Status of the SOI monolithic active pixel detector development

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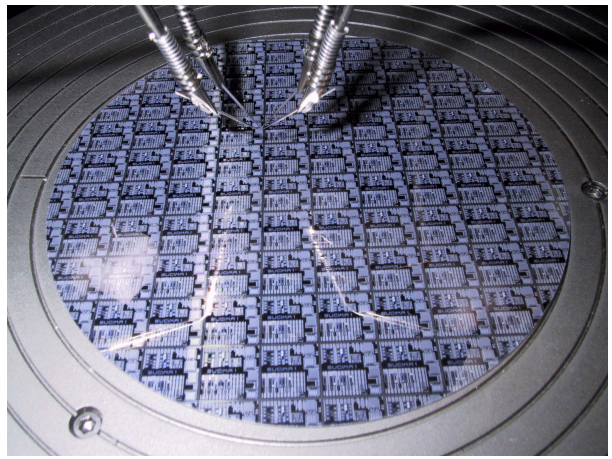
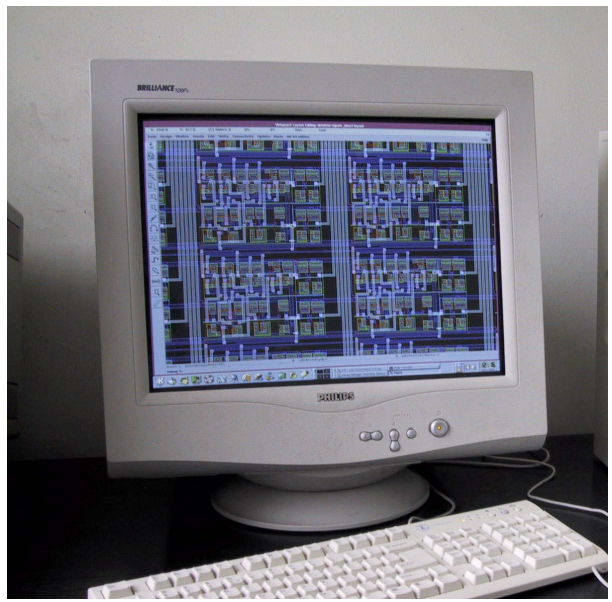
Outline

- Principle of the SOI sensor
- Advantages of the SOI monolithic active pixel sensor
- Preliminary measurements of the SOI sensors test structures – sensor response calibration and linearity measurements
- SOI detector measurements with SUCIMA Imager DAQ system
- Design of the full size SOI sensor – layout and readout scheme
- Alternative solutions of the SOI detector readout channel configurations





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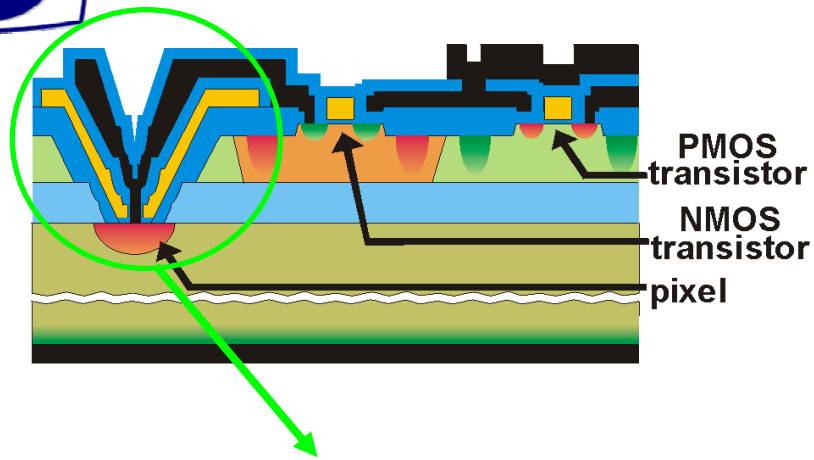
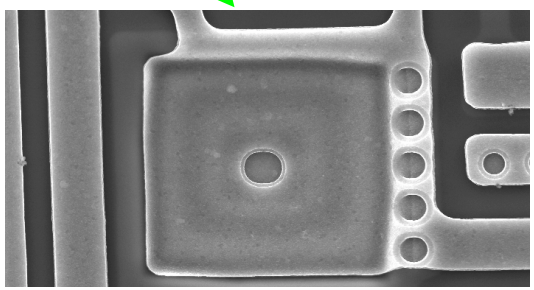
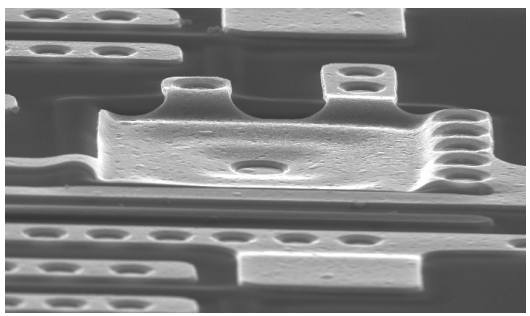
Principle of SOI monolithic detector







The idea:

Integration of the pixel detector and readout electronics in the wafer-bonded SOI substrate

Detector → handle wafer

- High resistive
  (> 4 kΩcm,FZ)
- 300 μm thick
- Conventional p^+-n
- DC-coupled

