LHC Run-2 Readiness: CMS tracker

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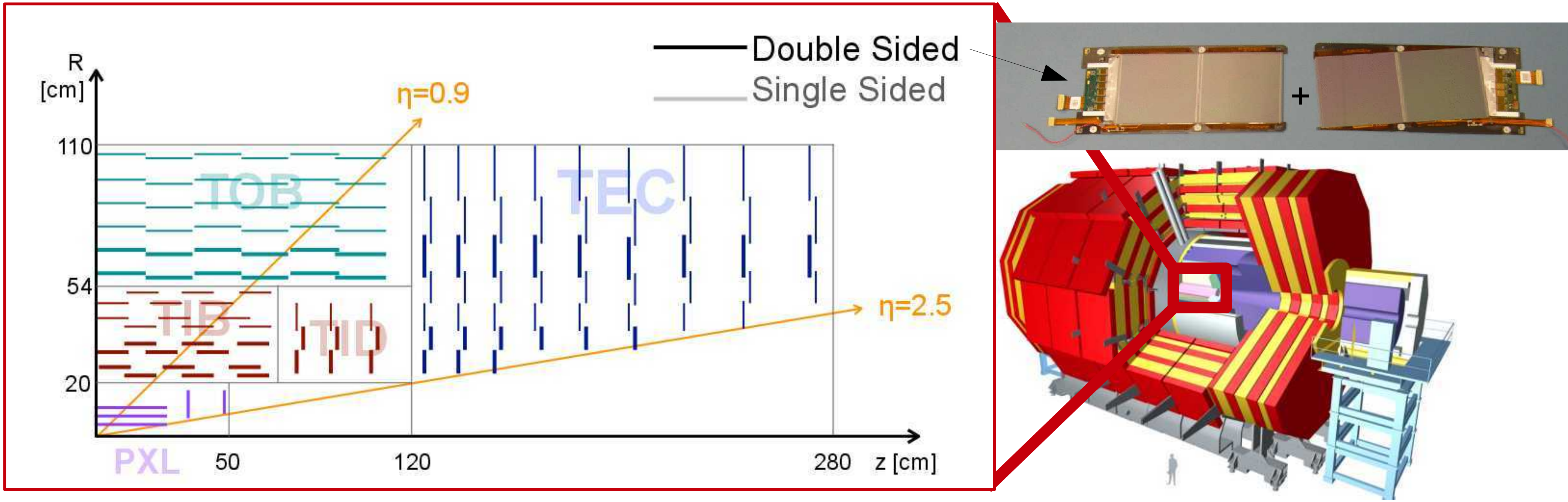
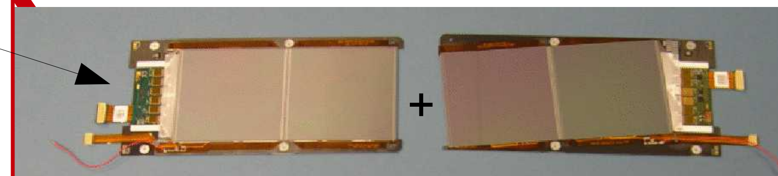
The CMS Silicon Tracker

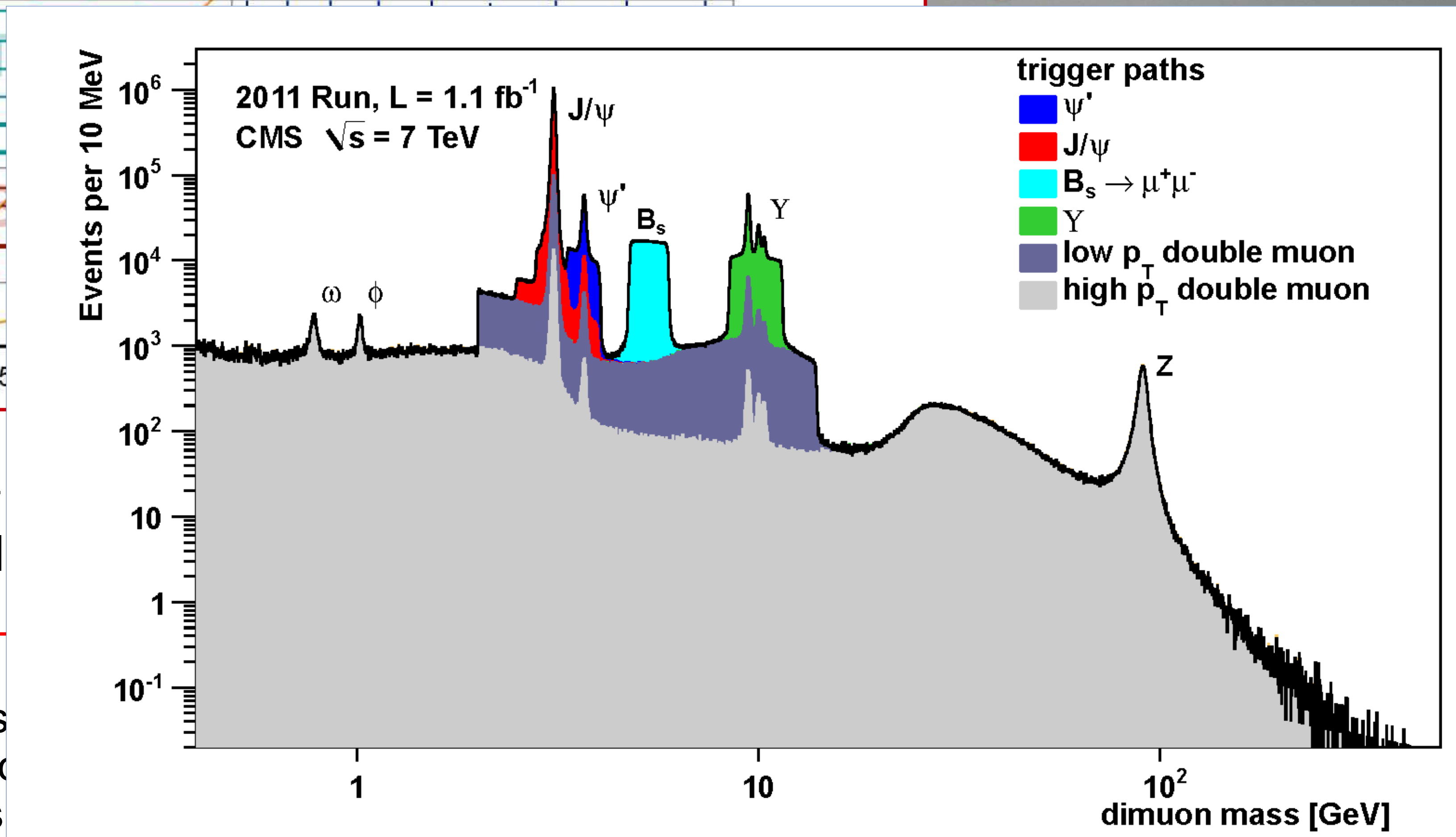


- Largest silicon tracker ever built: active area 200m^2, 5 m long, 2.5 m diameter
- First 'all-silicon' central tracker

Pixel	+	Strips	=	CMS Tracker
1.1 m^2 silicon 1440 modules 3 layers 2 discs 66 M channels 97% working fraction during LHC run 1		198 m^2 silicon 15148 modules 10 layers 12 discs 9.8 M channels 97.5% working fraction during LHC run 1		Together with 3.8 T magnetic field: $\sigma_{pt}/pt \sim$ 1-2% (p_t~100 GeV) IP resolution: ~ 10-20μm

The CMS Silicon Tracker





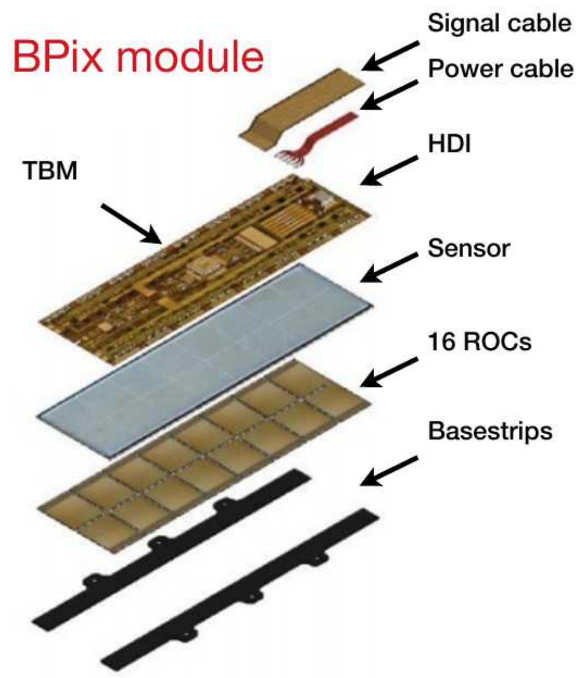
- Largest ... er
- First 'all

Pixel
1.1 m^2 s
1440 mo
3 layers
2 discs
66 M channels
97% working fraction
during LHC run 1

12 discs
9.8 M channels
97.5% working fraction
during LHC run 1

$\sigma_{pt}/pt \sim$ 1-2% ($p_t\sim$100 GeV)
IP resolution: ~ 10-20μm

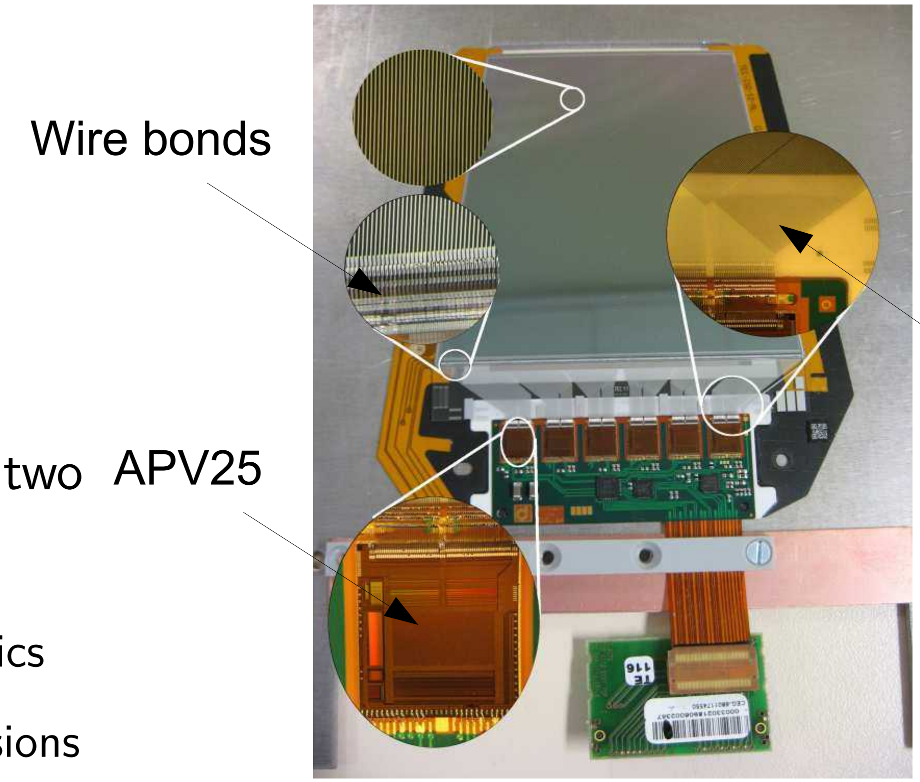
Modules and Readout Modes



- n-in-n silicon
- 285 μm silicon
- 100x150 μm pixels
- Bump-bonded readout chips
- Data sparsification on chip

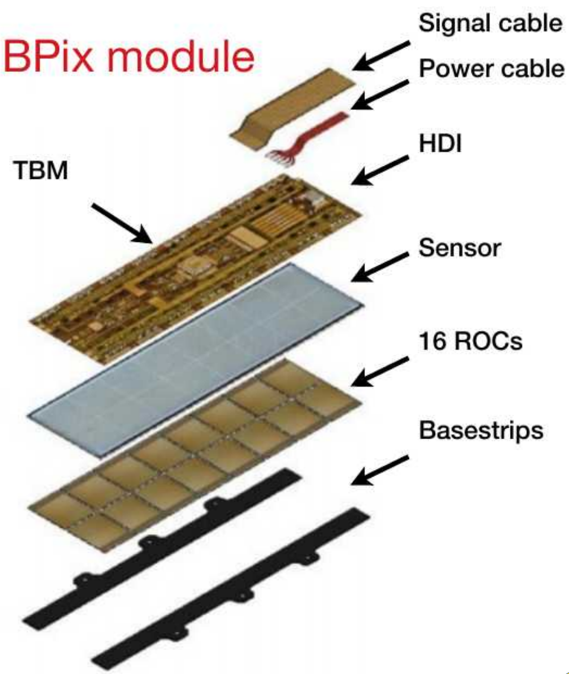
PIXELS

- p-in-n silicon
- 320 μm and 500 μm thick
- Strip pitch 83-205 μm
- Analog readout: **APV25 chip** with two readout modes:
  - **Peak**: robust timing, mostly for cosmics
  - **Deconvolution**: fast, mostly for collisions



