Achieved Performances with the Final JRA1-BT Sensor

(TC, alias MIMOSA-26)

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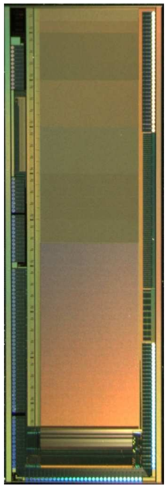
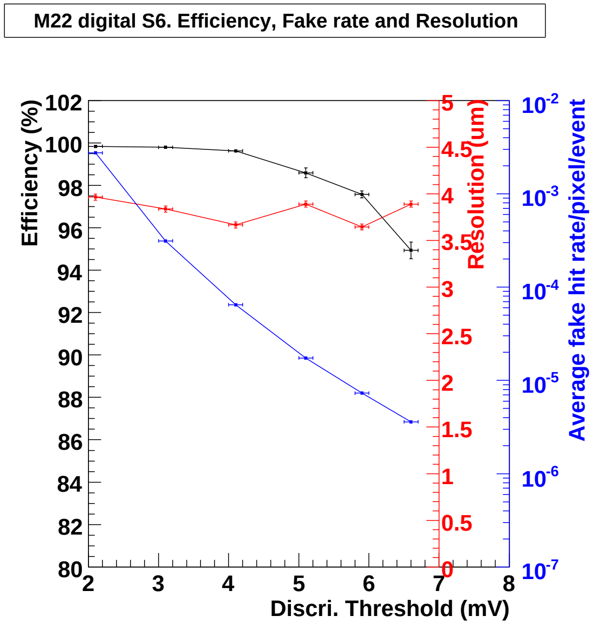
OUTLINE

- Reminder: IDC & SDC-2
- TC design characteristics
- TC laboratory test results
- TC PRELIMINARY performance assessment with m.i.p.
- 2010 Perspectives
- Summary

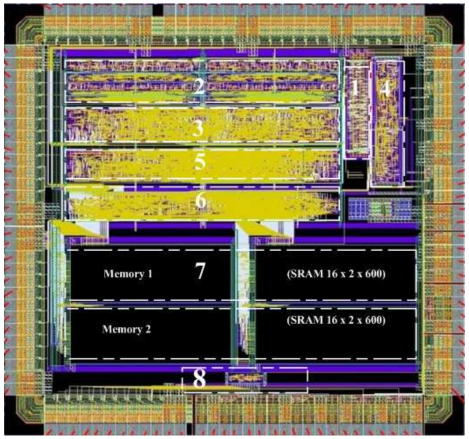
Reminder: IDC and SDC-2

- **IDC = pixel array with binary output (alias MIMOSA-22):**
  - fabricated in 2007/08
  - 136 columns of 576 pixels read out in //
  - 128 columns ended with integrated discriminator
  - pixel pitch = 18.4 $\mu m \Rrightarrow \ \sigma_{sp} \sim$ 3.7–3.8 μm
  - achieved read-out time = 92.5 μs





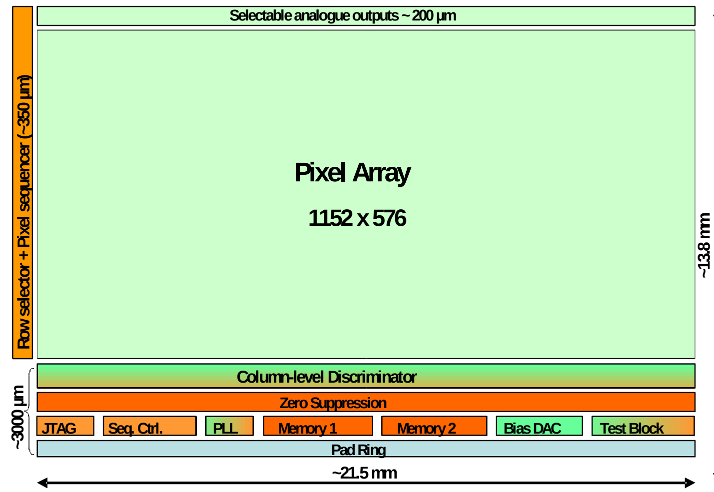
- **SDC-2 = zero-suppression μ-circuit with output memories (alias SUZE-01):**
  - fabricated in 2007
  - design adapted to signal processing of 128 column (discriminator) outputs
  - nominal performances observed up to 1.15 $\times$ specified clock frequency (100 MHz)



