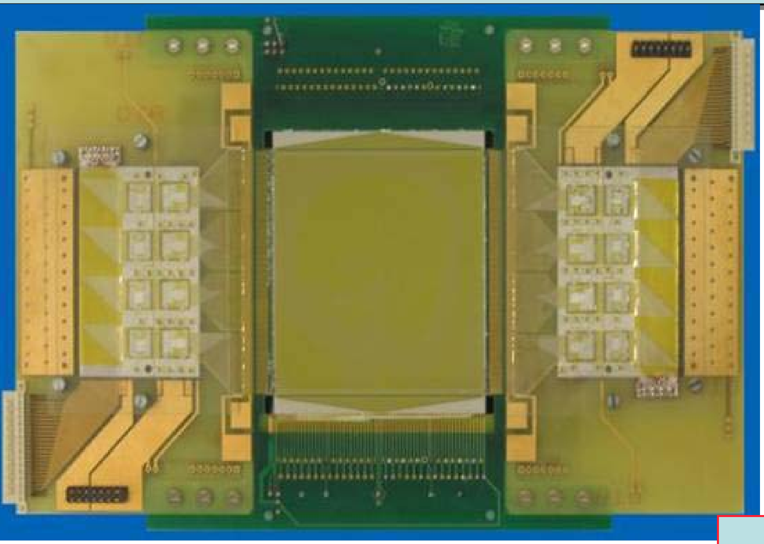
SDD from device modeling to mass production - practical experience



Outline

–Motivations ALICE at LHC

–ITS&SDD system

– From specs to detector

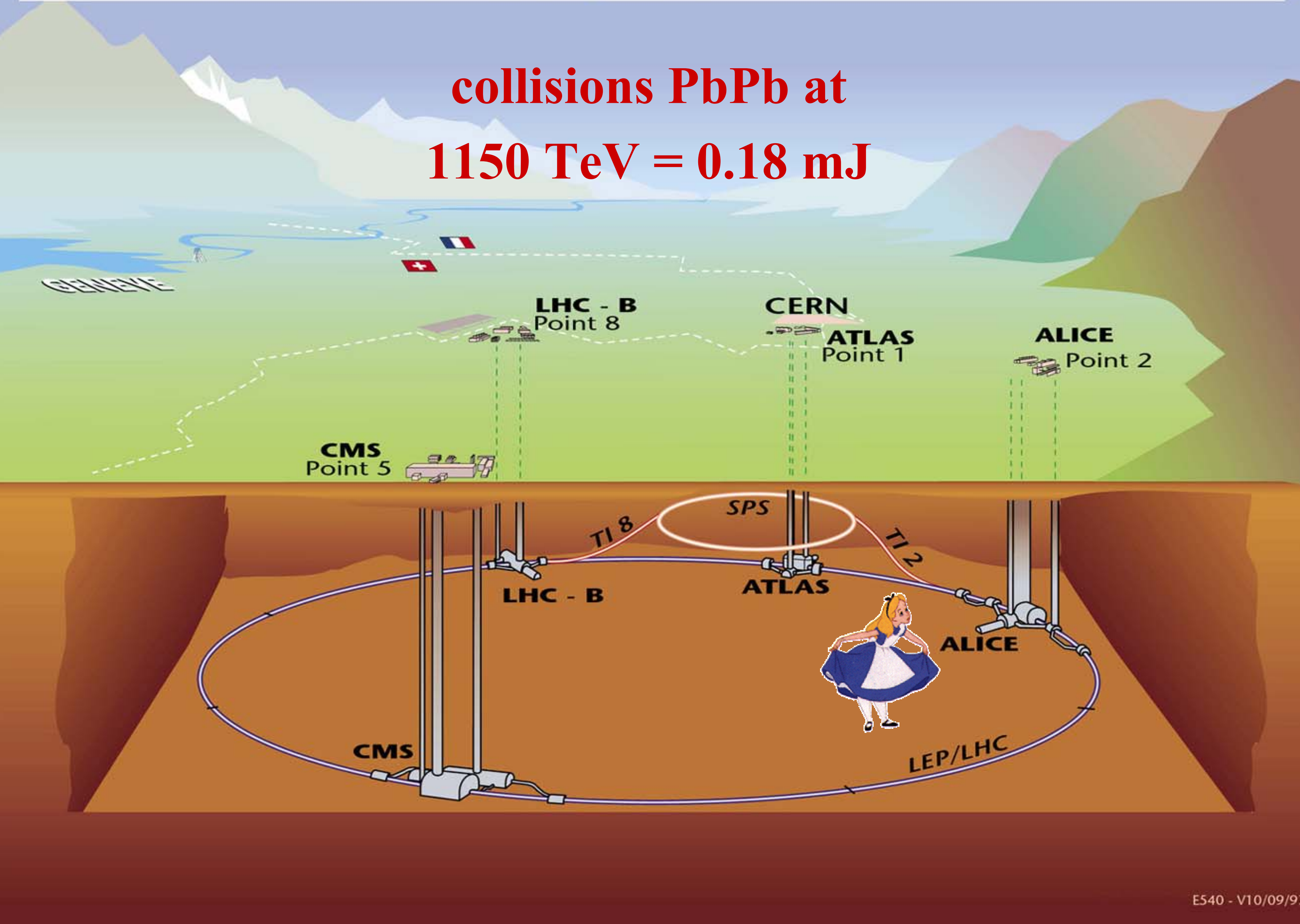
- –HV divider & stability
- –Injectors & speed variations
- –NTD fluctuations
- –Radiation damage

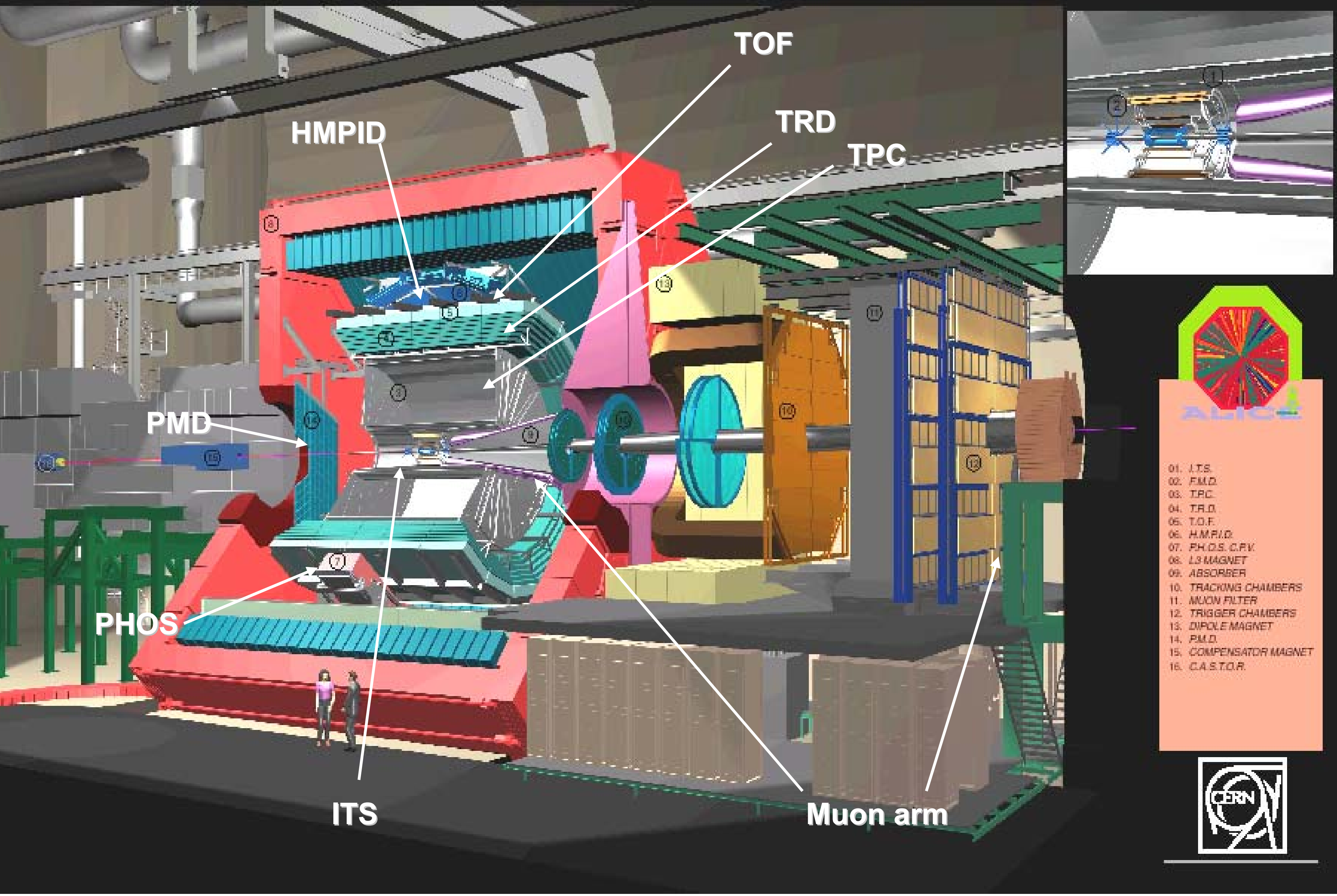
–Mass production first results

Overall view of the LHC experiments.

collisions PbPb at

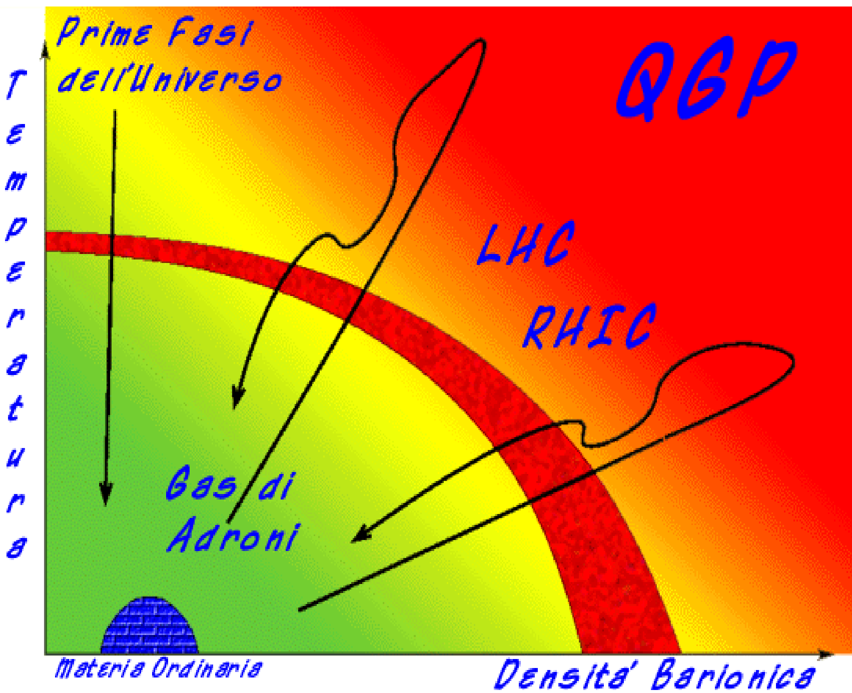
1150 TeV = 0.18 mJ

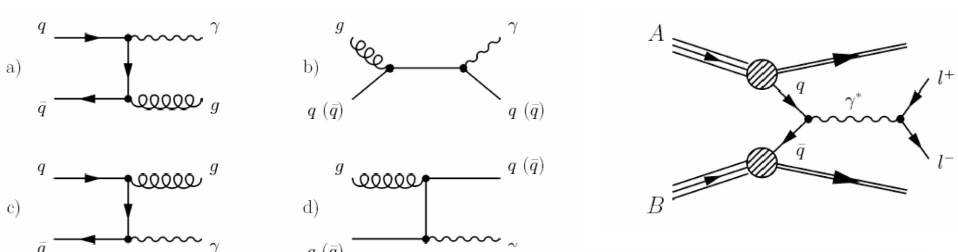


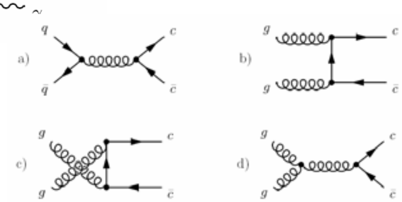


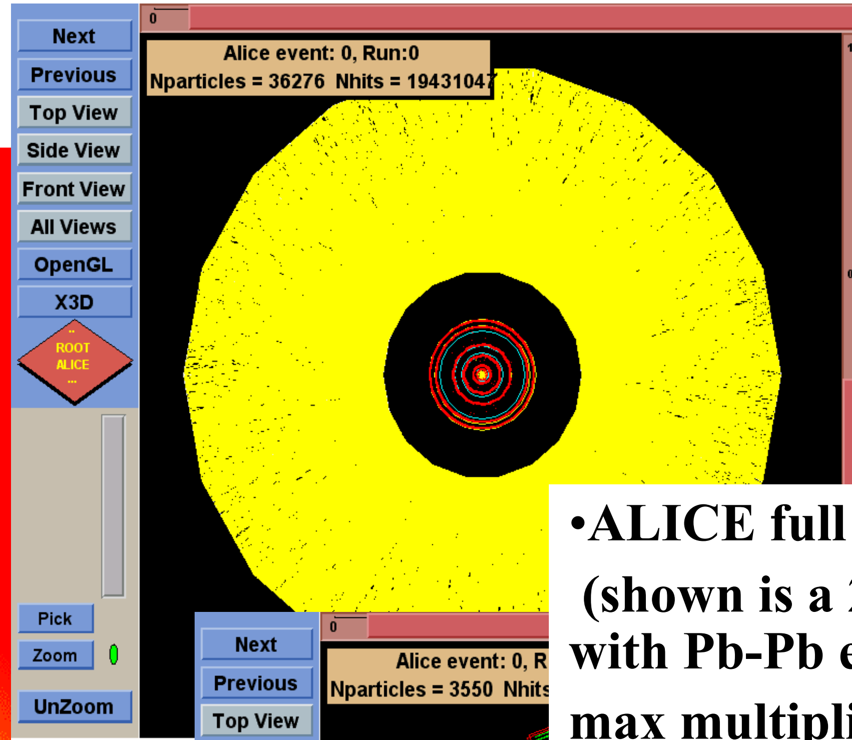
THE EXPERIMENT IS A CONDENSATE OF CUTTING EDGE TECHNOLOGIES

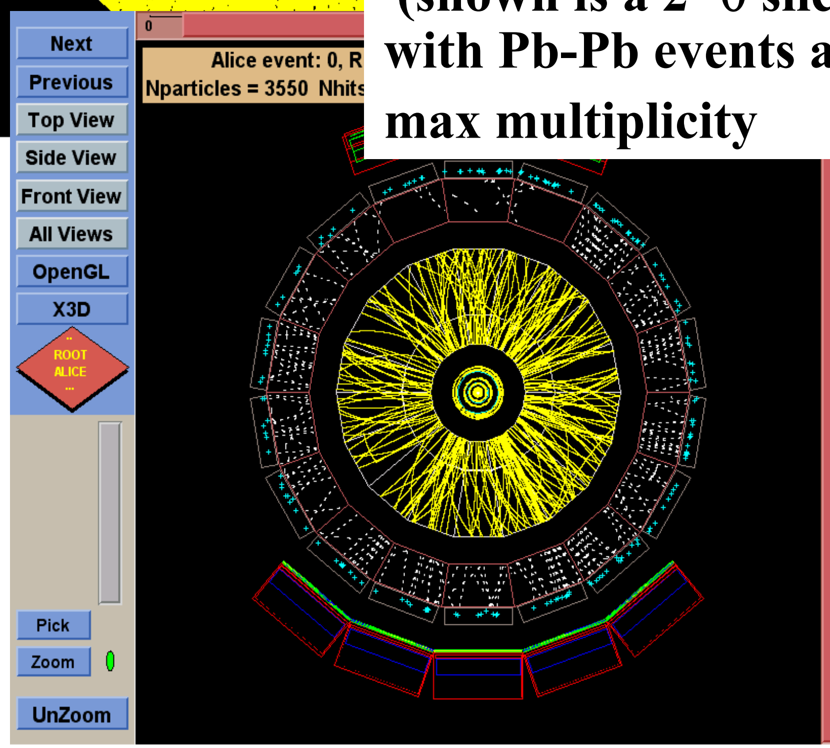
In Action







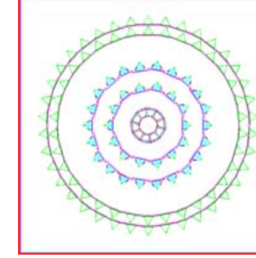


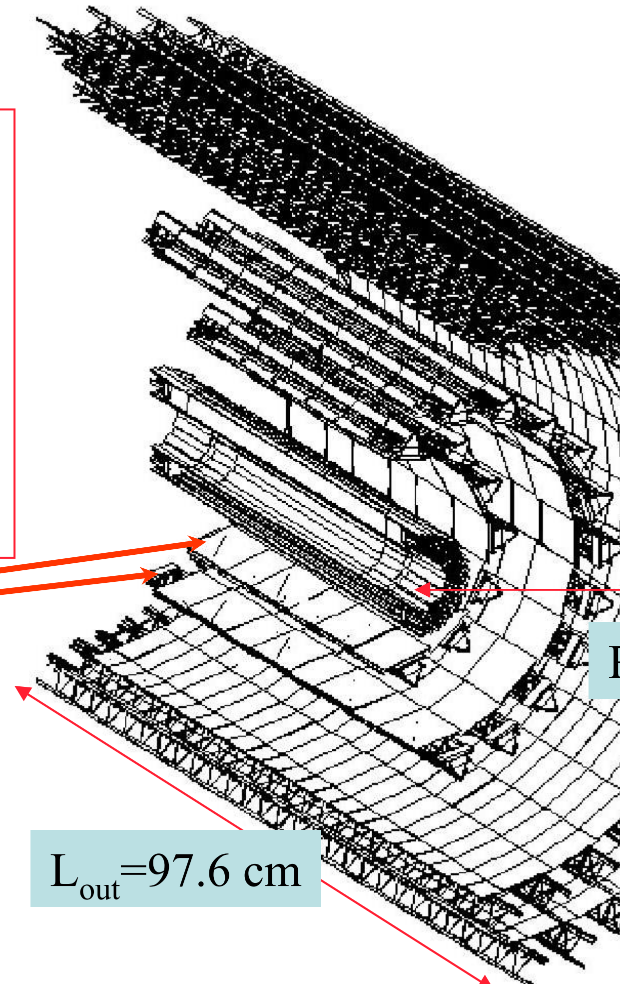


•ALICE full simulatio
(shown is a 2^0 θ slice)
with Pb-Pb events at
max multiplicity

The SDD collaboration

- INFN - Torino – Italy
- INFN - Trieste - Italy
- INFN - Bologna - Italy
- INFN - Roma - Italy
- INFN - Alessandria- Italy
- Ohio State University - Columbus - Ohio - USA
- University of Jyvaskyla - Jyvaskyla - Finland
- Nat. Acad. of Sciences, Bogolyubov Inst. for Th. Phys. - Kiev - Ukraine
- Scientific Res. Techn. Inst. of Instrument Making - Kharkov - Ukraine
- Acad. of Sciences of Czech Republic - Rez U Prahy - Czech Republic
- St. Petersburg State University - St. Petersburg - Russia





Silicon Drift Detectors

Tot. No. channels 133 •10^3

Tot. No. detectors 260

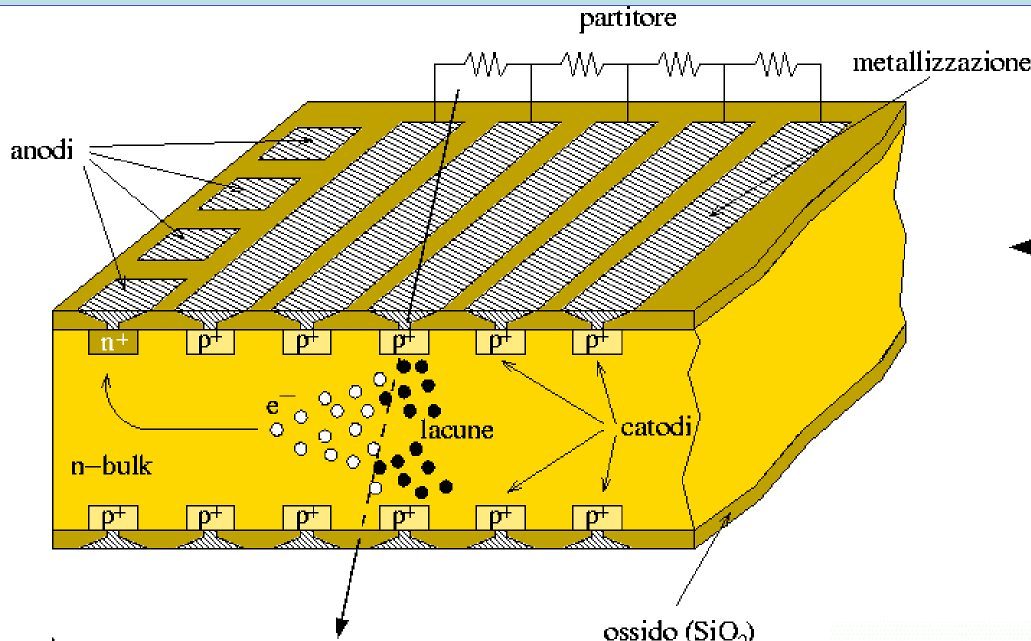
total area 1.31 m^2

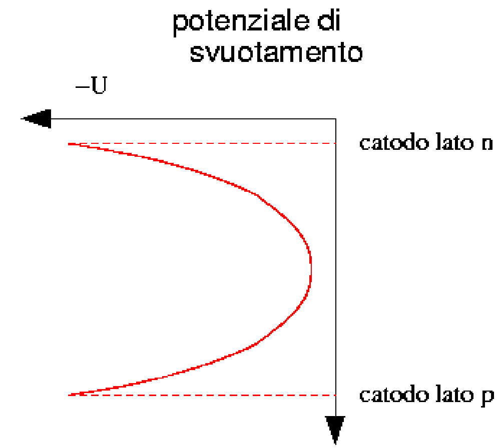
	Layer 3	Layer 4
Radius (mm)	14.9	23.8
Ladders	14	22
SDDs per ladder	6	8

