Profile Monitor SEM’s for the NuMI Beamline

*Dharmaraj Indurthy, **Sacha E. Kopp**, (Tom Osiecki),*
Zarko Pavlovich, Marek Proga, (Leif Ristroph)
University of Texas – Austin

www.hep.utexas.edu/~kopp/minos/sem/

- Foil Secondary Emission Monitors
  - Data from other laboratories
  - Thermal modelling of foils/wires in the NuMI beam
  - Experience from our May 2003 prototype
- Preliminary Design
  - ‘Bayonet’-style insertion mechanism
  - Review of materials in & out of the vacuum can
  - Tests of motion repeatability

Intro: Fermilab SEM's

- Essential features of Fermilab SEM's:
  - W-Rh wires, Au plated (75 μm)
  - Ceramic circuit board with Pt-Ag solder pads for stringing wires
  - No clearing field applied
  - Frame is on all four sides of beam
  - Frame swings in-out like a door
  - SEM aging observed (signal decreased by 37% by end of KTeV run).
  - Each plane (*X* and *Y*) Causes beam loss of order 6E-5 if have 1mm pitch
  - Wish to reduce device size along beam direction


courtesy Gianni Tassotto

Building on Past Experience …

While our requirements are different from SEM's ("multiwires") built at FNAL, the various ingredients of the SEM we want to explore are not different from instrumentation currently in use here and at other labs.

With time & budget constraints, we did not want to embark on an R&D effort. Thus, going with reasonably proven design choices was desirable.

Specifically, the proposed conceptual design has borrowed from:

• Active element – 5 μm Ti foils	CERN (G. Ferioli)
• Motion Feedthrough (bellows)	LANL (D. Gilpatrick), *also* MDC, Huntington catalogs
• Feedback – Schaevitz LVDT	FNAL (R. Reilly)
• Stepper Controls, Readback	FNAL (A. Legan)

With some modification, the design presented here might be of general utility.

Candidate SEM Materials

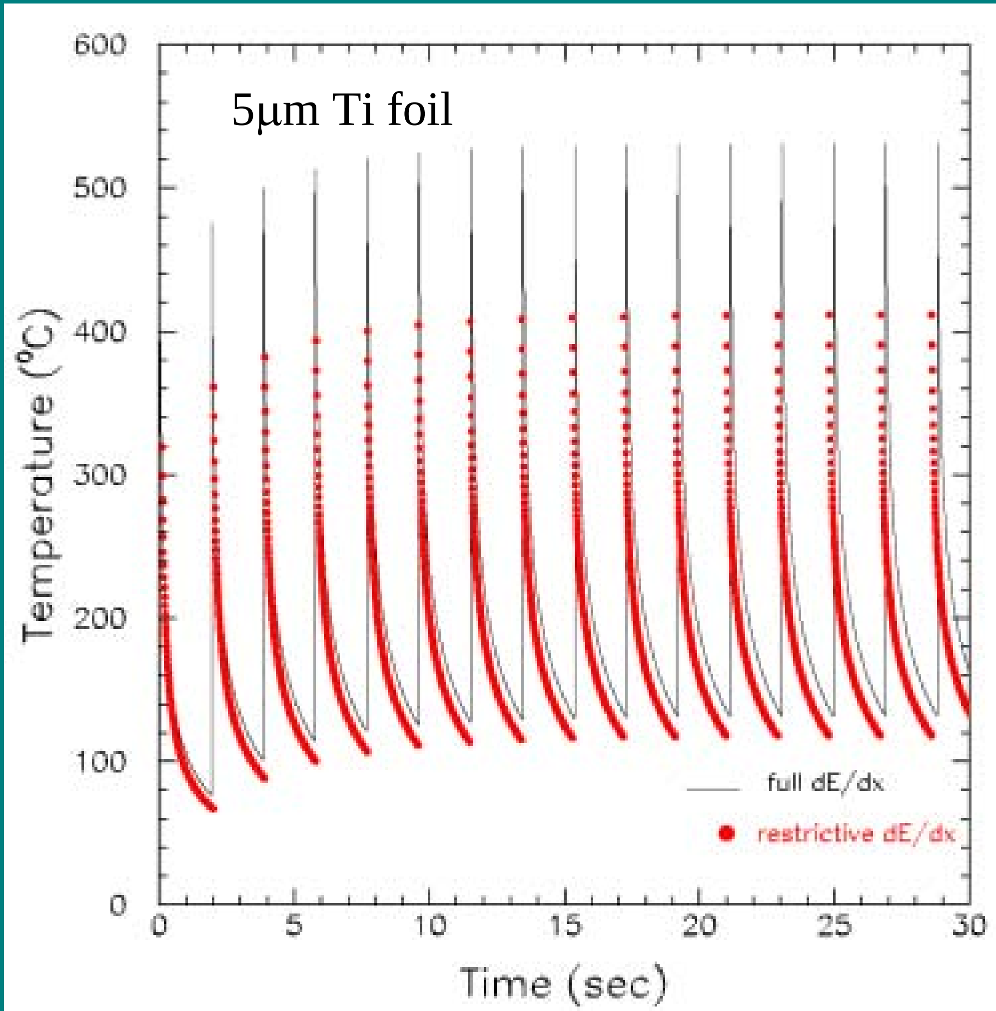
	Z	X_0 (cm)	λ_{int} (cm)	SEE (%)	Propose wire/foil	Thickness (μm)	Beam Loss $(10^{-6})^d$	Comments
Be	4	35.3	40.6	?	foil	25	12	SEE unknown; foils <0.001” difficult to procure; biological hazard
C	6	18.8	38.1	2-2.5	Wire	33	2.7	Used at LANL, SLAC (wire scanner); very fragile mechanically
Al	13	8.9	39.3	~7	Foil	5	2.5	SEE ages badly in beam (G. Ferioli)
Ti	22	3.6	27.5	3.5	Foil	5	3.6	Excellent longevity to 10^{20} dose (Ferioli)
Ni	28	1.46	~15[a]	3-5?	Foil	10	13	Ages in beam [16]
Ag	47	0.87	~9[b]	~6	Foil	5	~10	Data from [11], but requires great care because oxidation will degrade signal.
W	74	0.35	9.6	4	Wire	75	60	SEE is for Au-plated [15]. Degrades in beam. Experience of wire breakage if < 75μm?
Au	79	0.30	8.8[c]	~7	Foil	10	22	Does not oxidize, but does adsorb CO [11]; signal loss observed [13]

[a] Value for Cu (Z=29, ρ=8.9g/cc)
[b] Scaled from λ_{int}(Cu) using $\lambda^{-1} \propto A^{0.77}$
[c] Value for Pt (Z=78, ρ=21.5g/cc)

[d] Beam loss calculated from λ_{int} assuming σ_{beam}=1mm, 1mm pitch profile monitor, and 0.2mm wide strips for foil detectors.

