CUPS14 Hands-on Exercise

CBC2 Test Beam Analysis

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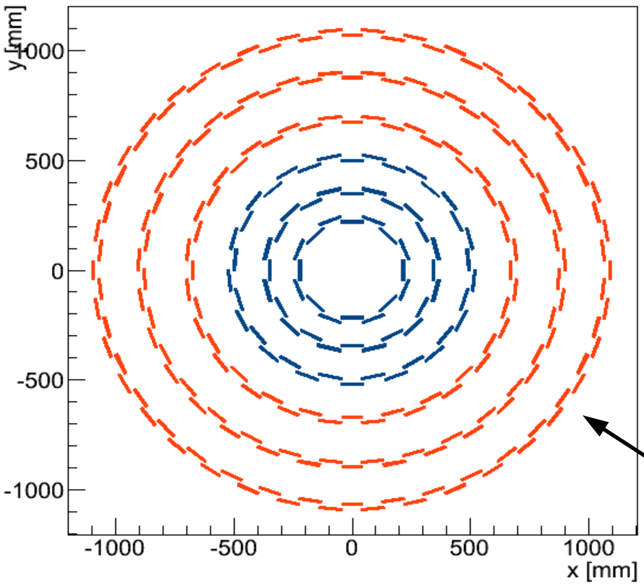
CMS Upgrade School 2014
DESY-Hamburg, Nov. 17-21

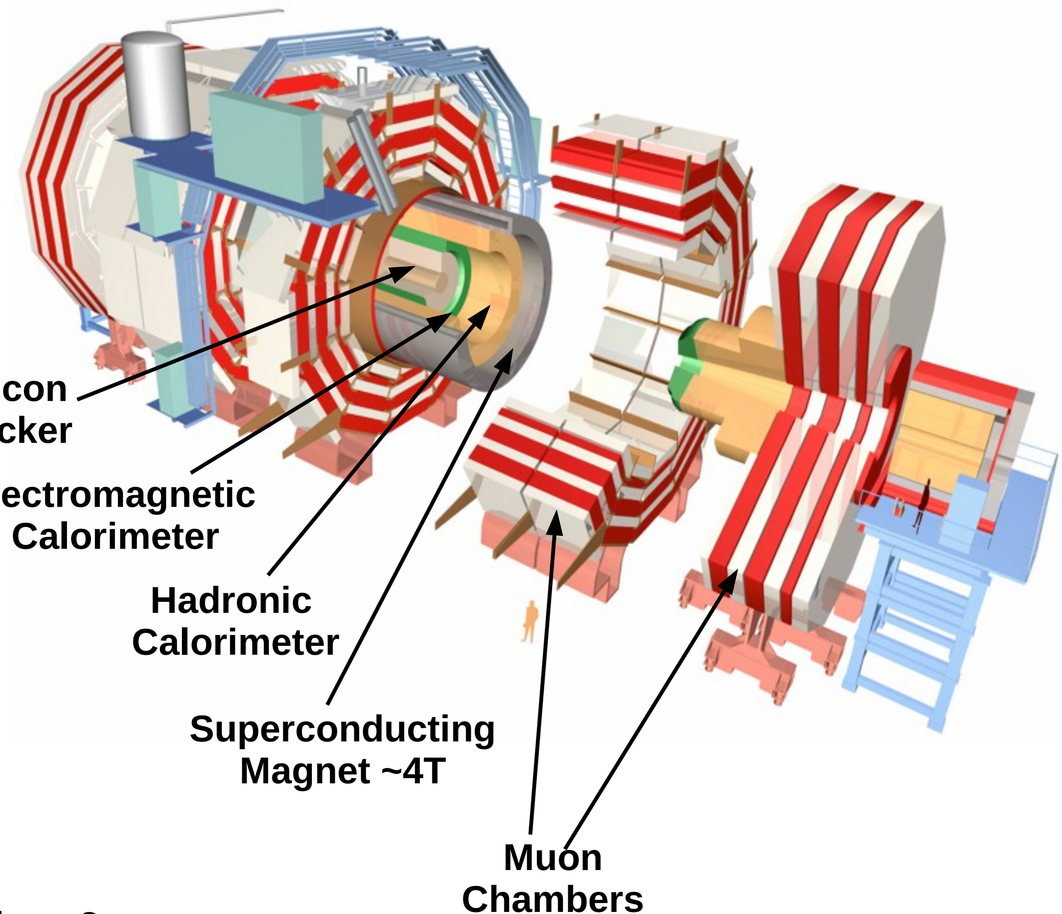
CMS Experiment and Phase 2 upgrade

> HL-LHC after Long Shutdown 3

- Entirely new tracker
- Will have to cope with 3000 fb^{-1} of integrated luminosity
- Resolve up to 200 collisions per bunch crossing (BX)