STRIPS

Modules and Readout Modes



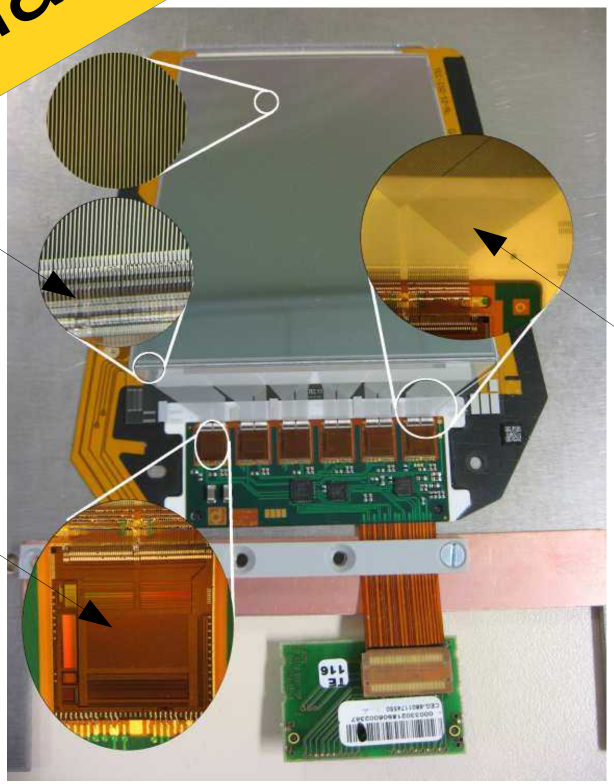
- n-in-n silicon
- 285 μm silicon
- 100x150 μm pixels ...
- Bump-bon... ...ips
- Da... ...on on chip

PIXELS

Analog Readout via optical links

- p-in-n silicon
- 320 μm and 500 μm ...
- Strip pitch 8...
- Analog read... ...V25 chip with two readout modes:
  - **Peak**: robust timing, mostly for cosmics
  - **Deconvolution**: fast, mostly for collisions

...ds



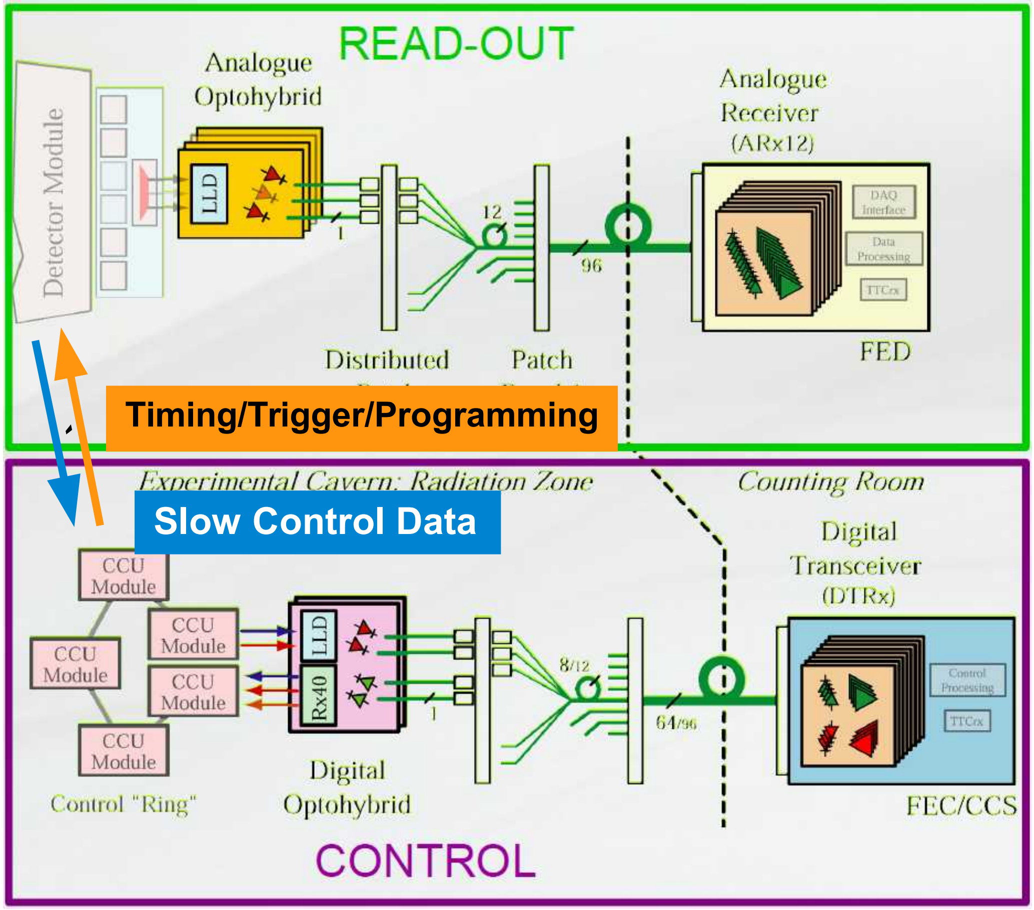
STRIPS

Detector Services

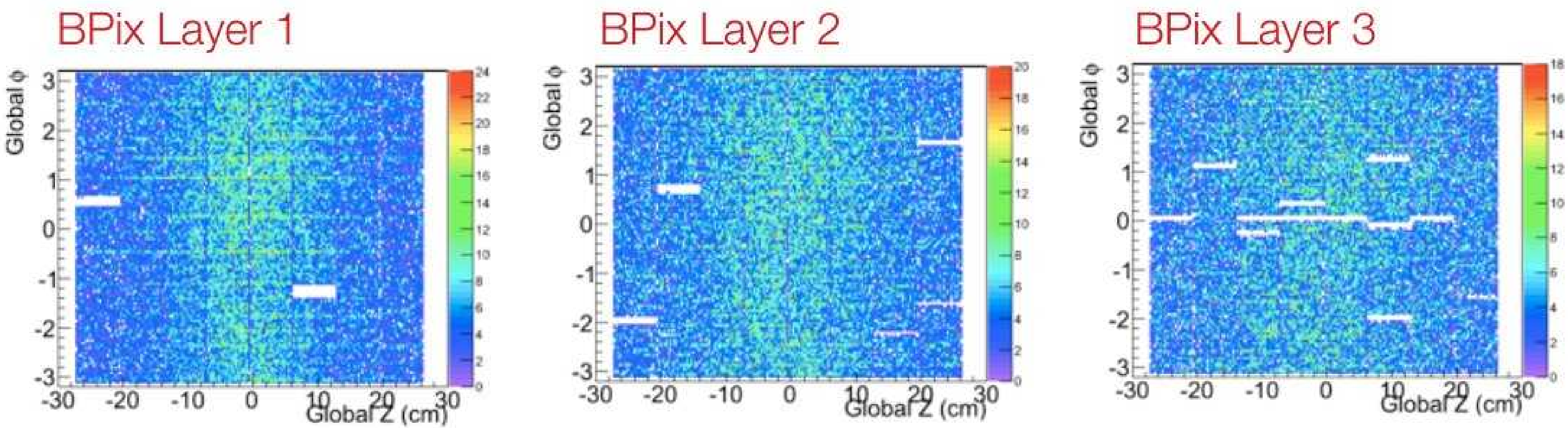
- Both Pixel and Strips are using C_6F_{14} mono-phase cooling
- Two plants with 90 cooling loops each for the strip tracker
  - 2nd plant with 5 loops closed because of leaks
- One plant with 18 loops for pixel tracker
- About 2000 power supplies for pixels and strips
- 480 FEDs for both detectors
  - 440 strips
  - 40 pixels

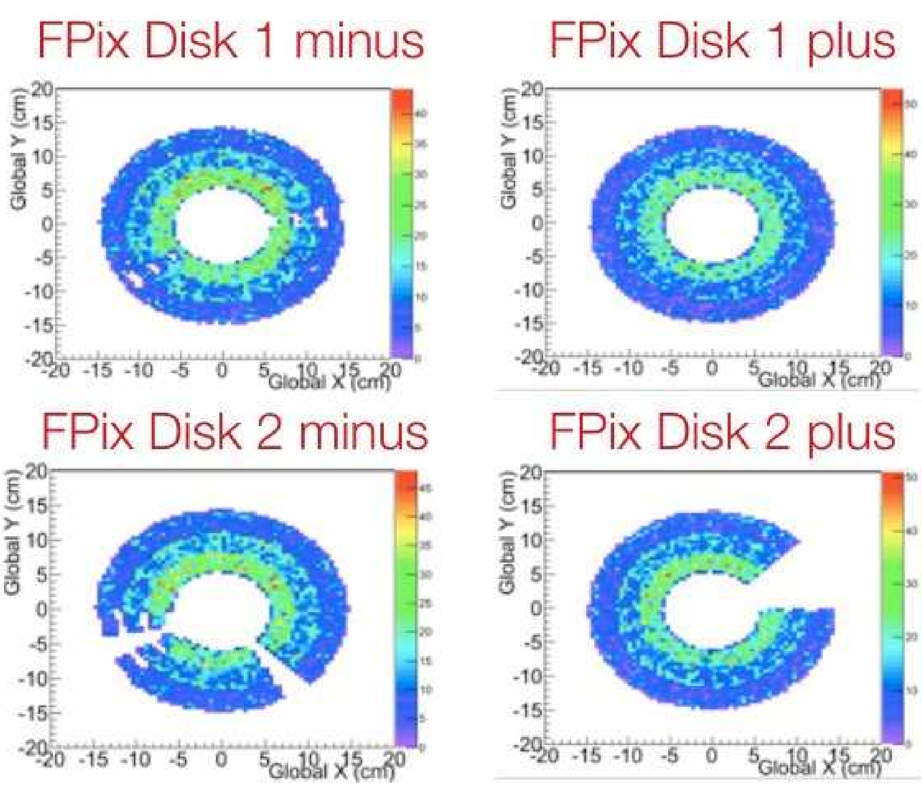
→ >60% of CMS DAQ

Example: strip tracker readout and control



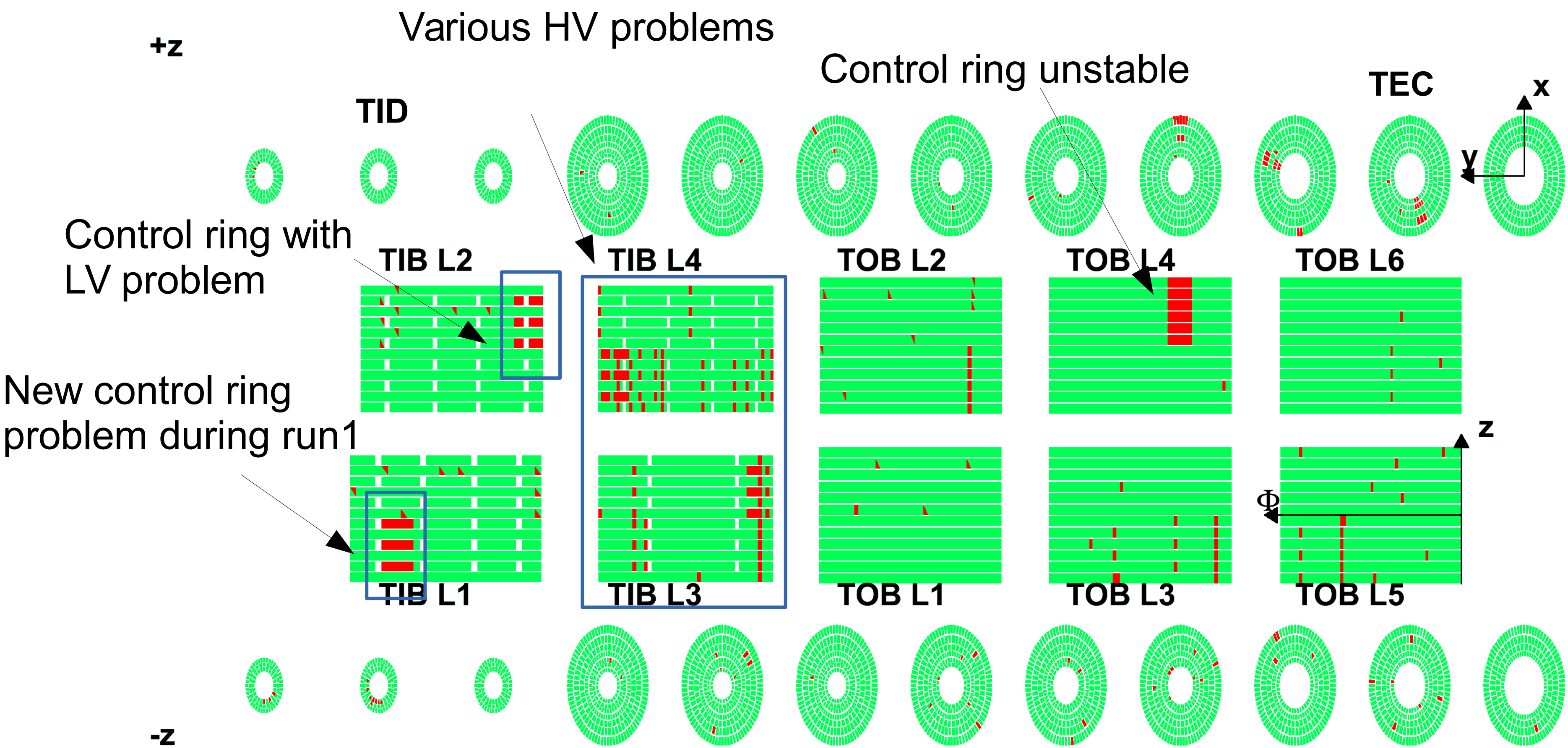
Detector Status at the end of Run1 – Pixels





