Pixel and Simulation

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for the SLAC ATLAS Group

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Motivation for Simulation

- ATLAS needs.
  - Identified in discussions with ATLAS and US ATLAS as area of need where SLAC can make significant contributions, e.g.
    - Detector description.
    - Physics performance, e.g. hadronic response.
    - Technical performance, e.g. speed.
    - Background calculations.
- SLAC interests and strengths.
  - Geant4 expertise.
    - Geant4 collaboration since the beginning.
    - Major positions of responsibility in G4 collaboration, e.g. hadronic coordinator.
    - Extensive application level experience in BaBar, GLAST, LCD, etc.
  - FLUKA expertise in Radiation Protection group.
    - Long time core developer and users of FLUKA.
    - Crucial help and consultation to ATLAS.
- Synergy with user community.

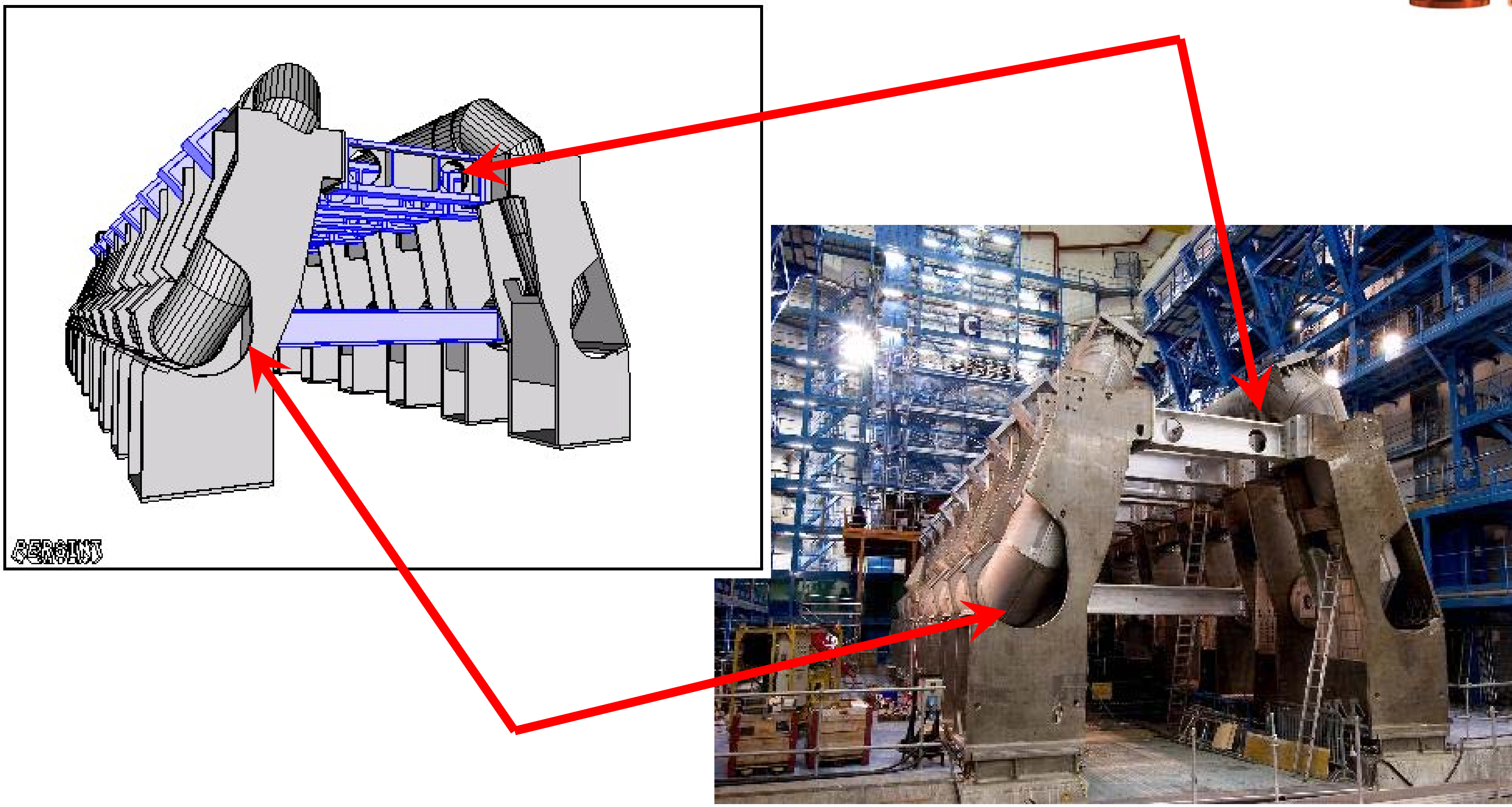
Simulation Activities

- Involvement from the beginning of SLAC participation in ATLAS.
  - Initiated parameterized shower effort and hosted workshop in November 2006 – project finished.
- Continued contributions since then, e.g.
  - Simulation Optimization Group – work finished.
  - Muon detector – few residual tasks.
  - Overlay validation – ongoing.
- Ramp up since 2008:
  - Tracker upgrade layout studies.
  - Cavern background.
  - Code optimization.
  - Co-convener of ATLAS simulation since 2009.

