WBS 1.1.1 Pixel System

DoE/NSF Review

June 2002

M. Gilchriese

Outline

- Summary
- Overview of pixel system.
- Technical status
- Construction project - ETC02 schedule
- Construction project - ETC02 cost estimate
- Preoperations, maintenance and operations
- R&D
- Concluding remarks

Cost Summary

(Project AYk$s)			
	Baseline Budget (ETC01 FY02-FY05 + Carryover)	Final ETC02 (FY02-FY05)	
WBS	Budget (AYk$s)	ETC Budget (AY$s)	Delta
111 Pixel System	5,243.4	5,553.4	(310.0)

Silicon ETC 02 Access Profile (Project FY02 K$s)

WBS	FY01	FY02	FY03	FY04	FY05	FY06	Total
111 Pixel System		COMMITTED 2,365.0	2,559.9	520.3	6.5		5,451.6

March 2002

WBS	Description	Funds Auth. through FY02				Paid to Date				Committed to Date			
		Totals($)	M&S($)	Labor($)	Travel($)	Totals($)	M&S($)	Labor($)	Travel($)	Totals($)	M&S($)	Labor($)	Travel($)
1.1.1	Pixels	2364.9	1175.2	1098.9	90.8	1113.4	444.6	647	21.8	80.4	75	0	5.3

- ETC02 cost increase relative to baseline from few month delay in IC and electronics design that required additional engineering time and projection of diminished base program support for engineering and technical staff.

Milestone Summary

Level 2 Milestones

Subsystem	Schedule Designator	Description	ETC 01 Schedule Date	ETC 02 Schedule Date
Silicon	Sil L2/6	Pixels 1st IBM Prototype Submitted	26-Jul-01	30-Nov-01 COMPLETE
	Sil L2/7	Pixels Start IBM Production	13-Mar-03	12-Jun-03
	Sil L2/8	Pixels Start IBM Outer Bare Module Production	22-Oct-03	29-Jan-04
	Sil L2/9	Pixels 'Disk System at CERN'	13-Oct-04	20-Jan-05

- About 3 month delay in submission of first full IC chip set submission propagates through schedule.
- Items not connected to ICs(sensors, mechanics) about on schedule.

Contingency Analysis

- A recent "high-level" contingency analysis has been done and is shown below.
- For ETC02(last December), a lowest-level contingency analysis was done and is largely the same apart from the sensors, which have since moved into production.

			U.S. ATLAS (ETC-02)			
			BASE COST	CONTINGENCY		TOTAL
		System or Item	**K$**	**%**	**K$**	**K$**
1.1.1	**Pixel System**		5452	38%	2090	7542
	1.1.1.1	Mechanics and Final Assembly	2387	40%	955	3342
	1.1.1.2	Sensors	241	14%	34	275
	1.1.1.3	Electronics	1227	44%	540	1767
	1.1.1.4	Hybrids, Cables and Optical Components	543	32%	174	717
	1.1.1.5	Module Assembly/Test	968	38%	368	1335
	1.1.1.6	System and Beam Tests	86	24%	21	107

2-Hit System - US Deliverables[1]

- Mechanics(1.1.1.1)
  - Support tube and plugs at end of support tube
  - Overall pixel support structure(frame)
  - Disks
  - Coolant pipes(shared with Europe)
  - Power and other cables(shared with Europe)
  - Tooling for final assembly of system(shared with Europe)
- Sensors(1.1.1.2)**(ABOUT 3% PRODUCTION COMPLETE)**
  - About 20% of production procurement and testing
- Electronics(1.1.1.3)
  - About 20% production procurement, 50% of testing of front-end ICs
  - About 50% production procurement and testing of optical ICs
  - Common test systems for all collaboration for front-end ICs, modules
- Hybrids(1.1.1.4)
  - All flex hybrids
  - Optical components and hybrids for disk region
- Modules(1.1.1.5)
  - Thinning, dicing of FE and die sort
  - Assemble and test about 25% of modules
- Test Support(1.1.1.6)
  - About 20% of support for system tests and beam tests at CERN

No changes in pixel deliverables since baseline established or last year's review. However, conceptual design of integration of beam pipe support into pixel system has been added and is supported under WBS 1.10. Support beyond conceptual design in FY02 remains to be decided and would come from management contingency.

[1]Assumes release of management contingency. Sensor MC has been released.

US Institutions and Management

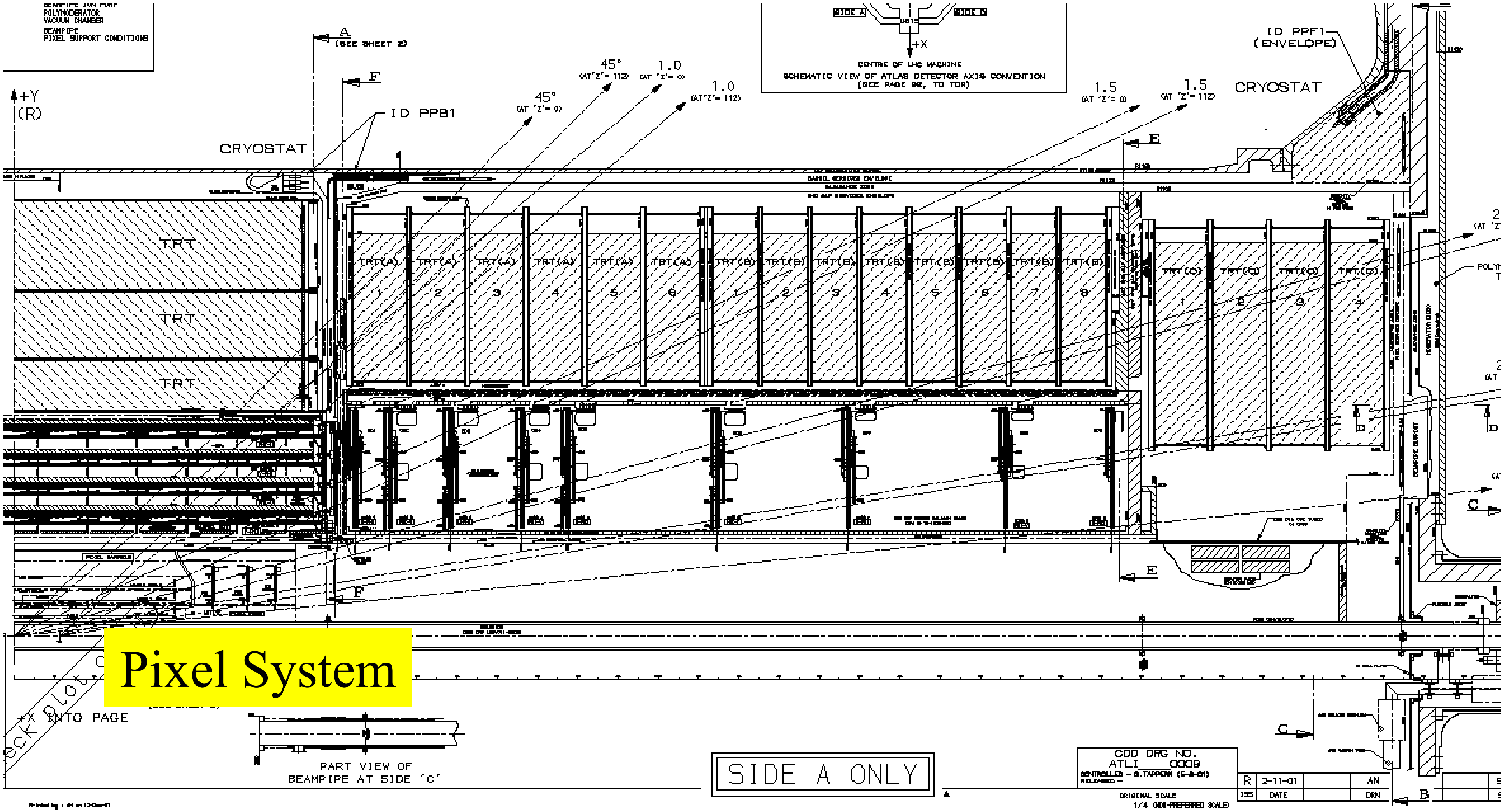
	ALB	LBL	UNM	UOK	OSU
1.1.1 Pixels(Gilchriese)					
1.1.1.1 Mechanics(Gilchriese, Anderssen)		x			
1.1.1.2 Sensors(Seidel, Hoeferkamp)			x		
1.1.1.3 Electronics(Einsweiler, Denes)		x			x
1.1.1.4 Hybrids(Skubic, Boyd, Gan)	x			x	x
1.1.1.5 Modules(Garcia-Sciveres, Goozen)		x	x	x	x
1.1.1.6 Test Support(Richardson)		x			

(Physicist, Engineer)

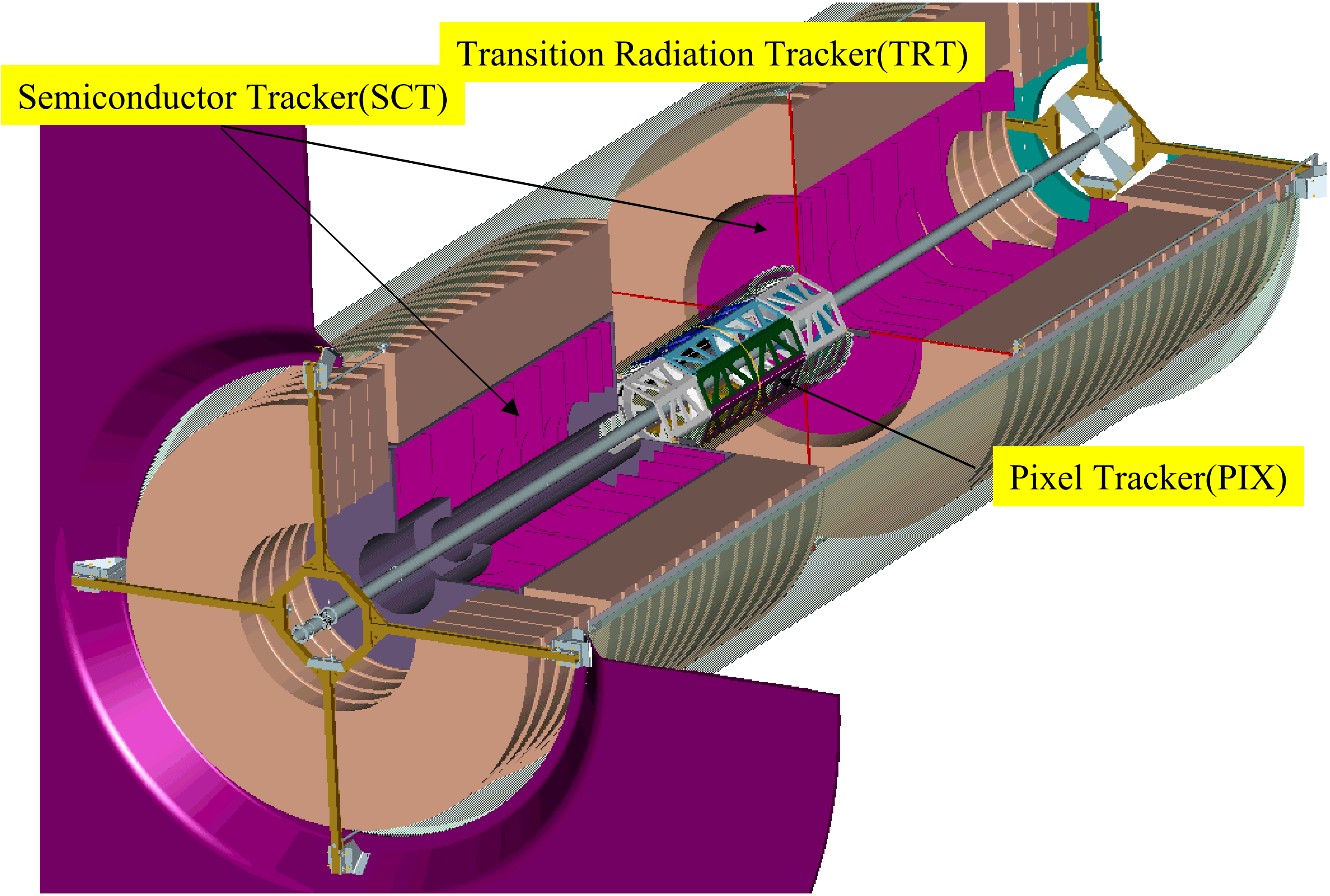
SUNY Albany, LBL, New Mexico, Oklahoma, Ohio State

In addition, off-detector electronics(ReadOut Drivers for both pixels and SCT) are separate project(Wisconsin, Iowa State and LBL).

ATLAS Inner Detector



ATLAS Pixel System



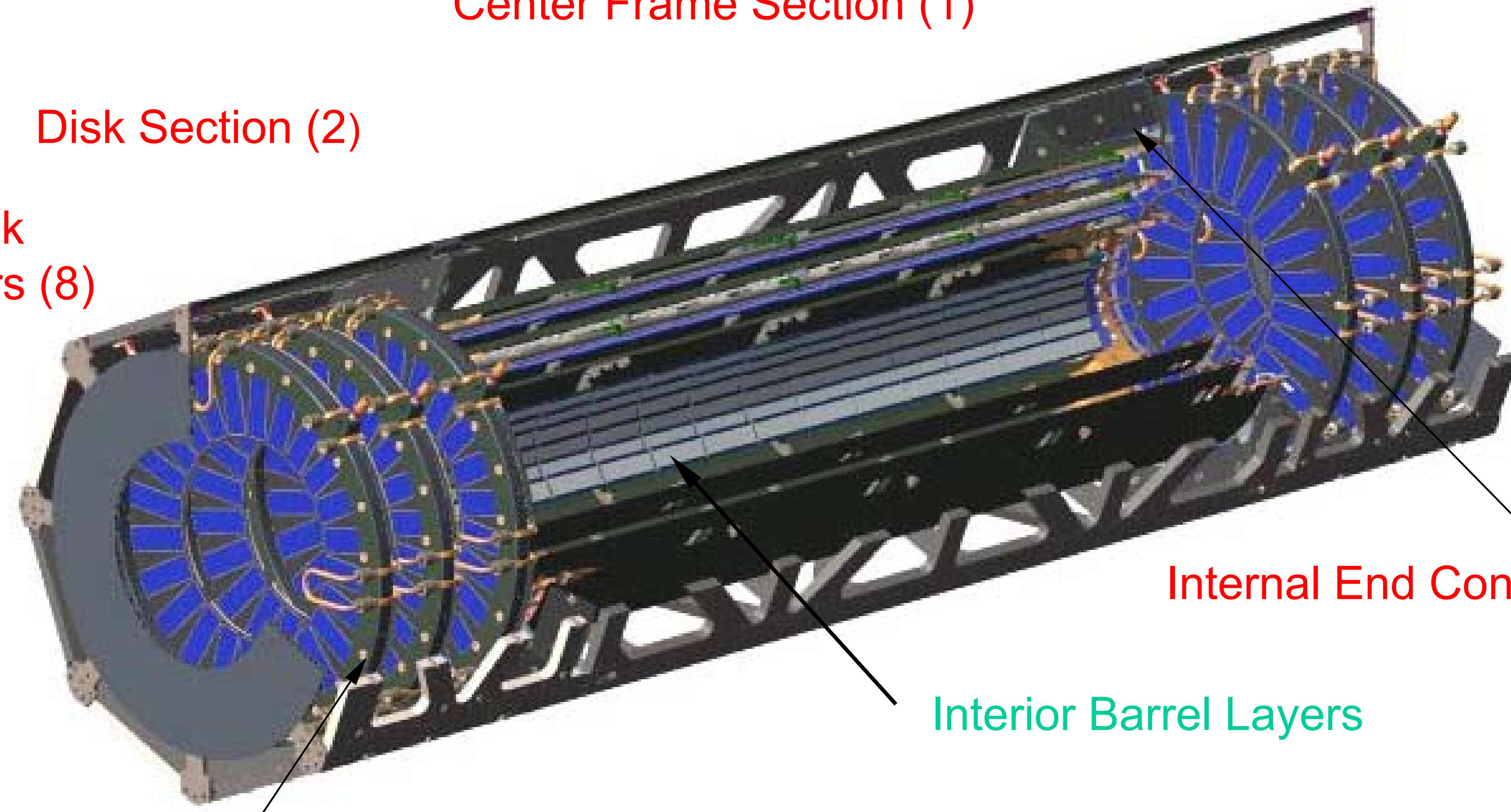
M. Gilchriese

Pixel Parameters

Barrel						Active	Tilt
	Radius(mm)	Staves	Modules	Chips	Channels	Area(m^2)	Angle(^{o})
B-layer	50.5	22	286	4576	1.76E+07	0.28	-20
Layer 1	88.5	38	494	7904	3.04E+07	0.48	-20
Layer 2	122.5	52	676	10816	4.15E+07	0.65	-20
Subtotal(3 hits)		112	1456	23296	8.95E+07	1.41	
Subtotal(2 hits)		74	962	15392	5.91E+07	0.93	
Disks			Pixel size is 50x400 microns				
	Inner	Outer				Active	
Z(m)	Radius(mm)	Radius(mm)	Modules	Chips	Channels	Area(m^2)	Sectors
495	88.1	148.9	48	768	2.21E+06	0.04	8
580	88.1	148.9	48	768	2.21E+06	0.04	8
650	88.1	148.9	48	768	2.21E+06	0.04	8
Subtotal(Both Sides - 3 hits)			288	4608	1.33E+07	0.27	48
Subtotal(Both Sides - 2 hits)			192	3072	8.85E+06	0.18	32
GRAND TOTALS(3 hits)			1744	27904	1.0E+08	1.68	
GRAND TOTALS(2 hits)			1154	18464	6.8E+07	1.11	

