Renewable & Consumable Collimators at the NLC

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SLAC

Halo '03 Montauk NY
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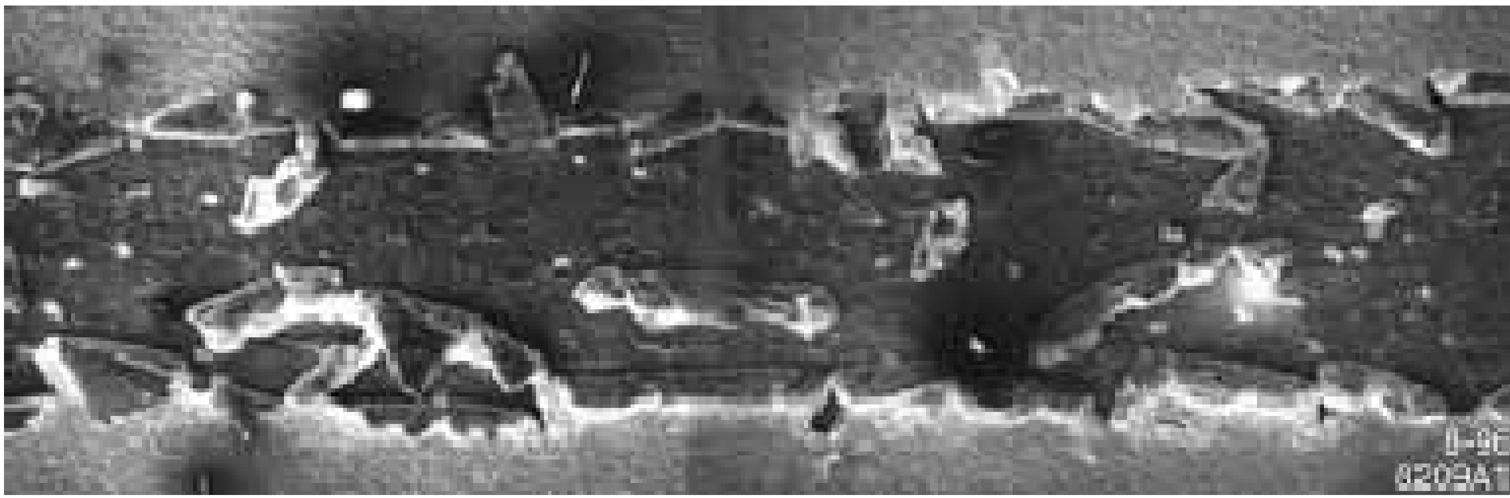
Collimator Damage

SLC Linac Collimators in 1995: Gold-coated Titanium

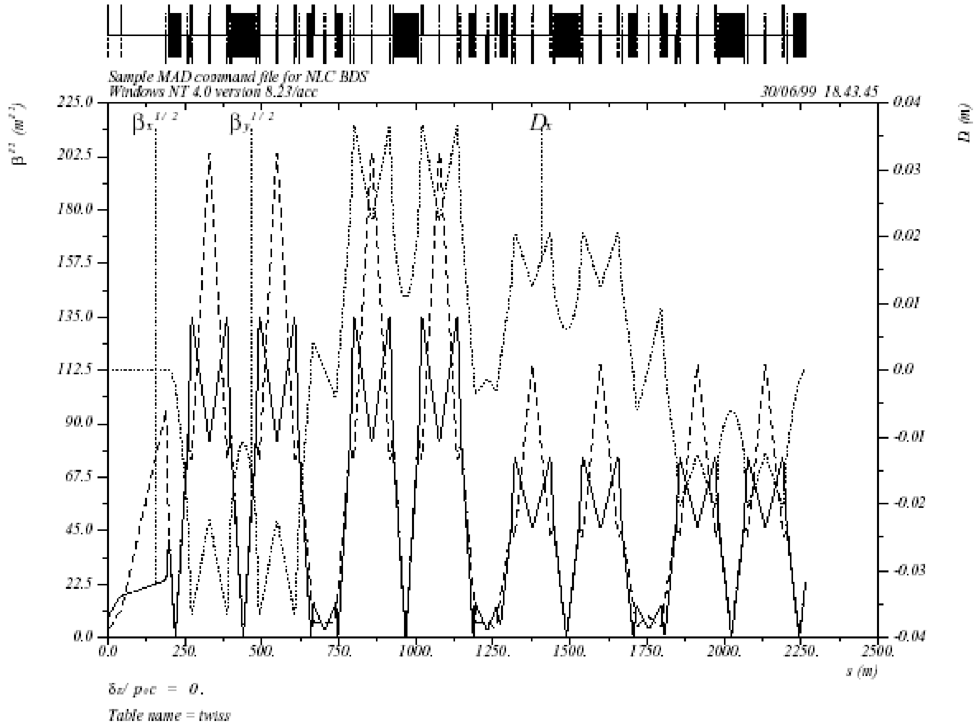
1mm

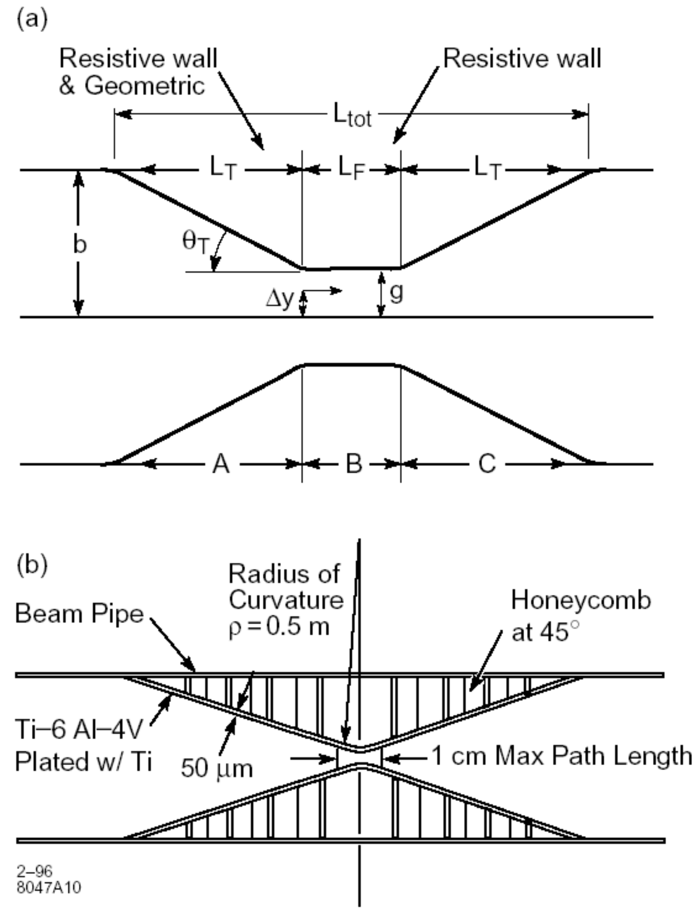


Feature size ~250μm

Wakefields x25-50 larger than before damage

1996 NLC ZDR Collimation Lattice based on thin spoilers and thick absorbers





- Large betatron function
- Large dispersion
- Large separation between spoilers and absorbers

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PASSIVE Protection Makes for SENSITIVE Lattice

- Long system length (~ 2.5 km per side)
- Several interleaved families of sextupoles for chromatic correction
  - Small bandwidth
  - Tight tolerances, particularly sextupole alignment
- Large $R_{12,34}$ elements from one sector to the next
  - Diurnal Quad Drift of a few μm in one sector would drive the beam into the collimators in the next sector, damaging downstream absorbers
- Interleaved Horizontal Betatron and Energy collimation
  - Many collimators
  - No additional spoilers could be added
  - Wakefields from the collimators were at the limit of tolerability
  - Horizontal collimation depth could not be adjusted independently of the energy collimation depth
- Looser IP- vs. FD-phase collimation in the 2nd pass (strong wakes)
  - Careful control of phase advance, both for on- and off-energy particles, to prevent phase migration
  - Careful control of the chromaticity