- BPix: ~2.3%
  - Broken wire-bond connections between ROC and HDI
  - Modules with old ROC design (readout errors requiring module reset)
- FPix: ~7.8%
  - “Slow channels”: long rise time in analog readout, pixel address misreading, miscounting of ROCs and events
  - Broken optical readout
- Repairs and substitution done in LS1

Detector Status at the end of Run1 – Strips

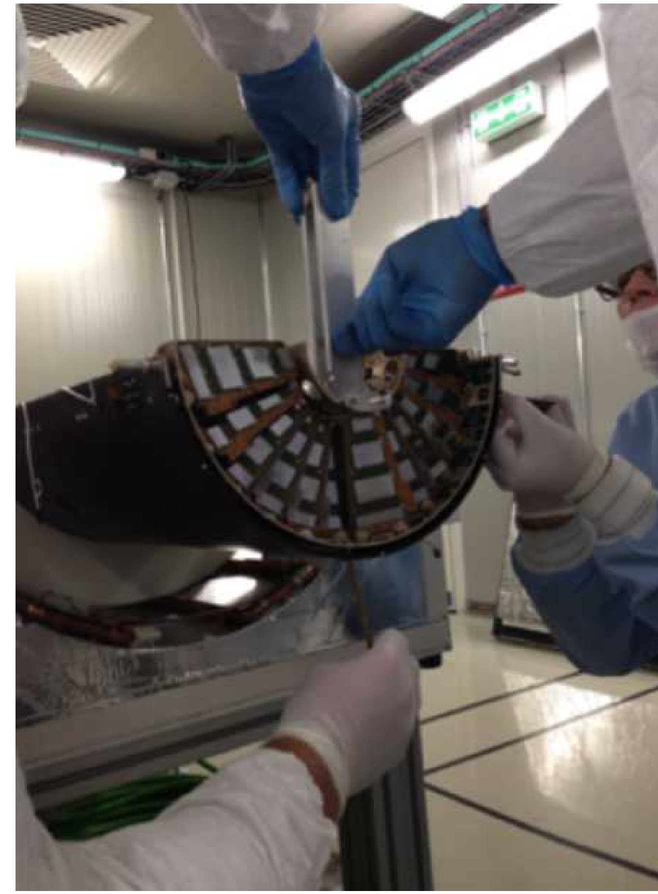


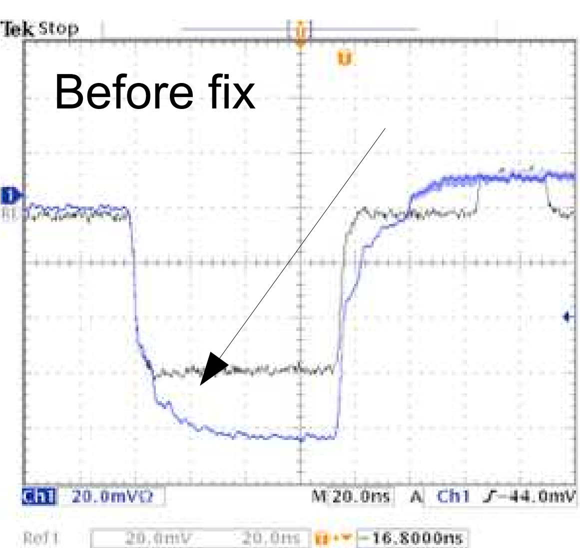
- Bulk of problems localized
  - Control rings, HV channels, LV channels
- Very few (0.5 %) of new problems during run 1 (2010 – 2013)
- Tracking efficiency not affected

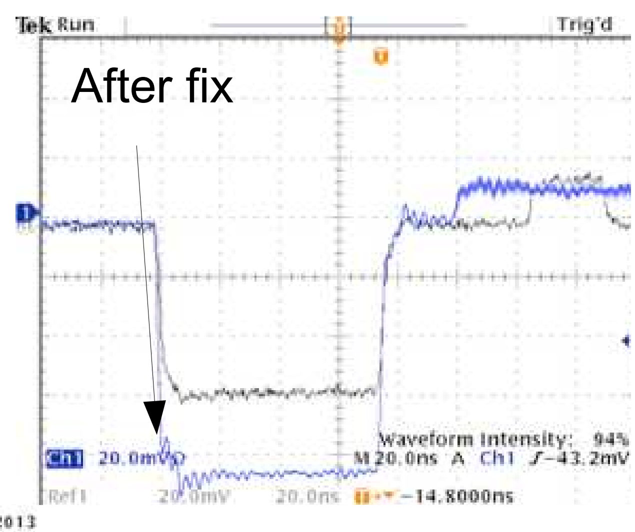
Total	97.48 %
TIB/TID	94.63 %
TOB	97.79 %
TEC+	98.81 %
TEC-	99.13 %

Repairs of the pixel detector during LS1 – FPIX

- At the end of Run 1
  - ~ 8% of FPix channels not operational
  - 46 %: failing digitization of the analog signal
    - distortion of the signal (“slow channels”) caused by misaligned flex cables
  - 40% unplugged analog electrical-to-optical converters (AOHs)
  - 14% of faulty channels: problematic panels
- Repairs performed during LS1
- 99.9% of FPix channel operational for run 2





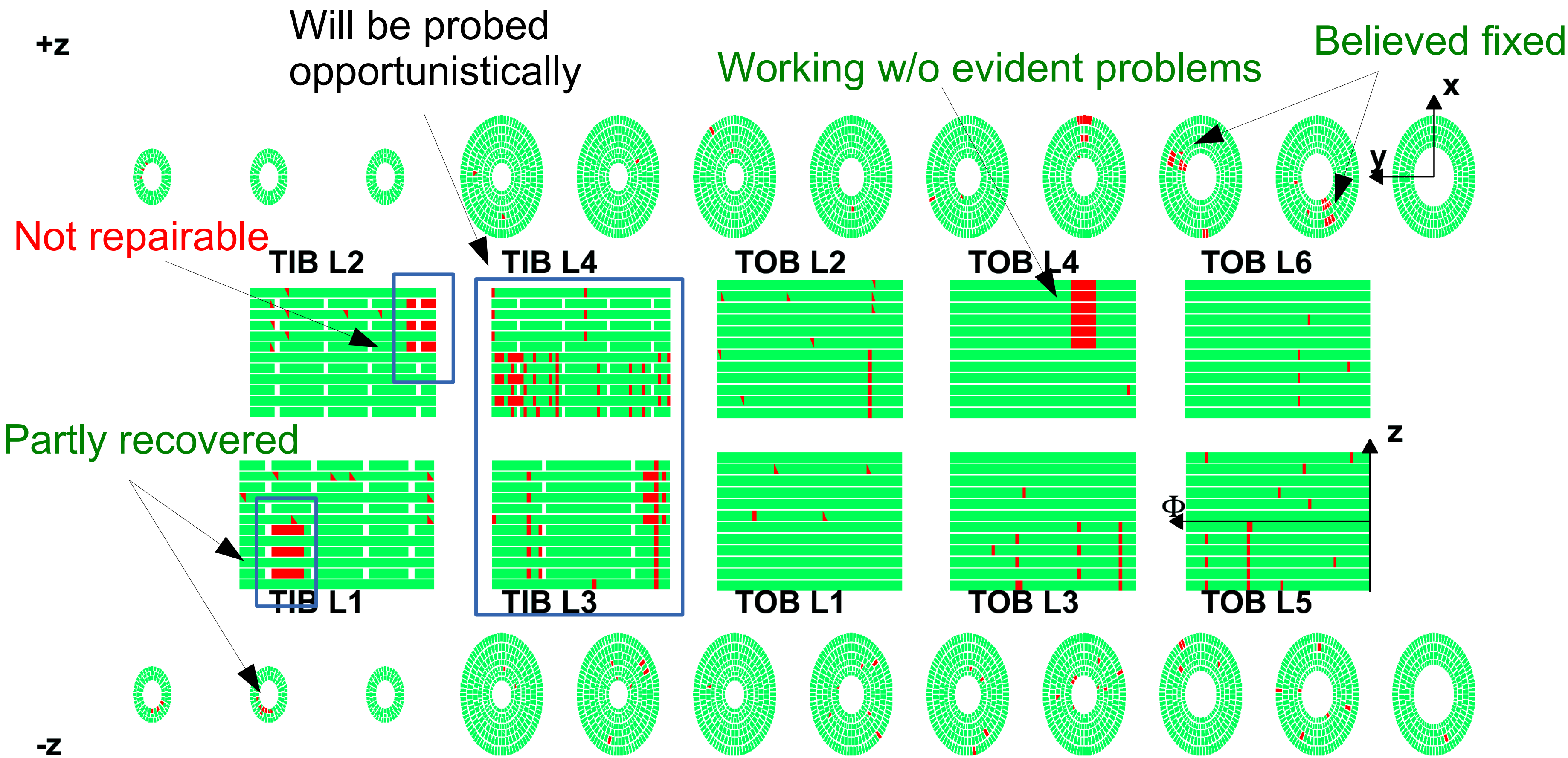


Repairs of the pixel detector during LS1 – BPIX

- About 2.3% of BPix channels not working at the end of Run 1
  - 52% of faulty channels: located on outer shell of Layer 3
  - 48% of faulty channels: placed on Layers 1 and 2 or inner shell of Layer 3
  - 2 AOHs not fully operative (workaround allowed proper data taking)
- Repairs performed during LS1:
  - AOHs successfully replaced
  - Most faulty modules replaced
  - 99% of BPIX working after repairs

Example: replacing module in layer 3

Repairs of the strip detector during LS1



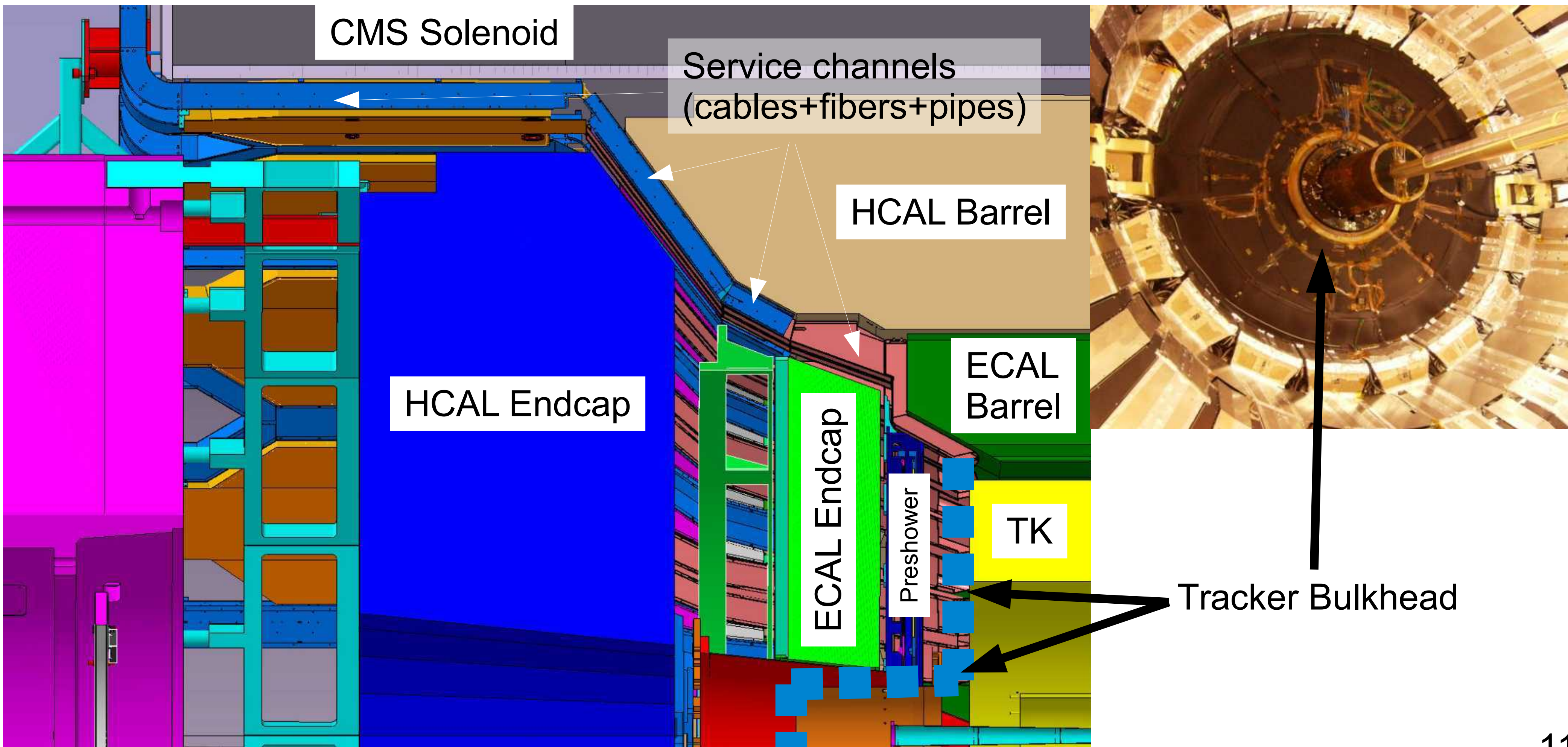
- Strip Tracker completely inaccessible for in-situ repairs
- Limited to interventions on patch panels and on bulkhead
- Few problems found and fixed, others still under investigation (no further hardware access needed)