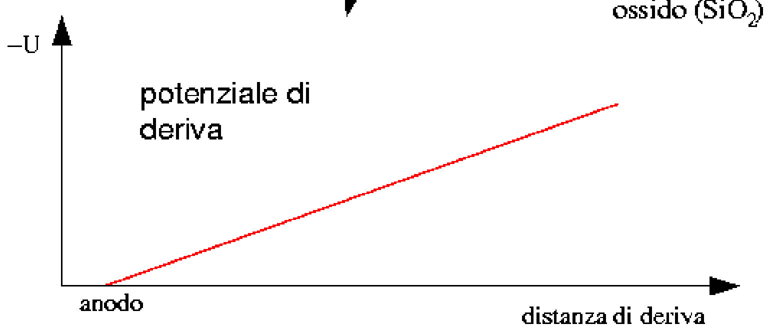
- 6 Layers, three technologies (keep occupancy ~constant ~2%)
  - Silicon Pixels (0.2 m^2, 9.8 M channels)
  - Silicon Drift (1.3 m^2, 133 k channels)
  - Double-sided Strip (4.9 m^2, 2.6 M channels)

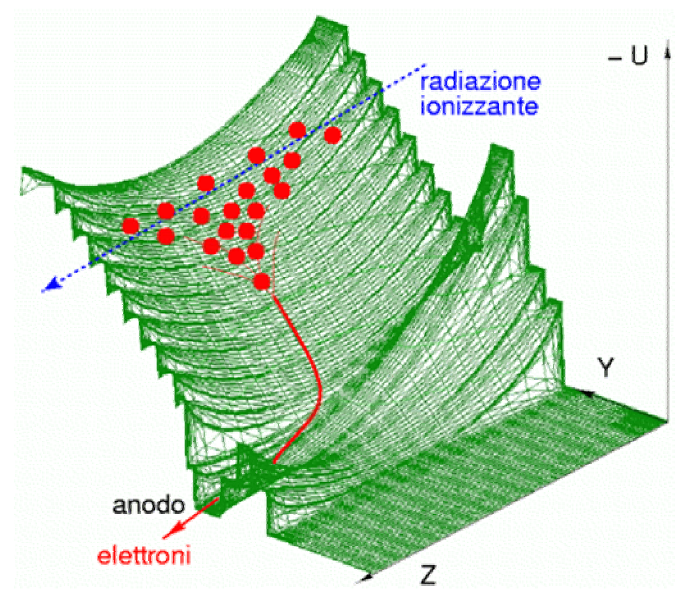
Two dimentional information no ambiguities

The silicon drift detector (SDD)







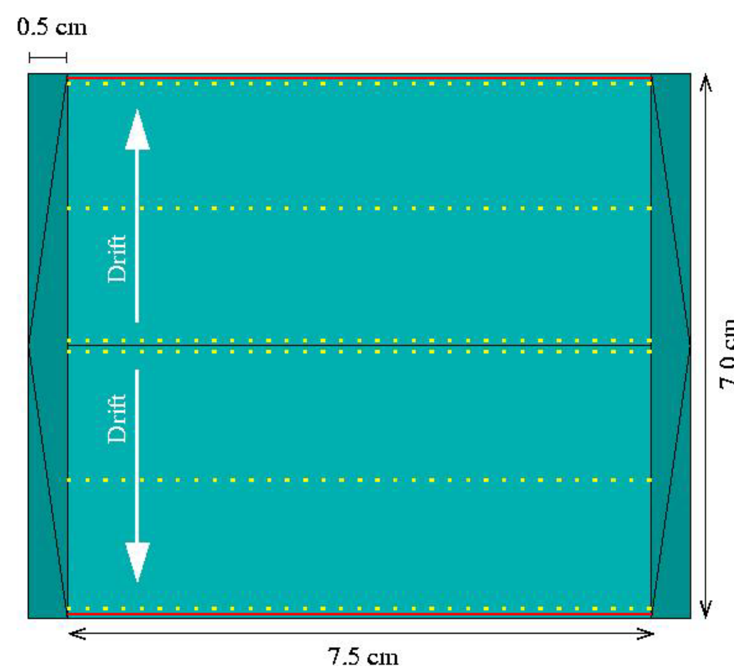


The silicon drift detector will equip two consecutive barrels for a total sensitive area of 1.1 m^2

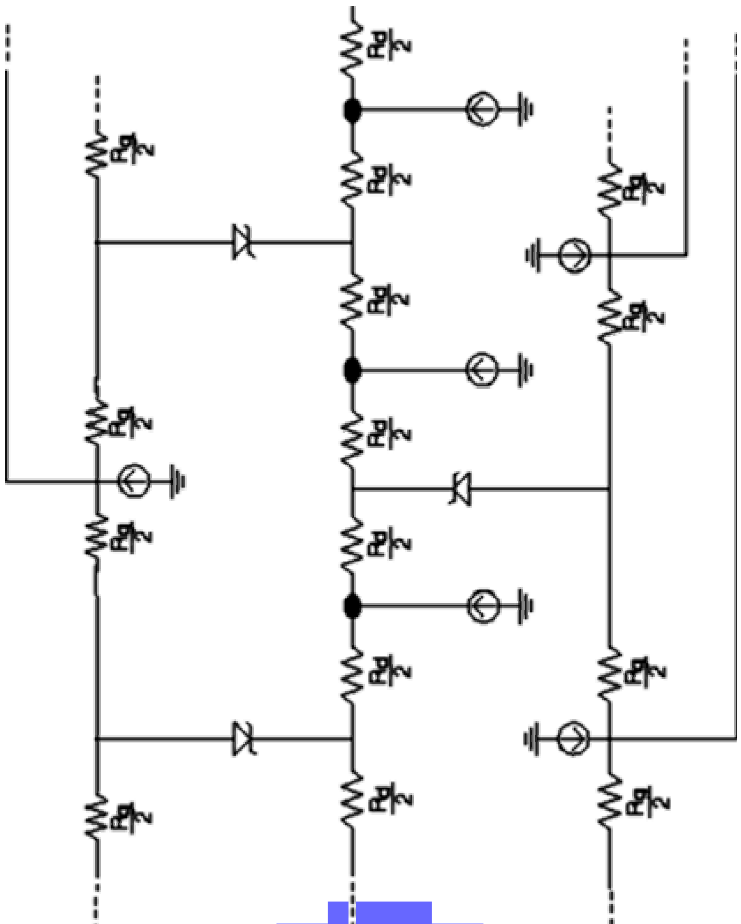
- The presented design points towards :
  - totally self supported on board high voltage divider,
  - injectors
  - high stability in the detector's performances
  - redundant design able to allow a satisfactory production yield.
  - the ability of the detector's design to withstand, with minimal consequences, the occurrence of a defect
  - control the effects of thermal dissipation and gradients across the sensitive area
  - resist to the foreseen dose in case of accelerator beam losses,
  - Contain and minimize NTD residual Doping fluctuations effects

Silicon Drift Detector

- **Wafer:** **5" Neutron Transmutation Doped <111> 3 kΩ.cm, 300 μm thick**
- **Area:** **sensitive: 7.02 × 7.53 cm², divided into two drift regions**
  total : 7.25 × 8.76 cm², (ratio = 0.81)
- **Each drift region:**
  - **35 mm long**
  - **290 cathodes driven by built-in voltage divider**
  - **256 anodes – 294 μm pitch**
  - **3 rows of 33 MOS charge injectors (v_{drift} calibration)**
- **Guard regions:**
  - **independent built-in voltage dividers**
- **Typical operating parameters:**
  Drift bias voltage: -2.4 kV, 8V/cathode E=670V/cm
  Maximum drift time : 4.3 μ s, v_d =8 μm/ns
- **Power dissipation on board: 1.13 W**
  - **Rtot equivalent of the all drift + guard dividers (kohm) 4781**
  - **Total current in all dividers, from Rtot equivalent (mA) 0.49**
  - **P_tot (W) 1.1**
- **Production yield: > 65%**
  - dedicated double sided process
  - Redundant design
  - Separated guard and drift dividers



Performance of the divider



Possible defects:

1) cathodes in short
2) high current generation center
3) interruption

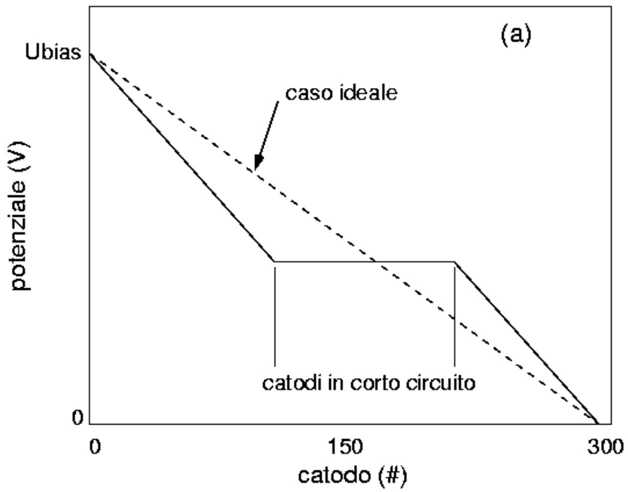
Simulations

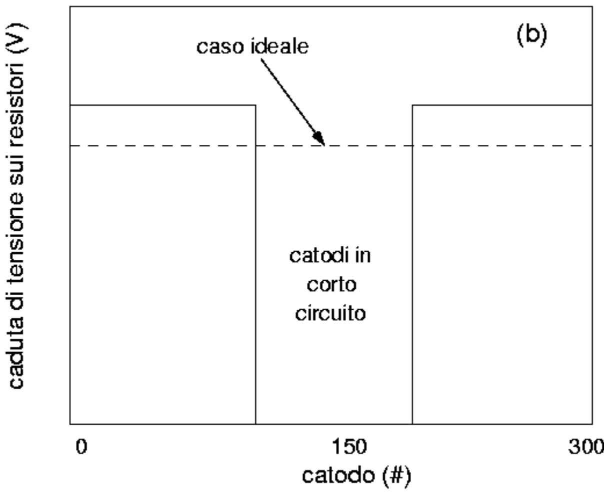
&

measurements

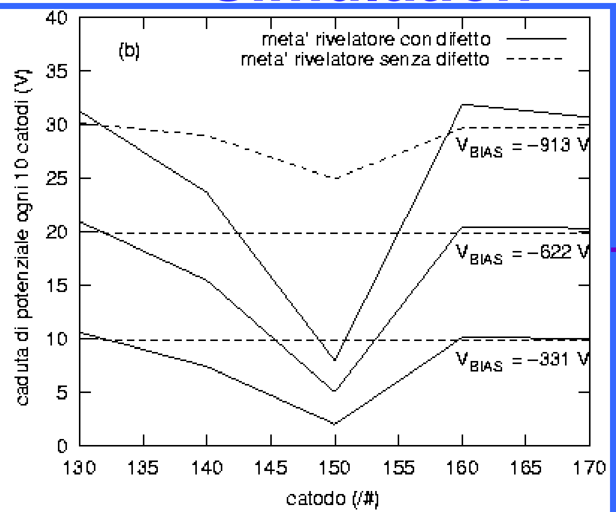
Pspice Simulator

(1) Short



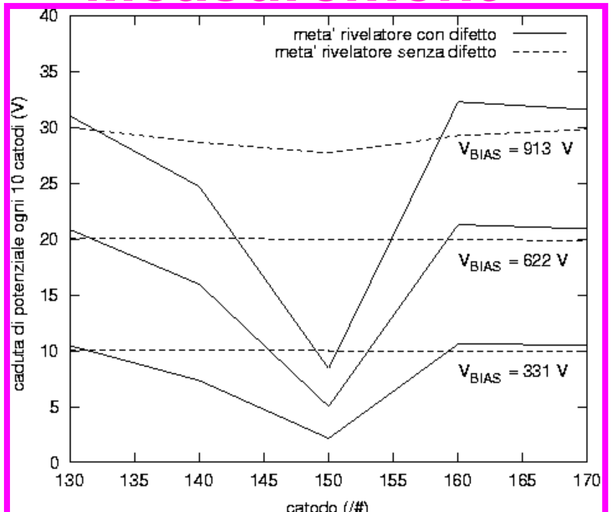


Simulation

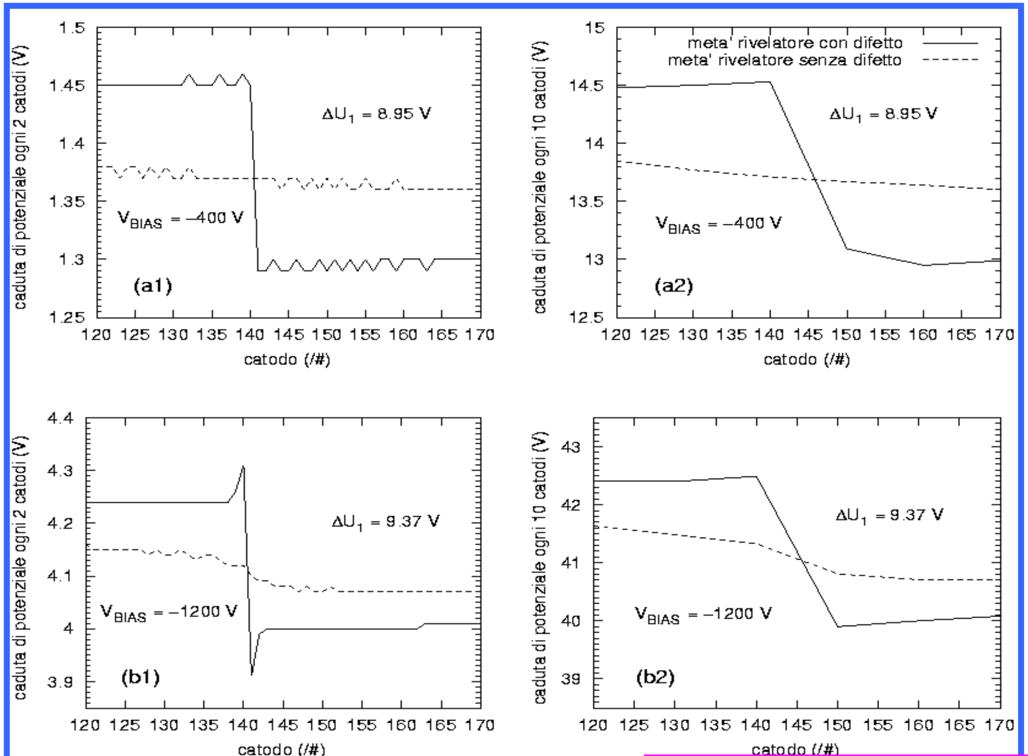


13 cathodes short

Measurement

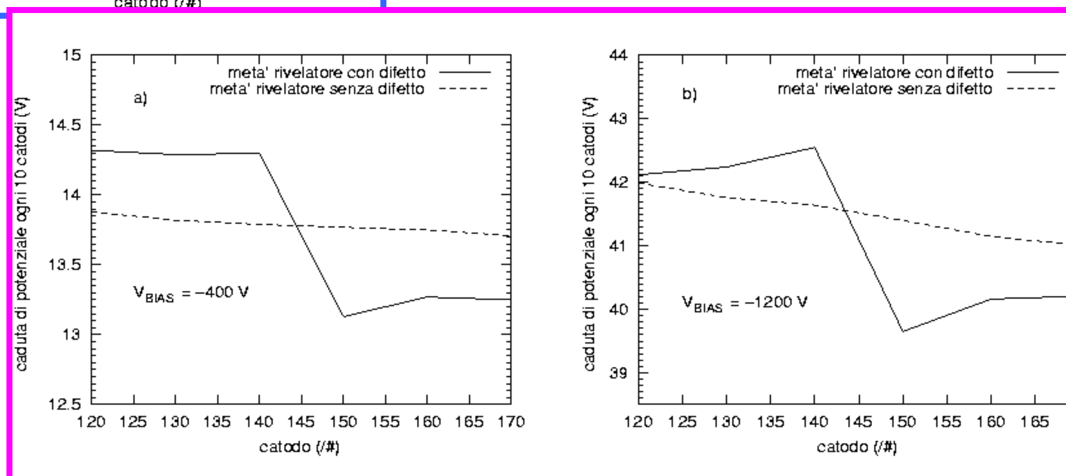


(2) High current centre

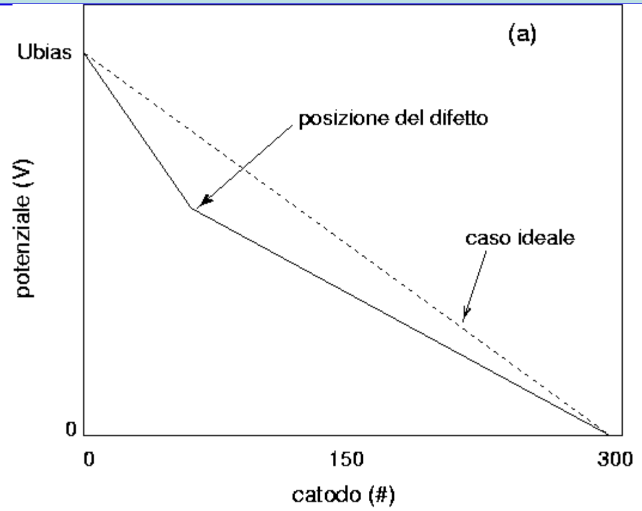


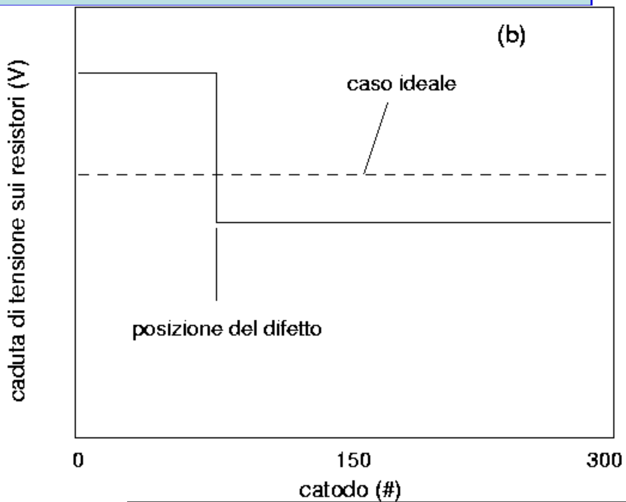
SIMULATION

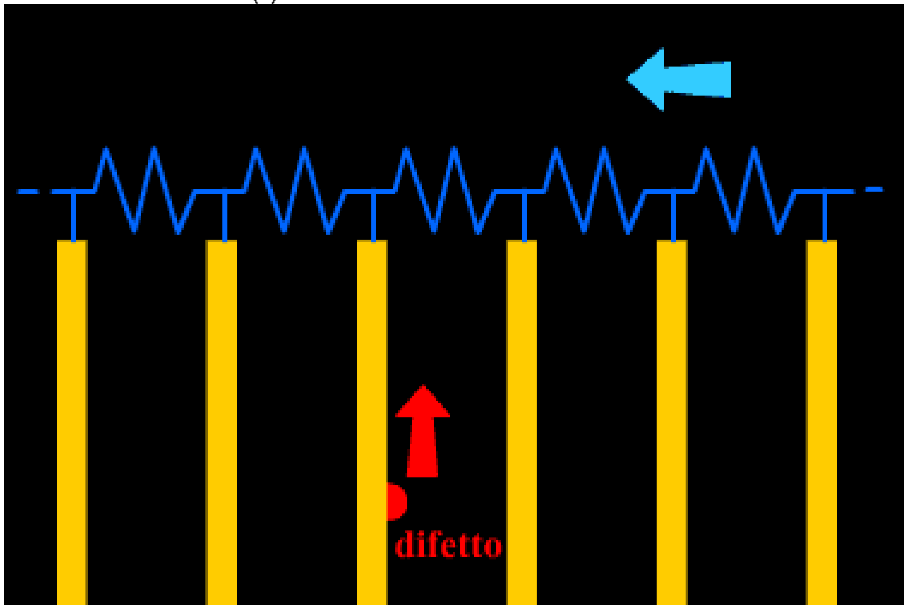
Measurement



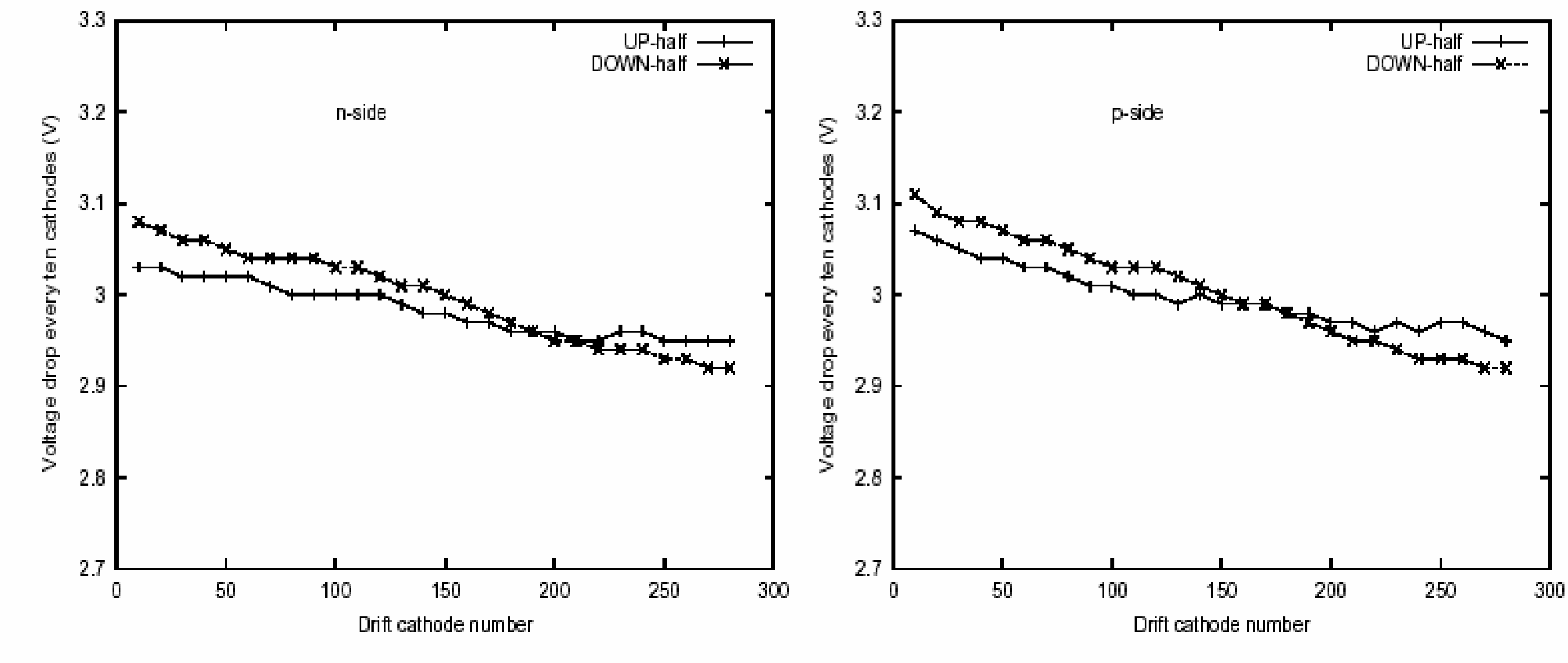
(2) High current centre





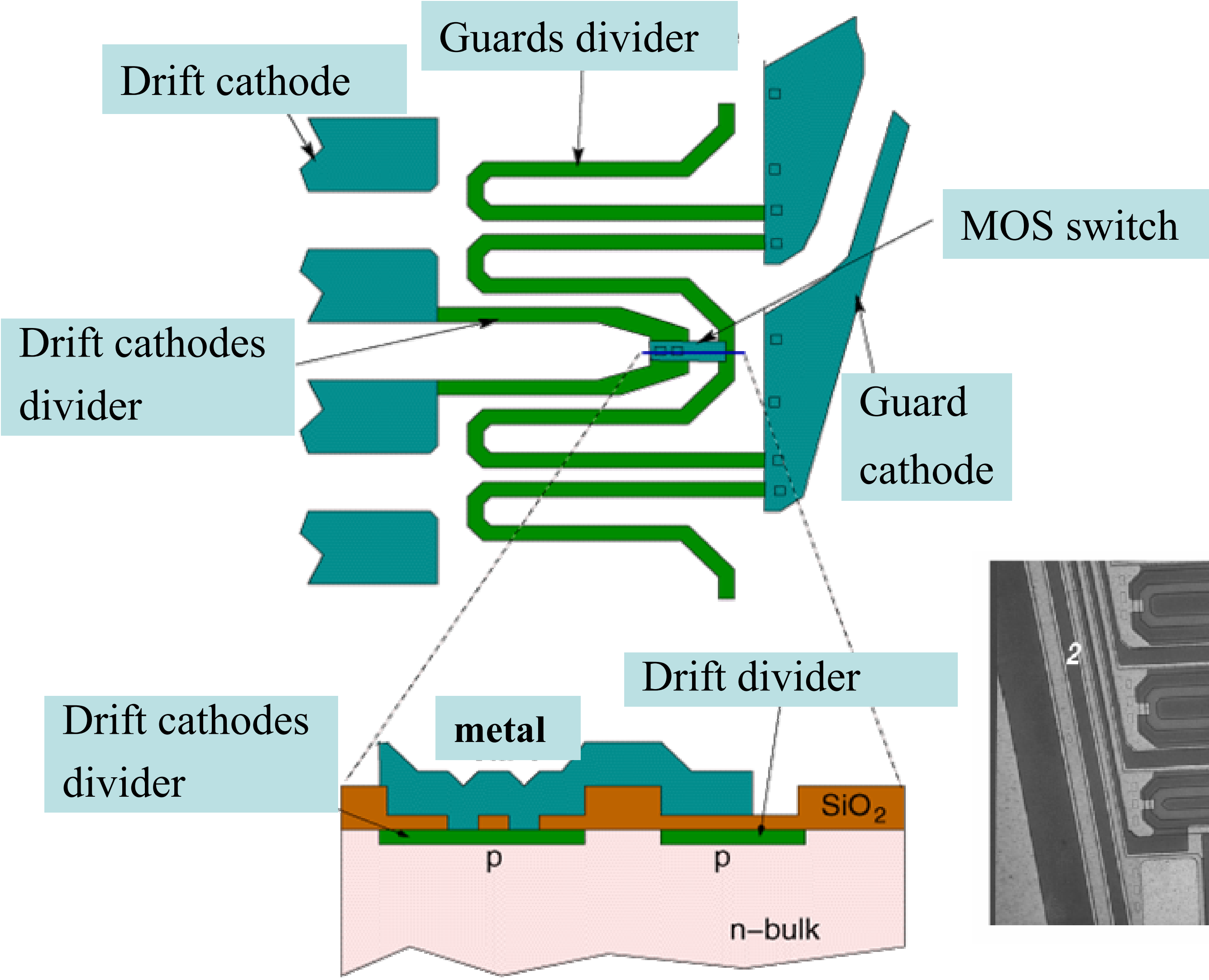


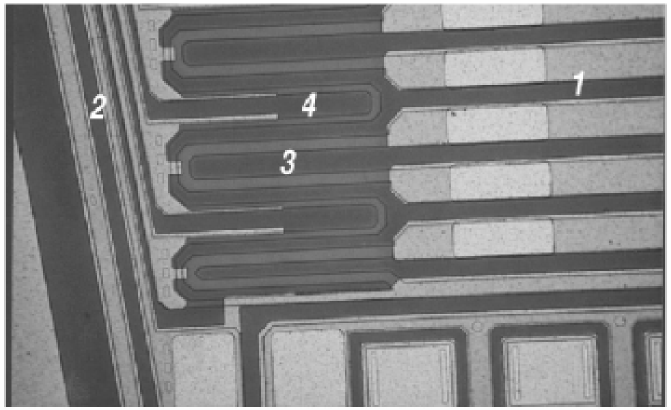
On board divider at -2400V



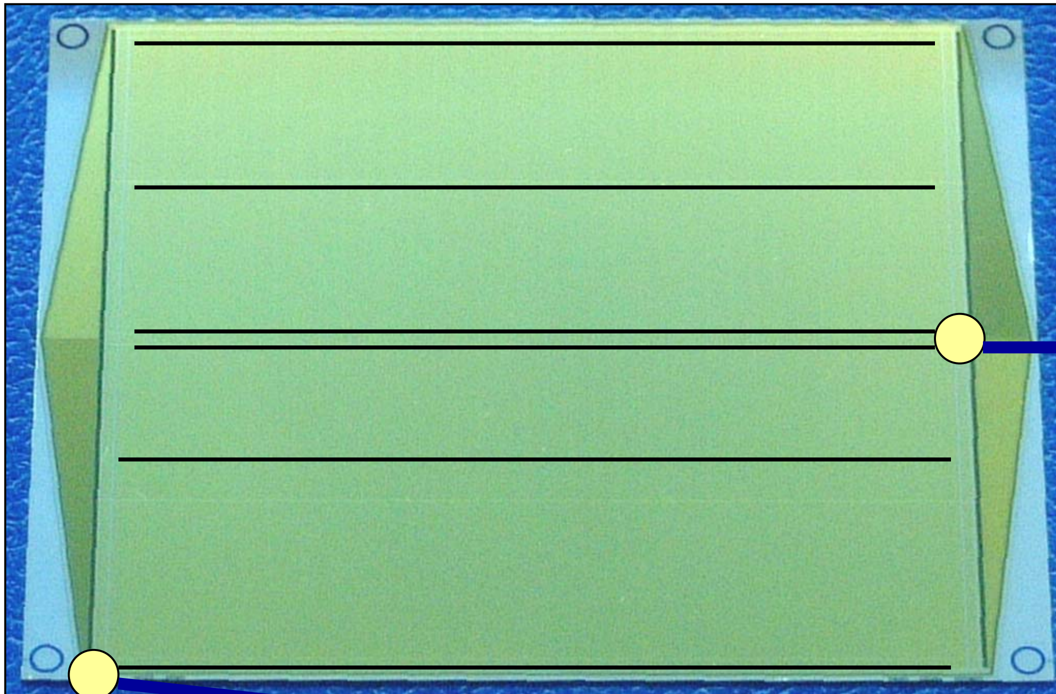
Voltage drop every 10 drift cathodes

Integrated divider

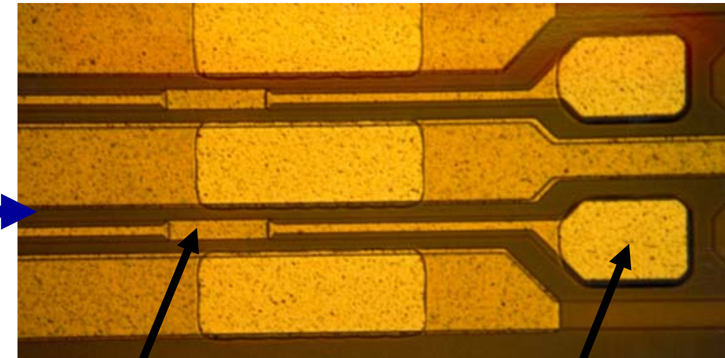




Detector design features



injector lines close-up



injector line bonding pad

MOS injector (every 8th anode)

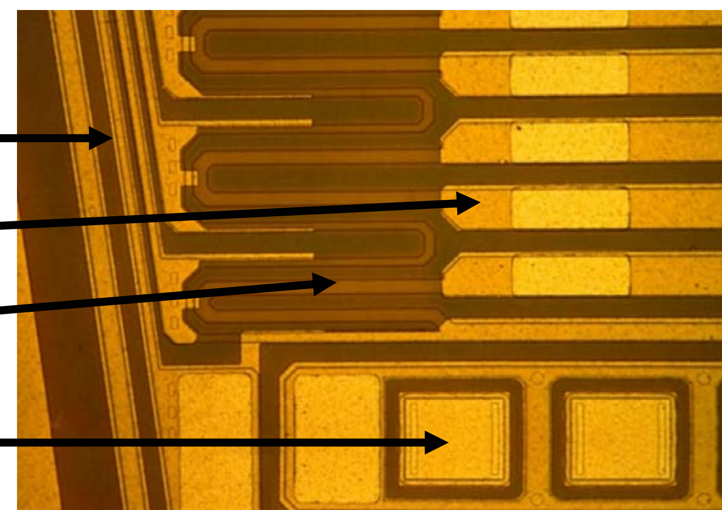
collection zone close-up

guard cathodes (32 μm pitch)

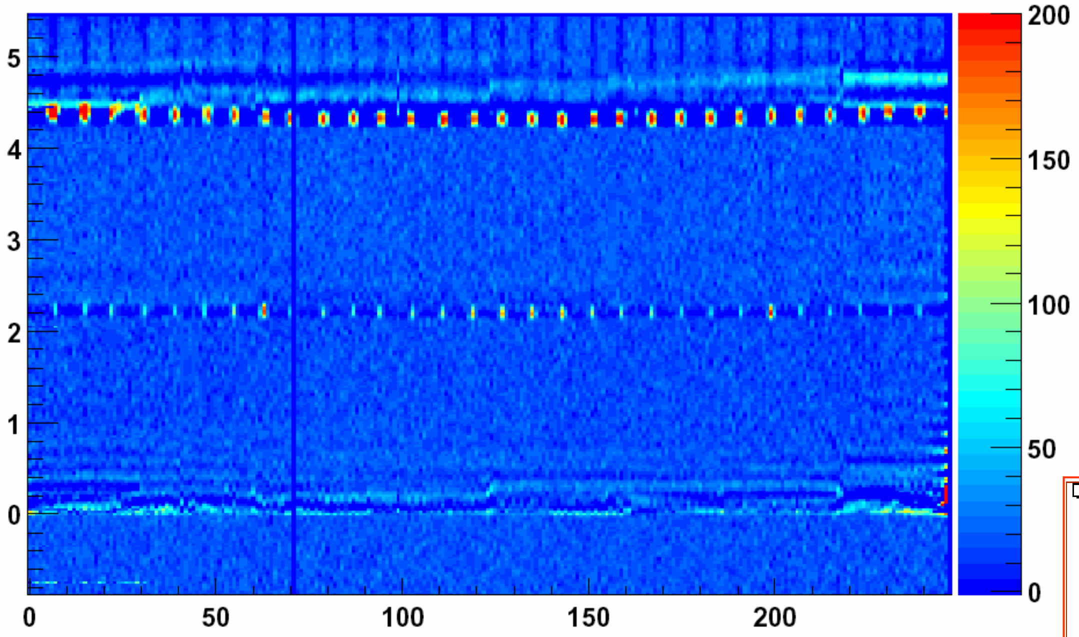
292 drift cathodes (120 μm pitch)

implanted HV voltage dividers

256 collection anodes (294 μm pitch)



