Beam End Erosion and Induction Cell

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Motivation

- Longitudinal stability of beams is important to prevent blow-up
- Designing a system to meet these specifications is already a challenge in itself
- Confine beam to a square pulse so we don't fool transverse measurements with an extracted beam that does not have the same current density.

Outline

1. Induction focusing versus RF focusing.

2. UMER System overview, parameters and operating ranges.

3. End erosion of the beam as it circulates.
   a. One-dimensional theory and the cusp point.
   b. MATLAB code for example end-erosion calculations.

4. Induction cell and HV Modulator operation.

5. Ear-field focusing and timing involved in setting fields. Results and comparison to one-dimension model

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RF Focusing vs. Induction Focusing

- In UMER, sinusoidal fields can not be used to focus a square bunch.

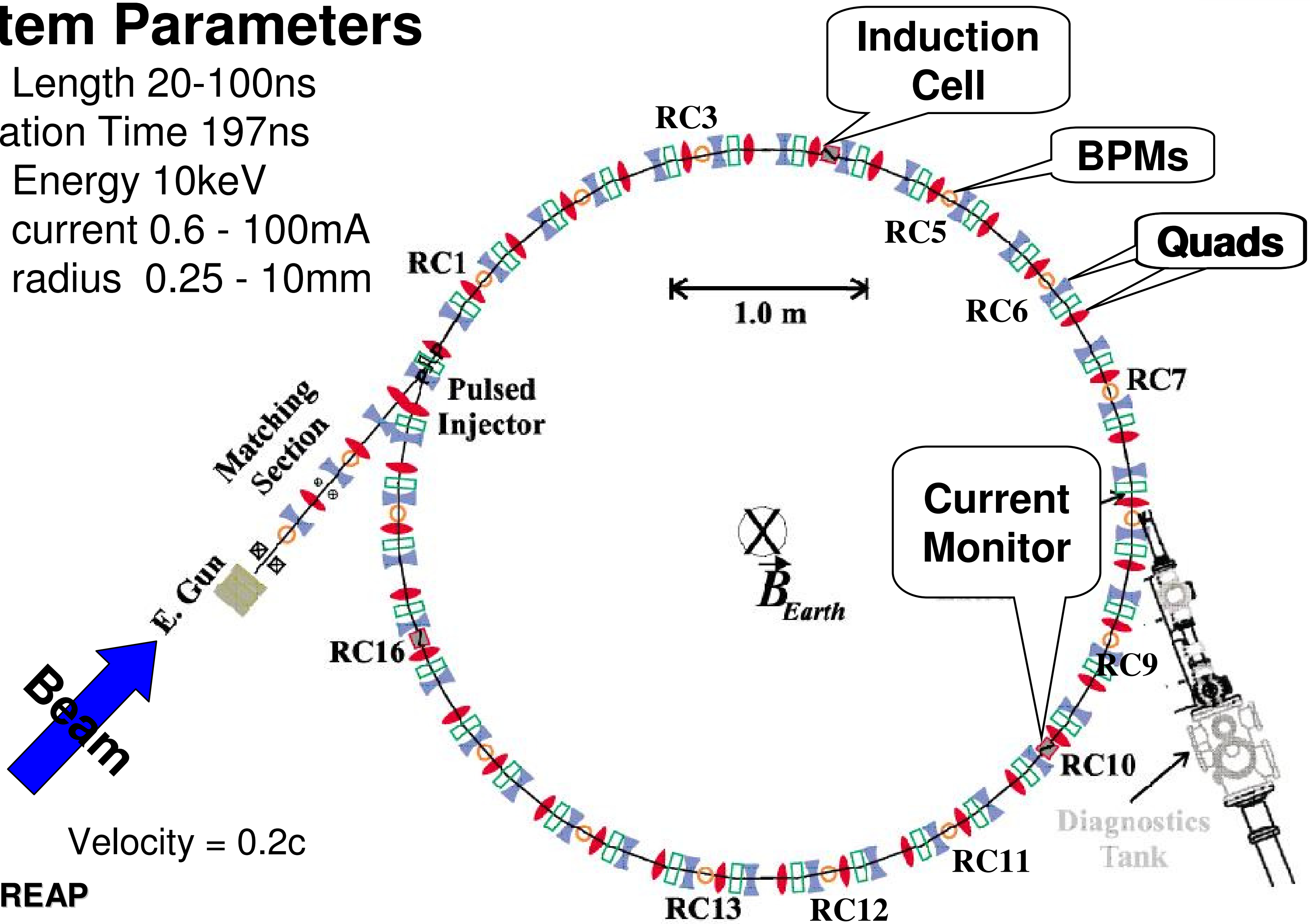
- With RF focusing, self-fields of the beam can distort the applied fields to the cavity

- For long pulses like in UMER, 100ns, need very low frequency current sources to drive an RF cavity, which means large cavities

System Overview

System Parameters

Beam Length 20-100ns
Circulation Time 197ns
Beam Energy 10keV
Beam current 0.6 - 100mA
Beam radius 0.25 - 10mm



Velocity = 0.2c

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Beam-End Expansion and 1D Model

