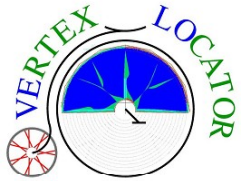


Commissioning the LHCb VErtex LOcator (VELO)

Mark Tobin

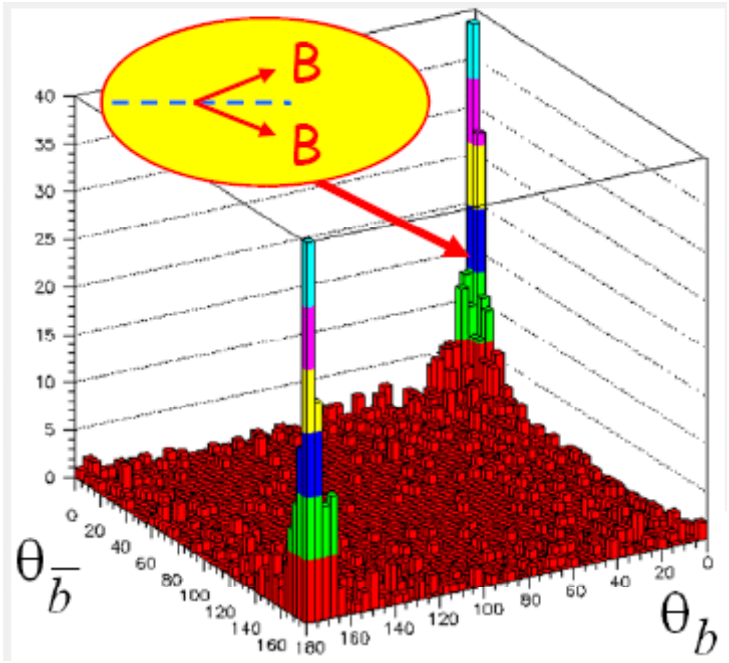
University of Liverpool

On behalf of the LHCb VELO group

Overview

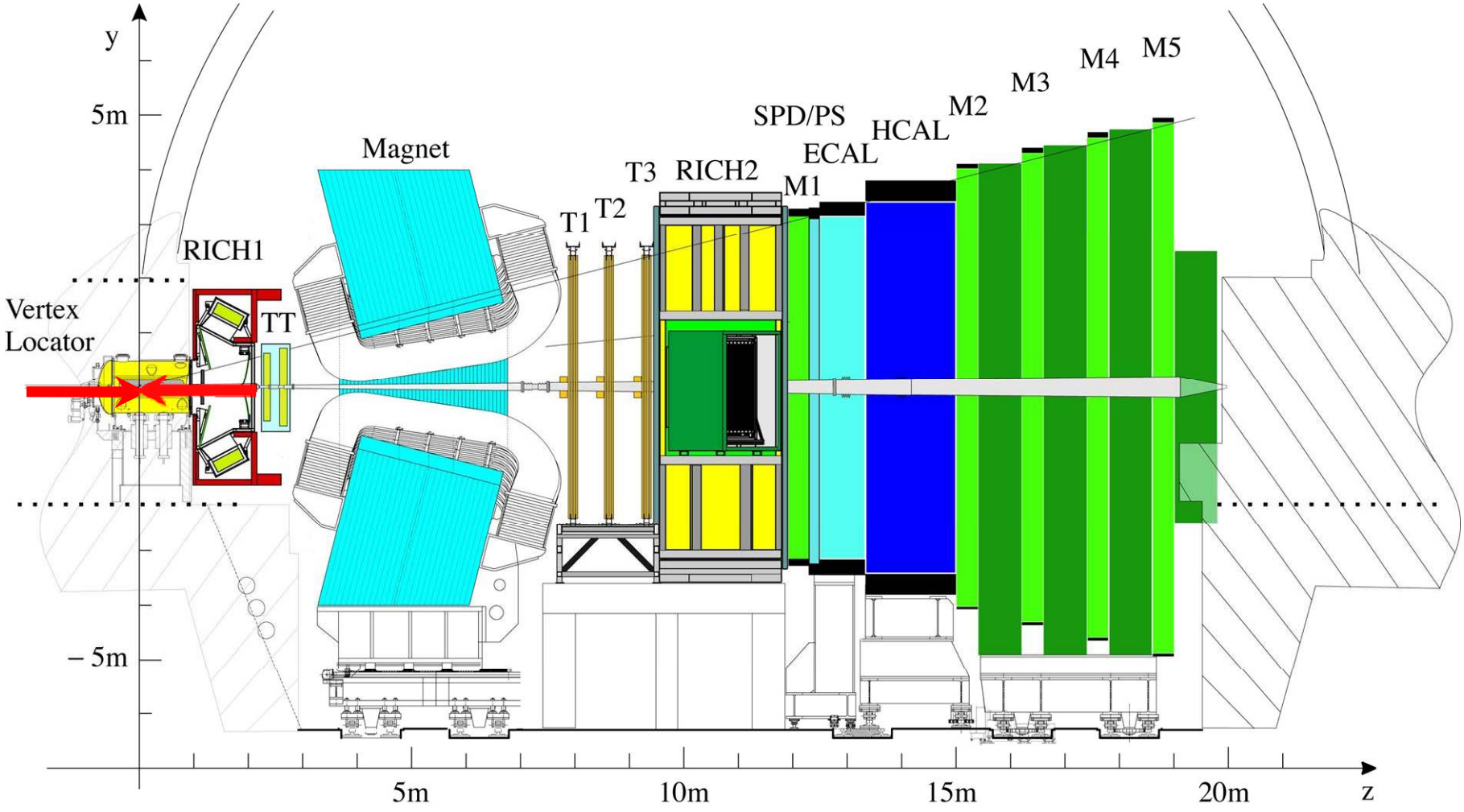
- Introduction
- LHCb experiment.
- The Vertex Locator (VELO).
- Description of System.
- Commissioning the subsystems.
- Commissioning the full system
- Status.

Motivation for LHCb

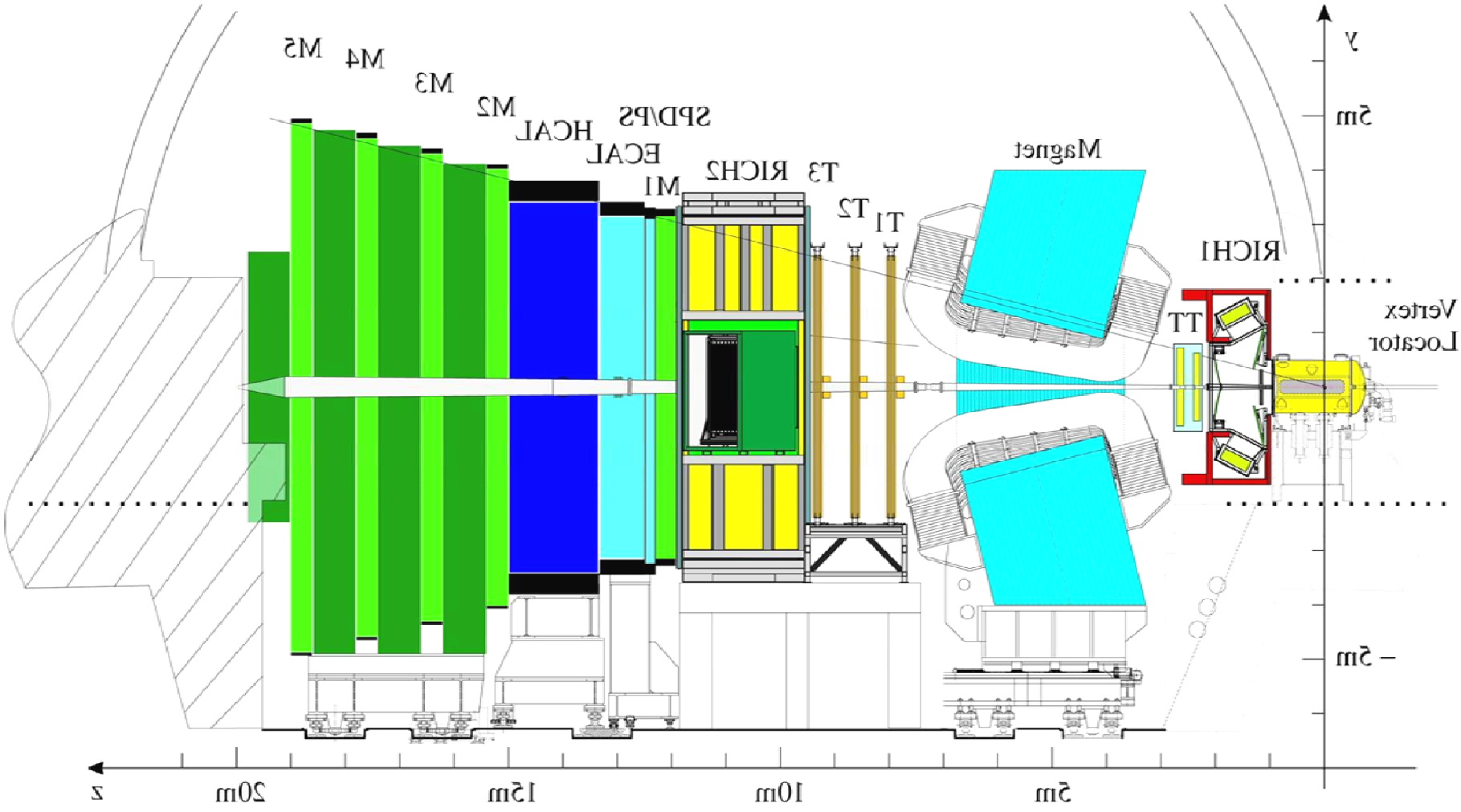


- LHCb designed to study:
  - Heavy flavour physics
  - CP-violation in b sector
  - Constrain unitarity triangles
  - Rare B decays
  - Search for New Physics
- B meson production:
  - bb-pairs correlated in space.