TC : 1st Sensor with Integrated $\emptyset$

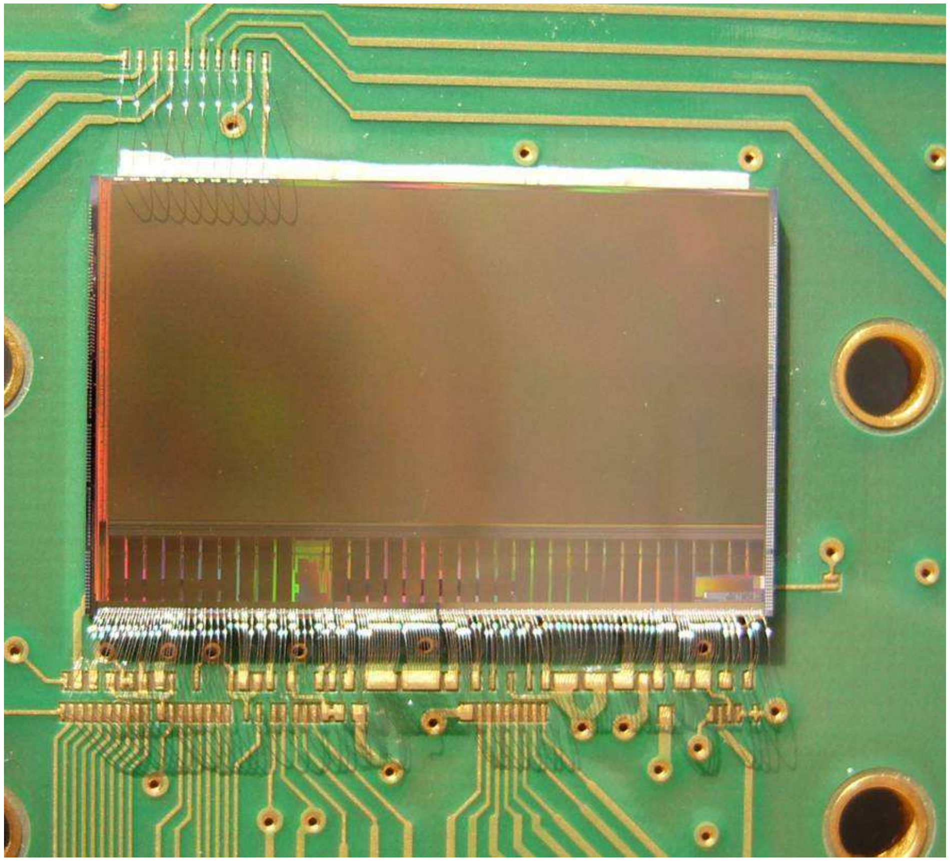
- **TC $\equiv$ 1st sensor with integrated zero-suppression**
  - ⋇ **MIMOSA-22 (binary outputs) combined with $\emptyset$ (SUZE-01)**
  - ⋇ **Active area: 1152 columns of 576 pixels (21.2$\times$10.6 mm^2)**
  - ⋇ **Pitch: 18.4 μm $\rightarrowtail$ $\sim$ 0.7 million pixels $\Rrightarrow$ $\sigma_{sp} \gtrsim$ 3.5 μm**
  - ⋇ **T$_{r.o.}$ $\lesssim$ 110 μs $\rightarrowtail$ $\sim$ 10^4 frames/s**

    $\Rrightarrow$ *suited to $>$ 10^6 particles/cm^2/s*
  - ⋇ *$\emptyset$ in 18 groups of 64 col. allowing $\leq$ 9 "pixel strings" / raw*
  - ⋇ *Sensor full dimensions : $\sim$ 22 x 14 mm^2*
  - ⋇ *Data transmission: 1 output at $\geq$ 160 Mbits/s or 2 outputs at $\geq$ 80 Mbits/s*



- **Fabricated in AMS-0.35 technology:**
  - ⋇ Replaces demonstrator sensor with $\sim$ 3.8 times larger sensitive area and $>$ 10 times faster read-out
  - ⋇ Architecture is baseline for STAR, CBM and ILC vertex detectors
  - ⋇ Sensor still being characterised $\Rrightarrow$ test results are **Preliminary**

