Test Beam Analysis of a Silicon-Strip Module for CMS Phase-II Tracker Upgrade

The 10th edition of the Beam Telescopes and Test Beams Workshop

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On behalf of the CMS collaboration

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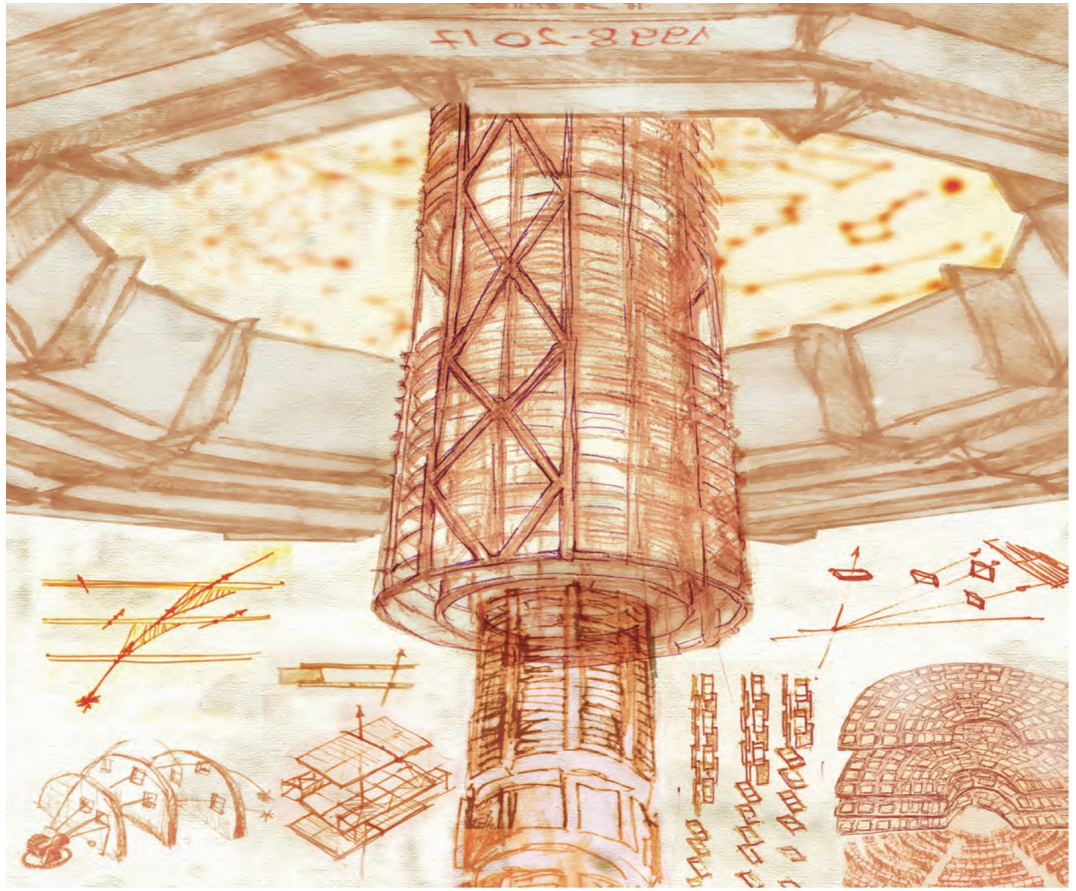
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Outline

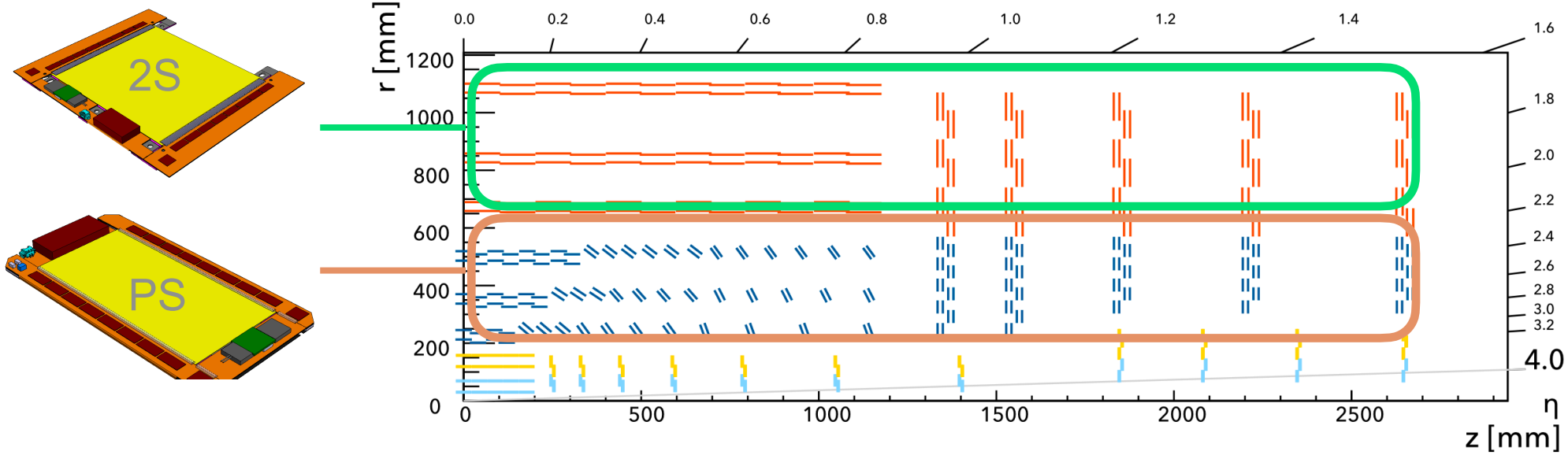
- CMS Phase II Outer Tracker Upgrade
- Strip-strip Module Assembly and Lab Test
- Test Beam @ DESY II
- Test Beam Data Analysis and Results
- Summary and Outlook



https://cds.cern.ch/record/1157741

CMS Phase-II Outer Tracker Upgrade

CMS Outer Tracker Upgrade

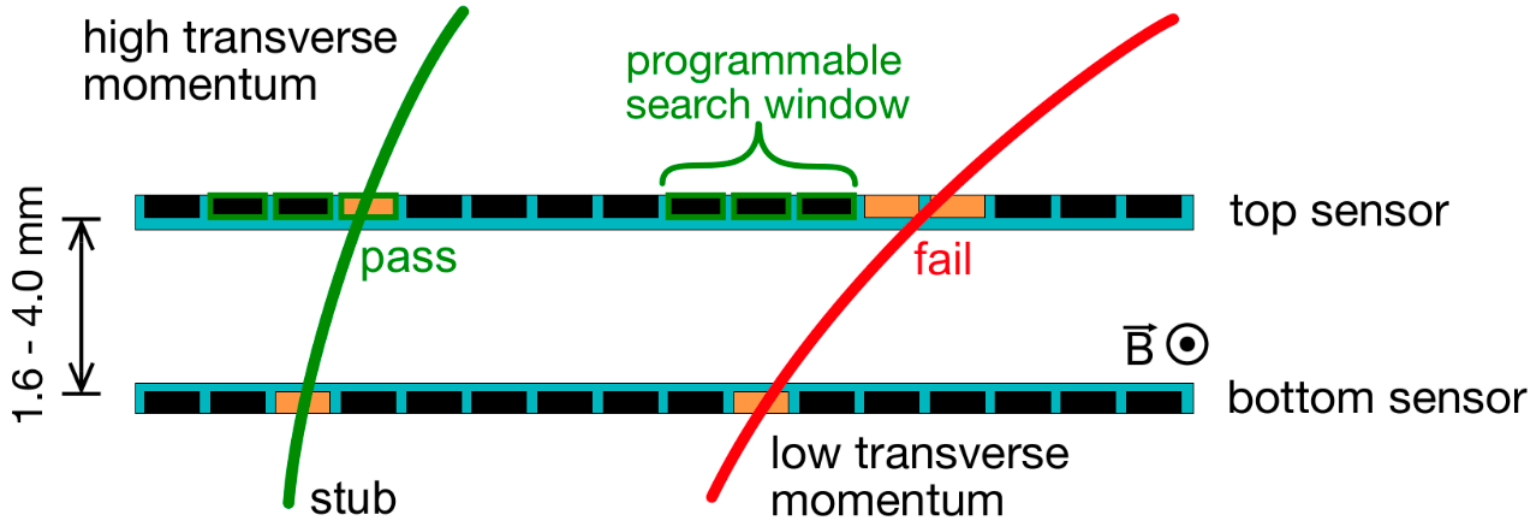


- Entering High Luminosity LHC era
  - Increase instantaneous luminosity by a factor of four
  - Yield 3k - 4k fb^{-1} integrated luminosity
- Challenges
  - Increase in pile-up
  - Higher data rate
  - Higher radiation level

- Outer Tracker
  - 6 barrel layers and 5 end cap discs
- P_T Discriminating Silicon Modules
  - Strip-Strip (2S) module
    - Stack of two strip sensors
  - Pixel-Strip (PS) module
    - Stack of pixel and strip sensors

