Observing and correcting the surface deformation of light pixelated detection surface

3rd beam telescopes and test beams workshop

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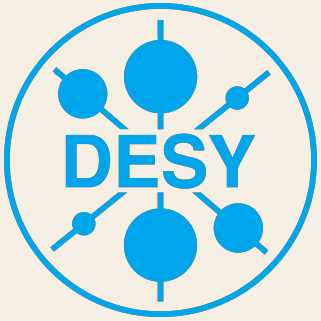
On behalf of the PLUME Collaboration

DESY - Hamburg

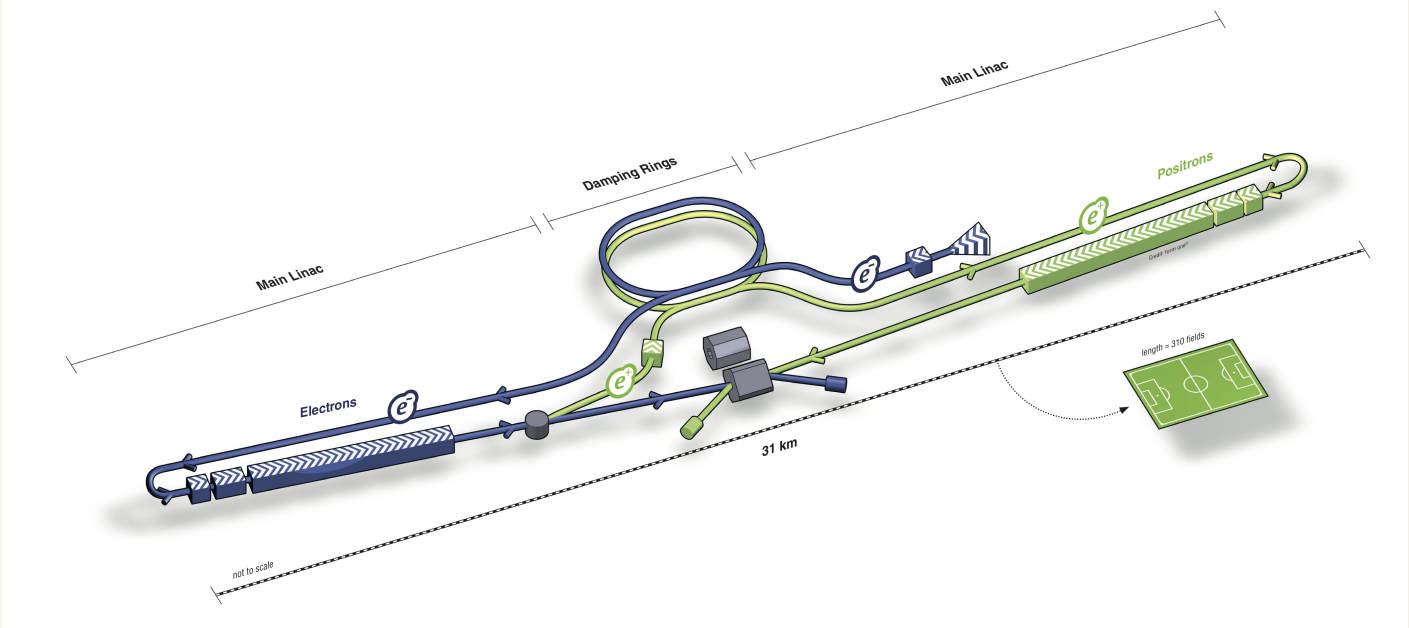
January 21, 2015



Outlines

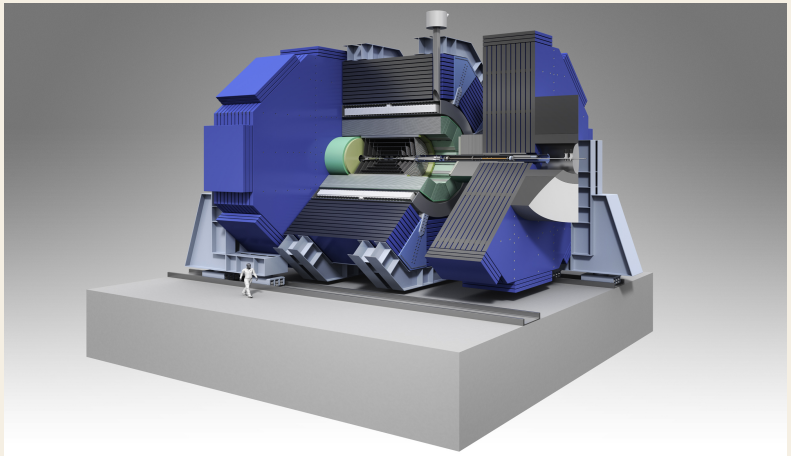
1. About ILC
   - What is ILC?
   - Two experiments
   - Vertex Detector at ILD
2. An intelligent ladder : PLUME
   - PLUME project
   - Desgin
   - Main aims
3. Study of the alignment and the spatial resolution
   - Test Beam @ SPS
   - Origin of deviations and how to take them into account
   - Results on the correction of deviation

International Linear Collider



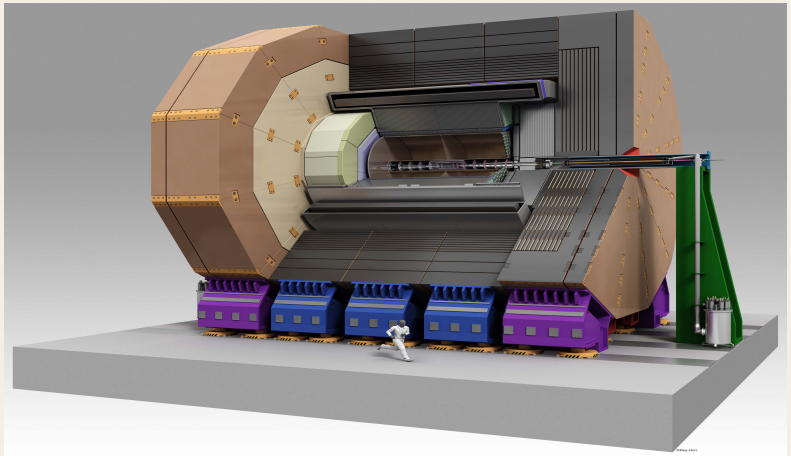
- Future e^+e^- linear collider at $\sqrt{s}$ = 250 - 500 GeV (upgrade up to $\sqrt{s}$ = 1 TeV);
- Polarised beam;
- Luminosity $\simeq 2x10^{34}$ cm^{-2} s^{-1};
- Candidate site : Kitakami in nothern Japan;
- To study the properties of the Higgs boson, the Top physics...

SiD and ILD



Silicon Detector

- Silicon tracking (radius = 1.2m);
- B_{field} = 5 T.



International Linear Detector

- TPC + silicon envelope (raidus = 1.8 m);
- B_{field} = 3.5 T.

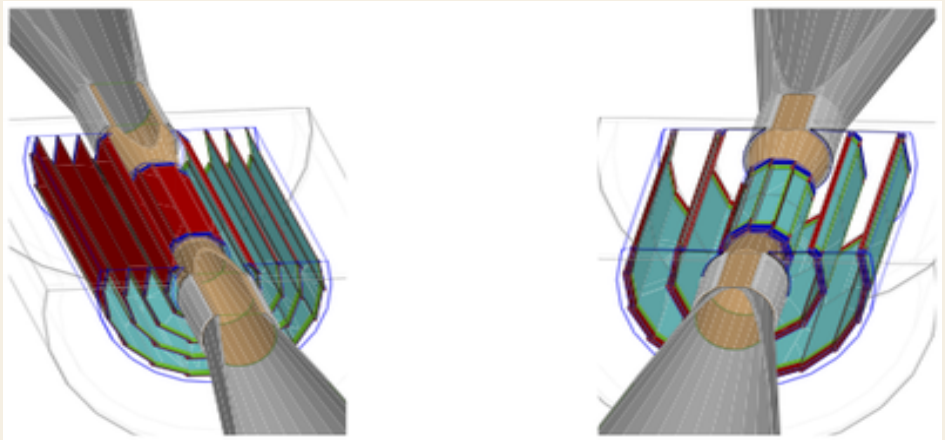
Both detectors designed for Particle Flow Calorimetry

- High granularity calorimeters (ECAL and HCAL) inside solenoid;
- Low mass tracker to reduce interactions and conversions.