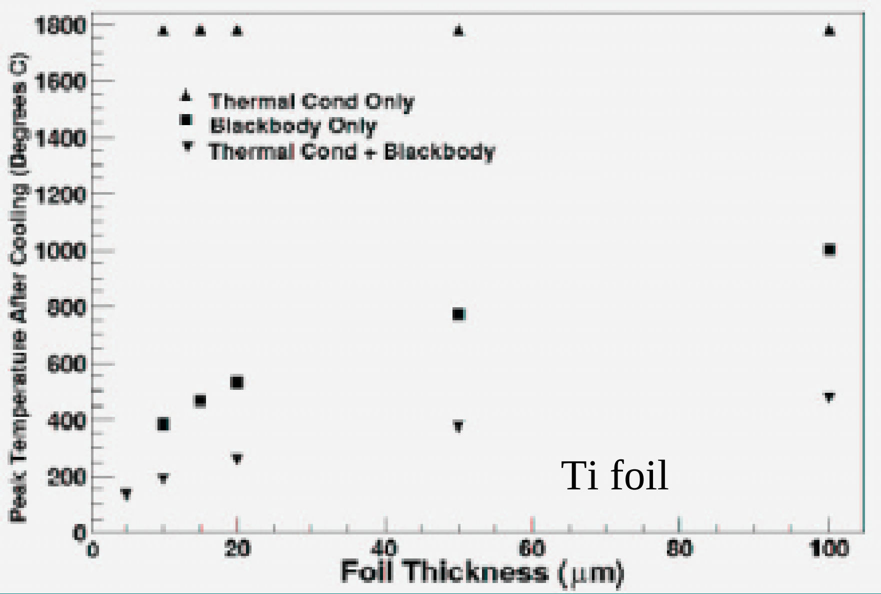
Foil/Wire Heating
(see NuMI-B-929)

- Wire heating grows with ***volume***
  - For round wire:
    - Wider wire intercepts more beam -- goes like ~ r
    - dE/dx dumped into wire grows – goes like ~ r
  - For flat foil
    - Wide foil intercepts more beam – goes like width
    - dE/dx dumped in goes like thickness t
- Blackbody cooling grows with ***surface area***
  - Gas cooling assumed nil
  - Blackbody radiation goes like surface area ~ r
    (Emissivity of bare Aluminum is poor ~ 0.1)
- Conduction to the ends grows with ***cross-sectional area***
  - But note many materials have poor thermal conduction (in W/cm-°C)
  - Don't expect this to be dominant heat loss.
- Suggests that surface to volume ratio is critical
  - Wire surface/volume ~ $2/r$
  - Foil surface/volume ~ $1/t$
- Crude thermal model of center foil/wire
  - σ ~ 1mm beam at 4×10^{13}/pulse every 1.9 sec
  - Assumed ε, k_{cond}, C_p, dE/dx, ρ from CRC, PDG
  - Also tested if *restrictive* energy loss important (loss of δ rays out back of device – more imporatant for thin foils).



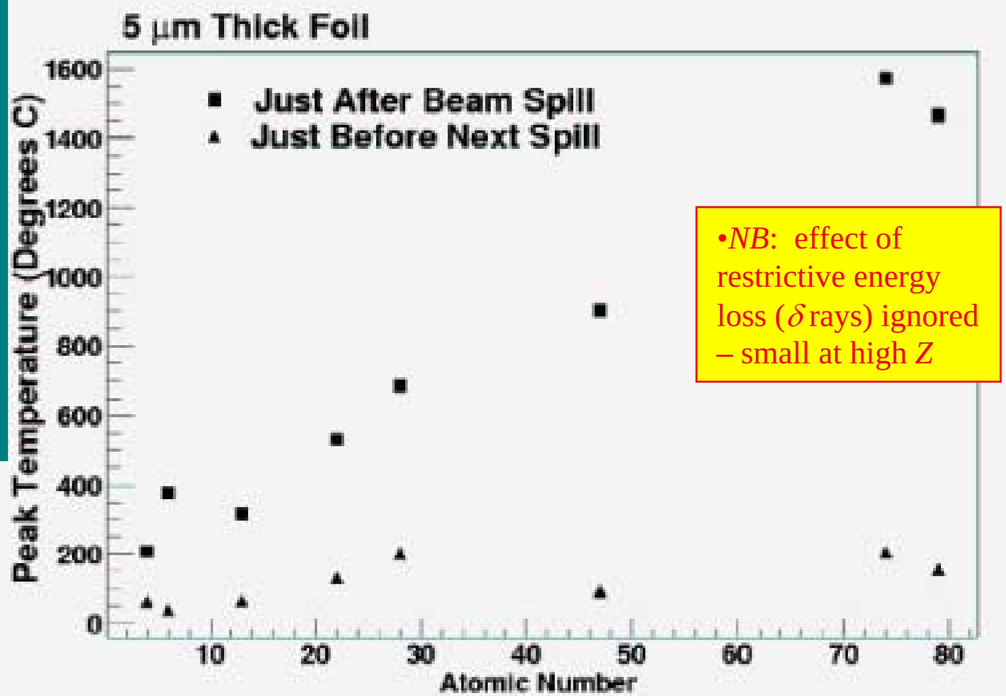
Foil *vs.* Wire?

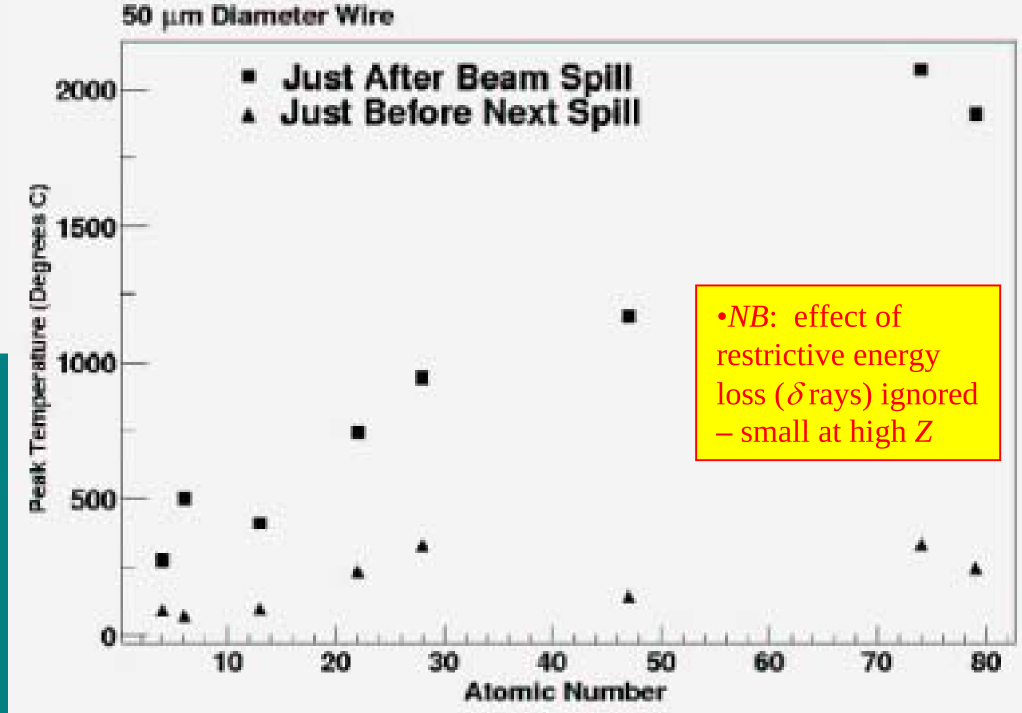
•As a check of these assertions, tried 'turning off' either blackbody radiation or thermal conduction through foil/wire



•Looked at all materials, modelling with correct thermal and bulk properties

- •C and Al ideal,
- •Ti is not far behind.