Talk by Y. Otarid

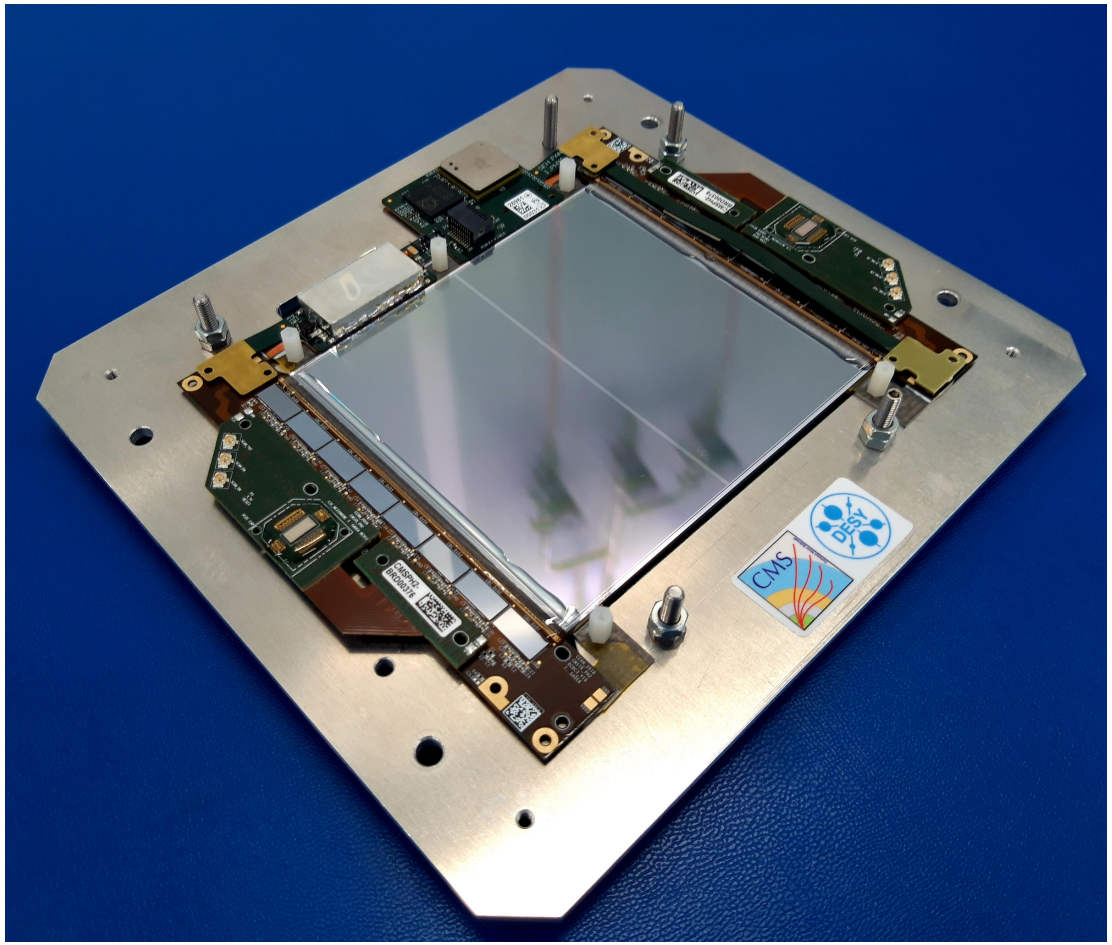
Momentum Discrimination Concept



- P_T modules :
  - Transverse Momentum Discrimination
    - Interests : P_T > 2 GeV
  - Module contains two closely spaced silicon sensors, The module correlates the clusters in the two sensors on the front end ASIC.
  - Programmable search window : the momentum cut is tuned by the size of the window

- Level-1 Trigger Contribution
- Concept :
  - Compare cluster position in top and bottom sensors with common readout
  - Event data are buffered and read full data out only when L1 accept

Two-Strip (2S) Module - Sensors

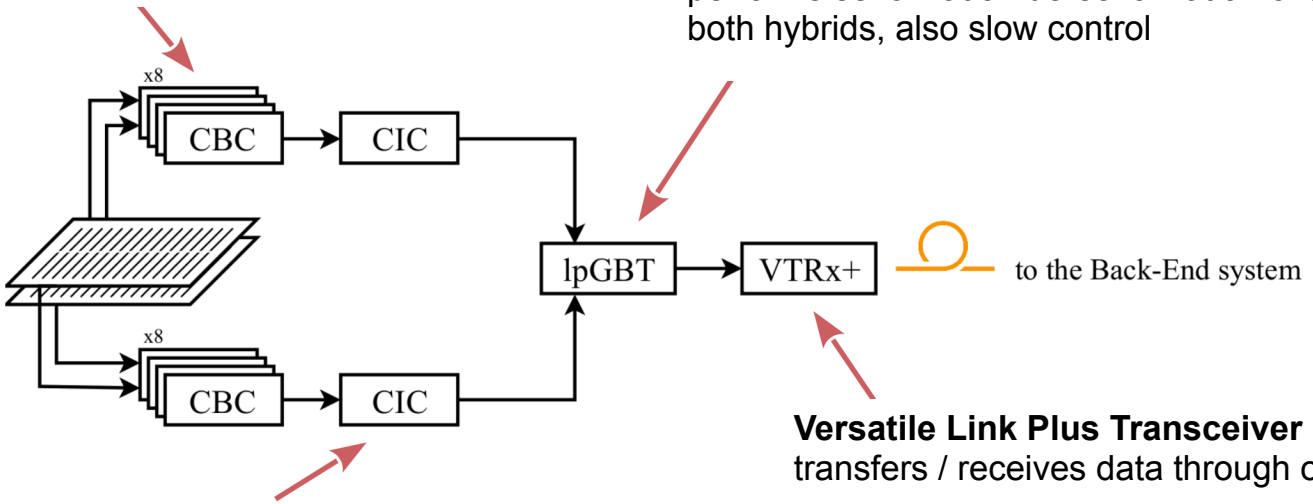


- Silicon Strip Sensor :
  - 10 cm × 10 cm size
  - 2 × 1016 strips, 90 µm pitch
  - DESY module : 240 µm in thickness
  - AC-coupled n-type strip in p-type bulk

2S Module - Electronics

CMS Binary Chip (CBC)
performs strip sensor readout and stub generation

Low Power Giga-Bit Transceiver (lpGBT)
performs serialization/de-serialization of the data from both hybrids, also slow control



Versatile Link Plus Transceiver (VTRx)
transfers / receives data through optical fibers

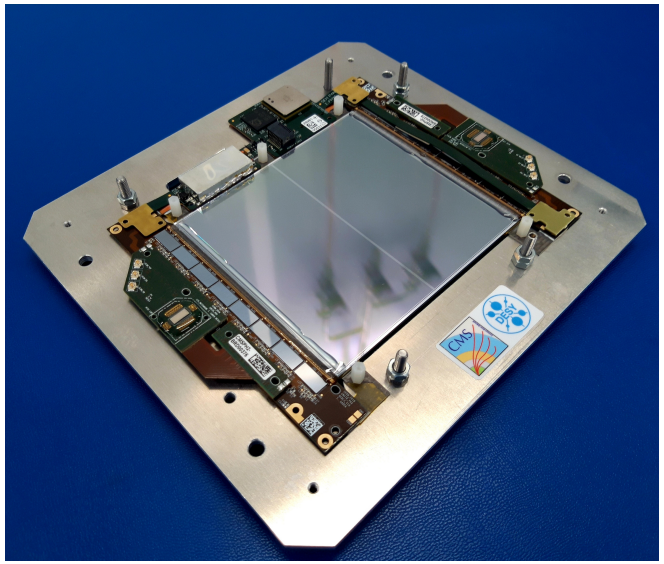
Concentrator Integrated Circuit (CIC)
performs aggregation of the data from 8 CBC chips (one hybrid)

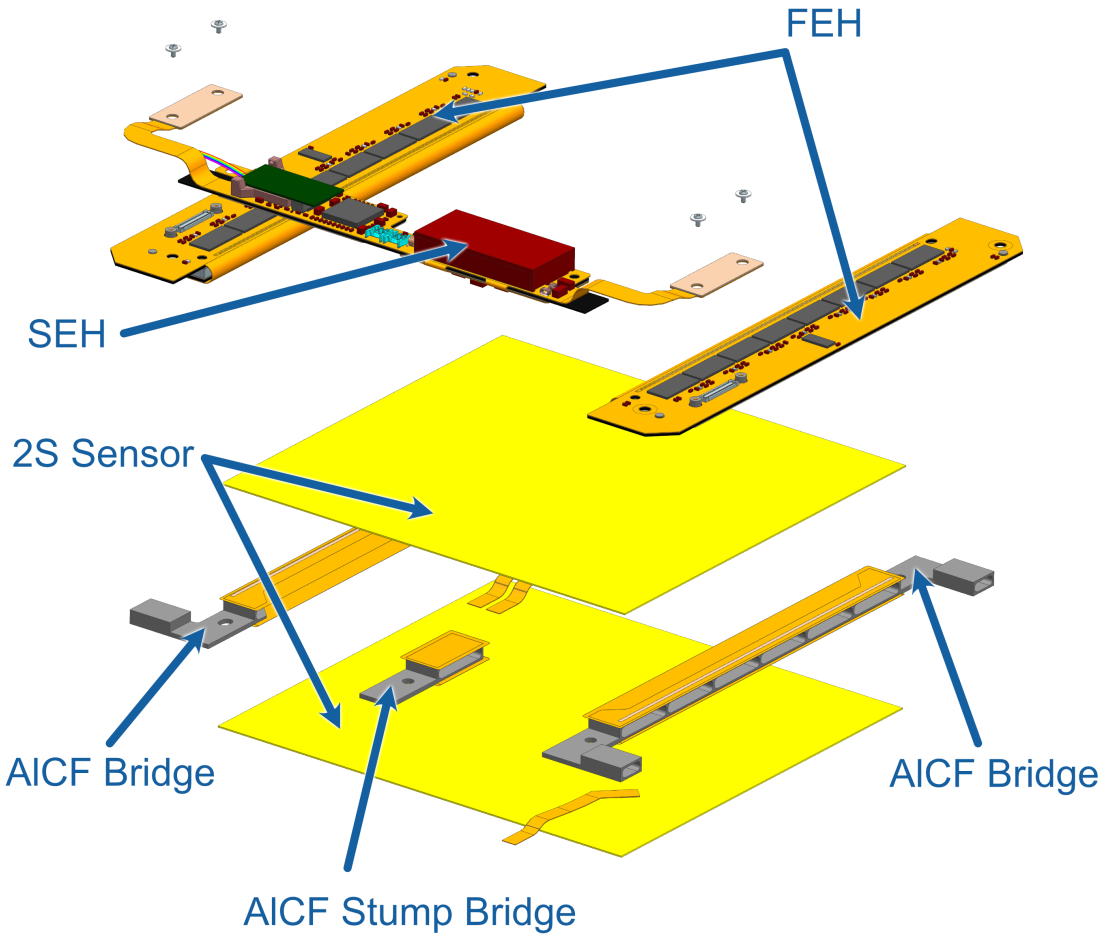
In the test beam,
2S module electronics are :

Readout ASIC	CBC3.1	Final version
Concentration ASIC	CIC2	Second version
Readout	GBTx	Optical
Control	GBT-SCA	Optical

Legacy GBT chipset

Two-Strip (2S) Module

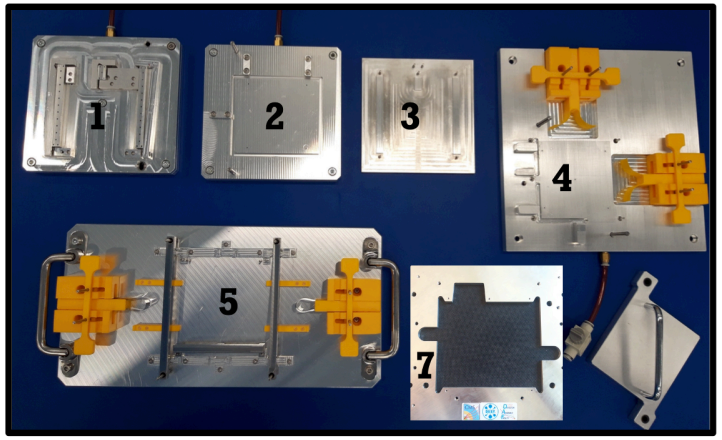




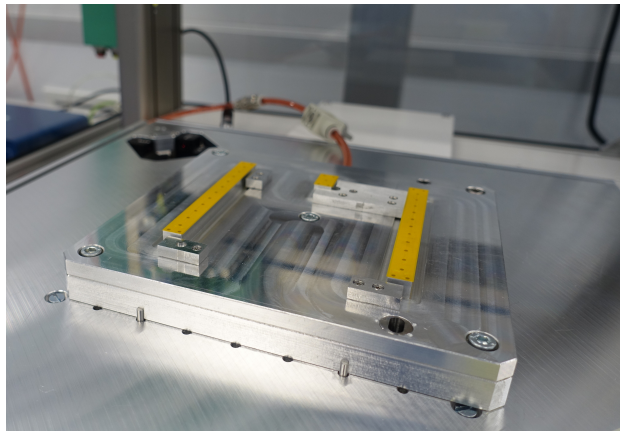
- 2S Module :
  - 2 strip sensors with spacer in between
  - 2 × Front-End Hybrid (FEH) with CBC3.1
  - 2 × Concentrator Integrated Circuit (CIC)
  - 1 × Service Hybrid (SEH)