Electronics → active layer

- Low resistive
  (9-13 Ωcm, CZ)
- 1.5 μm thick
- Standard CMOS technology

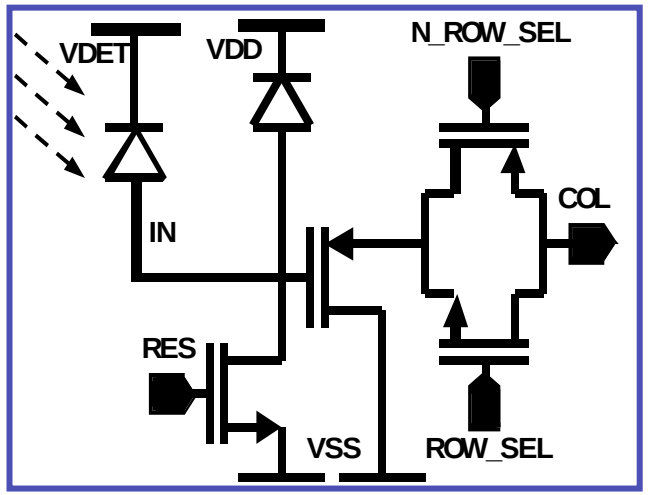
Advantages of the SOI detectors

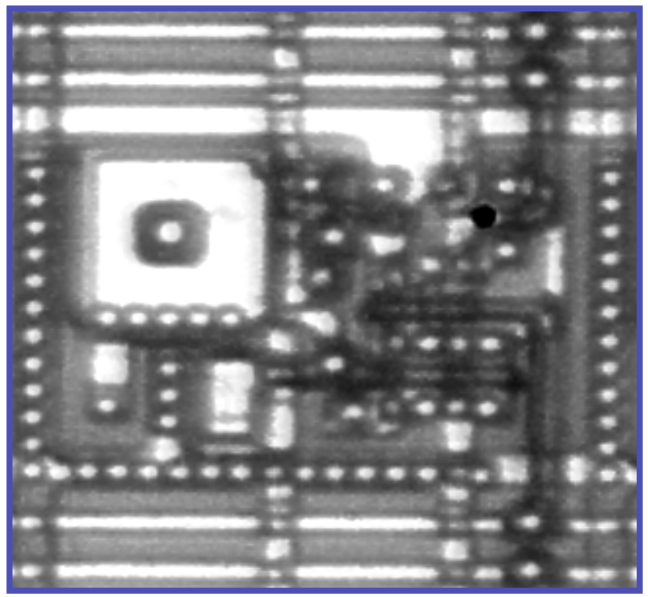
The SOI sensor may merge the advantages of the monolithic and hybrid detectors

- As a monolithic device eliminates bump-bonding process and allows reduction of total sensor thickness → reduction of multiple scattering
- Allows using high resistive detector substrates and operation in fully depleted region → good detection efficiency, enables detection of particles with limited range in the silicon without backthinning process
- Gives possibility to use both type of transistors in readout channels → increased flexibility of the design, design optimisation for different application
- Tolerance of readout electronics for SEE benefits from reduction of active silicon thickness

Test structures of the SOI detector

- Small readout matrices (8x8) with associated detector diodes were fabricated on the SOI wafers at the IET, Warsaw
- Optimised for medical imaging applications and high particle fluxes
- No digital control blocks
- Basic readout channel configuration similar to 3T cell, two variants:
  - with NMOS transistor switch
    - → cell dimensions 140x122 μm^2
    - → Measured dynamic range up to 150 MIP
  - with transmission gate
    - → cell dimensions 140x140 μm^2
    - → Measured dynamic range up to 300 MIP



