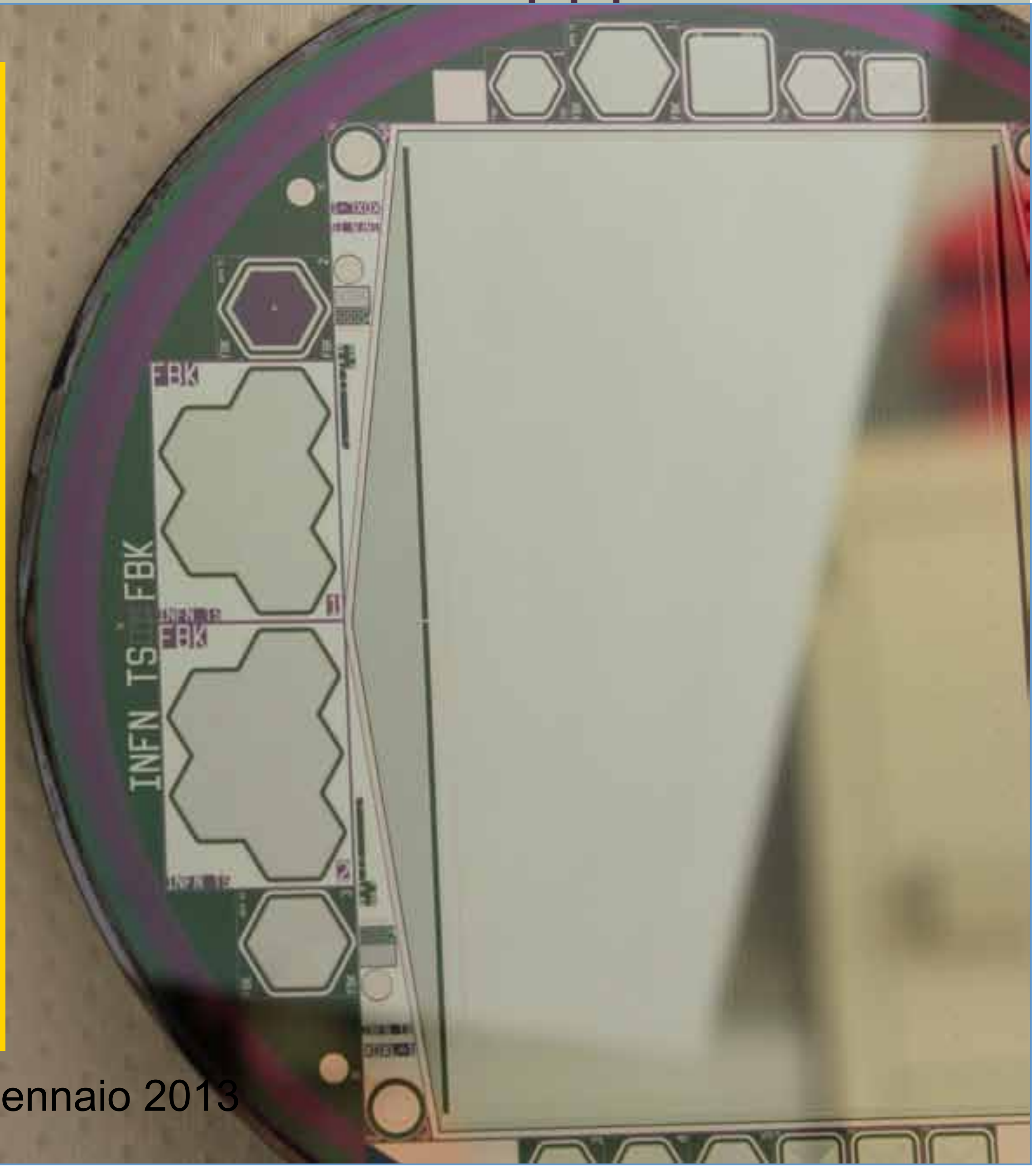
La camera a deriva di silicio (SDD)
1983-2013 30 anni di svilupppi



AGENDA

- Un poco di storia
- Come funziona
- ALICE più di 1 m^2
- raggi X di bassa energia

- **Gli sviluppi per:**

a) X-ray astronomy
LOFT

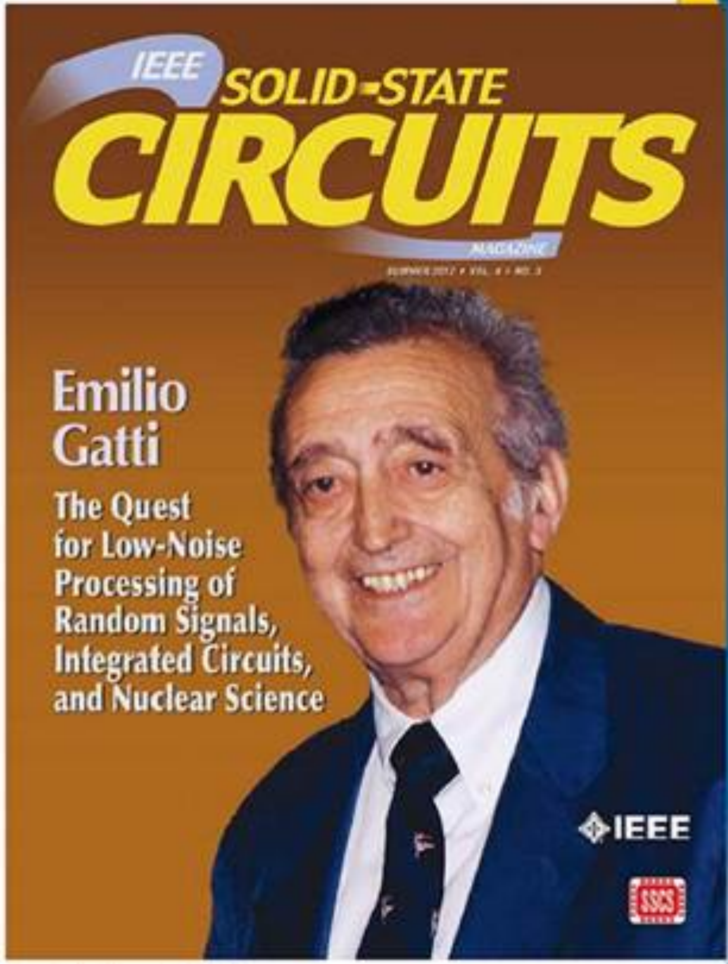
b) Sorgenti di Luce

- **Syncrotrone**
- **FEL**

Andrea Vacchi Napoli 24 gennaio 2013

La camera a deriva di silicio (SDD) fu proposta da E. Gatti e P. Rehak nel 1983.

- Un dispositivo molto versatile ed elegante nel suo principio di funzionamento. Ne sono derivati importanti sviluppi di sensori ed elettroniche dedicate nei successivi decenni:
  - prima camera di grande superficie per il tracciamento in presenza di altissima molteplicità (1990),
  - al sistema di rivelazione attivo su ALICE-LHC.
  - La caratterizzazione degli stessi rivelatori per la rivelazione di raggi X di bassa energia ha dato risultati rilevanti.
  - La possibilità di disegnare, modellare e sviluppare rivelatori ad hoc spinge ad inoltrarsi verso il contesto difficile e stimolante dei rivelatori per sorgenti di luce avanzate (ALS) come sincrotrone e Fel.
  - Il campo è tutt'altro che esaurito e sembra capace di fornire soluzioni a molte sfide sia scientifiche che per l'avviamento di processi di industrializzazione ed avvio al mercato .



Ore 14.15

Sala Conferenze

Dipartimento di Elettronica e Informazione Politecnico di Milano

4 ottobre 2012

In occasione dell'uscita del numero speciale a lui dedicato,

alla presenza e in onore di **Emilio Gatti**

Erik H.M. Heijne terrà il seminario:

Imaging and imagination: the use of nanoelectronics for particle physics experiments

Maggiori dettagli sono disponibili al sito: www. dei.polimi.it

POLITECNICO DI MILANO

DIPARTIMENTO DI ELETTRONICA E INFORMAZIONE

PAVEL REHAK

BROOKHAVEN NATIONAL LABORATORY Features Media & Communications Office

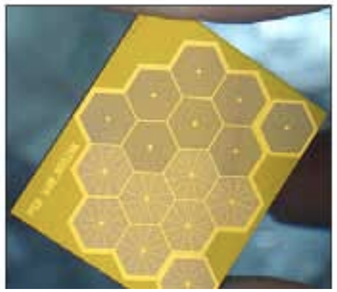
News Releases | Features | Photos | Videos | Fact Sheets | Lab History | Contacts

By Satya Sharmugham | December 19, 2008

25th Anniversary of Rehak's and Gatti's Innovative Detector

1983

Brookhaven's Instrumentation Division develops state-of-the-art instrumentation required for experimental research programs at BNL and throughout the world. Much of their work is focused on detectors that track particles after a collision or detectors that identify the energy and location of absorbed x-rays. Some of the current silicon detector developments are for RHIC and ATLAS upgrades, NSLS and NSLS-II, and NASA missions, to name a few.



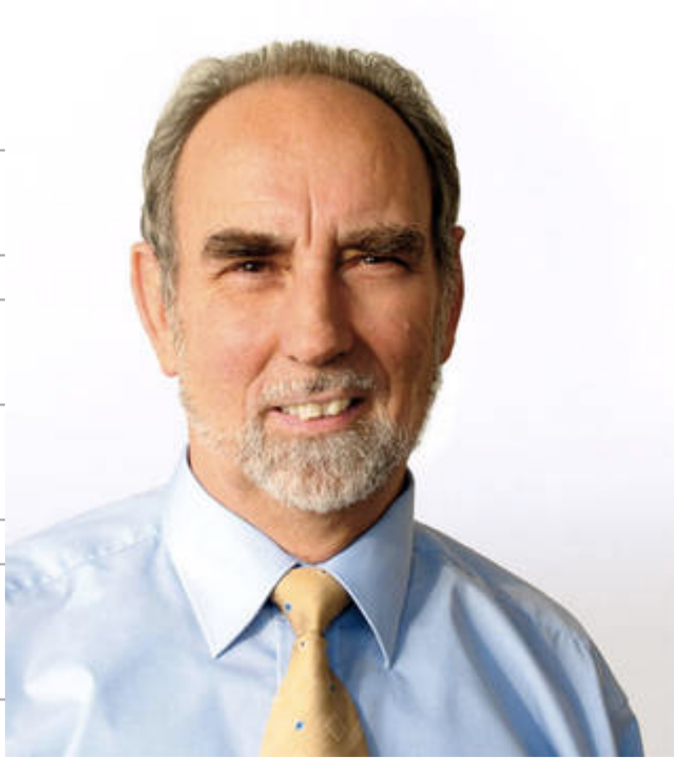
Dr. Josef Kemmer

KETEK
Creative Detector Solutions

HOME PRODUCTS COMPANY DOWNLOADS NEWS CONTACT

1980 Publishes **planar technology** with ion implantation in Nuclear Instruments and Methods (NIM)

HISTORY



Development of the planar technology for the fabrication of silicon radiation detectors by Dr. Josef Kemmer at the Technical University of Munich (TUM).
Fabrication of the first SDDs by Dr. Josef Kemmer at the TUM utilizing the planar process. The detector principle was proposed by Emilio Gatti from Politecnico di Milano and Pavel Rehak from Brookhaven National Laboratory.
Formation of Ketek GmbH by Dr. Josef Kemmer.
Main business of KETEK is technology transfer to industry and to research institutes. Contribution to some of the world's most advanced detector projects in high energy physics and space research like XMM Newton.
Development and launch of the first generation of commercial SDD modules. Introduction of KETEK SDD to the XRF and EDX market within a strong co-operation with Röntec.
Development of monolithic and discrete multi-channel SDD systems.
Manufacturing and delivery of the 1000th commercial SDD Presentation of the 3rd generation of SDD with an energy resolution < 128eV at Mn Kα. Innituation of the electronic product line with the KETEK Analytical X-ray Acquisition System (AXAS) with own development and production.
The MER-Rover in NASA's Mars Lander carries six KETEK alpha particle detectors and a customized SDD.

PATENT Josef KEMMER 1980

United States Patent [19] | [11] **4,442,592**
Kemmer | [45] **Apr. 17, 1984**

[54] **PASSIVATED SEMICONDUCTOR PN JUNCTION OF HIGH ELECTRIC STRENGTH AND PROCESS FOR THE PRODUCTION THEREOF**

[76] Inventor: **Josef Kemmer**, No. 41 D, Hauptstrasse, 8041 Haimhausen, Fed. Rep. of Germany

[21] Appl. No.: **225,069**

[22] Filed: **Jan. 14, 1981**

[30] **Foreign Application Priority Data**

Jan. 31, 1980 [DE] Fed. Rep. of Germany 3003391

[51] **Int. Cl.**³ **H01L 31/18**
[52] **U.S. Cl.** .... **29/572**; 29/576 B; 29/578; 148/1.5; 148/187
[58] **Field of Search** .... 148/1.5, 187; 29/571, 29/572, 569 R, 576 B, 578; 156/643, 662

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,769,109 10/1973 MacRae et al. .... 148/1.5 X
3,891,468 6/1975 Ito et al. 148/1.5

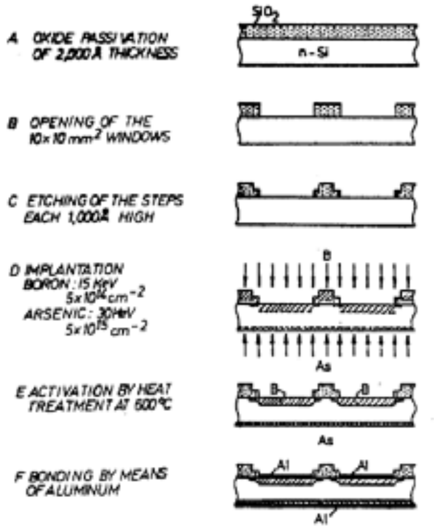
Primary Examiner—Brian E. Hearn
Assistant Examiner—David A. Hey
Attorney, Agent, or Firm—John C. Smith, Jr.

[57] **ABSTRACT**

A passivated semiconductor pn junction is provided which has a high electric strength, one area being heavily doped and being very thin, in particular for radiation detectors. The pn junction has an edge zone at which a depletion zone (surface channel) is provided underneath the passivation layer.

12 Claims, 2 Drawing Figures

PATENT Josef KEMMER 1980



4,442,592

CRITICAL STEPS :

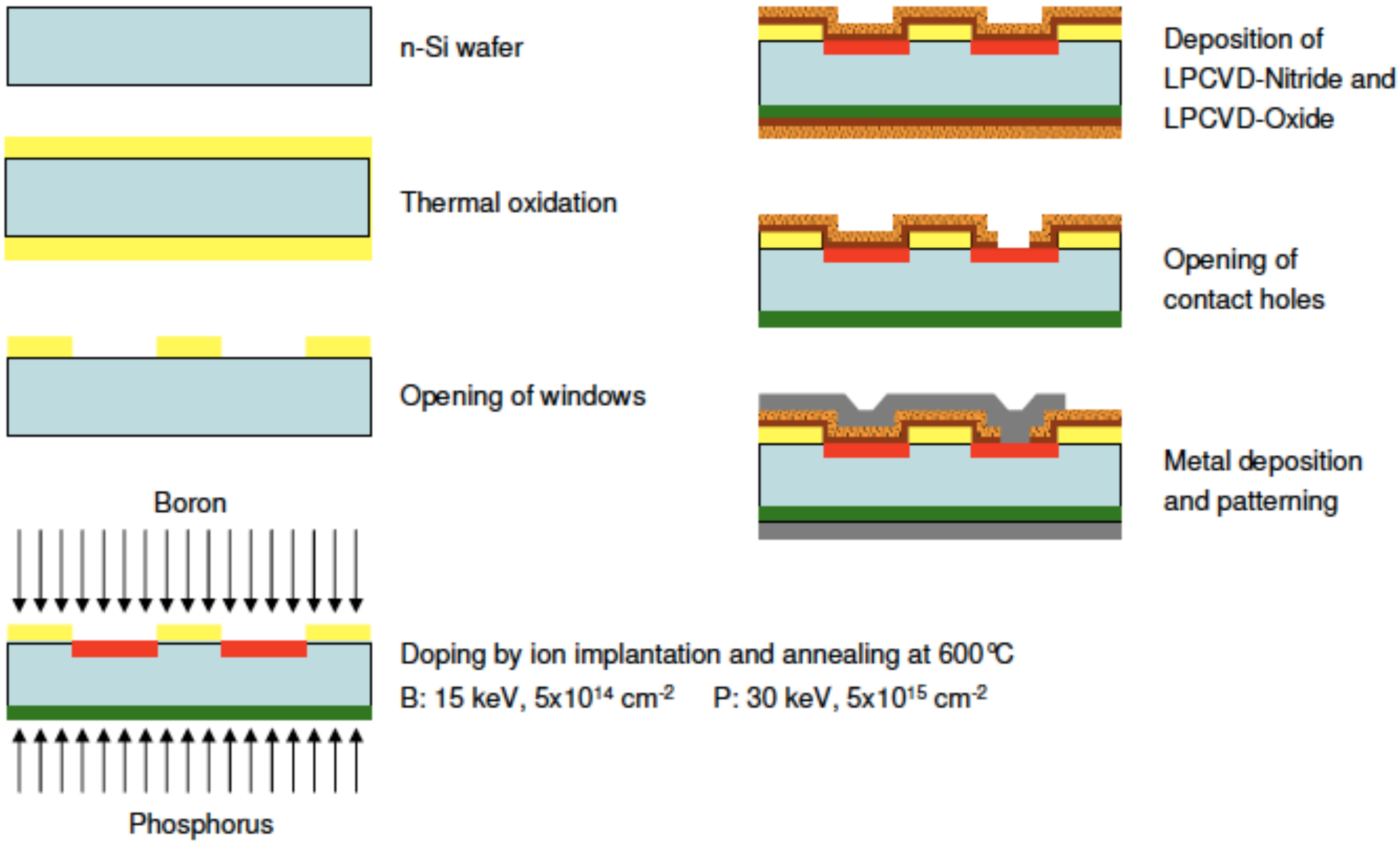
OXIDE GROWTH USING HCl
(not mentioned)

OXIDE STEPS

REAR IMPLANT

PATTERNING of Al in CONTACTS
(not mentioned)

Planar Technology



Nuclear Instruments and Methods in Physics Research A273 (1988) 865–868
North-Holland, Amsterdam

SILICON DRIFT CHAMBER PROTOTYPE * FOR THE UPGRADE OF THE UA6 EXPERIMENT AT THE CERN $p\bar{p}$ COLLIDER

Emilio GATTI, Antonio LONGONI and Marco SAMPIETRO

Politecnico di Milano, Dipartimento di Elettronica and Centro di Elettronica Quantistica e Strumentazione Elettronica CNR, Milano, Italy

Paolo GIACOMELLI and Andrea VACCHI

Rockefeller University, New York, NY, USA

Pavel REHAK

Brookhaven National Laboratory, Upton, NY, USA

Joseph KEMMER **

Fakultät für Physik der Technischen Universität, München, FRG

Peter HOLL ** and Lothar STRUDER

Max Plank Institut für Physik und Astrophysik, München, FRG

Werner KUBISCHTA

CERN, Genève, Switzerland

A large-area (~ 4×4 cm^2) silicon drift chamber has been designed and constructed in order to investigate its possible use in the UA6 experiment ***. The drift chamber will supply unambiguously (x, y) space points on each track; each arm of the UA6 spectrometer could be provided with two layers of drift detectors.

* Research supported in part by the US Department of Energy and by the Italian INFN.

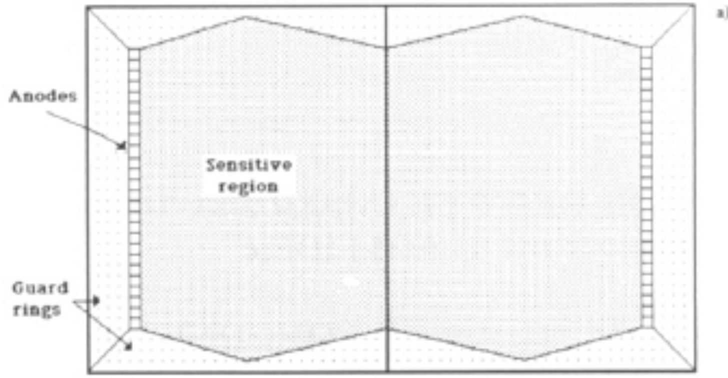
** Also Messerschmitt, Bolkow-Blohm GmbH, München, FRG.

*** CERN–Univ. Lausanne–Univ. Michigan–Rockefeller Univ. Collaboration.

1. Introduction

An internal hydrogen jet target in the Super Proton Synchrotron (SPS) main ring is used by the CERN UA6 experiment [1–4] to study final states from antiproton–

n-type silicon wafer	
doping concentration	$\simeq 2.5 \times 10^{12}/\mathrm{cm}^3$
Resistivity	$\simeq 2\ \mathrm{k}\Omega\ \mathrm{cm}$
Thickness	$= 280\ \mu\mathrm{m}$
Total area	$= 4.5 \times 5.4\ \mathrm{cm}^2$
Sensitive area	$= 3.3 \times 4.2\ \mathrm{cm}^2$
Anode pitch	$= 200\ \mu\mathrm{m}$
Field electrode pitch	$= 150\ \mu\mathrm{m}$
Drift field	$\simeq 1000\ \mathrm{V/cm}$
Drift speed	$\simeq 1.3\ \mathrm{cm}/\mu\mathrm{s}$
Drift length	$= 2.1\ \mathrm{cm}$
Drift-time	$= 1.6\ \mu\mathrm{s}$



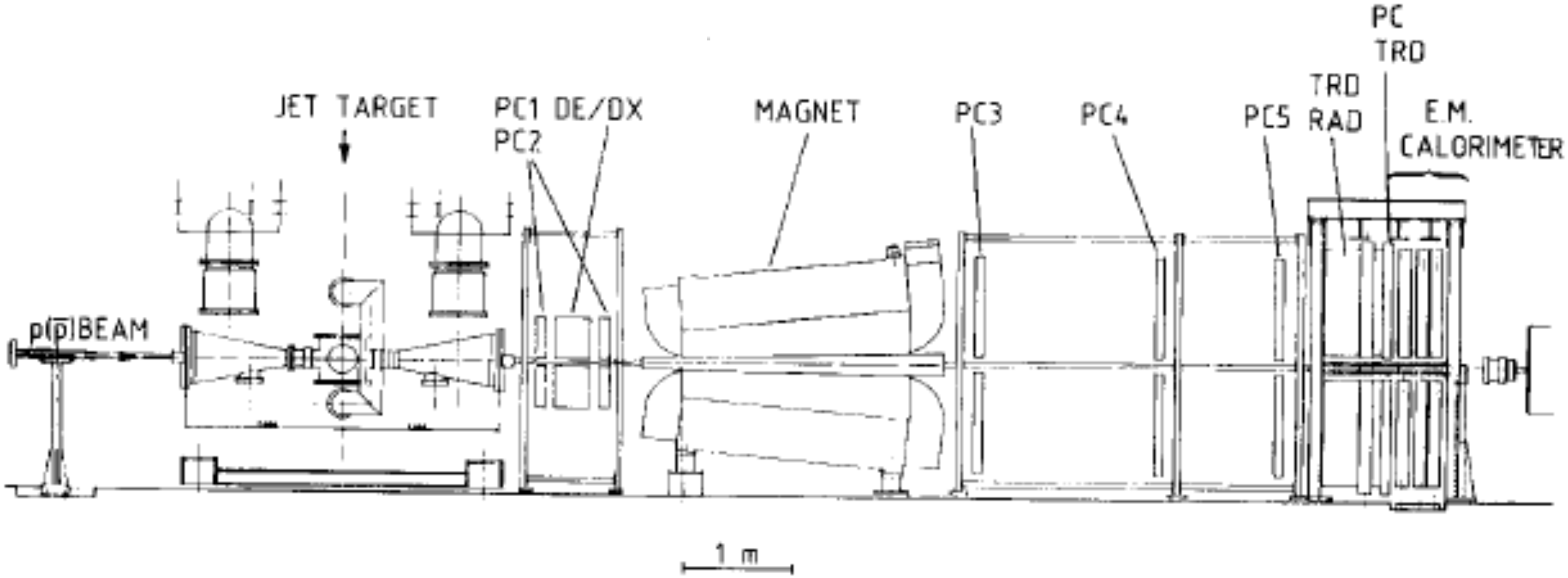


Fig. 1. The UA6 experimental set-up in the SPS ring.

