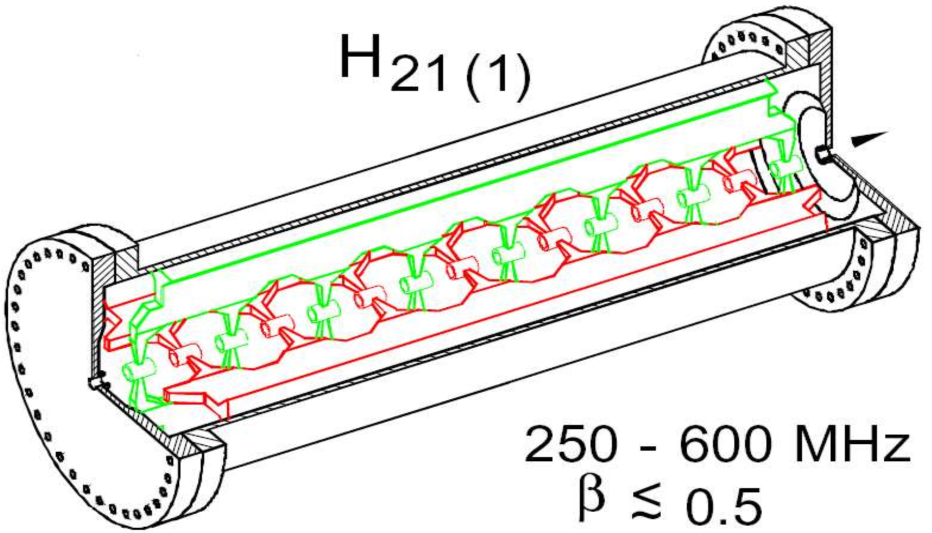
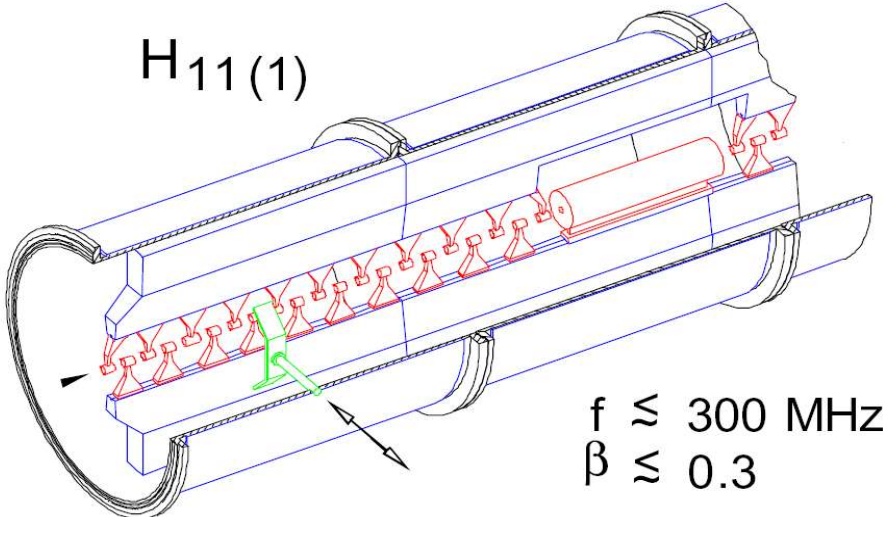
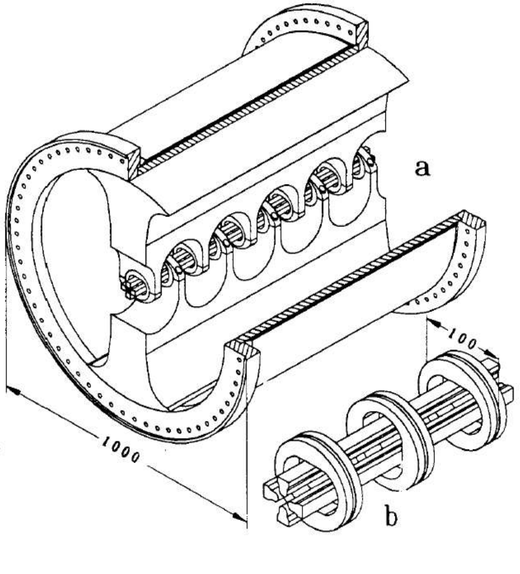


Group 2 – RF Acceleration

John Staples, Andy Sessler
Building 71, Room 233





RF Linac Approach to HEDP

- Motivation
  - Potentially cheaper than other approaches
- See if it is viable at all
- Challenges
  - Can it compete with other acceleration methods?
  - Can the beam be compressed to 1 nsec?
  - Can ampere beams be provided before compression?

A Set of Strawman Parameters

- Ne^{1+}, accelerated to 19 MeV
  - deliver about a microcoulomb to the target, or 10^{13} ions
  - compressed to a nanosecond
- This is a real challenge for an rf-based accelerator
- Assume a compression factor of 1000 after linac
  - 1000 realistic at all?
  - 1 microsecond requires a current of 1-2 amps
  - How to get this much current through an rf linac?
  - Multiple beamlets?
    - 7 or 13 reduces compression to 100 for a 100 nsec pulse

Technical Issues

- Delivering beams suitable for large compression is a major issue
- Multi-beamlet acceleration
  - emittance of merged beams
- Focusing – strength of magnets, ES quads
- Space charge limitations

Goals and Methods

- See if RF scenario viable at all
- Come up with some strawman scenarios
  - push the envelope - “go wild”
  - Develop several approaches / scenarios
- Identify areas of technological development
- Develop scenarios that use existing facilities to test limits of accelerator in scaled regime
- Do a rough cost estimate of
  - development of critical technology demos
  - a demonstration system

