Beam
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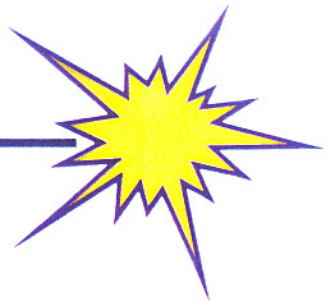

New Trends in Induction Accelerator Technology*

G. J. Caporaso

Lawrence Livermore National Laboratory

Workshop on Recent Progress in Induction Accelerators

KEK, Tsukuba, Japan

October 29-31, 2002

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NNSA

Acknowledgements

- Hugh Kirbie - LANL
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New pulsed power technology for high current accelerators

- Recent advances in solid-state modulators now permit new classes of high current accelerators
  - burst mode at frequencies of several MHz with unprecedented flexibility and precision in pulse format
  - permit precision beam manipulations
  - high average power capability

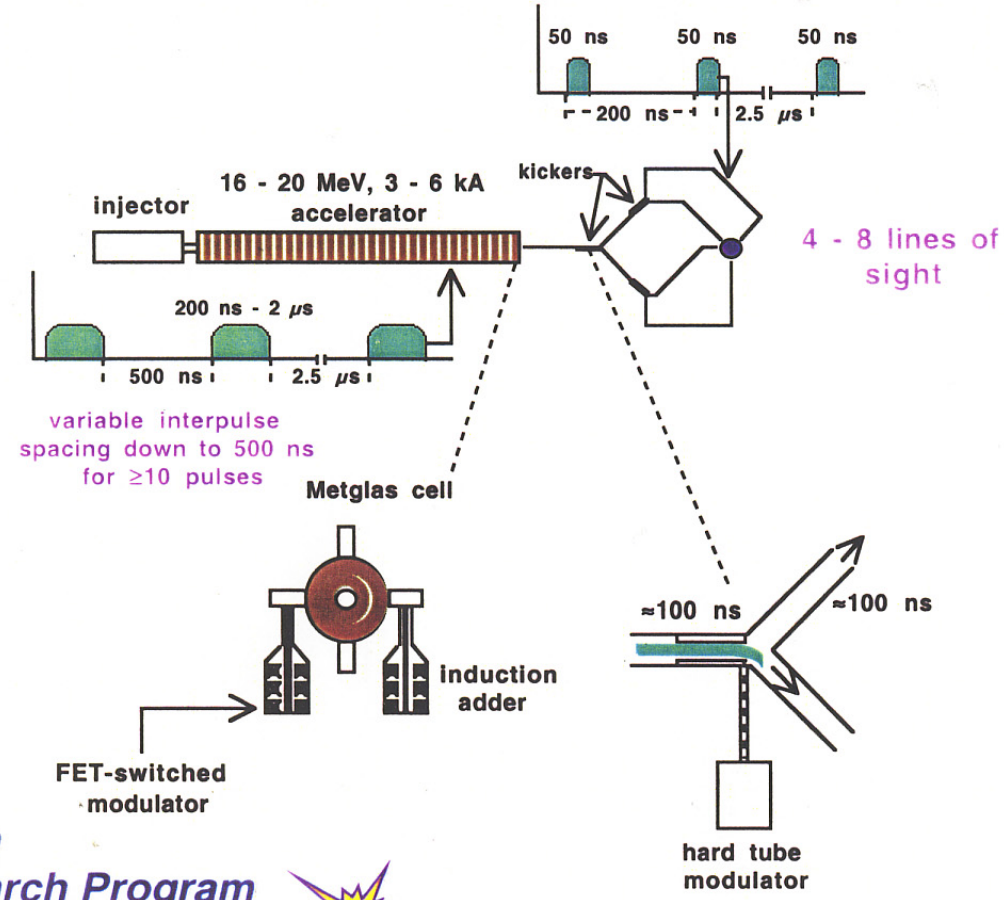
- New insulator technology combined with novel pulse forming lines and switching may enable the construction of a new type of high gradient, high current accelerator

Outline

- Advanced Radiography as a driver for technological development
- Solid-state modulator technology
- Fast kicker and pulser development
- NLC klystron driver
- High gradient insulator technology
- Dielectric wall accelerator concept and recent experiments

Induction accelerator concept for Advanced Radiography drove technology development

Providing multiple pulses and multiple lines of sight from a single accelerator



- Solid-state pulser system drives accelerator at up to 2 MHz repetition rate producing many variable width pulses
- Fast kicker system splits beam pulses into different lines producing multiple pulse trains into multiple lines of sight

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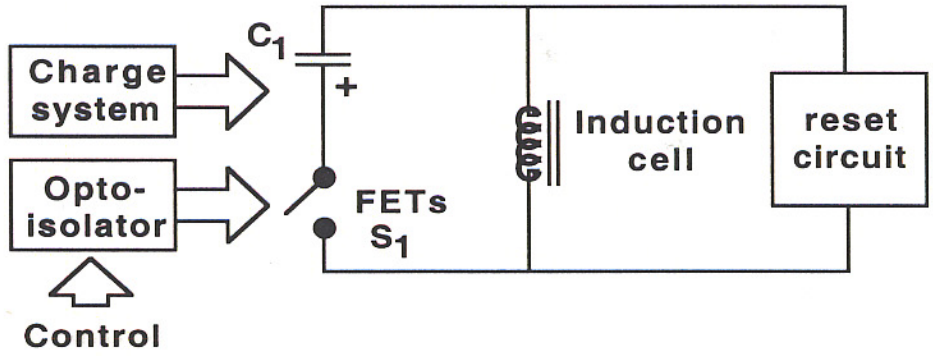
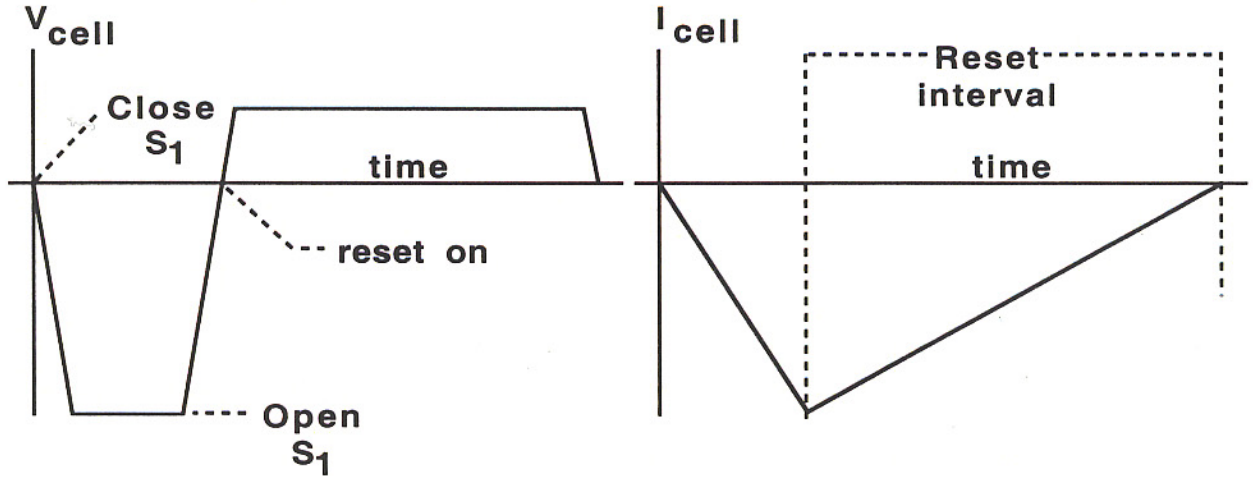
ARM-II solid-state modulator concept





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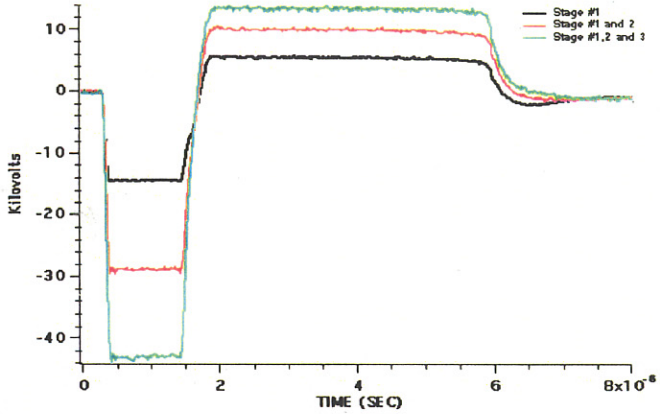
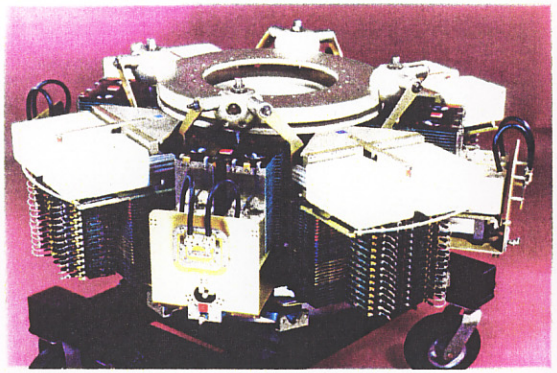
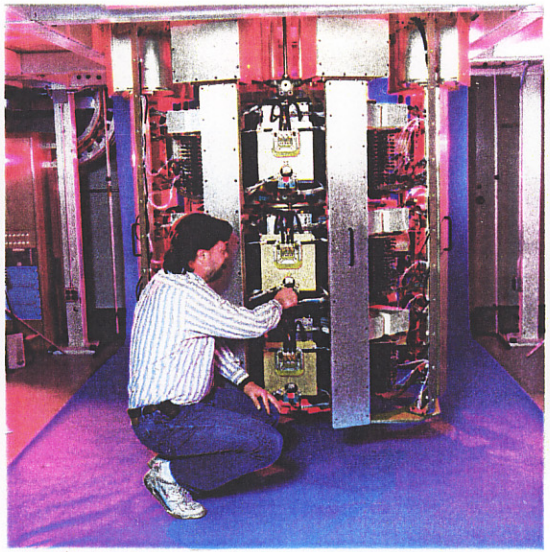
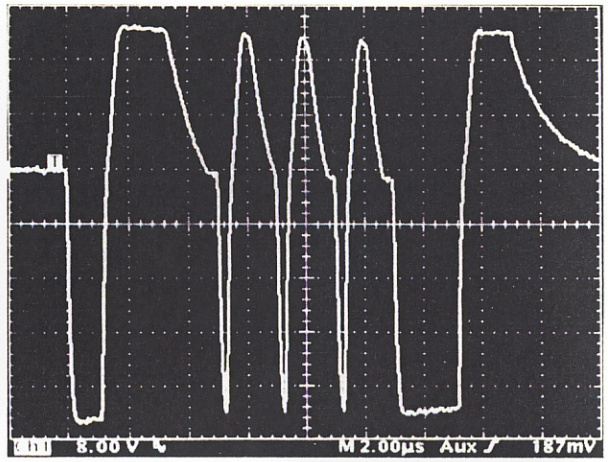
3-stage induction adder delivers variable pulse format up to 2 MHz @ 45 kV, 4.8 kA









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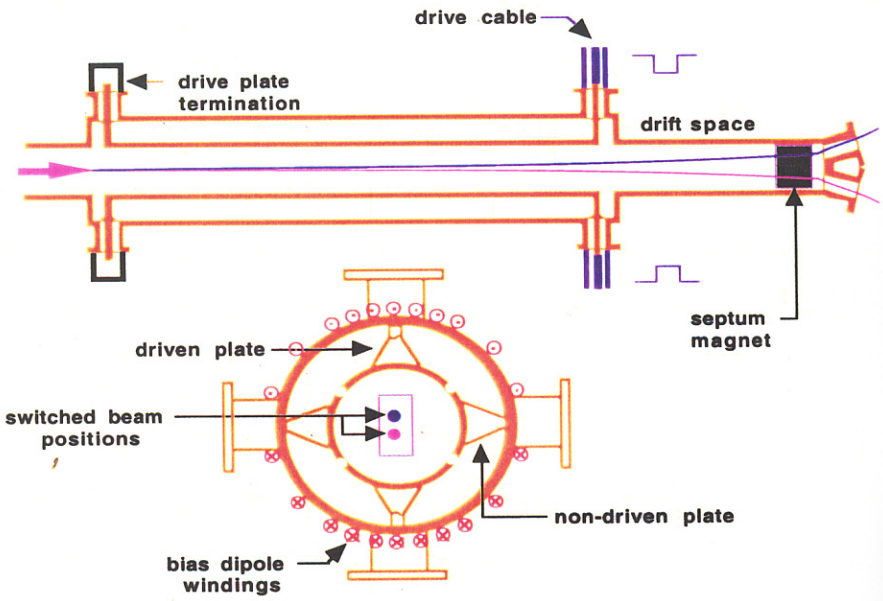
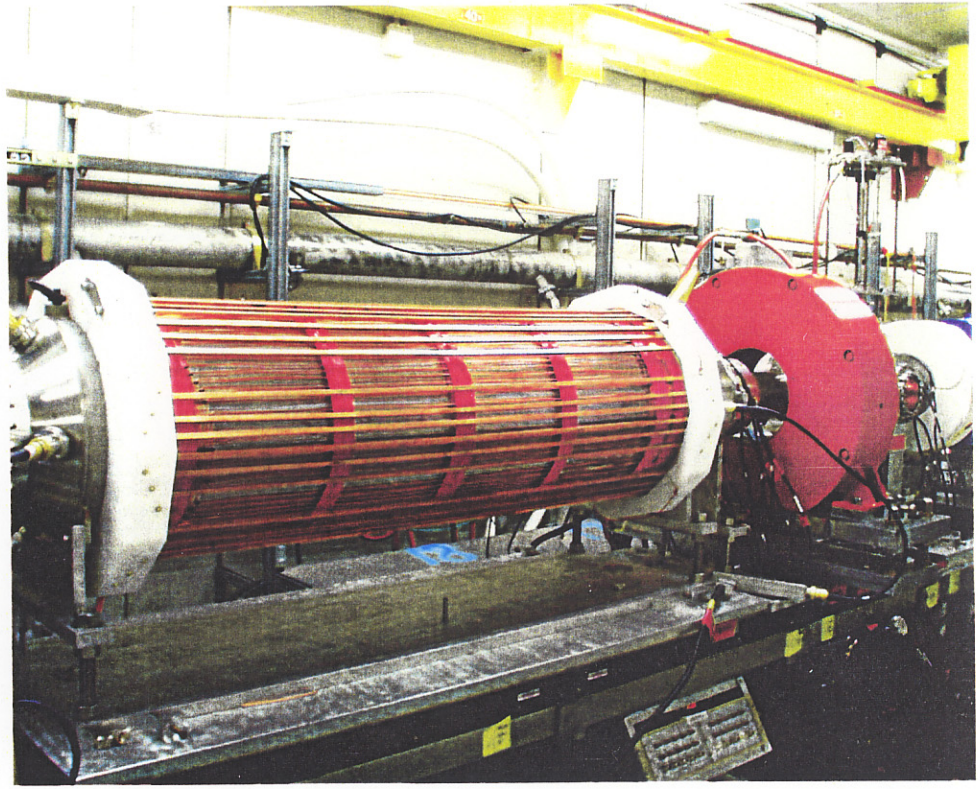
R&D

