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Monolithic Active Pixel Sensors for Charge Particle Tracking tests results

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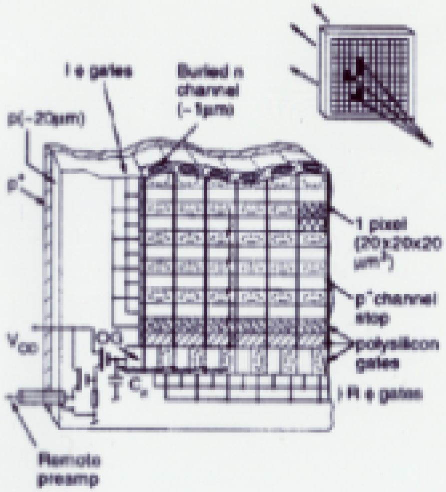
Contents

- Idea and basic architecture of a CMOS MAPS
- Prototype MIMOSA chip
- High energy particles beam test results :
  S/N, efficiency, charge distribution, spatial resolution
- Magnet test results
- Conclusion and Future Development Prospects

PIXEL DETECTORS

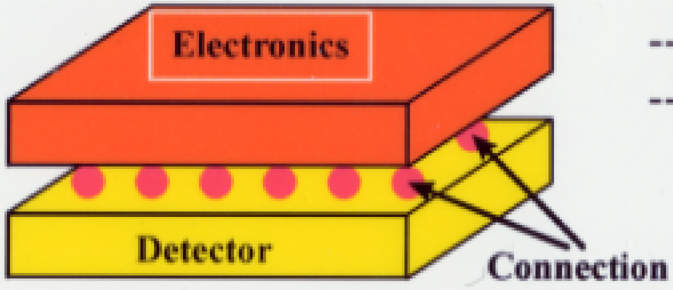
CCD



--> Imaging
--> High Energy Physics (SLD)

APS (Active Pixel Sensor)

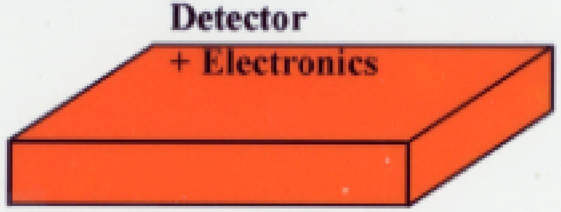
hybride APS



--> High Energy Physics (DELPHI, ...)

High Resistivity monolithic APS

--> High Energy Physics
--> Complex technology



Low Resistivity monolithic APS

--> Imaging
--> Standard VLSI Technology

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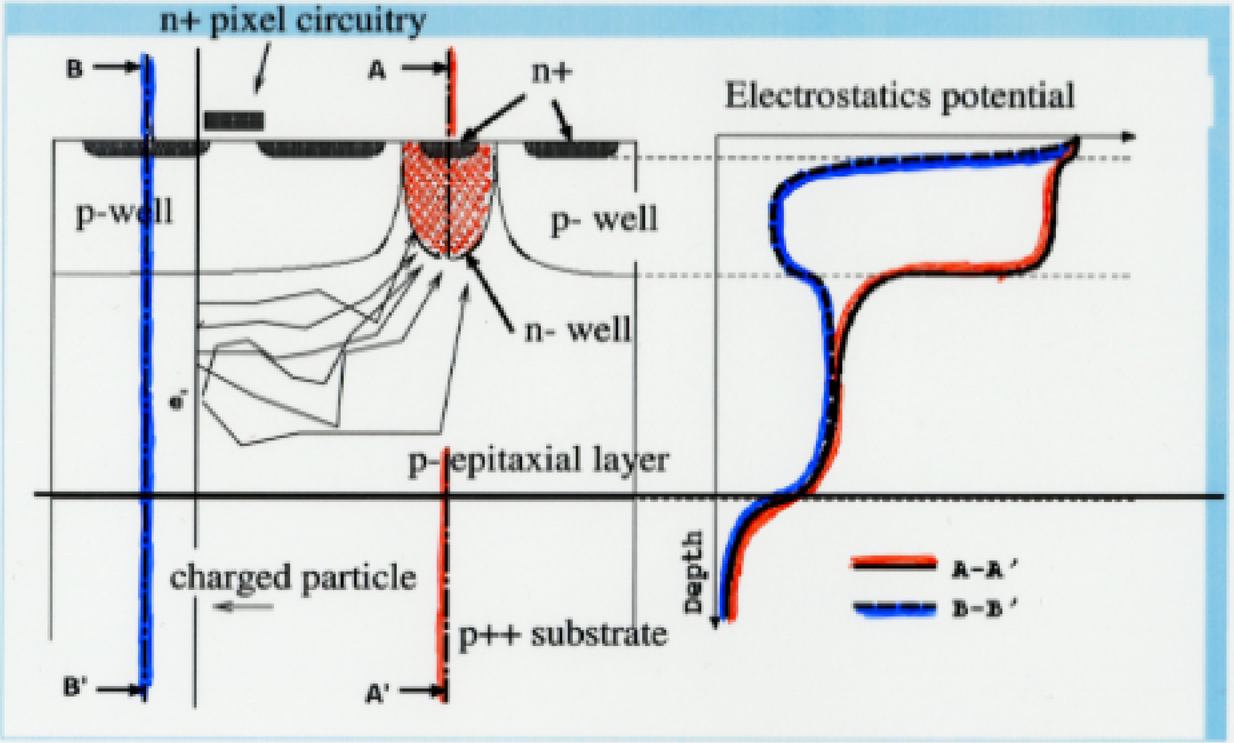
Cross-section of a CMOS wafer with a charge collecting structure allowing 100% Fill Factor, essential for tracking application