Connections with Other WG's

- Will require a very high voltage injector
  - input from pulsed-power working group
- Will require post-accelerator bunch compression and possible multi-beamlet merging
  - input from final-focus / compression group
- Develop ion source parameters

Critical Subsystems

- Multi-beamlet ion source
- Very high-energy injection into linac
- Buncher and LEBT
- Accelerator RF structure
- Focusing
  - beam dynamics
  - technological limitations
- Post-accelerator beam compression/merging
- Reliability of each shot
  - targets destroyed each shot

Simulation Codes

- Beam Design
  - putting together cells in a linac
    - parmila for DT linacs, RFQ generation codes, etc
- Beam Dynamics Simulations
  - parmila, parmteq, dymac, ...
  - Simulating unusual and semi-periodic structures
  - Space charge treatment
- RF Structures
  - Superfish, MAFIA, etc, etc
- Spreadsheet designs

The Emittance Issue

- Single-charged neon source may be able to produce rms normalized emittances in the range of 0.1 pi mm-mrad in the 100 mA range
- Emittance growths by a factor of 3 are to be expected through the linac
  - bunching and time compression will add, too
- Adding N multiple beamlets increases emittance faster than N, so power density at target actually *drops* as N increases (absolute power increases) for a constant beta function at target.

Pre-Bunching

- Will be at a relatively high energy
- Discrete rather than adiabatic?
- Multi-harmonic?
- Parallel beamlets?
- “Good enough” to get most of beam and preserve emittance as much as possible
  - Low average beam loss in structure, low DF

Bunch Compression

- Final bunch length about a nanosecond
- Compression constrained by longitudinal phase space coming out of accelerator
  - want most of Bragg peak in target so the energy deposited in the target is relatively constant over the target volume
- Energy spread in linac beam will limit ultimate compression
- A very large energy spread will be needed for ballistic compression
  - introduced in the HEBT, not in the accelerator in our case

RF Structures

- Alvarez structures
  - very mature technology
  - codes everywhere for structure, beam dynamics
- Sloan-Lawrence structures
  - IH, RFQ's, etc
  - More adaptable for low-frequency
  - Need 3-D modeling
  - Fewer beam dynamics codes available
- Pulsed drift-tube structures
- Low duty factor

Single or Multiple Beams?

- Number of ions at target spot radius dependent
- Multiple beams probably required
- For a neon beam, $N_{ions} > 1.4x10^{13}*(r_b/1mm)^2$
- Can a single beam satisfy target requirement?
  - must focus down to spot smaller than 1 mm radius
  - with normalized emittance ~ .1 pi mm-rad, a final focus system with neutralized transport can
  - 10 kG/cm quads, 2 cm radius can produce needed beta function, 3.5 cm, from 1-2 meters away, of fully neutralized beam.

An RF Linac Example

- 100 MHz Alvarez, 1 channel
  - easiest, quickest before workshop
- 2 MV Ne^{+1} injector, 200 emA
- 13 meters long, 143 cells
- 20 kG/cm quads, FFFDDD sequence
- 86% transmission to 20 MeV (1 MeV/n)

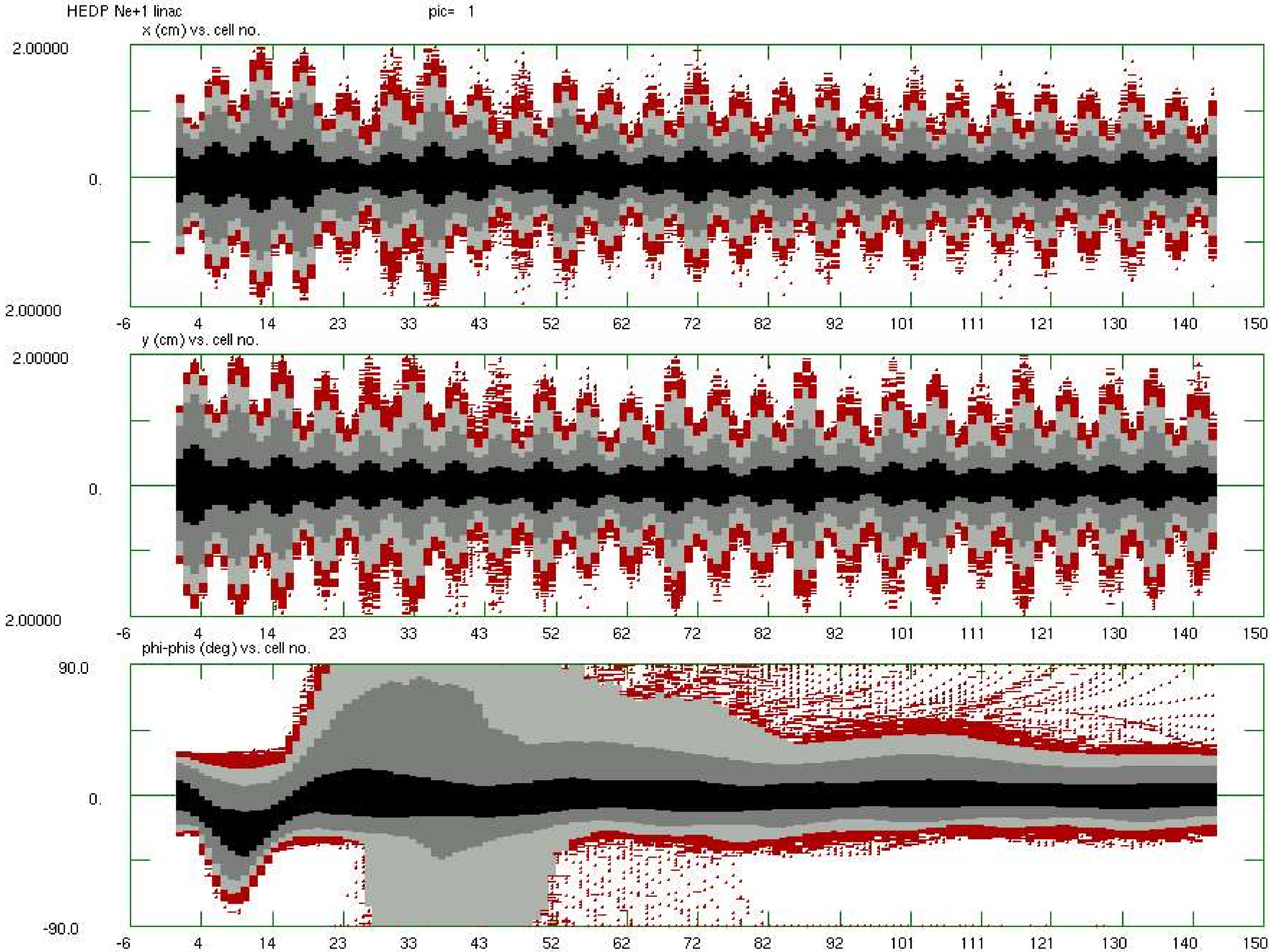
```
***************************************
 HEDP Ne+1 linac
***************************************

 title
 linac 1 2.0 100.0 20.0
 tank 1 20.0 -30.0 .02 0 0 0 0 0.5 -0.5 -0.6 4 2 11 0 2.0 0 0 0 0
 sfdata
        .004 .8 .05 .4 .05 .2 50.
        .05  .8 .05 .4 .05 .2 50. -1
 beam current used for power calculation= 0
 (excluding beam power) tank=    1, Cu power*1.3=     0.200 MW
 linout
```

