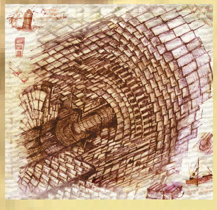
Design and development of a micro-strip stacked module prototype to measure flying particles directions

A.Messineo University and INFN, Pisa



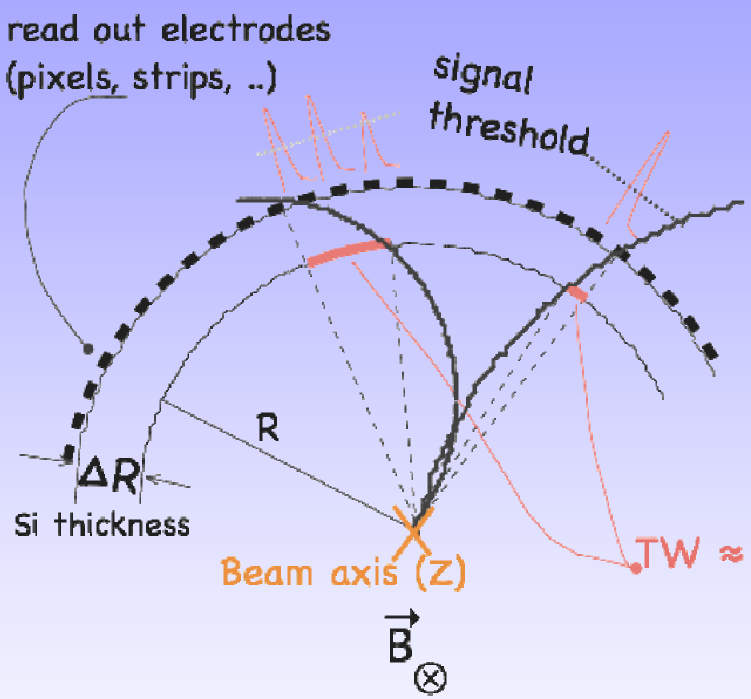
J. Bernardini [2], F.Bosi [1], R.Dell'Orso [1], F.Fiori [3], A.Messineo [3], F.Palla [1], A.Profeti [1]
(INFN [1], Scuola Normale Superiore [2] & University [3], Pisa)

Talk Outline

- **Ideas**
  - Stacked modules
  - Track flying performance: test of the method
- **Prototypes**
  - Modules with two configurations
- **Performance and results**
  - Module test with β source
  - Tracking with cosmic rays
- **Integration**
  - Large array construction

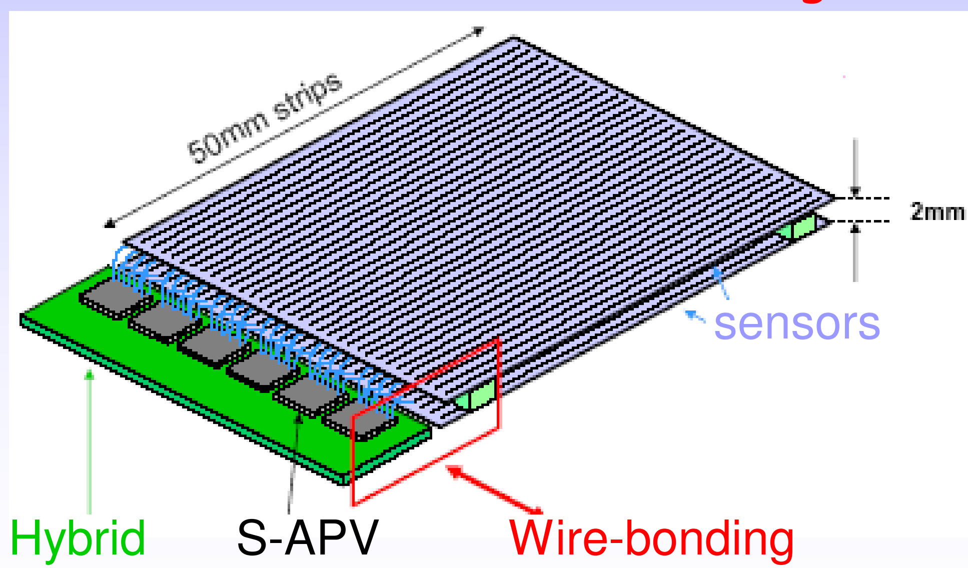
Ideas: Stacked modules

- **Two micro-strip sensors**
  - Good performance for:
    - Track path length measurement
    - Simple Logic Correlation in space
    - Track direction of Flight



R-Φ plane , "ideal" barrel layer

Model by F. Palla & G. Parrini



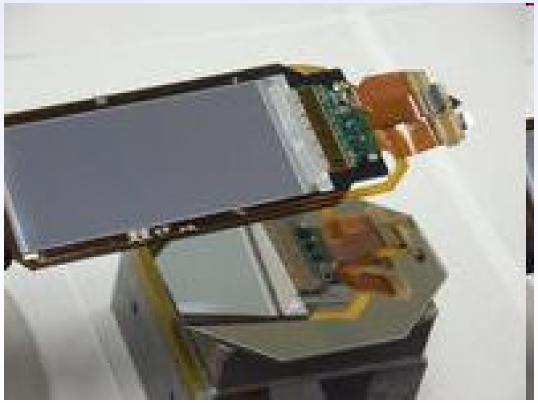
Ideas by R. Horisberger

Method applied to data: performances

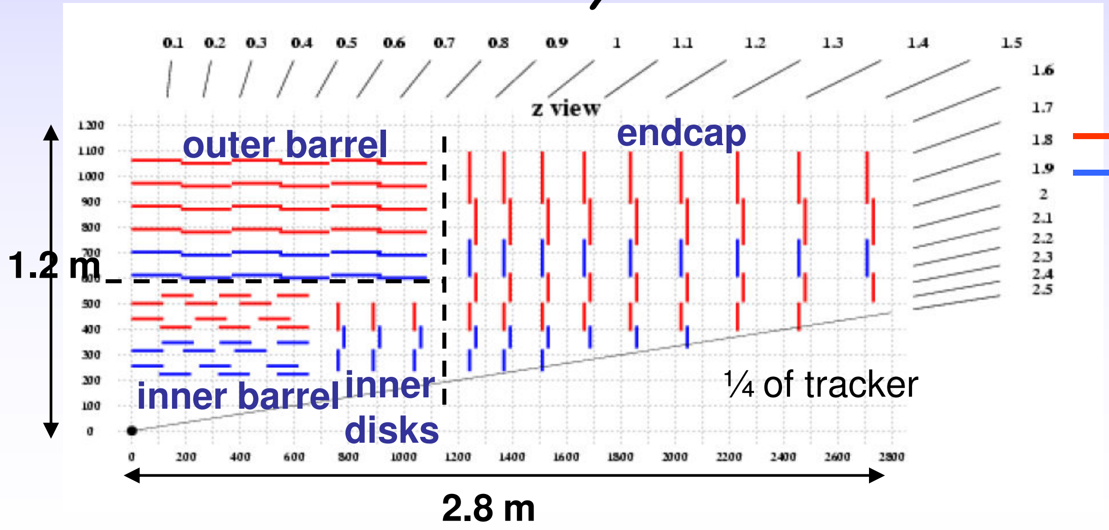
- **Performance has been evaluated with**
  - Simulation
  - Real data collected with CMS tracker: cosmic rays & first (2009) LHC collision events

Modules used in this study:

-Single Sided
-Double Sided



CMS tracker Layout

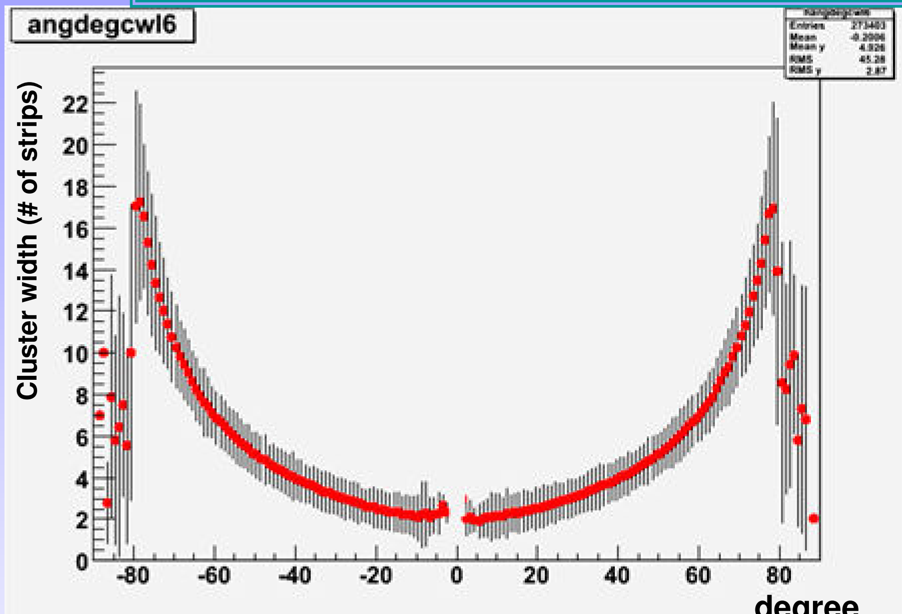


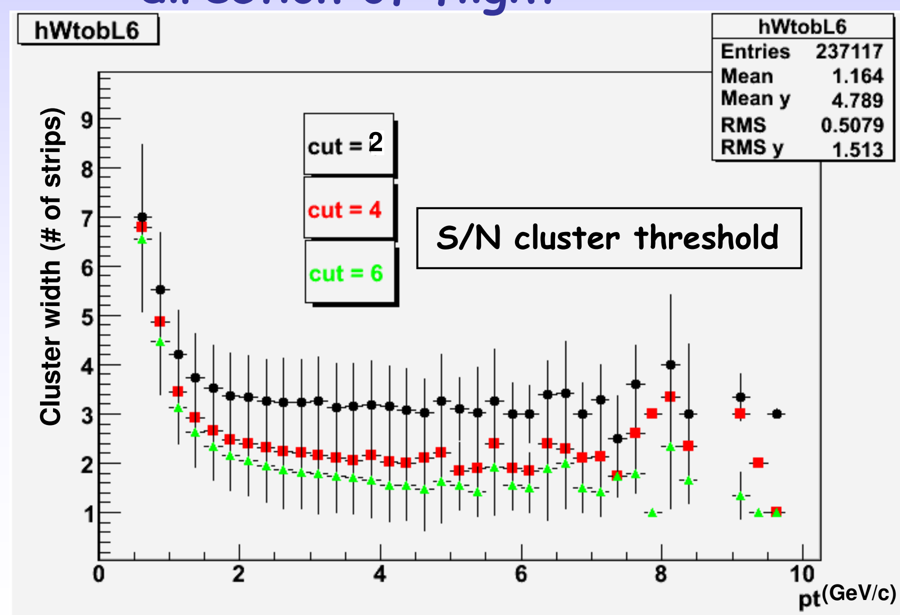
Performance with CMS data

- Single sided modules to measure Cluster Width

SST module

- 108 cm from beam line
  - 500 μm thick
  - 120 μm strip pitch
- Cluster width affected by track direction of flight

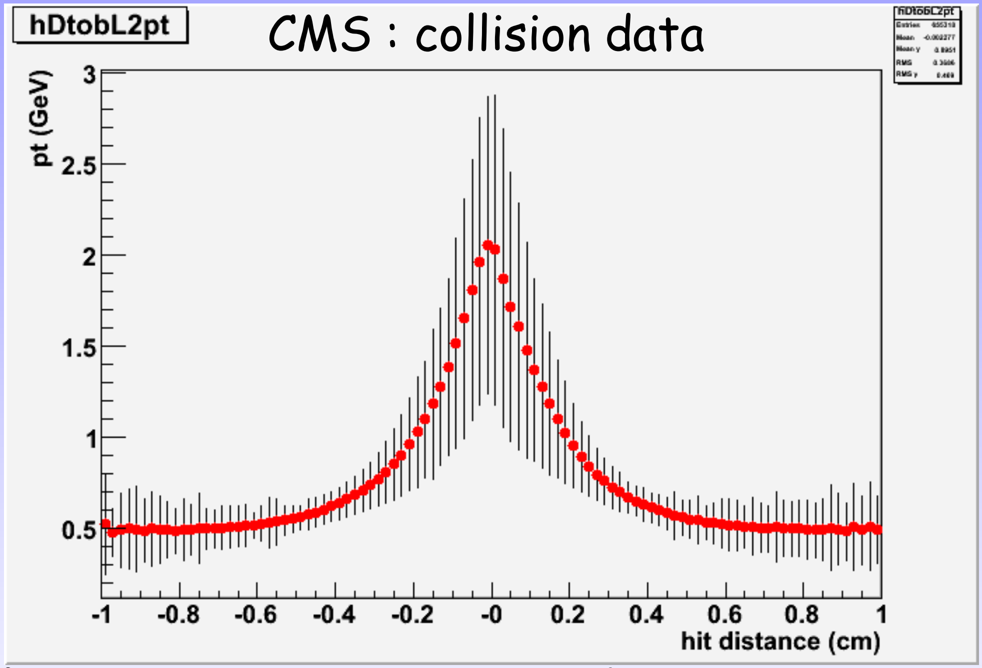




- **CW measured by a Single sensor**
  - Can be a tool for Pt track selection

"stacked" module performance

- Double sided modules equivalent to "stacked"
- SST module
  - 70 cm far from beam line
    - 500 μm thick
    - 120 μm strip pitch
  - Sensor planes ~ 2 mm apart
  - Strips direction tilted by 100 mrad



