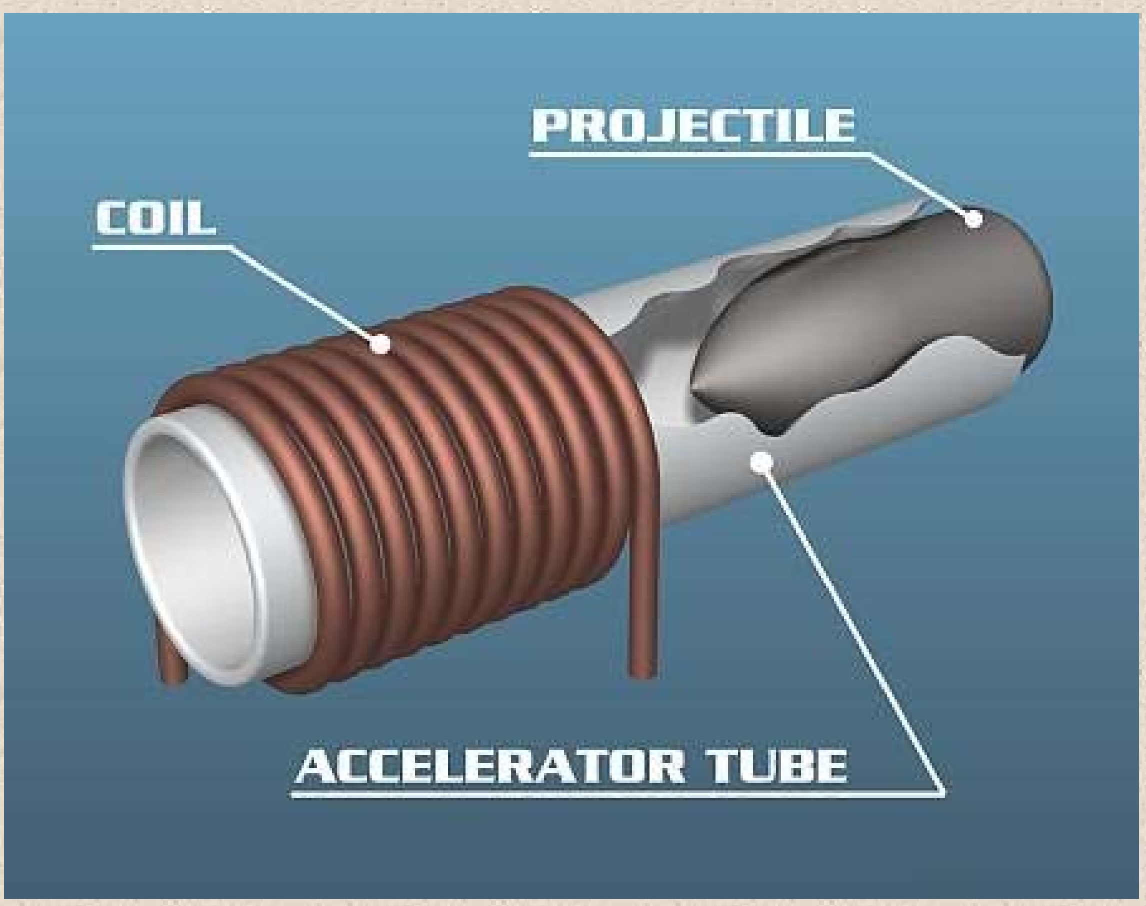
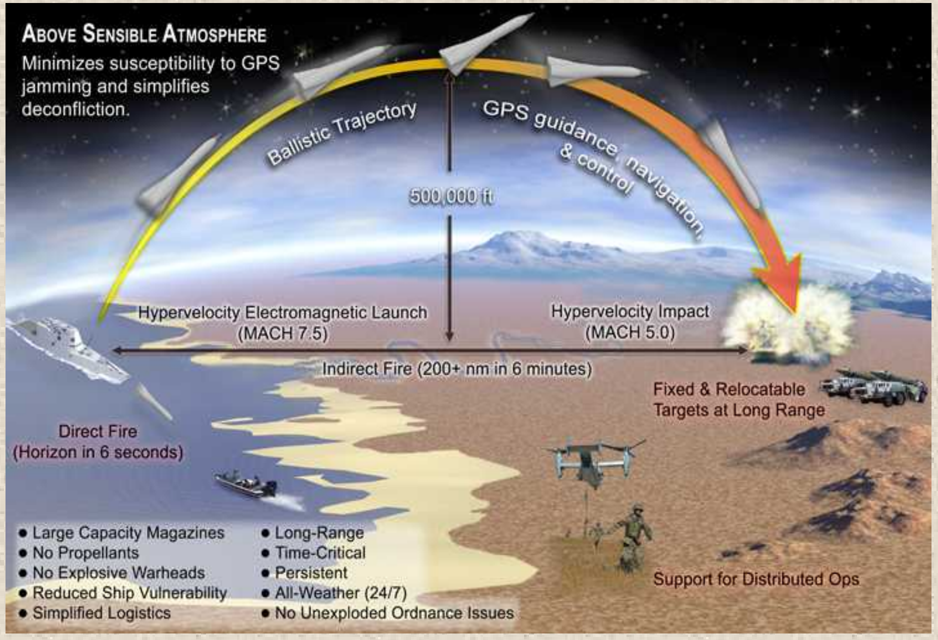
№1. Electromagnetic cannon

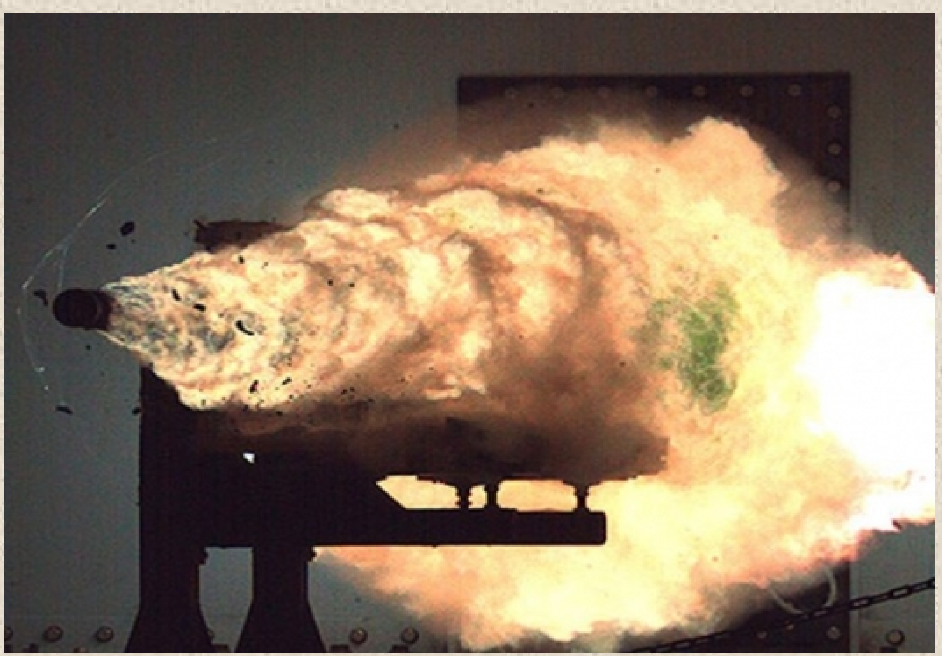
GEORGIA

Alexander Barnaveli



A solenoid can be used to fire a small ball. A capacitor is used to energize the solenoid coil. Build a device with a capacitor charged to a maximum 50V. Investigate the relevant parameters and maximize the speed of the ball.