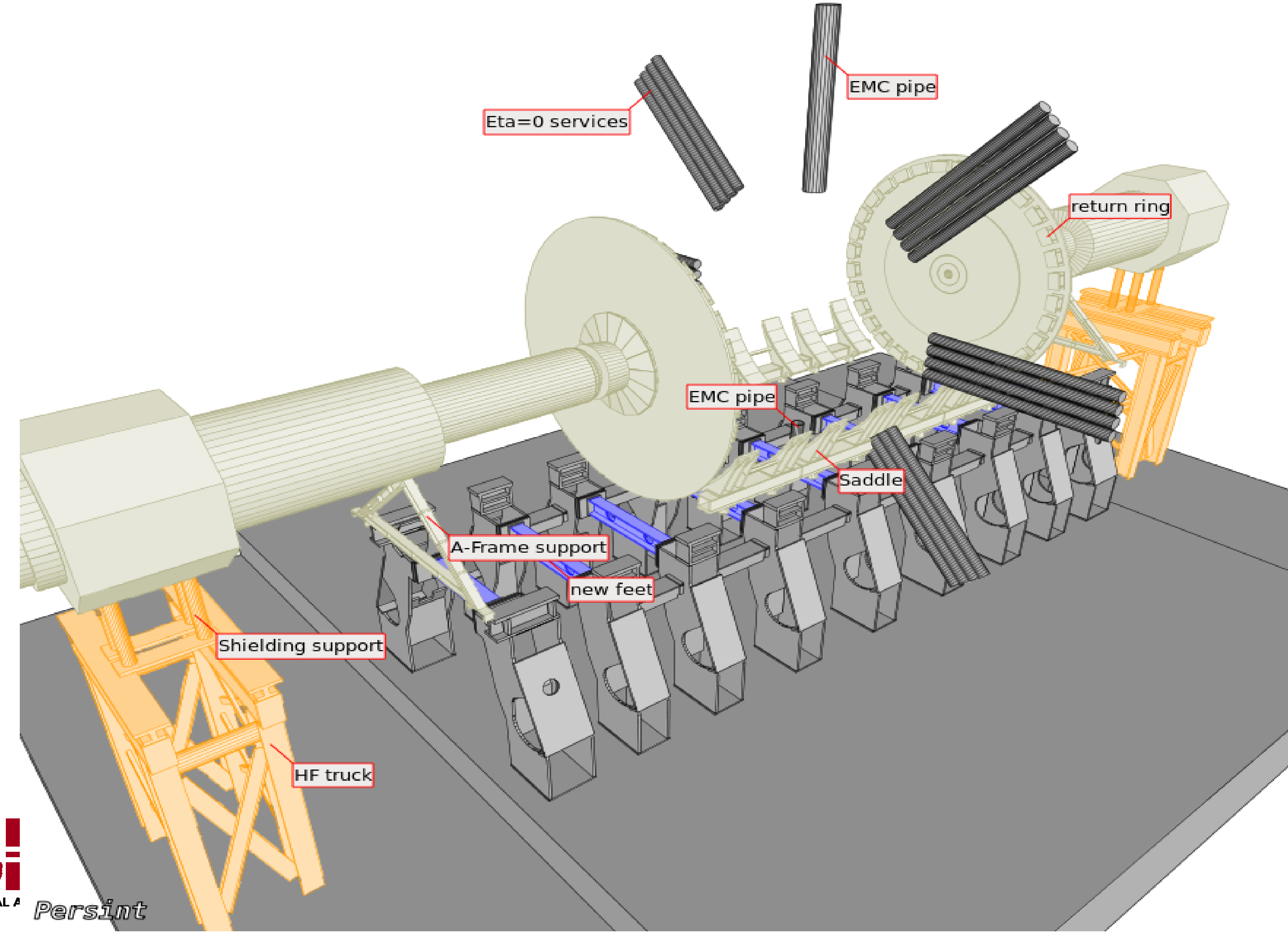
Muon Detector Simulation

- Geometry debugging and upgrades.
  - Removal of volume clashes.
  - Implementation of cut-outs.
    - Real detector is not made up entirely of regular shapes.
    - Cut-outs in detector to go around supports, alignment laser path, access ports, etc.
  - Add missing inert material.
- Performance improvements.
  - Reduce unnecessary volume hierarchy.
  - Replace string comparisons with faster code.
- Mentored newcomers to sustain this effort.
- SLAC personnel: Makoto Asai and Dennis Wright, in collaboration with muon group.

Example of Cut-Outs



Recently Added Inert Material



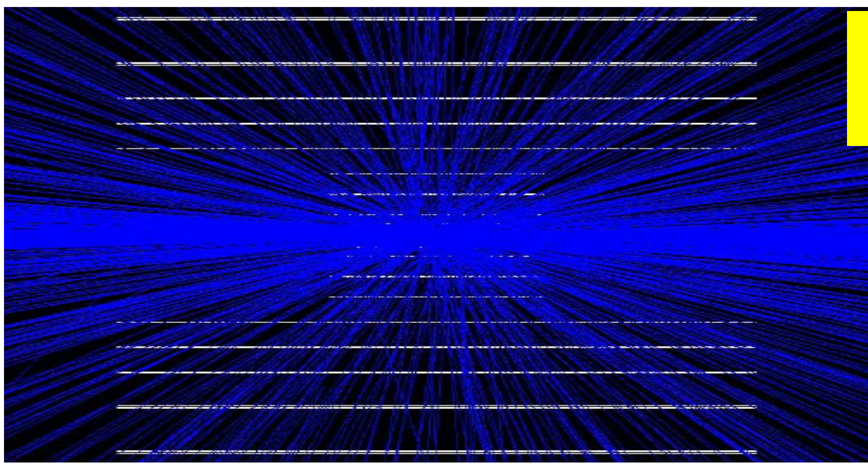
Tracker Upgrade Simulation

- Need to replace inner tracker for Super LHC.
  - Baseline is an all silicon tracker: pixels and strips.
  - See Su Dong's talk on upgrade for details.
- Several simulation tools available for layout studies.
  - Athena/Geant4 – based on standard ATLAS code.
    - LBNL, NIU, Oxford and UCSC
  - ATLSIM/Geant3 – from original design phase of ATLAS.
    - BNL and Bonn.
  - LCSIM/Geant4 – developed at SLAC originally for LCD design.
- LCSIM well suited for this task.
- SLAC personnel: Matthias Bussonnier[*], Elizabeth Fine[*], Matt Graham, Tim Nelson and Rich Partridge.

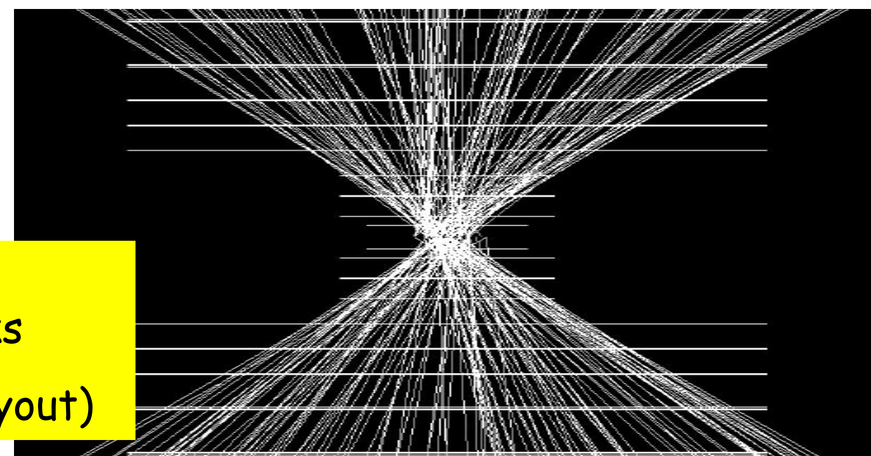
[*] undergraduate students

Tracker Upgrade Simulation

- LCSIM combines flexibility with standard Geant4 toolkit.
  - Easily modified geometry.
    - New geometry in studies implemented within a day.
  - Geant4 simulation + detailed detector response models.
  - Geometry driven tracking finding.



r-z distribution of generated tracks (p_T > 1 GeV) at $L = 2.5 \times 10^{34}$

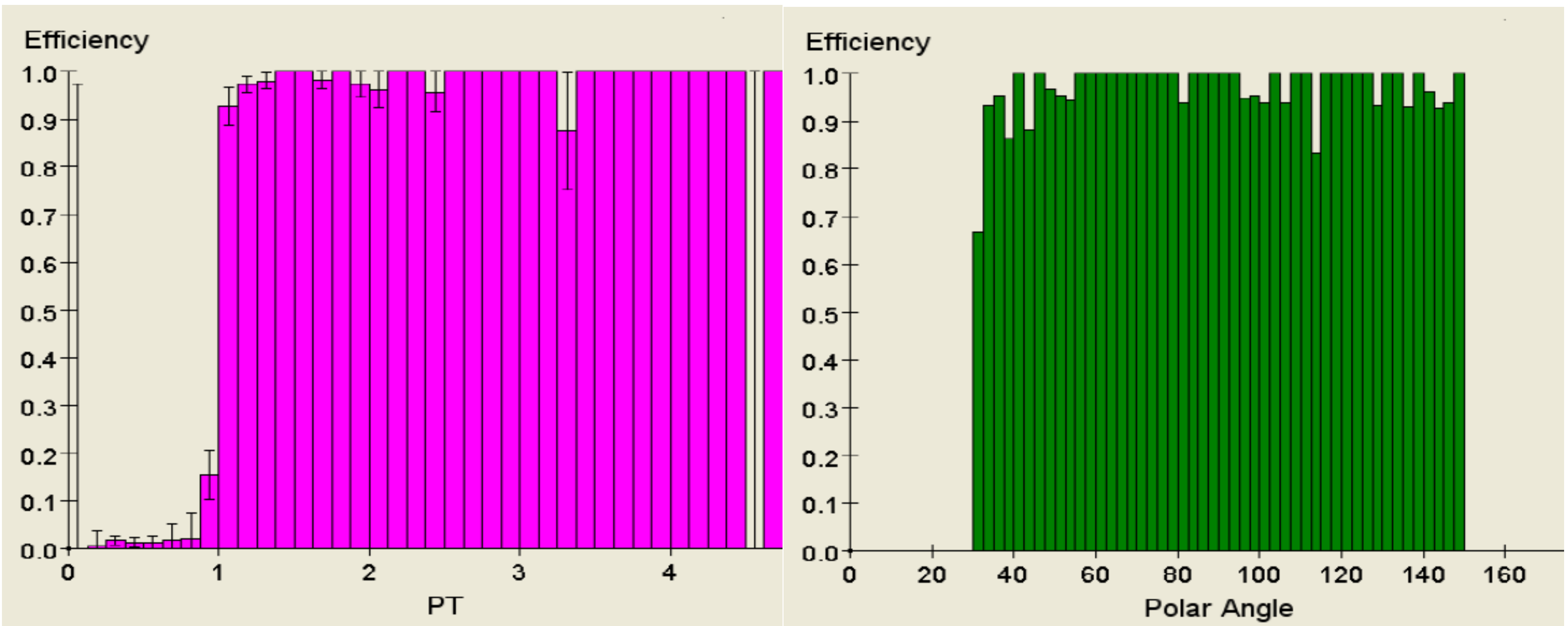


r-z distribution of reconstructed tracks

(no endcap in this layout)

