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ON POSSIBLE USE OF INTENSE BEAMS OF THE BIG PROTON ACCELERATORS FOR EXCITATION OF A LINEAR ACCELERATOR STRUCTURE

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This work belongs to the mainstream of research pursued by the Institute in the recent decade, initiated by G.Budker. The principal idea stems from the possibility of generation of intense beams of relativistic charged particles in modern accelerators which possess rather great stored energy per unit length of the beam[1)]. An efficient conversion of this energy into that of the electromagnetic field in an accelerator structure[2)] could significantly enhance the accelerating gradient in linacs and provide new possibilities in high energy physics[1].

In this paper we consider a method of generation of accelerating electric field of an ultimately high intensity in a waveguide structure of the UHF range which is based on the use of intense ultrarelativistic beams with small emittance and small energy spread obtained in modern high energy cyclic accelerators and storage rings. We describe the arrangement of the accelerator structure with a strong-focusing guidance lattice and schemes of bunching. We study the capability of electron and proton beams in the existing installations. It has been shown that there is a principal possibility to obtain an average accelerating gradient of $\gtrsim 1$ MeV/cm with the use of existing machines. We discuss the potential applications of such linear accelerators.

1. Let us consider the excitation of a E_{010} mode electromag-

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1) E.G. the SPS 400 GeV proton beam with $3\cdot10^{13}$ ppp ($\sim$0.25A) corresponds to about 3 million Joules stored energy and to some 100 GWt power in one-turn extraction pulse.

2) Obviously, the smaller is the operation wavelength of the structure (and respectively the smaller is the volume occupied by the UHF field into which the energy stored in the beam should be supplied) the higher is the acceleration field intensity: $E \propto \lambda^{-2}$.

netic field in a cylindrical cavity with radius a and length h. The cavity is penetrated along its axis by a beam with the current density $\vec{j}(\vec{r}, t)$ which comprises N charged particles bunched in a long periodic sequence of k identical bunches so that their frequency is ω_{010}/n (n is integer). We assume that these feebly coupled cavities are in fact the cells of the linear accelerator structure (iris - loaded waveguide), wherein the properly bunched accelerated beam is injected past the exciting beam. The energy conservation gives:

$$\frac{1}{8\pi}\int \vec{E}^2 dV = \frac{1}{2}\int dt \int \eta \vec{j}(\vec{r},t)\vec{E}\, dV; \quad (1)$$

here the integration is made over the cavity volume V; $\vec{E}$ is the electric field at $t \gg T = 2\pi/\omega_{010}$; η stands for the fraction of the beam fitting in the cavity aperture. Thus for the amplitude E of E_{010} mode we obtain:

$$E = \left(\frac{2}{J_1(\alpha_{01})}\right)^2 \frac{Ne}{a^2}\cdot\eta\cdot k_t\cdot k_f\cdot k_b\cdot k_r, \quad (2)$$

where - $J_m(x)$ is the 1-st kind Bessel function of the m-th order, α_{ml} is the l-th zero of J_m;

- the transit-time factor

$$k_t = \sin\frac{\pi h}{\beta\lambda} \Big/ \frac{\pi h}{\beta\lambda},$$

with $h \approx a$ and $\beta \equiv v/c \approx 1$ is close to unity;

- the formfactor k_f is a characteristic of the beam coupling with the electric field of the mode in question:

$$k_f = \int \vec{j}\vec{E}\, dV \Big/ j_{max}\cdot E\cdot V < 1;$$

- the bunching factor k_b is actually the amplitude of the Fourier harmonic of j/j_{max} at the frequency of ω_{010} ($k_b < 1$);

- the last factor k_r accounts for damping in the cavity;

$$k_r = \frac{1}{k}\cdot\frac{1-\exp(-knT/\tau)}{1-\exp(-nT/\tau)},$$

here τ stands for the mode damping time.

