ATLAS

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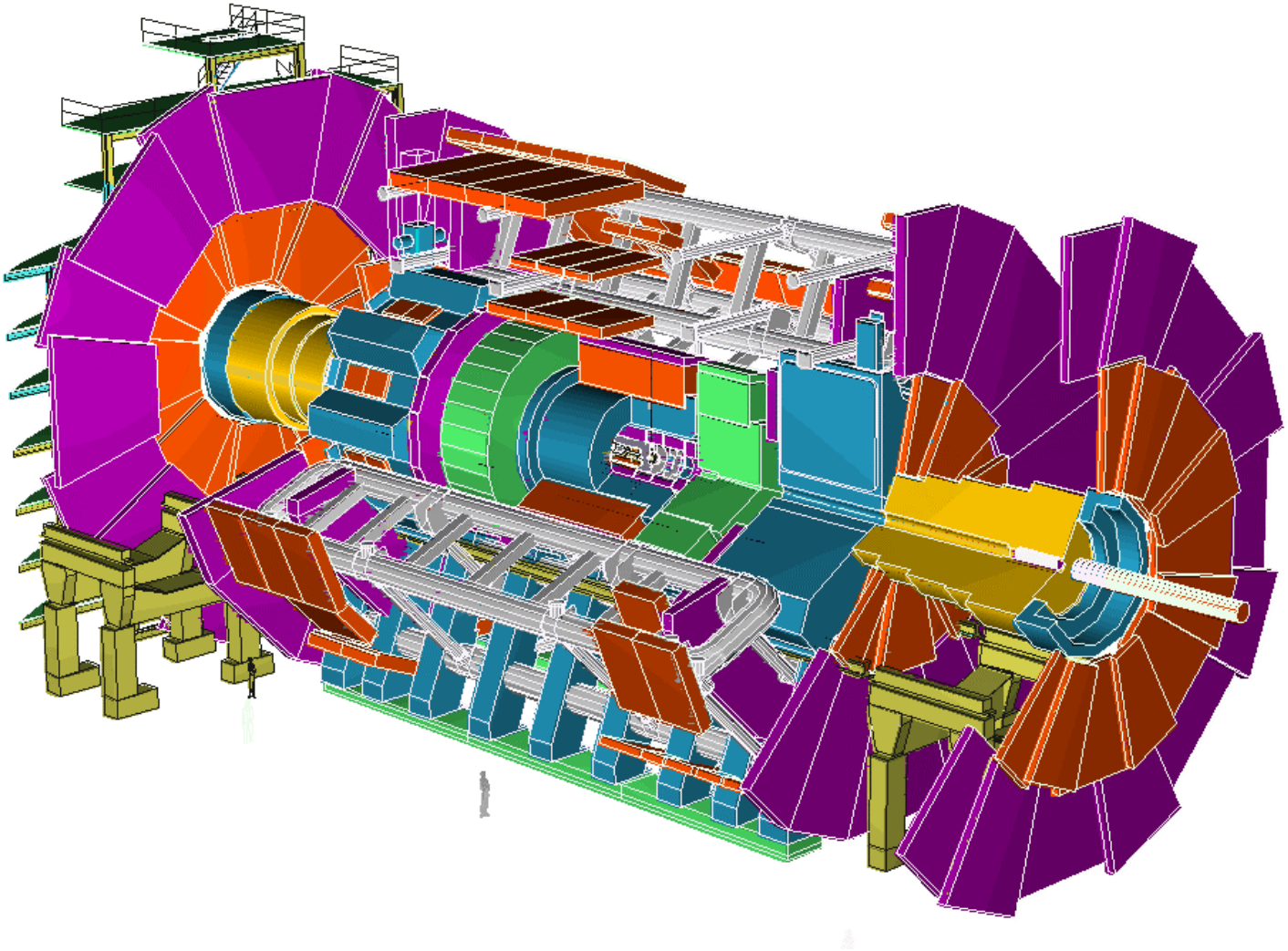
The ATLAS Detector

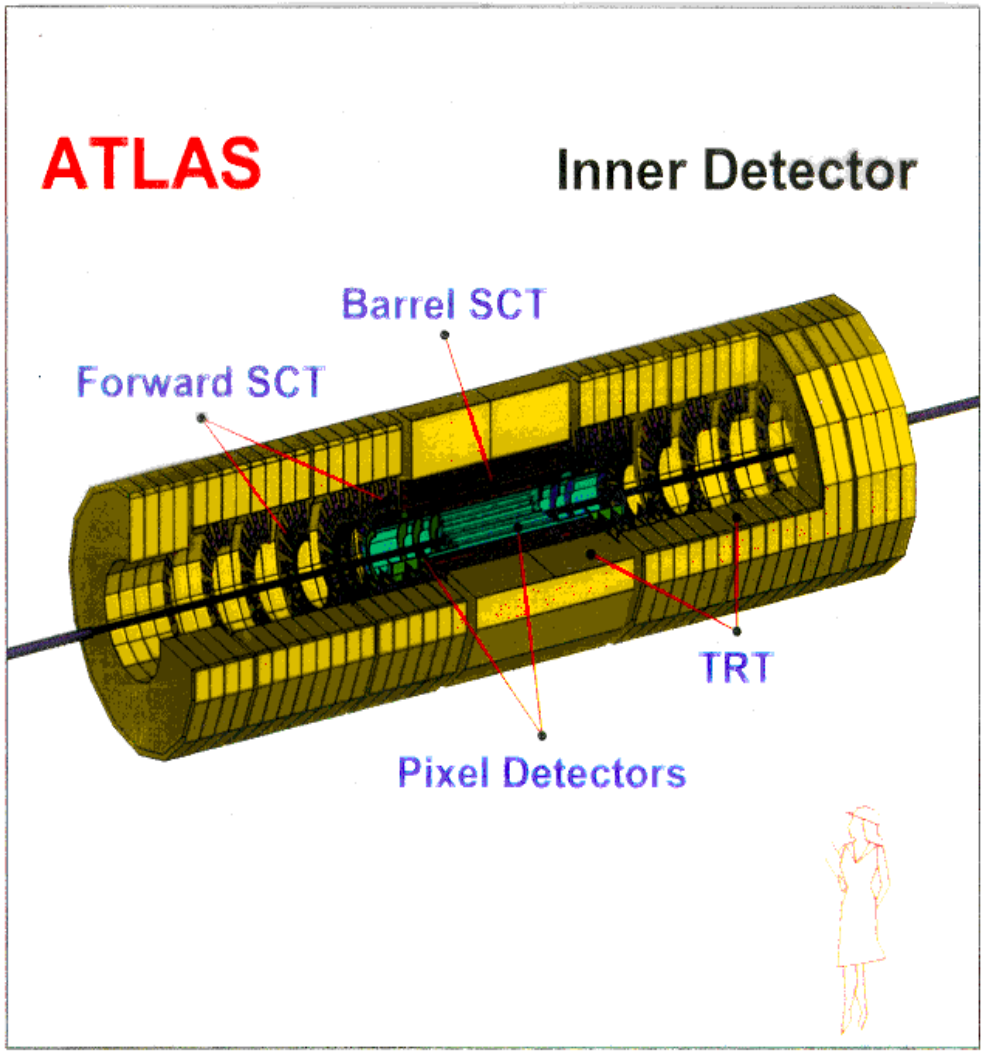


LBNL and ATLAS

- **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 block of the system.**
- **Software and computing**
  - **Development of core software needed for data storage and framework for analysis.**
  - **Specific contributions to Inner Tracking Detector software**
- **Physics simulation and studies**
  - **Coordination of physics simulation codes**
  - **And use of same to establish computing/software requirements and for physics studies.**

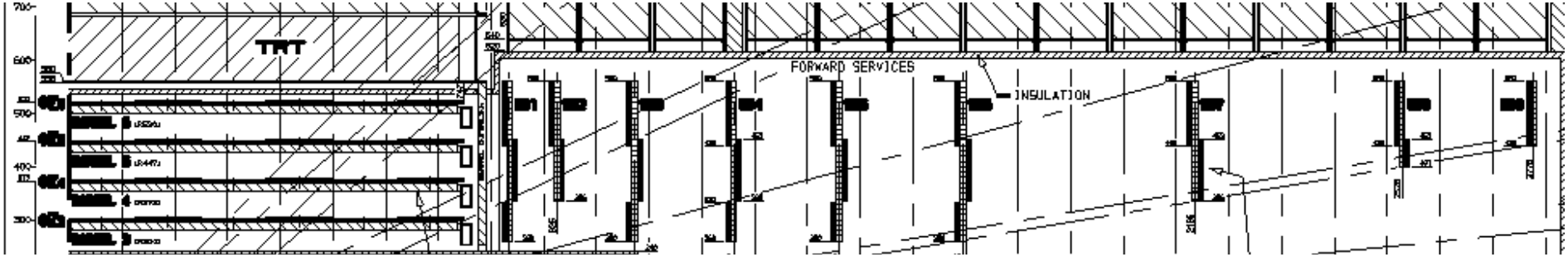
Inner Detector and LBNL

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



Semiconductor Tracker(SCT)

- **Lots of silicon**
  - **About 60 m^2**
  - **About 6 million channels**
  - **Single-sided, p-on-n detectors bonded back-to-back to provide small angle stereo => modules**
- **Radiation environment is about 10MRad worse case over lifetime.**
- **US, and LBNL, have concentrated on electronics and module construction.**



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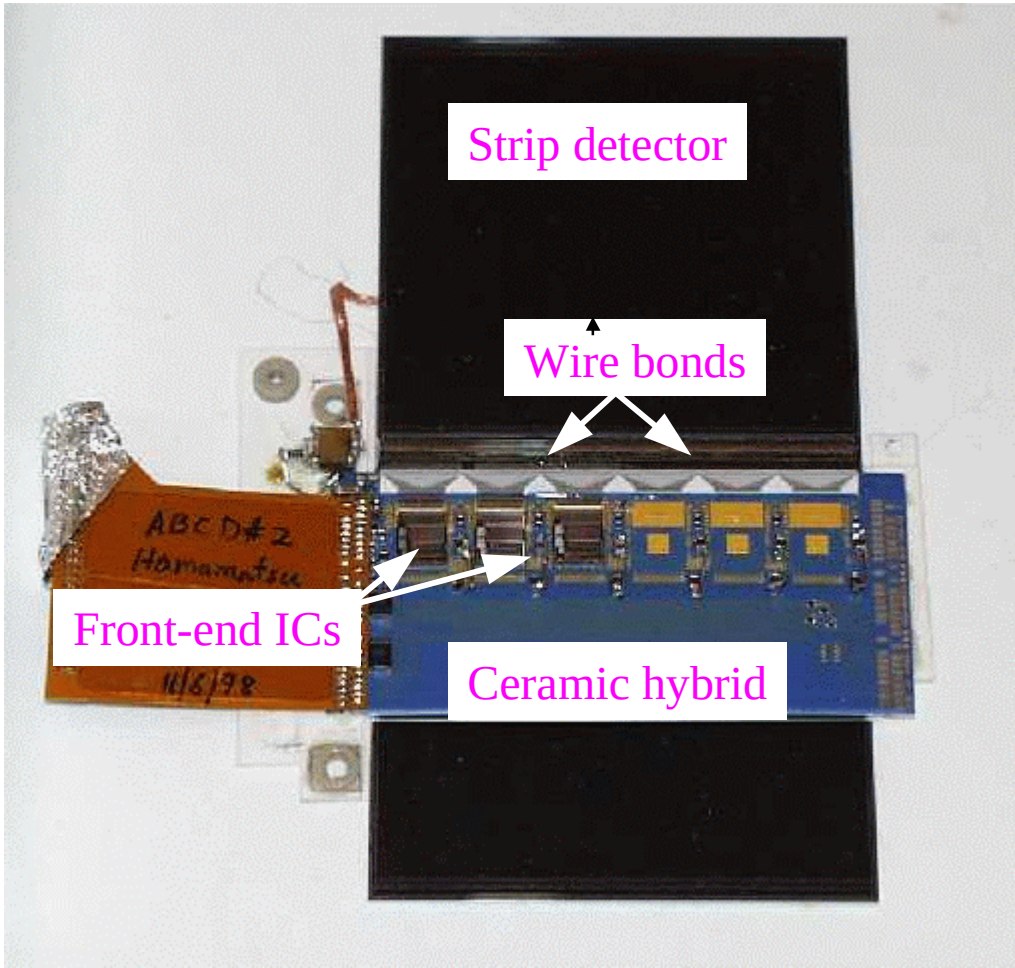
Semiconductor Tracker and LBNL

