WBS 1.1.1 Pixels

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(LBNL)

DoE/NSF Review
October 1998

WBS 1.1.1 Institutions

SUNY Albany
UC Berkeley/LBNL
University of New Mexico
University of Oklahoma/Langston Univ.
UC Santa Cruz

UC Irvine and Wisconsin support the pixel effort through the "Test Beam" activitities in 1.1.3 RODs.

Ohio State University has joined ATLAS and would work on the Pixel System(WBS 1.1.1)

WBS 1.1.1 Pixels - Overview

- Approved for pre-baseline funding of $2582K(FY97) in February.
- Through FY98, we will have spent or committed $830K of the total pre-baseline funding.
- Have adjusted development costs and schedule to fit within $2582K cap - this is a very tight squeeze.
- This assumes that almost all technical staff are supported off project.
- Contingency is $440K or 34% of base cost funds remaining (FY99 and FY00).
- Major uncertainties are (1) role of US in mechanics, which continues to expand(although so far by removing other financial responsibilities) and (2) fabrication errors eg. failure of ICs.
- Development continues through FY00, leading to baseline cost review by June 2000 or before fixing FY01 budget. The critical milestone is to complete cost baseline process by start of FY01.

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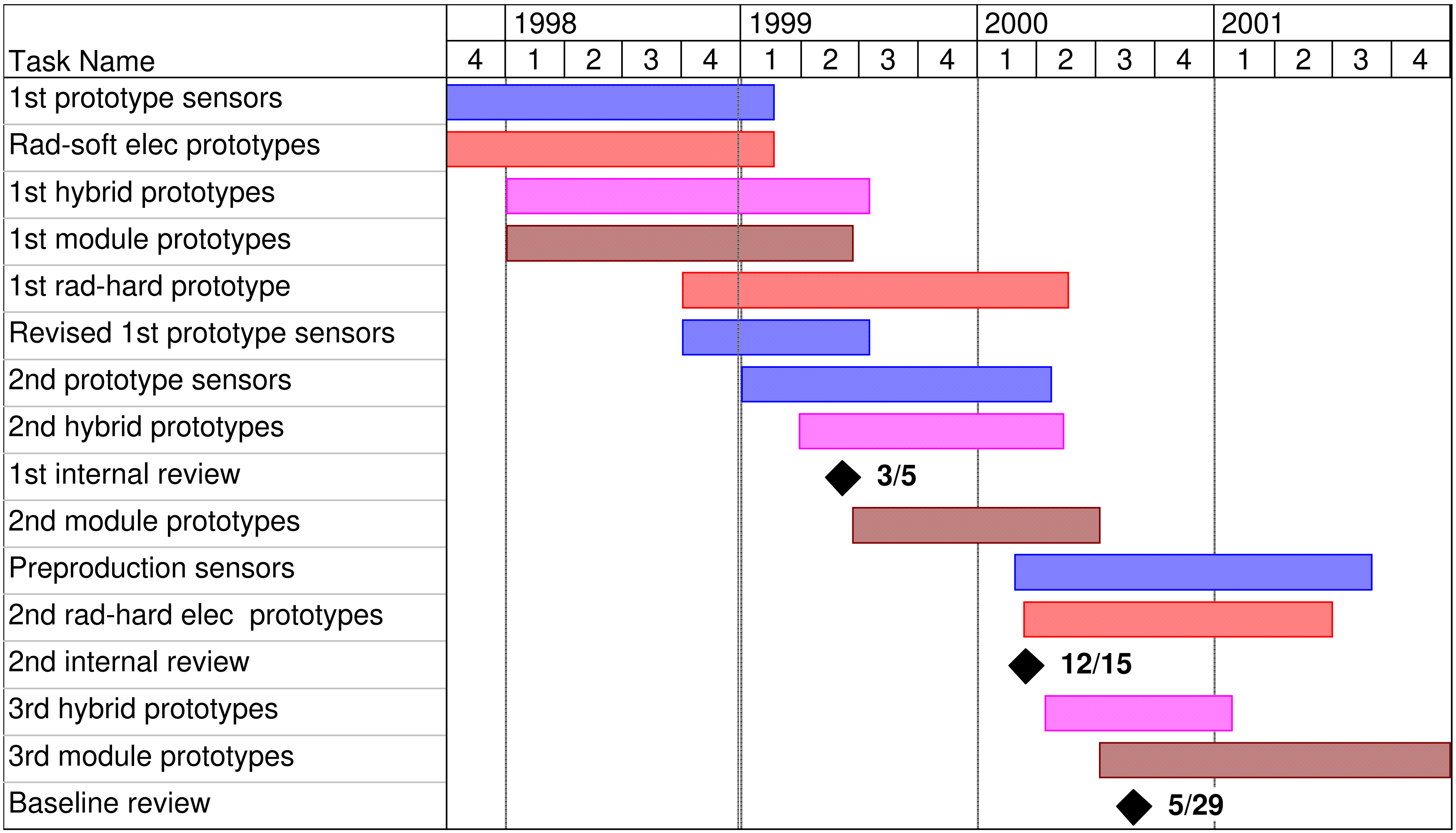
WBS 1.1.1 Pixel Schedule



Does not include mechanics

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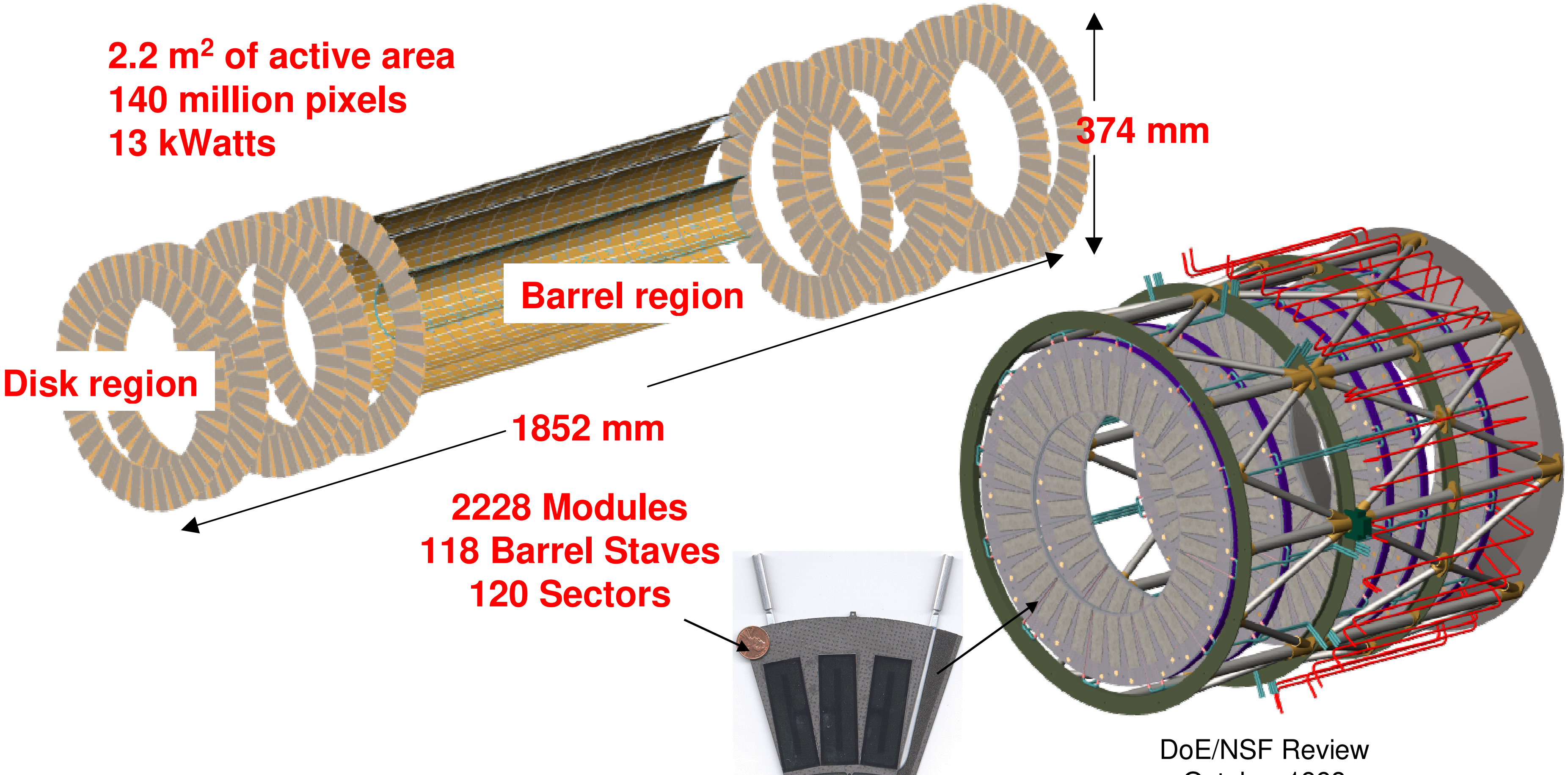
WBS 1.1.1 Pixel System

- **Pixel Technical Design Report completed on May 30, 1998.**
- **LHCC review July 7, 1998. LHCC approval in September.**

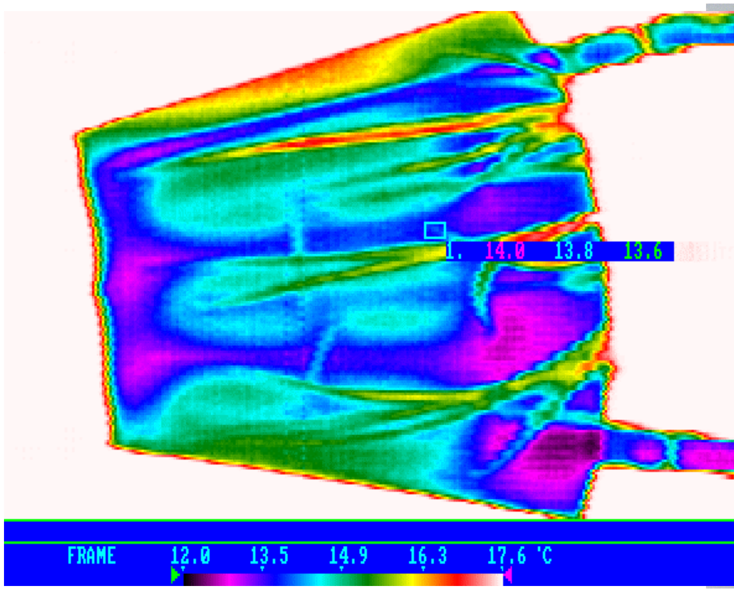


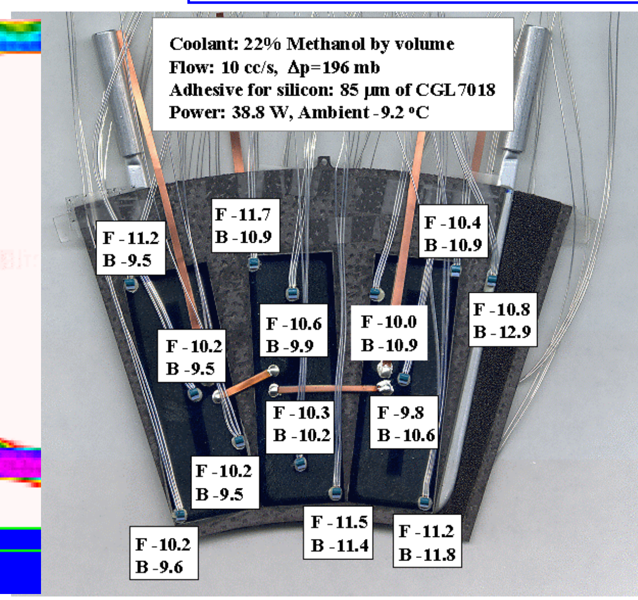
WBS 1.1.1.1 Pixel Mechanics

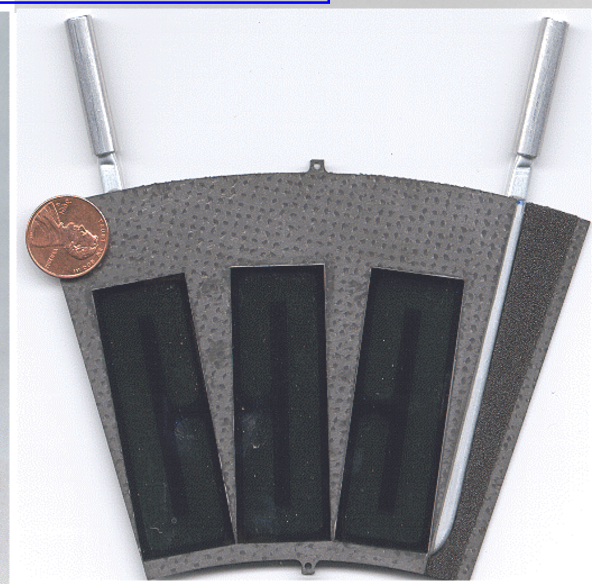
- **Disk sectors**
  - **Three design approaches are under investigation**
    - **All in-house construction using carbon-carbon faceplates and thinn wall aluminum tube glued to faceplates.**
    - **All-carbon construction from ESLI in San Diego(supported by Phase II SBIR)**
    - **Alternative all-carbon from Hytec, Inc in Los Alamos (supported by Phase II SBIR)**
  - **All work thermally, differ in material and mechanical stability**

Pictures of Al-tube sector #3

http://www-atlas.lbl.gov/pixel/mech/proto_al_tube.html







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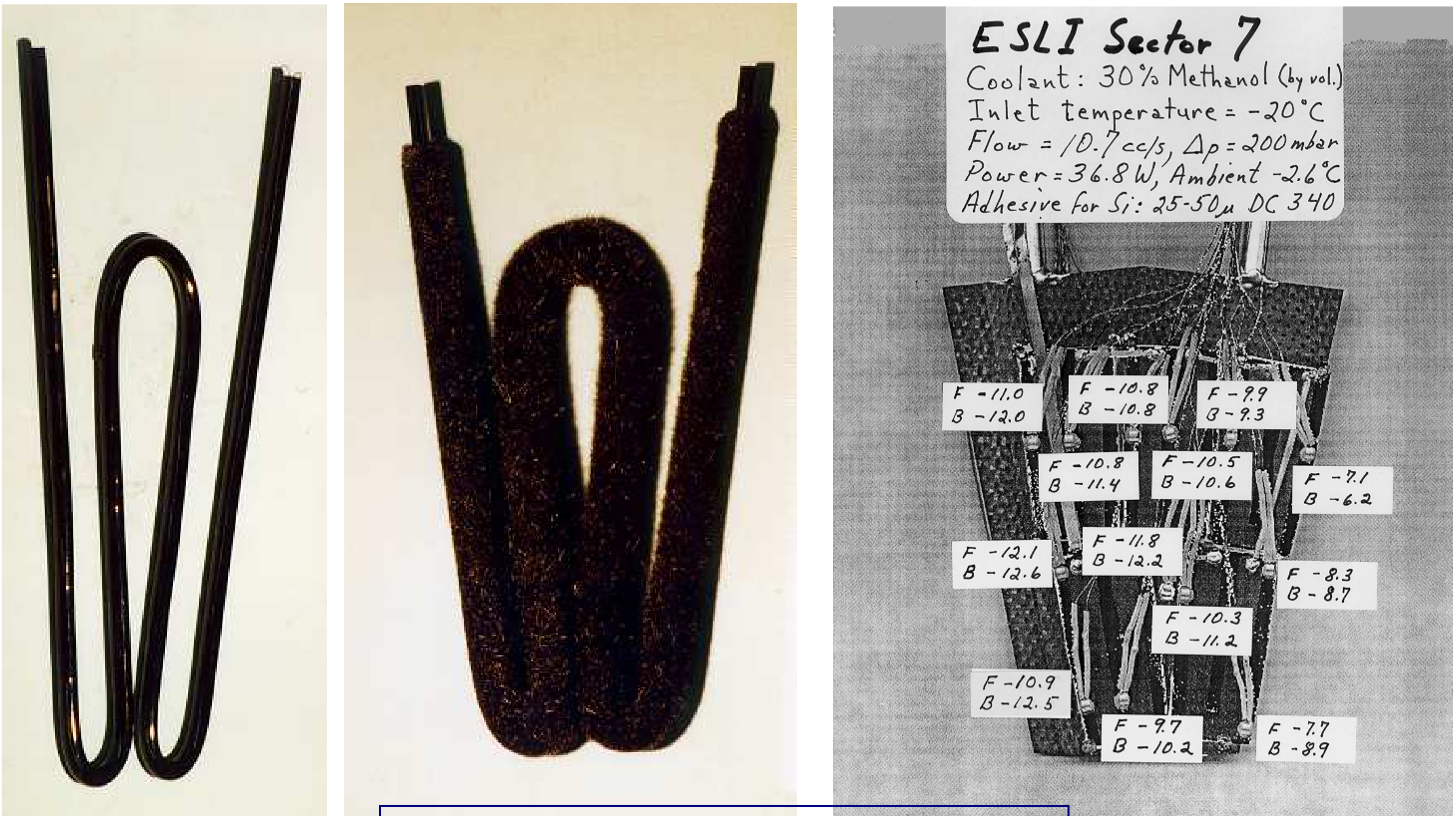
WBS 1.1.1.1 Pixel Mechanics



