ATLAS

Physics Division

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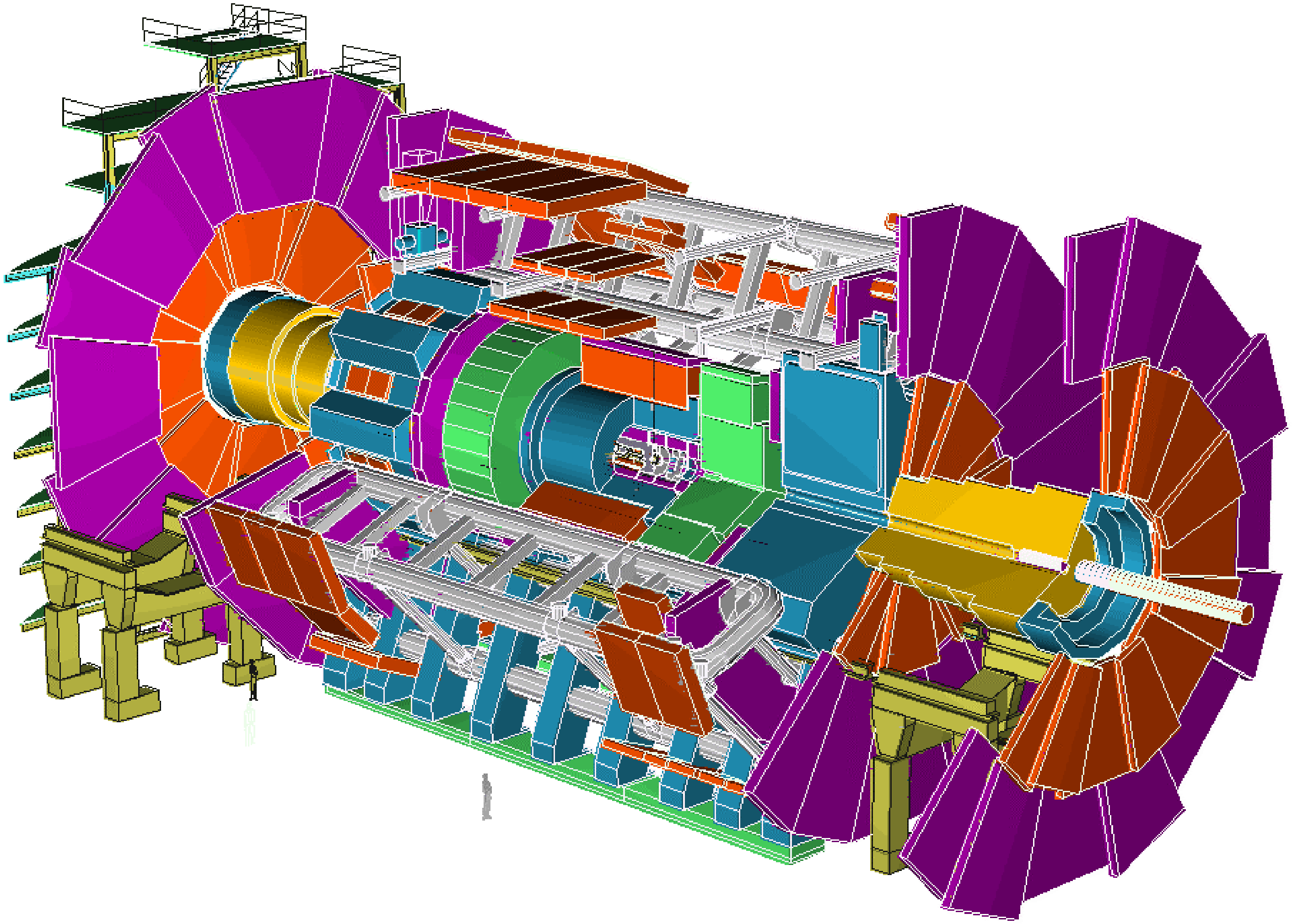
The ATLAS Detector

Physics Division



M. Gilchriese
DoE Review March 1999

LBNL and ATLAS - Overview

- Pixel detector system
  - Development of this new technology
  - Later production of about one-third of system
- Silicon strip detector system
  - Completing development to meet demanding LHC requirements
  - Later production with emphasis on integrated circuit electronics and modules, the building blocks of the system.
- Software and computing
  - LBNL was selected in January by U.S. ATLAS as lead institution for U.S. ATLAS computing => talk by Ian Hinchliffe.

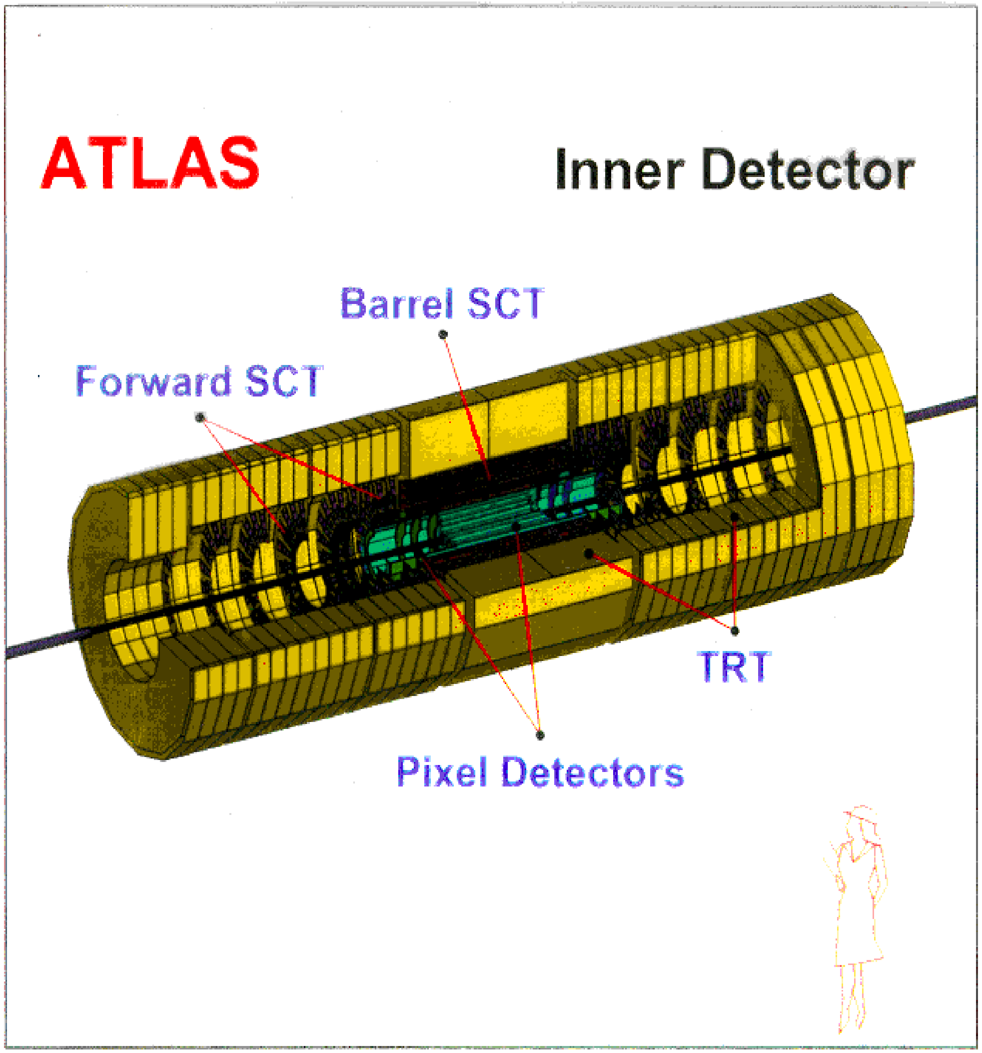
Highlights in Last Year

Physics Division

- Successful operation in test beam of pixel detectors irradiated to lifetime LHC dose with realistic prototype electronics.
- First operation of pixel module prototypes
- Demonstration that all-carbon structures can meet thermal, mechanical and material requirements for pixel system.
- Redesign(to fix errors) of front-end electronics for silicon strip detectors nearly complete(finally).
- And most recently, designation of lead role in U.S. ATLAS computing for LBNL and I. Hinchliffe.

Inner Detector and LBNL

- **LBNL is currently involved in both the Pixel Detector System and the Semiconductor Tracker(SCT) for the ATLAS Inner Detector**

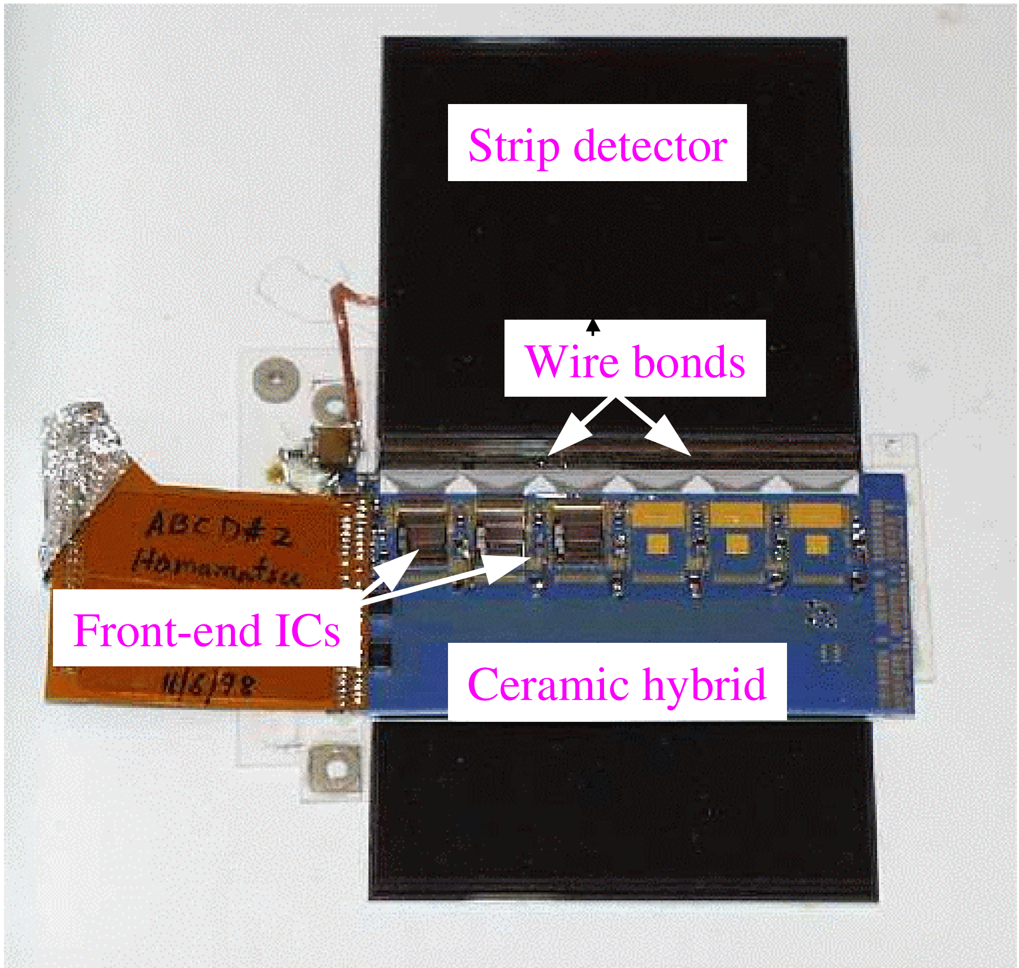


Semiconductor Tracker and LBNL

- LBNL is currently involved in the following aspects of the SCT
  - Integrated circuit electronics design and testing
  - Hybrid design and testing
  - Module design and testing
  - Development of module assembly tooling for production
  - Irradiation of electronics (mostly) and some module components.
  - Test beam and lab data acquisition
- LBNL production responsibilities
  - Final design of integrated circuits
  - Testing of integrated circuits
  - Irradiation (quality control) of integrated circuits
  - Barrel hybrid design
  - Hybrid fabrication and testing
  - Barrel module assembly and testing