(Strip) Tracker Work during Long Shutdown 1

Aka 'Going Cold'

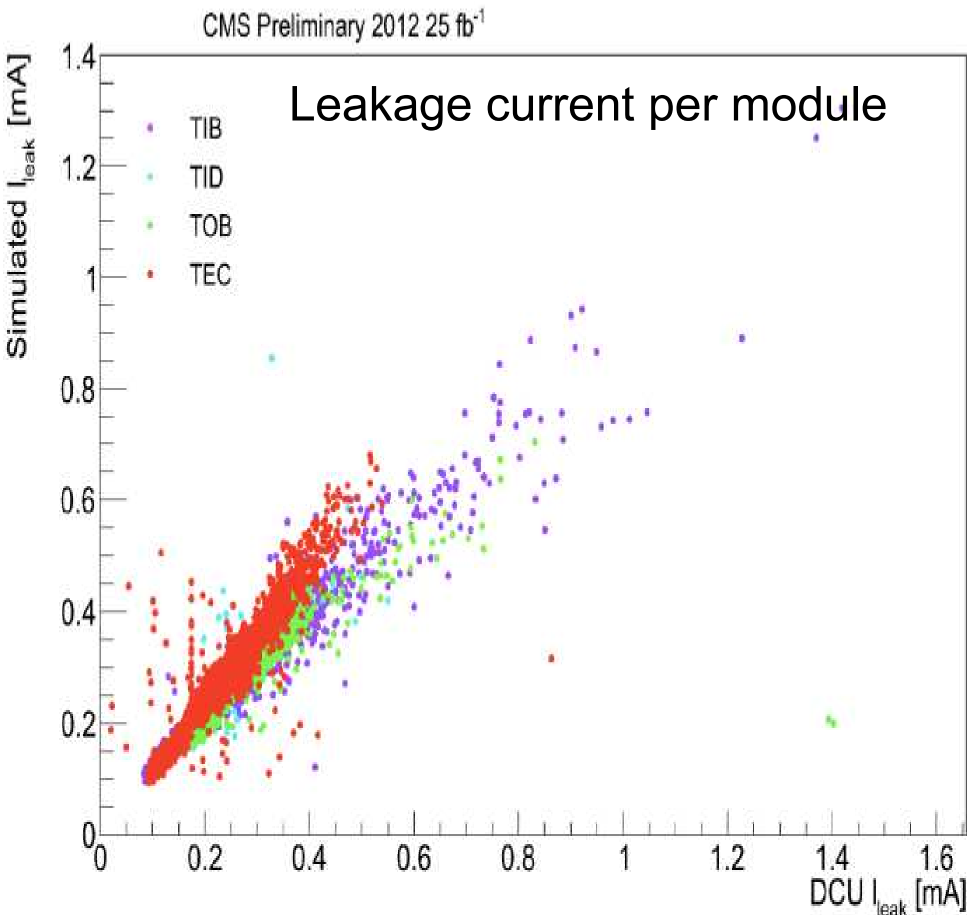
Setting the stage – Nomenclature

- Lots of work happened on
  - Service channels
  - Tracker bulkhead



Setting the stage

- Strip Tracker Run 1 operating temperature +4°C (Pixel first +7°C, later 0°C)
- "Why do you need to go cold anyway?"
  - Silicon sensor leakage current doubles every ~7°C of temperature
  - At the end of 2012 already at 30-40% of power supply limit in some cases
    - With <10% (for strips) of radiation dose expected over the lifetime of the detector
  - In addition **severe** long-term effect which renders detector **inoperable** because of too high depletion voltage (reverse annealing)



Simulated vs Measured leakage current in run 1 after 25 fb-1 of integrated luminosity

Setting the stage

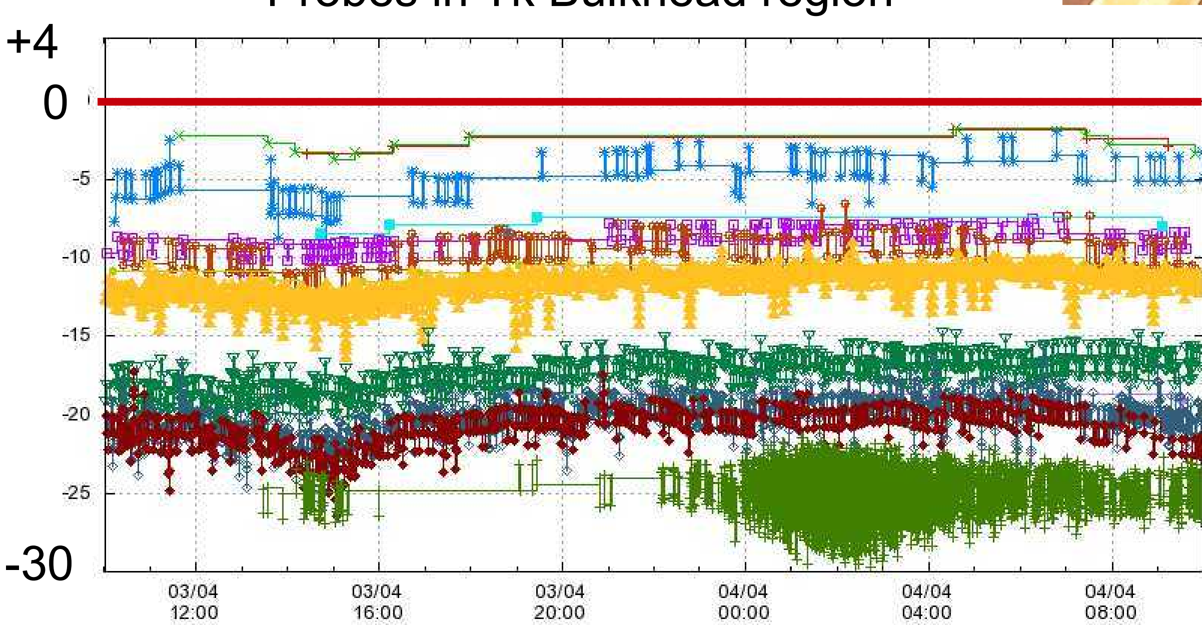
"Why didn't you go cold earlier?"

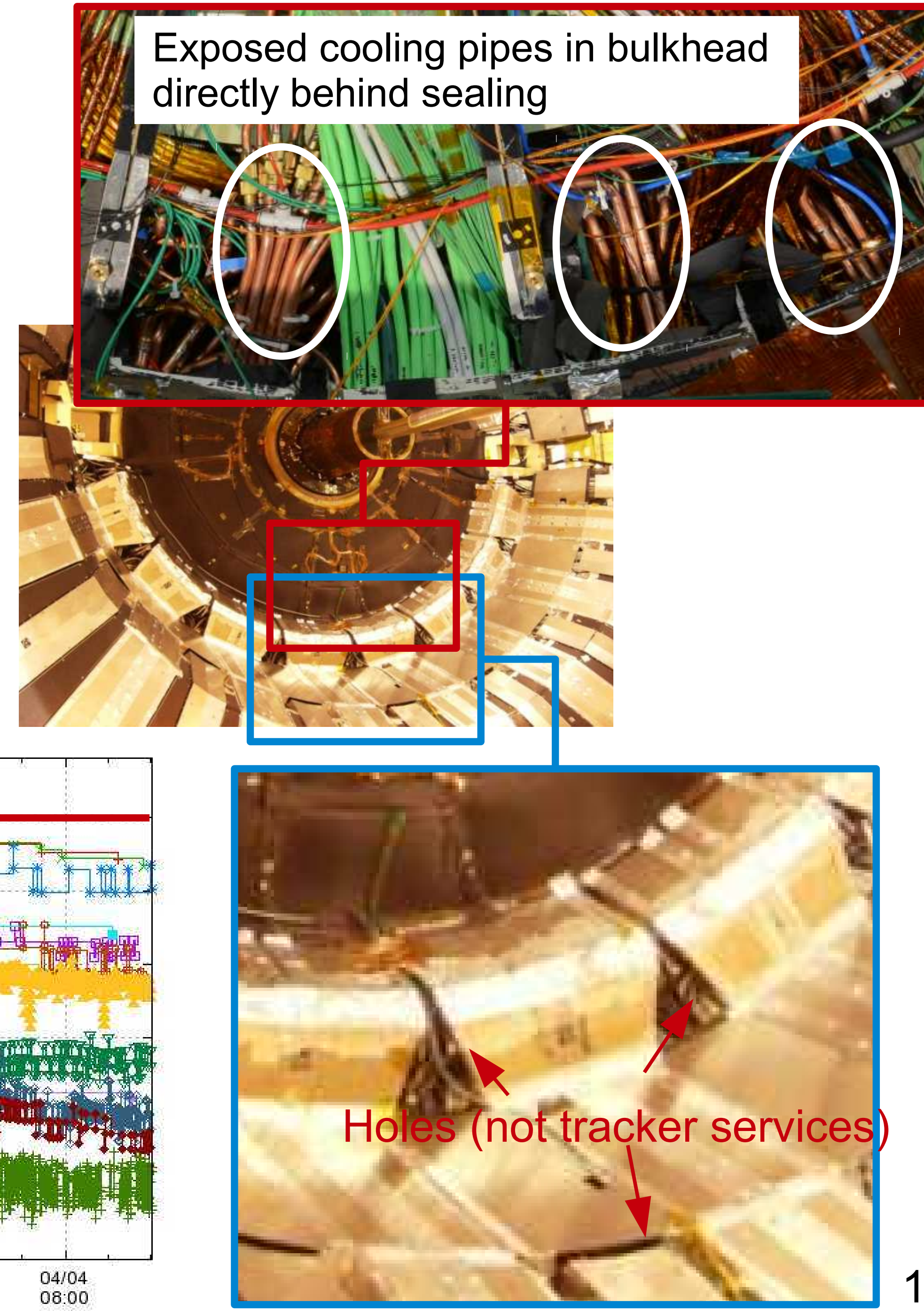
- Dew points in tracker bulkhead and service channels not low enough

  (Tracker volume itself was fine)

- Consistent with being relatively open to ambient/cavern air

Probes in Tk Bulkhead region





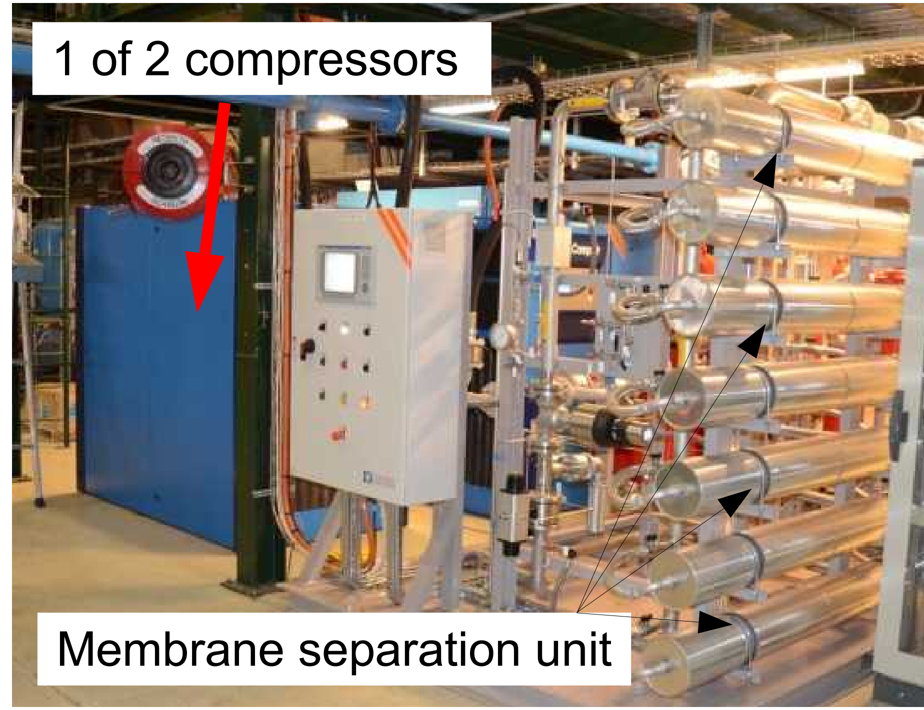
Work on Cooling

- Completely new cooling plant cabinets for all C_6F_{14} cooling plants
  - Improved insulation and vapor tightness
- Work on interfaces
  - New heat exchangers on plants
  - New evaporator on primary circuit
- Improved monitoring and regulation
- No increase in leak rate on strip tracker plants when operating at low temperature

