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# Advanced Collimator Prototype Results for the NLC

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# Advanced Collimator Prototype Results for the NLC

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**Abstract.** The Next Linear Collider accelerator will include a large (kilometer scale) and complex collimation system. The size and complexity of this system could be reduced if the collimator jaws could be made immune to damage from the electron beam. We describe two collimation systems currently under development. Construction of a prototype system which uses wheels that can be moved to a new position after damage is underway. The second system, currently in the R+D phase, uses rotors which are continuously reformed from a bath of liquid metal as the collimation surface. This second system allows operation at beam intensities which damage the jaws on every pulse. We describe results of tests on both systems.

## NLC COLLIMATION SYSTEM REQUIREMENTS

The NLC requires collimation both before and after the main linacs. The post linac collimators in particular are technically challenging as the beam intensities and small spot sizes are sufficient to damage any solid material. Designs to avoid damage by increasing the beam size in the collimation section result in very long system lengths, and impracticably sensitive optical designs. We base the engineering designs here on a beam optics design which provides reasonable tolerances and

**TABLE 1. NLC beam parameters in the Collimation Section (maximum values)**

| Parameter | Value |
|---|---|
| Beam Energy | 500GeV |
| Bunch Charge | $1.4\times10^{10}$ |
| Beam Emittance (normalized) | $300 \times 3\ 10^{-8}$m |
| Spot Size (in x, x' collimation system) | $50 \times 5$ μm |
| Bunch Length | 145 μm |
| Number of Bunches | 95 |
| Peak Current | ~1200A |
| Required Edge Stability | ~5 μm |
| Required surface roughness | <1 μm RMS |
| Collimator Gap (half gap) | ~100 μm |

# DAMAGE MECHANISMS

Beam damage in materials results from melting and vaporization due to energy deposition. In addition, if the thermal stress caused by the temperature rise exceeds the yield strength (or fatigue strength for multiple shots) of the material, damage can also occur.

## Electromagnetic shower damage

This is the most serious source of damage in most high energy accelerators. For each incident particle which intercepts the collimator surface, an electromagnetic cascade of particles is created over a depth of several radiation lengths. For the NLC beam parameters, peak materials temperatures of $>10^5$ C would be created at the peak of such a shower. We plan to avoid this damage mechanism by using a combination "spoiler" and "absorber" collimation scheme. The spoiler is a thin (~1/4 radiation length) object which produces a large transverse momentum spread in intercepted particles, but which does not absorb any significant fraction of the beam. Downstream optics are used to convert the transverse momentum spread to a large radial spread where a larger radius absorber can be used.