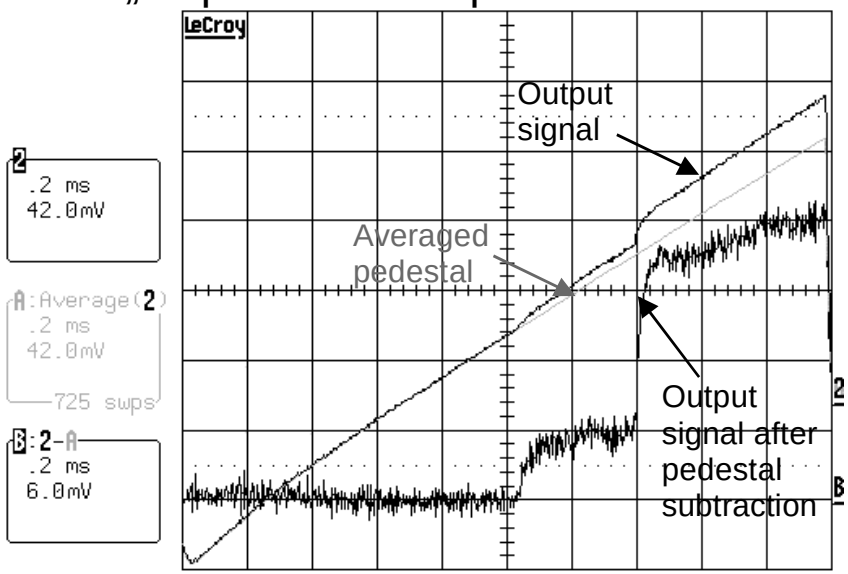


Preliminary measurements of the SOI sensor test matrices

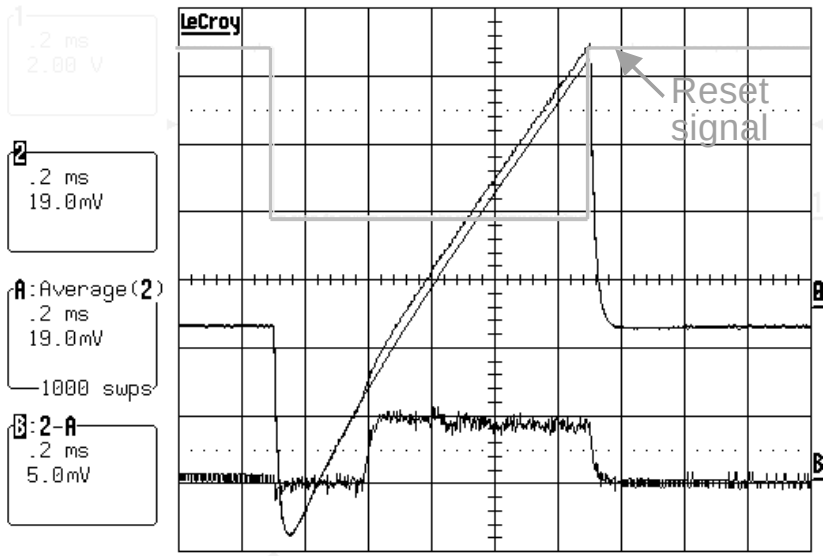
- Matrices with one-transistor switches were chosen for the preliminary tests of the sensor. Matrix dimensions: 1120 μm 976 μm.
- Detector leakage currents from 400 nA/cm^2 down to 10 nA/cm^2 depending on the process were achieved.
- Detector full depletion voltage of Vdet = 60 V down to 50 V for different iterations were measured.
- Detector sensitivity for ionising radiation have been tested with infrared laser light and alpha and beta particle sources

Strontium 90 beta source – recorded events in the detector

- „Steps" on the output waveforms indicate detected particles



T_{integ}=2 ms

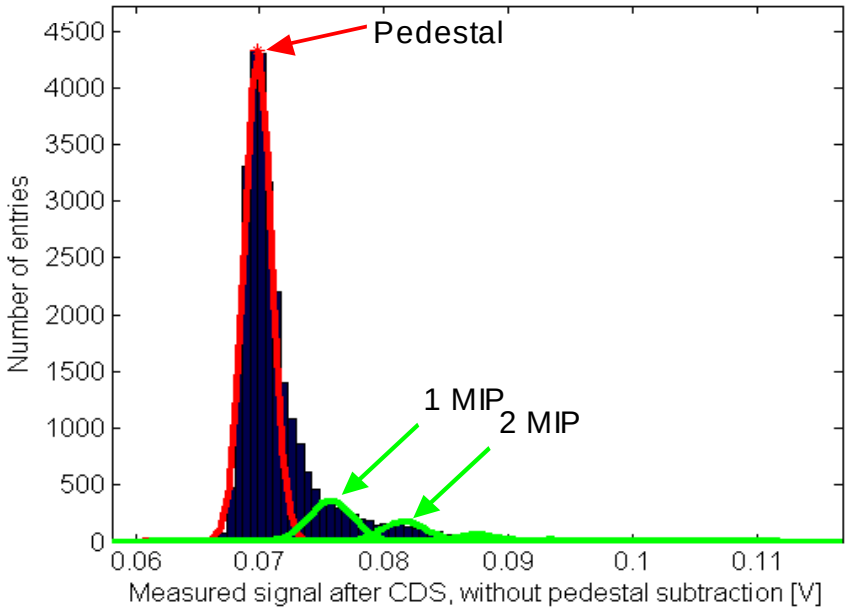


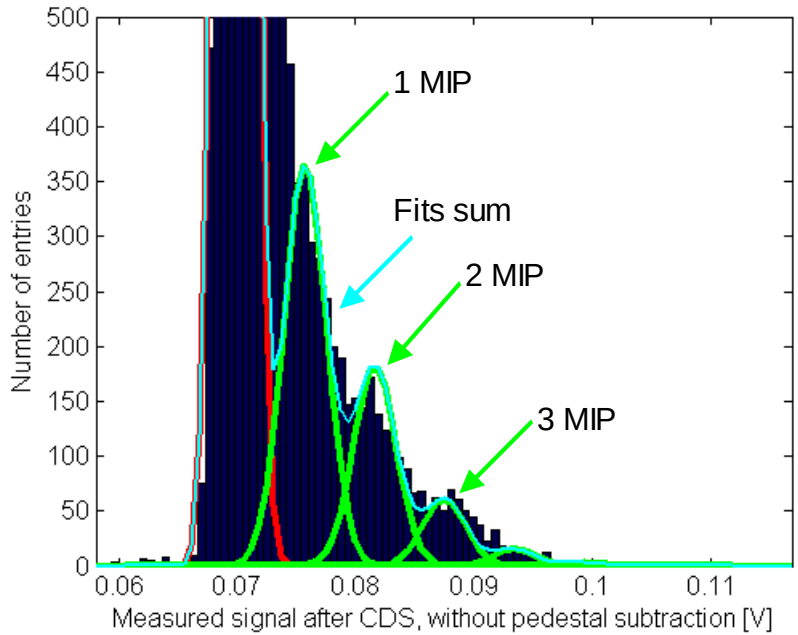
T_{integ}=1 ms

Calibration of the SOI sensor

- Radioactive source: Sr90 beta source
- Integration time: T_{int} = 500 μs
- Detector polarization: V_{det}= 60 V

