

Quality assurance related to system integration of the VELO detector.

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On behalf of the VELO collaboration.



Outline

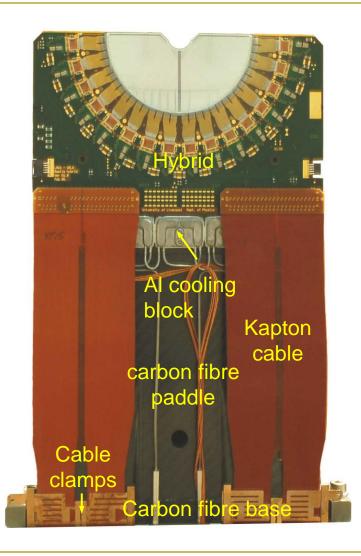


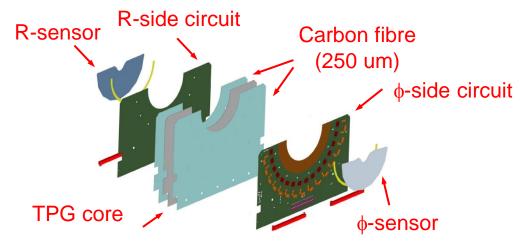
- Quick overview of the VELO detector.
- QA during module production, burn-in and installation.
- Further QA during the later stages of system integration.
- Summary



VELO Module





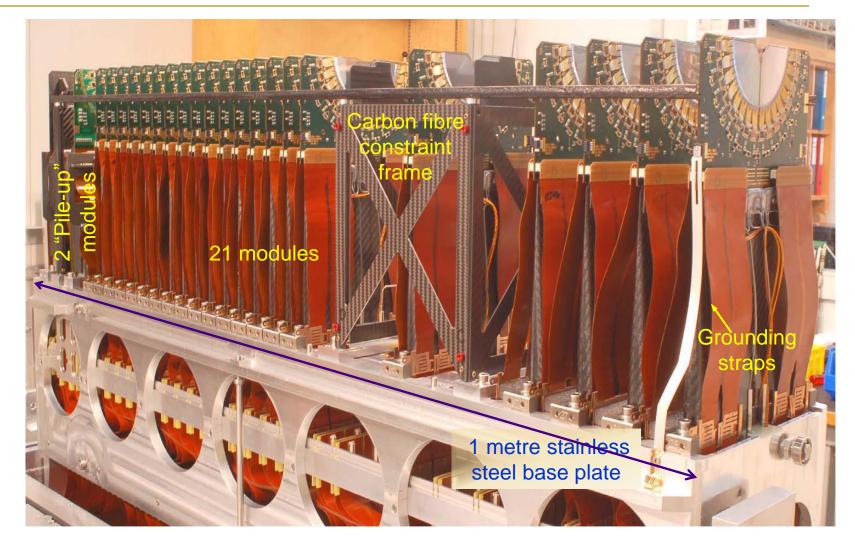


- double-sided symmetric build to balance stresses due to "bi-metallic" effects.
- N-on-n sensors (300um).
- Thermal pyrolitic graphite (400um)
- analogue read-out asic's : 2 x 16 Beetle chips (~18 Watt)
- Cooling: 2-phase CO₂ [silicon tip @ -7° C]
- 3 layer kapton cable for signals and power.



One VELO detector half



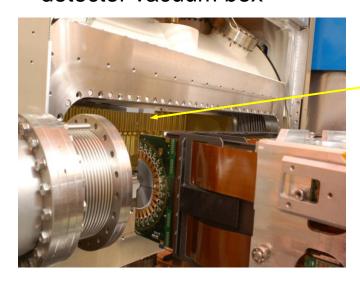




Detector vacuum box.

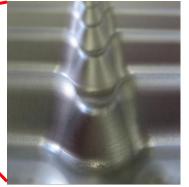


... insertion of one half into detector vacuum box





Thin (300 um) Alu shaped foil separates detector from primary LHC beam vacuum.



Detector box pressure < 10⁻⁴ mbar



Signal electronics.



Repeater boards:

- Pre-emphasis circuit for cable transmission.
- Rad-hard power regulators



60 m cables:

Analogue signal transmission



Digitizing board (Tell1):

- 64 channels 10 bit ADC @ 40MHz
- signal processing FPGAs [cross-talk, common mode, pedestal subtraction & clustering]





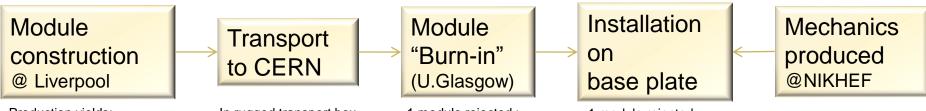


Quality assurance during module production, burn-in and installation.



