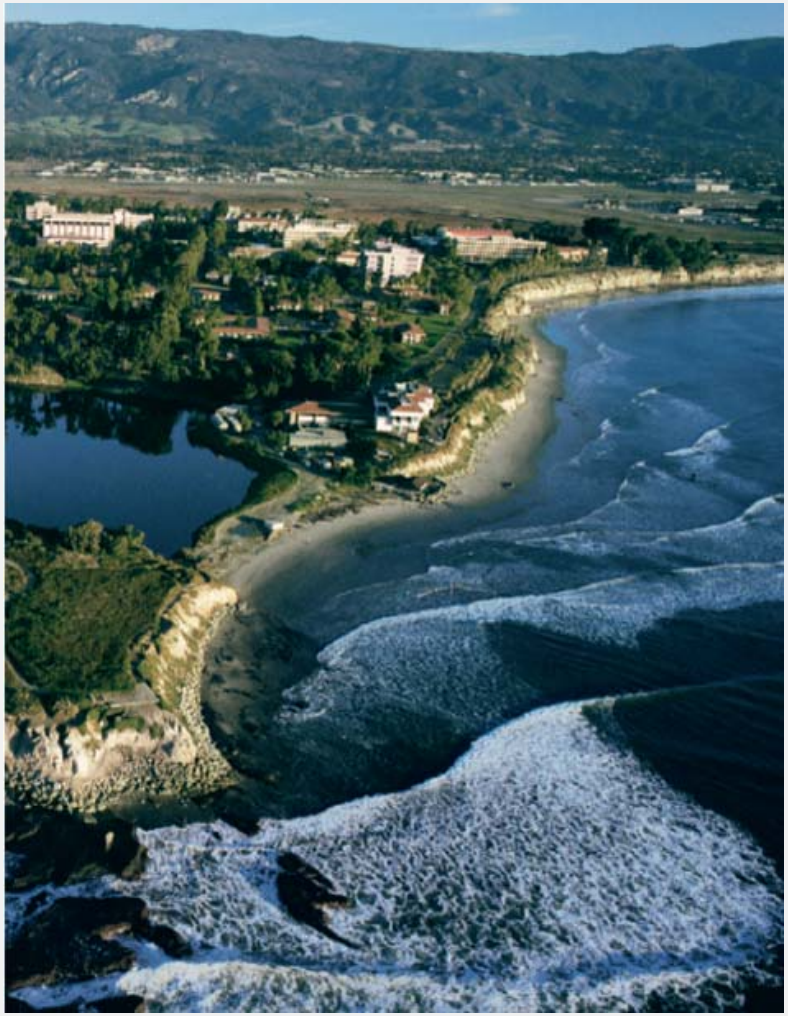
Lessons Learned From A Large Scale, Large Volume Production At A Small University