ABOVE SENSIBLE ATMOSPHERE
Minimizes susceptibility to GPS jamming and simplifies deconfliction.
Ballistic Trajectory
GPS guidance, navigation & control
500,000 ft
Hypervelocity Electromagnetic Launch (MACH 7.5)
Hypervelocity Impact (MACH 5.0)
Indirect Fire (200+ nm in 6 minutes)
Fixed & Relocatable Targets at Long Range
Direct Fire (Horizon in 6 seconds)
Support for Distributed Ops
• Large Capacity Magazines
• No Propellants
• No Explosive Warheads
• Reduced Ship Vulnerability
• Simplified Logistics
• Long-Range
• Time-Critical
• Persistent
• All-Weather (24/7)
• No Unexploded Ordnance Issues



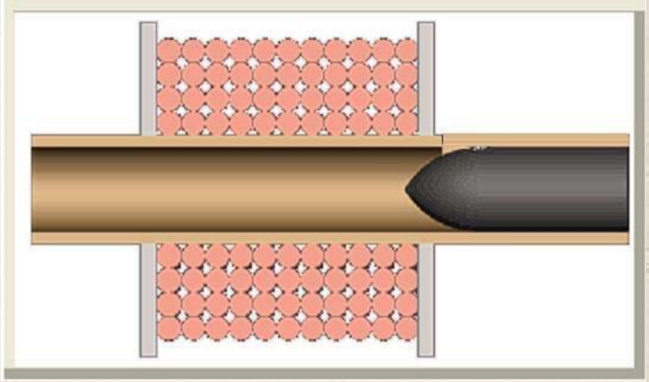
Presentation Plan

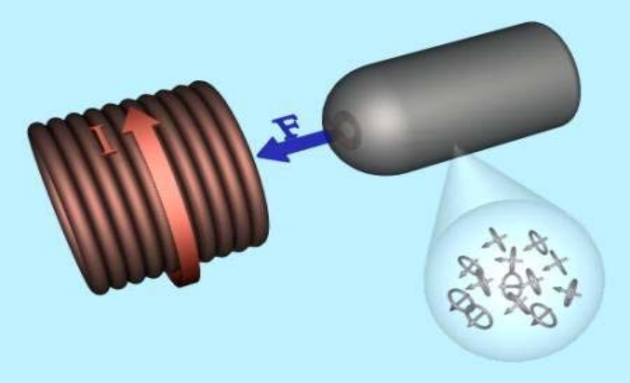
- **Principles of the Electro-Magnetic Cannon action,**
- **Experiment (EM cannon in action);**
- **Preliminary theoretical consideration;**
- **Our version of Coil-Gun construction;**
- **Results. Progress achieved by our optimization.**

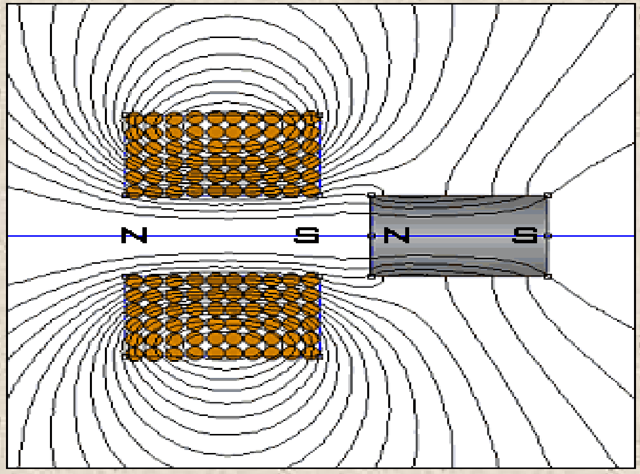
Principles of EM Cannon Action

Components:

- Solenoid (coil)
- Tube (barrel)
- Ferromagnetic projectile
- Power Source / Capacitors







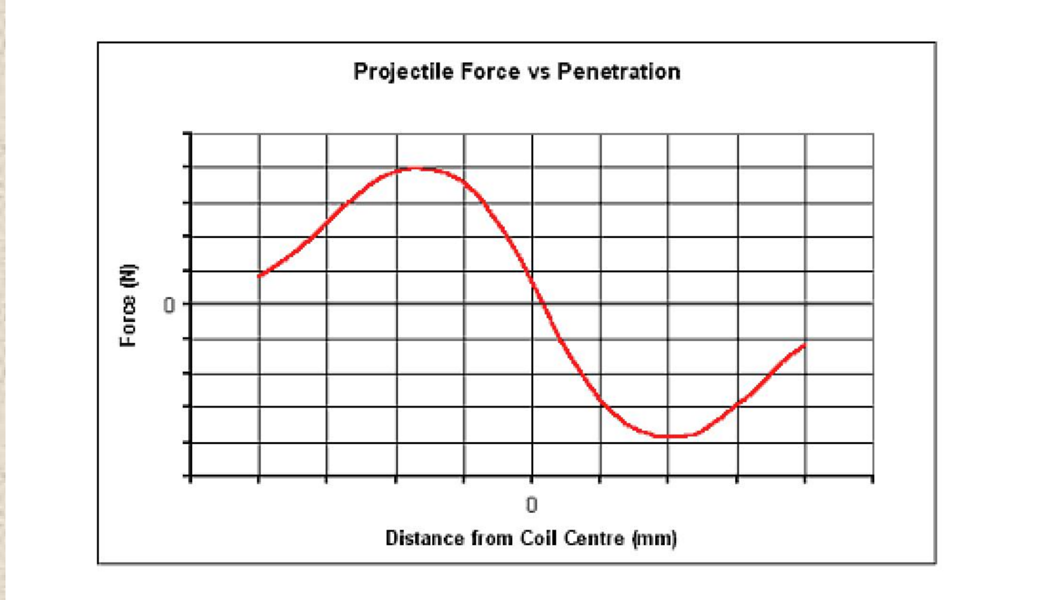
1. Electric current in the solenoid creates the magnetic field
2. External magnetic field causes alignment of micro-current domains in ferromagnetic projectile
3. The Projectile gets magnetized

   The pole signs of the coil and of projectile are mutually symmetric

4. The projectile is attracted to the coil center

Figures 1,2,3

"EM Cannon middle-point" Problem



- After passing the coil center the projectile will be **attracted backwards**.
- In the coil center the **electric current must be turned off;**
- We must use the special switching scheme.

Electro - Magnetic Cannon in Action

Action


Entrance
Exit

Preliminary Theoretical Considerations

The force applied to the projectile by solenoid:
[http://www.coilgun.eclipse.co.uk/coilgun_fundamentals_1.html]

$$F \sim N \cdot I \cdot \frac{d\Phi}{dx} \qquad (1)$$

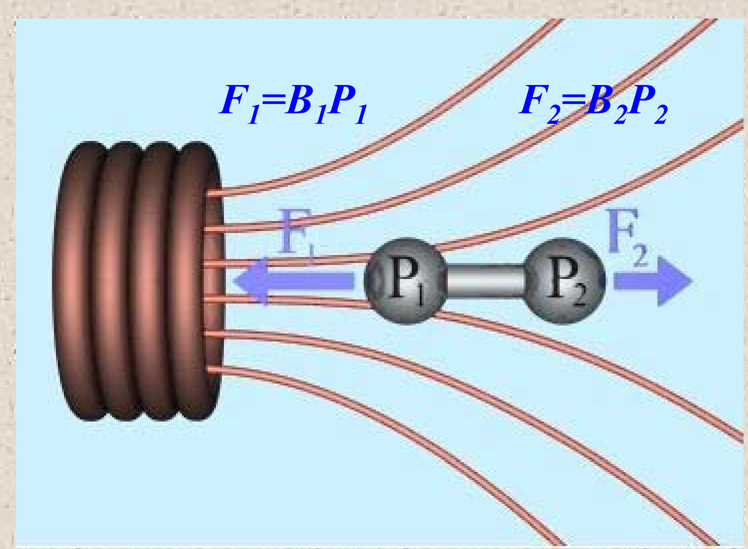


Fig 4
The sum of the forces applied to the dipole by field gradient

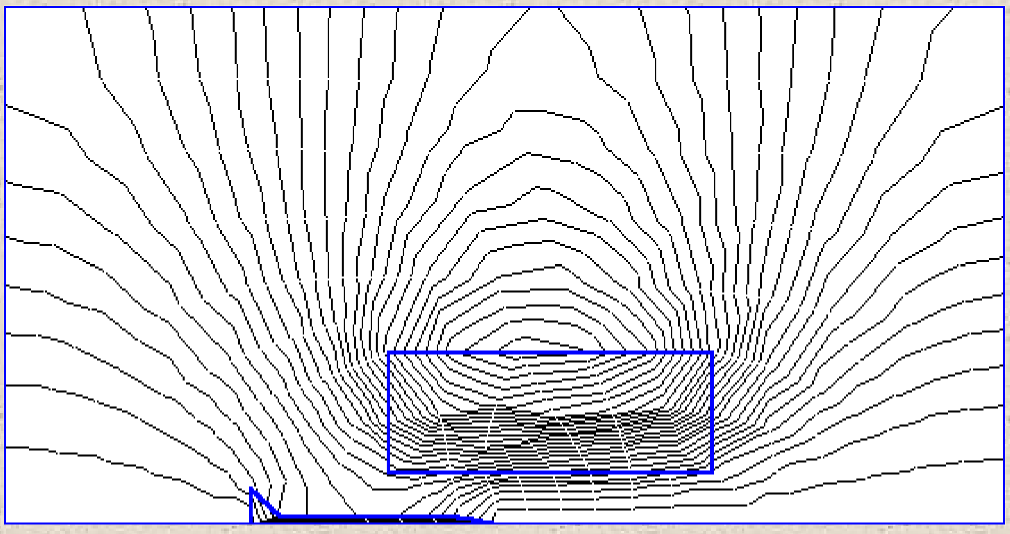
N – number of turns (loops) in solenoid,

I - current,

$\frac{d\Phi}{dx}$ - the **Magnetic Flux Gradient at the projectile** with respect to displacement in tube

($\Phi = \vec{B} \cdot \vec{S}$)

Fig 5. Change of the field linked to the projectile



Construction of coil-gun must provide the *maximal* value of the expression

$$N \cdot I \cdot \frac{d\Phi}{dx}$$

Preliminary Theoretical Considerations

a) Optimal Barrel

b) Optimal Projectile

c) Optimal dimensions of Solenoid

d) Optimal number of Turns / Wire Diameter

e) Capacitors

f) Iron Shell

Pro:

The iron shell increases the concentration of the magnetic field power lines at the ends of the coil.

