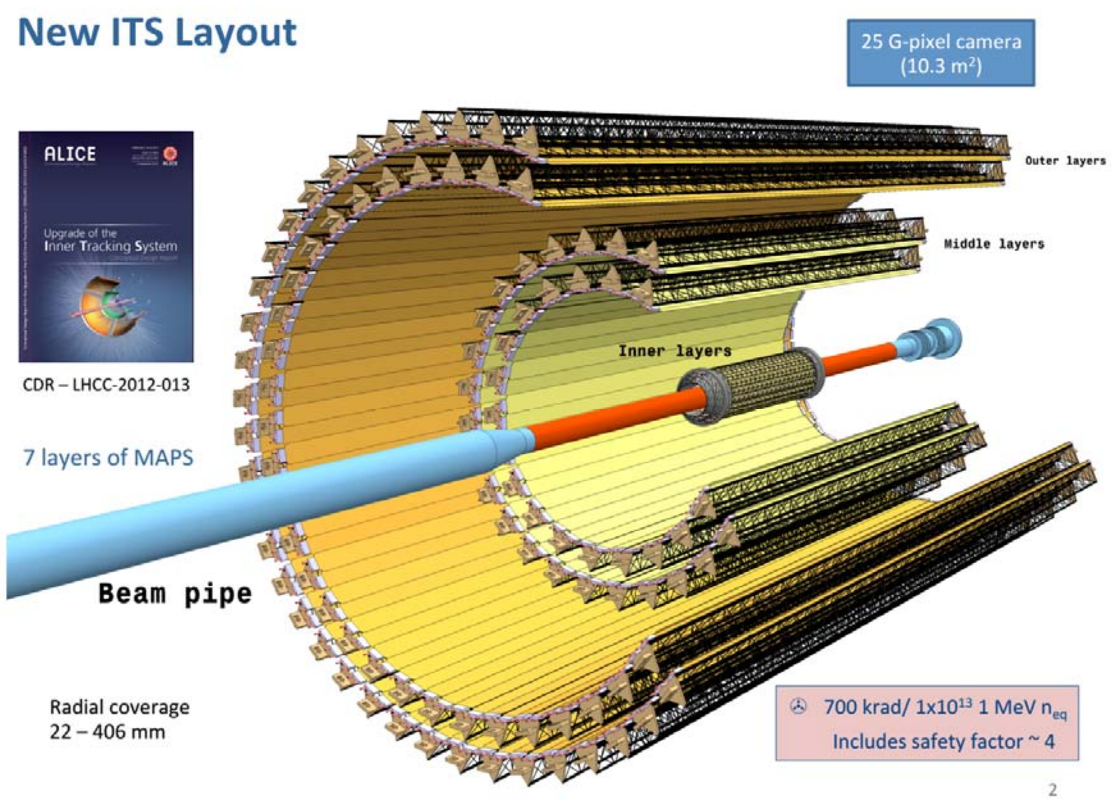
Development of MISTRAL & ASTRAL Sensors for the Upgrade of the Inner Tracker System of the ALICE experiment at LHC

Christine Hu-Guo (on behalf of PICSEL-ALICE team of IPHC-Strasbourg)



