Resolution with CMS 2S modules

Giovanni Abbiendi (INFN - Bologna)

MUonE weekly Meeting - 19 February 2020

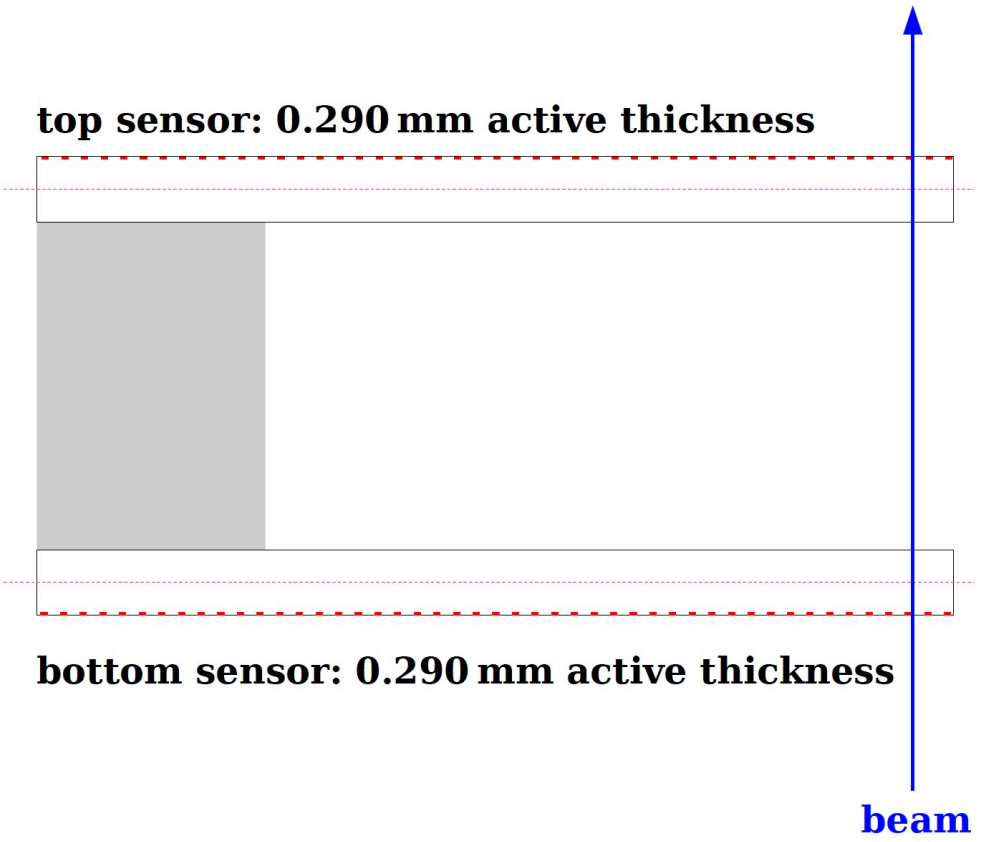
After the CERN workshop

- Thread with Duccio, Mark, Jeoff, Umberto: about the performance of the CMS modules
- Dependency on the spacing of the sensor planes of 2S modules
- Recent beam test at DESY: dependency on the tilt angle
  - Consequences for MUonE design
- Alternative design: staggered sensor layers

