rho = 2\rho_0\gamma_{CM} \approx 10\rho_0$, where ρ_0 is the density of normal nuclei and γ_{CM} is the Lorentz factor of each beam in the center of-mass system. Recently, a heavy ion collider, the so-called PS collider(PSC) has been proposed at KEK[1]to create high nuclear density matter($\rho \approx 10\rho_0$), in which various heavy ions from proton to gold ions are accelerated, stored, and collided with the colliding energy of 4-7GeV/u . A preliminary design report of the PSC was published in the KEK Report written in Japanese and English[2][3].

The PSC is a superconducting accelerator and collider for heavy ions, which it is possible to construct in the present East Experimental Hall(EP-2) of the KEK 12GeV proton synchrotron(PS) eliminating the need for the construction of new buildings. The PS will be used as an injector of the PSC with modifications of the vacuum and RF systems for heavy ion acceleration. In designing the PSC, the following four points were considered as the design principles.

1. Colliding beam energy is 4-7GeV/u for gold ions.
2. Luminosity for colliding beams should be at least 10^{25} cm^{-2} sec^{-1} for gold ions.
3. The PS to be used as an injector of the collider.
4. Collider rings and detectors can be placed in the EP-2 East Experimental Hall.

In addition to this, another option with spin-polarized proton beam is also being considered recently. To avoid depolarization during acceleration and storage of polarized beams in the PSC, a siberian snake scheme can be adopted.

2. Design of the PS Collider

we have planned to utilize the existing accelerators (linac, 500MeV Booster and 12GeV-PS) as an injector and also to build the collider inside the present experimental hall (the East Experimental Hall) which is 54 m wide and 108 m long as shown in Fig.1.

The collider consists of two identical rings in order to make positively charged beams collide each other. They are installed in the same plane and are designed to intersect horizontally at two intersecting points. The ring is composed of two π-arc sections and two straight sections including low-β insertion. The circumference of one ring is 287.7m, which is five sixth of that of the 12GeV-PS. Since the harmonic number of the 12GeV-PS is 18, we chose h=15 for the collider. The injected beam into the collider will be accelerated up to a top energy of 7GeV/nucleon, and debunched by turning off the accelerating voltage for colliding experiments. The total number of the dipole magnets per ring is 52. They are superconducting, and 48 of them are located in the π-arc sections and the others in the straight sections. The number of the quadrupole magnet per ring is 86 (50 for the arc sections and 48 for the straight sections). Four pairs of two quadrupole magnets are superconducting, but the others are normal. The main machine parameters are summarized in Table 1.

Table 1. Main parameters of the PS-Collider

Injection energy, ^{197}Au		500 MeV/nucleon
Final energy, ^{197}Au		4 ~ 7 GeV/nucleon
Luminosity, ^{197}Au at final energy		~10^{25} cm^{-2}sec^{-1}
Crossing angle		$2\phi = 3.6^\circ$
Betatron amplitudes at intersecting point		$\beta_x{}^* = 5$ m
		$\beta y^* = 1$ m
Dispersion function at intersecting point		$\eta_x = 0.00128$ m
		$\eta_x{}' = -0.0370$
Diamond length(full) at 5 GeV/nucleon		230 mm
Average radius		R = 45.0 m
Circumference,5/6 of PS-MR		C = 282.7433 m
Curvature of arc section	outer	25.78 m
	inner	24.83 m
Cell length in arc section	outer	6.75 m
	inner	6.5 m
Number of superperiods		$N_s = 1$
Betatron wave number		$\nu x = 10.2$
		$\nu_y = 11.2$
Momentum compaction factor		$\alpha_p = 0.00286$
Transition (kinetic) energy		$\gamma_t = 18.7$
		$T_t = 16.6$ GeV/u
Magnet Parameters		
Magnetic rigidity	at injection	$B\rho = 9.09$ Tm
	at final 7 GeV/u	$B\rho = 65.6$ Tm
Number of dipole magnets per ring	in arc	48
	in insertion	4
Number of quadrupole magnets per ring	in arc	50
	in insertion	36

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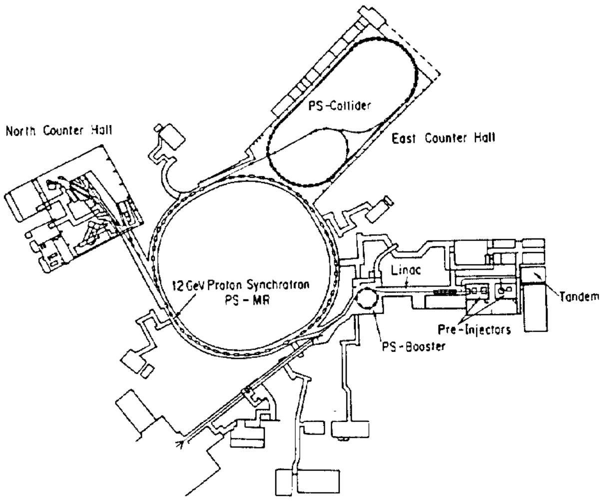


Fig.1 Schematic layout of the PS-Collider.