Module Assembly and Lab Test

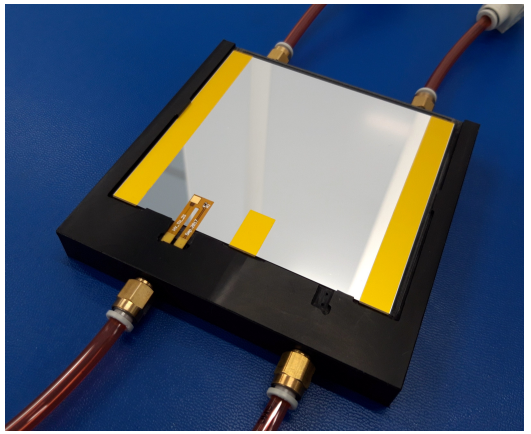
Assembling a 2S module



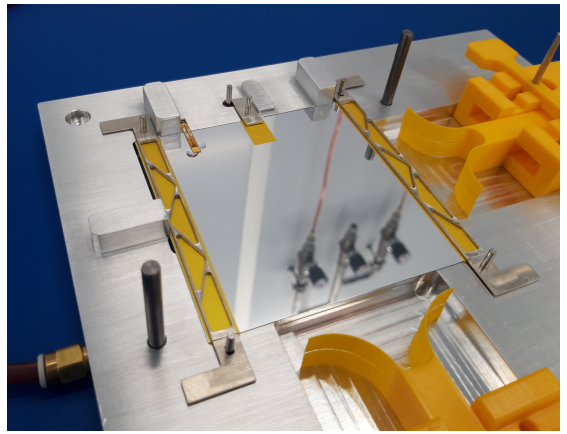
Multiple module jigs with vacuum holes for different assembly steps



