US CMS Si Tracker [redacted]

J. Incandela

PAC Meeting
Aspen
June 18, 2000

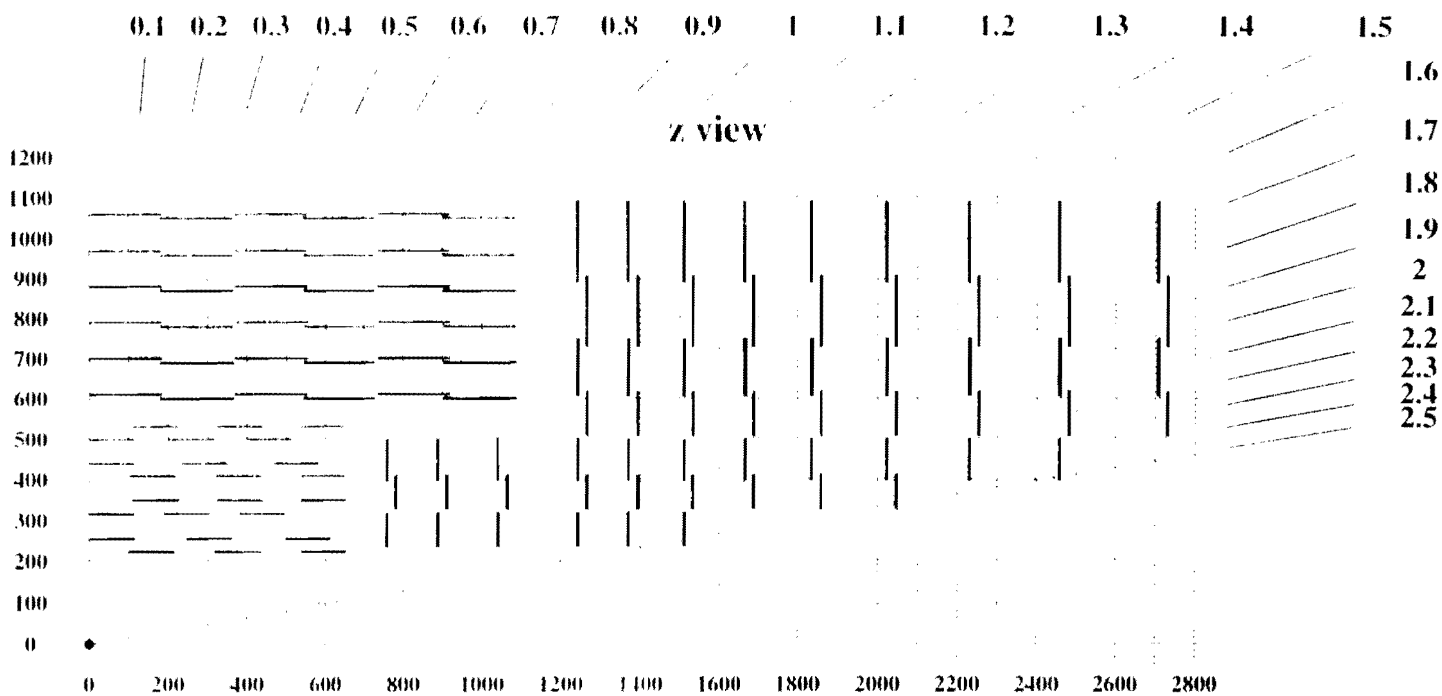
Silicon Tracker Gr

- Fermilab
  - B. Flaugher, J.Goldstein, J.Incandela, R.Lipton, P.Lukens, S.Mishra, T.Nelson, P.Rapidis, L. Spiegel, D. Stuart, S.Tkaczyk
- Kansas State University
  - T.Bolton, R.Demina, M.Kubantsev , W.Reay, R.Sidwell, N.Stanton
- Northwestern University
  - D. Buchholz
- Purdue University
  - I.Shipsey, D.Miller
- University of Illinois, Chicago
  - C.Gerber
- University of Kansas
  - A.Bean, P.Baringer
- University of Rochester
  - S.Blusk, M.Kruse, P.Tipton

Out[redacted]

- Recent Developments
  - All Silicon Tracker Decision and Current Layout
- Organization of CMS tracker group into consortia
  - Role of proposed US Consortium
- Cost and Schedule

Tracker Layo



- December 1999 - Decision to use silicon in the outer tracker.
- April 2000 - New Layout approved
  - 10 barrel layers, 3 small disks and 9 forward disks.
    - 5 barrel layers and 3 disk rings rings have 100 mrad stereo (blue)
    - Increase surface area from < 100 m^2 to ~240 m^2

Desc

- Tracker Inner Barrel (TIB)
  - 4 layers with 300 μm thick sensors.
    - Modules tilted 9° in "shell" support mechanics
    - 2 innermost layers DS
- Tracker Outer Barrel (TOB)
    - 6 layers with 500 μm thick sensors
    - Layers 1,2 and 4 DS
  - Modules contained in "rod" support mechanics
- Tracker Small Disks (TSD)
  - 3 small end-cap disks/end
    - Each has 3 rings
    - Rings 1 and 2 are DS
    - 300 μm thick sensors
  - "petal" support mechanics
- Tracker End Cap (TEC)
  - 9 large end-cap disks/end
    - each has 7 rings
    - 3 inner rings same as TSD
    - Ring 4 has 300 μm thick sensors
    - Outer 3 rings have 400 to 500 μm thick sensors
    - Rings 1,2 and 5 are DS
  - "petal" support mechanics

Barrel [redacted]

TIB

Layer	Radius [mm]	Modules In ϕ	Total Modules	APV Chips	ϕ pitch [μm]	Stereo [μm]	Total APV's
1	239	28	336	6+6	80	80	4032
2	331	38	456	6+6	80	80	5472
3	423	46	552	4	120	-	2208
4	515	56	672	4	120	-	2688

