Objectives of Multi-gap Pulse Power Group

- Stimulate ideas, new thinking on how to generate ion pulses for WDM/HEDP

  (< 1 ns duration focused to mm spot sizes at ~ Bragg peak velocity 10(7) m/sec, few joules to 10's of joules)
- Consider innovative ways to develop near term capabilities at minimal cost
- Develop conceptual designs of "entry-level" and "user-facility level" accelerators

Conceptual approaches identified in brainstorming sessions at LBNL

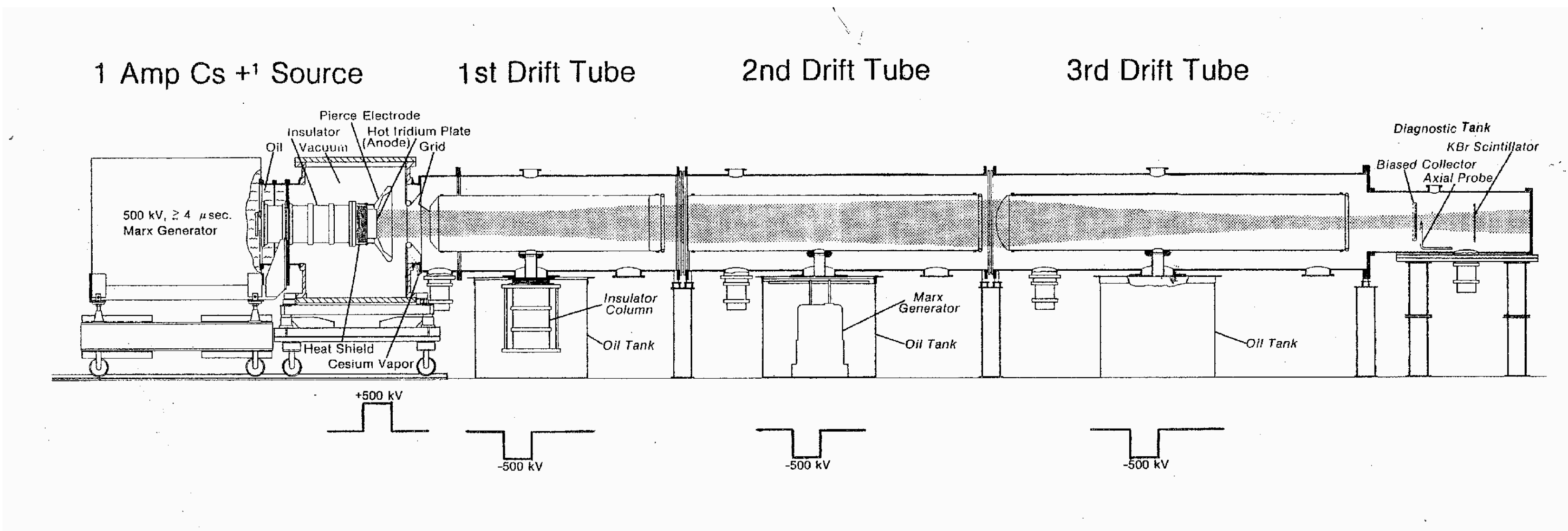
- Multiple beam, ES quad focused pulse power driven "DTL“ (similar to Cs+1 system built by HIF program 20+ years ago)

- Multi-pulse induction accelerator with a sequence of high line charge density beam pulses using solenoid focusing

- Broad band pulse on a traveling wave structure (helix) located inside a solenoid focusing system for very high acceleration gradients

The pulsed DTL concept is similar to the 2 MeV Cs+ injector built many years ago

Line charge densities of 0.5-1 microcolomb/meter were accelerated to 2 MeV



Reference parameters for a DTL with robust HEDP capability (Andy Faltens)

