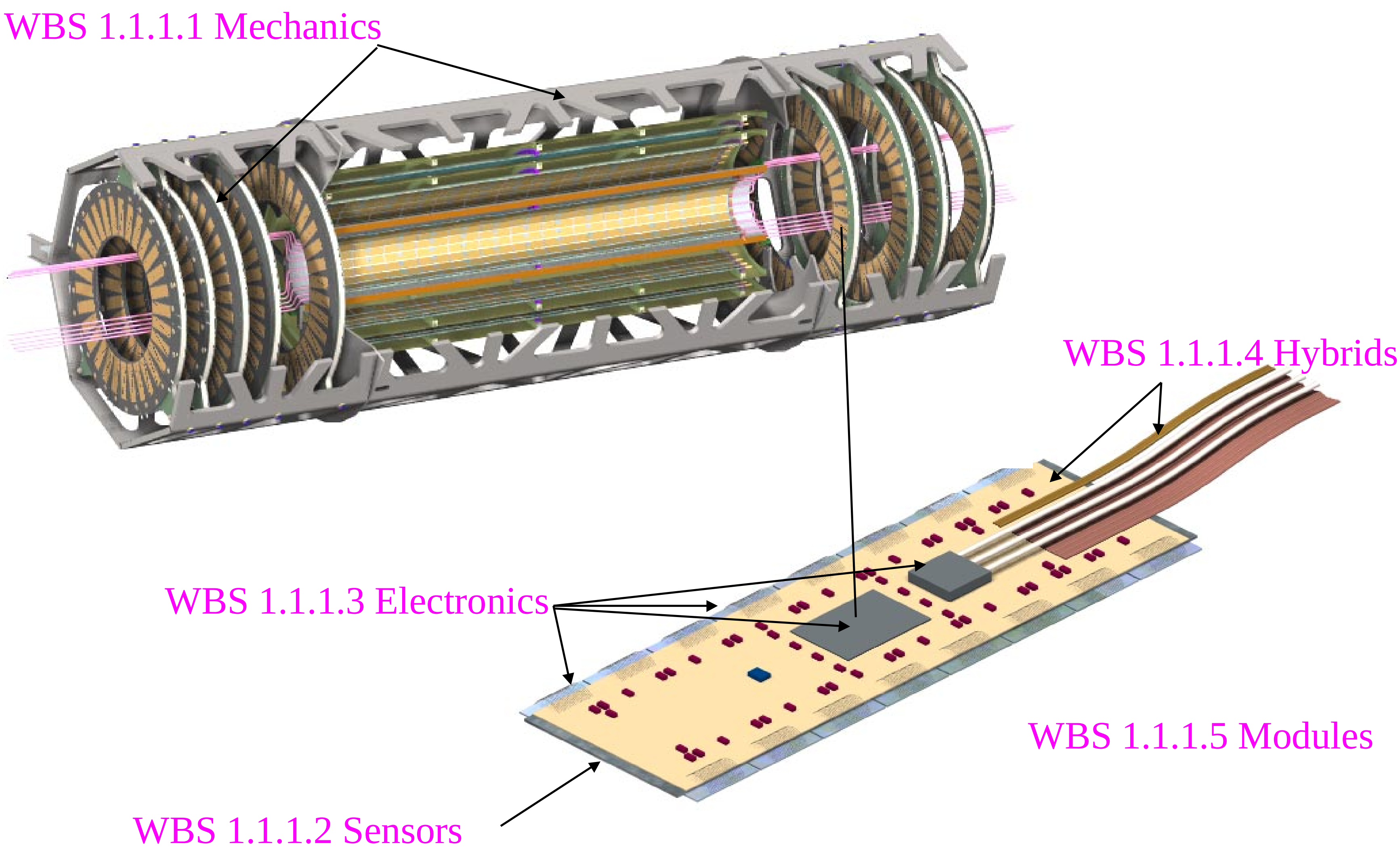
WBS 1.1.1 Pixel System

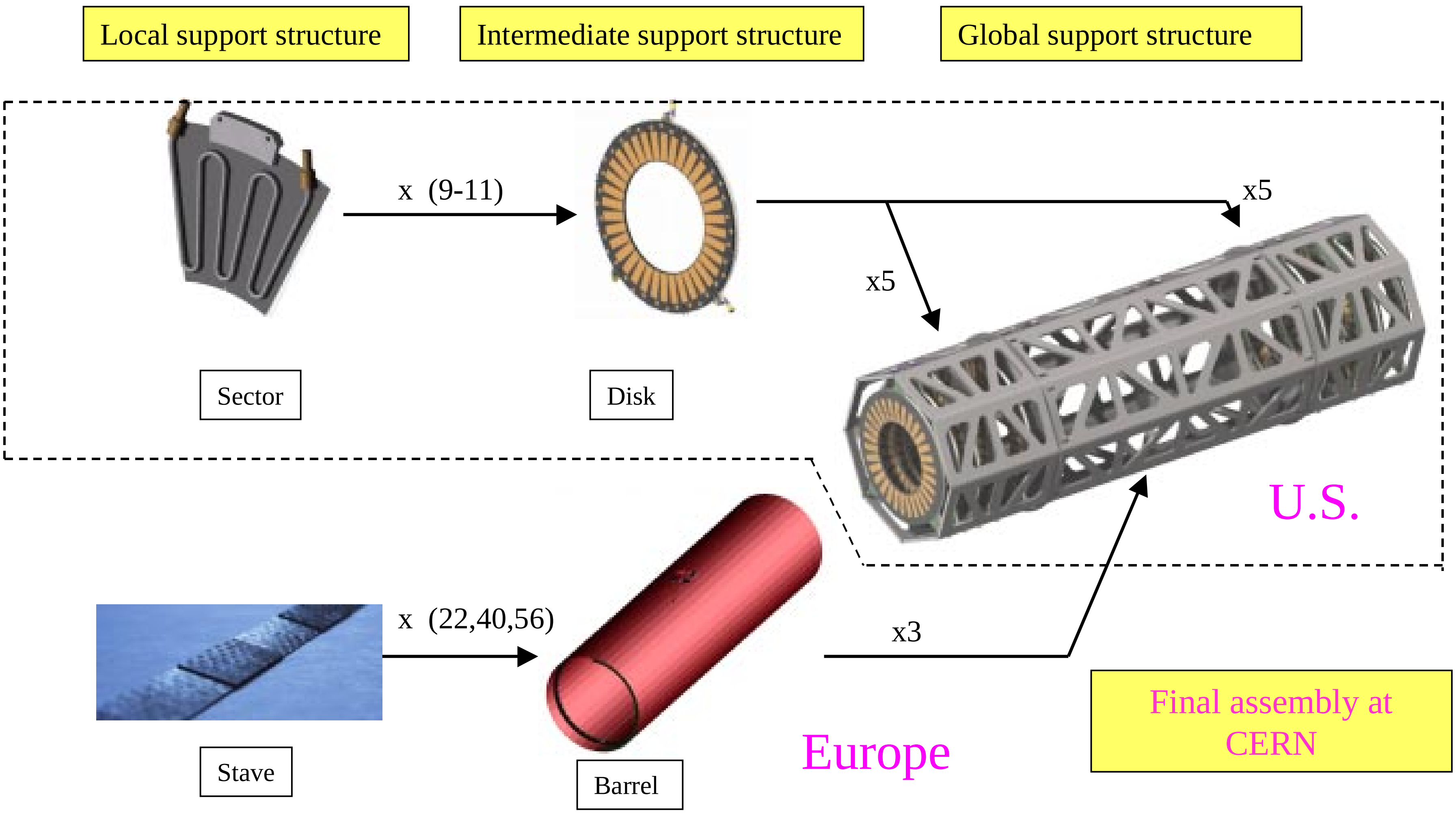
Mechanics, Hybrids and Modules

M. Gilchriese - February 2000

WBS 1.1.1 Pixel System



WBS 1.1.1.1 Pixel Mechanics



WBS 1.1.1.1 Deliverables

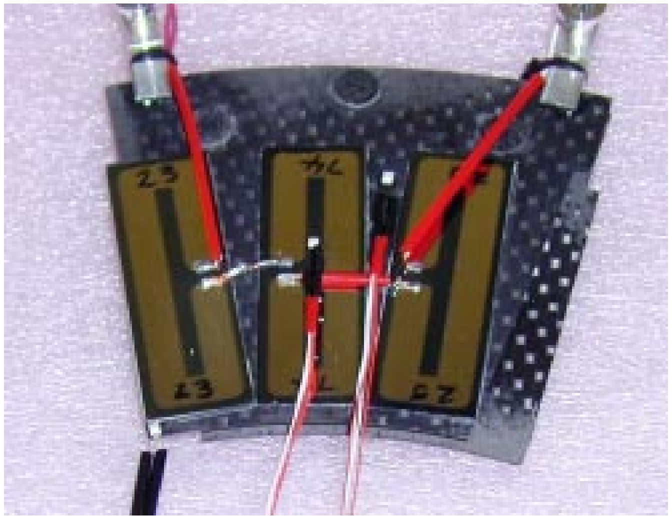
- The proposed US pixel mechanics deliverables are listed below (these are fabrication costs only- design is separate)
- Design and development has occurred and continues in all of these areas.
- There is a very good partitioning of the work between the US and European institutions that is reflected in these deliverables.
- These deliverables chosen to focus US effort, minimize interfaces and advance experiment.

WBS Number	Description	Base Cost	Cont Cost (k$)	Cont %	Total Cost	EDIA Labor	Mfg Labor	EDIA Matls	Mfg Matls	FTEs Project	FTEs Other
1.1.1.1.3	**Production**	1571	559	36	2129	0	563	0	1008	6.3	7.5
1.1.1.1.3.1	**Disk Sectors**	231	65	28	296	0	153	0	78	1.7	0.0
1.1.1.1.3.2	**Disk Support Rings**	220	71	32	291	0	0	0	220	0.0	0.0
1.1.1.1.3.3	**Support Frame**	328	105	32	433	0	0	0	328	0.0	0.0
1.1.1.1.3.4	**Thermal/EMI Barriers**	49	16	33	65	0	33	0	16	0.4	0.0
1.1.1.1.3.5	**Services**	396	135	34	530	0	276	0	120	3.1	0.0
1.1.1.1.3.6	**Disk Assembly**	83	45	54	128	0	50	0	34	0.5	2.3
1.1.1.1.3.7	**Disk Final Assembly and**	135	73	54	208	0	7	0	128	0.1	5.3
1.1.1.1.3.8	**Test Equipment**	73	29	39	102	0	0	0	73	0.0	0.0
1.1.1.1.3.9	**B-layer Installation**	53	21	39	74	0	43	0	11	0.5	0.0

WBS 1.1.1.1.3.1 Disk Sectors

Al-tube
LBNL made
Current baseline

ESLI, Inc
All-carbon



Hytec, Inc
All-carbon
Option

WBS 1.1.1.1.3.1 Disk Sectors

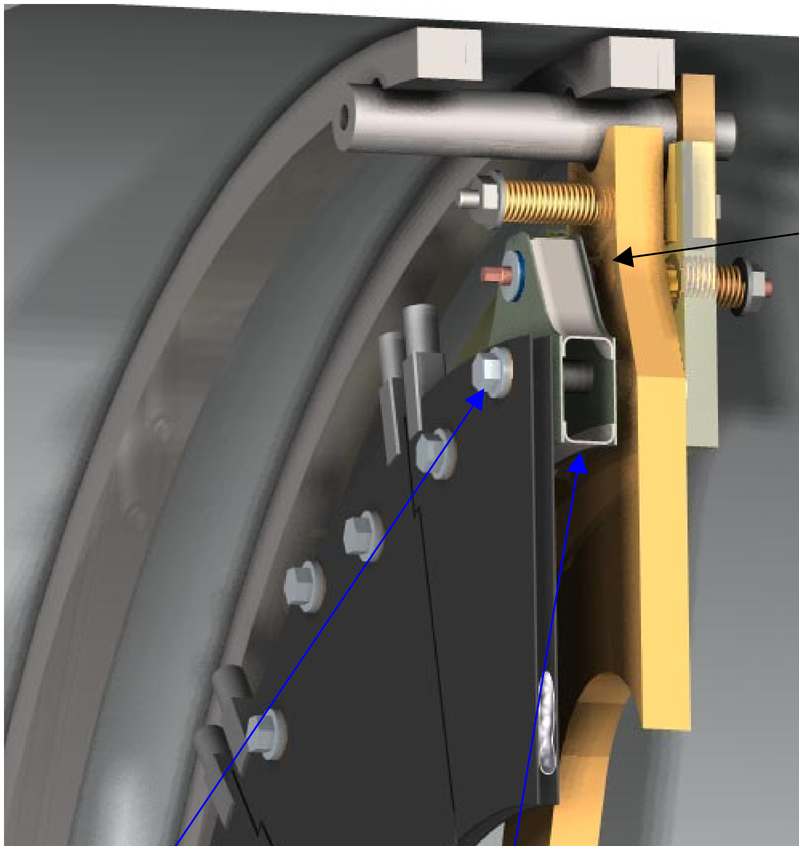
	SPEC	ESLI	AL TUBE	SEALED TUBE
Thermal performance (silicon temperature) PreRad After 50 Mrad	<-6°C	 OK ?	 OK OK(22 MRad	 OK ?
Z distortion(μ/°C)(ΔT=40) PreRad After 50 Mrad	[1]	 <1 ?	 <1? ?	 <0.5? ?
In-plane distortion(μ/°C)(ΔT=40) PreRad After 50 Mrad	<10	 ? ?	 ? ?	 ? ?
Radiation length(%X_o)(active area)	<0.7	<0.6	<0.65	<0.7
Average thickness uniformity(μ)	[1]	Bad	<50	?
Face uniformity(μ)	[1]	?	<15	?
Maximum pressure(bar absolute)	10	<7	10	10
Pressure distortion(μ/bar) PreRad After 50 MRad	[1]	 ? ?	 2-10(wings) ?	 <0.3 ?
Robustness(relative scale, 1 is best)	N/A	3	1	2
Cost per sector(relative scale)	N/A	3	1	1
Production rate(sectors/month)	>12	?	OK	OK
Other risk factors(relative scale, 1 is best) Sole source procurement Corrosion resistance Potential for leakage[2] Compatibility with fittings	N/A	 3 1 3 2	 1 3(but OK) 1 1	 2 1 2 1

[1]Total z distortion resulting from temperature changes, thickness nonuniformity and distortions from pressurization must be less than ? microns.

