Double-sided pixelated layers studies from the PLUME collaboration

LCWS15

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On behalf of the PLUME Collaboration

Whistler, Vertex/Tracking session

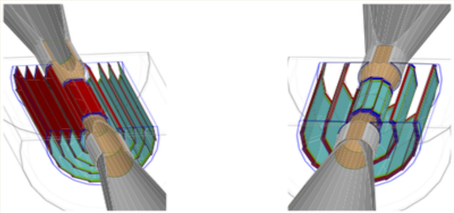
November 4, 2015

Outlines

The ILD Vertex Detector

The ILC vertex detector requirements

- Spatial resolution: $< 3\ \mu m$
- Material budget per measurement point: $\simeq 0.15\%\ X_0$



Two geometry options for the ILD vertex detector: 5 layers of single-sided detector (left) or 3 layers of double-sided detector (right)

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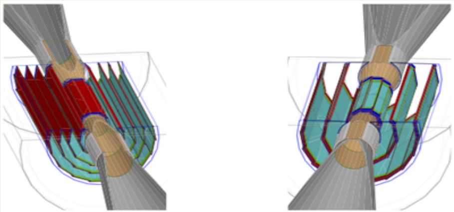


Two geometry options for the ILD vertex detector: 5 layers of single-sided detector (left) or **3 layers of double-sided detector** (right)

Double-sided vertex detector: PLUME

PLUME = **P**ixelated **L**adder with **U**ltra-low **M**aterial **E**mbedding

IPHC
- DAQ
- Flex circuits
- Test beam analysis

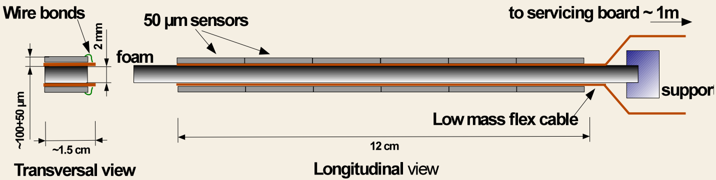
DESY
- Lab validation of ladders
- Test beam analysis

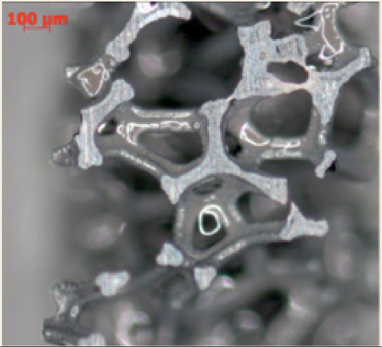
University of Bristol
- Mechanical design
- Assembly
- Metrology

Goals

- To build double-sided vertex detector with CMOS sensors
- To demonstrate the feasibility of the mechanical structure
- To get expertise on the mechanical structure production
- To support benefits of double-sided layers

Ladder design



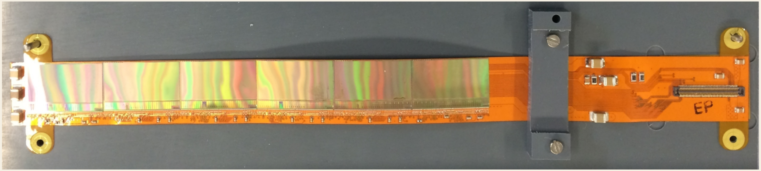


Design

- Double-sided ladder with an active area of $1 \times 12 cm^2$
- On each side: six MIMOSA-26 CMOS sensors thinned to 50 µm glued on a kapton-metal flex cable
- 2 mm of silicon carbide foam as mechanical support and spacer between two modules

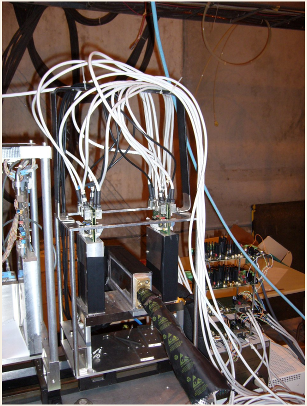
Evolution of the design

- Version 0: proof the feasibility
- Version 1:
  - Full electrical ladders with six Mi-26 on each side
  - Wide flex cable with copper traces
  - Material budget: 0.6% X_0 (8%-foam)
- Version 2:
  - Reduction of the dead area (flex cable less wide)
  - Reduction of the material to 0.35% X_0 (4%-foam and aluminum traces)



