Status of the Dielectric Wall Accelerator*

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*Patents Pending. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

High gradient induction linacs are possible for short pulses

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- Dielectric wall accelerator (DWA)
  - Early concepts
  - High gradient possibilities
  - Component status
- Issues with the current approach
- New architecture concept
- Summary

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An early dielectric wall accelerator concept*

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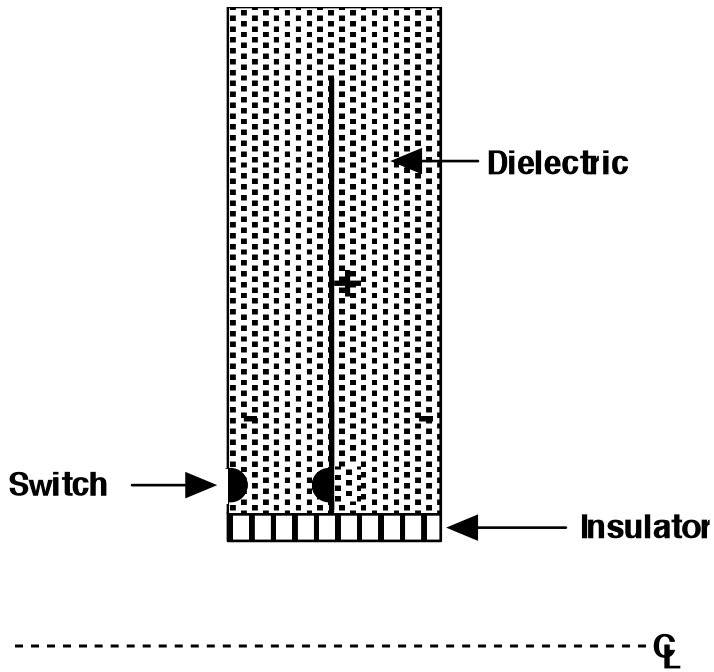
Coreless induction accelerator



*A. I. Pavlovski, et. al. Sov. At. En. 28, 549 (1970)

40 MeV, 100 kA, 25 nsec*

LIU 30
Sarov, Russia
Gradient ≈ 1 MV/m

*Courtesy of Anatoly Krasnykh, SLAC

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High gradient insulators (HGIs) perform 2 - 5 x better than conventional insulators

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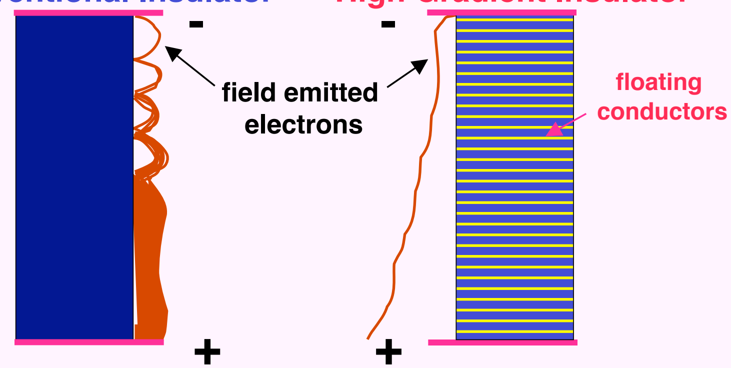
Closely spaced conductors inhibit the breakdown process

Conventional Insulator   High Gradient Insulator

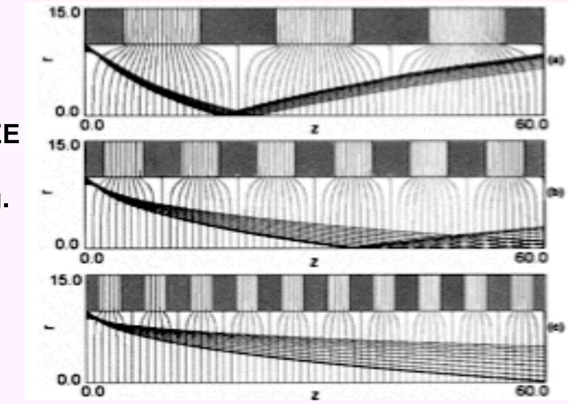


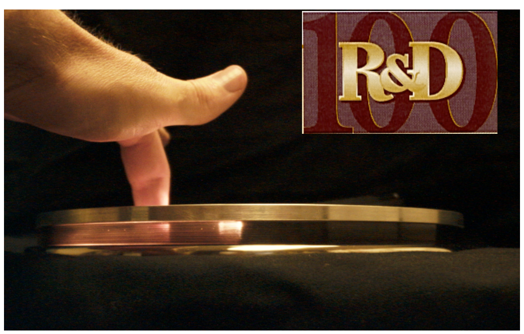
Emitted electrons repeatedly bombard surface

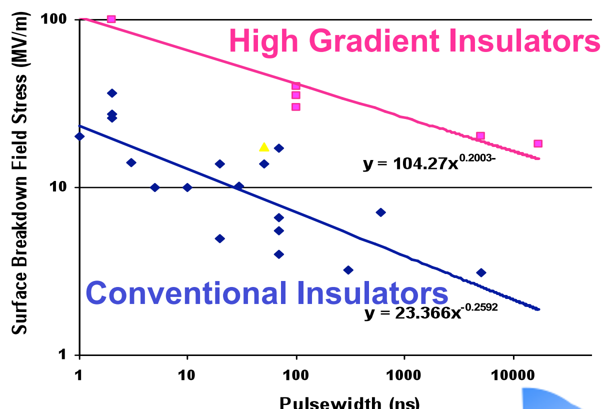
Emitted electrons repelled from surface

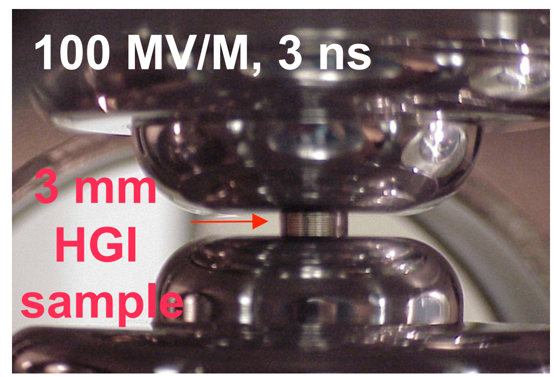
HGI structure forms a periodic electrostatic focusing system for low energy electrons

Leopold, et. al., IEEE Trans. Diel. and Elec. Ins. 12, (3) pg. 530 (2005)









* U. S. Patent No. 6,331,194

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A basic pulse generator is formed from two transmission lines

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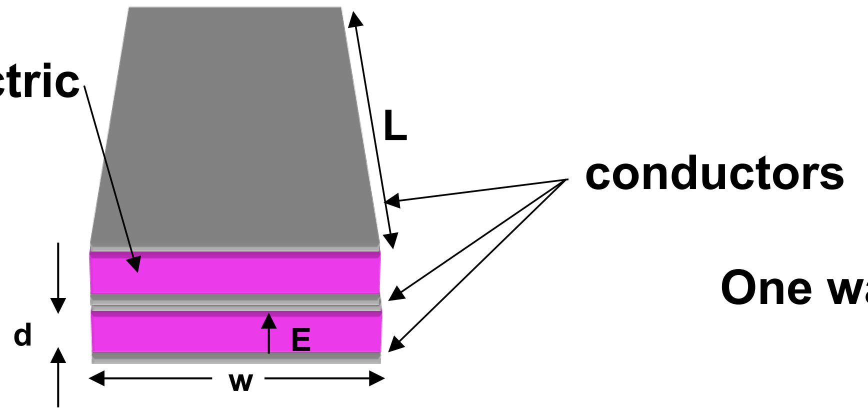
All DWA configurations employ parallel plate transmission lines



One way transit time $\tau = \frac{L}{c}\sqrt{\varepsilon_r}$

Impedance of each transmission line $Z = \frac{120\pi}{\sqrt{\varepsilon_r}}\frac{d}{w}$

Typical current flow in the line with a gradient E $I = \frac{V}{Z} = \frac{Ed}{Z} = \frac{\sqrt{\varepsilon_r}wE}{120\pi}$

$$Example: E = 100\ MV/m, w = 1\ cm, \varepsilon_r = 3 \Rightarrow 4.6\ kA$$

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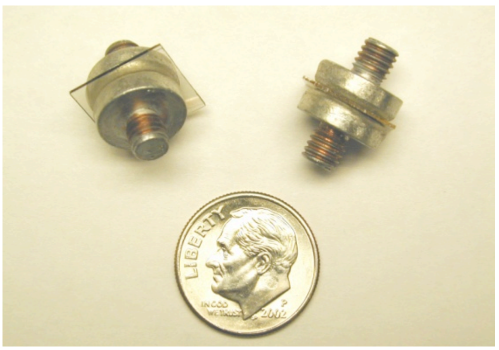
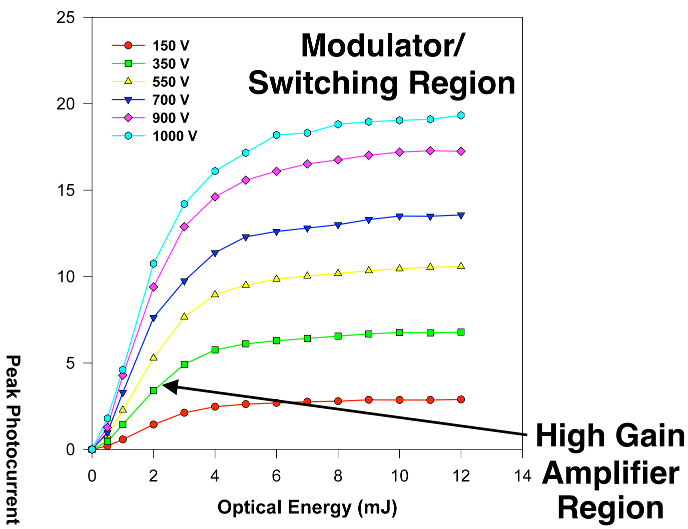
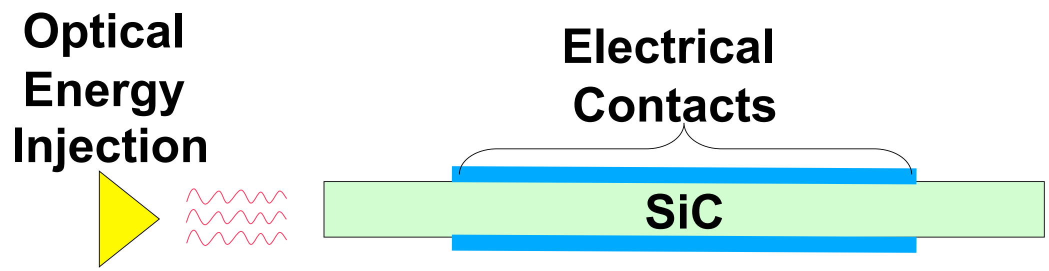
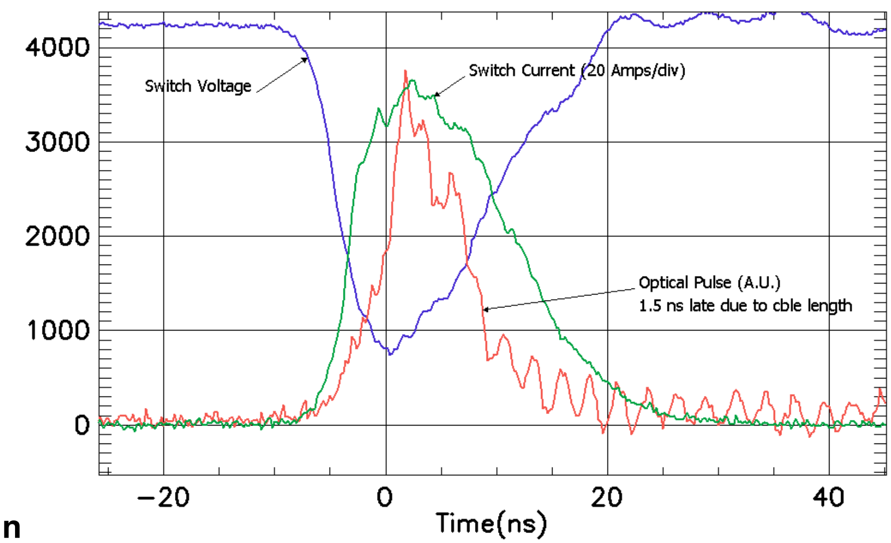
SiC photoconductive switch has demonstrated fast operation at > 30 MV/m average gradient*

