ATLAS Pixel Detector Commissioning

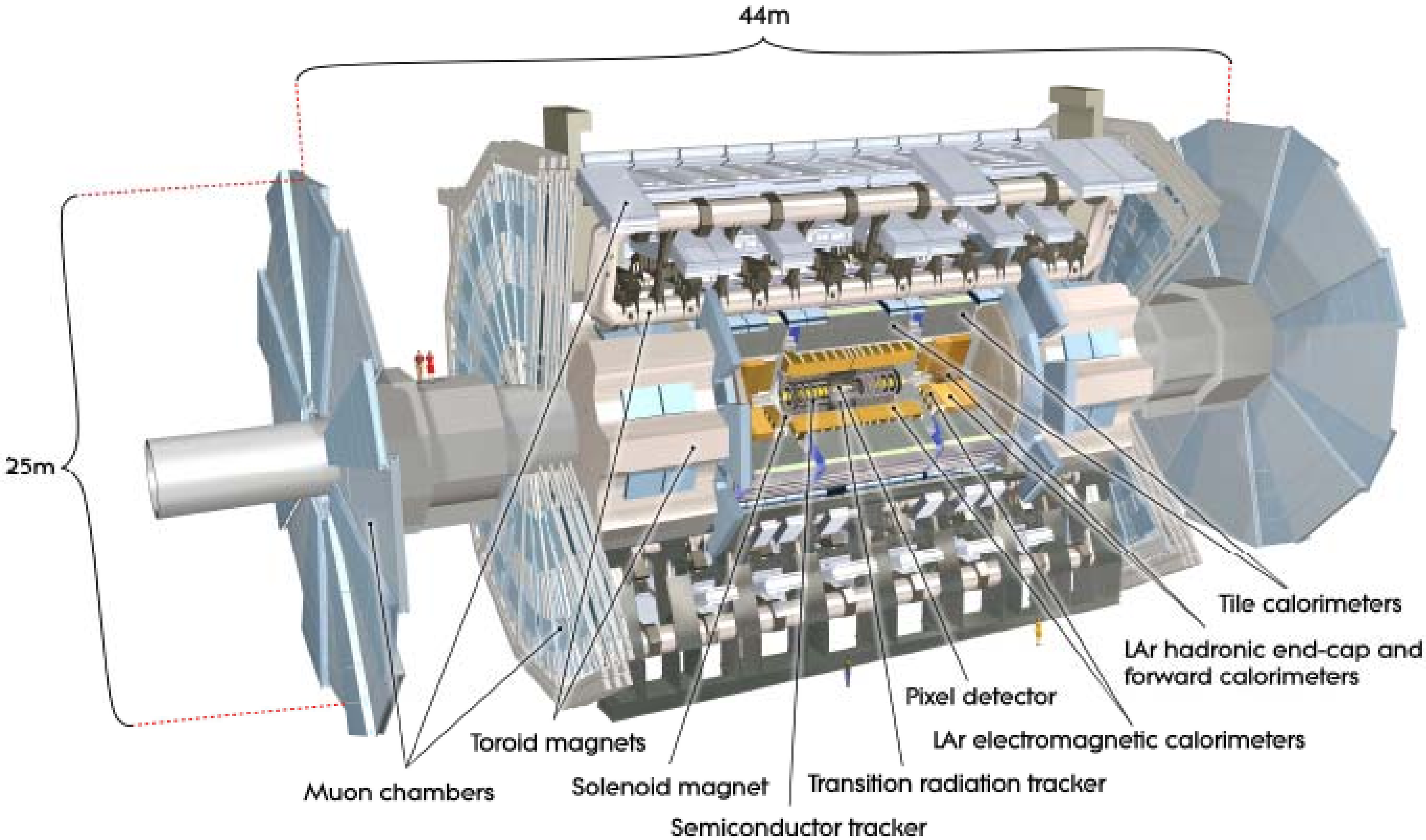
Charles Young (SLAC)

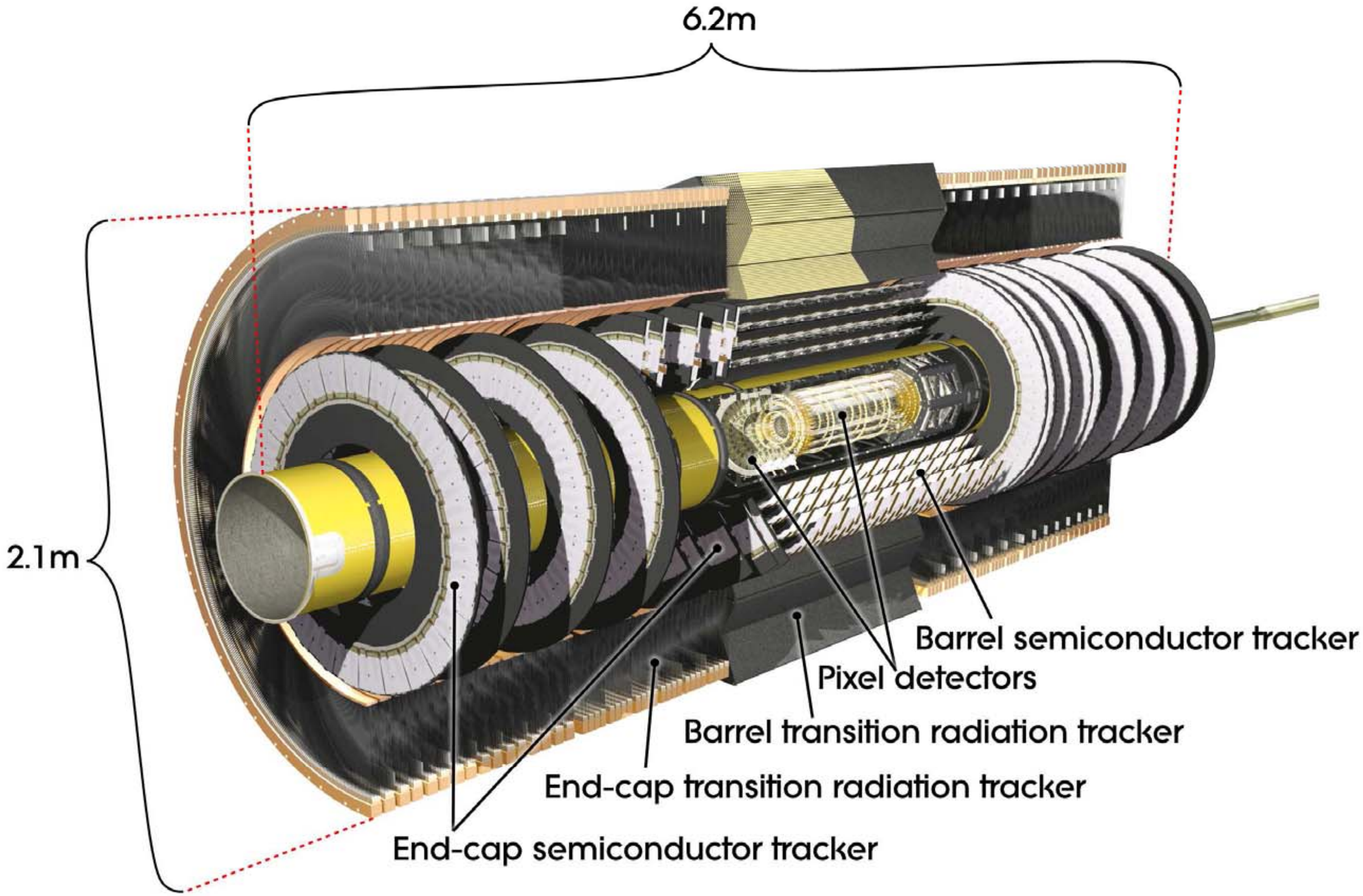
Many thanks to all the members of the ATLAS pixel community

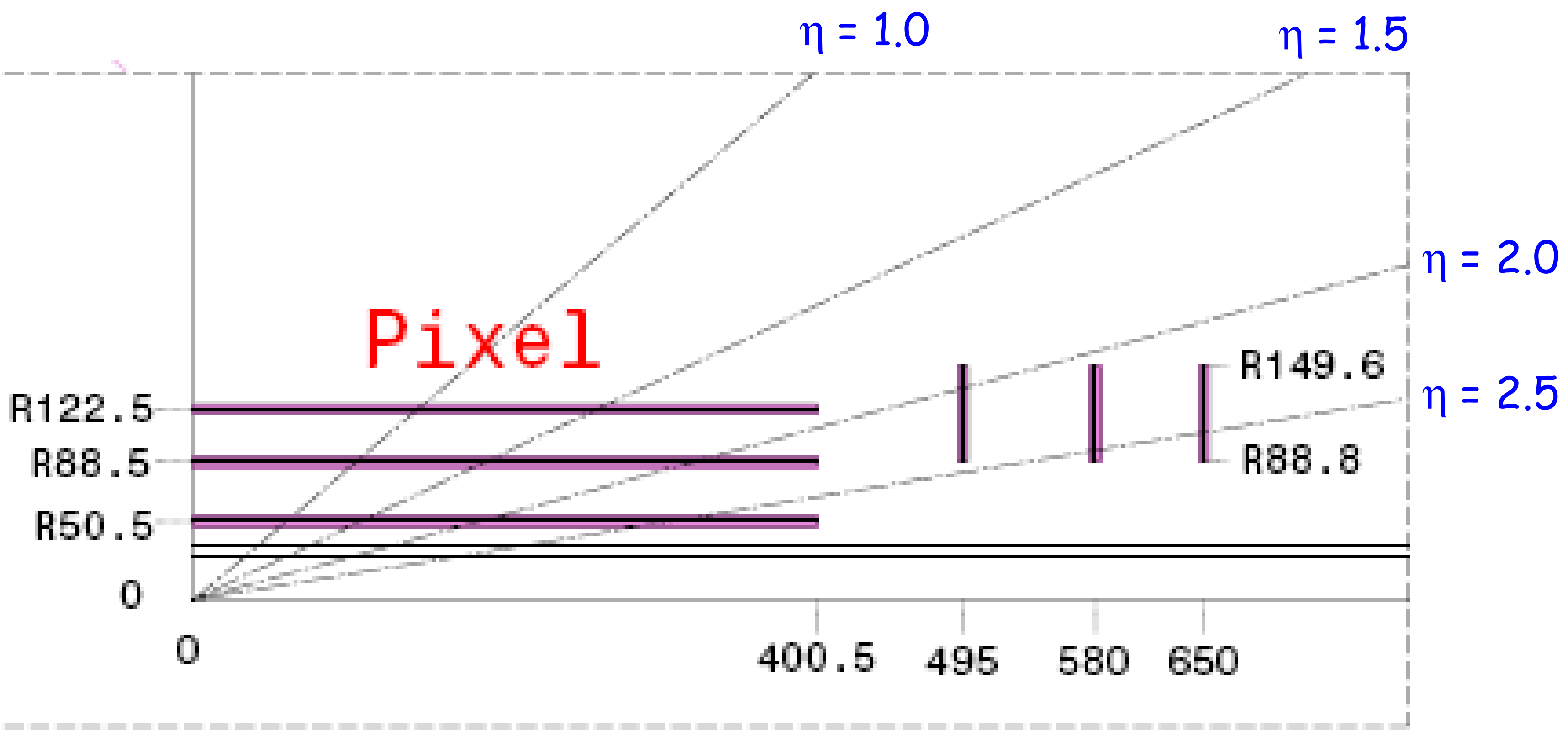
Pixel Detector Package

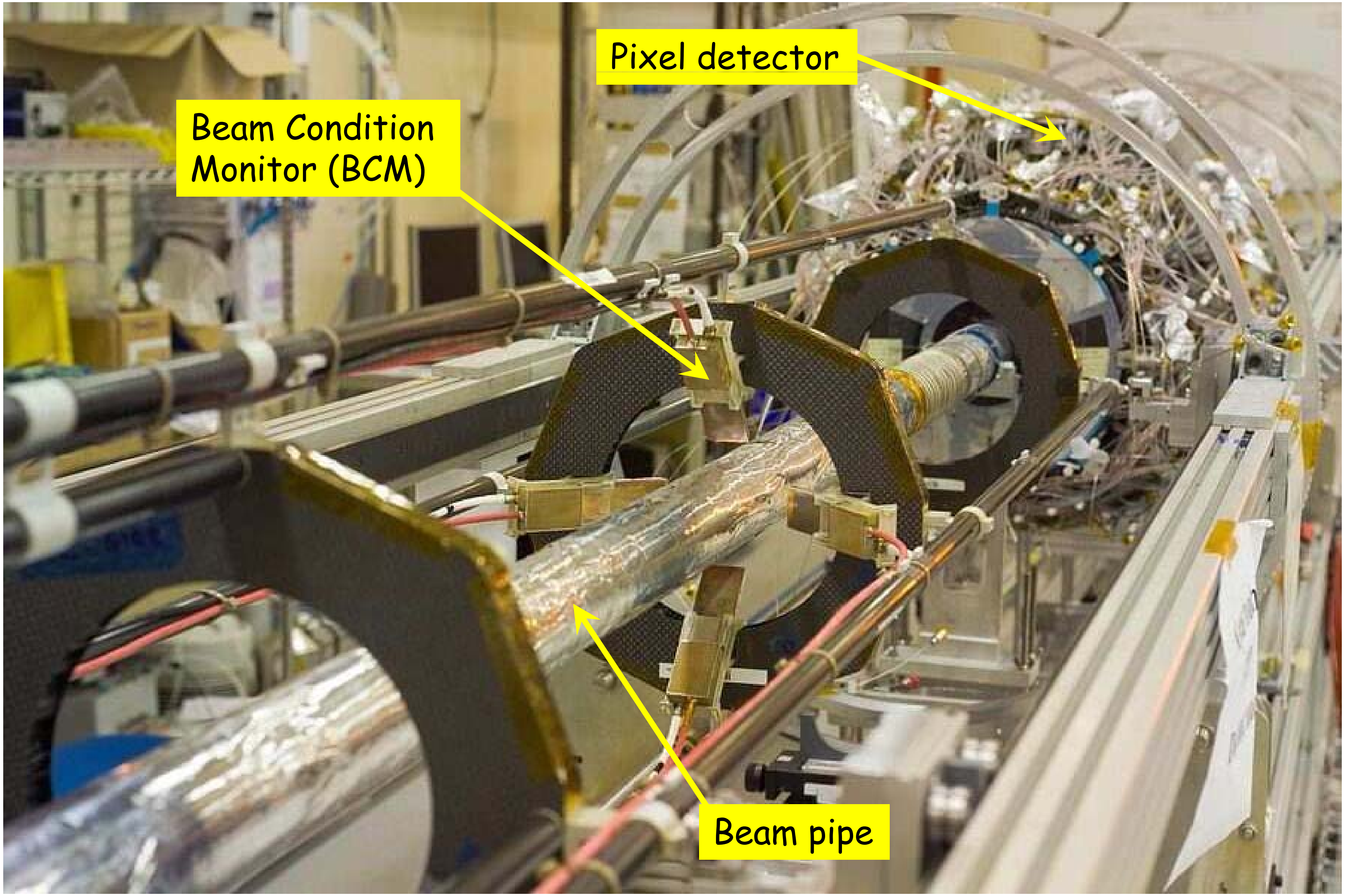
Pixel Package

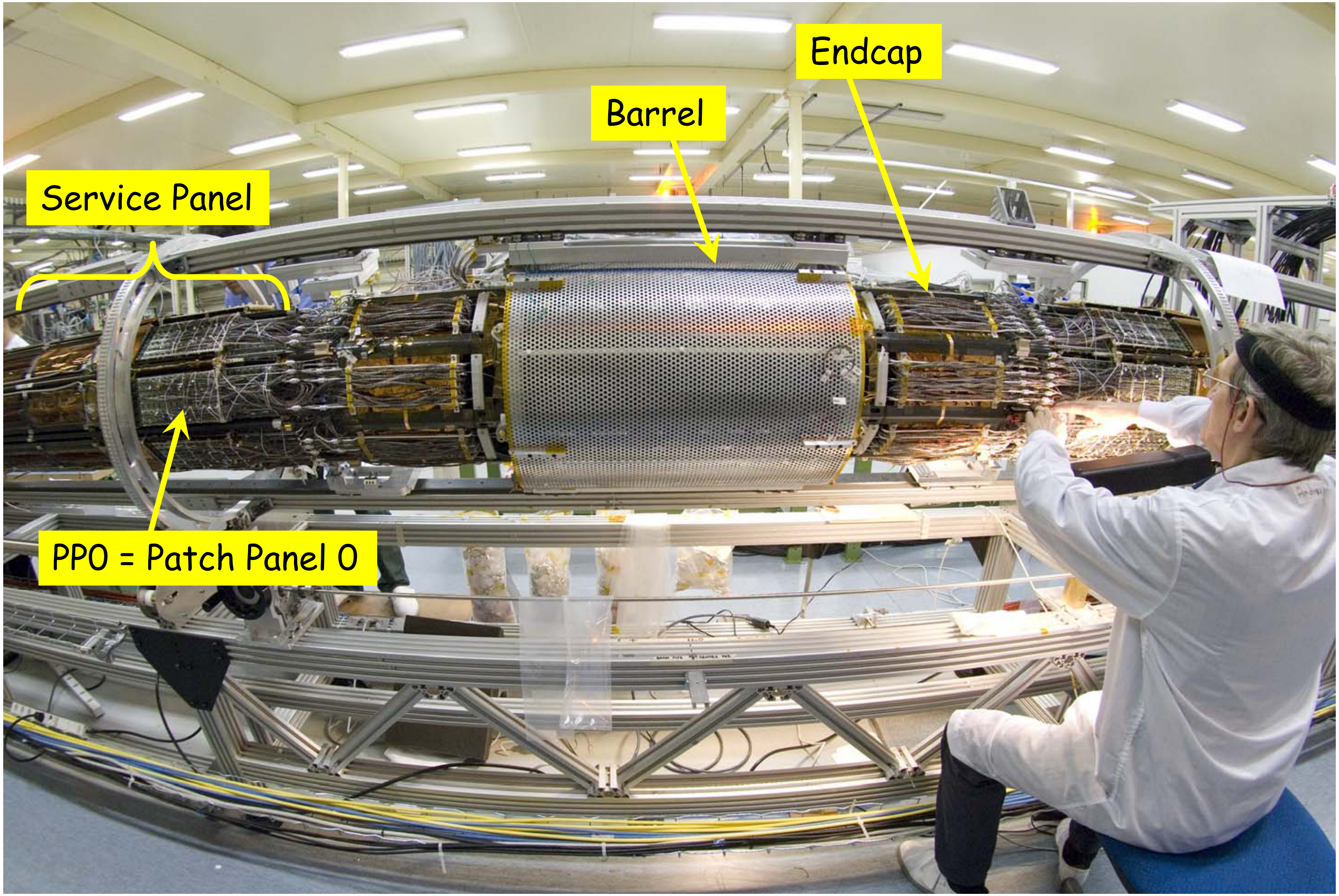
- Pixel detector.
  - Three layers in barrel.
    - 22, 38 and 52 staves x 13 modules.
  - Three disk layers in each endcap.
    - 48 modules in each layer.
  - 46K pixels / module x 1744 modules = 80 10^6 pixels.
  - Envelope: R ~ 15 cm, |z| ~ 70 cm.
- Service panels.
  - Patch Panel 0 (PP0) contains all connections to modules.
    - At small |z| end.
    - Electrical and cooling connections.
  - PP1 has all external connections.
    - At large |z| end.
    - Optical, electrical and cooling connections.
  - Electrical <-> optical conversion.
- Beam pipe captured inside pixel detector.
  - Beam Condition Monitor (BCM), etc also attached.

