Metrology

Kirk Arndt, Purdue University

Greg Derylo, Gordon Gillespie, Jorge Montes, FNAL

Metrology

- Metrology is the science of measurement.
- A core concept in metrology is *metrological traceability,* usually obtained by calibration, to validate the data obtained from measuring equipment.
- Calibration is the process where metrology is applied to measurement equipment and procedures to ensure conformity with a known standard of measurement, usually traceable to a national standards board.

Calibration

- Both metrology and calibration laboratories must isolate the work performed from influences that might affect the work.
- Temperature, humidity, vibration, electrical power supply, radiated energy and other influences are often controlled.
- Metrology and calibration work is always accompanied by documentation.

Dimensional Metrology

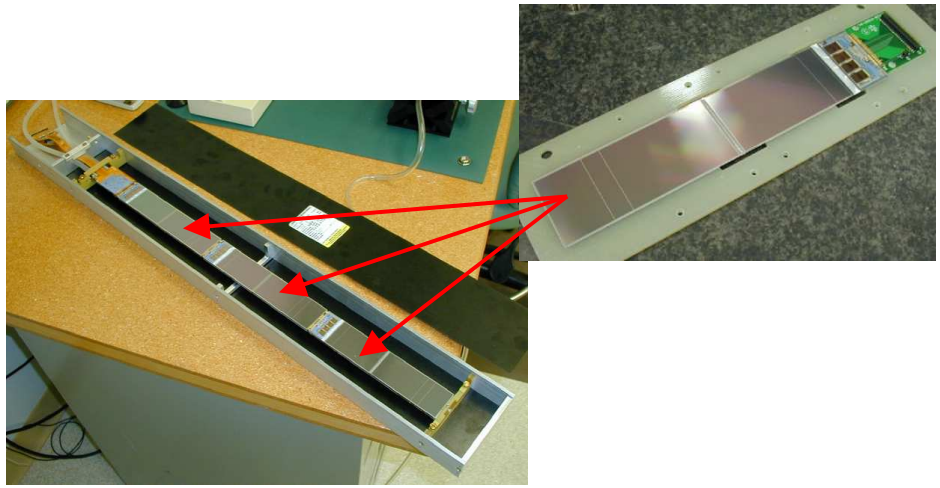
- Modern measurement equipment includes hand tools (i.e. caliper and micrometer), CMMs (Coordinate-Measurement Machine), machine vision systems, laser trackers, and optical comparators.
- A CMM is based on CNC technology to automate measurement of Cartesian coordinates using a touch probe, contact scanning probe, or non-contact sensor.
- Data is collected and compared to a print, illustrating crucial features. Prints can be hand drawn or automatically generated by a CAD model.

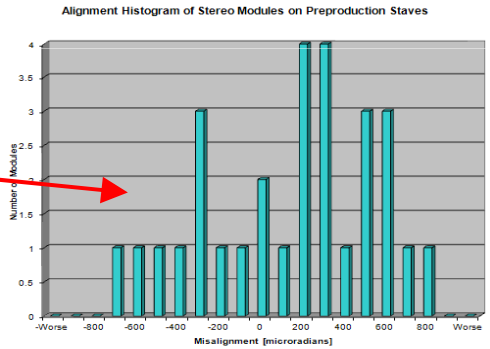
CMM Usage

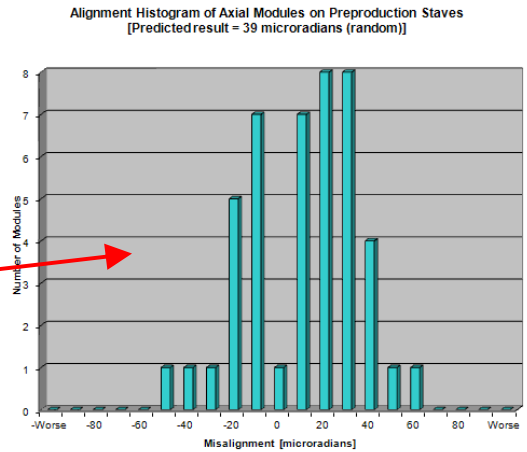
- CMMs can be used with different purposes:
  - Measure the geometry of a completed detector component or assembly. The data can then be used to create a more accurate mathematical model of positions within the detector.
  - Use the CMM to actively aid in component construction, using its measurement accuracy to place parts precisely during fabrication. Example follows:

Actively Using CMMs During Fab.

- CDF Run2B Stave Example:
  - Stave has 3 axial modules on one face and 3 small-angle stereo modules on the other
  - STEREO modules are not in the trigger. Their position must be measured but since fast math is not needed they do not need to be accurately aligned
    - Position set mechanically (edges against pins, pins engage holes, etc.)
    - Angular misalignment abt. +/- 500 microradians
  - AXIAL modules are in the trigger so they must be accurately aligned in order to accommodate fast math decisions
    - CMM used to guide module positions during installation onto a stave
    - Angular misalignment abt. +/- 40 microradians



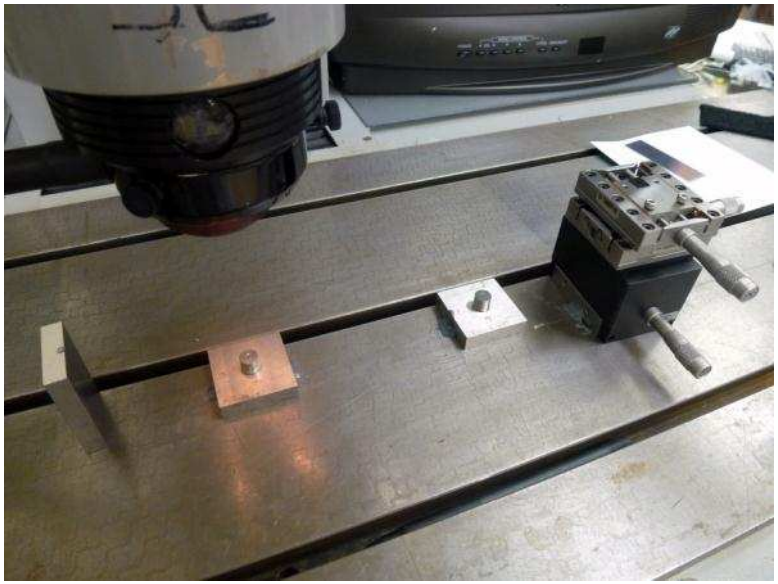




Zeiss CMM with optical probe

- Demonstrate:
  - Building part coordinate system, compare with machine coordinates
  - Aligning “IC chip” to “silicon sensor” using manipulator