Beam-Induced Sag for Wire SEM's

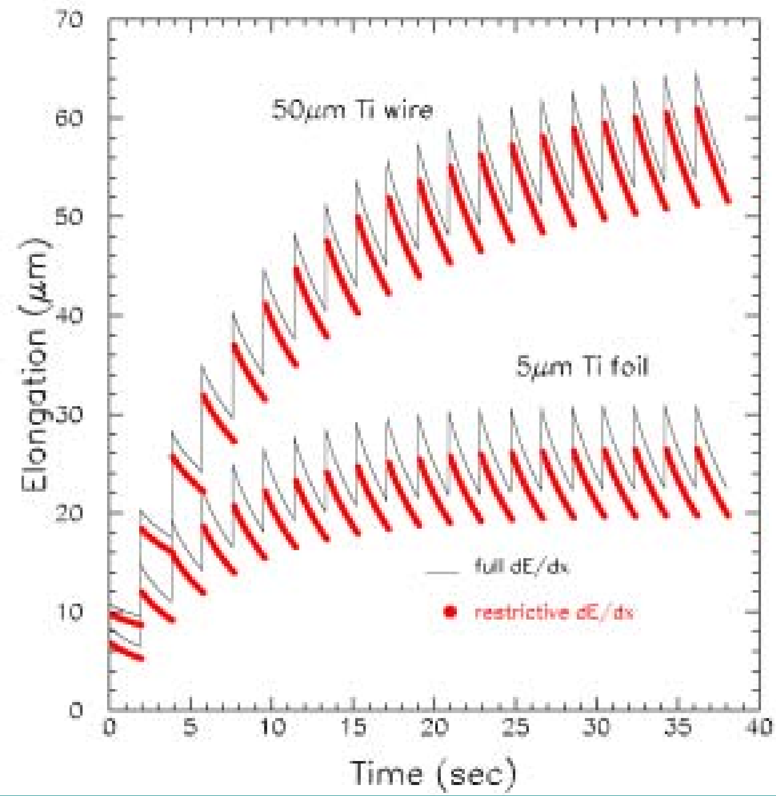
Material	Z	CTE ($10^6/°C$)[3]	Yield Strength [4] (MPa)	(grams)[a]	Young's Mod. (GPa)[4, 5]	Fractional Elongation at Yield Str.($\times10^{-3}$)	Fractional Elongation from Beam Heating ($\times10^{-3}$)[a,b]
Beryllium	4	12	240[d]	48	287	0.84	0.28
Carbon	6	0.6-4.3	469[c]	40-45[c]	40.3[c]	11.6	< 0.083
Aluminum	13	25	10-35[d]	2-7	70.3	0.14-0.50	0.68
Titanium	22	8.5	140-250[e]	28-50	115.7	1.21-2.16	0.27
Nickel	28	13	1580[d]	316	199.5	7.9	1.1
Silver	47	19	-	-	83	-	-
Tungsten	74	4.5	550[d]	110	411	1.34	0.63
Gold	79	14.2	205[f]	41	82.7	2.48	1.46

[a] For a 50μm diameter wire
[b] Taken from data in Figure 13
[c] Our measurements of 33μm diameter C monofilaments
[d] soft
[e] annealed
[f] hardened

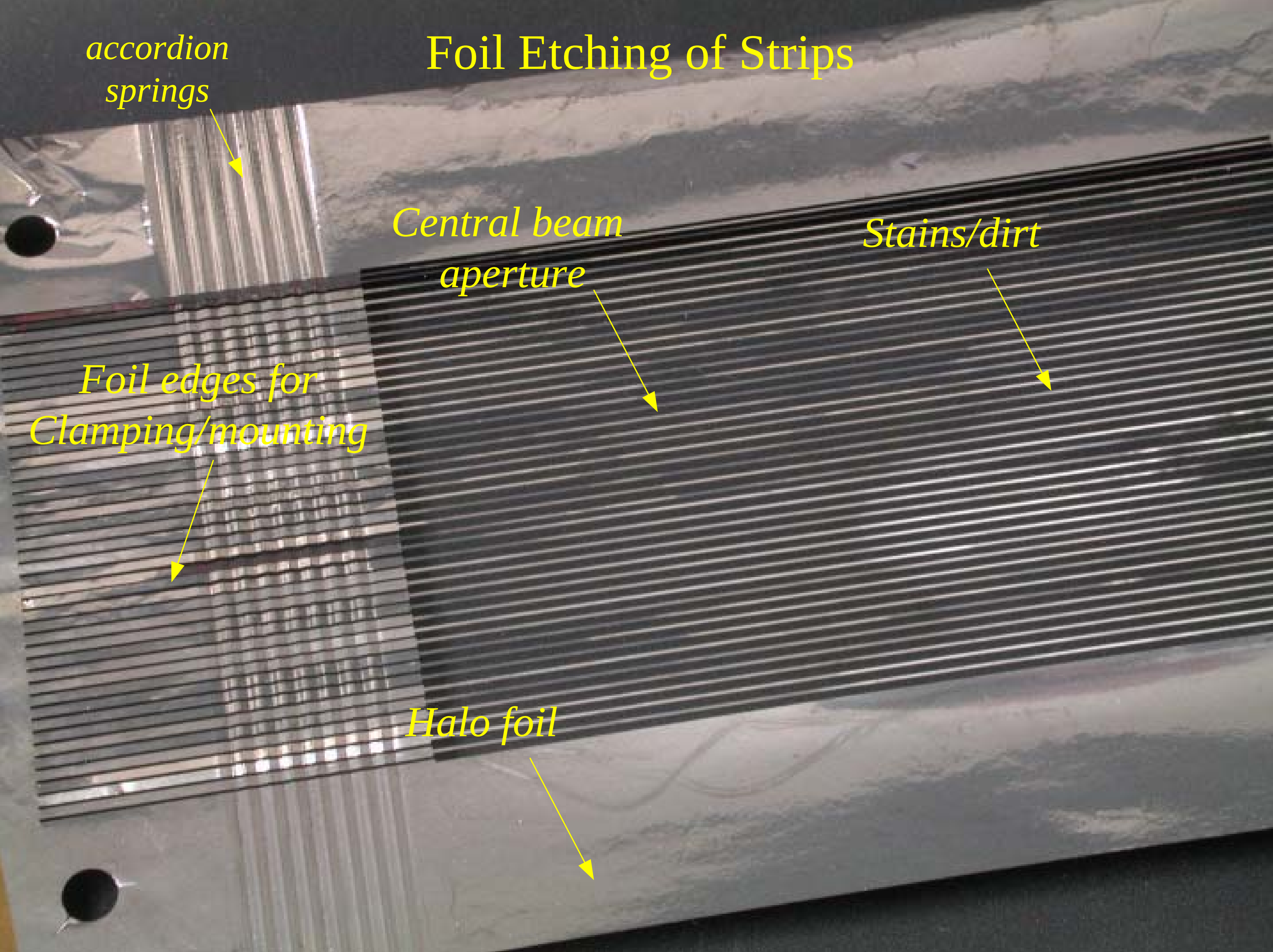
- Gravitational sag δy improves with greater *stress* (=T/A)

