Coreless Concept for High Gradient Induction Cell

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Coreless Concept
for High Gradient Induction Cell

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Outline

- Introduction. Items for Consideration
- Accelerating Gradient in Induction Linacs
- Analyze Ways How to Increase Gradient
- High Gradient (HG) Cell based on Solid State Approaches
- SLIM$^{©}$: SLAC Induction Module (or Method)
- Conclusion

Items for Consideration

- Why accelerating gradient of existing induction linacs is weaker than classical rf-linacs? Can the induction linacs possesses the accelerating gradient similar to rf-linac gradients?

- A typical pulse width for an induction system is several tenth of nanoseconds (let's say 30-100 nsec). Can the induction system deals with 10 times shorter pulses?

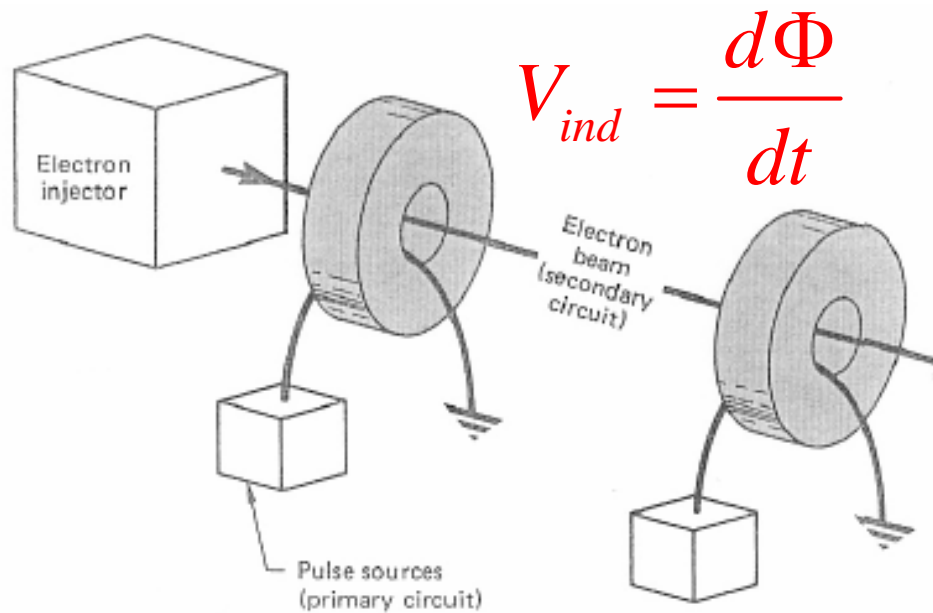- Presentation is based on our R&D results

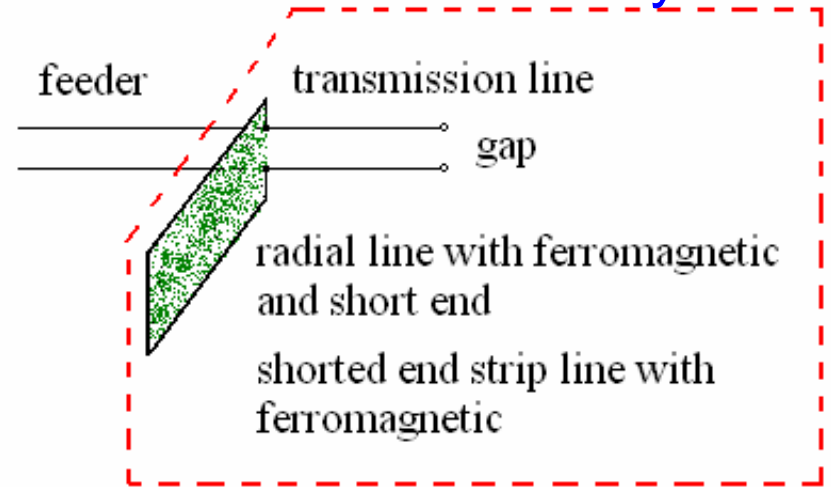# What is a typical accelerating gradient of induction linacs?
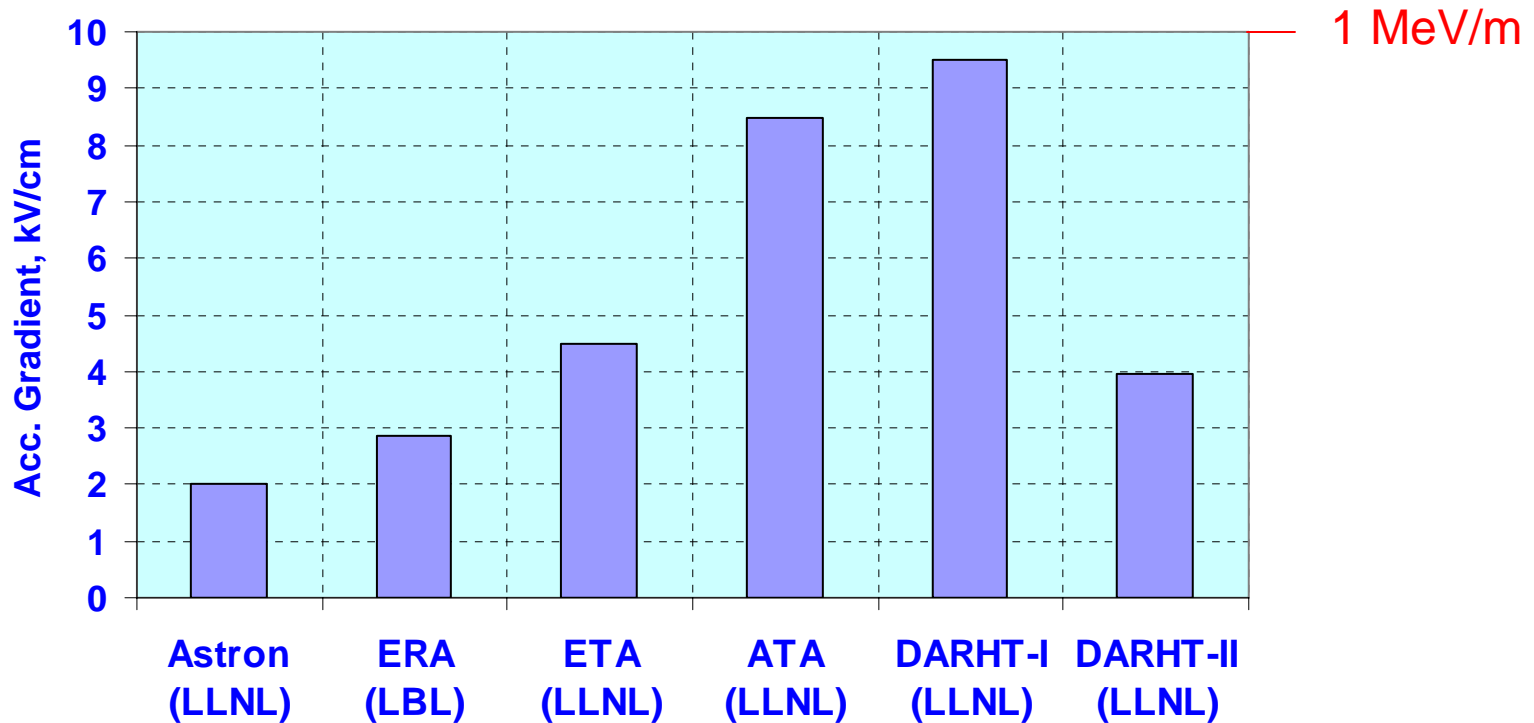
The machines were build in the period 1963-2003 (i.e. the 40 years progress)