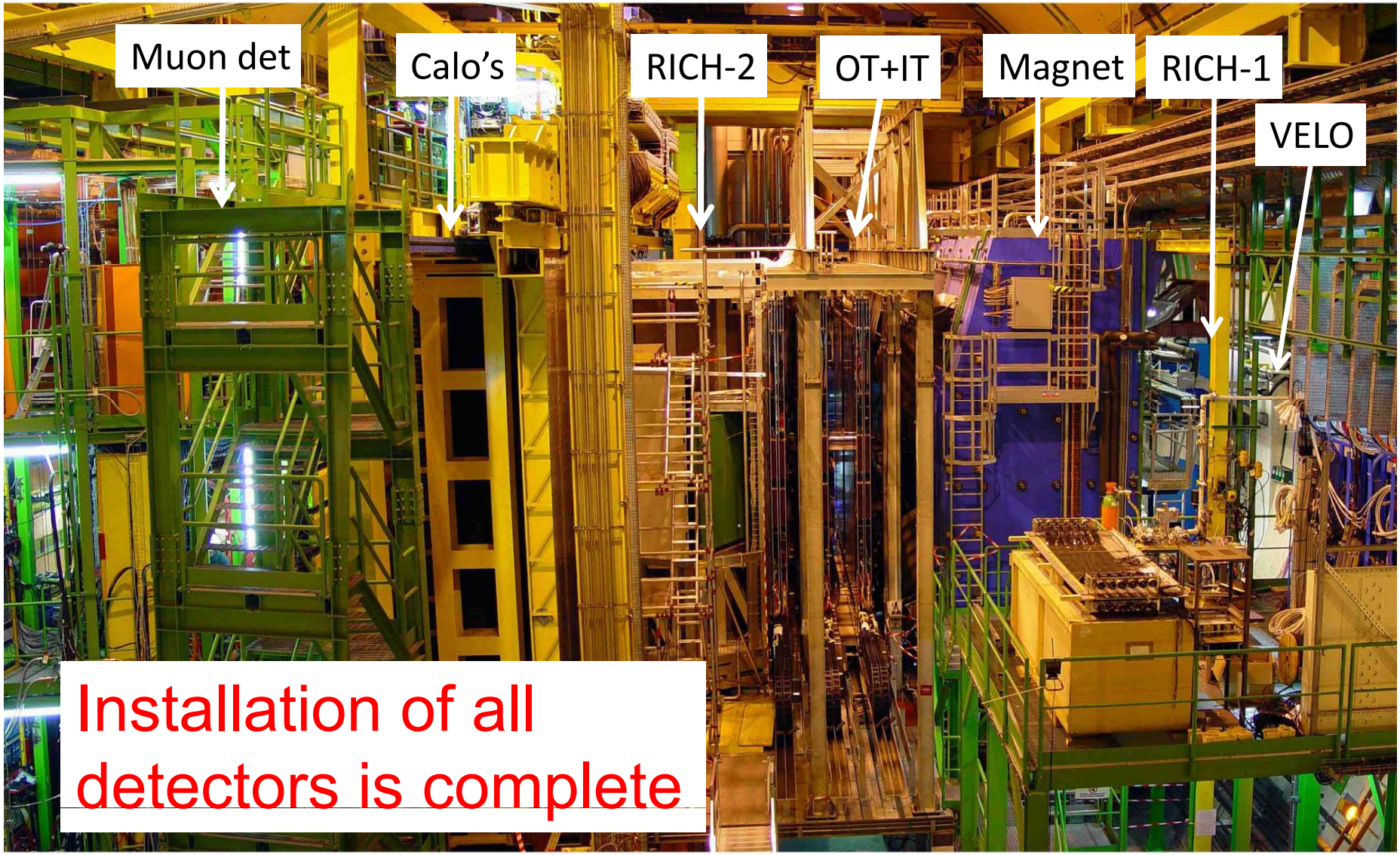
LHCb detector design



LHCb detector rotated



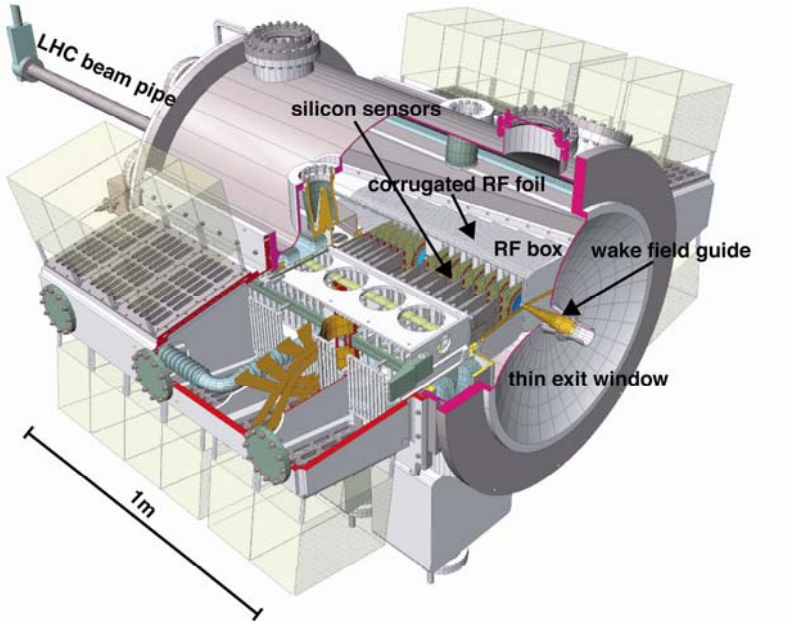
LHCb detector (Reality)



Vertex detector requirements

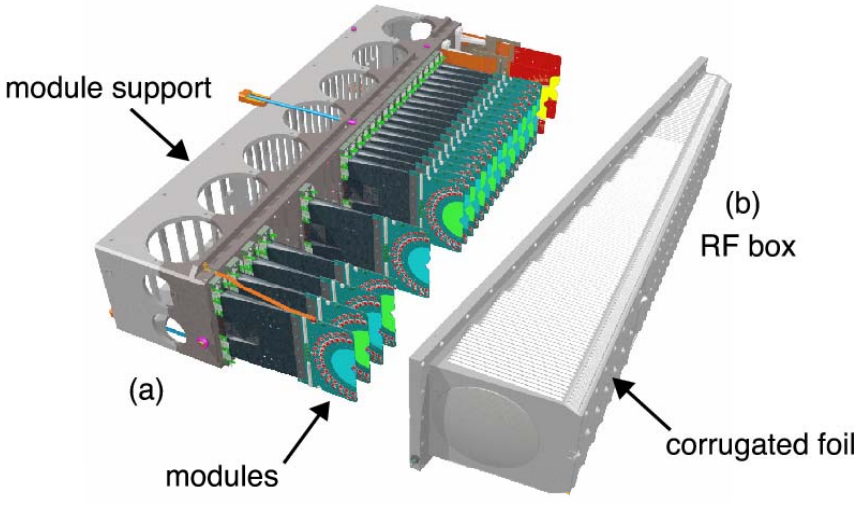
- **Event reconstruction:**
  - Precise tracking
  - Low mass
- **Vertexing:**
  - Need to separate primary/secondary interactions
  - Close to beam in extreme radiation environment.
- **Trigger:**
  - Fast reconstruction of primary vertices.
  - R-Φ sensor geometry.
- **LHC beam tolerance:**
  - Detector must be 30mm from beam at injection

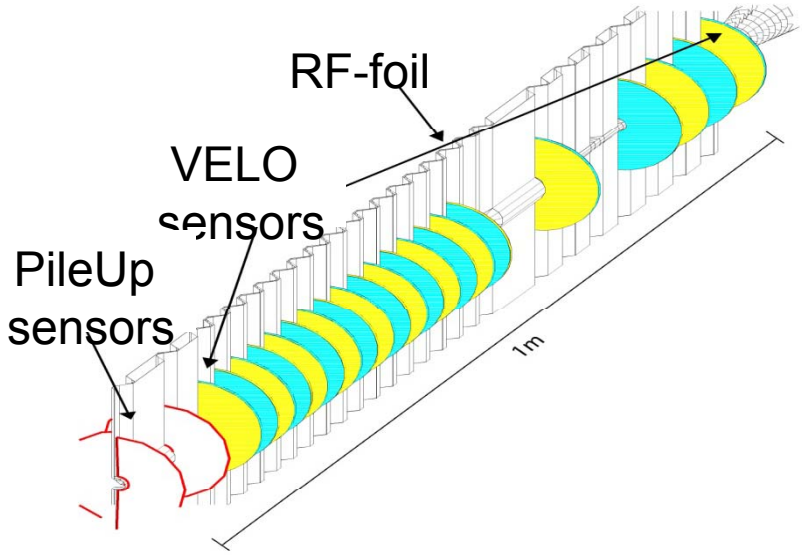
VErtex LOcator



- 2 retractable halves
  - 5mm from beam when closed
  - 30mm from beam during injection
- 21 R-Φ modules/half
- Operates in secondary vacuum (<10^{-4} mbar)
- 300μm foil separates detector from beam vacuum (<10^{-8} mbar)
- 2 phase CO_2 cooling system

Vacuum system

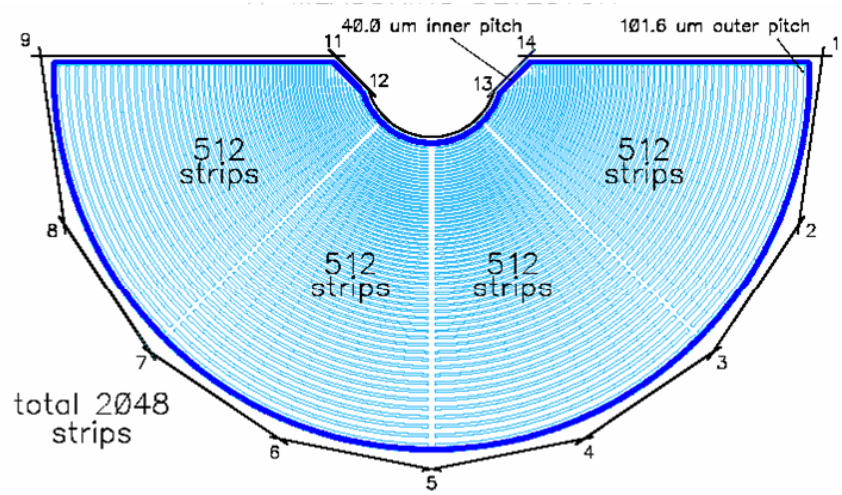


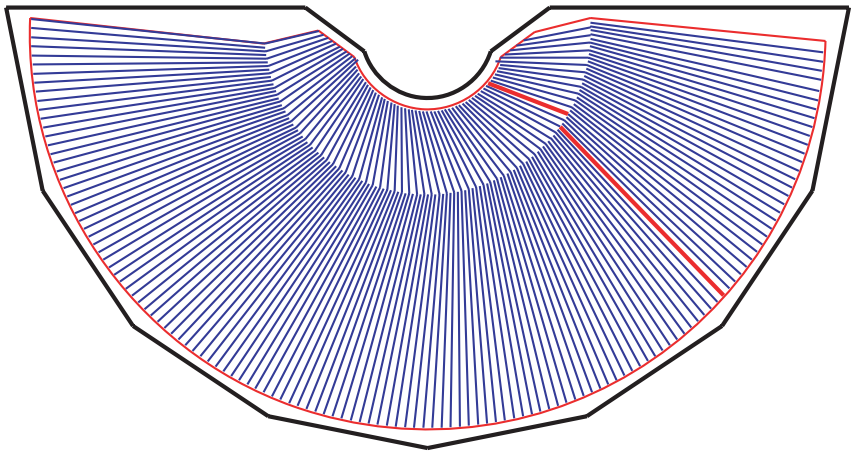


- Detector separated from beam vacuum by 300µm Aluminium foil
- Maximum allowed differential pressure is 5mbar
- Shape allows overlapping sensors

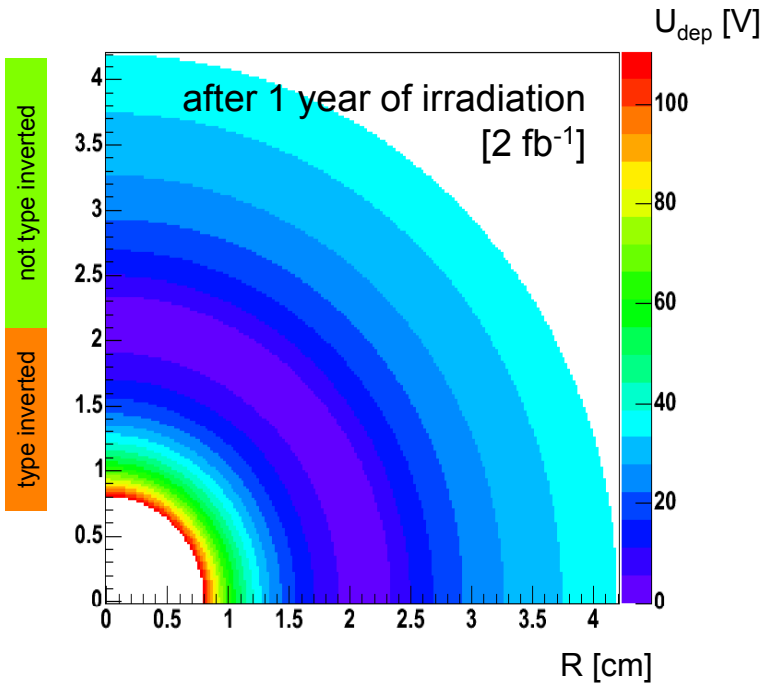
Sensor Design

- n strip sensor technology (Micron)
- Double metal layer for signal routing.
- R sensors:
  - 45 degree quadrants
  - Pitch=40-101µm
- Φ sensors:
  - 2 regions
  - Short/long strips
  - Pitch=38-100µm
  - Stereo angle.