First Large area SDD for tracking applications 1987

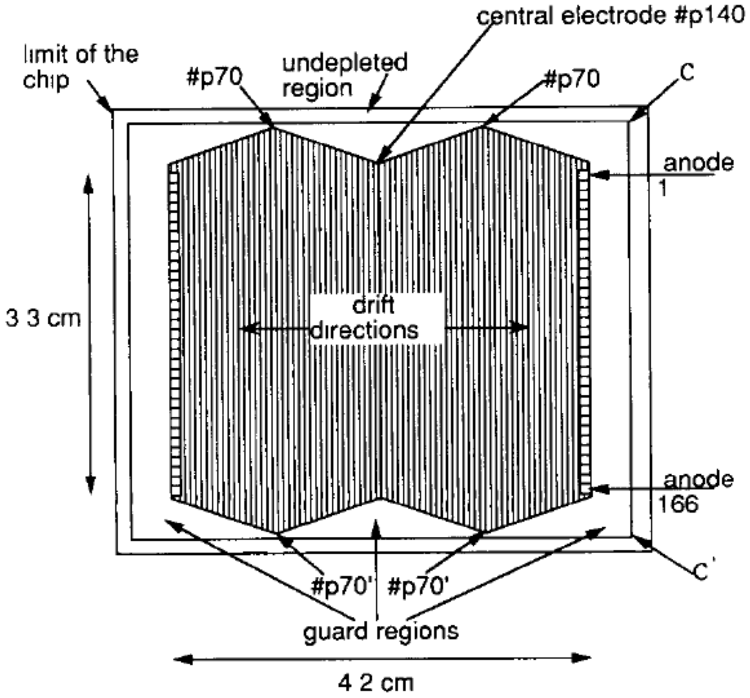


Fig. 1. Schematic top view of the large-area SDC prototype. The sensitive area of the detector is split into two regions, with electrons drifting in opposite directions from the centre towards the two rows of 166 anodes each.

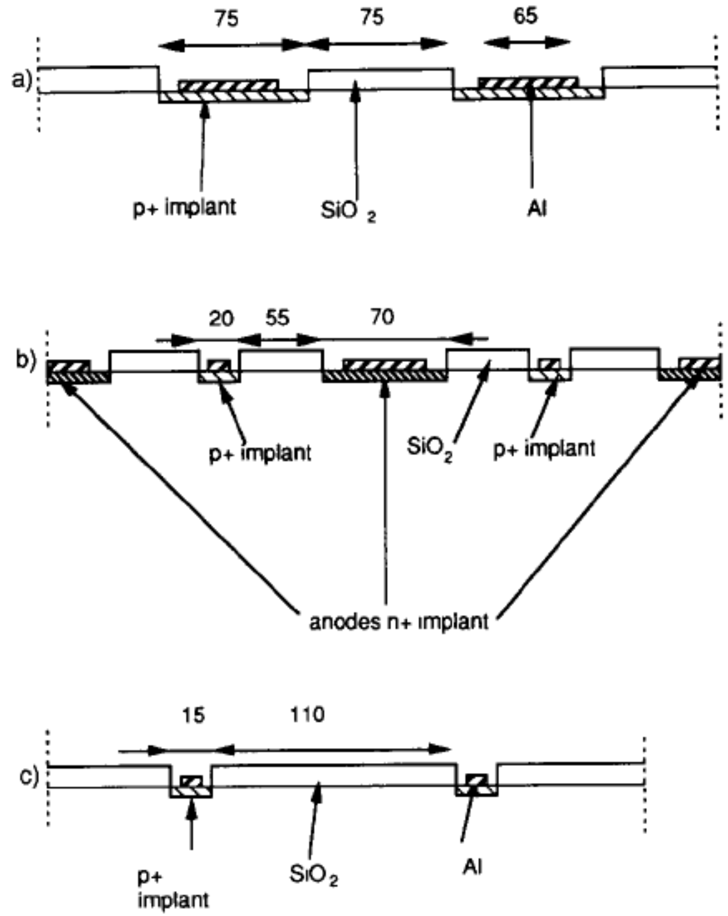


Fig. 2. Cross-section of (a) the drift region, (b) the anode region and (c) the guard region, of the SDC. All dimensions are in μm.

A. Vacchi et al. / Performance of the UA6

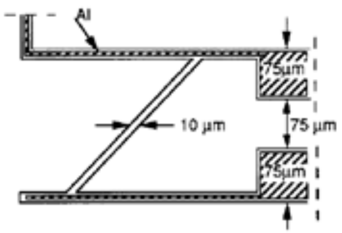
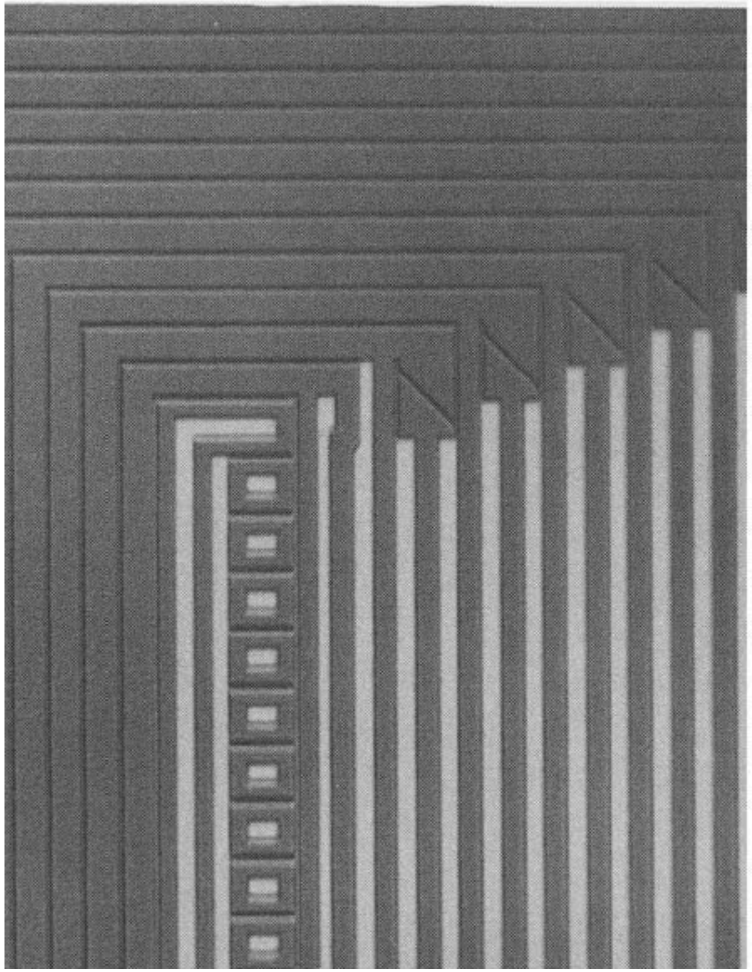


Fig. 3. Detail showing the extremities of two p+ field strips, where the divider's resistor is obtained by implanting a thin connection between them, inclined by 45°. This particular topology leads to a resistance value of about 80 kΩ.

A. Vacchi et al. / Performance of the UA6 large-area Si drift chamber prototype



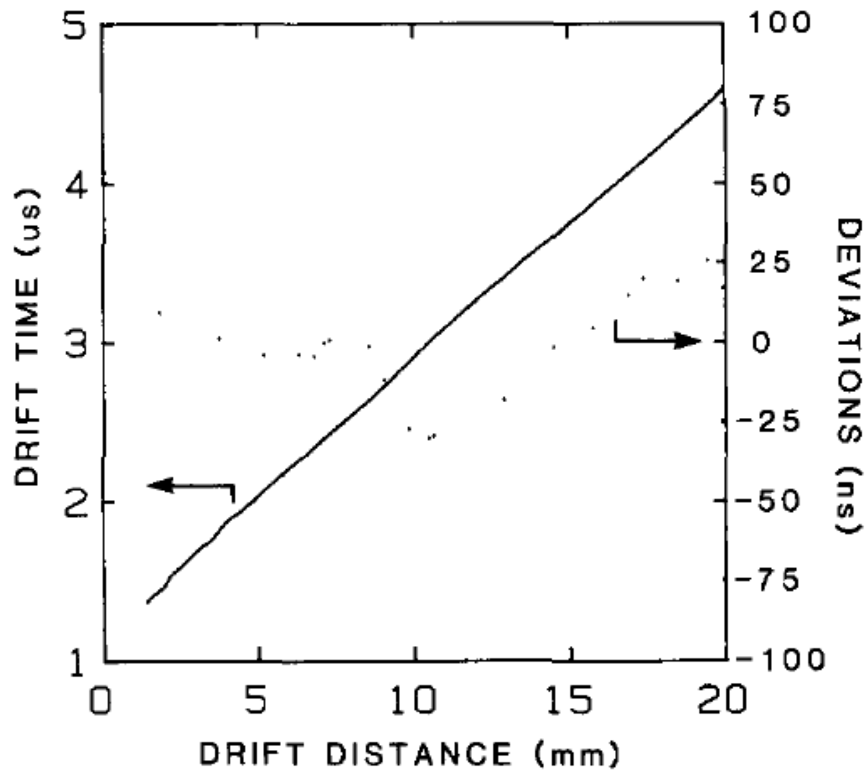
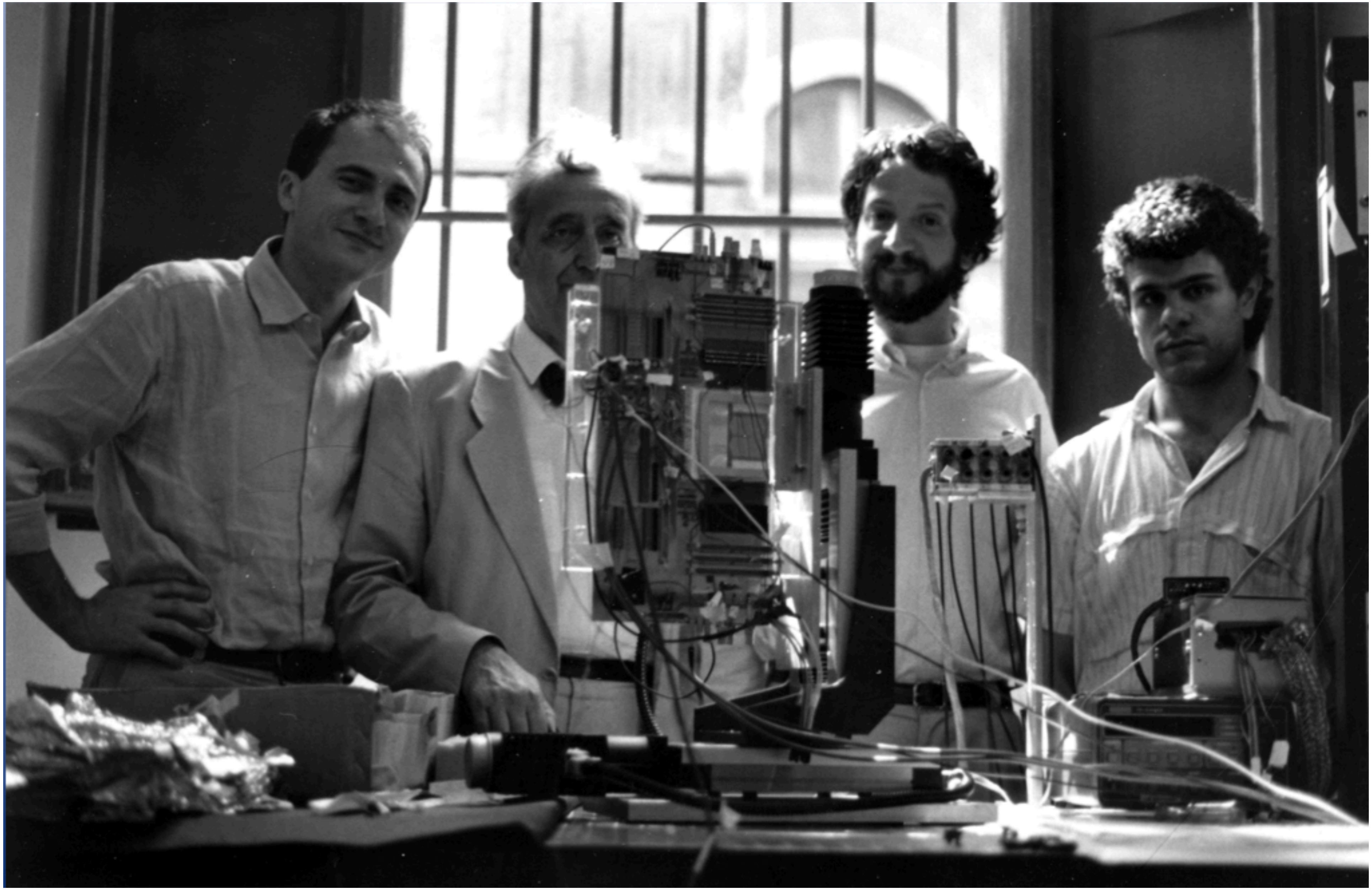


Fig. 6. Linearity of the detector (solid line) over the full drift length of 2 cm, obtained with an additional external voltage divider. The right vertical axis shows the time deviations (dotted line) with respect to the interpolating line (not shown).

1987 Milano Politecnico first large area SDD



Nuclear Instruments and Methods in Physics Research A306 (1991) 187–193
North-Holland

Performance of the UA6 large-area silicon drift chamber prototype

A. Vacchi
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P. Rehak
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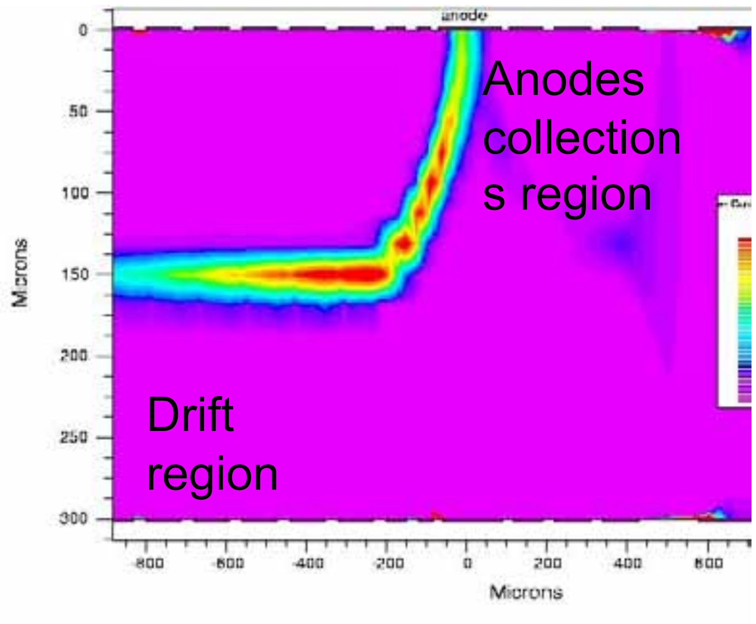
J. Kemmer
Facultät für Physik der Technischen Universität, Munich, Germany

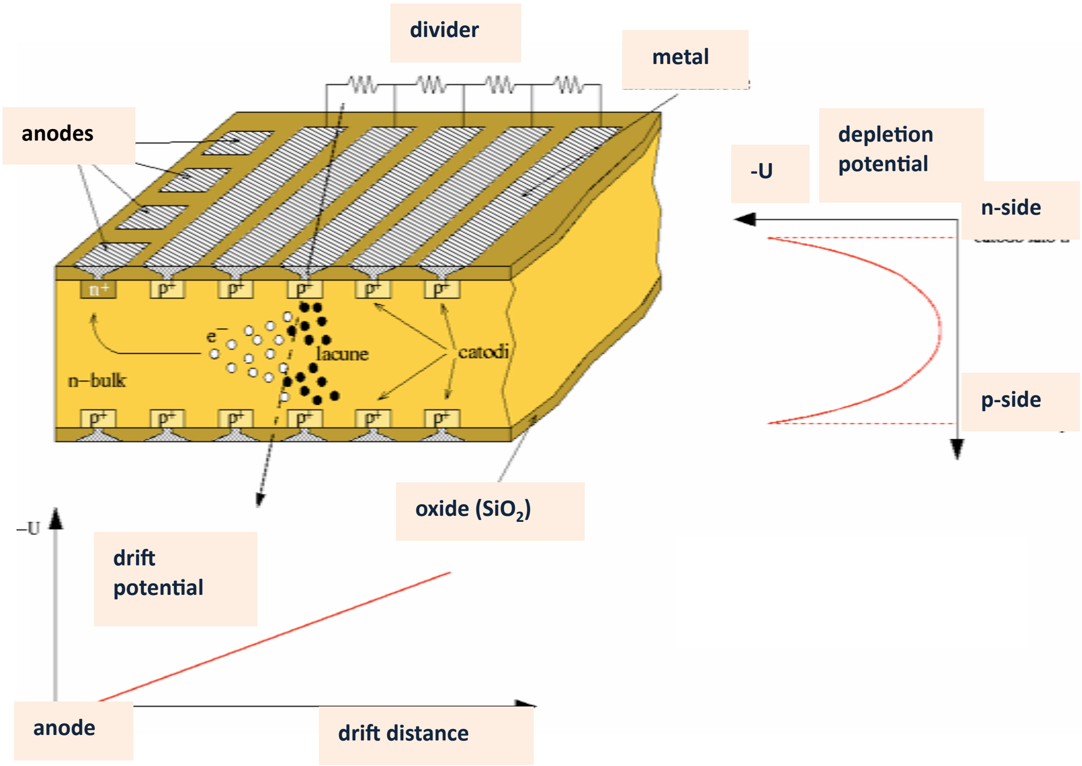
Received 30 November 1990

This report presents results on the performance of a large-area silicon drift detector (~ 4×4 cm^2), which has been designed for

Silicon drift detectors (SDD)

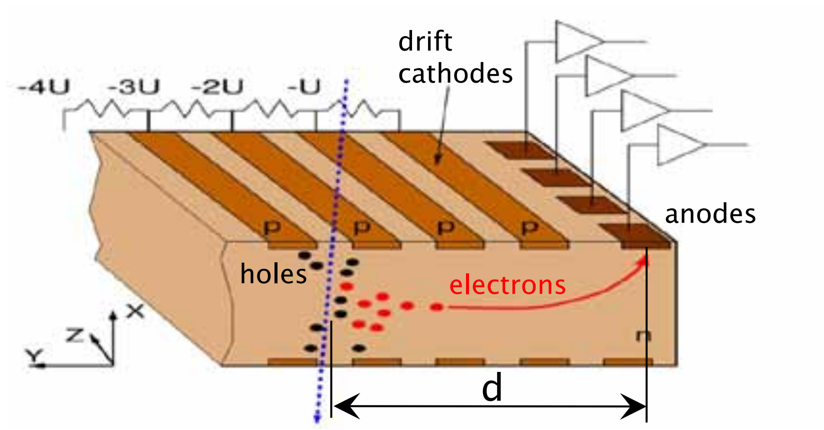
By means of a series of cathodes (biased with a scaling potential) a highly-linear drift field is established from the center of the detector towards two arrays of anodes placed at opposite sides of the SDD.

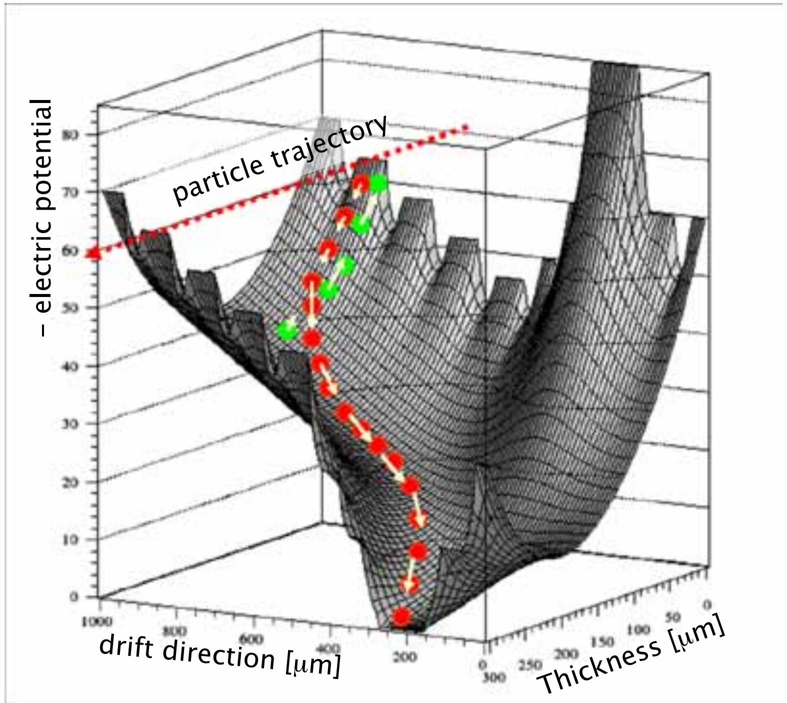




- due to their collection electrode geometry, SDD have excellent noise performance and are well suited for low-energy X-ray spectroscopy applications.

