Dalian-Strasbourg Collaboration on Smart Sensors R&D

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(on behalf of the DUT-IPHC coll.)

OUTLINE

- Context of collaboration between IPHC and DUT
- Questions addressed by the collaboration
- Status of work and plans

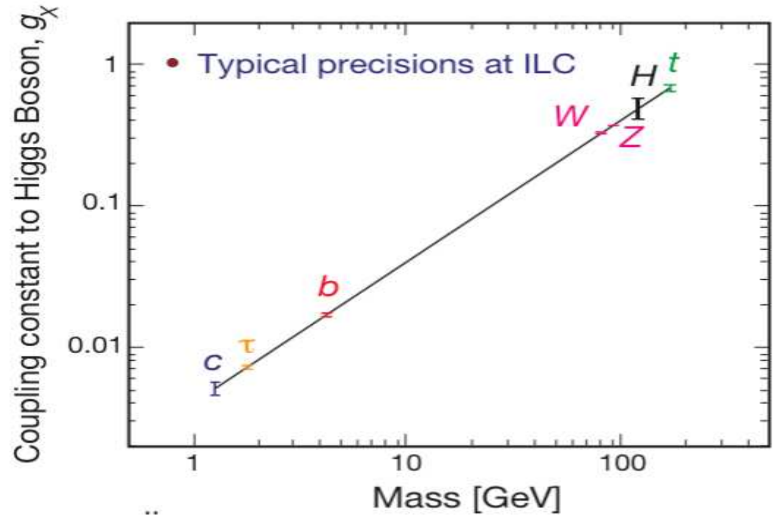
- **Development of pixel sensors for future vertex detectors: ILC, STAR, FIRST, CBM, ALICE, ...**

  ↪ *Figure of merit :* $\sigma_{\mathbf{ip}} = \mathbf{a} \oplus \mathbf{b/p} \cdot \sin^{\mathbf{3/2}} \theta$

  ⋇ $\mathbf{a}$ *governs high momentum*

  ⋇ $\mathbf{b}$ *governs low momentum* *(~ 30 % particles < 1 GeV/c)*

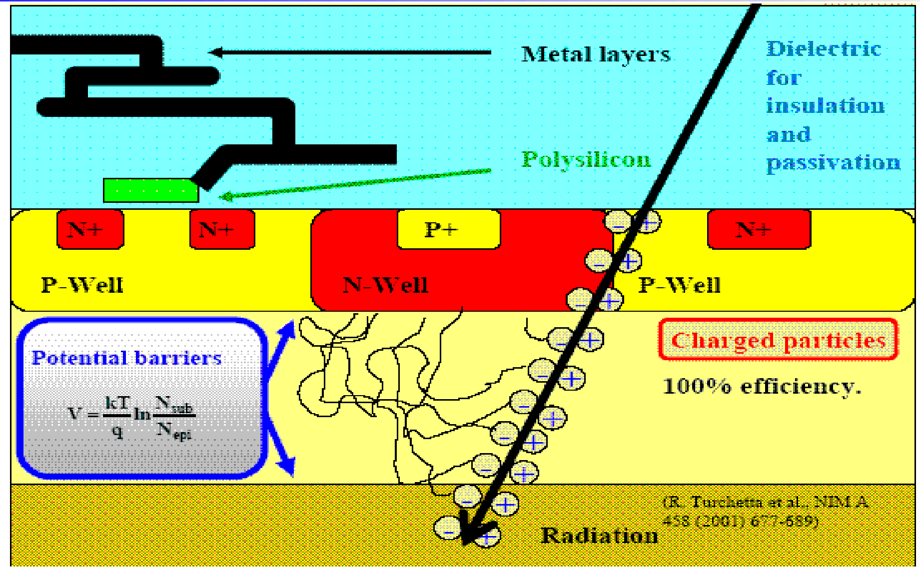
Accelerator	a (μm)	b ($\mu m \cdot GeV$)
LEP	25	70
SLD	8	33
LHC	12	70
RHIC-II	13	19
ILC	< 5	< 10