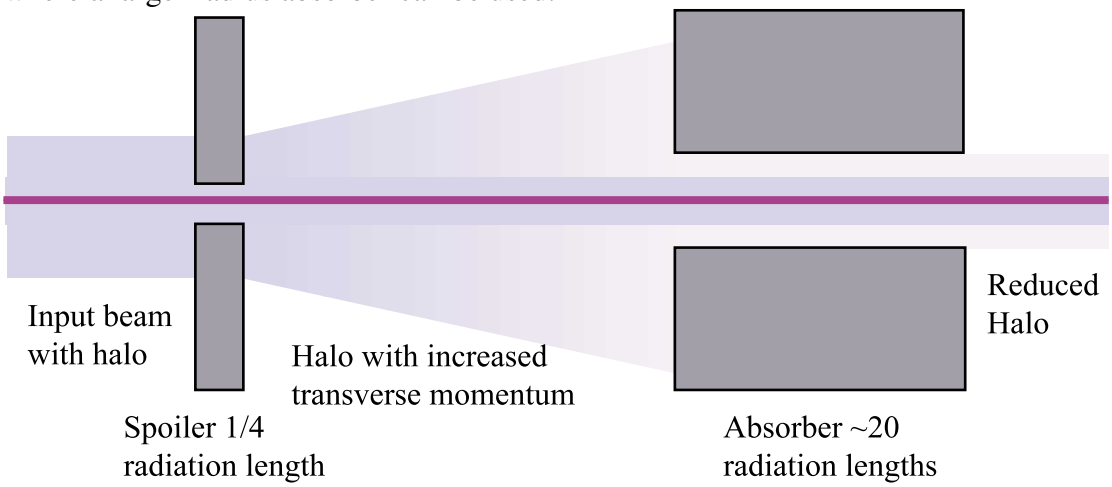



**FIGURE 1.** Spoiler / Absorber combination

## Direct ionization damage

Even without showering, the direct ionization loss of high energy particles is sufficient to destroy any material at full beam intensity and nominal beam size. Under normal operating conditions, only the beam halo will be intercepted, and the collimator should not be damaged. A Machine Protection System is used to dump errant pulses, however some percentage will still reach the collimation system.

## Collective Damage

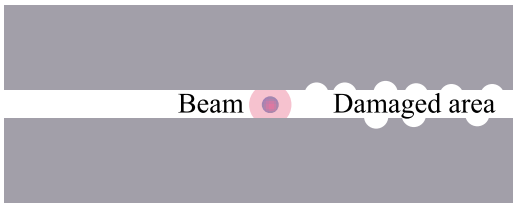
The high peak currents in the NLC can produce damage from collective beam effects, even without beam interception. Image current heating and direct electric field

ionization are both significant damage sources for the NLC collimators. For small collimator jaw gaps (<100μm full gap) these effects can cause damage on every pulse.[1]

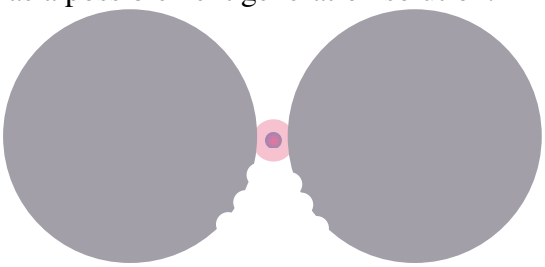
## DAMAGE RESISTANT COLLIMATOR TECHNOLOGY

### Consumable Collimators

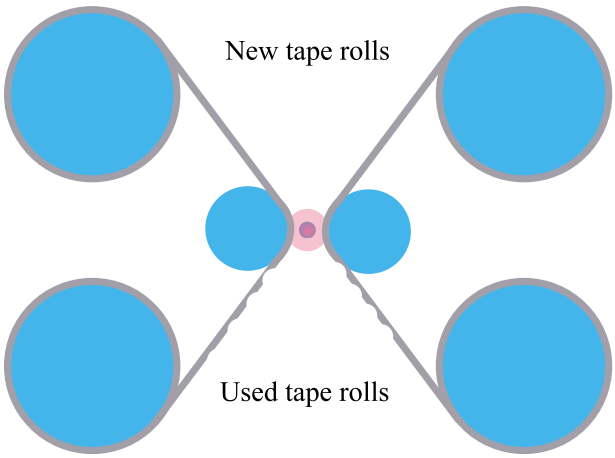
These are collimators where the jaws can be moved to a new position a finite number of times (~1000) after being damaged by the beam. They are suitable for use under conditions where damage will occur on occasional errant pulses. We have considered schemes which involve rotating wheels, bars or tapes which can be moved after damage. Of these, the rotating wheels seem the most promising technology. Tapes, which can allow a larger number of damaging shots, but are considerably more complex mechanically, are being considered as a possible next generation solution.




Bar collimator does not required any vacuum moving parts, but is large for its active area.



Wheel collimator requires vacuum bearings but is otherwise simple




Tape collimator has a large usable area but requires complex vacuum mechanical system

**FIGURE 2.** Various consumable collimator concepts

We are proceeding with construction of a prototype "wheel" collimator, and are considering design options for a "tape" collimator.

