A High Gradient Coreless Induction Method of Acceleration

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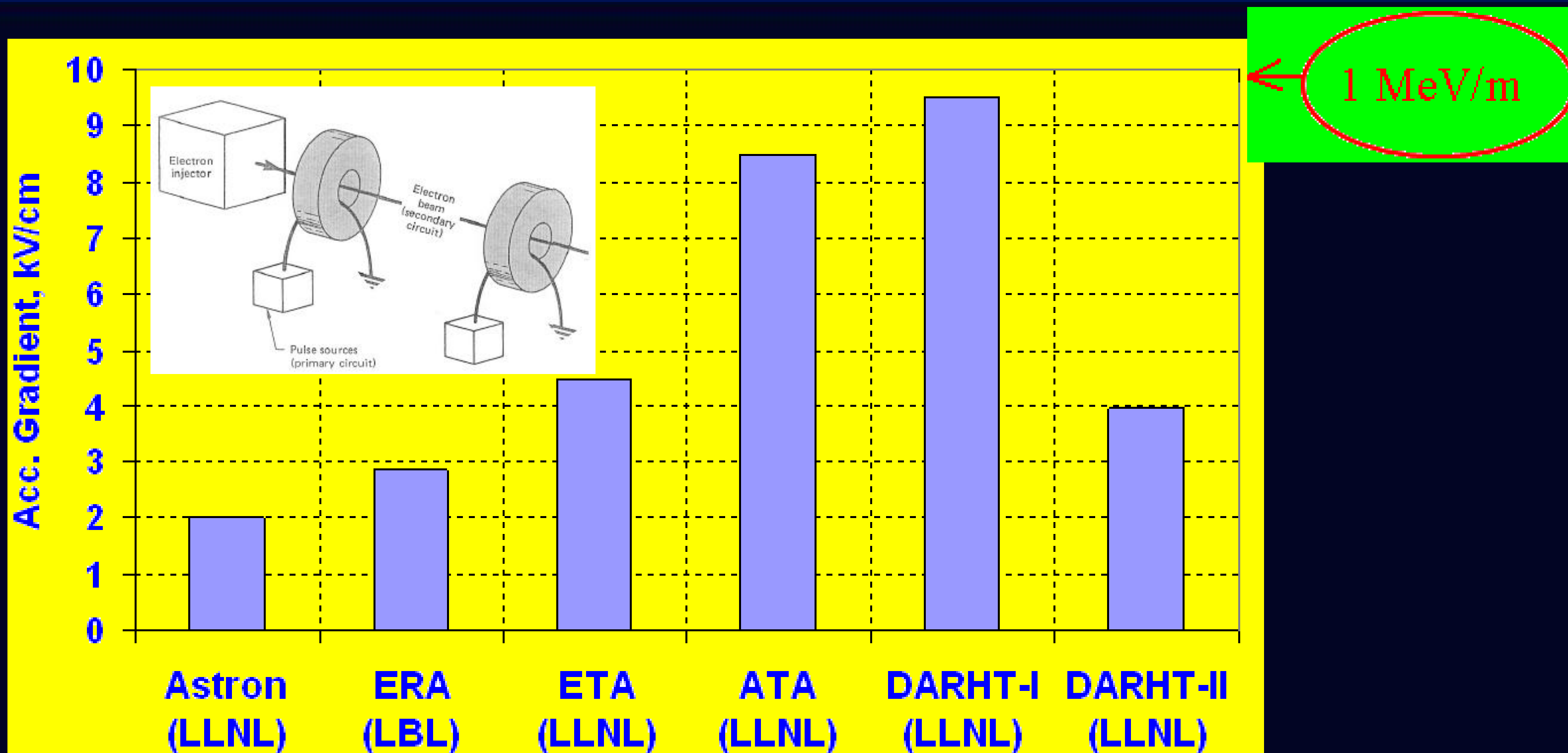
Outline

- Accelerating Gradient in Induction Linacs
- Analyze Ways How to Increase Gradient
- High Gradient Induction Cells Based on Solid State Approaches (DWAs)
- SLIM: ***SL***AC ***I***nduction ***M***odule (or Method)
- SLIM Embodiment
- Main SLIM Components and Parameters
- Some Advantages with Developing of the SLIM-based Concept
- Conclusion

Accelerating Gradient in Induction Linacs



The machines were build in the period 1963-2003 (i.e. the 40 years progress)

Machines in other countries (France, Russia, China, etc.) have similar accelerating gradient