Outlines

Test beam @ SPS with 120 GeV π^- in November 2011



- Beam test on line H6a @ SPS
- Reference plane: four Mimosa 26
- Validation of the first PLUME double sided ladder equipped with 12 Mi26 sensors

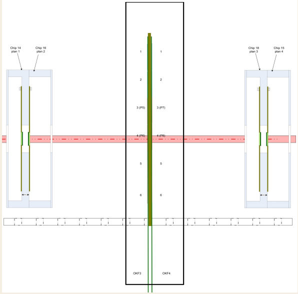
Results:

- Efficiency measured as a function of the fake hit rate
- Pointing resolution: $\simeq 3\mu m$
- Measurements done with different air flow speed ($\simeq$ 3 to 6 ms^{-1}) and position

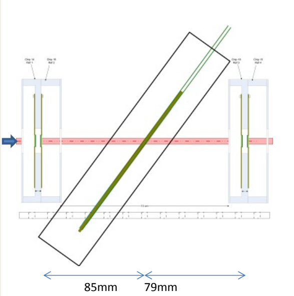
Jérôme Baudot, Gilles Claus, Loic Cousin, Mathieu Goffe, Rohrry Gold, Joel Goldstein, Ingrid Maria Gregor, Robert Maria.

Test beam @ SPS with 120 GeV π^- in October 2011

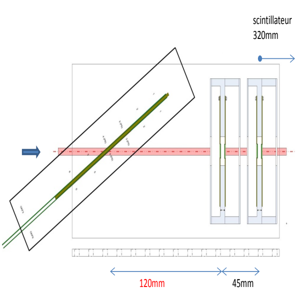
Three configurations studied:



Module perpendicular to the beam.



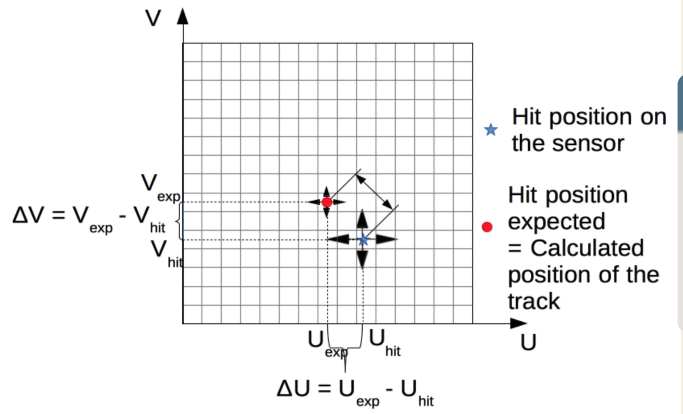
Module tilted (between 28°and 40°).



Module tilted ($\simeq 60°$).

$\Rightarrow$ Advanced analysis to study track-hit residual and the distribution of this residual as a function of the relative position of the beam on the sensor.

Track-hit residual



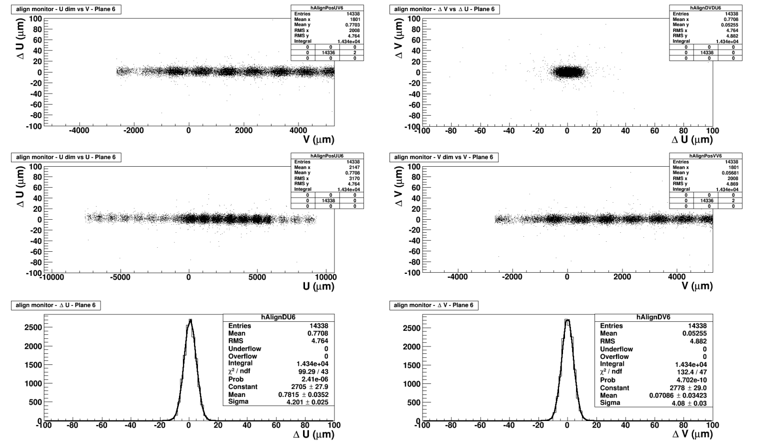
Alignment of the device under test (DUT)

- The track of a particle is defined by the telescope
- Measure the distance between the track extrapolated and the closest hit position

$$\sigma^2_{res} = \sigma^2_{DUT} + \sigma^2_{tel}$$

Module perpendicular to the beam

Threshold of 6 σ, fan speed < 5m/s and 1.8M events.

