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The CMS Binary Chip

Overview and results

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Outline

Introduction to CMS Silicon Strip Tracker (SST)

High Luminosity LHC (HL-LHC) and implications for the tracker

Strip readout – present and future

CMS Binary Chip (CBC)

UA9 beam test

Results from beam test → Beam profile
→ Residual distributions
→ Cluster positions
→ Efficiency

Summary

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CMS Silicon Strip Tracker (SST)

The Tracker sits at the centre of CMS

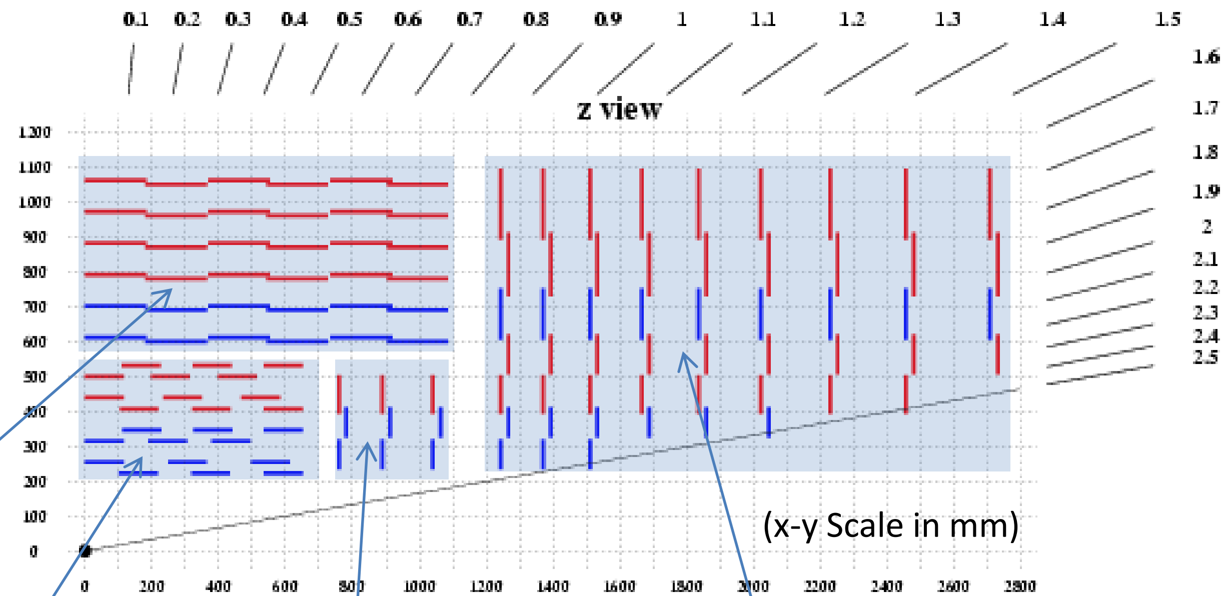
Provides precise, efficient measurement of charged particle trajectories

Pixels at centre

- 41 mm < r < 150 mm
- 60 million pixel channels, 100 x 150m pitch
- 3 barrels layers, 2 end cap disks either end
- <35 μm transverse IP resolution

Silicon Strip Tracker (SST)

- 22 cm < r < 110 cm
- ~200 m^2 total area
- ~10^7 strips (≤180 μm pitch)
- ~75,000 readout chips
- 4 sub detectors :



Tracker Outer Barrel (TOB)

Tracker Inner Barrel (TIB)

Tracker Inner Disk (TID)

Tracker End Cap (TEC)

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Tracker at the HL-LHC

HL-LHC foresees an increase in luminosity towards 5×10^{34} $cm^{-2}s^{-1}$

Principal aim is to increase data rate → better statistics

BUT, increased luminosity has significant implications for the CMS tracker...

- **Radiation damage**
  Increases due to greater particle fluence
- **Detector occupancies**
  Occupancies will increase → higher granularity required
- **Power consumption**
  Higher granularity → more strips → more power and cooling
- **Trigger**
  Level 1 trigger rate must remain at 100 kHz → Tracker must be used