$$\delta y = g\rho AL^2/T$$

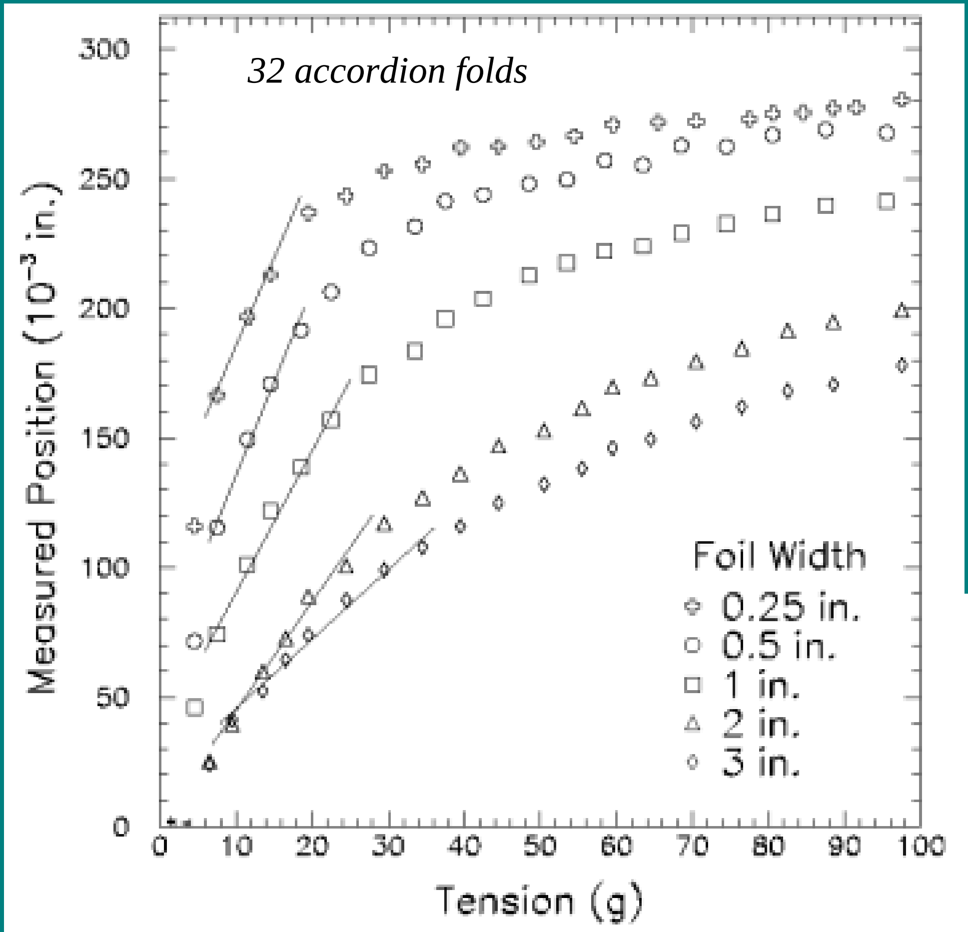
  (T=tension, L=length, A=cross sect. area, ρ=density, g=9.8m/s^2)
- Elongation from beam heating is linearly worsens gravitational sag.
- Yield stress is where wire breaks. Elastic limit typically lower. For sake of discussion, assume can tension wire to yield stress.
- Compare tension elongation to beam heating elongation.
- Only Carbon is an attractive material for wire SEM



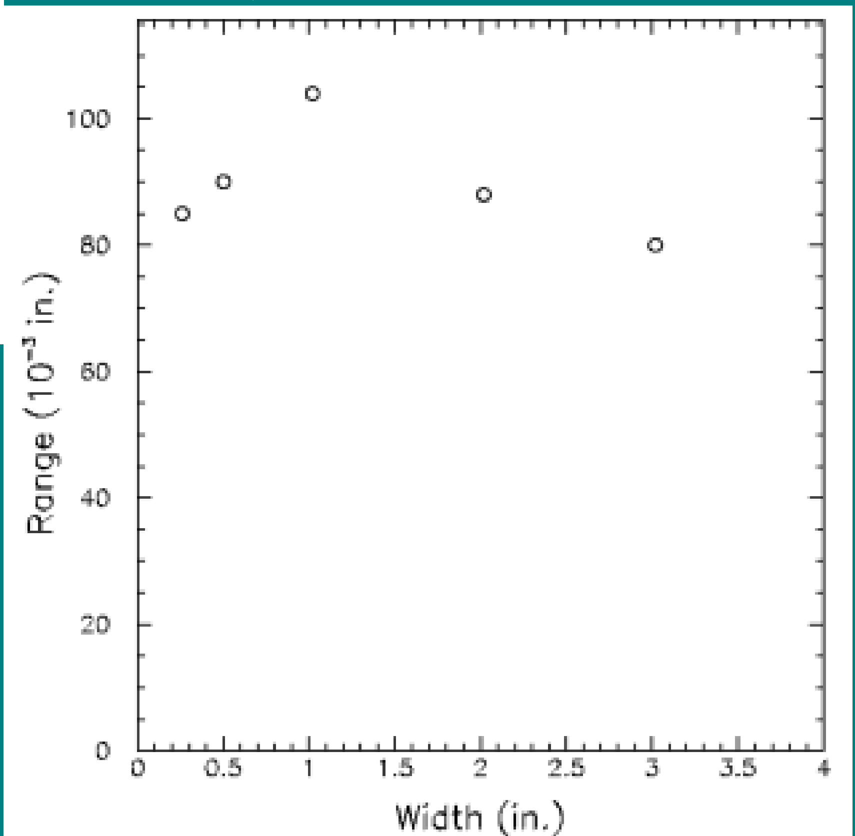
Foil Etching of Strips



Accordion Spring Tension



- Tests performed of elasticity of accordion springs (measure elongation *vs* appl tension)
- *NB:* large systematic as foil "straightens out" other (non-accordion) wrinkles
- Observe near-elastic region and then region of inelastic deformation of accordions (don't return to original length when tension released).

