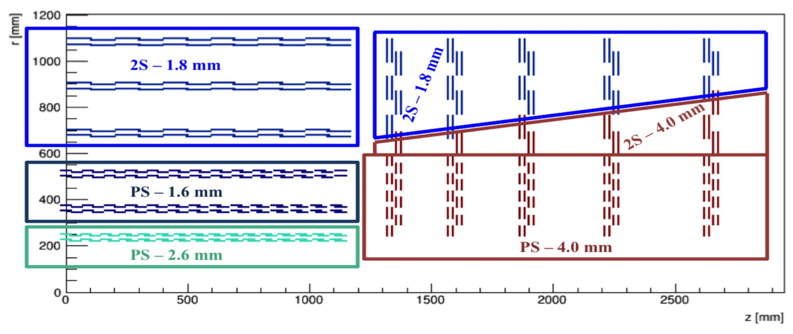
Test beam of the first CMS P_T-module using the CBC2 read-out chip for the Phase-II Upgrade.

Ali Harb, Johannes Hauk, Andreas Mussgiller, on Behalf of the CMS Tracker Collaboration. ESHEP, Bansko, Bulgaria, Sep. 2 – 15, 2015

The CMS Phase-II Tracker Upgrade

Upgrade Motivation

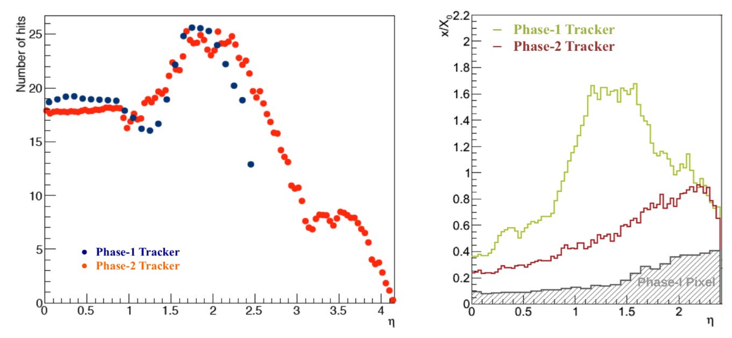
For the High Luminosity LHC (HL-LHC) a major upgrade is planed for the CMS experiment. In its Phase-II, the accelerator will reach luminosities up to $5 \times 10^{34}\,cm^{-2}\,s^{-1}$. To cope with the increased rates and occupancies, CMS will replace the current tracker with an entirely new system, which must be able to withstand the increased radiation corresponding to 3000 fb^{-1} integrated luminosity and resolve up to 200 collisions per bunch crossing while being able to provide information to the first level trigger (L1) and maintain the excellent tracking performance.



Map of the sensor spacing adopted in the Tracker. The sensor spacing is optimized at the same time as the acceptance window using tkLayout, to obtain a P_T threshold of 2 GeV for the stub selection in all module locations. The optimal acceptance window is then recalculated and fine-tuned using the Monte Carlo simulation [1].

Upgrade Requirements

> Radiation tolerance
> Increased granularity
> Improve two-track separation
> Reduced material in the tracking volume
> Robust pattern recognition
> Compliance with the L1 trigger upgrade
> Extended tracking acceptance

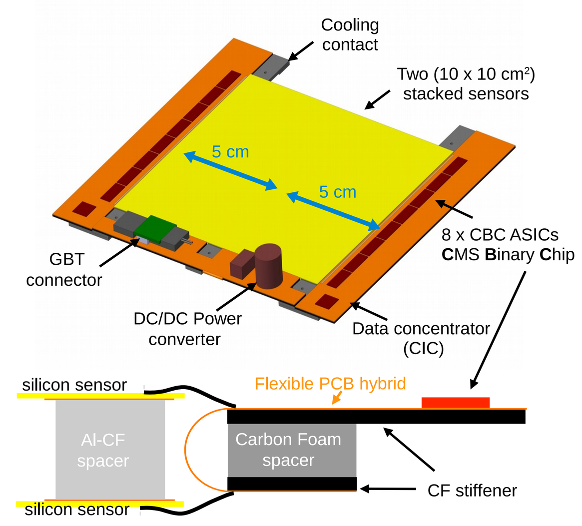


Number of hits (left) and radiation length (right) versus η for the Phase-II Tracker and the Phase-I Tracker. The radiation length distribution is shown for the tracking acceptance of the Phase-I Tracker, and reflects only the material inside the tracking volume; the expected contribution of the Phase-I pixel detector (hashed histogram) is provisionally used also for the Phase-II Tracker [1].