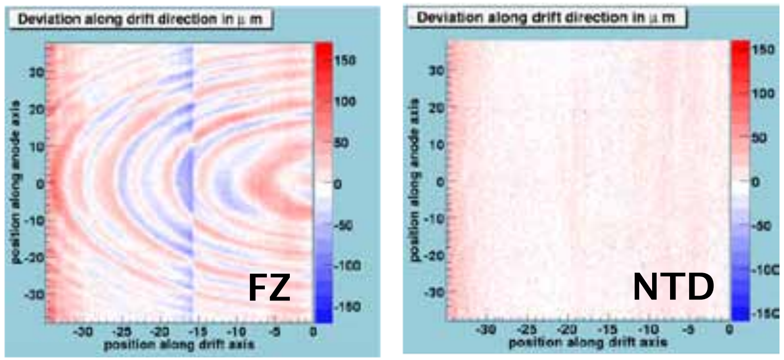
The Linear Silicon Drift Detector – working principle





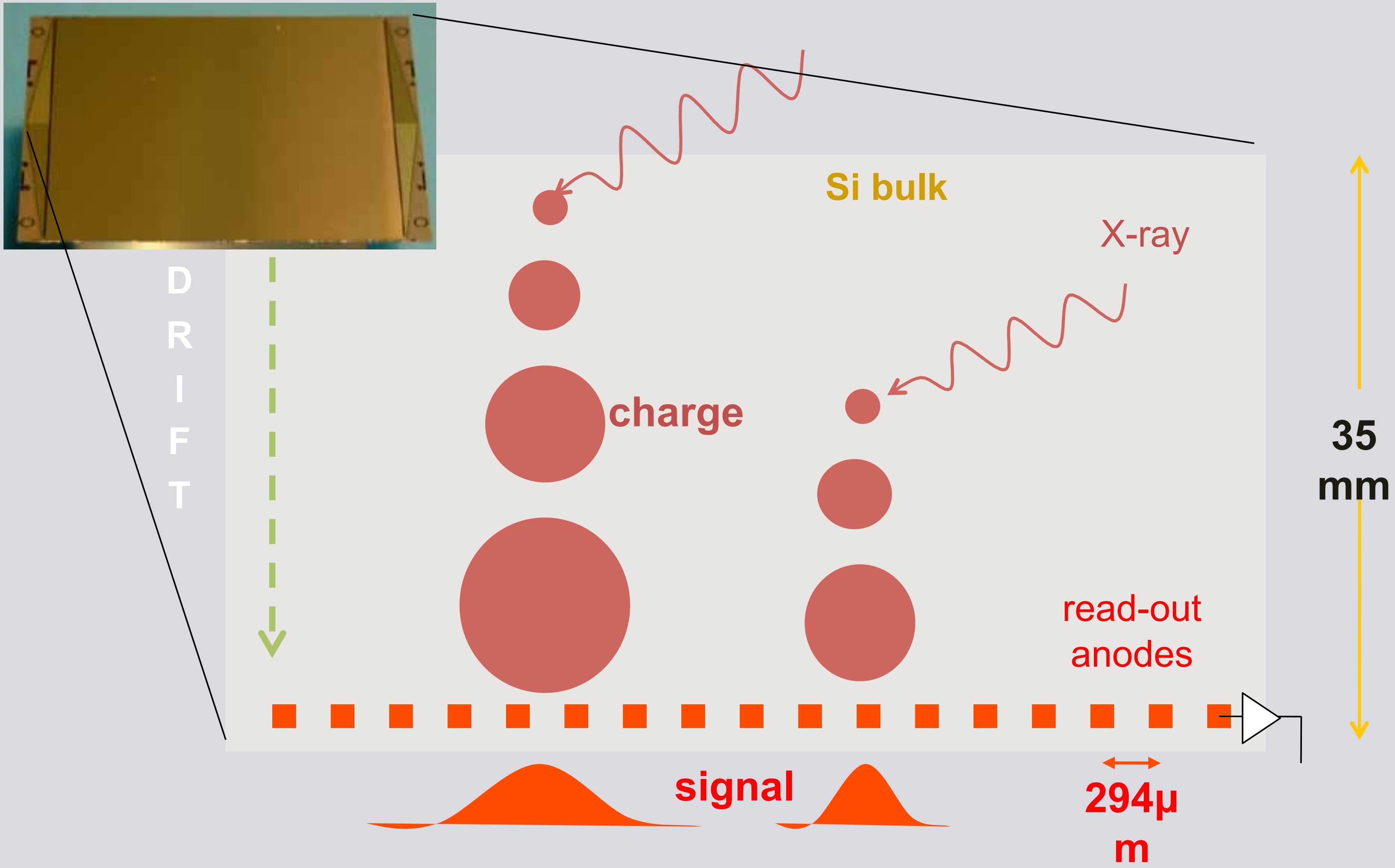
- designed to provide unambiguous 2D tracking of ionizing particles with very good resolution in a high-multiplicity environment with a very limited number of channels
- linearly scaling potentials are applied to drift cathodes to generate a constant electric field
- the first coordinate is determined by the center of gravity of the signal at the anodes
- the second coordinate (drift axis) is determined measuring the time required by the electron cloud to reach the anodes

$$v = \mu \cdot E = const. \Rightarrow d = v \cdot \Delta t$$

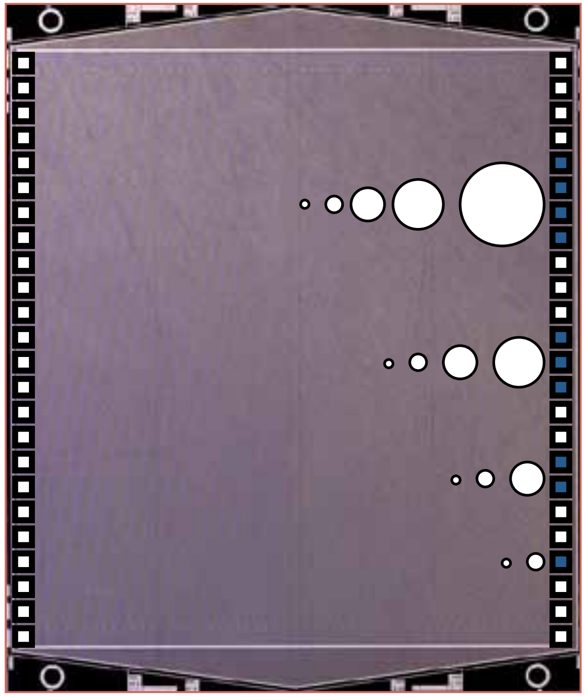


- for high position resolution the electric field must be very uniform → Neutron Transmutation Doped substrates
- for Floating Zone material → corrections must be applied to the reconstructed position (e.g. lookup tables) → precise characterization of every single detector !!!

The SDD: Working Principle



The SDD signal: charge diffusion



The charge cloud has a Gaussian shape. Its width depends on the drift time which, for a constant electric field, is a linear function of the drift distance:

$$D = \frac{k_B T}{q}\mu$$ diffusion coefficient

$$v = \mu E$$ drift velocity

$$t = \frac{x}{v}$$ drift time

$$\sigma = \sqrt{2Dt + \sigma_0^2} = \sqrt{2 \cdot \frac{k_B T}{q}\mu \cdot \frac{x}{\mu E} + \sigma_0^2} = \sqrt{2\frac{k_B T}{qE}x + \sigma_0^2}$$

For low energy X-ray photons it is possible to take $\sigma_0 \approx 0$

Fig. 1. Picture showing one large-area SDD near one of the small prototypes ($3.5 \times 2.0\ cm^2$) designed during the DSI R&D project.

ELSEVIER Nuclear Instruments and Methods in Physics Research A 439 (2000) 476–482

Section A

www.elsevier.nl/locate/nima

Laboratory and test beam results from a large-area silicon drift detector

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[a] *INFN - Sezione di Trieste, Italy*
[b] *INFN - Sezione di Torino, Italy*
[c] *INFN - Sezione di Catania, Italy*

Abstract

A very large-area ($6.75 \times 8\ cm^2$) silicon drift detector with integrated high-voltage divider has been designed, produced and fully characterised in the laboratory by means of *ad hoc* designed MOS injection electrodes. The detector is of the "butterfly" type, the sensitive area being subdivided into two regions with a maximum drift length of 3.3 cm. The device was also tested in a pion beam (at the CERN PS) tagged by means of a microstrip detector telescope. Bipolar VLSI front-end cells featuring a noise of 250 e^- rms at 0 pF with a slope of 40 e^-/pF have been used to read out the signals. The detector showed an excellent stability and featured the expected characteristics. Some preliminary results will be presented.

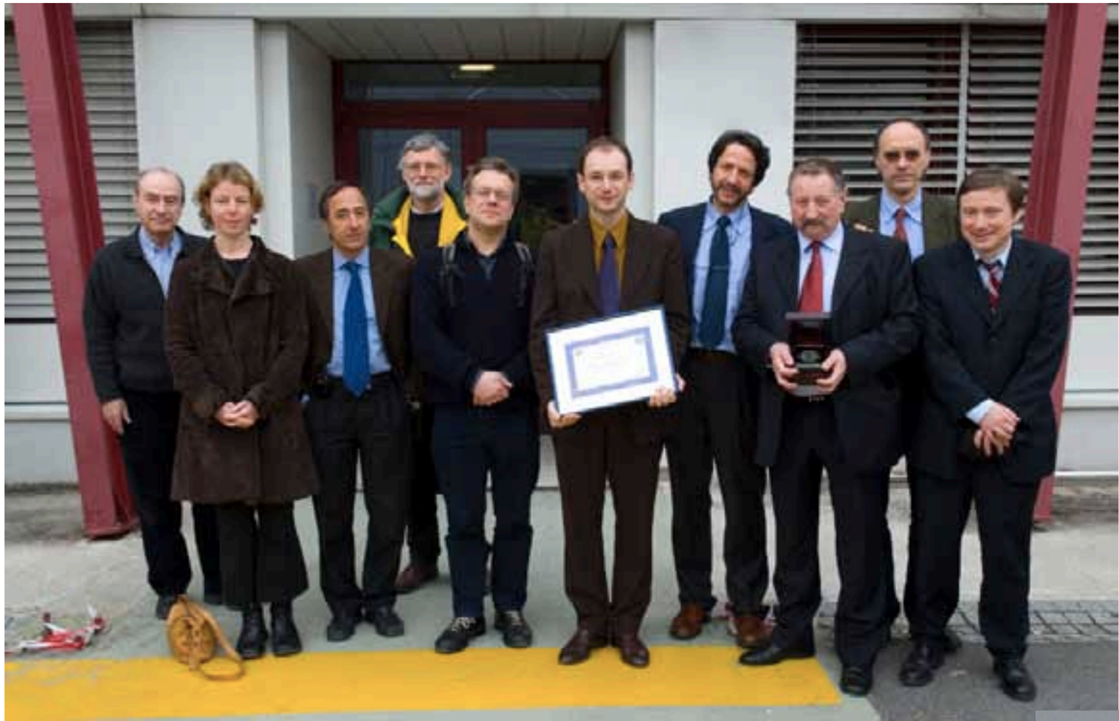
1. Motivation and detector description

Silicon drift detectors (SDDs [1,2]) have been adopted to equip the two middle layers of inner tracking system (ITS) of the ALICE experiment at LHC [3]. The detector presented in this paper is the result of an extensive R&D work started in 1992 and carried on by the INFN DSI project. The aim of the project was the production of *large-area SDDs with integrated high-voltage divider* [4–10]. The use of a large number of SDDs in ALICE (about 250 detectors) requires the assessment of large-scale production in industry with good reliability. Following this approach, the program initially developed by DSI has found a natural continuity within the ALICE ITS Collaboration.

The detector is the first prototype of large-area SDD for the ALICE ITS and is produced by Canberra Semiconductors N.V. (Belgium) on neutron transmutation doped (NTD) 5″ silicon wafers with a resistivity of 3 kΩ cm and a thickness of 300 μm.

* Corresponding author. Tel.: + 39-40-3756224; fax: + 39-40-3756258.

E-mail address: bonvicini@trieste.infn.it (V. Bonvicini)



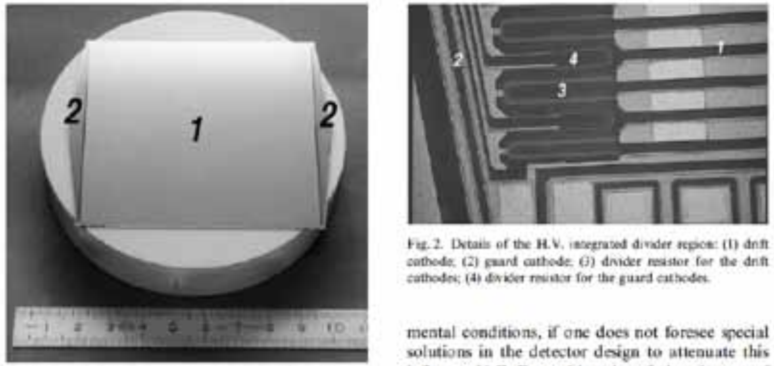


Fig. 1. Picture showing a SDD of the design ALICE-D1B. The numbers correspond to (1) sensitive area; (2) guard area.

Fig. 2. Details of the H.V. integrated divider region: (1) drift cathode; (2) guard cathode; (3) divider resistor for the drift cathodes; (4) divider resistor for the guard cathodes.

mental conditions, if one does not foresee special solutions in the detector design to attenuate this influence [4,5]. From this point of view, in case of the SDD, the punch-through phenomenon is the most critical. When the voltage difference between adjacent p^+ cathodes reaches a critical value U_{pt}, a

www.elsevier.nl/locate/nima

Characteristics of the ALICE

i[a], P. Burger[b], P
, A. Kolojvari[c]
F. Tosello[c], A.

o Area di Ricerca, Palazz
berra Semiconductor, NV,
[c]INFN Sezione di To

For the ALICE Coll

n active area of 7.0 × 7
elopment of the SDD
work without an external support to the integrated high-voltage
design in order to increase the robustness and the long-term ele

SDD layout details and terminology

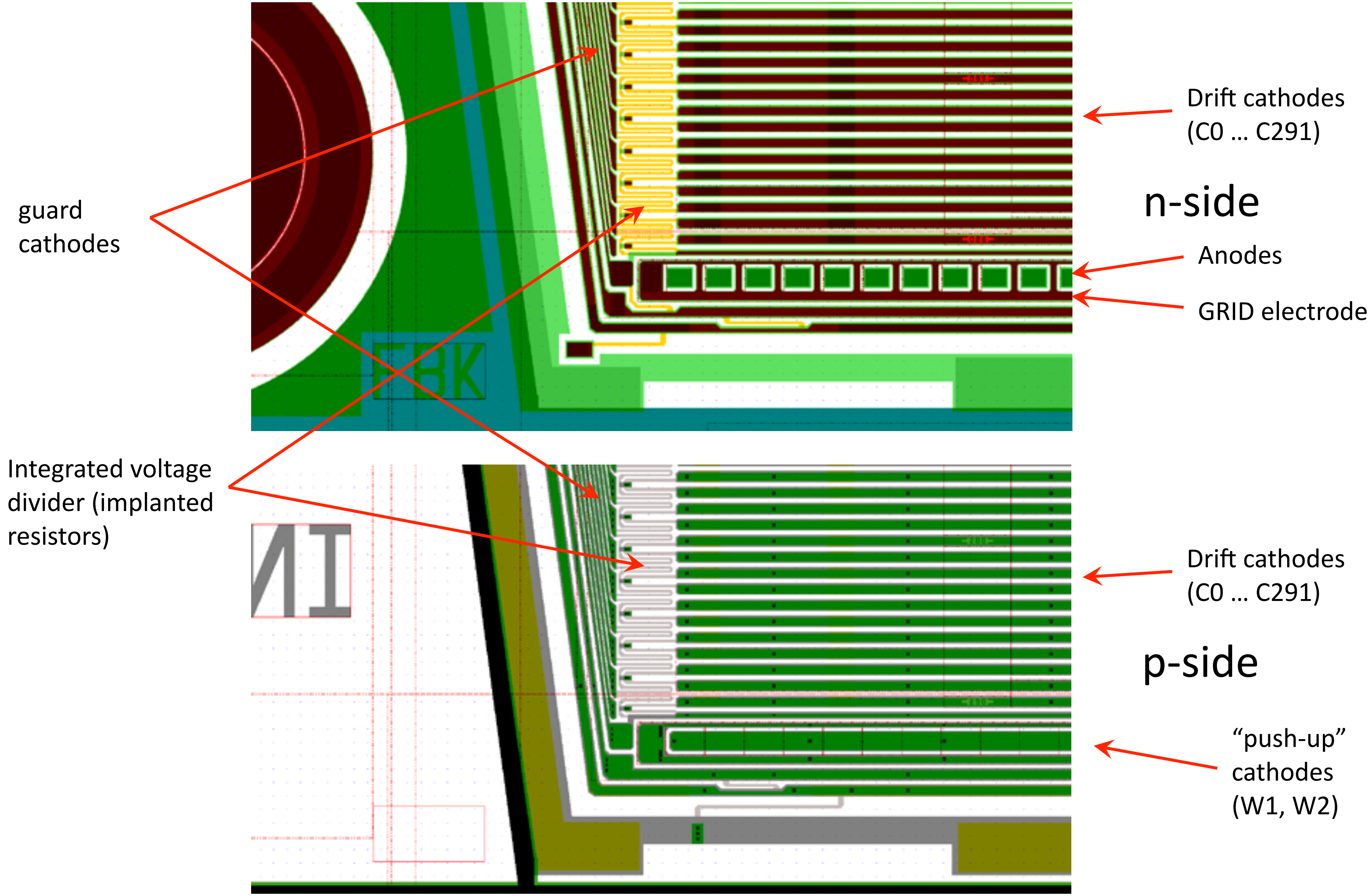
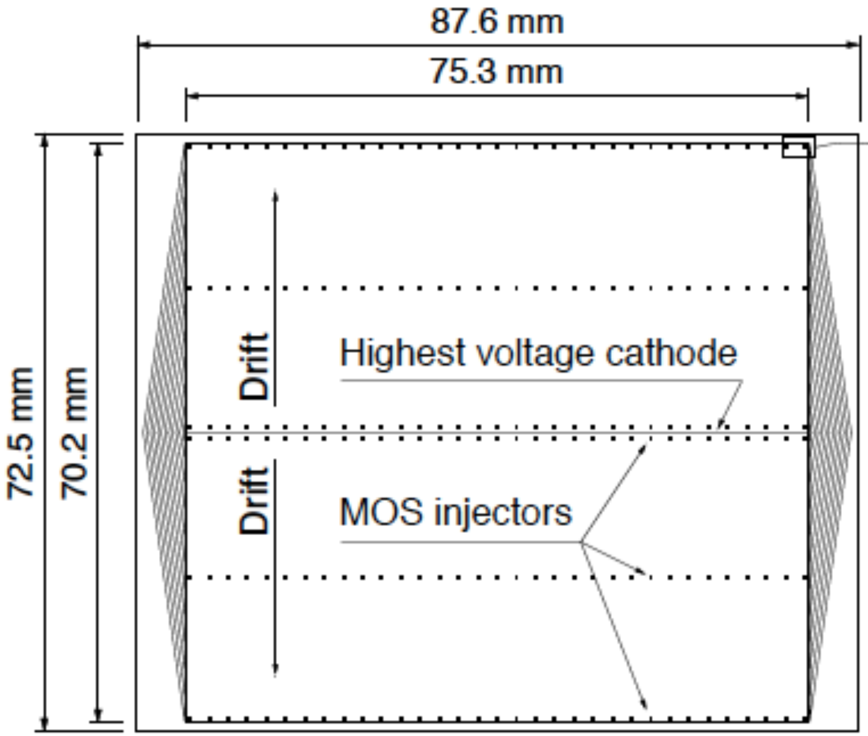
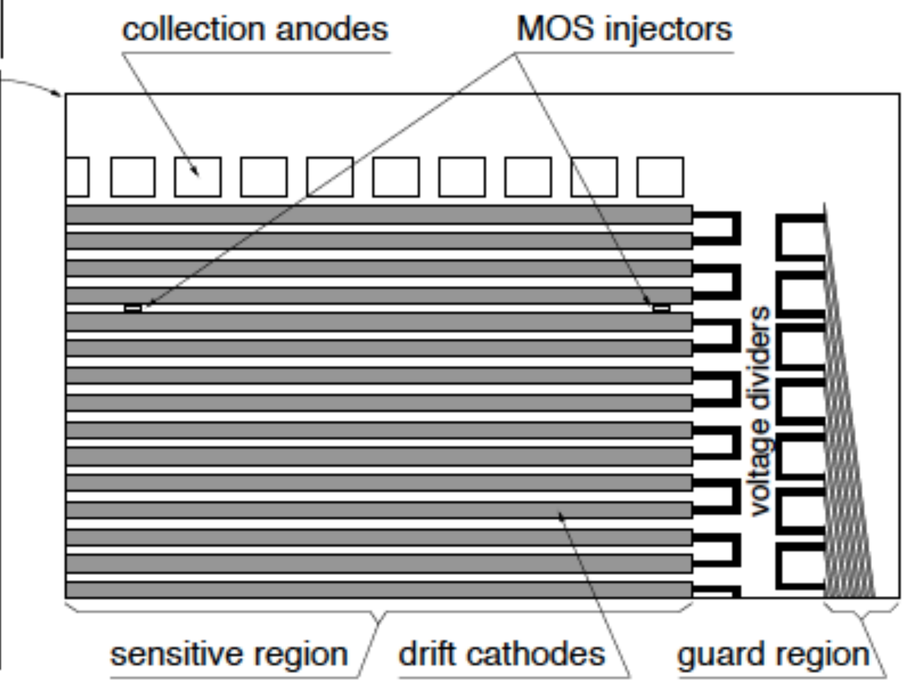


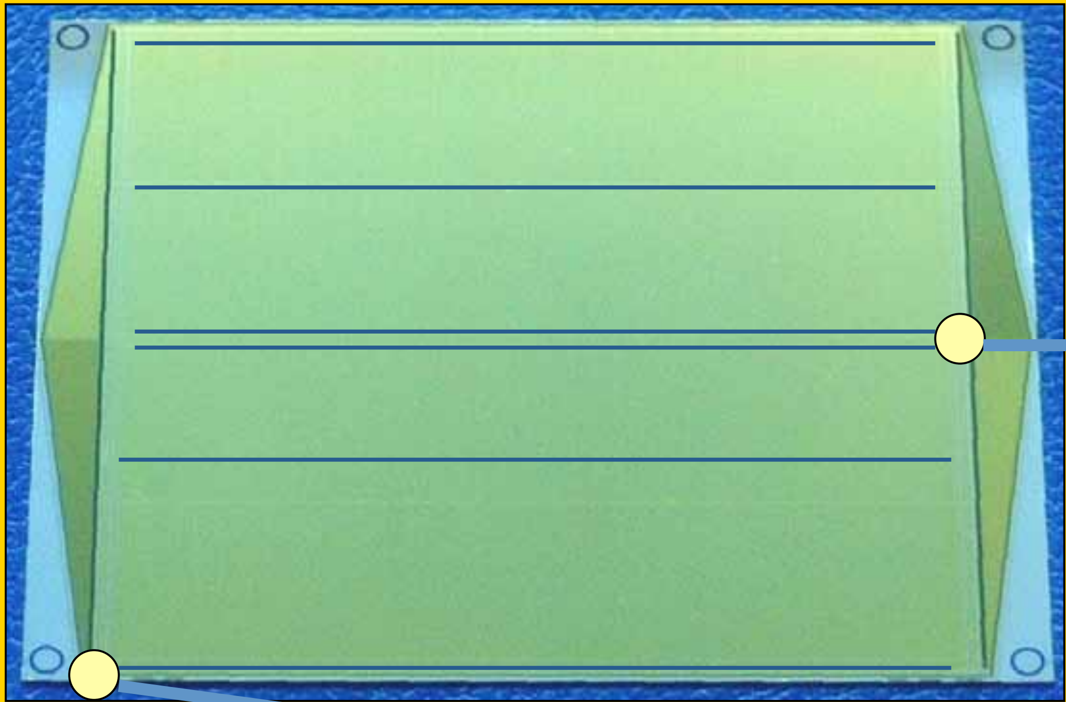
Table 1. SDD main characteristics.