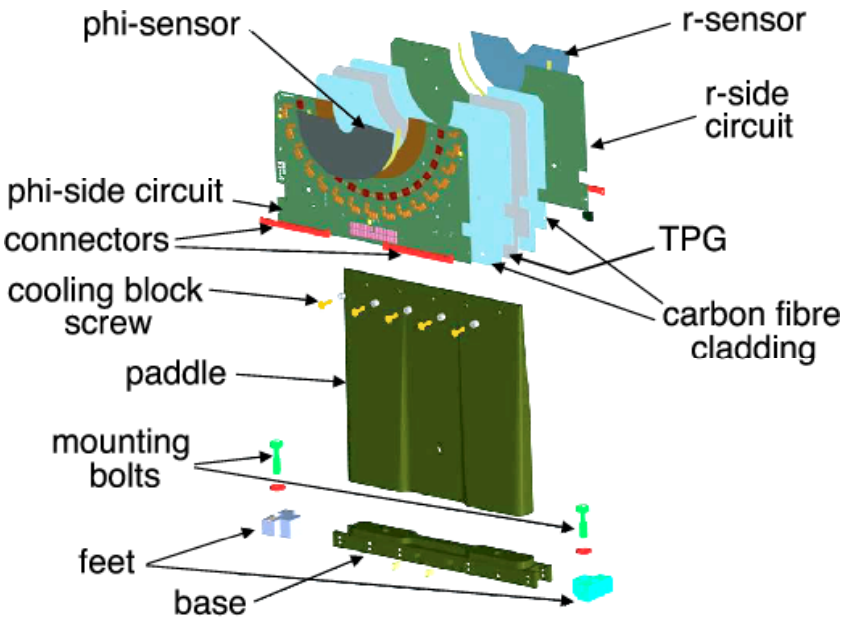


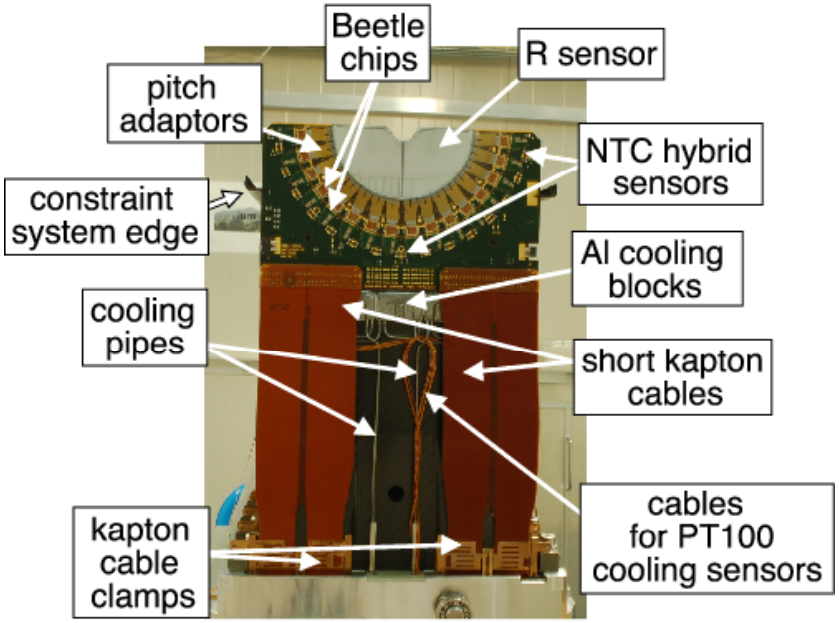
Radiation tolerance



- n^+ in n-bulk sensors
- Strip isolation via p^+ spray
- 300µm thick
- Harsh non-uniform radiation environment
  - $1.3 \times 10^{14} n_{eq}/cm^2$/year at 8mm
  - $5 \times 10^{12} n_{eq}/cm^2$/year at 42mm
- Run partially depleted after 3-4 year ($8 fb^{-1}$)
  - Reduced CCE

Module design

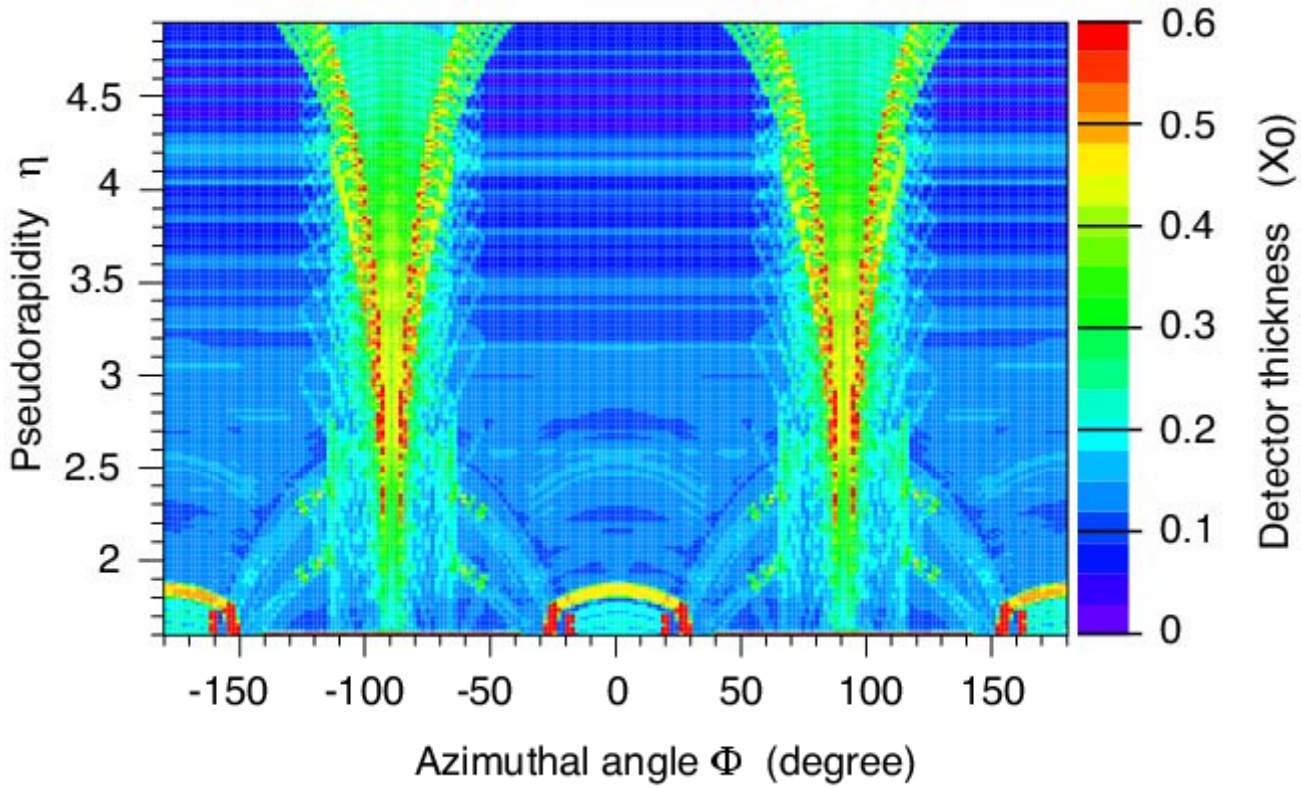




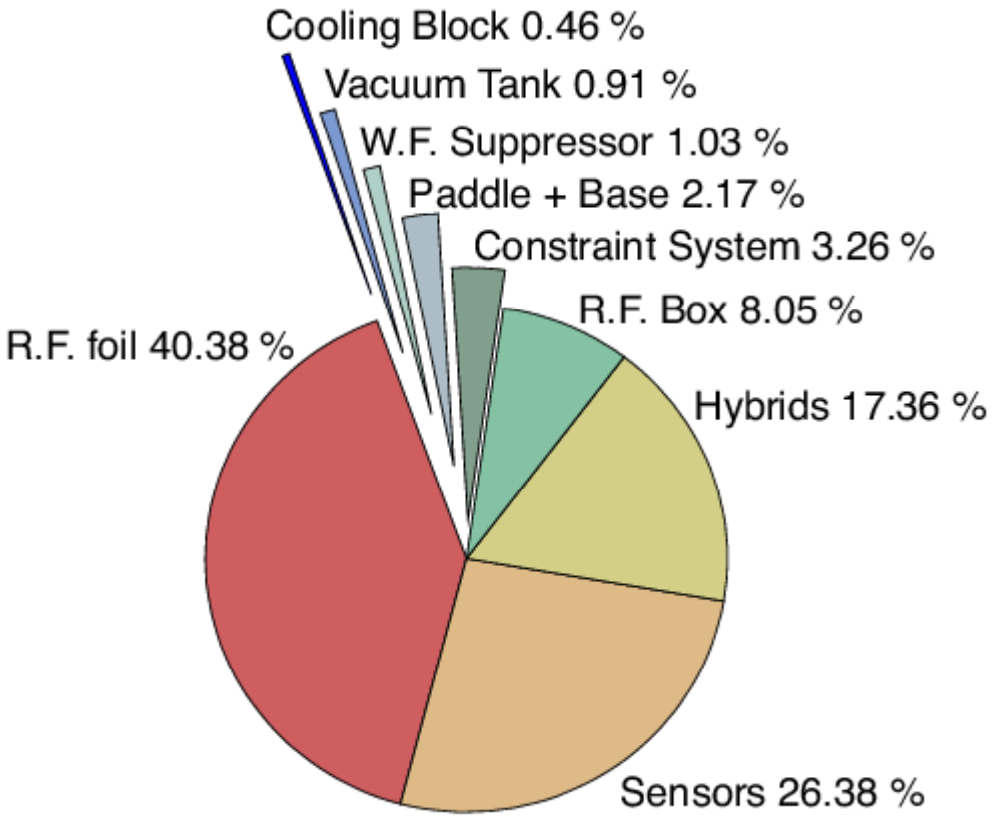
- Double sided hybrid to balance stresses due to "bi-metallic effects".
- Thermal pyrolytic graphite core removes 24W of heat (ΔT=20C).
- Carbon fibre cover for rigidity.
- 2 phase CO_2 cooling system
  - Sensors operate at -5C

- Non-planarities ~250µm
- Sensor-sensor < 10µm
- Readout with 16 Beetle chips:
  - 2048 channels/sensor.
  - 172032 channels in VELO.