ILD Vertex Detector

Impact parameter resolution

- $\sigma_{r\phi} \simeq \sigma_{rz} \simeq a \oplus \frac{b}{p \cdot sin^{3/2}\theta}$
- Hit resolution : $a \simeq 5\mu m \Rightarrow \ \sigma_{spatial} < 3\mu m$
- Multiple scattering : $b \simeq 10 - 15\mu m \Rightarrow$ material budget/layer $\simeq 0.15\%\ X_0$ for an excellent flavour tagging performance.



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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Double-sided VXD : PLUME

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

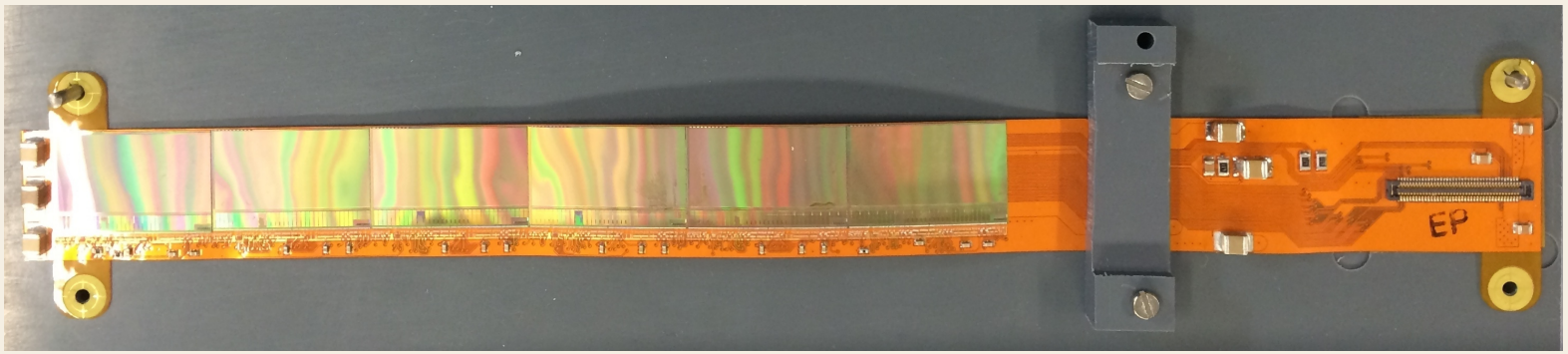
Motivation

ILD Vertex detector at ILC

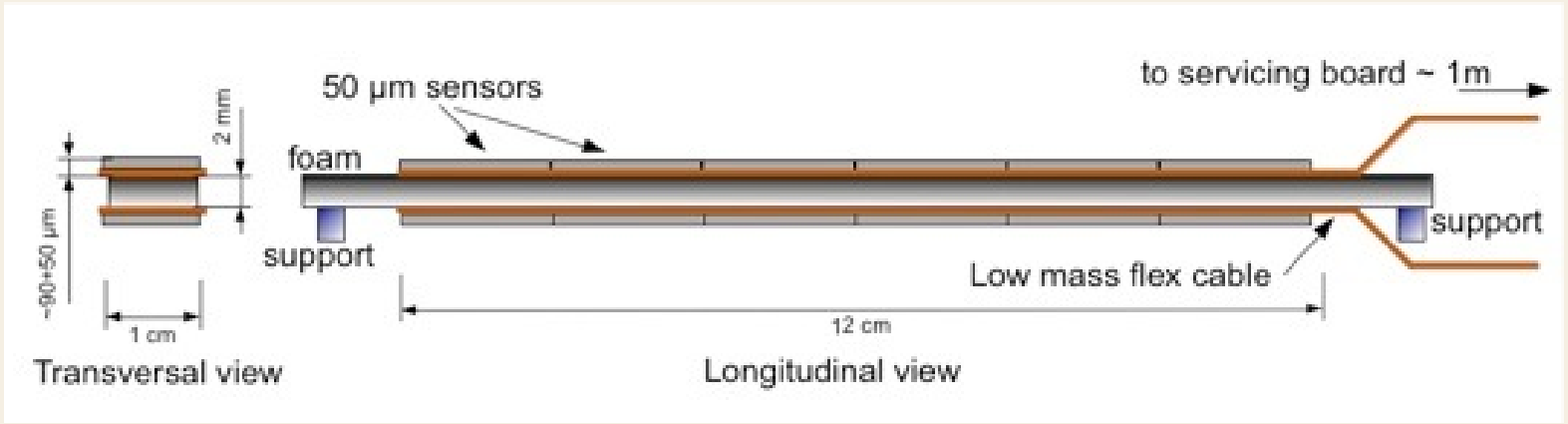
Design

- Double-sided ladder with an active area of 1x12cm^2;
- On each side : six MIMOSA-26 CMOS sensors thinned to 50 μm on a kapton-metal flex cable;
- 2 mm of silicon carbide foam as mechanical support and spacer between two modules.

How does it look like?

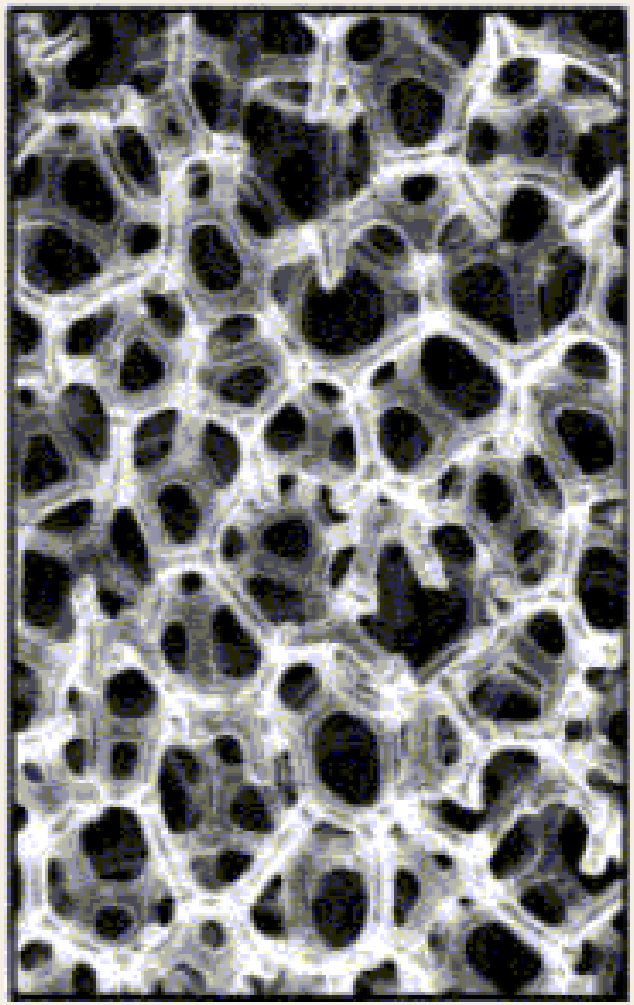


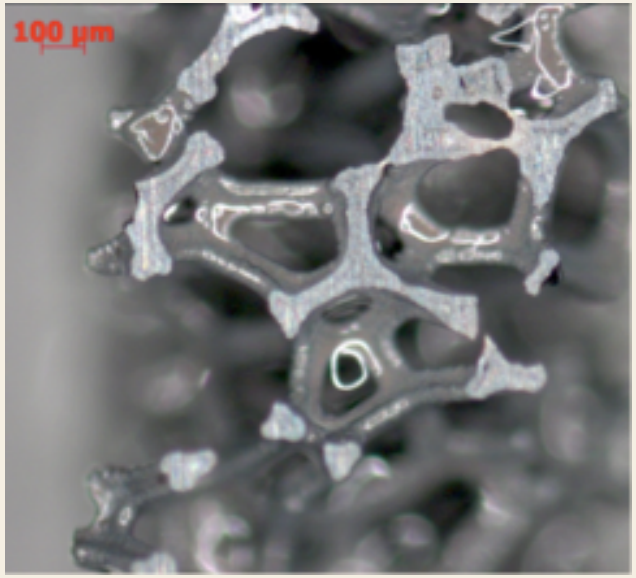
Pictures of one module with copper traces.



Scheme of one PLUME ladder.