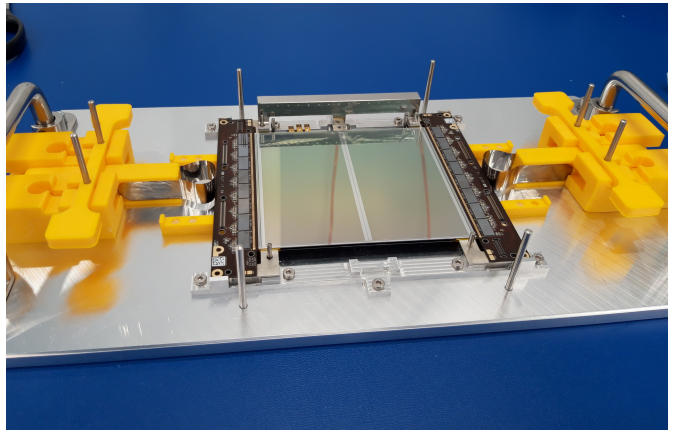
1. Kapton gluing



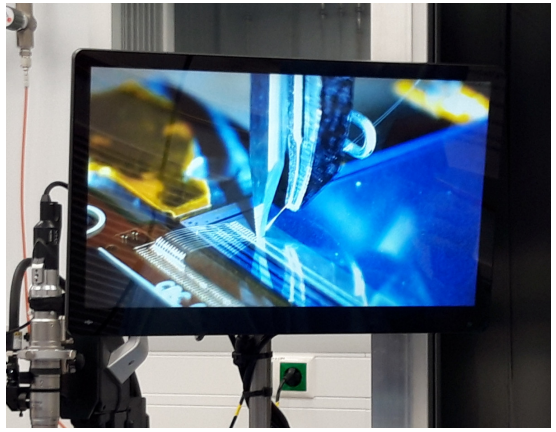
2. HV tail gluing



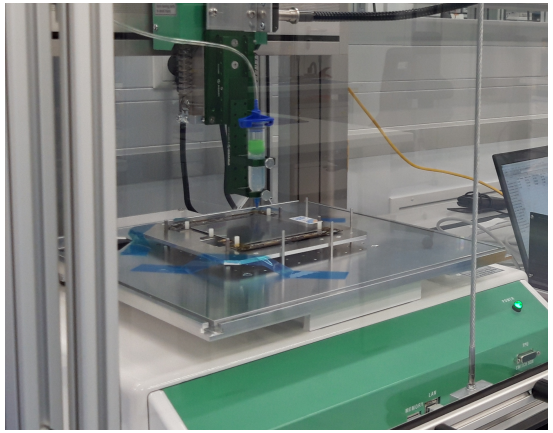
3. Spacer gluing



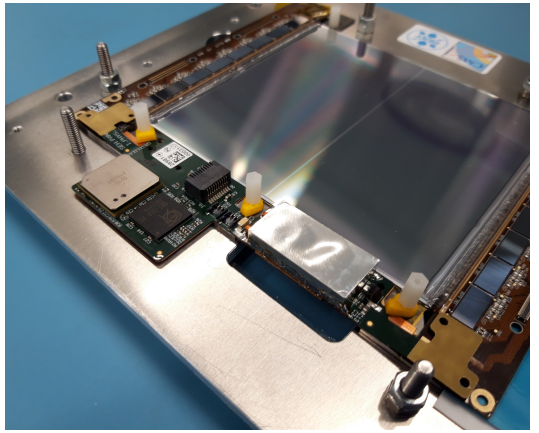
4. Front-End Hybrid gluing



5. Wire Bonding



6. Encapsulation

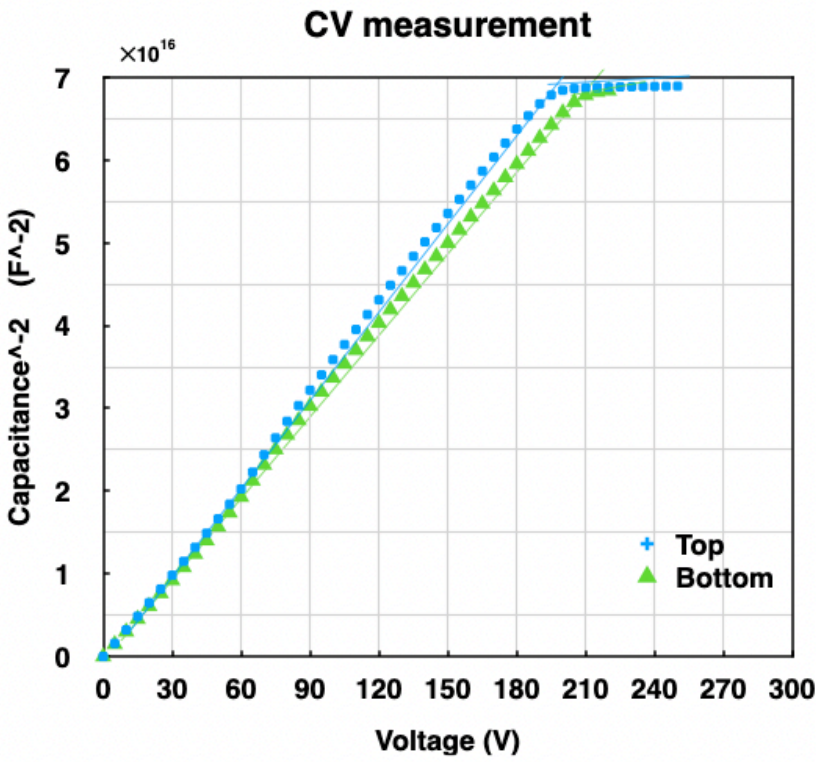


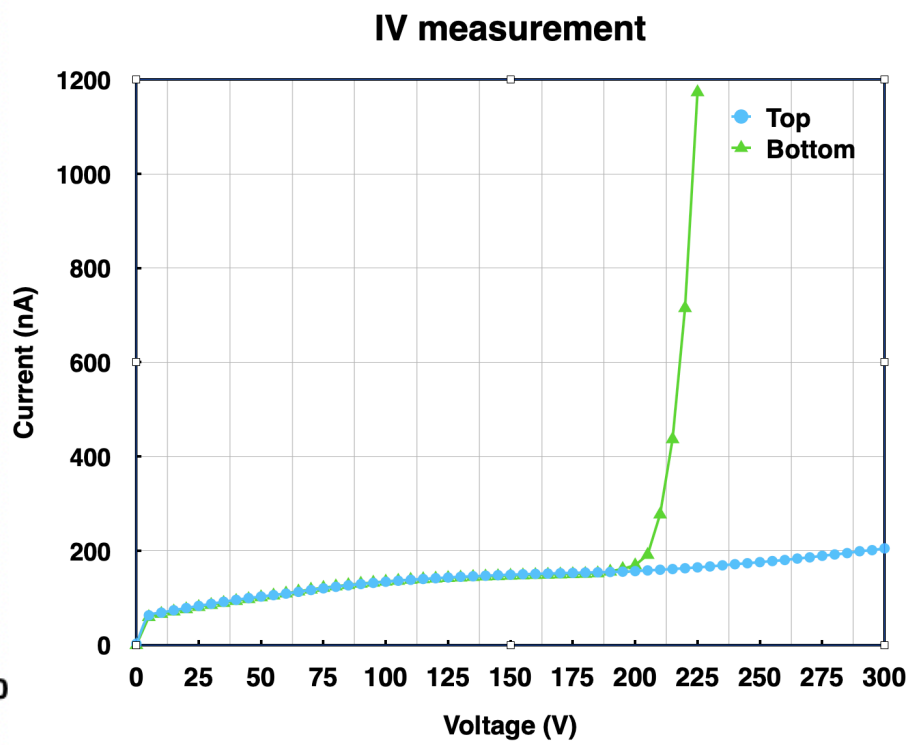
7. Service Hybrid gluing

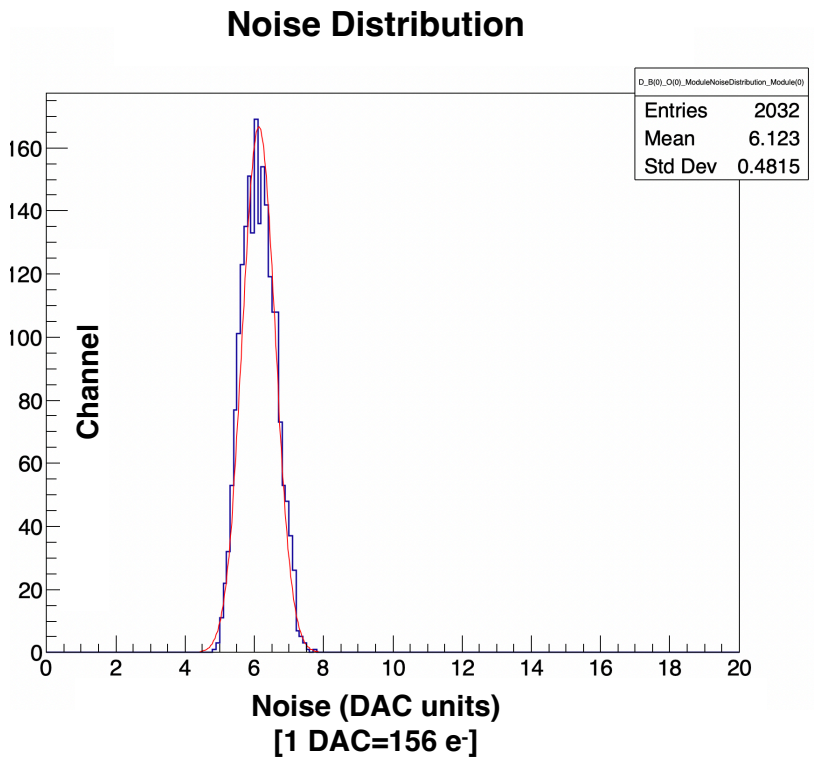
Lab Test

- Pre-assembly Test: on a probe station
  - CV measurement : depleted at 192 V and 205 V
  - IV measurement : bottom sensor breakdown at 205 V
    → operate bias voltage : 200 V
- Post-assembly Test
  - Electrical testing: noise level check
  - Comparable results with other modules

→ Functional module for beam test

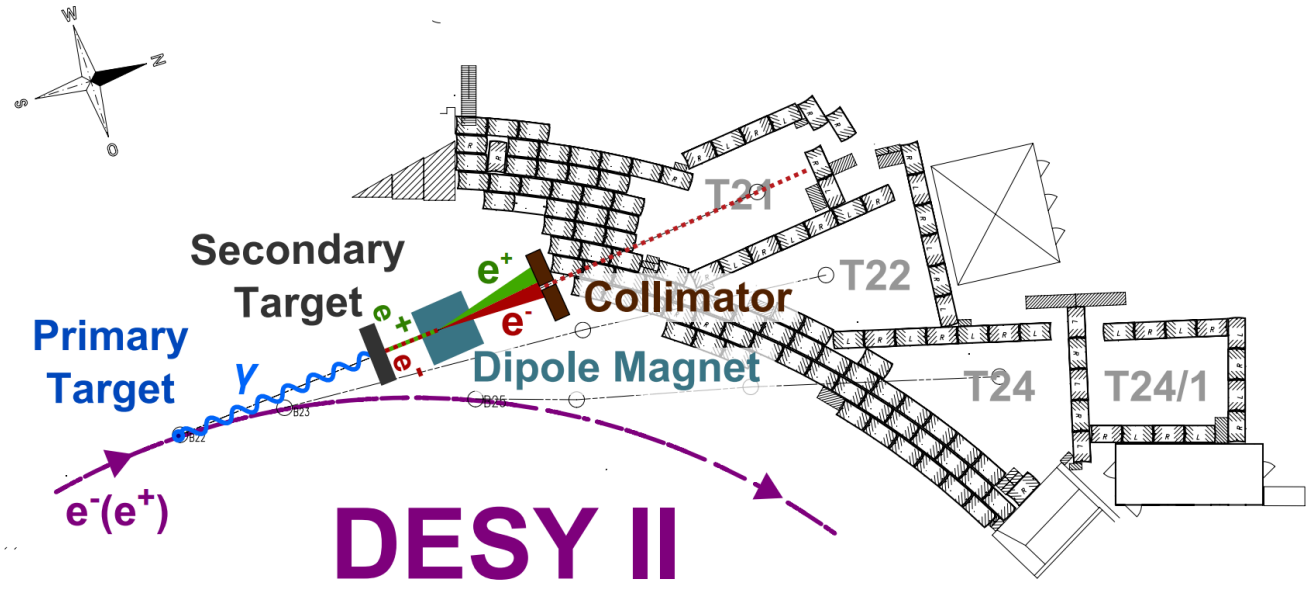


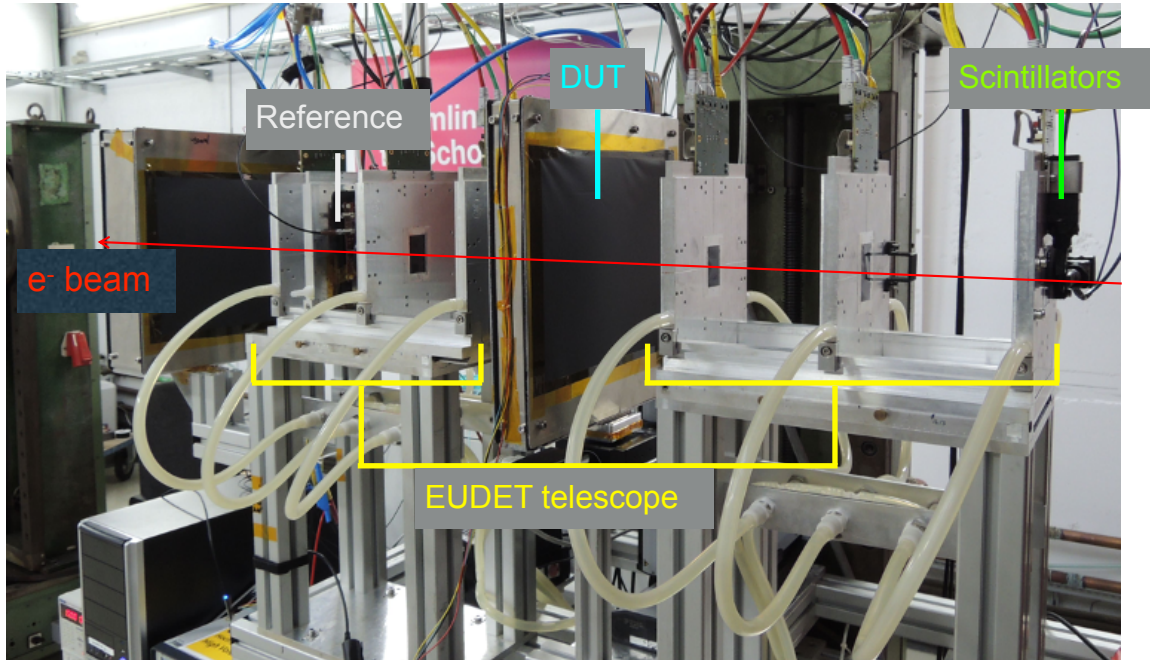




Test Beam

DESY II Test Beam & Setup





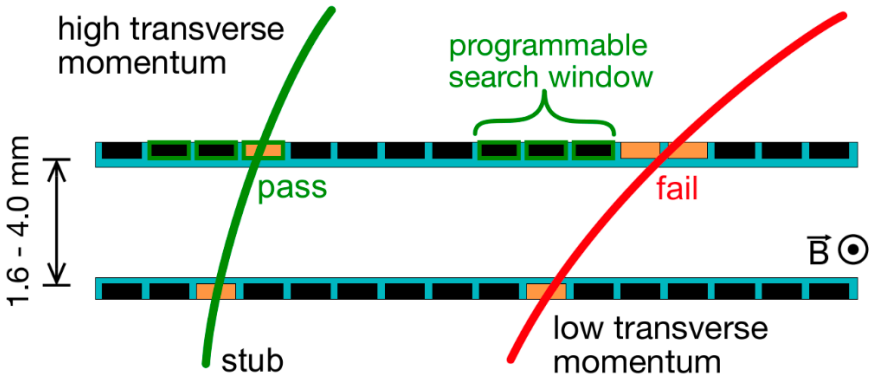
- Test Beam is generated by double conversion
  - Dipole Magnet : bend particles of desired momentum and charge
- During our testbeam :
  - 4 ~ 6 GeV/c electron beam @kHz rate

- Our setup
  - EUDET telescope (MIMOSA 26 sensor, 2 cm × 1 cm active area, 18.4 µm squared pixels)
  - Two Scintillators & PMTs, Reference plane (CMSPixel), Device under test (DUT) on a rotation stage
- Data acquisition
  - Trigger Logic Unit (EUDET TLU), Software (EUDAQ2)

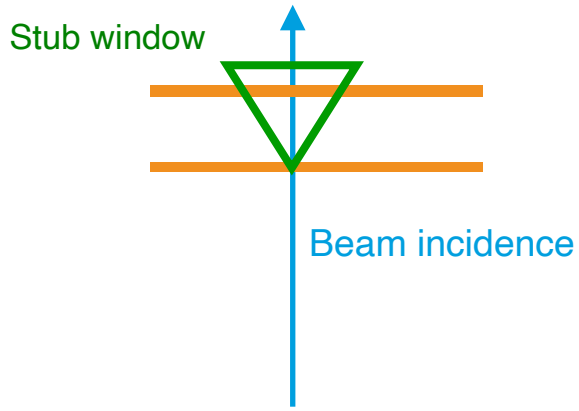
Test Beam Measurements

- Threshold scan
- X-Y scan : along hybrid, along strips
- Bias scan
- **Angular scan : from -30 deg to 30 deg**

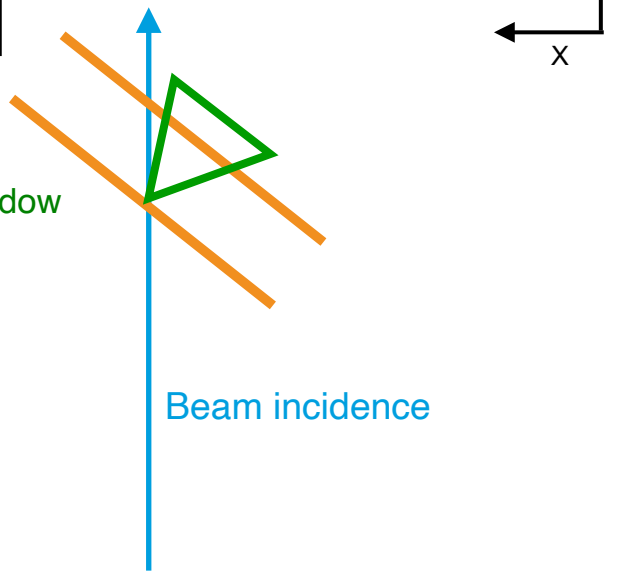
  → verifying stubs!