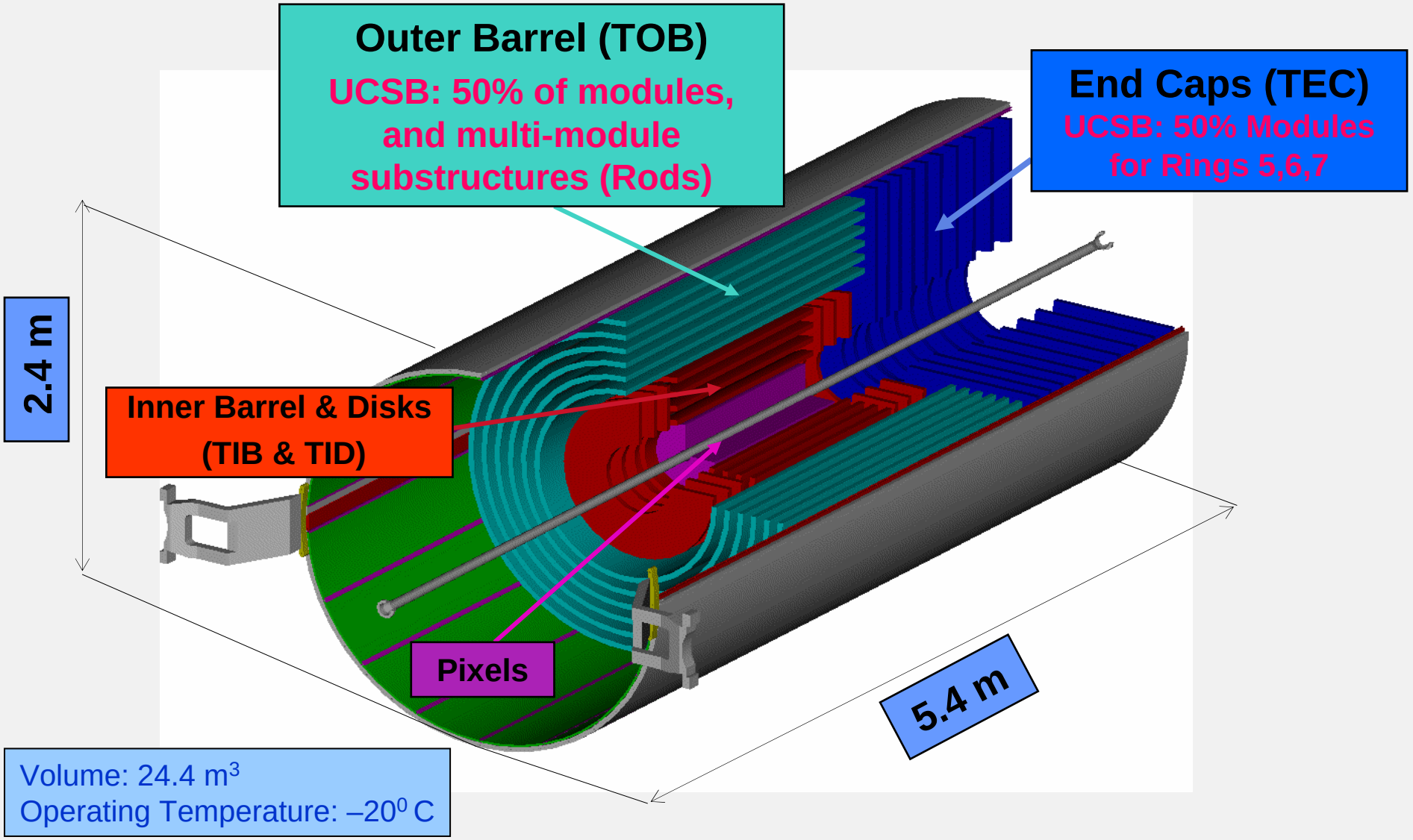
Anthony Affolder

for the UCSB CMS Group

SiLC Workshop

June 13, 2006

UCSB in CMS Tracker



Volume: 24.4 m^3
Operating Temperature: -20^0 C

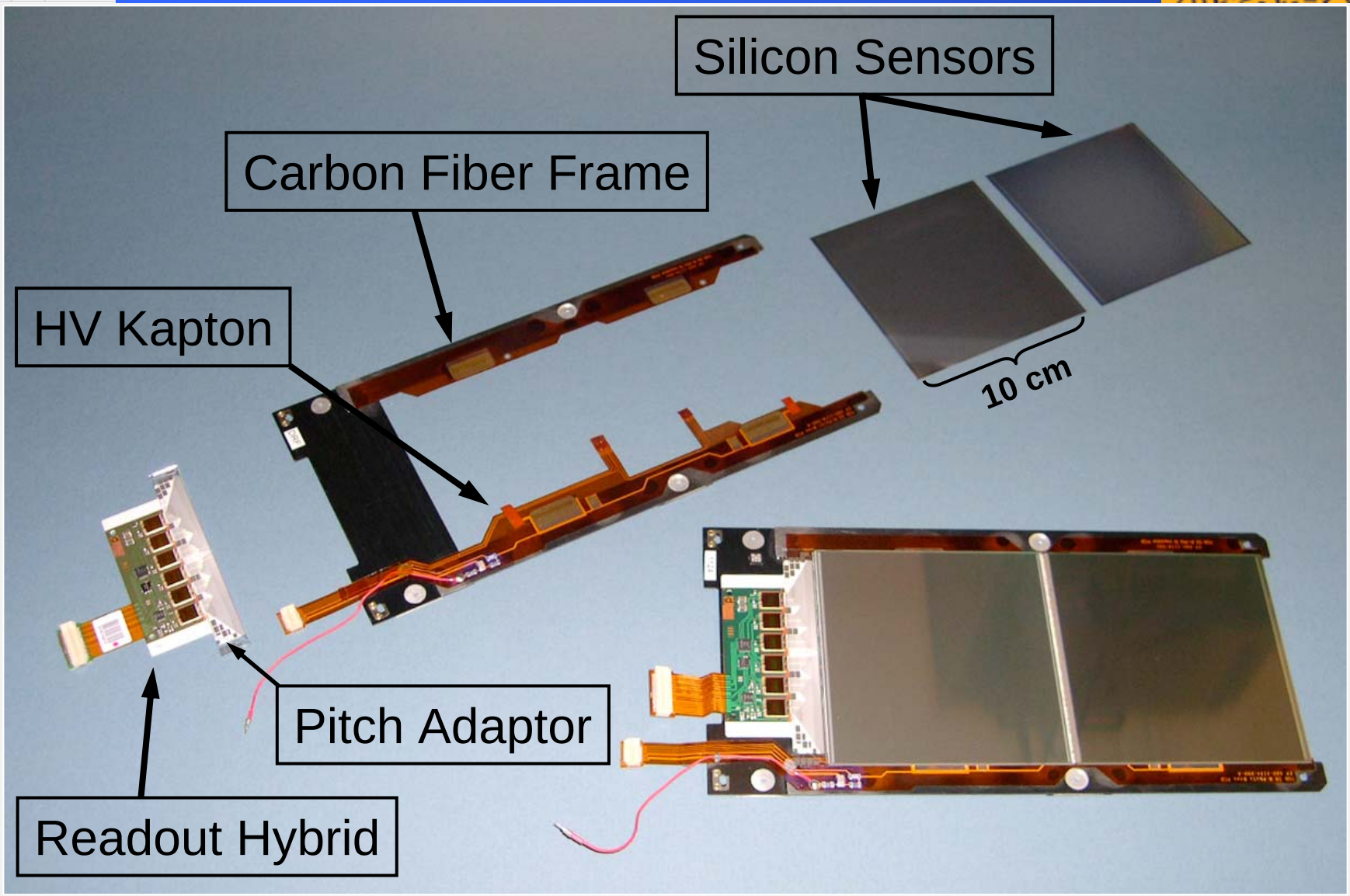
LESSON 1

Don't make things more difficult than necessary.

"Make everything as simple as possible, but not simpler."