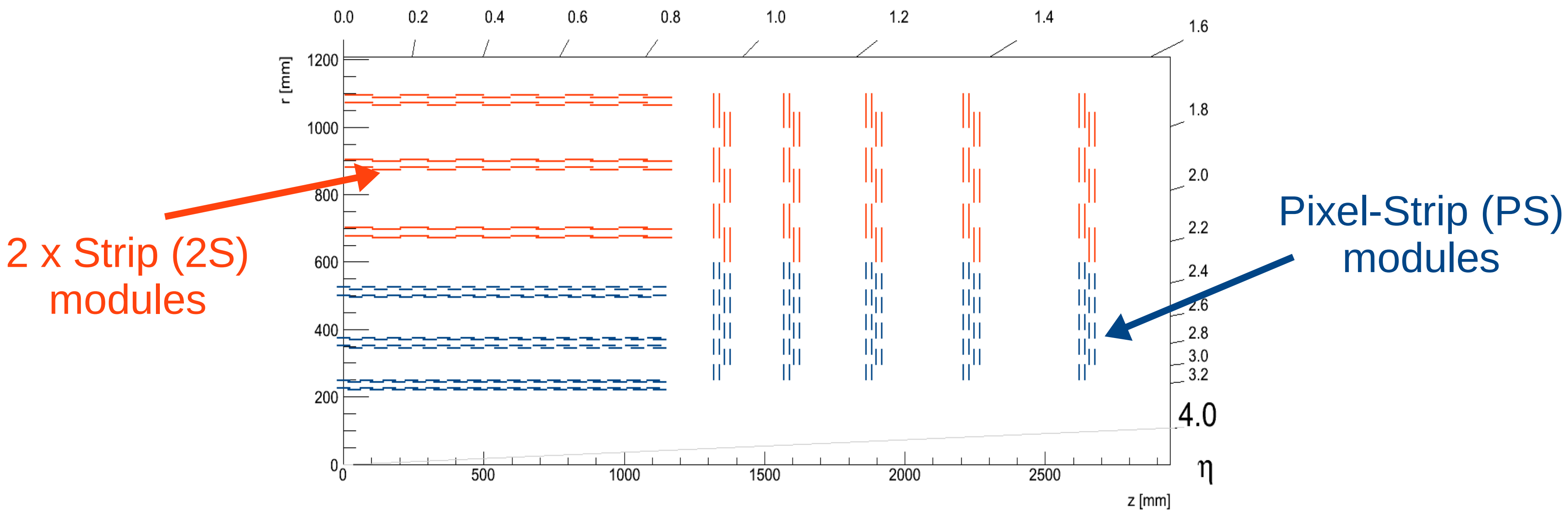


Phase2 outer tracker barrel layout



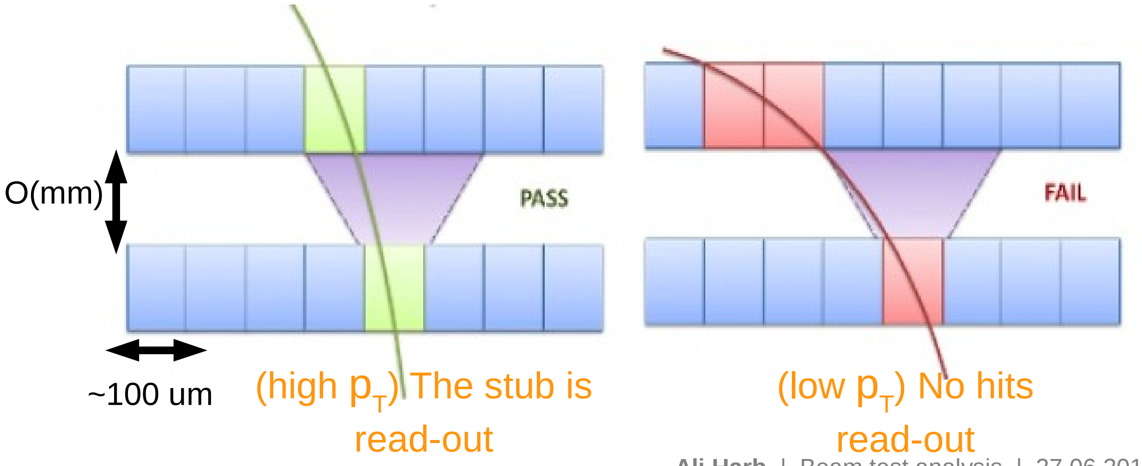
Phase2 Tracker Upgrade – main features

- > Provides Level-1 trigger (12 hits available up to η = 2.4)
- > p_T modules
  - 8424 x 2S and 7084 x PS modules
- > Average of x4 granularity in strip sensors
- > Total active surface 218 m^2



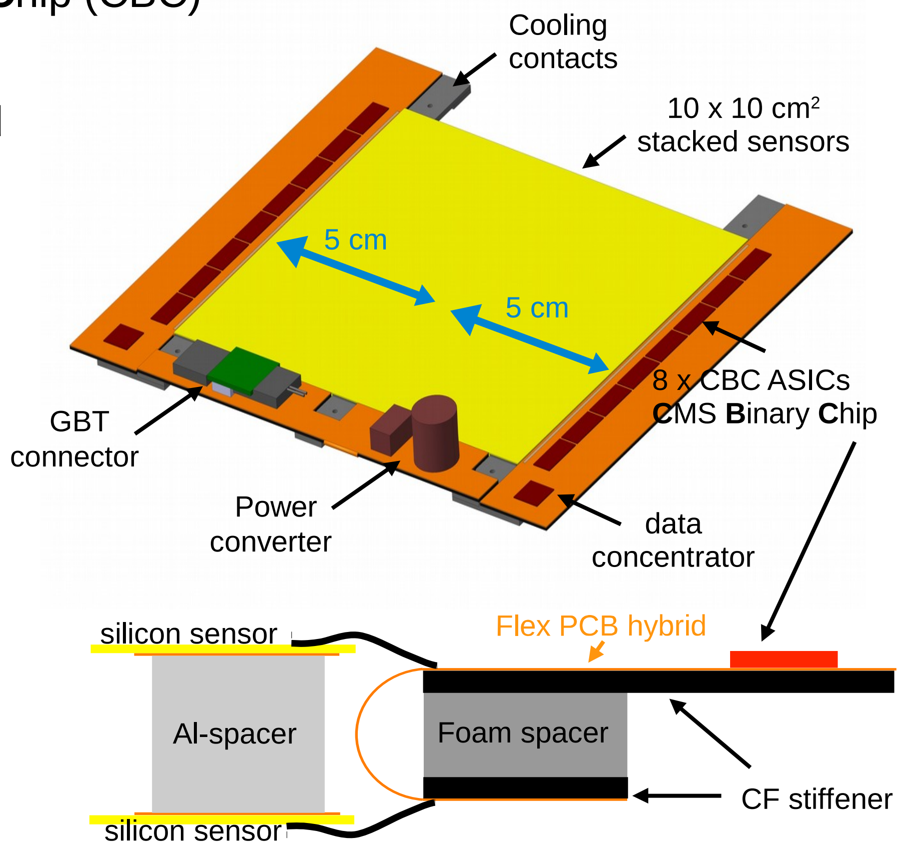
Concept of p_T modules

- Modules will provide Level-1 triggering (@40MHz) and readout data at same time
- Modules with p_T discrimination design
  - correlating signals in two closely spaced sensors
  - hit in first sensor passes within acceptance window of the second = “pass stub”
  - using p_T threshold of ~2GeV
  - accepted “stubs” sent out at every BX
  - leading to data reduction of at least one order of magnitude
- p_T threshold implemented by tuning the “stubs” acceptance windows and sensors spacing at different radii



The 2S p_T- Modules

> 2 Strip (2S) stacked sensors with **C**MS **B**inary **C**hip (CBC) readout chip
  - two sensors wire bonded to same FE-hybrid
  - CBC ASICs bump-bonded on flex hybrid
  - whole electronics system (readout & power) on module



> Each sensor:
  - 2 columns of 5 cm long strips
  - 90 um pitch
  - ~ 10 x 10 cm^2 area

> CBC read-out chip
  - 130 nm CMOS technology
  - correlates signal from both stacked sensors
  - 254 readout channels
    (1x CBC handles signals from 127 channels from each sensor)
  - cluster width discrimination(> 1,2,3 strips)
  - programmable window width (up to +/- 8 strips) for p_T cuts