Pictures of ESLI Carbon Sector

http://www-atlas.lbl.gov/pixel/mech/proto_ESLI.html

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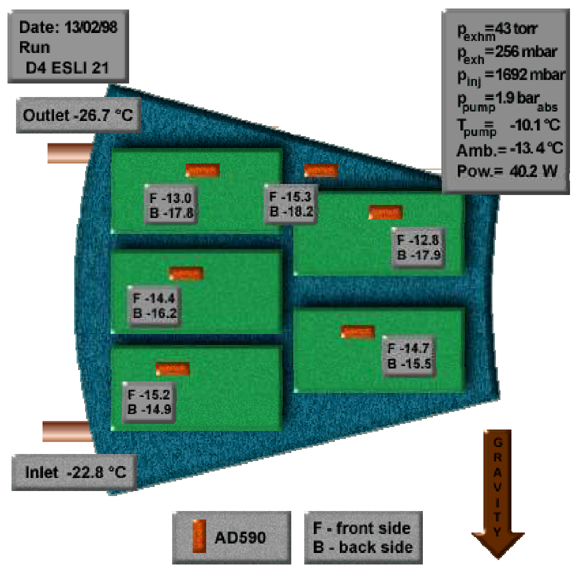
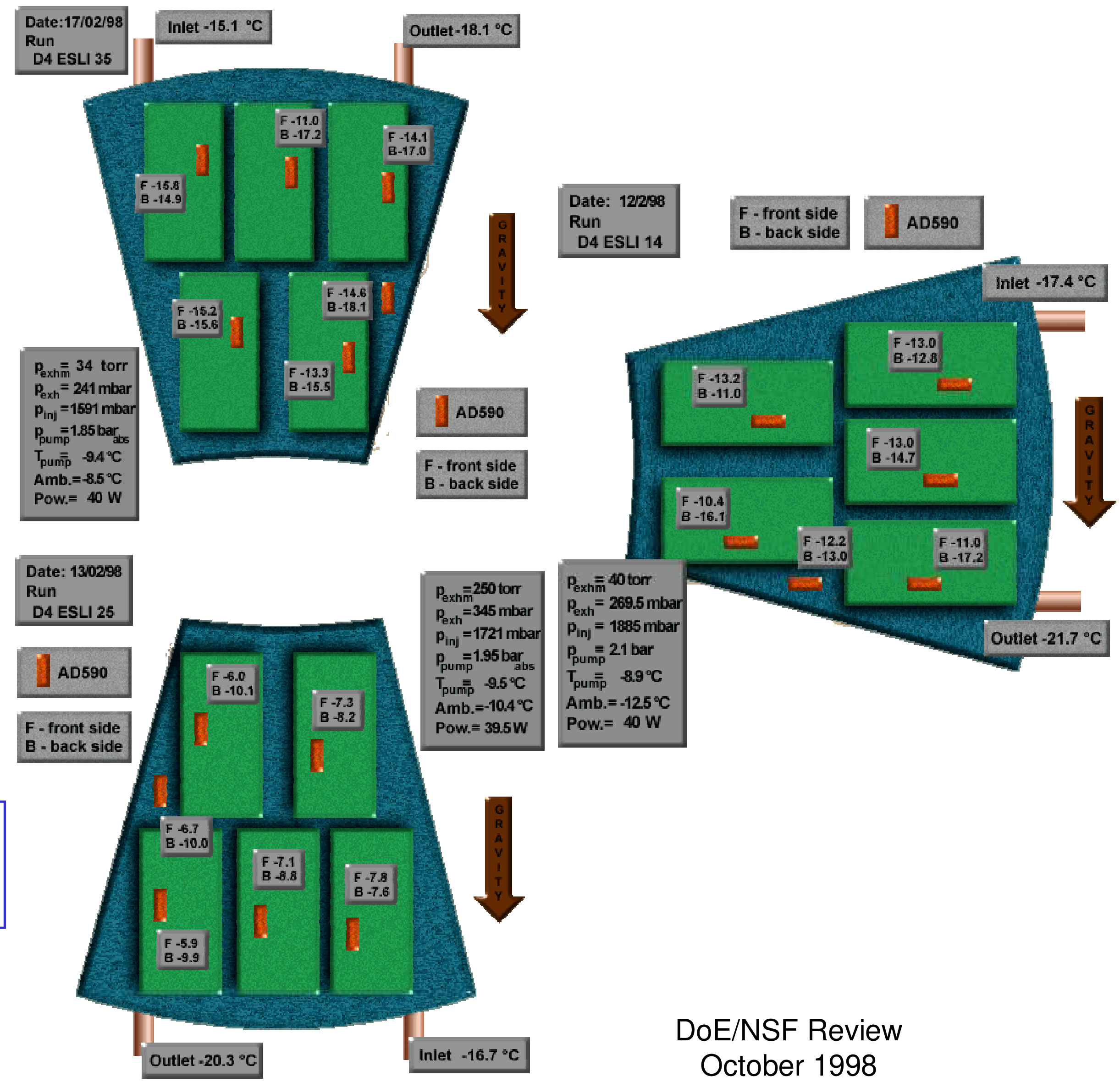
Evaporative Cooling Tests Successful

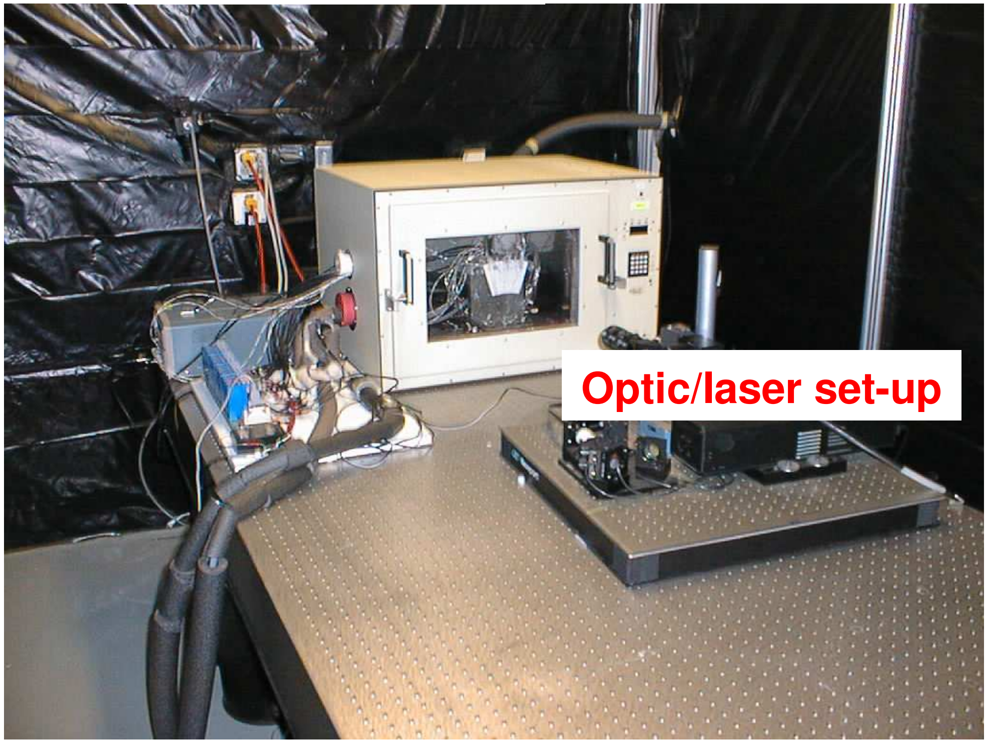




Evaporative fluorocarbon coolant tests - all orientations

Sector TV Holography

- Capability for TV holographic measurements established at Hytec, Inc under Phase II SBIR.
- Used for dynamic measurements(drive sectors with speaker and measure response) and deflections under cooldown.



TV holography arrangement for thermal strains

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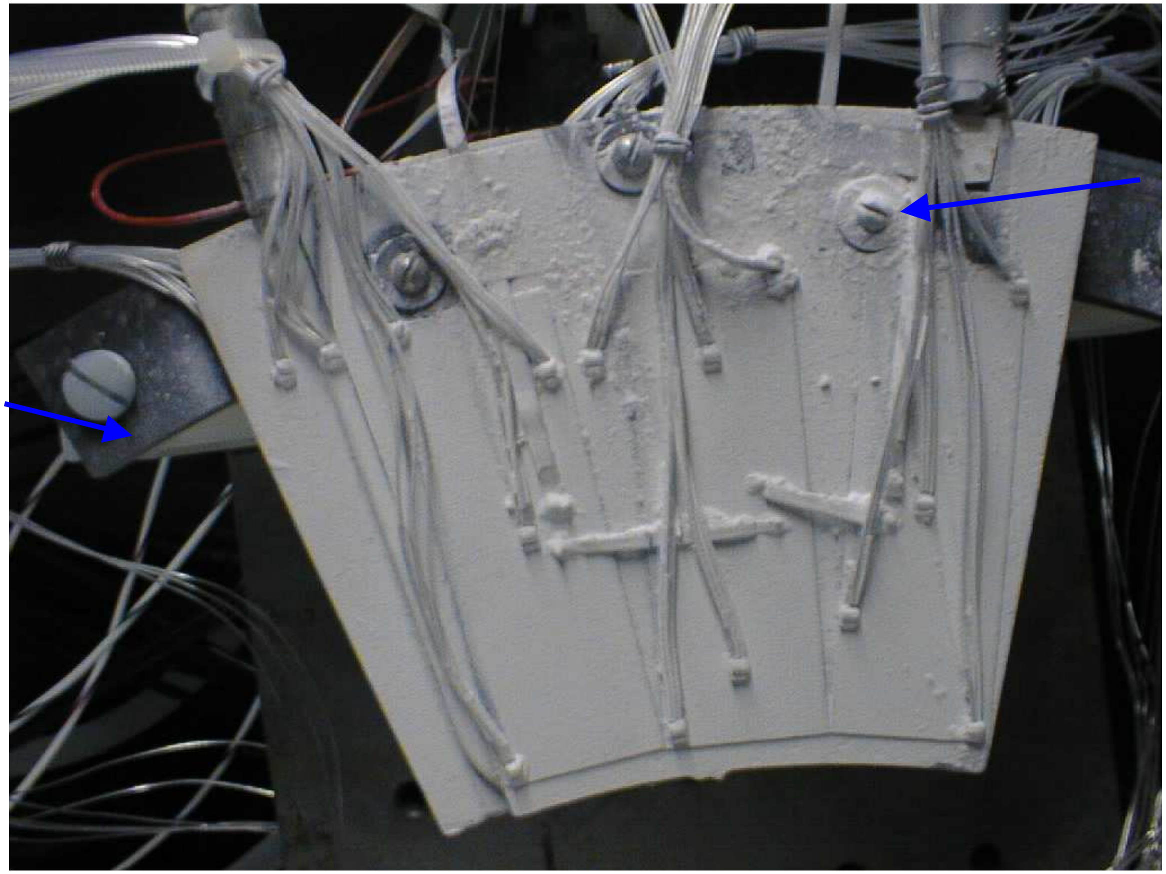
Sector TV Holography

3 fixed points

C-C arc segment



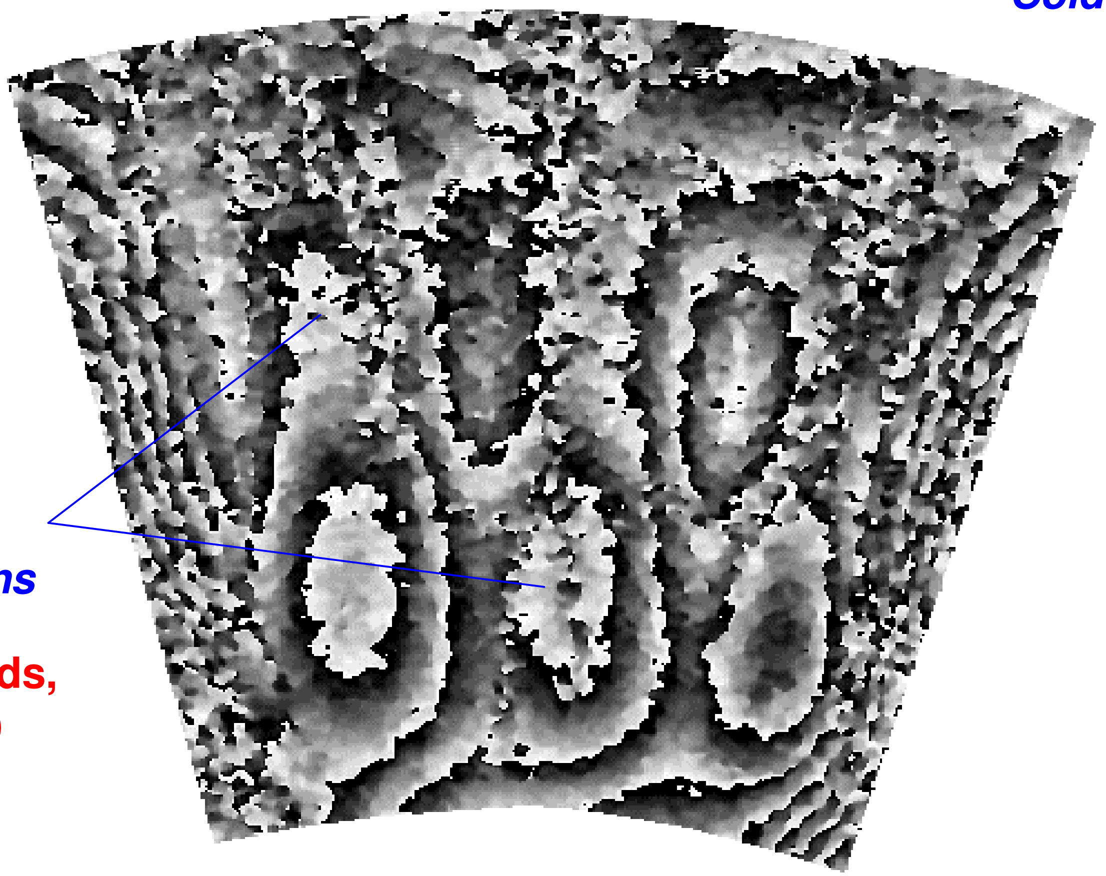
Evaluation of design and support concept

Sector TV Holography

Thermal Strain Example

Cold

Edge support



Phase map
data imperfections

(RTD's, RTD leads, power leads)

ΔT=1.1 ºC @ T=-15.3 ºC

~2 μm's peak out-of-plane

Phase Map after Removal of Tilt Fringes

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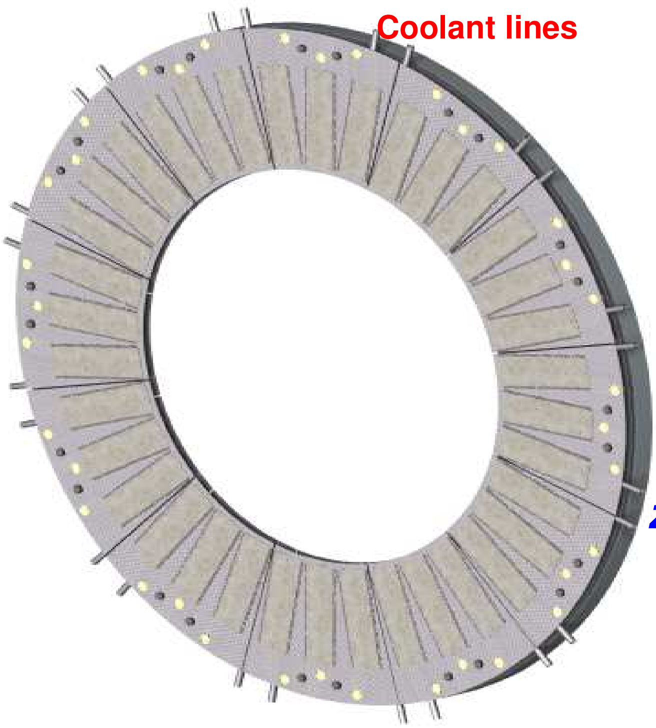
WBS 1.1.1.1 Pixel Mechanics

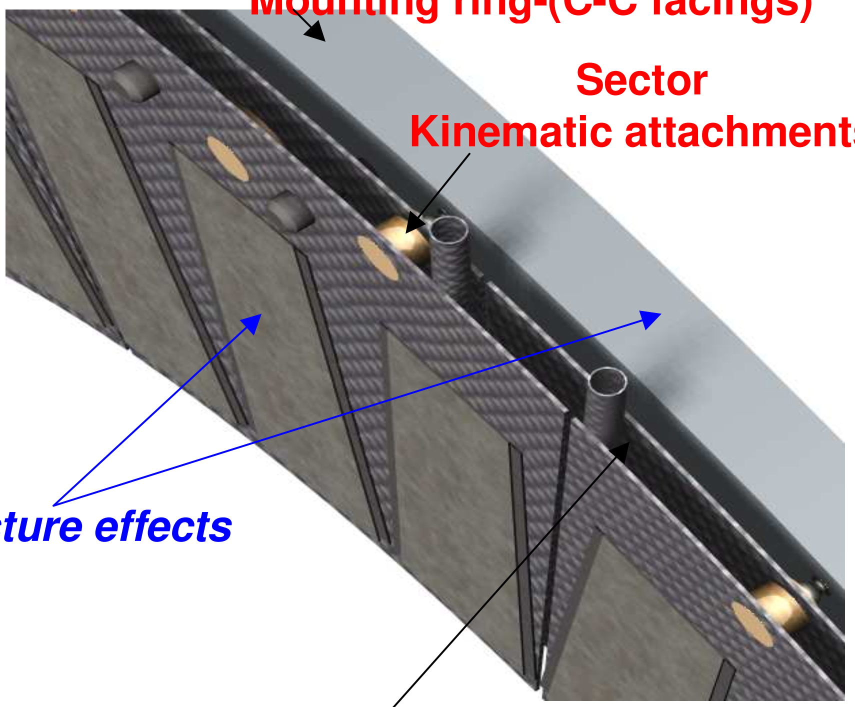
Composite Materials-Sandwich Construction
Carbon-Carbon Materials