- R&D priority: achieve high resolution, highly integrated and thin pixel sensors

  ⇛ detector R&D on CMOS pixel sensors with application dependent optimisations

Main Features and Advantages of CMOS Sensors



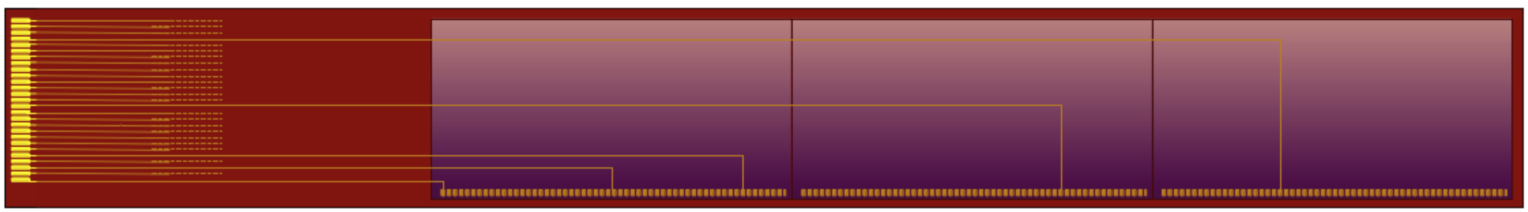
- P-type low-resistivity Si hosting n-type "charge collectors"
  - signal created in epitaxial layer (low doping):
    Q $\sim$ 80 e-h / μm $\mapsto$ signal $\lesssim$ 1000 e^-
  - charge sensing through n-well/p-epi junction
  - excess carriers propagate (thermally) to diode
    with help of reflection on boundaries
    with p-well and substrate (high doping)

- Prominent advantages of CMOS sensors:
  - ◇ granularity: pixels of $\lesssim 10 \times 10\ \mu m^2$ $\Rightarrow$ high spatial resolution
  - ◇ low mat. budget: sensitive volume $\sim$ 10 - 15 μm $\Rightarrow$ total thickness $\lesssim$ 50 μm
  - ◇ signal processing μcircuits integrated in the sensors $\Rightarrow$ compacity, high data throughput, flexibility, etc.

- Difficulties:
  - ⋇ Technical:
    - ◇ thinning to epitaxial layer + $\sim$ 5 μm ($\lesssim$ 30 μm in total)
    - ◇ dicing with negligible insensitive frame
    - ◇ integration of μcircuits in small pixels (nb of ML)
  - ⋇ Structural: technology potential not exploited in industry
    - ◇ industrial manufacturing param. not optimised for HEP: epitaxial layer properties, nb of ML, ...

Collaboration Goals

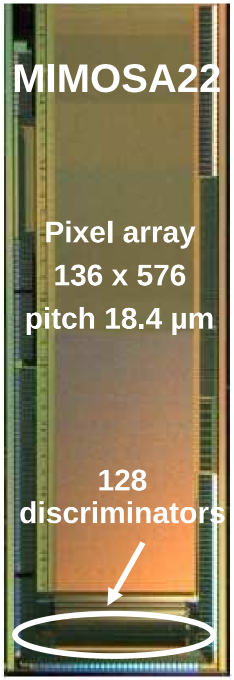
- **2 categories of research lines:**
  - ⁕ sensor manufacturing $\Rrightarrow$ optimised process parametres:
    - ◇ epitaxial layer (sensitive volume) characteristics: thickness, resistivity, etc.
    - ◇ number of Metal Layers: $\geq$ 5-6
    - ◇ others: T design, etch stopper implantation, ...
  - ⁕ sensor conditionning:
    - ◇ thinning $\lesssim$ 50 μm
    - ◇ edgeless dicing ($<$ 5 μm dead zone)



- **Added value of collaboration:**
  - ⁕ control of fabrication timeline and costs
  - ⁕ independence from industry policy
  - ⁕ contacts and synergy with numerous young Chinese designers

    $\Rrightarrow$ design tutoring at IPHC (several PhDs)