Zeiss CMM with optical probe

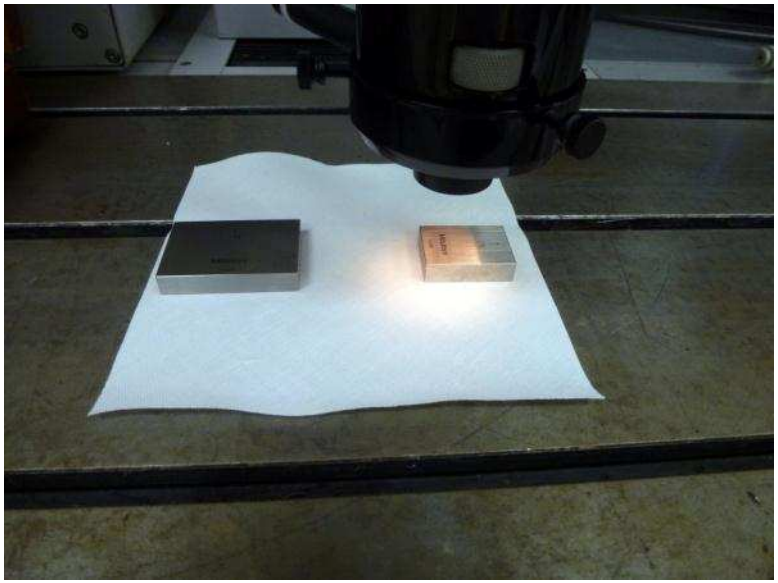


- Demonstrate:
  - Use of joystick to manually acquire locations of fiducial targets
  - Use of program control to move to desired locations
  - Use of glass optical target centered on metal post to relate non-contact to touch probe measurements

OMIS II Vision Measurement

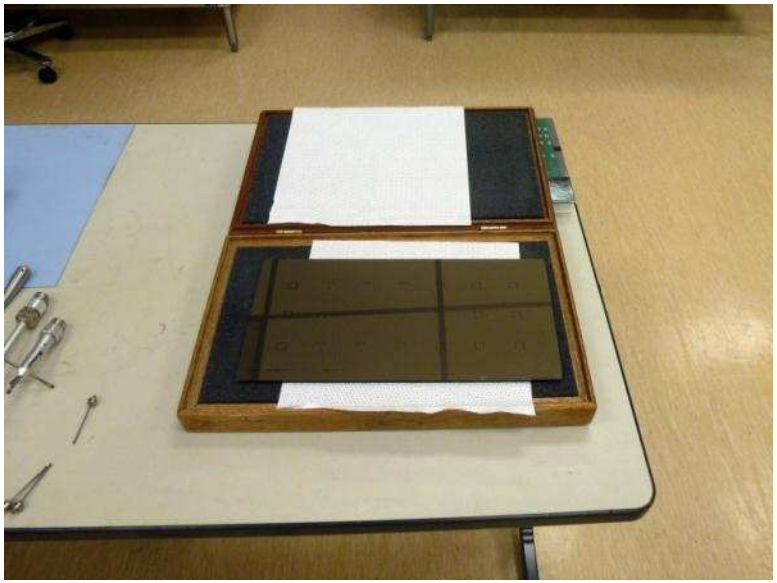
- Example of silicon sensor fiducials in a finished (D0 strips endcap) module
- Use of glass scale to check linear measuring accuracy

Zeiss CMM with optical probe



- Students perform hands-on measurement of precision gauge blocks using joystick control
- Compare measured length with certified length of gauge blocks (grade 2 tolerance = +/-1 micron on deviation of measured central length)

CMM Calibration Equipment

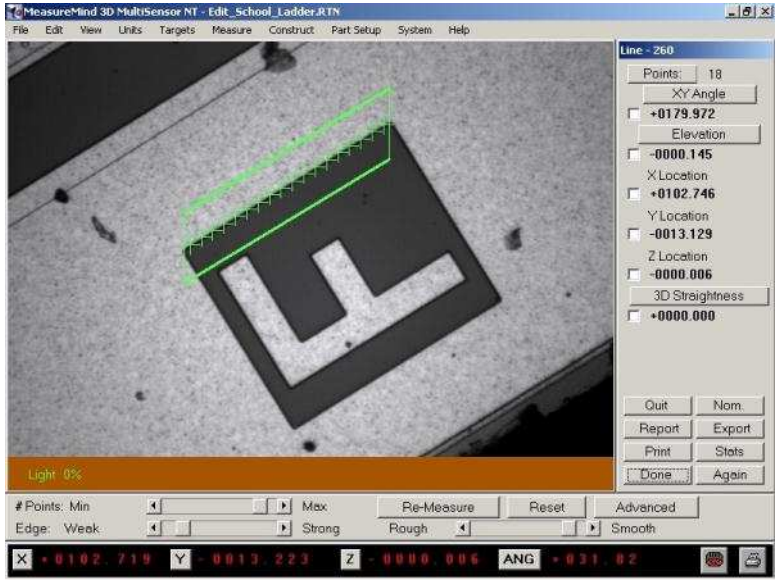


- Explain:
  - use of large glass scale to periodically check accuracy of 2-D optical measurements on the CMMs
  - use of ball bar for volumetric and traceable evaluation of CMM measurement errors using a touch probe
  - use of master ball for calibration of probe stylus diameter

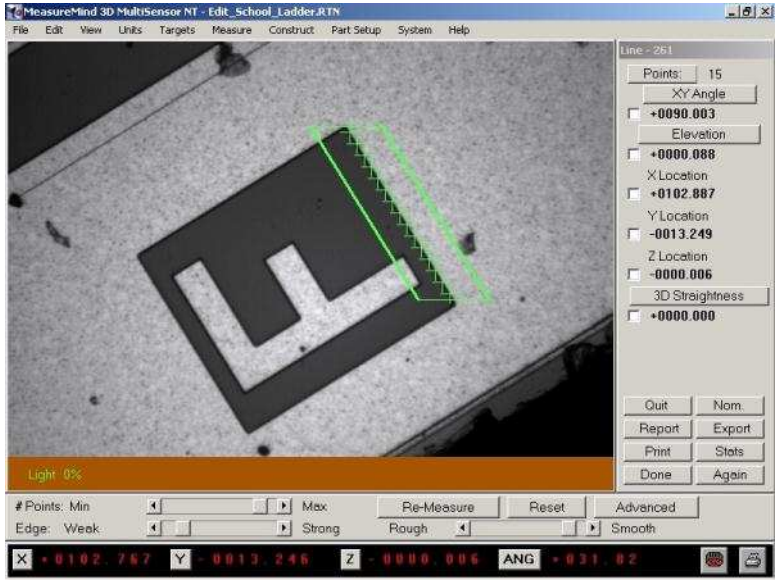
OGP measurement of CLEO III ladder

- Demonstrate:
  - Constructing part coordinate system using fiducial markings at ends of sensor ladder
  - Semi-automatic acquisition of X- and Y-axis measurement points using pattern recognition and Z-axis measurements using auto-focus