- Track direction of flight can be measured by the hits distance on the 2 planes
  - Independent module readout
  - Clusters are correlated off-line
    - High Pt tracks have coincident clusters
    - Low Pt ones have cluster far by more than a pitch

- Design of stacked modules
- Qualification in laboratory
- Performance on tracks direction of flight

Prototypes: modules

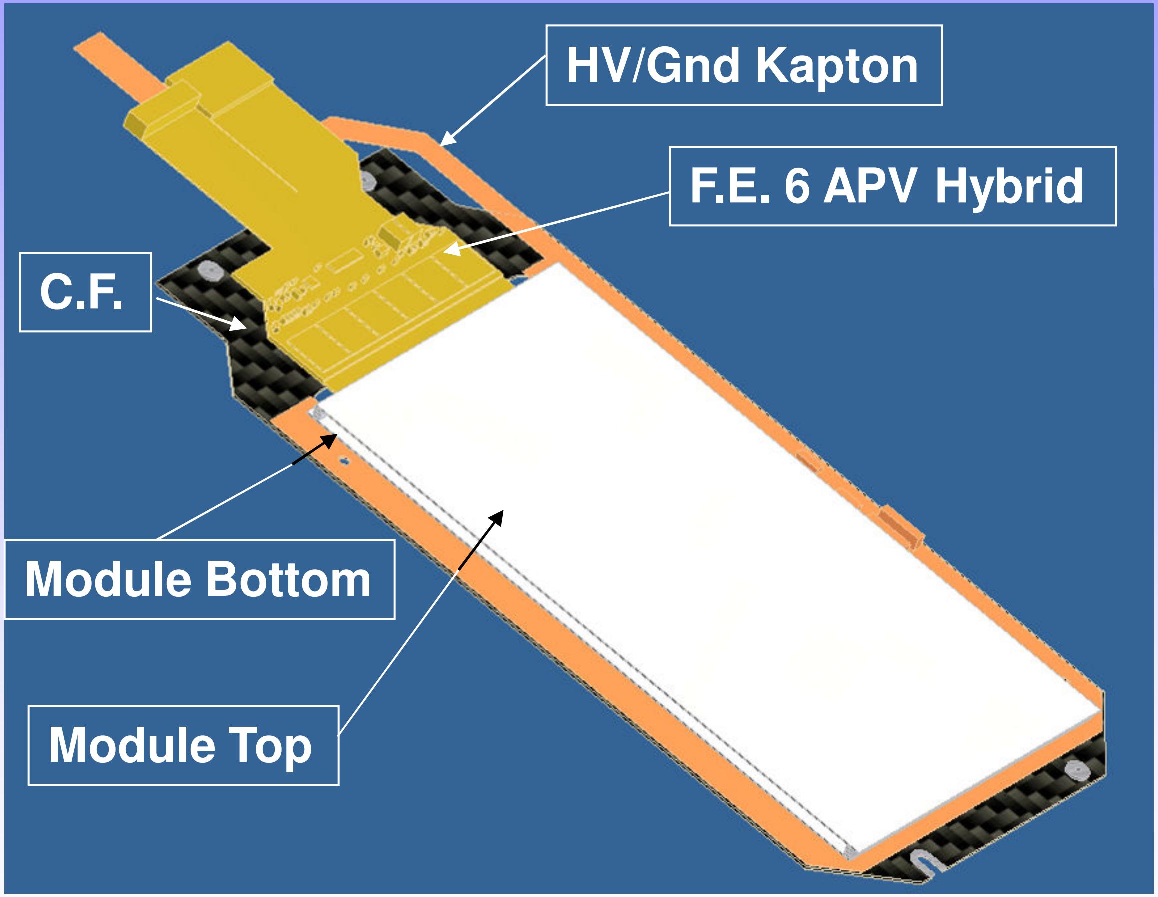
- **Material used:**
  - Spare parts of the CMS tracking detector

- **Two configurations**
  - Stacked modules
    - 2.3 mm apart
    - Strip length 9 cm

  - Module A
    - Pitch 80 μm
    - Strips from top and bottom sensor read out by consecutive F.E. channels
      - Proposal by R. Horisberger
  - Module B
    - Pitch 120 μm
    - Strips from top and bottom sensor read out by the same F.E. channel
      - Proposal by G. Parrini

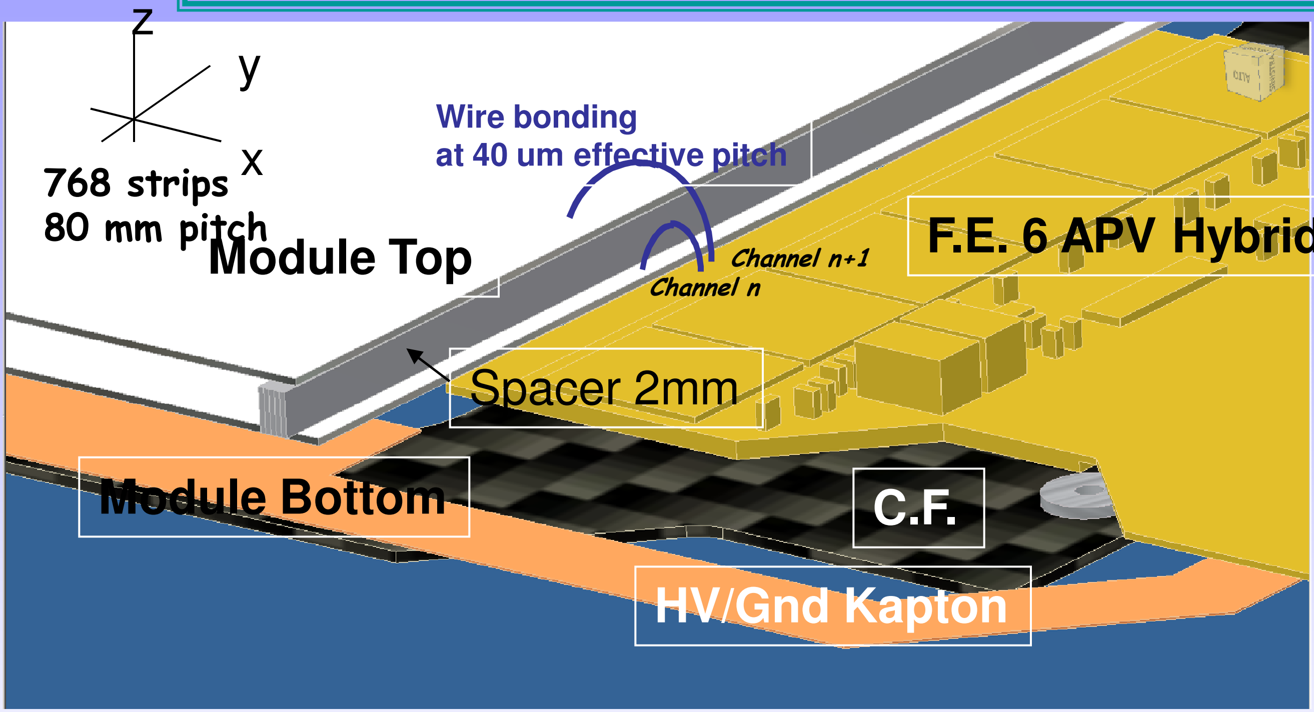
Stacked layers

- **Materials:**
  - 2 TIB sensors
    - (80/120 um pitch)
  - 1 F.E. 6/4 APV
  - No P.A. / with P.A.
    - (44/120 um pitch)
  - Standard
    - Carbon Frame
    - Kapton connections



Engineering CAD block drawing

Module A details

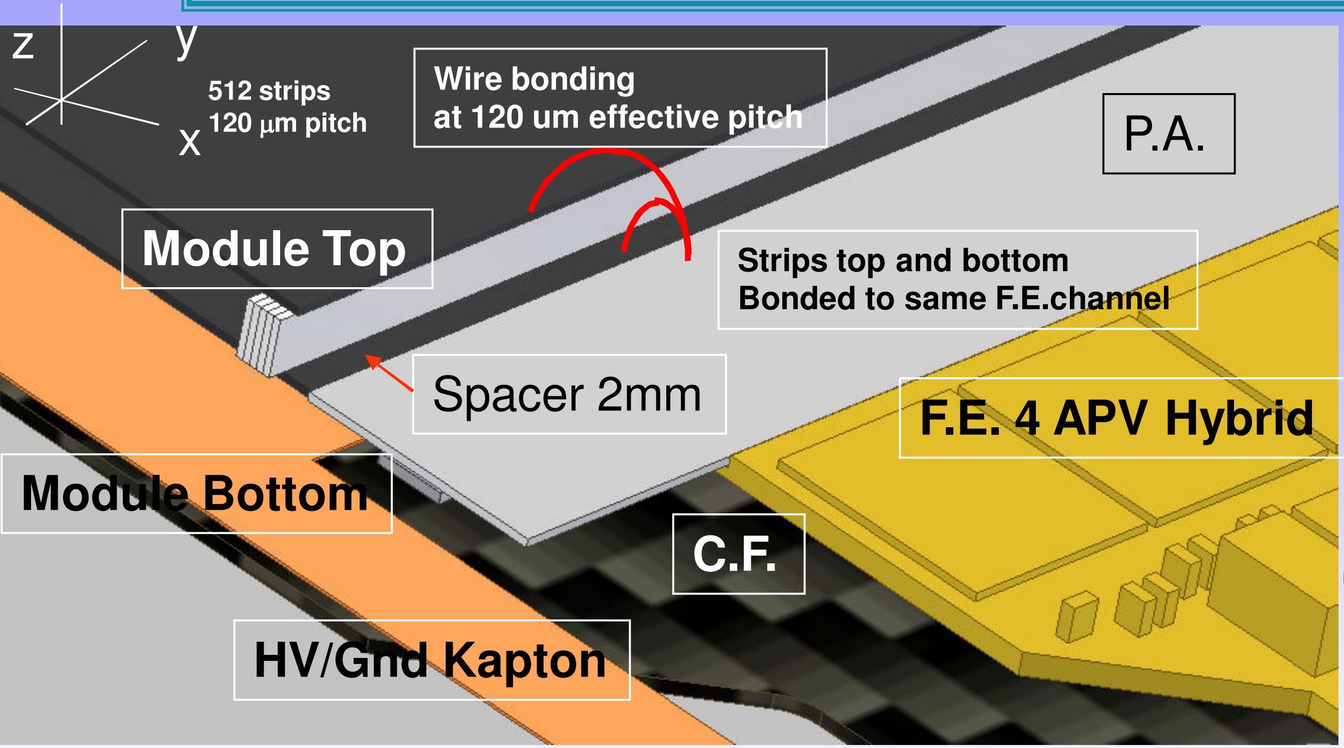


Parts :
New F.E.
New Carbon Frame
2 new micro-strip sensors

Assembly:
Performed in a plane
Bottom sensor wire-bonded before top module assembly

- Sensor Top aligned within 10 μm to Bottom
- F.E. has enough channels to readout 1/2 of the sensor area
  - 348 strips connected
  - Between F.E. chips groups of a few floating (unconnected) strips
- Wire bonding performed at ~40-44 um effective pitch

Module B details



Parts :
Module L3 CMS
1 new micro-strip sensor

Assembly:
Performed in a plane
Bottom sensor wire-bonded before top module assembly

- Sensor Top displaced w.r.t. Bottom by 40 μm
  - Strips on F.E. channels are all connected one-to-one
  - Full detector readout
    - 1 F.E. chip, out of 4, wire bonded only to bottom sensor
- Wire bonding performed at 120 um effective pitch through P.A.