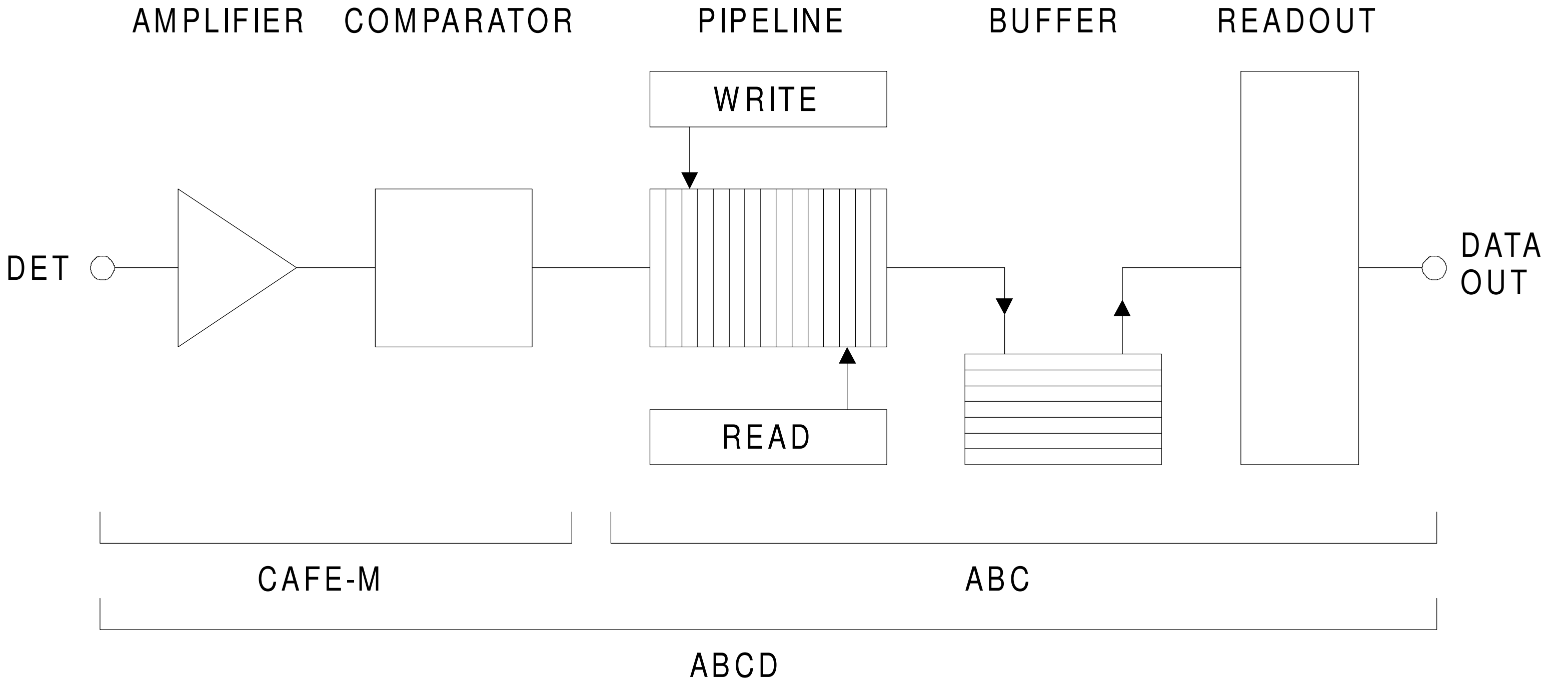
SCT Module

- Modules are the building blocks of the SCT system
- We have concentrated our efforts in the last year on
  - the design and testing of the integrated circuits(as die, on hybrids and with detectors attached)
  - a prototype hybrid that holds the integrated circuits
  - completing the precision tooling needed for module assembly



Silicon Strip IC Electronics

- Major part of effort has been the development of integrated circuits using binary readout for the SCT.
- Two rad-hard solutions under development
  - CAFÉ-M(bipolar from Maxim) + ABC(CMOS from Honeywell) - 2 chips..
  - ABCD(BiCMOS from Temic) - 1 chip.


AMPLIFIER
COMPARATOR
PIPELINE
BUFFER
READOUT
WRITE
DET
DATA OUT
READ
CAFE-M
ABC
ABCD

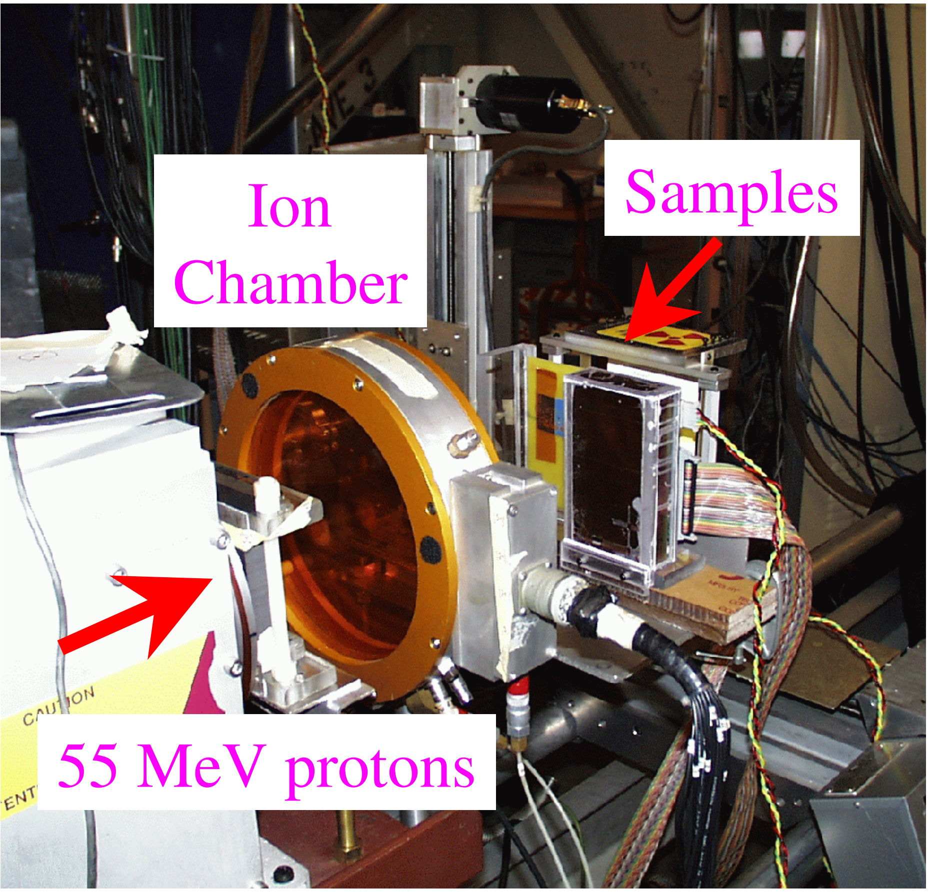
Silicon Strip IC Electronics

- First prototypes of all three ICs have been fabricated and tested. None of them meet specifications and we have spent the last year understanding these problems and in redesign.
- This includes testing after irradiation to 10MRad
- In this work we have been collaborating closely with Santa Cruz, Rutherford Lab and CERN.
- New version of CAFÉ, CAFÉ-P is in fabrication.
- ABC and ABCD are in final simulation/verification and will be submitted shortly.
- We are upgrading our testing capability to be ready when wafers appear in July-September.

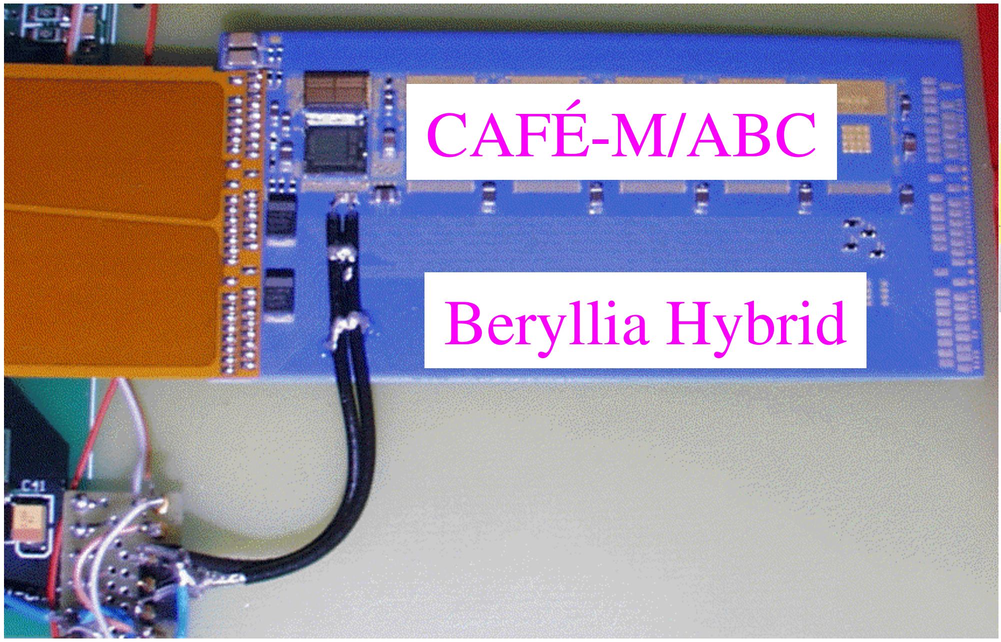
Irradiation Studies

Physics Division

- The 88” cyclotron has been used for irradiation studies of all three ICs.
- The CAFÉ-M/ABC(fixed) pair and the ABCD-2 have been mounted on hybrids, irradiated and read out in place for full functionality tests.



