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A Possibility to Study Proton-Proton Interactions at Extremely High Energies

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Abstract

We discuss the possibility of colliding an extracted booster beam with the main accelerator beam from NAL or CERN machines to obtain super high energy proton-proton interactions and the class of interesting experiments that one can do with such a set up.

Introduction

Recent results from the CERN-Rome [1] and the Pisa-Stony-Brook [2] groups on the increasing total proton-proton cross section σ_T in the region $s = 500\text{-}2700\ \mathrm{GeV}^2$, where s is the total C.M. energy square, indicate that there may be new physics of strong interactions to be explored at higher energies [3]. For example, the current data would indicate that $\sigma_T > 50$ mb for $s = 16000\ \mathrm{GeV}^2$. We propose here a simple way to study this high energy phenomenon without building expensive accelerators.

We made the following observations:

1. We have $s = 4E_1E_2$ where E_1, E_2 are the colliding beam energies. For a normal accelerator beam with energy E_1 interacts on proton target we have $E_2 = m_p$ the mass of proton and $s = 2E_1m_p$. For storage rings with two beams of energy E_1 and E_2 we have $s = 4E_1E_2$ with $E_1 \approx E_2$. We note that the value of s increases quickly (lineary) even though $E_2 << E_1$ but $E_2 > m_p$. For example, for a 400 BeV proton beam to collide with a 10 BeV beam we have $s = 16000\ \mathrm{GeV}^2$ or an equivalent 8000 BeV accelerator beam interacts with a proton target.

2. To study the general features of pp-interactions we do not need very high intensity beams. With $\sigma_T > 40$ mb, and multiplicity > 10; the measurements of total cross sections, multiplicities, etc. can be easily done with colliding beam techniques of extremely low luminosity $\approx 10^{24}\ \mathrm{cm}^{-2}/\mathrm{sec}$.

3. The two new accelerators being built (NAL and SPS) both have an energetic booster which operates at the same frequency as the main ring. This makes it possible to have the low energy beam extracted from the booster to collide with the main ring to achieve super high energies. For simplicity we use the NAL accelerators as an example:

We first extract a 10 GeV bunched beam from the booster. There are 84 bunches, each 2ns long. We obtain $10^{12}/84 = 10^{10}$ protons per bunch. We then transport the beam onto head on direction to collide with an extracted 400 BeV beam to obtain a pp-interaction at $s = 16000\ \mathrm{GeV}^2$. We need only 84 of 1113 bunches from the main ring with an intensity of $10^{13}/1113 = 10^{10}$ per bunch, each 2ns long. The rest of the 400 BeV beam can be used for other experiments. Thus over a 2' interaction region we have 84 collisions per pulse with a $(1\ \mathrm{mm})^2$ cross sectional area per beam in the 2' region and a luminosity of

$$\frac{10^{10} \cdot 10^{10}}{0.01\ \mathrm{cm}^2} \cdot 84 = 10^{24}\ \frac{1}{\mathrm{cm}^2\,\mathrm{pulse}}$$

For a 40 mb total cross section, $2 \cdot 10^4$ pulse/day we have

$$10^{24} \cdot 40 \cdot 10^{-27} \cdot 2 \cdot 10^4 = 800 \text{ interactions/day.}$$

The center mass system (denoted by *) is moving with $\beta^* = 0.95$ or $\gamma^* = 3.2$ in the direction of the 400 GeV beam. The maximum number of interacting regions is 168, and spacing between the interaction regions is 9'.

Similar statements can be made of collisions between 30 BeV protons from the CERN proton-synchrotron and the 400 GeV protons from the main accelerator. Here we have $s = 48000\ \mathrm{GeV}^2$ or an equivalent of 24000 GeV proton beam interacts with a liquid hydrogen target.

Backgrounds due to beam gas interactions: with a vacuum of 10^{-11} torr (the same as the current ISR value) in an interaction region of 1 meter by $(1\ \mathrm{mm})^2$ we have total of 10^7 nucleons. Comparing this with beam intensity of 10^{10}/bunch we conclude that the backgrounds from beam gas interactions are $< 1\ \%$.

Measurement of luminosity: In the normal storage rings the determination of luminosity has always been a major technical problem. The basic difficulty has been not knowing the intensity and the profile of the two interacting beams. In the proposed set up the beams interact once only. One can measure the intensities, the cross sectional areas, and the divergences of the beams after they have passed through the interacting region.