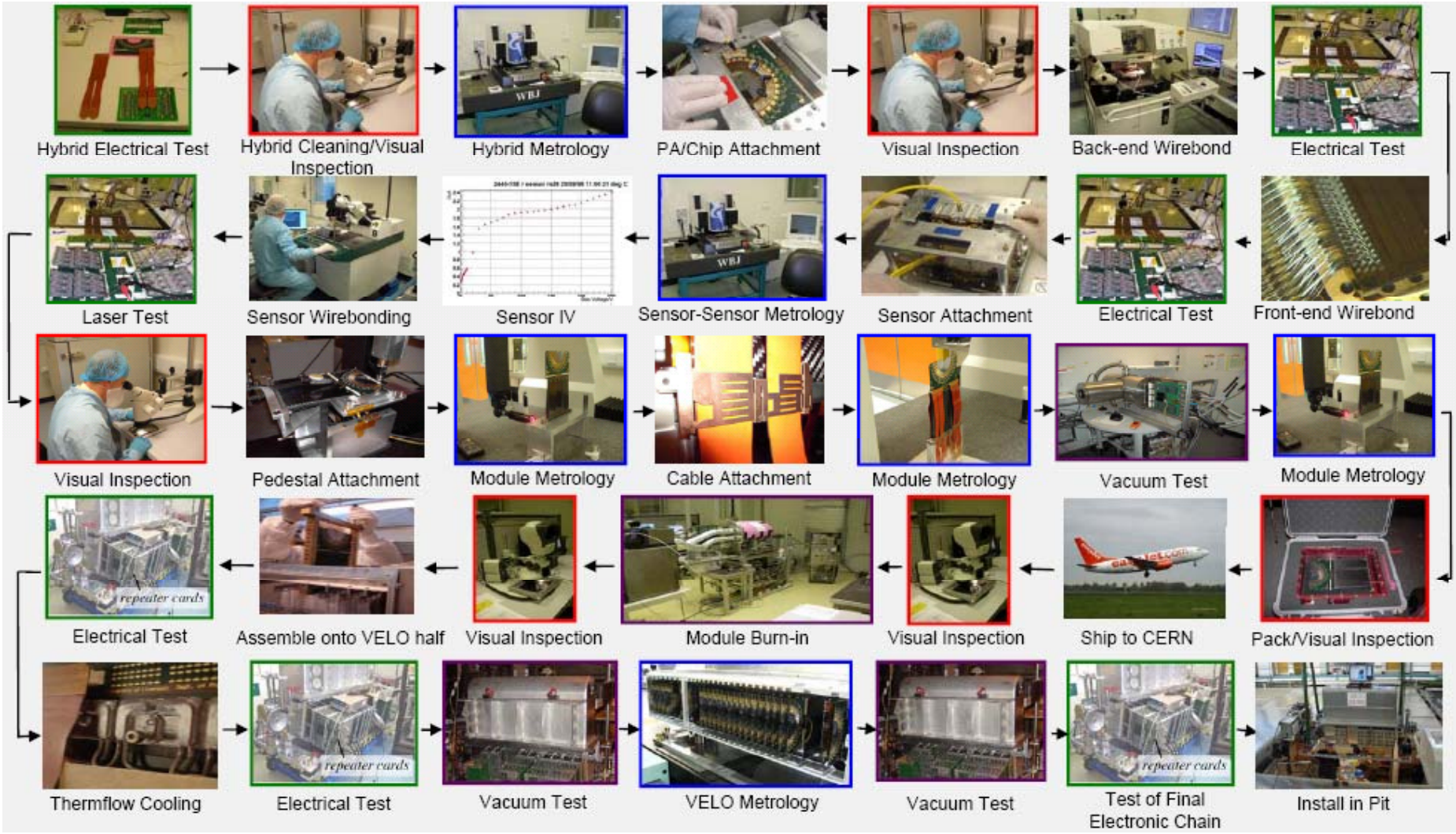
Material budget



Material budget/component

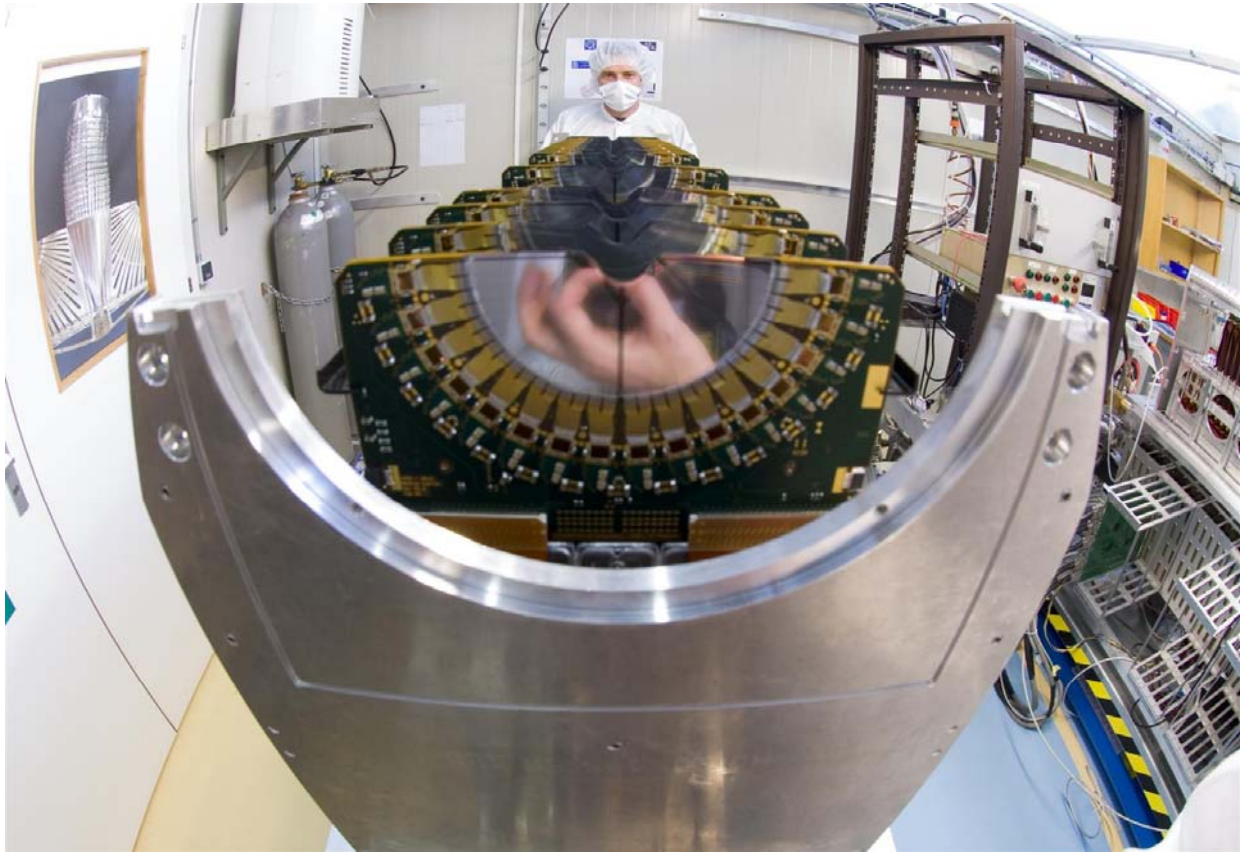


Module production (to be repeated)

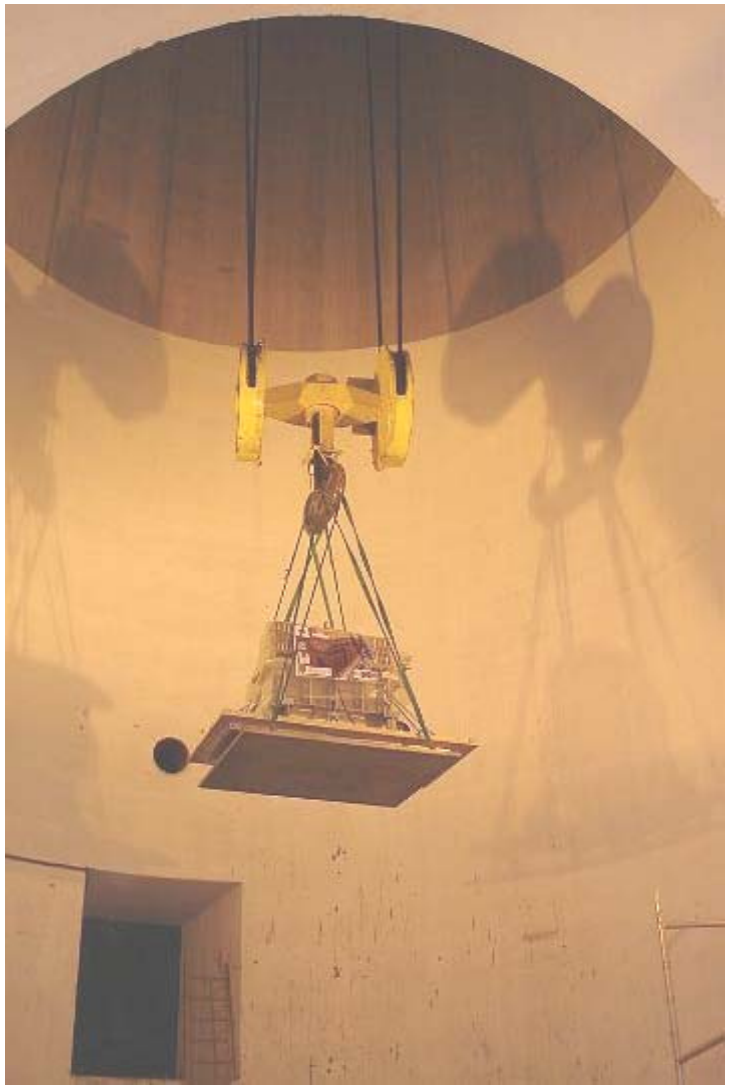


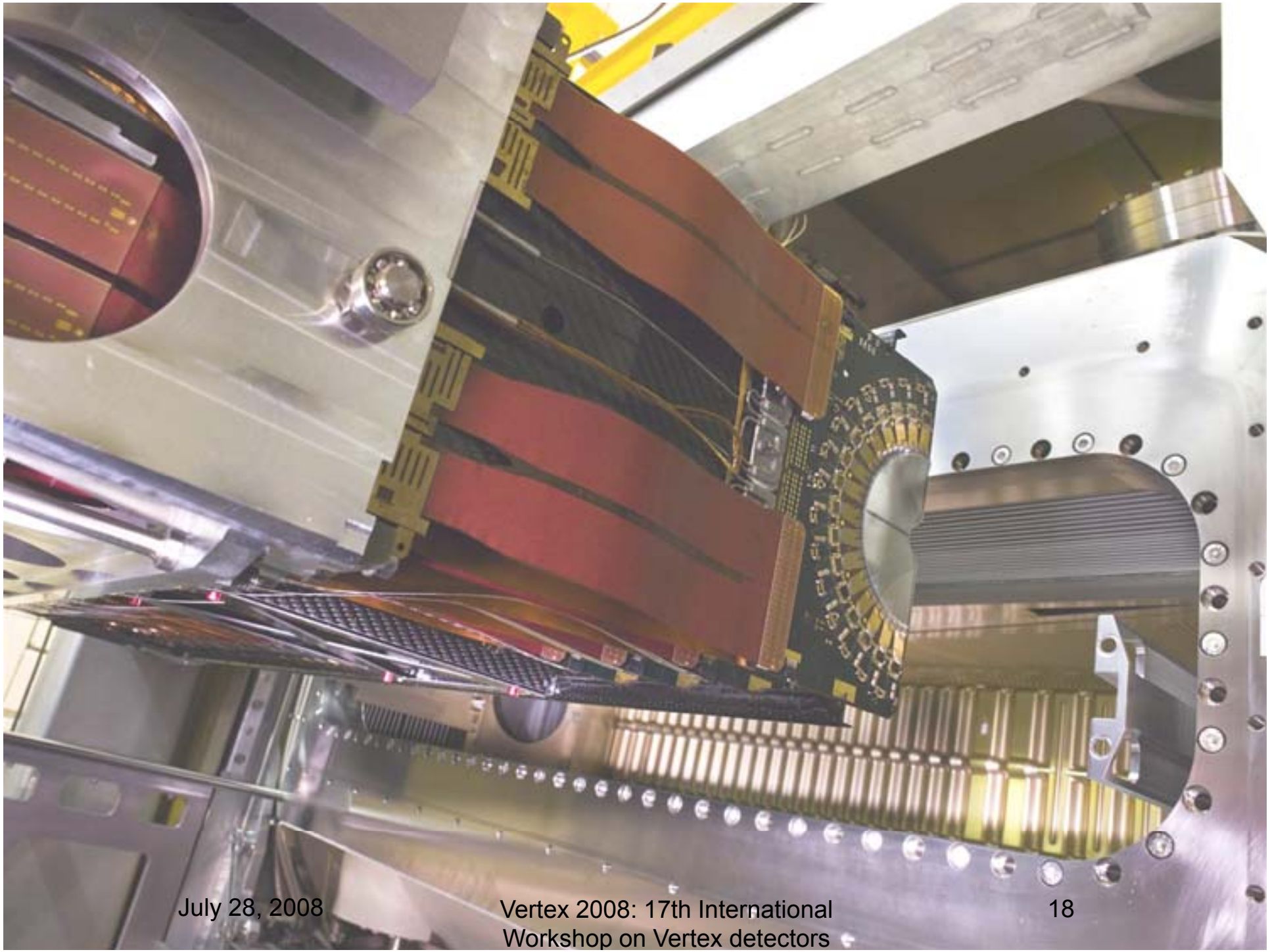
6 Visual Inspections, 6 Metrologies, 7 Electrical Tests, 4 Vacuum Tests