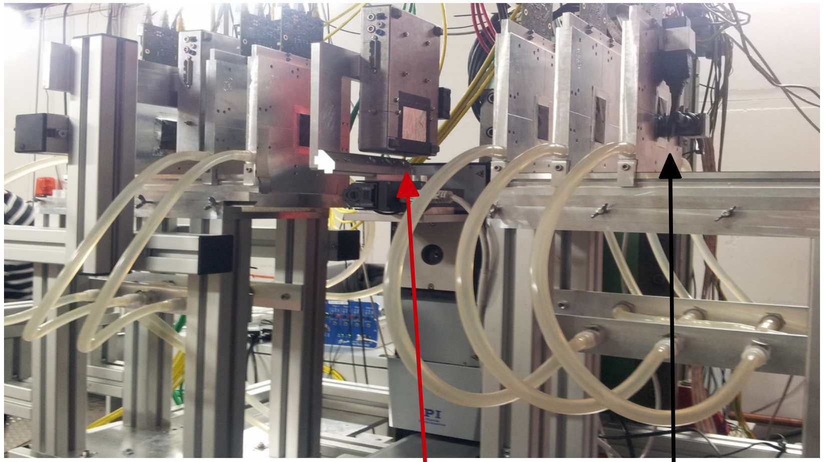
Experimental Setup

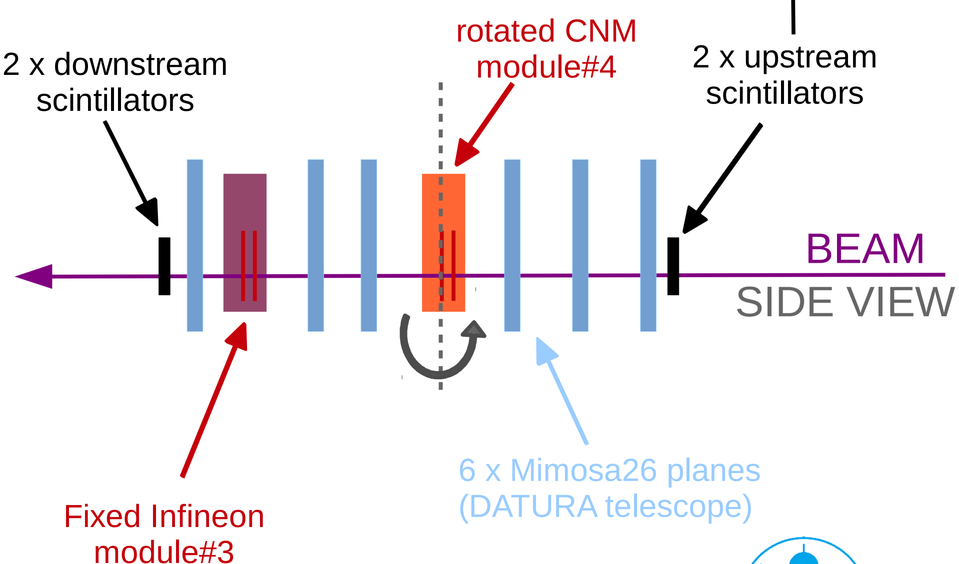
> DESY-II test beam Nov. 2013

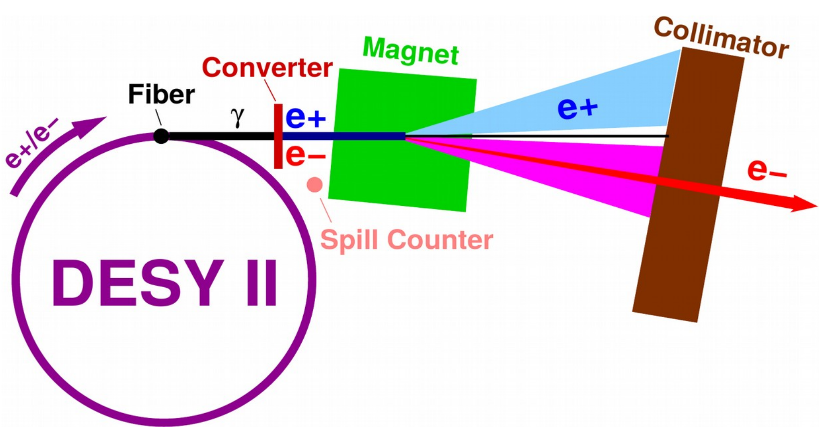
- positron beam
- 2 to 4 GeV ~O(1)kHz rate

> DATURA telescope

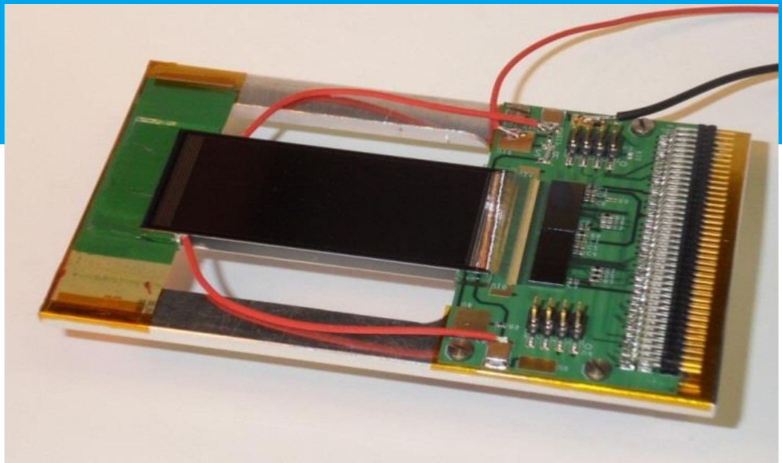
- 6 x Mimosa26 pixel sensors
- 50 um thick, 18.4 um pitch
- 224 mm^2 active area
- 4 x Trigger scintillators
(2 x upstream and 2 x downstream)