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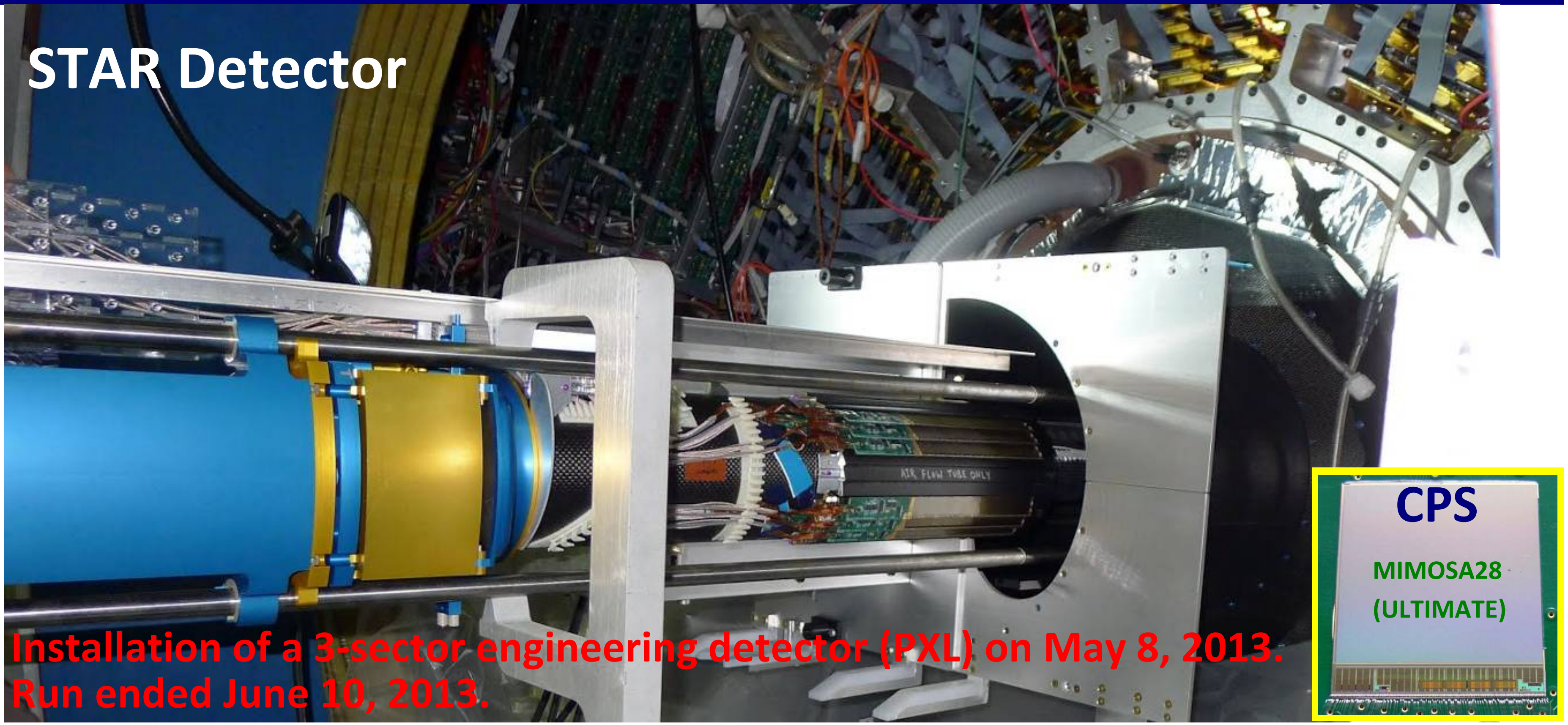


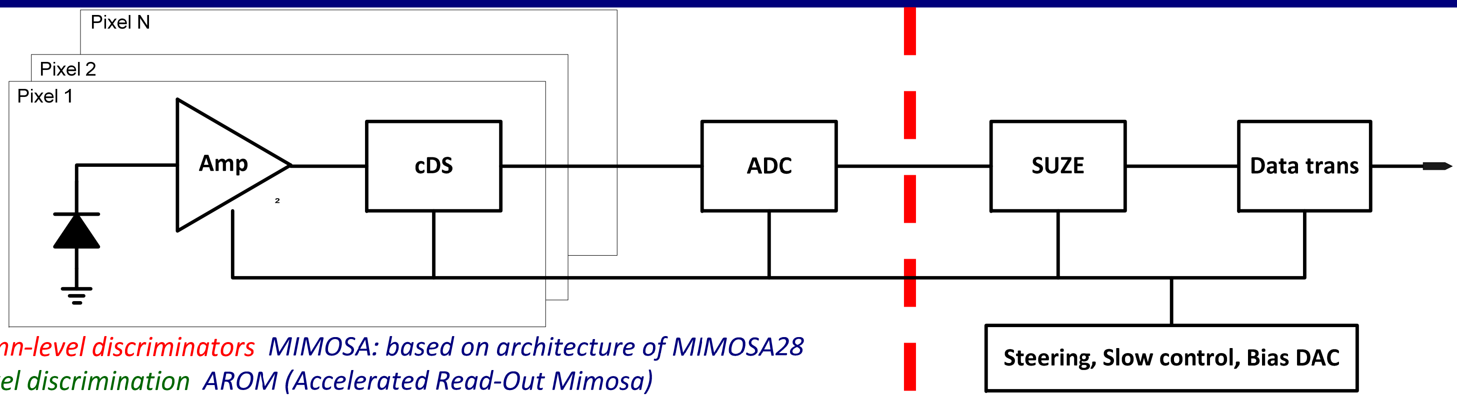
Towards Higher Read-Out Speed and Radiation Tolerance