Fast stripline kicker can be used to split pulses from the accelerator



Steering is accomplished by a combination of electric and magnetic fields. The balance between these effects depends on how the striplines are terminated. For example, a matched termination results in equal contributions from both fields.



ETA-II Kicker, bias dipole and sextupole coils

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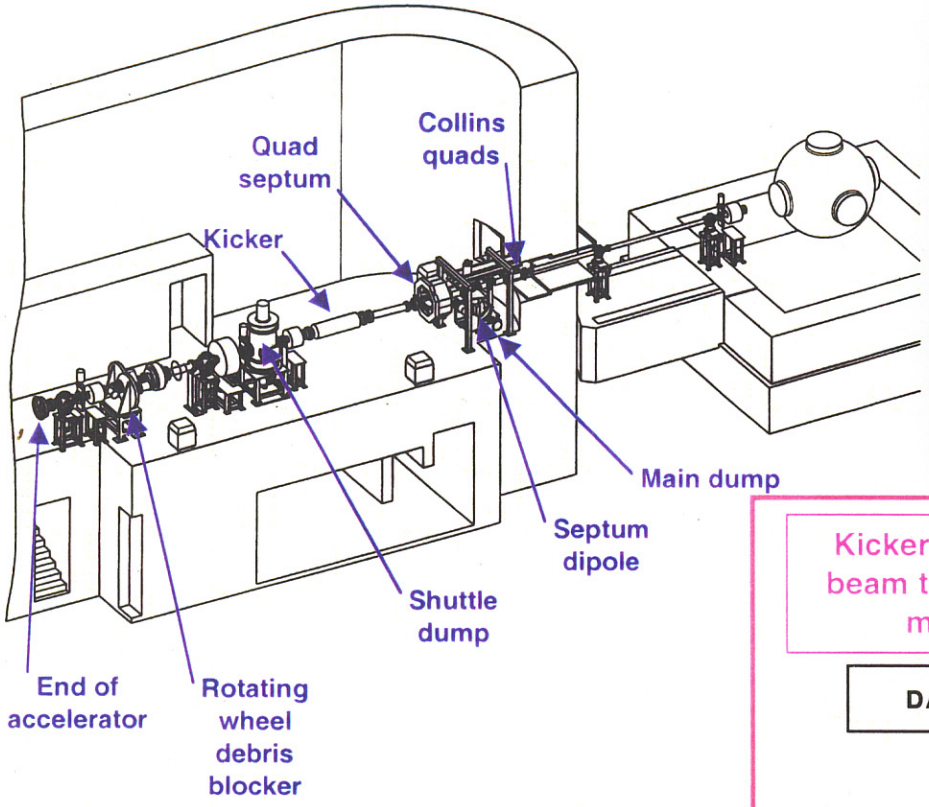
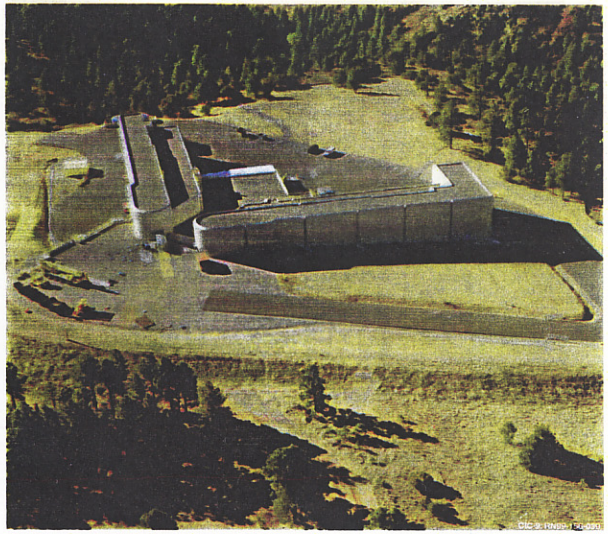
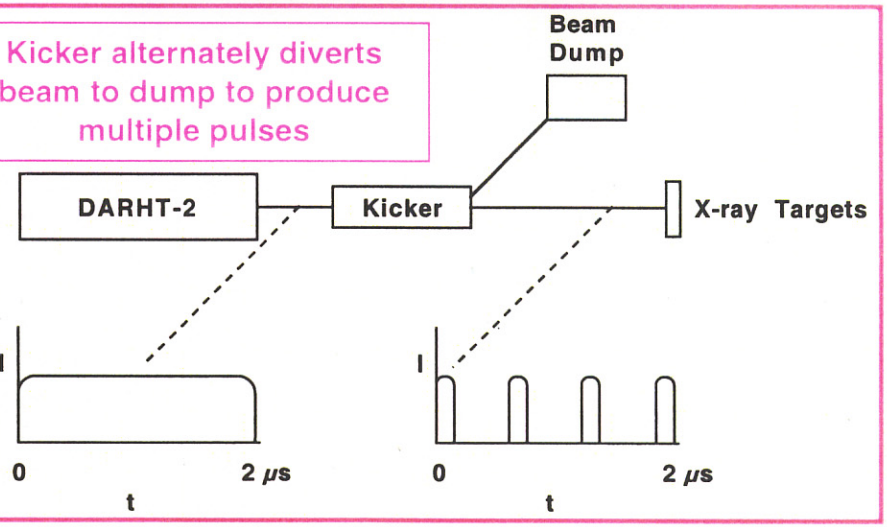
DARHT-2 uses advanced technology to provide four radiographic pulses

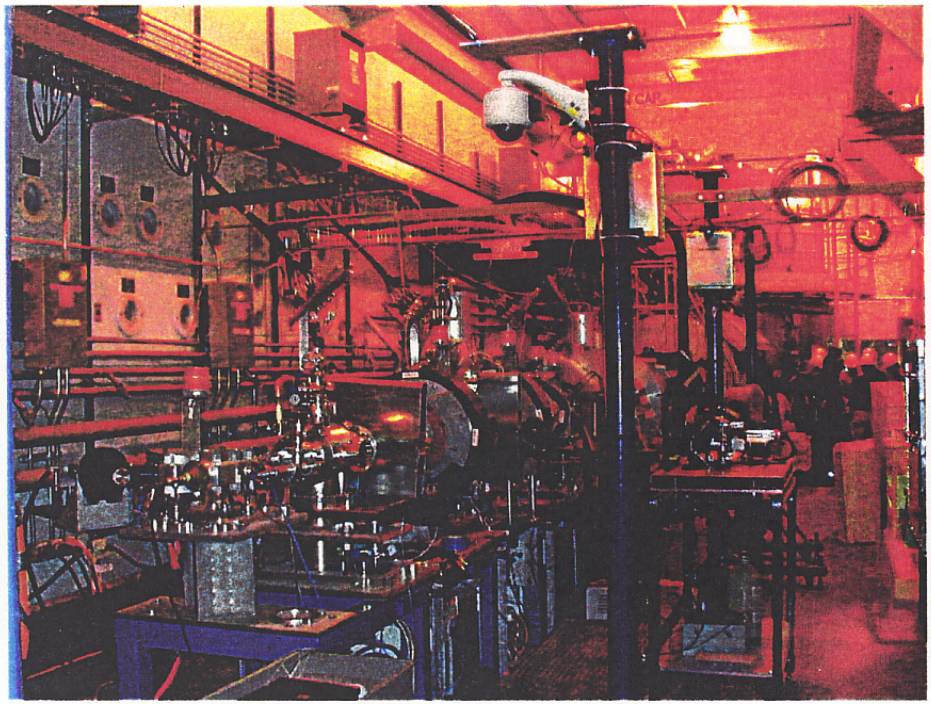




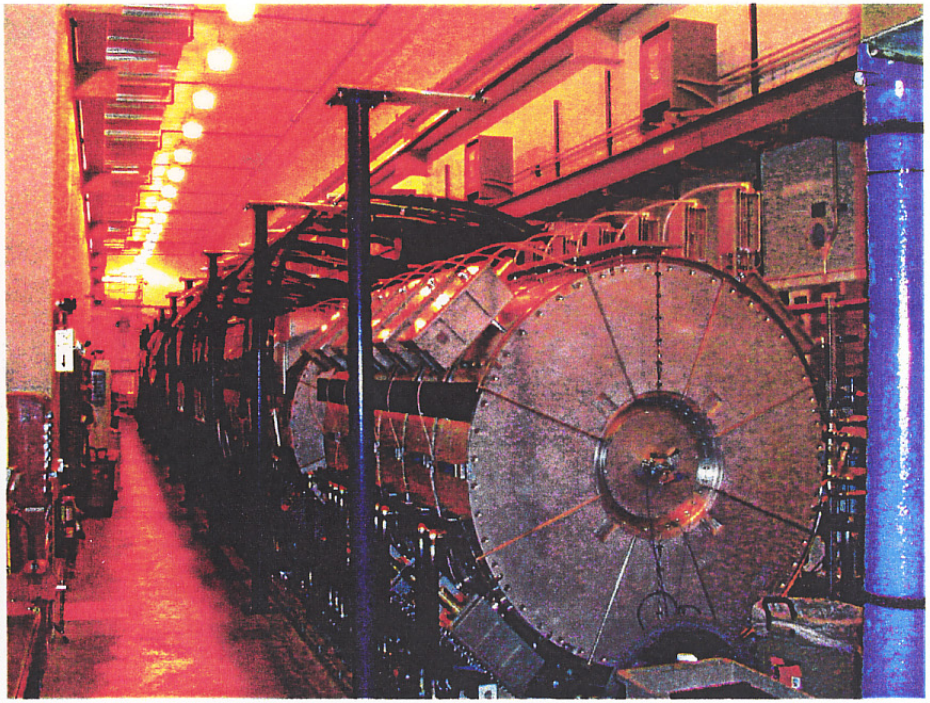
Kicker alternately diverts beam to dump to produce multiple pulses



