Towards a 10 μs, thin high resolution pixelated CMOS sensor system for future vertex detectors

Rita De Masi

IPHC-Strasbourg

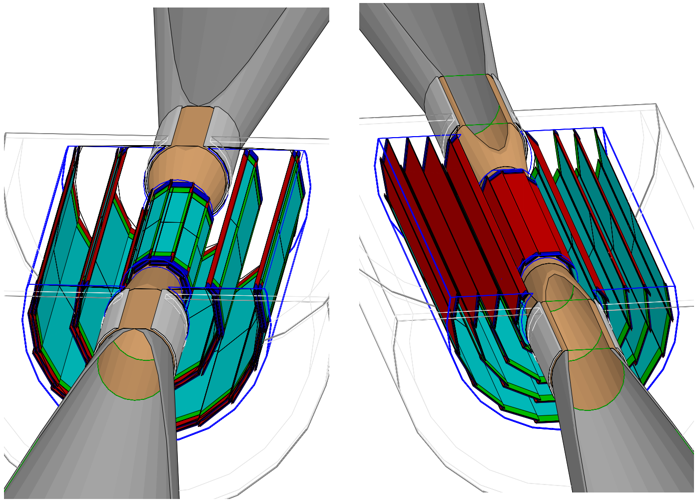
On behalf of the IPHC-IRFU collaboration

- Physics motivations.
- Principle of operation and performances.
- MIMOSA-26 and its applications.
- System integration.
- Developments.
- Summary and conclusions.

A vertex detector for the ILC

<u>Two alternative geometries</u>

- 5 single-sided layers.
- 3 double-sided layers.



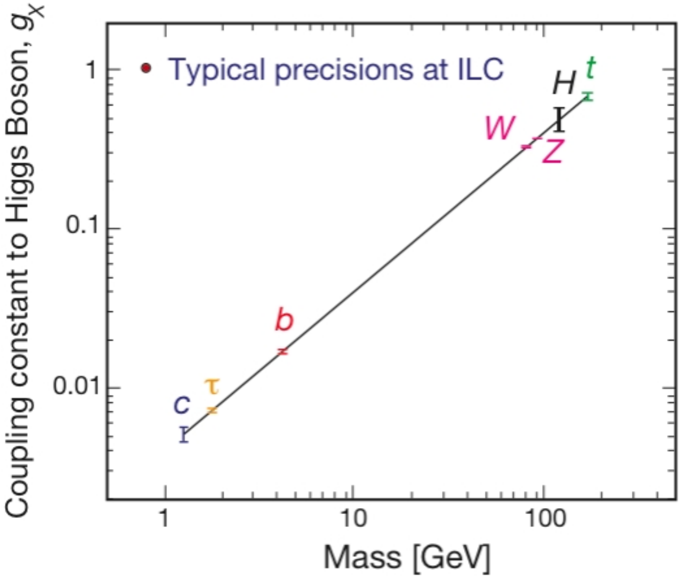
<u>Sensor requirements</u>

- Single point resolution ~ 3μm.
- Material budget 0.16/0.11% X_0/layer.
- Integration time 25 – 100 μs.
- Radiation tolerance ~0.3MRad, few $10^{11} n_{eq}/cm^2$.
- Averaged power dissipated << 100 W.

$$\sigma_{IP} = a \oplus b/p\sin^{3/2}\theta$$

$a \leq 5\mu m$, $b \leq 10\mu m$ GeV

($a = 12\mu m$, $b = 70\mu m$ GeV @ LHC)