Jig for sensors positioning & module assembly

Jig designed to

1) Maintain Sensors planarity

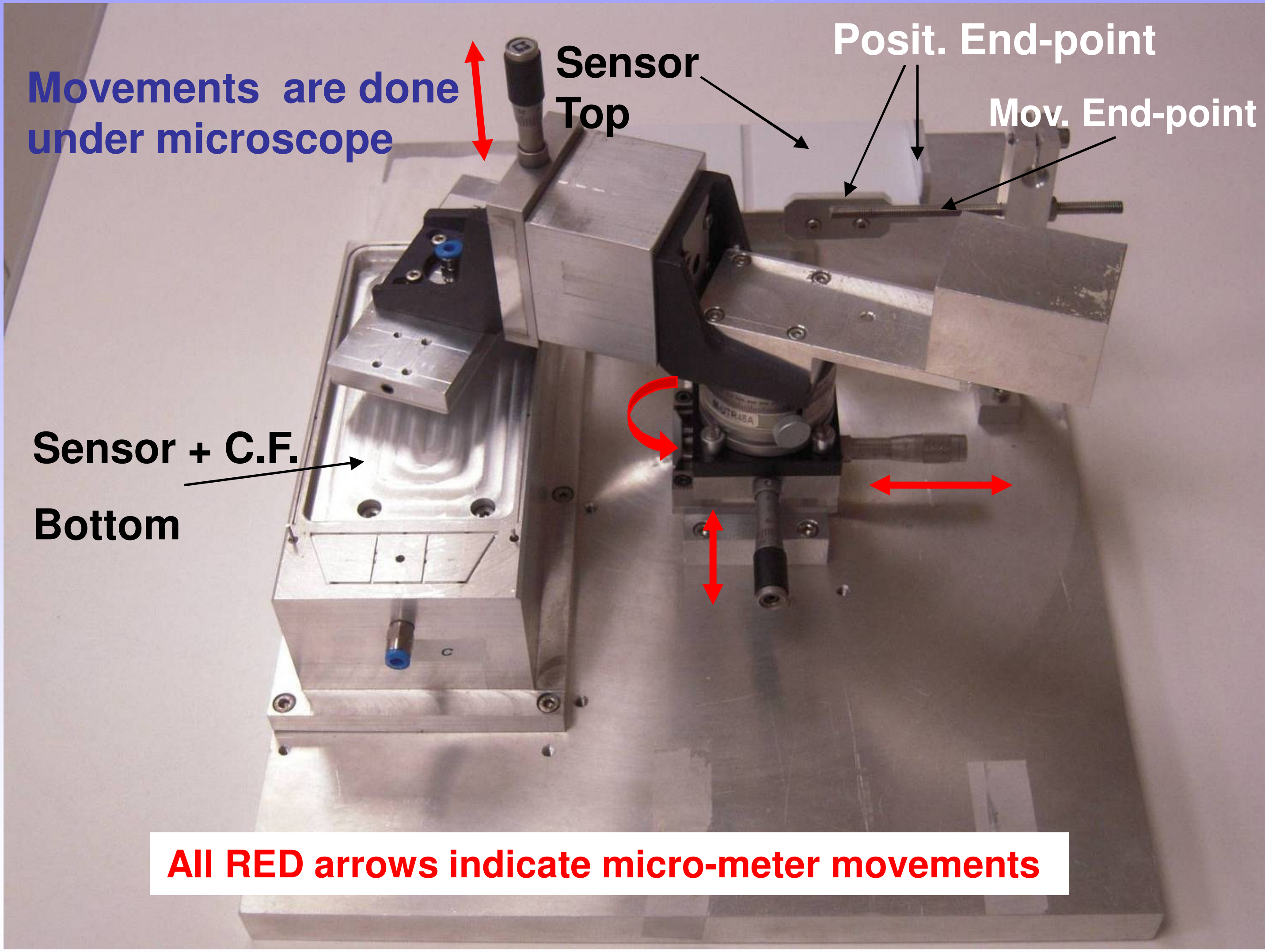
2) Allow Sensors/strips alignment

3) Allow shifts in 3 orthogonal directions

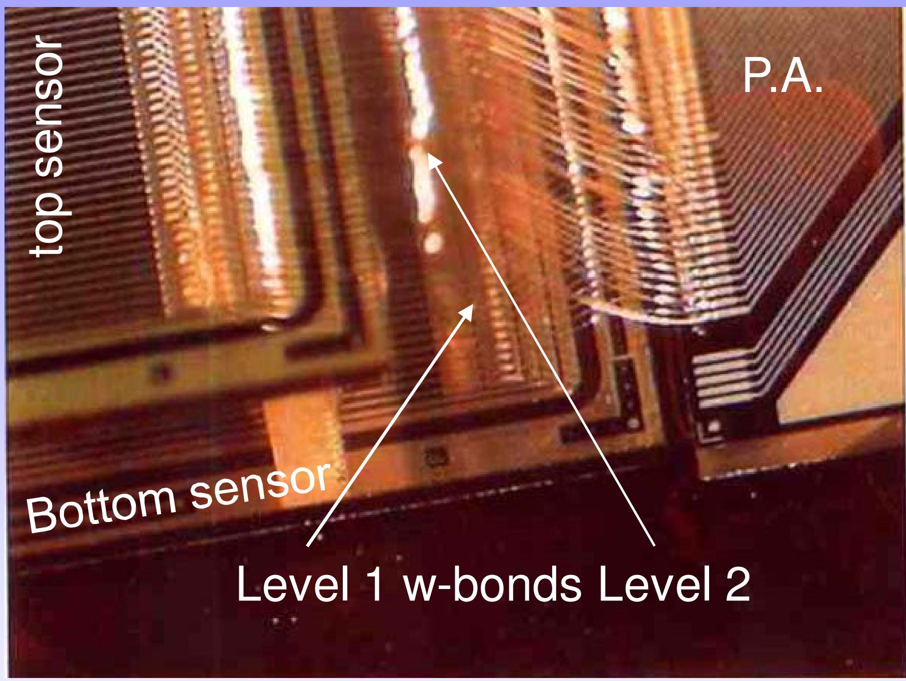
4) Module assembly

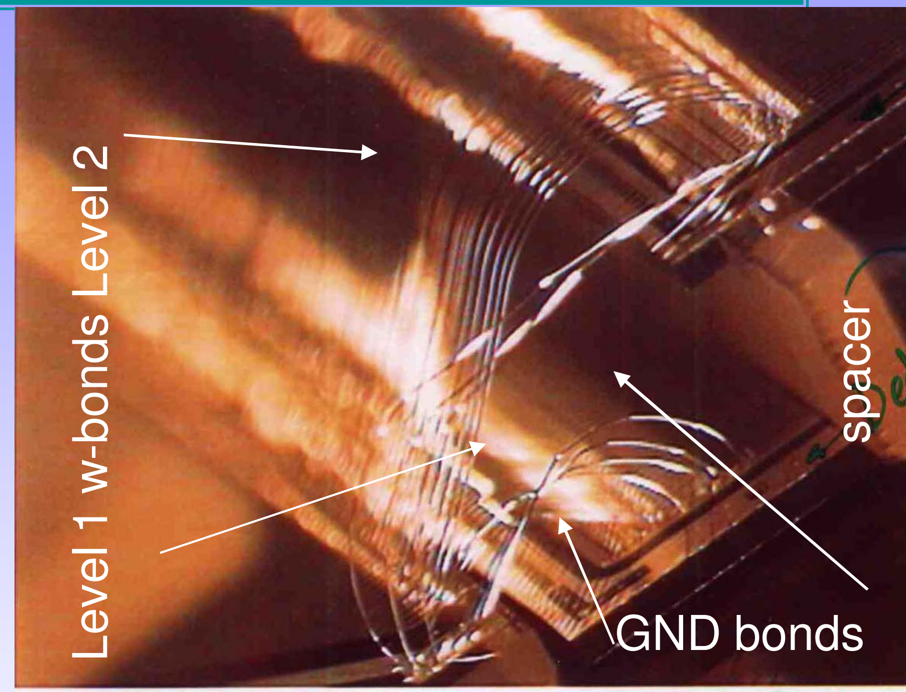
5) Use adaptor jigs for different module or sensor designs

Sensors assembly has been done using a CMM equipped with optical inspection



Module B detail Pictures

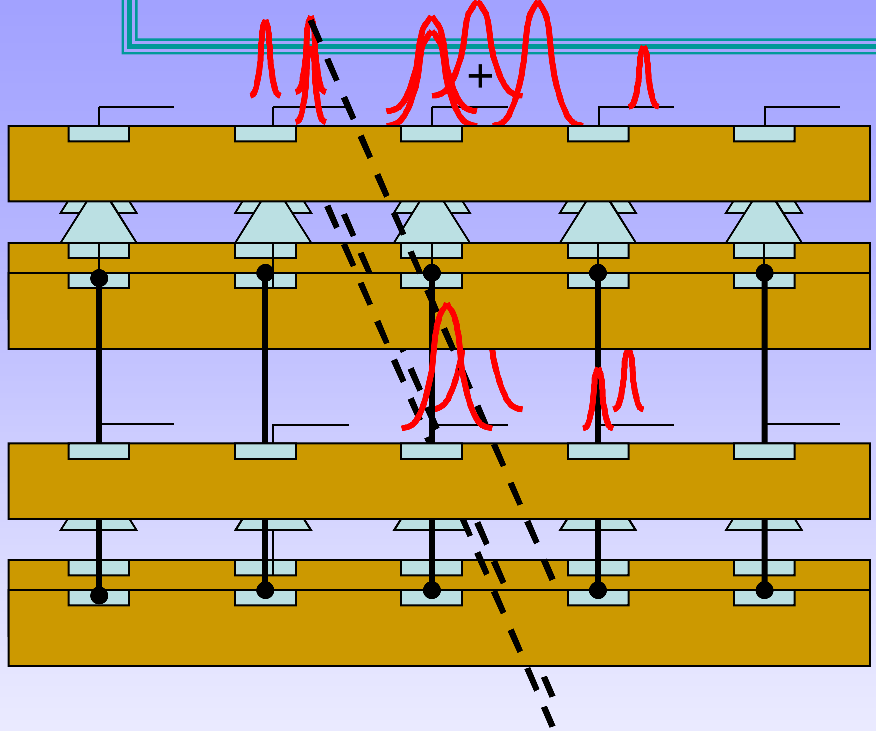




Two wire-bonding levels needed

Top and Bottom sensors share: HV connection, ground line and noise filters

Working principle



- Tracks generate signal on both sensors
  - PH
  - Clusters position & width
  - Correlation
- Off detector cluster analysis to exploit "stacked module" performance

- Module type A :
- Module type B :
  - Larger PH, wider clusters, simplified spatial coincidence
  - Wider clusters, Larger PH, simplified coincidence

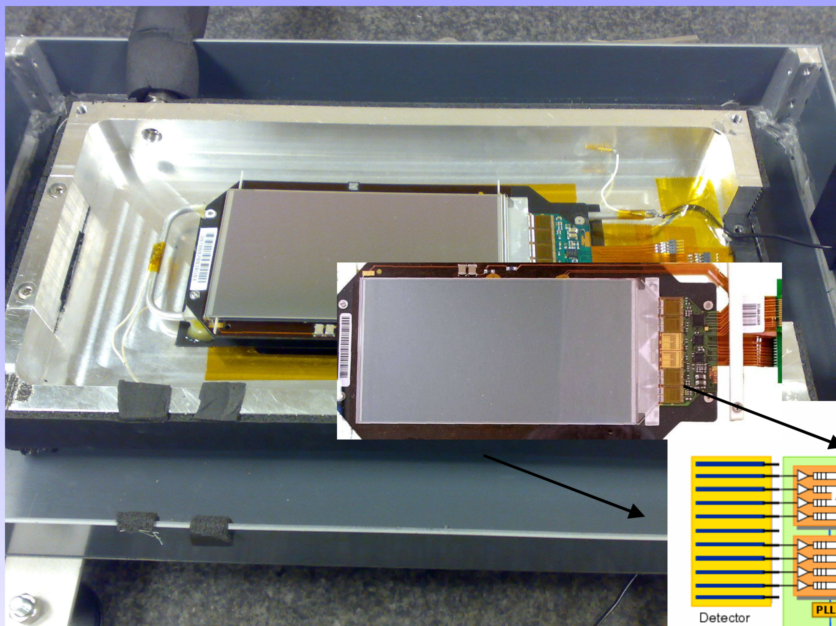
Performance and results

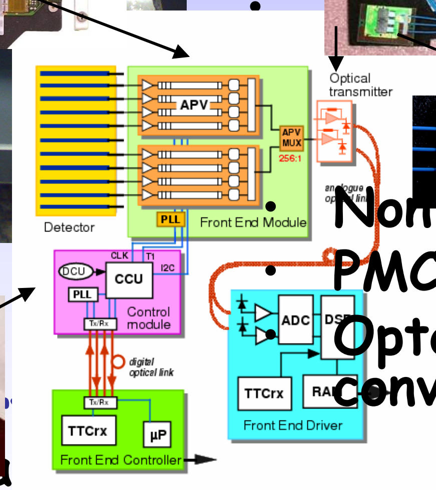
– Tests list:

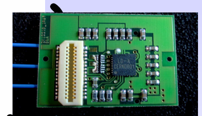
- Module qualification (noise, CM noise, stability, I/V)

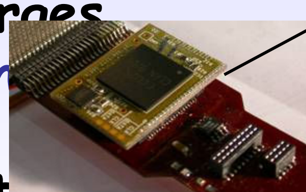
- Charge Collection : ^{90}Sr β, cosmic rays