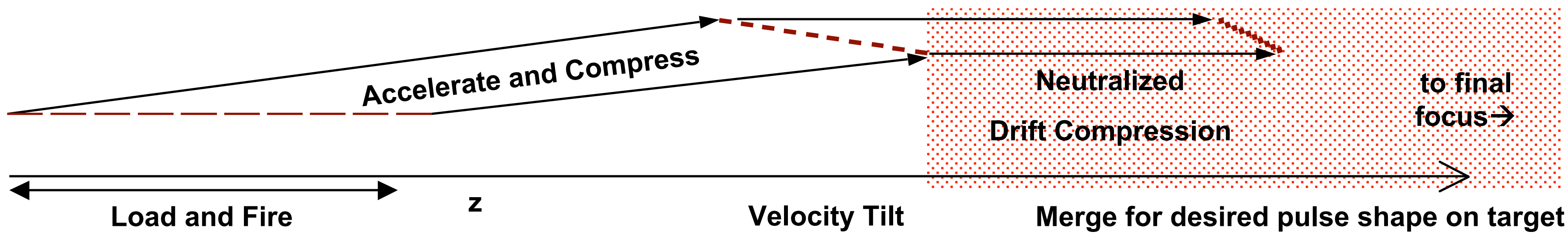
- 12 Ne+ beams with 0.25 microcoul/meter line charge density each transported in ES quad channels
- Drift tubes ~ 2 meters long pulsed to +/- 750 keV, accelerating beam pulses ~ 1.5 meters long (500 ns pulse duration at 1 MeV point,

  ~ 50-100 ns risetimes are adequate)
- Total charge of 4.5 microcoulomb accelerated at average gradient of 2/3 MeV/m (30 meters for 20 MeV)

Multi-Pulse Induction Approach

Grant Logan Accelerator-Driven HEDP Workshop LBNL Oct. 26, 2004

Concept : Consider multi-pulse linacs for HEDP and IFE. Replace long injected bunch with many short pulses into load and fire section, drive induction cores with smaller volt-seconds repetitively with fast-reset pfn networks. Tailor (z) and waveforms for continuous acceleration and compression to desired pulse train with velocity tilts into neutralized drift region for longitudinal merging.



Constraints: For any linac, minimum length for last pulse to catchup to first pulse. Longitudinal invariant limits input pulse train length for acceptable momentum spread on target. Achromatic focusing (Lee) or assisted pinches (Yu) accept higher momentum spreads→ longer input pulse trains allowed.

Potential Benefits : For any linac, multi-pulsing reduces upstream , perveance. Allows more pulse shaping and data sampling on target per shot. ***For induction linacs, multi-pulsing increases acceleration gradients (due to shorter pulses). Lower core mass (volt-seconds) savings offset higher pfn network costs.***

Examples of recent MathCAD model for multi-pulse induction acceleration and compression-G. Logan

Multi-Pulse Induction Linac examples for Ne^{+1} beam driven HEDP (τ target = 1 ns, max Lmp0 =14 m)

- Single linac, 40 joules total energy delivered with Np =1, 2, 5, 10 pulses
- Energy ramped 20 MeV (head pulse) → 24 MeV (tail pulse) for 10% tilt
- 30 ns minimum bunch and reset durations going into neutralized drift
- 0.2 Volt-sec/m T0 up to variable Tm<Tf, lower Vs_{mf} for Tm<T<Tf (solved)
- Peak tail induction gradient increased by $-E_z$(self) for parabolic $\lambda(z)$ ear control
- Head pulse induction gradient $\delta * E_z$(self), maximum for minimum linac length solution

No. of pulses	Injected pulse width $\tau 0$ (μs)	Injected current bunch(A)	Injected Energy T_z0 (keV)	Init. pulse train length Lmp0 (m)	Linac length z (m)	Peak tail gradient@ T_m(MV/m	λ(μC/m)@ beginning of NDC	Integrated Core Volt-sec	NDC length (m) L_{mpa} /0.1
1	2	1.8	83	1.1	16	0.6	6.6	2.9	4.1
2	1.4	0.6	42	1.6	36	1.5	3.3	2.3	12
5	1	0.36	28	2.9	40	1.6	1.3	1.7	37
10	0.7	0.26	23	4.0	43	2.3	0.66	1.3	78

Multi-Pulse Induction Linac examples for Ne^{+1} beam driven IFE (τ target = 8.5 ns, max Lmp0 =370 m)

- 25 linacs, 6.4 MJ total energy delivered with Np =1, 2, 5, 10, 20 pulses
- Energy ramped 200 MeV (head pulse) → 240 MeV (tail pulse) for10% tilt
- 150 ns minimum bunch and reset durations going into neutralized drift
- 0.6 Volt-sec/m T0 up to variable Tm<Tf, lower Vs_{mf} for Tm<T<Tf (solved)
- Peak tail induction gradient increased by $-E_z$(self) for parabolic $\lambda(z)$ ear control
- Head pulse induction gradient $\delta * E_z$(self), maximum for minimum linac length solution