For a narrow ($\eta = k_f = 1$) completely bunched ($k_b = 1$) beam with the pulse duration $knT \ll \tau$ ($k_r = 1$) eq. (2) yields:

$$E = E_1 \equiv \left(\frac{2}{J_1(\alpha_{01})}\right)^2 \frac{Ne}{a^2} k_t \simeq 14.9\,\frac{Ne}{a^2} k_t. \quad (3)$$

With the account of the relation: $\omega_{010} = c\,\frac{\alpha_{01}}{a}$ we rewrite E_1 in terms of λ:

$$E_1 = \left(\frac{4\pi}{\alpha_{01} J_1(\alpha_{01})}\right)^2 \frac{Ne}{\lambda^2} k_t \simeq 102\,\frac{Ne}{\lambda^2} k_t. \quad (4)$$

For practical estimations we express E_1 in MV/cm:

$$E_1\left(\frac{MV}{cm}\right) = 1.47\,\frac{10^{-11}\cdot N}{\lambda^2(cm)} k_t. \quad (4')$$

If the case is that the damping is essential: $knT \gtrsim \tau$ (but, of course $nT \ll \tau$), we have:

$$k_r = \frac{\tau}{knT}\left[1-\exp(-knT/\tau)\right],$$

and rewrite eq. (4):

$$E = E_1 k_r = 102\,\frac{I\tau}{\lambda^2}\left[1-\exp(-knT/\tau)\right] k_t; \quad (5)$$

here $I = \frac{Ne}{knT}$ is the average current. For a long beam $knT \gg \tau$ and the stationary field amplitude is completely determined by $I\tau/\lambda^2$ *). Using the relation between τ and λ:

$$\tau \approx \frac{\alpha_{01}}{2\pi s}\left(\frac{\sigma\lambda^3}{c^3}\right)^{1/2} \propto \lambda^{3/2}, \quad (6)$$

we obtain in this limiting case, that $E \propto \lambda^{-1/2}$. Eq. (6) assumes $h \approx a$; s ($s \gtrsim 1$) stands for wall smoothness factor, σ is the wall conductivity. Introducing the unit length shunt impedance:

$$R = 51\,\frac{\alpha_{01}}{2\pi s}\sqrt{\frac{\sigma}{\lambda c^3}}\, k_t \simeq \frac{2.2\, k_t}{s\sqrt{\lambda(cm)}}\left[\frac{MOhm}{cm}\right],$$

*) If the current I is not high enough to achieve the value of the E wanted, it is possible to use the preliminary compression of the proton beam (in a single or multibunch mode) by the rotation through a proper angle in the longitudinal motion phase space.

we express the stationary amplitude in the form:

$$E=2IR\simeq 4.5\frac{I(A)}{s\sqrt{\lambda(cm)}}\,\eta\, k_t k_\ell \left[\frac{MV}{cm}\right]. \qquad (7)$$

However at short λ the above consideration is no more valid since the beam transverse size is no more negligible as compared to the cavity diameter. This results in decrease in the field generation efficiency. The former is due to the reduction of the fundamental mode electric field averaged over the beam cross section ($k_\ell < 1$) and besides to the diminution of the beam transmission $\eta(\lambda) < 1$. In this case the outer part of the beam cross section is of no use and should be eliminated with a proper cut-off (or it may be separated and used as an ordinary proton beam of the lower intensity).

2. It has been shown in section 1 that in order to achieve the amplitude E as high as possible one has to reduce wavelength λ providing complete beam transmission. To this end it is reasonable to put the accelerator section into a strong focusing magneto-optical lattice which keeps small lateral size of the beam throughout the section length. In this section we shall work out conditions upon λ under which the maximum intensity E can be achieved for a specified emittance $\epsilon_x\cdot\epsilon_z$ of the exciting beam.

To calculate the beam transmission factor $\eta(\lambda)$ we consider a model of the FODO-period lattice consisting of thin quadrupole lenses with the optical strength P spaced by the drift lengths L. We find for the increment μ of the betatron phase on the period:

$$\cos\mu = 1-\frac{1}{2}(LP)^2, \qquad (8)$$

and for the maximum of the β - function:

$$\beta_{max}=\frac{2}{P}\sqrt{\frac{2+LP}{2-LP}}, \qquad (9)$$

and choose the operation point so as to ensure the stable motion of decelerating particles with energies from E_{min} to the initial one of E_0 and besides the stability of the accelera-

ted beam in the energy range from E_0 up to E_{max}($E_{max} \gg E_{min}$):

$$\mu=\frac{\pi}{2}\,\frac{E_{min}}{E_{max}}. \qquad (10)$$

Having expressed P in terms of the short lens length L_ℓ *) and magnetic field H_0 at its aperture radius a (which is assumed to be equal to that of the cavity), using eqs. (8) and (lo) we obtain an equation for L_ℓ :

$$\mu\simeq LP=L\,\frac{H_0L_\ell}{a\,H\rho}=\frac{\pi}{2}\,\frac{E_{min}}{E_{max}}. \qquad (11)$$