DARHT-2 Is > 98% Complete With Final Fabrication and Installation Well Underway

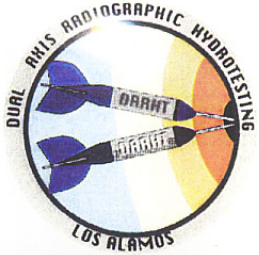


Injector & Commissioning Hardware

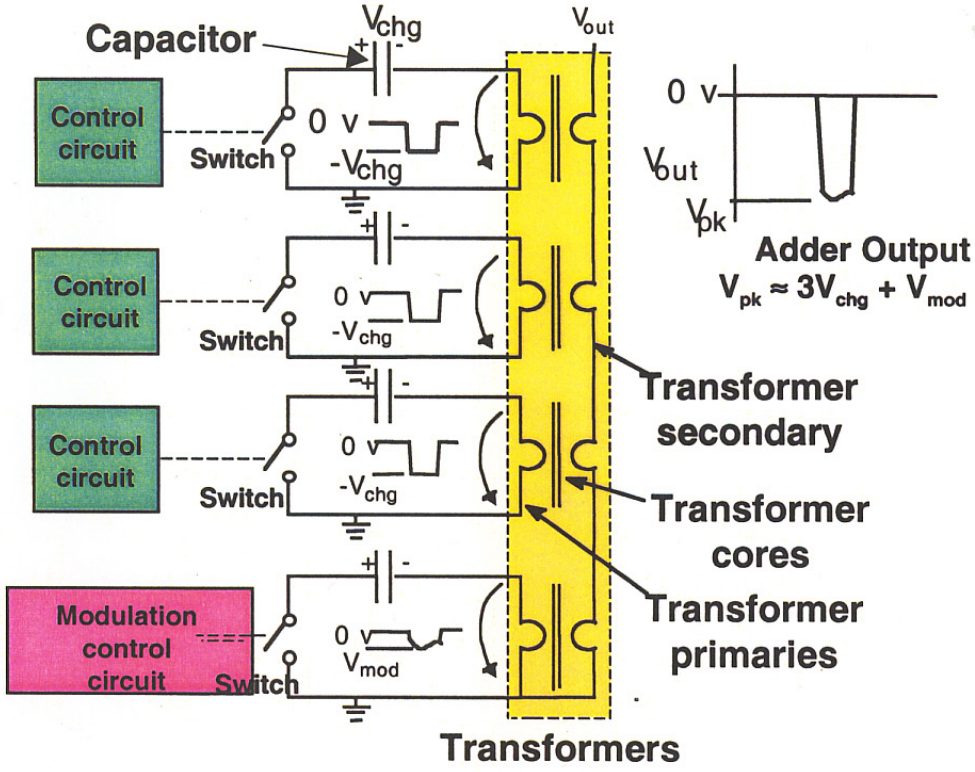


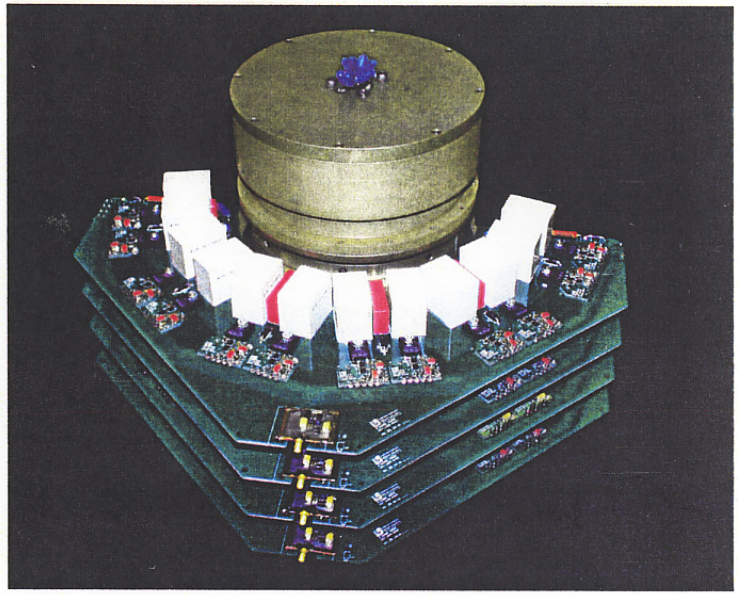
70 of 70 Accelerators + 8 Inj. Cells

Solid-state inductive adder technology produces fast, flexible waveforms at high repetition rates

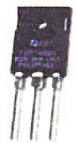


Simplified Electrical Schematic of Adder (3 Switched Cells plus One Analog Cell)





4 layers around Metglas cores



1000 V, 30 A pulsed FET, ≈ 10 ns risetime

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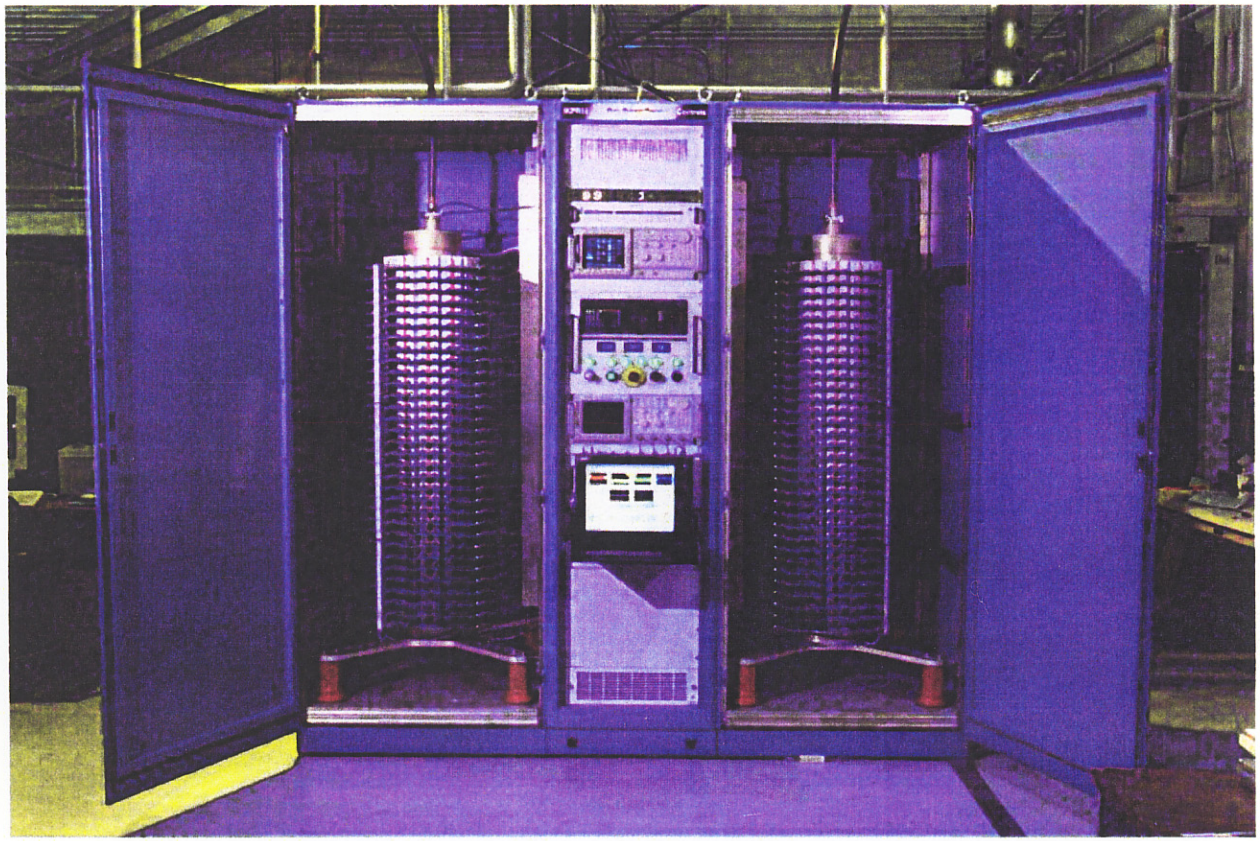
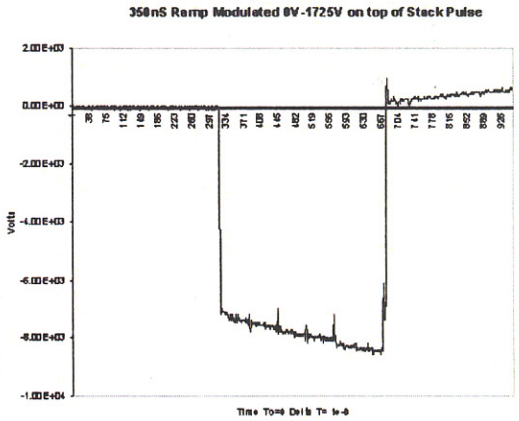
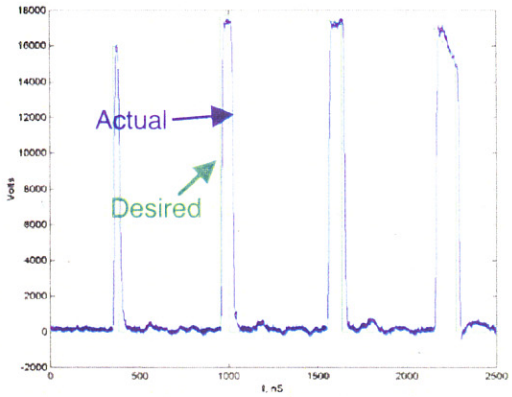
The DARHT-2 kicker is driven by solid-state modulators



DARHT kicker pulsers and control rack (20 kV into 50 Ω with 20% modulation capability)



350 ns ramp



4 pulse burst with modulation

Kicker technology can be used for dipoles and quadrupoles with response times of ≈ 20 ns

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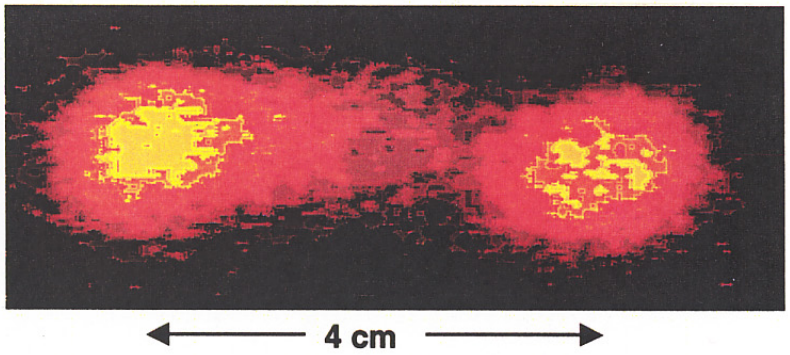
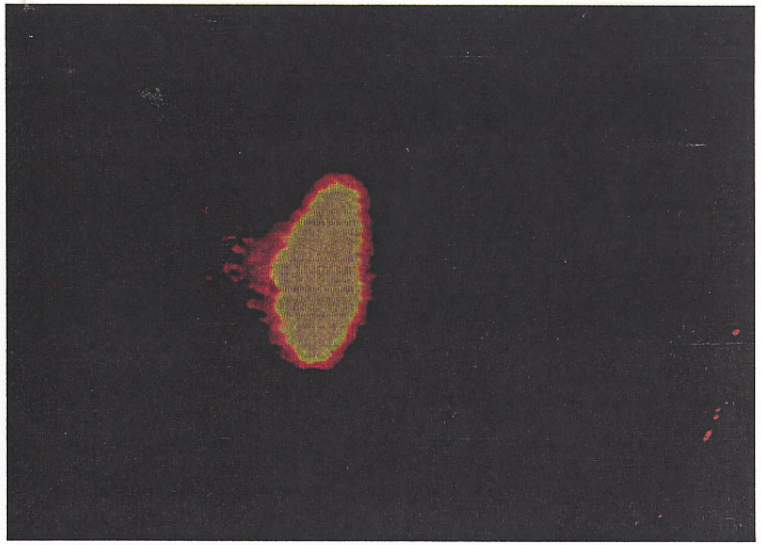
gated TV image from quartz foil of a single beam pulse switching position





Dipole Configuration

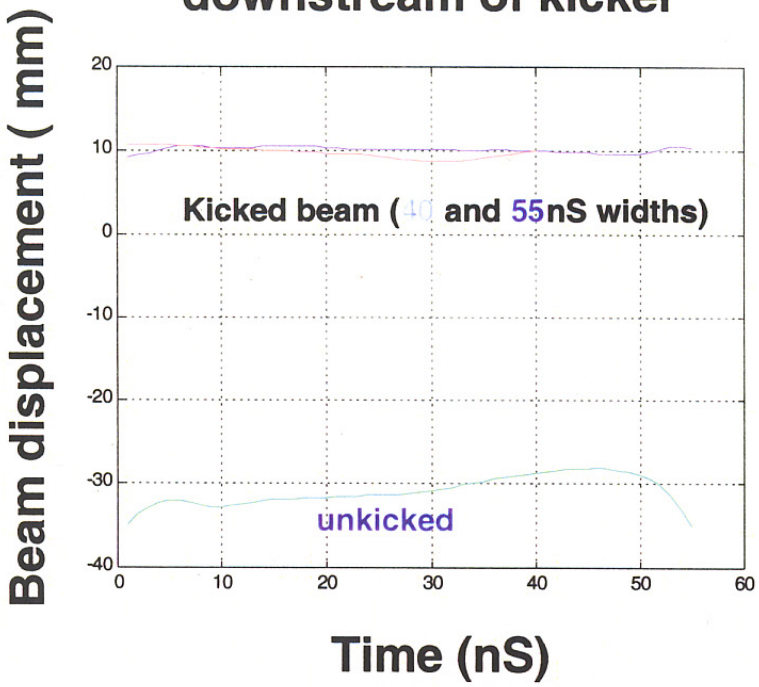
plates driven with opposite polarities

Quadrupole Configuration

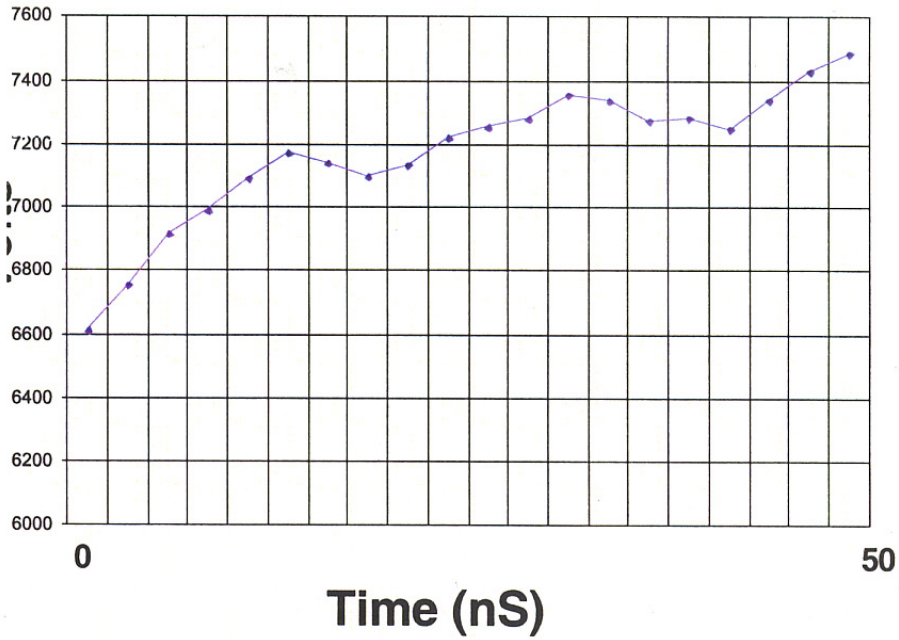
plates driven with same polarities

Regulation of the kicker output position to ± 1 mm has been demonstrated at ETA-II

