The 8CBC2 Test Beam at DESY

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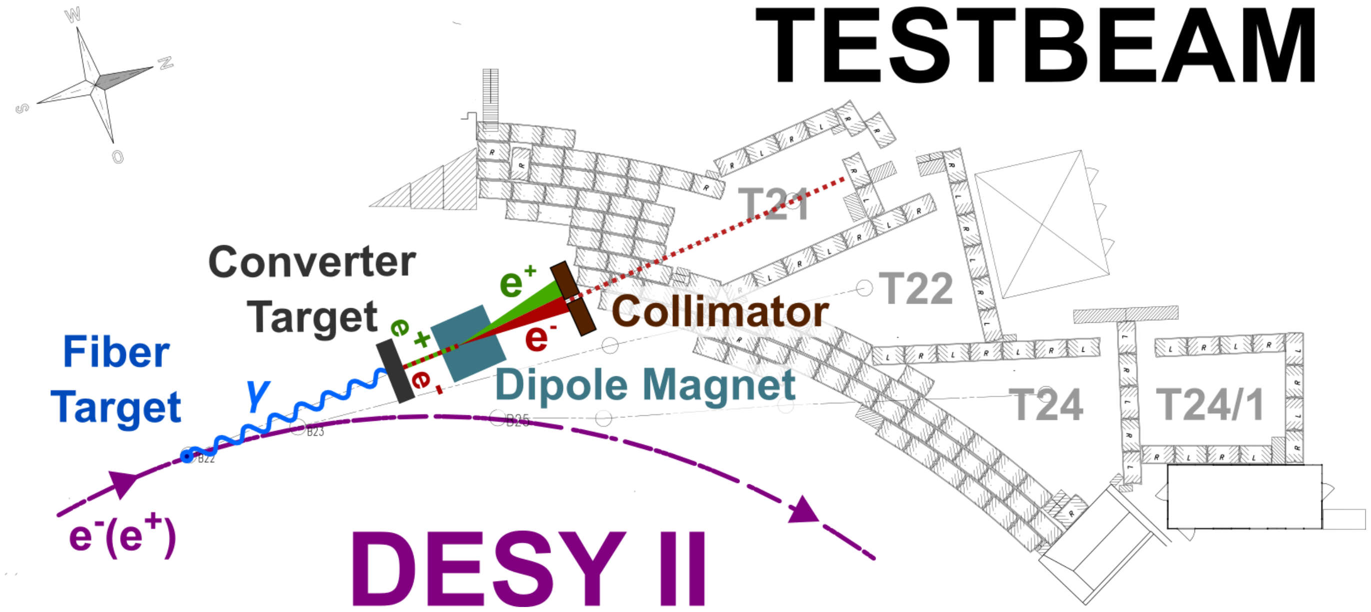

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Outline

Introduction

- CMS Phase-II Outer Tracker Upgrade
- pT Modules

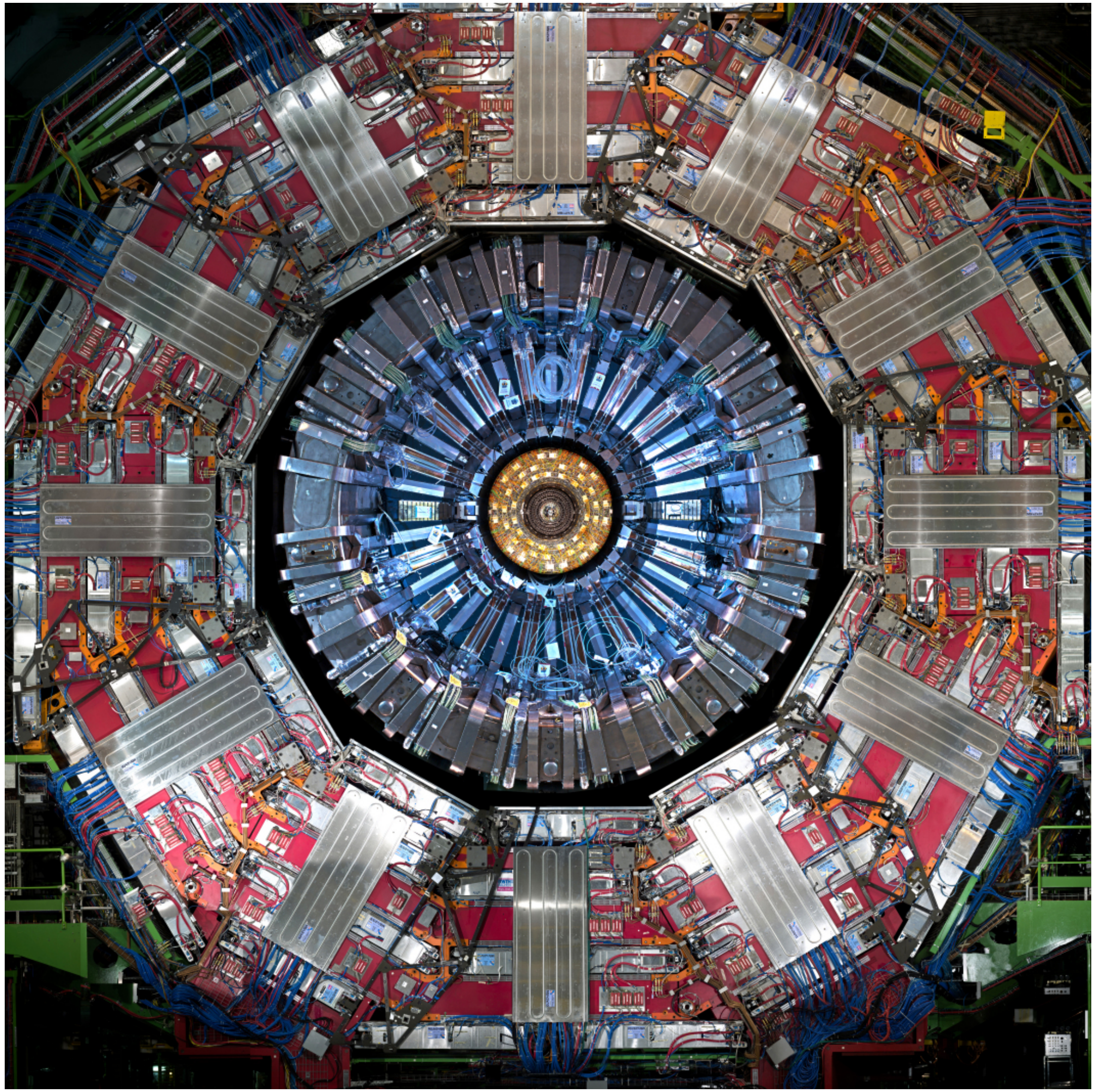
Module Assembly

- Design
- Manufactured TB Module

Beam Test Hardware Setup

Analysis Structure

First Results



The CMS Phase-II Outer Tracker

An Overview

HL-LHC environment

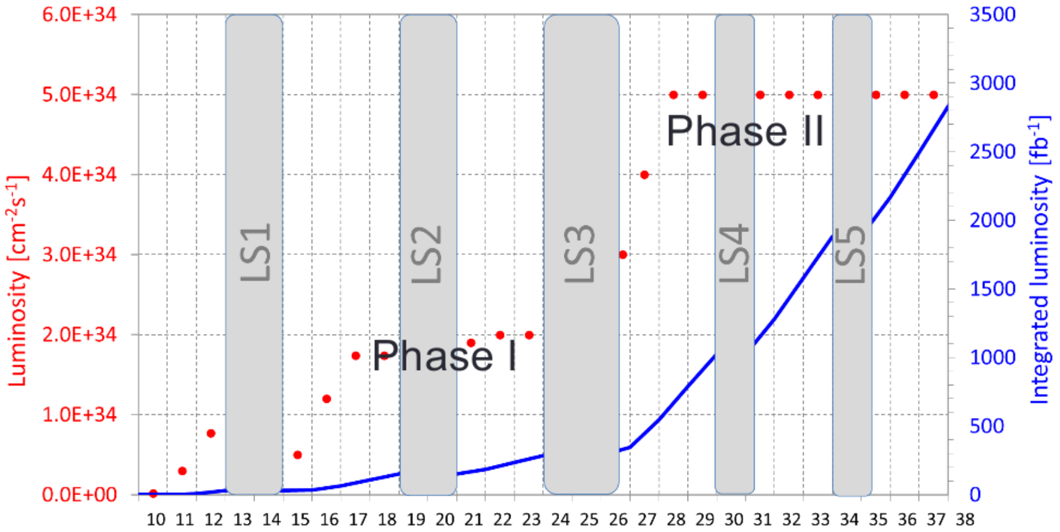
- Instantaneous luminosity of up to **7.5×10^{34} cm^{-2}s^{-1}**
- Integrated luminosity of over **3000 fb^{-1}**