Sensitive area	70.17×75.26 mm^2		
HV (nominal)	-1800 V	Bias (MV)	-40 V
Anode pitch	294 μm	Drift velocity	$\sim$6.5 μm/ns
Av. z resolution	25 μm	Av. $r\varphi$ resolution	35 μm

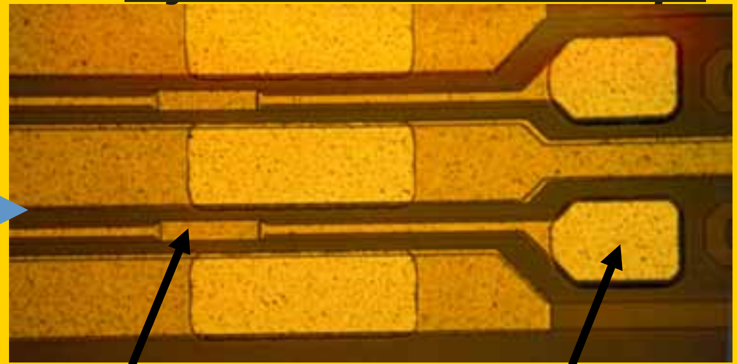




Detector design features

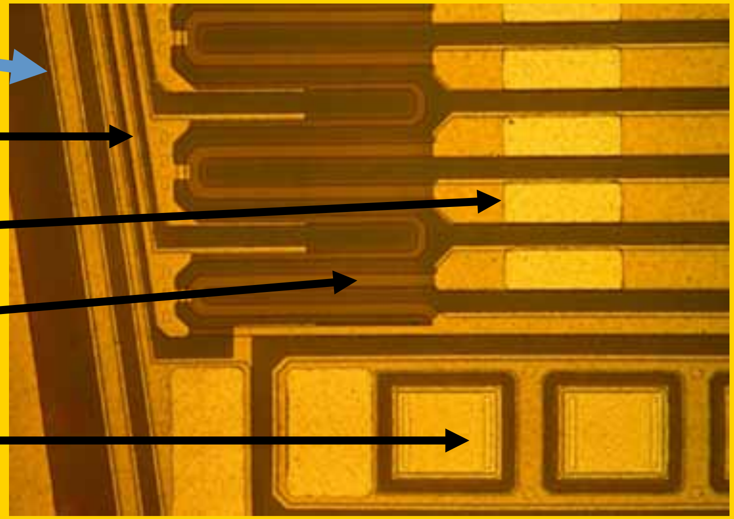


injector lines close-up



injector line bonding pad

MOS injector (every 8th anode)



guard cathodes (32 μm pitch)

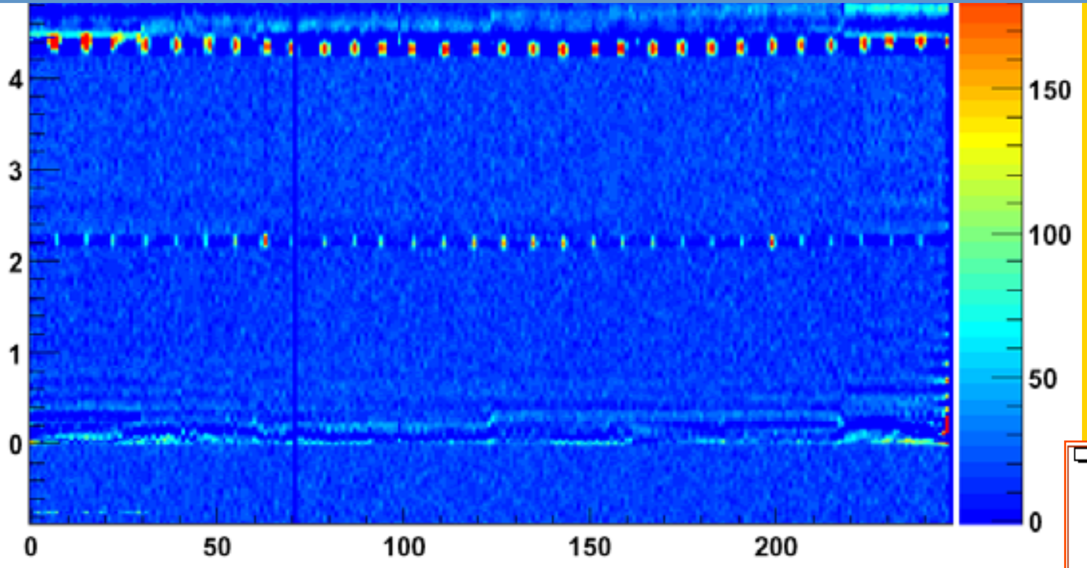
292 drift cathodes (120 μm pitch)

implanted HV voltage dividers

256 collection anodes (294 μm pitch)

collection zone close-up

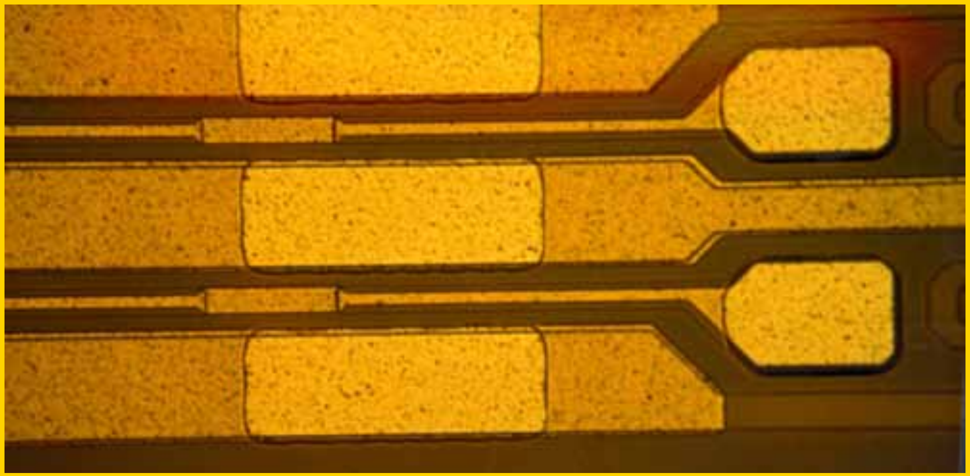
Unique feature Point like charge injectors> continuous on line calibration

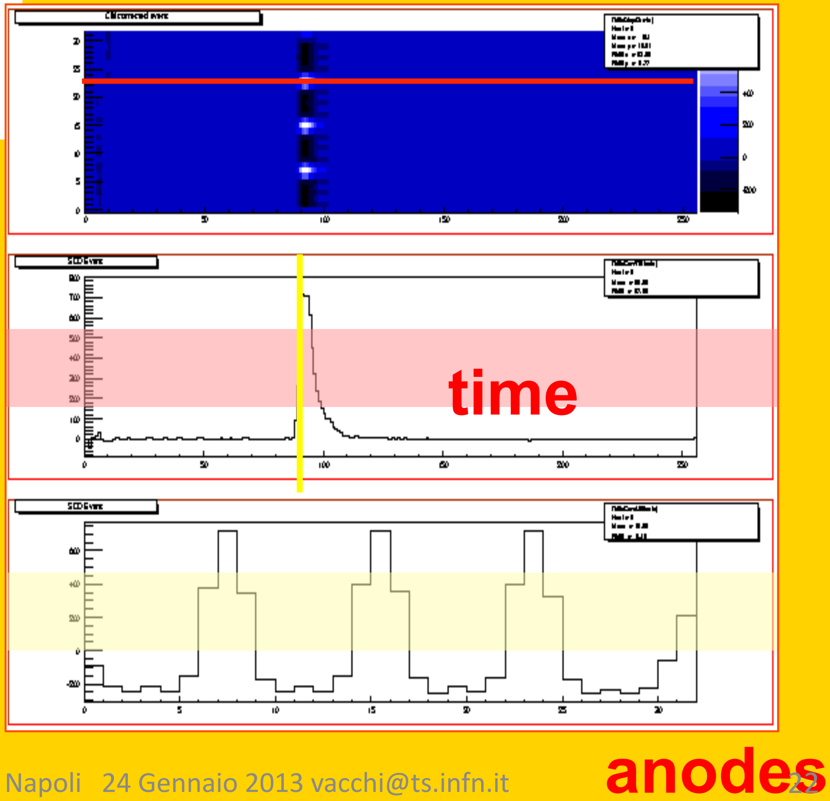


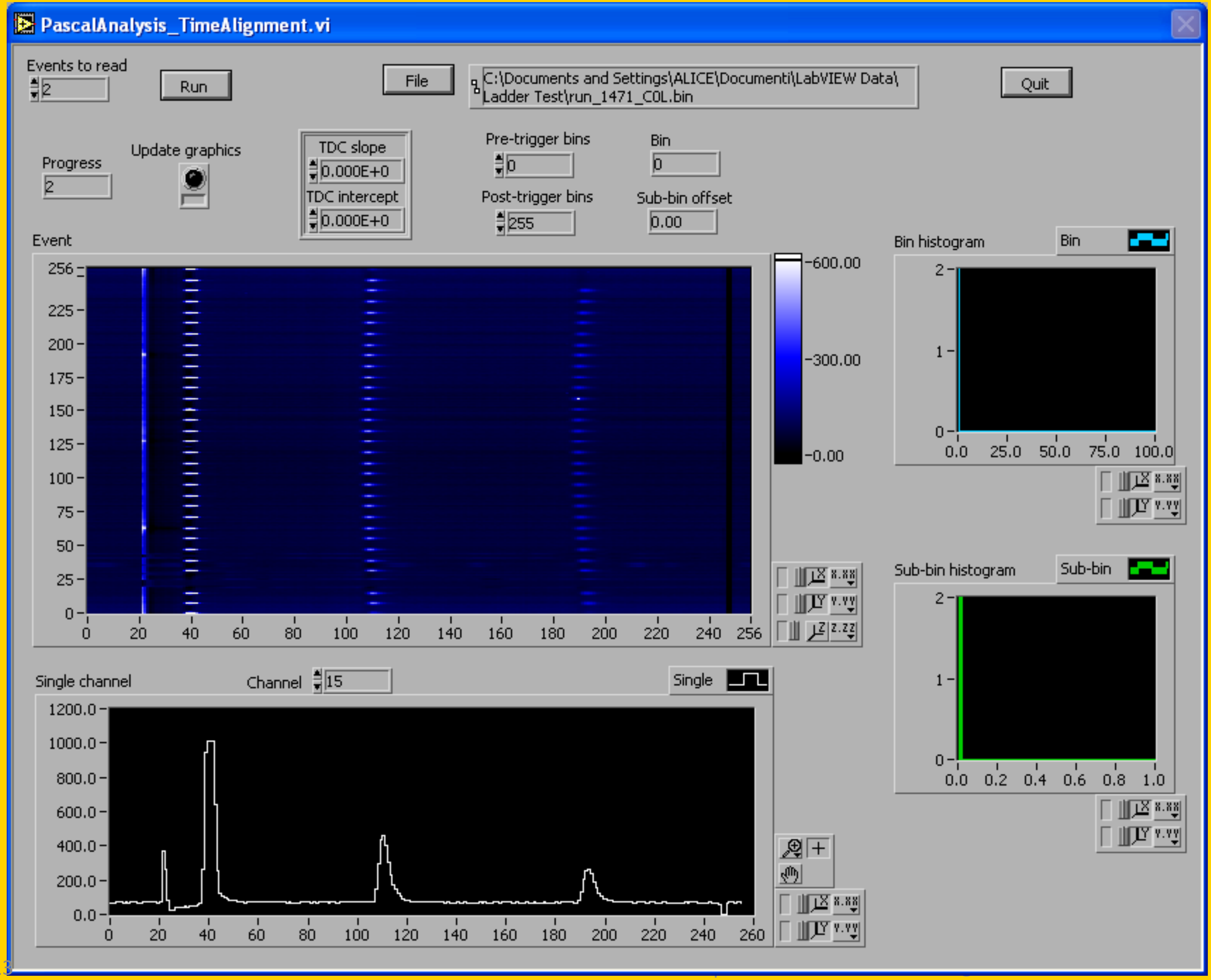
$\mu \propto T^{-2.5}$

$v_d = \mu \times E$

Monitoring v_d fluctuations



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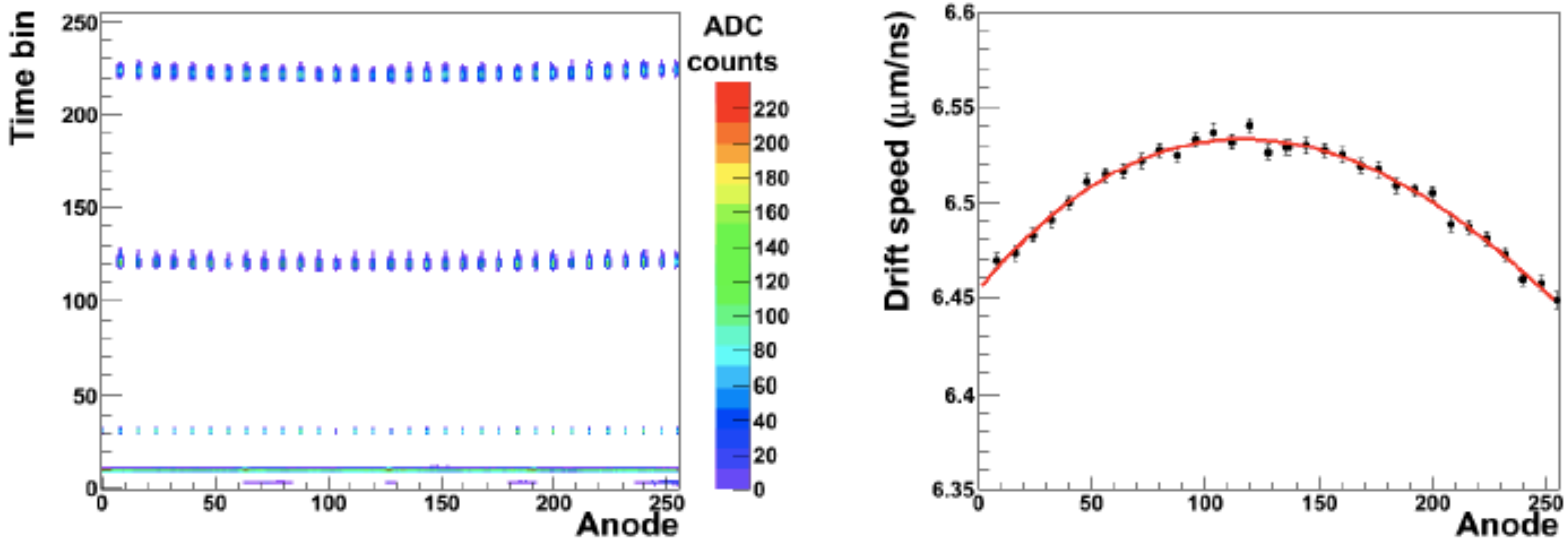
Single channel
Channel
15
Single

A precise knowledge of the drift speed is a crucial element for the correct operation of any drift detector. Given its strict dependence on the detector temperature, the drift speed must be very frequently monitored. To reach the design precision of 35 μm on a drift distance of as much as 35 mm (from the point farthest from the anodes) the drift speed must be known with an accuracy of better than 0.1%.



Drift values as a function of the anode number of one half module; each point represents the result of the fit on the three corresponding injectors.

ALICE-D4 SDD for the LHC-ALICE experiment

Wafer type:

- 5” Neutron Transmutation Doped <111> 3 kΩ·cm, thickness 300 μm

Area:

- Sensitive: 7.02 × 7.53 ≈ 53 cm², divided in 2 drift regios
- total: 7.25 × 8.76 cm², (ratio = 0.83)

Each drift region:

- has a length of 35 mm
- has 291 cathodes biased by an integrated voltage divider
- has 256 anodes – pitch of 294 μm
- has 3 lines of 33 MOS charge injectors for the drift velocity calibration

Guard region:

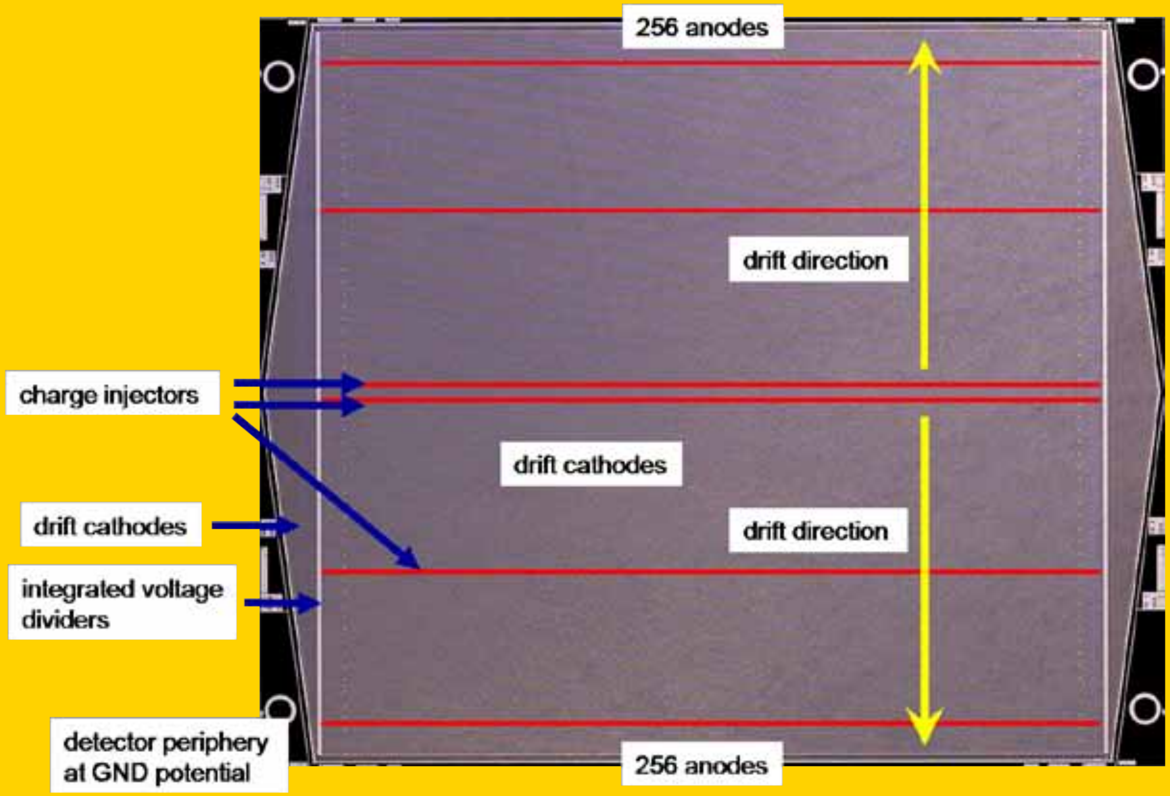
- independent voltage dividers

Integrated dividers:

- Equivalent resistance of all voltage dividers R_{tot} = 4781 kΩ

Each anode:

- has a very small capacitance of ~100 fF
- reads an area of 10 mm²

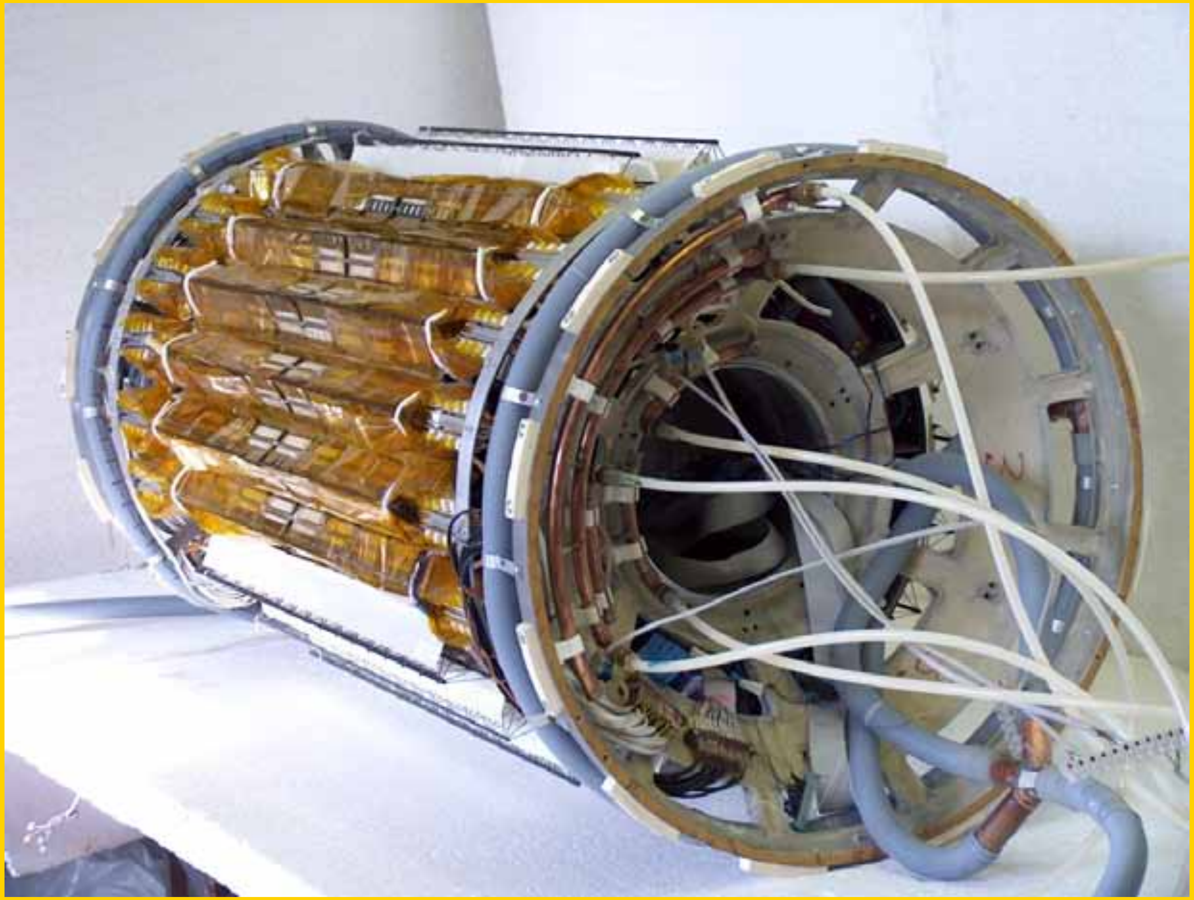


Maximum ratings for the detector bias:

- HV bias: −2.4 kV, 8V/cathode E = 670 V/cm
- for a drift time of 4.3 μs, v_d = 8 μm/ns
- total current on the voltage dividers ~0.48 mA
- on board power consumption: 1.15 W

for a maximum drift time of 4.3 μs (v_d = 8 μm/ns)

Approximately 300 Alice-D4 units have been produced for ALICE by Canberra, and tested, integrated and calibrated by INFN-Ts and then delivered to the ALICE experiment.