Modules qualification





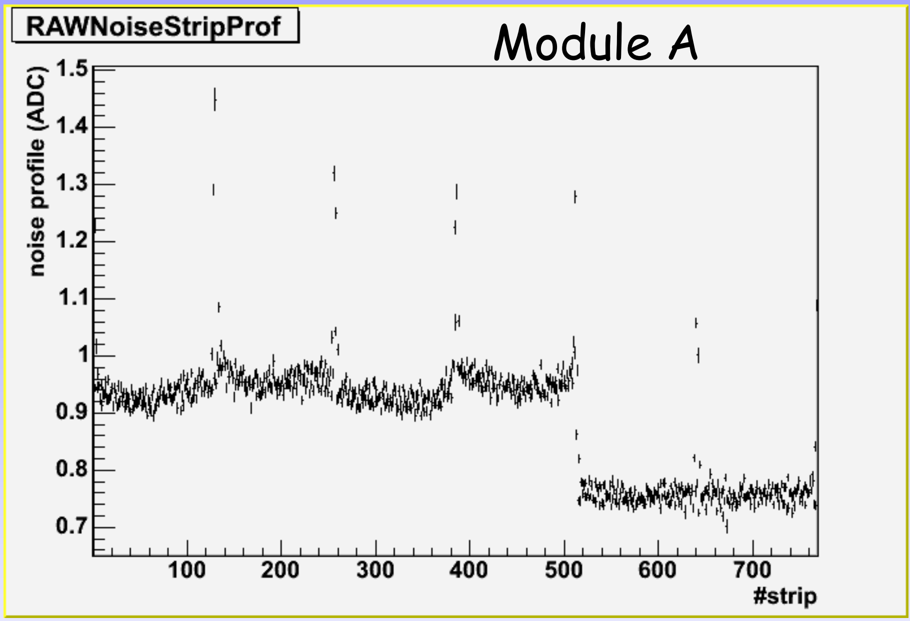


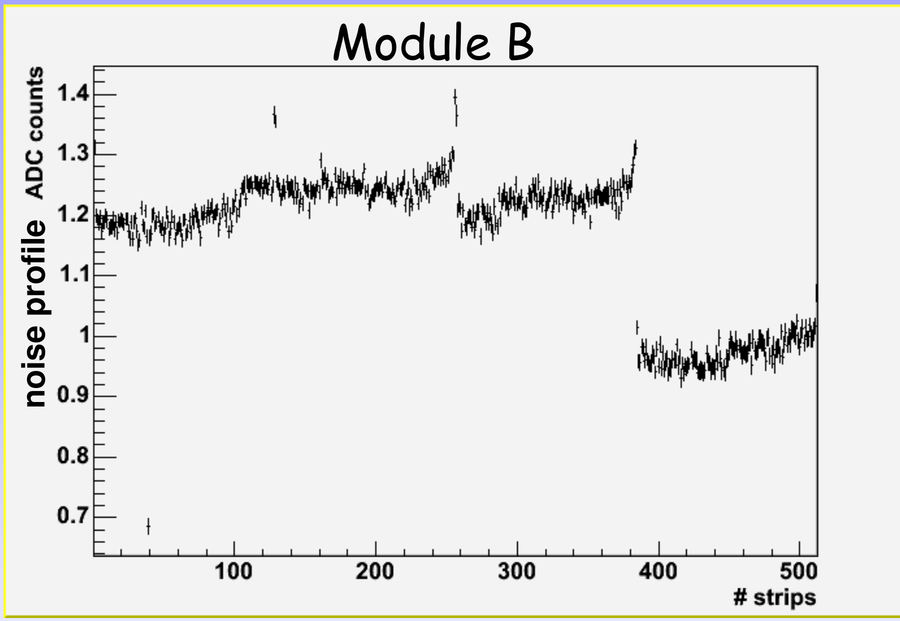


- Modules housed in dark & shielded box
- A couple of scintillators equipped with fast PM (... erneath the box), ... he "event" trigger
- ... rmed in LHC ... stic condition (peak ...
- Non standard parts:
  - PMCIA FED +
  - Opto/electrical VME converter

- No discharges
  - HV conn...
  - bonding ...
- Stability te... ...me need for high statistic run)
- IV sum of qualification single sensors data

Strip noise: raw noise CM



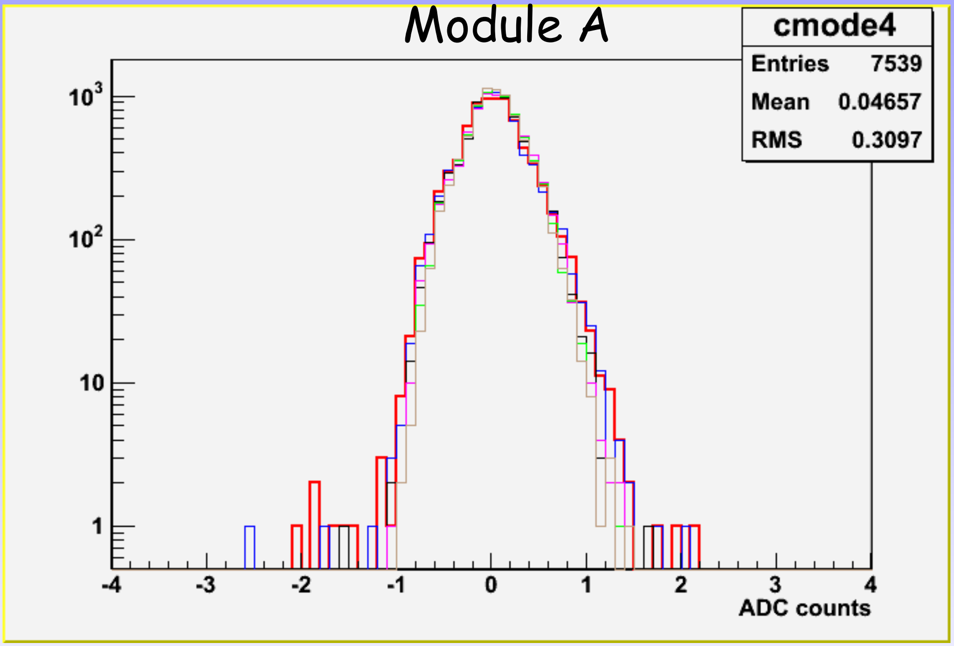


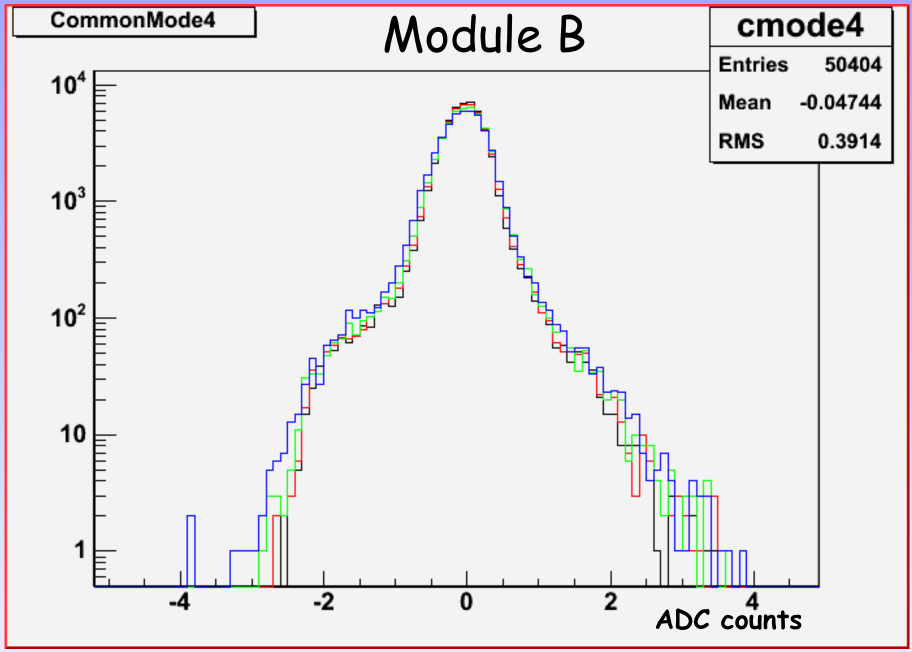
- Single strip noise performance
- Spikes at the chip edge, induction from floating strips (unconnected between chips)
  - Constraint from the design of parts available

- Higher noise level "two strips" connected in parallel to one read-out (Chip 1, 2 , 3)
- Chip 4 : Single strips connected (bottom sensor)

Noise is stable: no structure is seen, no dependence on strips connection scheme

Strip noise: Common Mode



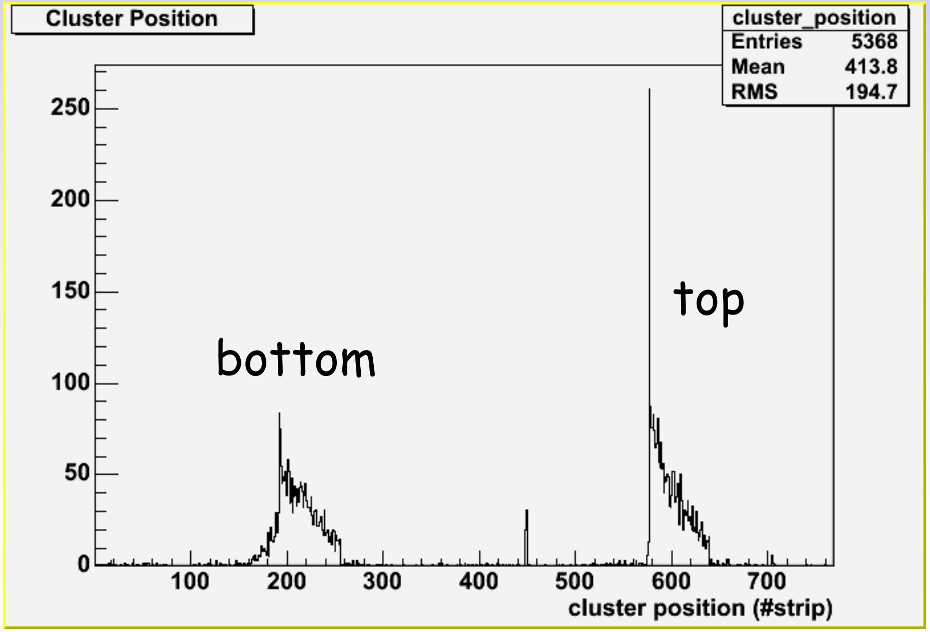


- **Common Mode noise seems OK:**
  - shape, average and tails area acceptable and under control
  - Subtraction on strips is ok

- **No cross-talk or induction between modules is seen**
  - i.e. back-plane (top module) to junction plane (bottom)

Module A performance

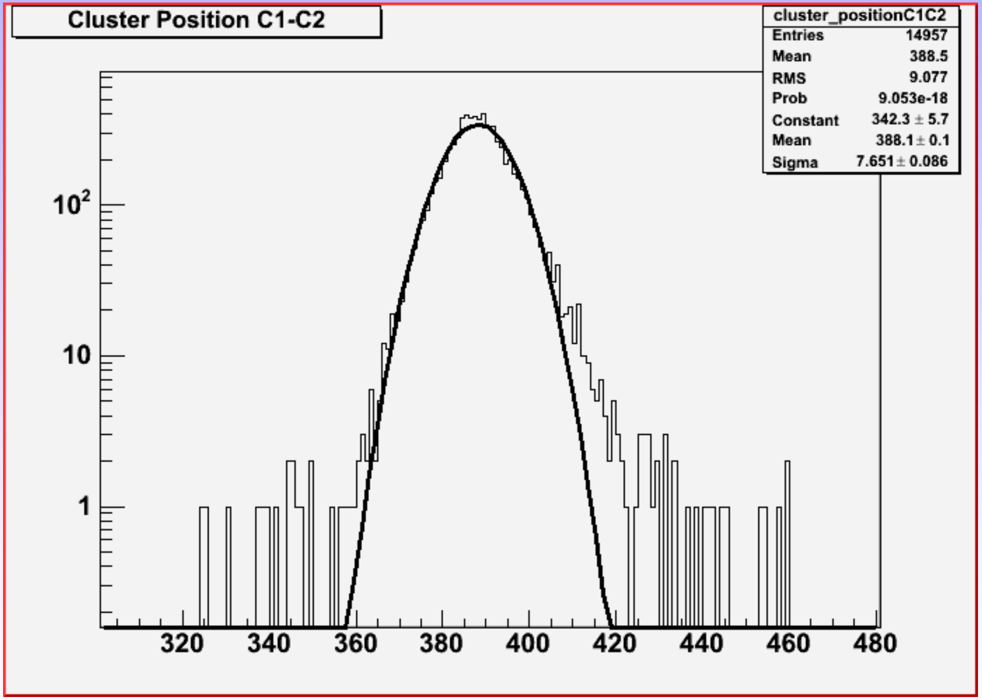
- Preliminary results achieved with β source
- A simplified version of strip pattern reconstruction
    - (algorithm of cluster reconstruction is under refinement)
  - Separate reconstruction for top and bottom sensors
    - Total number of strips connected for each sensor: 384



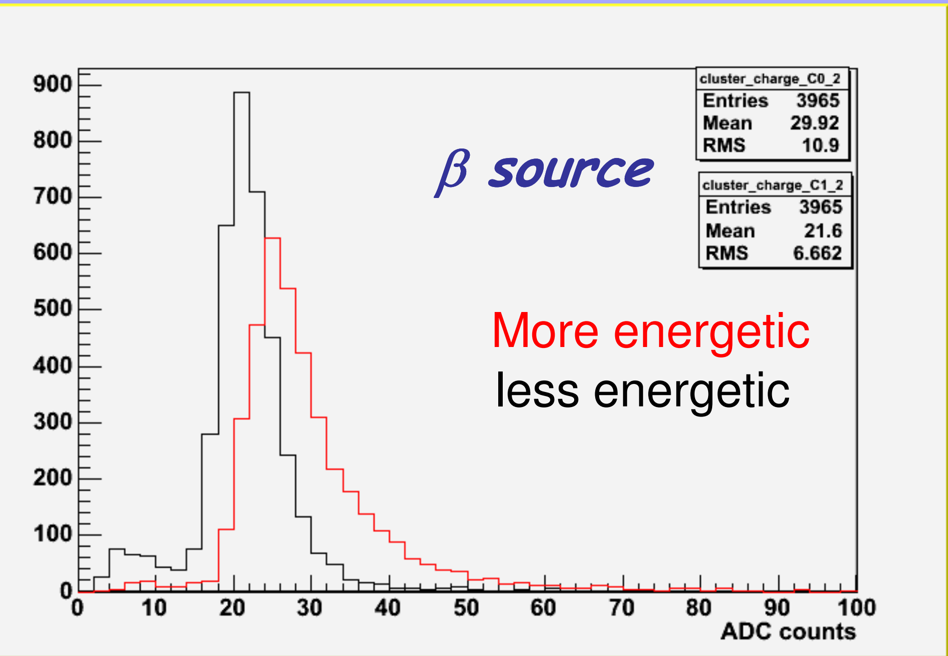
- pattern is a replica for each sensor.
  - Shape affected by beta source spectrum and m.s.

