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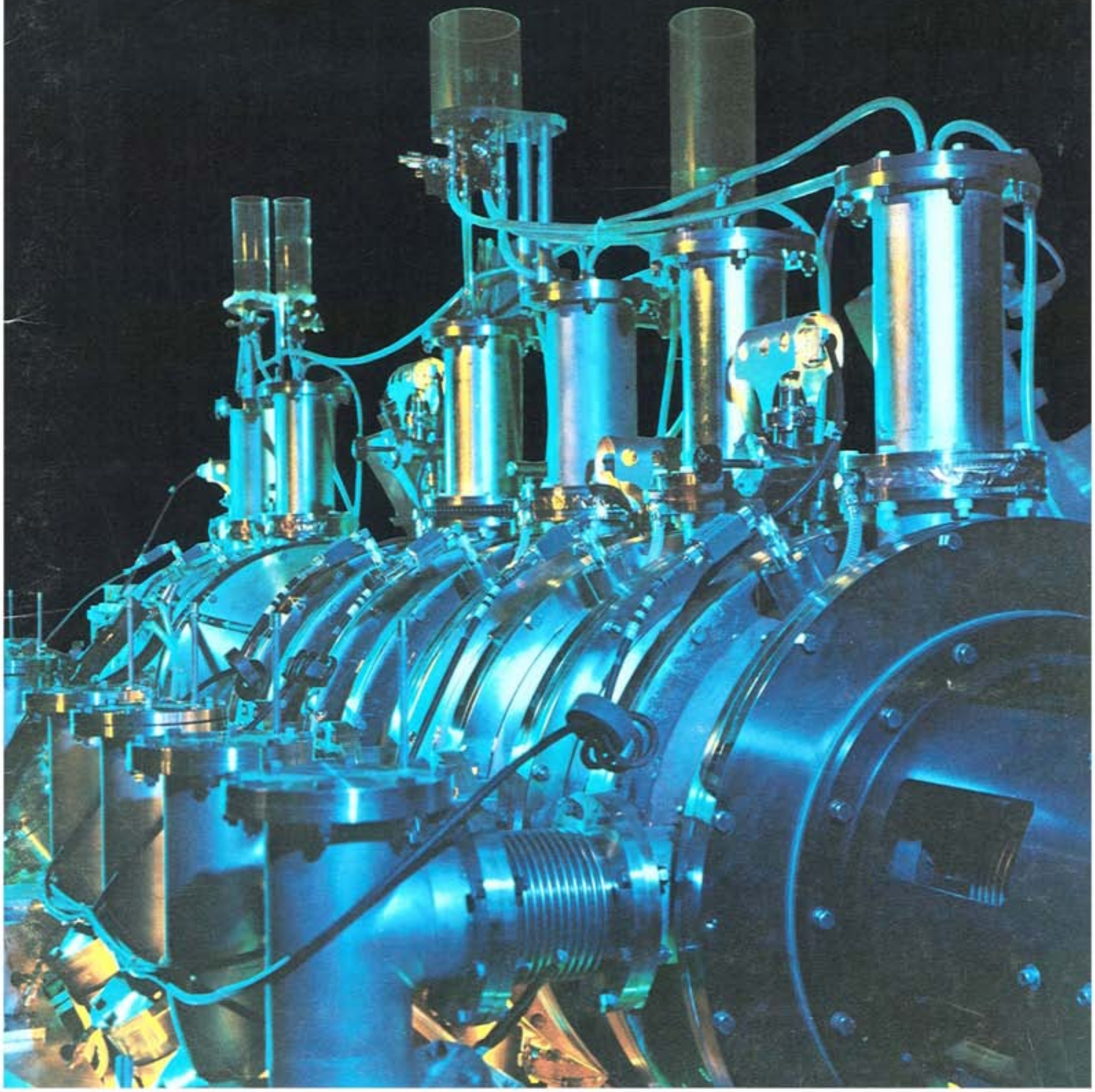