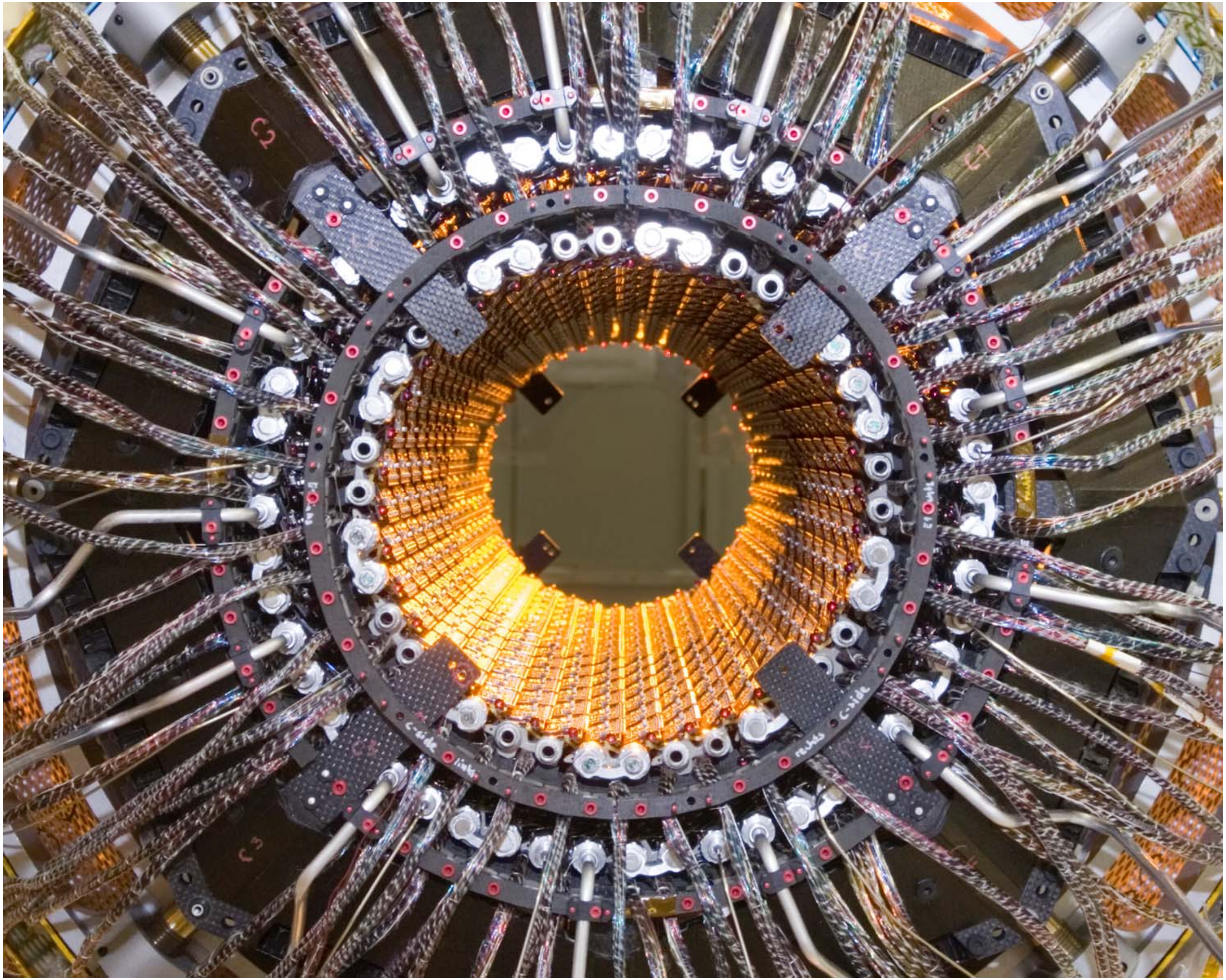

44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker


6.2m
2.1m
Barrel semiconductor tracker
Pixel detectors
Barrel transition radiation tracker
End-cap transition radiation tracker
End-cap semiconductor tracker

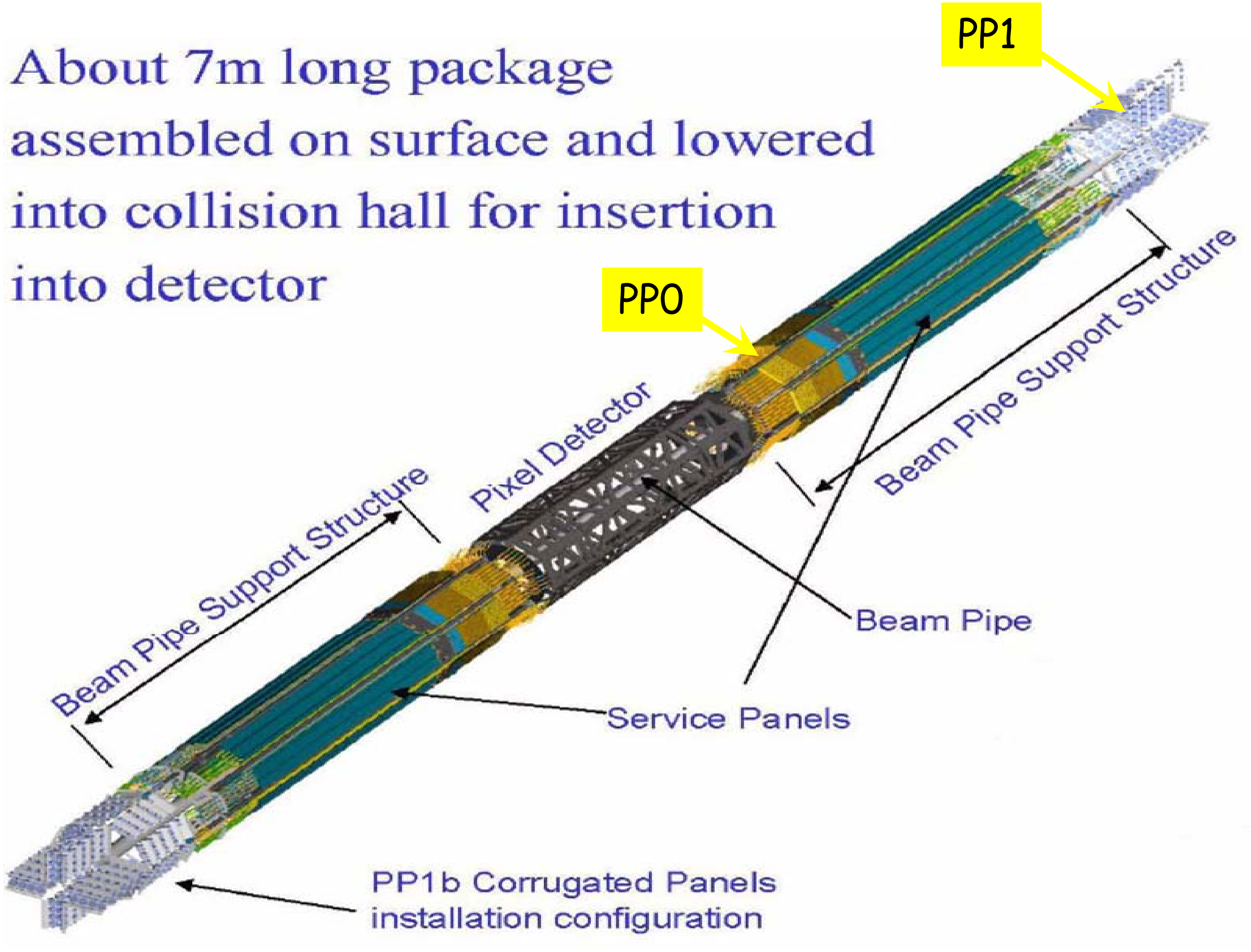

η = 1.0
η = 1.5
η = 2.0
η = 2.5
Pixel
R149.6
R122.5
R88.5
R88.8
R50.5
0
0
400.5
495
580
650


Pixel detector
Beam Condition
Monitor (BCM)
Beam pipe


Endcap
Barrel
Service Panel
PP0 = Patch Panel 0



About 7m long package assembled on surface and lowered into collision hall for insertion into detector

