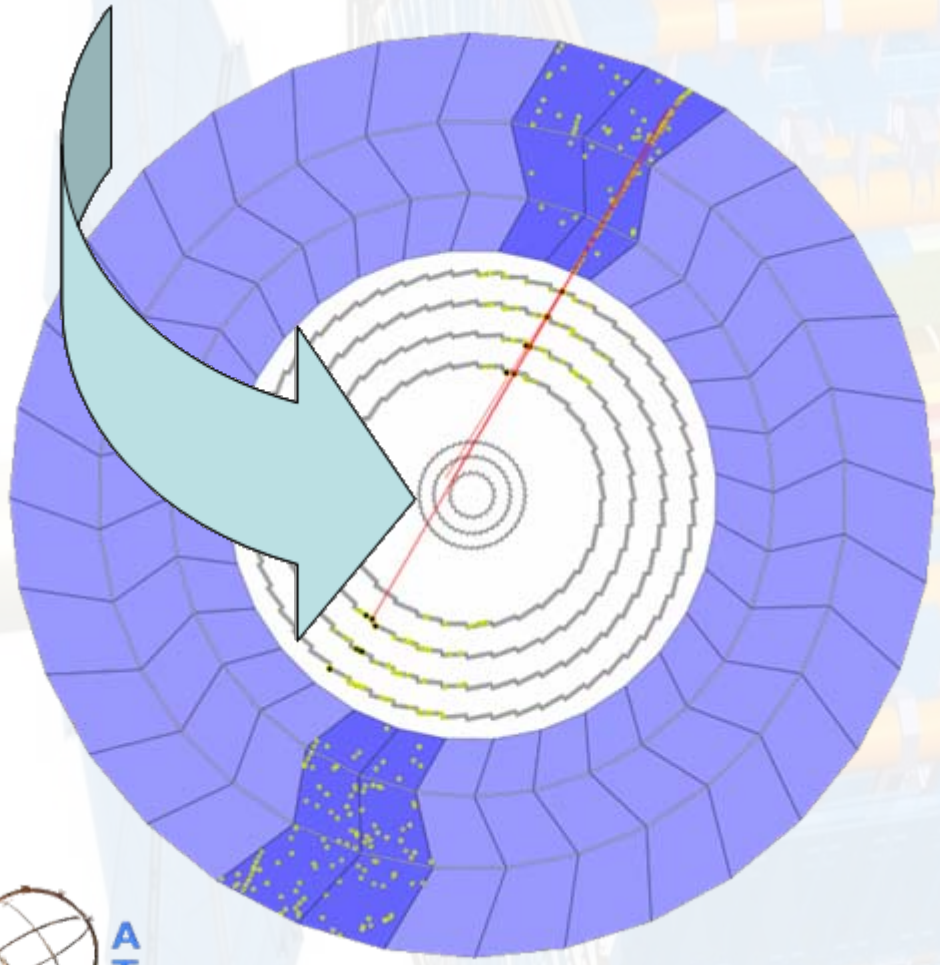
Commissioning of the ATLAS Pixel Detector with Cosmic Data, Present Status, and the First Look at LHC Collisions



- Overview
  - A Brief Introduction
  - LHC and ATLAS
  - Pixel Detector
- Commissioning
  - Pixel Opto-heaters
  - Slow Controls
- Device Readout
- Calibration
- Cosmic Runs
- ATLAS Recent News
- Summary

Dr. Evgeny Galyaev
On behalf of the ATLAS Collaboration

March 22, 2010, for the BROOKHAVEN NATIONAL LABORATORY RHIC relativistic heavy ion collider

Introduction and the Talk Outline

1976: Born in Protvino, Russia

1992/93: Trip to the US - the SSC

SSC

First chance to see a HEP project of such an unprecedented scale!...

1993/99: Moscow State University

1996/99: MSU/IHEP Institute

IHEP ИФВЭ

1999/06: University of Notre Dame

- Fiber Tracker
- PhD work
- b-tagging

2001/06: Working at Fermilab

2006/09: Joined ATLAS at CERN

- Pixel Detector installation, commissioning
- Building the pixel opto-heater system
- Inner Detector work: new heater electronics

ATLAS

In this talk:

LHC and ATLAS: General overview ATLAS Pixel Detector	Pixel Detector: Commissioning Pixel Opto-heaters	Pixel Detector Operation: Calibration Procedures Cosmic Runs, Very First Data

?

ATLAS: Overview

ATLAS: A Toroidal LHC ApparatuS

- 44m long
- 22m high
- 7K tons heavy

Muon Detectors
The "Big Wheels"

Tile Calorimeter

Liquid Argon Calorimeter

y
x
z

Side C

Side A

Toroid Magnets
~ 4 Tesla at coil,
~ 1 Tesla average

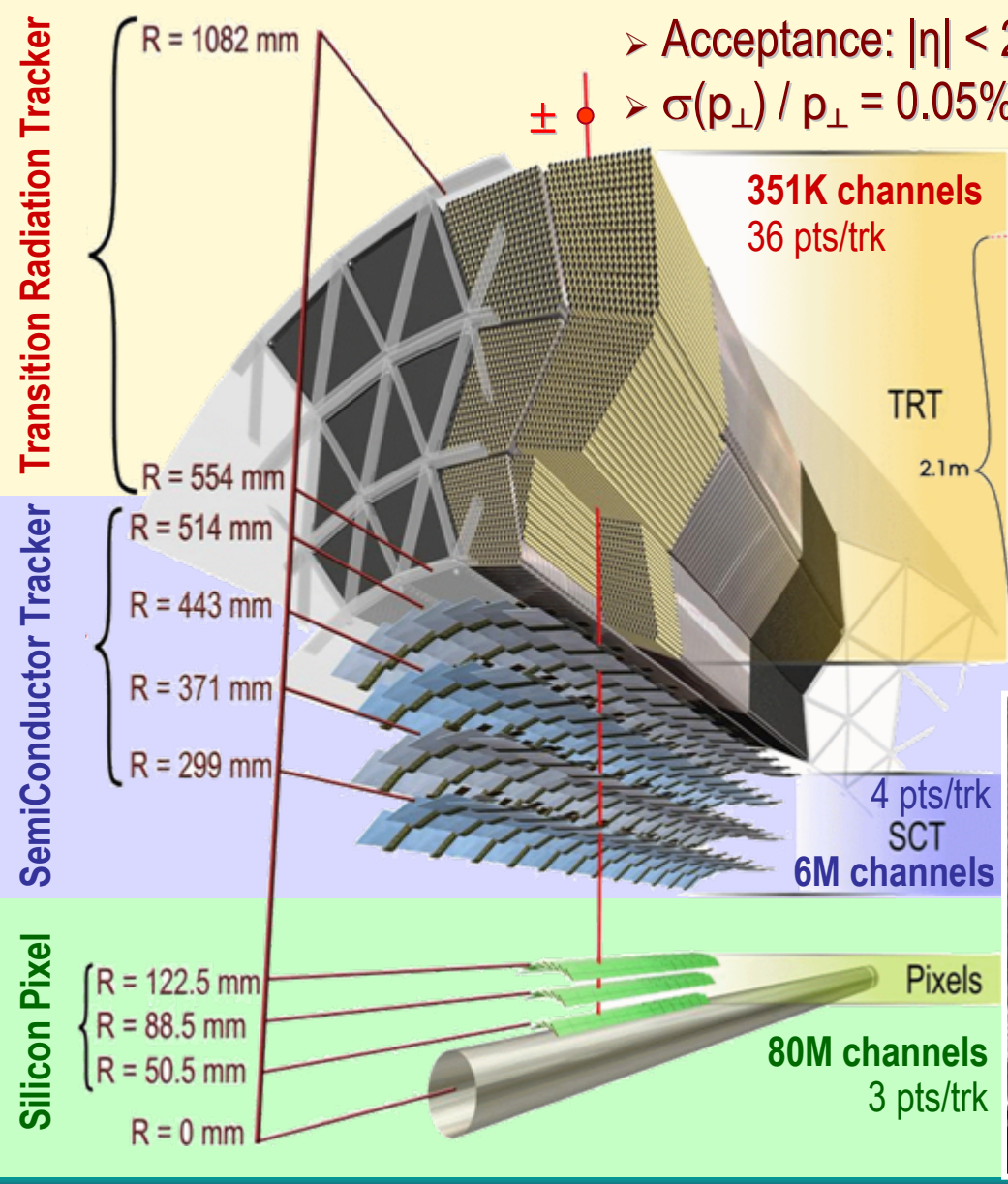
Solenoid Magnet
~ 2 Tesla

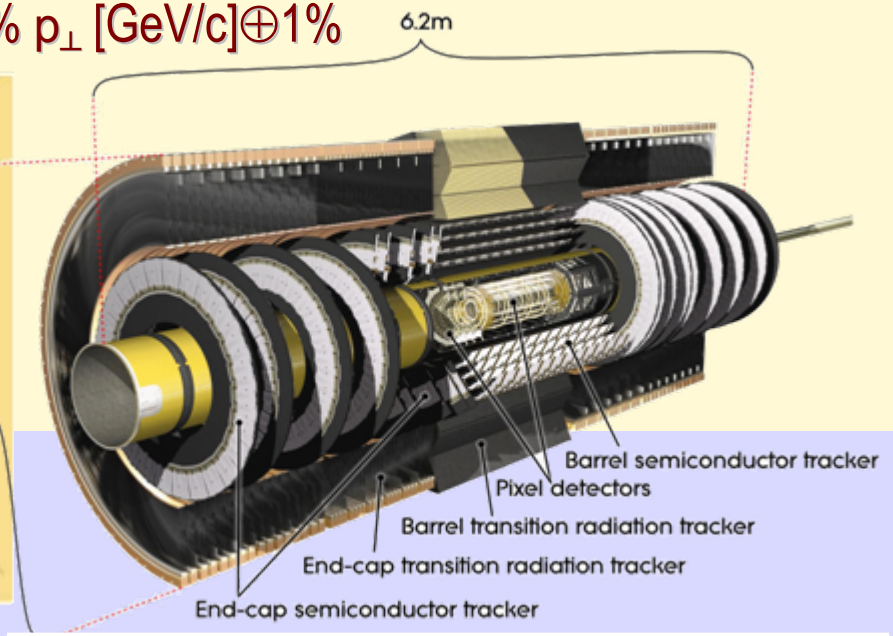
SCT Tracker | Pixel Detector | TRT Tracker

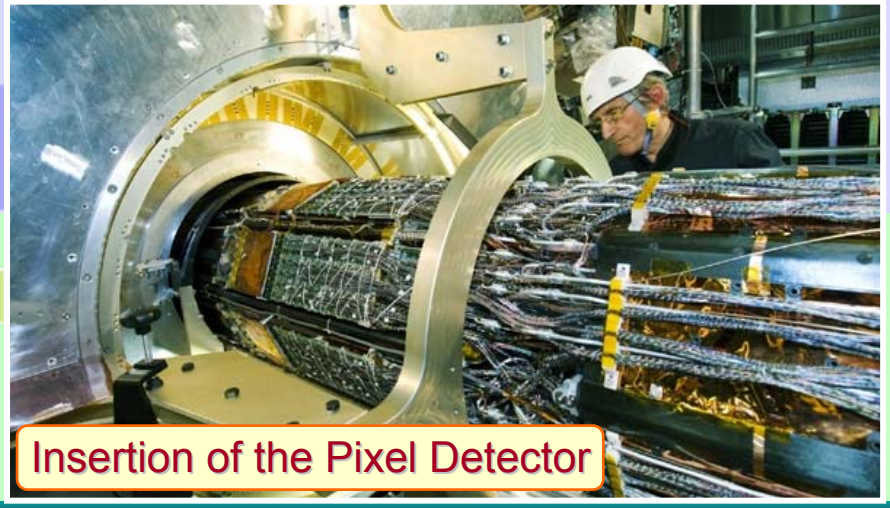
ATLAS Inner Detector

ATLAS Inner Detector

- Acceptance: $|\eta| < 2.5$ ($|\eta| < 2$ for the TRT)
- $\sigma(p_\perp) / p_\perp = 0.05\%\ p_\perp\ [\mathrm{GeV/c}] \oplus 1\%$

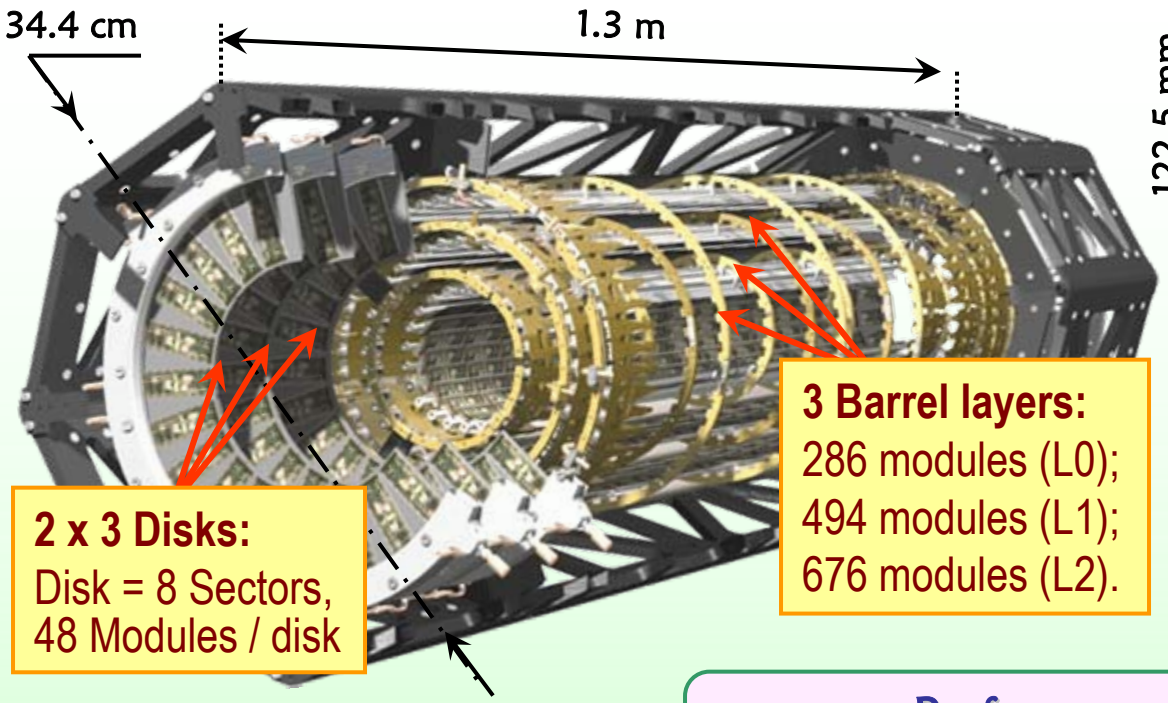






Insertion of the Pixel Detector

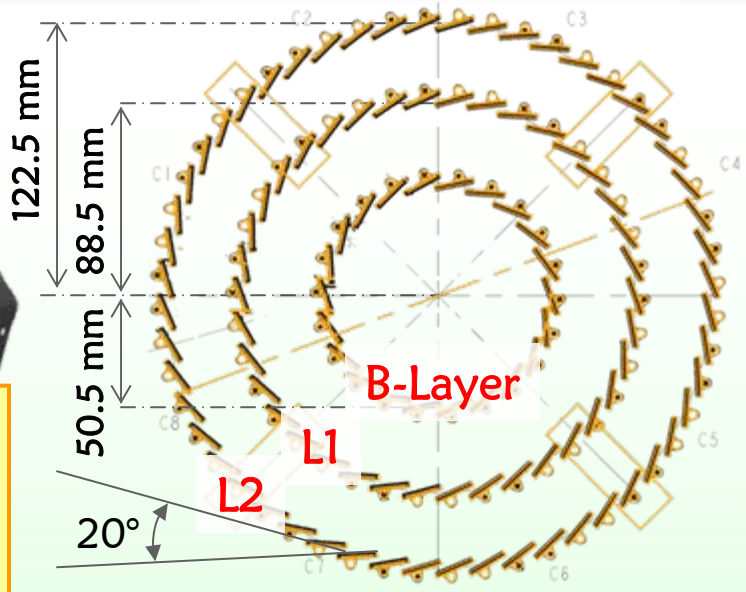
ATLAS Pixel Detector



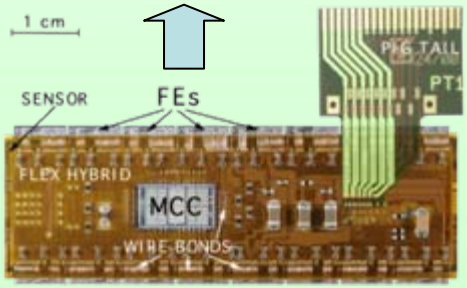
2 x 3 Disks:
Disk = 8 Sectors,
48 Modules / disk

3 Barrel layers:
286 modules (L0);
494 modules (L1);
676 modules (L2).

Pixel Barrel Cross Section



Staves with 13 Modules



Pixel Module
= 46080 channels

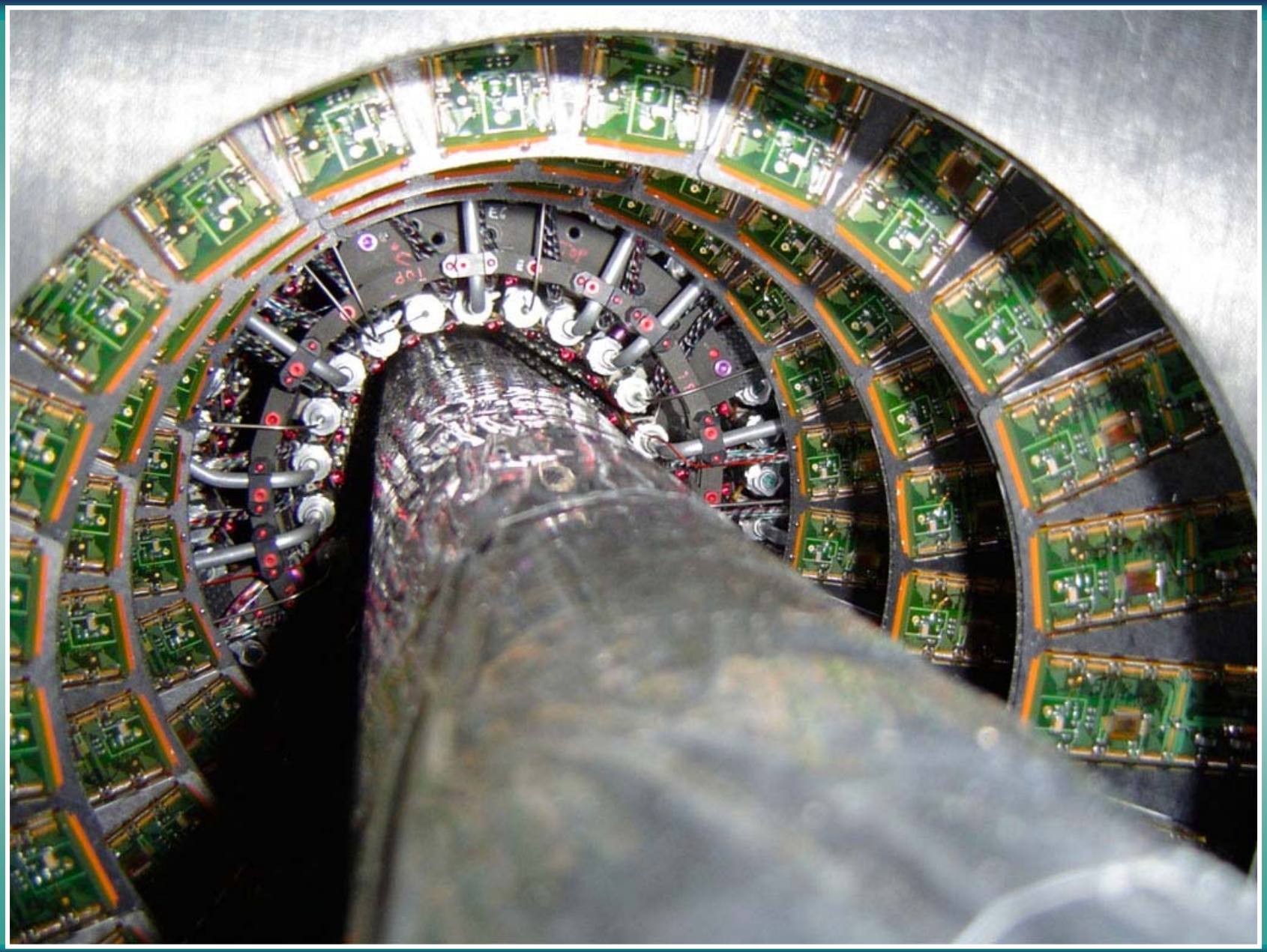
Construction

- Package weight ~ 4.5 kg
- Active sensor area ~ 1.7 m²
- Bi-phase C_3F_8 cooling
- 500 kGy or 10^{15} n_{eq}/cm^2 radiation hardness: 5 yrs/L0

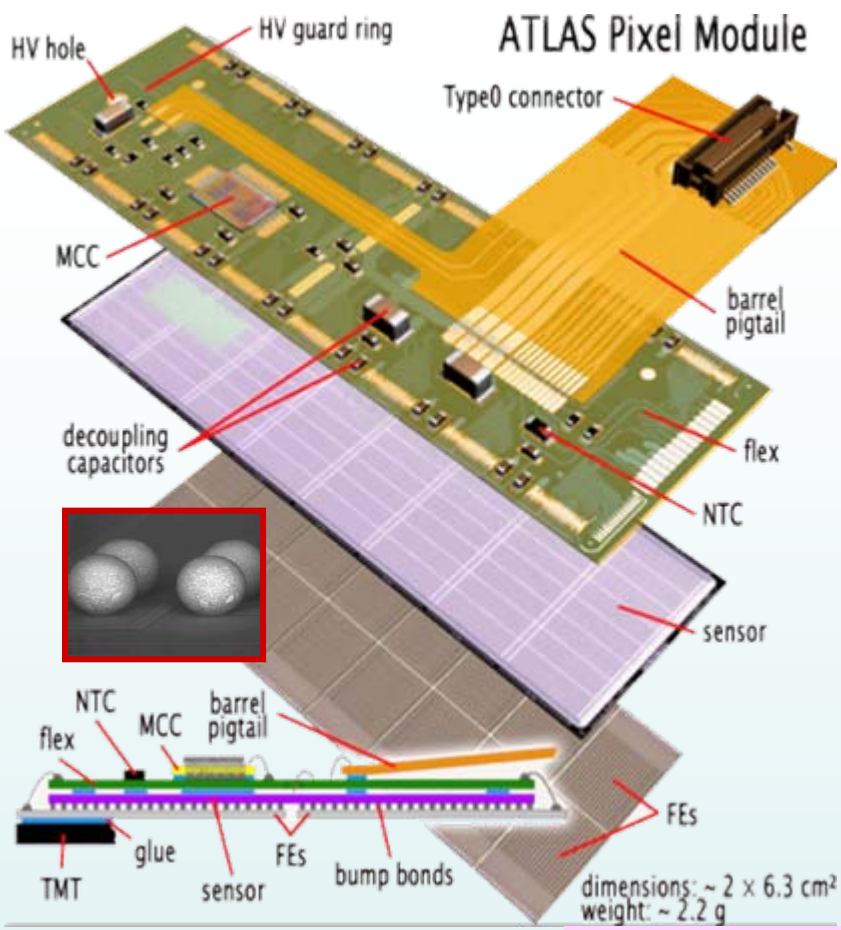
Performance

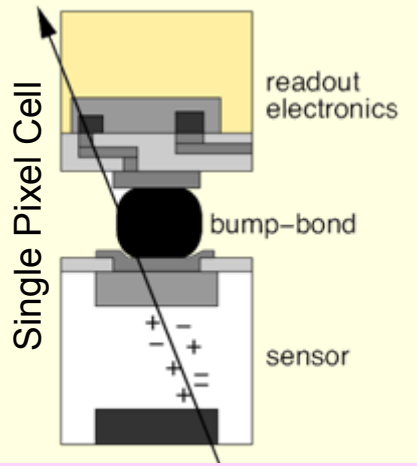
- 1744 pixel modules
- Total of ~ 80M channels
- 3-Hit Tracks
- $|\eta| \leq 2.5$
- Spatial resolution: 15 μm in R-ϕ, 115 μm in Z

Pixel Detector - Up Close!