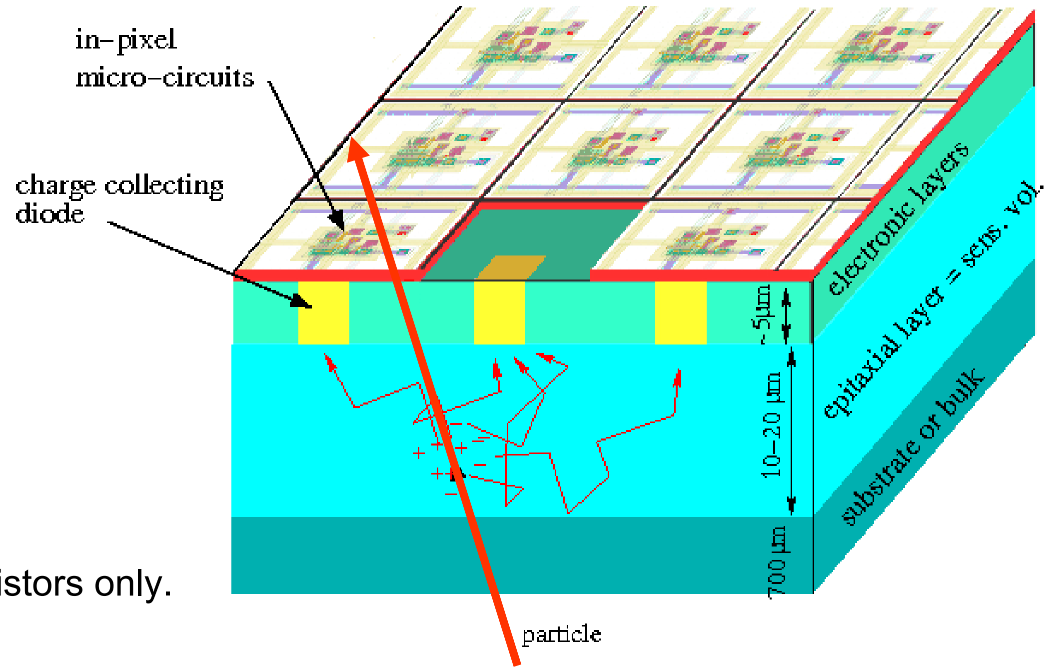
CMOS sensor principle

Signal collection

- Charges generated in epitaxial layer → ~1000 e^- for MIP.
- Charge carriers propagate thermally.
- In-pixel charge to signal conversion.

Advantages

- High granularity.
- Thickness (~O(50μm)).
- Integrated signal processing.

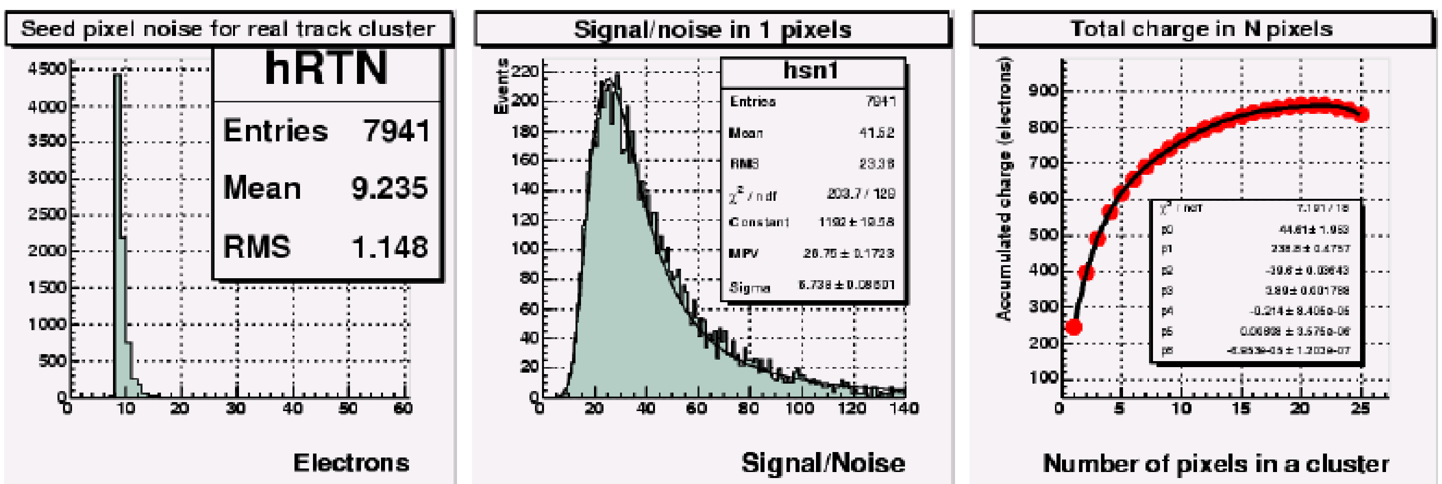


Issues

- Undepleted volume limitations .
  - radiation tolerance.
  - intrinsic speed.
- Small signal O(100e^-)/pixel.
- In-pixel μ-circuits with NMOS transistors only.

Basic performances

- More than 30 different sensors designed, fabricated and tested (lab & beam).
- Extensive use of 0.35μm CMOS technology.
- Room temperature operation.
- Noise ~10-15e^-.
- S/N ~ 15-30.
- Detection efficiency ~100% @ fake hit rate O(10^{-4} -10^{-5}).
- Radiation tol. > 1MRad and $10^{13} n_{eq}/cm^2$ with 10μm pitch (2x$10^{12} n_{eq}/cm^2$ with 20μm pitch).
- Spatial resolution 1-5 μm (pitch and charge-encoding dependent).
- Macroscopic sensors (Ex. MIMOSA-5: 1.7 x 1.7 mm^2, 10^6 pixels).
- Used in beam telescopes and VTX demonstrators (EUDET, TAPI, STAR, CBM).