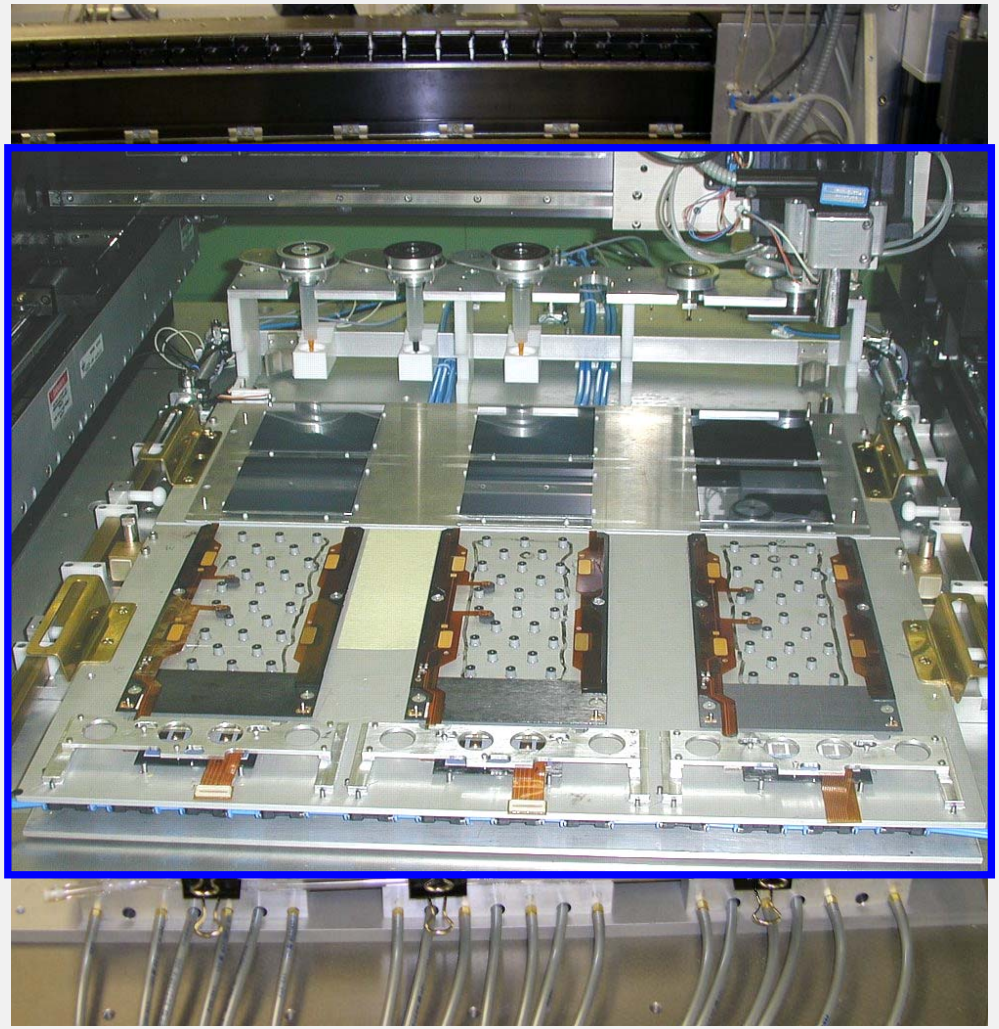
- Albert Einstein

Module Components

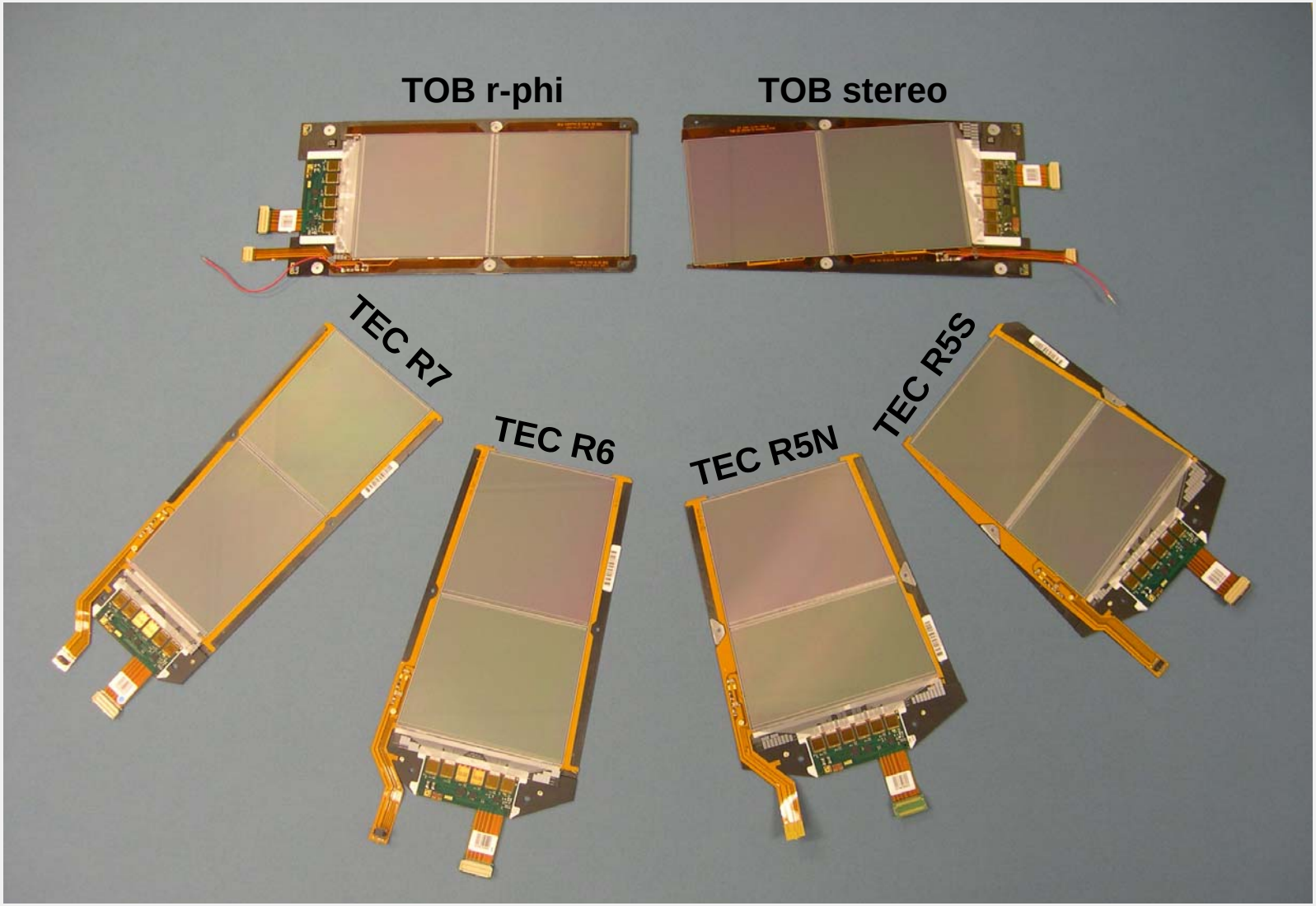


Flexible Module Assembly

- Commercial Aerotech Gantry system
  - Developed and customized at CERN
    - Uses complex, laminated assembly plates
  - Modified at UCSB
    - Simplified assembly plate design. Gave us the ability to add new module types in only 1 month.



Modules Produced at UCSB

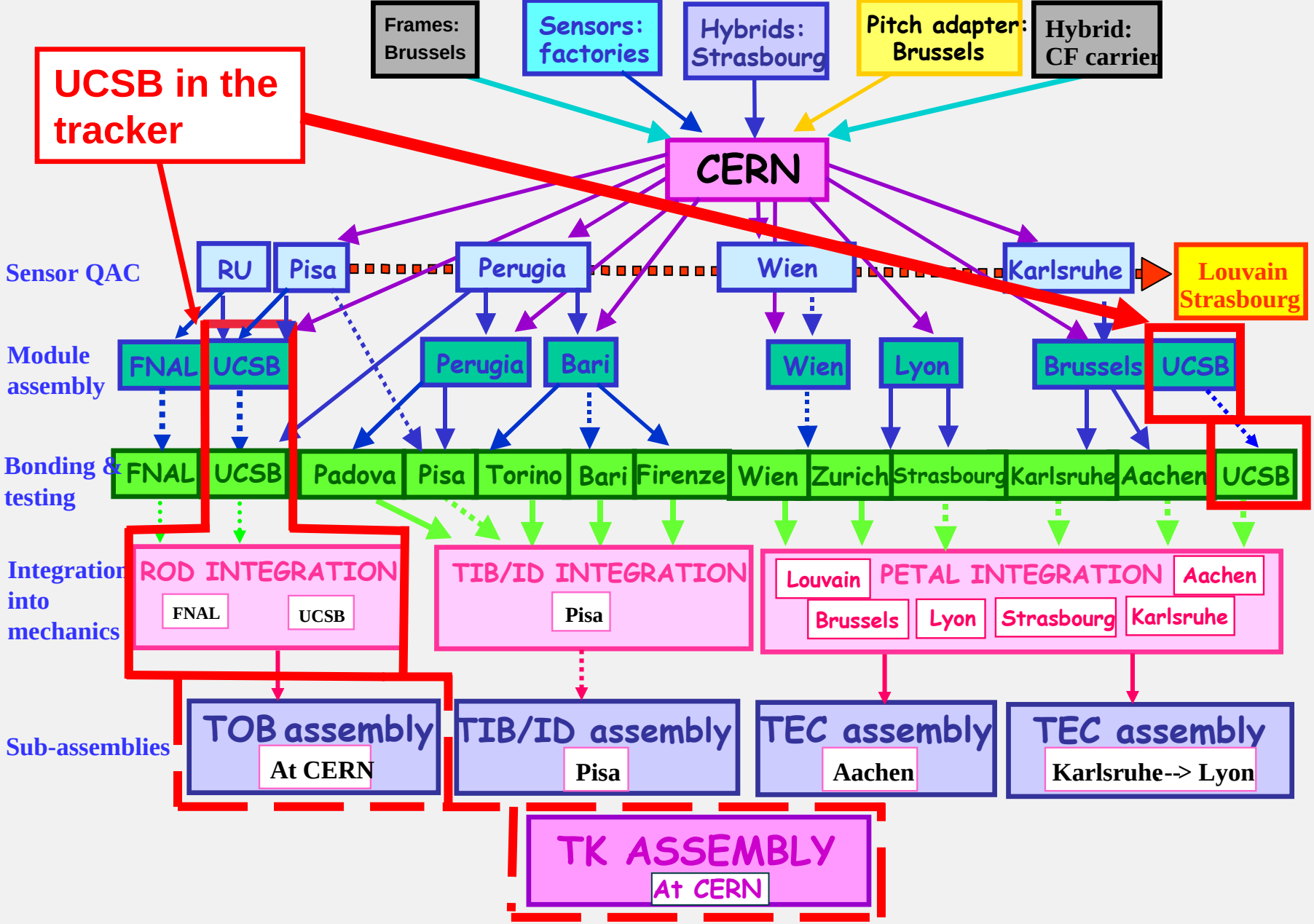


LESSON 2

Centralized production has it's advantages

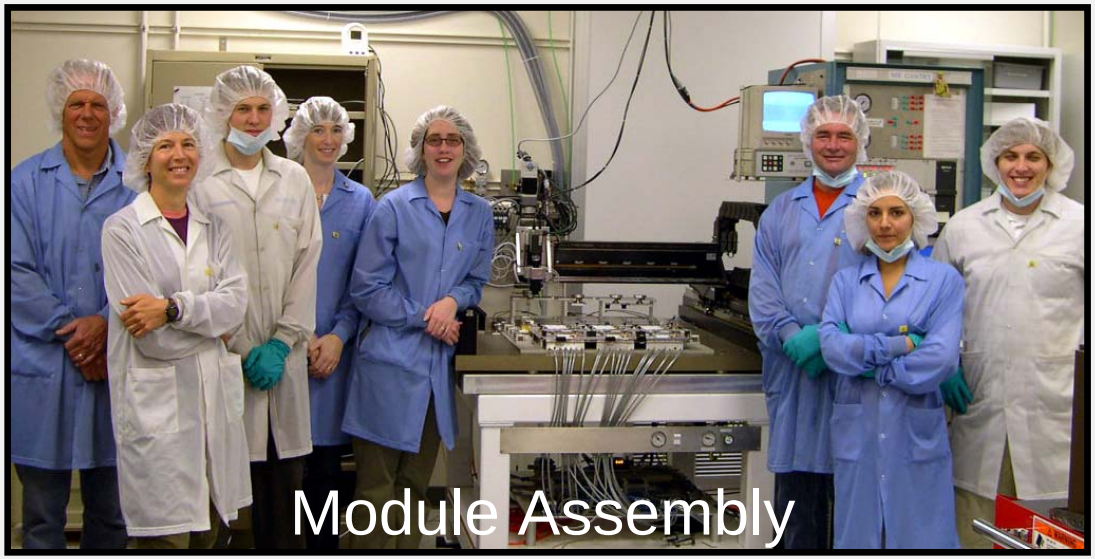
"One man alone can be pretty dumb sometimes, but for real bona fide stupidity, there ain't nothin' can beat teamwork."