Disk with 12 Sectors



Sector support, cantilevered from outer edge

Enlarged view



Carbon-Carbon thermostructure
(fiber core omitted)

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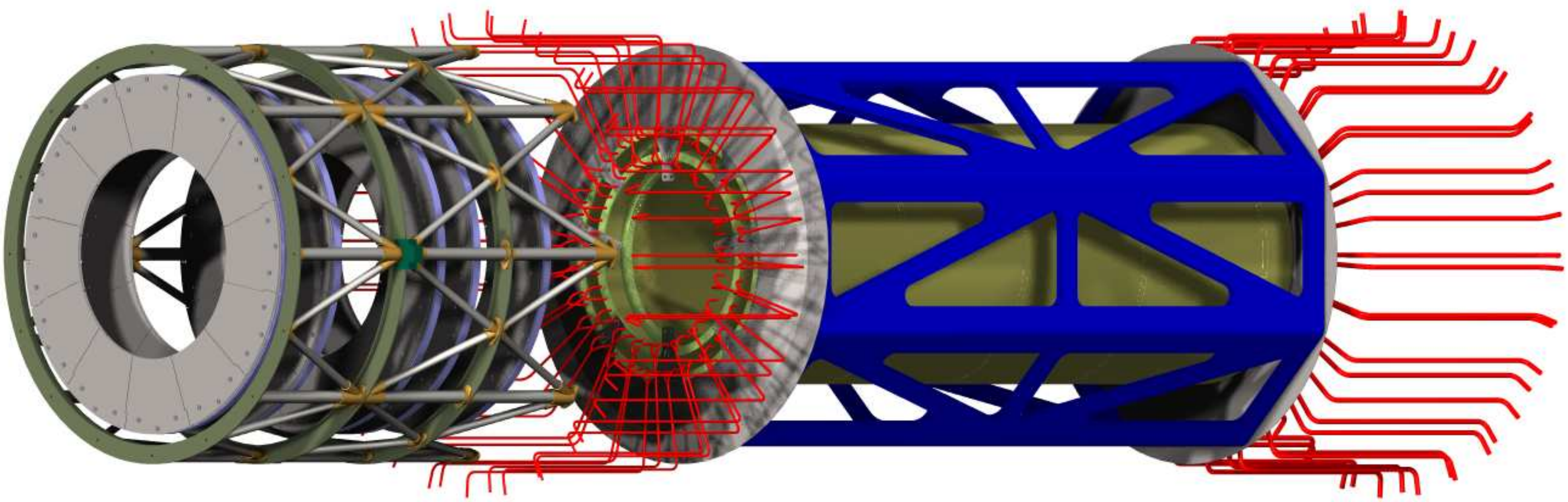
WBS 1.1.1.1 Pixel Mechanics

- **Structure and Integration**
  - LBNL engineer at CERN since Dec. 1997 as lead for integration(50% CERN supported).
  - Multi-national contract completed with Hytec, Inc for conceptual design of support structures.
  - Detailed 3D model and preliminary finite-element-analysis completed
  - Preliminary services/cable routing completed
  - Essentially now have conceptual design framework to proceed



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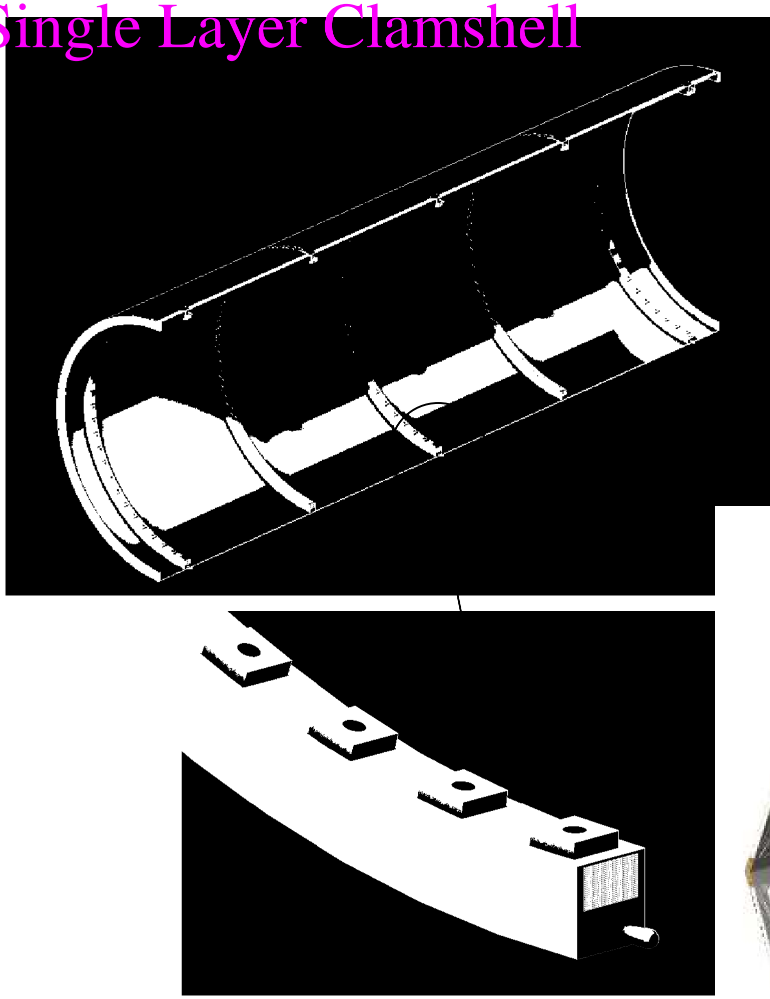
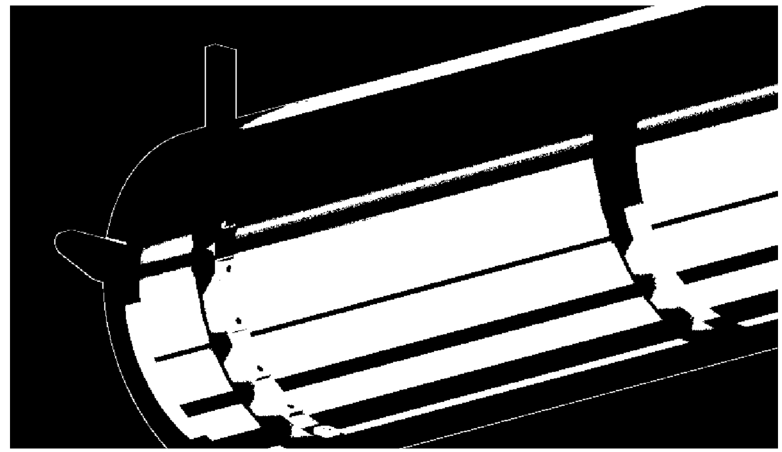
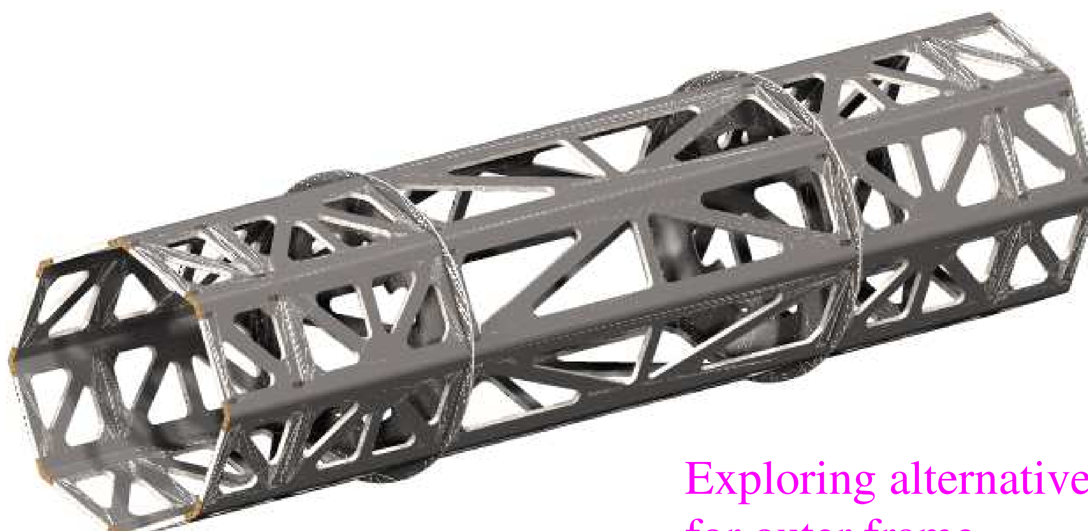
Barrel and Overall Structure

Middle and Outer Barrel
Single Layer Clamshell



B-layer
Sandwich Clamshell



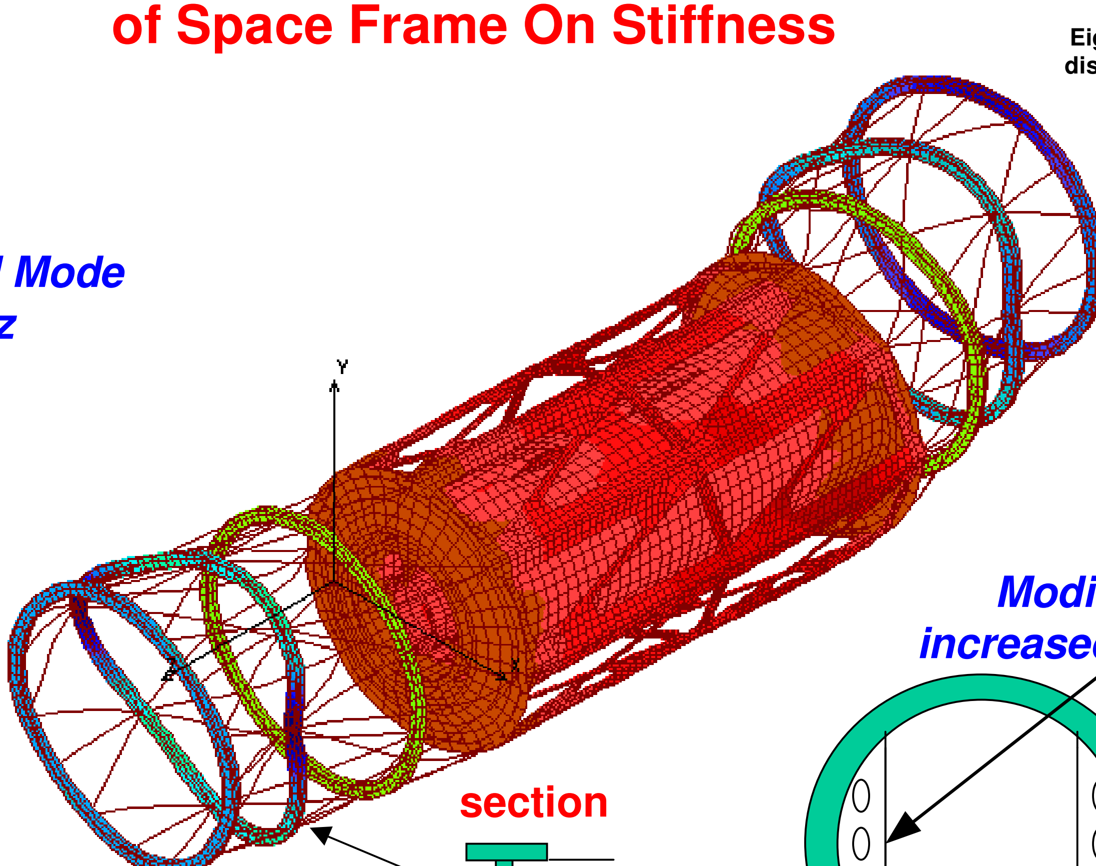


Exploring alternatives
for outer frame

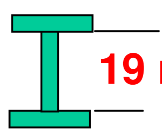
Example of FEA Calculation

Influence of Transverse Frame Member of Space Frame On Stiffness

Fundamental Mode
70.89 Hz



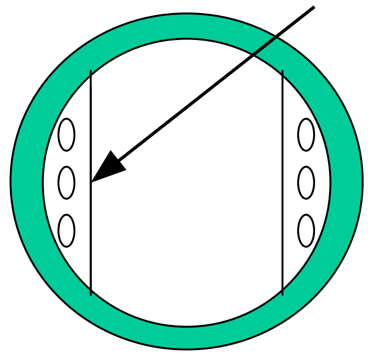
section



I-beam

15 mm-2 places

Modify ring with increased local stiffness



WBS 1.1.1.1 Pixel Mechanics - Development

- Layout
  - We are looking at modified layouts to simplify installation and remove interference problems - see drawing.
- Sectors
  - Build more in each of the three designs.
  - Enough sectors for at least one complete prototype disk
- Disk
  - Fabricate at least one prototype disk(two are planned). We hope these will be done under SBIRs.
- Module attachment
  - Design tooling and prototype for module attachment and measurement (optical)
- Supporting structures
  - The US has agreed to largely fund the continued design and development of the supporting structures primarily via subcontract with Hytec in 1999. Long term role not finalized.
  - Plan to construct prototypes of barrel shells, disk ring and overall flat panel support
- Integration
  - LBNL engineer at CERN extended until May. Expect Italy to take over. Long term not finalized.
  - Work is ongoing on cabling and coolant connections.

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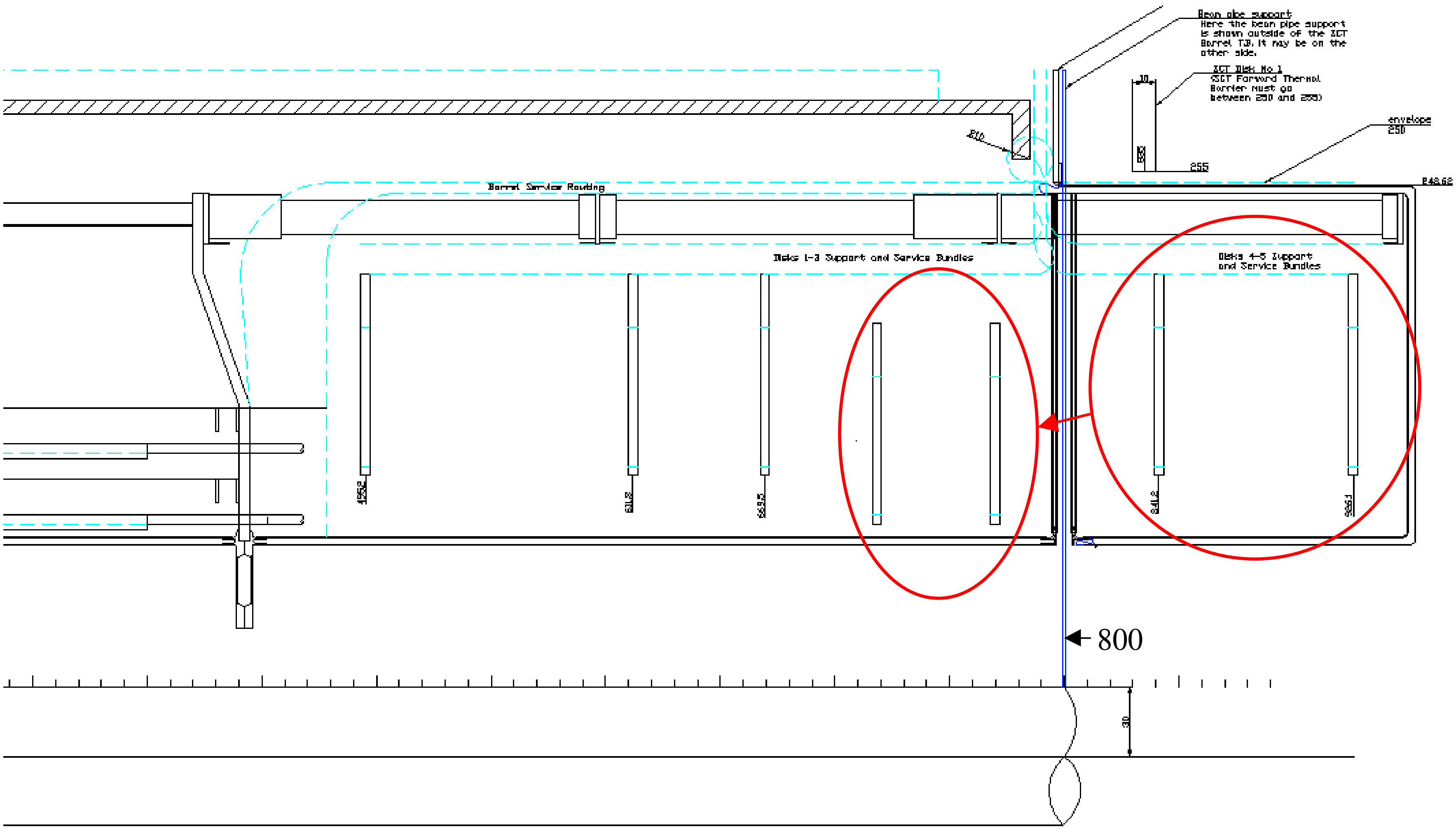
Layout Alternatives Under Study