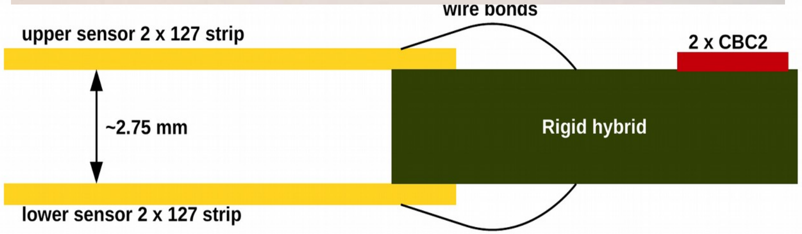




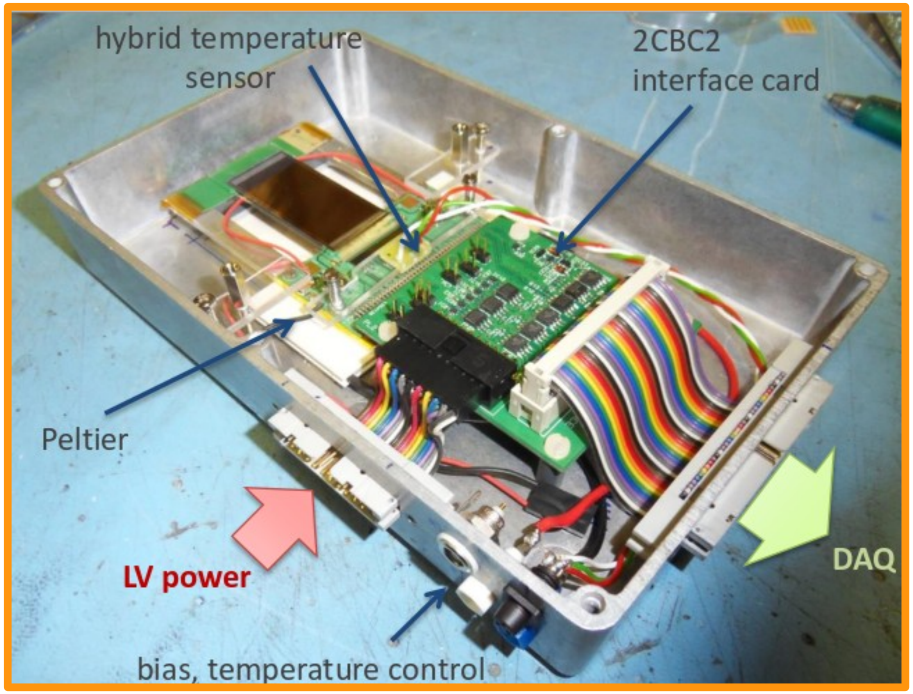


Tested modules





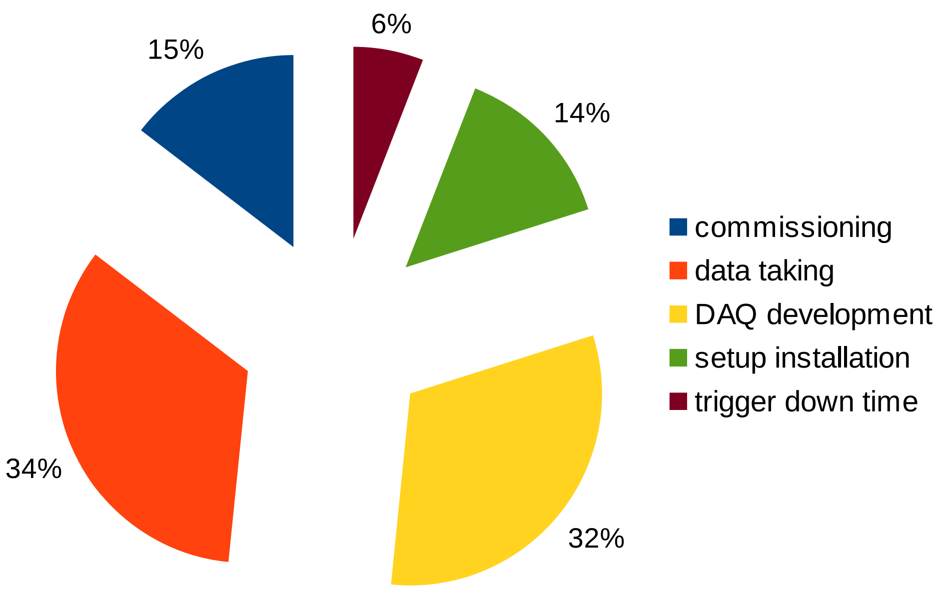
- Two mini-2S modules with CBC2 readout
  - 2 x CBC bump-bonded to rigid hybrid
  - Sensors separated by ~3mm wire bonded to the hybrid
  - Aluminum frame as support for the sensors and the hybrid
- CNM module
  - p-type, 270um thick
  - 25 x 54 mm^2 (23.1 x 50.2 mm^2 active area)
  - 254 strips, 90um pitch
- Infineon module
  - n-type, 300um thick
  - 23 x 50mm^2 (20.6 x 48.3mm^2 active area)
  - 256 strips, 80um pitch



Recorded data sets

> 543 runs recorded, 120M events
  - 3 days of continuous data taking
  - 186 measurement runs

run	measurement type
219-238	Threshold scan
296-302	Trigger latency scan
331-342	Data latency scan
350-357	Trigger latency scan
365-373	Angular scan
375-386	Angular scan
413-457	Threshold scan
467-477	Trigger and data latency scans
478-496	Threshold scan
499-503	Angular scan
504-540	Threshold scan
540-543	Cluster width scans



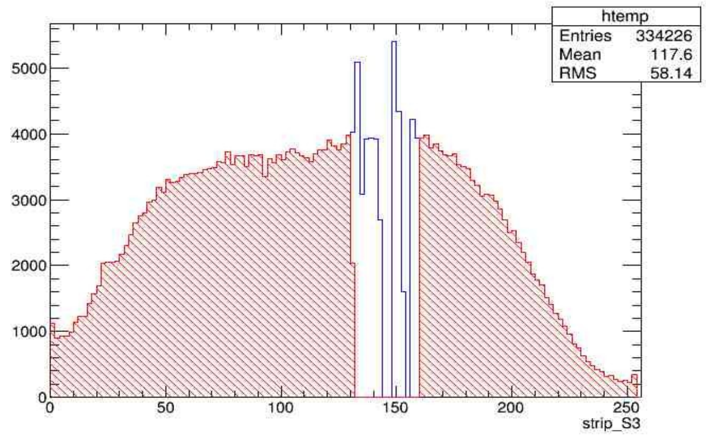
Analysis workflow

> Stage 1: from edm files to “raw Ntuples”

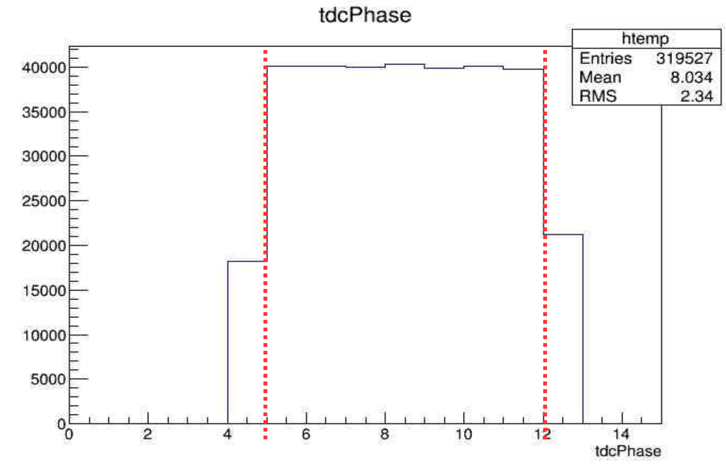
- The only CMSSW dependent step using edm analyzer
- Containing all needed information

> Stage 2: from “raw Ntuples” to “reconstructed Ntuples”

- TDC cut
- Masking
- Clustering
- Stubs reco
- Histograms (monitoring)



Cut: $5 \leq TDC \leq 11$



> Stage 3: analysis macros

- Beam divergence
- Efficiency, residuals ...
- Angular scan ...

RAW Ntuple

RAW Ntuple

```
******************************************************************************
*Tree    :tree      : Simple Tracking Tree                                   *
*Entries :   319527 : Total =        58039851 bytes  File  Size =   16320802 *
*        :          : Tree compression factor =   3.56                       *
******************************************************************************
*Br    0 :event     : event/i                                                *
*............................................................................*
*Br    1 :run       : run/i                                                  *
*............................................................................*
*Br    2 :lumiSection : lumiSection/i                                        *
*............................................................................*
*Br    3 :time      : time/L                                                 *
*............................................................................*
*Br    4 :unixtime  : unixtime/L                                             *
*............................................................................*
*Br    5 :dut0_row  : vector<int>                                            *
*............................................................................*
*Br    6 :dut1_row  : vector<int>                                            *
*............................................................................*
*Br    7 :dut2_row  : vector<int>                                            *
*............................................................................*
*Br    8 :dut3_row  : vector<int>                                            *
*............................................................................*
*Br    9 :dut0_channel : vector<int>                                         *
*............................................................................*
*Br   10 :dut1_channel : vector<int>                                         *
*............................................................................*
*Br   11 :dut2_channel : vector<int>                                         *
*............................................................................*
*Br   12 :dut3_channel : vector<int>                                         *
*............................................................................*
*Br   13 :tdcPhase  : tdcPhase/i                                             *
*............................................................................*
```