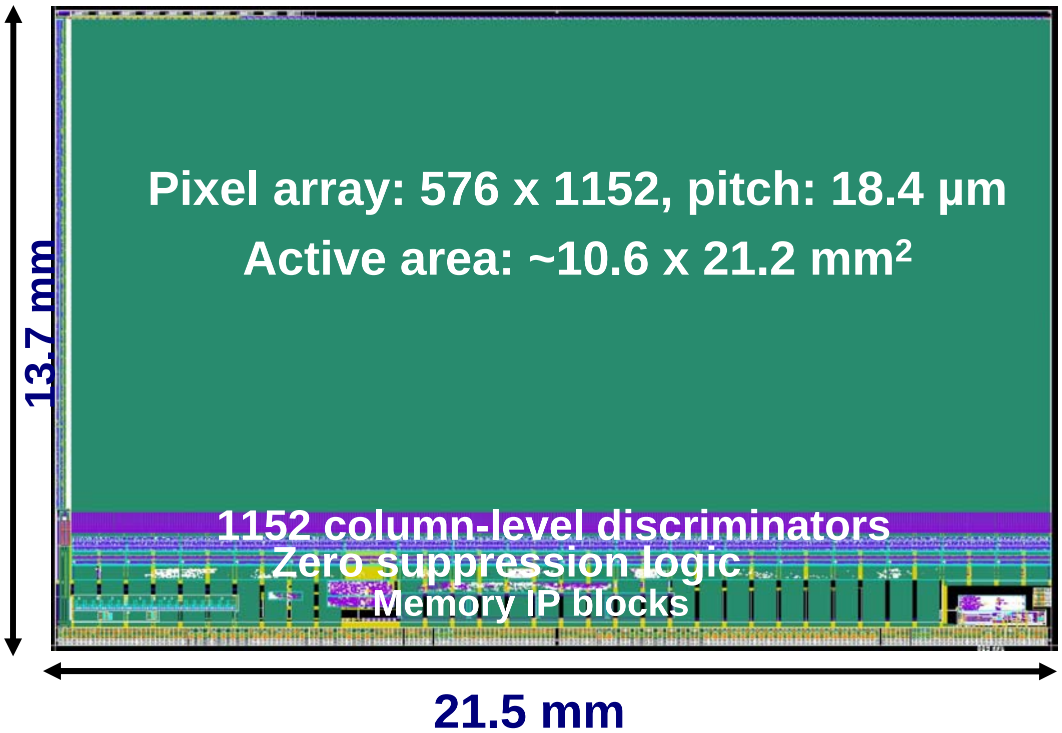


Mimosa-26

Fast full scale sensors: ~10kFrame/s

column parallel architecture + integrated zero-suppression

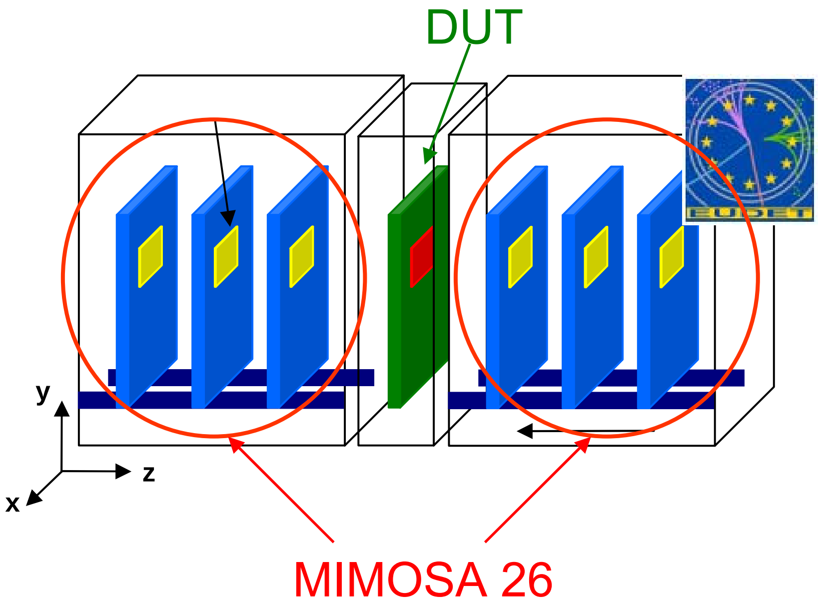
(prototyping with MIMOSA-22 for binary output + SUZE-01 for ∅)



- Active area ~2 cm^2.
- 0.35 μm technology.
- Binary output (3.5 - 4 μm spatial resolution).
- In-pixel CDS + preamp.
- Column level discrimination.
- Power dissipated ~280 mW/cm^2 (rolling shutter).
- Integration time ~100μs.