Shell supports Φ and $\frac{d\Phi}{dx}$

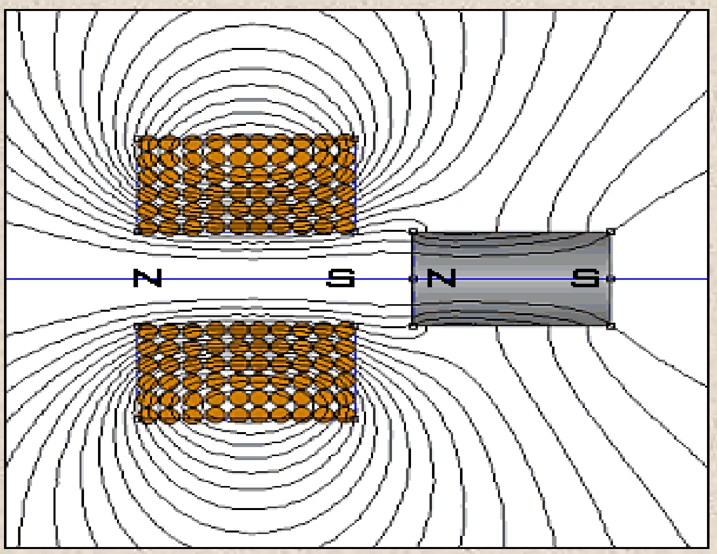
Con:

- **Shell increases the inductance of the coil:** $L \sim \mu$ (μ - magnetic permeability of the shell)

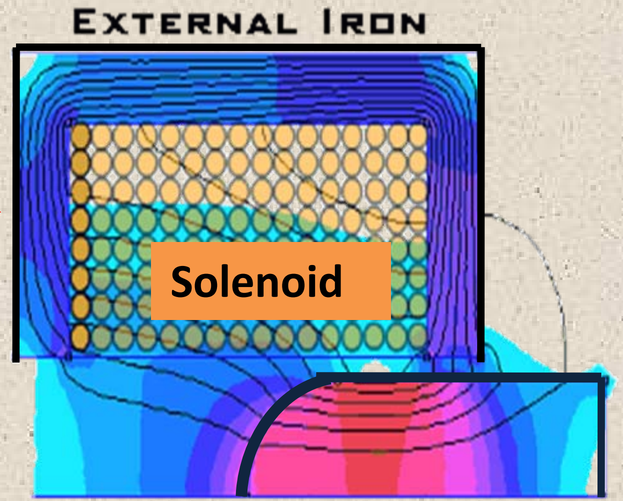
  Larger strength of induced voltage (ElectroMotive Force – EMF) decreasing the current change rate

$$\varepsilon = -L\frac{dI}{dt}$$

- **Parasite currents**.



Iron shell →

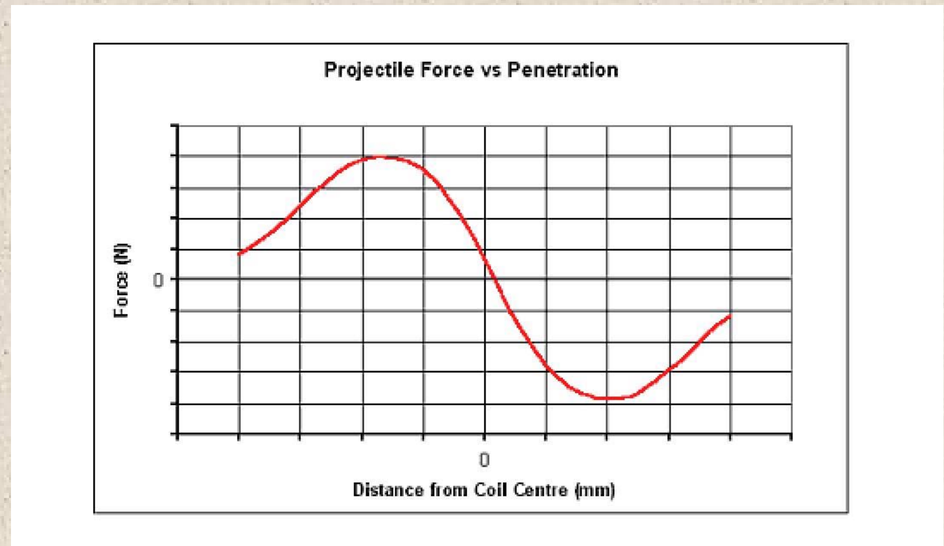


Magnetic lines in case of iron shell

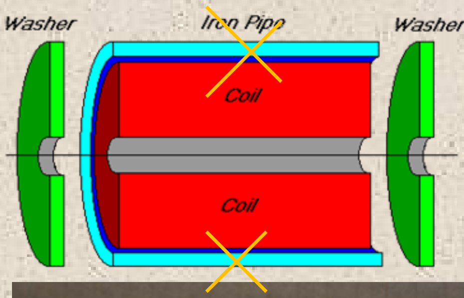
g) Switching off the coil power supply

- After passing of the coil center the acting force **changes its sign (direction)**
- The projectile **starts to slow down**
- For the **maximal speed** we have to **switch off** the power supply when the projectile reaches the centre.

The force, applied to projectile



Our construction of coil gun



We focused our attention on:

1. **Optimization of the solenoid shell:**

Only closing washers - solenoids (B, C)

(2 From side of projectile load and 1 from back side) 2 mm thick iron.

- **Higher gradient** $d\Phi/dx$ at the place of projectile input
- No significant increasing of coil inductance L
- No significant **parasite current**
- No suppression of discharge current.

(A)

(B)

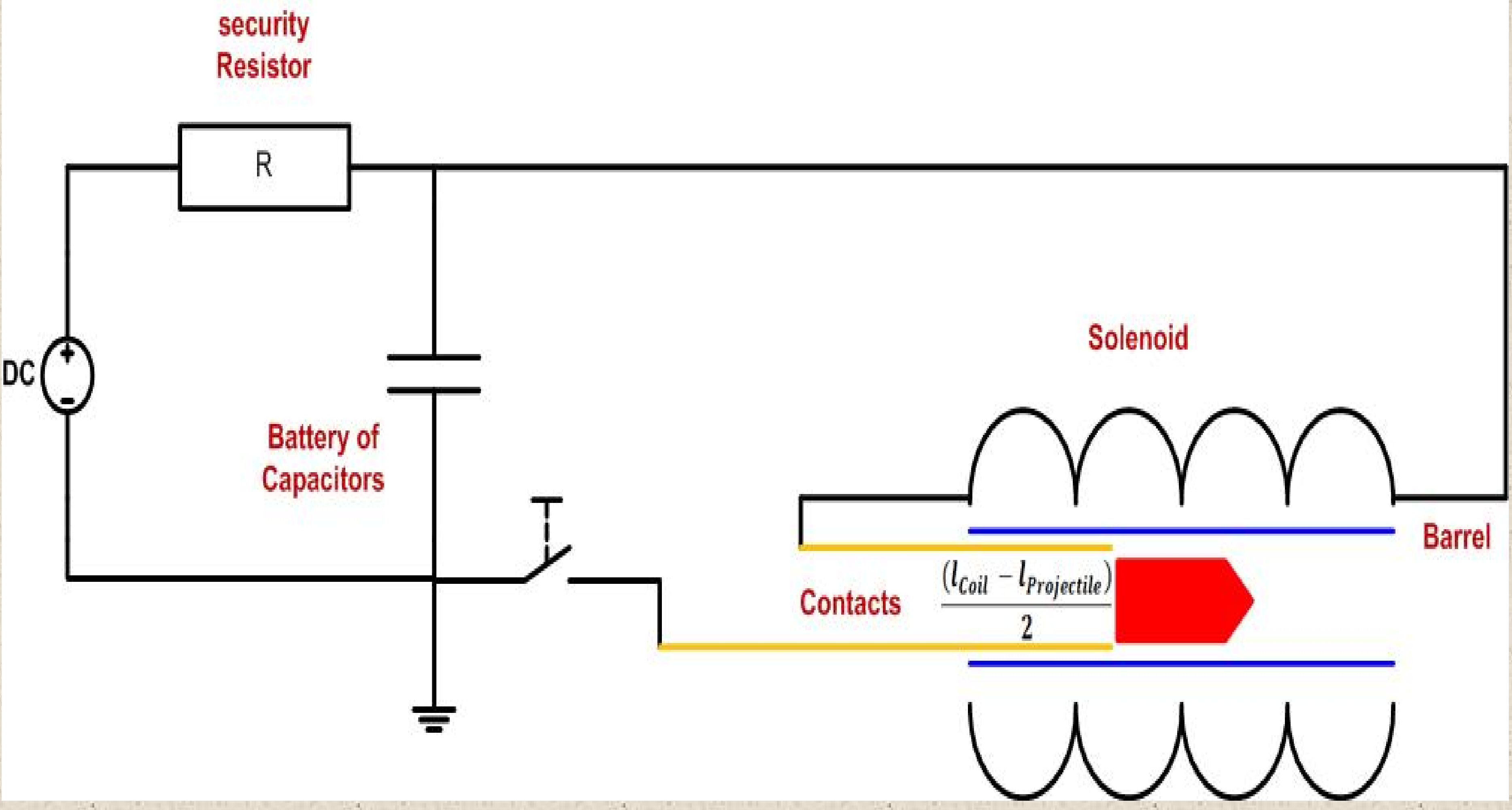
2. **Optimization of the solenoid center problem solution:**