LCC-0052, Tenenbaum

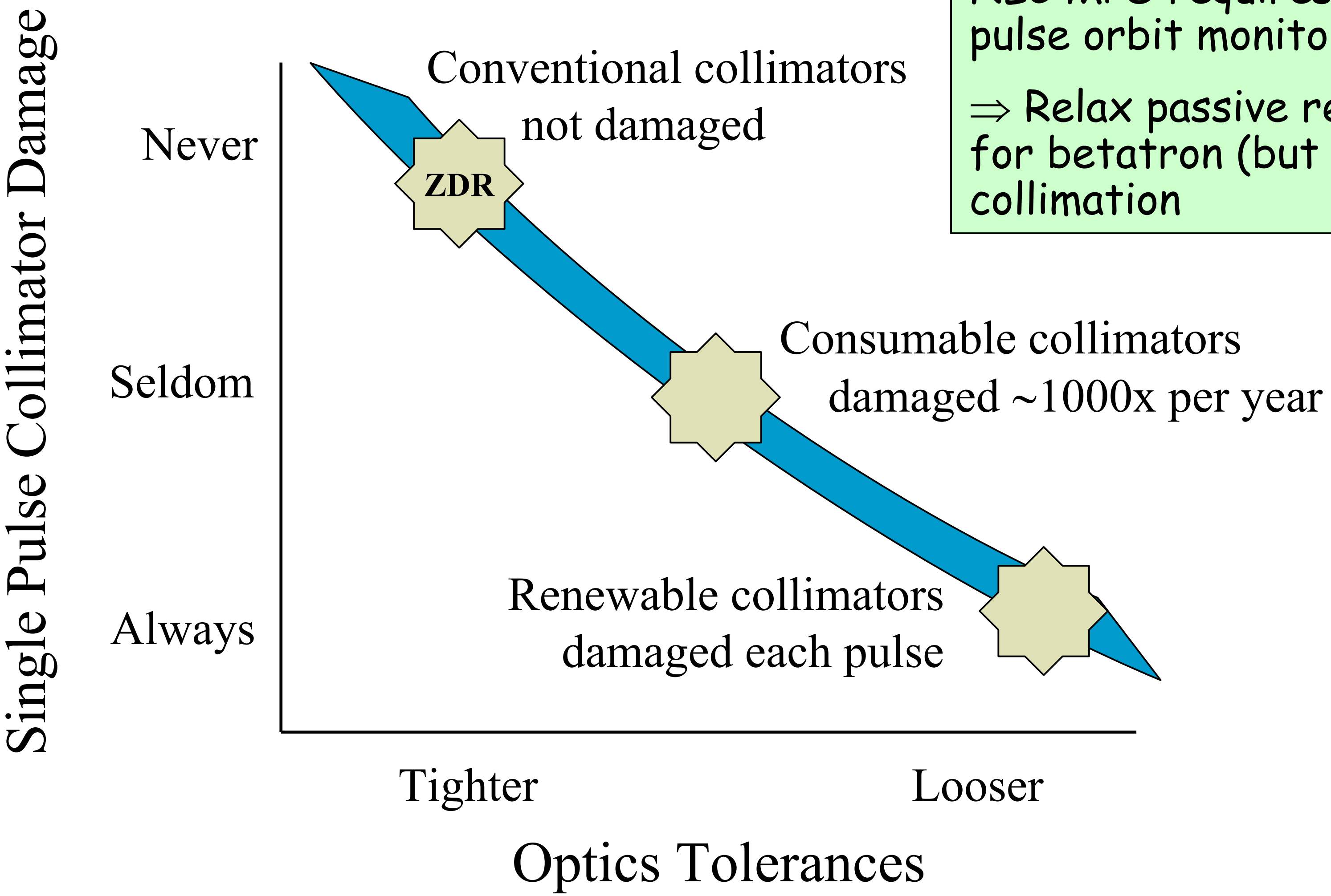
Damageable Collimators Share Pain

SLC experience

- Frequent energy errors &/or feedback system problems
- Few catastrophic quad failures

NLC MPS requires pulse-to-pulse orbit monitoring

⇒ Relax passive requirement for betatron (but not energy) collimation



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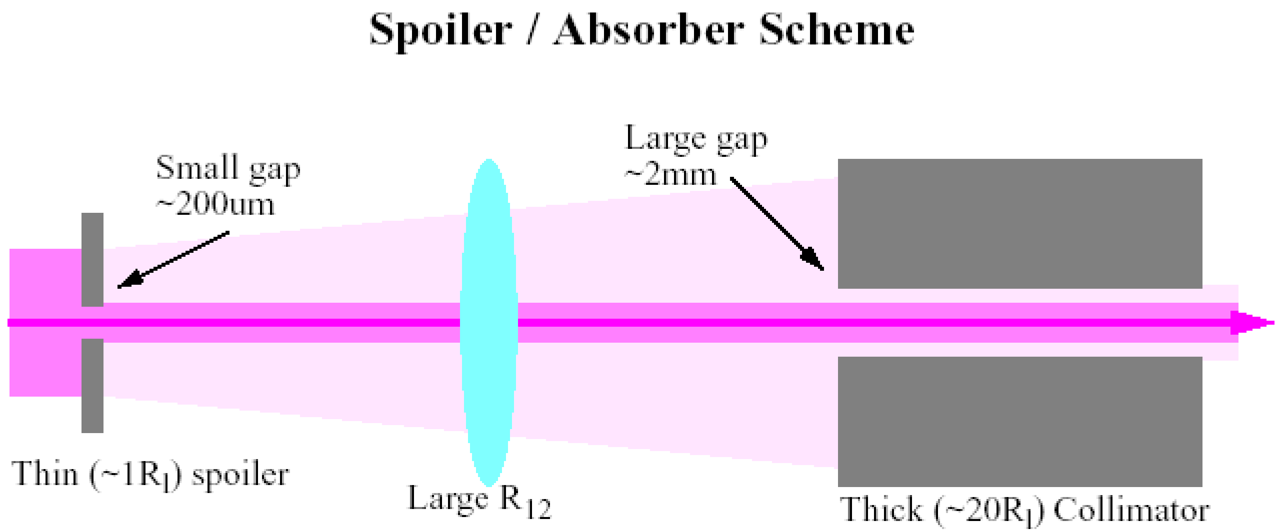
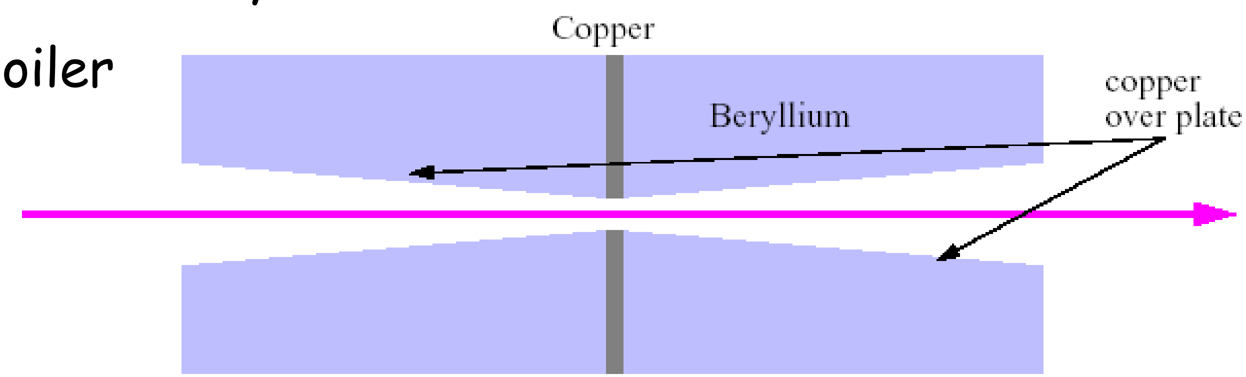
Consumable/Renewable Spoilers