MAPS performance Improvement



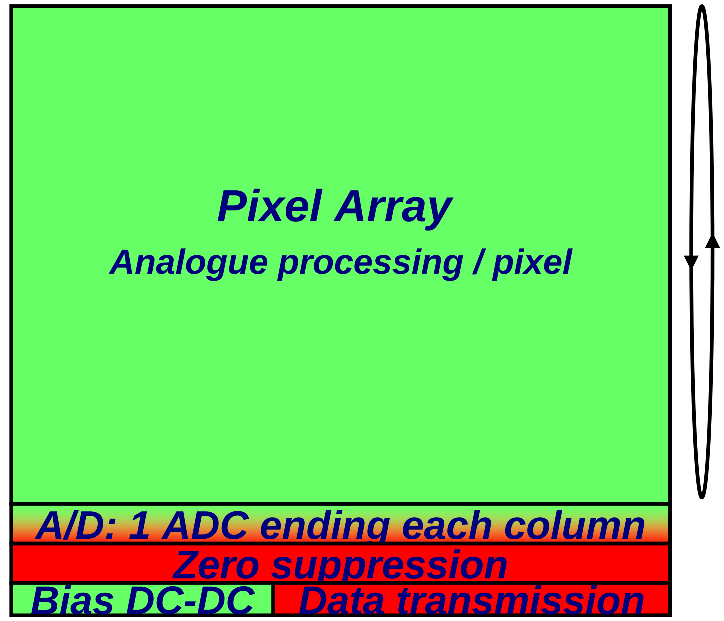
➔ *R&D on high readout speed, low noise, low power dissipation, highly integrated signal processing architecture with radiation tolerance*

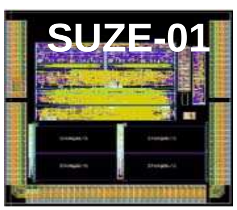
⓪ *Pixel optimisation :*

- *MIMOSA8 (2004), MIMOSA15 (2005), MIMOSA22 (2007/2008) …*

❶ *Architecture of pixel array organised in // columns read out:*

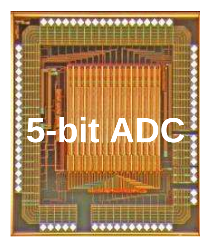
- *Pre-amp and CDS in each pixel*
- *A/D: 1 discriminator / column (offset compensation)*
- *Power vs Speed ➔ trade off*
- *MIMOSA8 (2004), MIMOSA16 (2006), MIMOSA22 (2007/08)*





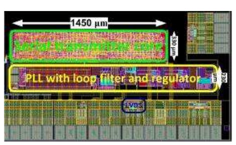
❷ *Zero suppression logic:*

- *Reduce the raw data flow of MAPS*
- *Data compression factor ranging from 10 to 1000, depending on the hit density per frame*
- *SUZE-01 (2007)*
  Anti-latch-up memory (2010)



❹ *4–5 bits ADCs (~10³ ADC per sensor)*

- *LPCC, LPSC, IRFU, IPHC collaboration*
- *Potentially replacing column-level discri.*
- *5 bits: σ_{sp} ~1.7–1.6 µm*
  4 bits: σ_{sp} < 2 µm for 20 µm pitch
- *Next step: integrate ADCs with pixel array*

