The LHCb VELO: Status and Upgrade Developments

Overview

• The LHCb detector and the VELO
• VELO sensor performance
• Possible upgrade solution
  – Czochralski Silicon
• Current status

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LHCb

Aim: to study CP violation in B meson systems

- Detector at the LHC analysing 14 TeV proton-proton collisions
- \(\sim 10^{12}\) bb pairs produced every operational year

\[ \mathcal{L} = 2 \times 10^{32} \text{cm}^{-2}\text{s}^{-1} \text{ with } \sigma_{bb} \approx 500\mu\text{b} \]
VErtex LOcator

- Vertex reconstruction is a fundamental requirement for LHCb

- 21 silicon tracking stations placed along the beam direction
- 2 retractable detector halves for beam injection periods (up to 30 mm)
**VELO Sensor design**

- 2 sensor types: R and Φ
  - R measuring gives radial position
  - Φ measuring gives an approximate azimuthal angle

- Varying strip pitch
  - 40 to 102 μm (R – sensor)
  - 36 to 97 μm (Φ – sensor)

- First active silicon strip is 8.2 mm from the beam line

- n⁺-on-n DOFZ silicon
  - minimises resolution and signal loss after type inversion

- Double metal layer for detector readout
VELO in the Vacuum

- Double sided modules
  (1 x R and 1 x Φ sensor)

- 16 Beetle chips

- Silicon Sensor

- Secondary vacuum Chamber

- TPG* substrate with carbon fibre frame

- Cooling contacts

- Carbon fibre paddle

Silicon operating temperature -7°C

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*Thermalised Pyrolytic Graphite
VELO environment

- VELO sensors operate in a harsh non-uniform radiation environment
  - fluence to inner regions $1.3 \times 10^{14} \, n_{eq.}/\text{cm}^2$
  - fluence to outer regions $5 \times 10^{12} \, n_{eq.}/\text{cm}^2$
- Estimated to survive 3 years
May 2004 test beam results

300μm n^+-on-n R sensor

16 readout chips
(Beetle 1.3)

Prototype hybrid (K03)

300μm S:N = 18:1
200μm S:N = 12:1

spillover: signal at 25ns after peak in % of the peak signal

30% (100V bias)

(30% is the maximum before displaced vertex trigger performance degraded.)
**Possible upgrade choices for 2010**

n^+ -on-p, pixels, 3D, …many possibilities

- Magnetic Czochralski silicon
  - Standard industrial method of producing silicon
    - Cheap
    - Naturally high Oxygen content
      - more radiation hard?

- Test beam at the CERN SPS of a MCz detector* before and after irradiation
  - LHC speed electronics (40 MHz)
    - (3 SCTA (analogue) chips)
  - p^+ -on-n MCz material
  - Area \( \text{read out} = 6.1 \times 1.92 \text{ cm} \)
  - 380 \( \mu \text{m} \) thick, 50 \( \mu \text{m} \) pitch

*Many thanks to the Helsinki Institute of Physics for the MCz detector
MCz test beam results

- Depleted the detector (~550 V) (CV measured Vdep ~ 420 V)
- $S/N > 23.5 + 2.5$ (380 µm thick)

- $1.3 \times 10^{14}$ 24 GeV p/cm$^2$ $S/N = 15$
- $4.3 \times 10^{14}$ 24 GeV p/cm$^2$ $S/N = 11$ (under depleted)
- $7.0 \times 10^{14}$ 24 GeV p/cm$^2$ $S/N = 7$ (under depleted)
Further MCz benefits

• The VELO currently uses $n^+-on-n$ DOFZ silicon detectors
  – This is necessary because we want material where the high field side is always on the strip side in order to prevent loss of resolution and signal
  – However, $n^+-on-n$ is expensive and restricts the choice of processing company (requires double-sided processing)

We have found that MCz does not type invert using the Transient Current Technique (measured to $5 \times 10^{14} \text{ p/cm}^2$)*

*Work performed under the PH-TA1/SD group, CERN (A Bates & M Moll)
Transient Current Technique

- experiment which probes the electric field inside the detectors

type inversion in FZ silicon

$\Phi = 1.74 \times 10^{13}$ 24 GeV/c p

$\Phi = 3.61 \times 10^{14}$ 24 GeV/c p
TCT in MCz

MCz silicon always has the high field on the strip side of the detector

=> standard p⁺-on-n MCz detectors could replace the VELO n⁺-on-n DOFZ silicon, however, further investigation of the radiation tolerance of MCz is required

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Status & Conclusions

• The VELO is moving from the last prototype testing to sensor production
  – first pre-production sensors are just arriving (October 2004)
  – test beam of final module configuration in November 2004

• R&D for possible upgrade solutions is continuing e.g. for MCz
  – first operation of full size MCz sensor with LHC speed electronics in test beam
    • further test beam studies planned
  – non-inversion of MCz material under radiation demonstrated
    • additional microscopic studies underway
TCT Review

- Illuminate front (p⁺) or rear (n⁺) side of detector with 660 nm photons
- Light penetrates only a few μm depth
- Ramo’s theorem dictates signal will be dominated by one type of charge carrier
- \[ I(t) = q \cdot E(u(t)) \cdot v(t)_{drift} \]
- e.g. hole dominated current (hole injection)
  - Illuminate rear (n⁺) side of detector
Signal treatment

- Deconvolution of the true signal from the measured signal

Measured signal = detector signal $\otimes$ transfer function

Transfer function:

$$I(t) = \tau_{TCT}/R \times dU_{osc}(t)/dt + U_{osc}(t)/R$$

$R = 50\,\Omega$ from input of preamp

$\tau_{TCT} = RC_d \ (C_d = \text{detector capacitance})$
Back up slide 2 – signal examples

**Corrected induced current pulse shapes**

Black = signal as measured on the scope

Red = Trapping corrected signal
IV/CV analysis

- CV measurements - 10kHz
- Measurement at room temperature, then corrected to 20°C
- Guard rings grounded
- Annealed for 4 min / 80°C
TCT Diagram

- Pulse duration: min 1.5 ns FWHM
- Rise time of signal: 1.5 ns
- Almost no detector shaping from electronics

- Custom written LabVIEW DAQ
- ROOT analysis of data
Beam Test: Setup

Far station
RΦ

test module

first telescope station
ΦR  RΦ  ΦR

CERN SPS X7
120GeV μ/π

Back up slide from D Eckstein, Vertex 2004
Modules recently tested

- in Summer 2003:
  - 200µm thick PR03
  - n-on-n R-sensor
  - 1 Beetle1.2 on PCB
  - 1 chip region read out

- in June 2004:
  - 300µm thick PR03
  - n-on-n R-sensor
  - fully populated K03 hybrid
  - Beetle1.3 tested
  - many regions read out

Data with tracks in telescope
single sample

track data not yet analysed – use stand-alone
15 consecutive samples read out

Back up slide from D Eckstein, Vertex 2004
Beam Test 2003 – Results

S/N and Spillover for a set of Beetle Bias settings

Minimum at LHCb startup

Minimum requirement for Trigger

Spillover: signal at 25ns after peak in % of the peak signal

S/N for 200μm at the lower side

→ test 300μm

Back up slide from D Eckstein, Vertex 2004
new 2004 Data- Results

→ S/N for 300µm agrees with scaled 200µm

→ the K03 hybrid (and other components in the chain) do not add noise

→ S/N in agreement with requirements – should we use the thicker sensors?
new 2004 Data- Results

medium strip length

shortest strips

it is safer to run at ~100V

October 2004

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Back up slide from D Eckstein, Vertex 2004