## Repairable Collimators

These are collimators where the jaws can be continuously repaired during operation, allowing use under conditions where damage occurs on many or all beam pulses. We are developing a system where a low melting point liquid metal is frozen on the surface of slowly turning metal drums. The solidified surface is rolled flat with smoothing rollers.

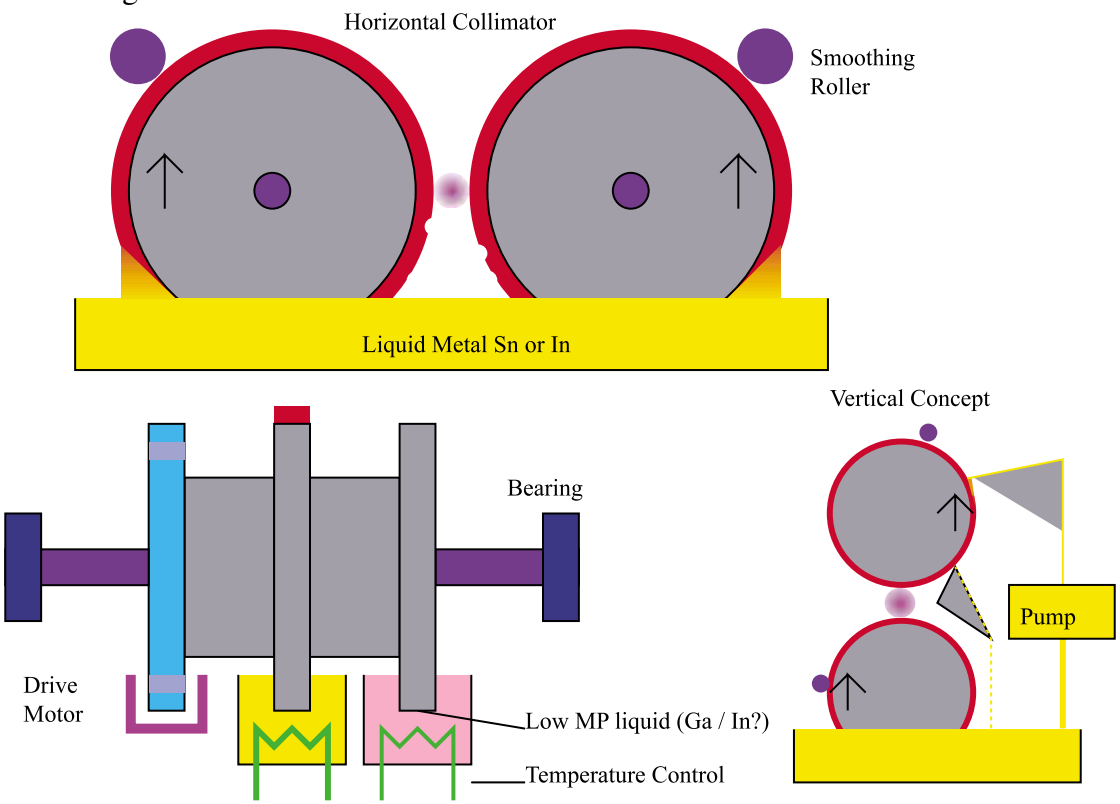



**FIGURE 3.** A layer of Tin or Indium is frozen onto slowly rotating drums, then rolled flat to form the collimation surface.

# R+D ON CONSUMABLE COLLIMATORS

A R+D program is underway to develop a prototype Consumable collimator. Test devices have been constructed for the critical components and detailed design work is proceeding on the final prototype.

## Collimation Surface Design

There are two contradictory requirements on the collimation surface. The collimation depth should rise rapidly with radial distance from the beam line in order to provide effective collimation. The surface seen by the beam wake fields, on the other hand, must taper gradually into the beam to avoid emittance degradation. We are developing a system where a high Z material (probably Copper) is combined with a low Z material (probably Beryllium) to meet these requirements.