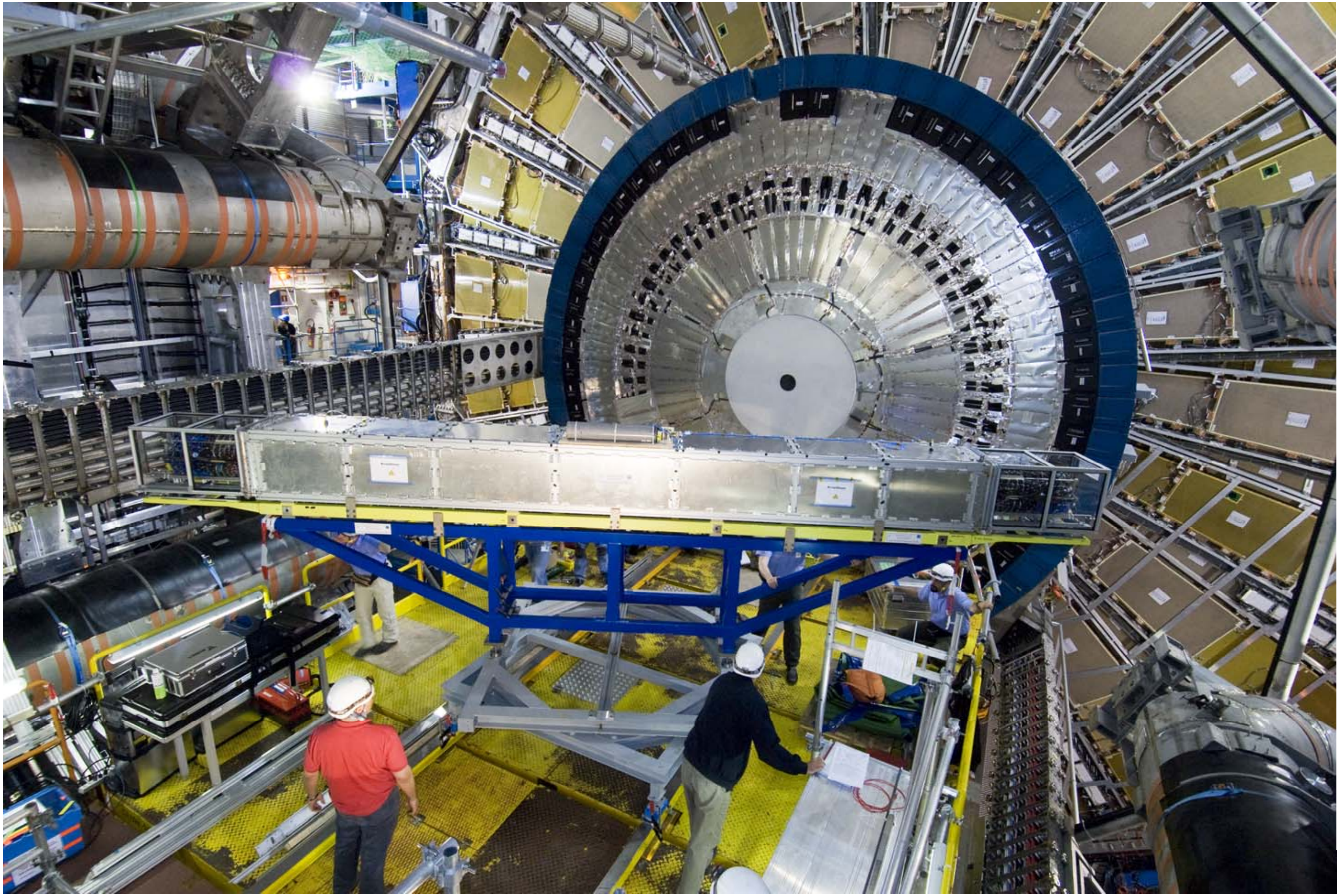


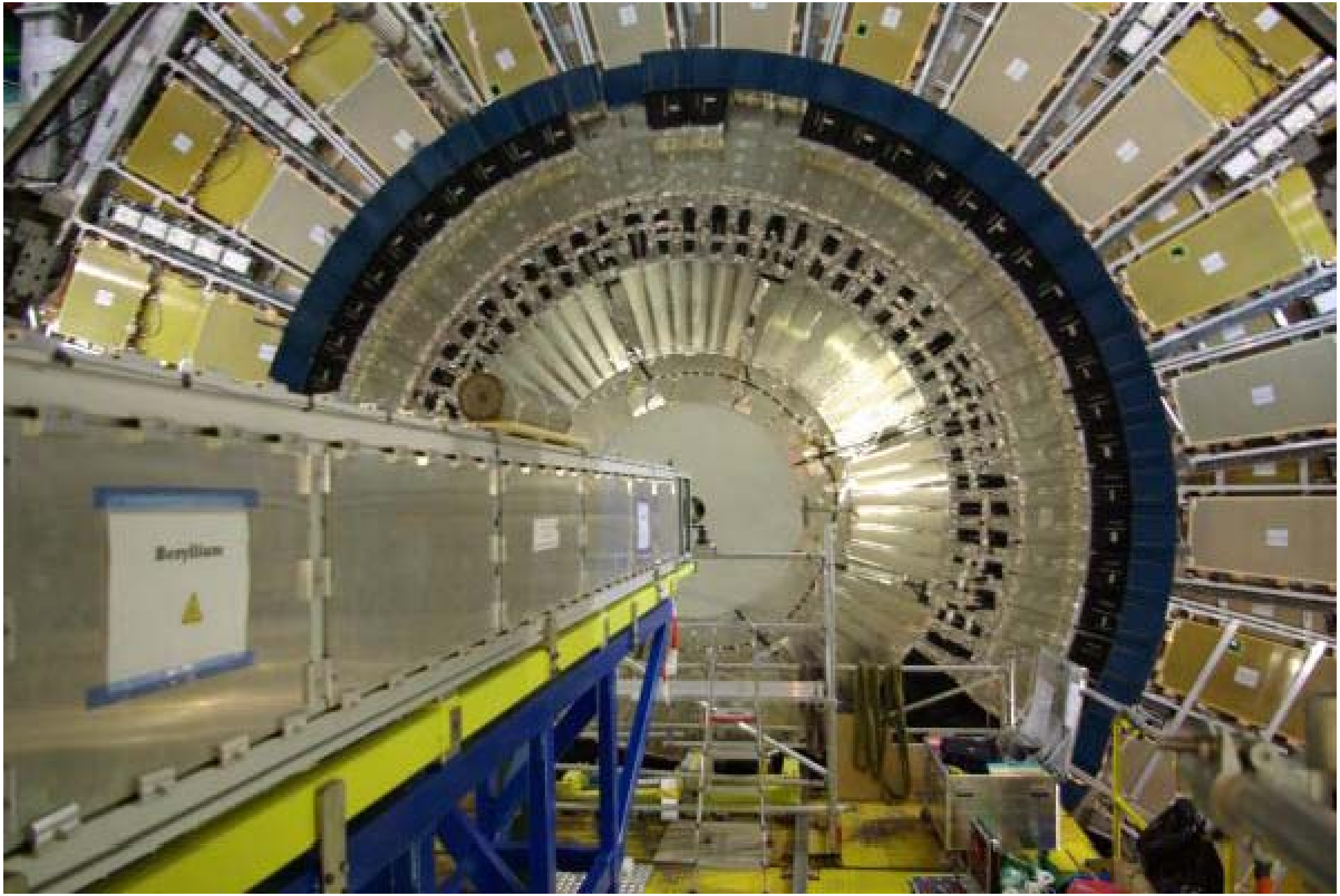
Installation

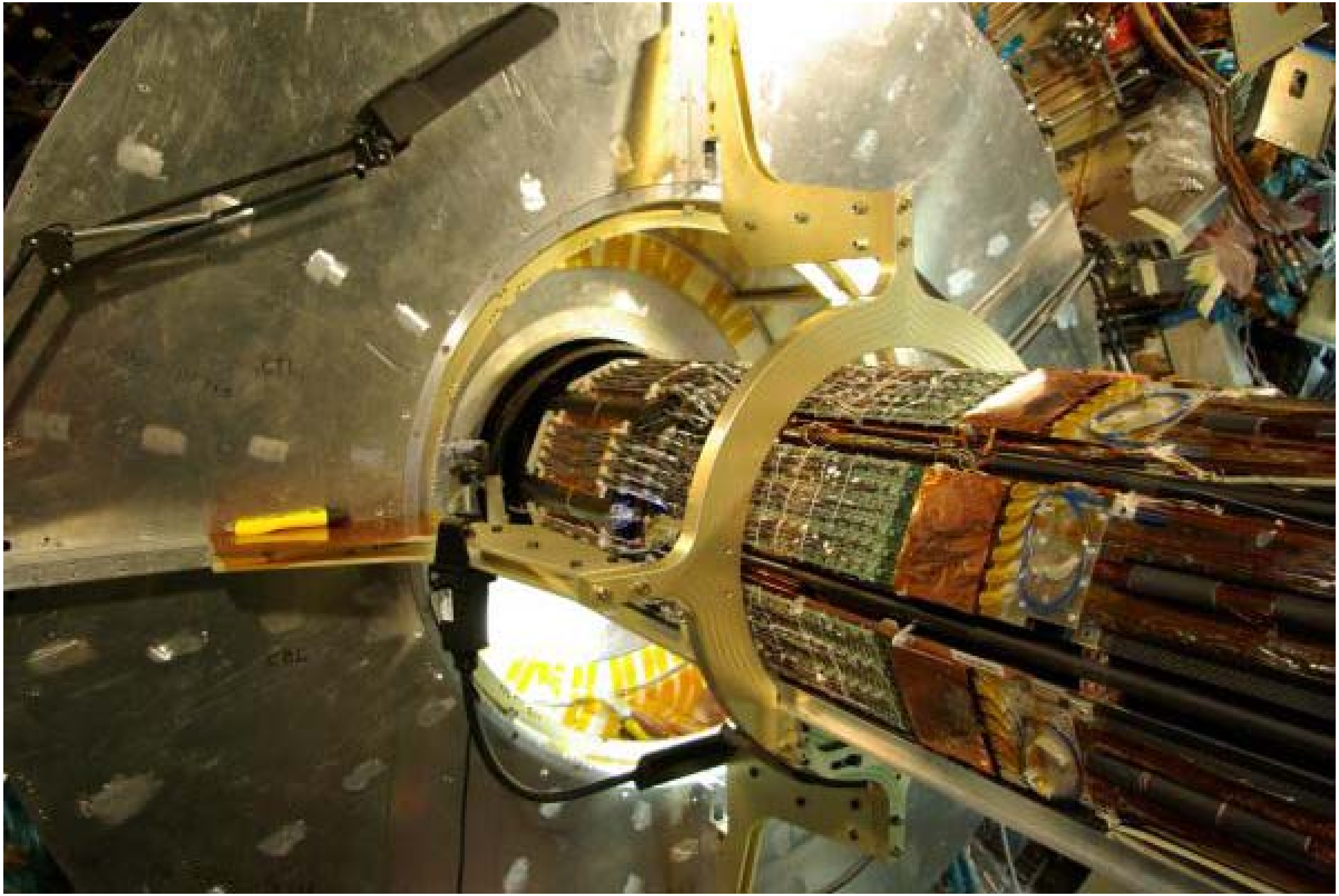
25-Jun-2007 Transported to the Pit.

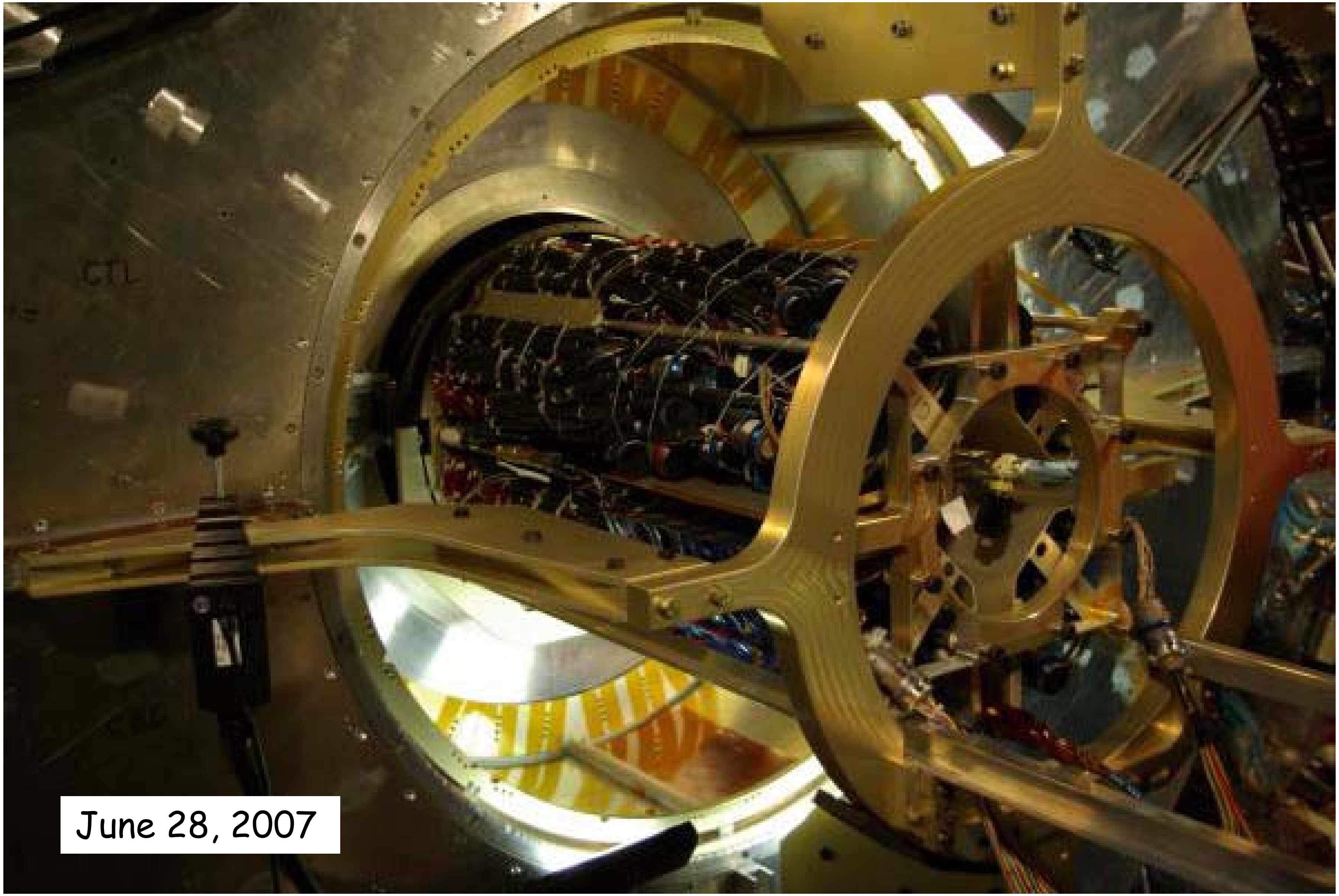
28-Jun-2007 Installed into ATLAS.


June 25, 2007
SX1
05




Beryllium




June 28, 2007

Connectivity

During Assembly

- Checked not only the full pixel detector assembly but also sub-assemblies (and sub-sub-…-assemblies).
- Electrical connections.
  - Power, NTC[*] and humidity sensors.
  - Use shorting connectors.
  - Measure and record loop resistance channel by channel.
  - Compare with expectations.
- Optical.
  - Turn on one laser channel at a time.
  - Measure laser power and/or PIN current.
- Cooling guaranteed by sub-assembly.

* NTC = negative temperature coefficient (thermistor)

After Installation

- Service connections delayed until access to end plate surfaces became available in late 2007.
- Used that time to check every external circuit.
  - One circuit at a time.
    - Dummy load for power lines.
    - Resistors to mimic NTC thermistors.
    - Loop back for cooling.
- No cross connections found in subsequent commissioning and data taking.

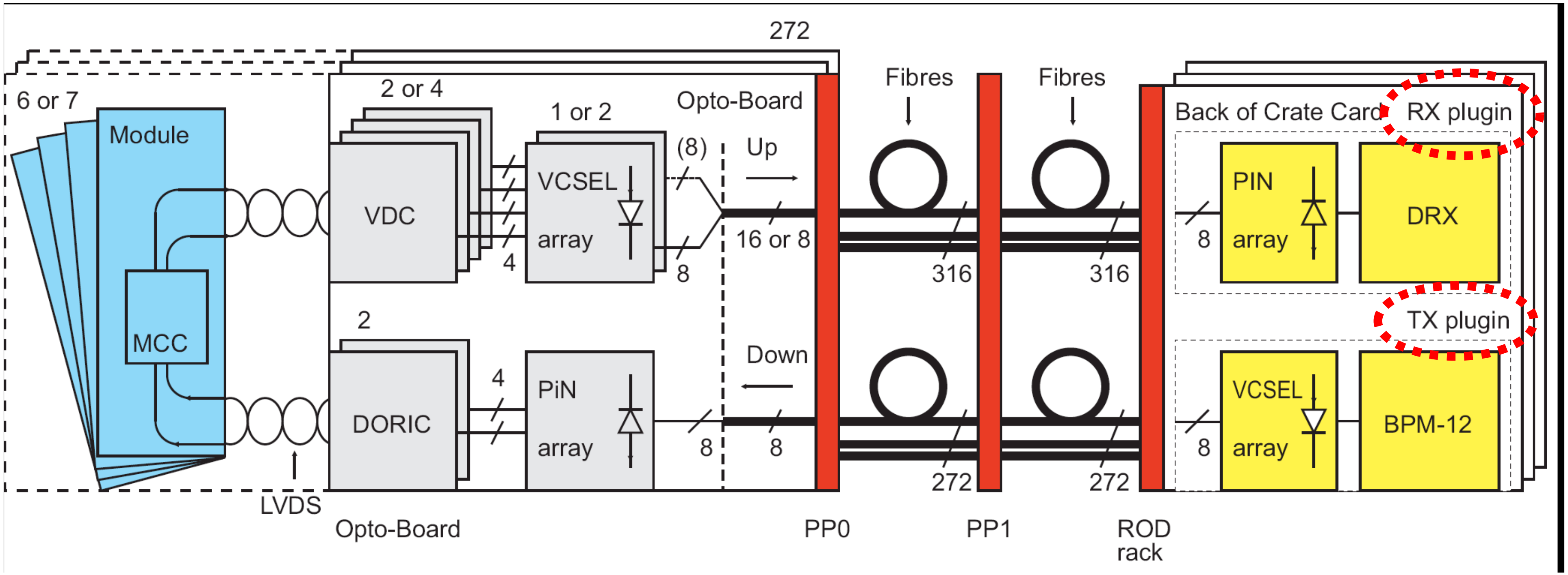
Commissioning

Commissioning

- Determine the operating points for best performance, e.g.
  - Optical communication parameters.
  - Measure noise.
  - Adjust gains and thresholds.
  - Masks for noisy pixels.
- Status:
  - About 6% of 1744 modules not used in cosmic tests now.
  - Approximately 10 modules likely not recoverable.
    - Broken HV connection on module.
  - Three leaky cooling loops, all in endcaps, will not be operated in 2008.
  - Other problematic modules will be studied in detail and (we hope) recovered.

TX and RX Plug-ins

- TX array = optical transmitters that send clock and control signals to modules.
  - One laser channel per module, and up to 6 modules per array.
- RX array = optical receivers for optical signals from modules.



TX Failures

- Individual lasers in an array can stop working.
- Problem became apparent in Spring 2008.
- Hard to characterize failure rate precisely.
  - TX turned on and off.
  - Tracking of operating conditions.
  - Order of magnitude: 1 channel per week.
- Located off-detector in ROD (Read-Out Driver) crates in electronics counting room.
  - Accessible for service.
- Similar optical transmitters on detector package have not failed.
  - Would be impossible to service.

TX Plug-in Remediation

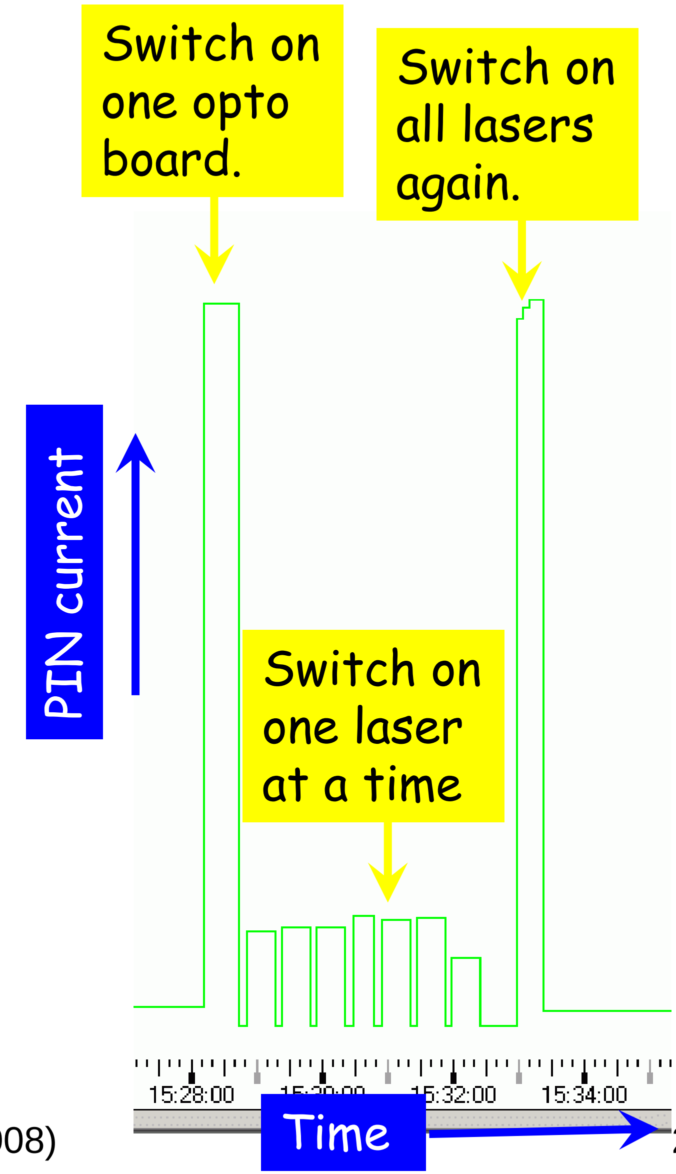
- Workshop in June 2008 to pool knowledge from pixel and SCT.
  - Only differ in packaging (8 vs 12 channels per array).
- Investigations and tests point strongly to damage from ESD (electrostatic discharge) during assembly of TX arrays.
  - This can explain why optical transmitters on detector package are not affected.
- 30 new TX plug-ins recently received and installed in ROD's. It was a major undertaking.
  - Optical cables are fragile.
  - Cleaning and alignment affect insertion losses.
  - Laser safety issues.
  - Re-tune optical connections.
- Complete replacement on order.

Optical Connectivity In (Internal)

- Internal check of pixel package.
  - Done in SR-1 clean room during assembly.
  - From PP1 to modules.
- Use <u>one</u> fiber from <u>one</u> TX to all PP1's.
- Procedure:
  - Switch on all lasers in one TX.
    - Eight lasers per TX, but not all used.
  - Switch on one module (corresponding to one laser).
  - Send configure command to that one module.
  - Measure PIN current increase in that module.
  - Repeat for all modules.

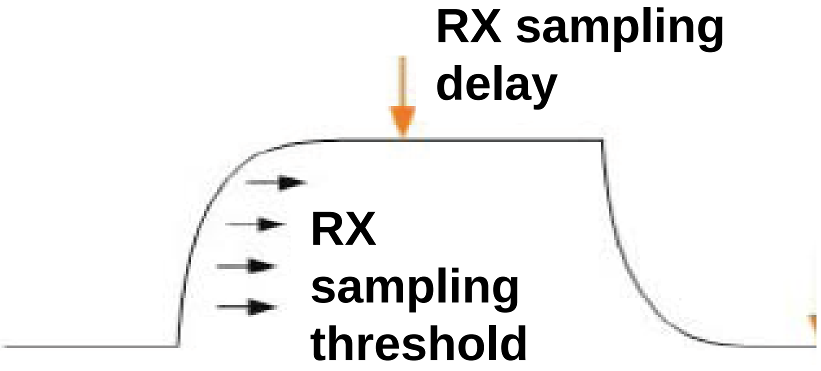
Optical Connectivity In (External)

- Check optical connection from TX to opto-boards.
- Use installed and connected production fibers.
- Procedure:
  - Switch on one opto-board.
  - Turn off all lasers in TX and then turn on one laser in TX at a time.
  - Measure individual module PIN current.