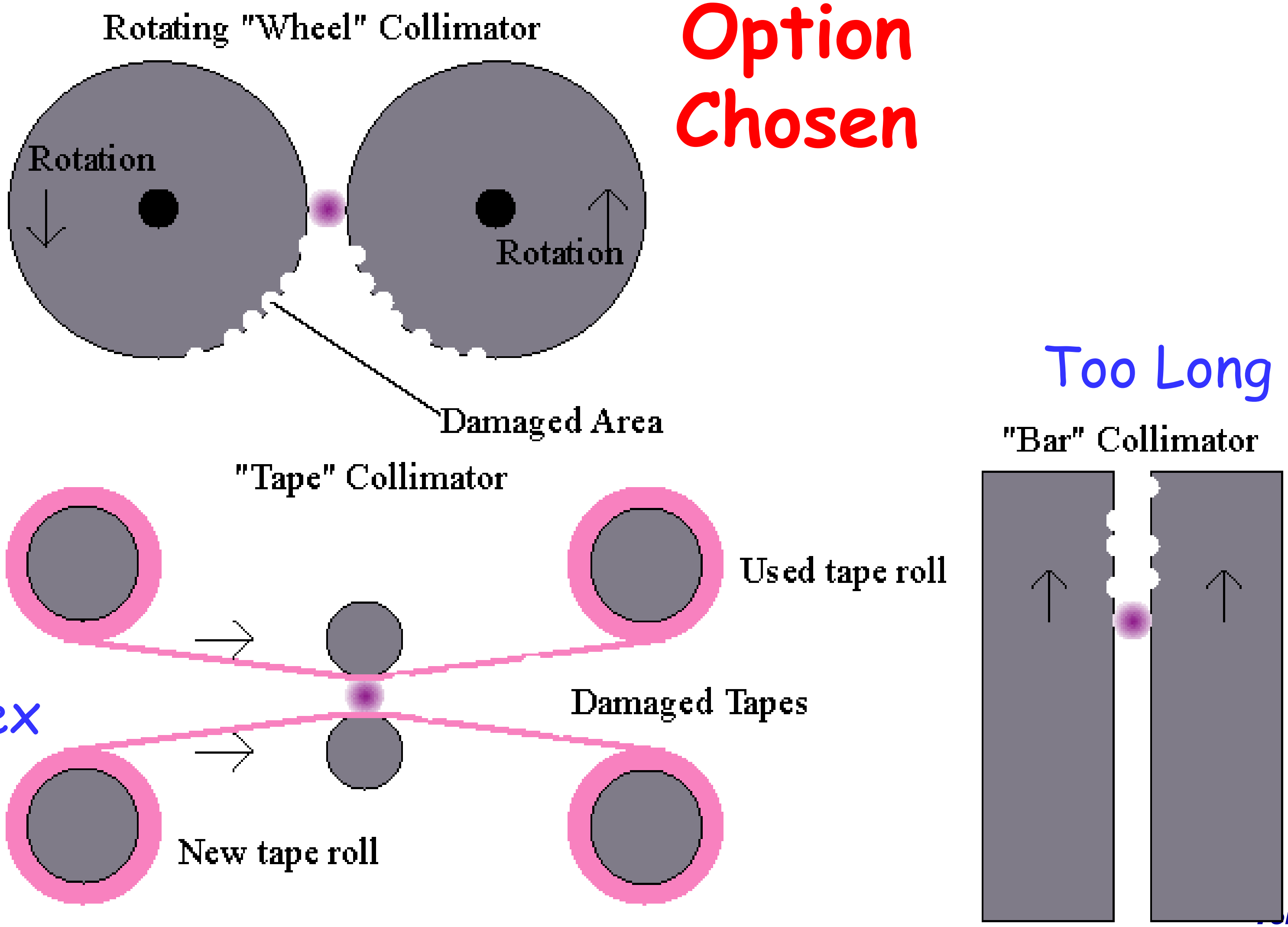


Tapered low resistivity surface for wakefields

Thin hi-Z spoiler



Consumable Options Considered



Option Chosen

Too Long

Too complex

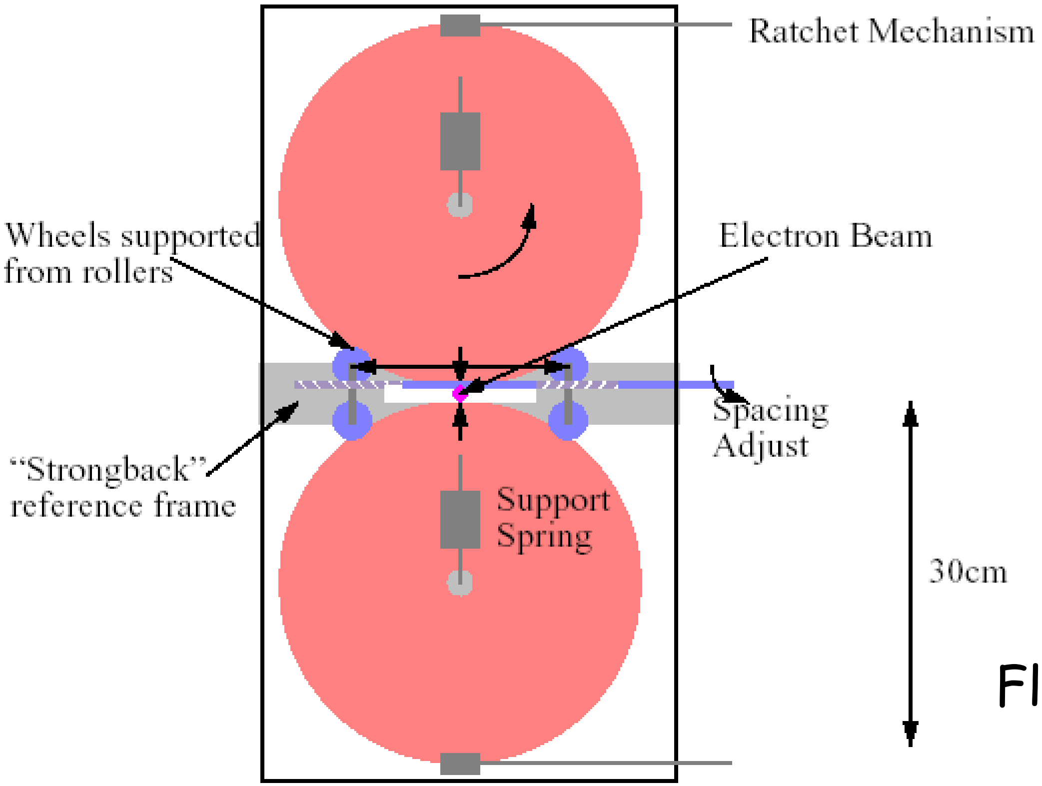
Consumable Spoiler Requirements

Max.# Damaging Hits	1000
Length @ Min. Gap	0.6 rl
Radius of curvature	.5 m
Aperture	200-2000 μm
Edge Placement Accuracy	10-20 μm
Edge Stability under rotation	5 μm
Beam Pipe ID	10 mm
% Beam Intercepted per side	.05%
Beam Halo Heating	~0.2 W
Image Current Heating	~0.5 W
Radiation Environment	10^5-10^6 rad/hour
Vacuum (tbd)	<10^{-7} torr