Tracker Upgrade Simulation

- Regular interaction with other groups to cross check.
  - Detector occupancy.
  - Tracking efficiency and fake rate.
- Plan to host next workshop at SLAC in August.



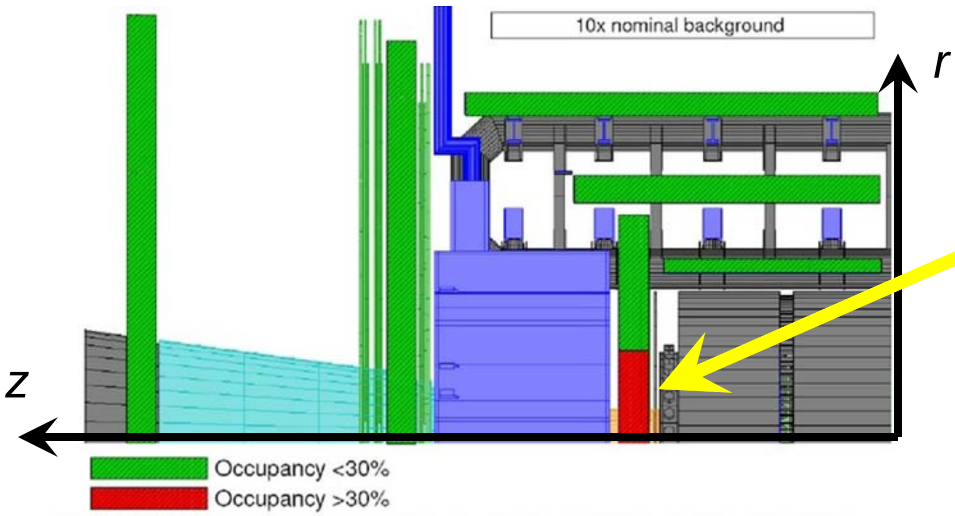
LCSIM: tracking efficiency at $L = 10^{35}$

NATIONAL ACCELERATOR LABORATORY

Cavern Background

- Interaction of *p*-*p* collision products with detector and beam line results in a "gas" of background particles (mostly low-energy neutrons and γ).
  - Radiation damage.
  - Increased occupancy, fake tracks and triggers.
- Radiation Background Task Force (RBTF) report in 2005.
  - Now obsolete detector and beam line geometries.
  - Large uncertainties (up to 5x).
  - Correspondingly large range of muon upgrade scenarios for SLHC.

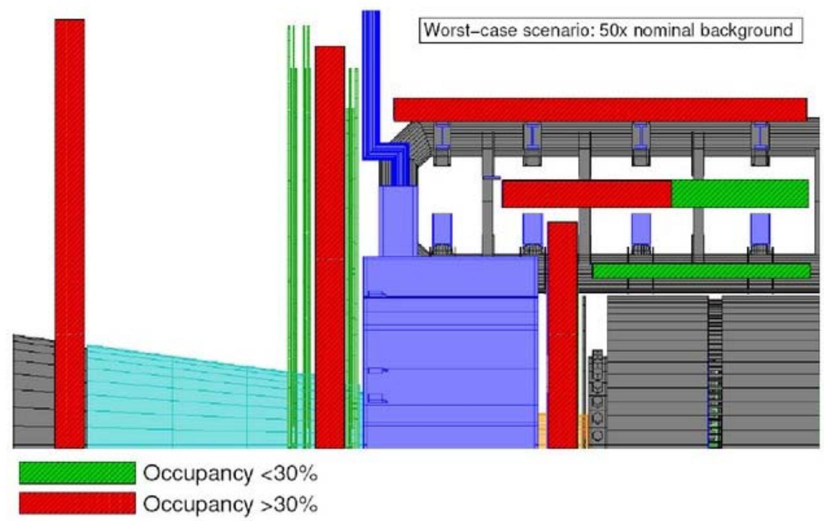
Range of Muon Detector Upgrades



At least half of the chambers in the inner end-cap disk would have to be replaced by chambers with higher high rate capability.

Replace only inner endcap chambers if background is at low end of RBTF estimates.

Replace almost all chambers if background is at high end of estimates.



Almost all chamber would have to be replaced.

Cavern Background

- New effort initiated in March 2009 at request of ATLAS Spokesperson.
- Progress and plans:
  - Move away from Geant3 for maintenance reasons.
    - FLUGG combines Geant4 geometry with FLUKA physics.
  - First comparison with RBTF encouraging.
  - Workshop planned for late July.
    - Make detailed cross checks with RBTF.
    - Implement geometry for beam start-up in 2009.
  - Compare with collision data.
  - Project to SLHC luminosity and detector + shielding layout.
- SLAC personnel: Alberto Fasso (Radiation Protection group), Norman Graf, Tatsumi Koi and Dennis Wright, working closely with David Brown (Louisville), Andrea Dell'Acqua (CERN).

Code Optimization

- Large impact even for modest improvements.
  - ATLAS spends ~$10M / year on CPU, and comparable amount on storage.
- Simulation takes ~20 minutes CPU time per physics event.
  - Optimization of ATLAS application.
  - Trade off accuracy vs speed when appropriate, e.g. frozen shower library.
  - Develop new Geant4 capabilities, leveraging SLAC's core expertise.
  - Gains sometimes offset by greater physics details.
- Each (Z → qqbar) event occupies ~1.2 MB on disk.
  - Intelligent compression of Transition Radiation Tracker (TRT) hits reduced its size by factor of 4 without any loss of physics.
    - Work done by Andrew Beddall (University of Gaziantap).
  - Overall events size reduced almost factor of 2.
- Management role to drive these efforts.
- SLAC personnel: Makoto Asai, Dennis Wright and CY (fostering TRT work).

Simulation Plans

- Direct involvement.
  - Upgrade studies, cavern background, etc.
  - New topics.
- Foster and coordinate broad based improvements.
  - CPU and storage optimizations.
  - Ease of use: common user interface for various flavors of fast and full simulation.
  - Scalability for lifetime of ATLAS: tracking detector conditions.