Module production, burn-in & installation





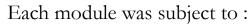
Production yields:

- 63% of hybrids (flatness)
- 87% of sensors
- 0.6% average bad channels

In rugged transport box under N2 atmosphere. As hand luggage by plane.

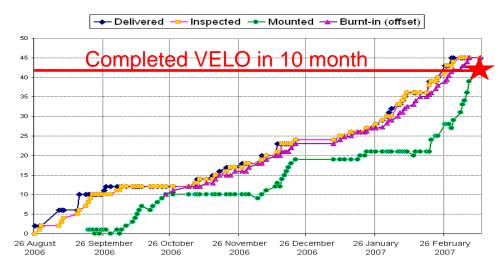
1 module rejected : suspicious evolution of sensor leakage current

1 module rejected : Insufficient cooling performance.



- 6 Visual Inspections,
- 6 Metrologies,
- 7 Electrical Tests,
- 4 Vacuum Tests
- 3 cooling Tests
- 2 thermal cycling test.

... 100 man-hours per module



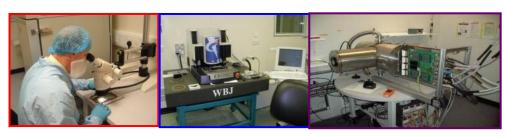
But we had a long prototyping period before!

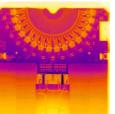


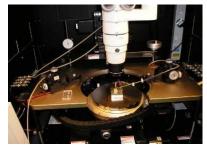
QA during production.

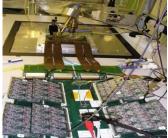


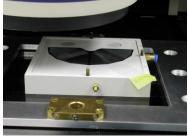
Extensive QA was done at <u>component level</u> during production : sensor, pitch adapter, substrates, circuits, bonding, hybrids

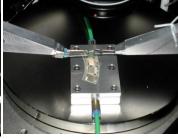












Detailed reports in:

LHCb VELO module production and performance NIMA 596 (2008)25-28) and NIM A 583 (2007) 18-22. Presentation RD07, firenze, 2007 by A. Affolder.

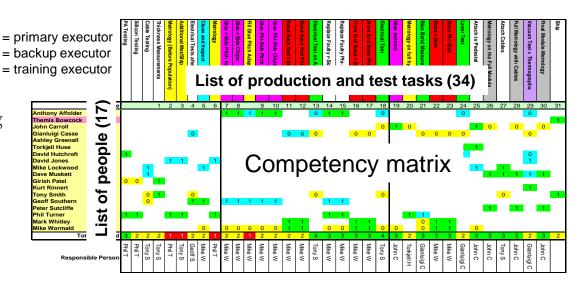


QA 'soft' tools @ production



Competency matrix:

Allowed efficient planning of a complex production and ensure competence redundancy.



Production database:

- Provided up-to-date production status of all modules.
 - Very useful given tight production schedule and complex production flow ...
- Gave easy access to test results of every module, e.g.: http://hep.ph.liv.ac.uk/velodb/velo1/moduledata.php?label=75&modID=28
- Has some built-in functionality, e.g. validation of test results and release to next production step.
- In-house developed.



QA during module burn-in.



Main activities

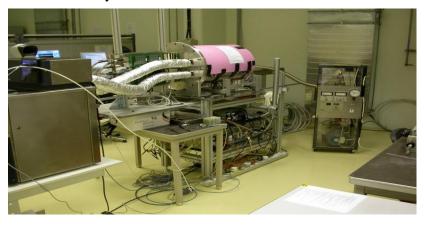
Detailed visual inspection under microscope (3hours)

Thermal cycling 4 x [-22C/+28C] (3h)

Long (24h) power up under vacuum

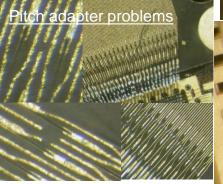
Monitoring of leakage current and strip noise. Thermal imaging IR camera.

Burn in system



1 module was rejected due to suspicious leakage current evolution.

Major visual findings







Documented in "LHCb VELO module characterisation and long term quality assurance tests" NIM A 611(2009) 41-51.



Further system QA



- The aim is to assure that all components perform to expectation when integrated in the system ...
 - Major full system test in SPS beam test.
 - Study of high voltage breakdown in vacuum.
- Some failures have appeared at system level
 - Instability of electronic amplifiers
 - Connector reliability problem
 - Unexpected behaviour of the front-end asic.
 - Problem of mechanical clearance of sensor to RF foil



Putting all pieces together.



