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Optimization Of The Lattice For Intrabeam Scattering For Short Bunches Operation Mode (60 Degree Phase Advance Cell)

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OPTIMIZATION OF THE LATTICE FOR INTRABEAM SCATTERING FOR SHORT BUNCHES OPERATION MODE (60° PHASE ADVANCE CELL)

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The Collider is made of 6 periods.
Each period is made of an arc with radius of curvature $R_0 = 381.2325$ m and a long straight section of length $L_s = 239.7358$ m
In the arc we are going to install regular FODO cells each with length $2L$.
The bending angle per half regular cell is

$$\theta = 2\pi / N \qquad (1)$$

where

$$N = 2\pi R_0 / L \qquad (2)$$

is the number of ½ regular cells.
We require the phase advance per cell is $60°$.
For a thin lens approximation this gives: for the quadrupole gradient B'

$$\frac{B' l_Q}{B\rho} L = 1 \qquad (3)$$

l_Q, quadrupole length
$B\rho$, beam magnetic rigidity

$$\beta_{max} = 2\sqrt{3} \quad L$$
$$\beta_{min} = 2/\sqrt{3} \quad L \qquad (4)$$

$$\eta_{max} = 5 L \theta$$
$$\eta_{min} = 3 L \theta \qquad (5)$$

Let us define the averages

$$\bar{\beta} = (\beta_{max} + \beta_{min})/2 = 2.3094 \quad L \qquad (6)$$

$$\bar{\eta} = (\eta_{max} + \eta_{min})/2 = 4 \quad L\theta \qquad (7)$$

Taking into account (1) and (2), (6) becomes

$$\bar{\eta} = 4 \frac{L^2}{R_0} \qquad (8)$$

Therefore if the cell half-length L is given, we obtain $\bar{\beta}$ and $\bar{\eta}$ from (6) and (8).
This is shown in the Table at the end of the note.

We have done intrabeam scattering calculation at the computer for a smooth machine defined by the parameters $\bar{\beta}$ and $\bar{\eta}$. We have calculated the diffusion rate in energy τ_E^{-1} and betatron size τ_β^{-1} for a 0.001 Amp-particle bunched beam at 100 GeV/A for Gold ($A = 197$, $Z = 79$).

We have assumed a normalized emittance

$$\varepsilon_N = 4\pi \text{ mm}\cdot\text{mrad}$$

and an rms energy spread within the bunch

$$\sigma_E / E = 4 \times 10^{-4} .$$

The diffusion rates are shown in the Table. The energy diffusion rate decreases whereas the betatron diffusion rate increases with the half-length L of a cell.

These diffusion rates affect the luminosity lifetime with the same order.

For a luminosity of $\approx 10^{27}$ cm^{-2} s^{-1} one requires 57 short bunches each with $N = 6.24 \times 10^8$ and an rms bunch length of $\sigma_\ell = 10$ cm. This corresponds to a peak current of 0.12 Amp-particle.

In the Table we give the luminosity

diffusion time

$$t_L = \frac{1}{120\left(\tau_E^{-1} + \tau_\beta^{-1}\right)}$$

As one can see the shorter the length cell the longer the luminosity lifetime.
Possibly the luminosity lifetime could be actually longer that the values reported by ~ 50% because of the long straight sections where the dispersion is zero and there is no local betatron diffusion due to intrabeam scattering.
Therefore a cell length of about $2L = 22$ m seems to be adequate for a luminosity lifetime of about one hour which is a long period of time compared to the filling time of 2×1 minute.

In the same Table we report the approximate estimate of the transition energy γ_T

$$\gamma_T \approx \sqrt{R/\bar{\eta}}$$

where $R = 610.17$ m is the average radius.

Our choice, marked with a star, corresponds to $\gamma_T \simeq 22$.
We also give the maximum coupling impedance Z/n allowed for ~~....~~ longitudinal beam stability according to the formula

$$|Z/n| \lesssim \frac{E\,|\eta|}{e\,I_p}\left(2\,\frac{\sigma_E}{E}\right)^2 \frac{A}{Z^2} .$$

The beam we have specified above corresponding to a short bunch mode of operation as an invariant longitudinal emittance of

$$S = 0.25 \ \text{eV/A-sec} \ /\text{bunch}$$

for 95% of the particle distribution.
Can one produce such a bunch from the AGS?