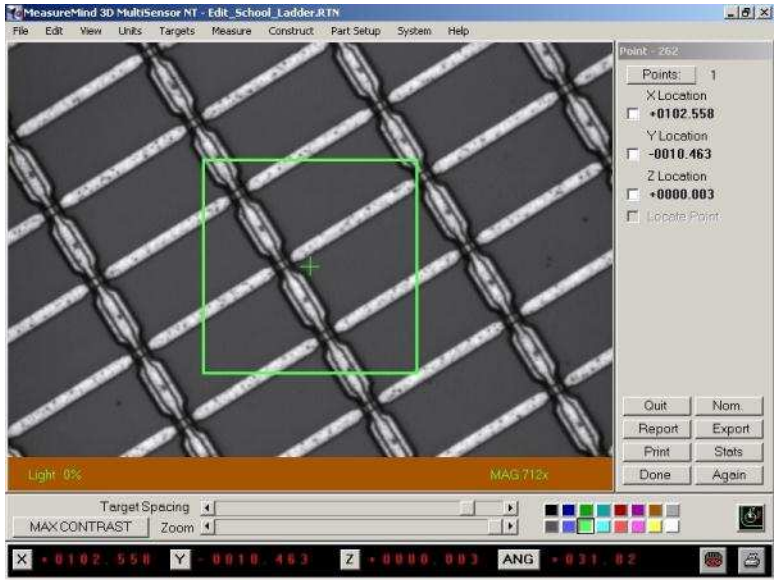
Pattern recognition



- Demonstrate programming to automatically acquire X- and Y-axis measurement points = intersection of fiducial edges found using pattern recognition



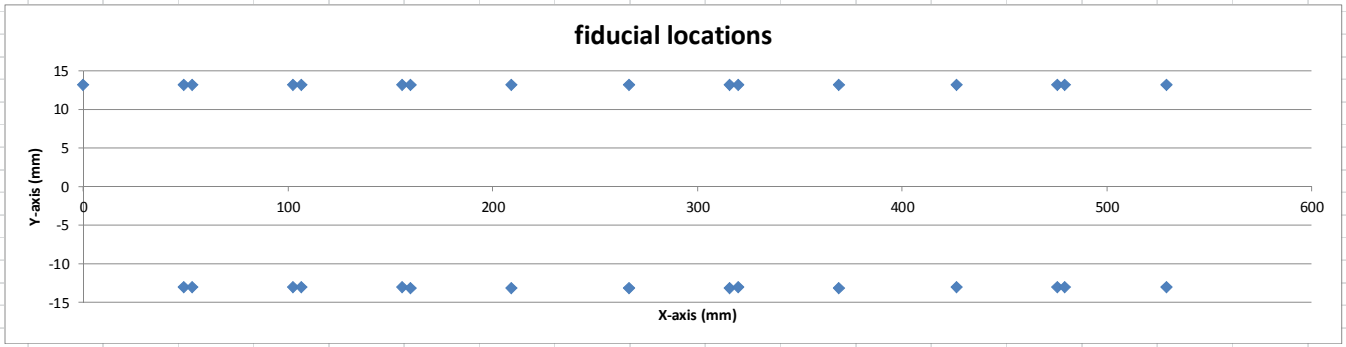
Auto focusing



- Demonstrate automatic Z-axis measurements using auto-focus function
- Program automatically acquires 60 X-Y-Z measurement points along ladder (6 points per sensor x 10 sensors), saved in a text file