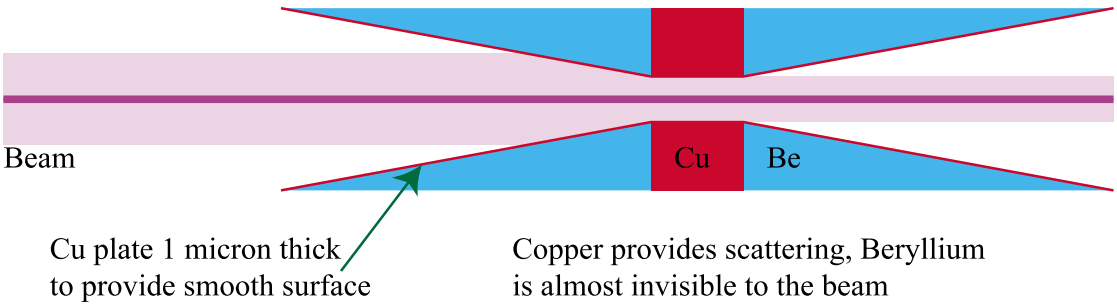



Figure 4. Composite Be / Cu spoiler

We have constructed a test sample consisting of a Copper plate brazed to a Beryllium plate. Both plates are polished, and then coated with a 1 micron layer of copper. A profile across the plate gave a surface roughness of ~ 200 nm RMS, with a 2.5 μm step at the junction between Beryllium and Copper. The roughness meets our spec, but the step may be too large. The step is believed to be due to the difference in hardness between the materials, and may be reduced by replacing the Copper with Nickel, Molybdenum, or a similar hard metal.

## Wheel Collimator Mechanical Design

We have designed a system where the two main rollers are sprung onto two pairs of smaller guide rollers. The guide rollers act as a reference surface and eliminate alignment effects from expansion of the main rollers. The separation of the guide rollers can be changed, resulting in a change in the gap between the main rollers.

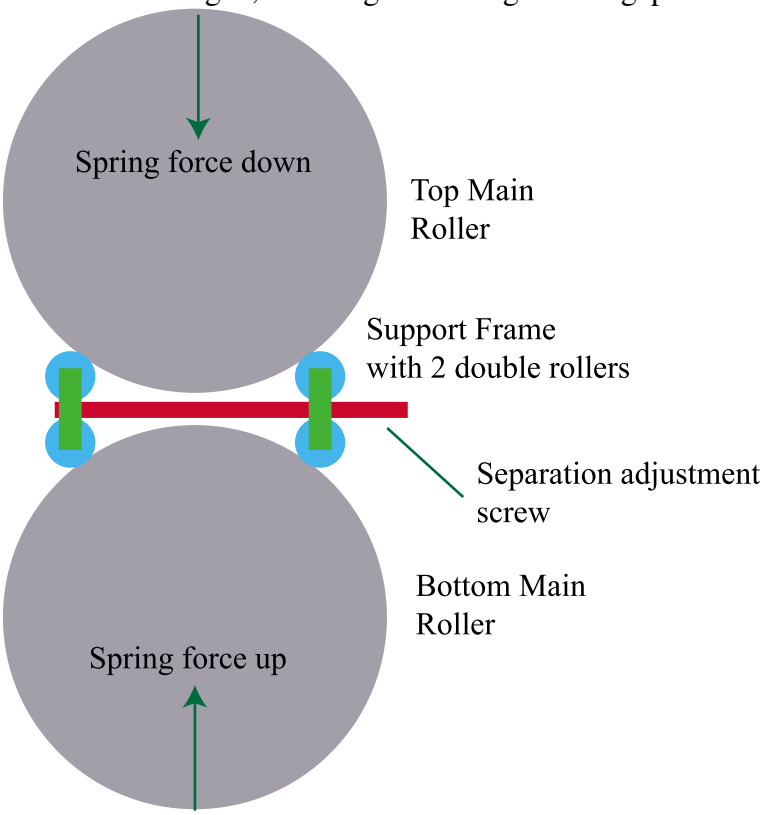



**FIGURE 5.** Rollers are supported from a central support. Spacing is adjusted varying the separation of the roller pairs