With our choice of $L \sim 11$ m we have

$\beta_{max} = 37.5$ m
$\eta_{max} = 1.54$ m

Let us considere the case of Gold at 5 GeV/A with a full momentum spread

$$\Delta p/p = 2 \times 10^{-3}$$

and

$$\varepsilon_{H,V} = 0.8 \ \pi \ \text{mm} \cdot \text{mrad}$$

The maximum beam full height is

$$a_V = 2 \times \sqrt{0.8 \times 37.5} \ \text{mm} = 11 \ \text{mm}$$

and the maximum full width is

$$a_H = 2 \sqrt{(1.54 \times 1)^2 + (0.8 \times 37.5)} = 11.4 \ \text{m}$$

or at most

$$a_H = \left[(1.54 \times 2) + 2 \sqrt{0.8 \times 37.5} \right] \text{mm} = 14 \ \text{mm}$$

Sketch of a Regular Cell (Approximated)

Take $L = 10.8$ m

Quadrupole length $\ell_Q = 1.2$ m

$B\rho$ for Gold at 100 GeV/A = 800 T-m

Quadrupole Gradient = 62 T/m

Bore Radius = 4 cm

Field at Pole Tip = 2.5 T

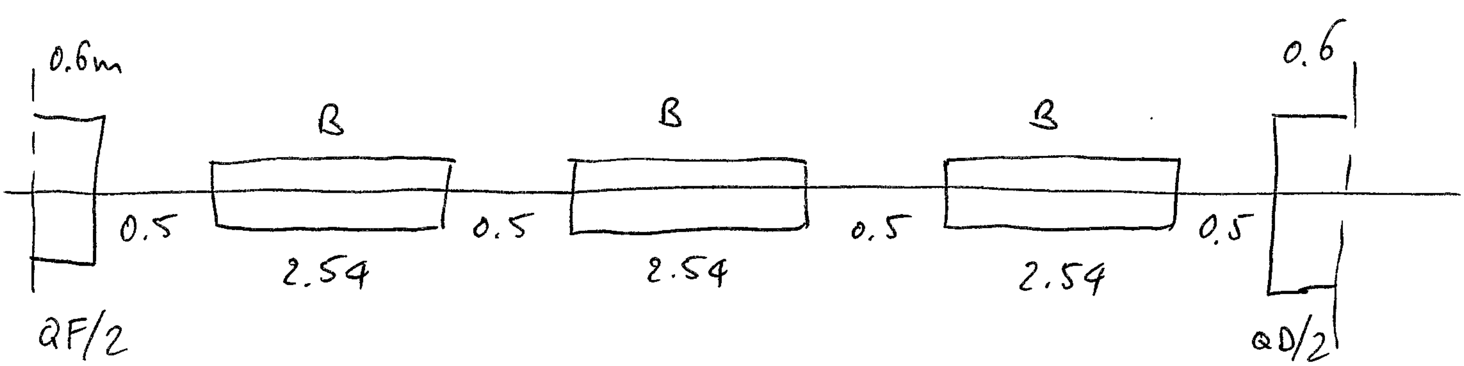
$N = 220$ half-cells

$\theta = 28.56$ mrad bending angle / half-cell

Assume 3 bending magnet / half cell

Take $B = 3.0$ T then $3\ell_B = 7.616$ m

That is $\ell_B = 2.54$ m



I believe one single curved dipole is better

L	$\bar{\beta}$	$\bar{\eta}$	τ_E^{-1}	τ_β^{-1}	t_L	γ_T	Z/n	
m	m	m	h^{-1}	h^{-1}	hours		ohm	
2.16	5	0.05	–	–	–	110	0.3	
4.33	10	0.2	–	–	–	55	3.9	
6.49	15	0.44	.0044	.0034	1.1	37	10.6	
8.66	20	0.786	.0033	.002 / .0073	1.6/0.8	28	19.8	
10.82	25	1.23	.0025	.0051 / .01	1.1/0.7	22	33	*
12.99	30	1.77	.002	.0076 / .0119	0.9/0.6	18.6	47	
15.15	35	2.41	.0016	.0133	0.56	16	64	
17.32	40	3.146	.0013	.0143	0.53	14	84	
19.48	45	3.98	.0011	.0181	0.43	12.4	108	
21.64	50	4.92	.0009	.0211	0.38	11	137	