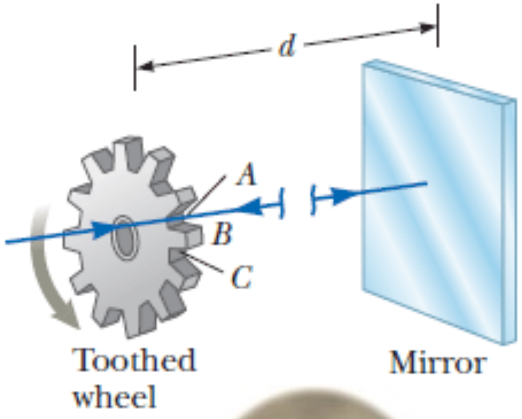
New Classroom Demonstrations in Introductory Electromagnetism and Modern Physics

Carmen Cuestas and Calin Reamy
Department of Physics, Astronomy and Geosciences
Towson University

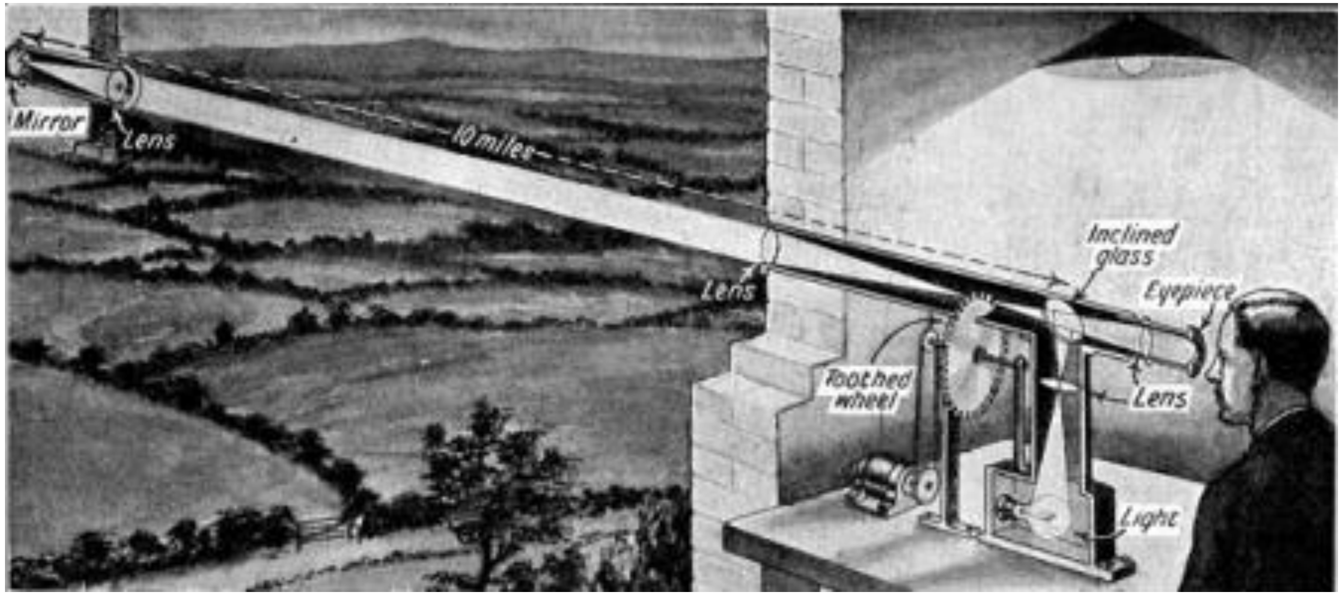
Mentors: James Overduin, Jim Selway, Jeff Klupt

PART 1: Speed of Light

- Based on Fizeau’s experiment with the rotating gear (1848)