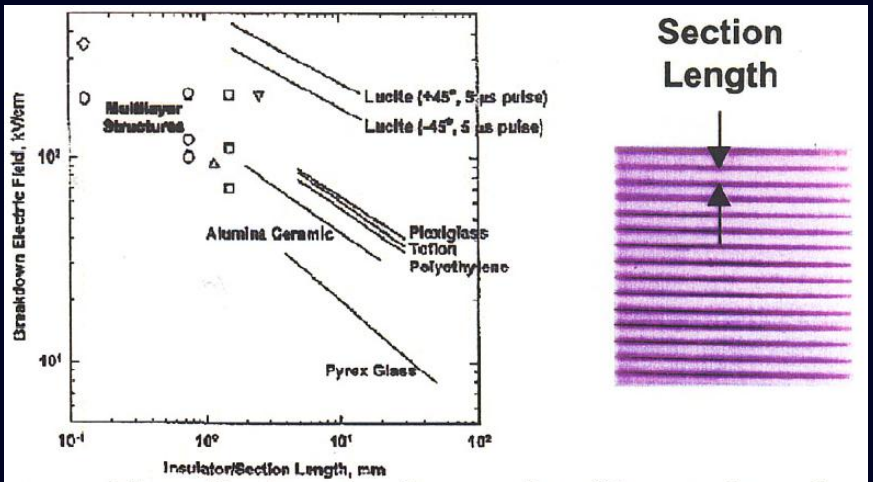
Analyze Ways How to Increase Gradient

There are two natural ways to increase the acc. gradient

• a reduction of the pulse width

• a reduction of the section length

$$E_{gain} \propto \sqrt[3]{\frac{t_{1u\,sec}}{t_p}}$$



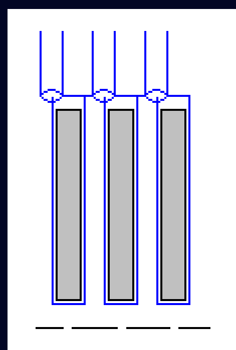
The effect scales inversely with spacing of the conductive planes

Culled from the published articles

Can the classical induction system deal with pulse widths in the nsec range?

There is the same V*sec integral

but the core does not react in the same manner

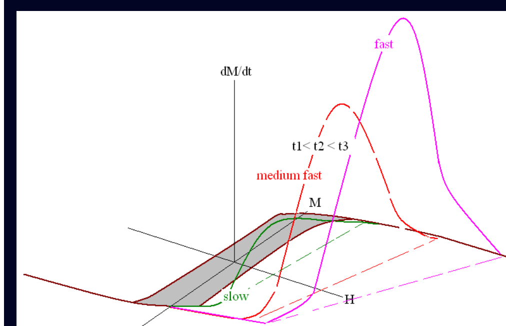


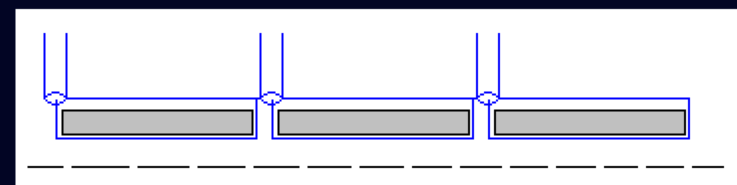
A dynamic of magnetization is slow

(long accelerating pulse widths)

$$\frac{dm}{dt} = \frac{\lambda}{M_s} \cdot H(t) \cdot [1 - m(t)^2]$$

$$m = \frac{M(t)}{M_s}$$





A dynamic of magnetization is fast

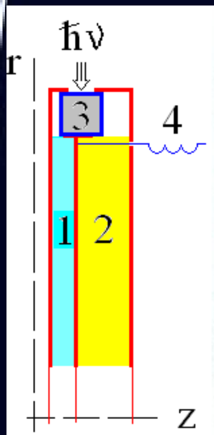
(short accelerating pulses are possible)

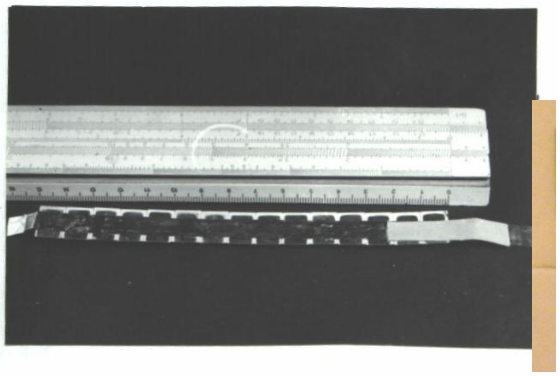
$$r(m) = \frac{dm(t)}{dQ} M_s$$

This is a core parameter for the effectiveness of driven accelerating gap (it is similar to the “shunt impedance” in the rf engineering)

