Pulsed Drift Tube Accelerator
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The pulsed drift-tube accelerator (DTA) concept was revived by Joe Kwan and John Staples and is being considered for the HEDP/WDM application. It could be used to reach the full energy or as an intermediate accelerator between the diode and a high gradient accelerator such as multi-beam r.f. In the earliest LBNL HIF proposals and conceptual drivers it was used as an extended injector to reach energies where an induction linac with magnetic quadrupoles is the best choice. For HEDP, because of the very short pulse duration, the DTA could provide an acceleration rate of about 1MV/m.

This note is divided into two parts: the first, a design based on existing experience; the second, an optimistic extrapolation. The first accelerates 16 parallel K^+ beams at a constant line charge density of 0.25μ C/m per beam to 10 MeV; the second uses a stripper and charge selector at around 4MeV followed by further acceleration to reach 40 MeV. Both benefit from more compact sources than the present 2MV injector source, although that beam is the basis of the first design and is a viable option.

A pulsed drift-tube accelerator was the first major HIF experiment at LBNL. It was designed to produce a 2μs rectangular 1Ampere C_s^+ beam at 2MeV. It ran comfortably at 1.6MeV for several years, then at lower voltages and currents for other experiments, and remnants of that experiment are in use in present experiments, still running 25 years later. The 1A current, completely equivalent to 1.8A K^+, was chosen to be intermediate between the beamlets appropriate for a multi-beam accelerator, and a single beam of, say, 10A, at injection energies. The original driver scenarios using one large beam on each side of the reactor rapidly fell out of favor because of the very high transverse and longitudinal fields from the beam space charge, circa 1MV/cm and 250 kV/cm respectively, near the chamber and because of aberrations in focusing a large diameter beam down to a 1mm radius spot at a distance of 10m. Almost all subsequent work and the present concept have invoked multiple beams. For HEDP the major differences are that the focal distance can be centimeters instead of meters, provided strong-enough lenses exist and they do, thereby allowing much higher transverse and longitudinal emittances than driver concepts, and focusing parallel small beams is easier than one big beam.

After and in parallel with the DTA experiment, the first two major LBNL HIF proposals, the 500J Ion Induction Linac [1], and the reduced cost 50J Ion Induction Linac [2] included pulsed drift tubes. The first proposal, in 1979, included two drift tubes with bipolar 750kV pulses to accelerate a 2.75A C_s^+ beam, equivalent to 5A K^+. The second proposal, in 1980, included five unipolar 500kV drift tubes to accelerate a 5μs, 1A C_s^+ beam. The second proposal's DTA was very similar to the 2MV, 2μsec, 1A C_s^+ accelerator which was built, which used 3 drift tubes of 500kV and a 500kV gun to create a 1MV triode at the source and two 500kV acceleration gaps downstream. The first proposal's DTA required some development for the bipolar pulsing and the higher voltage whereas the second proposal's DTA had an experimental base. The drift tube concept is described in the second HIF Symposium

[3], at LBL in 1977, and in the above proposals. A schematic of the experiment is shown in Fig. 1.

The amount of charge that can be contained within a drift tube is a crucial parameter that depends on the size of the drift tube and the type of focusing employed. Grids, Einzel lenses in circular and ribbon beams, neutralization with electrons or thin wires, electric quads, magnetic quads, higher multi-poles, and solenoids have all been considered. The first conceptual drivers included a DTA section within a 4T superconducting solenoid. Shortly thereafter the solenoid was superseded by electrostatic quad focusing inside of the drift tube – similar to the magnetic quad focusing within the drift tubes of some Alvarez linacs. This configuration is shown in Fig.2. When the Test Bed proposals were set aside, work was in progress on multiple beam electrostatic quad arrays within the drift tubes, and it is that scheme, now enhanced by experiments in SBTE, MBE-4, and HCX which all used electric quads (singly or in arrays, and at reduced and full quad operating voltages), that we consider here for HEDP. In an electric quad channel the line charge density of a space charge dominated and space charge limited beam is directly proportional to the quad voltage. The voltages envisaged here are +/- 75 kV, which are well below those used in the HCX injector and matching section quads, and the same as the nominal operating voltages of the HCX electric quad transport line. The line charge density corresponding to this choice is a quarter microcoulomb per meter. The 16 beams carry a total of 4 μC/m, which is 4 times greater than was carried in the original experiment. As the number of beams in the array is increased, the number of electrodes tends toward one electrode per beam, as contrasted to 4 electrodes for a single beam, and the array packs more efficiently into a circular container, so there is an incentive to use a large number of beams. 16 was chosen as a case which exhibits some of these scaling features, but an economic analysis including the cost of sources and acceleration might find a better optimum.

Much of the experimental work alluded to above was directed at transporting the maximum current through an expensive induction core which requires a powerful pulser, circa 100MW per module, to supply the magnetizing current and drive the beam. The drift tube, on the other hand, is essentially a capacitor of a few hundred pf and the beam currents for HEDP are low, so the pulser is different and in most respects easier to make. In the induction core case, doubling the current through a given core halves the pulse duration, allowing the core radial build to be halved and the core volume to be more than halved, thus reducing the cost of the core and pulser. With the drift tube there is little incentive to making its diameter small, with much of the cost of making a small accelerator being associated with the number of parts rather than their size and weight. Electrically, driving a 1m diameter drift tube within a 1.5m vacuum tank is similar to driving a 2m tube in a 3m tank as far as capacitance is concerned, but the beam current would quadrupole. The strategy thus is to use as many beams as necessary to get the desired beam power, overlapping the beams only at the focal spot.

The drift tube functions by hiding the beam bunch within a cylindrical metal enclosure while its voltage is switched. The beam is accelerated exactly as by a sequence of DC accelerating gaps, except that the voltage of the drift tubes stays around the 1MV level while the beam energy accumulates at the rate of about 1MV