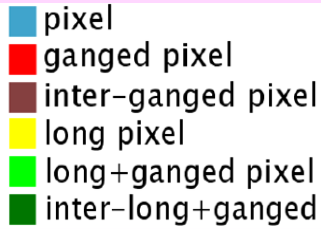
ATLAS Pixel Module



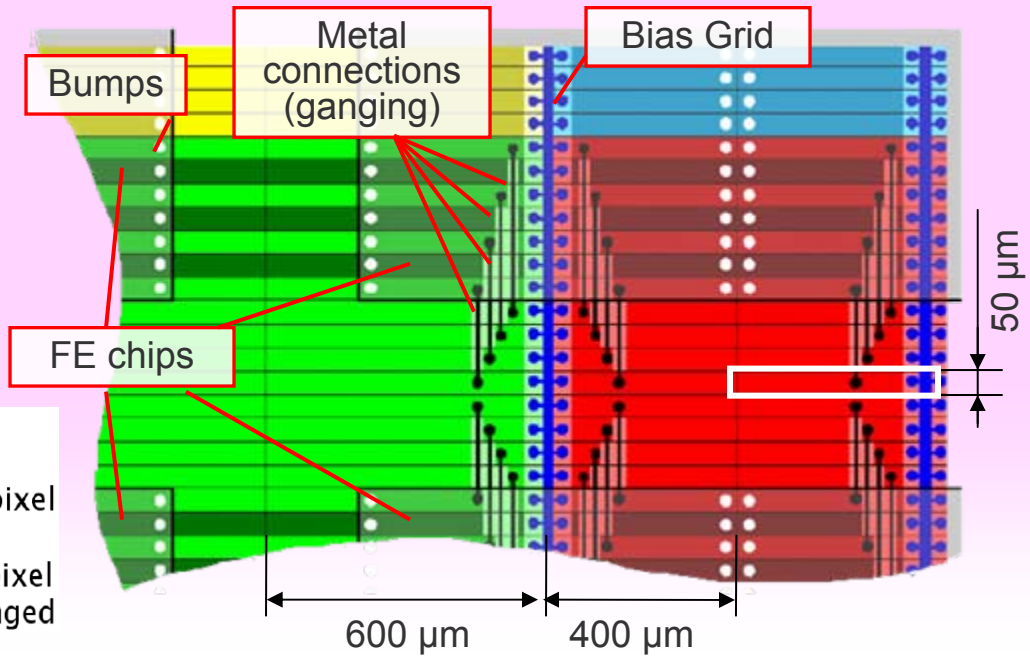


- Sensor = 47232 pixels
- n^+-in-n DOFZ
- Bias 150-600 V
- 2 x 8 readout FE chips
- 18 x 160 cells in each

- Charge-sensitive preamps in cells
- Local threshold generators in cells



The Inter-chip region (zoomed-in)



The Timeline

Extremely tight schedule was met successfully

2007

June 22-27 — Installation ★

★ Pixel detector is disconnected, with no access to it

2008

February - April	Initial connection, connectivity tests and pixel detector sign-off
May - August	Environmental systems commissioning, Final integration in the ATLAS DCS
July	Beam pipe "bake out": successful, on-time ***Pixels are on the beam pipe, cooled!***
August	First pass calibration (communication links)
End of August	All cooling loops on
September 14th to November	Combined cosmic data taking: continuous calibration adjustments, modules recovery
September 19th	LHC accident in sectors 3-4

Running with cosmic rays is the top priority

1. Opto-Link Tuning

Goal: Reliable communication between the modules and off-detector Back-Of-Crate readout cards via the optical links.

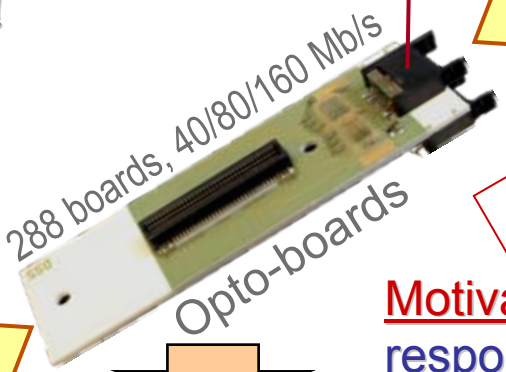
- Find optimal conditions for all modules
- There are 6 or 7 modules on each link ⇒ not an easy task!

OFF-DETECTOR READOUT

Optical communication links: commercial laser arrays (VCSELs) and receiving PIN diodes at both ends.

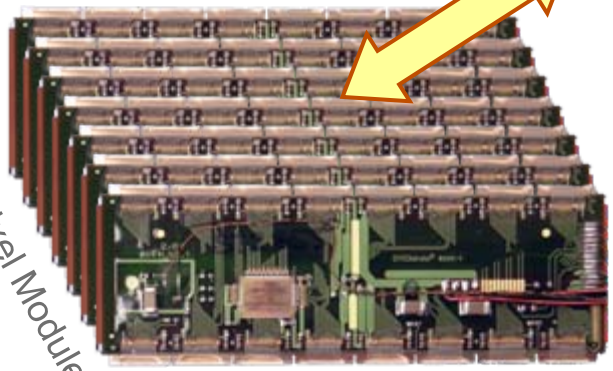
~100m long optical cables

Data readout:
Data-push (no busy)
Receiving:
Cell control logic signals:
Thresh, ToT, test charge…



288 boards, 40/80/160 Mb/s

Opto-boards



Pixel Modules

ON-DETECTOR

Significant technical challenge appeared in course of system tests in fall of 2006! !

My 'entry point' to ATLAS

2. Module Tuning

Motivation: Initial homogenous detector response; account for degradation due to irradiation in the future.

Threshold – level to tell signal from noise

Time-Over-Threshold – ToT, an indirect measurement of the deposited charge from the above-threshold signal amplitude

For every pixel cell

Pixel Opto-Board Heaters (I)

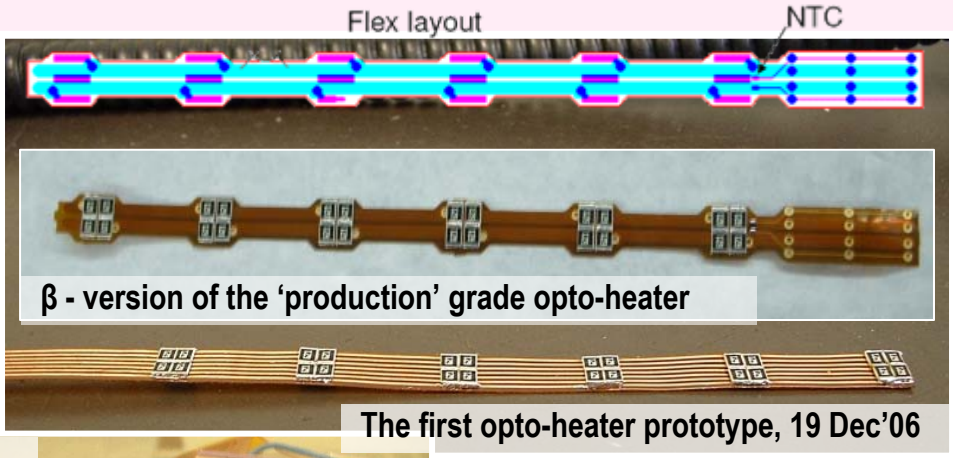
December 2006: UTD joins work ATLAS…

- Initial hardware involvement: **ATLAS Pixel Detector**
- **Problem:** Many Optical Data Links *do not work right when cold!*

- Slow signal turn-on
- Low optical power
- No laser output…

Only 7 months left to detector insertion!..

Absolutely **CRUCIAL** to have the opto-links operating stably and reliably!

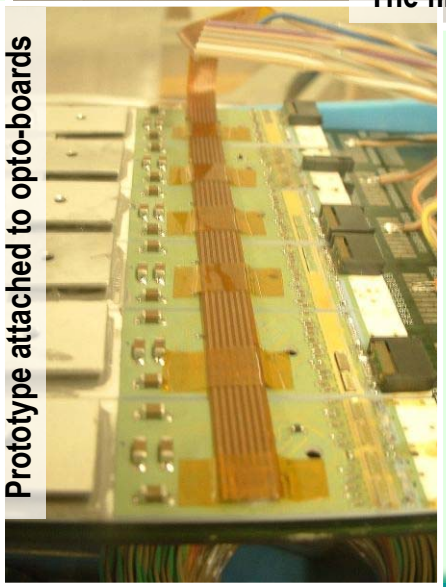


β - version of the 'production' grade opto-heater

The first opto-heater prototype, 19 Dec'06

Solution: The idea of the opto-heaters:

- A system of tiny, regulating heater elements on the opto-boards
- 6 groups of resistors and an NTC sensor placed on a flex strip
- ~105Ω @ 48V, pulse-regulated
- 48 opto-heaters in total required



Prototype attached to opto-boards

I became responsible for:

- Initial prototyping/engineering
- Feasibility studies
- Reliability/operation studies

Lots of prototyping work, assembly of test set-ups, testing, obtaining/reporting the results..

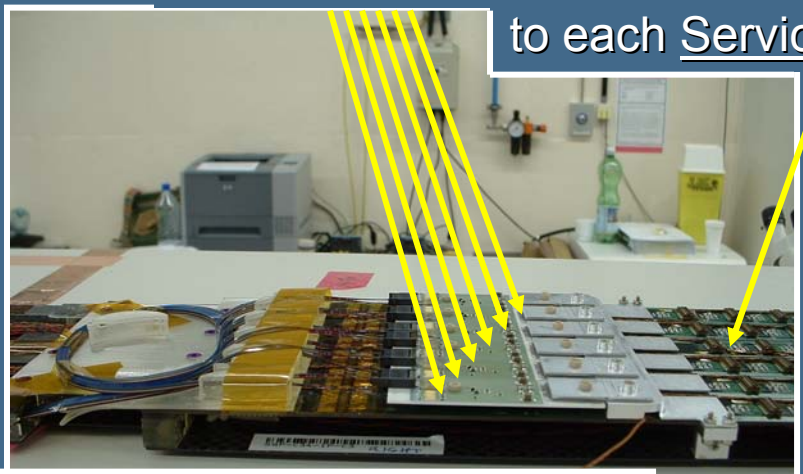
- Production/on-detector instrumentation
- Assembly and testing of the control system
- Final deployment and integration to ATLAS DCS

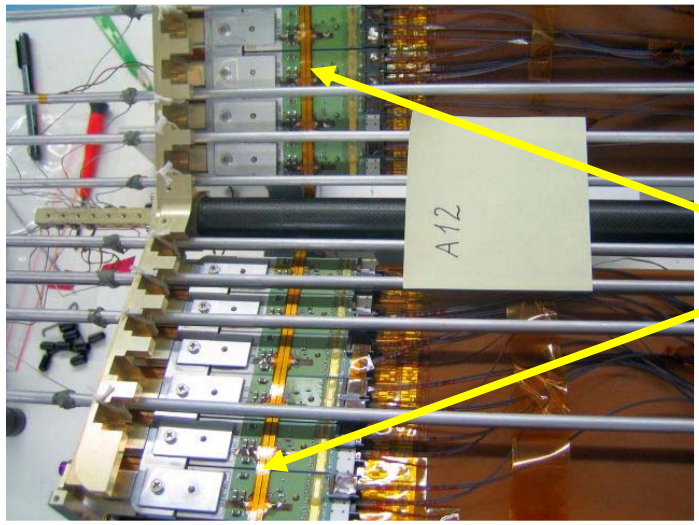
Connections
Electronics
Firmware
Software

Pixel Opto-Board Heaters (II)

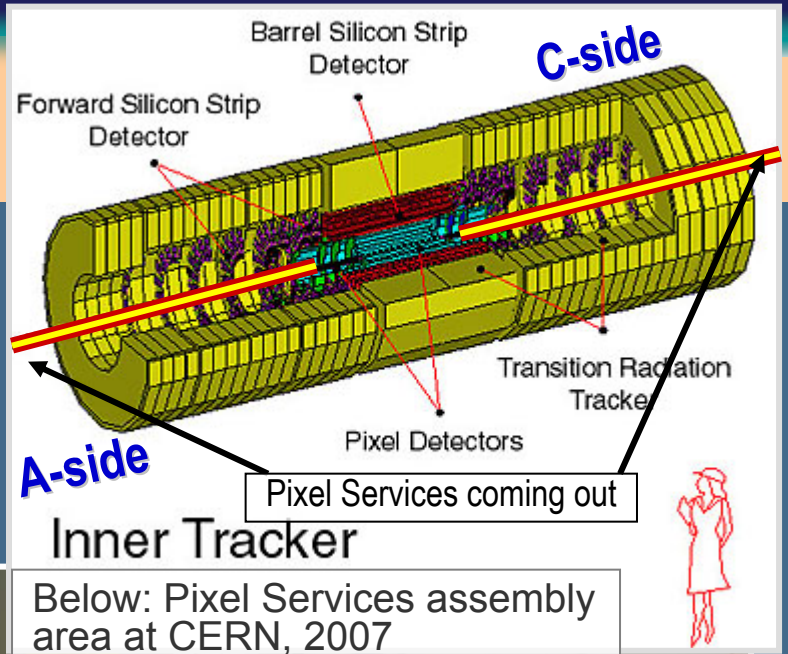
Connections to pixel detector are routed outside the inner tracking volume via the 'Service Panels' by which all electrical, optical, and cooling services are facilitated.

6 Opto-boards are attached to each Service-Panel

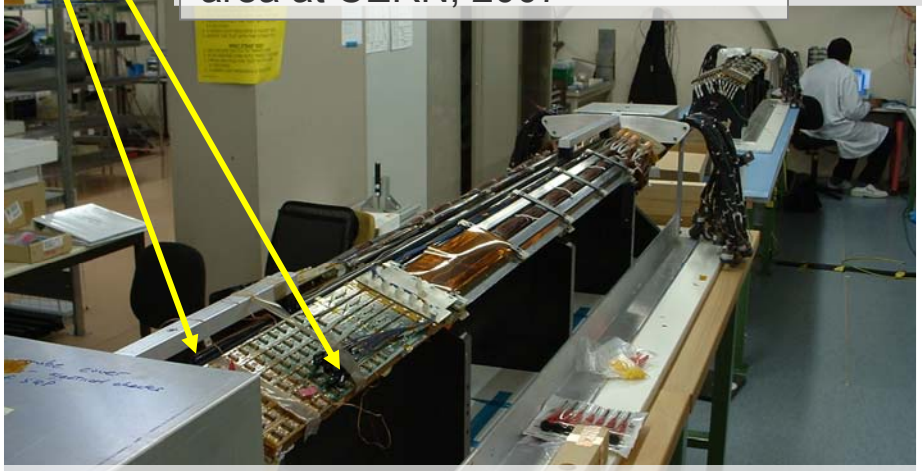




Heater Strips



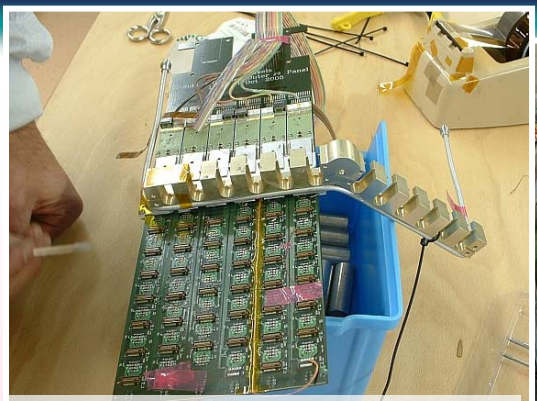
Below: Pixel Services assembly area at CERN, 2007



There are INNER and OUTER Service Panels which were assembled into 'octants' from the outside and the inside, then the 'quadrants'…

Pixel Opto-Board Heaters (III)

Lots of work with prototyping and testing!…



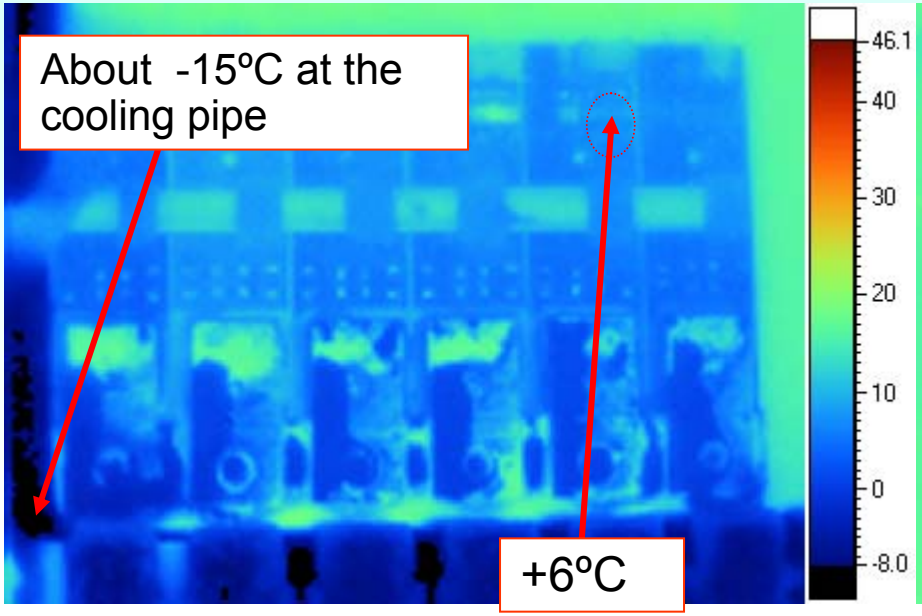
Mounting the cooling pipe…

Cold box gets to -45ºC!

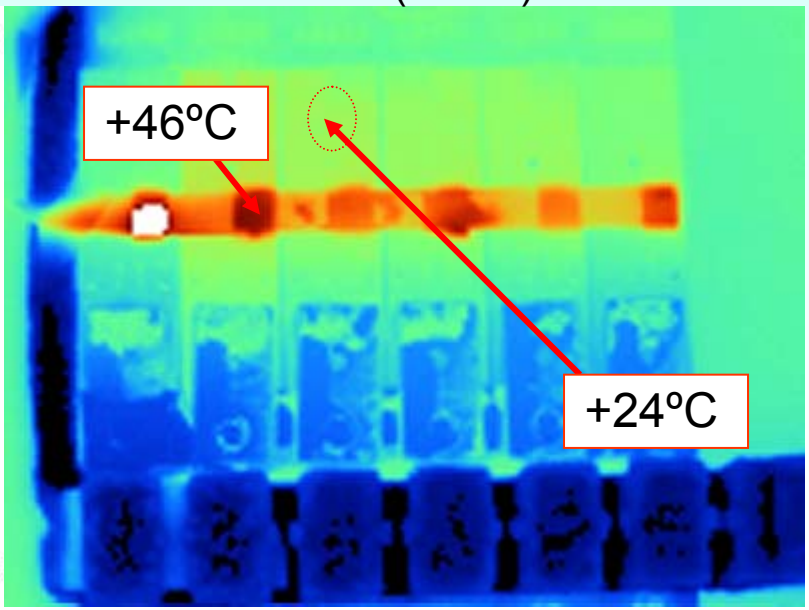
One of tests being assembled…

…Just to illustrate the effect of the heater strip:

Pic.1: Heater is OFF



Pic. 2 Heater is ON (~16W)

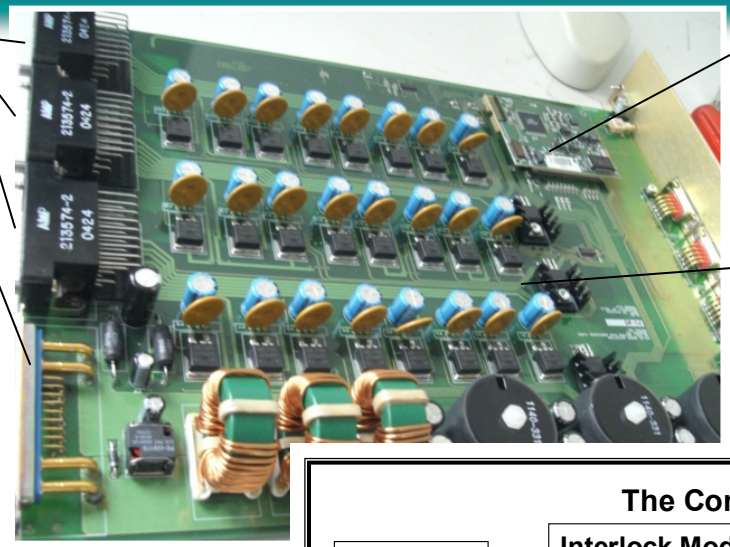


Opto-Board Heaters: Electronics

Switching Cards

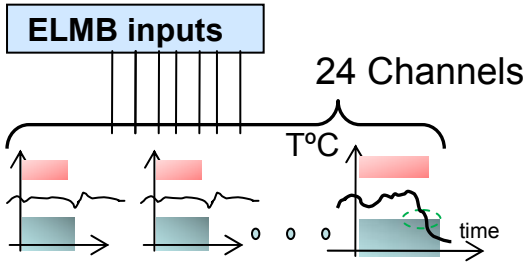
"AMP" connectors lead to cavern and connect to heaters.

Power from, and Data to crate BP



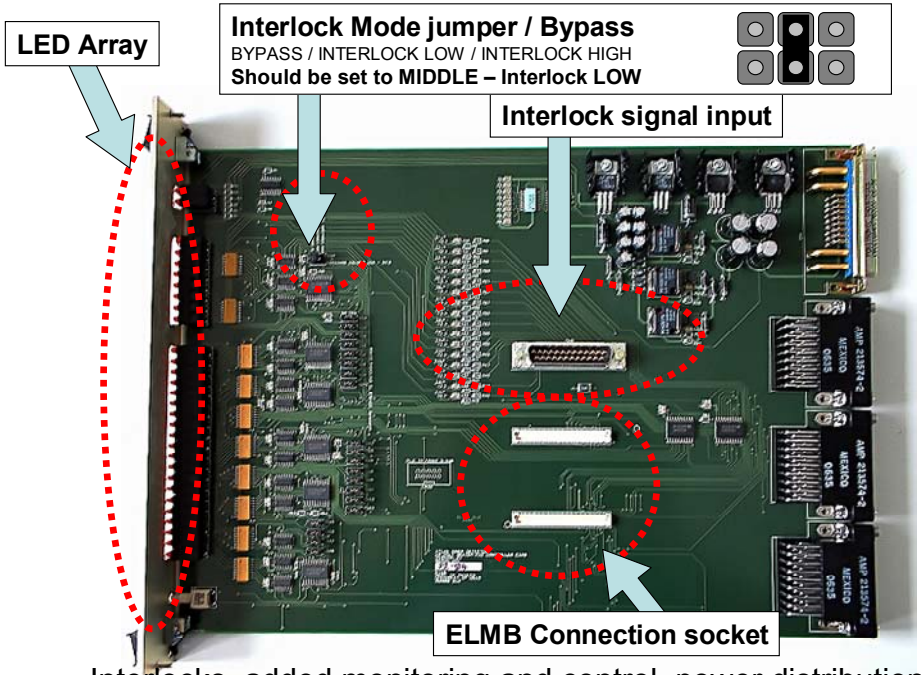
ELMB microcontroller:
Control algorithm embedded
3*8 pairs = Current and temperature measurements

Switches:
24 x Switches 48V, 1.6A per channel, frequency set by the microcontroller program



- Crate-based system
- CAN: multi-master broadcast serial bus
- Shares same components w/ID heaters

The Control Card (side view).



Interlocks, added monitoring and control, power distribution,…

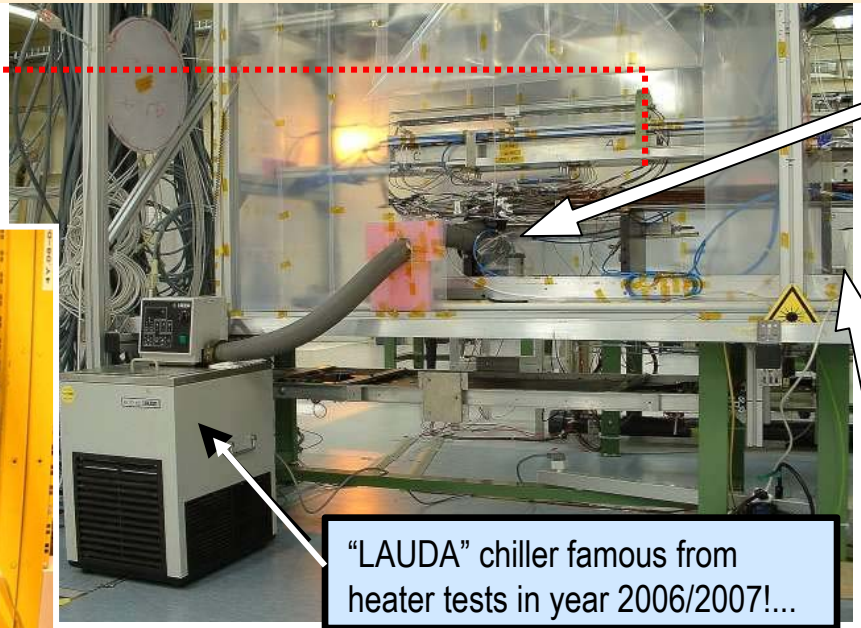
Pixel Opto-Board Heaters (IV)

- Test "ToothPix" has everything: modules, opto-links, electronics, cooling
- My task was to integrate and attempt to run the opto-heater system
- No possibility to work on real detector, but need to have many answers!