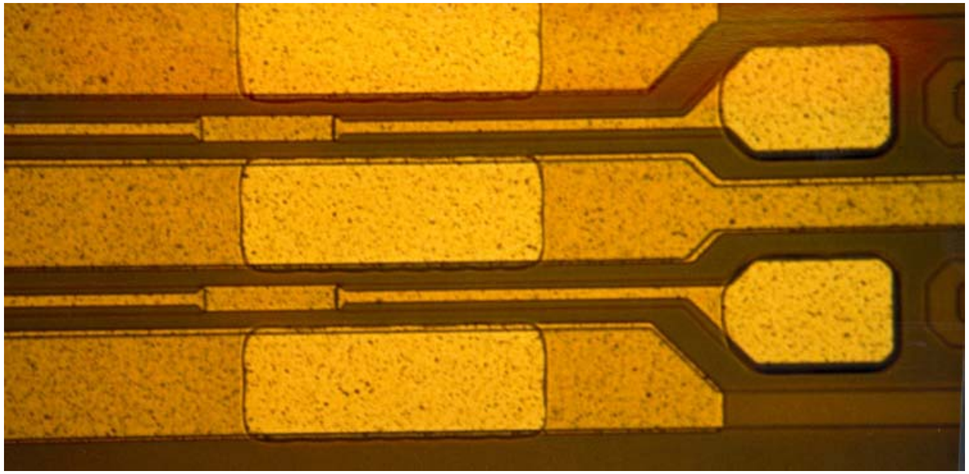
Point like Injectors

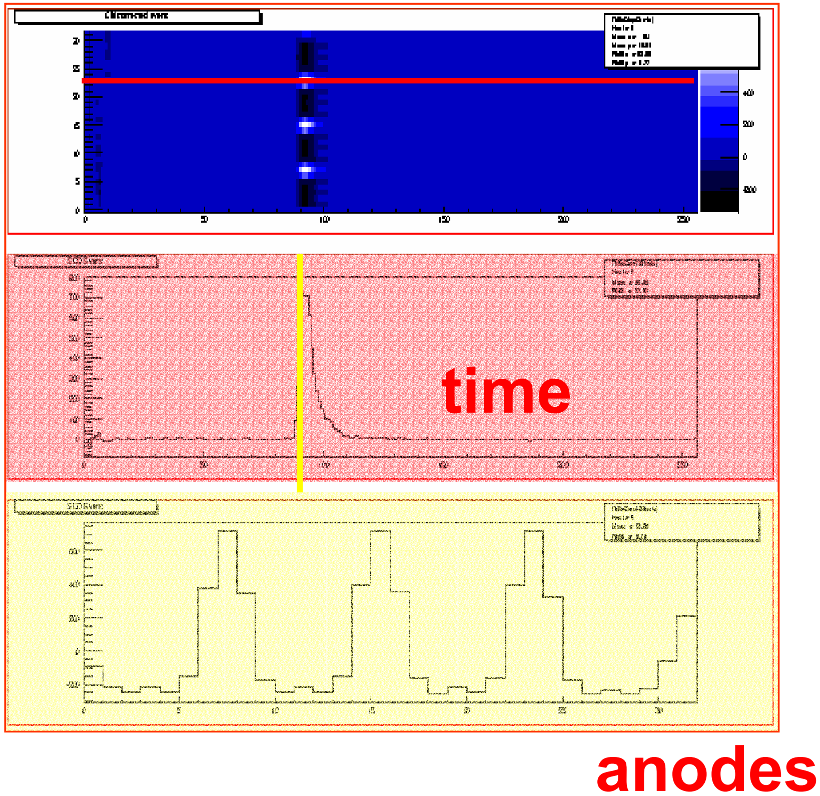


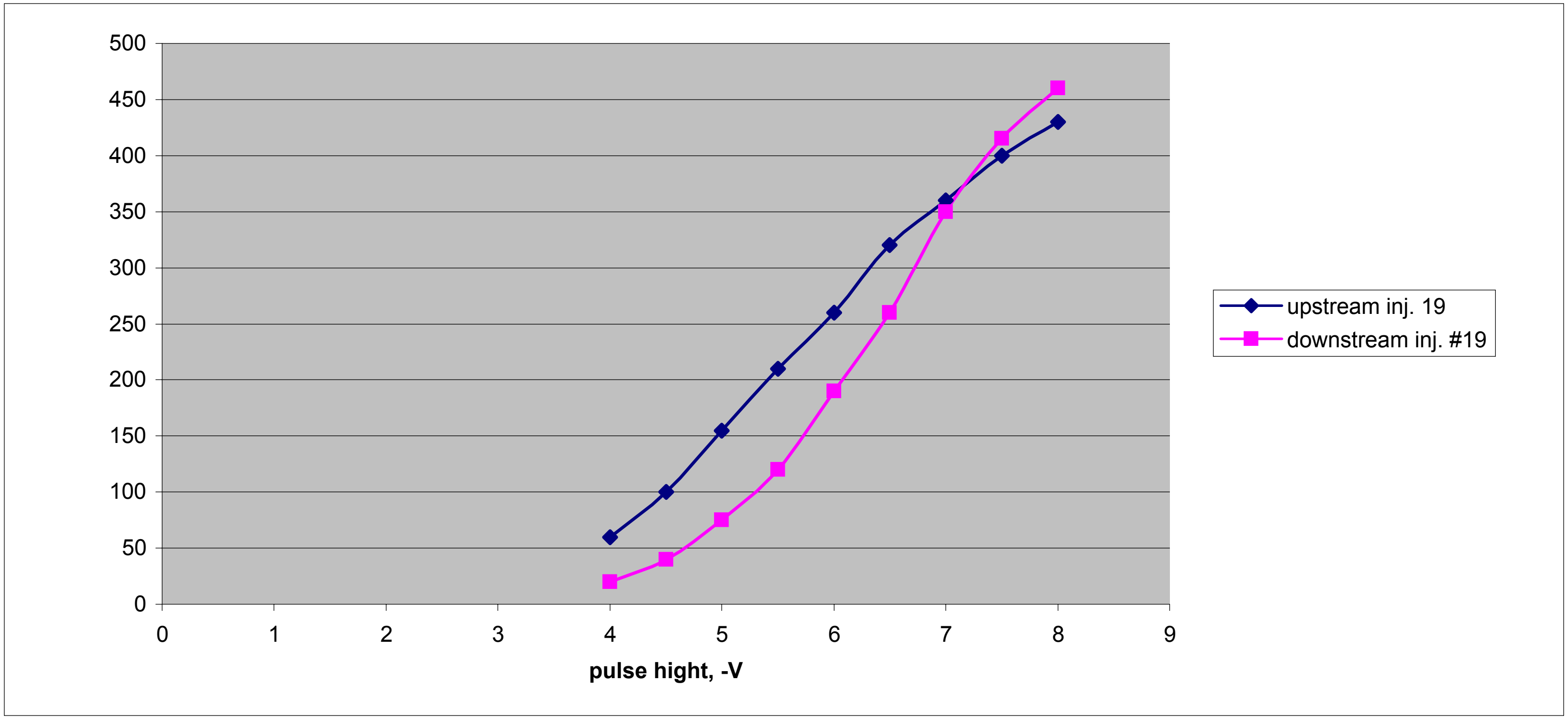
$\mu \propto T^{-2.5}$

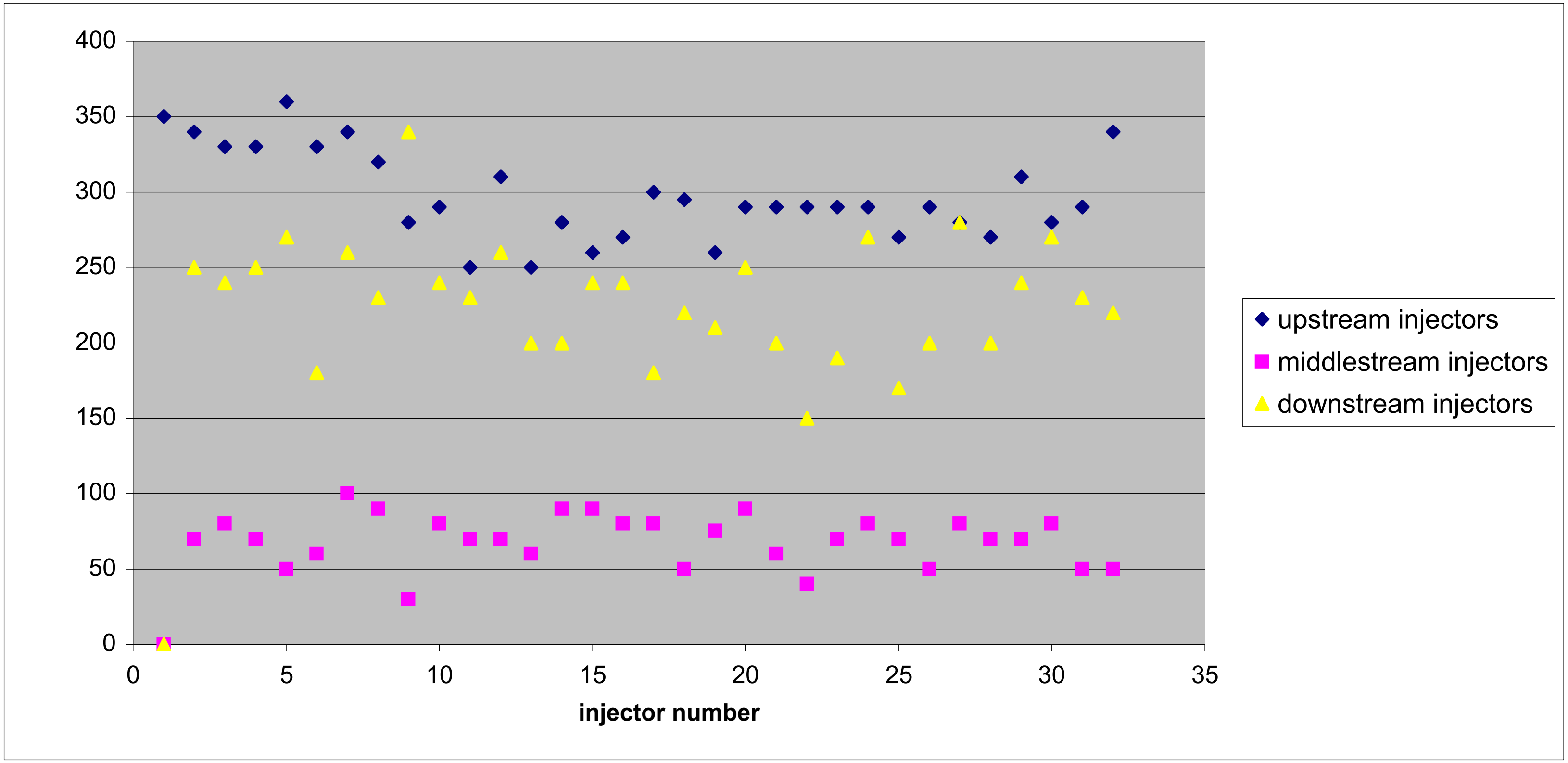
$v_d = \mu \times E$

Monitoring v_d fluctuations

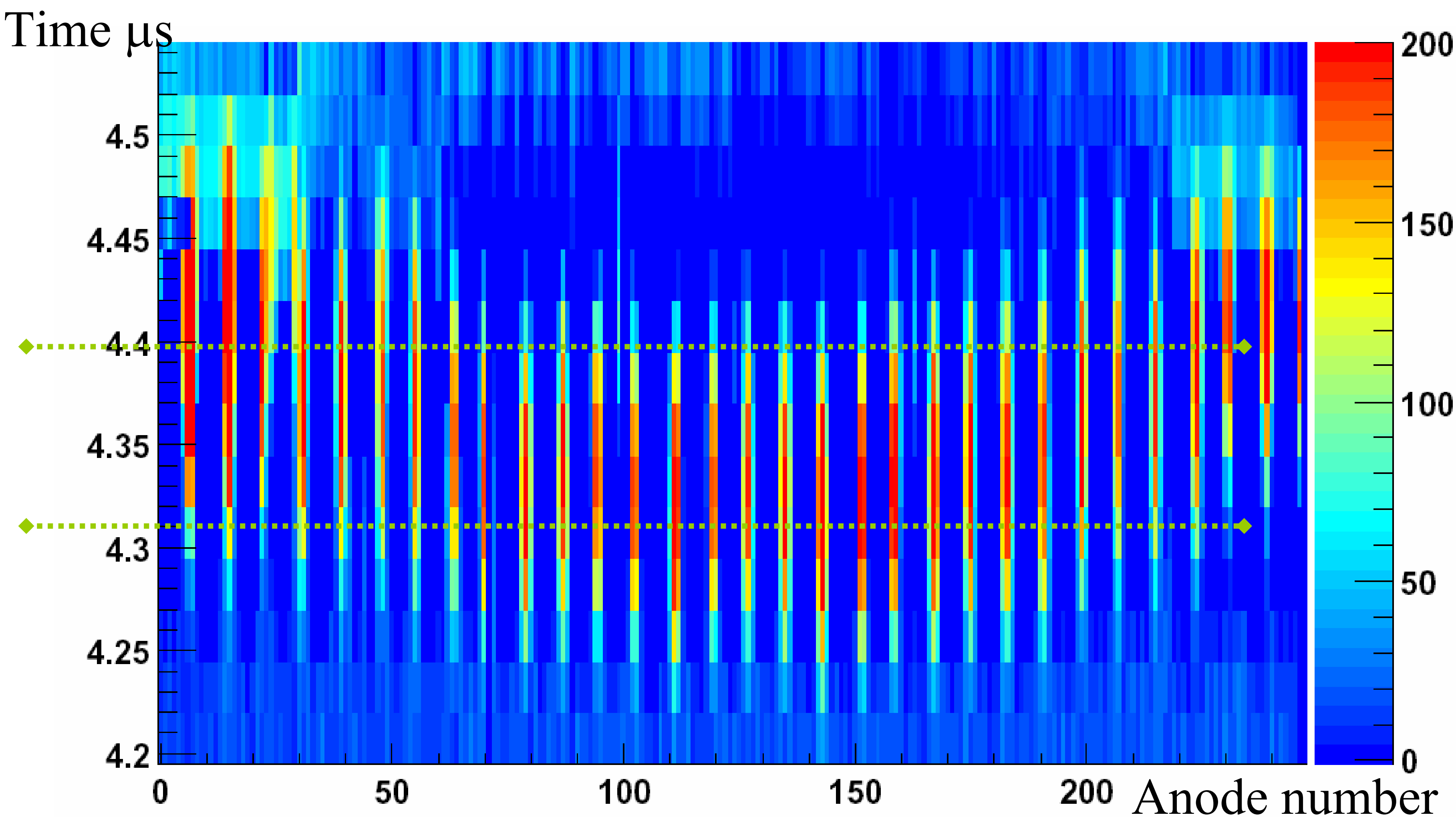




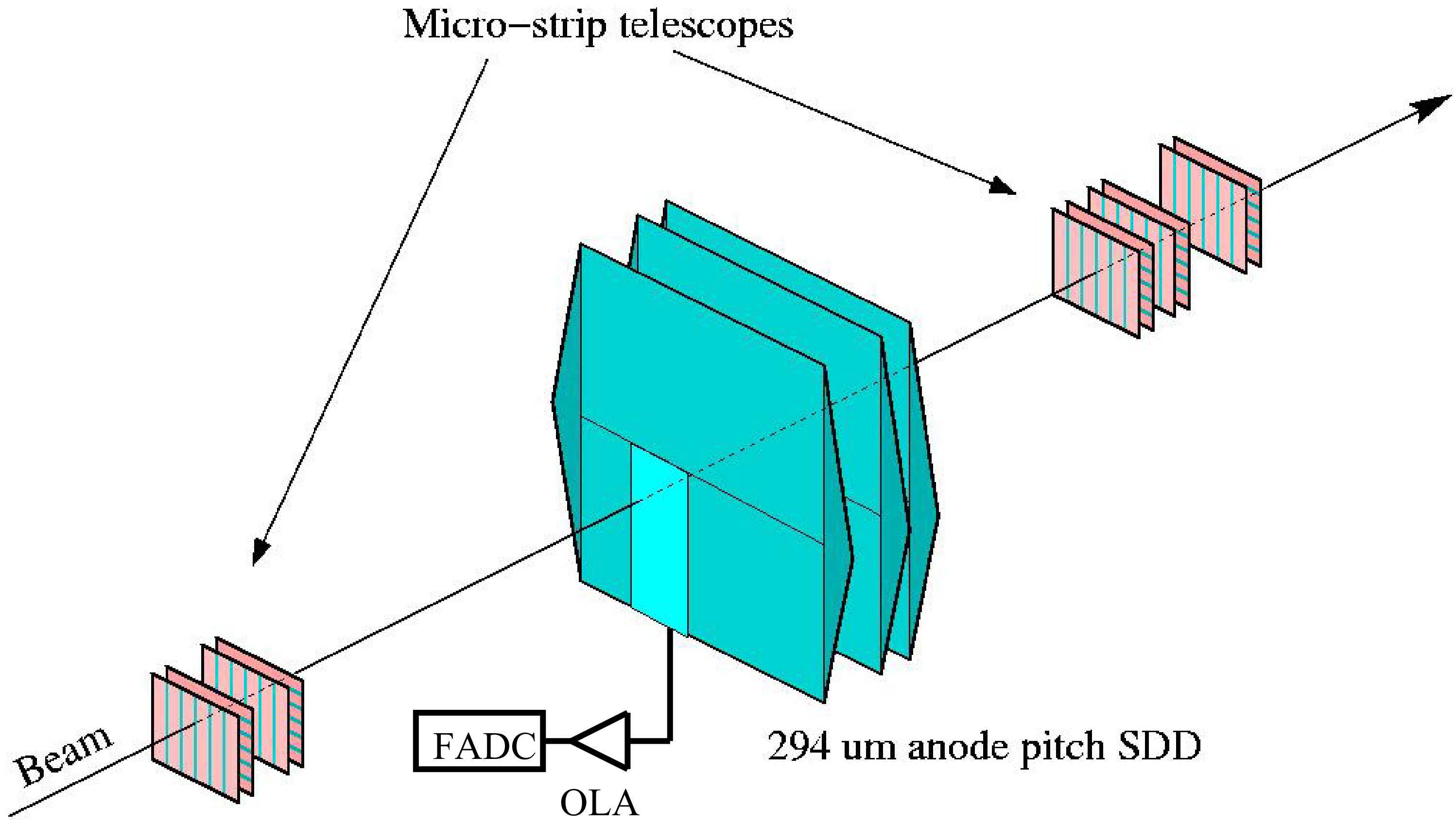

500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
pulse hight, -V
upstream inj. 19
downstream inj. #19


400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
injector number
upstream injectors
middlestream injectors
downstream injectors

Temperature gradient and drift time as seen by the first line of injectors. The centre to edge induced delay is Approximately 80-100 ns

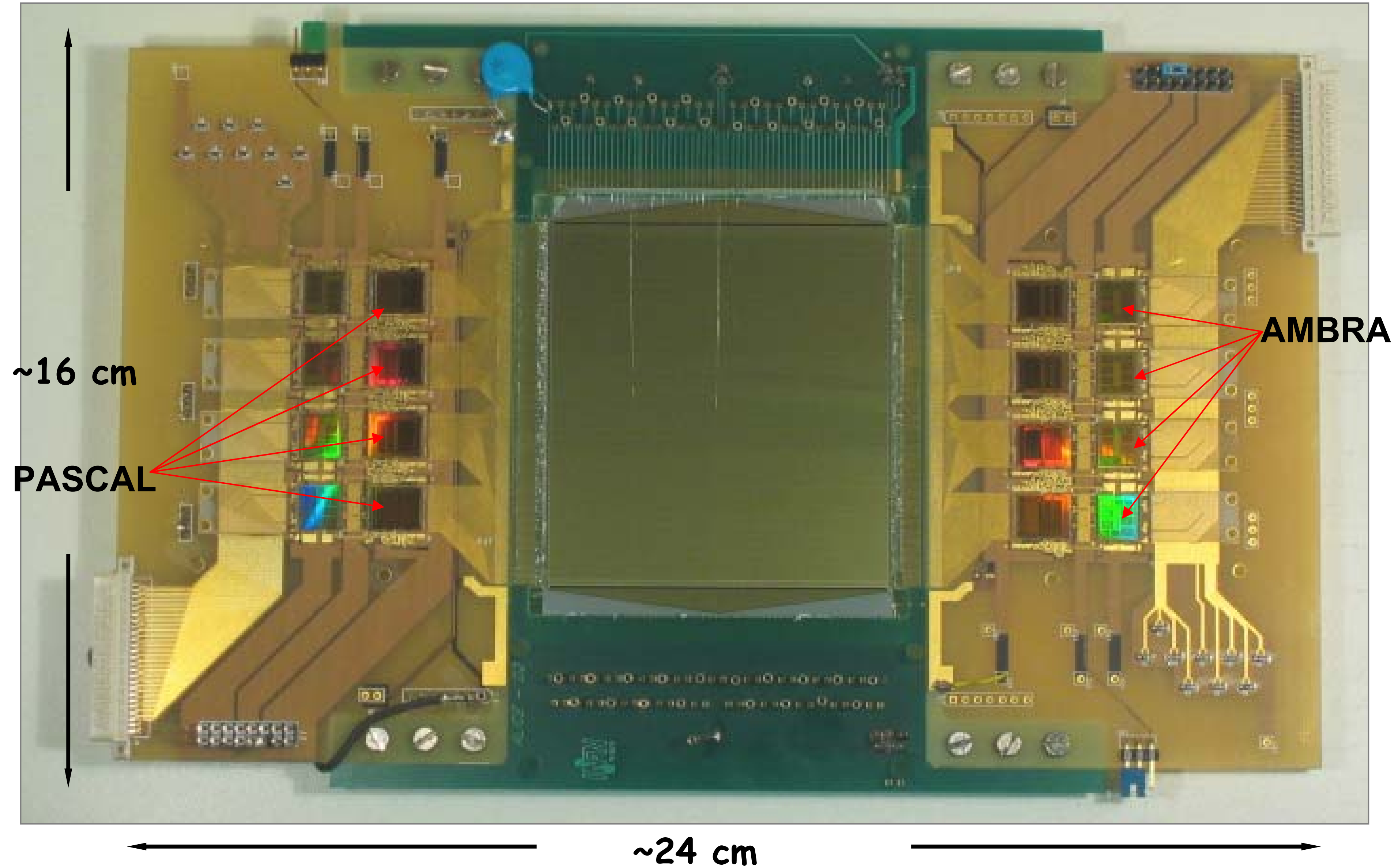


Beam Test - Setup



PS / SPS π,p
(up to 375 GeV/c)

Two Front-end PCB's, with the same layout as the hybrid, connected to an SDD for the August 03 beam test



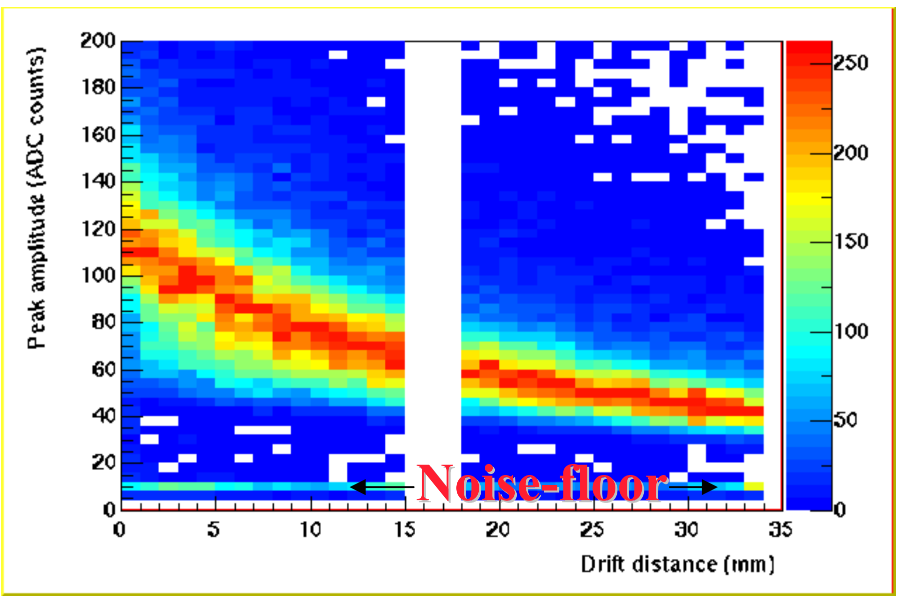
SDD front-end electronics

Beam test of SDD with PASCAL-32 & AMBRA-2 (first results)

ADC's running at 20MHz - some missing codes at 40MHz

Design specifications

- dynamic range: up to 8 MIPs
- noise: 250 e^-
- readout time < 1ms
- power consumption: <5 mW/channel
- chips thinned to 300µm



PASCAL (64 channels)

- Preamplifier (τ ~ 40ns, RC-CR^2 shaping)
- Analog memory (64 ×256 cells)
- 32 10-bit linear ADC (1 every 2 channels)

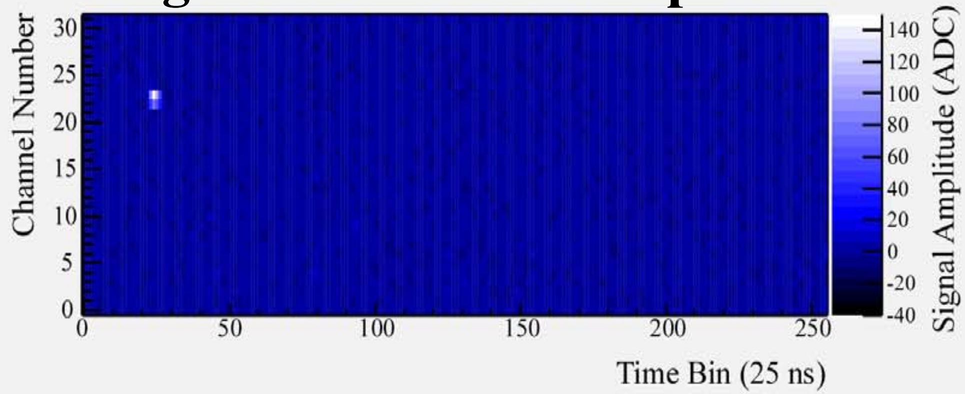
AMBRA (64 channels)

- Four 16 kB buffers
- 10 to 8-bit compression

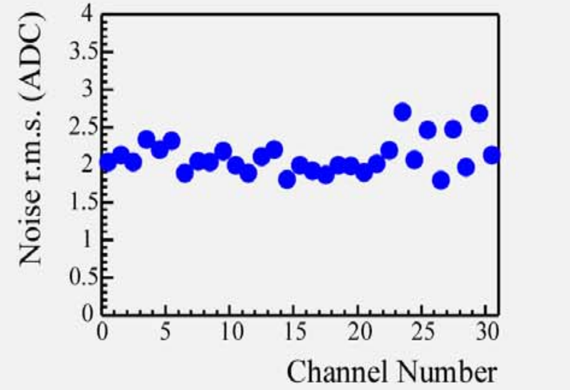
SDD front-end electronics

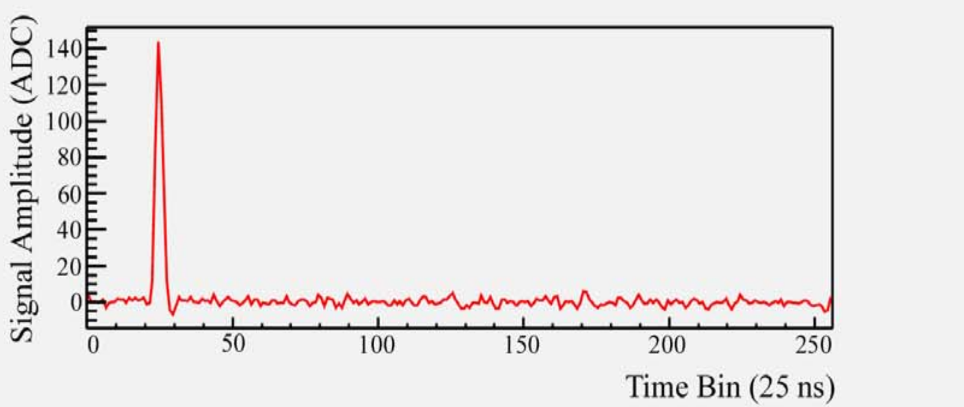
Beam test of SDD with PASCAL-32 & AMBRA-2