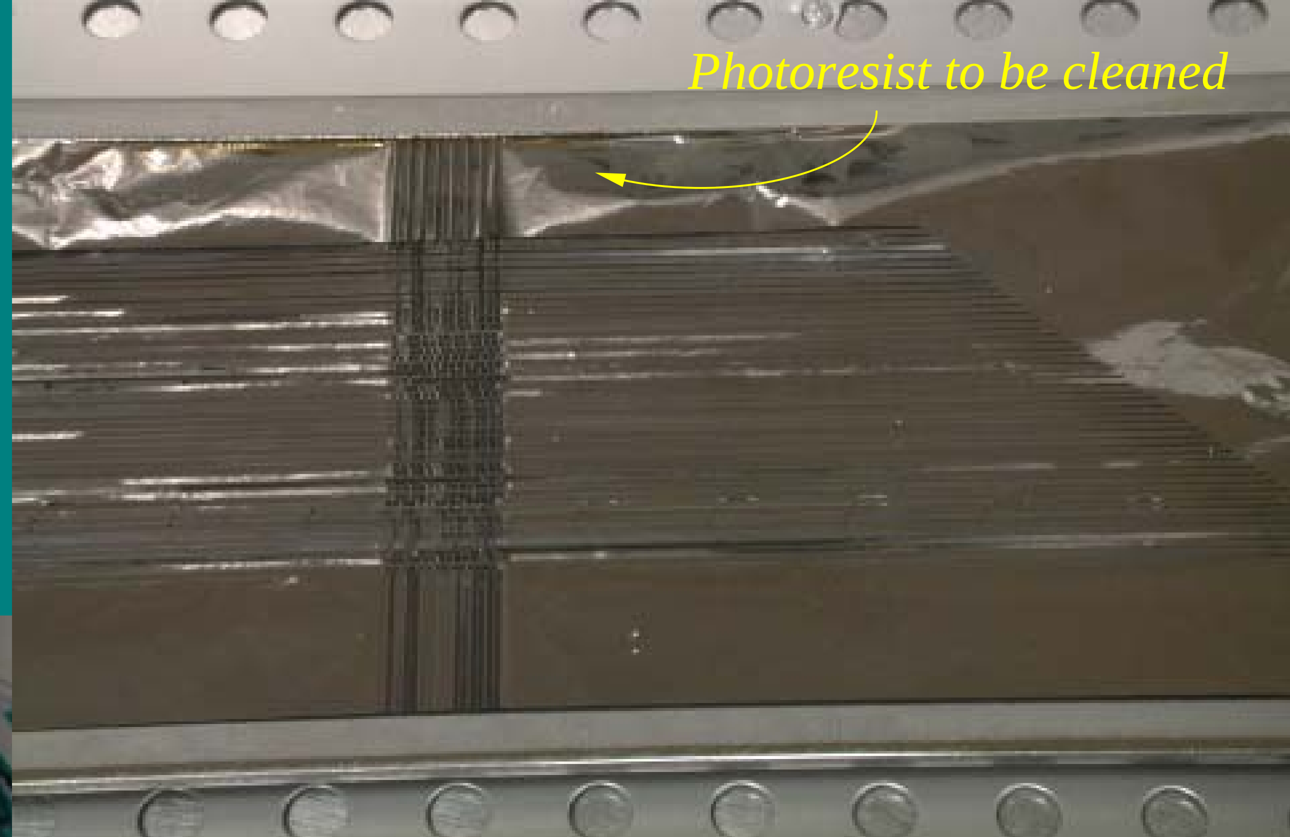


- Max elastic tension scales with foil width: 1mm width ⇒ achieve 0.7g
- Max elongation at elastic tension limit does not scale (?) with foil width
  - may tension 32 folds by ~ 2.0mm
  - beam heating causes ~ 2.5µm

BEAM HEATING → ~1% TENSION LOSS

Foil Cleaning

- •Sulfuric acid effective in removing chem-etching photo-resistive coating
- •Cleaning technique improved (no burning!)
- •Found new aqueous-based photo-resitive layer that is easier to clean off.