β_{max} is lower if $L_\ell \approx L$. Then (9) and (11) yield:

$$\beta_{max}=2\,\frac{a\cdot H\rho}{H_0}\sqrt{\frac{2}{\pi}\cdot\frac{E_{max}}{E_{min}}\cdot\frac{H_0}{a\,H\rho}},$$

thus the acceptance phase area A of the accelerator section imposed inside the strong focusing lattice may be written in the form:

$$A=\frac{d^2}{4\beta_{max}}=\frac{d^2}{4}\left(\frac{\pi}{8}\,\frac{E_{min}}{E_{max}}\,\frac{H_0}{H\rho\, a}\right)^{1/2}, \qquad (12)$$

where $d = 2\xi a$ is the iris diameter. With the account of the relation $a=\frac{\alpha_{01}}{2\pi}\lambda$ we have:

$$A(\lambda)=\left(\frac{\pi}{8}\,\frac{E_{min}}{E_{max}}\,\frac{H_0}{H\rho}\left(\frac{\alpha_{01}}{2\pi}\right)^3\xi^4\lambda^3\right)^{1/2}. \qquad (13)$$

If a gaussian density distribution is assumed in the exciting beam, if the energy spread in the beam does not contribute to its lateral size (i.e. the dispersion function $\psi \equiv 0$ along the section), then the beam transmission factor is readily obtained:

$$\eta(\lambda)=\left[1-\exp\left(-\frac{A(\lambda)}{2\epsilon_x}\right)\right]\left[1-\exp\left(-\frac{A(\lambda)}{2\epsilon_z}\right)\right], \qquad (14)$$

*) Note that in case the highest possible accelerating field E conditions no magnetic field in the accelerating structure, the focusing lenses could be placed only between the accelerating sections, and consequently the focusing gradient should be augmented according to the shorter lenses lengths, while the aperture may be made as small as the iris size.

here $A(\lambda)$ is given by (13). In the case $A \ll \epsilon_{x,z}$ we have

$$\eta(\lambda) \approx \frac{A^2}{4\epsilon_x \epsilon_z} \propto \lambda^3, \tag{15}$$

and substituting (15) into (4) one can see that in this case of a large emittance $E \propto \lambda$, and the phase-space density of the beam $N/\epsilon_x \epsilon_z$ plays a decisive rôle.

Assuming for the sake of simplicity $\epsilon_z \approx \epsilon_x = \epsilon$, we substitute (14) into (5) where k_t and k_ℓ are taken fixed and $\tau \to \infty$ (short beam pulses), and obtain:

$$E = 102 \frac{Ne}{\lambda^2} \left[1 - \exp\left(-\frac{A(\lambda)}{2\epsilon}\right)\right]^2 = 102 \frac{Ne}{B^2} \Phi\left(\frac{\lambda}{B}\right). \tag{16}$$

In the above equation we have introduced a dimensionless function $\Phi(x) = [1 - \exp(-x^{3/2})]^2 / x^2$, and

$$B = \left[\frac{\pi}{32\epsilon^2} \frac{E_{min}}{E_{max}} \frac{H_0}{H\rho} \left(\frac{\alpha_{01}}{2\pi}\right)^3 \xi^4\right]^{-1/3}. \tag{17}$$

The maximum of $\Phi(x)$ $\Phi_{max} = 0.4086$ is reached by an optimum choice of λ:

$$\lambda_{opt} = 0.835 B \simeq 1.33 \left[\frac{E_{max}}{E_{min}} \cdot \frac{E_0(GeV)}{H_0(kGs)} (5\xi)^{-4} \epsilon^2 (\mu rad \cdot m)\right]^{1/3}; \tag{18}$$

at λ_{opt}

$$E = 0.286 \cdot \left(102 \frac{Ne}{\lambda_{opt}^2}\right). \tag{19}$$

In the opposite limiting case for a long-pulse beam the accelerator structure transits in the c.w. operation and the stationary amplitude is found by the substitution of (14) into (7):

$$E\left(\frac{MV}{cm}\right) = 4.5 \frac{I(A)}{s\sqrt{B}} F\left(\frac{\lambda}{B}\right). \tag{20}$$