No. of pulses	Injected pulse width $\tau 0$ (μs)	Injected current bunch(A)	Injected Energy T_z0 (keV)	Init. pulse train length Lmp0 (m)	Linac length z (m)	Peak tail gradient@ T_m(MV/m	λ(μC/m)@ beginning of NDC	Integrated Core Volt-sec	NDC length (m) L_{mpa}/0.1
1	17.5	66	920	40	633	0.3	270	380	130
2	10	58	840	46	980	0.59	134	256	200
5	7	33	580	80	700	0.8	54	148	590
10	5	23	460	115	580	1.5	27	104	1240
20	3.5	17	360	160	560	1.6	13.5	78	2540

Preliminary conclusions from multi-pulse study

- Multi-pulsing up to 5-20 pulses appears feasible under “conventional” (but still-to-be-determined) longitudinal momentum spread limits, and induction gradient limits.
- For reasonable maximum core radial builds (Vs/m limits) minimum induction linac lengths for tail pulse to catch up to the head pulse will likely be ~ 2-3 x longer than for single pulse cases for short pulse HEDP cases, *but comparable for longer pulse IFE cases*.
- Multi-pulsing can lower total linac core volt-seconds and peak line charge densities by a factor roughly ~ $Np^{1/2}$, for the same total delivered beam energy.
- Fast-reset pfn network costs need to be evaluated. If future fast switching costs go down, multi-pulsing is likely to reduce total costs, while enhancing target pulse shape capability.
- Gas and electron cloud effects for multi-pulses need to be evaluated. (Total beam charge ~ same, load-in times longer, peak line-charge densities lower with multi-pulses compared to single pulse)

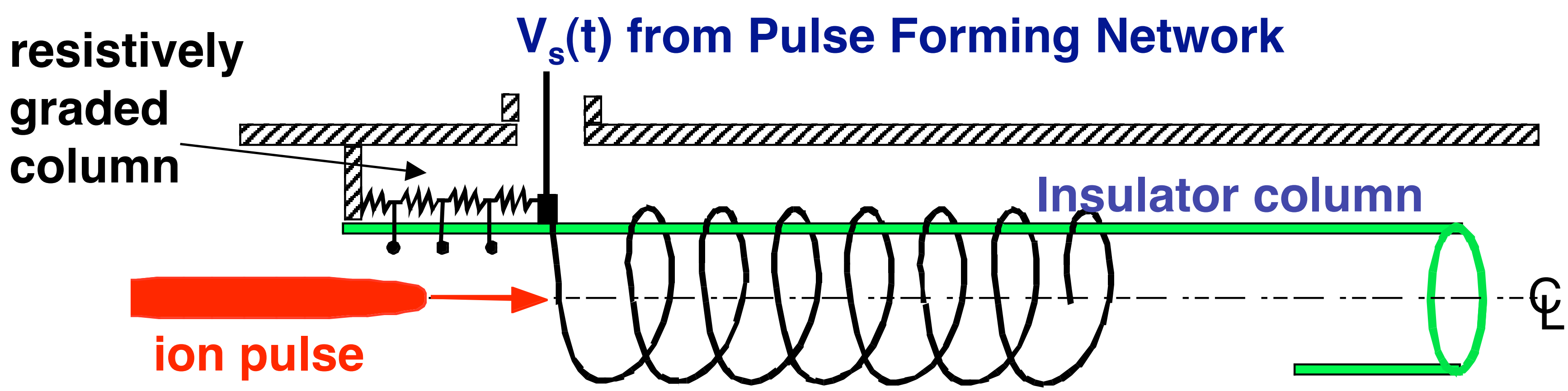
The pulse line concept for HEDP was stimulated by several observations

- 0.1 - 1 microcolombs of Ne+/K+ charge can be transported in bunch lengths of 10’s of cm in commercially-available large bore 5 - 9T superconducting solenoids
- Required axial compression following the accelerator is then only 10-30x (shorter distance, less delta v)
- Shorter ion bunches open up many new possibilities for cheaper, higher gradient accelerators (the traveling wave/ helix is one example – the workshop might uncover others)

Concept for a Traveling Wave Accelerator

Accel-decel injector with "load-and-fire" column → **Pulsed resistive column** → **Broadband Traveling Wave Accelerator** → **Energy ramping** → **Neutralized Drift Compression**