SiC offers the potential of high voltage, high current operation at elevated temperature with long lifetime and low jitter









* Patent pending

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DWA can be used in the single pulse "traveling wave" mode to accelerate any charged particle*

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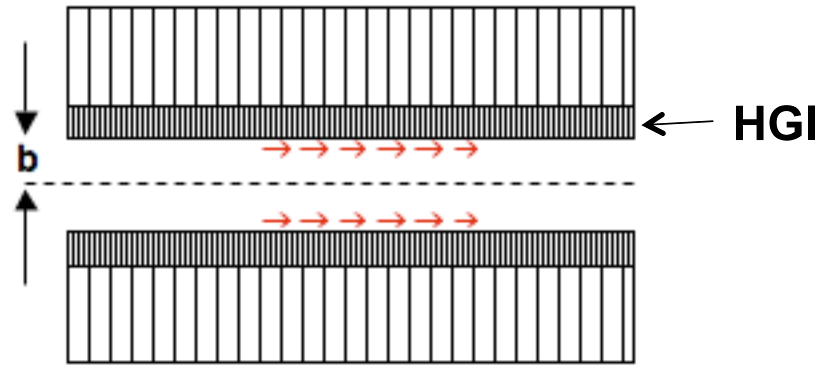
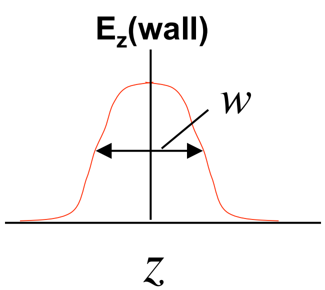
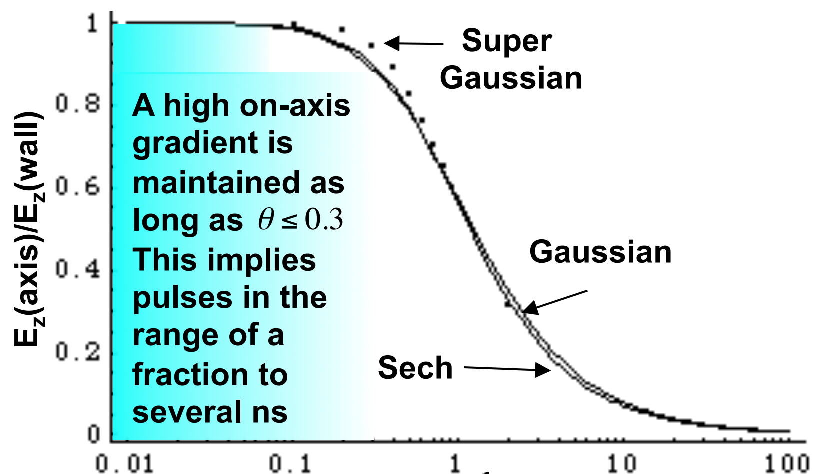
Along the wall $E_z(r,t,z) = E_z(r,\tau)$

$$\tau \equiv t - z/u$$

HGI characteristics imply that the highest gradients will be attained for the shortest pulses







$$\theta \equiv \frac{b}{\gamma w}$$

w = full width at half maximum

u = speed of wall excitation

γ = Lorentz factor $= 1/\sqrt{1 - u^2/c^2}$

*patent pending

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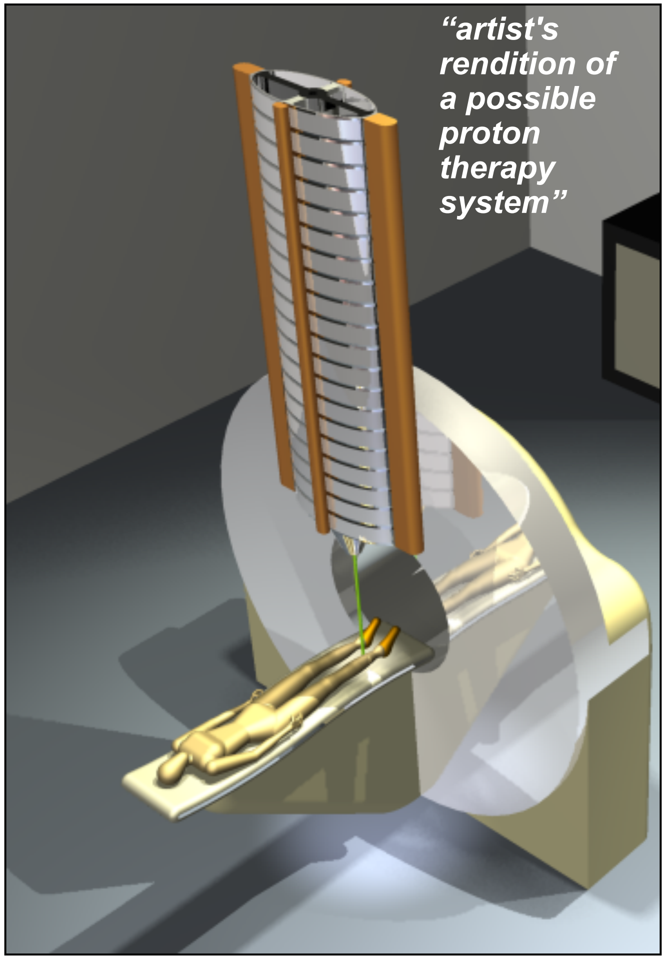
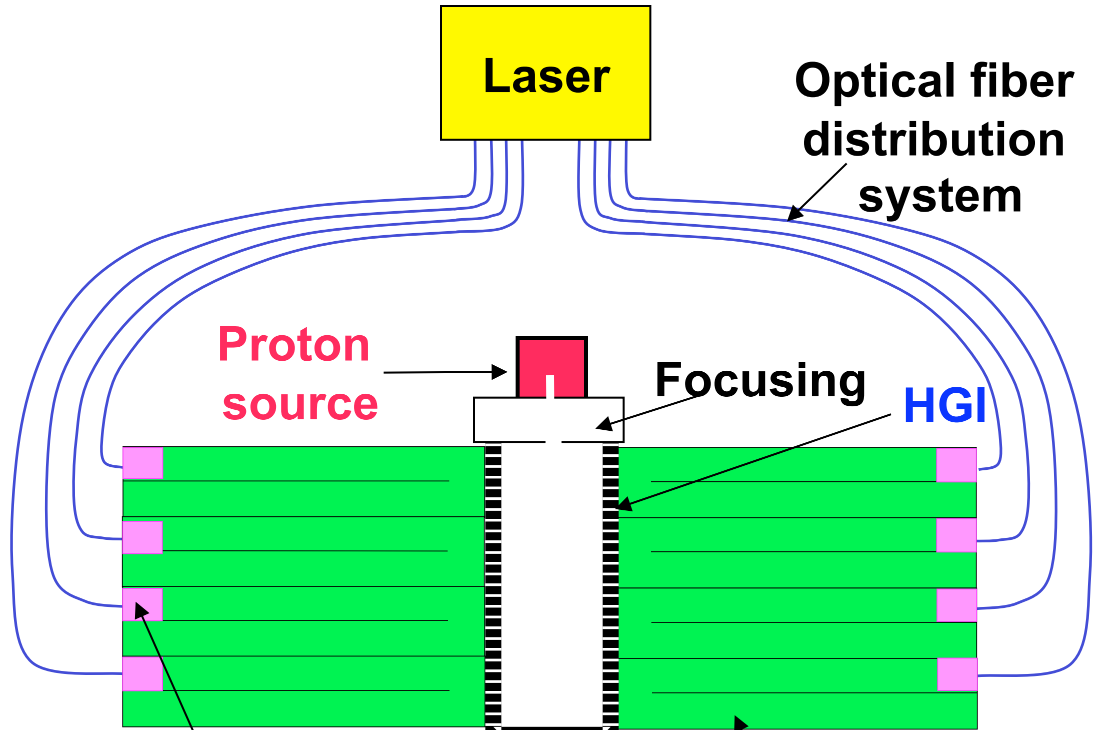
Stacks of Blumleins with independent switch triggers implement the virtual traveling wave* accelerator





