Tracker Outer Barrel Silicon

Lenny Spiegel

Fermilab

US CMS Silicon Tracker Project

Project Responsibility

The U.S. CMS "Si-Tracker" group will build and test all 5,208* silicon detector modules for the CMS Tracker Outer Barrel (TOB). These will be installed in 688 rods and delivered to CERN.

A rod consists of either 6 or 12 modules (for the R-phi and stereo versions respectively).

- 2/3 of the modules will be built and tested at Fermilab.
- 1/3 of the modules will be built and tested at Santa Barbara.
- All of the rod testing will be done at Fermilab.

*plus spares

Si-Tracker Group

Fermilab

B. Flaugher, R. Lipton, P. Rapidis, L. Spiegel, S. Tkaczyk

Kansas State University

T. Bolton, R. Demina, W. Kahl, S. Korjenevski,
W. Reay, R. Sidwell, N. Stanton

Northwestern University

D. Buchholz

Texas Tech University

A. Sill

University of California, Riverside

G. Hanson

University of California, Santa Barbara

C. Campagnari, D. Hale, J. Incandela

University of Illinois, Chicago

L. Chabalina, C. Gerber

University of Kansas

P. Baringer, A. Bean, L. Christofek, X. Zhao

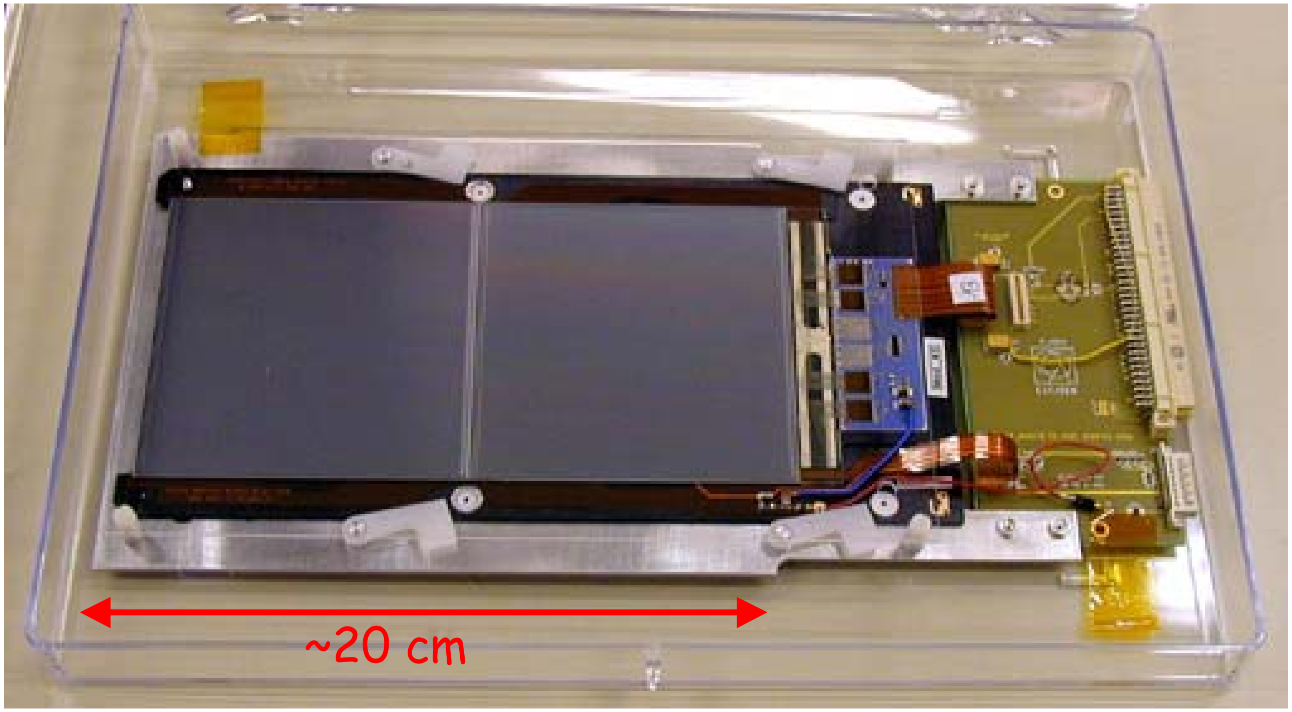
University of Rochester

R. Eusebi, E. Halkiadakis, A. Hocker, P. Tipton

Institutional Responsibilities

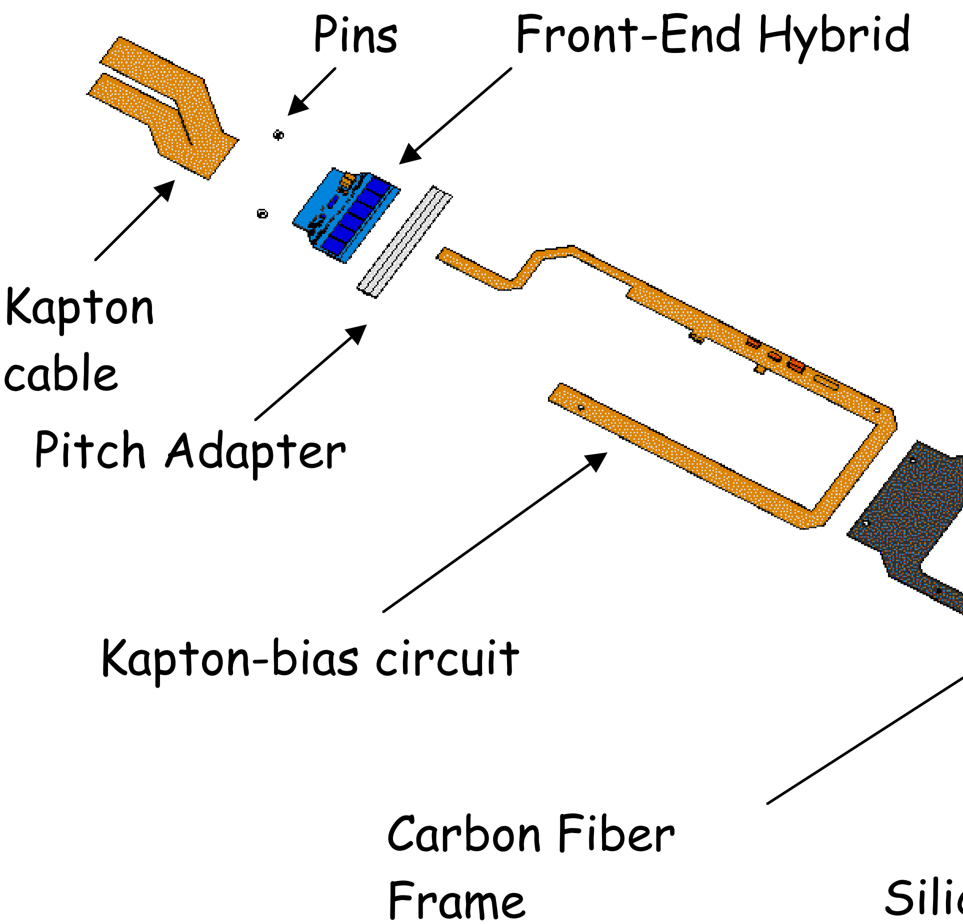
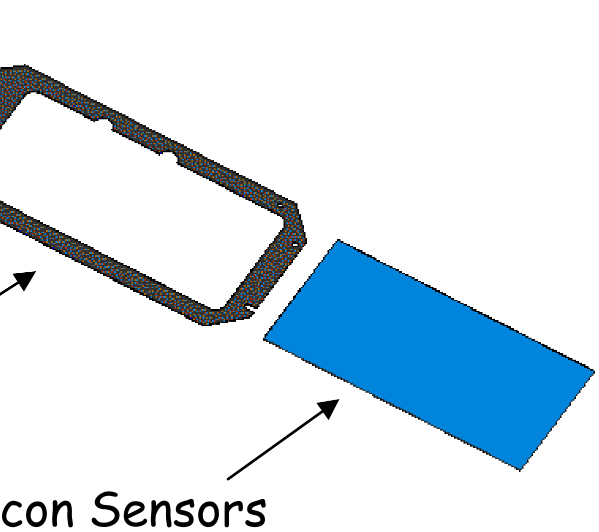
Task	Location	Responsible
Sensor probing	KSU	KSU
Hybrid testing	FNAL	FNAL,KU,UIC
Module assembly	FNAL (UCSB)	FNAL (UCSB)
Bonding	FNAL (UCSB)	FNAL (UCSB)
Module testing	FNAL (UCSB)	FNAL,KU,UIC (UCSB,TTU,UCR)
Optical inspection	FNAL (UCSB)	Rochester
Rod assembly	FNAL (UCSB?)	FNAL (UCSB?)
Cooling setup	FNAL	Rochester
Interlocks	FNAL	Rochester
Quality control	NU, UIC	NU, UIC
Burn-in testing	FNAL	FNAL,KU,UIC
Repair	FNAL (UCSB)	FNAL (UCSB,TTU,UCR)
Transportation boxes	FNAL	UCSB, Rochester,KU
Documentation	FNAL (UCSB)	FNAL (UCSB)