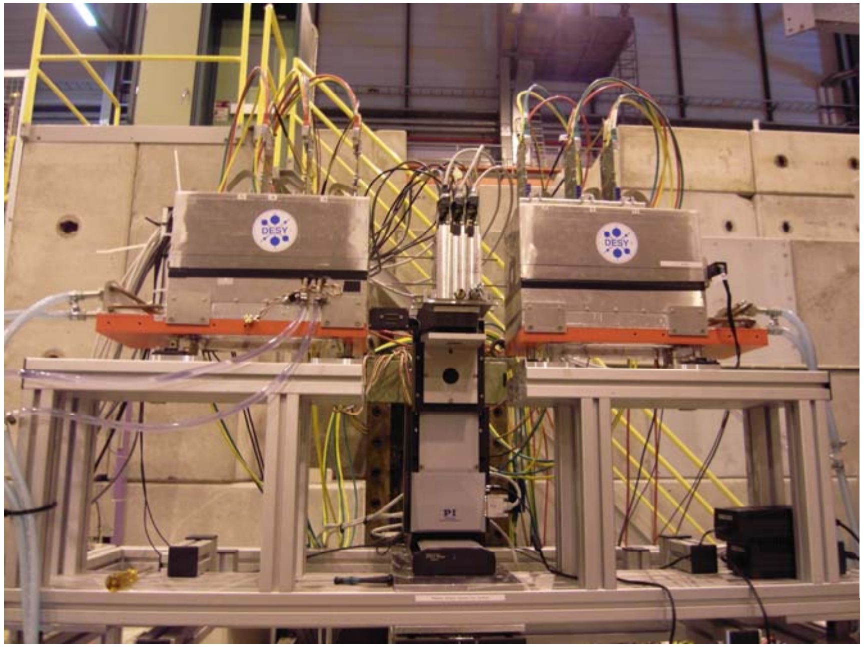
It was tested extensively in the laboratory: performances as expected

EUDET beam telescope



<u>Reference planes of EUDET Beam Telescope</u>

- Supported by EU FP6.
- Infrastructure to support the ILC detector R&D.
- Specifications:
    - Extrapolated resolution <2 μm.
    - Sensor area ~2 cm^2.
    - Read-out speed ~ 10 kframe/s.
    - Up to 10^6 hits/s/cm^2.



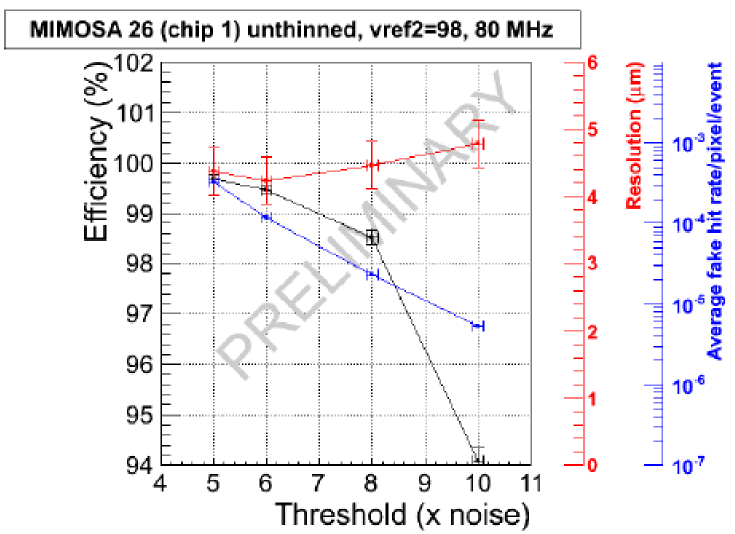
<u>Commissioning @ CERN-SPS last year:</u>

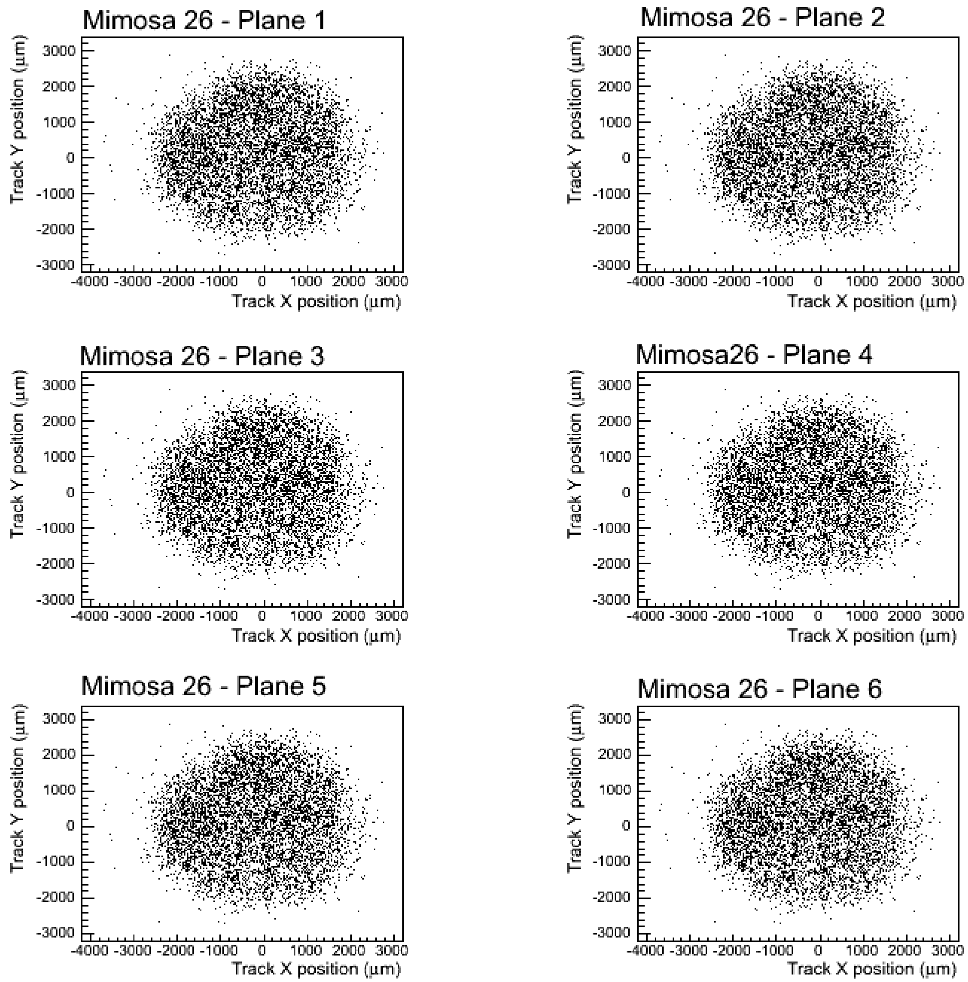
- BT completely equipped with MIMOSA-26.
- Residuals compatible with σ = 4μm.