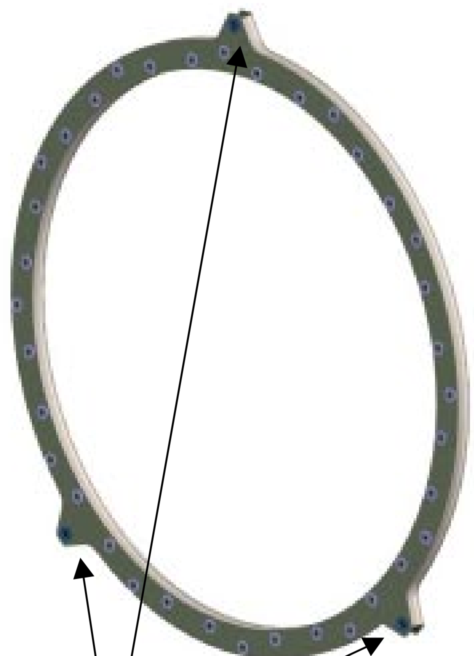
[2]Assumes no cracks in ESLI design occur, no corrosion in Al tube design.

- Extensive measurement program with some holes to fill in next months.
- Now moving to production issues.
- Internal review on April 10.
- ATLAS Final Design Review planned for June, 2000
- ATLAS Production Readiness Review planned by October.

WBS 1.1.1.1.3.2 and 1.1.1.1.3.6



Test set-up, low CTE equipment

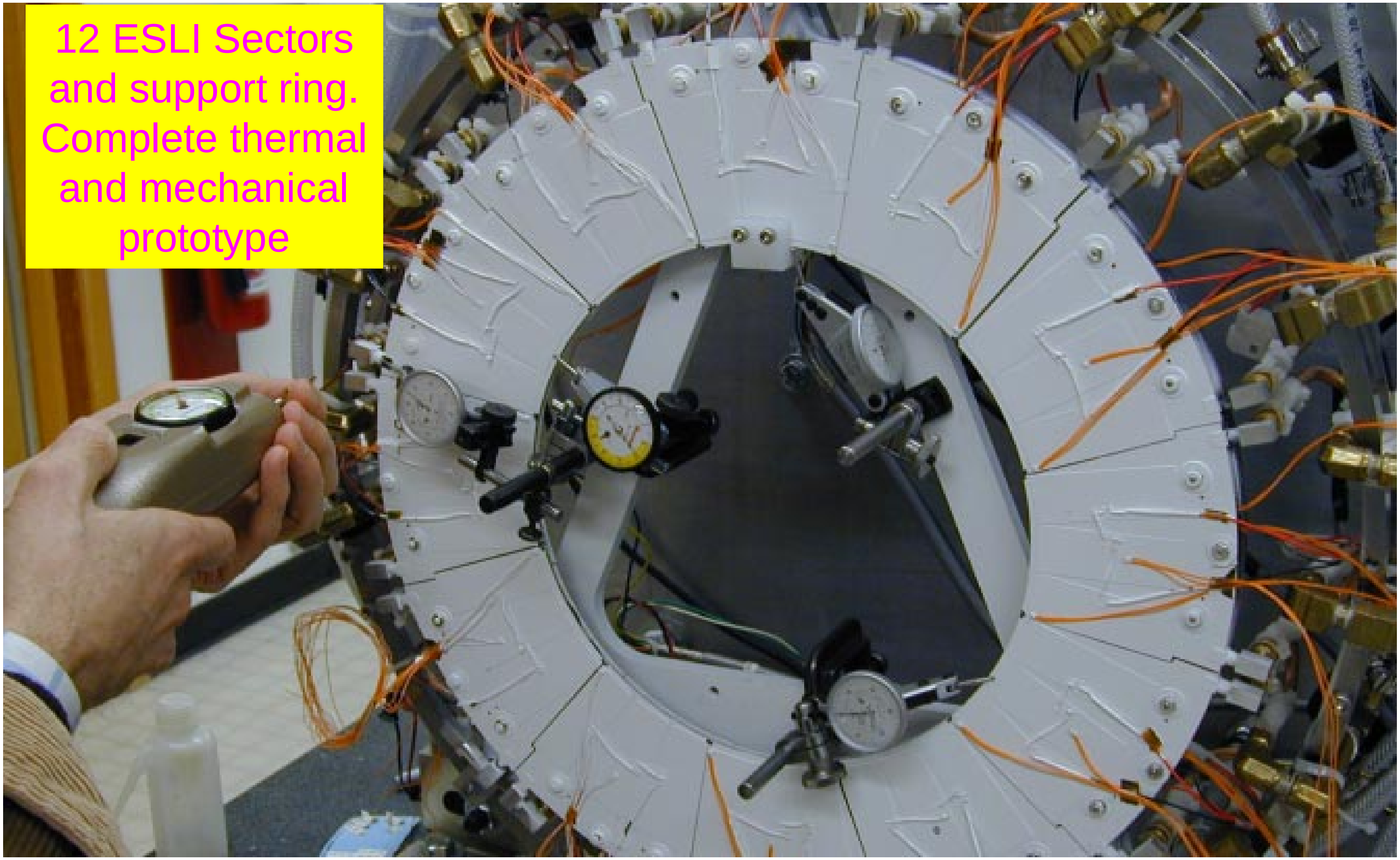


C-Channel

Precision locating screws

3 support points

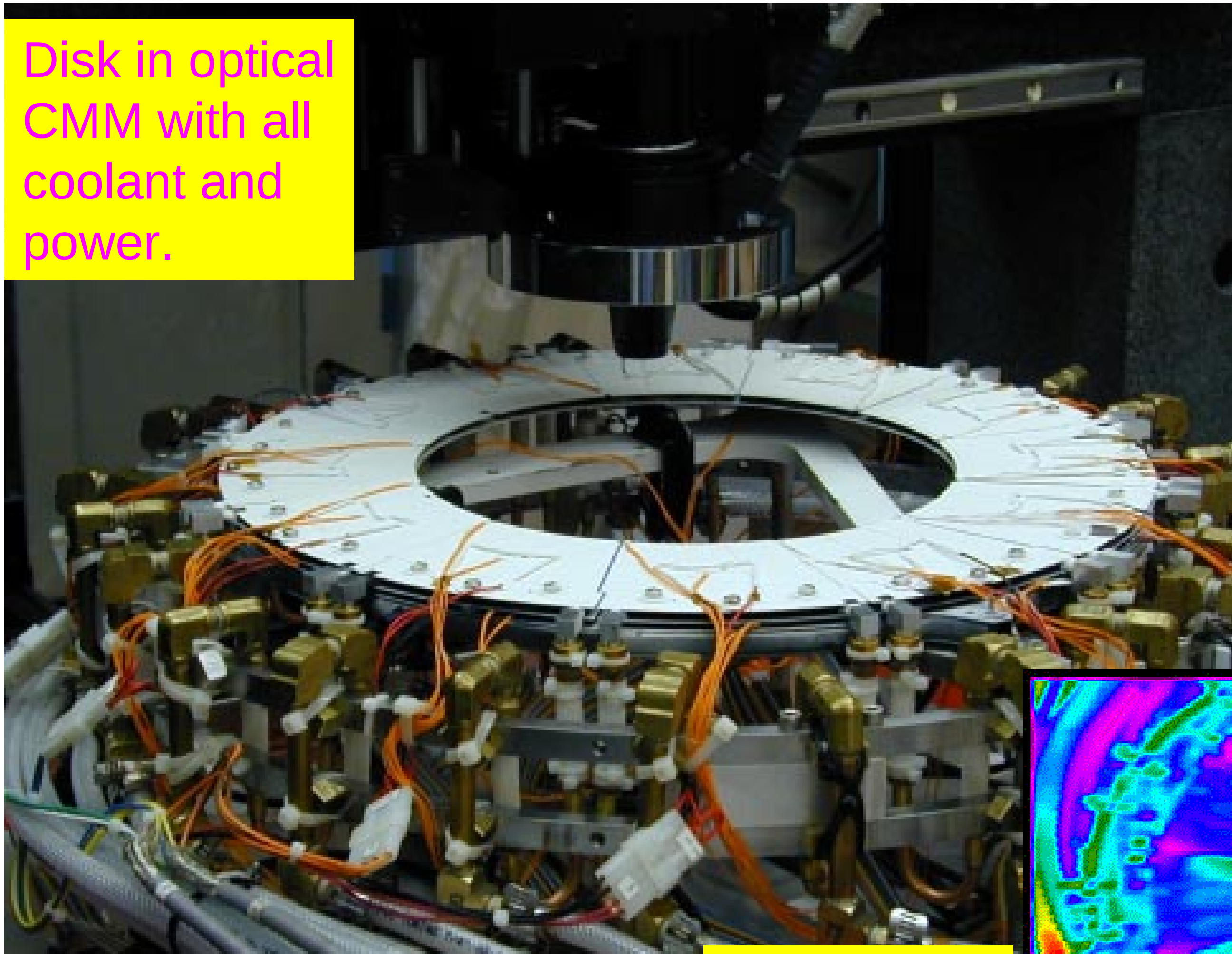
WBS 1.1.1.1.3.2 and 1.1.1.1.3.6



12 ESLI Sectors and support ring. Complete thermal and mechanical prototype

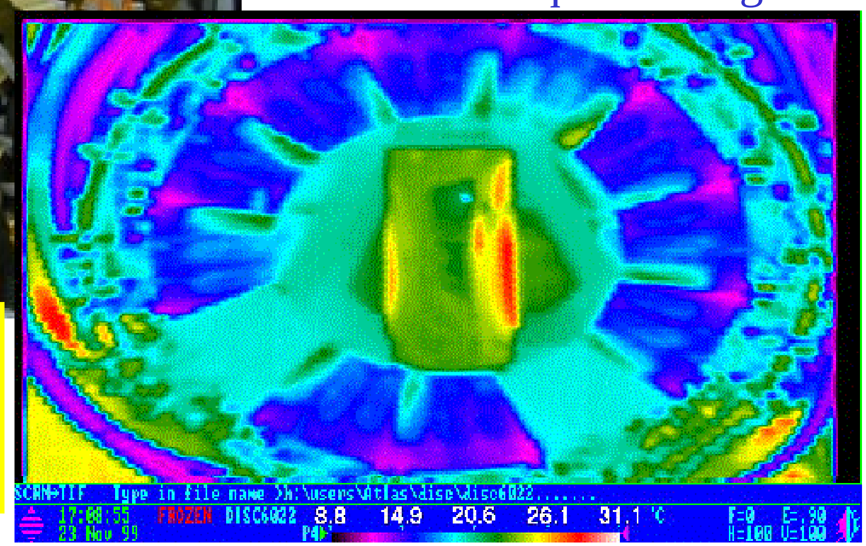
WBS 1.1.1.1.3.2 and 1.1.1.1.3.6

Disk in optical CMM with all coolant and power.