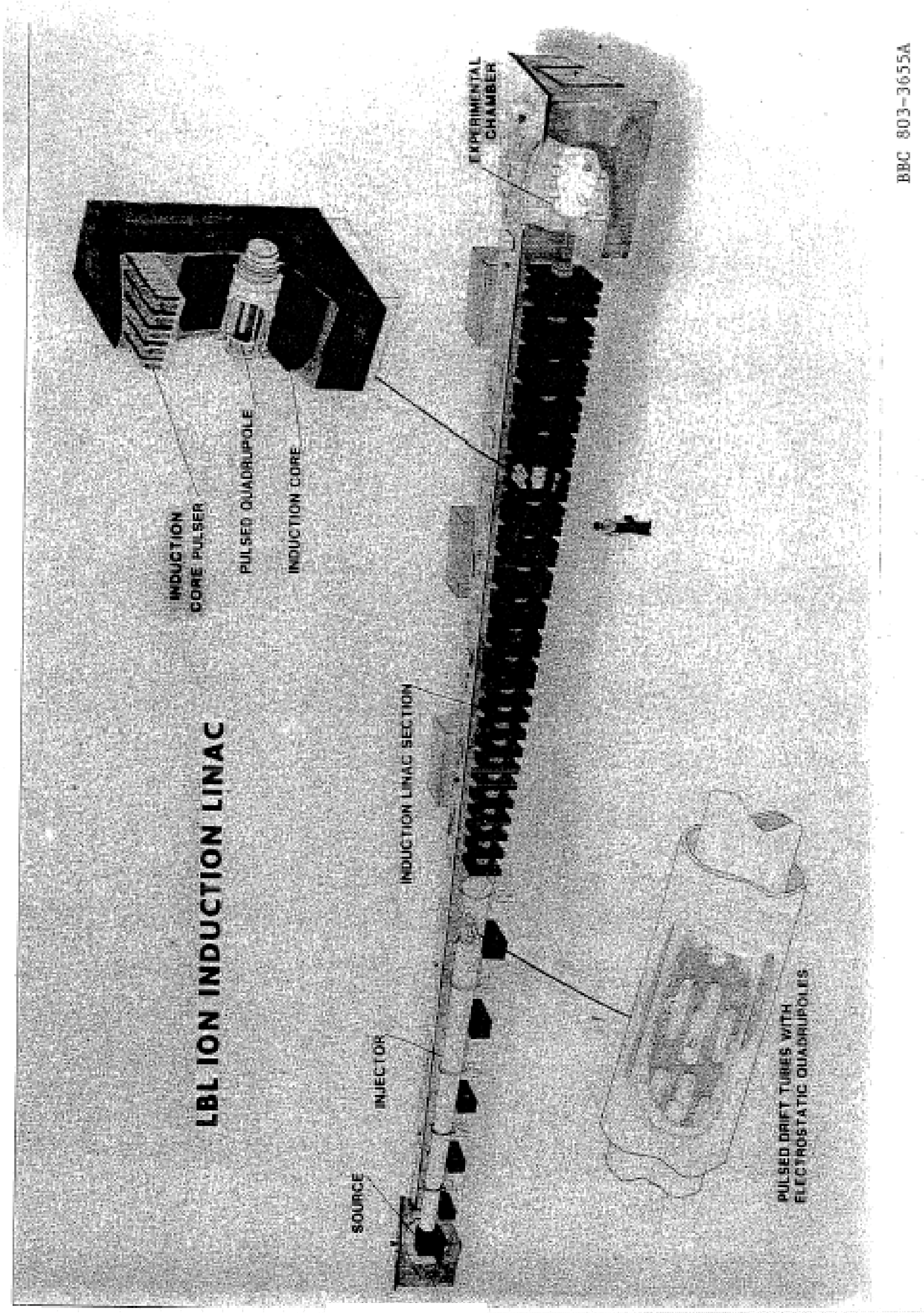

LBL ION INDUCTION LINAC
INDUCTION CORE PULSER
PULSED QUADRUPOLE
INDUCTION CORE
EXPERIMENTAL CHAMBER
INDUCTION LINAC SECTION
INJECTOR
SOURCE
PULSED DRIFT TUBES WITH ELECTROSTATIC QUADRUPOLES
BBC 803-3655A

Figure 2

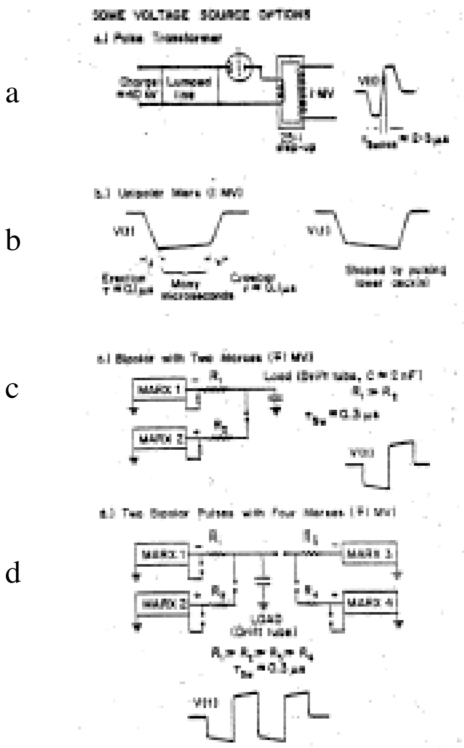


Figure 3 Some pulse modulator choices: (A) Thyratron and pulse-transformer. (B) Unipolar Marx generator, (C) Bipolar Marx generator combination, (D) Double pulsing (Bipolar) Marx Generator Combination. The natural RC droop of the Marx pulse can be removed and a positive ramp created by pulsing the lower decks.

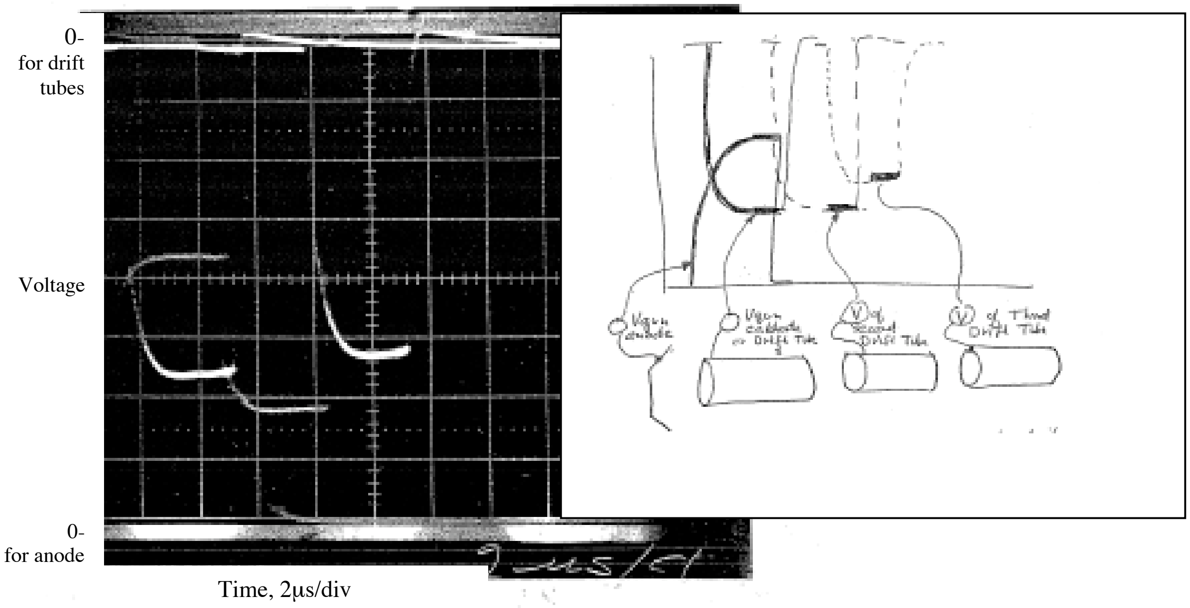
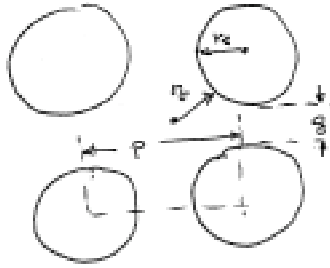


Figure 4

Figure 5. The four Marx generator plus crowbar voltages used to drive the gun, positively, and the three drift tubes negatively and delayed by the beam time of flight. Horizontal sweep 2μs/div. Voltage is from capacitive dividers each of which has its own calibration. Voltages were held to about 1% tolerance at a typical operating level of 400 kV. The parts of the waveforms when beam is present are darkened, at the right, ν.
The gun and each drift tube had its own Marx generator and crowbar. The portions of the waveform used in accelerating beam are shown with heavy lines on the right.