www.eudet.org

Preliminary beam test results

- TAPI = IPHC-Strasbourg BT for MIMOSA development.
- Test @ CERN-SPS (120 GeV π^- beam).
- 6 MIMOSA-26 sensors running simultaneously at nominal speed (80 MHz).
- 3 x 10^6 triggers.

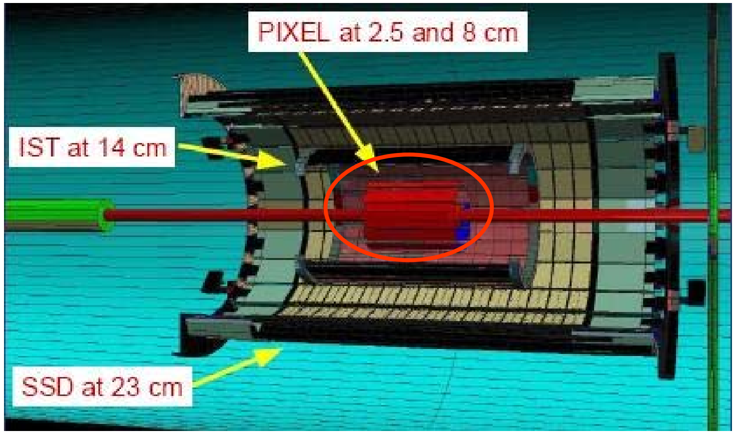




ε = 99.5 ± 0.1 (stat.) ± 0.3 (prel.) %

@ fake hit rate O(10^{-4})

Mimosa-26 architecture: evolutions

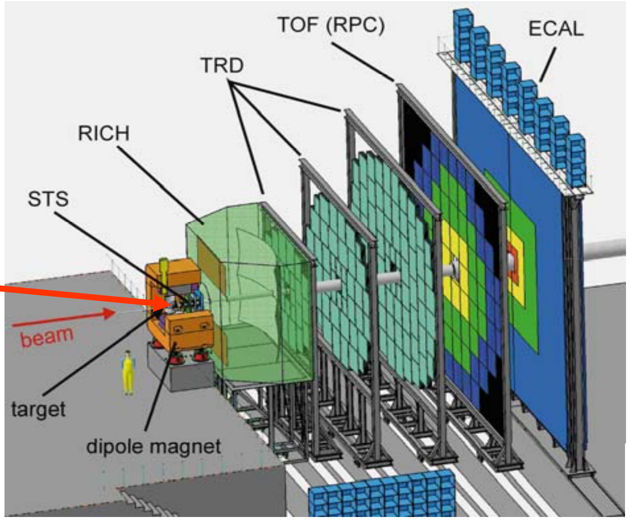


STAR @ RHIC Heavy Flavour Tracker

- 1152 x 1024 pixels; 200μs integration time.
- Improved radiation tolerance.
- Submission late 2010.
- First data in 2013.

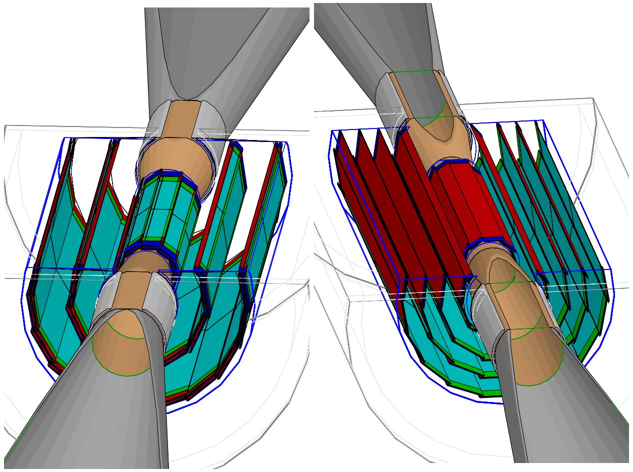
CBM @ FAIR Micro Vertex Detector

- Double sided readout.
- 0.18 μm (40$\rightarrow$20μs integration time).
- Prototyping until 2012.