Optical Connection Out

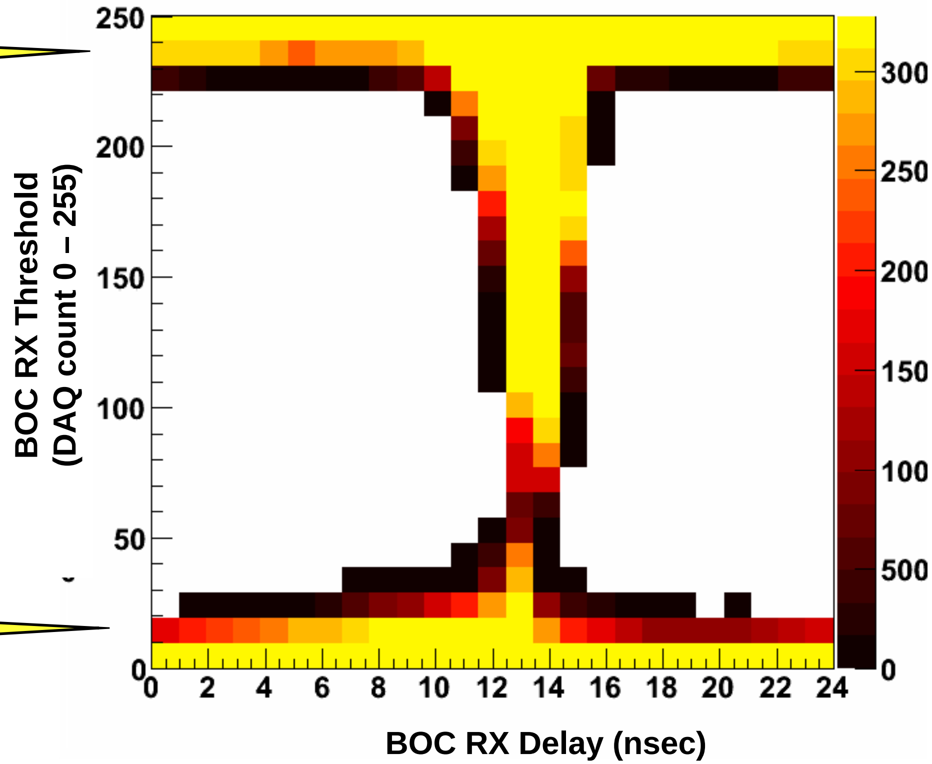
- BOC = Back Of Crate card.
  - Receives optical signal from modules.
- BOC tuning to optimize the performance of optical transmission from detector to counting room.
  - "Fast" scan counts 0's and 1's.
  - "Slow" scan checks each bit.
- Three parameters.
  - Laser power from detector.
    - Controlled by VIset.
  - RX parameters:
    - Delay, i.e. sampling time.
    - Threshold.



Transmission error rate as a function of delay and threshold at one VIset (i.e. one laser power setting).

Threshold too high
=> 1's turn to 0's

Threshold too low:
=> 0's turn to 1's



Complications

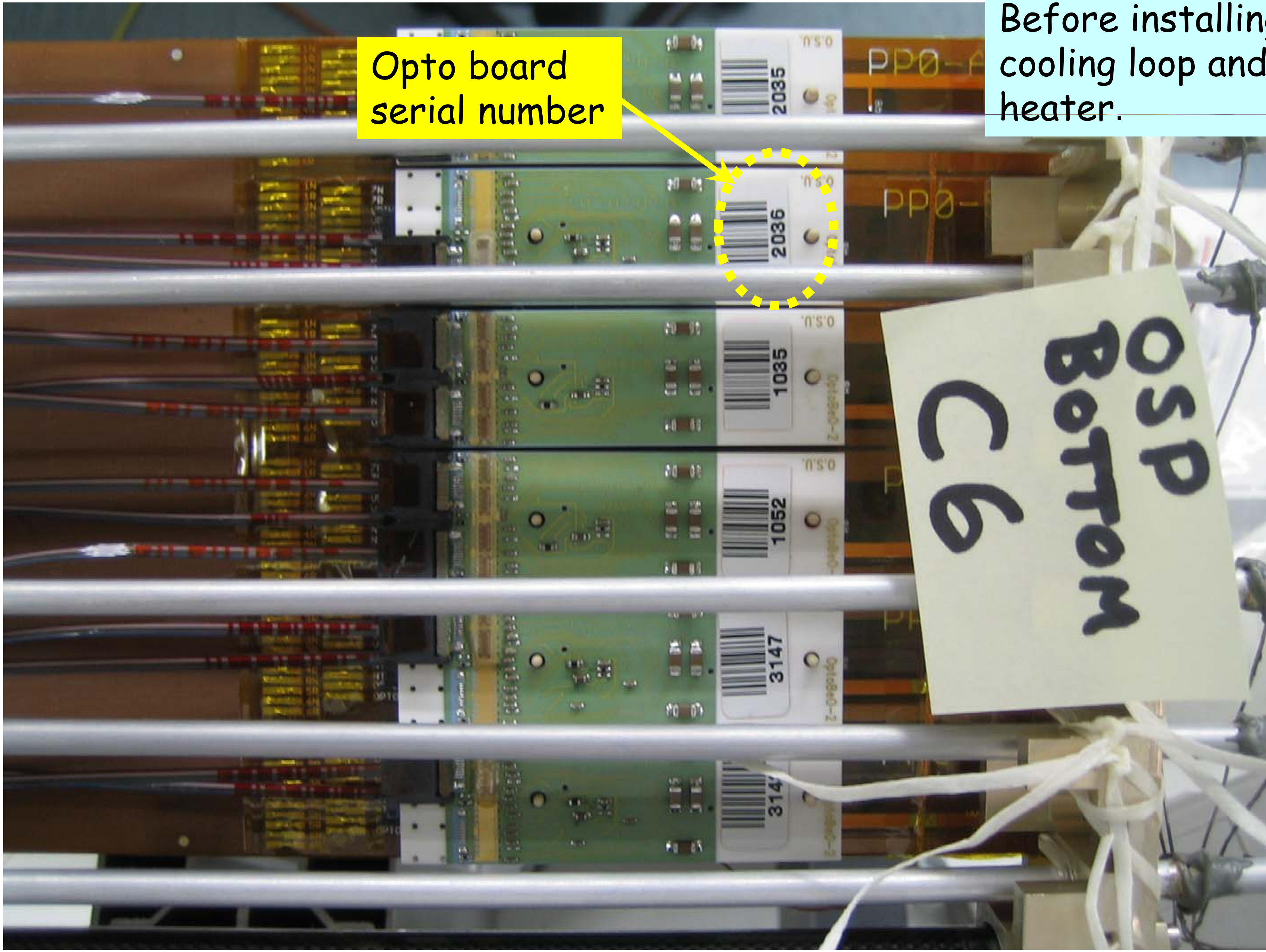
- Delay and threshold controls are by <u>module</u>, but one VIset per <u>opto-board</u>, i.e. up to 6 modules.
- Opto-boards are temperature sensitive.
  - Specified to work at O(-10°C).
    - Incorrect testing means actual testing at around room temperature.
  - Marginal performance at +15°C.
  - Heated to approximately +20°C during operations.

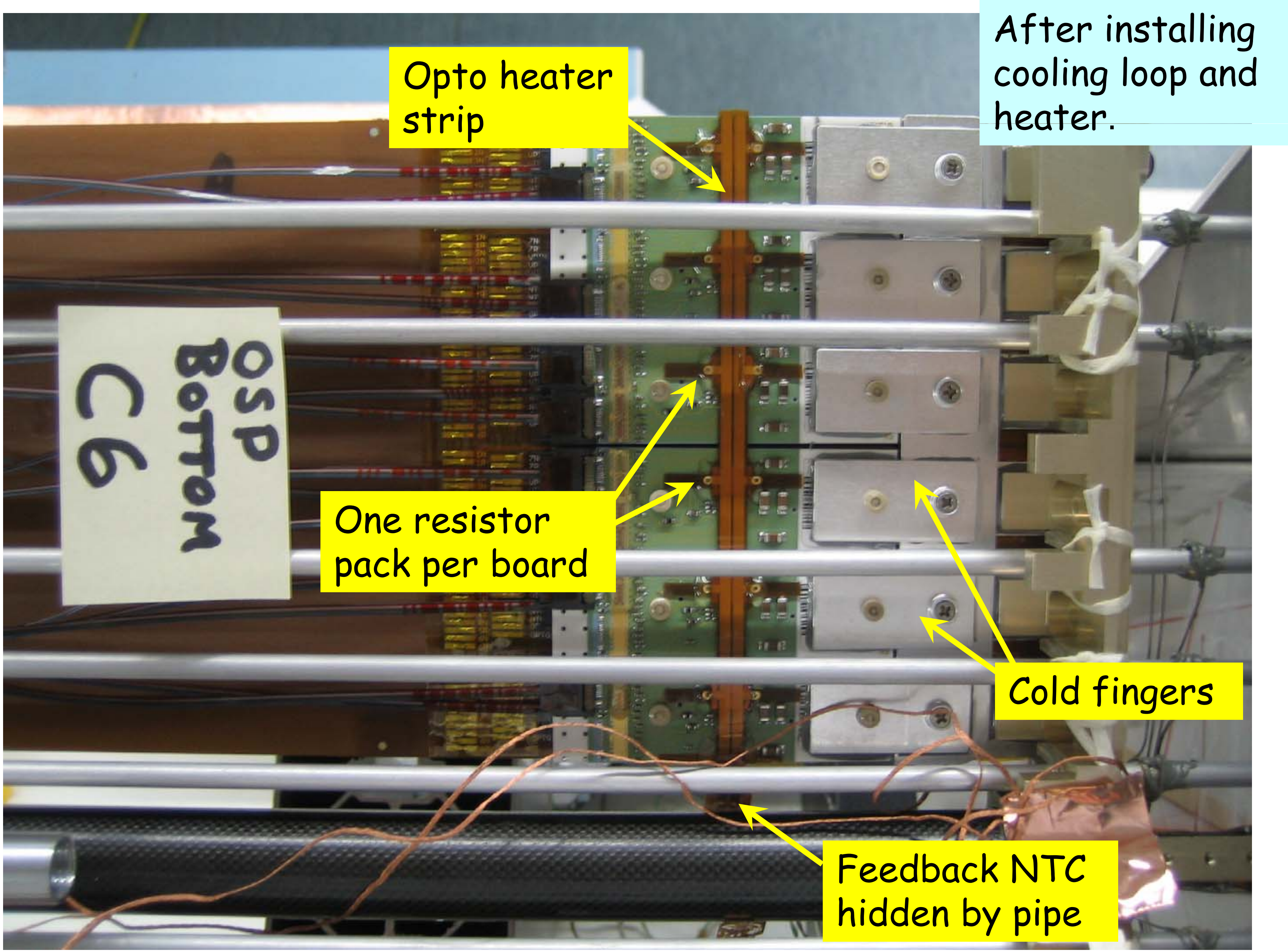
Opto Heater System

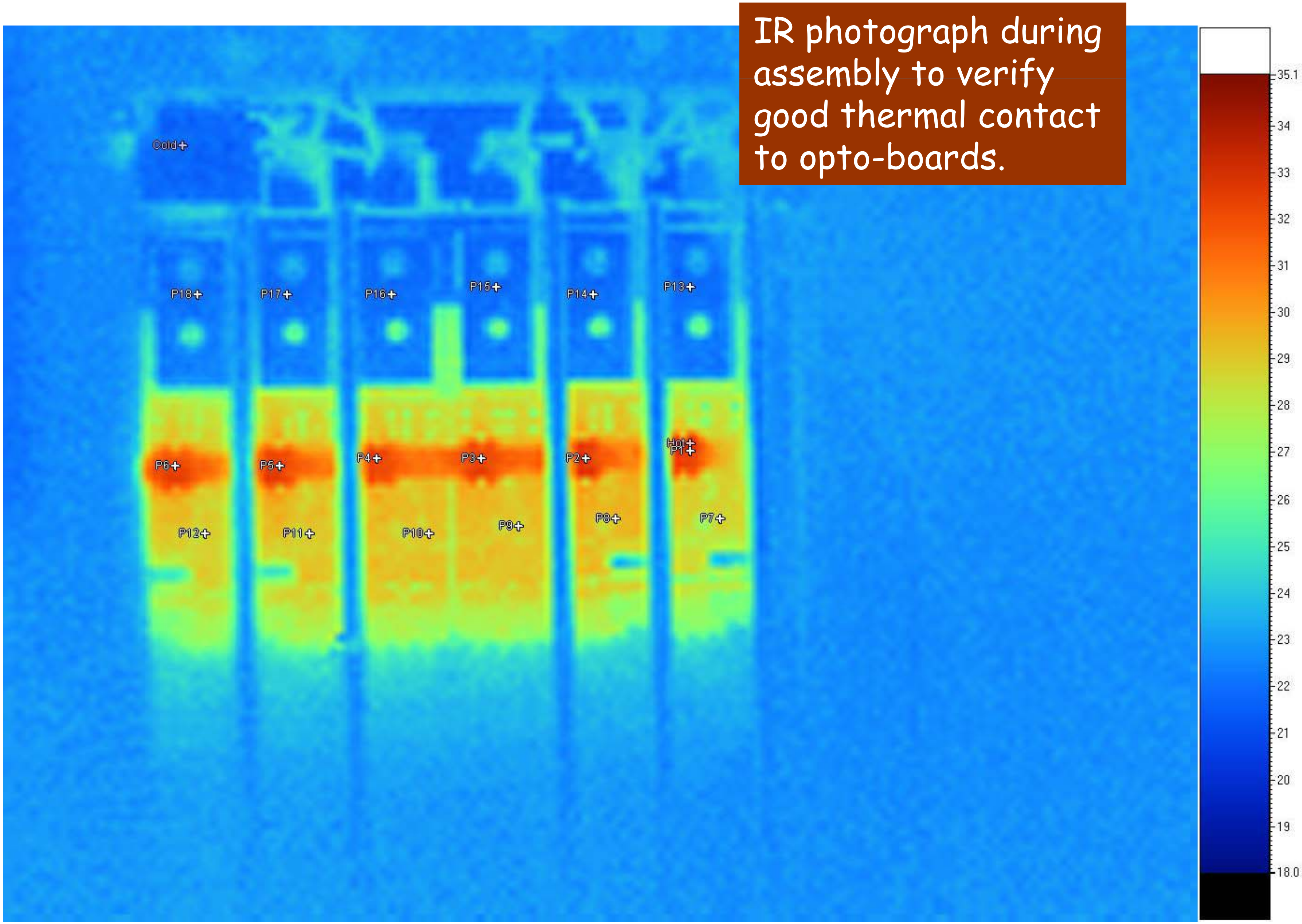
- One heater strip for up to 6 boards.
- Feedback control using one NTC on heater strip.
  - Poor proxy for actual opto-board temperatures.
  - Requires manual re-tuning when one or more opto-boards turned on/off.
- Control software poorly done.
  - Non-intuitive controls.
  - Some important quantities not archived.
- Power supplies plagued by mystery trips.
  - Manual reset required in access-controlled area.
  - Up to several times an hour.
- Bypassed that part of the circuit for now.
- Plan to re-do entire system.