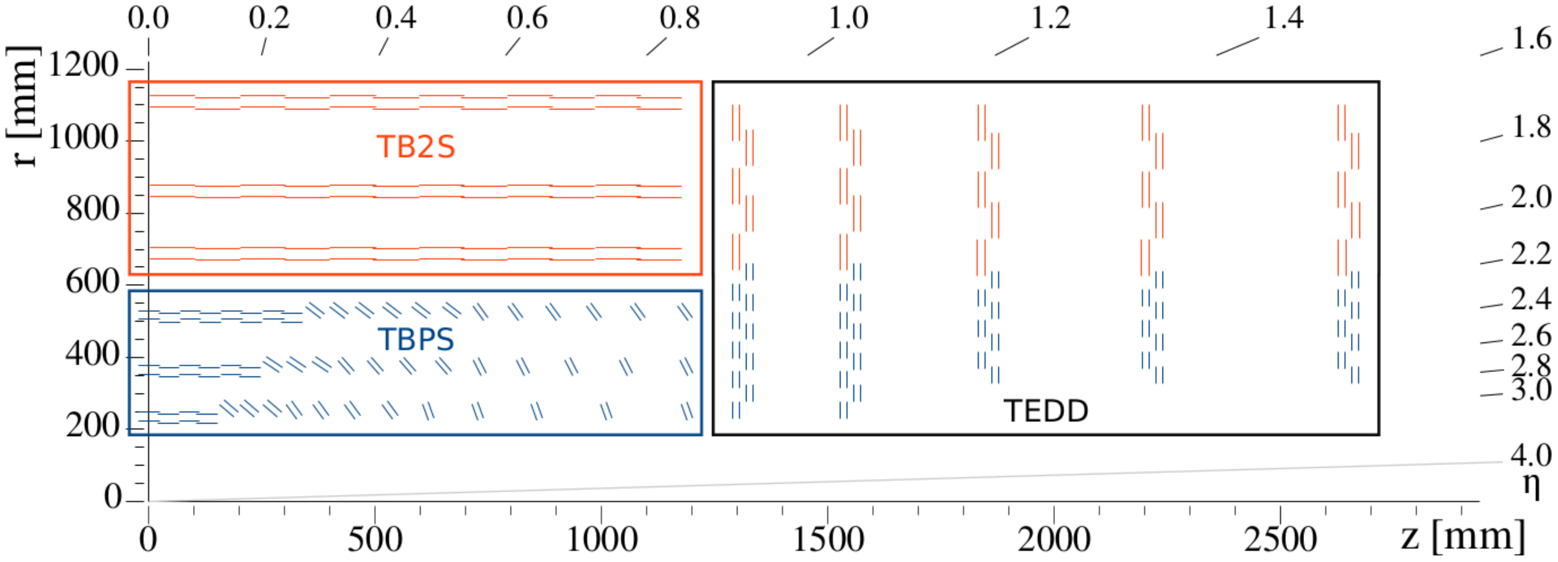
All-new OT baseline geometry

- 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

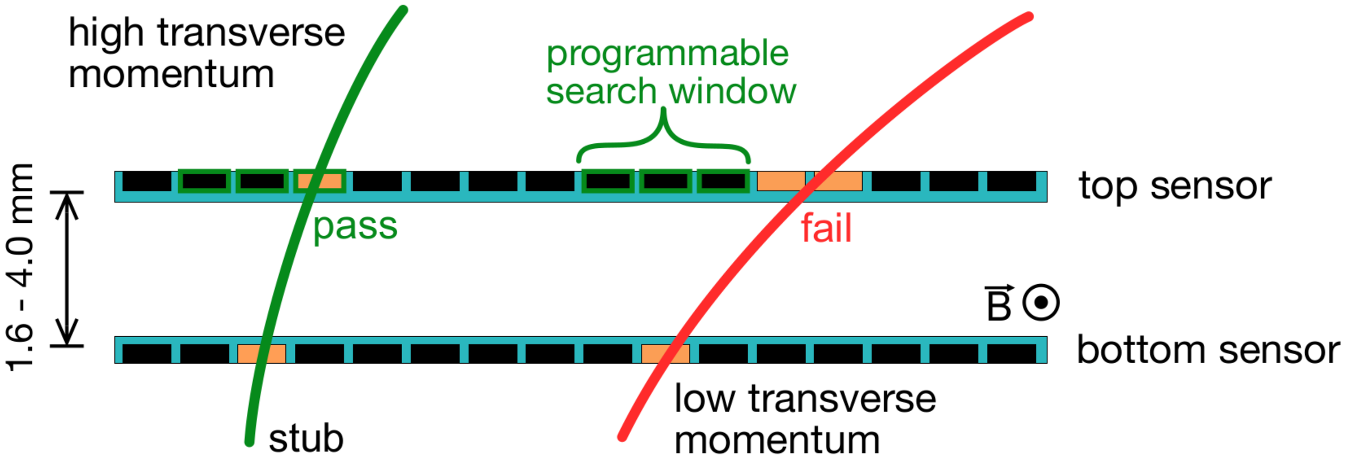
- Exploit bending of charged particle tracks in B-field
- **CMS Binary Chip (CBC)**: Correlate hits from 2 closely spaced sensors to form **stubs**
- Tuneable offset and window for **homogeneous pT threshold** throughout the OT

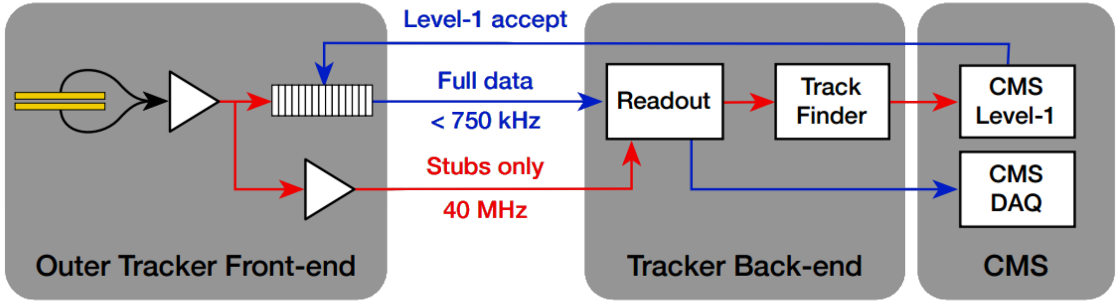
Tracker input to the L1 trigger

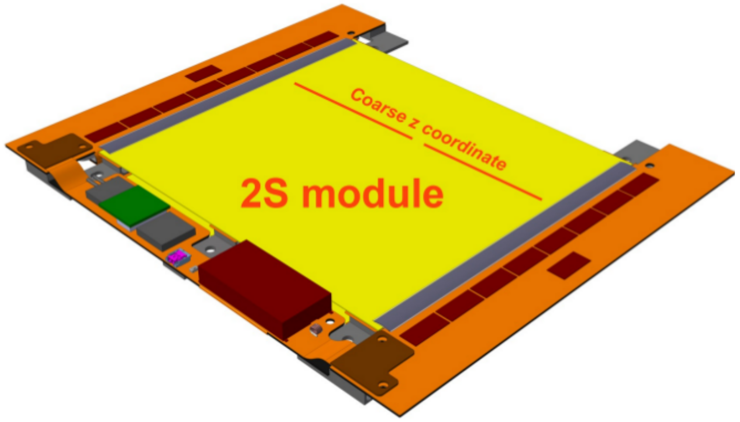
- Stub information is sent out at BX frequency of 40 MHz
- 2 data lines: trigger information and hit data
- Full data read-out at 750 kHz

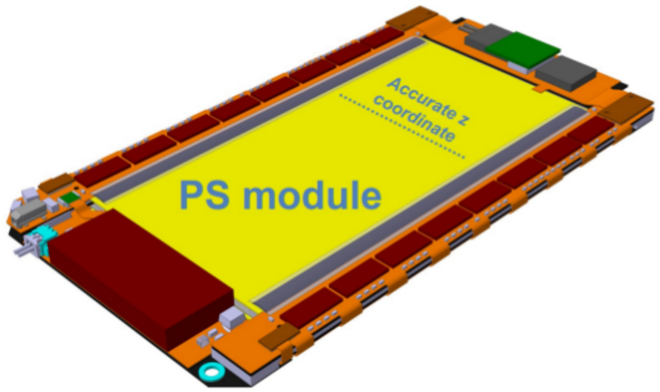
Two module variants

- **2S Module**: two strip sensors
- PS Module: (macro) pixel sensor and strip sensor