TOB

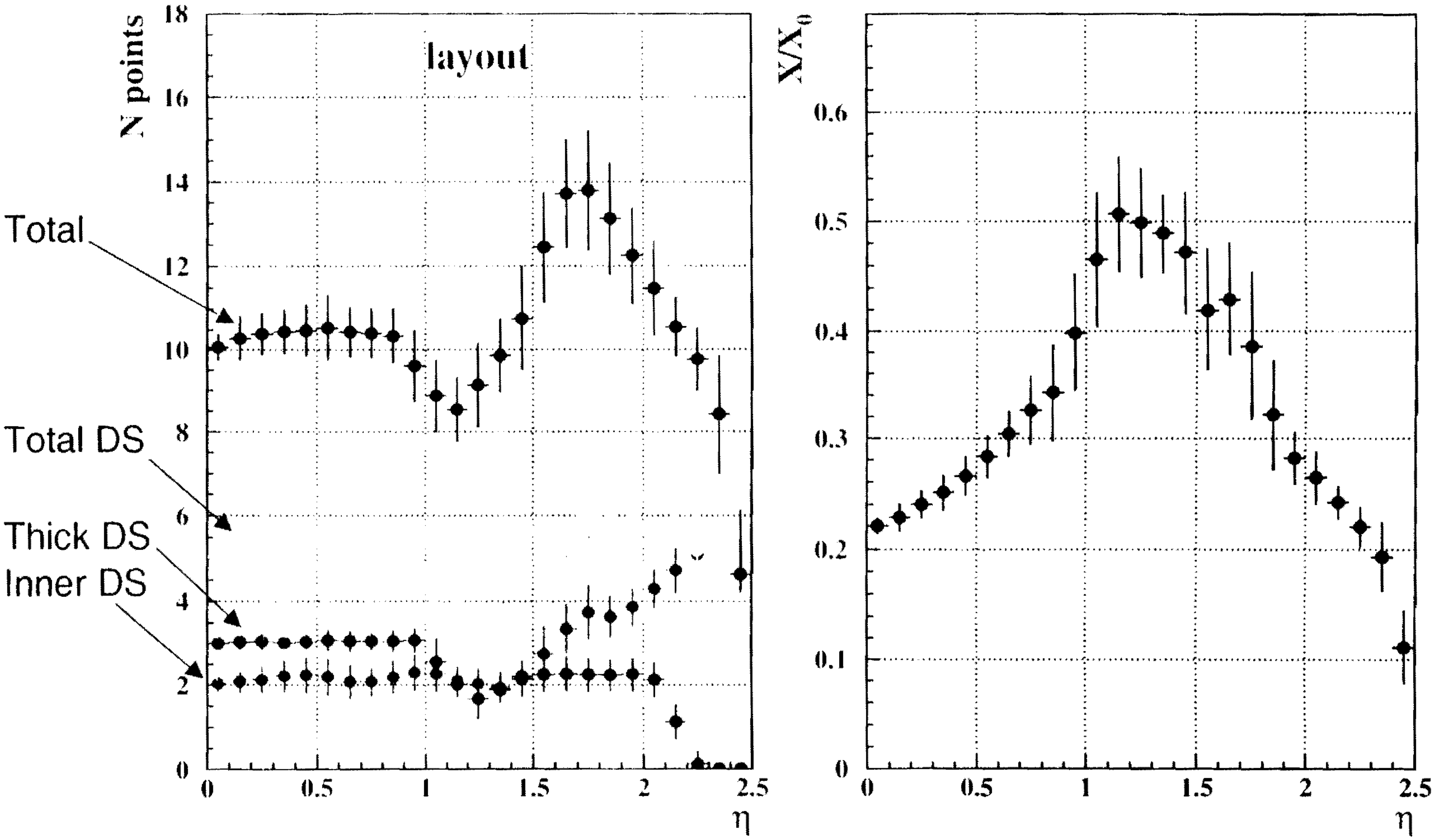
Layer	Radius [mm]	Modules In ϕ	Total Modules	APV Chips	ϕ pitch [μm]	Stereo [μm]	Total APV's
5	605	42	504	6+4	122	183	5040
6	695	48	576	6+4	122	183	5760
7	785	54	648	4	183	-	2592
8	875	60	720	4+4	183	183	5760
9	965	66	792	6	122	-	4752
10	1055	74	888	6	122	-	5328

Forward [redacted]