Dry Gas: Surface Membrane Plant

- New main source of dry gas to the tracker
- Can provide nitrogen and dry air (nitrogen during beam operation → inertion)
- Adds 350 m³/hr of gas pumped into YB0

  → about 10 – fold increase



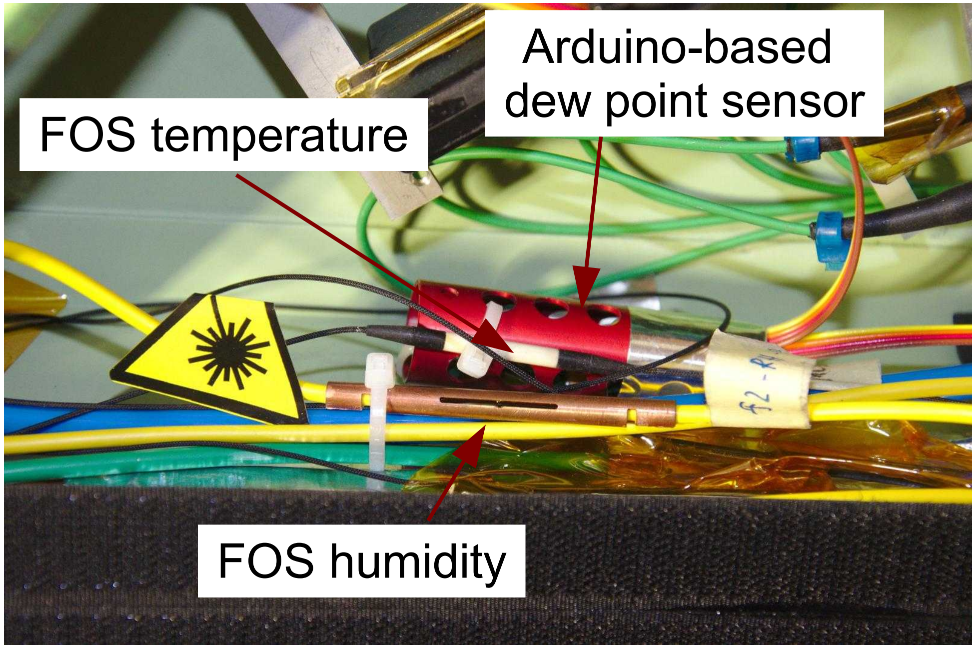
New dry gas distribution:

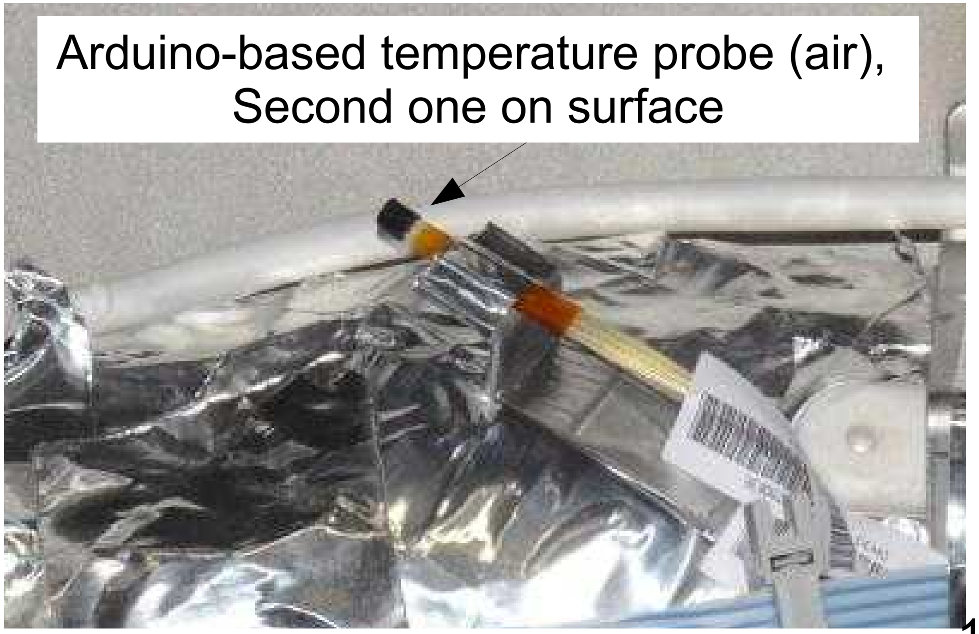
- 2x18 new high capacity dry gas injection pipes around bulkhead and into cooling pipe bundles
- 3 new dry gas distribution racks in service cavern

  → allows fine-grained control of dry gas distribution even during beam operation

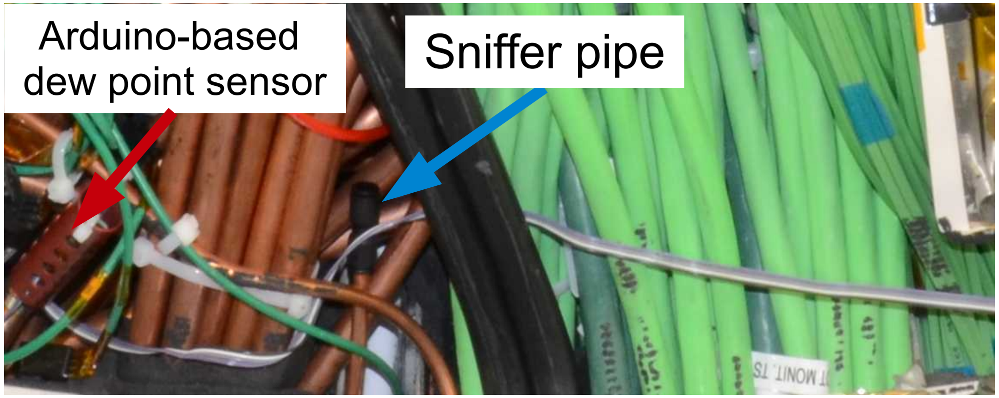
Humidity Monitoring – Part 1

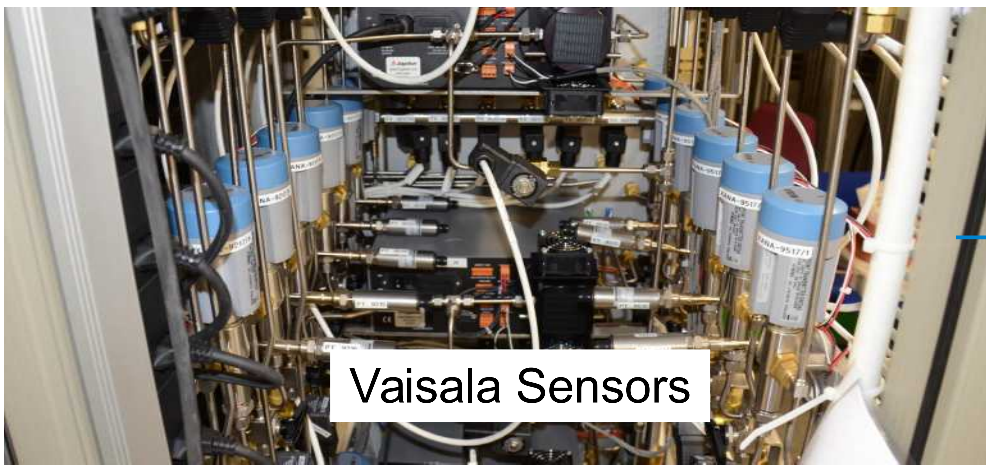
- Added lots of sensors to
  - Tracker bulkhead
  - Service channels
  - Cooling pipe bundles
- Two main types of sensors in-situ
  - Fiber optic sensors (FOS)
    - Radiation hard
  - Dew point sensors (T+RH) and digital thermometers read out by Arduino microcontrollers
    - Not radiation hard
    - In bulkhead and service channels will not survive long when beam starts
    - On cooling pipe bundles will stay alive