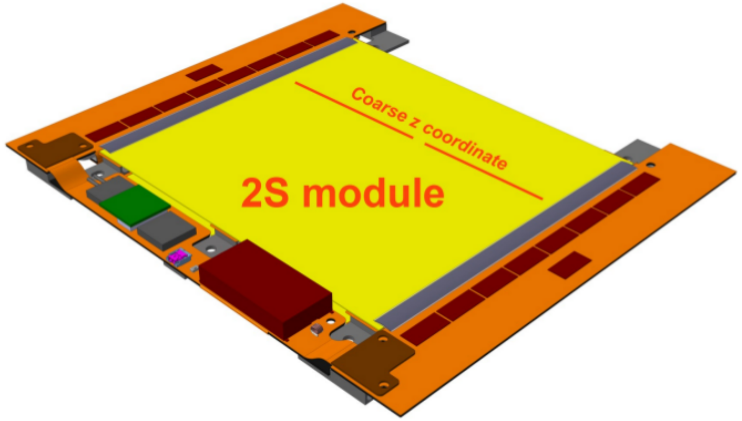






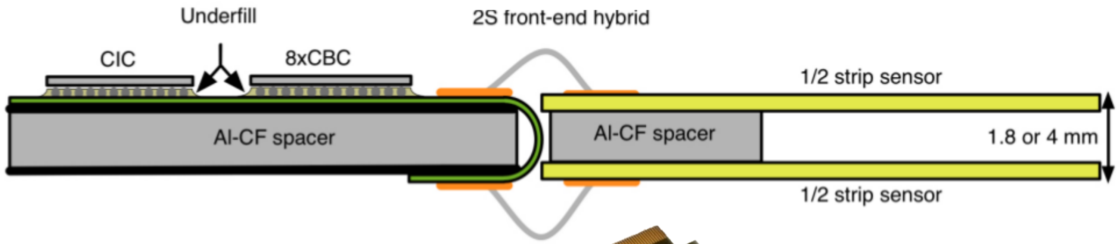
The 2S Tracker Module

Components and Design



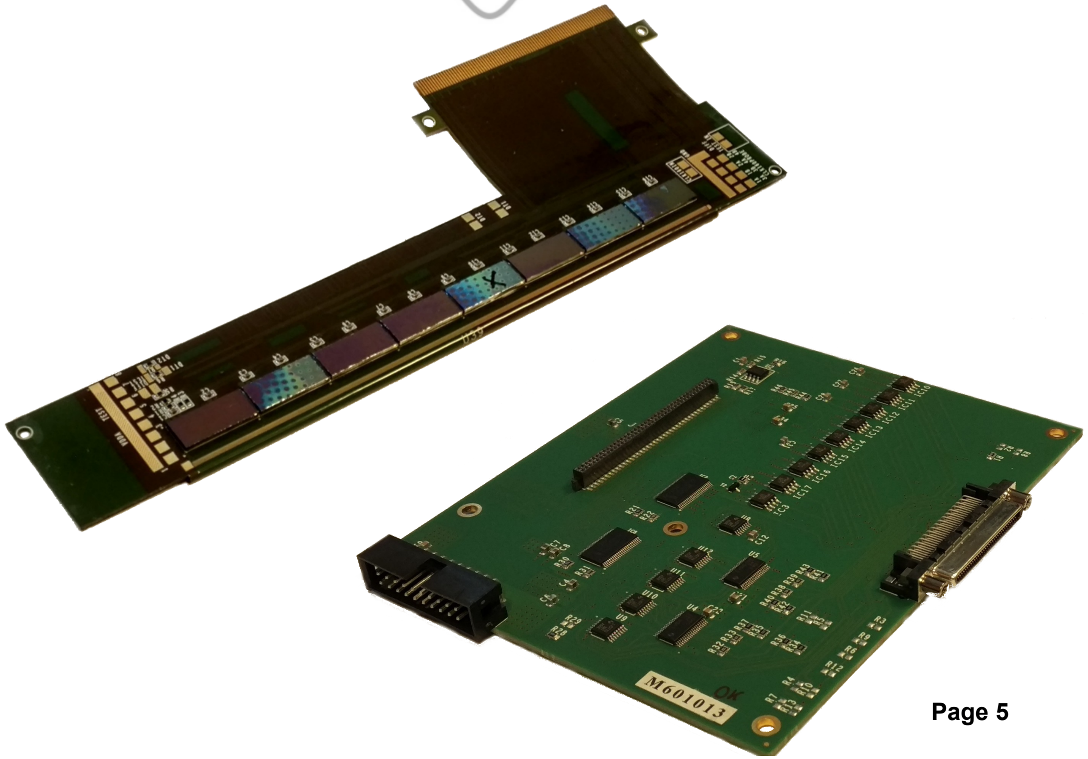
CBC read-out chip

- Correlates signals from top and bottom sensor
- 2nd prototype iteration; CBC3 already undergoing qualification
- 254 input channels with 90 µm 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

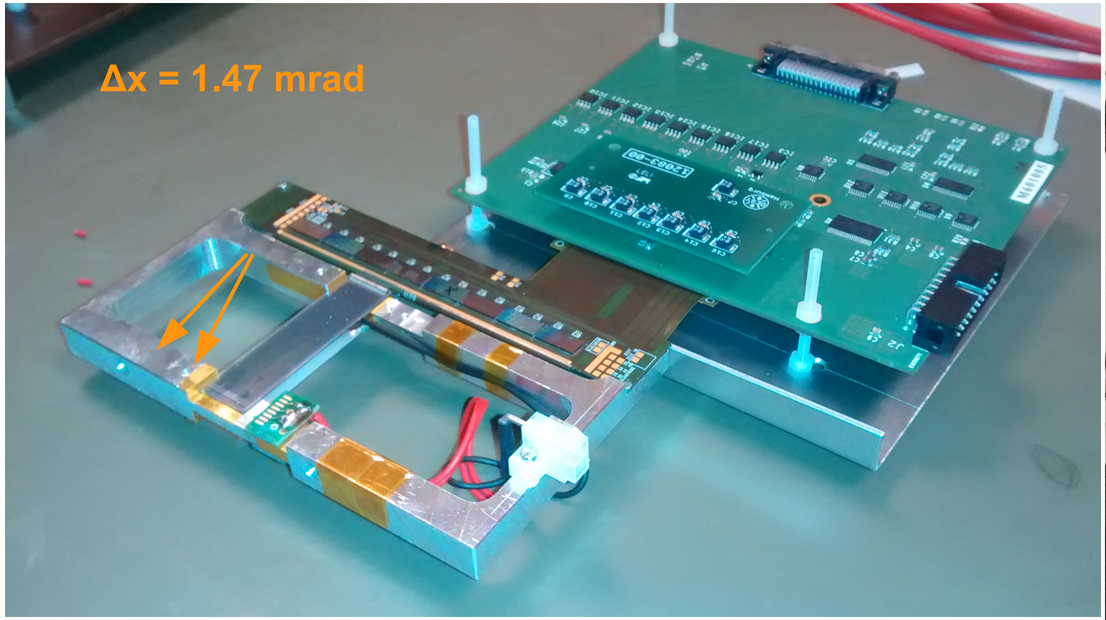
- Correlation of top and bottom sensor signals requires precise mechanical assembly

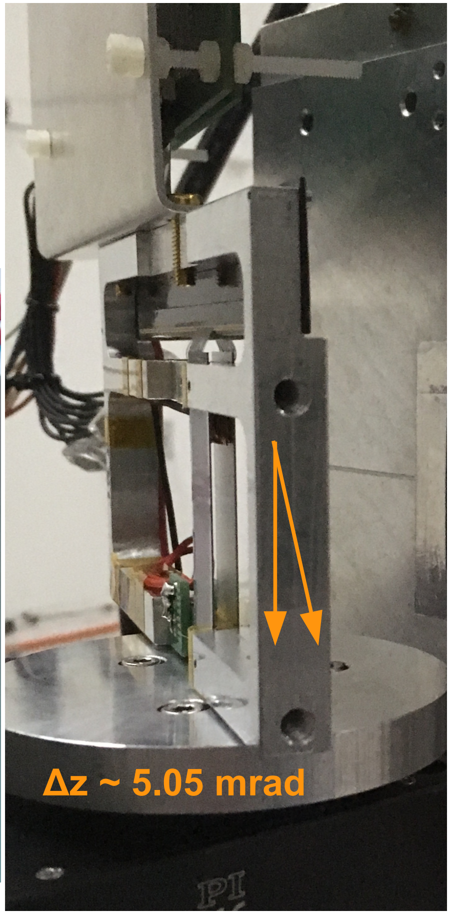
The ‘8’CBC2 Micro-Module

Assembly

Design due to available sensors

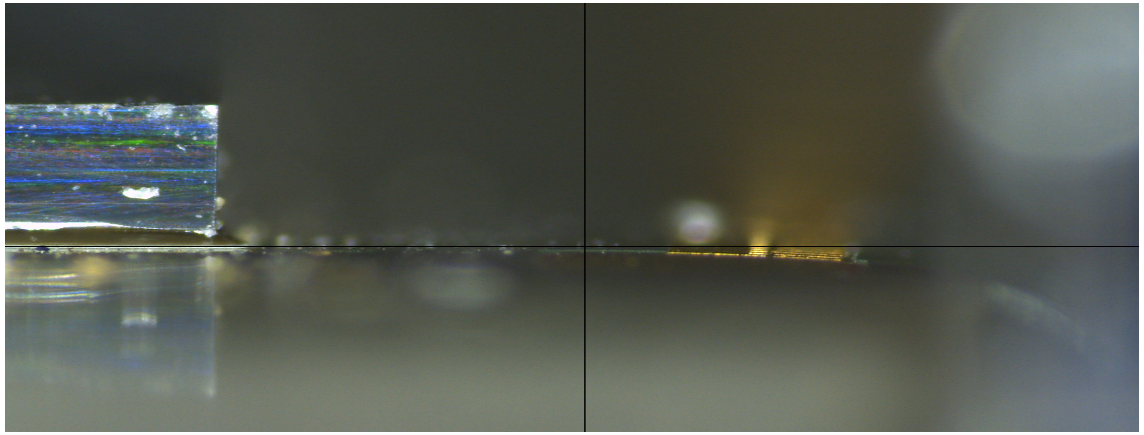
- 2 × HPK 2S baby sensors with 127 strips
- p-type ddFZ with 320 µm physical, 200 µm active thickness
- Connect to 2 CBC chips to test inter-chip communication
- Aluminium frame for rigidity and alignment of sensors
- Smartscope optical measurement: Δx ~ 1.47 mrad, Δz ~ 5.05 mrad