The Drift Tube

Taking the recently "standard" electric quadrupole geometry as in HCX, the electrode radius is $\frac{8}{7}$ of the aperture radius of 2.33cm.



$$p = \sqrt{2}\,(r_b + r_e)$$
$$= (\sqrt{2})(\tfrac{15}{7})\,r_b$$
$$p = 7.06\ \mathrm{cm}$$
$$g = p - 2r_e$$
$$g = 2.4\ \mathrm{cm}$$

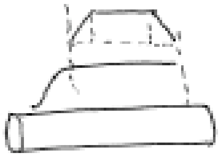
This geometry eliminates the next higher allowed multi-pole, n=6, can transport 0.25μ C/m at electrode voltages of ±75kV, and shields the beams from each other. A surrounding o potential shell requires a spacing of at least 0.5g. A 4X4 array thus fits into a drift tube of diameter

$$D = 4\sqrt{2P} + 2R_e + g$$

$$D_{16} = 48cm \qquad (D_{12} = 40cm)$$

The length of the drift tube is the sum of the bunch flat top, bunch rise and fall distances, the switching time multiplied by beam speed, and the field penetration distance into the drift tube ends.

$$L_{DT} = 2r_g + (tr + tp + tf)v_g + t_{sw}v_g$$



For a bunch with 50ns rise, 100ns flattop, 50ns fall and a switching time of 100ns,

$$L_{DT} = 50 + (50 + 50 + 100 + 100)(3mn/ns) = 1200mm$$

Doubling the useful portion to 200ns adds 300mm, for $L_{DT} \rightarrow 1500mm$

Adding room to hold off 1.5MV increases the accelerator length per drift tube to $L/_{DT} = 140cm$ for the 100ns-flat bunch and 170cm for the 200ns-flat bunch.

The drift tube capacitance is

$$C = \frac{2\pi\varepsilon_0\ell}{\ln\frac{6}{a}} = \frac{(2\pi)(8.854)(1.4)}{\ln(1.5)} = 200\,pf \quad (radially)$$

$$Cstem \cong 20\,pf/ft \to 50\,pf$$

$$Cends = \frac{2\varepsilon_0 A}{d} \to 15\,pf$$

$\Sigma C = 265\,pf$ for "100ns" and 300pf for "200ns"

The energy in the fields is

$$V_{DT} = \frac{1}{2}CV^2 = \left(\frac{1}{2}\right)\left(300x10^{-12}\right)\left(\frac{3^2}{4^2}x10^{12}\right) = 84 \text{ joules}$$

The beam takes out 2 joules on each end, when the bunch enters and when it leaves.

If these beam sizes are scaled up in order to better match an injector, the above values stay the same.

As the bunch accelerates, the physical lengths of the bunch are kept fixed, but the portion of the drift tube length attributable to switching time lengthens as velocity: (100ns) (3m/μ sec) at injection $\to (100ns)[9m/ns\,or\,18m/ns]$ for a lengthening of 60cm or 1.5m for the 10MeV or 40MeV cases respectively.

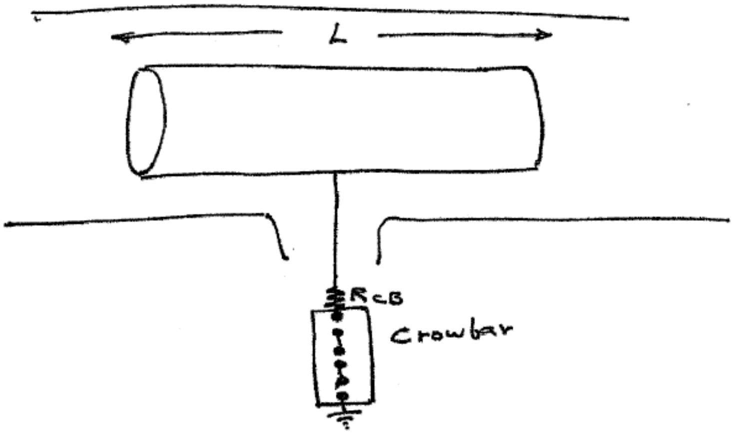
The bunch fall time portion is carried along to act as a buffer for the "good parts" of the pulse. The ends have the space charge and longitudinal ear fields in addition to acceleration and bunching fields and hence get more heated up longitudinally and mismatched transversely than the body of the bunch.

The 10MeV Design

The 10MeV designs basically assumes the appearance of a matched, small beam at the entrance of the first drift tube, at an energy of about 1.8MeV, 750keV from the drift tube, ~1MeV from the gun. During the rest of the acceleration the beam gains 1.5MeV every time it crosses a gap. The lengths of the drift tubes are adjusted as required to match the focusing lattice, and diagnostics, correctors, and focusing arrays are placed between drift tubes as required.

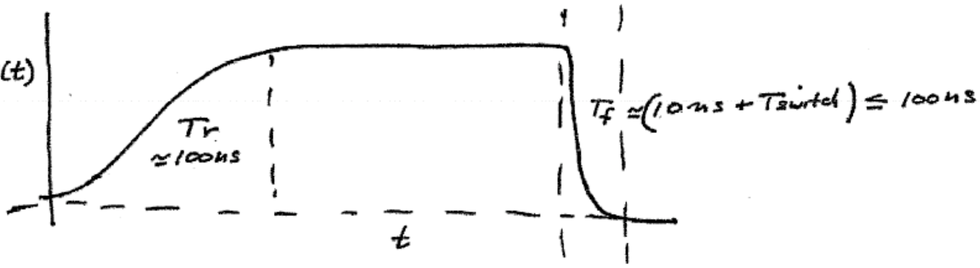
The K^+ focusing periods are about 40cm at injection and increase to $\left(\sqrt{\frac{10}{1.8}}\right)(40) = 94cm$ at the end. Therefore, the first few drift tubes have ~6 arrays and the last ones ~4 arrays. The quads and drift tubes both lengthen with velocity, the quads linearly and the drift tubes somewhat less rapidly as discussed above. The drift tube lengths must also be adjusted to contain full half-periods.

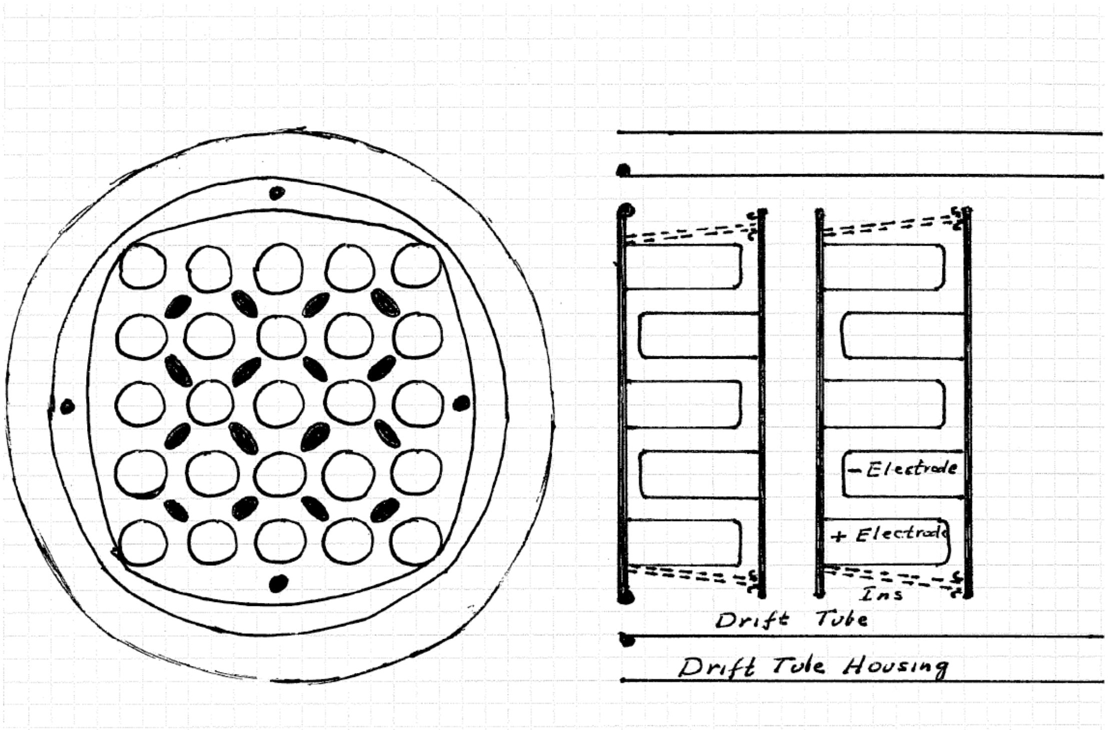
$$L_{DT\cong}\upsilon\left(T_{beam\ \ flat\ \ part}+T_{beam\ \ rise\ \ \&\ \ fall}\right)+\upsilon T_{switch}+\left(G+2a\right)$$