~30cm diameter

Radiative Cooling

Rotating Wheel Design Features



1 d.o.f. internal mechanism referenced to rigid backplane provides aperture

Control through transversely adjustable stops

Flexure pivots eliminate backlash

Vacuum bearings

Housing aligned to beam via external movers & BPMs

Engineer to minimize thermal effects

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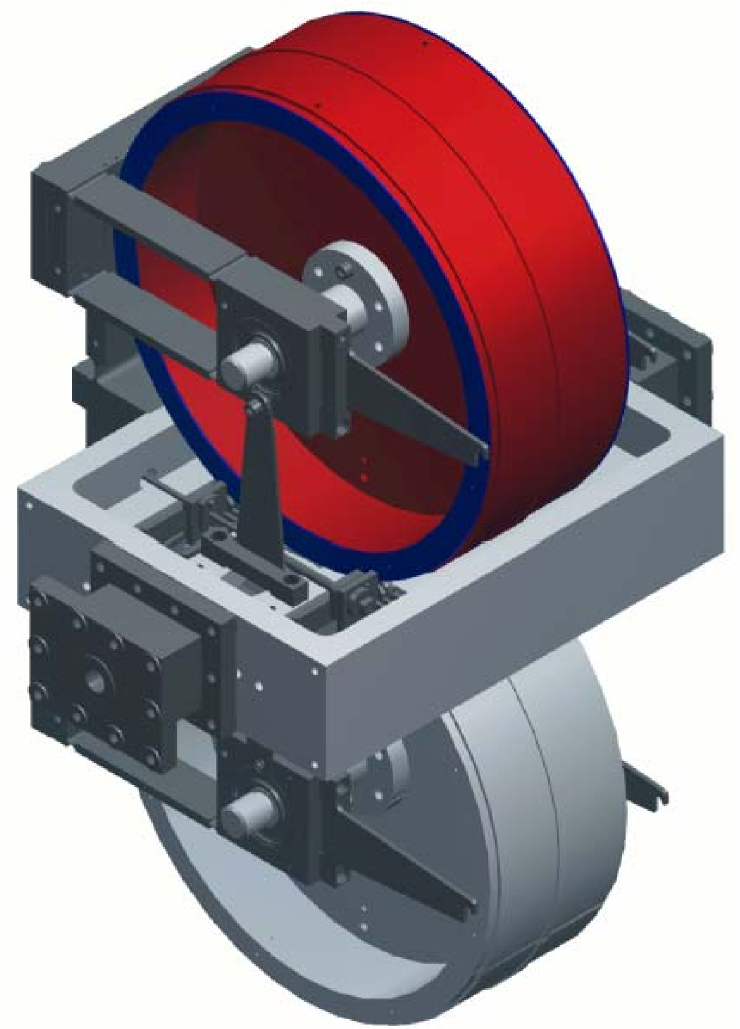
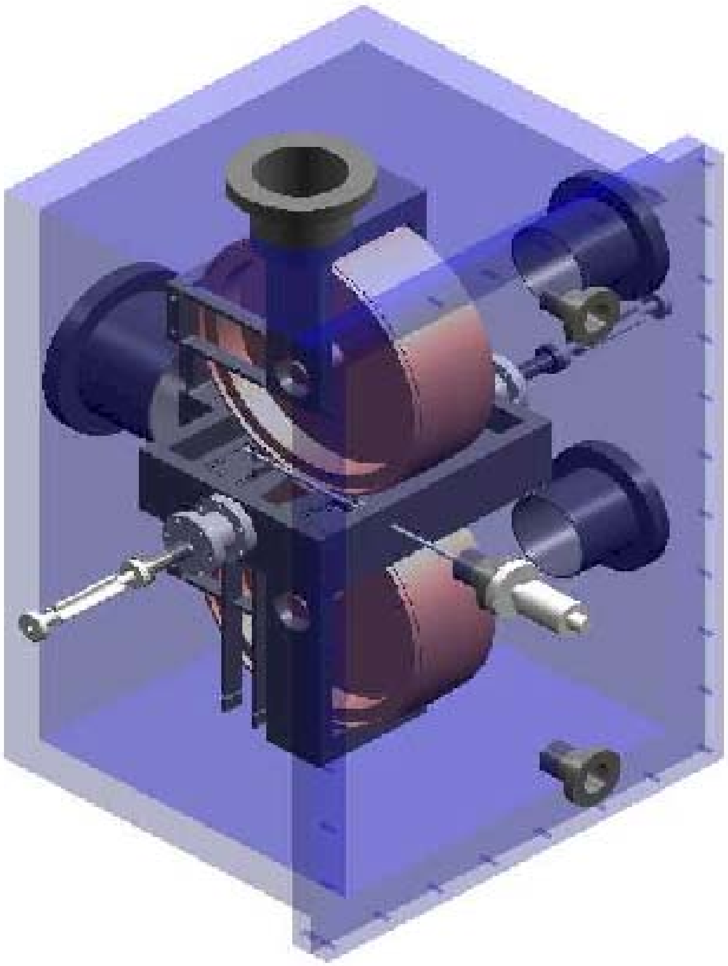
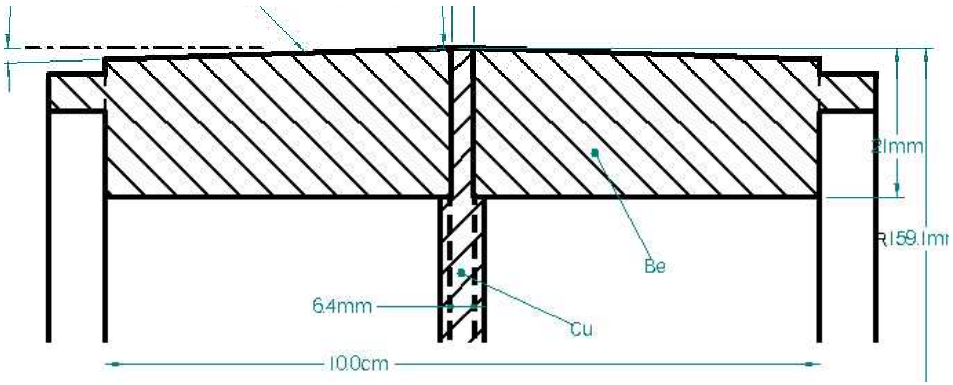
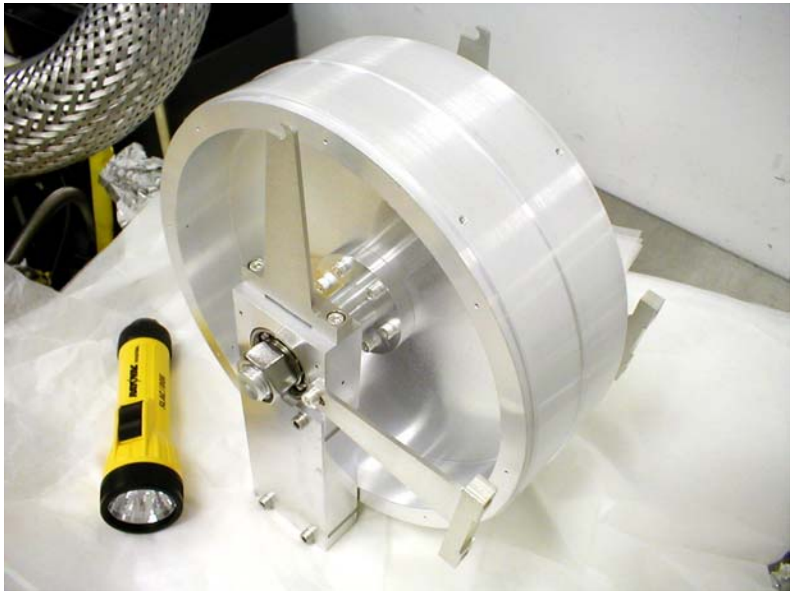
Consumable Spoiler Prototype

