Charged particle detection performances of CMOS Pixel Sensors designed in a 0.18 µm CMOS process based on a high resistivity epitaxial layer

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ECFA-LC Workshop – 27-31 May 2013 – DESY, Hamburg

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- ***Upgrading to the 0.18 µm technology***
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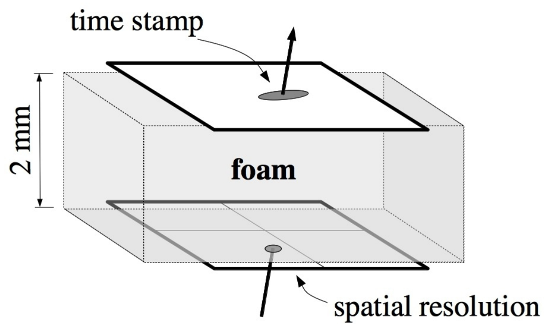
  - ✗ *Test results on full pixel design*
- ***Roadmaps***
  - ✗ *Sensors*
  - ✗ *System integration*
- ***Summary & outooks***

Vertex detector based on CPS

Concept of vertex detector

- ✗ Doube-sided layer → 2 different optimisations inner/outer side



	Radius (mm)		√s = 500 GeV		√s = 1 TeV	
Side	**inner**	**outer**	**Inner**	**outer**	**inner**	**outer**
Layer 1	16	18	3 µm / 50 µs	6 µm / 10 µs	3 µm / 50 µs	6 µm / 2µs
Layer 2	37	39	4 µm / 100 µs		4 µm / 100 µs	10 µm / 7 µs
Layer 3	58	60				