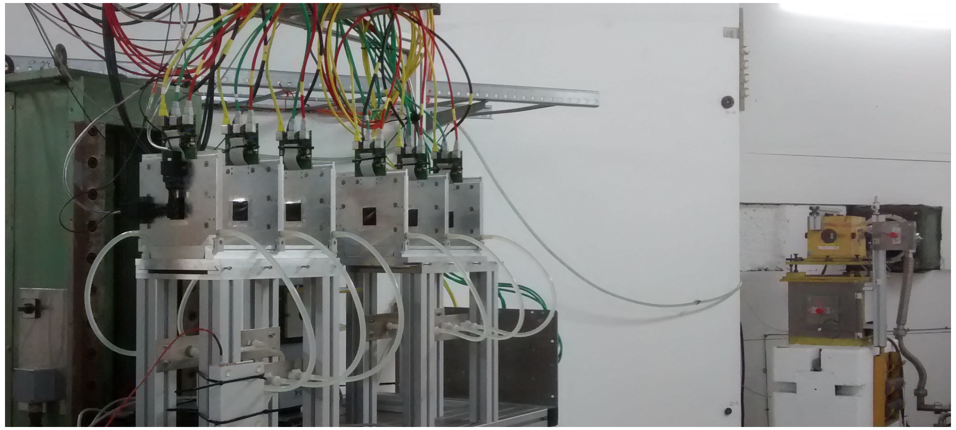
Issues encountered:

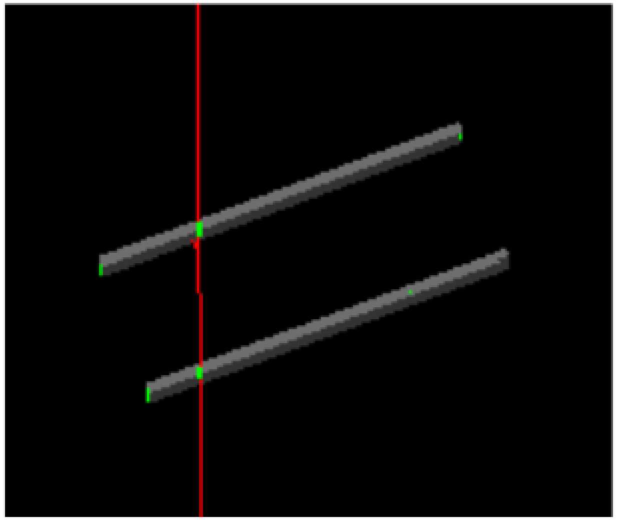
- Wire-bonding: bond-pads on hybrid not entirely flat
- Our glueing jig seems to have left some residue on the sensors
- At first very high noise levels → partially fixed by GND interconnection of HV and LV



Overall Setup – part I

Used Hardware

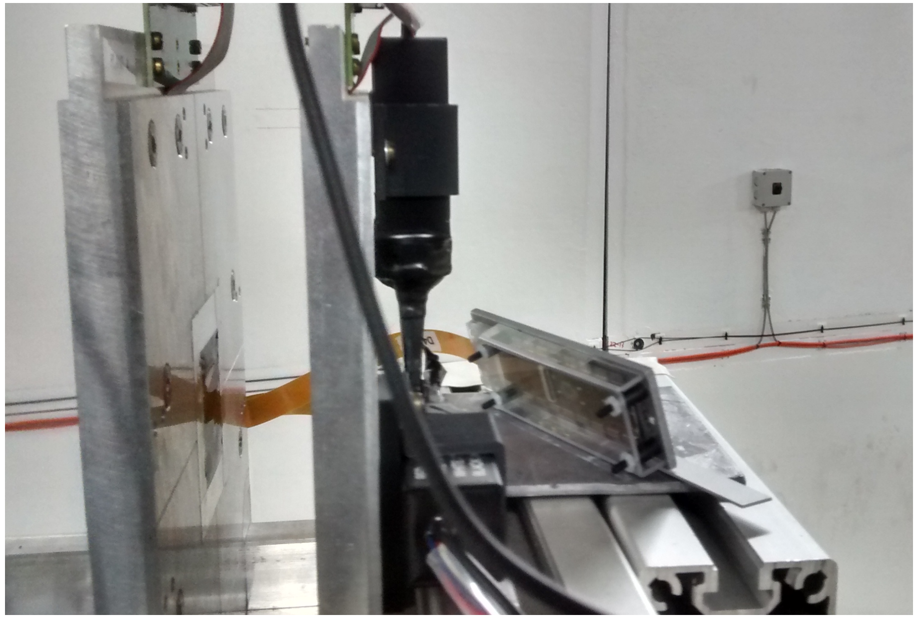




DURANTA Telescope

- 6 × MIMOSA-26 sensors (21.2 mm × 10.6 mm) with NI-based DAQ
- XYφ-rotation stage for DUT

  → use module rotation to mimc particles of different momentum

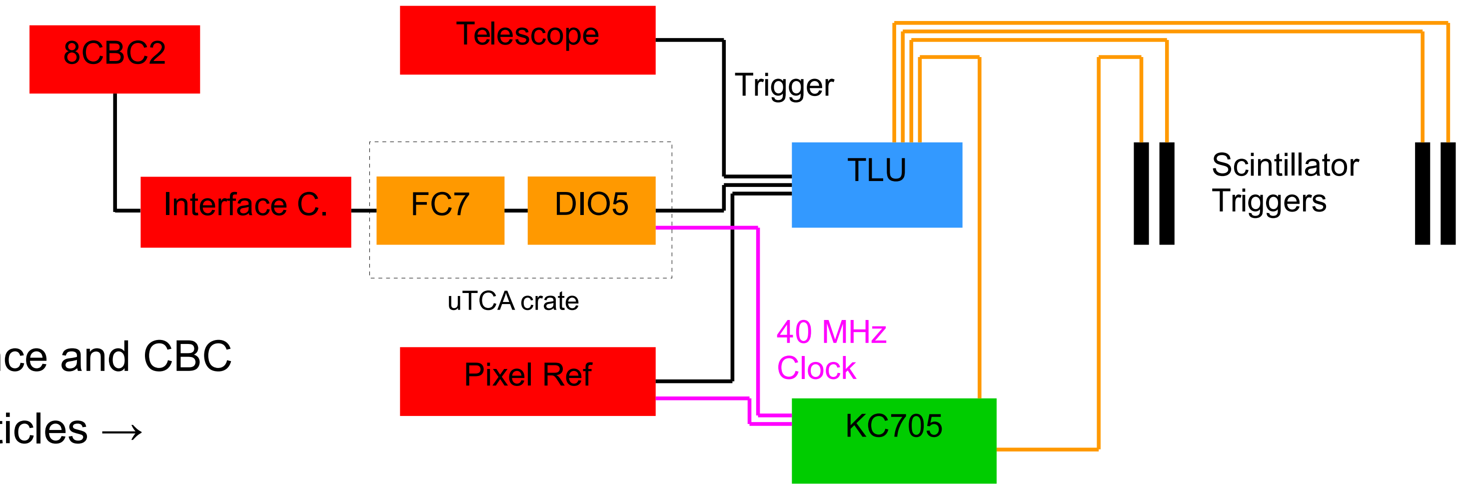


CMS Phase-I Pixel Reference Module

- Use as timing reference
- Full coverage of telescope window
- Rotated in α and β for optimal resolution

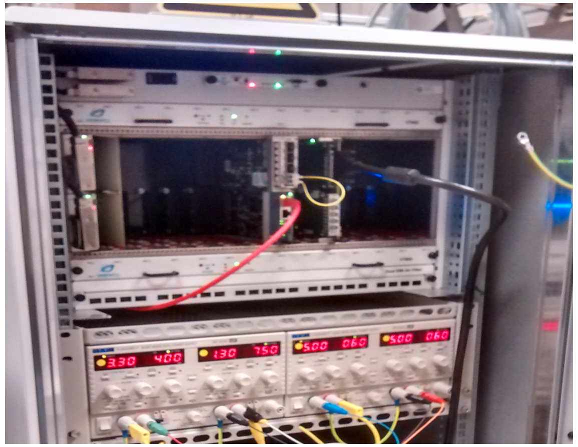
Overall Setup – part II

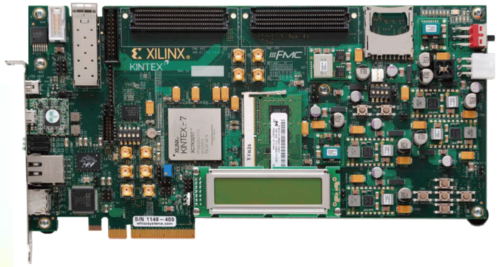
Used Hardware & DAQ



Clock: Xilinx KC705 FPGA

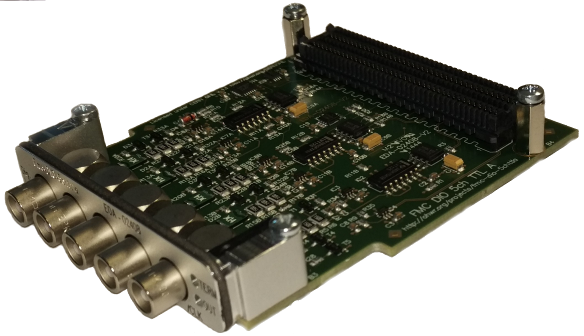
- Generate common 40 MHz clock for pixel reference and CBC
- With scintillator trigger input: veto out-of-time particles → 'sync' clock to beam, but rate limited
- CERN AMC13 was to be used at first, but external output not easily usable...