VELO Assembly @ CERN

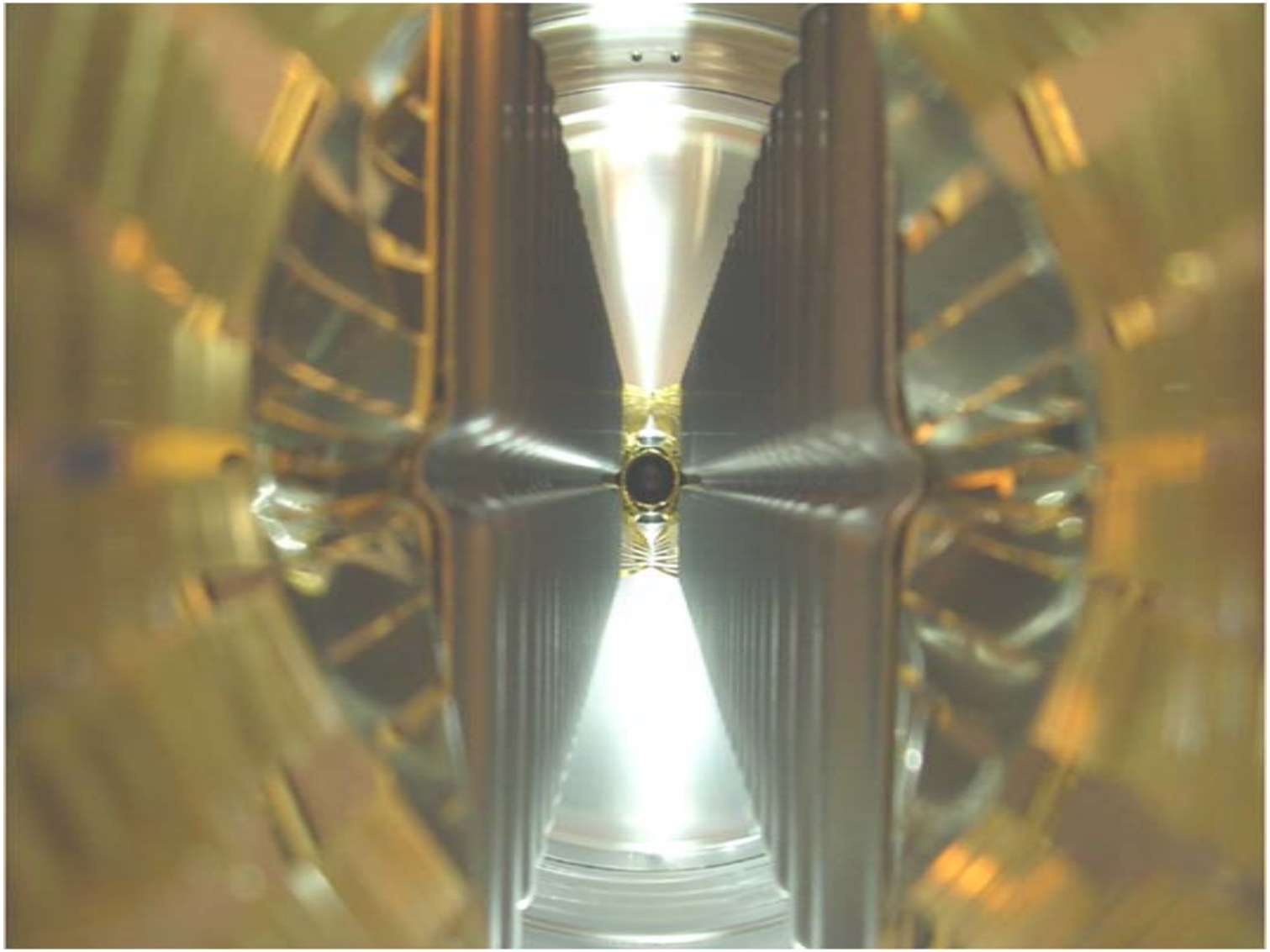


Installation

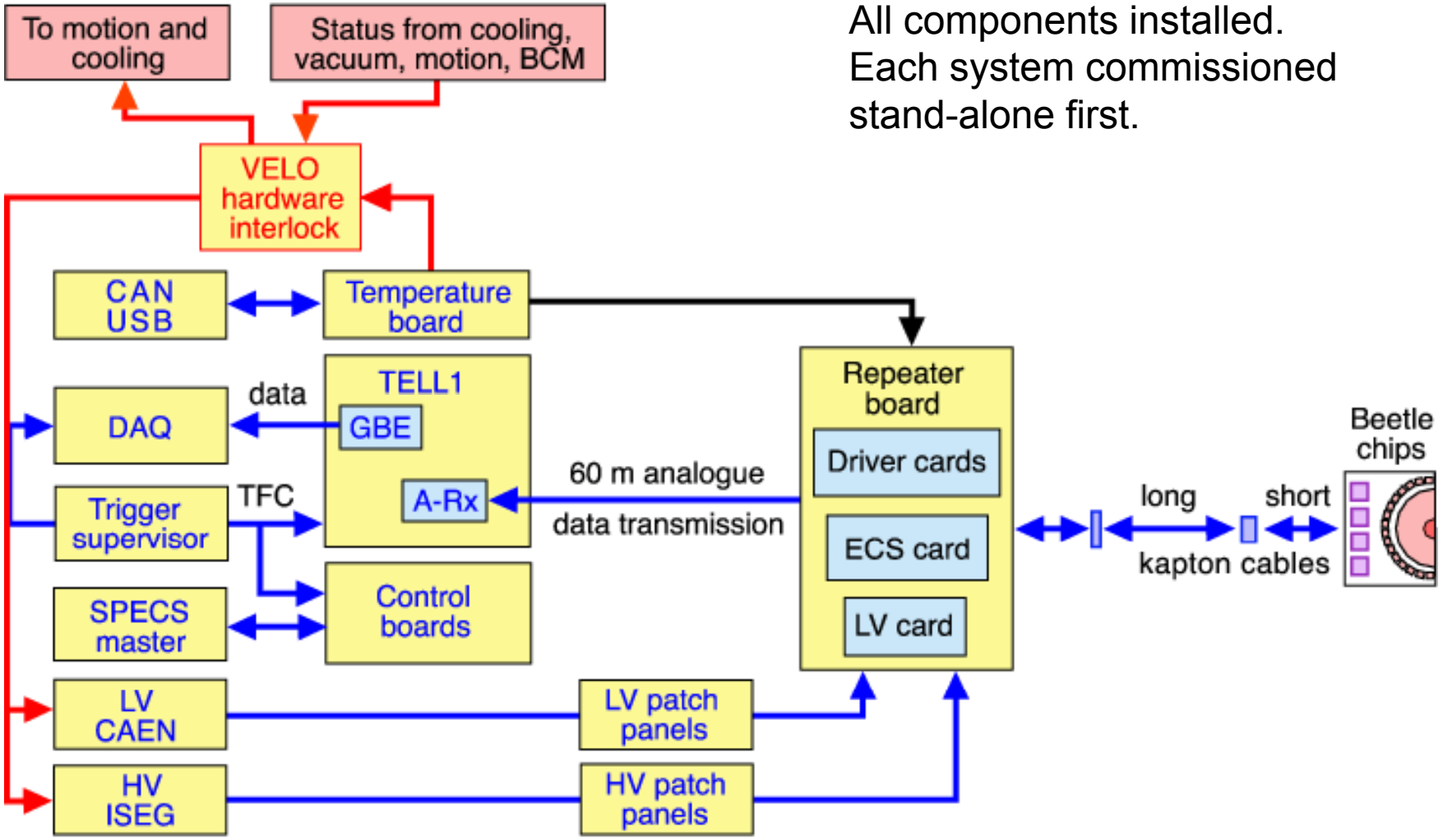




What the LHC sees during injection…

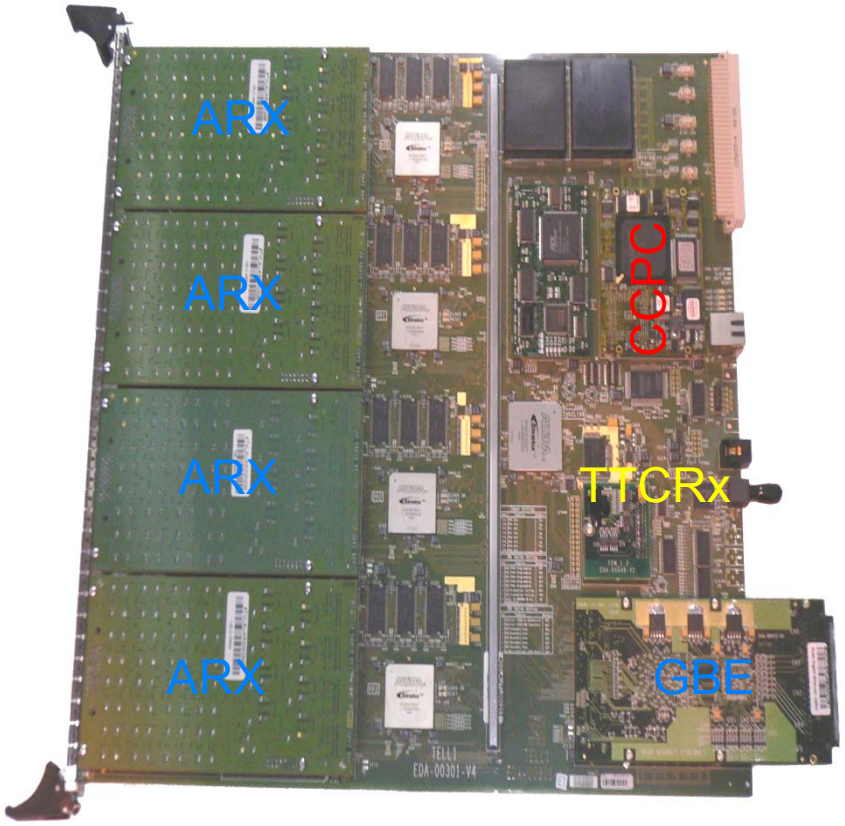


Overview of VELO electronics



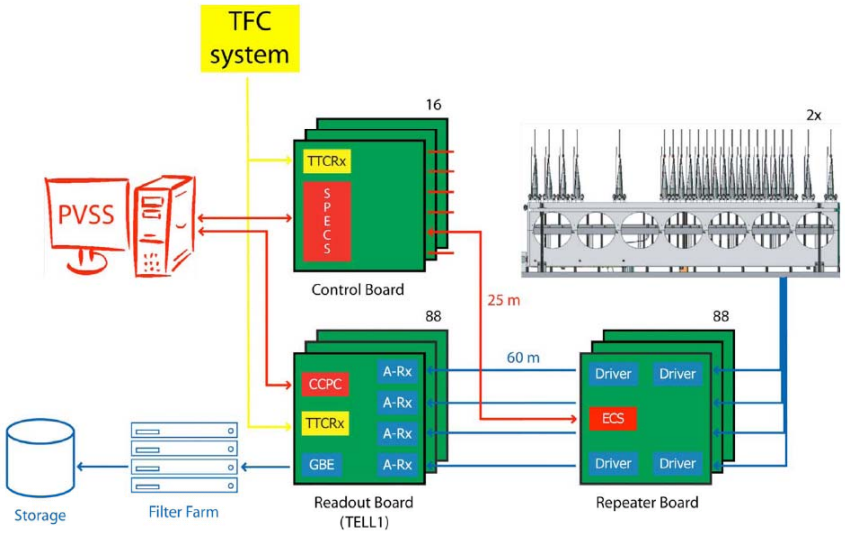
All components installed.
Each system commissioned stand-alone first.