Modules

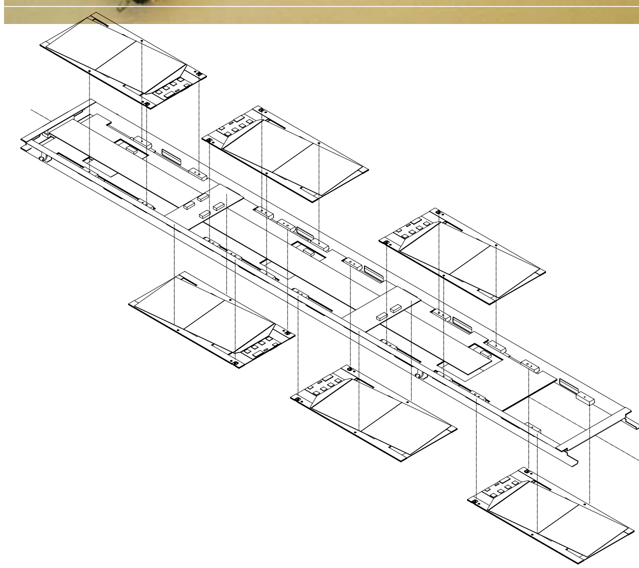


500μ thick, high breakdown voltage sensors. Stereo (0.1rad) units consist of back-to-back modules. Relatively easy to handle but thousands of modules.