tank no. 1 tank length 1302.623 centimeters 143 cells power= 0.200 MW frequency=100.00 MHz

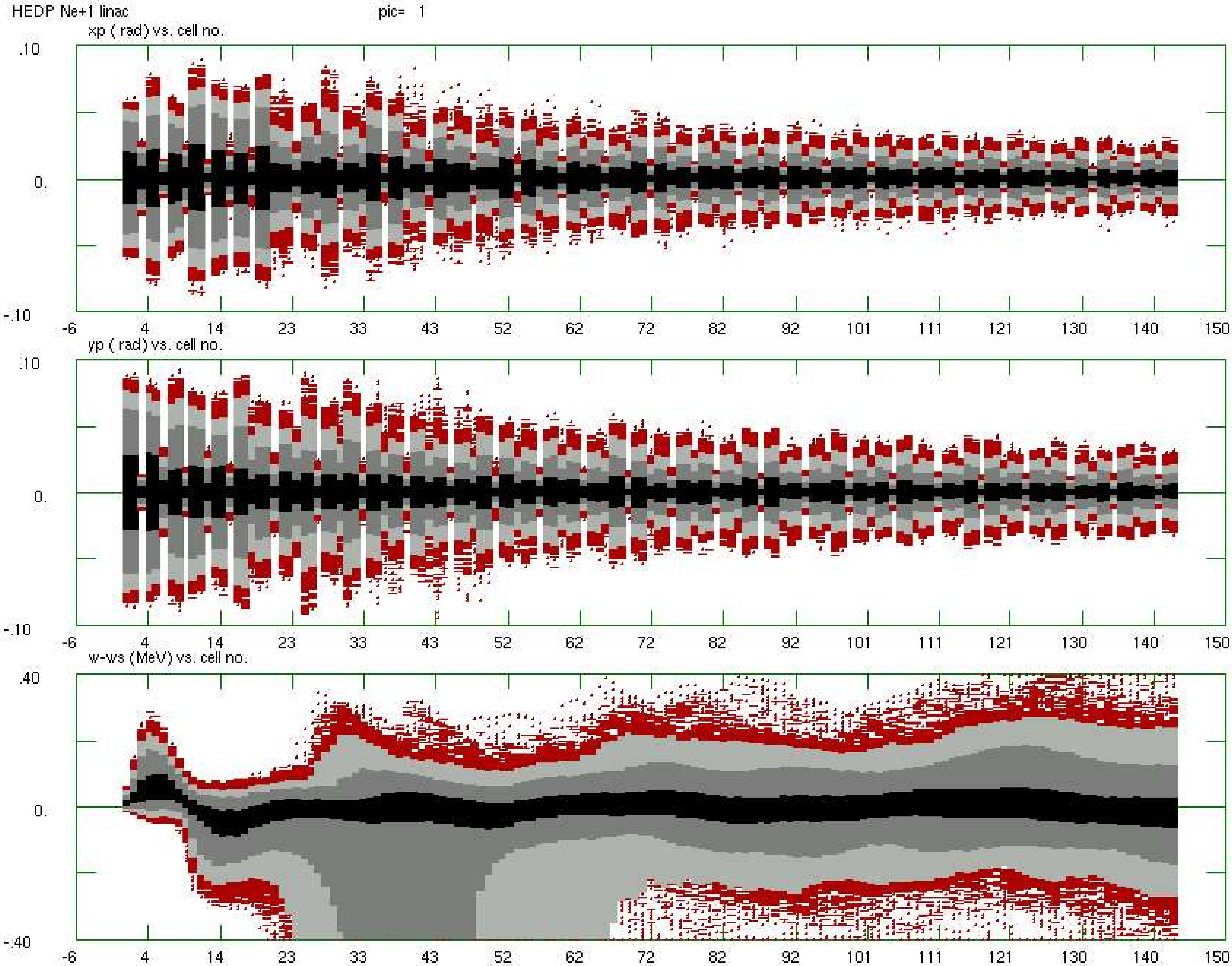
cell number	kinetic energy	beta	length	t	tp	s	sp	quad length	quad gradient	ezero MV/m	phis	total length
0initial	2.0000	0.0146						2.6259	20.4265			0.000
1	2.0610	0.0148	4.4074	0.7991	0.0500	0.4000	0.0500	2.6657	20.1141	2.0000	-30.00	4.407
2	2.1229	0.0150	4.4736	0.7991	0.0500	0.4000	0.0500	2.7054	-19.8110	2.0000	-30.00	8.881
3	2.1858	0.0153	4.5398	0.7991	0.0500	0.4000	0.0500	2.7452	-19.5170	2.0000	-30.00	13.421
4	2.2495	0.0155	4.6060	0.7991	0.0500	0.4000	0.0500	2.7849	-19.2315	2.0000	-30.00	18.027
5	2.3142	0.0157	4.6723	0.7991	0.0500	0.4000	0.0500	2.8246	18.9543	2.0000	-30.00	22.699
6	2.3798	0.0159	4.7385	0.7991	0.0500	0.4000	0.0500	2.8644	18.6849	2.0000	-30.00	27.438
7	2.4463	0.0161	4.8047	0.7992	0.0500	0.4000	0.0500	2.9041	18.4231	2.0000	-30.00	32.242
137	18.9059	0.0449	13.4115	0.7997	0.0500	0.4000	0.0500	8.0682	6.5341	2.0000	-30.00	1220.765
138	19.0925	0.0451	13.4777	0.7997	0.0500	0.4000	0.0500	8.1079	6.5019	2.0000	-30.00	1234.243
139	19.2801	0.0453	13.5438	0.7997	0.0500	0.4000	0.0500	8.1475	6.4701	2.0000	-30.00	1247.787
140	19.4686	0.0455	13.6099	0.7997	0.0500	0.4000	0.0500	8.1872	-6.4385	2.0000	-30.00	1261.397
141	19.6581	0.0457	13.6760	0.7997	0.0500	0.4000	0.0500	8.2269	-6.4072	2.0000	-30.00	1275.073
142	19.8484	0.0460	13.7422	0.7997	0.0500	0.4000	0.0500	8.2666	-6.3763	2.0000	-30.00	1288.815
143	20.0397	0.0462	13.8083	0.7997	0.0500	0.4000	0.0500	8.3062	6.3456	2.0000	-30.00	1302.623

```
 input -8 10000 -0.5 90 .02 -0.5 50.0 .02 30 .01 0
```

```
Longitudinal emittance(n) is in deg MeV
 Longitudinal beta(n) is in deg/MeV
 HEDP Ne+1 linac
 cell   ngood   plane           emittance,cm-mrad          alpha      beta(u)
                            100%        90%        rms(n)              cm
                                                                       mrad

   1   10000     x-xp      0.3898     0.2354     0.0589    3.487      0.075184
                 y-yp      0.3719     0.2372     0.0584   -4.997      0.072378
                 phi-w     2.4587     0.7150     0.1625   -0.406   1057.711030
 Emittance       100%/RMS    90%/RMS
          X         6.62       4.00
          Y         6.37       4.06