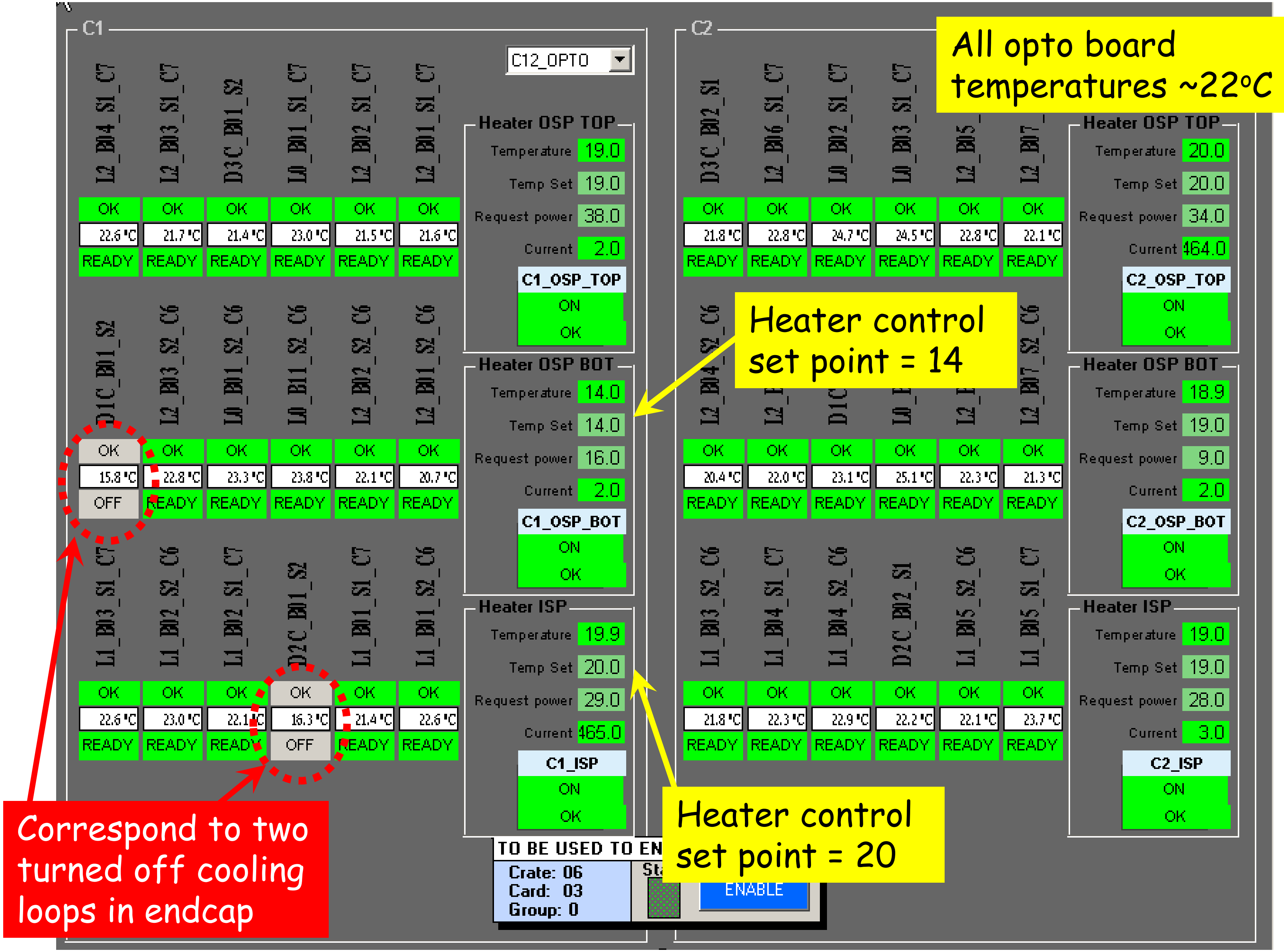
Opto board serial number

Before installing cooling loop and heater.




Opto heater strip
After installing cooling loop and heater.
OSP BOTTOM C6
One resistor pack per board
Cold fingers
Feedback NTC hidden by pipe


IR photograph during assembly to verify good thermal contact to opto-boards.
Cold
P18
P17
P16
P15
P14
P13
P6
P5
P4
P3
P2
P1
Hot
P12
P11
P10
P9
P8
P7
35.1
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18.0
°C


All opto board temperatures ~22°C
Heater control set point = 14
Heater control set point = 20
Correspond to two turned off cooling loops in endcap
C1
C2
C12_OPTO
Heater OSP TOP
Heater OSP BOT
Heater ISP
Temperature
Temp Set
Request power
Current
C1_OSP_TOP
C1_OSP_BOT
C1_ISP
C2_OSP_TOP
C2_OSP_BOT
C2_ISP
TO BE USED TO EN
Crate: 06
Card: 03
Group: 0
ENABLE


USA15-L1-01 DSS ID Gen
2008-09-05 CEST 01:04:37
Reset button
Street person / shifter
Menu

Cooling for Pixel Detector

- Pixel detector dissipates ~7 KW today.
  - Go up by ~2X with radiation damage and higher depletion voltage.

	Power dissipation [W]			
	Q1	Q2	Q3	Q4
Modules	1434	1521	1531	1633
OptoHeater	64	69	83	94
OptoBoard	52	47	48	46
Total	1549	1638	1662	1773

- Need to operate sensors at or below 0°C.
- Want to minimize module to module temperature variations.

Evaporative Cooling System

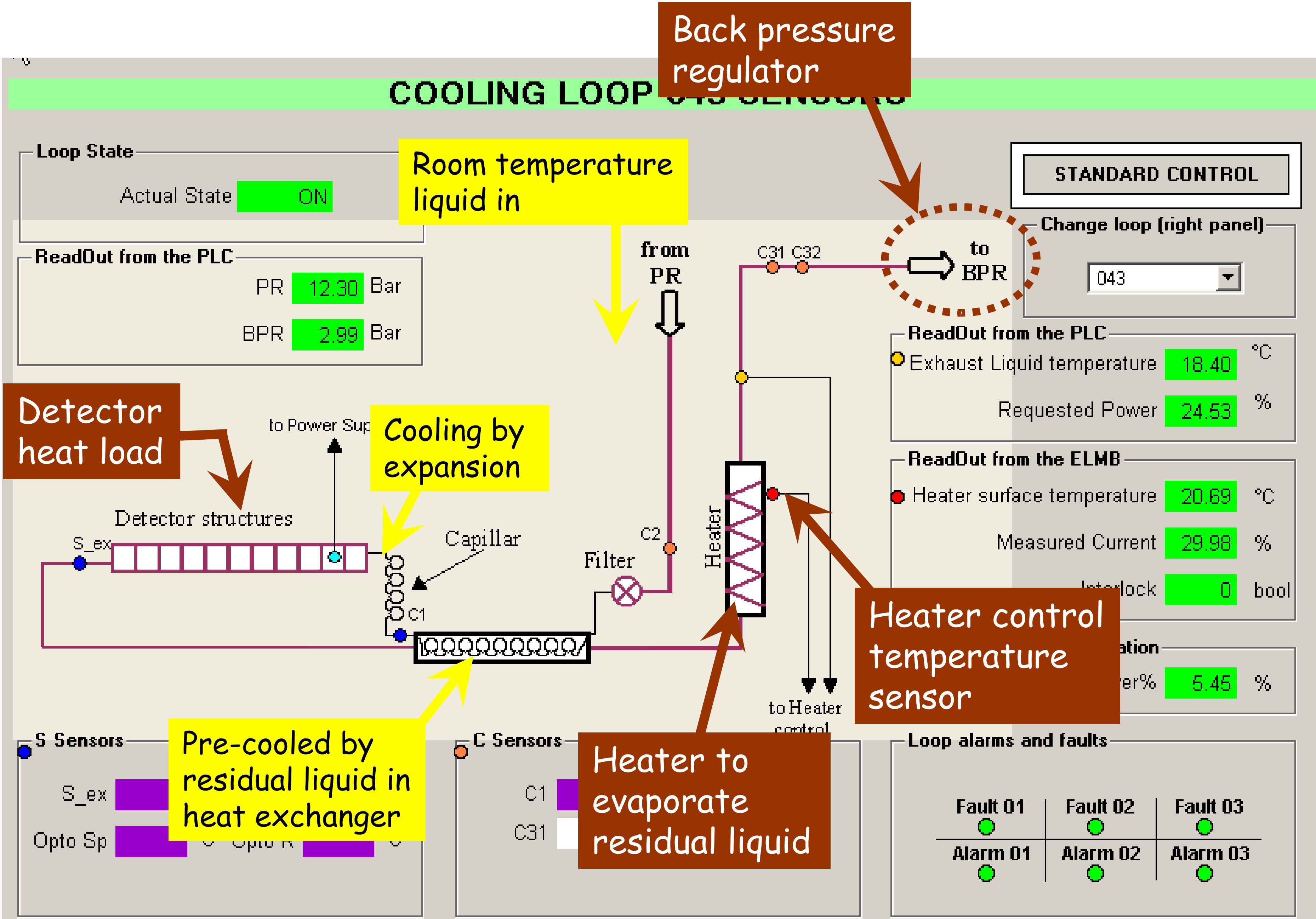
- Shared by pixel and SCT (Semiconductor Tracker).
- Cooling plant.
  - Accessible during beam running.
  - 6 (+1) compressors.
  - Recovery/storage tank.
- Four cooling racks.
  - In detector cavern.
    - No access during beam running.
    - Marginal access at other times.
  - Distribution racks and individual loop controls.
- Cooling loops.
  - 88 for pixel.
  - 116 for SCT.
  - 204 total.

Mono-Phase Cooling Example

- Assumptions.
  - 10 KW power dissipation.
  - Water cooling.
  - Temperature rise < 5 ^oC.
- 10 KW ~ 2400 calories / second.
- Mass flow ~ 2400 / 5 = 480 gm / sec.

Evaporative Cooling

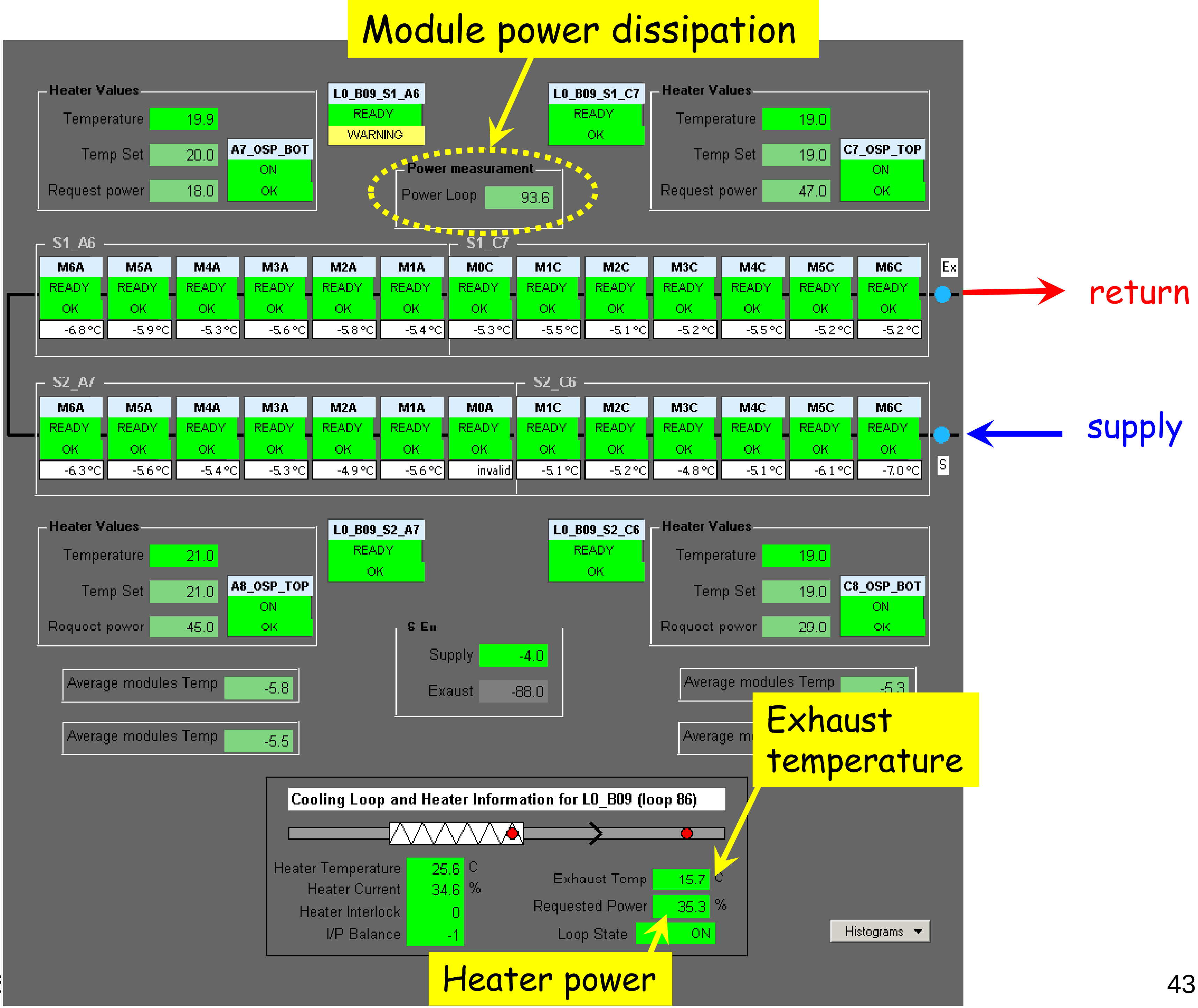
- Coolant = C_3F_8.
- Actual mass flow = 6.2 gm / sec.
- Temperature variation < 2 ^oC.
  - Dominated by systematic effects from module to module.
  - Supply to exhaust temperature change is smaller.
- Operational temperature controlled by back pressure (and therefore evaporative temperature).

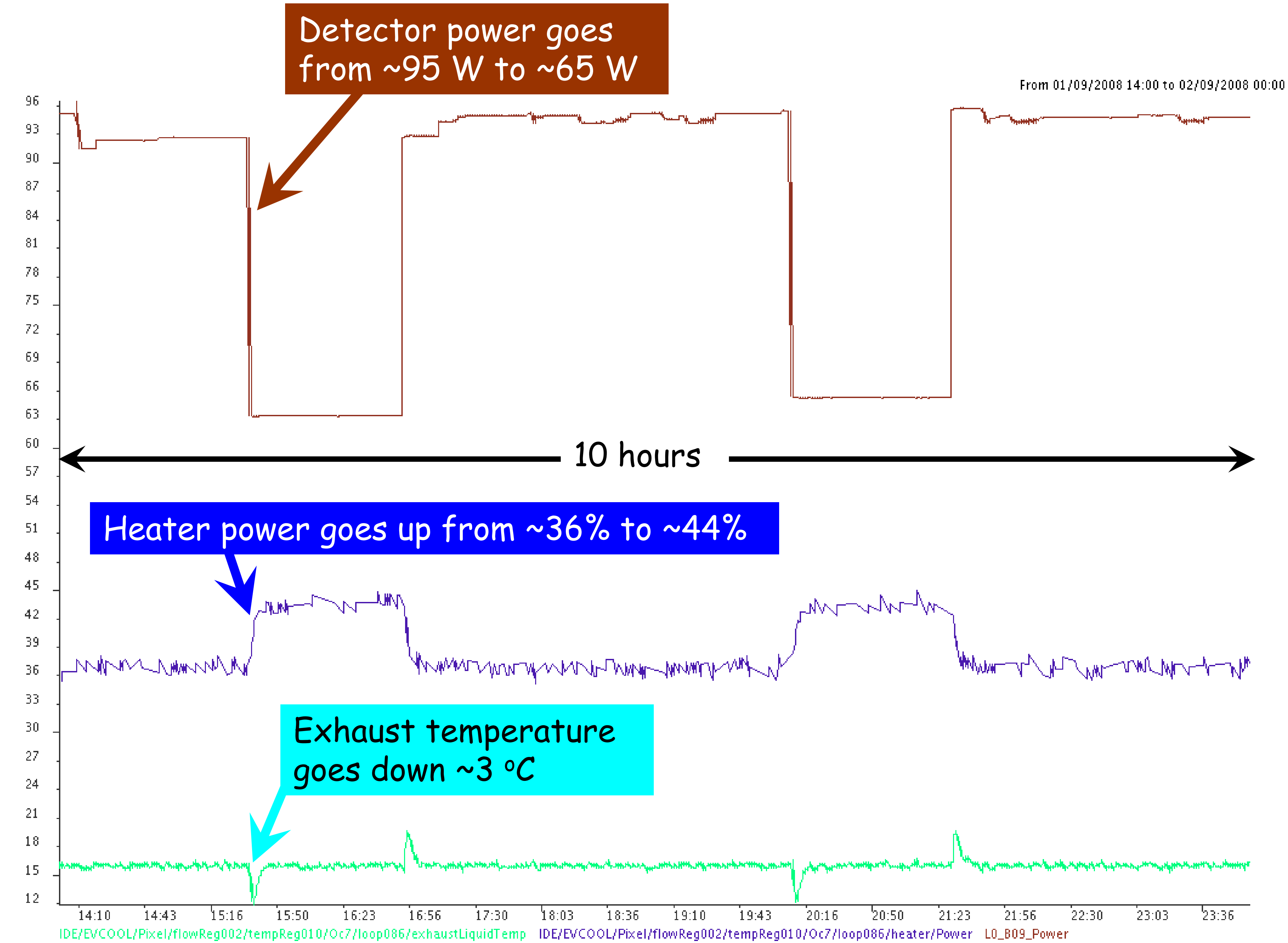


COOLING LOOP
Back pressure regulator
Loop State
Actual State ON
Room temperature liquid in
STANDARD CONTROL
ReadOut from the PLC
PR 12.30 Bar
BPR 2.99 Bar
from PR
C31 C32
to BPR
Change loop (right panel)
043
ReadOut from the PLC
Exhaust Liquid temperature 18.40 °C
Requested Power 24.53 %
Detector heat load
to Power Sup
Cooling by expansion
ReadOut from the ELMB
Heater surface temperature 20.69 °C
Measured Current 29.98 %
0 bool
Detector structures
Capillar
C2
S_ex
Filter
Heater
C1
Heater control temperature sensor
5.45 %
to Heater
S Sensors
S_ex
Opto Sp
Pre-cooled by residual liquid in heat exchanger
C Sensors
C1
C31
Heater to evaporate residual liquid
Loop alarms and faults
Fault 01
Fault 02
Fault 03
Alarm 01
Alarm 02
Alarm 03

Normal Behavior

- Reduce heat load from detector.
  - Unconfiguring modules reduces detector heat load from ~95 W to ~65 W.
- Exhaust liquid gets colder.
- Heater power goes up to compensate.
- Corresponding effects when configuring modules and increasing detector power.
- Regulation OK without detector heat load.