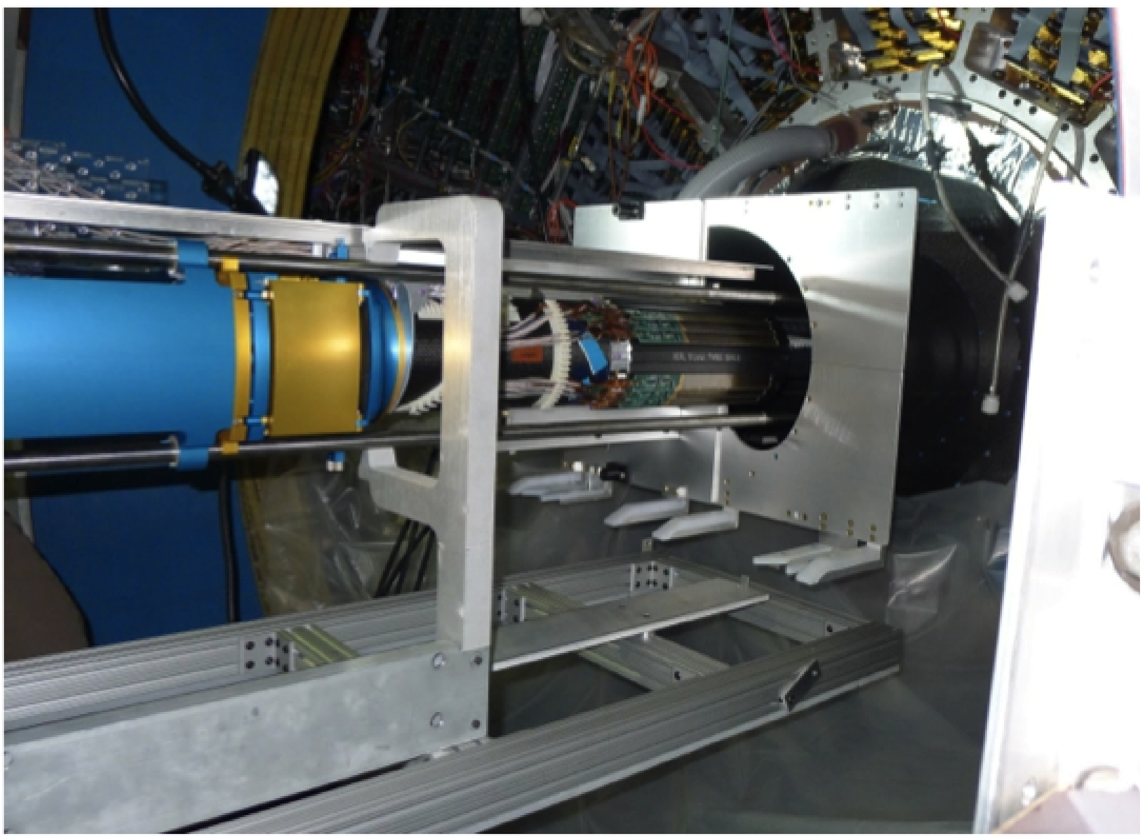
State-of-the-art with process 0.35 µm

- ✗ sensitive volume :
  - ↪ ~14 µm thick
  - ↪ Resistivity > 0.4 kΩ.cm
- ✗ MIMOSA 26 sensor → Eu-EUDET
- ✗ MIMOSA 28 sensor → STAR-PXL

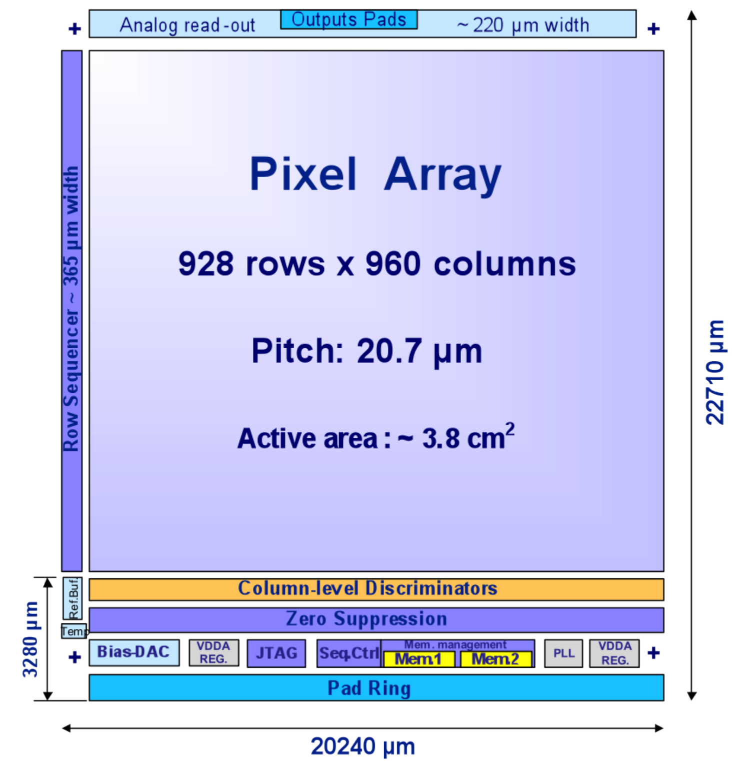
State-of-the-art based with process 0.35 µm

STAR – PXL detector

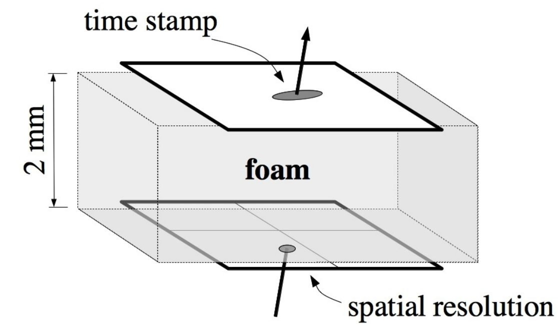
- ✗ data sparsification on sensor
- ✗ column-// rolling-shutter read-out → t_{int} = 200 µs
- ✗ 10 sensors / ladder of 0.37 % X_0
- ✗ power dissipation ≲150 mW/cm^2 → air cooled
  - ➡ 3 sectors installed on 2013 May 8
  - ➡ p+p data taking from May 9