TC Tests: General Features

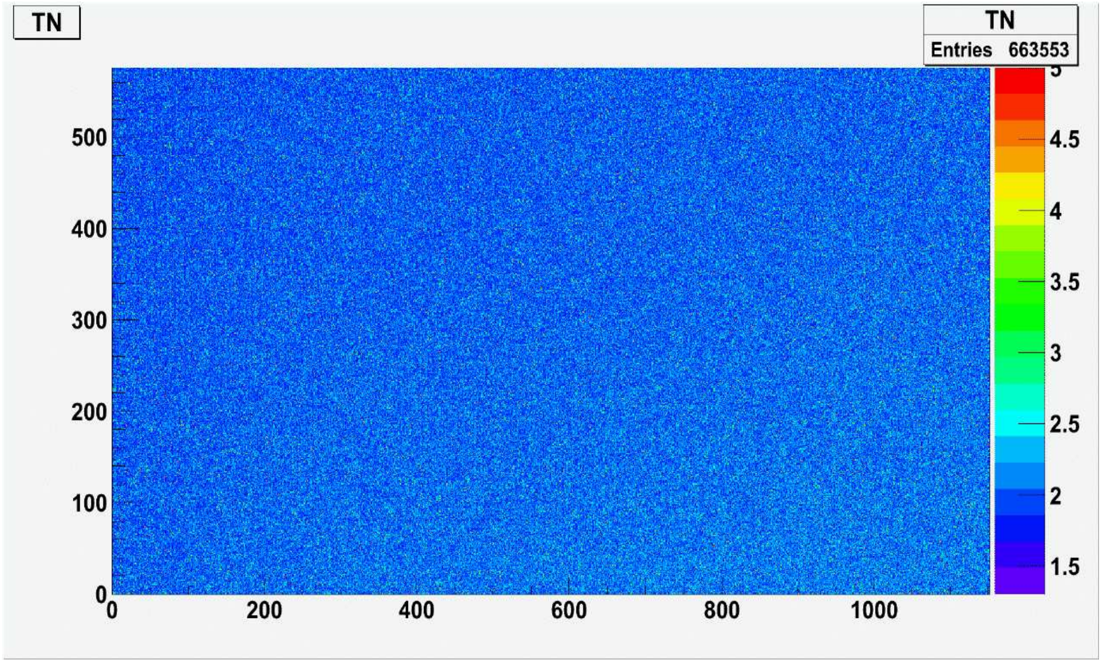


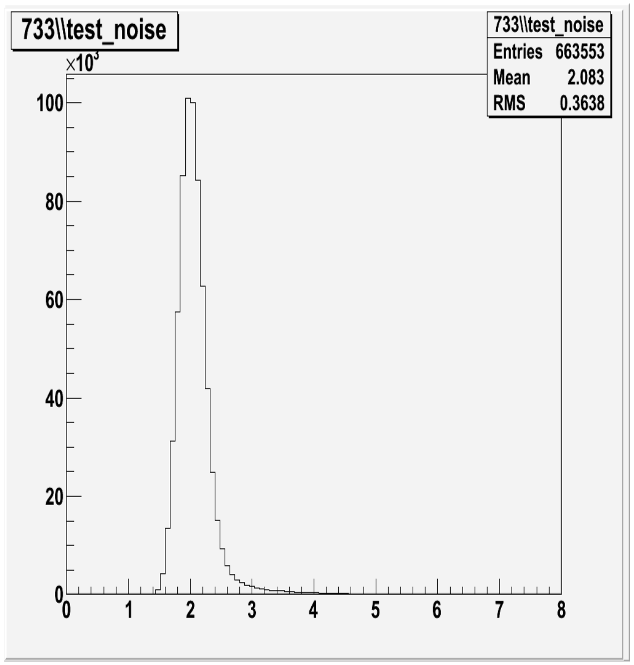
- **Sensor manufacturing:**
  - 0.35 μm OPTO fabrication process:
    $\sim$ 14 μm thin epitaxial layer
  - 6 wafers fabricated: 77 sensors per wafer
  - 1 wafer thinned to 120 μm and diced
  - 1/2 wafer diced without thinning

- **27 unthinned ($\sim$ 700 μm thick)**
  + 6 thinned sensors tested in the laboratory:
  - 20+6 sensors fully operational
  - 2 sensors unusable
  - 1 sensor with 1 faulty row and 1 faulty column (0.26 %)
  - 1 sensor with 1 dead row (0.17 %)
  - 1 sensor with 1 dead column (0.09 %)
  - 2 sensors with $< 10^{-4}$ faulty pixels

$\Rrightarrow$ **Fabrication yield $\sim$ 90 %**

TC Lab Tests: Noise Performance



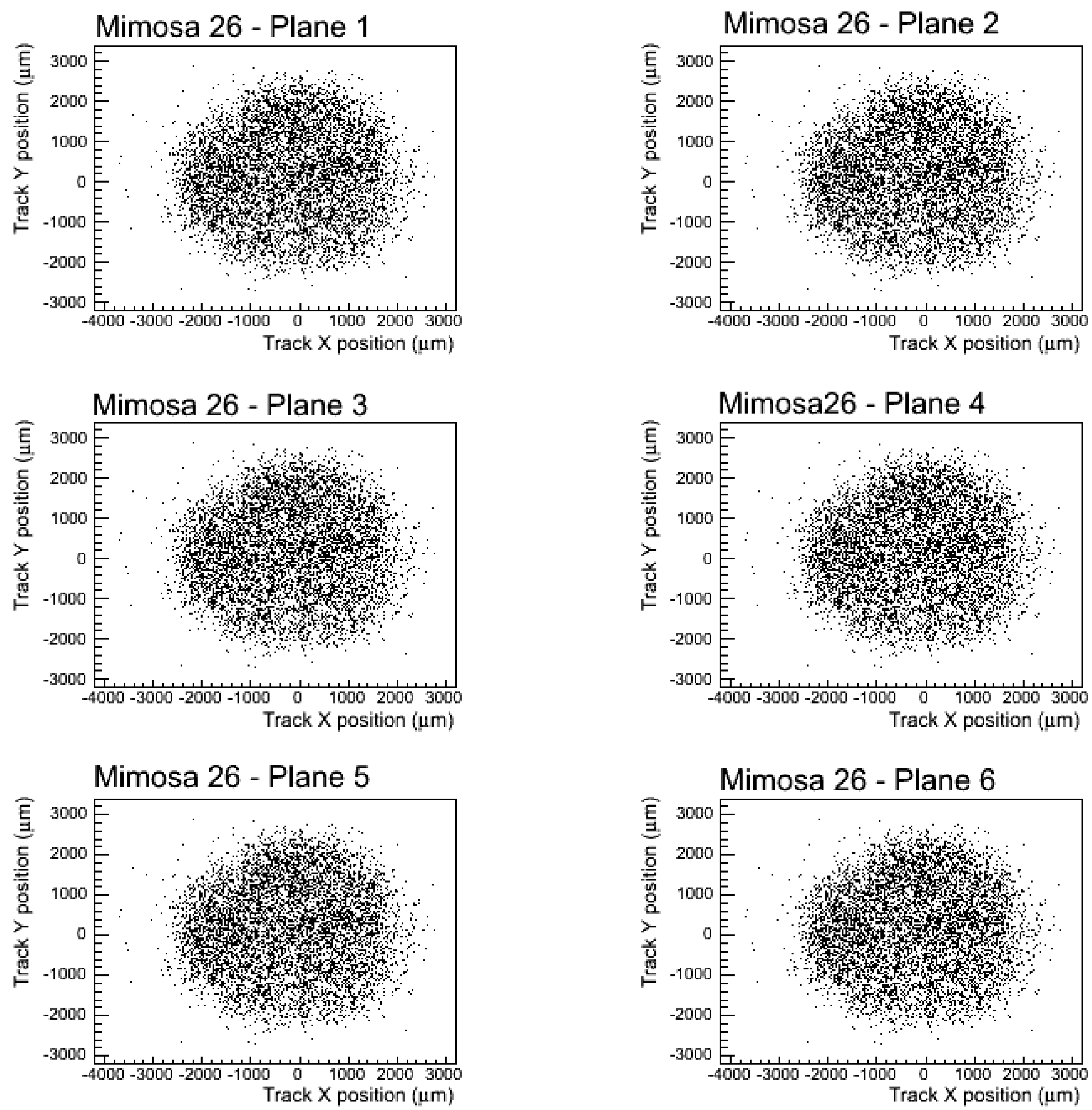


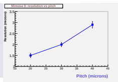
- **Noise uniformity tested on 8 sensors (analogue output)**