          Z        15.13       4.40
 Matched beam phase advance from rms beam size:
   deg/cm, deg/two beta lambda, +-RMS size(cm), sig.emit, Bore/RMS,  Bore(cm)
      0.779857     6.929517     0.546513     0.408004     3.659563     2.000000
      0.773565     6.873606     0.534052     0.401447     3.744951     2.000000
      1.064684     9.460379     0.161811     0.068235     2.288061     0.370234
 Long. rms (cm/mrad)(cm mrad) alpha beta(u) emittance(n)=
      0.405808      0.053815      0.007213
 RMS X,Y,averageX+Y eV energy=     1432.56131     2913.71393     2173.13762
 RMS Z eV energy=                                                  21.54310


  Starting DTL cell  143
  scheff dist=  13.8082794
  scheff beam current=  200.
  pbar(deg)= -29.4406366
  phimc(deg)= -30.

 143    8294     x-xp      1.1365     0.2664     0.0636   -2.193      0.116309
                 y-yp      1.4046     0.3764     0.0770    0.986      0.046126
                 phi-w   179.6624     5.0294     0.9821   -0.060    118.674623
 Emittance       100%/RMS    90%/RMS
          X        17.86       4.19
          Y        18.25       4.89
          Z       182.94       5.12
 Matched beam phase advance from rms beam size:
   deg/cm, deg/two beta lambda, +-RMS size(cm), sig.emit, Bore/RMS,  Bore(cm)
      0.711303    19.694142     0.400158     1.253382     4.998027     2.000000
      0.860265    23.818521     0.277133     1.833322     7.216762     2.000000
      0.312751     8.659262     0.415144     0.377378     2.778896     1.153642
 Long. rms (cm/mrad)(cm mrad) alpha beta(u) emittance(n)=
      0.060312      0.183199      0.043581
 RMS X,Y,averageX+Y eV energy=     1375.36153     1424.70744     1400.03449
 RMS Z eV energy=                                                 103.69892
     end of run    1
  Average beam center(...deg MeV)= -0.000251732919  5.00109351E-06
 -0.0034037607  0.000251440015 -29.3018907  20.0201858
  Parmila finished at Mon Oct 25 08:16:47 2004
```



HEDP Ne+1 linac
pic= 1
x (cm) vs. cell no.
2.00000
0.
2.00000
-6
4
14
23
33
43
52
62
72
82
92
101
111
121
130
140
150
y (cm) vs. cell no.
2.00000
0.
2.00000
-6
4
14
23
33
43
52
62
72
82
92
101
111
121
130
140
150
phi-phis (deg) vs. cell no.
90.0
0.
-90.0
-6
4
14
23
33
43
52
62
72
82
92
101
111
121
130
140
150