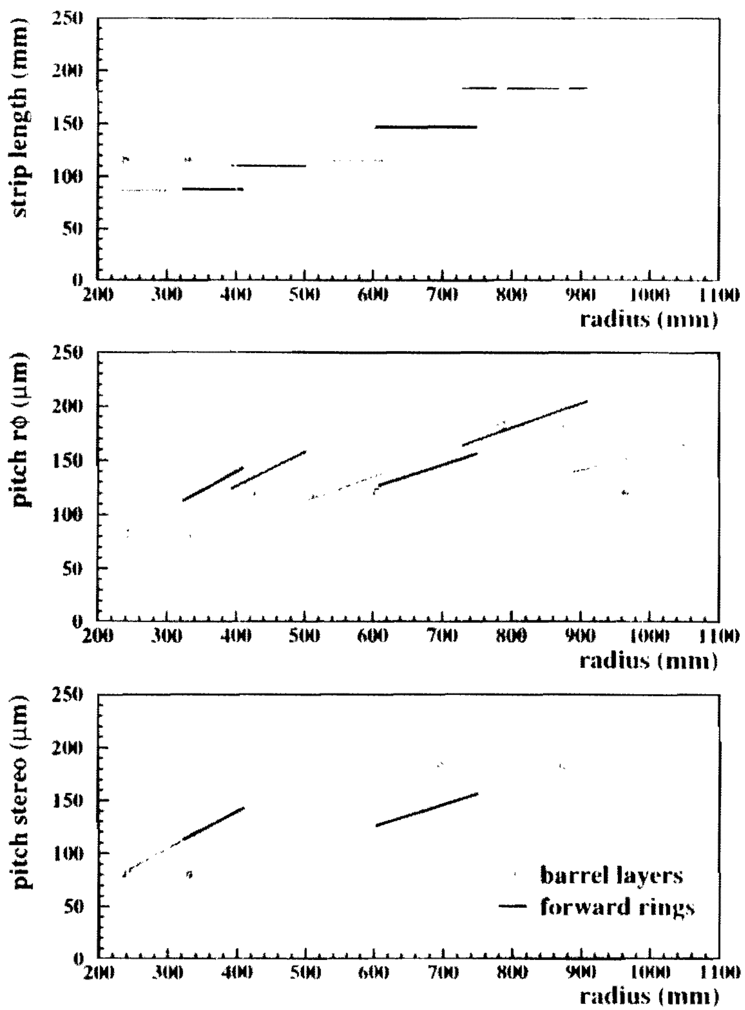
TSD + TEC

Ring	Modules In φ	No. of Rings in z	Total Modules	APV Chips	Pitches φ [μm]	Stereo [μm]	Total APV's
1	24	12	288	6+6	81/112	81/112	3456
2	24	18	432	6+6	113/143	113/143	5184
3	40	22	880	4	123/158	-	3520
4	56	18	1008	4	113/139	-	4032
5	40	18	720	6+6	126/156	126/156	8640
6	56	18	1008	4	163/205	-	4032
67	80	18	1440	4	140/172	-	5760

Layers,Material traverse



Pitch vs Radius



- TIB
  - 1224+ 792 SS+DS modules
  - 2808 6” wafers
  - 14400 APV chips
  - 5.5 M wirebond wires
- TOB
  - 2328+1800 SS+DS modules
  - 11856 6” wafers
  - 29232 APV chips
  - 11.2M wirebond wires
- TSD+TEC
  - 1888+720 thin SS+DS modules
  - 3328+2448 thick SS+DS
  - 3328+7776 thin+thick 6” wafers
  - 34624 APVs
  - 13.3 M wirebond wires

Tracker Group Organ

- 4 Consortia with proposed roles as follows:
  - Central Europe (CE): (previously MSGC groups)
    - All Forward Modules (TSD + TEC) and installation in pedals.
    - Assembly of TSD+TEC
  - CERN
    - Overall integration, general support structures, cooling and inert gas flow. Position monitoring and alignment. Mechanics, cooling and final assembly of the outer barrel....
  - INFN
    - Responsible for Inner barrel modules (TIB)
    - TIB Mechanics and assembly of the inner barrel.
  - USA
    - All Outer barrel modules (TOB) and installation on rods
    - assemble some support structures for inner barrel

LHCC

The LHCC has approved the Tracker TDR Addendum during its last session 17-18 May. The LHCC believes that the full silicon tracker as proposed by CMS is very elegant. The simplified layout has many virtues. I append an extract from a message sent by Giorgio Goggi to the EP Division:

'Addendum to the Tracker TDR: streamlined concept and enhanced performance.Very good progress on layout, logistics, maintenance, installation, detector and system design'

Congratulations to the Tracker community for this beautiful achievement.

- Michel

Tracker Outer Barrel

l=91.514	
w=93.696	
dl=1.5	
dw=1.35	P1=122
gap=0.1	P2=183
2*l+2*dl+gap=186.128	
Ltot=189.128	
Wtot=96.396	

- ϕ(stereo) pitch = 122 (183) μm
- Sensors sensitive areas 91.514 x 93.696 mm^2
- Assumed non-sensitive regions 1.5 (1.35) in length (width)
- Gap between two sensors 100 μm
- Length (width) of silicon in module = 189.128 (96.396) mm

Tracker S

- Preproduction (200 modules) Nov.2000 - Aug.2001
  - TOB (US CMS) will build roughly 80 modules
  - The exercise calls for use of final production methods
    - We need to set up a gantry system (purchase in early FY01).
    - We need to setup a test stand and some preliminary version of a burn-in system with interlocks this Autumn/Winter.
    - Right now many parts are being purchased/prepared for us in Europe. We will need to pay for them in FY 01.
- Module Production Aug. 2001 - Jan. 2004
  - TOB however needs to be completed earlier
    - Installation of rods into the outer wheels Jun.2003 - Dec.2003
    - We would aim to complete module production by Autumn 2003

  ⇒Overlap with FNAL Collider Run 2b silicon upgrades

Production Tas[redacted]

- Technician tasks included in cost estimation:
  - Probing of sensors (few % of total)
  - Module assembly and Module inspection (~10 % of total)
  - Wirebonding (average of ~5 APV/module x128 channel/APV x 2 wires/channel = 1280 wires/module)
  - Repairs (Minor repairs at 50% level ? Significant repairs 5% level ?)
  - Testing (hybrids and completed modules)
  - Sandwiches of 2 Single Sided modules for Double Sided layers
  - Installation on Rods (6 modules per)
  - Burn-in on rods
  - Quality assurance testing (0.2% to 10%)
  - Receiving and shipping of components and completed rods
  - Documentation and inventory control
- All setup of procedures and all production and testing will be managed and overseen by physicists in the group (in shifts)

Relevant [redacted]