- **Switching off the circuit when the projectile reaches solenoid center (A,B).**
- **Enhanced "Consequent switching-off" scheme - solenoid (C).**

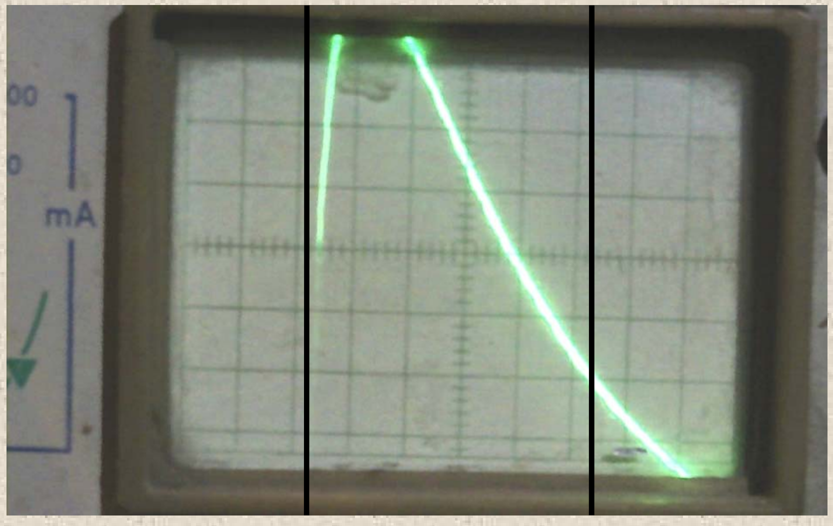
(C)