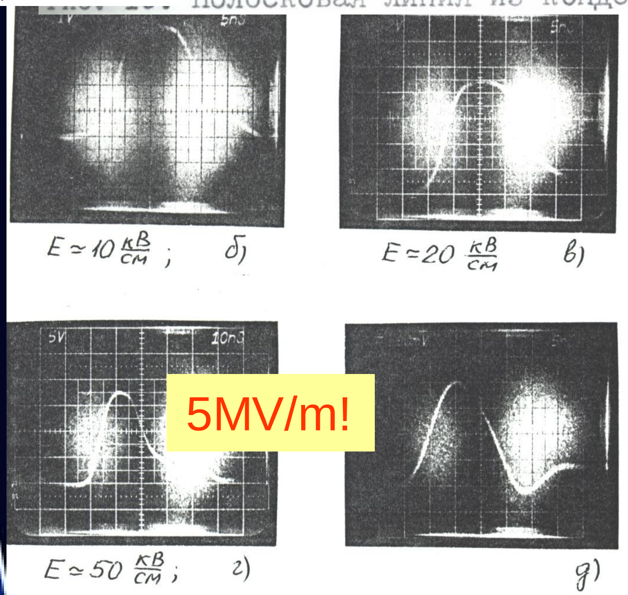
The induction system that has a large core ratio OD/ID, will not work effectively in nsec range. The power supply energy goes to the core instead of to the beam.

High Gradient Induction Cells Based on Solid State Approaches (our DWAs in the ‘80s)

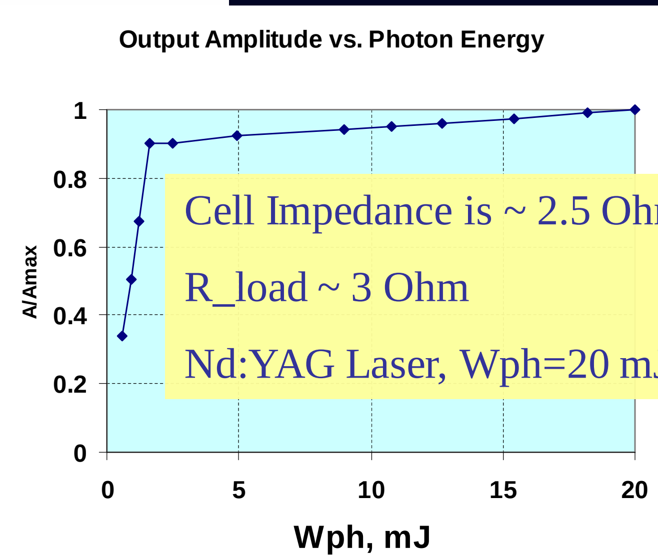




Полосковая линия из конденсаторо



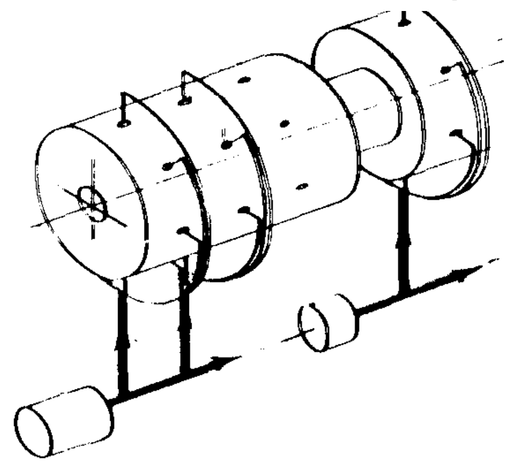
5MV/m!



Cell Impedance is ~ 2.5 Ohm

R_load ~ 3 Ohm

Nd:YAG Laser, Wph=20 mJ, t_p=10 nsec



$$\frac{W_{\hbar\nu}}{W_{ind}} \simeq 10^{-3}$$

t_{ch} [illegible] t_p

$$E_z^p \leq E_z^{ch}$$

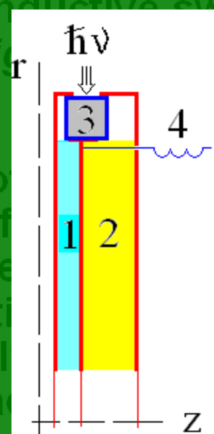
Recent Result from the LLNL Team
(Courtesy of G. Caporaso)

Control of the temporal laser profile potentially can compensate for beam loading in high-current accelerators