A dimensionless function $F(x) \equiv [1 - \exp(-x^{3/2})]^2 / x^{1/2}$ reaches its maximum value $F_{max} = 0.6262$ under condition:

$$\lambda_{opt} = 2.044 B = 3.26 \left[\frac{E_{max}}{E_{min}} \cdot \frac{E_0(GeV)}{H_0(kGs)} \cdot (5\xi)^{-4} \epsilon^2 (\mu rad \cdot m)\right]^{1/3}, \tag{21}$$

and the relevant maximum electric field intensity in this stationary c.w. regime is

$$E = 0.894 \cdot \left(4.5 \frac{I(A)}{s\sqrt{\lambda(cm)}}\right) \left[\frac{MV}{cm}\right]. \tag{22}$$

Note that the first nimerical factor in (19) and (22) corresponds to the optimum value of the beam transmission $\eta(\lambda_{opt})$ in the two limiting cases respectively. Fig. 1 shows the dependence of E on λ in the two cases in question (eqs. (16) and (20)).

To give illustrative examples on the two limiting cases (19) and (22) consider parameters of the 1,5 GeV electron beam extracted from the storage ring VEPP-3 (Novosibirsk) and those of the 400 GeV proton beam of the SPS (CERN). The results of the considerations relevant to the problem of generation of high intensity accelerating fields are summarized in Table 1.

3. To justify the choice of the strong-focusing lattice parameters based on an oversimplified treatment of Section 2 (Eqs. (8) - (12)) we study in more detail the motion the decelerated and accelerated particles in this magneto-optical system. Let us consider the usual linearized equations of the particle transverse oscillations in paraxial approximation:

$$\frac{d}{ds}\left(p \frac{dz}{ds}\right) - p \frac{G}{H\rho} z = 0, \tag{23}$$

$$\frac{d}{ds}\left(p \frac{dx}{ds}\right) + p \frac{G}{H\rho} x = 0. \tag{23'}$$

Here s is the longitudinal coordinate, z and x stand for the particle lateral excursions, G is the magnetic field gradient in the lenses, momentum p(s) is assumed to be a specified function of s. Having written the solutions of (23) and (23') in the Floquet form:

$$z = \sqrt{\frac{\epsilon_0 p_0}{p(s)}}\, W(s) \cos \chi(s),$$

we obtain equations for the betatron phase $\chi(s)$ and for the envelope function w(s):

$$\chi' = \frac{1}{W^2}, \tag{24}$$

$$W'' + \left(\frac{1}{4}\frac{p'^2}{p^2} - \frac{1}{2}\frac{p''}{p} - \frac{G}{H\rho}\right)W = \frac{1}{W^3}. \tag{25}$$

An equation for the horizontal envelope can be obtained from (25) by replacement: $G \to -G$.

Thus finding a numerical solution of (25) with initial conditions, which describe the incident beam and with a specified p(s), then computing the transverse size of the beam that is travelling through the accelerator section:

$$\left(\overline{A^2_{x,z}}\right)^{1/2} = \left(\frac{\varepsilon_0 p_0}{p(s)}\right)^{1/2} W(s), \tag{26}$$

one can make an optimum choice of the strong-focusing lattice parameters so as the beam dimensions corresponding to the accelerated (decelerated) particles in all RF phases of the induced field did not exceed the aperture of the waveguide iris.