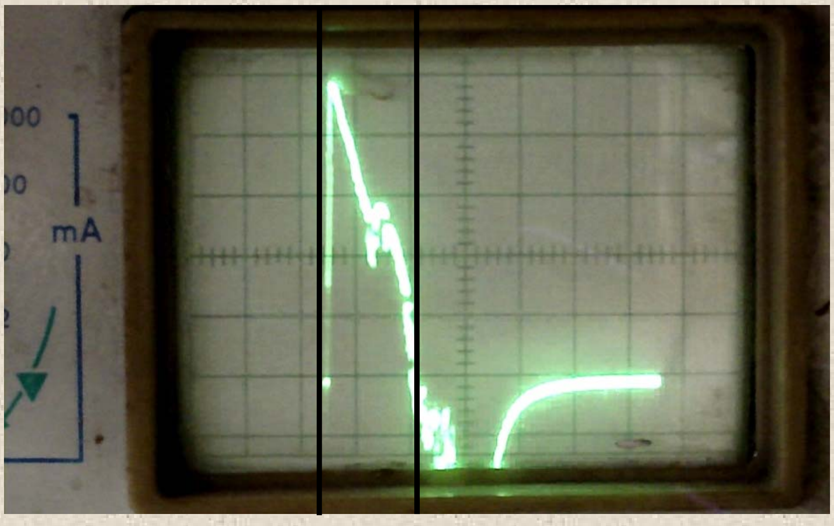
Circuit Scheme No1

Switching - off at the middle-point



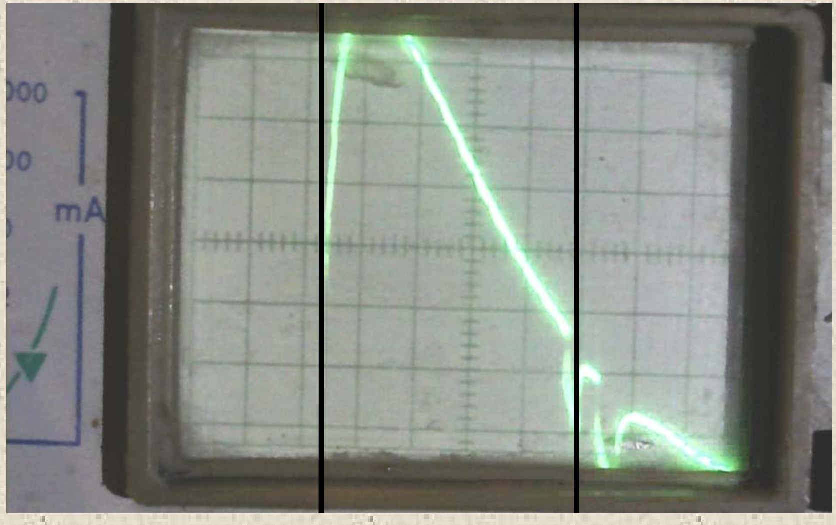
Impulse

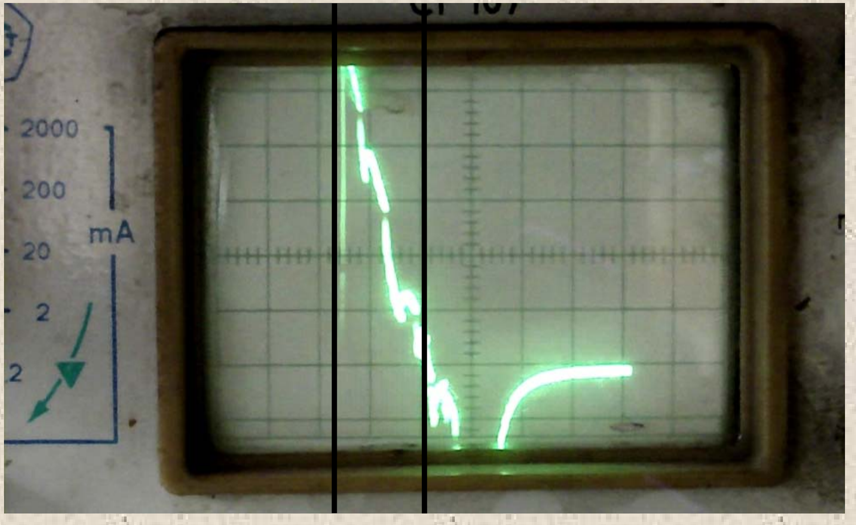




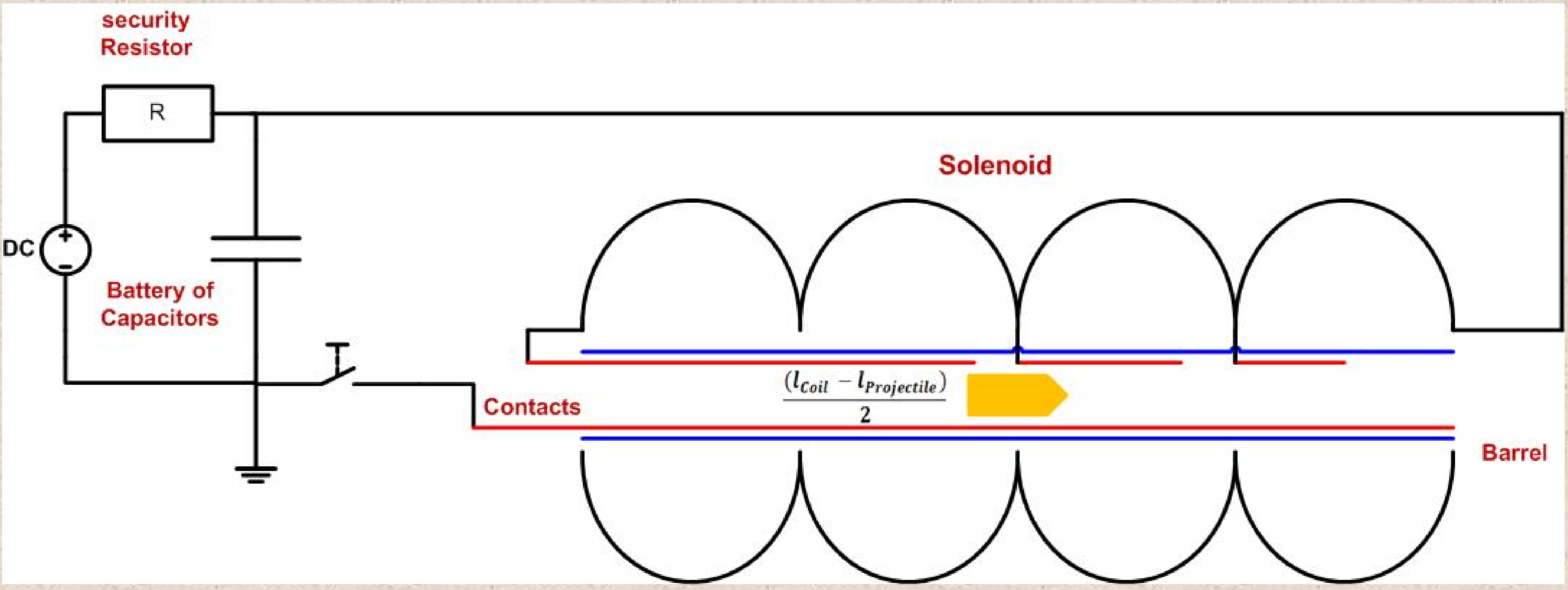
Not cut

Cut





Enhanced scheme



Consequent switching-off the parts of solenoid behind the projectile

About 17% higher velocity

Additional EMF in front parts !!

With **300V** and enhanced scheme we get → **42 m/sec**

Parameters of our coil gun

We experimented with two basic configurations (50V and 300V):

Voltage	*Capacity*	*Length*	*Wire D*	*Outer D*	*Inner D*	*Turns*
50 V	**12 000 µF**	5.5 cm	1.4 mm	4 cm	0.9 cm	350
300 V	**900 µF**	4.8 cm	0.45 mm	4.5 cm	0.9 cm	900

(A)

(B)

(C)

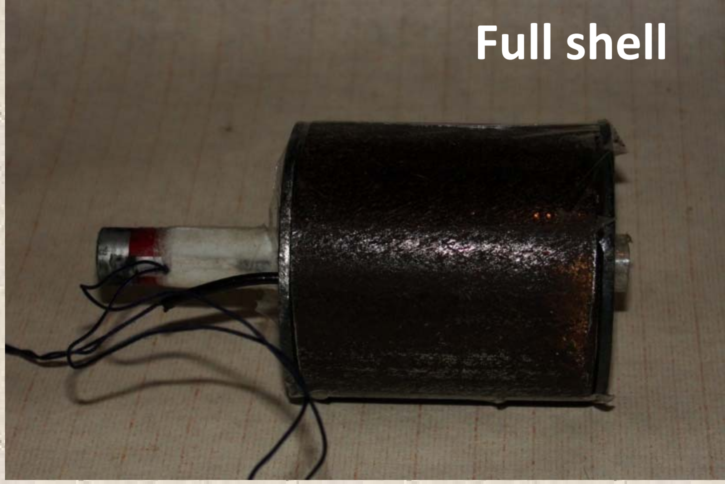
Batteries of capacitors

300V

50V

Our coils

(A)



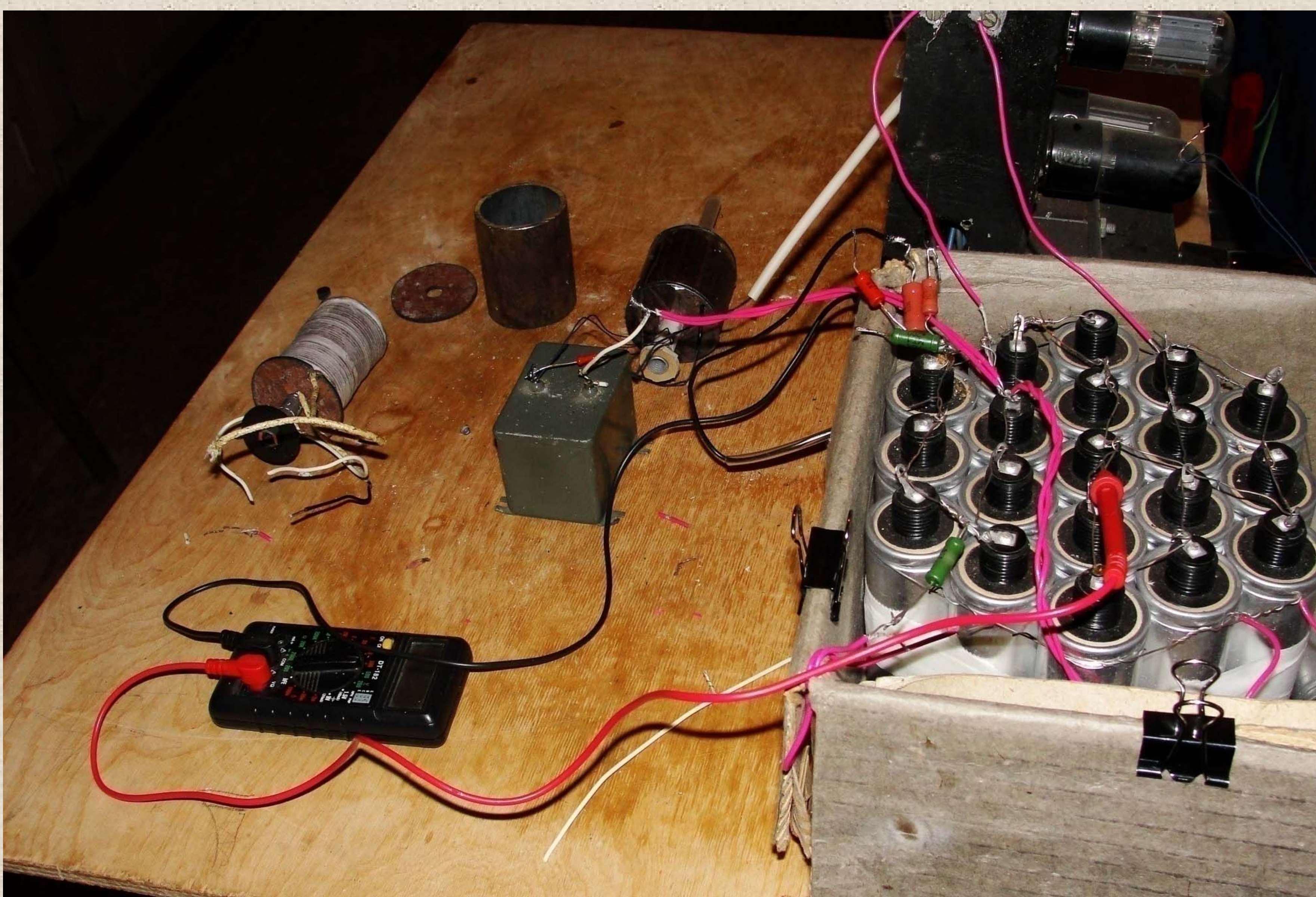
(B)

(C)