Events and run number (Br 0–1)

Time (Br 3–4)

Strips data (S0, S1, S2, S3) (Br 5–8)

Channels (S0, S1, S2, S3) (Br 9–12)

→ TDC Phase (Br 13)

RECO Ntuple

RECO Ntuple

```
******************************************************************************
*Tree    :recotree  : reconstructed                                          *
*Entries :   280059 : Total =       110347727 bytes  File  Size =   28257018 *
*        :          : Tree compression factor =   3.91                       *
******************************************************************************
*Br    0 :events    : events/i                                               *
*............................................................................*
*Br    1 :run       : run/i                                                  *
*............................................................................*
*Br    2 :row_S0    : vector<int>                                            *
*............................................................................*
*Br    3 :row_S1    : vector<int>                                            *
*............................................................................*
*Br    4 :row_S2    : vector<int>                                            *
*............................................................................*
*Br    5 :row_S3    : vector<int>                                            *
*............................................................................*
*Br    6 :row_S2_masked : vector<int>                                        *
*............................................................................*
*Br    7 :row_S3_masked : vector<int>                                        *
*............................................................................*
*Br    8 :channel_S0 : vector<int>                                           *
*............................................................................*
*Br    9 :channel_S1 : vector<int>                                           *
*............................................................................*
*Br   10 :channel_S2 : vector<int>                                           *
*............................................................................*
*Br   11 :channel_S3 : vector<int>                                           *
*............................................................................*
*Br   12 :clusters_S0 : vector<double>                                       *
*............................................................................*
*Br   13 :clusters_S1 : vector<double>                                       *
*............................................................................*
*Br   14 :clusters_S2 : vector<double>                                       *
*............................................................................*
*Br   15 :clusters_S3 : vector<double>                                       *
*............................................................................*
*Br   16 :clusterwidth_S0 : vector<int>                                      *
*............................................................................*
*Br   17 :clusterwidth_S1 : vector<int>                                      *
*............................................................................*
*Br   18 :clusterwidth_S2 : vector<int>                                      *
*............................................................................*
*Br   19 :clusterwidth_S3 : vector<int>                                      *
*............................................................................*
*Br   20 :stubs_module_1 : vector<double>                                     *
*............................................................................*
*Br   21 :stubs_module_2 : vector<double>                                     *
*............................................................................*
*Br   22 :tdc       : tdc/i                                                  *
*............................................................................*
```

- Branches 0–1: Events and run number
- Branches 2–5: Strips data (S0, S1, S2, S3)
- Branches 6–7: Masking (S2, S3)
- Branches 8–11: Channels (S0, S1, S2, S3)
- Branches 12–15: Clustering (S0, S1, S2, S3)
- Branches 16–19: Clusterwidth (S0, S1, S2, S3)
- Branches 20–21: Δstrip for both modules
- Branch 22: TDC Phase

Exercise

Use the raw data files of the angular scan runs shown in Table 4 to do:

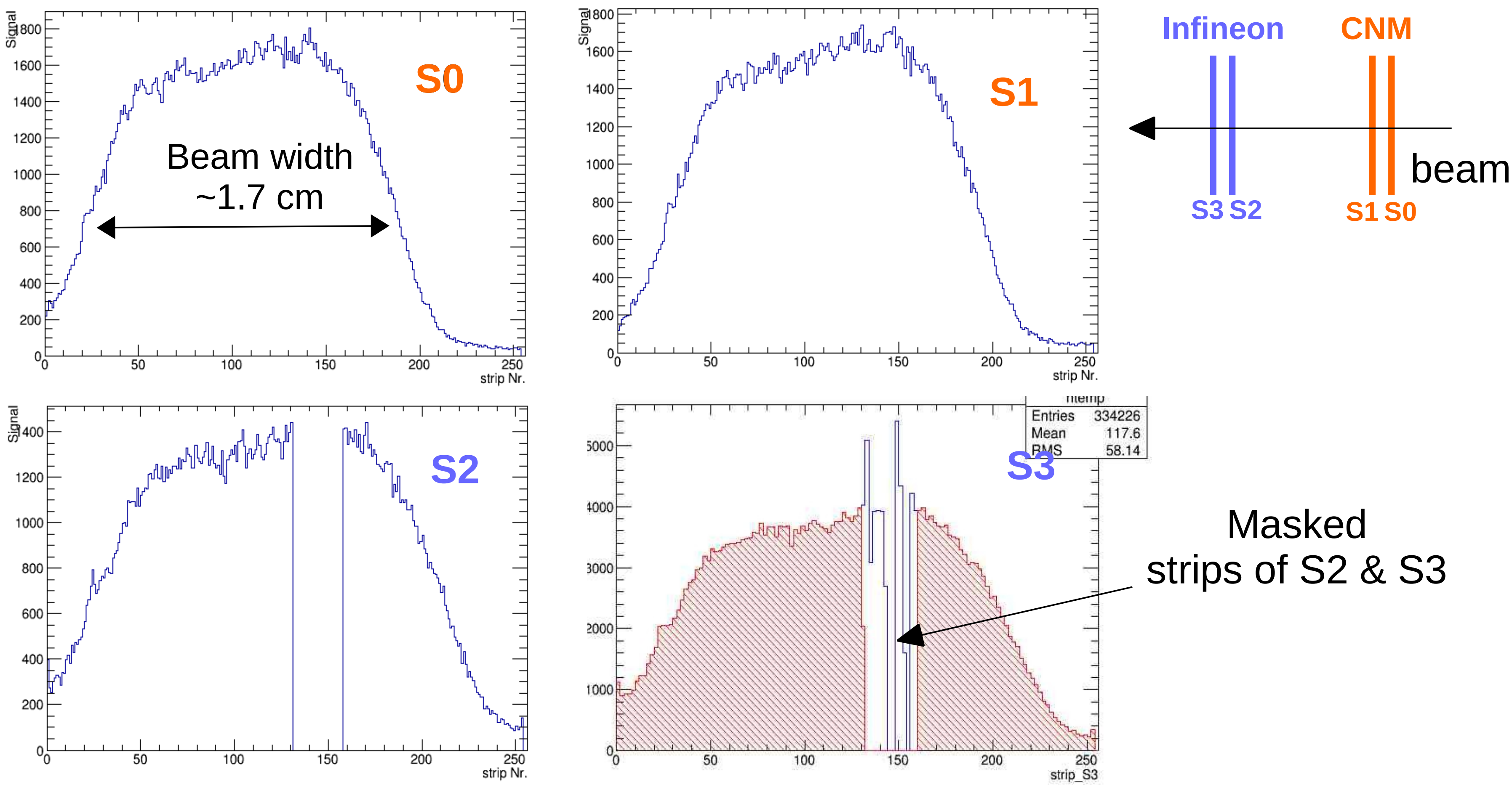
1. Masking of noisy strips in S2 and S3.
2. Clustering as defined in Equation 1.
   (a) Plot the cluster width, defined in Equation 2, versus angle.
   (b) Plot cluster width versus cluster position at $0°$ and $15°$ (TProfile).
3. Stubs reconstruction as described in Equation 3.
   (a) Plot the reconstructed stubs mean value versus the rotation angle;
   (b) from the fit, obtain the angular offset and the distance separating the sensors S0 and S1, assuming that the two sensors are perfectly aligned.