# The Nova plasma shutter

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***We have developed a relatively inexpensive way to protect the Nova laser system against damaging back-reflected light. Our new plasma shutter shoots a reflective plasma across the beam path in the 400-ns interval between the passage of the main beam pulse and the return of the reflected light. Testing shows that this plasma is more than adequate to stop light of the intensity expected from Nova. Faraday rotator-polarizer isolators of the kind we are now using to protect the Shiva laser system from back-reflected light would cost $500 000 apiece if designed for the Nova system. Each plasma shutter will cost only $80 000.***

The Nova laser system will consist of 20 separate lasers in parallel, in each of which a relatively narrow beam of 1.05-$\mu$m light grows progressively larger in diameter and more intense as it passes through a long series of neodymium-glass amplifiers (Fig. 1). All 20 beams will be finally focused on a tiny deuterium-tritium target so as to produce a fusion reaction. However, not all of the laser light will be absorbed by the target capsule; some will be reflected; and if this reflected light were to get back into the amplifiers it would travel back down the chain in the wrong direction wreaking havoc on our equipment.

To protect the existing Shiva laser system from back-reflected light, we use optical "diodes" known as Faraday rotator–polarizer isolators. These devices contain a pair of polarizing plates separated by a paramagnetic material that rotates the plane of polarization of light passing through it by 45°. Light going toward the target can get through, but light coming back is stopped because the second 45° rotation puts the plane of polarization at 90° with respect to the original polarizer.

Faraday isolators are expensive. Furthermore, they introduce unnecessary losses, thus making added amplification a necessity. Units scaled for the Nova laser system would cost about $500 000 apiece, plus the cost of the additional amplification.

One alternative way of protecting the laser would be to close a shutter across each of the beam paths after the main pulse passes by and before the reflected light gets back. However, the forward and return beam pulses are only 400 ns apart. Thus, such a shutter would have to be extremely fast. To cross the full beam aperture (46 cm) in 400 ns, a shutter would have to move at an impossible speed of more than 1000 km/s.

There are places in the laser chain (the spatial-filter pinholes) where the beam is focused to a diameter of 6 mm or smaller. However, a shutter placed at one of these points would still need to move at an extravagant 15 km/s to

bridge the gap in time. Furthermore, where the beam diameter is small, the beam energy is very concentrated, and thus, any conventional shutter placed directly in a pinhole would be instantly vaporized. What we need, then, is a renewable shutter-like device that can be placed in the beam path reliably at a speed of more than 15 km/s.

## Operating principles

Above a certain critical density, a plasma (a cloud of electrons and ionized atoms) will totally reflect light. Because it is vaporized, plasma is relatively easy to accelerate to high velocities. Since it consists of charged particles, we can use a magnetic field (generated by a pulser circuit) to fire it across the beam. With these basic principles in mind, we have developed a plasma shutter that meets all our requirements for the Nova laser system.