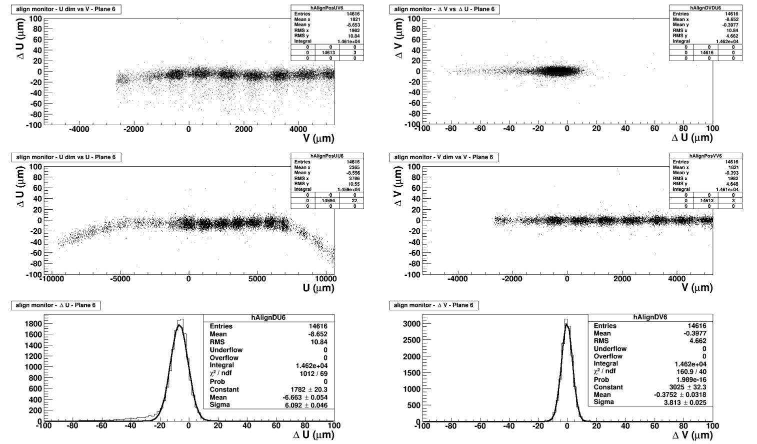


Spatial residual obtained after alignment:

$$\sigma_U \simeq 4.2 \pm 0.1\ \mu m \text{ and } \sigma_V \simeq 4.0 \pm 0.1\ \mu m$$

Module titled in one direction (w.r.t. to the beam axis)

Threshold of 6 σ, fan speed < 5m/s, 720k events and a tilt of 36 °.



Spatial residual obtained after alignment:

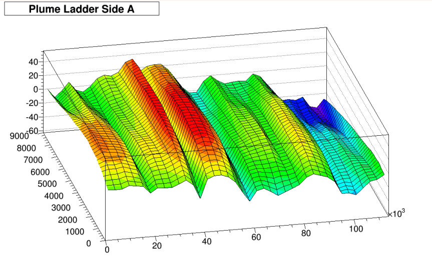
$$\sigma_U \simeq 6.1 \pm 0.1\ \mu m \text{ and } \sigma_V \simeq 3.8 \pm 0.1\ \mu m$$

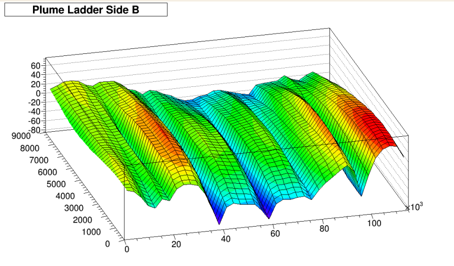
Origin of the deviations

Consequence of the ladder's characteristics

- Use of ultra-thin (50 μm) and precise sensors (spatial resolution less than 4 μm)
- Mechanical constraints induce permanent deformations ($\simeq$ 50 μm) which can not be flattened during the ladder assembly

Metrology of the module's surface (performed at RAL by Bristol)

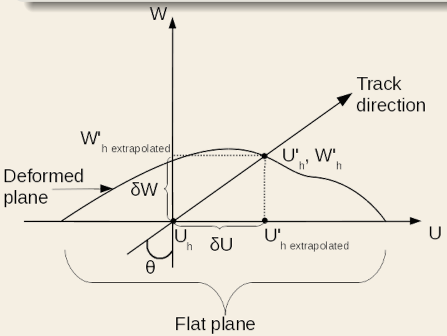




Origin of the devations

Artefacts from the modelling of our sensors during the analysis

- Modelling the sensors as completely flat planes
- The track extrapolation is sensitive to the exact position of the hit on the plane and the angle of incidence



Deviations of the residual

$$\delta W = \frac{\delta u}{\tan\theta}$$

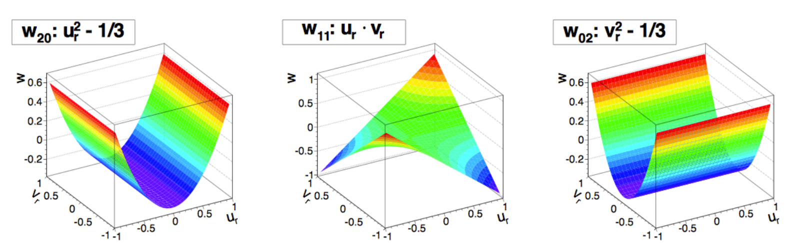
How to describe deviations from the flat plane?