- US baseline has always been 2-hit system. ATLAS baseline was 3-hit system but has changed since last review to 2-hit system also(general LHC funding problem)

WBS 1.1.1.1 Mechanics

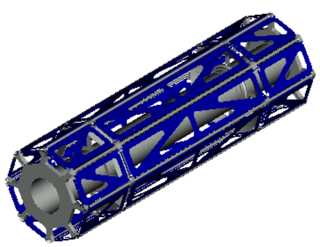


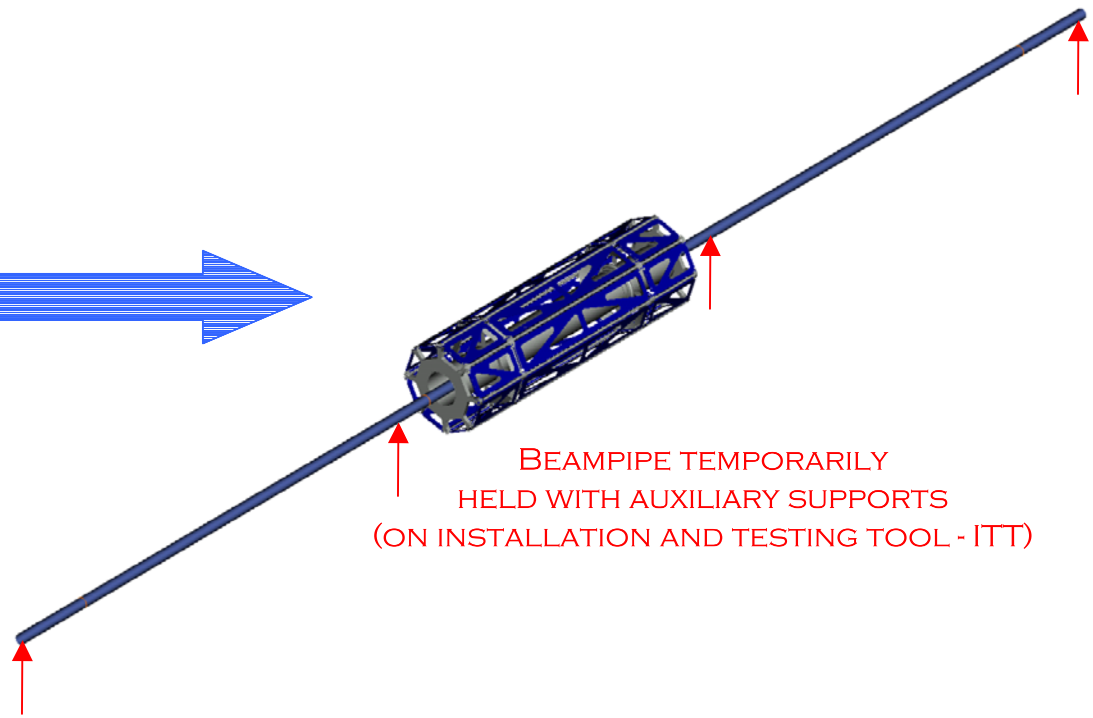
LBNL responsibilities shown in red
(Services not shown)

M. Gilchriese

Pixel and Beam Pipe Assembly

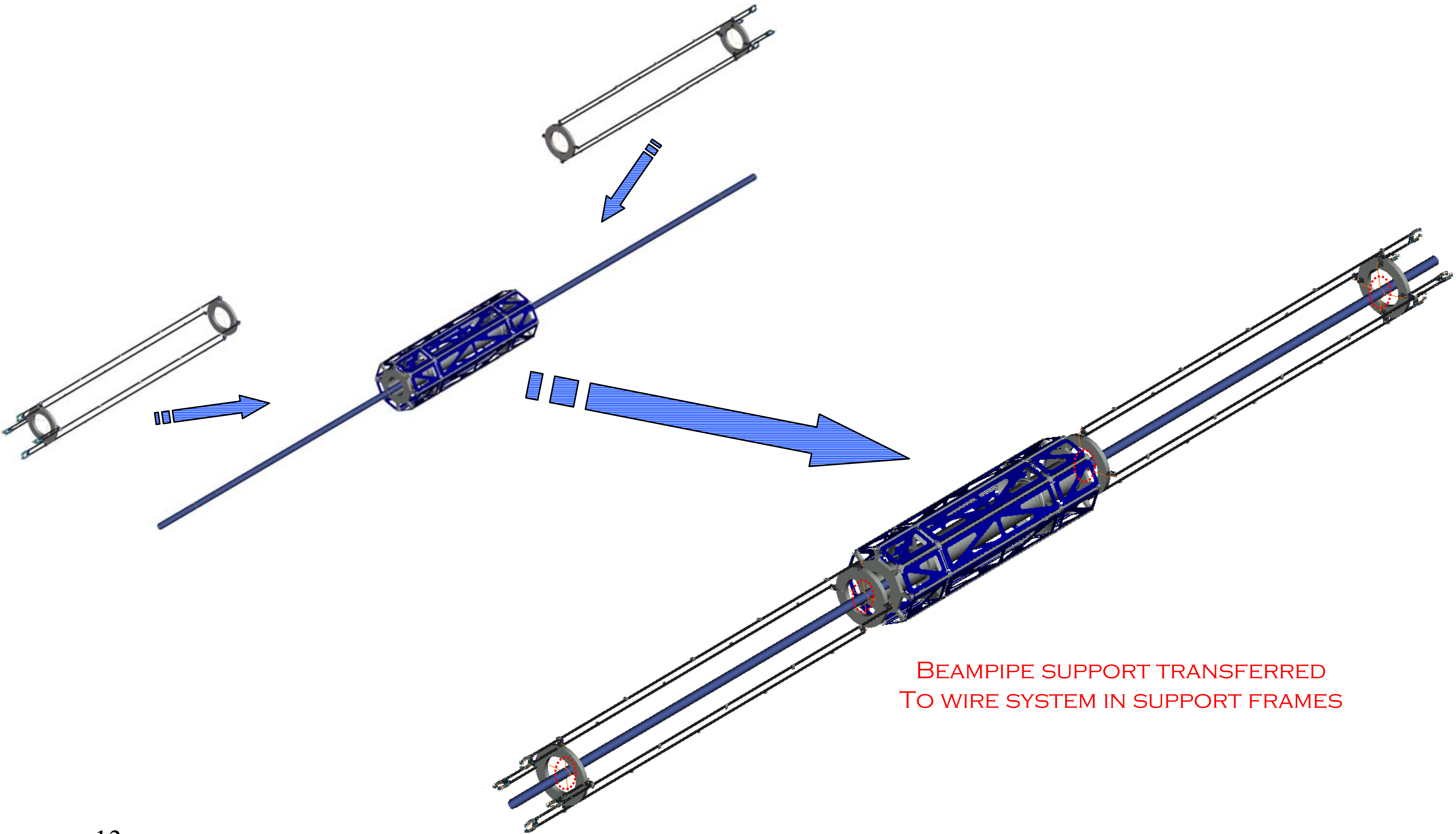
Pixel system and beam pipe will be
Assembled on the surface and lowered
As a package into the collision hall





M. Gilchriese

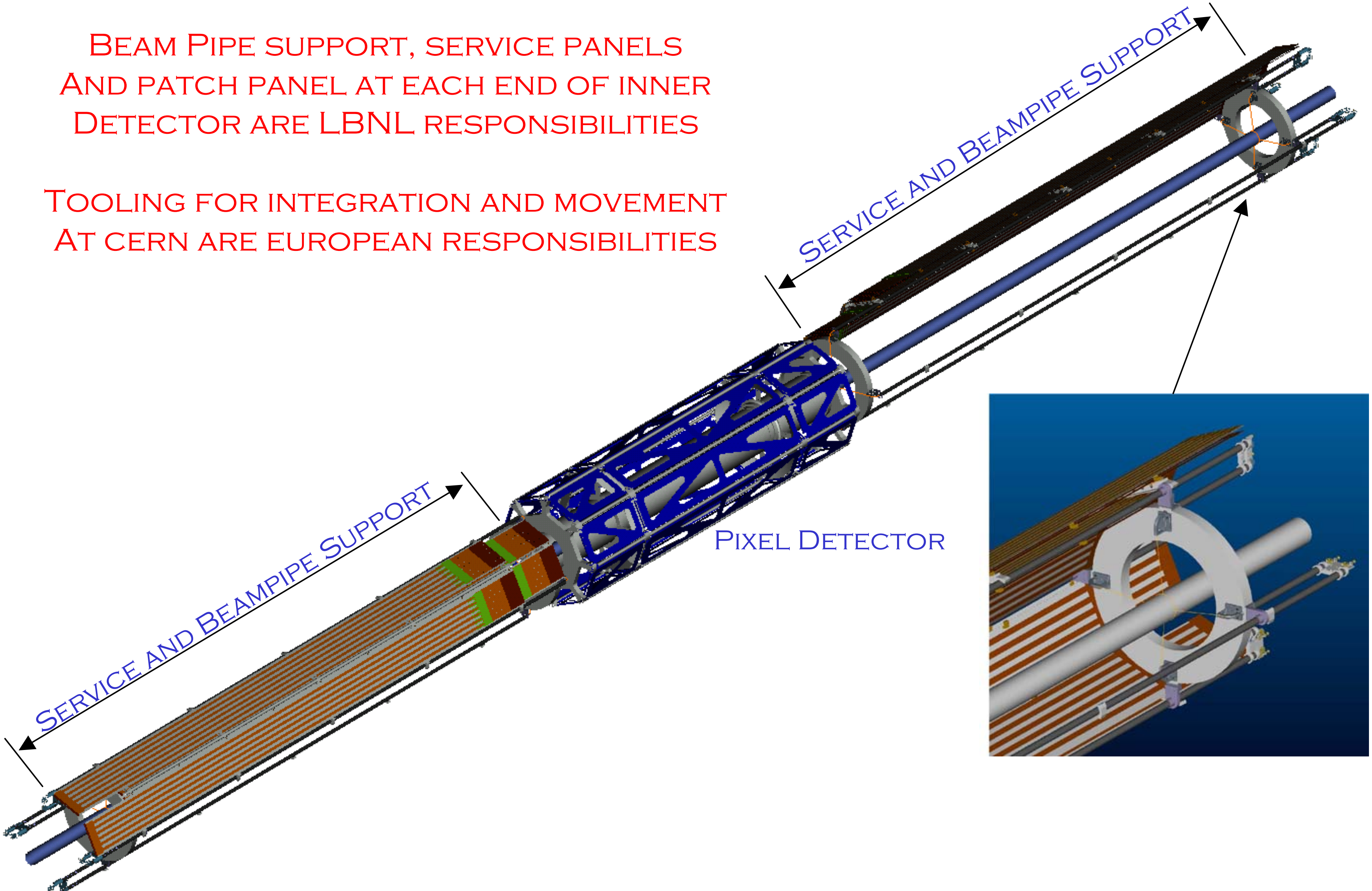
Pixel and Beam Pipe Assembly



Pixel and Beam Pipe Assembly

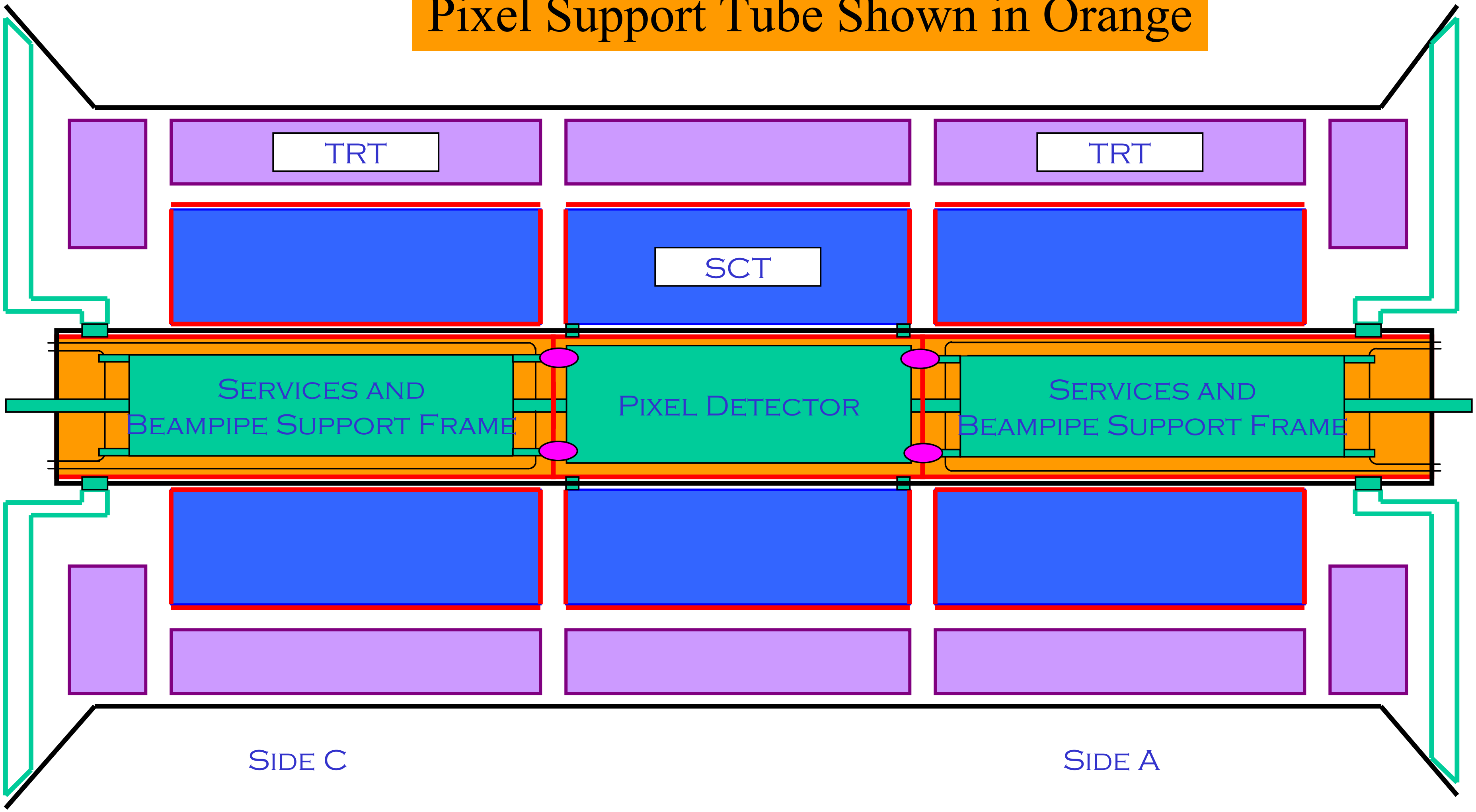
Beam Pipe support, service panels and patch panel at each end of inner Detector are LBNL responsibilities