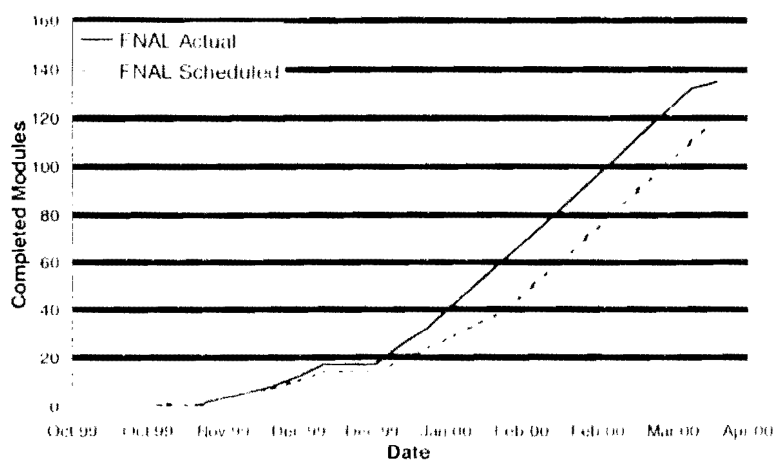
- CDF ISL Module Production
  - Simple module design w/Hybrids mounted off silicon
  - Construction is not difficult:
    - Assembly less than 1.5 h.
    - Wirebonding ~ 1 h.
    - Repair ≤ 1 h per module.
- CDF L00 single-sided silicon
  - An industrial product: High quality, rad-hard, Short lead times
    - From final specifications to delivery of all CDF L00 silicon was ~4 months. CMS prototypes similar experience.
  - Commercial capacity:
    - HPK can start 10k wafers/mo.
    - ST-Catania has similar capacity

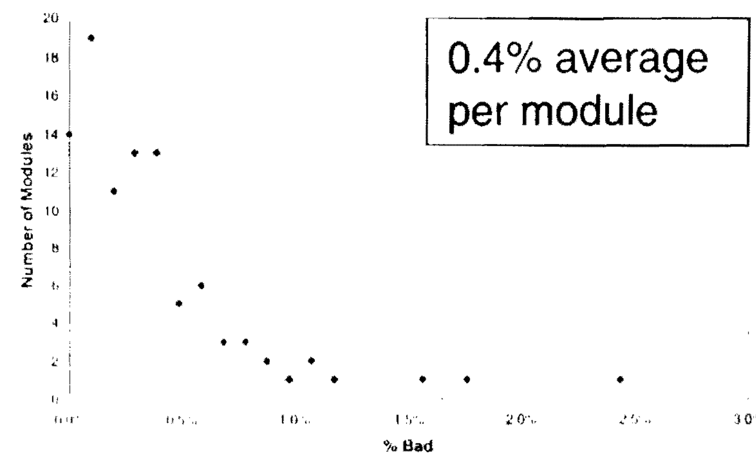
Rad-tolerant Layer 00 Silicon (HPK)

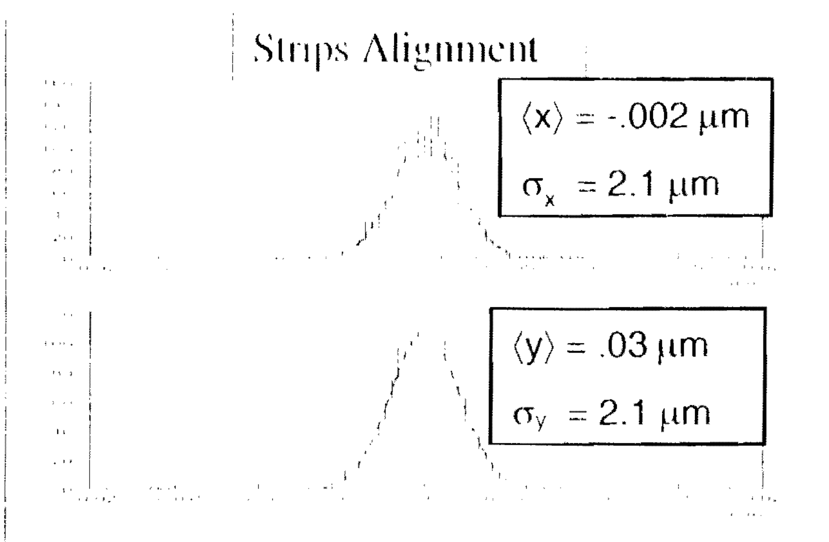
Specications	wide	narrow
# channels	256	128
active area (cm^2)	9.7	4.8
implant pitch	$25\mu m$	
readout pitch	$50\mu m$	
implant width	$8\mu m$	
Test Results		
bad strips (@100 V)	0.10 %	0.047 %
depletion voltage	≈65 V	≈65 V
current @ 500V (nA/strip)	0.5-1.0 typ.	0.5-0.8 typ.

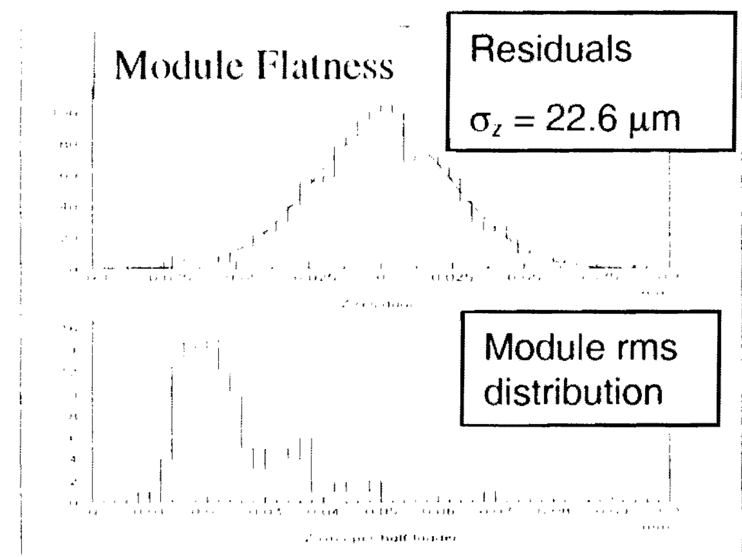
single-sided p-in-n silicon

CDF ISL Exper[redacted]