- **Main conclusions:**
  - ⋇ no dead pixel over 6 arrays of 660,000 pixels !
  - ⋇ N $\lesssim$ 14 e^- ENC
  - ⋇ marginal noise dispersion between chips

- **6 sensors used:**
  - ⋇ some thinned to 120 μm
  - ⋇ assembled in telescope configuration
  - ⋇ for minimum ionising particle detection performance evaluation

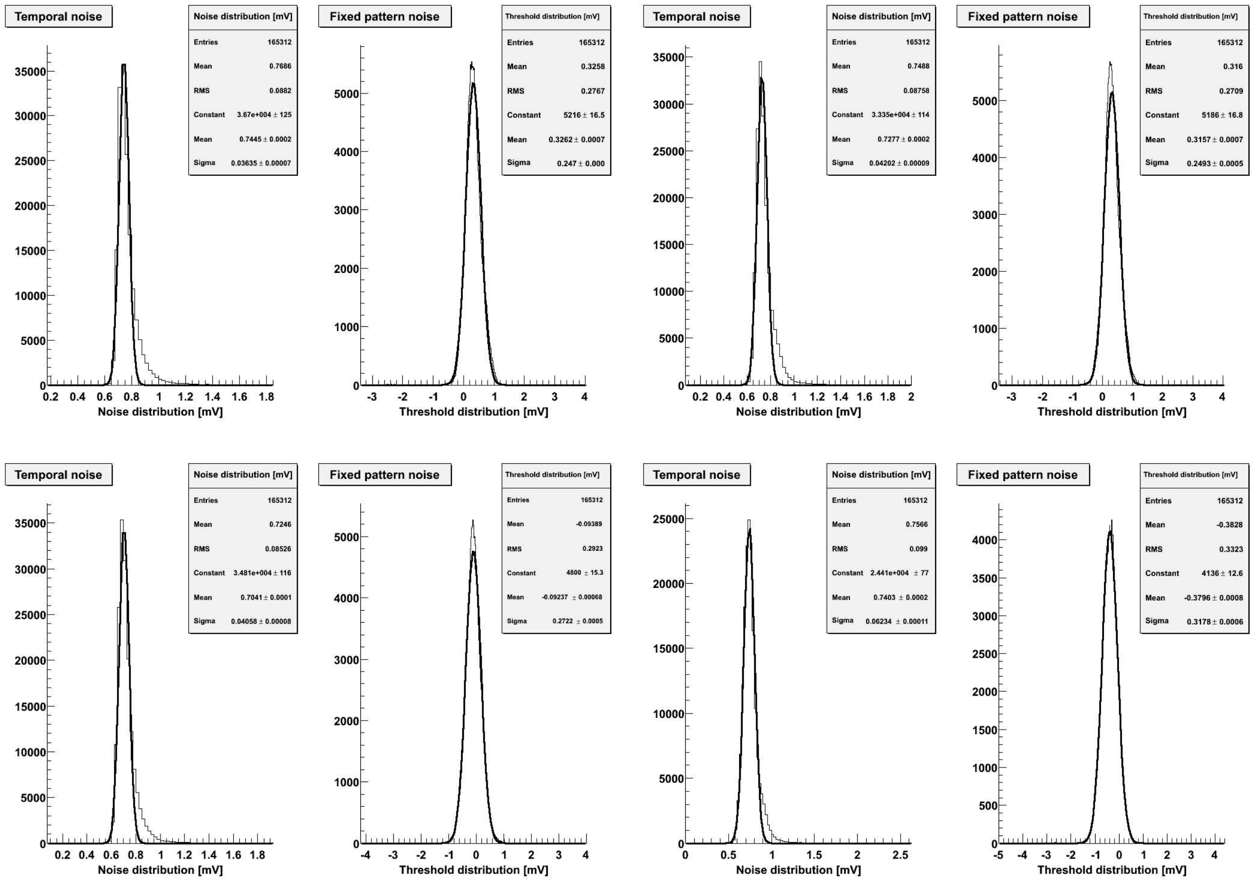
- **CRN-SPS (T4-H6)**
  - ⋇ $\gtrsim$ 120 GeV π^- beam
  - ⋇ 10 days of run in Sept. 2009
  - ⋇ 3×10^6 triggers collected, out of which $\sim$ 80 % events reconstructed