Module Components

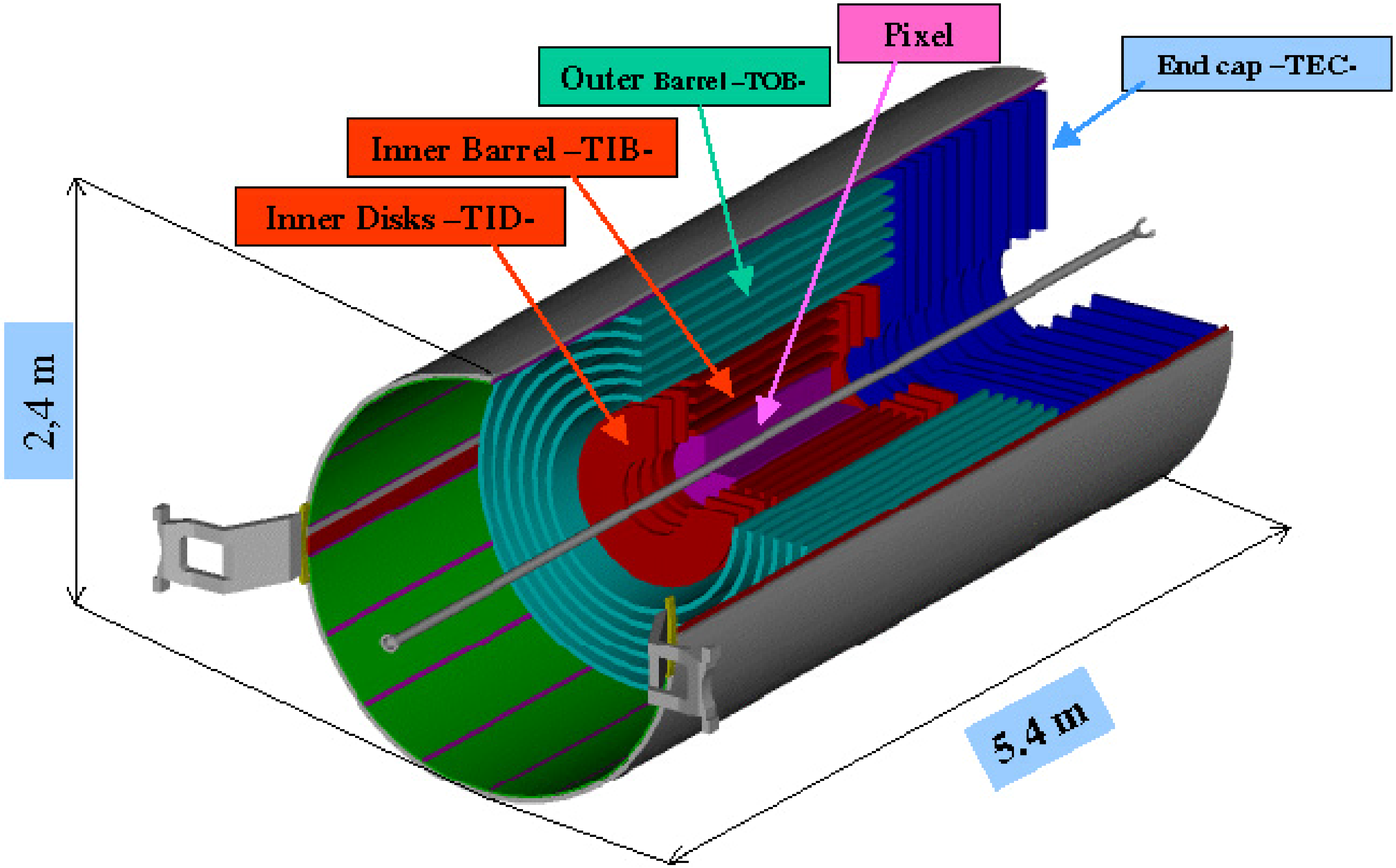
Rods



TOB Geometry

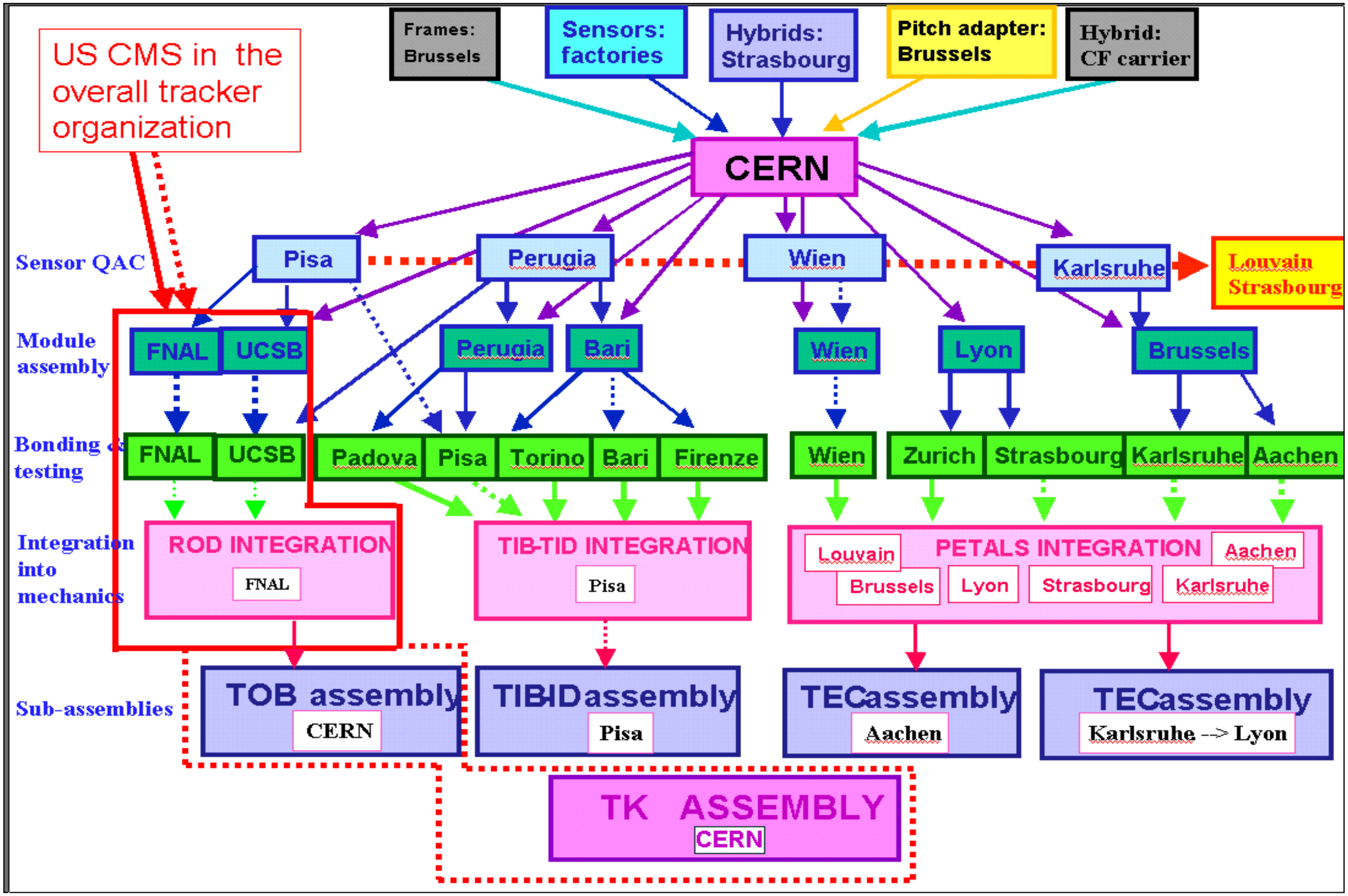
Layer	Avg. radius	Modules / phi	Total # of modules	APV / det	Pitch phi	Pitch stereo	Total # of APVs
TOB1	610	42	504	4 + 4	183	183	4,032
TOB2	696	48	576	4 + 4	183	183	4,608
TOB3	782	54	648	4	183	-	2,592
TOB4	868	60	720	4	183	-	2,880
TOB5	965	66	792	6	122	-	4,752
TOB6	1080	74	888	6	122	-	5,328