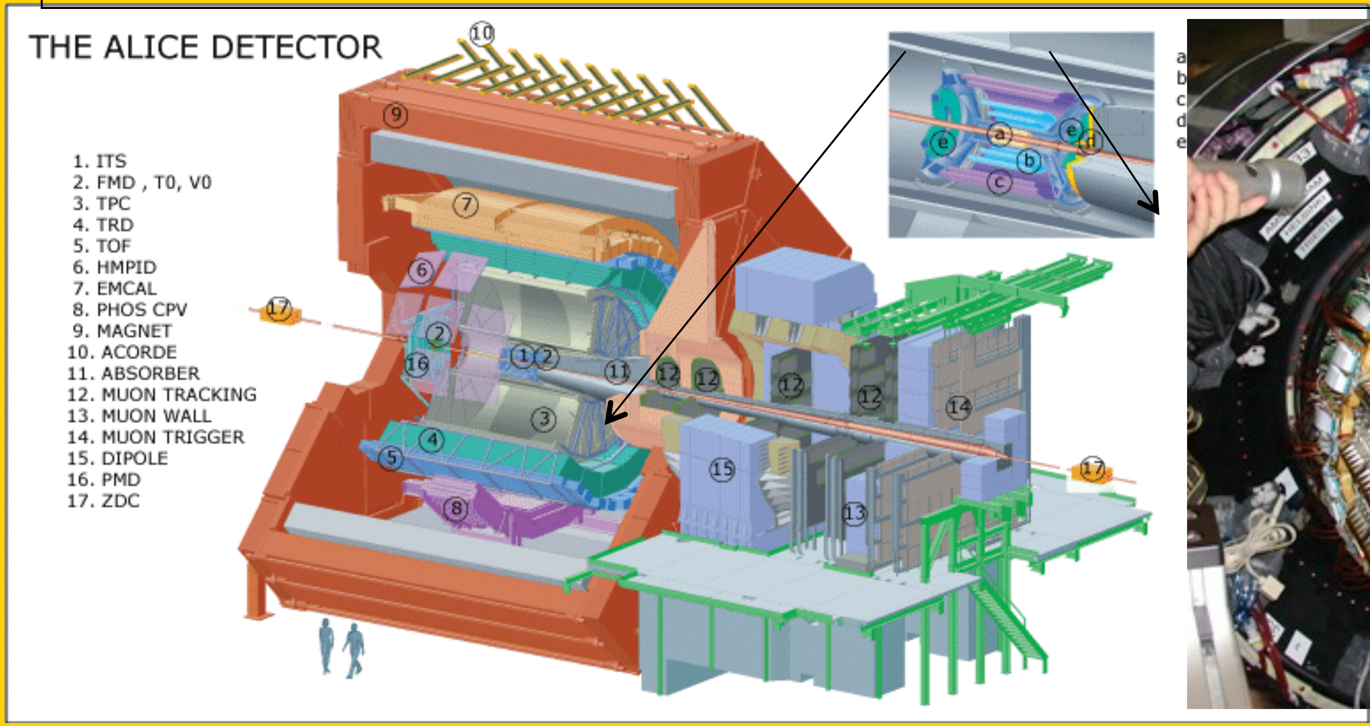


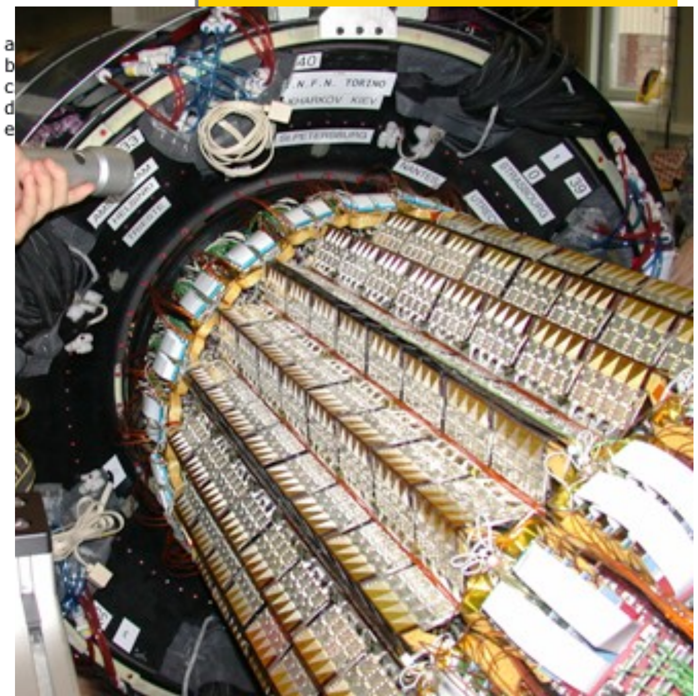
It is worth noticing that after finishing the early learning phase, the Canberra foundry has been able to manufacture the Alice-D4 with production yields up to 80%. A key feature if one assumes to manufacture thousands of detectors.

ALICE-ITS-SDD

- 600 detectors realized and tested for compliance with specifications
- production yield better than 60%
- (> 90% for last batches)

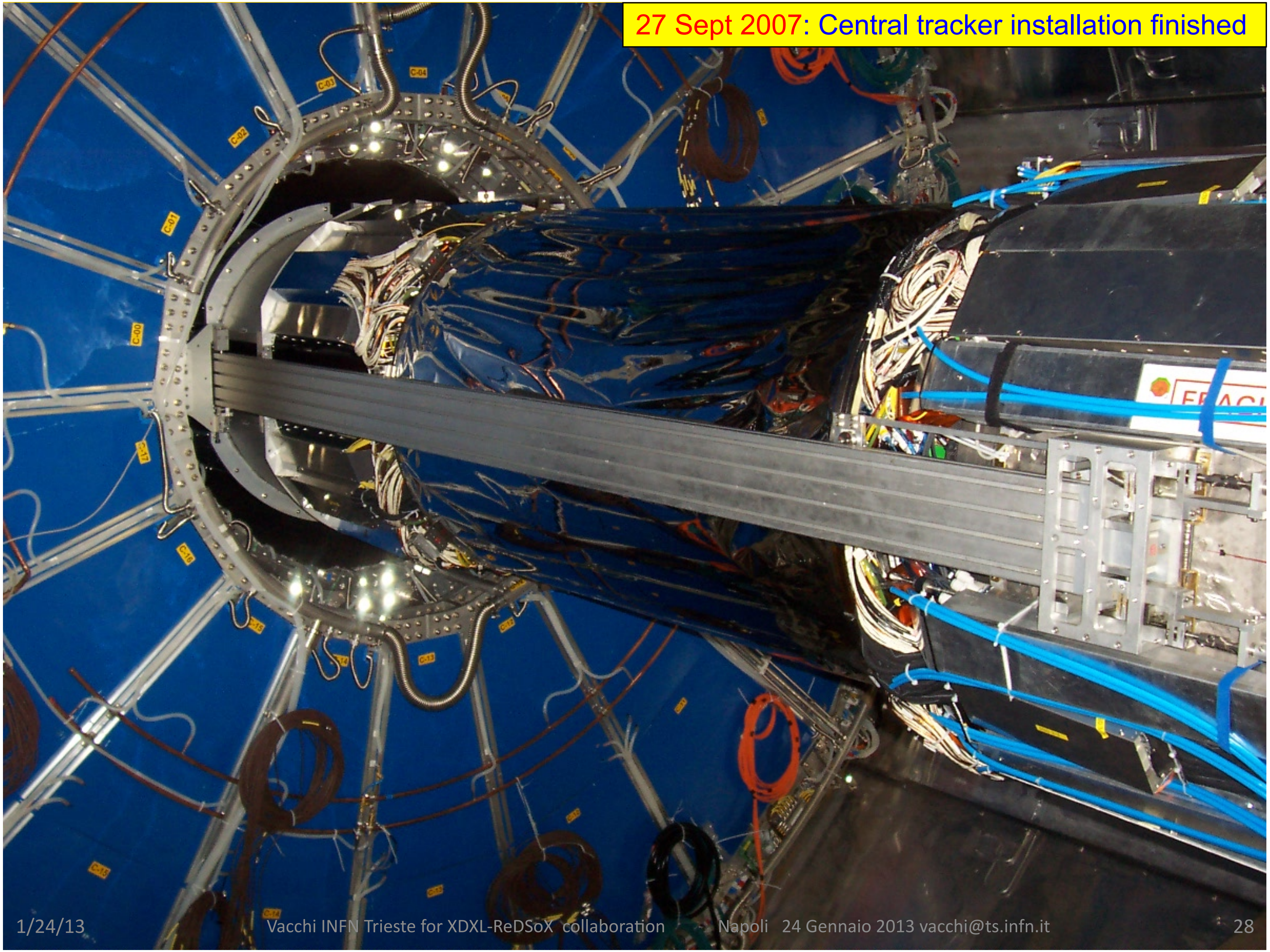
260 detectors (~**1.37 m^2**) operational in LHC. Manufactured by Canberra under design, control and test by INFN-Ts.





Nuclear collisions at the LHC have allowed experimenters to study strongly interacting matter in unprecedented conditions of temperature and density and with a much enhance range of probes unveiling new features of the quark-gluon plasma in these extreme conditions.

27 Sept 2007: Central tracker installation finished



The Inner Tracking System

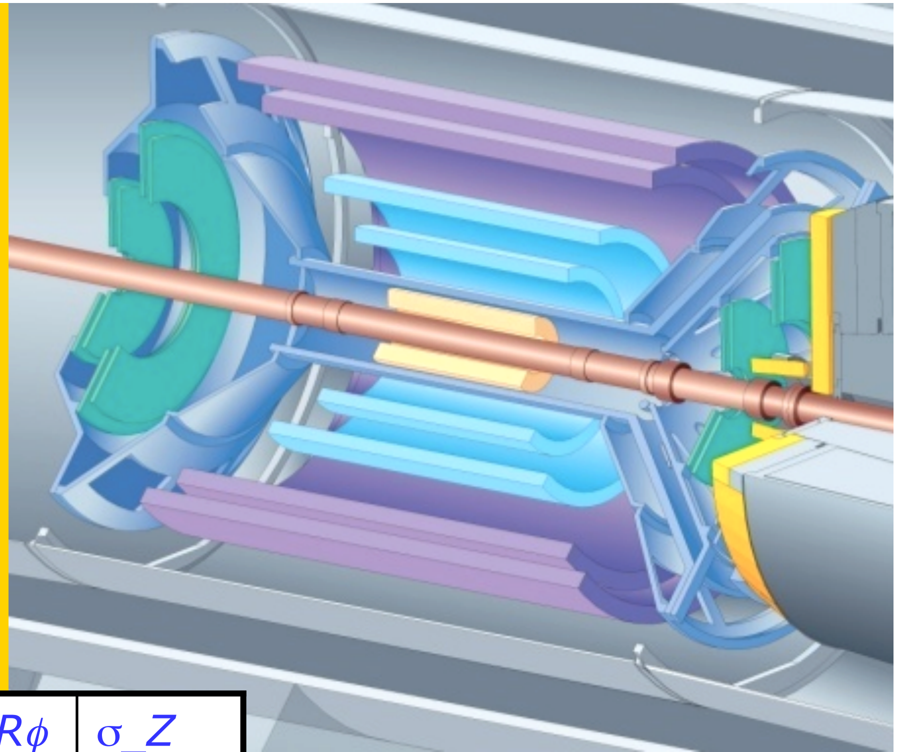
low mass: 8 % X_0

SPD 2.3 %

SDD 2.4 %

SSD 1.7 %

structure 1.3 %



all silicon, 6 layers

layer	type	R [cm]	area [m^2]	chan-nels	occu-pancy	$\sigma\_R\phi$	σ_Z
1	pixels SPD	4	0.07	3.3 M	2.1	12 μm	100 μm
2		8	0.14	6.6 M	0.6		
3	drift SDD	15	0.42	43 k	2.5	35 μm	25 μm
4		24	0.89	90 k	1		
5	double sided strip SSD	38	2.2	1.1 M	4	20 μm	830 μm
6		43	2.8	1.5 M	3.3		

specials

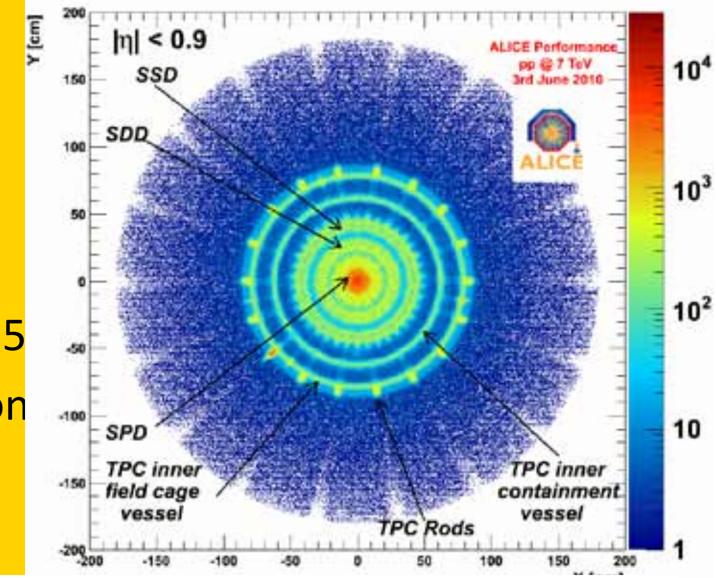
SPD: fastOR trigger

SDD: ΔE signal

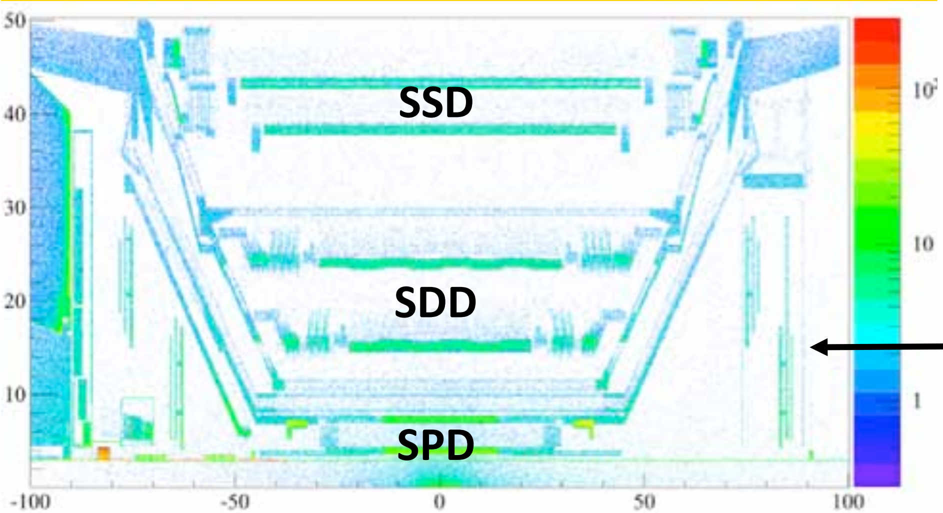
SSD : ΔE signal

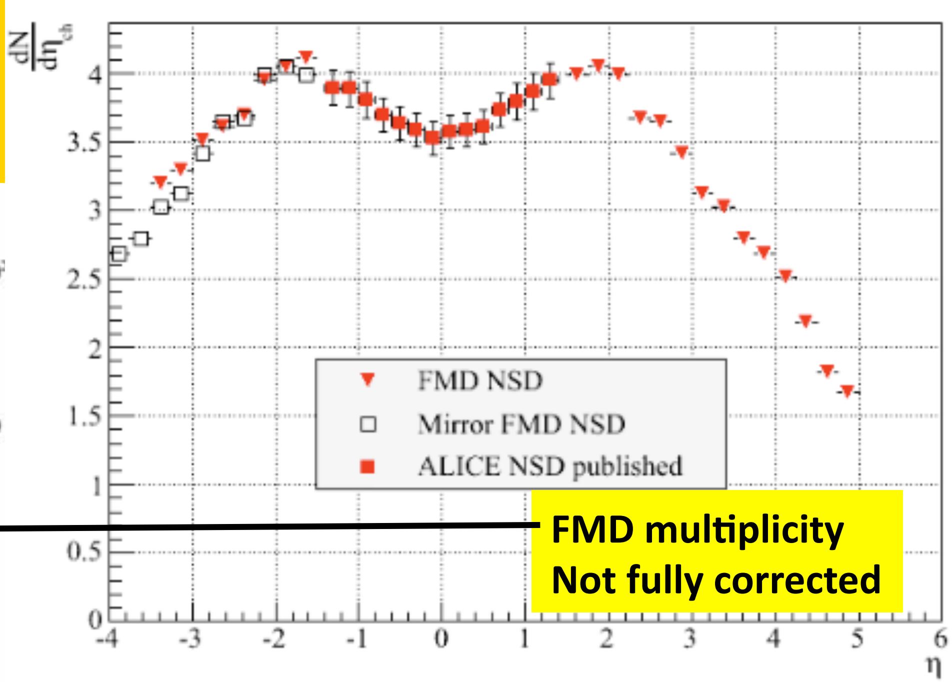
ALICE_LHC Material Budget

- Improving Detector Simulation
  - **central part** (< 45^0): very precisely measured (< 5
  - **forward part:** improved description in simulation (using design drawings/installation photo's)

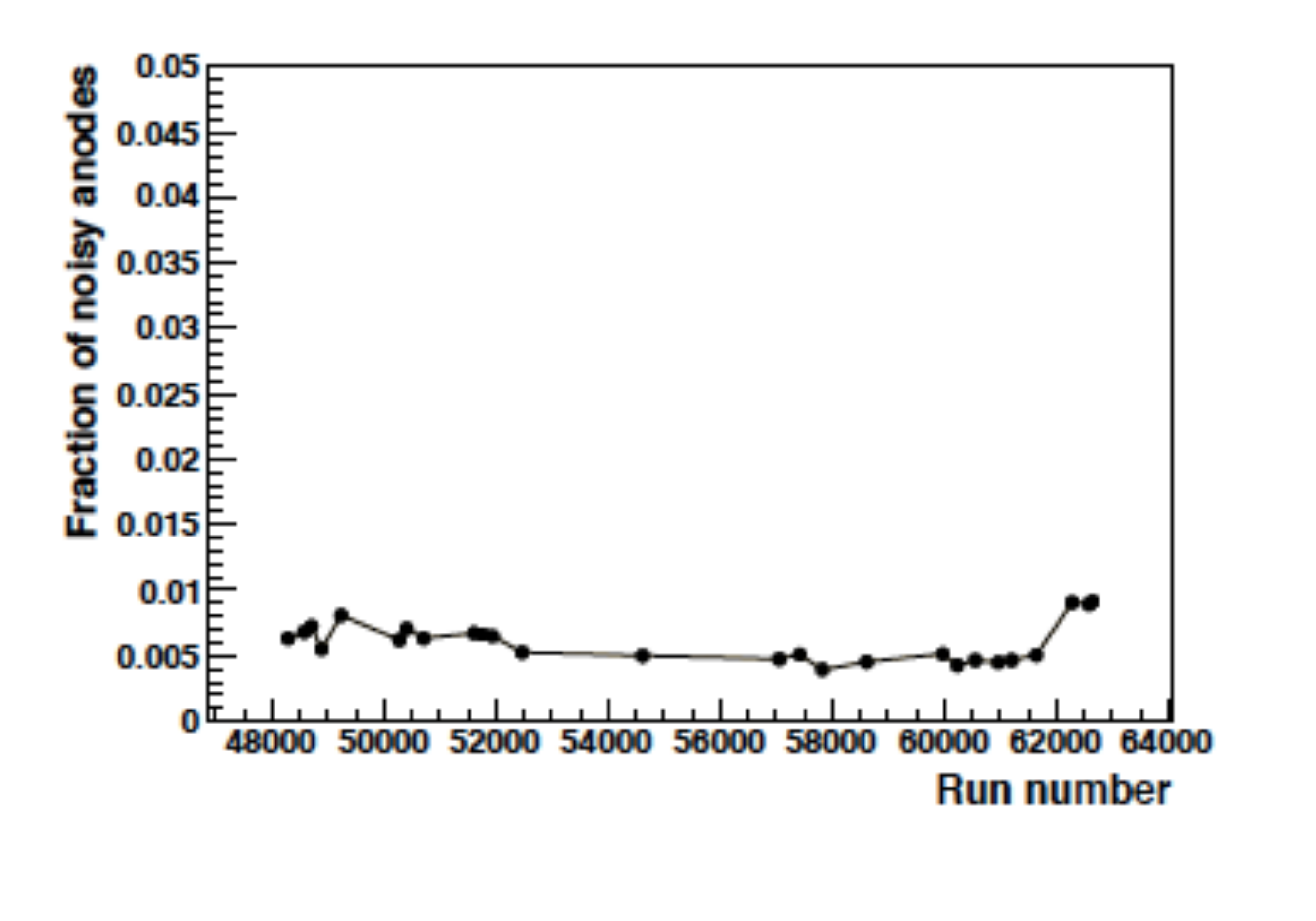


Material in simulation





fraction of bad anodes as a function of the run number during the 2008 cosmic run (from mid July to mid October); stays below 1% over the same period of time