HEDP Ne+1 linac
pic= 1
xp (rad) vs. cell no.
.10
0.
-.10
-6
4
14
23
33
43
52
62
72
82
92
101
111
121
130
140
150
yp (rad) vs. cell no.
.10
0.
-.10
-6
4
14
23
33
43
52
62
72
82
92
101
111
121
130
140
150
w-ws (MeV) vs. cell no.
.40
0.
-.40
-6
4
14
23
33
43
52
62
72
82
92
101
111
121
130
140
150

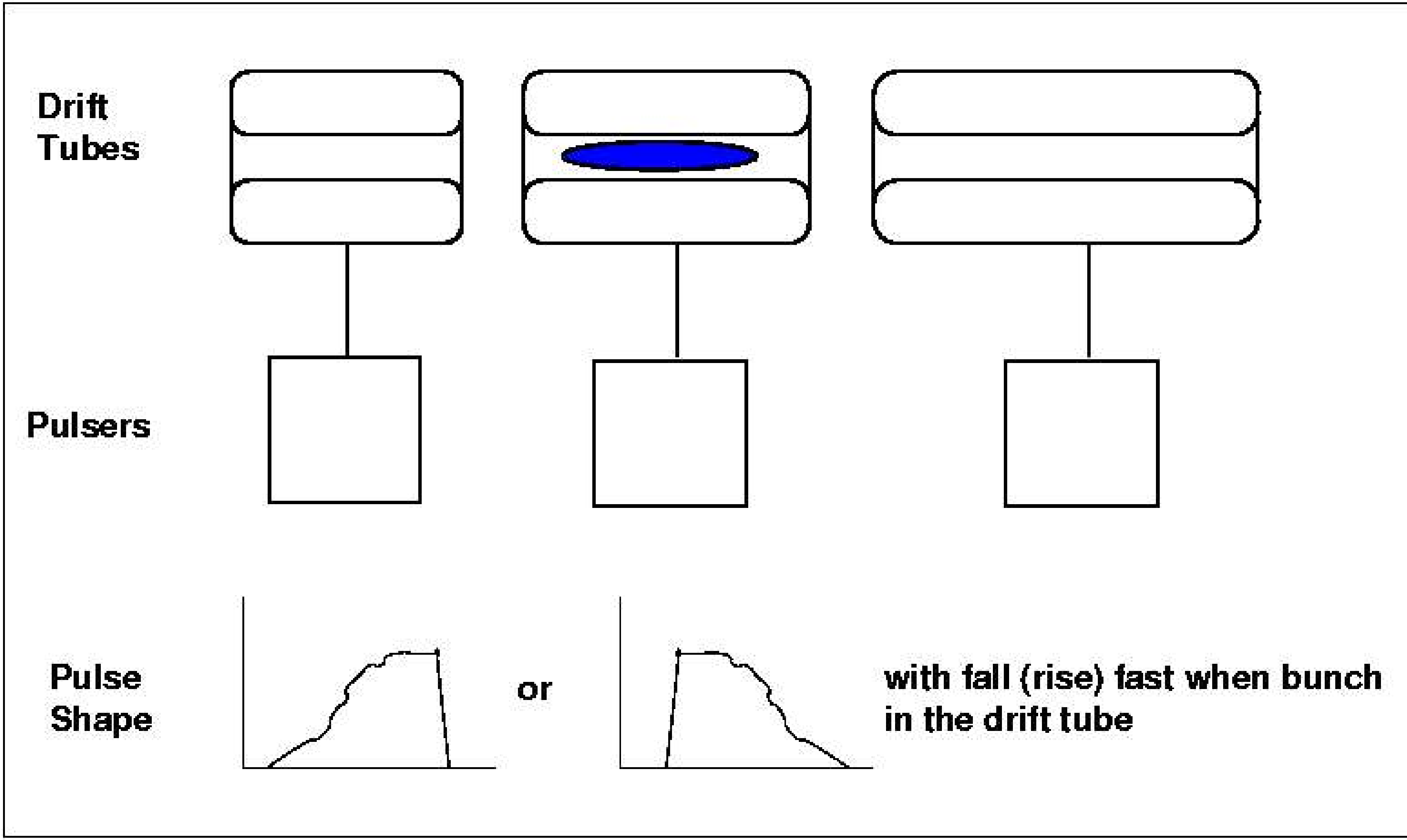
Analysis

- FFFDDD focusing and 2 MV injector to get quad strength down to 20 kG/cm
- 2 MV/m average axial field
- Factor of 3 transverse emittance growth
- Extendible to parallel beams?

A Pulsed Drift Tube Example

- One bunch Ne^{+1}, 20 MeV final energy
- Series of drift tubes on pulsers
- Can add energy tilt in linac for compression
- Risetime of pulsers major contributor to length
  - pulse must remain in DT while voltages slew
- Assume 500 kV/gap
- 100 nsec risetime of field
- longitudinal dynamics only