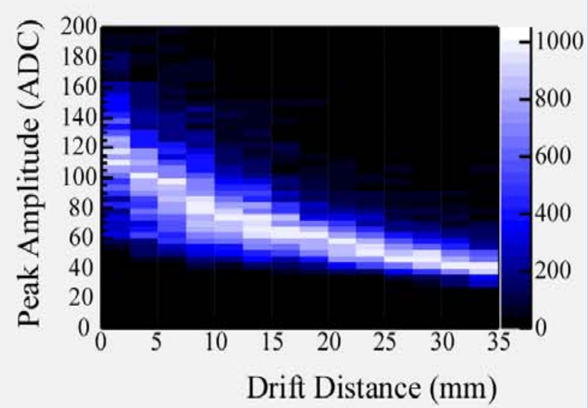
Charge cluster of 1 MIP particle



Noise level







The S/N ratio is the same or better than that obtained with the previous electronics

Parasitic Electrostatic Field,

Residual doping inhomogeneity causes
charge clusters to deviate from their ideal trajectory

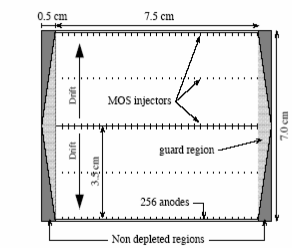
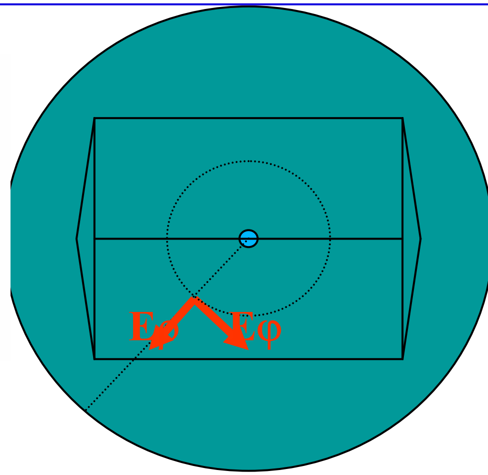
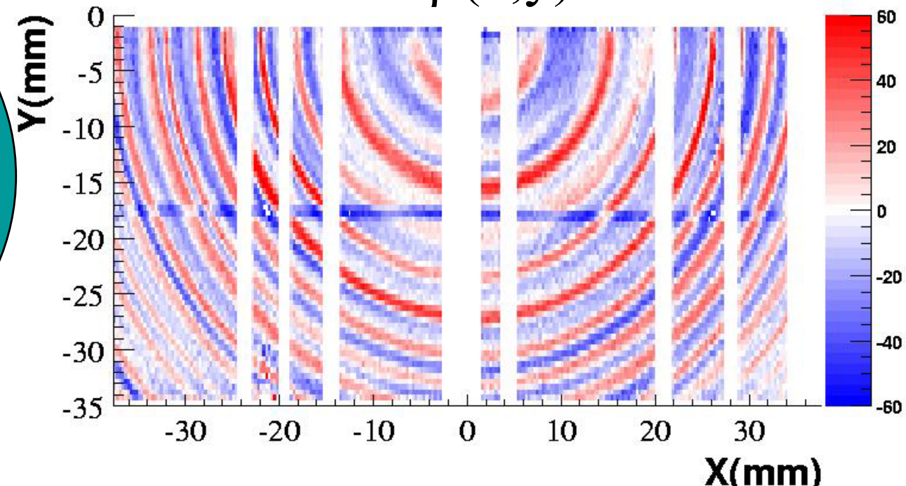
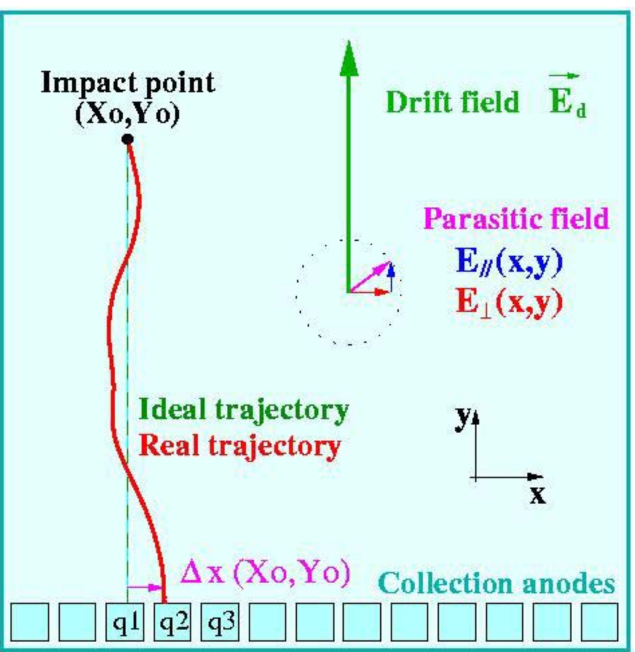


FIGURE 1. Scheme of the final ALICE SDD prototype.

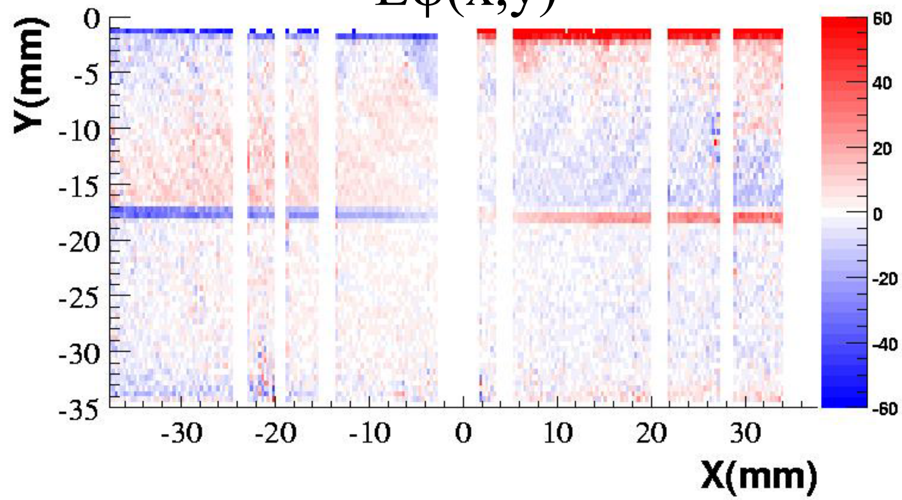


Eρ(x,y)





Eφ(x,y)



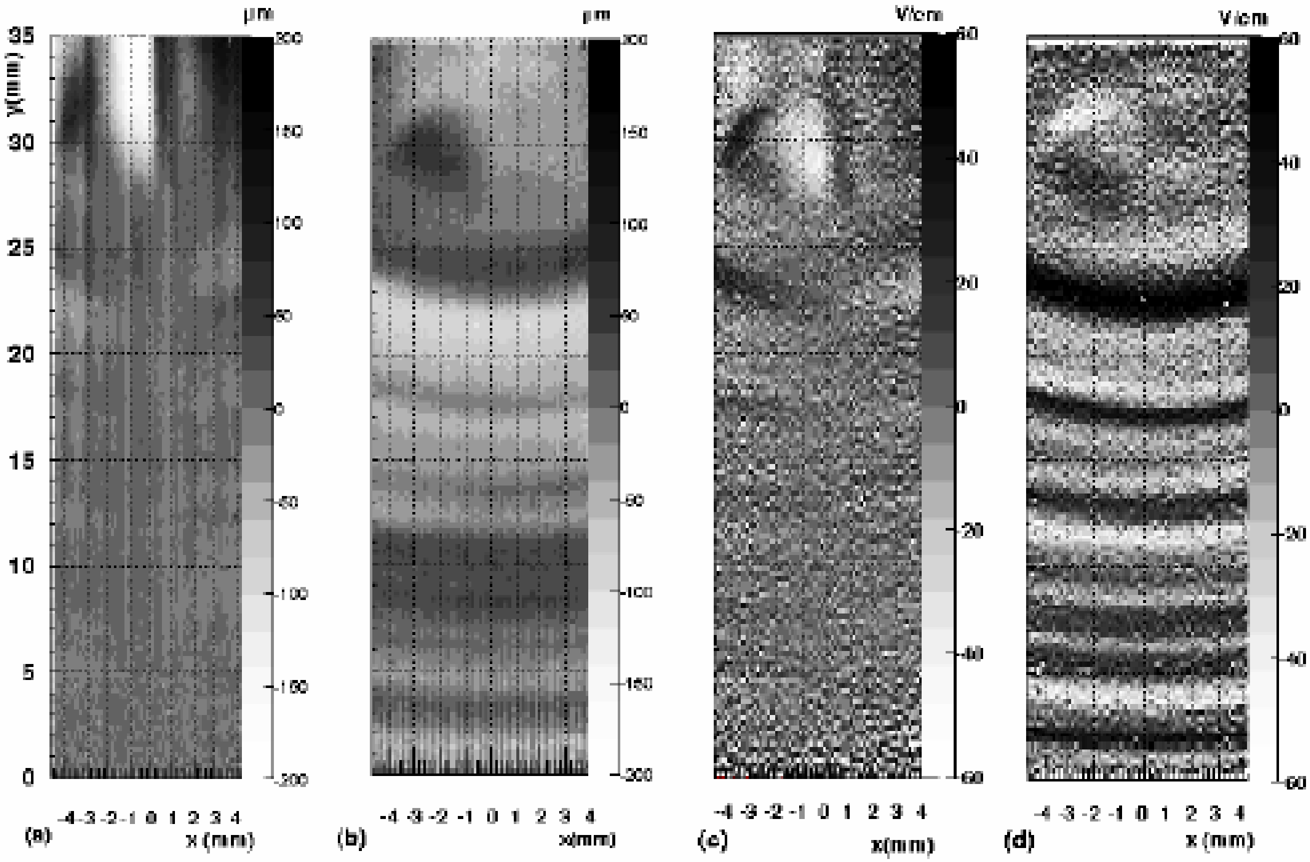


FIGURE 6. Systematic deviations (gray scale in μm) of the anode coordinate (a) and the drift coordinate (b) of the electron cloud with respect to the reference position of the crossing point of the particle coordinate, as a function of the anodic coordinate x and the drift distance y. Component of the parasitic electric field (V/cm) perpendicular to the drift axis (c) and parallel to the drift axis (d) induced by doping fluctuations as a function of the anodic coordinate X, and the drift distance Y.

Spatial Resolution

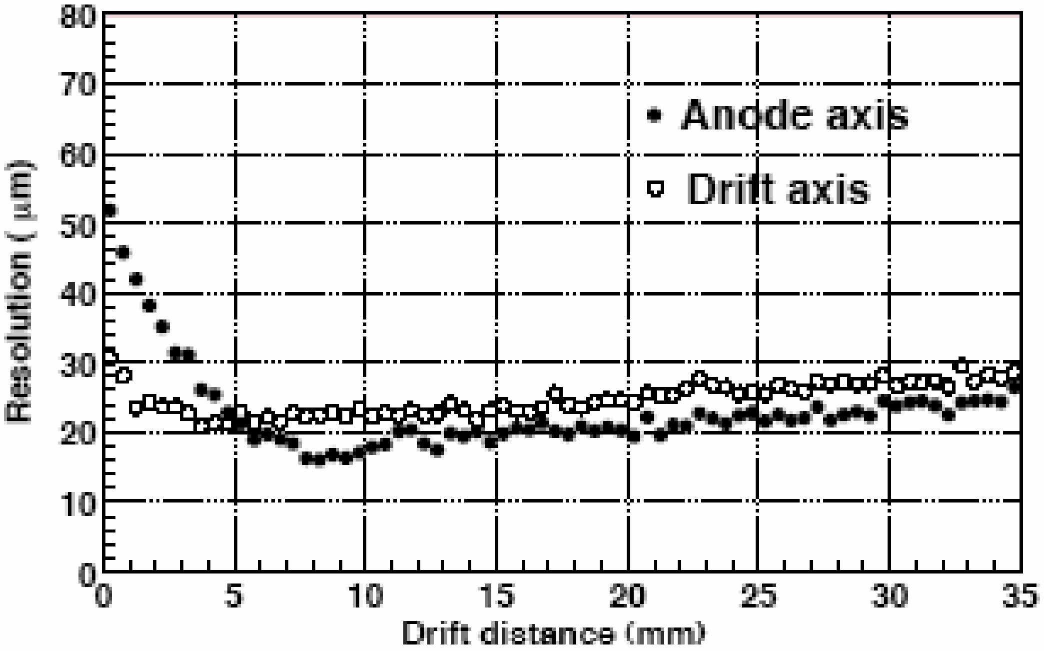
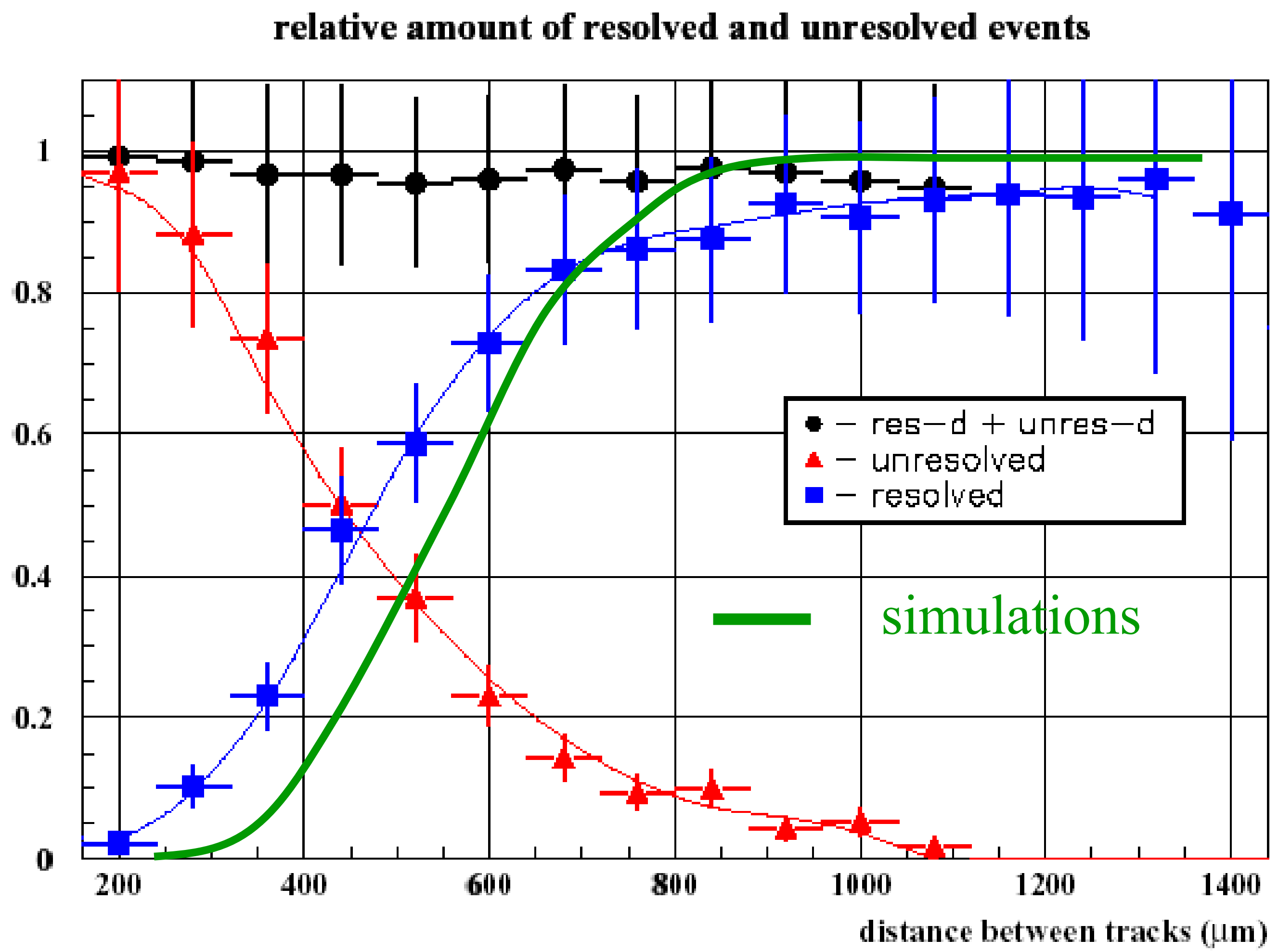


FIGURE 7. Drift axis (light circles) and anode axis (dark circles) spatial resolution of the ALICE SDD as function of the drift distance, after the correction of the doping inhomogeneities.

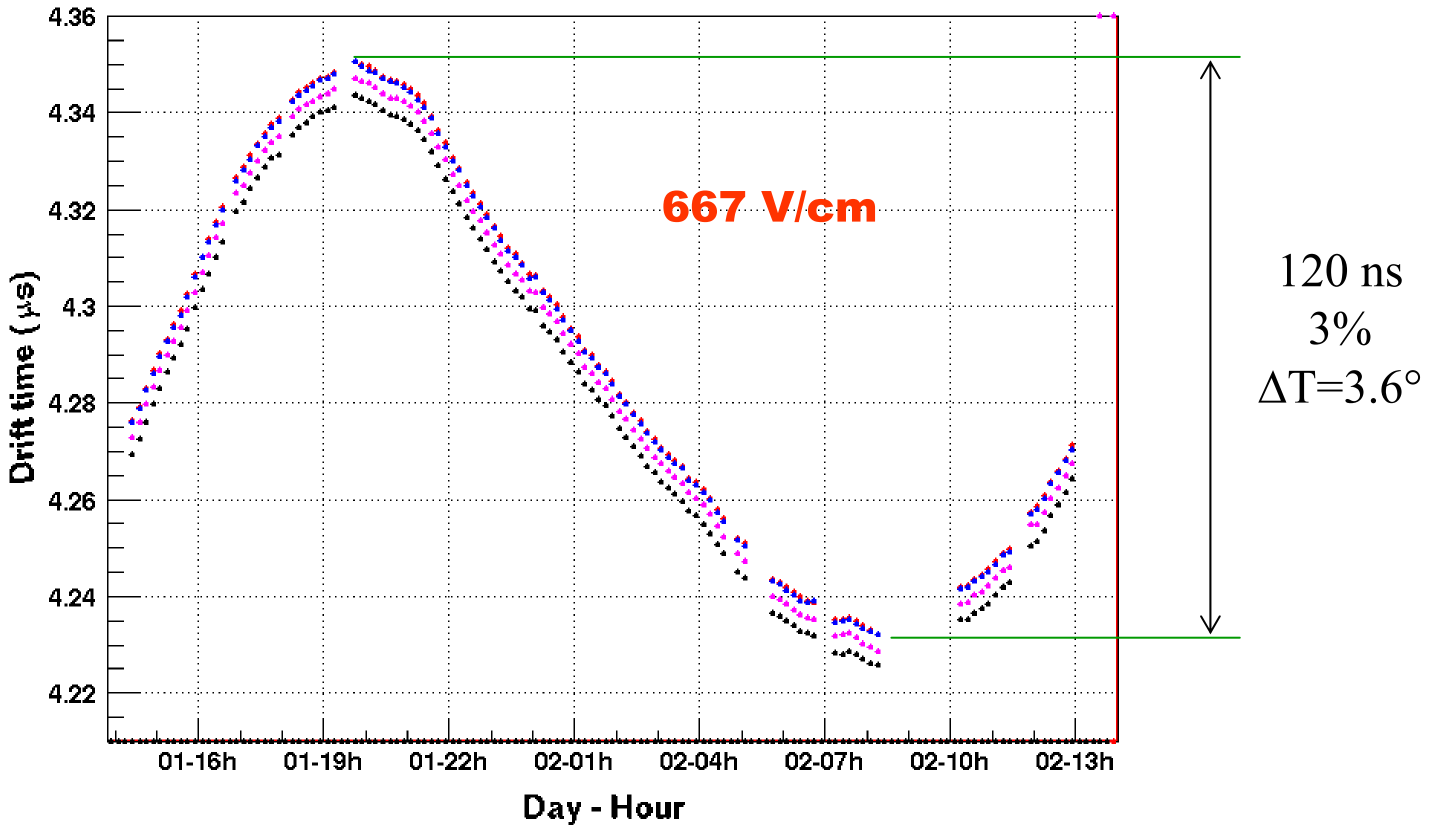
Performance from beam test (2)



Double track resolution compared with simulations

Performance from beam test (3)

Drift velocity calibration



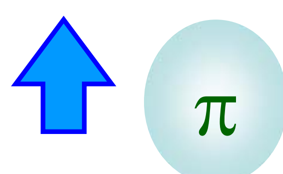
Drift time of 4 MOS injectors during 24 hours

Irradiation tests

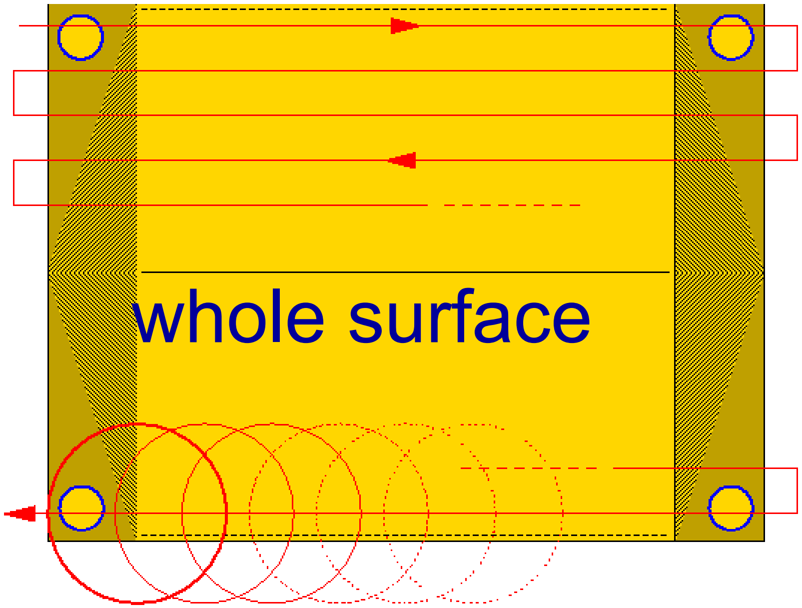
At the **LINAC** of the **ELETTRA** synchrotron in Trieste.