Readout Board (Tell1)

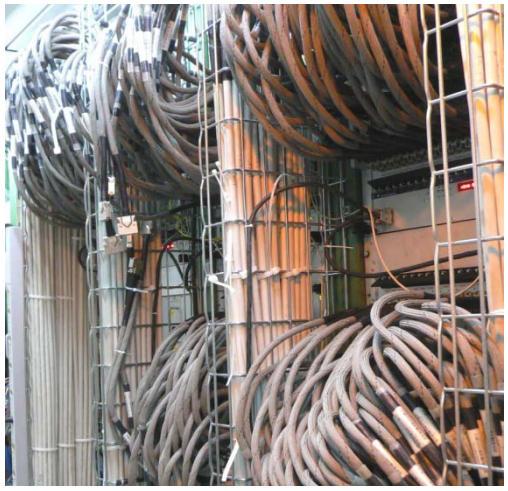


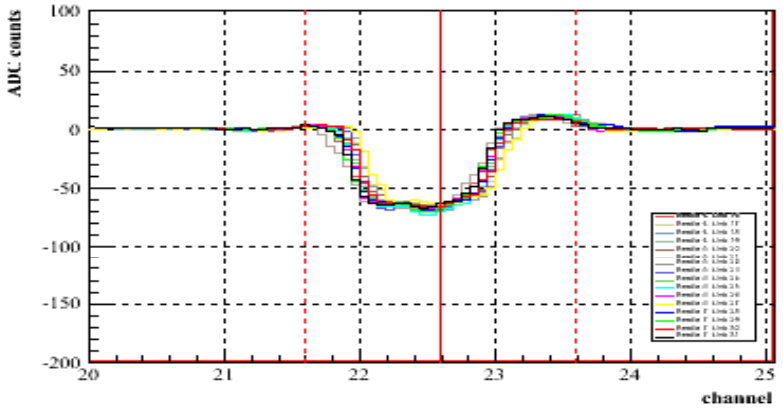
- Analog input from 64 links
- 10 bit ADC @ 40MHz [A-Rx]
- FPGA for pre-processing
  - Cross-talk, common mode suppression, clustering
  - Zero suppression of data
- Data sent out by Gigabit ethernet
- Max output rate is 1.1MHz
- Control via credit card PC

Control system and DAQ



- All cables and boards installed
- Extensive testing programme:
  - ADC cards [A-Rx]
  - Readout boards [Tell1]
  - Control boards
  - Readout slices
    - Timing
    - Cable checks
    - Noise levels

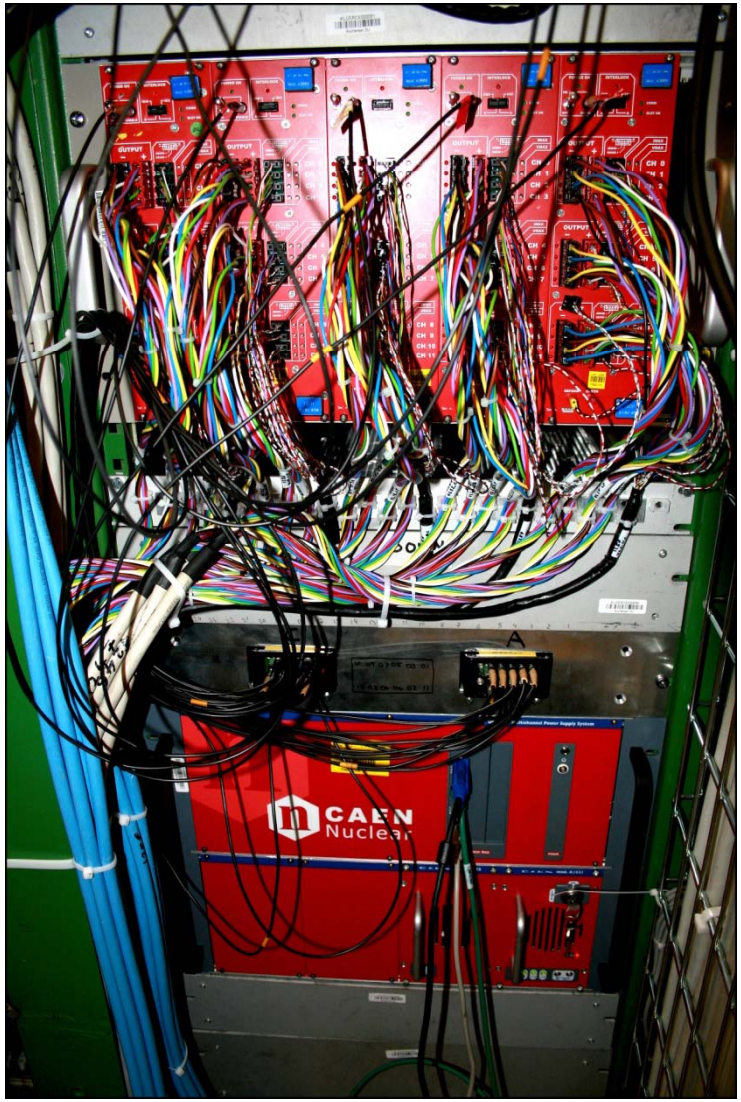




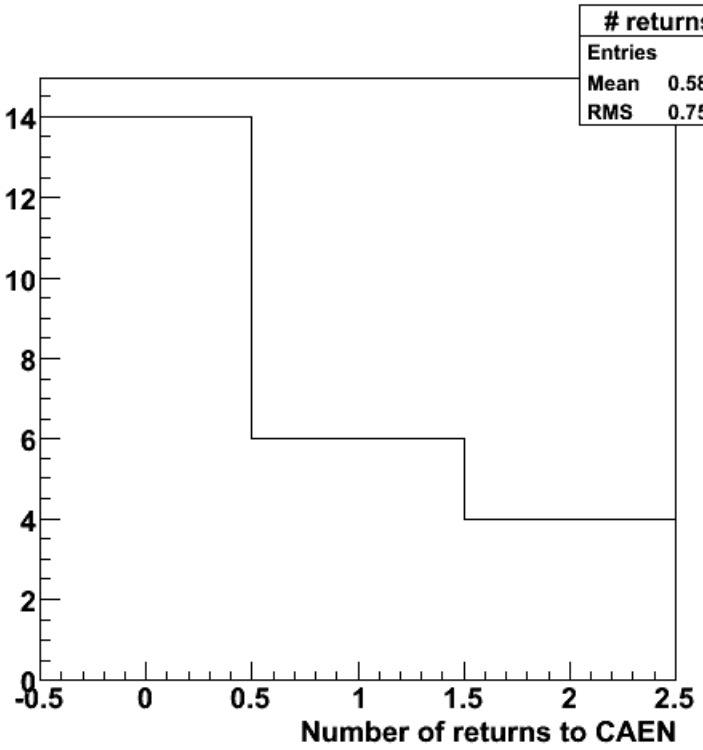
adjustment of timing to 0.65 ns

Low voltage system

- Standard Easy3000 CAEN system
- 1 mainframe controller
- 3 48V power convertors
- 22 8V/9A 12 channel power supply boards.
- 2 modules per power supply board.

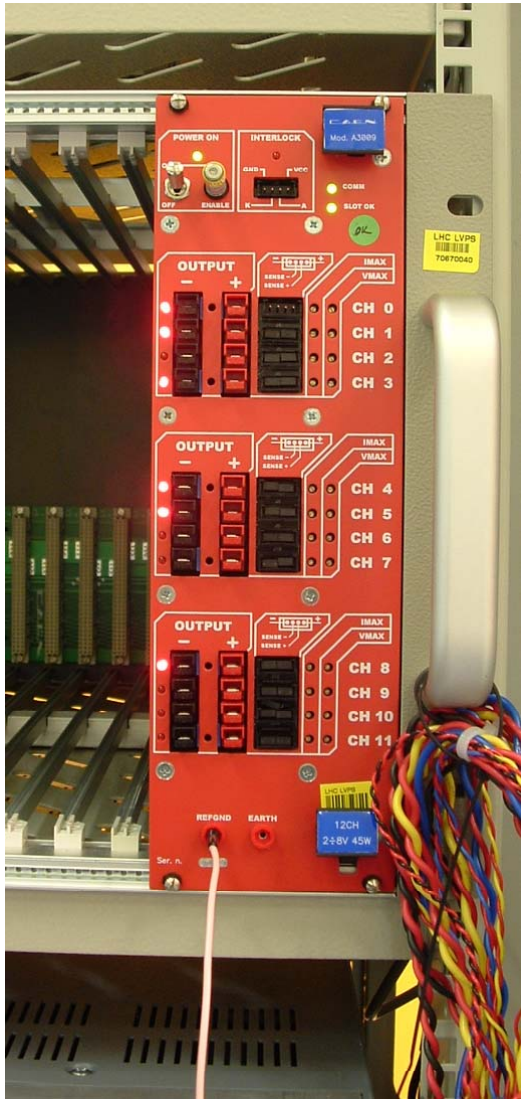


Problems with LV system



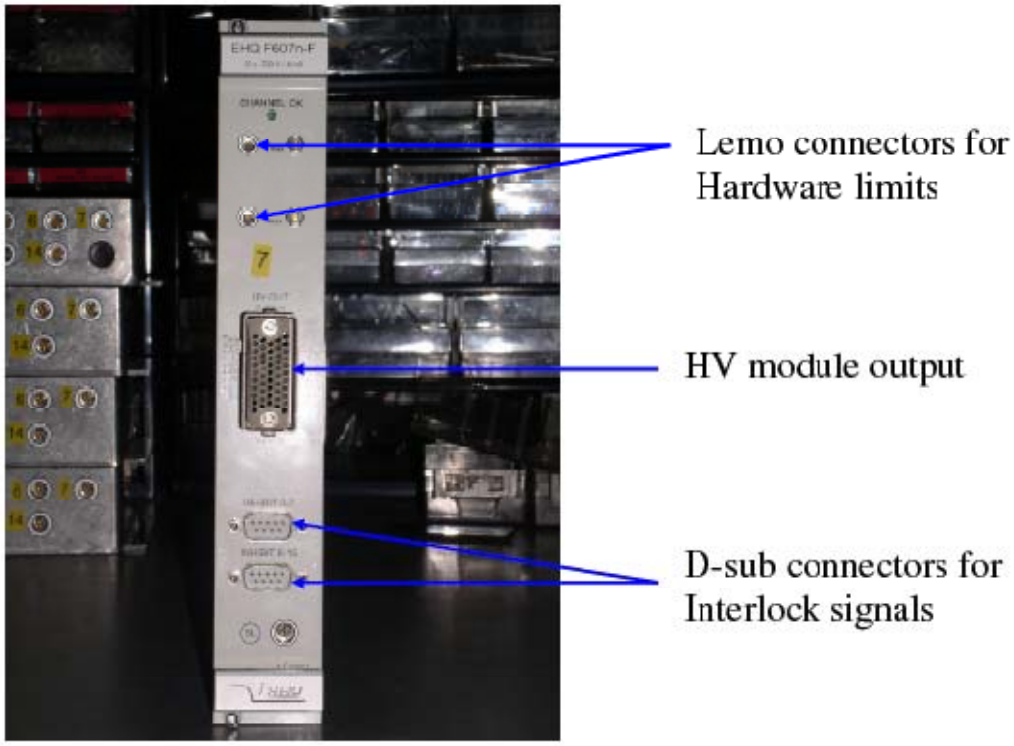
- Reliability of A3009 8V/9A supplies
  - Many were sent back to CAEN
  - Mean = 0.58
- Bad connections to front of supply.
  - Solder leakage on manufacture of connectors.