Physics Division

- **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**

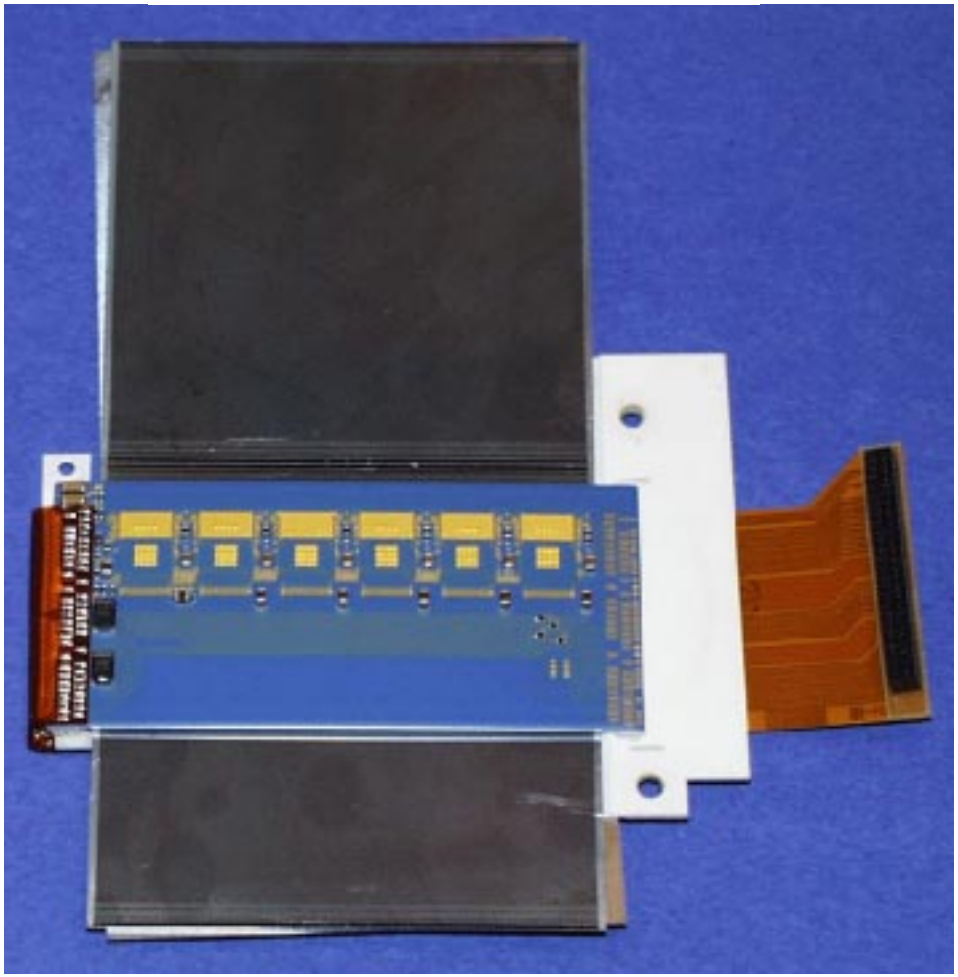
SCT Module

- **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**

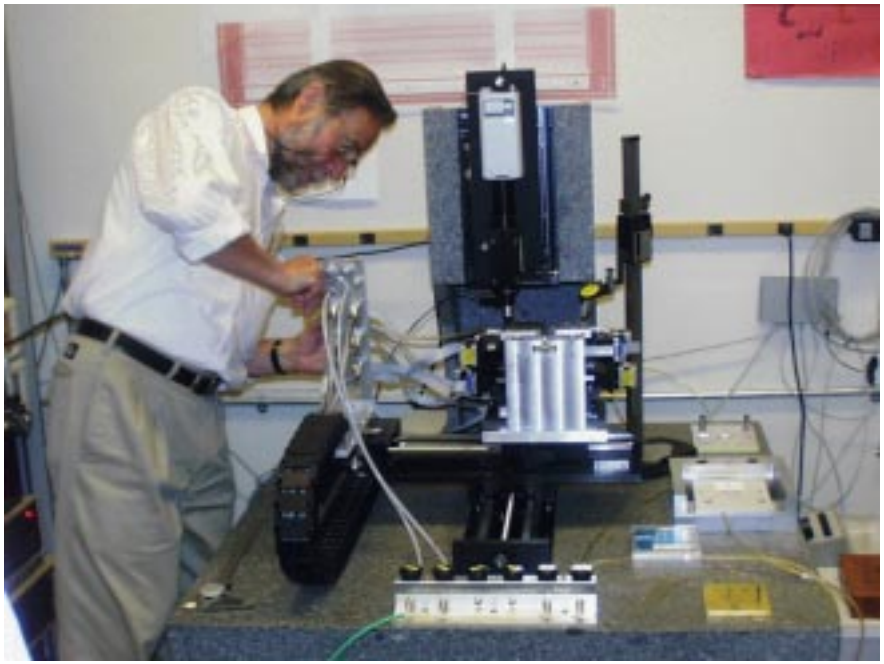


Barrel Silicon Strip Modules

Double-sided dummy module



- **Tooling for large-scale production(we have to assemble 700 modules)**
- **Practice(dummy) and few real modules built.**



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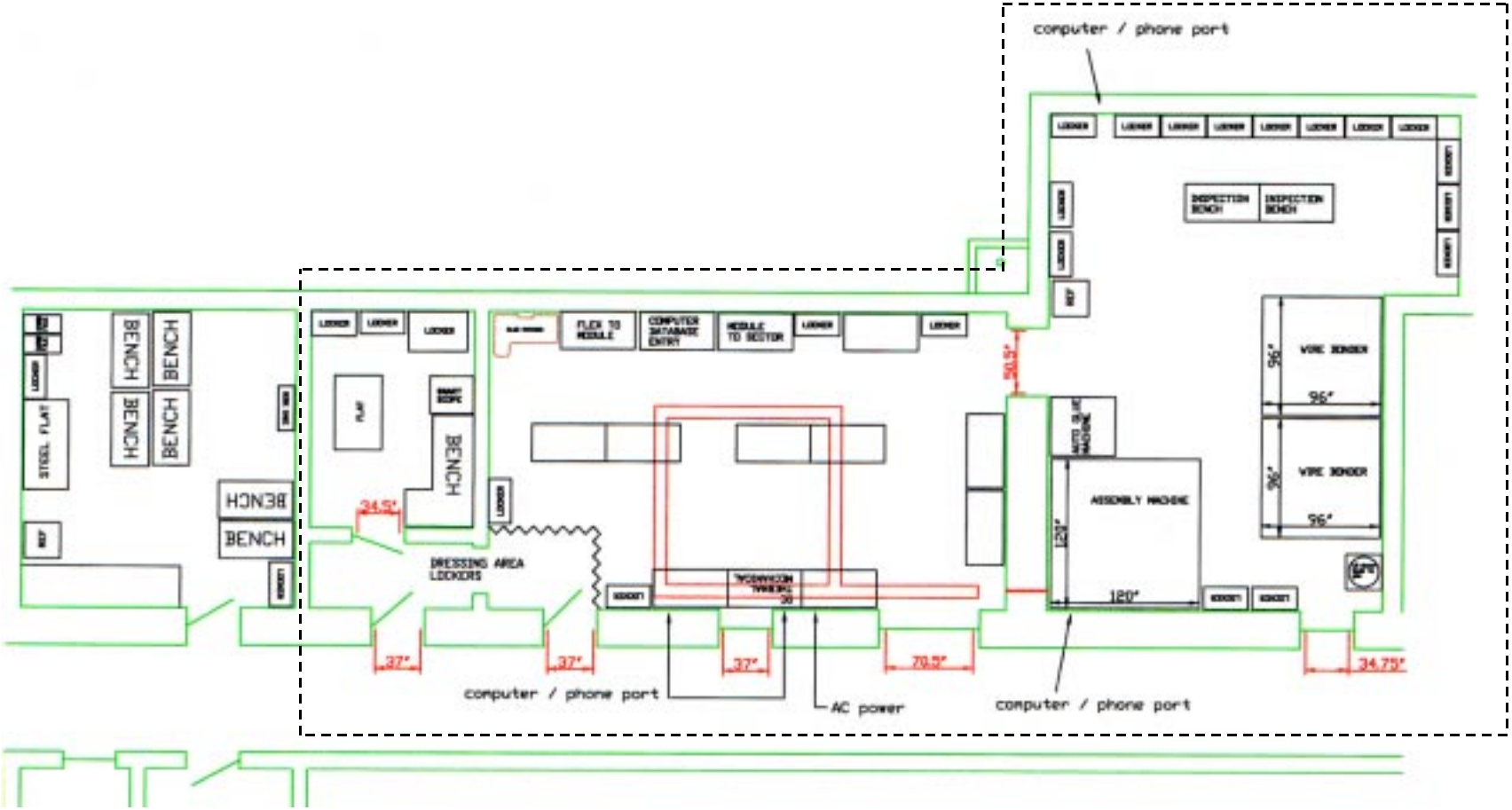
Assembly Space

Physics Division

- **Thanks to the Directorate, space in Bldg. 50 has been renovated to be "clean rooms". Work is complete and we are moving in.**



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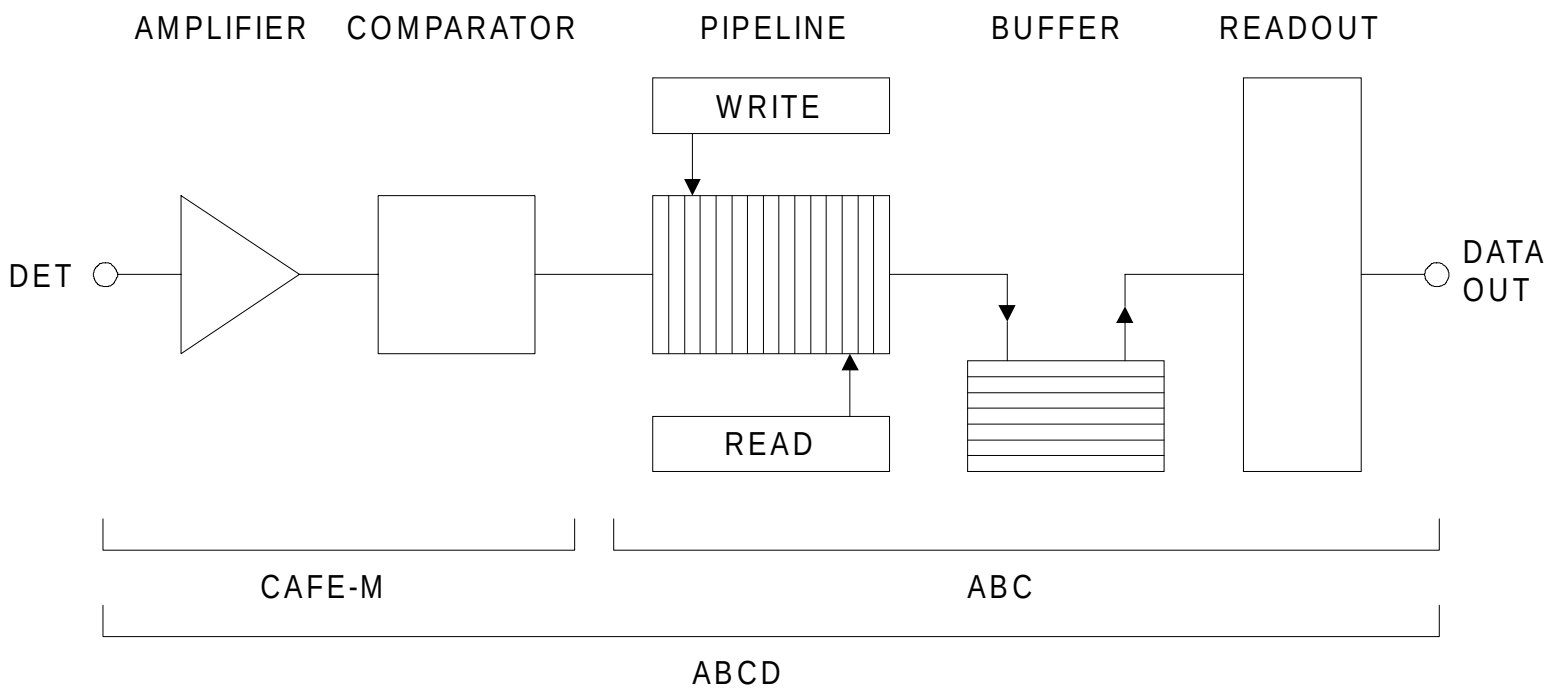
New Clean Space

Physics Division

Silicon Strip IC Electronics

- **Major part of effort in last year has been the continued 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.**

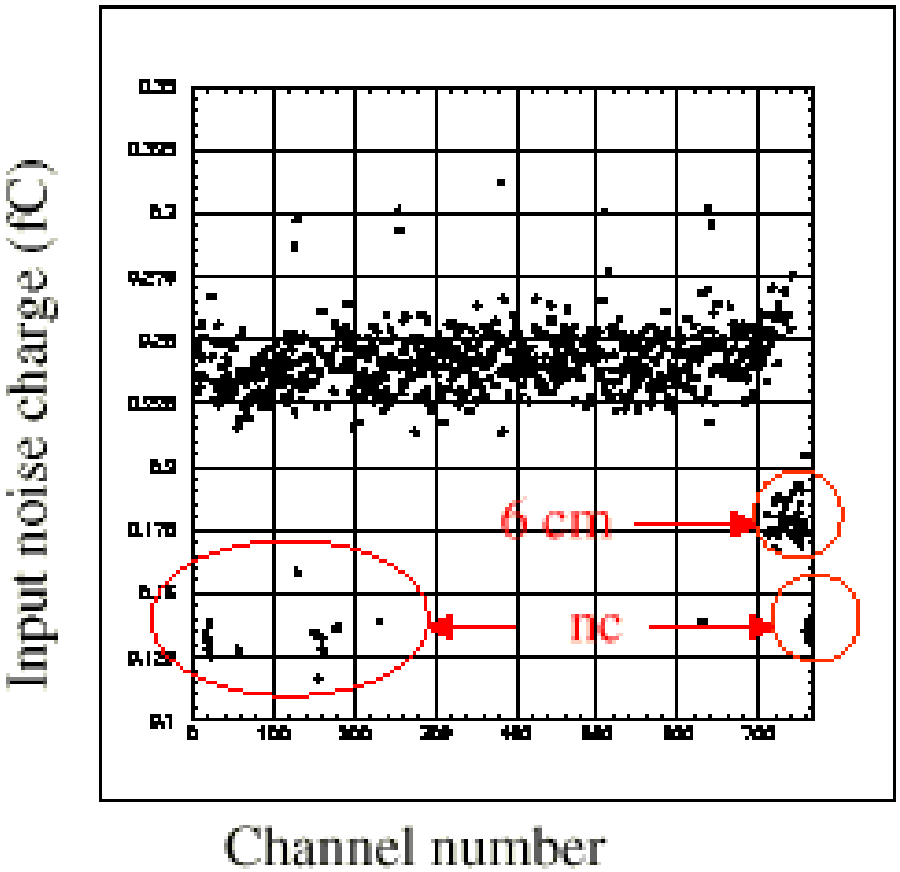


Silicon Strip IC Electronics

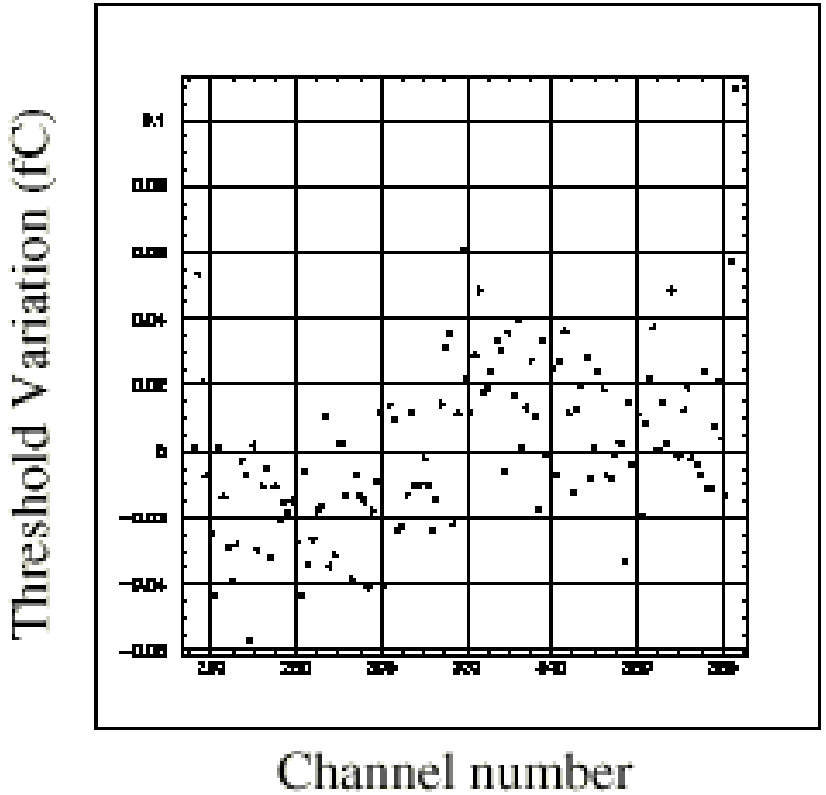
- First prototypes of all three ICs were fabricated and tested.
- None of them met specifications and we have spent the last year understanding the design flaws and contributing to the redesign.
- In this work we have been collaborating closely with Santa Cruz, Rutherford Lab and CERN.
- Second prototypes of all three integrated circuits are now in hand and testing has been ongoing for 3-6 months.
- Although there are a few minor flaws, all ICs work(pre-rad) but
  - detailed characterization underway - are all specs met?
  - irradiation studies are not complete and we still have much to learn about dose rate effects, operation at low temperature, differences between neutron and charged particle damage,….
  - And system tests - on modules - have just started last month or so, including first test beam studies at CERN.
- We continue to take advantage of LBNL facilities for irradiation - the 88” cyclotron and a Cobalt source - for critical studies of performance after irradiation.
- We plan to select between the design options by December, if enough data(irradiation and system tests) have been taken.