* Patents pending

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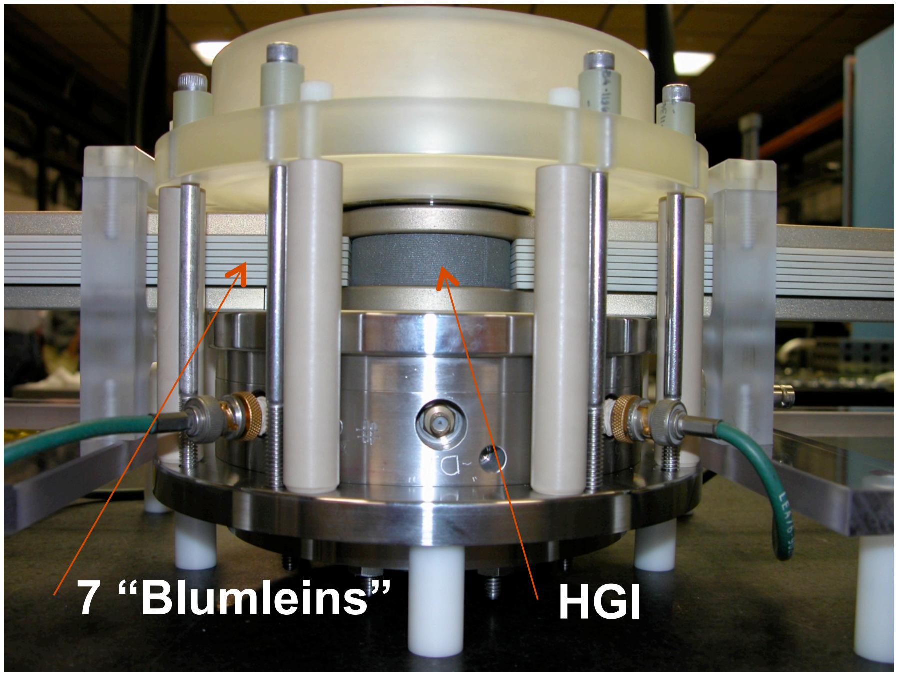
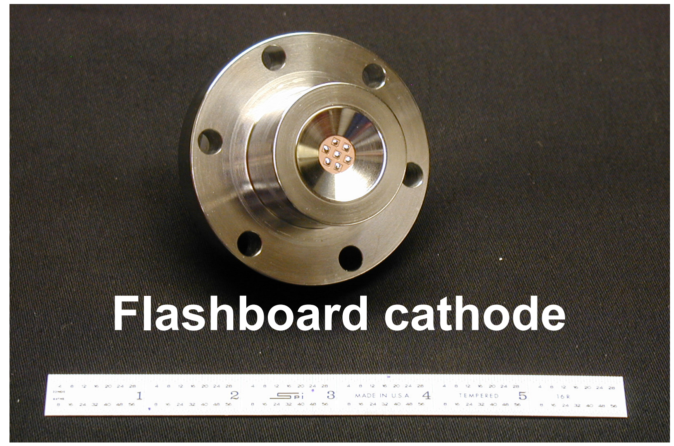
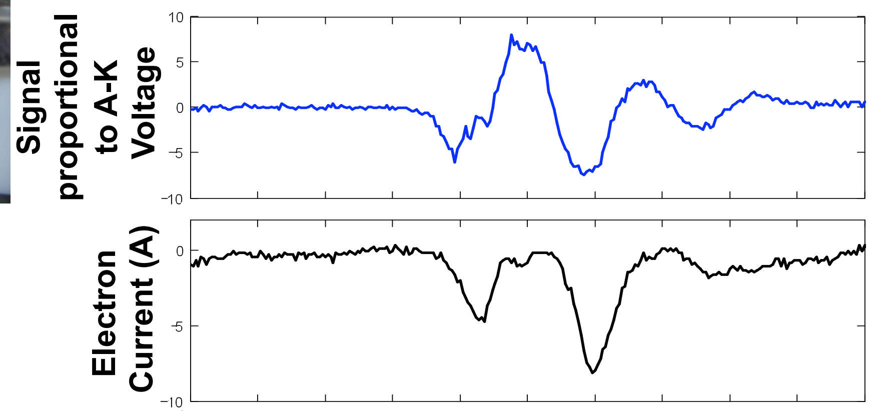
F.A.S.T. was built to test components in an integrated system







Initial tests used F.A.S.T. as an electron diode

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Proton injector and F.A.S.T. accelerator section

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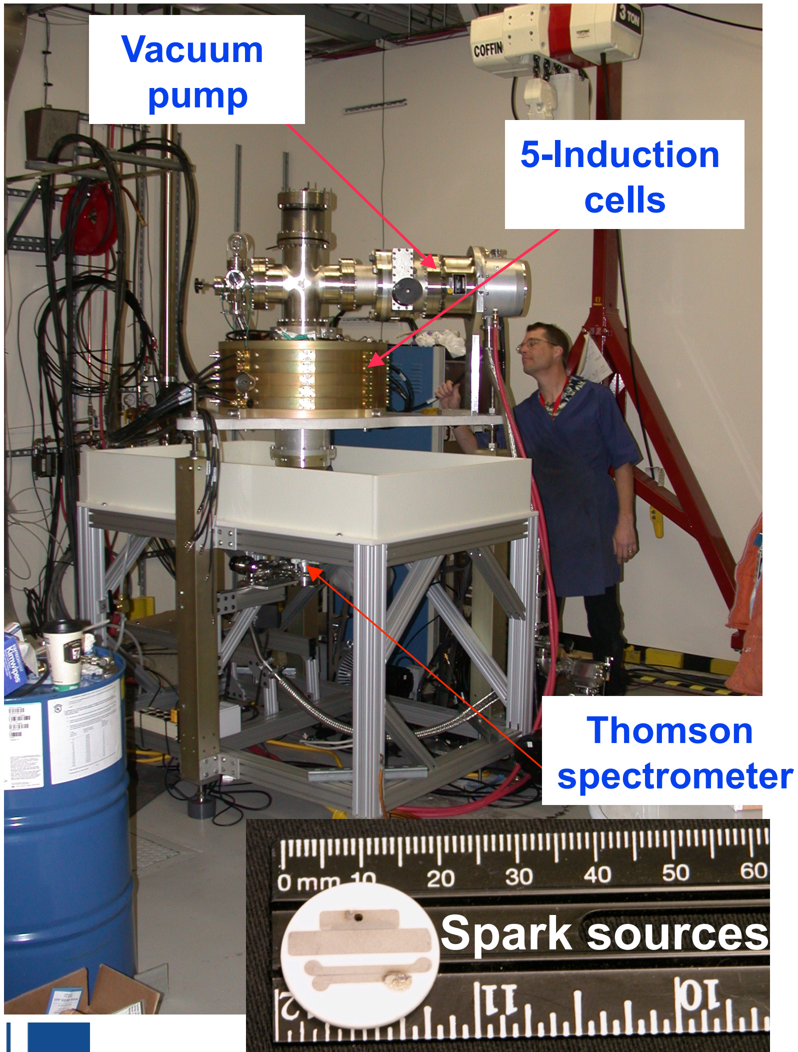
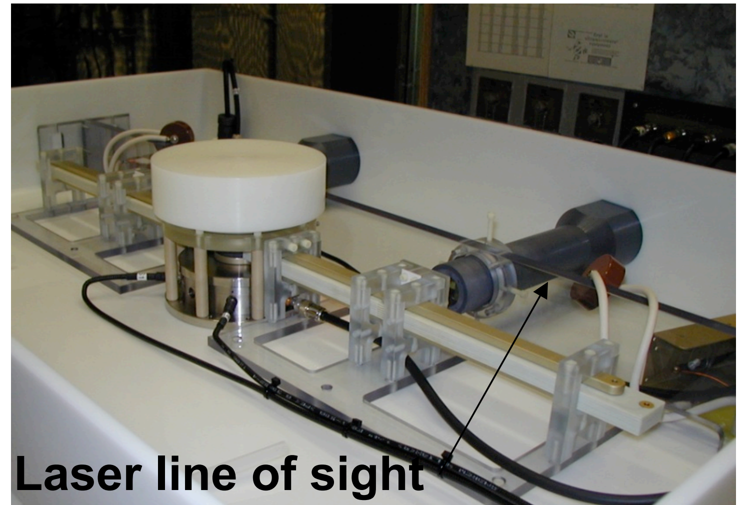
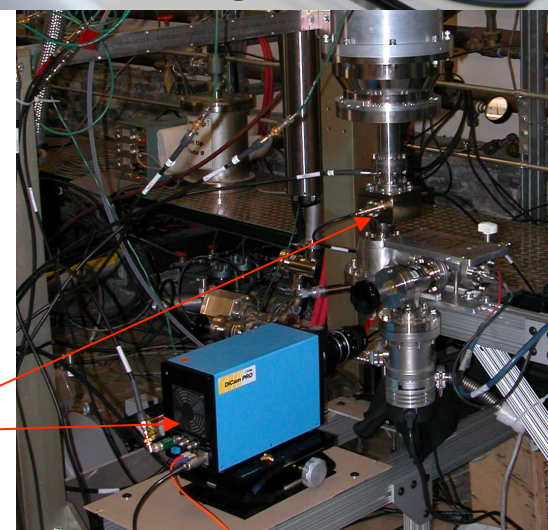




Spectrometer & camera



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F.A.S.T. acceleration of protons is measured with spectrometer

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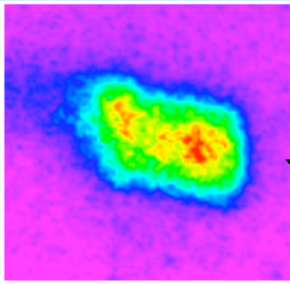
Accel. phase



8352dp84_sd.png FC(0-65520)

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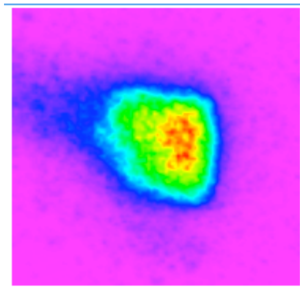

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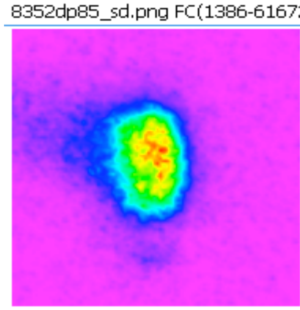
Decel. phase



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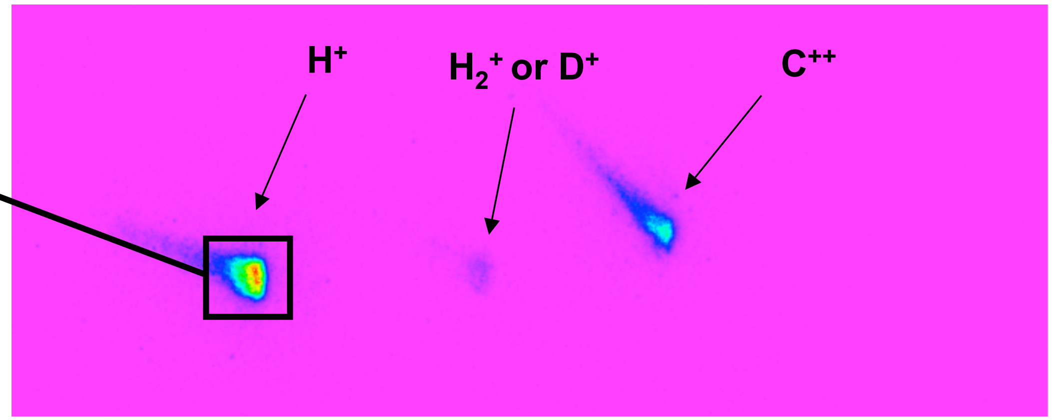
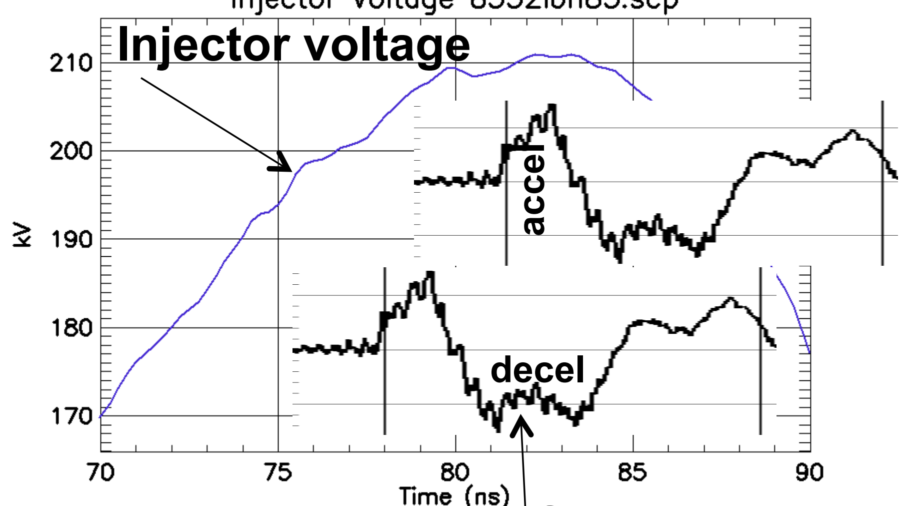
Energy ⟶