High P_T case



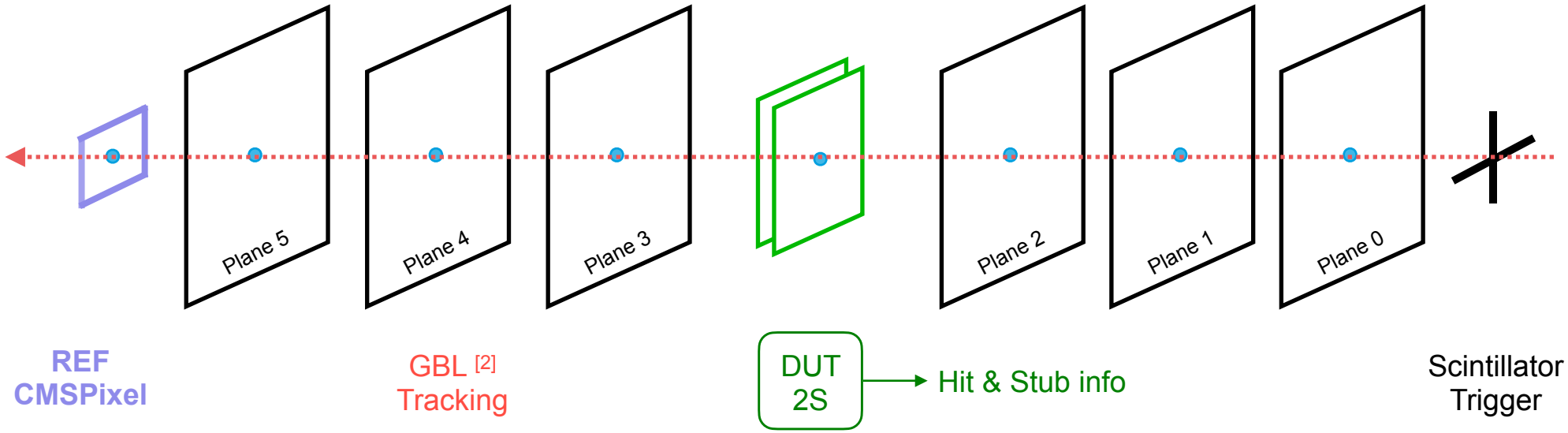
Low P_T case

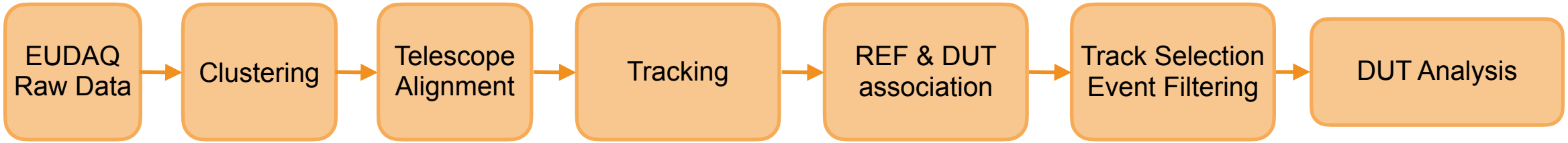


Track Reconstruction and Analysis Steps

- Performed using Corryvreckan[1] framework

Reconstructed Track = Telescope track with a matching hit on reference plane

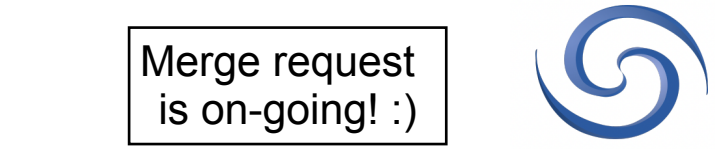




[1] https://project-corryvreckan.web.cern.ch/project-corryvreckan/ [2] https://www.desy.de/~kleinwrt/GBL/doc/cpp/html/index.html

Corryvreckan - adding big pixel detector

Merge request is on-going! :)



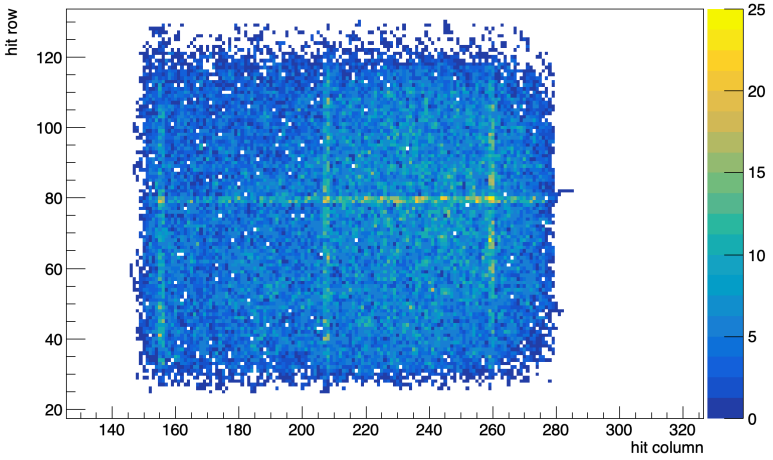
- Track reconstructions are correlated to alignments among devices
- In Corryvreckan : pixel columns, rows ⇋ cluster position

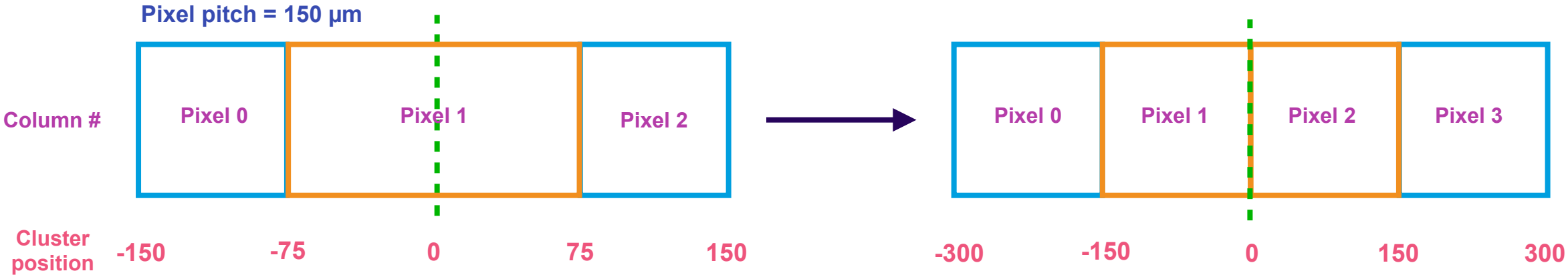
  → pixel size are treated uniformly

- Problems occur when pixel detectors have non-uniform pixel size, i.e. CMSPixel

  → Pixels are elongated at the readout chip edges, twice the size of a normal pixel