Tooling for integration and movement At cern are european responsibilities



Pixels Installed

Pixel Support Tube Shown in Orange

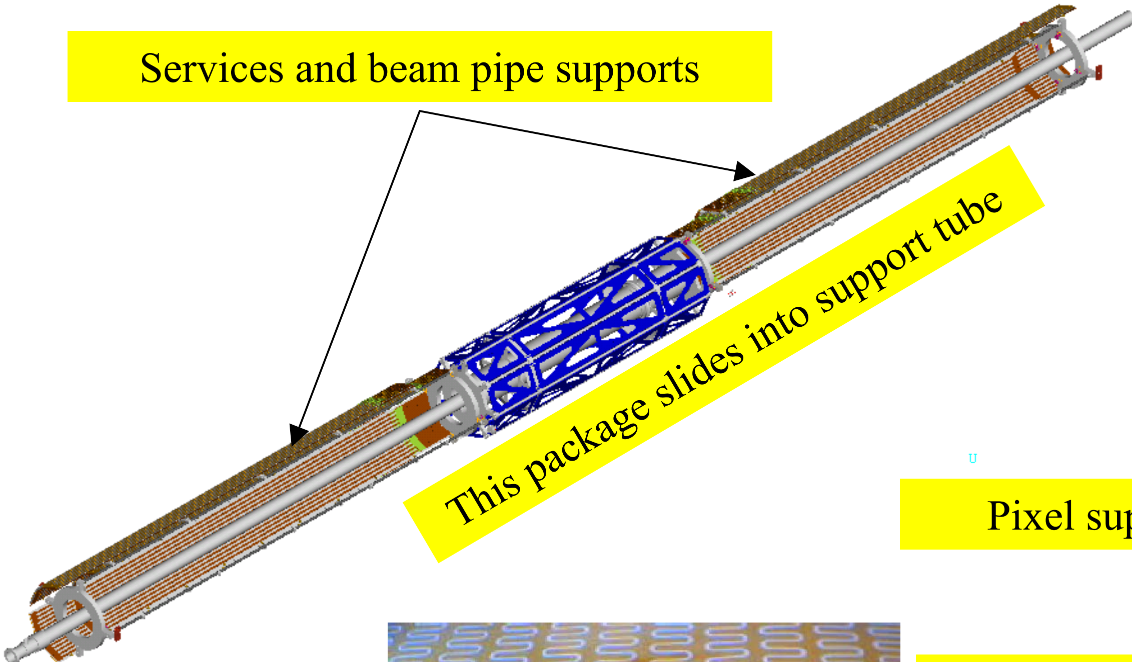


Pixel Support Tube is LBNL Responsibility

M. Gilchriese

Pixel Support Tube, Beampipe Support and Service Panels

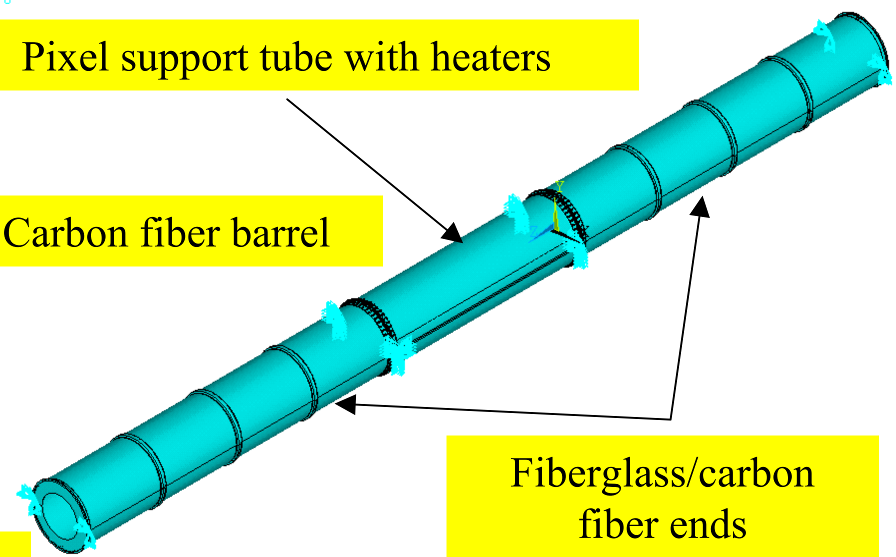
Services and beam pipe supports



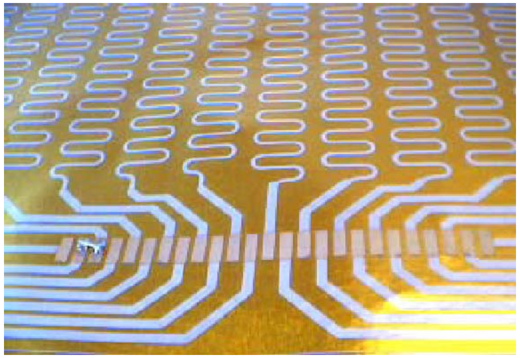
This package slides into support tube

Pixel support tube with heaters

Carbon fiber barrel

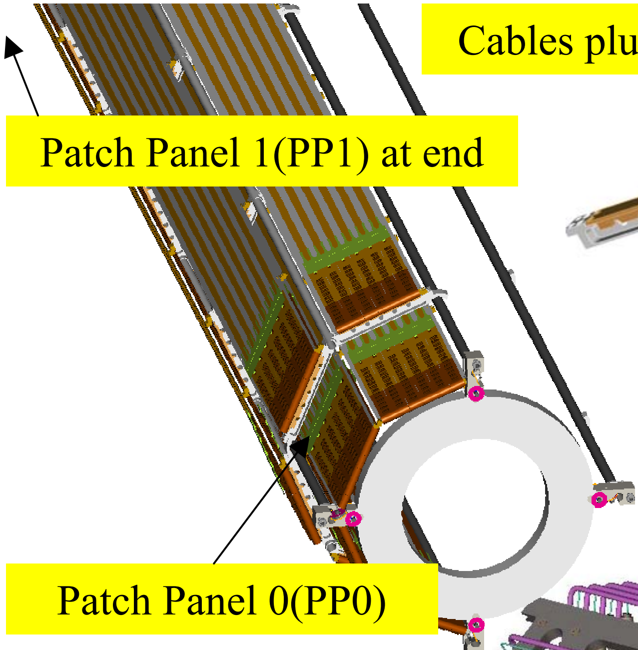


Fiberglass/carbon fiber ends



Aluminum-on-kapton heaters on outside of support tube

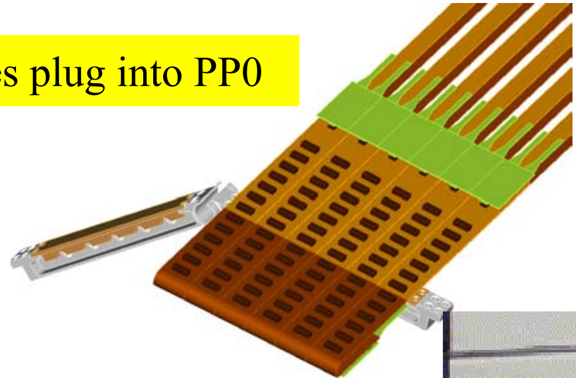
Service Panels and Patch Panels

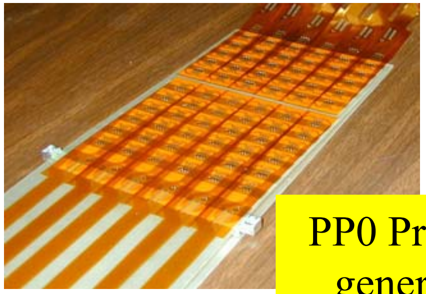


Patch Panel 1(PP1) at end

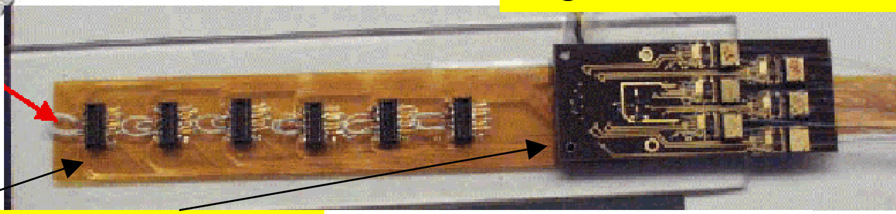
Patch Panel 0(PP0)

Cables plug into PP0

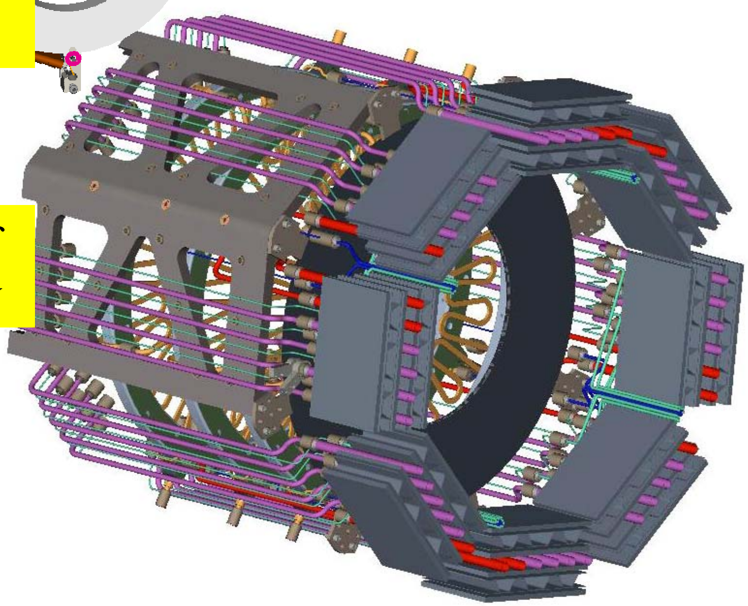




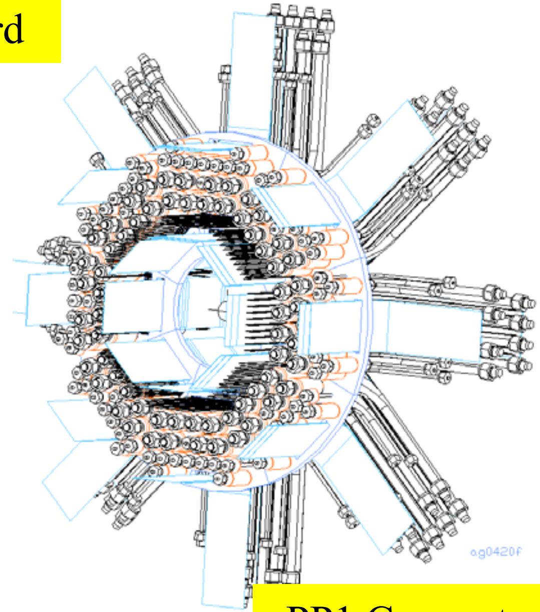
PP0 Prototypes. 2nd generation soon.



PP0 connectors and opto-board



Detailed modeling of PP0 region underway

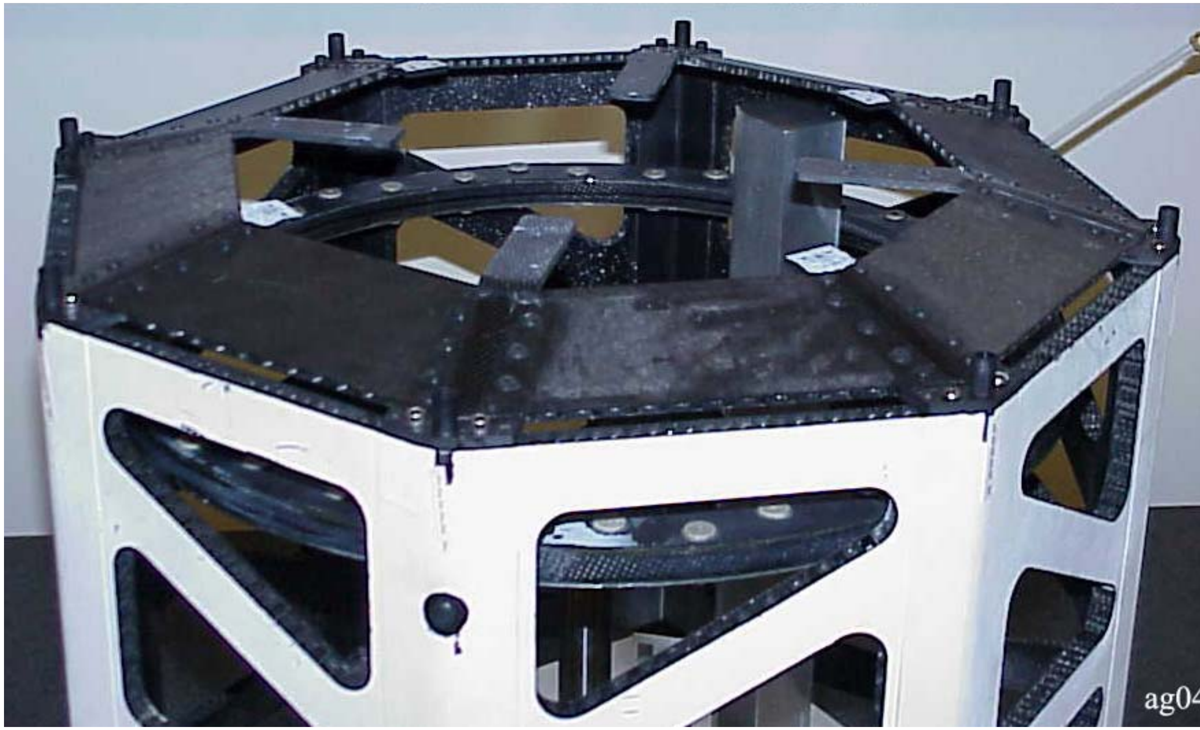


PP1 Concept

Support Frame

- Design of support frame complete.
- Assembly contract just placed, materials just ordered.
- Tooling being done in parallel with multiple vendors and will be provided to assembly vendor, as will much of the raw material. Detailed assembly procedures established by full prototype, documented and provided to vendors.
- On course to complete frame by end 2002, 3-4 months early.

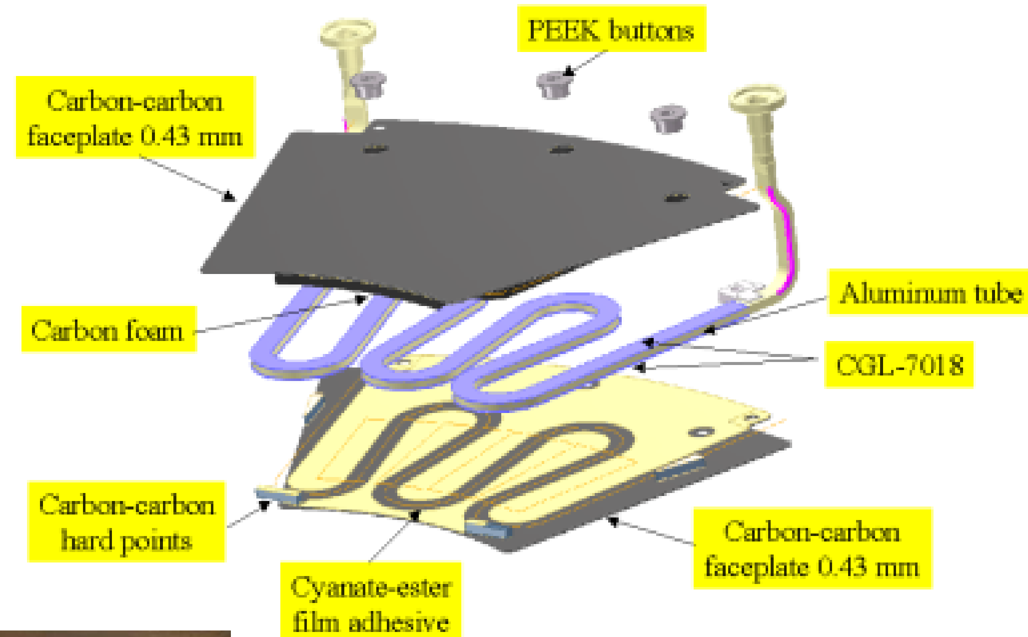
Global support and disk ring prototypes.



Disk Support Rings

- Pre-production support ring nearly completed and will be inspected shortly.
- Looks very good so far.
- Would then place contract for production, to be completed this year.

Disk Sectors

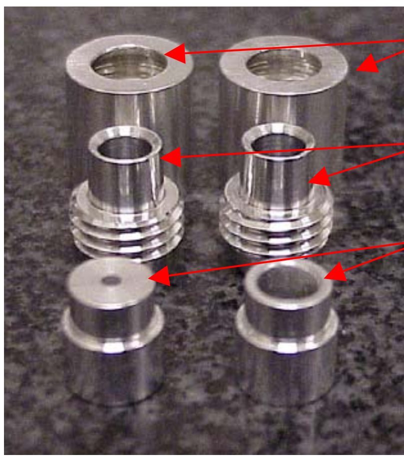


Pre-production disk sector being assembled.

- More than a dozen prototypes made successfully
- 32(48) sectors needed for 2-hit(3-hit) system
- Parts for 60+ available.
- One production item assembled (without final coolant fittings) and is OK.
- Coolant fittings have delayed assembly – see next page.