The Phase-II Outer Tracker Detector

The outer tracker consists of two types of P_T-modules, which are capable of rejecting signals from particles below a certain P_T threshold. The PS (7084) modules composed of two closely-spaced pixel/strip sensors. The 2S (8424) modules with two closely-spaced strip sensors. The stacked sensors in each module are read out with a common chip which correlates signals of both sensors for the L1 trigger that pass the P_T threshold, which are called stubs.

The 2S module Design



The 8424 2S modules populate the outer regions of the tracker, above R~60 cm, with ~150 m^2 sensing area. The design of the module is driven by the requirements of efficient removal of the heat, accurate geometrical positioning, minimal mass, and reproducible assembly procedure [1].

Module Design

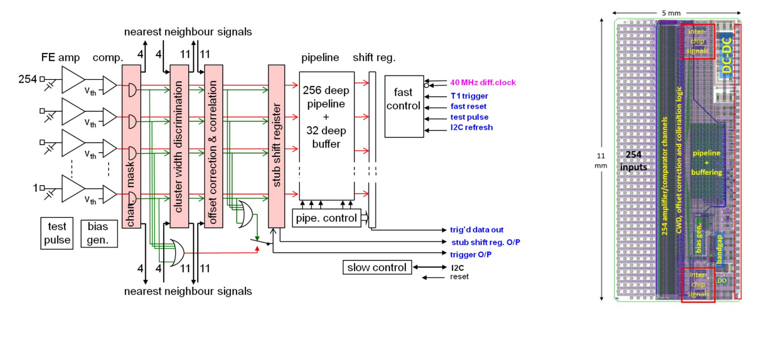
> Two sensors, with parallel strips, wire bonded to the same flexible-hybrid and glued to two long Al-CF spacers
> 5 cooling contacts, 4 at the end of the spacers + 1 close to power components
> CBC ASICs bump-bonded on the flexible hybrid
> Single service hybrid carries low power GBT data link, and DC/DC power converter

Sensors

> n-in-p Silicon bulk
> 2 columns of 5 cm long strips with 90 µm pitch
> ~ 10 x 10 cm^2 active area

Read-out chip:The CMS Binary Chip (CBC)

The CBC2[2] is the second, version of the CBC produced in 130 nm CMOS technology. It has 254 input channels (127 per sensor) and is designed to provide an on-board L1 trigger using stub-finding logic for high-P_T track identification.



CBC2 block diagram and layout [2].

Stub-finding logic:

1. Cluster width discrimination (CWD), max. 3 adjacent strips.
2. Offset correction (±3 strips) & correlation logic (±8 strips).

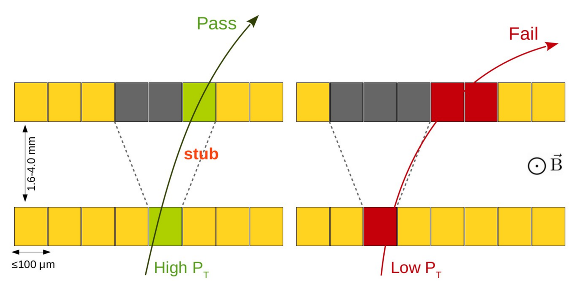
Read-out

> Neighboring CBCs exchange data to identify boundary clusters.
> The data flow separates L1 readout (DAQ) from Trigger (TRIG).
> 2 bits of DAQ and 10 bits of TRIG data sent out every 6.2 ns.
> Unsparsified binary readout data up to a 1MHz L1 rate per CBC.

The "stub" concept for high-P_T track selection

The first stage of stub finding starts with adjacent strips analysis, and wide clusters rejection on both sensors. Then for every valid cluster on the lower sensor the correlation logic will look for a valid cluster in the coincidence window on the upper sensor. Finding any indicates that a valid stub is found.

> Stub data are sent out to the L1 trigger at each bunch crossing (40 MHz).
> 5 to 10% (~125 stub per bunch crossing) belong to primary tracks with P_T > 2 GeV [1].
> Tracks are reconstructed by the L1 Track Finding system based on pattern recognition.



The concept of the two layers P_T-module of discrimination between high and low-momentum tracks identified as "pass" and "fail" stubs respectively.

The tracks P_T discrimination is highly dependent on the position of the module in the tracker volume. To keep a uniform P_T threshold across the tracker (~2 GeV), different sensor spacings (~1.6-4.0 mm) and incidence window sizes (max. ±8 strips) must be implemented in different regions of the tracker.