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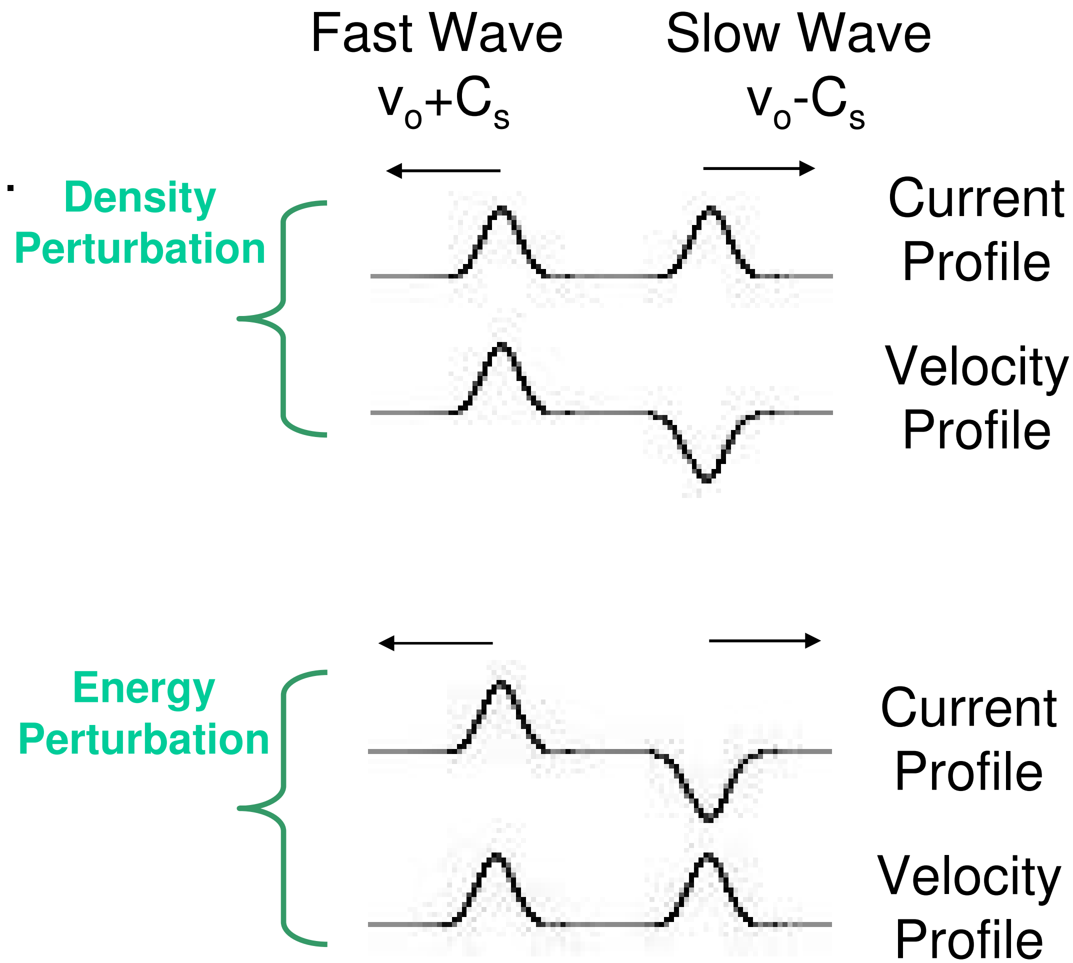
Sound Speed and Perturbations

- C_s is the sound speed, the speed of the wave moving on the flat top region of the beam.
- γ is the Lorentz factor.
- **I** the main beam current.

$$C_s = \sqrt{\frac{egI}{4\pi\varepsilon_o m v_o \gamma_o^5}}$$

- In the linear regime, waves travel undistorted so that the shape is preserved.
- In lab, keep the amplitude of perturbation small.



$$u(z,t) = Ff\left(t - \frac{z}{v_o + C_s}\right) + Gf\left(t - \frac{z}{v_o - C_s}\right)$$

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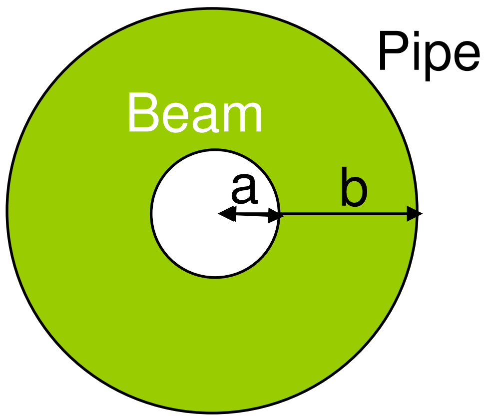
Geometry Factor

- **g** the geometry factor is a factor determined by the ratio of the beam size to pipe size.

$$g = \alpha + 2\ln\left(\frac{b}{a}\right)$$

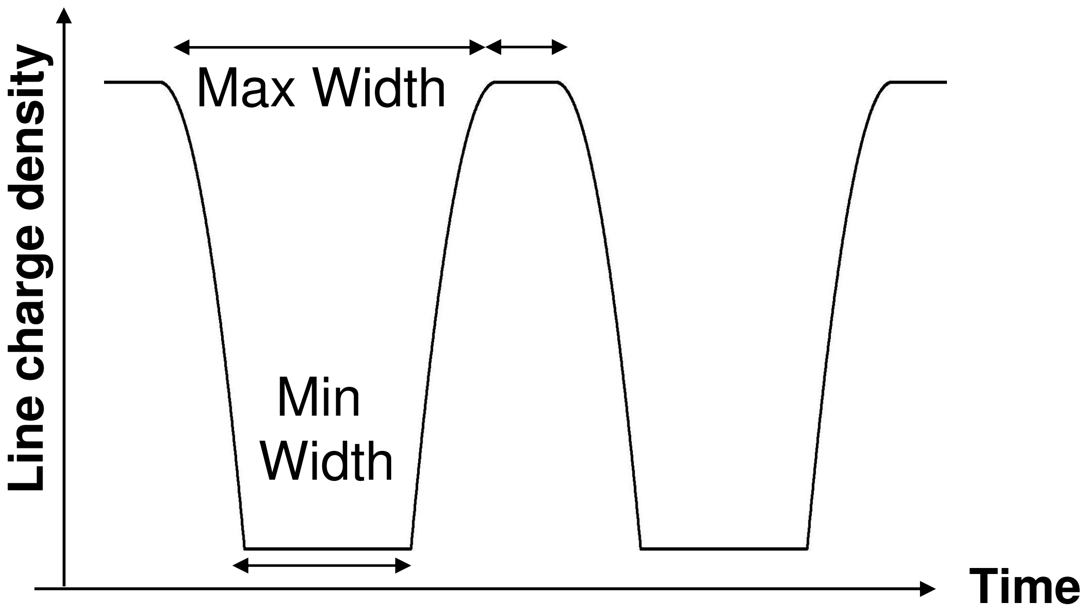
- α is a correction factor that is 0 for a space charge dominated beam, and 0.5 for an emittance dominated beam.

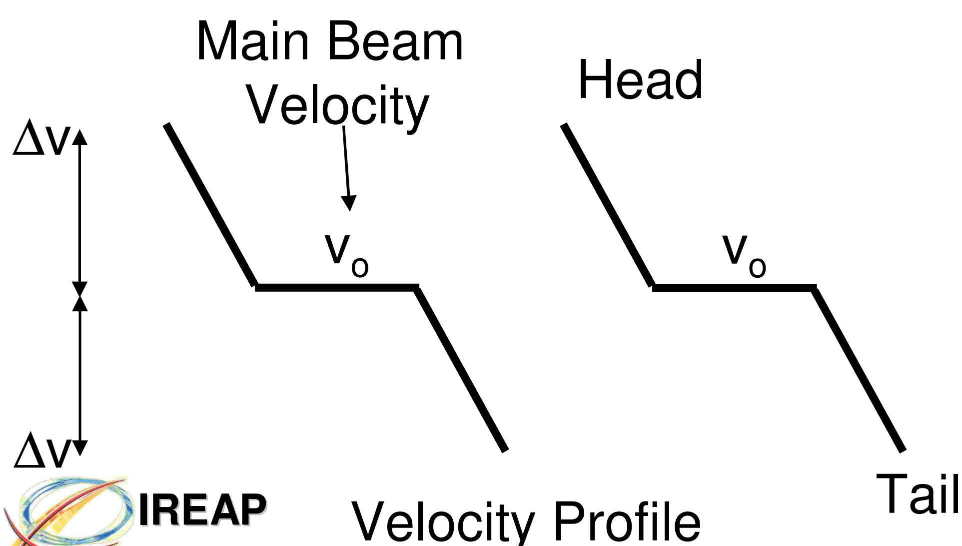
- Don't forget if quads are running at reduced currents. What happens to beam size?