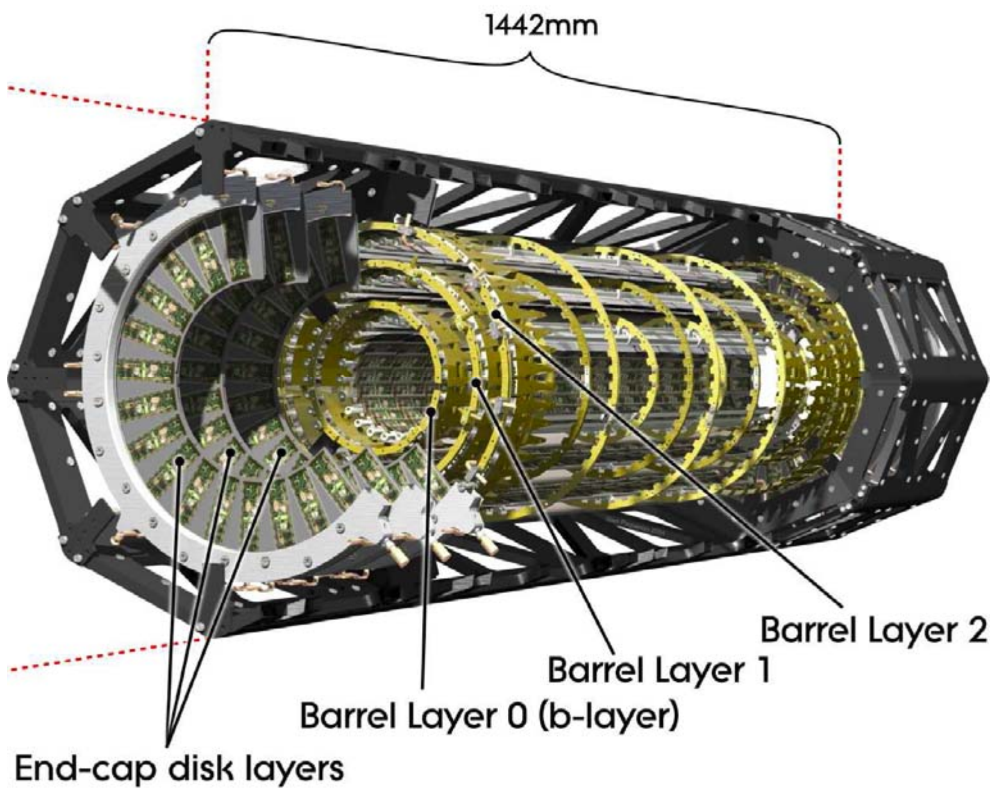
Motivations for Pixel Involvement

- ATLAS needs.
  - Discussions with ATLAS and US ATLAS identified this as an area to contribute.
- SLAC interests and strengths.
  - *b*-tagging in SLD and D0.
  - Experience and interest in silicon detectors.
    - MK-II, SLD, BaBar and GLAST at SLAC.
    - Experience on other experiments, e.g. CDF.
    - SiD design and development.
- Synergy with user community, e.g.
  - Close working relationship with LBNL and UCSC on ATLAS.
  - Future silicon detector such as SiD.

Pixel Work

- Started working before formally joining ATLAS.
  - Module testing at LBNL.
- Assembly and commissioning at CERN.
  - Assembly, repair and installation.
  - Commissioning tests.
  - Monitoring of detector conditions.
  - Digital Signal Processor (DSP).
  - Analysis Framework.
  - In-situ crate by crate timing.
  - Tracking studies.
  - Alignment.
  - Monitoring Coordinator and Run Coordinator roles.

ATLAS Pixel Detector

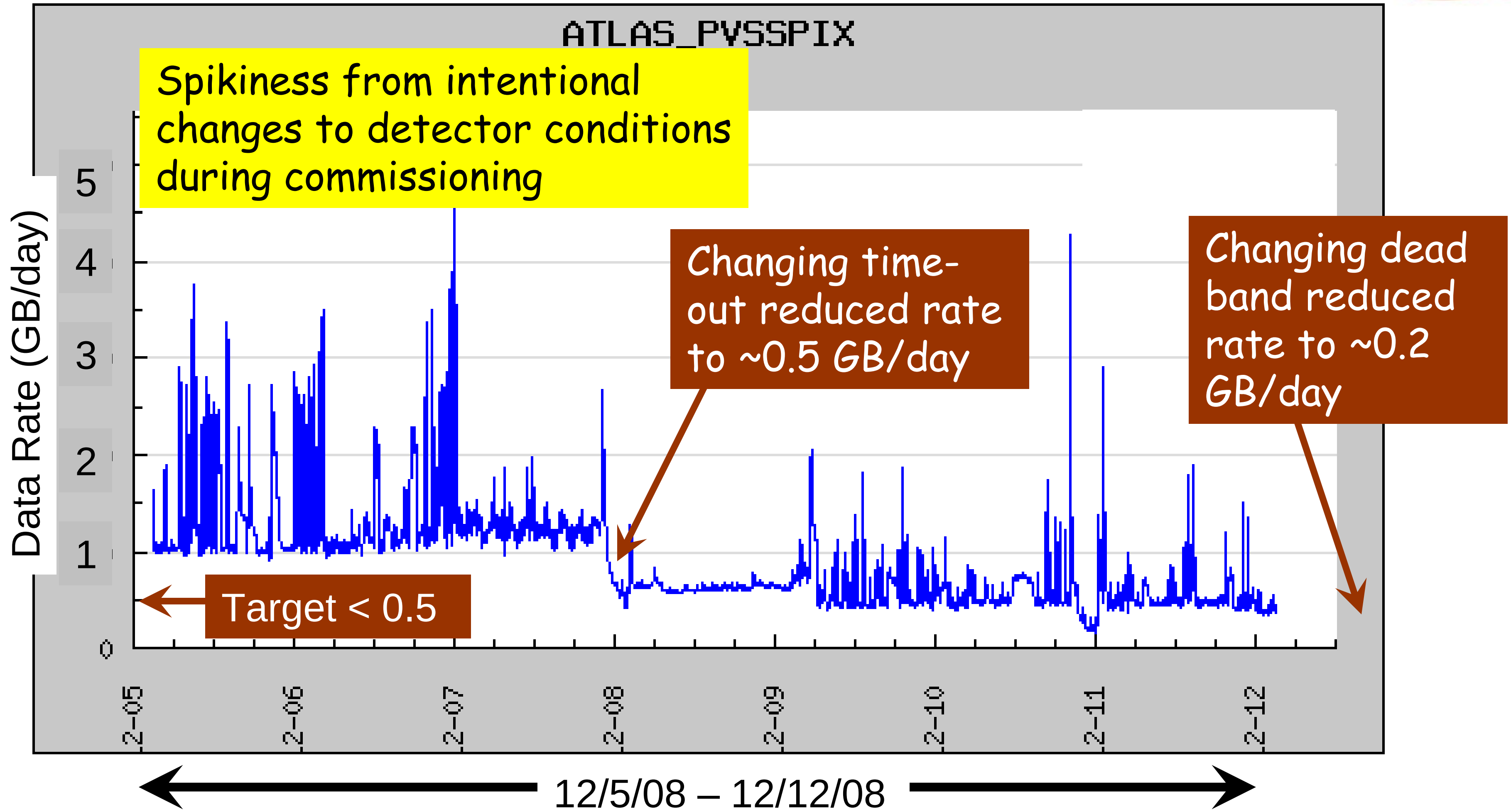


Barrel			
Layer	r (mm)	Modules	Pixels (10^6)
0	50.5	286	13.2
1	88.5	494	22.8
2	122.5	676	31.2
One Endcap			
Disk	z (mm)	Modules	Pixels
1	495	48	2.2
2	580	48	2.2
3	650	48	2.2
Barrel + Both Endcaps			
		Modules	Pixels
Total		1744	80.4