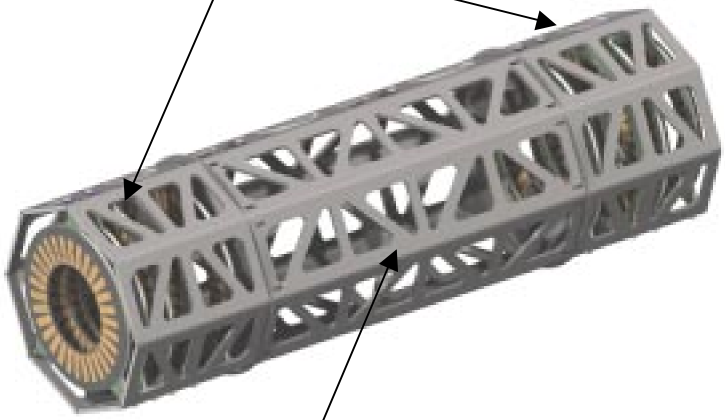
- Assembly experience very valuable.
- Thermal performance OK
- Stability testing underway. Looks good so far.
- Precision(as built) spec not met.
- 2nd full prototype under fabrication with revised fab technique for ring.

IR image at full power at room temp.



WBS 1.1.1.1.3.3

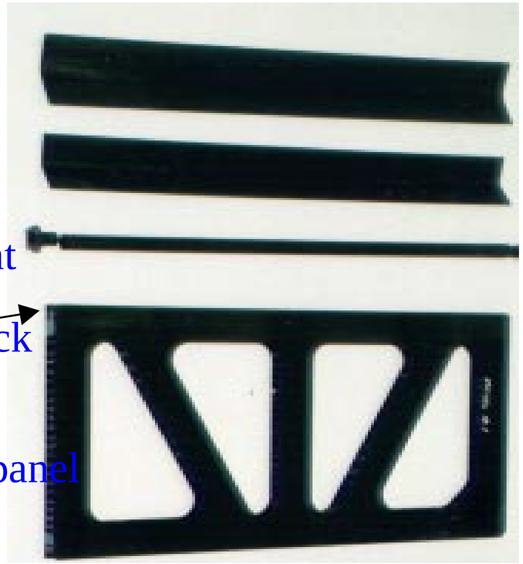
Prototype end section fabricated by December 1999 and under test.



Two end sections

Central frame section and end cones supporting barrel shells

WBS 1.1.1.1.3.3



Vertex joint

Corner block

Sandwich panel

Outer corner splice

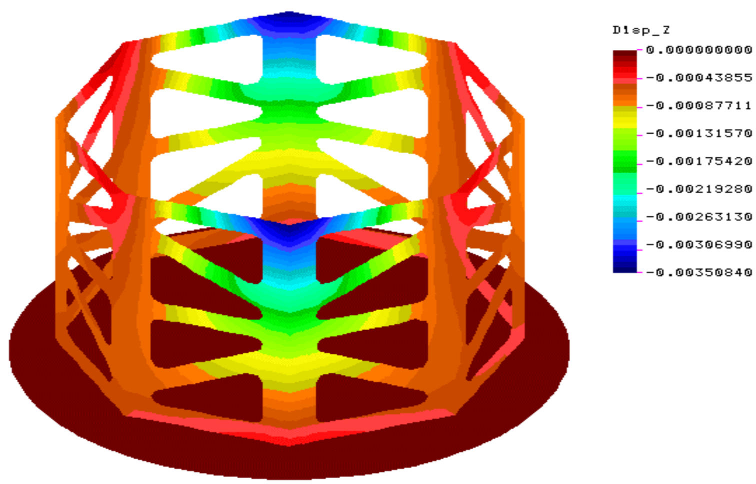
Inner corner splice

Corner tube

- Detailed comparison of measured deflections with FEA.
- Next step is to prototype disk supports and overall support. Designs for these have started.

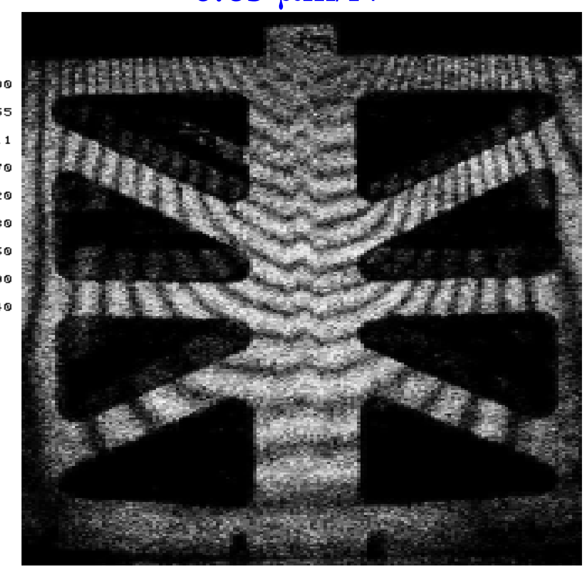
Deflections measured with TV holography

0.53 µm/N

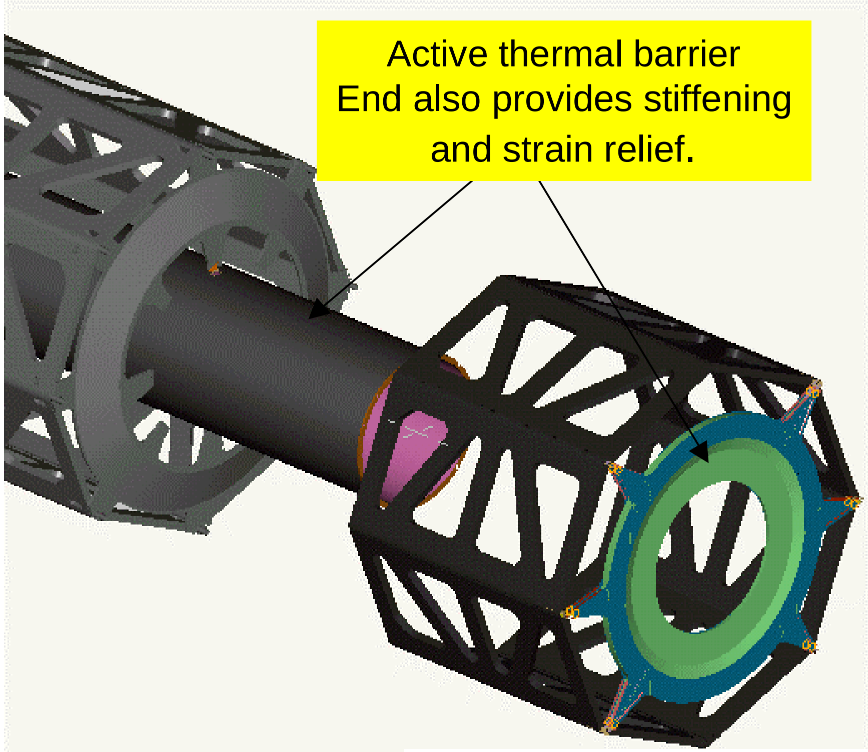


Finite element model result

0.69 µm/N

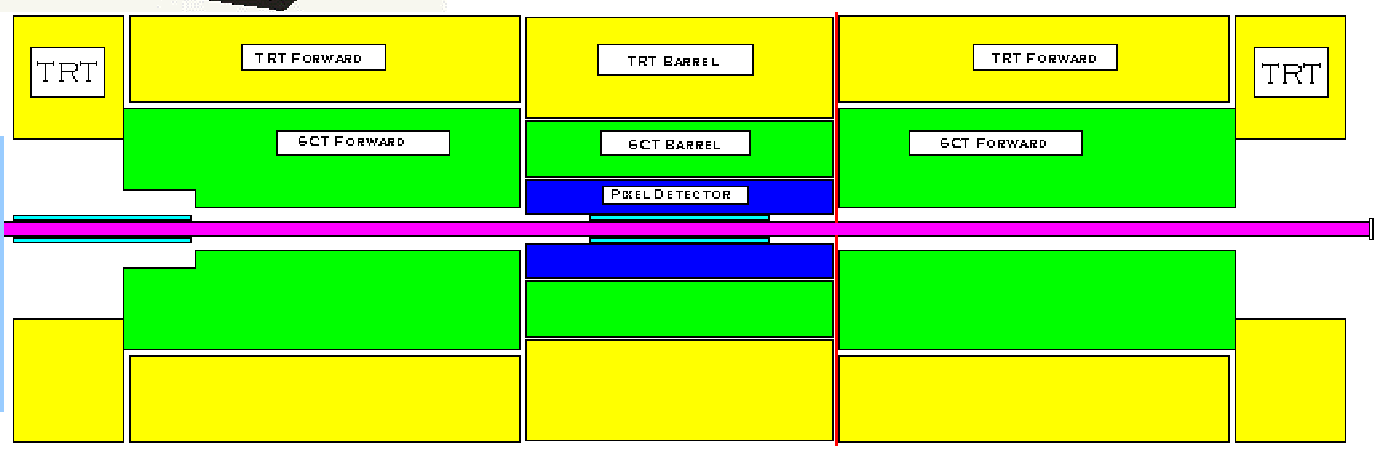


WBS 1.1.1.1.3.4 and 1.1.1.1.3.9



- Thermal barriers required to keep pixels(and SCT) cold when B-layer removed/replaced.
- Integrated into frame and strain relief(at ends).
- Also supports rails for B-layer insertion/removal
- Implies integrated design with frame and services => US proposed responsibility.

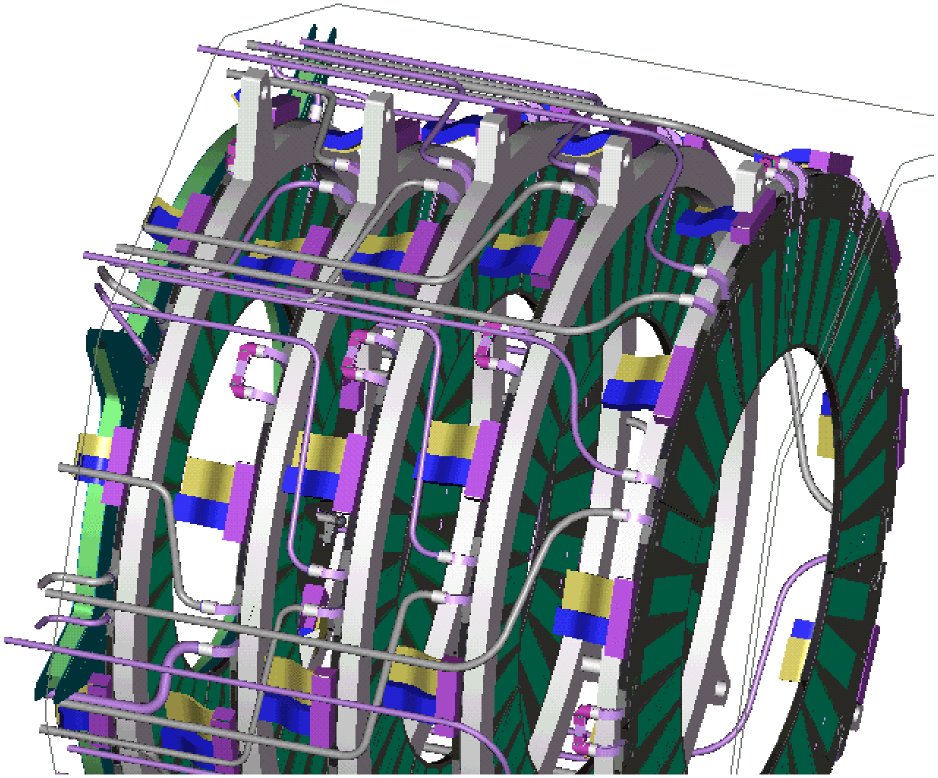
B-layer clamshelled and inserted from this end on rails attached to thermal barriers.