arXiv:1403.2286 [physics.ins-det] CMS paper

- Sensor shape parametrised as a sum of products of modified Legendre polynomials:

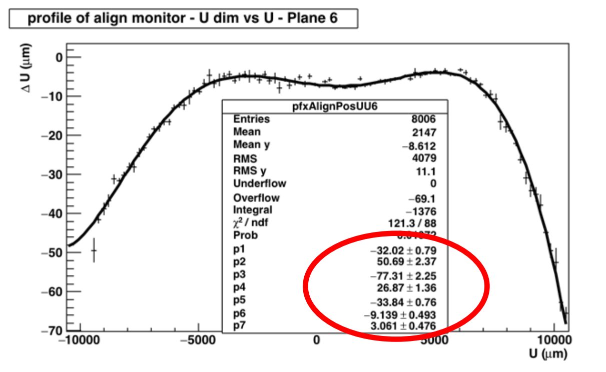
$$\begin{aligned} w(u_r, v_r) &= w \\ &+ w_{10} \cdot u_r + w_{01} \cdot v_r \\ &+ w_{20} \cdot (u_r^2 - 1/3) + w_{11} \cdot (u_r \cdot v_r) + w_{02} \cdot (v_r^2 - 1/3) \end{aligned}$$

- In our case, we used Legendre polynomials of the 7^{th} order only in the direction of the deformation.



Parametrization of the deformation

Parametrize deformation with Legendre polynomials of the 7^{th} order on the U direction only



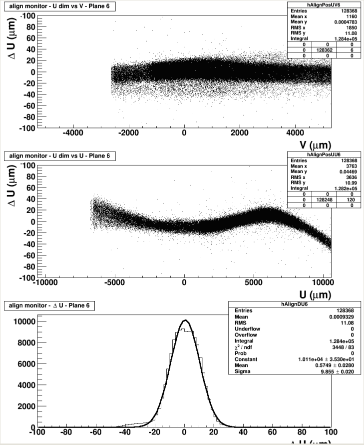
New plane position:

Extrapolation of the plane position in the W direction thanks to the 7^{th} coefficients obtained after fitting

Module tilted with an angle of 28°

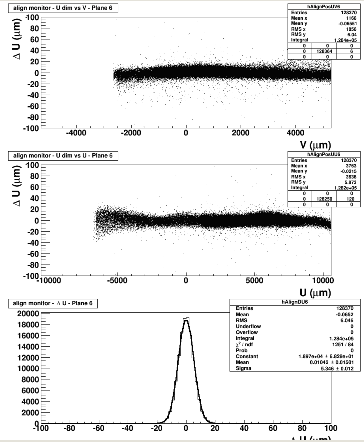
Threshold of 5 σ, fan speed of 6 m/s, 720k events.

Before correction



$\sigma = 9.9 \pm 0.1 \mu m$

After correction



$\sigma = 5.3 \pm 0.1 \mu m$

Summary of correction for different angles and same planes

Spatial residuals

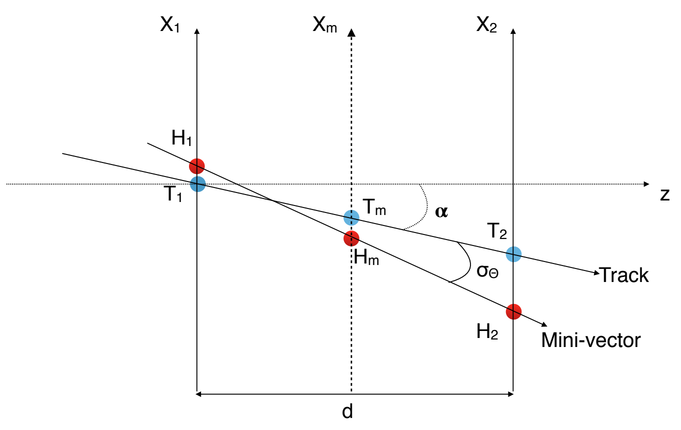
Side	Tilted angle	σ_U^{Def} (μm)	σ_U^{Cor} (μm)	Improvement
Front	28	8.8 $\pm$ 0.1	4.8 $\pm$ 0.1	45.5 %
Back	28	5.6 $\pm$ 0.1	4.5 $\pm$ 0.1	19.6 %
Front	36	13.4 $\pm$ 0.1	6.3 $\pm$ 0.1	52.9 %
Back	36	7.5 $\pm$ 0.1	6.8 $\pm$ 0.1	9 %
Front	60	41.2 $\pm$ 0.15	25.8 $\pm$ 0.2	37.4 %
Back	60	23.3 $\pm$ 0.13	21.7 $\pm$ 0.1	6.8 %