DCS Monitoring

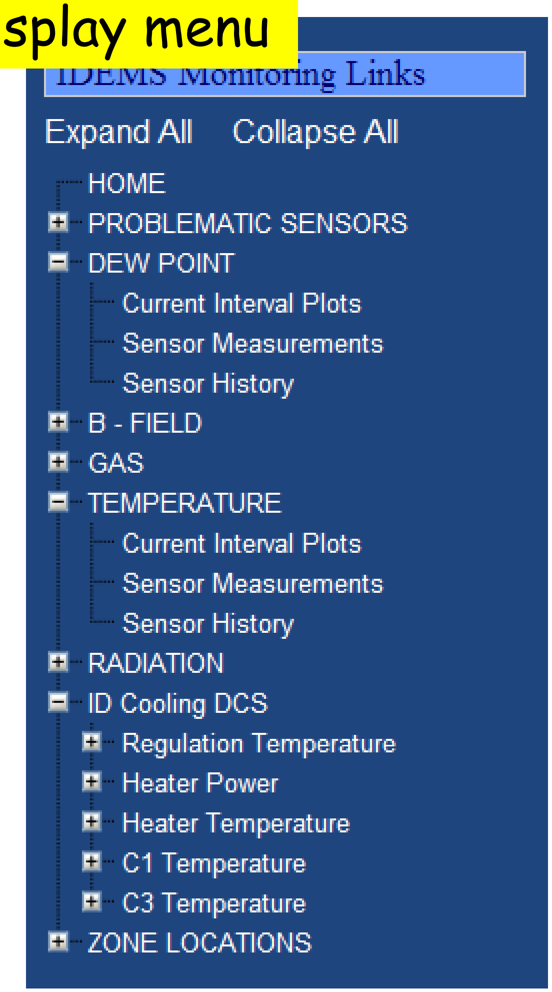
- Detector Control System (DCS) monitors and archives temperature, humidity, voltages, currents, etc, as a function of time.
- Data volume presents two major challenges.
  - Total volume to be archived is large.
    - Tune "dead band" and "time out" parameters to reduce data volume without sacrificing information.
  - Difficult to have overview with 1000's of numbers.
    - Automated web based displays.
    - Time-line plots, geographically grouped and logically grouped.
- SLAC personnel: Claus Horn and CY (supervising Lawrence Carlson from Cal State Fresno).

Reduction in DCS Archive Volume



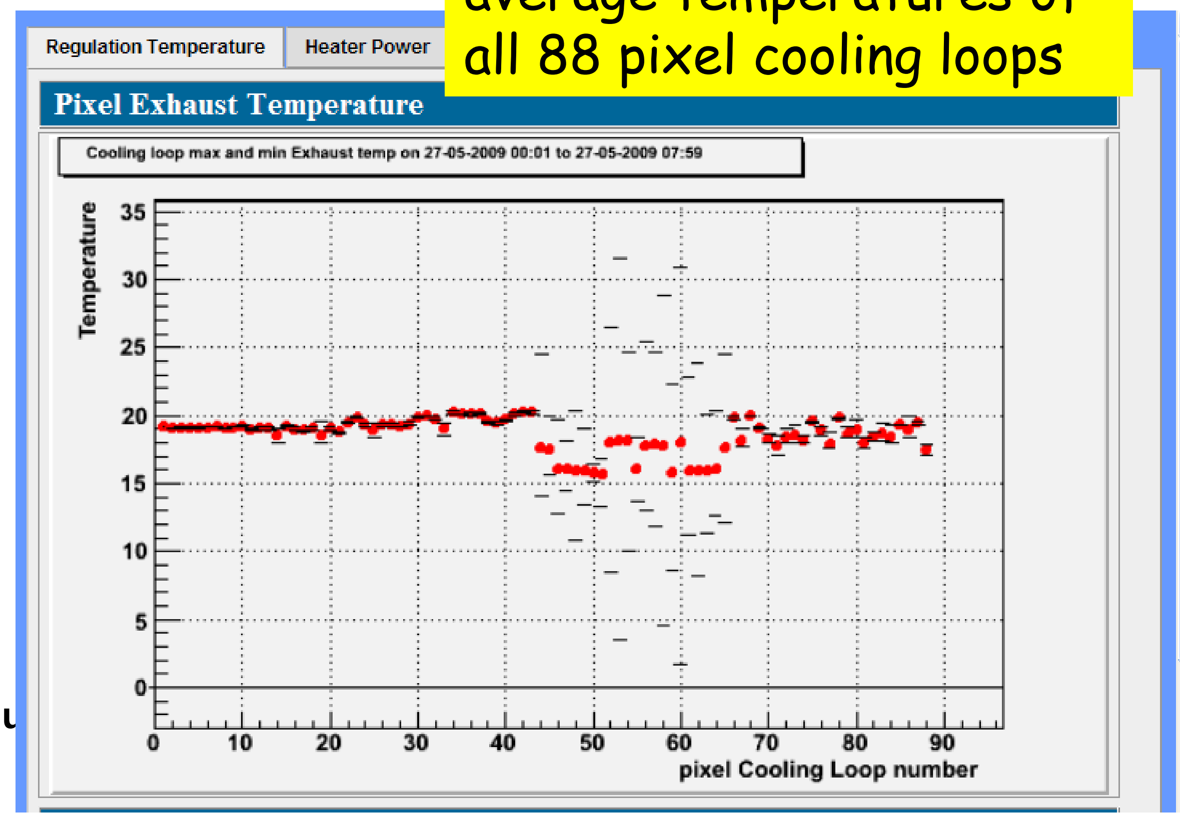
Environment Monitoring Example

Display menu



Work done by Lawrence Carlson (Cal State Fresno)