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

Two Induction Approaches

$$V_{ind} = \frac{d\Phi}{dt}$$

Electron injector

Electron beam (secondary circuit)

Pulse sources (primary circuit)

One Cell of Induction System

feeder   transmission line
                gap

radial line with ferromagnetic
and short end

shorted end strip line with
ferromagnetic

A classical approach of a working principle for
the induction system does not allow us to make
a leap forward on the gradient improvement

The transmission line approach
helps to understand the role of
components of individual cells (there
is a contrasting view of the energy
transfer from the source to the beam)

Heart of Coreless Approach

- Sub nanosecond mode operation
- Induction system is an array of the solid state cells with a tiny section length (in mm range)
- High accelerating gradient is formed by a transition process in induction system
- Solid state switches are integrated into cells
- Normal switch condition is close. Energy is storied in a magnetic form
- Switches are controlled by a form of the pumping induction system current

Results of Pioneering R&D for the Solid State Coreless HG Induction Linac (cont.)

10 nsec Sicond© stripline

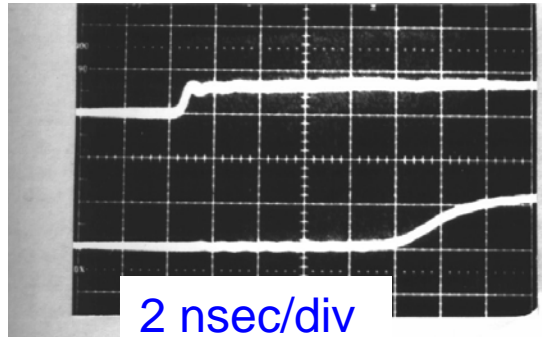(Slide-rule is for a scaling)
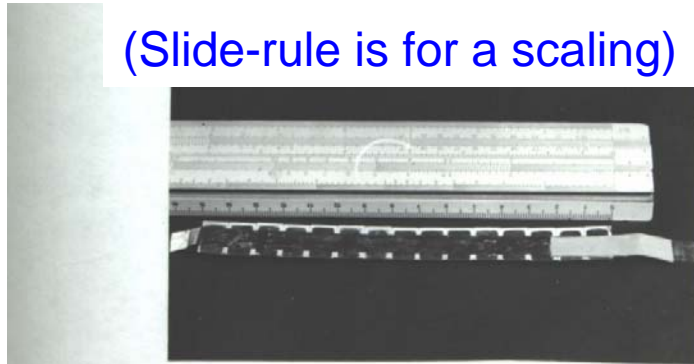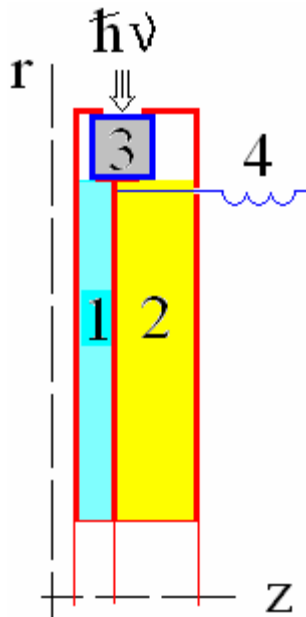
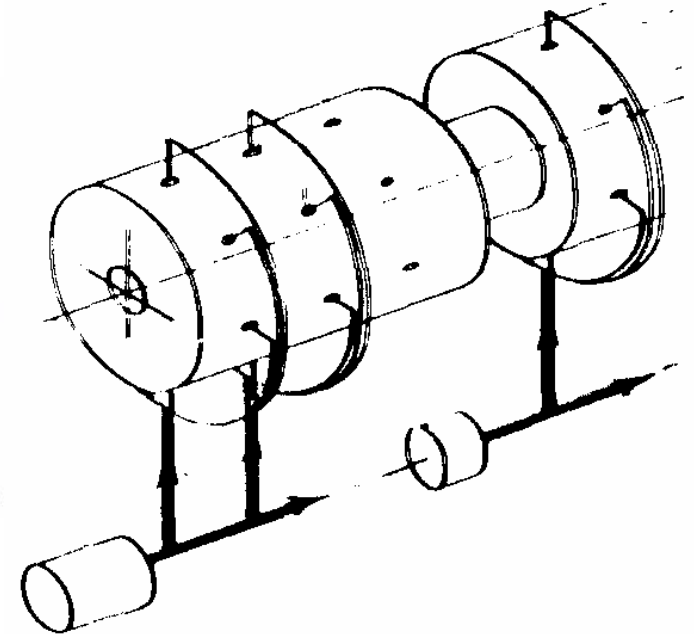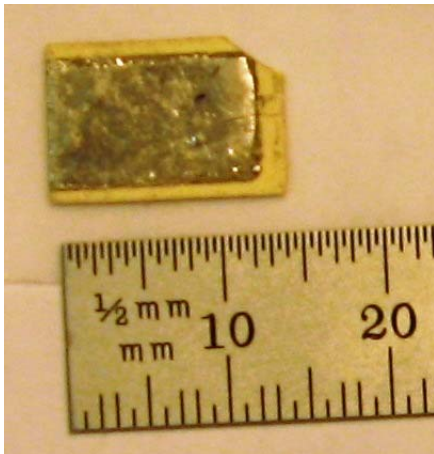Рис. I9. Полосковая линия из конденсаторов

2 nsec/div

Рис. 20. Временная задержка по линии.
Верхний луч — импульс на входе;
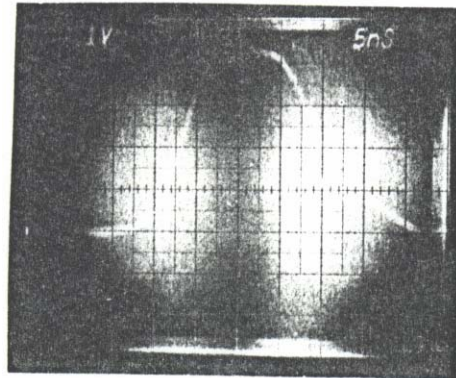Нижний луч — на выходе;

Solid State Switch driven by Pulsed Photon Flux in HG DWA Concept
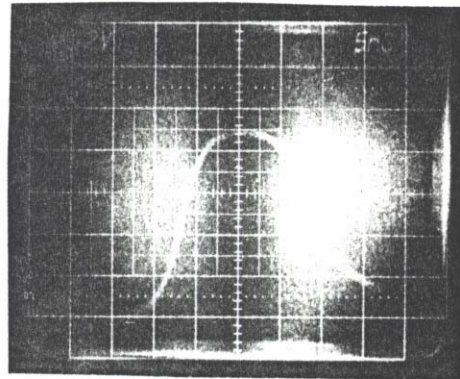The cell thickness is ~1.6 mm.