- 2 test beams in SPS with the aim of integrating :
 - Multiple modules and final mechanics.
 - □ Signal chain : repeater electronics/long cables/TELL1.
 - Final LHCb DAQ HW and event building SW.
 - □ Final LHCb Timing and Fast control ("ODIN")
 - Final low and high voltage systems.(found bug on interlock input of CAEN LV!)
 - Under vacuum and CO2 cooling.
 - □ PVSS based configuration software.
 - □ elog ...
- 'Last check' before installation on LHC.
- Large effort, but it proved there was no showstopper towards the final system!



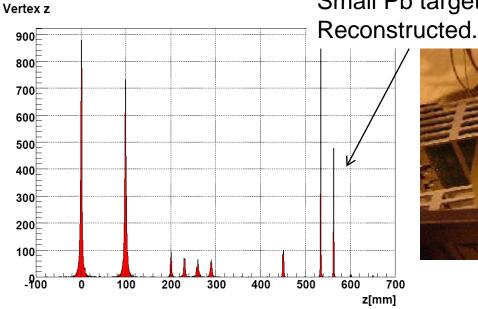


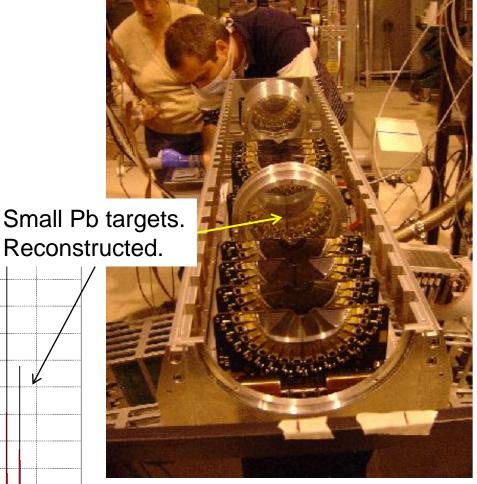
QA on software ...



- This test also produced the first real data to feed into software:
 - Alignment
 - □ Pattern recognition & tracking
- Vertex finding

It exposed many bugs and was key to tune all the software



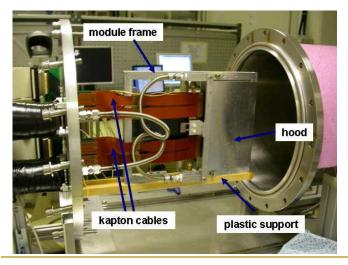




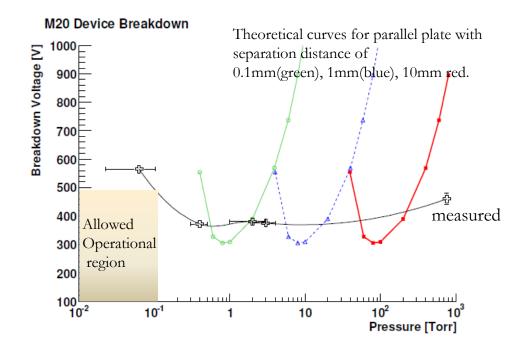
Study of HV breakdown in vacuum



- The expected dependence on pressure is described by Paschen's curve :
- It was measured on a complete module.
- The study was done in air.
- Measured minimum breakdown voltage
 = 370V. The breakdown was likely not on the sensor (looking at strip noise map.)
- Fully described in LHCb note 2007-104, 2007.



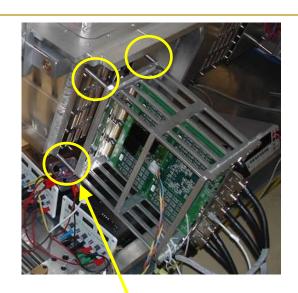
$$V \text{ breakdown} = \frac{B.p.d}{(C+\ln(p.d))} \\ B = 365 \text{ V/cm/Torr for air} \\ P = \text{pressure (Torr)} \\ D = \text{distance (cm)} \\ C = 1.18 \text{ for air} \\$$

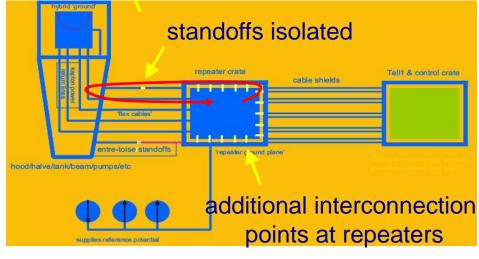


Electrical Oscillations...



- The amplifiers on the repeater boards exhibited unstable behaviour under certain conditions when inserted in their crates.
- It was caused by a feedback through a parasitic path (metallic frame and standoff feet).
- It was solved by modifying
 - the mechanics (isolated standoffs)
 - the grounding scheme (additional interconnections).