Test of pixel detector readout chain is set-up in above-ground lab next to ATLAS cavern: the SR-1

I had to pull a new 42m long cable

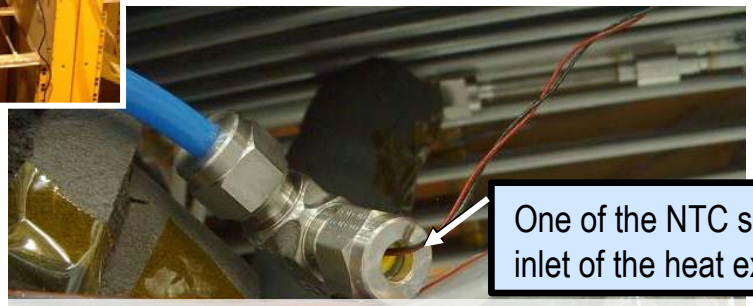
Opto-heater control crate



"LAUDA" chiller famous from heater tests in year 2006/2007!...

Above: A former tin can, now heat exchanger!
Below: Quite literally, a tea kettle has found its place in the experiment!

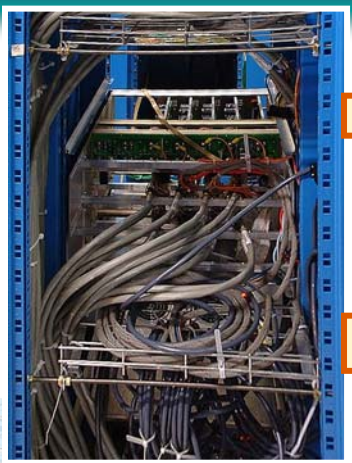
Electronics:
-Switching Cards
-Controller
-CAN interface
-5V, 24V, 48V power supplies

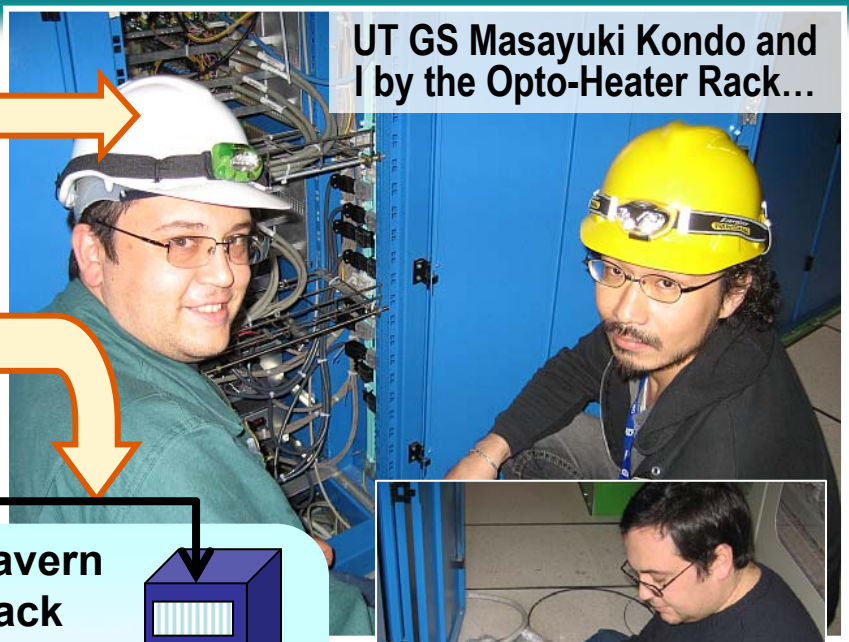


One of the NTC sensors in the inlet of the heat exchanger

Mission accomplished: test results have proven functionality of the opto-heaters while having no impact on the readout chain & data quality.

Opto-Board Heaters: Deployment





UT GS Masayuki Kondo and I by the Opto-Heater Rack…

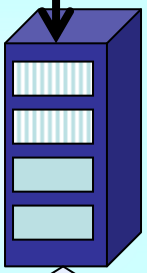
…where did it all come from?

ATLAS Control PC

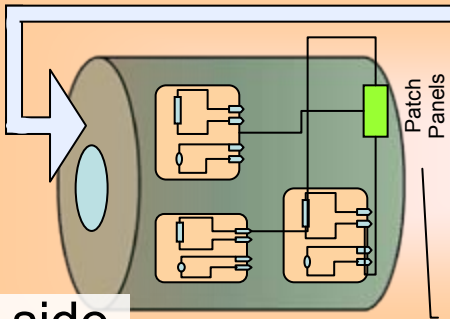
Underground cavern "USA 15" (Y.29-21-A1)

~120m!

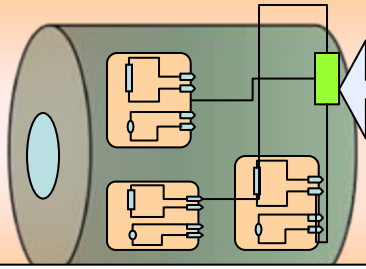
Down in cavern "US 15" Rack (Y-22-07.S2)



CANbus connection cable have been pulled, connectors made, communication tested! = 1 week!



Patch Panels



Cables to the opto-heaters

New cables have been pulled

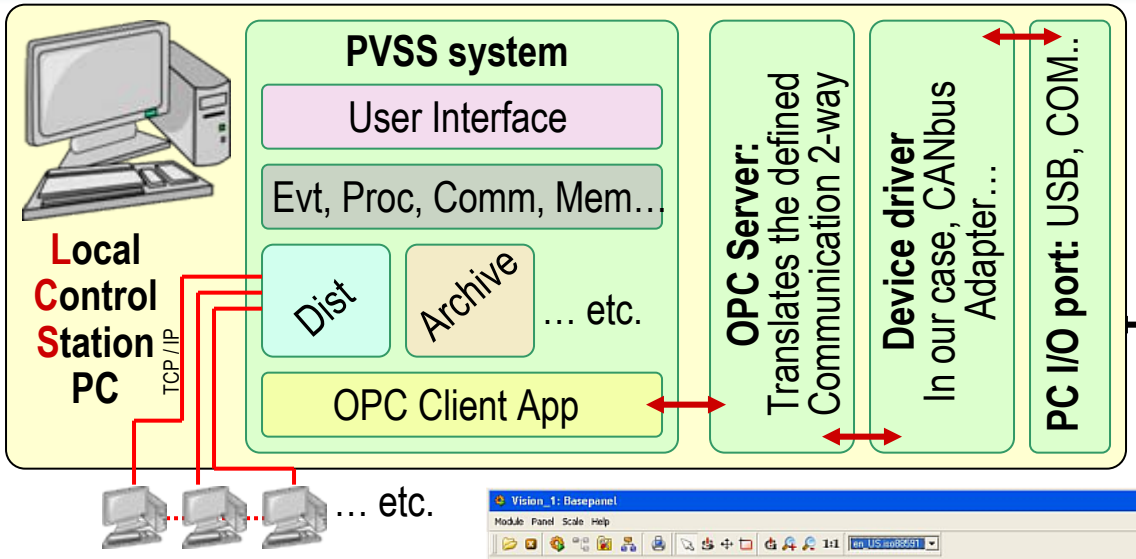
A side

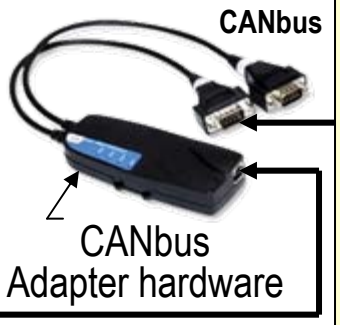
Inside ATLAS central volume

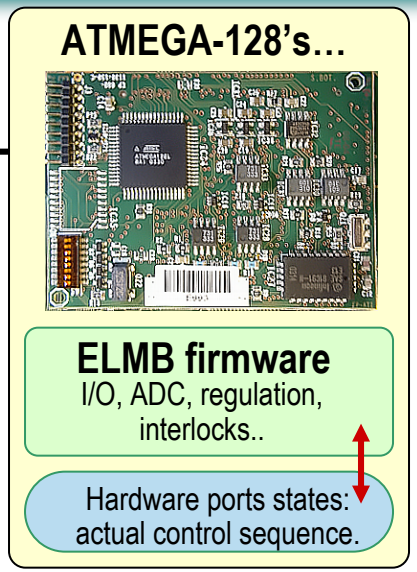
C side

BIG problem was discovered: A short of one NTC sensor to ground, making control of one of 48 heaters impossible. I have researched it and tried, and finally **was able to fix it!!!**

Opto-Board Heaters: the Control Interface

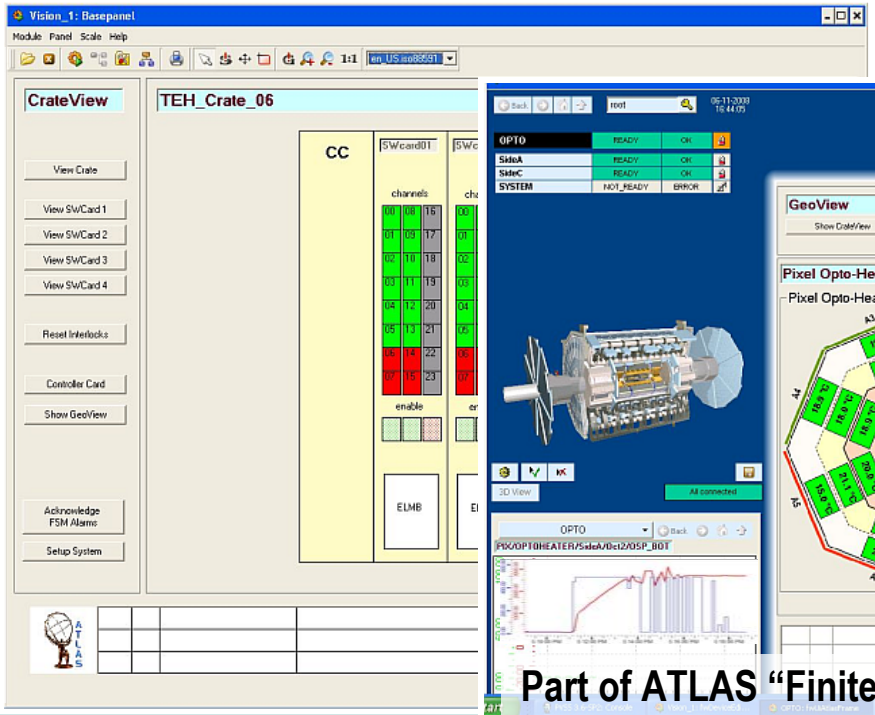


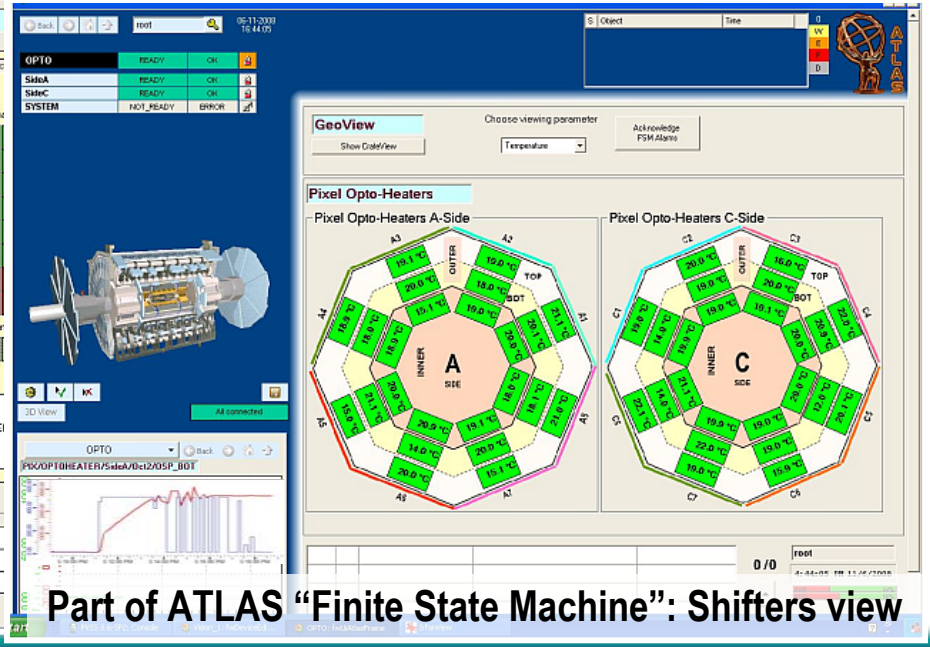




- Used for all detector 'slow controls' at CERN
- SCADA system
- C++ -like syntax and functionality
- **Highly scalable**
- OPC standards

Expert GUI that runs on the LCS PC





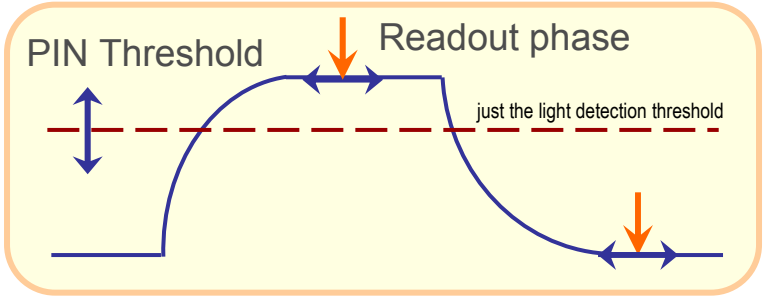
Part of ATLAS "Finite State Machine": Shifters view

Opto-link Tuning

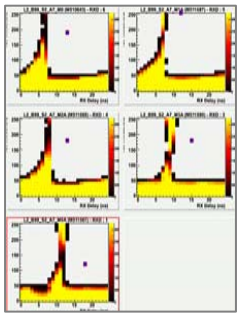
Back to pixel detector calibration!

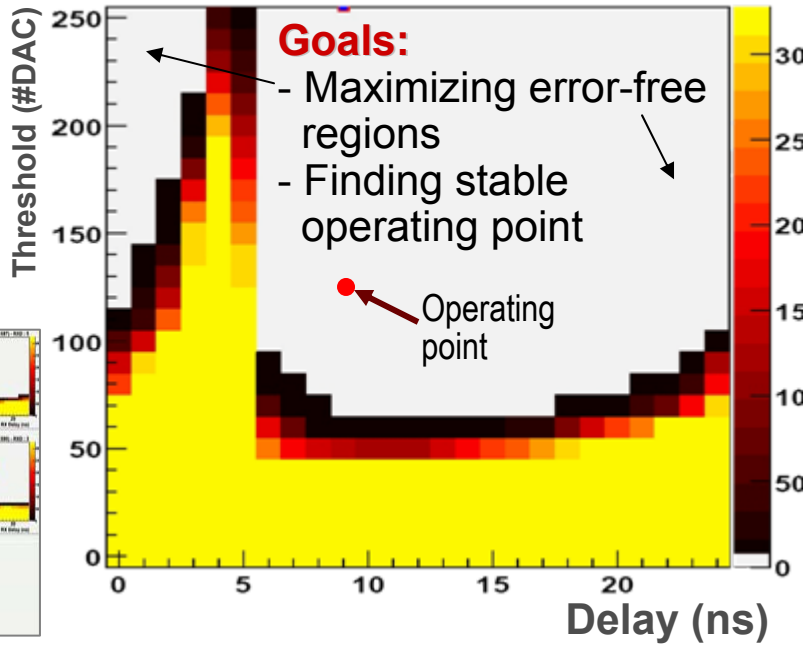
- The optical communication uplink is tuned by adjusting
  - The power of the on-detector lasers
    - Power of VCSEL lasers is temperature-dependent !!
    - One laser power setting / opto-board (6/7 channels)
  - The delay of the off-detector sampling clock
  - The PiN current thresh of the off-detector receiver diode

Opto-heaters have been delivered!



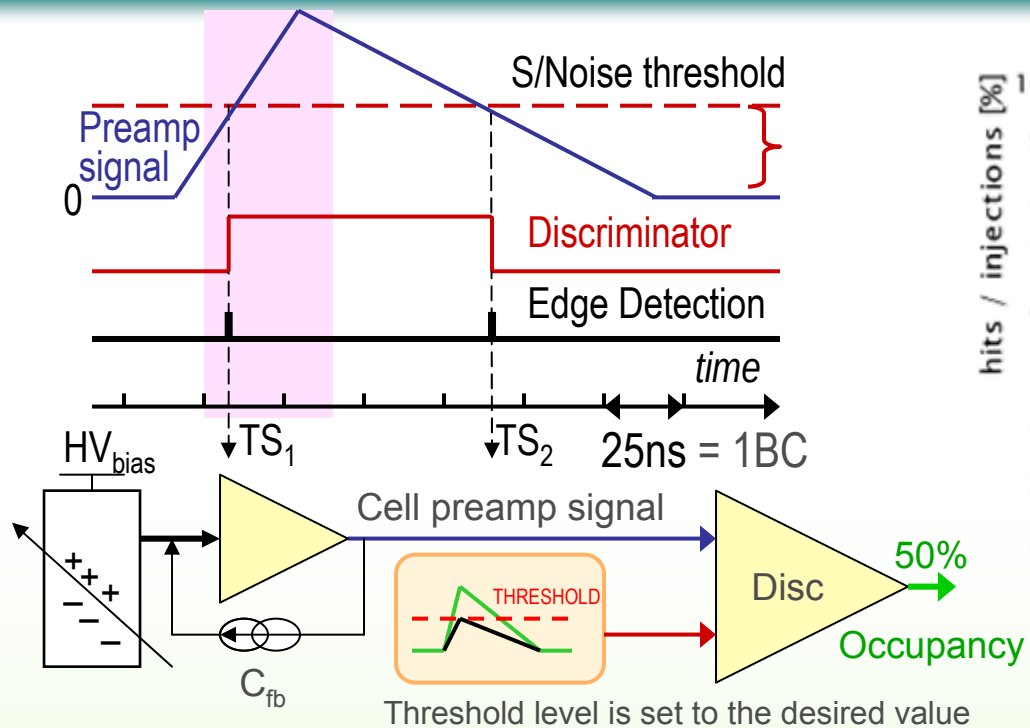
- Modules cannot be operated without good optical tuning
- Scanning 2-D parameter space
- Common stable operating point for 6/7 links has to be found
- Tuning takes ~15 min (all links)

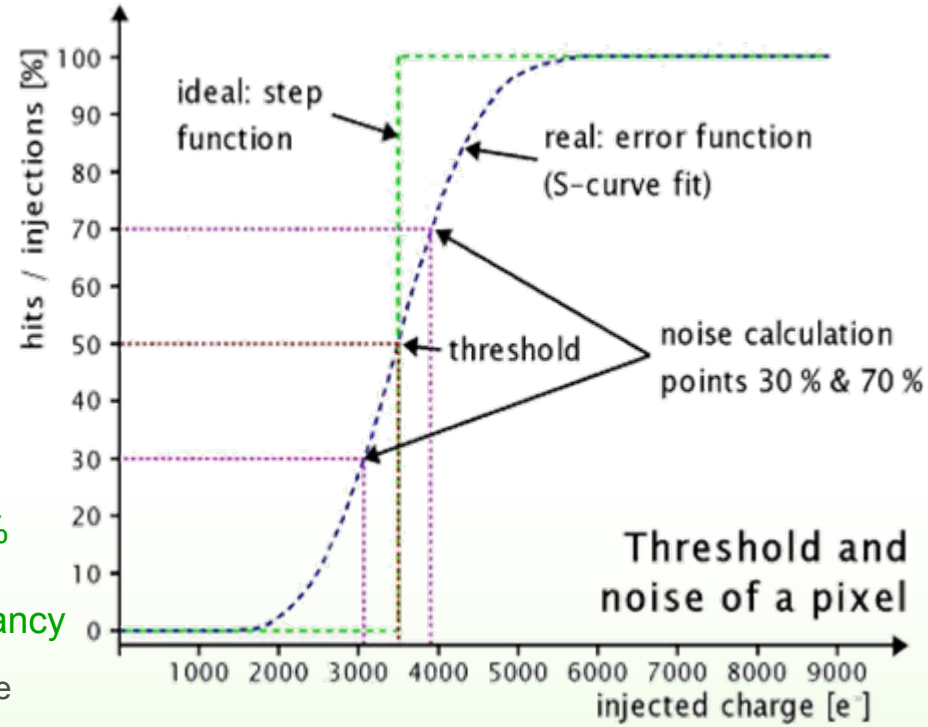




Error rate when sending a 20 MHz clock 0-1-0-1 pattern

Threshold Tuning

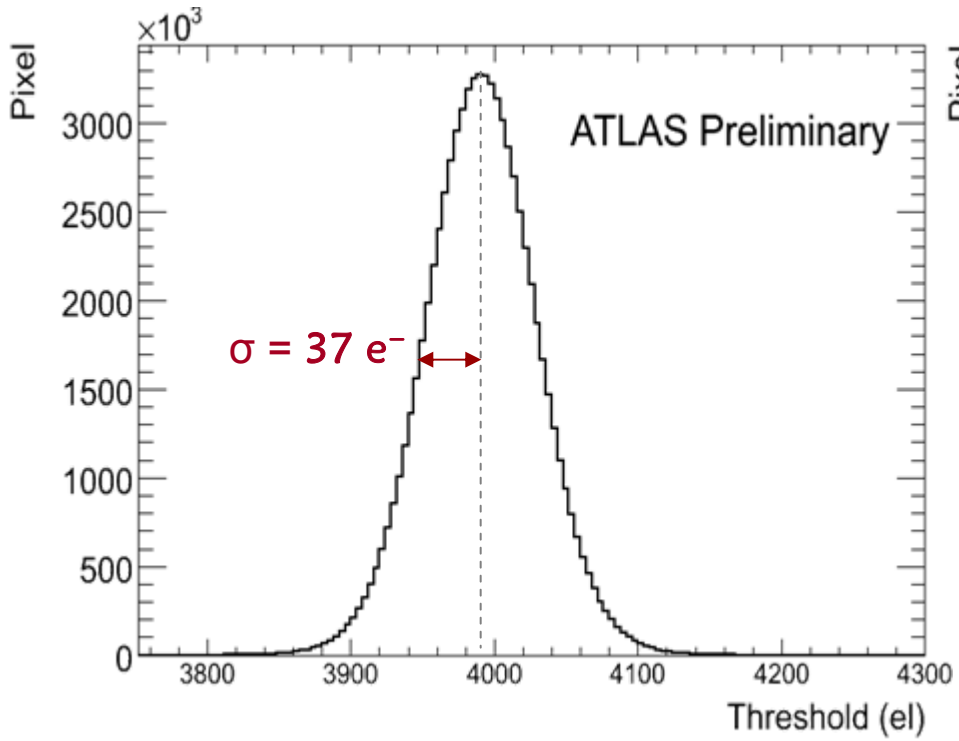


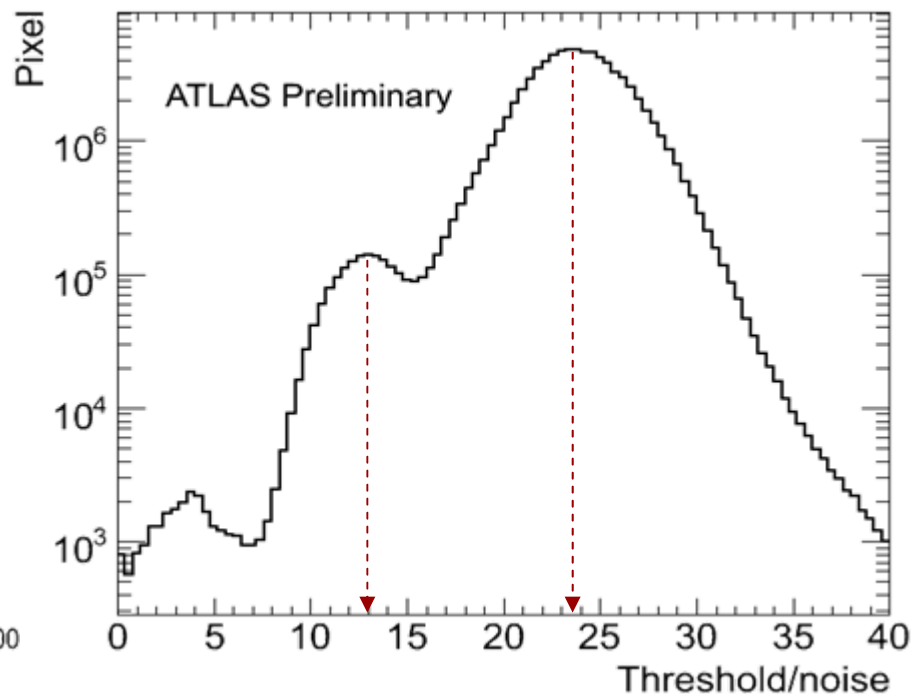


- Thresholds are adjusted individually, on pixel cell level
  - Varying charge injections in the preamp of each pixel cell via the integrated in-cell calibration circuitry;
  - Fit error function to number of events vs. charge;
  - 1.5 hrs to tune the entire detector.
- September 2008 cosmic runs ⇒ initial, production tuning
- November 2008 cosmic runs ⇒ fully tuned configuration