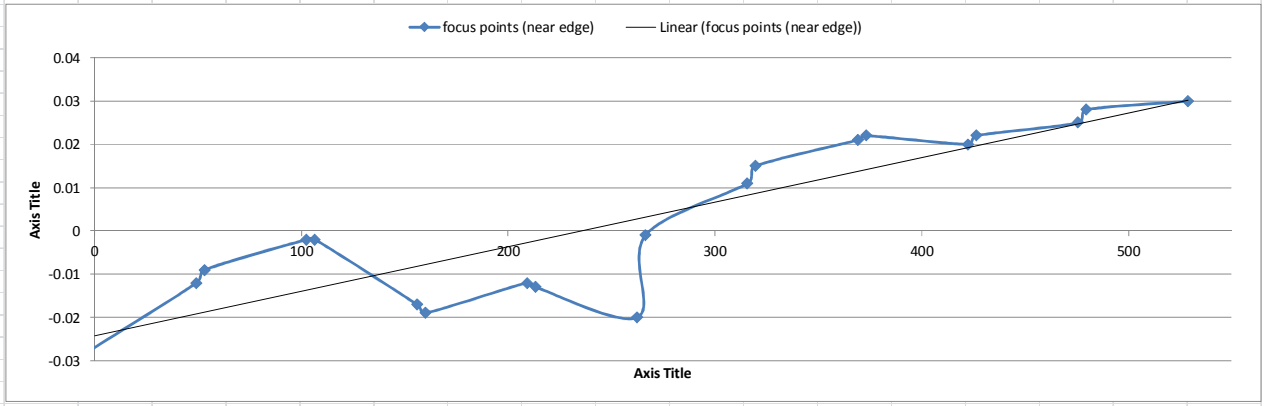
Data and analysis

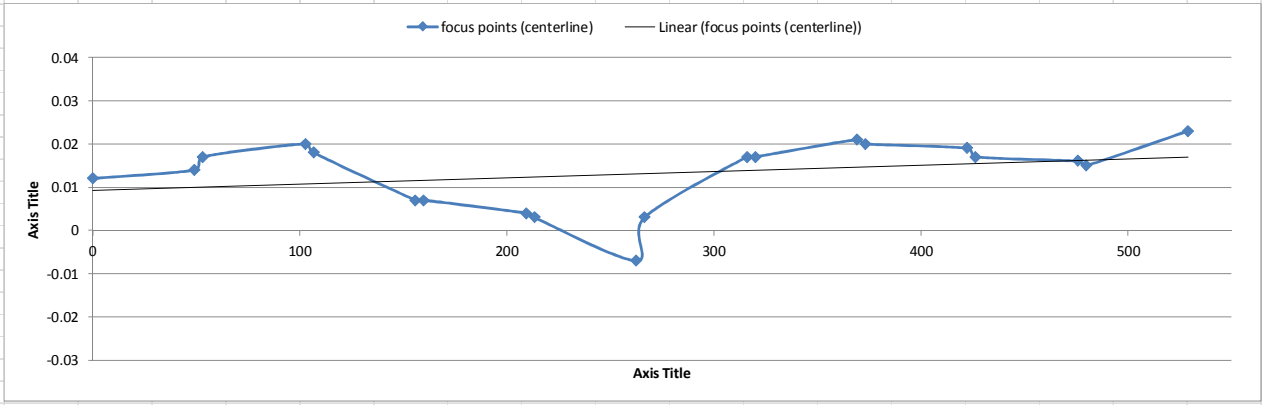
Edit_School_Ladder.RTN02:13:1213:45:11				
S1-1	X	-0.002	Y	-13.128
S1-2	X	0.002	Y	13.128
S1-3	X	49.313	Y	-13.131
S1-4	X	49.315	Y	13.124
S2-1	X	53.288	Y	-13.132
S2-2	X	53.288	Y	13.123
S2-3	X	102.604	Y	-13.131
S2-4	X	102.603	Y	13.122
S3-1	X	106.597	Y	-13.126
S3-2	X	106.599	Y	13.129
S3-3	X	155.911	Y	-13.131
S3-4	X	155.912	Y	13.124
S4-1	X	159.896	Y	-13.138
S4-2	X	159.893	Y	13.118
S4-3	X	209.212	Y	-13.133
S4-4	X	209.208	Y	13.122
S6-1	X	266.485	Y	-13.134
S6-2	X	266.484	Y	13.123
S6-3	X	315.802	Y	-13.133
S6-4	X	315.8	Y	13.122
S7-1	X	319.783	Y	-13.132
S7-2	X	319.782	Y	13.124
S7-3	X	369.098	Y	-13.133
S7-4	X	369.096	Y	13.123
S9-1	X	426.386	Y	-13.13
S9-2	X	426.383	Y	13.125
S9-3	X	475.7	Y	-13.125
S9-4	X	475.697	Y	13.13
S10-1	X	479.677	Y	-13.132
S10-2	X	479.677	Y	13.124
S10-3	X	528.987	Y	-13.128
S10-4	X	528.987	Y	13.128

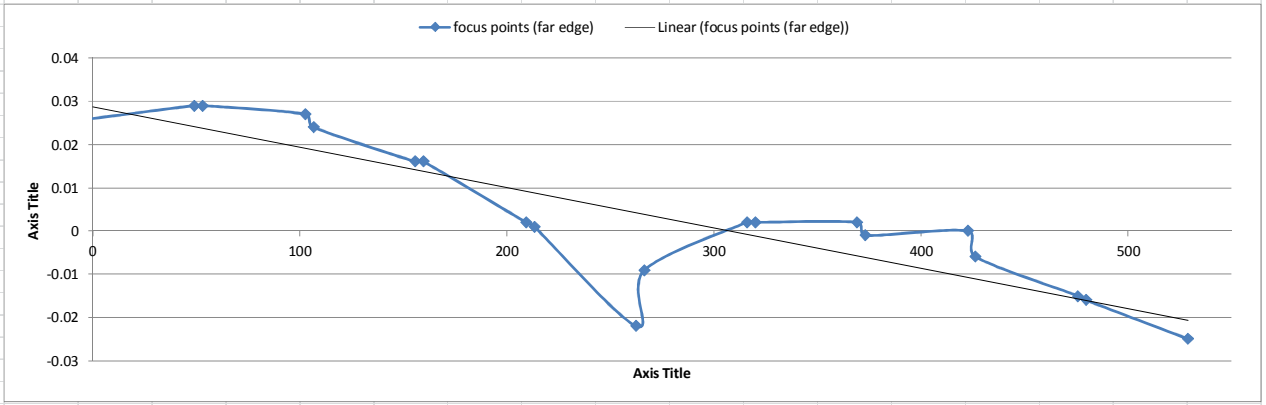


- Discuss analysis of measurement data to describe the shape of and interrelationship between parts (i.e. ladder sensors)
- Show Excel plots of X, Y measurement points in the ladder X-Y plane, and Z-axis measurement points and linear fit along ladder near edge, centerline, and far edges, and OGP software reported flatness and straightness (see next slide)