DESY-II Test Beam Setup and Measurements

DESY-II electron/positron beam

> DESY operates a test beam facility with three test beam lines [3].

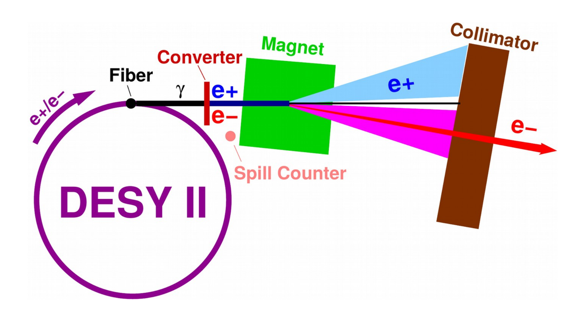
> Electron/positron beam converted into bremsstrahlung photons.

> Bremsstrahlung photons are converted via thick copper target into electron-positron pairs.

> The beam is spread by a dipole magnet.

> Cut out with a collimator slit to the experimental hall.

> The beam has an energy of 1GeV to 6GeV with spread of ~ 5%, a divergence of ~ 1 mrad, and a rate of O(1) kHz.



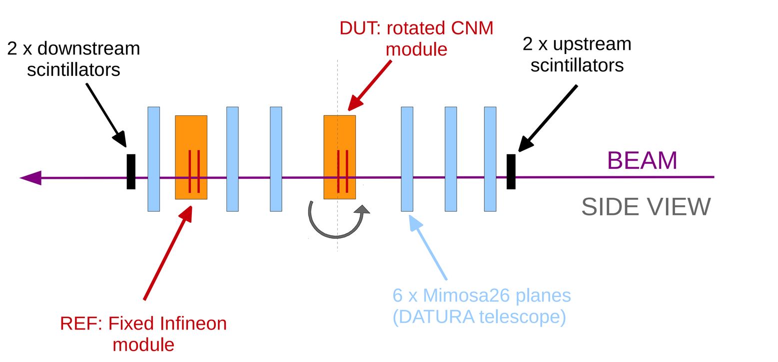
Setup for data taking

> DATURA telescope : 6 x Mimosa-26 pixel sensor planes

> 2 x mini-2S modules, device under test (DUT) and reference (REF), see table

> 2 x upstream and 2 x downstream trigger scintillators

> Trigger Logic Unit (TLU)



Module	Vendor	Bulk	Pitch [μm]	Thickness [μm]	Length [mm]	strips #
DUT	CNM	p-type	90	270	54	254
REF	Infineon	n-type	80	300	50	256

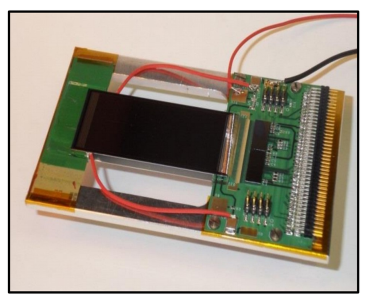
Measurements

> Positron beam, 2-4 GeV energy, O(1) kHz rate.

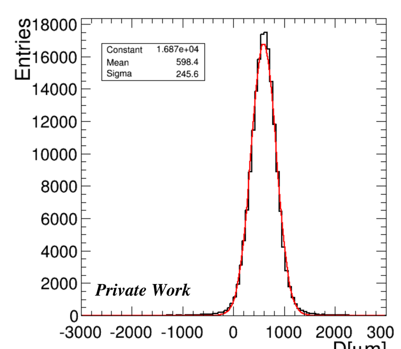
> DUT mounted on xy&rotation stage, with REF fixed downstream.

> Threshold scans (6ke- to 40ke-).

> Angular scans simulating magnetic field effect.



mini-2S module with 2 CBC2 chips wire bonded to 2 sensors (~3 mm spacing) with 254 strips each [1].

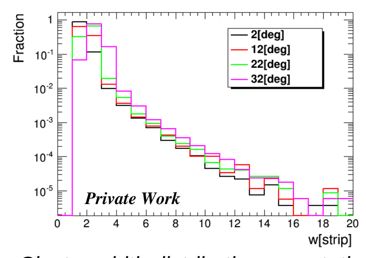


Beam Divergence obtained by the DUT&REF modules ~1mrad.