- *Next generation of experiments calls for improved sensor performances:*

Expt-System	σ_t	σ_{sp}	*TID*	*Fluence*	T_{op}
STAR-PXL	***<~ 200 µs***	***~ 5 µm***	***150 kRad***	***$3x10^{12}$ n_{eq}/cm^2***	***30 °C***
	⬇ ?		⬇ ?	⬇ ?	
ALICE-ITS	***10-30 µs***	***~ 5 µm***	***700 kRad***	***10^{13} n_{eq}/cm^2***	***30 °C***
CBM-MVD	*10-30 µs*	*~ 5 µm*	*<~10 MRad*	*<~ 10^{14} n_{eq}/cm^2*	*<<0 °C*
ILD-VXD	*<~2 µs*	*<~ 3 µm*	*O(100) kRad*	*O(10^{11} n_{eq}/cm^2)*	*<~30 °C*

- *Main improvements required while remaining inside the virtuous circle of spatial resolution, speed, material budget, radiation tolerance ➔ move to* ***0.18*** *µm process*
  - *For aim of higher radiation tolerance*
    - *High resistivity epitaxial layer*
    - *Smaller feature size process*
  - *For aim of high readout speed*
    - *More parallelised read-out*
    - *Optimise number of pixels per column*
    - *New pixel array architectures*
    - *Smaller feature size process*

Sensors R&D for the upgrade of the ITS: Our Strategy



- *Column-level discriminators MIMOSA: based on architecture of MIMOSA28*
- *In-pixel discrimination AROM (Accelerated Read-Out Mimosa)*

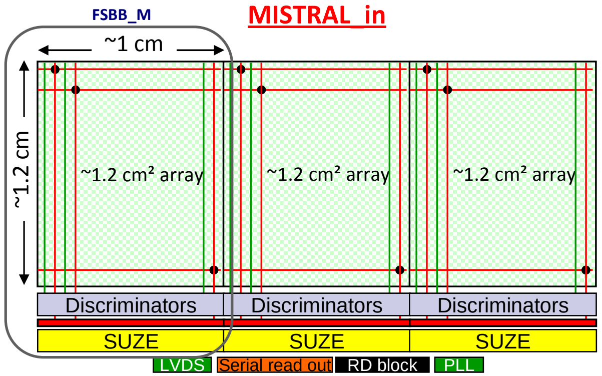
➔ *2 rows read out at once in a Rolling shutter mode*

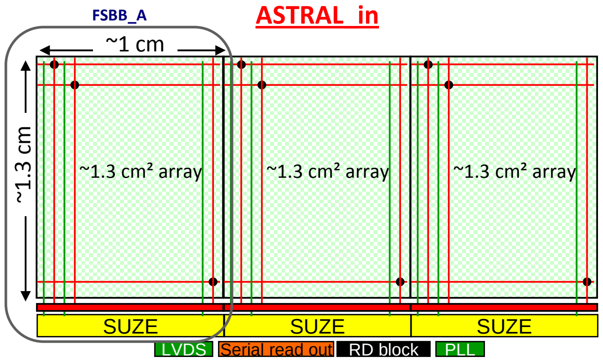
Upstream ← → **Downstream**

- *R&D of up- & down-stream of sensors performed in parallel at IPHC in order to match the ITS timescale*

for 2 final sensors (~3x1 cm²)

- *Mature architecture: MISTRAL* = ***MI****MOSA* ***S****ensor for the inner* ***TR****acker of* ***AL****ICE*
  - *Relatively low readout speed (200 ns/ 2rows)*
    - *~ 200 mW/cm² for inner layers*
- *Promising architecture: ASTRAL* = ***A****ROM* ***S****ensor for the inner* ***TR****acker of* ***AL****ICE*
  - *Higher speed (100 ns/ 2rows) + Lower power*
    - ***~ 85 mW/cm² for inner layers, ~ 30-60 mW/cm² for outer layers***