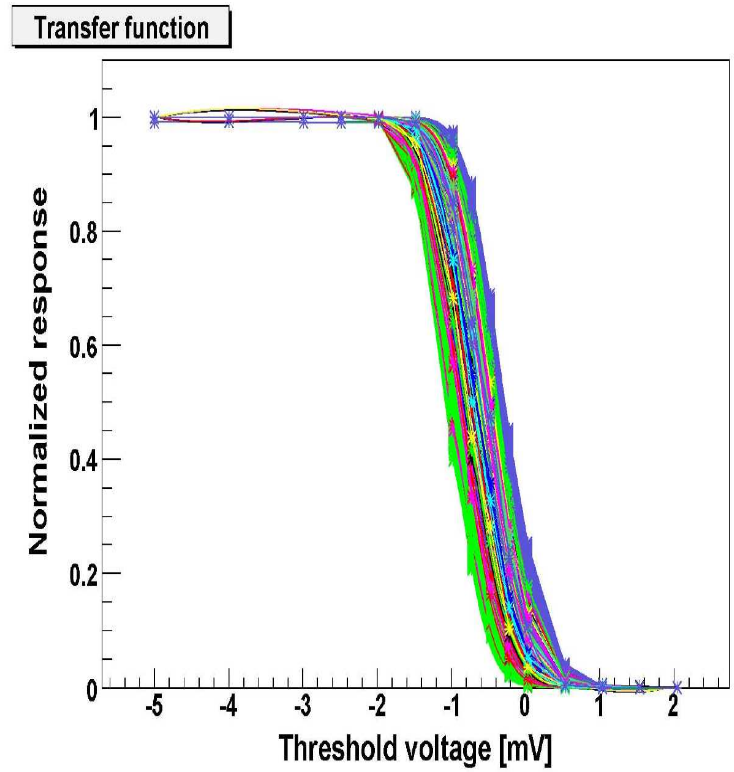




TC Beam Tests: Noise studies

- Threshold scan of 1152 discriminators without beam:





- Noise performance (Thermal Noise and Fixed Pattern Noise):
  - ⁕ TN and FPN derived from threshold scan slope and dispersion (digital output)
  - ⁕ Values ∼ identical to those of MIMOSA-22: ▷ TN ∼ 0.6–0.7 mV ▷ FPN ∼ 0.3–0.4 mV
  - ⁕ Homogeneous response of all 4 sub-arrays (288 columns each)

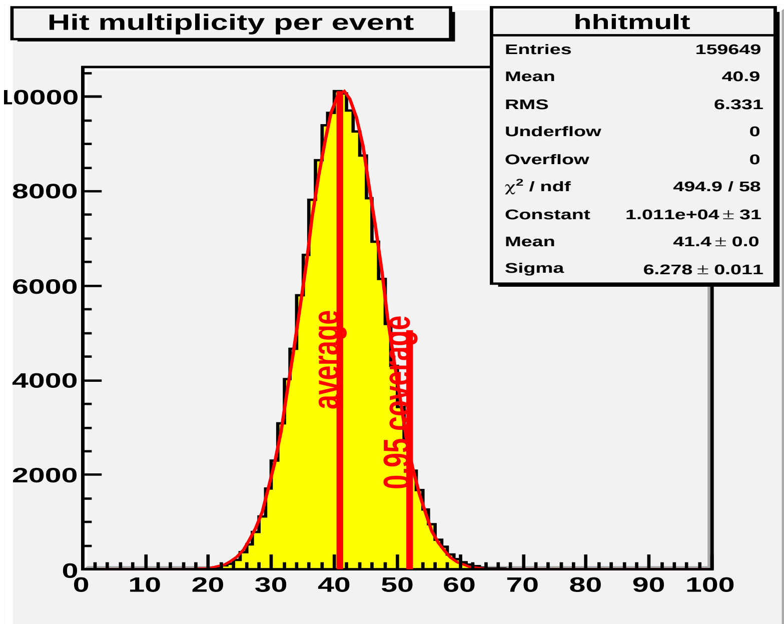
TC Beam Tests: Fake Hit Rate

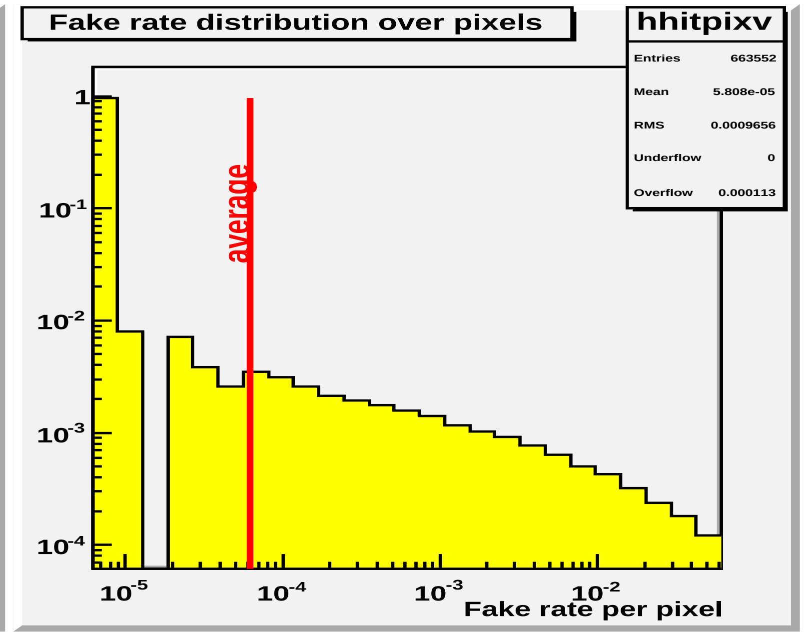
- **Avoid saturating the zero-suppression logic and output memories with noise fluctuations**