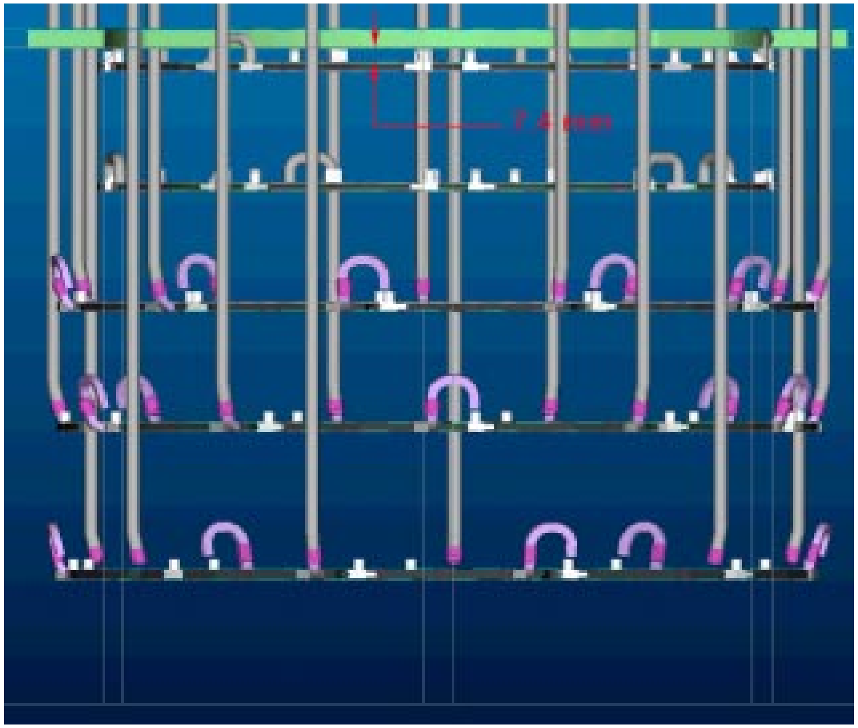


WBS 1.1.1.1.3.5 - Services

- Services includes integration of cables and coolant pipes(all have to pass through or be supported by frame), coolant pipes for disk region and specific cables for complete detector.
- It is critical to do the integration correctly to define precisely interfaces to disk sectors, rings and frame and we have just recently brought this under control.
- We are proposing to fabricate/purchase cables/connectors within the tracking volume. This both gives us control of these interfaces and takes advantage of our ability to fabricate low-mass kapton cables. The remainder of the cables, outside the tracking volume would come from Europe.

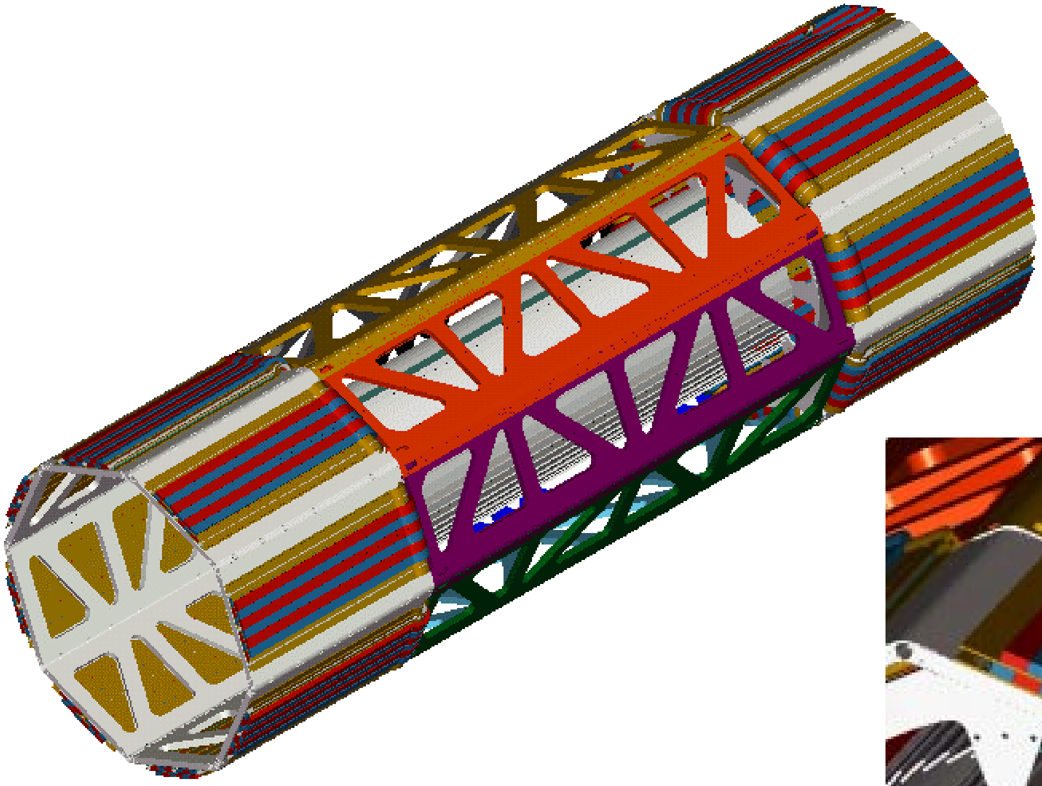
WBS 1.1.1.1.3.5 - Services

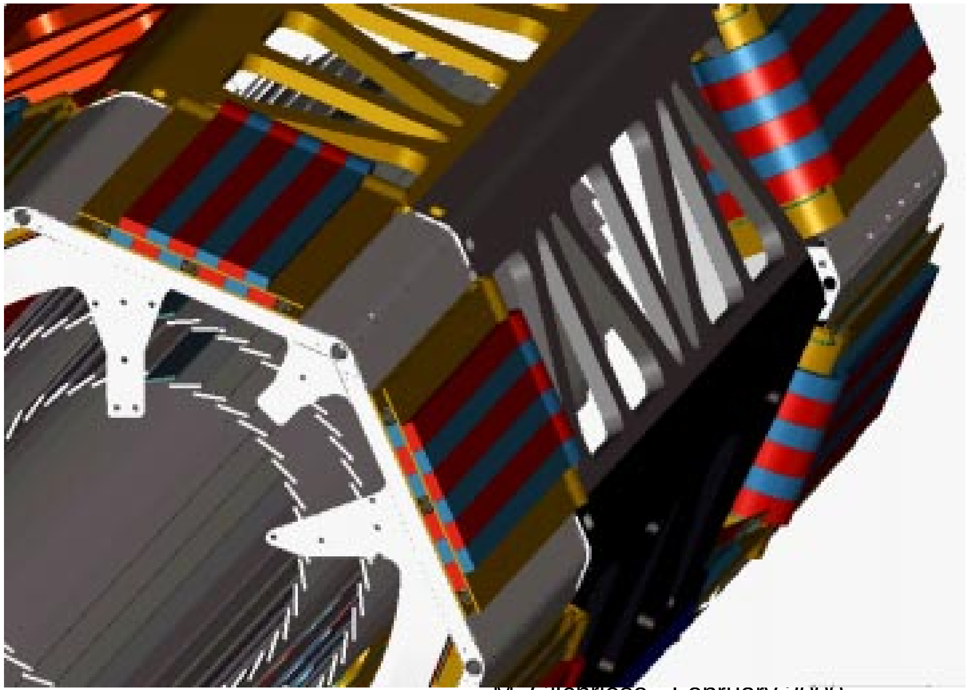




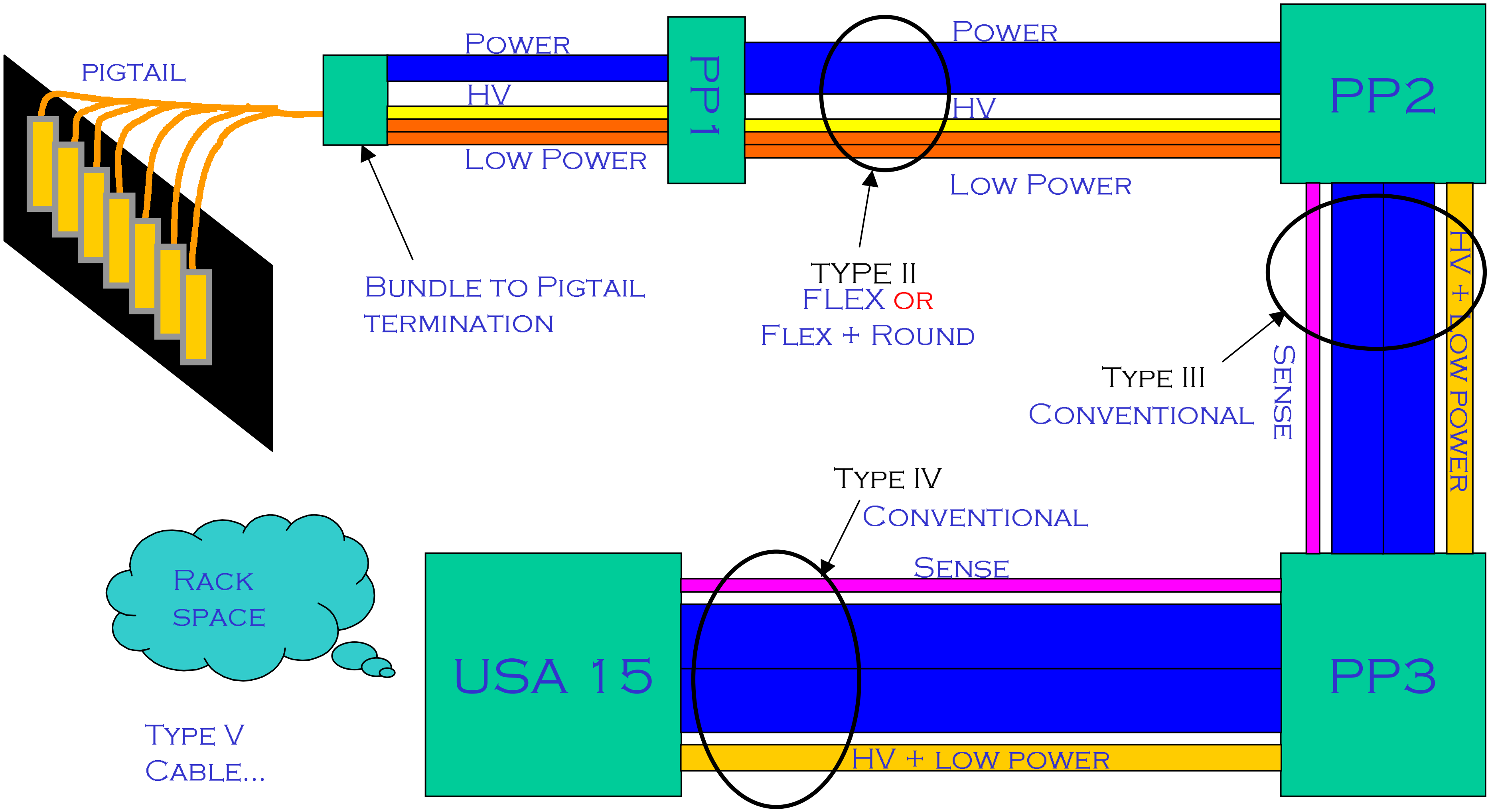
- Detailed CAD models exist. Must define precisely interfaces, strain relief to frame.
- Physical mockups within pixel volume under construction at LBNL.
- ATLAS is constructing full mockup of 90^o of complete inner tracker, cryostat, Lar crates, …… and we propose to take responsibility for pixel cable part of this. This is critical to understanding feasibility.