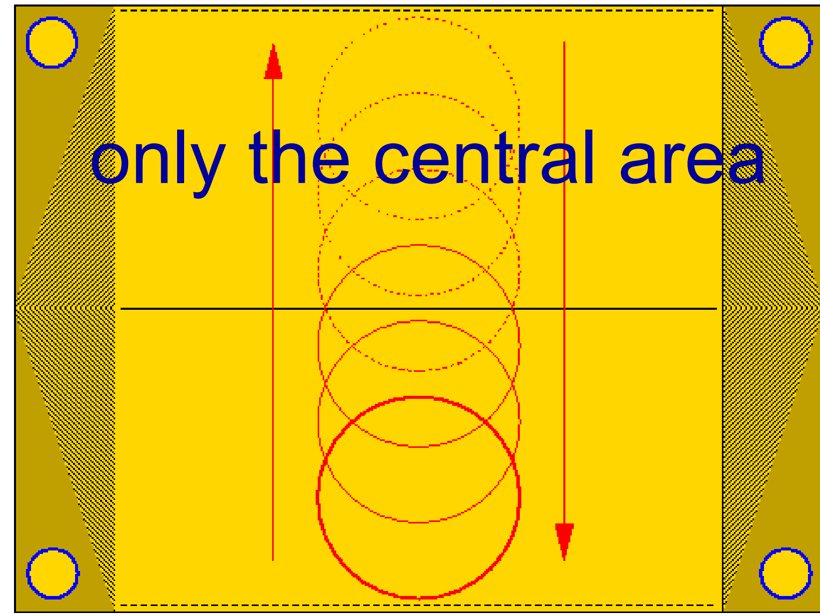
expected in ALICE

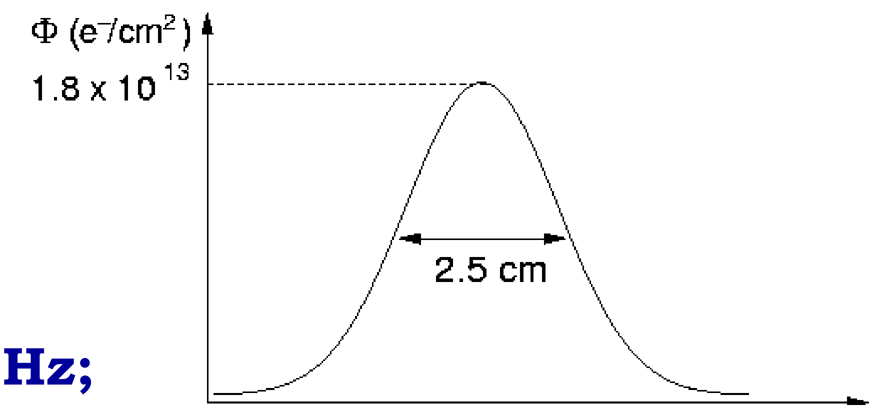
Layer	Dose (krad)	neutron Flux ($\times 10^{11}$ cm^{-2})
SDD 1	13.4	3.5
SDD 2	5.4	3.3



Various irradiation tests



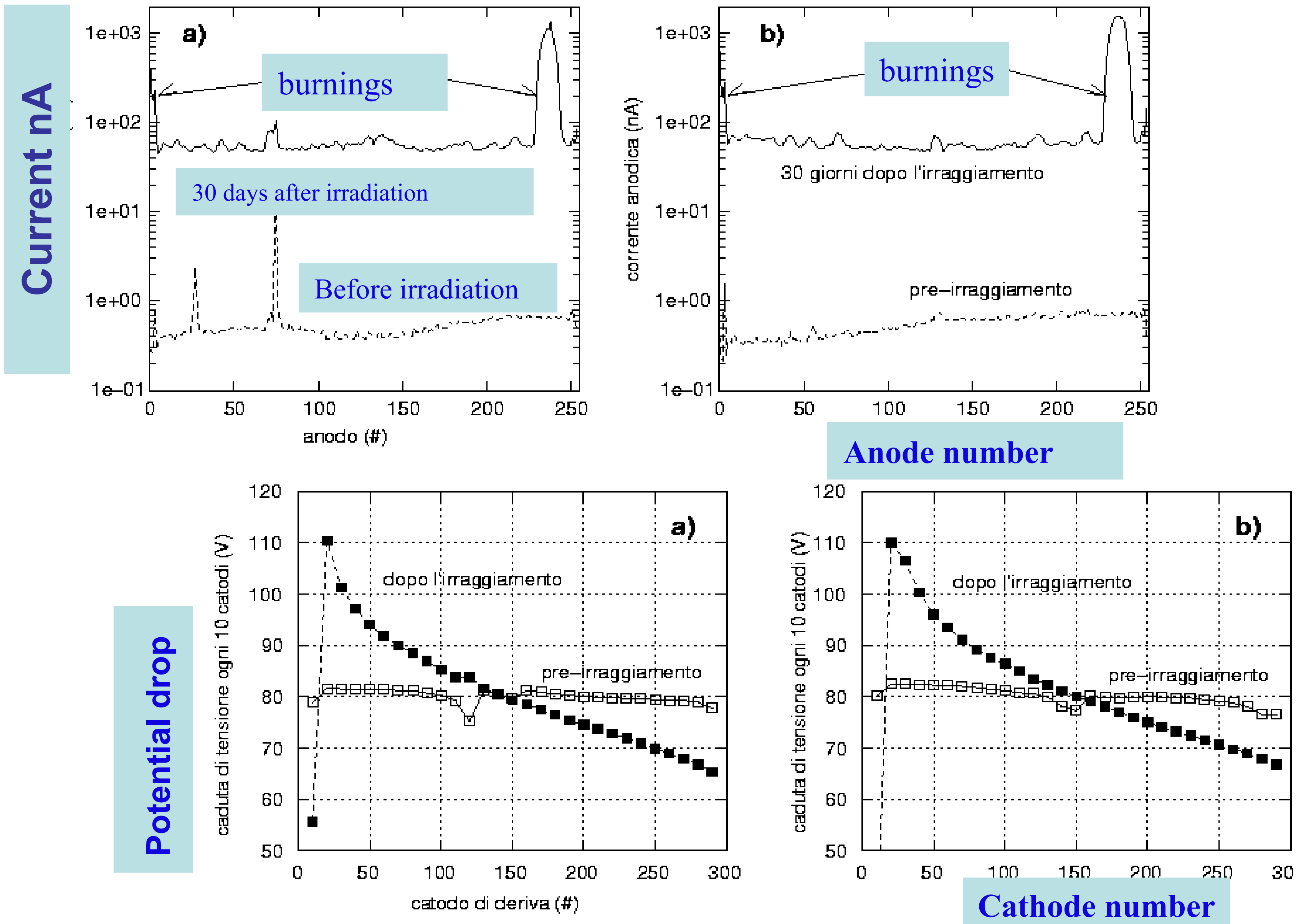




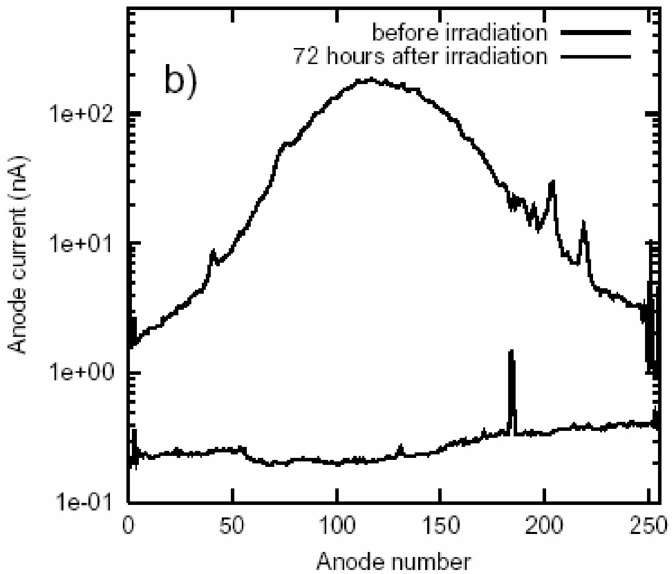
(micrometric movement)

Pulsed beam~ 10^{10} e^-/cm^2s - at 10 Hz;

whole surface

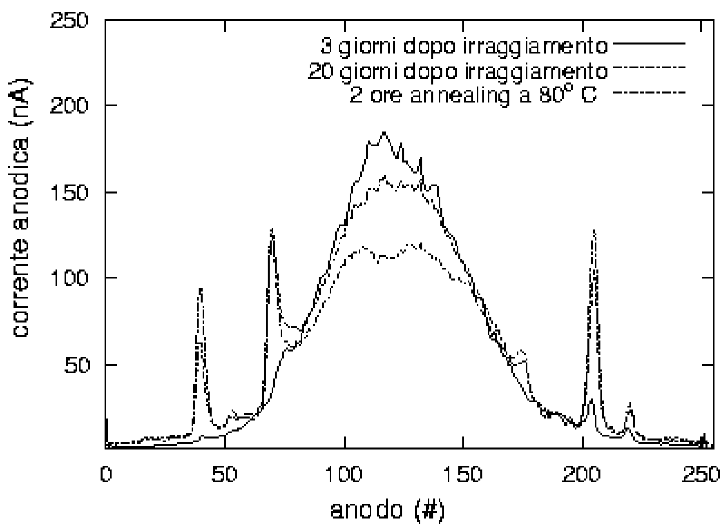


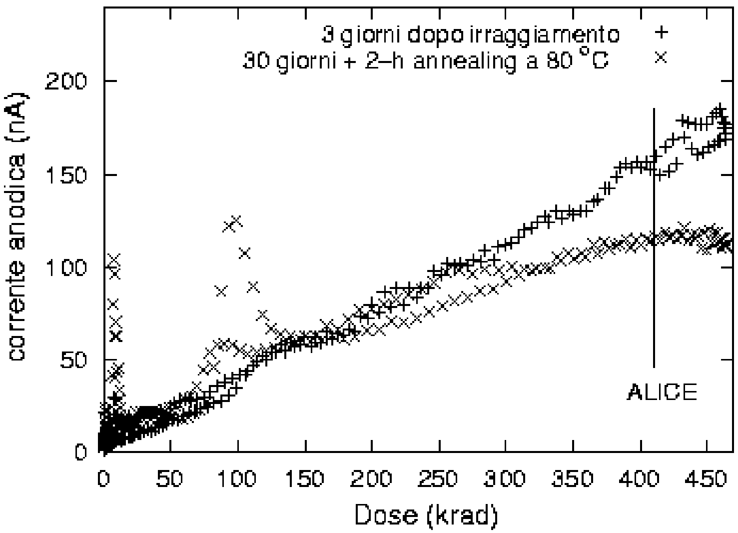
only the central area



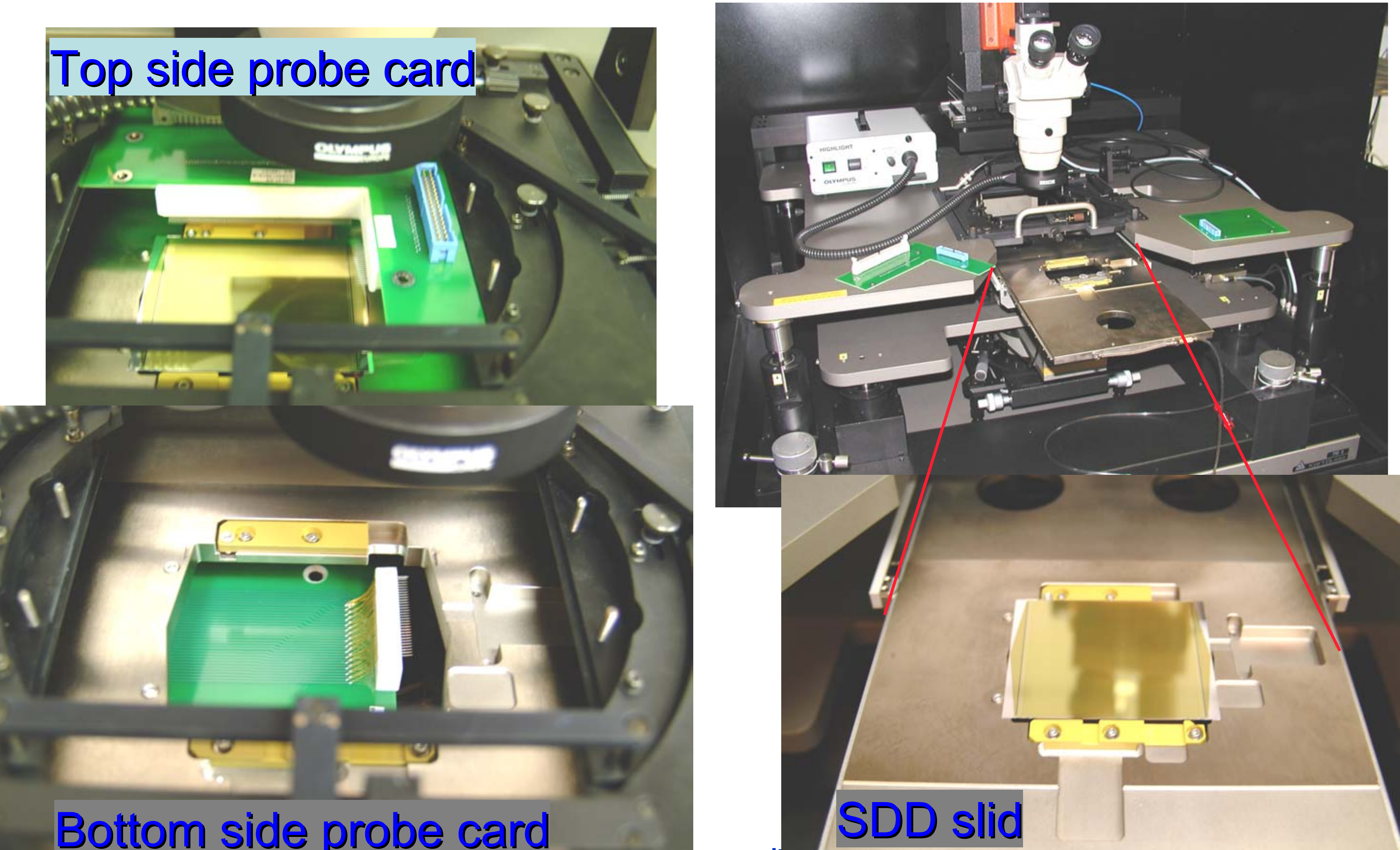
The beam pattern is reproduced on the anodes current measurement

Some annealing effect, current within the limits

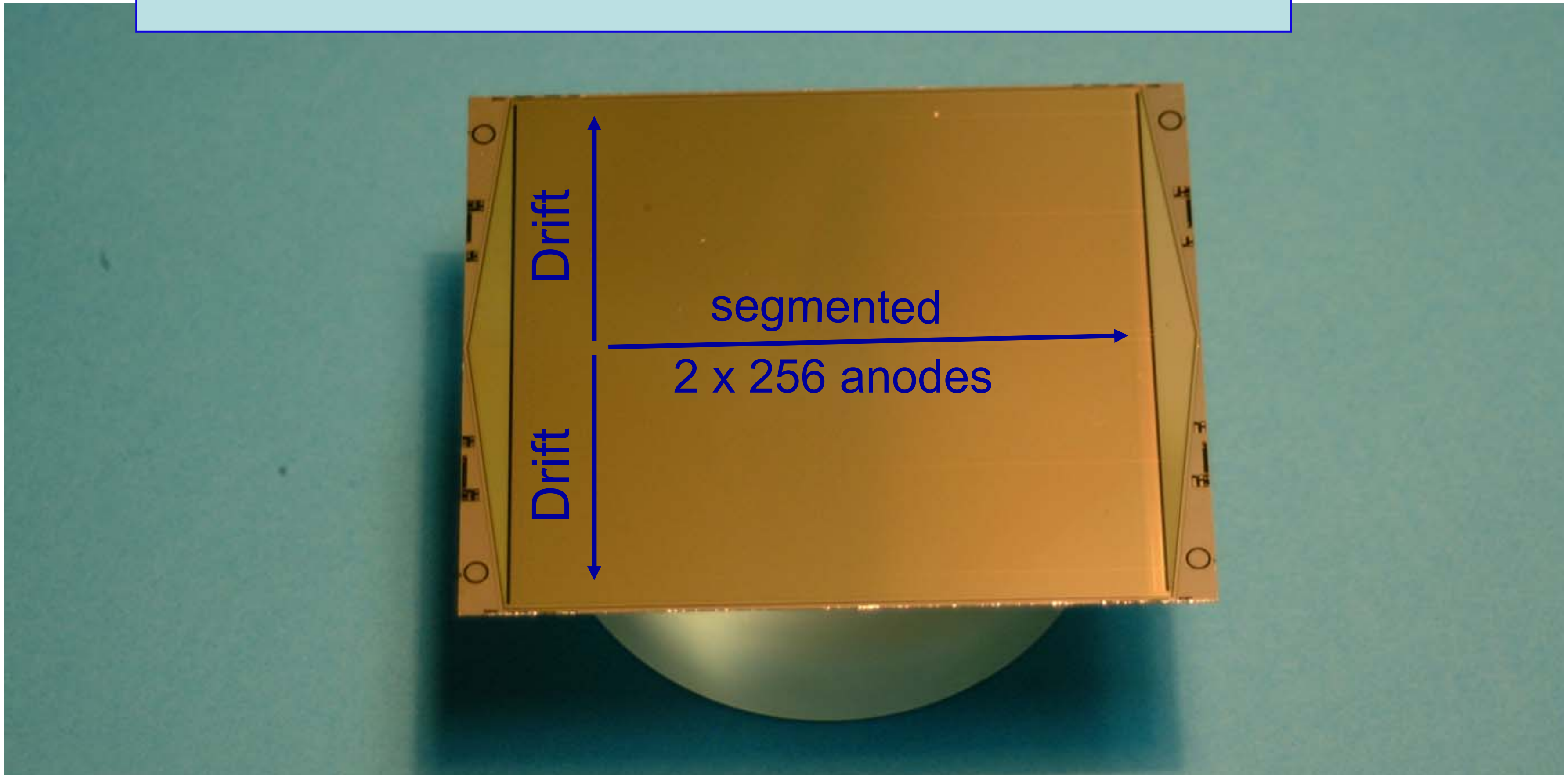




SDD test systems with 2-sided probe stations



ALICE Silicon Drift Detector

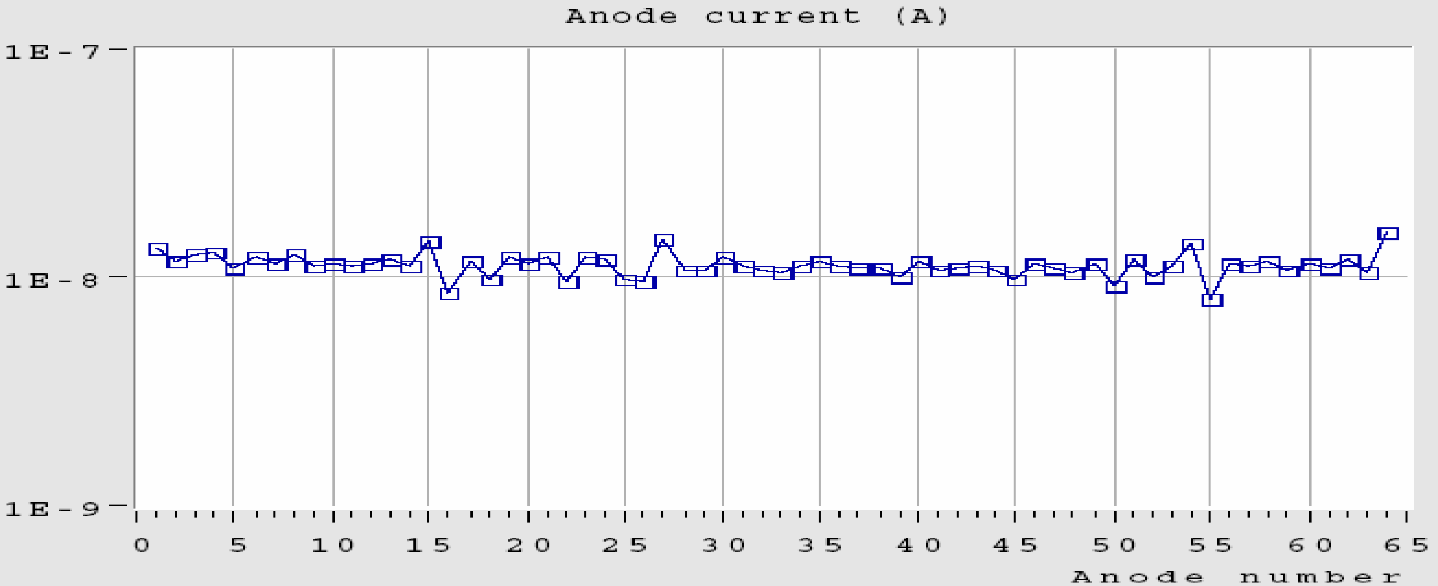


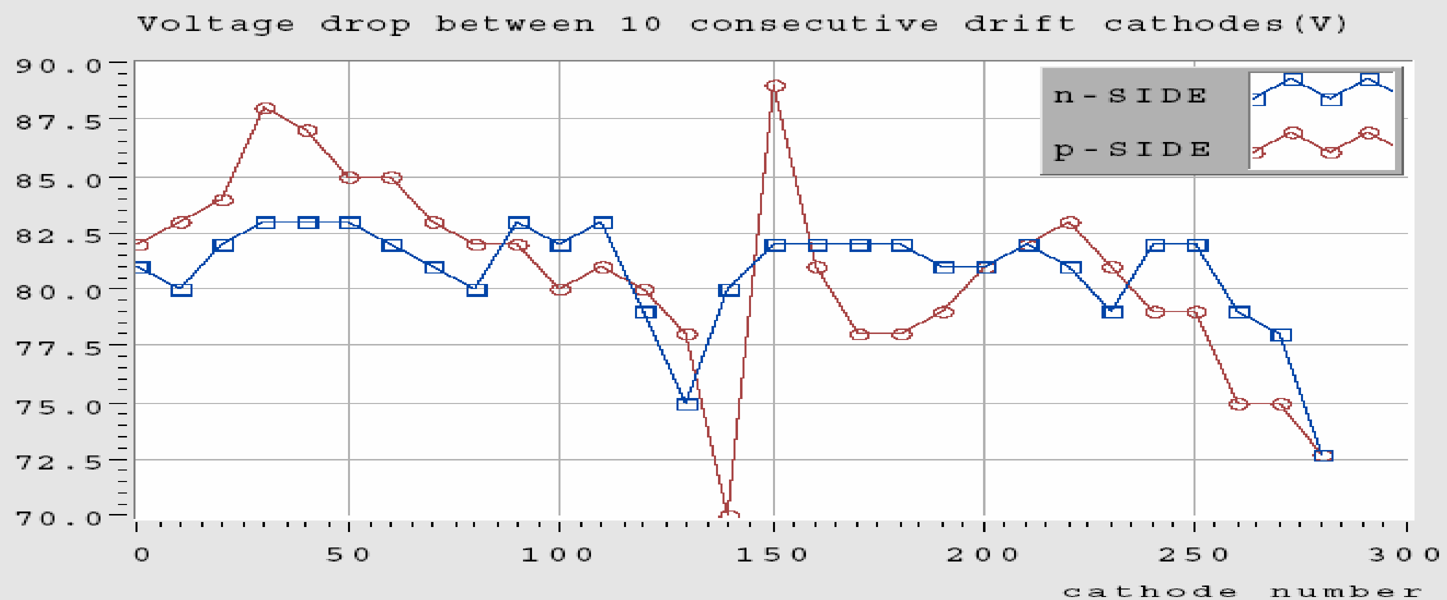
Wafer: 5", Neutron Transmutation Doped (NTD) silicon, 3 k$\Omega \cdot$cm resistivity, 300 μm thickness