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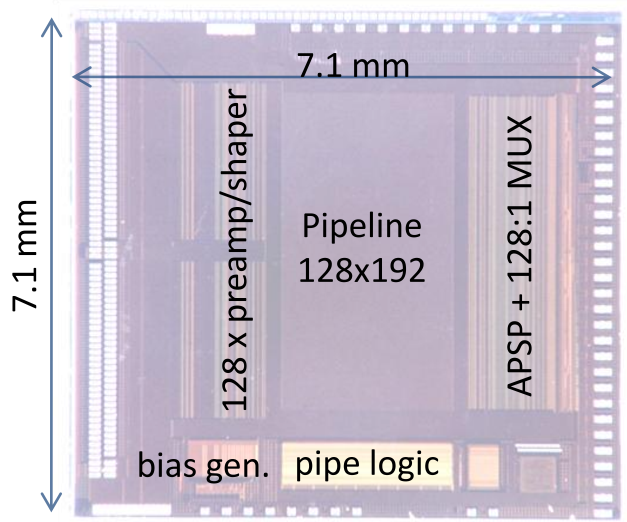
Strip readout

Strips are currently read out by the APV25 chip...

- 128 channel analogue pipeline readout chip, 0.25 µm CMOS
- Analogue → pulse height information remains (good for position resolution)
  → all detector information available off detector
- Simple system → zero suppression is not required, due to manageable data rates
  → fixed data rate... fully synchronous



However, at the HL-LHC...

High speed off-detector digital links will be used...

- FE digitisation would be needed for compatibility
  → very complicated chip
- Zero suppression would be needed due to high data volume and adc power
  → extra buffering required due to varying data volume per trigger

For simple non zero suppressed system → lose pulse height info → **binary**

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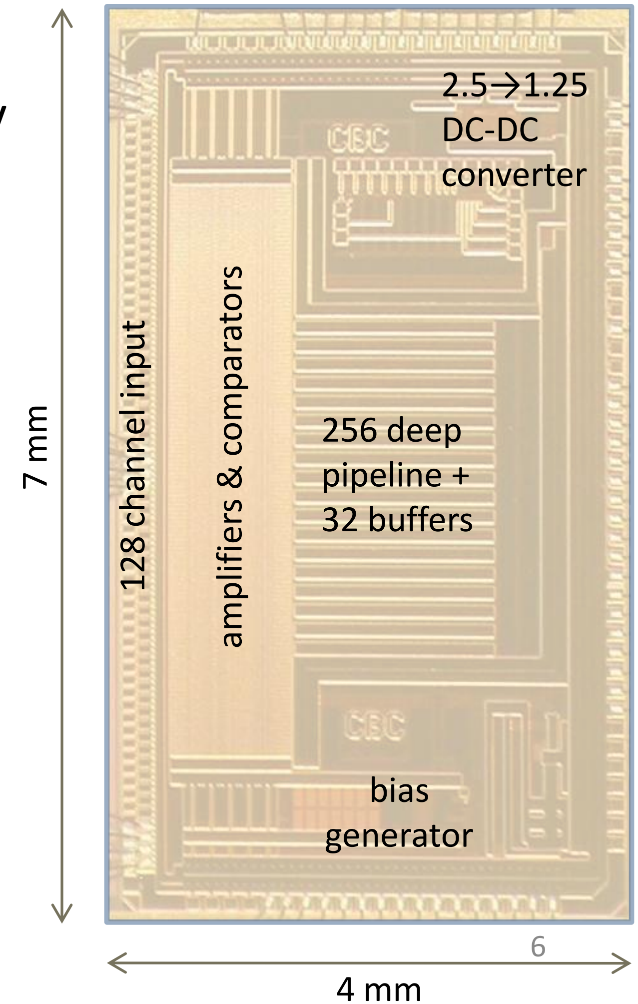
CMS Binary Chip (CBC)

Prototype binary readout chip for short microstrips at the HL-LHC

Binary → uses a comparator to select "hit" or "no hit" on each strip

- 128 channels
- Individually programmable thresholds, bias, latency
- Fabrication: 130nm CMOS
- Pipeline depth: 256 (40MHz → 6.4μs latency)
- Power consumption: ~300μW/channel



Advantages of binary system

- Simple design - less material/power
- Data volume remains manageable
- Zero suppression not required
  → data volume per trigger is constant
- Simple triggering algorithms are possible

Disadvantages

- Loses pulse height information
  → implications for position resolution?