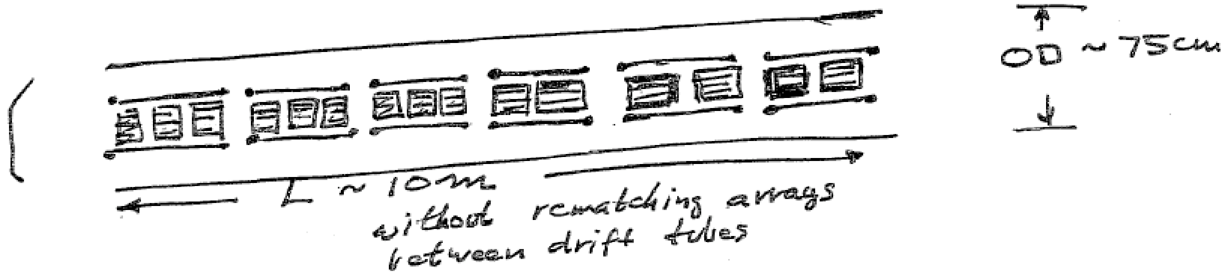


If $R = \frac{Z_{oDT}}{2}$

$T_{f\,min} \approx \frac{L}{c} \sim 10\ ns + T_{switch}$







If the last gap provides the tilt, $\frac{\Delta \mathrm{E}}{\mathrm{E}} \sim \frac{.75}{10}$, $\frac{\Delta v}{v} \sim \frac{.75}{20} \sim 4\%$ and 25bunch lengths are needed for the drift line. Here, since the beam us going into plasma, only the flat part of the pulse needs to be tilted, so 25 times 30cm = 7.5m. Applying tilt at the entrance and exit of the last drift tube could roughly halve the drift distance.

The 40 MeV Design with a Stripper and Charge Separator at 4 MeV

The desire is to increase the acceleration rate by using a high charge state q of the ion, obtained by passing the beam through a thin jet or ribbon of gas, followed by a magnetic dipole in a short neutralized region which is long enough to allow a separation of 1 beam "diameter" per charge state. Among all the possible gases and stripping energies, there must be optimum pairs for every desired charge state. Here we simply assume that near 4MeV the yield is 25% into charge state 4. With further work, some other nearby charge state and energy may turn out superior.

Starting with the nominal $\frac{1}{4}\mu C/m$, after stripping the electrical charge is $\frac{1}{4}\mu C/m$ and the particle number is $\frac{1}{16}p\mu C/m$. With the same acceleration system, the

$1.5 MV/drift$ tube becomes 6 MeV/drift tube. Adding 36MeV thus requires 6 more drift tubes. The focusing is still at the limit of its capabilities, but the lattice has to be rearranged to match the higher charge state and faster acceleration schedule. The bunch maintains its length.

The beam entering a neutralized region just before the stripper would focus to a smaller size that with space charge, in one plane, reducing the required bend for charge separation. All of this takes place between drift tubes, with some focusing and re-matching arrays in that elongated space.

End containment

The end focusing ears, which counteract the space charge defocusing fields, are calculated below for assumed bunch ends of 15 cm each. The required voltage of about 25 kV per drift tube is modest compared to the acceleration voltage of 750 kV, but the 50 ns long triangular voltage pulse and the means by which it is superimposed on the drift tube may require a more powerful independent pulser and combining circuit. Such circuits using inductive adding were used on SBTE, for a short pulse, and on MBE-4 for a long pulse for tilt control. The waveform tolerance for accelerator pulsers has usually been in the range of 1% for the flat portion, and it is possible that some of the main pulser ripple or rise times could be of use for end containment.

$$\lambda = \frac{1}{4}\mu C/m$$

$$\Phi \cong 2.5 kV$$

$$Tr_1 T_f = 50 ns = 15 cm$$

$$Eq = \frac{2.5}{.15} = 16.7\, kV/m$$

$$V_q \cong 25\, kV/dt$$

Between pulsers, the ends elongate with the space charge wave speed λ inwards and about twice the wave speed outwards. $\upsilon_\lambda = \sqrt{\frac{\Phi_G}{m/e}}$ is the space charge wave speed and the end erosion is approximately thrice that.

$$\upsilon\lambda = 7.9\, cm/\mu s$$

$$\upsilon_{end\ \ crosion} \cong 24\, cm/\mu s$$

$$\text{Travel time through } 1DT \sim \frac{1.5m}{3m/\mu s} = \frac{1}{2}\mu s$$

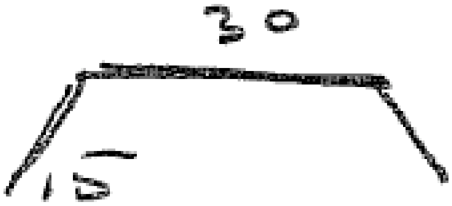
$\therefore$ End motion ~ 12 cm in first DT

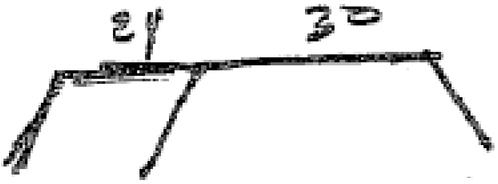
~ 4 cm in, 8 cm out

So even here we need a pulser to restore the end or a longer end, which is sacrificial.

Through the entire accelerator the transit time is ~3 μsec leading to 6 times longer erosion distances on the bunch.