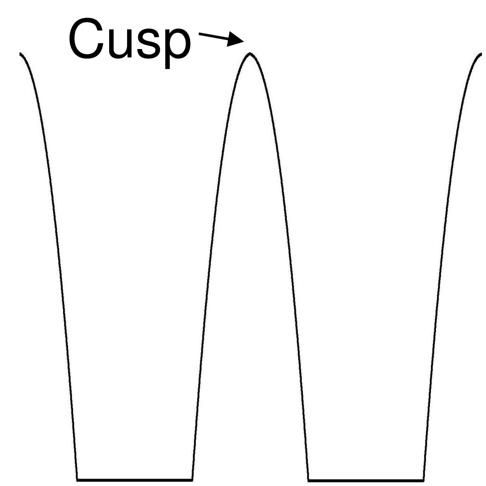
-Kishek / O'Shea class notes and Reiser's Book 1st ed. p.505

Longitudinal Expansion

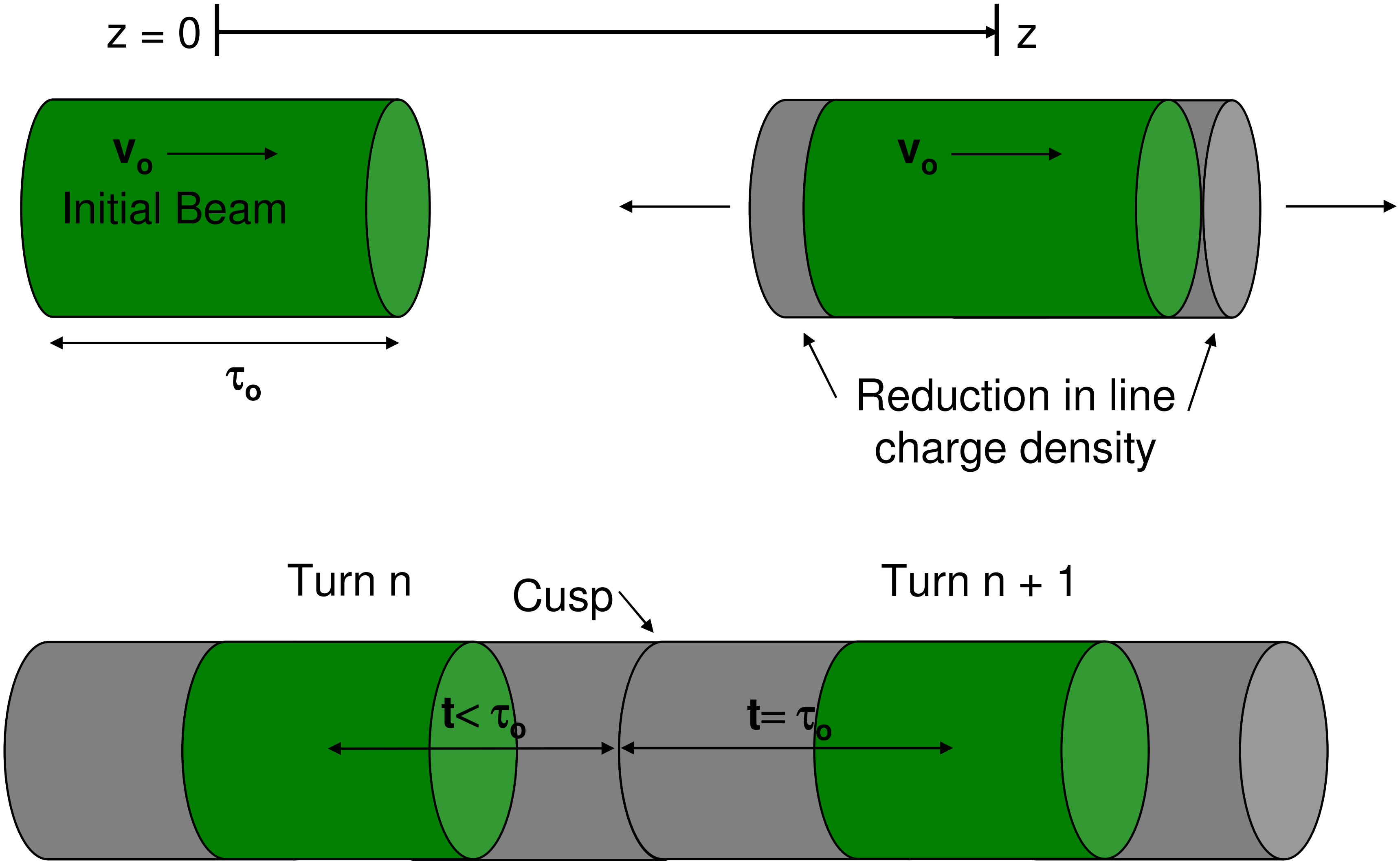




- **Cusp Point**
  - As Beam circulates in the lattice, the head and tail will eventually touch each other.
- **Head/Tail Energy**
  - Head will accelerate from the main beam at a ΔE and tail will decelerate at the same amount.



Cusp Point



-Wang D. X. PhD Thesis, “Experimental Studies of Longitudinal Dynamics of Space-Charge Dominated Electron Beams", 1993