ULTIMATE sensor MIMOSA 28



Vertex detector based on CPS



Concept of vertex detector

- ✗ Doube-sided layer → 2 different optimizations inner/outer side

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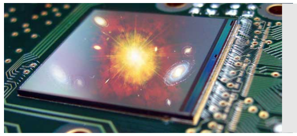
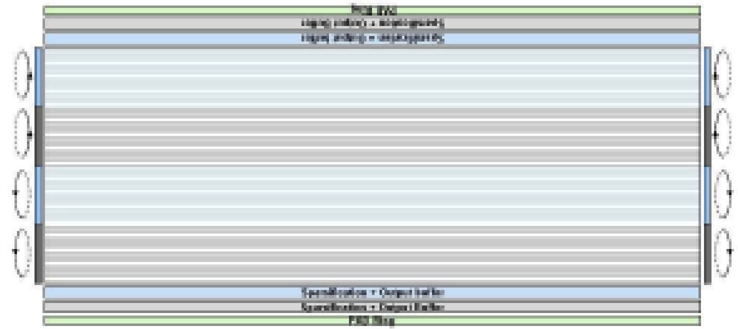
New process 0.18 µm

- ✗ Higher µ-circuits integration & 6 metal layers
  - ➡ faster & smarter pixel
- ✗ Sensitive volume:
  - ↪ 18 to 40 µm thick
  - ↪ resistivity > 1-2 kΩ.cm
  - ➡ allow larger pixel size / aspect ratio

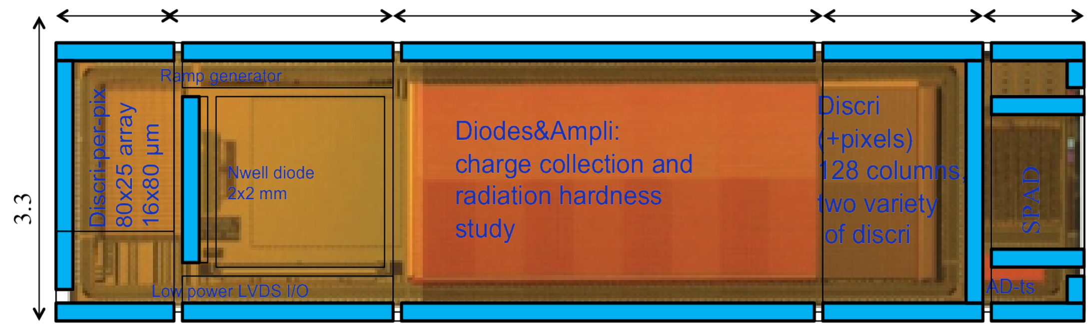


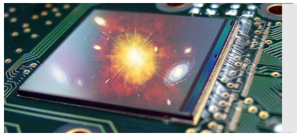
Upgrading to the 0.18 µm technology

- **Benefits for accelerating the rolling-shutter read-out**
  - ✗ Elongated pixels
    - ↪ less pixels/col. or in-pixel discri. → 3 to 8x faster
  - ✗ Higher parallelisation
    - ↪ 2 to 4 rows read-out simultaneously
    - ↪ 4 to 8 sub-arrays read-out simultaneously
  - ✗ Within limits of desired spatial resolution/ power dissipation / material budget



- **First prototypes**
  - ✗ Sensitive volume: ~18 µm thick, >kΩ.cm
  - ✗ Read-out time = 32 µs
  - ✗ MIMOSA 32
    - ↪ Fabricated Q1/2012
    - ↪ Charge collection properties
      various pixel sizes and shapes
    - ↪ Beam test Spring 2012 ➡ "MIP" detection performance validated, reported by M.Winter at LCWS 2012
  - ✗ MIMOSA 32ter
    - ↪ Fabricated Q4/2012
    - ↪ In pixel amplification & CDS
    - ↪ Beam test Fall 2012 ➡ this talk