Basic drift-tube configuration



Spreadsheet design adds few percent voltage tilt for compression

Cell	Tot tilt	KE front	KE mid	KE rear	Beta f	Beta m	Beta r	Lgap	Lth due t	Lbunch	Ldrift	t to next gap	t thru gap	Lbunch	accum l	energy sprea	% energ	dtilt/dtime	drise/dtime
	(volts)								risetime	before	(m)	(sec)	(sec)	after gap			spread	(V/sec)	(V/sec)
0	1.50E+04	9.93E+05	1.00E+06	1.01E+06	0.0103	0.0103	0.0104	0.05	0.31	0.310	0.67	0.00E+00	9.96E-08	0.377	0.00	1.50E+04	1.50	1.51E+11	5.00E+12
1	1.50E+04	1.49E+06	1.50E+06	1.51E+06	0.0126	0.0126	0.0127	0.05	0.38	0.376	0.80	7.73E-08	9.87E-08	0.431	0.67	1.50E+04	1.00	1.52E+11	5.00E+12
2	1.50E+04	1.99E+06	2.00E+06	2.02E+06	0.0145	0.0146	0.0147	0.05	0.44	0.428	0.92	8.57E-08	9.74E-08	0.475	1.47	3.00E+04	1.50	1.54E+11	5.00E+12
3	1.50E+04	2.48E+06	2.50E+06	2.52E+06	0.0163	0.0163	0.0164	0.05	0.49	0.471	1.01	9.05E-08	9.57E-08	0.511	2.39	4.50E+04	1.80	1.57E+11	5.00E+12
4	1.50E+04	2.97E+06	3.00E+06	3.03E+06	0.0178	0.0179	0.0180	0.05	0.54	0.506	1.09	9.36E-08	9.38E-08	0.541	3.40	6.00E+04	2.00	1.60E+11	5.00E+12
5	1.50E+04	3.46E+06	3.50E+06	3.54E+06	0.0192	0.0193	0.0194	0.05	0.58	0.535	1.16	9.57E-08	9.18E-08	0.565	4.49	7.50E+04	2.14	1.63E+11	5.00E+12
6	1.50E+04	3.96E+06	4.00E+06	4.05E+06	0.0205	0.0207	0.0208	0.05	0.62	0.559	1.23	9.72E-08	8.97E-08	0.586	5.66	9.00E+04	2.25	1.67E+11	5.00E+12
7	1.50E+04	4.45E+06	4.50E+06	4.55E+06	0.0218	0.0219	0.0220	0.05	0.66	0.578	1.29	9.83E-08	8.75E-08	0.602	6.89	1.05E+05	2.33	1.71E+11	5.00E+12
8	1.50E+04	4.94E+06	5.00E+06	5.06E+06	0.0229	0.0231	0.0232	0.05	0.69	0.594	1.34	9.92E-08	8.53E-08	0.616	8.17	1.20E+05	2.40	1.76E+11	5.00E+12
9	1.50E+04	5.43E+06	5.50E+06	5.57E+06	0.0241	0.0242	0.0244	0.05	0.73	0.607	1.38	9.99E-08	8.30E-08	0.626	9.51	1.35E+05	2.45	1.81E+11	5.00E+12
10	1.50E+04	5.93E+06	6.00E+06	6.08E+06	0.0251	0.0253	0.0254	0.05	0.76	0.616	1.43	1.00E-07	8.07E-08	0.633	10.89	1.50E+05	2.50	1.86E+11	5.00E+12
11	1.50E+04	6.42E+06	6.50E+06	6.58E+06	0.0262	0.0263	0.0265	0.05	0.79	0.623	1.46	1.01E-07	7.84E-08	0.639	12.32	1.65E+05	2.54	1.91E+11	5.00E+12
12	1.50E+04	6.91E+06	7.00E+06	7.09E+06	0.0271	0.0273	0.0275	0.05	0.82	0.628	1.50	1.01E-07	7.61E-08	0.642	13.78	1.80E+05	2.57	1.97E+11	5.00E+12
13	1.50E+04	7.40E+06	7.50E+06	7.60E+06	0.0281	0.0283	0.0285	0.05	0.85	0.630	1.53	1.02E-07	7.38E-08	0.643	15.28	1.95E+05	2.60	2.03E+11	5.00E+12
14	1.50E+04	7.90E+06	8.00E+06	8.11E+06	0.0290	0.0292	0.0294	0.05	0.88	0.631	1.56	1.02E-07	7.15E-08	0.642	16.81	2.10E+05	2.63	2.10E+11	5.00E+12
15	1.50E+04	8.39E+06	8.50E+06	8.61E+06	0.0299	0.0301	0.0303	0.05	0.90	0.630	1.58	1.02E-07	6.93E-08	0.639	18.36	2.25E+05	2.65	2.17E+11	5.00E+12
16	1.50E+04	8.88E+06	9.00E+06	9.12E+06	0.0308	0.0310	0.0312	0.05	0.93	0.627	1.61	1.02E-07	6.70E-08	0.635	19.94	2.40E+05	2.67	2.24E+11	5.00E+12
17	1.50E+04	9.37E+06	9.50E+06	9.63E+06	0.0316	0.0318	0.0320	0.05	0.95	0.622	1.63	1.02E-07	6.47E-08	0.630	21.55	2.55E+05	2.68	2.32E+11	5.00E+12