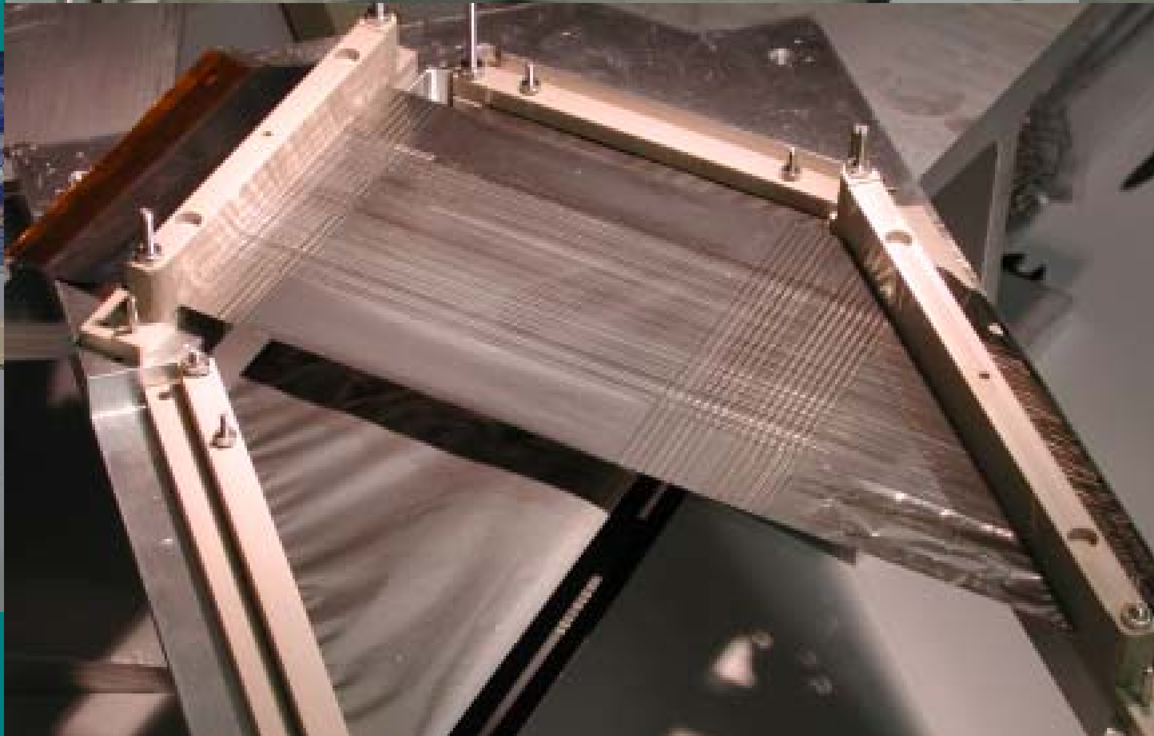


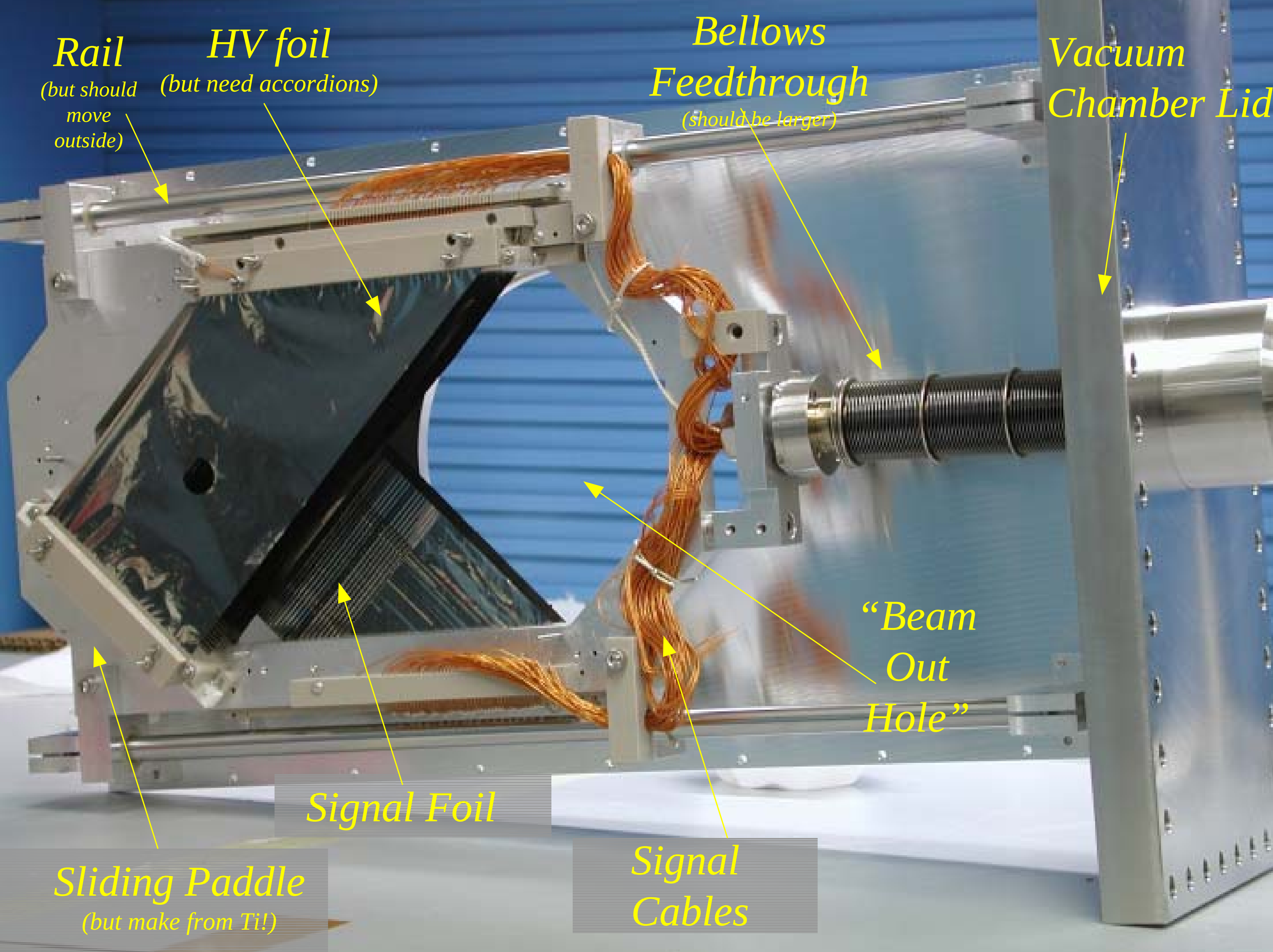
Rinsing acid off in H_2O bath

Dirty acid after cleaning

Foil Mounting

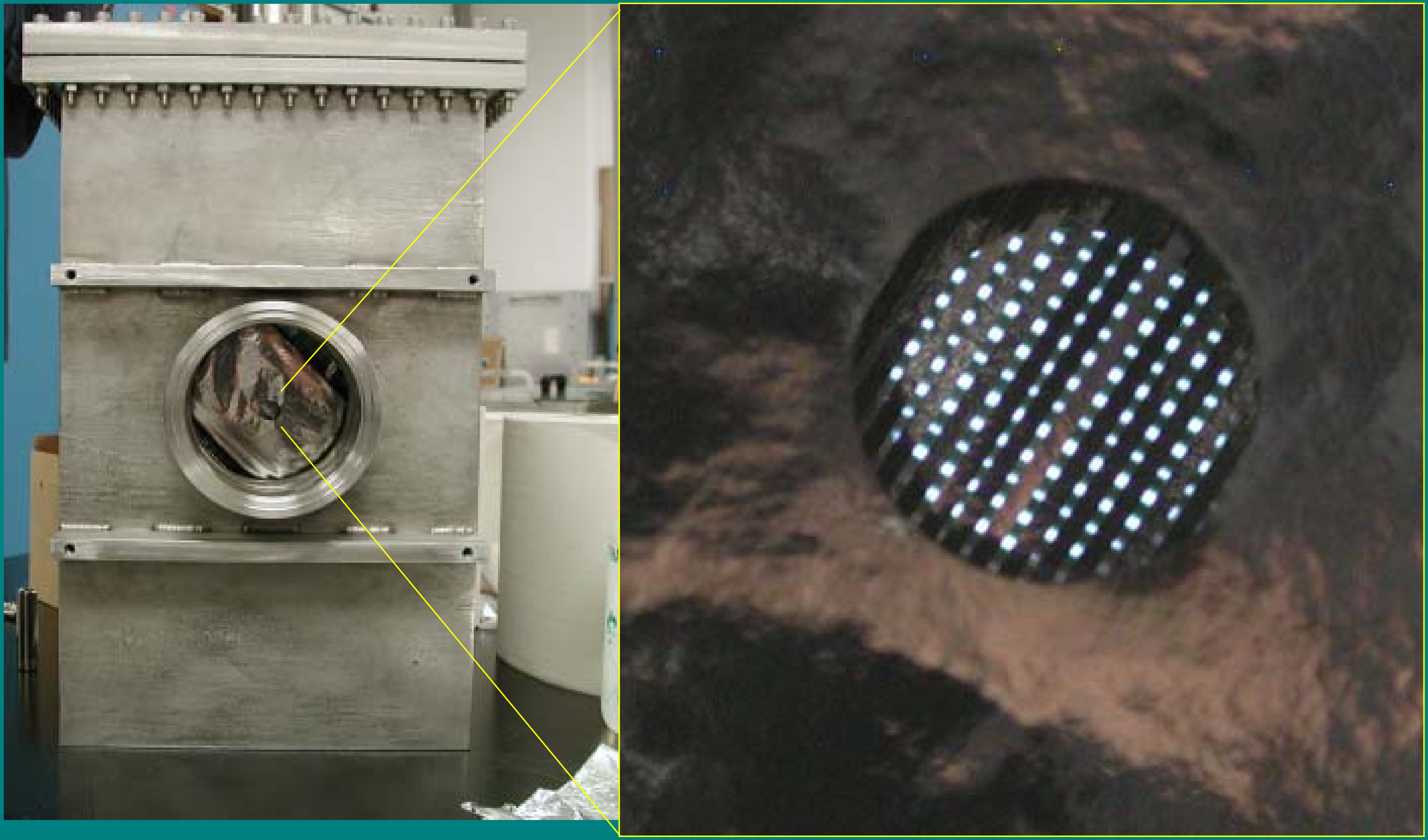
- Epoxy to comb using Epo-Tek H27D (*cf* UT-Austin condensed matter physicists).
- 10^{-12} Torr vapor pressure
- Cures at 200ºC, bakeable to 350ºC
- Note handling affected a couple strips (1mm pitch not maintained)




Rail
(but should move outside)
HV foil
(but need accordions)
Bellows Feedthrough
(should be larger)
Vacuum Chamber Lid
"Beam Out Hole"
Signal Foil
Sliding Paddle
(but make from Ti!)
Signal Cables

Signal Connections

Assembled SEM Chamber



Motion of Foil Paddle

- Actuate paddle in/out of beam
- Driven by DC stepper motor
- Must repeat 'in' position within 50μm.
- We achieve this via precise limit switch
- Confirm 'in' position using LVDT

LVDT

- Schaevitz Sensors, Inc.
- "High radiation" series
- ~6mm full stroke, 1mV/μm out

Bellows

- Standard Bellows Corp.
- 20K cycle lifetime, 13cm stroke
- 6.3cm ID, effective area ~45cm^2.