Foam support structure

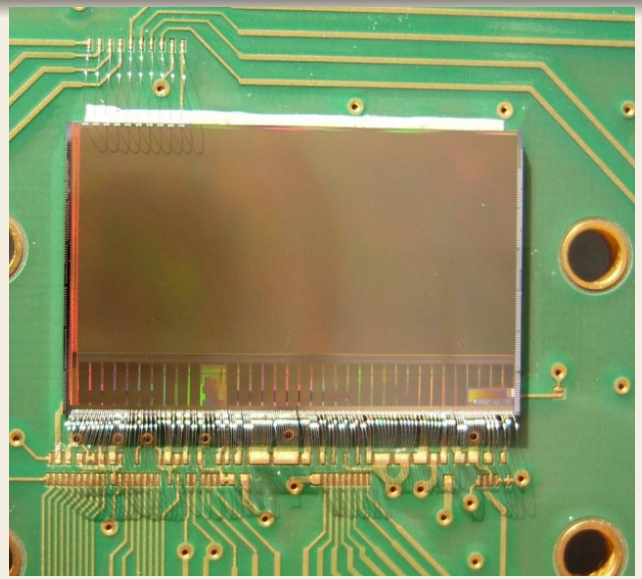


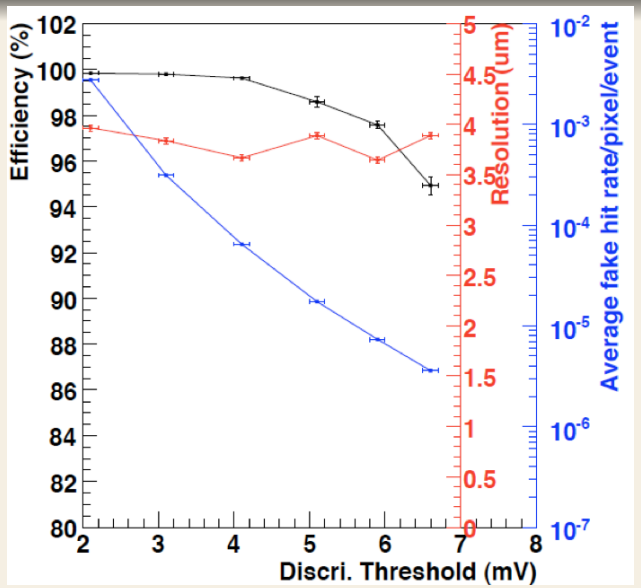


Properties

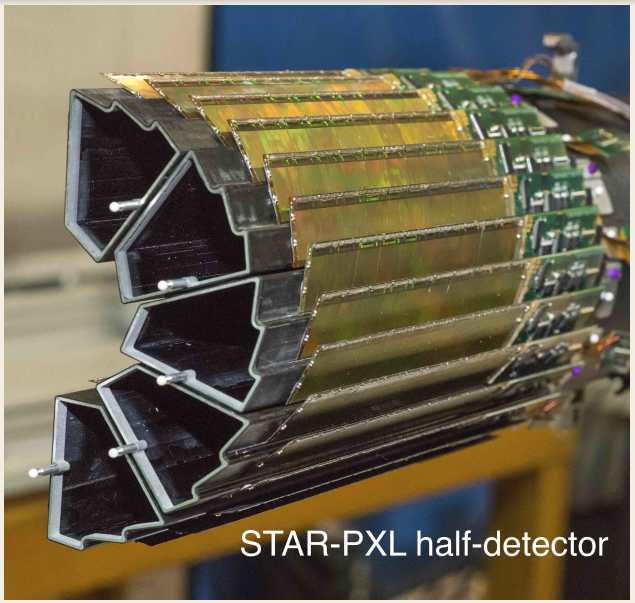
- Open-cell foam;
- Macroscopically uniform;
- No tensioning need;
- 4 to 8 % fill factor (2-3 % possible);
- Low thermal and electrical conductivity (50 W/m/K).

MIMOSA-26 sensor





From IPHC - Strasbourg



- Monolithic 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 sensor $\Rightarrow$ used for EUDET telescope;
- Extended to MIMOSA-28 exploited in STAR-PXL vertex detector @ RHIC-BNL since 2014.

Main aims

- Try to reach a material budget of less than 0.3 % X_0;
- Use the power pulsing (200 ms period) in a strong magnetic field with air cooling to decrease the power consumption of the ladder;
- Study of mini-vectors;
- **Study of the alignment and the spatial resolution.**

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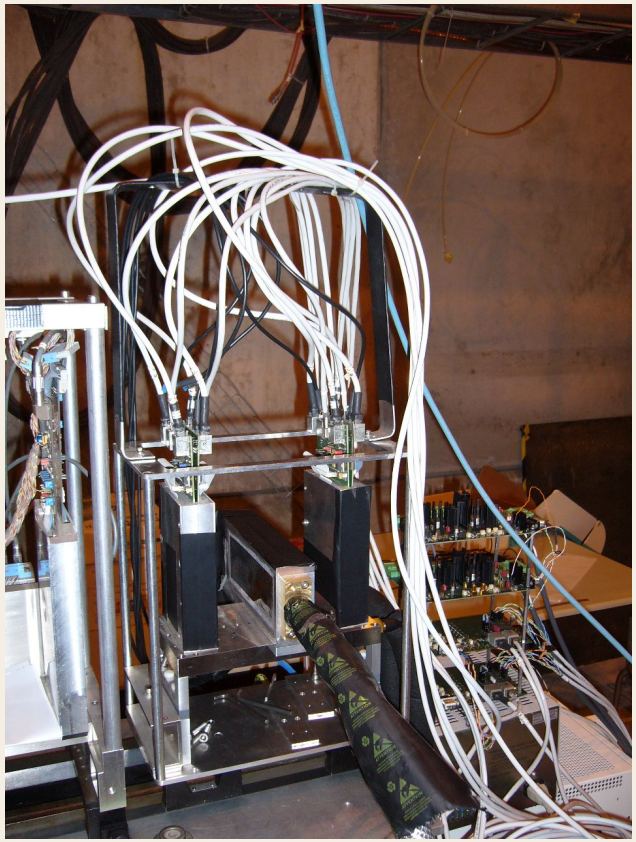
Test beam @ SPS with 120 GeV π^- in November 2011



- Beam test on line H6a @ SPS;
- Reference plane : 4 Mimosa 26;
- Validation of the first PLUME double sided ladder equiped with 12 Mi26 sensors.

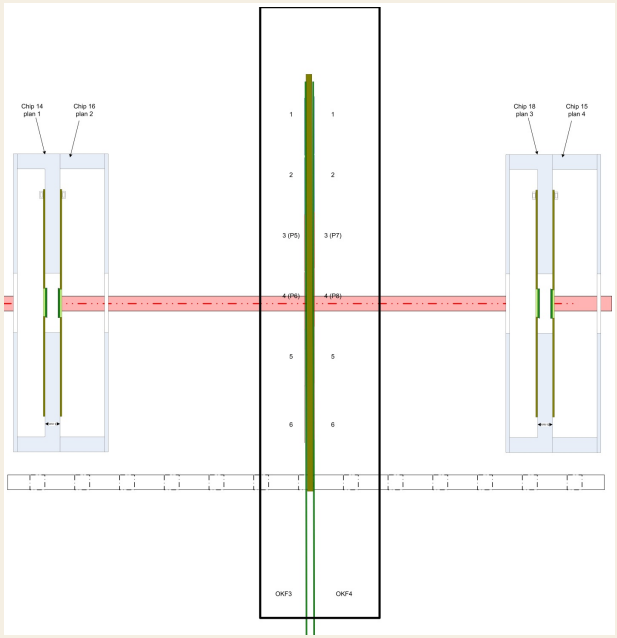
Scan on the ladder :

- In threshold (5 and 6 mV);
- In position (sensor 1-2, 3-4 and 5-6);
- Without and with and angle (between 30 and 40 degres);
- With two differents air flow speed ($\simeq$ 3 to 6 m/s).

