Longitudinal Beam Physics Experiments at the University of Maryland Electron Ring

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Outline

- Motivation: “Intense” Beams
- University of Maryland Electron Ring (UMER)
- Longitudinal Effects
- Evolution of Modulated Beams
- Longitudinal Focusing
- Future Work
- Conclusions

Motivation

- New Accelerators and Applications – High Quality, High Current Needed

  “High quality” = “low emittance”

- Limit of:

  Low Emittance

  Low Energy

  High Current

  Coulomb Forces Dominate

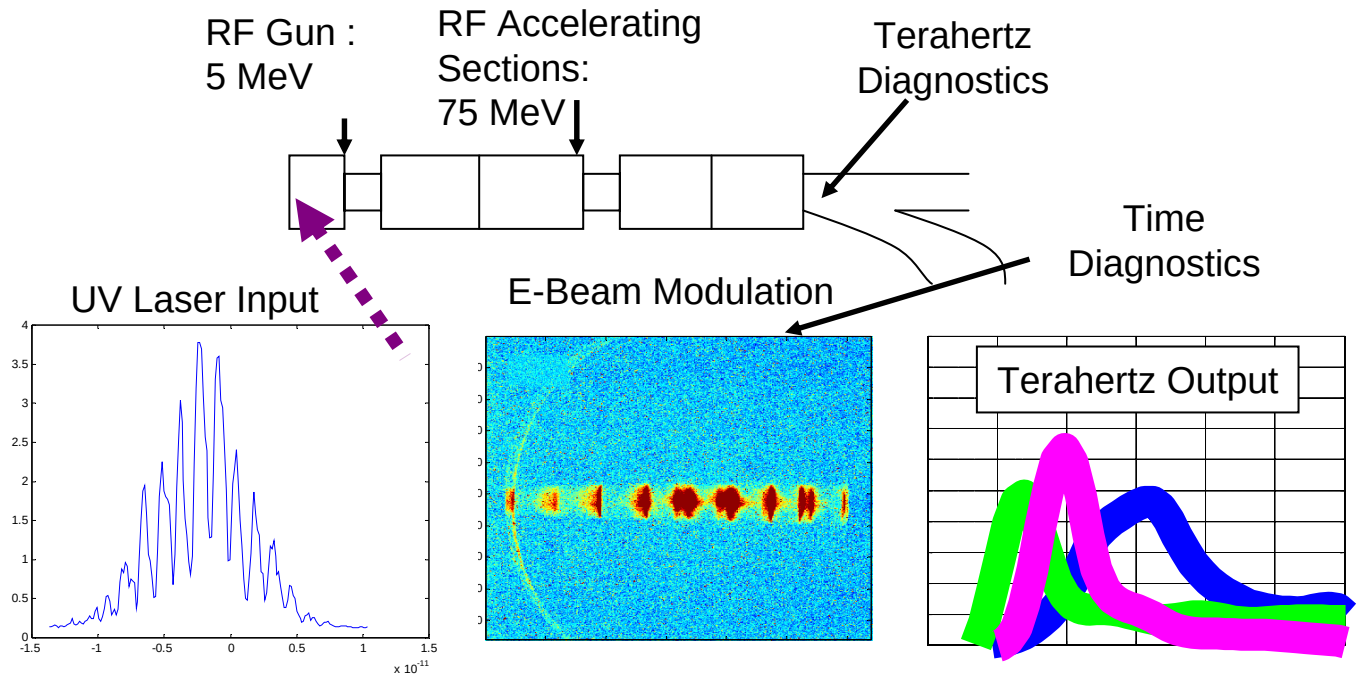
  “Space Charge Dominated”

  “Intense”

Motivation

- All Beams: SCD at birth (low γ)

- SC-driven effects "frozen in" as $\gamma \rightarrow$ big



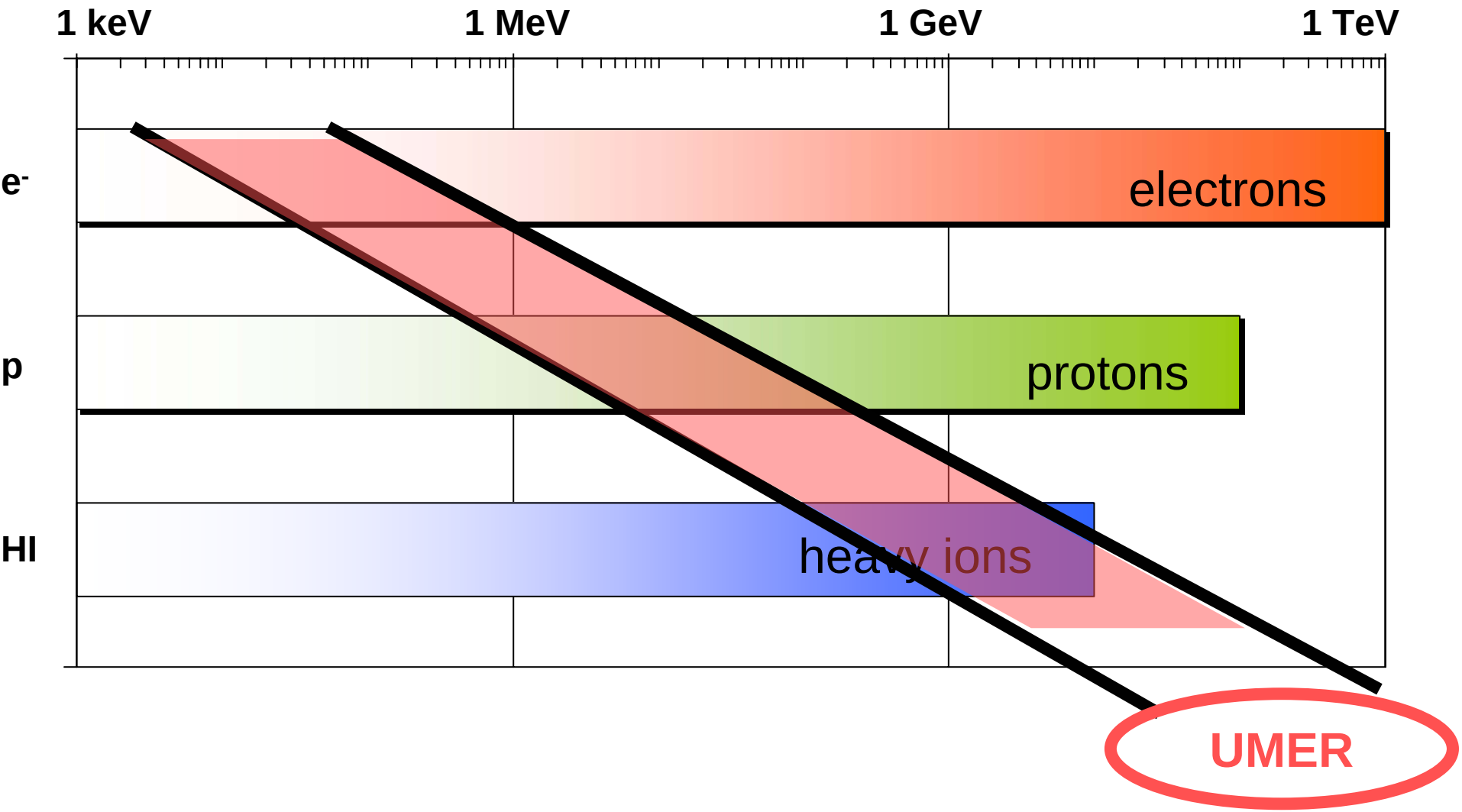
(J. Neumann, U. Maryland; Experiment performed at Brookhaven Source Development Lab)