WBS 1.1.1.1.3.5 - Services

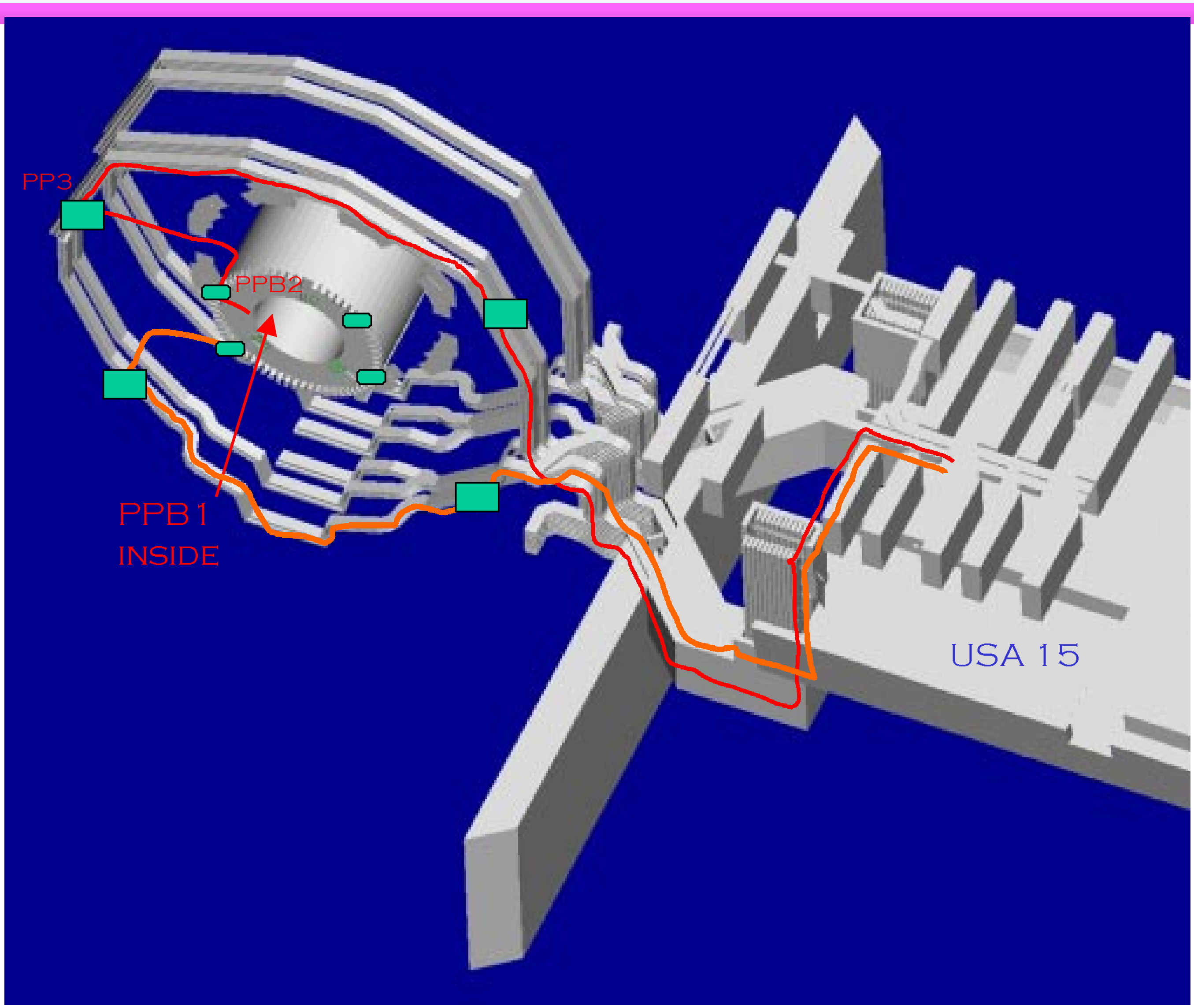




Cable Bundles Schematic



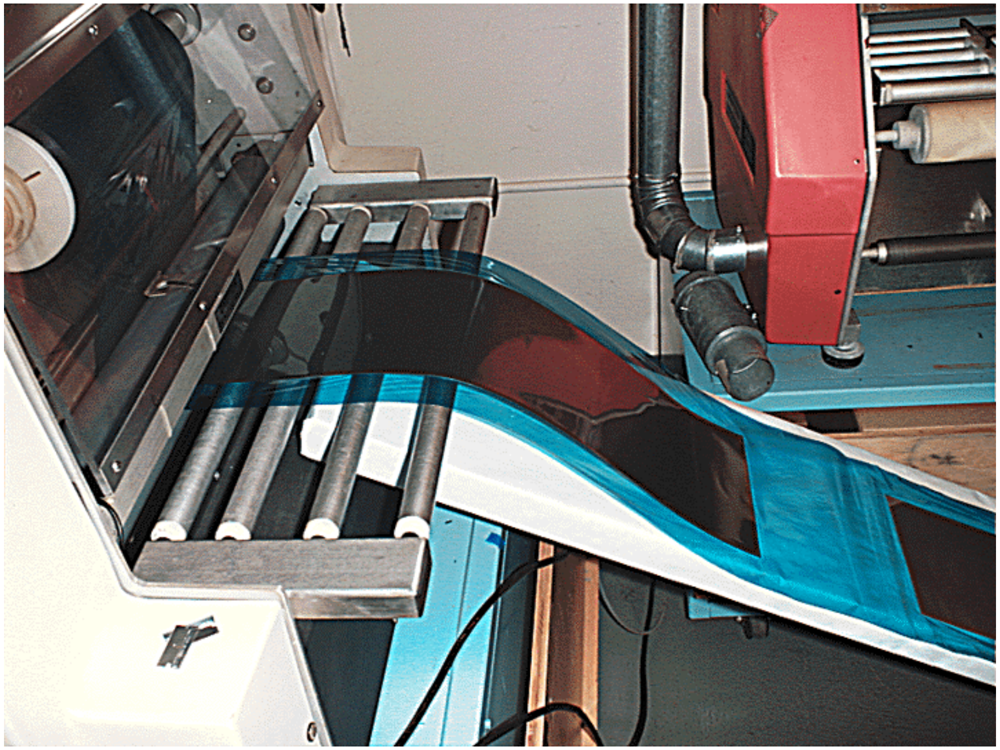
Service Plant Physical Layout



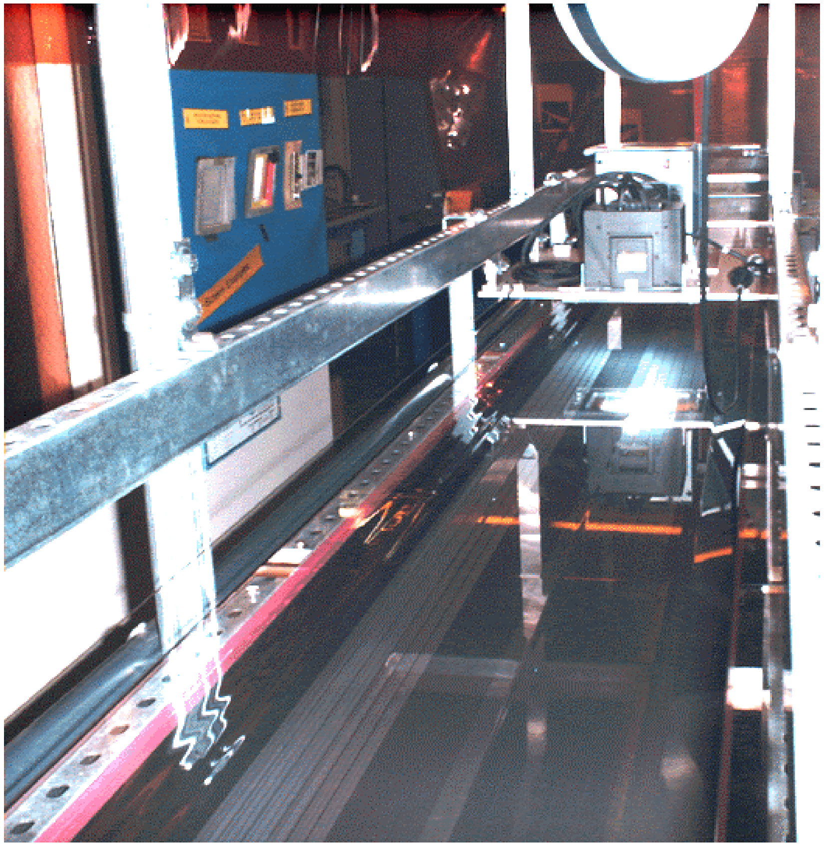
WBS 1.1.1.1.3.5 - Cables

Handling equipment is simple, but effective

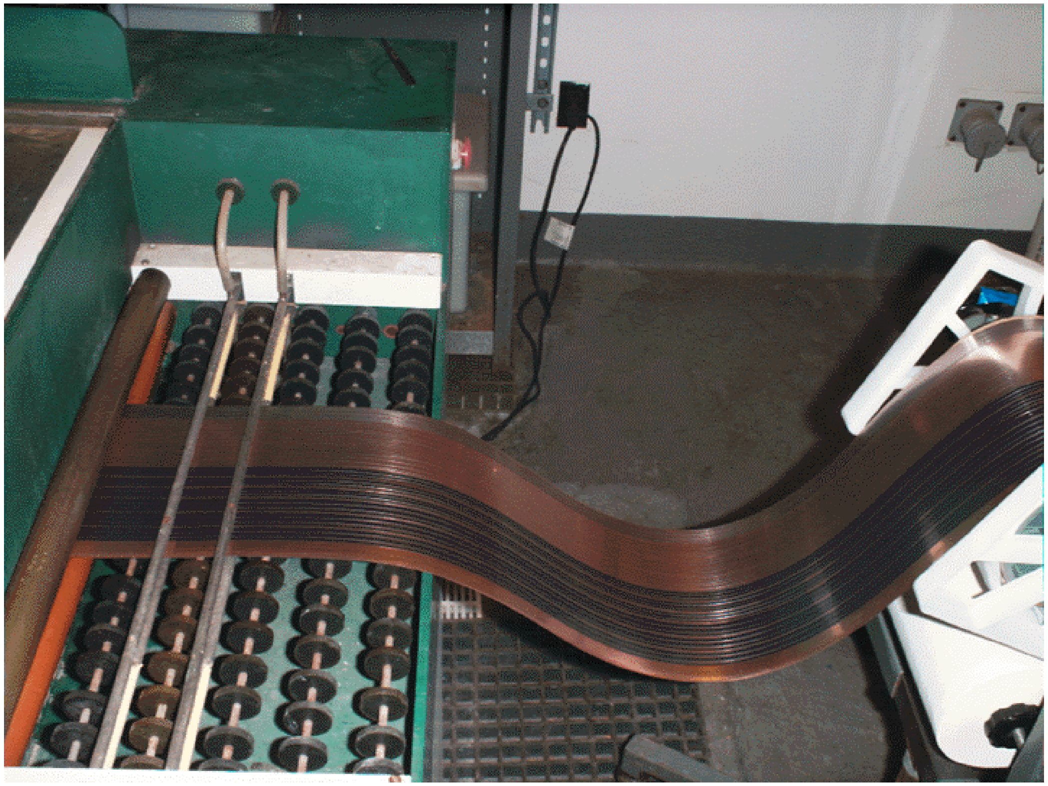
Roll Lamination process is used to apply photo-resist and photo-imageable coverlay



WBS 1.1.1.1.3.5 - Cables

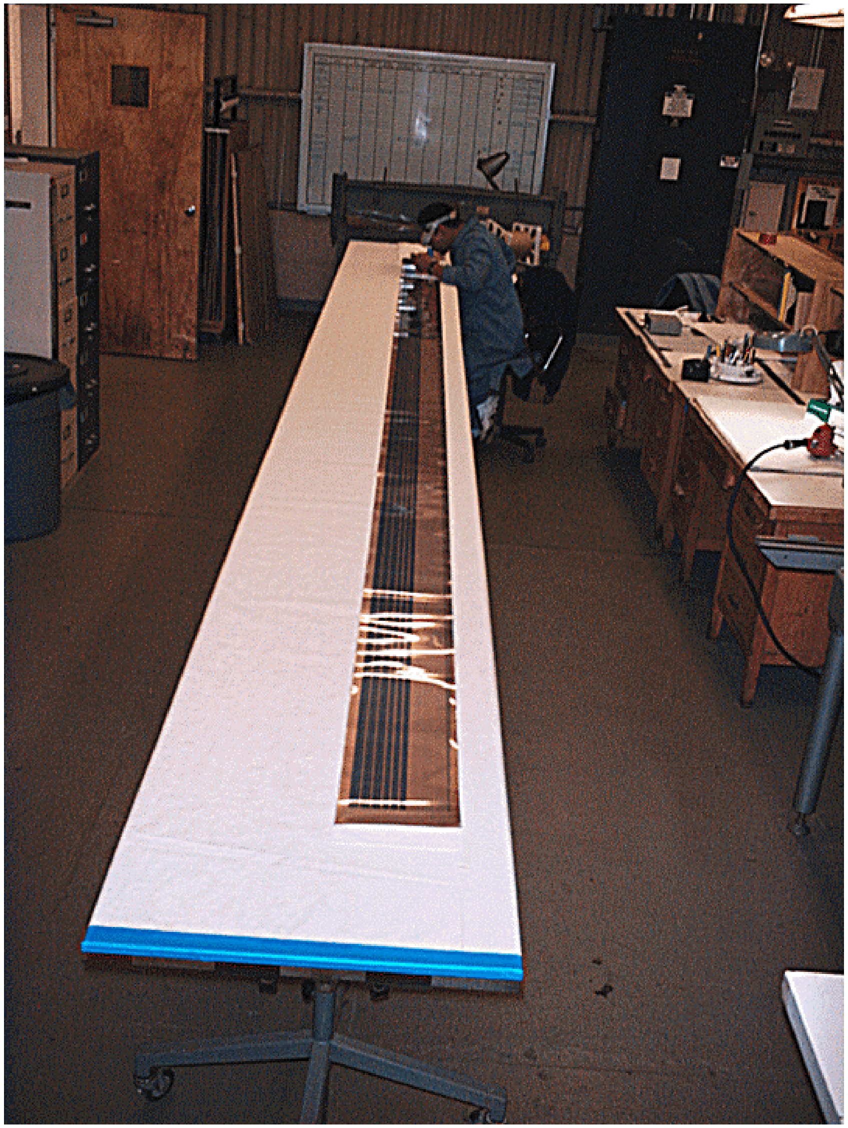


Continuous Feed Developer removes photo-resist that is not exposed. Etching bath is in a similar machine. Same rolls are used to handle material at each step