5.9 mV/MIP





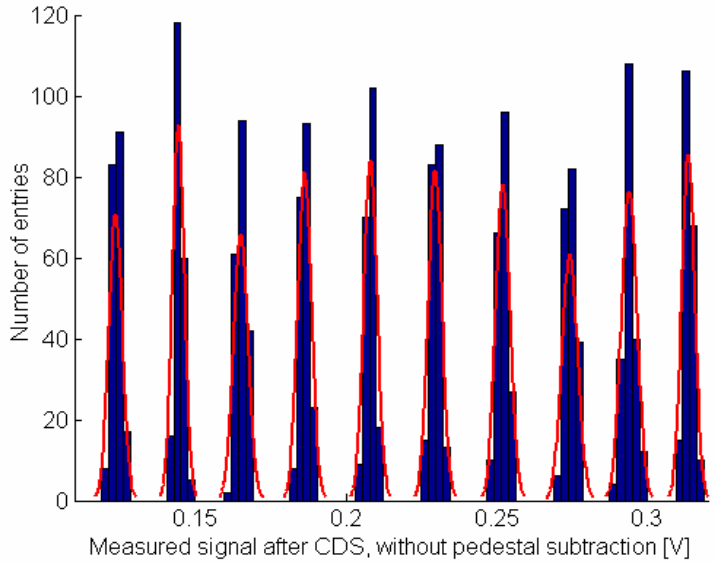
Pedestal value =69.9 mV ; pedestal width = 2·1.1 mV

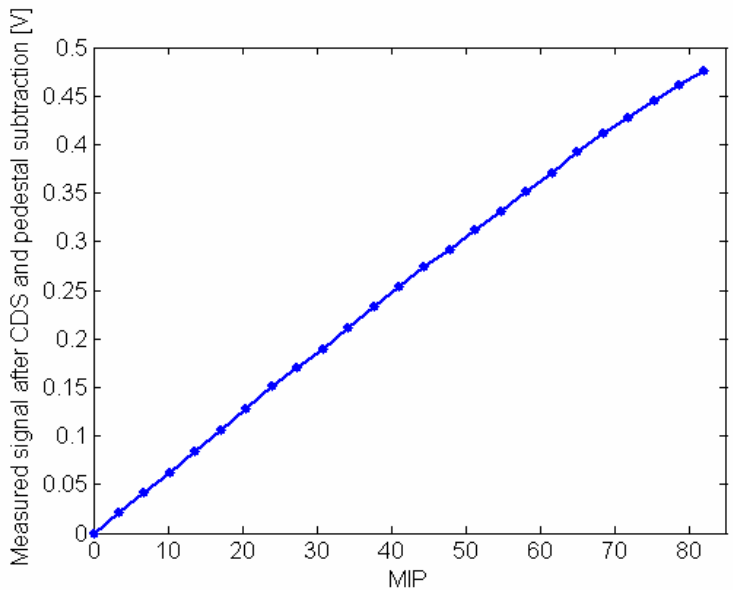
First signal peak= 75.8 mV; signal peak width = 2·1.8 mV

Preliminary tests with the laser light

- Laser light not focused, shining from the backplane (biased by metal mash)
- Wavelength = 850 nm
- 4 μs wide light pulses - each corresponding to 3.4 MIP
- Integration time = 1 ms
- Detector polarization=60V
- 10 000 events recorded

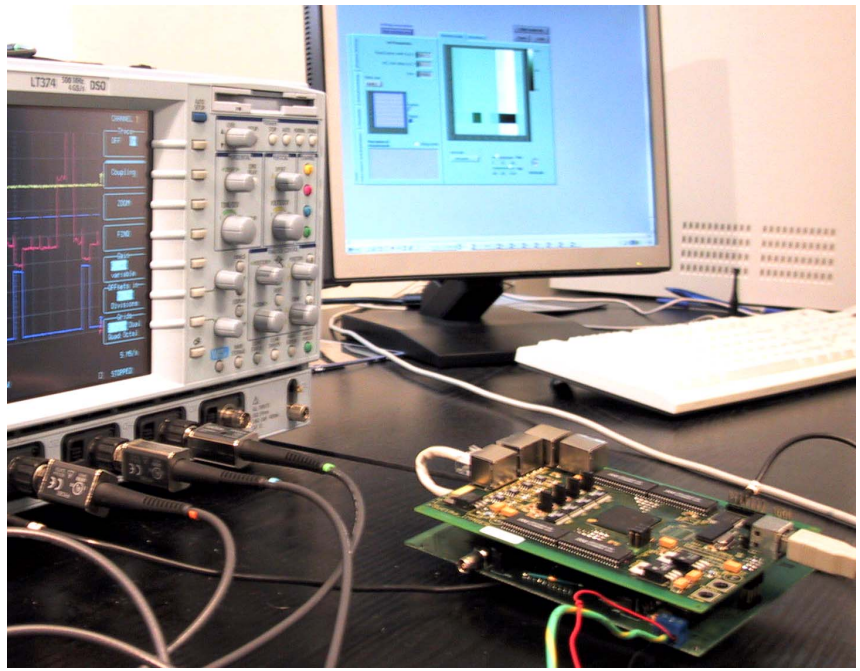
Good detector sensitivity for the ionising radiation and linear response as a function of the generated charge was observed.