Signal proportional to F.A.S.T. voltage

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Cast dielectric sustains interesting field levels in relevant configurations

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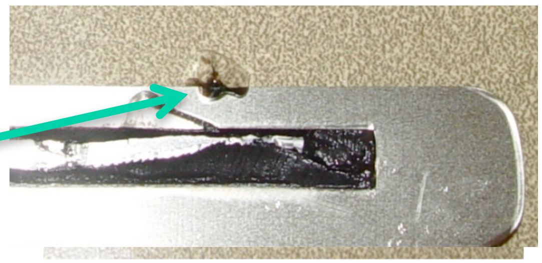
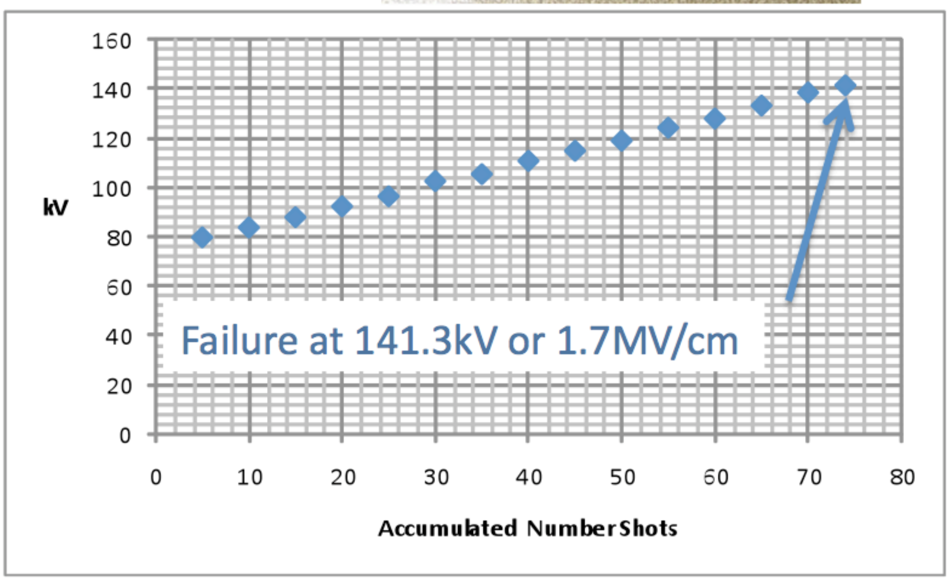
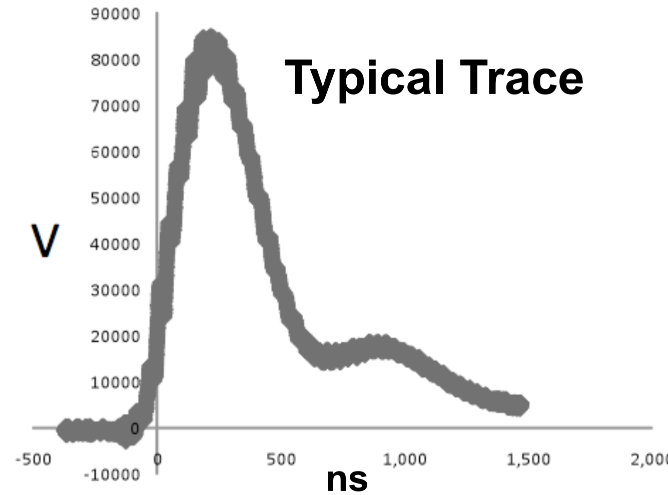
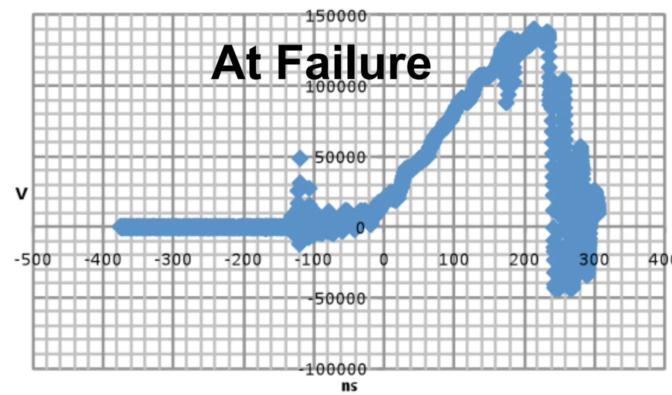
4 cm x 56 cm x 0.8mm gap between electrodes

Failure point









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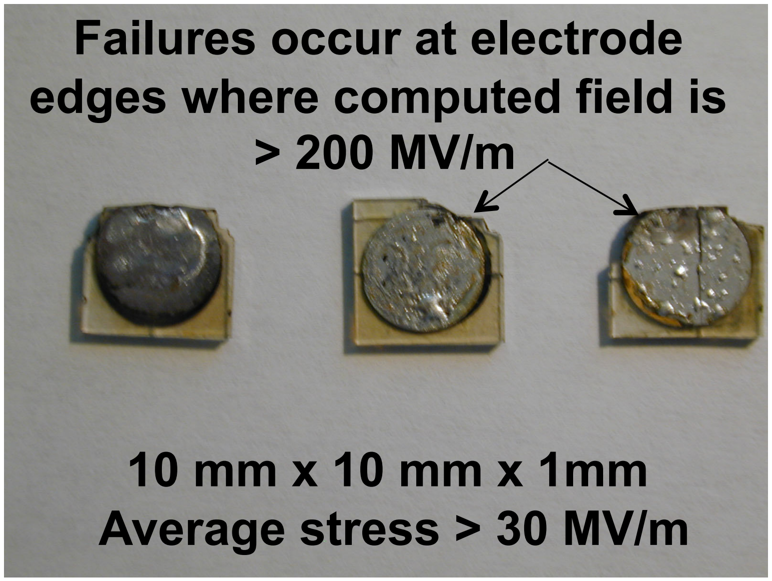
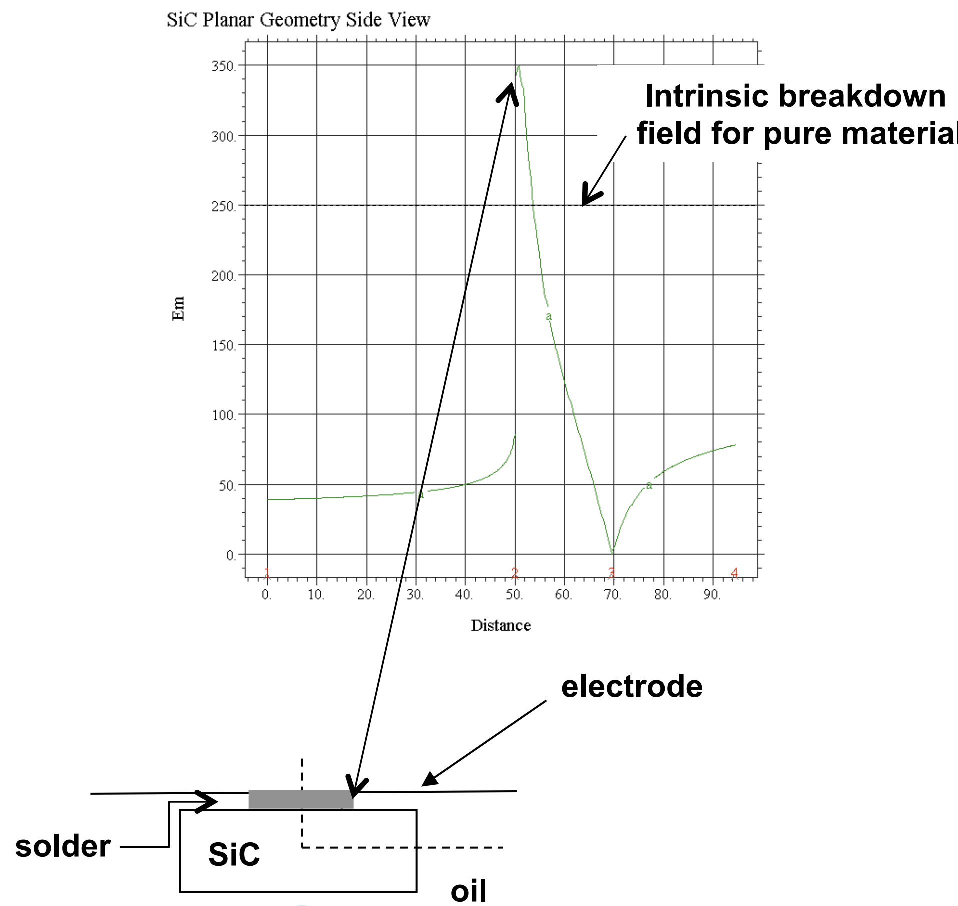
New SiC material fails at enhanced stress > 200 MV/m

Failure of 3 Blumlein switches at > 30 kV



Present work is focused on developing an integrated switch package that eliminates these enhancements



Stacked Blumleins are subject to parasitic coupling

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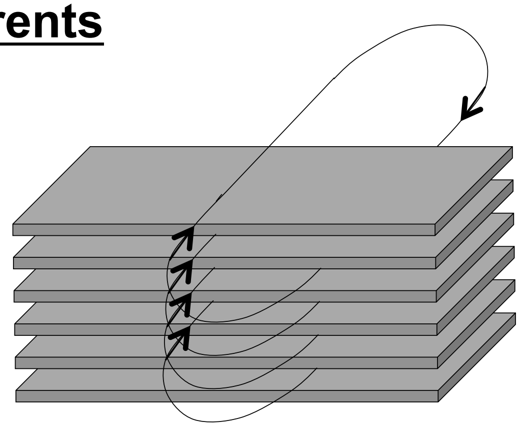
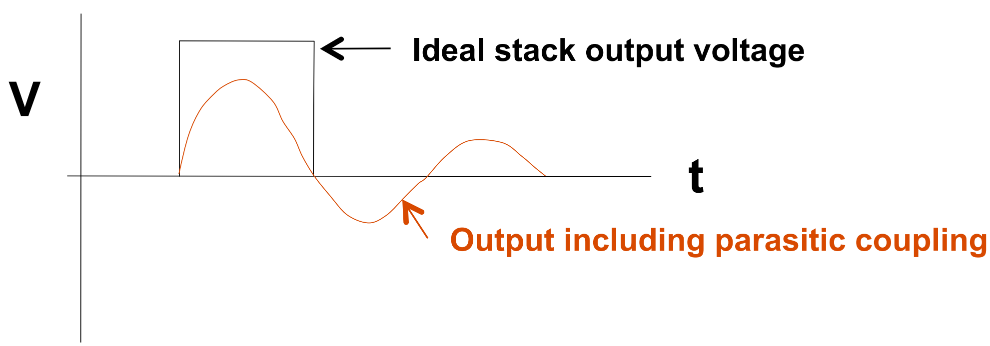
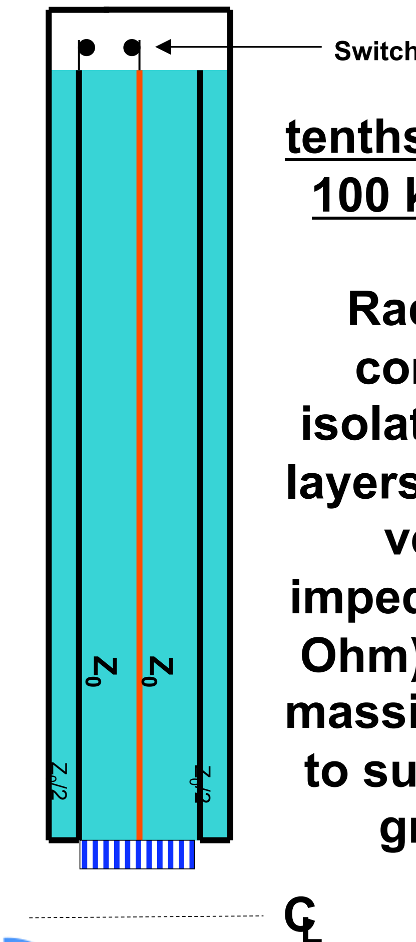
Stripline impedances can be <u>tens of Ohms, ~ kA currents</u>