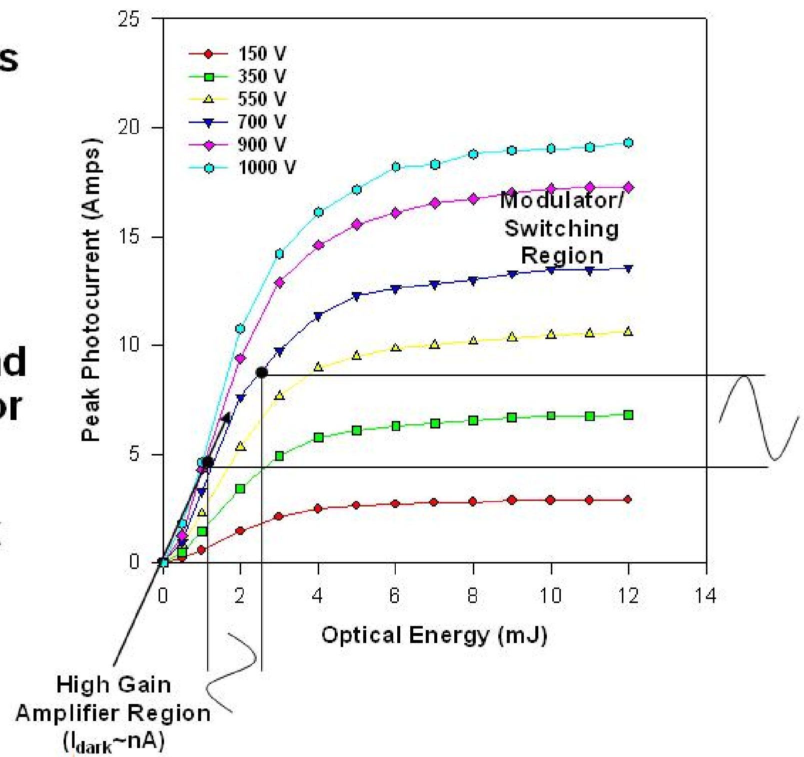
Beam Research Program
Lawrence Livermore National Laboratory

- Phot[...] is reall[...] resis[...]
- Cont[...]ral laser prof[...]nge the shape accel[...]rm and pote[...]ate for beam loa[...]

... H[...]ork is TB[...]