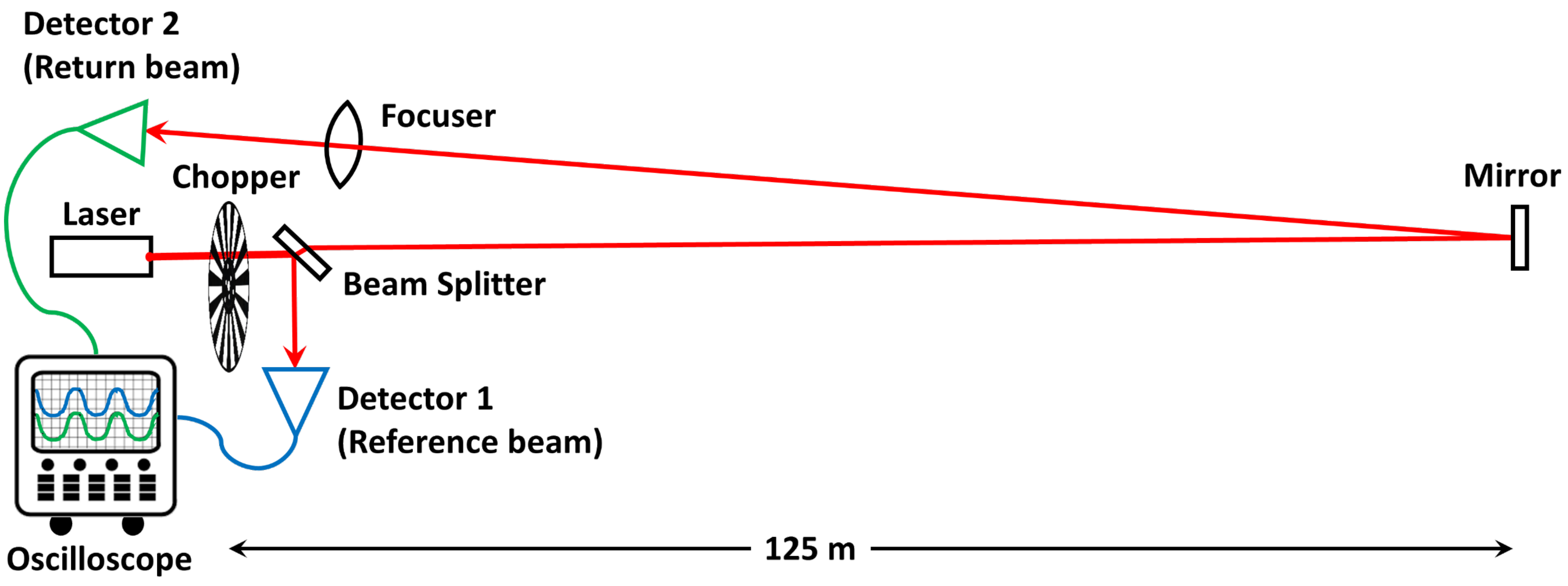


Armand Fizeau
(1819-1896)