Magnetic field lines close through adjacent layers, inducing currents in neighboring lines





<u>tenths of Ohms, ~ 100 kA currents</u>

Radial lines completely isolate adjacent layers but have a very low impedance (sub-Ohm), requiring massive currents to support high gradients

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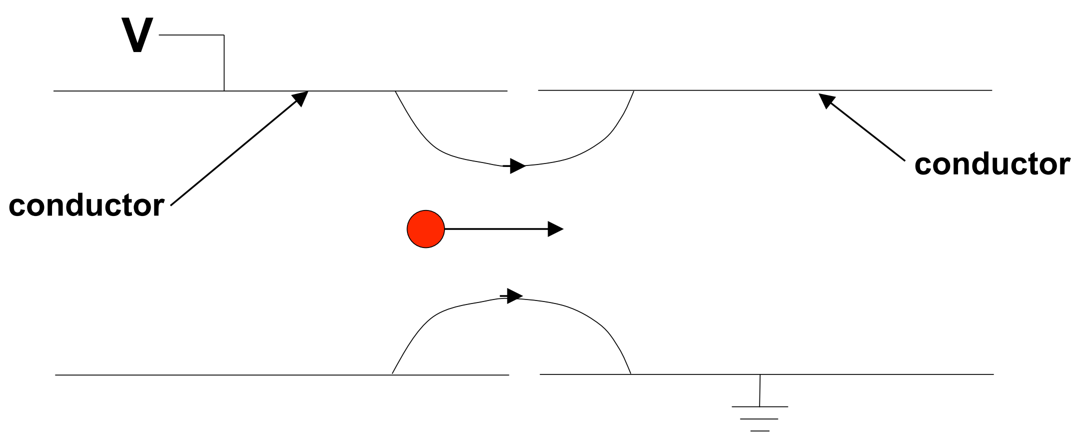
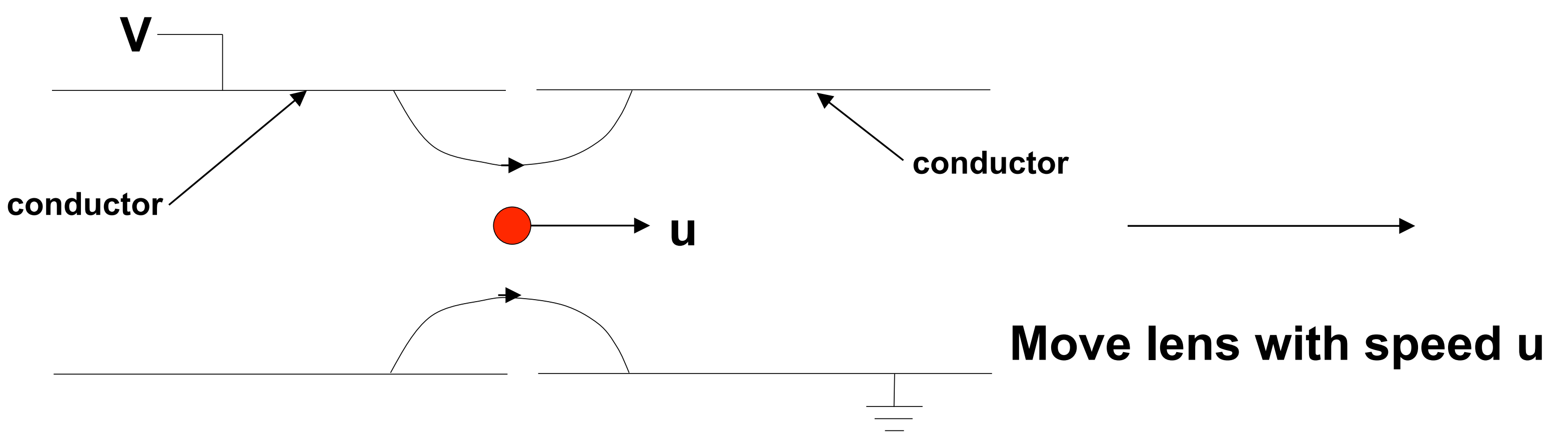
Classical bipotential lens can be used to accelerate particles



If we could move the lens at the correct speed, a particle could be continuously accelerated



Move the lens without moving the assembly - a moving virtual gap*

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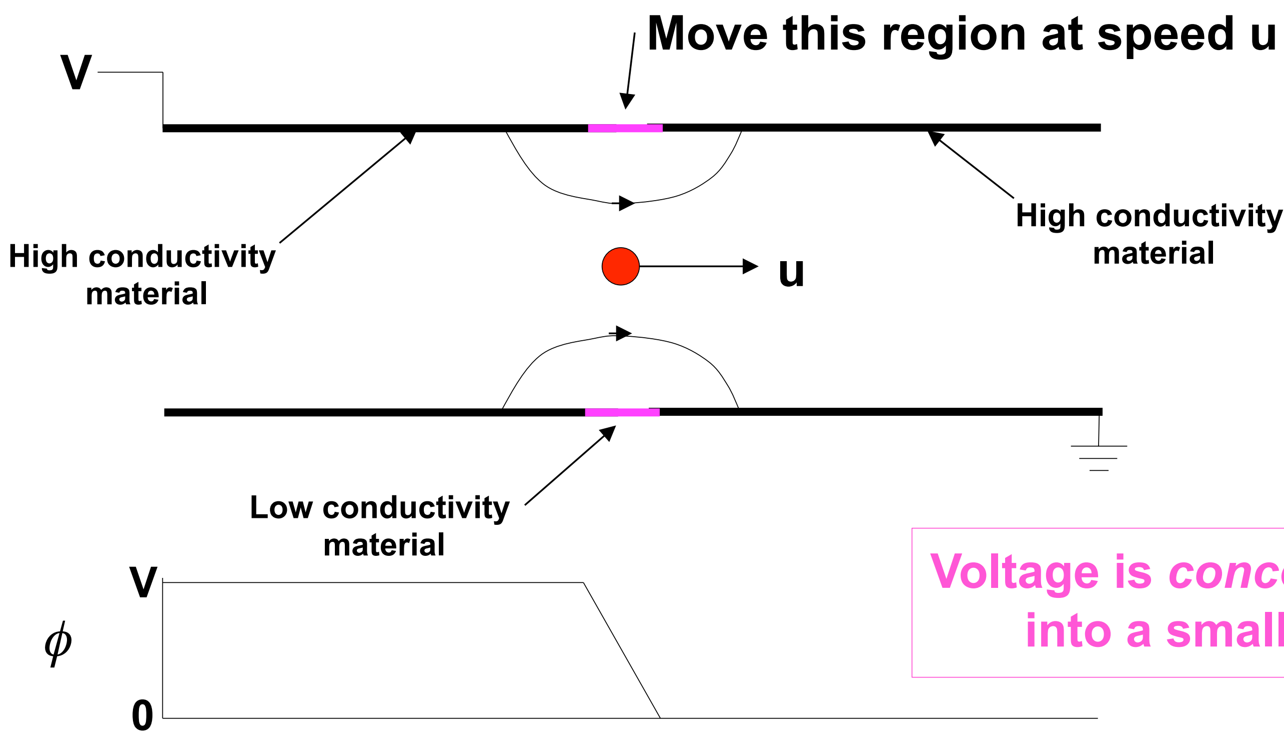

Voltage is *concentrated* into a small gap

• **Need a material whose conductivity can be rapidly changed from a high conductivity state to a low conductivity state and back again**

*** Patent pending**

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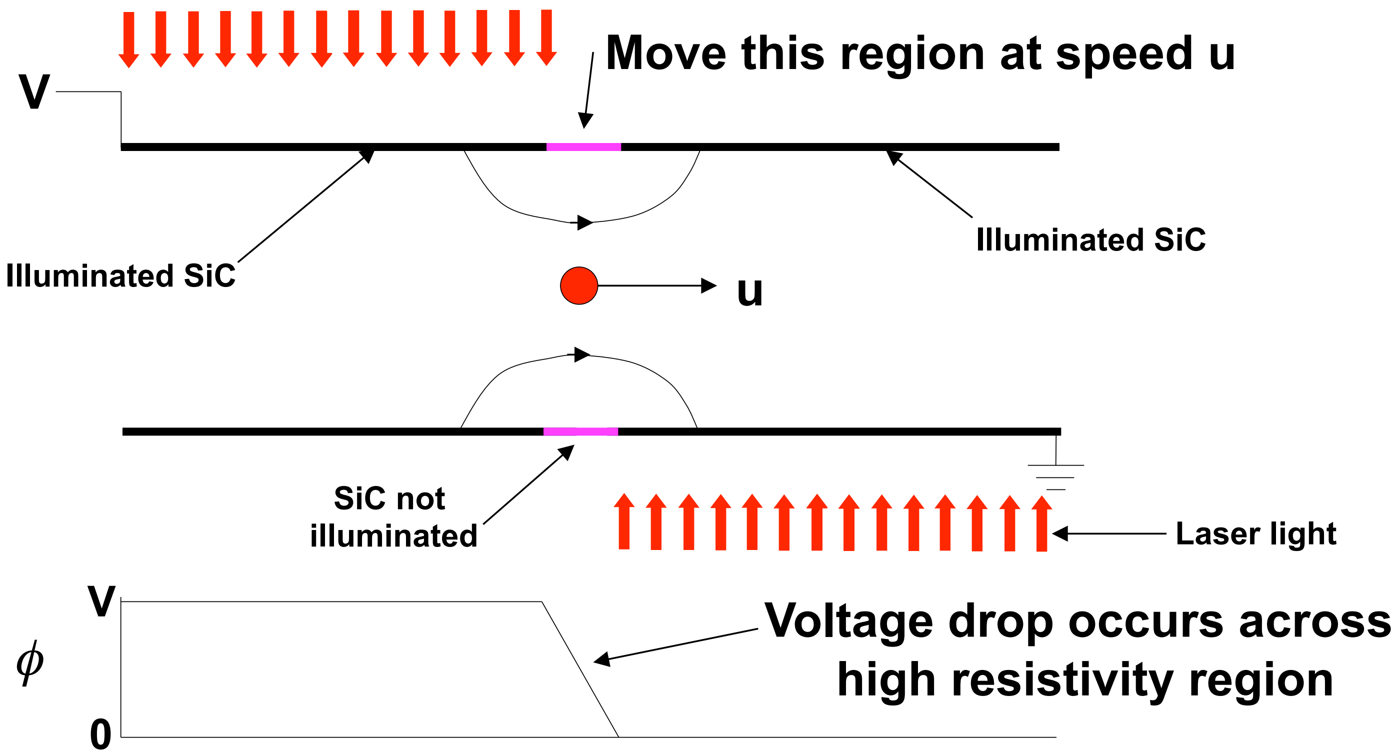
One way to do this is with photoconductivity*