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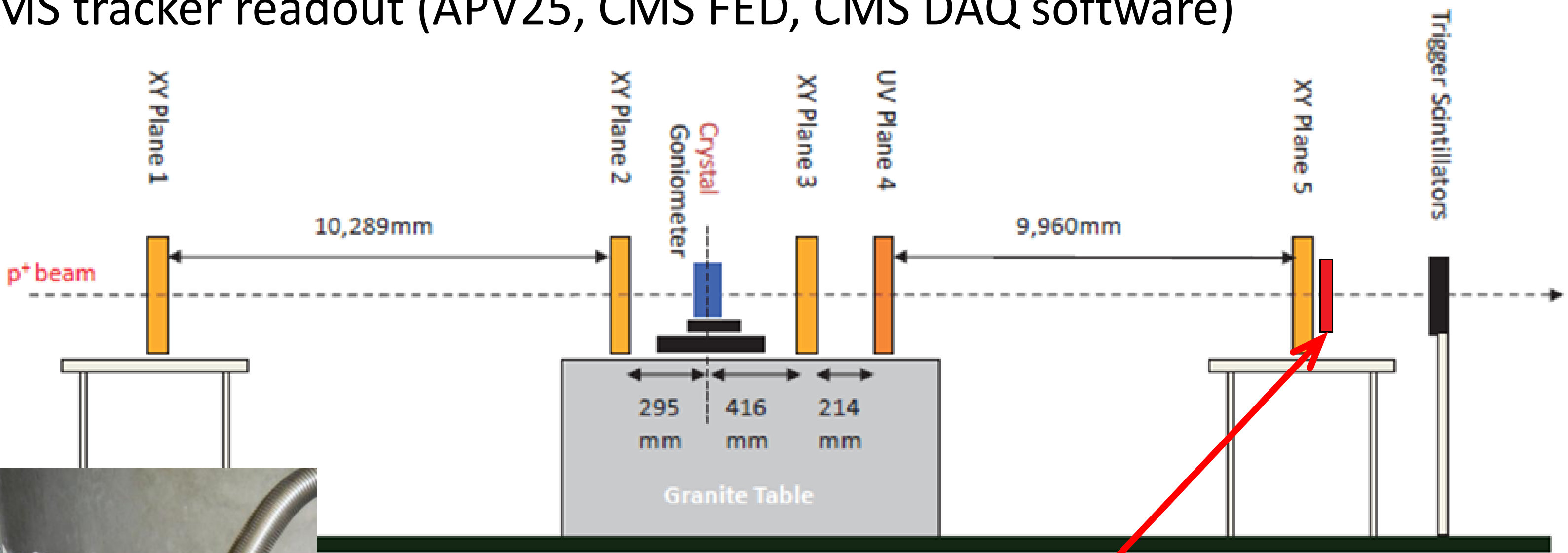
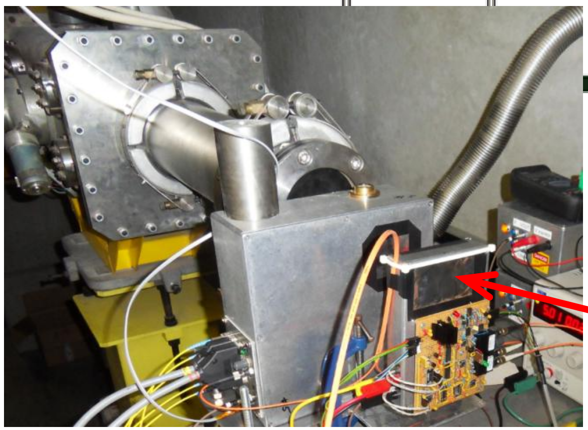
UA9 beam test, Sept 2011

UA9 → looks at crystal channeling of protons for collimation purposes

H8 beam line - 400 GeV protons

Imperial provided tracking telescope – 5 pairs of orthogonal silicon strip sensors using CMS tracker readout (APV25, CMS FED, CMS DAQ software)





CBC operated parasitically in test beam
(using sensor of ~134 μm pitch)
→ allows comparison with telescope data