Interest expressed by the ALICE collaboration for the upgrade in view of sLHC

The ILD applications



Physics requirements

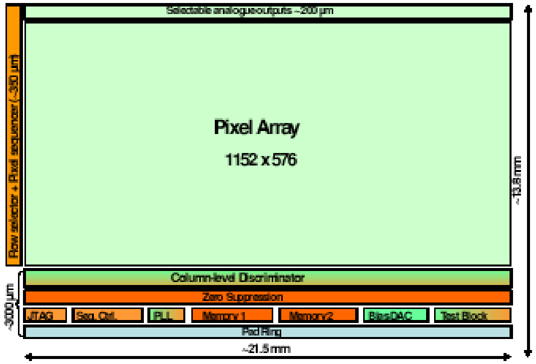
- single point resolution ~ 3μm.
- integration time 25 – 100 μs.
- …

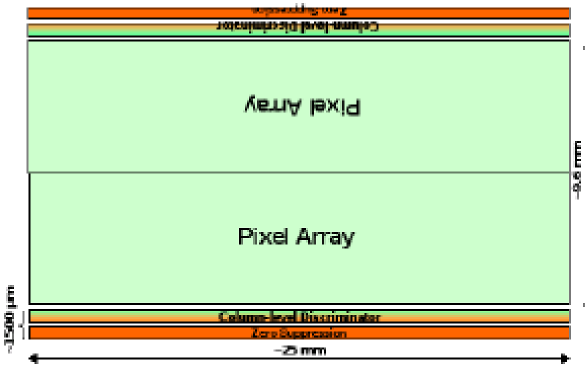
Extension for the outer VTX layers:

- σ ~ 3 μm: 4-5 bits ADC and a ~ 35 μm pitch (r.o. ~100 μs).

For the inner layers:

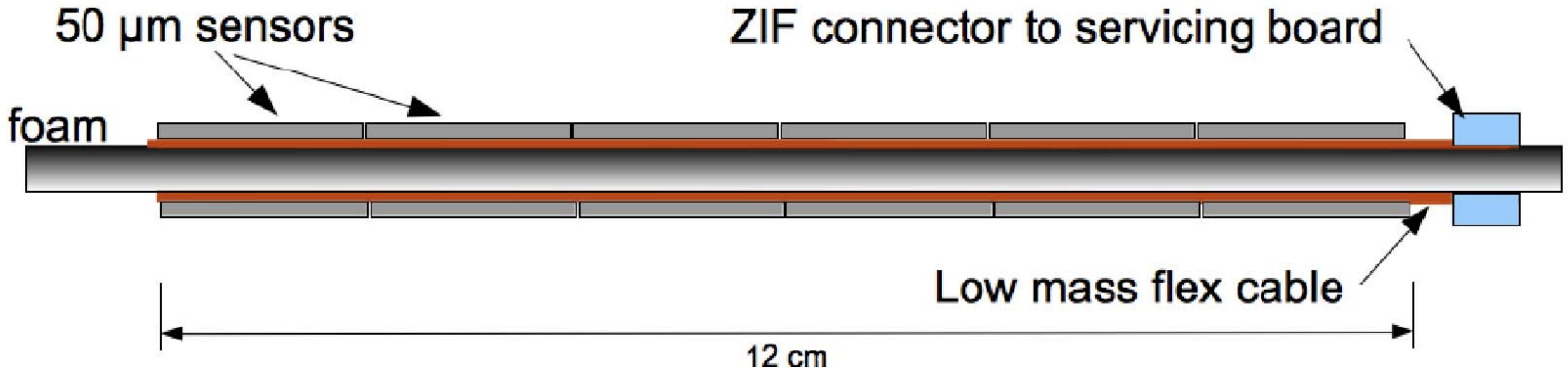
- ~ 15 μm pitch → binary readout.
- Double-sided r.o. → r.o. ~ 50 μs.
- Smaller feature size → 35 – 40 μs.
- Double sided ladders → << 35 μs.





System integration: the PLUME project

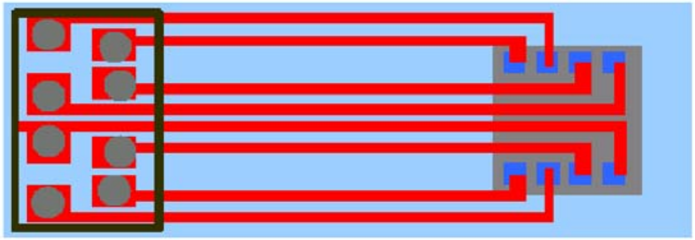
- **P**ixel **L**adder with **U**ltra-low **M**aterial **E**mbedding.
- Bristol - DESY - Oxford - Strasbourg.
- Double sided ladder equipped with 2x6 MIMOSA-26 (ILC DBD 2012).
- 0.2 - 0.3 % X_0.
- Explore feasibility, performances and added value of double-sided ladders.
- Allows for improved time resolution (outer layer with longer and fewer pixels).
- First prototype (reduced scale) tested at CERN-SPS last November.
- Double sided ladder prototype expected in 2012.
- Use of infrastructures foreseen in AIDA (FP7 project in preparation).