Tuned Thresholds

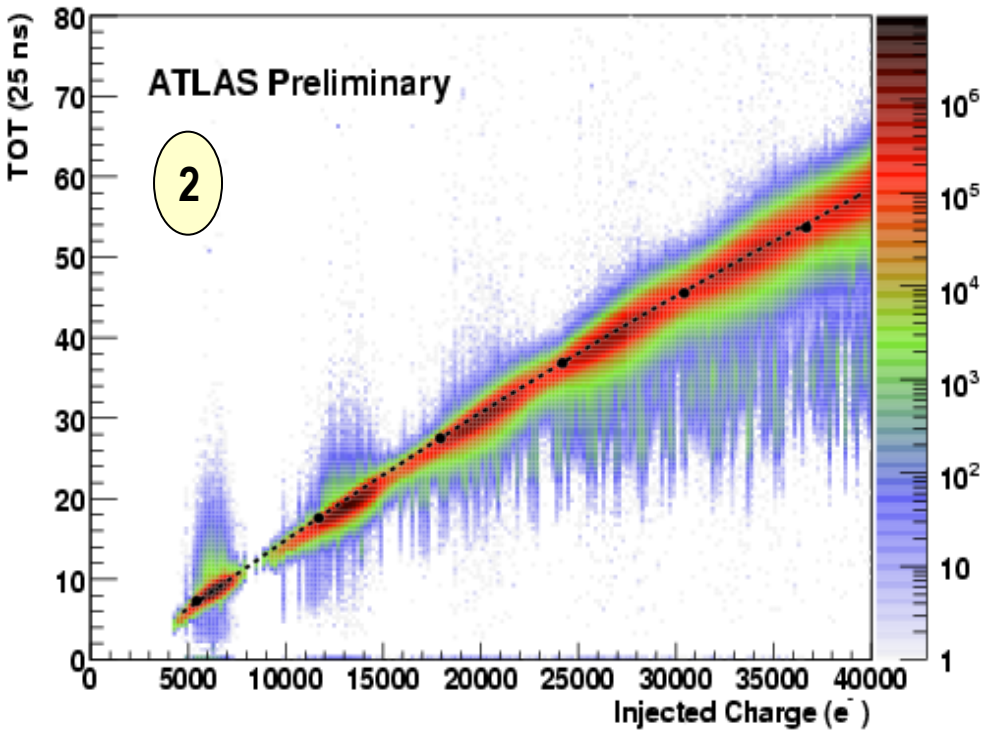
- Thresholds are tuned to 4000 e^- in November 2008
- Dispersion is only **~ 37 e^-**
  - Threshold over noise is **~ 24** for most pixels
  - Threshold over noise is **~ 13** for those few special inter-chip pixels…
- New calibration has been just done in late August 2009
  - New plots are not ready yet…

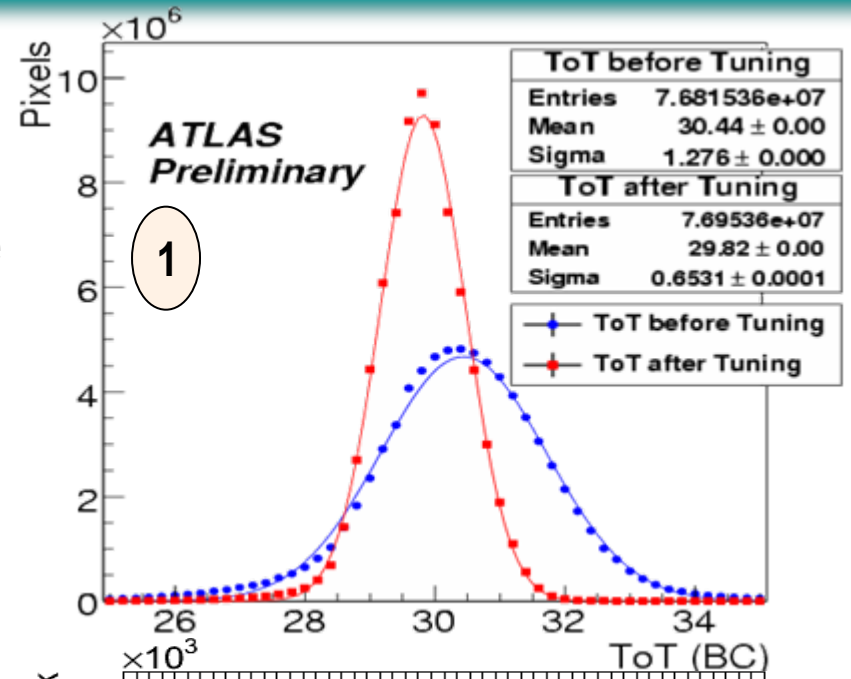


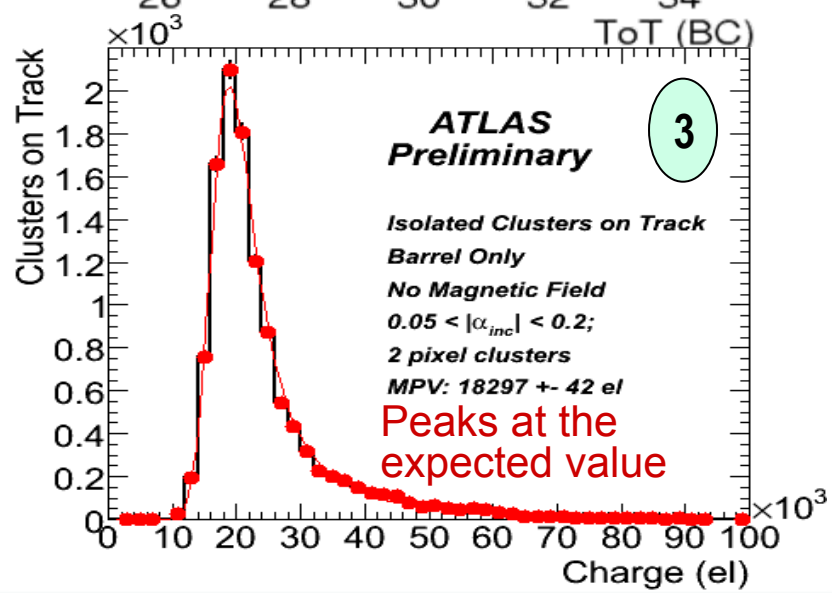


ToT (Time over Threshold) Tuning

- Adjust the preamplifier feedback current on FE's until a M.I.P. (20 ke$^-$) corresponds to a Time-over-Threshold value of 30 BC's
- Uniform response improves accuracy for the cluster position determination
- Extract full ToT vs. charge calibration curve for each FE to use off-line

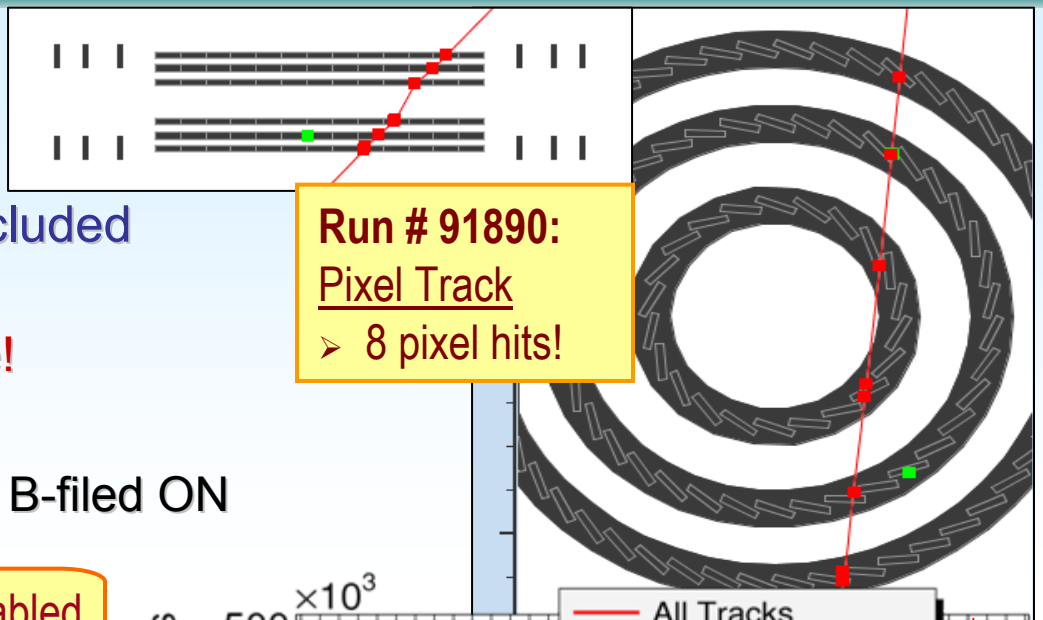


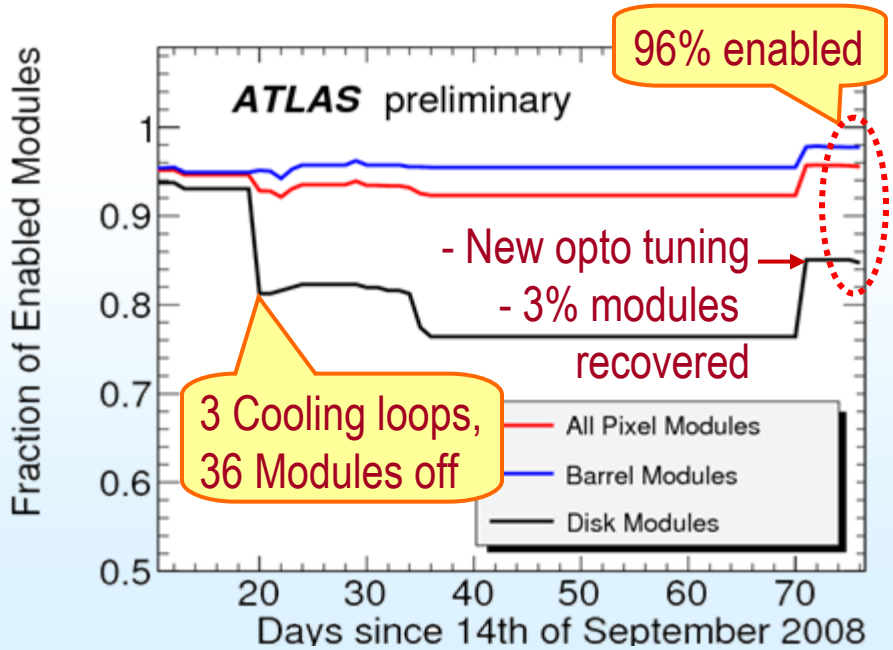


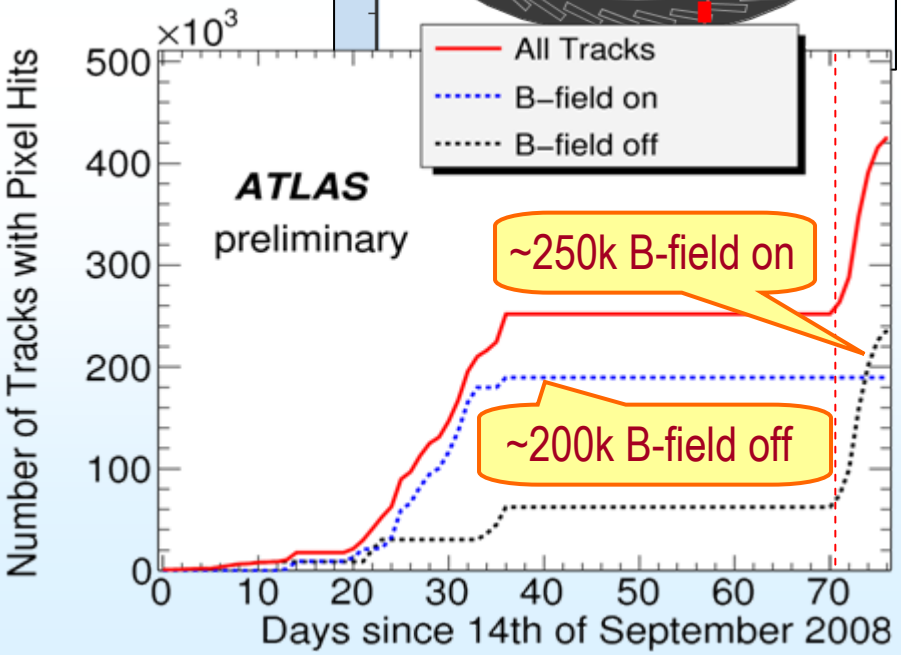


Cosmic Data Taking: Fall 2008

- Sept 14th, 2008: First tracks!
  - Trigger used: muon triggers
- Some modules were initially excluded
  - Improved optical tuning ⇒ most modules now are on-line!
- During cosmic data taking:
  - 2/3 time B-field OFF, 1/3 time B-filed ON



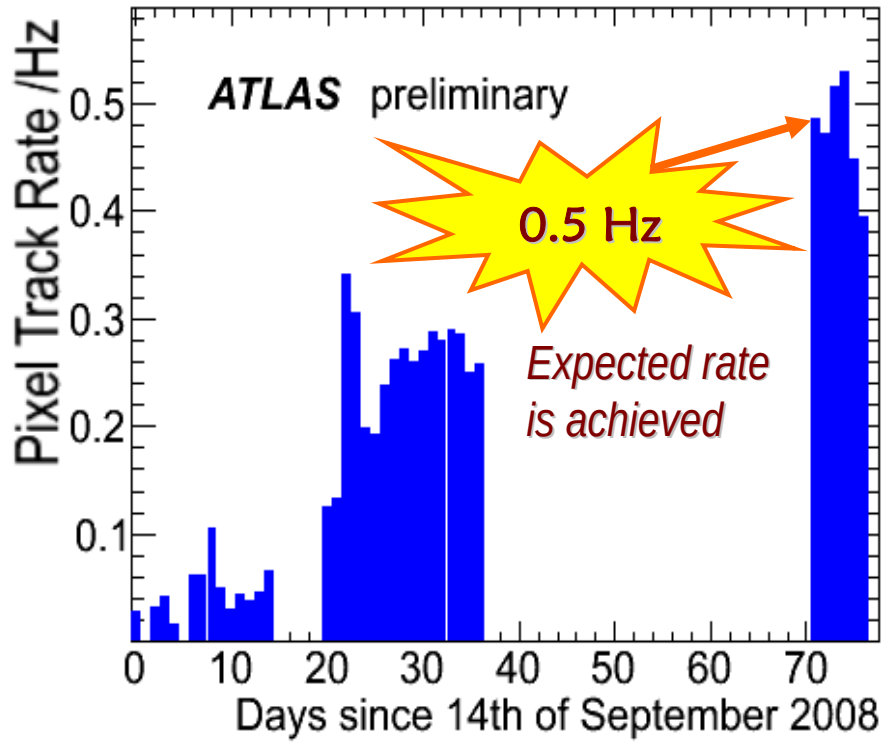


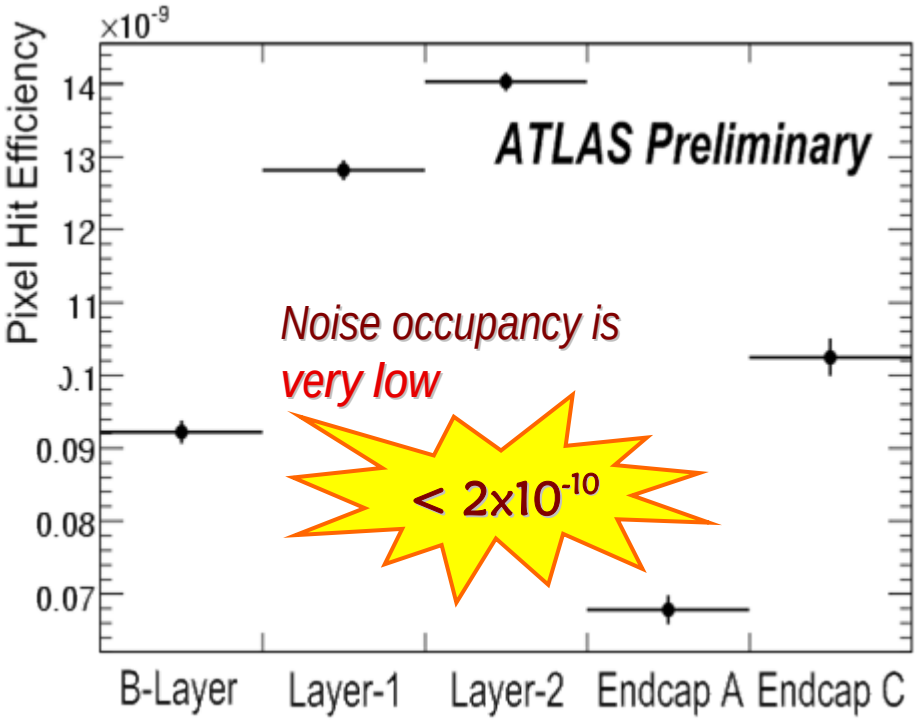


Running with Cosmic Data

- improvements to muon trigger timing
- commissioning of HLT & TRT L1 triggers

➔ increased pixel track rate to ~0.5Hz (expected from sim.)



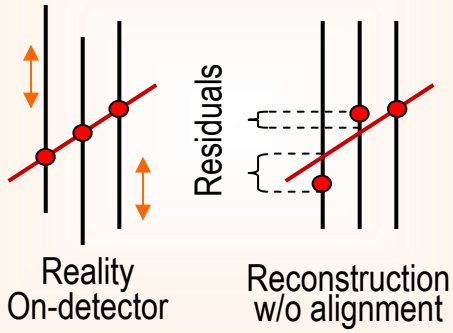


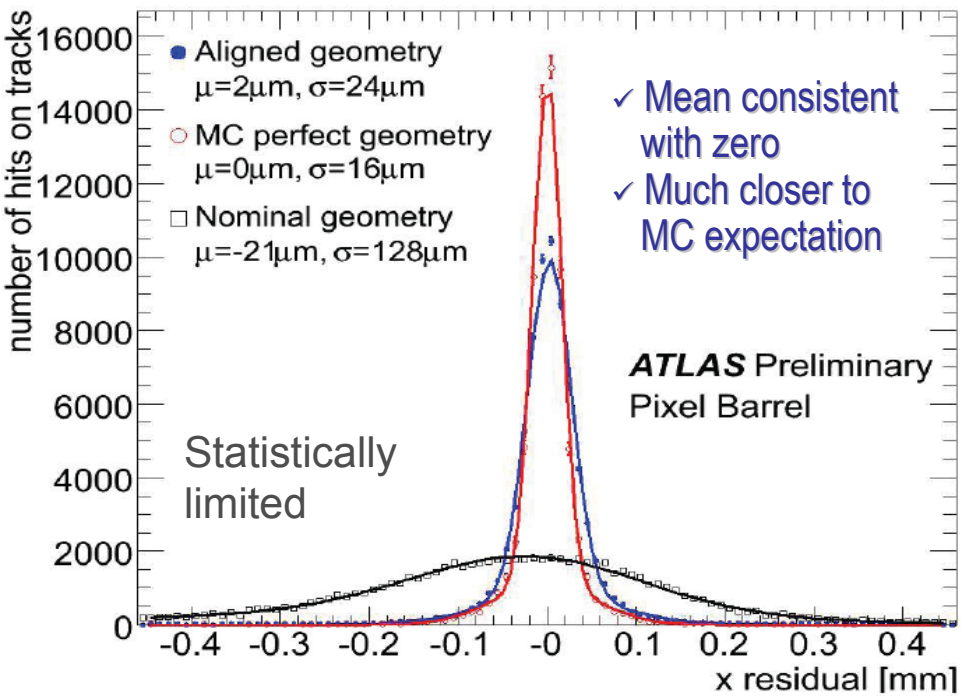
Noise: < 2×10^{-10} pixel / crossing

0.3-0.7 noise hits in full detector per crossing!

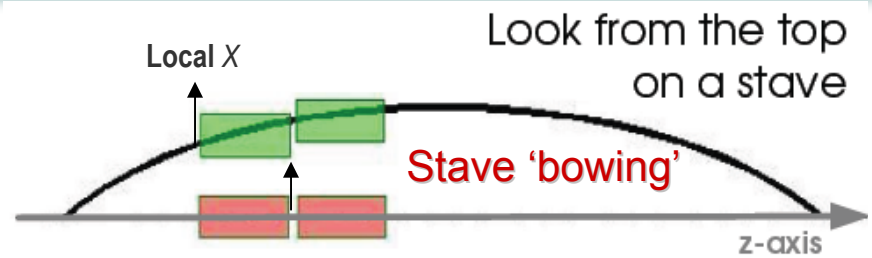
Alignment with Cosmic Data

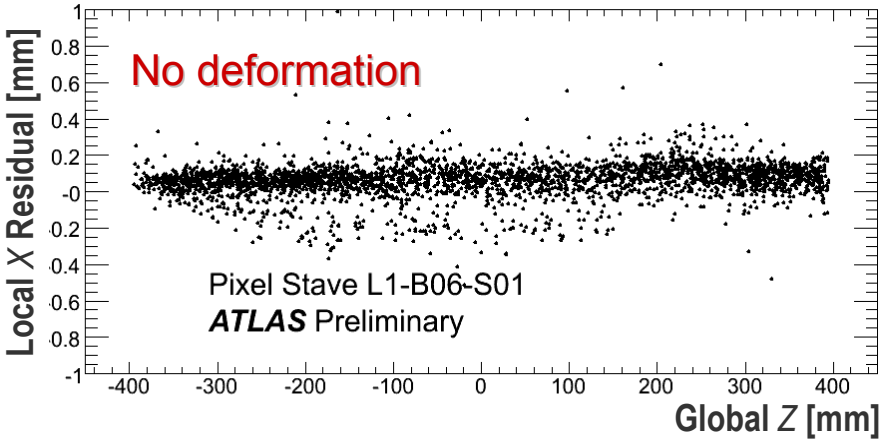
Alignment task:
Minimization of the Residuals

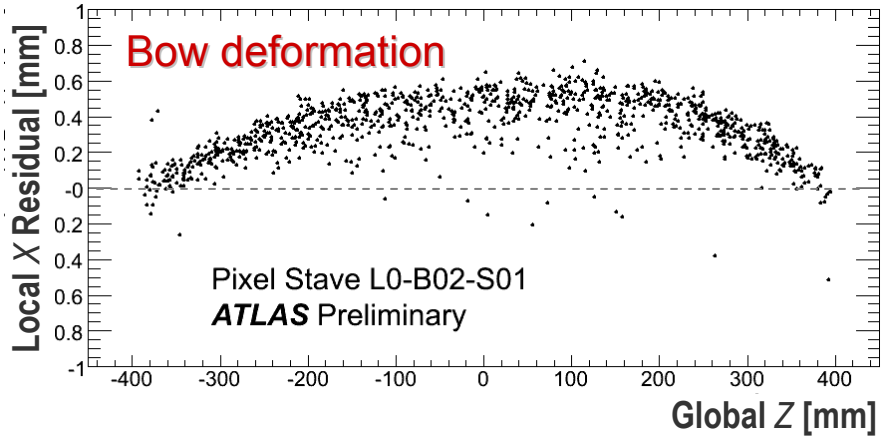




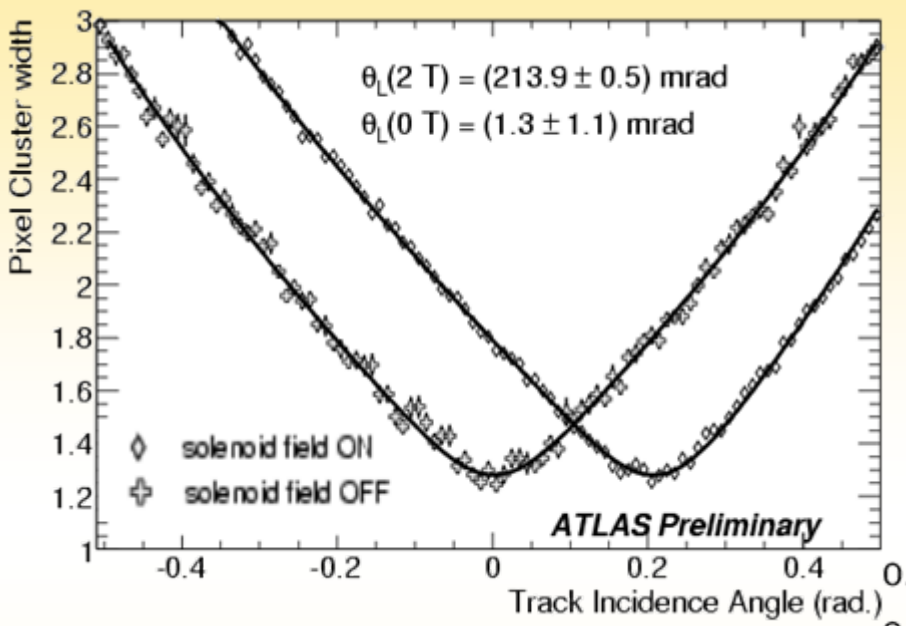
✓ Mean consistent with zero
✓ Much closer to MC expectation





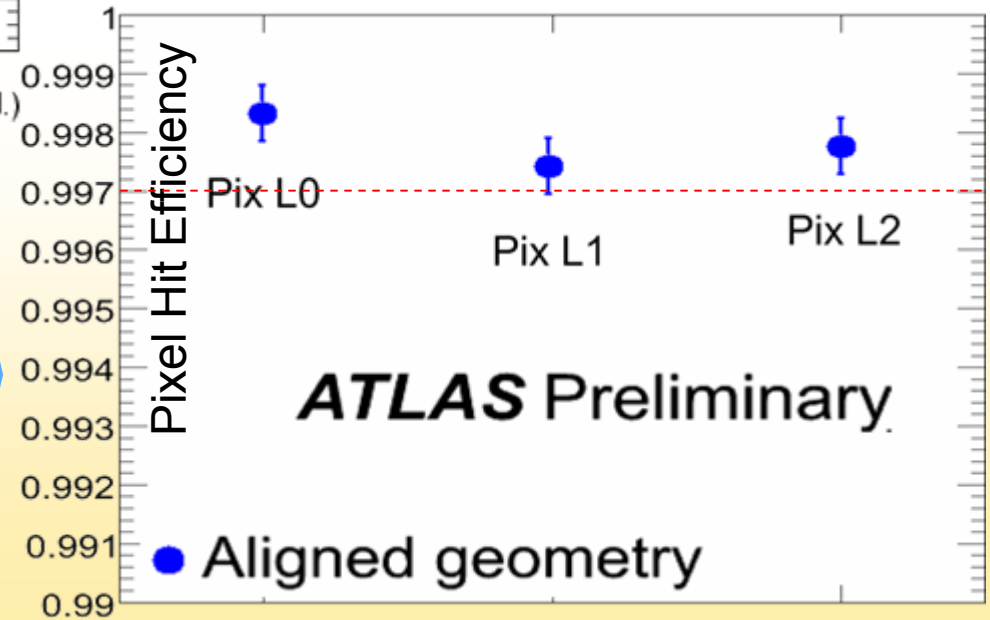


Lorentz angle: 214 ± 0.5 mrad (expect ~224 mrad)



- Quantifies the electron drift in the sensor due to the B-field.
- Measured by fitting the cluster size vs. the incidence angle.
- Data measurement agrees with the expectation to within **5%**.
- Angle with the B-field OFF is consistent with zero.