Humidity Monitoring – Part 2

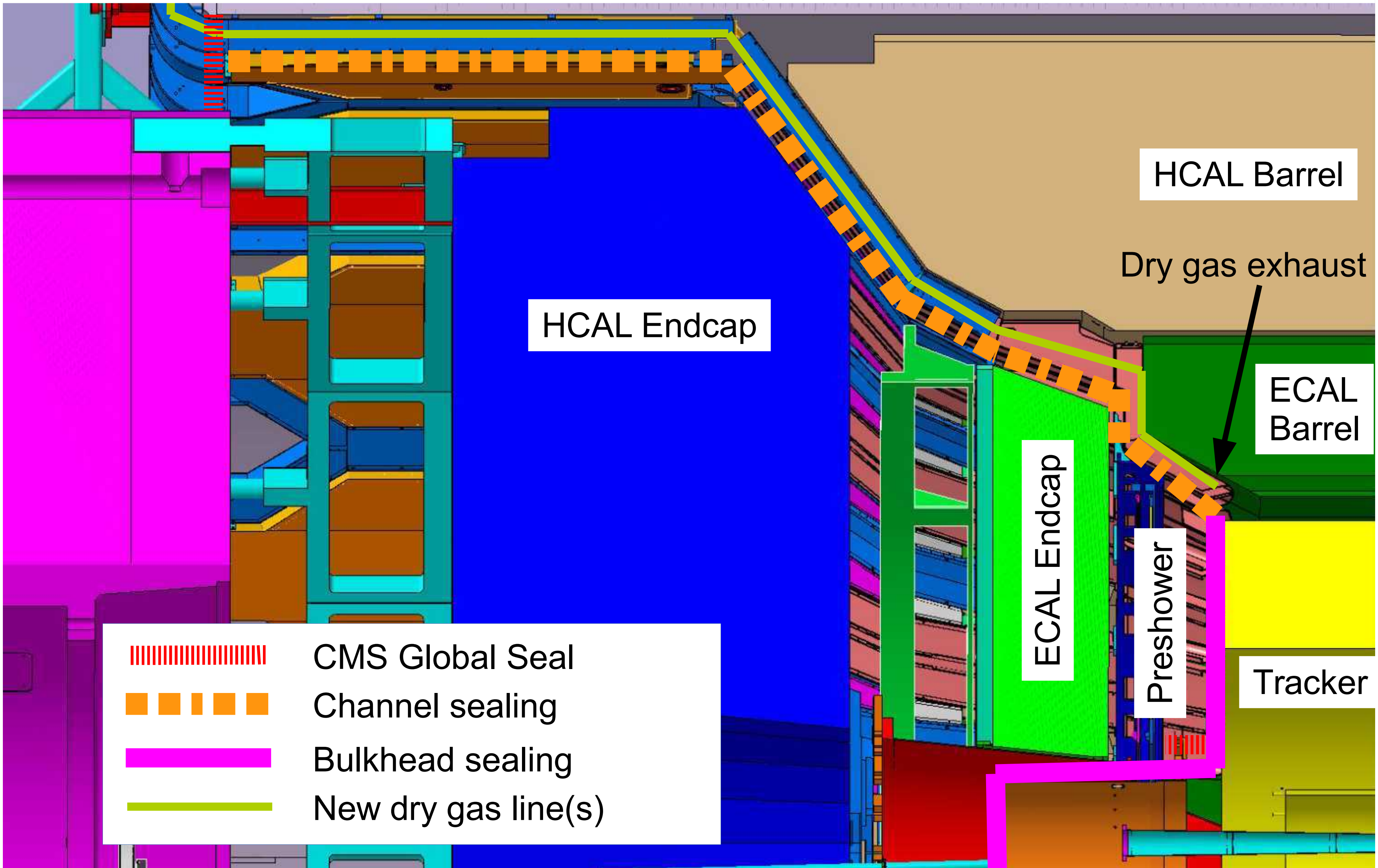




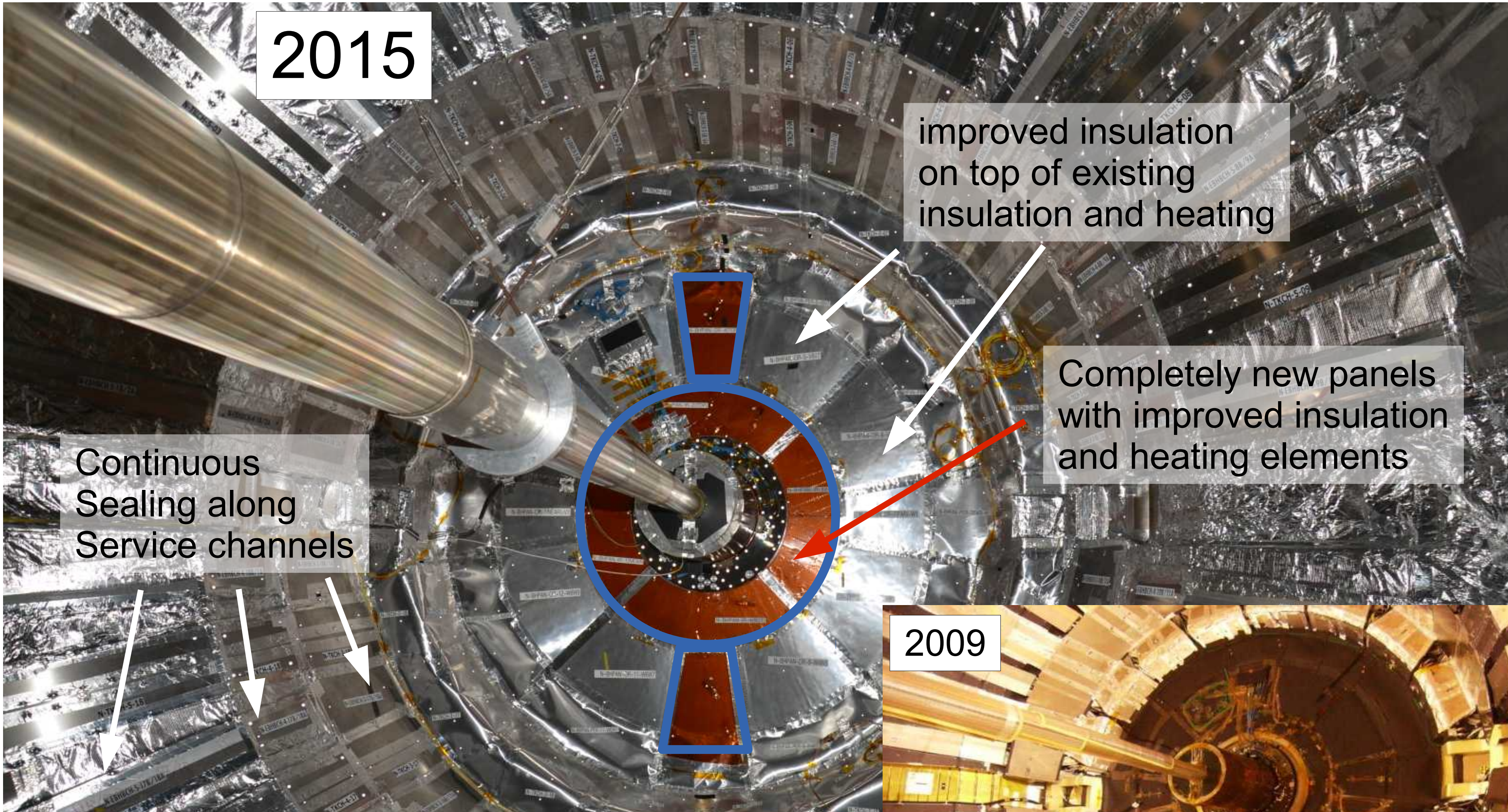
- In addition to in-situ sensors:
  - Installed sniffer system with 20 new lines (+6 existing inside tracker volume)
  - Sniffing from various places inside the detector, analysis of gas properties in service cavern
- Dew point measurements from 26 Vaisala industrial dew point sensors + 5 chilled mirrors for absolute scale

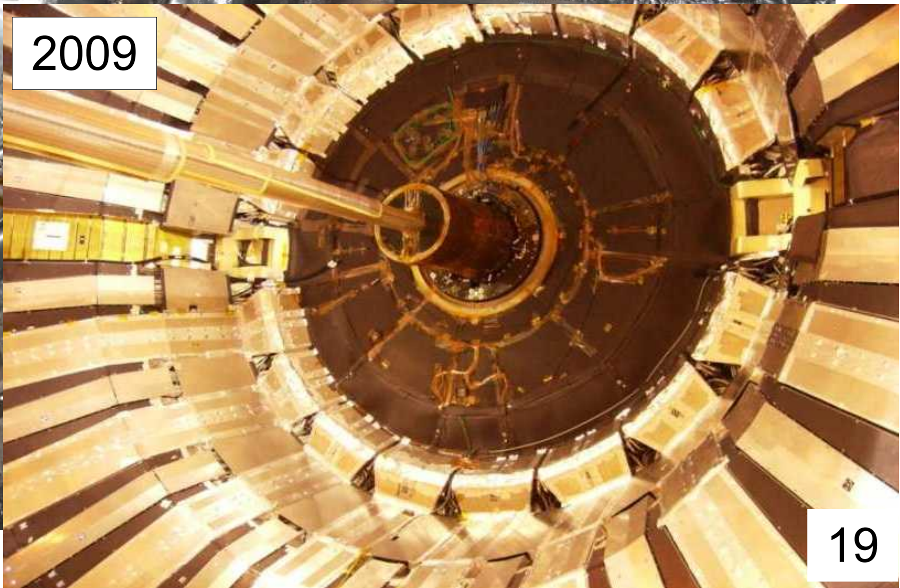
Sealing Concept

- Close holes wherever possible to create seamless surface
- Add thermal insulation where necessary



The Final Product

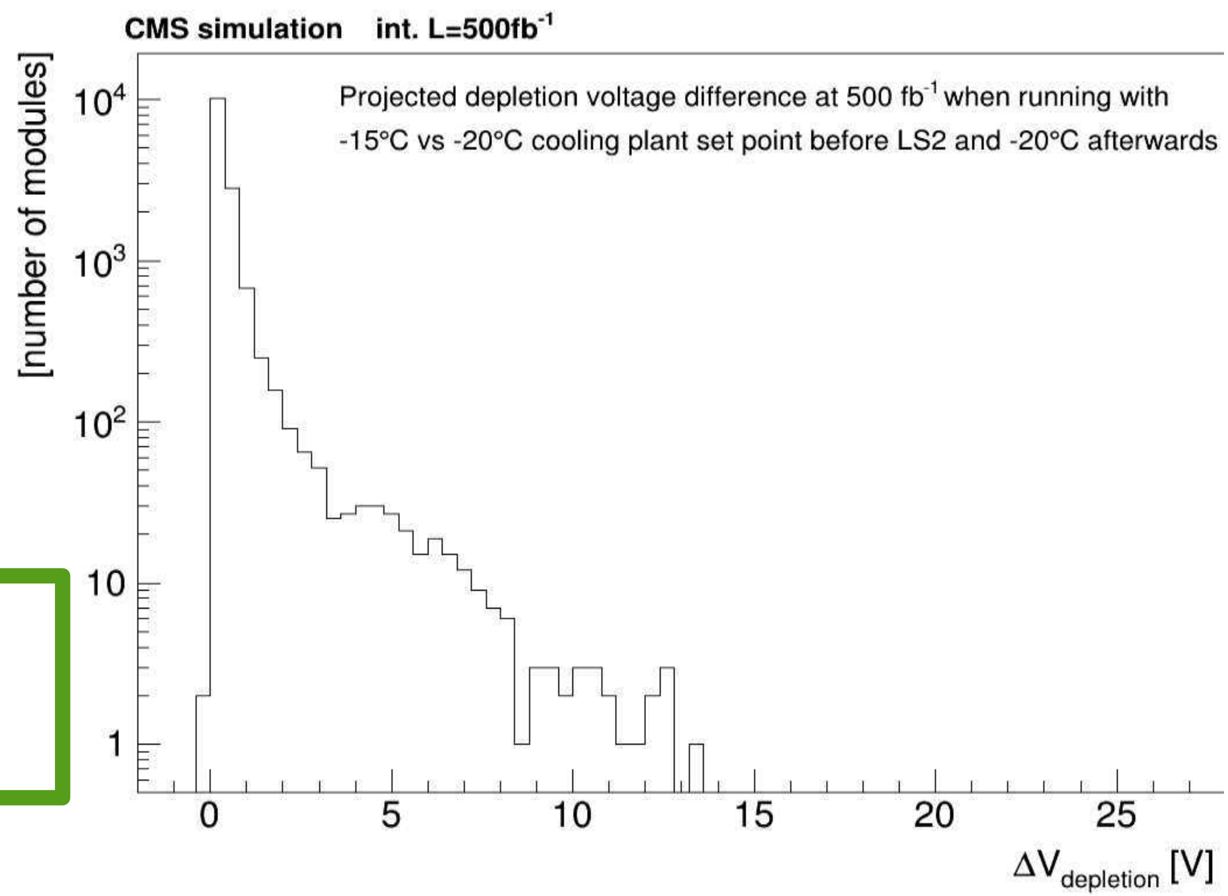




Heating elements:
- Keep temperature above dew point in less controlled regions
- Maintain thermal neutrality towards ECAL (needs very stable T)

Choice of Run 2 Operation Temperature

- 'Cold Test' showed that tracker can be operated down to -20°C with safety margin
- Decision between running at -15°C and -20°C for strip tracker
- -20°C mechanically more demanding, but need to verify that no long term penalty is incurred by running at -15°C until LS2
- Very small penalty in full depletion voltage
  - 10-15 V @500 fb^{-1}
  - To be compared to 300-400 V projected depletion voltage by LS3 (end of life)

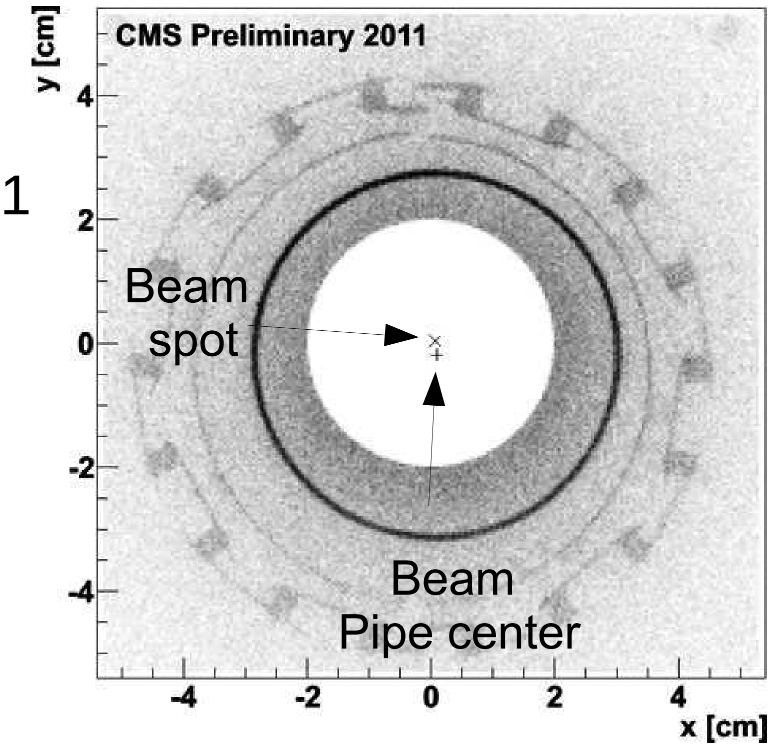


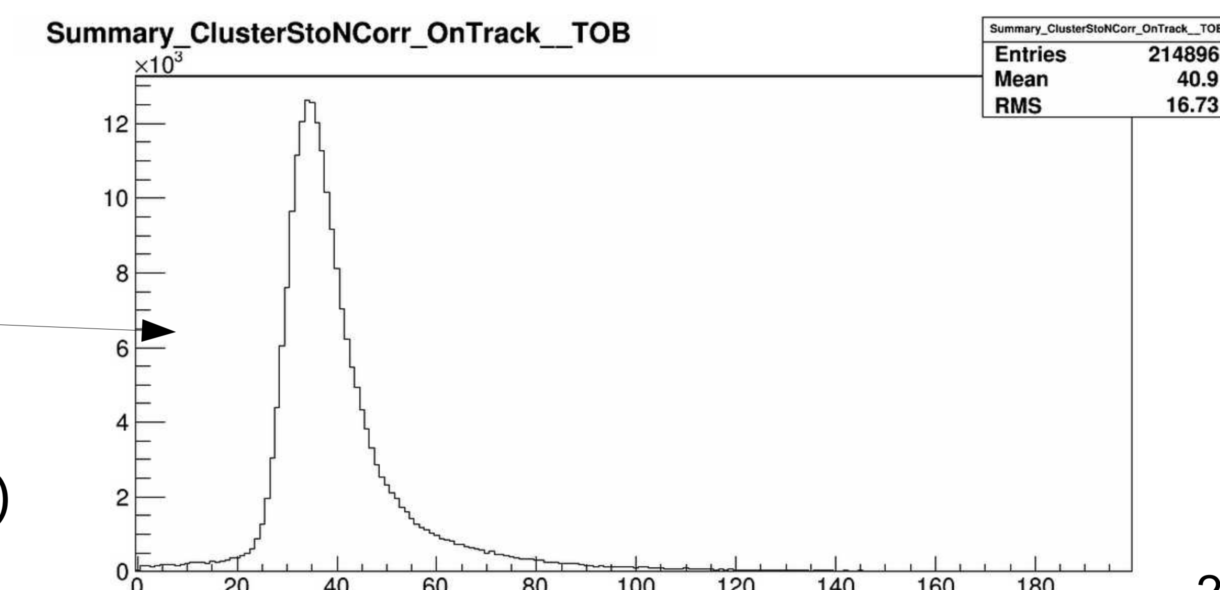
→ safe to run with -15°C cooling plant set point until LS2 (~150fb^{-1})

