The 8CBC2 Test Beam at DESY

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Outline

Introduction
• CMS Phase-II Outer Tracker Upgrade
• pT Modules

Module Assembly
• Design
• Manufactured TB Module

Beam Test Hardware Setup

Analysis Structure

First Results
The CMS Phase-II Outer Tracker

An Overview

HL-LHC environment

- Instantaneous luminosity of up to $7.5 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- Integrated luminosity of over 3000 fb$^{-1}$

All-new OT baseline geometry

- Barrel with 6 detector layers
- End-caps with 5 disks per side
- Double-sided pT modules for input to the CMS L1 trigger

Design highlights

- Over 200m$^2$ of silicon sensors
- 44M strips, 174M macro-pixels
- 40 MHz stub rate, 750 kHz L1 trigger rate
**pT Modules**

**Basic Concept**

Local rejection of low pT tracks
- Exploit bending of charged particle tracks in B-field
- **CMS Binary Chip (CBC):** Correlate hits from 2 closely spaced sensors to form **stubs**
- Tuneable offset and window for **homogeneous pT threshold** throughout the OT

Tracker input to the L1 trigger
- Stub information is sent out at BX frequency of 40 MHz
- 2 data lines: trigger information and hit data
- Full data read-out at 750 kHz

Two module variants
- **2S Module:** two strip sensors
- **PS Module:** (macro) pixel sensor and strip sensor
The 2S Tracker Module
Components and Design

CBC read-out chip
- Correlates signals from top and bottom sensor
- 2\textsuperscript{nd} prototype iteration; CBC3 already undergoing qualification
- 254 input channels with 90 \( \mu \)m pitch

8CBC2 front-end hybrid
- Hosts 8 CBC2 chips
- Flexible bent hybrid for wire-bonding of upper and lower sensor
- Electrical read-out and LV supply via interface card

Module construction
- Correlation of top and bottom sensor signals requires precise mechanical assembly
The ‘8’CBC2 Micro-Module

Assembly

Design due to available sensors

• 2 × HPK 2S baby sensors with 127 strips
• p-type ddFZ with 320 μm physical, 200 μm active thickness
• Connect to 2 CBC chips to test inter-chip communication
• Aluminium frame for rigidity and alignment of sensors
• Smartscope optical measurement: $\Delta x \sim 1.47$ mrad, $\Delta z \sim 5.05$ mrad

Issues encountered:

• Wire-bonding: bond-pads on hybrid not entirely flat
• Our glueing jig seems to have left some residue on the sensors
• At first very high noise levels $\rightarrow$ partially fixed by GND interconnection of HV and LV
Overall Setup – part I

Used Hardware

DURANTA Telescope
- 6 × MIMOSA-26 sensors (21.2 mm × 10.6 mm) with NI-based DAQ
- $XY\varphi$-rotation stage for DUT
  → use module rotation to mimic particles of different momentum

CMS Phase-I Pixel Reference Module
- Use as timing reference
- Full coverage of telescope window
- Rotated in $\alpha$ and $\beta$ for optimal resolution
Overall Setup – part II
Used Hardware & DAQ

Clock: Xilinx KC705 FPGA
- Generate common 40 MHz clock for pixel reference and CBC
- With scintillator trigger input: veto out-of-time particles → 'sync' clock to beam, but rate limited
- CERN AMC13 was to be used at first, but external output not easily usable...

DAQ system based on uTCA
- FC7 FPGA for read-out
- Running d19c firmware
- DIO5 for connection to TLU (via optional LVDS converter box) and trigger / clock input
Data Taking
Online Software

Telescope and pixel reference plane already fully integrated into EUDAQ

- EUDAQ producer for Ph2_ACF → single data file written, no need for offline merging
- Still possibility to shift data streams offline
- Both ZS and VR data formats possible
- Online monitoring available
Analysis Structure – part I

Offline Software

Use existing EUTelescope framework with ALiBaVa strip sensor analysis (c.f. last BTTBs)
- Only really new code needed for stub creation / checking, remainder is easily adapted

Clustering
- Telescope, Pixel Reference and CBC data is clustered individually
- Possible CBC cluster cuts: cluster size and clusters per event → reduce (common-mode) noise