  $\Rrightarrow$ adjust discriminator threshold to high enough value

$\sim 4{\cdot}10^4$ frames

threshold at $6\times$N



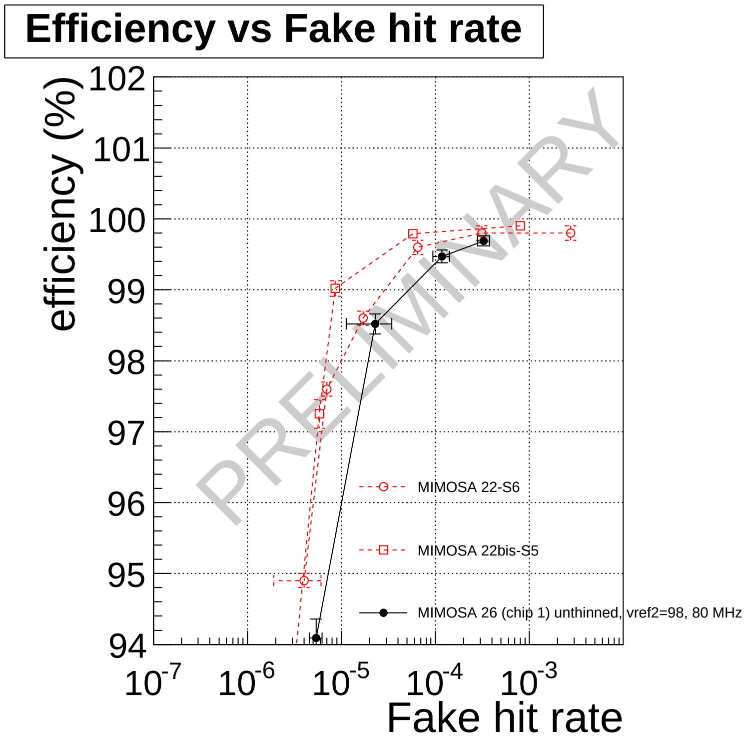


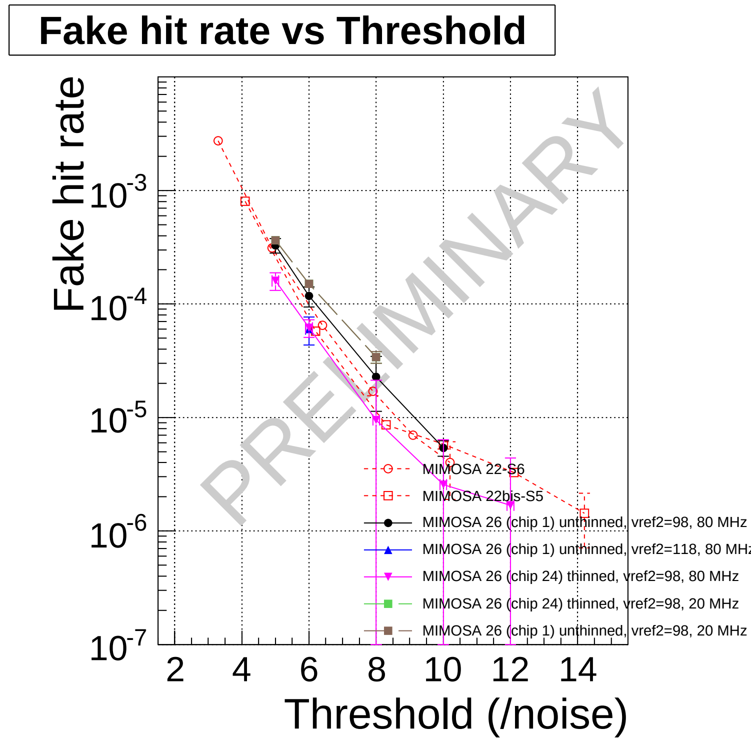
Discriminator threshold	5 N	6 N	7 N	8 N	10 N	12 N
Fake rate of chip Nr. 24 (10^{-4})	1.6	0.6	0.24	0.095	0.026	0.017
Fake rate of chip Nr 1 (10^{-4})	3.3	1.2	–	0.23	0.054	–

- **Fake hit rate :**
  - ⋇ Dominated by a few % of the pixels
  - ⋇ Affordable with threshold $\gtrsim 5\times$ Noise value ($10^{-4} \equiv 66$ pixels)

TC Beam Tests: Detection Efficiency

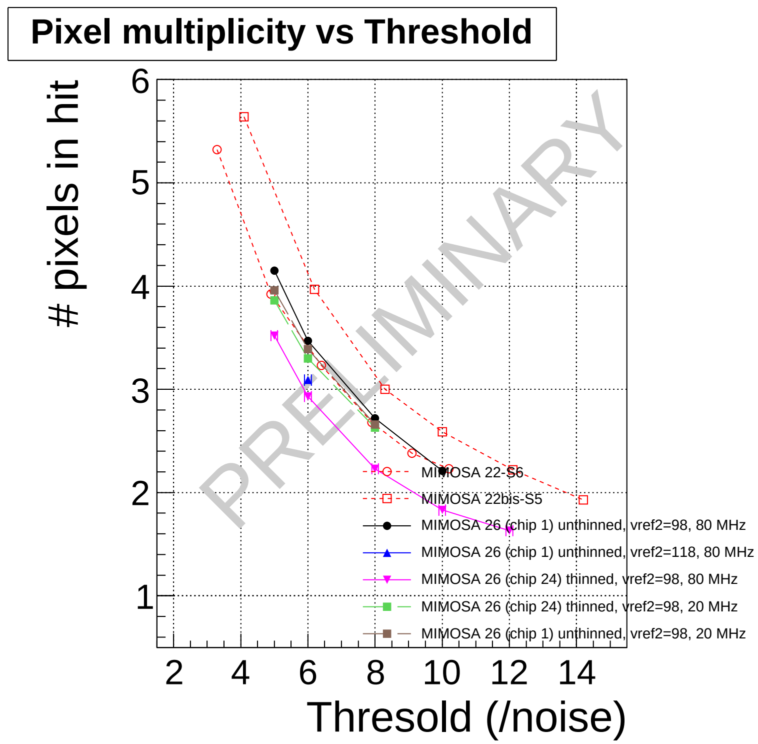
- **Avoid mitigating detection efficiency because of too high discriminator threshold (fake rate !)**