Some First Results

Noise

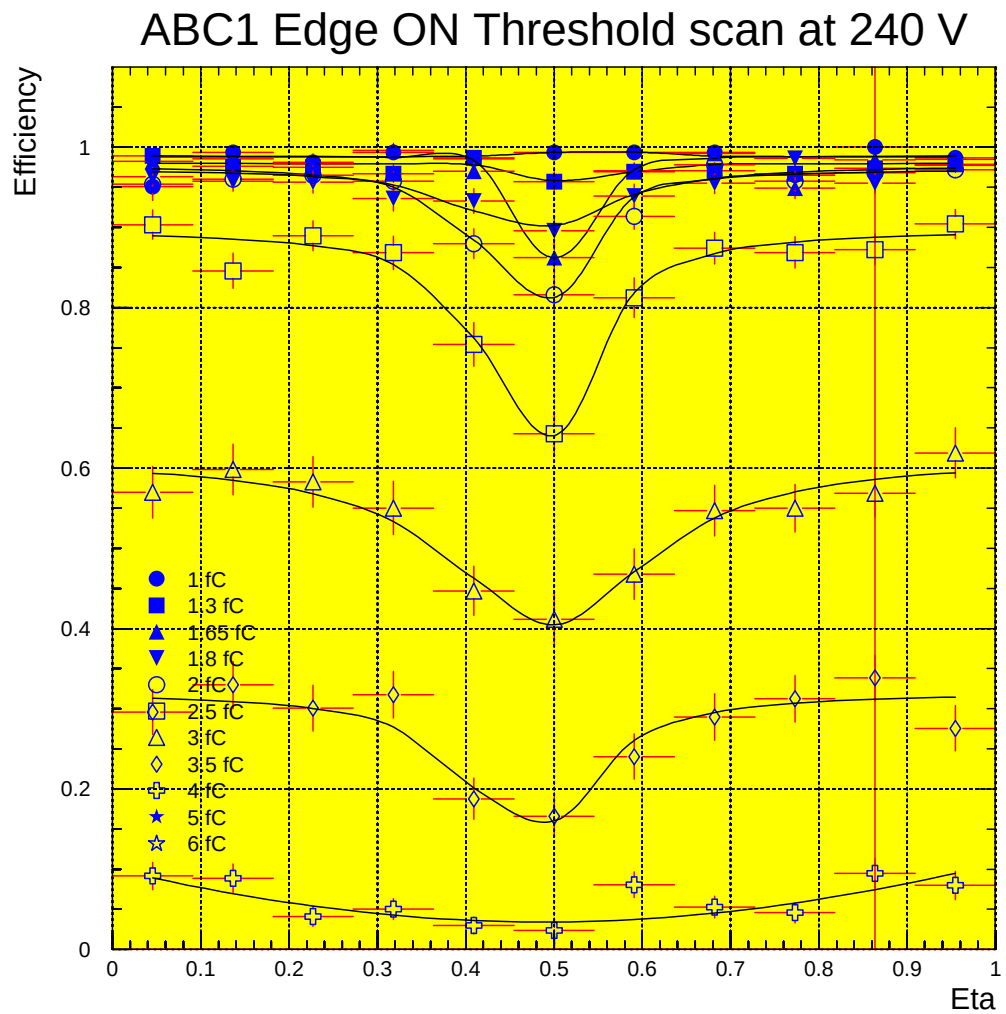


Threshold Uniformity



- **Top plot is the efficiency of single-sided, 6 chip module with CAFÉ/ABC chips made here.**
- **Bottom plot is the noise occupancy, which is expected to be about 10^{-4} at a threshold of 1 fC.**

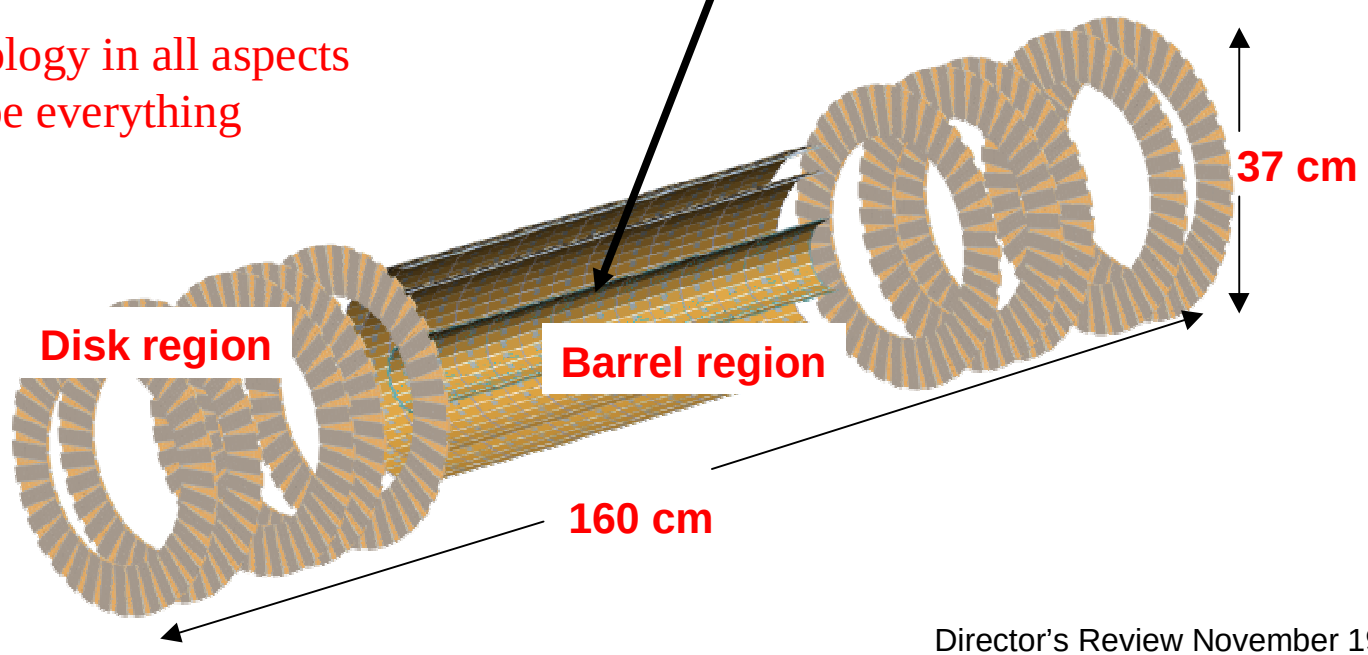
- **Efficiency vs location for different thresholds showing results of charge sharing.**
- **Eta =0 is center of one strip and eta=1 is center of adjacent strip.**
- **The efficiency is flat, or nearly so, for operational thresholds of 1-1.2 fC**



The ATLAS Pixel System

- **Layout**
  - 3 barrel layers, 2 x 5 disk layers
  - Three space points for $|\eta| < 2.5$
  - Modular construction(about 2000 modules)
- **Radiation hardness**
  - Lifetime dose - 50 MRad at 10 cm
  - Leakage current in 50μx300μ pixel is - 30 nA after irradiation.
  - Signal loss in silicon by factor 4-5 after 10^{15} n/cm^2)
- **Pattern recognition**
  - Space points. Occupany of - 10^{-4}
- **Performance**
  - Critical for b tagging(big physics impact)
  - Need for 3 hits confirmed by simulation
- **Trigger**
  - Space points-> L2 trigger
- **B-Layer**
  - More demanding in almost all aspects
  - Evolving to essentially separate project

New technology in all aspects
=> prototype everything

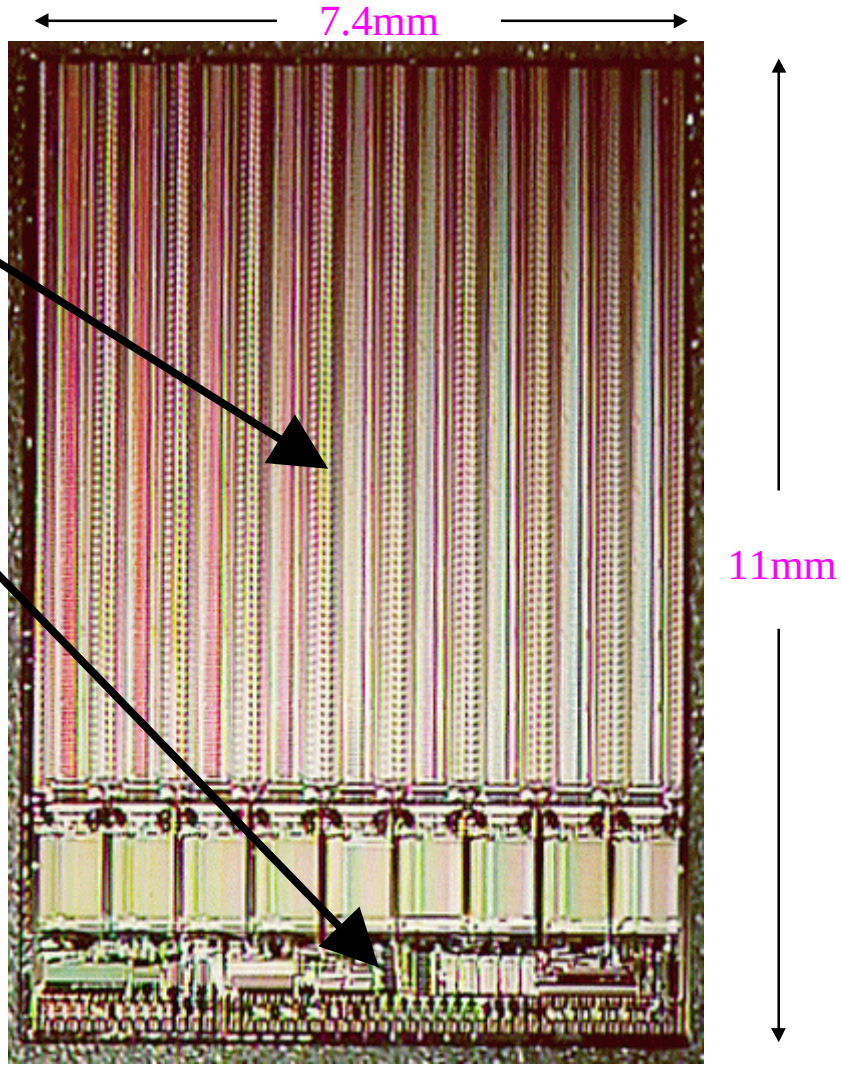


ATLAS Pixel System and LBNL

- **LBNL is currently involved in the following aspects of the Pixel System design**
  - **Front-end integrated circuit electronics design and testing(K. Einsweiler is electronics coordinator for Pixel Collaboration)**
  - **Module design and assembly**
  - **Mechanical design of the disk part of the system(D. Bintinger is co-coordinator of mechanics for Pixel Collaboration)**
  - **Overall system integration of the mechanical system(in part led by A. Anderssen)**
  - **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), overall support frame and other parts of the mechanical structures.**
  - **Systems integration(in part), particularly of services.**

