The front-end electronics of the LHCb Ring-Imaging-Cherenkov system

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Introduction to the system

Photon-detector: the pixel HPD

Pixel front-end chip

Bump-bonding

Readout electronics

Conclusions

LHCb RICH photon-detector system

Reference: talk by Thierry Gys

4 arrays of HPDs covering 2.6m^2 in total

~ 500 pixel HPDs

~ 500,000 channels of data

HPDs mounted on columns together with readout electronics, power distribution & active cooling

Each column = one independent module

Electronics System

Column
Side-view

The pixel hybrid photon detector

DEP, The Netherlands

Advantages of this hybrid, pixel structure:

low noise: excellent resolution of single photoelectrons

high channel number/density

Flip-chip (bump) bonding

Sensor from Canberra, Belgium,
designed specifically for HPD
application

Custom chip fabricated in
commercial CMOS

HPD high voltage of 20kV
⇒ 5000e⁻ signal

But.....

- Charge sharing
- Back-scattering

Both reduce signal size

Pixel chip requirements

- Low detection threshold $< 2000e^-$
- Low noise $< 300e^-$
- $500\mu\text{m} \times 500\mu\text{m}$ channel size (focus x 5)
- $16\text{mm} \times 16\text{mm}$ active area
- 25ns time precision (LHC) & fast pulse recovery
- Event rate $\sim 1\text{MHz}$ ('frame rate')
- Consecutive reading & writing
- Compatible with HPD manufacturing

Other design issues:

Physics performance not improved by resolving 1 or 2 or 3 photoelectrons

- $\Rightarrow$ choice of binary architecture: output = 0 or 1, threshold applied
- $\Rightarrow$ All digital I/Os – try to make it plug-and-play!

Pixel chip design – LHCbPIX1

- Commercial 0.25 μ m CMOS process
- 6 metal layers
- Radiation-tolerant layout
- 13 million transistors
- 1.8W total power (40MHz clk, 1MHz trig)
- Digital I/Os
- Internal bias DACs

Pixel cell

One super-pixel ($500\mu\text{m} * 500\mu\text{m}$) = 8 mini-pixels ($62.5\mu\text{m} * 500\mu\text{m}$)

Internal logic makes a logical OR of hits => 2 modes of operation

1024 or 8192 channels

Electrical results – signal sensitivity

Discriminator threshold and noise distributions across all pixels

Maximum signal at 20kV = $5000e^-$

Charge-sharing & back-scattering $\Rightarrow \sim 2000e^-$

Threshold distribution

Noise distribution

Electrical results – pulse shaping

Analog front-end fast recovery
=> low risk of pile-up

Shaper output

Maximum mean pulse rate
per channel ~ 3MHz

New bump-bonding technique

'Standard' eutectic solder (Sn/Pb 60/40) melts during

1. high T curing of glue (non-outgassing) used for packaging at 400°C
2. high temp processing of HPD at 300°C (bake-out to remove contaminants)

=> Weak bumps (electrically and mechanically)

VTT, Finland: bump-bonding recipe using solder with high melting-point (SnPb 10/90)

25um

Long programme of tests (bake-outs, SEM analysis, pull-strength tests, prototype HPDs) has successfully proven the bump reliability

VTT producing assemblies with > 99% good bumps

Interface to HPD: L0 board

Designed using radiation-tolerant components

Data-formatting by fuse-based gate array

ADCs for temperature monitoring

High speed optical data links:

Each fibre transmits at 1.6Gbit/s
Full system = 800Gbit/s

High Voltage Distribution

High Voltage (20kV) boards for dividers, filters, monitoring

Board after cleaning & encapsulation in silicone rubber

Prototype readout electronics system

Conclusions

Pixel chip designed for specific HPD application

New bump-bonding technique developed for HPD compatibility

Specific readout electronics boards designed for data transmission & power distribution

Electronics in production for large system of 500 HPDs

Spare slides

Power distribution gets hot..... needs cooling

LV board

Pixel chip design – LHCPIX1

Production run of 48 wafers received beginning 2004

Fully tested (3400 chips) on probe-station & good chip selected according to criteria:

- Threshold & noise calibration in spec
- Configuration & power supply tests
- Correct operation at 45MHz

Yield of 55% => 3 times the number of HPDs

Wafer maps provided for bump-bonding at VTT

Eutectic before bake

Under
Bump
Metal
(UBM)

Eutectic after bake

Sensor

Chip

10/90 SnPb before bake

10/90 SnPb after bake

Anode

Ceramic carrier produced by Kyocera, Japan
- Good thermal conduction