1D MATLAB Code to Study End-Erosion

Editor - C:\Documents and Settings\Brian\Desktop\USPAS\Rectangular bunch expansion\Bunch_Expansion.m

```matlab
function [arrayC,arrayV]=Bunch_Expansion()
b=1*2.54; %pipe radius in cm
a=0.37; %beam radius in cm for 7mA 83% quads
%a=0.15; %beam radius in cm for pencil beam (~0.5mA) 83% quads
%a=0.63; %beam radius in cm for 23mA 83% quads
e = 1.60217733E-19; %C
m = 9.1093897E-31; %kg
Energy = 10000;  %eV
c = 2.997924E8;
I = .007;     %mA
%I = .1;     %mA
Epsilon_o = 8.854187817E-12;     %C^2 / N*m^2
g = 2*log(b/a);    %Geometry factor
gamma = 1+((Energy)/(511000)); %Lorentz factor
beta = sqrt((gamma*gamma)-1)/gamma;
v_o = beta*c;    %m/s
Main_Beam_Energy = (.5*m*v_o*v_o)/(e);
Turns = 5;  %Number of Turns
Travel_Dist = 11.52;  %m

Long.t_o = 100E-9;   %ns

Cs = sqrt((e*g*I)/(4*pi()*Epsilon_o*m*v_o*(gamma^5)));
Long.Scusp = ((v_o^2)*Long.t_o)/(2*Cs);
Delta_E=(2*m*Cs*(v_o+Cs))/(1.6E-19);   %in eV

Add_On=1;  %either 0 or 1 add distance from gun to RC10

%Initial_T1 = Add_On*(  ((7.66666/1)/(2*Long.Scusp)))*Long.t_o;  %initial pulse travel from gun to RC10
%Initial_T2 = Add_On*(  ((7.66666/1)/(Long.Scusp)))*Long.t_o;  %initial pulse travel from gun to RC10
Initial_T1 = Add_On*(  ((3.82/1)/(2*Long.Scusp)))*Long.t_o;  %initial pulse travel from gun to RC4
Initial_T2 = Add_On*(  ((3.82/1)/(Long.Scusp)))*Long.t_o;  %initial pulse travel from gun to RC4



for S=1:Turns
```

Important Part of Code

Vary Parameters and see what happens

Parameters to Vary
Energy,
Current,
Beam Length

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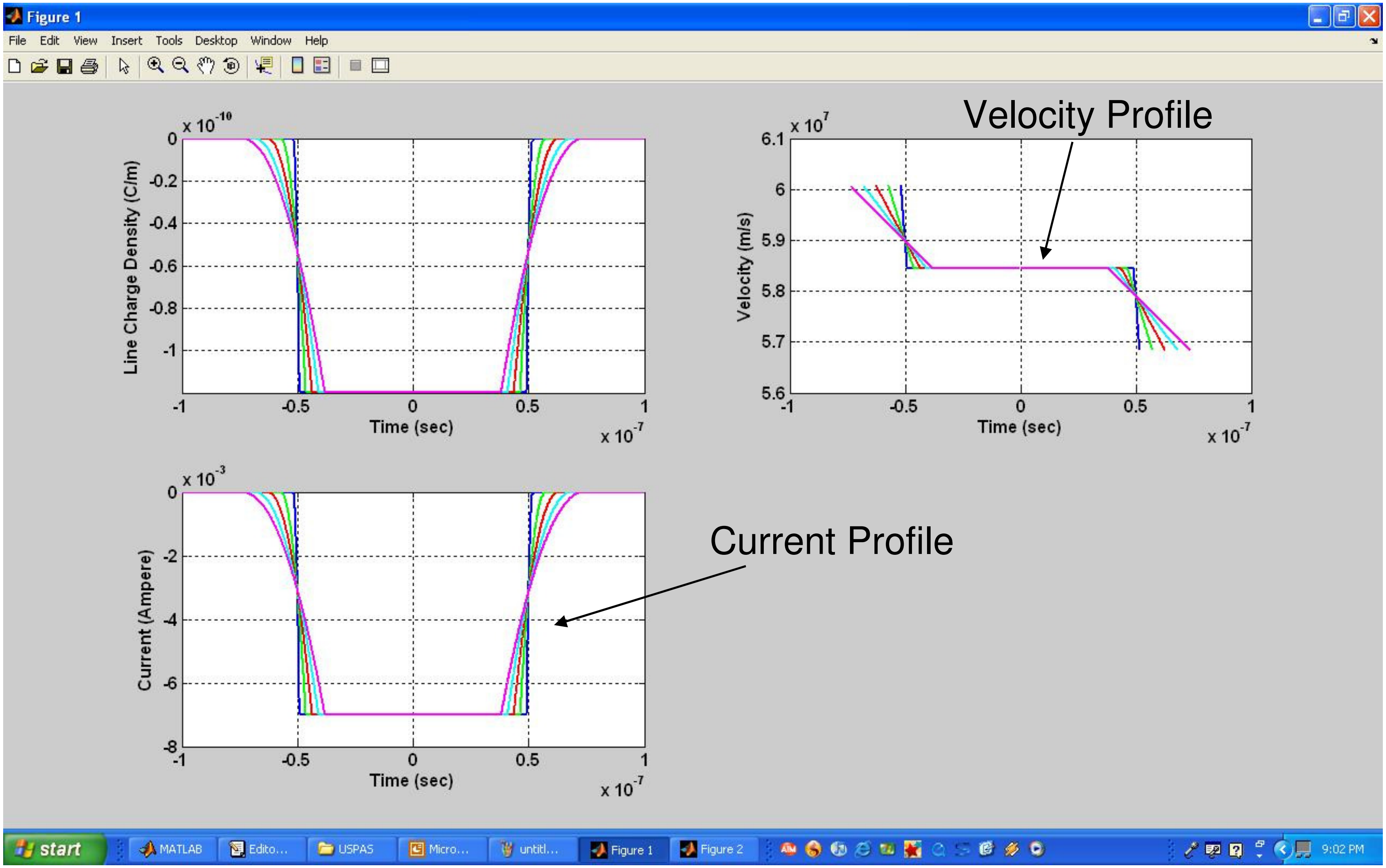
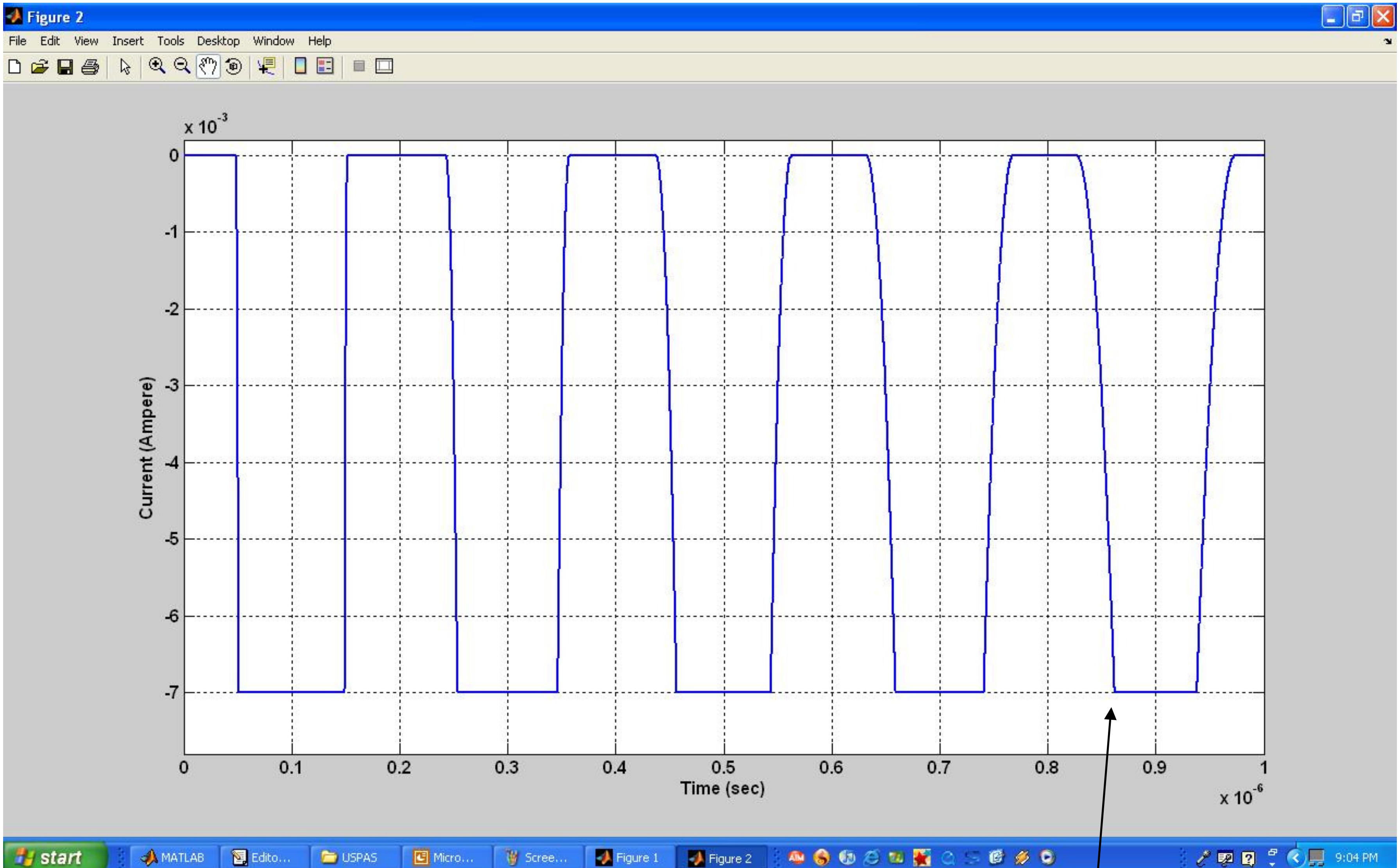
M-File Output