4. For bunching of the ultrarelativistic beam with the period close to $\lambda_{opt} \sim 1$ cm a klystron principle seems to be reasonable: after an energy modulation by an external system voltage $U = E_0 \cdot u \cdot \sin\omega t$ the beam passes through a bending magnet with the field H(s) wherein, provided the dispersion function $\psi(s) \neq 0$, the path length difference Δs arises in correlation with the particle energy excursion $\varepsilon = \Delta E/E_0$:

$$\Delta s = \int_0^s \varepsilon\psi(s')\frac{H(s')}{H\rho}ds' \equiv \varepsilon L. \tag{27}$$

This results in occurence of modulation in charge linear density $\varkappa(s)$ while the primary beam is assumed to be gaussian in the energy phase plane:

$$\varkappa(s) = \int_{-\infty}^{\infty} \frac{1}{2\pi\sigma_\varepsilon\sigma_s} \exp\left(-\frac{\varepsilon_0^2}{2\sigma_\varepsilon^2} - \frac{s_0^2}{2\sigma_s^2}\right)d\varepsilon, \tag{28}$$

$$\varepsilon_0 = \varepsilon - u\sin\frac{2\pi}{\lambda}(s - \varepsilon L), \tag{29}$$

$$s_0 = s - \varepsilon L. \tag{30}$$

Assuming $\sigma_s \gg \lambda$ we obtain a periodic $\varkappa(s)$, expandable in Fourier series:

$$\varkappa(s) = \sum_{n=-\infty}^{\infty} \varkappa_n \exp\left(-in\frac{2\pi}{\lambda}s\right).$$

The Fourier-harmonic amplitudes have the same meaning as the "bunching factor" k_ℓ introduced in Section 1; they are determined by

$$\varkappa_n = J_n\left(n\cdot\frac{u}{\sigma_\varepsilon}\cdot\frac{2\pi}{\lambda}\cdot\sigma_\varepsilon L\right)\exp\left[-\frac{1}{2}\left(n\frac{2\pi}{\lambda}\sigma_\varepsilon L\right)^2\right]. \tag{31}$$

The maximum value $\varkappa_1 = 0,582$ is reached at $\sigma_\varepsilon = 0$ and $2\pi uL = 1,84\lambda$. The energy spread in the beam $\sigma_\varepsilon \neq 0$ causes reduction in $\varkappa_n$, however the reduction is inessential in practice if $u/\sigma_\varepsilon \geqslant 3$. For the SPS 400 GeV proton beam $\sigma_\varepsilon \lesssim 10^{-4}$ which comes to some 30 MeV in absolute units, and the modulator voltage should exceed 100 MV.

Thus the "klystorn" technique provides the bunching factor $k_\ell \approx 0,5$ readily. An enhancement of k_ℓ can be achieved by repeated use of the transformation (29), (30). In the theory of multi-resonator klystorns it is generally known that even for 2 - stage cascade bunching with an optimum choice of the parameters u, L and phase shift, the bunching factor comes to $k_\ell \approx 0,78$ ($\sigma_\varepsilon = 0$). However at ultrarelativistic energies such a multi-stage cascade bunching seems to be inconvenient as it requires additional drift sections, i.e. additional bending magnet arrays of large curvature radius.

Another way to enhance the bunching efficiency is provided by an admixture of higher harmonics in the beam modulator voltage. In an idealistic case the saw-tooth-shaped modulator voltage with the normalized amplitude $u = U_{peak}/E_0$ yields:

$$\varkappa_n = \frac{\sin\frac{2\pi n}{\lambda}\left(\frac{\lambda}{2} - uL\right)}{\frac{2\pi n}{\lambda}\left(\frac{\lambda}{2} - uL\right)}\cdot\exp\left[-\frac{1}{2}\left(n\frac{2\pi}{\lambda}\sigma_\varepsilon L\right)^2\right], \tag{32}$$

and maximum $k_\ell = \varkappa_{1max} = 1$ at $\varepsilon = 0$. An optimum approximation of the saw-tooth by three harmonics can raise k_ℓ up to ~ 0.8. With more harmonics the approximation is known to converge slowly, therefore k_ℓ enhancement is not significant.

Note that one can use the synchrotron ring itself as a bending magnet for beam density modulation if the beam after energy modulation is made to travel around a part of whole turn or several (such) turns before the final beam ejection. The energy modulator structure could be placed in a synchrotron straight section or it could be placed in a special by-pass, the proton beam passing through it only once before ejection (such a solution looks like the cheapest one).

5. In the last section we dwell on the new possibilities in high energy physics in the framework of the proposed technique of the linear accelerator excited by intense proton beam.