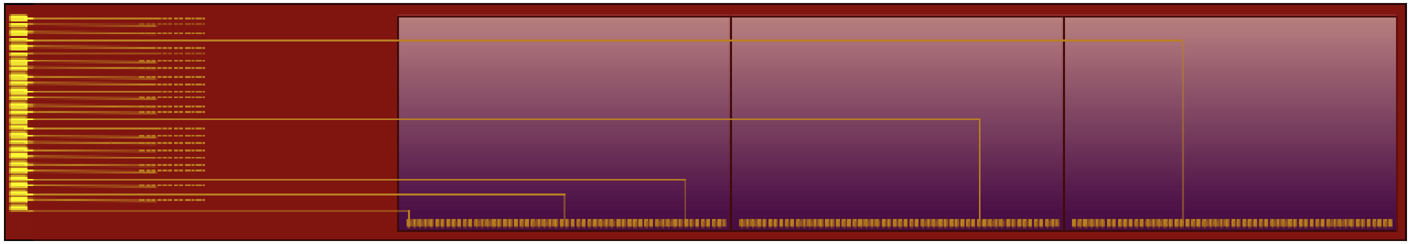
System integration: SERWIETE

- **SE**nsor **R**ow **W**rapped **I**n **E**xtra-**T**hin **E**nvelope (HP 2 Project).
- Frankfurt – Darmstadt – Strasbourg.
- Sensors wrapped in thin polymerised film.
- <0.15% X_0 expected for sensor (35 μm thin) $\oplus$ flex $\oplus$ film (no mechanical support).
- May match cylindrical surfaces.
- Proof of principle in 2012.

Proto 1 ▷ Spring 2010



Proto 2 ▷ Summer 2011



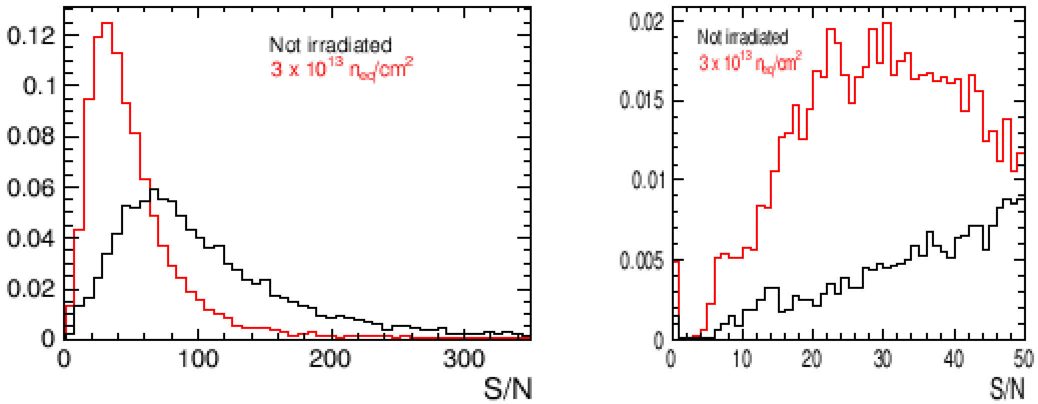
Further developments: high resistivity epi layer

High resistivity epitaxial layer ($O(10^3)\ \Omega\cdot cm$) $\Rightarrow$ depleted sensitive volume!

- Faster readout.
- Improved radiation tolerance.

Exploration of the technology: MIMOSA-25 (0.6 μm)

- Fabricated in 2008 and tested at CERN-SPS before and after irradiation.
- Cluster size ~ 2×2 pixels (3×3 for low resistivity epi-layer).
- S/N ~ 60 for seed (20-25 for low resistivity epi-layer - ~ 30 @ $3 \cdot 10^{13} n_{eq}/cm^2$).
- ε = 99.9% (99.5% @ $3 \cdot 10^{13} n_{eq}/cm^2$).
- Improved tolerance to non-ionizing radiation (1-2 OoM).