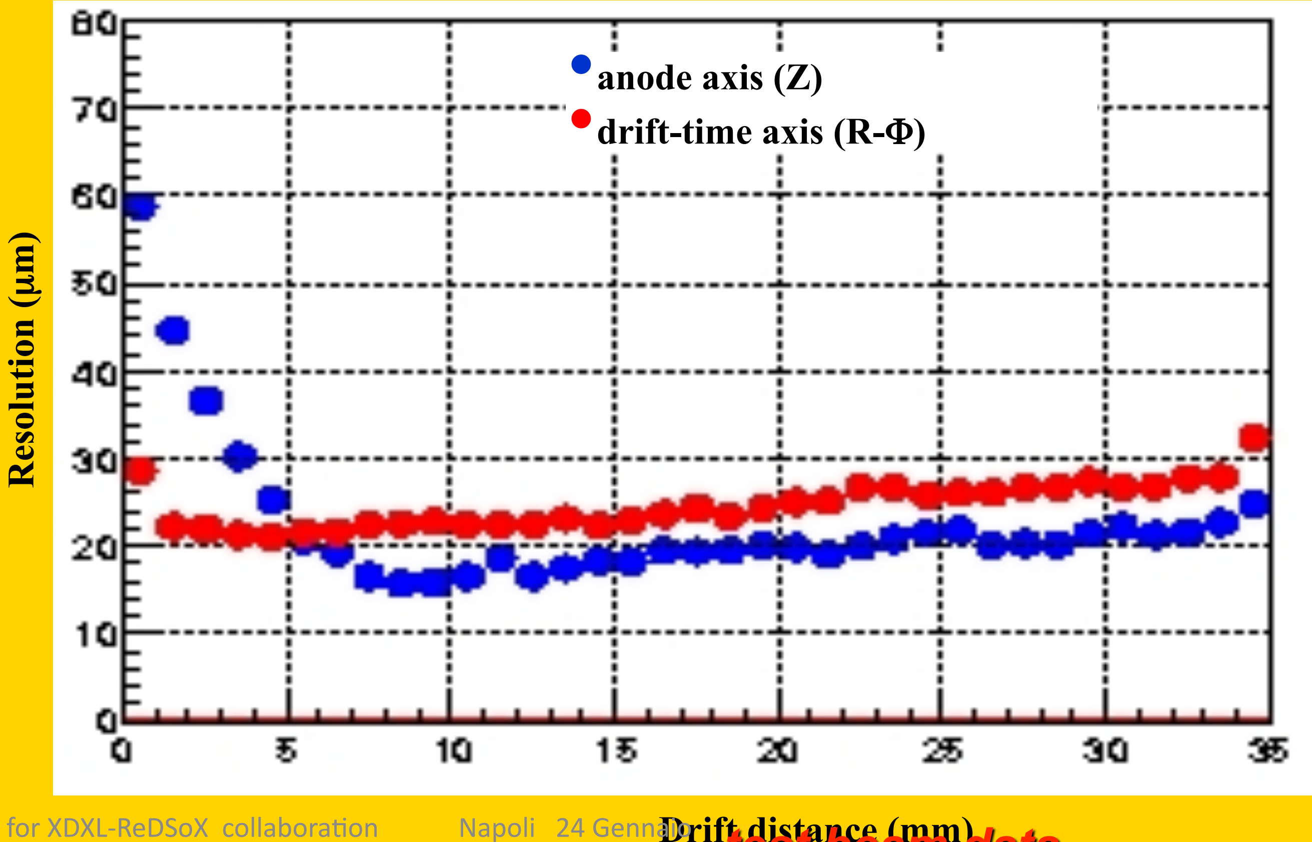


The space precision

along the drift direction, is better than 38 µm over the whole detector surface.

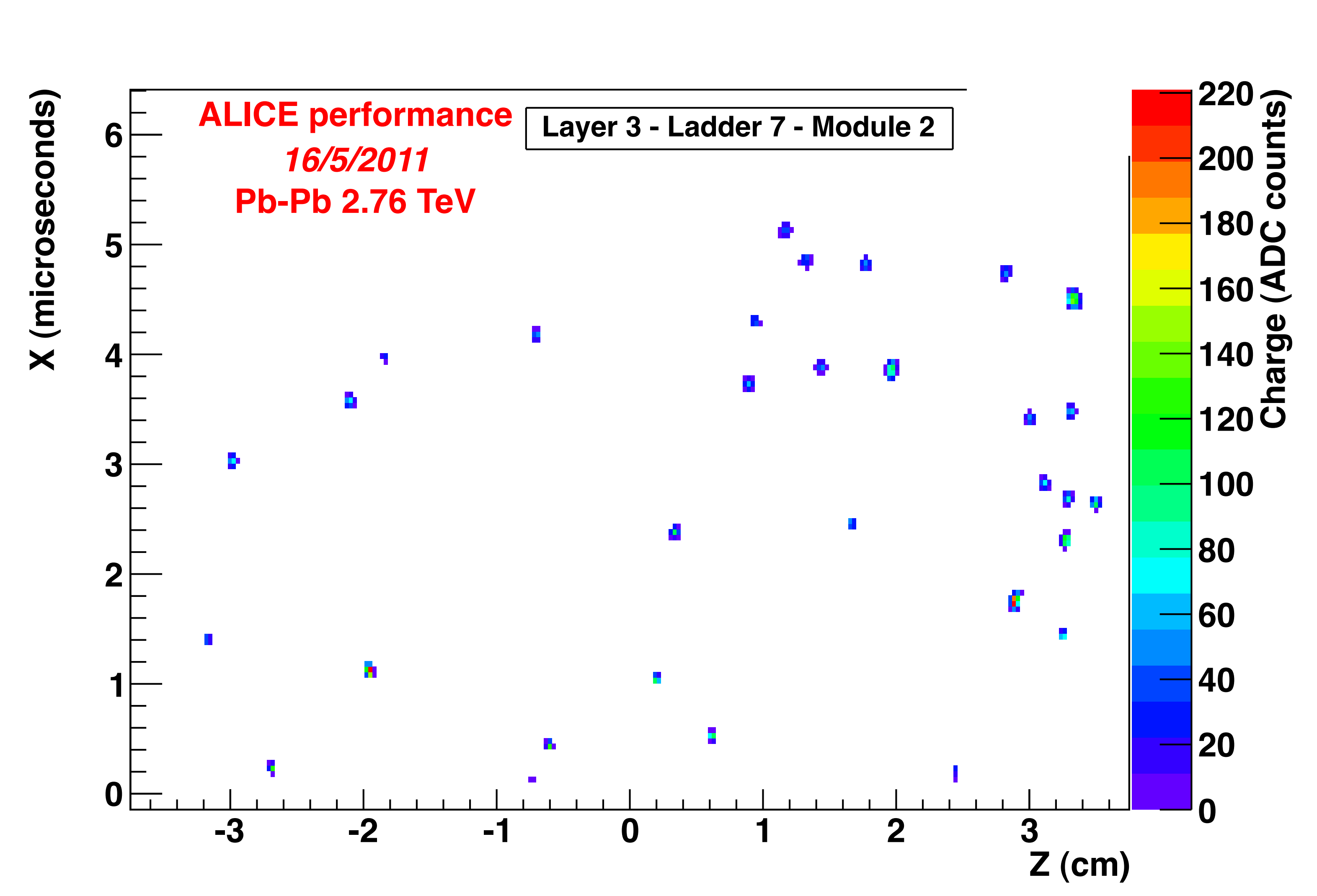
The precision along the anode, is better than 30 µm over 94% of the detector surface and reaches 60 µm close to the anodes, where a fraction of clusters affects only one anode.

The average values are 35 µm x 25 µm respectively.



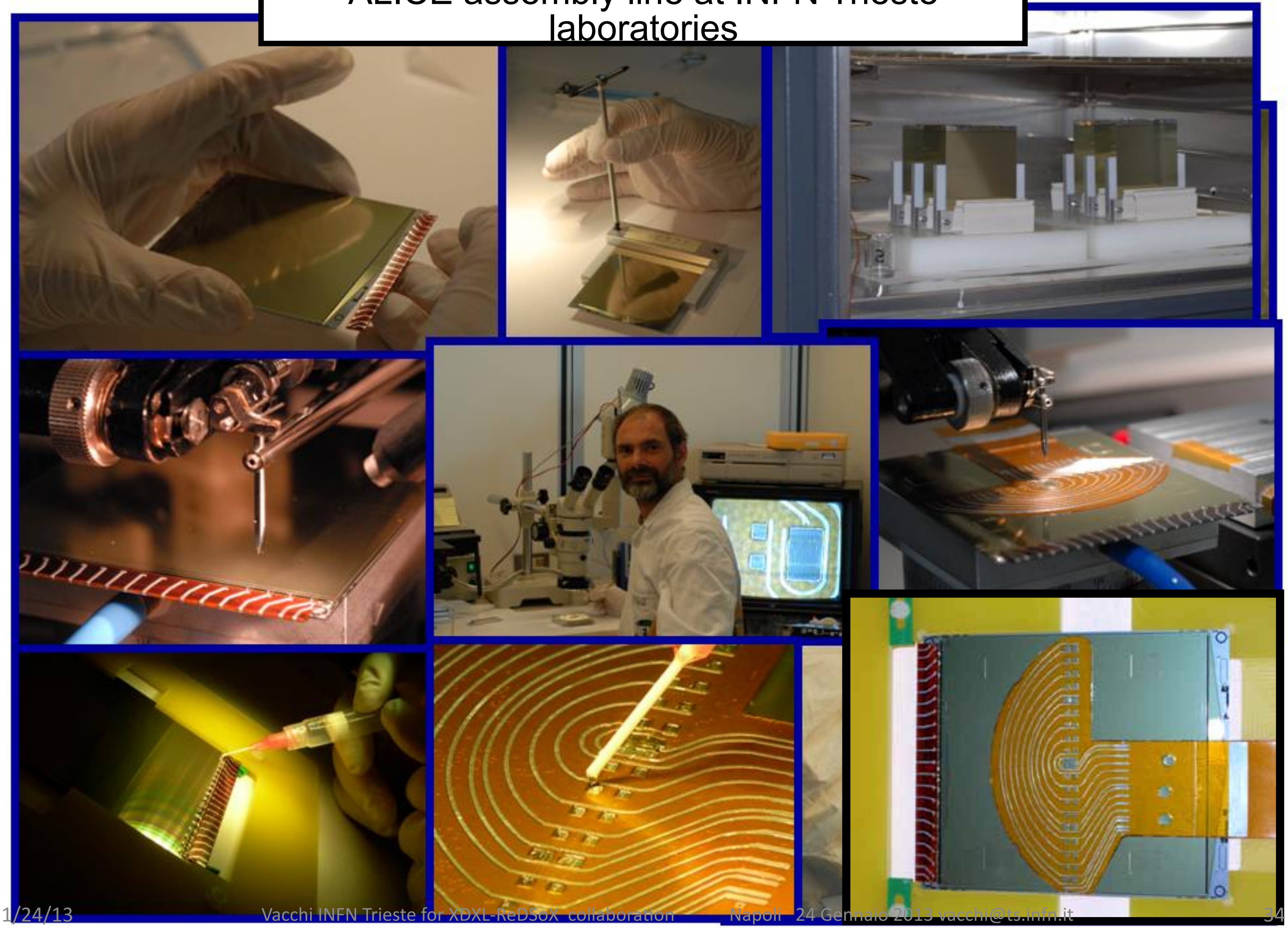
test beam data

Clean!



ALICE performance
16/5/2011
Pb-Pb 2.76 TeV
Layer 3 - Ladder 7 - Module 2
X (microseconds)
Z (cm)
Charge (ADC counts)
0
1
2
3
4
5
6
-3
-2
-1
0
1
2
3
0
20
40
60
80
100
120
140
160
180
200
220

ALICE assembly line at INFN Trieste laboratories



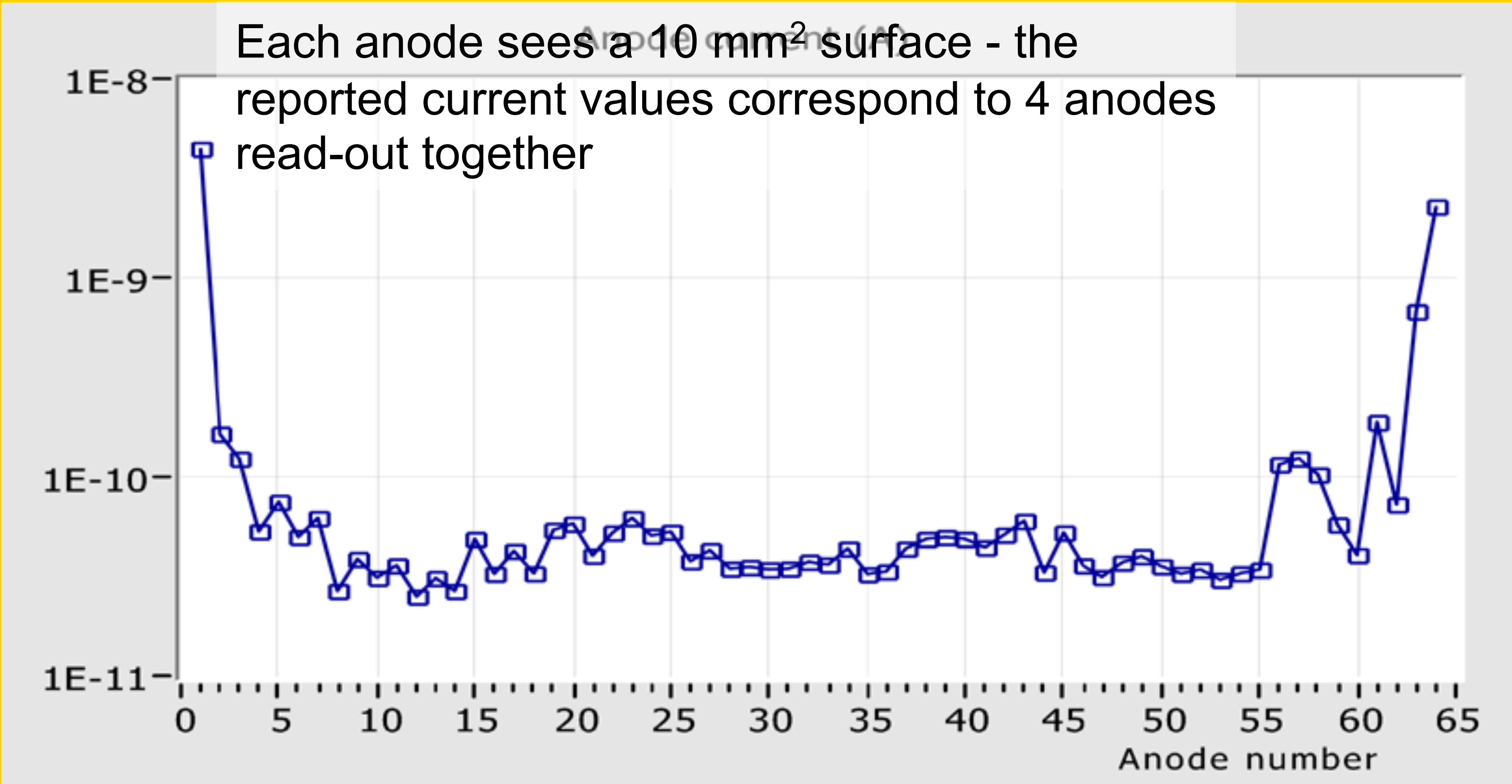
suitable for low-energy X-ray spectroscopy applications:

+ anode capacitance is about 50 fF,

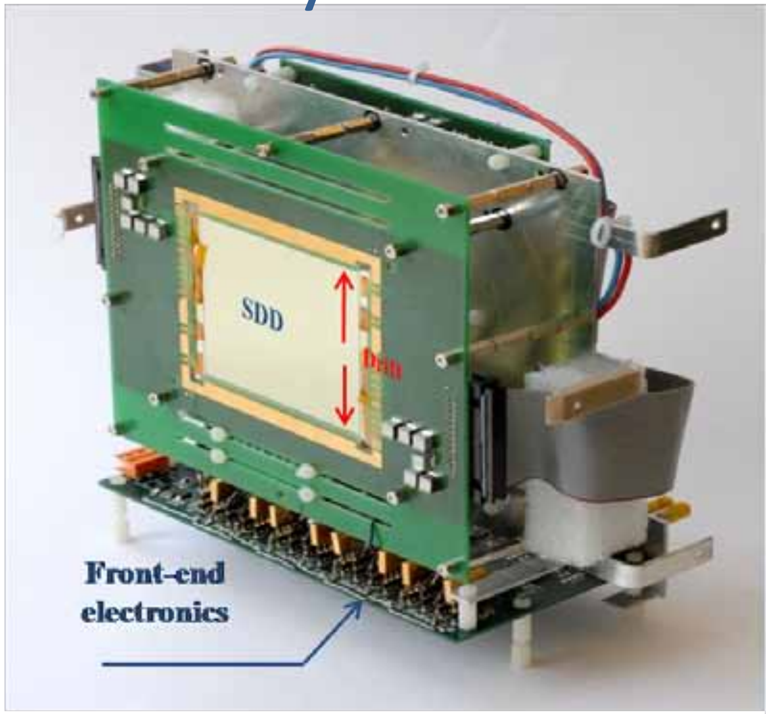
+ the leakage current at the anode measured at room temperature is very low.

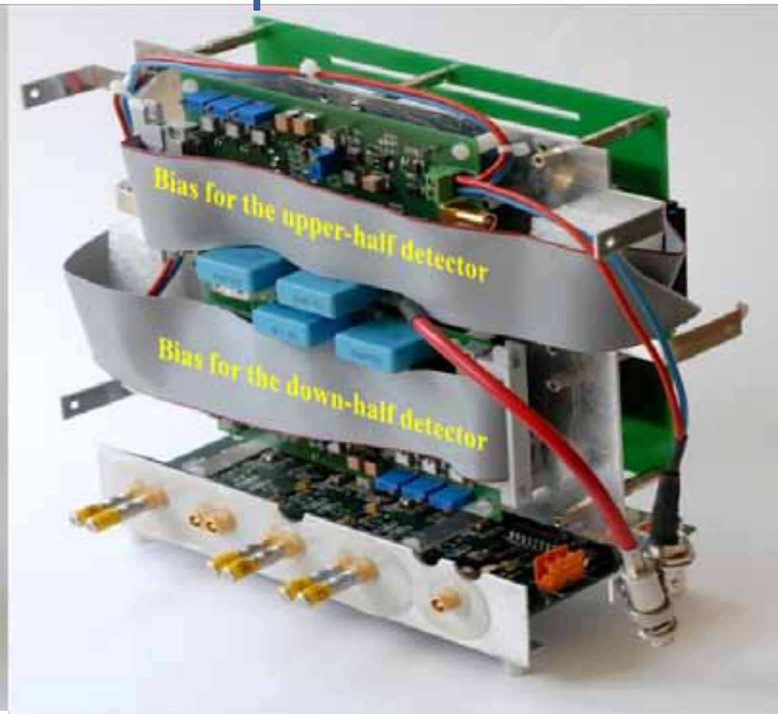
This allows a very-low noise contribution from the front-end electronics.

More than two order of magnitudes larger sensitive area than standard spectroscopic SDDs, this detector can open the way to application areas of the X-ray spectroscopy that require wide surface coverage.