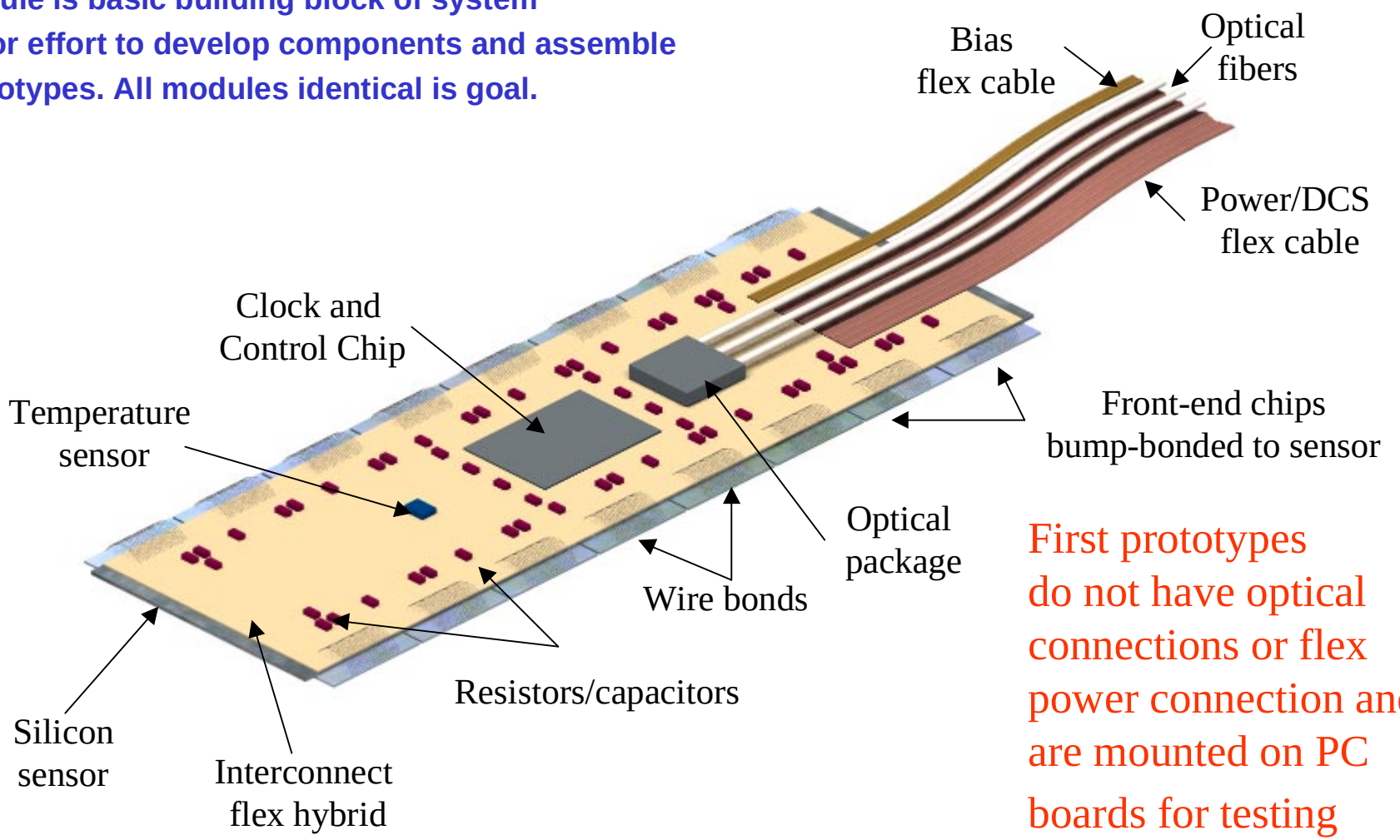
Pixel Electronics

- **General features**
  - Active matrix 18x160 pixels. 50x400 microns except in B-layer, which is 50x300.
  - Inactive area for buffer and control
- **Critical requirements**
  - Time walk <20 ns
  - Timing uniformity across array(<few ns)
  - Low threshold(2-3K e^-s)
  - Threshold uniformity (implemented by having DAC in each pixel)
  - Low noise(<few hundred e)
  - Low deadtime(<1% or so)
  - Robust(dead pixel OK, dead column not good, dead chip bad)
  - All of the above at 25 Mrad or more
- **Important requirements**
  - Time-Over-Threshold(TOT) measurement of charge
  - Maximize active area
  - Die size with acceptable yield
  - Thin(150 micron goal)



Pixel Module

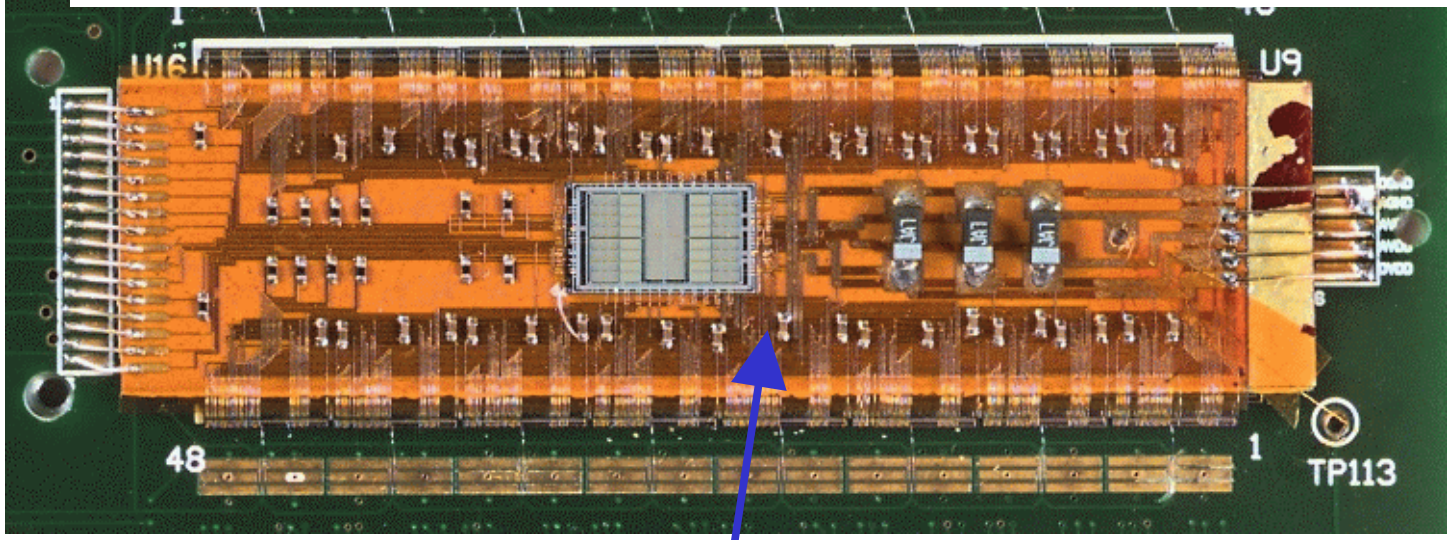
Module is basic building block of system
Major effort to develop components and assemble prototypes. All modules identical is goal.

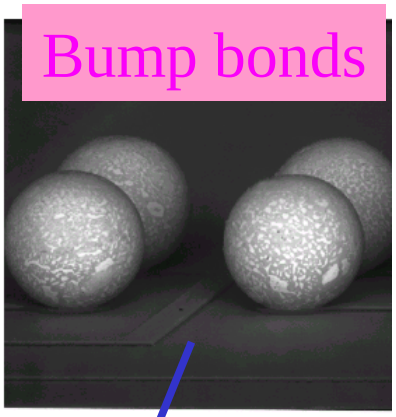


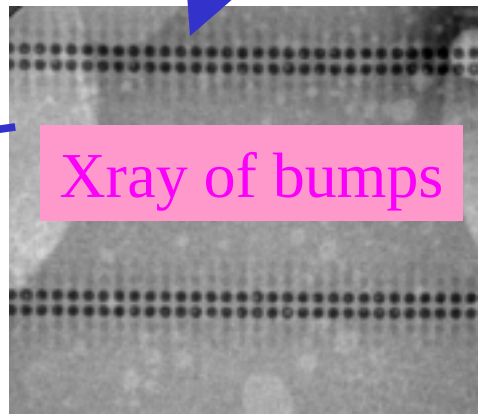
First prototypes do not have optical connections or flex power connection and are mounted on PC boards for testing

Pixel Modules

Module with flex hybrid and controller chip on PC board







Sensor

ICs

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What Has Been Tested

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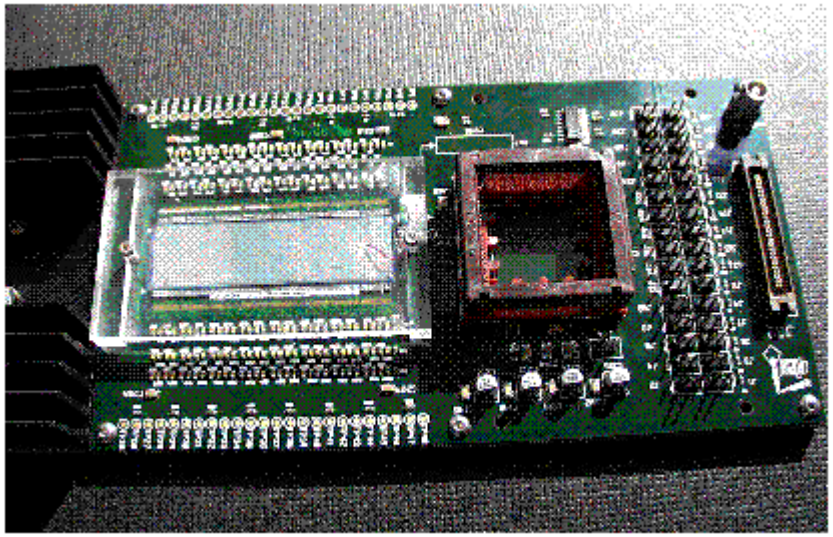
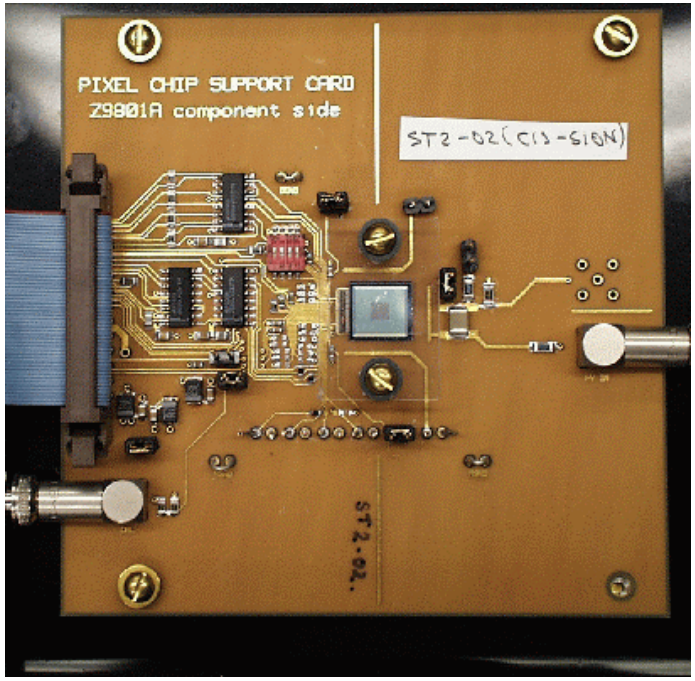
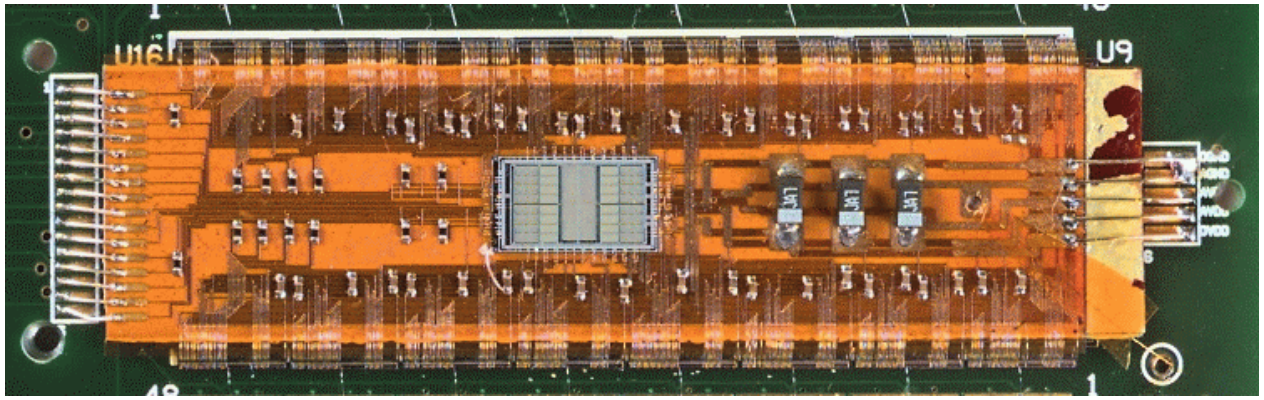


Bare 16-chip modules



Dozens of single chip/sensor assemblies of different types



16-chip modules with flex hybrid

Lab and Test Beam Results - Summary

- **Extensive lab tests, test beam runs at CERN in 1998 and this year.**
- **Highlights**
  - **Only rad-soft ICs so far(3 variants used - FE - A, - B, - C)**
  - **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, albeit not at full system level.**
  - **Operation at thresholds 2,000-3,000 electrons demonstrated**
  - **Threshold uniformity demonstrated.**
  - **Spatial resolution as expected**
- **Conclusion**
  - **Proof-of-principle of pixel concept successful**

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Photon Source Test

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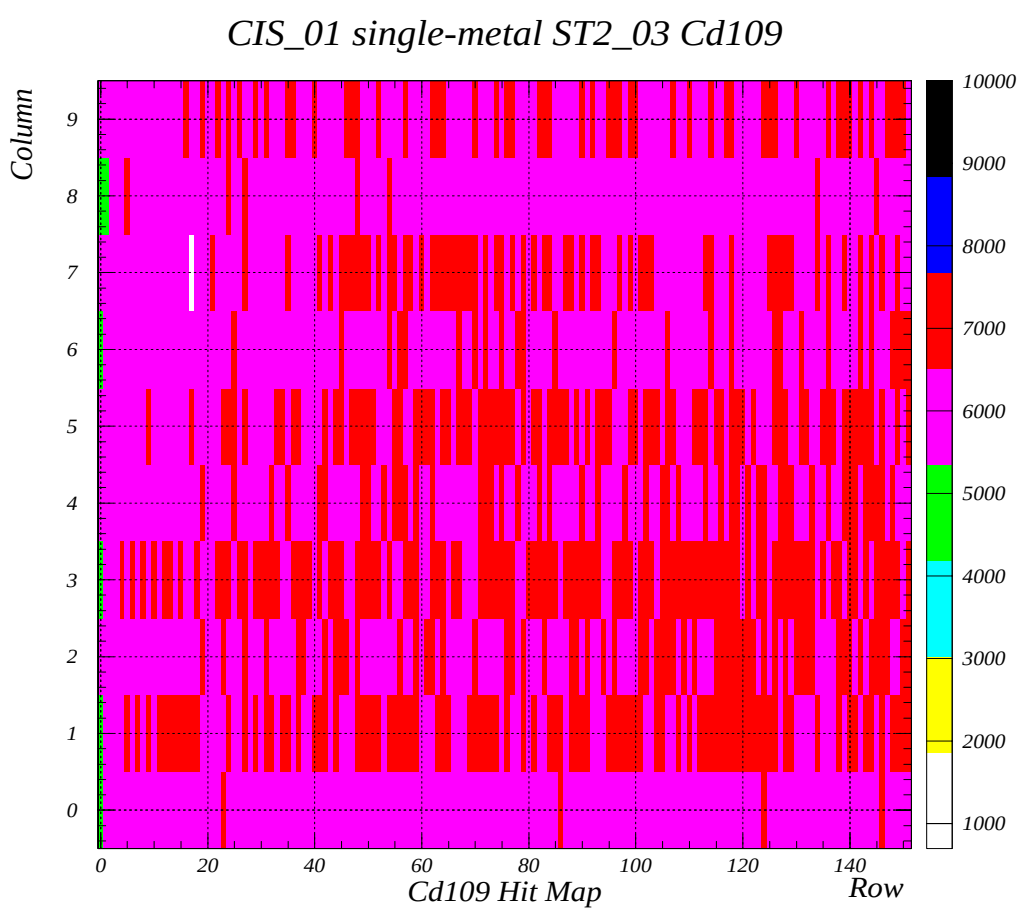