-Edward Abbey



Our position gave us a wider view of the project which has proved to be useful

Production Crew
22 people (14 FTE)

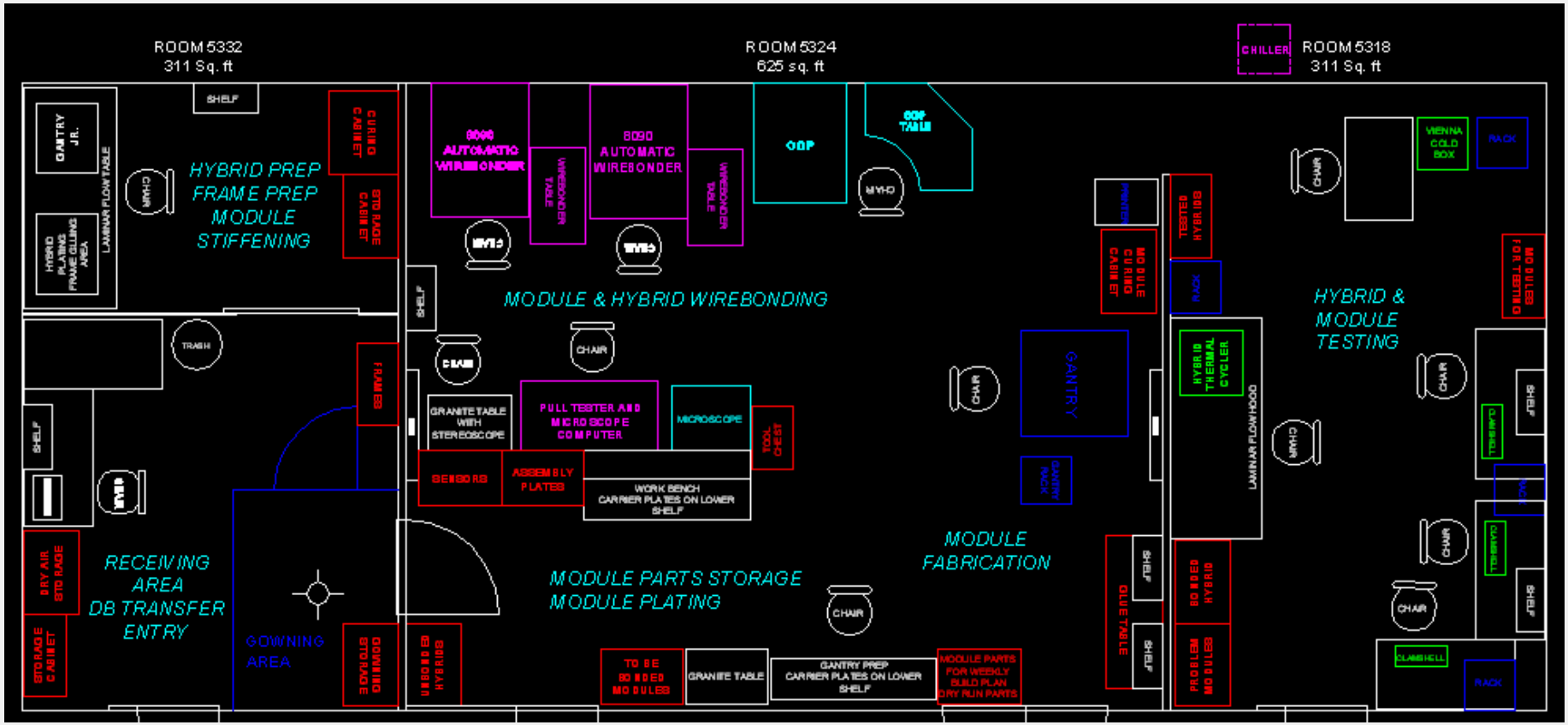

Module Assembly


Wire Bonding


Hybrid/Module Testing


Rod Assembly/Testing

Clean Room



1/3 of the CMS hybrids and ¼ of the CMS modules will be assembled, bonded, and tested in a 116 m^2 clean room!!!
Less equipment was needed per module produced.

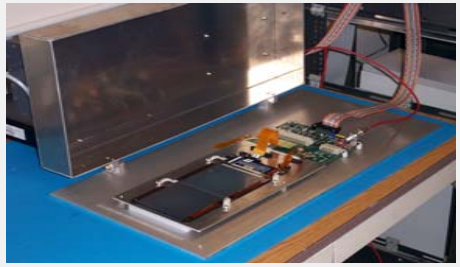
Production Cycle

Wire bond hybrid

Thermal test hybrids

Assemble modules

Wire bond module

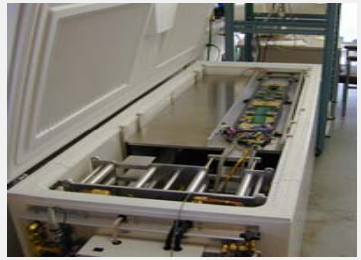


Test bonded module

Thermal test module

Assemble rods

Single rod test



Rod burn-in

Ship to CERN

Shorter production line, quicker feedback

LESSON 3

Exploit the youth, they do not know any better

”I am looking for a lot of men who have an infinite capacity to not know what can’t be done.”

-Henry Ford

Electrical Testing

- All electrical testing is performed by undergraduates, recent graduates, and graduate students
  - In order to be successful with such a crew, you must give each student their own project, have high expectations, and show confidence in their ability to complete the project
- They all meet or exceeded all expectations and caused less breakage than other sites

LESSON 4

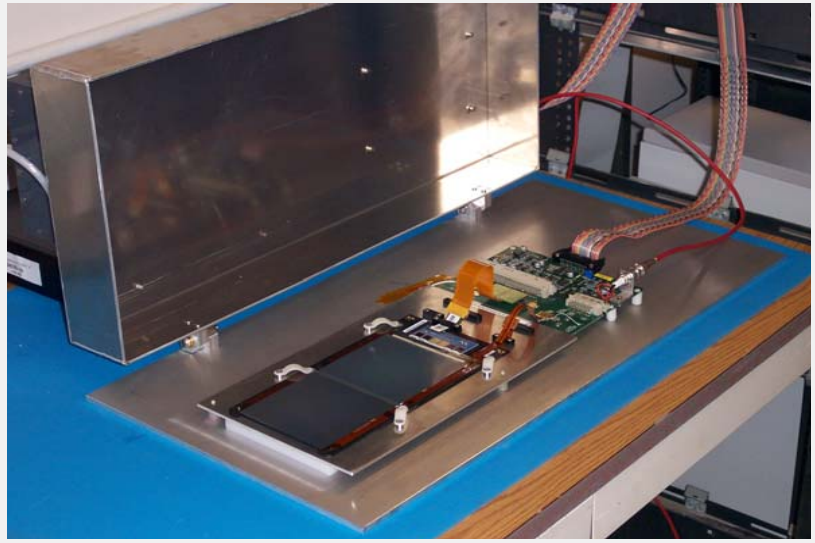
Make everything repeatable over the length of the production