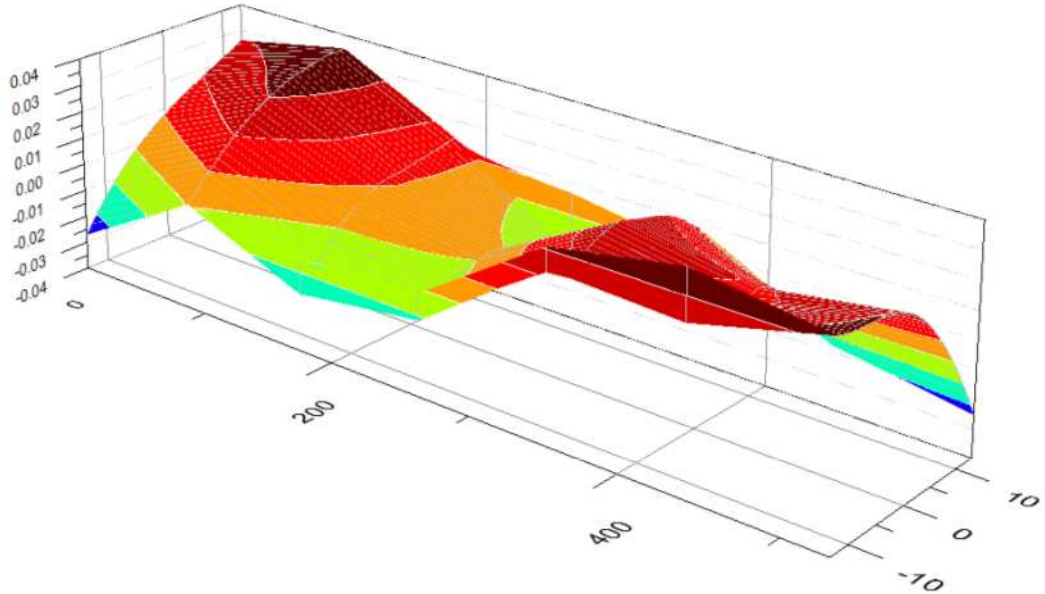
Flatness	Grid	Points			
X	-0.023	Y	-13.138	Z	-0.027
X	49.309	Y	-13.14	Z	-0.012
X	53.288	Y	-13.127	Z	-0.009
X	102.6	Y	-13.142	Z	-0.002
X	106.598	Y	-13.121	Z	-0.002
X	155.908	Y	-13.137	Z	-0.017
X	159.892	Y	-13.133	Z	-0.019
X	209.209	Y	-13.137	Z	-0.012
X	213.201	Y	-13.118	Z	-0.013
X	262.488	Y	-13.128	Z	-0.02
X	266.482	Y	-13.123	Z	-0.001
X	315.804	Y	-13.125	Z	0.011
X	319.776	Y	-13.144	Z	0.015
X	369.103	Y	-13.123	Z	0.021
X	373.092	Y	-13.132	Z	0.022
X	422.393	Y	-13.136	Z	0.02
X	426.389	Y	-13.124	Z	0.022
X	475.707	Y	-13.117	Z	0.025
X	479.674	Y	-13.139	Z	0.028
X	528.992	Y	-13.144	Z	0.03
X	0.01	Y	0.005	Z	0.012
X	49.313	Y	-0.008	Z	0.014
X	53.291	Y	0.009	Z	0.017
X	102.605	Y	-0.01	Z	0.02
X	106.601	Y	0.009	Z	0.018
X	155.912	Y	-0.009	Z	0.007
X	159.897	Y	0.011	Z	0.007
X	209.211	Y	-0.011	Z	0.004
X	213.201	Y	-0.009	Z	0.003
X	262.497	Y	-0.007	Z	-0.007
X	266.444	Y	-0.007	Z	0.003
X	315.807	Y	0.006	Z	0.017
X	319.783	Y	-0.006	Z	0.017
X	369.1	Y	0.01	Z	0.021
X	373.098	Y	-0.011	Z	0.02
X	422.397	Y	-0.009	Z	0.019
X	426.392	Y	-0.01	Z	0.017
X	475.705	Y	0.007	Z	0.016
X	479.676	Y	-0.008	Z	0.015
X	528.993	Y	-0.011	Z	0.023
X	-0.004	Y	13.123	Z	0.026
X	49.321	Y	13.116	Z	0.029
X	53.281	Y	13.119	Z	0.029
X	102.61	Y	13.118	Z	0.027
X	106.567	Y	13.155	Z	0.024
X	155.917	Y	13.118	Z	0.016
X	159.882	Y	13.121	Z	0.016
X	209.213	Y	13.115	Z	0.002
X	213.2	Y	13.118	Z	0.001
X	262.497	Y	13.117	Z	-0.022
X	266.481	Y	13.119	Z	-0.009
X	315.794	Y	13.124	Z	0.002
X	319.779	Y	13.117	Z	0.002
X	369.093	Y	13.121	Z	0.002
X	373.1	Y	13.118	Z	-0.001
X	422.402	Y	13.117	Z	0
X	426.383	Y	13.113	Z	-0.006
X	475.701	Y	13.127	Z	-0.015
X	479.673	Y	13.116	Z	-0.016
X	528.987	Y	13.121	Z	-0.025
60 Point Best Fit Plane				FLT	+0000.064
Sensor Straightness Near Edge				STR	+0000.013
Sensor Straightness Far Edge				STR	+0000.012

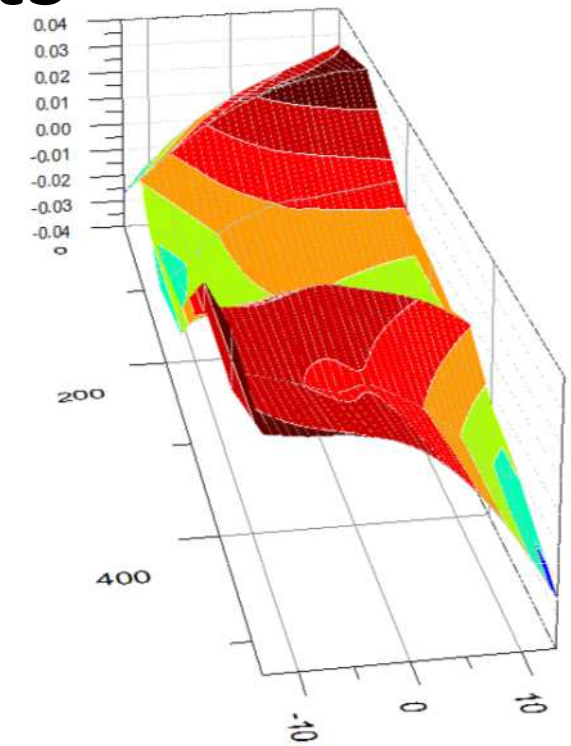






Contour plots



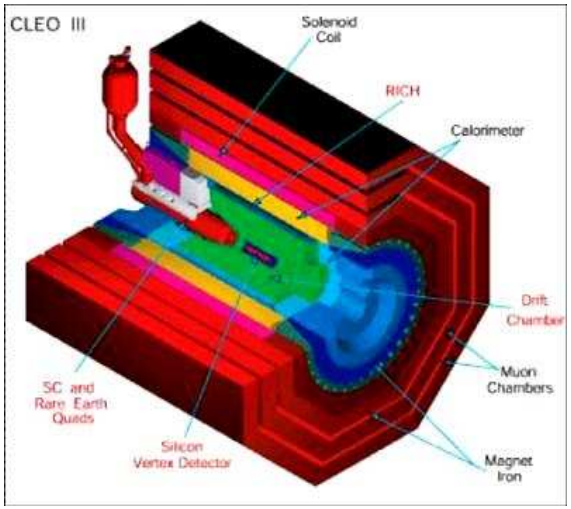


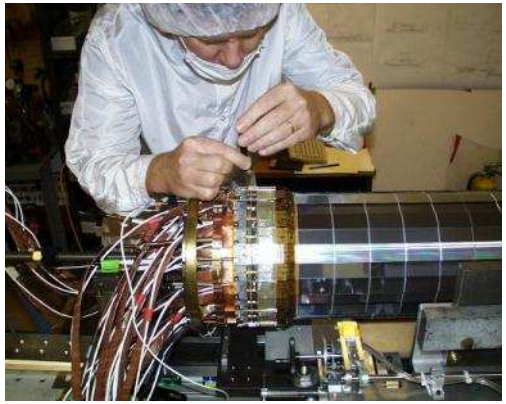
- Show contour plots made from all X-Y-Z measurement points
- 3-D plot shows ladder is twisted, but not bowed
- Discuss how measurement results (both electrical and dimensional) used for Quality Control, and to grade parts to determine which are best for installation in the experiment