M-File Output



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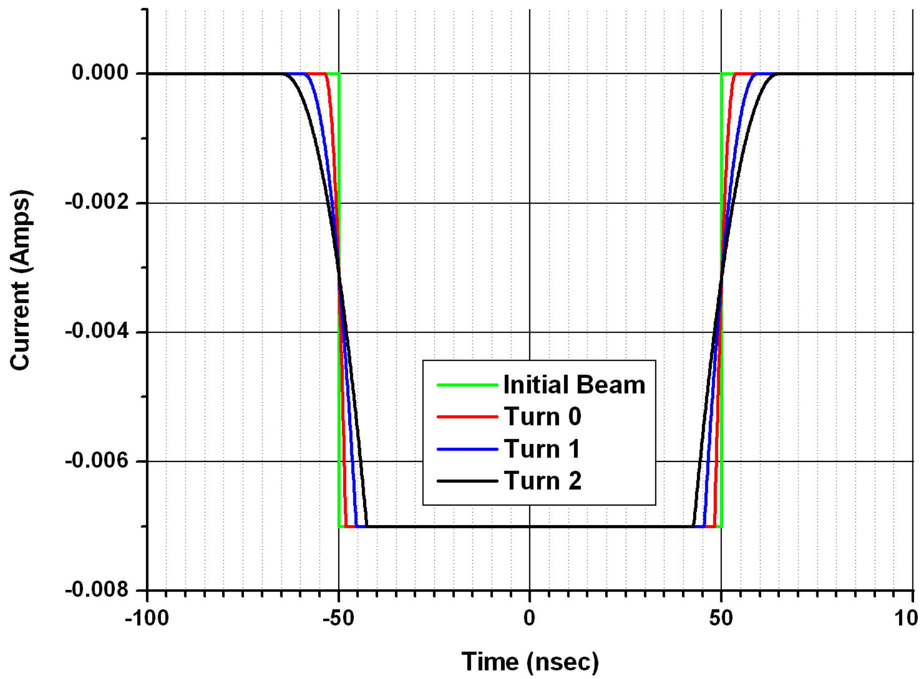
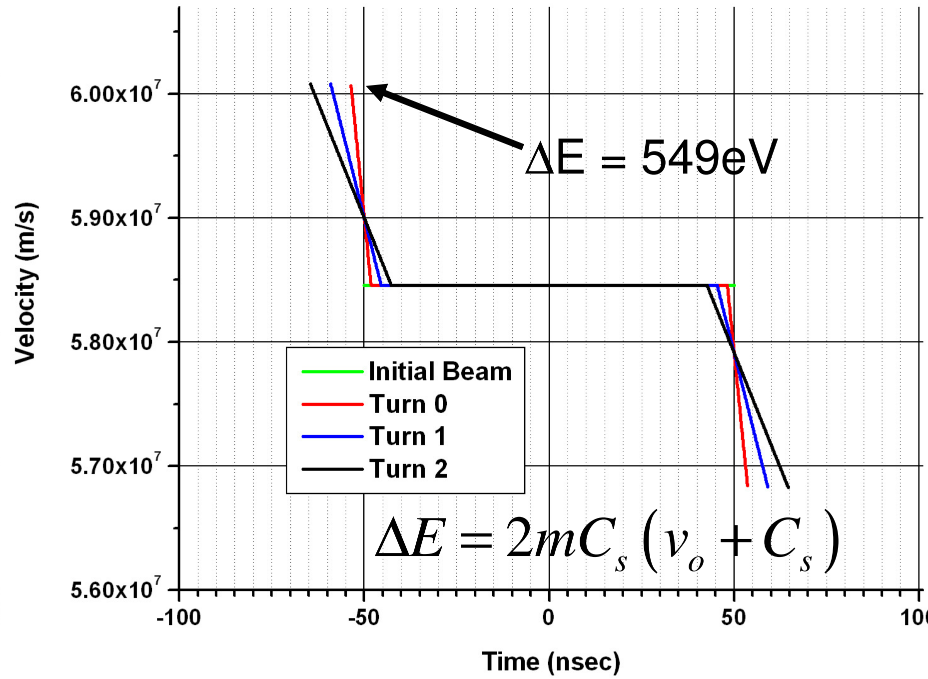
Simulation of Multi-Turn
Invalid past "simple wave regime"

My 1-D Calculations

For 7mA Beam measured at RC10





- Initial beam length when formed is 5.93m.
- The rate of expansion for the 7mA beam is 5.5nsec / Turn, assuming no loss in current. So that by the 9th turn, the beam head and tail are touching each other, for 83% quads.