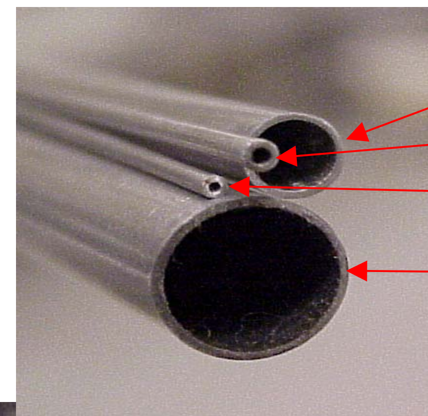
Coolant Fittings

- Low mass(aluminum), all metal seals(syringe-like fitting) and laser welded to aluminum tubes.
- Seal concept validated via extensive prototype testing.
- Laser welding has been difficult(getting alloys straight, procedures at vendor) and is just starting to be on track. Fittings welded on to sector tubes before assembly -> delayed assembly. All tubing inside detector will be welded(maybe some brazing for barrel done in Europe). Welding is US responsibility(US vendor).



NUT, MALE, FEMALE
FITTING PIECES

MALE AND FEMALE
PIECES ASSEMBLED

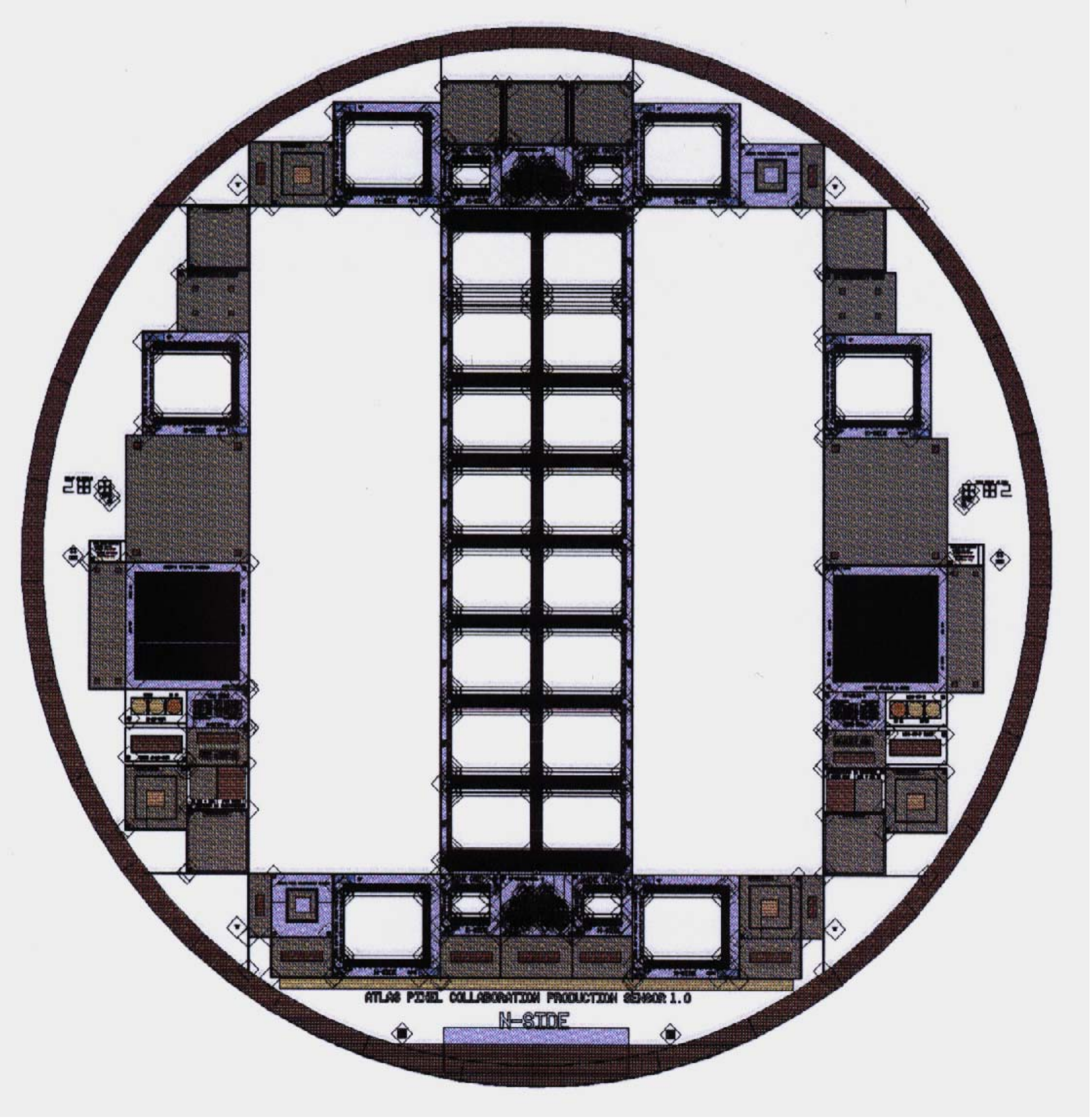


1.1.1.1 Mechanics Cost and Schedule

- Sectors and Fittings – will be delayed by about 2 months(relative to ETC02), some cost increase from additional work on fittings. All sectors not needed(for dry assembly) until April 2003, still have >6 months slack for this and another >6 months until needed for actual modules.
- Rings and Frame – need to evaluate bids, but preliminary indications are that these will be about on cost and on or ahead of schedule.
- Support tube and service panels – lots of interfaces with items being done outside US, have been significant changes since baseline established. Major risk here is need for additional engineering time, reflected in our cost contingency.
- Beam pipe support – was added since pixel baseline established(design change by ATLAS). Funds only from Management Contingency, only for FY02 so far.
- In general, mechanics is on or close to baseline schedule for delivery of items.

1.1.1.2 Sensors

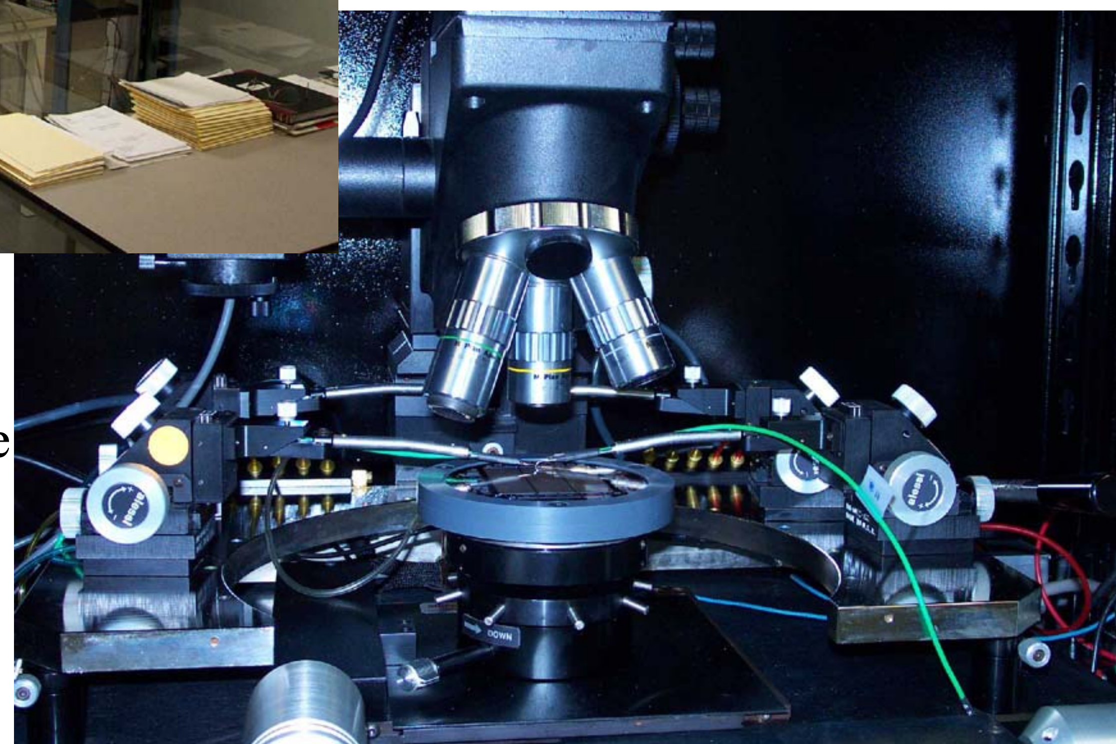
- 4-inch diameter, 250 µm thick, with:
  - 3 full-size Tiles
  - 6 single-chip sensors
  - various process test structures to monitor oxide breakdown voltage, flat-band voltage, oxide-silicon interface current, p-spray dose
- Two vendors
  - One has just delivered 1st 31 production wafers
  - 2nd in advanced pre-production
- S. Seidel, New Mexico, is co-coordinator for sensors.
- Multiple testing sites, New Mexico in US, ready to go for production



M. Gilchriese

1.1.1.2 New Mexico Sensor Testing

The sensor wafers are handled and measured in a clean room environment



Quality Assurance measurements are performed at the wafer level using a probe station and a custom chuck.

1.1.1.2 Schedule/Cost

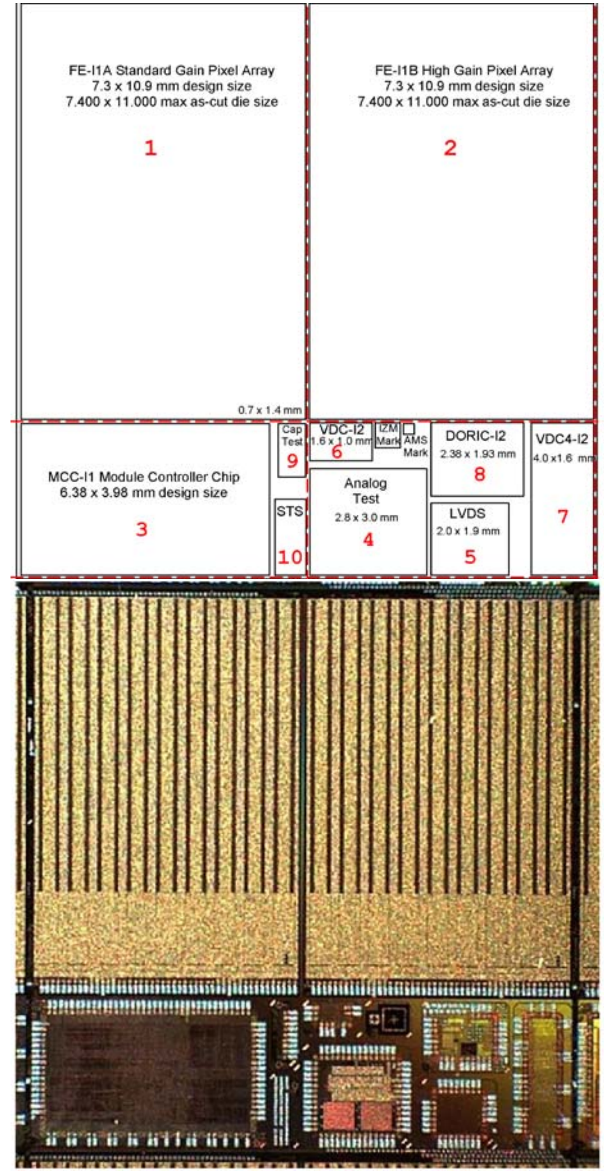
- For vendor already in production, 1000 tiles total(remember there are 1154 good modules needed for 2-hit system), under contract already

	Complete Delivery
25 % (= first 250 good tiles)	28 June 2002
50 % (= another 250 good tiles)	28 February 2003
75 % (ditto)	31 March 2003
100% (ditto)	30 April 2003

- Second vendor would begin this fall, after we have some experience with 1st vendor. 2nd vendor already under contract.
- Costs are about at baseline estimate, production slightly lower, testing slightly higher.
- There is about a year of float in the schedule.

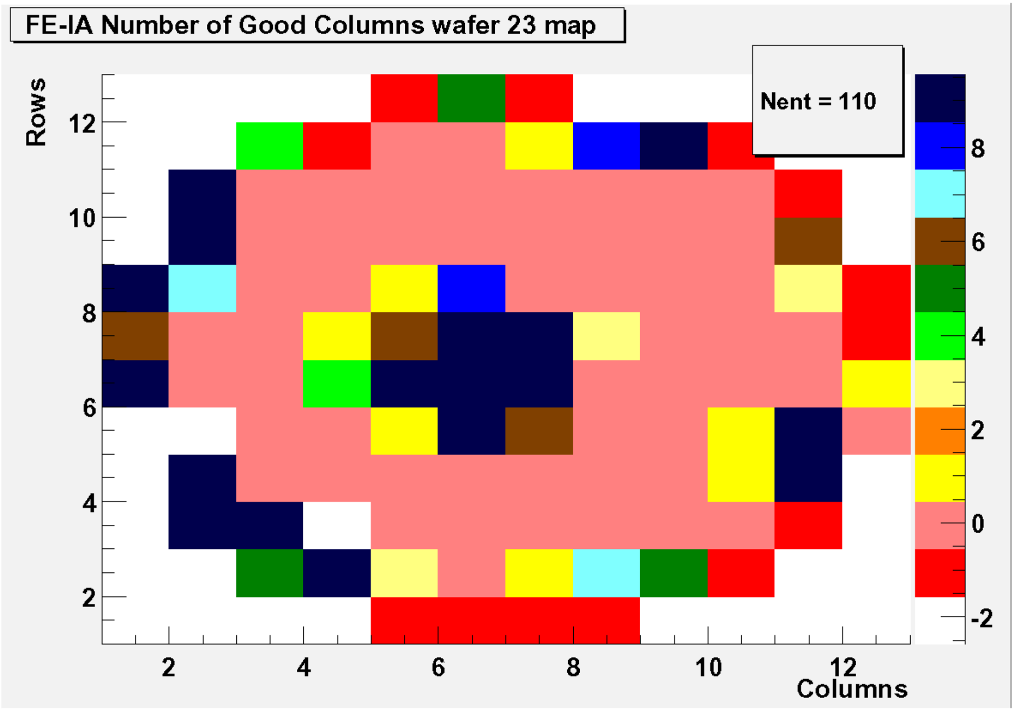
Pixel Integrated Circuits

- Overall electronics coordinator K. Einsweiler (LBNL)
- ICs Required
  - FE – front-end chip, 16 per pixel module. Mostly US design(about 80%, rest Germany)
  - MCC – Module control chip, one per module. Done in Italy
  - VDC and DORIC – optical receivers and driver chips for conversion of optical ⇔ electrical signals. Primarily US, some in Germany.
- Fabrication of the 1st full set of prototypes of these in the IBM 0.25 micron process(8 wafers) was completed at the end of January.
- Preliminary testing complete, minor bugs found so far and yield is low(all chips).
- But sufficient to carry out complete irradiation and beam test program this summer! All chips.
- This irradiation and beam test program has just started in the last month.



Pixel IC Testing

- Typical wafer probe result for FE chips is shown below.
- Yield is low(about 15%) and pattern is clearly indicative of processing problem.
- Some wafers have been returned for analysis to IBM, ongoing.
- IBM has made an additional lot(25 wafers) and a 2nd lot is being held during processing.