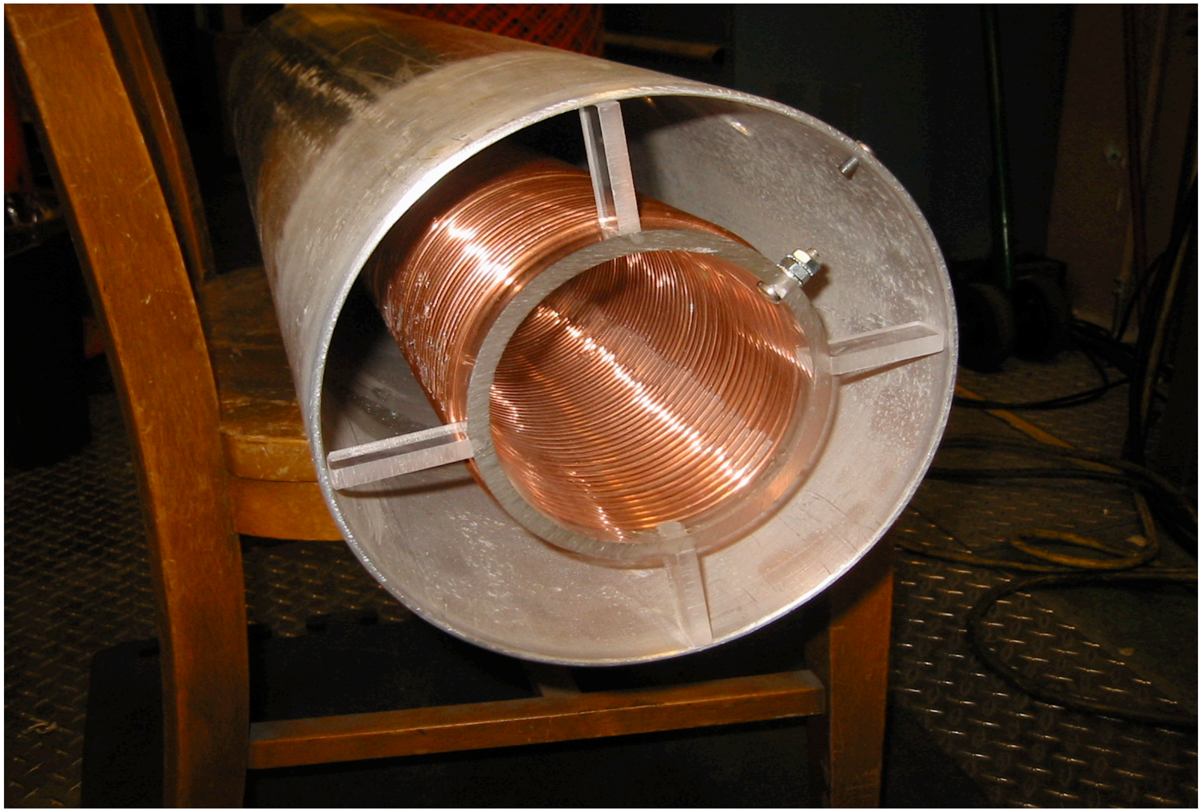
- **Traveling Wave Accelerator is based on slow-wave structures (helices)**
- **Beam "surfs" on traveling pulse of E_z (moving at ~ 0.01 c in first stage)**
- ***One possible configuration:***