  → Treat big pixels as two normal pixels



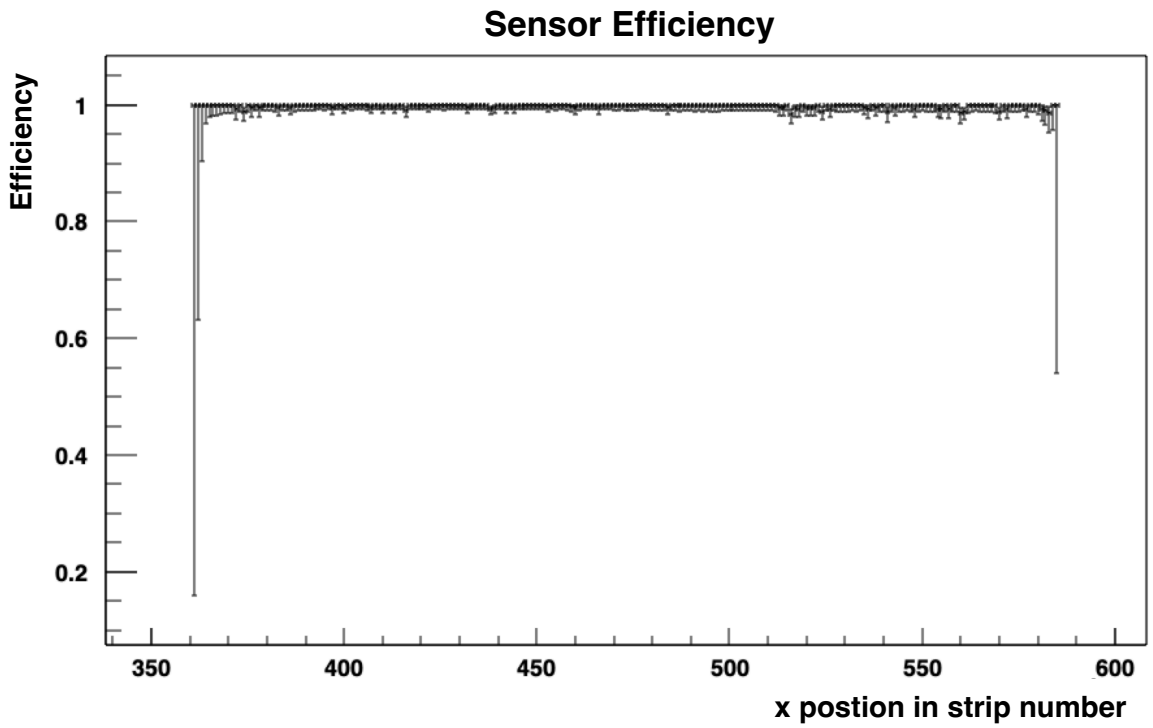


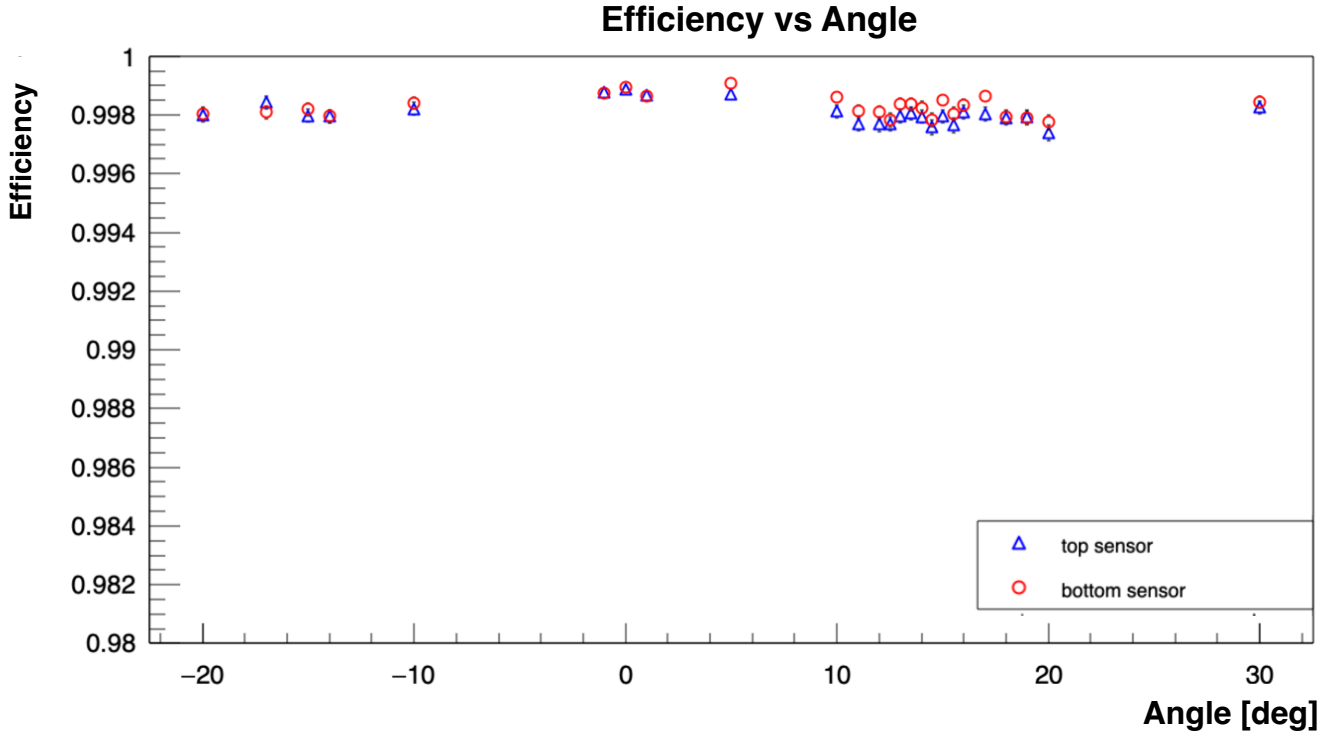
Test Beam Data Analysis and Results

Hit Efficiency

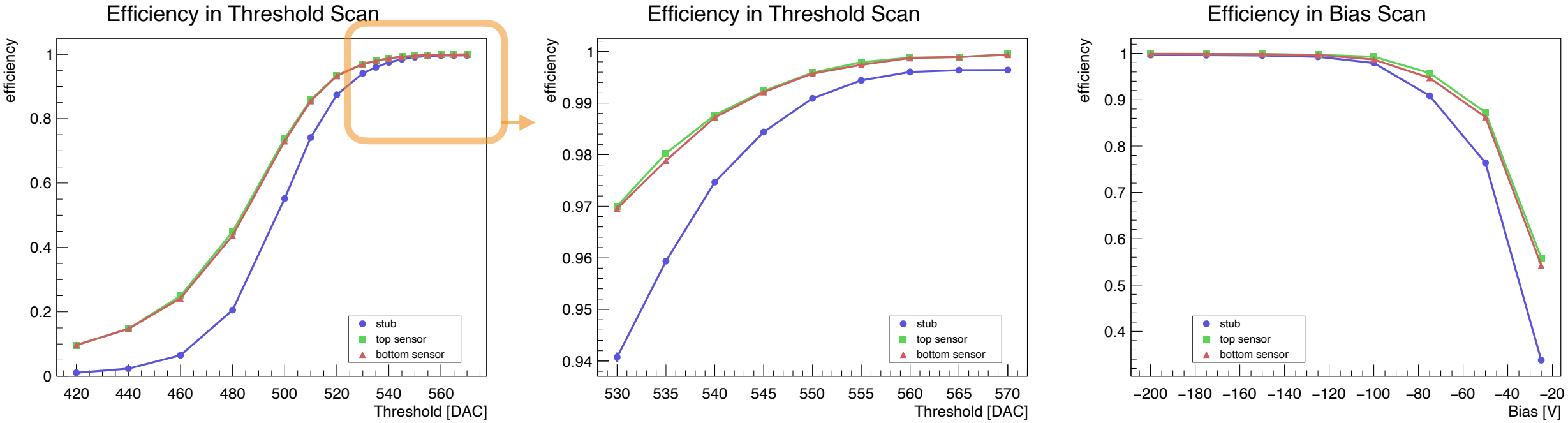
$$\text{Eff.} = \frac{\text{Number of DUT hits linked to telescope track with link to REF hit}}{\text{Number of telescope track with link to REF hit}}$$

- DESY 2S Module
- Uniform along illuminated channels
- Global hit efficiency > 99.7%





Hit Efficiency

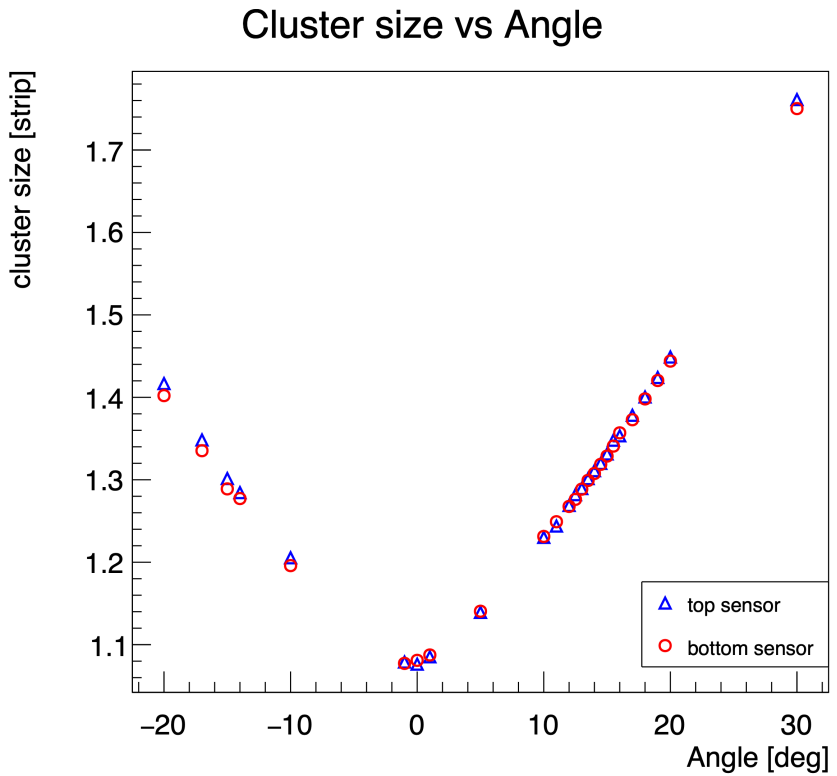


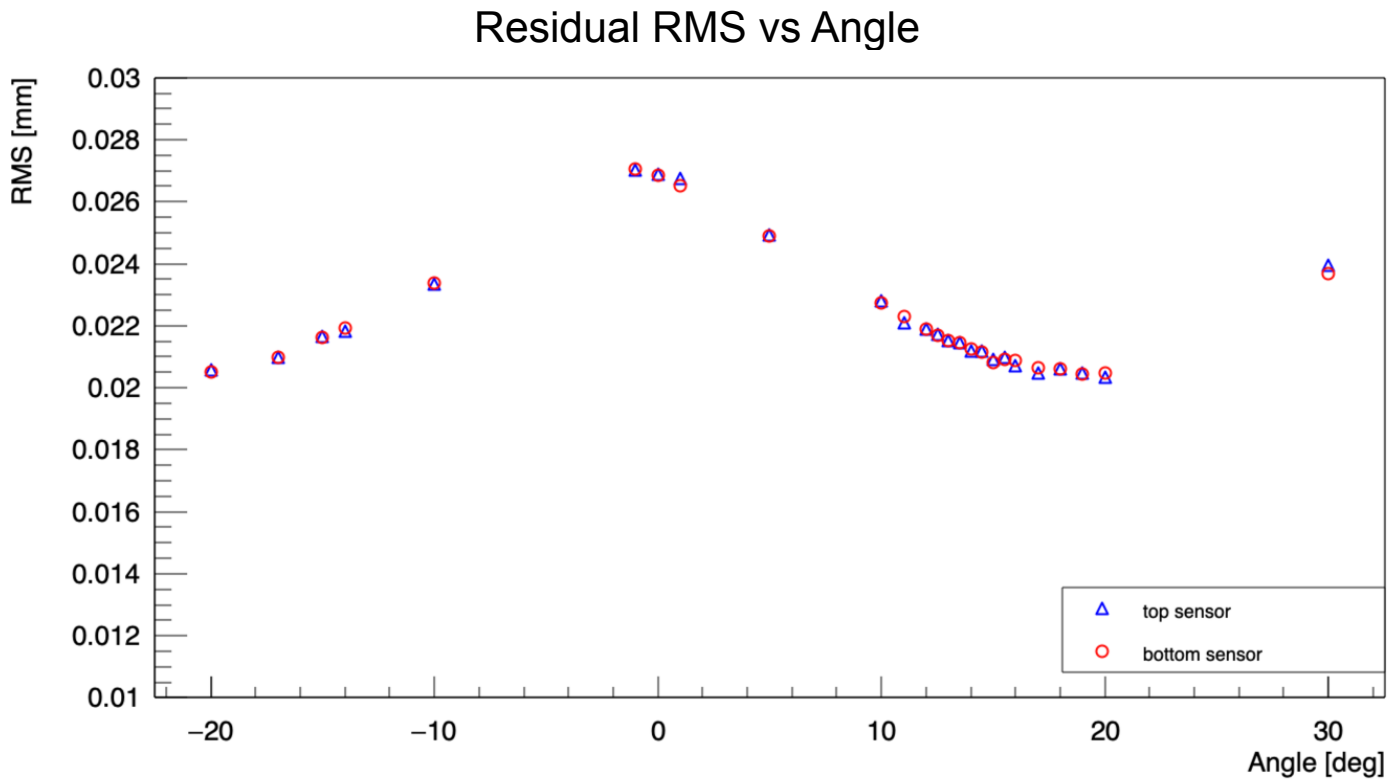
- Threshold scan: Hit efficiency > 99.9% at operating threshold (560 DAC)
- Efficiency > 99.9% at operating voltage (200 V)