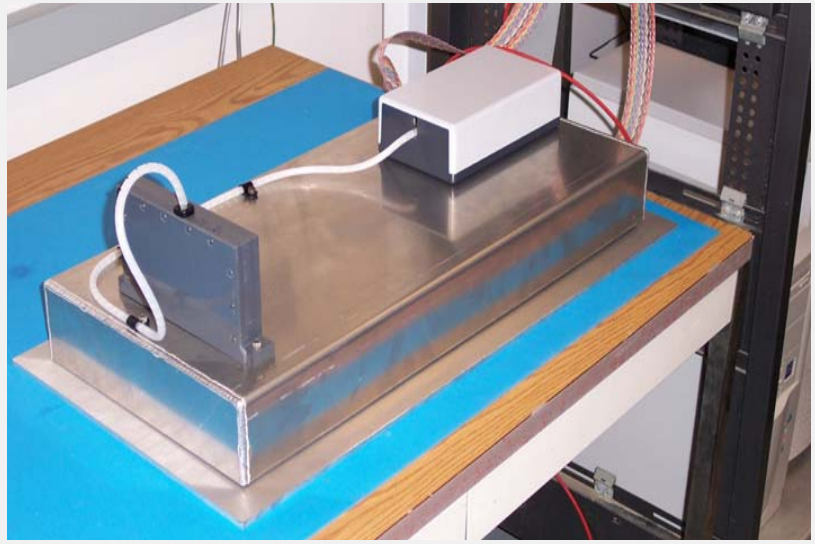
"Consistency is better than truth"

-Unknown

Solid Testing Equipment

- Durable equipment as essential for success
  - We developed the shielding and grounding strategy for module testing and designed test fixtures to ensure uniform testing results
    - Module defects appear in the same manner at all testing sites





List of Procedures

We wrote 30 detailed procedures for all aspects of handling, assembly, bonding, testing, and shipping to ensure continuity over 3 years of personnel turnover

- Encapsulation of Module Bias Bonds
- Frame Receiving - TEC Inspection & Prep
- Frame Receiving - TOB Inspection & Prep
- Hybrid Packing & Shipping
- Hybrid Receiving
- Hybrid Inspection and Plating
- Hybrid Tailing
- Hybrid Un-Tailing & Un-Plating
- Module LT Testing
- Module ARCS Testing
- Module Assembly on the Gantry
- Module Packing & Shipping
- Module Plating & Handling
- Module Stiffening/Encapsulation
- Module Tailing & Handling - TOB
- Module Un-Tailing – TOB
- Module Tailing & Handling – TEC
- Module Un-Tailing
- OGP Assembly Plate Commissioning
- OGP Module After-Cure Survey
- Rod Assembly
- Rod Receiving
- Rod Shipping
- Rod Testing
- Encapsulation of Module Backsides
- Sensor Receiving and Sorting
- TEC Module Re-Plating
- Wire bond Plucking
- Wire bond Pull-Testing
- Module Wire Bonding

LESSON 5

You will end up doing more than you first expected

"Sometimes it is not enough to do our best; we must do what is required."

- Sir Winston Churchill

UCSB Responsibilities

November 2002

- 1/3 of TOB modules
  - 1700 Modules (31 m^2 Si)
    - 8.1K Readout Chips
    - 1,000K Channels
    - 2,000K Wire Bonds

Comparison: CDF II
- 5 m^2 Si
- 5.6K Readout Chips
- 722K Channels
- 1,761K Wire Bonds

Final

- ½ of TOB modules and ½ of TEC R5, R6 and R7 modules
  - ~4100 Modules (72 m^2 Si)
    - 20K Readout Chips
    - 2,500K Channels
    - 7,500K Wire Bonds
- 1/3 of Readout Chip-to-Pitch Adaptor Bonding/Thermal Testing
  - ~4200 Hybrids
- ½ of Assembly/Testing/Burn-in of TOB Rods (344 rods)

Production Rates Needed

November 2002

- 2 year production schedule
  - Modules
    - 6 assembled per day
    - 6 bonded per day
    - 6 tested per day

Comparison: CDF II
• 4 ladders assembled, bonded, and tested per day

Final

- 1 year production schedule
  - Modules
    - 21 assembled per day
    - 21 bonded per day
    - 21 tested per day
    - + retrofits (≈20 per day)
  - Hybrids
    - 20 bonded per day
    - 20 tested per day
- 5 month production schedule
  - Rods
    - 4 assembled per day
    - 4 tested per day
    - 24 burn-in per week

LESSON 6

Schedules slip. On day one, start planning to increase your capacity

"If everything seems under control, you're just not going fast enough.

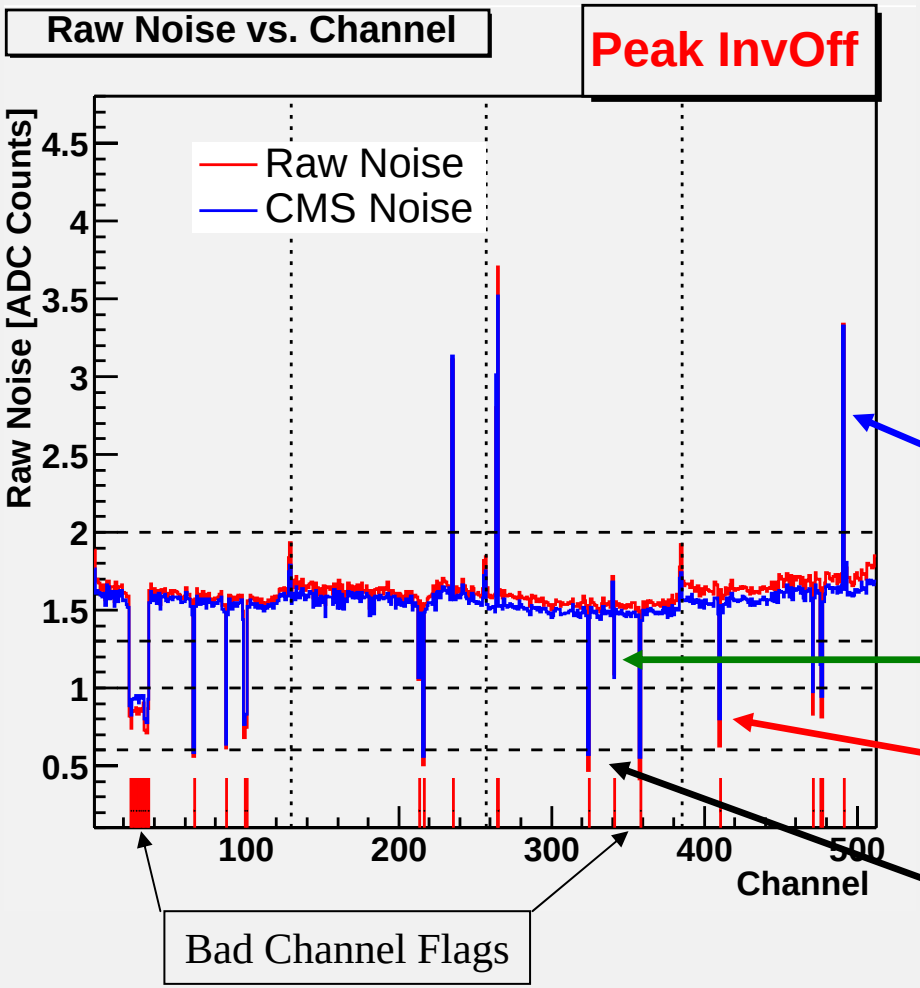
- Mario Andretti

Automated Wire Bonding

- We used the full capabilities of our 2 K&S 8090 wire bonders
  - Fully automated wirebonding
    - Maximal use of pattern recognition
    - Solid but easy-to-change bonding fixtures
  - Reduced hybrid bonding time from 15 to 6 minutes and module bonding time from >20 to 10 minutes