Minimum, maximum and average temperatures of all 88 pixel cooling loops



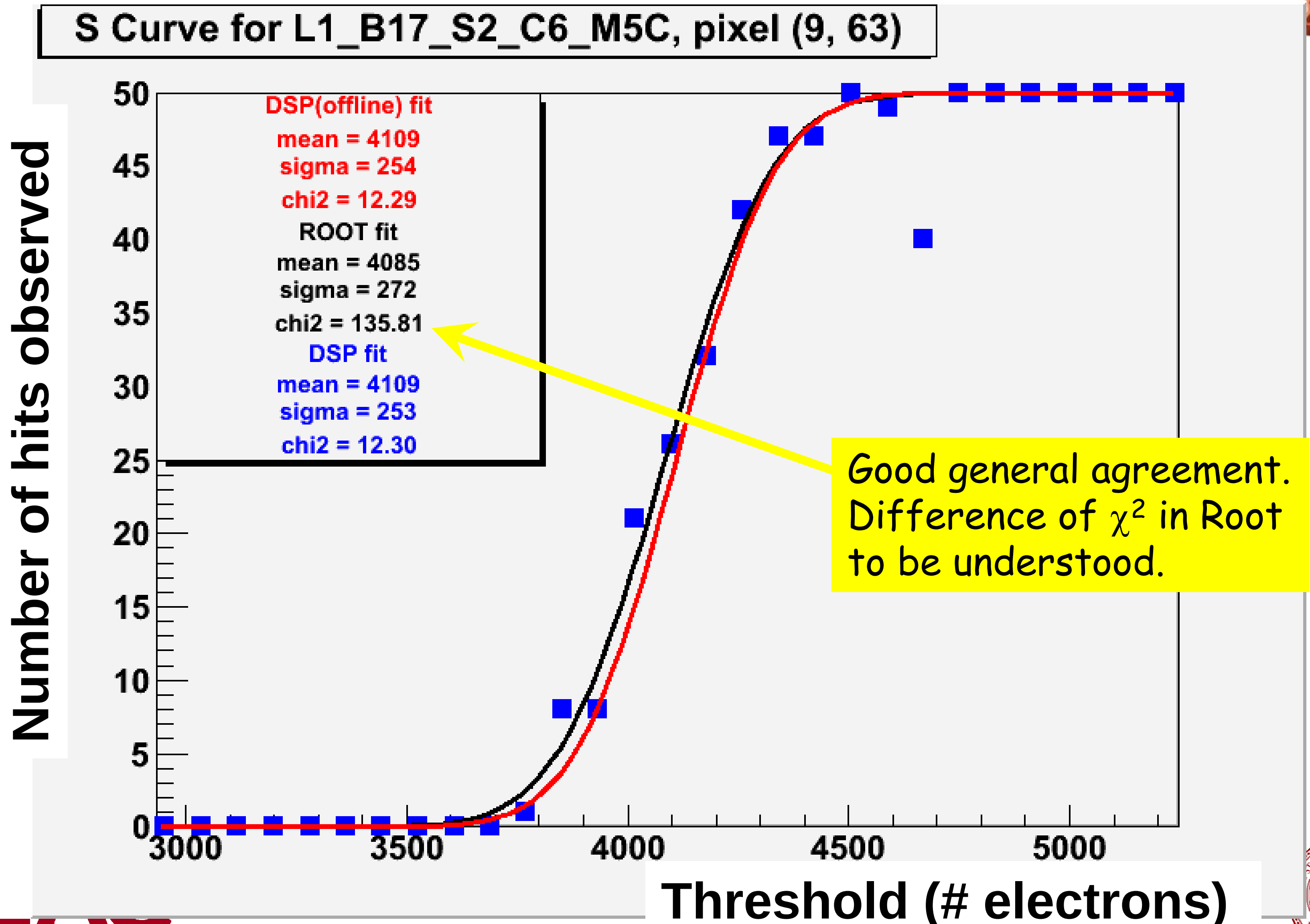
DSP

- Digital Signal Processors (DSP) crucial element in data path.
  - Format and transmit data.
  - Pixel detector calibration function.
- HW issue: Test stands crucial to development and testing.
  - Moved a test stand to SLAC, and revived the system.
  - Now supports test stands at CERN and LBNL.
- SW issue: Greater productivity from code clean-up and better development environment.
  - Facilitate development on Linux. Reduce reliance on unfamiliar and difficult environment of DSP.
  - Embedded time profiling tools and code optimization.
    - Calibration scans now run up to 4x faster.
- Manpower issue: Sustainable long term support by SLAC technical staff instead of rotating post-docs and students.
- SLAC personnel: Paul Jackson, Daniel Silverstein and Matthias Wittgen, working with Alex Schreiner (Iowa) and others.

Example of Threshold Calibration

- Calibration procedure:
  - Set threshold, inject signal and look for hit.
  - Fit # hits vs threshold with error function or s-curve.
- Compare three s-curve fits:
  - Performed by DSP.
  - Ported DSP code to Linux environment.
  - Re-implement algorithm in Root.
  - Very similar results. Some small differences to be understood.
- Impact on development:
  - Root environment allows convenient development of <u>algorithms</u>.
  - DSP code on Linux facilitates development of <u>code</u>.
  - Minimize work in the difficult environment of DSP.

S-Curve Fits



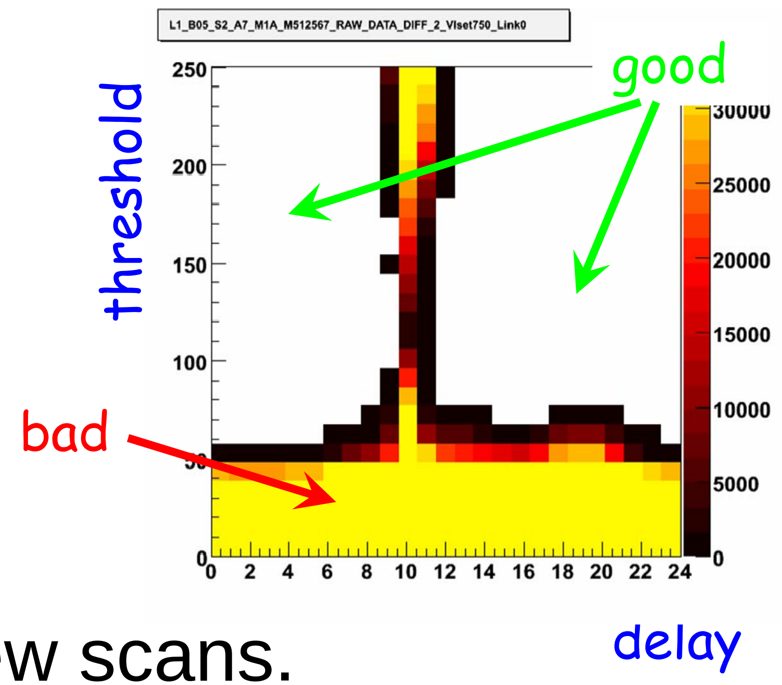
S Curve for L1_B17_S2_C6_M5C, pixel (9, 63)
DSP(offline) fit
mean = 4109
sigma = 254
chi2 = 12.29
ROOT fit
mean = 4085
sigma = 272
chi2 = 135.81
DSP fit
mean = 4109
sigma = 253
chi2 = 12.30
Number of hits observed
Threshold (# electrons)
0
5
10
15
20
25
30
35
40
45
50
3000
3500
4000
4500
5000
Good general agreement.
Difference of χ^2 in Root
to be understood.

Analysis Framework

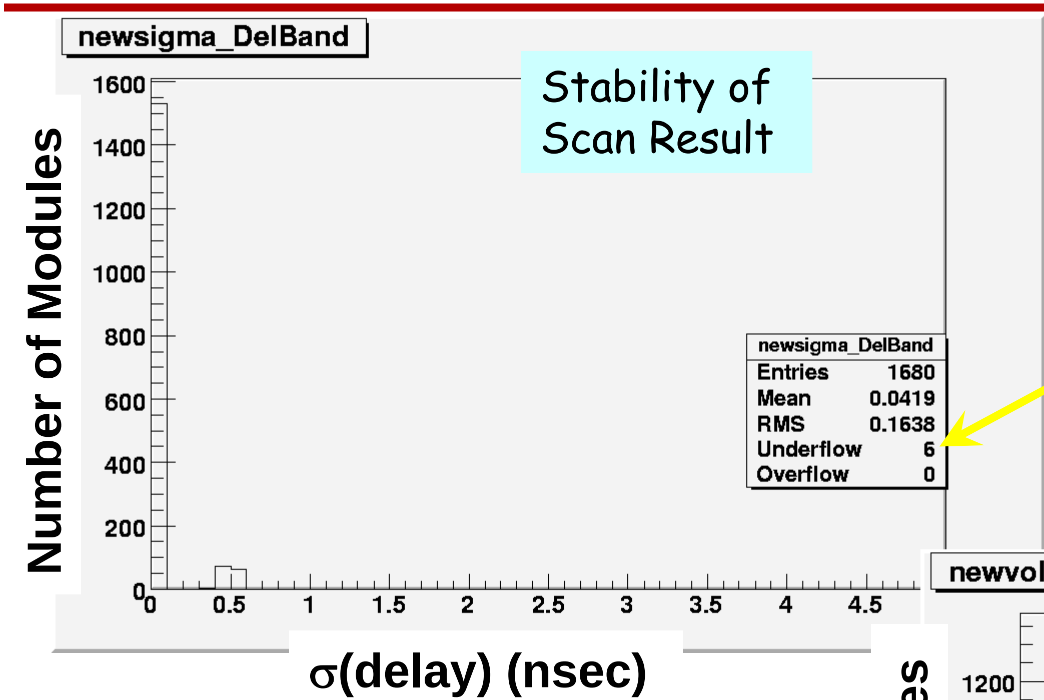
- Calibration of threshold, time over threshold (ToT), etc.
  - Frequent scans especially during commissioning.
- Online tool designed to look at one scan at a time.
- Need a flexible tool for analysis.
  - Combine multiple runs, e.g. 4 runs, one for each quadrants.
  - Variation between two or more runs for stability study.
  - Long term trends.
  - Selection of pixels, e.g. outliers for detailed examination.
    - Out of 80 10^6 pixels.
- Analysis Framework.
  - Developed to enable these studies.
  - Widely used by pixel community.
- SLAC personnel: David Miller, Ariel Schwartzman.