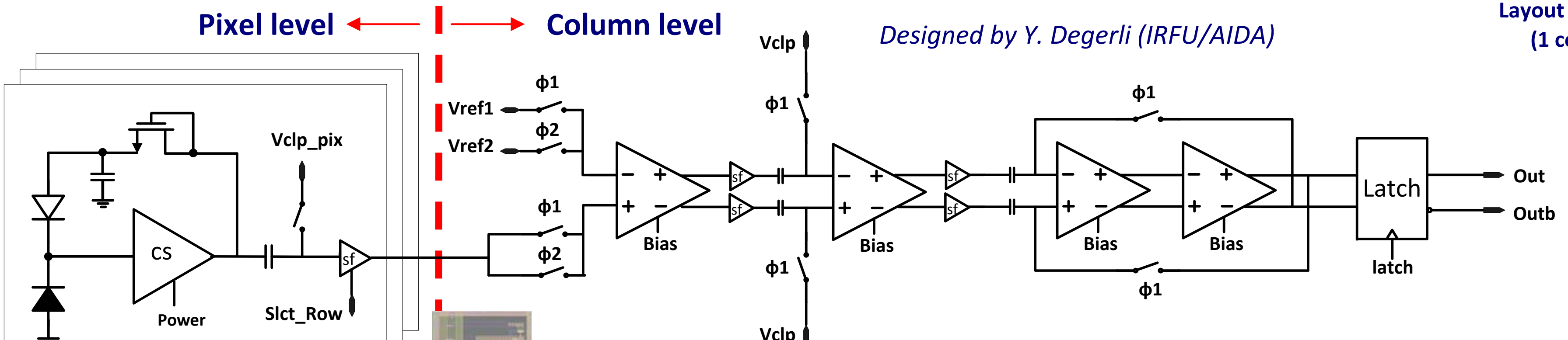


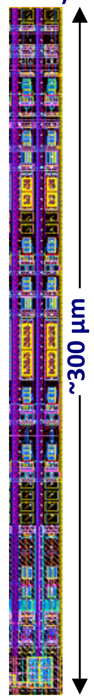


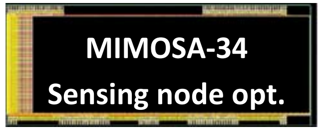
- *Modular design + reused parts* ➔ *optimising R&D time*
- *Several groups involved in the ITS design*

  ➔ *see T. Kugathasan's & H. Hillemanns' (CERN) talk in this conference*

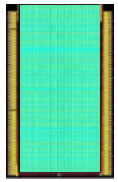
Upstream of MISTRAL Sensor



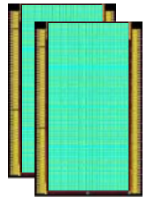




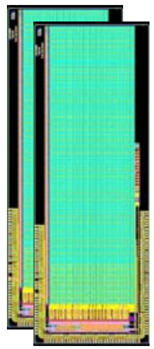
- *Pixel level:*
  - *Sensing node: N_{well}-P_{EPI} diode*
    - *Optimisation ƒ(diode size, shape, No. of diodes/pixel, pixel pitches, EPI)*
  - *In-pixel amplification and cDS:*
    - *Limited dynamic range (supply 1.8 V) compared to the previous process (3.3 V)*
    - *Noise optimisation especially for random telegraph signal (RTS) noise*
      - *Sensing diode: avoid STI around N-well diode*
      - *RO circuit: avoid using minimum dimensions for key MOS & avoid STI interface*
      - ➔ *Trade off between diode size, input MOS size w.r.t. S/N before and after irradiation*
- *Column level:*
  - *Discriminator: similar schematic as in MIMOSA26 & 28*
    - *Offset compensated amplifier stage + DS (double sampling)*
    - *200 ns per conversion*
  - *Read out 2 rows simultaneously ➔ 2 discriminators per column (22 µm)*



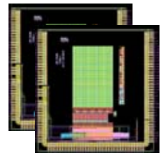
MIMOSA-32FEE
Amp opt.



MIMOSA-32N
RTS opt.