Residual increases with incidence angle, in line with telescope resolution degrading (under quantitative evaluation)

Refinement of the correction with an iterative procedure is ongoing

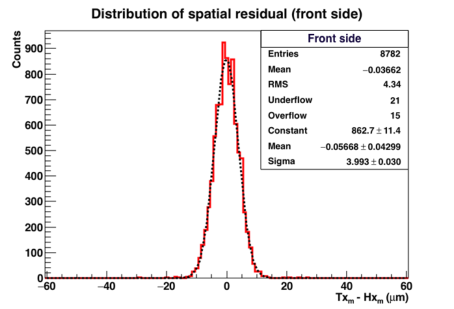
Outlines

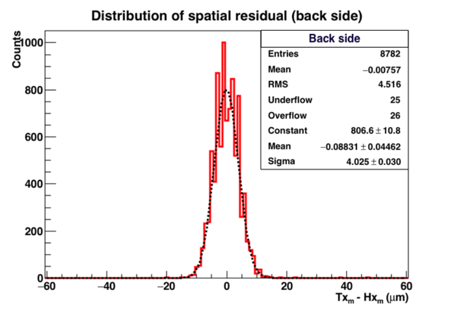
Two points measurement combination



Spatial residual

Study of two planes in normal incidence (w.r.t the beam axis)



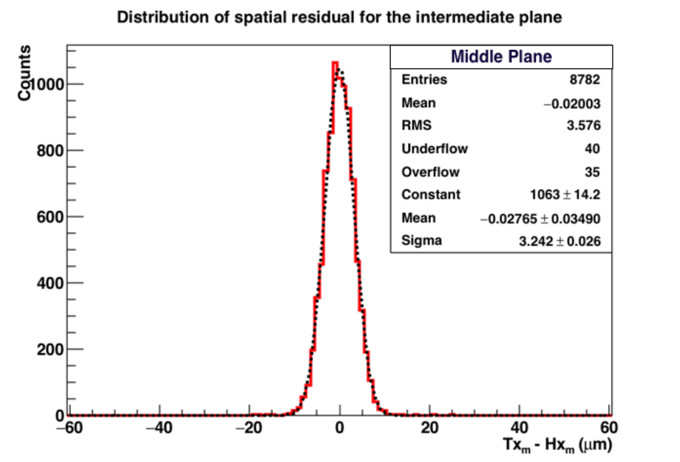


Combination of the residuals information

$$\sigma_m^2 = \frac{\sigma_{front}^2 + \sigma_{back}^2}{4} + \sigma_{tel}^2$$
$$\sigma_m \simeq 3.4\mu m$$

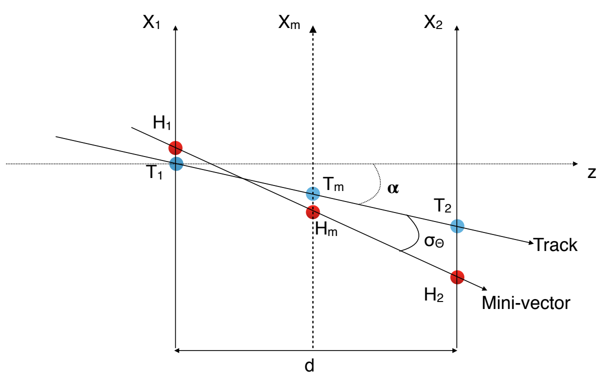
$$\Rightarrow \sigma_{resolution} = \sqrt{\sigma_m^2 - \sigma_{tel}^2} \simeq 2.9\mu m \text{ with } \sigma_{tel} \simeq 1.8\mu m$$