Alignment: Hit Efficiency (Barrel Layers)



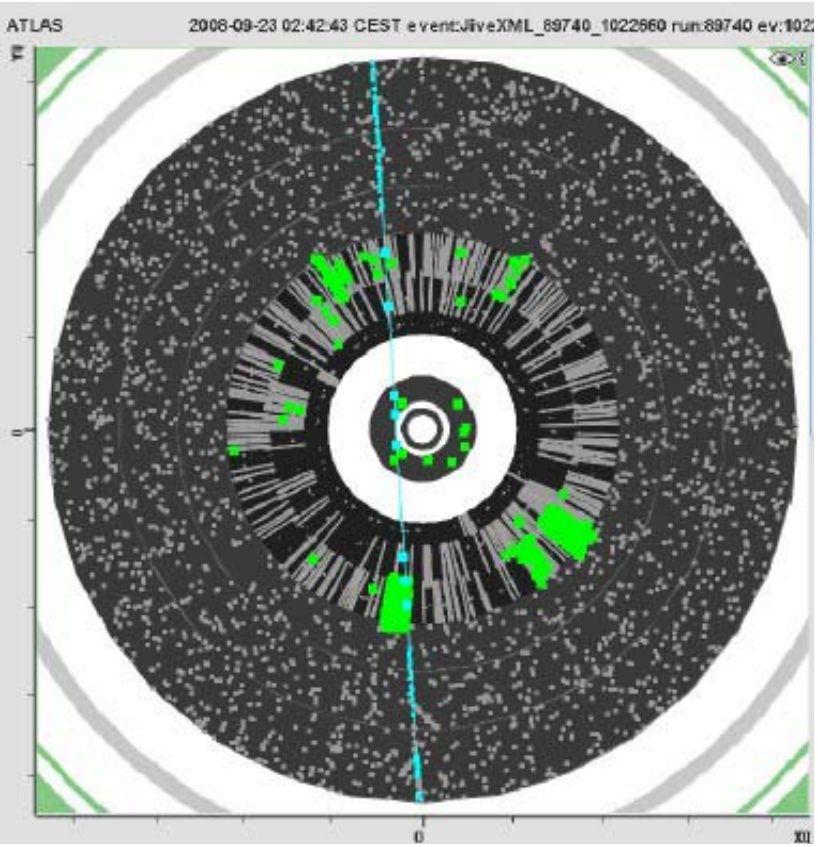
- Improvements with alignment
- Hit efficiency in barrel layers

> 99.7%

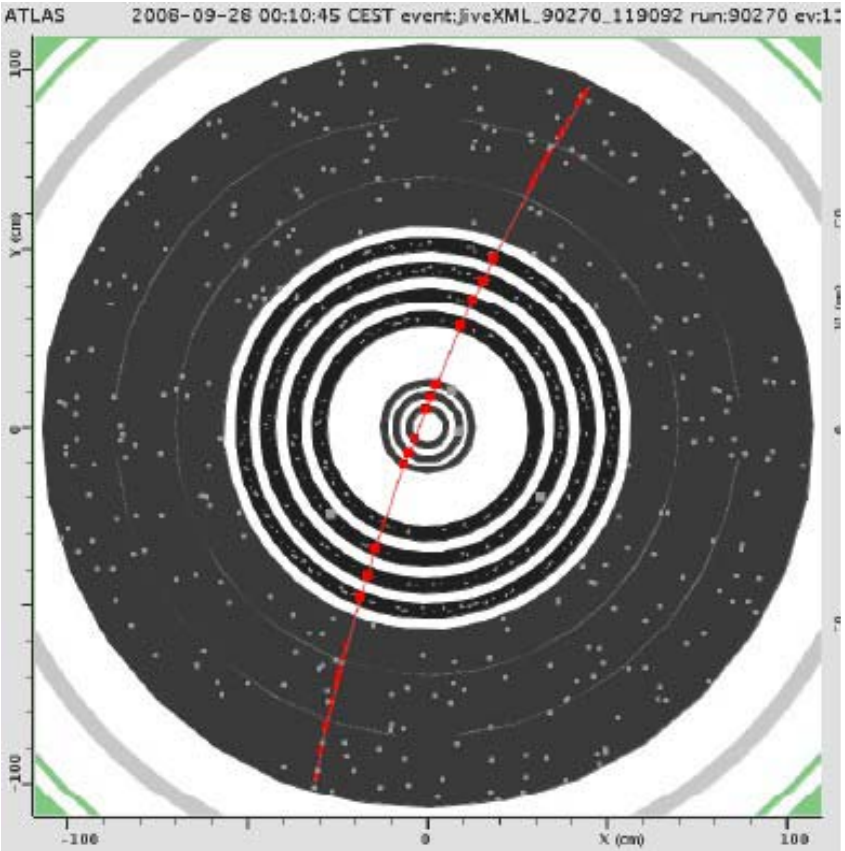
Noise Masking

- Noise mask is created off-line, and then applied on-line
- Noisy, "hot" pixels are defined having $\geq 10^{-5}$ hits per event
- ~ 5K pixels are being masked $\Rightarrow$ only 0.006% of all pixels

w/o the noise mask



with the noise mask



5 UTD Physics interest
- Quarkonia / exotics

ATLAS Pixel Detector

4 Running Pixel Detector
- Detector operations
- Calibration: opto-links etc.

Inner Detector Heater Pads ⟷ **Pixel Opto-Heaters**

Systems share the same electronics so it was decided to keep a high degree of unification

Documentation

The main goal was set to get the subsystem that UTD had started to support, up and working, and do whatever it takes to get ATLAS operational on schedule.

1 Hardware Tasks
- Installation and testing
- Troubleshooting
- Functionality improvements and mods
- New heater hardware electronics development

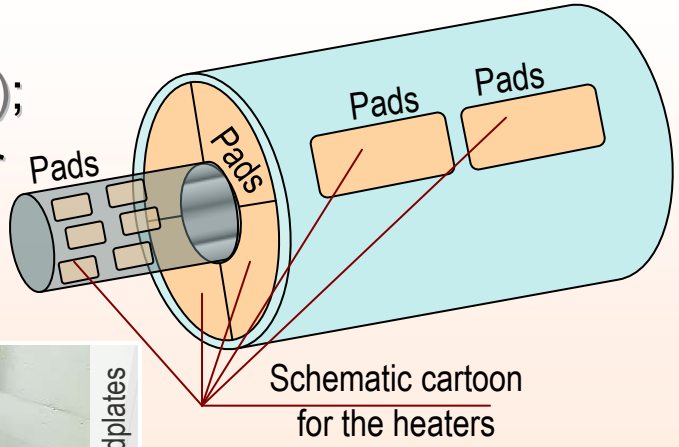
2 Firmware (front end)
- Develop the ELMB code
- Further PID mods, two choices / regimes
- Implementing hardware functionality features
- Troubleshooting
- FSM features
- **New development**

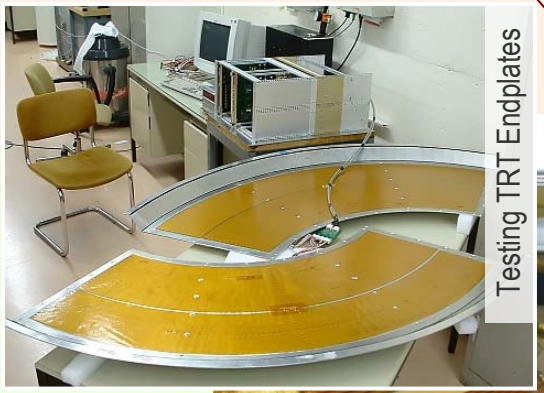
3 Software / GUI / FSM
- PVSS project installation
- PVSS development
- Maintenance/debugging
- Finite State Machine
- Troubleshooting (additional scripts, DP's)
- Integration into Pixel DCS → ATLAS DCS

Inner Detector Heater Pads

- **Purpose and general scope:**
  - About 270 auxiliary heat sources glued to various components of the ID (~480 channels);
  - Independently driven, heaters compensate for undesired aggressive cooling in target areas;
  - Maintain thermal neutrality between sub-detectors boundaries;
  - Prevent condensation.

Thermal **E**nclosure **H**eaters (**TEH**)





- **More detail on heater pads:**
  - Sized from 0.04 to 0.64 m^2;
  - Various shapes, some quite complex;
  - Copper on Kapton, 5-8 μm thick;
  - Sensors: NTCs attached to pads.

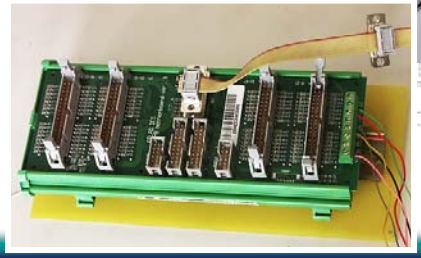
4 configurations of pads:

Sorted by 'complexity'

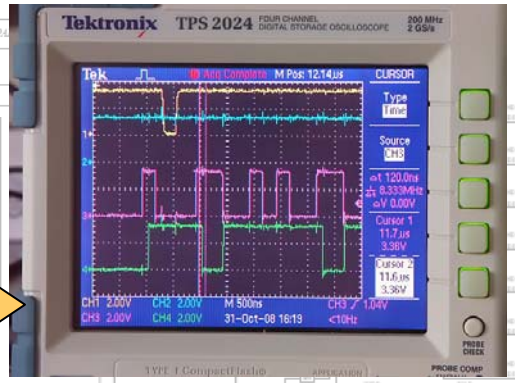
$1^{NTC}/1^{HE}$	$1^{NTC}/2^{HE}$	$2^{NTC}/2^{HE}$	$2^{NTC}/4^{HE}$
Scheme D	Scheme A	Scheme C	Scheme B

- Time frame: July 2008 – present time;
- All of the designs have been made, passed the Safety Review at CERN in 2008!
- PCB boards (switching and controller cards), crate mechanics, backplanes… all have been developed, and now prototyped and tested!
- New electronics design philosophy: all logic is in the ALTERA 10K10 FPGAs
- One of my main challenge was making the ELMBs talk to the FPGAs
- PVSS-based testing programs
- Have passed the final expert peer review at CERN!

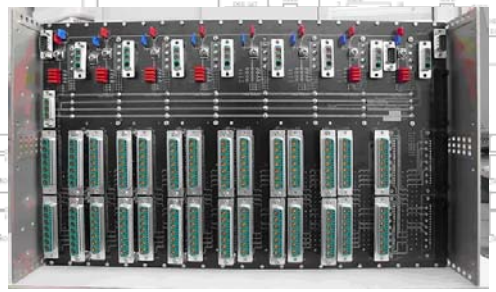
I was the one putting together the technical write-up



A small ELMB test stand was put together, and…

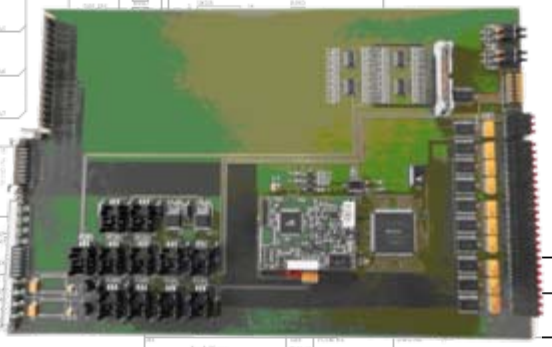


… this is the correct WRITE cycle to the FPGA visible on the scope!



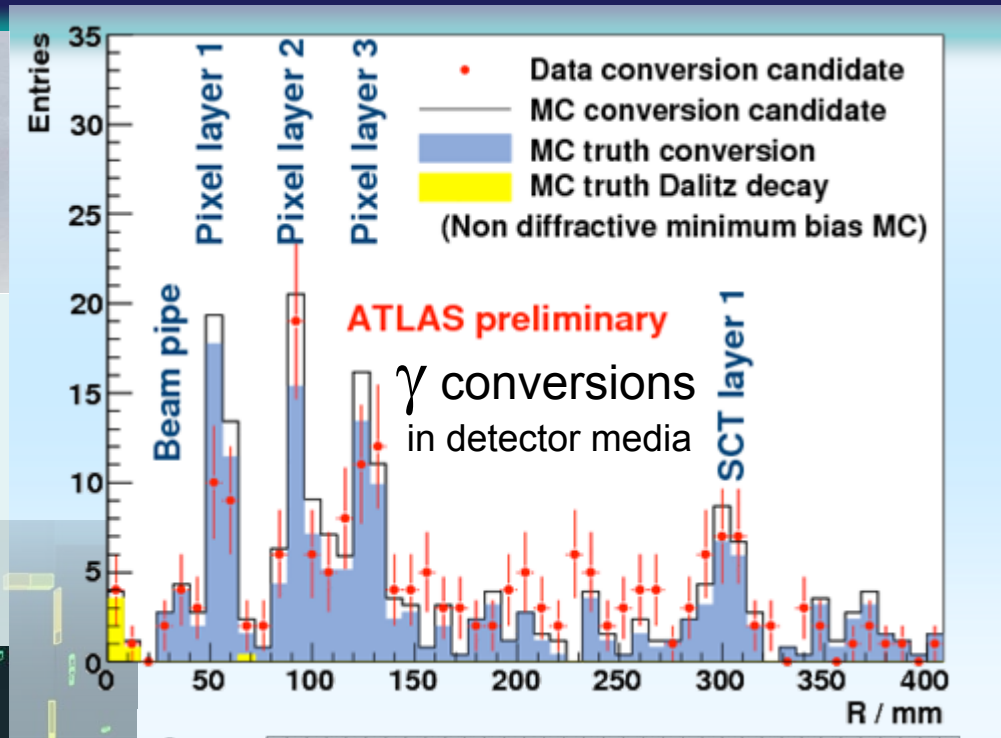
New instrumented switching card

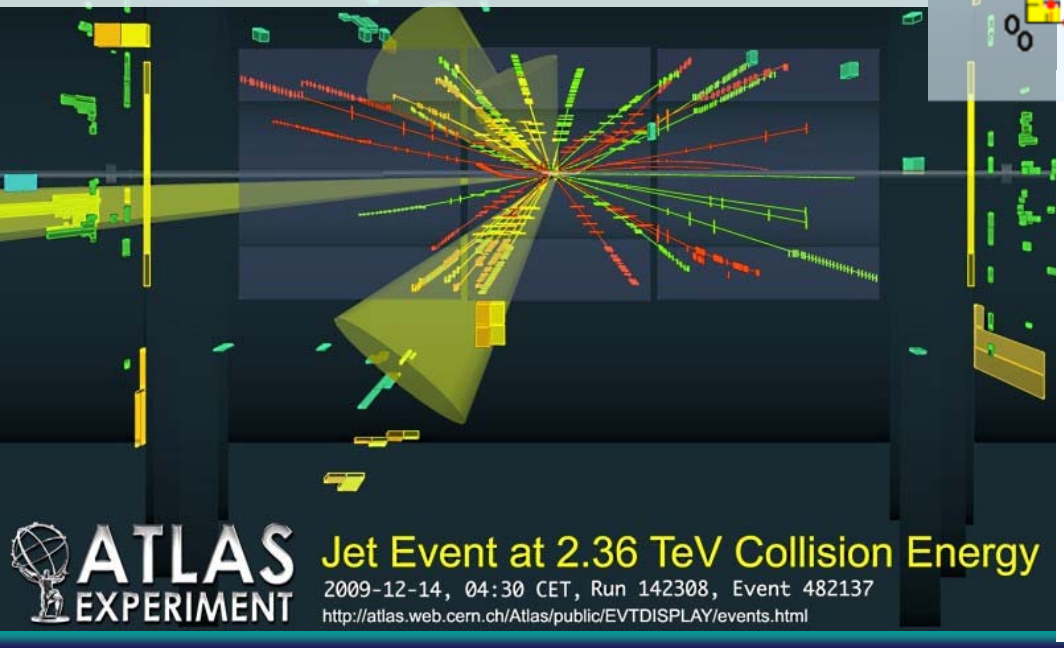
New instrumented controller card

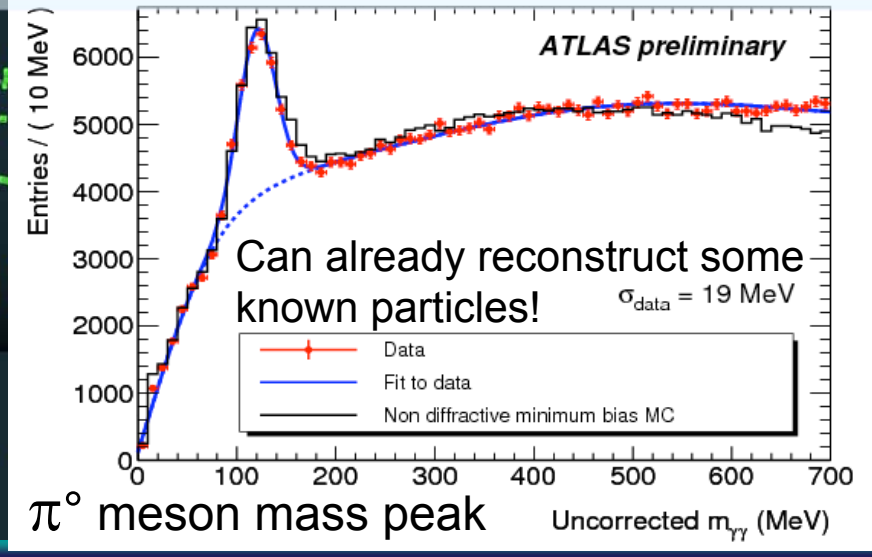


ATLAS Records First LHC Collisions in Late 2009!

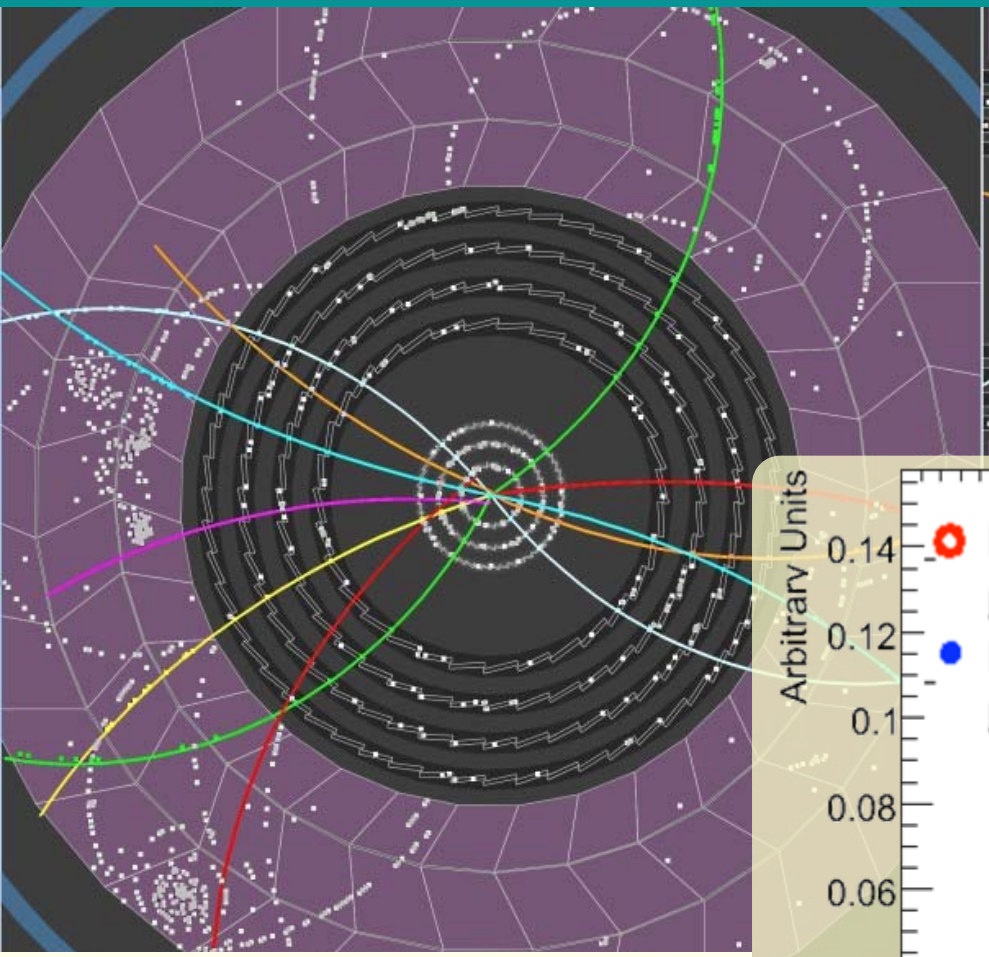
- The entire ATLAS detector responds to collisions predictably.
- While the collected collision data set is very small, it is crucial for further calibration and alignment.
- Many essential responses are already observed, as expected.