(a) Lattice

The ring has two π-arc sections of which average curvatures are 25.783m and 24.828m, respectively. Each of the π-arc sections is made of four arc superperiods and each superperiod consists of three normal FODO cells. The requirements for the arc sections are to be dispersion free at both ends and to have a small momentum compaction so that the transition energy (Et) of the ring should be far away from the flat top beam energy, to avoid crossing it. For the former requirement, the phase advance of one superperiod is chosen to be 2/3π radian so that the matrix of each arc can become a unit matrix. To achieve a lattice with a high transition energy (so-called γ_t lattice), the field strength of the several quadrupole magnets of the one superperiod are modulated[4][5].

The lattice between the two arcs consists of a low-b insertion and a matching straight section. In the straight section of the inner π-arc side, injection septum and kicker magnets are situated. On the other side of the straight section, rf-cavities are installed. Considering the relations of the achievable luminosity and the emittance growth associated with intrabeam scattering, coasting beams might be of benefit to both the operation of the machine and the colliding beam experiments. In this case, the diamond length, which is defined as the length of the interaction area, should be finite and may be limited by the detector size. If coasting beams are used, therefore, a certain crossing angle will be necessary. In the PS collider, the crossing angle (2ϕ) is about 3.6degree. The length of the interaction region (full diamond length), assuming three standard deviations for the beam size, is estimated to be approximately 230mm. In Fig.2, the beam parameters of the PS-Collider is presented.

(b) Luminosity

One of the most important parameters limiting the luminosity in high energy heavy ion collider is beam blow up, especially in horizontal and longitudinal directions, due to intrabeam scattering as described later. To minimize the luminosity degradation during an experimental period of about 1 hour, we choose to use the scheme of coasting beam collisions with a horizontal crossing angle because the beam luminosity does not depend upon the horizontal beam size in the coasting beam collision.

The luminosity for the coasting beam collisions is given by[6],

$$L = \frac{f_{rev} N_c^2}{4\pi R\sqrt{\pi}} \times \frac{1}{\sigma_y \tan\phi} \approx \frac{f_{rev} N_c^2}{4\pi R\sqrt{\pi}} \times \frac{1}{\sigma_y \phi}$$

For gold beams at 7Gev/u, $L = 1.3 \times 10^{25}\ \mathrm{sec^{-1}cm^{-2}}$.

(c) Beam-Beam Tune Shift

In colliding mode operation, each of beams may affect the other at the intersection point, because of their repulsive coulomb force. This causes a beam-beam tune shift ($\Delta\nu_b$). In the case of fully stripped heavy ionic elements, the tune shift is larger than that for a proton beam by a factor of (Q^2/A). Assuming that a beam has a Gaussian particle density distribution, in case that the beams intersect with a horizontal crossing angle (2ϕ), for gold beams at 7GeV/nucleon we estimate,

$$\Delta\nu_x = 5.6 \times 10^{-6}$$

$$\Delta\nu_y = 1.1 \times 10^{-6},$$

where we take $N_c = 3.22 \times 10^{10}$ ppp. The beam-beam tune shift is negligibly small.

(d) Aperture

The maximum aperture(Amax) is summarized at several magnets in Table 2.As shown in table, sagitta occupies two third of the beam aperture A_{max} and A_{max} at several dipole magnets in the inner arc reaches ~ 70m. When superconducting dipole magnet has a curved structure, the required bore radius can be reduced to 35~40 mm. Development of the curved structure superconducting magnet has been started at KEK.

Table 2 Summary of Apertures

Q-magnet		$\sigma_{x\,rms}$	Sagitta	Amax
QQ2	straight	11.7	—	47
QLL	outer arc	13.5	—	54
Dipole Magnet		$\sigma_{x\,rms}$	Sagitta	Amax
BS1	straight	5.5	1.6	24
BX	inner arc	11.5	22.9	69

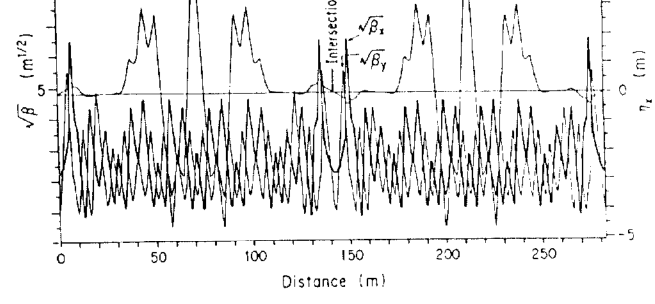


Fig. 2 Beam parameters for the PS-Collider.