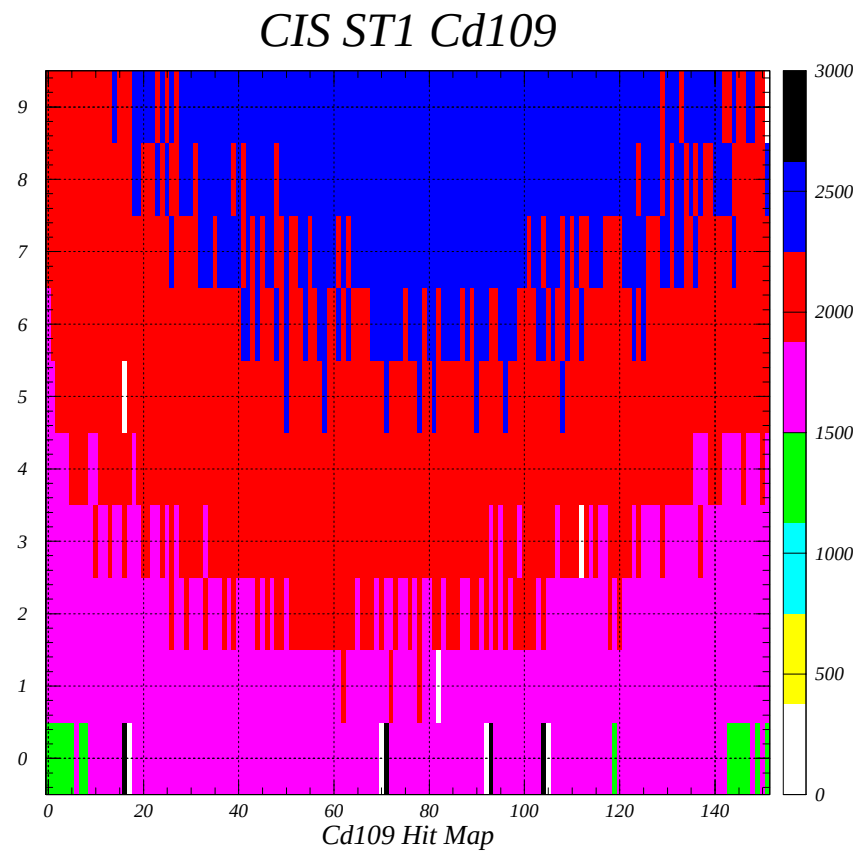

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Threshold Tuning and Noise

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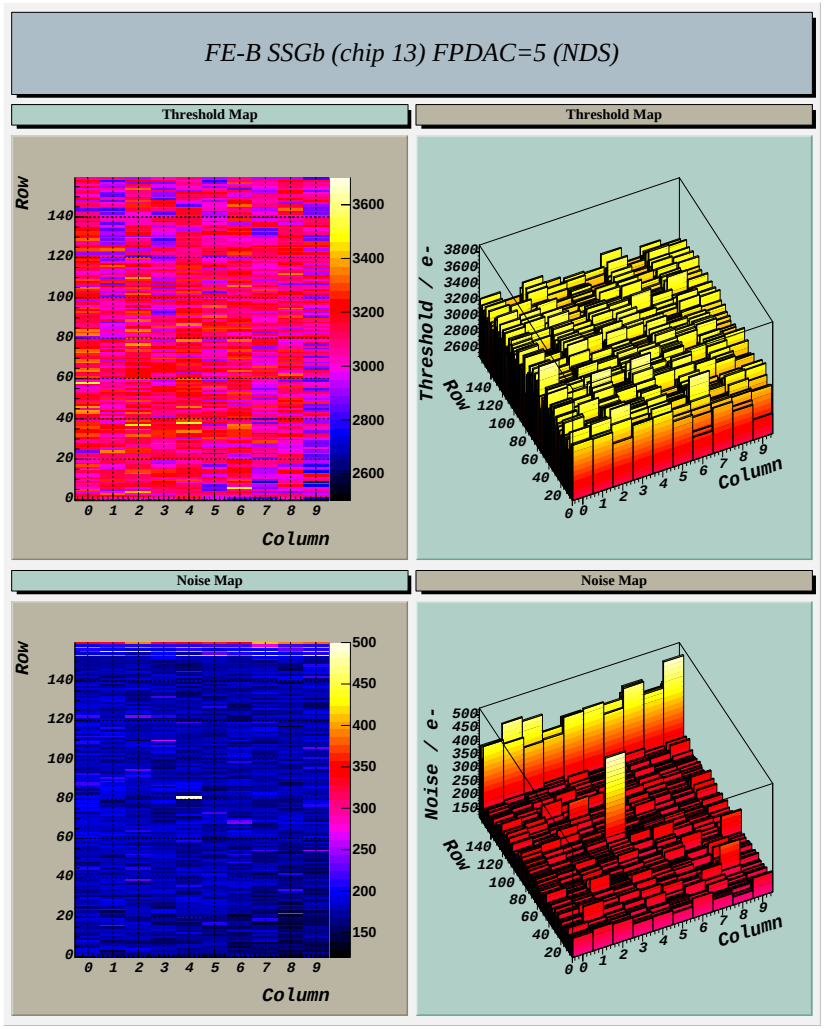
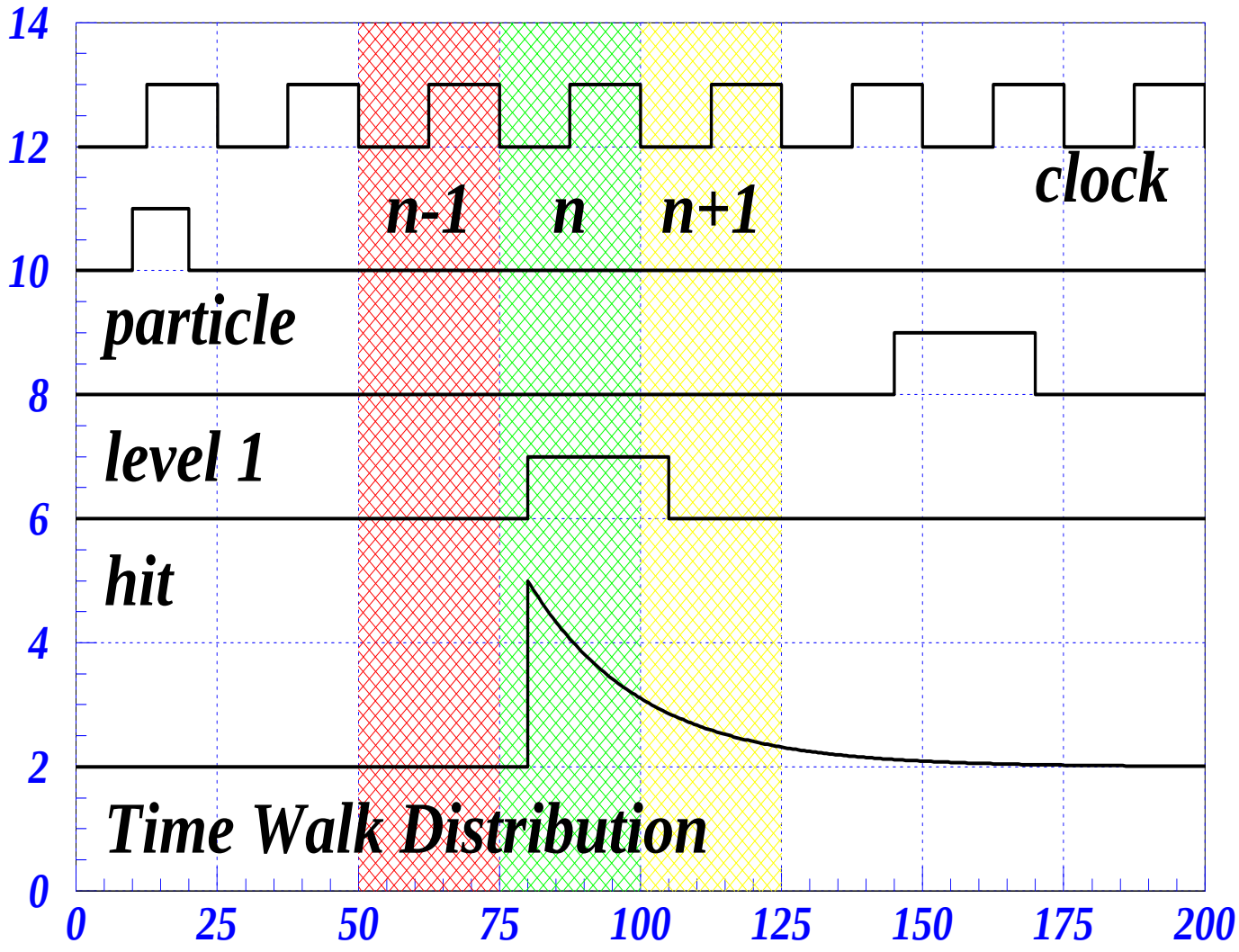


Untuned threshold σ=306 e, tuned =119

Efficiency and Timing in Test Beam



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In-Time Efficiencies

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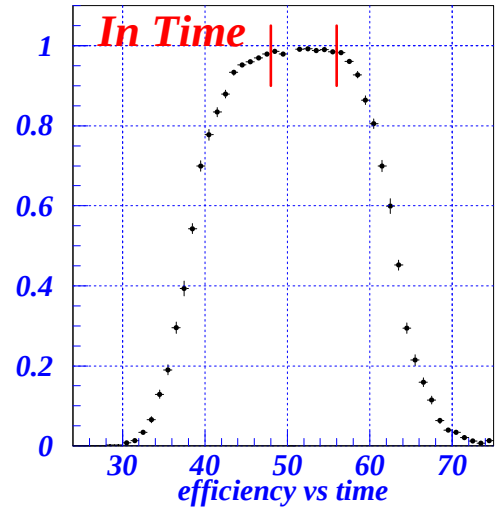
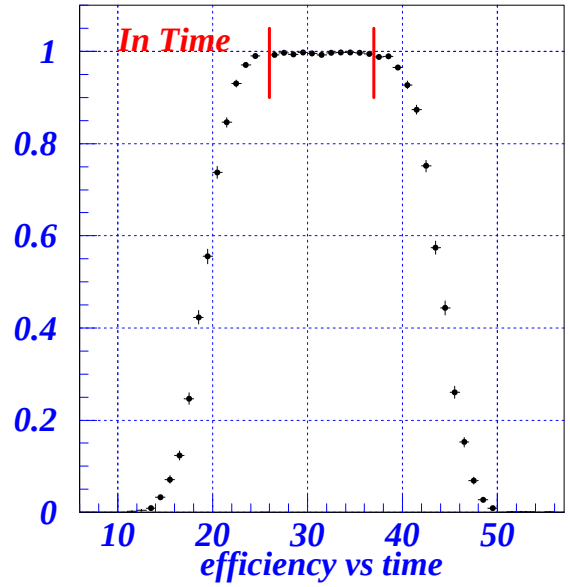
Detector Tile 2 v1.0 - not Irradiated - Thr. 3 Ke

Efficiency	98.8%	Losses	1.2%
1 hit	82.0	0 hits	0.4
2 hits	14.6	not matched	0.2
>2 hits	2.2	not in time	0.6



Detector Tile 1 v1.0 - not Irradiated - Thr. 3 Ke

Efficiency	99.6%	Losses	0.4
1 hit	72.0	0 hits	0.1
2 hits	25.2	not matched	0.2
>2 hits	2.4	not in time	0.1

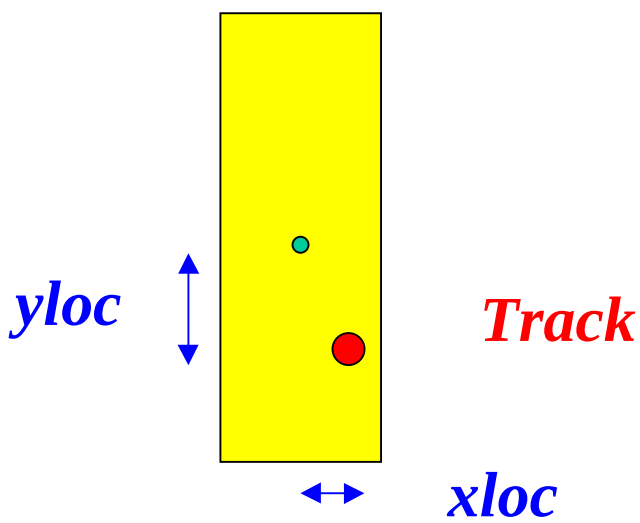


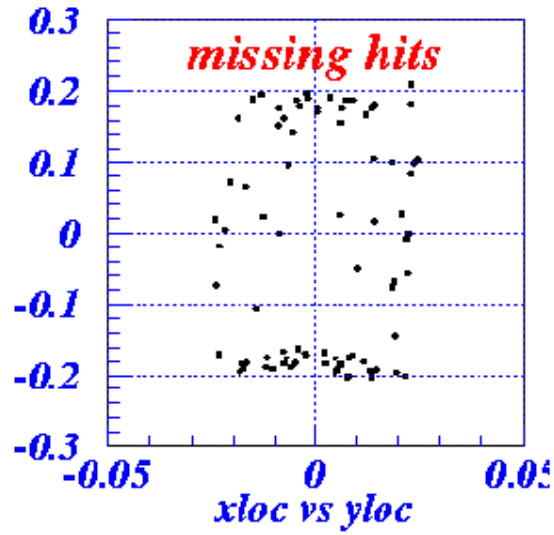
Irradiated Detectors

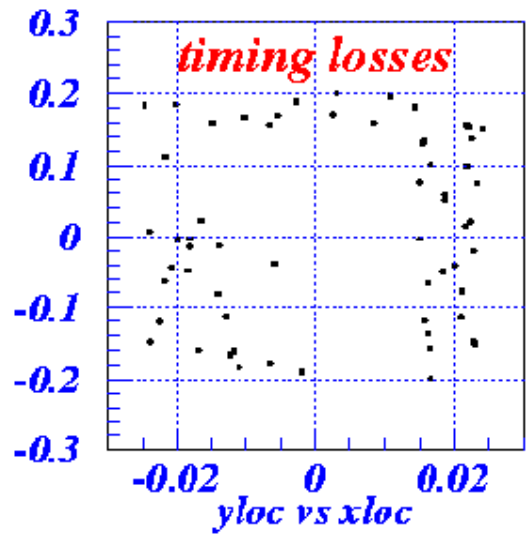
Tile 2 - Irradiated V_{bias} = 600 V

Fluence 10^{15} n/cm^2 - Thr. 3 Ke

Efficiency	95.3%	Losses	4.7%
1 hit	86.3	0 hits	2.2
2 hits	7.6	not matched	0.1
>2 hits	1.4	not in time	2.4