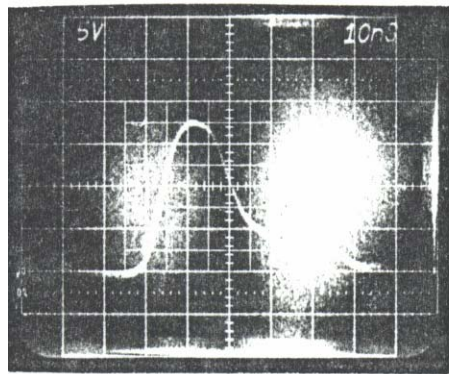Cells with a tiny section length are a prototype for the SLIM©

Results of Pioneering R&D for the Solid State Coreless HG Induction Linac (cont.)
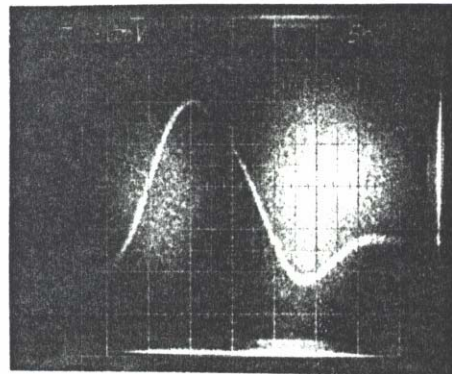

$E \simeq 10 \frac{\kappa B}{cm}$;　　б)

$E \simeq 20 \frac{\kappa B}{cm}$　　в)

$E \simeq 50 \frac{\kappa B}{cm}$;　　г)

г)

Cell Impedance is ~ 2.5 Ohm
R_load ~ 3 Ohm

Nd:YAG 1064nm Laser,
Wph=20 mJ, t_p=10 nsec

Output Amplitude vs. Photon Energy

Wph_min=1.6mJ

A/Amax

Wph, mJ
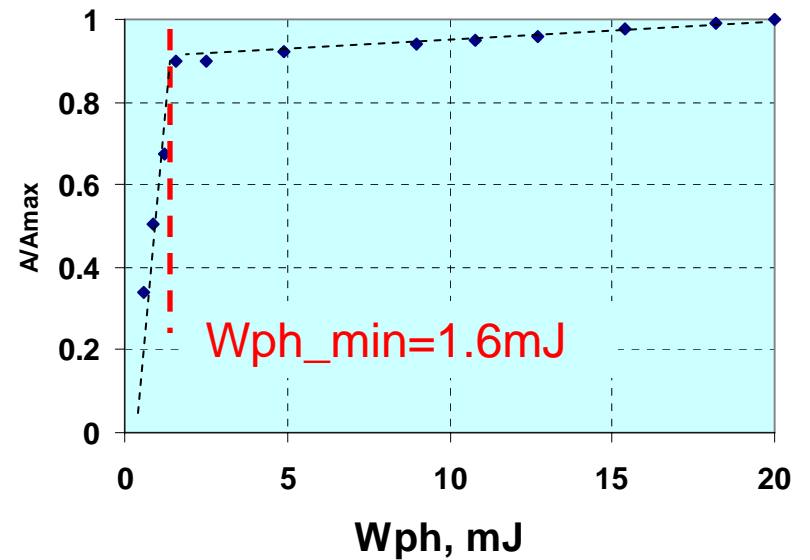
5 MeV/m was shown, **see Proc. on Collective Methods of Acceleration, Dubna, 1982**
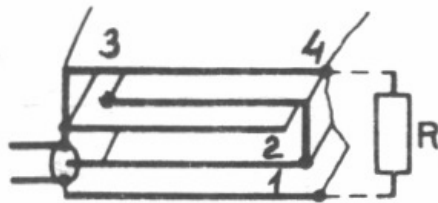
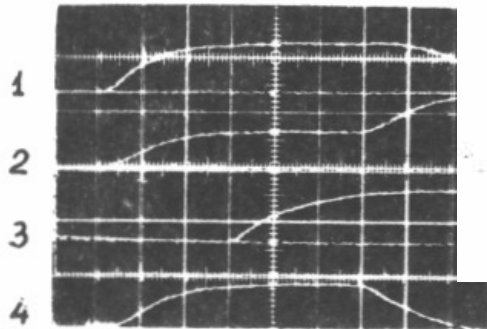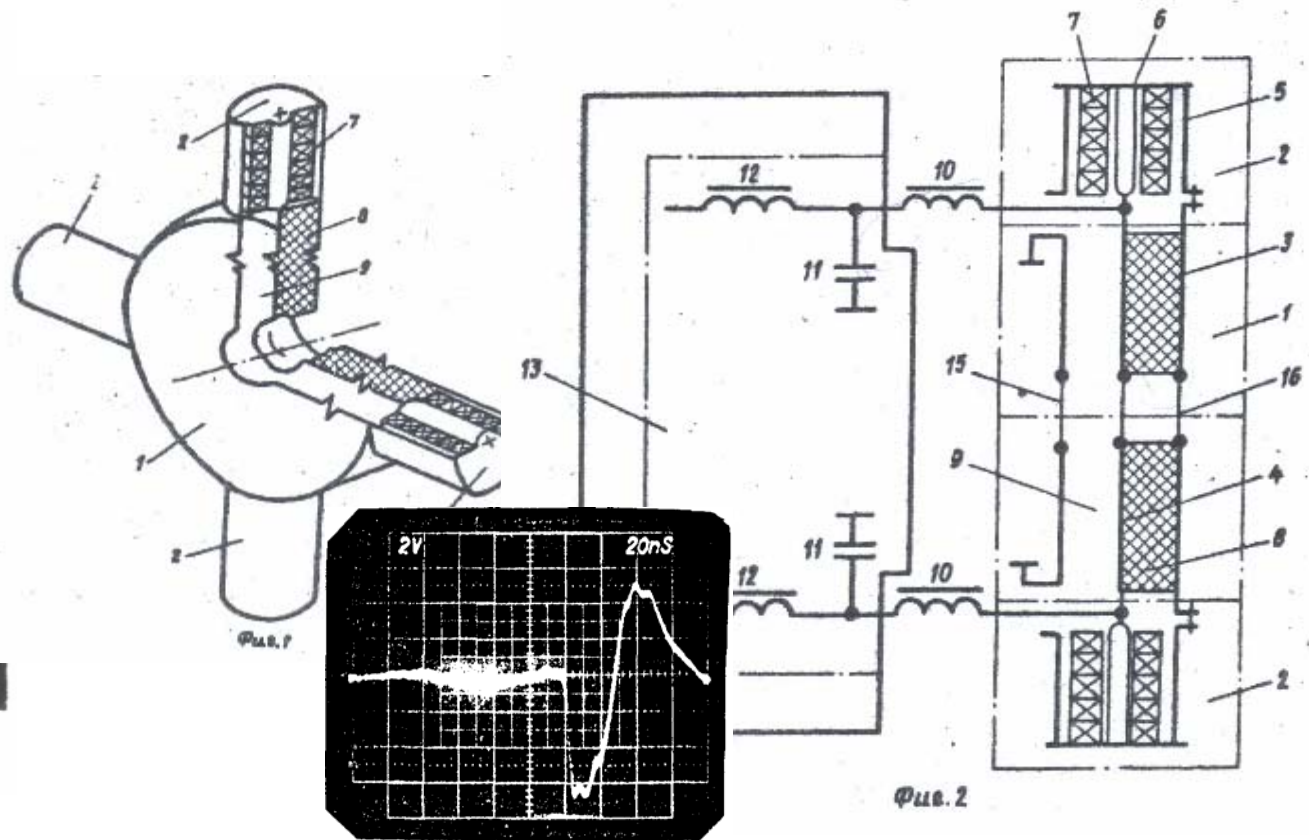# A DW Cell with a Ferromagnetic Switch