Safety problem with A3009 modules



- Tried many safety test.
- One problem found.
- Communication cable was pulled.
- Channels stayed on.
- Jumpers from interlock were pulled.
- Channels stayed on.
- Simultaneous loss of cooling
- Rapid heating of hybrid.
- Firmware fix from CAEN
- Currently not used.

High Voltage System



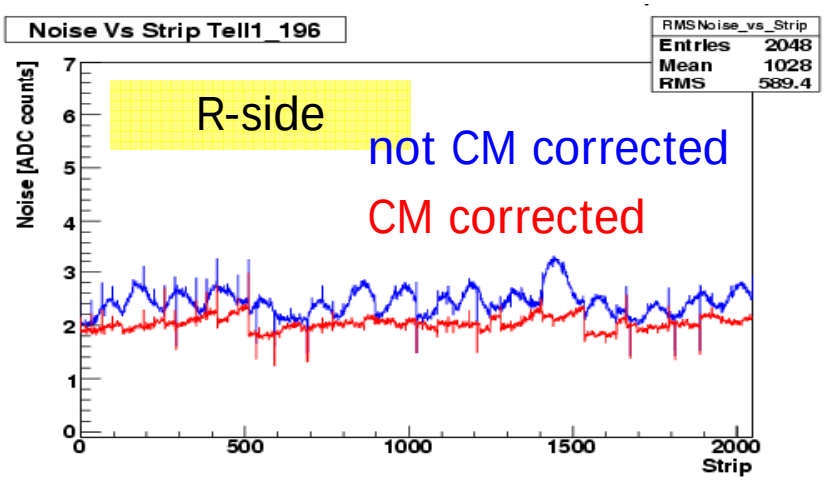
- ISEG EHQ 607n-F

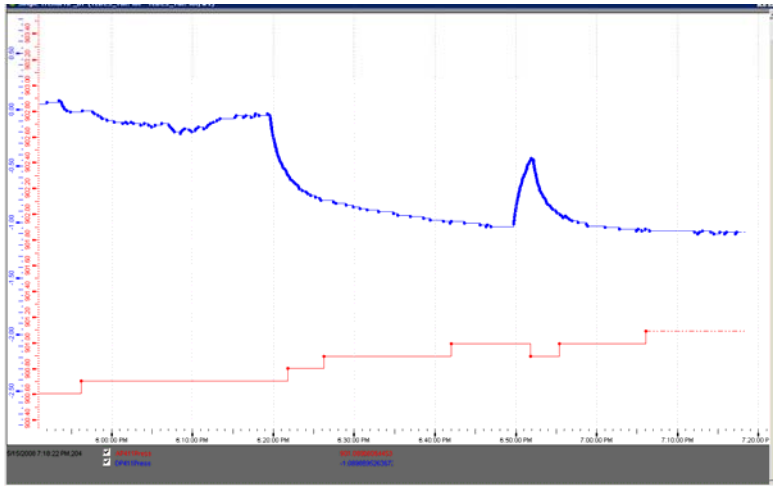
- 5 Iterations of OPC Server from ISEG
- An example problem:
  - Ramp channel one
  - Turn on channel two
  - Channel one jumps to target voltage
- Remaining problem
  - OPC server crashes ~ once per week

- Company engineers extremely helpful but a long (and not yet finished) process

Commissioning the VELO (I)

- Single module operation under Neon atmosphere – 18th March 2008.
  - Final cooling, vacuum, LV, HV, interlocks, DAQ and control software
  - Looked at IV scans
  - Data taken in various configurations
- Noise level compared with previous data taken in assembly
- Single module test repeated for all modules on 1st side – 5th May onwards
- Warm cooling (8C)
- Modules operated at 25C
- Differential pressure between 2 and -5mbar
- Operation of 15 modules on 15th May 2008



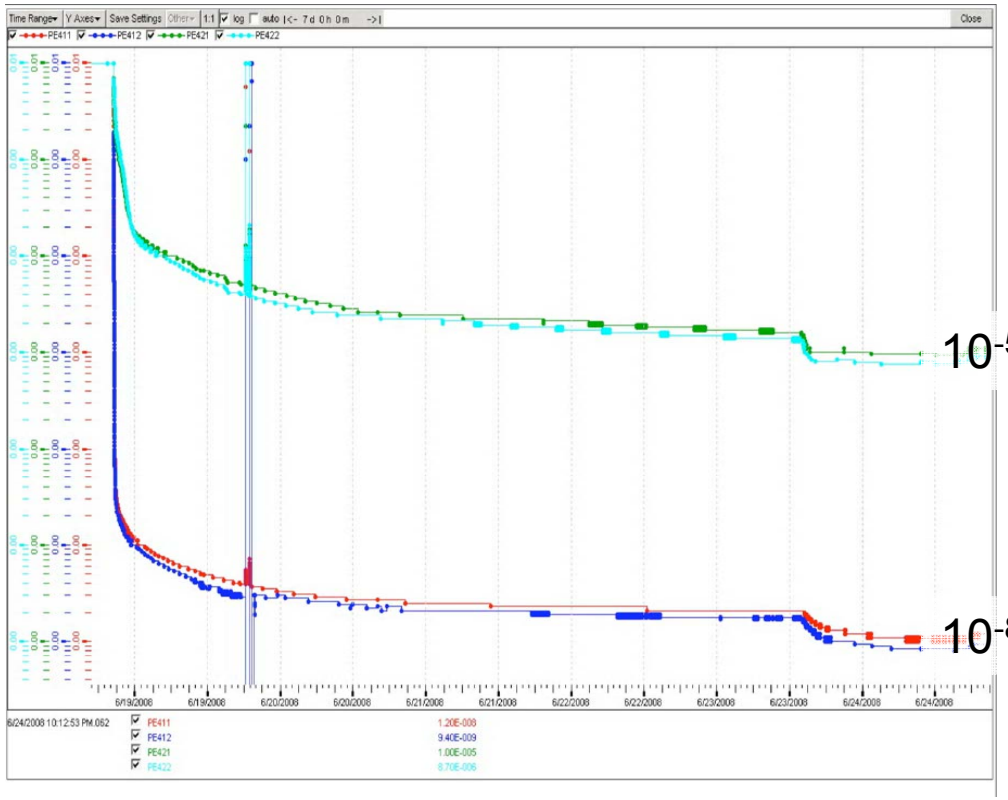


Differential pressure

Commissioning the VELO (II)

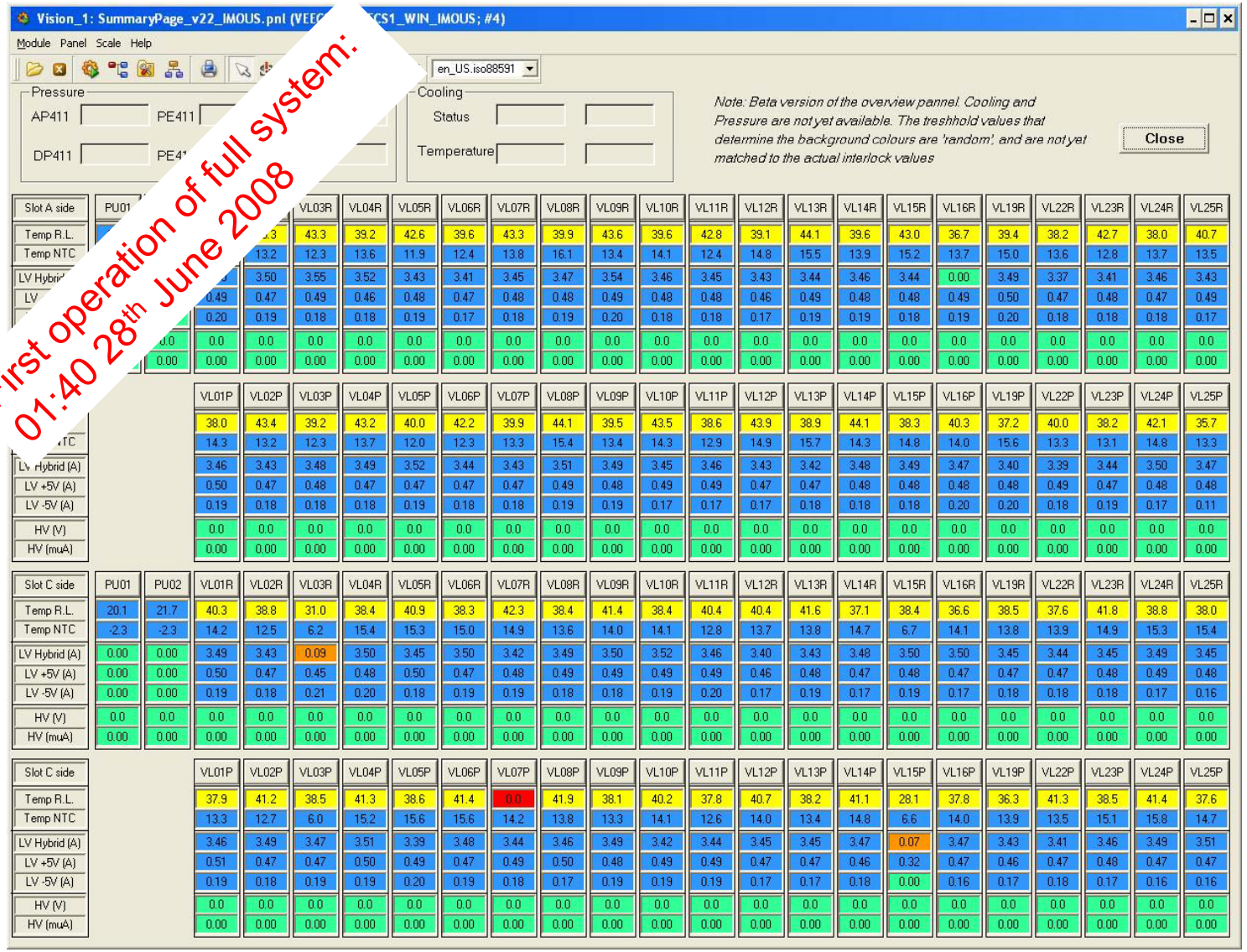
- Single module test of 2nd half – from 2nd June.
- Full half powered for first time – June 10th.
- Many problems found.
  - Failure and replacement of broken read-out boards.
  - Problems related to fabrication of Tell1 boards.
- Preparation for operation under vacuum.

VELO under vacuum

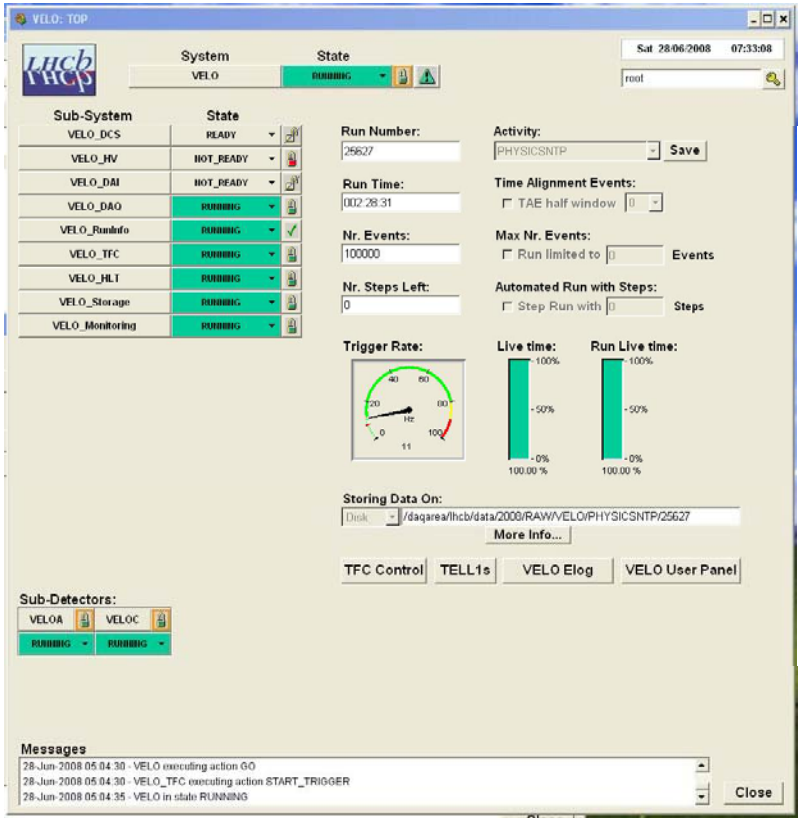


- Full detector operated under vacuum after beam evacuated.
- Operated cooling fully loaded at -25C
  - Modules @ -5C
  - Cooling of rf foil affects beam pressure.
- Majority of data taking during commissioning at -5C
  - Modules @ 14C.
  - Minimize thermal cycling of modules.