- Need a material whose conductivity can be rapidly changed from a high conductivity state to a low conductivity state and back again

* Patent pending

Induction machines have been used for decades to concentrate voltage

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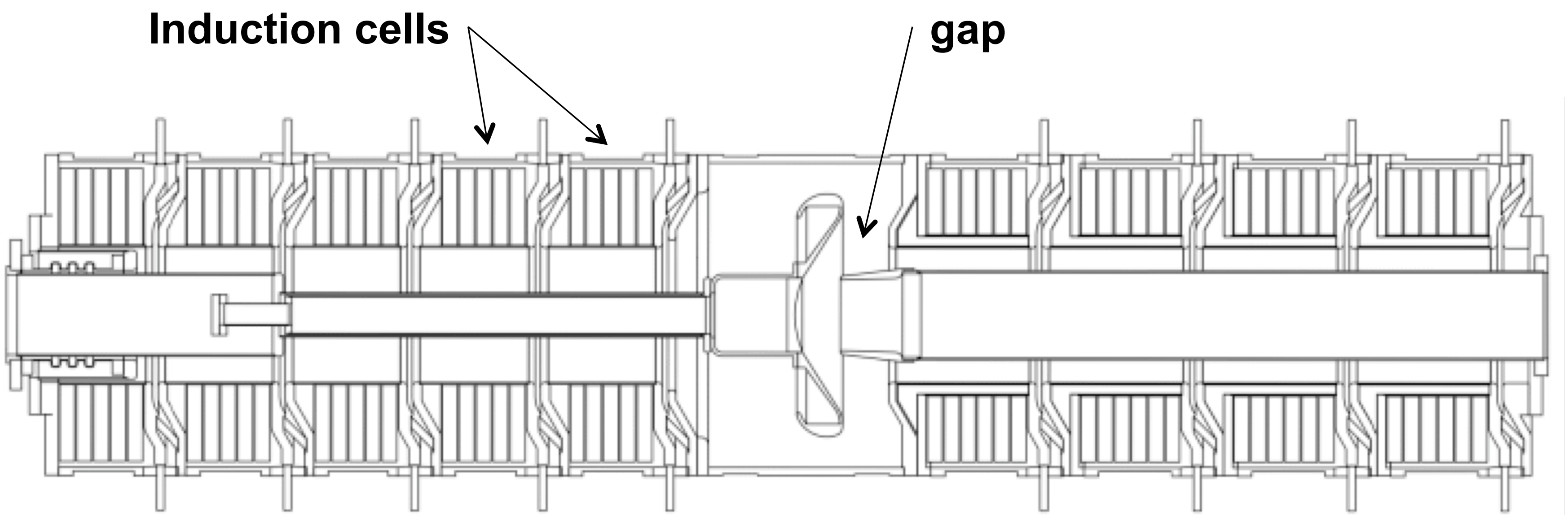
Typical electron injector



Inductive voltage adders are *induction concentrators*

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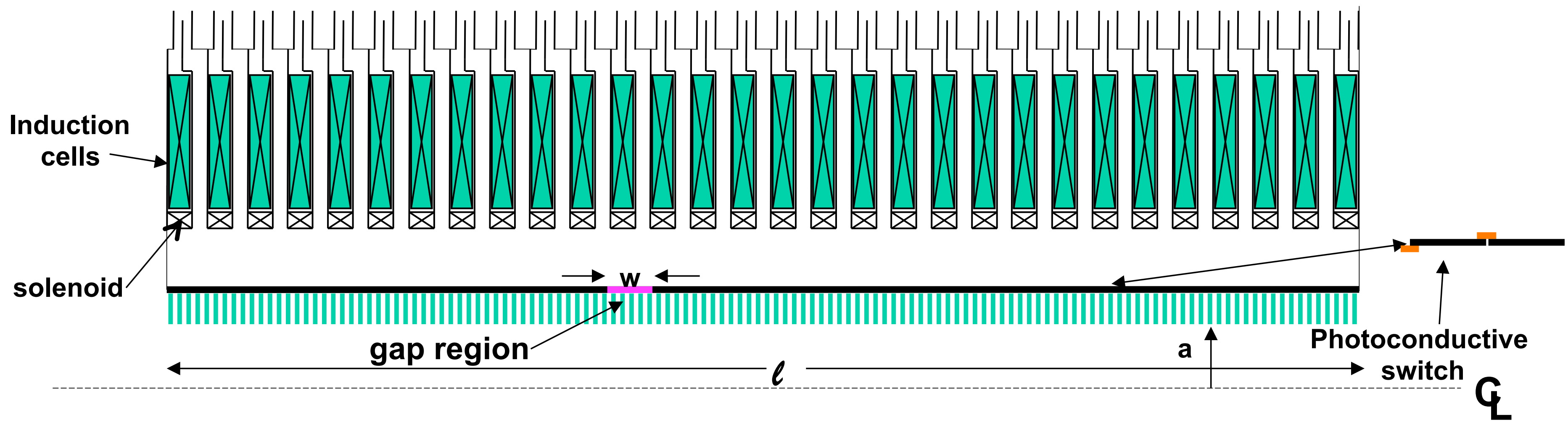
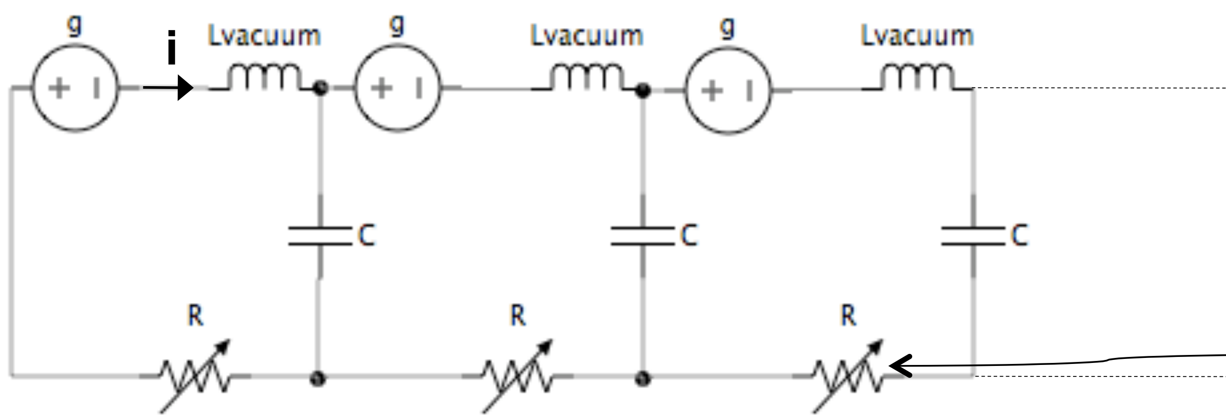
To what extent can this be achieved dynamically?





Virtual gap* is created by shutting off photoconductive switches

* Patent pending

Continuous model for moving virtual gap*

Transmission line equations

$$\frac{\partial V}{\partial x} = -g - L\frac{\partial i}{\partial t} - Ri \qquad \frac{\partial i}{\partial x} = -C\frac{\partial V}{\partial t}$$

Acceleration field

$$E_a = -Ri$$

$$R = R_o f(ut - x) \qquad g = g_o \hat{g}(t)$$

u (w) is speed (width) of the virtual gap

Define dimensionless variables

$$\xi \equiv \frac{x}{w} \qquad \eta \equiv \frac{R_o t}{L}$$

$$\psi \equiv \frac{iR_o}{g_o} \qquad \Omega \equiv \frac{V}{g_o w}$$

*** Patent pending**

Seek a traveling wave (similarity) solution for a long system

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$$\frac{\left(1 - LCu^2\right)}{wR_oCu}\frac{\partial\psi}{\partial\sigma} - f\psi = 1$$

$$E_a = -g_o f(\sigma)\psi(\sigma)$$

u *is the speed of the virtual gap* $\qquad \sigma \equiv \frac{ut - x}{w} = \frac{Lu}{R_o w}\eta - \xi \equiv \mu\eta - \xi$

$\frac{1}{\sqrt{LC}}$ = *speed of an electromagnetic wave on the line*

There are two distinct regimes*:

$LCu^2 < 1$ "subluminal"

$LCu^2 > 1$ "superluminal"

*** Patent pending**

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Idealized solutions for constant accelerating field (subluminal)

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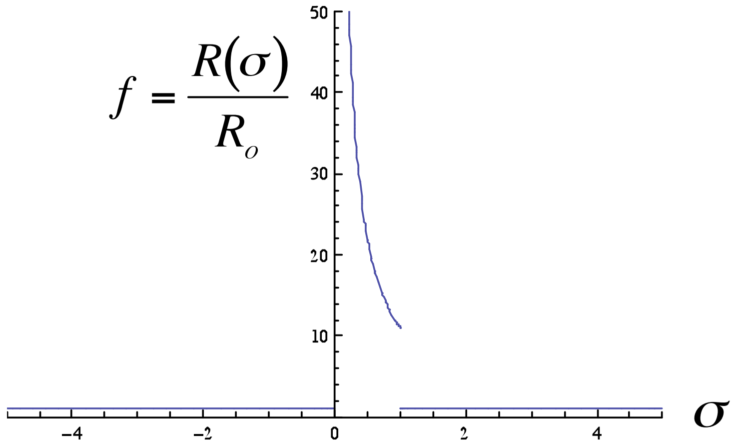