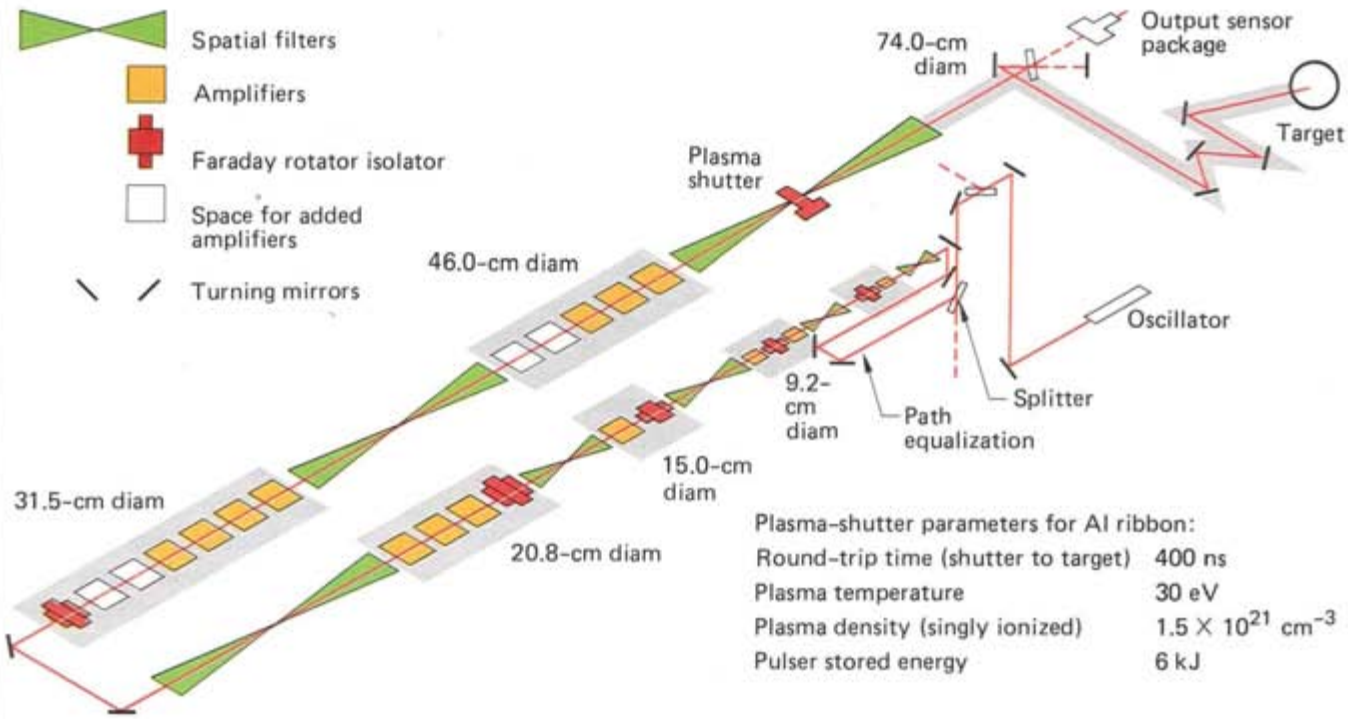


**Fig. 1** *Schematic representation of one of Nova's 20 laser chains. The oscillator fires a narrow beam of 1.05-μm laser light that broadens and gathers energy as it passes through the amplifiers. Periodically, spatial filters (pinholes through which the beam must pass) smooth the beam, and isolators prevent destructive back-reflection. Also shown is the location of the newly-developed plasma shutter.*

In our plasma shutter (Figs. 2 and 3) a fast electronic switch dumps a current of 500 kA from four large capacitors charged to 35 kV through a thin (50 $\mu$m) aluminum ribbon. The ribbon explodes, forming a dense plasma ($1.5 \times 10^{21}$ ions/cm$^3$). Magnetic fields, generated by the heavy currents flowing through the connecting leads and the plasma, accelerate the plasma to 20 km/s as it moves across the laser beam path.

Two plasma-shutter modules have been built to date, and both of them are undergoing testing and refinement. We are using one to study the plasma generated, to characterize the high-voltage electronics of the pulser circuit, and to investigate the reliability and life expectancy of the device. With the other module, we are evaluating the control system, investigating ways of minimizing electromagnetic interference, testing the ribbon-changing mechanism, and