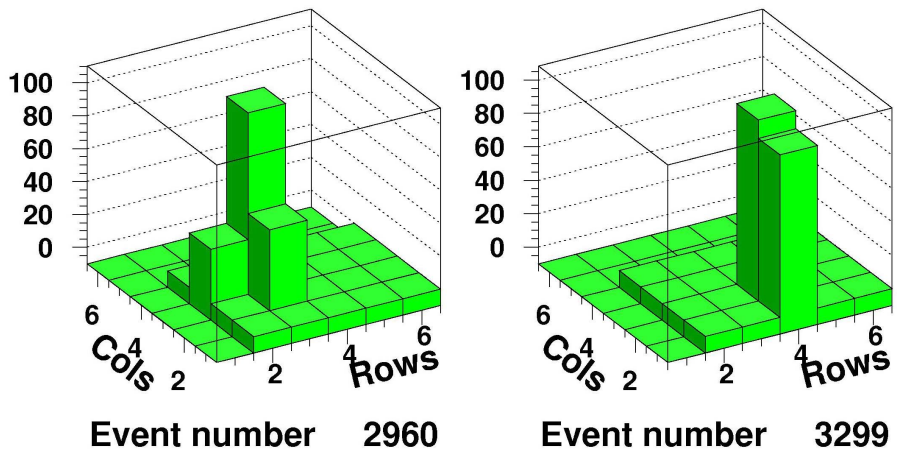




SUCIMA Imager DAQ for the SOI detector

- Further measurements of the SOI detector test structures were performed with DAQ system called „SUCIMA Imager" – developed at INP Krakow* for the SUCIMA project
- The DAQ is equipped with 4 independent analogue input channels with 12 bit ADCs and a 1MB fast Static RAMs, the FPGA Virtex II XC2V1000 chip for advanced algorithms and the high speed USB 2.0 port for a fast data transfer to and from a PC computer.
- GUI – developed in LabVIEW environment, allows setting: the matrix size to be readout, readout frequency; it provides: the CDS or Last Frame readout mode, masking noisy pixels, subtracting pedestals, suppressing signals bellow threshold and writing data to the file.

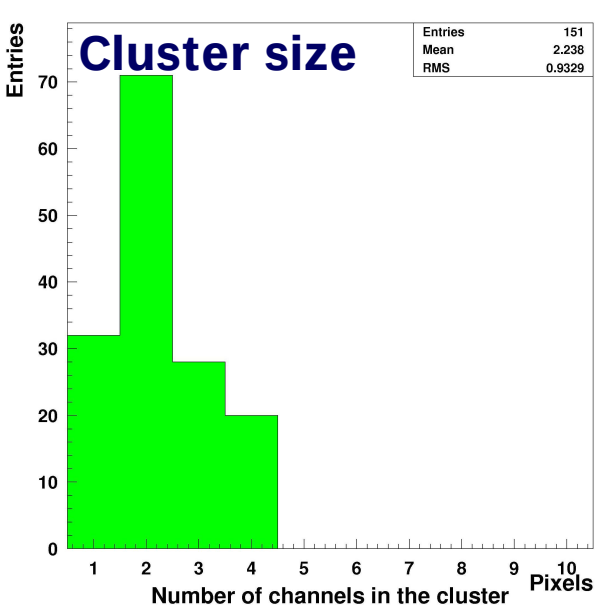


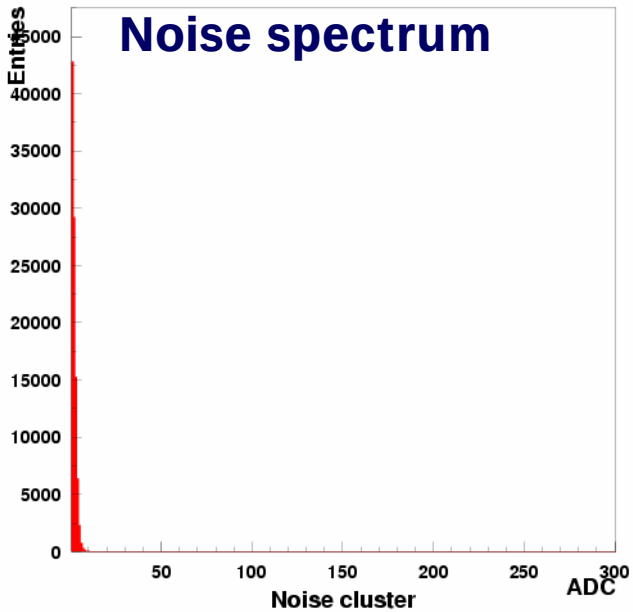


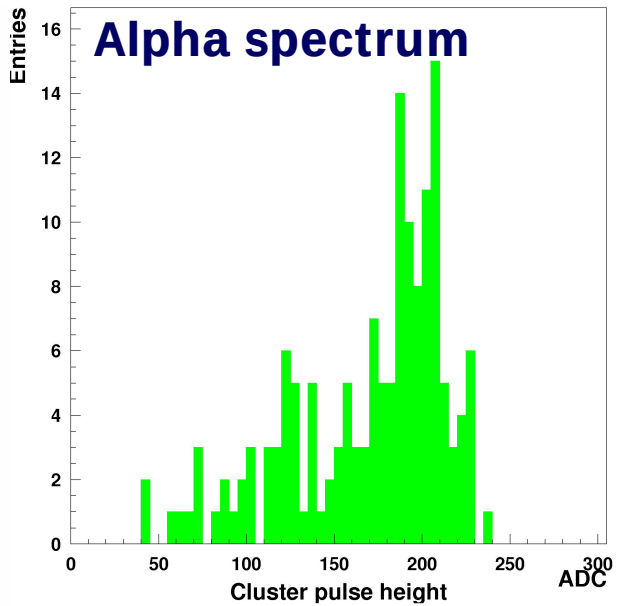
*INP Team: A. Czermak, B. Dulny, B. Sowicki, A. Zalewska

Measurements of alpha particles spectrum

- Alpha source placed at the distance of 1 cm from the detector backplane, detector fully depleted (V_D=70 V), integration time 720 μs
- On-line CDS processing, off-line pedestal subtraction, common mode suppression and cluster search
- Initial energy of particles = 5.5 MeV
- Typical measured cluster pulse height ≈ 200 ADC – corresponding to about half of the alpha particles initial energy (roughly 25 MIPs)
- Pedestal width – about 1.5 ADC, S/N for typical cluster pulse height ≈130
- Broad spectrum due to the air presence and the large distance between the detector and the source. Wide dynamic range of the detector was proved.