Output position downstream of kicker



Time dependent pulser voltage under regulation



Pulse to pulse control system regulates output beam position

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Solid-state inductive adder technology is being applied to drive the PRAD AHF kickers

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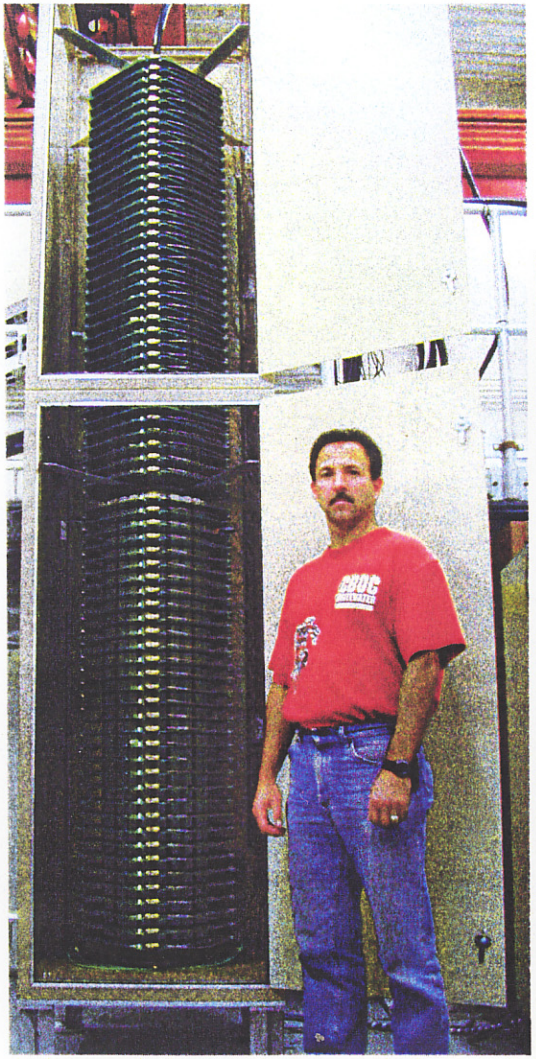
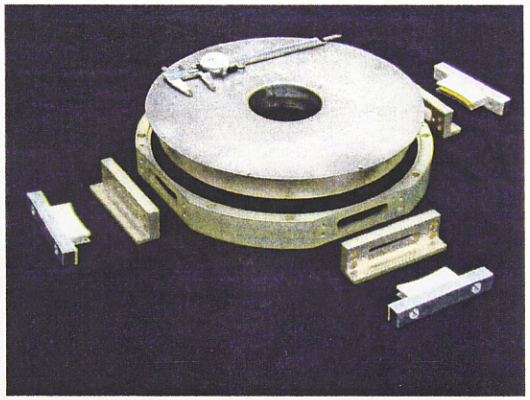
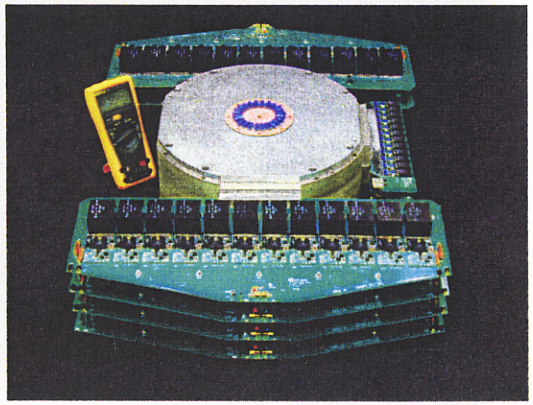
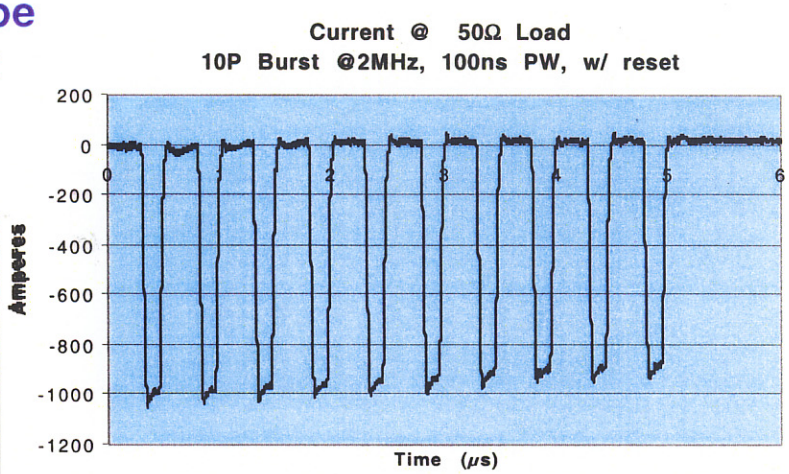
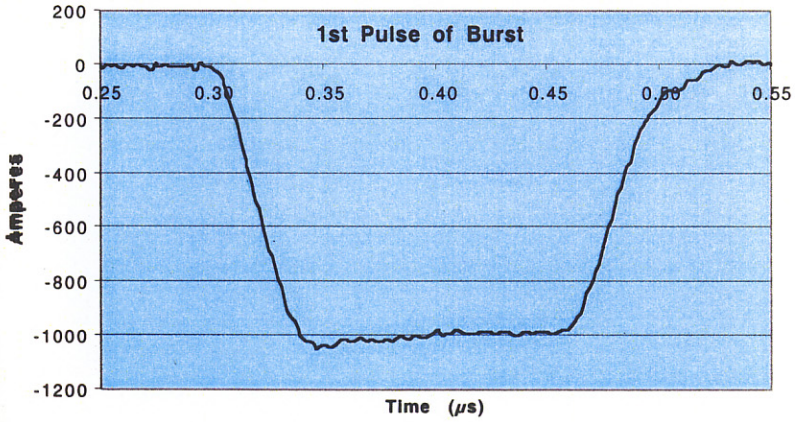


Completed 50 kV Prototype PRAD AHF Adder Stack Assembly



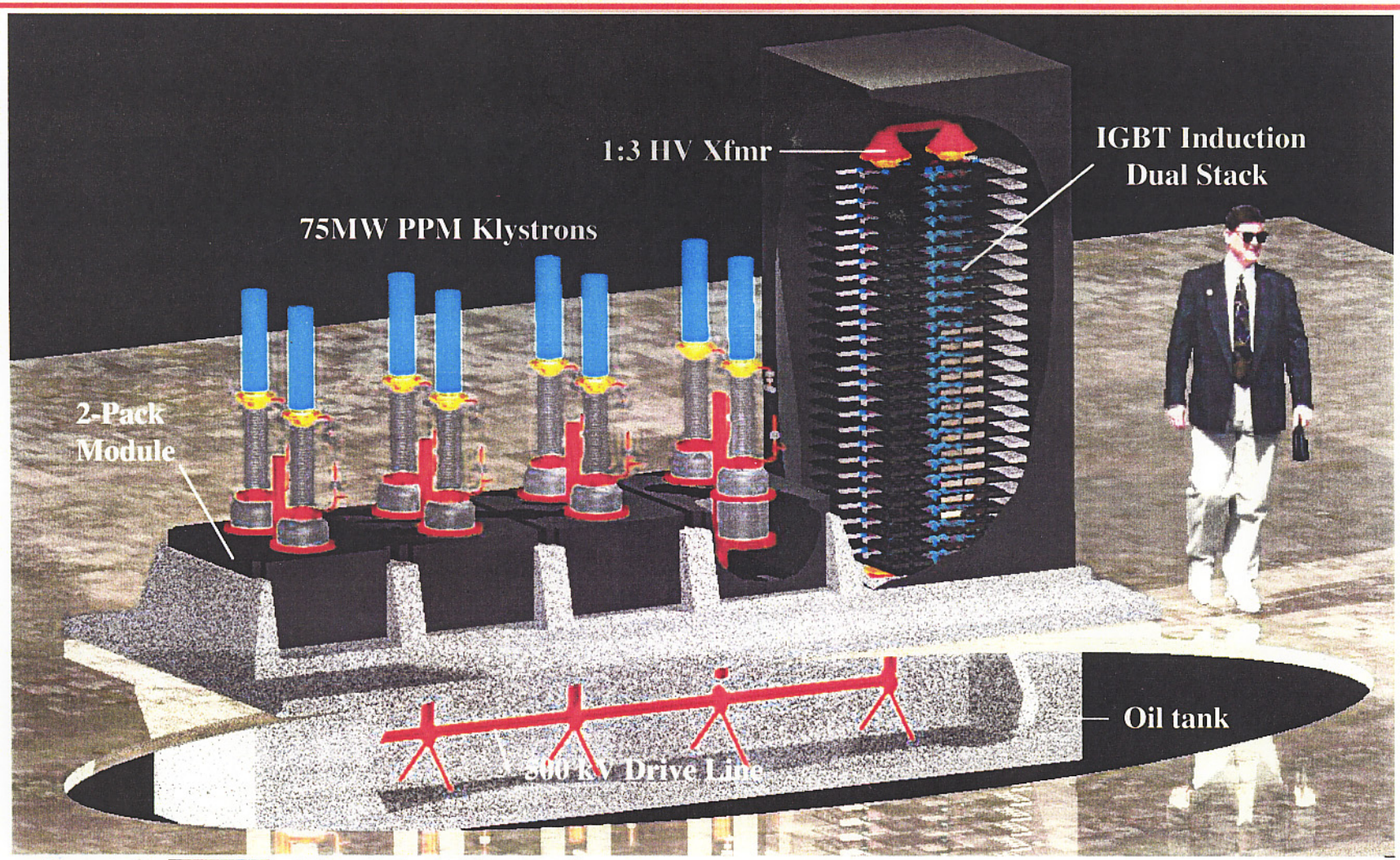






NNSA

Solid-state modulator will produce 500 kV at 2 kA to drive 8 klystrons



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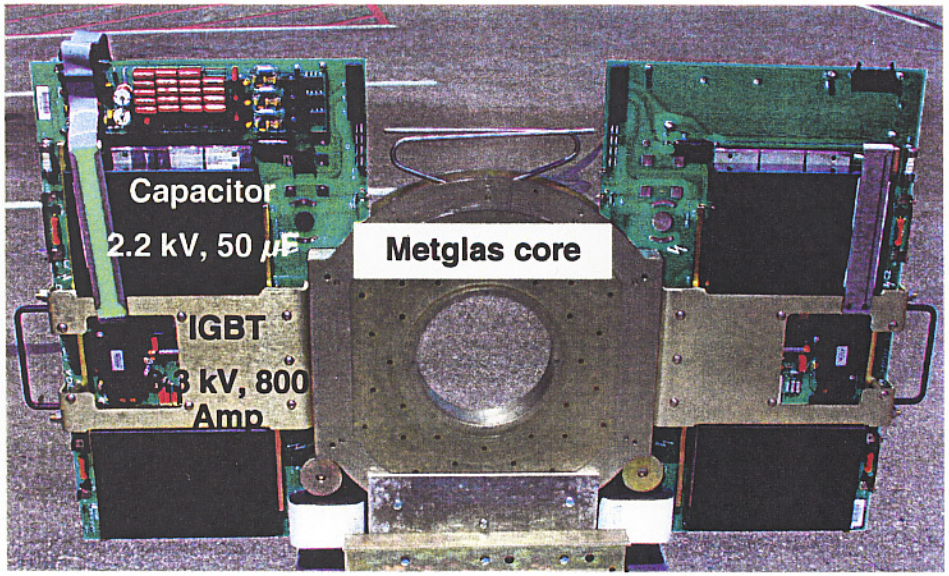
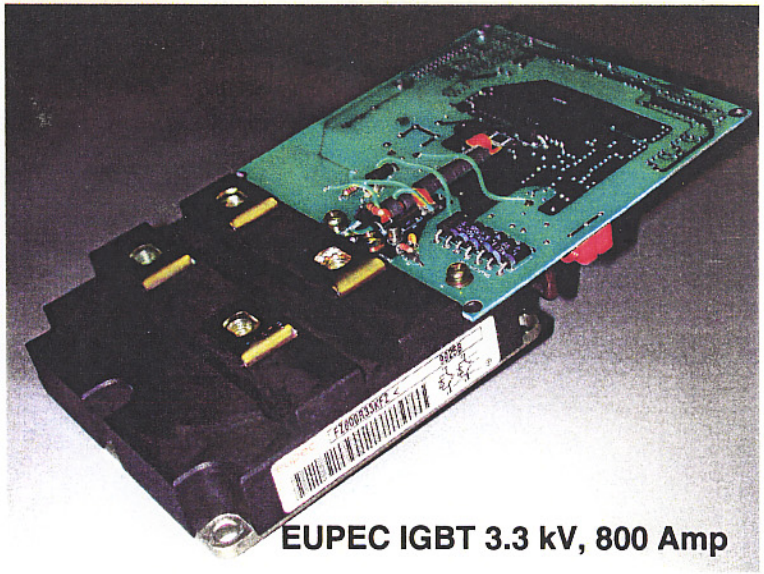
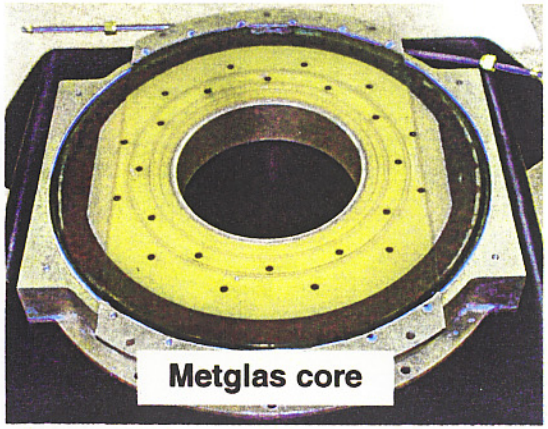
Core with Both Drive Boards (IGBT switches)