Рис.5

5nsec/div

Рис.6

See:

• **Proc. on Collective Methods of Acceleration, Dubna, 1982**

• **SU patent #1263189, H 05h 9/00, filed January 1985**

The rebirth of DW cell was in USA by B. Carder in 1997, patent # 5,757,146

see also G. Caporaso application US2007/0145916 filed Oct. 24, 2006
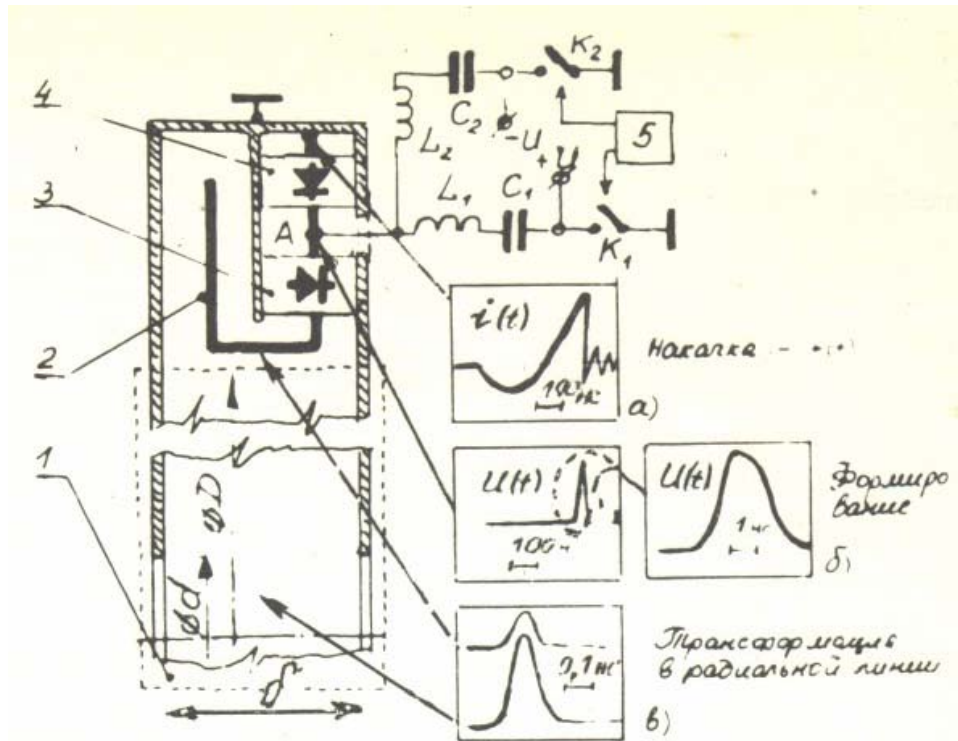
DW Cell driven by the DSRDs

Рис.I.

Pulse transformation in the radial line that
is imposed in the inductor
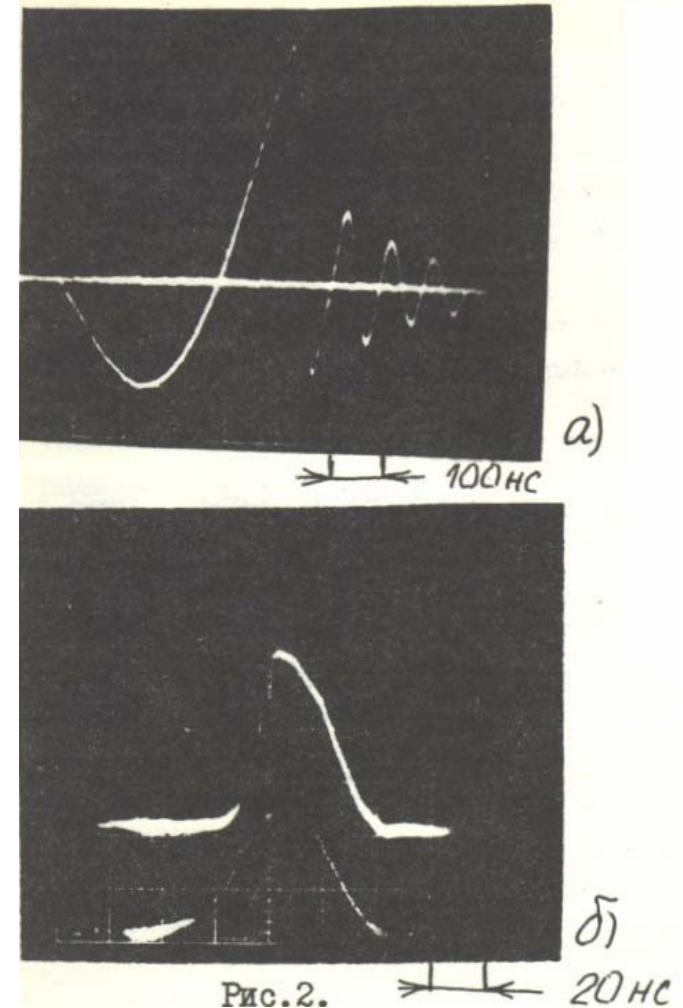
Рис.2.