$$\frac{W_{\hbar\nu}}{W_{ind}} \cong 10^{-3}$$

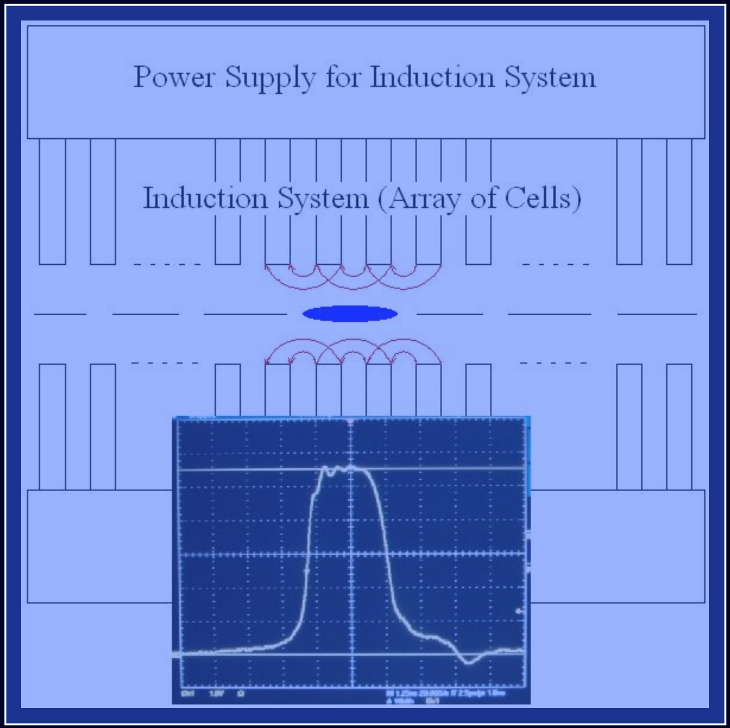


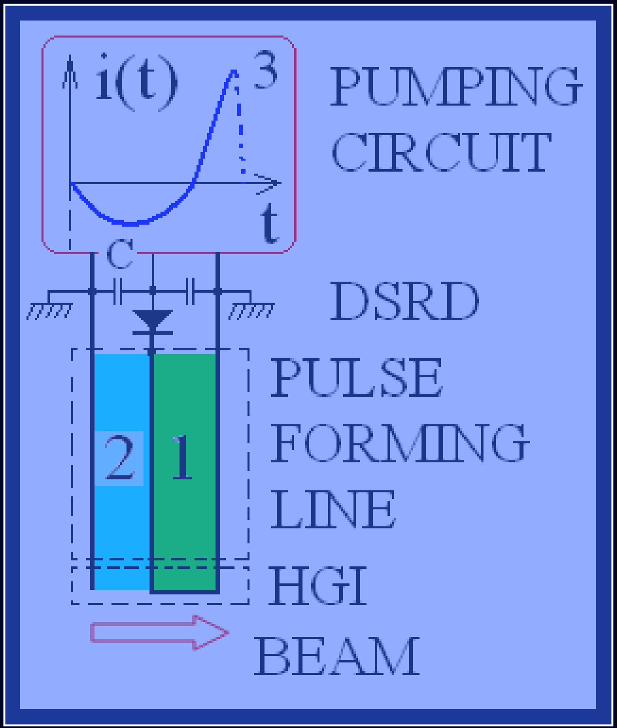
TomoTherapy
UC DAVIS CANCER CENTER
CPAC COMPACT PARTICLE ACCELERATION CORPORATION

SLIM: *SL*AC *I*nduction *M*odule (or *M*ethod)

- SLIM employs the coreless induction linac concept
- SLIM is based on the nsec TEM pulse mode operation with no laser or RF systems
- The SLIM induction system produces the “traveling mono-pulse” of the electric field that propagates in synchronism with the accelerating beam (like the DWA concept)
- The induction system of SLIM contains three components; an opening switch (a Drift Step Recovery Diode), an inductive energy storage, and a sleeve (solid-to-vacuum interface)
- Advanced solid state semiconductor technology and modern microfabrication techniques are used in the SLIM concept

SLIM Embodiment

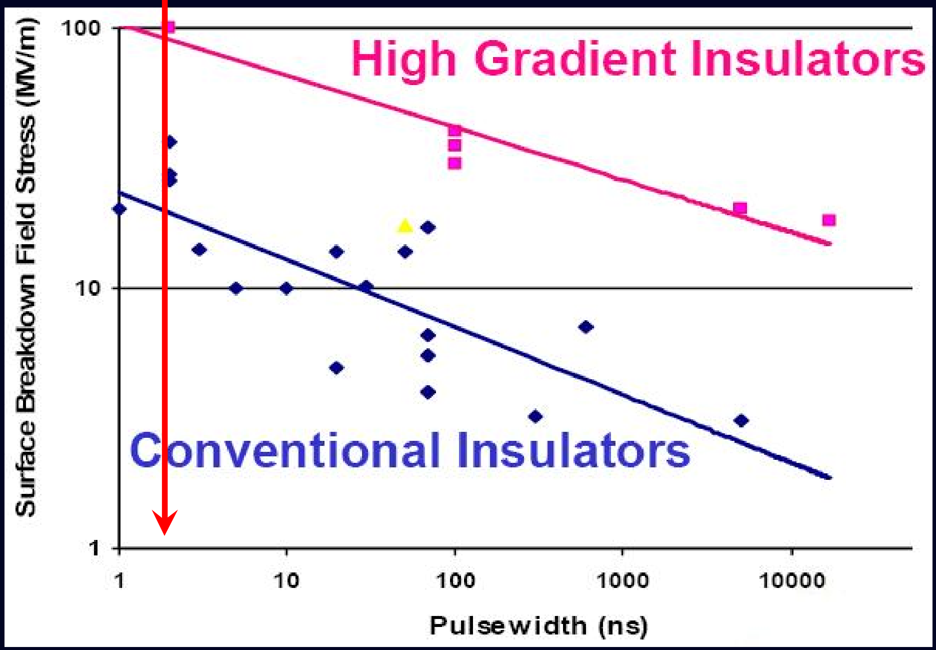


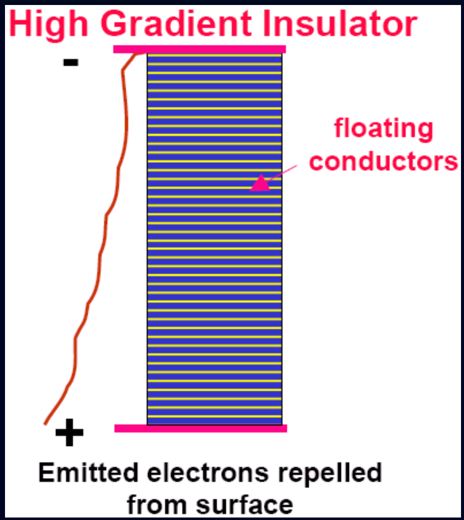


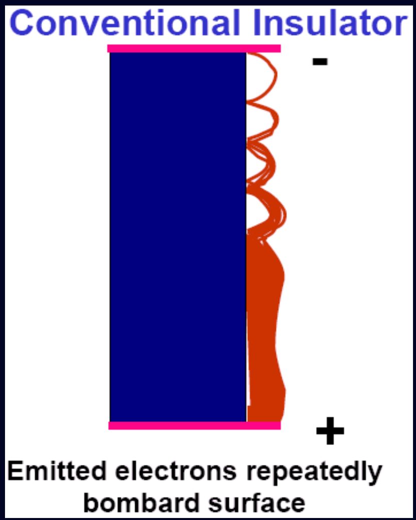
A presence of 100 MV/m field in the cell is only for 2 nsec. The rest of time the DSRD switch keeps gradient at zero level.