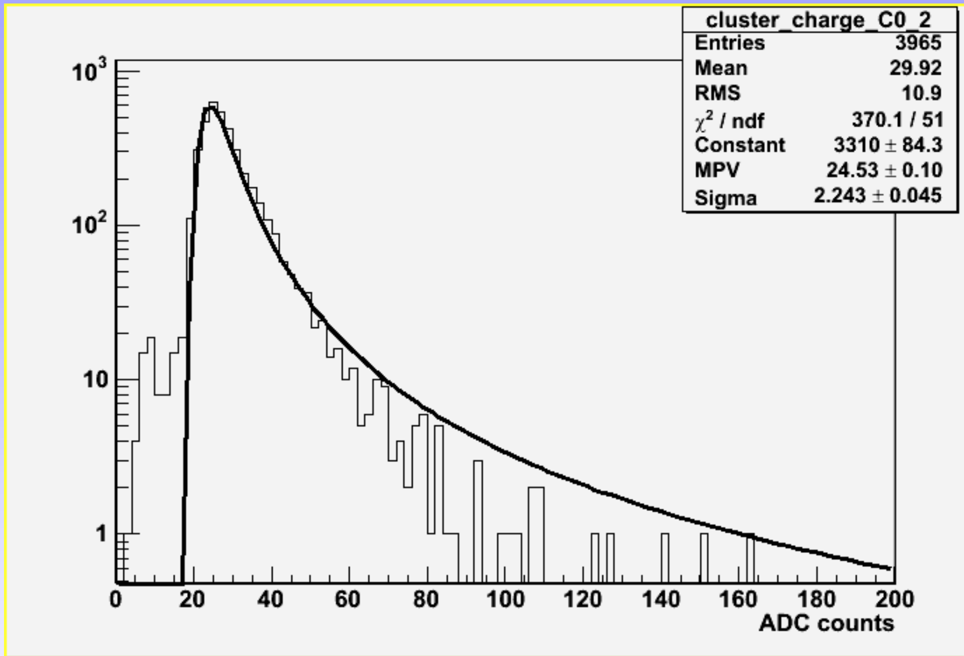
Module A

- **Clusters on top and bottom sensor are well correlated**
  - Distance between reconstructed cluster positions is in average 388 strips
  - Width of the distribution is compatible with m.s. spread (~8 strips)



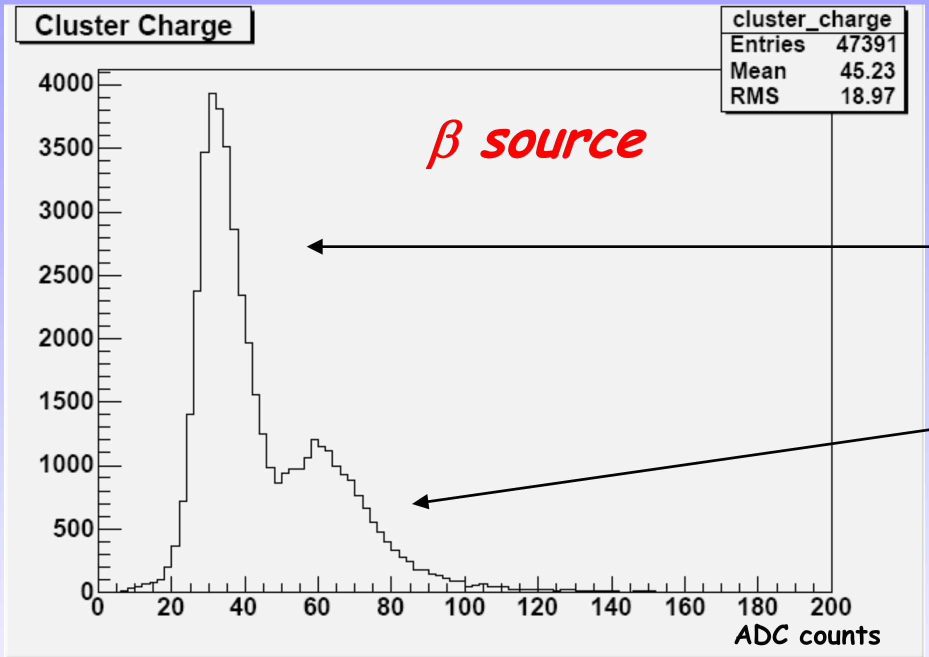
Module A - Collected Charge





- **Clustering performed for event with 2 clusters**
  - We expect Landau behavior for higher PH cluster
    - Fit result compatible with standard module performance

Module B - Collected Charge

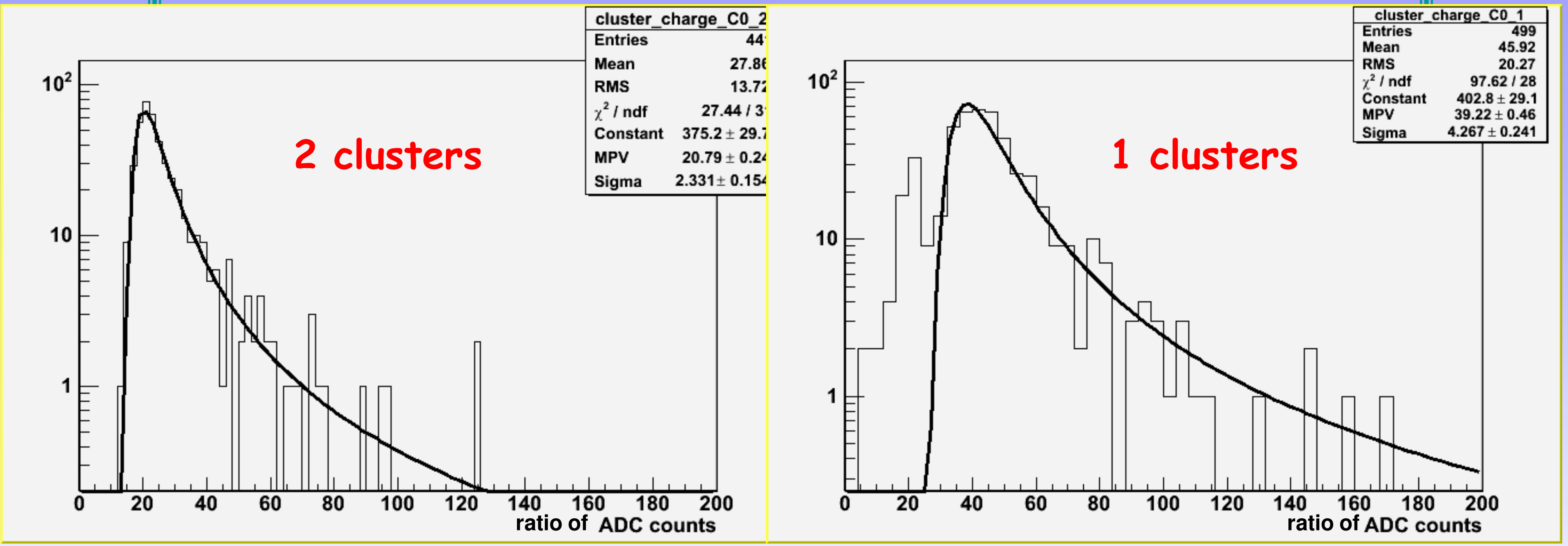


Events with 2 clusters reconstructed

Events with 1 cluster reconstructed

- Standard cluster reconstruction algorithm
- We expect a "double peak" in the Collected Charge spectrum:
  - Signals from top and bottom sensors add up when track hits the same strip
    - Coincidence in space
- Multiple scattering effect
    - Events have more often 2 clusters

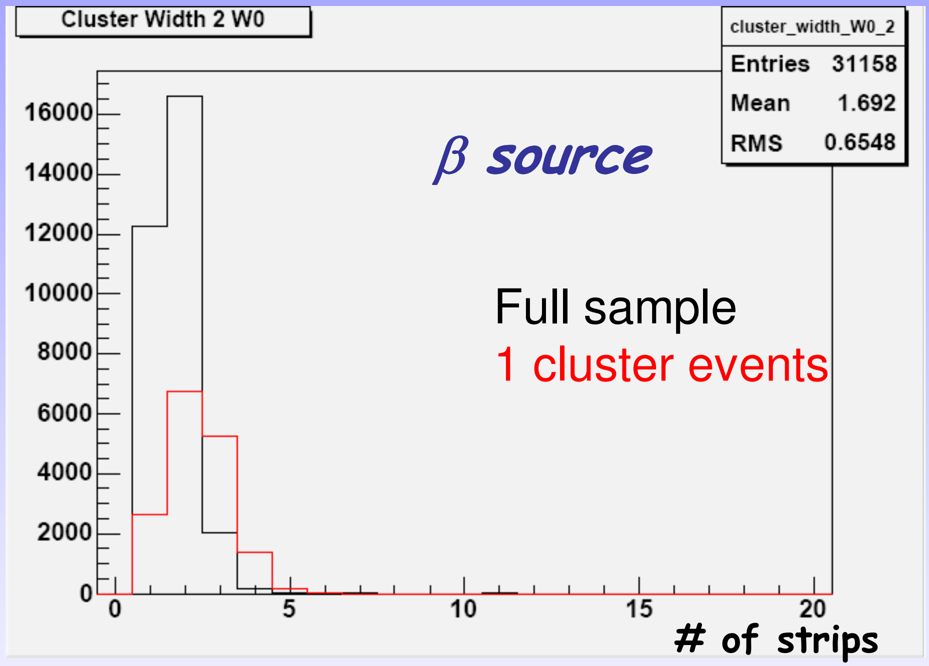
Module B - Signal/Noise



- **Landau fit of S/N distributions**
  - "1 Cluster" events have MPV (and CC average) twice compared to "2 Clusters" event values

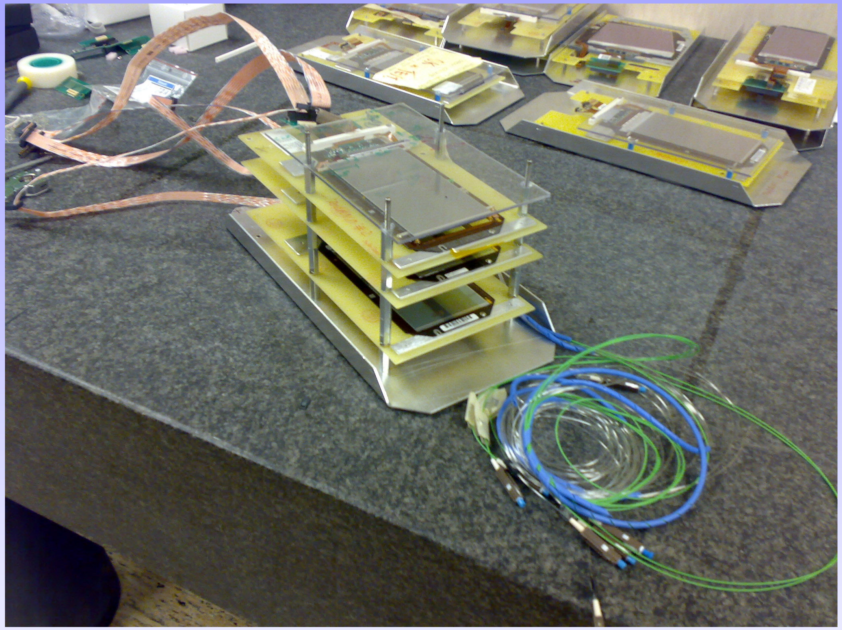
- MPV "1 Cluster" = 39.2 $\pm$ 0.5
- MPV "2 Clusters" = 20.8 $\pm$ 0.2

Module B – Cluster Width



- **Cluster average width larger for 1 cluster events**
  - **Cluster broadened by strips neighborhood to cluster seed**