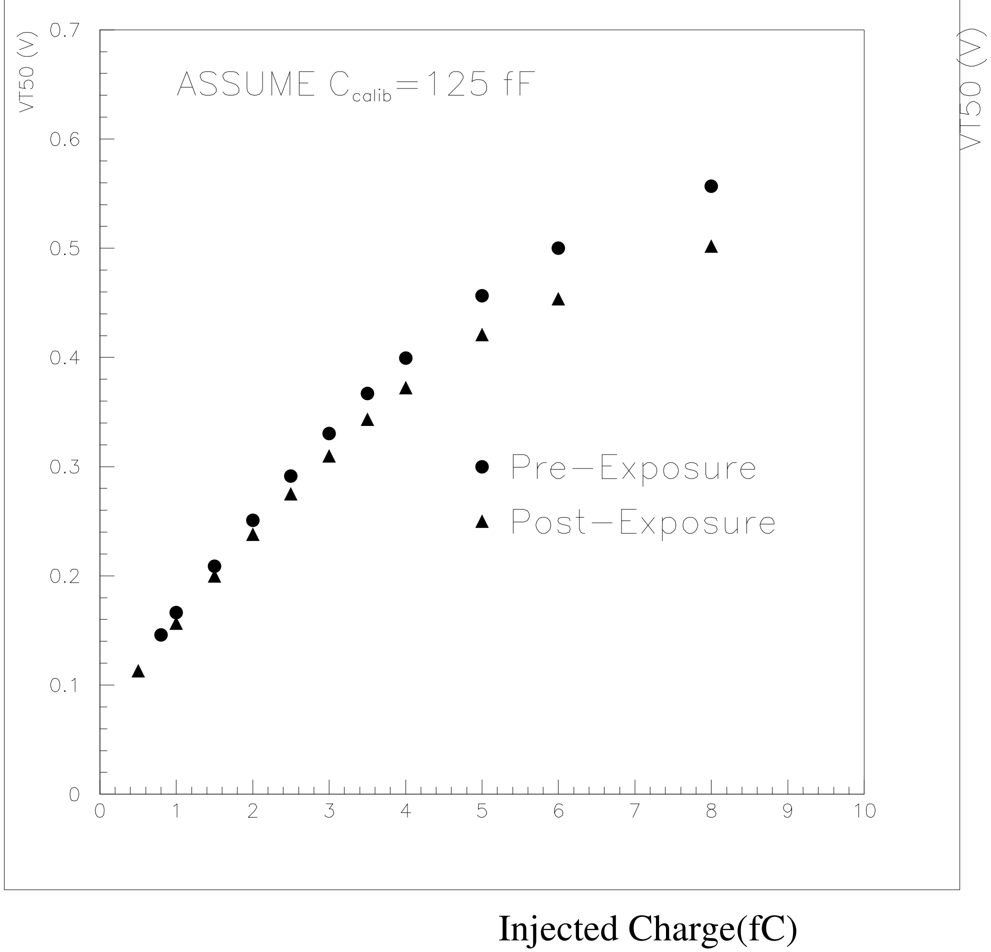
88” Cyclotron



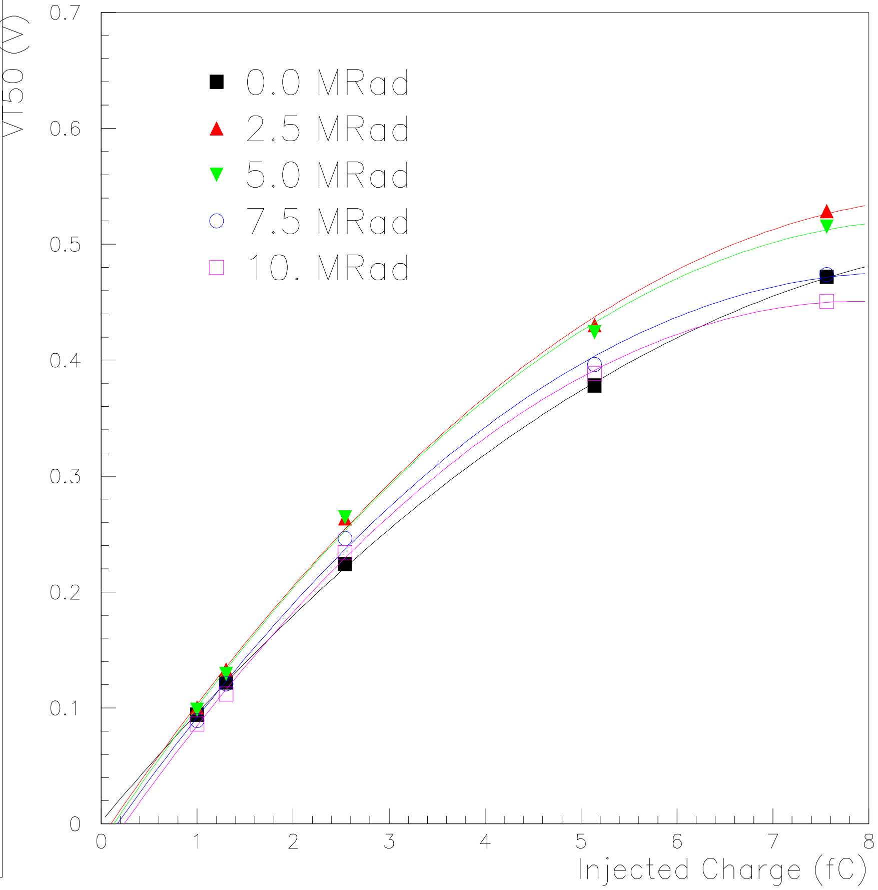
M. Gilchriese
DoE Review March 1999

Pre-rad/post-rad Comparison

CAFÉ-M/ABC(10 MRad)

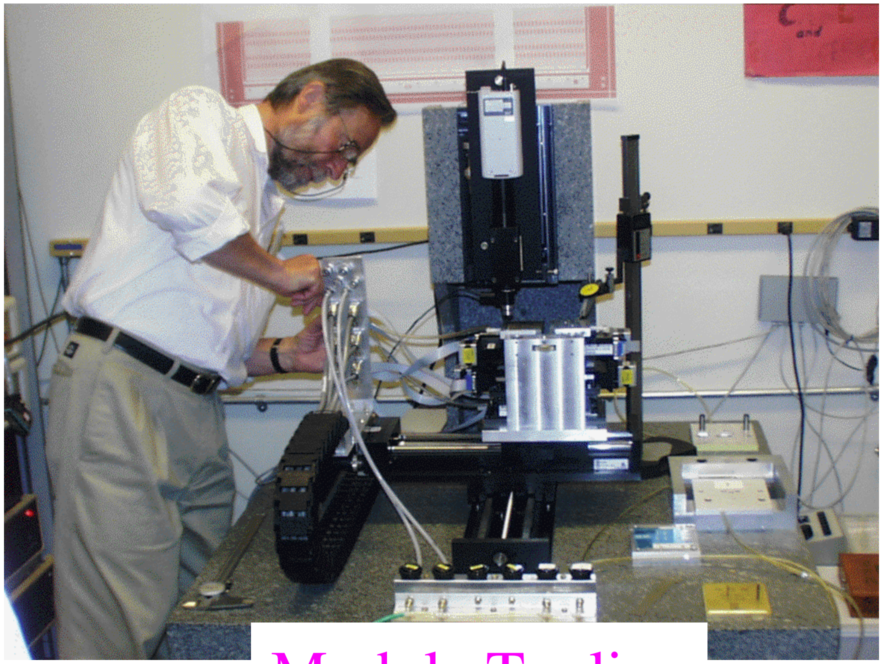


ABCD-2

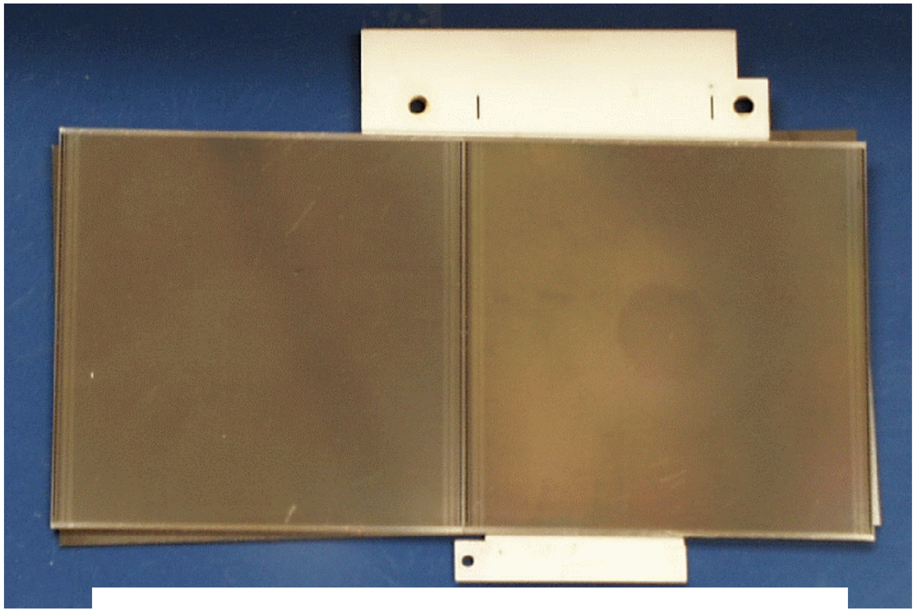


SCT Modules

- Tooling and equipment for module assembly is largely in place at LBNL, although some aspects(primarily related to measurements after assembly) will appear only later in FY99.
- Dummy parts ready and have started dummy module fabrication to debug system. First dummy modules fabricated.
- Work is underway for “clean room” facilities. Ideally this would be a very beneficial upgrade to our general facilities and capabilities for silicon detectors.



Module Tooling



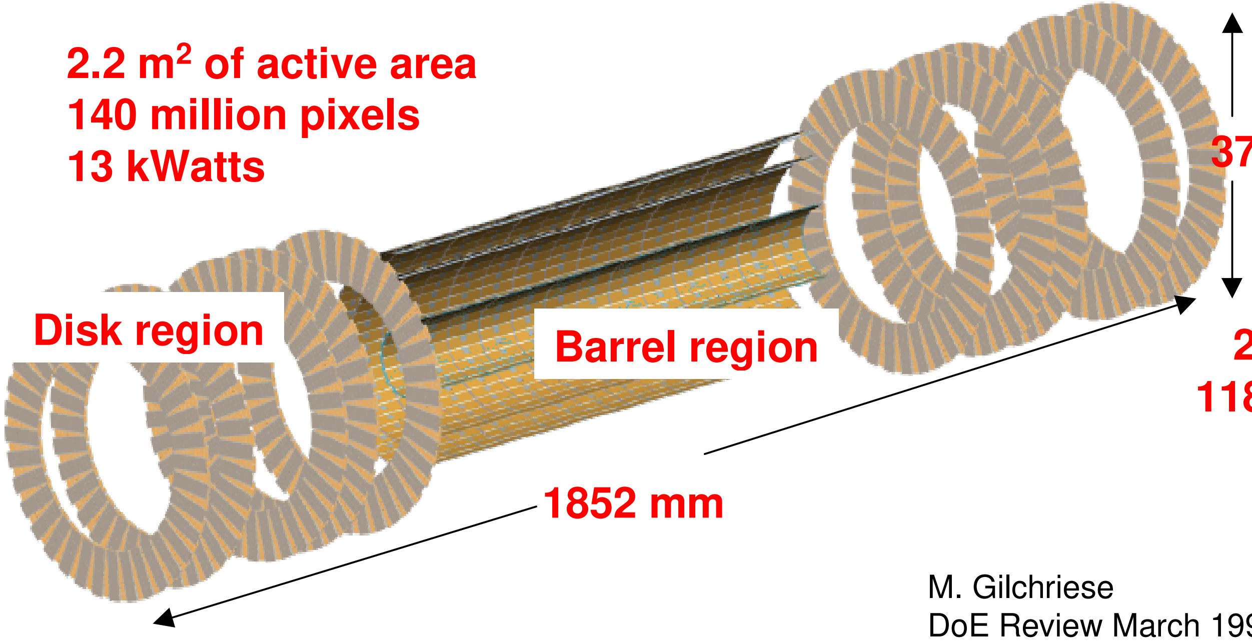
Mechanical dummy module

The ATLAS Pixel System

Physics Division

- Layout
    - 3 barrel layers, 2 x 5 disk layers
    - Three space points for |η|< 2.5
    - Modular construction(2228 modules)
- Radiation hardness
    - Lifetime dose - 25 MRad at 10 cm
    - Leakage current in 50μx300μ pixel is - 30 nA after 25 MRad.
    - Signal loss in silicon by factor 4-5 after 25 MRad(or - 10^{15} n/cm^2)
- Pattern recognition
    - Space points(1.4 x 10^8 pixels)
    - Occupancy of - 10^{-4}
- Parametric performance
    - Impact parameter
    - z resolution
- Trigger
    - Space points-> L2 trigger