The Physics: We discuss here a few important experiments that can be done with such a set up:

1. Measurement of σ_T: This can be done by surrounding the interacting region with counters (proportional chambers) including 6' up and 6' down stream detectors located ~ 1 cm away from the beam to collect particles produced ≥ 5 mr. Since the average multiplicity is > 10, the chance of missing a charged particle is small.

If the total cross section continues to raise from the trend discovered at CERN,[1] [2] we will get $\sigma_T = 51$ mb at $s = 16000$ GeV^2 (NAL) and $\sigma_T \approx 60$ mb at $s = 48000$ GeV^2 (CERN) - a most interesting result indeed.

2. Multiplicities: This can be measured with the set up that measures σ_T. Putting counters 6' downstream and 1 cm away from the 400 BeV beam enables us to collect all particles with $\theta \geq 5$ mr or a center of mass angle $\theta^* > 63$ mr.

It should be possible to measure the multiplicity distributions as function of s by changing one of the beam energies.

3. Particle distributions: Here one can set up a movable magnetic spectrometer, using large solid angle dipoles (with vertical bending to decouple angle and momentum, thus reducing beam gas interactions) and Cerenkov counters to identify π, P, K, etc. Since the yields decrease as $e^{-6P_\perp^*}$, the kinematical region one can explore are restricted to $P_\perp^* < 500$ MeV/c, where one gets $\approx$ 100 events/day.

The relative production ratio of π/K/P from ISR [4] is quite different from low energy values. It would be interesting to see what happens to this ratio at extremely high energies.

A region of particular interest would be the so-called "pionization region", where one studies the distribution of π's with $P_\perp^* < 100$ MeV/c and $P_\parallel^* = m_\pi E^{in}/m_p \cdot c \ll 1$ BeV/c from the reaction

$$P + P \rightarrow \pi^\pm + X.$$

If we integrate the $\pi^\pm$ distribution $d^3P/E\ f(P_\perp^*)$ we have

$$\int \frac{d^3P}{E} f(P_\perp^*) = \sigma_T < n >$$

where $\langle n \rangle$ is the average multiplicity. Since both $\langle n \rangle$ and σ_T increase with s, this implies that $d^3P/E\ f(P_\perp^*)$ must increase with s faster than σ_T. Thus we have the breakdown of Feynman scaling [5].

The soft pions are produced in abundance and can be easily measured as functions of s.

5. Correlations: Correlations can be measured with magnetic detectors. However, since the interaction region has a volume of 1000 mm x $(1\ \mathrm{mm})^2$. In order to ensure the booster beam stays within this region, there should be no magnetic field in the interaction region. A possible magnet would be the split field magnet [6] of CERN where 4 coils produce opposite fields on two sides of the intersection region. The field on the intersection region itself is zero.

We note that because of strong $P_\perp^*$ dependence of particle productions, a 4π solenoid commonly used as storage ring detectors is not suited for our purpose.

6. Elastic scattering, diffraction slopes etc: Finally we remark that with either a split field magnet or a large septum magnet we will be able to measure $\frac{d\sigma}{dt}$ el at very small t values. For example, putting counters 6' downstream from the interaction region, and 1 cm away will enable us to measure the angle and momenta of the elastically scattered 10 GeV protons with a minimum $|t|_{min} = 0.005\ \mathrm{GeV/c^2}$. The maximum $|t|$ is determined by counting rate and typically will be $|t|_{max} = 0.12\ \mathrm{GeV/c^2}$.

The s dependence of the total elastic cross section σ_{el}, [1] is also interesting. If both the slope b and σ_{el} continue to increase as fast as σ_T as indicated by the ISR data we will get for $s = 16000\ \mathrm{GeV}^2$, $\sigma_{el} = \sigma_T * 17.5\ \%$ = 9.0 mb for $\sigma_T = 51$ mb, and the slope $b \approx 15.6\ \mathrm{GeV}^{-2}$. We expect 144 elastic events per day.

One can determine σ_T by measuring the elastic scattering differential cross section.

Using the optical theorem,

$$\sigma_T = \left(\frac{16\pi}{(1+\rho^2)} \frac{d\sigma}{dt}_{t=0} \right)^{1/2}$$

where ρ is the ratio of the real to imaginary amplitudes, since ρ^2 is expected to be negligible in high energy, the extrapolation error from $|t| = 0.005$ to $t = 0$ due to uncertainty in the slope b is less than 1 % for $13.1 < b < 15.6$ GeV^{-2}.

In this method σ_T is proportional to the square root of the luminosity. Thus the error due to luminosity determination is reduced by a factor of two.

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