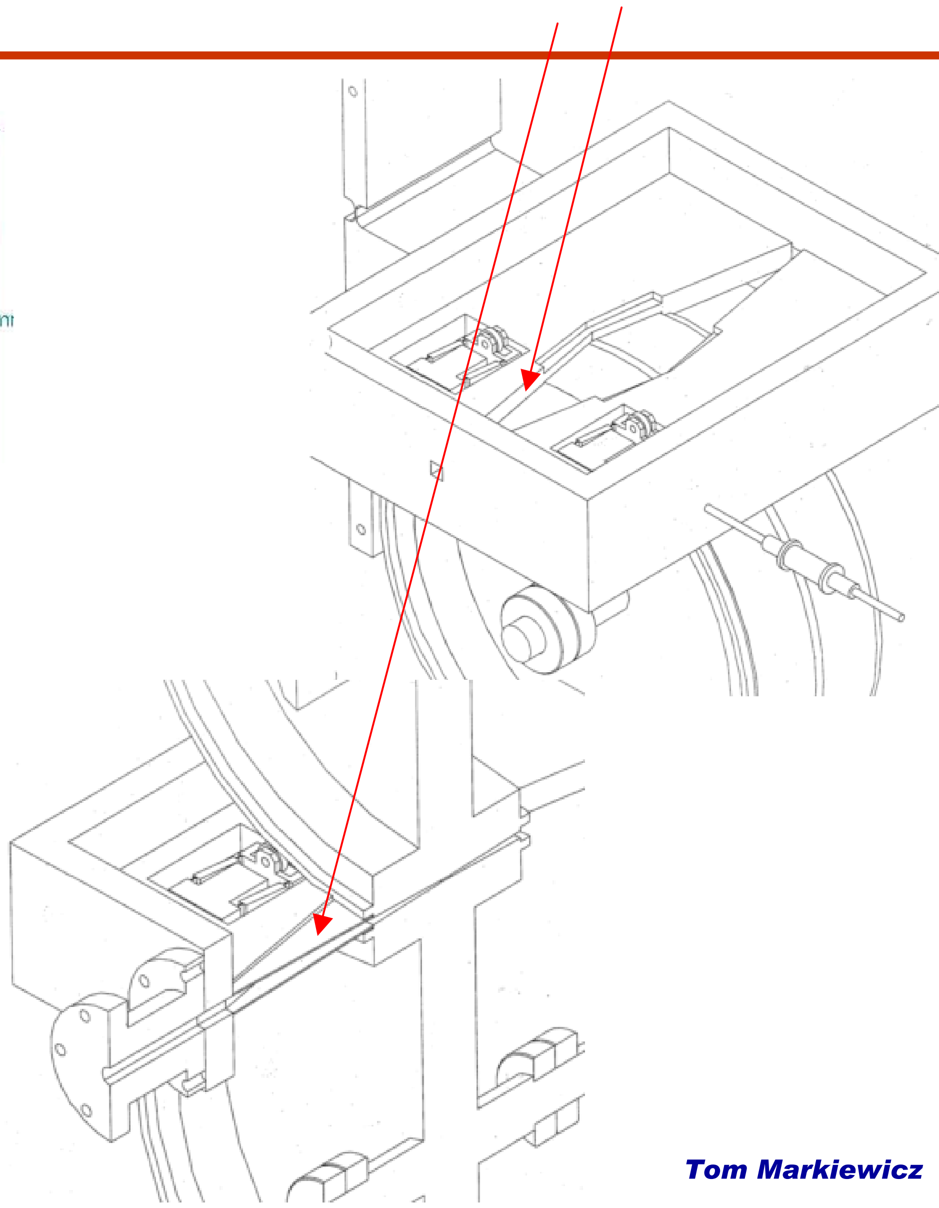




Tapered Wheels & Wakefield Wedges







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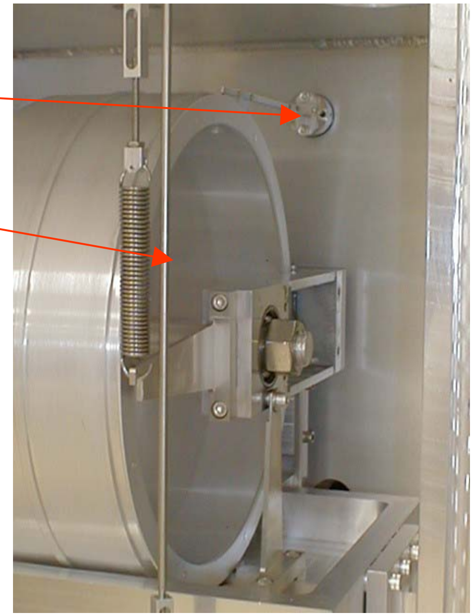
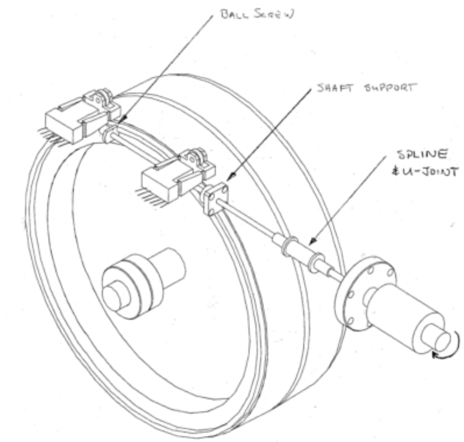
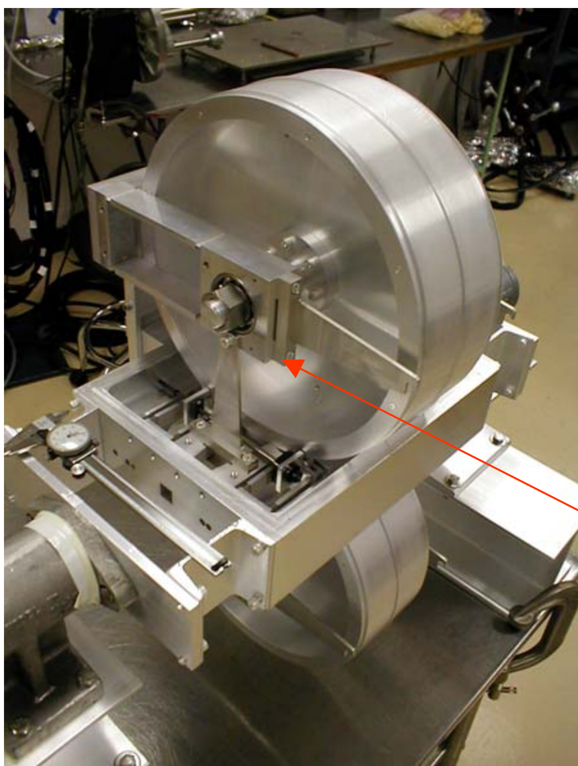
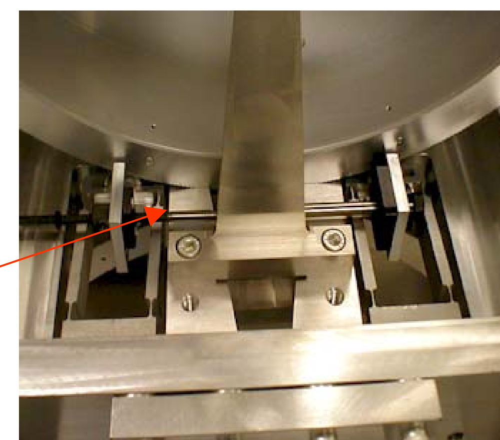
Adjustment Mechanisms

Wheel Ratchet & Support









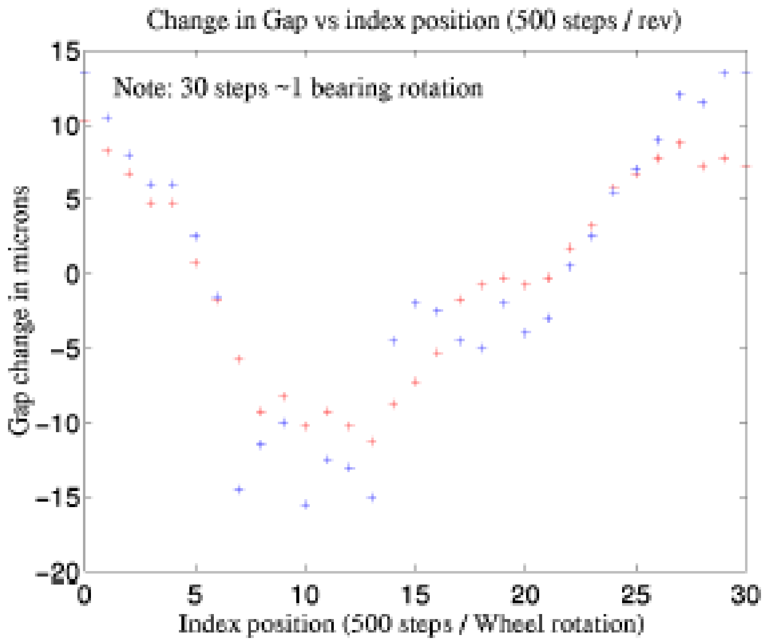
Aperture Adjust

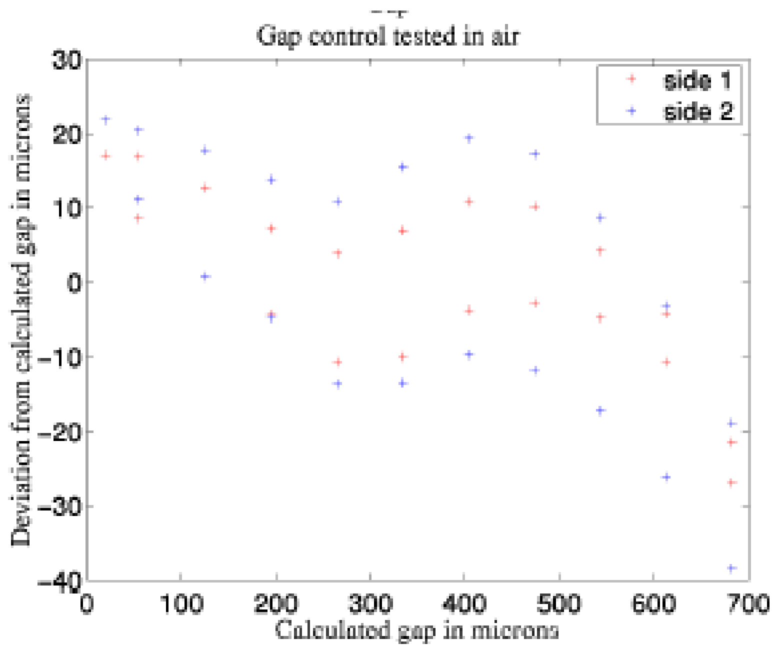
Mounted in Vacuum Vessel

Consumable Spoiler Performance (1)

Stability with Wheel Rotation
~ ±15 μm
Runout in support bearings;
Use higher precision bearings

Motion accuracy ~±15 μm
OK





Consumable Spoiler Performance (2)