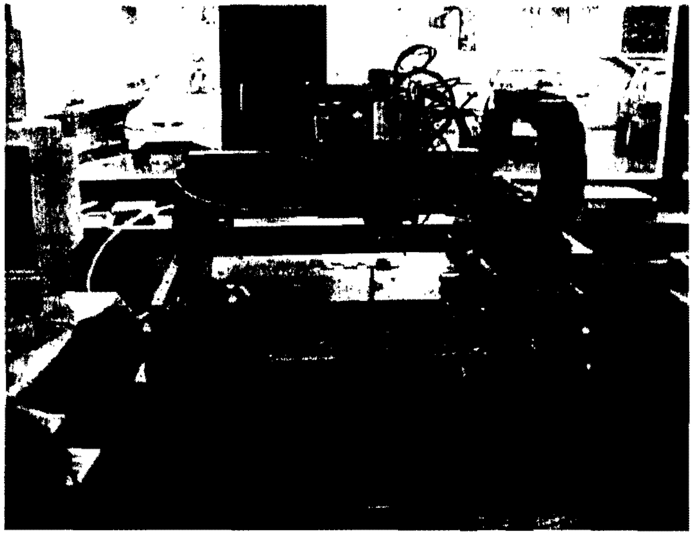


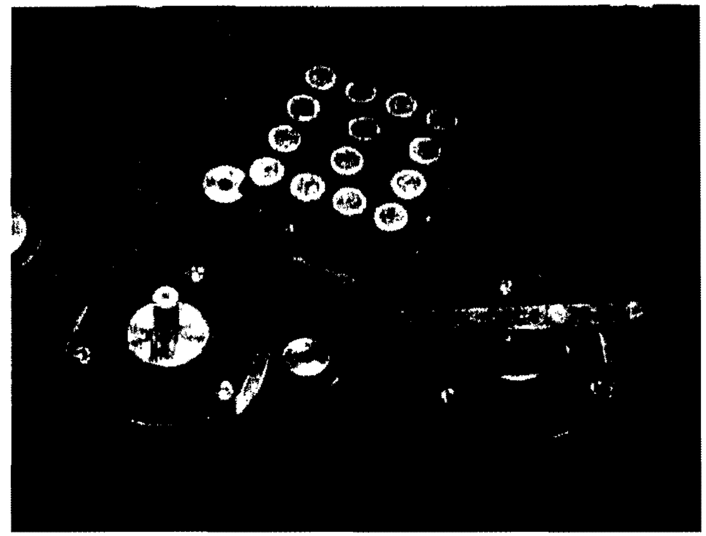




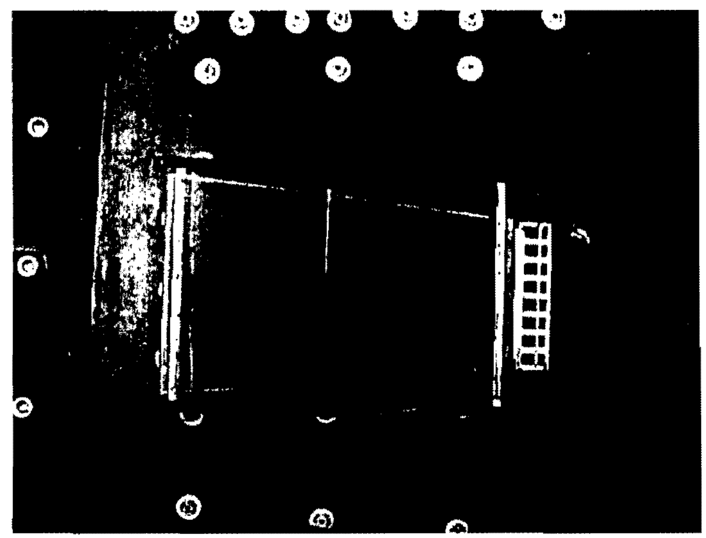


Automated

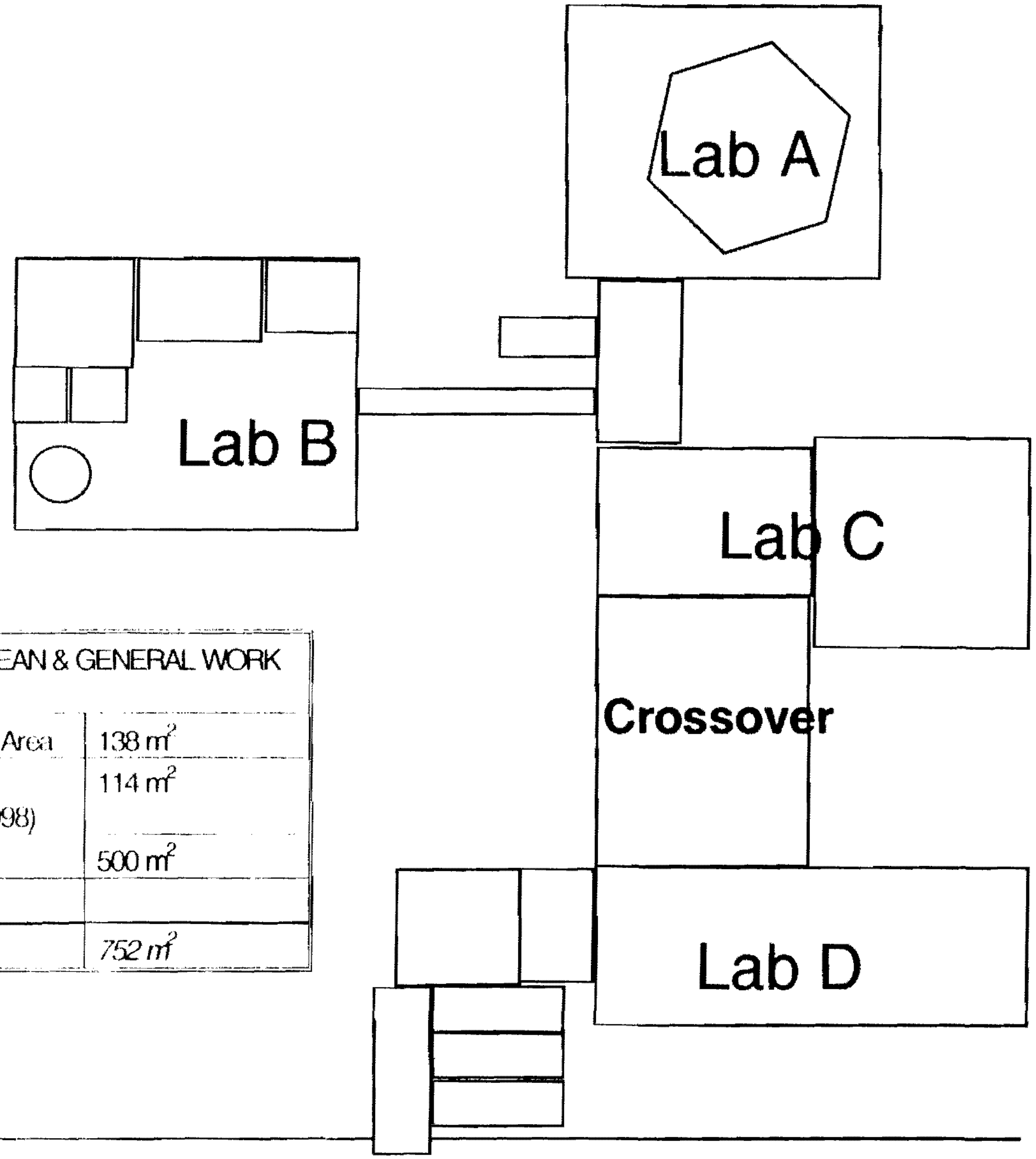




- CERN Automatic pick-and-place
  - Off the shelf hardware
  - Vacuum pieces by CMS
  - 1-2 technicians can assemble 3 TOB modules per hour
  - With 2 K&S 8090 Aluminum wedge wirebonders FNAL can wirebond 4 modules per hour



SiDet Space



CLEAN ROOM		SEMI-CLEAN & GENERAL WORK	
Lab D	218 m^2	Lab D Test Area	138 m^2
Lab D extension	74 m^2	Crossover (Autumn 1998)	114 m^2
Lab C	293 m^2	Lab B	500 m^2
Lab A	272 m^2		
Total	*857 m^2*	*Total*	*752 m^2*

SiDet [redacted]

- Coordinate Measuring Machines
  - 16 in service, ~20 trained operators
- Wirebonders
  - 5 in service ~9 trained operators

COORDINATE MEASURING MACHINES

MACHINE	CNC/ MANUAL	MEASURING RANGE (X-Y-Z IN METERS)			VOLUMETRIC ACCURACY (MM)
Brown & Sharpe XCEL 123010/5P/UHA	CNC	1.2	3.0	1.0	.012/900
Brown & Sharpe XCEL 091509/5P/UHA	CNC	1.0	0.9	1.5	.012/900
LK G80C	CNC	1.0	2.0	0.8	.013/450
Zeiss UMC850	CNC	0.85	1.2	0.8	.010/400
Zeiss UPMC850	CNC	0.85	0.7	0.6	.008/400
6 Zeiss UMM500	CNC	0.5	0.2	0.3	.005/200
Giddings & Lewis 1808 MZ (2 machines)	CNC	1.0	0.625	0.5	.012/400
Giddings & Lewis 1808 MH	MANUAL	1.5	0.625	0.5	.018/400
Giddings & Lewis 1808 MEA (2 Machines)	MANUAL	0.75	0.625	0.5	.016/400

OPTICAL MEASUREMENT SYSTEMS