5.1 Obviously, in the first stage the use of the technique shall be the acceleration of some fraction of the initial proton beam, shifted in accelerating phase. So, it is possible to have the proton beam of doubled energy (roughly speaking) with the intensity of about one tenth of primary beam. Using several such accelerating sections in series excited by separated fractions of initial beam, one can proportionally increase the final energy with proportionally decreased proton intensity.

5.2 It looks very important, that the using of such linear accelerator excited by high energy proton beam gives the possibility of having very intense beams of unstable secondary

particles with energy equal to that of protons, good emittance and not bad monochromaticity (if good phasing).

For the unstable particles not to decay during acceleration, it is necessary to have energy gain per $c\tau_o$ of the particle (τ_o - the rest frame lifetime) more than 2 times larger than m_oc^2 (m_o - the rest frame mass); that means

$$E \gtrsim 2\,\frac{m_o c}{\tau_o} . \qquad (33)$$

For muons this means $E \gtrsim 3.2$ keV/cm, for $\pm$ pions $E \gtrsim 0.36$ MeV/cm, for $\pm$ kaons $E \gtrsim 2.8$ MeV/cm.

5.3 The most difficult problem for pions is to design a converter system, which gives about 10% efficiency of collecting several GeV pions produced by hundred GeV protons in small enough transversal emittance. There are possibilities to solve this problem using a multi-sectioned target and parabolic and/or lithium lenses. Maybe it would be necessary to use a special initial accelerating section.

Several words about the phasing problem. It is better to organize the initial phasing in pion beam using the properly bunched initial proton beam. The good phasing during acceleration, when difference between velocities of exciting and accelerated particles is not small (rather low energy of secondary particles, for example), gives more trouble. In this case, after an accelerating section of the length equal to $\frac{1}{2}\lambda\gamma^2_{min}$ it is necessary to install a wiggler magnet section, giving phase shift about $\frac{3}{2}\lambda$ (for low energy accelerated particles relative to exciting particles). To keep the pion beam free of muons it is necessary to accelerate them as fast as possible thus preventing pions from decaying. To clean the positive pion beam from protons of the same momentum it is better to use the difference in their velocities - during the acceleration the above mentioned phasing efforts give the dephasing effect in the accompanying proton motion (the kind of RF-separator).

5.4 To have intense, very low emittance (and pure) muon beams we need several steps: to collect as many pions of GeV region as possible in the smallest phase space volume using hadron cascade; to let them decay in very strong focusing channel (to prevent the emittance increase); to cool muons in a special storage ring or linear accelerator using ionization energy loss in a target, placed in very low β- value region, and compensating the average energy losses [6] to bunch the ejected muons properly and, finally, to accelerate them in the main linear accelerator.

5.5 The charged kaon acceleration would be feasible after great success in increasing of strength of accelerating field—about 3 MeV/cm or more. And the only crucial problem is the breakdown limitation of the electric field value on the reasonator cavity surface, because it is possible to achieve the needed peak proton current even now, using preliminary phase compression, as mentioned above. For purifying of beam it is possible to use the mentioned "RF-separator" trick.

5.6 Of course, it will be possible to accelerate in such an accelerator previously stored and cooled beams. This approach looks reliable for antiprotons, electrons, positrons, ions. In the case of electrons, light ions and, maybe, positrons the average intensity would be limited by the intensity of the main proton accelerator (about 10% of proton intensity). For antiprotons and heavy ions the average intensity should be limited by production efficiency of the beams.

It is necessary to mention especially the possibility to accelerate a polarized beam in such a linear accelerator without loss of the polarization degree. And in the near future the intensity of polarized proton and electron beams can achieve the energy conservation limit (10% of proton beam intensity). The intensity of polarized positron and antiproton beams should be limited by the production efficiency.

5.7 Using the acceleration of pions, muons and kaons in such an accelerator it would be possible to have intense and well collimated full energy neutrino beams ($\nu_{e,\mu}$; $\tilde{\nu}_{e,\mu}$). Especially good results could be obtained by using a special high field storage-decay ring (for muons and even for pions).

5.8 This technique gives new possibilities for solving the problem of superhigh energy colliding beams of unstable particles and electrons, namely: $\pi^\pm p$, $\pi^\pm\pi^\mp$, $\mu^\pm\mu^\pm$, $e^\pm e^\pm$ colliding beams [5,6].