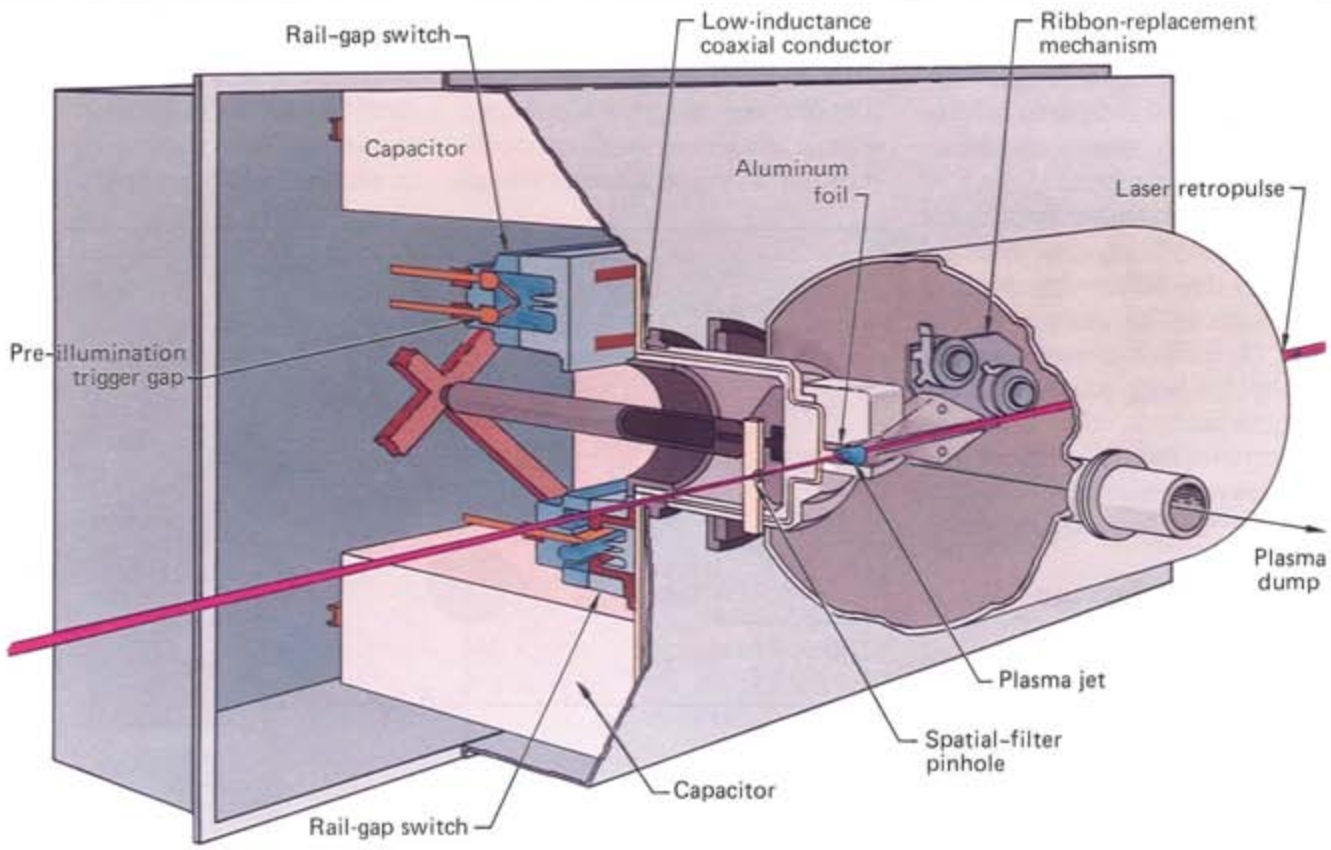


**Fig. 2** *The physical layout of the plasma shutter. For redundancy the circuit uses four rail switches (two shown in cutaway) to dump four large capacitors (two shown) into a low-inductance coaxial connector to explode an aluminum foil. The magnetic fields of the currents flowing in the copper connectors and in the discharge combine to expel the resulting plasma violently. Measured plasma velocities exceed the 15 km/s needed to place the plasma in the beam path in the 400-ns interval between forward-beam passage and the return of the reflected light.*

performing high-power tests on the Shiva laser system.

### The pulser

The basic design requirement of the pulser circuit is that it have a current in excess of 300 kA when the ribbon explodes, and hence a fast current rise-time (implying a very low inductance). Furthermore, since we want magnetic propulsion after the burst, the current must continue and even increase. The circuitry must be extremely reliable because a single misfire could ruin one of the laser's arms.

There must be a mechanism for replacing the ribbon after each shot, and this equipment must operate inside the evacuated spatial filter. Each ribbon changer must hold a large supply of fresh ribbon to facilitate reloading. Furthermore, the design must prevent vaporized aluminum from depositing on the nearby spatial-filter optics.