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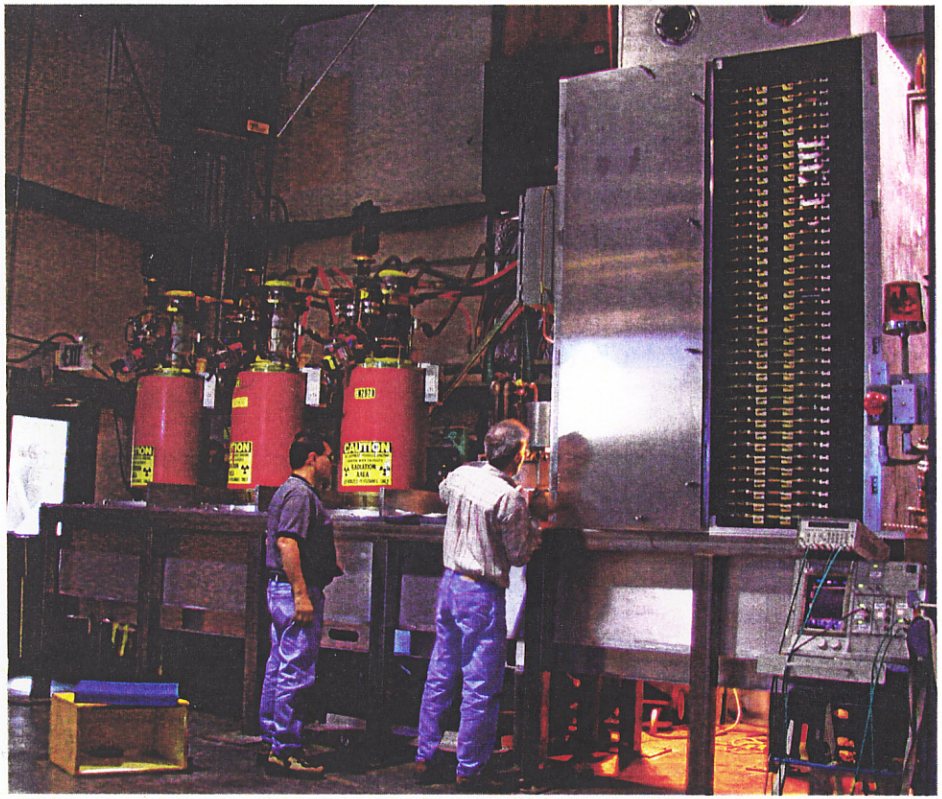
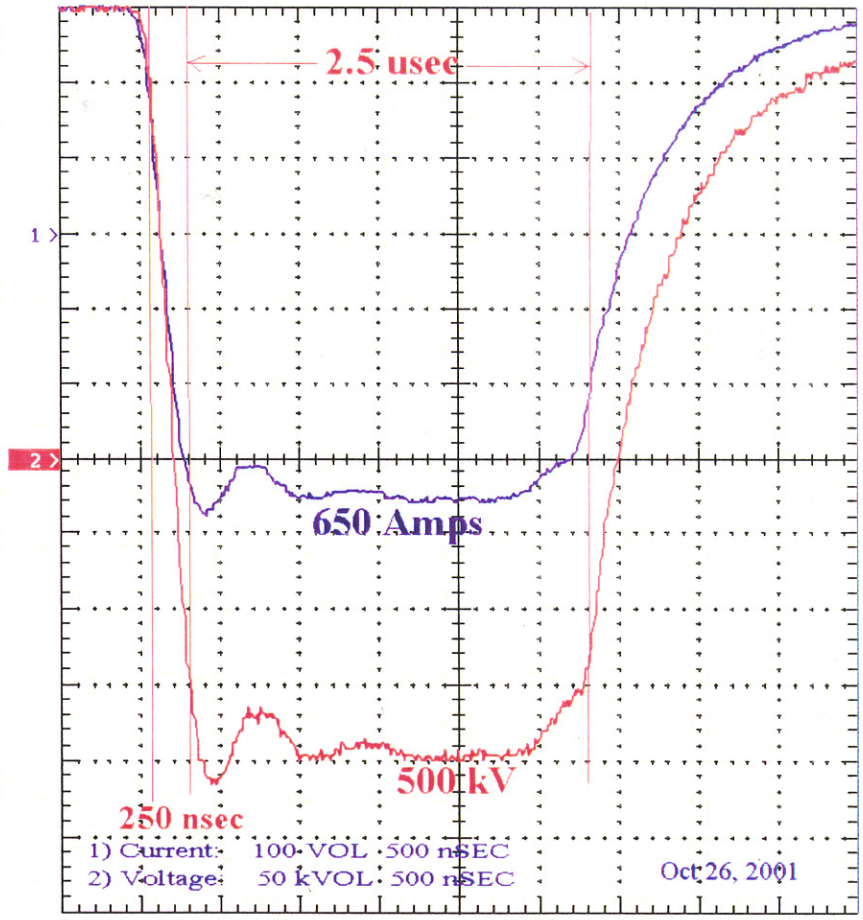
Prototype induction modulator and pulse into a water load





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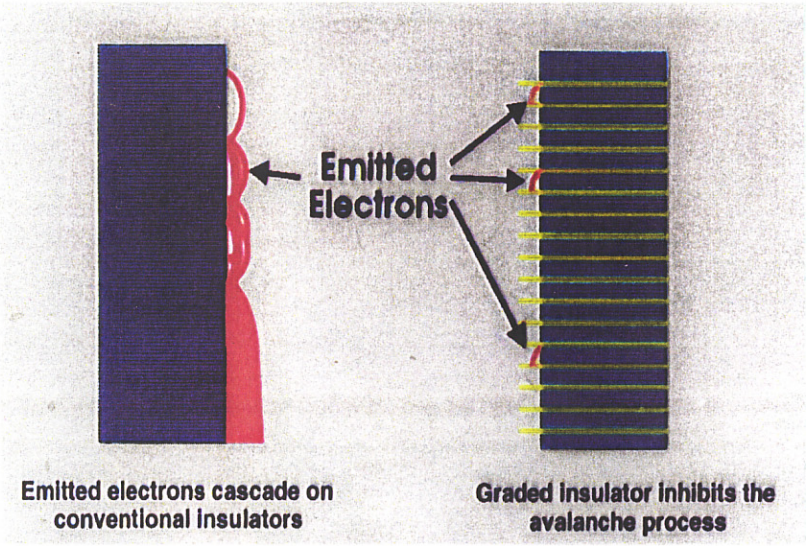
High gradient insulator (HGI) technology serves as one of the building blocks for advanced accelerators

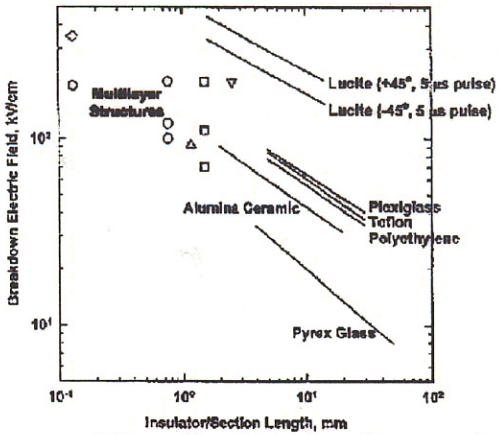


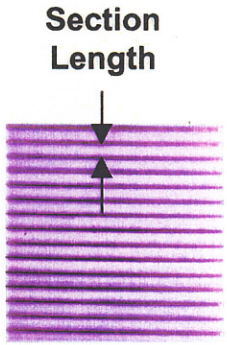
Emitted electrons cascade on conventional insulators

Graded insulator inhibits the avalanche process

Closely spaced conductors are believed to inhibit the breakdown process

Experimentally, we have demonstrated superior breakdown characteristics





The effect scales inversely with spacing of the conductive planes

The ability to manufacture these structures is being perfected

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HGI's show dramatic improvement over conventional insulators

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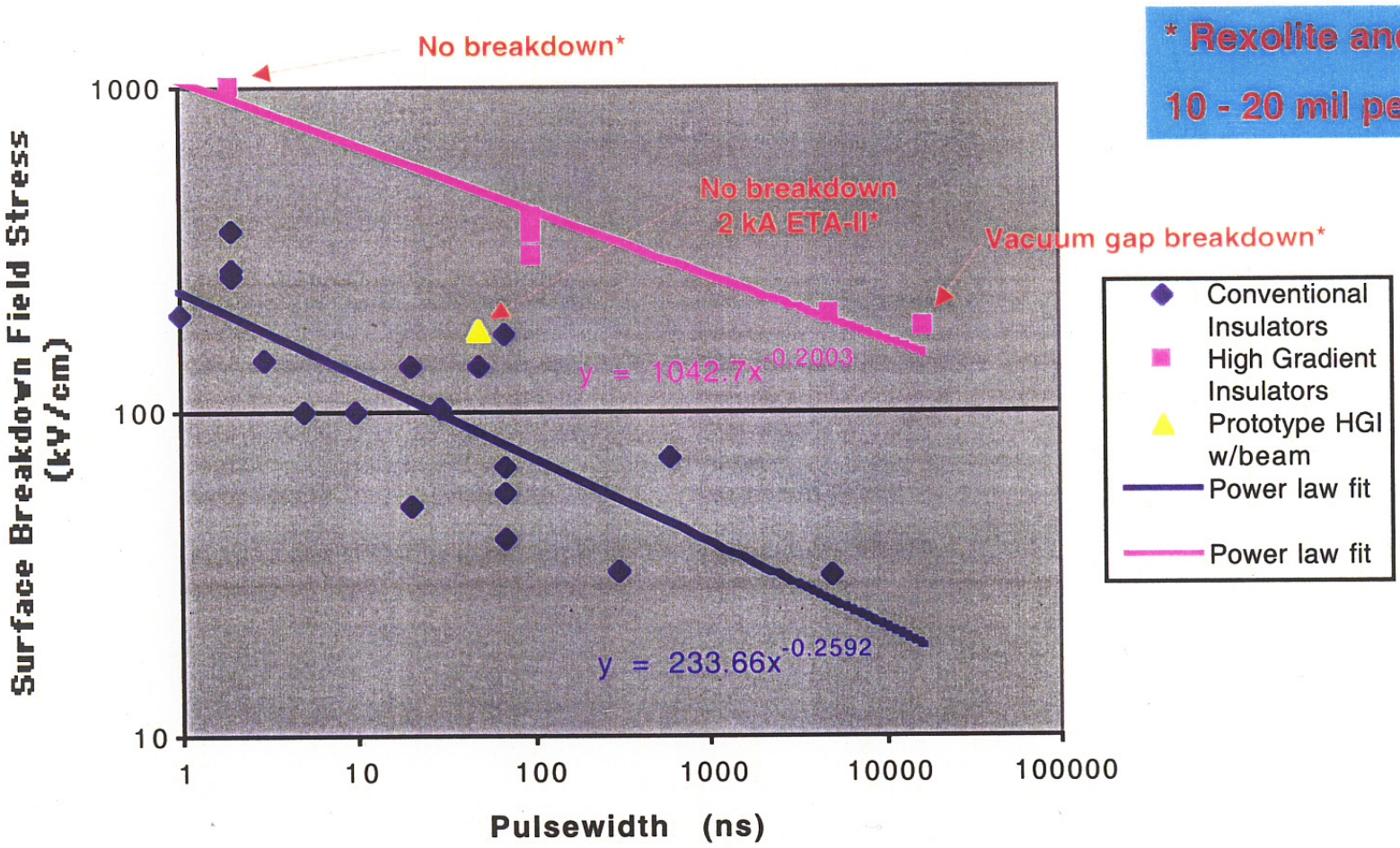
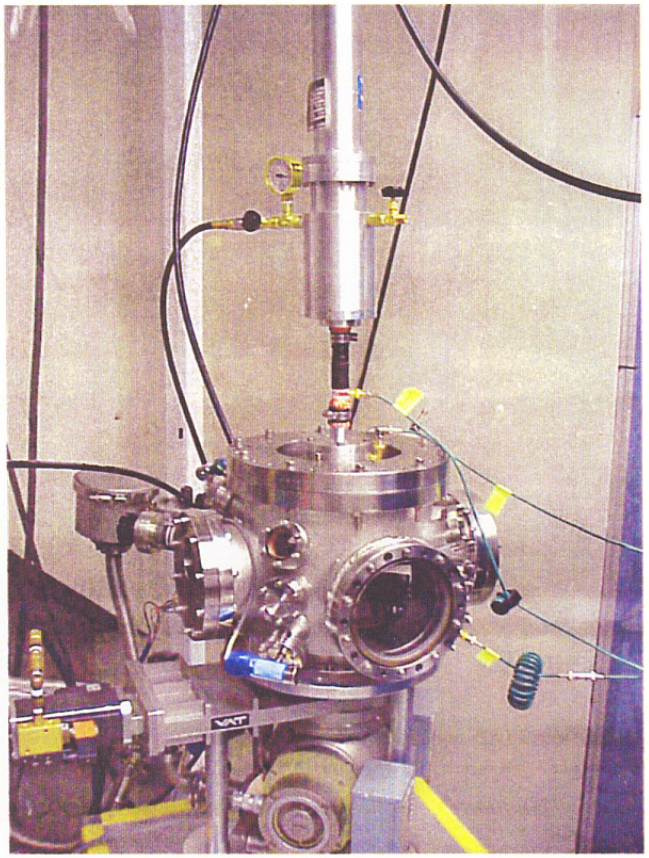
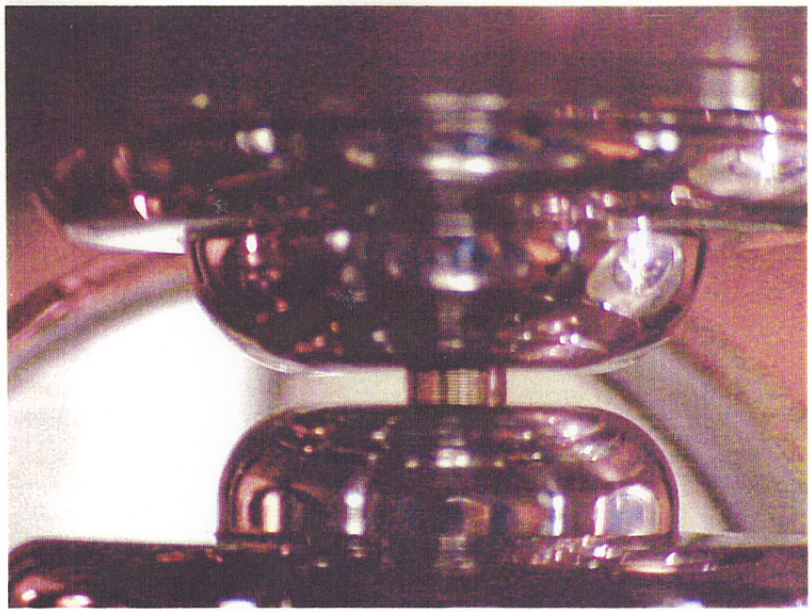