Small cosmic ray telecope



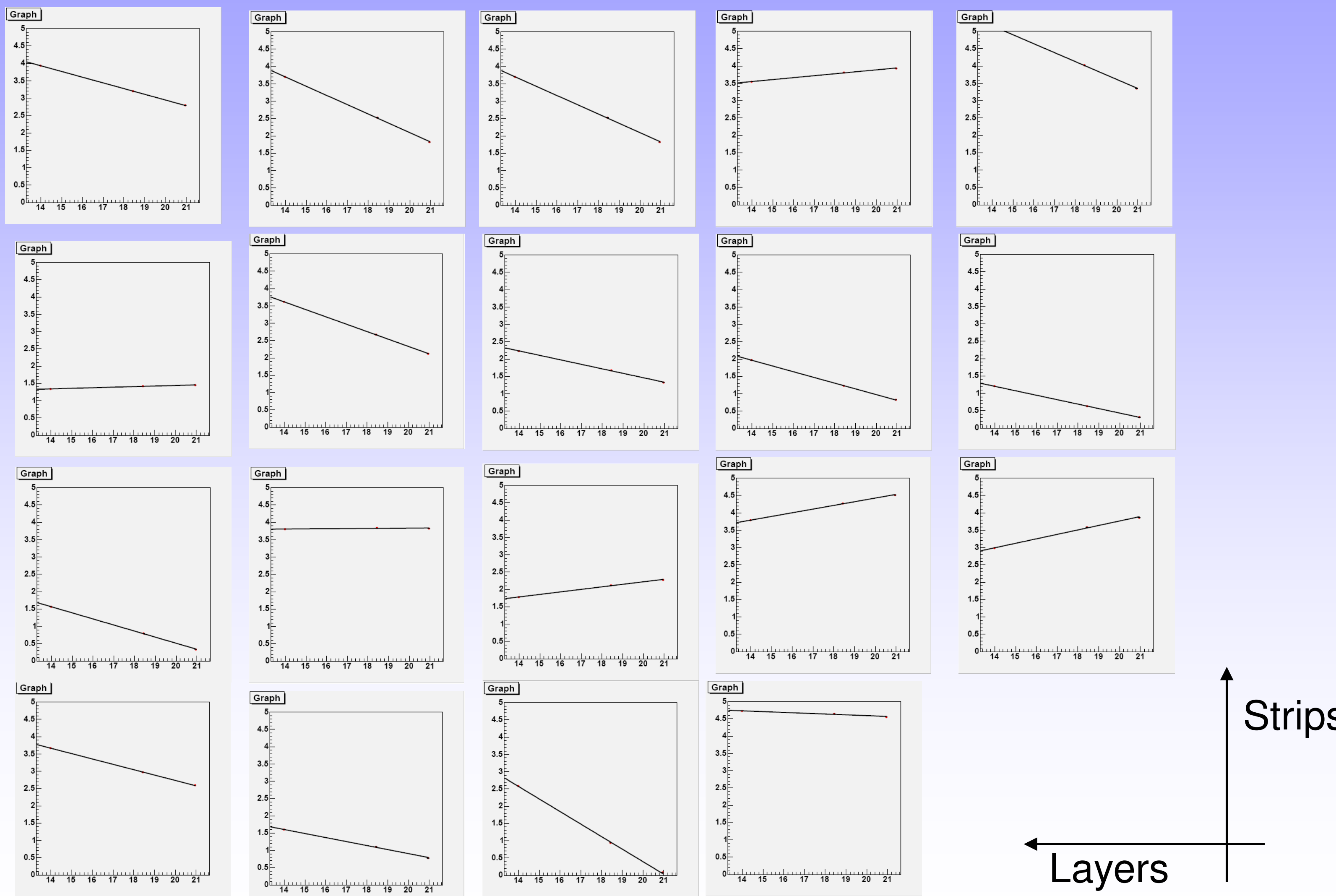
- Three layers
  - 2 for tracking
    - Standard CMS tracker modules
  - 1 for prototype test
    - Module A or B
- Optical CMM alignment
  - measurement performed with a few micron resolution

- 5 cm Lead Absorber to filter cosmic rays momentum at 61 MeV
  - Reduces m.s. effect
- Angle cut geometry 0.37 rad
  - Max track angle 20 deg (low momentum tracks in collider events)
- Trigger generated by a pair of scintillators in coincidence
  - Acceptance rate ~0.2 Hz

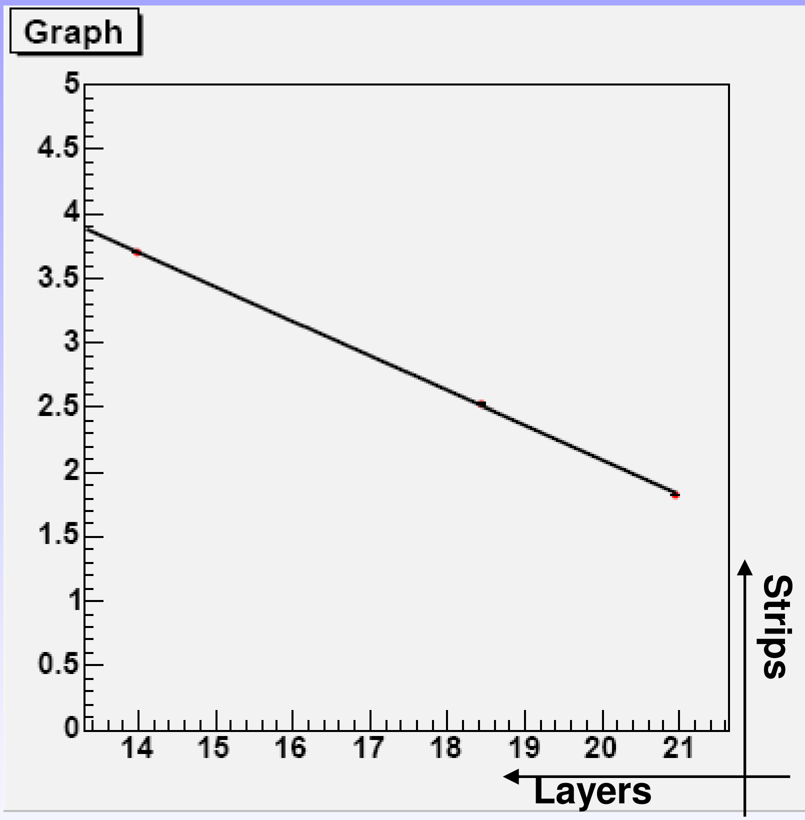
Performance and results

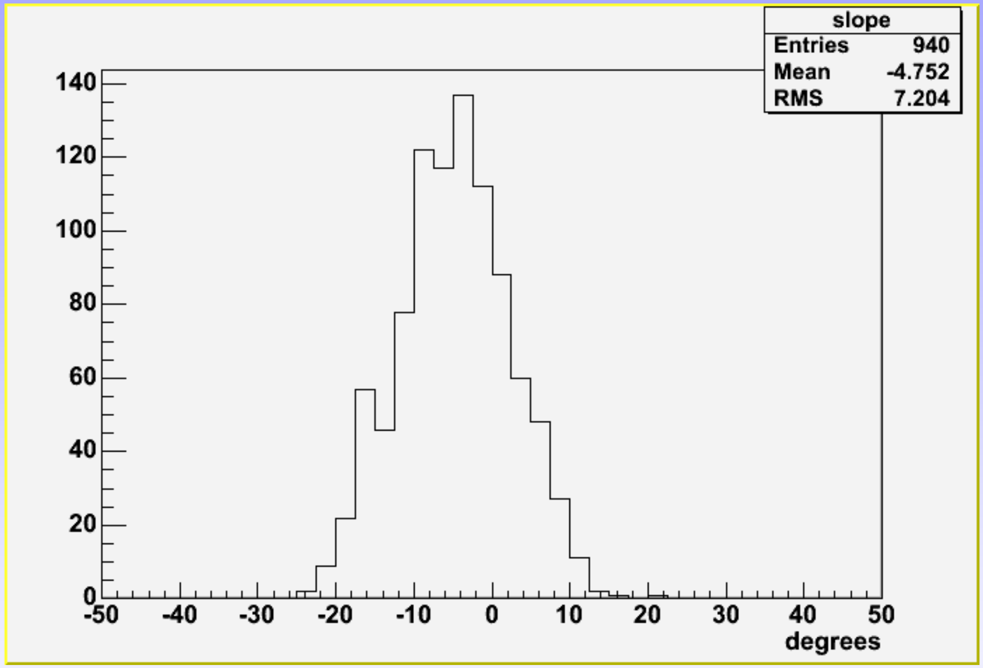
- 3 telescopes build
  - TS-CMS equipped with 3 standard CMS modules
  - One out of 3 modules was Module A or B for other 2 telescopes (TS-A, TS-B)
- Noise qualification
  - TS-CMS bench mark
- Reduced effect of m.s. on
  - S/N
  - Cluster width
- Track flying direction study
  - Performance studied for TS-B

TS-CMS: Collection of tracks



TS-CMS: tracks

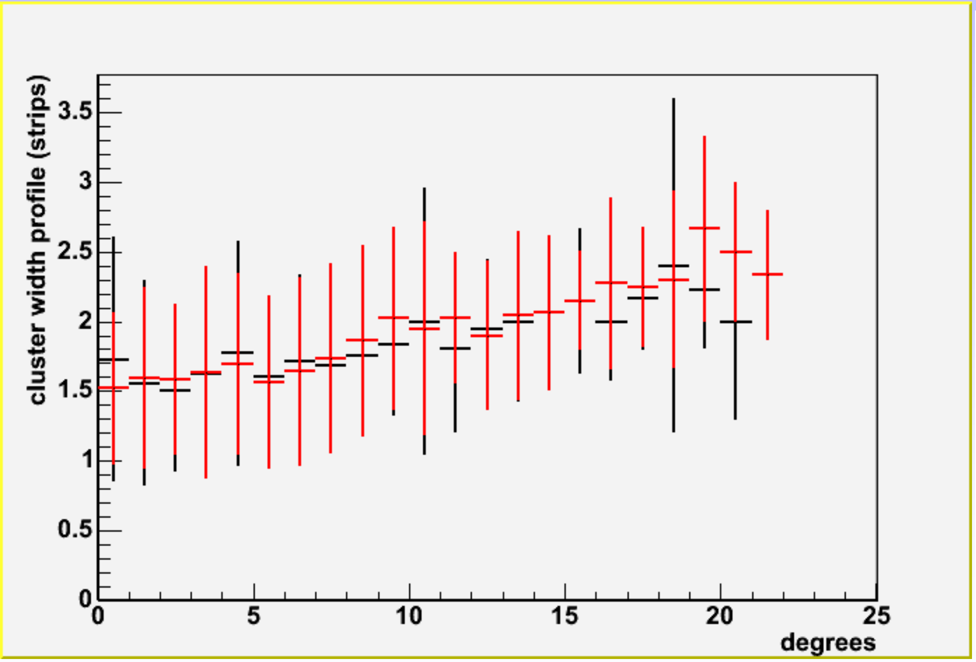




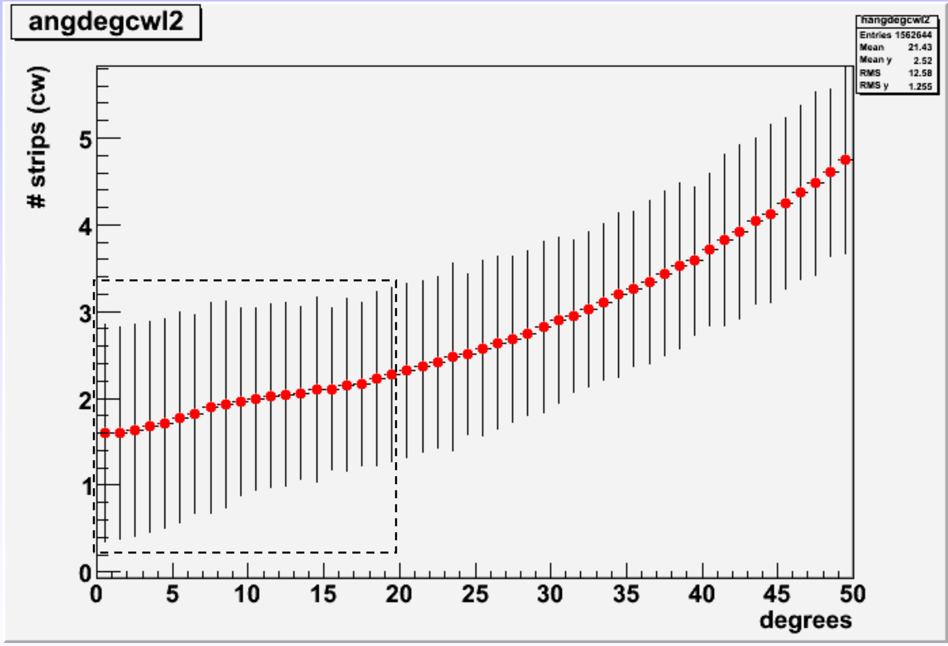
- Event collected show well aligned clusters
- Small incidence angle
  - Compatible with telescope acceptance
  - Opening angle 20 deg.

Module performances : TS-CMS

- Cluster width increases with particle direction of flight
- Results of TS-CMS compatible with the ones of sensors with similar thickness (320 mm) installed in the CMS tracker