Clear, robust fault signatures

Noise Measurement



We made faults responses appear as different as possible

Noisy Channels

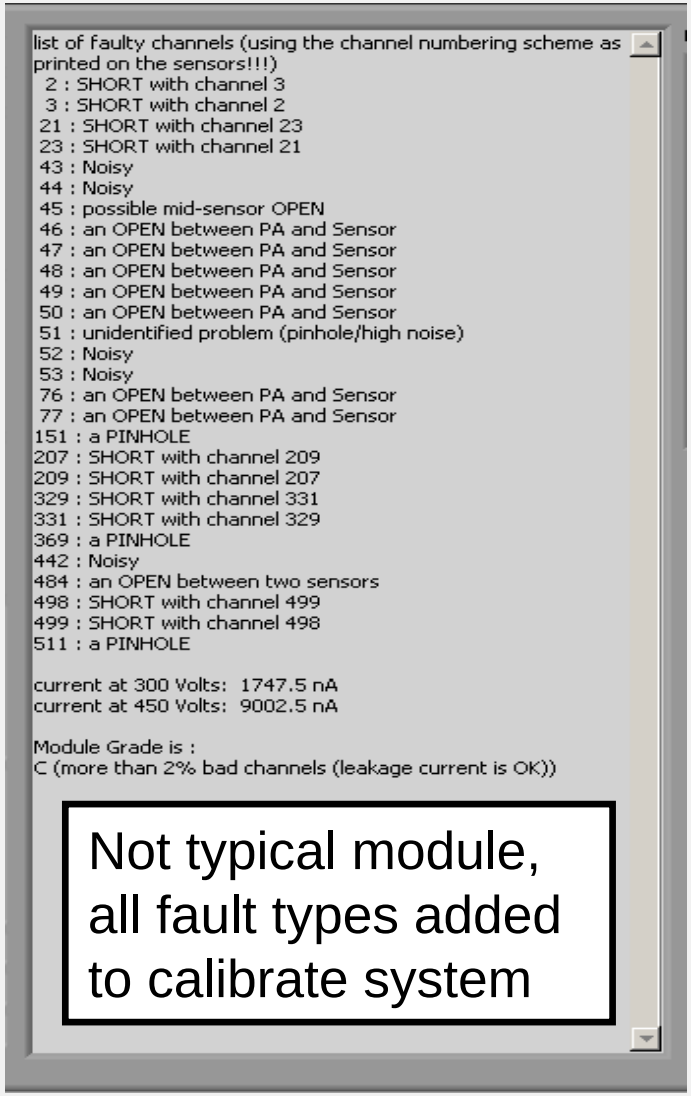
1 Sensor Opens

2 Sensors Opens

Pinholes

Efficient Fault Finding

- Developed the fault finding algorithm which correlates the different test results in order to diagnose the fault type and location
  - >99.9% faults are found with <0.01% of channels falsely flagged
- Automated testing to the point that a student can test 3 modules at once
  - 10 modules/hour



LESSON 7

Assume the worst case scenario

"In theory, there is no difference between theory and practice. But, in practice, there is."

- Jan L.A. van de Snepscheut

Systems Failure Analysis

- Studying the weaknesses in the equipment and having a contingency plan for failures is a necessity.
  - Wrote an operations/failure analysis for all our equipment. It paid great dividends during the production.
    - We negotiated an exchange of our 2nd bonder, a K&S 8060, for a K&S 8090 that was not fully utilized at FNAL. Gave both sites 2 machines that can bond modules.
    - We found that there are 48 unique cables in the testing systems. At the time, **29 of them had no spares**.
  - We have had less than 3 days downtime due to equipment failure on any stand at any US site.

LESSON 8

Study anything unexpected. You never know what is going to be dangerous.

”Only the paranoid survive”

-Andrew Grove

A Healthy Level of Paranoia

- Because we studied every anomaly, we were able to uncover and help solve many potentially fatal flaws:
  - Hybrids
    - Broken traces on hybrid tails:
    - Poorly plated hybrid vias:
  - Silicon Sensors
    - STM issues
    - Damage due to discharge between bond wires and surface of sensor
  - Mechanical
    - Broken wirebonds on modules due to vibration:
  - Electrical
    - Silver epoxy bias connection degradation:
    - Slow control communication failures on rods/petals:

These problems delayed the start of module production by 1½ years.

But we delivered a better detector

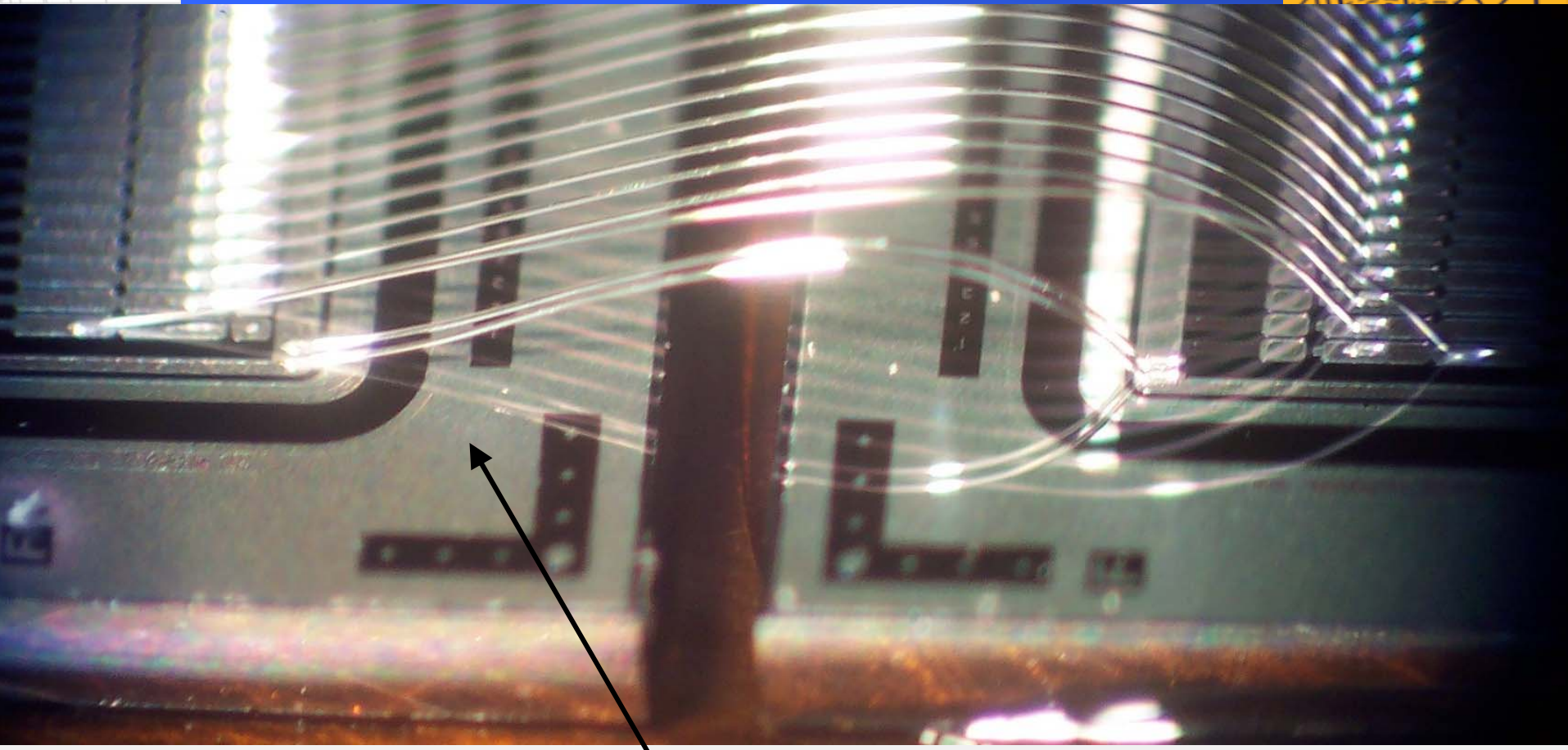
LESSON 9

A loss of information between design and production can cost you dearly

"There is nothing more frightful than ignorance in action."