Module power dissipation
Heater Values
Temperature 19.9
Temp Set 20.0
Request power 18.0
A7_OSP_BOT ON OK
L0_B09_S1_A6 READY WARNING
Power measurament
Power Loop 93.6
L0_B09_S1_C7 READY OK
Heater Values
Temperature 19.0
Temp Set 19.0
Request power 47.0
C7_OSP_TOP ON OK
S1_A6
S1_C7
M6A M5A M4A M3A M2A M1A M0C M1C M2C M3C M4C M5C M6C
-6.8°C -5.9°C -5.3°C -5.6°C -5.8°C -5.4°C -5.3°C -5.5°C -5.1°C -5.2°C -5.5°C -5.2°C -5.2°C
Ex
return
S2_A7
S2_C6
M6A M5A M4A M3A M2A M1A M0A M1C M2C M3C M4C M5C M6C
-6.3°C -5.6°C -5.4°C -5.3°C -4.9°C -5.6°C invalid -5.1°C -5.2°C -4.8°C -5.1°C -6.1°C -7.0°C
S
supply
Heater Values
Temperature 21.0
Temp Set 21.0
Request power 45.0
A8_OSP_TOP ON OK
L0_B09_S2_A7 READY OK
L0_B09_S2_C6 READY OK
Heater Values
Temperature 19.0
Temp Set 19.0
Request power 29.0
C8_OSP_BOT ON OK
S-Ex
Supply -4.0
Exaust -88.0
Average modules Temp -5.8
Average modules Temp -5.5
Average modules Temp -5.3
Exhaust temperature
Cooling Loop and Heater Information for L0_B09 (loop 86)
Heater Temperature 25.6 C
Heater Current 34.6 %
Heater Interlock 0
I/P Balance -1
Exhaust Temp 15.7 C
Requested Power 35.3 %
Loop State ON
Histograms
Heater power

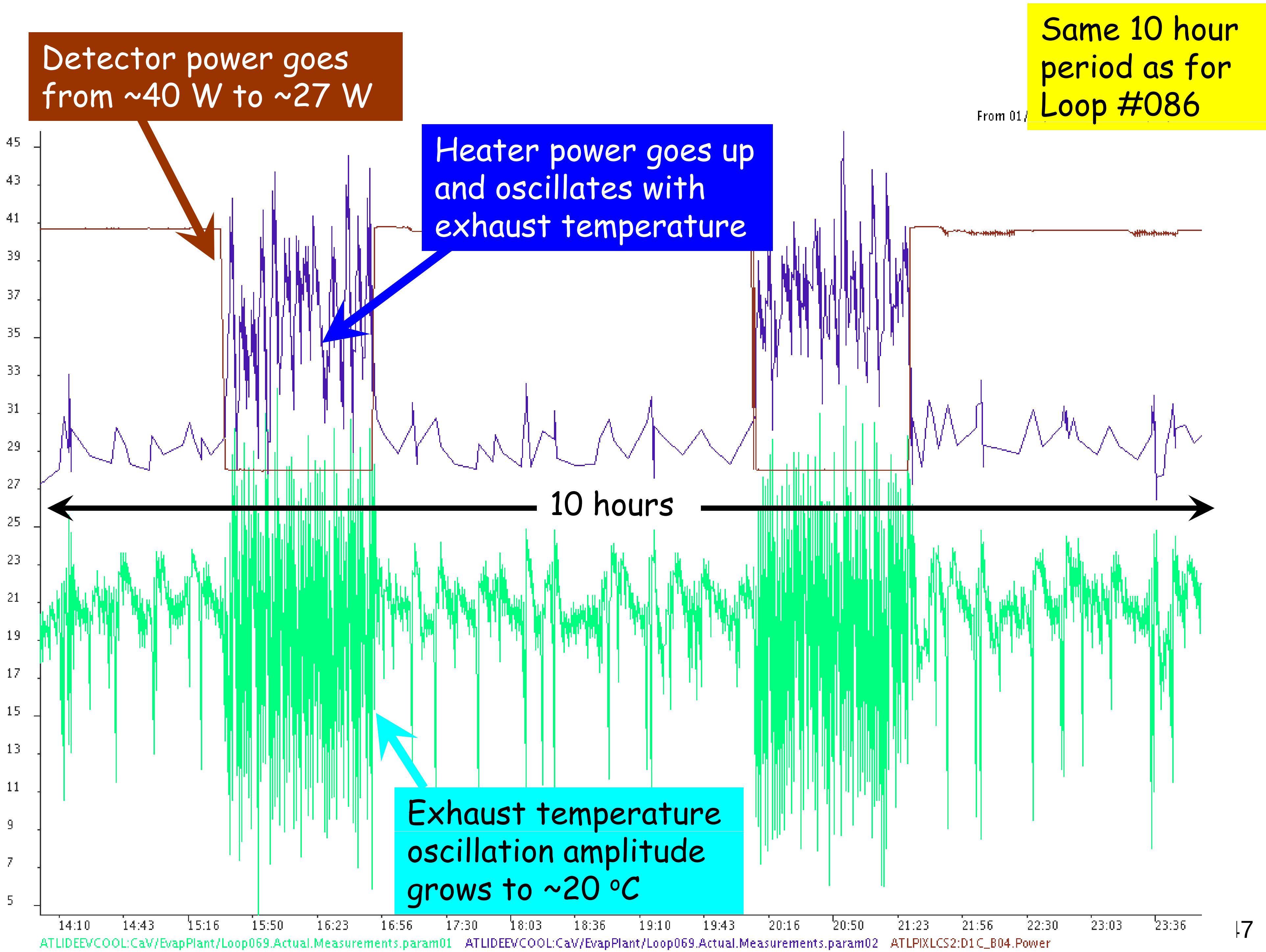

Detector power goes from ~95 W to ~65 W
From 01/09/2008 14:00 to 02/09/2008 00:00
10 hours
Heater power goes up from ~36% to ~44%
Exhaust temperature goes down ~3 °C
96 93 90 87 84 81 78 75 72 69 66 63 60 57 54 51 48 45 42 39 36 33 30 27 24 21 18 15 12
14:10 14:43 15:16 15:50 16:23 16:56 17:30 18:03 18:36 19:10 19:43 20:16 20:50 21:23 21:56 22:30 23:03 23:36
IDE/EVCOOL/Pixel/flowReg002/tempReg010/Oc7/loop086/exhaustLiquidTemp
IDE/EVCOOL/Pixel/flowReg002/tempReg010/Oc7/loop086/heater/Power
L0_B09_Power

Cooling System Problems

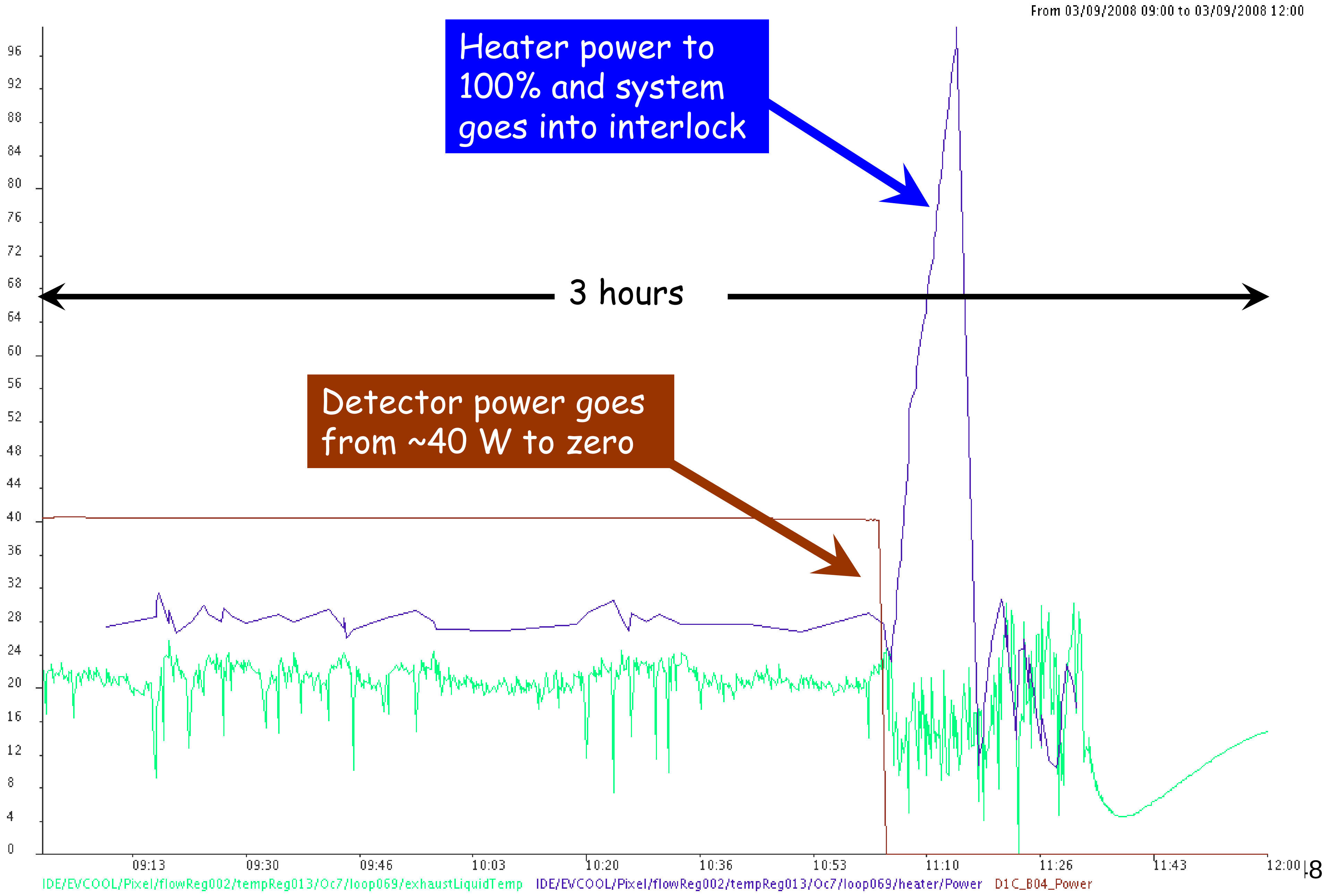
- Cooling pipe corrosion in pixel barrel staves.
  - Solved by sleeving affected pipes.
- Cooling system heater failures.
  - Two separate major incidents in last year.
- Compressor failures.
  - 2-month down time after catastrophic failure on 1-May-2008.
- Continuing operational problems.
  - Controls are problematic for some channels.
  - New leaks develop, e.g.
    - "Ice ball" easy to find, but others more subtle.
    - Pressure gauge "fell off" overnight on Sunday.
  - Slow leaks not noticed (at least not reported) by shifters until it becomes more serious.

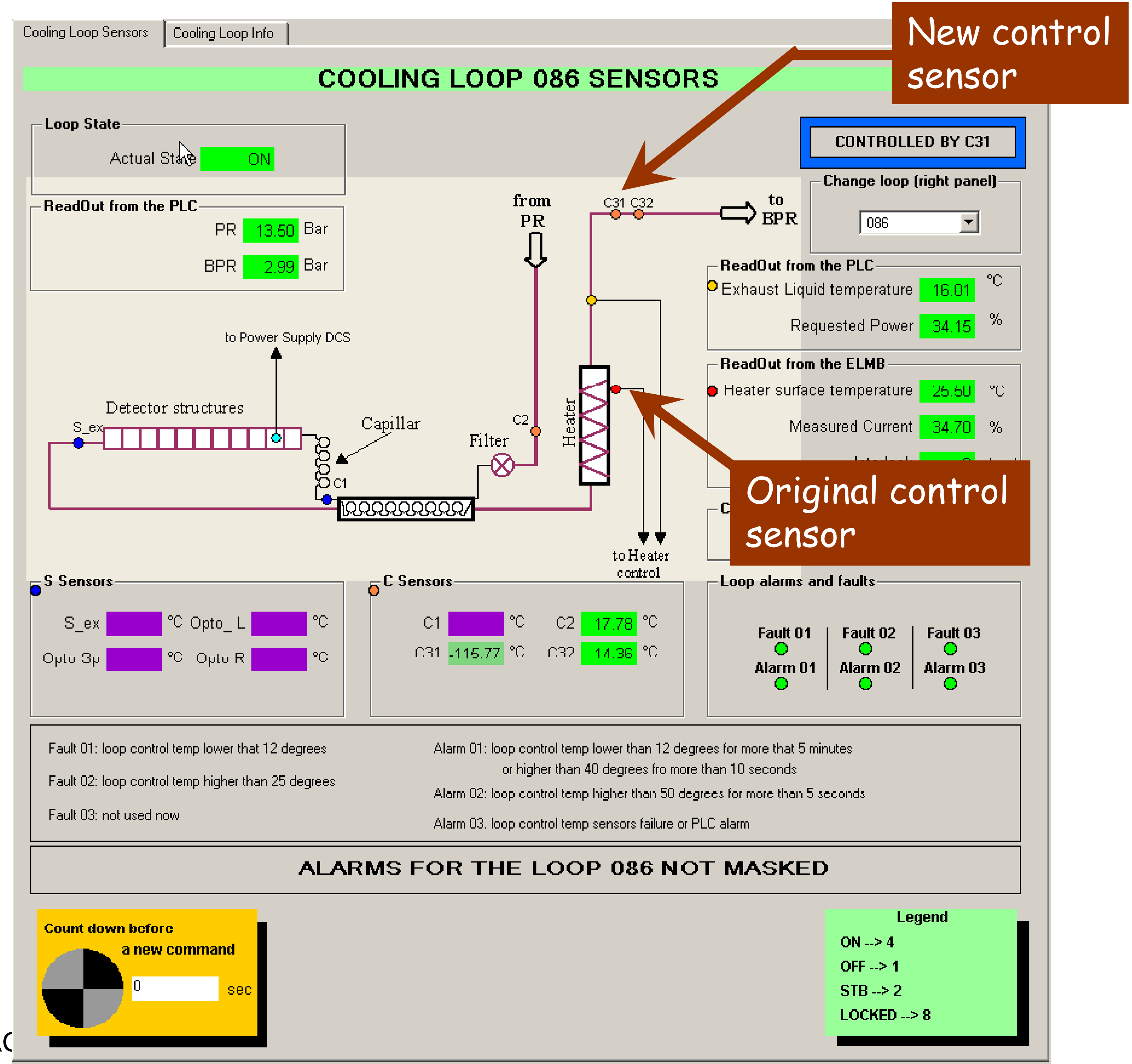
Abnormal Behavior

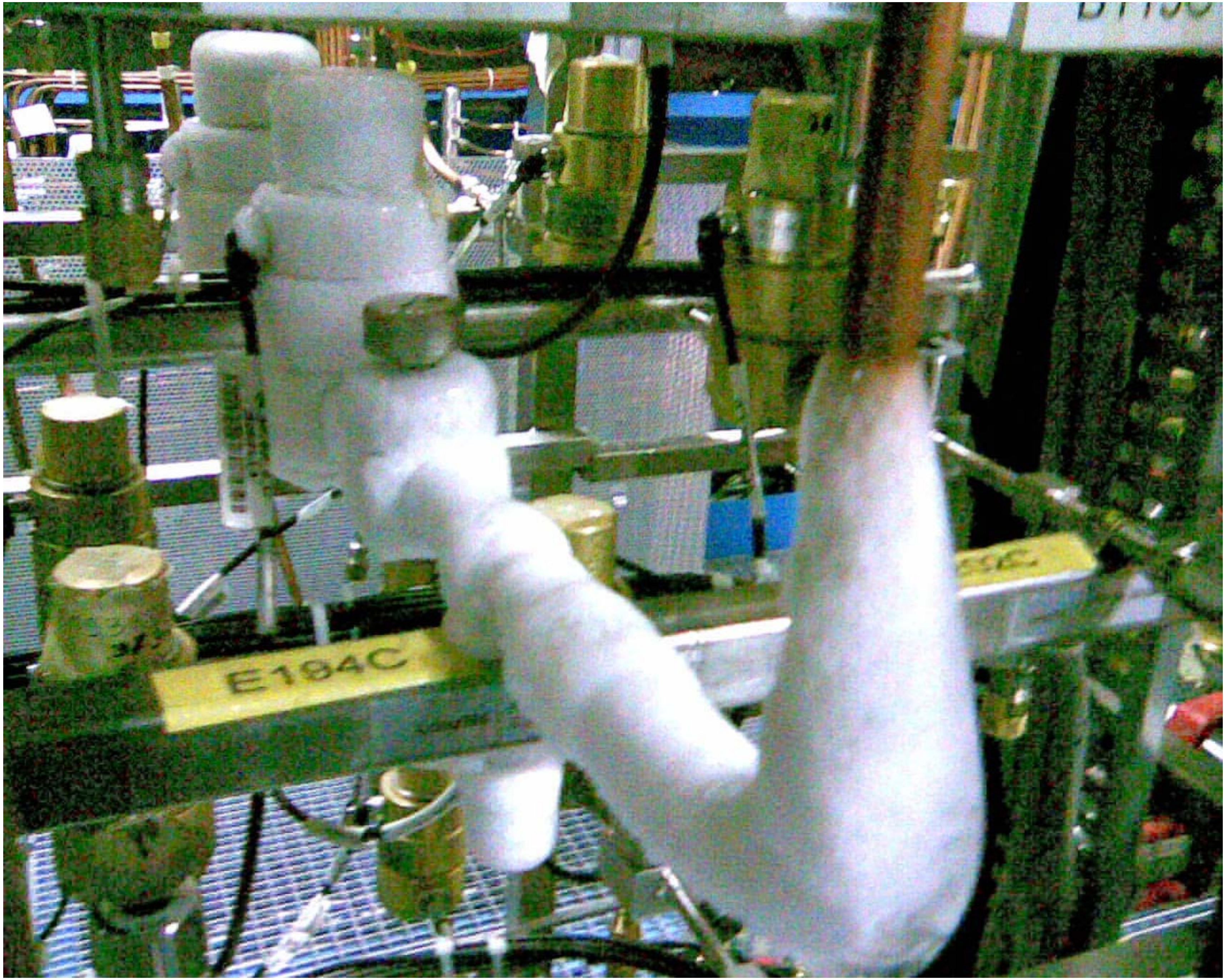
- Exhaust temperature and heater power varies a lot under normal operating conditions.
- Reducing detector heat load from ~40 W to ~27 W:
  - Exhaust temperature and heater power oscillations become worse.
  - Heater power went from 29% to 40% of maximum.
- Turning off detector (~40 W to 0 W):
  - Heater power swings up to 100%, and becomes not operable.
- Can be made more stable by moving control sensor away from heater.
  - Heater has more than enough head room.
  - Strictly a control problem.