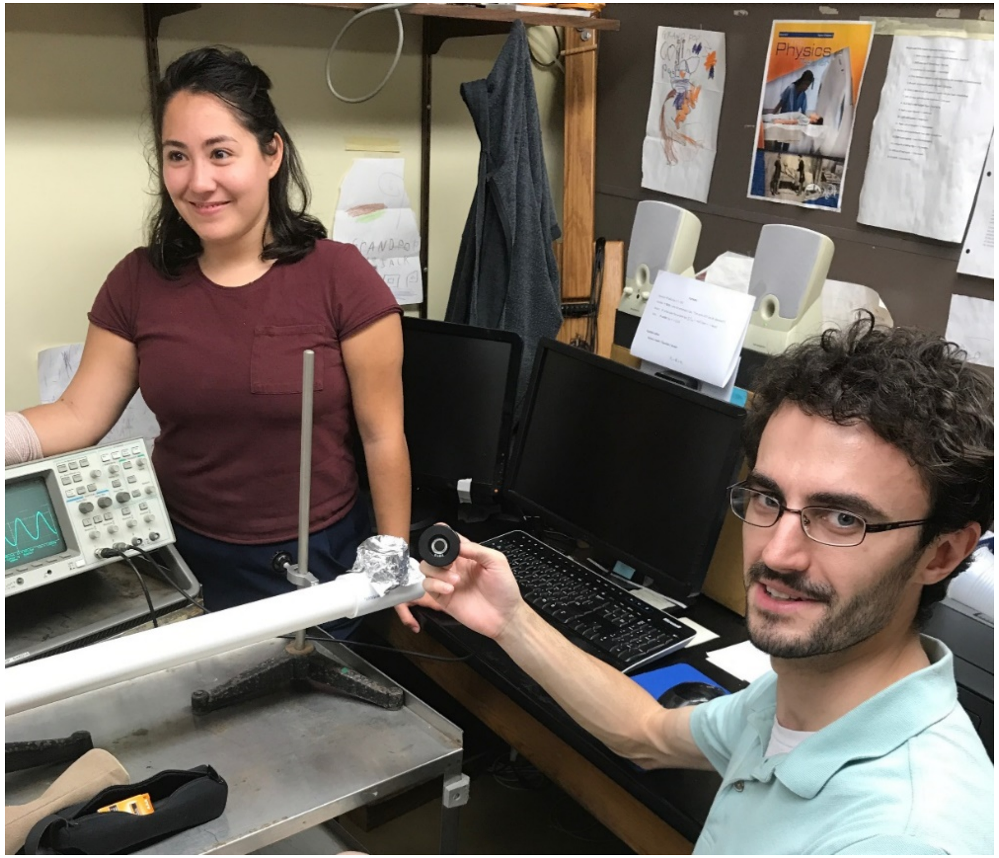
Schematic

- Many advantages over Fizeau (laser source, photodiode detectors, oscilloscope)
- But a much shorter distance! (125 m-long hallway)



Detectors

- Off-the-shelf silicon photodiodes



Carmen and Calin with oscilloscope and unknown detector #1

Jon with Mark 2 with Photologic OPL562-OCA detector and housing (to block ambient light)

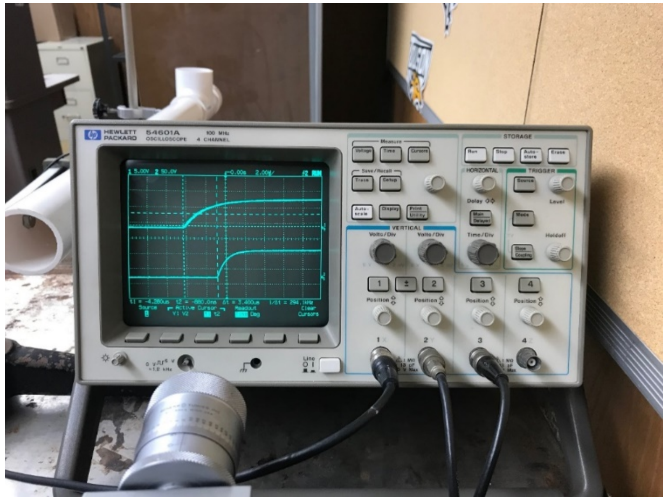
Setup

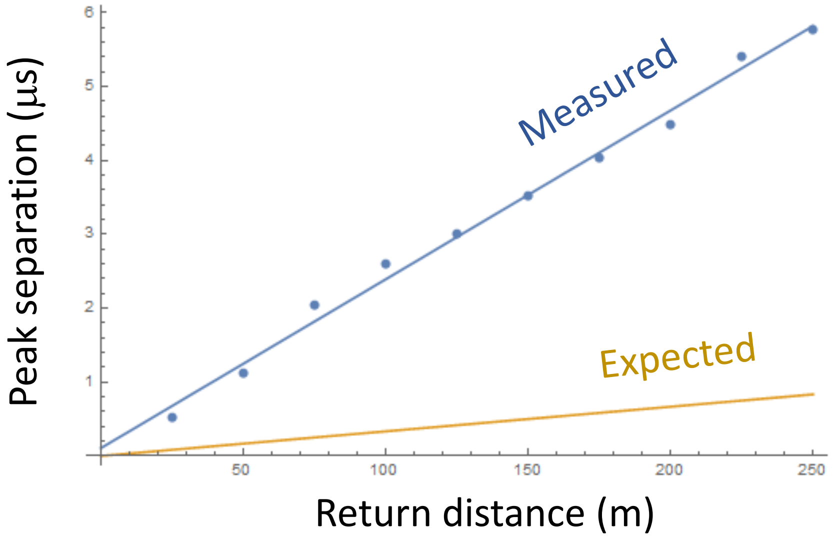
- Important to use mounts with fine directional control for the laser and mirror(s)

Conducting a short-distance trial

Preliminary Results

- Two peaks (travel & reference beam) clearly seen on oscilloscope

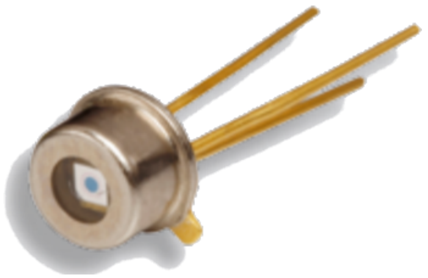




- Separation between peaks increases with distance as expected
- But 7 times larger than expected!
- Problem appears to be propagation delay in detectors (~5 µs), plus losses due to divergence of the laser beam (~0.7 mrad)