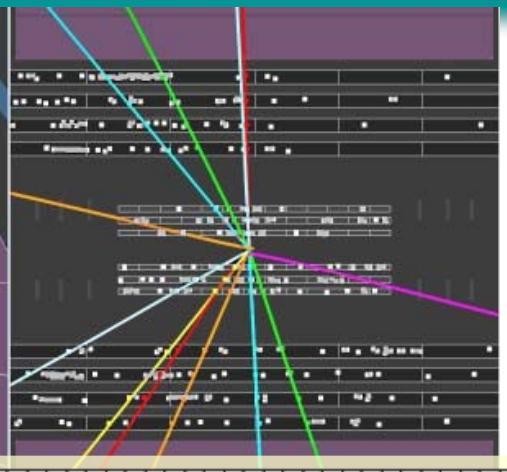


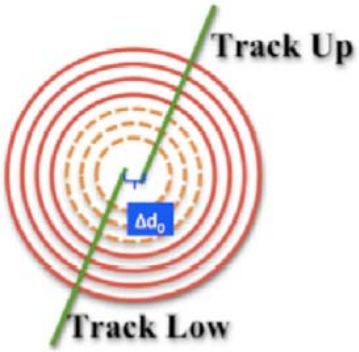


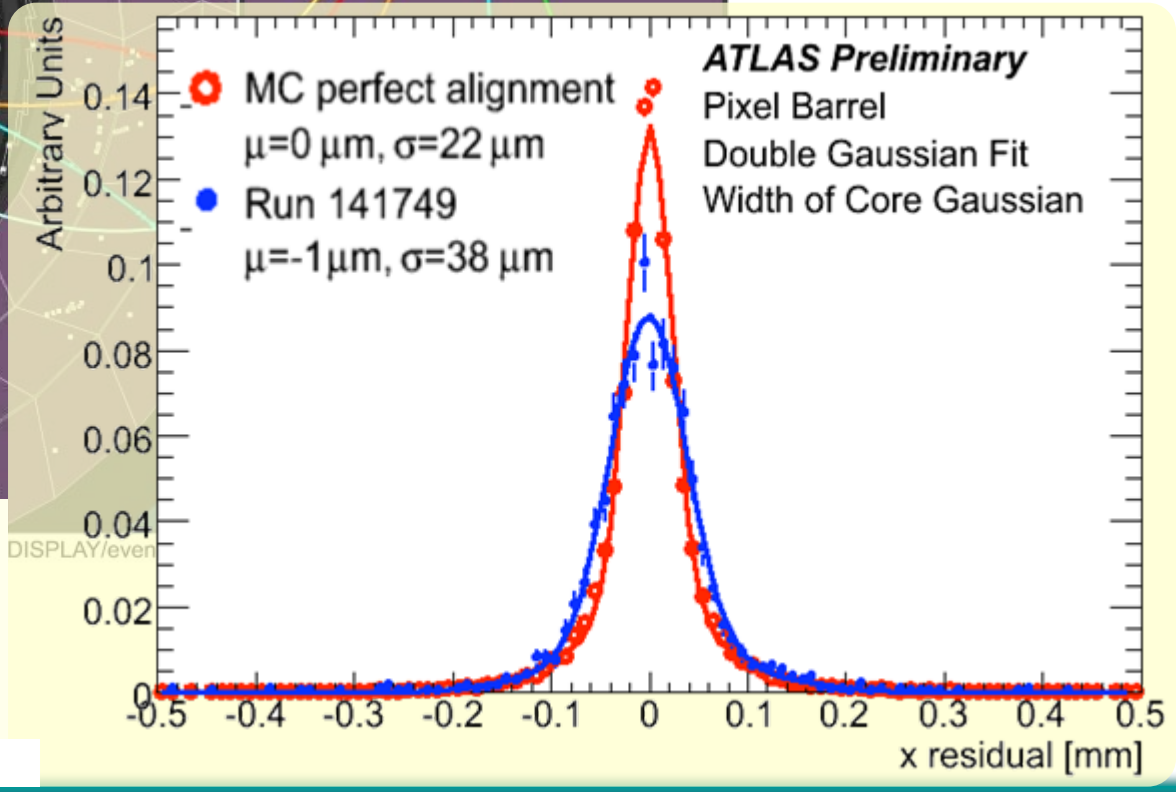


New Alignment Progress





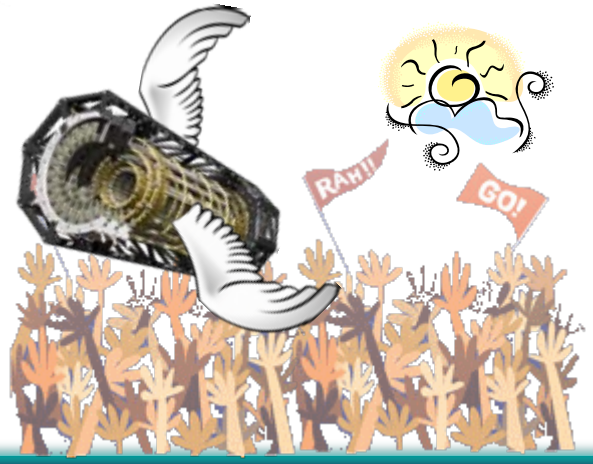




- The alighnment constants obtained with cosmic muons are better
- Present alignment results are still statistically limited

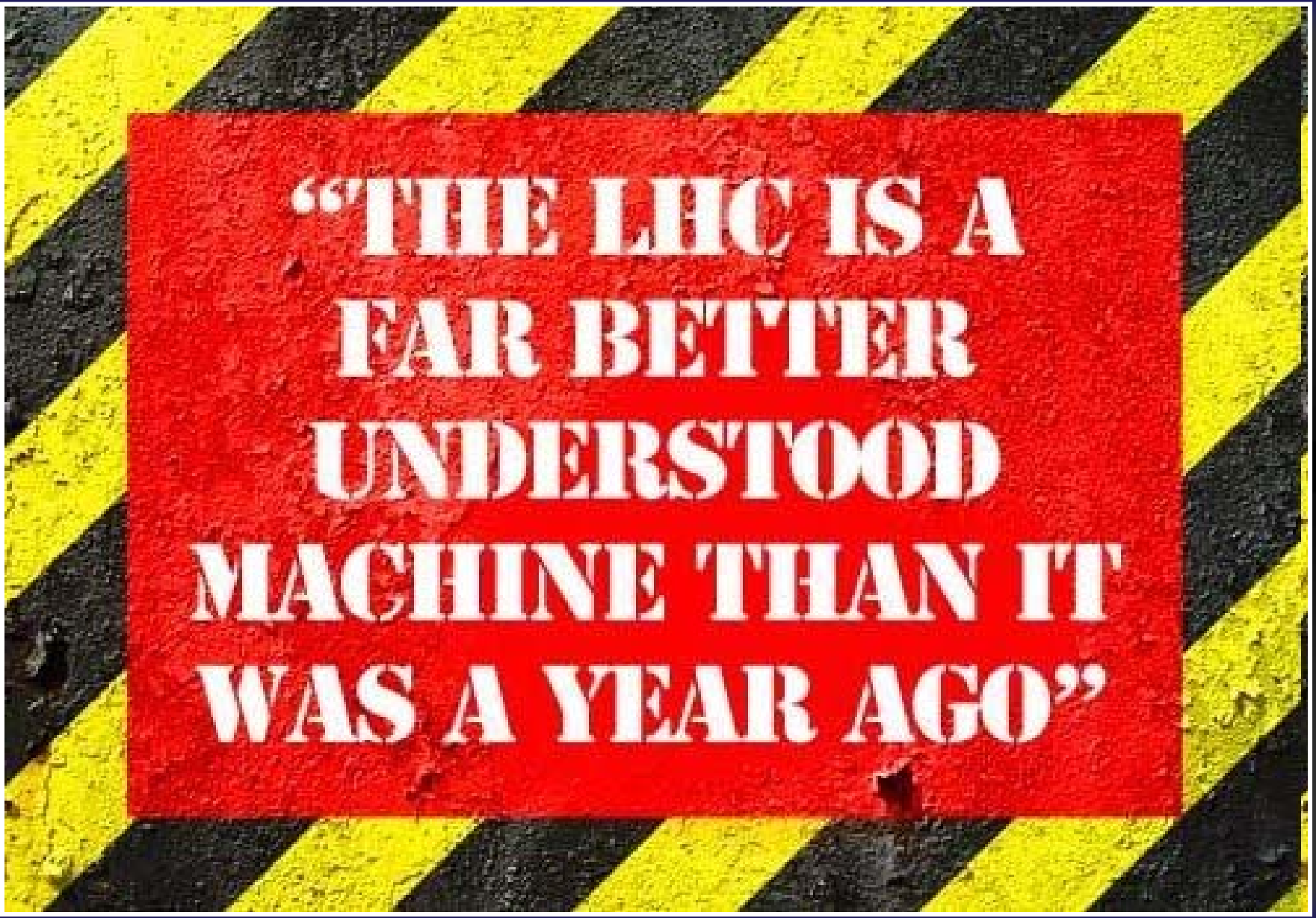
The Summary for the Pixel Detector

- Extremely tight commissioning schedule was successfully met.
- All of the commissioning challenges were successfully resolved.
- **97%** of all modules were included in cosmic ray data taking.
- **3%** were initially disabled due to problematic cooling loops (all in the disks):
  - ⇒ June 2009: Cooling fixed, modules are qualified, tuned, and operate.
  - ⇒ January 2010: 97.9% of modules are included in data taking.
- Hit efficiency in the enabled modules (barrel layers) is above 99.7%.
- Noise occupancy is **$< 10^{-10}$** ⇒ Well below one noise hit per event.
- Resolution (R-φ) after recent alignments with available cosmics: **~24 μm**.
- Resolution (R-φ) obtained with the first collisions data: **~35 μm**.



ATLAS pixel detector has been successfully commissioned, and took first collision data!

Thank you for your attention!



Notes

BACKUP SLIDES
FOLLOW

ATLAS Collision Data Taking Summary

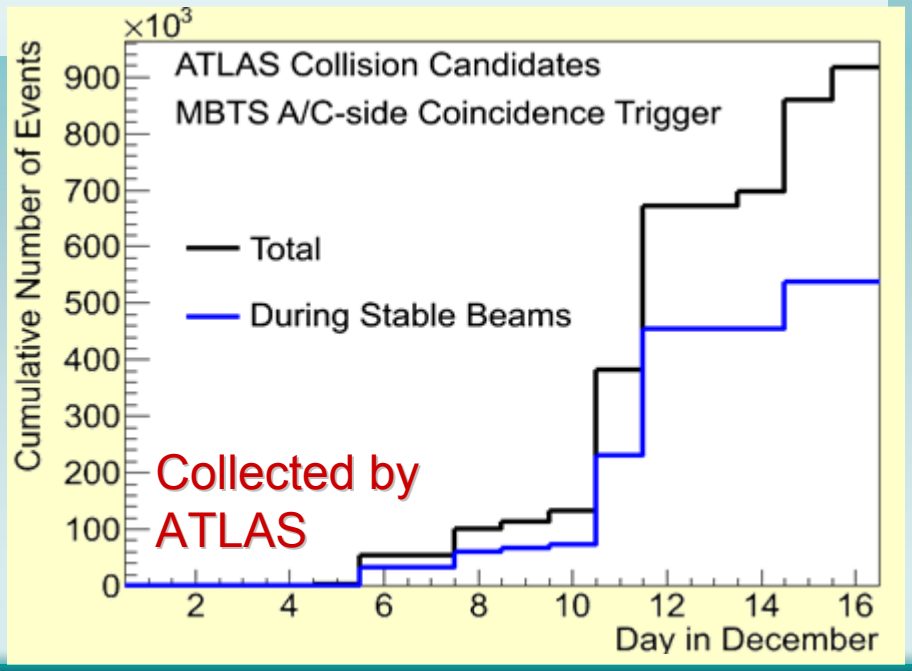
Nov 20	Single beams circulating
Nov 23	First Collisions at 450 GeV First ramp: 560 GeV
Nov 29	First ramp to 1.18 TeV
Nov 30	ATLAS Solenoid is ON
Dec 06	Stable colliding beams: 4x4 bunches at 450 GeV
Dec 08	Ramp 2x2 to 1.18 TeV
Dec 11	Collisions with stable beams: 4x4 @ 450 GeV, > 10^{10} ppb
Dec 13	Ramp 2x2 to 1.18 TeV Collisions for ~90 min
Dec 14	Collisions with stable beams: 16x16 @ 450 GeV, > 10^{10} ppb
Dec 16	Ramp 4x4 to 1.18 TeV

>1 million events at 450x450 GeV
50,000 events at 1.18x1.18 TeV

Delivered

Integrated lum recorded by ATLAS in 2009: 20 μb^{-1}
Integrated lum recorded during stable beams: 12 μb^{-1}
Systematic uncertainties of up to 30% in these numbers.

Number of collision candidates in 2009: 917,000
Number of collision candidates during stable beams: 538,000
Number of collision candidates at 2.36 TeV: 34,000



ATLAS Detector Readiness Summary — Ready to Take Physics!

- **Inner Detector**
  - Pixel Detector
  - Silicon Strip Tracker
  - Transition Radiation Tracker
  - Services and cooling
- **Calorimetry**
  - LAr
  - Tile Calorimeter
  - L1 Calorimeter trigger
- **Muon Spectrometer**
  - Precision chambers
  - Trigger chambers
  - Muon System stand alone resolution: $\Delta P_{\perp}/P_{\perp} < 10\%$ (up to 1 TeV)

Pixel Detector:
- ✓ ~ **98.5%** channels good
- ✓ Hit efficiency **99.7%**
- ✓ Noise occupancy **~10^{-10}**

Silicon Strip Tracker:
- ✓ **> 99%** modules good
- ✓ Hit efficiency **> 99.5%**
- ✓ Noise occupancy: **4.4×10^{-5}** (BRL), **5×10^{-5}** (EC)

Transition Radiation Tracker:
- ✓ e-π separation: 0.5 < E < 150 GeV
- ✓ **> 98%** of 52K channels operational

Services and cooling:
- ✓ Leaky loops **got fixed**
- ✓ Upgraded cooling plant
- ✓ Uptime efficiency **~ 96%**
- ✓ New opto-heater system
- ✓ New ID TEH electronics is coming, **pixel upgraded**

LAr:
- ✓ **99.98%** operational
- ✓ Noisy channels ~ **0.003%**
- ✓ Calibration systems OK

Tile Calorimeter:
- ✓ **99.6%** operational
- ✓ Calibration systems OK

L1 Calorimeter trigger:
- ✓ Dead channels **< 0.4%** (**+0.3%** to be recovered) of 7200 analogue channels
- ✓ Channel to channel noise suppression allows $E_{\perp}$= 1GeV cut (aim is 0.5 GeV)

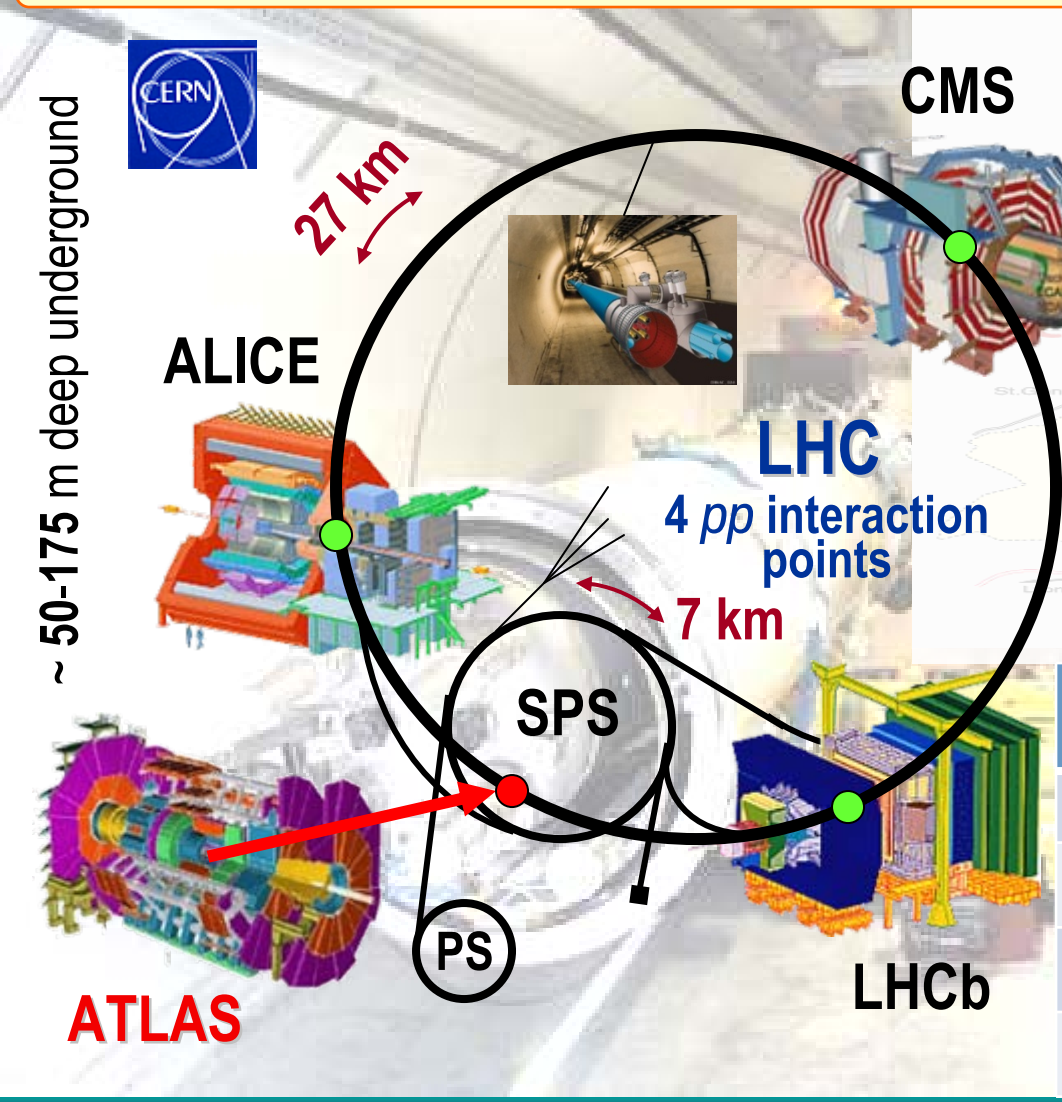
Precision chambers:
- ✓ Resolution 5-10mm;
- ✓ Time res. < 25ns;
- ✓ RPC (BRL): **96%** good;
- ✓ TGC (EC):
  - **99.8%** good;
  - Noisy cnls < **0.02%**

Trigger chambers:
- ✓ Resolution 35-40μm;
- ✓ MDTs (BRL/EC):
  - **99.3%** good, 0.5% recoverable;
- ✓ CSC ('small wheel'): **98.5%** good;
- ✓ Optical alignment system (12232 ch.):
  - **99.7%** (BRL), **99%** (EC) good.

Large Hadron Collider (LHC)

November 15, 2006: Research Scientist at UTD; *December 6: Landed in Geneva…*

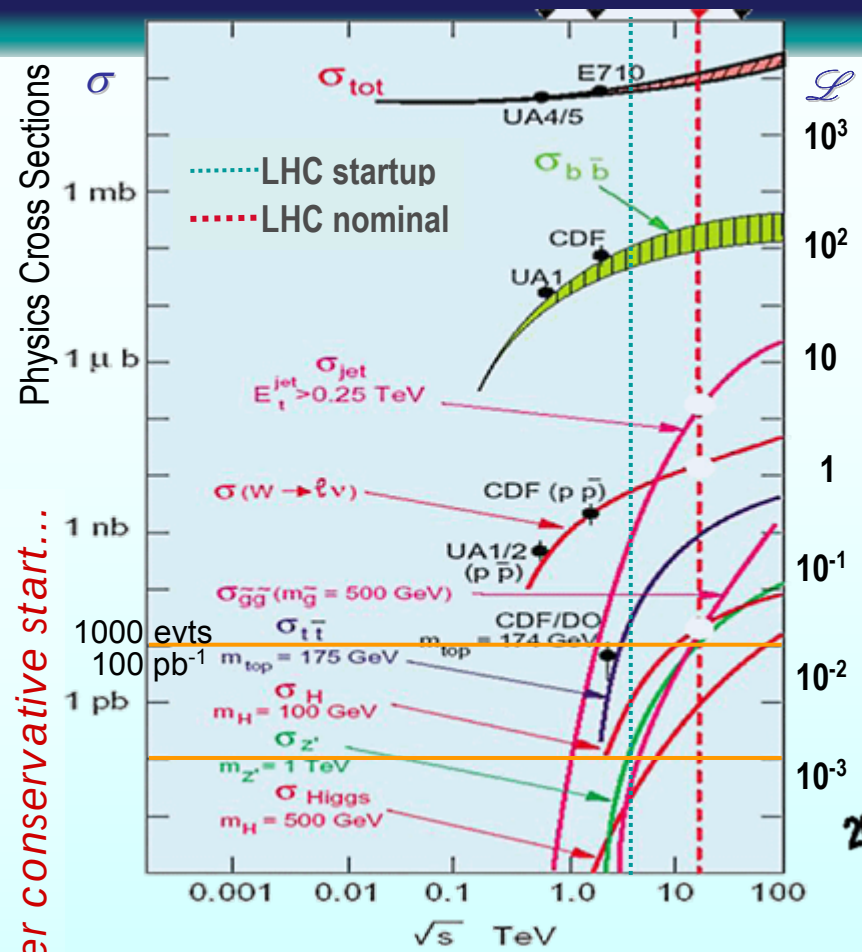
MOTIVATION: To find Higgs Boson and discover New Physics beyond Standard Model

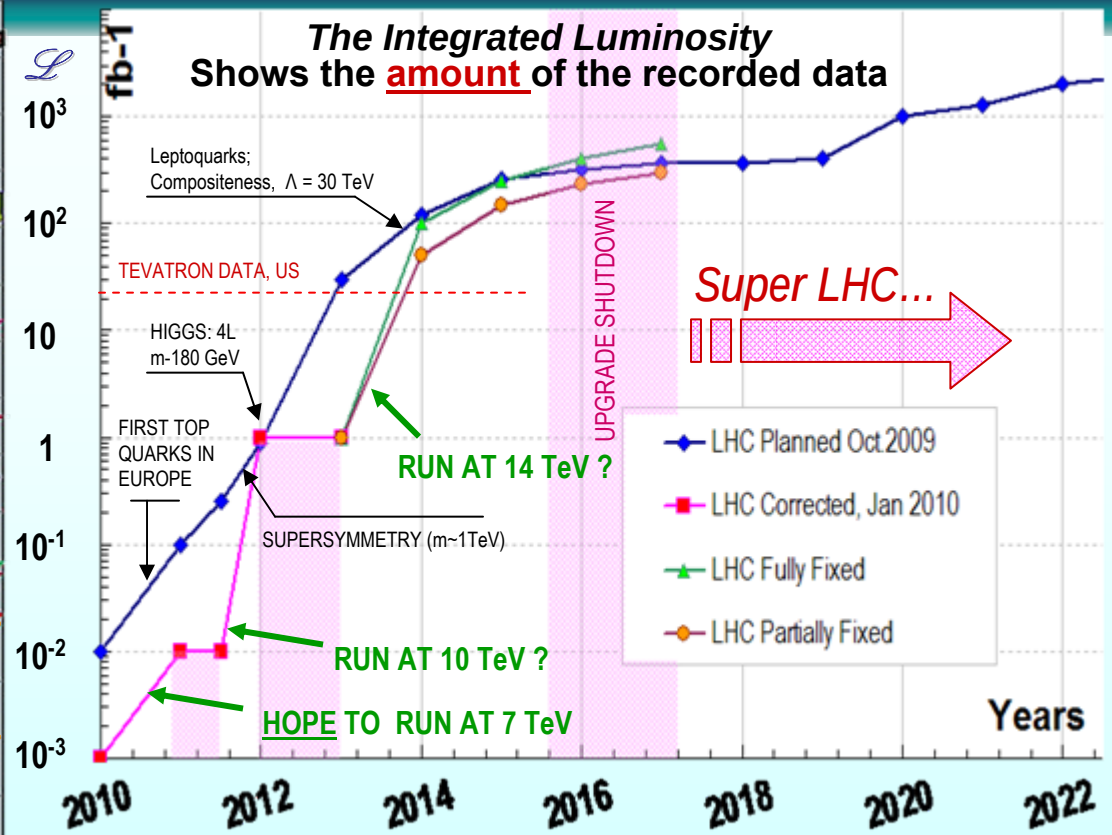


- 1232 dipoles, 858 quadrupoles;
- Dipole field 8.3T at 1.9˚K;
- 96 tons of liquid *He*;
- 2808 proton "bunches"
- 25 ns bunch crossings
- ~1.15 x 10^{11} protons / bunch
- 40M collisions / second!
- 350MJ stored energy / beam

37 kgs worth of cheese fondue!