MACHINE	MEASURING RANGE (X-Y-Z IN METERS)			PLANAR ACCURACY (MM)
OGP Avant 600	0.45	0.61	0.15	.013/300
Metronics	0.2	0.15	0.15	.013/300

OTHER EQUIPMENT

2 Kulicke & Soffa 8090 Automatic Wirebonders - 5 Hz auto. Bond rate
3 Kulicke & Soffa 1478 Automatic Wirebonder - 1 Hz auto. Bond rate
1 Hughes 2470 V Automatic Deep access wirebonder
1 Kulicke & Soffa Manual (deep access) Wirebonder
4 Probe stations
4 Laser test stands with xy-tables
6 stereo video Microscope with xy-tables for inspection and repairs
2 Omis-II systems

Organization

- Organize main production at FNAL assisted by physicists from all participating institutions
  - Management and QA shifts
  - Transport to CERN
- Outside Institution Roles:
  - Sensor Probing (5-10%)
  - Design/build multi-rod burn-in case(s) w/cooling&interlocks
  - Modules repair
  - Module QA Testing (irradiation/beam-tests/cosmics/lasers)
  - Contingency production
    - To limit conflict with Run 2b, we could set up a second production center outside of FNAL

Division o

Task	Location	Responsible Party
Sensor probing	Universities	UIC, KSU, Northwestern
Hybrid testing	FNAL	KU
Module assembly	FNAL	FNAL
Bonding	FNAL	FNAL
Testing	FNAL	FNAL,KU
Rod assembly	FNAL	FNAL
Cooling setup	FNAL	Rochester,FNAL
Interlocks	FNAL	Rochester,FNAL
Quality control	UIC,KU	UIC, Northwestern
Burn in testing	FNAL	FNAL,KU
Repair	FNAL,Purdue	FNAL,Purdue
Transportation Boxes		Rochester