Stub Check
- Replicate the pT discrimination offline to verify functionality:
  - Compare hit positions on top and bottom sensor
  - If hits within search window: create an offline stub → Did the chip also record a stub?
Analysis Structure – part II

Offline Software

Stubs

- Stub flag does not identify a certain position, so a noise baseline is expected

- Use offline stubs for DUT alignment:
  - Create virtual hit at DUT centre
  - Constrain position of sensors w.r.t. each other
Analysis Structure – part III

Offline Software

Alignment

- 10 iterations of GBL (General Broken Lines) fitting, with tightening of residual cuts, resolutions, $\chi^2$ cuts, etc.
- Telescope planes 0 and 5 are fixed; other planes, pixel reference and DUT stub plane are left free

Final Tracking

- After successful alignment, tracks are re-searched with no requirement for a stub hit (unbiased tracking)
- Extrapolated track impact position on stub plane is compared with stub position → resolution, efficiency, etc.
- Track position on actual sensor planes can be calculated from the alignment constants and track parameters
Measurements

Acquired Data

Overall 490 GB of data on disk
  ~ 450 million events

Threshold scans with single and variable hit mode

Latency scans for data and stub read-out

DUT Rotation to verify stub functionality
  • Data taken both in single and variable hit mode

X0 scattering measurements
  • Measure X0 within a CBC chip from deflection angles
First Look at the Data
Preliminary Results

Read-out Efficiency
- Amount of stubs created over time is constant → no loss of synchronisation, no ‘hickups’ in read-out
  → already a major improvement!
- No tracking information used yet

Stub Hit Resolution for ~0° incidence
- 23.13 μm residual width
- GBL track resolution with our setup geometry and X0 is 3.83 μm
  → $\sigma_{CBC} = (23.13^2 - 3.83^2)^{0.5} = 22.81$ μm
- Still has to be unfolded for individual CBC sensors
- Alignment of reference plane not quite optimal yet
X0 Scattering

Preliminary Results

Basic Idea

- Measure track kink angle distribution at the DUT with the telescope
- Large statistics needed → data taken overnight ‘for free’
- 2 GeV particles for maximum rate and scattering

Analysis ongoing...
Summary

Lessons Learned

Successful use of new uTCA-based DAQ & firmware
• First ever use in test beam environment
• Firmware proof-of-principle

Multiple severe issues encountered
• Curved wire-bond pads on hybrid are difficult to wire-bond
• 8CBC2 hybrid seems very susceptible to noise → to be investigated with xCBC3
• Low signal levels due to incorrect FE settings → no default setting is cast in stone!
• Loss of sync between telescope / pixel and CBC due to trigger level processing within DIO5 → fixed

For the next test beam
• More lab tests beforehand, more documentation during beam time
• FW code backed up / on the repo is good, but worthless without the corresponding binary file

Next steps
• More thorough analysis of data
• Comparison with previous beam tests and Allpix simulations
Backup
Spare Slides
The DESY II Test Beam Facility

Beam Properties

Facility is fed by the DESY II Synchrotron:

Bremsstrahlung / Conversion beam with $E_e$ from 1 – 6 GeV

- Carbon-fibre target inserted into primary beam
- Copper converter target
- Beam momentum changed by dipole magnet, with magnet current changeable by the user

Beam structure

- 500 MHz RF, basic magnet acceleration from 450 MeV to 6.3 GeV with 12.5 Hz
- 1 bunch per fill with 30 ps
- Rate depends on beam momentum, at 5 GeV $\rightarrow \sim 1$ kHz
- DESY II is the main injector for the PETRA III synchrotron ring
- Top-up of PETRA III ring every ~min – otherwise almost DC beam with no spill structure
Analysis Structure – Alignment

Offline Software

Data Conversion -> Clustering -> Filtering -> Hit Creation -> Stub Check -> Alignment -> Tracking

(Alignment-) Track finding

- Hit pairs on planes (0,2) and (3,4) are searched
Analysis Structure – Alignment

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Analysis Structure – Alignment

Offline Software

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• Triplets are extrapolated to the CBC stub and the Pixel Reference
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DESY. | The 8CBC2 Test Beam at DESY | Thomas Eichhorn | 19.01.2018
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- Triplets are extrapolated to the CBC stub and the Pixel Reference
- Triplets are validated by matching hits in the CBC and the Pixel Reference
- If both triplets match within a window at the CBC centre, a track is formed