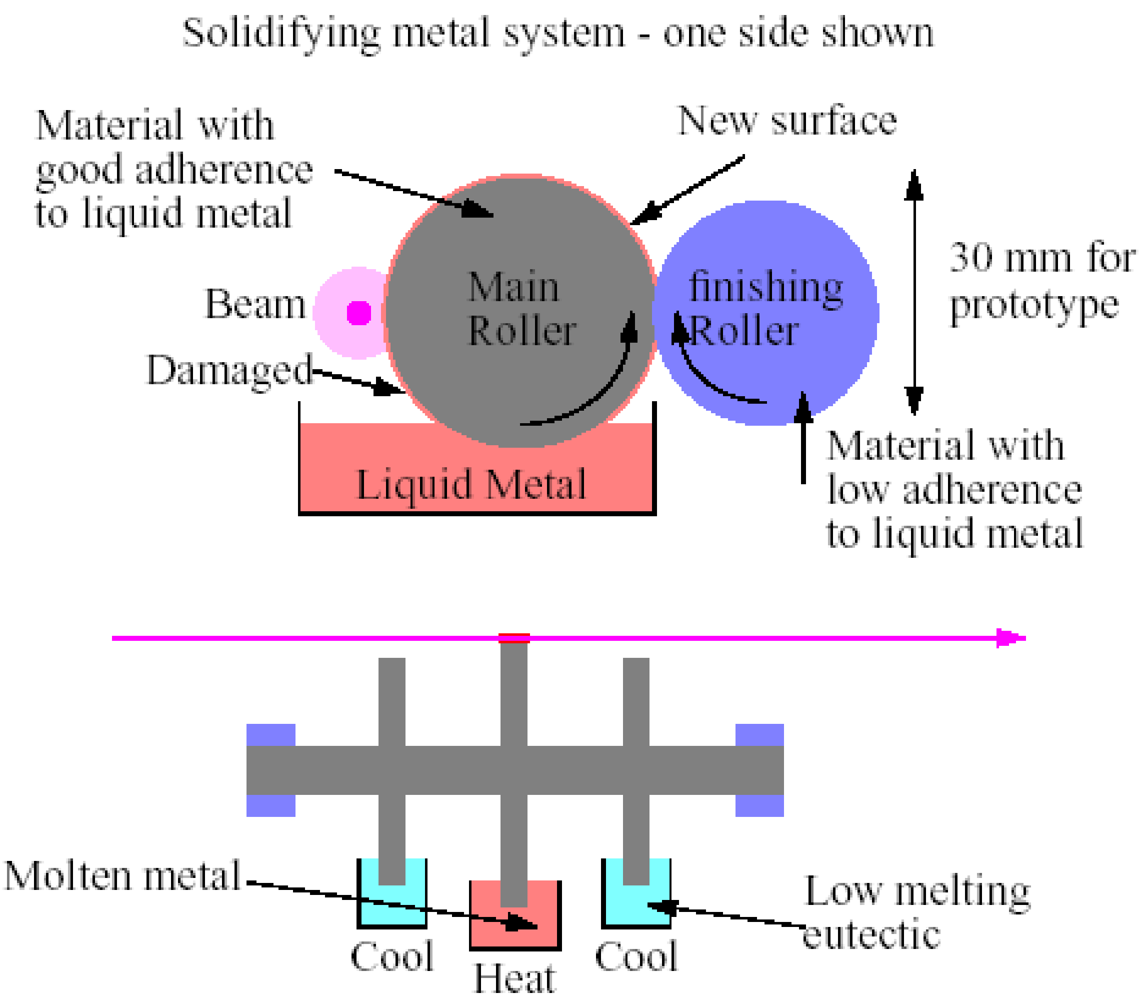
- Hysteresis in Gap as Wheel Rotated ~25 μm
  - Improve by reducing torque from support springs
- Vacuum 2 x 10^{-7} torr
- Heat performance

3.5W/rotor	10W/rotor	11W/rotor
ΔT=17°C	ΔT=42°C	ΔT=46°C
5/250 μm	8/250 μm	15/250 μm

Consumable Collimators at LHC?

- Minimum required jaw length for Be, C, Ti, Cu, W?
- Allowable impedance for each of the above?
- Maximum anticipated steady-state design power deposited?
- Maximum allowed radiation dose level in the collimation section 30cm from the beamline. To what extent must radiation hard materials be used?
- Vacuum requirements in the collimators? 1E-6 torr (easy), or 1E-10 torr (will required special materials).
- What is the separation between the two beams, and can they be run through the same chamber?
- Any other unusual constraints? Nonmagnetic materials? Low activation materials?…
- Reliability requirements? Obviously very high. Is there space for dual collimators?

Renewable Spoilers



Advantages:

- Very Small Gap relaxes optics tolerances
- No need to ask if surface is damaged or not

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Materials Studies

- **Which liquid metal?** **TIN**
  - low vapor pressure at its melting point
    - Indium is a possible alternate
- **Smoothing roller material?** **Molybdenum**
  - not coated or corroded by hot Tin
    - Tungsten is better but more difficult to machine.
- **Main spoiler wheel material** **Tin-coated Niobium**
  - Most difficult requirement: Need a material which can be repeatedly coated with but which will not dissolve
    - Metal coatings (i.e. soldering) dissolve outer surface of substrate
    - Solution: "Pre-treat" the substrate material in liquid Tin at high temperature (850 °C) for 24 hours. This dissolves the outer portion of the substrate and forms a good coating. Then operate the roller in low temperature liquid Tin (280 °C). At this lower temperature the dissolving rate is vanishingly small.

Liquid Metal Properties

Material	Melting Point C	Vapor Pressure MP/ MP+100C Torr	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	$10^{-8}/10^{-6}$	0.5
Pb	327	$10^{-8}/10^{-6}$	0.6
Bi	271	$10^{-10}/10^{-7}$	0.6

Desirable Properties:

Pure element

Low vapor pressure

Short Radiation Length

Tin chosen as indium activates and shows inferior adherence relative to tin

Substrate Materials

Goal: Corrosion free with good adherence

TESTED:

Beryllium: Long radiation length is an advantage

Carbon: Pyrolitic Graphite very corrosion resistant, long rad. length

Silicon: Corrosion resistant.

Titanium: Good mechanical properties, corrosion resistant.

Vanadium: Corrosion resistant

Iron: Resistant to some liquid metals. Cheap and easy to work with

Zirconium: Generally corrosion resistant.

Molybdenum: Corrosion resistant, high temperature

Tantalum: Corrosion resistant, high temperature

Tungsten: Very high temperature, corrosion resistant.

Stainless steel: Resistant to some liquid metals. Cheap, easy to work with.

Aluminum Oxide (ceramic): Corrosion resistant

Tungsten Carbide (ceramic): Corrosion resistant, high temperature.

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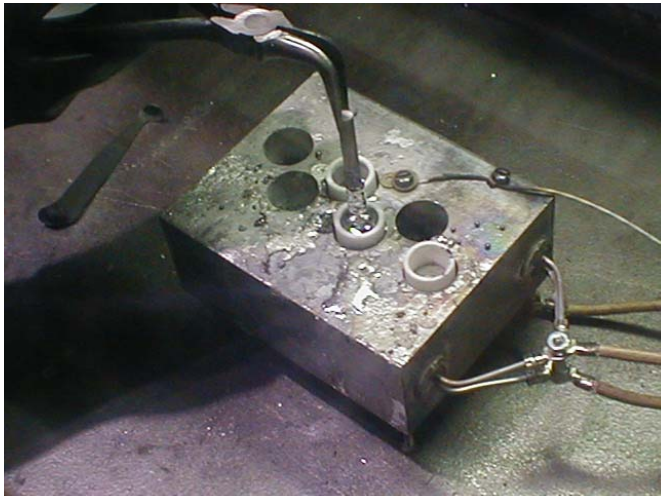
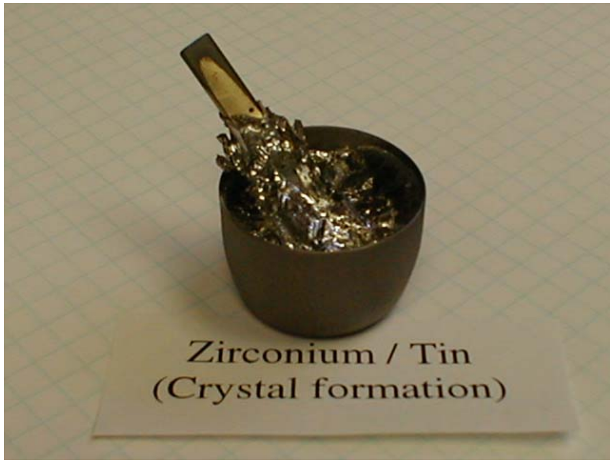
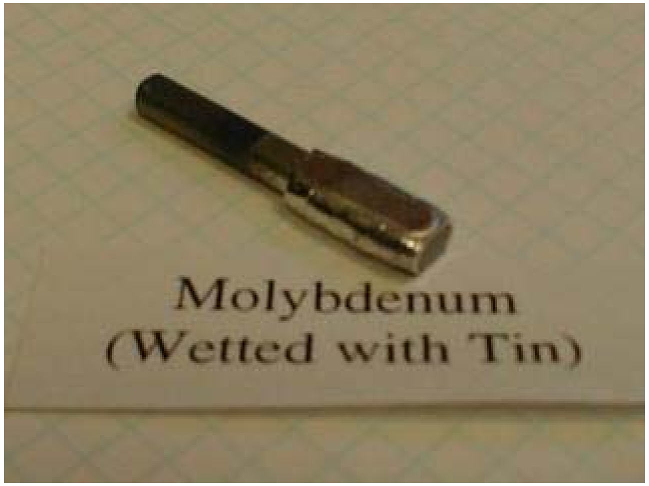
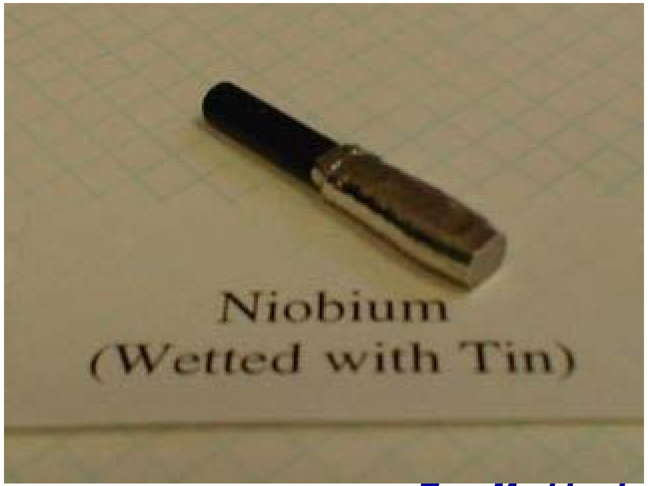
Materials R&D