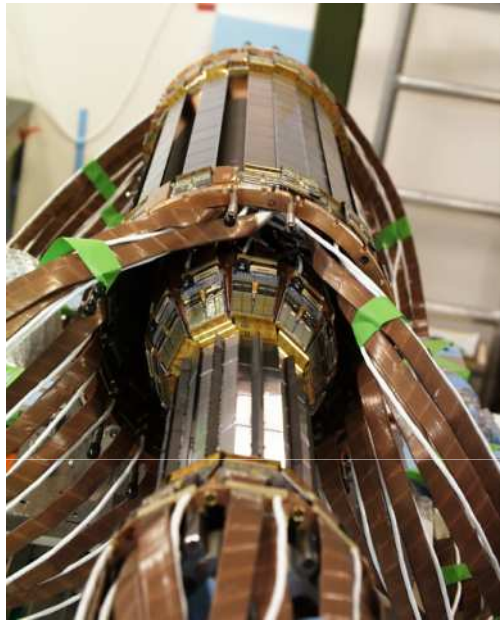
Backup slides

CLEO III Silicon Vertex Detector (Si3)

PURDUE UNIVERSITY

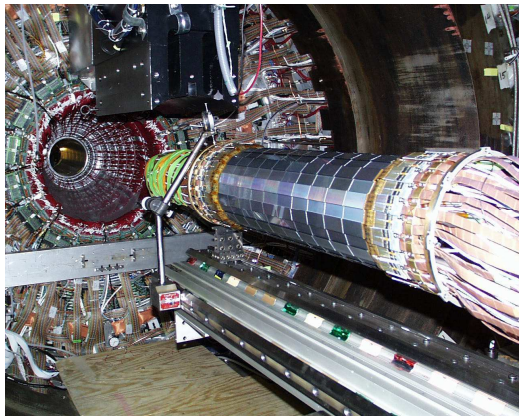




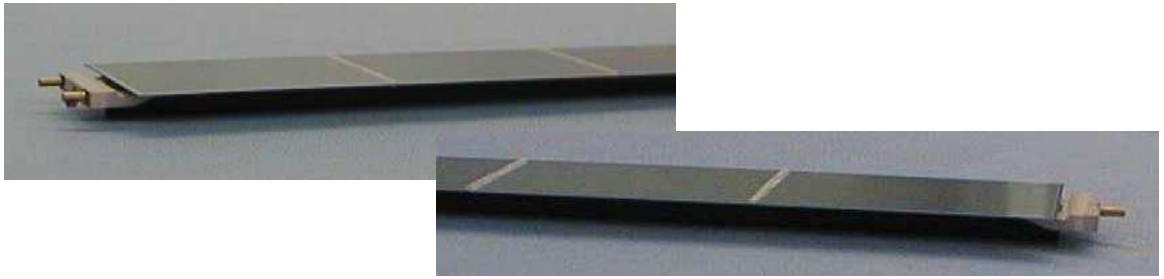


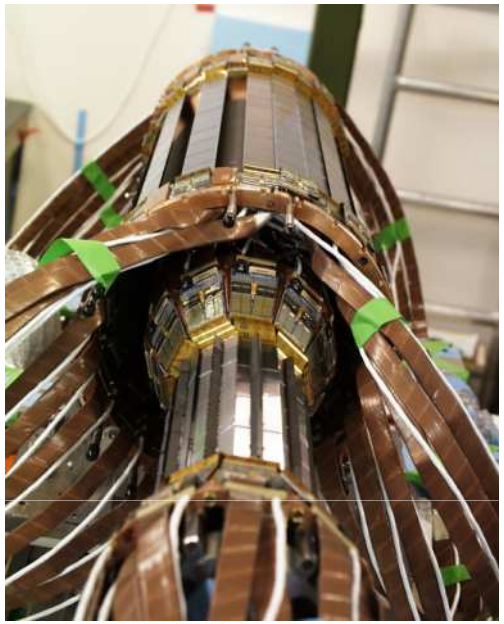
Purdue responsibilities:

- Mechanical design and engineering
- Assembly of silicon strip ladders using CVD diamond for support, wire bonding, module testing
- Kinematic mounting of ladders on end cones
- Cooling system
- Transportation to Cornell, SVX installation into CLEO

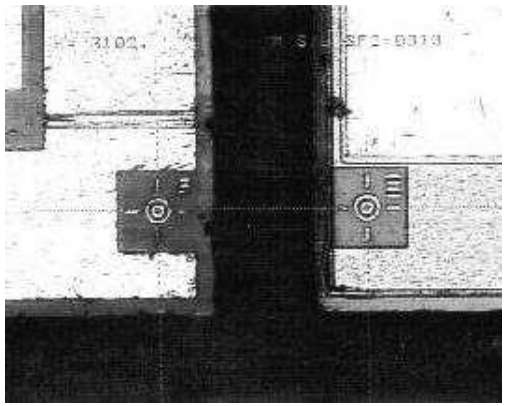


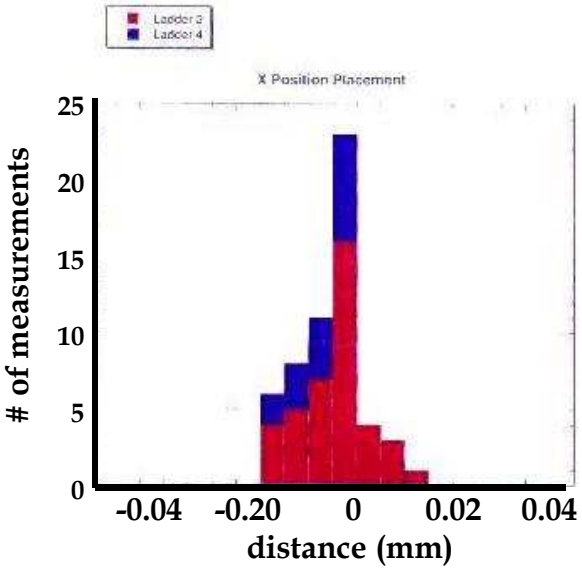
CLEO III SVX ladders – alignment precision