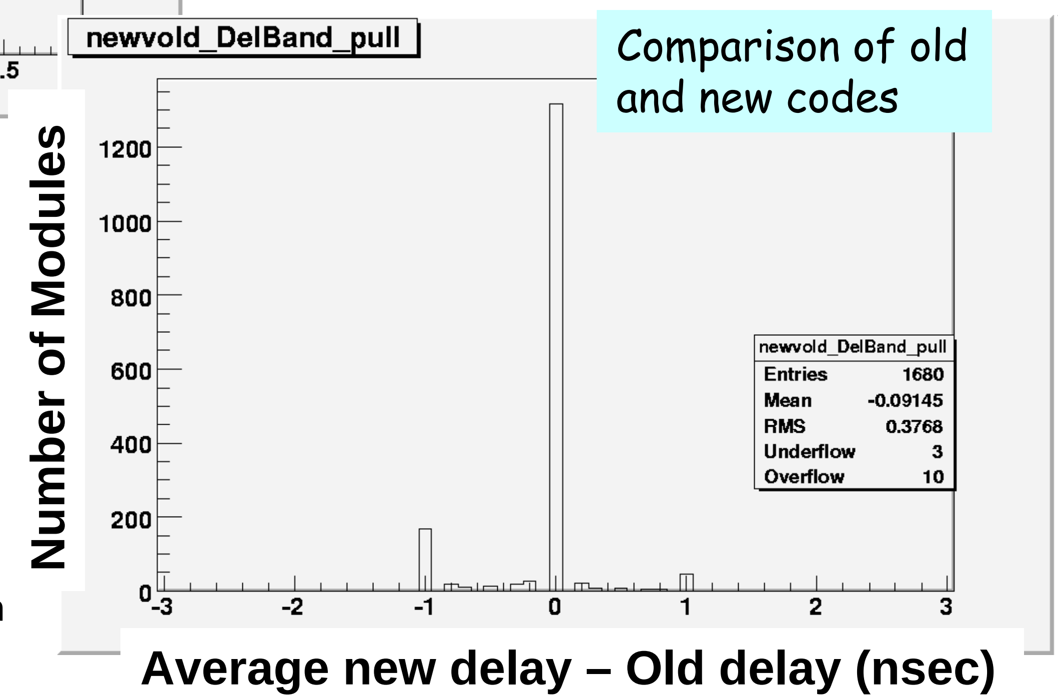
Example of BOC Scan

- Back of Crate (BOC) card receives optical signal from the detector.
- Performance depends on:
  - Delay.
  - Threshold.
- One scan using old code.
- Six scans using new code.
- Examine stability within 6 new scans.
- Compare average of new scans with old scan.



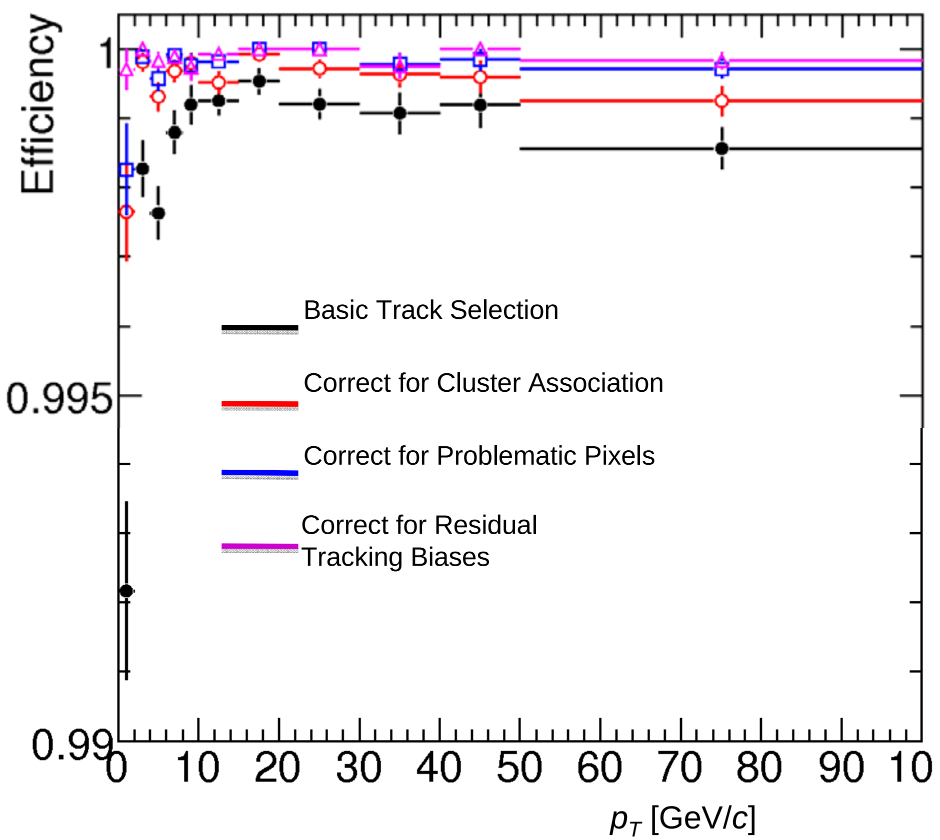
Analysis Framework Examples





Understanding Tracking Efficiency

- Cluster on track $\varepsilon > 99.8\%$.
- Clean cosmic data sample.
  - Multiple BC, i.e. no timing issues.
  - Single track events.
  - $O(10^{-10})$ pixels noise occupancy (after masking few noisy pixels).
- Detailed studies to understand small residual inefficiency:
  - Track fitting criteria. (black → red)
  - Dead pixels. (red → blue)
  - Tracks with poor constraints in SCT and TRT. (blue → magenta)
- Now consistent with 100%.
- SLAC personnel: Michael Wilson.



Pixel Plans

- Continuation in operational roles, including:
  - Remote monitoring.
  - Alignment studies.
- DSP support and development, e.g.
  - Detector calibration algorithms.
  - High-rate monitoring of data quality.
- Growing involvement in tracking and vertexing.
  - Beam spot.
    - See Rainer Bartoldus's talk.
  - Connection with physics tools.
    - See Ariel Schwartzman's talk.

Summary

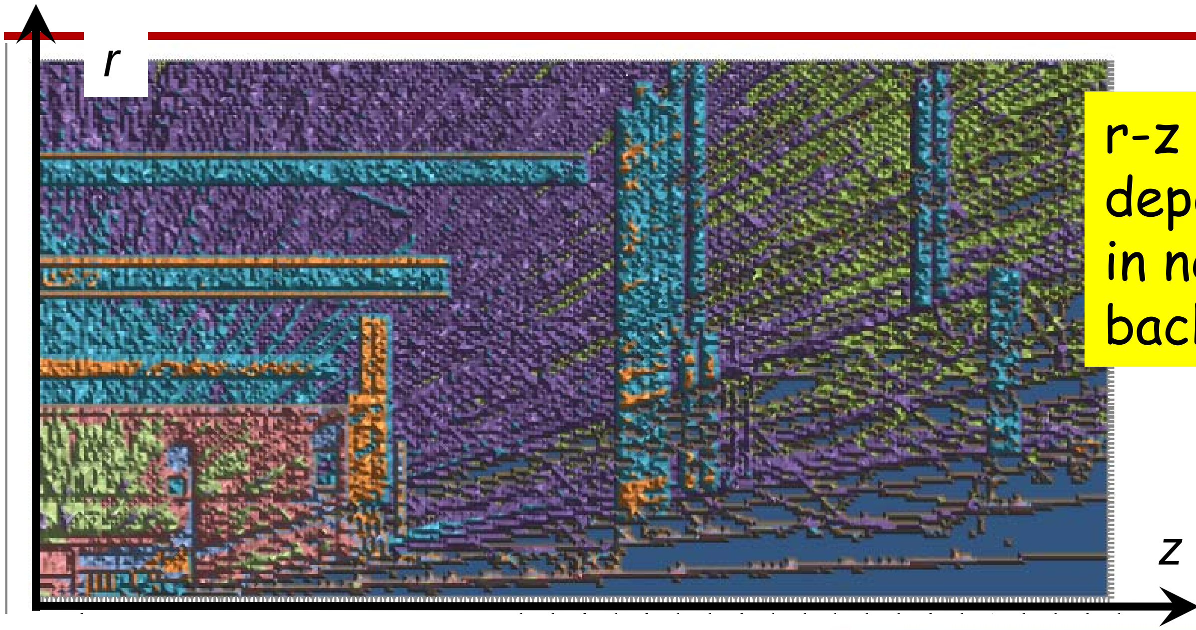
- Involvements in pixel and simulation motivated by:
  - ATLAS needs.
  - SLAC interests and strengths.
  - Synergy with user community.
- Major contributions and leadership roles.
- Continue engagement.
  - Guided by the same principles.
  - Moving in the direction of data and analysis.
    - For example, tracking and *b*-tagging.