TOB Module Produ[redacted]

- Preliminary Production model
  - ~ 6000 + 600 + 80 SS equiv. modules + spares
    - Pre-production 80 modules complete by Spring 2001
    - Ramp up with 600 modules Spring 2001 to Oct. 2001
    - Production of 6000 modules Oct. 2001-Oct. 2003
  - Contingency
    - Add 25% labor for continuity
    - Assume that for 6 months we must double our rate
- Production Rates & capacities (At Fermilab)
  - Basic Production Rate = 12 modules/day
    - Pace requires ~70% of a gantry robot, 66% of a K&S 8090 wirebonder, burn-in capacity for 36 modules.
    - Not a lot of space is required.
  - Double rate
    - We need to be prepared to step up to 24 modules/day
    - The only critical issues for SiDet will then be wirebonding capacity and perhaps testing&burn-in space.

TOB Module [redacted]

- Preliminary Production model continued
  - Probing and Repairs (To be done at possibly one or two other collaborating institutes as well as FNAL)
    - Probing (Kansas State University)
      - We can only probe a fraction of all sensors thoroughly. We assume this will be no more than 5-10%. Probing will be done at Universities.
    - Module repairs (FNAL and Purdue)
      - Will likely be at a low level due to the simplicity of the modules and the robustness of the single-sided silicon. We expect two basic classes
      - Simple Repairs (plucking bonds on channels with pinholes) can be done at FNAL
      - Complicated repairs that require more significant debugging may be done outside of FNAL in order to not disrupt production.

TOB Module Produ

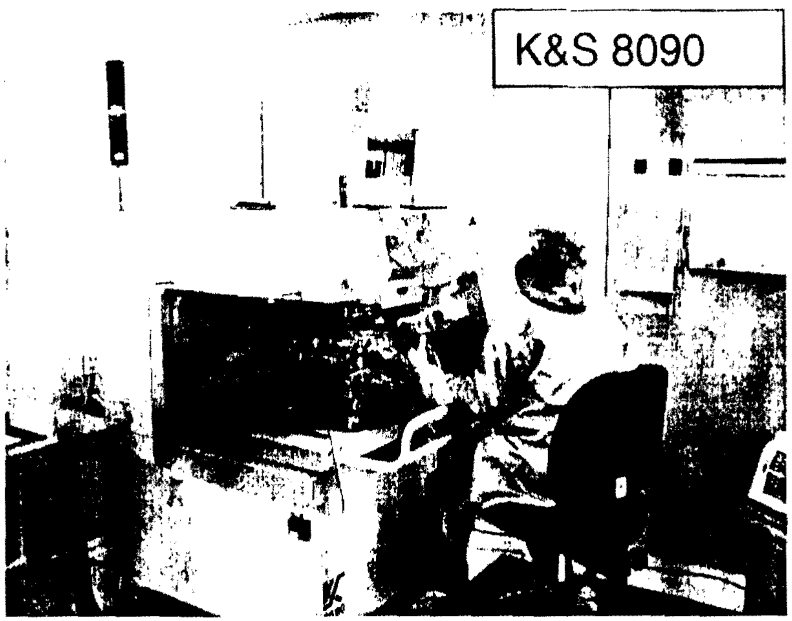
- Preliminary Production model continued
  - Hybrid and module testing & burn-in (FNAL & KU)
    - KU will help to setup test stands at FNAL
  - Extended Quality Assurance Testing (Northwestern & UIC)
    - Sample Testing - to assure quality production of modules at regular intervals in production period
      - Laser Scans (few % level) at FNAL
      - Cosmic Ray tests (Could be done on a stack of loaded rods - maybe even during burn-in at FNAL)
      - Radiation Studies (~0.2% level)

Sidet

- Equipment Requirements
  - Module Assembly: two robots (or 4 CMMs)
  - Cylinder Assembly: 3m B&S CMM
  - Test stands: 4 for module testing, 1-2 for burn-in system
  - Wirebonding: 1-2 K&S 8090 equivalent
- Space
  - Module, Rod, and Cylinder Assembly
    - 100-150 m^2 clean space (~20% of SiDet clean space)
  - Burn-in
    - Roughly half of the Run 2 burn-in space (55 m^2)
  - Storage
    - Plan to receive and ship frequently. Space requirements for storage should therefore be relatively modest.

Space & Equipm

Wirebonding



- SiDet has 5 automatic wirebonders now:
  - 2 K&S 8090
  - 3 K&S 1478
- Run 2 projects peak rate ~3M wires over ~8 months
- TOB: 8M wires in 2.5 years
  - K&S 1478 ⇒
    - 4 modules/shift/machine
  - K&S 8090 ⇒
    - 12/shift
  - Total capacity
    - 36/shift
- Project model ⇒
  - peak at ~67% of capacity.
  - If steady flow then 33% only

Goals

- Schedule
  - We use our experience to plan production in such a way that the probability of on-time completion is extremely high.
- Quality Goals
  - As perhaps the most experienced silicon group in CMS we intend to produce exceptionally high quality modules
    - Minimal losses and maximum quality
      - During pre-production and ramp we will develop iron-clad assembly and wirebonding procedures
        - » With SS sensors, there are ~0.1% inherent bad strips. It may be possible to fabricate with negligible increase in the bad strip count. We want to add no more than ~0.1% additional bad strips. This not only results in better quality, it reduces our work load.
    - Fast feedback to minimize faults
      - We plan to get from module assembly to final electronic test with a minimum of modules in between.