(e) Intrabeam scattering

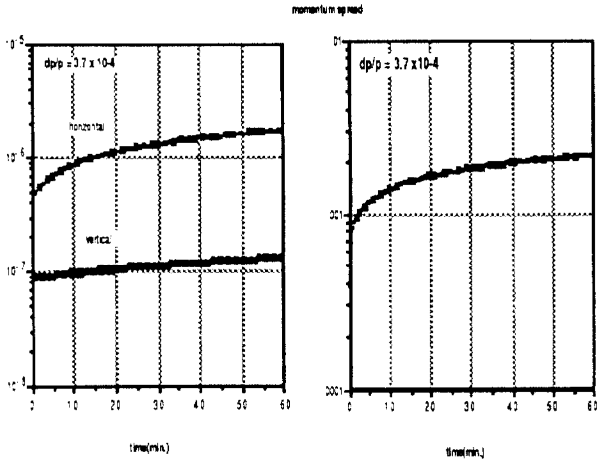
The long term emittance growth of accelerated particles due to intrabeam scattering is one of the major restrictions to limit the stacking rate and the luminosity of the beams in hadron storage accelerators.[7] The intrabeam scattering for heavy ion beams is considered to be more serious than that of proton beam. The beam emittance growth rate τ^a due to intrabeam scattering for heavy ions is $(A/Q^2)^2$ time larger than that for protons. For a gold (A=197, Q=79) ion beam, the beam emittance growth rate is approximately 1000 times faster than that of proton beam. This is, in general, the most crucial limitation for obtaining high luminosity beams in heavy ion collider.

The emittance growth for each direction was calculated for various momentum spreads as a function of time[8]. The results are shown in Figs.3(a) and (b).

As can be clearly seen from the figures, the horizontal and longitudinal emittances grow rapidly and, after an hour, these become more than twice of the initial emittances, respectively. On the other hand, the vertical emittance growth is very small. The luminosity for coasting beam collisions would not be influenced so much by intrabeam scattering if there is no couplings between each direction emittance and if the horizontal beam aperture is large enough for such emittance increase.

(f) Polarized beam collision

Protons can be accelerated up to the energy of 17.5GeV in the PS-Collider. There are so many depolarization resonances due to the betatron oscillation (intrinsic resonance) and the closed-orbit displacement (imperfection resonance) for accelerating and storaging spin-polarized protons up to this energy. To overcome the depolarization problem, a novel scheme, so called Siberian snake [9], may be adopted in our case. There are two practical ways to realize a Siberian snake scheme in the PS-Collider; one is to use a solenoid magnet placed at the long straight section and the other to use a helical dipole magnet. Figure 4 shows the required magnetic filed strength for solenoid and helical dipole magnets, respectively, in Siberian snake as a function of the proton beam energy. As can be clearly seen from the figure, required field strength of solenoid is proportional to the beam energy. For helical dipole magnet scheme, required field strength to keep the beam polarization is constant even when the beam energy increases, however, it depends on the number of twists of the helical dipole magnet. Both scheme seem to be applicable for accelerating and storaging polarized proton beams in the PS-Collider, however, a relatively long straight section is necessary even if a superconducting solenoid is used. The luminosity for the polarized proton beam collision is limited by the injected beam intensity from the PS and the luminosity of 10^{28} cm^{-2}sec^{-1} seems to be achievable. The beam collision with bunched beams may realize high luminosity of more than 10^{30}cm^{-2}sec^{-1}, however, the ring lattice configurations might be re-designed to allow the bunched beam collision.



(a)transverse

(b)longitudinal

Fig. 3(a) and (b) Beam emittance growth due to intrabeam scattering.

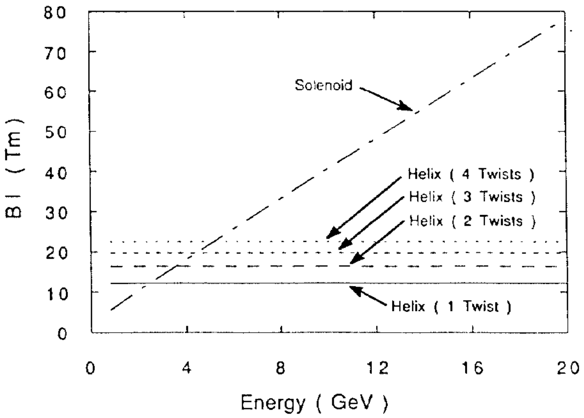


Fig.4 Required magnetic field strength for Siberian smake.

3 Summary

A preliminary design of the PS-Collider, in which various ions from proton(polarized) to gold ions are accelerated and collided at the energy of 7GeV/u for gold ions and 17.5 GeV for protons is described. A coasting beam collision is adopted in the collider design to minimize the luminosity degradation due to intrabeam scattering and the luminosity of 10^{25} cm^{-2}sec^{-1} is possible for gold ions and 10^{28} cm^{-2}sec^{-1} for polarized protons. Further luminosity increasing may be realized by adopting bunched beam collisions, however, careful re-design must be necessary.

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