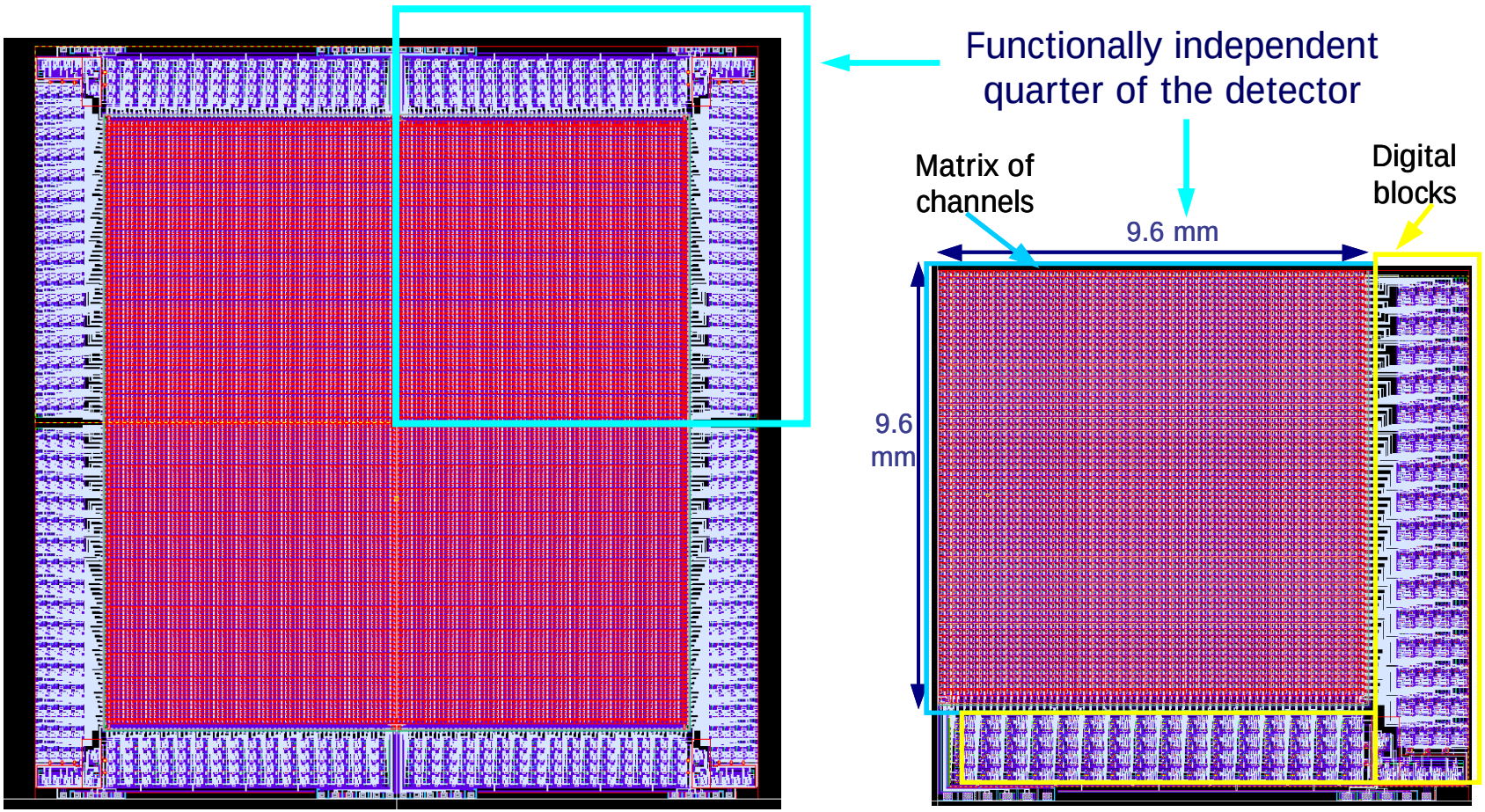






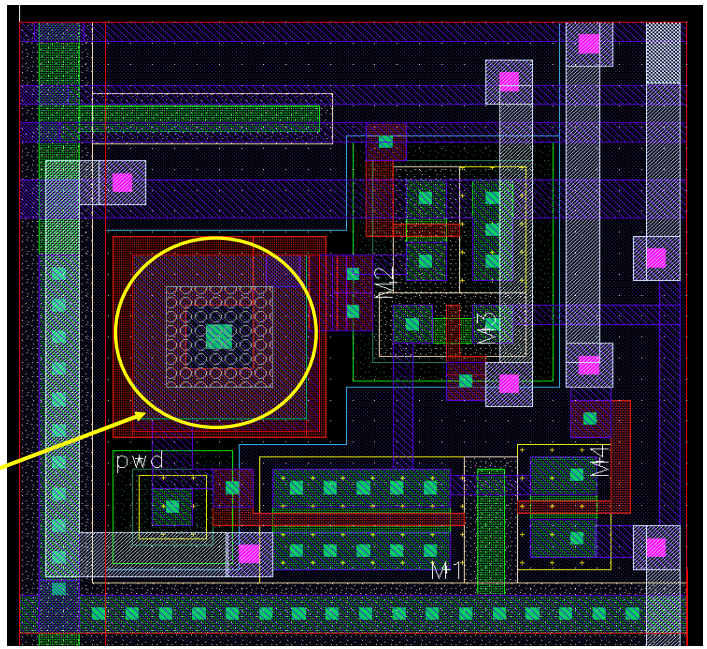
From test structures to the fully functional sensor...