Active area: 7.02×7.53 cm^2 (83% to total)

Detector n. 58856 Date: 25/10/200

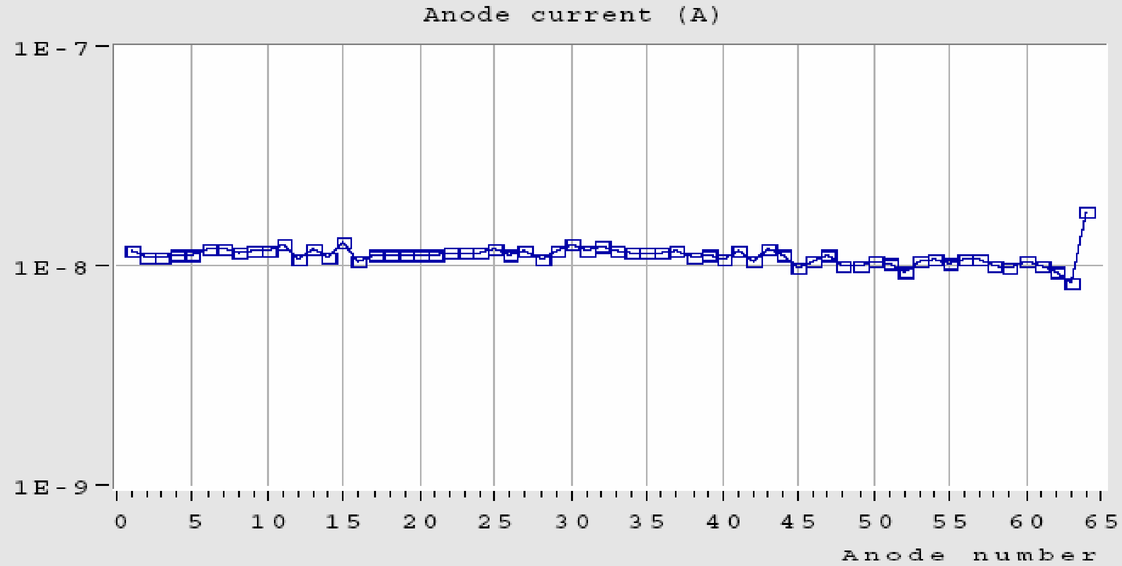
UP-half

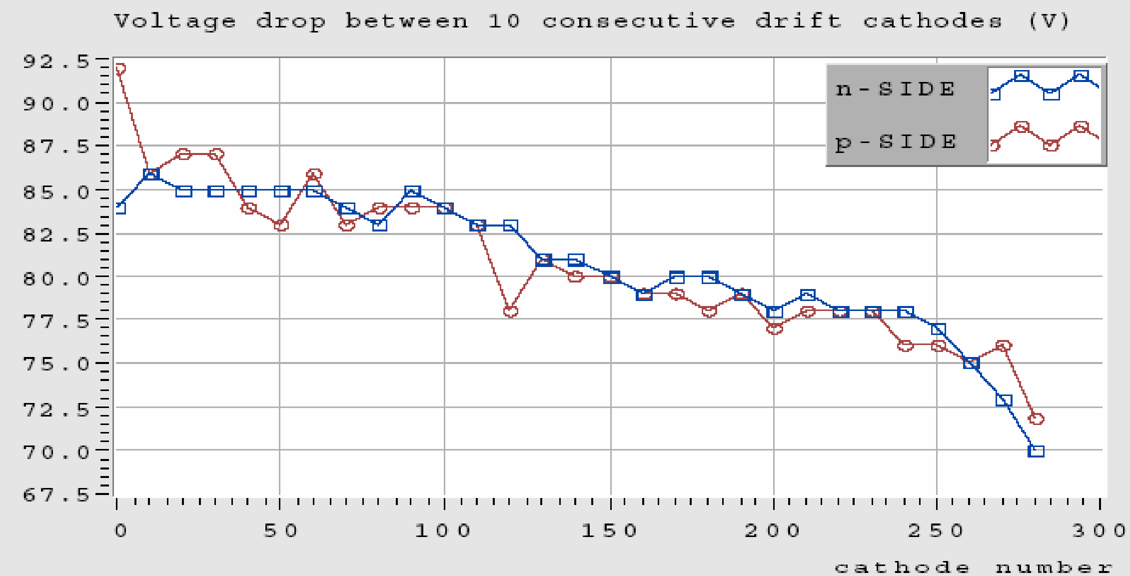




Detector n. 58865 Date: 25/10/200

DOWN-half

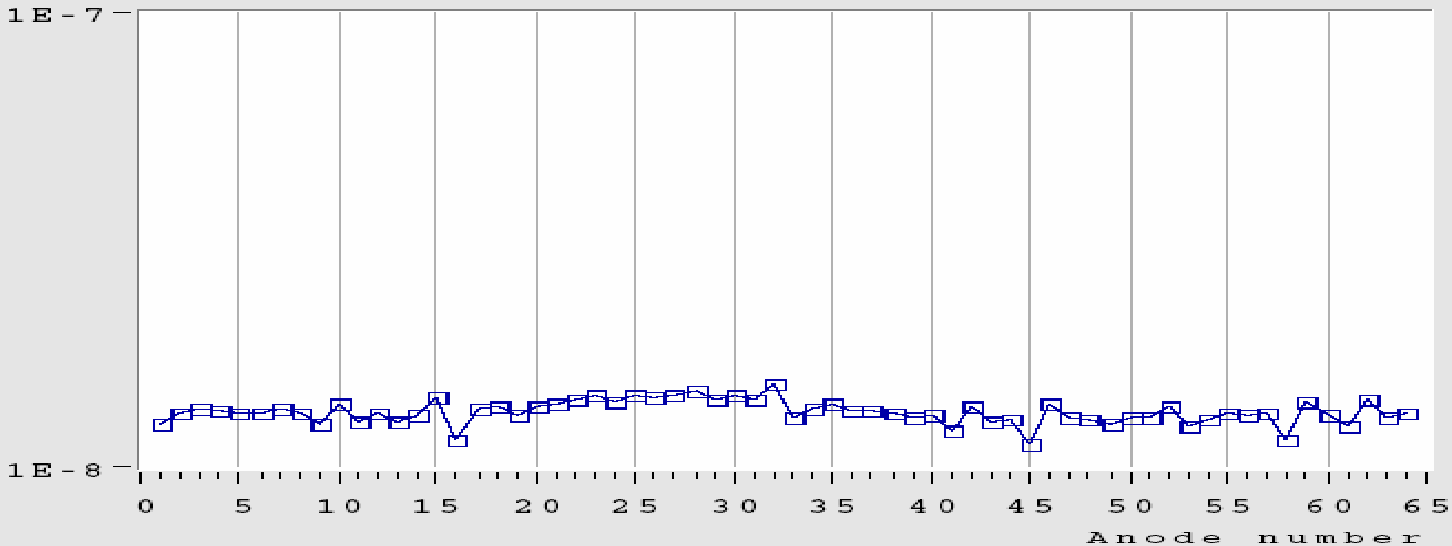




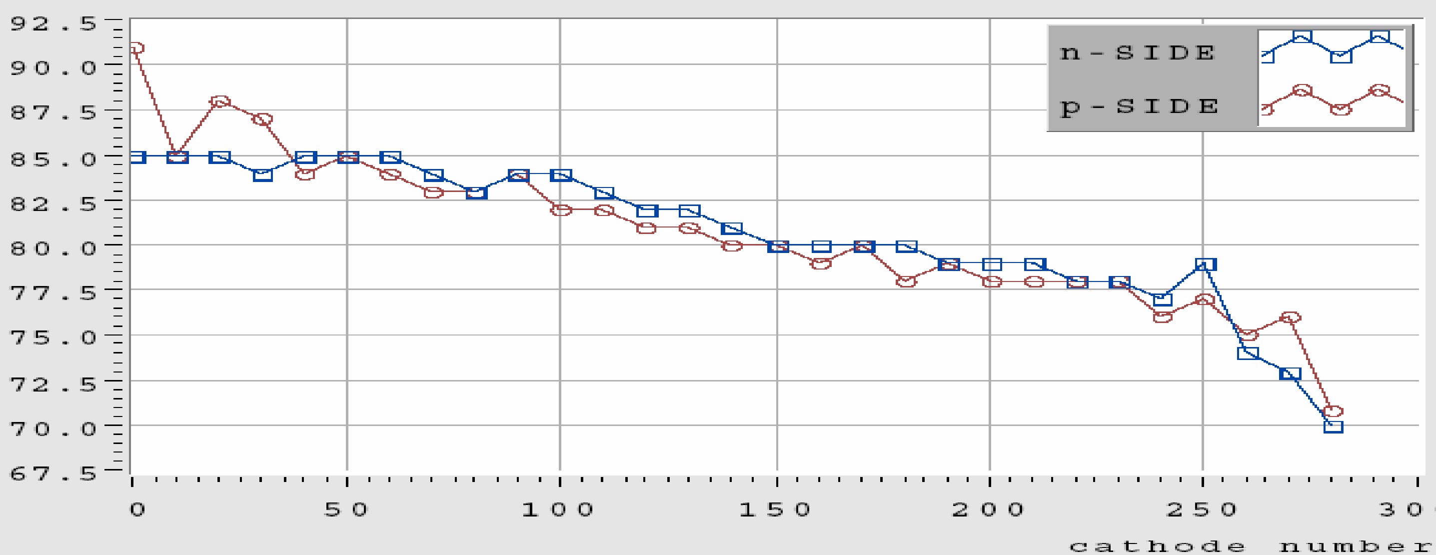
Detector n. 58865 Date: 25/10/2(

UP-half

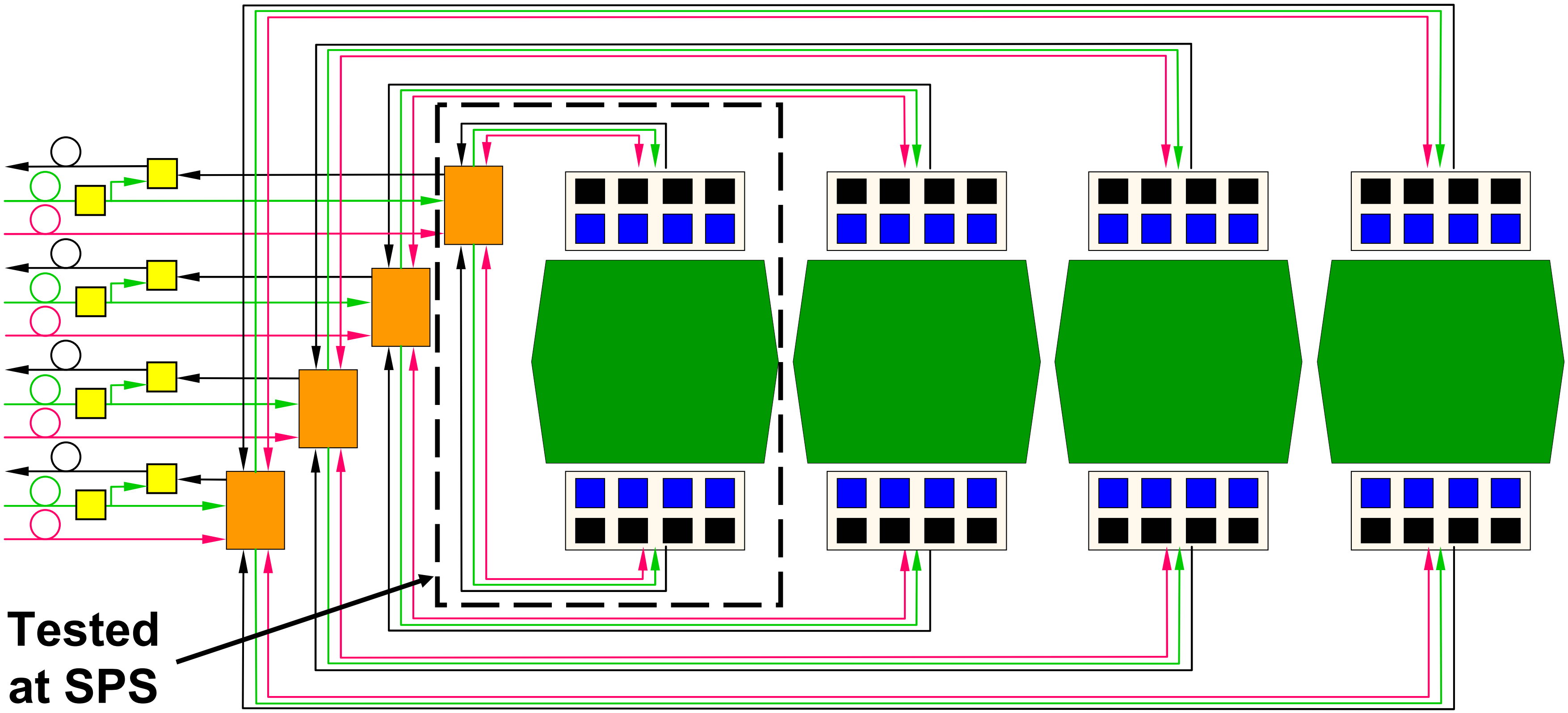
Anode current (A)



Voltage drop between 10 consecutive drift cathodes(V)



SDD readout architecture (each half-ladder)



PASCAL

AMBRA

CARLOS (data compression)

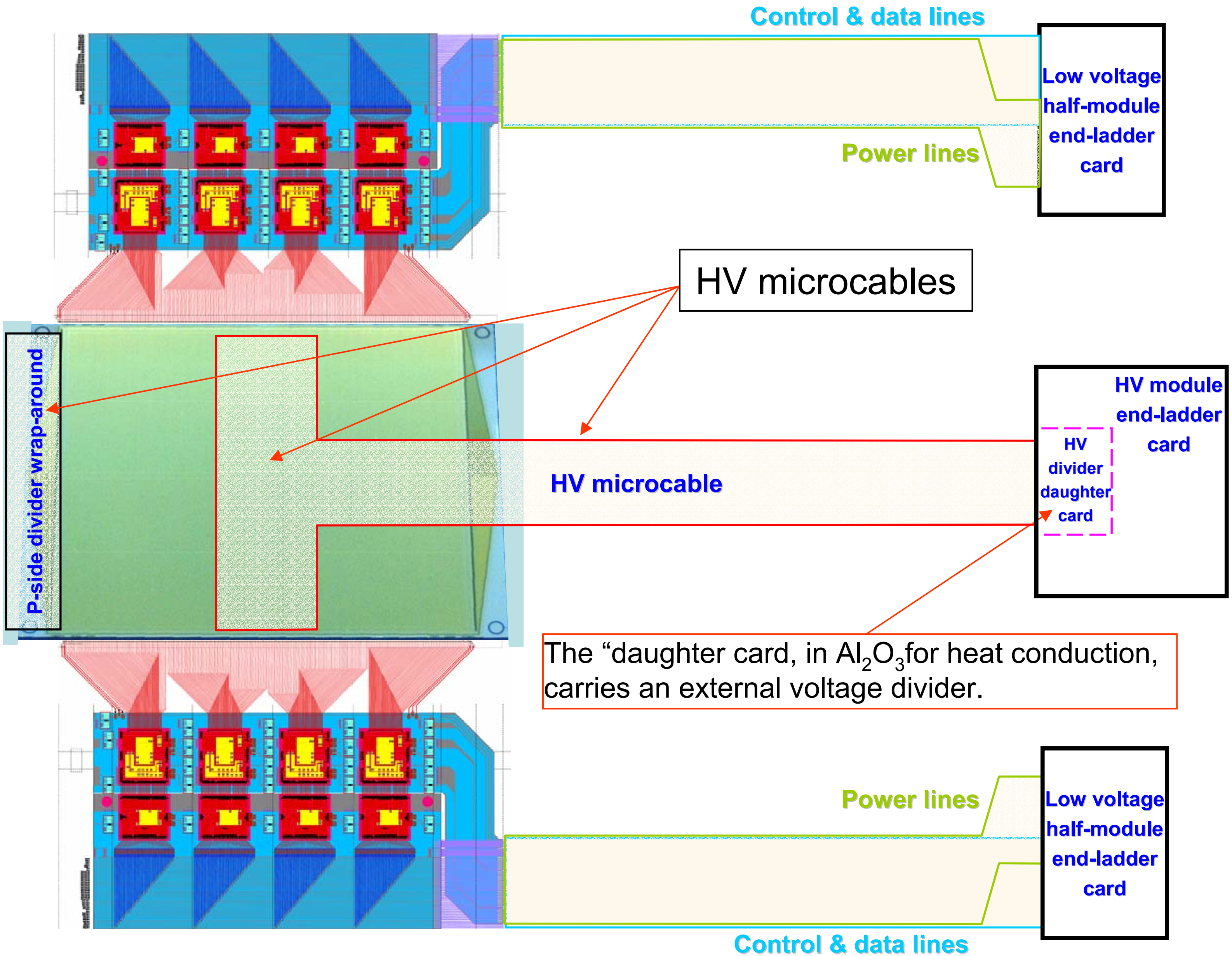
GOL (Gigabit Optical Link) / QPLL

40 MHz clock

Programming & monitoring

Data output & monitoring

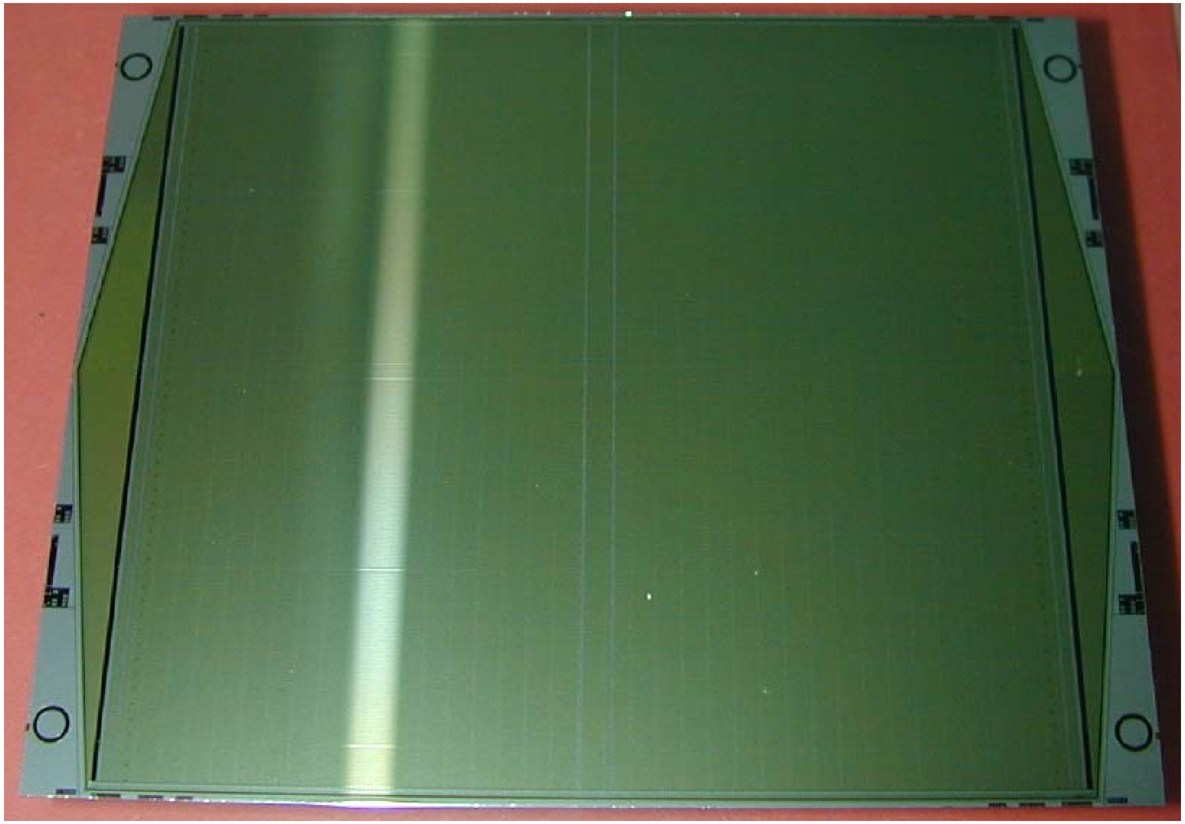
Layout of an SDD module with its microcables