Final Preparations for Run 2

- Pixel detector has been reinserted into CMS
  - During insertion corrected for offset with respect to nominal beam line during run 1
  - Successfully running with CMS at its run 2 operation temperature of -10°C
- Right now: CMS getting ready for beam
  - LHC Sector test with beams up to point 6 this weekend
- Cosmic data taking at
  - Zero Field (now)
  - Full Field (soon)
- One example signal to noise distribution
  - Strip Tracker Outer barrel

→ S/N excellent (Peak mode)





Summary

- Extensive work program during LS1 for both pixel and strip tracker successfully finished
- Detector repairs largely successful wherever possible
- Strip and Pixel tracker now running COLD
  - Detectors have been re-calibrated at low temperatures
- Now CMS preparing for beam data taking
- Cosmics campaign for initial detector alignment is underway

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The End

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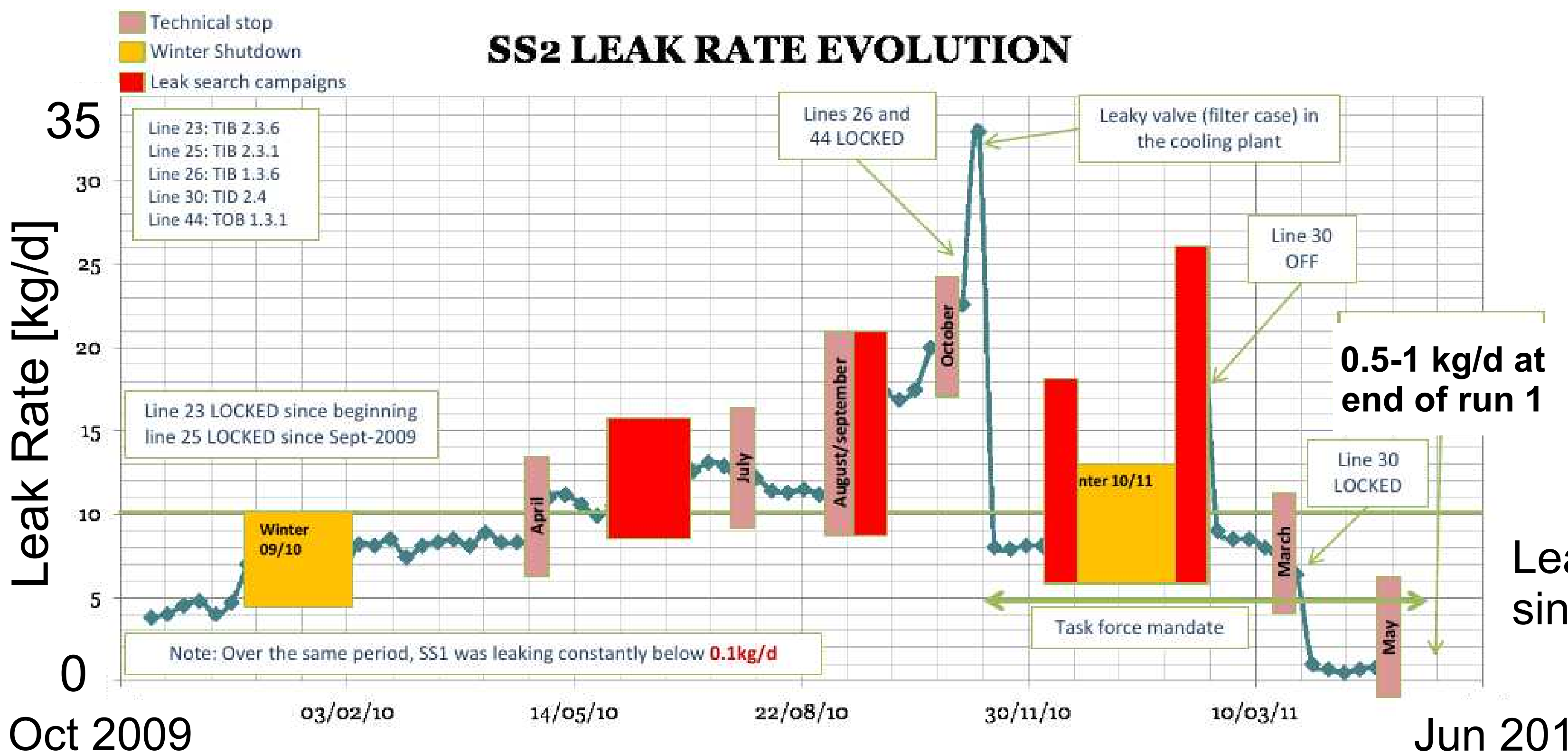
CMS

Backup

The Strip Tracker cooling saga

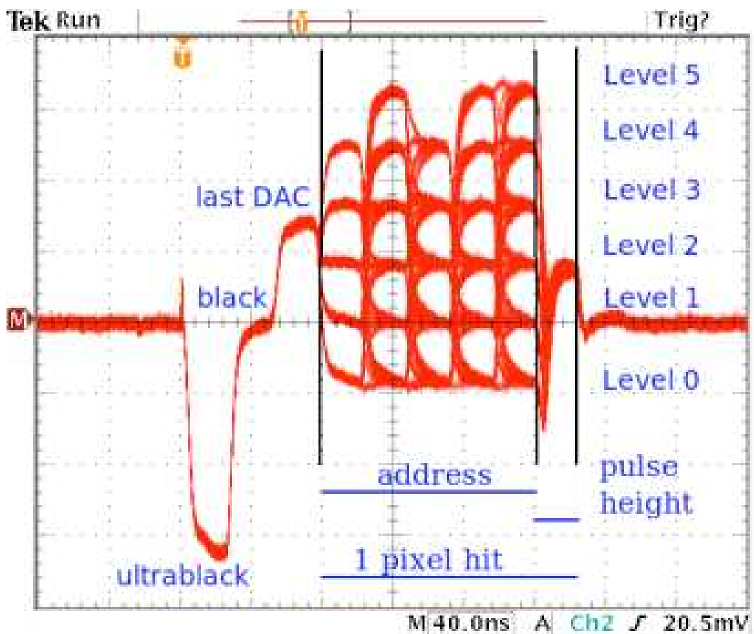
- in 2009 introduced overpressure on second cooling plant in an accident
  - caused an increase in leak rate in some cooling lines

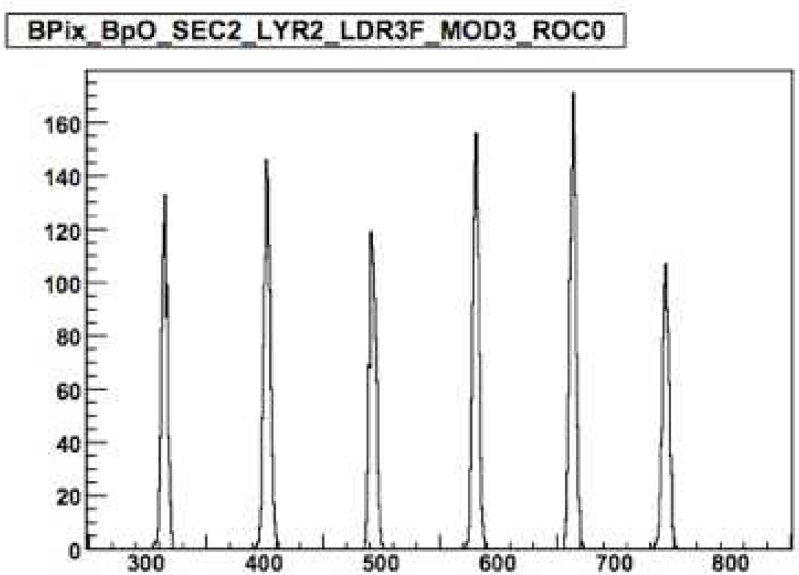


Leak rate stable since then

- pressure to the detector reduced (0.6-0.8 Bar reduction)
  → no change in module T
- CP pressure reduced from 9 to 7 bar and safety pressure switches were installed
- Pump running with Variable Frequency Driver: longer lifetime, no pressure glitches, vibrations (pump were replaced due to overheat)
- Bigger bypass valve installation to allow a smoother operation