Advantages of a standard (submicron) CMOS : availability, cost, radiation hardness,
feasibility of a "system on a chip" solution

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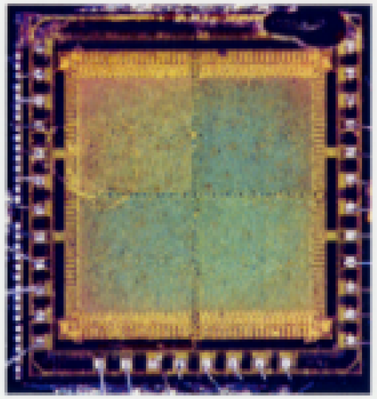
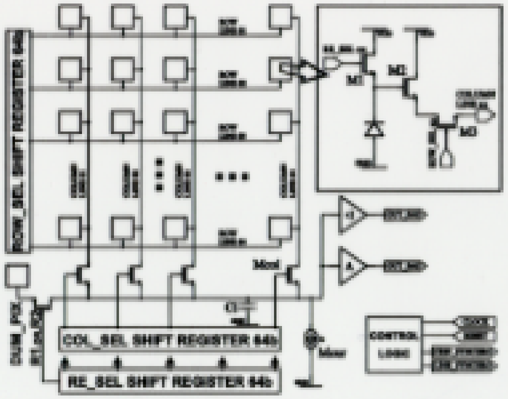
Mimosa I and Mimosa II single cell electronics and readout architecture



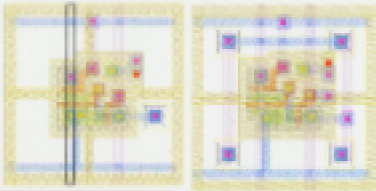
MIMOSA I die photo

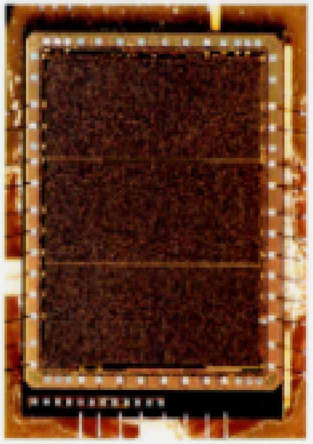


MIMOSA I block schematic diagram

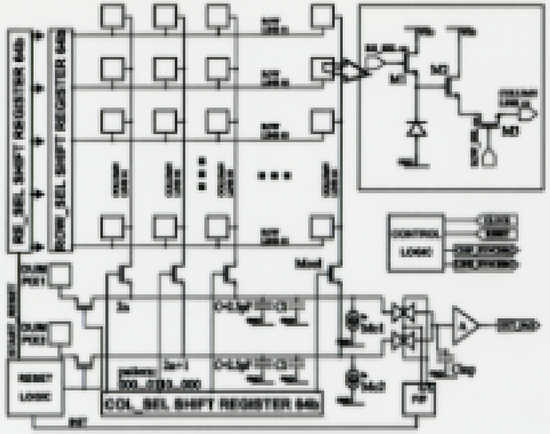
- standard 0.6μm CMOS (tox=12.7nm)
- 14μm thick EPI layer ($10^{14}cm^{-3}$)
- 4 arrays 64x64 pixels
- pixel pitch 20x20μm^2
- diode (nwell/p-epi) size 3x3μm^2 - 3.1fF
- serial analogue readout
- max. clock freq.: 5MHz
- die size 3.6x4.2mm2
- technology 3M+2P
- power supply 5V

MIMOSA I pixels layouts





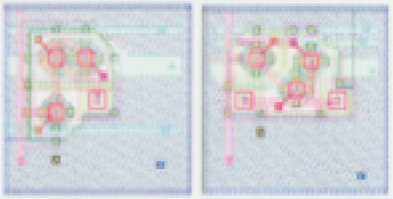
MIMOSA II die photo



MIMOSA II block schematic diagram

- standard 0.35μm CMOS (tox=7.4nm)
- 4.2μm thick EPI layer ($10^{15}cm^{-3}$)
- 6 arrays 64x64 pixels
- pixel pitch 20x20μm^2
- diode (nwell/p-epi) size 1.7x1.7μm^2 - 1.65fF
- serial analogue readout
- max. clock freq.: 25MHz
- die size 4.9x3.5mm2
- technology 5M+2P
- power supply 3.3V
- radiation tolerant
- transistor design