-Johann Wolfgang von Goethe

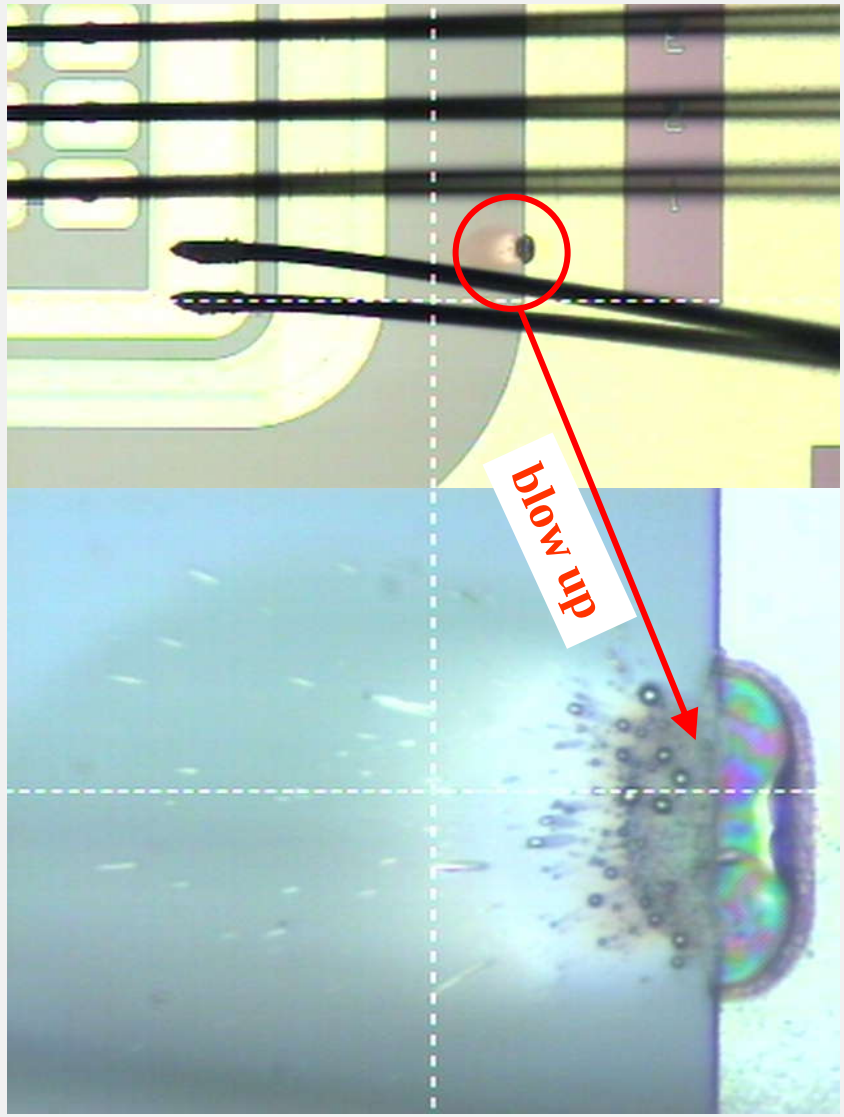
High Voltage Sparking



Bonds are at ground, this area (n^+) is at bias voltage (400 V). The height of the bonds over the area is ~100 μm⇨4kV/mm fields!!

High Voltage Sparking

- Sparking was found during rod testing. Caused by HV spikes.
  - Revealed weakness in the sensor bonding that we should address
- Controlled tests show that we had a ~ 4x safety margin
- Re-bonded low bias wires and encapsulated to increase safety margin
  - Retrofits took 6 man-months



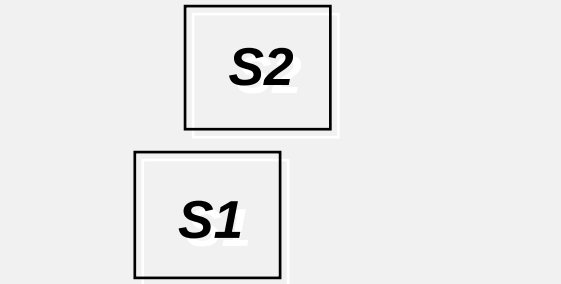
LESSON 10

In the end, the result is what matters

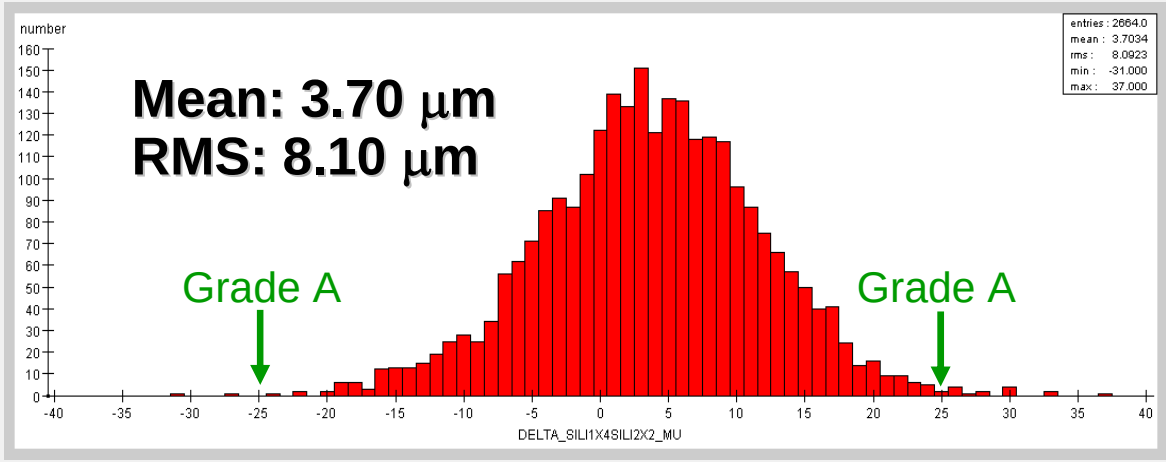
"Glory is fleeting, but obscurity is forever."