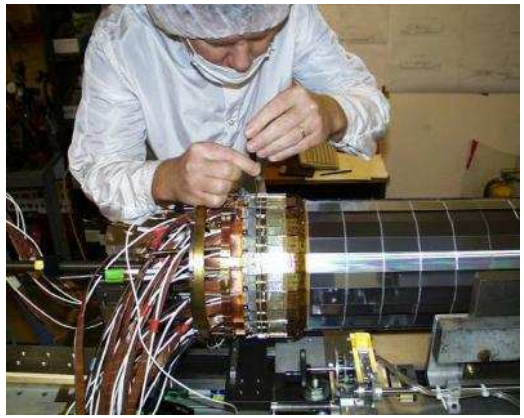




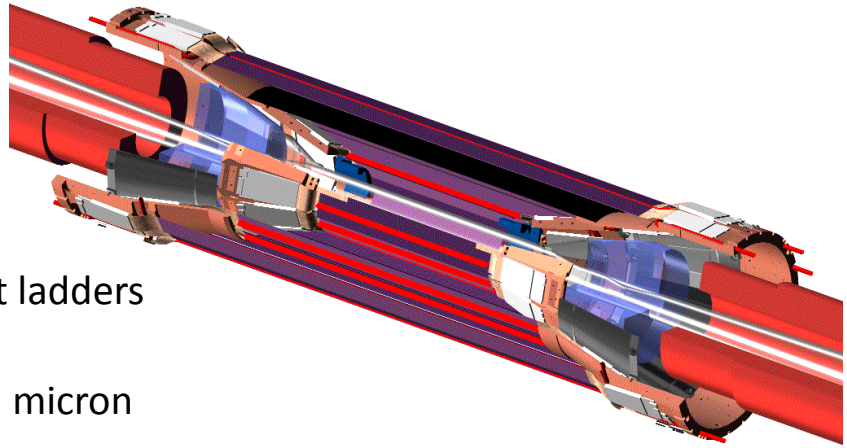
Location of individual sensors in all ladders <15 microns deviation from ideal







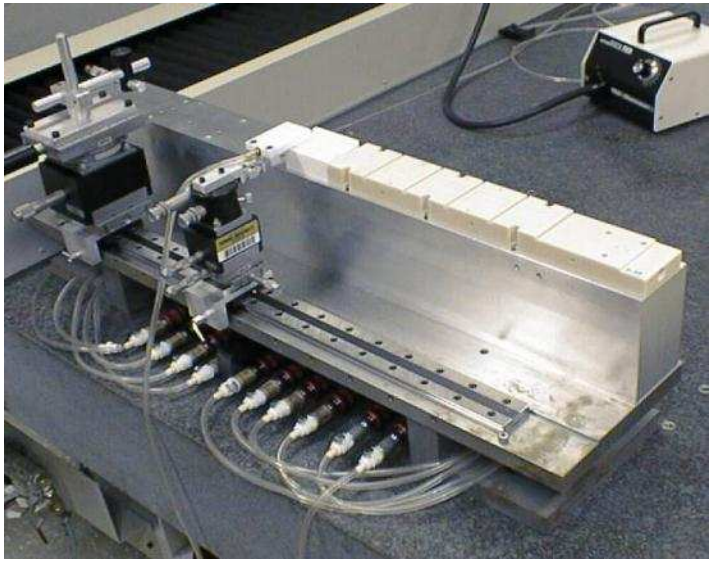
CLSO Si3 Mechanical Challenges

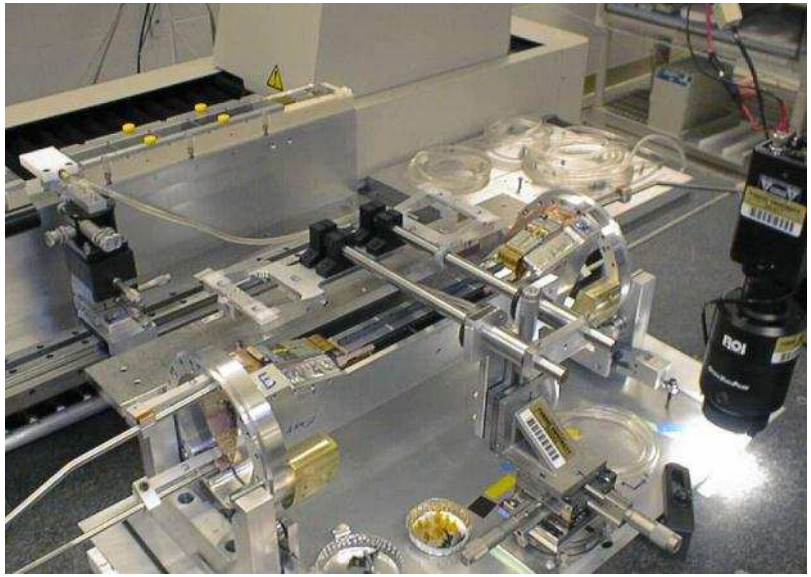


- **Silicon Ladders**
  - Outer layer 53.3 cm long – one of the longest ladders constructed for a collider geometry
  - Precision assembly of wafers over length <15 micron
  - Natural frequency >100HZ and self deflection <25 micron
  - CTE match between support beam and silicon
  - Electrical compatibility between support beam and silicon
- **Conical end supports**
  - Precision location of ladders to <75 microns
  - Mounting locations for hybrid electronics and cables
  - Thermal management of hybrids (500 watts)
- **Kinematic mounting**
  - Isolate ladders from end supports to mitigate forces due to external loads (i.e. transport) or thermal changes

Silicon Ladder Assembly

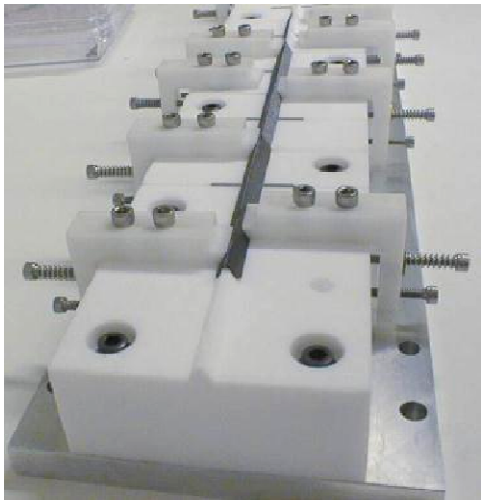
- Pick-and-place machine with 6-axis adjustment used to align arrays of wafers on 10 micron flatness fixtures. Epoxy applied to the joints between wafers after alignment
- Ladders aligned and mounted on end cones with custom placement tools
- Optical probe mounted on CMM with 3 micron accuracy over 1m x 0.7m x 0.5m volume used to locate wafers and ladders.