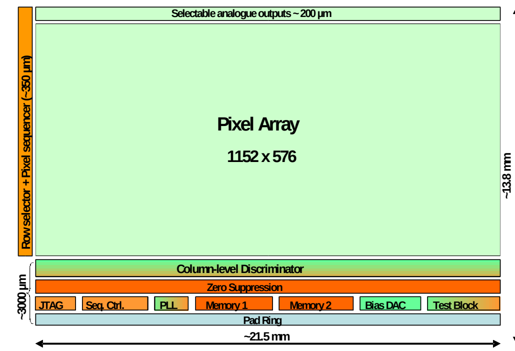


❸ *Serial link transmission with clock recovery*

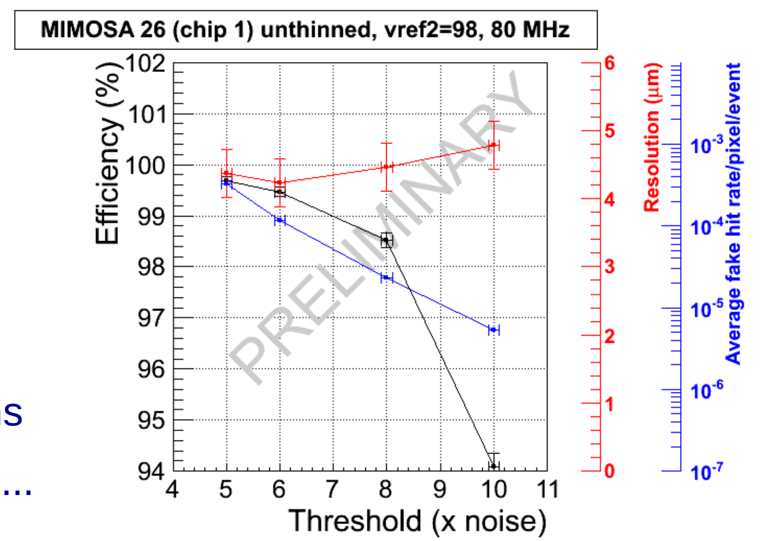
- *Prototype (2008-2009)*

❺ *Voltage regulator & DC-DC converter*

- **Full size sensor with integrated zero-suppression fab. in 2009:**
  - ⋇ Active area: 1152 columns of 576 pixels (21.2$\times$10.6 mm^2)
  - ⋇ Pitch: 18.4 $\mu m \rightarrowtail \sim$ 0.7 million pixels $\Rrightarrow$ $\sigma_{sp} \gtrsim$ 3.5 μm
  - ⋇ T$_{r.o.} \lesssim$ 110 $\mu s \Rrightarrow$ suited to $>$ 10^6 particles/cm^2/s
  - ⋇ P $\sim$ 300 mW/cm^2 (static) + 100 mW/cm^2 (dynamic with 1% occ.)
  - ⋇ Data transmission: 1 output at $\geq$ 160 Mbits/s (or 2 X 80 Mbits/s)
  - ⋇ 6 sensors equip the final set-up of the EUDET beam telescope
  - ⋇ 8 sensors will equip the FIRST vertex detector (hadrontherapy)



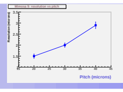
- **$>$ 50 sensors tested in lab and $\sim$ 10 sensors at CERN-SPS:**
  - ⋇ $\gtrsim$ 99.5 % detection efficiency routinely observed over the whole sensitive area, with a fake rate $\lesssim$ O(10^{-4})
  - ⋇ $\sigma_{sp}^{M26} \sim$ 4–4.5 μm (preliminary) $\longrightarrow$ expect $\sigma_{sp} \lesssim$ 4 μm



$\triangleright\triangleright\triangleright$ MIMOSA-26 architecture validated for numerous applications

$\Rrightarrow$ currently being extended for STAR-PIXEL and CBM-MVD, ...

also investigated as an option for ALICE–ITS upgrade



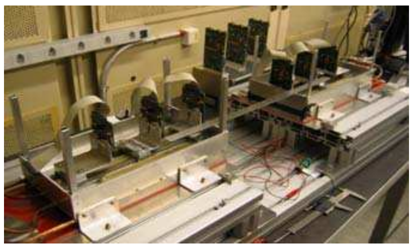
MIMOSA Sensors' Roadmap

Monolithic Active Pixel Sensors (MAPS): A Long Term R&D

- ***Main objective: ILC, with staggered performances***
  - *MAPS applied to other experiments with intermediate requirements*