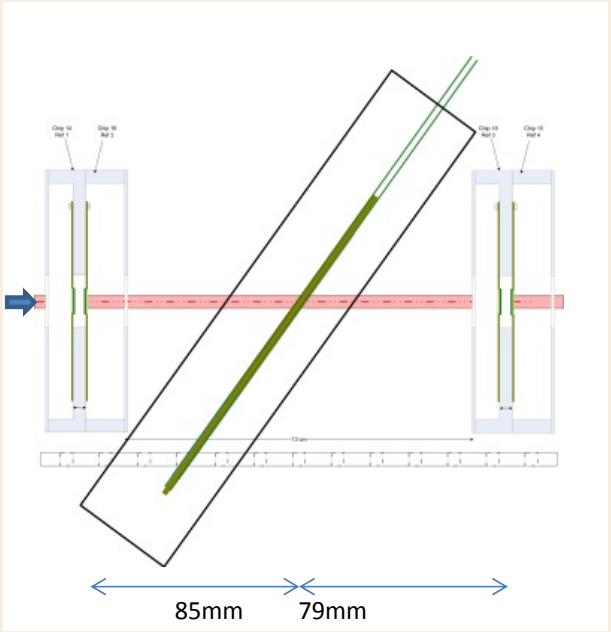
Jerome Baudot, Gilles Claus, Loic Cousin, Mathieu Goffe, Rohrry Gold, Joel Goldstein, Ingrid Gregor, Robert Maria.

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

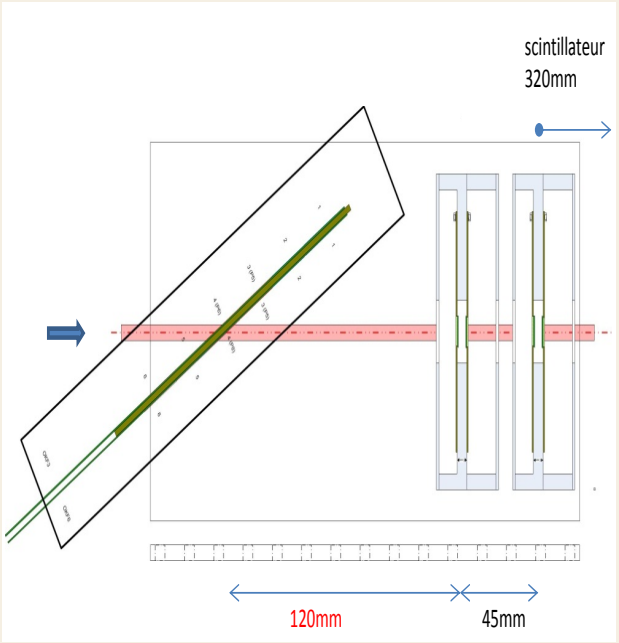
Three configurations studied :



Module perpendicular to the beam.



Module tilted (between 28°and 40°).



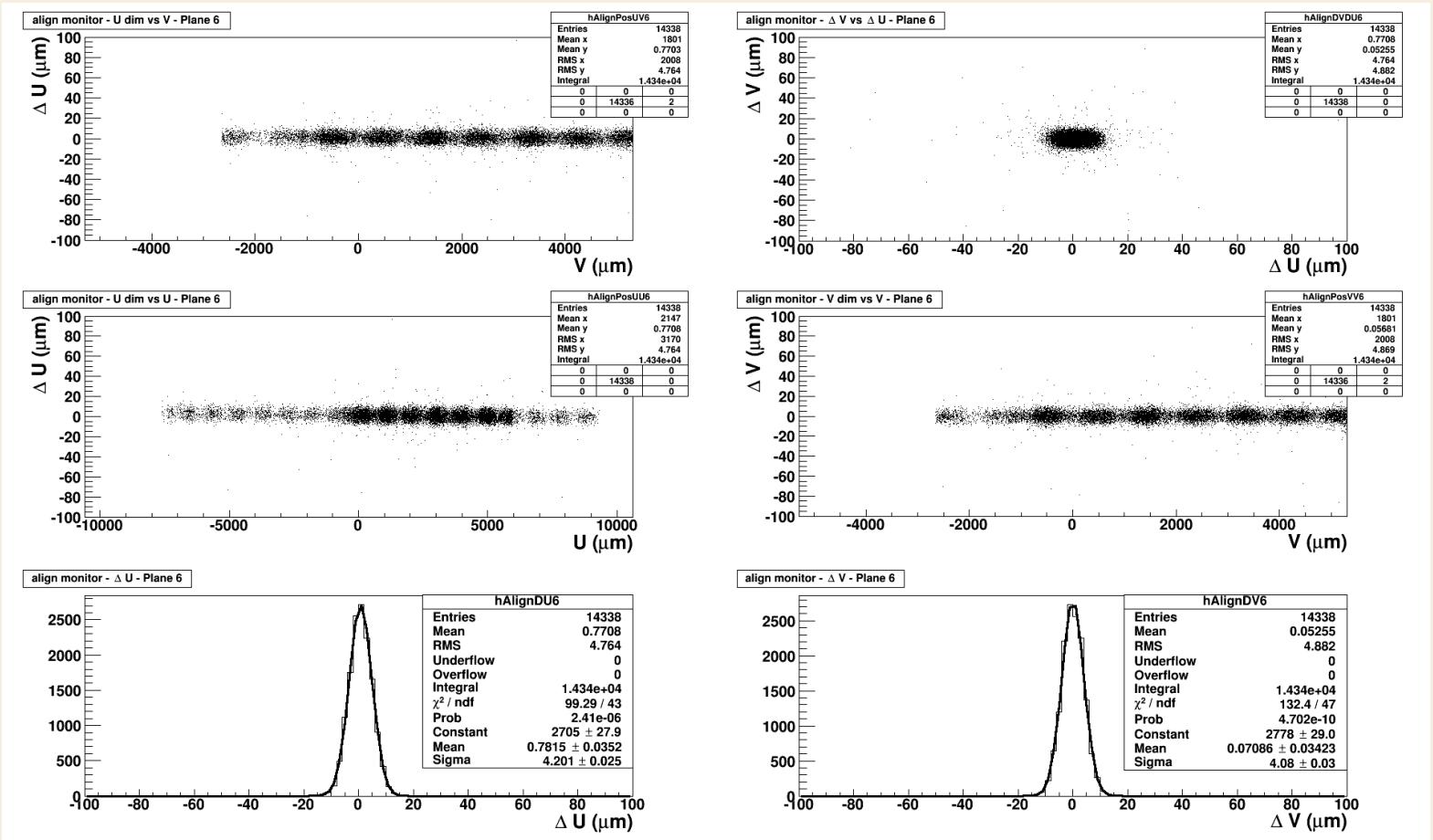
Module tilted ($\simeq 60°$).

$\Rightarrow$ Study track-hit residual and the distribution of the track-hit residual as a function of the relative positions of the beam on the sensor.

The analysis was performed with a software developped by IPHC-Picsel : TAF (TAPI Analysis Framework).