Mini-vector spatial residual



$$\sigma_{measured} \simeq 3.2\mu m (\sigma_{expected} \simeq 3.4\mu m)$$
$$\sigma_{resolution} \simeq 2.7\mu m (\sigma_{resolution\ expected} \simeq 2.9\mu m)$$

Estimation of the angular resolution



Estimation of the angular resolution

$$\sigma_\theta = \frac{\sqrt{\sigma_{s1}^2 + \sigma_{s2}^2}}{d}$$

$$\sigma_\theta \simeq 0.146^\circ$$

with $\sigma_{s1} = \sigma_{s2} \simeq 3.6\ \mu m$

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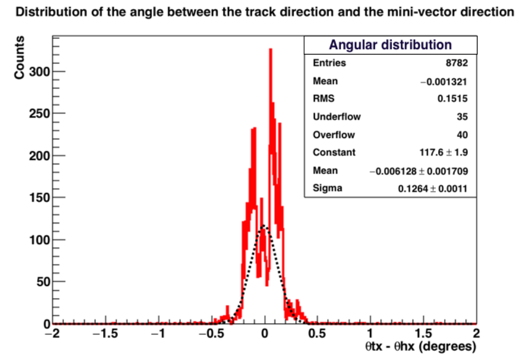


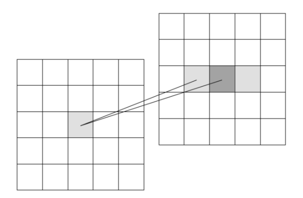
Angular resolution:

Can not be simply quoted by a Gaussian standard deviation

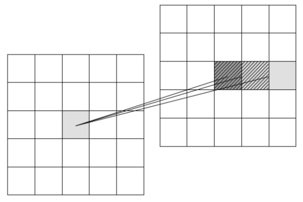
Origin of the peaks

- Cluster position determined by its centre of gravity
- Angle distribution is dependent of the cluster size taken into account

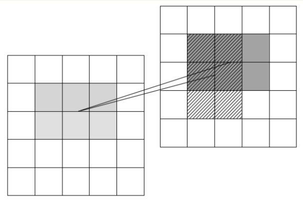
Cluster of 1 pixel on each side



Cluster of 2 pixels on one side, 1 pixel on the other



Cluster > 2px on each side



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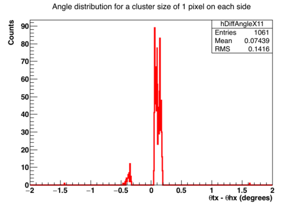

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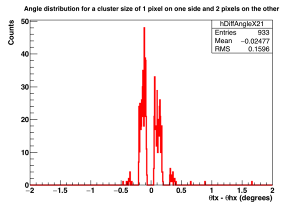

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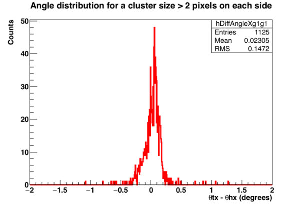


Conclusions

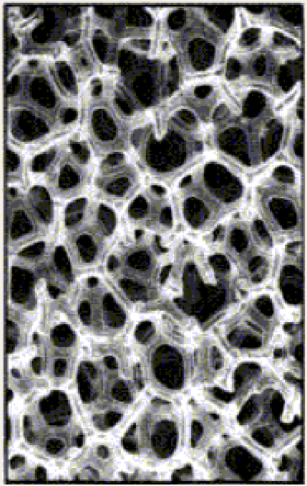
- Deformation impacts severely resolution at even modest incident angle
- Deformation can be corrected by software... but not yet perfectly (Iteration procedure is being implemented)
- Estimation of the angular distribution and the cluster position are correlated $\Rightarrow$ combination of these estimations in order to improve the spatial resolution is possible
- New prototype with lower material budget will be tested to compare the stability and deformation features
- Real ladder shall be mitigated by design (flatten the SiC foam done by machining it but requires more money than we have)

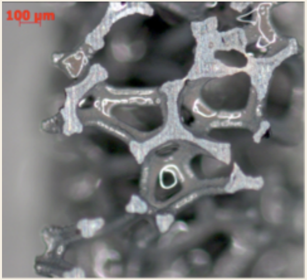
Outlook

Investigate how the findings on the first PLUME hold the thinner new prototype

Thanks for your attention!!!