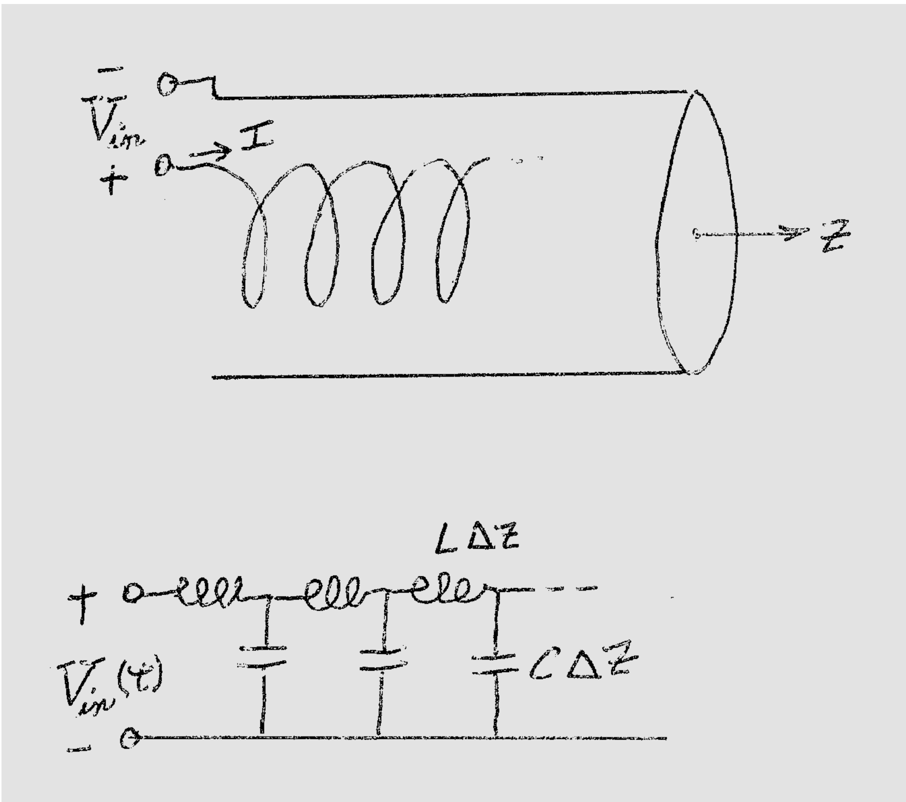
Short ion bunches are accelerated by a slowly propagating traveling wave pulse on a helix

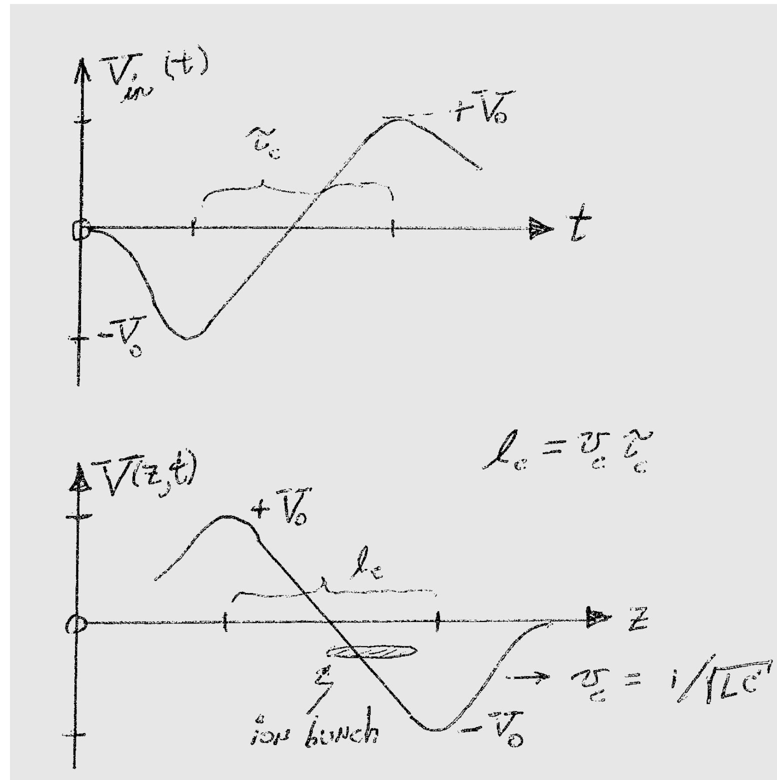
First low voltage model to test slow wave propagation