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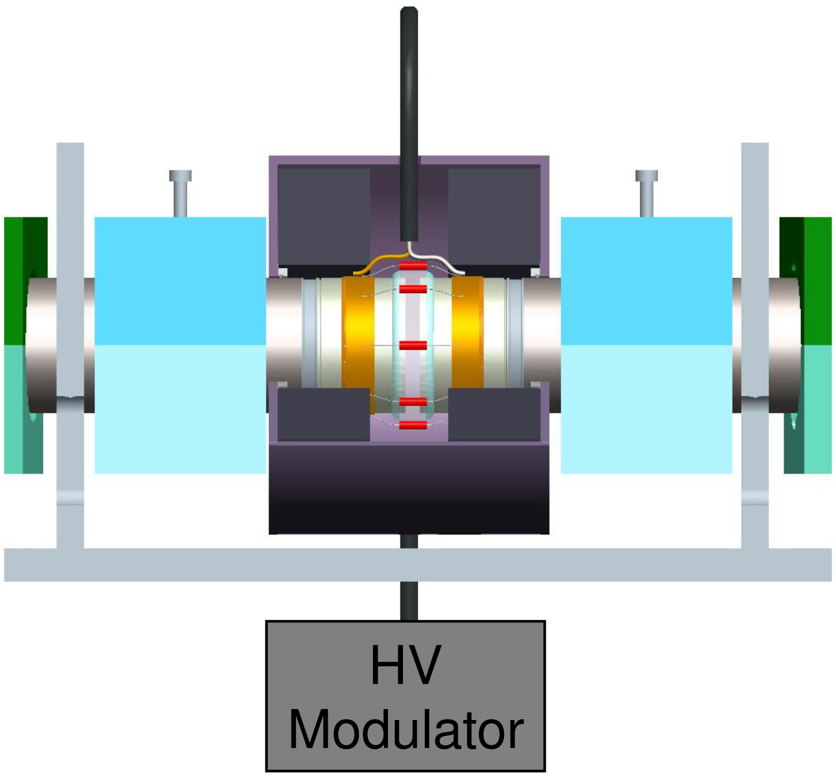
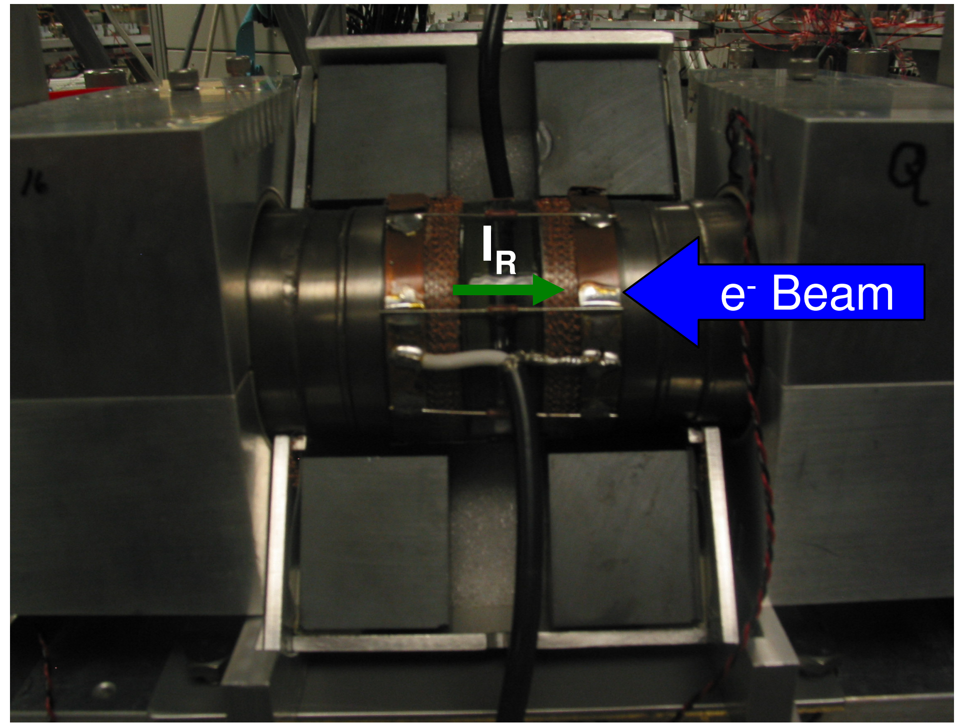
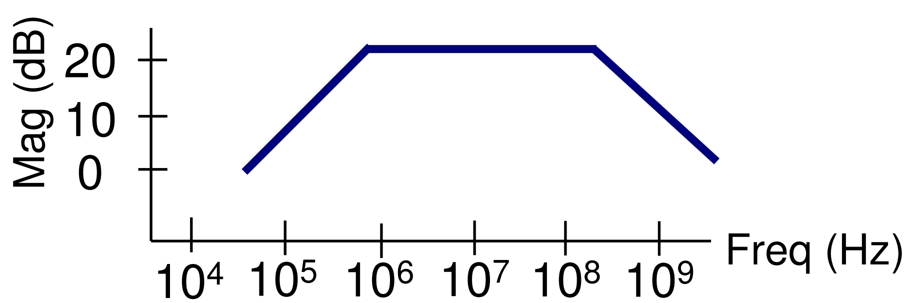
Induction Cell