Effects: Good *or* Bad

Motivation

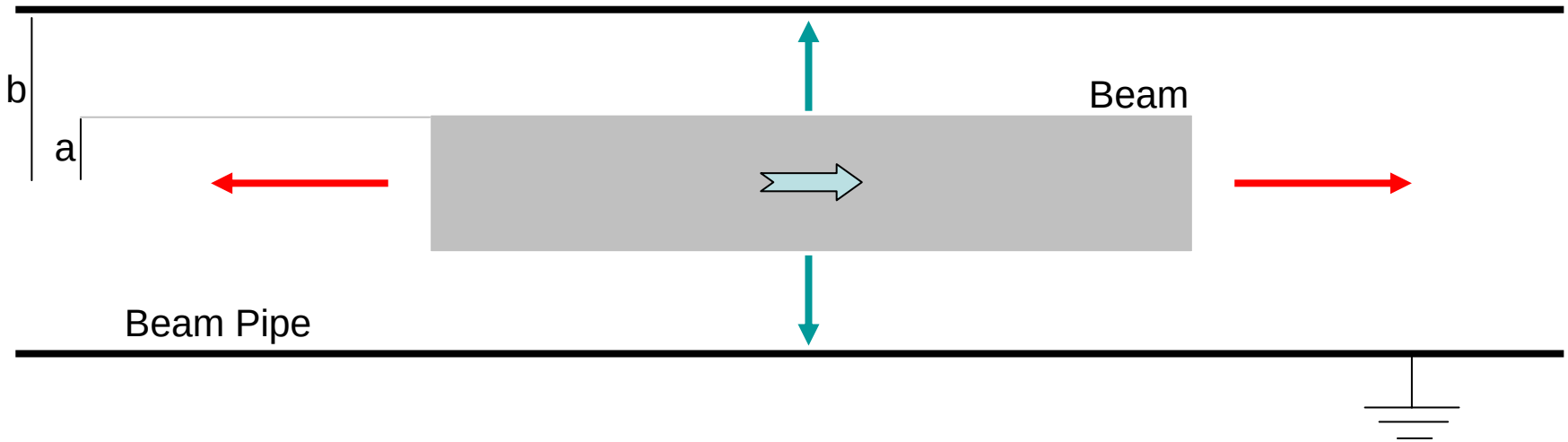
- Some Beams: Always SCD

  Ex: Heavy Ion Fusion



Longitudinal Expansion

- Space Charge – Beam tends to expand

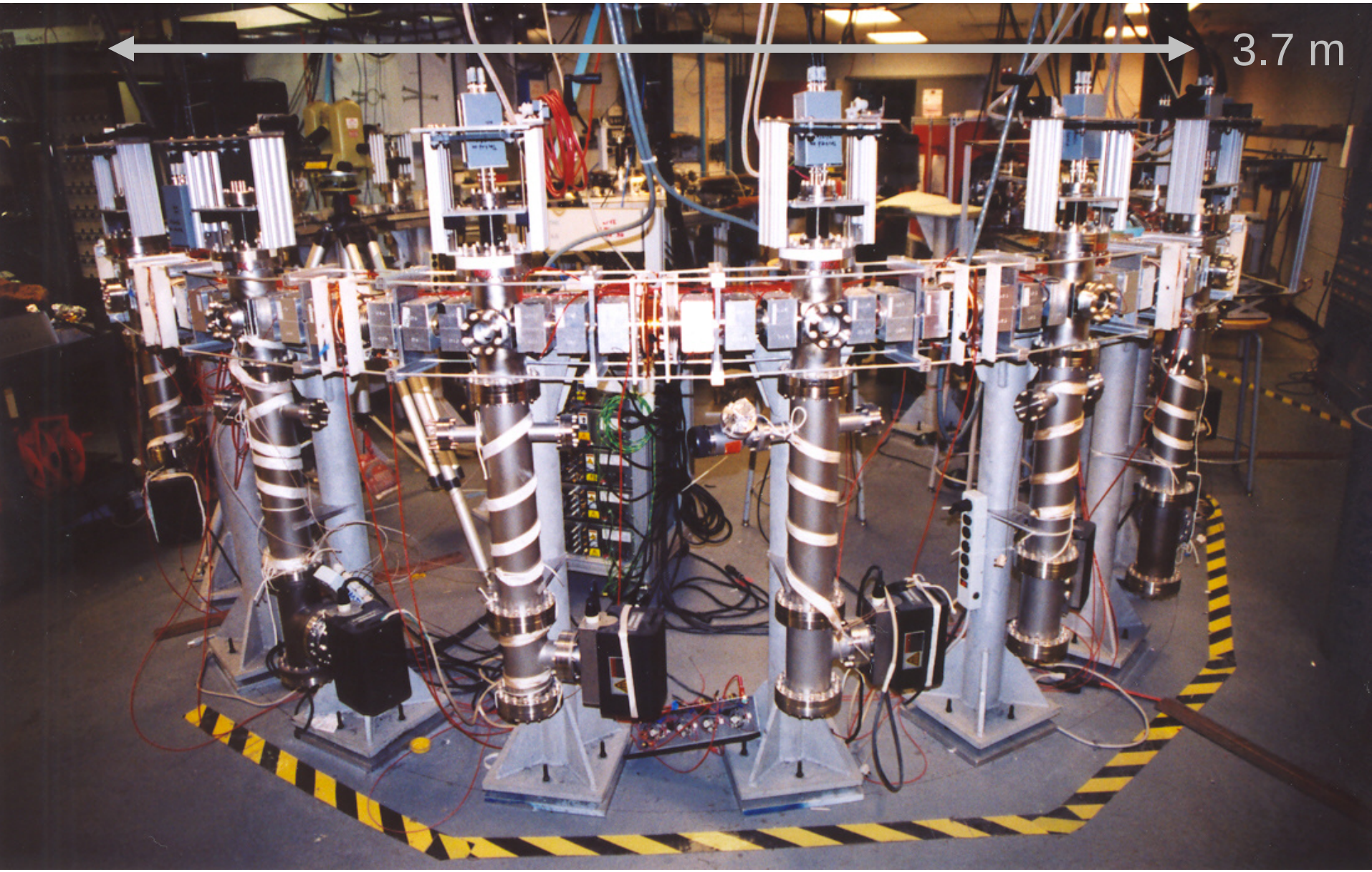


- **Transverse SC Force** – Contain using transverse focusing (Quads)
- **Longitudinal SC Force** – Beam will expand unless contained
- Longitudinal E-Field (long wavelength):

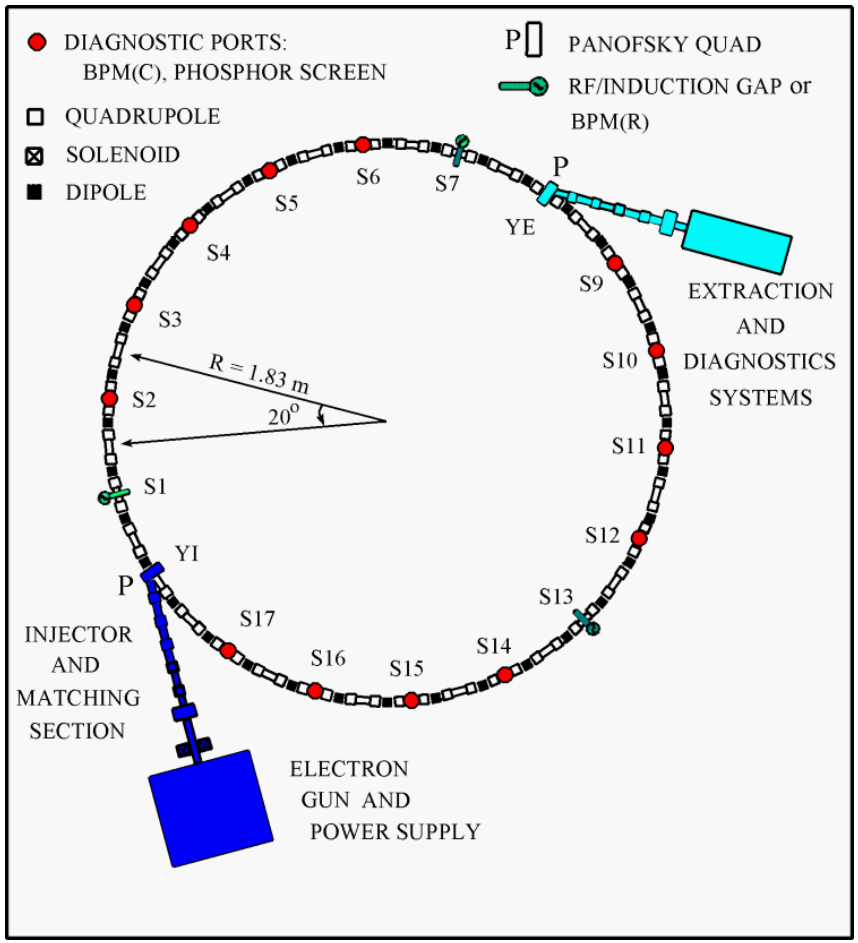
$$E_{sz} = -\frac{g}{4\pi\varepsilon_0\gamma^2}\frac{\partial\lambda}{\partial z} \qquad g \approx \alpha + 2\ln\left(\frac{b}{a}\right)$$

