MPS/DL - Note 70-2
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Notes on the January 23rd Meeting

THE I.S.R.

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1. AVAILABLE ENERGY FOR PARTICLE PRODUCTION

In a collision with a fixed target, the energy in the center of mass system E_{cM}, available for particle production is

$$E_{cM}/E_o \approx \sqrt{2\gamma} \qquad \text{where } E_o \text{ is the rest energy}$$

E_{cM} is 7 GeV for the PS and 50 GeV in the ISR.

The necessary γ to achieve the same E_{cM} in a collision with a fixed target would be :

$$\gamma = \tfrac{1}{2} \left(\frac{E_{cM}}{E_o} \right)^2 \approx 1300$$

2. INTERACTION RATE

With σ : interaction cross-section
h : beam height
w : beam width
n_1, n_2 : beam (1, 2) density
α : angle between the beams
v : particle velocity

The number of interactions per second and per collision region is :

$$\frac{dN}{dt} = n_1 \, h \, w \, v \, \frac{\sigma \, w \, n_2}{tg \, \alpha/2}$$

$$= \frac{\sigma v}{h} \, \frac{\lambda_1 \, \lambda_2}{tg \, \alpha/2}$$

λ_1 and λ_2 being the "line density" of each beam

$$\lambda = n \, w \, h$$

A useful parameter is also the luminosity L

$$L = \frac{v}{h} \, \frac{\lambda_1 \, \lambda_2}{tg \, \alpha/2} = \frac{v \, \lambda^2}{h \, tg \, \alpha/2} \qquad \text{if } \lambda_1 = \lambda_2$$

It is interesting to note that the luminosity is independent of the beam width, but depends on the square of the current.

The need of high currents implies that it is necessary to <u>store</u> many PS pulses to reach a workable luminosity.

If one used proton/antiproton collisions one ring would be enough as in the Novosibirsk project but it has the drawback that antiproton sources are weak.

3. STORAGE TECHNIQUES

In principle it is possible to store successive PS pulses in 3 different ways :

i) Put side by side particles travelling on parallel orbits corresponding each to a different momentum. This is called stacking in the longitudinal phase space.

ii) Put each PS pulse in a different area of the horizontal acceptance. This is "horizontal betatron stacking".
This process is more difficult and is reserved for a future improvement programme.

iii) Stack in the vertical phase plane. This is ruled out because it would require an expensive increase in the vertical aperture, while reducing the luminosity which varis as 1/h.

4. STACKING MECHANISM

There are 2 ways of bringing the newly injected PS pulse into the stack :

i) Accelerate the particles all the way through the stacked beam and leave them at an energy just above the maximum of the previously stacked particles.
Running an RF bucket upwards in energy through the stacked beam has the effect of displacing the whole beam downwards by an amount such that the displaced phase space area is equal to the bucket area.
In pratice there is some unavoidable dilution.
This is called stacking at the top.

ii) One can also stack at the bottom by accelerating only to an energy just below the minimum of the previously stacked particles.

The stacking efficiency is defined by :

$$\eta = \frac{\int \rho \, dE}{\rho_o \, n \, \frac{A}{2\pi}}$$

where :

ρ : density in longitudinal phase space.
ρ_o : mean density in longitudinal phase space.
A : bucket area
n : number of stacked pulses.

η increases with the number of stacked pulses. An efficiency of 0.7 has been reached in CESAR for 100 pulses.

The efficiency is influenced by the bucket size A. It is therefore necessary after trapping the PS bunches in a stationnary bucket and then accelerating it with a moving bucket, to shrink this bucket until it fits tightly to the bunch to avoid moving an empty phase space area through the stack.

Furthermore since the ISR radius is 1.5 times the PS radius a PS pulse fills only 20 out of the 30 ISR buckets. To avoid running empty buckets through the stack the RF voltage is cut during the passage of the 10 empty buckets so that these buckets are suppressed.

5. I.S.R. PERFORMANCE

The number N of particles that can be stacked is given by :

$$N \simeq \eta\, \rho_o \; \Delta E \,.2\pi .\, h_{ISR}$$

with $\eta = 0.5$, $h_{ISR} = 30$, $\Delta E/E = 2\%$ and $E = 25$ GeV

$N = 4.10^{14}$ protons/ring with the design density $\rho_o = 8.5 \; 10^3$

With h = 2cm we get the following table for various values of ρ_o

Conditions	ρ_o	I (current)	Luminosity $(\frac{\Delta E}{E} = 2\%)$
Design parameters	$8.5 \; 10^3$	20 A	10^{30}
PS with Q-jump	$5 \; 10^3$	12	$0.35 \; 10^{30}$
PS without Q-jump	$2.6 \; 10^3$	6	$0.09 \; 10^{30}$

The luminosity is proportional to the square of the density ρ_o and this density varies as the inverse of the square of the bunch length

$$L \simeq \rho_o^2 \simeq \tau^{-4}$$

The transverse properties of the beam have a much smaller effect on the ISR performances than the longitudinal ones :

$$L \approx \rho_o^2 \frac{\Delta R - 2\, a_H}{h}$$

where ΔR : radial aperture

a_H : horizontal beam width.

This holds as long as ΔR is much larger than a_H . Then the above relation does not depend strongly on a_H i.e. the horizontal emittance.

It has been shown that if all transfer errors are added linearly the luminosity is only decreased by a factor 2.

6. RESIDUAL GAS EFFECTS

It is desired to keep the beam for at least 10 hours without having to refill the ISR.

Two effects of the residual gas must be considered :

i) Small angle Coulomb scattering.
This is proportional to $Z^2 p$ where Z is the gas atomic number and p its pressure.
The pumping system must be able to pump heavy molecules.
To have 95% of the beam within the aperture after 10 hours an equivalent nitrogen pressure of 10^{-9} Torr.

ii) Interactions.
After 12 hours - 3.2% of the beam will be lost by beam - gas interactions,
- $2^o/oo$ of the beam will be lost by beam-beam interactions.

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