CMS Tracker

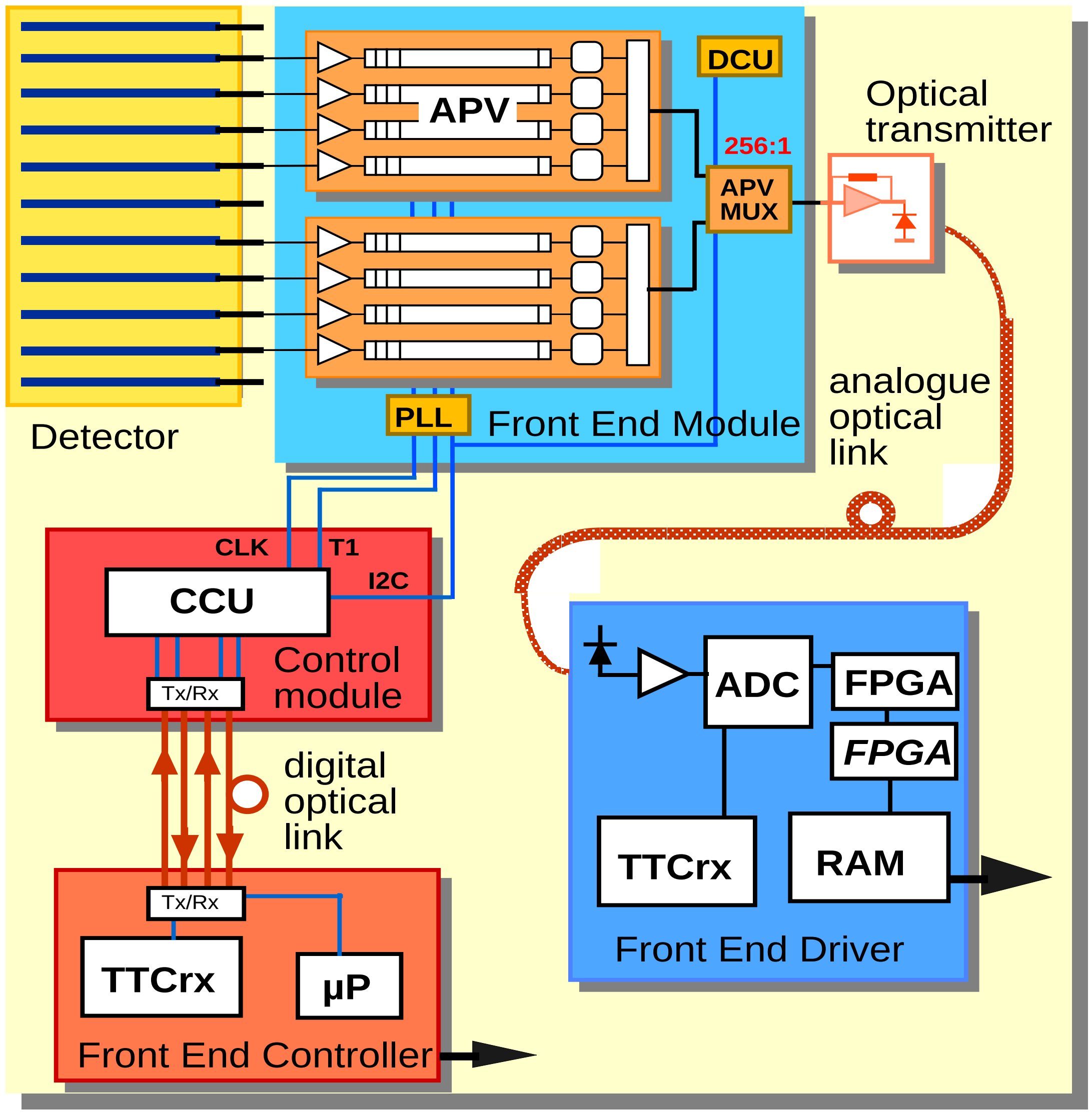


Pixel
End cap –TEC-
Outer Barrel –TOB-
Inner Barrel –TIB-
Inner Disks –TID-
2,4 m
5.4 m

CMS Tracker Organization



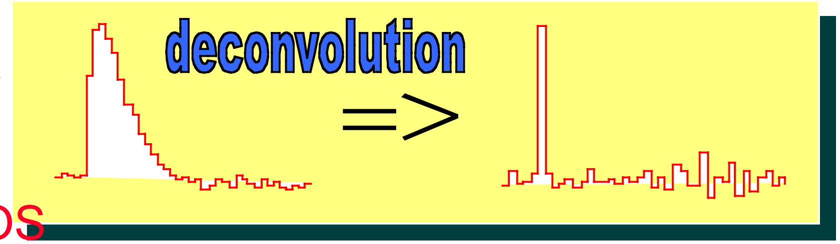
Tracker Readout System



APV History

Pre-history

- 1991… RD20 & deconvolution principle



1992 CMS LoI

1.2µm Harris AVLSIRA radiation hard CMOS

- 1993 - APV3 - 32 channel pipeline chip implementing CR-RC shaping and 3-weight deconvolution signal processing

1994 CMS TP

- 1995 - APV5 - 128 channels with addition of analogue multiplexer
- 1996 - APV6 - 128 channels with analogue multiplexer, bias generator, calibration control, and I^2C interface. Full CMS read-out functionality.
- 1998 - Development of APV6 into MSGC read-out chip, APVM

1998 CMS Tracker TDR

0.8µm DMILL radiation hard CMOS

- 1997-99 - APVD - development of DMILL versions

0.25µm CMOS

- 1998-2000 - development of APV25

1999 CMS all-silicon Tracker

Critical Path Items

- The Tracker group is presently evaluating a recently discovered feature of the APV25.
- The ‘feature’ manifests itself in two related ways - see the next few slides.
- It is very unlikely that the APV25 will be re-designed at this point.
- A test beam study in mid-May should hopefully resolve the remaining concerns.
- **These higher order concerns should in no way detract from the otherwise superb performance of the APVs.**

Four chip TOB hybrid

HIPs and Pinholes

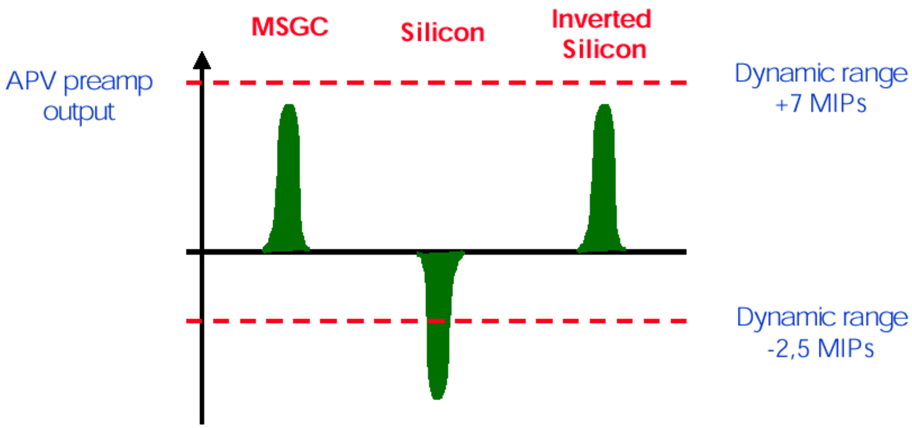
HIPs

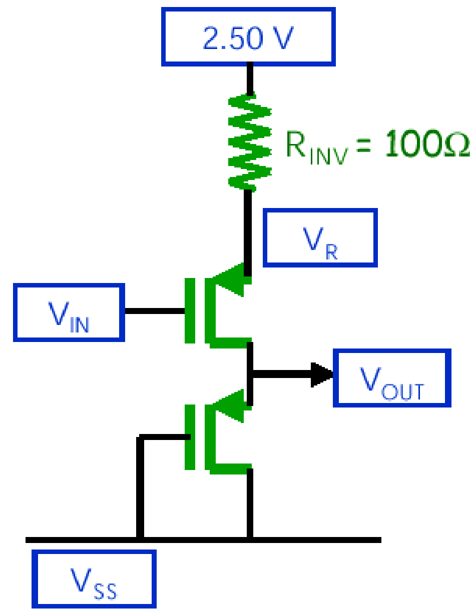
- Highly Ionizing Particle (1000X minimum ionizing) resulting from nuclear interactions in the silicon.
- These are rare events.
  - 3.9 x 10^{-4} per 500μ layer per incident pion.
- HIPs lead to large signals on a few strips.
  - This can saturate (disable) the entire APV (128 channels) for ~200 ns.