Local Line Charge Density λ [C/m]; Geometry Factor **g**; $0 < \alpha < 1$

University of Maryland Electron Ring (UMER)



University of Maryland Electron Ring (UMER)



$$\varepsilon_n \approx 2\mu m$$

Beam Energy: 10keV ($\beta = 0.2$)

Beam Current: 0.6 – 100 mA

Pulse length: 30 ns – 150 ns

(1/2 ring filled at 100ns)

Bunch charge: ~5 nC

Compact: 12m Circumference

Complex: 36 Dipoles

> 78 Quadrupoles

> 36 Steering Dipoles

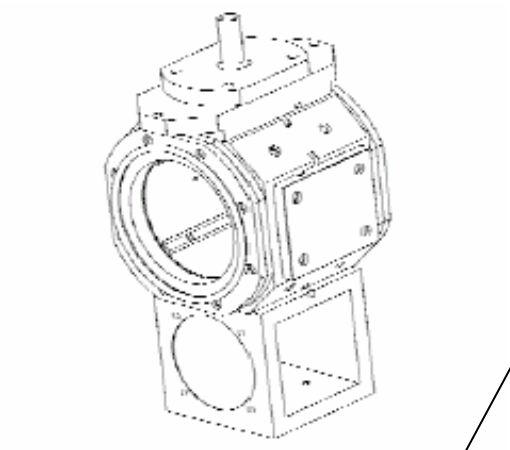
17 Diagnostics Ports

1 Diagnostic End Station

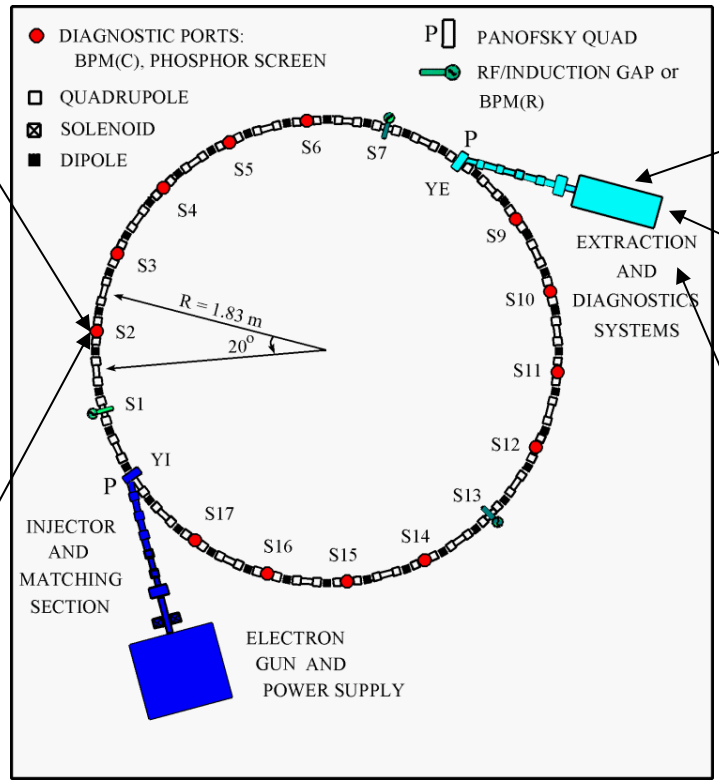
UMER Diagnostics

Every 64 cm:

Beam Position Monitors



Phosphor Screens



End Station:

Faraday Cup

Pepperpot and

Slit-Wire System

Energy Spread Analyzer

(Under development)

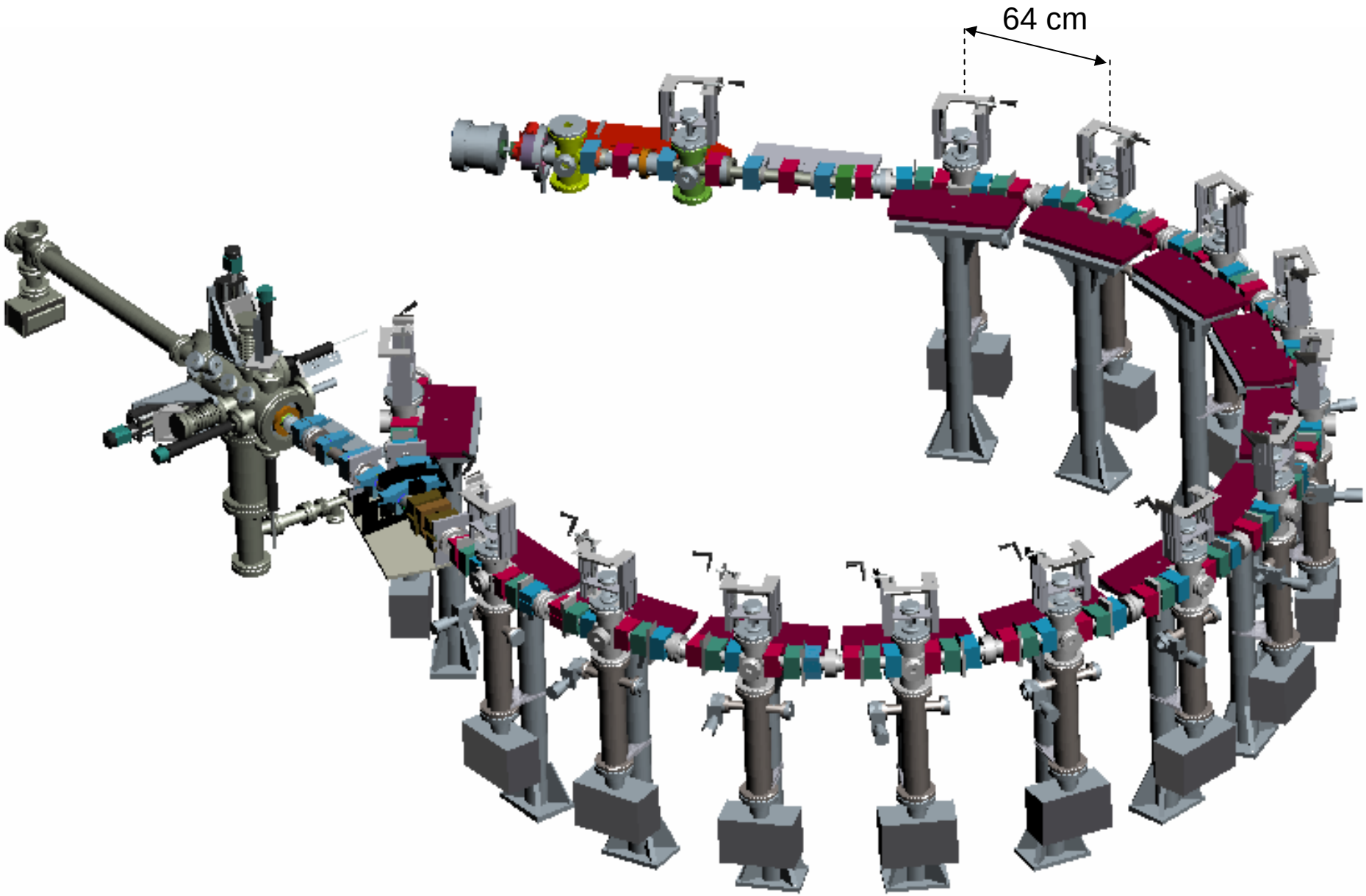
0.2 eV resolution

At Injection and Extraction:

Fast Current Monitors

(Bergoz)