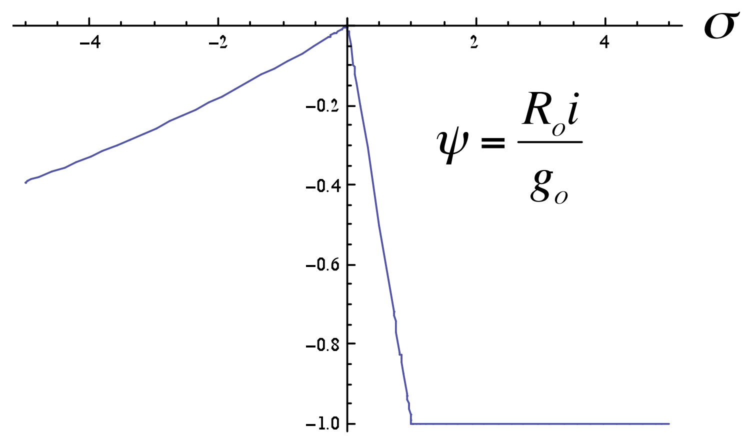

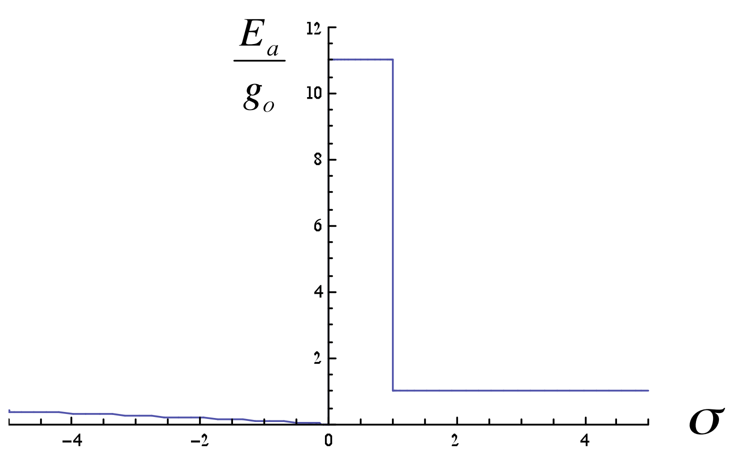

$$Gain = \frac{E_a}{g_o} \le 1 + \frac{1}{wR_o Cu} \propto \frac{1}{u}$$

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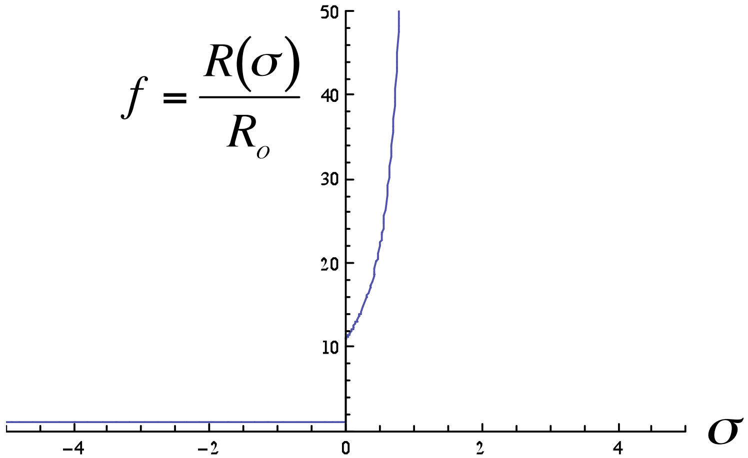
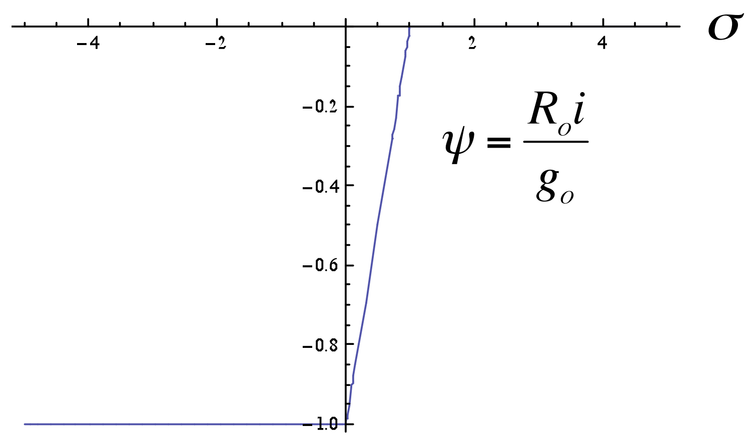
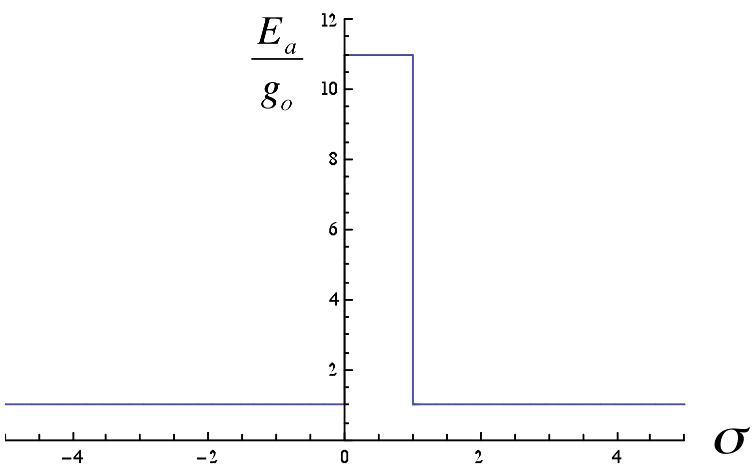
Idealized solutions for constant accelerating field (superluminal)







$$Gain = \frac{E_a}{g_o} \leq 1 + \frac{Lu}{R_o w} \propto u$$

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3D EM simulations (XFDTD)verify the effect*

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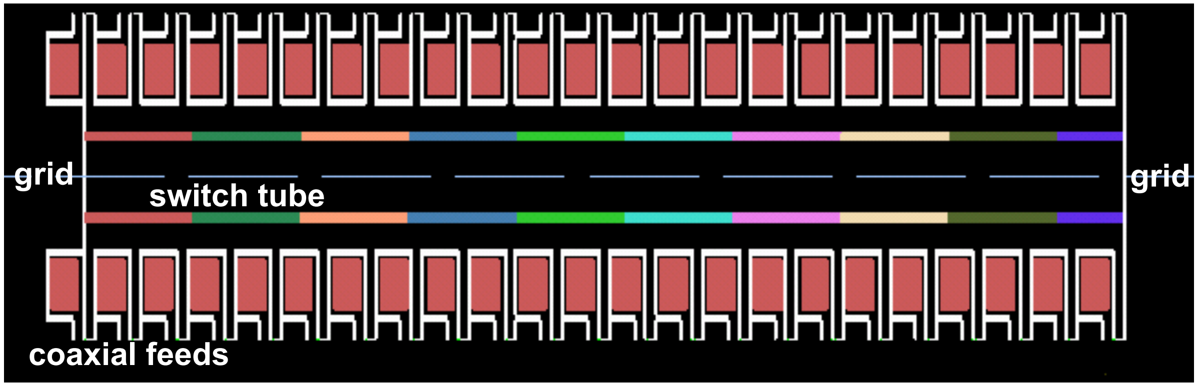
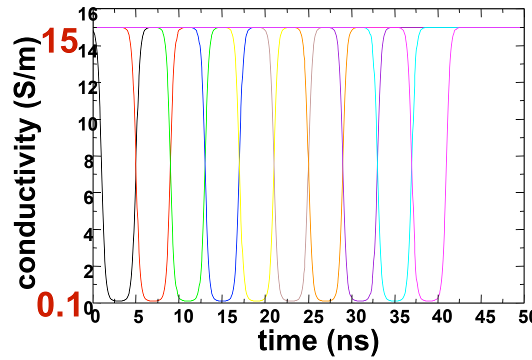
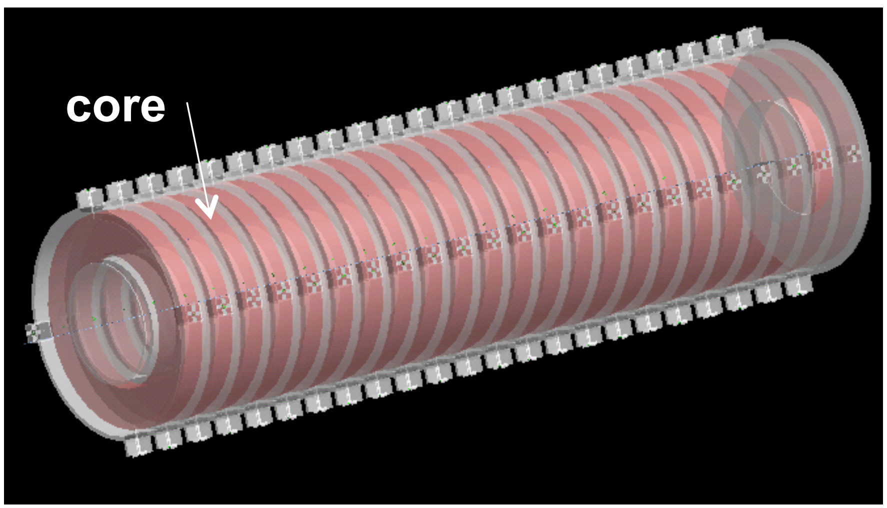
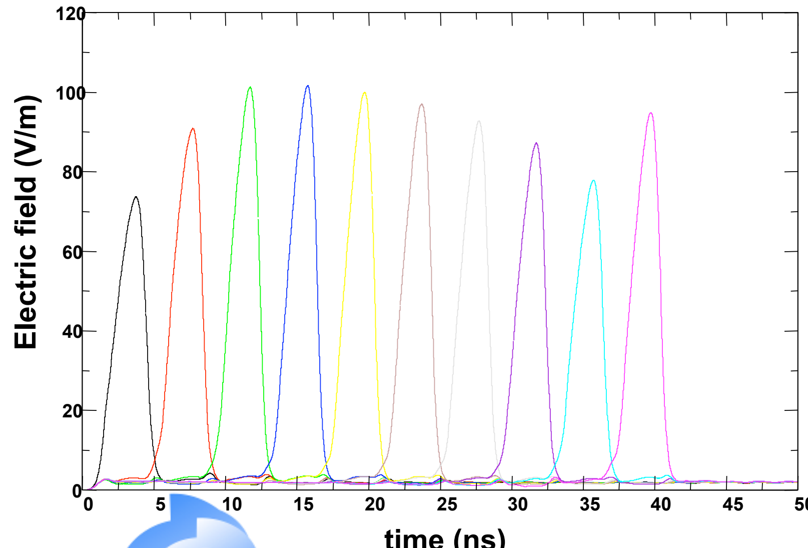






On-axis accelerating field in the middle of each switch tube segment (1 Volt drive per cell)