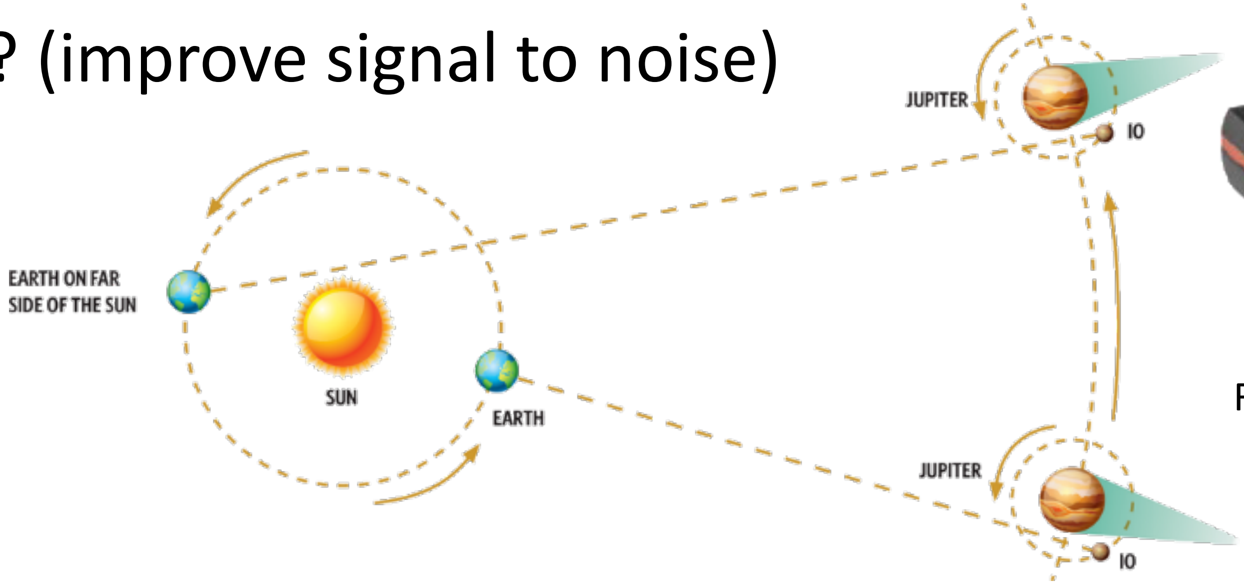
Next Steps

- Faster detectors (100 ps vs 5 μs propagation delay)
- Better laser (0.07 mrad vs 0.5 mrad divergence,
  25 mW vs 3 mW power)
- Modulated signal? (vs. chopper wheel)
- Lock-in amplifier? (improve signal to noise)
- Backup method?
  Astronomy!
  (Rømer, 1670)