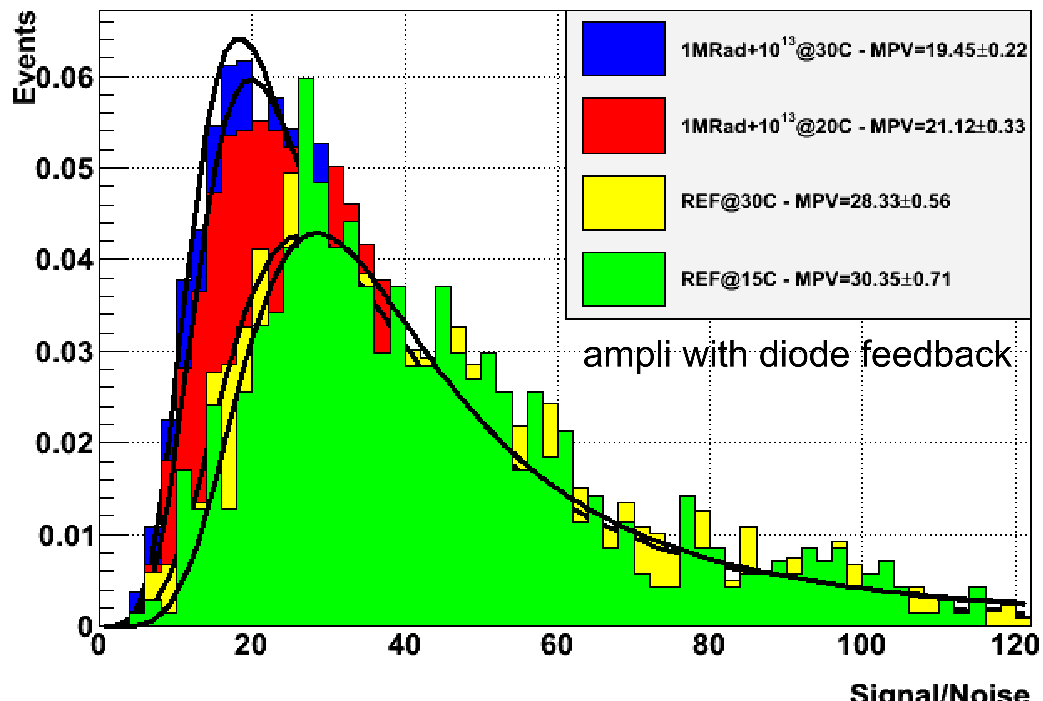
In-pixel amplification & CDS performance

Beam test conditions

- ✗ CERN-SPS: π at 80 to 120 GeV → 1500 to 3000 tracks per condition
- ✗ Coolant temperatures: 15, 20, 30 °C → sensor +5 °C
- ✗ Radiation loads: 0.3 MRad + 3x10^{12} n_{eq}/cm^2 or 1 MRad + 10^{13} n_{eq}/cm^2

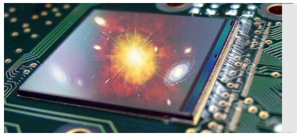
Pixels under test

- ✗ Pixel pitch 20x20 μm²
- ✗ In-pixel amplification with CDS
- ✗ 2 options for feedback look:
  - ↪ diode or transistor
  - ↪ yield similar results



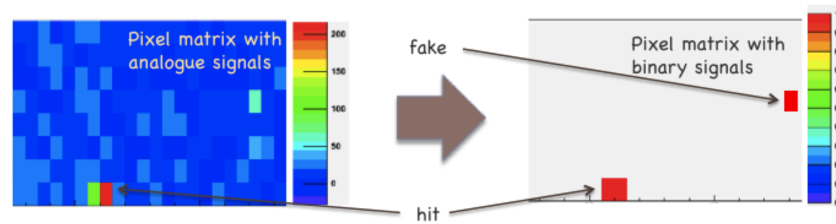
Radiation load	0 + 0		$3{\cdot}10^{12}$ n_{eq}/cm^2 + 300 kRad		10^{13} n_{eq}/cm^2 + 1 MRad	
Coolant temperature	15°C	30°C	20°C	30°C	20°C	30°C
SNR	30.4 ± 0.7	28.3 ± 0.6	22.0 ± 0.3	23.0± 0.3	21.1 ± 0.3	19.5 ± 0.2
Detection Efficiency	99.86 ± 0.14 %	99.59 ± 0.14 %	99.63 ± 0.13 %	99.49 ± 0.16 %	99.34 ± 0.19 %	99.35 ± 0.13 %

➡ No impact expected from ILC radiation level



Spatial resolution

- **Emulation of Binary output**
  - ✗ Same threshold applied off-line to all pixel signals
    - ↪ pixel outputs converted to 0 or 1