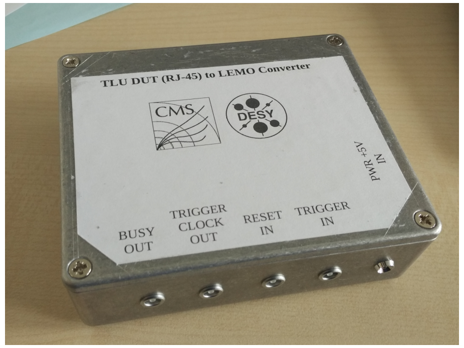




DAQ system based on uTCA

- FC7 FPGA for read-out
- Running d19c firmware
- DIO5 for connection to TLU (via optional LVDS converter box) and trigger / clock input



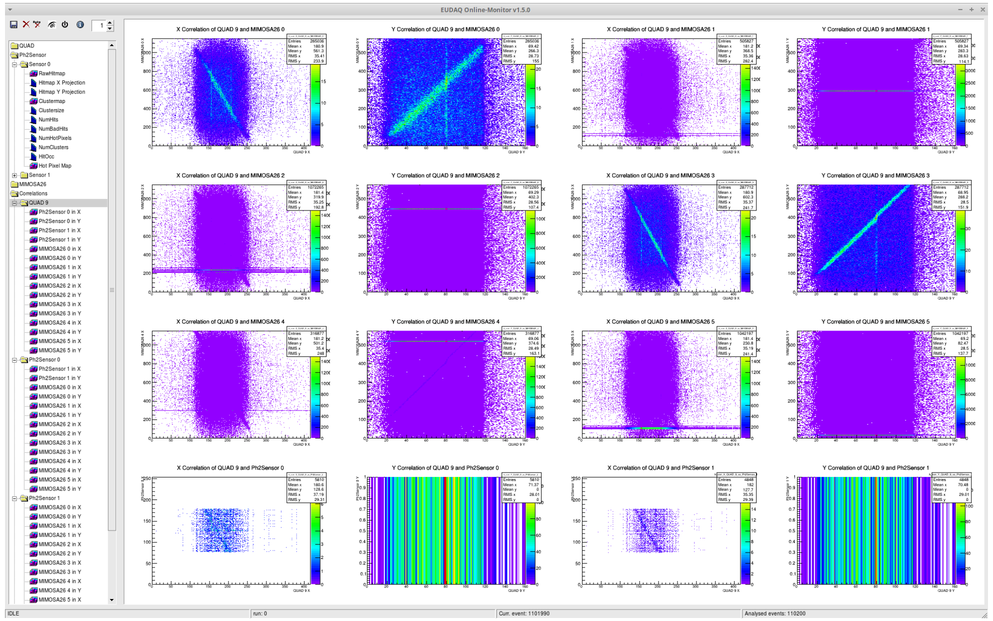


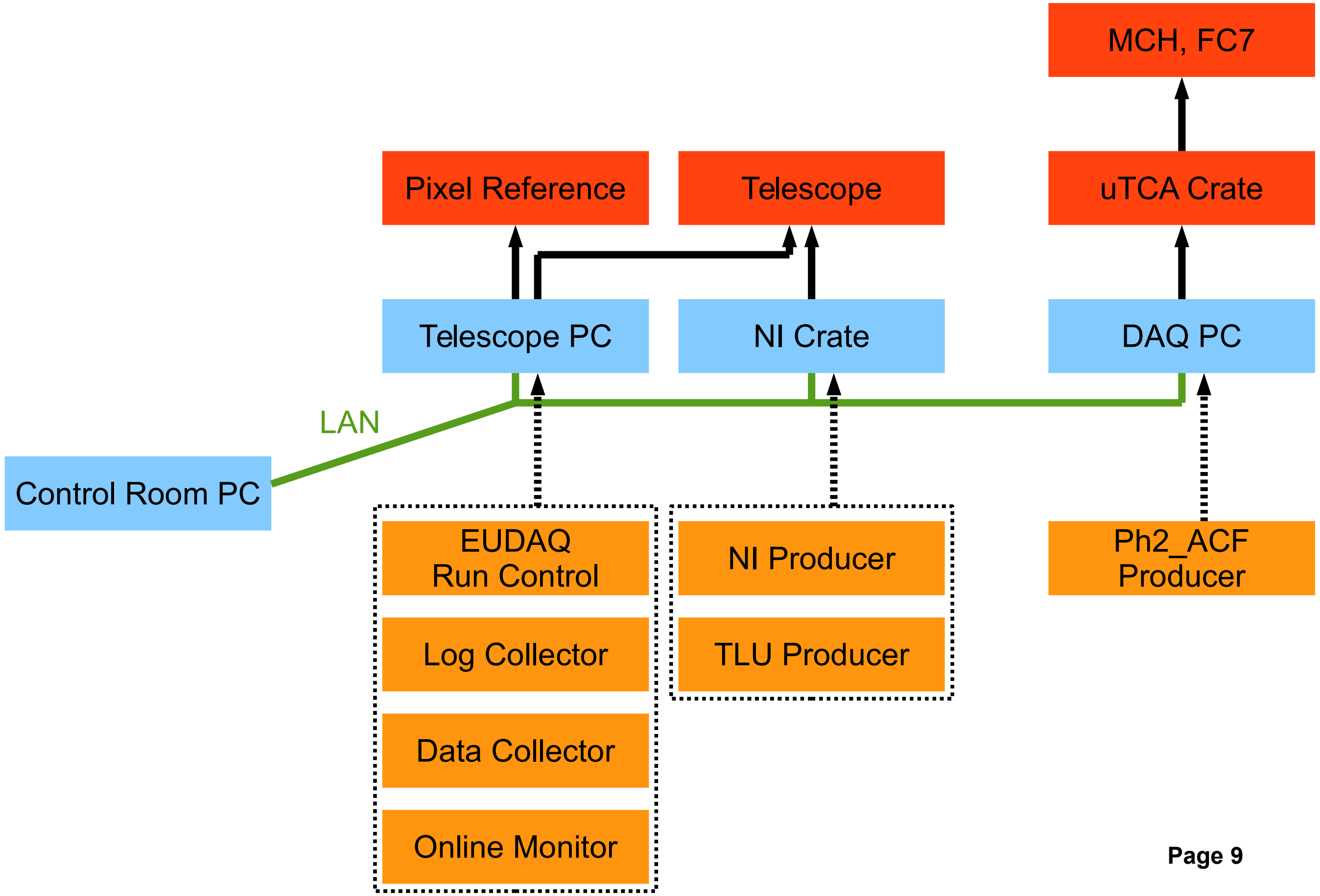
Data Taking

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



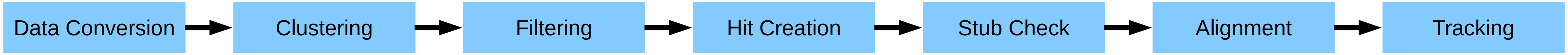


Analysis Structure – part I

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

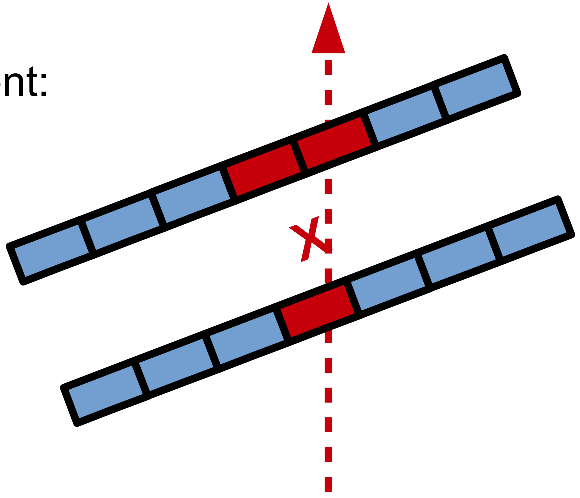
Offline Software

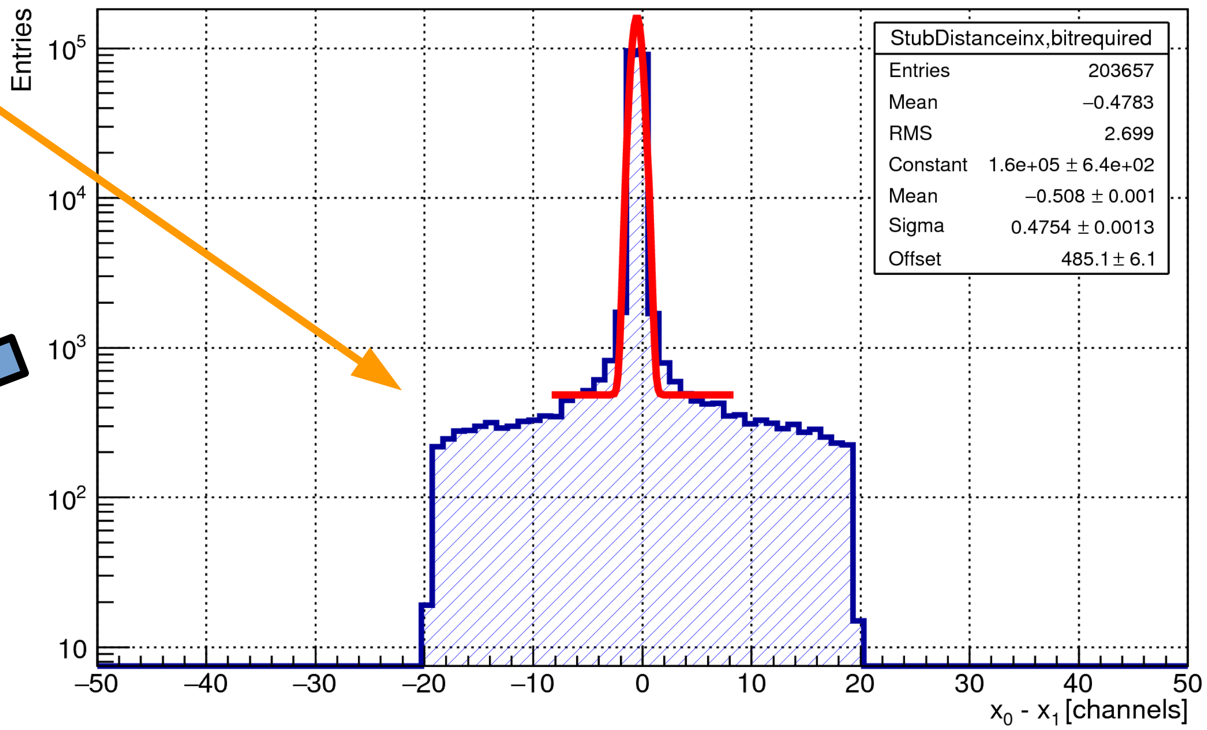