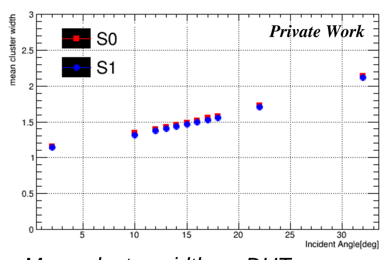
Events reconstruction

The CBC2 chips only provide binary read-out without information about the charge deposition on each strip, therefore, clusters are defined as group of neighboring strips registered a signal.

At low rotational angles the cluster width is dominated (~90%) by single strips, while more clusters with 2 and 3 strips arises significantly at 22º and 32º respectively.



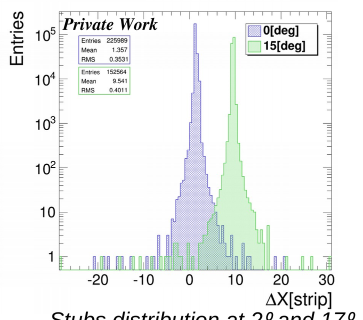
Cluster width distribution vs. rotation.



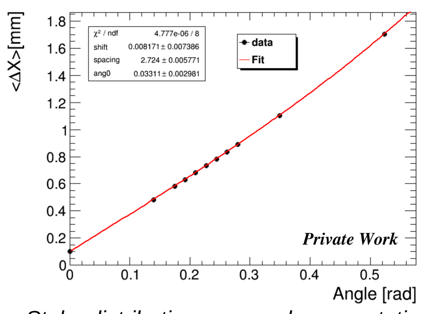
Mean cluster width on DUT sensors (S0 and S1) at different incident angles vs. simulation.

Stubs are reconstructed using the difference of the position of clusters on the upper and lower sensors ΔX. This difference increases with increasing incident angle.

From the fit of the mean value of ΔX at different angles we obtained an angular offset of 2º between nominal and real angle, 2.7 mm sensor spacing, and ~8 µm strips offset.

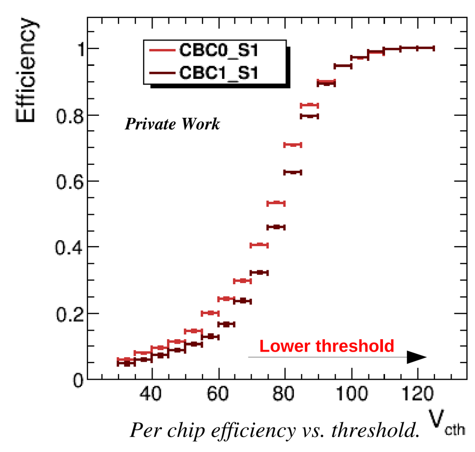


Stubs distribution at 2º and 17º.

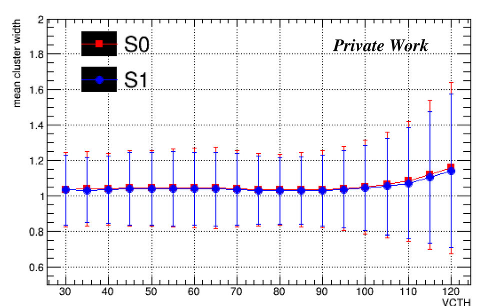


Stubs distribution mean value vs. rotation.

Efficiency Studies vs. Threshold and Rotation angle



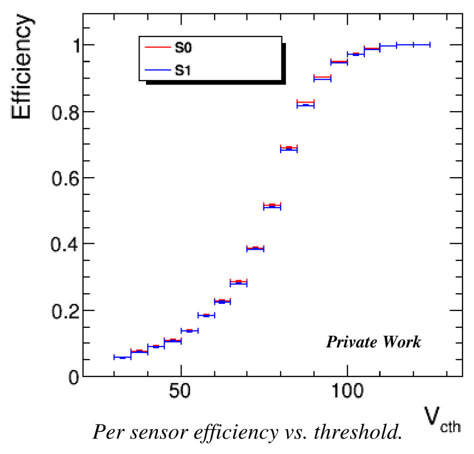
Per chip efficiency vs. threshold. V_{cth}



Mean cluster width vs. threshold S0 & S1.

DUT	Eff. S0
CBC2_0	99.97%
CBC2_1	99.96%

REF	Eff. S3
CBC2_0	99.97%
CBC2_1	99.96%



Per sensor efficiency vs. threshold. V_{cth}

A threshold scan was performed for the DUT during the test beam, which showed a similar behavior for both sensors and the chips of the module in terms of clustering and efficiencies.