* Rexolite and SS
10 - 20 mil period

High gradient insulators have been tested from 2 ns up to 17 μs

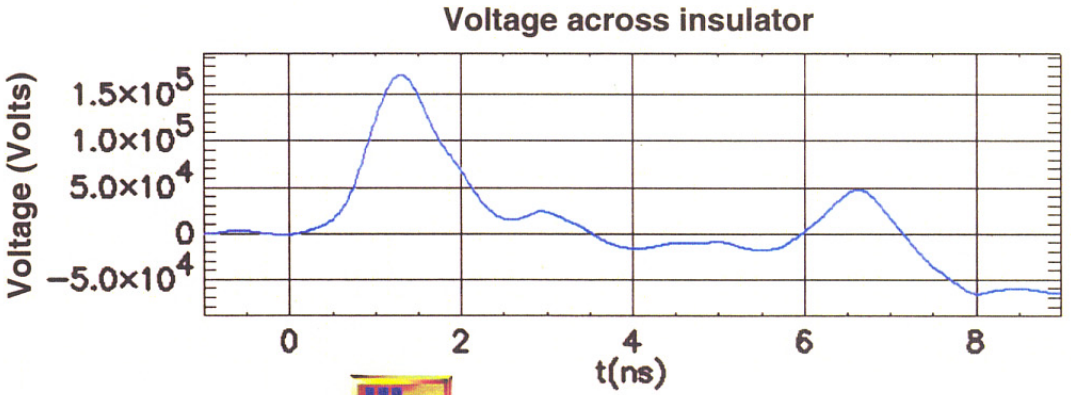


Vacuum chamber and short pulse Marx

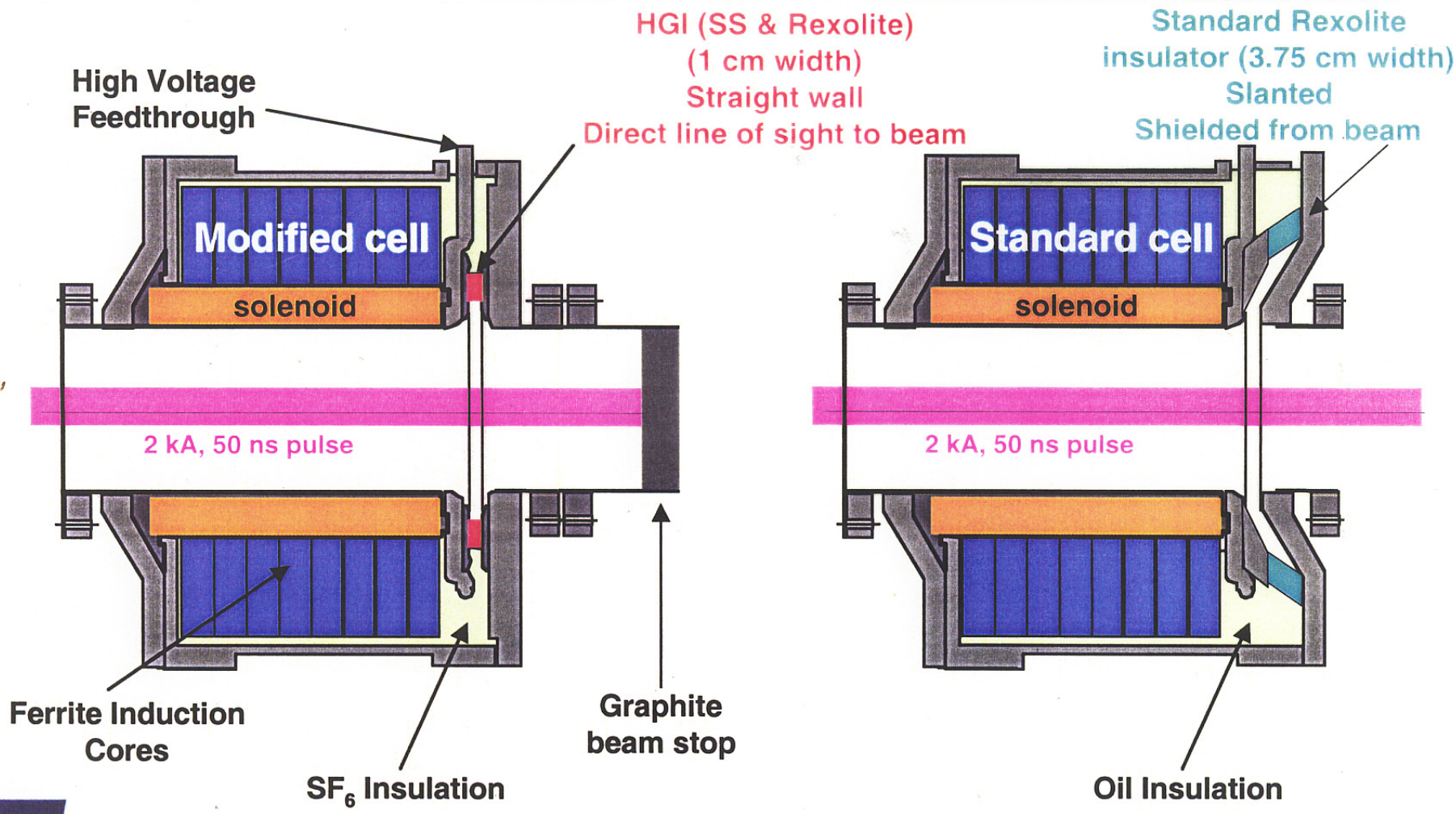


Rogowski profile test electrodes and HGI sample

3 mm



The High Gradient Insulator (HGI) has been "hot tested" using a 2-kA beam from ETA-II



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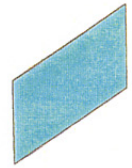
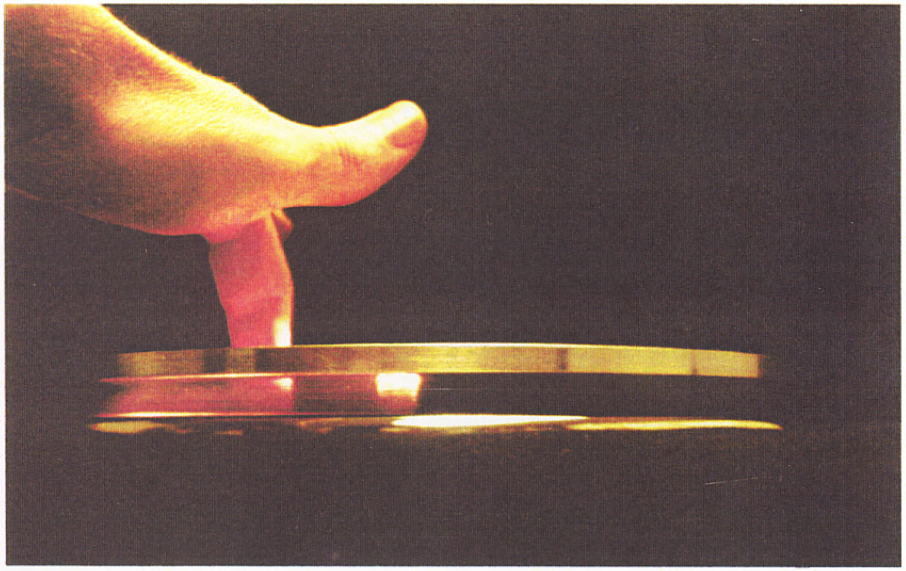
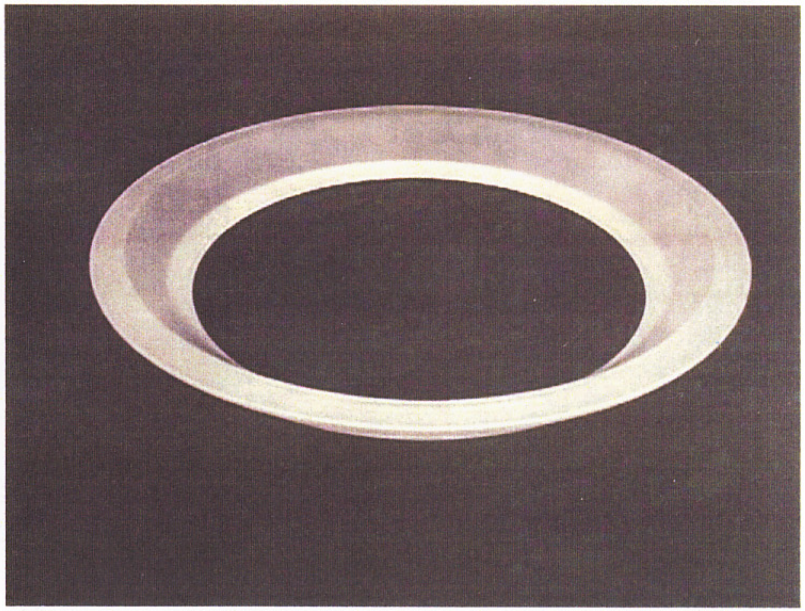
High gradient insulator and conventional insulator used in ETA-II cells