Data Conversion → Clustering → Filtering → Hit Creation → Stub Check → Alignment → Tracking

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

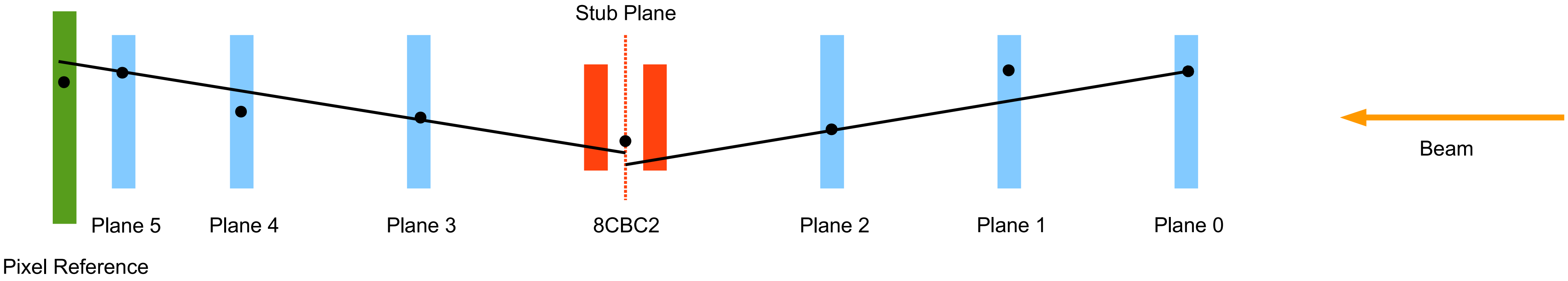
Data Conversion → Clustering → Filtering → Hit Creation → Stub Check → Alignment → Tracking

Alignment

- 10 iterations of GBL (General Broken Lines) fitting, with tightening of residual cuts, resolutions, χ^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

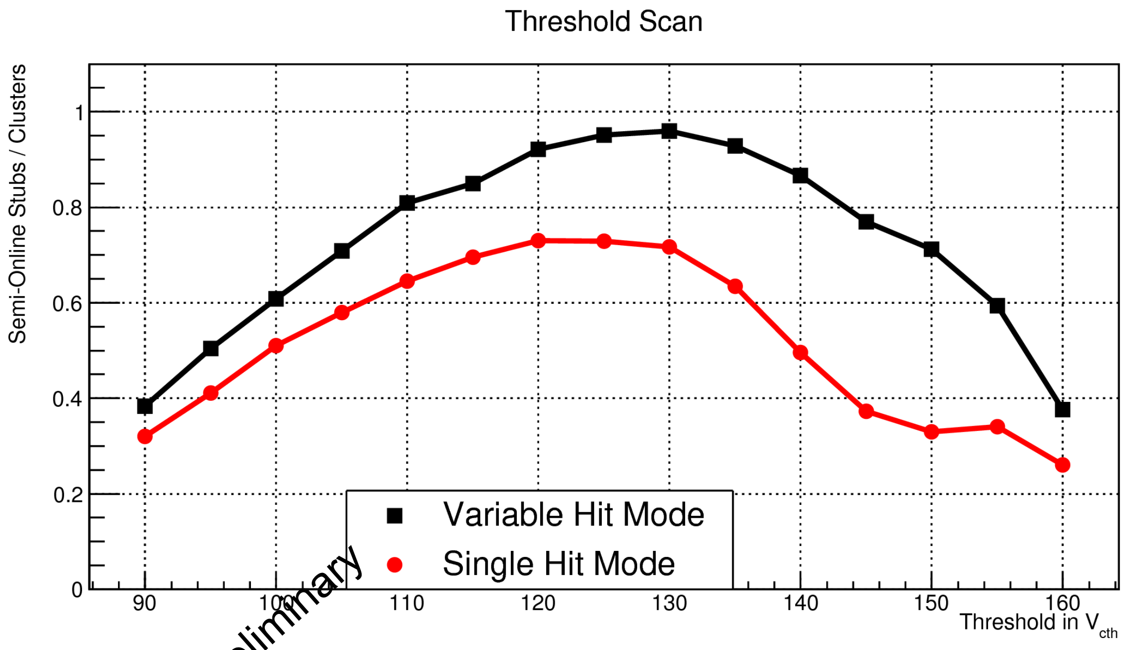
Latency scans for data and stub read-out

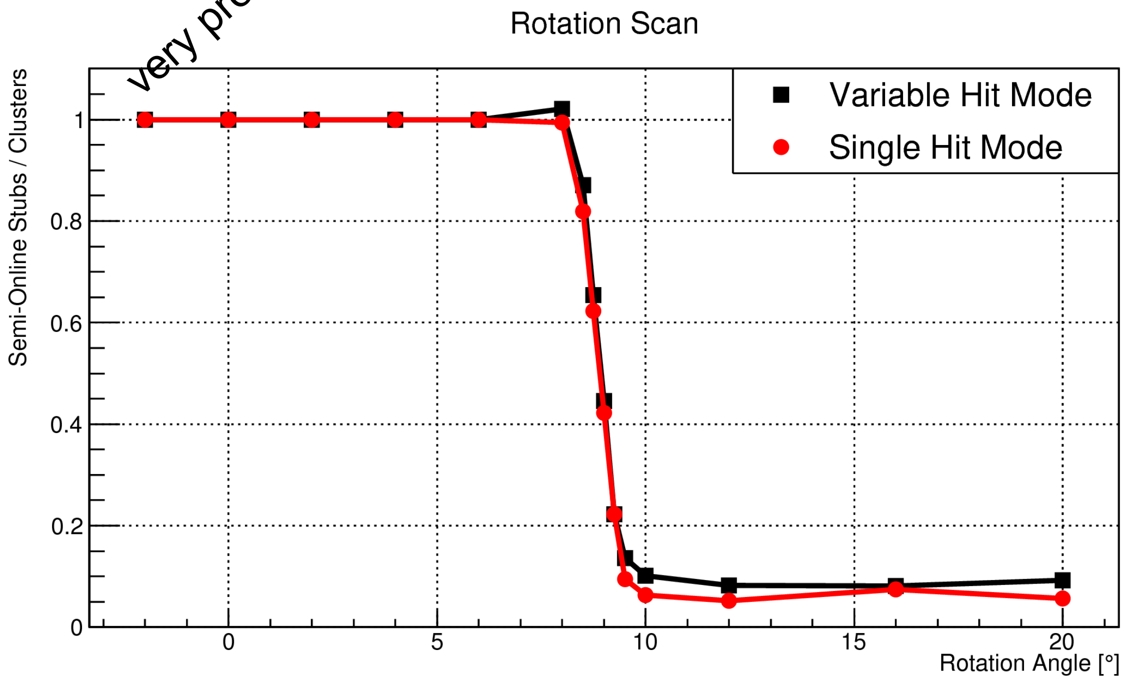
DUT Rotation to verify stub functionality