MIMOSA II pixels layouts



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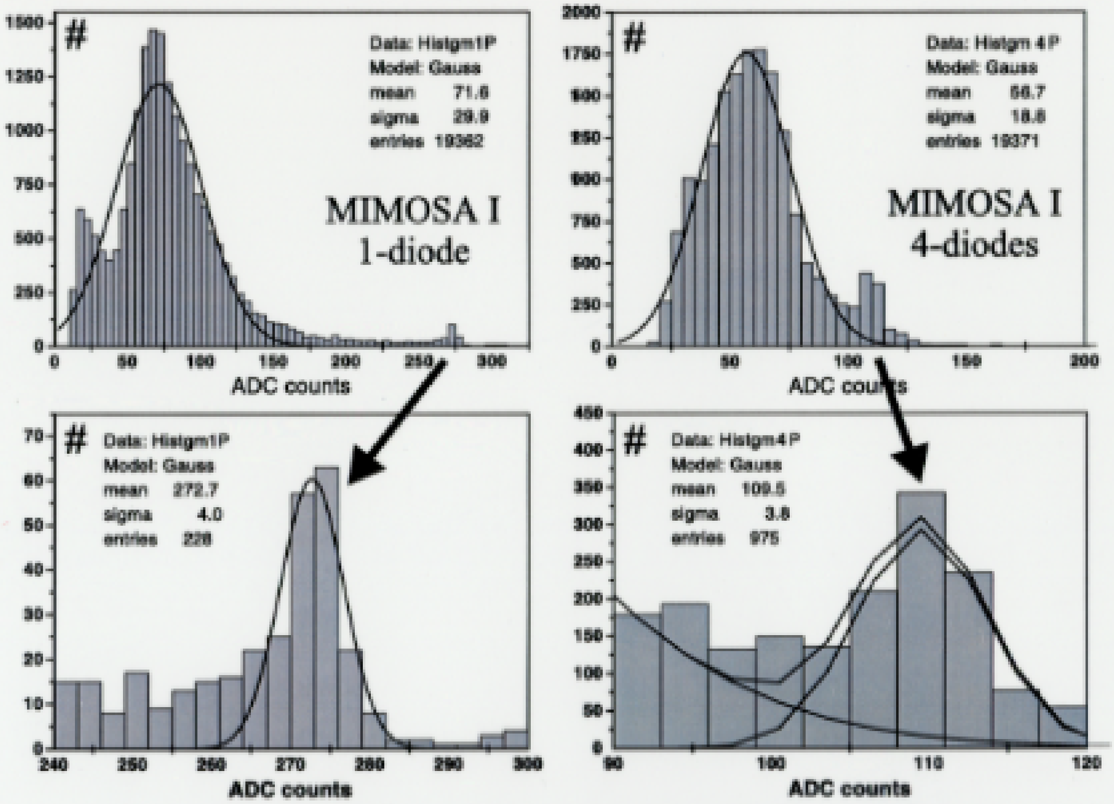
Gain calibration using soft X-rays (5.9 keV from ^{55}Fe)



- The "big peak" doesn't correspond with 100% of charge collection

- Taking second peak position (conversion in a depletion region of the collecting diode)...

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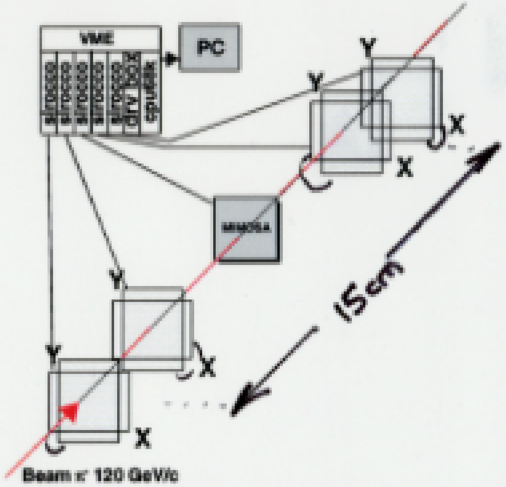
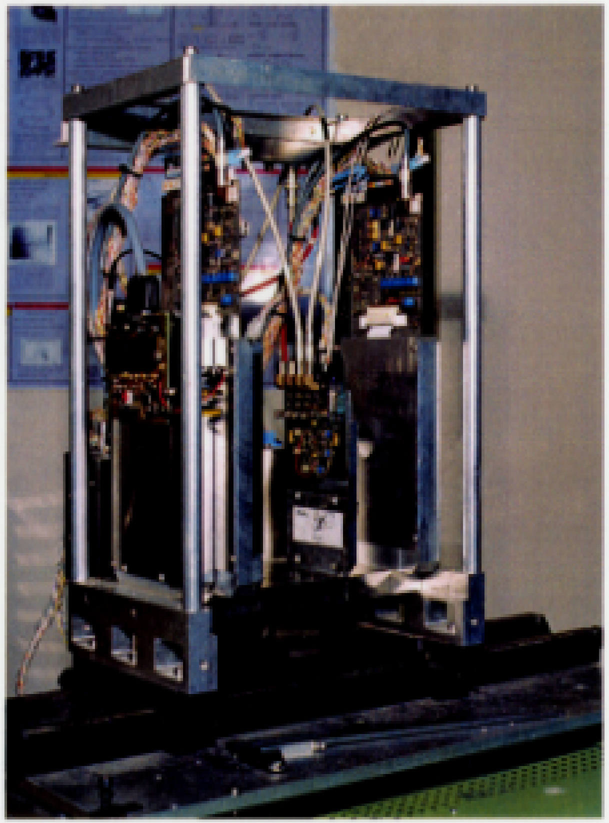
Testbeam setup

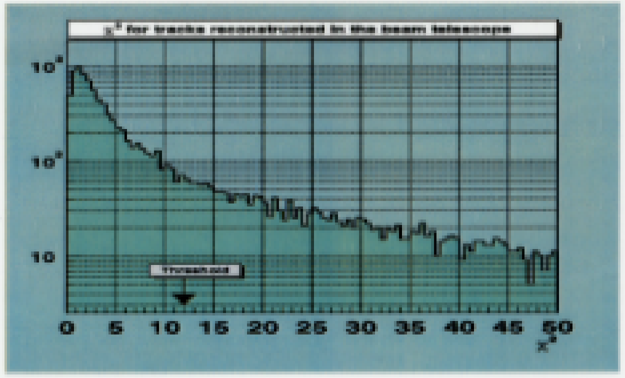
@CERN SPS: π 120 GeV/c
Precise silicon strip beam telescope with 8 planes (X,Y) with resolution of ~2μm

DAQ based on VME OS9





After the alignment, tracks reconstruction and selection...