2.2 m^2 of active area
140 million pixels
13 kWatts



Disk region

Barrel region

374 mm

1852 mm

2228 Modules
118 Barrel Staves
120 Sectors

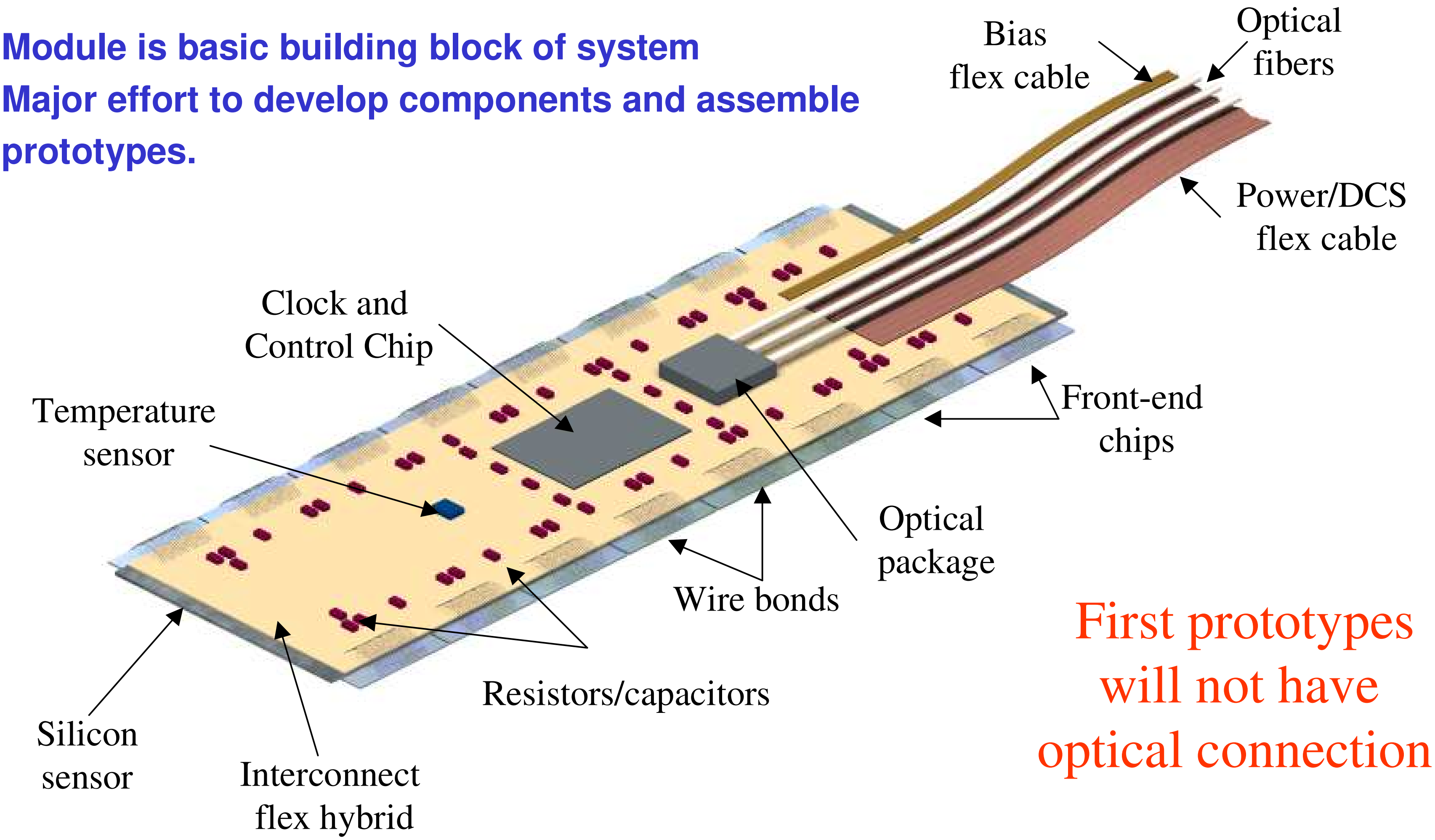
ATLAS Pixel System and LBNL

- LBNL is currently involved in the following aspects of the Pixel System design
  - Front-end integrated circuit electronics
  - Bump bonding
  - Module design
  - Mechanical design of the disk part of the system
  - Overall system integration of the mechanical system
  - Irradiation of electronics, detectors and mechanical components (mostly at the 88” cyclotron but also in Cobalt sources at LBNL and LLNL)
  - Test beam data acquisition and software
  - Test beam analysis
- Production responsibilities will be
  - IC electronics
  - Module construction and testing
  - Mechanical construction and delivery of the disk system(about 1/3 of the total) and other parts of the mechanical structures.
- Pixel Technical Design Report completed and approved by CERN

Pixel Module

Module is basic building block of system

Major effort to develop components and assemble prototypes.



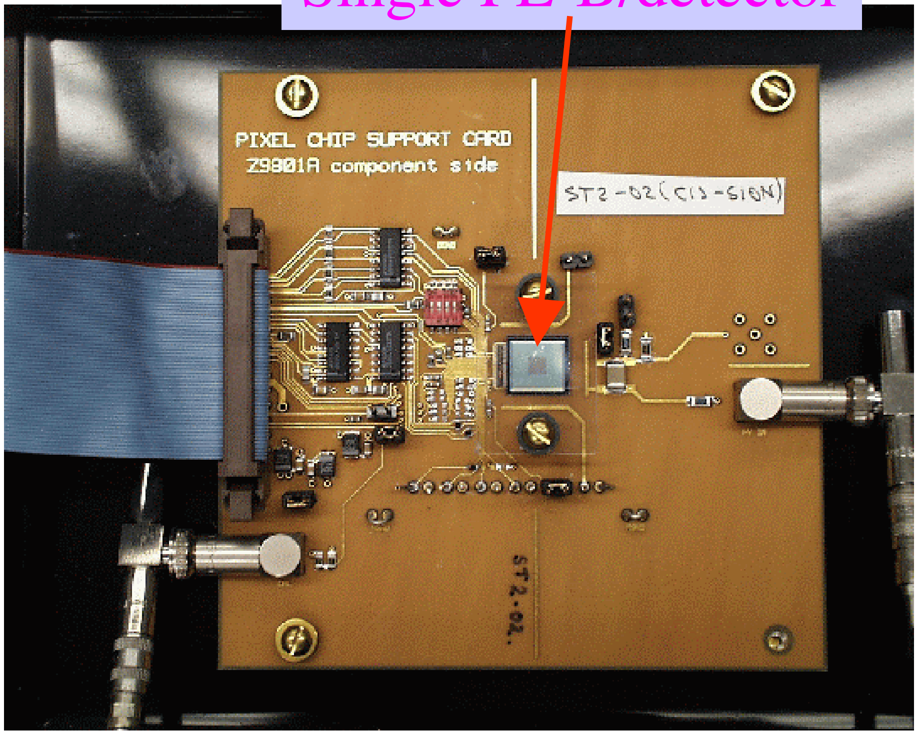
First prototypes will not have optical connections

Pixel Electronics

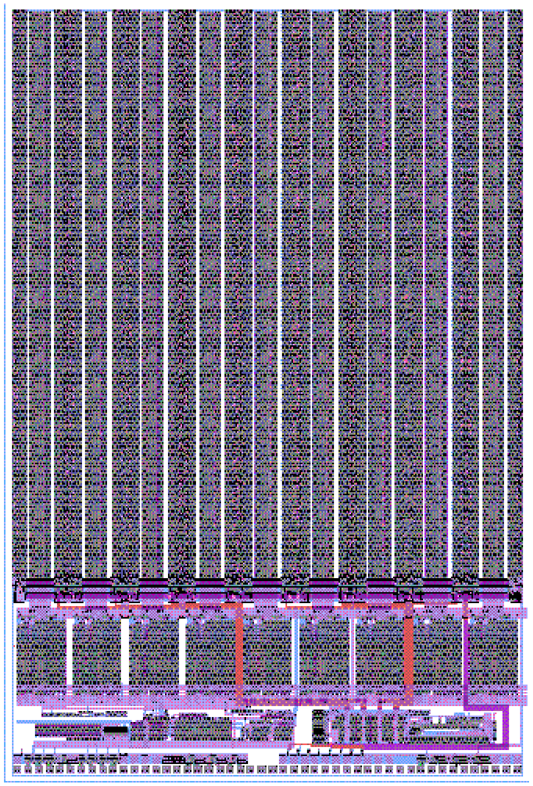
- Pre-prototype program completed successfully by end 1997.
- Full-scale prototypes fabricated in rad-soft technologies in 1998 and tested extensively.
- Different design approaches. FE-A and FE-B. Pin compatible.
- FE-A(AMS -> Temic/DMILL). Designed in Europe
    - First delivery in February of AMS chips
    - Functional although some errors
    - Yield about 5%. Processing problems?
    - Second run delivered in July(all CMOS version called FE-C). Yield about 80%.
- FE-B(HP -> Honeywell SoI). Designed at LBNL
    - First delivery in April 1998 of HP chips
    - Functional although some errors
    - Yield about 93%.
    - Extensively utlized by collaboration
- Unified design approach adopted some months ago for rad-hard design FE chips
    - K. Einsweiler is currently electronics coordinator for collaboration
    - All working on same design to be implemented in the two rad-hard processes - first in DMILL(FE-D) and then in enhanced Honeywell SoI(FE-H).
    - Expect submission of FE-D in April.