Same 10 hour period as for Loop #086
From 01/
Detector power goes from ~40 W to ~27 W
Heater power goes up and oscillates with exhaust temperature
10 hours
Exhaust temperature oscillation amplitude grows to ~20 °C
45
43
41
39
37
35
33
31
29
27
25
23
21
19
17
15
13
11
9
7
5
14:10
14:43
15:16
15:50
16:23
16:56
17:30
18:03
18:36
19:10
19:43
20:16
20:50
21:23
21:56
22:30
23:03
23:36
ATLIDEEVCOOL:CaV/EvapPlant/Loop069.Actual.Measurements.param01
ATLIDEEVCOOL:CaV/EvapPlant/Loop069.Actual.Measurements.param02
ATLPIXLCS2:D1C_B04.Power


From 03/09/2008 09:00 to 03/09/2008 12:00
Heater power to 100% and system goes into interlock
3 hours
Detector power goes from ~40 W to zero
96
92
88
84
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
09:13
09:30
09:46
10:03
10:20
10:36
10:53
11:10
11:26
11:43
12:00
IDE/EVCOOL/Pixel/flowReg002/tempReg013/Oc7/loop069/exhaustLiquidTemp
IDE/EVCOOL/Pixel/flowReg002/tempReg013/Oc7/loop069/heater/Power
D1C_B04_Power

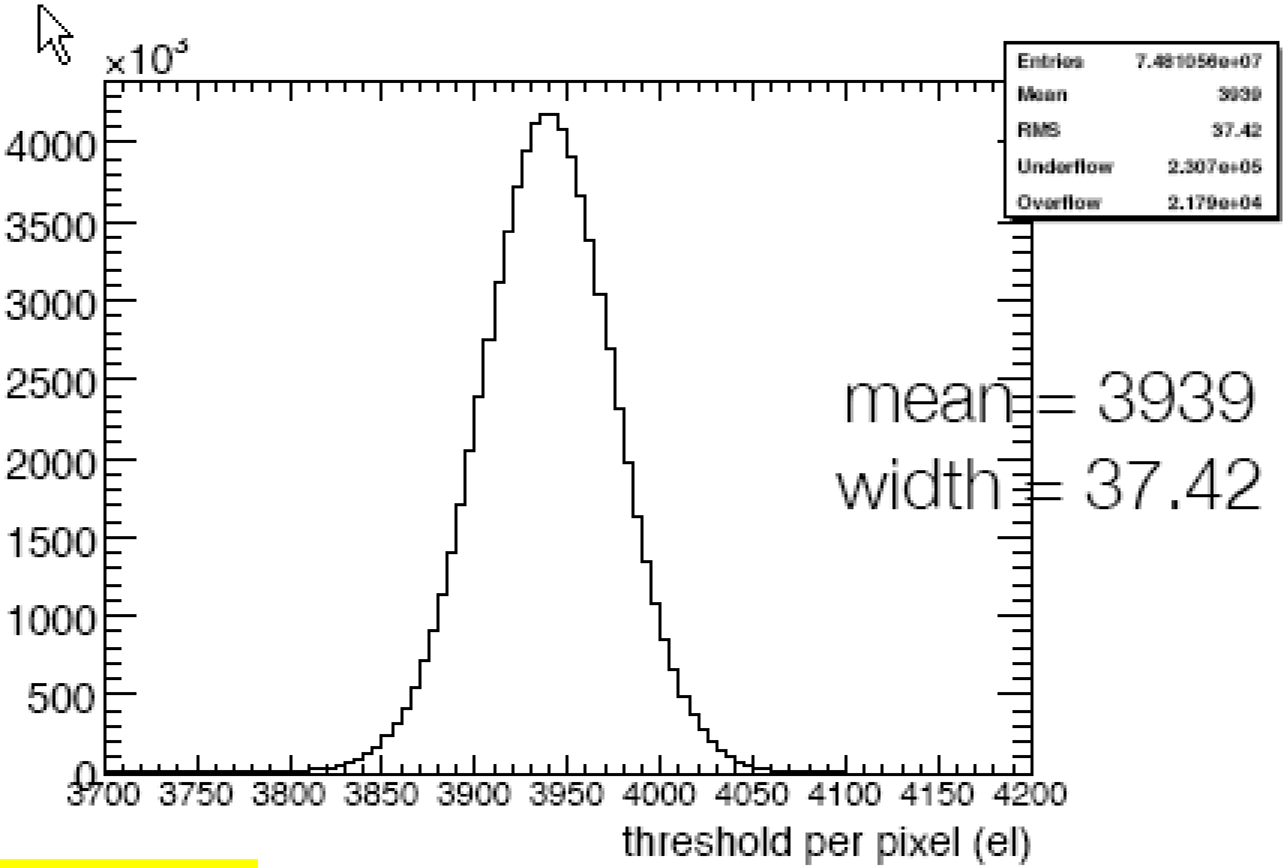

New control sensor
Original control sensor
Cooling Loop Sensors
Cooling Loop Info
COOLING LOOP 086 SENSORS
CONTROLLED BY C31
Loop State
Actual State ON
ReadOut from the PLC
PR 13.50 Bar
BPR 2.99 Bar
Change loop (right panel)
086
ReadOut from the PLC
Exhaust Liquid temperature 16.01 °C
Requested Power 34.15 %
ReadOut from the ELMB
Heater surface temperature 25.50 °C
Measured Current 34.70 %
from PR
to BPR
C31 C32
to Power Supply DCS
Detector structures
S_ex
Capillar
Filter
C2
C1
Heater
to Heater control
S Sensors
S_ex °C Opto_L °C
Opto Sp °C Opto R °C
C Sensors
C1 °C C2 17.78 °C
C31 -115.77 °C C32 14.36 °C
Loop alarms and faults
Fault 01 Fault 02 Fault 03
Alarm 01 Alarm 02 Alarm 03
Fault 01: loop control temp lower that 12 degrees
Fault 02: loop control temp higher than 25 degrees
Fault 03: not used now
Alarm 01: loop control temp lower than 12 degrees for more that 5 minutes or higher than 40 degrees fro more than 10 seconds
Alarm 02: loop control temp higher than 50 degrees for more than 5 seconds
Alarm 03: loop control temp sensors failure or PLC alarm
ALARMS FOR THE LOOP 086 NOT MASKED
Count down before a new command
0 sec
Legend
ON --> 4
OFF --> 1
STB --> 2
LOCKED --> 8


E184C

Commissioning Status

- Problems occupy most of our time and attention.
  - Natural to report in some detail.
  - Unduly pessimistic if taken as being representative of the status.
- Good progress since cooling was restored in early August.
  - First round of calibration and commissioning done in ~4 weeks.
  - Ready for data taking shortly after 10-Sep-2008.
    - ~95% of channels active.

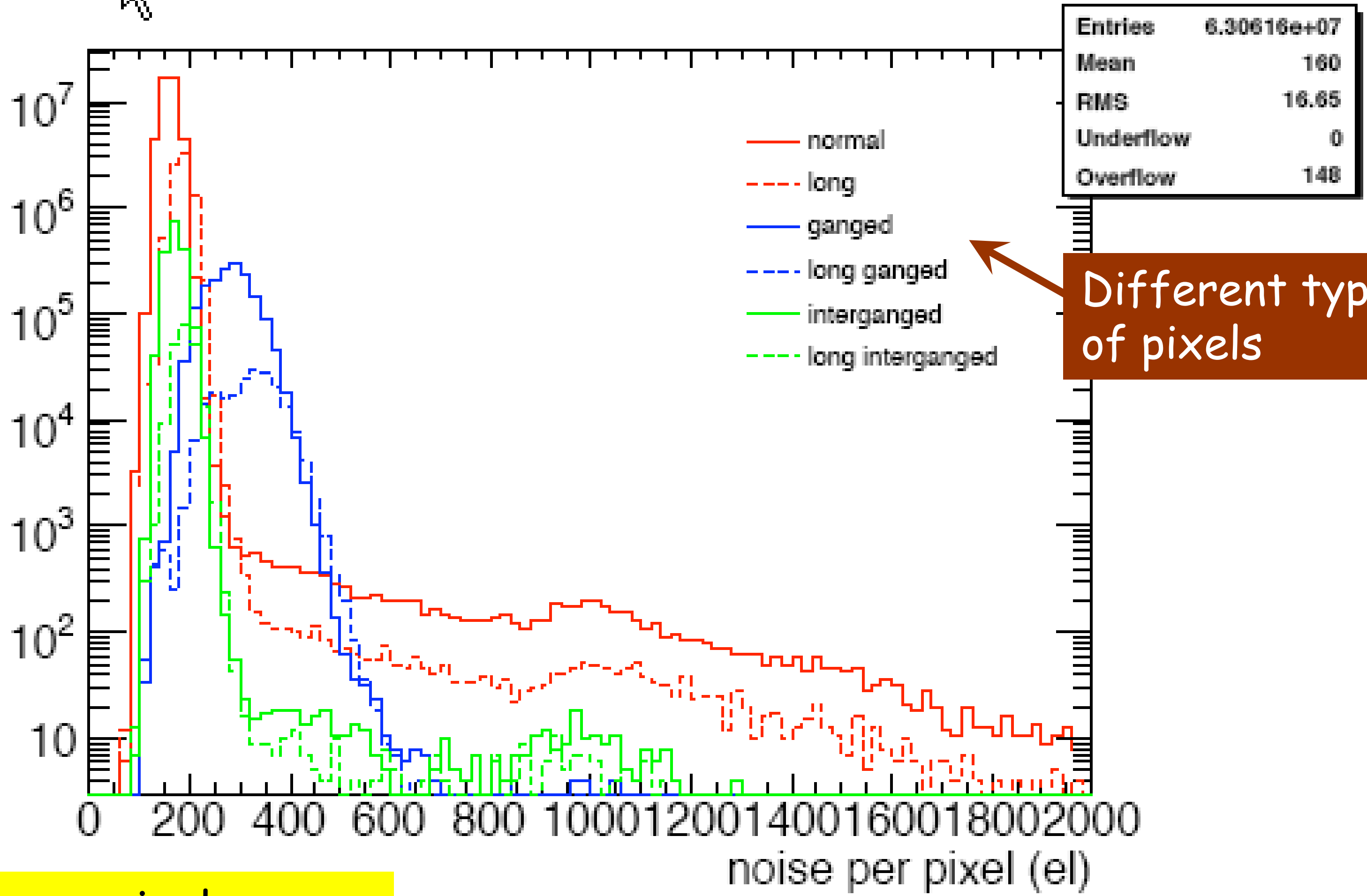
Threshold (~4000 electrons)



One entry per pixel

(linear vertical scale)

Noise (~160 electrons)

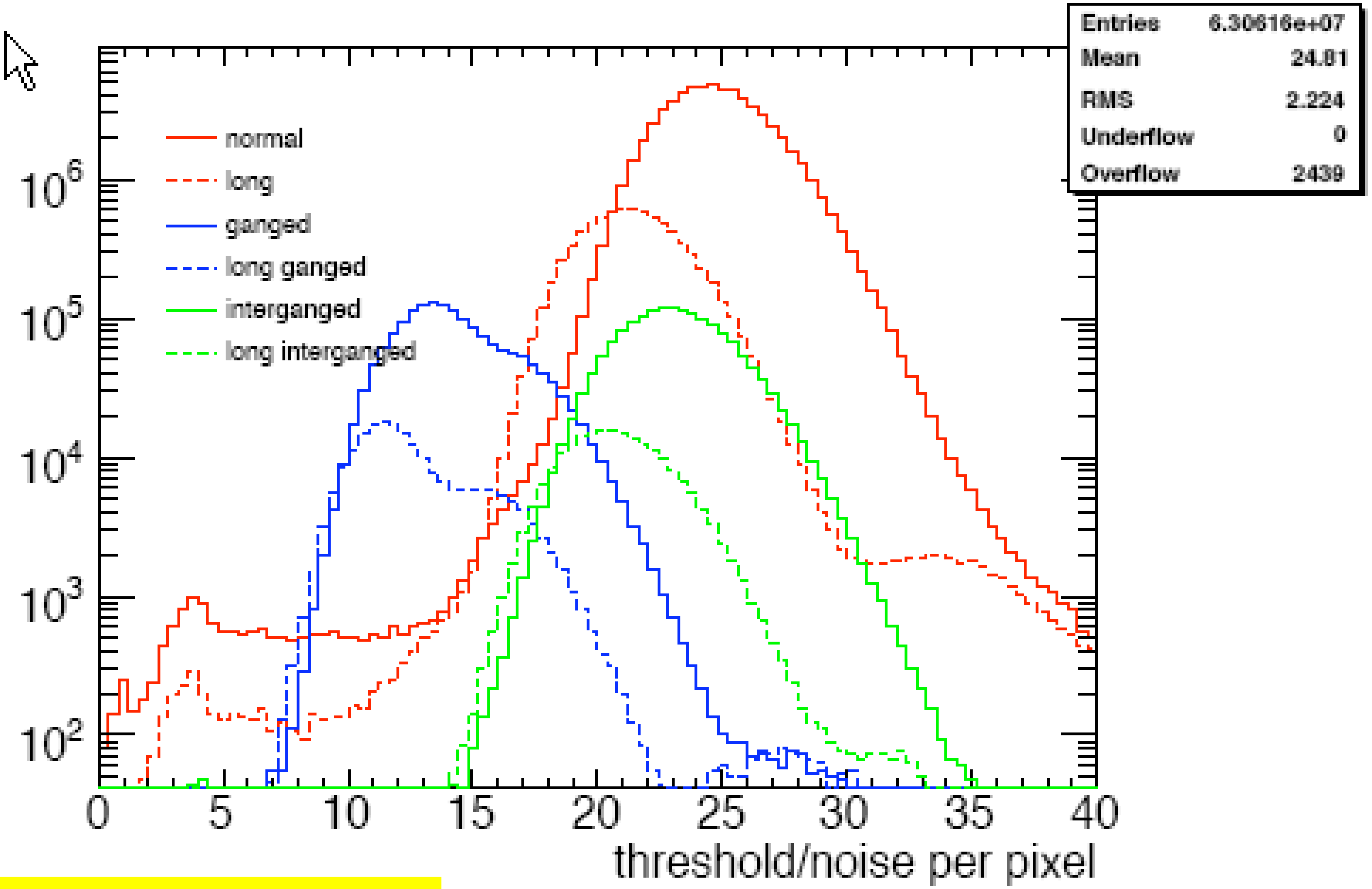


Different types of pixels

One entry per pixel

(logarithmic vertical scale)