- 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

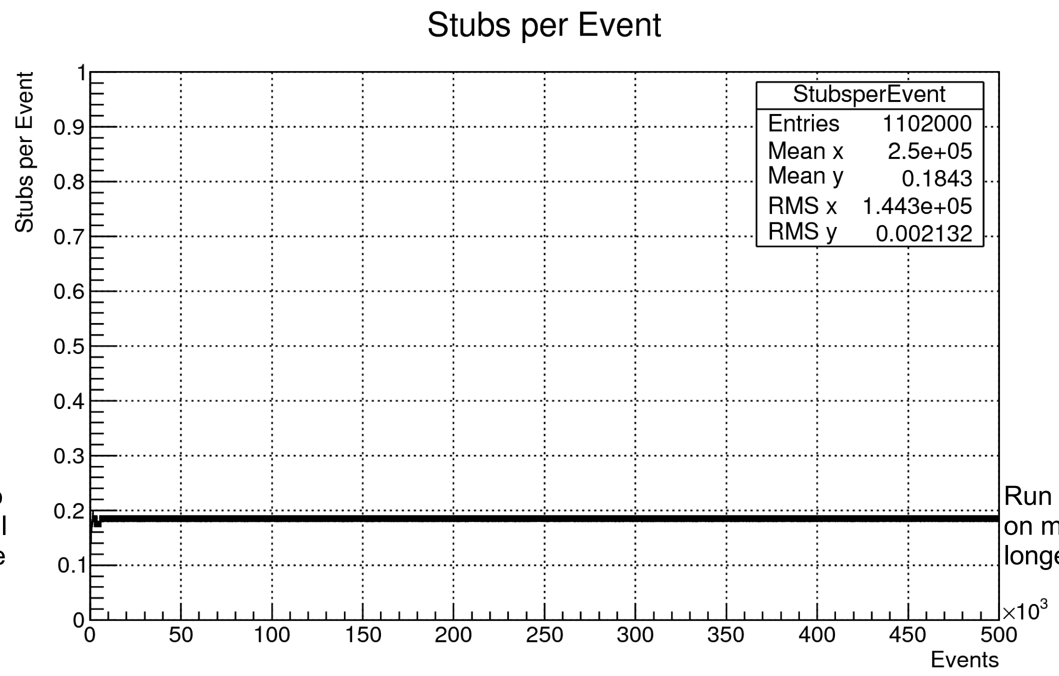
Preliminary Results

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

~0.2 due to geometrical acceptance

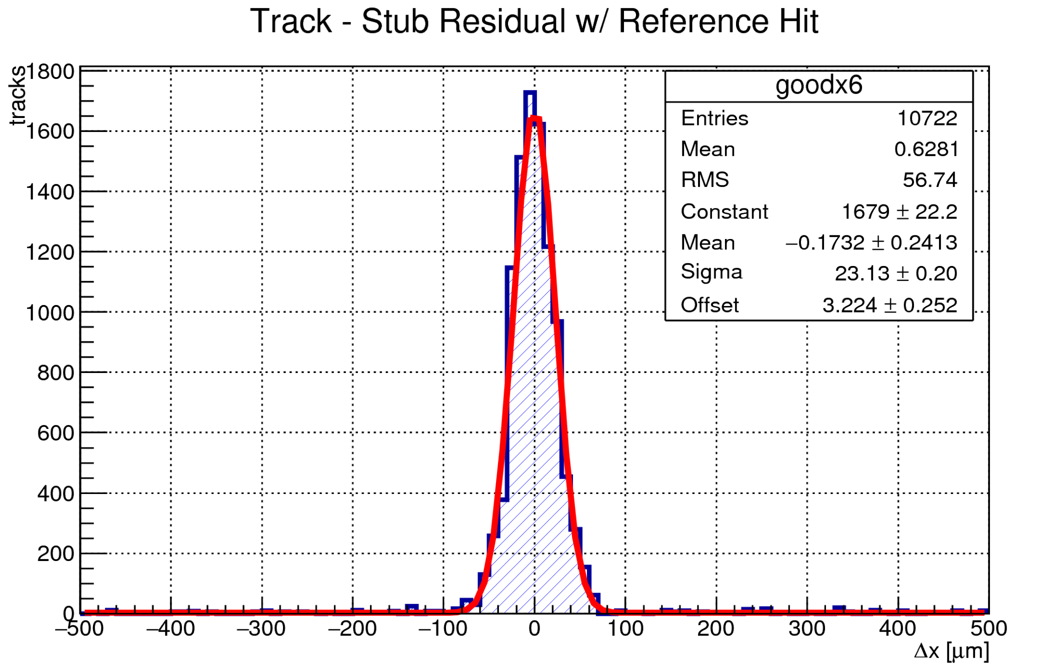


Run goes on much longer...

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



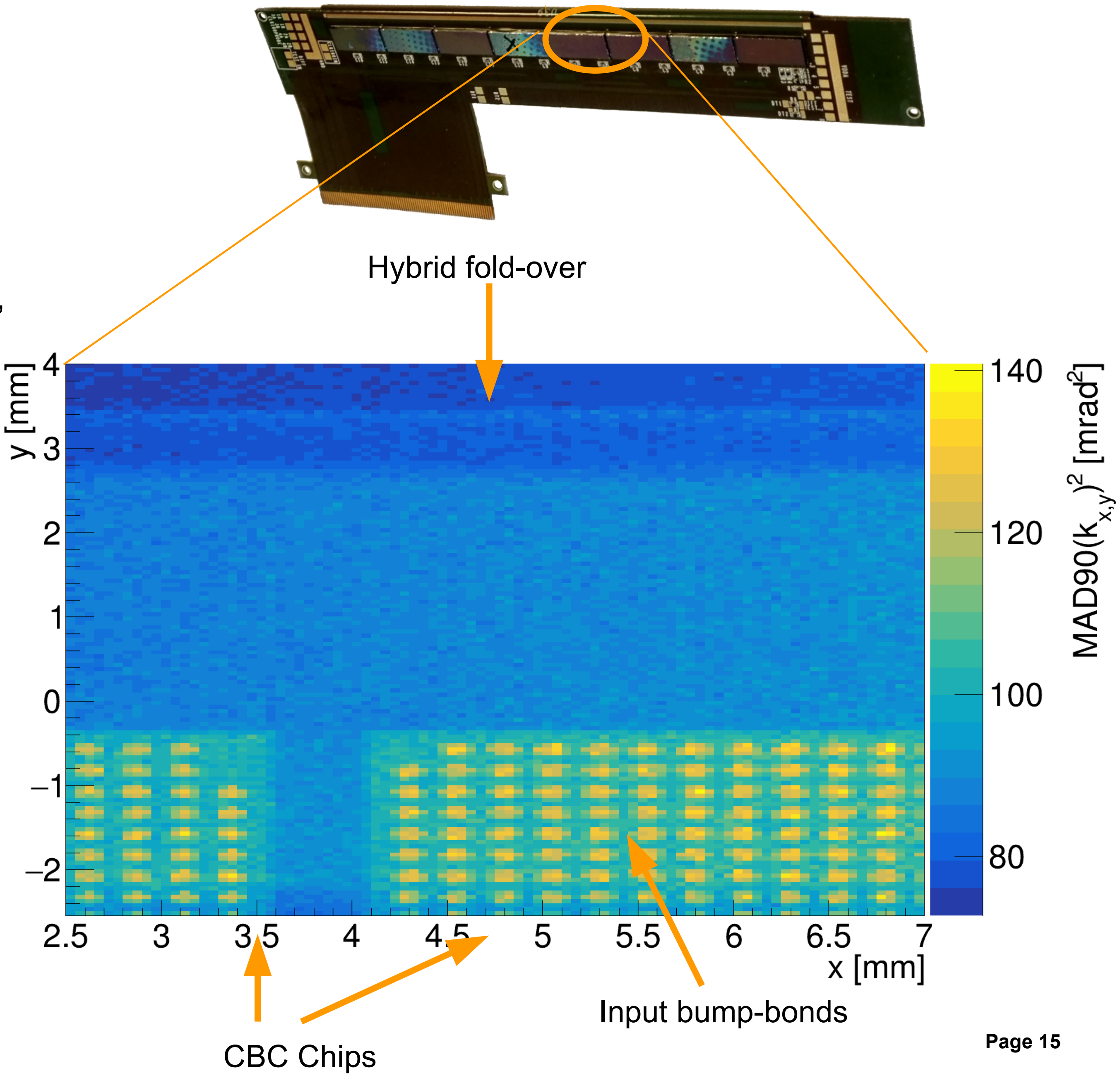
X0 Scattering

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

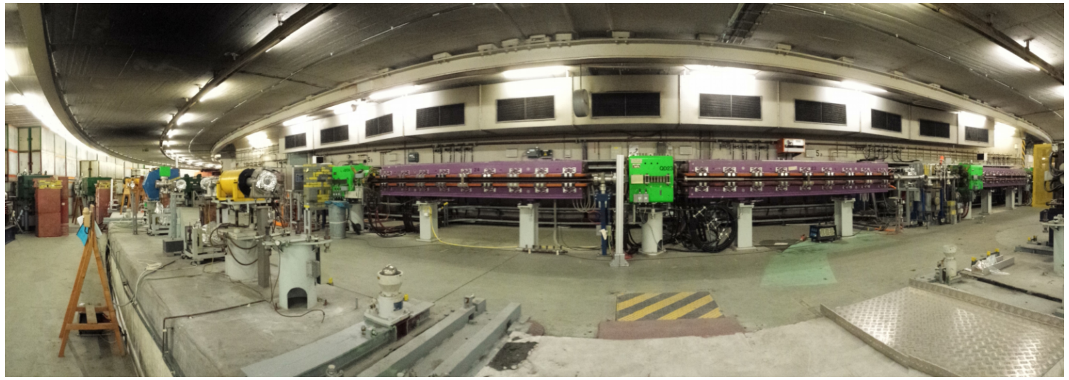
The DESY II Test Beam Facility

Beam Properties

Facility is fed by the DESY II Synchrotron:

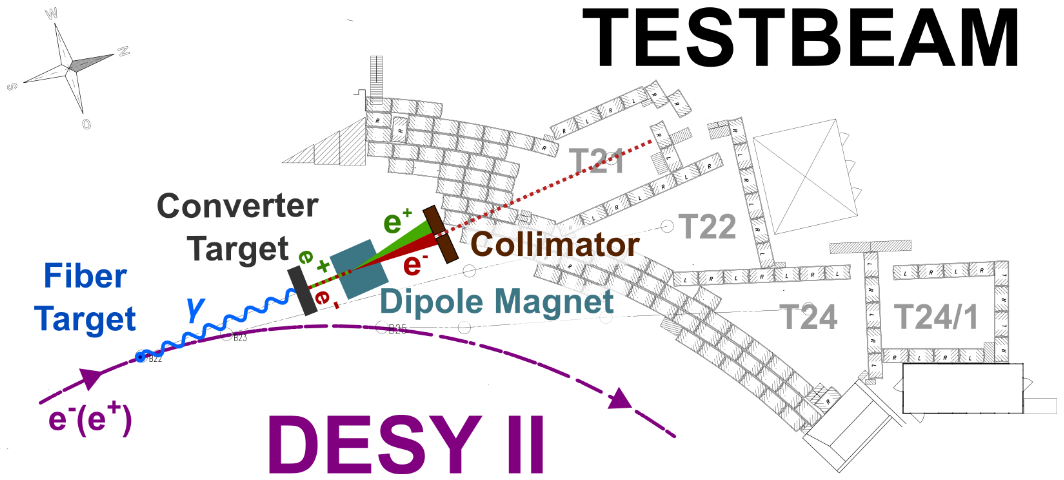
Bremsstrahlung / Conversion beam with E_e from 1 – 6 GeV

- 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 → ~ 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



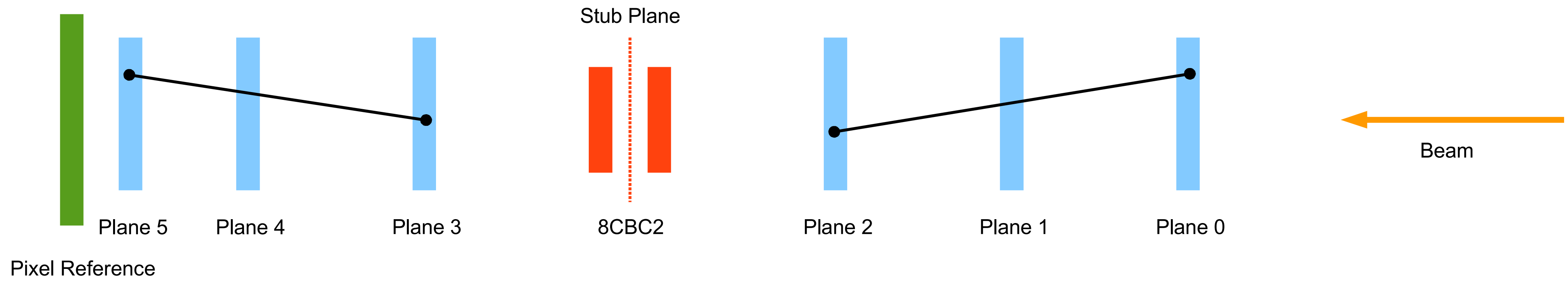
Analysis Structure – Alignment

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



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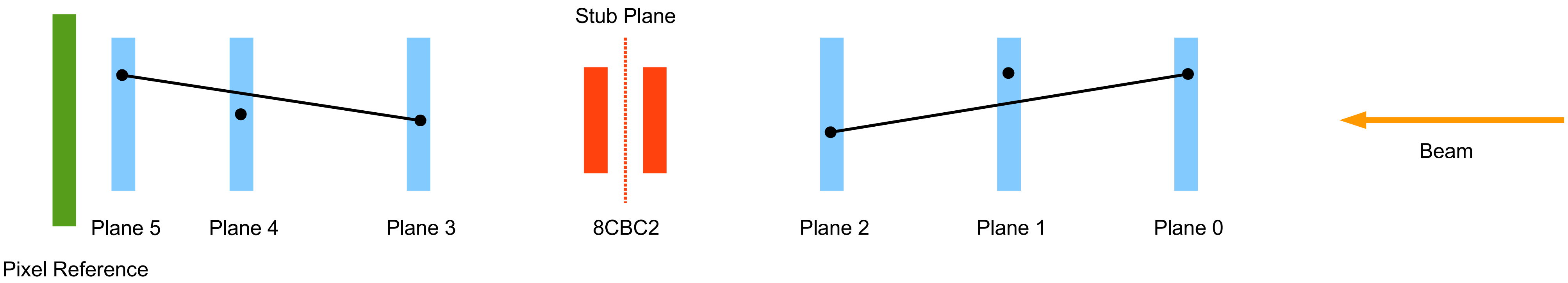

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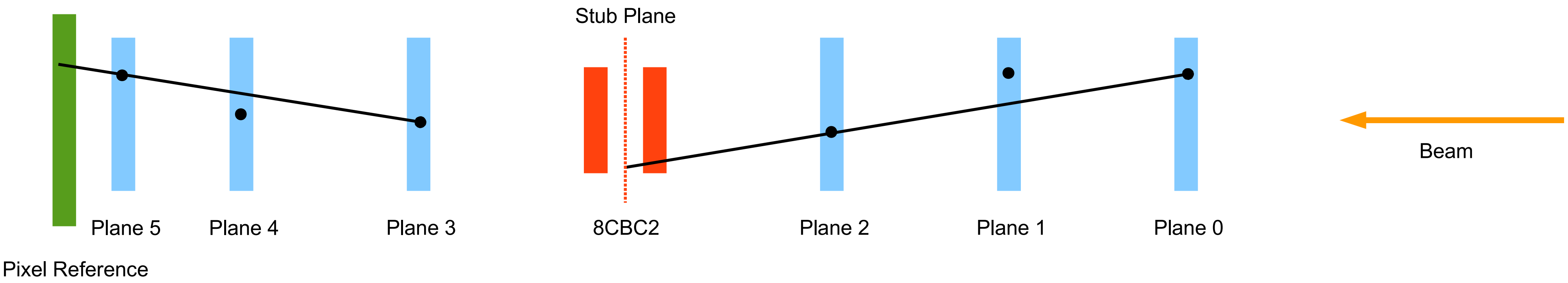

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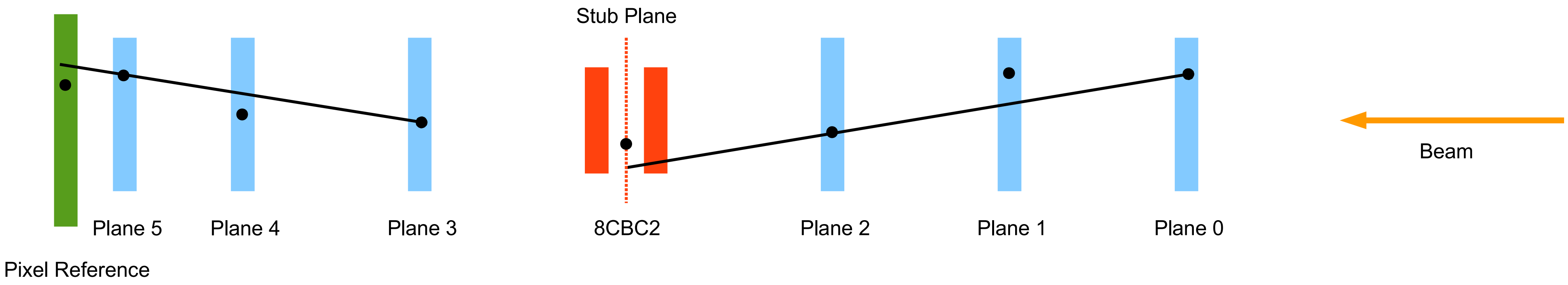

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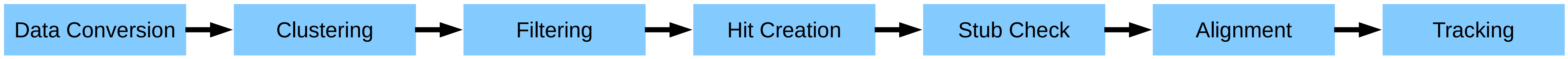

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- Triplets are extrapolated to the CBC stub and the Pixel Reference
- Triplets are validated by matching hits in the CBC and the Pixel Reference
- If both triplets match within a window at the CBC centre, a track is formed