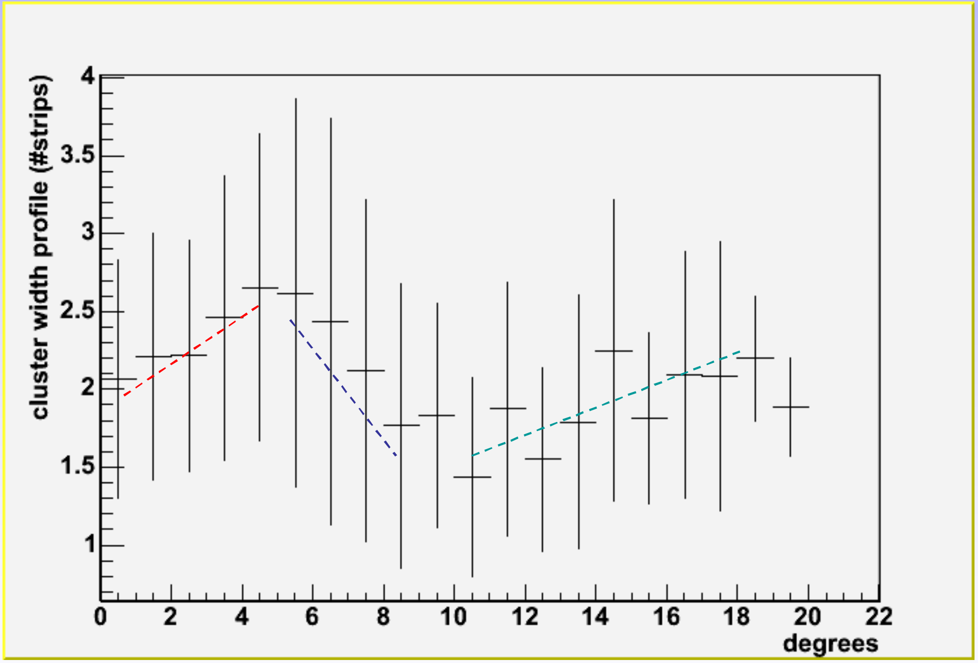
TS-CMS events



CMS tracker events

Module B performances : cosmic rays

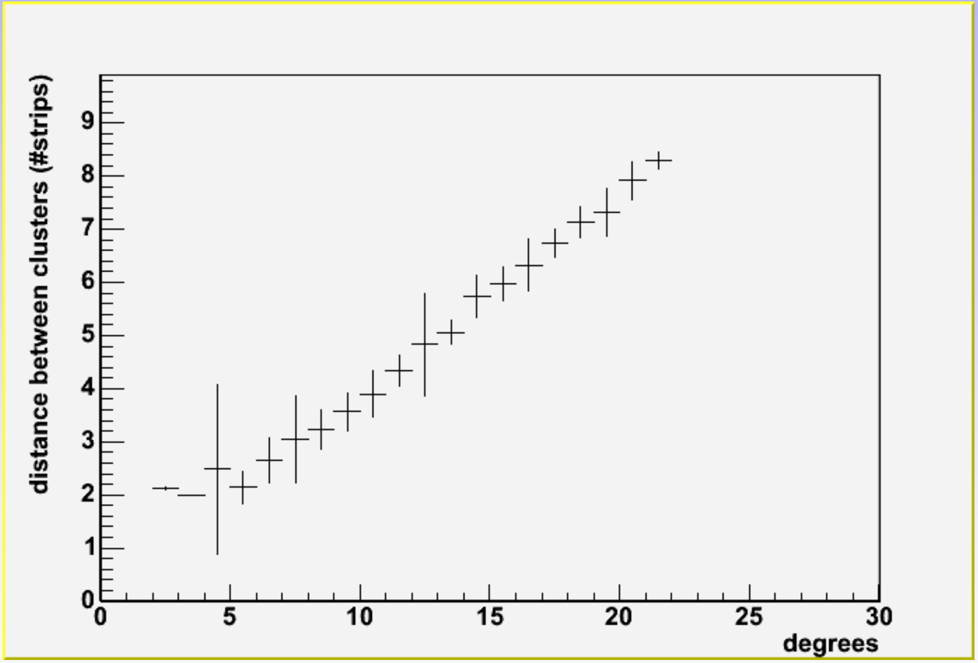
- **Cluster width shows a "Wave" like shape**



- **Width :**
  - Increases until top and bottom sensors produce a 1 cluster event
  - Drops down at 5÷6 degree
    - "Splitting cluster angle"
  - Follows a standard behavior at larger angles where 2 cluster events are more often collected

Module B performances : distance between clusters

- Cluster multiplicity defined by the track angle
- Measurement of the cluster distance is an evaluation of particle direction of flight



- Particle impinging with angles smaller than 5÷6 degree
  - Top and bottom clusters are merged
  - Distance between clusters statistically compatible with the minimum cluster width
- Particles impinging with larger angles
  - Events show 2 clusters
  - Linear relation distance vs. angle

- The angle 5÷6 degree can be considered as the threshold
  - The sensor geometry (pitch 120 μm, distance 2.3 mm) implies that below this angle we are unable to estimate flighty direction

Toward module integration on large array

- Module basic block developed:
  - Standard module
    - SLHC candidates for Pt Trigger Layers
- Sensor geometry defined by occupancy study
  - Hints from simulation layout results
    - Sensors dimension
    - Array of sensors (road) to cover large area

- How to build roads
  - Services
  - Mechanics…..
- Minimize parts design multiplicity

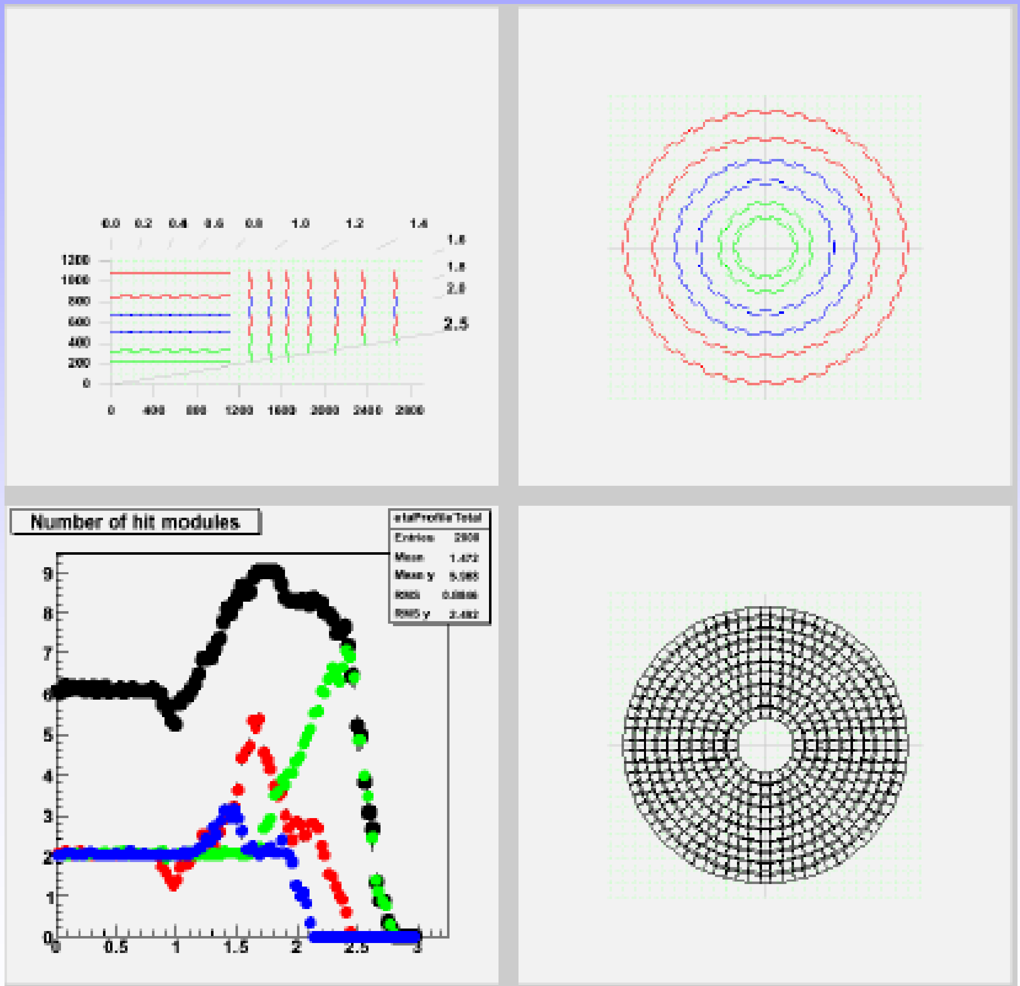
- Minimize assembly high risk operations
  - Assembly of parts in a fixed plane

SLHC Layout Example

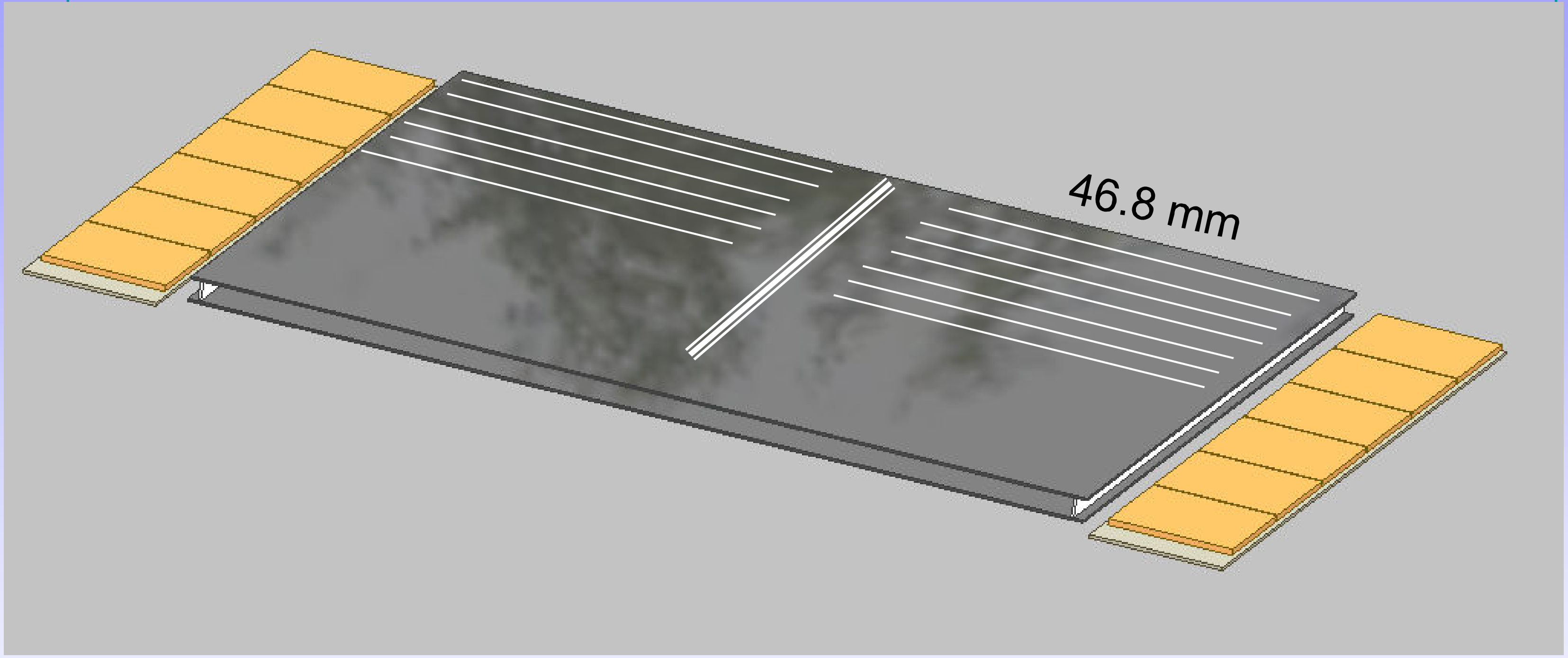
- **One of the current layout foresees Pt trigger modules to equip disks**
  - Strip length 46.8 mm
  - 59 μm minimum strip pitch
  - Sensor area 8578.8 mm^2

  (simulation by D. Abbaneo)

- **Disk covered by long array of packed units**
  - road with ~1 m length
  - radial orientation

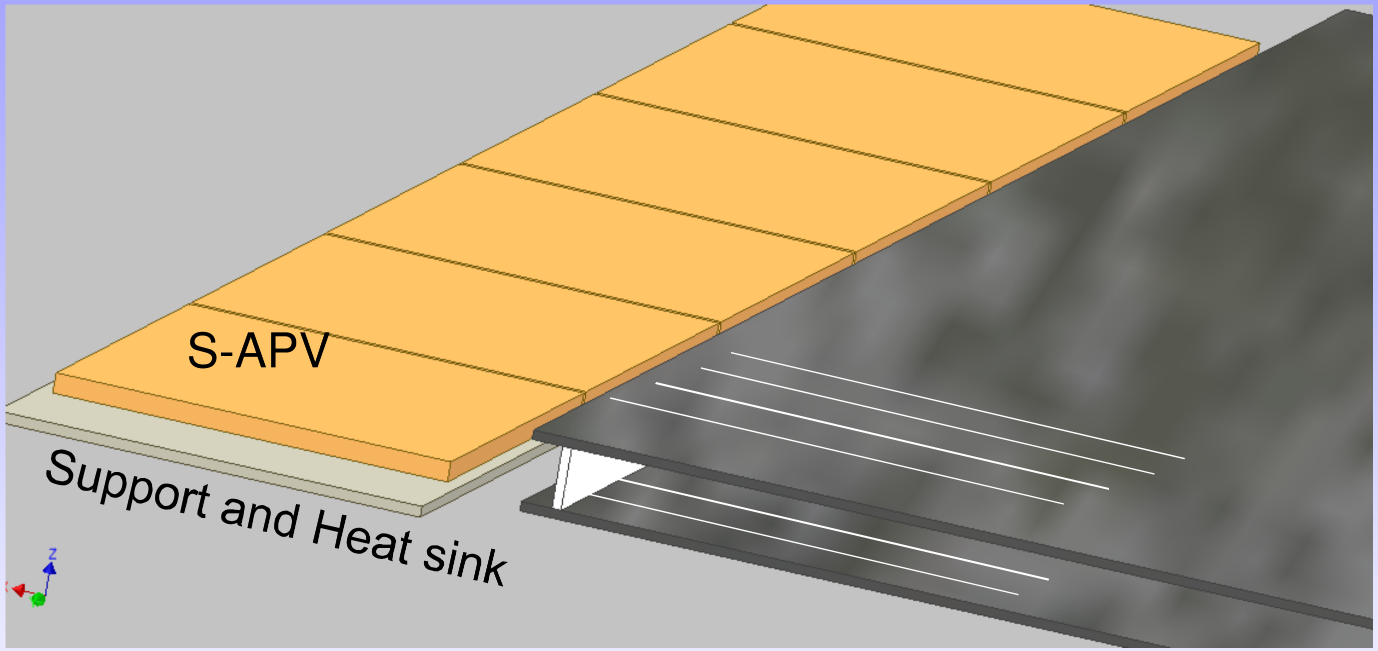


Full module : Pt Layer



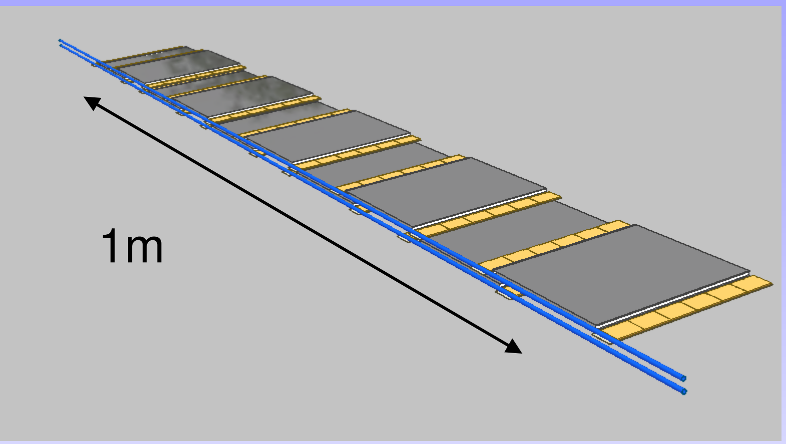
- **The unit is a "double" of the stacked layers studied here (modules A or B)**
- **Active/inactive area ratio as present CMS tracker modules**
  - Strip sensors can be designed in a single wafer
    - Reduced inactive areas
    - Reduce the number of parts