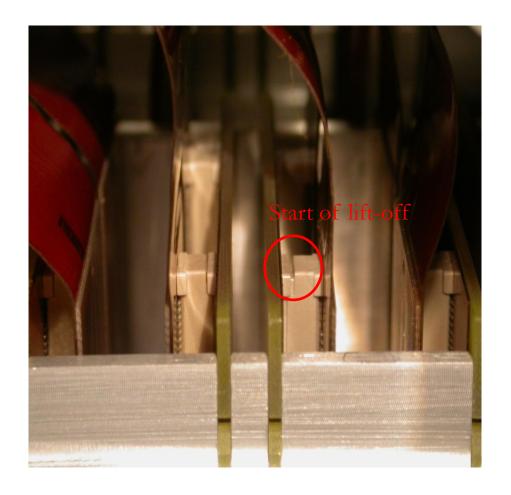




The usual culprits: connectors



- Use of a connector without locking mechanism for the interconnection between the 'short' and 'long' kapton cables.
- The retention force is large, but sometime not sufficient to resist the force from cable torsion.
- It has caused partial disconnection in a pile-up detector module (cables with higher torsion). The Velo detector is not affected.
- Careful last visual inspection ...



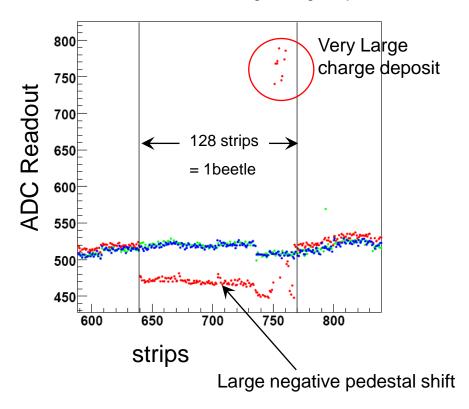


A Beetle weakness.



- Very large charge deposits in multiple channels cause large pedestal shift in all 128 channels of the ASIC
- This was accidentally observed in test beam data. (Rare event).
- The beetle was specified and tested for large charge deposits in <u>single channel only</u>.
- At LHC, these events are 0.1% of the data and can be corrected for by signal processing in FPGA.
- This was not detected despite 'good' specification and QA...

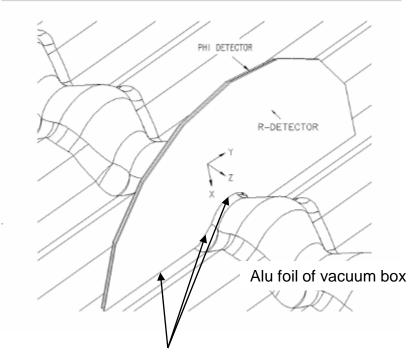
3 consecutive events (green, red, blue). Red event contains large charge deposit.





Achieving Sensor-foil clearance ...





By design in general, 1mm clearance

Achieved clearance depends on mechanical precision and stability of the modules, the base plate and the vacuum box foil.

Everything was tried to stay within the required tolerances



3D precision surveys













November 4, 2011



- → Modules:
 - very accurate construction in x and y (< 60um),
 - ☐ less in z, flatness ~200um
 - affected by kapton cable attachment
 - Expansion with cooling
- Module base:
 - combination of slots and dowel pins define position of modules in y and z
 - flatness of base defines x of modules
 - Deformation when installed
- ☐ RF foil:
 - x and z vary over foil length
 - depth of slots (x) critical parameter
 - □ can flex during venting

Obtained maximal excursions in z

0.8 mm

0.1 mm

0.45 mm

Total = 1.35 mm !! 0.35mm too much...



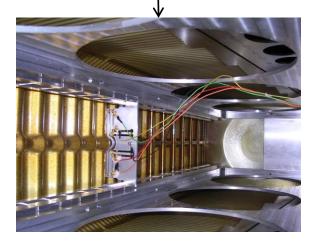
2. Constraint system

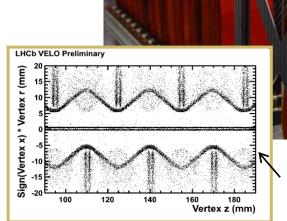


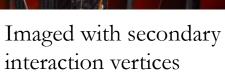
Finally decided to add a constraint system to hold hybrids at proper z-location along beam. Penalty of 0.6%<X/X0> on material budget...

In situ verification with a special designed measuring device with dimensions that are 0.5 mm larger than those for a module.

A micro-switch beeps if the foil is touched.









Summary



- We had a very intense period (12 month) of production and installation ... following a long and careful prototyping phase.
- Because of the modest production volume, we could afford extreme care and our QA succeeded in eliminating some few non conforming modules.
- There will 'unavoidably' be some features that escape through the maze of QA and show up during later integration. Luckily these were minor or correctable in our case.
- The VELO detector operates fully to the 'expected quality' regarding performance, stability and reliability... which is the whole purpose of QA!