Figure 3 is a simplified equivalent pulser circuit. To make the rail-gap switches fire reliably, we trigger them with a 100-kV, 8-ns spark that pre-illuminates their surfaces with ultraviolet light. By initiating electron avalanches and streamers, the ultraviolet light predisposes the railgaps to fire simultaneously when the trigger pulse arrives, reducing the jitter (the variability between firing times) to about 1 ns. This pre-illumination is especially important as the triggering blades become rounded with age.

One of the major innovations built into the design is a special silicone elastomer insulator for the coaxial connector. Coaxial design minimizes the number of exposed edges at high voltage, and the silicone minimizes arcing across insulator surfaces. Its elasticity enables it to bounce back after a magnetically induced impulse and to maintain contact with the conductors.

### Experimental results

We have investigated the operation of the plasma shutter experimentally and with a two-dimensional computer model. The model has been particularly useful to us in selecting an operating

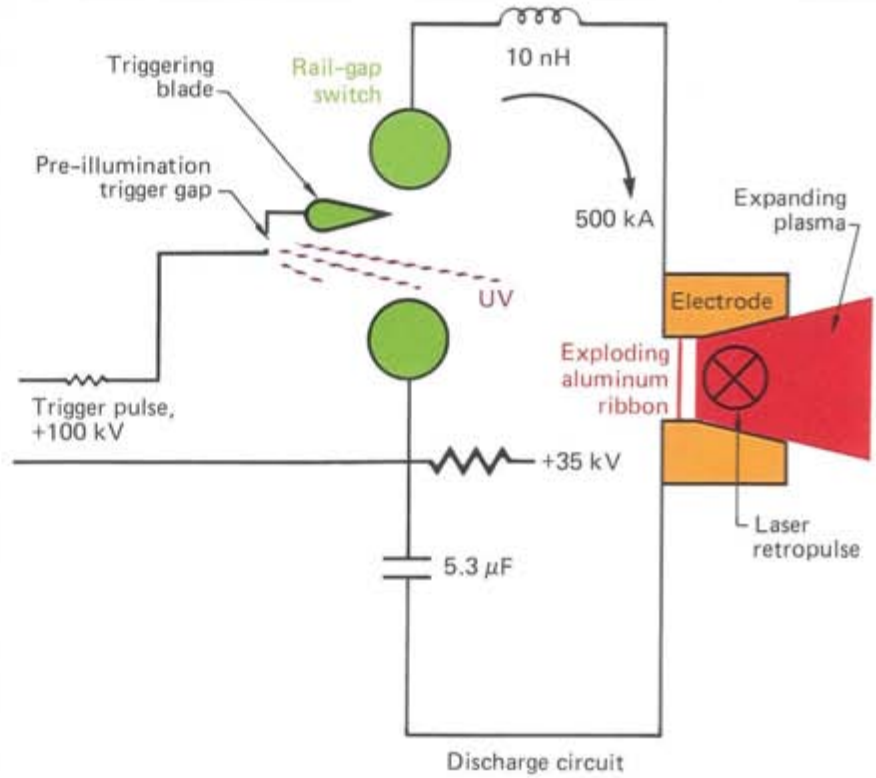


**Fig. 3** *Schematic drawing of the discharge and triggering circuits of the plasma shutter. A thyratron dumps a 100-kV pulse through each of the eight pre-illumination gaps (one shown) and into the rail-gap triggering blade, which in turn discharges to the lower rail. This discharge provides multiple paths for a fast-rising 500-kA arc in the rail gap, which explodes an aluminum ribbon to produce a dense plasma of electrons and aluminum ions.*

point, interpreting the experimental data, and scaling up from initial experiments. In our experiments, we have monitored the charge voltage of the capacitors and the current and voltage near the ribbon (with electrical instruments) and shutter closure with a probe laser. We have measured the angular distribution and density of the emitted plasma with glass witness plates and the plasma-front velocity with a Faraday cup and with a streak camera. Recently we installed an LLNL-developed, 5-keV, pulsed x-ray backlight source with which we radiographed the plasma as it emerged from the nozzle.