Machine	Beams	Energy	Luminosity
LHC	p p	14 *TeV*	10^{34} $cm^{-2}s^{-1}$
LHC	Pb Pb	5.5 *TeV*	10^{27} $cm^{-2}s^{-1}$
Tevatron	p $\bar{p}$	2.0 *TeV*	10^{32} $cm^{-2}s^{-1}$
LEP	$e^+ e^-$	200 *GeV*	10^{32} $cm^{-2}s^{-1}$





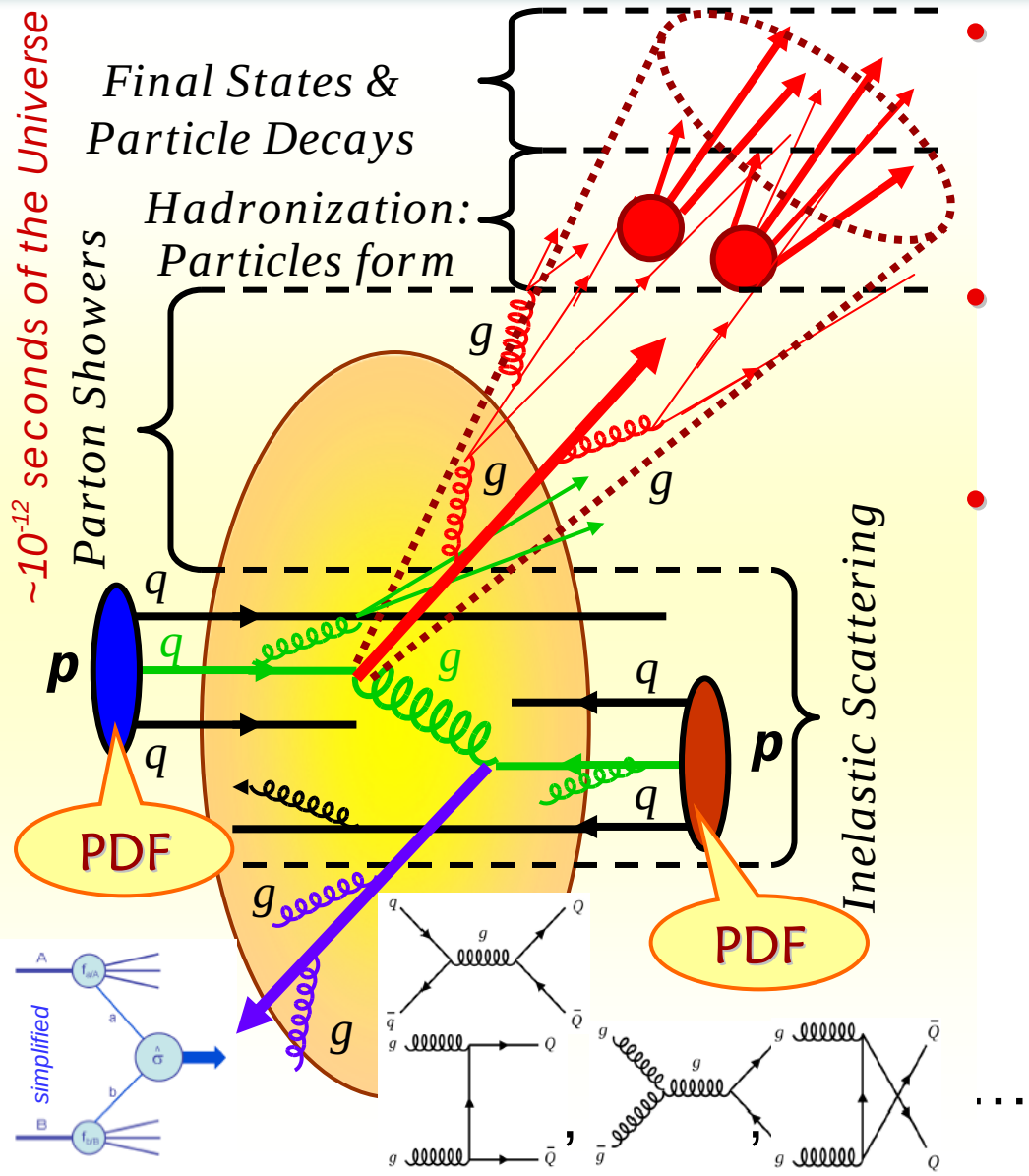
Despite a rather conservative start…

- *Still, a high probability of discoveries…*
- *Understand and improve the detector and accelerator performance*
- *Fine tuning of the Monte Carlo:*
  - Refine the Parton Distribution Functions
  - Tuning based on the known processes

The LHC starting parameters vs. designed:

Main Parameters	Reached	Hopes	Designed
$\mathcal{L}_{\text{instantaneous}}, \frac{1}{cm^2 s}$	7×10^{26}	10^{32}	10^{34}
CM Energy, TeV	2.36	7	14

On the Energy Frontier



- **LHC - The discovery machine:**
  - Probe deep into the *terascale*;
  - *pp* collisions: the abundance of possibilities!
- **LHC's assets:**
  - High *CM* energy;
  - High integrated luminosity;
- **Physics goals:**
  - Cover the SM topics well:
    - *W, Z, Jets, Top, QCD…*
    - Precision measurements
  - The Higgs Boson m_H **= 0.1~1 TeV**;
  - The new Physics:
    - Supersymmetry?..
    - Extra Dimensions?..
    - Leptoquarks?..
    - Compositeness?..

…the unexpected?

ATLAS Data Volume Statistics

Inner Detector	Channels	Fragment Size (KB)
Pixels	1.4×10^8	60
SCT	6.2×10^6	110
TRT	3.7×10^5	307

Muon Spectrometer	Channels	Fragment Size (KB)
MDT's	3.7×10^5	154
CSC's	6.7×10^4	256
RPC's	3.5×10^5	12
TGC's	4.4×10^5	6

Calorimetry	Channels	Fragment Size (KB)
LAr	1.8×10^5	576
Tile	10^4	48

Trigger	Channels	Fragment Size (KB)
LVL1	n/a	28

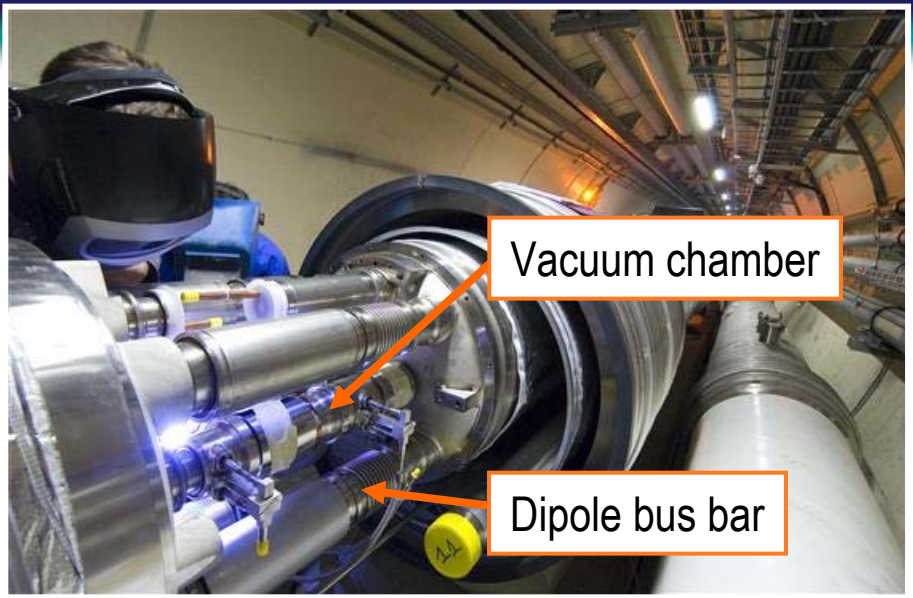
At 40 MHz: 1PB / s

Mass storage system bandwidth: ~300 MB / s

Total: ~3 Petabytes / year for the offline analysis!

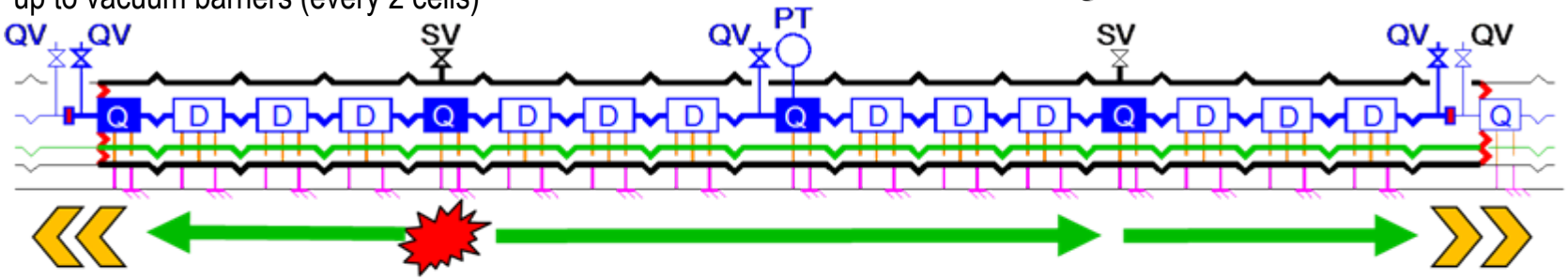
ATLAS event size: ~1.6 Mbytes
140 Million Channels
Organized into ~1600 R/O links

LHC Quench Accident (I)



He pressure wave travels along magnet inside insulation vacuum up to vacuum barriers (every 2 cells)

- Last commissioning step Sector 3-4: ramp to 9.3 kA (5.5 TeV)
- An electrical fault developed @ 8.7 kA in the dipole bus bar Q24.R34 (corr. to ~3.5 TeV)
  - R_{splice} in the interconnect of ~ 220 nΩ vs. 0.35 nΩ
- An electrical arc developed which punctured the ***He*** enclosure
  - Secondary arcs developed along the circuit
  - ~ 400 MJ / 600MJ were dissipated into the magnet coldmass and in electrical arcs.



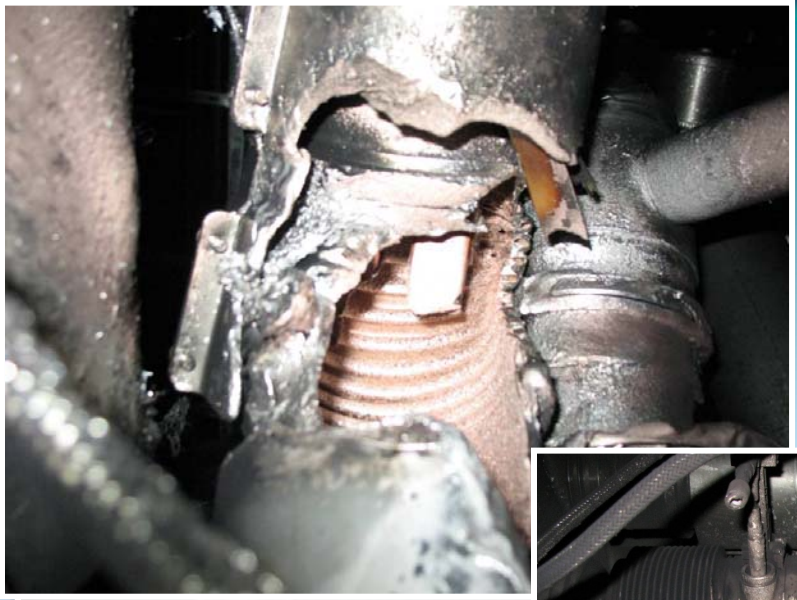
- Cold-mass
- Vacuum vessel
- Line E
- Cold support post
- Warm Jack
- Compensator/Bellows
- Vacuum barrier

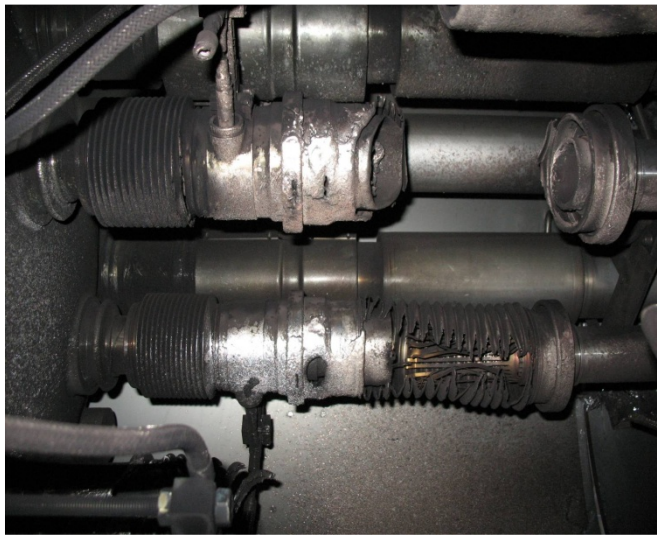
- **Self actuating relief valves:**
  - 2 kg He/s vs.~ 20 kg He/s
- **Large forces exerted on vacuum barriers:**
  - 1.5 bar vs. ~ 8 bar
  - Resulted in ~ 50 cm displacements of the magnets!

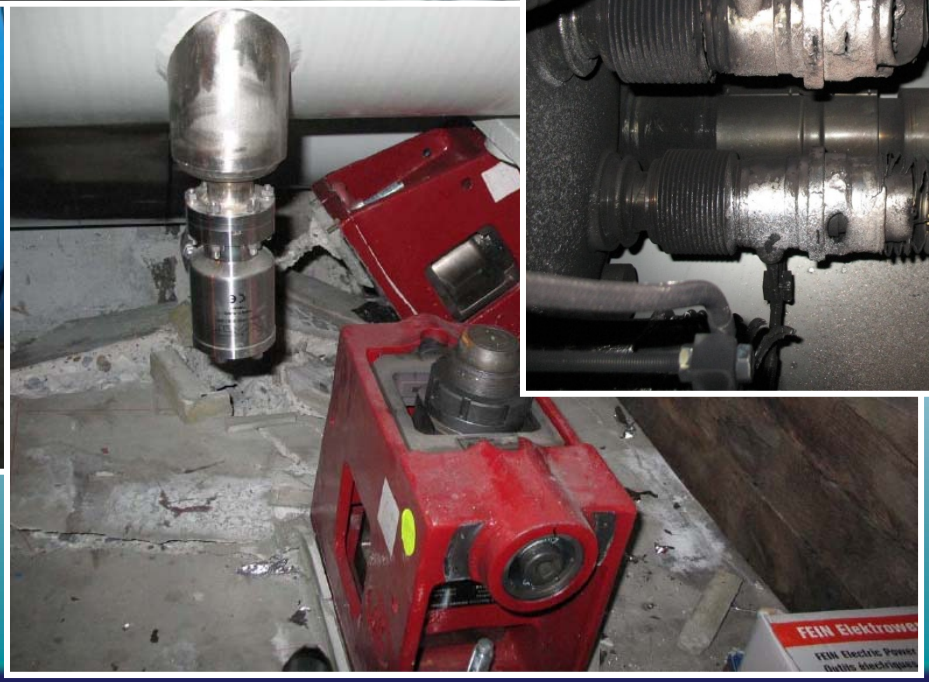
- Tons of liquid *He* were released into the insulation vacuum
  - **Pressure wave along the magnets in the insulation vacuum → collateral damage**

Based on: Mike Harrison

LHC Quench Accident (II)





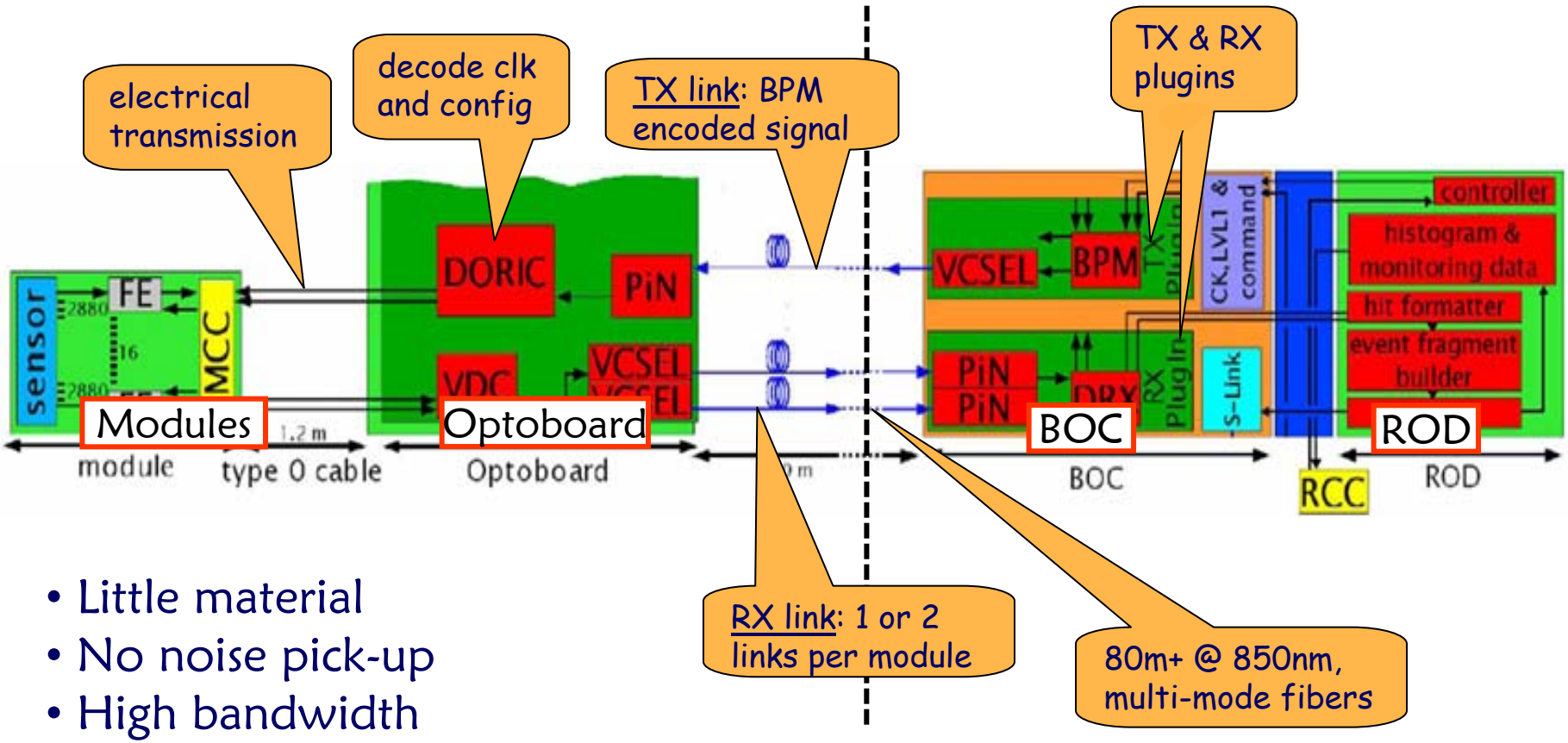


15 Quadrupoles (14 replaced)
42 Dipoles (39 replaced)

Optical Readout System Schematics

On-detector

Off-detector



- Little material
- No noise pick-up
- High bandwidth
- Low attenuation

➔ no buffers needed

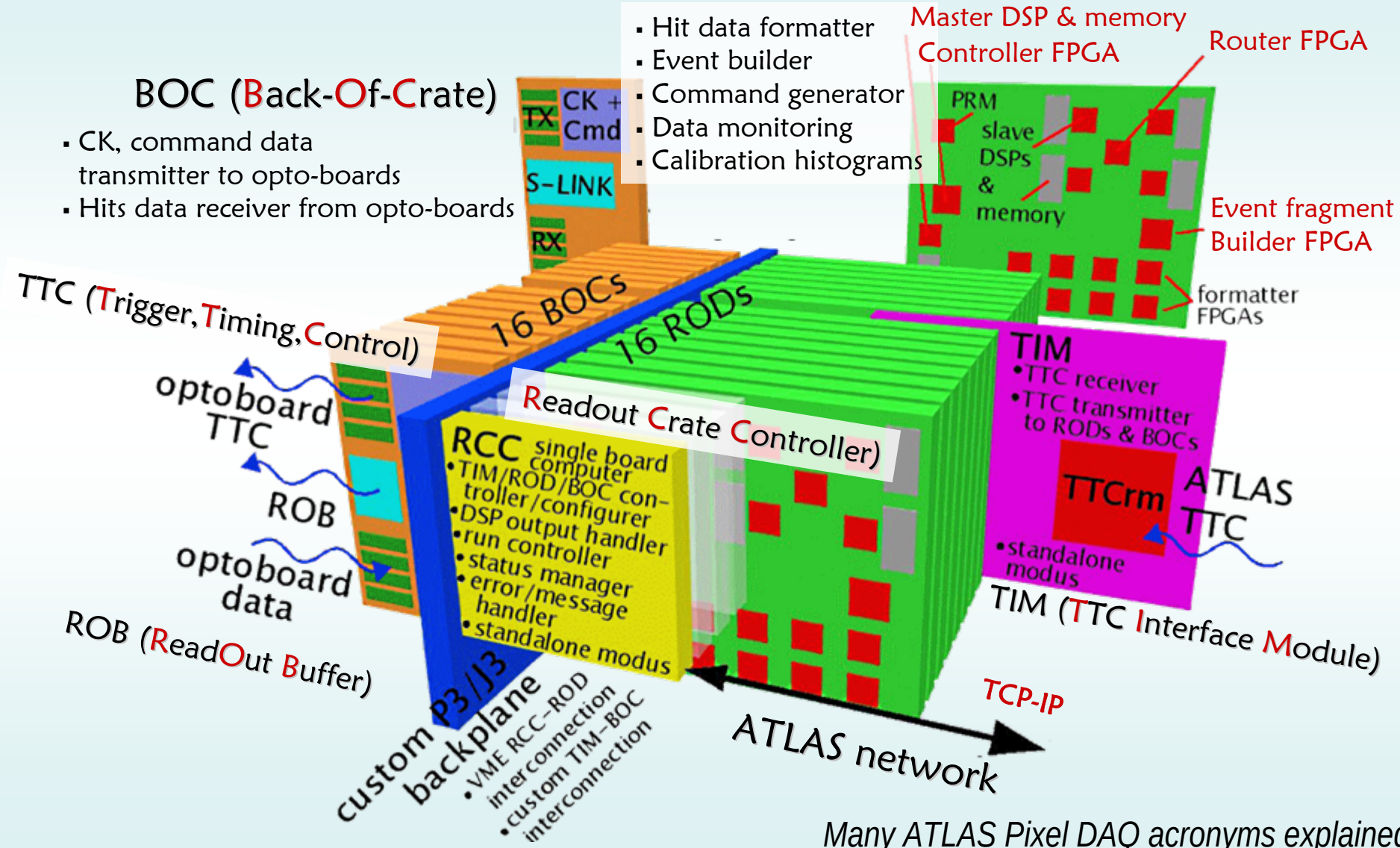
Off-Detector Readout Components

ROD (ReadOut Driver)

- Hit data formatter
- Event builder
- Command generator
- Data monitoring
- Calibration histograms

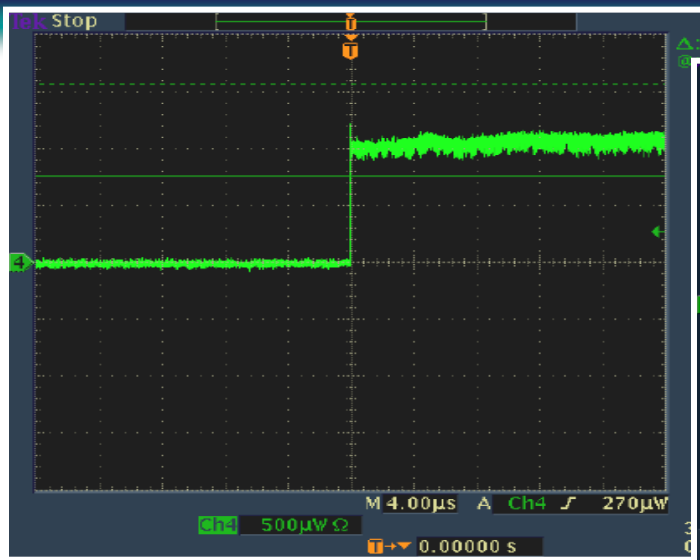
BOC (Back-Of-Crate)

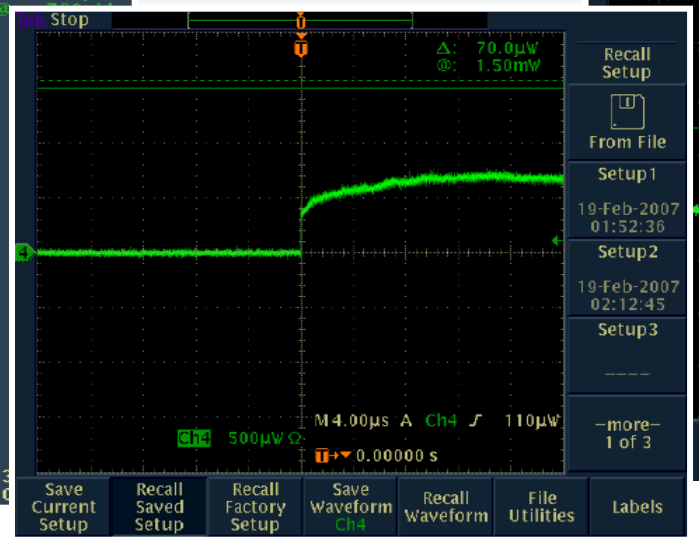
- CK, command data transmitter to opto-boards
- Hits data receiver from opto-boards

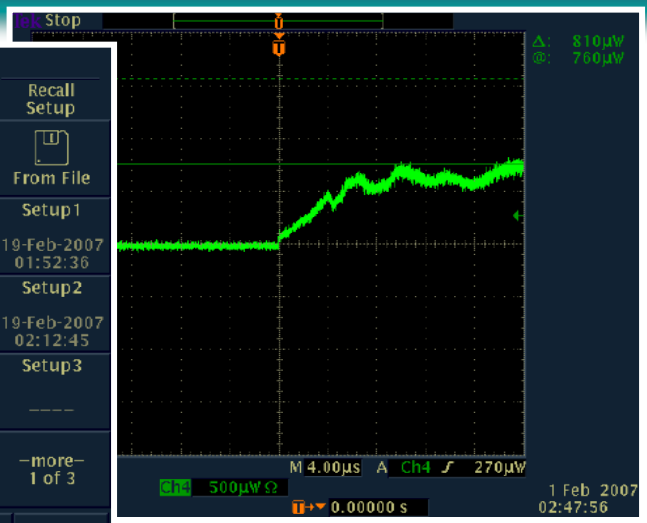


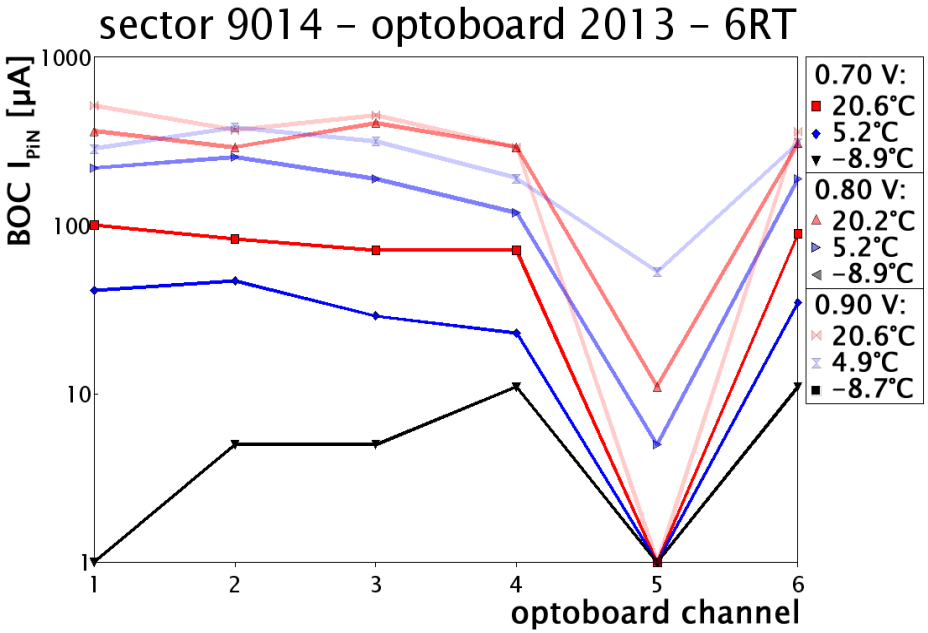
Many ATLAS Pixel DAQ acronyms explained!