Main SLIM components: HGI

Range of a Pulse Width is (1-4) ns

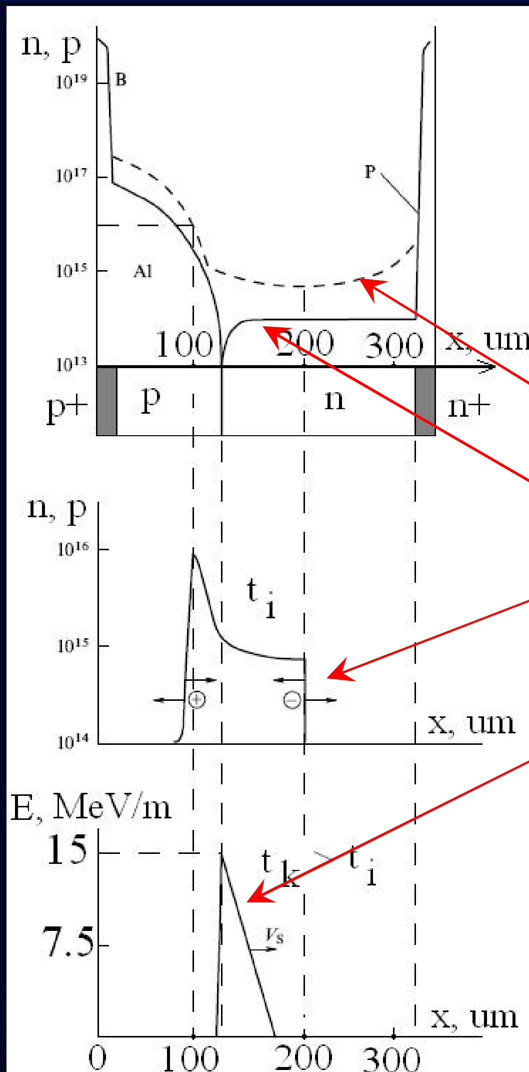


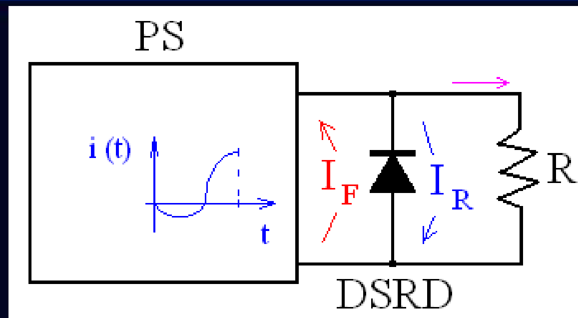


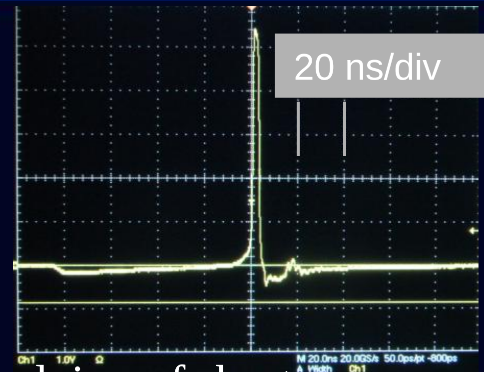


Courtesy of George Caporaso, LLNL

Main SLIM components: DSRD







A plasma distribution after applying of short forward current

A profile of dopant concentration

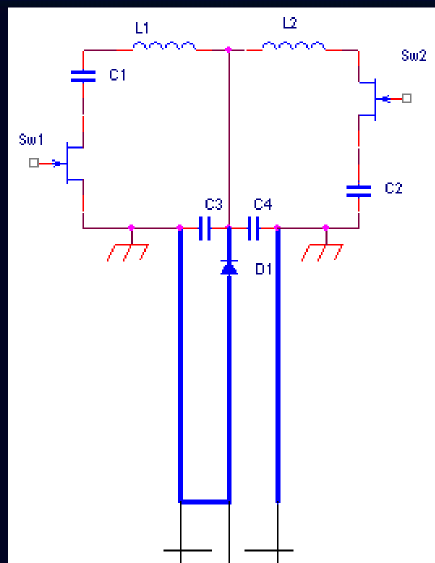
Two plasma fronts are moving fast ($v=10^7$ cm/sec) to each other toward to the p-n junction.