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Charge Collection - PreRad

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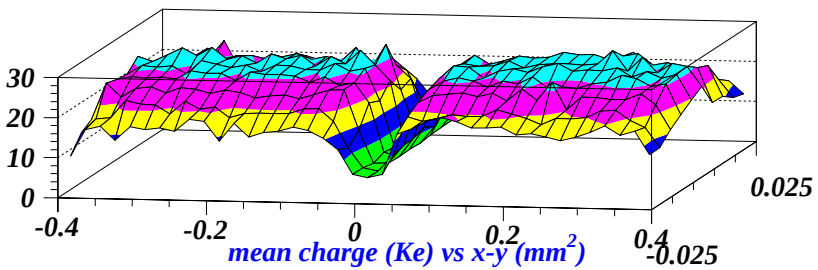
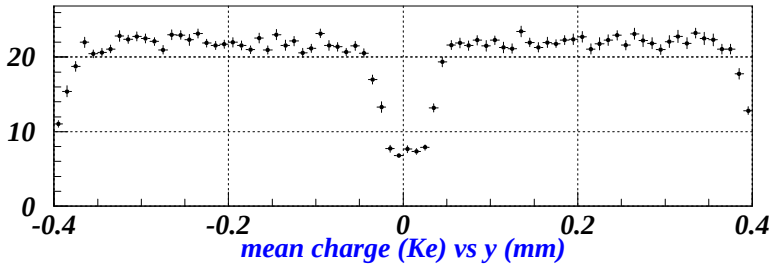
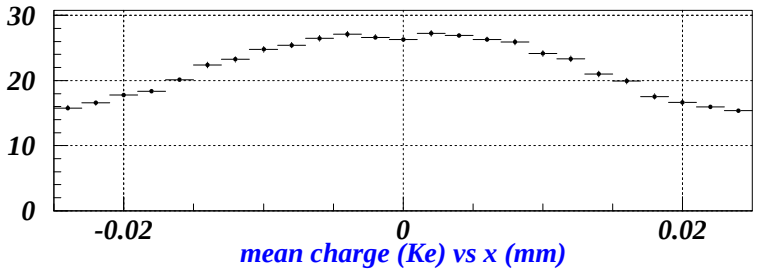
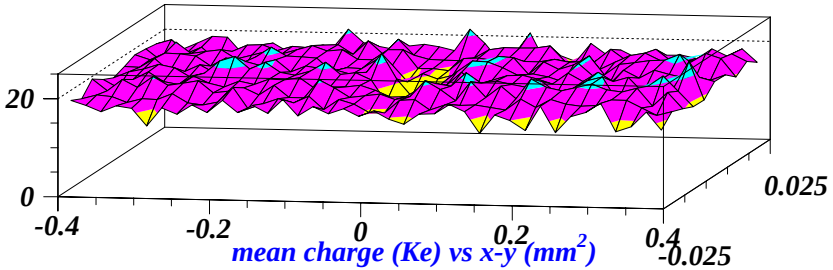
Tile 2 v1.0

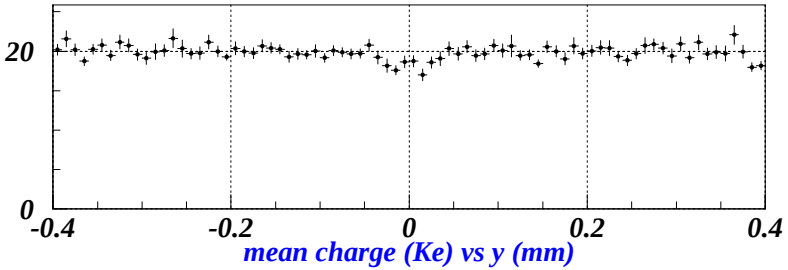


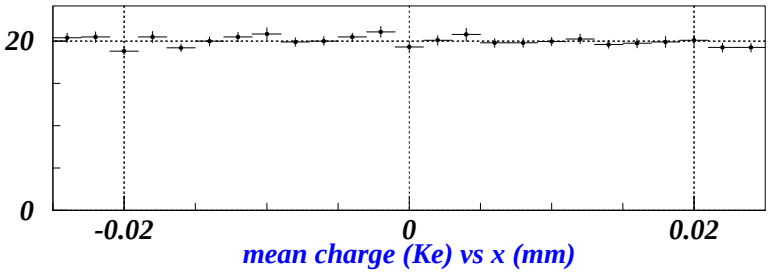




Tile 2 v1b







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Latest Detector Design Efficiency

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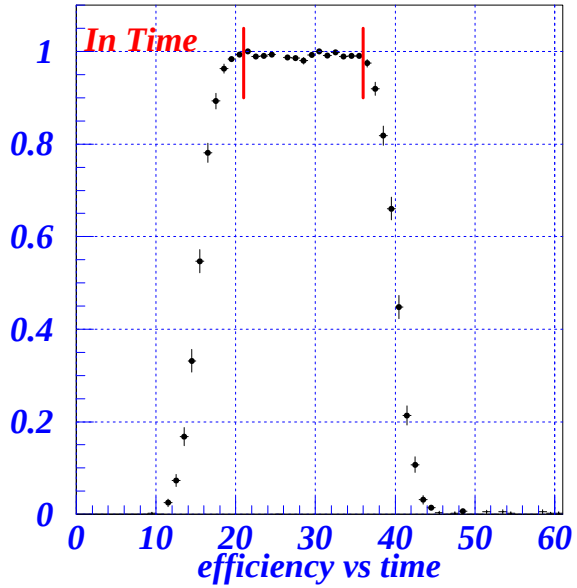
Detector Tile 2 new design (with bias grid)

Not Irradiated - Thr. 3 Ke

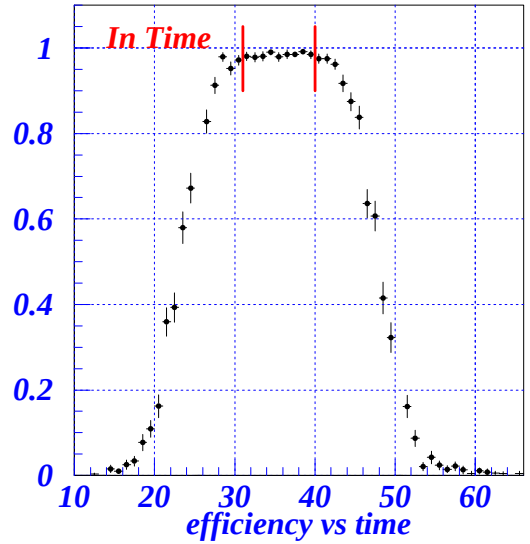
Efficiency	99.1%	Losses	0.9%
1 hit	81.8	0 hits	0.4
2 hits	15.6	not matched	0.1
>2 hits	1.7	not in time	0.4



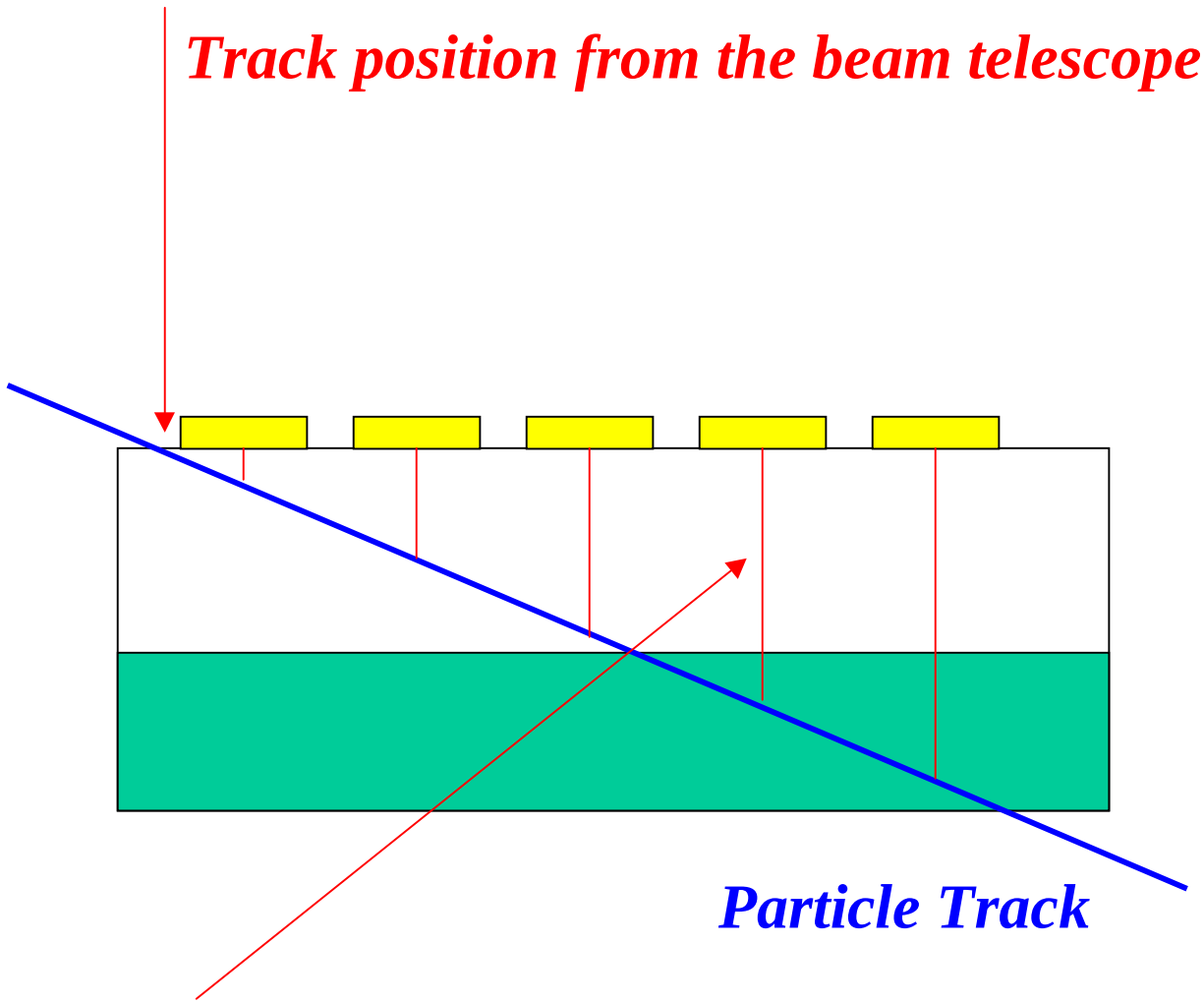
Detector Tile 2 - Irradiated V_{bias} = 600 V

Fluence 10^{15} n/cm^2 - Thr. 3 Ke

Efficiency	98.4%	Losses	1.6%
1 hit	94.2	0 hits	0.4
2 hits	3.1	not matched	0.0
>2 hits	1.1	not in time	1.2



Depletion Depth Measurements



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Depletion Depth Measurements

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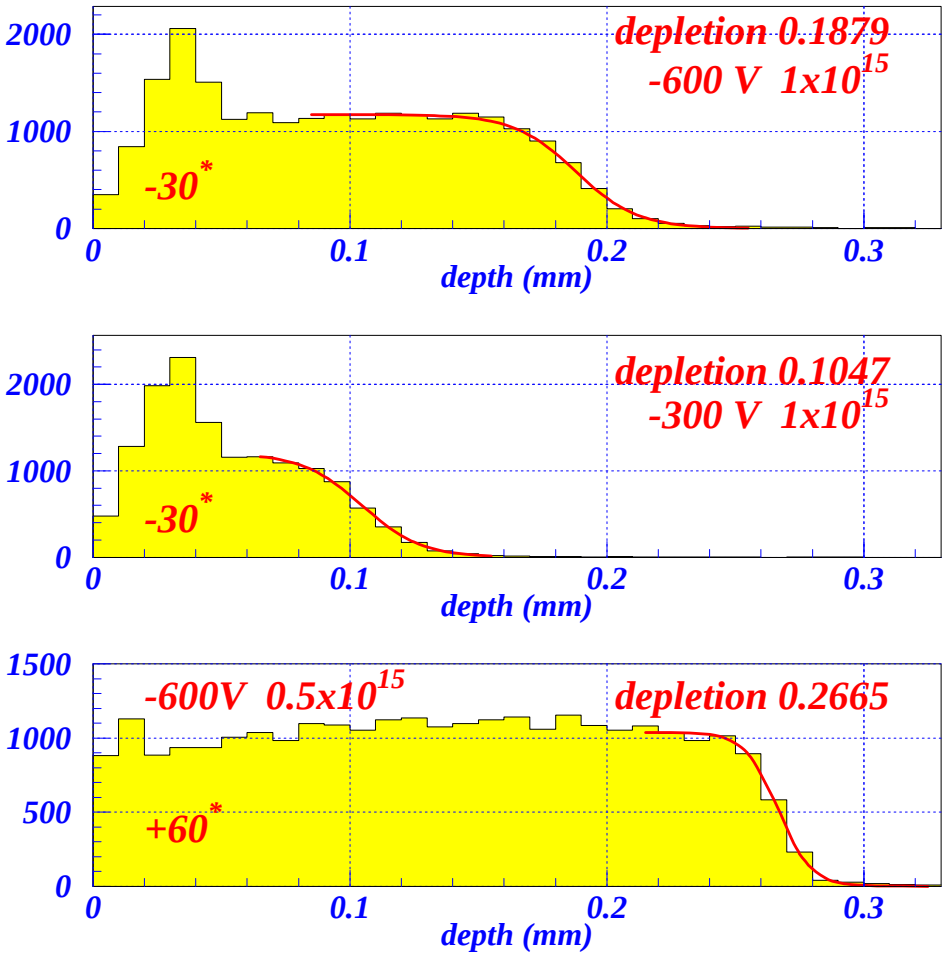
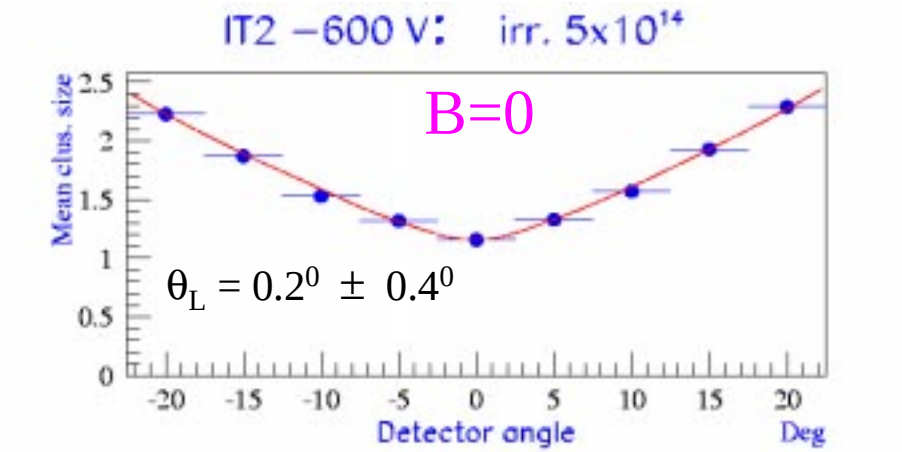
Not irradiated - depletion depth