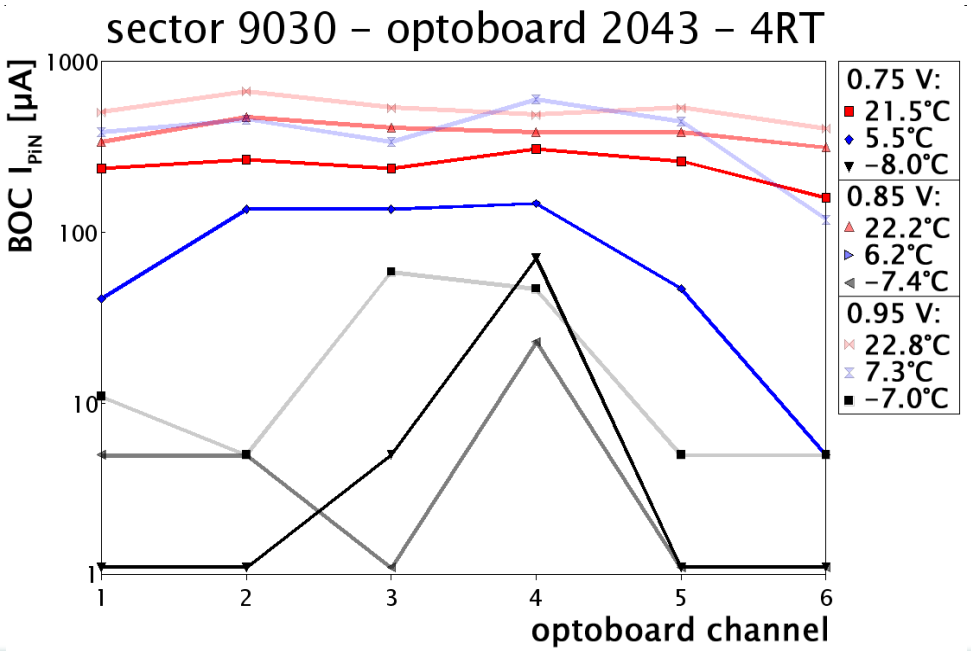
Opto-board Problems: Slow Turn-On







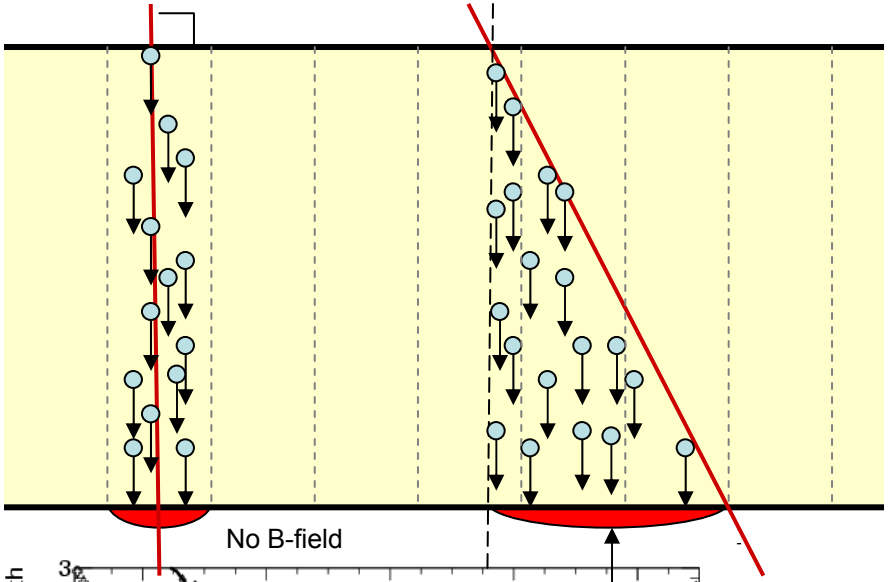


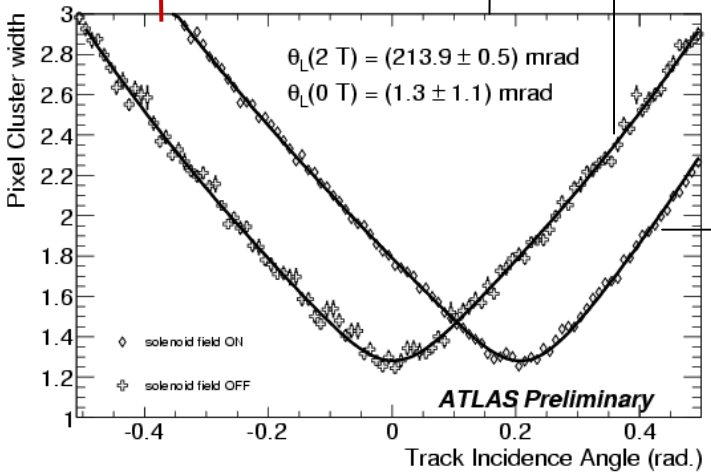


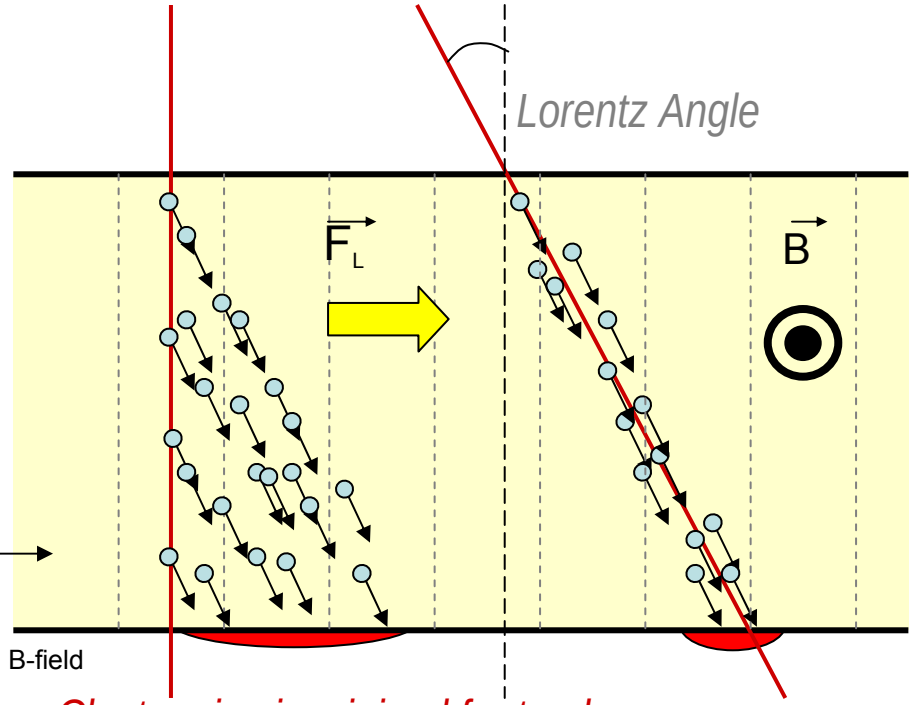
The Lorentz Angle – More Details…

Cluster size is minimal for track normal to the silicon sensor

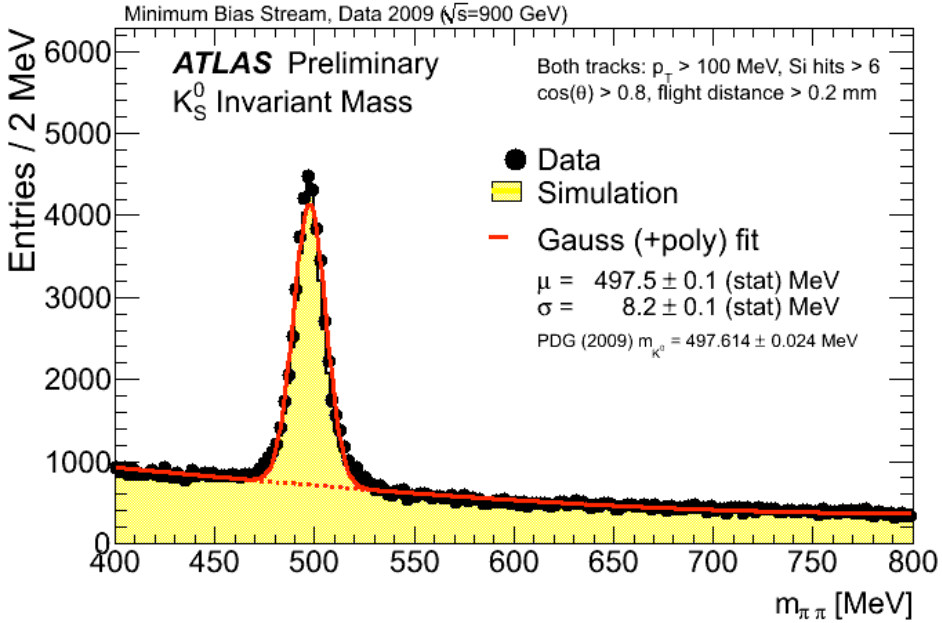
$$\vec{F}_L = q\left(\vec{E} + \vec{\upsilon} \times \vec{B}\right)$$

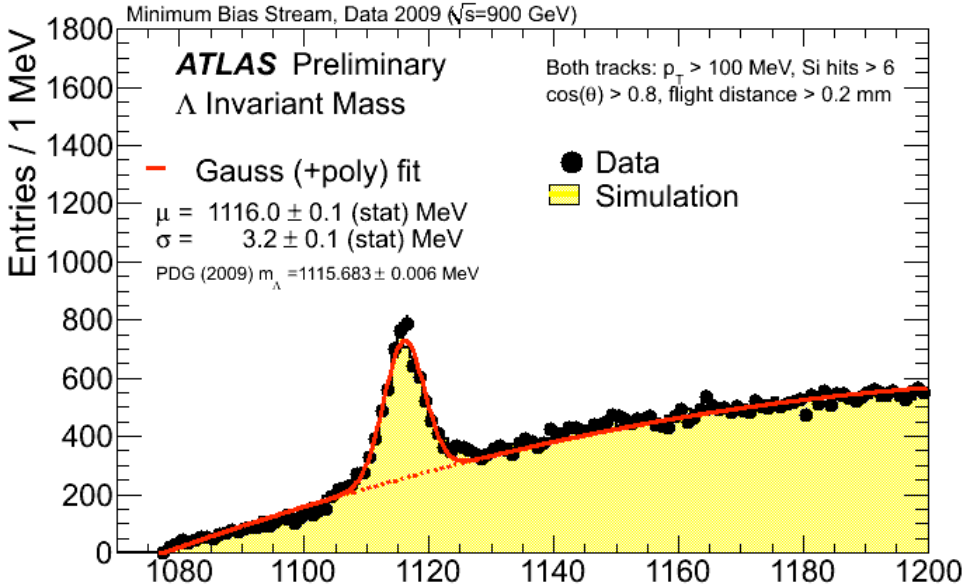


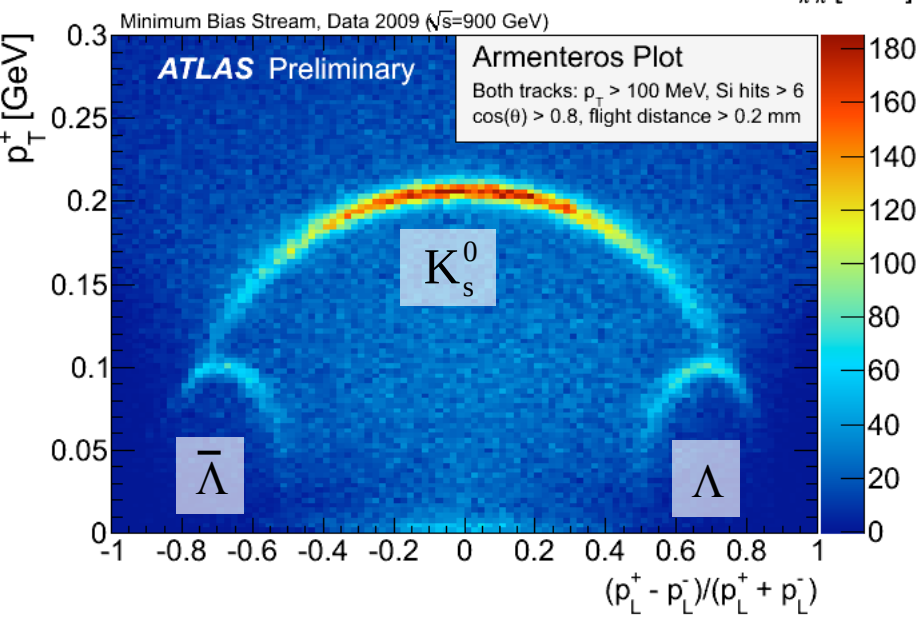


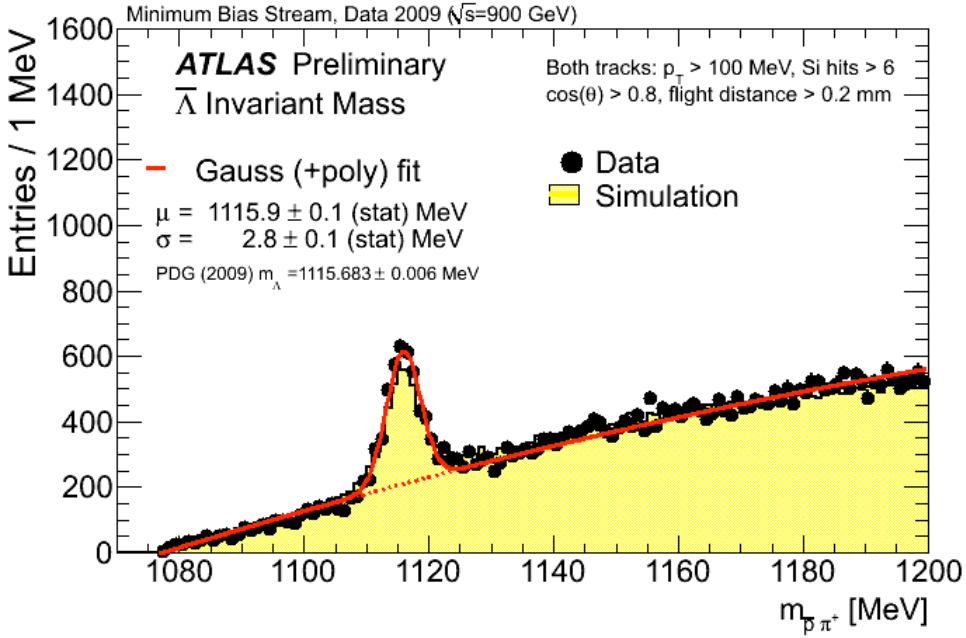


Cluster size is minimal for track incidental at the Lorentz angle


Minimum Bias Stream, Data 2009 (√s=900 GeV)
ATLAS Preliminary
K^0_S Invariant Mass
Both tracks: p_T > 100 MeV, Si hits > 6
cos(θ) > 0.8, flight distance > 0.2 mm
Data
Simulation
Gauss (+poly) fit
μ = 497.5 ± 0.1 (stat) MeV
σ = 8.2 ± 0.1 (stat) MeV
PDG (2009) m_{K^0} = 497.614 ± 0.024 MeV
Entries / 2 MeV
$m_{\pi\pi}$ [MeV]

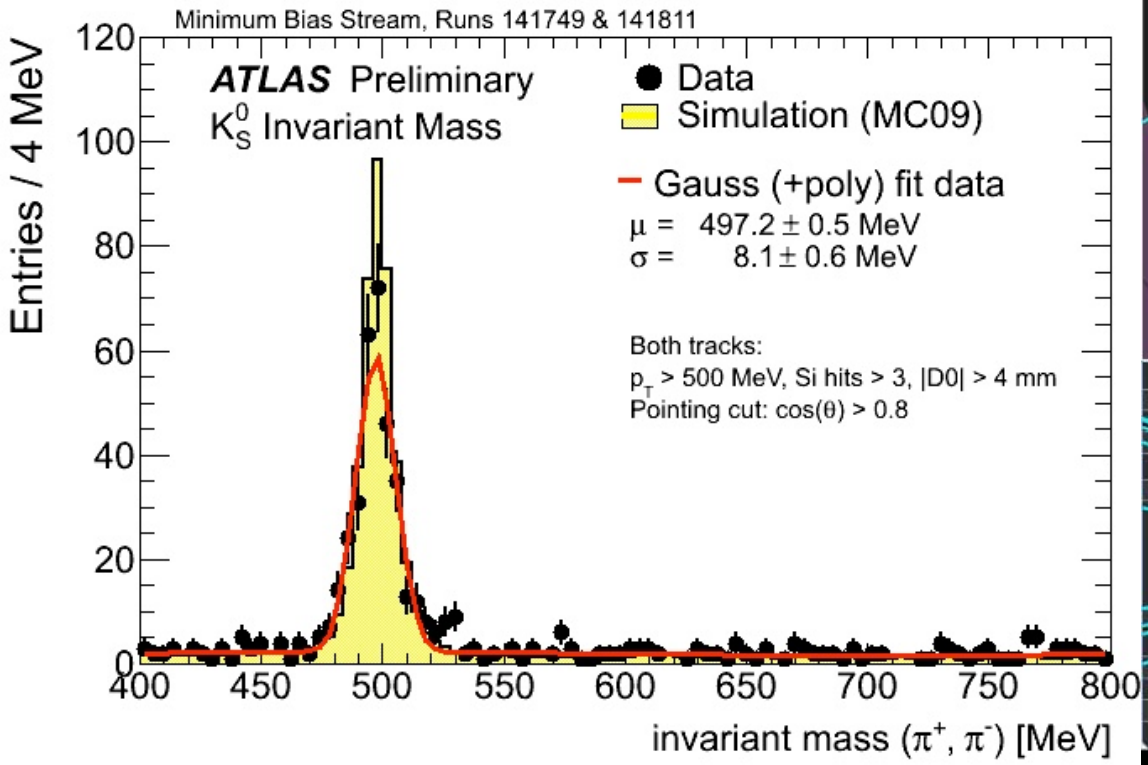
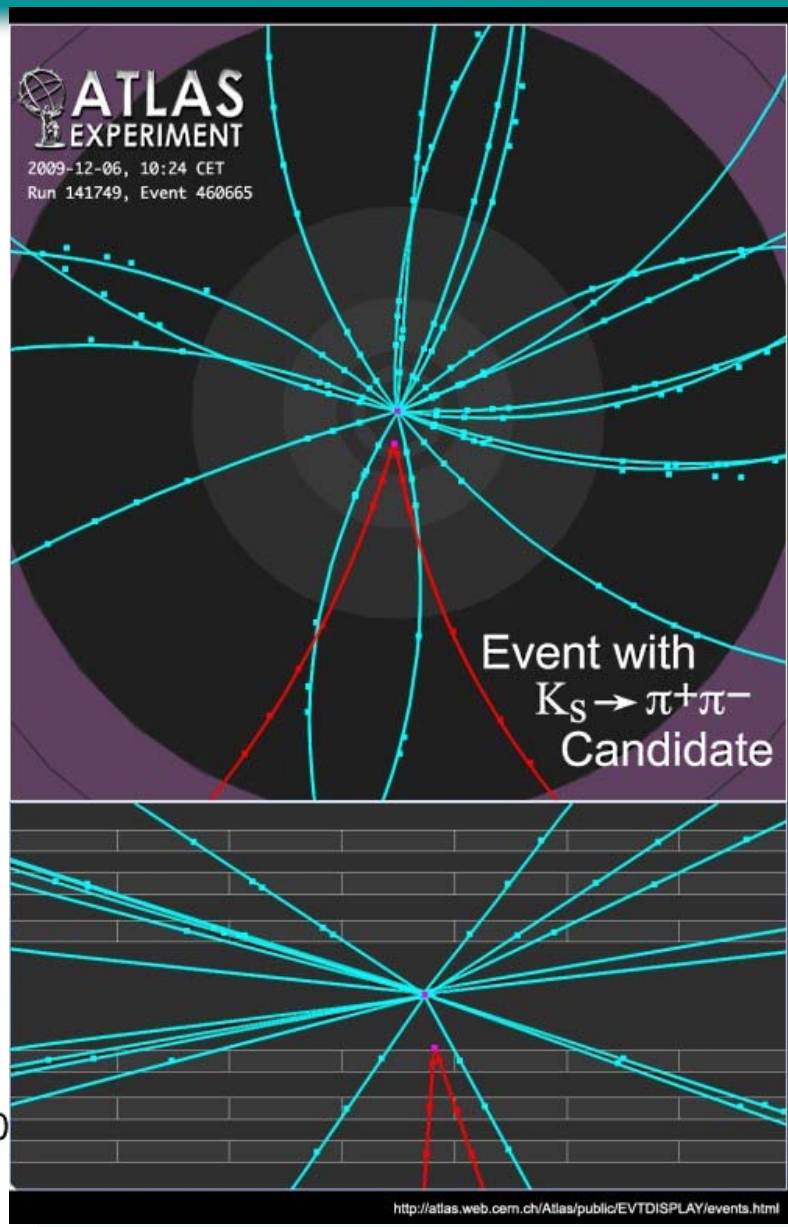

Minimum Bias Stream, Data 2009 (√s=900 GeV)
ATLAS Preliminary
Λ Invariant Mass
Both tracks: p_T > 100 MeV, Si hits > 6
cos(θ) > 0.8, flight distance > 0.2 mm
Gauss (+poly) fit
μ = 1116.0 ± 0.1 (stat) MeV
σ = 3.2 ± 0.1 (stat) MeV
PDG (2009) m_Λ =1115.683 ± 0.006 MeV
Data
Simulation
Entries / 1 MeV


Minimum Bias Stream, Data 2009 (√s=900 GeV)
ATLAS Preliminary
Armenteros Plot
Both tracks: p_T > 100 MeV, Si hits > 6
cos(θ) > 0.8, flight distance > 0.2 mm
K^0_s
$\bar{\Lambda}$
Λ
p^+_T [GeV]
$(p^+_L - p^-_L)/(p^+_L + p^-_L)$


Minimum Bias Stream, Data 2009 (√s=900 GeV)
ATLAS Preliminary
$\bar{\Lambda}$ Invariant Mass
Both tracks: p_T > 100 MeV, Si hits > 6
cos(θ) > 0.8, flight distance > 0.2 mm
Gauss (+poly) fit
μ = 1115.9 ± 0.1 (stat) MeV
σ = 2.8 ± 0.1 (stat) MeV
PDG (2009) m_Λ =1115.683 ± 0.006 MeV
Data
Simulation
Entries / 1 MeV
$m_{\bar{p}\pi^+}$ [MeV]

Recent Physics Results (II)

2 opposite-sign tracks:

- pT >500 MeV
- originating from common vertex
- impact parameter d0 > 4 mm
- momentum sum along flight direction

Data and MC normalized to the same area