Labor Fo[illegible]

Production Phase	Duration	Modules	Technical Labor Cost
Pre-production	5-6 months	80	31k$
Ramp-up	6 months	600	119k$
Production	2 years	6,000	913k$

Estimates	Modules	Years	Modules/d	Probers	Assembly	Inspect	Bond	Repair	Test	Burn-in	Doc/S&R	Total	Man-years	Cost
Manual	6000	2	12	0.4	4.0	0.4	1.7	0.2	1.5	0.9	1.2	10.3	20.7	$1,127,958
Semi Auto	6000	2	12	0.4	1.5	0.4	1.7	0.2	1.5	0.9	1.2	7.8	15.7	$854,958

- Labor Model
  - Based on CDF ISL
    - Conservative - the base estimate is high by 20-30%
  - Add 2 types of contingency (43% total)
    - Manpower continuity
    - Double peak rate for 6 months
- Module Labor = 1,063 k$ + 457 k$ contingency = 1,520 k$

Equipment, EDIA, Tran[redacted]

- Equipment costs

Item	Base	Contingency	%
Probe Station	50k$	22k$	44
Assembly Equipment	211k$	68k$	32
Wirebonder Equipment	66k$	264k$	400
Test Stands	225k$	126k$	56
Burn-in cooling stand & interlocks	100k$	56k$	56
Clean Room Supplies	60k$	13k$	21
Miscellaneous Instrumentation	50k$	63k$	125
EDIA	378k$	166k$	44
Equipment Setup & Maintenance	110k$	93k$	85
Storage, test & shipping boxes	115k$	76k$	66
Transportation	102k$	204k$	200
Totals	**1,467k$**	**1,151k$**	**87%**

Tota[redacted]

Item	Cost	Contingency	%
Module Production Labor	1,063 k$	457 k$	43%
Shell production & Rod assembly	126 k$	71 k$	56%
Equipment	1467 k$	1,151 k$	87%
Totals	**2,656** k$	**1,679** k$	**78%**

- Module Labor = 1,063 k$ + 457 k$ contingency = 1,520 k$
- Other Labor = 614 k$ + 330 k$ = 944 k$
  - Shell assembly = 126 k$ + 71 k$ = 197 k$
  - Eqpt. Setup and maintenance = 110 k$+ 93 k$ = 203 k$
  - EDIA = 378 k$ + 166 k$ = 544 k$
- Equipment Costs = 987 $ + 688k$ = 1,675 k$
- Transportation = 102 k$ +102 K$ = 204 k$

- TOTAL ESTIMATED COST 4.3 M$

- FNAL provides 0.5 M$

  ⇒ need 3.8 M$ = 2.4 M$ base cost + contingency

Cost Estimat

- Production Rates
  - 80 pre-production over 5-6 months: goal to achieve steady rate of ~2 per day
  - 600 ramp-up over 6 months: goal is to go from ~2 to ~10 per day
  - 6000 production over 2 years: run at an average of ~12 per day
  - Contingent doubling of capacity: To sustain ~24 per day for 6 months

- Equipment Required
  - Probing: 1 automated probe stand (~50k$)
  - Assembly: Automated (211k$)
    - 2 automated pick-and-place "gantry" systems - one is mostly needed for contingency (~100k$ each)
    - Alternatively ~4 CMMs and ~12 fixtures (~20k$ each. SiDet has CMM's)
  - Inspection: Plan to inspect a fraction (~10%) of modules on OGP (at SiDet)

Cost Est[redacted]

- Wirebonding: (66k$ fixtures & MHS + 264K$ in contingency)
  - Need one K&S 8090 nearly full time, therefore need a second as contingency. (2 at SiDet)
  - If conflict with Run 2b, need to buy a 3rd K&S 8090. (250k$)
  - Will use the K&S Material Handling System (MHS ~50k$)
  - For Wirebonding we will need simple fixtures, possibly many of them (16k$)
- Testing equipment: (~30-40k$, total 225k$)
  - Need one system for quick tests in the clean room after wirebonding
  - Need separate systems for full tests: We'll multiplex and fully test many modules.
  - For Burn-in, we also need 1-2 DAQ stands
  - Some testing outside FNAL.

Cost Estimating

- Miscellaneous equipment-related expenses
  - Clean room supplies (2k$/month for 30 months = 60k$)
  - Burn-in cooling stands& interlocks (100k$)
  - Engineering, Design and Machining support (378k$)
    - 0.5 FTE machinist, 0.5 FTE engineer, 0.5 FTE designer for 30 months
  - Miscellaneous instrumentation for metrology, electronics testing (50K$)
  - Equipment setup and maintenance is covered by SiDet except CMS specific items: DAQ & Gantries (110k$)
  - Storage,test, and transportation boxes (115k$)

Cost Est[redacted]

- Labor Costs for modules
  - 80 pre-production over 5-6 months: goal to achieve steady rate of ~2 per day
    - production labor cost 31k$
  - 600 ramp-up over 6 months: goal is to go from ~2 to ~10 per day
    - labor cost 119k$
  - 6000 production over 2 years: run at an average of ~12 per day
    - labor cost 913k$
  - Total production labor cost 1,063k$
    - Contingent 6 month doubling of capacity: Also include continuity of labor force.
  - Total contingency 457k$
- Labor Costs for assembly of TIB shell supports
  - 126k$ + 71k$ contingency

Conclusion

- CMS Tracker is now All-Silicon
- US CMS tracker group can play a significant role
  - Large scale production: more than 100 square meters
  - This is a seasoned, high quality group of physicists:
    - Significant experience not only in silicon production but also in tracking, pattern recognition, b tagging, and other aspects of hadron collider physics at the Tevatron
- Overall cost of production is 2.3M$
  - Less than 25k$ per square meter (a real bargain)
- We believe the tracker can be constructed on time