Transmission Line with a Close-Open-Close Switch

1 nsec
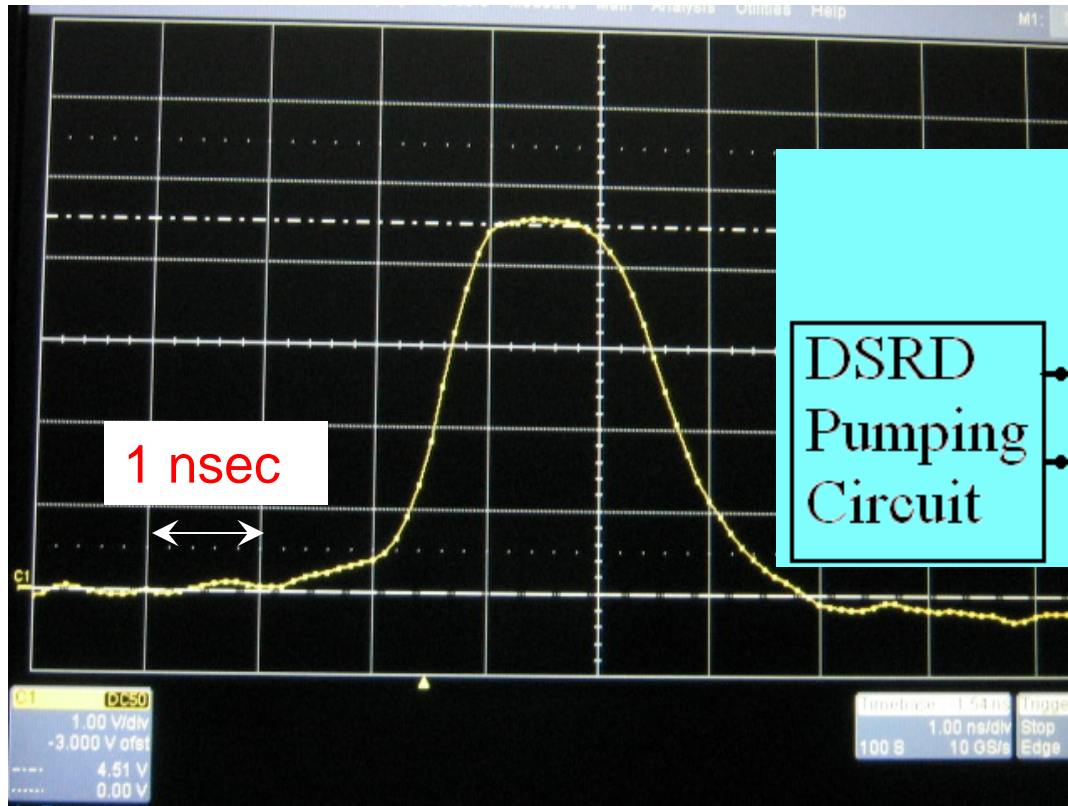
Simplified Diagram for the
DSRD Test at SLAC

~2 nsec
Transmission
Line

DSRD
Pumping
Circuit

DSRD

HV
Broadband
Attenuator
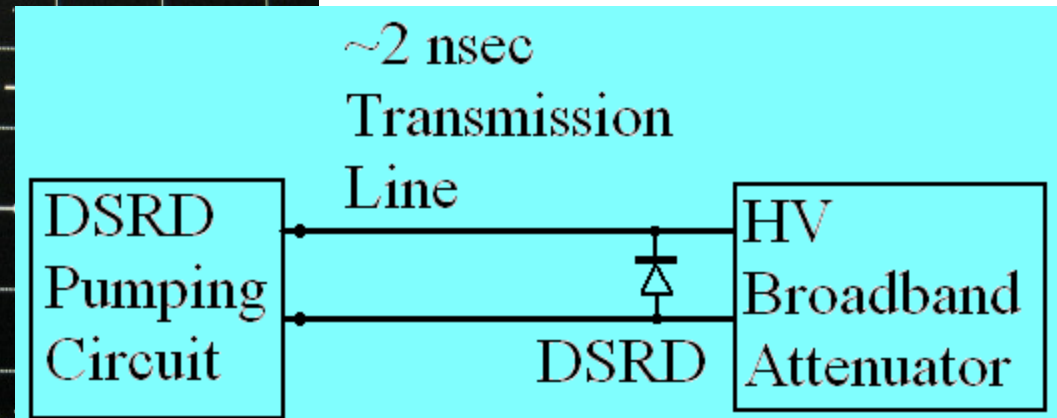
A_out = 4.5 x 600 = 2,700 V

(LeCroy oscilloscope @ 10GS/sec)

Work was performed in the frame of ILC
DR Kicker R&D

See presentation on ILCDR06 (Sept. 2006, Cornell University, SLAC-WP-077)