Module perpendicular to the beam

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

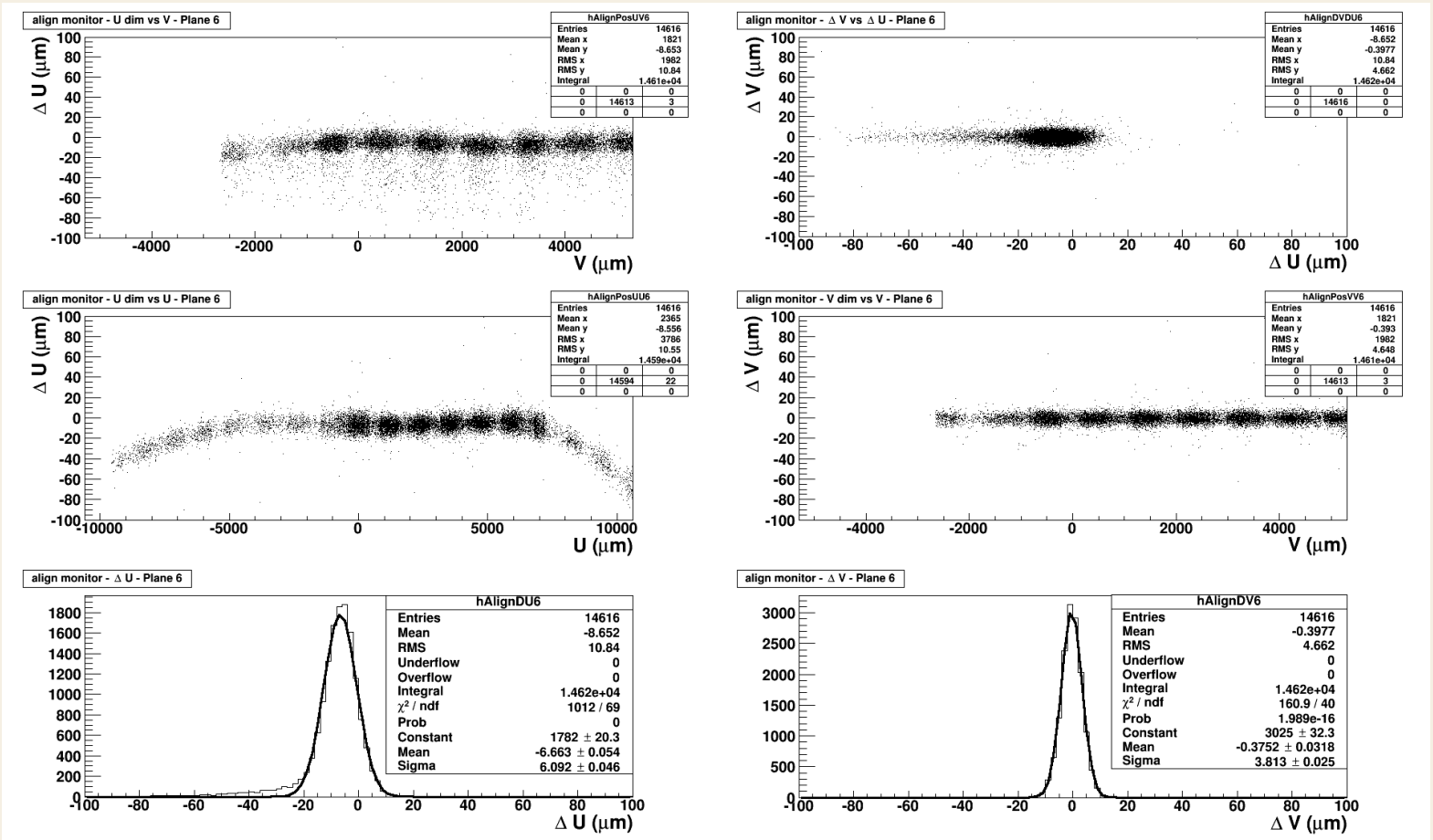


Spatial residual obtained after alignment :

$\sigma_U \simeq 4.2\ \mu m$ *and* $\sigma_V \simeq 4\ \mu m$

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 :

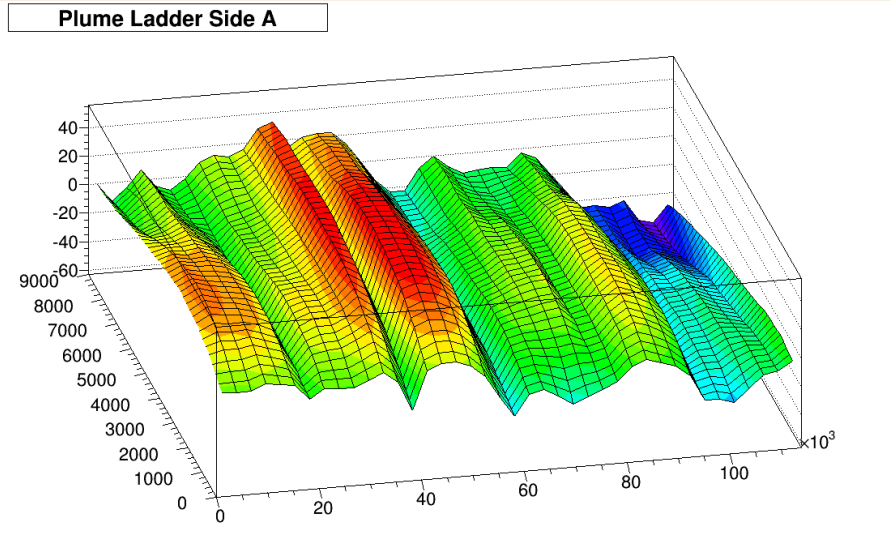
$\sigma_U \simeq 6.1\ \mu m$ *and* $\sigma_V \simeq 3.8\ \mu m$

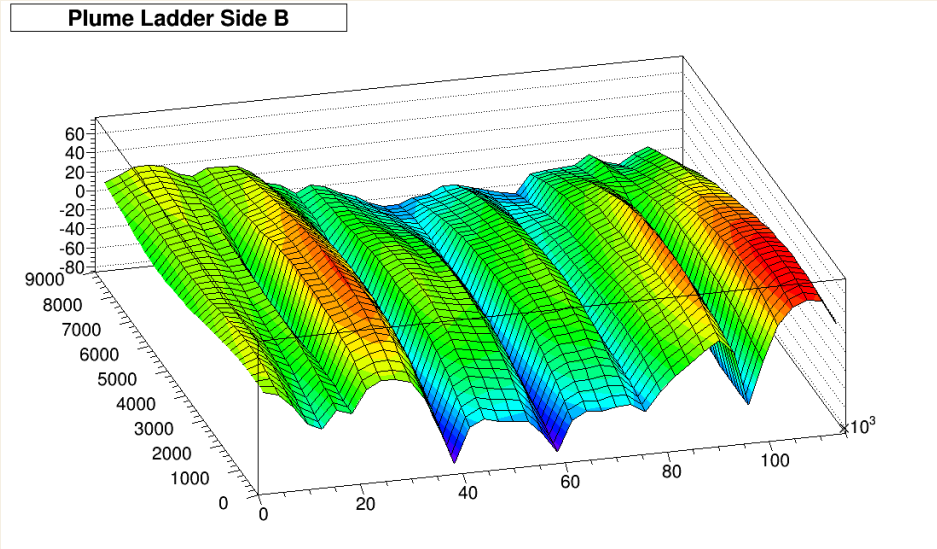
Origin of those deviations

Consequence of the ladder's characteristics

- Use of ultra-thin (thickness of 50 μm) and precise sensors (spatial resoluton less than 4 μm);
- mechanical constraints induce permanent deformation ($\simeq$ 10 μm) which can not be flatten when mounting the ladder.

Metrology of the module's surface (perfomed at Bristol)

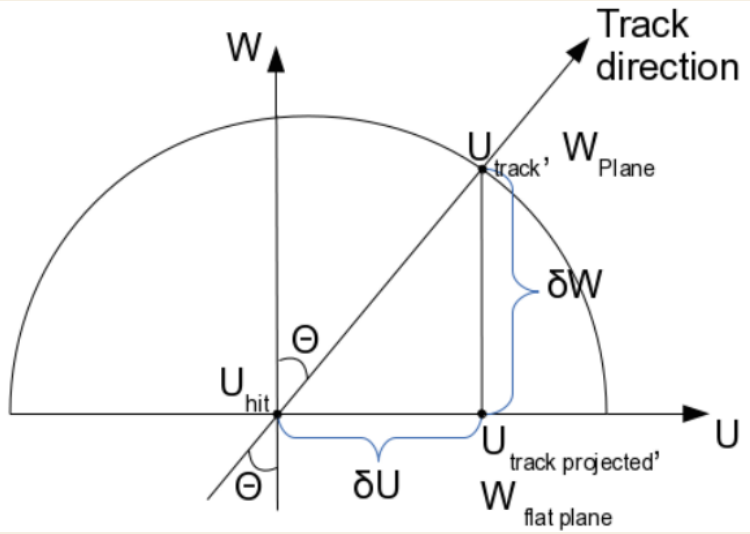




Origin of those devations

Artefact 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.



