SUMMARY REPORT OF THE WORKING GROUP 2 ON NEAR FIELD ACCELERATORS

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Participants in Working Group

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Group 2 considered three types of accelerators: Wake Field Accelerators (WFA)
Two-Beam Accelerators (TBA)
Laser Droplet Accelerators (LDA)

Most of the workshop was spent on presenting these three types of accelerators in detail. Only a small amount of time was left to actually "work" on any of these subjects. However, during the presentations a number of "weak" points were discussed. For each acceleration scheme a list of the problems was made that urgently need more theoretical and/or experimental work.

General problems common to all three types of accelerators were found to be:

Overall efficiency,
Wake Field effects/limitations,
Breakdown limit on gradients,
Bright sources.

But no time was left to do much more than prepare this list and identify the problems. Thus, here we will simply list these points and not repeat a description of the three schemes.

WAKEFIELD ACCELERATORS (WFA)

A major problem common to all types of wakefield accelerators is that the essential ingredient is a very short high-density driving beam of protons or electrons. Peak currents around 50000 amps or more are necessary to create sufficiently high wakefields to accelerate particles at a rate above the magic figure of 100 MeV per meter. In terms of bunch size one needs millimeter long bunches carrying 10^{12} to 10^{13} particles ($\approx 1\mu$ Coulomb). The generation of such short high density bunches may possibly be the real limitation for the wakefield schemes since space charge effects in the low energy region will counteract external bunching forces. Furthermore, the preacceleration of such beams is itself a very difficult problem since the wakefield effects mainly do harm, especially to high density short bunches.

If a TeV collider is based on the wakefield effect without transformation, then one has to provide about 1μ Coulomb at 500 GeV (or 10 times 50 GeV if built in 10 stages (say)) in a bunch of a few millimeters in length. No reasonable scheme is known for realizing this, whether one uses protons or electrons. If one uses the Wakefield-Transformer the situation looks better since only 50 GeV (or ten times 5 GeV if built in 10 stages (say)) have to be provided as acceleration of the 1μC bunch.

TWO-BEAM ACCELERATORS (TBA)

The TBA problems are mainly centred around the operation of an FEL that generates the rf-power for the high gradient standard type accelerating structure.

Steady state FEL operation was one of the problems considered and - as usual - the problem of tolerances on the wiggler field and in the period length. Also the slippage between the high energy beam and the low energy beam can become a problem. For a 3 MeV beam the slippage amounts to a few percent, i.e. some ten meters after one kilometer.

For successful operation the power output per unit length also has to be around 500 MW/m, a number which is not far from the results achieved at Berkeley (50 MW/m).

A second kind of problem occurs in the accelerating structure where wakefield effects will be a major limitation. These effects are common to all accelerating schemes which use metal near the beam, and thus they must be considered in all wakefield accelerator schemes.

LASER DROPLET ACCELERATOR (LDA)

The laser droplet accelerator is a quite unusual device and this implies that problems will be more difficult to forsee. However, the proper generation of droplets is an obvious problem as well as the wakefield effects and the determination of useful modes for acceleration. The fact that it is a scheme that is fully threedimensional makes the analysis quite cumbersome. 3D-codes will have to be used for studying these effects which are, after all, again very similar to those occuring in the WFA and TBA.

The laser providing the accelerating field will have to have some extreme properties such as 1 Joule per pulse, repetition rate of a few KHz, efficiency a few percent, ... etc. This is probably the most expensive part of the scheme and it was considered that this could provide the main obstacle to a realization.

It is somewhat difficult to compare the three schemes WFA, TBA and LDA since the first two promise gradients of some hundred MeV/m and the LDA of some GeV/m. This difference in gradient is also reflected in the different levels of practicability of the concepts. Whereas the WFA and TBA are being studied experimentally and appear to provide a possible solution for the next generation, the LDA is not yet at a stage where an experiment can be mounted (?). On the other hand, the LDA is destined to be used in the next but one generation of accelerators and so there is more time available for R&D.

GENERAL PROBLEMS

Breakdown:

Measurements at SLAC were reported that removed any fear that breakdown could be a problem. Field strengths of more that 100 MeV/m have been achieved at 3 GHz. If one believes the frequency scaling laws, there will be no problem for the TBA nor for the WFA. The WFA is in all cases considered the concept with the highest possible field strength since the pulses are much shorter than in a TBA or a standard pulsed linac. However, the general feeling was that no-one in the group knew very much about this area.

Wakefield effects:

Here we address the wakefield effects that do harm to the beam and not those that are used for acceleration. These wakefield effects lead to energy loss and spread, to transverse blow-up and beam break-up. General scaling laws are not easy to give since the collective effects depend strongly on the detailed geometry of the structure and on all the beam parameters. However, from scaling, it is already clear that there will be a severe problem for the WFA and the TBA. Experimental and detailed theoretical studies are under way and the effects are well understood, though not completely analyzed yet. Less obvious, since it is so different from the ordinary linac, are the wakefield problems in the LDA. Here one could use the same techniques as are usually used in standard structures for beam dynamics calculations, i.e. wakefield calculations, mode computations and tracking studies.