Pinholes

- Detector strips are capacitively coupled to the APV.
- The capacitors can occasionally be shorted (pinhole).
  - Leads to a DC current **into** the APV.
  - If enough pinholes are present the APV will be **permanently** disabled (until the pinholes are removed).

MSGC Legacy



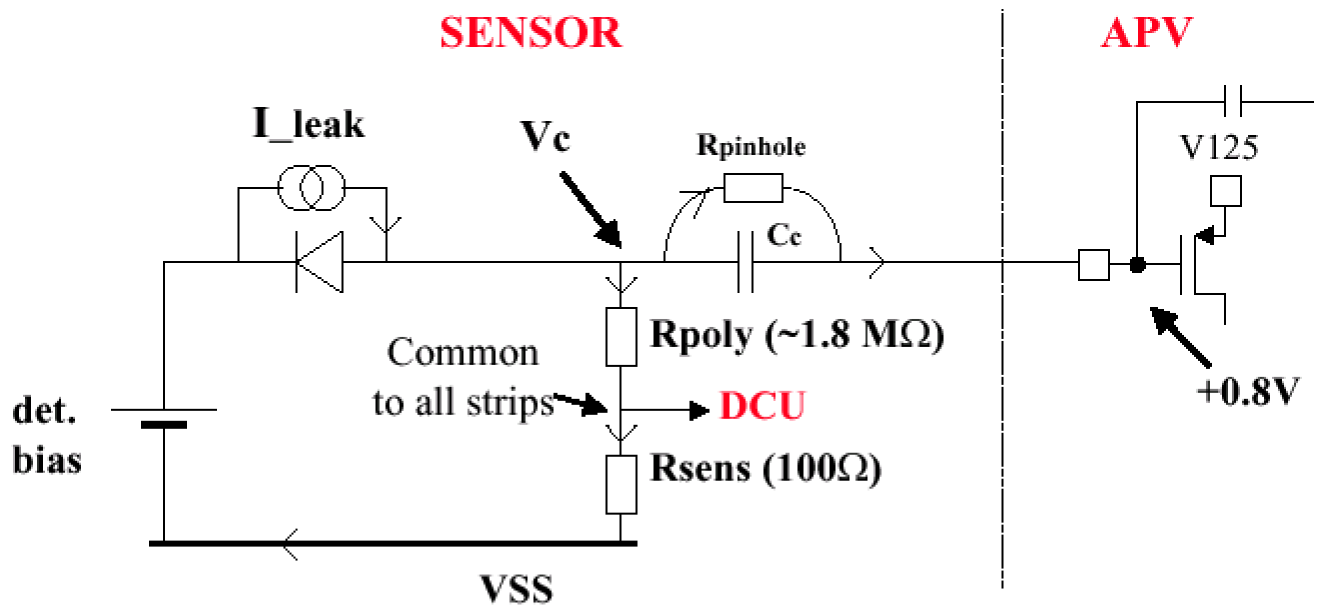


- **Big signal from silicon (holes) gives -ve pulse at V_{IN} :**
  - Inverter FET switches hard on, which steals current from 127 other inverters. (APV disabled until capacitor discharges.)
  - N.B. If R_{INV} were reduced, total current available to inverters would increase.

- **Leakage current via pinhole into APV :**
  - Same again, but permanent.

- **Leakage current via pinhole out of APV :**
  - Inverter FET switches hard off. Takes no current, so other 127 channels still work.

Bias Circuit

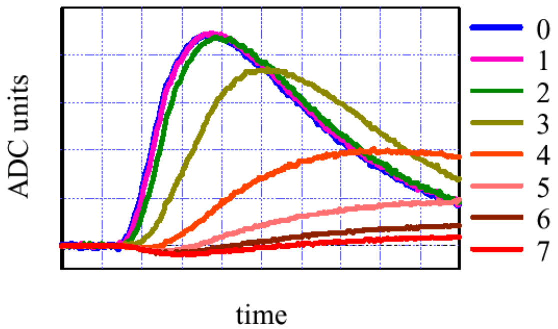


If Vc > 0.8 Volts, current flows into APV via pinhole (BAD).
If Vc < 0.8 Volts, current flows out of APV via pinhole (OK).

V_c will exceed 0.8 V in old (irradiated) detectors with large leakage current.

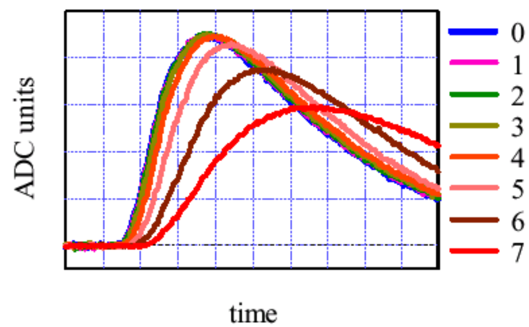
Number of Pinholes

Inject 1 μA of (pinhole leakage) current into 1-7 APV channels.
Then inject a 1 MIP charge into 1 other channel and see what it looks like:



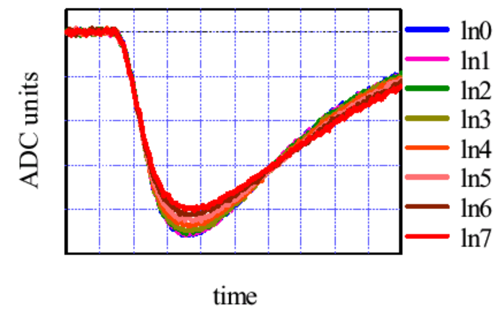
Rinv 100 Ω

Signal suffers if more than 2 pinholes



Rinv 50 Ω

Signal suffers if more than 4 pinholes



APV inverter off

Signal OK for more than 7 pinholes (but reduced dynamic range)

APV Concerns in Perspective

- Both HIP events and pinholes (after installation) are very rare.
  - CDF and D0 Run IIa: “A few pinholes”.
- Both problems can be mitigated by changing R_{inv} from 100 to 50 ohms.
- In cases where there are more than 4 pinholes per APV the inverter can be turned off (with loss of dynamic range).
- It may be possible to avoid the pinhole effect by applying a small voltage to the bias ‘ground’.
- The test beam activity at PSI in mid-May should confirm the understanding of the HIP effect.