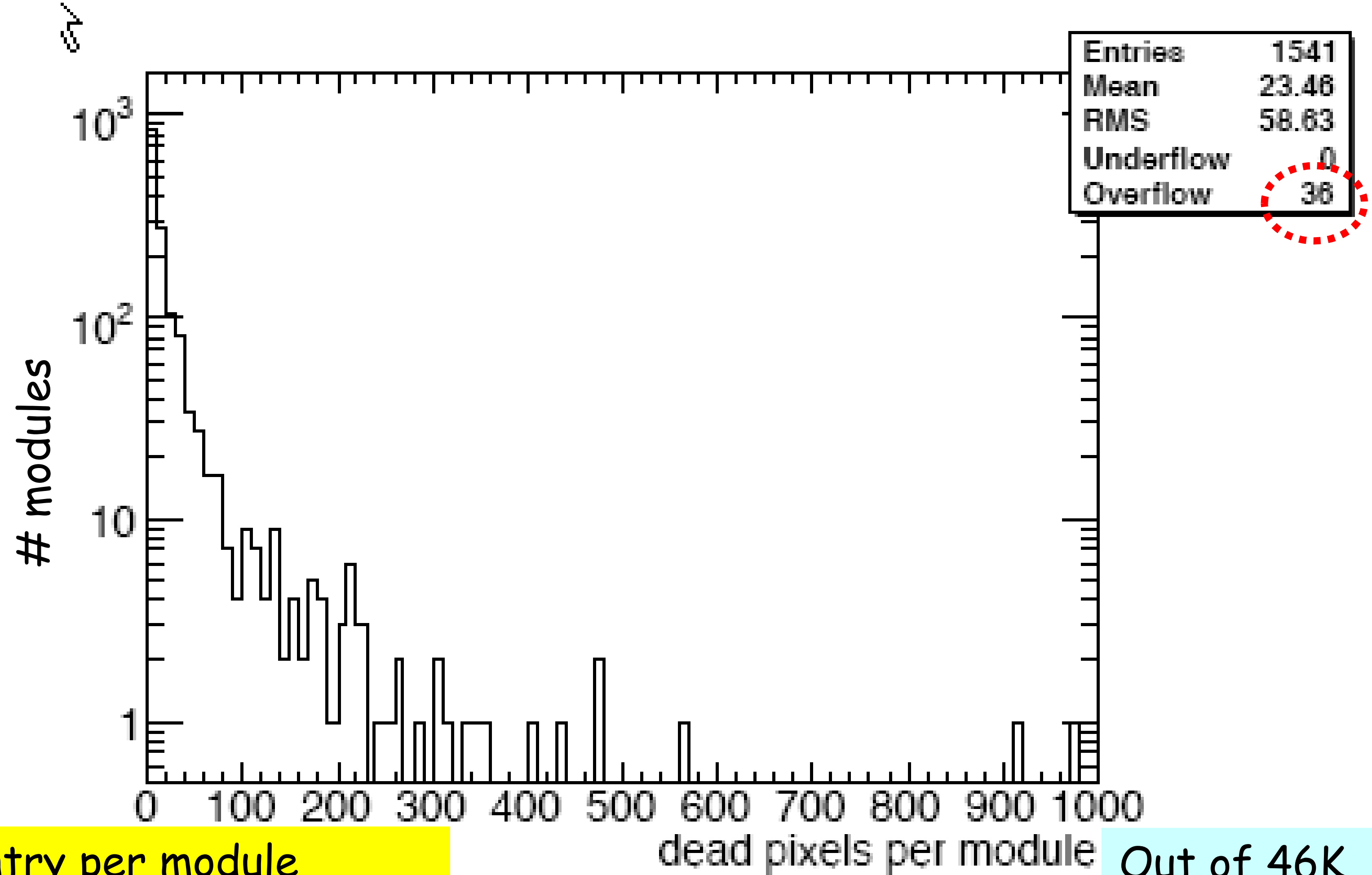
Threshold / Noise (~25)



One entry per pixel

(logarithmic vertical scale)

Dead Pixels



One entry per module

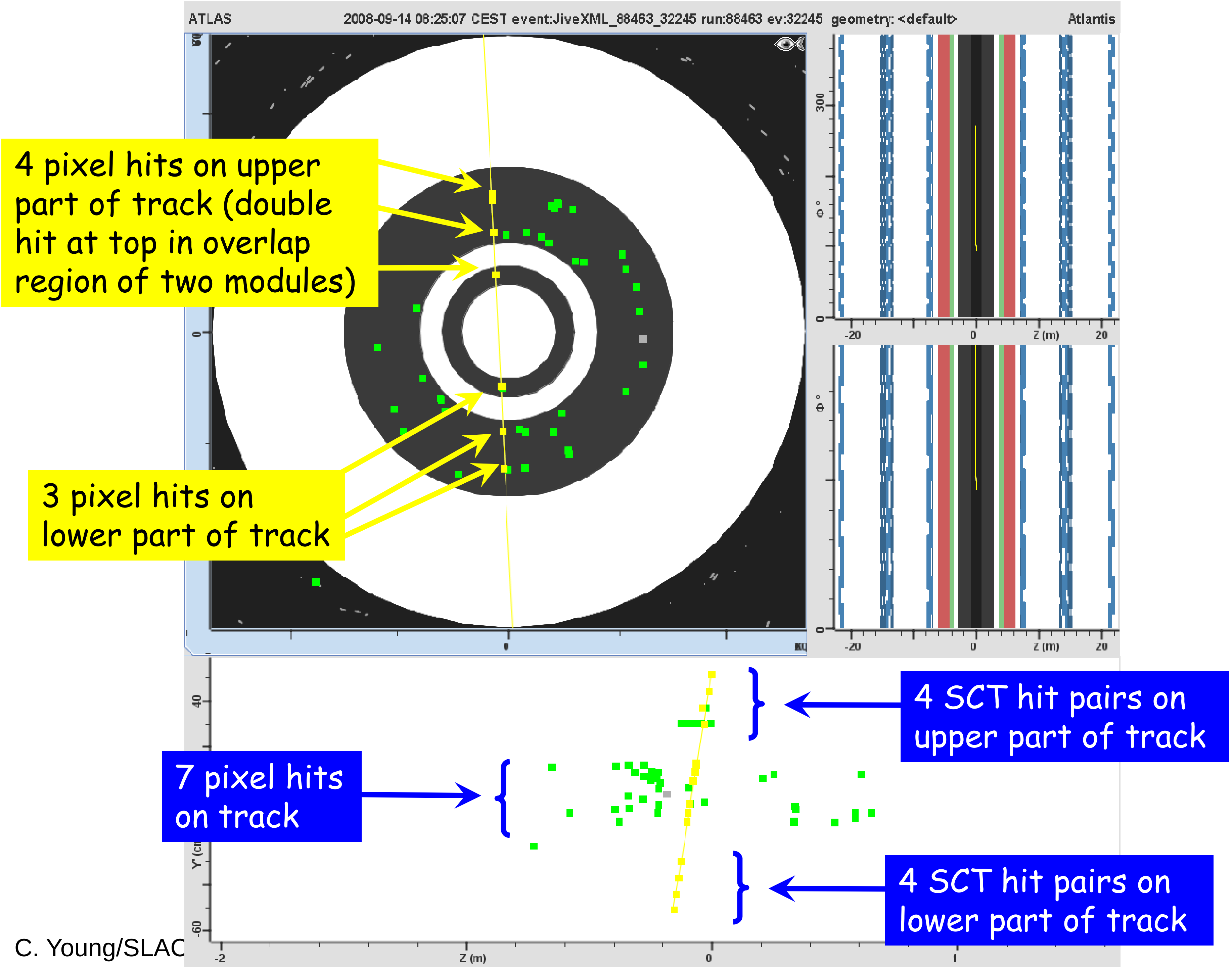
(logarithmic vertical scale)

Out of 46K pixels

Operations

Combined Operations

- First circulating beams in LHC on 10-Sep-2008.
- Decided to keep depletion voltage off for detector safety.
  - Large enough flux of particles could in principle dump all stored charge onto front-end chip.
  - Tests in PS beam indicate it should not damage FE.
  - But better safe than sorry.
- No beams on 13-Sep-2008.
- Approximately 95% of pixel detector ready.
  - Reasonably but not well tuned.
  - Noisy modules and noisy pixels masked out.
  - Average occupancy of $O(10^{-9})$ per bunch crossing.
- Turned on HV, join combined ATLAS run with magnets off.
  - Transition Radiation Tracker (TRT) not ready,
  - Quickly found and fitted combined pixel+SCT tracks.
  - First "perfect" track fitted within a few hours.

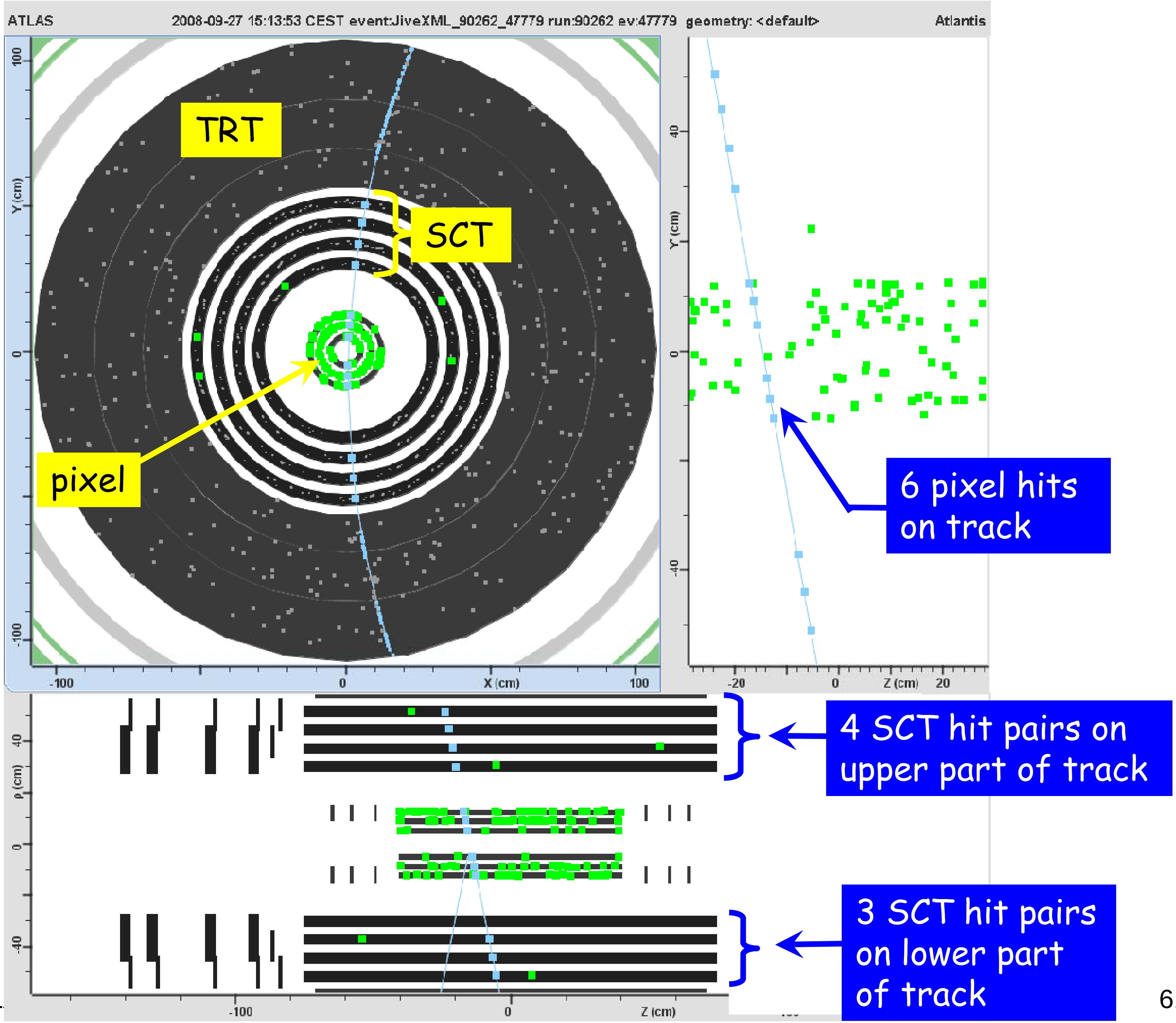

ATLAS
2008-09-14 08:25:07 CEST event:JiveXML_88463_32245 run:88463 ev:32245 geometry: <default>
Atlantis
4 pixel hits on upper part of track (double hit at top in overlap region of two modules)
3 pixel hits on lower part of track
4 SCT hit pairs on upper part of track
7 pixel hits on track
4 SCT hit pairs on lower part of track
Z (m)

19-Sep-2008 Incident

- Major incident in LHC during no-beam commissioning of Sector 3-4 magnets.
- Large helium leak into LHC tunnels.
  - Attributed to faulty electrical connection between magnets.
  - Hope to be back in operation by Spring 2009.
- ATLAS plans revised accordingly.
  - Original plan was to get ready for colliding beams at 450 GeV per beam.
  - Changed to combined cosmic data taking until 3-Nov.
  - Possible cosmic data taking beyond that, but not with all sub-detectors.
  - Switch to further calibration.
- Goal is to flush out and fix problems not evident in short runs.
- Good progress: runs are now quite stable.

Operations with Magnetic Field

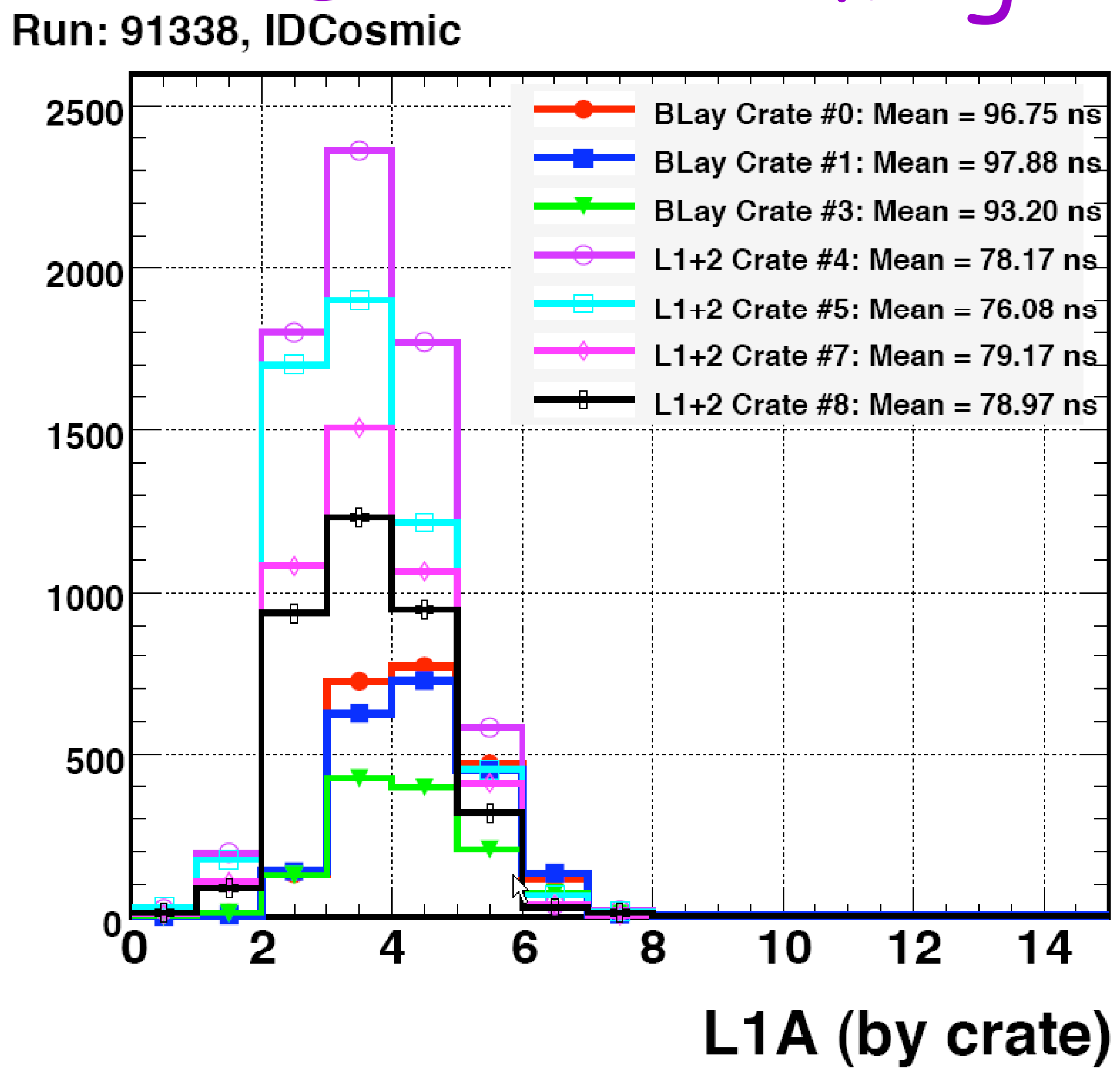
- Weekend of 27-Sep-2008 is first time all sub-detectors are in combined run with nominal magnetic fields.
  - Pixel, SCT and TRT.
  - Solenoid at 2 Tesla (7.7 Kamp).
  - Barrel and endcap toroids at 20 KAmp.
- Similar fraction of pixel detector ready as before.
  - Testing different tune configuration.
  - No noise masks employed.
  - Higher average occupancy ~100 hits per event.
- Found and fitted "near perfect" track within a few hours.


ATLAS
2008-09-27 15:13:53 CEST event:JiveXML_90262_47779 run:90262 ev:47779 geometry: <default>
Atlantis
TRT
SCT
pixel
6 pixel hits on track
4 SCT hit pairs on upper part of track
3 SCT hit pairs on lower part of track
X (cm)
Y (cm)
Z (cm)
ρ (cm)

Long Cosmic Run Period

- Currently in a long cosmic run period.
  - Expect to turn off on 3-Nov-2008.
- Turning attention to less critical items.
  - Mask out individual noisy pixels.
  - Improve timing.
  - Adjust warning and error limits, e.g.
    - Opto-board temperatures.
    - Crate and board temperatures.
  - Speed up transitions, e.g. begin run.
  - Better online (and offline) monitoring.
  - More stable operations.

ROD Crate Timing Study



Scope measurement of clock signal relative timing agrees well.

Conclusion

- Commissioning of pixel detector progressed well and we would have been ready to take colliding beam data, though not at optimal performance.
- We will use the next ~6 months to
  - Repair/replace defective or substandard parts.
  - Get better calibrations.
  - Improve operational reliability.
- Come back in Spring 2009 for fast ramp-up to physics data taking.