MIMOSA-22THRA1&2
Chain opt. => 1 D/col

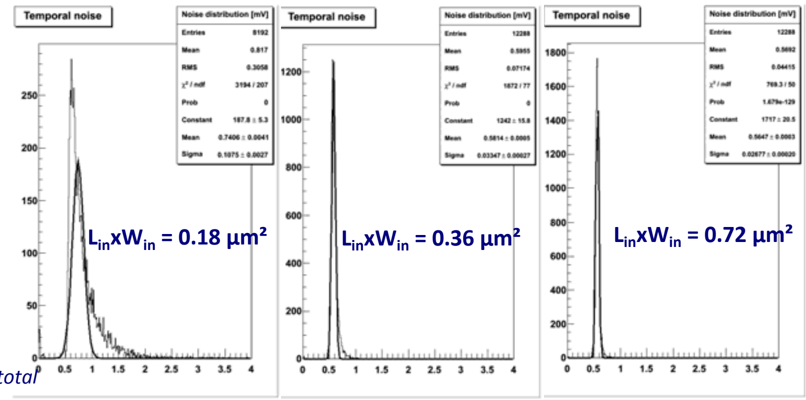


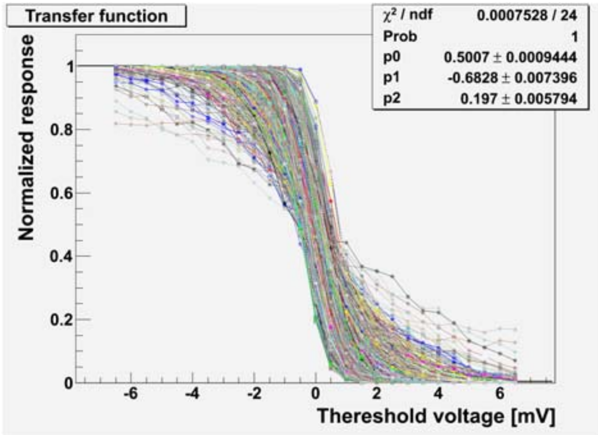
MIMOSA-22THRB
Chain opt. => 2 D/col

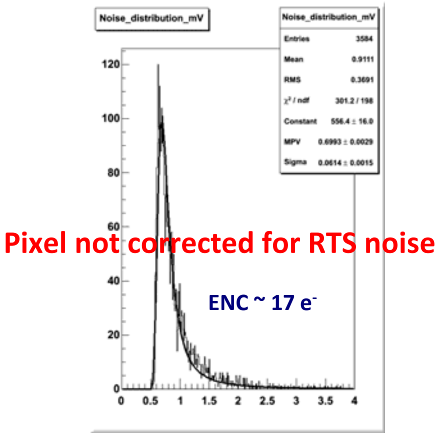
Test Results of the Upstream of MISTRAL Sensor

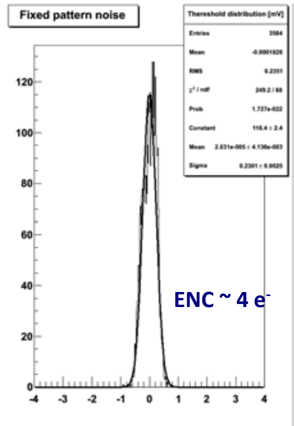
- *Lab test results @ 30 °C (MIMOSA22-THRA1 & 2, MIMOSA22-THRB) :*
  - *Diode optimisation ➔ see M. Winter's talk in this conference*
    - *CCE optimisation: surface diode of 8-11 µm² (22x33 µm²)*
  - *In-pixel amplification optimisation*
    - *Reduction of RTS noise by a factor of 10 to 100*
  - *MISTRAL RO Architecture: (single & double raw RO)*
    - *2-row RO increases FPN by ~1 e^- ENC ➔ negligible impact on ENC_{total}*