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1.1.1.1 Pixel Mechanics - Schedule

ID	WBS	Task Name	Milestone
7	**1.1.1.1**	**Mechanics**	
8	**1.1.1.1.1**	**Design**	
19		ID Engr Review at CERN	10/20
18		Sector PDR	9/1
21		Select Sector Baseline Concept	9/1
30		Module Attach CDR	9/1
22		PRR for Sectors	5/3
26		Disk PDR	5/3
32		Module Attach PDR	5/3
36		Support Struct CDR	5/3
28		Disk PRR	2/2
34		Module Attach PRR	2/2
38		Support Structure PDR	2/2
40		Support Structure PRR	1/1
42	**1.1.1.1.2**	**Development/Prototypes**	
52		Compl Testing of 5-Disk Protos	9/1
55		Compl Testing of Disk Prototypes	12/21
58		Compl Test of Proto Module Attacl	5/3
61		Compl Test of Support Structure F	2/2

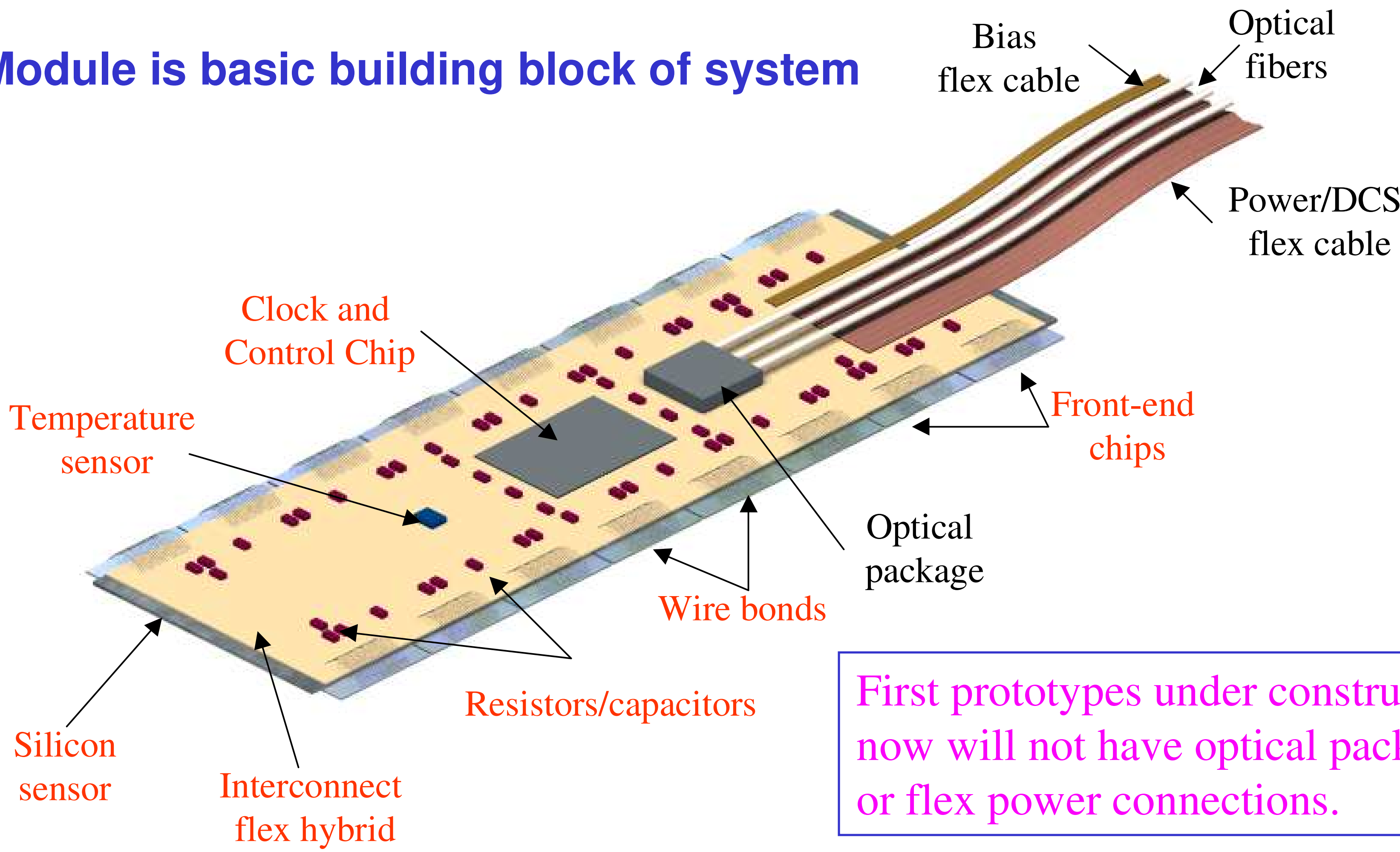
Timeline: 1997, 1998, 1999, 2000, 2001, 2002 (quarters 4, 1, 2, 3, 4, …, 1, 2, 3)

1.1.1.1 Pixel Mechanics - Issues

- A year or so ago, integration engineering was a significant concern. We addressed this by stationing an engineer from LBNL at CERN(50% supported by CERN). This arrangement will come to end next year(LBNL engineer will return), and Italian engineer will take over for a year or so(hopefully also supported partially by CERN). US was asked informally by Inner Detector chief engineer if we would take on integration role. We refused - lack of funds. We have no long term solution yet.
- In addition, Germany, Italy and US supported Hytec, Inc for conceptual design of support structures. This was completed in July and was very well done. Exploring possibility of continuing, but there are political problems in Europe for support of US firms for design engineering, which we are trying to overcome.
- We have 2 Phase II SBIRs. One with ESLI that ends next June and one with Hytec that just started. This is about $1.5M in total, but, of course, we do not have direct control over these funds. However, we must rely totally on these for development of all-carbon structures and for establishment of TV holography and evaporative cooling in US.

Pixel Module

Module is basic building block of system



First prototypes under construction now will not have optical package or flex power connections.

WBS 1.1.1.2 Pixel Sensors

- Fabrication of first round of full size prototypes was completed nine months ago with two vendors(CIS in Germany and Seiko in Japan).
- Wafer probing completed
- Extensive lab and beam tests with electronics, including with irradiated detectors.
- Two major design variants(+ many options on wafers)
  - Tile 1(p-stop) - “conventional”
  - Tile 2(p-spray) - includes structure to bias(test) pixels before mounting ICs
- Not enough parts to complete irradiation program => have initiated additional 1st prototype order(with CIS) with some modifications to bias structure and some 200 micron thick wafers.
- Conclusion
  - Tile 1 design as implemented does not give good performance after irradiation - breakdown at too low voltage(100-150 volts)
  - Tile 2 design appears to work up to at least 600 volts after irradiation, but there are small inefficiencies near edge of pixel, which we believe can be corrected.

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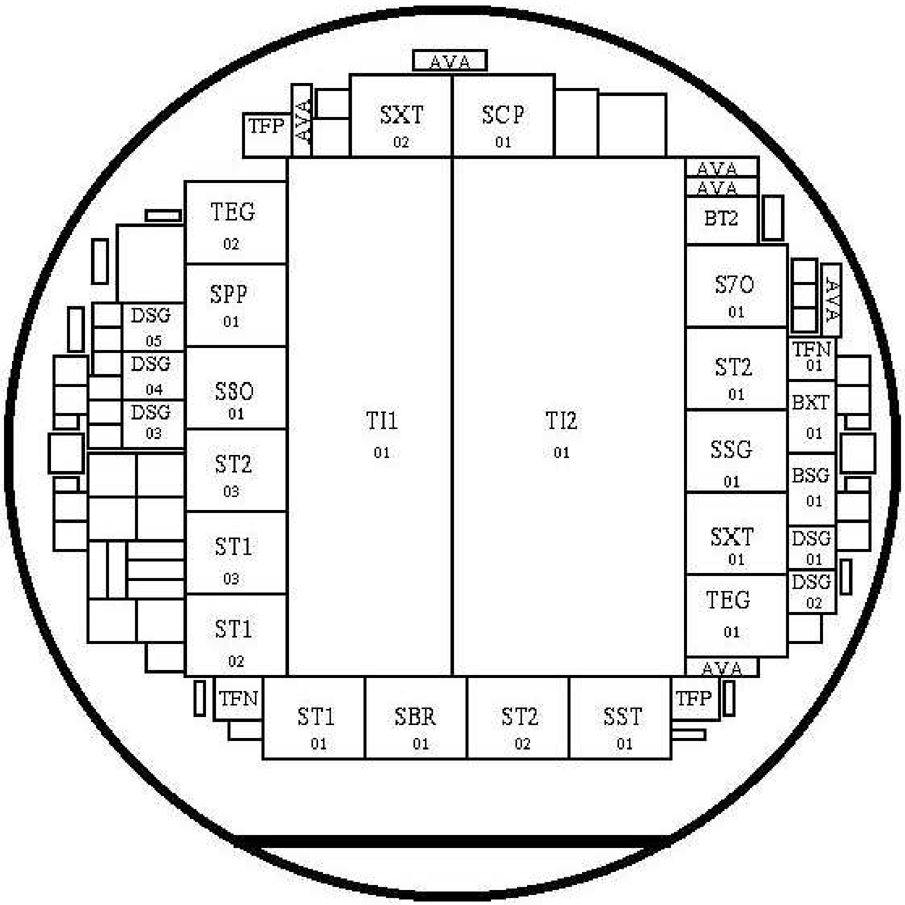
1.1.2 Pixel Sensors



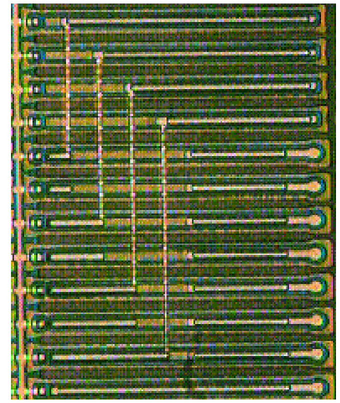


Figure 4-7 Photograph of a routing structure in tile 2. The four unconnected pixels are on the top. The bump pads are the circular structures on the right. Further visible is the punch through biasing grid on the left and the floating n+ implantation surrounding the read out pixel implant in tile-2.

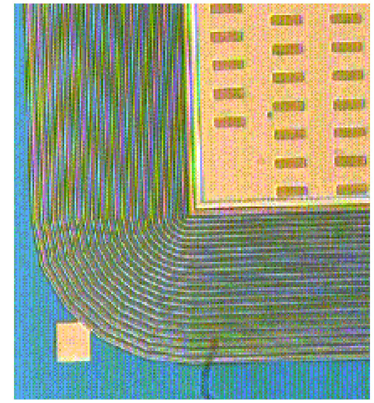


Figure 4-8 Photo of a sensor's back side. The 22 guard rings are visable. The rectangular structure in the inner area are openings in the aluminium for charge injection with a laser.

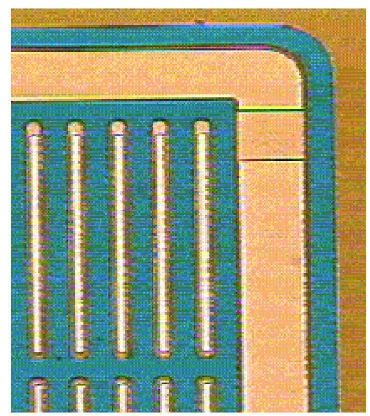


Figure 4-9 Photograph of a tile-1 corner showing the All-metallized n+ implants with bump pads on the top and the guard ring. The outer n+ region is not metallized and differs in colour. The p-stop implants are not visible due to the absence of an extra oxide step.

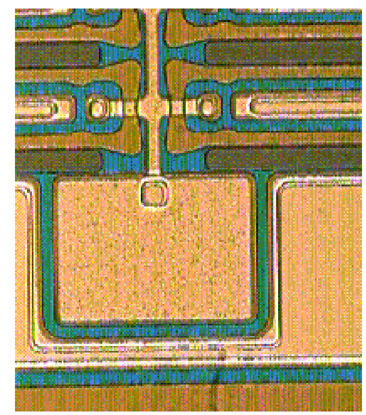
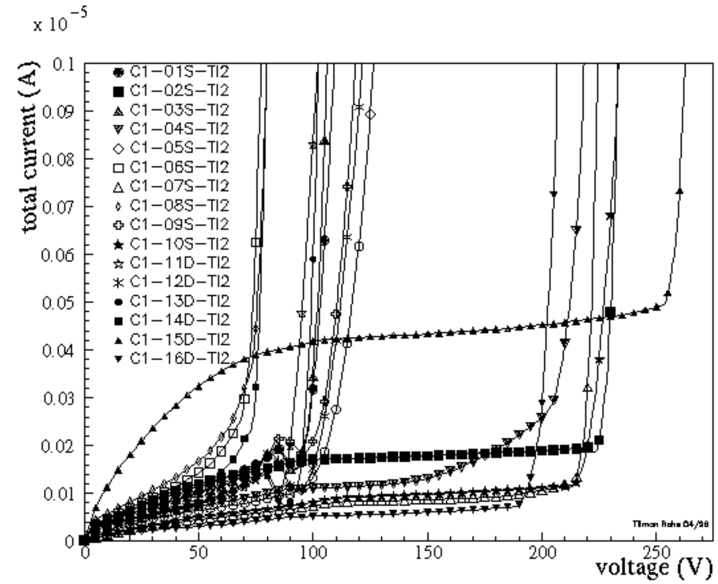
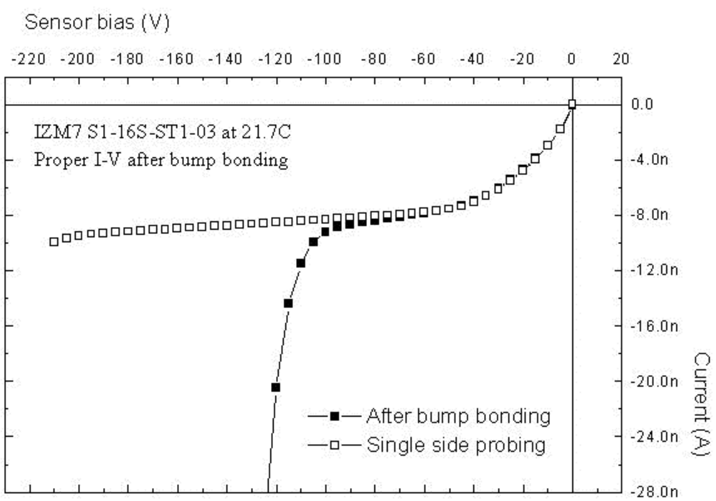


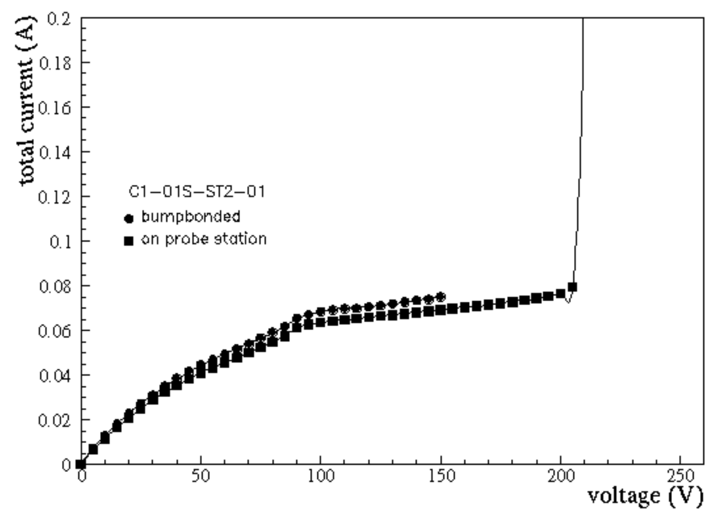
Figure 4-10 Photograph of the bias grid implemented on tile-2. The biasing is done via the "punch through dot" connected to the bus-like structure in the middel. With the pad on the bottom one double column of the array can be probed separately. The whole array can be tested when the guard ring is contacted.

WBS 1.1.1.2 Pixel Sensors

- Wafers probed in Germany and Italy
- Die before/after bumping measured in US and at CERN.
- For first prototype run, has been very successful.
- Insufficient statistics to understand yield







Pixel Sensors - Development

- As you will see in the test beam results section, the Tile 2 design looks very attractive after irradiation.
- However, there are small inefficiencies in the region of the biasing grid that we believe can be corrected. These corrections have been incorporated into revised 1st prototype wafers(modest mask changes) that are to be delivered by December.
- Assuming we can adequately test these(no easy test beam, so laser planned at minimum) then the results would be included in the design of a 2nd prototype round next year. The 2nd prototype wafer layout would aim to look like production wafers - three module tiles, a few single chip devices and test structures.
- The procurement process leading to the 2nd prototypes, preproduction and then production has started. 2nd prototypes would be fabricated by vendors planned for production.
- If we follow this schedule, then sensor preproduction could begin before the baseline cost review. US funds for preproduction are not included in the pre-baseline funding, so if this occurs, we would call on contingency to advance the funding, after a Production Readiness Revew.