System @ full power



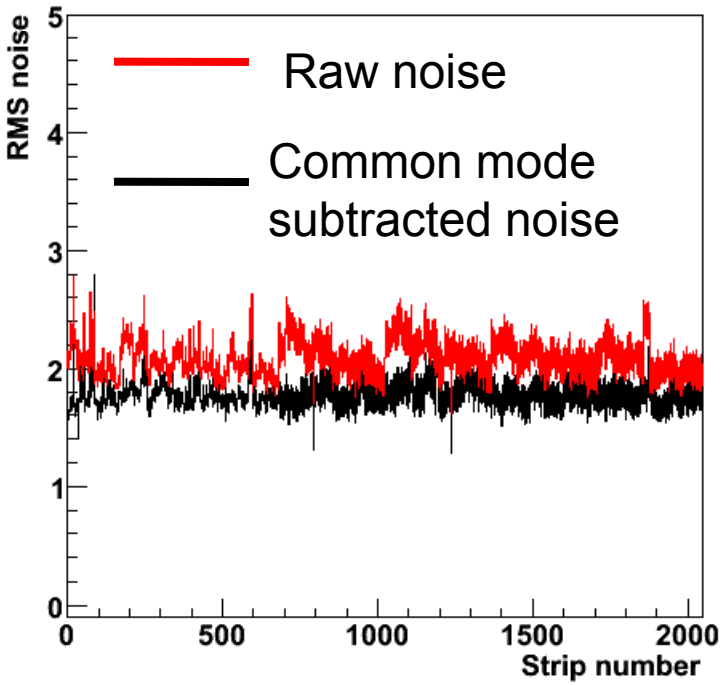
Data taking



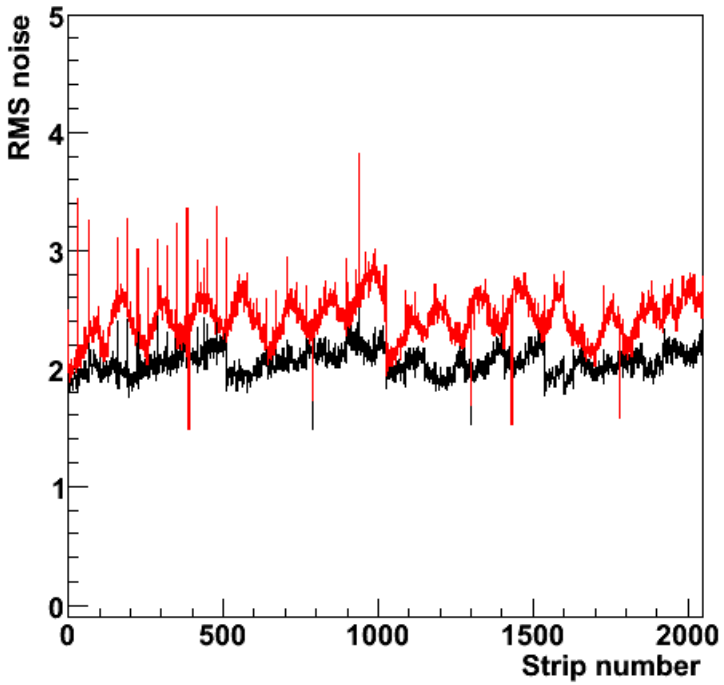
- Non-zero suppressed data:
  - 300000 events
  - 10Hz with limited event builder.
- Zero suppressed data (with test pulses)
  - 1kHz with limited event builder.
  - 1/100th of design rate.

Noise performance

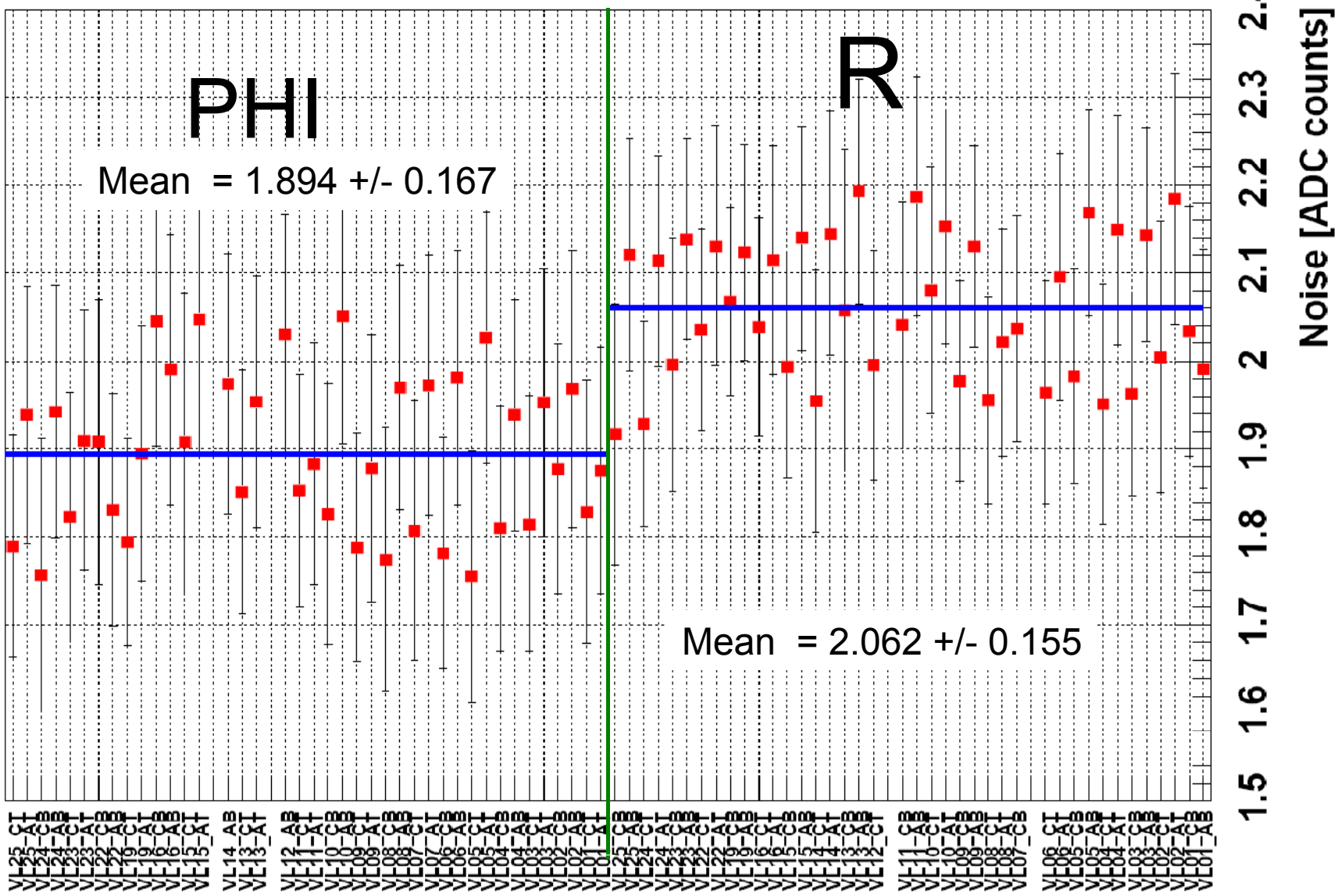
Phi sensor



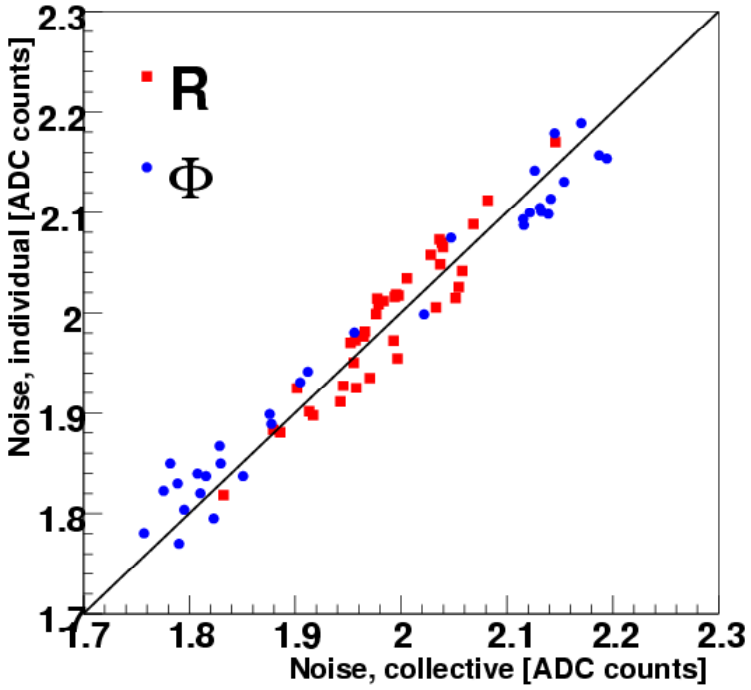
R sensor

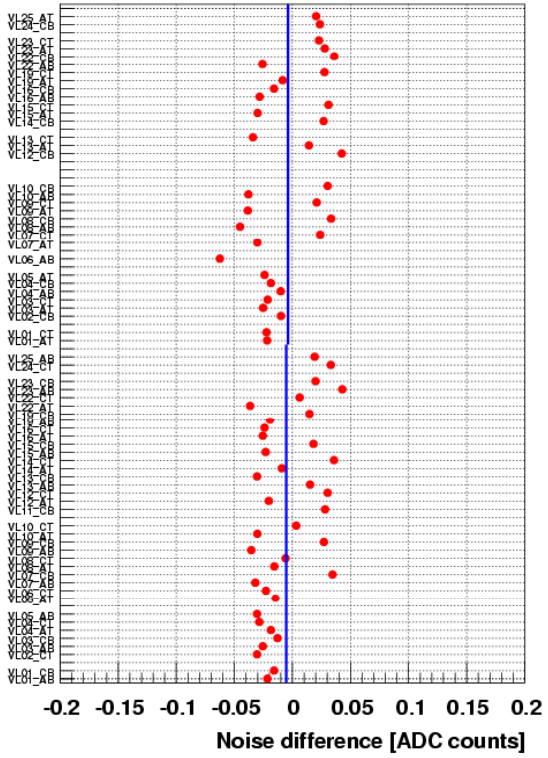


Noise all sensors



Noise comparison between single module power up and system power up





Status

Installation

- Module production and assembly of detector halves – March 2007
- All other systems installed:
  - Cooling
  - Vacuum
  - Positioning system.
  - High voltage
  - Low voltage
- Installation of detector halves – October 2007
- Connected the cables to the modules.
- Full system operation – June 2008

Outstanding issues

- Integration into LHCb global running.
- 3 broken Tell1 boards to be replaced.
- Data taking at high rates.
- Software improvements:
  - Online monitoring.
- Wait for first beams.

Conclusions

- All components fully installed and tested.
- Extensive commissioning programme over last year.
- First operation of whole detector under vacuum
- 99.2% of channels fully operational.
- LHCb VErtex LOcator in good shape for first beams