Deviation of the residual

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

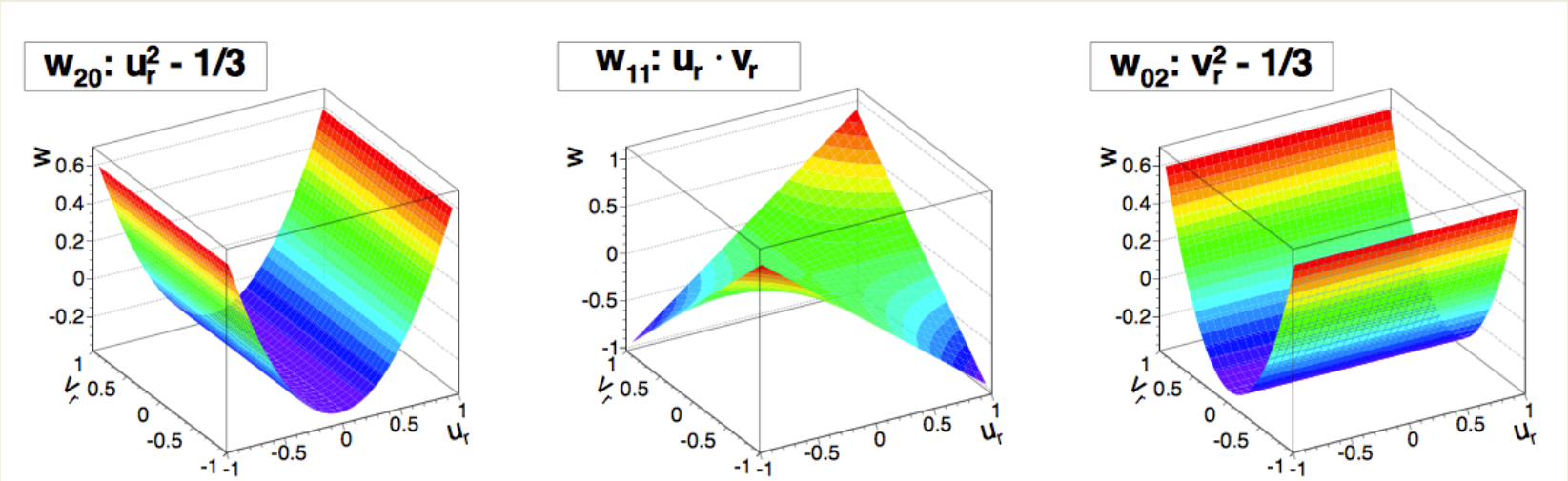
How to describe deviations from the flat plane?

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

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

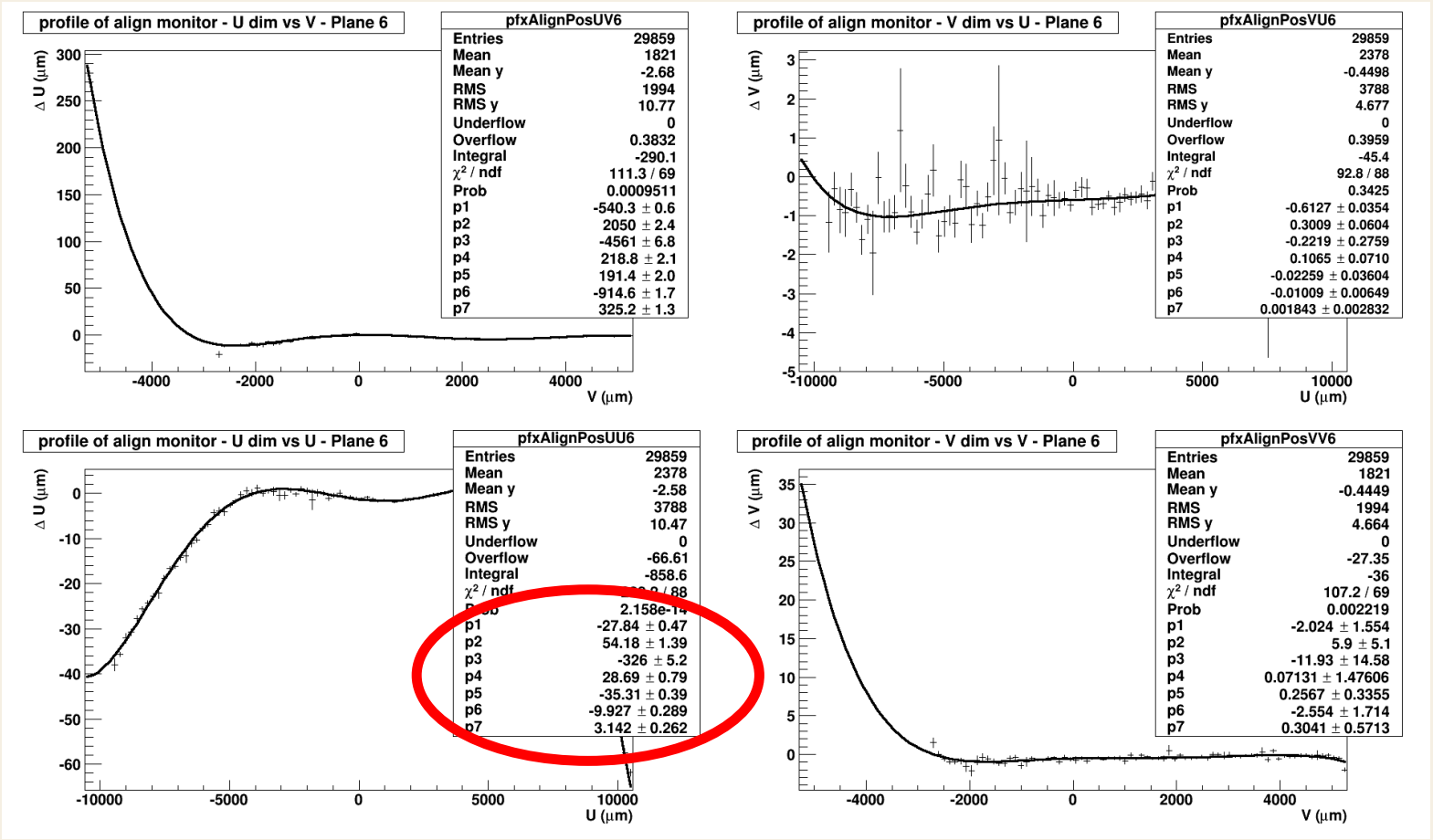
$$\begin{aligned} w(u_r, v_r) &= w \\ &+ w_{10} \cdot u_r + w_{01} \cdot v_r \\ &+ w_{20} \cdot (u_r^2 - 1/3) + w_{11} \cdot (u_r \cdot v_r) + w_{02} \cdot (v_r^2 - 1/3) \end{aligned}$$