Linear Stage

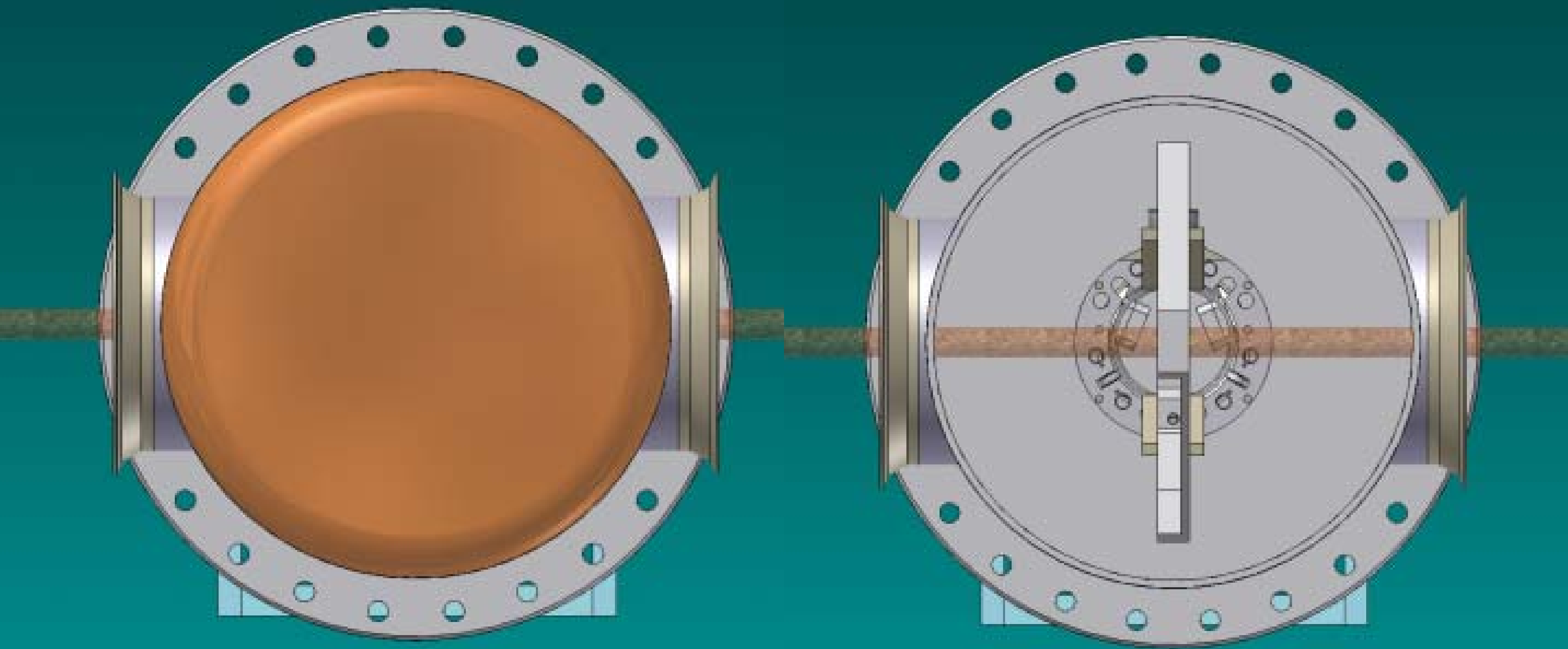
- Crossed roller bearing, 20cm travel
- Max 100kg axial load, 54 N-m torque
- Sold in PIC catalogue

Limit Switch

(end of travel)

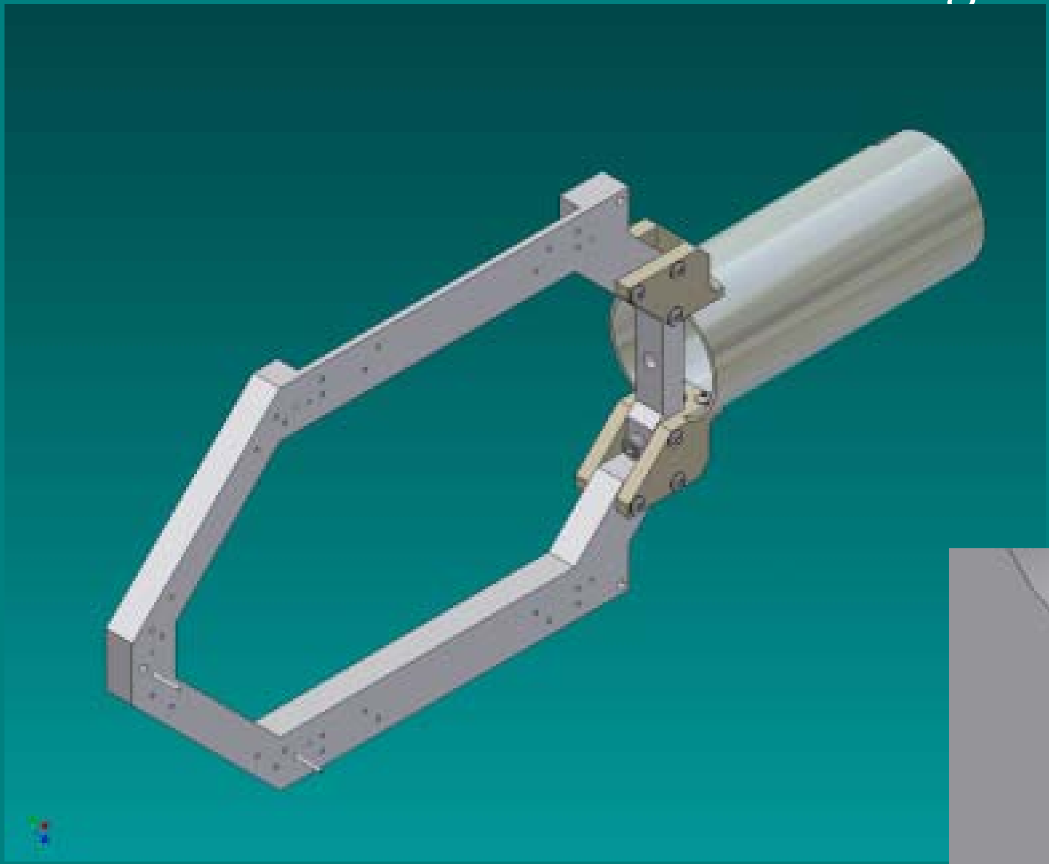
- Manufactured by Honeywell
- Ceramic insulators
- Used in Tevatron scraper system

End-on View

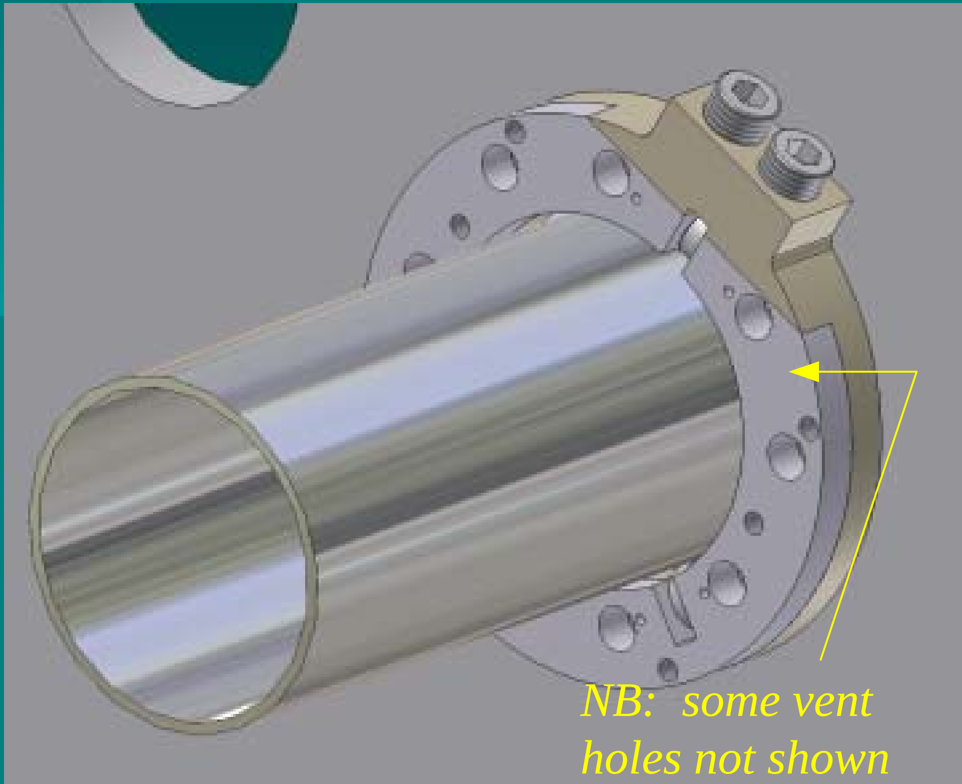


- Flange-to-flange distance is 23.5cm (less than required 26cm)
- Cylindrical chamber fabricated from 8” OD pipe, 8” vacuum endcap
- Upper lid is now 10” OD conflat (change from wire seal in prototype)
- Cylindrical design sacrifices longitudinal space along beam for ease of manufacture.
- Total mass to lift: <32kg.