Glove Box under N2









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Liquid Metal/Substrate Tests

Goal: Corrosion free with good adherence

400°C Tests with Sn (under N_2):

- No adherence for any substrate except iron
- Iron "wets" at 400 °C then continues down to 231 °C
- Nickel-coated steel, Silver-coated stainless:
  - coatings dissolve, then no adherence

800°C Tests (under N_2):

- Nickel, Zirconium, Aluminum, Steel, Iron, Silicon, Silver, Titanium, Tungsten Carbide: dissolve, distort &/or corrode
- Tungsten, Glassy Carbon, Aluminum oxide, Beryllium:No adherence
- Molybdenum: Adherence, which then continues at lower T, no sign of corrosion after 5 days at 380 °C ; Use as roller
- Tantalum: Adherence, continuation at lower T, then de-wets; sample reacts with N_2; suspect dissolved N_2 in Sn sample
- Vanadium: Adherence, but with mild corrosion; continuation at lower T without further corrosion
- Rhenium: Similar to Moly, but expensive
- Niobium: Wets & slightly dissolves at 850 °C; stable at300 °C for several weeks; Use as main rotor

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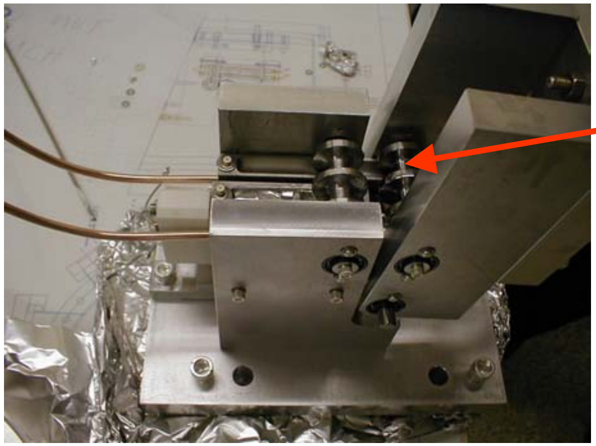
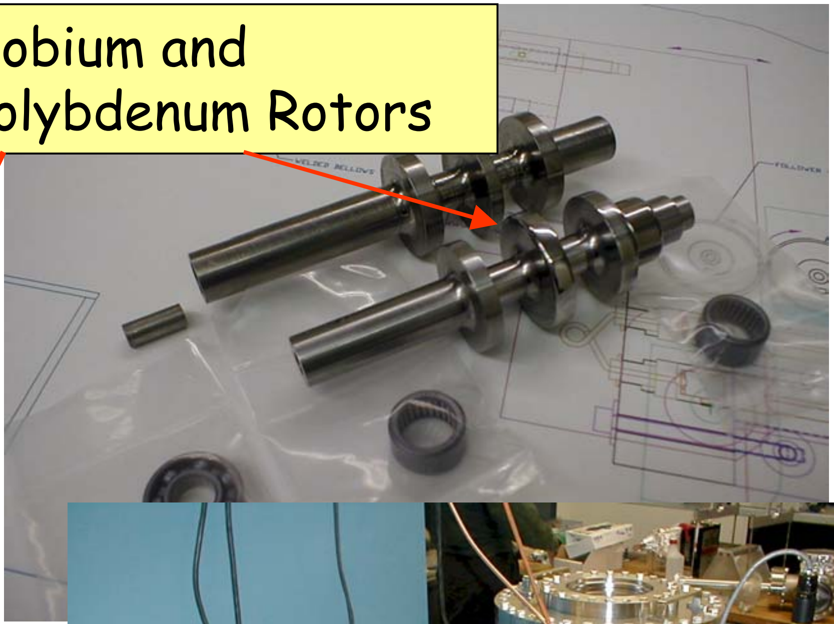
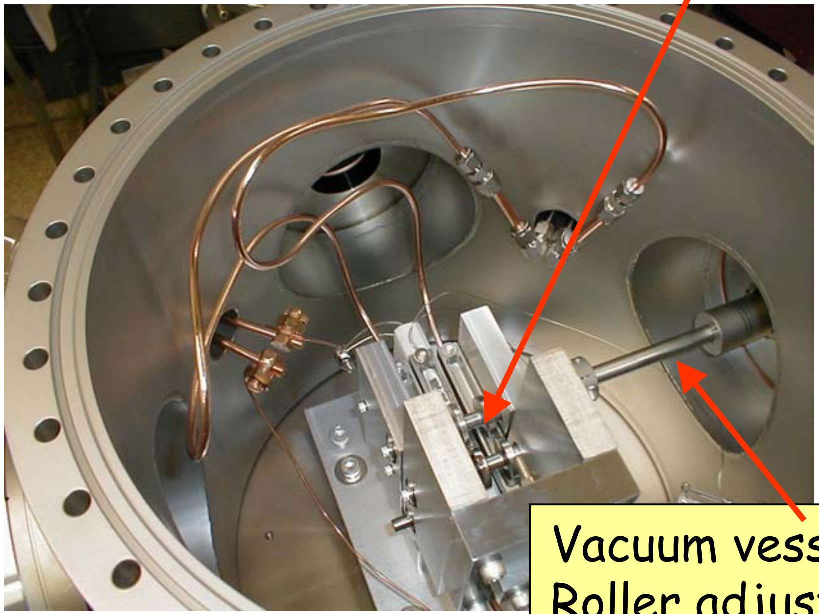
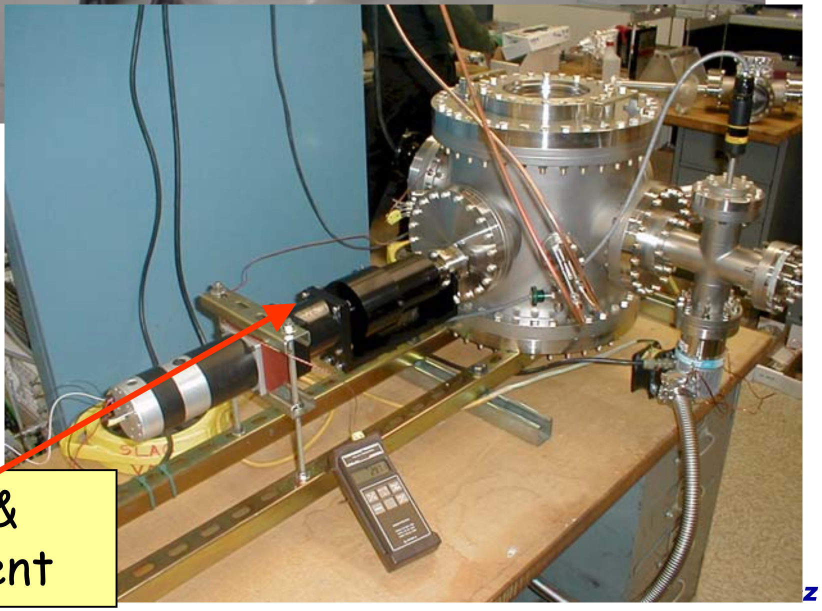
Renewable Spoiler Prototype Assembly