* Patent pending

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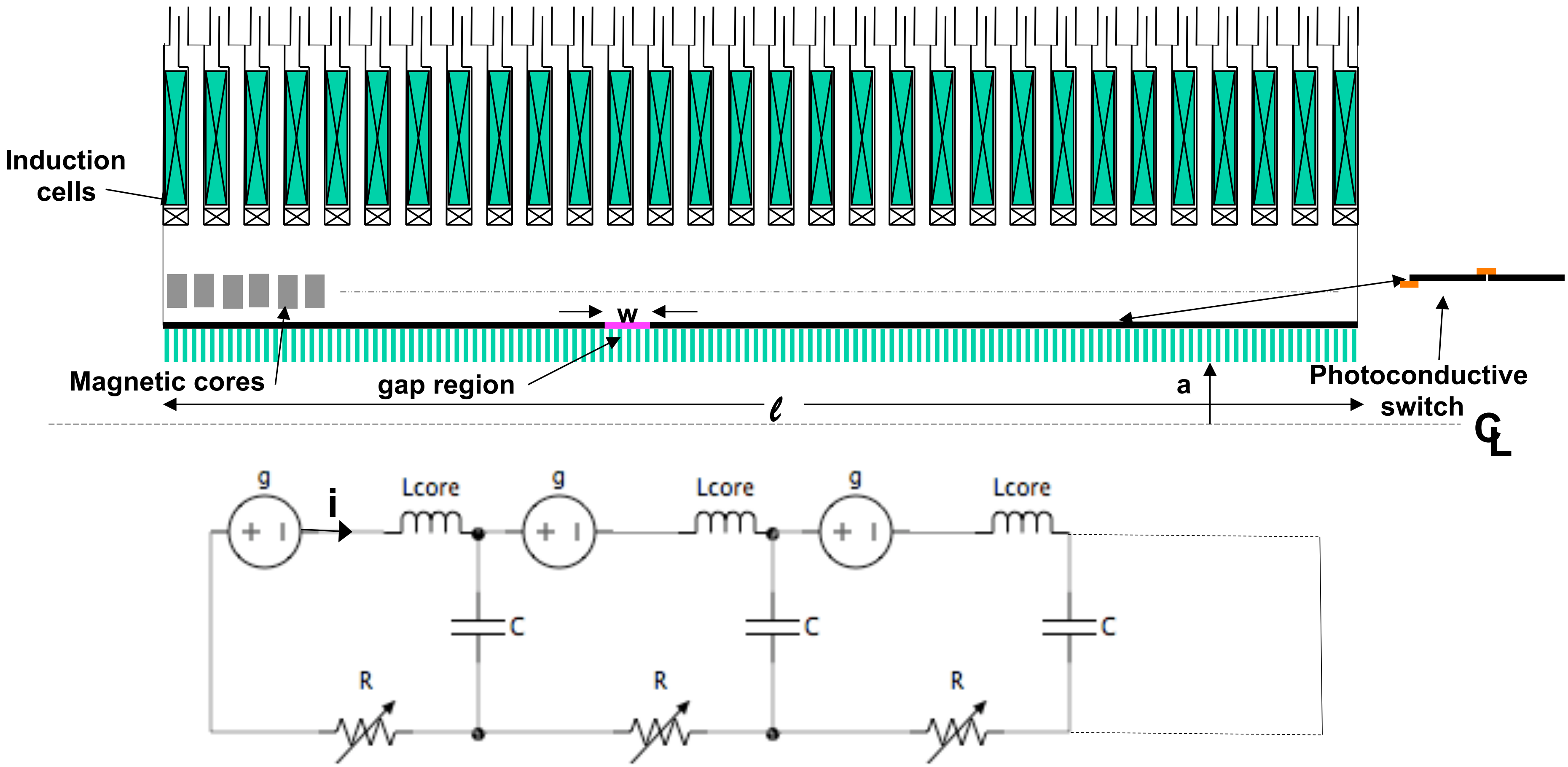
CPAC COMPACT PARTICLE ACCELERATION CORPORATION

Magnetic cores can enable the "superluminal" regime*

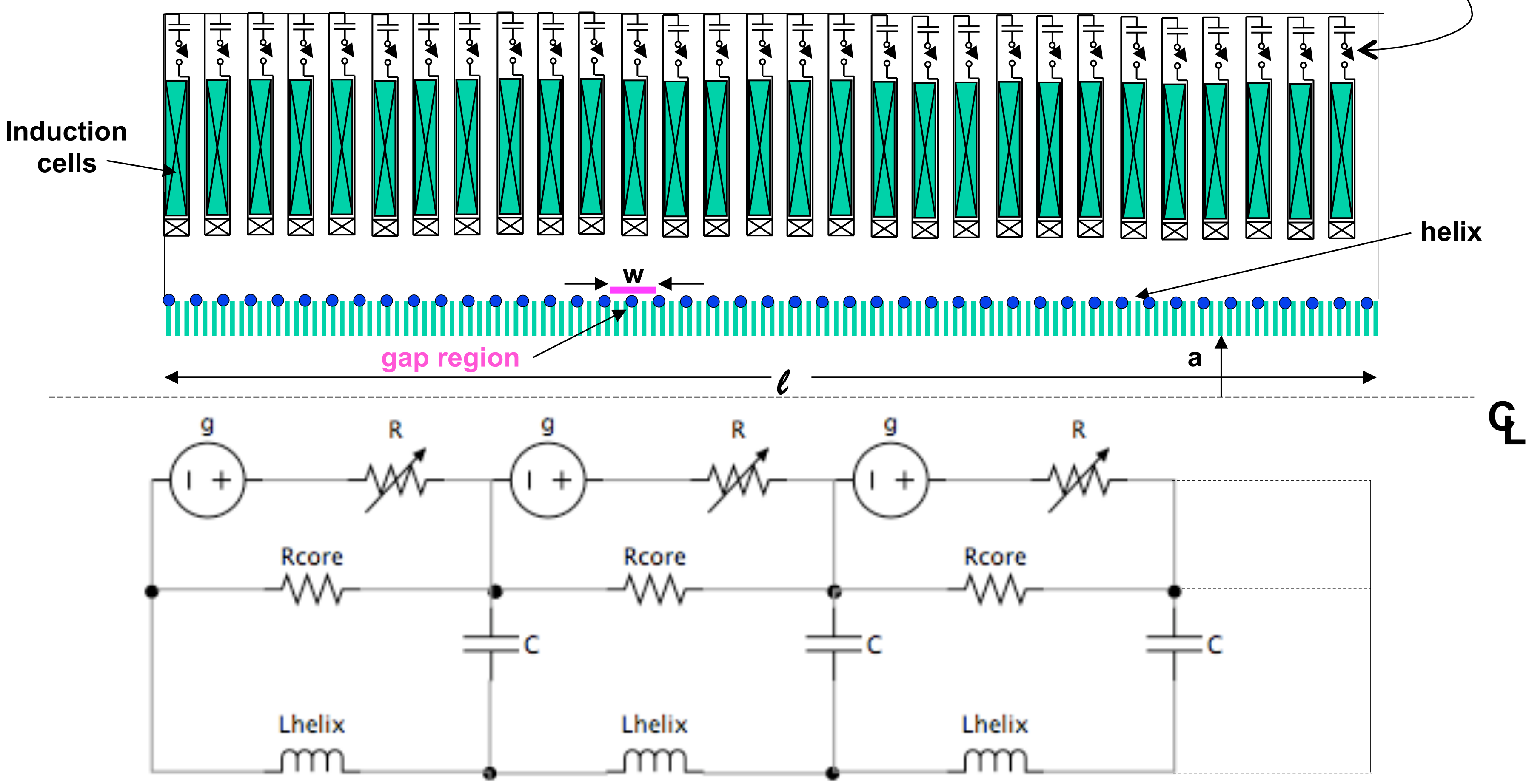


* Patent pending

A circuit dual exists using a helical inner conductor*

Beam Research Program
Lawrence Livermore National Laboratory

Virtual gap* is created by shutting off photoconductive switches



* Patent pending

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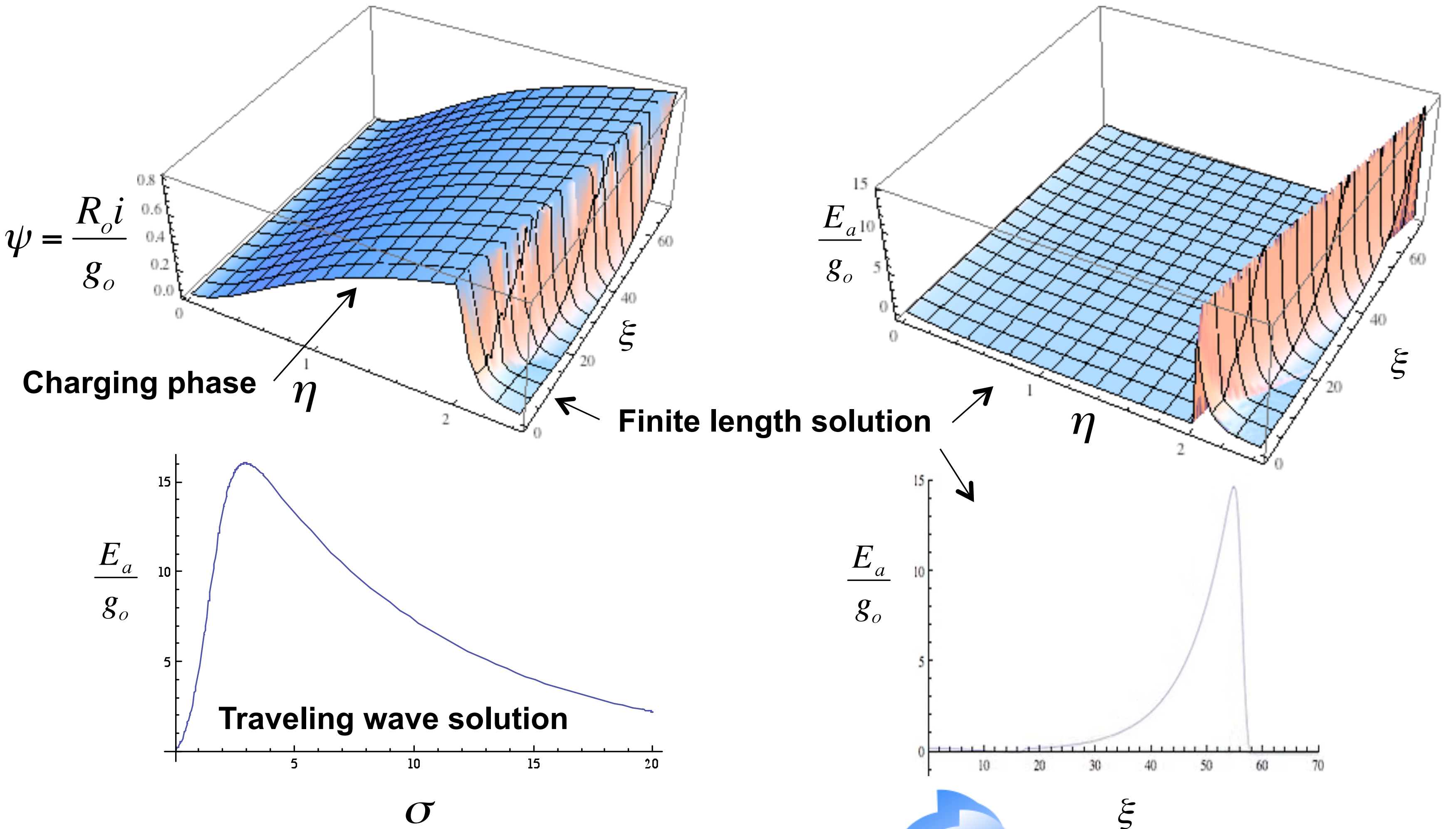
Traveling wave and finite length system solutions are similar

Beam Research Program
Lawrence Livermore National Laboratory



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Summary

- Key material strengths look to be consistent with 100 MV/m gradients for short pulses
- Near term goals
  - Improve switch material
  - Develop integrated switch package
  - Add focusing to injector and characterize
    - Source lifetime and repeatability
    - Beam quality
- New, “moving virtual gap” architecture idea to overcome parasitic effects