18	1.50E+04	9.87E+06	1.00E+07	1.01E+07	0.0324	0.0327	0.0329	0.05	0.98	0.616	1.65	1.02E-07	6.25E-08	0.623	23.18	2.70E+05	2.70	2.40E+11	5.00E+12
19	1.50E+04	1.04E+07	1.05E+07	1.06E+07	0.0332	0.0335	0.0337	0.05	1.00	0.609	1.66	1.03E-07	6.03E-08	0.615	24.82	2.85E+05	2.71	2.49E+11	5.00E+12
20	1.50E+04	1.09E+07	1.10E+07	1.12E+07	0.0340	0.0342	0.0345	0.05	1.03	0.601	1.68	1.03E-07	5.81E-08	0.606	26.49	3.00E+05	2.73	2.58E+11	5.00E+12
21	1.50E+04	1.13E+07	1.15E+07	1.17E+07	0.0348	0.0350	0.0353	0.05	1.05	0.591	1.69	1.03E-07	5.59E-08	0.595	28.16	3.15E+05	2.74	2.68E+11	5.00E+12
22	1.50E+04	1.18E+07	1.20E+07	1.22E+07	0.0355	0.0358	0.0360	0.05	1.07	0.580	1.70	1.03E-07	5.37E-08	0.584	29.86	3.30E+05	2.75	2.79E+11	5.00E+12
23	1.50E+04	1.23E+07	1.25E+07	1.27E+07	0.0363	0.0365	0.0368	0.05	1.10	0.569	1.71	1.03E-07	5.16E-08	0.572	31.56	3.45E+05	2.76	2.91E+11	5.00E+12
24	1.50E+04	1.28E+07	1.30E+07	1.32E+07	0.0370	0.0372	0.0375	0.05	1.12	0.556	1.72	1.03E-07	4.94E-08	0.559	33.27	3.60E+05	2.77	3.03E+11	5.00E+12
25	1.50E+04	1.33E+07	1.35E+07	1.37E+07	0.0377	0.0379	0.0382	0.05	1.14	0.542	1.73	1.03E-07	4.73E-08	0.545	35.00	3.75E+05	2.78	3.17E+11	5.00E+12
26	1.50E+04	1.38E+07	1.40E+07	1.42E+07	0.0384	0.0386	0.0389	0.05	1.16	0.528	1.74	1.03E-07	4.53E-08	0.530	36.73	3.90E+05	2.79	3.31E+11	5.00E+12
27	1.50E+04	1.43E+07	1.45E+07	1.47E+07	0.0390	0.0393	0.0396	0.05	1.18	0.513	1.74	1.03E-07	4.32E-08	0.515	38.46	4.05E+05	2.79	3.47E+11	5.00E+12
28	1.50E+04	1.48E+07	1.50E+07	1.52E+07	0.0397	0.0400	0.0403	0.05	1.20	0.497	1.75	1.03E-07	4.12E-08	0.498	40.21	4.20E+05	2.80	3.64E+11	5.00E+12
29	1.50E+04	1.53E+07	1.55E+07	1.57E+07	0.0404	0.0407	0.0409	0.05	1.22	0.481	1.75	1.03E-07	3.92E-08	0.482	41.95	4.35E+05	2.81	3.83E+11	5.00E+12
30	1.50E+04	1.58E+07	1.60E+07	1.62E+07	0.0410	0.0413	0.0416	0.05	1.24	0.464	1.75	1.03E-07	3.72E-08	0.464	43.70	4.50E+05	2.81	4.04E+11	5.00E+12
31	1.50E+04	1.63E+07	1.65E+07	1.67E+07	0.0416	0.0419	0.0422	0.05	1.26	0.446	1.75	1.03E-07	3.52E-08	0.446	45.46	4.65E+05	2.82	4.26E+11	5.00E+12
32	1.50E+04	1.68E+07	1.70E+07	1.72E+07	0.0423	0.0426	0.0429	0.05	1.28	0.428	1.75	1.03E-07	3.33E-08	0.428	47.21	4.80E+05	2.82	4.51E+11	5.00E+12
33	1.50E+04	1.73E+07	1.75E+07	1.77E+07	0.0429	0.0432	0.0435	0.05	1.30	0.409	1.75	1.03E-07	3.13E-08	0.409	48.96	4.95E+05	2.83	4.79E+11	5.00E+12
34	1.50E+04	1.77E+07	1.80E+07	1.83E+07	0.0435	0.0438	0.0441	0.05	1.31	0.390	1.75	1.03E-07	2.95E-08	0.390	50.72	5.10E+05	2.83	5.09E+11	5.00E+12
35	1.50E+04	1.82E+07	1.85E+07	1.88E+07	0.0441	0.0444	0.0447	0.05	1.33	0.370	1.75	1.03E-07	2.76E-08	0.370	52.47	5.25E+05	2.84	5.44E+11	5.00E+12
36	1.50E+04	1.87E+07	1.90E+07	1.93E+07	0.0447	0.0450	0.0453	0.05	1.35	0.350	1.75	1.03E-07	2.57E-08	0.350	54.23	5.40E+05	2.84	5.83E+11	5.00E+12
37	1.50E+04	1.92E+07	1.95E+07	1.98E+07	0.0453	0.0456	0.0459	0.05	1.37	0.330	1.75	1.03E-07	2.39E-08	0.329	55.98	5.55E+05	2.85	6.27E+11	5.00E+12
38	1.50E+04	1.97E+07	**2.00E+07**	2.03E+07	0.0458	0.0462	0.0465	0.05	1.39	0.309	1.74	1.03E-07	**2.21E-08**	0.000	57.72	5.70E+05	2.85	6.78E+11	5.00E+12