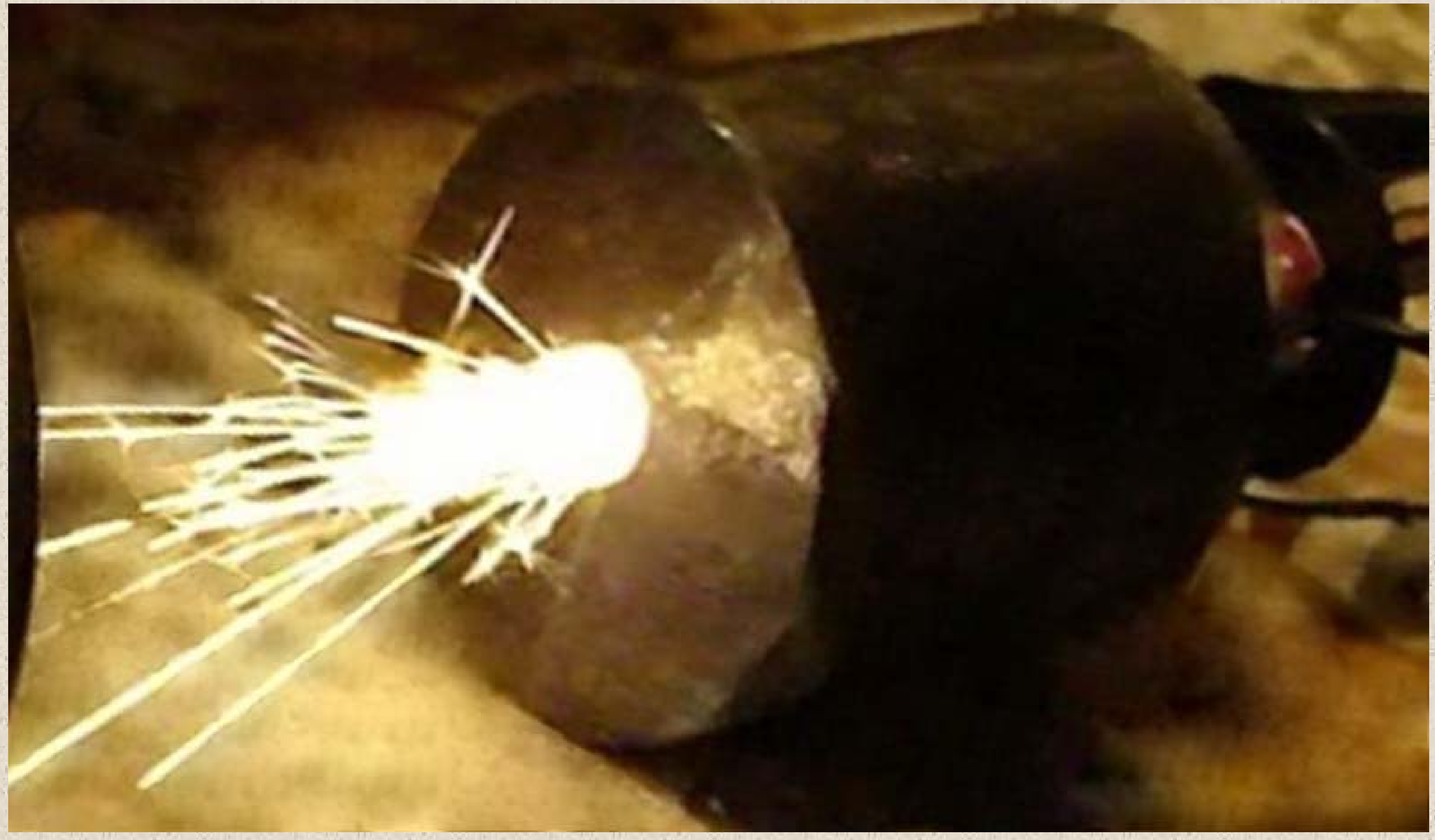
Projectiles

We have chosen following projectiles:
6 mm * 30 mm
6 mm * 15 mm , soft iron
6 mm * 10 mm
6 mm=D Ball, of soft iron

Full installation



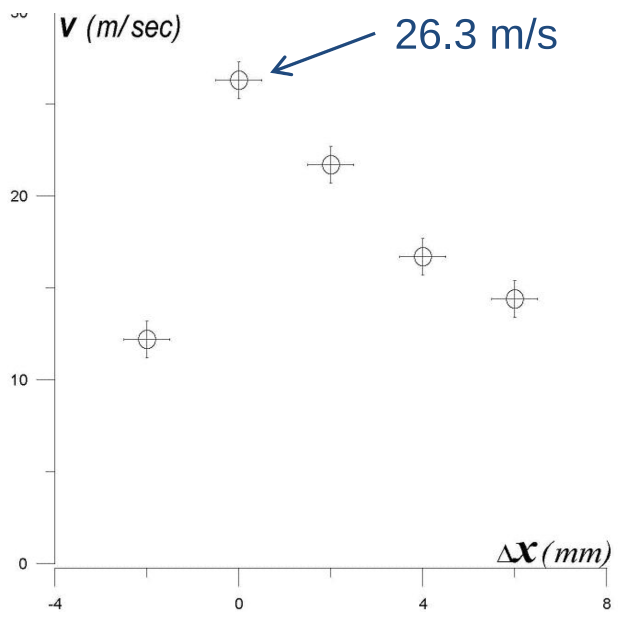
Shots



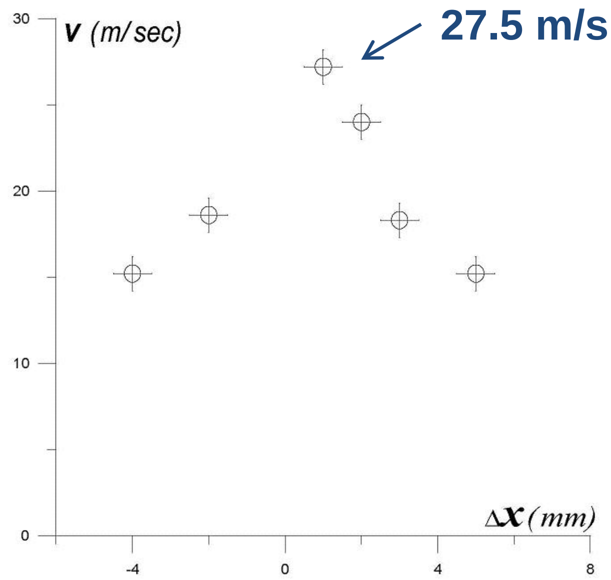
Shot

Velocity

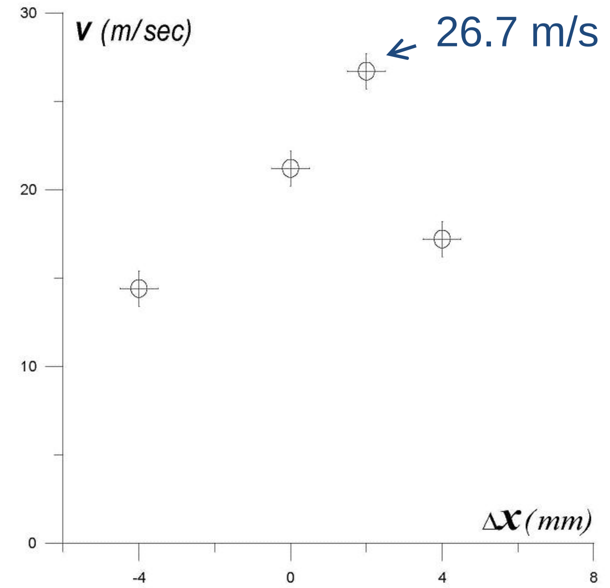
50v optimal shield



6 mm Ball



15 mm projectile



10 mm Projectile

300v

Switching Scheme	*Shell*	*Velocity*
Center switch-off	Full	30 m/s
Center switch-off	Optimal	36 m/s +20%
Consequent switch-off	Optimal	42 m/s +17%