- Napoleon Bonaparte

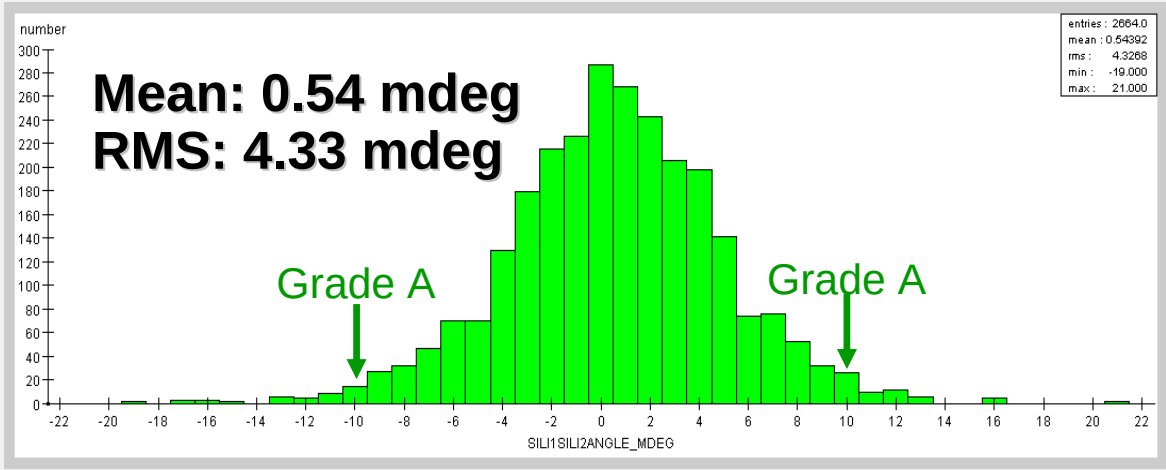
Module Assembly Precision



$\Delta(x_{sensor\ 1}, x_{sensor\ 2})$

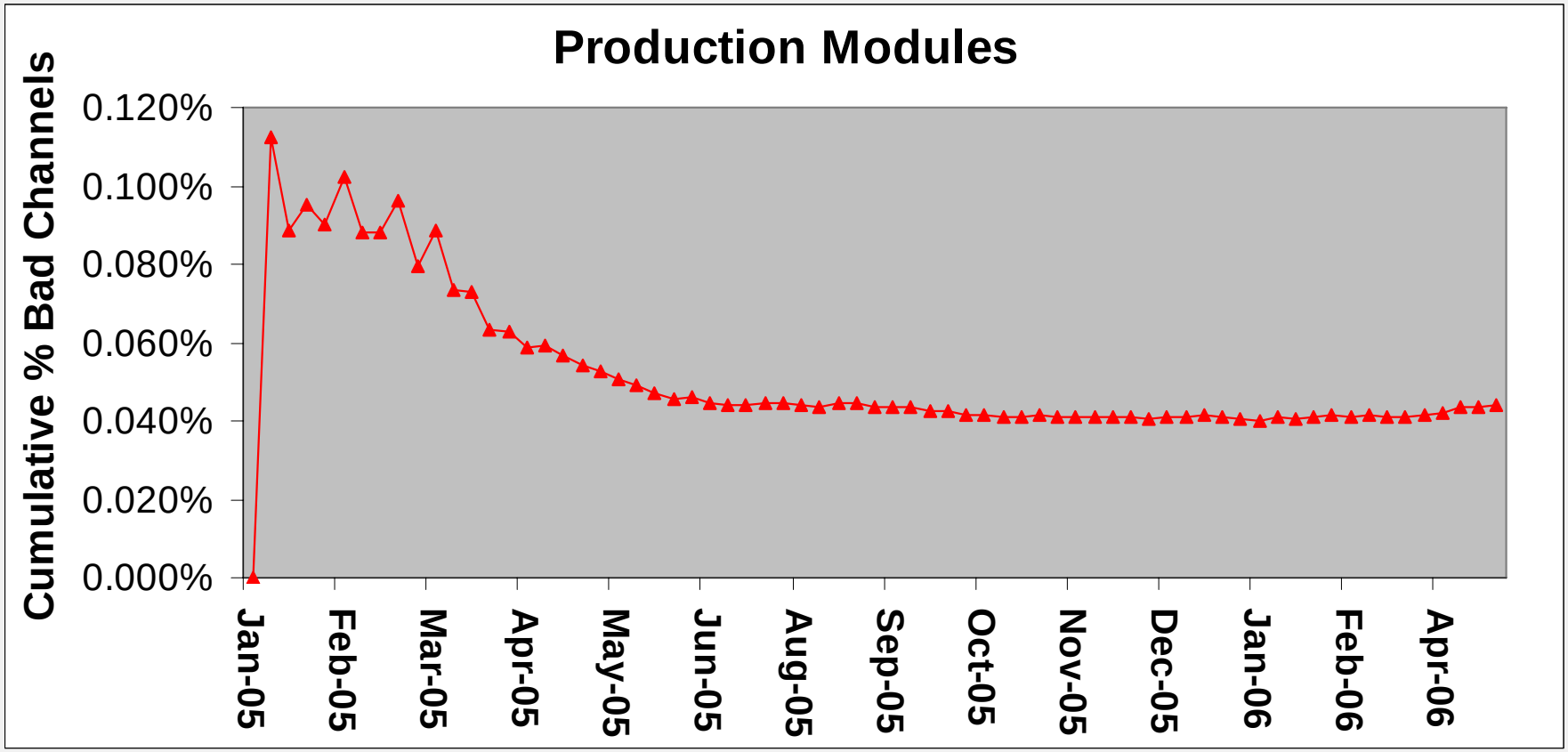


$\Delta(\theta_{sensor\ 1}, \theta_{sensor\ 2})$



Single hit resolution ~40 μm

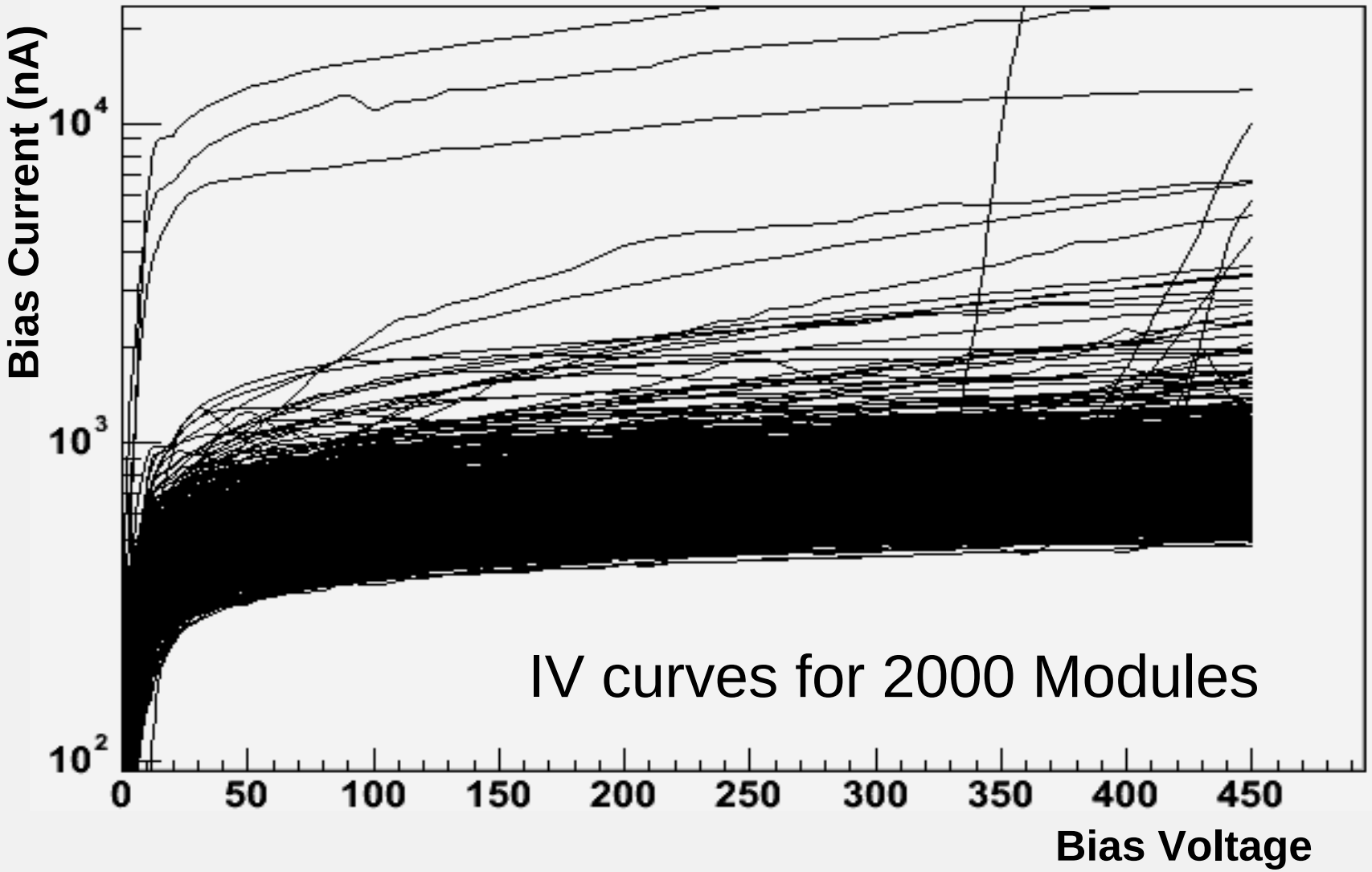
Module Quality



1072 bad channels out of 2,437,632 (0.044%)

Approaching the intrinsic fault rate of components

Module Quality



High Production Yields

Front End Hybrid Yields:

- Handling & Thermal Testing: 98.96%

Module Yields:

- Mechanical: 99.93%
- Electrical: 99.6%
- Thermal: 99.96%

Question Everything

- The high production quality/rates were made possible by careful planning, inspection, and testing
  - We made everything as uniform as possible
    - Made us maximally sensitive to any problems/changes
  - We studied any anomaly found
    - Discovered serious problems with module components, with mechanical stability, and with electrical sturdiness
  - With sound components, production progressed smoothly which allowed for the extremely high throughput