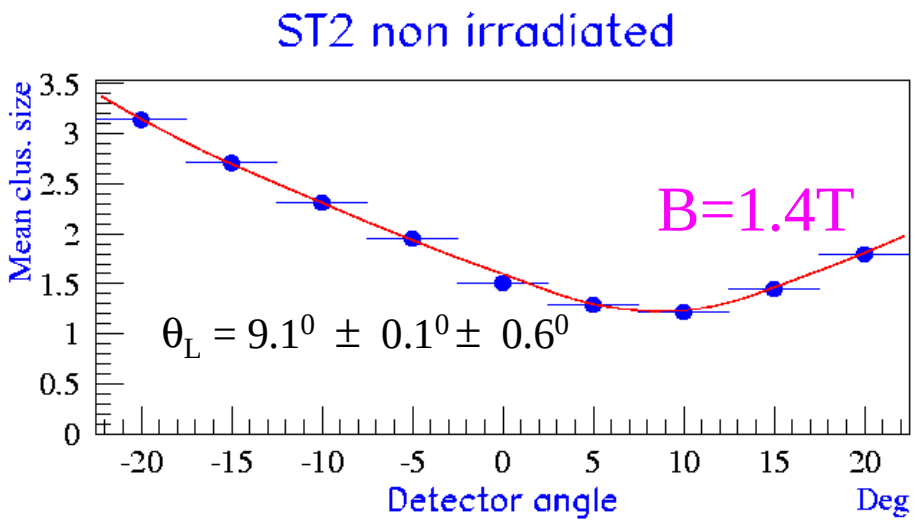
Irradiated - depletion depth

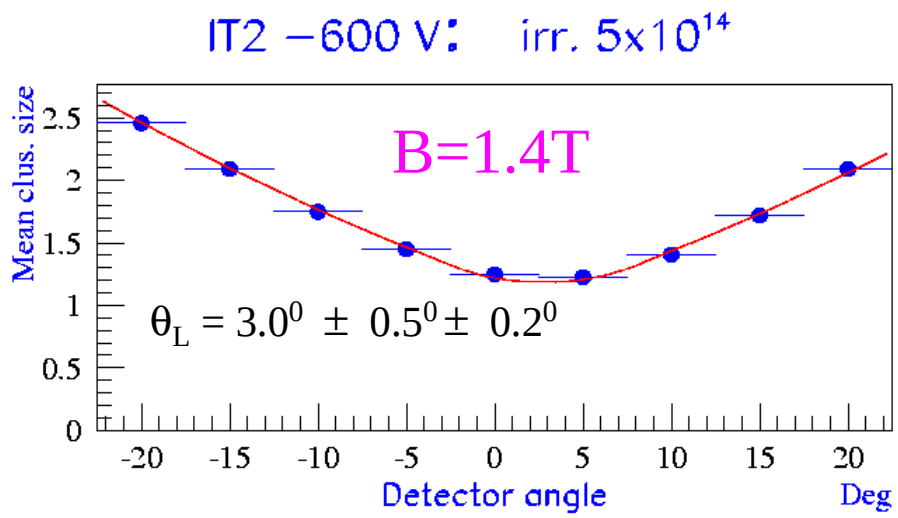


Lorentz Angle



not irradiated	**$9.1^0 \pm 0.1^0 \pm 0.6^0$**
dose 5 10^{14} n/cm^2	**$3.0^0 \pm 0.5^0 \pm 0.2^0$**
dose 10^{15} n/cm^2	**$3.2^0 \pm 1.2^0 \pm 0.5^0$**



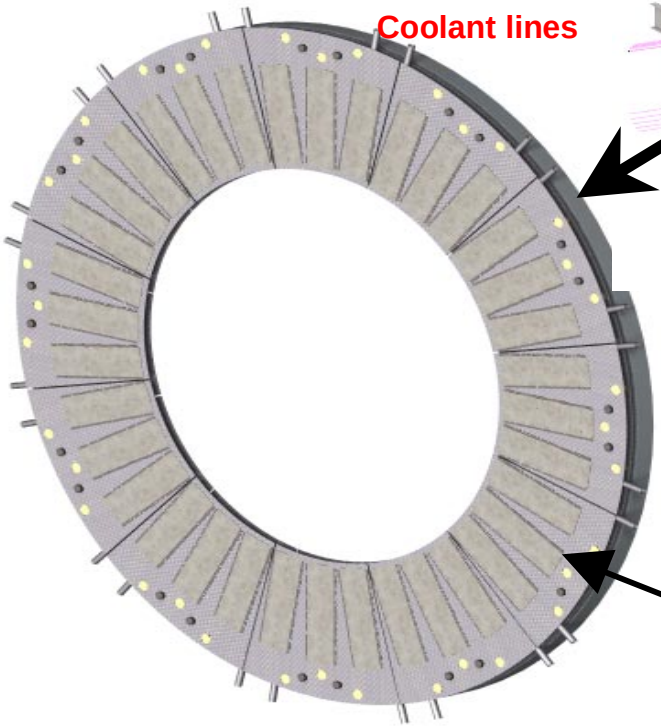


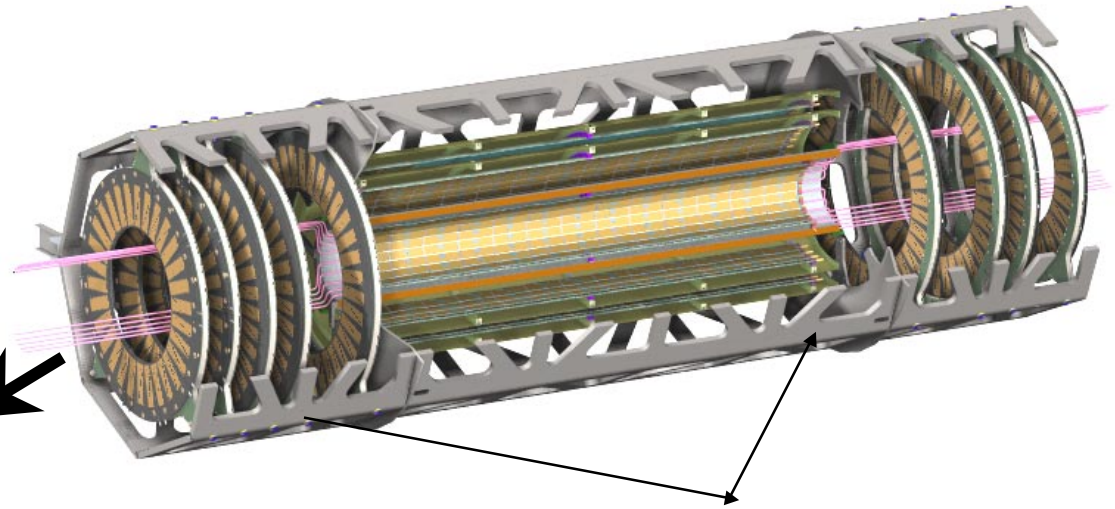
What Next?

- **Electronics**
  - **First full-size, prototype rad-hard ICs just available at end of last month and tests underway.**
  - **Meets performance specs? Rad-hard? Much work!**
- **Modules**
  - **We need much more experience with modules -> building more and aimed towards production design.**
  - **Design of production assembly tooling underway. Prototype assembly tooling exists.**
  - **Design of tooling for attachment of modules to mechanical structure underway.**
- **Key Goal**
  - **Demonstrate functionality of module(s) after 1 x 10^{15} irradiation in test beam next year.**

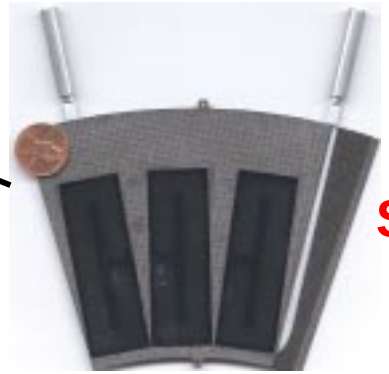
Pixel Mechanics

Disk with 12 Sectors





Support frame



Sector- local support of modules

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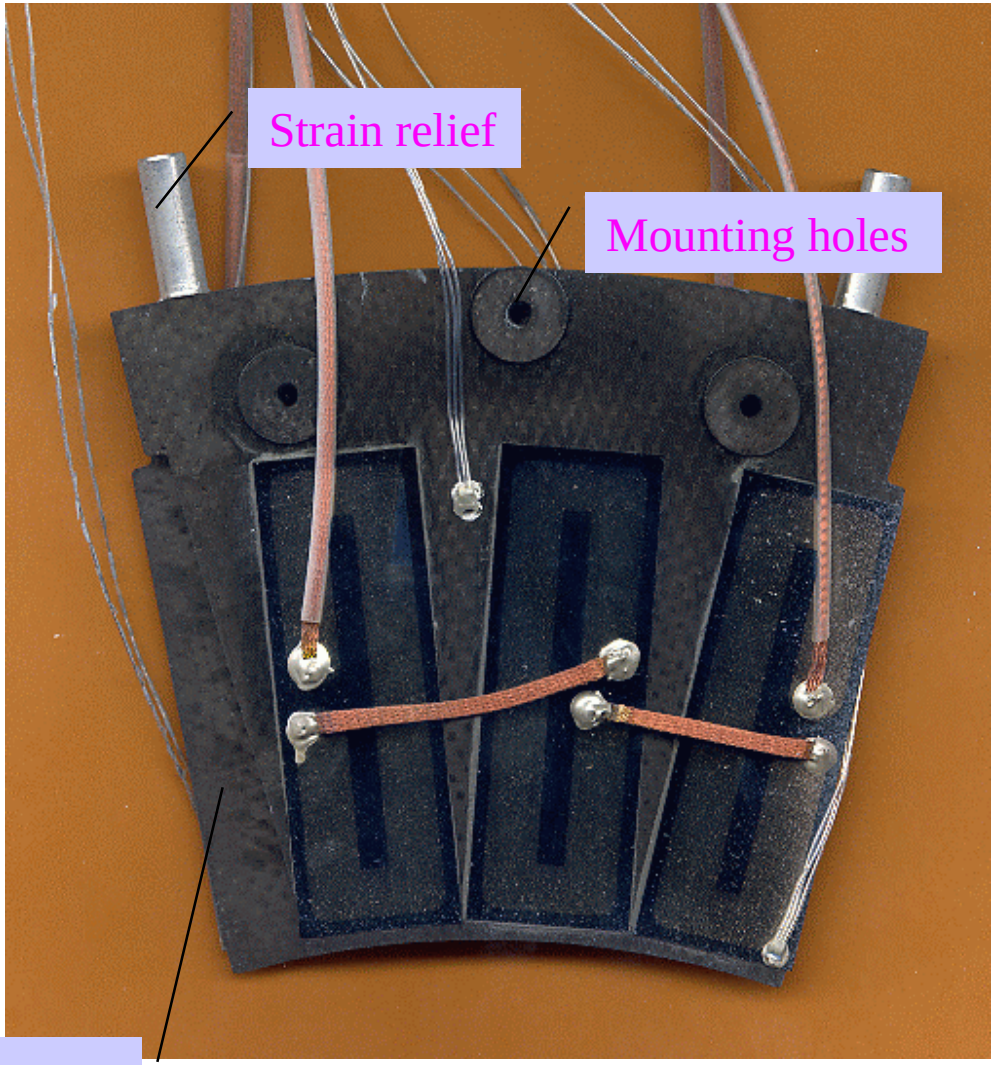
All-Carbon Sector

Physics Division

Leak tight carbon tube flocked with high thermal conductivity fibers.



300-500 micron carbon-carbon facings

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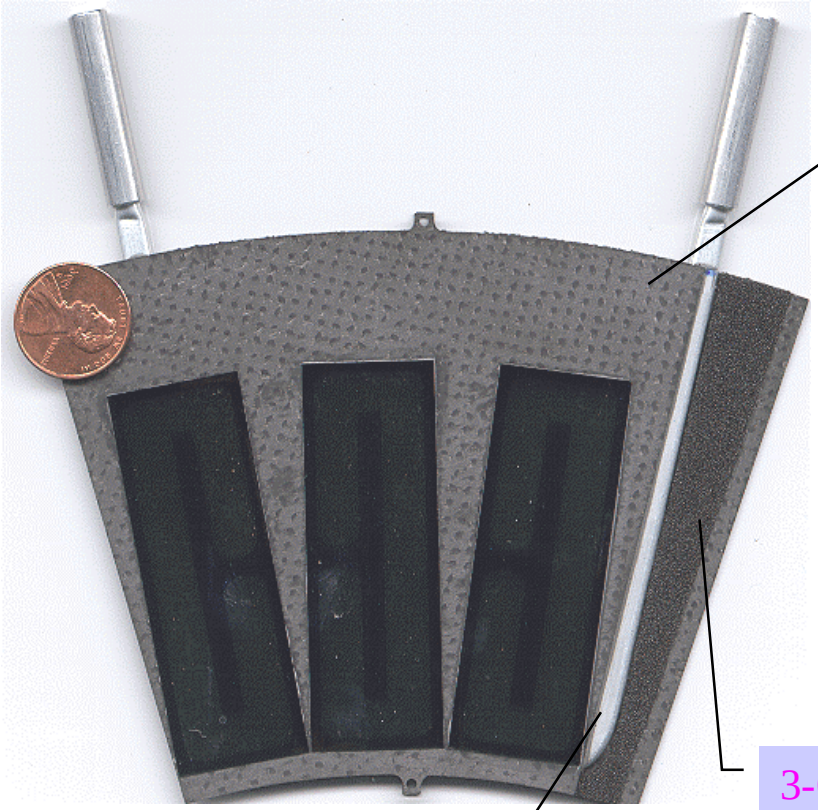
Al-Tube Sector