Niobium and Molybdenum Rotors

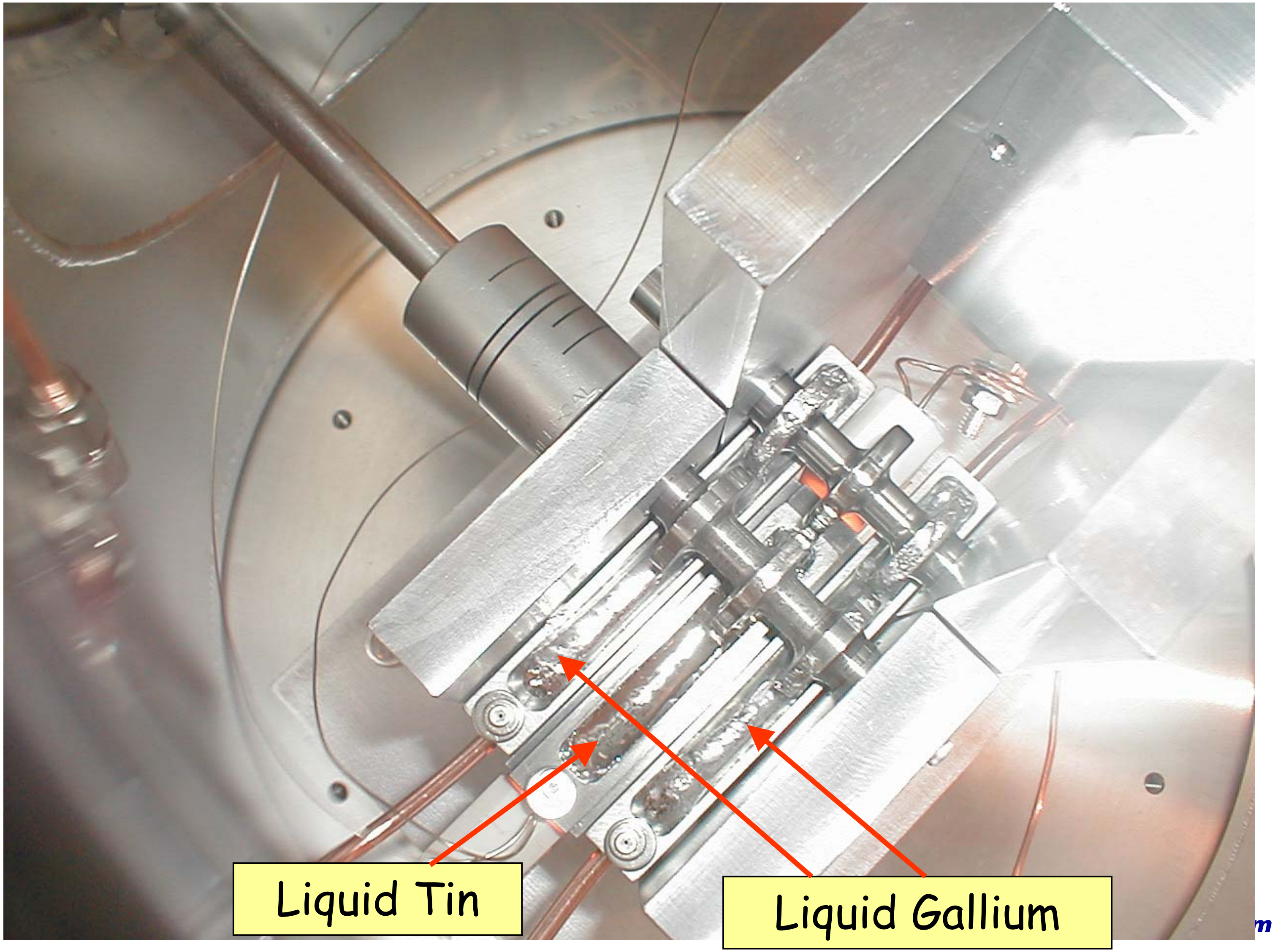




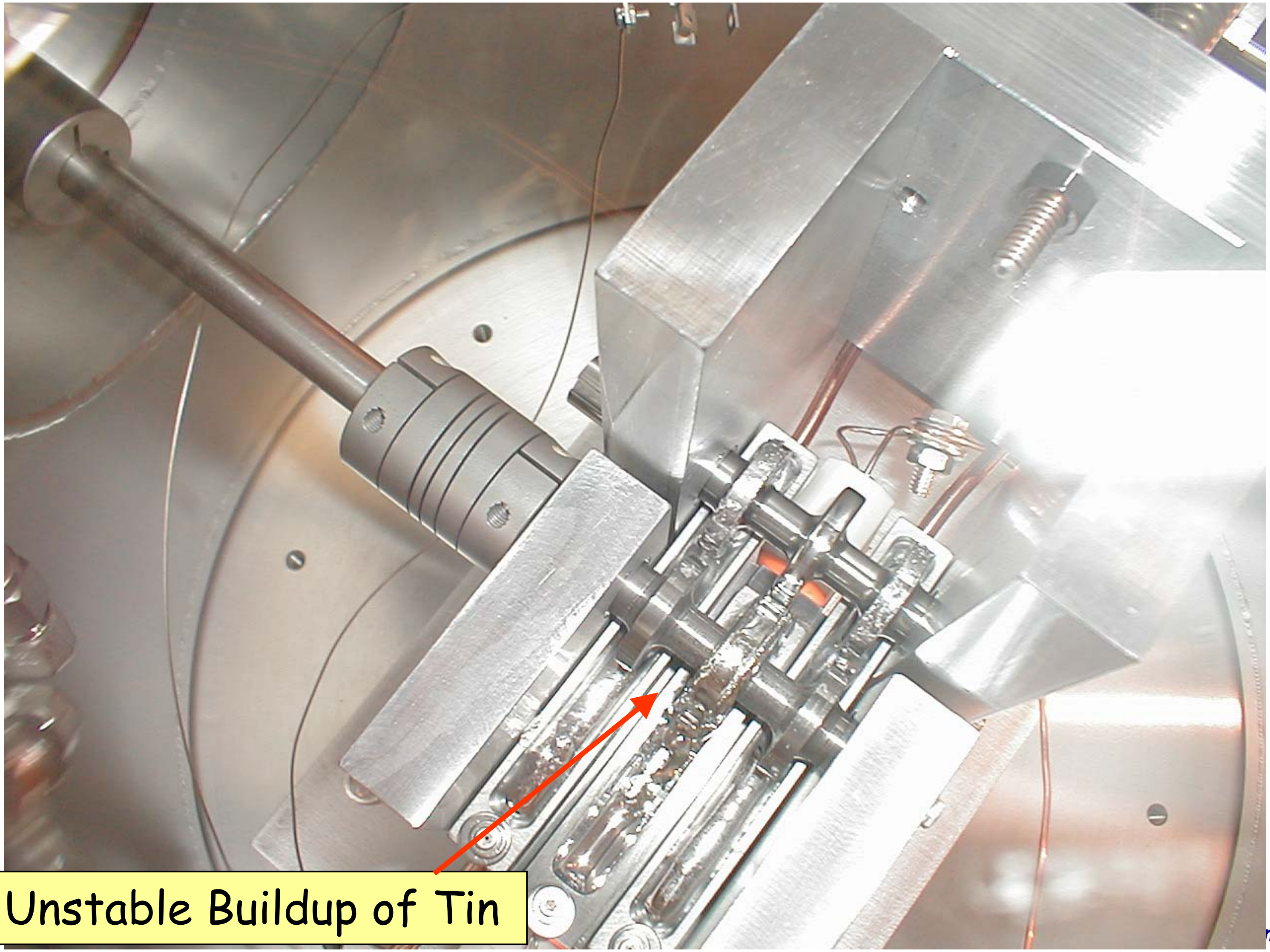


Vacuum vessel & Roller adjustment

Renewable Spoiler Operation



Spoiler with Thick Tin Coating



Renewable Spoiler Status

Test Results

- Niobium roller (?) bearing fails after ~ 1 day operation. Vacuum pressure ~2×10^{-8} Torr.
- With relatively high operating temperature (~300 °C), a thin (visually estimated as a few x100 microns) Tin coating was produced. The surface finish of the coating was similar to that of the finishing roller.
- With relatively low operating temperature (~280 °C), a thick (>1mm) coating of tin was produced. This coating was rolled to match the shape and finish of the finishing roller. This mode of operation was unstable, and within a minute all of the Tin solidified due to the increased heat leak.

Plans

- Replace roller bearings operating on Niobium with 400 series stainless bearings.
- Add a heated block to melt off the thick tin coating

Conclusions

- Prototype rotary consumable spoiler constructed and works well
  - NLC Baseline
  - Relatively minor modifications required for improved performance
- Test system for investigations of more exotic liquid metal based renewable spoilers constructed. Seems do-able, but much more work required.
- R&D on hold as baseline design seems in hand and other projects require attention