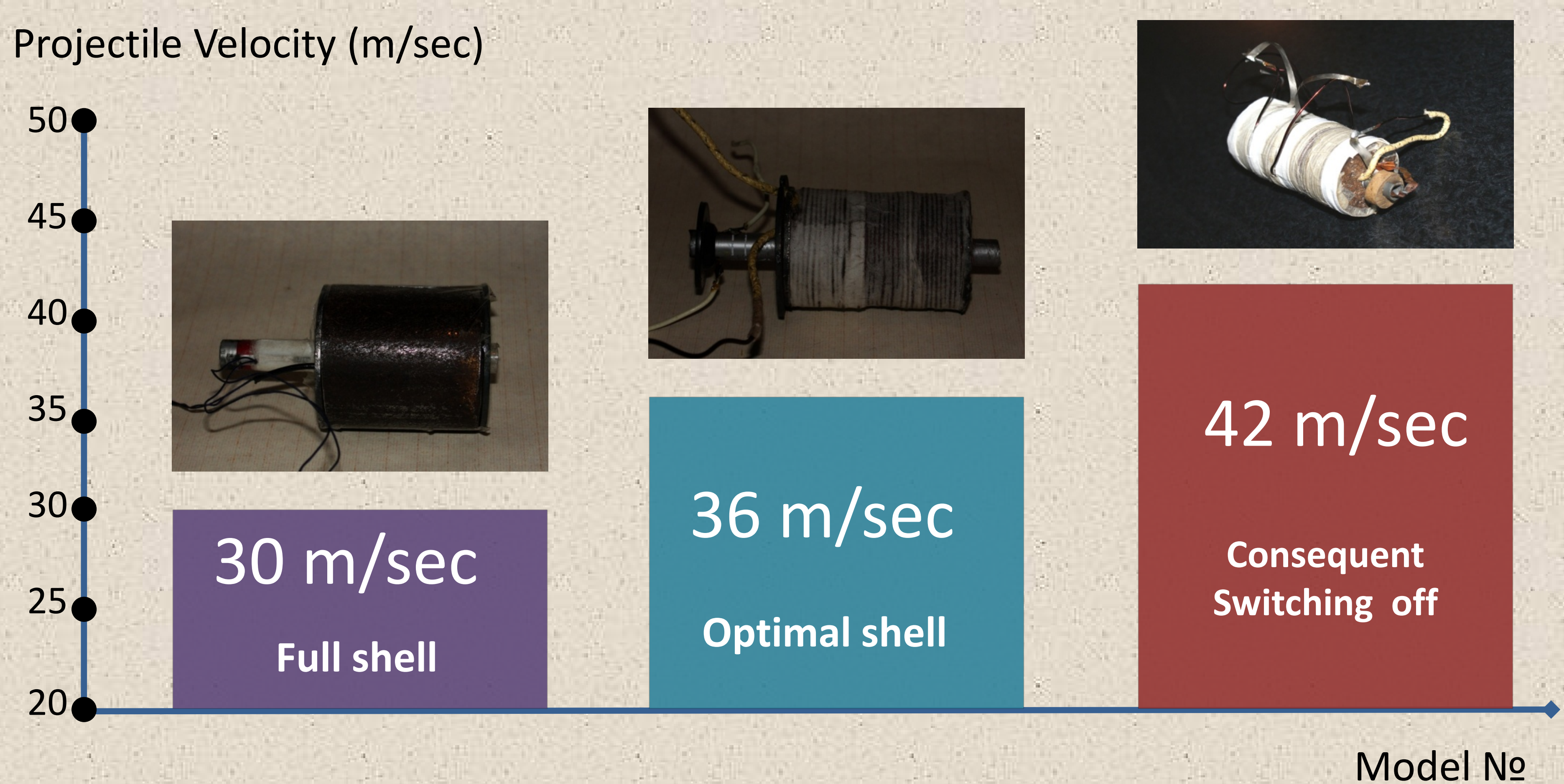
Voltage 300 V

Capacity - 900 μF battery of capacitors (20 x 45 μF).

Projectile 6mm x 15mm

40%

increase of result



Efficiency

Capacitor energy difference

$$\Delta E = \frac{C(U^2_{initial} - U^2_{Final})}{2}$$

Projectile kinetic Energy

$$E_{Kin} = \frac{mv^2}{2}$$

Efficiency

$$\chi = \frac{E_{Kin}}{\Delta E}$$

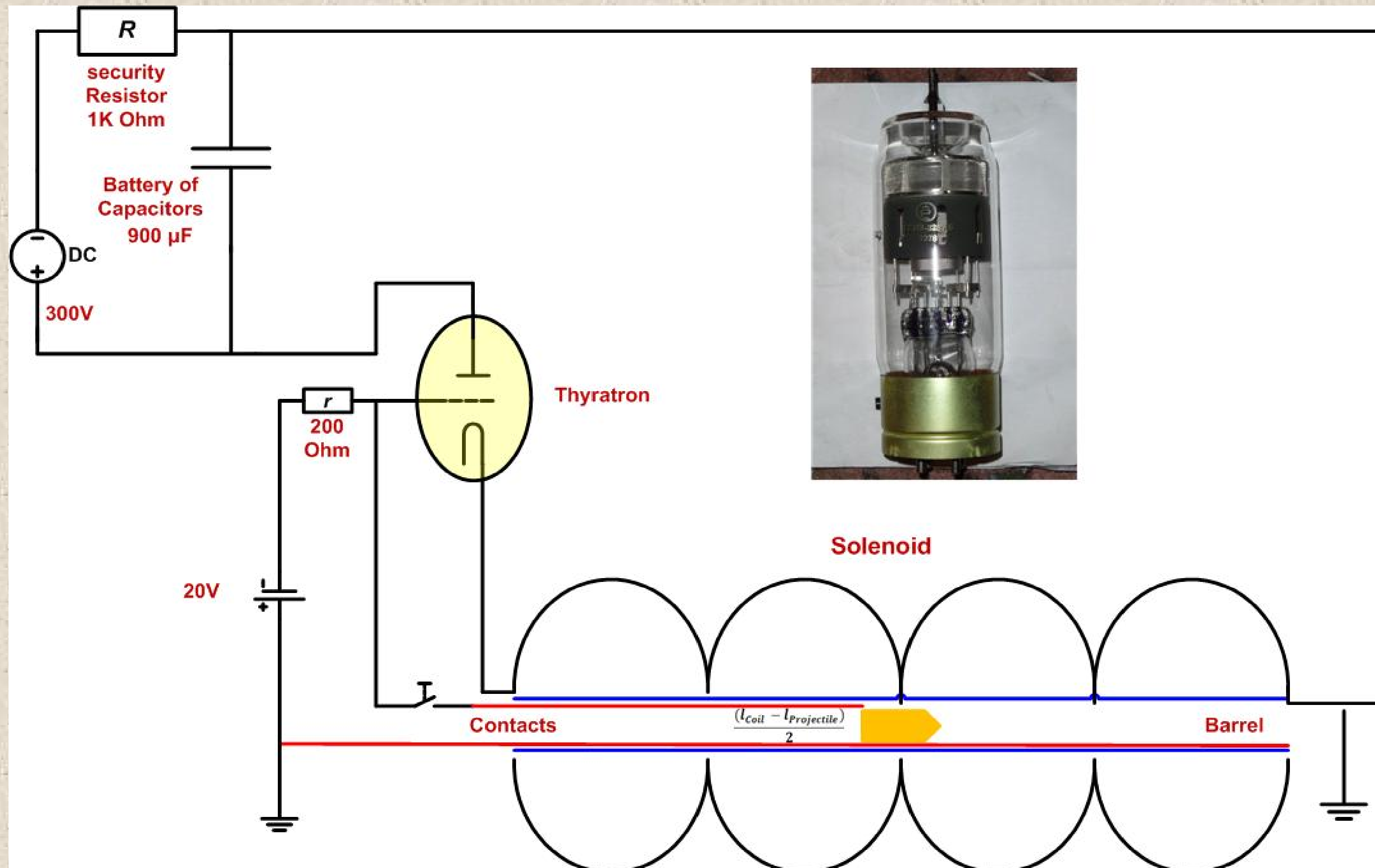
For $U_{initial}$ =300v ; U_{final} =260v ; m = 3.4g ; C= 900µF ; v= 36 m/sec

$$\chi \sim 21\%$$

For consequent switching scheme $U_{initial}$ =300V ; U_{final} =245V ; v= 42 m/sec

$$\chi \sim 22\%$$

Low-current switching-off scheme



- Switching-off the scheme by switching-off the circuit of the thyratron greed.
- Much lower current goes through the sliding contacts.
- Lower energy-loss.

Conclusion

- ✓ Found out that effectiveness of EM cannon strongly depends on:
  1. **Optimal external Iron shell**
  2. **Optimal scheme of Switching off the solenoid power**

- ✓ We show that Iron shell must consist **only of closing washers** :

  Velocity --> ***+~20%***

- ✓ We proposed advanced solution with **“consequent switching-off”** scheme **:**

  Velocity --> ***extra +~17%***

- ✓ Both optimizations together gave ***40%*** increase of velocity

- ✓ We obtained ***~42 m/sec*** velocity.

Action

Thank you for attention!

References

1. http://www.coilgun.eclipse.co.uk/coilgun_fundamentals_1.html .
2. http://www.coilgun.info/theory/externaliron.htm

ADDITIONAL SLIDES

a) Optimal Barrel

- It must be made of **dielectric;**
- Accelerator barrel must have **walls** as **thin** as possible
- Its **diameter** must fit the diameters of the coil and **projectile.**

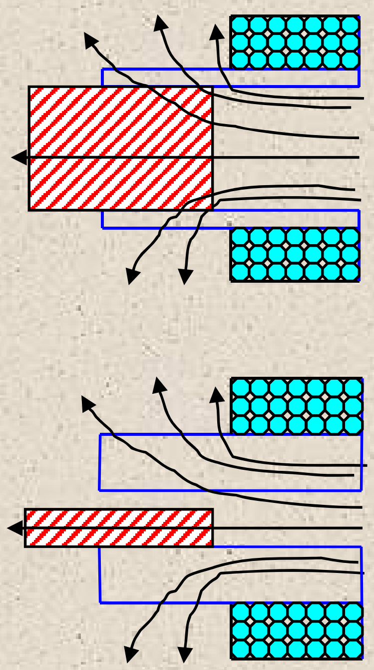


Fig.6

b) Optimal Projectile

- Projectile must be made of **ferromagnetic** or of magnet;
- We consider the projectiles made of **soft ferromagnetic** (i.e. easily magnetized and de-magnetized);
- So we use the projectiles, made of **soft iron;**
- To soften the iron we baked it out in the gas flame;
- Projectile diameter must fit the solenoid inner diameter;
- We tried the projectiles of different length - 6mm - 30mm

c) Optimal dimensions of Solenoid

- The **length** of solenoid - several lengths of the projectile.