A Progress in the HG Vacuum-to-Media Interface Development (results from the LLNL team)
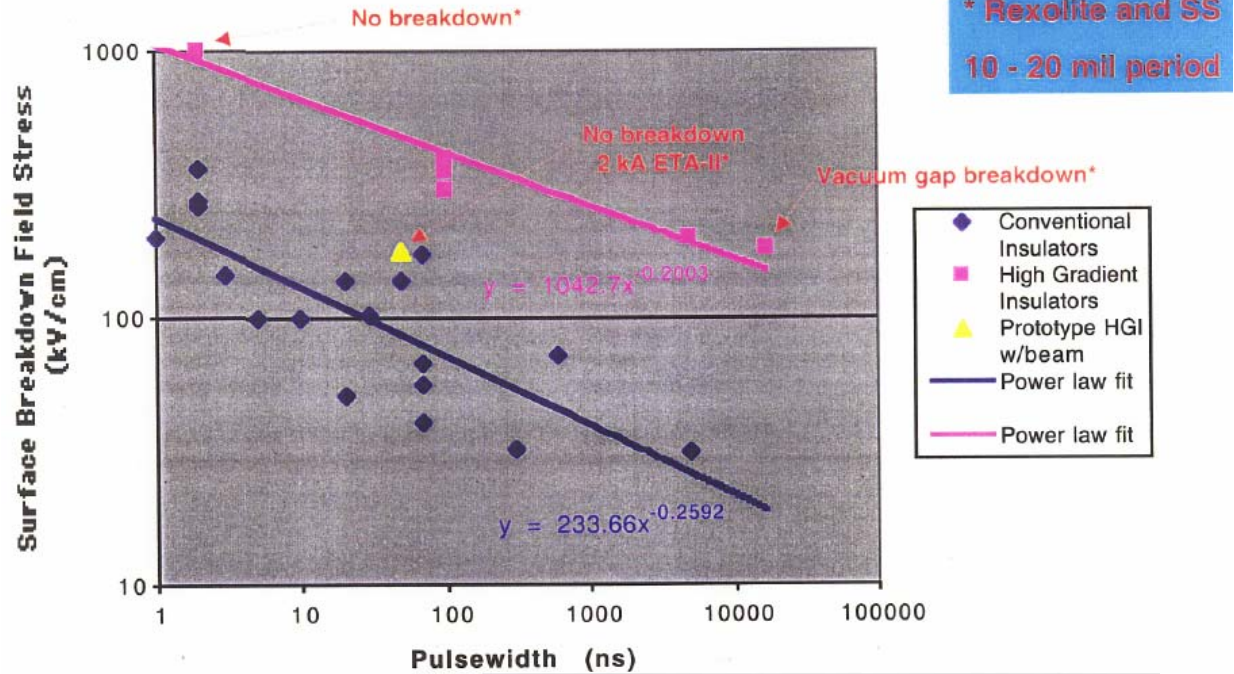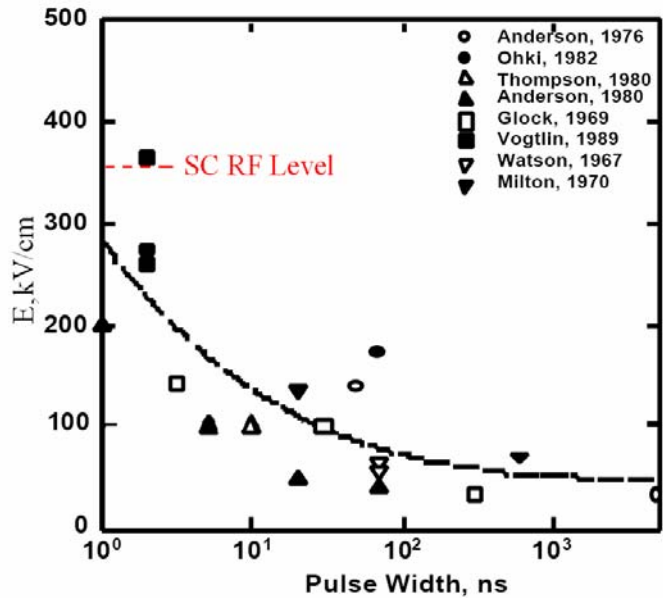
Pulsed surface breakdown electric field as a function of pulse width for single substrate, straight wall insulators
(see G. Caporaso et al, **UCRL-JC-127274)**
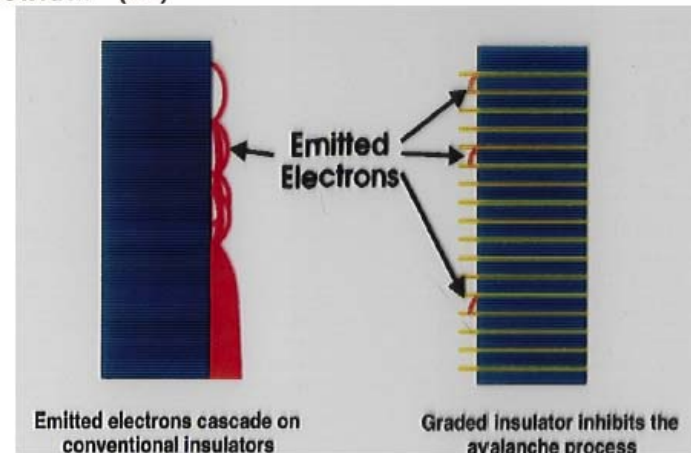
SLIM©: Feasible Topology for HG Coreless DW Cell
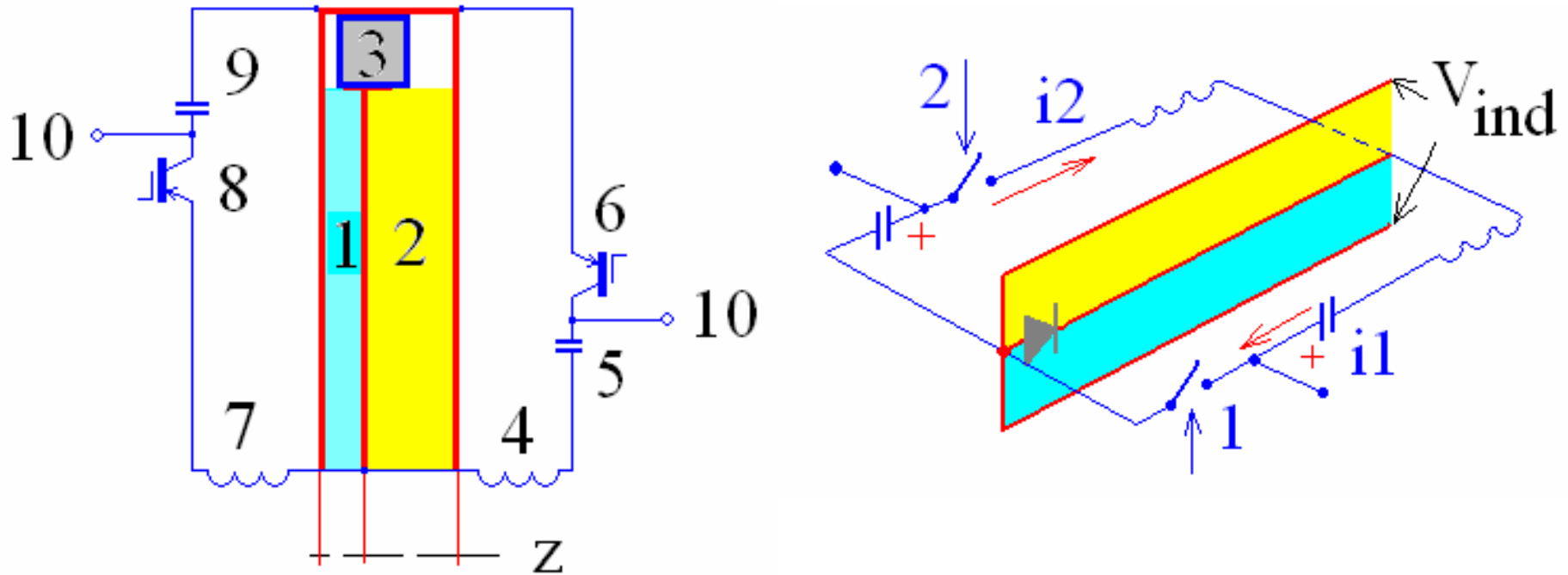
Thin in z direction Cell with a DSRD Mode Operation and the Open IR Ends