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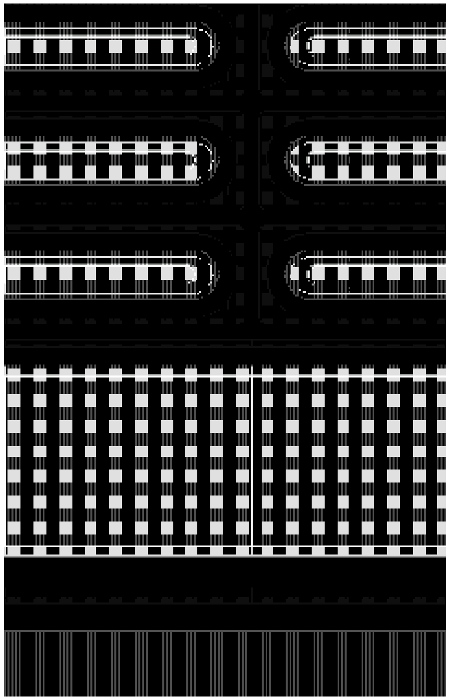
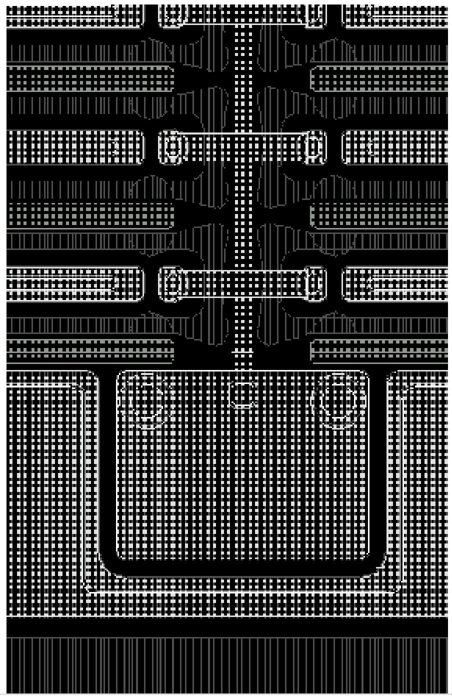
Sensor Designs

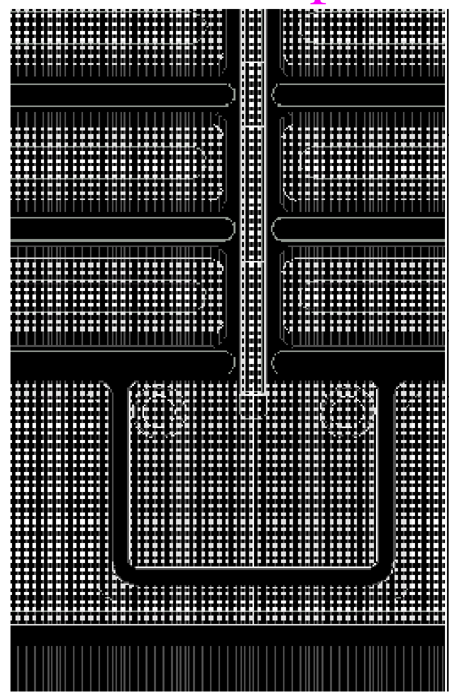
Tile 1



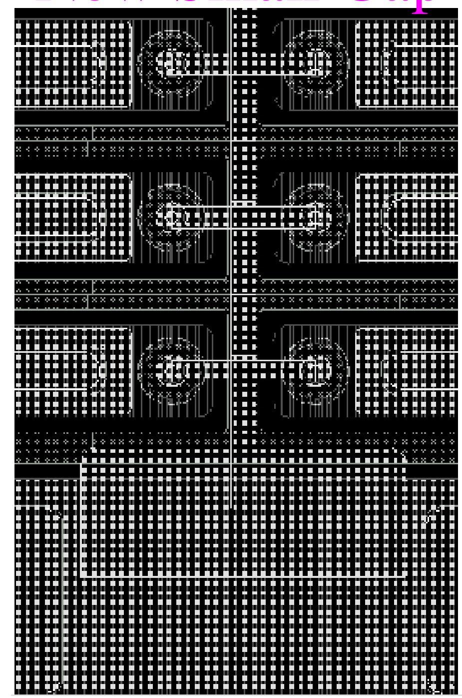
Tile 2



Small Gap



New Small Gap



p-stop

p-spray

1st prototype run

Revised 1st prototype run in fab now

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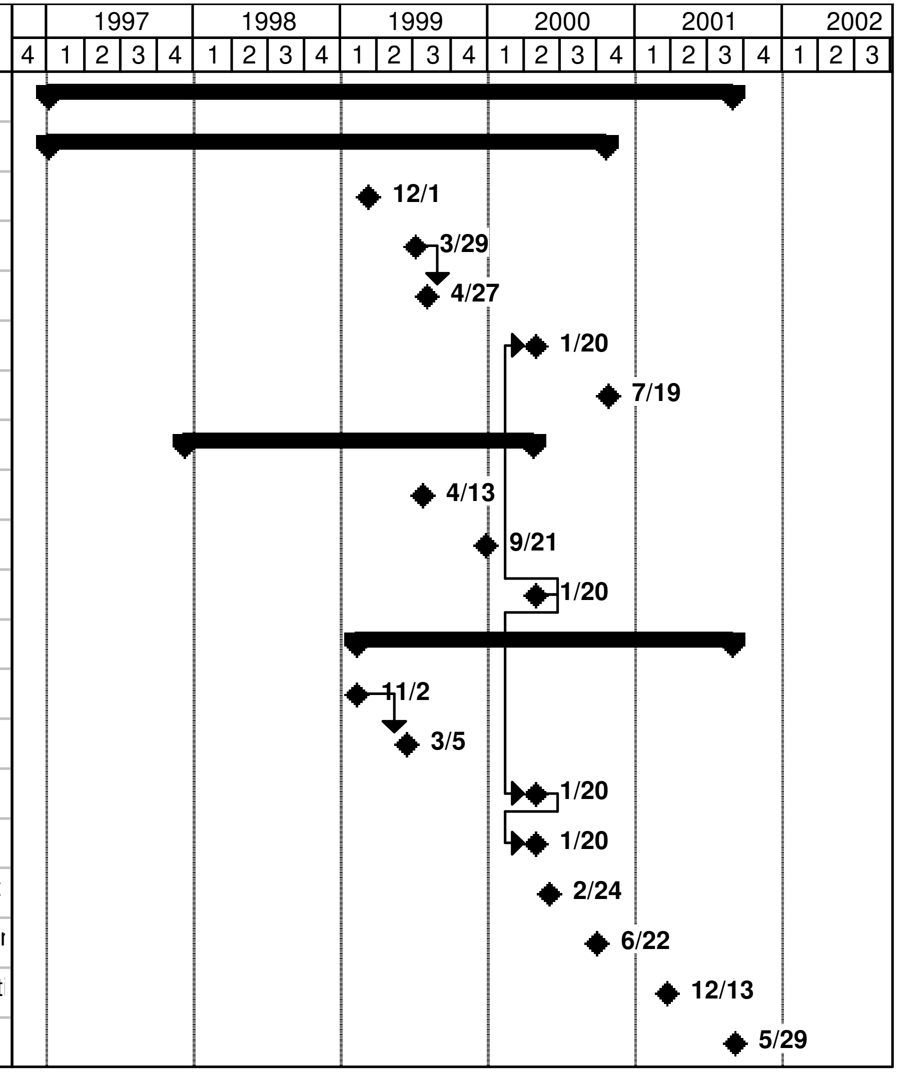
1.1.1.2 Pixel Sensors - Schedule

ID	WBS	Task Name
64	**1.1.1.2**	**Sensors**
65	**1.1.1.2.1**	**Design**
73		Second prototype PDR
74		Second prototype FDR
75		Compl Second Prototype Design
77		Sensor Final Design Review
78		Compl Preproduction Design
80	**1.1.1.2.2**	**Development/Prototypes**
90		Compl Testing First Protos
92		Compl Fabr of Second Protos
94		Compl Testing Second Protos
96	**1.1.1.2.3**	**Production**
97		Start Market Survey
98		Complete Market Survey
99		Select Production Detector Type
100		Select Detector Vendor(s)
101		Start Preproduction Procurement
102		Complete Preproduction Procurer
104		Complete Preproduction Fabricat
106		Compl Preprod Testing



DoE/NSF Review
October 1998

1.1.1.1 Pixel Sensors - Issues

- Sensor schedule appears now to be substantially ahead of electronics.
- Start preproduction before completing second rad-hard electronics prototype round? This is our current plan. No funds for preproduction are in pre-baseline. Call on contingency to advance funding. Modest commitment for preproduction.

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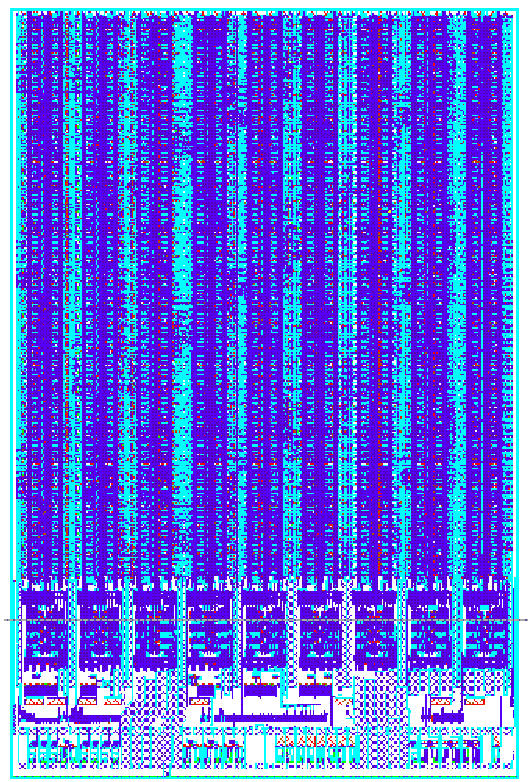
WBS 1.1.1.3 Pixel Electronics

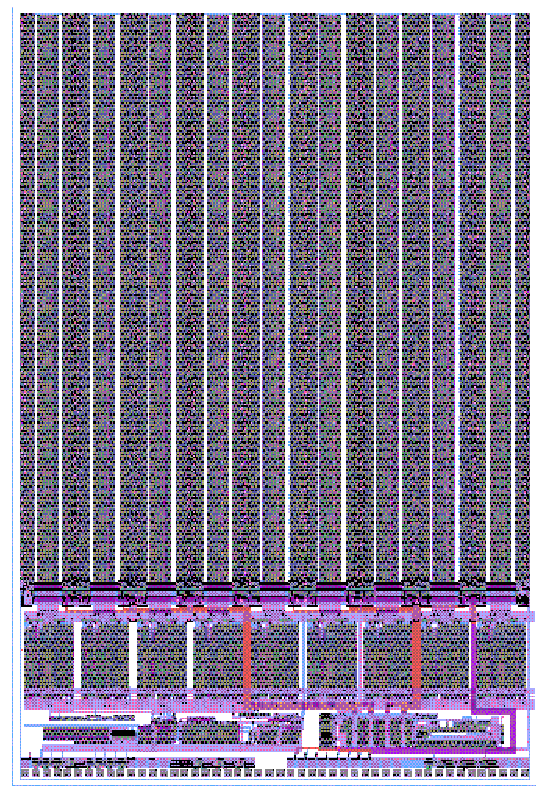
- Pre-prototype program completed successfully by end 1997.
- Full-scale prototypes fabricated in rad-soft technologies this year and tested extensively.
- Different design approaches. FE-A and FE-B. Pin compatible.
- FE-A(AMS -> Temic/DMILL).
  - First delivery in February of AMS chips
  - Functional although some errors
  - Yield about 5%. Processing problems?
  - Second run delivered in July(all CMOS version called FE-C). Yield appears higher, about 80%.
- FE-B(HP -> Honeywell SoI).
  - First delivery in April of HP chips
  - Functional although some errors
  - Yield about 93%.
- MCC(AMS -> Temic/Honeywell).
  - First delivery in July of AMS chips
  - Functional.
  - Yield about 80%.
- Unified design approach adopted for rad-hard design FE chips => all working on same design to be implemented in the two rad-hard processes - first in DMILL and then in enhanced Honeywell SoI.

WBS 1.1.1.3 Pixel Electronics

- FE-A and FE-B bonded to prototype detectors, including irradiated detectors.
  - 18x160 pixels(50x400 micron pixel size - final goal 50x300). Complete analog and digital to ATLAS specs.
  - Essential requirements met(efficiency, time resolution, noise, threshold,….)
  - Multiple test beam runs at CERN. Extensive lab tests. Principle established.

FE-A





FE-B

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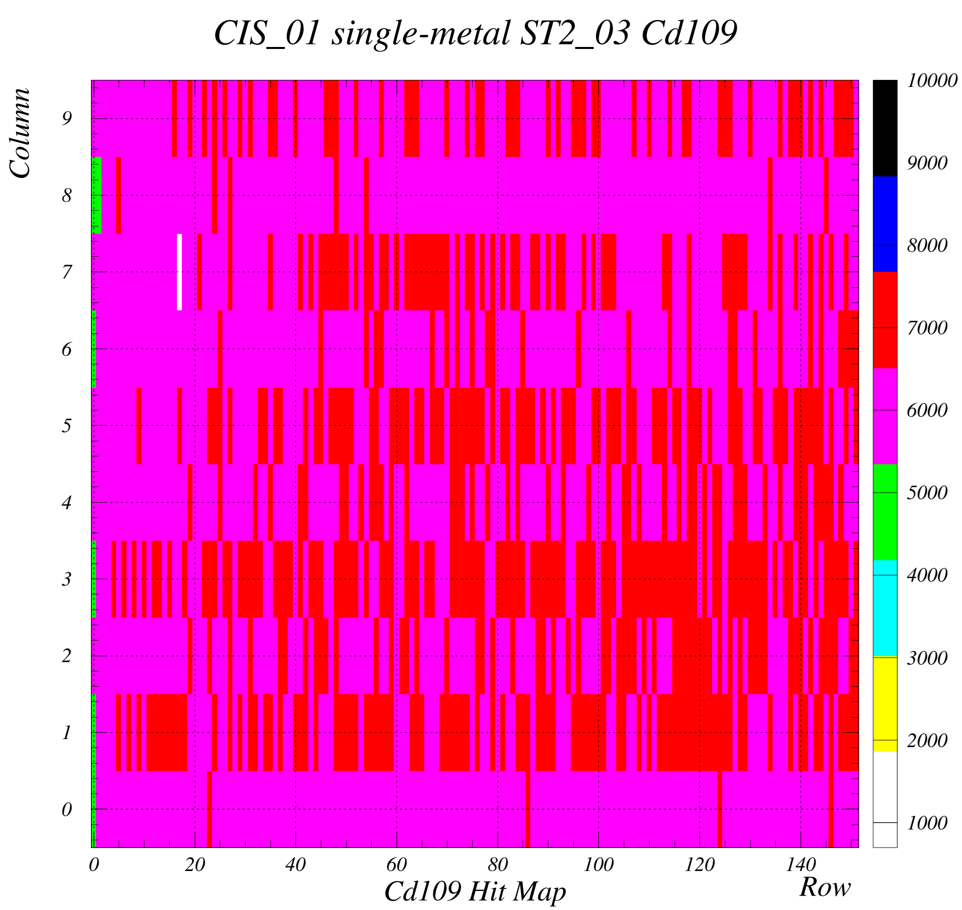
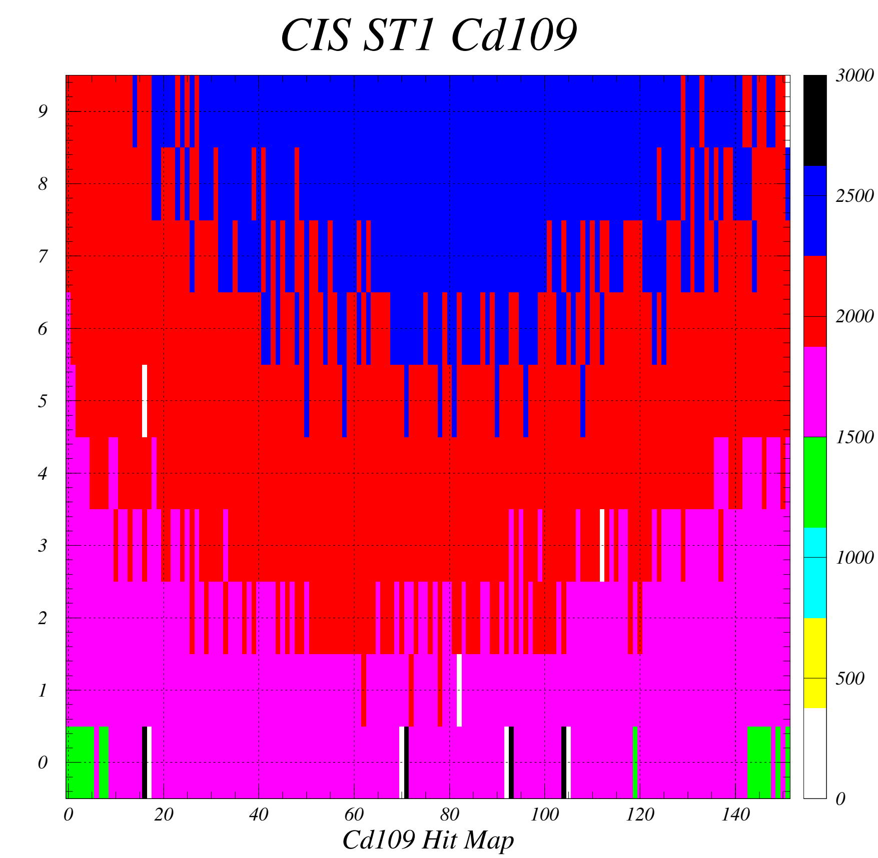
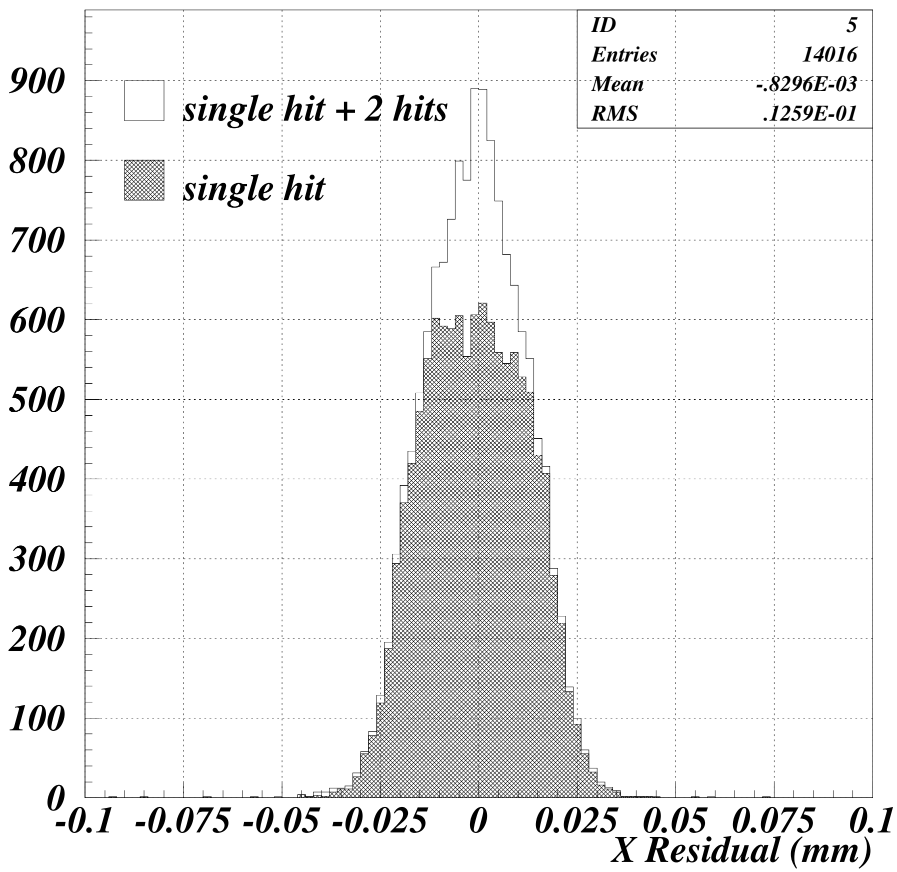
Photon Source Test of FE-B and Detectors