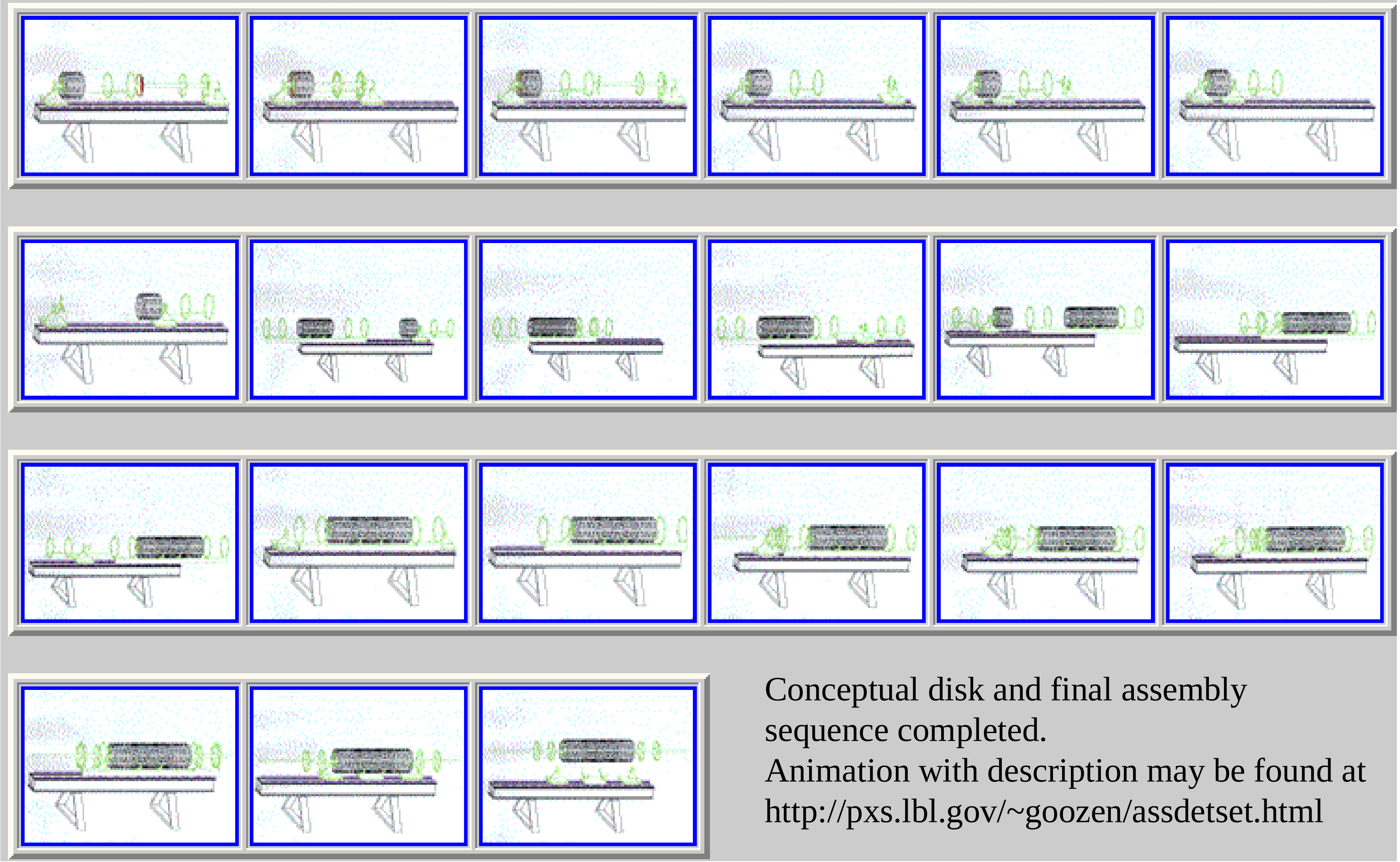
UV exposure lamp on trolley exposes full length of artwork. Laminated Cu-Kapton is held between art layers under vacuum

WBS 1.1.1.1.3.5 - Cables



- Prototype cables under fabrication now at LBL.
- These will be used for critical electrical tests with modules and prototype power supply.
- And guide the design integration via mockups.
- This is added cost to Development budget.
- Capability doesn’t exist anywhere else in collaboration.

WBS 1.1.1.1.3.7



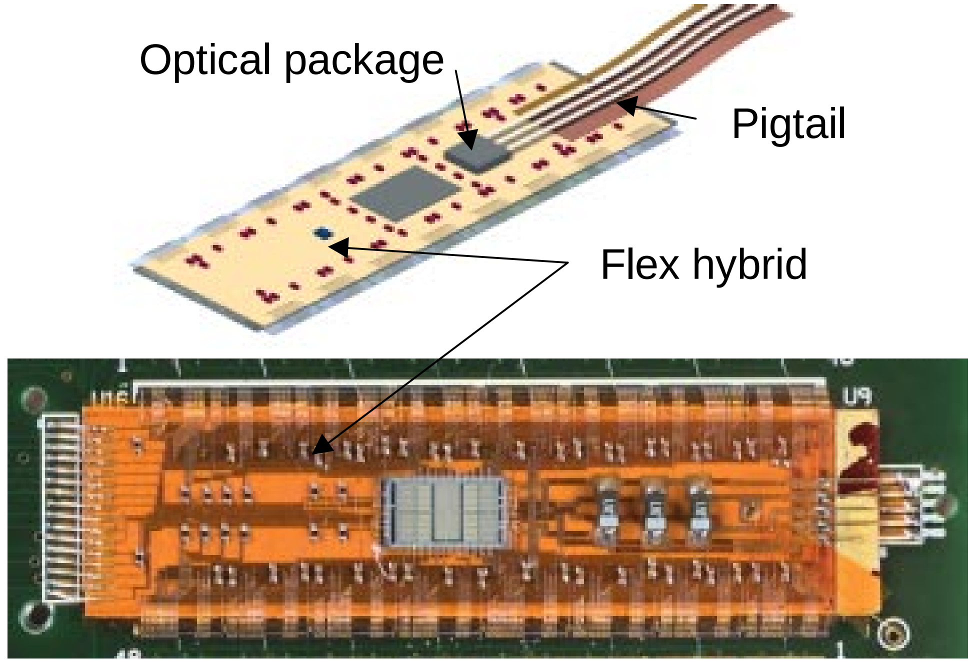
Conceptual disk and final assembly sequence completed.
Animation with description may be found at http://pxs.lbl.gov/~goozen/assdetset.html

WBS 1.1.1.1 Mechanics - Issues

- Cooling situation within ATLAS Inner Detector is not settled.
- History was described briefly yesterday.
- Current baseline is evaporative cooling with nominal maximum pressure of about 4 bar in structure but under certain(rare) fault conditions might reach 10 bar, in our opinion.
- Our response has been to be conservative and design for 10 bar accidental.
- The scope of US mechanics deliverables is greater than we thought in 97-98.
- However, it is well matched to needs of experiment, our capabilities and has been chosen to minimize interfaces with Europe, for practical reasons.
- In general, the mechanics is in good shape and we will be ready shortly to proceed with production design for many items.
- To do this efficiently may require some advance of production engineering design funding(for external design contract we have used for frame and rings) and we will know by April.

WBS 1.1.1.4 Hybrids

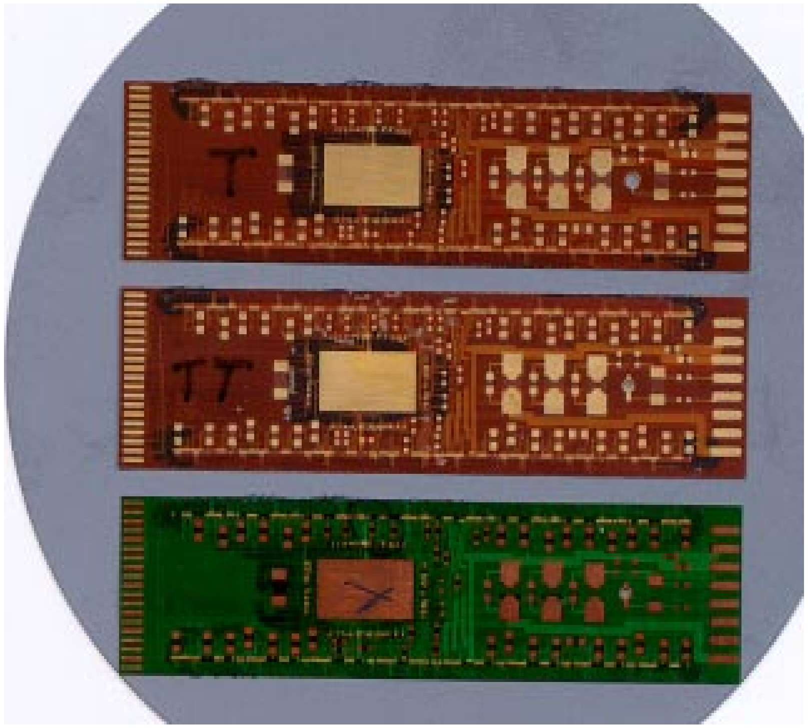
Hybrids connect the FE electronics to power and signals.
Flex hybrid - glued to bare module and wire bond connections made.
Pigtail attached to flex and most current design has optical package on pigtail(unlike the picture).
Other end of pigtail attached to power cables(connector).
Area of rapid development(have much to do to bring to production status).



WBS Number	Description	Base Cost	Cont Cost (k$)	Cont %	Total Cost	EDIA Labor	Mfg Labor	EDIA Matls	Mfg Matls	FTEs Project	FTEs Other
1.1.1.4.3	Production	614	444	72	1058	0	154	0	460	7.0	0.1
1.1.1.4.3.1	Flex hybrid	483	358	74	841	0	113	0	370	5.0	0.1
1.1.1.4.3.1.1	Bare Flex Hybrids	150	147	98	297	0	0	0	150	0.0	0.0
1.1.1.4.3.1.2	Components and Assembly	150	147	98	297	0	0	0	150	0.0	0.0
1.1.1.4.3.1.3	Testing	123	52	42	175	0	113	0	10	5.0	0.1
1.1.1.4.3.1.4	Flex singulation	60	12	20	72	0	0	0	60	0.0	0.0
1.1.1.4.3.2	Pigtails	84	68	80	152	0	20	0	64	1.0	0.0
1.1.1.4.3.2.1	Bare pigtails	36	35	98	70	0	0	0	36	0.0	0.0
1.1.1.4.3.2.2	Components and assembly	18	17	98	35	0	0	0	18	0.0	0.0
1.1.1.4.3.2.3	Testing	31	15	50	46	0	20	0	10	1.0	0.0
1.1.1.4.3.3	Optical packages	47	19	40	65	0	20	0	26	1.0	0.0

WBS 1.1.1.4 Flex Hybrids

- Flex hybrids v1.x manufactured at CERN(two generations) and most recently by US company (Compunetics).
- Few modules built and design looks OK but need more detailed verification with more modules
- Design of v2.x launched. Agreement reached on how, generally, to make connections to pigtails(different for barrel and disks) with identical flex hybrid. V2.x would be first to allow optical communication.
- Loading of flex hybrids so far done by hand but industry loading work just beginning in US and in Italy.
- Design of flex hybrid 100% responsibility of Oklahoma. Pigtail designs separated out: barrel in Europe and disk in US(UOK/LBL).
- In general, this has gone well but limited by availability of modules(in turn limited mostly by electronics). Recognize need to push harder now on production issues and are doing this.



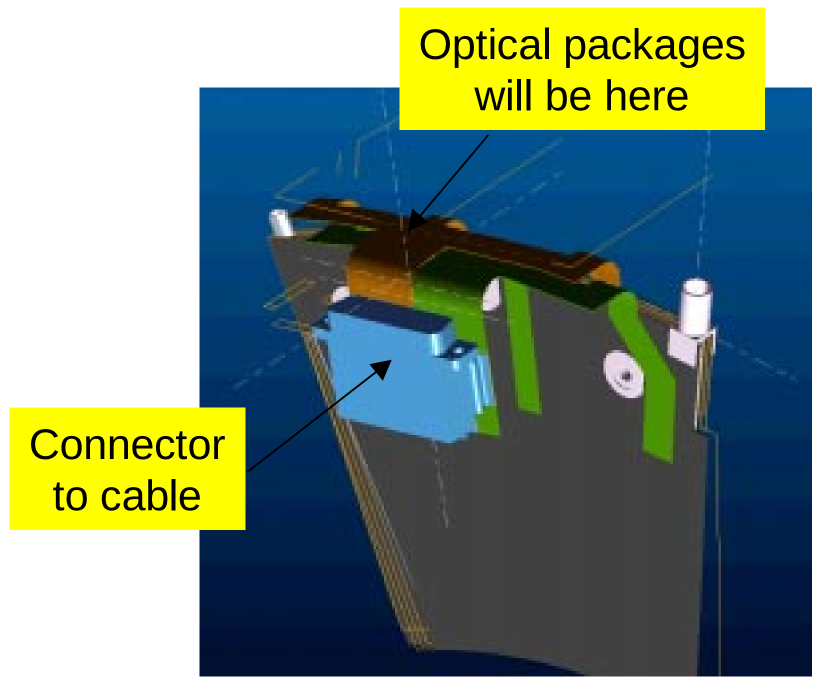
CERN - first version

CERN - second version

Compunetics

WBS 1.1.1.4 Pigtails and Optical Packages

- This area is much less developed than the flex hybrid.
- The pigtail is now intended to hold the optical package and make the transition(power and slow signals) from the flex hybrid to cables. We do not yet have a conceptual design(ie. good drawing) but will by about mid-April.
- Optical packages include VCSELs and PIN diodes + electronics.
- Development of optical aspects adapting what is done by SCT, work by Ohio State and from Taiwan.
- Taiwan has agreed to provide optical packages but are just starting on integration of these into pigtail design.
- We have a lot of work to do in these areas.