Bonus: Using the clusters from the four sensors get the beam divergence distribution.

1. Fit the beam divergence distribution;
2. from the fit obtain the beam divergence value and the miss alignment between the modules.

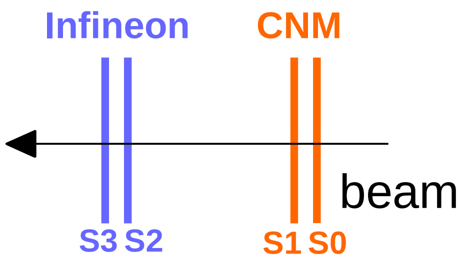
run	478	499	504	500	501	511	502	518	503	526
angle [°]	0	8	10	11	12	13	14	15	16	20

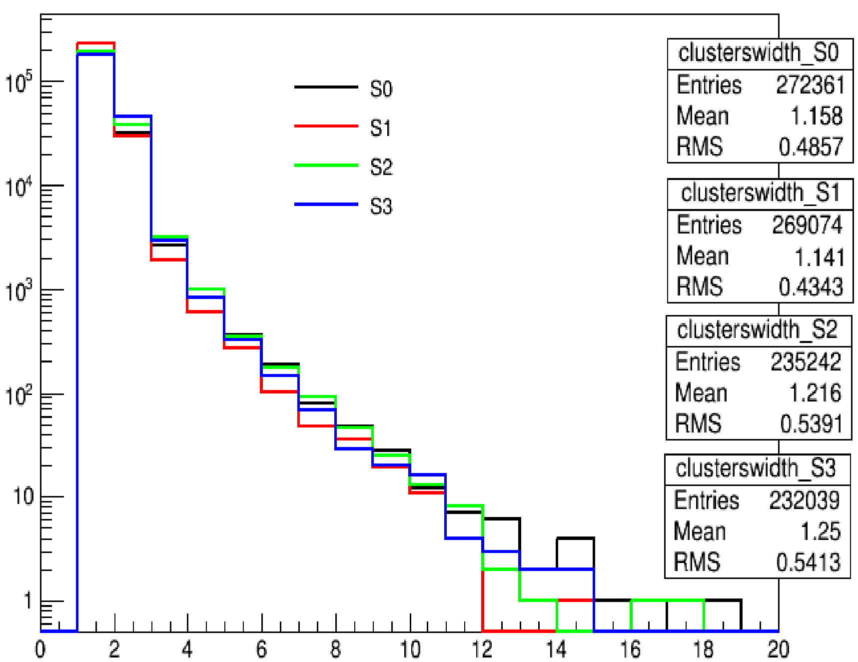
Beam profile and Masking

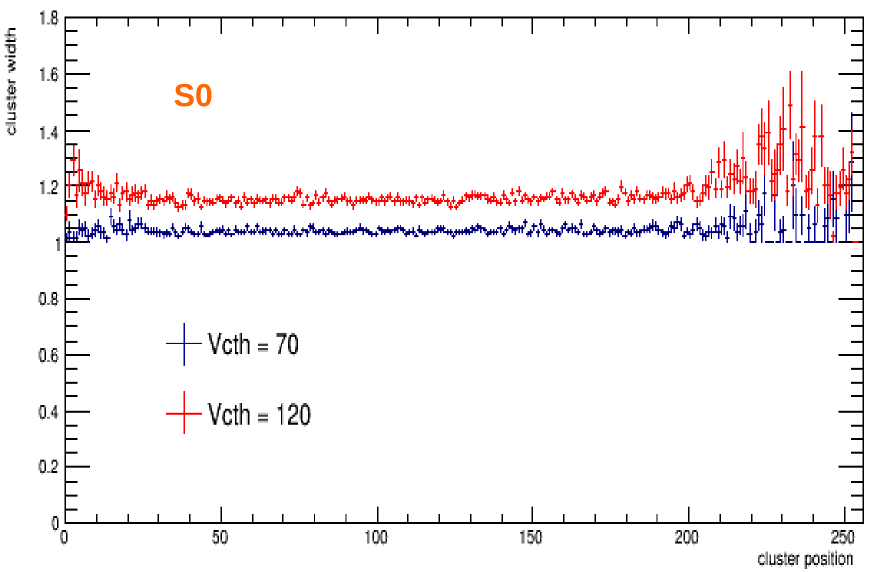


Clustering

- Binary read-out
- Group of neighboring strips registered hit signal
- Position: $X = pitch \times (\frac{n_{\text{first}} + n_{\text{last}}}{2})$
- Width: $W = n_{\text{last}} - n_{\text{first}} + 1$