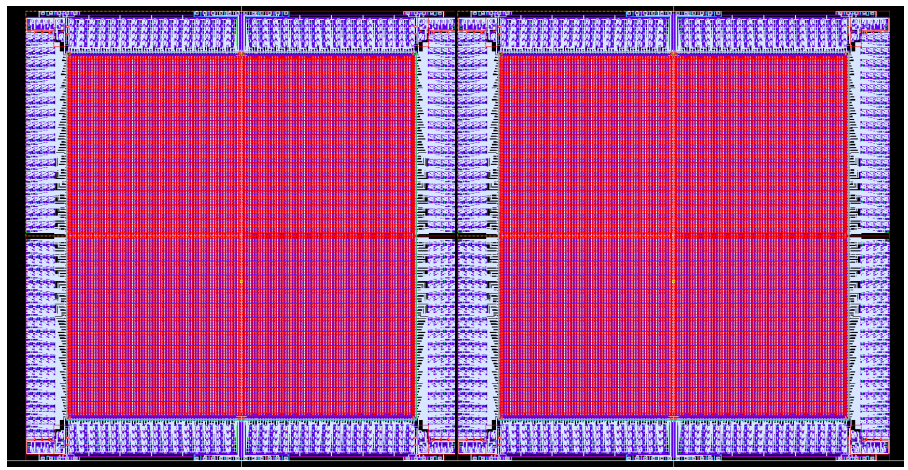
- Optimised for medical imaging applications and high particle flux
- Dimensions: 24x24 mm^2, 128 x 128 = 16 384 channels
- 4 sub-segments with independent parallel analogue outputs



Design of a fully functional SOI sensor

- Cell dimensions: 150x150μm^2
- Cell configurations like on the test structures
- Construction of pixel connection like on the test structures
- Signal per MIP: ~ 6 mV
- Dynamic range: 300 MIP
- The basic detectors may be extended to the ladders, but with dead areas



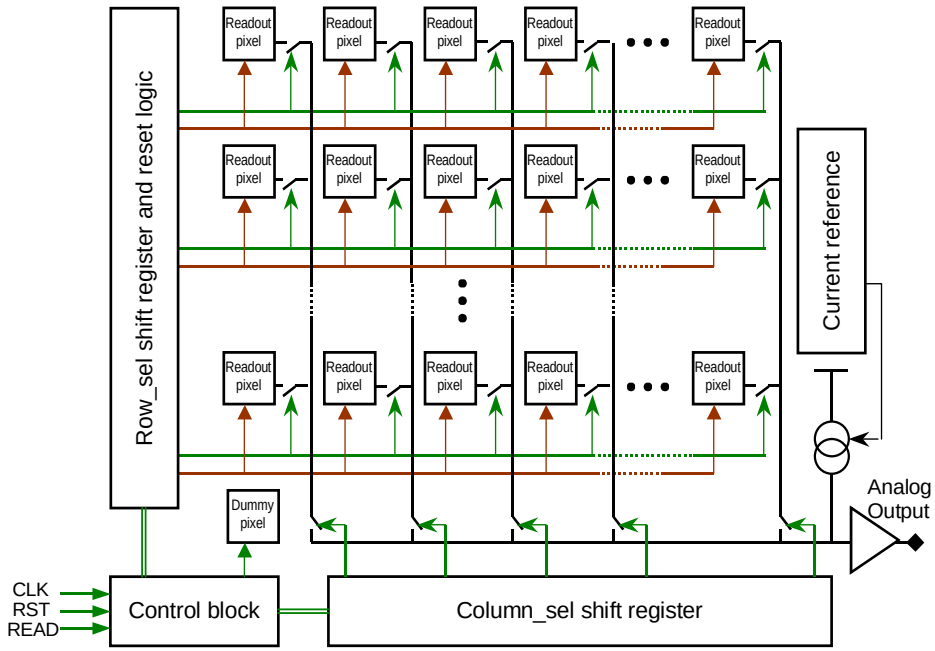


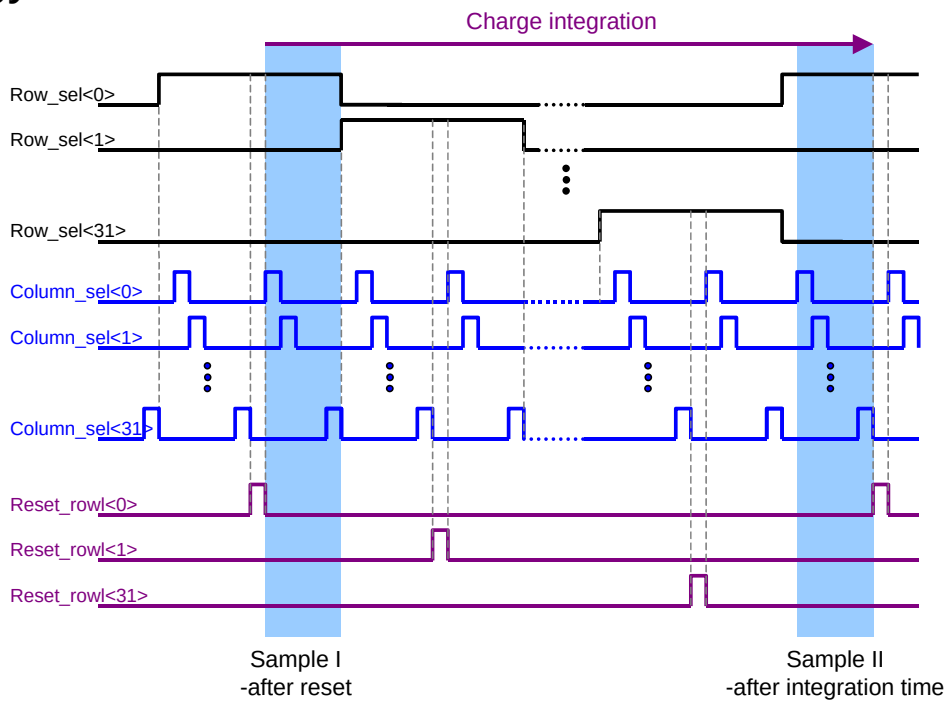
The design is completed.