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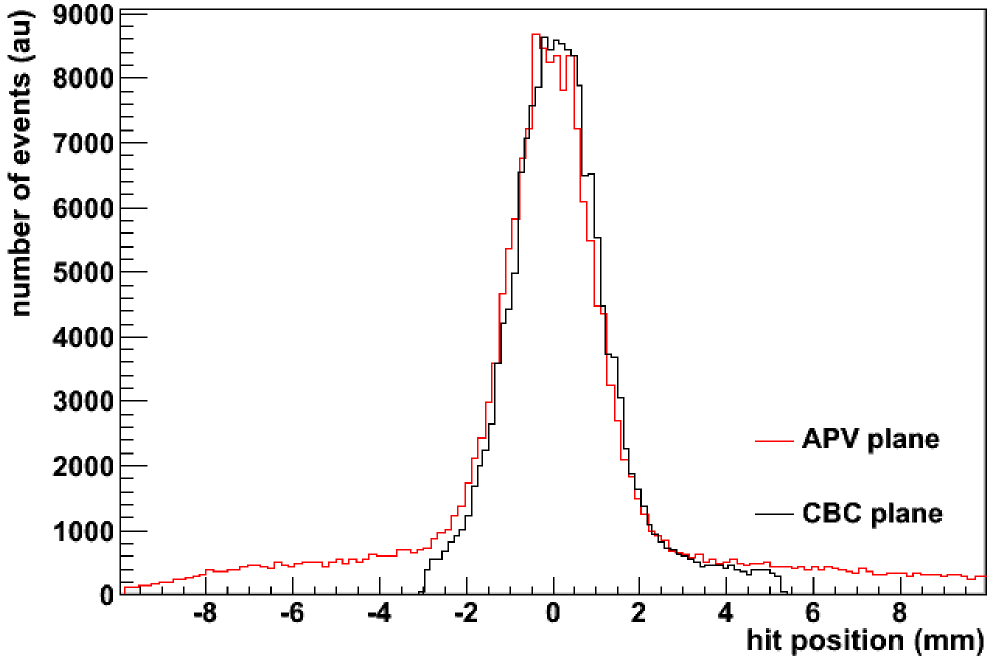
Results (I) – beam profile

Beam profile from telescope APV plane and CBC plane show consistency

→ Used for alignment



Subsequent analysis of resolutions and efficiencies is subject to selection cuts

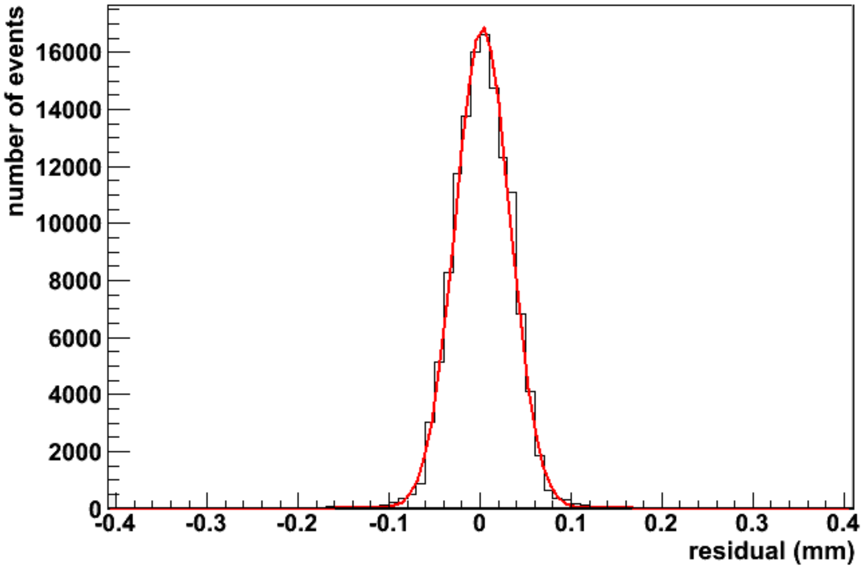
Event selection → one reconstructed downstream track in telescope