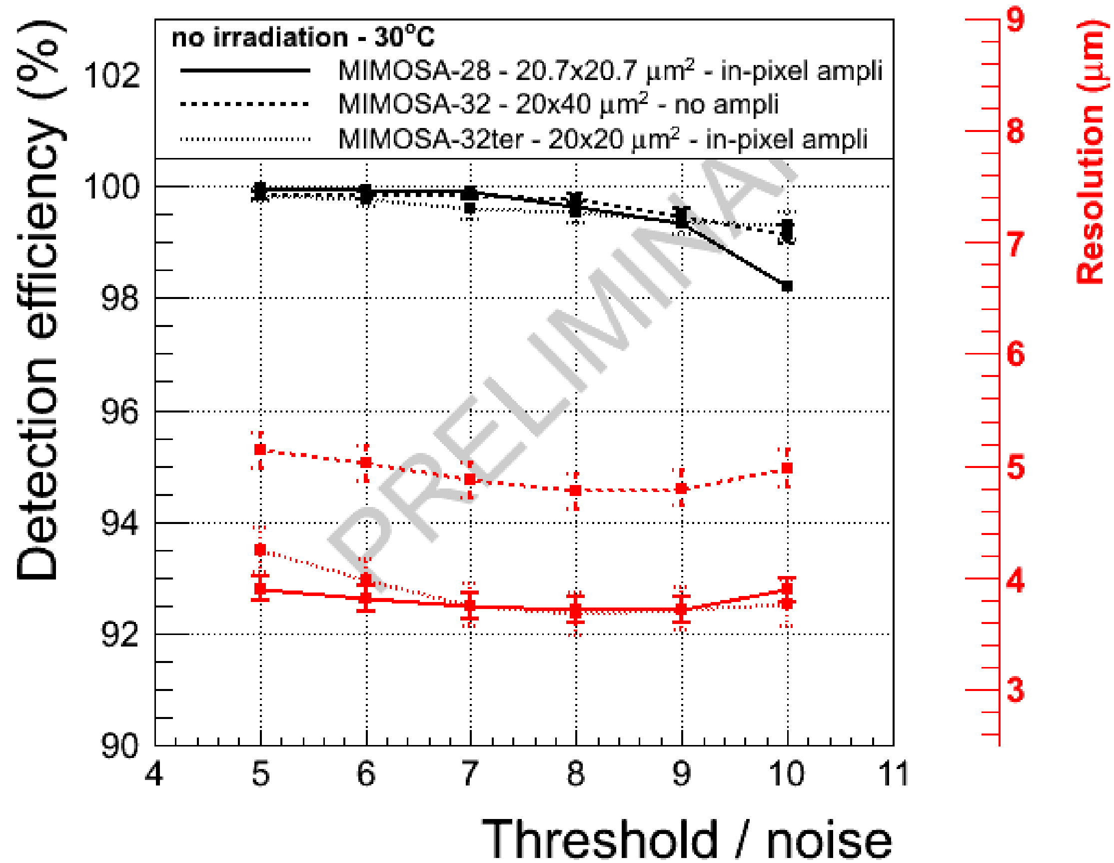


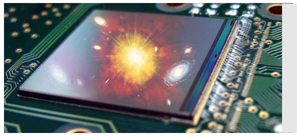
- **Comparison of**
  - ✗ **MIMOSA-28** (true binary output)

    0.35 µm technology (< 1 kΩ.cm)
    20.7x20.7 µm² pixel
    in-pixel ampli+CDS
  - ✗ **MIMOSA-32**

    0.18 µm technology (> 1 kΩ.cm)
    20x40 µm² pixel
    no ampli in-pixel
  - ✗ **MIMOSA-32ter**