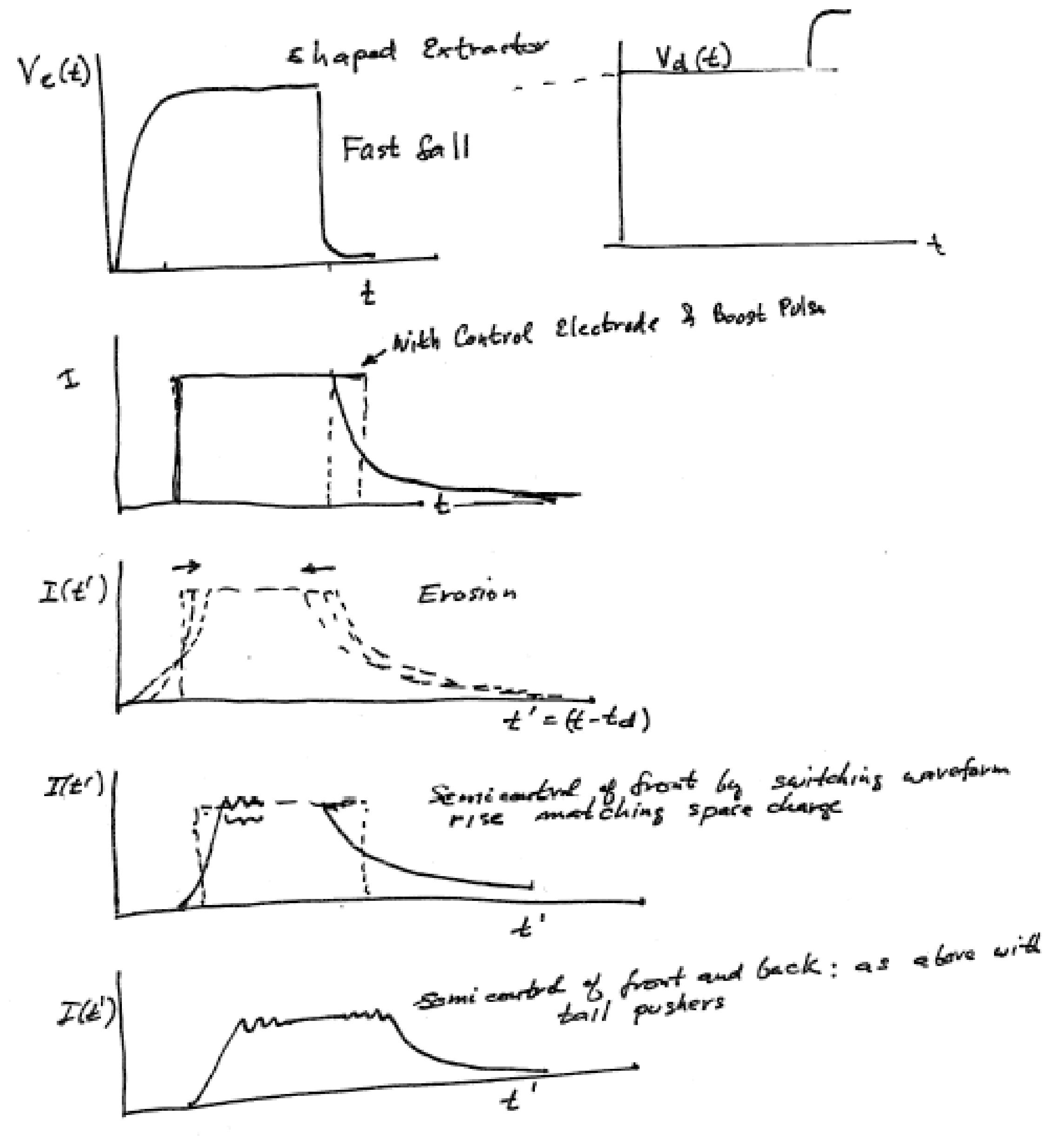
$\rightarrow \frac{(6)(24)}{2} = \frac{144cm}{2} = 72\ cm$ of which the inward wave is 24 cm and outward motion is <u>48</u> cm.





One choice is to approximately double the pulse length to get enough sacrificial beam. A more complete calculation of the end dynamics would have to have the current rise time and energy distribution of the bunch ends when the bunch leaves the injector.

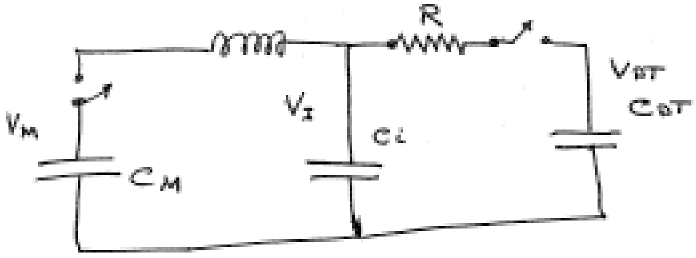
Bunch Length Control



The Pulser Circuit

The drift tubes may be charged up on any convenient time scale, using a Marx generator or a pulse transformer. The original experiment used Marx generators, but the choice was influenced by availability of some of the parts and a design base; pulsed transformers were looked at briefly, and one choice to look at would be a 30kV thyratron capacitor discharge into a 25:1 step up transformer for establishing the initial voltages before beam enters the drift tube. The Marx generators that were constructed had many meters of wire connecting the capacitors and spark gaps inside them so the voltage rise time, determined essentially by the wire inductance and the capacity to ground along the Marx and in the high-voltage terminal, was about 100ns. For beam dynamics reasons the rise time was slowed to 1μs with a series resistor to the emitter. The fall time, on the other hand, should be made short, and this was accomplished in the original experiment by a crowbar spark gap and a damping resistor. The resulting voltage pulses, representative of what could be achieved today with modest effort are shown in Fig. 4. The attained rise times of 100ns for a single polarity Marx and crowbar spark gap, and the estimated 300ns switching time for a bipolar drift tube were all acceptable when the beam pulse was several μs long. For HEDP, because the beam duration is only circa 100ns, it is desirable to shorten the switching time with a different circuit.

The causes of the slow Marx switching time are the stray and load capacities of the Marx driven through the Marx inductance. It is certainly possible to construct a lower inductance Marx, but the charging time varies only as $\mathrm{T}_{sw} \propto \sqrt{L_s C}$, so that the internal inductance must be reduced by a large factor to see a significantly shorter rise time. A more attractive solution is to use the Marx (or pulse transformer) to resonantly charge on intermediate low inductance capacitor, and use that capacitor, which is an inherently low inductance element, to rapidly charge the drift tube. The full circuit and important relations are shown in Fig. 5.



$$V_I = \left(\frac{2C_M}{C_M + C_i}\right) V_M$$

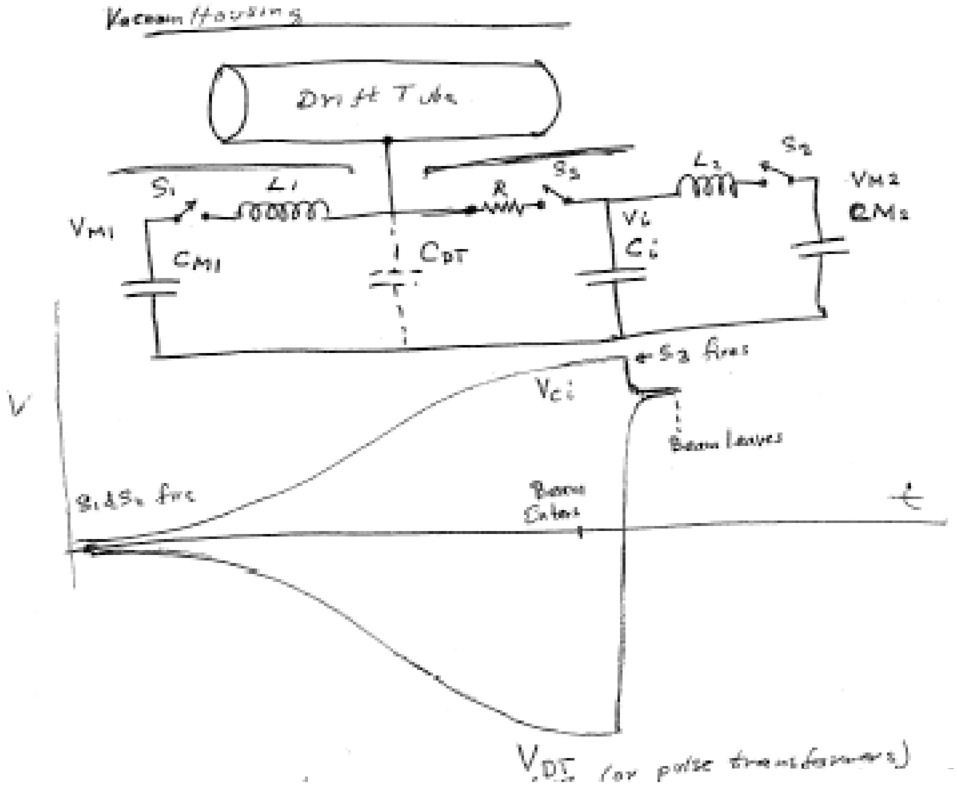
$$V_{DT} = \frac{C_i}{C_i + C_{DT}} \quad V_i$$