→ Fully depleted and even with margins

→ Good sensor and module performance

Cluster size and Resolution





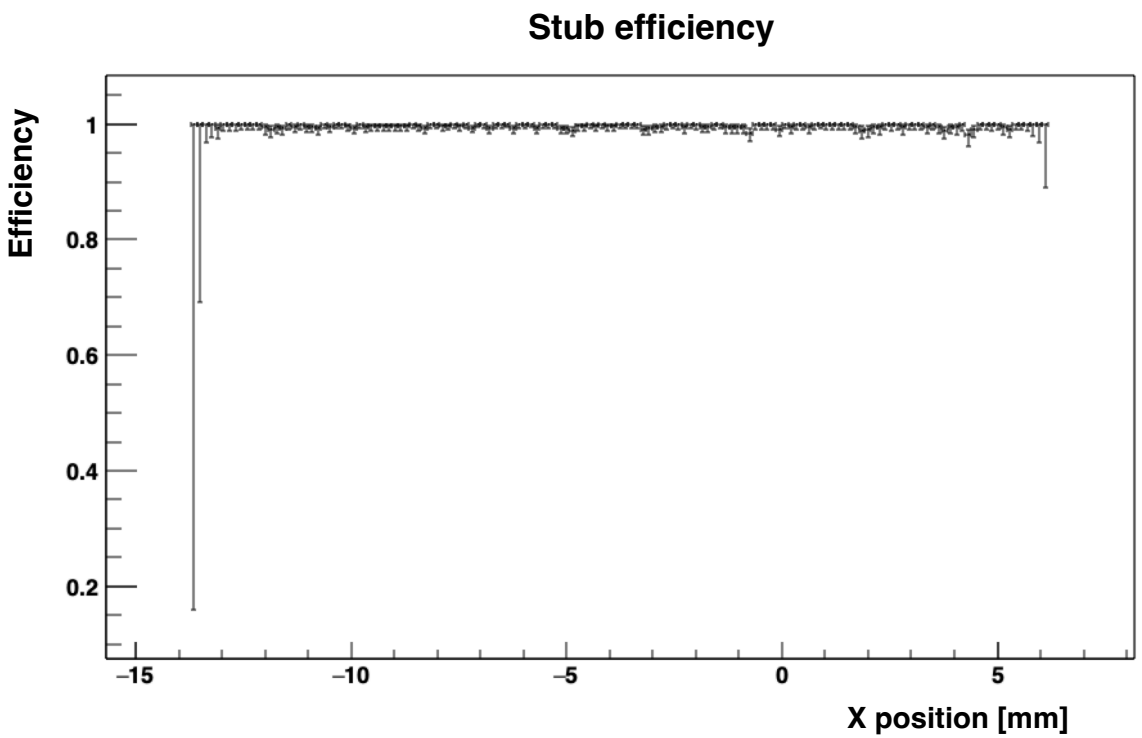
- Cluster size increases with rotation angle
- Residual RMS vs Angle: Benefit from the multi-strip charge sharing
- At 0 deg, the residual RMS 27.5 μm (telescope track resolution convolved)
- Compare with binary resolution with strip pitch of 90 μm : 26 μm

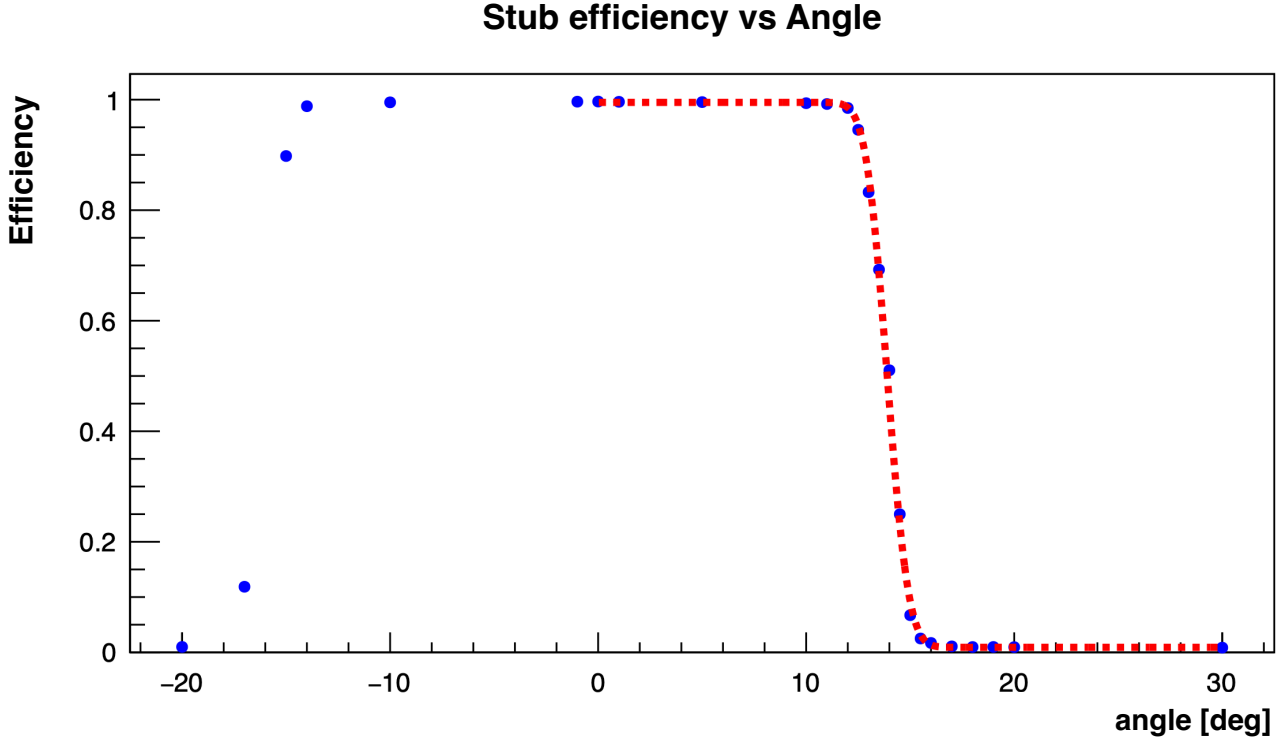
Stub Performance

$$\text{Stub Eff.} = \frac{\text{Number of Stubs associated with track position}}{\text{Number of telescope track with link to REF hit}}$$

- Global stub efficiency > 99.7%
- Uniform along illuminated channels

- Increasing displacement between top and bottom cluster with rotation angle
- Sharp drop in efficiency once displacement is larger than stub window
- Fit with error function, stub threshold at 13.89 ± 0.03 °
- For stub window ± 4.5 strips, efficiency drops sharply at ≈13.8° as expected





Summary and Outlook

- 2S module prototype with full DAQ chain under test beam was successfully performed.
  - Unirradiated modules with 240 μm thickness silicon sensors
- Uniform hit efficiency higher than 99.7% for all turning angles
- Uniform stub efficiency above 99.7%
- Stub efficiencies at different angles match the geometrical expectations.
- Prototype modules achieve P_T discrimination goal

- More testbeam analysis for other 2S modules (with 290 μm thickness silicon sensors) are on-going, and will be compared with the DESY module.

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Thank you.

Contact

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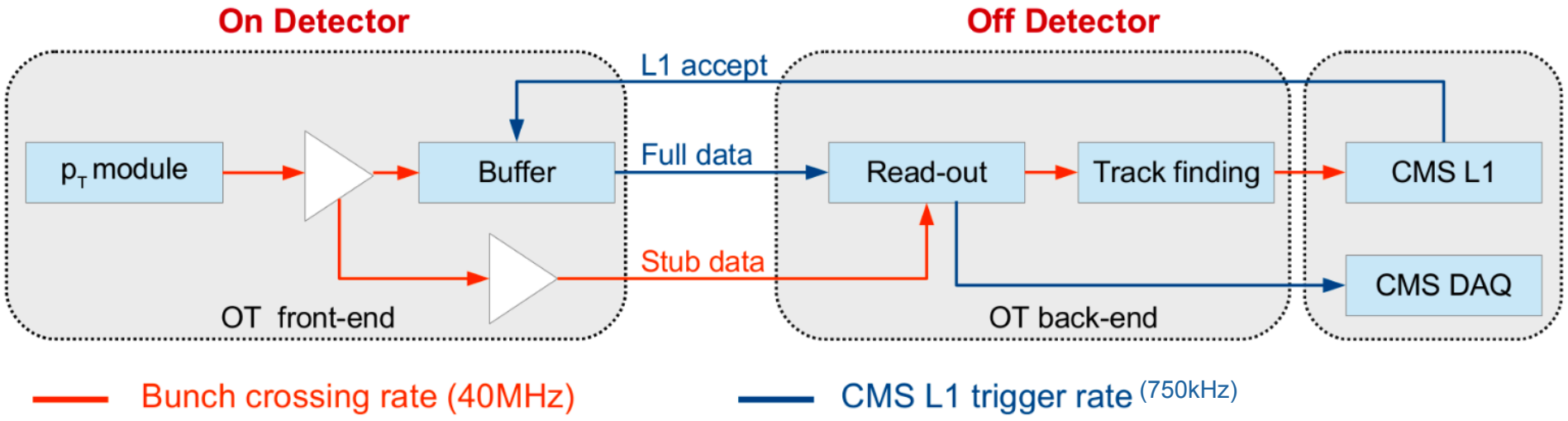
www.desy.de

Backup

Concept of the Outer Tracker Upgrade

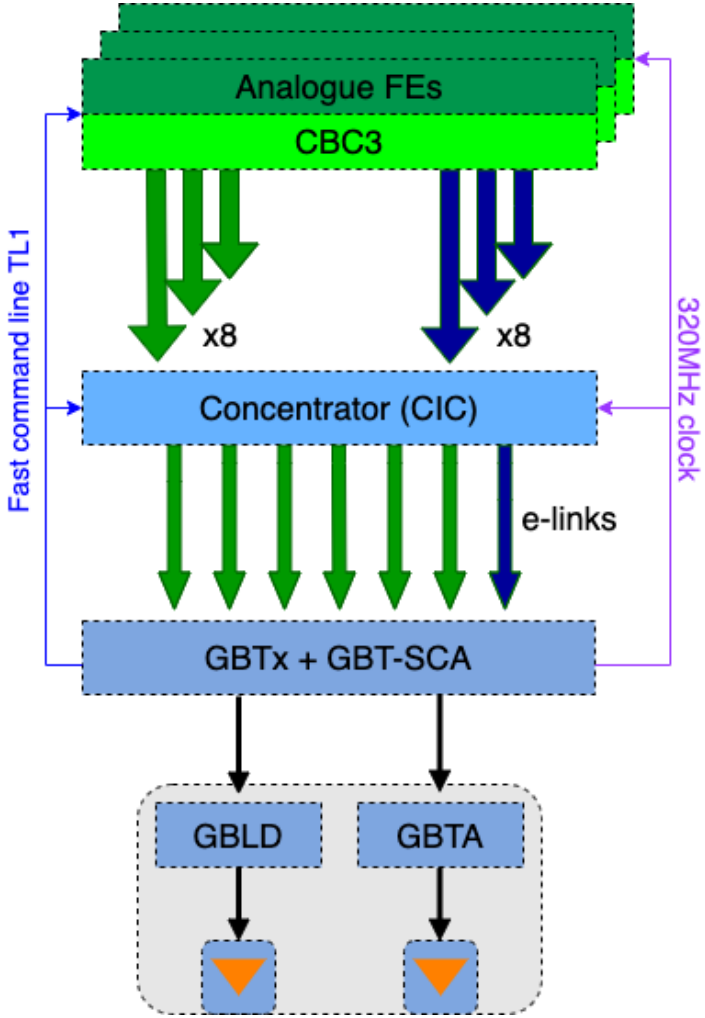
- Level-1 Trigger Contribution :
  - Stub information is passed at 40 MHz
  - L1 rate at 750 kHz
  - Event data are buffered
  - Read full data out only when L1 accept at 750 kHz rate