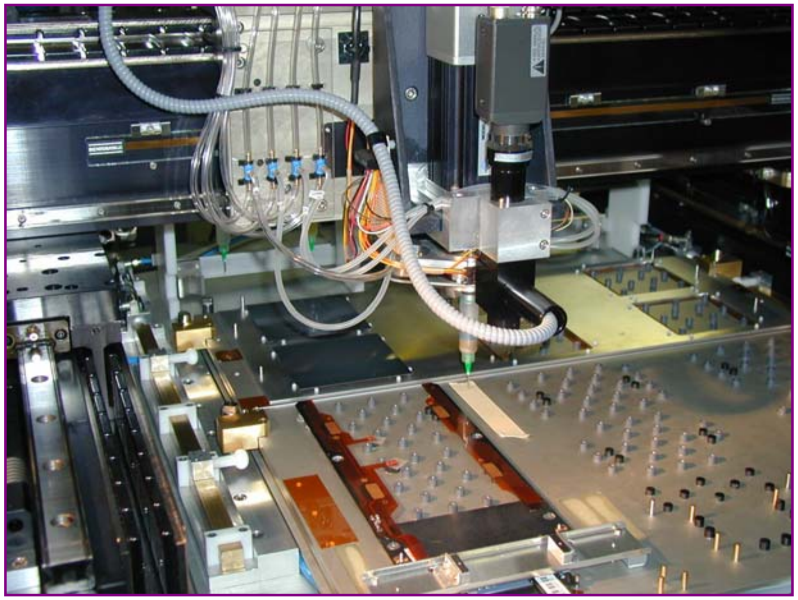
FE hybrid status

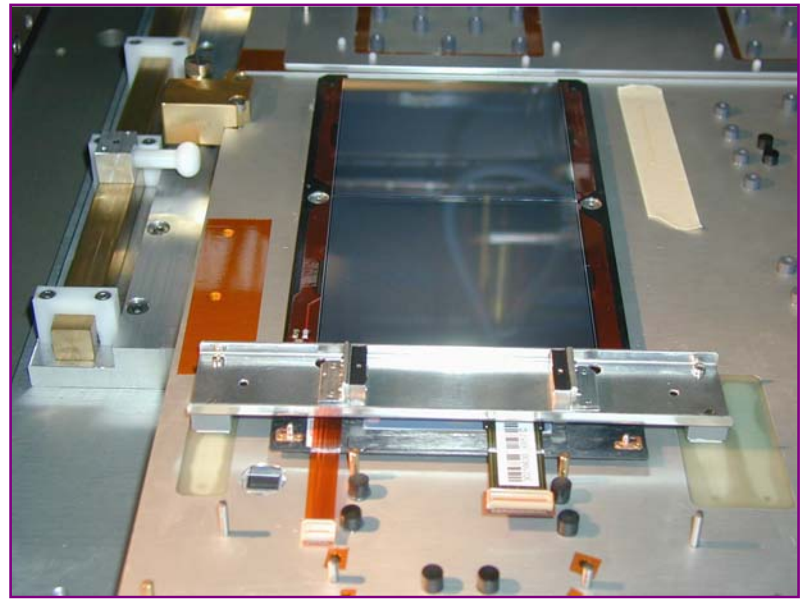
- Industrial hybrid (V0 – unpackaged chips on ceramics) production started with 1st producer. 160 hybrids delivered (yield 65%).
  - Vendor says that “the feature size” is too small for mass production.
- The 2nd producer has problems with shorts.
- (V1) Design of this version of the hybrid (packaged chips on ceramic) is done. Order will go to 1st producer after delivery of the 160(x0.65) hybrids
- (V2) 40 hybrids of this type (packaged chips on FR4) were received in Strasbourg. 10 have been populated and they look okay.
  - Robust media but needs to be evaluated –e.g. thermal issues

Status of Component Orders

- Sensors: Contracts signed
- Frames: Tender finished
- Pitch Adapters: Market Survey (MS) done, Small orders done/prepared
- FE Hybrids: MS done, waiting….
- Optoelectronics: Tenders (4) finished and LOI sent for some contracts
- Central tube Thermal screen: in preparation
- TOB mechanics: one tender finished, one in preparation

Robotic Assembly at FNAL



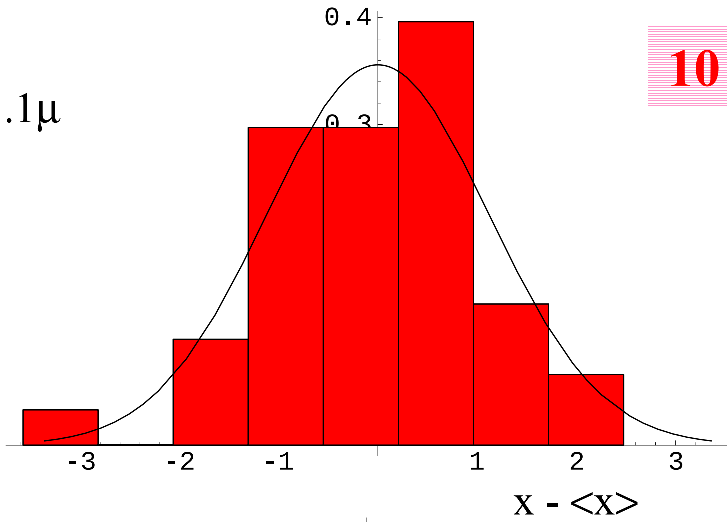


- FNAL pick and place gantry
  - Fully qualified for production
  - **Presently building modules as part of CMS M200 program**
    - **These will be used in the May test beam study.**