Foam support structure

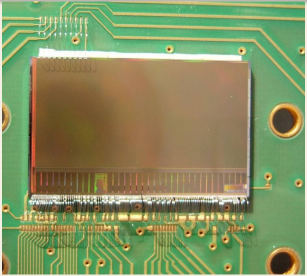


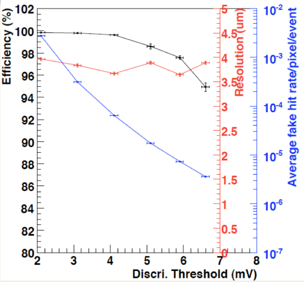


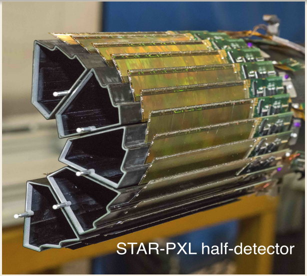
Properties

- Open-cell foam
- Macroscopically uniform
- No tensioning needed
- 4 to 8 % fill factor (2-3 % possible)
- Low thermal and electrical conductivity (50 W/m/K)

MIMOSA-26 sensor

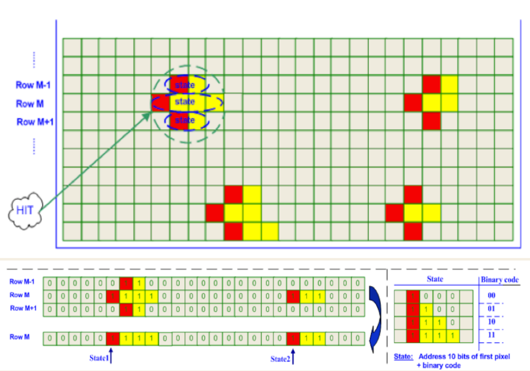






- Monolithic Active Pixels Sensor
- Pitch of 18.4 μm (square pixels)
- Active area: 10.6 x 21.2 mm^2 (576 rows x 1152 columns)
- Column-parallel readout: integration time of 115.2 μs (200 ns per line) for 80 MHz clock
- Zero suppression (to optimize data bandwith) with binary output
- Well known sensors $\Rightarrow$ used for EUDET telescope
- Extended to MIMOSA-28 exploited in STAR-PXL vertex detector @ RHIC-BNL since 2014

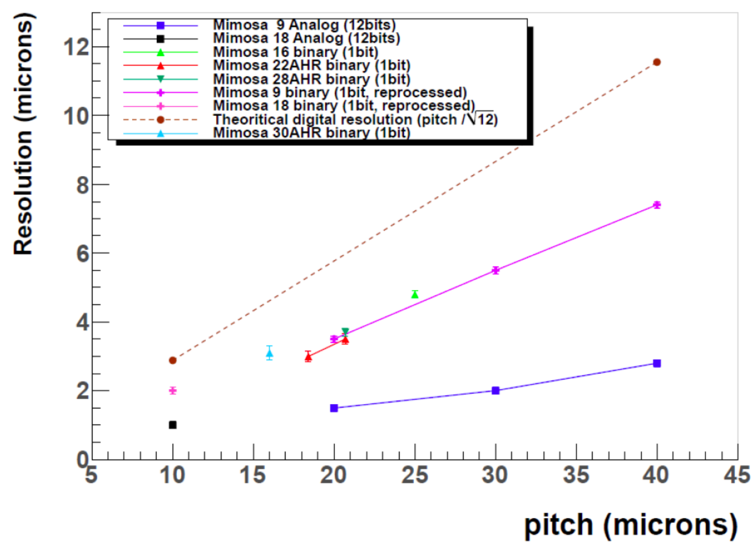
Zero Suppression logic (SUZE)



SUZE logic split in 3 blocks :

- **Sparse Data Scan (SDS)** Hit detection per line and data encoding, until 6 states consecutive pixels (1 to 4 pixels) per block of 64 columns;
- **Multiplexing Logic (Mux)** giving up to 9 states;
- **Memory storage** 2 blocks to store the states of the full frame, switching to avoid dead time (during one acquire states of event N, the other one transfer the information of frame N-1).

Spatial resolution for different pitch (IPHC-Strasbourg)



Young modulus VS radiation legnth