$$V_{DT} = \left(\frac{C_i}{C_i + C_{dt}}\right)\left(\frac{2C_M}{C_M + C_i}\right) V_M$$

$$\tau = \frac{(R)\,(C_{DT}\, C_i)}{(C_{DT} + C_i)}$$

Figure 5. Circuit for pulsing a drift tube, incorporating an intermediate capacitor.

Bipolar Pulsing Circuit



A slow charging circuit is used to charge up the intermediate capacitor C_2, and this is switched to the drift tube through a low resistance R.

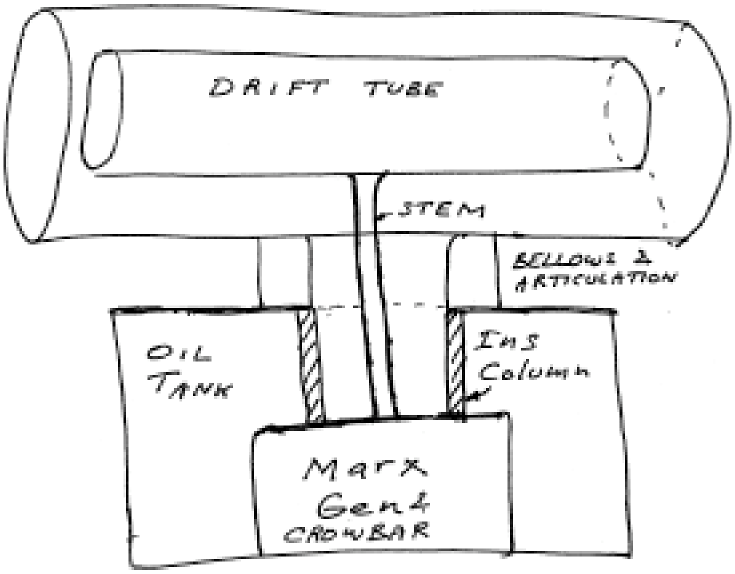
This circuit uses two Marx generators (or pulse transformers) with capacitances C_{M1}, C_{M2}. C_{M1} slowly and resonantly charges up the drift tube capacity C_{DT} through L_1. C_{M2} slowly and resonantly charges up the low inductance intermediate capacitor C_i. C_i then resistively charges the drift tube to a positive voltage.

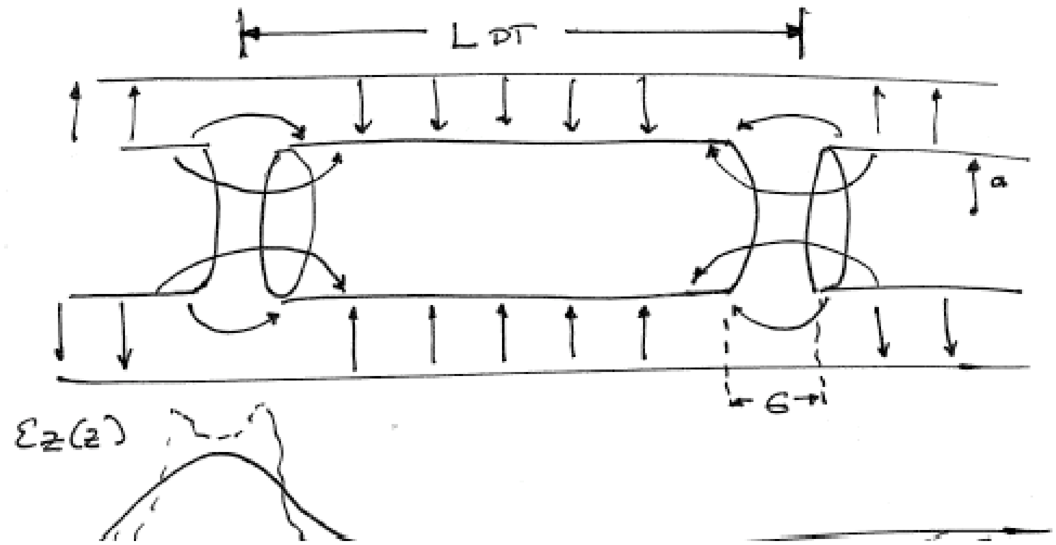
Initially, $Vdt = \dfrac{2C_{M1}}{C_{M1}+C_{DT}}V_{M1}, V_1 = \dfrac{2C_{M2}}{C_{M2}+C_i}V_{M2}$ after resonant charge.

After S_3 is closed, current flows through the small resistor R, with neglible current through the inductors, with

$$V_{dt} = \frac{C_i}{C_i + C_{dt}} V_i \approx \left(\frac{C_i}{C_i + C_{dt}} \right) \left(\frac{2C_{M2}}{C_{M2} + C_i} \right) V_{M2}$$

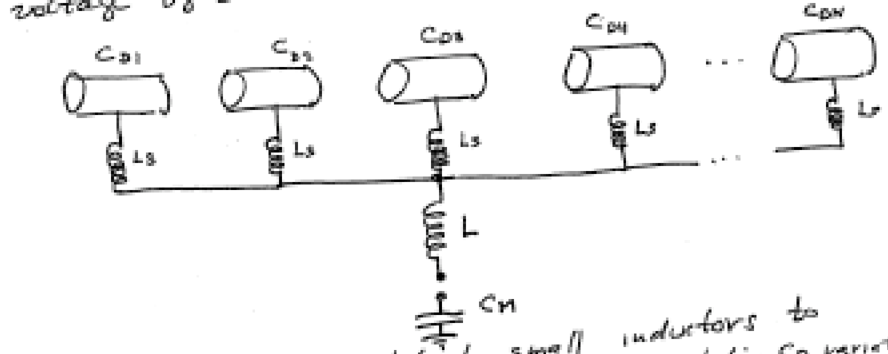
The resonant charging steps are efficient and may be used to increases the Marx voltages by about 50% at the drift tube and at the intermediate capacitor.