Drift detectors

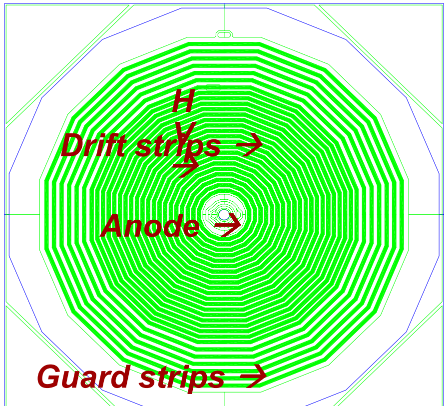
Features:

- **X – Y Position information**
- **High count rate**
- **Large area detectors**
- **High X-ray resolution**

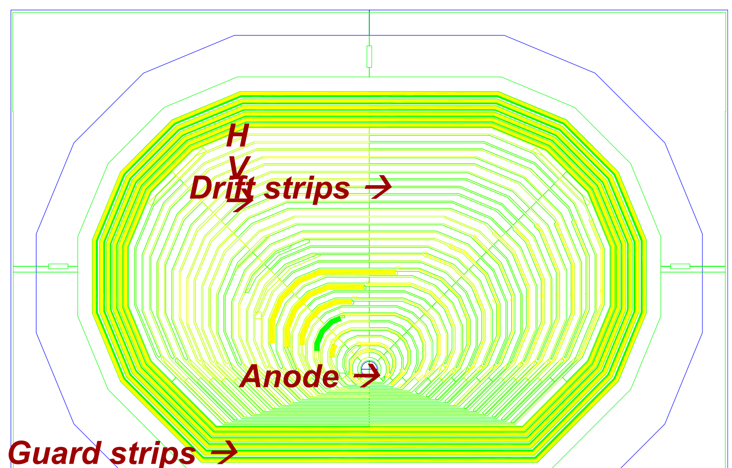


Largest drift detector in the world

- **Active area: 52 cm2**
- **Anode pitch: 294μm**
- **512 anodes on two rows**
- **Position resolution: <50μm**
- **MOS injectors for calibration**



Example of a 12 mm² area drift detector for X-Ray with a concentric anode

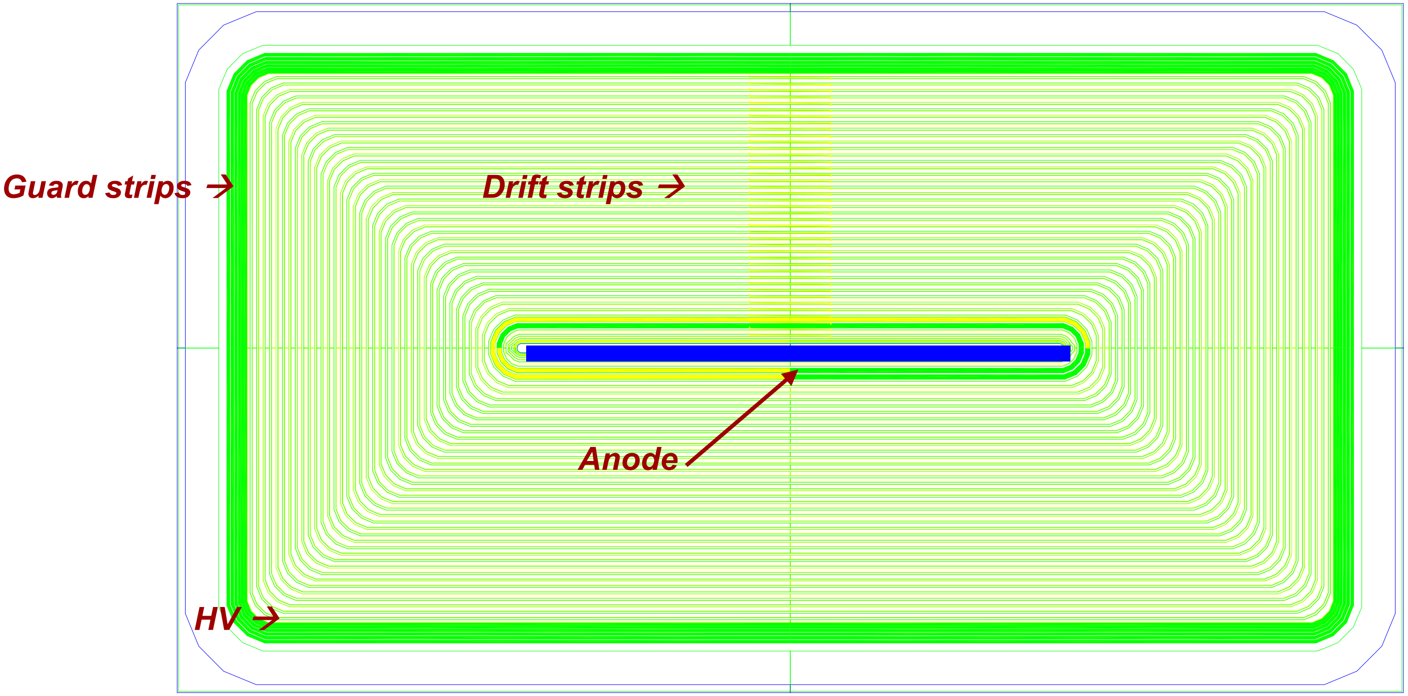


Example of a 11 mm² oblong area drift detector for X-Ray with the anode on side

Design of large drift detector

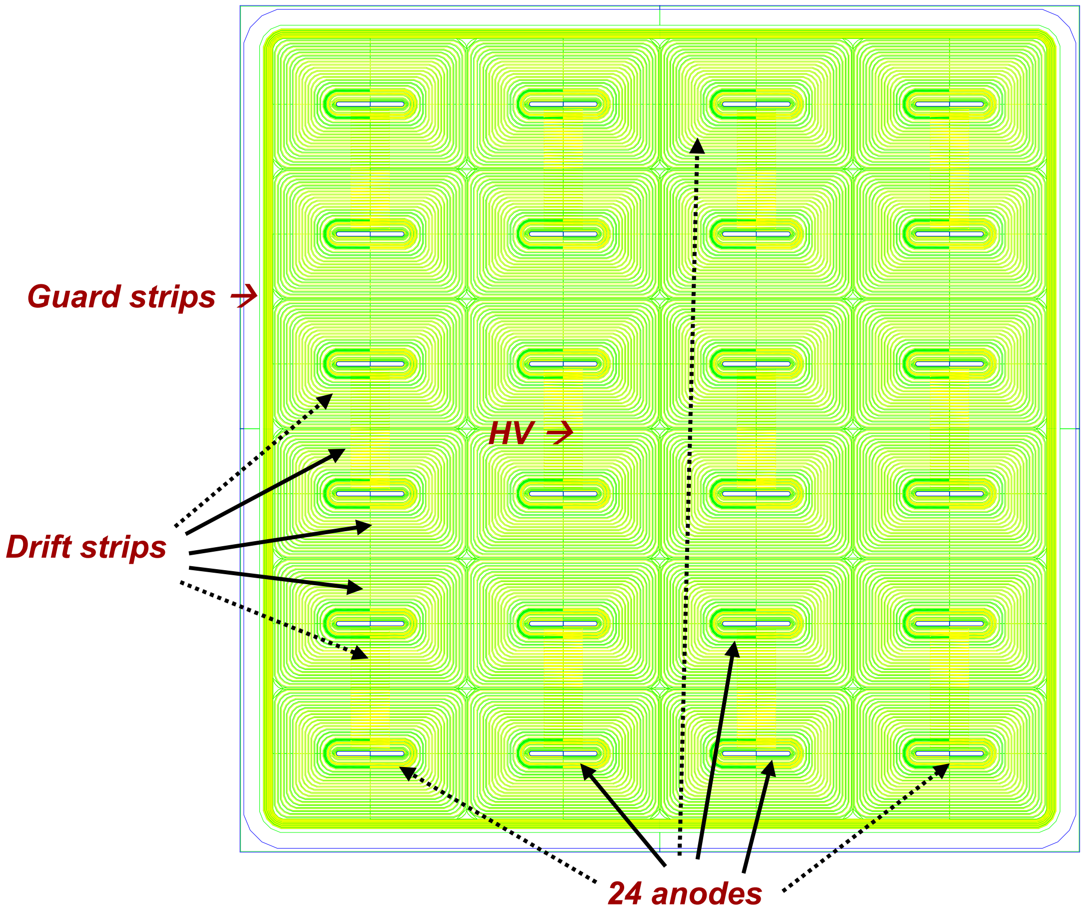
200 mm² area – one linear anode in the middle

4 detectors can be mounted in one housing

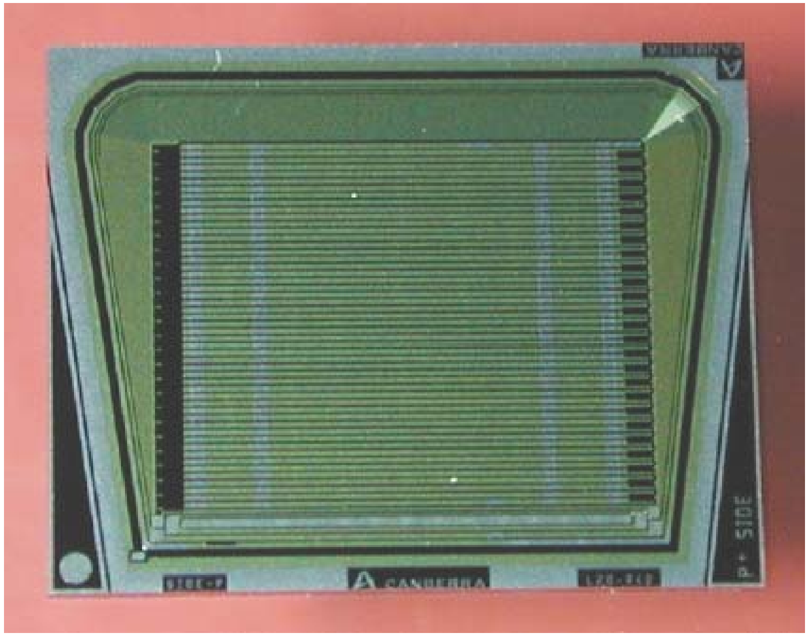


Design of large "pixel-drift" detector

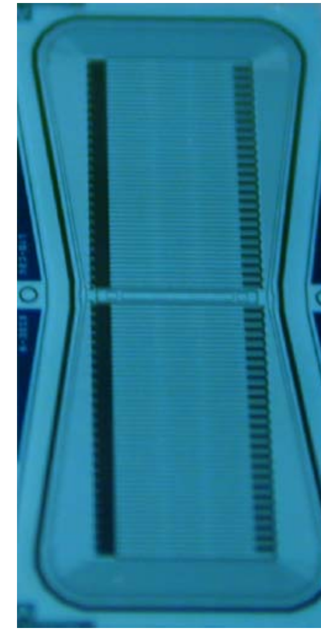
24 x 37.5 mm² = 900 mm² area – one linear anode in each "pixel-drift"



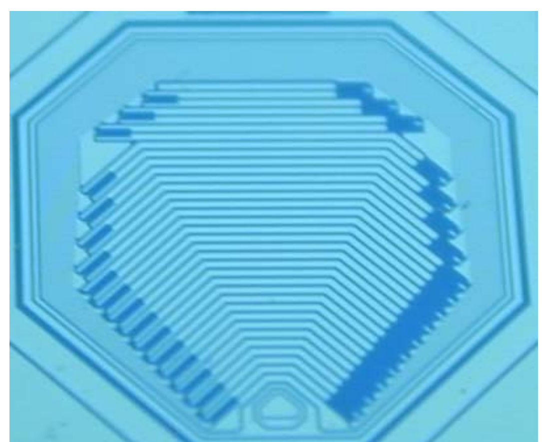
Based on the established structures design à la carte drift detectors



Linear drift detector – 40 mm2



12 x 2 mm2 rectangular drift detector with central anode



10 mm2 X- Ray detector with anode on chip side

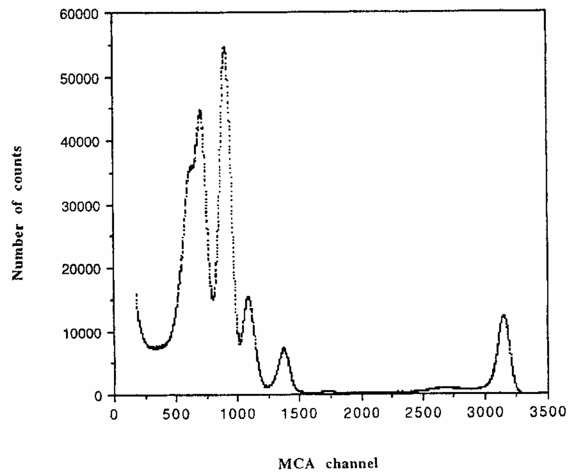


Fig. 6. ^{241}Am spectrum at $T = -20°C$, with a shaping time of 2 μs and a drift field of 110 V/cm (see text for the FWHM resolutions).

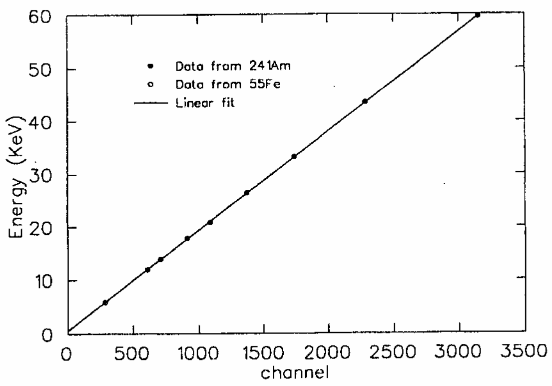


Fig. 7. Linearity plot obtained by fitting all experimental points.

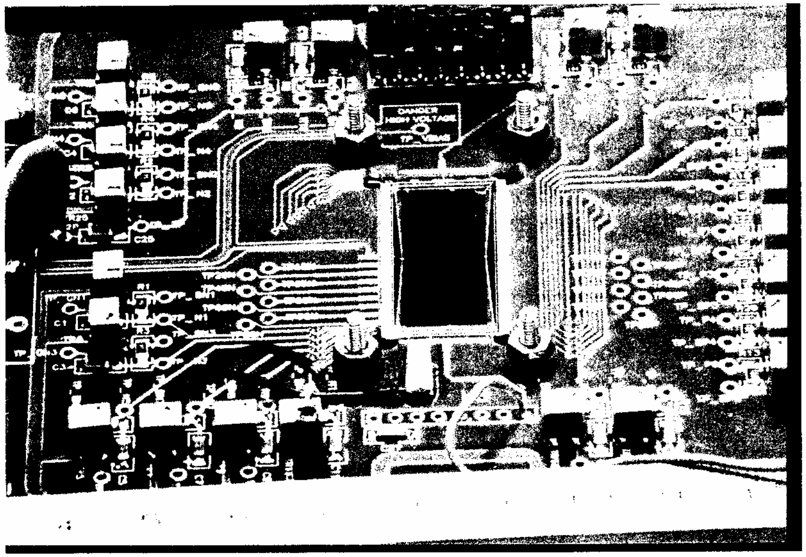


Fig. 3. Picture of the detector mounted in the test board, housing also the front-end preamplifier.

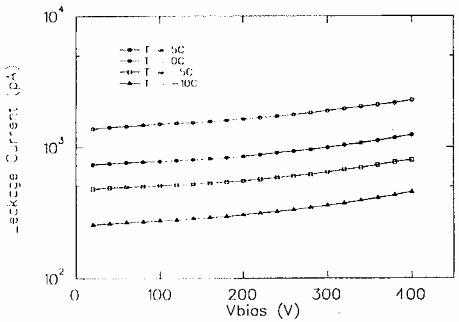


Fig. 4. Semilog plot of the measured anode currents as a function of the applied bias voltage for different temperatures.

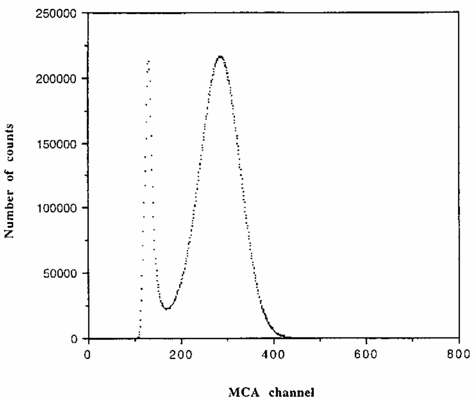


Fig. 5. Spectrum of ^{55}Fe (5.9 keV) obtained at $T = -20°C$, with a shaping time of 2 μs and a drift field of 110 V/cm (FWHM = 1.9 keV).

Also, at higher temperatures the results remain good; for example, at $T = -15°C$ we have for the

Conclusions

Satisfactory detector spatial resolution:

- along drift axis: 30-35 μm
- along anodic axis: better than 30 μm over 90% of the detector

Doping fluctuations :

- NTD silicon custom development
- Laser mapping of the detector

The detector after Alice like irradiation:

- **Anodic current remains within acceptable limits**
- **the potential distribution is altered by the highier current,**
- **requires drift speed calibration**

No defect propagation at Vbias for:

- short up to 5 cathodes
- up to 1 μA di corrente generation center
- divider interruption

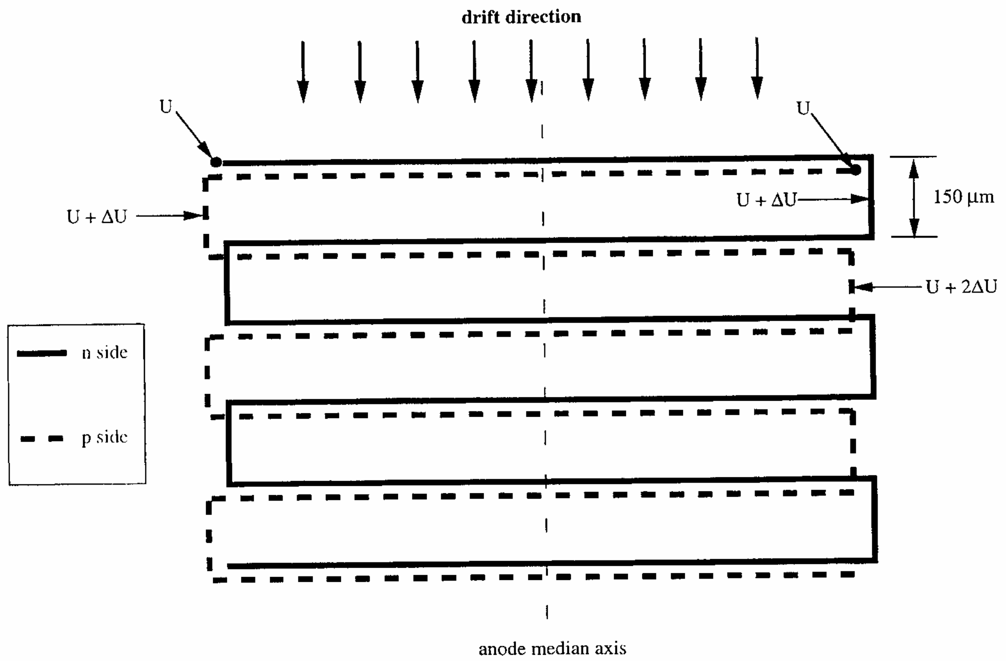


Fig. 2. Schematic view of high-voltage divider-drift electrode implantation on n- and p-side. The two implants are shown shifted only for the sake of clarity, but in reality they are perfectly overlapped.