Induction Cell Operation





$$Z = \frac{sLR}{sL + R + s^2 CRL}$$



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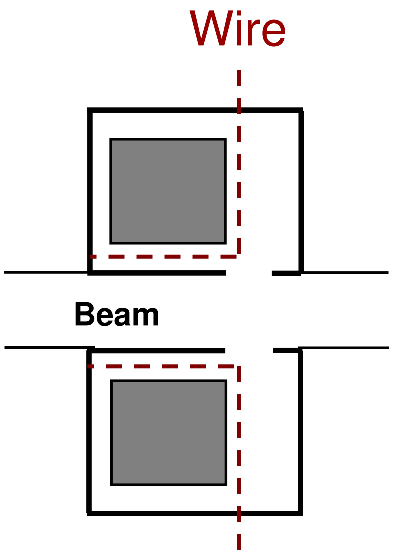
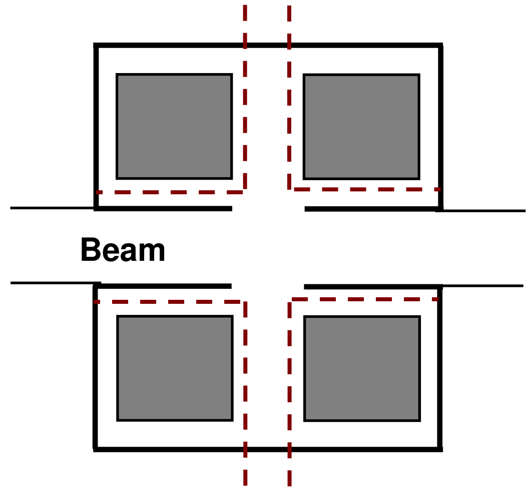
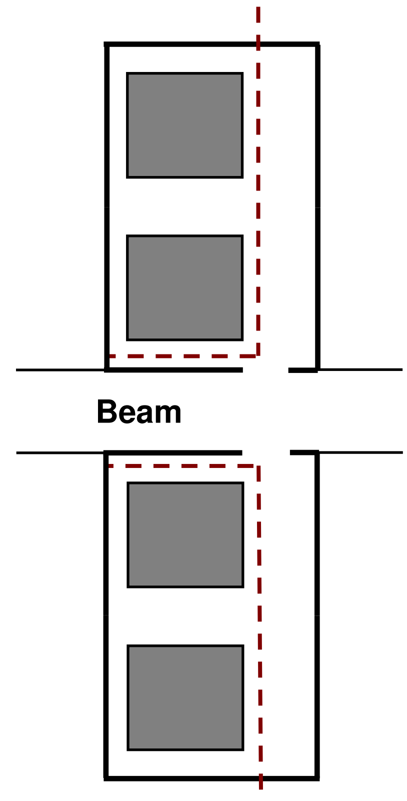
Multiple Cells and Orientations



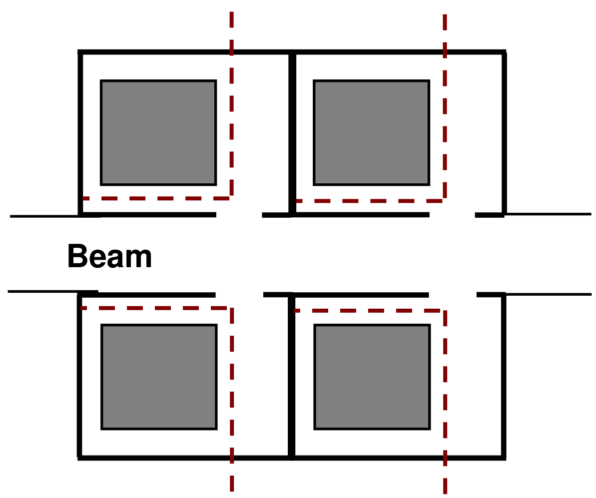
Single Core Cell



Double Core Cell



Dual Core Cell



Two Cells back to back

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Saturation Limits and Reset Pulses

$$V_{pulse}\Delta t_{pulse} = \Delta B A_{core}$$

$$V_{pulse} = 3000 volts$$

$$\Delta t_{pulse} = 10 ns$$

$$A_{core} = 22.82 cm^2$$

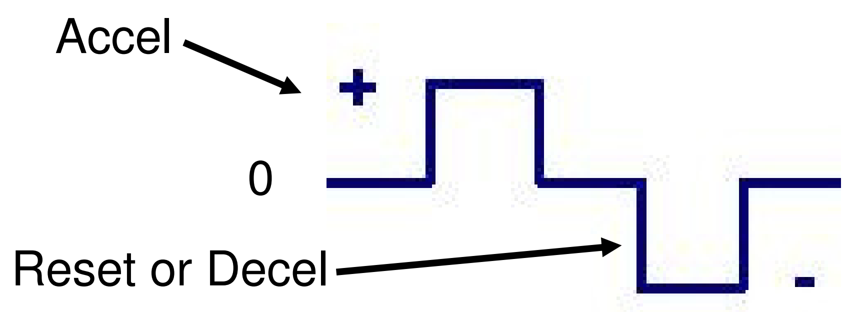
Flux swing

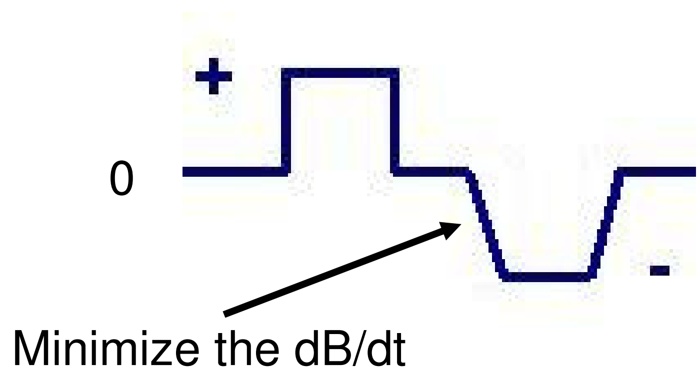
$$\Delta B = 131 gauss$$

B_s of CMD5005

$$B_s = 3200 gauss$$

Reset pulse using a bipolar HV modulator





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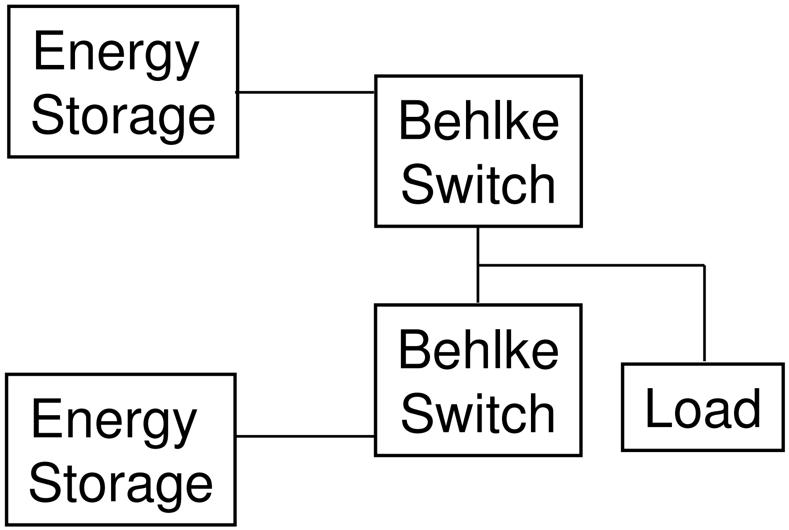
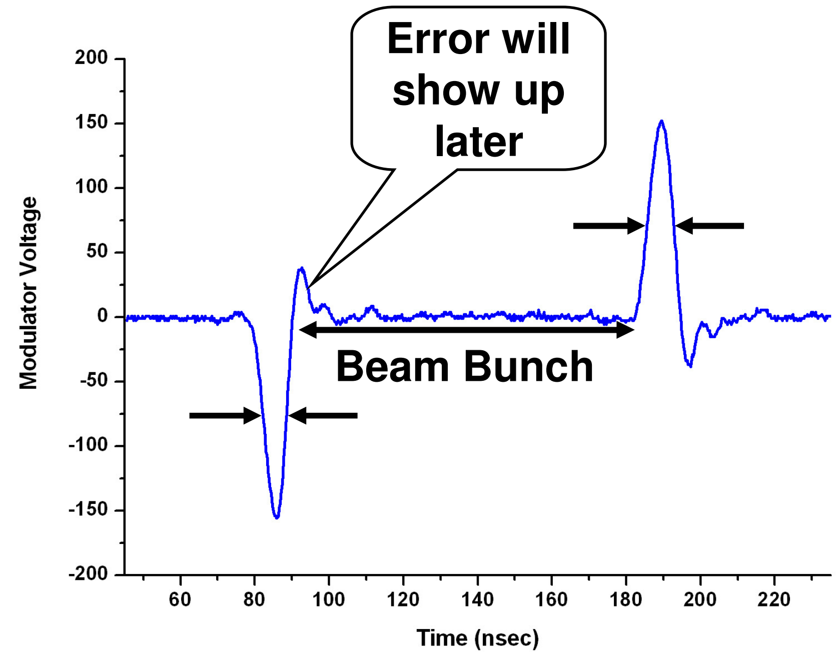
High Voltage Modulator





