Title
PEP II RF SYSTEM

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Summary

Stage II of PEP consists of adding a superconducting proton storage ring to the electron-positron ring now completing construction. To obtain the desired luminosity between the tightly bunched electron beam and the protons, the protons will be tightly bunched also. The proton bunch length and the number of bunches imposes unusual requirements on the RF system. Acclerating to full proton energy makes the bunching easier.

PEP is a positron, electron colliding beam storage ring being constructed as a joint project between the Stanford Linear Accelerator Center and the Lawrence Berkeley Laboratory at the SLAC site. It has a design value of 15 GeV on 15 GeV with a luminosity of 10^{32} and energy up to 18 GeV with reduced luminosity due to reduced current. The target date for beam turn-on is October 1, 1979.

The original concept included protons, electrons and positrons, hence PEP. However, the proton ring required superconducting magnets to fit a 200 GeV ring on the SLAC site. A decision was taken in 1974 to proceed with the electron, positron portion, since conventional techniques were available for the construction; and to wait for development of the magnets before proposing the addition of the proton ring. It appears possible to develop magnets with fields of 8 tesla so that a proton energy of 350 GeV could be contained in the PEP tunnel.

The possible future addition of the proton storage ring will require an RF system to bunch the protons tightly to somewhat match the length of the electron, or positron bunches to maintain the desired luminosity. The leptons will always be bunched due to the RF voltage required to replace the synchrotron radiation. The protons may be bunched or not, there are advantages to either decision. An unbunched proton beam <u>does not</u> require (1) synchronization between electron and proton bunches, (2) variation in path length of either particle to compensate for varying proton velocity with energy change, and (3) an RF system to keep the protons bunched. An unbunched proton beam <u>does</u> require (1) more protons in the beam, perhaps giving difficulty at injection due to space charge and increased background noise, and (2) depending on the crossing angle, more difficulty may be experienced with beam-beam tune shift on the proton beam due to longer exposure to the electron bunches. The present plan on PEP II is to use a bunched proton beam with a σ of .3 meters.

The proposed injection of energy is 5 GeV. The protons would be accelerated to 5 GeV in a small booster ring and may be injected into the electron ring of PEP where they would attain 20 GeV, which would allow a smaller aperture in the final proton ring. The electron ring would have to have added a small RF system for the acceleration. The electron RF system will not suffice because the frequency is too high as will be shown later.

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The protons in the final ring would be accelerated to 300 GeV to make it easier to make compact bunches. After the storage harmonic number is reached, the beam can be decelerated to the desired energy which might vary from 100 to 300 GeV depending on the desired center-of-mass energy, and the operating energy of the electron ring. The minimum required $S = E^2$ eM is set by the highest S accessible to μ - P scattering on a fixed target. The "Fermi Lab energy doubler" is projected to produce 800 GeV muons for an S of 1600 GeV^2. If the lowest convenient operating energy of the PEP electron ring is 4 GeV then 100 GeV protons would produce an S of 1600 GeV^2.

The synchrotron loss of protons at 300 GeV is trivial, less than 1 ev per turn, so that no damping of synchrotron motion can be expected. Accordingly they must be bunched by applying a large RF voltage which only bunches, but gives almost no net energy to the bunch.

$$(1) \qquad \sigma_\ell = \tfrac{1}{2} (RW)^{\frac{1}{2}} \left[\frac{2 \pi \eta \ M_o C^2}{e V h \gamma \cos\phi_s} \right]^{\frac{1}{4}}$$

Where R = radius (not magnetic radius)

W = ½ bunch length (~ 2 σ_ℓ)

X half Δ ($\beta\gamma$)

$$\eta = \frac{1}{\gamma_T} - \frac{1}{\gamma} \qquad \gamma = \frac{E}{M_o C^2}$$

Note that γ, h and V have equal effects in reducing the length of the beam bunch. The RF power required will be proportional to V^2 so that it is clear that H and γ should be as large as possible.

γ will be raised to the maximum before bunching tightly. h must be small enough to allow λ_{RF} to adequately contain the beam bunch. A rule of thumb stated by the theorists is $\lambda_{RF} \geq 16\ \sigma_\ell$, for long term storage. Clearly this may be violated at injection as is demonstrated by the many operating synchrotrons. Also it is believed that it may be violated briefly during bunching. It may be seen that the electron RF system with a λ_{RF} = .85 meters is not able to capture or bunch the proton beam. Fig. 1 shows the case of injecting from the 5 GeV booster directly into the proton ring. Note the dotted path of the bunching. If γ is raised to only 100 instead of 300 the RF power for bunching is 9 times higher. Also note that W, the injected longitudinal emittance, affects the required voltage by its square so that care in injection to avoid dilution is required. Two RF systems in the proton ring are required.