HGI (SS & Rexolite)
(1 cm width)
Straight wall
Direct line of sight to beam

Standard Rexolite
insulator (3.75 cm width)
Slanted
Shielded from beam







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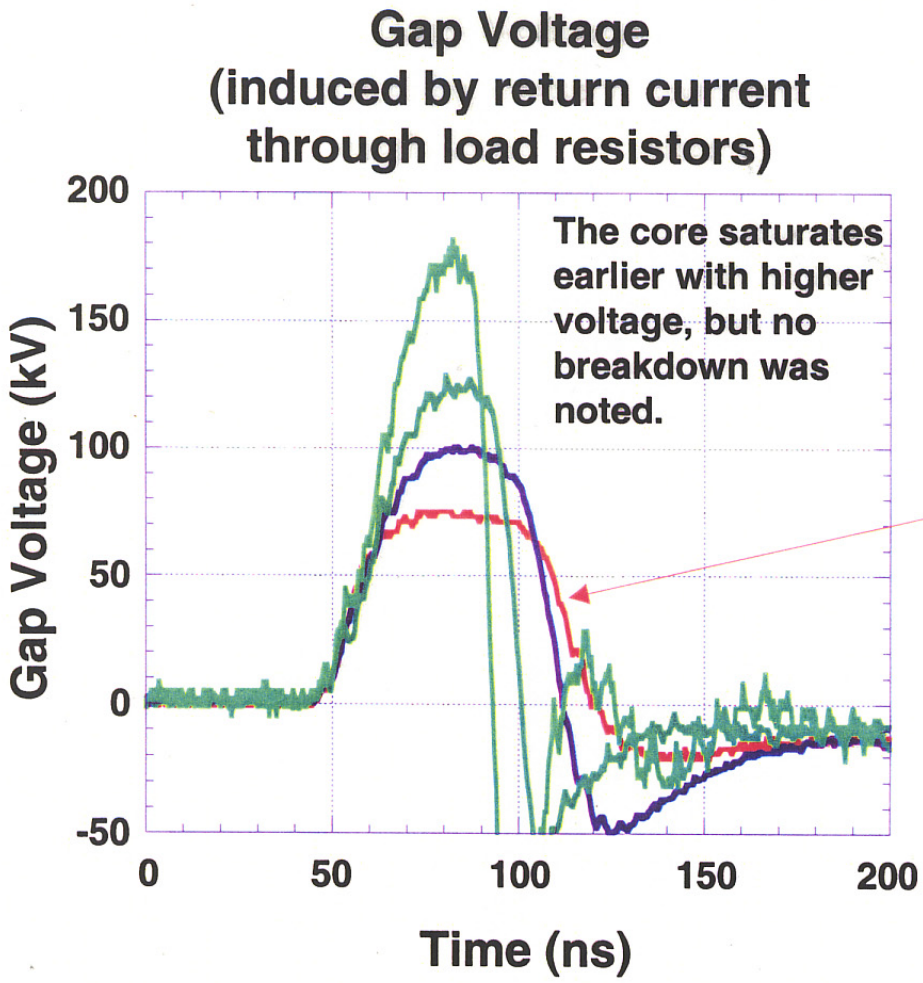
"Hot test" results of the High Gradient Insulator (HGI) reveal no breakdowns even at 17.5 MV/M



1 day operation (> 20,000 shots) without breakdown

normal ETA-II cell voltage level with slanted insulator

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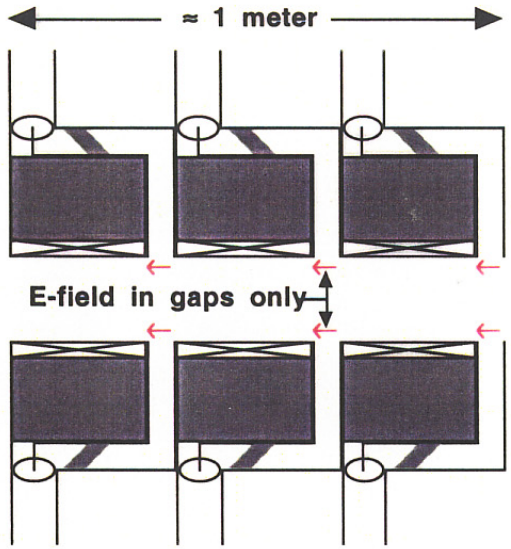
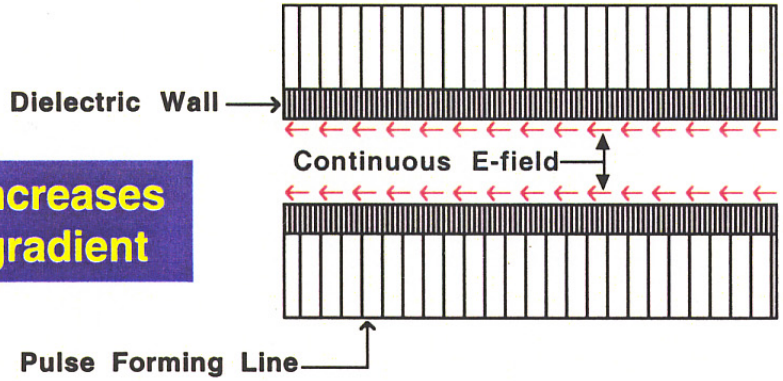
Dielectric Wall Accelerator (DWA) promises much higher gradients and currents than conventional induction linacs



State of the Art Induction Accelerator
≈ 0.75 MeV/meter Gradient

Beam current limited by BBU to ≤ 10 kA



Risk increases with gradient

Dielectric Wall Accelerator
≥ 20 MeV/meter Gradient

Low impedance structure capable of sourcing 100's of kA.....transport or insulator breakdown will impose limit (unknown at present)

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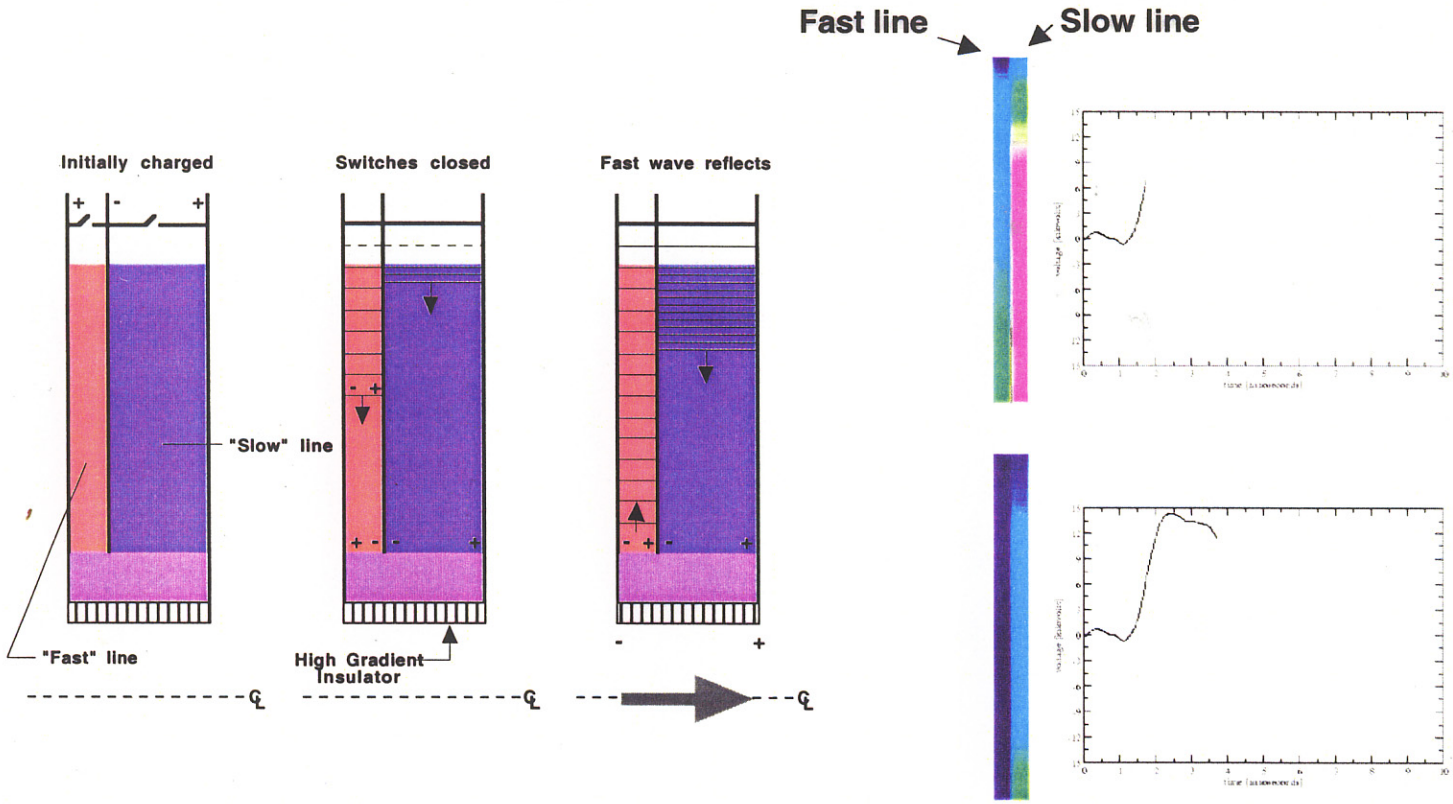
One of several candidate pulse forming lines for the DWA is the Asymmetric Blumlein



DWA uses transit time isolation and different wave speeds to produce an acceleration voltage

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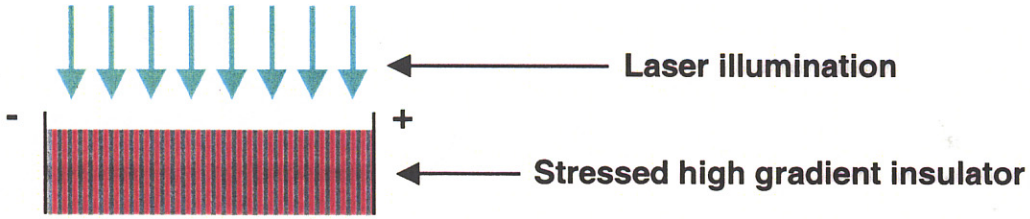
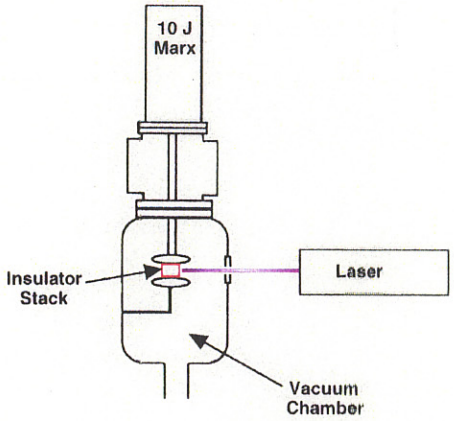
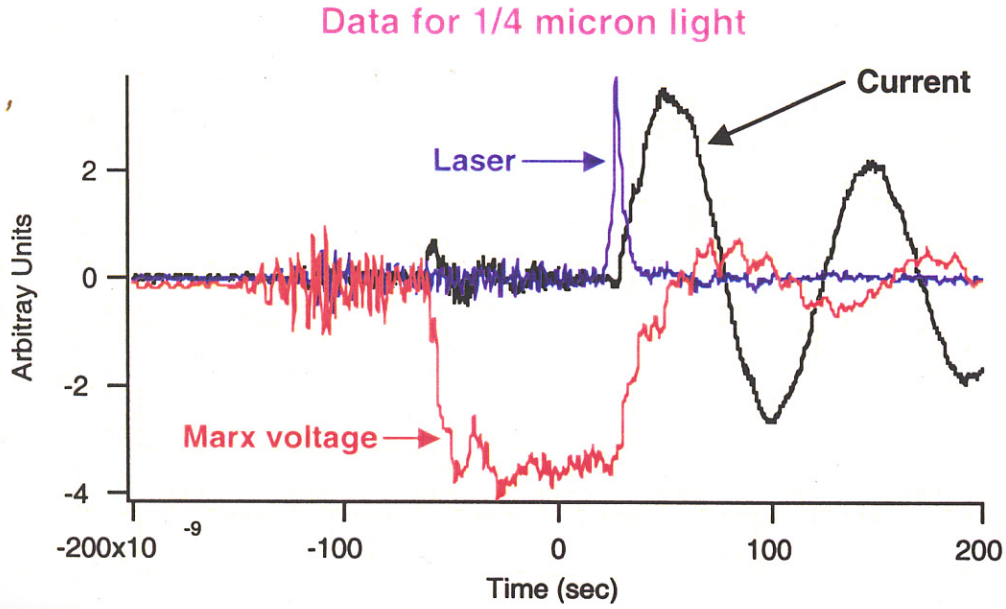
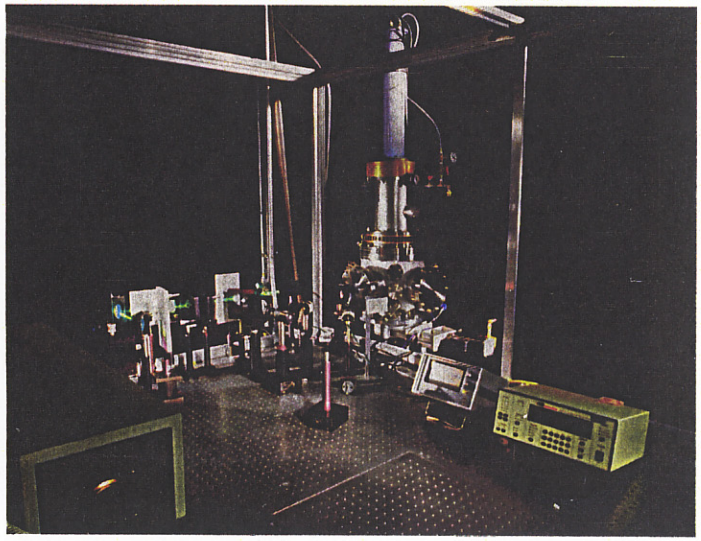
Another DWA building block is a fast laser-induced, surface flashover switch