SUMMARY

As a result from this week's work one could see that far too few accelerator people actually work for most of their time on new accelerator schemes.

If one compares the technology of LEP with that of PETRA/PEP and the technology of PETRA/PEP with that of DORIS/SPEAR one finds a more or less continous development and essentially only a change in scale but not in basic principles.

The next generation however, whether it is a WFA, TBA or LDA or even an extended SLC version, will be very much different from the existing accelerators. In spite of that, the amount of work currently being dedicated to the subject of the workshop was considered to be much too little.

The discussions during the week illuminated a large number of basic physical problems that have to be investigated both theoretically and experimentally.

Editor's note

Following the workshop W. Willis developed his proposal for a Switched Power Linac and his paper is included in this section.

Discussion (following Working Group 2 Summary presented by A. Sessler)

M. Tigner, Cornell

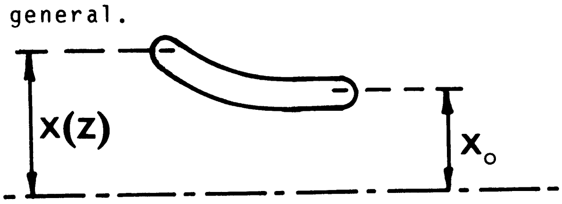
Could you make some further comment on the problem of the transverse wakes?

A. Sessler, LBL

We can discuss the transverse displacement in terms of the quantity

$$A = x(z)/x_0 ,$$

where x(z) is the transverse position at the back-end of a bunch for which the initial displacement off-axis is x_0. If x_0 is zero then everything is fine, but this is not the case in general.



Following P. Wilson, who analysed this effect at the Los Alamos Conference:

$$A = \frac{q}{4E_a} \cdot w_T \cdot \beta$$

where q is the charge, E_a the accelerating field, w_T is proportional to the transverse wake potential, and β is the betatron amplitude function. We can put

$$w_T = \frac{W(\sigma)}{\lambda \pi a^2}$$

where W(σ) is a function of bunch length only, and a is the <rad.> of the field; so this gives the correct $1/\lambda^3$ behaviour.

Then

$$A = \frac{1}{4} \frac{q}{E_a} \frac{W(\sigma)}{\pi a^2} \frac{\beta}{\lambda} ,$$

and this suggests that going to smaller λ can be compensated by enlarging the aperture, a. But then the efficiency of the accelerator goes down, so we try some more manipulation.

The efficiency can be written:

$$\mathcal{E} = \frac{E_a q}{\omega} = \frac{E_a q}{E_a^2 \pi a^2} ,$$

where ω is the stored energy per unit length.

Thus

$$A = \frac{\mathcal{E}}{4} \cdot W(\sigma) \cdot \frac{\beta}{\lambda} .$$

So, as we discussed at Los Alamos, if β/λ is constant, that is more focusing as you decrease the wavelength, then A is proportional to the efficiency; again we find a result driving us towards lower efficiency.

But is A really the quantity of interest? What we should be asking is how much the back is displaced compared to the width of the bunch. So we have defined

$$\alpha = x(z)/\sigma_x ,$$

and introduce the emittance, via

$$\sigma_x = \sqrt{\frac{\varepsilon_x \beta}{\gamma}} .$$

Next we decided that the initial displacement of the bunch should be measured in units of the wavelength:

$$\delta_x = x_0/\lambda .$$

Then

$$\alpha = \sqrt{\frac{\gamma}{\varepsilon\beta}} \cdot \lambda \delta_x A ,$$

or

$$\alpha = \frac{\mathcal{E}}{4} \delta_x \sqrt{\frac{\gamma\beta}{\varepsilon}} \cdot W(\sigma_z) .$$

For fixed δ this is again independent of λ; it improves as $\sqrt{\beta}$ decreases, but gets worse for high γ. But this has to be put into some big optimisation programme with lots of other factors; and, for example, it could be re-written as:

$$\alpha = \frac{\mathcal{E}}{4}\,\delta_x\, W(\sigma) \sqrt{\frac{\beta}{\varepsilon}} \sqrt{\frac{f\,\sigma_z\,\delta_B}{L}}\ ,$$

where δ_B is the beamstrahlung parameter, f the frequency and L the luminosity; now there is no overt γ dependence.

J. Mulvey, Oxford

Presumably the wakefield generated by the driving beam can also disturb succeeding bunches of the driving beam itself. Is this a serious problem?

Answer

We have always envisioned that such effects are small because you have enough separation between bunches. Therefore the repetition rate is sort of limited, say to ~ 10 kHz.