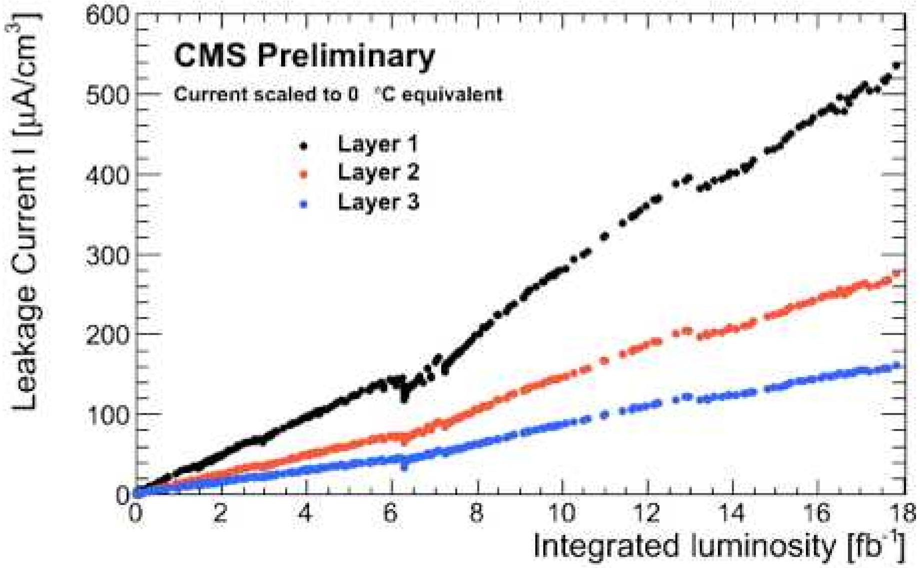
Pixel Analog Data



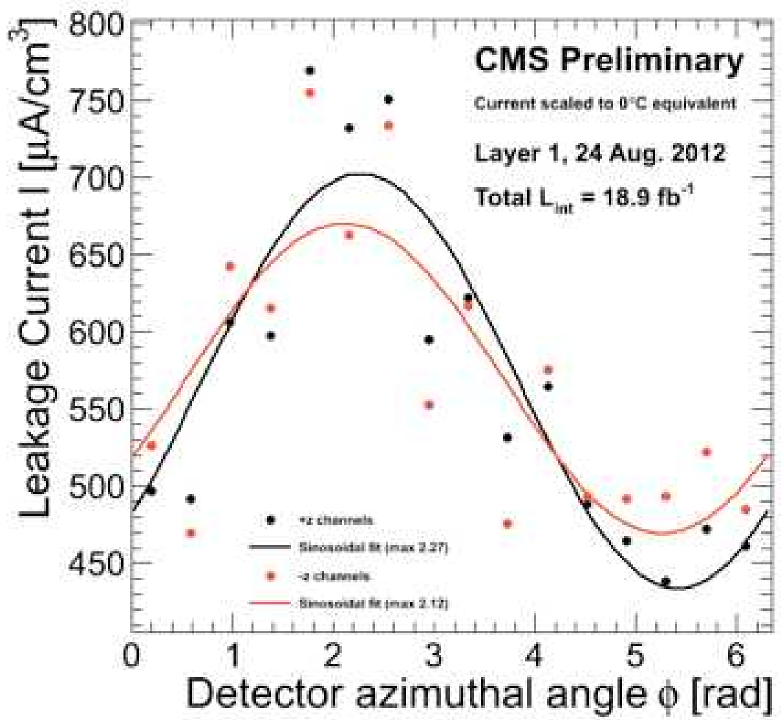


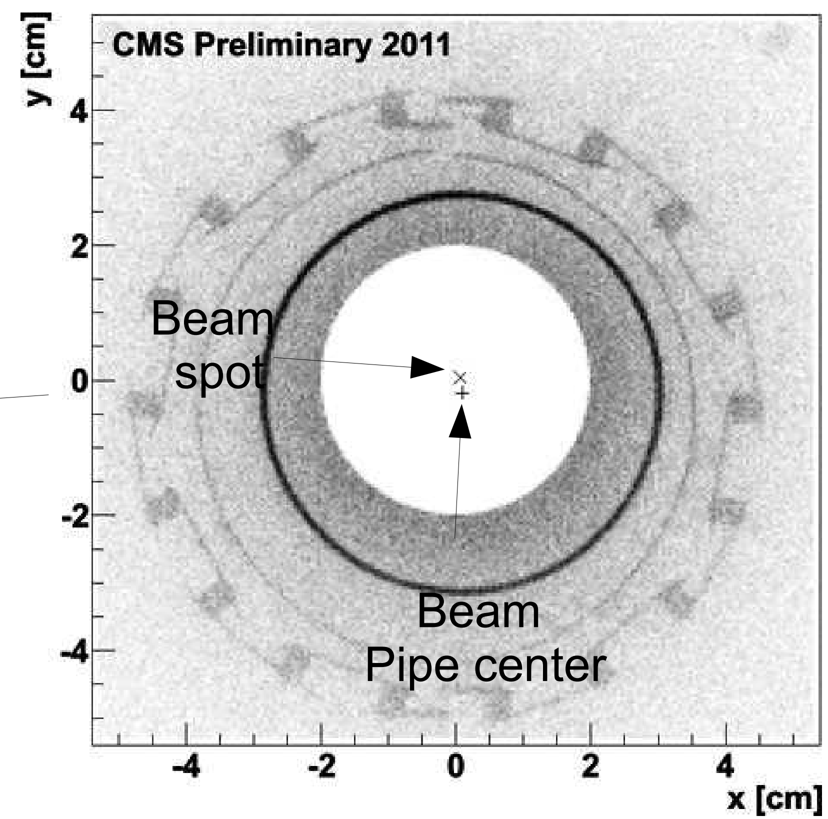
- Pixel Address encoded using different analog levels
- Sufficient separation of address levels imperative for proper decoding by FED
- Recalibrated 1/month

Radiation Monitoring – Pixel



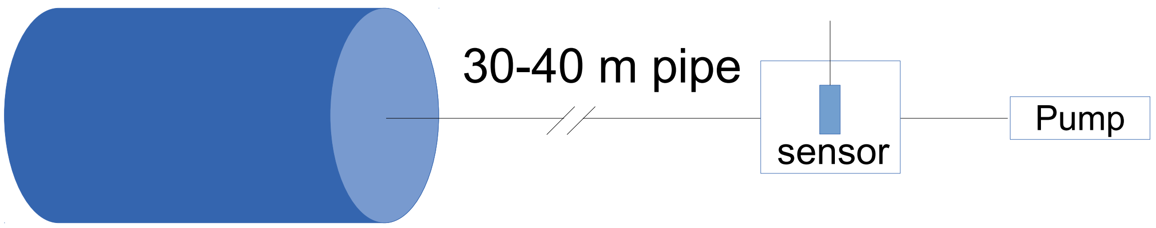
- Asymmetry in measured leakage current observed because of offset of pixel center compared to beam line



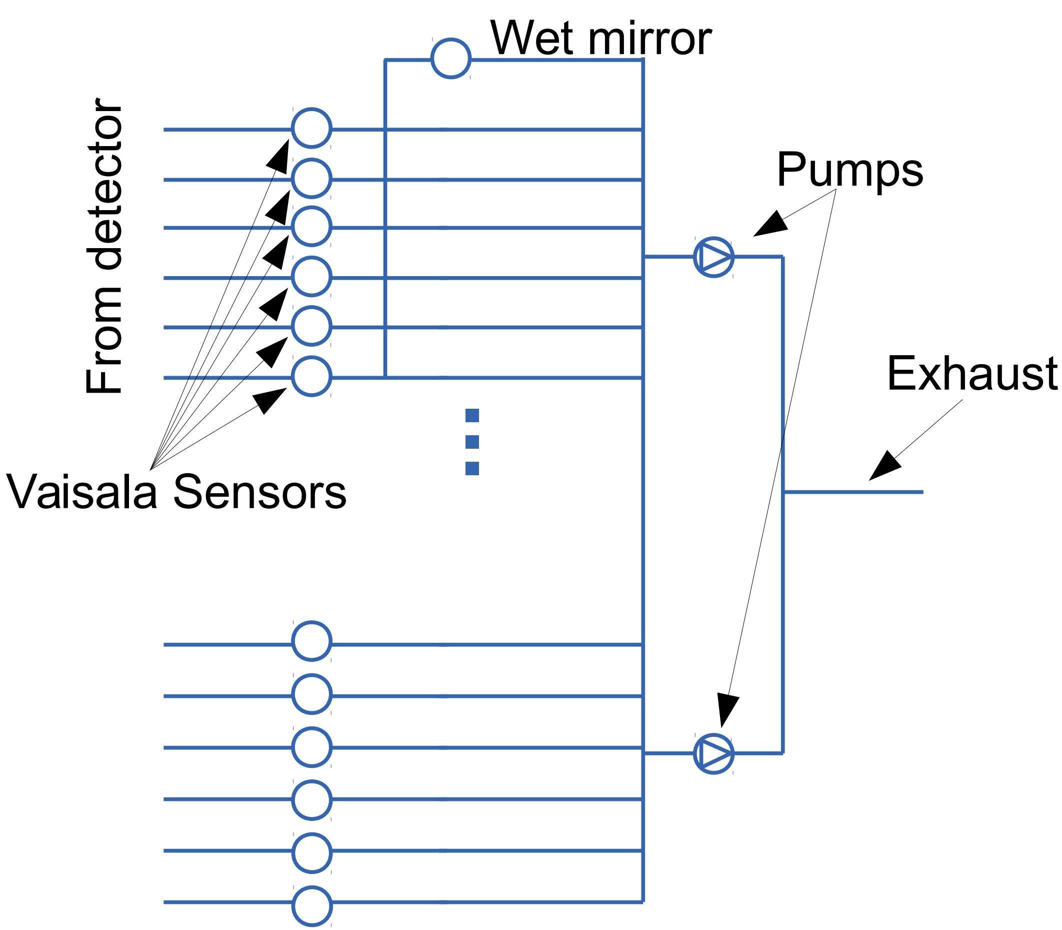


Sniffer System

Simplistic schematic view



Slightly more detailed schematic view

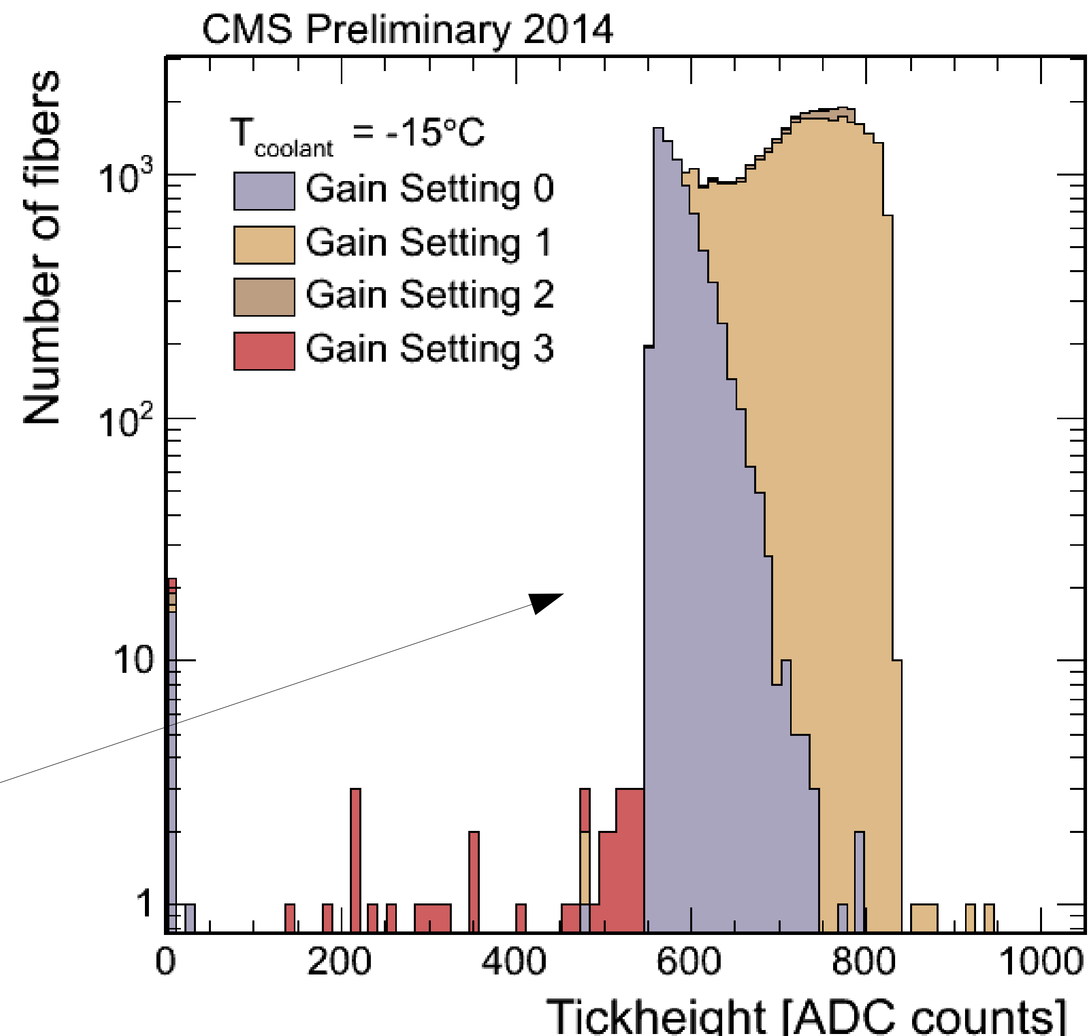


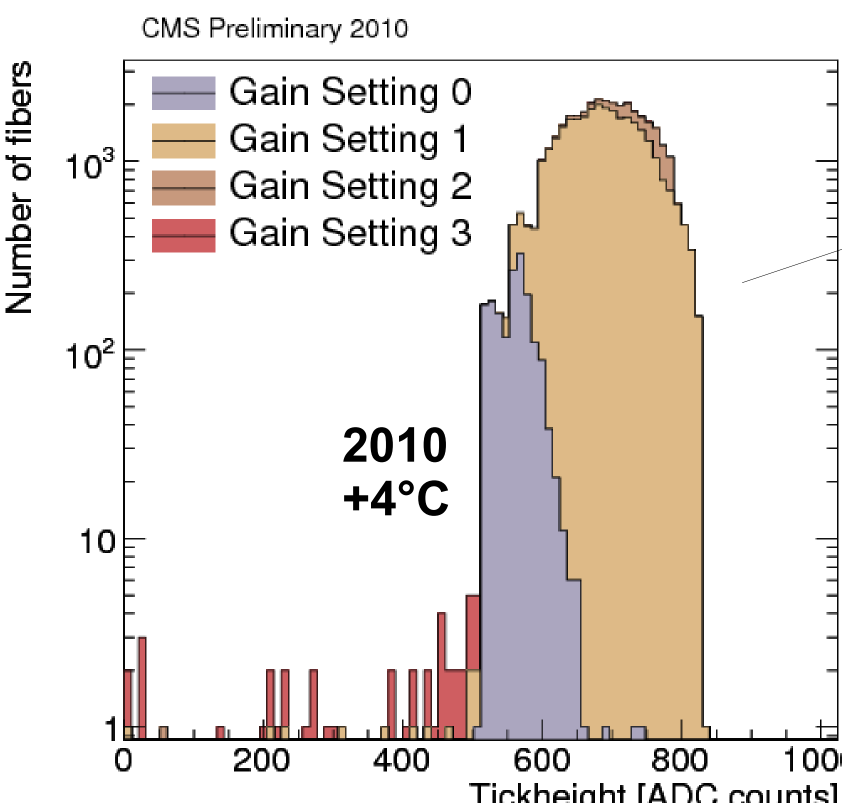
- System breakdown:
  - 3 groups with 6 lines
  - 2 groups with 4 lines
  - one line at a time per group can be connected to wet mirror **per group**
- 2 independent pumps
- Readout via PLC

  → can be used for interlock logic

DAQ and Commissioning – Strips

- Detector calibration at -15°C
  - Optical link gain
  - Checks of timing
  - APV baseline calibration
  - APV pulse shape optimization (next slide)





- Link gain increases with decreasing temperature
  → more links with lower gain settings
- No big effect from radiation (yet)
  → will decrease link gain in the future

DAQ and Commissioning – Strips

- Pulse shape calibration
  - Adjust pulse shape as close as possible to ideal CR-RC shape
  - Strongly affects deconvolution mode pulse → out-of-time pile-up, especially at 25 ns bunch spacing
  - Further mitigation strategies at HLT