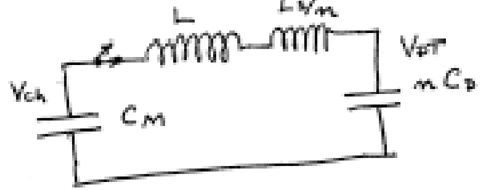


Initial Charging of the Drift Tubes

The drift tubes are all charged to a high negative voltage by one common slow pulser

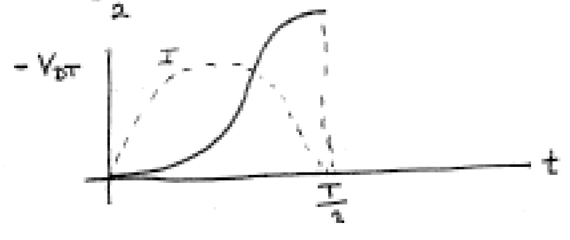


The L_S are relatively small inductors to isolate the drift tubes after switching. Neglecting C_D variation,



$$V_{DT} = V_{ch}\left(\frac{2C_M}{C_M + nC_D}\right)$$

$$\frac{T}{2} = \text{half cycle charging time} = \pi\sqrt{\left(L+\frac{L_S}{n}\right)\left(\frac{C_M\, nC_D}{C_M + nC_D}\right)}$$



η = Efficiency of energy transfer

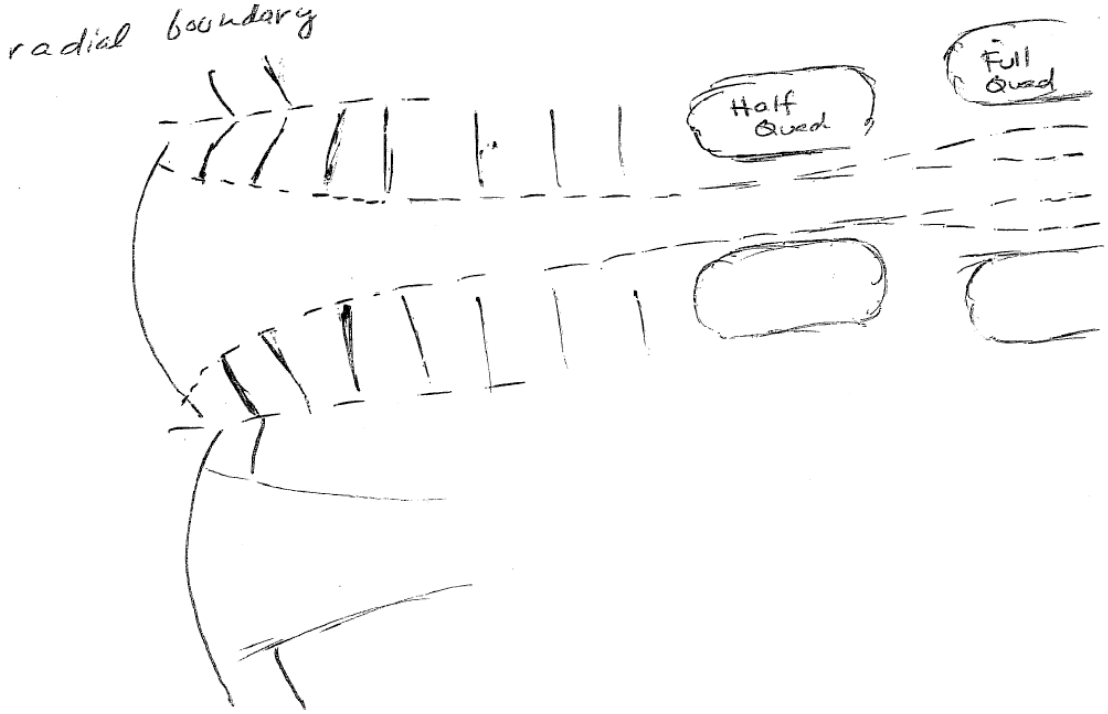
$\eta = \frac{4C_1C_2}{(C_1+C_2)^2}$ where C_1 is C_{M} and C_2 is nC_D plus the cable capacity.

Voltage waveforms of the anode emitter and the three drift tubes through capacitive dividers each of which has its own division ratio making the traces unequal. Actual voltages were controlled to equal each other to within 1%.

Sources

If the new multi-beam sources work out as expected, then the standard HCX lattice will be adequate, with a cell size of 7cm. If, however, they are delayed, then the existing ~10cm sources could be matched directly into a double size lattice of 14cm, especially if a converging beam enters the first "half quad". The larger quads, with voltage scaling as $\sqrt{d_g}$, would transport 0.35μC/m later on, so a beam tilt can be started in the first drift tube to arrive at the higher λ later downstream.

_ A gun geometry with a Pierce column or graded radial boundary is sketched below:



One of the problems in a multi-beam source array, especially at low energies where the space charge is high, is beam- beam interaction. This can be reduced to any level by providing a conducting boundary between the beams, with the potential distribution along this boundary matched to the distribution it would have in a converging spherical geometry. The design task is to find a small number of electrodes that satisfactorily approximate this.

Drift Compression and Final Focus

Drift compression and final focus have not been the major concerns of this note, only the accelerator. These would be similar to those of some of the other concepts. Of the several strategies possible at the end, the major choices are whether the energy tilt required for bunching is left on the beam or removed, whether the steering angles are left on the beams or removed, and whether the beam is focused or not in the drift region. If the beam were kept neutralized, then a long drift distance would enable compression with small tilt and small convergence angles. Because of the low particle energy the beams can be independently steered and the first order chromatic aberrations can be compensated with pulsed dipoles and quads working upstream of the final focus, when the pulse duration is some tens of ns. The biggest unknown is how much the transverse and longitudinal emittances grow during acceleration and beam manipulations. The data on the emittances of the beam at the end of the electrically focused section of HCX, which uses similar currents and technology are encouraging.

Conclusion

In the two major options discussed there are numerous choices, such as outlined in Fig. 6. Closely spaced sources of the existing type but with a Pierce column type of boundary could be designed and built on a short time scale, followed by matching and transport in a lattice with quads which are about twice as large as currently used, all at low risk. The currently developmental multibeamlet sources would shrink the matching section and array sizes, and presumably lower cost. Advantage could be taken of the short accelerator length and the short bunch duration to increase the filling factor; such a system optimizes at a smaller quad size than currently used. The large sources and quads could taper down to a smaller size along the length of the machine, if desired. Choices such as these would be partly clarified by cost estimates of the various options and contrasted with the risks involved. The option of using a stripper to raise charge state to get a higher acceleration rate needs more preliminary work. The full system is shown in Fig. 7. The full HCX beam could be stripped and charge separated at 1 and 2 MeV to get valuable experience, which would point towards the optimum stripping energy and yield. Modest development could also be devoted to the drift tube insulator stack and the pulsers, at low cost, because some of the original Marx generators and crowbar spark gaps exist and can operate in the interesting voltage and pulse duration regions. The switching speed limits and the bunch end containment which also depends on pulsers account for about one half of the length of the drift tubes for HEDP, and consequently about half of the total cost. This is why pulsers have a large part in the note and why pulser development could have a high payoff.