Physics Division

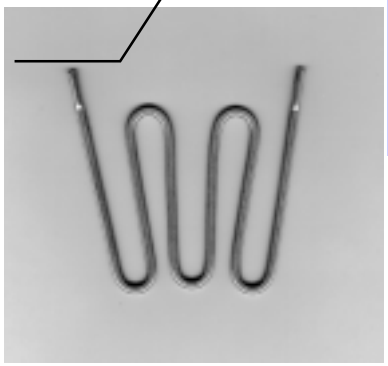
LBNL design and fabrication

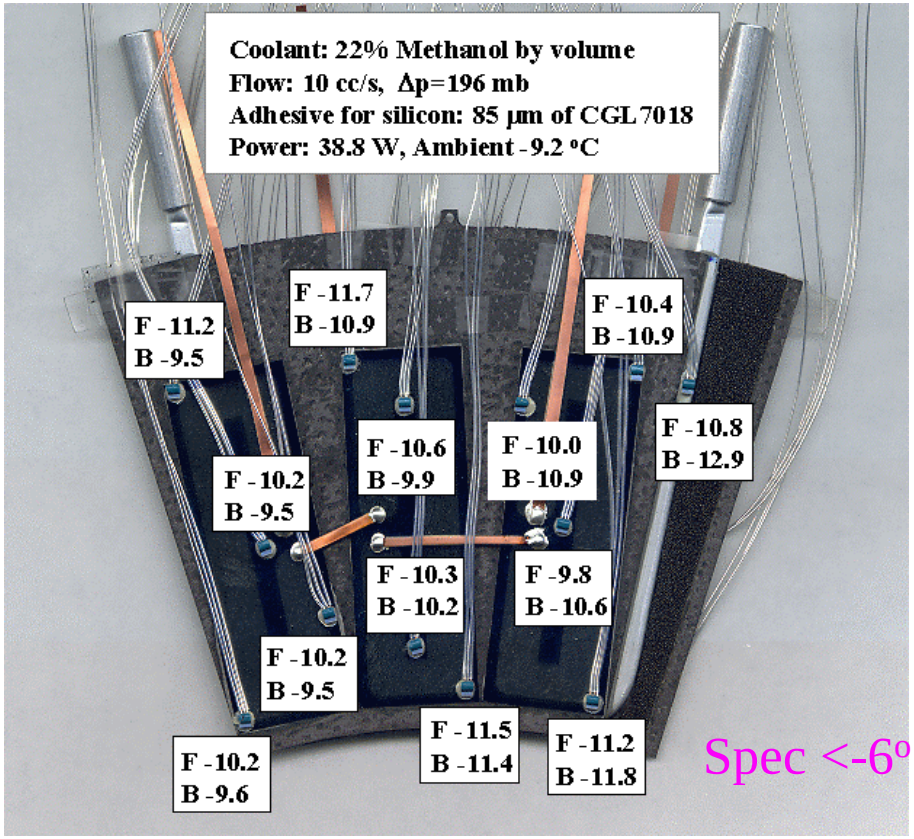


300-500 micron carbon-carbon facings

3-6% density carbon foam

200 micron wall Al tube





Spec <-6°

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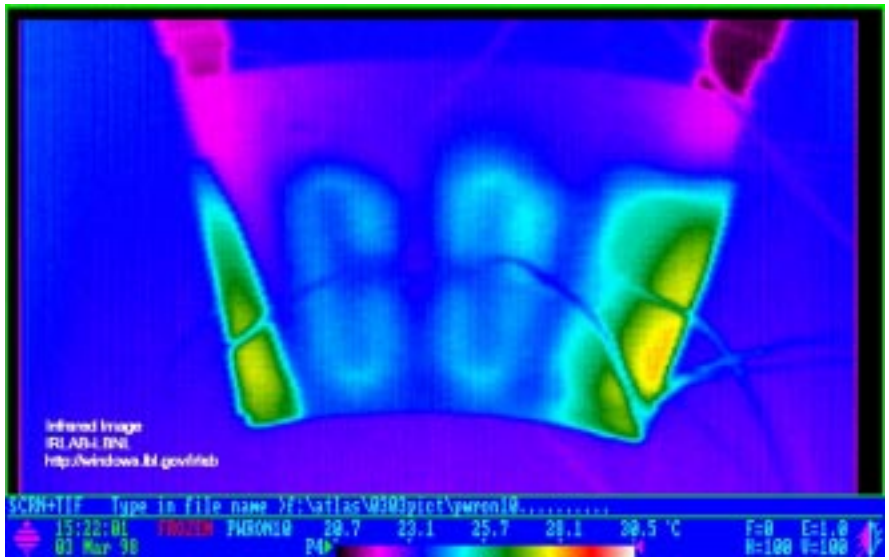
Thermal Measurements and Cooling

Physics Division

- In addition to direction temperature measurements, also use infrared imaging.
- Have used water-methanol, liquid C_6F_{14} and evaporative flurocarbons(C_4F_{10} and others).
- All can work thermally but water-based rejected(risk) and liquid fluorcarbon rejected because more material.
- Baseline cooling is evaporative. First tests show it works but much development needed at system level



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Mechanical Stability Measurements

Physics Division

- Trying for ultra-stable structure
- Validate using TV holography(<1 micron precision) and with direct optical CMM measurements

Thermal Strain Example

Cold

Edge support

Phase map data imperfections

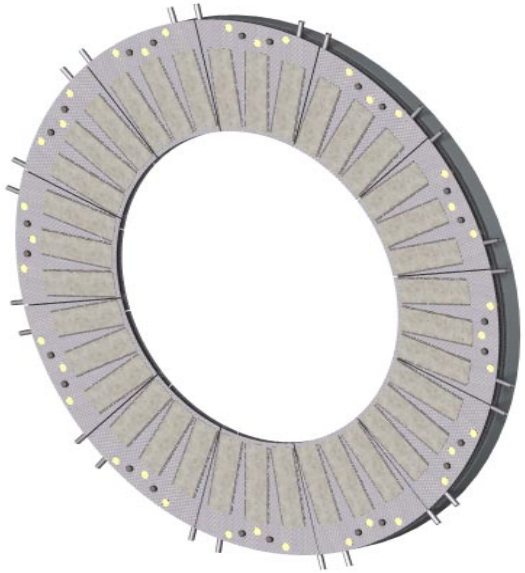
(RTD's, RTD leads, power leads)

ΔT=1.1 ºC @ T=-15.3 ºC
~2 μm's peak out-of-plane

Phase Map after Removal of Tilt Fringes

Disk Prototype

- **Two full-disk mechanical and thermal prototypes will be made**
- **Assembly of first one is nearing completion with 12 prototype sectors and disk support ring here at LBL.**



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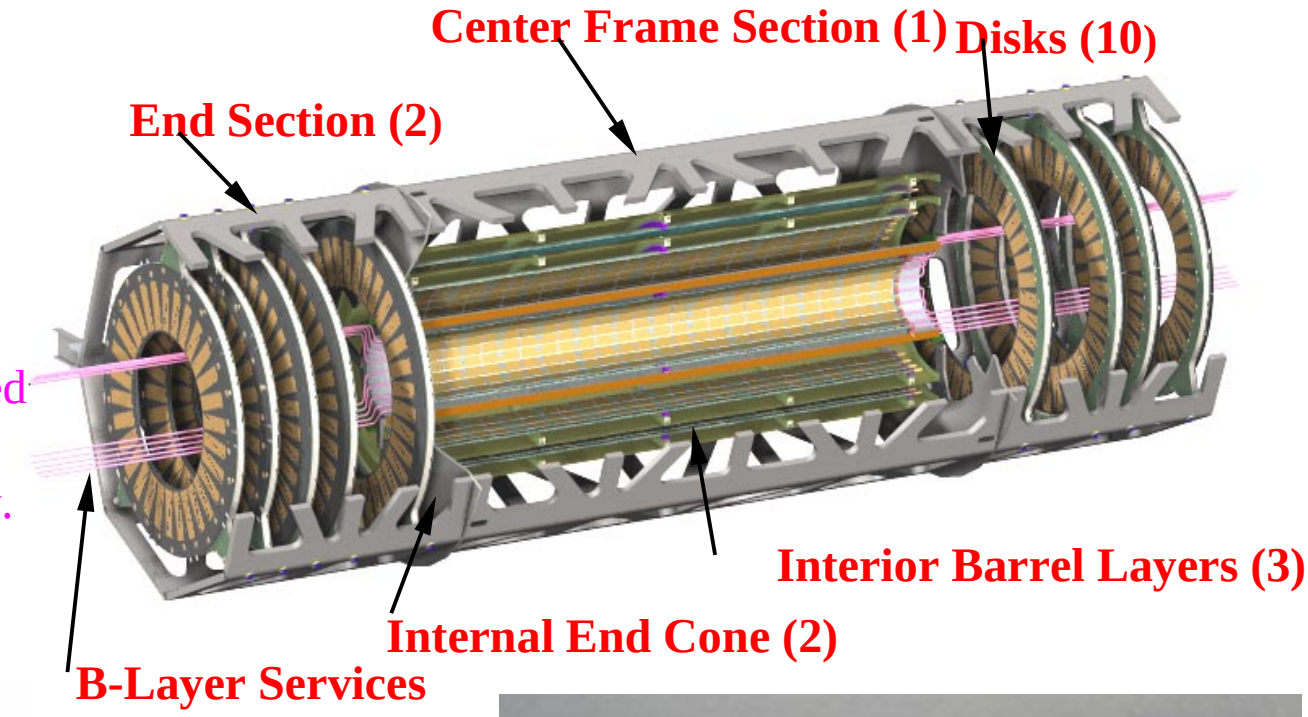
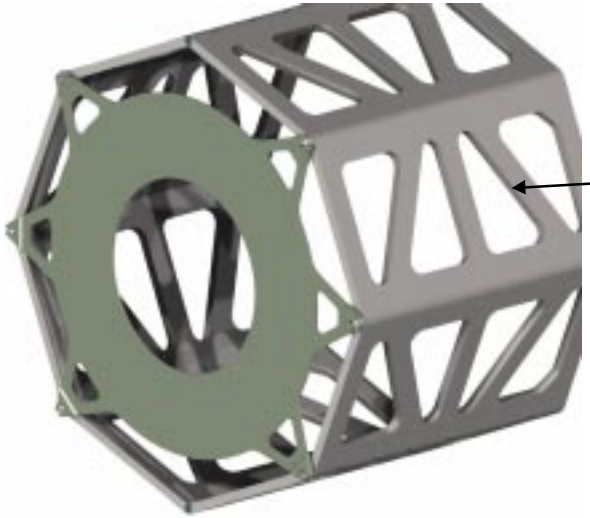
Prototype Frame Started

Physics Division

Tooling for prototype frame assembly is complete and assembly has started last month.

Prototype will be evaluated at LBNL and also to understand final assembly.





Physics Performance and Simulation

- ATLAS Detector and Physics Performance Technical Design Report was released in July 99 as two volumes.
- See http://atlasinfo.cern.ch/Atlas/GROUPS/PHYSICS/TDR/access.html
- Reviewed favorably by LHCC
- Ian Hinchliffe was co-editor
- Volume 1 summarizes performance as a whole, using combined systems
- Volume 2 provides overview of physics: QCD, electroweak, Higgs, t, b, supersymmetry and exotics
- It's impossible to do justice to a 1,000 page document - so I wont try.

Examples of Physics Reach

ATLAS Computing Generalities

- Large Data Volume
- Large, Globally Distributed Collaboration
- Long Lived (>15 years) Project
- Large (>2M LOC), Complex Analyses
- Distributed, Heterogeneous Systems
- Reliance on Commercial Software & Standards
- Evolving Computer Industry & Technology
- Object Oriented Programming
- Legacy Software
- Legacy Software Programmers(and physicists!)
- Limited Computing Manpower
- Most Computing Manpower are not Professionals

LBNL Computing People

- ATLAS Architecture Task Force (ATF)
  - Mandate: "specify the global architecture" ... "for data access, reconstruction, simulation, analysis & event display" ... "partitioning of the s/w effort into institutional commitments"
  - LBNL Members: David Quarrie, Marjorie Shapiro
  - Craig Tull - Member of use-case Sub-Group
- Ian is the manager of the Physics part of U.S. ATLAS computing
- US ATLAS Computing Advisory Group
  - LBNL Members: Ian Hinchliffe, Craig Tull

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What Are We Doing?

Physics Division

- **Physics simulation tools (Hinchliffe)**
  - **Coordinator of ATLAS Monte Carlo group**
  - **Develop and maintain physics generators**
  - **On US(and ATLAS) ends -> computing requirements**
- **Core software development**
  - **Working towards primary responsibility for ATLAS control framework(Tull, Calafiura, Leggett, Milford, Vacavant)**
  - **Critical, and early, part of software(Tull coordinating)**
    - **"Market Survey" of existing frameworks (eg. AC++, CARF, CLEO, D0, Gaudi, JAS, Object Nets, ROOT, StAF)**
    - **Object Networks vs Gaudi: Simulations Prototype - Laurent Vacavant**
    - **Control States on top of Object Networks: Test - Paolo Calafiura**
    - **Physics Transient Data Bus: Design - Paolo Calafiura**
    - **Analysis Objects (NTuples, Histos, etc.) Interface Layer - Charles Leggett**
    - **JavaCC/JavaTree IDL compiler - John Milford**

More Doing

- **Inner Detector Sofware**
  - **Vacavant US contact for pixels/SCT**
  - **Concentration on pixels so far**
  - **GEANT4 implementation, test beam**
  - **C++ “conversion”**
  - **But also ongoing studies using existing code to address immediate design issues eg. mechanical placement tolerances.**

Issues?

- Clearly we face many technical, cost and schedule challenges, but will focus here on local issues.
- Infrastructure
  - ATLAS follows on from very successful work on silicon detectors on CDF, D0 and BaBar and we are using or will use much of the infrastructure developed for these projects.
  - However, ATLAS is a larger scale and the pixel detector is new territory for us(and everybody else)
  - The Directorate has been very supportive(clean room renovations, equipment, IC design software,….) and we are close to having the complete infrastructure needed to cover all aspects of silicon detector design, fabrication and test, now for ATLAS but later for other projects.
  - But there are still needs in a few areas in which investment now will benefit all later
    - Space, equipment and personnel for composites engineering and fabrication.
    - Specialized inspection equipment(high resolution X-ray, flying probe,…)
- Technical personnel
  - Maintaining high quality engineering and other technical talent is a continuous challenge. This applies to mechanical and electrical engineering and software engineering.
- The combination of infrastructure, high quality engineering and physicists is what allows us to undertake large, and challenging, projects. We need all three.

Prototype Disk

- First mechanical and thermal prototype disk under construction now.
- Picture shows trial fit on temporary support frame.

Prototype Frame

- Prototype frame for disk region under construction now.
- Picture shows first two panels being joined on fixture.