Intrinsic resolution

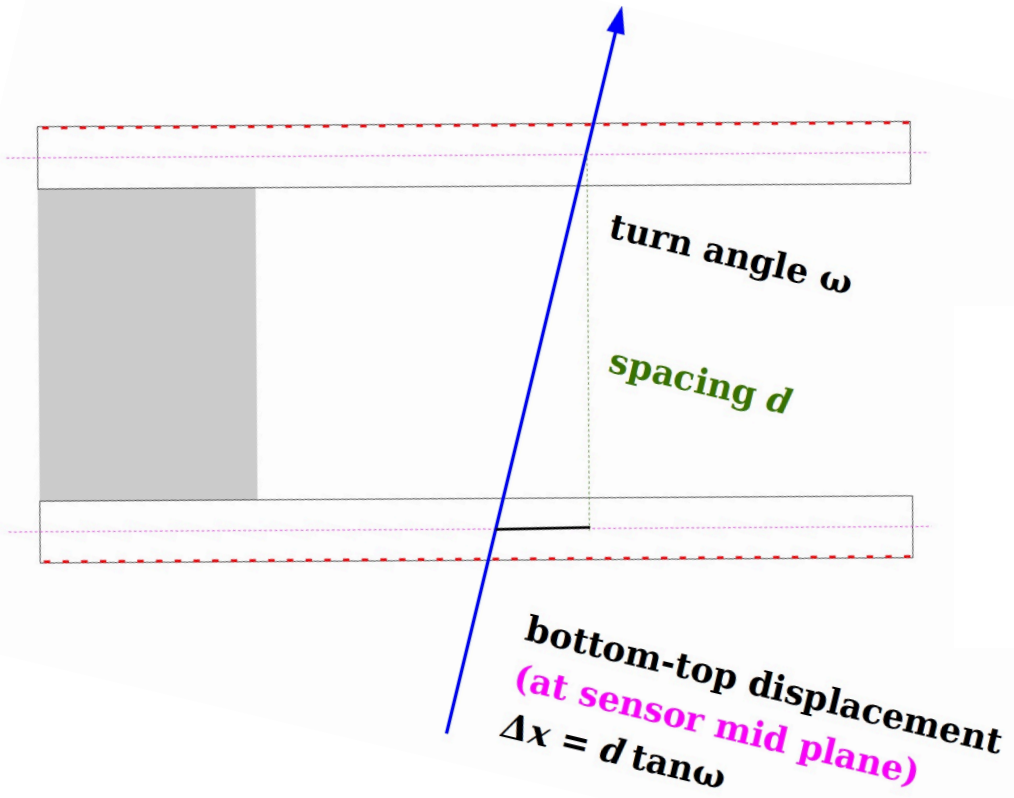
- Track incidence angles for MUonE kinematics: 0-30 mrad
- Intrinsic resolution dominates only for elastic scattering at very small angles $\lesssim$2.5 mrad
  - At larger angle the multiple scattering dominates
  - The signal region for the $\Delta\alpha_{had}$ is θ < 10-15 mrad
  - M2 beam divergence also expected to be very small 0.2-0.3 mrad
- For such small angles the cluster size on the two sensors comprising the 2S module is most of the times just 1 strip, and the top/bottom strip positions are completely correlated -> no resolution gain
  - Digital resolution: (strip pitch)/sqrt(12) = 26 μm

2S module



Digital resolution for normal tracks: (strip pitch)/sqrt(12) = 26 μm

Track incident with angle ω



For a spacing = 4.0mm we have a lateral shift of half a strip for angles of 10 μm
Could gain an effective factor sqrt(2)-2 in resolution *(not yet clear to me the correct gain)*

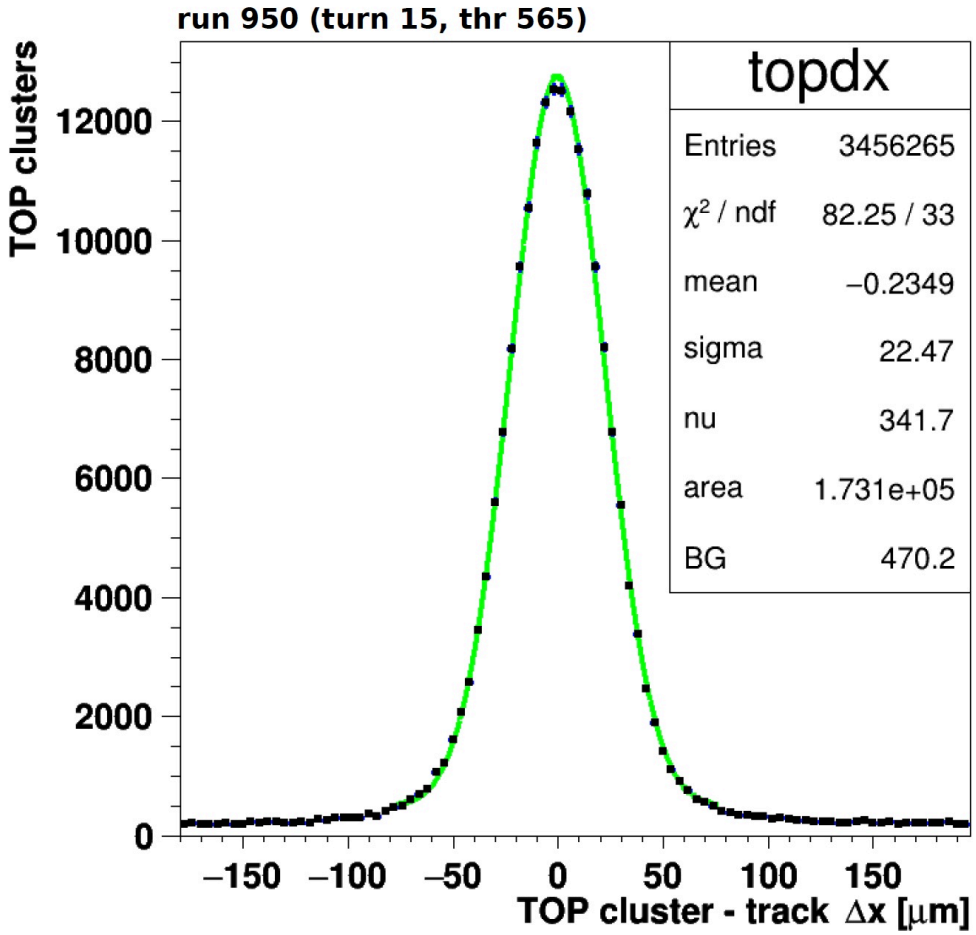
In principle modules with spacing of 4 mm should have better performance for us than modules with 1.8 mm spacing