For pion-pion ($\pm$) beams, accelerated in the linear structure, it is necessary to make a special high field storage ring and put there as many pions as possible in a time, and to repeat the cycle with all protons, accelerated in the main synchrotron. The average pion-pion luminosity will be in this case equal to

$$L_\Sigma^{\pi\pi} = \frac{\zeta \dot{N}_p}{l_t^{eff}} \cdot \frac{N_\pi}{l_b} \cdot \frac{p_\pi p}{(m_\pi c)^2} \cdot \frac{eH\tau_\pi}{2\pi m_\pi c},$$

where ζ - the efficiency of proton-pion conversion, N_π - number of pions in one super-bunch*), l_t^{eff} - effective length of the optimized conversion target, l_b- the length of pion super-bunch assumed to be equal to the β- value in the interaction region, p_π - the pion momentum at conversion, p - - the pion momentum in colliding beams, H - the storage ring magnetic field, τ_π - the rest frame pion lifetime. If we put $\dot{N}_p = 10^{13}$ ppsec, $N_\pi = 10^{11}\pi$pp, $\zeta = 10^{-1}$, $p_\pi = 5$ GeV/c, p = = 500 GeV/c, H = 100 kGs, l_t^{eff} = 1 cm, l_b= 1 m, we shall have

$$L_\Sigma^{\pi\pi} = 3\cdot 10^{27}\,cm^{-2}sec^{-1}.$$

One will have proton-pion colliding beams replacing positive pions by the proton bunch of the same momentum and length with N_p^1 protons. In this case

$$L_\Sigma^{\pi p} = L_\Sigma^{\pi\pi} \cdot \frac{N_p^1}{N_\pi}$$

and for $N_p^1 = 10^{12}$ and other parameters the same we could expect

$$L_\Sigma^{\pi p} = 3\cdot 10^{28}\,cm^{-2}sec^{-1}.$$

*) Actually, in a colliding beams facility maximization of N_π may force us to choose a greater operation wavelength λ so as to gain the amount of energy, stored in the accelerating structure.

If instead of pions we inject in the same storage ring muon bunches with N_μ muons in a super-bunch, cooled and accelerated by the way described previously, we shall have the average luminosity

$$L_\Sigma^{\mu\mu} = \frac{\zeta \dot{N}_p N_\mu}{\ell_{cool} \cdot \beta_0} \cdot \frac{p}{2 m_e c} \cdot \frac{e H \tau_\mu}{2\pi m_\mu c} ,$$

where ℓ_{cool} - the length of the cooling target equal to the β - function at this point, β_0 - the value of the β - function in the interaction region of the storage ring. It is necessary to mention, that we have made an optimistic assumption that during the collisions the muon beams have the same normalized emittance as after the ionization cooling. Assuming ℓ_{cool} = 1 cm, β_0 = 5 cm, $N_\mu = 10^{11}$ μpp and the other parameters the same as for pion beams, we shall have in such conditions

$$L_\Sigma^{\mu\mu} = 3 \cdot 10^{31}\ cm^{-2} sec^{-1}.$$

It looks possible to use the intense beams of big proton accelerators for excitation of accelerating structures of electron-positron linear colliding beams [7]. Of course, the special efforts should be made for fast damping of asymmetrical modes excited in accelerating structure by proton beams.

In this case the luminosity that can be achieved is difficult to evaluate because its value depends on how small the effective emittances of $e^\pm$ beams can be made in the collision point. If we follow the optimistic approach of [7], there would be the luminosity

$$L_\Sigma^{e^+e^-} = 10^{31}\ cm^{-2} sec^{-1}$$

with $\dot{N} = 10^{13}$ ppsec. And besides it is very probable that the productivity of proton accelerators will still be growing.

In conclusion we wish to take this opportunity to express our appreciation to V.E.Balakin, T.A.Vsevolozhskaya and M.M.Karliner for many discussions and for their interest in this work.

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Table 1.

