Radiation damage on the LHCb-VeLo

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on behalf of LHCb

The Detector

The VELO

VELO fully closed
(stable beam)

VELO fully open

- ✓ Retractable detector halves
- ✓ 21 R-Phi measuring modules per half
- ✓ Close to beam-line (8 mm)
- ✓ Operates in secondary vacuum
- ✓ A 300 μ m thick Al foil separates from the beam vacuum

VELO sensors

Radiation hard design → n-strip readout

82 n-in-n sensors

Depletion region grows from the backplane junction.

Conductivity type inversion after a few $10^{12} n_{eq} \text{ cm}^{-2}$.

Interstrip-isolation by p-spray.

2 n-in-p sensors

Depletion region grows from the strip implant. No type inversion.

Interstrip-isolation by p-spray.

Evaluation of Radiation Damage

Methods:

- Changes of Current vs Voltage (IV)
- Current vs Temperature (IT)
- Changes of the full depletion voltage
- Cluster Finding Efficiency

Reverse Bias Current

Two contributions: bulk and surface current

Influence of surface current negligible after irradiation

Bulk dominated before
Bulk dominated after

Surface dominated before
Bulk dominated after

Comparison with predicted fluence

Bulk current show an increase with fluence in line with delivered luminosity.

Trend of all sensors at 150V and -8° C:

~ 1.9 μA per
100 pb^{-1} at -
8°C

Comparison with predicted fluence

Measured and calculated currents with MC fluences.

Good agreement proves our understanding of the particle fluences in VELO.

- Accurate measurement of the effective bandgap energy:

Preliminary	“effective band gap E_g ”
100V 480 pb ⁻¹	1.12 +- 0.06 eV
150V 480 pb ⁻¹	1.11 +- 0.07 eV
150V 821 pb ⁻¹	1.10 +- 0.04 eV
150V 1204 pb ⁻¹	1.14 +- 0.04 eV

Literature: $E_g = 1.21$ eV

Changes of full depletion voltage

For n^+ -on-n sensors we expect type-inversion

For n^+ -on-p we expect initial decrease of V_{FD} followed by linear increase

Standard measurement method uses C-V scans only possible before irradiation

After installation V_{FD} depends on radius, so we need to use an alternative method.

Charge collection efficiency method

Using reconstructed unbiased tracks:

Extrapolate the track to a strip on the test sensor and record amount of charge in this area.

Vary the voltage of the test sensors between 0 and 150V.

CCE method

Collect data for each sensor at various bias voltages

Fit the MPV of the distribution and plot vs bias voltage.

Define the full depletion voltage (V_{FD}) as the voltage at which the MPV is 80% of maximum.

This method is still accurate after the fluences currently accumulated.

V_{FD} vs fluences

V_{FD} at different sensor (n-in-n) radii after various fluences:

- Decrease of V_{FD} with luminosity
- Type-inverted in low radius regions
- Min $V_{FD} \sim 20V$

V_{FD} vs fluence

V_{FD} at different sensor (n-in-p) radii after various fluences:

- Decrease of V_{FD} with luminosity
- Type-inverted in low radius regions
- Initial shallow acceptor (B) removal reduces V_{FD}

V_{FD} vs fluence

For all VELO sensors:

1. V_{FD} decreases with fluence to a minimum of $\sim 18V$ (n-type bulk sensors).
2. Inversion point is $\sim 10\text{-}15 \times 10^{12} n_{eq}$
3. After type-inversion, n⁺-on-n increase at a similar rate to n⁺-on-p.

V_{FD} vs fluence

Comparison with Hamburg parameterisation:

Good agreement a part from around type-inversion. The CCE method needs sufficient electric field for efficient charge collection.

CC(V) of n and p-type sensors

The MPV vs voltage for the outer region of n-on-n and an n-on-p sensors.

Cluster Finding Efficiency (CFE)

Cluster finding efficiency for all modules before and after irradiation.

Noticeable reduction for downstream R-type modules.

Cluster Finding Efficiency (CFE)

.... and more irradiation..

CFE for R-sensor 34 as a function of radius after various delivered luminosities.

CFE for R-sensor 34 as a function of radius at different bias voltages.

Routing via 2nd metal layer

1st metal layer AC coupled to the strips.

2nd metal layer to connect inner strips to read-out electronics.

For R-sensors, the routing lines are perpendicular to strips:

Phi-sensor routing lines to the inner section are above outer strips (screening).

$3.8 \pm 0.3 \mu\text{m}$ SiO_2 insulation between metal layers.

Routing via 2nd metal layer

The second metal layer routing lines in R-sensors:

Cluster finding efficiency in R-type sensors, low irradiation fluence:

Cluster finding efficiency in R-type sensors: higher fluence

CFE

Cluster finding efficiency in R-sensors:

RL dist = distance
to nearest routing line

d = distance to
nearest strip edge

Effect on “noise”

The charge picked by the routing line appears as ‘noise’ in the channel linked to this 2nd metal line.

Clusters appears at inner sensor regions at low ADC values

SUMMARY

- Variety of analysis techniques give us excellent understanding of the health of our detectors. The MC estimate of the received fluence with radius and z agrees with changes of the electrical performances of the sensors, giving confidence that the monitoring is well in hand.
- Second metal layer CFE decrease is as much at $\sim 10\%$ in worst effected regions. But there has been no significant decrease in tracking efficiencies (within 0.3% errors).
- “Annealing” for recovering both CCE and current is a weapon still saved for later days.
- Note: last week LHCb has passed the 1.5 fb^{-1} threshold!!