Additional Slides

Overlay Validation

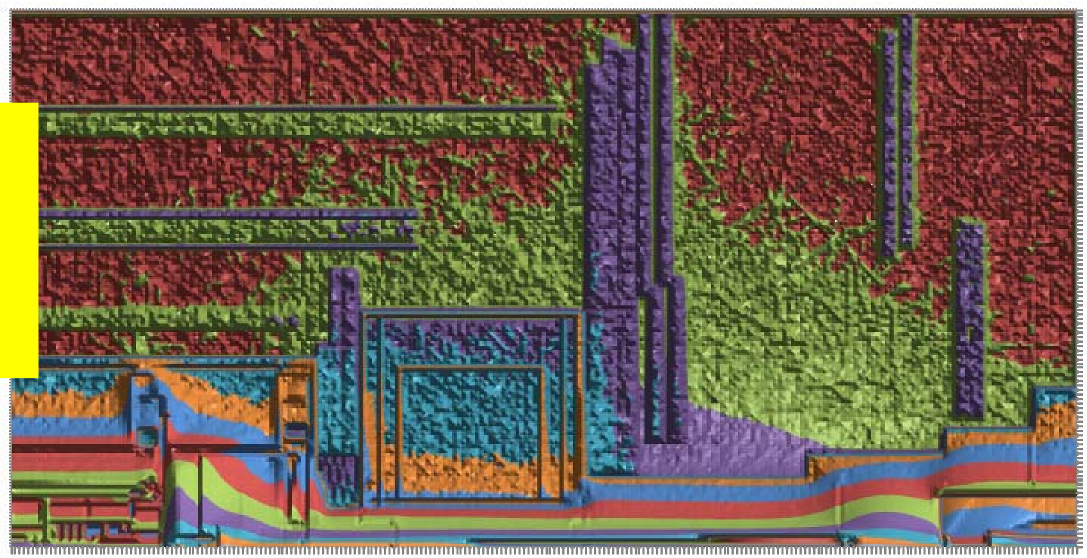
- Simulation typically treats one (hard scattering) event, while there are ~20 interactions per beam crossing at design luminosity.
- Overlay is the process of superimposing these additional events onto the one event.
  - Use simulated minimum-bias events before real data is available.
  - Same technology can be used to imbed other topologies for special studies, e.g. single track.
- Validation framework applicable to all sub-systems.
- Validation studies of muon detectors.
- SLAC personnel: Mike Kelsey and Peter Kim, working closely with Bill Lockman (UCSC).

First Results from New Calculation



r-z map of energy deposition from 1 TeV μ in new cavern background calculation.

r-z map of energy deposition in 7+7 TeV p-p collisions (from RBTF).

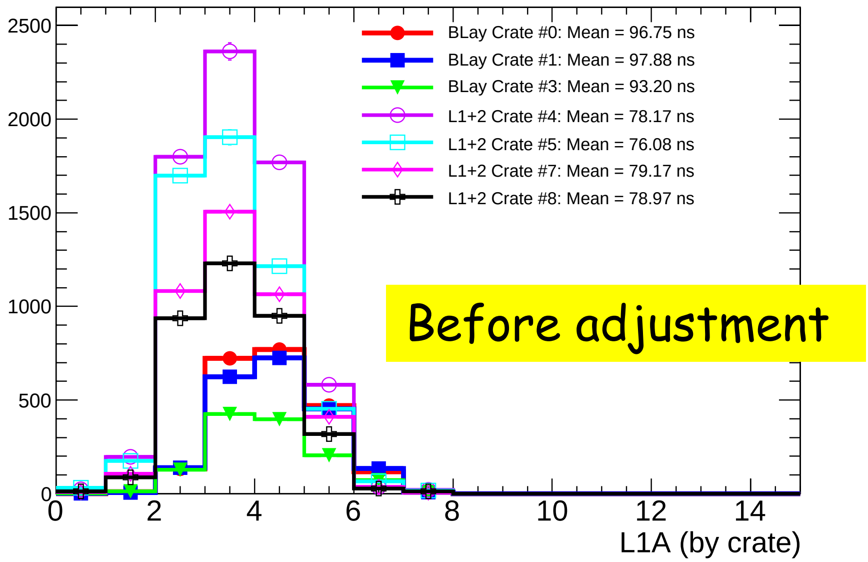


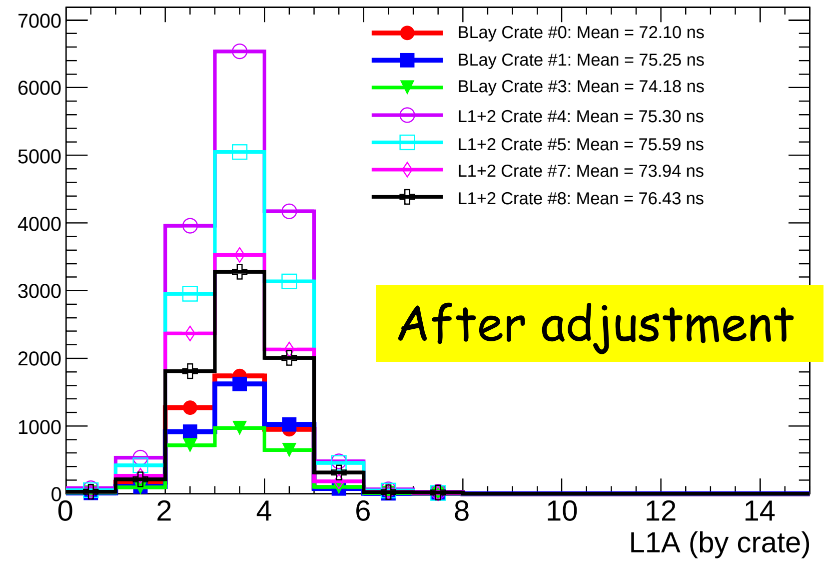
Crate by Crate Timing

- Read-out system can read out multiple bunch crossings (BC) per trigger.
  - Useful during commissioning.
  - Increased data volume.
  - Goal is to align all read-outs to within one BC, i.e. 25 nsec.
- One component is crate to crate difference.
- Determined in two independent ways.
  - Cosmic ray events.
  - Measurement of trigger signals.
  - Results are consistent.
- SLAC personnel: David Miller.

Improvement in Crate Timing

- Use clusters on cosmic tracks.
- Plot time distribution by crate.





Time in 25-nsec units

Alignment Studies

- Most studies use tracks from IP.
  - (Near) Degenerate solutions are likely.
- Cosmic rays provide different constraints but typically low rate and vertical.
- Offset IP at z = +/- 37.5 cm.
  - "Easily" done in LHC by injecting off by 1 RF bucket.
  - Different constraints.
  - Complement (not replace!) normal IP and/or cosmic.
  - Work is in investigatory stage.
    - Found some unexpected results with normal alignment already.
- SLAC personnel: Bart Butler.

Offset IP Collisions