...the track position in the middle of the telescope was predicted with precision ~1μm.

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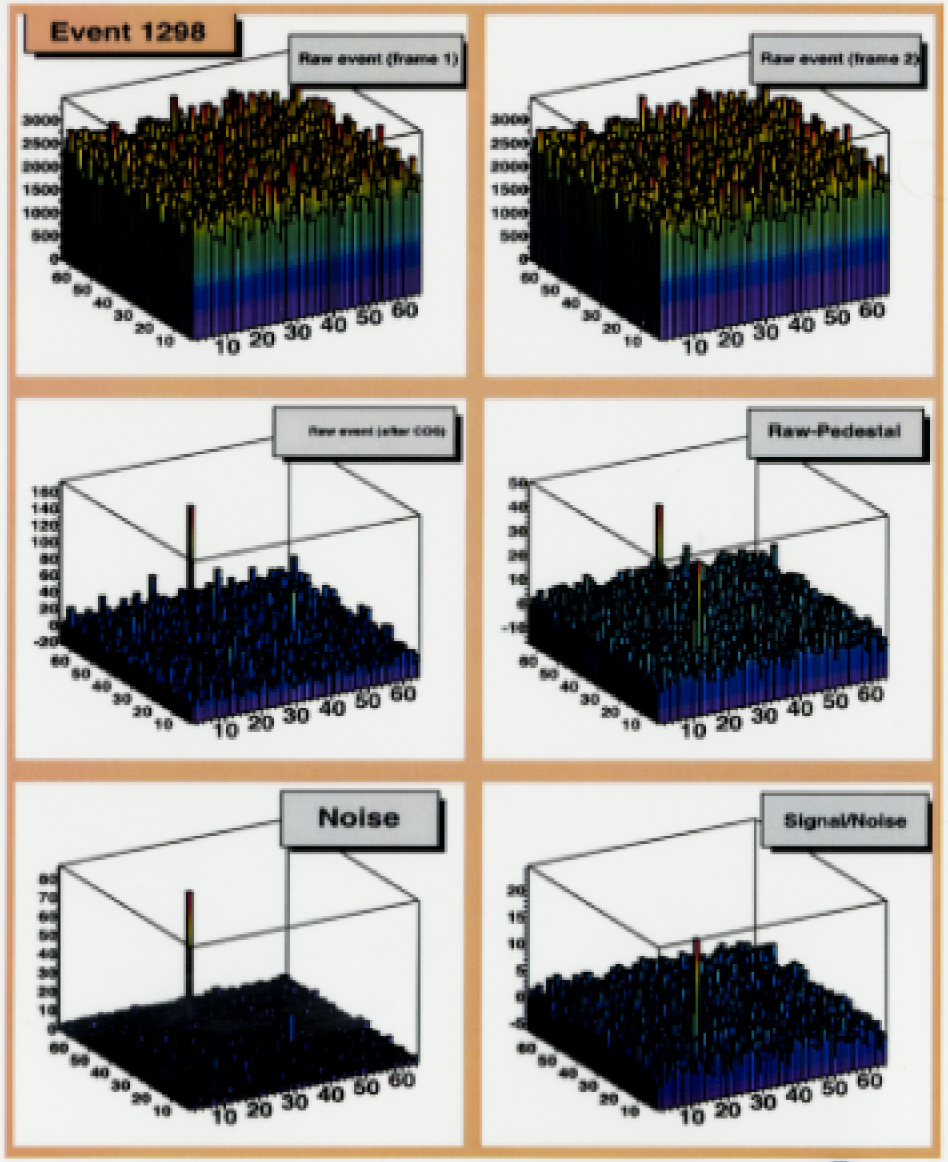
Signal processing



Off-line CDS processing to eliminate kTC noise, common mode, FPN...

Remaining noise due to leakage current fluctuations measured in first 250 events is used for S/N analysis in pattern recognition