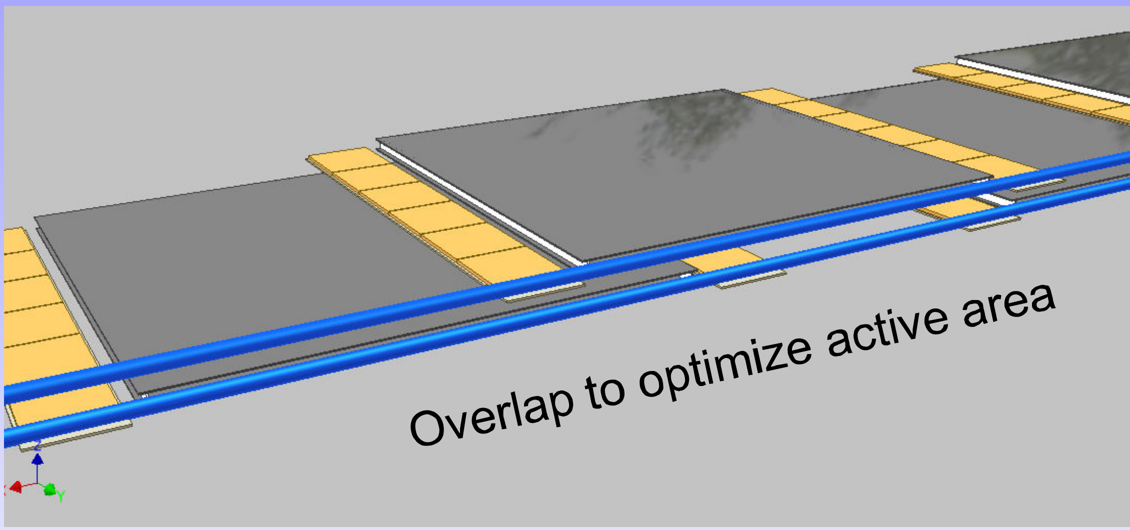
Module detail



- **Unit can be assembled on a fixed plane, following experience on module A or B**
  - Mechanical
  - Wire Bonding
  - Heat sink can be standard one

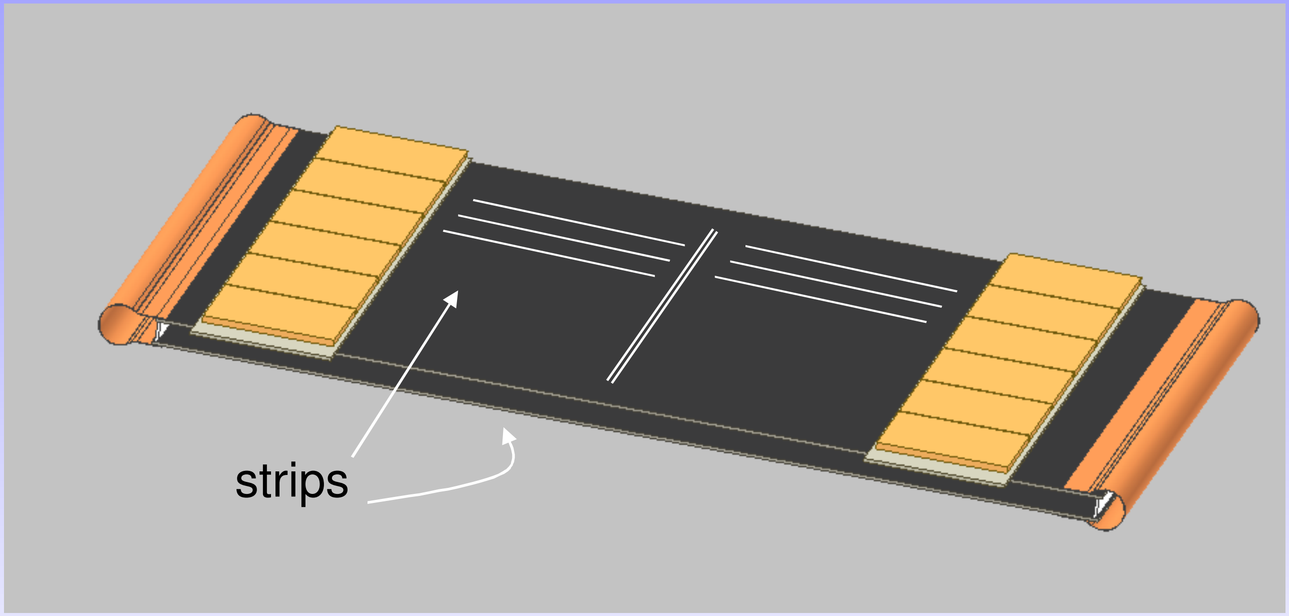
Long array integration





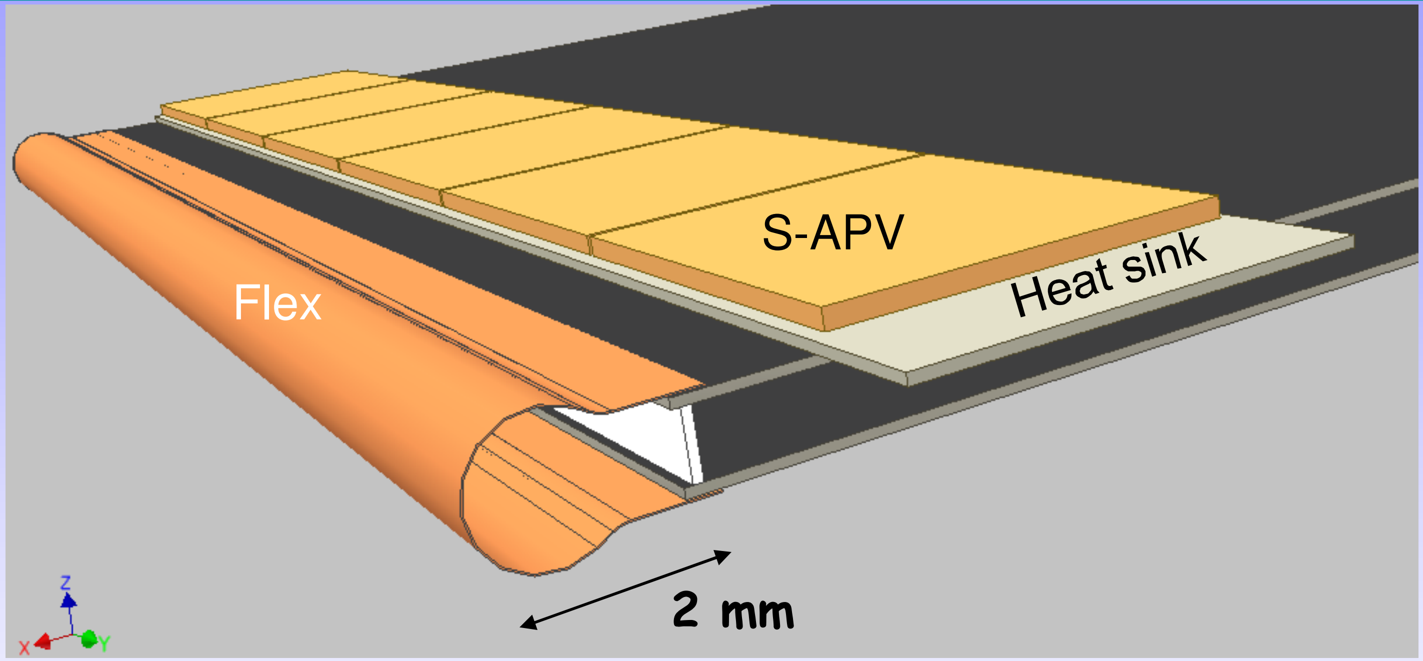
- **Large array integration**
  - Block design compatible with
    - Single layer mounting
    - Shared cooling service

New module design *(on going activity)*



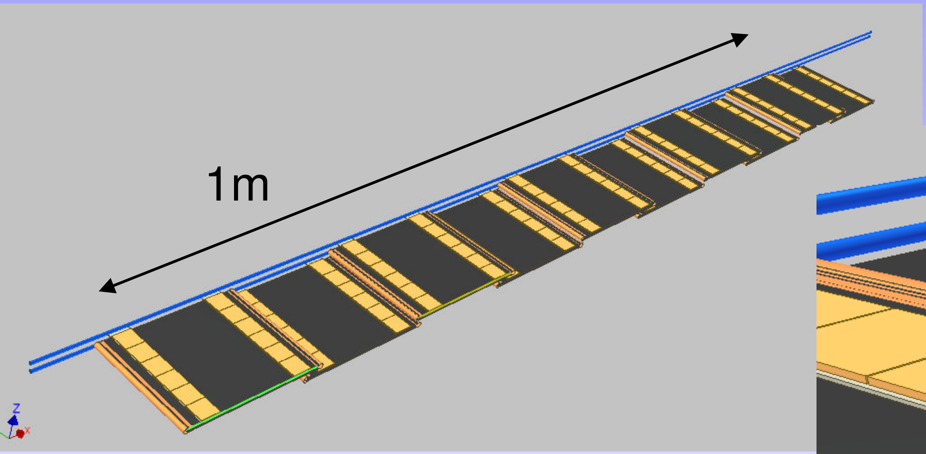
- **More conventional "back-to-back" configuration**
- **Smaller inactive area/module**
  - Strips on external sides
    - as present CMS tracker configurations
  - Strip sensors can be designed in a single wafer
    - To optimize assembly operation we need 2 different sensor design
  - F.E. mounted on top of the sensitive area
    - as current ATLAS SST (heat isolation and sink already developed)

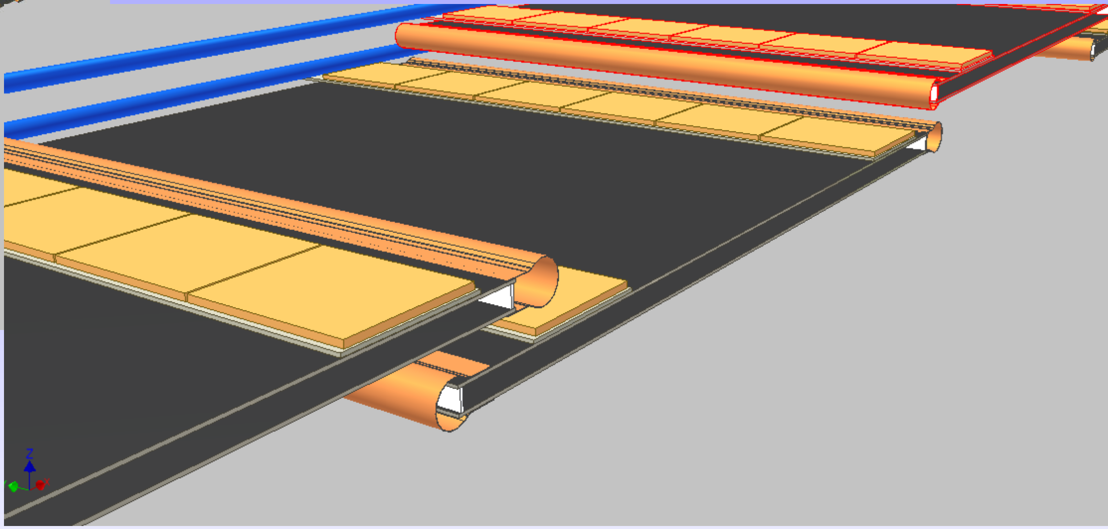
Module detail



- **Flex (pre-formed) Kapton circuit**
    - Present technology up to 40 micron pitch/implant width
  - Allows safe planar assembly
    - Mechanical
    - F.E.
    - Wire bonding
  - before back to back positioning and gluing

Long array integration





- Large array integration, good overlap design to optimize the array active area
  - Block design compatible with
    - Single layer mounting
    - Shared cooling service

Conclusion

- **Stacked modules experience**
  - Method applied to tracks produced by real collision events (CMS at LHC)
  - prototypes performance measured

- **Assembly of parts using CMS-SST rules/experience produced well performing "stacked" modules**

- **Cluster study results follows expectation (N, CC, S/N,..)**
- **Study with a "small cosmic ray telescope"**
  - Fairly good results and sensitivity on track direction of flight
- **Integration in large array**
  - Design of building blocks

- **Plans for next activity**
  - Increase the number of stacked modules prototypes
  - Play with sensor geometries and separation distance
  - Test beam experiment
  - Improved measurement of discriminating angle and flight particle direction
  - Design of "roads" and material budget study