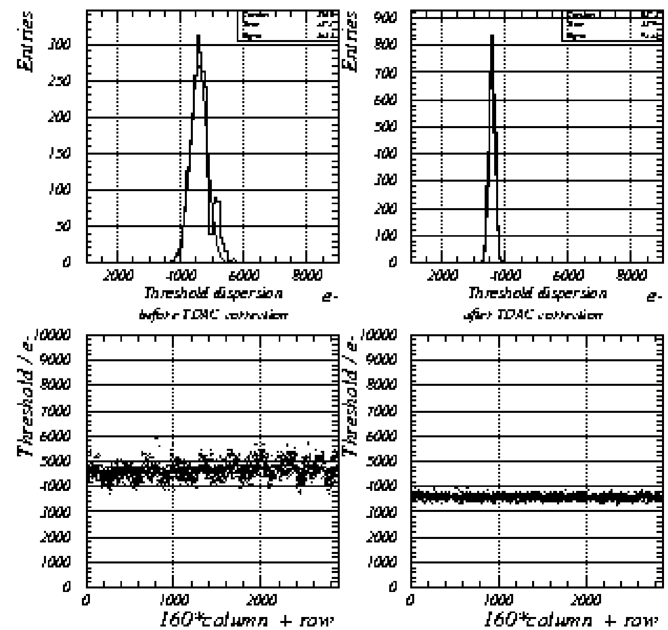


Lab and Test Beam Results

X Residuals - Analog



FE-B: double-discriminator mode



Threshold tuning

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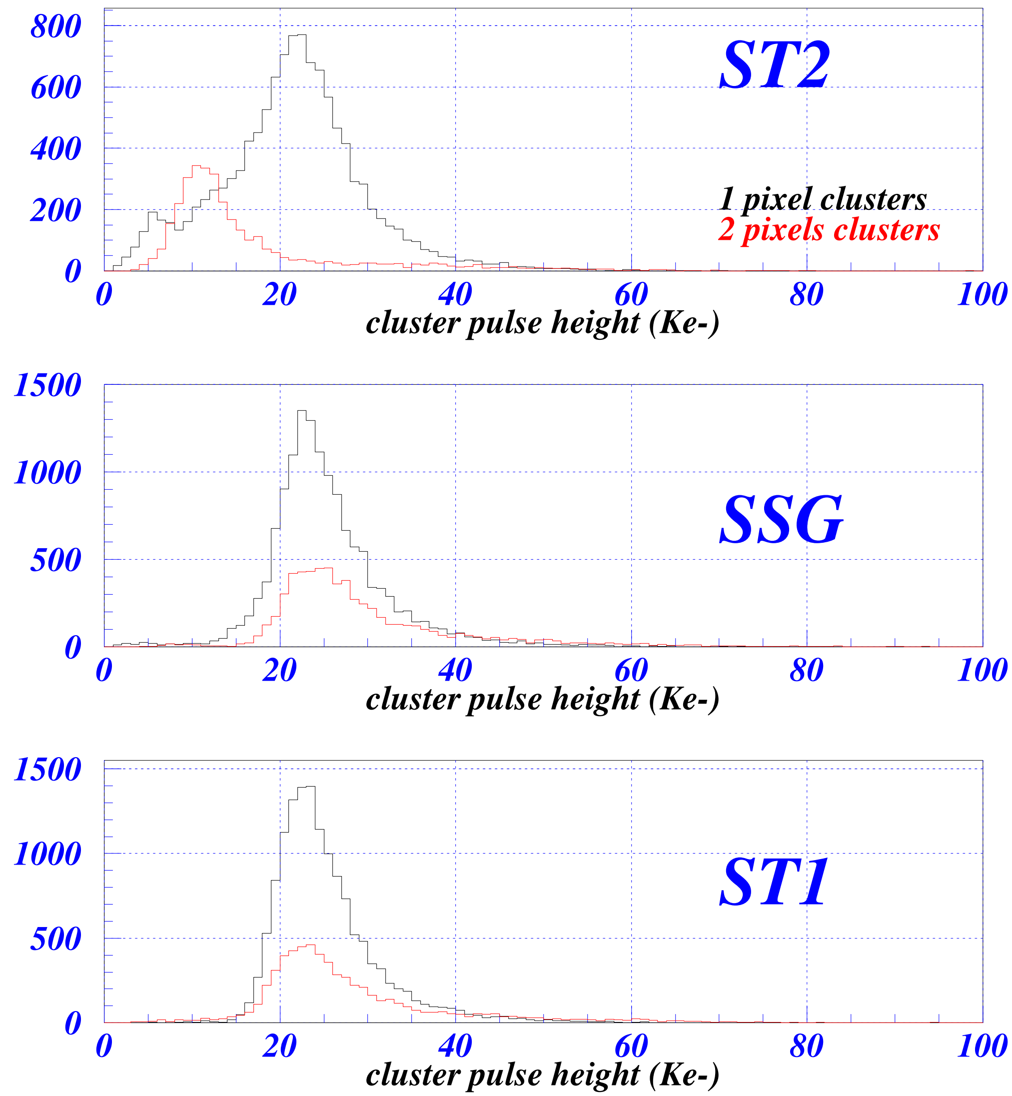
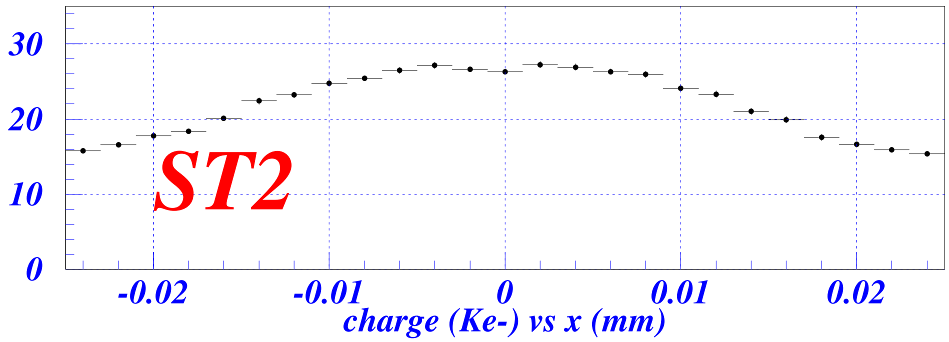
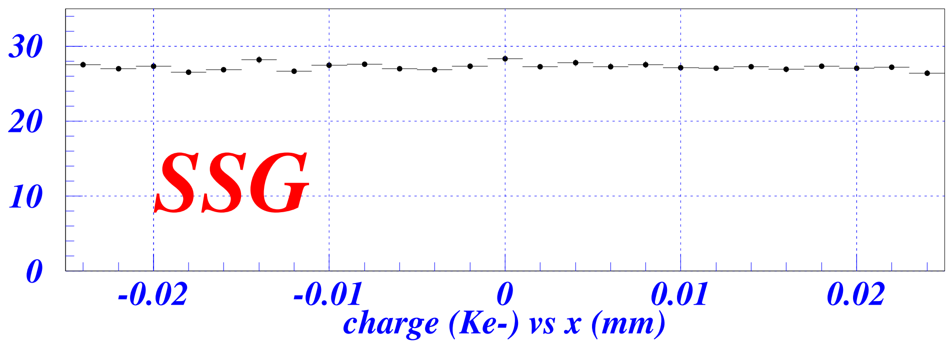
Lab and Test Beam Results

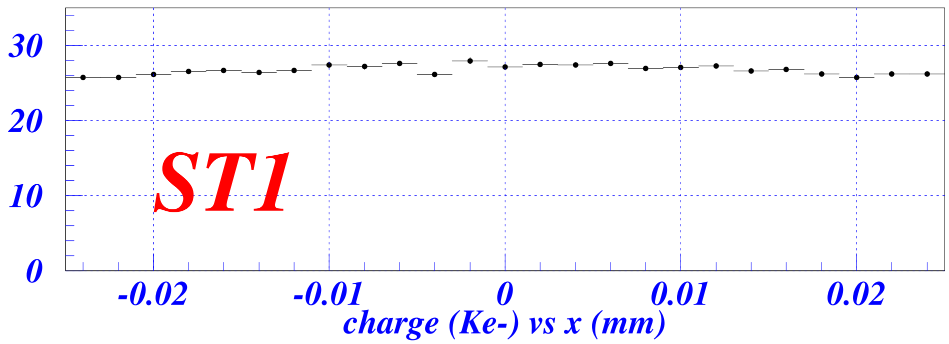


Charge distributions for three detector types. The difference between ST2 and the others is indicative of small charge losses, which has guided us in the design of additional prototype detectors under fabrication.

Charge Collection Efficiency







Charge measured as function of distance across the short pixel direction for unirradiated detectors

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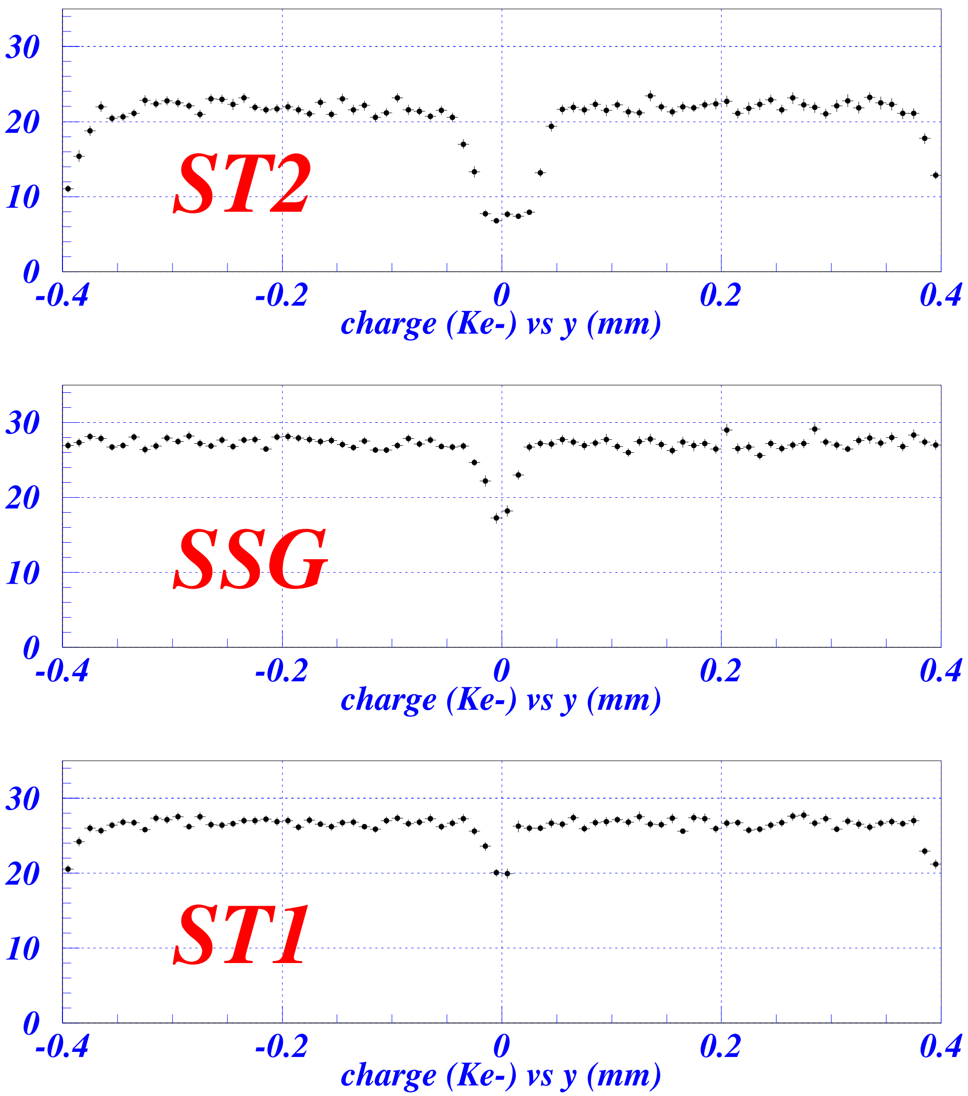
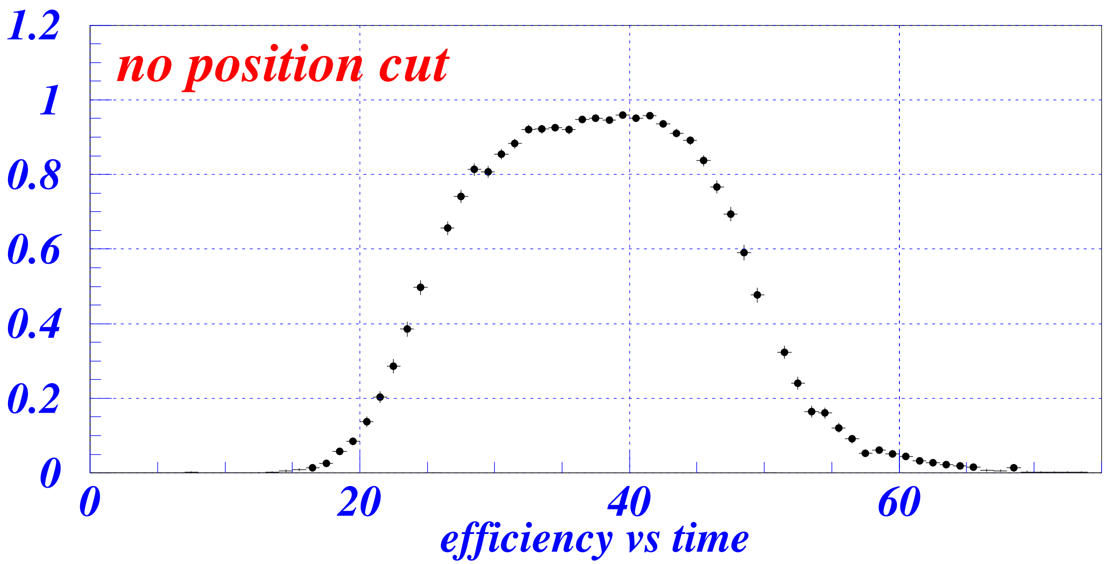
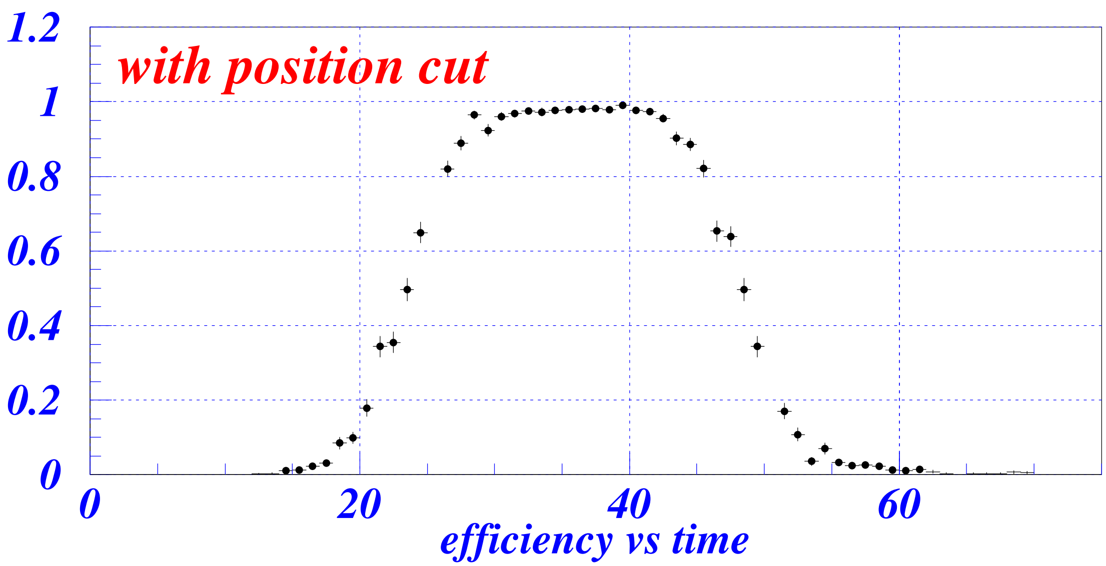
Charge Collection Efficiency