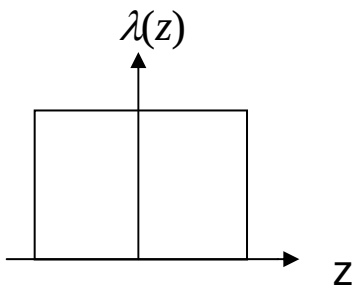
UMER Today

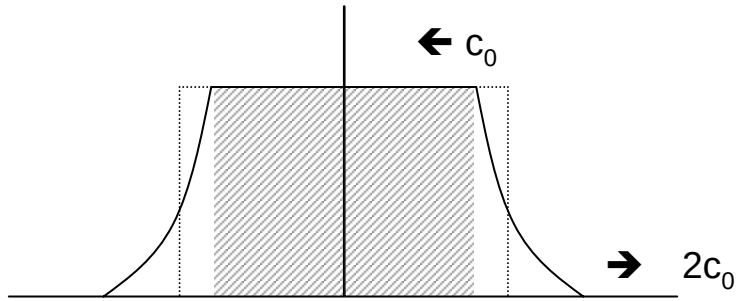


Longitudinal Effects and Experiments

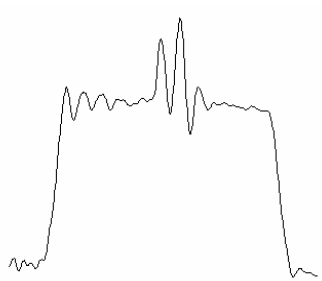
Longitudinal Effects (1)

- Beam Expansion/End Erosion



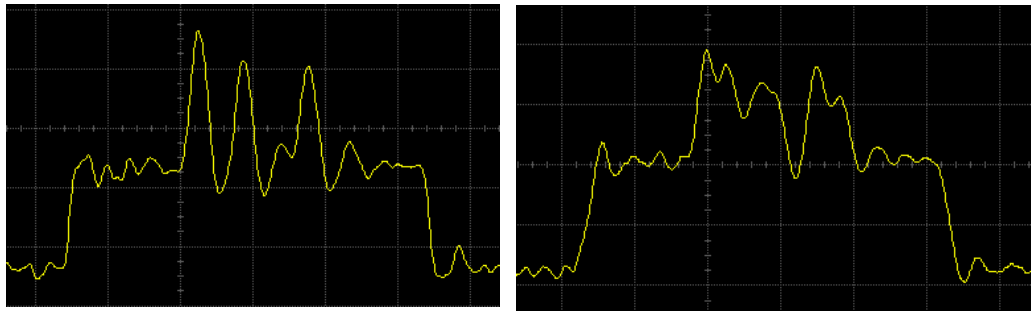


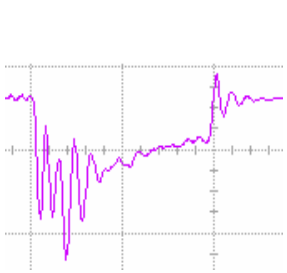
- Generating Perturbations/Wave Propagation

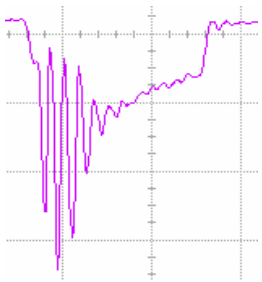


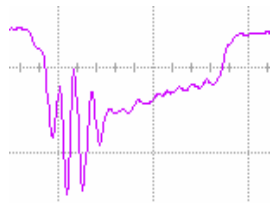
Longitudinal Effects (2)

- Modulation/Wave Interference

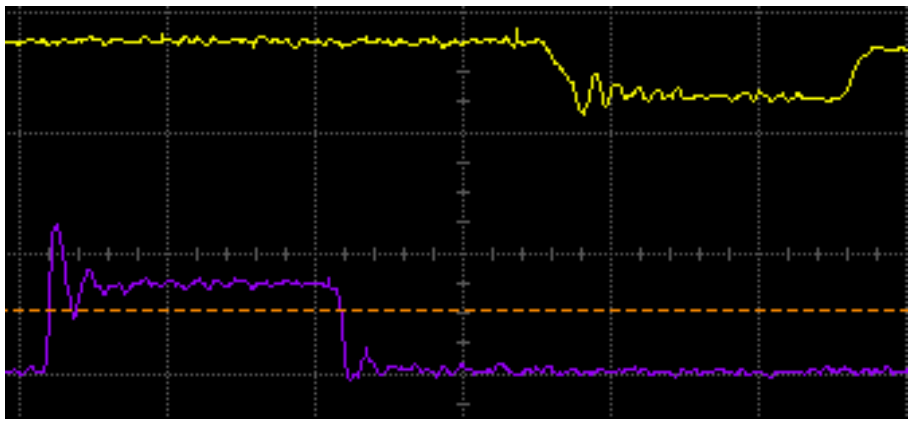








- Combinations



Longitudinal Effects (3)

Common Theme:

These effects all evolve at the Sound Speed

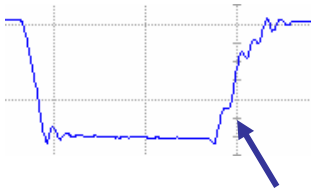
$$c_0 = \sqrt{\frac{Zqg\lambda_0}{4\pi\varepsilon_0 m\gamma^5}}$$

Z	Charge State
λ_0	Line Charge Density [C/m]
$g \approx \alpha + 2\ln\left(\frac{b}{a}\right)$	Geometry Factor
$c_0^{typ} \sim 10^6 \ m/s$	For UMER