6 cm helix radius, 0.5 cm period, 10 cm tube radius

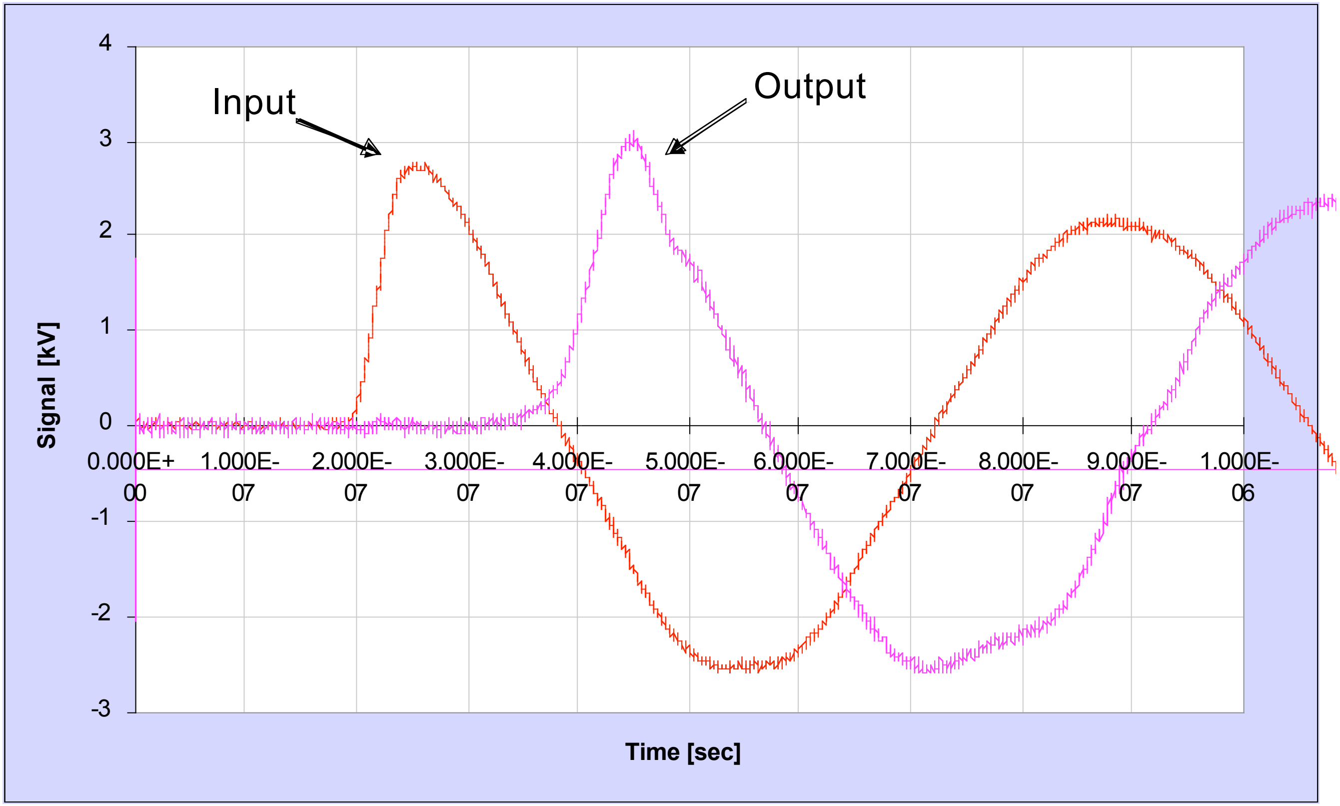


A ramped voltage pulse at the input of the helix pulse-line sets up a traveling wave that accelerates the ion pulse