Recent beam test at DESY

- Daniel Pitzl's presentation: https://indico.cern.ch/event/875383/contributions/3689215/attachments/1966161/3280803/beam-2019-12-2S.pdf

- In particular: Resolution dependency on the tilt angle of the module w.r.t. incident beam

2S position resolution

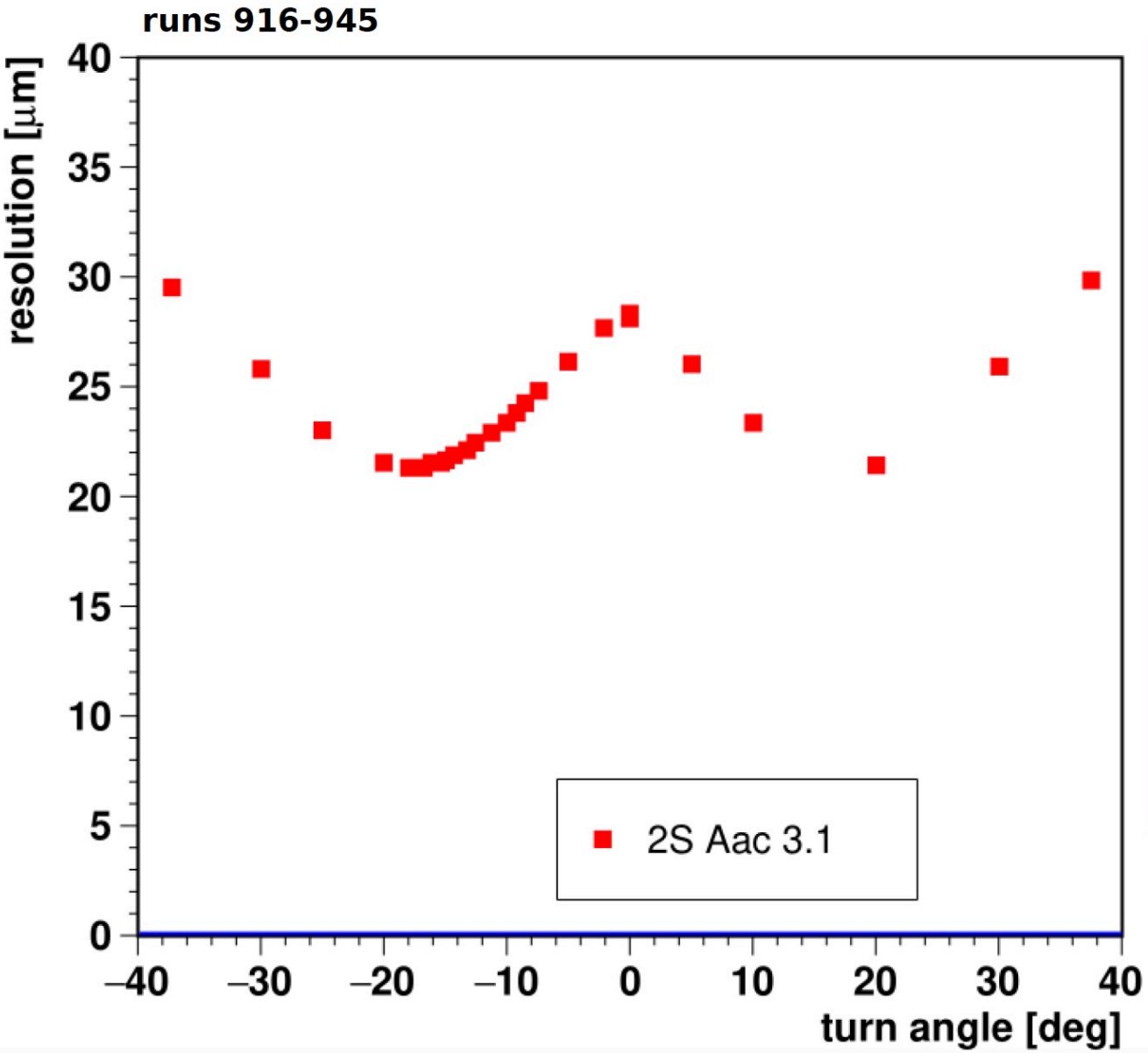


- Aachen 2S
  - CBC3.1
  - **threshold 5 σ**
  - turn 15°
  - bias 300 V
  - pitch 90 µm
  - binary readout
- residual width:
  - 22.5 µm
- telescope:
  - 12.3 µm at 4 GeV, 130 mm opening
- **resolution 19 µm**

D. Pitzl (DESY): 2S beam test 7 CMS OTK module meeting, 16.1.2020

Resolution of one sensor layer : 19µm with a 15-degree tilt
Improvement from charge sharing between adjacent strips on the layer

resolution vs turn angle

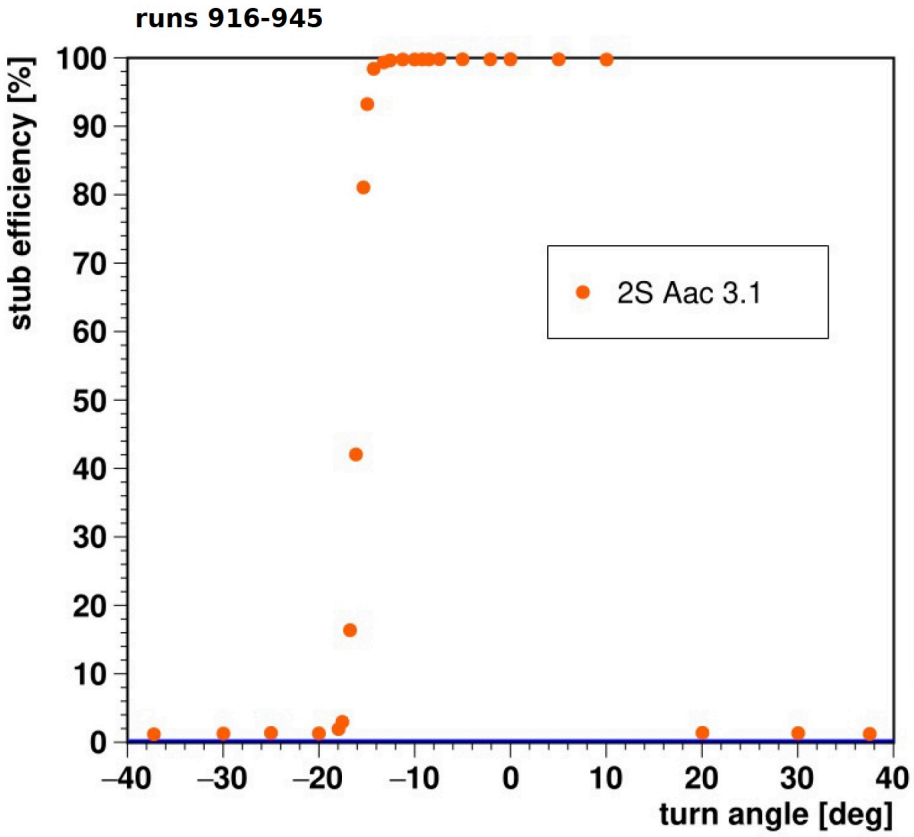


- Aachen 2S
  - CBC3.1
  - turn 15°
  - bias 300 V
  - threshold 8 σ
- resolution:
  - 12 μm telescope subtracted (quadratically)
  - best at ±18° (charge sharing)