SLIM©: Feasible Topology for HG Solid State Coreless Cell

Low Voltage and High Current Pumping Circuit

HG Solid State Coreless Cell with a DSRD Mode Operation
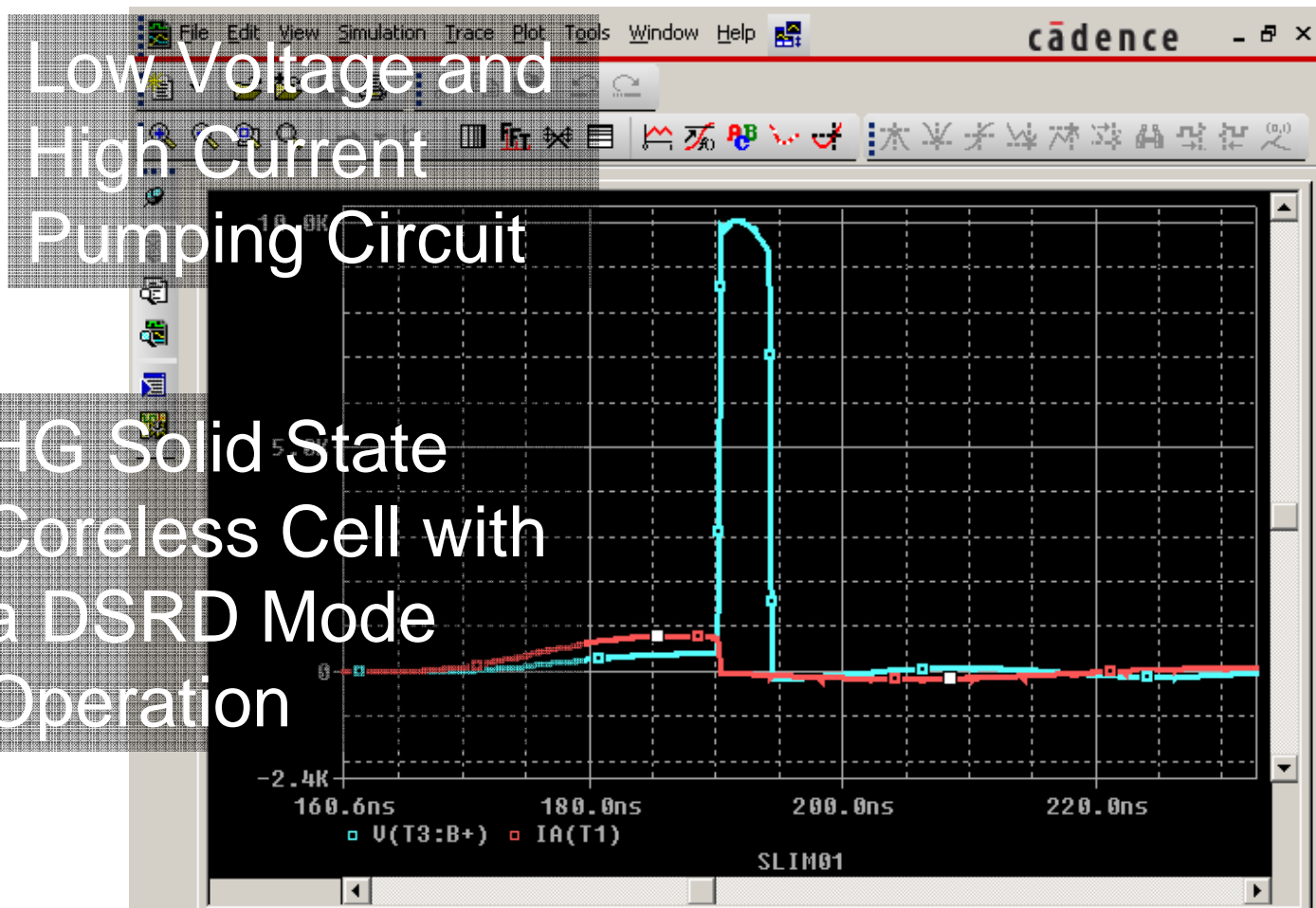
Tiny Cell with the Open and Short IR End

SLIM©: Feasible Topology for HG Coreless Induction Module
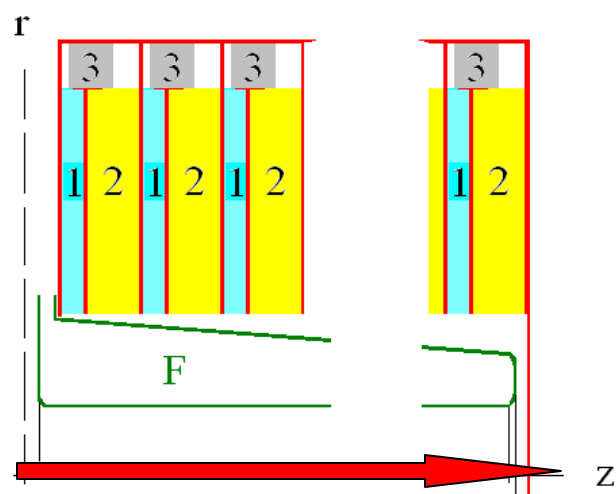
Induction system is not conflict with the SC Foc. System (no ferromagnetic cores)

High efficiency suitable to operate with the high rep. rate (the p+ synchrotron's cavity)

The induction system is a storage energy element

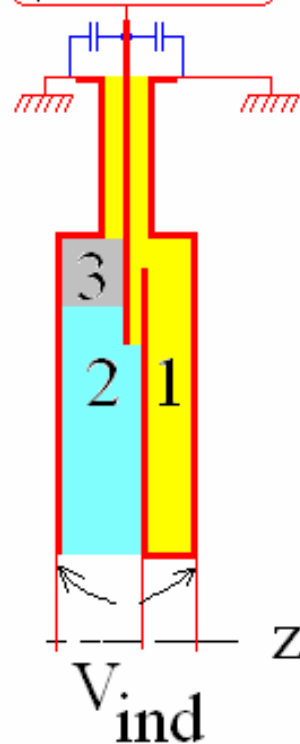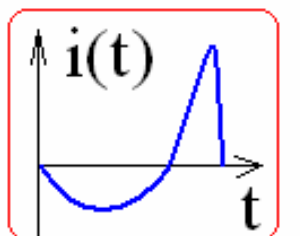The storage energy is practically delivered to the beam during interval of several nsec, i.e. the concept has high efficiency

The nsec mode operation may run with a high gradient that is comparable with the rf-linac gradient (~30 MeV/m@ 5 nsec FWHM)

DSRD solid state switches are controlled precisely (jitter ~30 psec) by the electrical trigger

High rep. rate (up to several MHz) is possible

The full size proposed SLIM© did not implement. There is a need for system technology design and tests.