WBS 1.1.1.4 Hybrids - Issues

- We have included in the ETC additional development funds beyond the baseline
  - May need to qualify additional vendors(eg. GE or others) for flex hybrid
  - Pigtail development was not part of baseline plan(didn't exist)
  - We want to move this more quickly to production quality with assembly vendors to understand potential problems.
- Again will review in April time frame, which is a bit tight to complete work by time of Production baseline review.

WBS 1.1.1.5 Modules

- US contributions to making bare modules. This is currently some X-ray inspection, thinning of all IC wafers(nominal spec is 150 microns), dicing of IC wafers after thinning, inspection. May change before production review.
- Module assembly is attaching flex hybrids to bare modules and pigtails to flex hybrids.
- Module testing includes testing of modules with flex hybrids attached(there is a sacrificial connection).
- Module attachment is attachment of tested modules to sectors.
- Sector electrical testing is testing of modules on sectors before disk assembly.

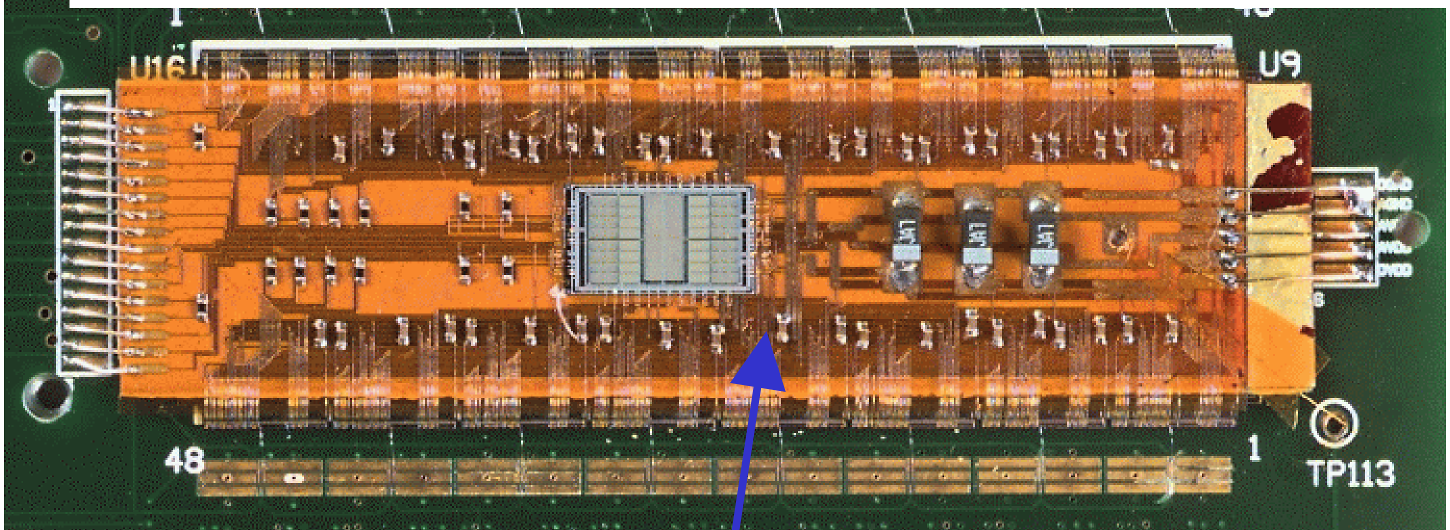
WBS Number	Description	Base Cost	Cont Cost (k$)	Cont %	Total Cost	EDIA Labor	Mfg Labor	EDIA Matls	Mfg Matls	FTEs Project	FTEs Other
1.1.1.5.3	Production	1063	359	34	1422	0	579	0	484	14.0	1.4
1.1.1.5.3.1	Bump bonding/X-ray	99	28	28	126	0	15	0	83	0.6	0.0
1.1.1.5.3.2	IC Wafer Thinning	17	5	27	21	0	0	0	17	0.0	0.0
1.1.1.5.3.3	Dicing of IC Wafers	64	17	27	82	0	0	0	64	0.0	0.0
1.1.1.5.3.4	IC Die Sort	72	16	22	88	0	30	0	42	1.1	0.0
1.1.1.5.3.5	Module Assembly	292	85	29	377	0	227	0	65	4.7	0.6
1.1.1.5.3.6	Module Testing	215	93	44	308	0	123	0	92	4.5	0.4
1.1.1.5.3.7	Module Attachment	249	94	38	343	0	144	0	105	1.6	0.4
1.1.1.5.3.8	Sector Electrical Testing	55	21	38	77	0	40	0	16	1.5	0.0

Bare Module and Bump Bonding

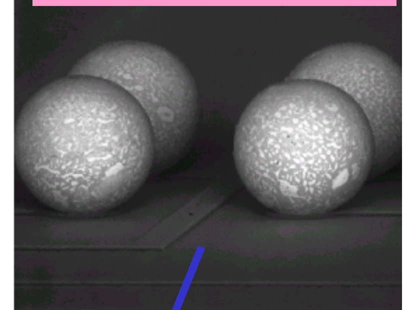
- Bump bonding is being done by IZM(Berlin), AMS(Rome) and third vendor(Sofradir) being started in France. These all use different processes, but as far as we can tell all will work.
- Have had recent site visits to IZM and AMS to discuss detailed outstanding issues. Qualification of Sofradir is just starting.
- Final Design Review for bump bonding scheduled for July this year.
- We will split order between at least two vendors, and possibly three if Sofradir works.
- US role much reduced. Currently
  - X-ray inspection for AMS(IZM has internal capability) at Bay Area firm.
  - IC wafer thinning(only success so far has been with US vendor). 150 micron thick IC modules assembled but final thickness is TBD. Material issue.
  - IC wafer dicing after thinning and subsequent inspection via Bay Area firms.
- More practical if as much as possible is done in Europe, so expect some evolution in this before baseline review.
- A dummy module program(wafers with correct bump patterns) is now in place with deliveries shortly so that we can practice steps(thinning, etc) in absence of real wafers.

X-Ray Inspection

Module with flex hybrid and controller chip on PC board



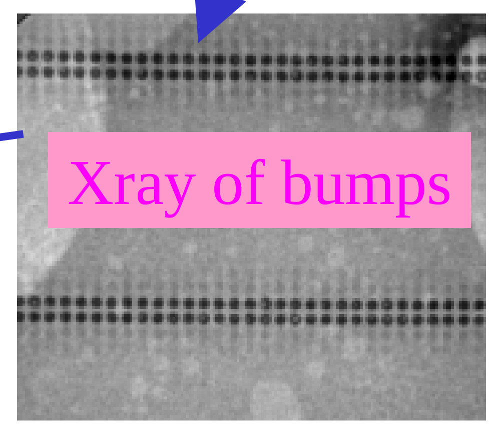
Bump bonds



16 chips with 46,000 bump bonds

Sensor

ICs

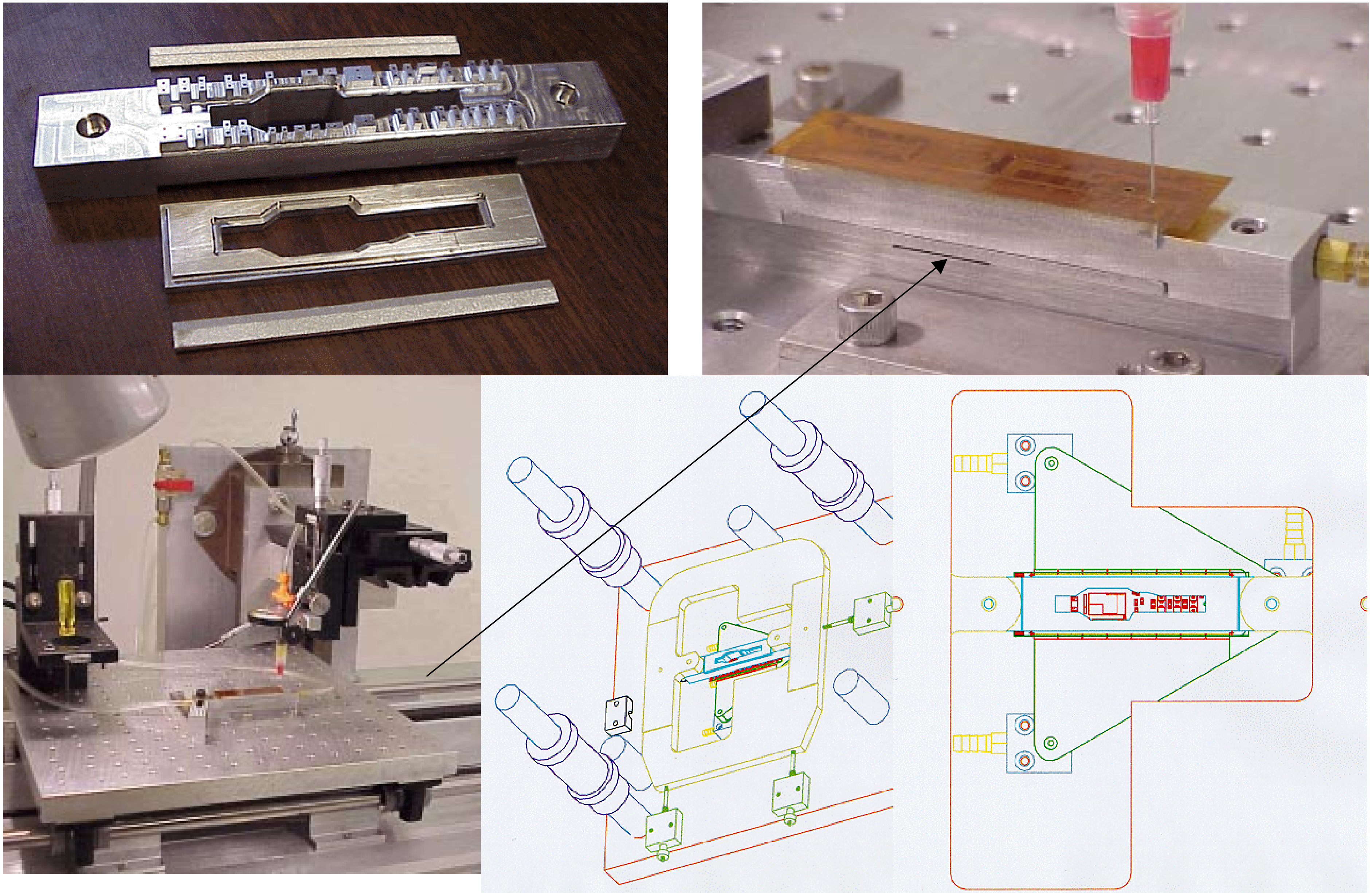


Xray of bumps

Module Assembly

- We have built a few modules with flex hybrids but all so far have required mounting on PC boards for test. Really electronics and hybrid test vehicles, not module assembly test vehicles.
- In parallel, we have developed conceptual design of tooling for module assembly and are now building a prototype version of this tooling.
- We have so far been using bare silicon to practice dispensing glue, for irradiation tests, etc. Some wire bonding tests done.
- Expect to proceed to use dummy modules and practice automated wire bonding at LBL and Ohio State by May.