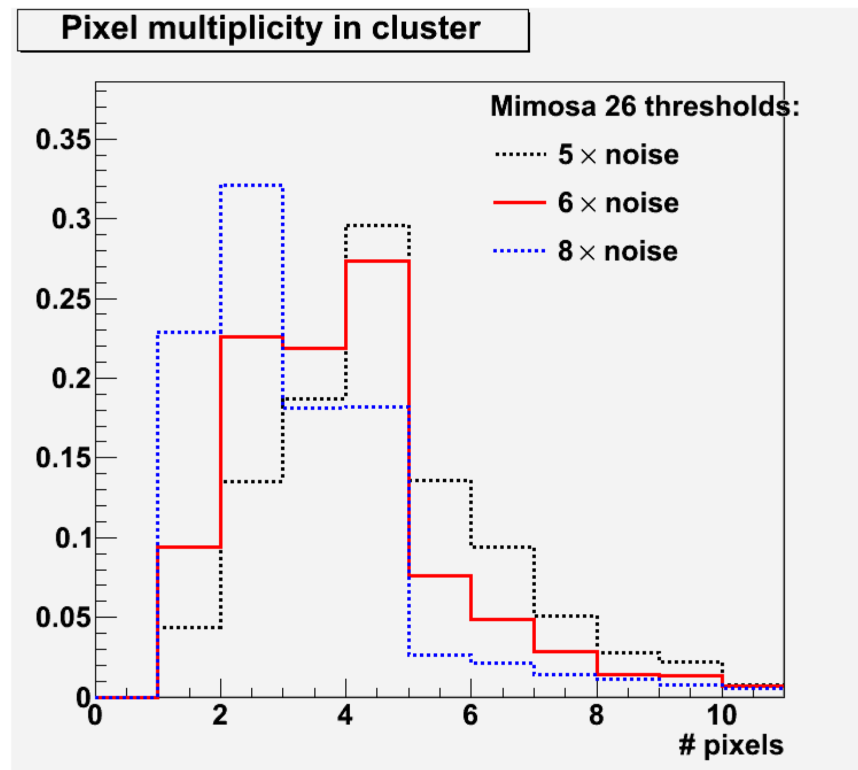




- **Detection efficiency:**
  - ✳ $\sim$ 99.5 $\pm$ 0.1 % for fake rate $\sim 10^{-4}$
  - ✳ Operational discriminator threshold $\sim$ 5–6 $\times$ Noise

- **Study of cluster multiplicity and single point resolution:**





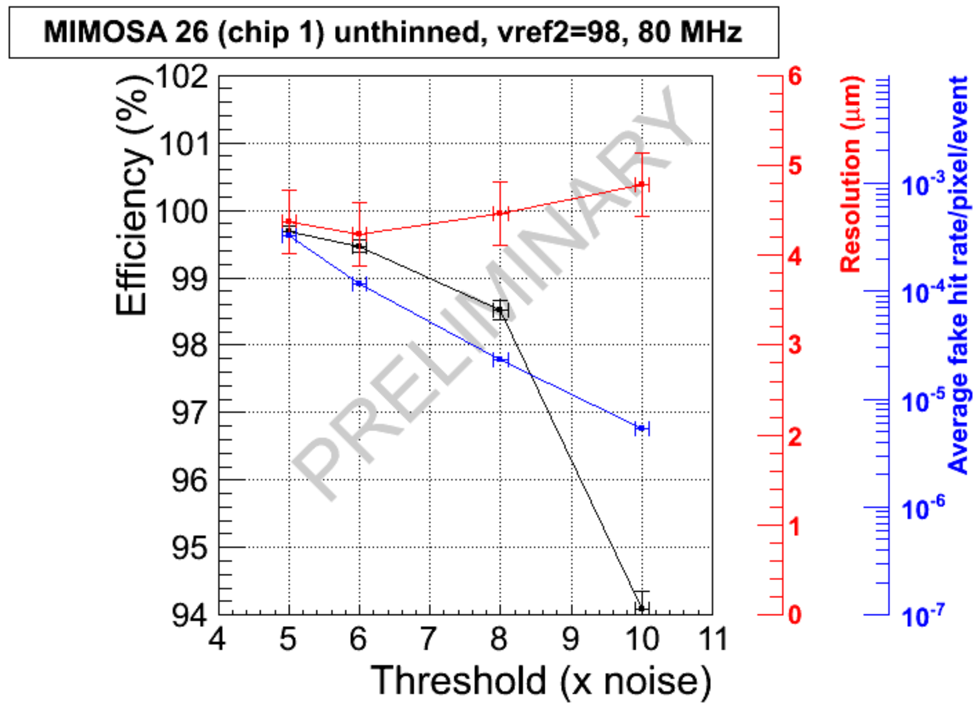
- **Consequences:**
  - ⋇ 1 pixel cluster $\gtrsim$ 5 % $\Rrightarrow$ fake hits difficult to reject using cluster multiplicity
  - ⋇ distribution $\sim$ identical to that of IDC (MIMOSA-22) $\Rrightarrow$ expect $\sigma_{sp}^{TC} \sim \sigma_{sp}^{IDC} < 4\ \mu m$