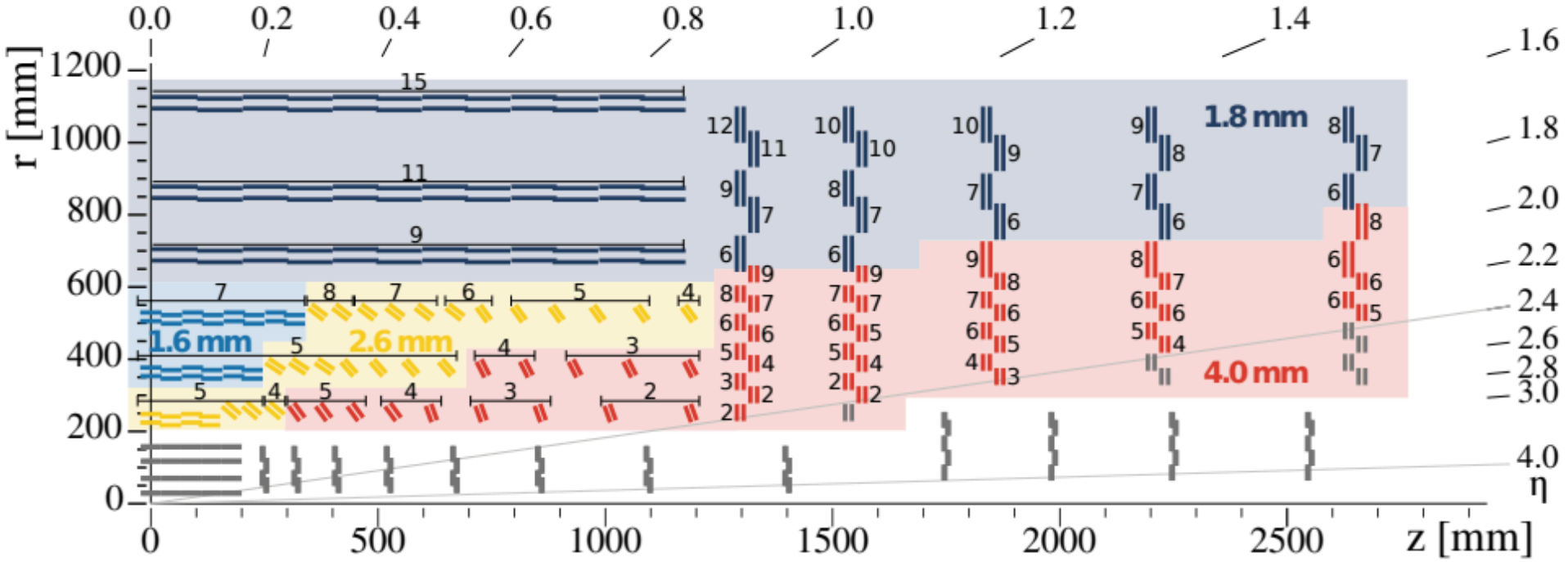
2S Module Optical Readout In Test Beam

Readout ASIC	CBC3.1	Final version
Concentration ASIC	CIC2	Second version
Readout	GBTx	Optical
Control	GBT-SCA	Optical
Back-end	uDTC	uTCA

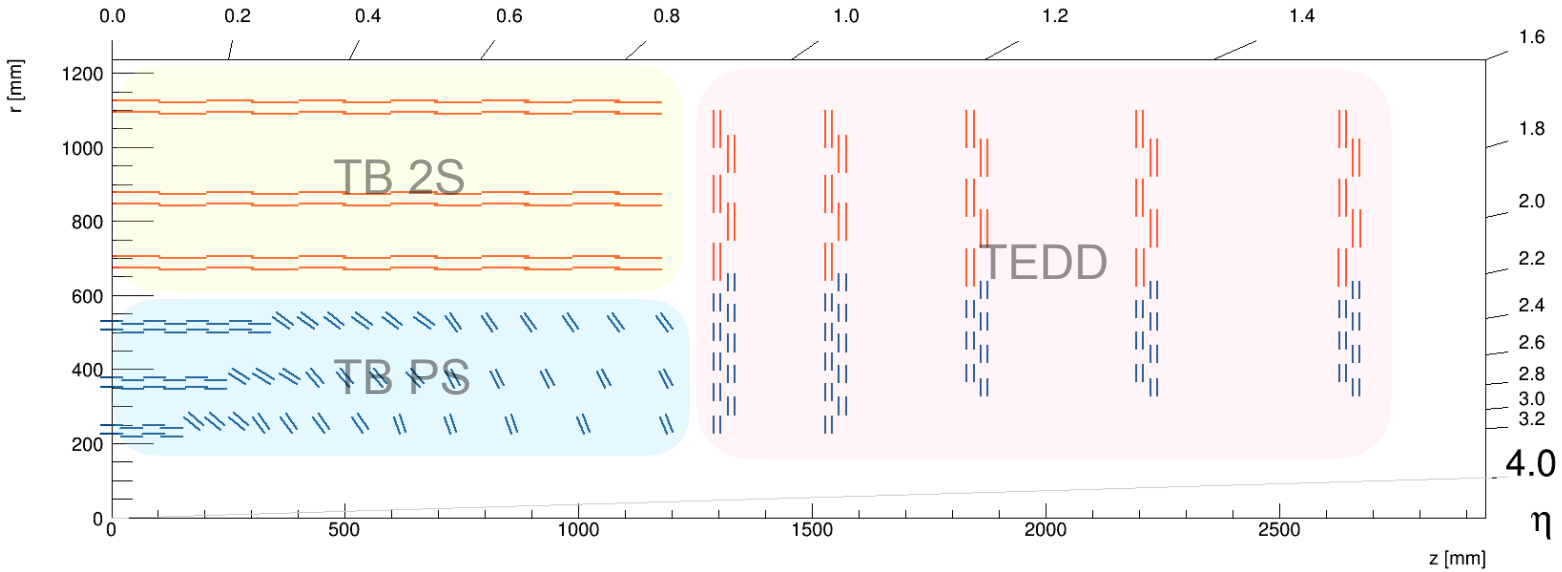
- Service hybrid prototype with legacy GBT chipset and DC-DC converter used for this prototype
- Steps required to prepare data-taking :
  - Configure GBTx and GBT-SCA on service hybrid
  - Configure all Frontend ASICs through GBT-SCA (I^2C Master)
  - Synchronizing and aligning lines between CBCs and CICs
  - Configure back-end to correctly decode data coming from GBTx



Tracker layout with stub windows and spacing info



CMS Outer Tracker Layout and Number of Modules



Module types	TB2S	TBPS	TEDD	Total
2S 1.8 mm	4464		2792	7256
2S 4.0 mm			424	424
PS 1.6 mm		826		826
PS 2.6 mm		1462		1462
PS 4.0 mm		584	2744	3328
Total	4464	2872	5960	13296

- 6 barrel layers and 5 end cap discs
  - Blue : Macro-Pixel-Strip (PS) modules
  - Red : Strip-Strip (2S) modules

- TBPS: Tracker Barrel with PS modules
- TB2S: Tracker Barrel with 2S modules
- TEDD: Tracker Endcap Double Disks

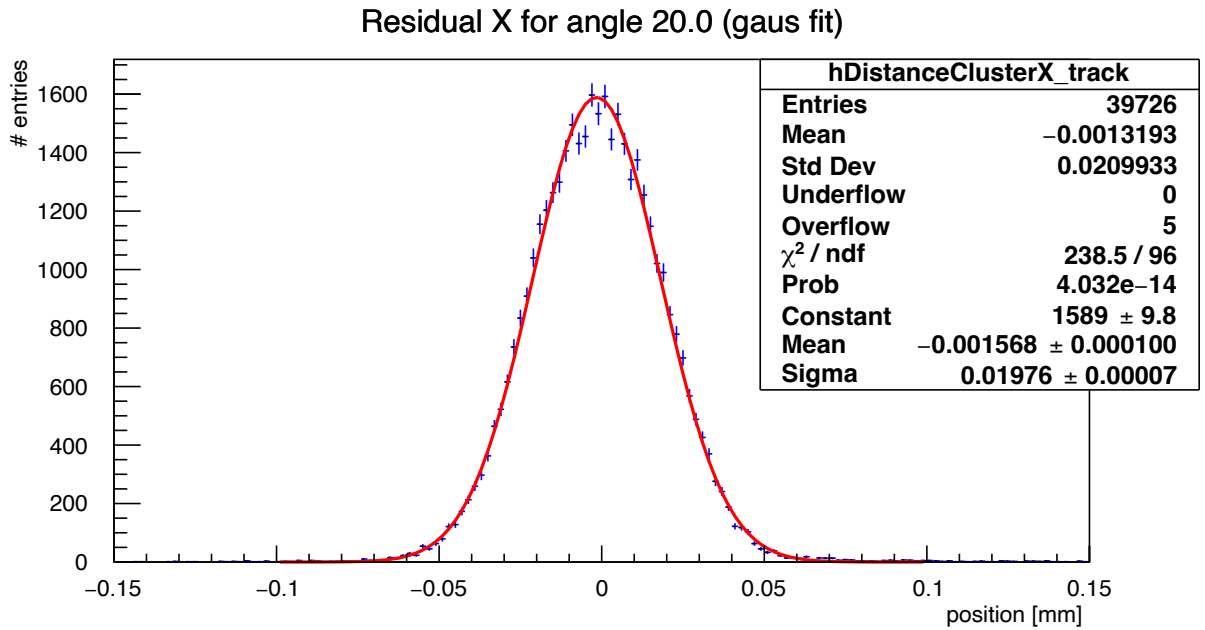
- Smaller discrimination window and larger spacing in inner layers

$$P_T = \frac{0.57R}{sin\theta} = 0.57R\sqrt{1+\left(\frac{d}{\Delta X}\right)^2}$$

R : radial position
d : spacing
ΔX : P_T window

(For magnetic field 3.8T and radial position 715mm)

Residual plot



Residual plot with gaussian fit at turning angle 20 deg