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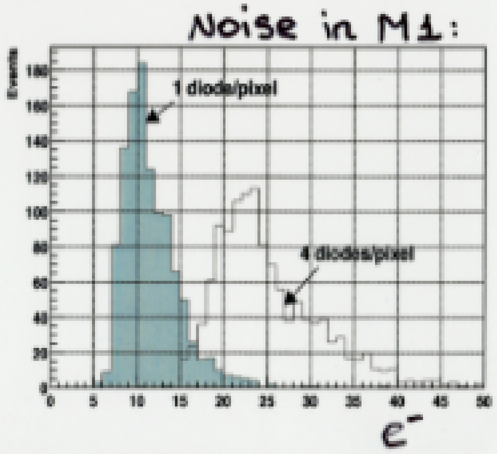
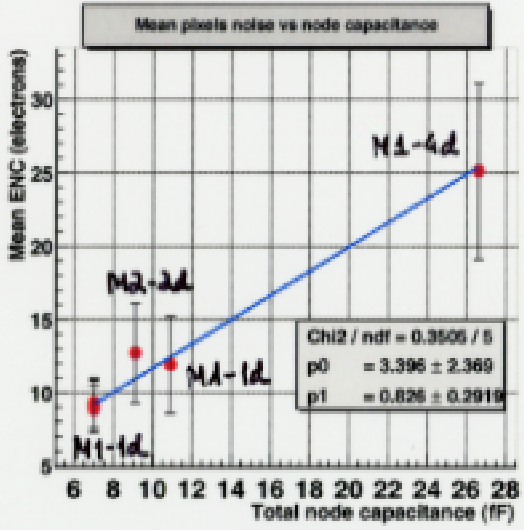
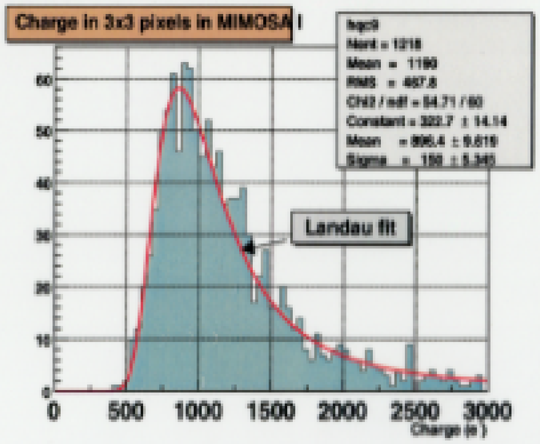
Charge collection

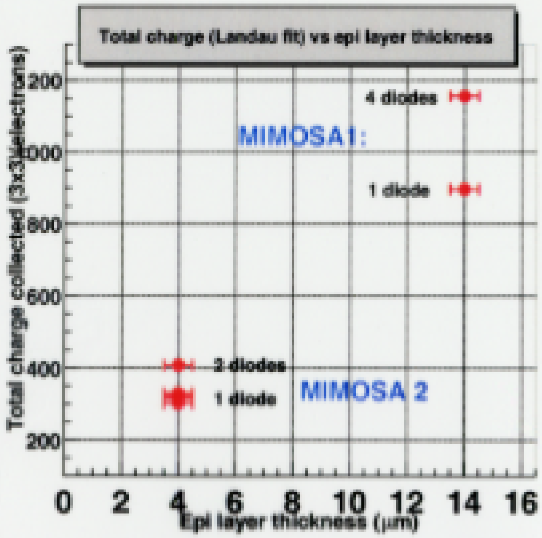
After CDS only noise due to the leakage current fluctuations at the level of a few electrons remained...





... and the signal of few hundreds of electrons was observed in accordance with the simulation





Collected charge: (e, δ ~ 1%)

		seed pixel	3x3 cluster
MIMOSA 1:	1 diode	302	896
	4 diodes	517	1155
MIMOSA2:	1 diode	110	315
	2 diodes	136	407

Signal-to-noise (mean):

MIMOSA I:	1 diode	42
	4 diodes	32
MIMOSA II:	1 diode	21

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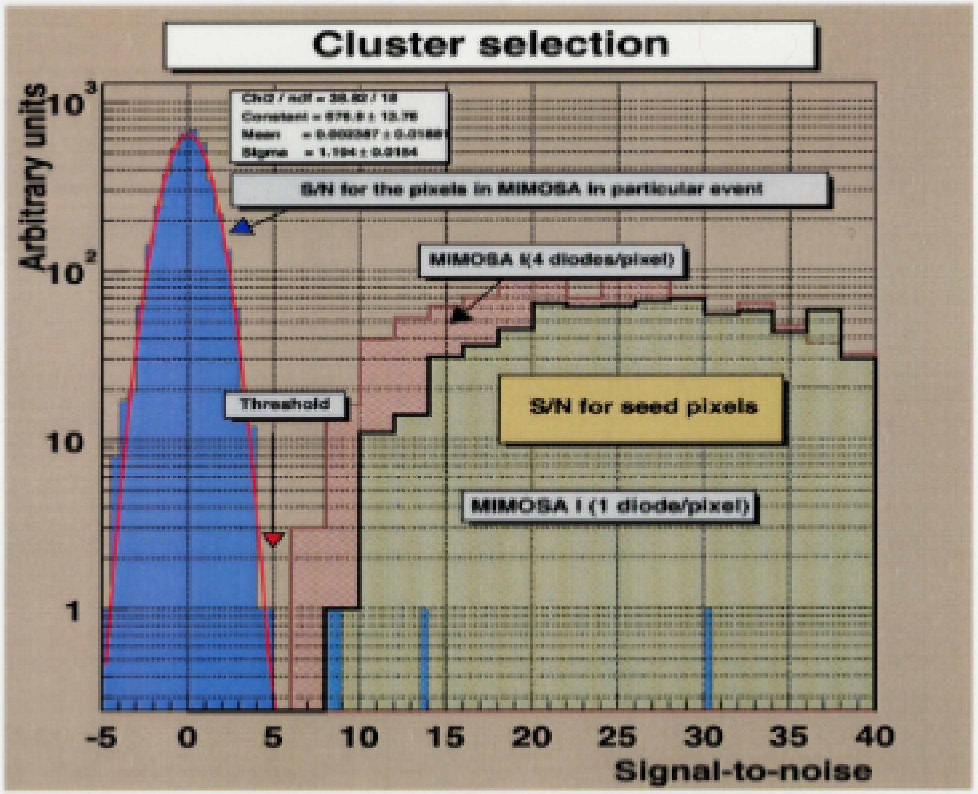
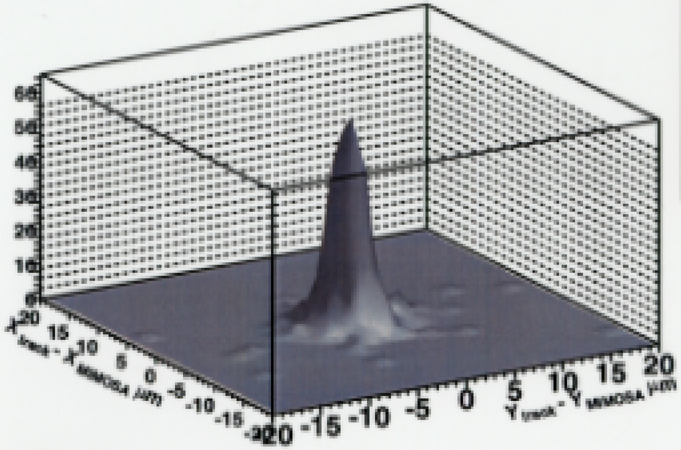
Pattern recognition and efficiency