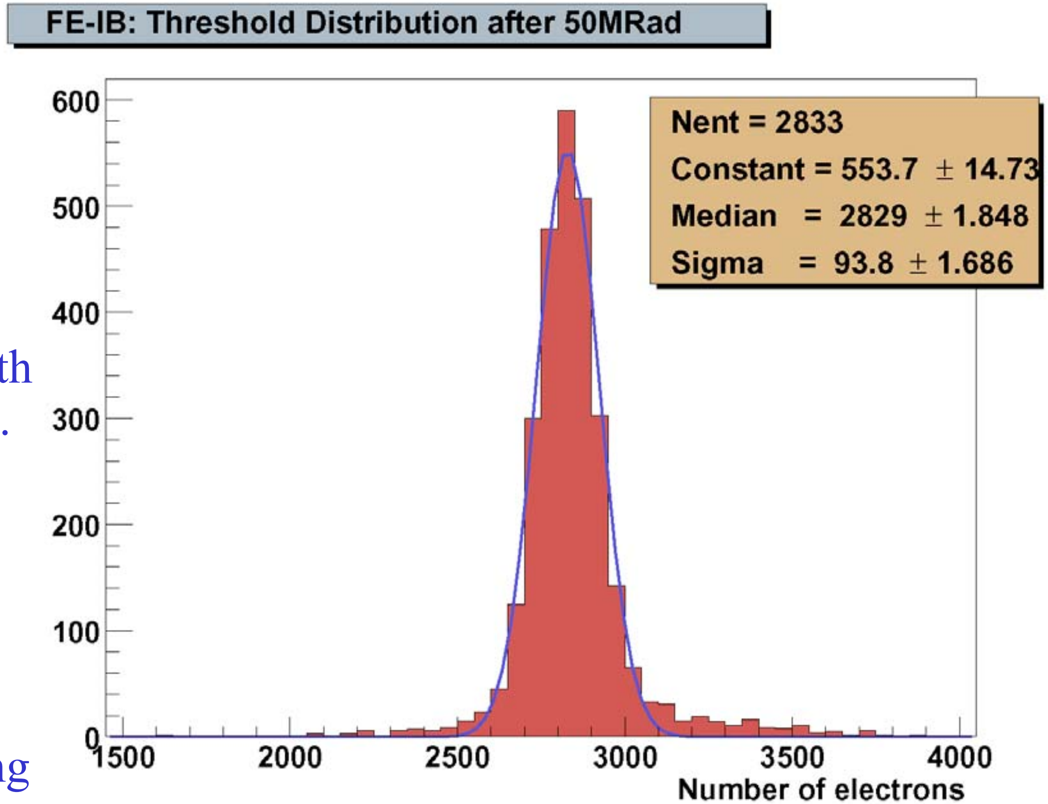
- Chips with no data appear White, bad Global Registers are Red, and other colors represent the Pixel Register test results. There are 18 (3) chips with working Global Registers and 9 (8) good column pairs in Pixel Register. This wafer was diced.

- We will “swap” existing for new wafers shortly and probe them.
- If they are even as good as current, we will purchase at least one additional full lot, perhaps both, to move forward on the module fabrication front, to advance this schedule.
- This is a change from ETC02, but of nominal cost(10 – 25K) to US.

M. Gilchriese

Pixel IC Testing

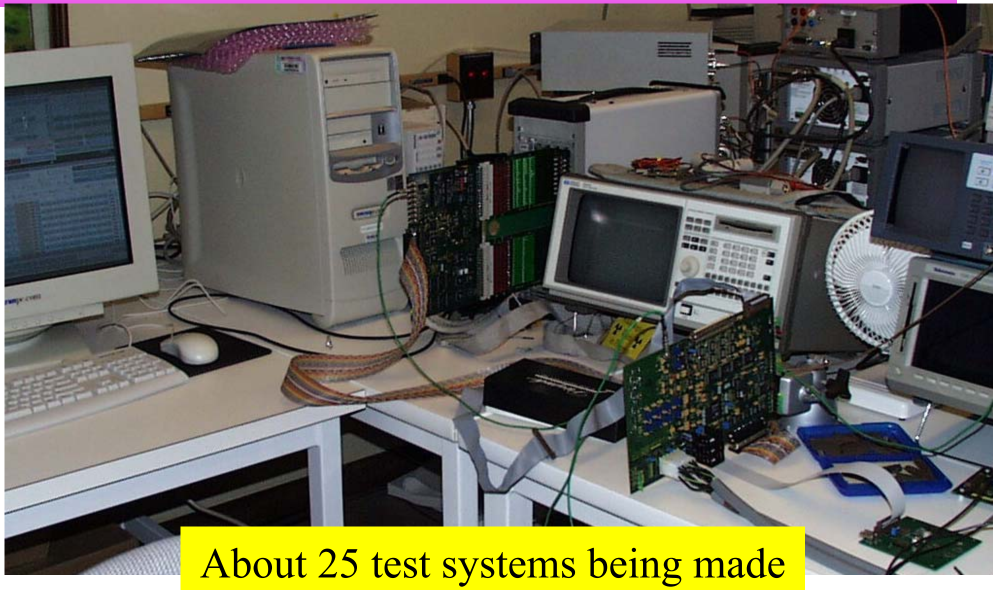
- Two FE chips have been irradiated at the LBNL 88” cyclotron to about 50 MRad. They worked during and after this irradiation. Previous test chips had been irradiated to over 100 MRad and still worked. See plot ->
- The first assemblies of the FE chips with sensors were received a few weeks ago.
- Preliminary lab tests indicate good functionality
- The first modules with these chips are about to arrive.
- First irradiations of chips with sensors have just been done and they are cooling off at CERN to allow handling.



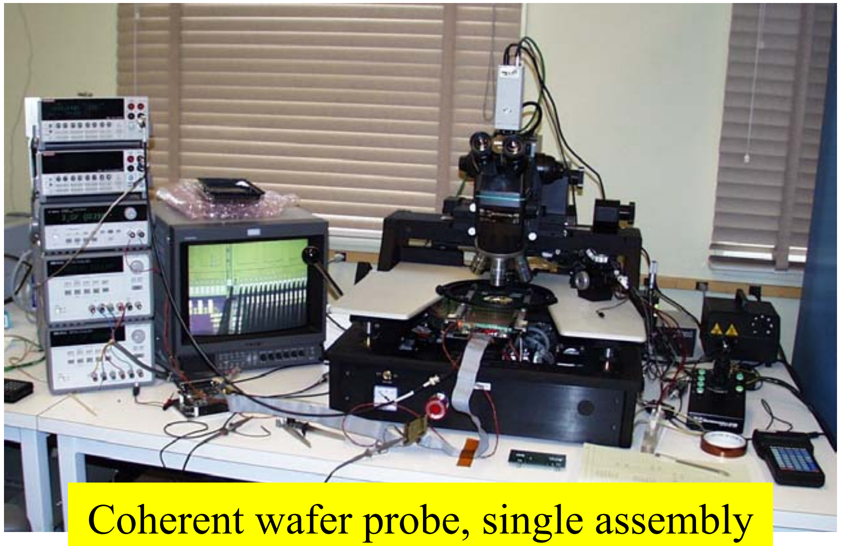
- On-line results indicate that primary areas of concern are increased threshold dispersion with irradiation and SEU effects. These must be addressed in the next submission(IBM-2)
- Test beam studies of these irradiation assemblies are about to start, followed by module studies. J. Richardson(LBNL) is the coordinator of this activity. By July we expect to have in hand sufficient performance data to complete IC design evaluation.

Pixel Testing

- The US is also responsible for providing most of the FE IC, single assembly and module electronics test systems for the overall collaboration.



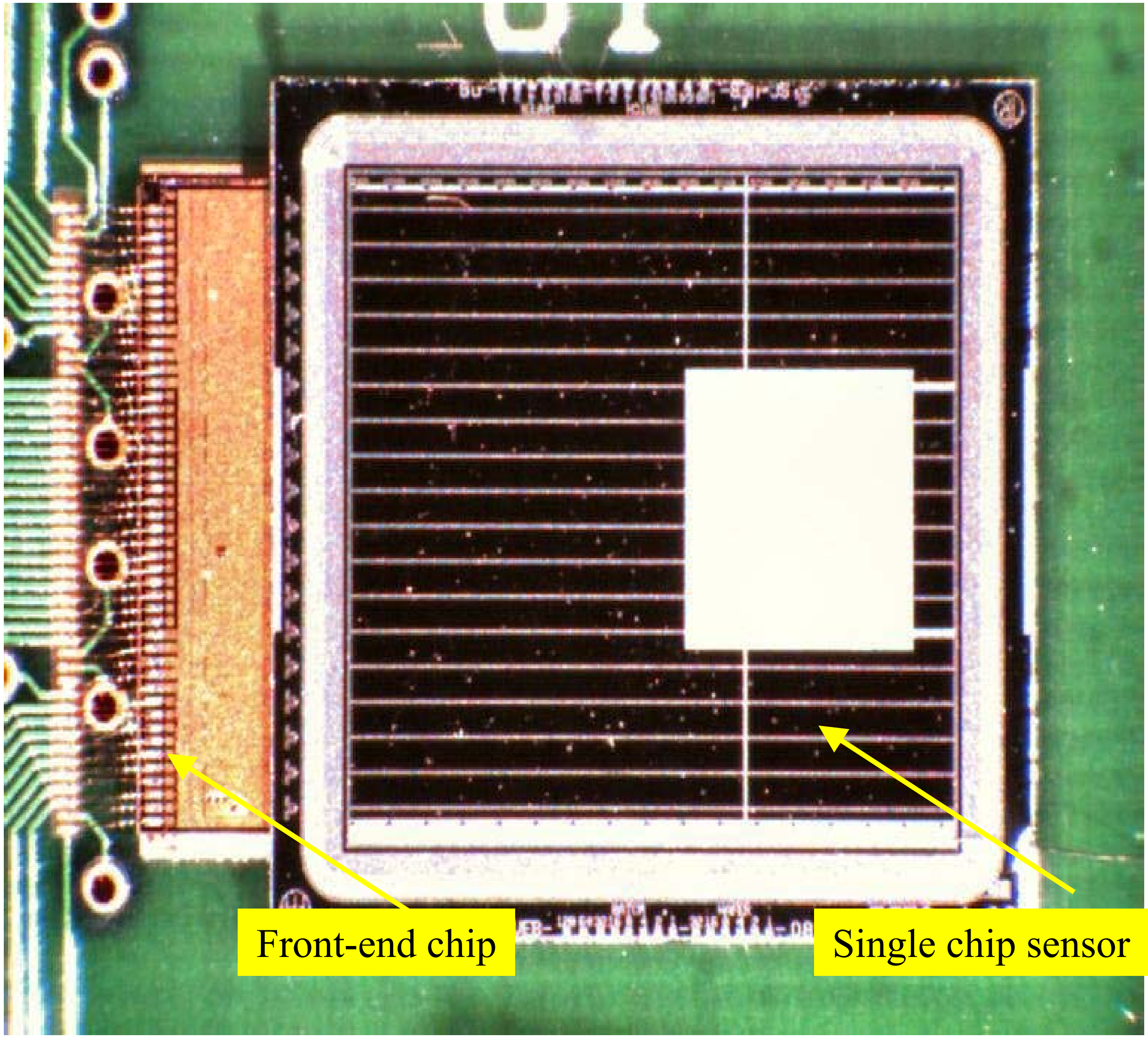
About 25 test systems being made for pixel collaboration.



Coherent wafer probe, single assembly module test system developed.

- This work is going well, and is expected to be complete by the end of the year, schedule is OK.
- However, costs are running higher than expected. Will require adjustment in FY03.

Single IC/Sensor Assembly



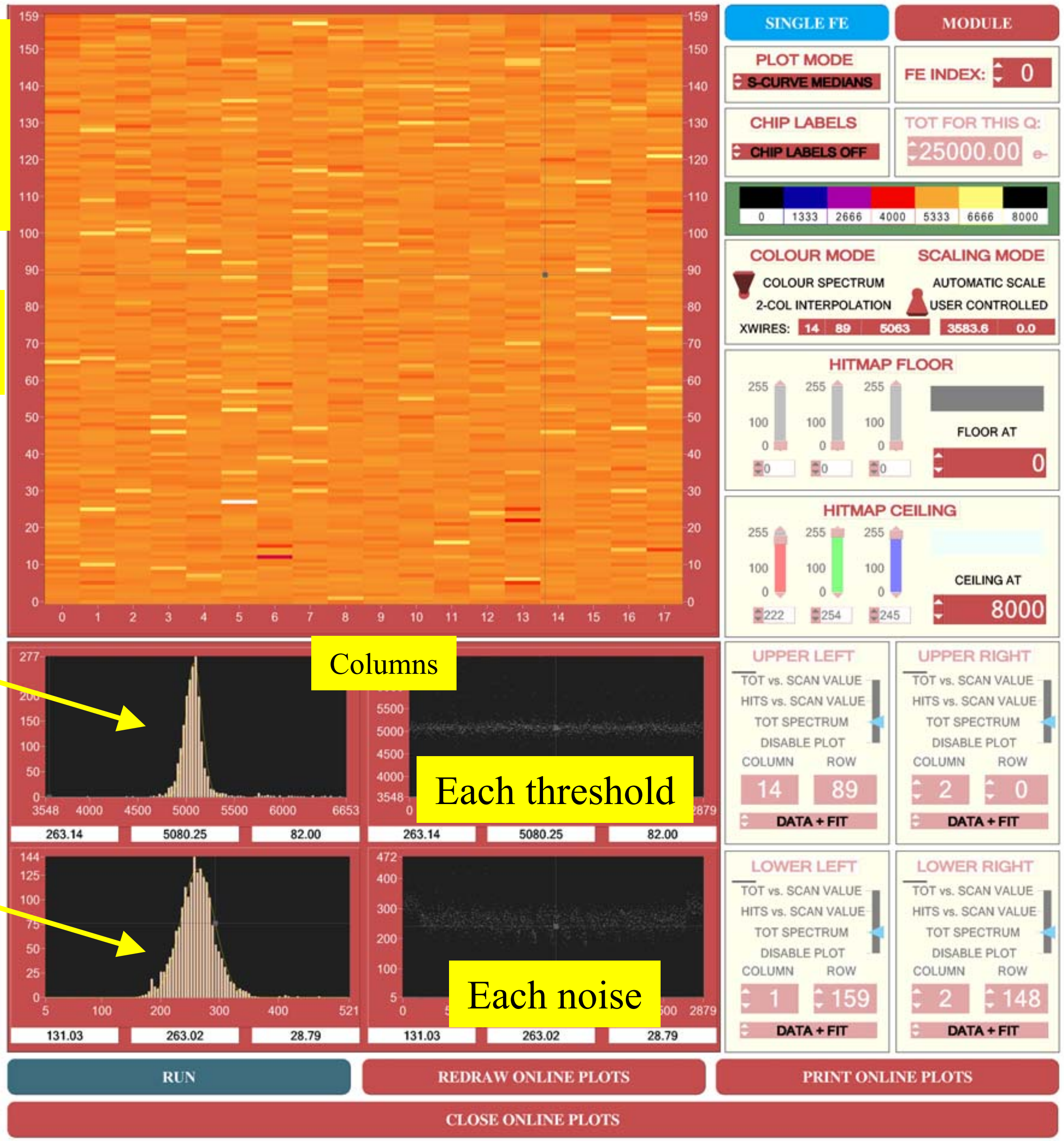
Screen Dump of Single Chip/Sensor

Hit map from charge injection(pre-rad). There is a DAC in each pixel to tune the threshold.