    ➔ Design of the upstream of MISTRAL validated



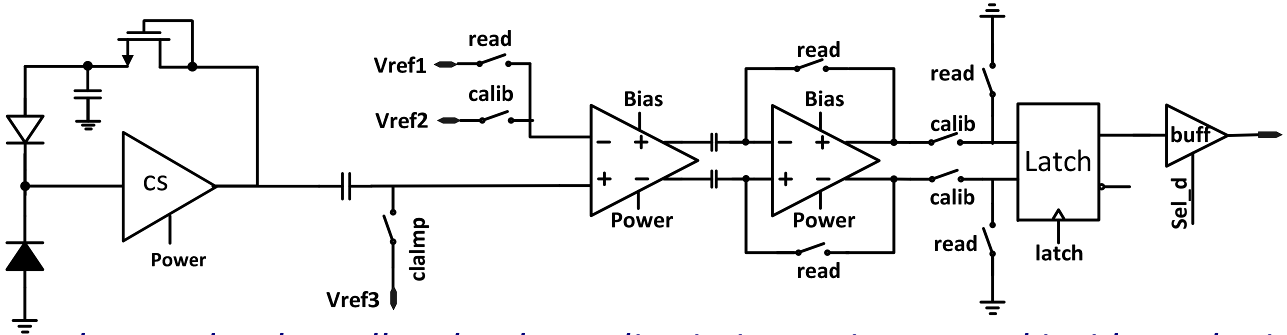


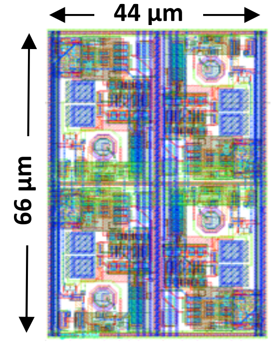




- *Beam test results (DESY): ➔ see M. Winter's (IPHC) talk in this conference*
  - *SNR for MIMOSA-22THRA closed to 34*
    - *8 µm² diode features nearly 20 % higher SNR (MPV)*
  - *Detection efficiency ≥ 99.8% while Fake hit ratio ≤ $O(10^{-5})$*
  - *22×33 µm² binary pixel resolution: ~5 µm as expected from former studies*
  - *Ionisation radiation tolerance assessment under way*

Upstream of ASTRAL sensor

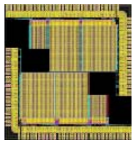


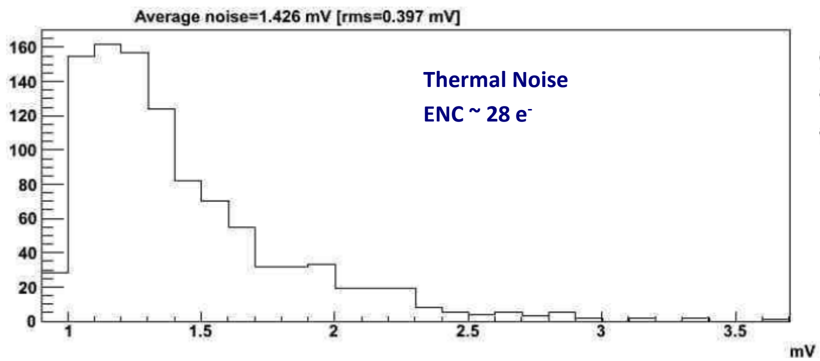


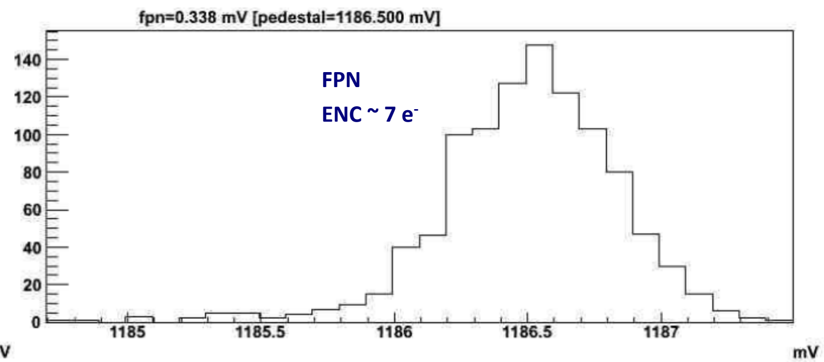
2x2 pixels

- *Thanks to the quadruple-well technology, discriminator integrated inside each pixel*
  - *Analogue buffer driving the long distance column line is no longer needed*
    - *Static current consumption reduced from ~120 µA to ~14 µA per pixel*
  - *Readout time per row can be halved down to 100 ns (2 rows at once) due to small local parasitic*
- *Sensing node & in-pixel pre-amplification as in MISTRAL sensors*
- *In-pixel discrimination*
  - *Topology selected among 3 topologies implemented in the 1st prototype AROM0*
  - *Test results in laboratory: total noise ~30 e-, ➔ ENC ~2 times higher than expected but phenomena understood*
  - *AROM0: Full functionality validated*