Possible Design with Tilted modules

- Maximum gain in resolution for tilt angle ω~18°
- To gain in both the X and Y coordinate one should tilt the two paired modules (with strips along Y and X resp.) with a rotation around the corresponding strip direction
  - Mechanics is quite more complex
  - Positioning and alignment/monitoring/reconstruction more complex
- Improvement of resolution would be ~sqrt(2) for each layer of the doublets
- The two hits on the top/bottom side of a 2S module would be almost indipendent, bringing another factor sqrt(2) on the particle trajectory at the middle plane of the module
  - Hence ~ 26μm -> 13 μm
- BUT: lateral displacement for tilted modules is $\Delta x = d \tan\omega$. For ω=18°
  - Δx = 1.3 mm = 14.4 strips for d=4 mm
  - Δx = 0.585 mm = 6.5 strips for d=1.8 mm
- And CBC maximum correlation window is 7 strips, and maximum fixed offset is 3 strips, so one wouldn't be able to read out stubs at 40 MHz with this scheme
- One could use modules with 1.8mm spacing and a smaller tilt, but other drawbacks remain:
  - the stub efficiency suddenly drops at ω~15° (hence no trigger, no data!)
  - Enlarging the correlation window would increase the rate of background hits
- In addition readout of sensor data for a tilted design imply need of a trigger and larger amount of data to deal with in DAQ… Mark: *«In terms of triggering the FEs to transmit full hit data – this comes for free in CMS. The difficulty would be to decide when to read out this data, and of course adds yet another thing to synchronise when commissioning the system. For the final system, if we can do event selection to cut the rate to ~400kHz then this signal could be used to trigger the FEs. The only difficultly might be in buffering the data in the FPGA for long enough until the hits have arrived so needs to be checked. For the Test Run however we were planning to read out everything, so we wouldn't be able to get the full hit data out for every event, only a subset perhaps.»*

stub efficiency vs turn angle



- Aachen module
  - CBC 3.1
- T = tracks with links to Top and Bottom clusters
- S = Stubs matched to Top cluster
- stub efficiency:
  - ε = S&T / T

Sharp drop around ~15°

We should stay far from it as we need absolutely flat efficiency as a function of the incidence angle (here flat means variations smaller than 10^{-5})

Alternative design: staggering the 2S sensor planes

- Half-strip staggering (45 μm) gain an effective factor sqrt(2)-2 in resolution (not yet clear to me the correct gain) ~ 26μm -> 18-13 μm
- No other change to the detector/readout needed: no drawbacks as for tilted modules
- BUT: clear statement from Duccio: *«staggering is definitely feasible, if you find a group that takes the responsibility of modifying the assembly jigs to implement the stagger between the two sensors, and assemble these special modules, with wire bonding at an angle (because the wire bond pads on the sensors would then be shifted wrt the wire bonds pads on the hybrids). In short, these would not be CMS modules anymore.»*

Conclusions

- Position resolution of the 2S tracker modules could be improved w.r.t. MUonE current design (from the LoI)
  - Cheap improvement: using modules with 4.0mm gap rather than 1.8mm (but this improves only for incidence angles larger than 10 mrad)
  - Tilted module design: significant improvements but with several complications and drawbacks. Difficult compromise has to be reached.
  - Staggered sensor layers on the 2S modules. Advantageous with no complications/drawbacks. But CMS cannot commit to the technical changes needed in the production of the modules. Would need new responsible institution/manpower.
- Improved resolution could better constrain the scattering kinematics in MUoNE
- How much would this improve the a_μ^{HLO} measurement, considering both statistical and systematic effects ? Is this worthwhile ?
- Quite necessary and urgent to work on simulations to better understand the effects at play. Not necessary to have full GEANT4 simulations. CMS Tracker people have a detailed but relatively simple/fast tool to study the relevant aspects of the detector design and geometry. Need a dedicated student to work on this.