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ACCELERATOR DEPARTMENT
Informal Report

CAN HIGHER π p LUMINOSITY BE OBTAINED AT THE ISA?

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CRISP 72-75
ISABELLE PROJECT

INTERSECTING STORAGE ACCELERATOR NOTES

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Two reports have already been written on πp interactions at the ISA.^{1,2} In both, relatively conventional π beams are formed, collimated and refocused onto the circulating proton beam. The rates quoted by both authors are very low, so low that one doubts if the experiments are worthwhile despite the large intrinsic interest in the interactions. I am reminded of the time when γ beams were first considered and similarly low rates predicted. The relatively higher rates we obtain now were made possible by abandoning the idea of a conventional beam yielding interactions at a single energy. Instead pulsed horns are used to focus all pions over a wide momentum range and experiments are performed in which the interaction energy is not fixed.

Exactly the same approach can be taken for πp interactions at the ISA. Horns can again be used to focus a large fraction of all pions made at a target. Experimental rates are then much higher at the expense of knowledge of the interaction energy. No doubt one can learn to live with this loss of knowledge just as we have so learned in neutrino interactions.

First we calculate the ultimate theoretical luminosity of πp interactions if we assume that ideal targeting and focussing could be achieved. We then consider a real design that comes as near this ideal as possible, bearing in mind that future ingenuity might get one even nearer to the ideal.

Ideal πp Luminosity

Consider the use of 200-GeV protons to make the pions. We assume that targeting can be performed in a region where the beam proton angular divergence is larger than the production angles of pions above a given momentum, say 20 GeV. The pions produced will then have an emittance equal

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to that of the proton beam used to make them. If all these pions, independent of their momentum, could be refocussed into low β intersection in which the β for the pions and the stored protons are the same, then the luminosity is given by:

$$L = \pi \beta_o \frac{2}{S} \frac{N_{st}}{C} \cdot n_{\pi} \quad (1)$$

where β_o is the β value at the center of the interaction region, S is the area of the beam cross sections, C is the circumference of the ISA, N_{st} is the number of stored protons, and n_{π} is the number of pions produced per second. This formula may be compared to that for pp interactions given in the Grey book³ which is the same but for n_{π} being replaced by cN_{st}/C , where c is the velocity of light, i.e. the number of protons/sec passing the intersection region.

$$\begin{aligned} \text{We take } \beta_o &= 70 \text{ cm} \\ S &= .6 \times 10^{-2} \text{ cm}^2 \text{ (.44 x 1.4 mm)} \\ N_{st} &= 6 \times 10^{14} \\ C &= 2 \times 10^5 \text{ cm.} \end{aligned}$$

For making pions, we take a proton intensity of 6×10^{14} every 200 seconds (30 sec to fill, 120 sec acceleration, 50 sec to bring the magnet down again). We assume a given charge pion multiplicity of pions > 20 GeV of 2 (total charged multiplicity⁴ is 7.6, median momentum $\sim$ 20 GeV); thus

$$\begin{aligned} n_{\pi} &= 6 \times 10^{12} \text{ pions/sec} \\ \text{then } L &= 1.3 \times 10^{27} \text{ cm}^{-2} \text{ sec}^{-1} \end{aligned}$$

Thus for a cross section of 20 millibarns we have an interaction rate of 26 interactions/second,

which can be compared with the rates estimated by Baltay¹ and Lee² of 1.4×10^{-2} and 0.6×10^{-2} respectively.

In order to achieve such a rate we assumed firstly that targeting be done where the proton beam divergence exceeds that of the produced pions. This requires a focus with half angle $> 1^\circ$ and image size $< .1$ mm diameter. This corresponds to a β function less than 1 cm, which seems to be impossible (70 cm is the shortest now being discussed). And even if it could be achieved the question of how to collect and refocus the pions from such an image seems equally insoluble.

Nevertheless the difference between this ideal rate and those of Baltay and Lee suggest that some improvement might yet be possible. I will give one possible arrangement.