Paddle Mounting to Manipulator



- Paddle to be bolted to the 5cm OD shaft
  - Cables transmitted up hollow shaft
  - Bolt slop used to help align paddle on jig
- Cantilevered by ~22cm from the support at the conflats at “connector box”
  - Deflection of tube is <25μm due to paddle weight
  - Can keep paddle weight <2kg including clamps if make from Ti



- Worried about vibration of paddle down in tunnel
- Add roller bearing assembly inside vacuum chamber lid
  - Two stiffly mounted rollers
  - Roller at top is spring-loaded to contact shaft
- Now cantilever distance is <3cm when paddle is drawn up toward lid (“in beam position”)

Repeatability Test

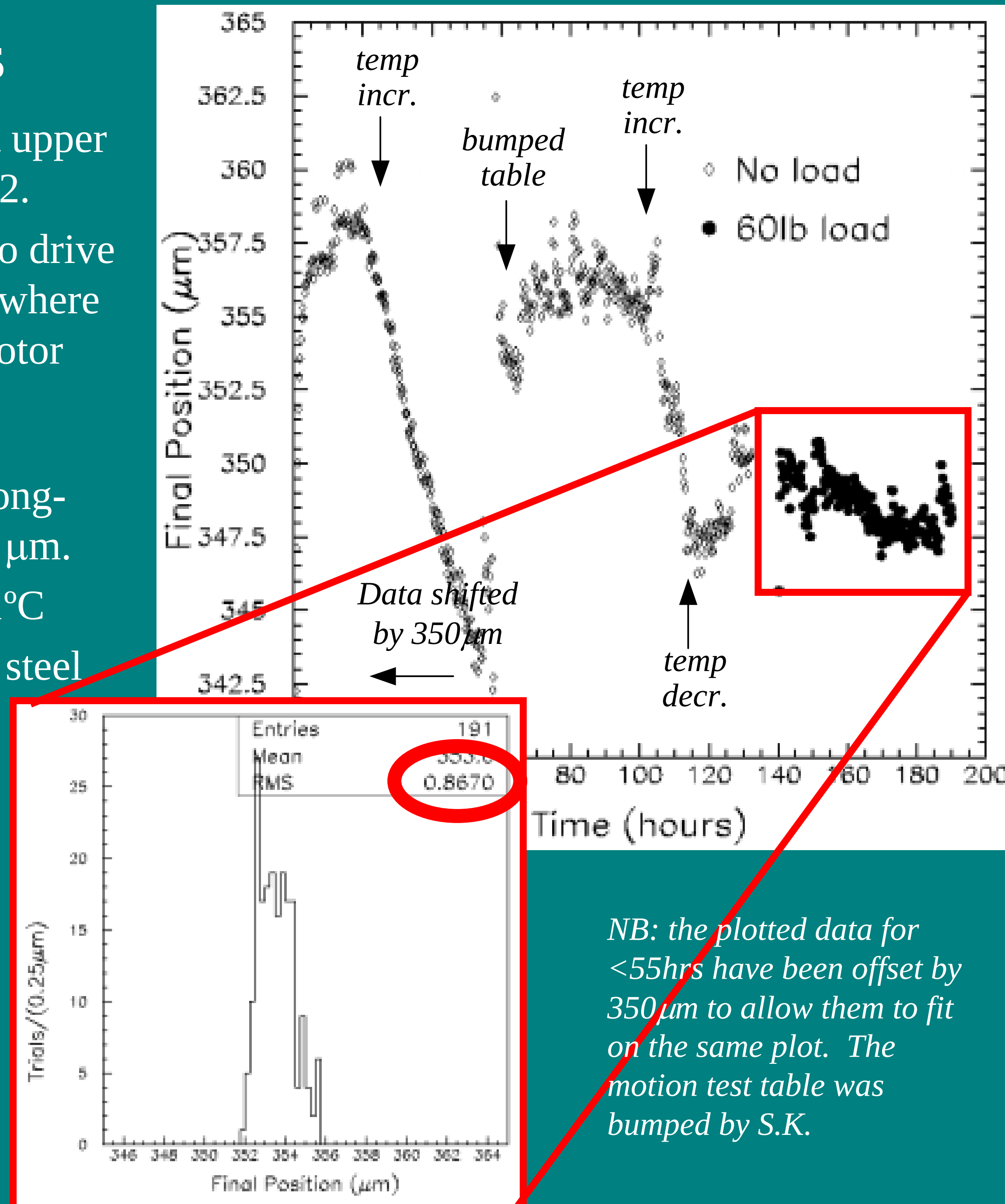
- Cycle motion up and down until motor cuts off at the limit switch
- Paddle weight simulated at end of shaft
- Vacuum suction simulated by Pb brick over a pulley

- LVDT measures position along axial motion (cross-check with dial indicator)
- Additional dial indicator monitors lateral position of shaft at fully-inserted or fully-retracted position.

Motion Test Results

- We found better repeatability at upper switch than the lower by factor 2.
- We conjectured that it's better to drive the system to the upper switch, where gravity + vacuum helps slow motor down after switch engages.

- Observed ~1μm accuracy, but long-term drift in system of order 10 μm.
- Temperature in lab varies by ~1°C
- Motion manipulator is stainless steel (CTE~12×10^{-6}/°C), but stand is aluminum (CTE~25×10^{-6}/°C)
- Differential expansion of materials ⇒ shifts ~8μm/°C
- NuMI SEM will be all stainless and Ti (ΔCTE~4×10^{-6}/°C), so effect there may be smaller, but at the ±10μm level things will move?



NB: the plotted data for <55hrs have been offset by 350μm to allow them to fit on the same plot. The motion test table was bumped by S.K.

Summary

- Foil SEM design borrows from demonstrated techniques employed elsewhere
- Design has solved salient requests made for NuMI beamline
  - Beam loss 7×10^{-6} (*cf* 1.2×10^{-4} current multiwire)
  - Longevity in 120 GeV beam up to $\sim10^{20}$ protons (*cf* 2×10^{18} for W, Au)
  - Accurate (1μm) insertion of foils without interruption of beam
  - Smaller size in beamline direction (23cm, *cf* 41cm current multiwire)
  - Integrates well into FNAL readout, controls
- Hopefully simplified design will allow completion for July 1, 2004
- Prototype detector yet to see beam; hope for exposure during MiniBoone re-commissioning this/next week.