Charge measured as function of distance across the long pixel direction for unirradiated detectors

Efficiency - Irradiated Detectors





Efficiency of the Tile 2 design for irradiation of 1×10^{15} without and with a position cut to remove tracks near the edge of the pixel.

Efficiency Summary

- In time efficiency of unirradiated detectors is > 99% for thresholds about 3,000 electrons(or less)
- For Tile 2 type detector irradiated to $1x10^{15}$

Volts	No Cut	Pos. Cut	Thresh.
600 volts	95.3	98.2	2.8Ke
300 volts	87.9	TBD	2.2Ke
150 volts	72.8	TBD	2.2Ke

- Analysis of other irradiated detectors in progress

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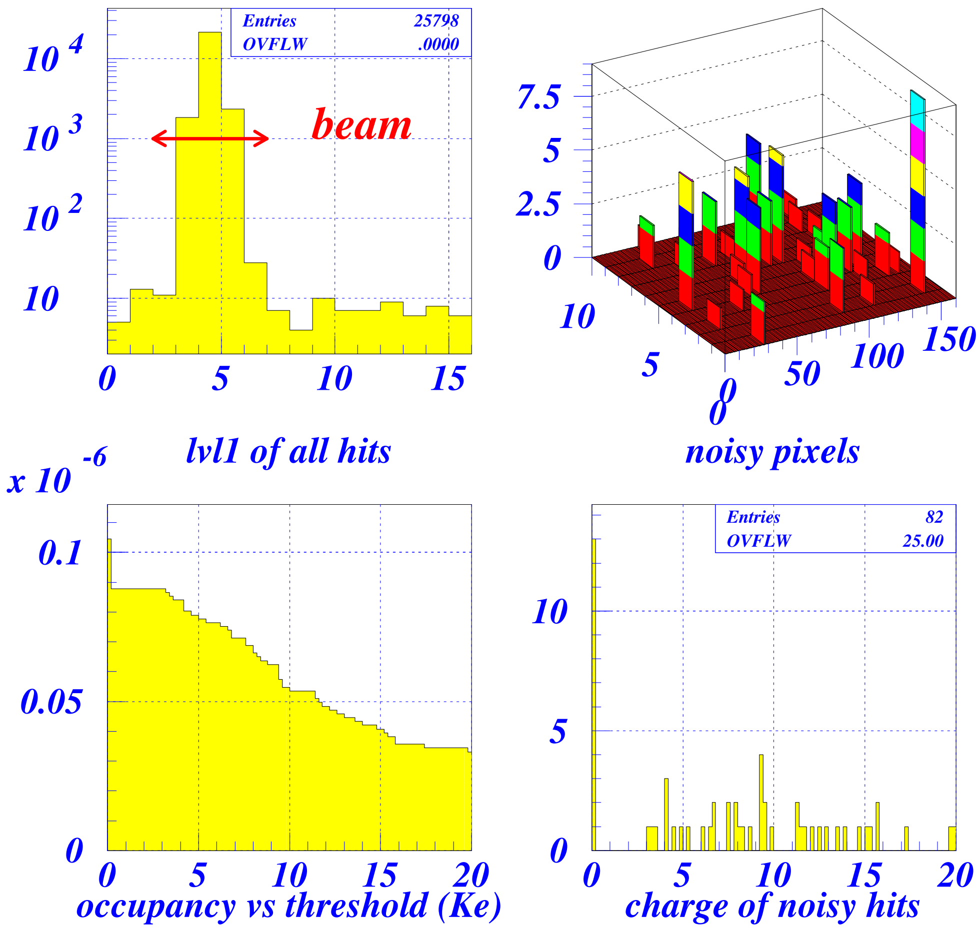
Preliminary "Noise" Results



<u>Preliminary</u>

Tile 2 design

Fluence 1 x 10^{15}

Occupancy about 10^{-7}

This is well below spec

1.1.1 Pixel Electronics -Development

- Unified design effort for first prototype front-end rad-hard IC using FE-A and FE-B as basis.
  - Division of design tasks among LBNL, Bonn, Marseille advanced
  - First submit to Temic/DMILL(0.8 micron, 2 metal process). Pixel size may be limited to 400 microns or more - impact on pattern recognition under study.
  - Second to Honeywell enhanced SoI process(0.8 micron, 4 metal process). Pixel size of 300 microns appears feasible.
  - Before this submission, additional run with analog test chips to understand better Honeywell SoI analog performance. This is on track for early November as part of multi-project run.
  - Honeywell SoI test structures irradiated to 50 Mrad and being characterized - so far so good. Will do same with DMILL.
- MCC
  - All design so far done by Genoa.
  - OSU has visited Genoa to understand MCC design and may become involved in this design or in design of optical drivers/receivers. Current manpower in Italy is not sufficient, particularly including need for optical drivers/receivers.

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1.1.1.3 Pixel Electronics - Schedule

ID	WBS	Task Name	Date
109	**1.1.1.3**	**Electronics**	
110	**1.1.1.3.1**	**Design**	
118		Final Design Review DMILL Rad-Hard Proto	1/25
119		Compl Design DMILL Rad-Hard Proto	2/26
121		Compl Des Honeywell Rad-Hard Test Devices	4/16
123		Final Design Review Honeywell 1st Proto	3/5
124		Compl Des Honeywell FE Rad-Hard Proto	4/2
125		Review Design Approach	1/19
127		Final Design Review of 2nd Rad-Hard Proto	6/12
128		Compl Des 2nd Rad-Hard Proto	7/7
130	**1.1.1.3.2**	**Development/Prototypes**	
140		Compl Fabr of Honeywell Sol Test Devices	8/26
143		Compl Fabr of DMILL Proto	7/23
145		Compl Testing DMILL Prototype	12/9
147		Compl Fabr Honeywell Protos	8/25
149		Compl Testing Honeywell Prototype	2/15
150		Vendor Selection	2/29
152		Compl Fabr of 2nd Rad-Hard Proto	11/29
154		Compl test 2nd Rad-Hard Proto	3/29

1.1.1.3 Pixel Electronics - Issues

- Maintaining unified design effort among US, Germany, France and Italy is continuous challenge.
- Balance between meeting milestones and thorough job - thorough job must have priority.
- In US, manpower is almost completely supported off-project. This is critical.

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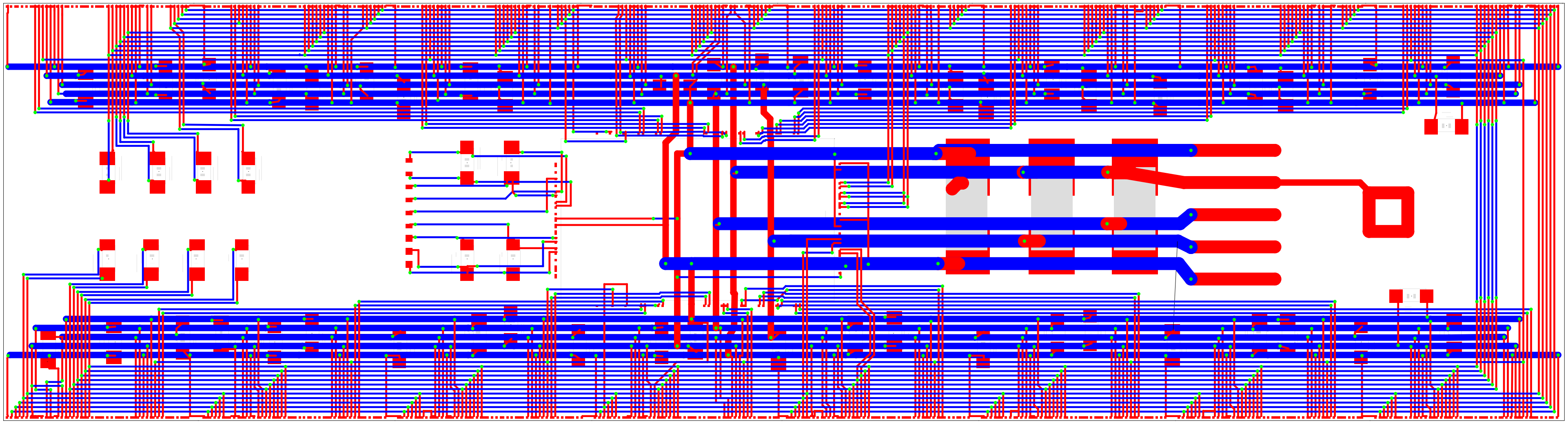
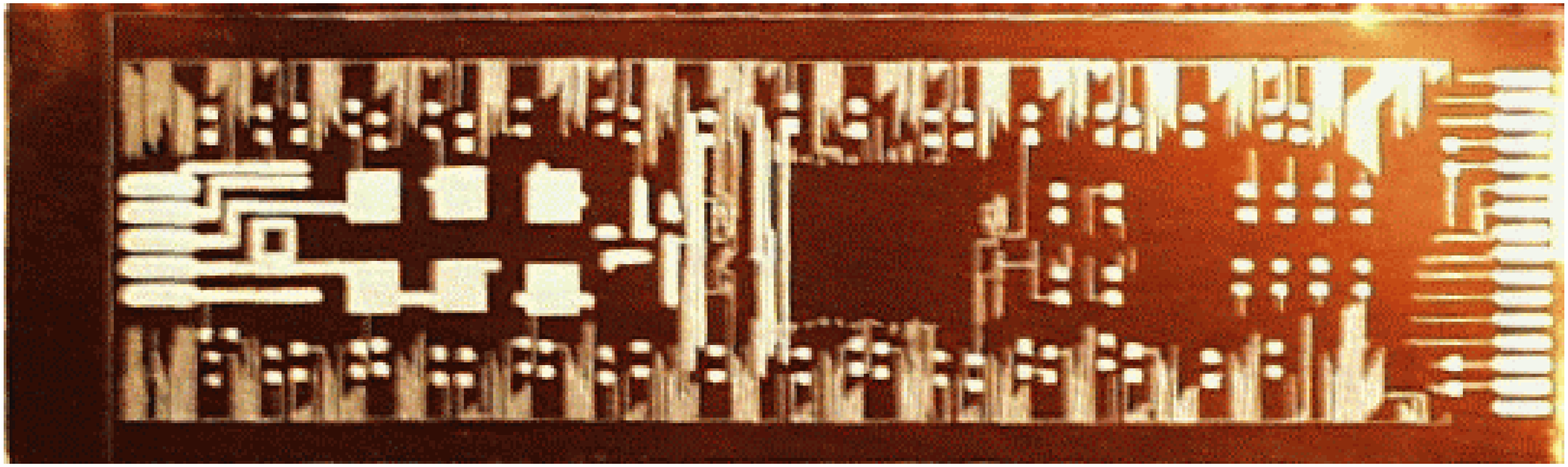
WBS 1.1.1.4 Pixel Hybrids

- Prototype design of flex hybrid completed by Oklahoma
- First prototype does not have optical capability
- Electrical connection to module support PCB



WBS 1.1.1.4 Pixel Hybrids

- First prototypes fabricated at CERN(in Cu on kapton) in mid-July - see below
- Testing underway in US and in Europe
- Contract in place with GE to have additional vendor, will begin fabrication after first prototypes from CERN are understood(can make small design changes)
- Aluminum prototypes start later this year if Cu successful



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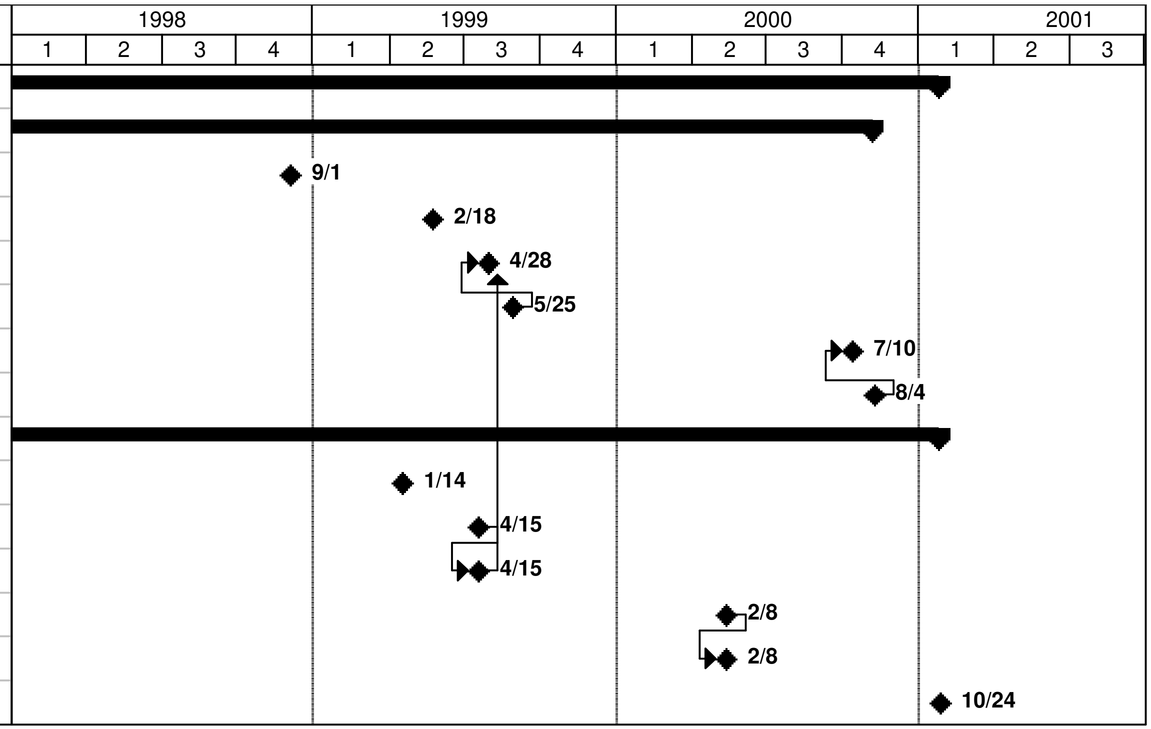
1.1.1.4 Pixel Hybrids - Schedule

ID	WBS	Task Name
157	**1.1.1.4**	**Hybrids**
158	**1.1.1.4.1**	**Design**
165		Compl First Proto Design
166		1st Prototype Design Review
168		2nd Prototype Design Review
169		Compl Second Proto Design
171		3rd Prototype Design Review
172		Compl Third Prototype Design
174	**1.1.1.4.2**	**Development/Prototypes**
182		Compl Fabr/Assy of 1st Proto
184		Compl Tests of First Protos
185		Select Hybrid Type
188		Compl Tests of 2nd Prototypes
189		Select Hybrid Prod Vendor(s)
192		Compl Tests of 3rd Proto Hybrids



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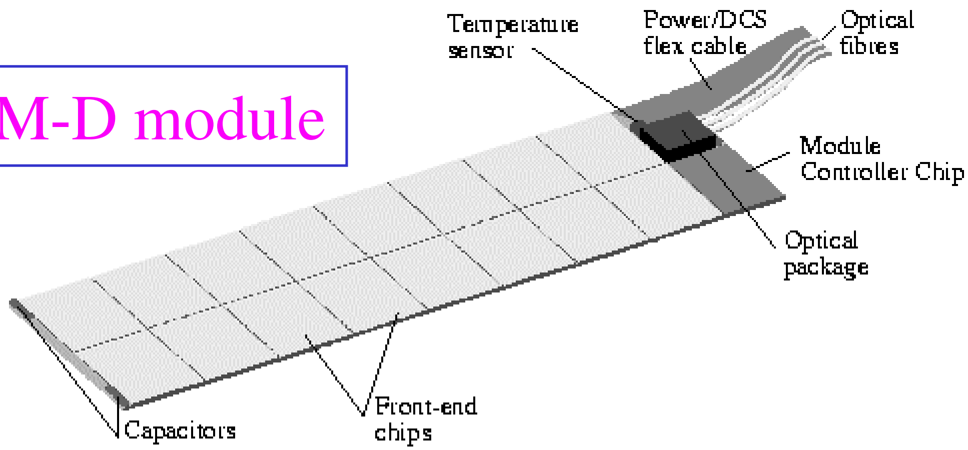
1.1.1.4 Pixel Hybrids - Issues

- Alternative to flex hybrid(MCM-D) under investigation - no US involvement so far.
- Decision by early next year.
- If flex, major design and testing role for US. If not, US role not clear.