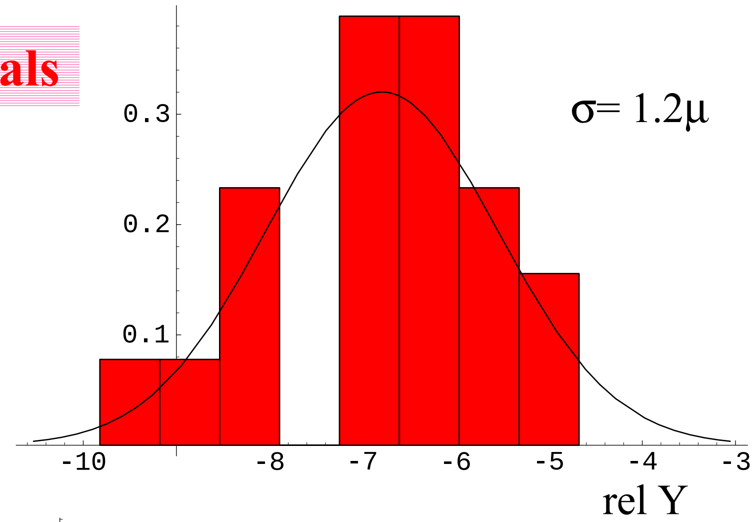
Silicon-Silicon-Frame Assembly

10 trials

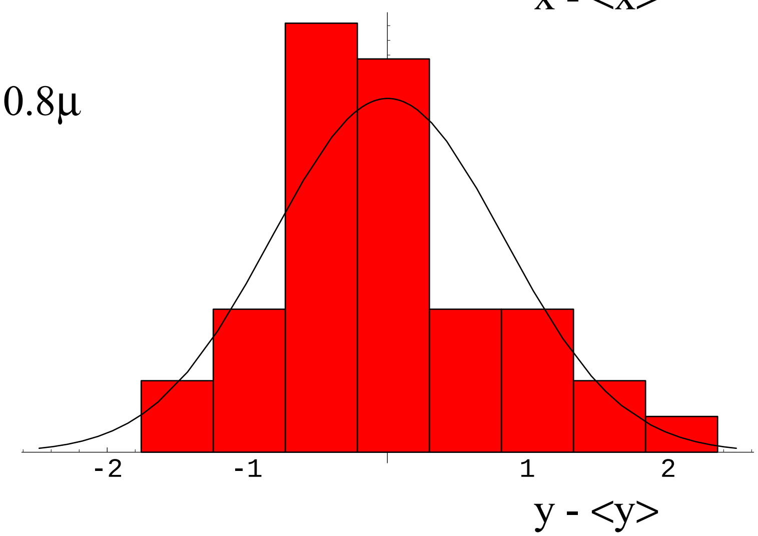
σ= 1.1μ



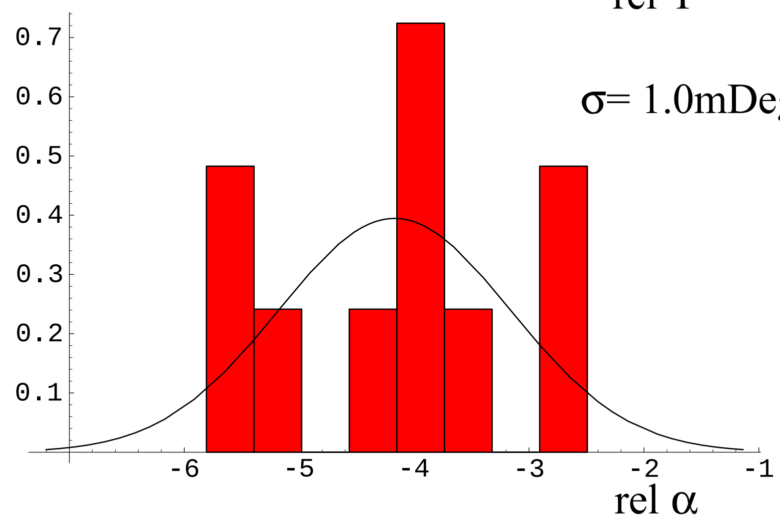
σ= 1.2μ



σ= 0.8μ



σ= 1.0mDeg



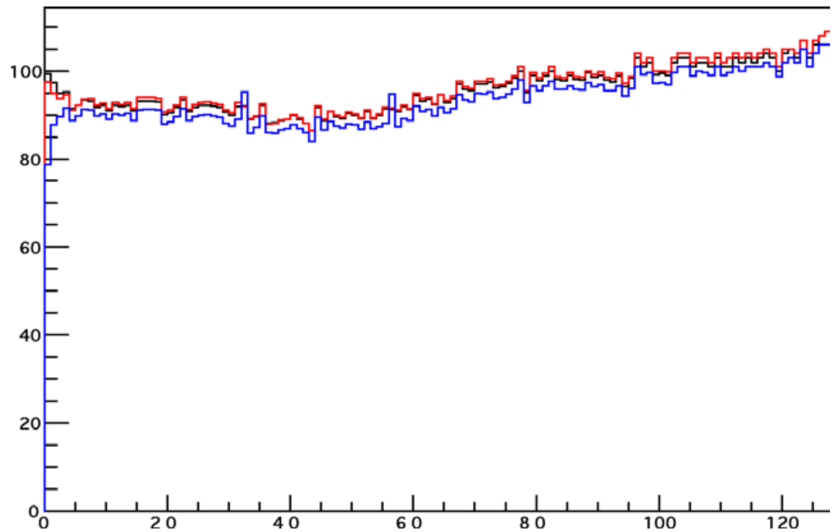
Module Testing at SiDet

ARCS (2/7)

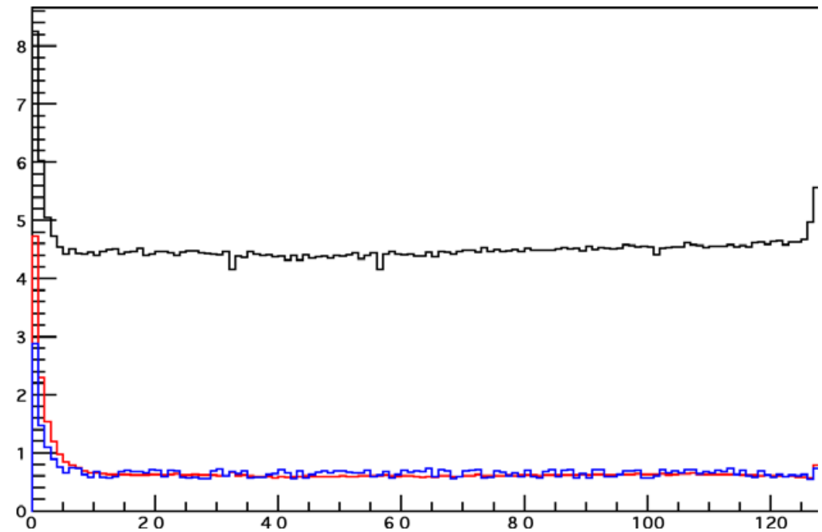
CMS DAQ (3/4)

Two PC-based test systems are now in operation at SiDet. The DAQ system represents a pre-prototype version of the final system.