The high S/N made the pattern recognition easy, clusters were selected using the pixels with S/N>5 as a seed



The cluster matching the track impact point was found in MIMOSA...



...with high

Efficiency (%)

MIMOSA I: 1 diode	99.5 +/- 0.2
MIMOSA I: 4 diodes	99.2 +/- 0.2
MIMOSA II: 1 diode	98.5 +/- 0.3

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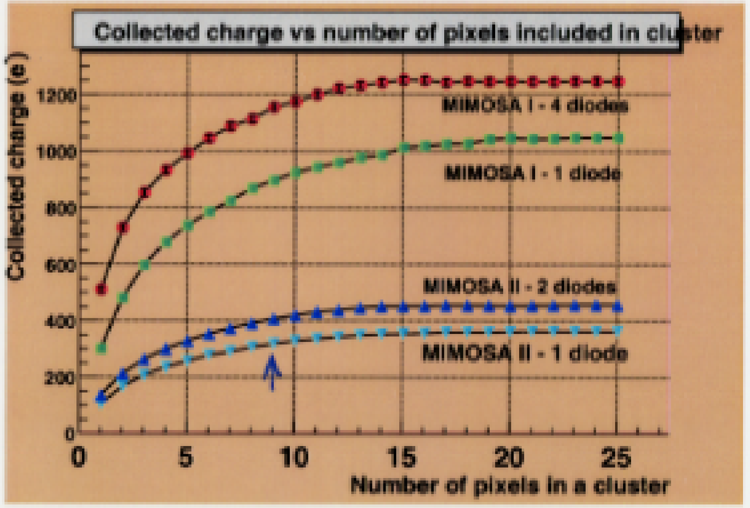
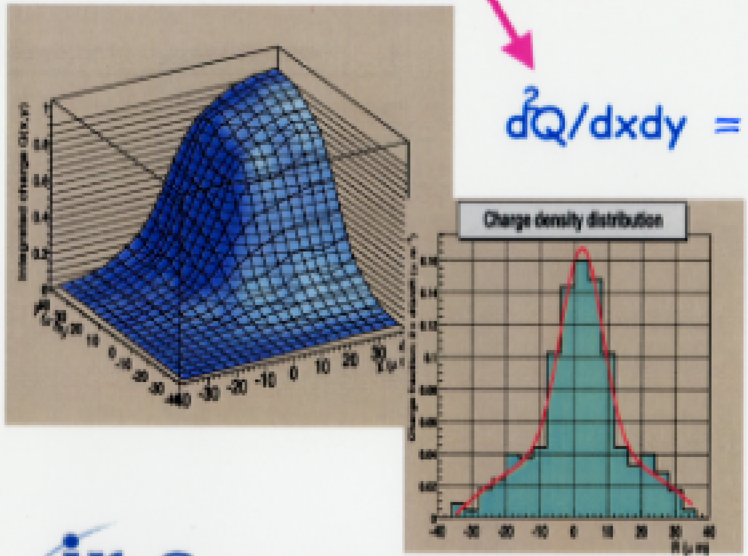
Charge distribution

Charge is spread within a cluster of few pixels:

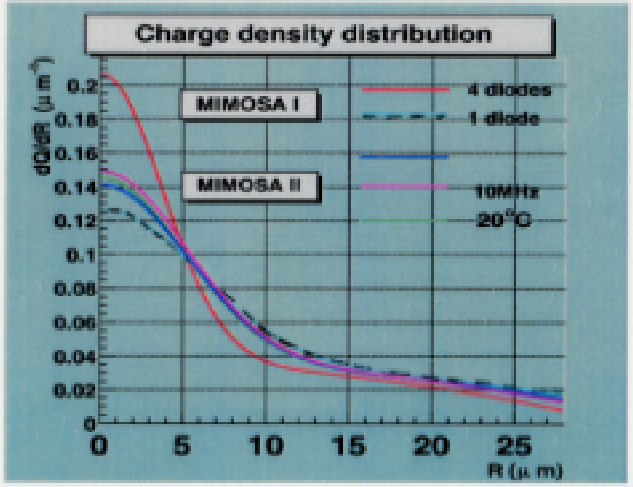


Charge density distribution was measured as follows:

$$Q(x_0,y_0)=\int_{-\infty}^{y_0} dy \int_{-\infty}^{x_0} q(x,y)dx$$



$$d^2Q/dxdy = q(x,y) = q(R)$$



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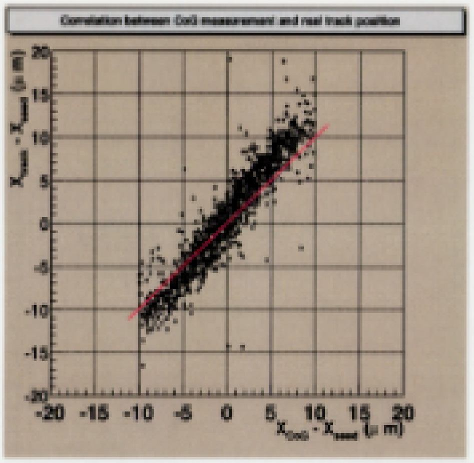
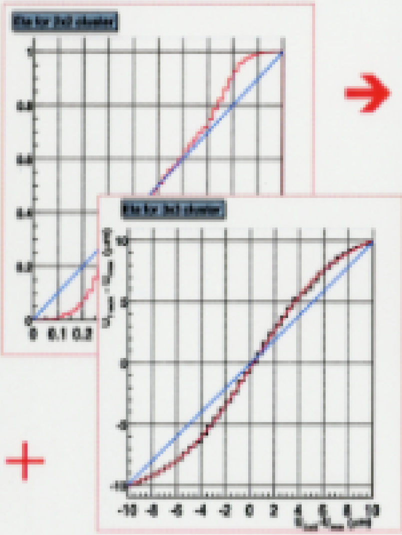
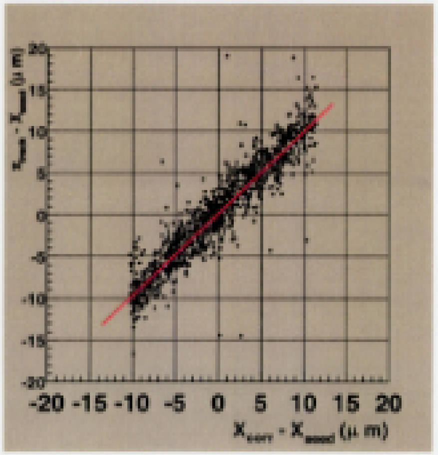
Spatial resolution

Measure the hit position as a CoG of charge in the cluster...