Figure 4 combines the results of Faraday-cup and streak-camera measurements with SHUT-code predictions for the plasma-front velocity. We also combined the divergence measurement, the nozzle geometry, the initial ribbon size, and the Faraday-cup arrival time to estimate the peak plasma density at $1.5 \times 10^{21}$ ions/cm$^3$. (These data have now been verified with the x-ray backlight diagnostic.) This is 50% more than the critical density for 1.05-$\mu$m light.

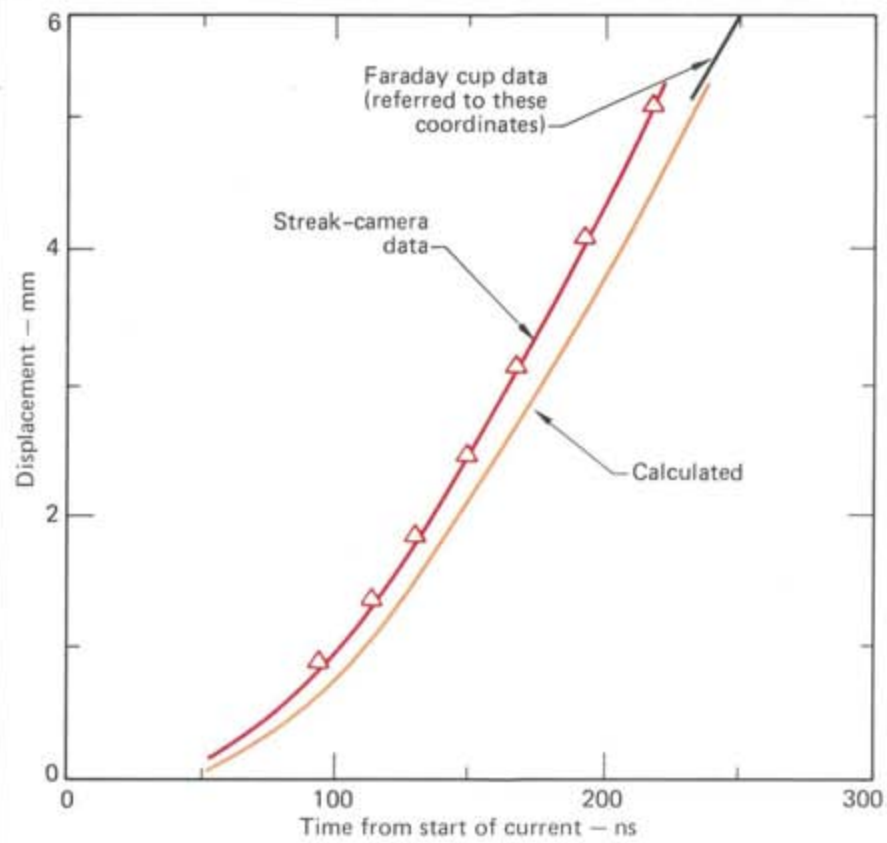


**Fig. 4** *Comparison showing the excellent agreement between SHUT-code-calculated plasma velocity and streak-camera and extrapolated Faraday-cup measurements. (The experimental data were not used in developing the code.) This close agreement increases our confidence in other calculations involving the beam fluence of the full Nova system.*

At the location planned for the plasma shutter in the Nova laser, we expect a reflected beam intensity of 1 TW/mm$^2$. Calculations with LASNEX (a code for simulating the interactions of laser light with plasma) indicate that a beam of this intensity will burn through only 2% of the plasma thickness. We recently tested the second prototype plasma shutter on the Shiva system and successfully blocked a 5-ns, 400-J pulse focused to 10 TW/mm$^2$.

Despite its mechanical complexity and its technical sophistication, the plasma shutter is an economical replacement for the Faraday isolator. Whereas isolators suitable for use in the Nova laser system would cost $500 000 each, we can build a plasma shutter for $80 000.

**Key words:** critical density; Faraday isolator; SHUT; Nova laser system; plasma shutter; Shiva laser system.