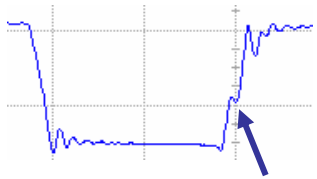
One example…

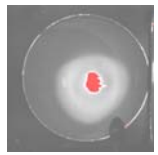
Modulation in UMER

Modulation observed when Bias Voltage ≈ 60

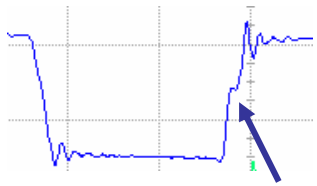


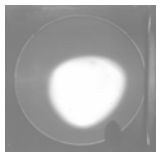
BV = 0



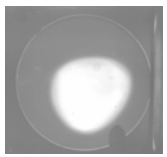


BV = 5

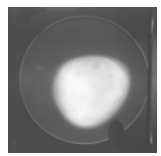




BV = 10

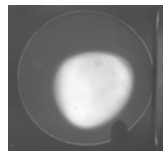


BV = 20

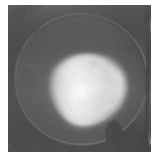


BV = 30

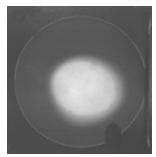
BV = 40

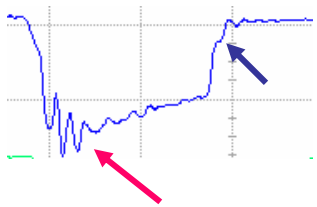


BV = 50

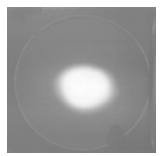


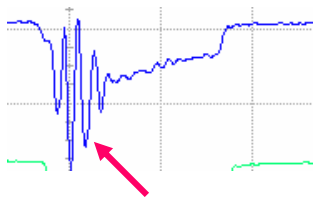
BV = 55



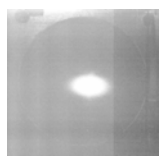


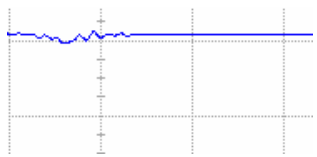
BV = 60





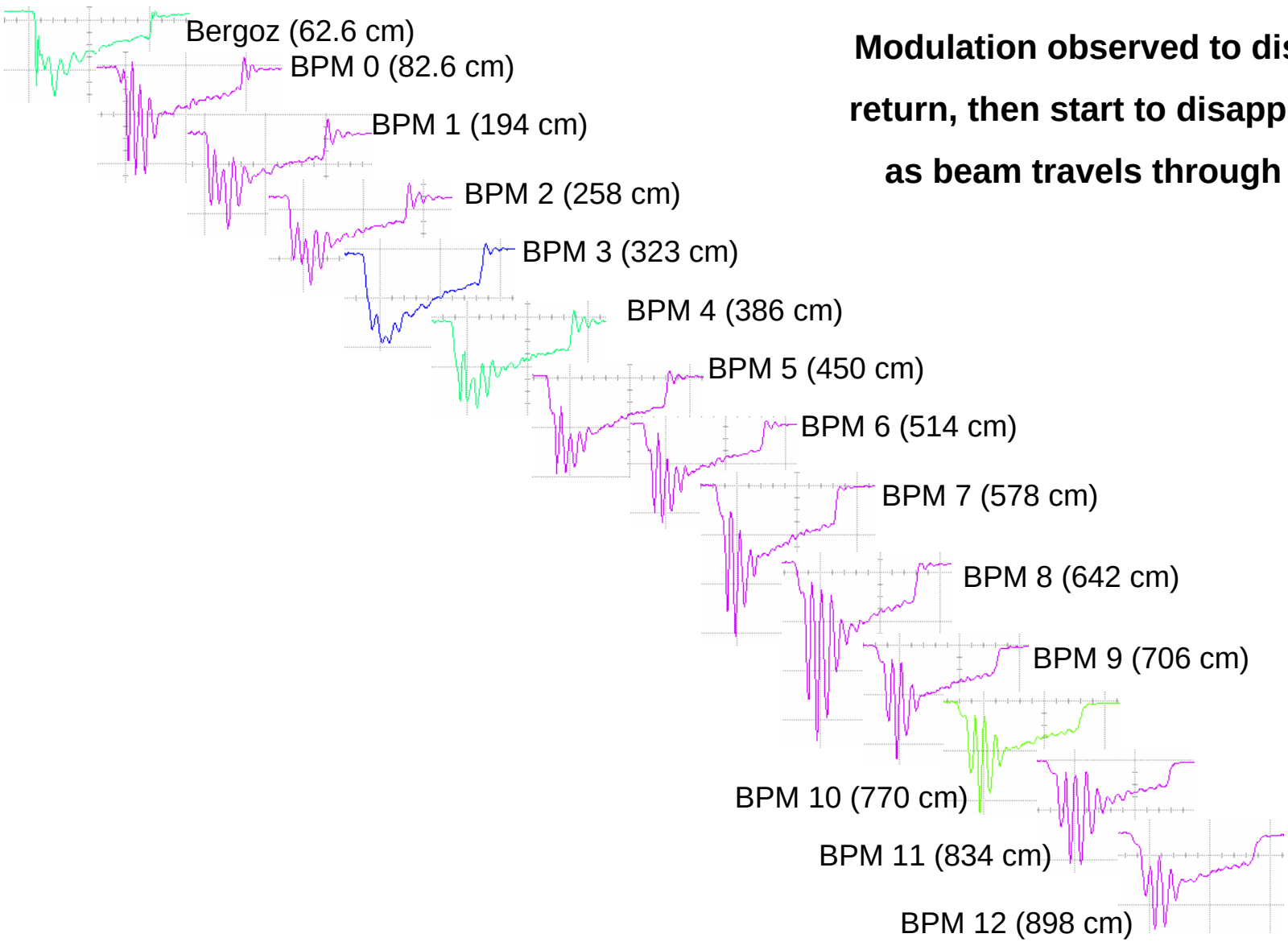
BV = 66





Simple Argument – density mod. should become energy mod., vice versa

Modulation in UMER



Modulation observed to disappear, return, then start to disappear again as beam travels through UMER

Modulation in UMER

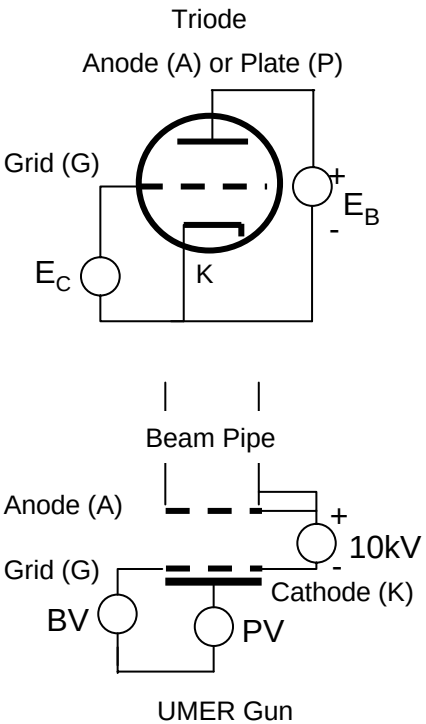
Two Questions:

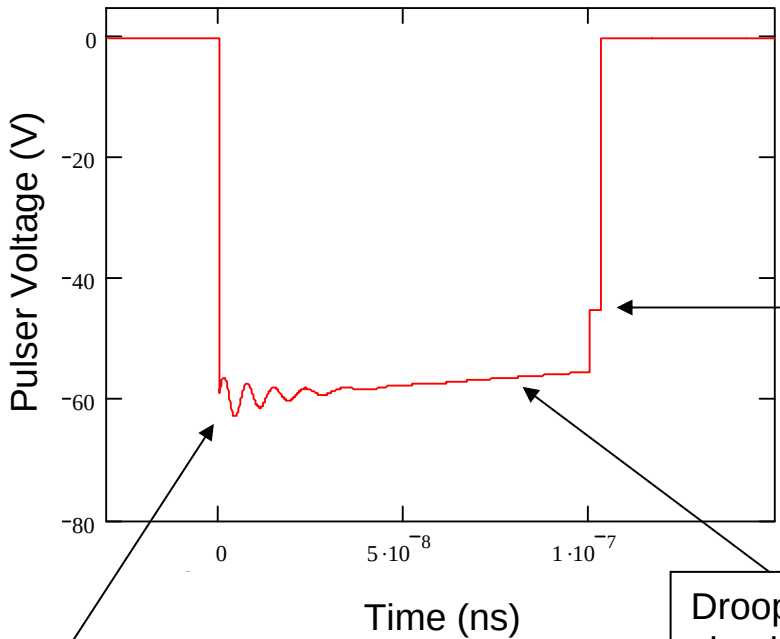
1. Where does it come from?

2. Why does it disappear, then come back?

Source of Modulation

- Gun acting like Triode
- Increase BV – no longer space charge limited
- Gun amplifies ripple, droop, etc., of pulser
- Assume Triode/Diode behavior and pulser voltage shape:





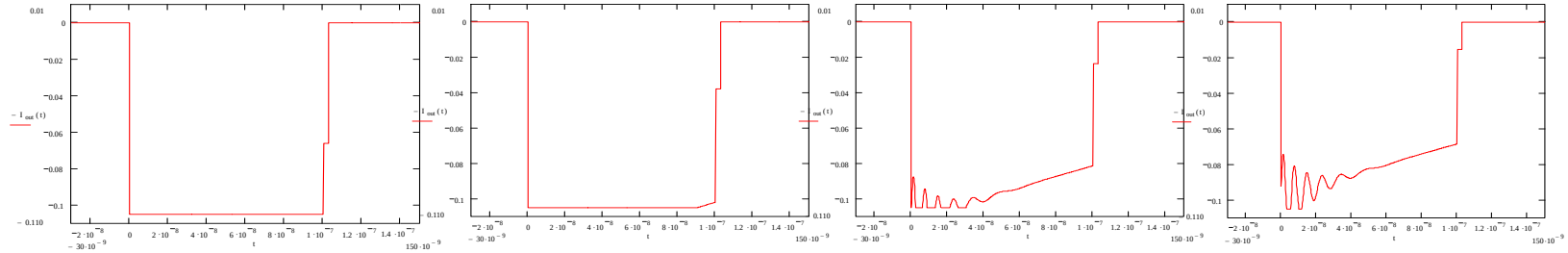
"Step"