When both fronts are collided the Space Charge Region is formed.

The reverse current is abrupt in the DSRD and it jumps to the load.

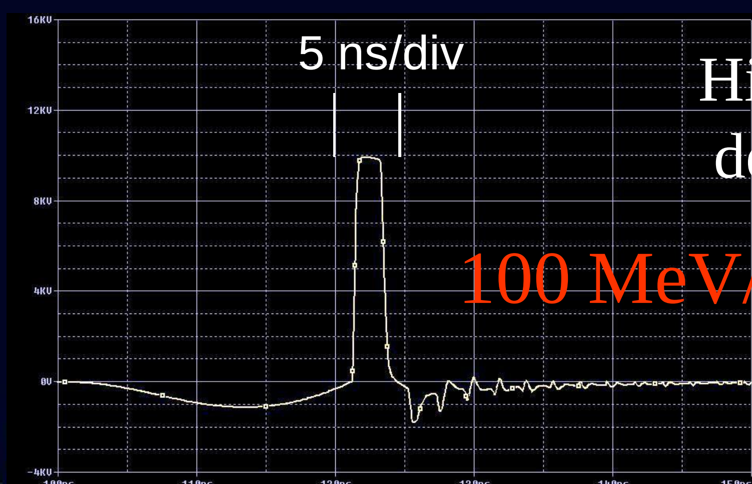
The voltage on the load is erected quickly. The stored energy starts to be delivered to the load.

More Details of the SLIM Embodiment



A simplified circuit to pump of the SLIM cell

A variant of the SLIM cell with the integrated DSRD opening switch



High Accelerating Gradient depends on the di/dt rate in DSRD

100 MeV/m ⟶ di/dt ~ 4 kA/ns

Table of Main Beam and SLIM Parameters

Luminosity	L	(sq cm*sec)^-1	2e34
Gradient	G	MeV/m	100
Pulse Width	tp	nsec	2
Rep. Rate	f	kHz	100
Beam Spot Size	σx/σy	nm	500/2
Peak Beam Current	Ip	kA	2
Ave. Beam Current	Ia	A	0.4
Cell Impedance	Zc	Ohm	5
Cell Voltage	Vc	kV	10
Efficiency	η	%	30
Wall Power	Pac	MW	135

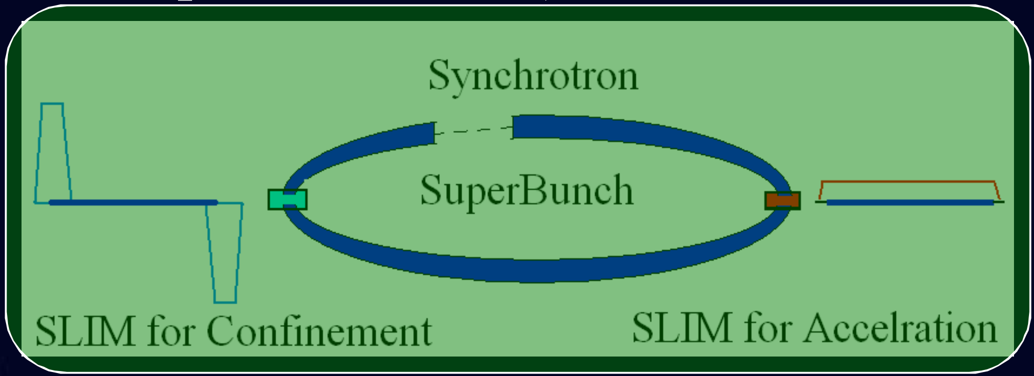
Some Advantages with Developing of the SLIM-based Concept

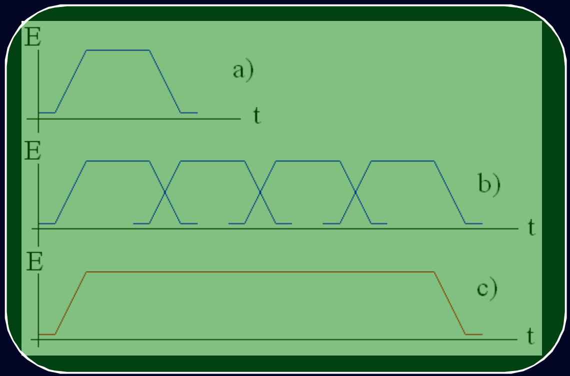
- In the USA a 4 GeV, 10 kA, 10 ns, 6 PPS Induction Linac for Heavy Ion Fusion Program is based on 1.5 MeV/m gradient.

