A.2: Particle source part II(10, December, 2013) by Masao KURIKI

Answer the following questions.

Q.A2.7 It is hard to find positron in nature and we have to generate artificially. What is the fundamental process to generate positron? Among them, what is the appropriate way? What is the reason?
(Answer) There are two processes to generate positrons. One way is the pair creation by gamma with a field of nucleus. Another way is nucleus beta + decay. In our case, we need a time structure (the positrons has to be concentrated in a short period). By the beta + decay, the process can not be controlled at all and the decay is purely random process. On the other hand, we can make the bunched positron if we generate gamma rays in a short period. Therefore, the pair-creation is the appropriate way in our case.

Q.A2.8 In undulator positron production of ILC, the system has to satisfy some condition on the path length. Please explain the condition and why any timing adjustments do not work.
(Answer) In the undulator positron production, two conditions have to be satisfied simultaneously. One is the collision condition where the e+ and e- bunches collide at the interaction point. Another condition is the self-reproduction condition to guarantee the generated positron is always accommodated in a DR bucket. Since we have two conditions and one timing knob (relative timing between e+ and e- DR extraction), another adjustment is necessary. This adjustment has to be made by "physical length" of some section.

Q.A2.9 Let us assume 20 MeV gamma ray energy as 1st cut off is required for positron generation. How much drive beam energy is required for undulator radiation and laser-Compton scattering, respectively? Please assume 10mm undulator period, $K = 1$, and 1μm laser wavelength for each methods.
(Answer) The first cut off energy from unudlator radiation is given in eq(3-10).We get the drive beam energy required to make 20 MeV cut off as

$$E = \sqrt{\frac{20 \times 10^6 \times 0.01 \times 2}{9.50}} = 205(GeV) \quad (1)$$

For the laser Compton scattering, the cut off energy of the fundamental mode is give as eq(3-16). In the denominator, mc^2 is dominant if

γ is in order of 1000, then the equation can be approximated as

$$E \sim 4\gamma^2 E_L \tag{2}$$

Energy of 1μm laser photon is

$$1.05 \times 10^{-34} \times 2\pi \frac{2.99 \times 10^8}{1.0 \times 10^{-6} \times 1.60 \times 10^{-19}} = 1.23eV, \tag{3}$$

then the required γ factor of the drive beam is

$$\gamma = \sqrt{\frac{2.0 \times 10^7}{4 \times 1.23}} = 2.02 \times 10^3, \tag{4}$$

giving 1.03 GeV.

Q.A2.10 Conventional choice of e+ booster is S-band (2.6 GHz) because a wide variety of device such as klystrons, wave-guides, are available. However, S-band is not suitable for ILC e+ booster by considering ILC DR acceptance. Please explain the reason. If we optimize the system by adjusting the accelerator RF frequency, what is the most optimized frequency? Please ignore energy spread of initial positron distribution and consider only energy spread by RF curvature.
(Answer) If the energy spread is dominated by RF curvature of the e+ booster, expected energy spread is calculated as

$$\frac{\Delta E}{E} = 1 - \cos\left(\omega \frac{t_b}{2}\right), \tag{5}$$

where t_B is bunch length, ω angular frequency of RF. If it is 1.5% corresponding to DR acceptance in energy, the requirement is

$$\omega \frac{t_b}{2} < \cos^{-1}(0.985) = 0.173 \tag{6}$$

If we put $70mm$ as bunch length ($t_b = 234ps$)

$$f = \omega \frac{t_b}{2} < \cos^{-1}(0.985) = 0.173 \times \frac{2}{2\pi \times 2.34 \times 10^{-10}} = 2.35 \times 10^8. \tag{7}$$

The answer is 235 MHz.

Q.A2.11 Positrons at the end of the injector section (250 MeV) are distributed $\pm$20ps in z and $\pm$20MeV in energy. Please show this bunch does not fit to the DR acceptance (5.0 GeV energy, 1.5% in energy spread, and

70 mm in z) by assuming S-band 2.6 GHz accelerator for e+ booster.
(Answer) The expected energy spread by RF is

$$\frac{\Delta E}{E} = 1 - \cos\left(2\pi \times 2.6 \times 10^{9} \times 20 \times 10^{-12}\right) = 0.053, \qquad (8)$$

which means that the energy spread is 5.3% which is more than the DR acceptance. The beam can not be accepted by DR.

Q.A2.12 By considering an EC(Energy Compressor) before DR injection, the beam phase-space distribution can be fit to DR acceptance. Please obtain an appropriate EC design (R_{56}) to give a good matching of the beam given in Q.A2.11.
(Answer) At the end of the booster linac, the positrons are distributed up to $s_1(z, \delta) = (0.012, 0.061)$ if other end is placed at origin, i.e. $(z, \delta) = (0, 0)$. s_2 is transformed by EC as

$$s_2 = \begin{pmatrix} 1 & R_{56} \\ -1/R_{56} & 0 \end{pmatrix} \begin{pmatrix} 0.012 \\ 0.053 + 0.008 \end{pmatrix} = \begin{pmatrix} 0.012 + 0.061 R_{56} \\ -0.012/R_{56} \end{pmatrix}. \qquad (9)$$

Because the origin is transformed to the origin after EC, s_2 should be within the DR acceptance in full-width. Then,

$$0.070 > 0.012 + 0.061 R_{56}, \qquad (10)$$
$$0.015 > abs(-0.012/R_{56}), \qquad (11)$$

Each conditions give

$$R_{56} < 0.95, \qquad (12)$$
$$R_{56} > 0.80. \qquad (13)$$

Then, $0.80 < R_{56} < 0.95$ gives a good matching the beam to the DR acceptance.