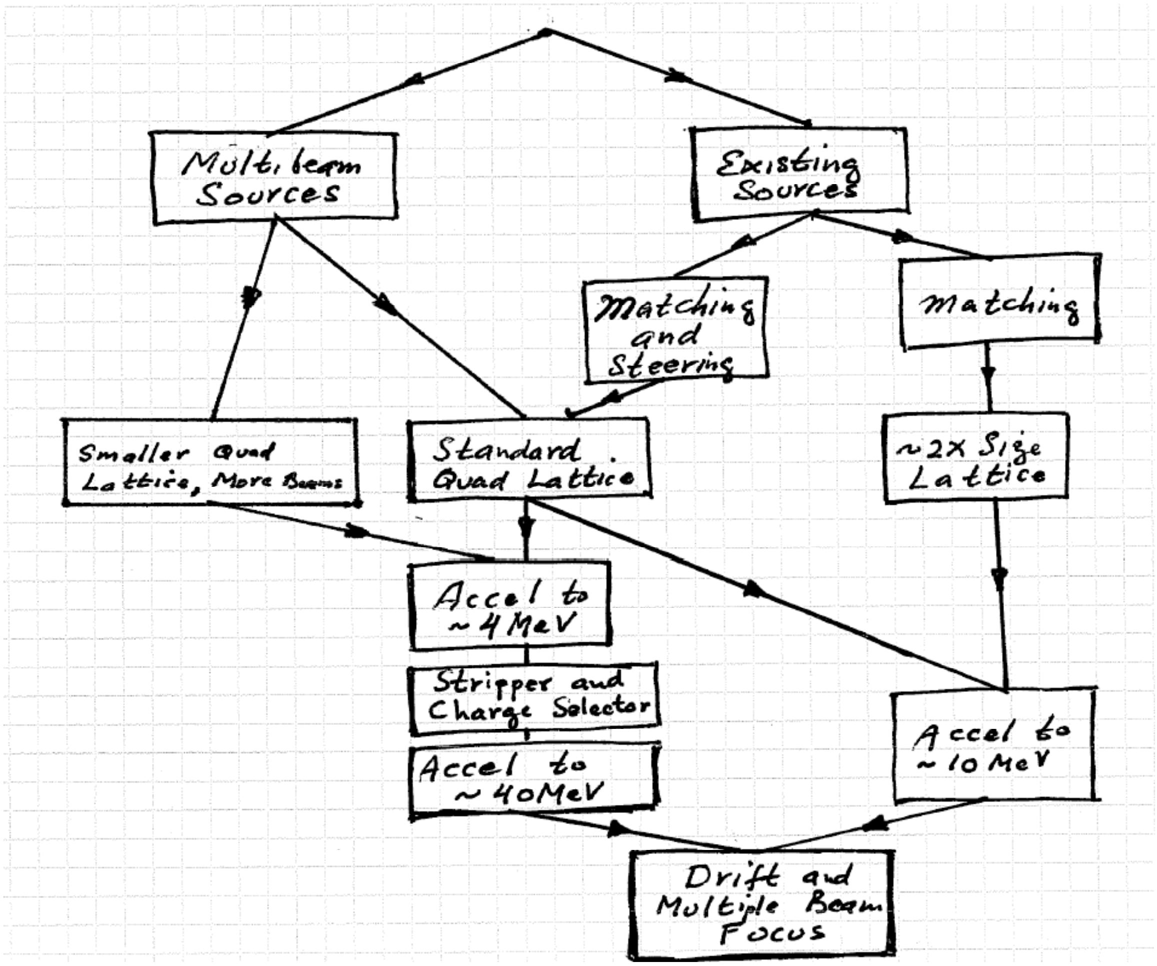
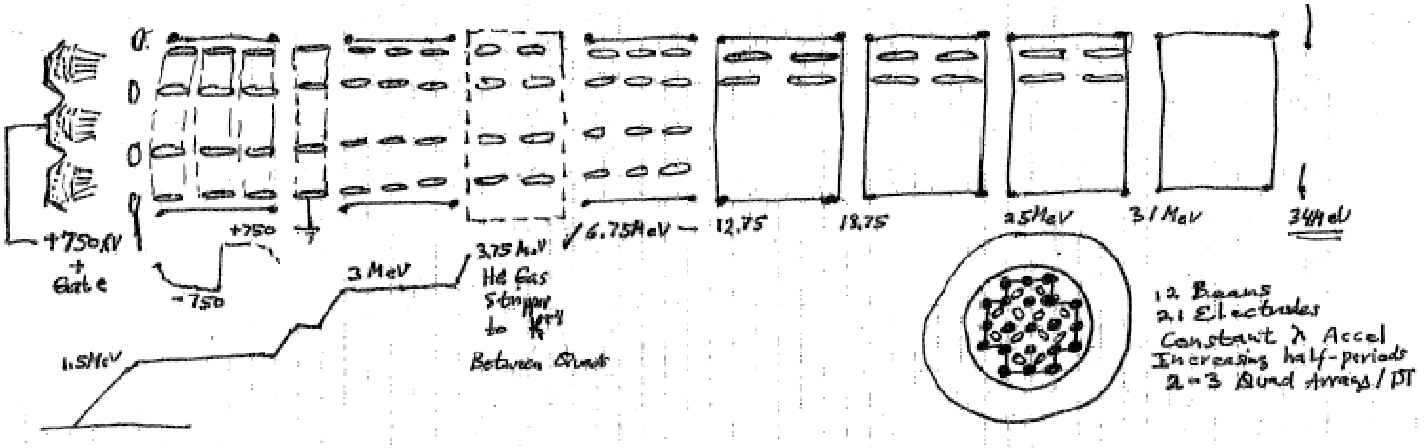


Fig. 6. Various accelerator choices using standard size, larger and smaller quadrupole lattices.



Estimate* $\frac{1}{4}$ of Beam goes to +4

$Q_0 = \frac{1}{4}\mu C/m \times 12$ Beams $\times \frac{1}{3}$ m Flat-top $= 1\mu C$ ⟶ $\frac{1}{4}\mu C_{\text{particle}}$

$1\mu C$ electric, $\frac{34}{4}$ J = 8.5

Front & back tamper ends → $1\mu C$

$\phi = 10\,kV/\mu C \times \frac{1}{4}\mu C/m \simeq 2.5\,kV$

$E_z = \frac{2.5\,kV}{\frac{1}{3}\,m} = 7.5\,kV/m$

Focusing and bending at end easy because of high $\frac{q}{m}$

Acceleration and focusing tailored for +4 after stripper

ed Cluster outer diam ~ 40 cm, Beam cluster outer diam ~ 25 cm

Drift tube diam ~ 40 cm, Outer Container ~ 80 cm

Drift tube length ~ 1 meter

Total length ~ 8 meters, $\langle E \rangle \simeq 4\,MeV/m$

1 Pulser for all the −750kV slow rise pulses

7 Independent fast pulsers for the ∓750kV and Shaping

Inter-drift tube quads as needed for HV, rematching

* Hope

Figure 7. Drift tube accelerator including a stripper at 4 MeV, to reach higher particle energies.

References

[1] Ion Induction Linac, 500 Joule Test Bed, PUB-5031, Sept., 1979, LBL.
[2] Ion Induction Linac Test Bed, PUB-5039, Ap. 1980, LBL
[3] Proceedings of the Heavy Ion Fusion Workshop, BNL 50769, Oct. 1977

Issues

1. Putting on a bunch-maintenance tilt, which is too big and too abrupt, leads to mismatch.

   Slow and gentle leads to adiabatic

2. Potting on a large energy increase, in the early gaps, with a beam, and an abrupt lattice change also leads to mismatch

   How big and bad are these mismatches
   Is pulsed rematching required between Dt's

   Replacing Dt's with Il gives smaller, more frequent energy gains and allows any pulse duration; as before, accel rate is low from cost, but this may be desirable from beam dynamics.

3. Trade between beam spacing, number of shielding and potential grading electrodes

4. Fill factor for short pulse, short length machine

5. Magnetic lenses in neutralized stripping section
   Plused plasma region and question of nearly HV

   Salvage valve in arrays, correctors, multi-beam source array
   Not much value in DT's, but could explore $\frac{\Delta E / gap}{E}$ issue