Rows

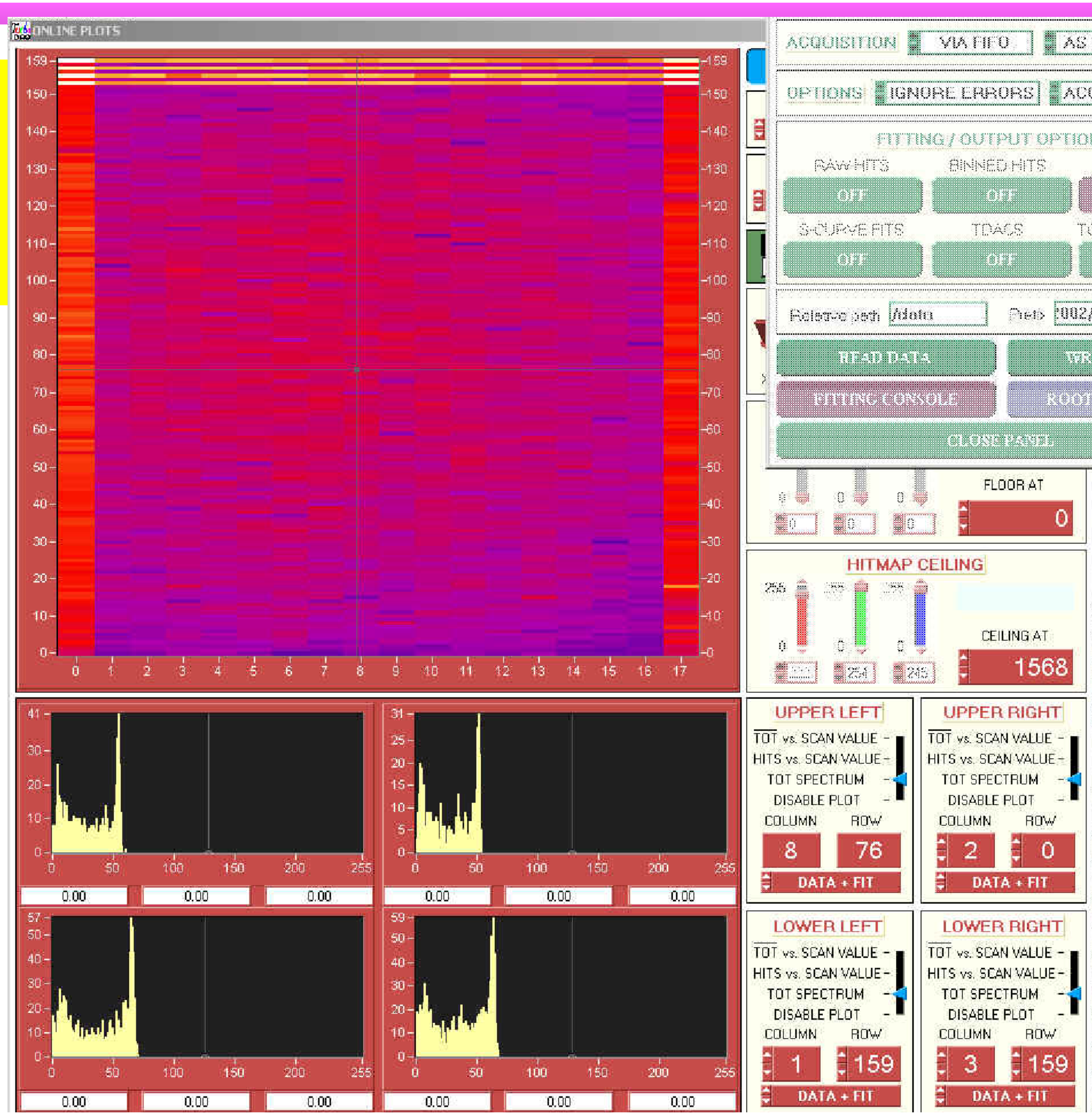
Pixel thresholds after tuning(e's). Mean is about 5080

Pixel noise(e's) Mean is about 260



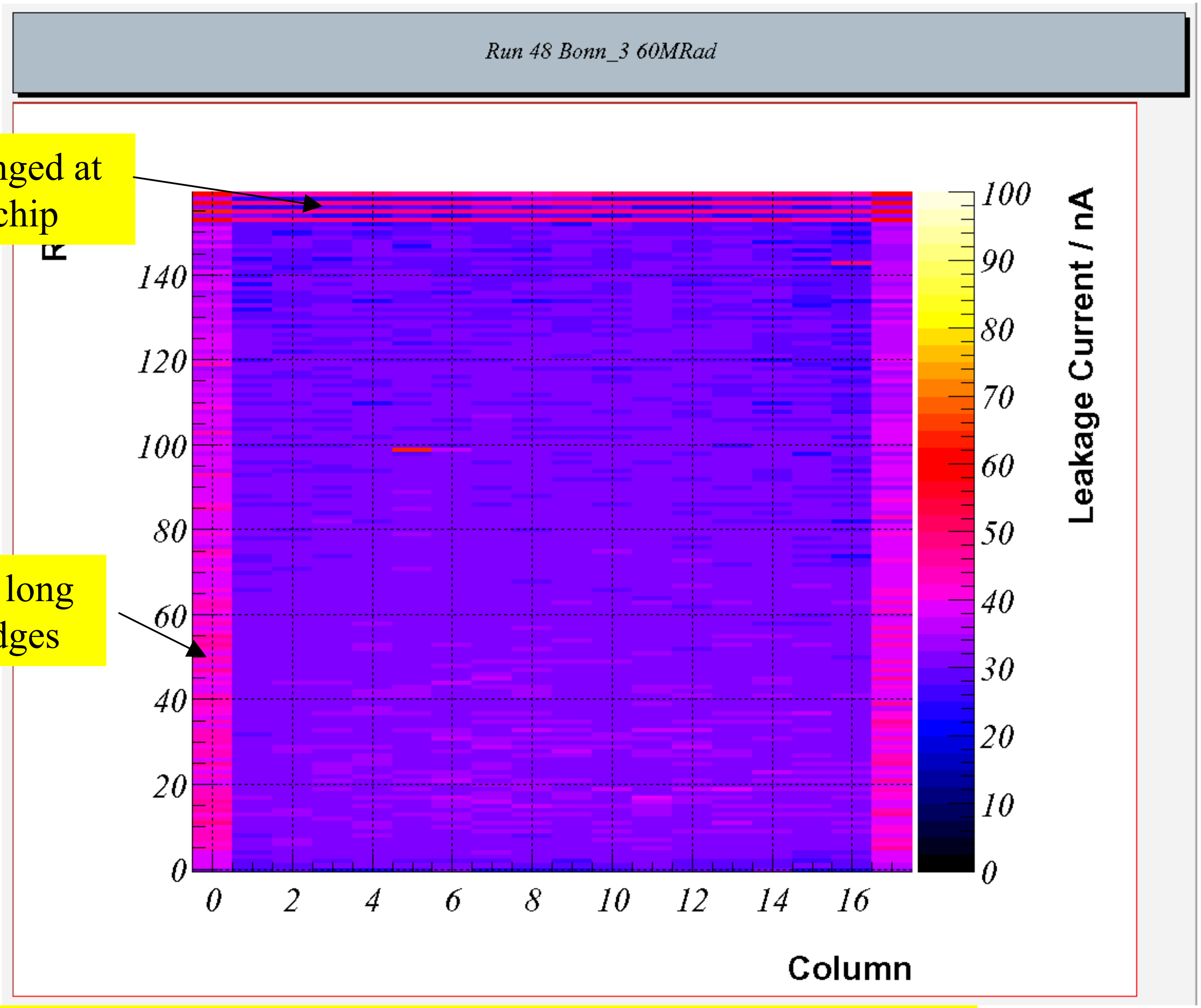
Source Measurement Different Assembly

Hit map showing charge from gamma source as measured by time-over-threshold in each pixel(pre-rad).



Pulse heights in different regions of the assembly.

Leakage Current After 60 MRad



Pixels ganged at top of chip

600 micron long pixels at edges

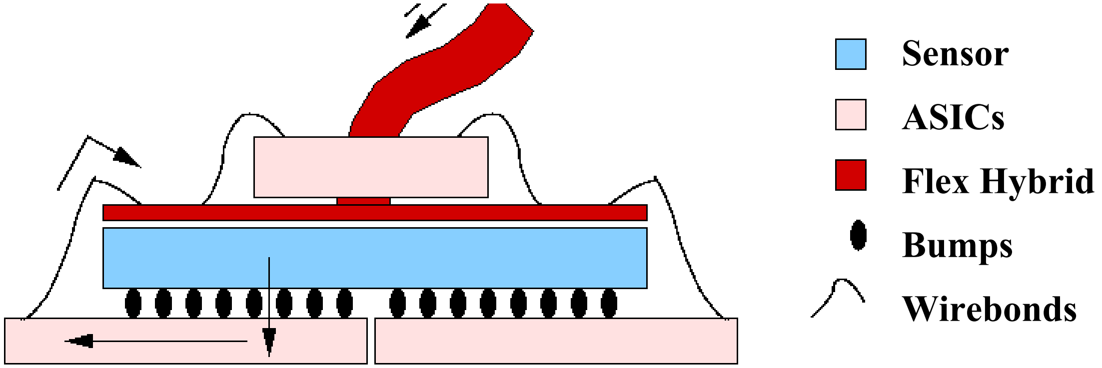
Chip has ability to measure leakage currents in each pixel

1.1.1.3 Electronics – Cost&Schedule

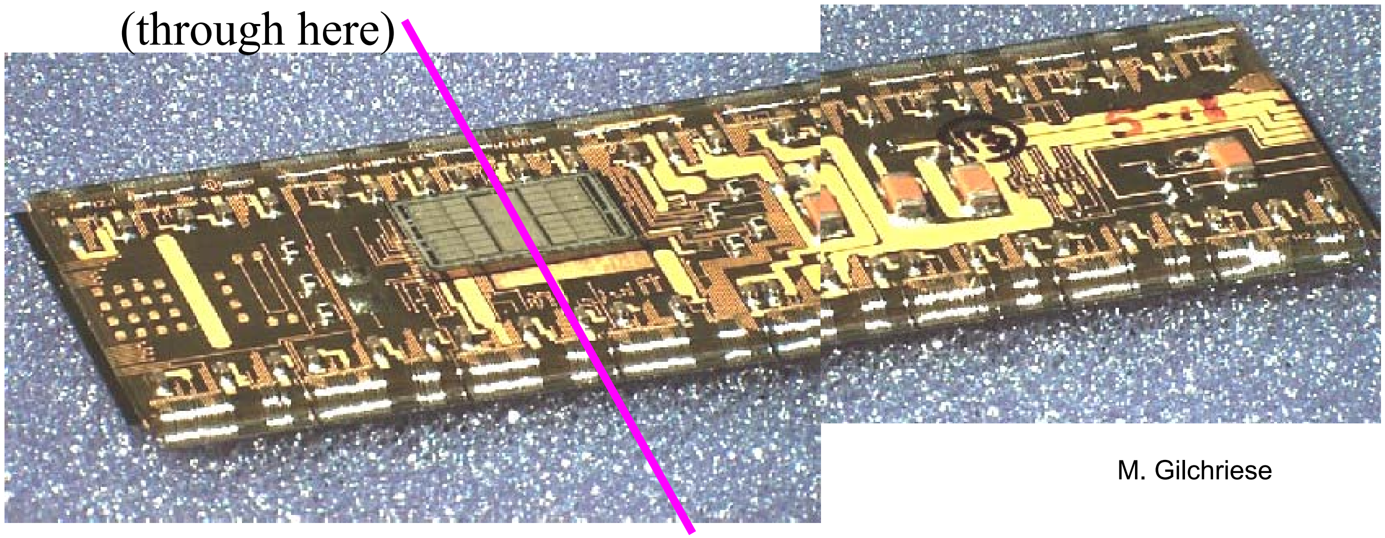
- Procurement costs for IBM wafers set by existing contract with CERN, and so major uncertainty is yield. For 50% yield, US cost roughly 100K, so not a large cost risk.
- Test system costs will largely be complete this FY.
- Major costs are personnel, mostly IC engineering design. This carries significant contingency.
- Electronics are the current critical path item. Current plan
  - Purchase additional lot or lots of current wafers as soon as probed to see if yield is >15% or so. This will be used to advance schedule(relative to ETC02) for modules and system tests.
  - IBM2 submission(48 wafers, 2 lots) by end of year. Followed by validation in 2003 as this year via irradiations, lab and test beam
  - IBM3 production start summer 2003
  - So far, IBM fab time has been about ½ that assumed in baseline(about 10 rather than 20 weeks)

Pixel Hybrids and Modules

- M. Garcia-Sciveres(LBNL) has become since February this year the overall ATLAS module coordinator.
- R. Boyd from Oklahoma is coordinator of and engineer for flex hybrids.
- KK Gan from Ohio State coordinates US work on optical ICs and boards.

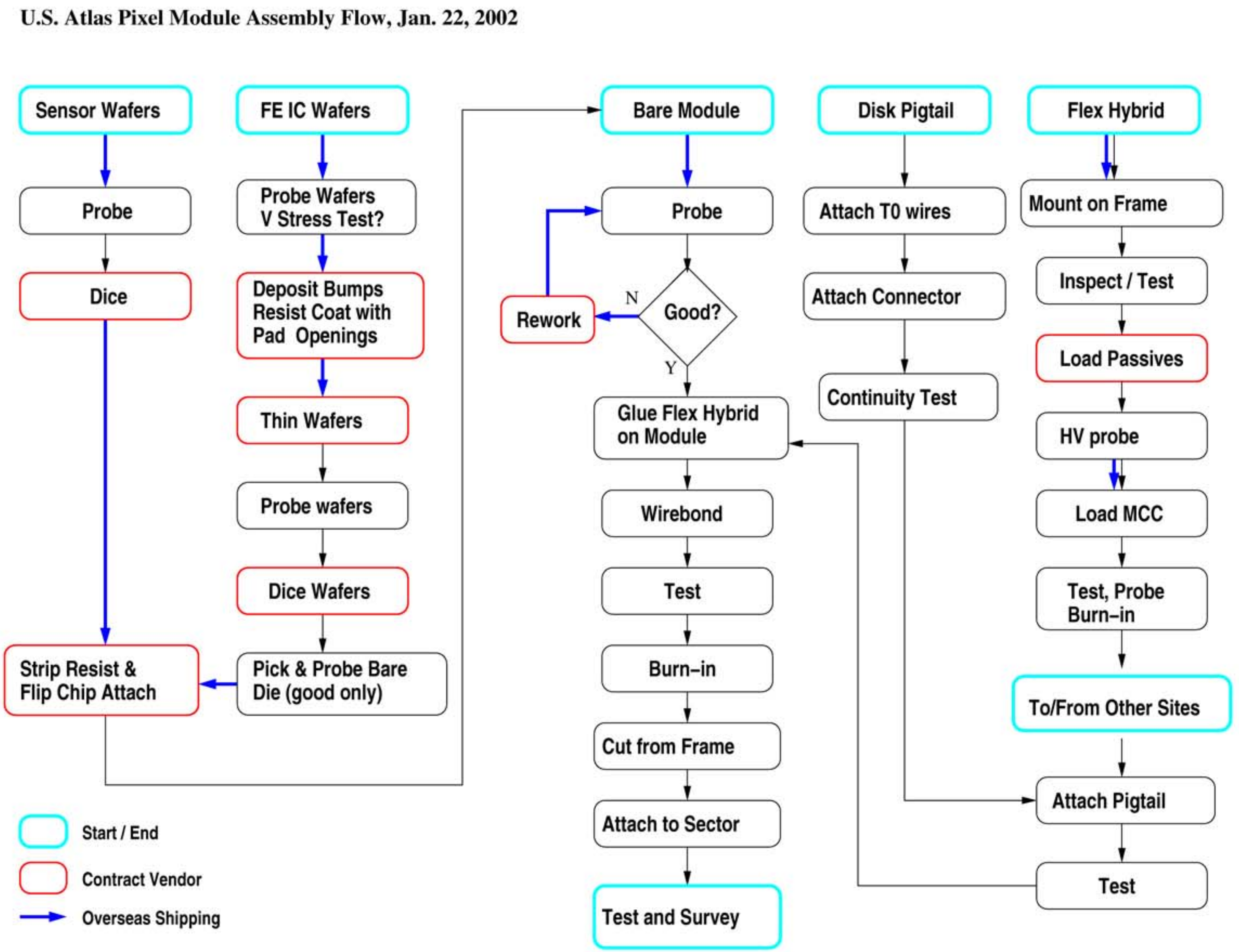


Schematic Cross Section
(through here)



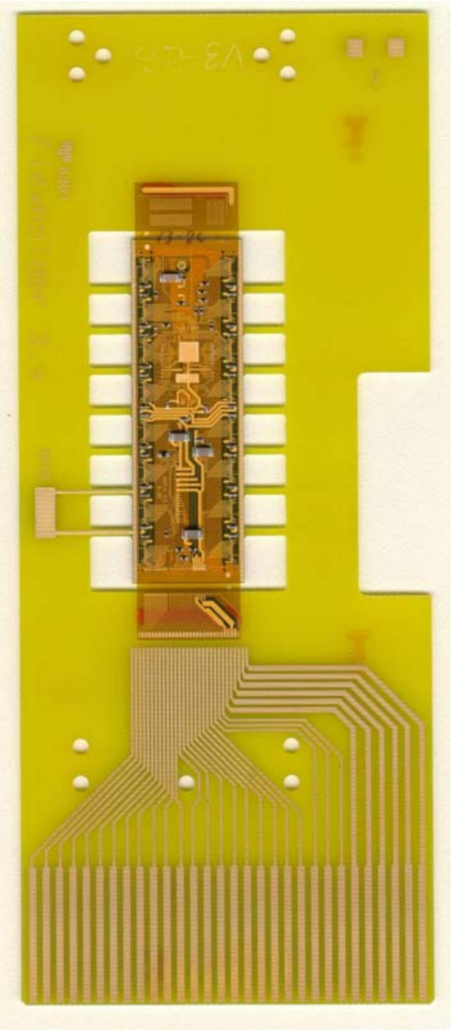
M. Gilchriese

Pixel Module Work Flow(US)