Possible Higher Rate πp Interaction Region

I start by assuming that the 200-GeV protons in one ring can be brought to a symmetric focus at a region with $\beta = 0.7$ meters, giving an image of about 1 mm diameter. A short target of high-density material is used (e.g. Al_2O_3) and the pions made at the target are focused at unit magnification to an image two meters away. A pulsed magnetic horn is used and a simple design of such a horn can be made to accept 80% of all 20-GeV pions from the target. Higher momentum pions are also accepted but are brought to a focus somewhat further away; lower momentum pions are focussed nearer. If we use an "interaction region" about 1.1 meter long, then we find that the momentum acceptance is between 16 and 26 GeV, i.e. a momentum bite of $\pm 25\%$. The total number of pions of given charge per interaction is about 4. We estimate the number accepted by this momentum bite to be about 1.5. Folding in angular acceptance we should obtain about one pion per interacting proton.

In order to obtain interactions with 200-GeV protons we now require that the interaction region be at the focus of a low β intersection region of the other p ring. If we do nothing about it, the protons of this ring will also pass through the target which is not acceptable. The entire horn is therefore placed in a low-field magnet (~ 2 Kgauss) the effect of which is to deflect the 20-GeV pions without much affecting the 200-GeV protons.

The resultant arrangement is shown in Fig. 1. In this figure the vertical scale is 10x the horizontal scale. The circulating proton beam passes through the interaction region, then through the center of the horn and finally past the target at a distance of 5 mm (the beam is ≈ 1 mm diam). The extracted proton beam approaches the target from the other direction. The pions made in the target are then focussed by the horn and simultaneously deflected by the bending magnet. They become refocussed in the 1.1-meter-long interaction region, different momenta interacting at different points along the region, the region for any given momentum being about 7 cm long. Actually the foci of different momenta are not strictly on a straight line. In practice, however, they are found to lie on a focus that does not deviate from straight by more than .2 mm in the momentum range required. This is negligible compared to the beam diameter and could be further reduced by suitable shimming of the magnet poles.

Prior to targeting, both proton beams could pass almost parallel down the same vacuum pipe displaced by a small distance so that they do not interact. The target could also be placed inside the vacuum pipe also such that neither beam touched it. A very fast kicker could then be employed to displace, momentarily, the beam of protons onto the target. The pulses must be short enough to avoid overheating the target. Particles that do not interact in the target could be recaptured by a second kicker and thus a high target efficiency maintained. It is important to use many short kicks rather than a slow extraction in order to keep the duty cycle short and thus the signal-to-background low as pointed out by Lee.

The luminosity is given by

$$L = n_{\pi} \cdot 2\ell \cdot \frac{N_{st}}{CS}$$

where

$$\begin{aligned} n_{\pi} &= \text{number of pions/sec} \\ &= \text{pions per proton} \times \text{protons per pulse/cycle time} \\ &= 1.0 \times 6 \times 10^{14} / 200 = 3 \times 10^{12} \end{aligned}$$

$$\begin{aligned} N_{st} &= \text{number of stored protons} = 6 \times 10^{14} \\ C &= \text{circumference} = 2 \times 10^5 \text{ cm} \\ S &= \text{beam cross section} = 0.6 \times 10^{-2} \text{ cm}^2 \\ \ell &= \text{interaction length in the lab} \\ &= \text{beam diameter/mean pion angle} \\ &= 0.1/0.015 = 7 \text{ cm.} \end{aligned}$$

The factor 2 arises because both protons and pions are relativistic and as the pion moves a distance ℓ it sweeps through a column of protons of length 2ℓ . Then

$$L = 2 \times 10^{25}$$

yielding for $\sigma = 20$ mbarns .4 events/second.

This rate, though two orders of magnitude less than the ideal, is still more than an order of magnitude higher than those of the earlier reports.

The problem remains, however, of how the events might be detected. Lee has shown that provided the targeting is performed in very short pulses the background from gas interactions is negligible. The difficulty with the arrangement proposed here is that the horn is directly in the path of many

of the products of the interaction. These products would be focussed or defocussed by the horn and would have to be detected upstream of the target where the background of tracks from the target should be small and of low energy. Probably only a device of the impactometer type would have sufficient acceptance, time resolution, and insensitivity to the background of low-energy back-scattered particles.

Another problem is the high level of radiation that the horn and intersection region would be exposed to. This, however, is no worse than that encountered by horns in neutrino beams and this seems soluble.

I conclude that πp interaction rates of the order of 30/minute might be possible at the ISA and that experiments might be done around such interactions. The experiments would, however, be hard and considerable ingenuity would be required.

REFERENCES

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3. 200-GeV ISA, A Preliminary Design Study (1972), p. 74.
4. G. Charlton et al., Phys. Rev. Letters 29, 515 (1972).

Fig 1