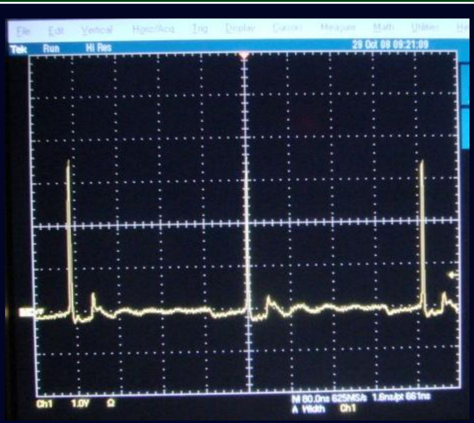
The SLIM-based concept may bring a new impulse for a development in this national program

Some Advantages with Developing of the SLIM-based Concept (cont.)

- Hadron synchrotron RF cavities (for example, for the LHC upgrade) will require the gain of 3 MeV/turn for a 25 A peak current and a pulse width of 500 ns (super bunch operation mode).





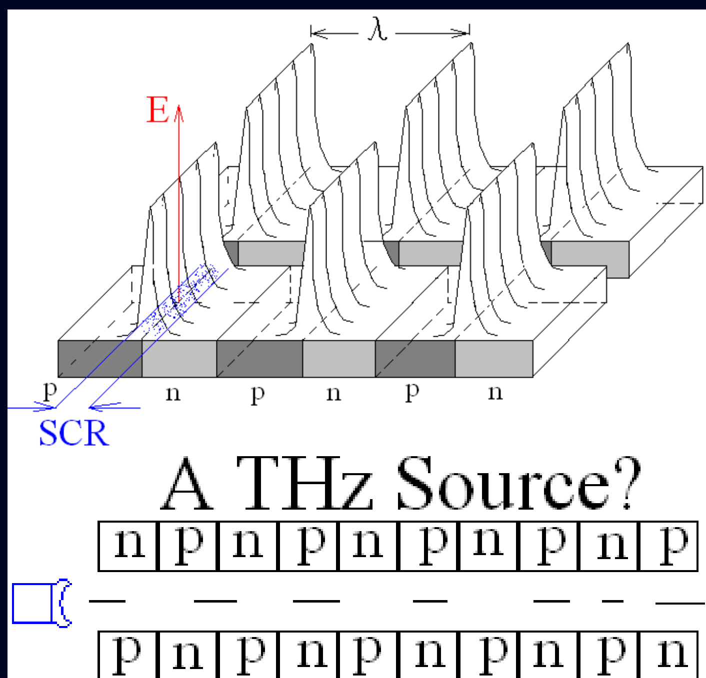


There are possibilities of

- A fast control of the spatial E(z,t) distribution along SLIM cells
- A 3MHz mode operation

Some Advantages with Developing of the SLIM-based Concept

- A modulation of the solid state plasma in the SLIM concept is produced by the gradient of a doping concentration and the pumping of the p-n junction by the pulse current (in forward and reverse directions). The array of lined up and activated DSRD may be a potential structure for the advanced accelerating technology



For example,

$$E \cong 15\frac{MeV}{m}$$

$$\lambda_w \approx 200\mu m$$

a strong B_z is acceptable

Conclusion

- The gradient of the SLIM-based technology is believed to be achievable in the same range as it is for the gradient of a modern rf-linac technology (~100 MeV per meter)
- The SLIM concept is based on the nsec TEM pulse mode operation with no laser or rf systems
- Main components of SLIM are not stressed while the energy is pumped into induction system. Components can accept the hard environment conditions such as a radiation dose, mismatch, hard electromagnetic nose level, etc. Only several nanoseconds the switch is OFF and produces a stress in the induction system. At that time, the delivery of energy to the beam takes place

Conclusion (cont.)

- The energy in the induction system initially is storied in the magnetic field when the switch is ON. That fact makes another benefit: a low voltage power supplies can be used. The reliability lower power supply is higher and they are cheaper
- The coreless SLIM concept offers to work in the MHz range of repetition rate. The induction system has the high electric efficiency (much higher than the DWA)
- The array of lined up and activated SLIMs is believed to be a potential solid state structure for the novel accelerating technology. The electron-hole plasma in the high power solid state structure is precisely controlled by the electromagnetic process of a pulsed power supply

Acknowledgement

- Authors would like to thank for your attention

- The pioneering high gradient study for the induction method of acceleration was performed in the Prof. Sarantsev Dept. in 80's (JINR, Dubna)

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