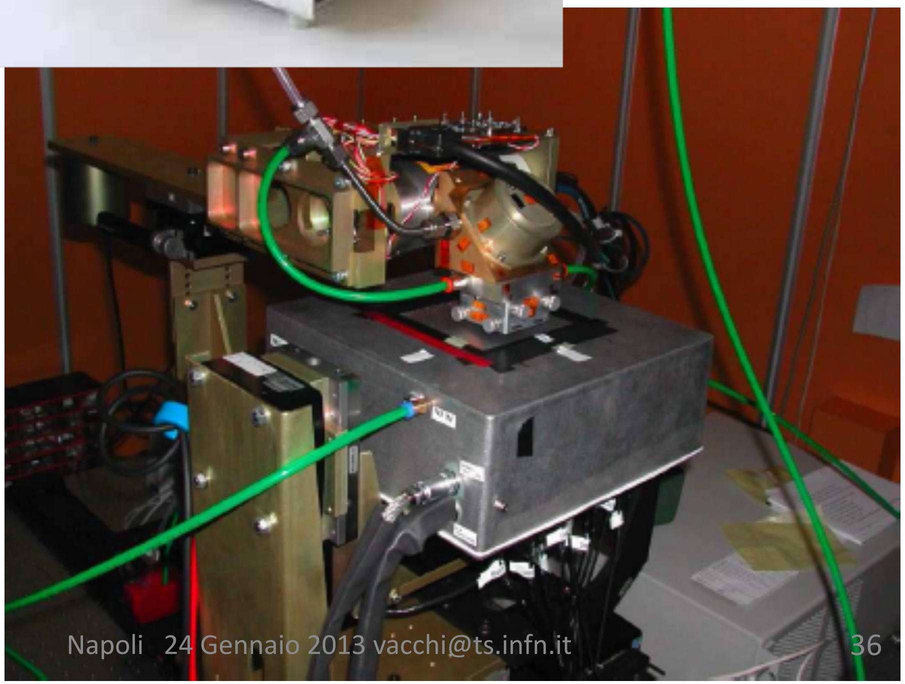
X-ray measurement setup: the detector box

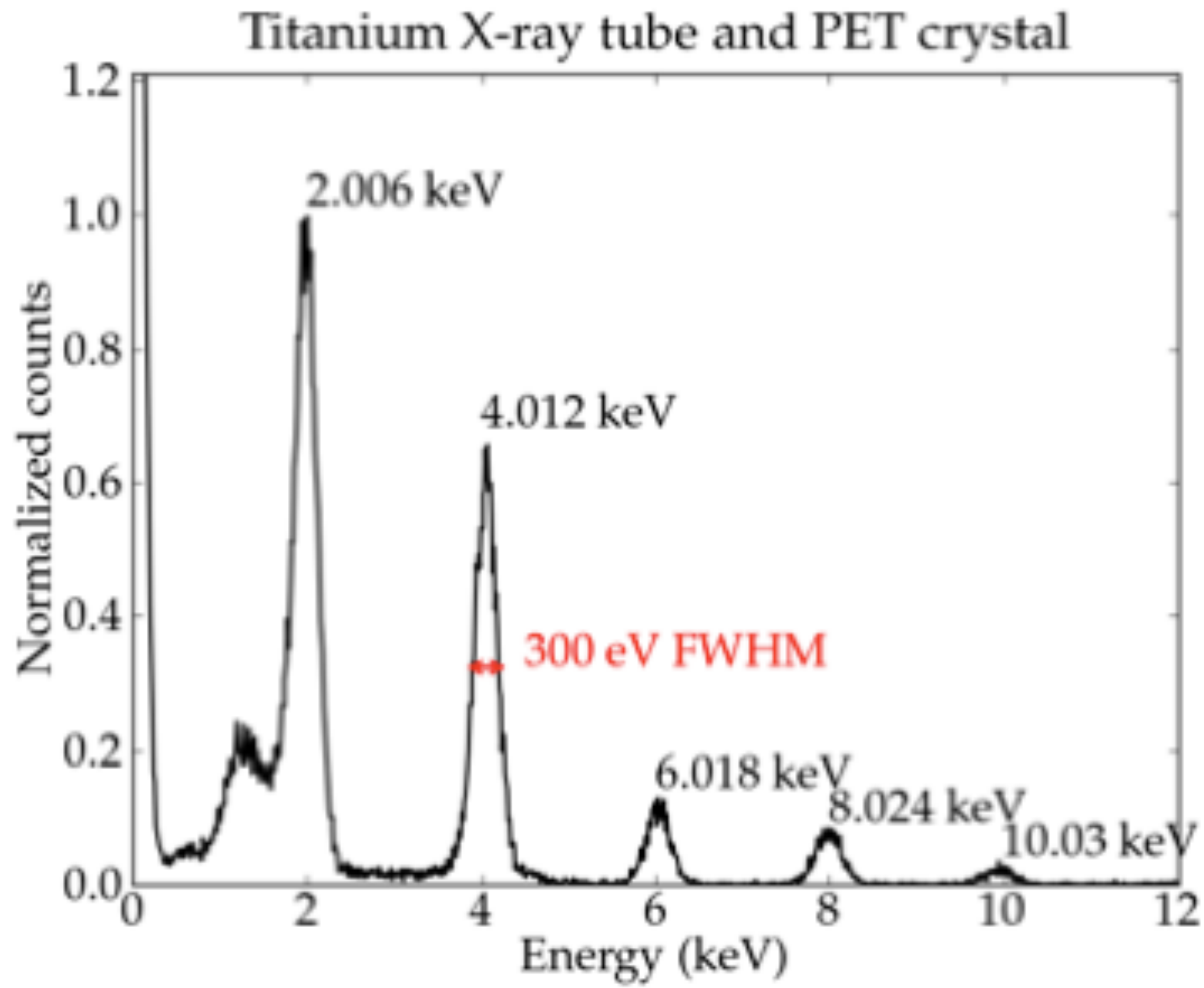




SDD operated at 1300 V

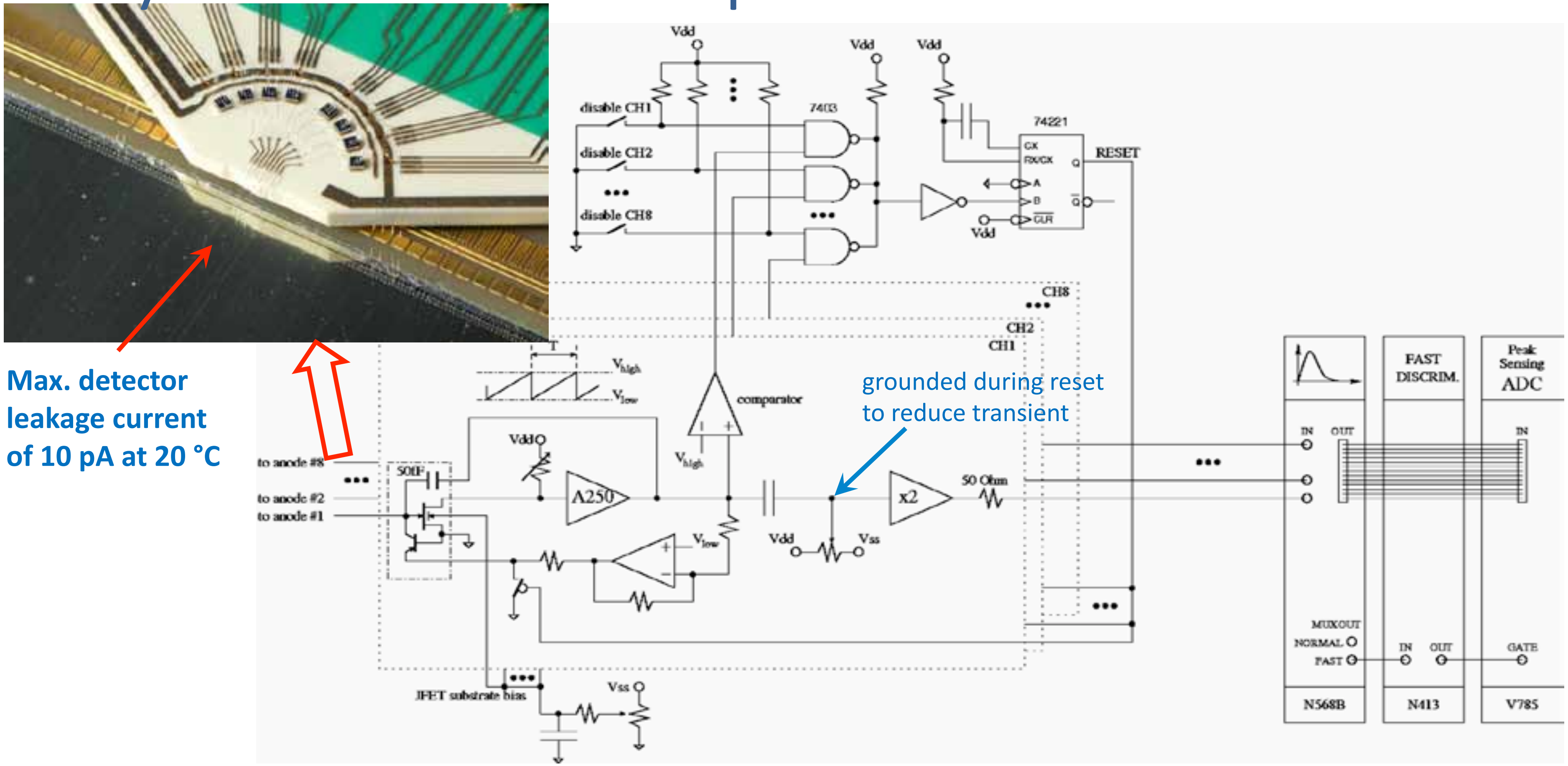
- SDD, bias and front-end boards are mounted inside an aluminum box which provides
  - shielding from irradiated noise
  - mechanical support and protection
- X-ray facility at the IASF-Rome laboratory:
  - radioactive sources (^{55}Fe, ^{241}Am, …)
  - X-ray tubes (with or without crystal polarizers to generate monochromatic lines)
  - Motorized stages allow micrometric positioning of the detector wrt the source





Spettro con SDD di Alice, a temperatura ambiente

X-ray measurement setup: the discrete FE electronics



- 8-channel discrete front-end electronics based on Amptek A250F/NF preamplifiers and a low gate-source capacitance JFET (C_{GS} = 0.4 pF)
- SF51 JFET (TSN Technology Ltd) incorporates a feedback capacitor (C_F = 50 fF) and a reset transistor
- synchronization of the reset commands to optimize signal processing
- 16-ch. NIM spectroscopy amplifier: 0.2, 1, 3, 6 ms time constants, 2nd order shaping, 50ns fast output mux for trigger generation
- 32-ch. VME 12-bit peak-sampling ADC

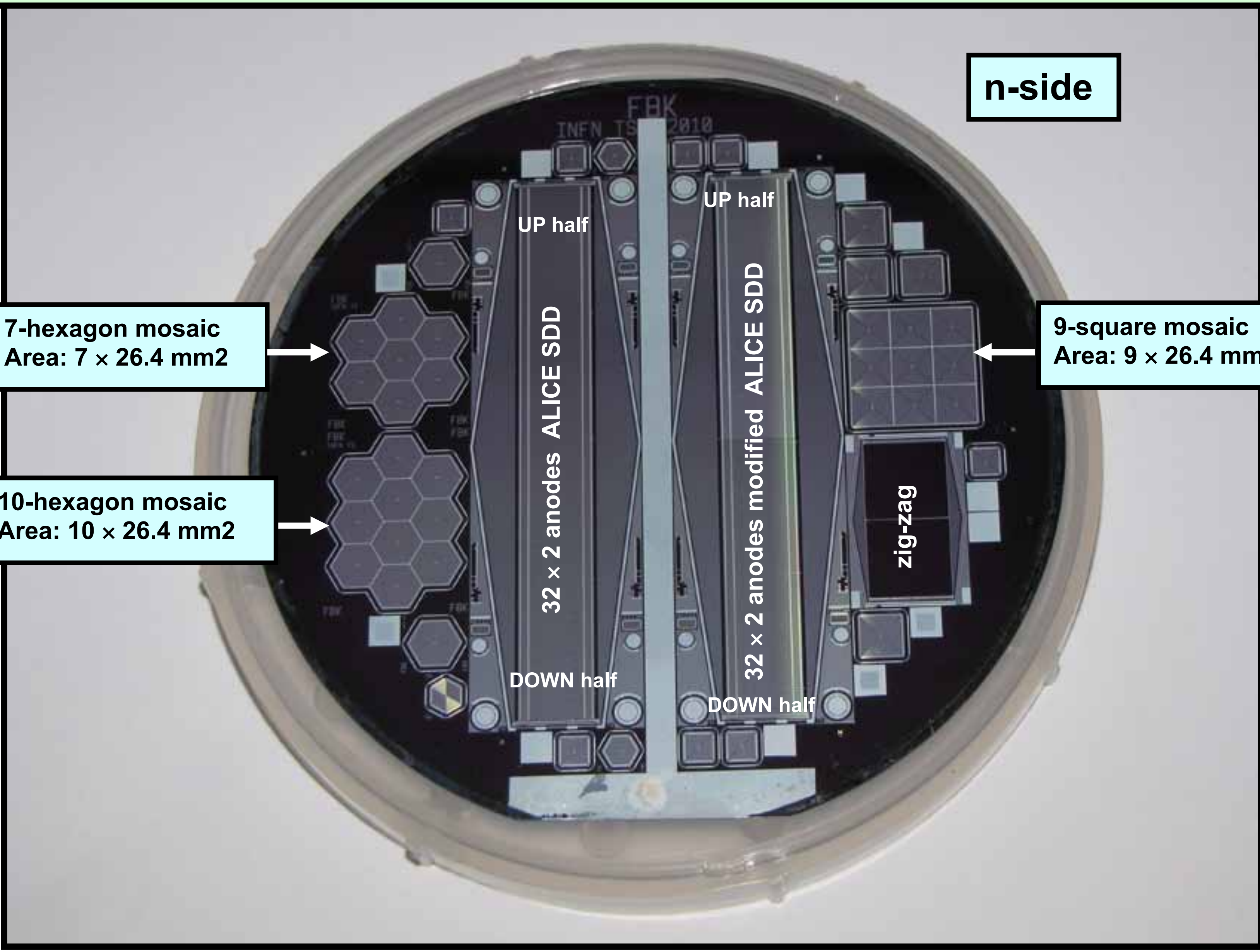
2009-2012 esperimento XDXL 2013-esperimento ReDSoX: motivazioni

- La tecnologia INFN delle SDD lineari di grande area è la più avanzata al mondo, c'è l'interesse a svilupparla ulteriormente soprattutto dal punto di vista dell'efficienza quantica

  - Forte motivazione da parte della comunità ***Advanced Light Sources (ASL)***, i.e. EuroFEL, di rivelatori a deriva aventi prestazioni estreme di efficienza, risoluzione energetica, velocità. Questa richiesta viene anche da **Sincrotrone Trieste,** con il quale si vuole consolidare la collaborazione iniziata a fine 2011;

  - Proposta ***LOFT per la mission call M3 dell'ESA***, **conseguenza diretta di XDXL**: ora il progetto promuove il passaggio alla tecnologa a 6 ", il consolidamento, l'affidabilità e la robustezza della tecnologia delle SDD lineari per l'applicazione nello spazio durante le fasi di ASSESSMENT e DEFINITION di LOFT;

XDXL: first production batch. Wafer diameter 4” / thickness 450 μm
Material FZ-silicon (ρ=7-9 kΩ•cm).

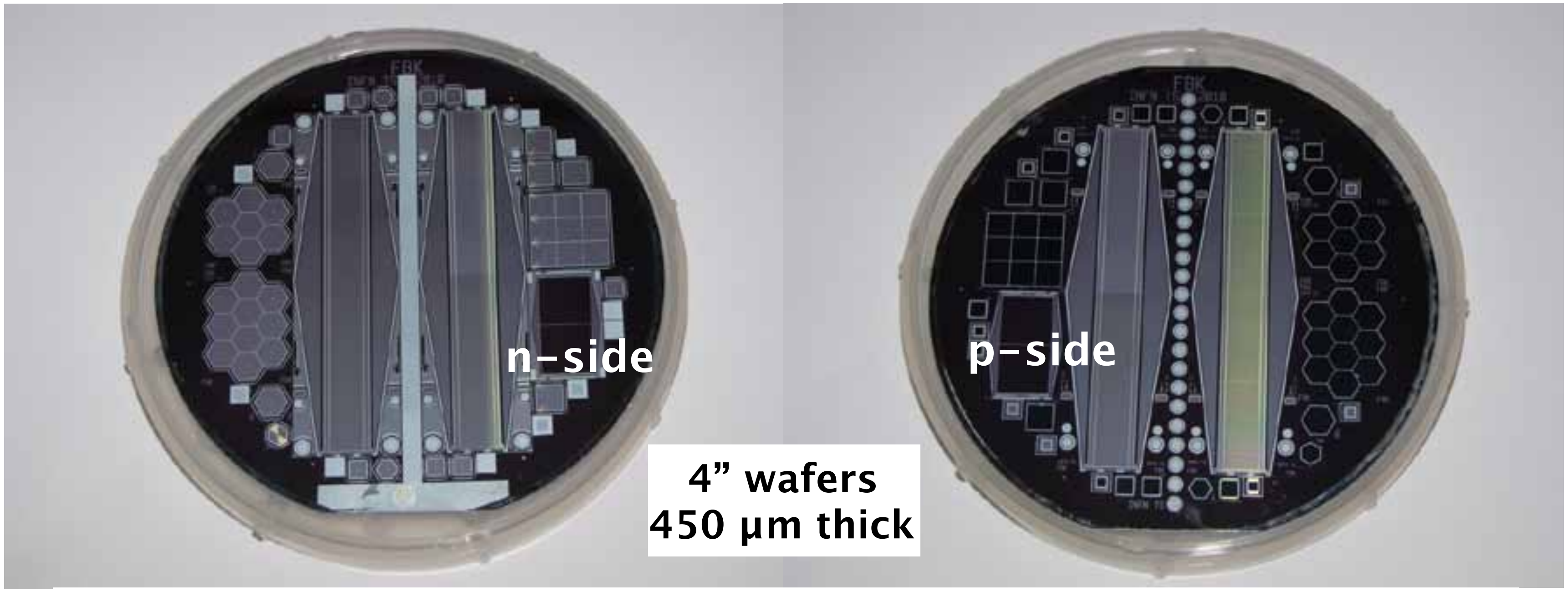


7-hexagon mosaic
Area: 7 × 26.4 mm2

10-hexagon mosaic
Area: 10 × 26.4 mm2

9-square mosaic
Area: 9 × 26.4 mm2

First prototype run with FBK (2010)

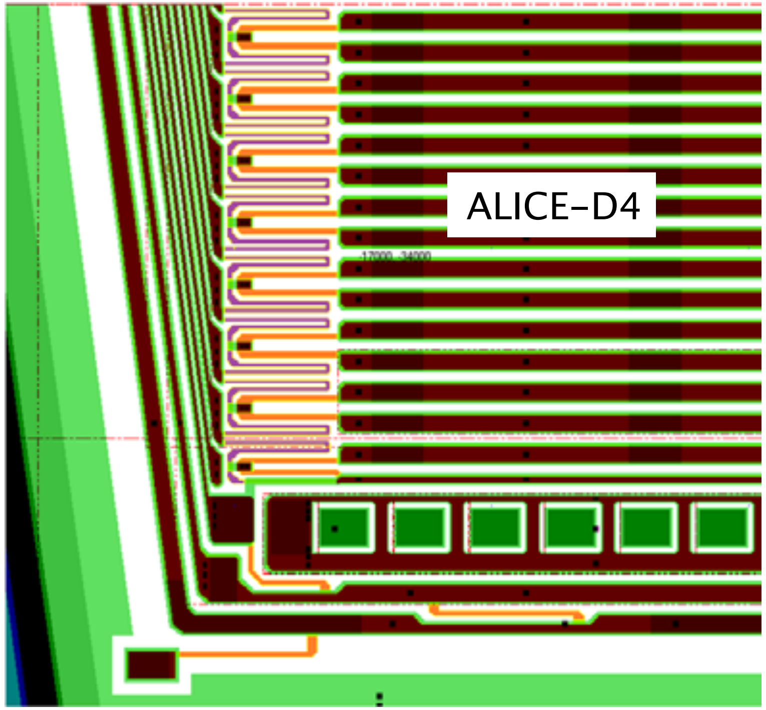


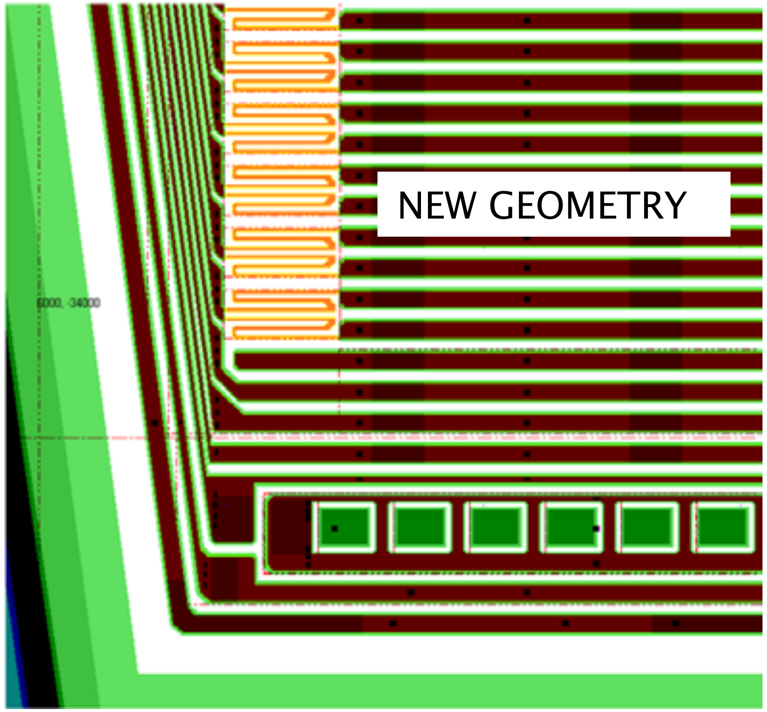
A initial run was necessary to evaluate the fabrication process and gather the information required to optimize the detector in the following iterations

The wafer comprises:

- One SDD having the same layout of ALICE-D4 but only 32 anodes for each side (ALI1)
- One SDD having the new biasing scheme for improved power consumption, and Si-SiO_2 interface minimized in one half of the detector to reduce surface leakage and improve detection efficiency at low energy (ALI2)
- Hexagonal and square single-anode SDDs having sensitive areas of 10 and 25 mm^2 (and arrays) , one “zig-zag” SDD where the drift cathodes themselves are the voltage divider
- Test diodes

Power consumption reduction





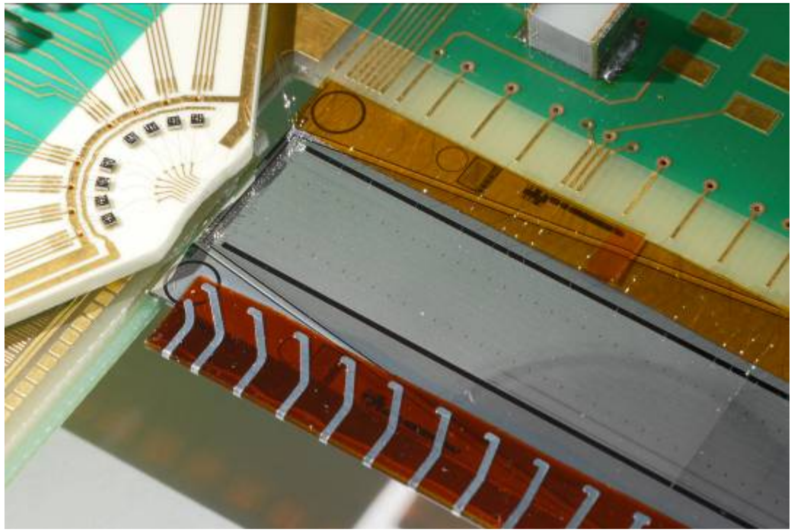
- By removing the guard voltage dividers it is possible to increase the resistance of the drift one. The guard cathodes are then connected to the drift divider → lower power consumption (goal: 1/10 wrt ALICE-D4)