Some Important Features for the SLIM©

$E_{ind}(t)$
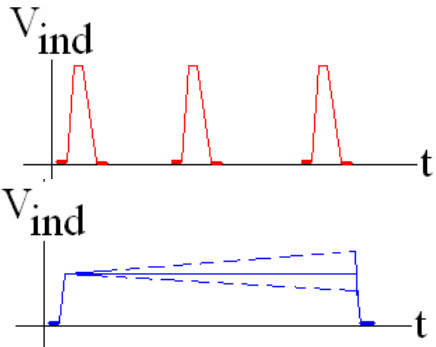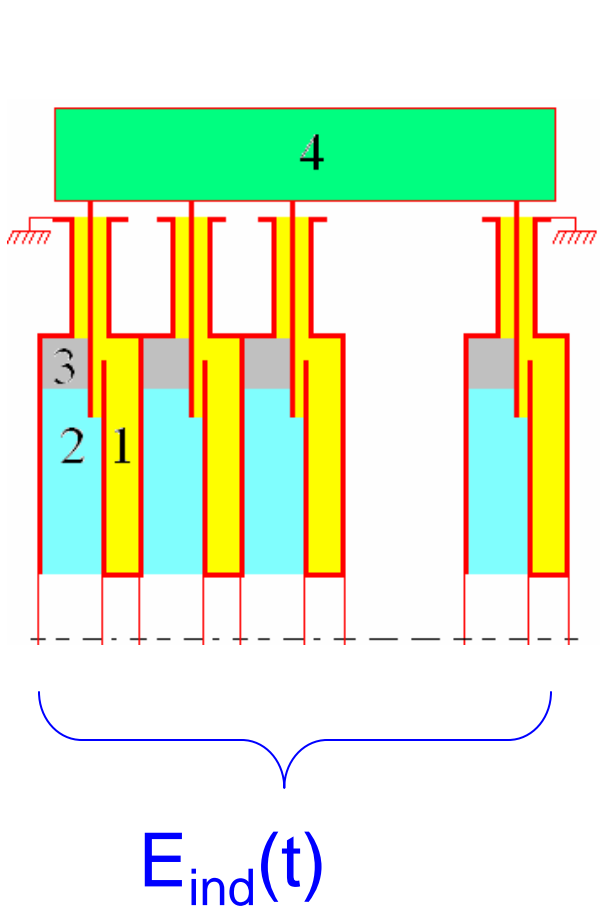
HG Mode Operation with High Rep. Rate (synchronization all DSRDs as one switch)
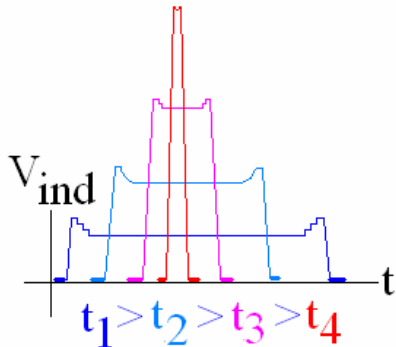
Possible Fast Control of the Spatial E(z,t) Distribution along Induction System

Acc. Structure with Q=1 (Broadband Impedance) and Alternating Gradient in the MHz range is feasible

Other Programs Based on Induction Linac Topology

Summary of applications for induction accelerators

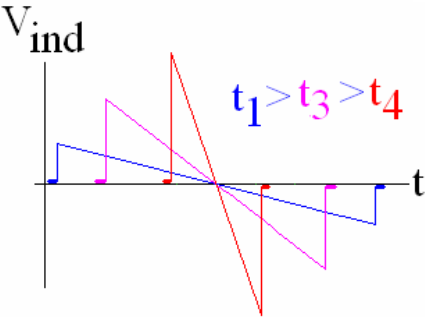| Application/ Architechture	Voltage	Beam Current	Pulse length	Rep. rate	Issues/comments
Hadron collider/ p^+ ind. synchrotron	31 TeV; 3 MeV/turn	25 A	500 ns	100 kHz CW	feasibility study going on; require upgrade of most existing detector components for higher L. competitor: low harmonic rf
RK Two Beam Acc for Linear Colliders/e^- ind. linac	10 MeV, 0.3 MeV/m	1 kA	50 - 200 ns	180 Hz	fundamental aspect has been demonstrated; no current funding
Neutrino factory;μ- collider / μ –ind. linac	200 MeV 2 MeV/m		100 ns	4 pulse @ 3 MHz; 15 Hz avg.	feasibility study going on; competition with low freq rf device; can survive rad. env.;
Heavy Ion Fusion/ HI^+ ind. linac	4 GeV 1.5 MeV/m	0.2 - 10 kA	20 μs - 10 ns	~6 Hz	Significant program ongoing

Summary of applications for induction accel's-cont'd

Application/ Architechture	Voltage	Beam Current	Pulse length	Rep. rate	Issues/comments
Spallation n- source/ p^+ ind. linac	1 GeV	60 - 100 A	1600 - 160 ns	50 Hz	Will be easier to sell if induction technology more widespread
Radiography/ e^- ind. linac	18.4 MeV	2-4 kA	~50 ns	~2 MHz bursts of 4 pulses	DARHT-II built and undergoing testing. Ion-hose, beam-target interactions AHF to use protons/synch.
Sub-critical reactor/ ind. FFAG; H- driver for spallation n-source; Accel. Trans. Waste (H-ind. FFAG)	~ 1 GeV 1-3 GeV	30 mA 10 mA (avg)	~few 100 ns	1 kHz CW	May combine rf + ind.(Ind barrier only); cost/MW beam power is low rel. to rf linac; early design, at idea stage
Driver for Microwave source FEL's, BWO	~few MeV	~kA	~few 100 ns	~kHz	Very attractive match

See, for example

http://nonneutral.pppl.gov/HIF04/US-Japan/02.Barnard.pdf

i.e.
- fusion field,
- synchrotron with induction cell
(superbunch, barrier bucket, Fixed-Field Alternating-Gradient)
- high-gradient accelerator (TBA-like)
- spallation neutron and neutrino factory projects
- induction-linac-driven free electron lasers, relativistic rf-sources
- etc.

The SLIM© can be well suited for these programs!

Conclusion

An induction linac cell for a high gradient is discussed. The proposed solid state coreless approach for the induction linac topology (SLIM$^©$) is based on nanosecond mode operation. This mode may have an acceleration gradient comparable with gradients of rf- accelerator structures. The discussed induction system has the high electric efficiency. The key elements are a solid state semiconductor switch and a high electric density dielectric with a thin section length. The energy in the induction system is storied in the magnetic field. The nanosecond current break-up produces the high voltage. The induced voltage is used for acceleration. This manner of an operation allows the use of low voltage elements in the booster part and achieves a high accelerating gradient. The proposed topology was tested in POP (proof of principle) experiments.