Pixel Electronics

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



Single FE-B/detector



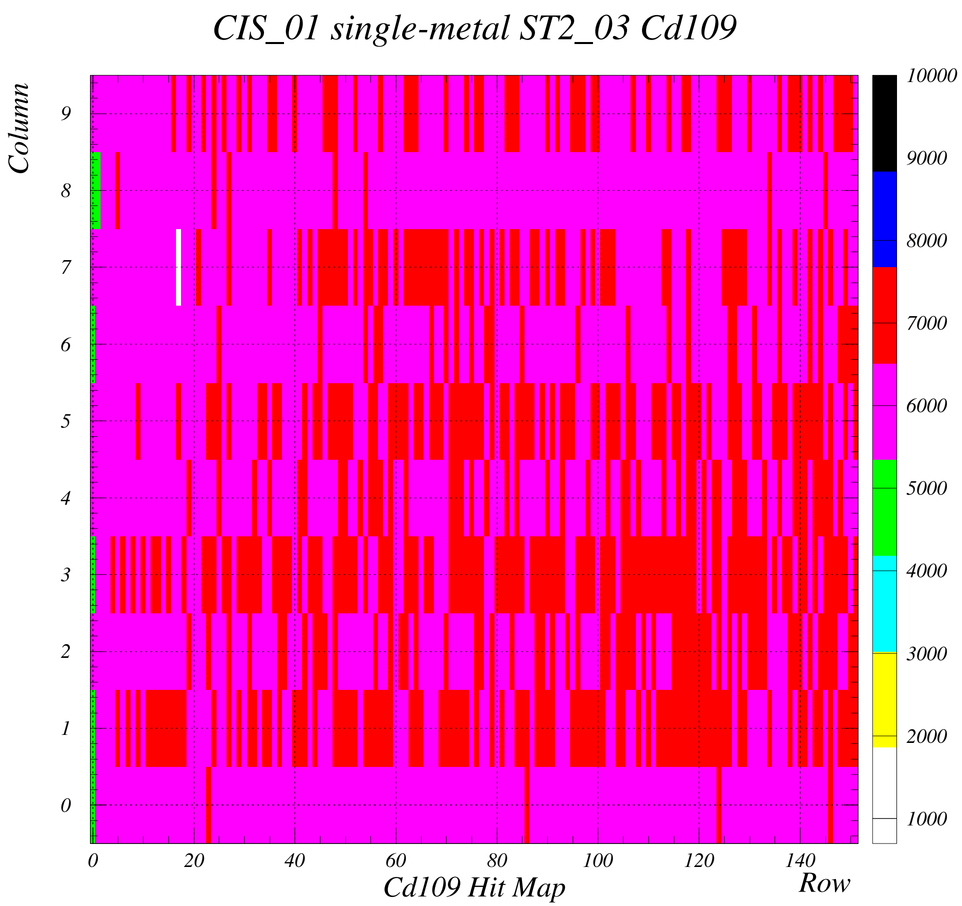
FE-B

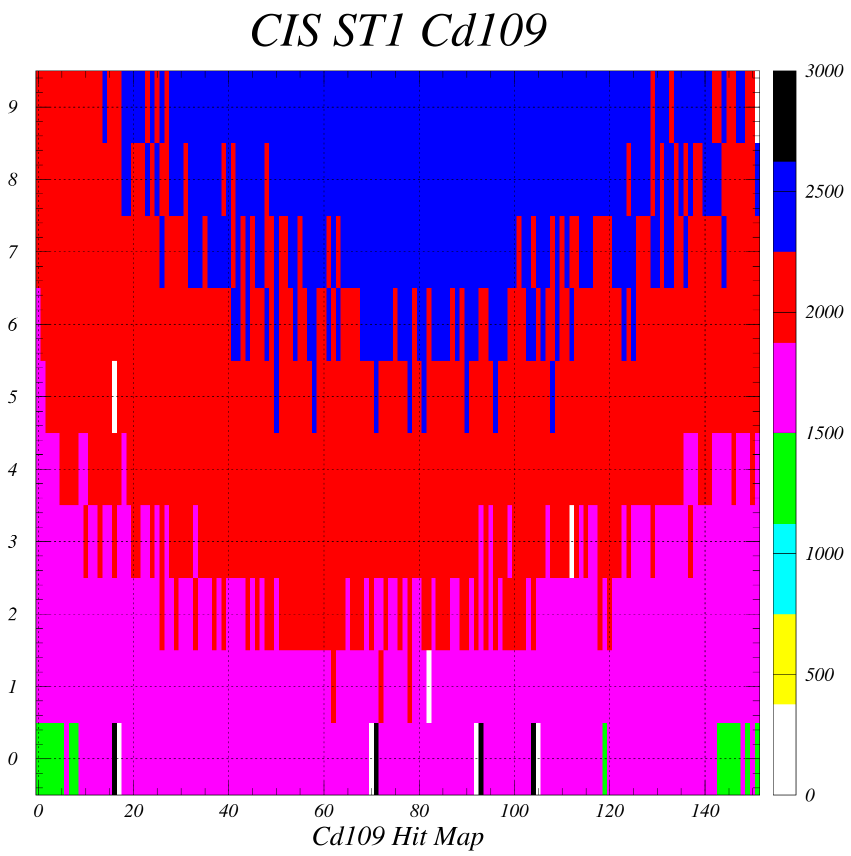
Lab and Test Beam Results - Summary

Physics Division

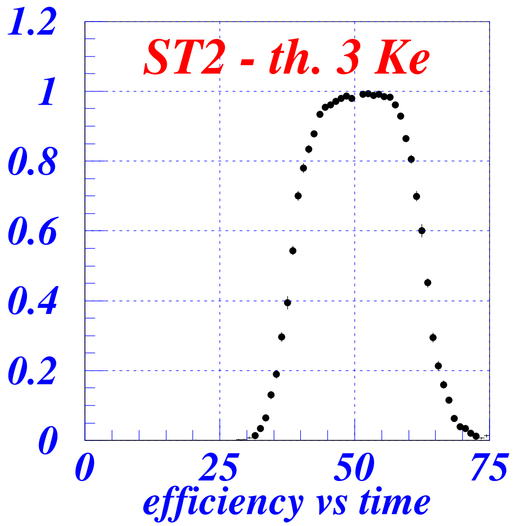
- Extensive lab tests and three test beam runs in 1998. Very successful.
- Highlights
  - Dozens of single-chip/detectors have been operated successfully with multiple detector types and front-end ICs
  - 16 chip modules have been operated successfully
  - Detectors irradiated to lifetime fluence expected at LHC(10^{15}) have been read-out in a test beam with efficiency near 100%
  - Operation below full depletion voltage demonstrated
  - Preferred detector type identified in these studies
  - Timing performance needed to identify bunch crossings has been demonstrated.
  - Operation at thresholds 2,000-3,000 electrons demonstrated
  - Threshold uniformity demonstrated.
  - Spatial resolution as expected
- Conclusion
  - Proof-of-principle of pixel concept successful

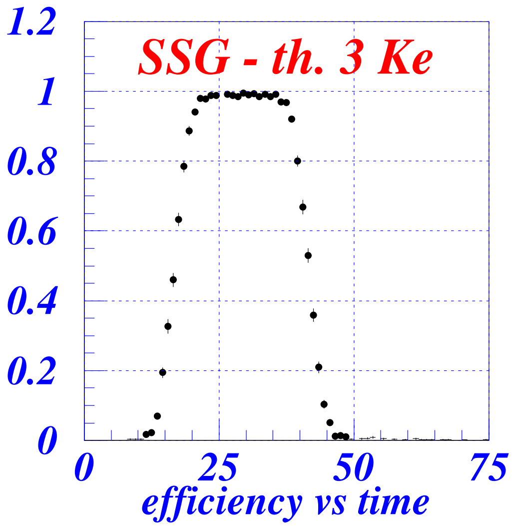
Photon Source Test of FE-B and Detectors

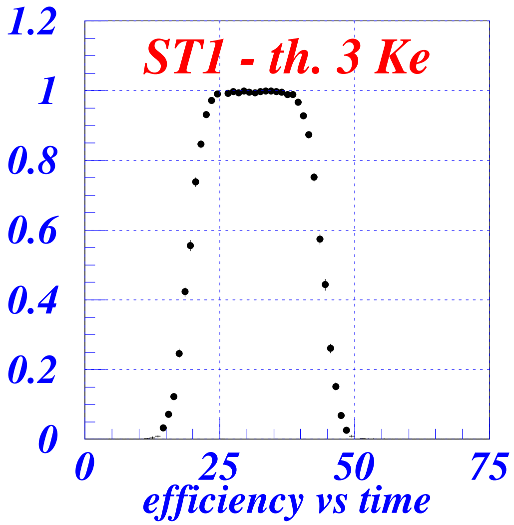

CIS_01 single-metal ST2_03 Cd109


CIS ST1 Cd109

Lab and Test Beam Results - Examples



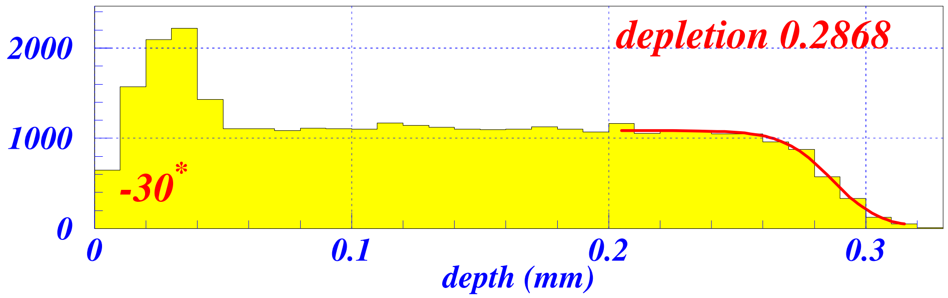


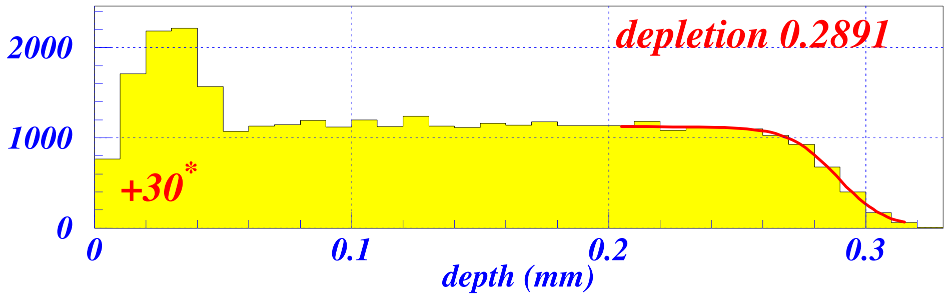


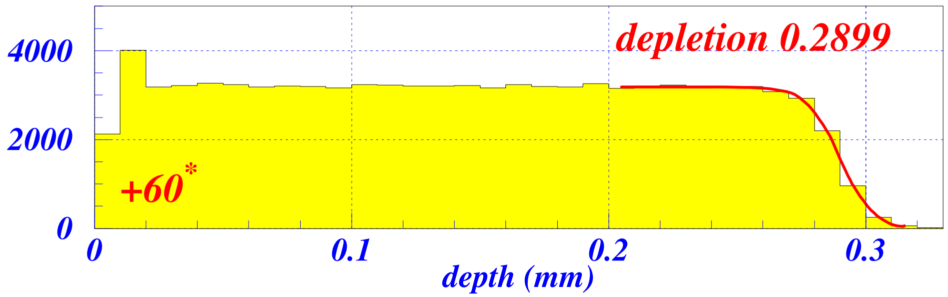
Efficiency vs time of particle passage for three different detector types before irradiation. The efficiency is near 100% in each case and there is a substantial plateau, indicating good timing performance of the electronics