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

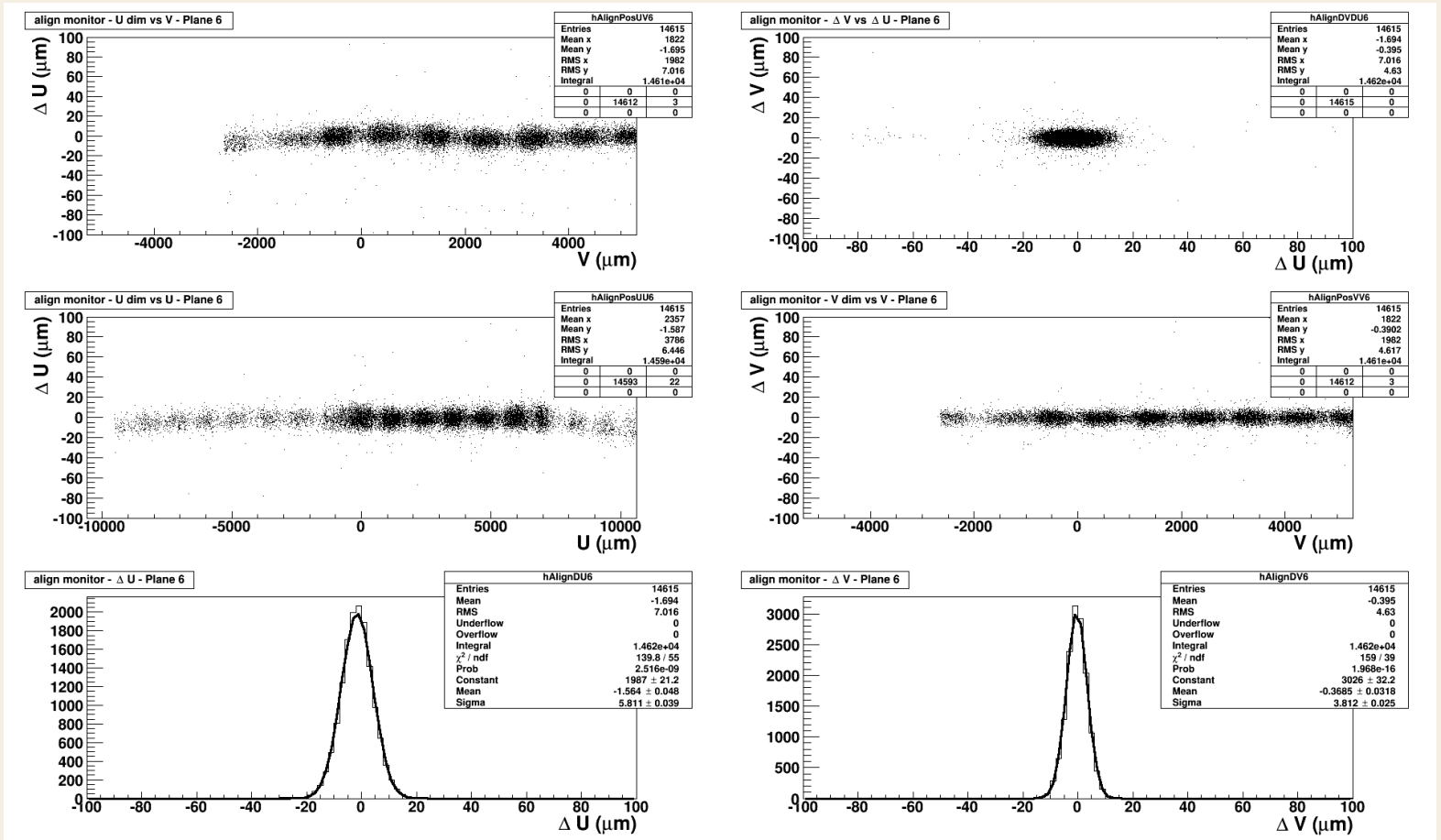


Parametrization of the deformation

Possibility to parametrize the deformation with Legendre polynomials of the 7^{th} order .



Correction of the deviation between real hit and extrapolated hit

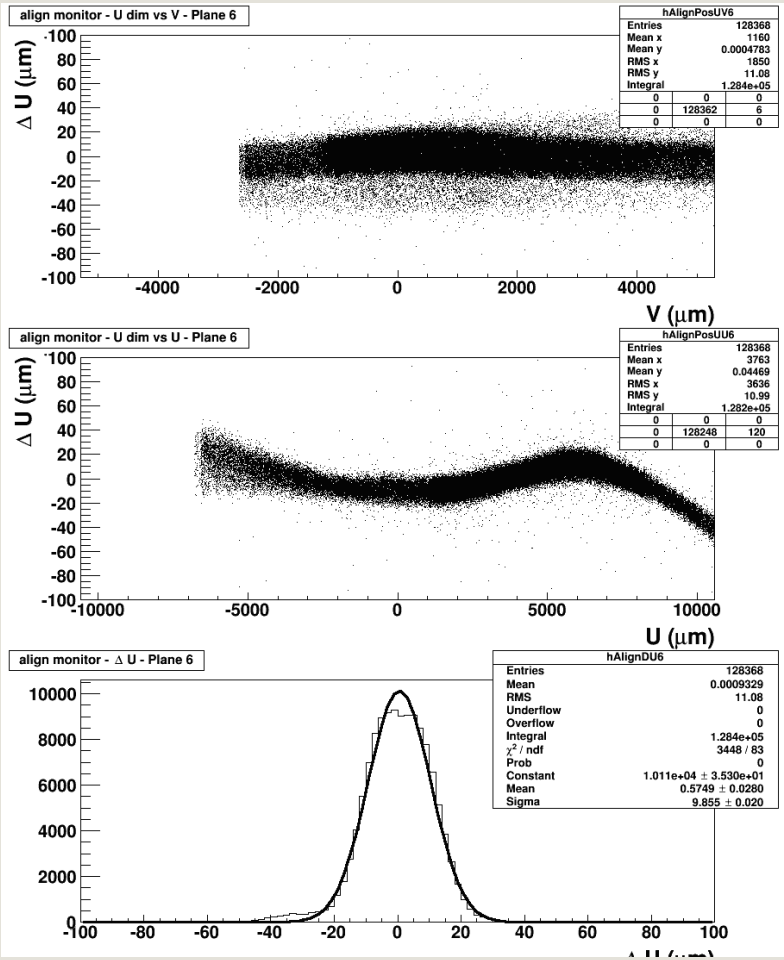


Spatial residual obtained after correction :
$\sigma_U \simeq 5.8\ \mu m$ *instead of* $\sigma_U \simeq 6.1\ \mu m$

Module tilted with an angle of 28°

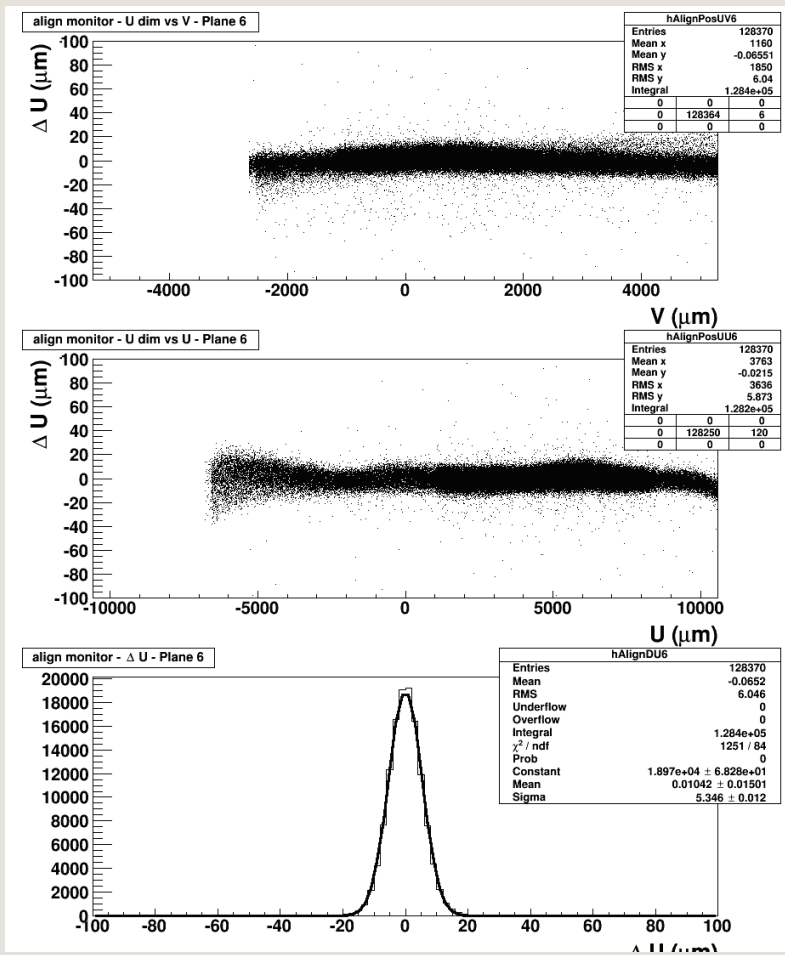
Threshold of 5 σ, fan speed of 6 m/s, 720k events.

Before correction



$\sigma = 9.855 \mu m$

After correction



$\sigma = 5.346 \mu m$

Summary of correction for different angles and same planes

Spatial residual

Run Number	Plane Num-ber	Fan speed (m/s)	Tilted angle	σ_U^{Def} (μm)	σ_U^{Cor} (μm)	σ_U^{DUT} (μm)
226020	6	3	28	9.586	5.568	5.115
226020	8	3	28	6.507	5.533	5.077
226025	6	6	28	8.781	4.841	4.312
226025	8	6	28	5.592	4.488	3.912
226026	6	3	36	13.43	6.4	6
226026	8	3	36	7.922	7.134	6.786
226071	6	3	60	41.19	25.81	17
226071	8	3	60	23.32	21.67	10.77

$\sigma_{tel} = 2.2 \mu m$ for $36°$ and $\sigma_{tel} = 18.8 \mu m$ for $60°$.