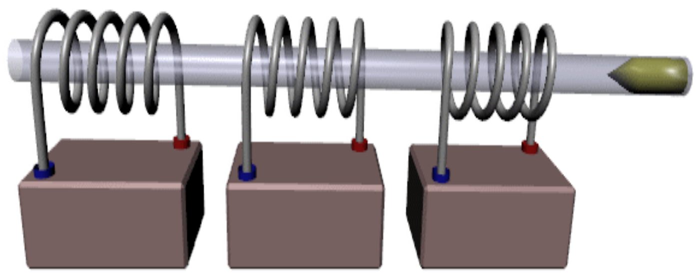
OptoElectronics BPX-65

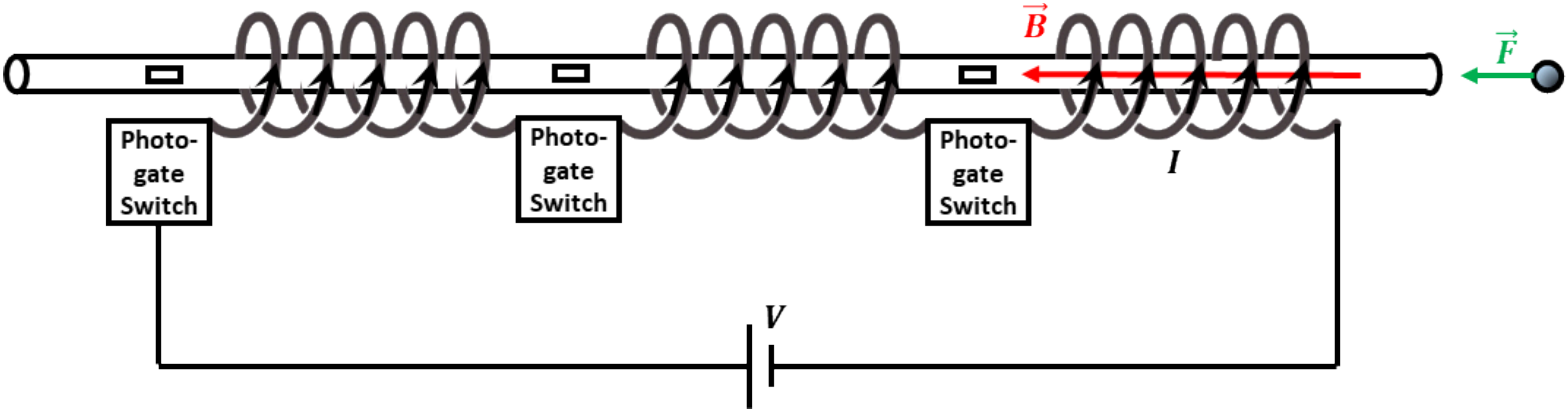
Flexpoint FP-LR-520-25



PART 2: Electromagnetic Accelerators

- Design (a): Magnetic cannon





Implementation

- Maxwell's pulling force formula:

$$F = \frac{B^2 A}{2\mu_0}$$

where A=area of ferromagnetic test body

- Using $B \sim 0.01\ \mathrm{T}, A \sim (3\ \mathrm{mm})^2$ expect:

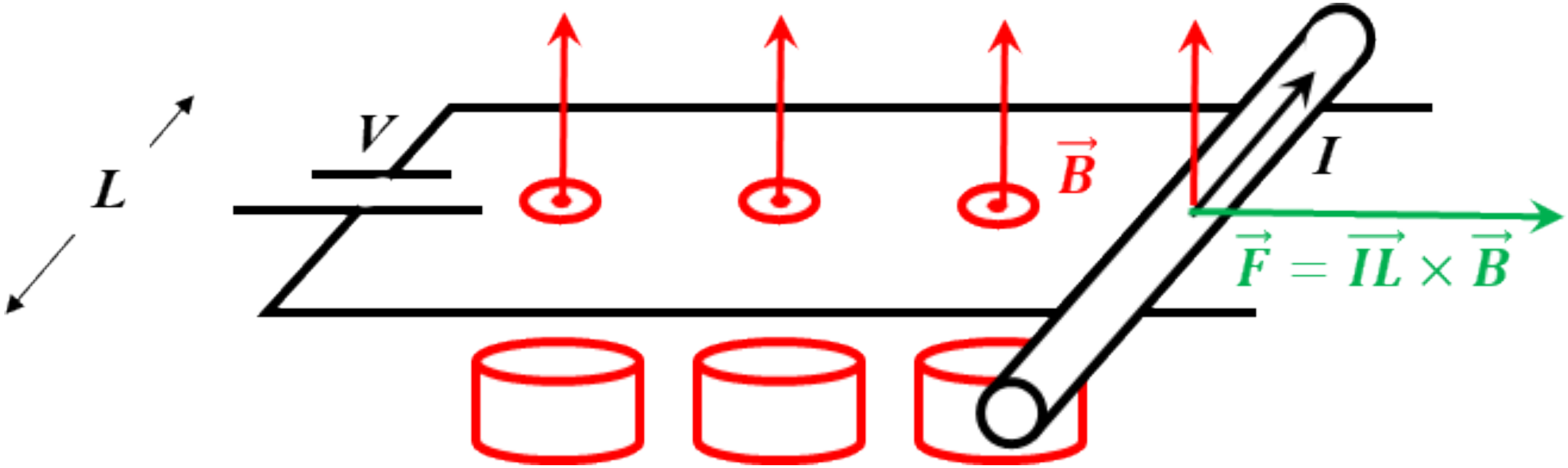
$$F \sim 0.4\ \mathrm{mN}$$

- Gives $a \sim 0.4\ \mathrm{m/s^2}$ for $m \sim 1$ g (weak)
- *Problem:* high current melts tube!
- *Next step:* design and implement photogate switch