    0.18 µm technology (> 1 kΩ.cm)
    20x20 µm² pixel
    in-pixel ampli+CDS



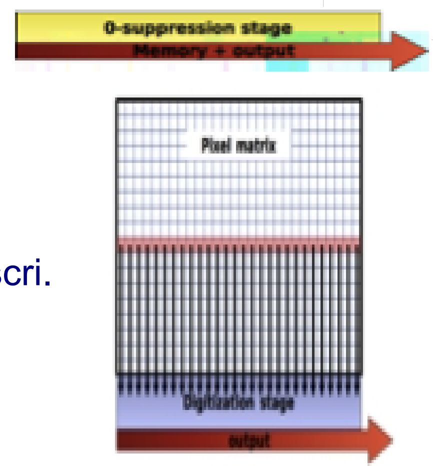


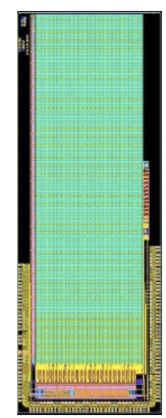
Sensors in 0.18 µm techno. roadmap – 1/2

- **2012 achievements**
  - ✗ Charge collection properties validated (elongated pixel incl.)
  - ✗ In-pixel amplification with CDS solution identified

- **Intermediate prototypes**
  - ✗ MIMOSA-32/34
    - ↪ Optimization (noise, collect. diode, ampli.) sensors
  - ✗ SUZE-02
    - ↪ 2D zero-suppression logic (320 MHz / output)
    - ↪ clusters encoded on 4x5 pixel window
  - ✗ MIMOSA-22THR
    - ↪ 136 col. X 320 pixels (22x33 µm²)
    - ↪ 128 discriminators
    - ↪ In-pixel ampli + CDS with column-level discri.
  - ✗ AROM-0
    - ↪ In-pixel ampli + CDS + discriminator
  - ✗ MIMADC
    - ↪ In-pixel 3-bits ADC

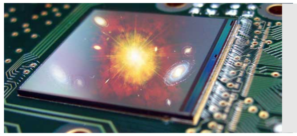
- **Sensors for ALICE-ITS**
  - ✗ MISTRAL
    - ↪ Pixel 22x33 µm²
    - ↪ Column-level discriminators
    - ↪ Multi-row read-out → 30 µs
    - ↪ Power < 350 mW/cm2
  - ✗ ASTRAL
    - ↪ Pixel 22x33 µm²
    - ↪ Pixel-level discriminator
    - ↪ Read-out → 15 µs
    - ↪ Power < 200 mW/cm2





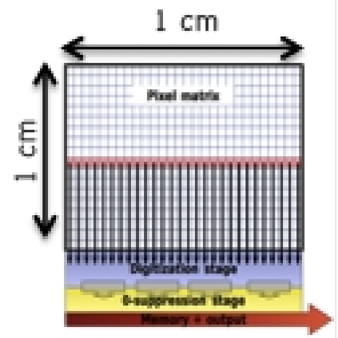
➡ All submitted in same engineering run in Q1-2013 -> delivery June 10

➡ Beam-test foreseen for MIMOSA-34 & MIMOSA-22THR in August 2013 at DESY



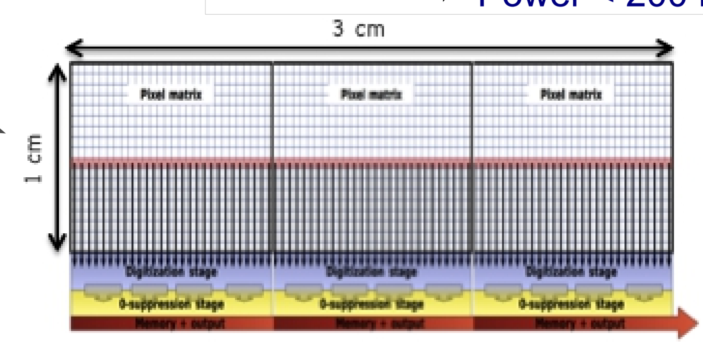
Sensors in 0.18 µm techno. roadmap – 2/2

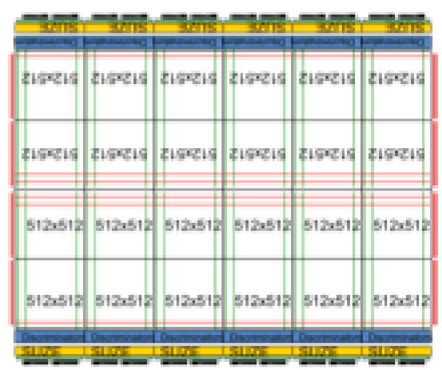
- **Intermediate prototypes continued**
  - ✗ Full Scale Basic Bloc = FSBB
    - ↪ Array of final pixel design (~1 cm^2)
    - ↪ Combined with 0-suppression
  - ✗ FSBB-M (MISTRAL) Q1/2014
  - ✗ FSBB-A (ASTRAL) Q2/2014