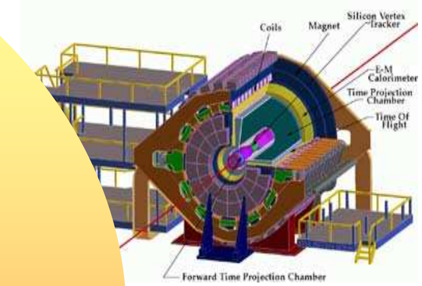
EUDET 2007/2009

Beam Telescope



STAR 2010

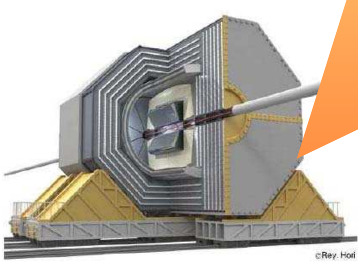
Solenoidal Tracker at RHIC



- ***FP6 EUDET Project (DESY-Hamburg, Germany)***
  - *Surface* — *6 x 2 cm²*
  - *Read-out speed* — *A. 20 MHz → D. at 100 MHz*
  - *Temp. & Power:* — *No constraints*
- ***STAR Experiment (RHIC – Brookhaven, USA)***
  - *Surface* — *~1600 cm²*
  - *Read-out speed* — *A. 50 MHz → D. up to 250 MHz*
  - *Temp. & Power* — *30° C, ~100mW/cm²*
- ***CBM Experiment (GSI – Darmstadt, Germany)***
  - *Surface* — *~500 cm²*
  - *Read-out speed* — *D. 15 x 10⁹ pixels/sensor/s*
  - *Rad Tol* — *1 MRad, > 10¹³ N_{eq} /cm²*
- ***ILC Experiment***
  - *5-6 layers of detection* — *~3000 cm²*
  - *Read-out speed* — *D. 15 x 10⁹ pixels/sensor/s*
  - *Temp. & Power* — *30° C, ~100 mW/cm²*
  - *Rad Tol* — *~300 kRad, ~10¹² N_{eq} /cm²*

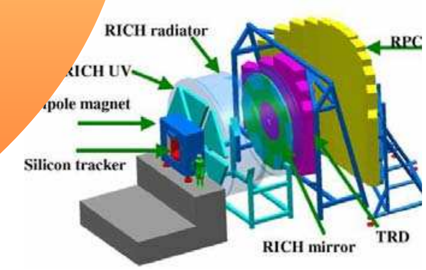
ILC >2012

Internatinal Linear Collider



CBM 2012

Compressed Baryonic Matter



→ *Spinoff: Interdisciplinary Applications, biomedical, …*

- *Partnerships: GIS IN2P3/Photonis & GIS IN2P3/SAGEM & Ohio University & Michigan University…*

Dalian VDSM CMOS Fabrication Chain

- **0.25 μm fabrication chain elements from INTEL:**
  - ⁕ provided by INTEL (agreement with Chinese government)
  - ⁕ INTEL is installing a 0.065 μm fab. chain in Dalian
  - ⁕ DUT supposed to use the 0.25 μm chain
    to educate engineers for INTEL-0.065 fab.

- **Difficulties encountered:**
  - ⁕ find, buy, refresh a large building to host fab. chain
    - ⇛ 3000 m^2 (2000 m^2 clean room)
  - ⁕ missing elements (10 Meuros):
    - ◇ elements of fab. chain
    - ◇ elements for fab. monitoring & quality control
  - ⁕ no subvention for running costs (2 Meuros/yr)
    - ⇛ mask lithography: 300 kUSD
      - ⇛ search for industrial partners

▷▷▷ Fabrication chain commissioning delayed to end of 2010

- **Collaboration addressing several crucial issues for future high precision vertex detectors based on CMOS sensors ⟼ ILC, STAR, CBM, FIRST, ALICE, ...**
  - ⋇ sensor manufacturing: customised VDSM CMOS fab. chain
  - ⋇ chip designs for various applications

- **Very constructive and fruitful collaboration ⇛ several talks at conferences and publications**
  - ⋇ contribution to development of MIMOSA-26 (CMOS sensor state of the art)
  - ⋇ contribution to generic data stream optimisation
  - ⋇ contribution to 3D sensor design

- **Difficulties encountered ⇛ delays introduced in the customised fab. chain availability**
  - ⋇ expected to be solved by 2011
  - ⋇ hope to start testing the chain next year

8 Doctorants, 1 subventionné par FCPPL