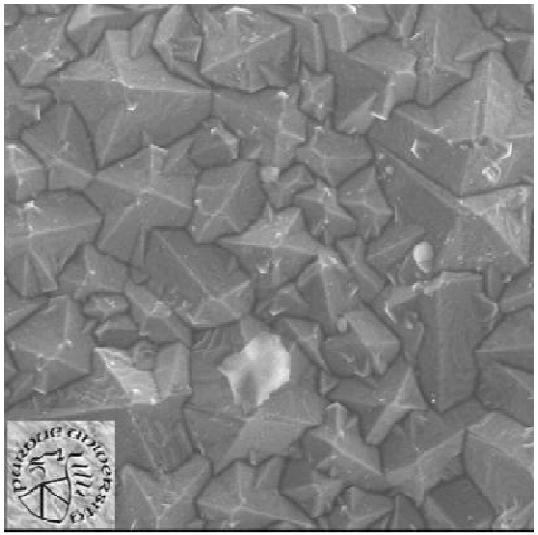


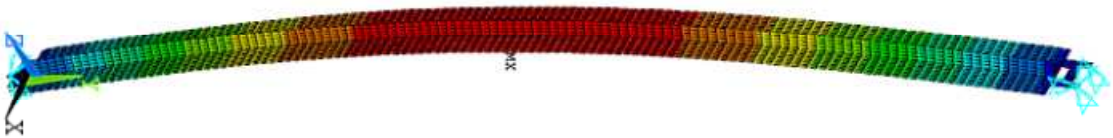


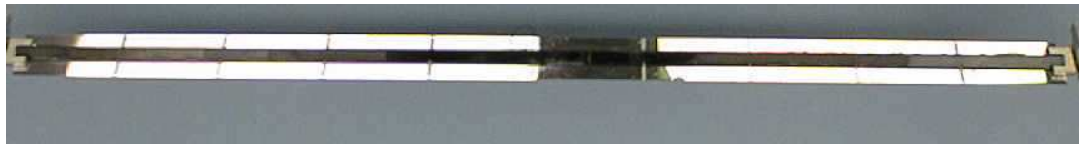
Silicon Ladder Support

- Beam geometry
  - Several considered (side rails, vertical strip, tubes, V-beam)
  - A closed geometry was chosen to provide torsional stiffness. The V-beam geometry is easily constructed from sheet materials and makes use of the stiffness of the silicon which closes the triangular beam section.
- Beam material
  - Many materials (Be, SiC, carbon fiber & Kevlar composites) evaluated for stiffness, radiation length and CTE match to silicon
  - CVD diamond was a clear winner for CTE and stiffness, as well as being an electrical insulator and excellent thermal conductor.



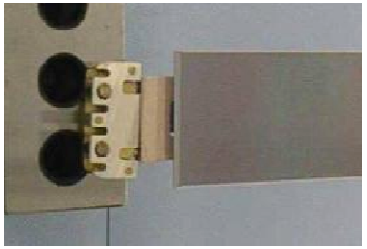


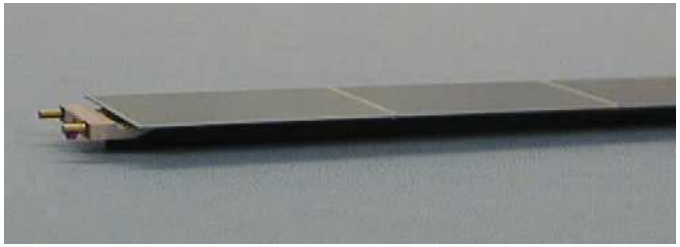




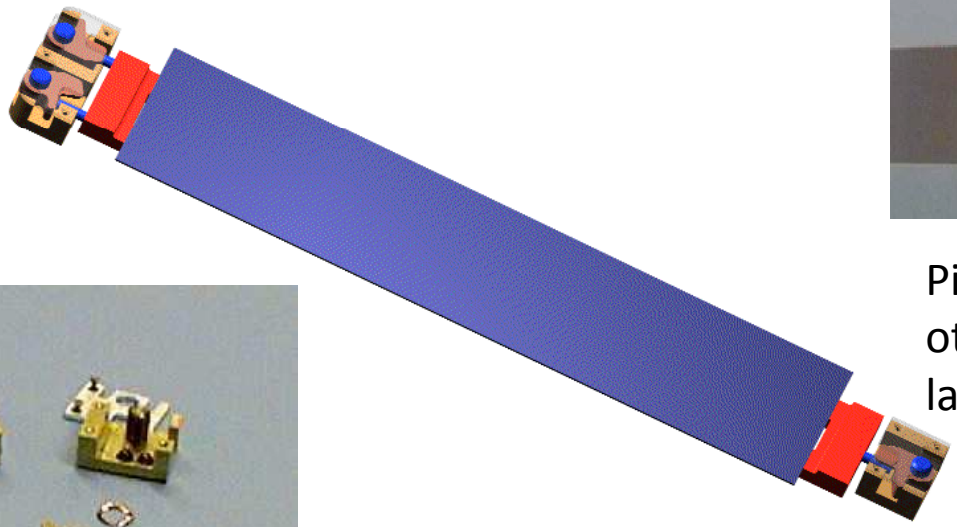
Kinematic mounts

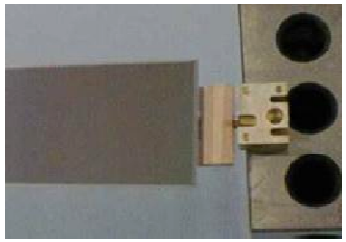
Custom wave spring loaded “clips”
for kinematic mounting ladders to conic end supports





Ball-in-socket joint and crossed pins at one end of ladder





Pin on two balls at other end of ladder