Summary and outlooks

Summary

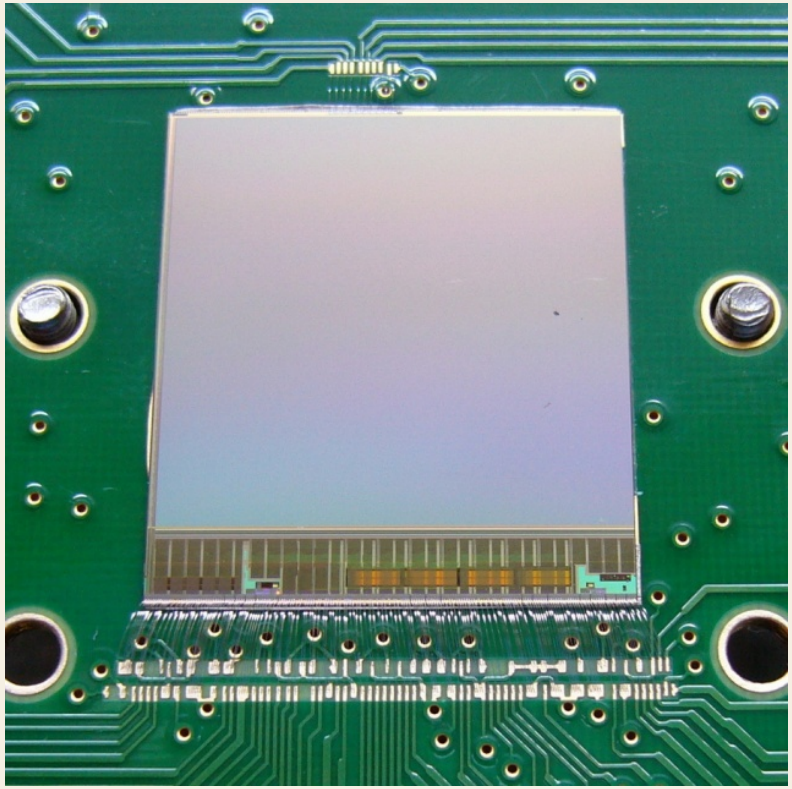
Parametrization of the residual as a function of the hit position on the plane by Legendre polynomials improves the spatial residual obtained.

Outlooks

- New version of the ladder with a reduced material budget is being produced;
- This new version will be tested $\Rightarrow$ will comparate results obtained with those I showed today.

Thanks for your attention !!!

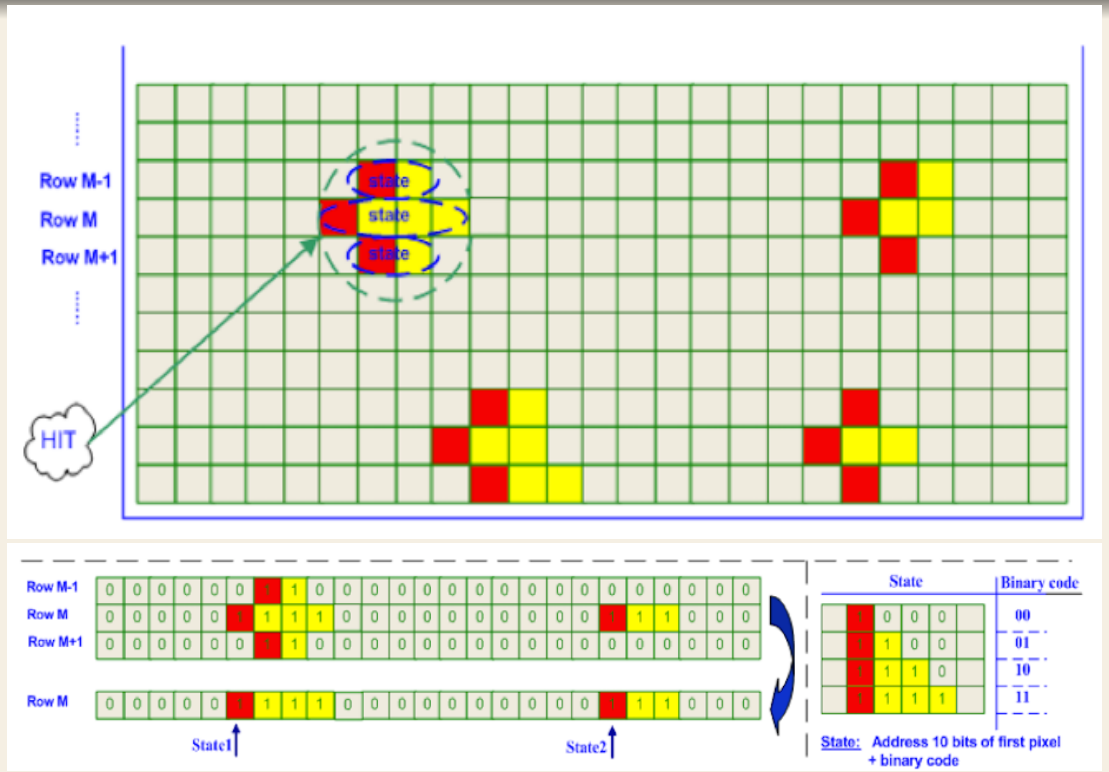
MIMOSA 28/ULTIMATE



CMOS sensors used for the PXL Detector @ STAR experiment

- Square pixels with a pitch of 20.7 μm
- Full reticle 960 x 928 pixels matrix;
- Integration time : 200 μs;
- Zero suppression with binary output;
- Space resolution < 10 μm;
- Power consumption : 150 mW/cm^2.

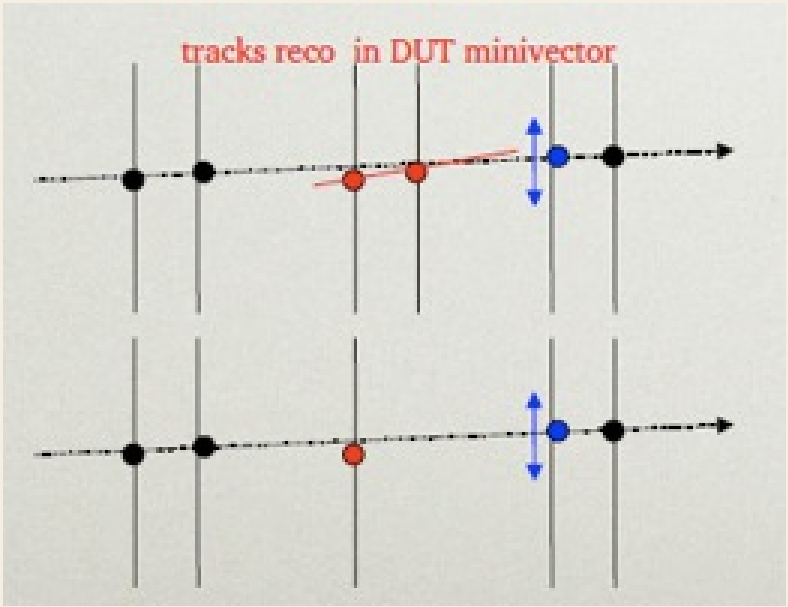
Zero Suppression logic (SUZE)



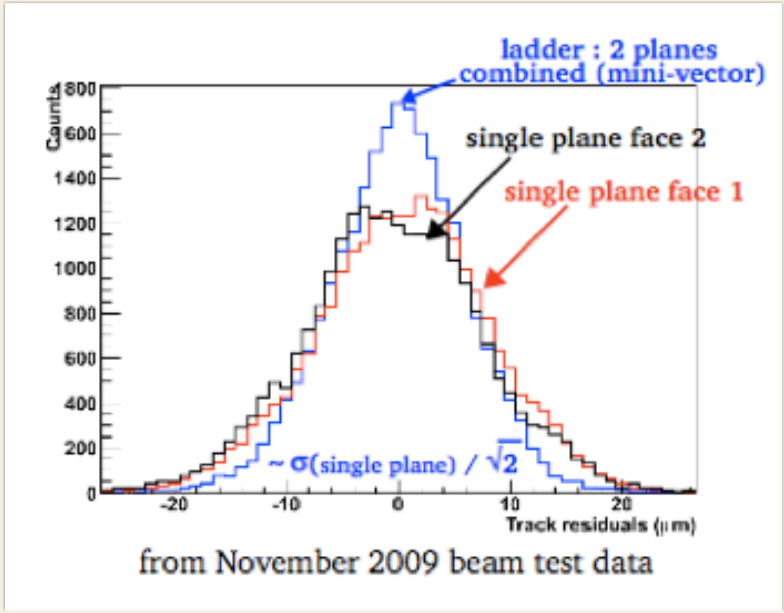
SUZE logic split in 3 blocks :

- **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).

Mini-vectors



Two hits on double sided ladder can be correlated and used to reconstruct a mini-vector.



Beam test data : mini-vectors have better resolution than single plane (20-30 %).

Spatial resolution for different pitch (IPHC-Strasbourg)