		VEPP-3	S P S
Energy	GeV	1.5	400
Beam current	A	0.3 [4]	0.24 [2,3]
Intensity	particles pp	$5\cdot10^{11}$	$3\cdot10^{13}$ [2]
Emittance	mm·mrad	0.3	0.017 [3]
Energy spread	MeV	1.5	40 [3]
λ_{opt}	cm	0.6	0.9
E	MV/cm	5.7	0.75

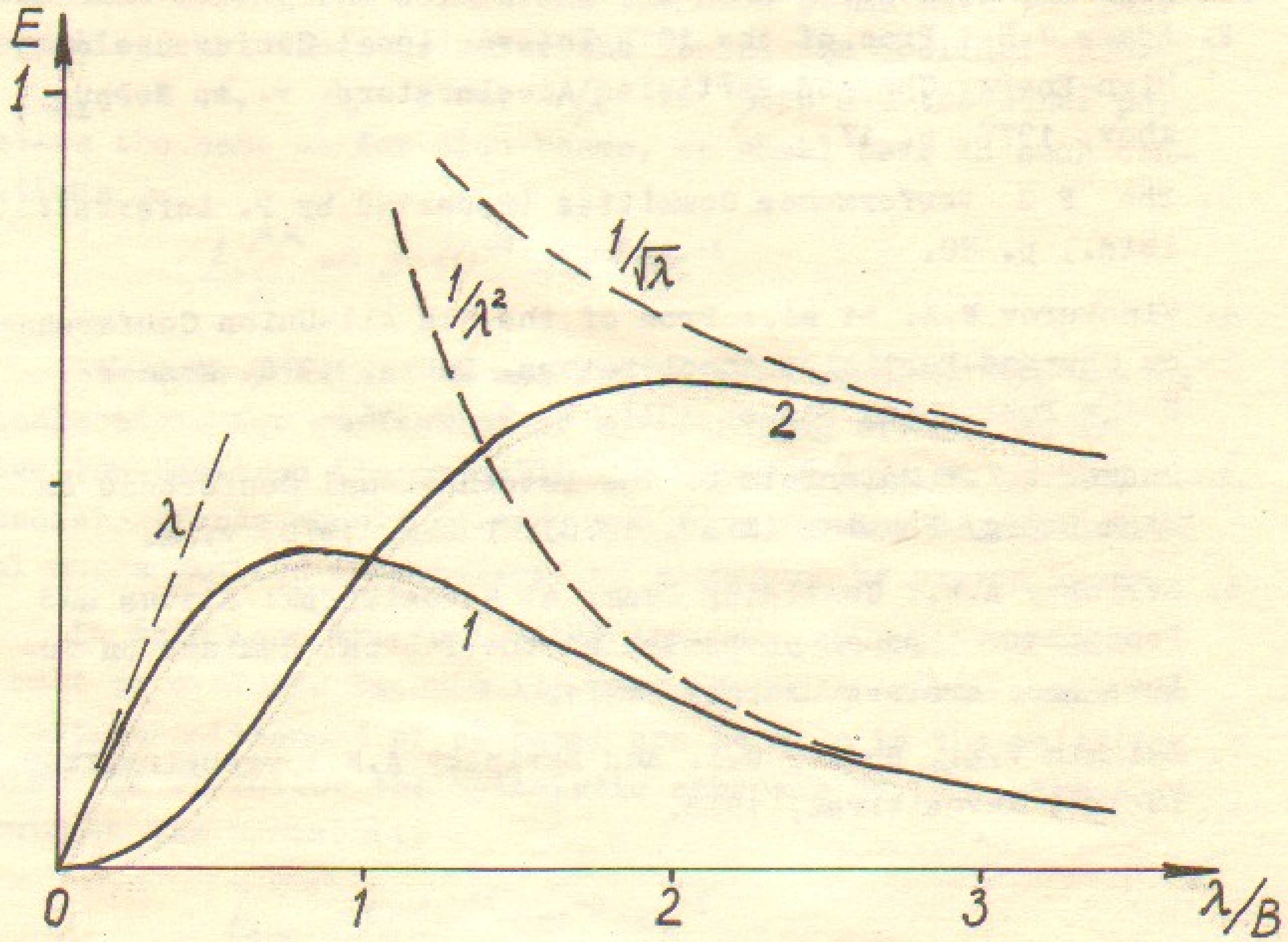

Fig. 1. The induced electric field amplitude E (arb. units) vs. operation wavelength λ. Curve 1 - short bunch, curve 2 - long bunch (Eqs. (16) and (20) respectively).

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