Requires 5MV/microsecond slew rate of pulsers

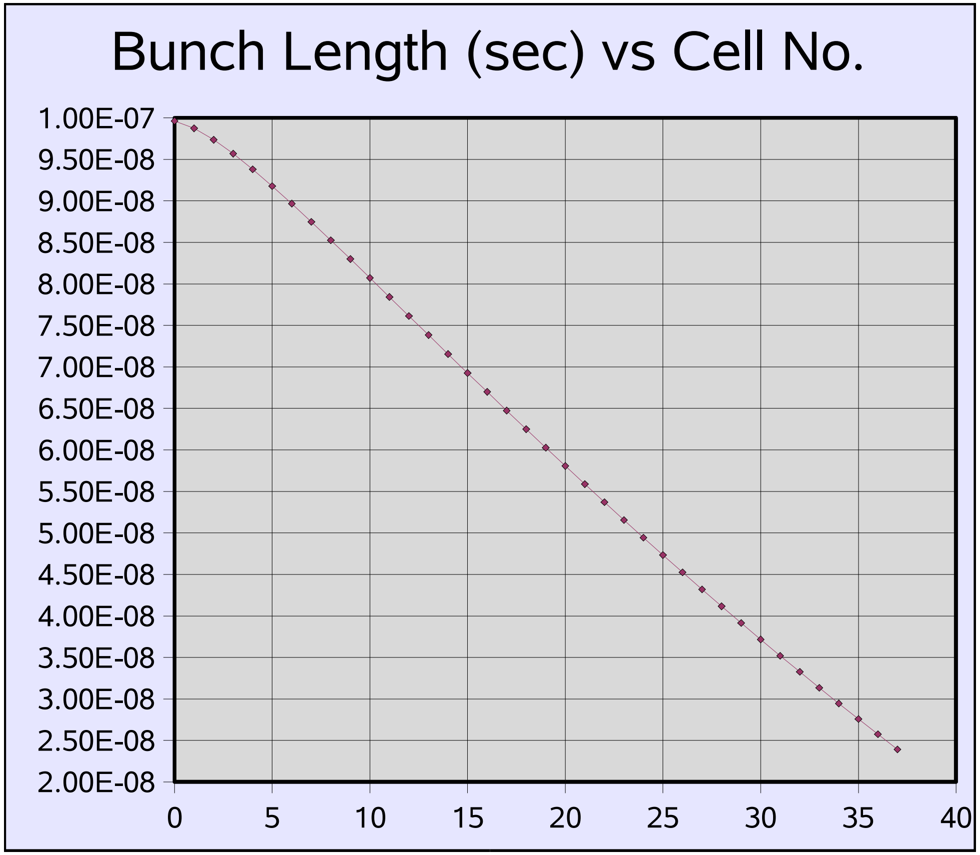
- risetime still dominates length of linac

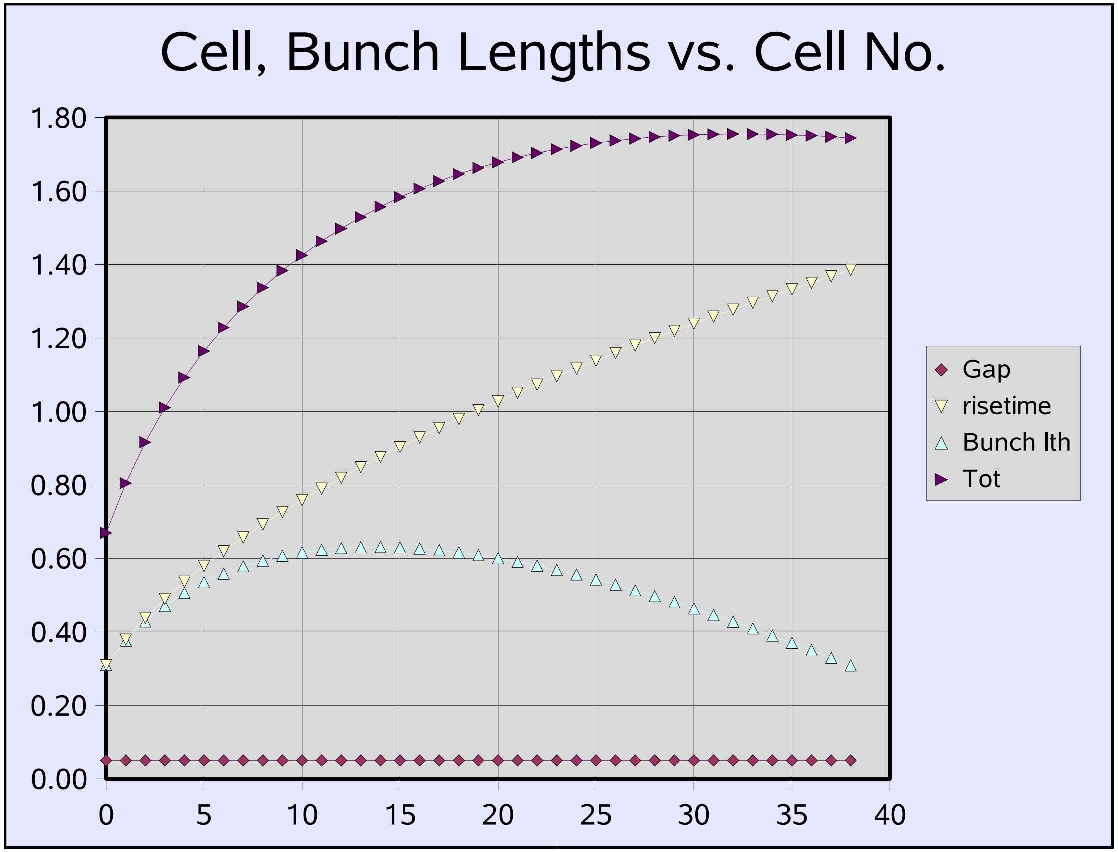
Beam compression from 100 to 20 nsec in linac

100 nsec pulse slew time

57 meters long, 38 cells, pulsers

Only a spreadsheet analysis so far





Various Approaches

- "Conventional" linac
  - how to deal with SC, compression and emittance
- Multiple beam linac
  - Generating and merging multiple beamlets
- Other approaches
  - pulsed drift tube
  - ???

Logistics

- RF group will meet in 71-233
- Computers available in 71-280
  - I can supply some Linux SW codes/support
- Appoint group secretary, speakers
- Breakout meetings
  - 4:00 Tuesday organizational meeting
  - 4:15 Wednesday for 15 minute status report
  - 10:10 Friday for 30 minute status report
- Workshop report and writing assignments