The efficiency was studied at different thresholds, where the threshold of the DUT was varied by 1.8ke- steps, from V_{cth} = 120 (~6ke-) to V_{cth} = 30 (~40ke-).

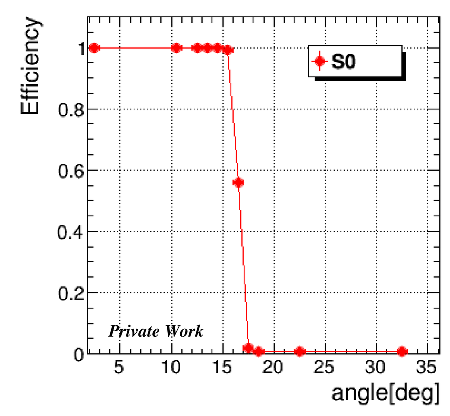
$$\epsilon_{sensor\ (or\ chip)} = \frac{Events\ selected\ on\ sensor\ (or\ chip)\ under\ study}{Total\ number\ of\ events}$$

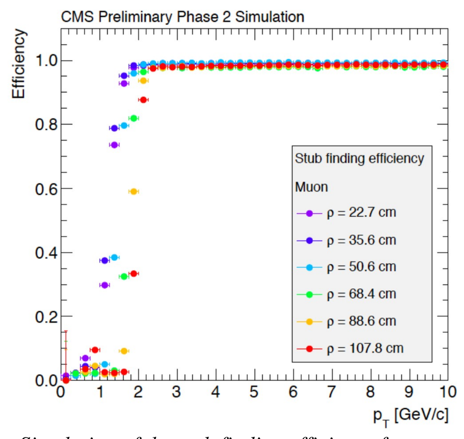
For V_{cth} > 110 an efficiency higher than 99% was obtained per sensor (and chip).

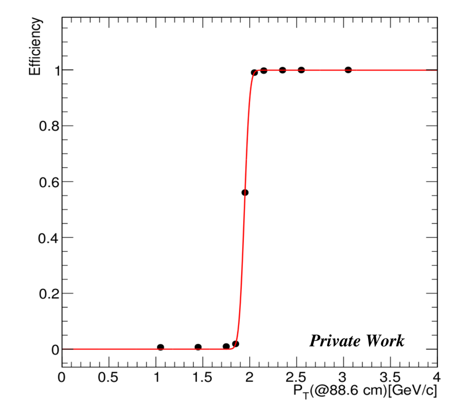
The efficiency was studied at different rotational angles of the DUT simulating the effect of the CMS magnetic field on the transverse momentum of charged particles. The P_T values at distance D from the beam pipe center are obtained using the following equation, where θ is the angle of rotation.

$$P_T[GeV] = \frac{0.57D[m]}{\sin(\theta)}$$

For a barrel layer with a distance D = 0.886 m from the interaction point a P_T threshold of 2 GeV can be obtained when the module's parameters (sensor's spacing, acceptance window size, and pitch size) are properly adjusted as shown in the lower right plot.







Simulation of the stub finding efficiency for muons (left)[1], in all barrel layers of the outer tracker, and stub finding efficiency (right) measured during the test beam; the angle between the beam and the DUT is translated into an equivalent P_T at a radius of 88.6 cm in the barrel region.

Conclusions

> A first test beam with mini 2S-module read out by CBC2 chip was performed with a positron beam (2 to 4 GeV) successfully at DESY.

> The stub concept was proven to be working as expected by performing an angular scan, obtaining a plateau of ~99% efficiency for tracks with P_T higher than 2 GeV.

> A threshold scan per sensor and chip showed that at low thresholds (6ke-10ke), an efficiency of 99% is achieved.

Outlook

> A test beam with irradiated mini-2S modules took place in June 2015. Data is currently being analyzed including Telescope data in order to perform precise tracking.

> A first full 2S module with 8 CBCs will be tested at CERN in November this year.

> A third version of the CBC (CBC3) is under development

References

[1]Technical Proposal for the Phase-II Upgrade of the CMS Detector, CERN-LHCC-2015-010 ; LHCC-P-008

[2]Characterization of the CBC2 readout ASIC for the CMS strip-tracker high-luminosity upgrade - Braga, D. et al. JINST 9 (2014) C03001

[3]http://testbeam.desy.de/

Contact:
ali.harb@desy.de

HELMHOLTZ
GEMEINSCHAFT