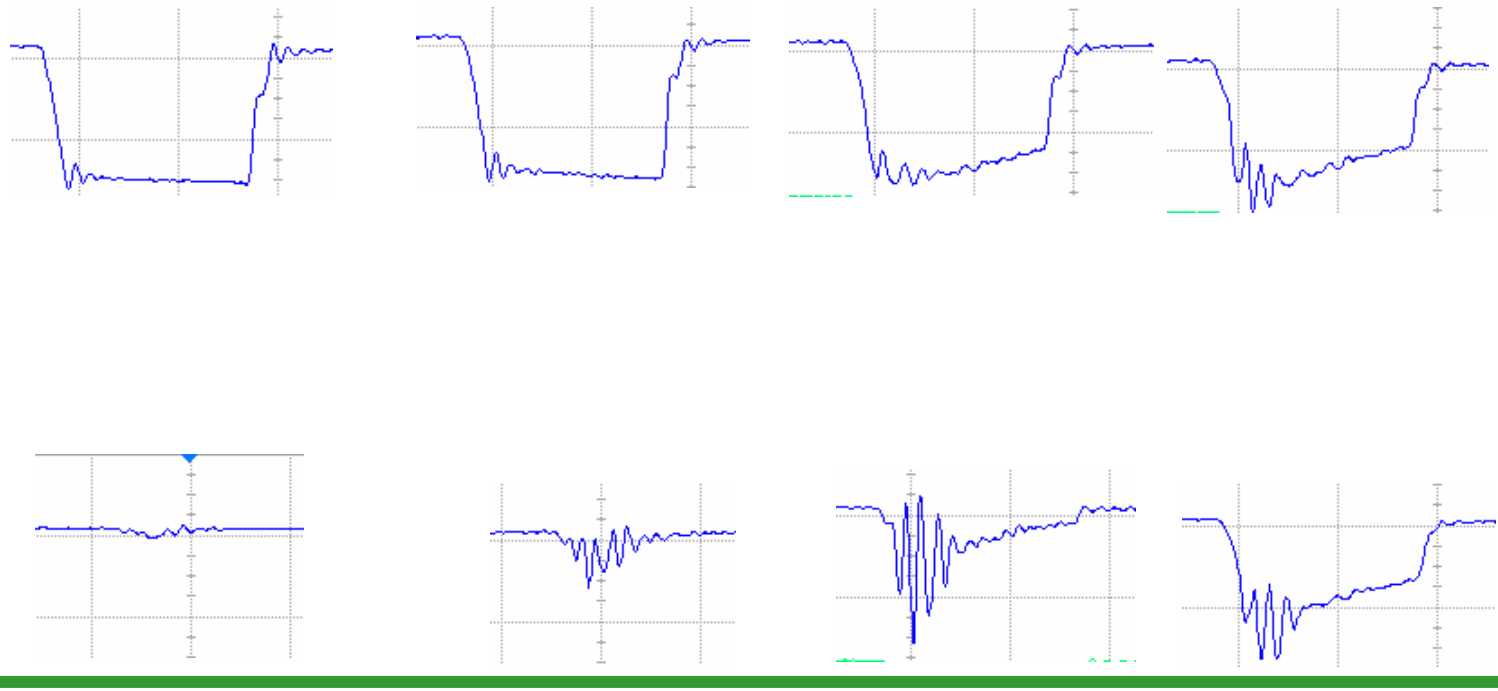
(short path length reflection?)

Droop (Common in pulse circuits)

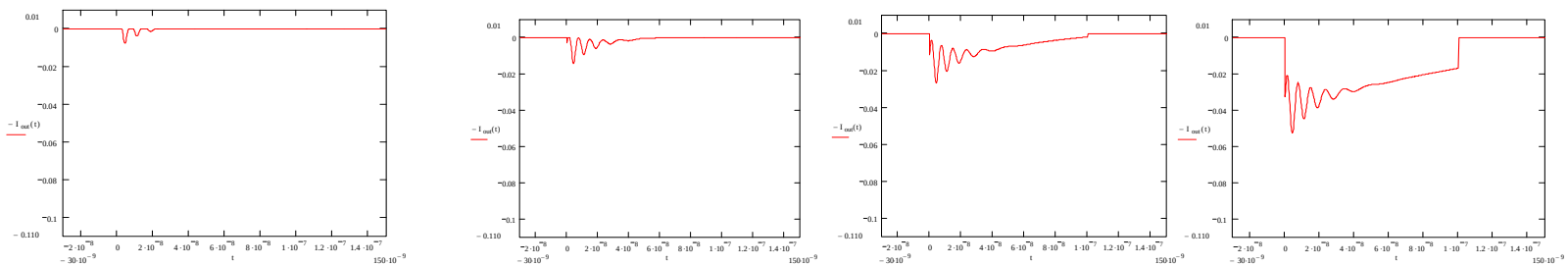
Ringing (Common in pulse circuits; frequency chirp assumed)

BV ~ -10 V

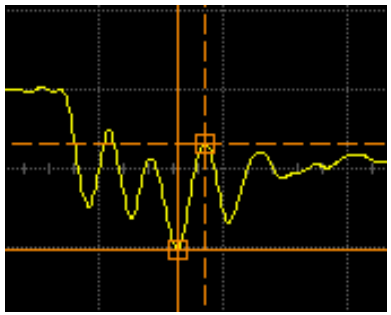


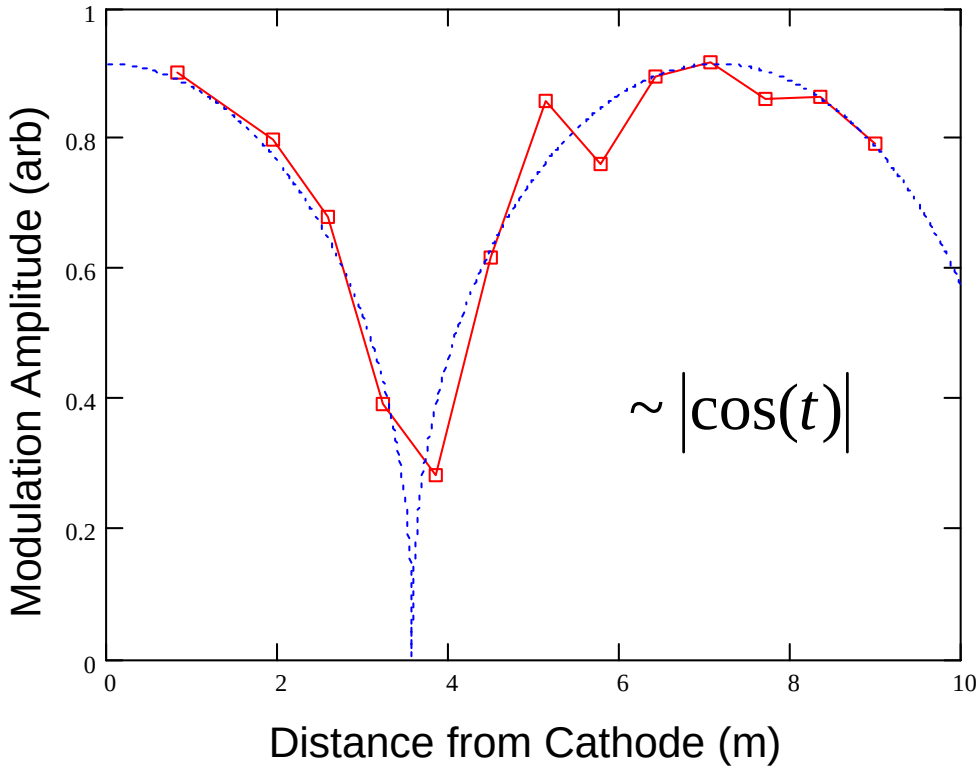


BV ~ -70 V

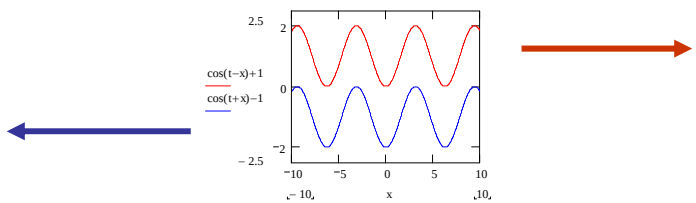


Modulation Amplitude vs. Distance





This would make sense for interfering cosine waves



Phase Velocity of Waves

Calculate phase velocity from location of nulls in data:

$$v_p = \pm 1.80 \times 10^6 \ {}^{m}\!/_{s}$$ (85 mA settings)

Compare with sound speed:

$$c_0 = \sqrt{\frac{qg\lambda_0}{4\pi\varepsilon_0 m\gamma^5}}$$

$$c_0 = 1.76 \times 10^6 \ {}^{m}\!/_{s}$$ (85 mA settings)