Module Assembly

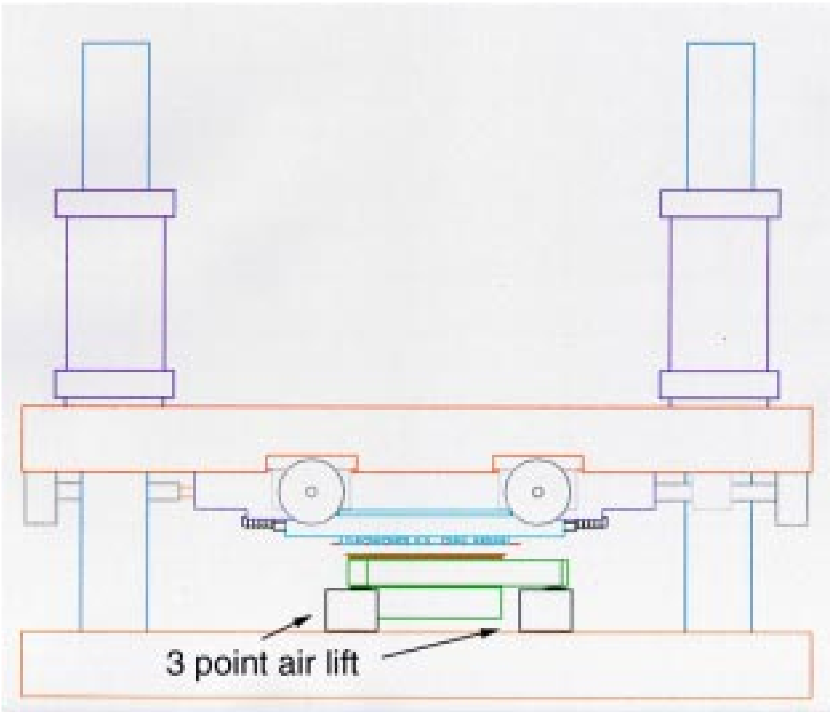


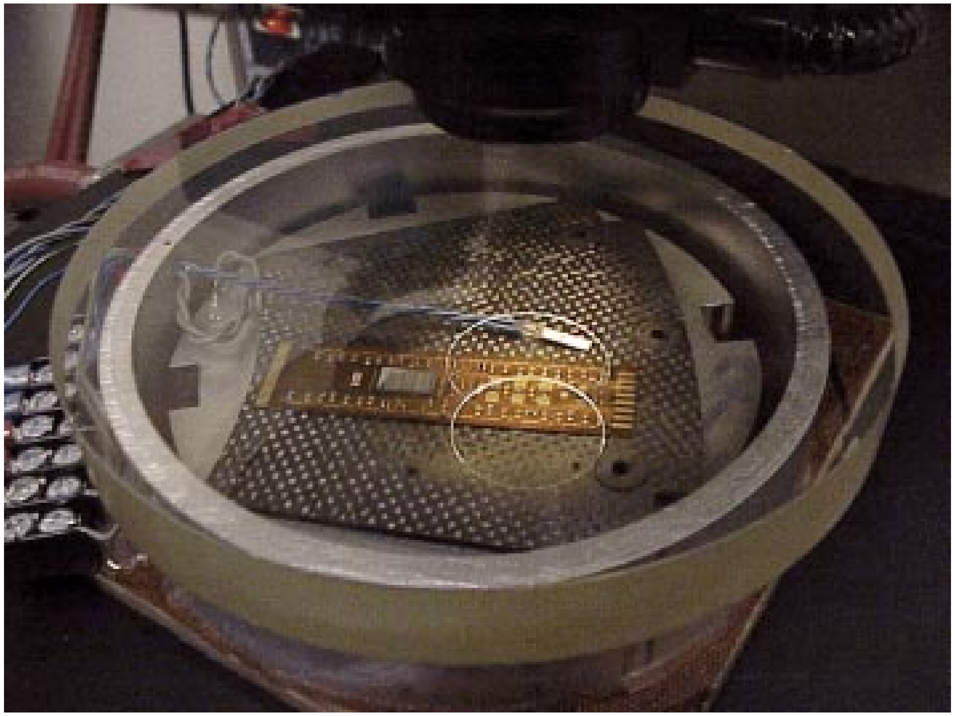
Module Assembly Yield Model

Pixel Module Yield Model							
Last Update: January 14, 2000							
ICs		Detectors		Flex		No of L1/2&diskmodules	1980
Yield(%)	Step	Yield(%)	Step	Yield(%)	Step	No of B-layer modules	273
30.0%	Fab	100.0%	Fab	100.0%	Fab	No of L1/2&disk FE die	31685
99.5%	Ship	99.5%	Ship	100.0%	Inspect(in fab)	L1/2&disk FE die/ wafer	130
97.0%	Probe	95.0%	Probe	99.5%	Ship	No B-layer FE die	4368
99.5%	Ship	99.5%	Ship	99.0%	Cut	B-layer FE die/wafer	130
97.0%	Bump deposition	97.0%	Bump deposition	99.5%	Ship	Detectors/wafer	3
99.5%	Ship	99.5%	Ship	95.0%	Mount components	Number of optical die	2253
97.0%	Inspection	97.0%	Inspection	99.5%	Ship	No optical die/wafer	1000
99.5%	Ship	99.5%	Ship	97.0%	Wire bond MCC		
98.0%	Thin	97.0%	Dice	99.5%	Ship		
99.5%	Ship	99.0%	Sort	97.0%	Probe/burn-in	Total modules started	2993
98.0%	Dice	99.5%	Ship	99.5%	Ship	Total L1/2&disk modules started	2630
98.0%	Sort	99.0%	Inspect			Total B-layer modules started	363
99.5%	Ship					Total L1/2&disk FE die required	169974
99.0%	Inspect					Total L1/2&disk FE wafers	1307
Yield(%)	*25%*		*83%*		*86%*	Total B-layer FE die required	23432
	per die		*per tile*		*per flex*	Total B-layer FE wafers required	180
						Total optical ICs needed	2837
Yield(%)	Optical Components	Yield(%)	Module Assembly	Yield(%)	Pigtails	Total optical wafers needed	3
87.0%	IC fab	99.5%	Flip chip/die	100.0%	Fab	Total detector wafers	1204
99.5%	IC Ship	92.3%	Flip chip/module	100.0%	Inspect(in fab)	Total flex needed	3047
97.0%	IC Probe	99.5%	Inspect(X-Ray)	99.5%	Ship	Total optical pkgs needed	2652
99.5%	IC Ship	99.5%	Ship	99.0%	Cut	Total opt fiber ribbon needed	2626
98.0%	IC thin	97.0%	Probe bare module	99.5%	Ship	Total pigtails needed	2494
99.5%	IC Ship	99.5%	Ship	98.0%	Mount components	Flip chip modules	2993
98.0%	IC dice	98.0%	Attach flex	99.5%	Ship	Total bump IC	1488
99.5%	IC Ship	95.0%	Wire bond(with repair)	95.0%	Test/burn in	Total bump detector	1204
79.4%	*Opt. IC yield*	98.0%	Attach pigtail	99.5%	Ship		
100.0%	Fiber fab	99.5%	Ship			20,42,56 staves, 2*[3x11+2*9]sectors	
100.0%	Fiber ship	95.0%	Test/burn in			5% spare modules included	
95.0%	Fiber inspect/connect	99.5%	Ship			B-layer is not flex	
95.0%	*Fiber ribbon yield*					Temic optimum yield assumed	
100.0%	Package fab						
99.5%	Package ship						
95.0%	Package inspect/test						
99.5%	Package ship		*75%*		*90%*		
94.1%	*Package yield*		*per module*		*per pigtail*		
99.5%	Shipping yield						

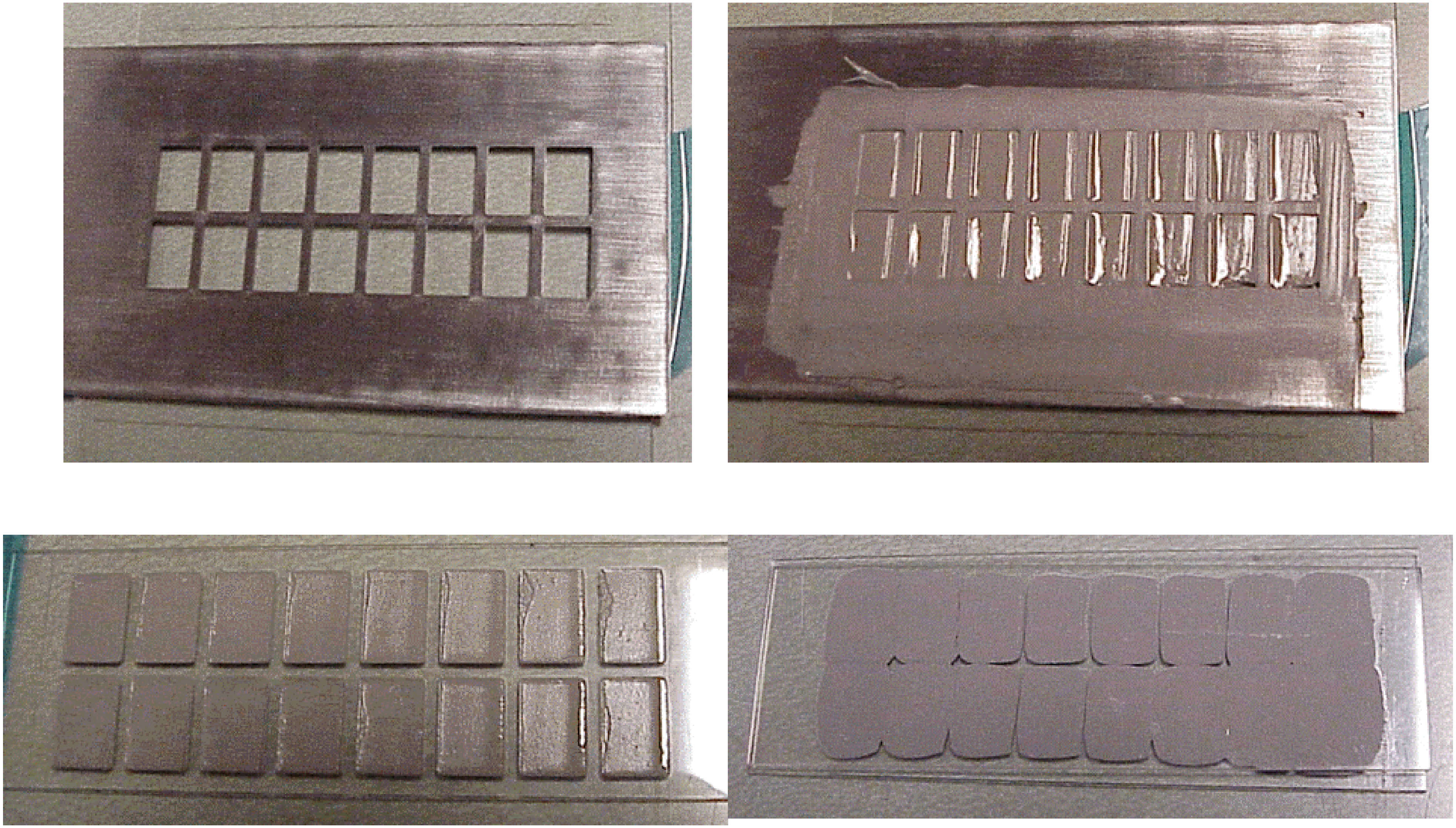
Module Attachment to Sectors

- Have also developed conceptual design for attaching modules to sectors and are practicing.
- Key element is control of adhesive(which is good thermal conductor) - see next page.





Modules Attachment Adhesive Tests



Module and Sector Testing

- Conceptually how we do this is understood but we are far from actually doing it - need real modules and parts
- Individual module testing will be done after attachment of flex hybrid that has sacrificial extension with connector so that tests can be done without optical connections.
- Pigtails can be tested separately also.
- Current concept is to mount modules with extension on sectors and retest, then attach pigtails and retest again.
- All sector-related mounting and testing at LBL and all individual module and pigtail testing outside LBL is current plan.

Hybrids and Modules - Issues

- To the greatest extent possible, we plan to move ahead with design and prototyping, cost and schedule of all mechanical aspects of hybrids and modules.
- We believe we can do this well enough to have a credible plan for a Production baseline review in September.
- However, our experience then with electrically functional modules will be limited.
- And we wont have a large experience to accurately predict assembly yields.
- These uncertainties will have to be covered by the appropriate contingencies - in all areas, since module assembly losses affect all areas but mechanics.

Conclusions

- Mechanics
  - Good progress so far on all fronts.
  - Proposed deliverables well defined, take advantage of US strengths and minimize interfaces with non-US groups.
  - Need additional development funds for sector prototypes, services mockup and cable prototypes. Review in April.
  - May require advance of production design funding to meet ATLAS schedule.
- Hybrids and Modules
  - Good progress on flex hybrids and module assembly concepts but need to broaden effort and move to production-like
  - Have focussed our deliverables to again minimize interfaces.
  - Need additional development funds to qualify additional vendors, do pigtail development and move more rapidly to production mode to avoid potential problems later.