## Consumable Collimator Prototype Design

The overall layout of the consumable collimator is complete. Work is proceeding on detailed drawings

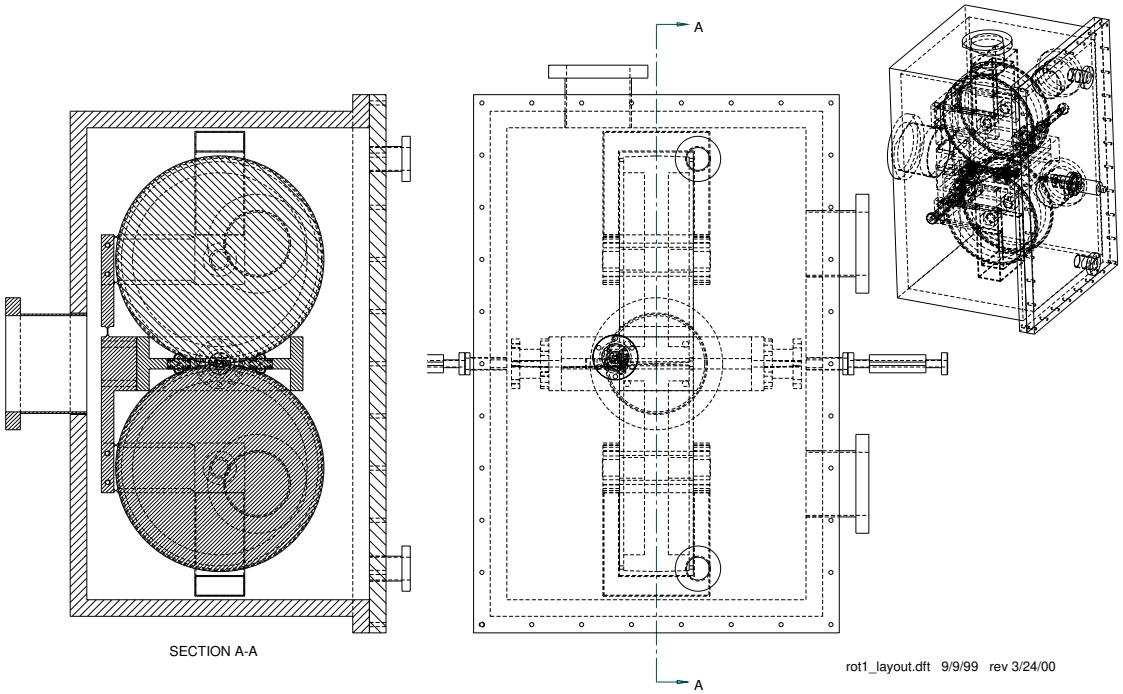



**FIGURE 6.** Layout drawings of the consumable collimator prototype

## Bearing Tests

The bearings on the support frame were considered to be a possible technical issue. A bearing of a type similar to that proposed for the collimator was tested under UHV conditions. The bearing was operated without lubrication. We are also planning to test a bearing with $MoS_2$ lubricant. The bearing performance was found to be adequate for this application where approximately 10,000 cycles at loads of approximately 10 pounds are expected.

**TABLE 2. Bearing Test conditions**

| Parameter | Value |
|---|---|
| Bearing type | Berg B1-26-Q3 |
| Bearing Size | 0.5” OD |
| Bearing Material | 440C Stainless |
| Bearing Design Load | 67 Pounds |
| Test system vacuum | ~$10^{-8}$ Torr |

**TABLE 3. Bearing Tests**

| Load | Temperature | Cycles |
|---|---|---|
| 45 pounds | Ambient | 32 days static |
| 32 pounds | Ambient | 3000 |
| 45 pounds | Ambient | 3000 |
| 45 pounds | 125 $^{o}$C | 9000 |

There was no measurable torque increase (~25% experimental uncertainty) after the ambient temperature tests. The torque increased a factor of 2 after the high temperature tests, but was still acceptable. After testing, the bearing was disassembled and inspected. Slight wear was found on the bearing race, and deposits, possibly due to incomplete cleaning were found.