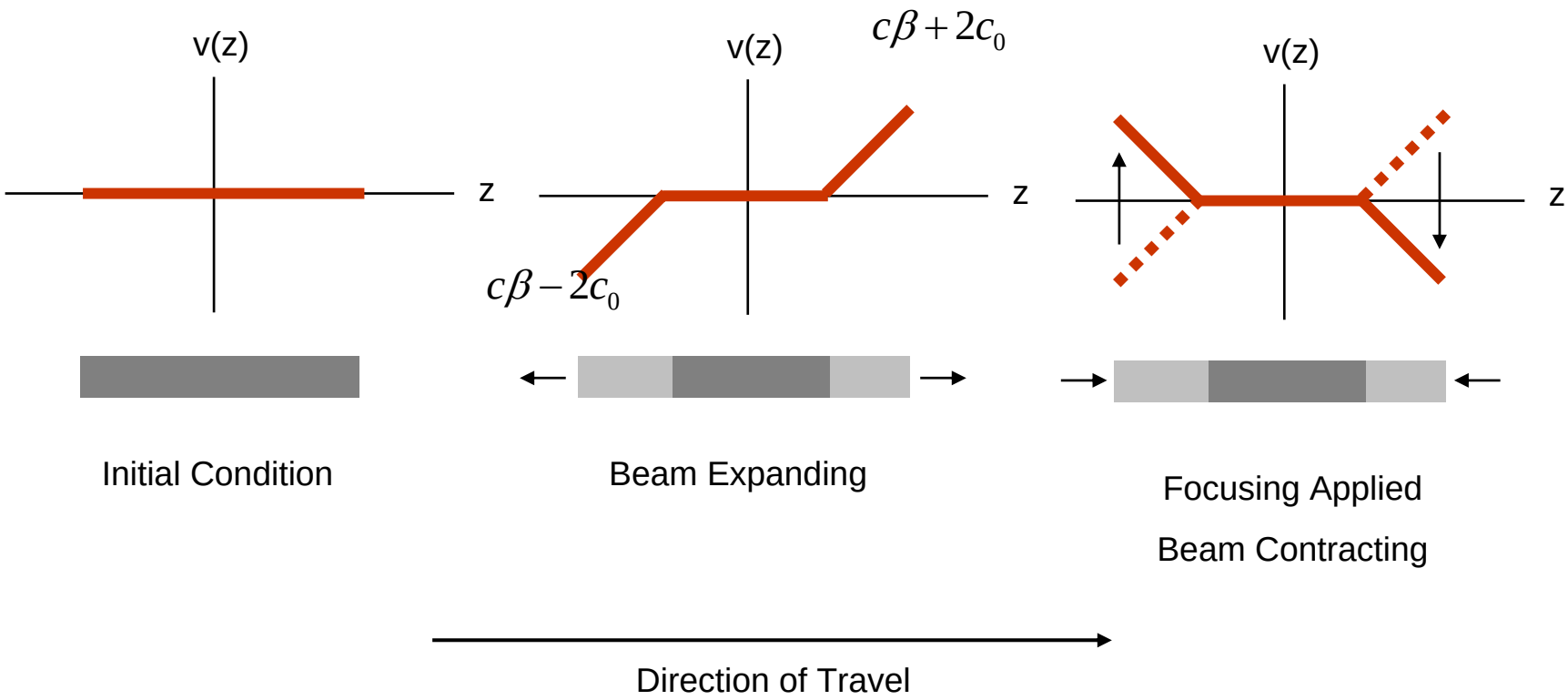
2.3% Error

Result: Modulation splits into forward, backward traveling space charge waves

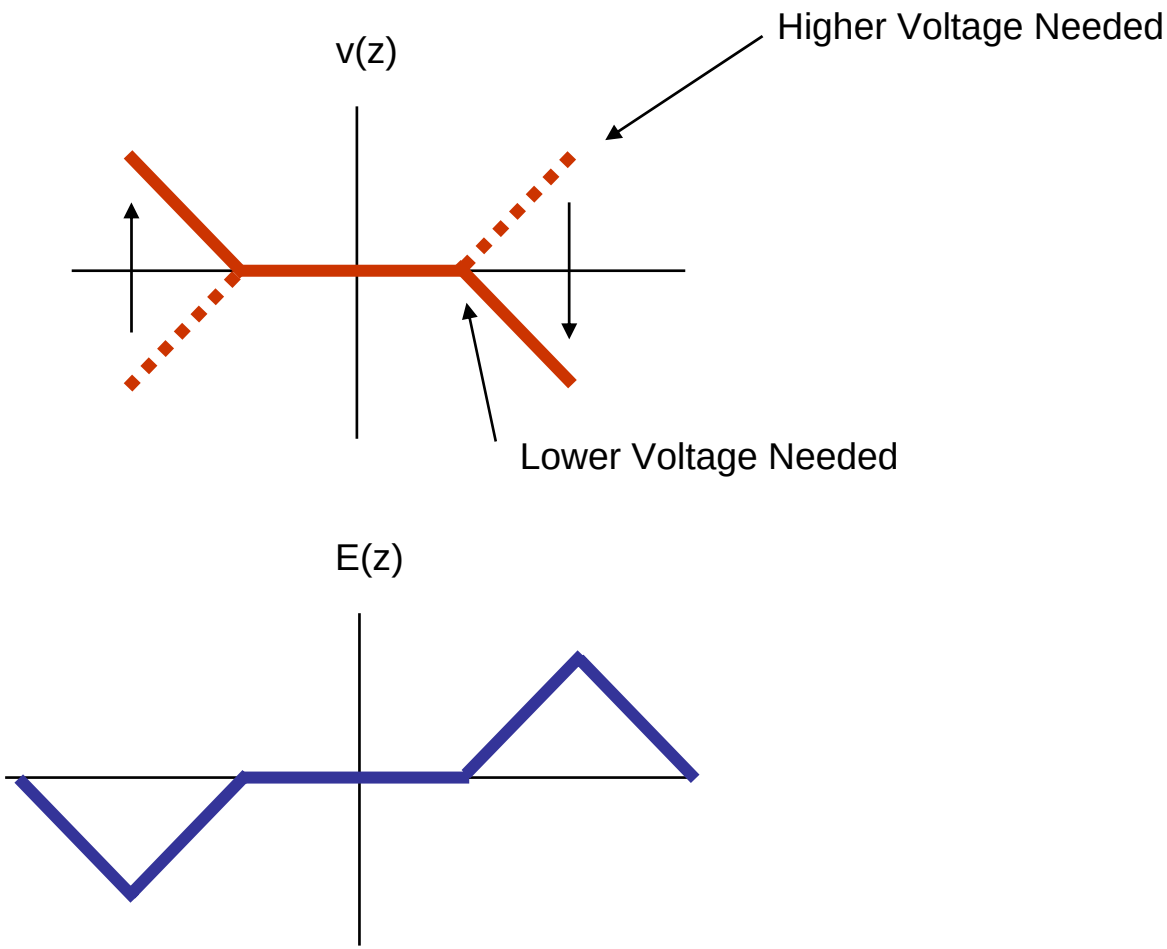
Longitudinal Focusing

Longitudinal Focusing

- Prevent beam expansion to enable extraction
- Study compression for HIF
- Allow direct manipulation of beam
- Concept:



Longitudinal Focusing Voltage

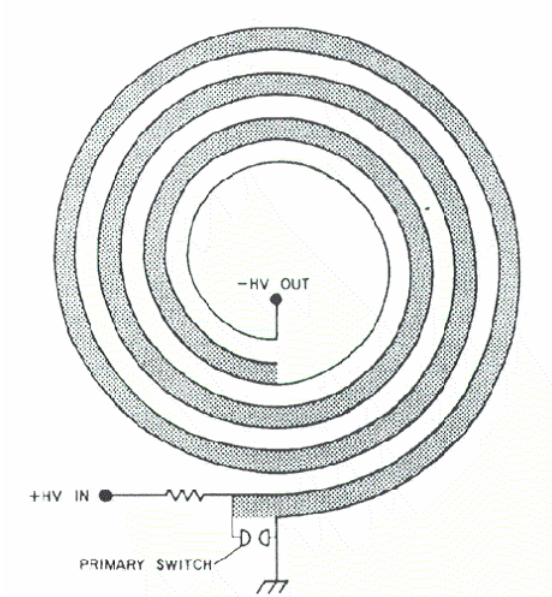


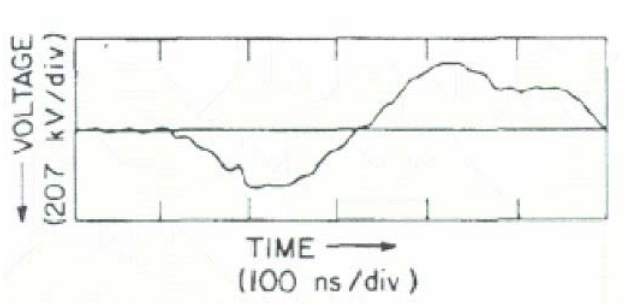
Focusing Voltage – Triangular Pulses

Spiral Generator

Advantages:

