Developing Radiation Hard Silicon for the Vertex Locator

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On behalf of LHCb VELO:

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- Introducing VELO
- Sensor Design
- Radiation Environment
- Upgrade ?

• Dedicated B system CP violation Experiment

- Full spectrum of B hadrons: $B^\pm, B_{d,s,c}^0$, baryons
 - B_s system
 - All angles, sides of both CKM Δ s
- Lots of events !

$$\mathcal{L} = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \text{ with } \sigma_{b\bar{b}} \approx 500 \mu\text{b}$$

$\mathcal{O}(10^{12})$ $b\bar{b}$ pairs per year

• LHCb

- single arm spectrometer
- 15-300mrad angular acceptance
- recently optimised to minimise material and improve triggering

Velo Rôles

- Primary / b decay Vertex reconstruction
- Stand alone Tracking
 - A principle tracking device for the experiment
- Second Level Trigger
 - Fast tracking

One set of half disks

- In vacuum
- Retract each fill
- Align each fill

Design

- VELO sensors as close as possible to beam

- no beam pipe,
- sensors ~7mm away from beam

BUT

- Injection: retraction by 30mm
- Protect sensors against RF pickup from LHC beam
- Protect LHC Vacuum from possible out-gassing of detector modules

- Place sensors in a secondary vacuum in Roman pots

Secondary Vacuum – RF Foil

- Made from 250 μ m thick Al
- Inner corrugations :
Minimal material before the first sensor is hit
- Outer corrugations:
allow for overlap of detector halves
for full azimuthal coverage and for alignment
- Prototyping at NIKHEF
method: Hot gas Forming
full size foil
vacuum tight and stiff

A few microns in a few minutes

- Need alignment for displaced vertex trigger
- Detector resolution 4 μm

series of discs

small
overlap

Use computing power of
online / trigger farm

Detectors separated
6cm during injection

Sensor Design

•R & Phi sensors

- Fast stand-alone tracking and vertexing for trigger
- Design allows to optimise resolution vs. number of channels

•Baseline design of sensors:

- Active area 8mm to 42 mm
- Smooth pitch variation from inner (40 μ m) to outer radii (100 μ m)
- 2nd metal layer to route signal to chips
- n⁺-on-n DOFZ
- Analogue readout 40MHz

R-measuring sensor:
(concentric strips)

Φ -measuring sensor:
(Radial strips with a stereo angle)

Module

- mechanically stable
- low material
- cooling connection

Double Sided Modules:

1. Single Sided Silicon sensors
2. thin kapton flex circuit laminated onto
3. carbon fibre/ TPG composite
4. cooling block
5. low mass carbon fibre paddle
6. precision aluminium base plate

Extreme Radiation Environment

- LHCb VELO will be **HOT!**

- Maximum Fluence
 - 1.3×10^{14} 1MeV $n_{eq}/cm^2/year$

- Strongly non-uniform
 - dependence on $1/r^2$ and station (z)
- Maintain a good S/N performance
 - for several years (replacement)
- Extensive R&D program to select Sensor and Front-End chip

May 2004 test beam results

300 μ m n⁺-on-n R sensor

16 readout chips
(Beetle 1.3)

Prototype hybrid (K03)

300 μ m S:N = 18:1

200 μ m 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.)

Performance

S/N and Spillover for a set of FE chip
(Beetle) bias settings

Minimum at LHCb startup

Minimum requirement for Trigger

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

Maximum requirement from Trigger

have to find a compromise

S/N for 200μm at the lower side

Velo Upgrade?

- First upgrade at LHC?
 - Sensors expected to survive 3 years, so 2010...

- Radiation Tolerance
 - $3.3 \times 10^{14} \text{ n}_{eq}/\text{cm}^2/\text{year}$ at 5mm
 - Edgeless technology, save guard ring space
7mm rather than 8mm
10% better impact parameter resolution

- Low Material
 - Keep electronics, cooling mostly outside acceptance

19 % λ_0 (4% before first run)

R/Phi Strip geometry has advantages

- fast tracking for trigger
- matches occupancy
- minimal material in acceptance

Strip Technology Options

Holes Aspect Ratio 40:1

3D

Join holes with strips

n^+ -on-p (GianLuigi), MCz...

MCz test beam results

- Test beam at the CERN SPS of a MCz detector

p^+ -on-n MCz material, 6.1 cm x 1.92 cm, 380 μm thick, 50 μm pitch, with LHC electronics

- ✓ Depleted the detector (~550 V)
(CV measured $V_{\text{dep}} \sim 420 \text{ V}$)

$S / N > 23.5 + 2.5$
(380 μm thick)

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

Status & Conclusions

- VELO moving from last prototype testing to sensor production
 - first pre-production sensors arriving now
 - test beam of final module configuration in November 2004
- R&D for possible upgrades started
 - first operation of full size MCz sensor with LHC speed electronics in test beam
 - further studies planned