Lab and Test Beam Results - Examples

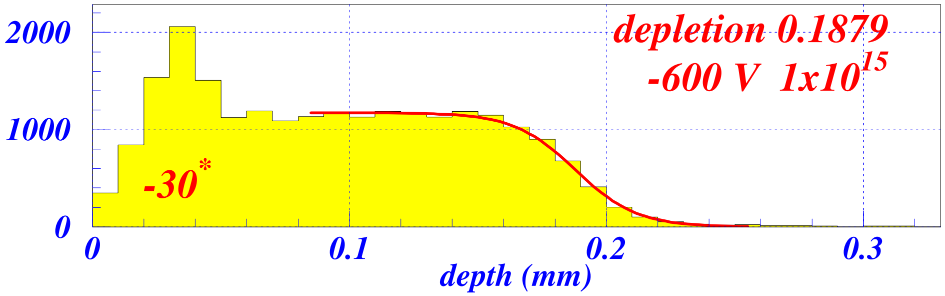
Not irradiated - depletion depth

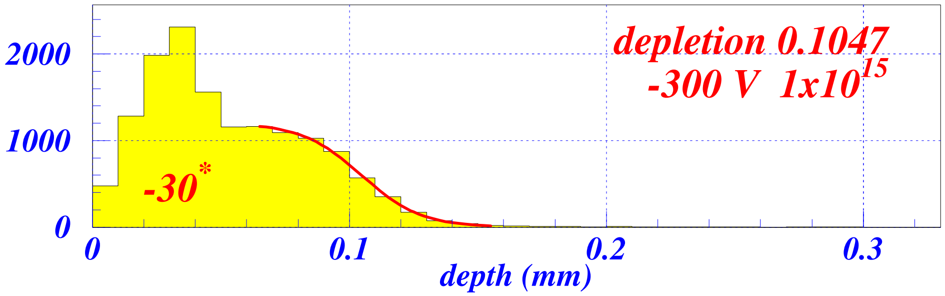


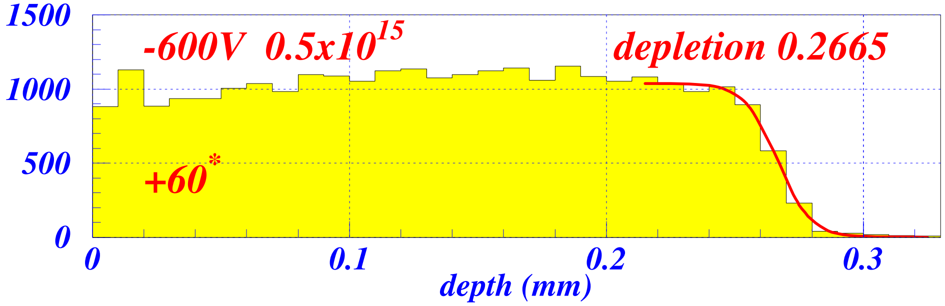




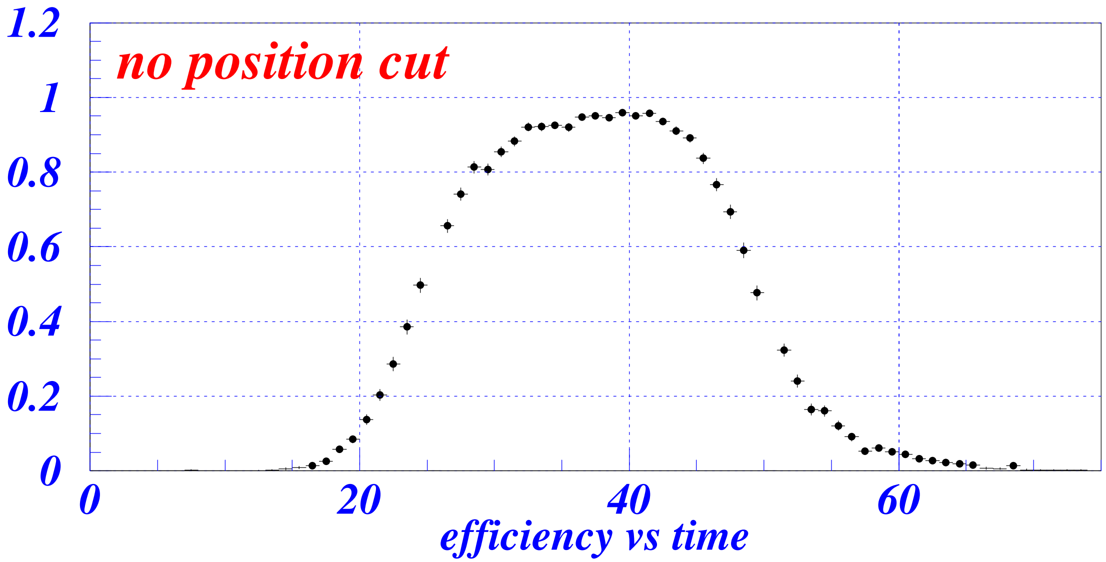
Irradiated - depletion depth

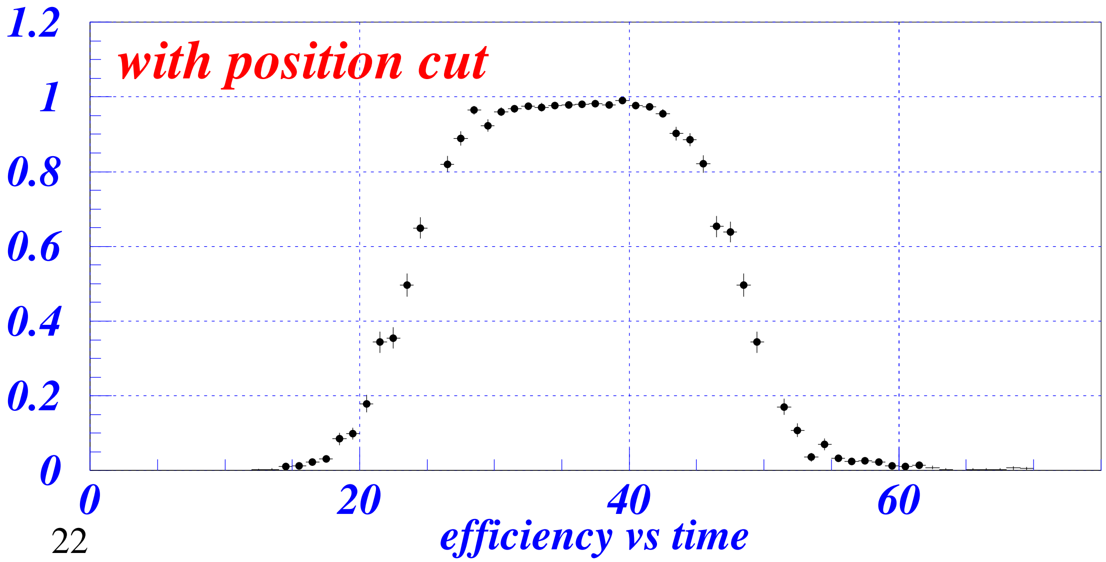






Efficiency - Irradiated Detectors

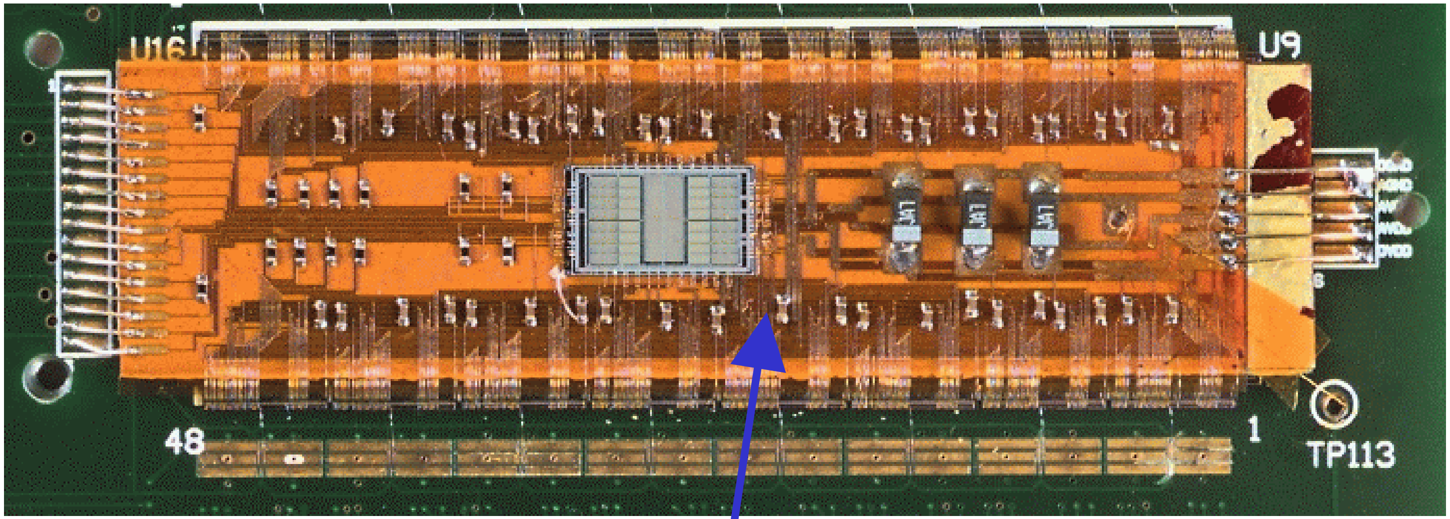


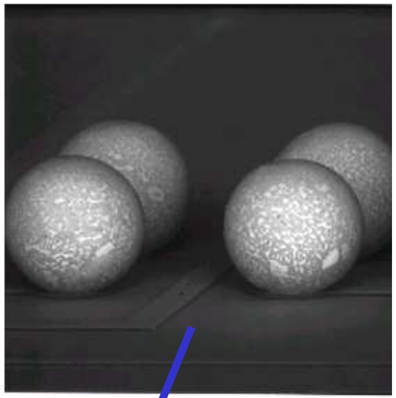


Efficiency after irradiation of 1x10^{15} without and with a position cut to remove tracks near the edge of the pixel.