Module Testing at SiDet



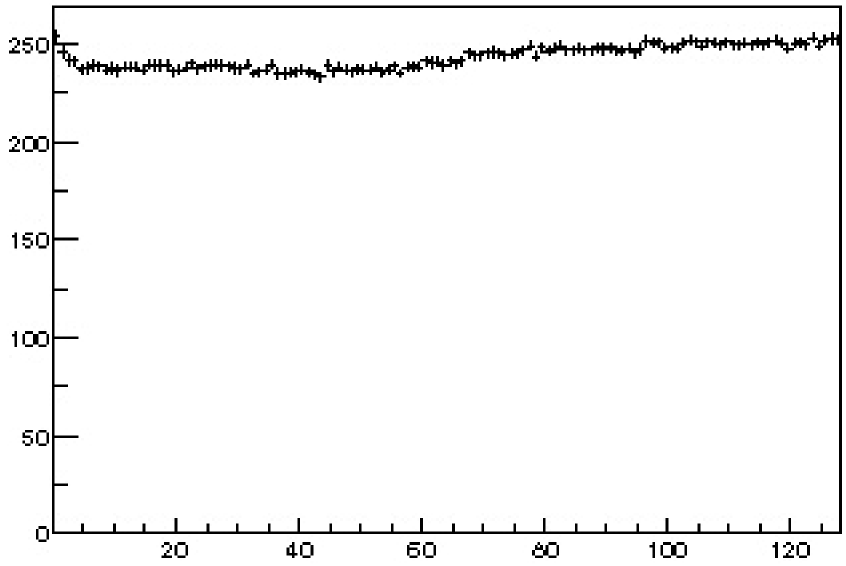
Pedestals



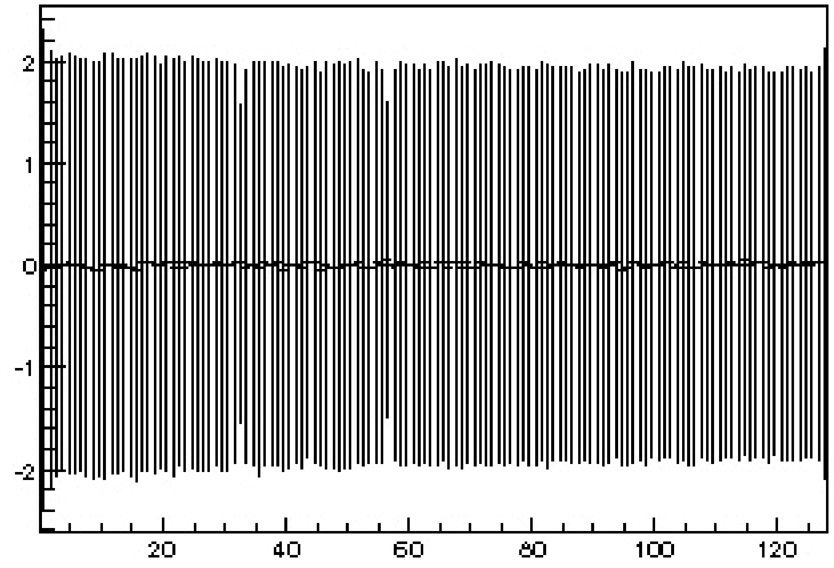
Noise

Results from testing a milestone module at SiDet. Blue = CERN hybrid data; red = FNAL hybrid data; and black = FNAL (unbiased) module data from the ARCS system.

Hybrid + Module



Pedestals



RMS Noise

Same module and chip as before but with detector biased and on the DAQ system.

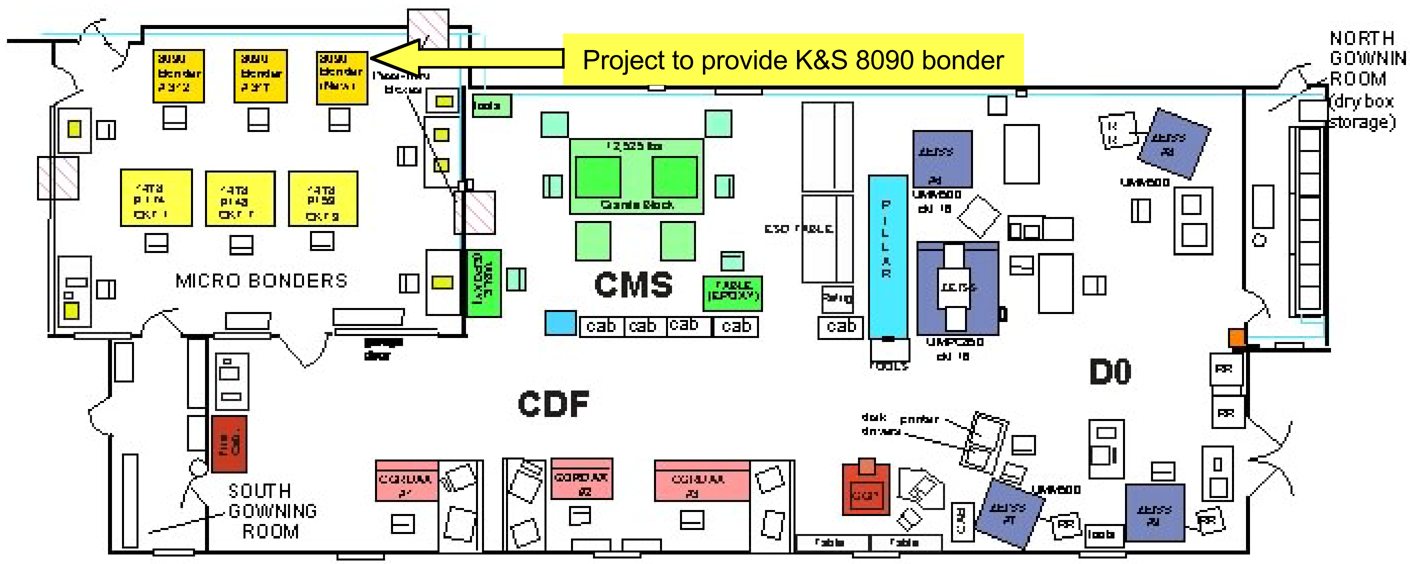
Rod Testing

- We are still planning on performing module burn-in once rods are assembled
  - We are studying use of commercial chest freezers and commercial chillers for the burn-in facility
  - We're in discussion with CERN physicists and engineers to specify the thermal-cycling tests to be done during burn-in.
  - This will drive the design of the cooling and controls.
- We hope to prototype much of the system this summer/fall.
- We are also pursuing using the Vienna tracker group's test box for module testing before rod assembly.

Current TOB Schedule

Task	Start	Finish
Assembly of M200 at gantry	12/01	3/02
Pre-series sensors (ST)	2/02	6/02
Production sensors (ST)	5/02	1/04
Start delivery of TOB sensors to gantry centers		6/02
Frames production	7/02	9/04
Start delivery of TOB frames to gantry centers		8/02
Hybrids pre-production	2/02	4/02
Assemble 400 hybrids	6/02	9/02
Start delivery of 1st batch of 100 hybrids to gantry centers		4/02
Start delivery of 2nd batch of 250 hybrids to gantry centers		8/02
Start delivery of production hybrids to gantry centers		12/02
TOB module construction	1/03	3/05
First 8 production FEDs delivered		6/03
Installation of TOB modules on rods	7/03	4/05
Installation of rods in barrel	1/04	4/05
TOB complete		4/05

Production at SiDet



Lab D Clean Room

Resources at SiDet have been allocated **assuming a significant overlap** between the CMS Si-Tracker project and the Run IIb upgrades.

UCSB Production line

- Significant progress
  - Clean room expanded
  - K&S 8090 wirebonder up and running, operators trained
  - OGP functional – for module inspection
  - Gantry arrived in March
- New groups (TTU and UCR) will provide support to the production line at UCSB.
- Ready for production by year end.

Conclusions

- The U.S. CMS Si-Tracker effort is part of a larger effort to build the CMS Tracker system.
- Our project budget is based on a factory model where we receive quality components on a timely basis and assemble these into modules and rods.
- We will need to be a bit patient until the CMS collaboration is thoroughly convinced as to the viability of the final APV25 + hybrid design and parts become available in sufficient quantity. The current schedule has us starting production in early 2003.
- We are now fully up to speed in terms of building and testing prototype modules at SiDet.
- W need to complete the Santa Barbara gantry and eventually purchase and install the second FNAL gantry and the dedicated K&S 8090 wire bonder.