  No sense of the long solenoid: near the center

$$d\Phi/dx \approx 0$$

- The **inner diameter** must be close (just a little exceeding) to projectile diameter (thin walls of tube)

- The **outer diameter** must not be large, because the field inside the loop

$$H \sim \frac{I}{r}$$

so the **contribution of large (outer) Loops is small**.

d) Optimal number of Turns / Wire Diameter

Optimal number of Loops (Turns)

- Pro: more turns N - larger F
- **Con: more turns N - larger resistance R and inductance L:**

$$L = \mu_0 \mu_i \cdot \frac{S \cdot N^2}{l_{sol}} \quad \text{where -} \quad \begin{cases} \mu_0 \text{ - magnetic constant,} \\ \mu_i \text{ - magnetic permeability of the coil core,} \\ S \text{ - area of the coil turn ,} \\ N \text{ - the number of turns, } l_{sol} \text{ - the length of the coil.} \end{cases} \qquad (2)$$

- Larger strength of induced voltage (ElectroMotive Force - EMF.)

$$\varepsilon = -L \frac{dI}{dt} \qquad (3)$$

- **Slower growth of *I*** when the circuit switch on.

Optimal Wire Diameter

- Pro: Larger wire diameter - smaller R and larger I
- **Con: Larger wire diameter - less turns (smaller N)**

So it is necessary to *optimize I·N*

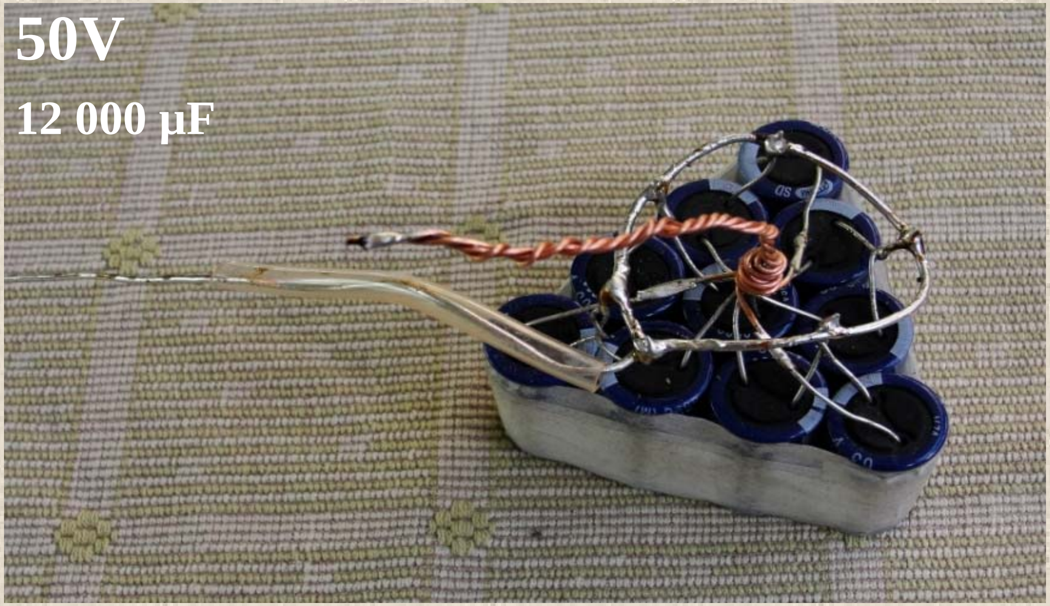
e) Capacitors

- The power source of Gauss Gun is the battery of capacitors
- The energy, accumulated in capacitors

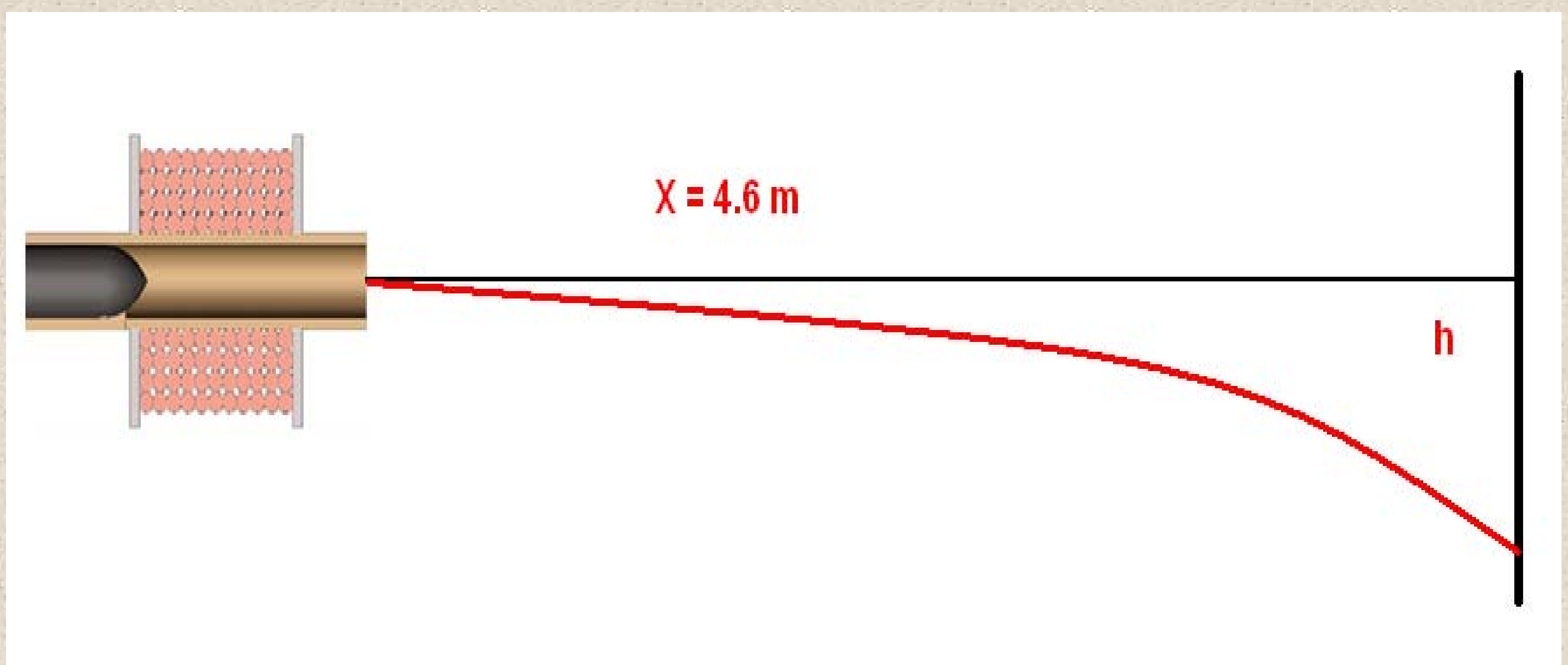
$$E = \frac{CU^2}{2} \tag{4}$$

We must choose capacitors of the **maximal** C.

Also, **the higher voltage -** ***the better result***



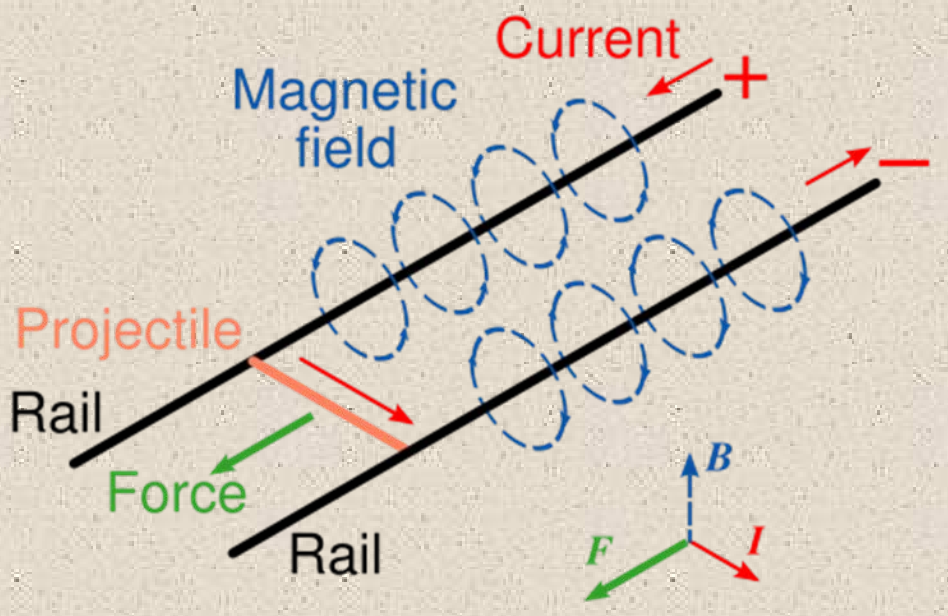
Calculating velocity



$$t = \sqrt{\frac{2h}{g}}$$

$$v = \frac{X}{t} = X\sqrt{\frac{g}{2h}}$$

RailGun



A rail gun works with magnetic fields. Unlike the coil gun and Gauss cannons, rail guns use rails to generate a magnetic pull/push rather than coils of wire.

As shown the rail gun runs electricity through one of the rails which then crosses through the bullet itself and goes back through the other rail causing a magnetic field that pushes the projectile forward.