Measuring pulling force for a single coil

(b) Simple Railgun

- Uses Lorentz force on a current in the field of *permanent magnets:*



Implementation

- Lorentz force:

$$F = ILB$$

- Using $I \sim 5\ \mathrm{A}, L \sim 2\ \mathrm{cm}, B \sim 0.5\ \mathrm{T}$:

$$F \sim 50\ \mathrm{mN}$$

- For $m \sim 10\ \mathrm{g}$, gives:

$$a \sim 5\ \mathrm{m/s^2}$$

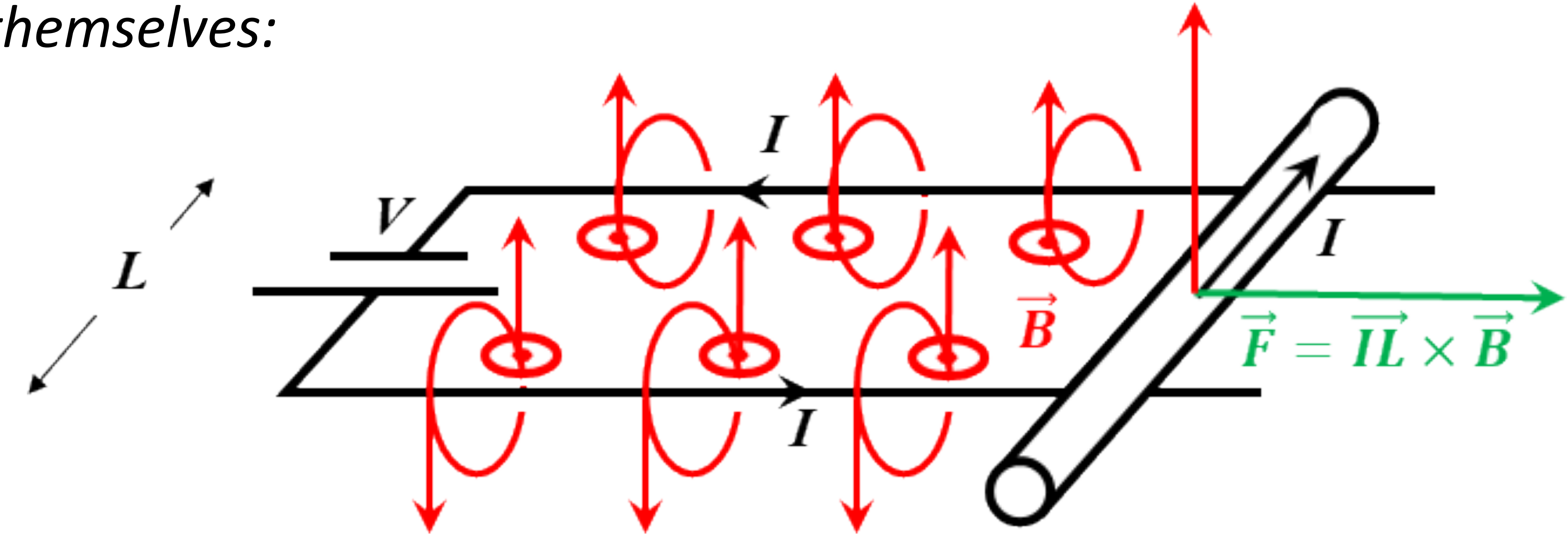
- *Problems:* sparking, pitting, "welding" to rails;
  projectile rolls off rails
- *Next steps:* taller rails, spherical projectiles

Mounting the magnets under the rails --- trickier than it may seem!

Trial runs

(c) Real Railgun

- Uses the magnetic field generated by the *current in the rails themselves:*



- With $B = \frac{\mu_0 I}{2\pi r} \sim 4\times 10^{-7} I/L$, get $F = ILB \sim 4\times 10^{-7} I^2$
- *Problem:* need at least 1000 A of current to reach $a \sim g$!

Scaled-up version

- US Navy tests with energy 32 MJ (Dahlgren VA, 2012)

Capacitor banks to supply current

- Can accelerate a 3 kg projectile to *Mach 7* = 2400 m/s

Summary

- We will be satisfied with a $\sim$10% measurement of c and a railgun that reaches $a{\sim}g$
- Still works in progress!

- Thanks to Towson University's College of Science and Mathematics and the Maryland Space Grant Consortium for support