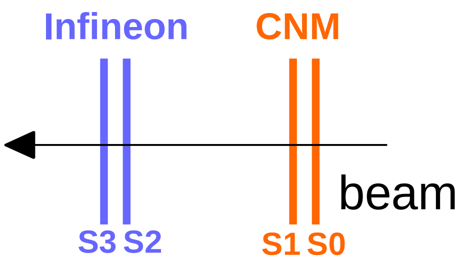


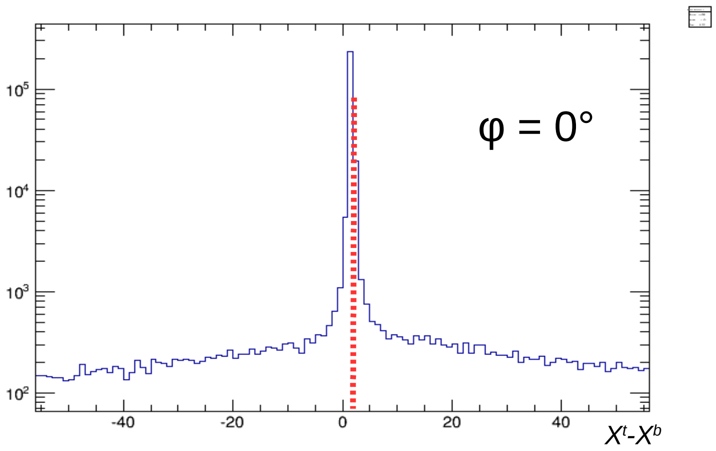


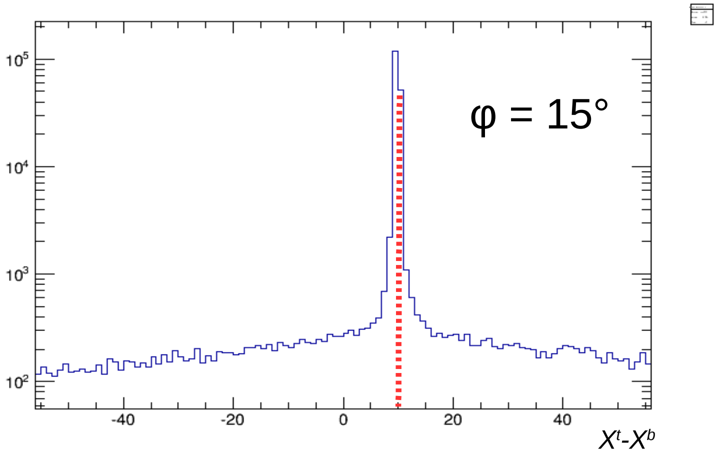


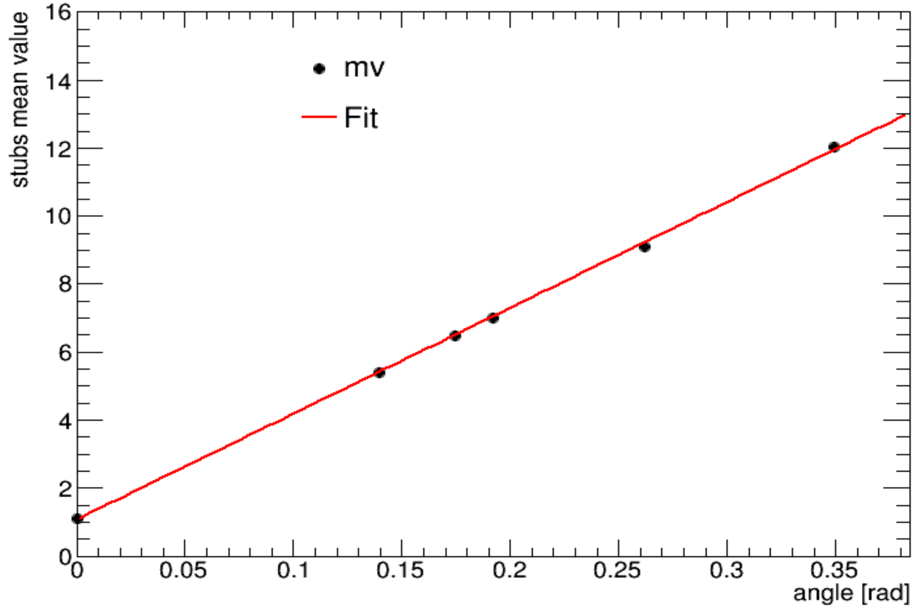
Stubs reconstruction

> The difference of hit position between the 2 stacked sensors
  - Xt = hit position in top sensor (S0)
  - Xb = hit position in bottom sensor (S1)









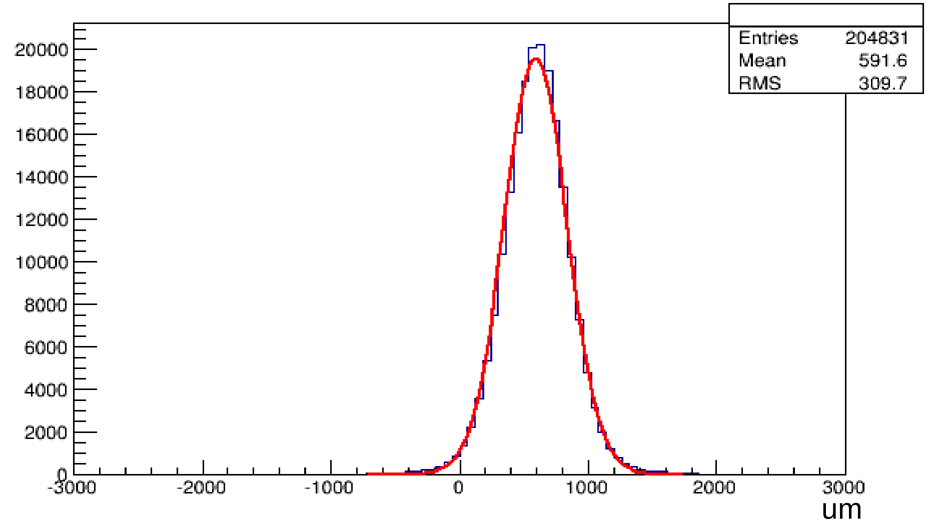
$\varphi^{initial} \sim 2.1°$

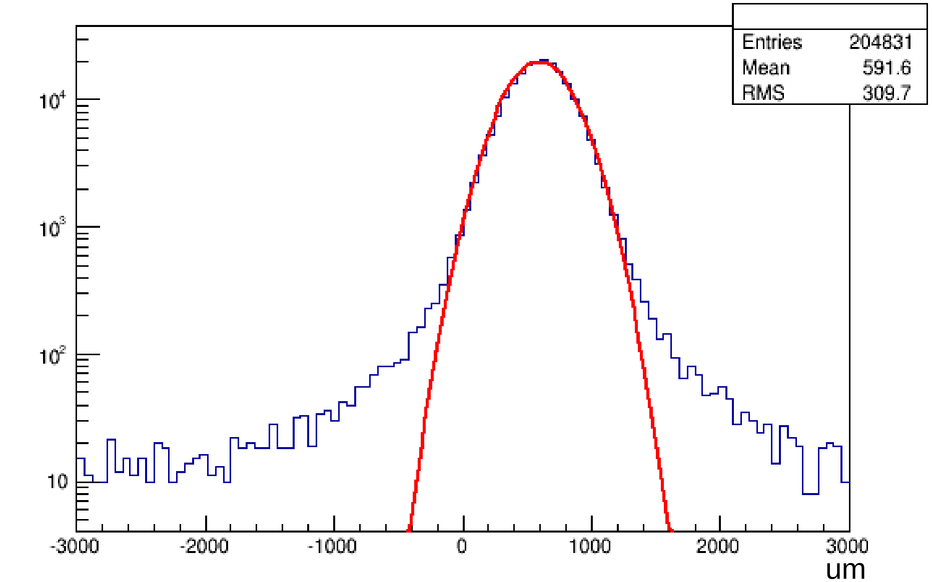
Beam divergence

- The difference between the Mean hit position on both modules
- Mean of the fit: ~ 600um offset between the two module
- Divergence:

$$\theta = arctan(\frac{\sigma}{d})$$

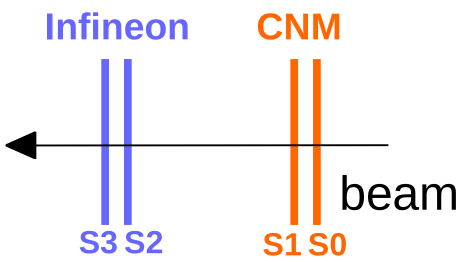
θ ~ 1.1 mrad

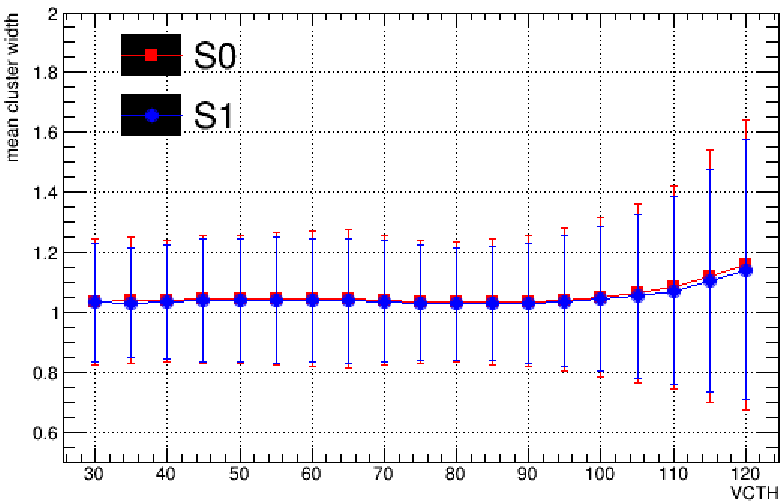


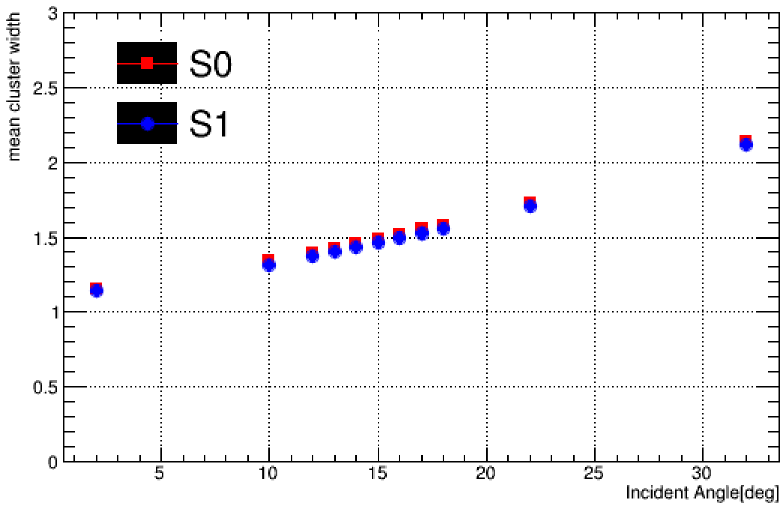


Cluster width

> Mean cluster width
  - vs. threshold (left)
  - vs. angle (right)

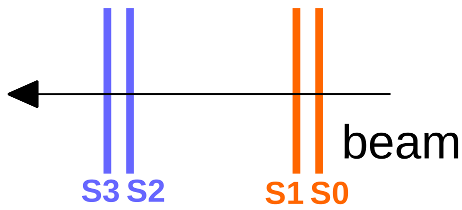




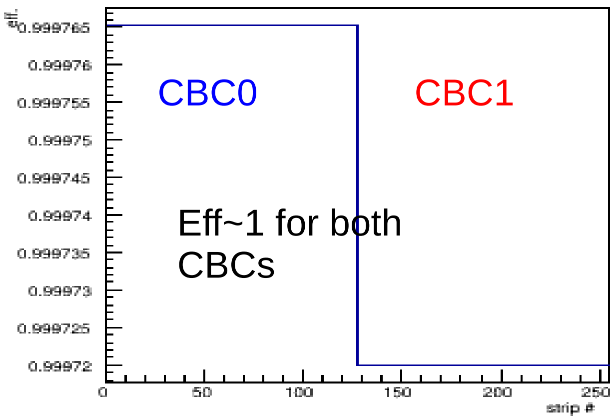


Efficiency vs threshold

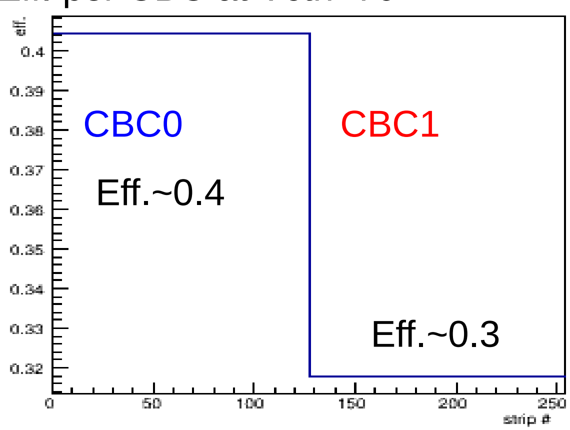
> Efficiency per CBC at two different threshold values for S0

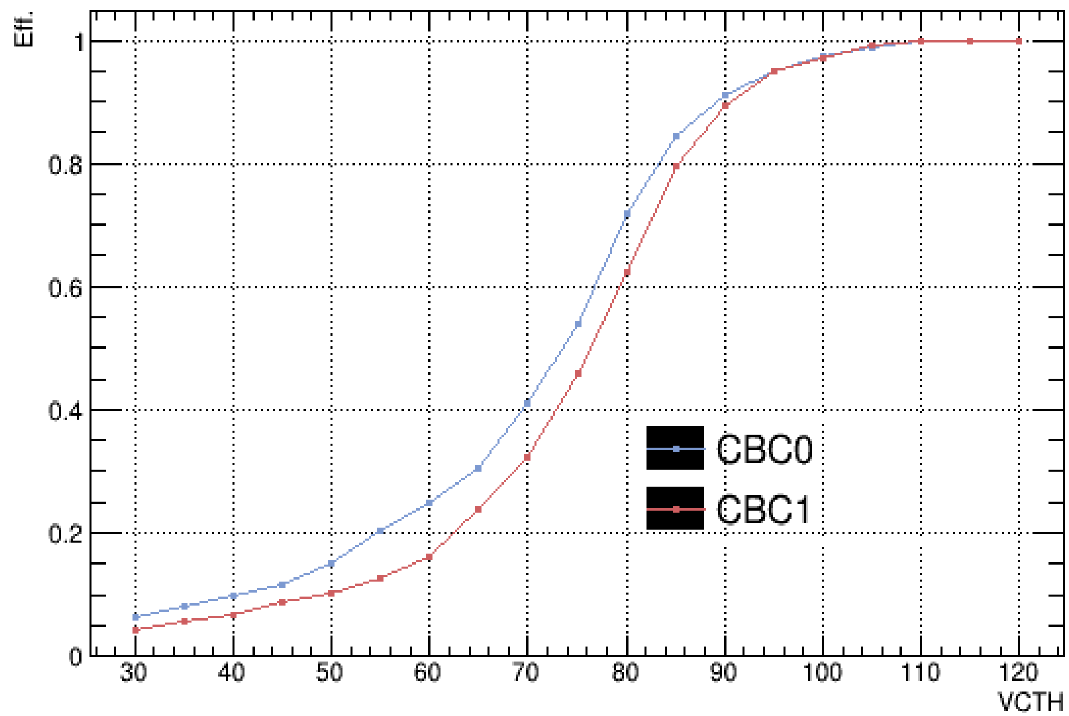


- Eff. per CBC at Vcth=120



- Eff. per CBC at Vcth=70





DESY

Residuals

- Using events with only one cluster in 3 sensors
- Getting predicted hit in fourth sensor from track fitting
- Compare to measured hit on the fourth sensor
  R = Predicted hit – measured hit ~ 28um (RMS)