MCM-D module



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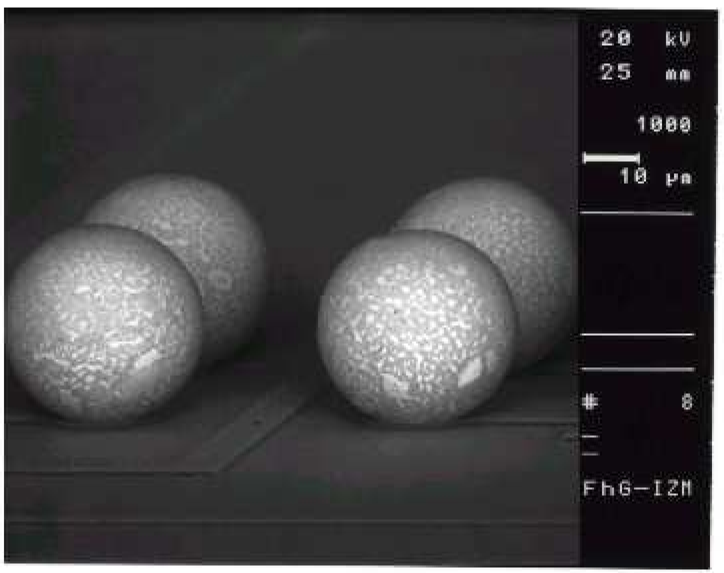
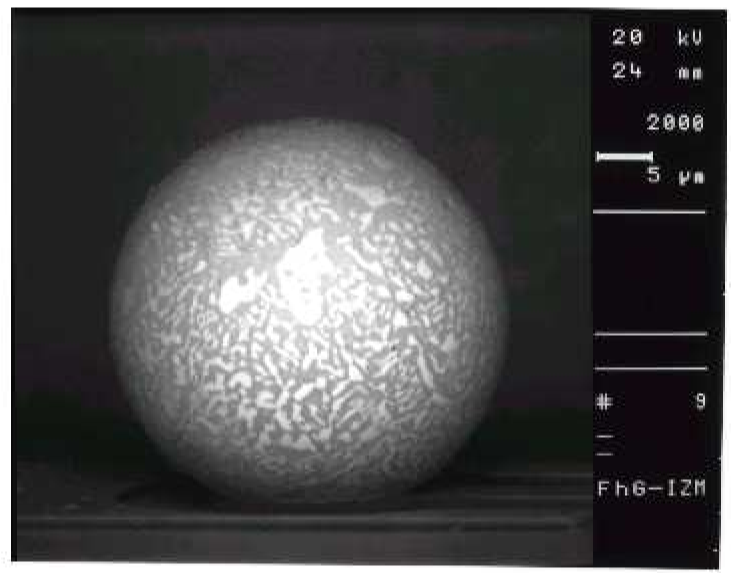
WBS 1.1.1.5 Pixel Modules

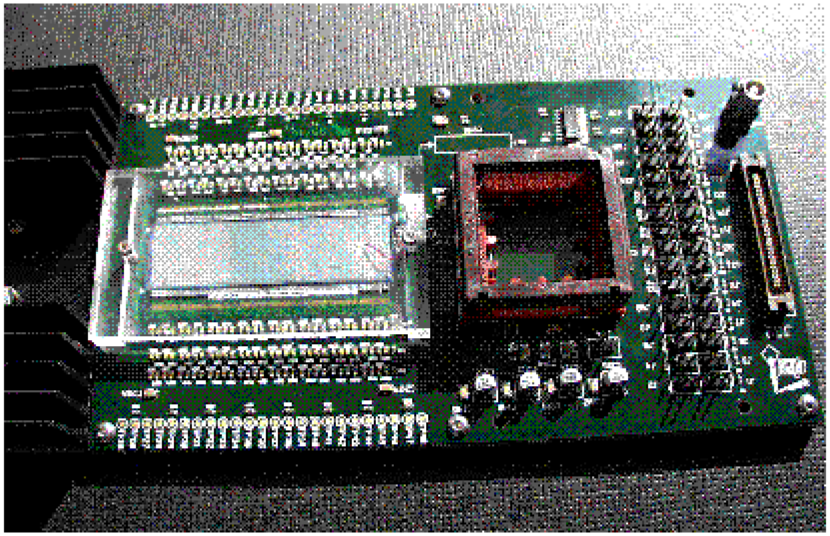
- Bump bonding has been successful with multiple vendors - Boeing(US), Leti/Tronics(France), IZM(Germany), Alenia(Italy), Seiko(Japan) and there are other companies that appear to have capability but which we have not yet tried - AIT(Hong Kong), GEC(UK), Rockwell(US). Both indium and solder bumping works.
- Dozens of single chip-detector assemblies work with nearly 100% yield.
- Bump defect rate as measured from dummy parts is < 10^{-4}
- No bad effects seen so far on detector after bumping, including after irradiation
- We have had some first success in thinning wafers after bumping to 150 microns but much more work needed to understand yield. 16 chip module with 150 micron ICs has been assembled.

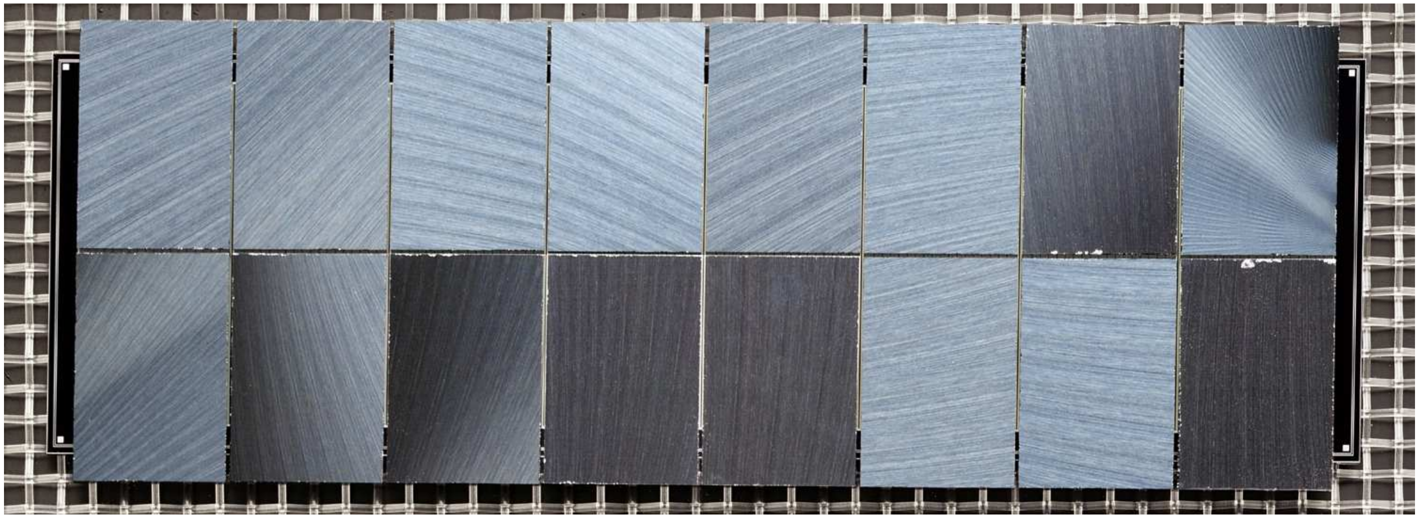




WBS 1.1.1.5 Pixel Modules

- 16 chip modules assembled successfully with FE-B ICs(all ICs working after assembly)
- Modules on supported card under test
- Assembly of complete module prototypes(sensors bonded to electronics and flex hybrid but with electrical connections - no optical yet) is underway in Italy and the US.





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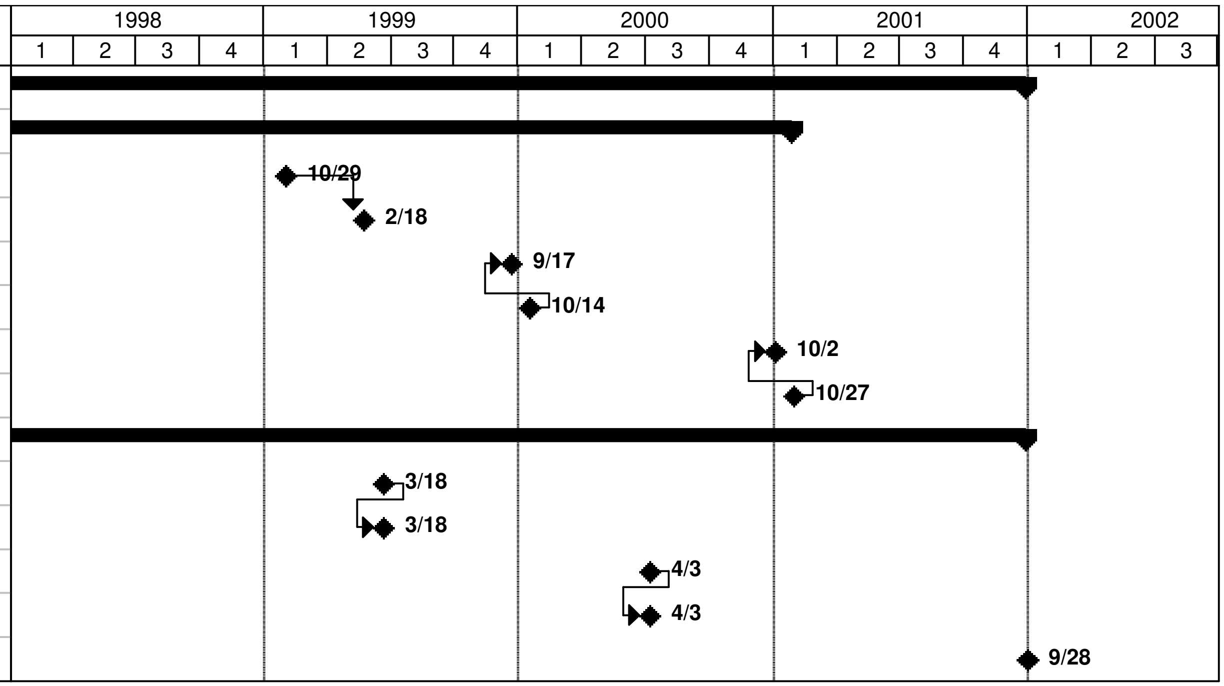
1.1.1.5 Pixel Modules - Schedule

ID	WBS	Task Name
195	**1.1.1.5**	**Modules**
196	**1.1.1.5.1**	**Design**
203		Compl First Prototype Design
204		1st Prototype Design Review
206		2nd Prototype Design Review
207		Compl 2nd Proto Design
209		3rd Prototype Design Review
210		Compl 3rd Proto Design
212	**1.1.1.5.2**	**Development/Prototypes**
221		Compl Tests of First Protos
222		Select Module Type
225		Compl Tests of 2nd Prototypes
226		Select Module Prod Vendor(s)
229		Compl Tests of 3rd Proto Modules



DoE/NSF Review
October 1998

1.1.1.5 Pixel Modules - Issues

- Choice of bump deposition, dicing, thinning and flip-chip vendor(s), will affect responsibilities since substantial interaction required. Likely that bump bonding will be done outside US(Boeing has decided not to pursue this).
- Choice of module technique(flex or MCM-D) will also affect responsibilities.

WBS 1.1.1 Pixel Milestones

- Overall milestones as part of each Level 4 schedule.
- There will be additional, more detailed milestones developed for each year for me to track progress at Level 5(as we do now).
- Have included two internal reviews before baseline cost review.

WBS 1.1.1 Pixel Profile

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WBS Profile Estimates

Funding Source: All | **Funding Type:** Project | 9/28/98 11:43:23 AM

Institutions: All

WBS Number	Description	FY 96 (k$)	FY 97 (k$)	FY 98 (k$)	FY 99 (k$)	FY 00 (k$)	FY 01 (k$)	FY 02 (k$)	FY 03 (k$)	FY 04 (k$)	FY 05 (k$)	Total (k$)
1.1.1	Pixels	119	303	408	750	563	0	0	0	0	0	2142
1.1.1.1	Mechanics and Final Assembly	46	120	127	292	174	0	0	0	0	0	759
1.1.1.1.1	Design	25	61	91	117	97	0	0	0	0	0	391
1.1.1.1.2	Development and Prototypes	22	59	35	175	77	0	0	0	0	0	368
1.1.1.2	Sensors	0	59	39	30	30	0	0	0	0	0	158
1.1.1.2.1	Design/Engineering	0	35	0	10	10	0	0	0	0	0	55
1.1.1.2.2	Development and Prototypes	0	24	39	20	20	0	0	0	0	0	104
1.1.1.3	Electronics	72	46	139	262	207	0	0	0	0	0	726
1.1.1.3.1	Design/Engineering	0	46	29	81	81	0	0	0	0	0	237
1.1.1.3.2	Development and Prototypes	72	0	110	181	126	0	0	0	0	0	489
1.1.1.4	Hybrids and Cables	0	48	29	64	44	0	0	0	0	0	186
1.1.1.4.1	Design/Engineering	0	28	8	17	17	0	0	0	0	0	71
1.1.1.4.2	Development and Prototypes	0	20	21	47	27	0	0	0	0	0	115
1.1.1.5	Module Assembly/Test	0	30	73	102	108	0	0	0	0	0	313
1.1.1.5.1	Design/Engineering	0	0	0	19	29	0	0	0	0	0	48
1.1.1.5.2	Development and Prototypes	0	30	73	83	79	0	0	0	0	0	265

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WBS 1.1.1 Pixel Costs

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WBS Summary Cost Estimates

Funding Source: All **Funding Type:** Project 9/28/98 11:42:38 AM

Institutions: All

WBS Other Number	Description	Base Cost	Cont Cost (k$)	Cont %	Total Cost	EDIA Labor	Mfg Labor	EDIA Matls	Mfg Matls	FTEs	FTEs
										Project	
1.1.1	**Pixels**	2142	440	21	2582	772	121	10	1239	10.4	28.4
1.1.1.1	**Mechanics and Final Assembly**	759	183	24	942	381	74	10	294	4.1	11.9
1.1.1.1.1	**Design**	391	77	20	468	381	0	10	0	3.2	8.2
1.1.1.1.2	**Development and Prototypes**	368	106	29	474	0	74	0	294	0.9	3.7
1.1.1.2	**Sensors**	158	31	19	189	55	20	0	83	1.9	3.0
1.1.1.2.1	**Design/Engineering**	55	5	10	60	55	0	0	0	0.8	2.5
1.1.1.2.2	**Development and Prototypes**	104	25	24	129	0	20	0	83	1.1	0.5
1.1.1.3	**Electronics**	726	93	13	819	237	0	0	489	2.0	10.2
1.1.1.3.1	**Design/Engineering**	237	13	5	250	237	0	0	0	2.0	10.2
1.1.1.3.2	**Development and Prototypes**	489	81	16	570	0	0	0	489	0.0	0.0
1.1.1.4	**Hybrids and Cables**	186	44	23	229	52	26	0	107	1.9	0.5
1.1.1.4.1	**Design/Engineering**	71	9	13	79	52	0	0	18	0.7	0.5
1.1.1.4.2	**Development and Prototypes**	115	35	30	150	0	26	0	89	1.2	0.0
1.1.1.5	**Module Assembly/Test**	313	90	29	402	48	0	0	265	0.5	2.8
1.1.1.5.1	**Design/Engineering**	48	13	28	62	44	0	0	4	0.3	0.9
1.1.1.5.2	**Development and Prototypes**	265	76	29	341	4	0	0	261	0.2	1.9

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WBS 1.1.1 Summary

- Pixel Technical Design Report completed
- Excellent technical progress made.
- Overall, the ATLAS effort leads pixel development in the world at this time.
- About two more years of development needed before construction costs well understood.
- Pre-baseline funding will be adequate, if we can continue to receive personnel and other support outside the project to advance this area of detector development.
- Schedule and resources(profile) developed under this assumption.