The chips are expected to be produced in July 2004

Implemented SOI sensor readout

- Operation in un-triggered mode (for imaging applications)
- Analogue serial readout organisation
- Readout sequence similar to rolling-shutter but double sampling performed for every row
- External subtraction of samples for CDS
- Well defined integration time and short dead time
- Exercised and validated on the prototype chip designed in commercial AMS 0.8 technology

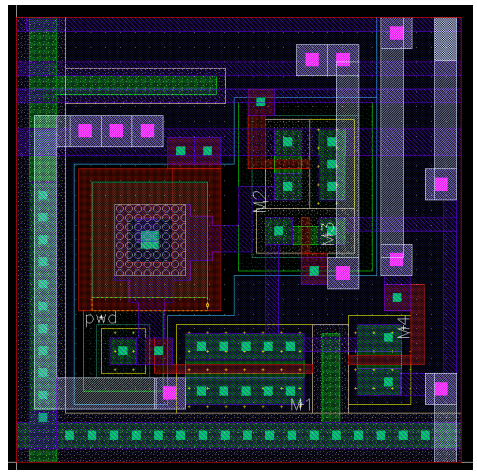


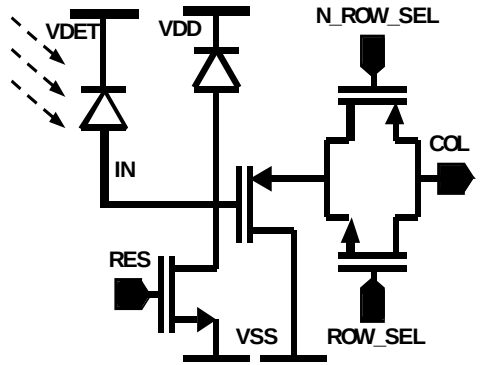


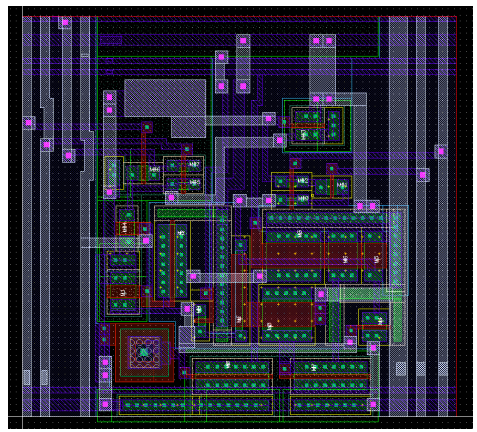
Alternative solutions of the SOI detector cell

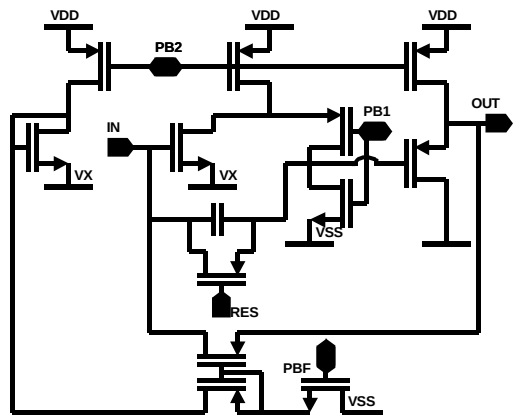
For the purpose of applications were lower signals levels expected alternative solutions of sensor cells proposed:

- Cell configuration similar like on the main detector but new construction of the contact to the pixel
  - Input capacitance reduced by factor of ~ 2
  - Signal per MIP ~ 12 mV
  - Dynamic range of 150 MIP
  - Test matrix of 16 x 16 cells
- Traditional charge sensitive amplifier
  - Signal per MIP ~ 160 mV
  - Better noise performance
  - No input protection diode required
  - Global reset and sample & hold
  - Test matrix of 16 x 8 cells
  - Detector contacts both standard and with reduced input capacitance









Summary

- An alternative solution of a monolithic active pixel detector, which allows efficient detection in high resistive substrate, has been proposed.
- First small area SOI pixel sensors have been fabricated.
- Preliminary tests with a laser light and radioactive sources have indicated detector sensitivity for the ionising radiation and wide dynamic range. Detailed tests are carried-on.
- The SOI sensor with the active area of 2 cm x 2 cm, optimised for medical imaging applications and high particle fluxes has been designed and will be fabricated this summer.
- Alternative solutions of sensor cells dedicated for low particle fluxes have been proposed.