- **Sensors for ALICE-ITS**
  - ✗ MISTRAL
    - ↪ Pixel 22x33 μm^2
    - ↪ Column-level discriminators
    - ↪ Multi-row read-out → 30 µs
    - ↪ Power < 350 mW/cm2
  - ✗ ASTRAL
    - ↪ Pixel 22x33 μm^2
    - ↪ Pixel-level discriminator
    - ↪ Read-out → 15 µs
    - ↪ Power < 200 mW/cm2

- **Final prototypes**
  - ✗ MISTRAL (3 cm^2) Q1/2015 (TBC)
  - ✗ ASTRAL (3 cm^2) Q4/2015 (TBC)
  - ✗ MIMAIDA: 2015
    - ↪ Sensitive area = 4x6 cm^2

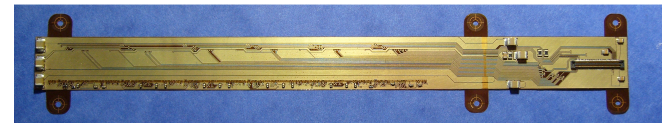




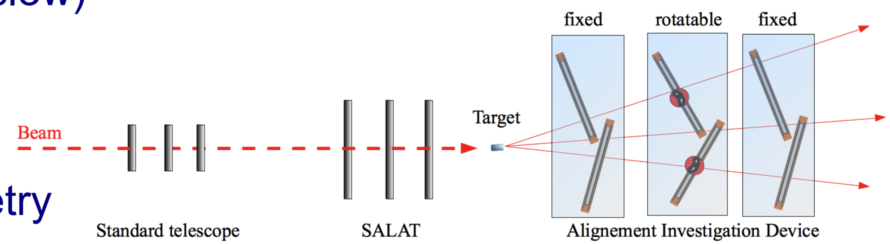
System roadmap

PLUME

- Double-sided ladders with ILD geometry and material budget 0.6 % X_0
  - ↪ produced, tested in beam, power-pulsing in progress



- New double-sided ladders with material budget 0.35 % X_0
  - ↪ Production in progress (aluminum cable fab. slow)



Alignment Investigation Device

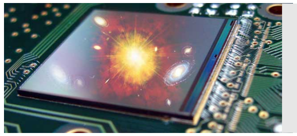
- 3 stations with 2 ladders each in sector-like geometry
  - ↪ delayed due to collaboration recomposition

Integration studies performed by ALICE collaboration

- Internal Tracker System upgrade → 9 m^2 equipped with CPS
  - ↪ 7 single-sided layers from r = 2.2 cm to r = 43 cm
  - ↪ material budget goal = 0.3 to 0.5 % X_0 (depends on radius)

- Mechanical support
  - ↪ light carbon-fiber trussed structures
- Cooling
  - ↪ micro-channel manufactured in polyimide cable

- Bonding
  - ↪ “cold” ball-grid array type interconnection



Summary and Outlooks

- Technology unveiling real CPS potential identified
  - ✗ TowerJazz 0.18 µm process
  - ✗ First prototypes (2011-12) validated detection features of the technology
  - ✗ Prospect to reach CPS matching 1 TeV running conditions

- Roadmap
  - ✗ Intermediate prototypes: fabrication 2013-14, tests 2013-14
  - ✗ Final sensors for ALICE-ITS: 2015
  - ✗ Adaptation to ILC-VTX: 2017-19

- Progress on systems exploiting CPS
  - ✗ First CPS-based vertex detector operating in STAR since this month
  - ✗ Integrations studies ongoing in ALICE for a 9 m^2 CPS-system (<u>inner and outer layers</u>)
    - ↪ Installation foreseen in 2017

ADDITIONAL SLIDES