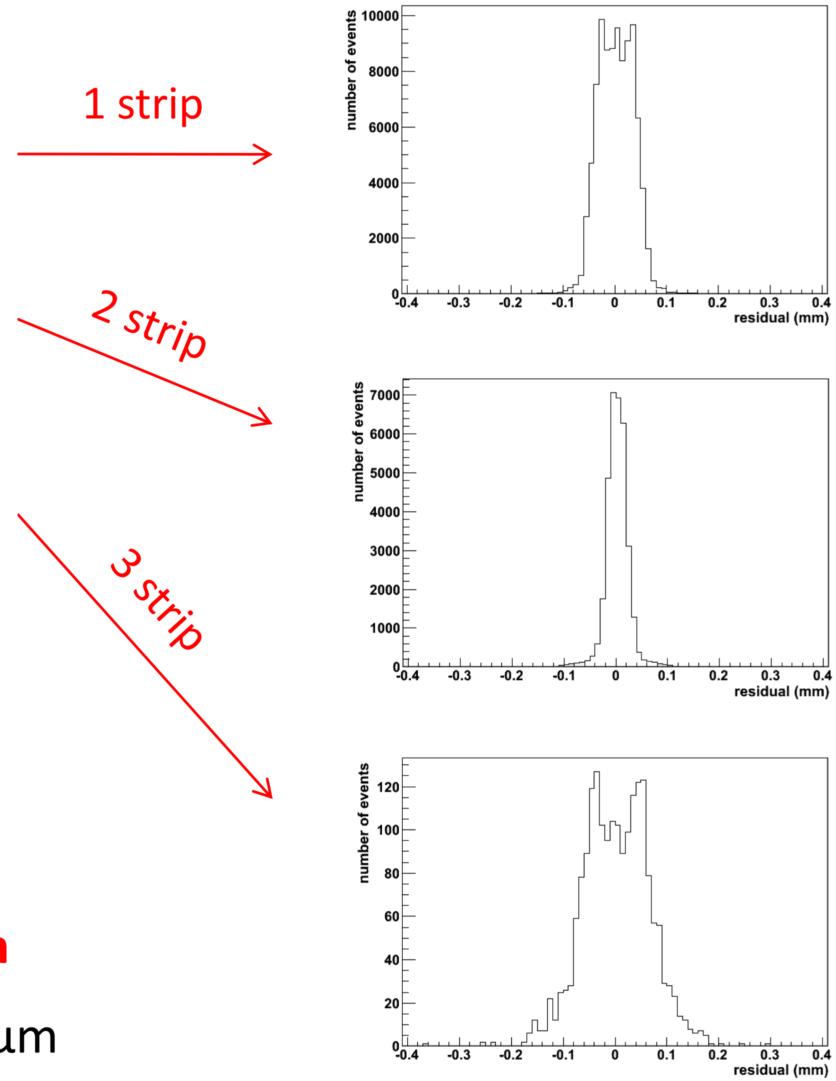
→ one hit in 5^{th} telescope plane

→ x alignment (track incident on CBC)

→ y alignment (track within 3mm vertical range)

Results (II) – residual plots





Residual = CBC hit posn – APV hit posn

Spread in residuals = 30.22 ± 0.06 μm

APV plane resolution = 7.0 ± 0.1 μm

→ **CBC resolution = 29.4 ± 0.1 μm**

→ better than pitch/$\sqrt{12}$ = 38.8 μm

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Results (III) – cluster distribution

One and two strip clusters dominate

Proportion of each depends largely on position on CBC strip...