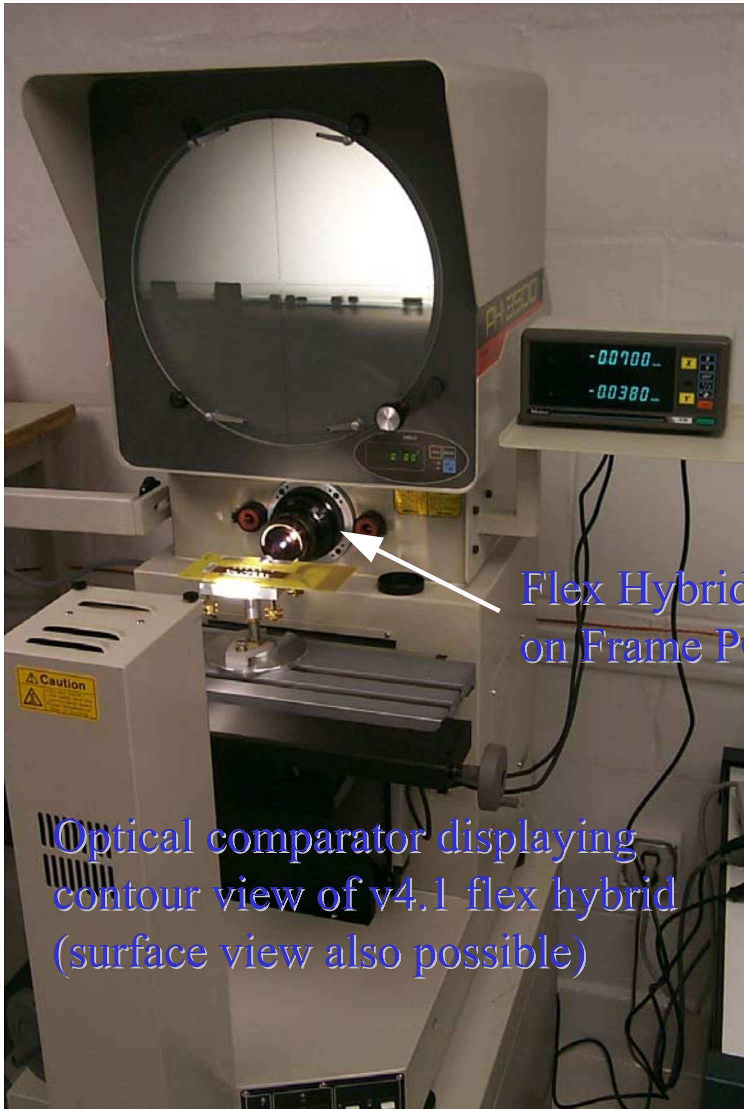
1.1.1.4 Flex Hybrids

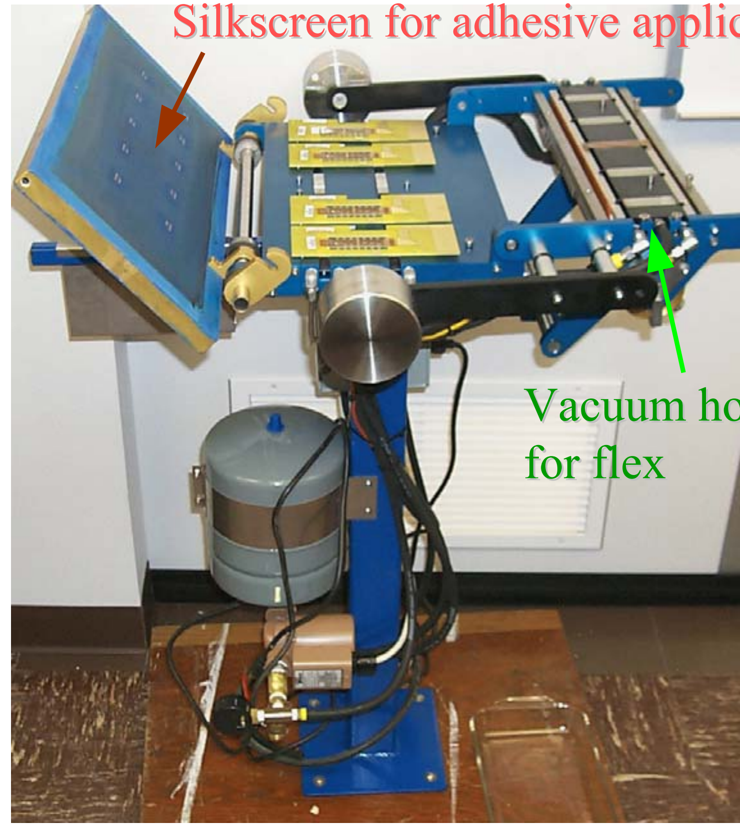
- Versions 1.x and 2.x(x representing different vendors) were made long ago for rad-soft chips and associated modules. These prototypes demonstrated proof-of-principle.
- 50 v3 flex built by Compunetics
  - Passive components loaded at Surface Mount Depot (SMD, OKC)
  - 24 loaded with AMS MCC and tested at Genoa
  - 5 of these now at UOK for test development and cross-calibration
  - Remainder used for wire bonding tests, other studies
- 100 v4.1 flex built by Compunetics
  - 43 built with 1.5 (increased from 1.0 mil) Pyralux cover layers to compensate for increased Cu thickness (now 17 microns, min.)
  - 50 loaded at SMD to date
  - 10 tested and distributed to Bonn, Genoa and LBNL for module construction
- 100 v4.2 flex built by Dyconex (Switzerland)



V3 flex on frame PCB

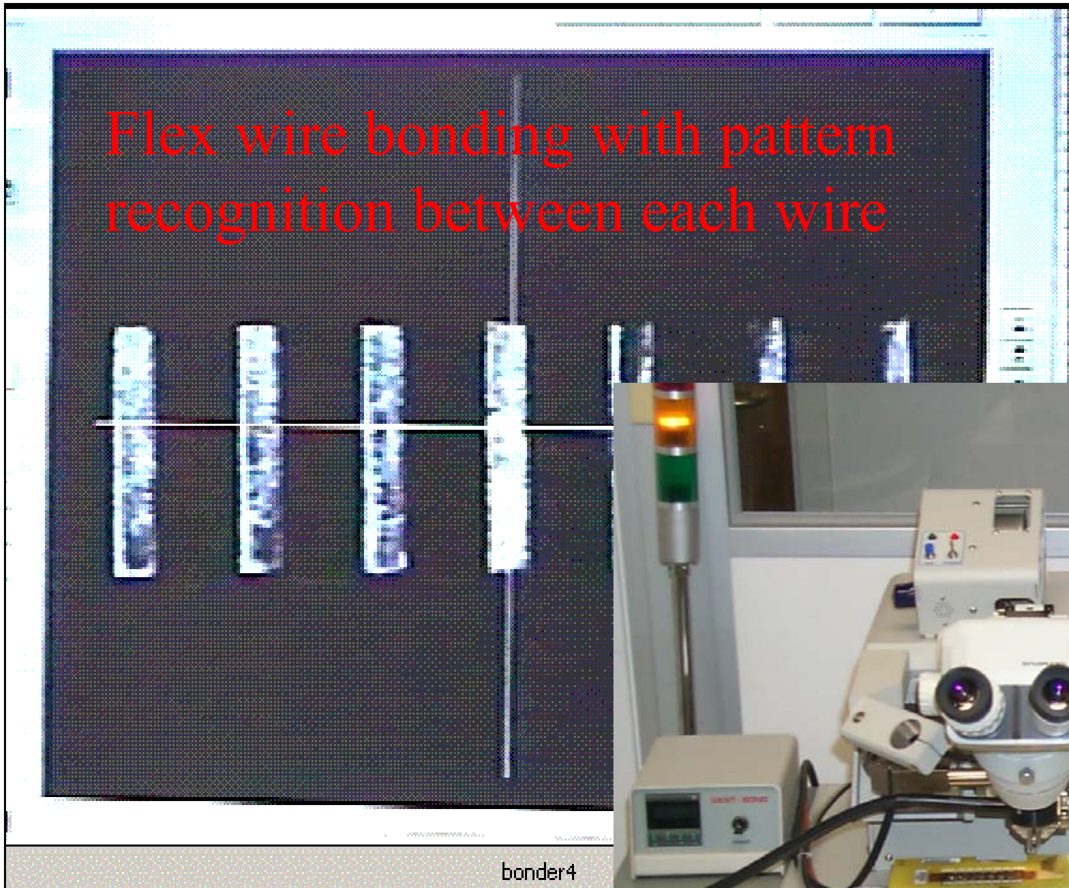
Oklahoma Flex Handling



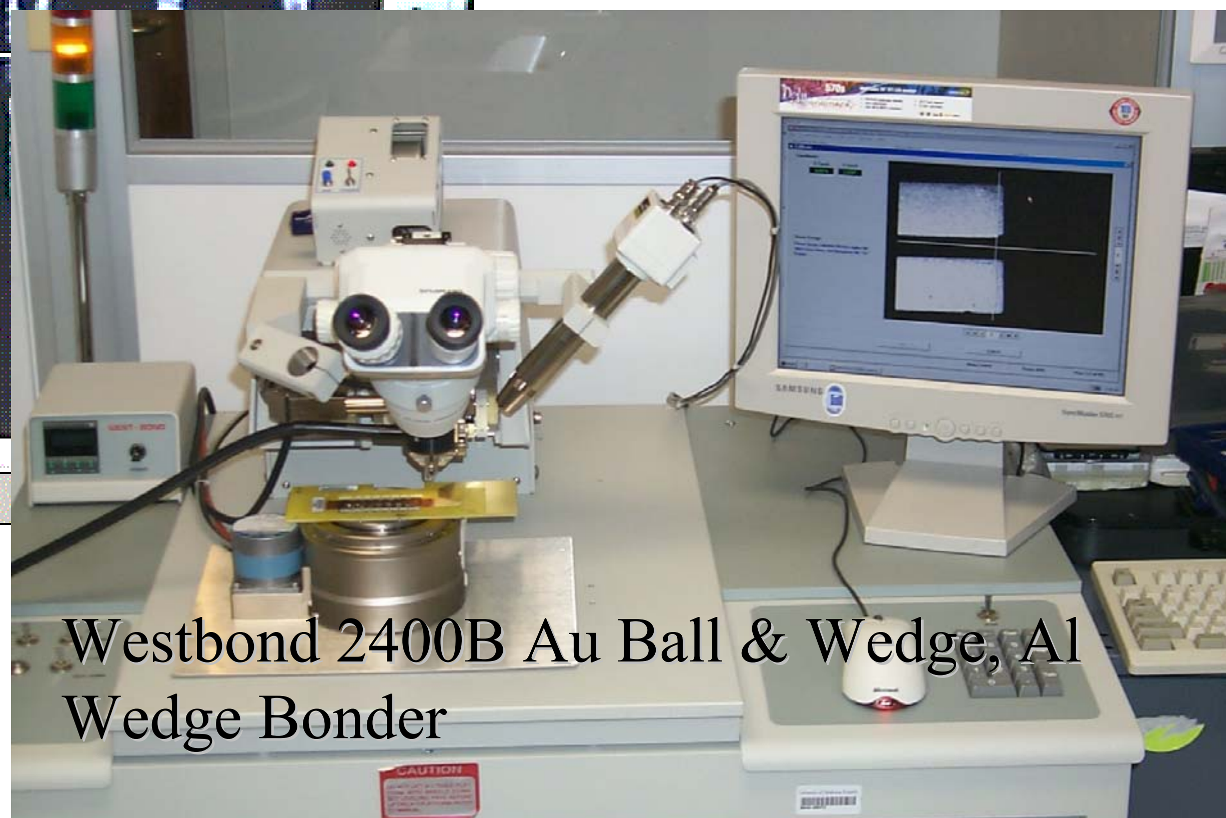


Custom made flex to frame PCB laminator. Aligns, places and heat sets adhesive for 5 flex at one time. Water cooled to prevent thermal expansion of critical parts.

Oklahoma Flex Bonding



Flex wire bonding with pattern recognition between each wire



Westbond 2400B Au Ball & Wedge, Al Wedge Bonder

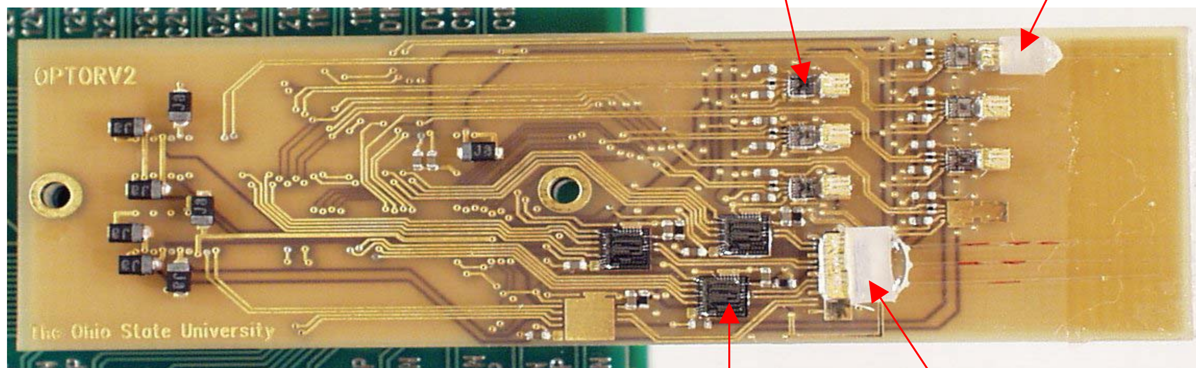
1.1.1.4 Optical Hybrids

- Ohio State is responsible in US for both electronics design of optical chips(in collaboration with Germany, some interaction with LBNL) and for optical boards(nominally only for disk system).
- Optical packages from Taiwan.
- IC prototypes were done via multi-project runs, and version 3 was included in IBM-1 wafer run. Version 4 has been submitted via multi-project run and will be back next month. Design evolving, in part, to keep up with changes in optical package. Version 5(pre-production) would be part of IBM-2 wafer run.
- Three versions of optical board prototypes made(in FR4) and extensive test systems(bit-error-rate custom board, others for irradiation).
- Used for system and irradiation tests, generally OK but need to keep up with electronics and package design changes, since obviously these affect performance.
- Next step is opto-board 4(in FR4 first, then BeO) with version 4 electronics, hopefully nearly final optical packages and 2nd generation PP0. This would occur after Final Design Review planned for October this year.

OSU Optical Board Prototypes

VDC-D2

VCSEL opto-pack

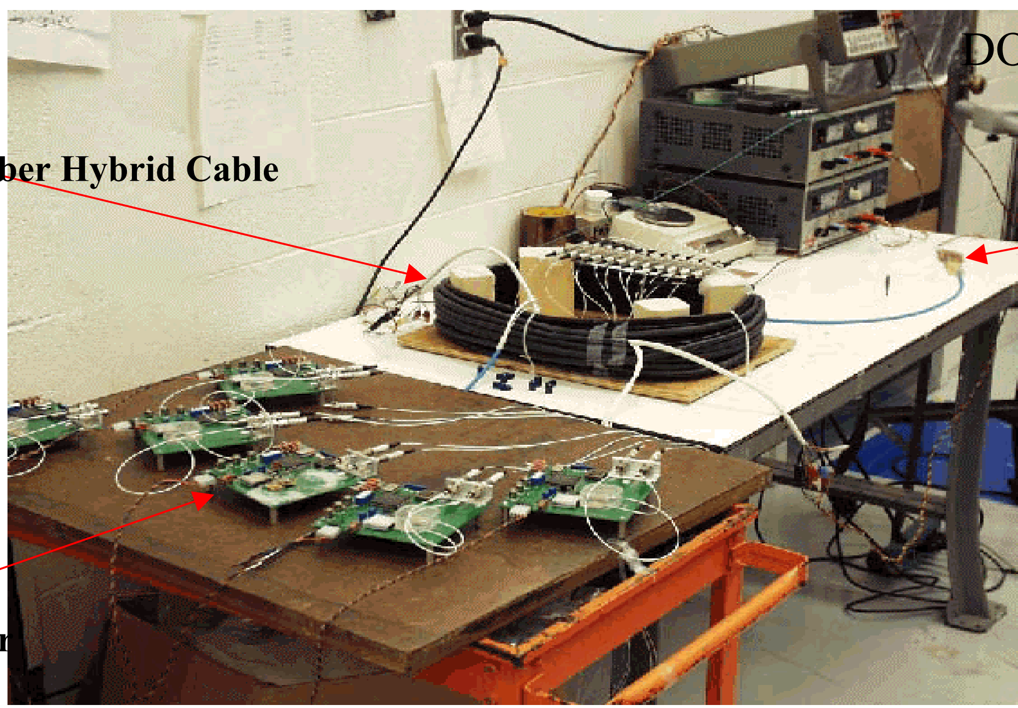


DORIC-D2

3-PIN opto-pack

Copper/Fiber Hybrid Cable

Opto-Board

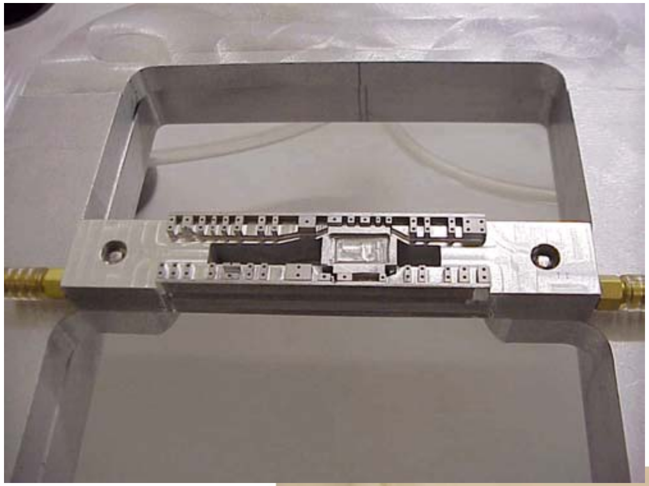


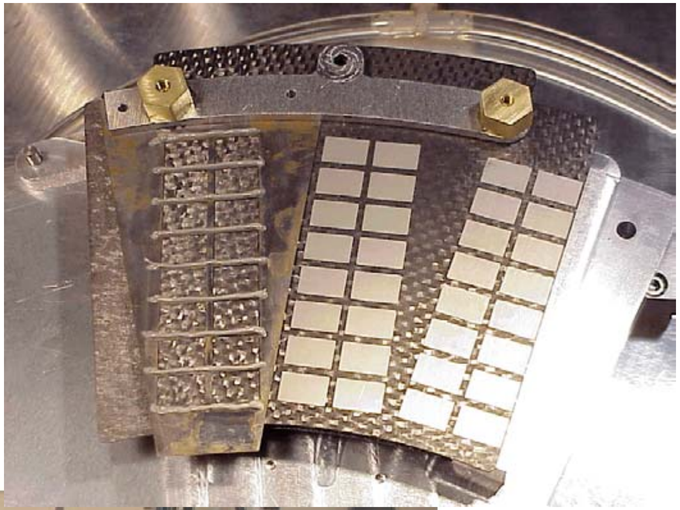
BER Tester

1.1.1.5 Pixel Modules

- Prototype tooling and procedures in place and have been used for more than a year to assemble dummy and a some real modules.
- All module assembly is done “by hand” given the small number of modules(roughly 300) that the US will do.
- The tooling lends itself to easy replication so that multiple modules can be in different steps in the process at any given time. And we have already made 6 sets of the basic structure but will modify the detailed vacuum chuck, and other tooling and procedures over the next year
- As has already been mentioned, many production-quality test systems will be completed this year.