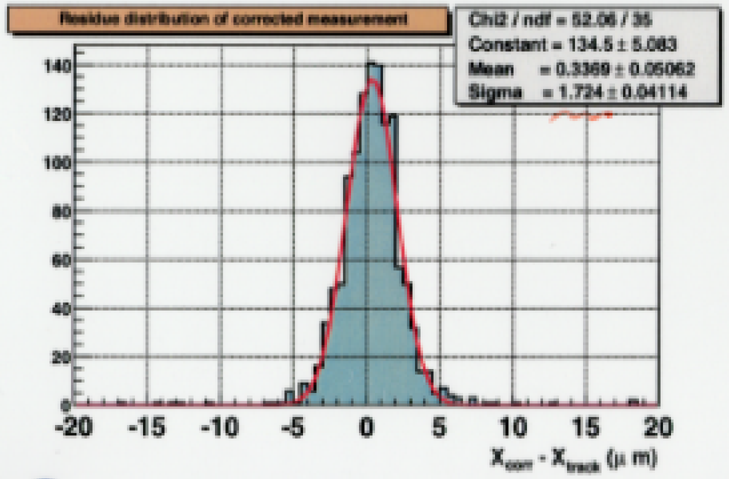






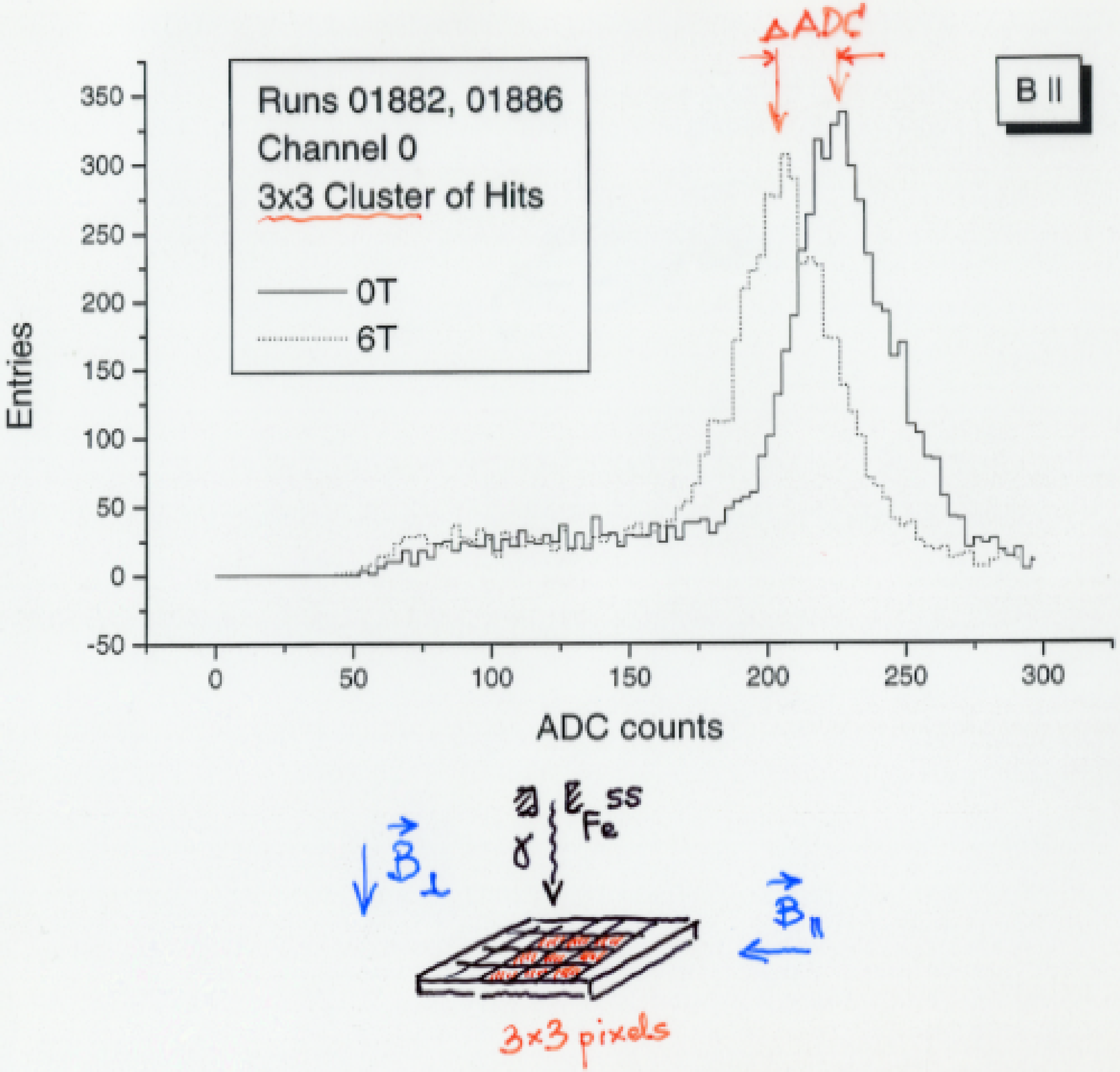
...with correction

... comparing measurements with the BT prediction, and taking into account its resolution (1μm)



Spatial resolution (μm):

MIMOSA I:	1 diode	1.4+/-0.1
	4 diodes	2.1+/-0.1
MIMOSA II:	1 diode	2.2+/-0.1


ΔADC
B II
Runs 01882, 01886
Channel 0
3x3 Cluster of Hits
0T
6T
Entries
ADC counts
350
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
300
γ
B⊥
B∥
3x3 pixels

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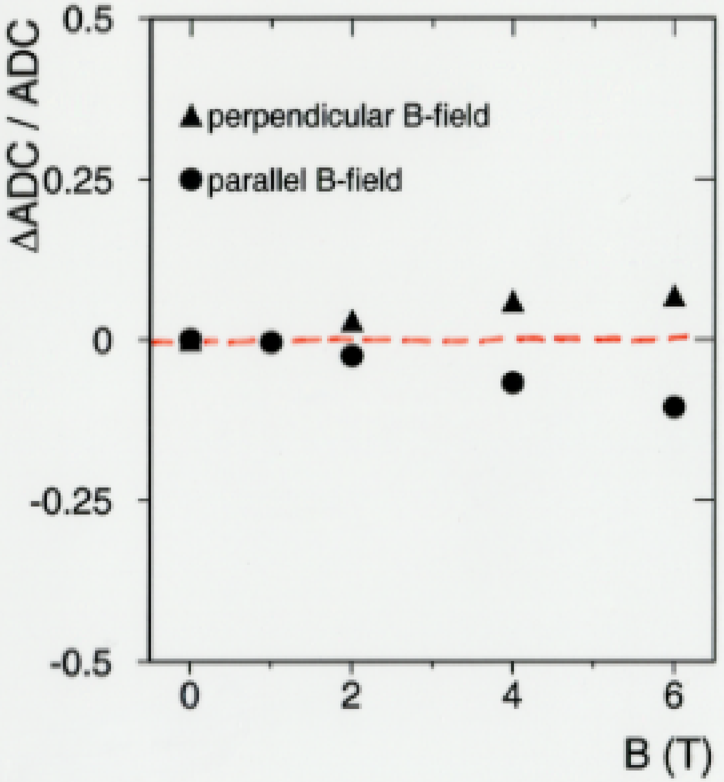
Magnet tests

Magnet tests were performed at superconductive magnet of ITP (Karlsruhe)...

...only modest influence was observed



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Conclusion and prospects

- Both prototypes 0.6 and 0.35 μm CMOS Monolithic Active Pixel Sensor work as a minimum ionising particles detector!

- Charge collection : reasonably fast (~100ns), spread limited to few pixels, good agreement between device simulation and measurements, only modest effects of magnetic field (up to 6 Tesla, both directions)

- High energy particles beam test results :

S/N 20-40, ~100% detection efficiency, spatial resolution up to <1.5μm

- Radiation hardness tests soon

- Short term future : large area (~10 cm^2) device (~mid 2001)

- Long term future : intelligent, high precision, ultimately thin, large area and low cost device.

- Other potential application (in addition to MIP tracking) : ?????