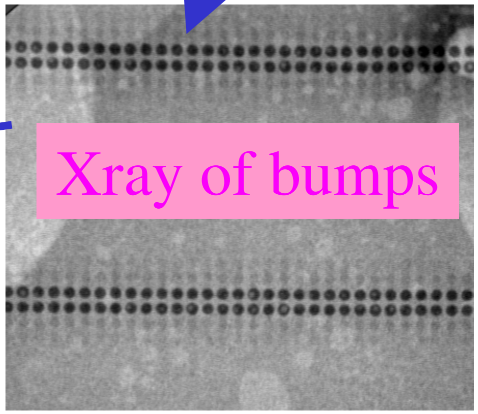
Pixel Modules

Module with flex hybrid and controller chip on PC board



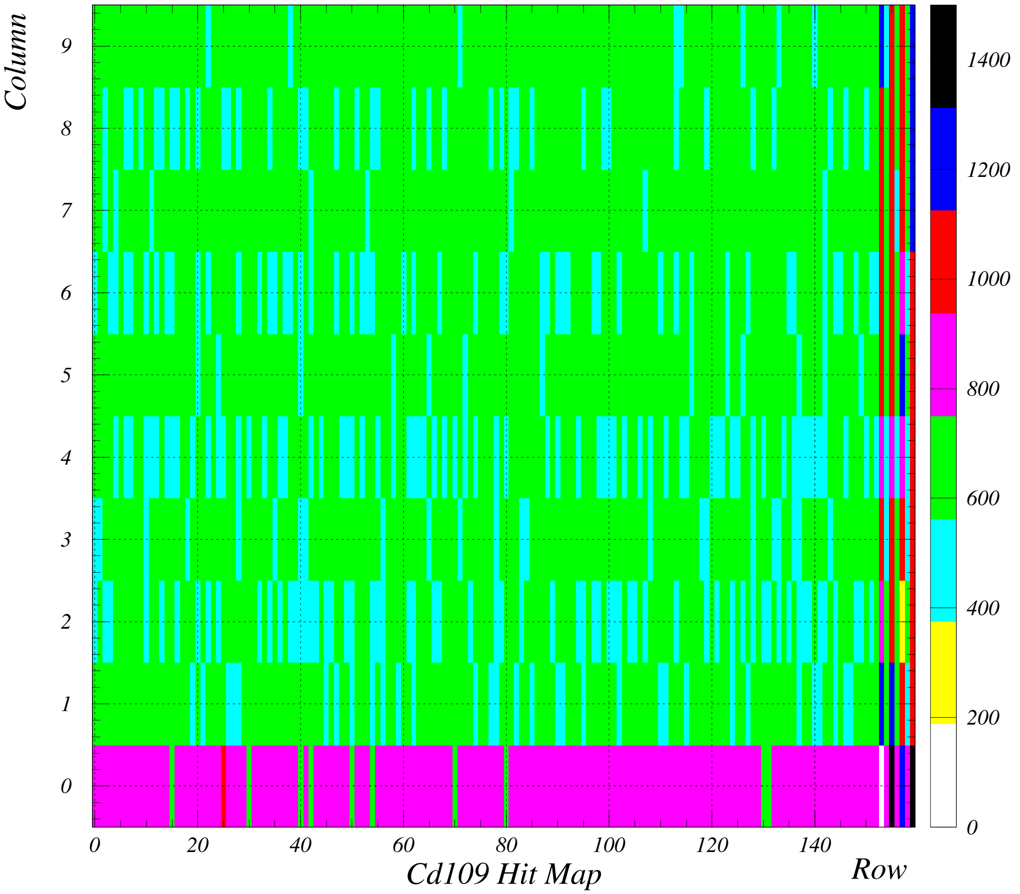



16 chips with 46,000 bump bonds


Xray of bumps

Photon Source on Module

Tile-1 module

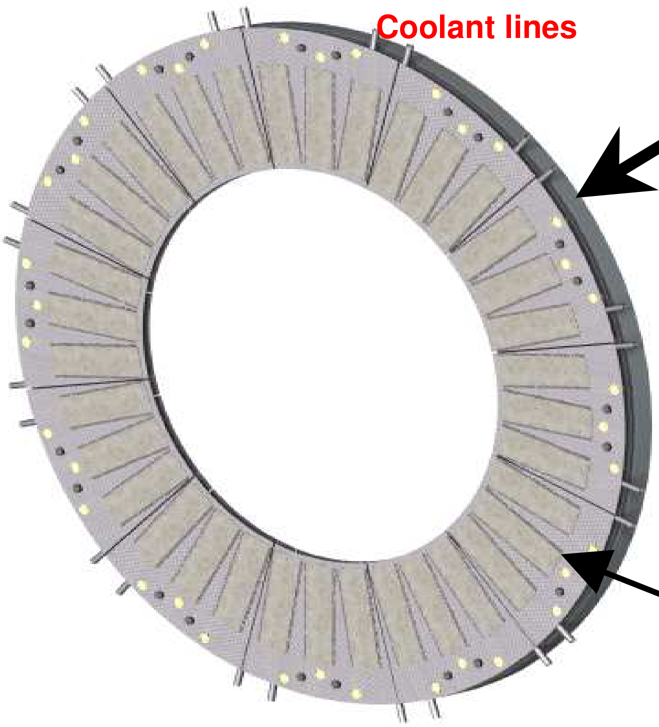


Cd109 Hit Map

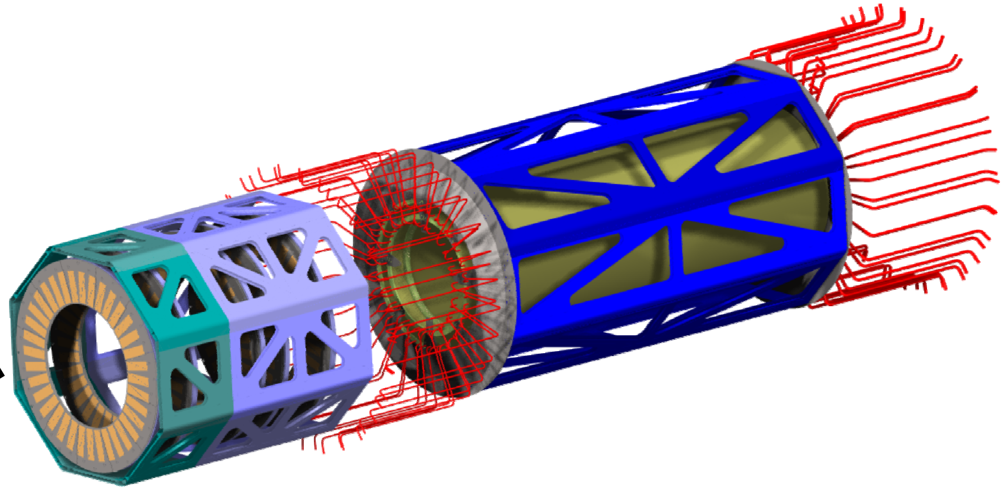
- A number of modules have now been built and tested in the lab.
- All mounted on PC boards
- No test beam yet but this will occur this year at CERN.
- Module, 16-chip operation is clearly more challenging than one chip/detector.
- Noise and stability are the major issues being addressed now.

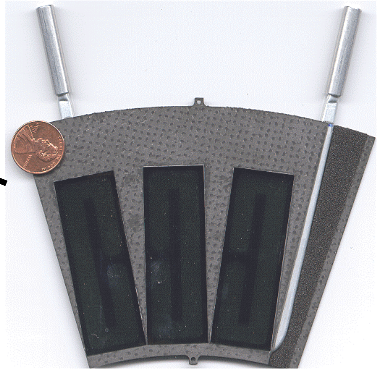
Disk Region

Disk with 12 Sectors



Sector support, cantilevered from outer edge





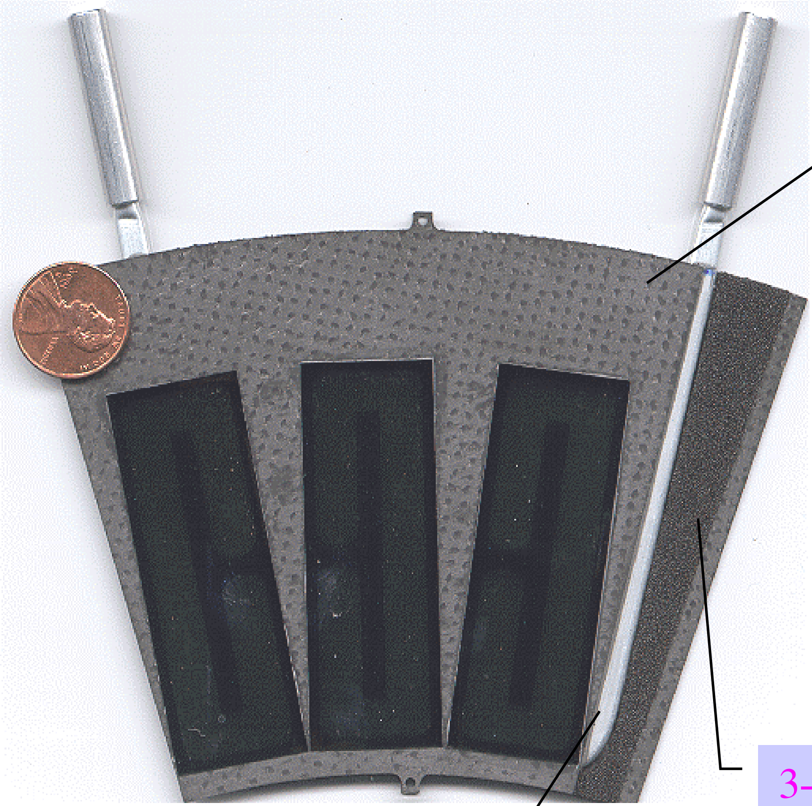
Sector - support/cooling for pixel modules

Disk Mechanics

- Modular mechanical construction - sector
  - A convenient size for testing(with modules)
  - Size limit for some fabrication techniques
- Investigating two general approaches
  - All-carbon design
    - Minimum CTE mismatch
    - Low material
    - Supported totally by DoE SBIR funding
  - In house construction of hybrid approach(carbon-carbon facings+Al tube)
    - Entirely under our control
    - Relatively cheap
    - Major issue is tradeoff between stability and material
- Over next year plan to complete sector prototype program, fabricate 1-2 full disk prototypes and prototype frame.
- We have benefitted enormously from SBIR funding related to the sector design and analysis.
- The next step is the support frame, which is a challenge to have minimum mass and extreme stiffness => needs development and again we have found another potential SBIR participant that is interested in meeting this challenge.