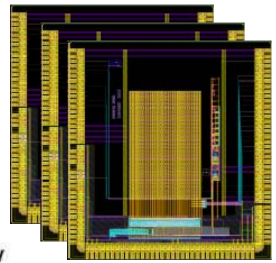
AROM-0







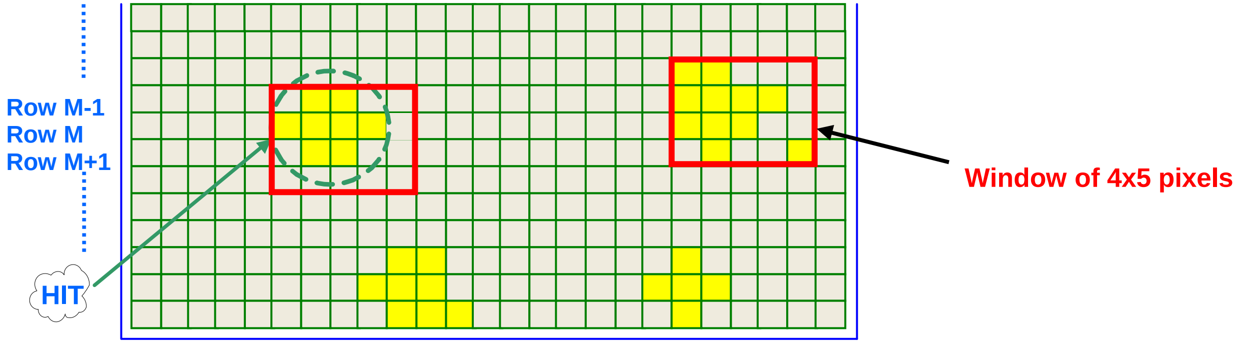
AROM-1

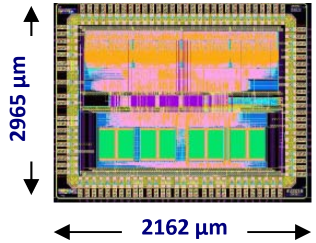


- *Further R&D will focus on large sensor integration along with power consumption and noise reduction*

Downstream of Sensors: Zero Suppression Logic (SUZE02)

- *Identical both for MISTRAL & ASTRAL sensors*
  - *AD conversion (pixel-level or column-level) outputs are connected to inputs of SUZE*





- *Encoding: more efficient than SUZE01 implemented in MIMOSA28 sensor*
  - *Sizable and suitable to process the binary information generated by a 1 cm long pixel array*
    - *Hit density of ~100 hits/collision/cm² + safety factor of 3-4*
    - *Compression factor: 1 to 4 order of magnitudes*
  - *Hit clusters identified in 4x5 pixel windows*
  - *Results stored in 4 SRAM blocks allowing either continuous or triggered readout*
  - *Sparsified data multiplex onto a serial LVDS output*
    - *Prototype data rate: 320 Mbit/s per channel (1 or 2 channels in SUZE02)*
- *SUZE02 preliminary test results: functional and works well @ full speed*
  - *Full sequence of signal processing steps validated using various types of patterns*
  - *SEU needed to be evaluated*

- *MISTRAL / ASTRAL: 500 Mbits/s data rate required*
  - *One channel output per sensor*
    - *INFN Torino is working on data transmission up to 2 Gbit/s*

Conclusions

- *2 sensors being developed at IPHC for the ALICE ITS upgrade:*
  - *MISTRAL: validation of the upstream and downstream architectures confirmed*
    - *Spatial resolution (22x33 μm^2 pixel) ~5 µm*
    - *Detection efficiency > 99.8 % for fake hit rate ≤ $O(10^{-5})$*
    - *Integration time: ~30 µs*
    - *Power consumption ~200 mW/cm^2*
  - *ASTRAL: architecture validation on going*
    - *ASTRAL pixel front-end amplification (same as MISTRAL part) validation confirmed*
    - *Downstream of ASTRAL (shares the same logic with MISTRAL) validation confirmed*
    - *Feasibility of the In-pixel discrimination validated ➔ fine optimisation on going*
    - *ASTRAL performs 2 x higher readout speed and lower power consumption than MISTRAL*
      - *Integration time: <~20 µs*
      - *Power consumption ~85 mW/cm^2 for inner layers & ~30-60 mW/cm^2 for outer layers*

- *At beginning of 2014, a large sensor about 1 cm^2 will be submitted to verify full chain and full functionalities*