- **Triangular Pulse**
- **Simple Construction**
- **Inexpensive**
- **Voltage Gain**



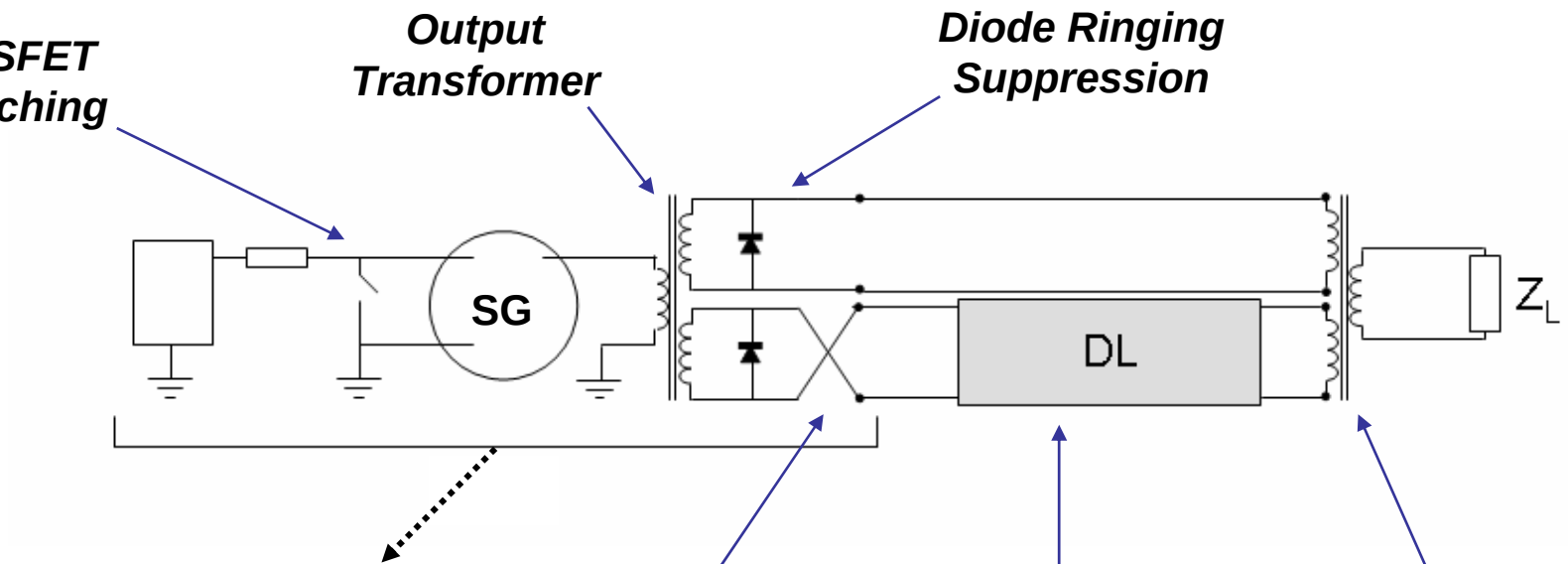


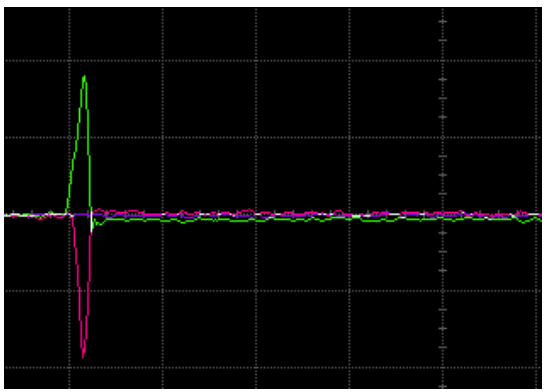
Disadvantages:

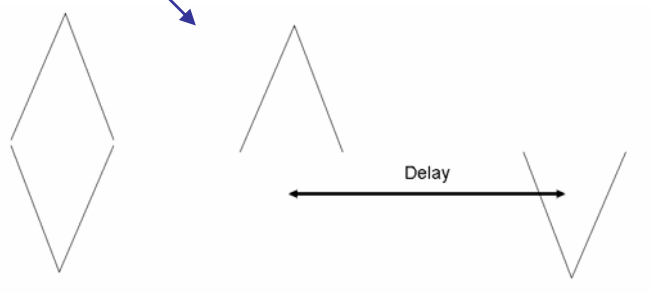
- **"Swingback" Voltage**
- **Spark Gap switching usual**

Brau et al., RSI, Sept. 1977

Spiral Generator Improvements

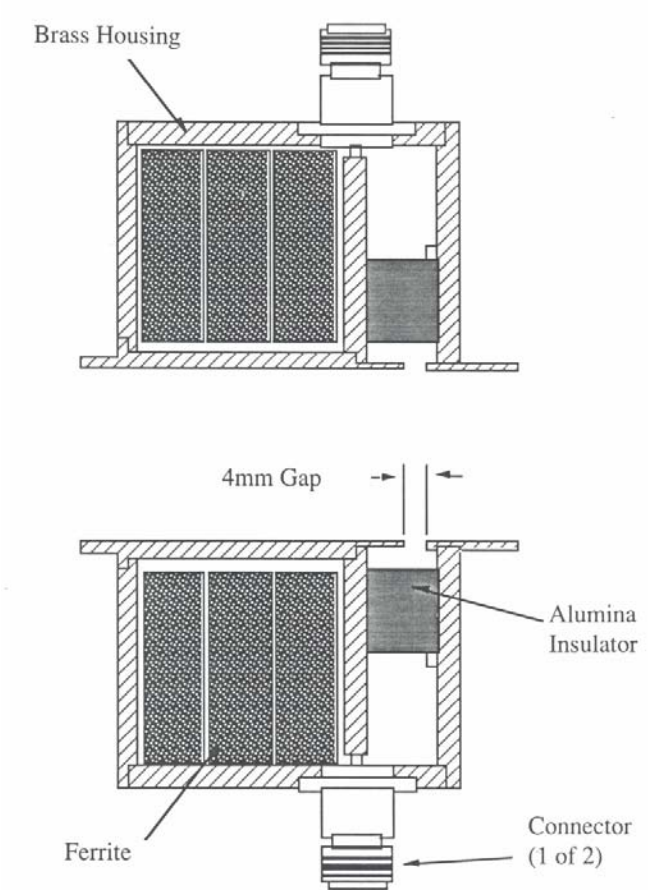






Patents Pending

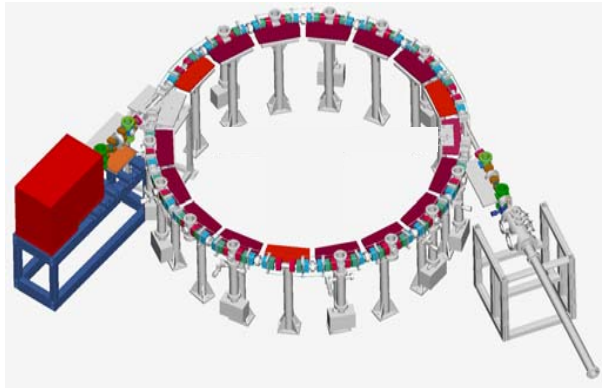
Longitudinal Focusing – Induction Modules



D.X. Wang, UMD, 1993

Future Work

- Closure
- Refine work
- Multiple Perturbations
- Modulation (esp. simulation)
- LF – HV tests, Beam tests



Conclusion

***All* beams are *sometimes* Intense; *Some* beams are *always* Intense!**

- UMER – Intense Beams
- Many interesting Longitudinal effects
- Lots of work to be done