C-Al Tube Sector

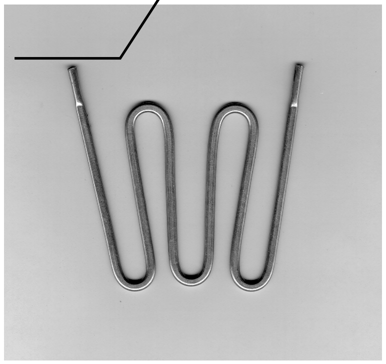
LBNL design and fabrication

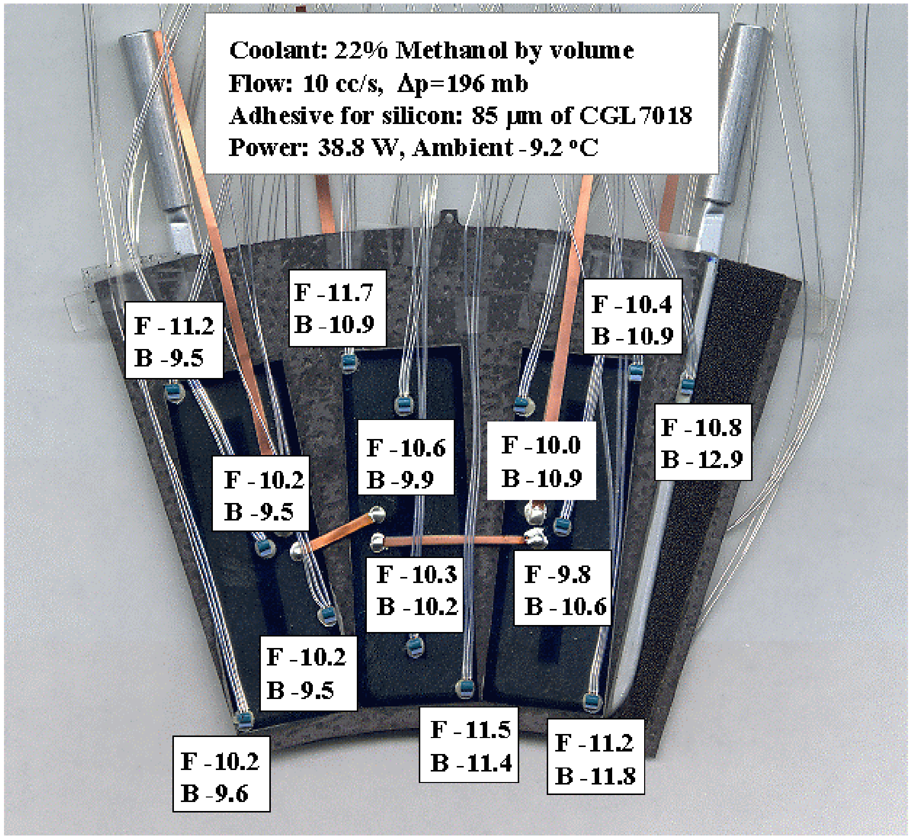


300-500 micron carbon-carbon facings

3-6% density carbon foam

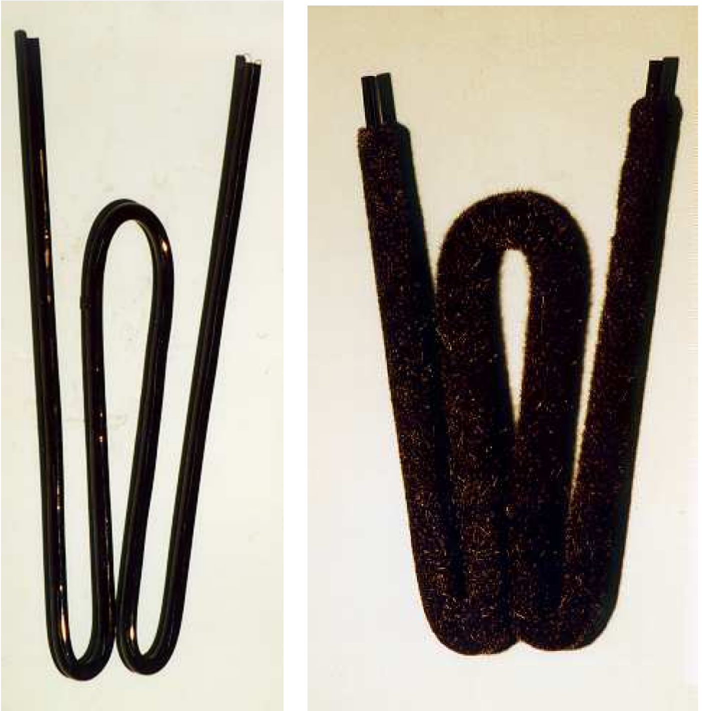
200 micron wall Al tube





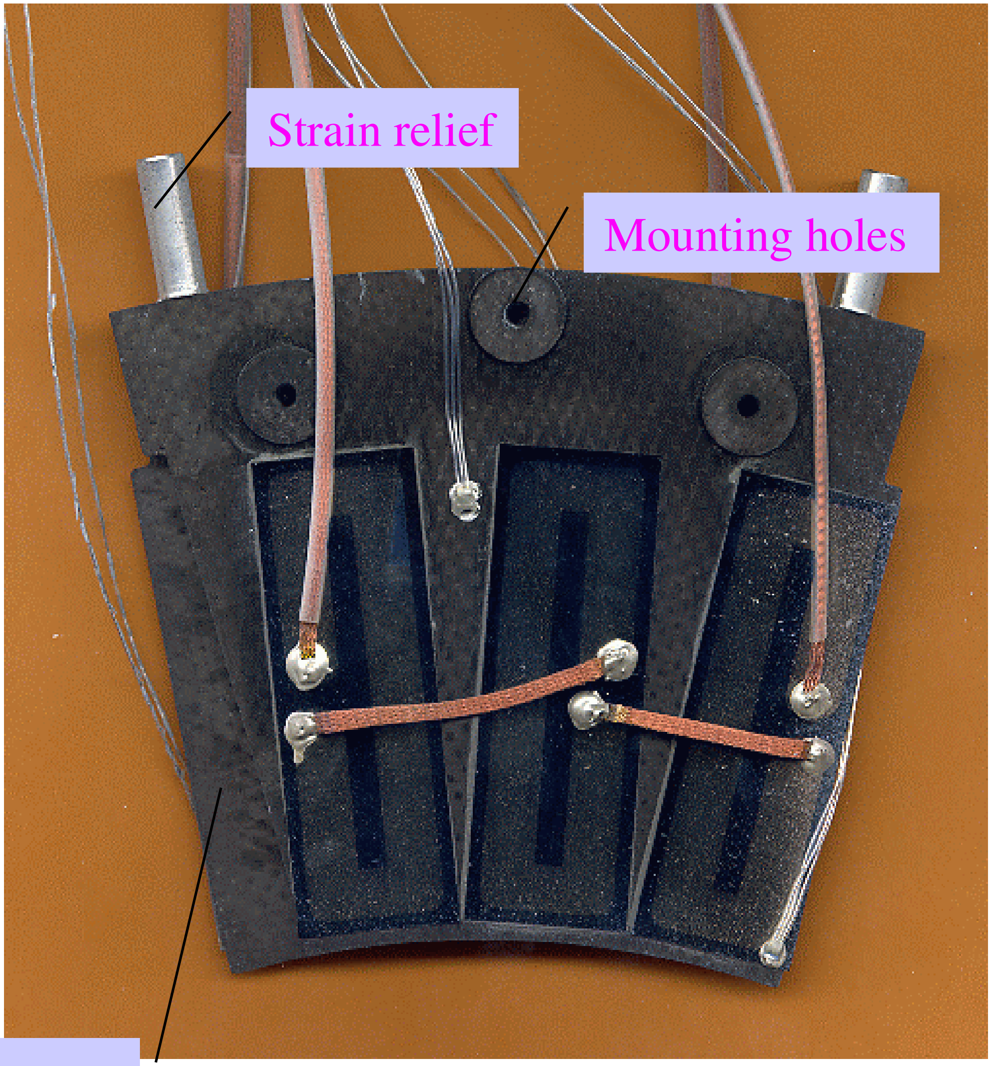
Coolant: 22% Methanol by volume
Flow: 10 cc/s, Δp=196 mb
Adhesive for silicon: 85 μm of CGL7018
Power: 38.8 W, Ambient -9.2 °C

All-Carbon Sector



Leak tight carbon tube flocked with high thermal conductivity fibers.

SBIR supported



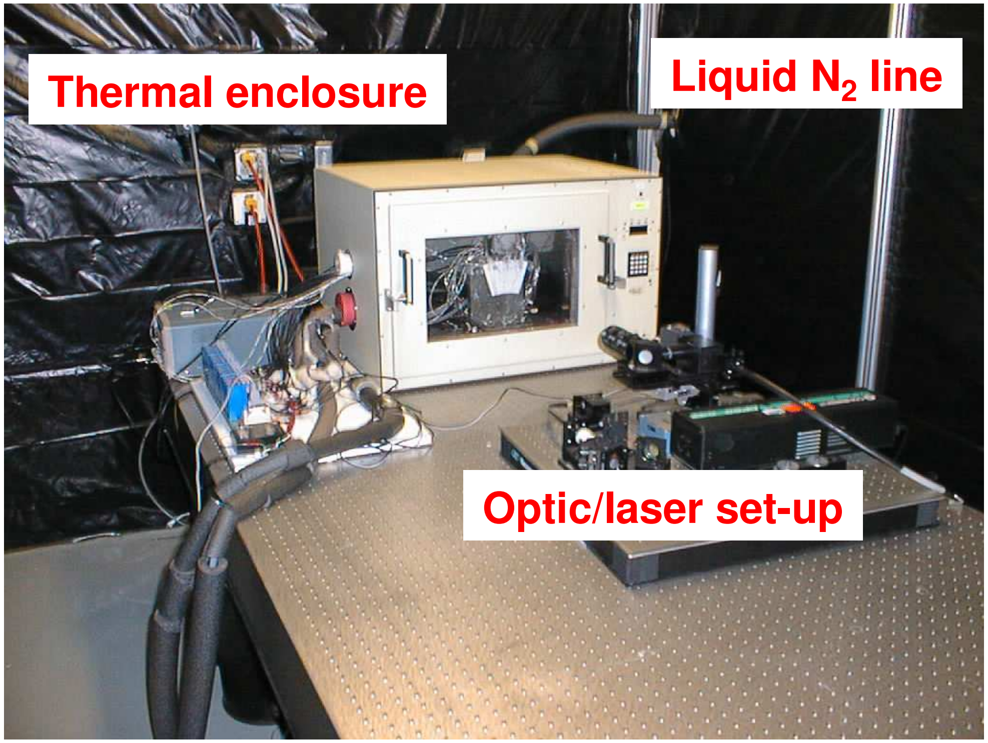
Strain relief

Mounting holes

300-500 micron carbon-carbon facings

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. Primary means of assessing stability.



TV holography arrangement for thermal strains

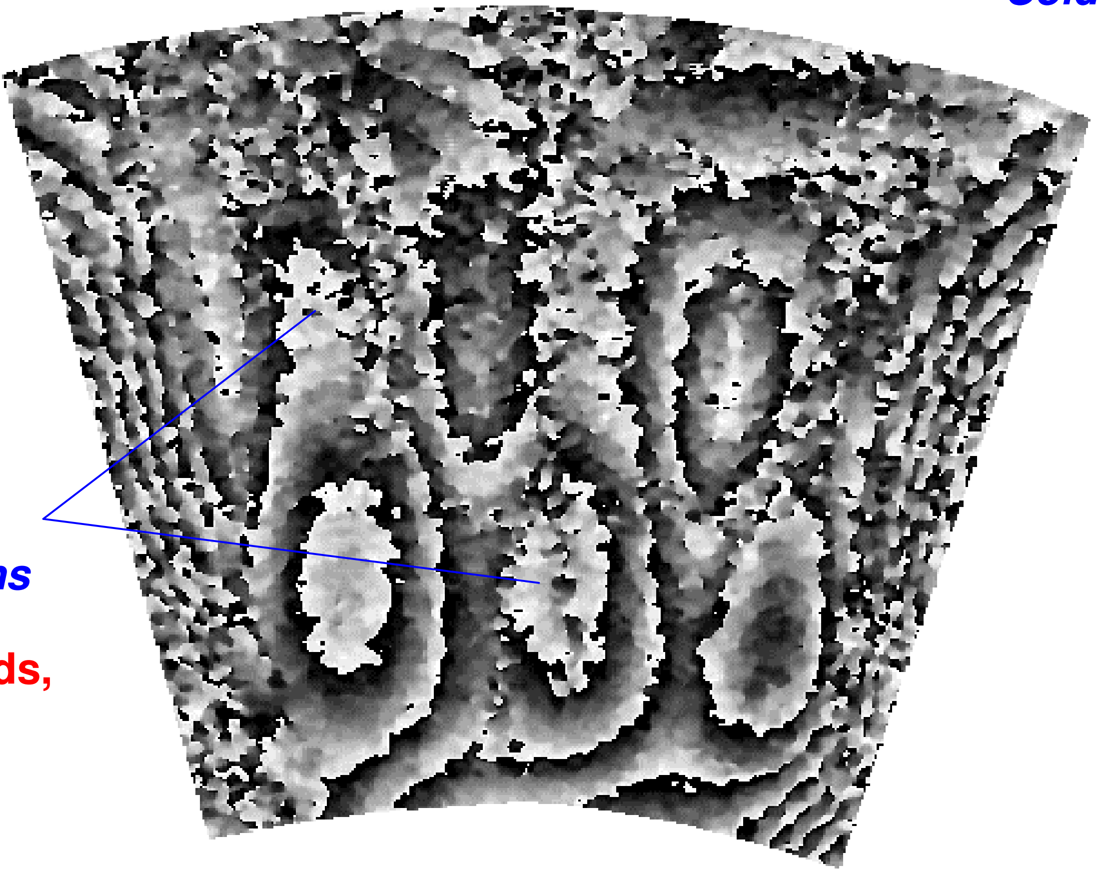
Sector TV Holography

Physics Division

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

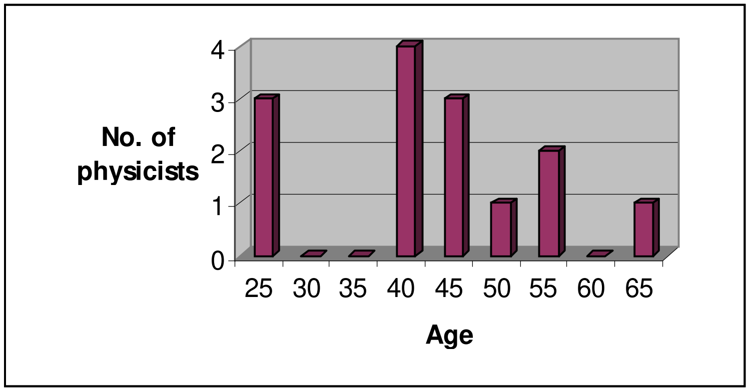
Phase Map after Removal of Tilt Fringes

Related Future R&D

- The innermost layer of the pixel system will die in 1-2 years at LHC design luminosity.
- In collaboration with UC Santa Cruz, Ohio State and UC Irvine, we are proposing to DoE to address the "100 MRad" problems that prevent pixel detectors from operating at such large doses.
- Our contribution would be in the area of ultra-radiation hardened electronics
  - Push the limits of Honeywell SoI technology, including the 0.35 micron technology that is in development now
  - Explore feasibility of using commercial CMOS "deep submicron(0.25 micron or less)" technology that has promise of radiation hardness at much reduced cost.

Issues

- Operating funds
  - We have many people with leadership positions within ATLAS, and they can’t do their jobs without substantial travel.
  - The addition of major computing responsibility will apparently break an already inadequate travel budget this year.
- Engineering support
  - Finances OK for FY99. Overall systems engineering in ATLAS is well known to be inadequate. LBNL can help but coherent US position(and funding) needed.
- Demographics
  - Some of us aren’t getting younger



- SBIR
  - The SBIR program has been critical in advancing the state of the art in pixel thermomechanical design, and we hope that this can continue for the very light, stiff structures that are needed with additional companies involved.

Conclusions

- This has been a year of substantial progress.
- Proof of pixel concept demonstrated in test beam - it can work!
- Very substantial progress made in all aspects of the Pixel System.
- Critical contributions have been made to IC design and testing for the Semiconductor Tracker(SCT)
- Hybrids and module assembly tooling have been successfully developed for the SCT
- LBNL selected by U.S. ATLAS to lead computing.