- Pulse fields have a fixed on-time of 10-15nsec with a FWHM of ~8nsec.
- Fields are purely composed of fixed rise times so Δt can not be changed for this pulser.
- Amplitude can vary from 0 – 3kV.
- Both positive and negative pulses must be “on” to reset the core.

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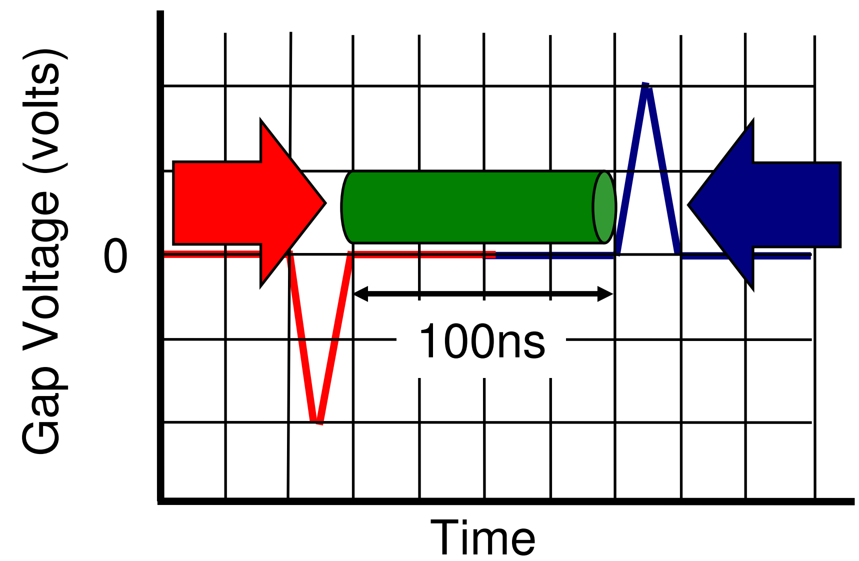
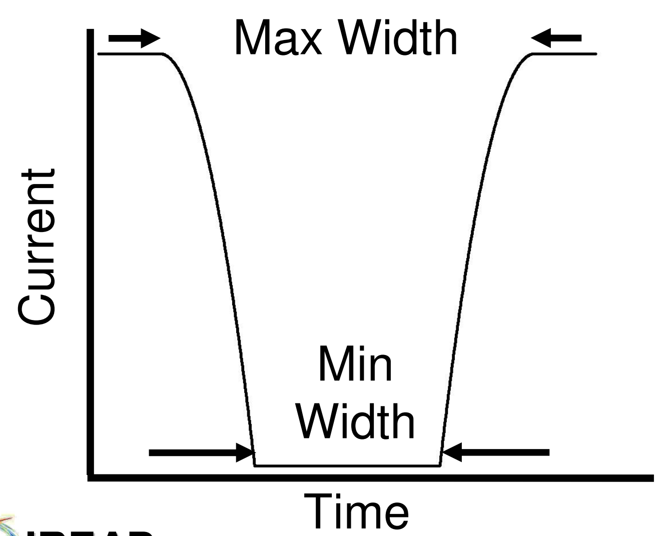
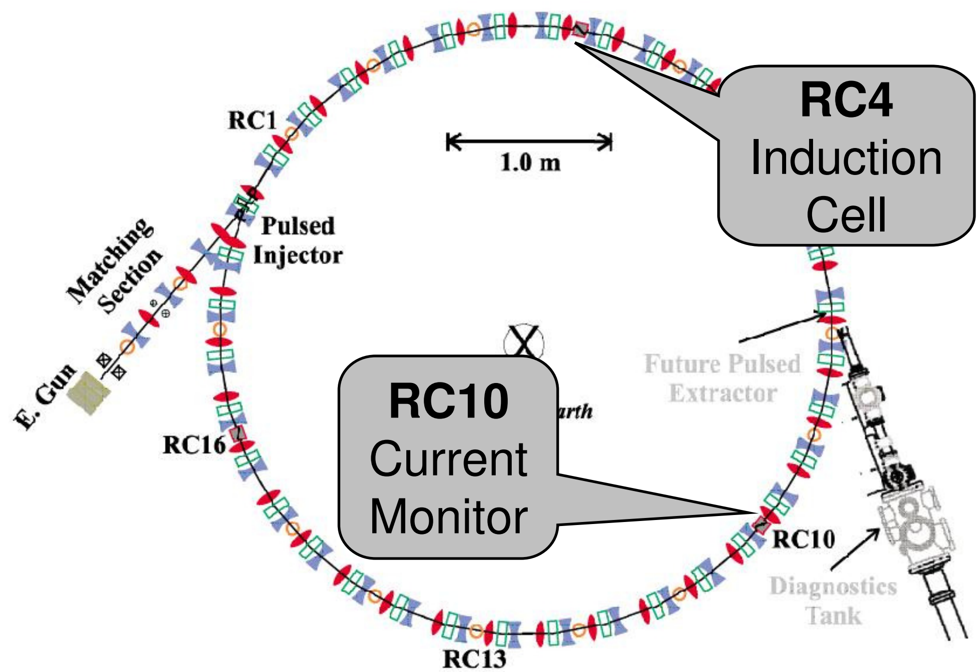
Longitudinal Focusing

Focusing Experiment

- The compensation voltage is set based on the one dimensional longitudinal expansion calculations for a rectangular bunch.
- Ear-fields are applied for a single turn.
- Pencil Beam = 176eV







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