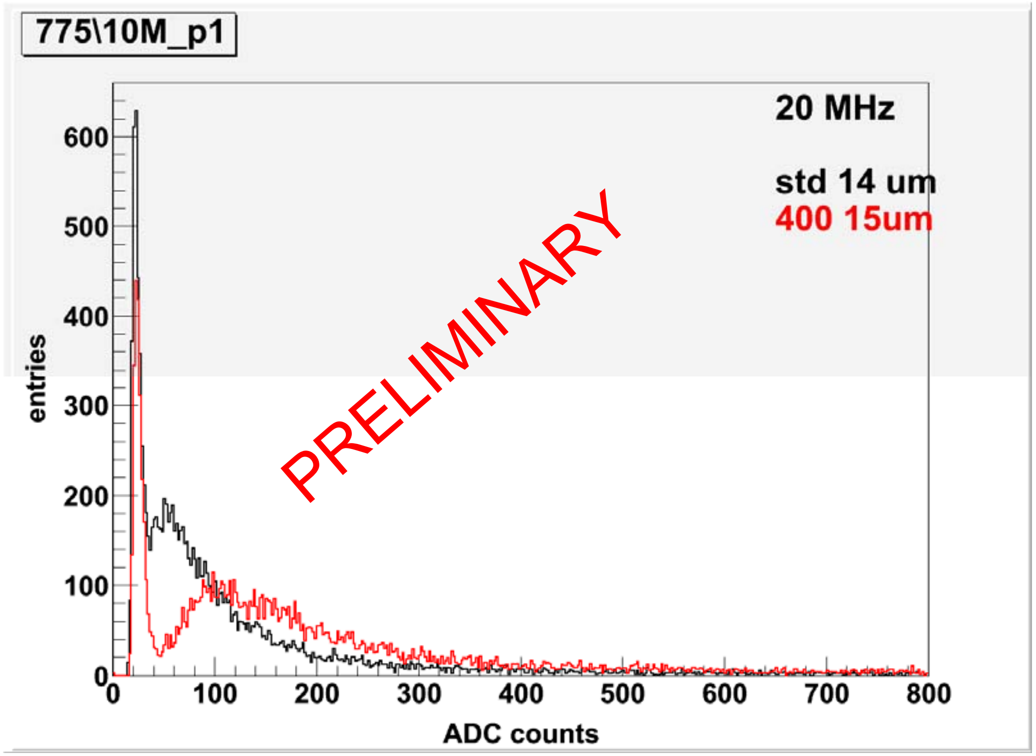


New VDSM technology under study in collaboration with CERN for sLHC

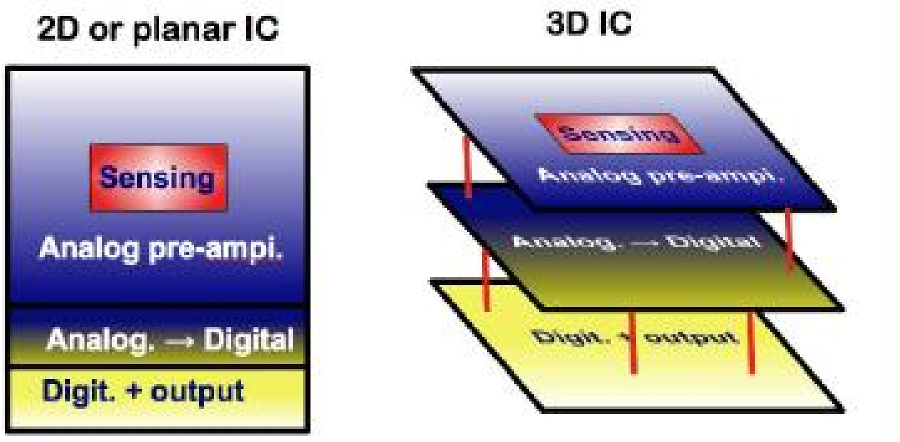
MIMOSA-26 with high resistivity epi layer

NEW!

MIMOSA-26 high res.(400 Ω·cm) 0.35 μm presently under test (for STAR-HFT)



Further developments: 3D



<u>Benefits:</u>

- Increase integrated processing.
- 100% sensitive area.
- Select best process per layer task.

<u>To be assessed:</u>

- Material budget?
- Power dissipation?

<u>Example</u>

- Tier1: charge collection.
- Tier2: analog signal processing.
- Tier3: digital signal processing.
- Tier4: data transfer.

FNAL + IN2P3 + INFN + … consortium (3DIC)

First chips (2-Tier 130nm technology) being fabricated

Summary and future perspectives

Current CMOS sensors

- Mature technology for real scale applications.
- High resolution, very low material budget.

First full scale sensor with high read-out speed: MIMOSA-26.

- Binary output + integrated zero-suppression.
- Tested in laboratory and on beam.
- EUDET-BT, STAR-HFT, ALICE tracker, CBM-MVD, ILD-VTX (option).

System integration studies started: PLUME, SERWIETE, …. ➔ Material budget << 0.5 % X_0

New perspectives

Depleted sensitive volume:

- Technology prototyped with MIMOSA-25.
- MIMOSA-26 high res. under test.
- Expectations: fast charge collection and non ionizing radiation tolerance > $10^{14} n_{eq}/cm^2$.

3D integration technology:

- 4 CAIRN prototypes being produced (low power, few μs r.o., delayed readout with timestamp).
- Heterogeneous chip (depleted sensitive volume).

More information on

http://www.iphc.cnrs.fr/-CMOS-ILC-.html