Position on CBC strip is estimated from 5th telescope plane

Strip region

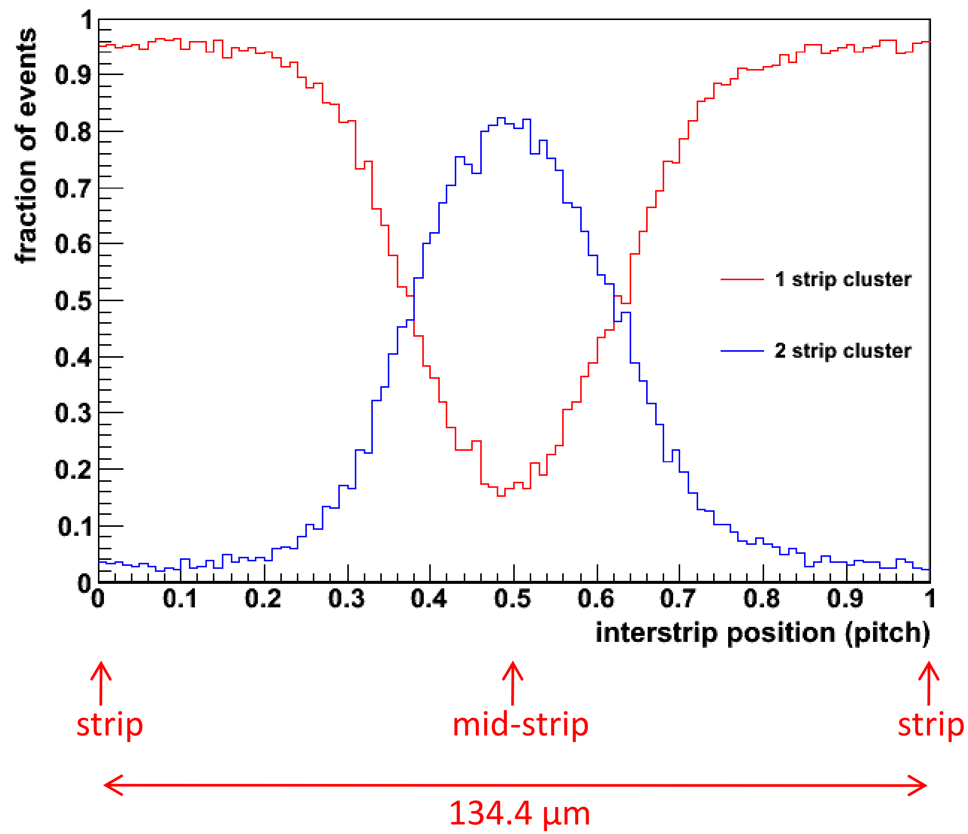
→ charge mostly on one strip

→ one strip clusters

Mid-strip region

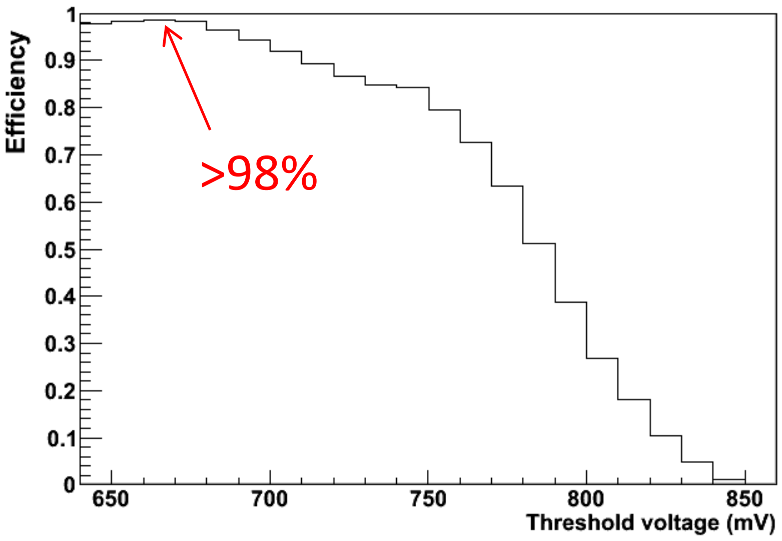
→ charge shared evenly between strips

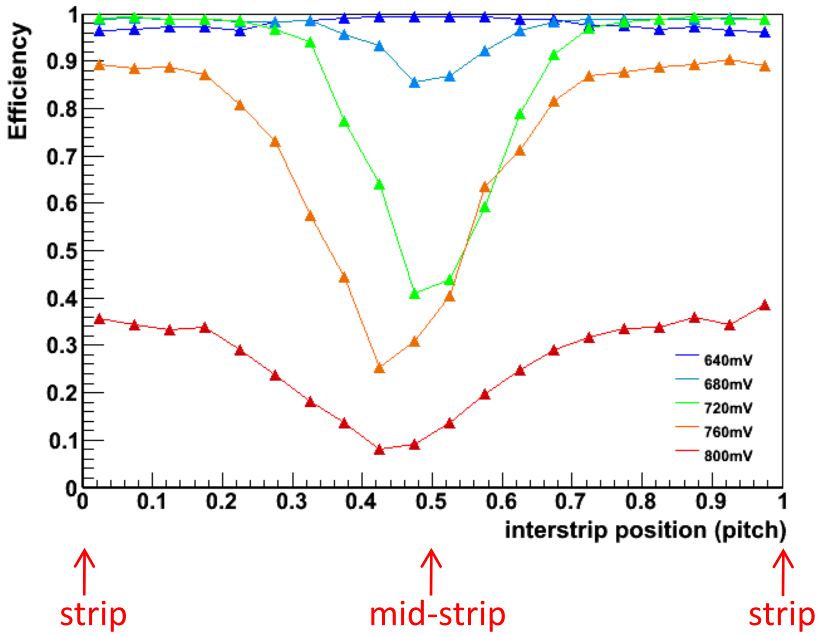
→ two strip clusters



Results (IV) – efficiency

Efficiency → proportion of selected events that lead to an event in CBC sensor





Characteristic S-curve

→ Efficiency reduces with threshold voltage as charge is less likely to exceed threshold

Efficiency drops in mid-strip region as charge is shared between strips

Effect is greater at large thresholds

Summary

CMS tracker will move to a binary readout in preparation for the HL-LHC

Prototype has been tested in the H8 400 GeV proton beam

Beam profile is consistent with telescope

Residual distribution shows better position resolution than pitch/$\sqrt{12}$

Cluster sizes are strongly related to hit positions over sensor strip period

Efficiency is ~98% at operating thresholds, but is reduced in the mid strip region at larger thresholds