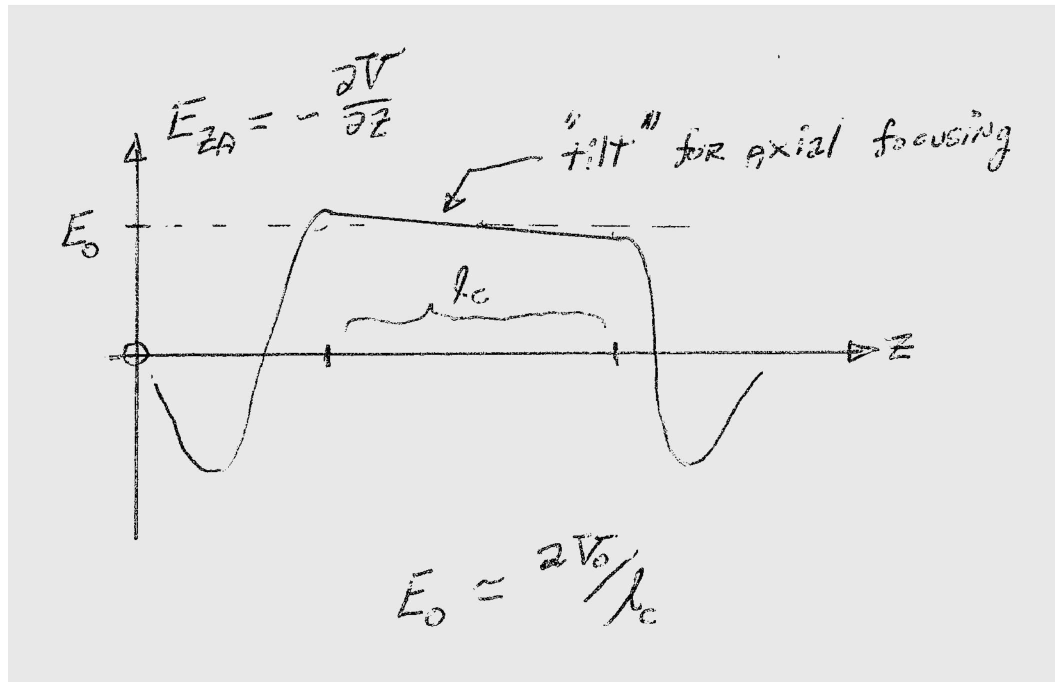


Propagation of a pulsed voltage ramp over 0.9m on the 6 cm radius air dielectric helix is as expected (velocity ~ 4.6x10(6) m/sec)



The axial electric field of the traveling wave pulse is the gradient of the helix voltage

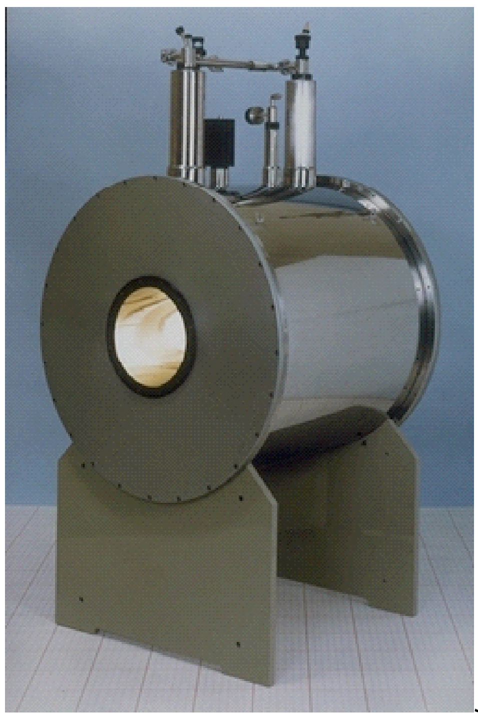
Example: with
Vo = 750 KeV,
Ramp length
Lc = 30-40 cm,
Accel gradient
is 4 -5 MeV/m



Helix pulse-line reference parameters for HEDP (can also consider multi-pulse to increase target heating and/or reduce the charge/pulse)

- Total charge 1 microcoulomb, 20 MeV Ne+ beam
- Parabolic profile bunch with length constant at 30 cm, peak line charge = 5 microcoulomb/meter,
  beam radius 3 cm in 9T solenoid
- Helix radius 6 cm, peak radial voltage
  +/- 750 KeV, peak radial stress 125 KV/cm in
  30 cm diameter bore tube
- Peak axial space charge field +/- 0.8 MeV/m, acceleration gradient 5 MeV/m = vacuum stress along insulator column

The transport magnets will likely be the major cost driver in the helix traveling wave concept, and (because of NMR/MRI) large bore superconducting solenoid systems are commercially available that meet the requirements



300/183 Horizontal bore ICR magnet system

7T, 18.3 cm bore

Typical costs for system (Matthaeus Leitner, LBNL)

~ $150-200K for

5T, 30 cm bore, or

10T, 10 cm bore,

0.65 m magnet length

Plans and goals for Group 3: Single and multi-gap pulsed power concepts

- Develop a list of promising (pulsed power based) conceptual approaches and architectures (a "free think session" to stimulate ideas, not to debate relative merits).

- Condense the results of the "free think session" into categories of "broadly similar" architectures, and select 2 -4 specific approaches as "attractive examples" for detailed consideration by the Group (attempting a consensus of the Group)
  - Note: the full list of conceptual approaches organized into these architectural categories will be included in the workshop report.

Plans and goals for Group 3 (II)

In sub panels, as appropriate, for each of the examples

Develop straw man conceptual ("notional?") designs and parameters for:

- Entry-level capability (demo) that does "something interesting" in WDM/HEDP as soon as possible.
- User facility capability (the "end product" of the development).

Develop "interface requirements" for:

- Injector, front end
- Pulse compression
- Final focus
- Target (multiple beams, etc.)

Plans and goals for Group 3 (III)

- Identify scientific/technical challenges of the approach
- Develop modest cost development path scenarios utilizing existing equipment where ever possible for each concept
- Consider the contributions each approach could make
  - towards the development of IFE
  - towards other accelerator and basic science applications
- Outline report and make writing assignments