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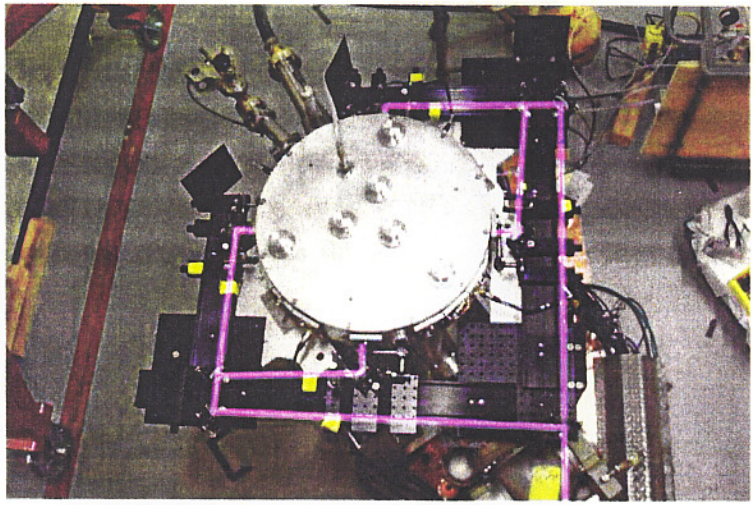
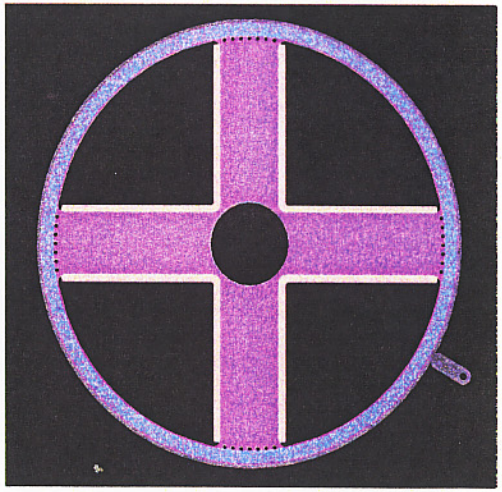
Recent DWA development

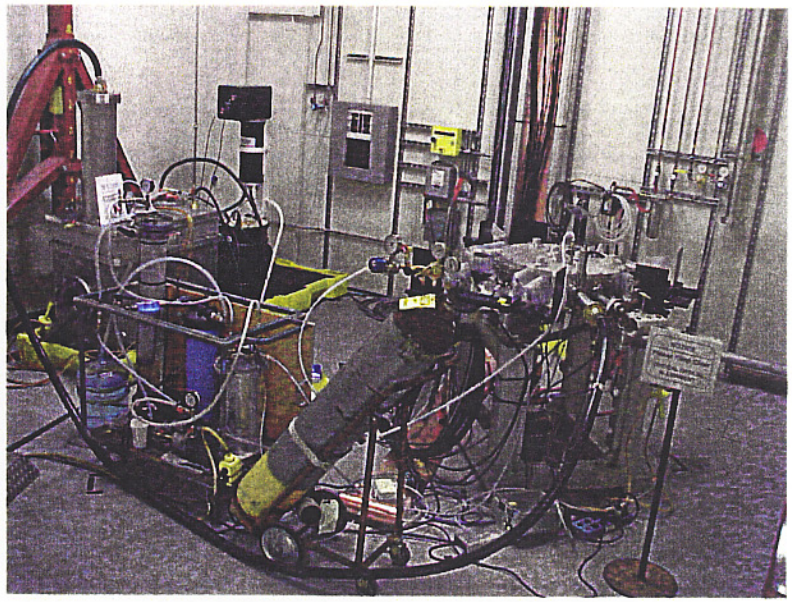


24" dia. Chamber for intial DWA tests



"Cross" configuration

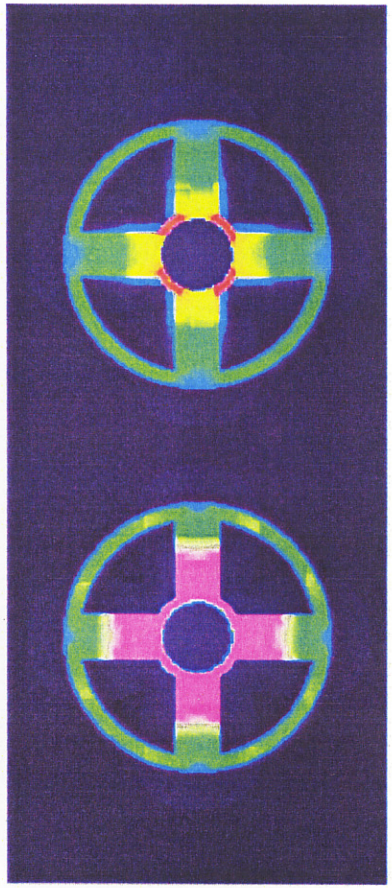
- Initial tests
  - De-ionized H_2O as slow dielectric
  - RT-Duroid as fast dielectric
  - Frequency tripled Nd-Yag laser pulses to initiate vacuum surface flashover
  - Pulse charging of transmission lines



Charging supply, water treatment system and 24" Chamber

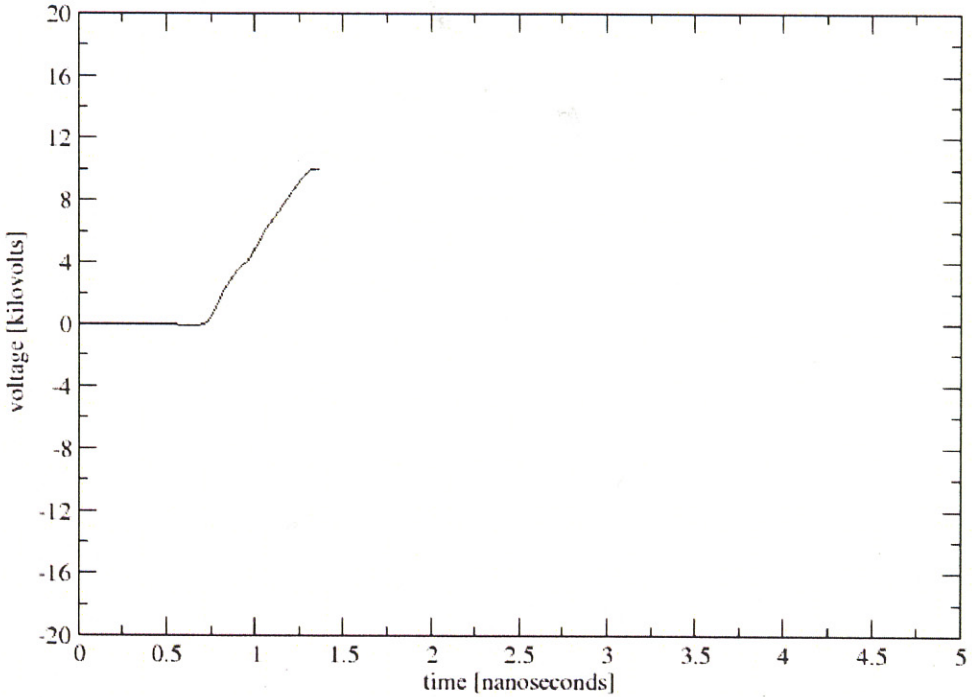
Initial DWA experiments used de-ionized H_2O and RT-Duroid as dielectrics in a cross configuration

Fast line



Slow line

Output Voltage



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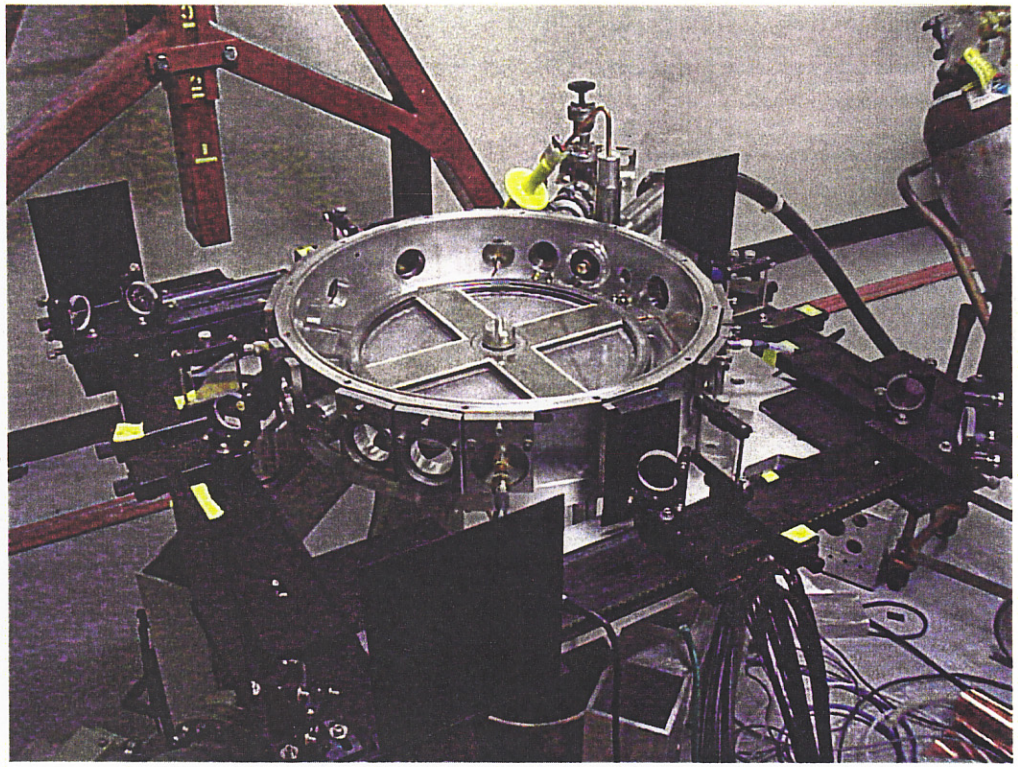
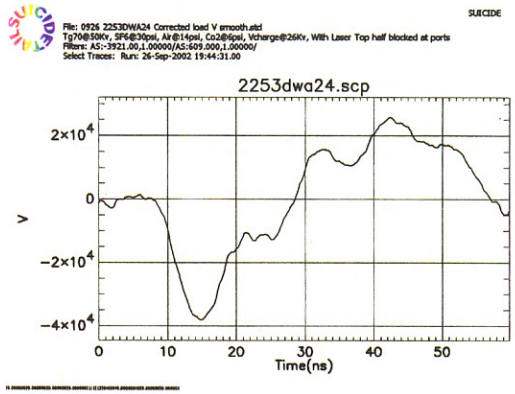
Output gradients > 5 MV/m have been achieved using *conventional insulators*

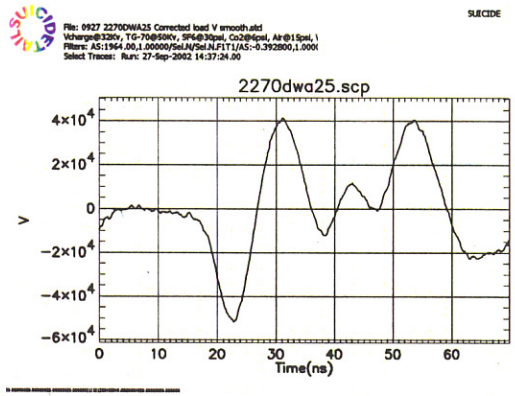


Vacuum chamber and double stack of a cross configuration

De-ionized H_2O and RT-Duroid dielectrics



Single Module Output



Multi-module Output

We have developed 36" substrates for pulse forming lines

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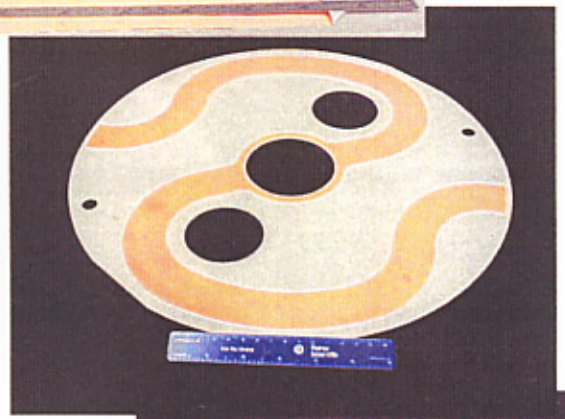
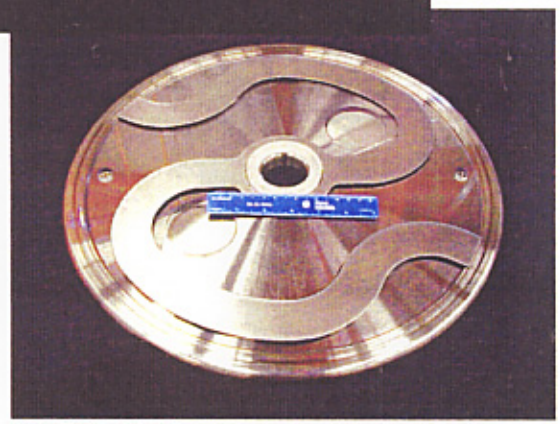
- 36" Wide Stock of "nanoparticle/plastic" dielectric
- $E_{bd} > 300$ kV/cm
- $\varepsilon_r > 30$



16" DWA slow line (nanoparticle)

16" Patterned Pre-prototype for high voltage tests



16" DWA fast line (Lexan)

Summary

- Solid-state drivers make possible a new class of high repetition rate, high current accelerators
- Fast, precision, adjustable dipoles and quadrupoles can now be built
- New insulator technology holds much promise for accelerator and pulsed power applications