# R+D ON REPAIRABLE COLLIMATORS

We are developing a prototype for the solidifying metal collimator described in figure 3. The primary technical issue is materials properties. A variety of materials combinations were tried. Experiments were done in an inert Nitrogen or Argon environment.

## Materials Options

The materials search was restricted to elemental liquid metals in order to avoid fractional crystallization during solidification. The only liquid metals with sufficiently low vapor pressure at their melting point are [2]

**TABLE 4. Liquid Metals with low vapor pressure at melting point**

| Material | Melting Point C | Vapor Pressure at MP / MP+100C | Radiation Length cm |
|---|---|---|---|
| Li | 180 | $10^{-10}/10^{-7}$ | 150 |
| Ga | 30 | $<10^{-11}/<10^{-11}$ | 2.1 |
| In | 156 | $<10^{-11}/<10^{-11}$ | 1.2 |
| Sn | 231 | $<10^{-11}/<10^{-11}$ | 1.2 |
| Tl | 303 | $10^{-8}/10^{-6}$ | .5 |
| Pb | 327 | $10^{-8}/10^{-6}$ | 0.6 |
| Bi | 271 | $10^{-10}/10^{-7}$ | .6 |

Of these, Li was rejected due to its long radiation length. Bi, Pb, Tl were rejected due to marginal vapor pressure and toxicity. Ga was rejected due to its forming a brittle solid which could not be rolled flat after solidification.

Based on liquid metal corrosion data [3], a variety of inert materials were tested for the liquid metal container, and for the smoothing roller. $Al_2O_3$, Glassy Carbon, Tungsten and Beryllium were found to be resistant to molten Tin and Indium. Molybdenum was moderately resistant.

The liquid metal must adhere to the substrate material, but must not corrode it. This is a difficult requirement because adhesion is closely related to corrosion. A variety of

materials were tested, including Mo, W, Be, Ta, which did not wet, and Ni, Al, Ti, Zr which wet, but were also corroded.

The solution found was to heat the solid material in liquid metal at 800 C for 24 hours to form a coating (through solution or intermetallic reactions). Then at low temperature (near the melting point) the liquid metal would wet the coated material repeatedly. The most successful combination was liquid Tin and solid Molybdenum.

Samples of Molybdenum coated at 800 C were dipped in low temperature (250 C) liquid tin which formed a thick (1mm) coating. This coating was then rolled at room temperature to form a flat surface. The adherence between the solid Tin and Molybdenum was not broken by the rolling process. The is some sign of corrosion of the coating after 3 months in liquid tin at 370 C, and more study is needed.

## Repairable Collimator Test System

A test system which will operate in moderate vacuum ($10^{-6}$ Torr) is being designed. It will use Molybdenum rollers, pre-treated in Tin at 800 C. The smoothing roller will be either Molybdenum, or Tungsten (if there are problems with the tin adhering to the smoothing roller under pressure).

## SUMMARY

The high beam energy density in the NLC requires the use of advanced collimator technology. A prototype consumable collimator, which can survive on the order of a thousand events of beam damage from errant pulses is being constructed. Component tests have demonstrated the most critical technologies for this systems. Work is also underway to develop a repairable collimator based on a continuously formed solidifying metal surface. This collimator could operate even if there were beam damage on every pulse. Materials tests for this system are underway, and a technology demonstration prototype is being designed.

## REFERENCES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3. Lyon, Richad N, "Liquid-Metals Handbook", Office of Naval Research, (1952)