    $\hookrightarrow$ present measurement: $\sigma_{sp}^{TC} \lesssim 4.5\ \mu m$

- **TC sensors quite extensively characterised by now (but quantitative results still preliminary):**
  - ⋇ TC operating with $\gtrsim$ 99.5 % detection efficiency over the whole sensitive area, with a fake rate $\lesssim$ O(10^{-4})
  - ⋇ Optimal discri. threshold $\sim$ 5–6 $\times$ Noise value
  - ⋇ $\sigma_{sp}^{TC} \lesssim 4.5 \pm 0.2\ \mu m$ (preliminary)

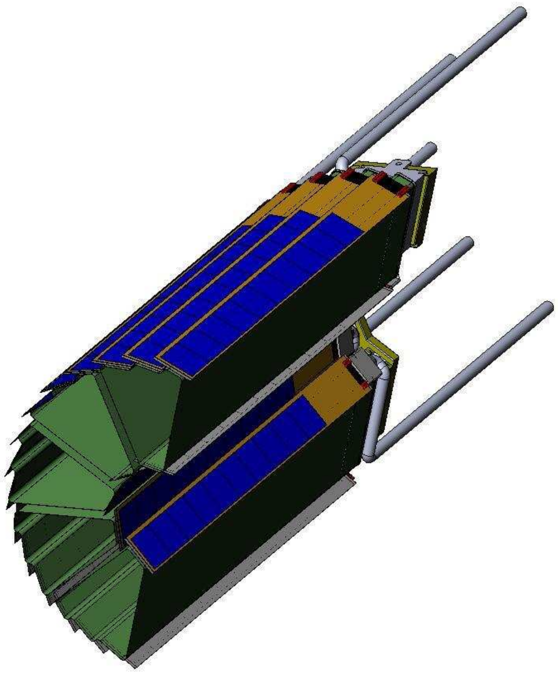
    $\Rrightarrow$ room for improvement towards

    $$\sigma_{sp}^{TC} \equiv \sigma_{sp}^{IDC} \sim 3.5\text{–}4\ \mu m$$



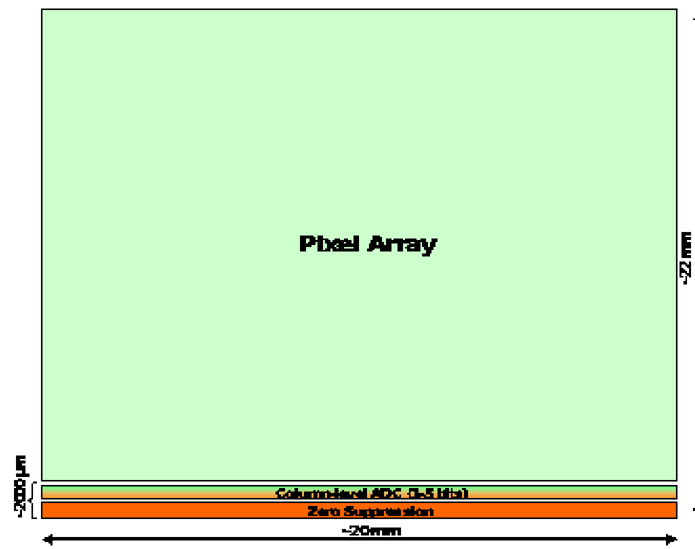
- **Conclusion:**
  - ⋇ TC operational for the final EUDET BT ✓
  - ⋇ Can we improve something during the last year of the project ?

- **2010 sensor development objectives:**
  - ⋇ sensors with larger sensitive area
    (same pad rows, steering and read-out)
  - ⋇ pixels with improved ionising radiation tolerance
    (in perspective of extensive use of BT
    at high intensity hadron beam facilities)



- **Context:**
  - ⋇ extension of MIMOSA-26 for the STAR vertex detector ↗
  - ⋇ sensor to be fabricated during Q1/2010 (design under way)

- **Main characteristics:**
  - pixel pitch: 18.4×18.4 μm^2
  - 1088 columns of 10^3 pixels
    - ⇛ active area $\sim$ 20.0×18.5 cm^2
      - ⇛ 1.7 times TC active area
  - in-pixel processing μ-circuits with improved tolerance to ionising radiation :
    $\hookrightarrow$ $\gtrsim$ 500 kRad ($>10^{13}$ pions/cm^2)
  - potentially $\sim$ twice larger in-pixel signal amplification
    - ⇛ improved SNR
  - read-out time $\lesssim$ 200 μs



- **Time line:**
  - design completed by February-March 2010 ⇛ foundry submission
  - sensor expected to be available for EUDET-BT commissionning in Summer 2010
  - no extra cost (masks funded by STAR collaboration)

SUMMARY

- **Final sensor for EUDET-BT:**
  - TC fabricated and $\sim$ commissionned in EUDET-BT
  - performances within specifications:
    - t$_{r.o.}$ $\sim$ 100 μs ($\sim$ 10 kframes/s)
    - $\sigma_{sp} \lesssim$ 4 μm (to be confirmed)
    - active area $\sim$ 21$\times$10.5 mm^2
    - 120 μm thinning validated $\rightarrowtail$ soon 50 μm

- **Ultimate sensor for EUDET-BT:**
  - realised for STAR vertex detector upgrade (RHIC/BNL)
  - 1.7 times larger active area (20$\times$18.5 mm^2)
  - improved ionising radiation tolerance
  - read-out time $\lesssim$ 200 μs
  - steering and read-out fully compatible with TC servicing and read-out system
  - to be fabricated in Spring 2010 $\Rrightarrow$ ready for commissionning in Summer 2010