1.1.1.5 Pixel Modules



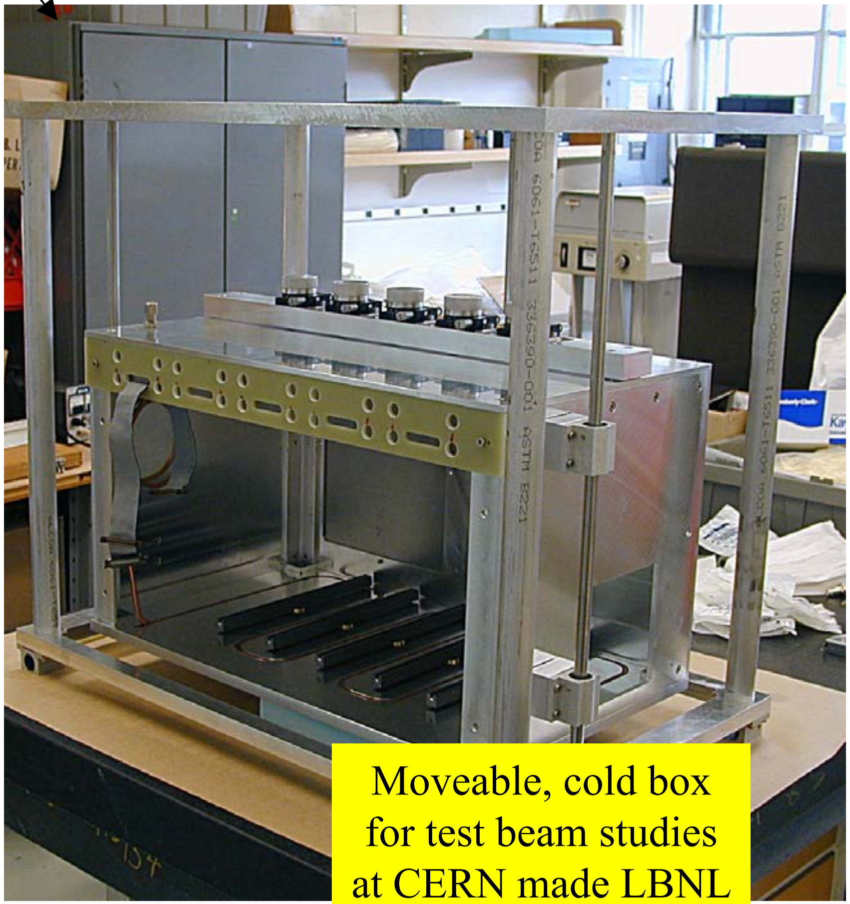


1.1.1.4&1.1.1.5 Cost&Schedule

- Flex hybrid Production Readiness Review planned for October this year. Production could start after this Review, but we have enough float in schedule to complete multi-module tests before issuing production orders.
- Preliminary indications from fabrication at Compunetics and Dyconex are that should be about on cost. Schedule will be dominated by availability of MCC chips, needed for final assembly.
- Optical Final Design Review planned for October this year. Prototypes of optical boards going well but need final parts from Taiwan + system test before going forward with production of boards in US that are needed in '04.
- Already said, current plan is to move up schedule relative to baseline for exercising module assembly flow so that it's well oiled by '04 for final production.

1.1.1.6 Test Support

- This covers primarily costs at CERN and items supplied in-kind or cash for pixel common fund.
- Most of this currently goes into test beam support and support of lab infrastructure at CERN(there is no CERN group involved in pixels).
- These costs will increase over what we expected in ETC02 by some tens of K per year. We had hoped for M&O support, but this will not be available in FY03-FY05 for pixels.



Moveable, cold box for test beam studies at CERN made LBNL

Pixel Schedule Overview

FY2002

Start production of sensors and part of mechanics(sectors, rings, frame). Electronics, hybrid and module prototypes.

FY2003

Complete production of sensors. Complete production of mechanics items started in 2002. Start construction of remaining mechanics items. Start electronics production. Start hybrid production.

FY2004

Complete electronics, hybrid and mechanics production. Start module production and assembly of disks. Deliver support tube to CERN.

FY2005

Complete module production and disk assembly and test. Deliver to CERN early calendar 2005. Integrate system at CERN.

FY2006

Complete surface integration of pixel system and beam pipe. Lower and start insertion into detector(>February 2006, no new date yet fixed by ATLAS).

Pixel Key Milestones

	Name	Baseline Milestone	ETC02 Milestone	Current Projection
	Outer Structure Complete/Ready for Modules	23-Sep-03	22-Sep-03	Aug-03
	Outer Structure Needed for Modules	7-Jan-04	15-Apr-04	May-04
	Support tube/service panels complete	***	18-Jun-04	Jun-04
	Support tube need date	***	***	Feb-05
	First production wafers delivered	18-Jan-02	24-May-02	Complete
	Sensors Testing Complete	3-Oct-03	26-Sep-03	Sep-03
	Sensors Need to Begin Module Production	31-Jul-03	7-Nov-03	Dec-03
Sil L2/6	1st IBM prototype submitted(FE-I1)	26-Jul-01	30-Nov-01	Complete
	2nd IBM prototype submitted(FE-I2)	19-Jun-02	26-Sep-02	Nov-02
Sil L2/7	Start IBM Production	13-Mar-03	12-Jun-03	Aug-03
	1st outer IBM wafers arrive	30-Jul-03	6-Nov-03	Nov-03
	Outer IBM FE Testing complete	14-Jul-04	21-Oct-04	Oct-04
	Flex Hybrid PRR	3-Jul-02	10-Oct-02	Oct-02
	Optical FDR	31-Jan-02	10-Oct-02	Oct-02
	Optical PRR	5-Mar-03	12-Jun-03	Jun-03
	First outer flex available for module assembly	12-Feb-03	22-May-03	May-03
	Need date for first outer flex	20-Nov-03	27-Feb-04	Feb-04
	Bare module PRR	26-Jun-02	10-Oct-02	Dec-02
	Module assembly FDR	26-Jun-02	10-Oct-02	Dec-02
	Module assembly PRR	28-May-03	4-Sep-03	Jun-03
Sil L2/8	Start IBM outer bare module production	22-Oct-03	29-Jan-04	Jan-04
	Complete testing disk sectors	4-Aug-04	11-Nov-04	Jan-05
Sil L2/9; S	Disk System at CERN	13-Oct-04	20-Jan-05	Mar-05
	Start pixel installation in experiment	15-Apr-05	24-Feb-05	>Feb-06
		(red)	Current-ETC02 > 2 months	
		(green)	Current-ETC02 < 2 months	

ETC02 Funding Profile

Installation from Management Contingency in FY05(656K)

ETC02(FY02 $K)						
		FY02	FY03	FY04	FY05	Totals
1.1.1 Pixels		2365	2560	521	7	5452
1.1.1.1	Mechanics	1039	1105	236	7	2386
1.1.1.2	Sensors	133	107	0	0	240
1.1.1.3	Electronics	786	402	40	0	1229
1.1.1.4	Hybrids	141	398	5	0	544
1.1.1.5	Modules	224	504	240	0	968
1.1.1.6	Test Support	43	43	0	0	86

Top-Down Cost Risk Analysis

- Does the contingency calculation make sense?
- The primary cost risks are (a) loss of base program support of engineering and technical staff and (b) need for additional engineering (mechanical, electrical or both).
- The materials cost risks are relatively small compared to these.
- FY02 base program support of engineering and technical staff(mostly but not only at LBNL) is about \$1.4M. Some of this is at risk in FY03(and later).
- Each additional FTE year of engineering needed is 150-200K, depending on the type of engineer. In FY03, there will be about 7 FTE engineers working, of which about 4 are now base supported.
- For example, if we lose \$0.5M in base support per year for two years and need another 3 FTE years of engineering, very roughly the extra cost would be \$1.5M. Our contingency estimate is \$2.1M, in principle allowing some considerable room for procurement increases and production labor increases(not included in base support).
- However, we recognize that it will be very difficult to liberate contingency as ATLAS moves into the endgame and other crises arise.

3.1.1 Pixel Maintenance and Operations

- Preoperations, operations and maintenance phase begins in FY06.
- We have had so far the major role in both the mechanics and electronics systems and our cost estimate is based on providing some ongoing technical support in both these areas.
- The pixel-specific costs are all personnel and travel costs.
- Consumables and other materials costs, or money supplied to CERN are covered under the general Inner Detector WBS.
- Note that we are anticipating little or no base program support of technical personnel in this estimate. This is consistent with the steady erosion of this support, which we expect to be near zero by FY06.
- We have assumed that physicists will continue to be base supported.

3.1.1 Pixel Maintenance and Operations

	FY05	FY06	FY07	FY08	FY09
Pixels (WBS 3.1.1)					
Mech. Eng.		1.0	1.0	1.0	0.4
Elect. Eng.		1.0	0.5	0.5	0.2
Technician		1.5	1.8	1.8	1.4
Software		1.0	1.0	1.0	1.0
Designer		0.5			

- We assume US has lead ME at CERN for final integration and installation FY06-FY07. We also assume pixel system comes out after 1st run to install 3rd hit. Conservative at this time, to be confirmed clearly.
- EE help for integration, installation, commissioning
- Techs at CERN, either from US or cash.
- Software support and coordination of commissioning from J. Richardson, who will be resident at CERN once pixel system arrives.

3.1.1 Profile

WBS Number	Descriptio	FY 03 (k$)	FY 04 (k$)	FY 05 (k$)	FY 06 (k$)	FY 07 (k$)	FY 08 (k$)	FY 09 (k$)	FY 10 (k$)	FY 11 (k$)	FY 12 (k$)	Total (k$)
3.1.1	Pixels	0	0	0	795	732	732	498	498	498	498	4252
3.1.1.1	Pre-operations	0	0	0	795	0	0	0	0	0	0	795
3.1.1.1.1	SR Building Facilities	0	0	0	0	0	0	0	0	0	0	0
3.1.1.1.2	Mechanical support	0	0	0	383	0	0	0	0	0	0	383
3.1.1.1.3	Electrical support	0	0	0	246	0	0	0	0	0	0	246
3.1.1.1.4	Software support	0	0	0	166	0	0	0	0	0	0	166
3.1.1.1.5	Physicist support	0	0	0	0	0	0	0	0	0	0	0
3.1.1.2	Operations	0	0	0	0	422	422	302	302	302	302	2050
3.1.1.2.1	Mechanical Support	0	0	0	0	165	165	101	101	101	101	732
3.1.1.2.2	Electrical Support	0	0	0	0	104	104	48	48	48	48	401
3.1.1.2.3	Software support	0	0	0	0	153	153	153	153	153	153	918
3.1.1.2.4	Physicist support	0	0	0	0	0	0	0	0	0	0	0
3.1.1.3	Maintenance	0	0	0	0	310	310	197	197	197	197	1406
3.1.1.3.1	Mechanical support	0	0	0	0	169	169	123	123	123	123	832
3.1.1.3.2	Electrical support	0	0	0	0	141	141	73	73	73	73	575
3.1.1.3.3	Software support	0	0	0	0	0	0	0	0	0	0	0
3.1.1.3.4	Physicist support	0	0	0	0	0	0	0	0	0	0	0
3.1.1.3.5	Spares	0	0	0	0	0	0	0	0	0	0	0

4.1.1 Pixel R&D

- Replace pixel system, starting with innermost layer, some years into operation. When depends on luminosity, actual radiation levels, overall system performance.
- Electronics
  - Increase/understand radiation hardness > 100 MRad. This looks promising but much more study needed.
  - Follow the technology from 0.25µ to smaller feature sizes. Work on 0.12µ could begin very soon, this year in fact.
  - Reduce pixel size below 50x400µ. There is already significant confusion in at least innermost pixel layer that limits b-tagging. Smaller pixels improve performance.
- Sensors
  - A follow on to the successful ROSE collaboration is starting to address the 10^{35} challenge.
- Hybridization
  - Reduce the pitch of bump bonding to allow smaller pixels, or use redistribution in electronics.
  - Development of MCM-D technology to mostly eliminate kapton hybrids has been ongoing for some time and needs further development.
- Mechanics and systems issues
  - Reduce material and complexity of the mechanics/cooling. Material reduction directly improves electron and photon energy resolution and tracking performance.
  - Complexity of current cabling/cooling is formidable. Reliability will be problem.
  - Radioactivation of pixel elements is already significant at 10^{34}. There are as yet no good ideas about how to handle this for higher luminosities.

4.1.1 Pixel R&D Profile

- We believe it takes 5-6 years from starting R&D on new ICs, module concepts, mechanics to deliver new system.
- This implies start in FY04.

WBS Number	Descriptio	FY 03 (k$)	FY 04 (k$)	FY 05 (k$)	FY 06 (k$)	FY 07 (k$)	FY 08 (k$)	FY 09 (k$)	FY 10 (k$)
4.1.1	Pixels	0	238	859	1492	1291	1968	1444	366
4.1.1.1	Replacement R&D	0	238	859	1492	0	0	0	0
4.1.1.1.1	Mechanics/Services	0	0	118	205	0	0	0	0
4.1.1.1.2	Sensors	0	0	105	114	0	0	0	0
4.1.1.1.3	Electronics	0	238	470	671	0	0	0	0
4.1.1.1.4	Hybrids	0	0	86	203	0	0	0	0
4.1.1.1.5	Module assembly	0	0	57	277	0	0	0	0
4.1.1.1.6	Test beam support	0	0	23	23	0	0	0	0
4.1.1.2	Replacement	0	0	0	0	1291	1968	1444	366
4.1.1.2.1	Mechanics/Services	0	0	0	0	339	501	630	366
4.1.1.2.2	Sensors	0	0	0	0	104	204	0	0
4.1.1.2.3	Electronics	0	0	0	0	512	596	304	0
4.1.1.2.4	Hybrids	0	0	0	0	192	283	186	0
4.1.1.2.5	Modules	0	0	0	0	143	384	324	0

Concluding Remarks

- Excellent technical progress in the last year.
- Sensors in production, mechanics production started, prototypes of electronics, hybrids and modules ready for extensive testing.
- Major cost risk is likelihood of reduced base program support.
- Major schedule risk remains electronics. Partial mitigation of schedule risk by early buy of many wafers to advance module and system readiness.
- We remain on track to complete deliverables by early calendar 2005.
- Initial planning for preoperations, operations, maintenance and replacement R&D completed.