To minimize the RF power required for bunching, the locus of the path should be along the $\lambda_{RF} = \eta\ \sigma_\ell$ where η is as small as workable. However, h must change in discrete intervals, equal to M times the number of bunches. In this case 36. The transition from one frequency to the next will be accomplished by increasing the higher frequency while maintaining the lower frequency until the bunches are contained by the higher frequency. Recall that little energy

Table 1 SOME STAGE II PARAMETERS

		Proton	Electron	
Momentum - Peak	P	300	15	GeV/C
Injection	P_i	5	15	GeV/C
Number Particles	N	1.5×10^{13}	$.8 \times 10^{13}$	
Number Bunches	n_b	36	36	
Cross Angle	2_δ	2 X 1		m rad
Emittances at Peak Energy	ϵ_x	.01564	.03128	mm-m rad
	ϵ_y	.01564	.03128	mm-m rad
	ϵ_ℓ	.025	.340	m
Bunch Length	σ_ℓ	.3	.012	m
Momentum Width	$\sigma_{\Delta P/P}$	.001	.001	0/00
Interaction Point Values	β_x	1.0	.50	m
	β_y	1.9	1.25	m
	η_x	0	0	m
	η_y	0	0	m
	η_θ		0	
Beam-Beam Tune Shifts	$\Delta\nu_x$	.004	.054	
	$\Delta\nu_y$	.005	.049	
Luminosity	$\mathcal{L}$	1.0×10^{32}		$cm^{-2}\ s^{-1}$

is being imparted to the beam so the synchronous phase is almost 180°. The lower frequency voltage will then be lowered and the cavity shorted. [1]Cavity tuning must be such as to provide more voltage from the generator than from beam induction to avoid longitudinal instability. [2]Previous measurements indicate that RF noise problems can be controlled well enough to allow storage times of several hours.

1 - P. B. Wilson, IX International Conference on High Energy Accelerators, May 2 - 7, 1974.

2 - E. C. Hartwig, et al., International Conference on High Energy Accelerators, Mar. 5 - 7, 1973.

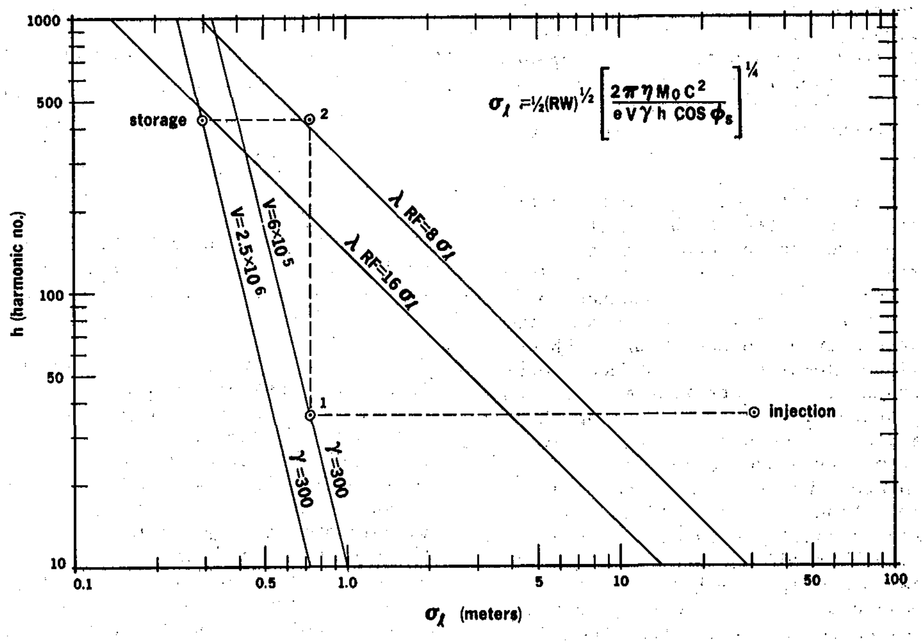

Fig. 1

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