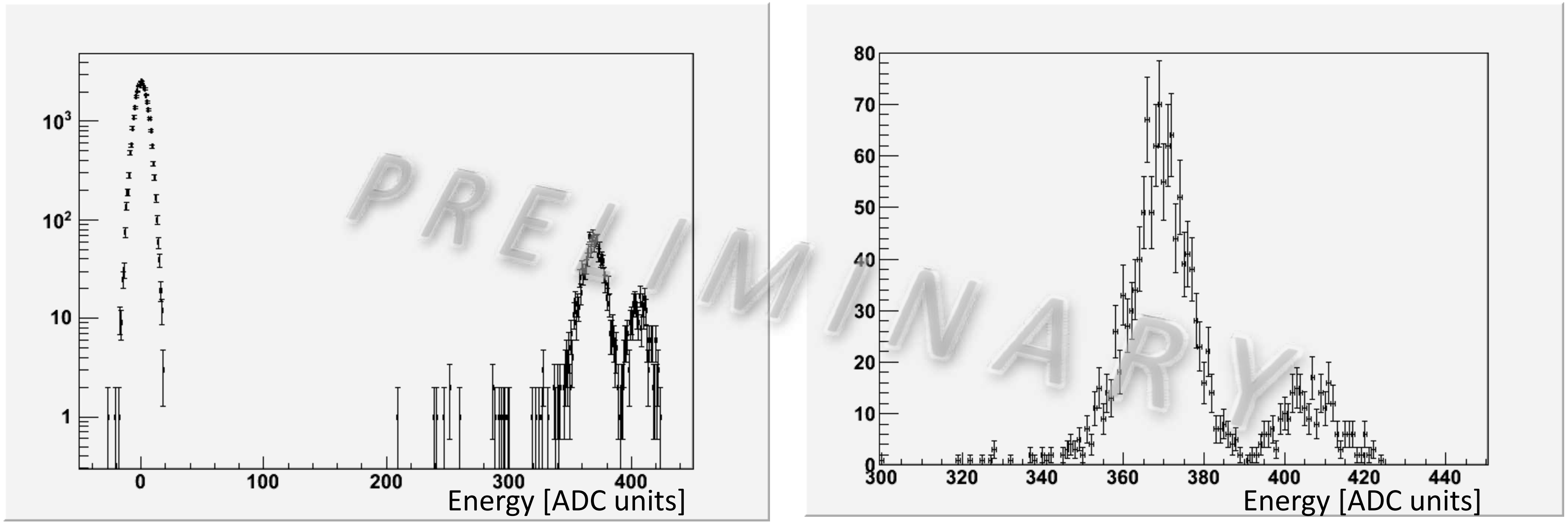
- Last few cathodes not connected to integrated voltage divider to assess influence of divider noise on the detector performance

ALI2: first X-ray test with a ^{55}Fe source

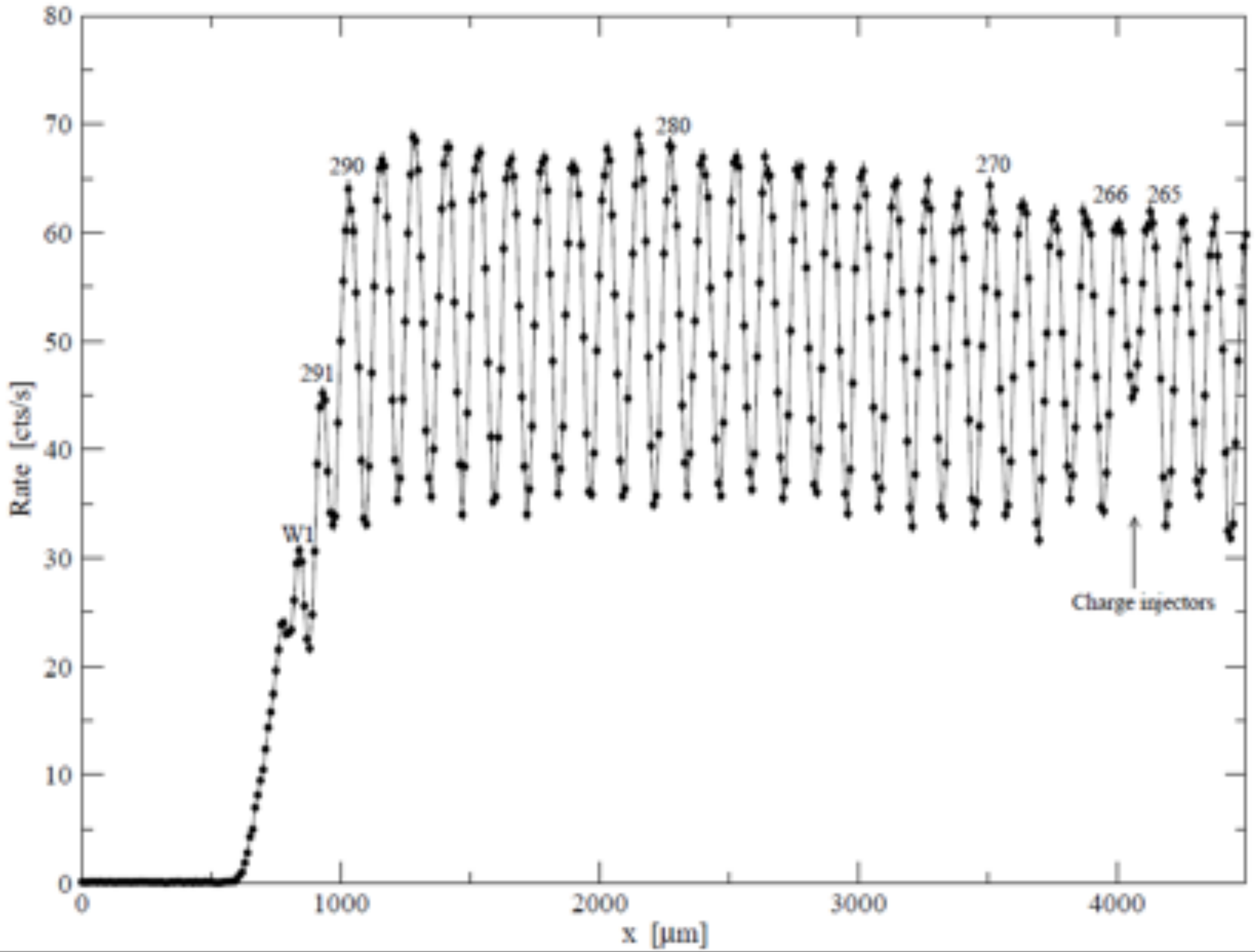
- Measurements taken with the same discrete front-end electronics used for the ALICE SDD characterization

- Due to mechanical constrains the anode wire bonding are a bit longer → slightly higher stray capacitance at the input



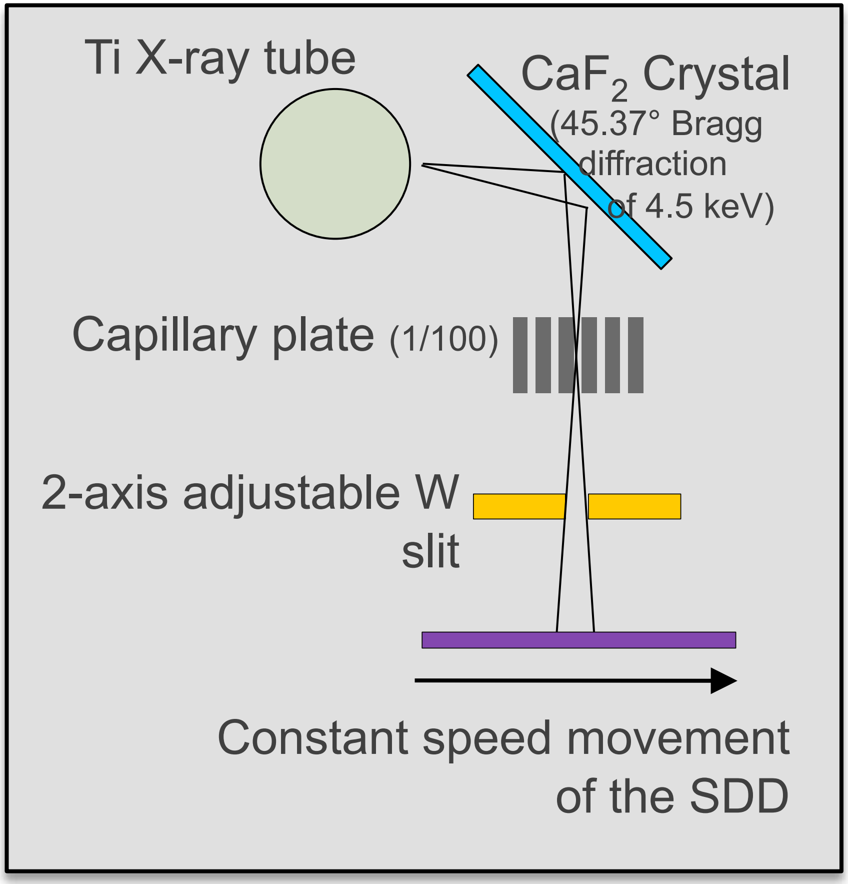


Single-anode event spectrum at 0 °C, τ_{shaper} = 3 μs

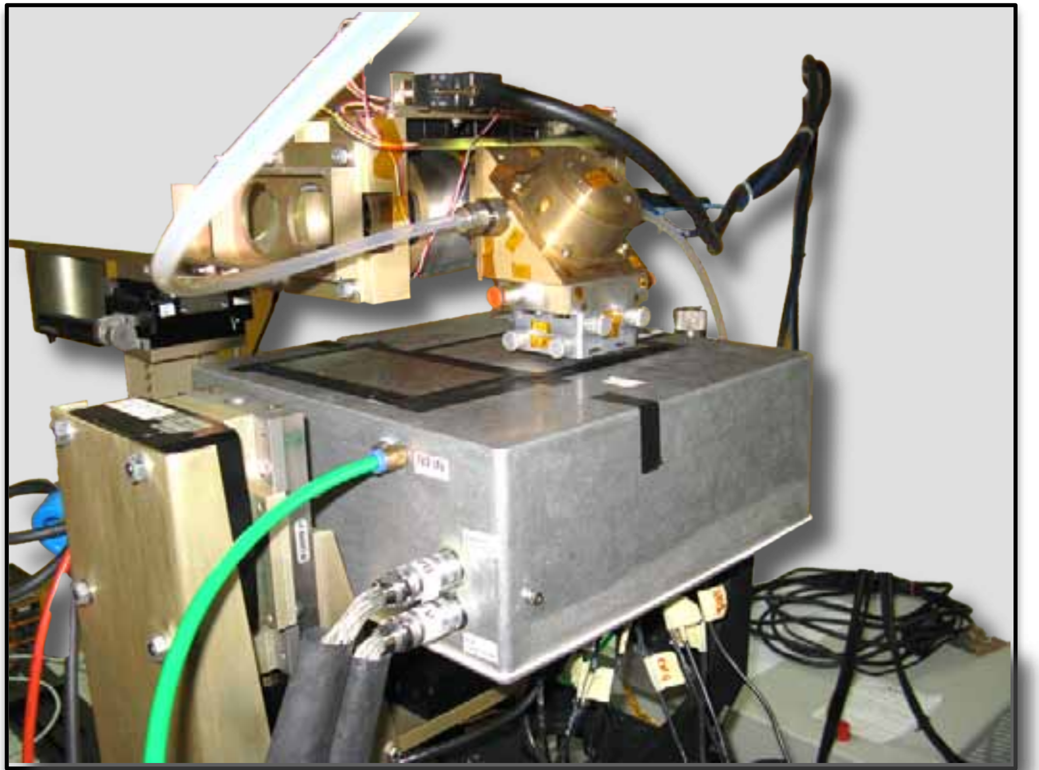


Scansione di una SDD di Alice con fascio da 100 µm a 4.5 keV. Le varie strutture dei catodi e delle zone morte sono ben visibili.

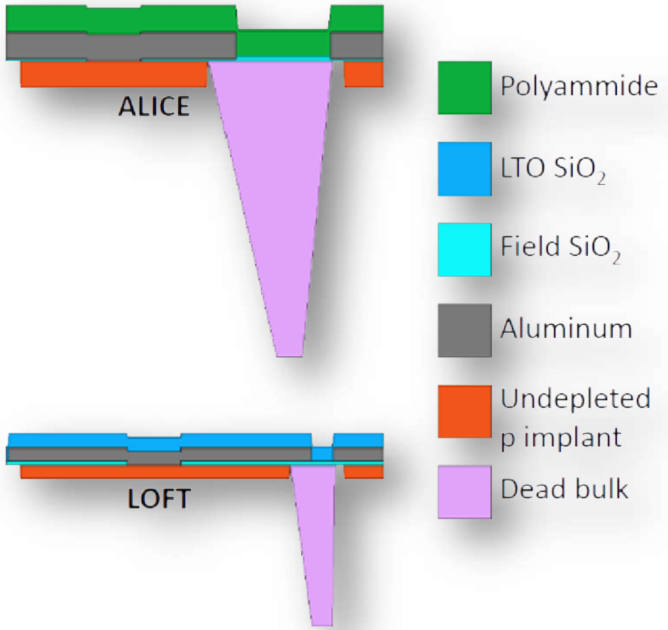
ALICE-D4 X-ray efficiency and dead layers

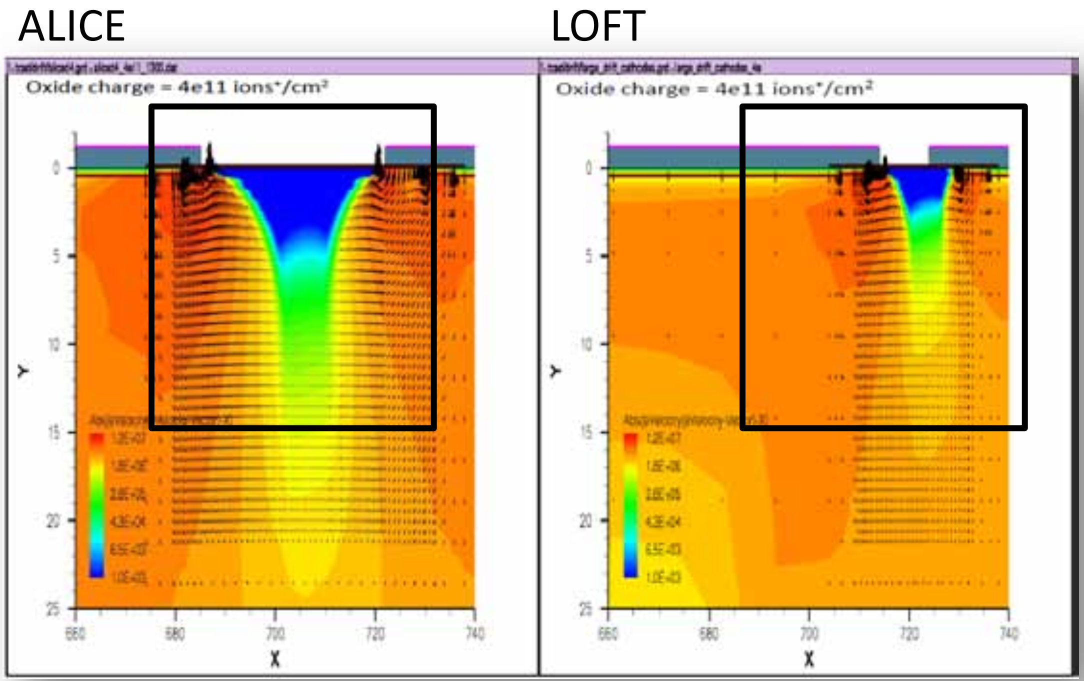


Experimental set-up used for detector characterization



Evolution of ALICE-D4 design

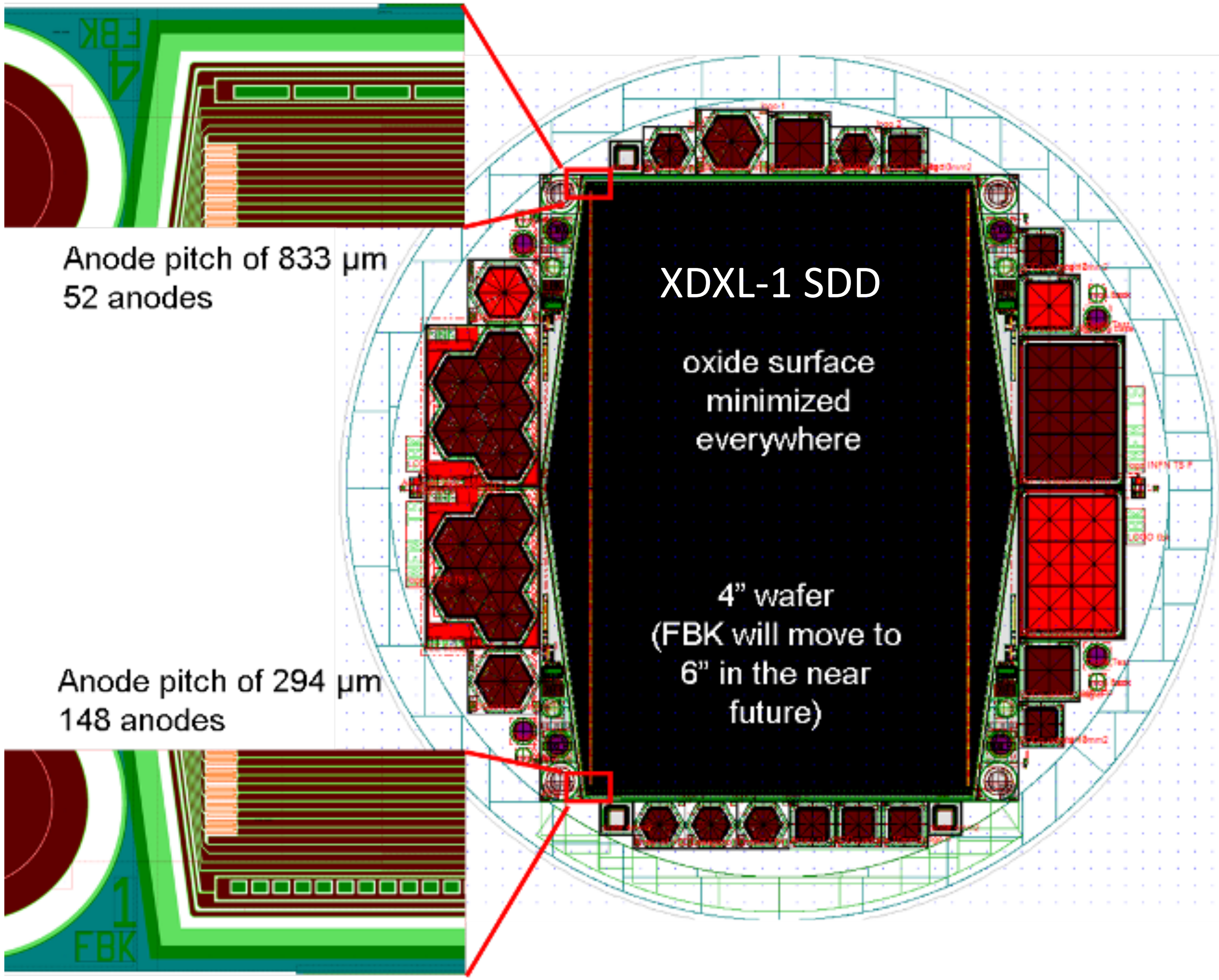




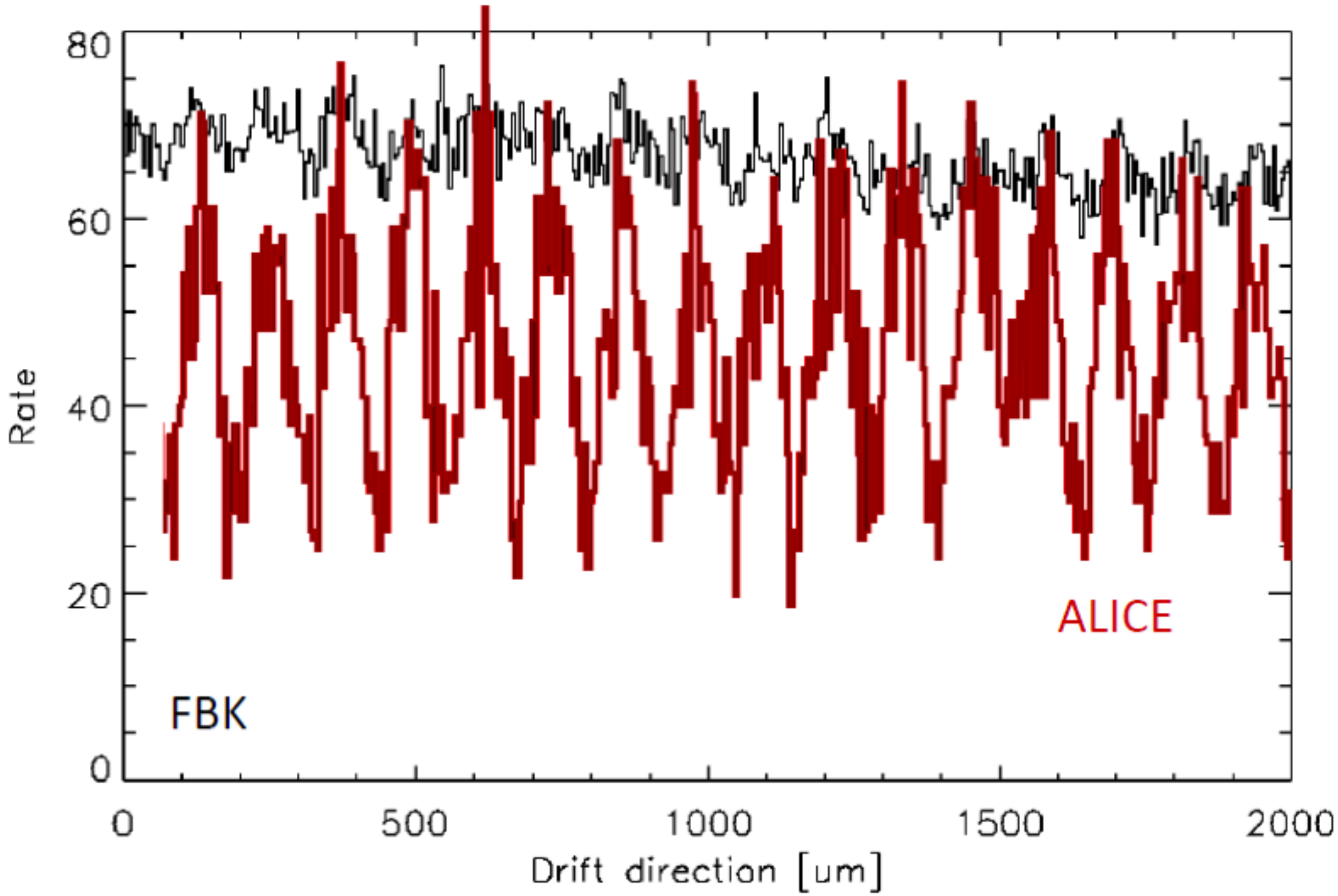
The new FBK prototypes include design modifications (**drift cathodes have been enlarged** keeping the same pitch, so that their distance equals that between guards)

In this way **the potential minimum is pushed closer to the surface** and the dead volume in the substrate is **reduced by a factor of about 4**.

Second FBK prototype run

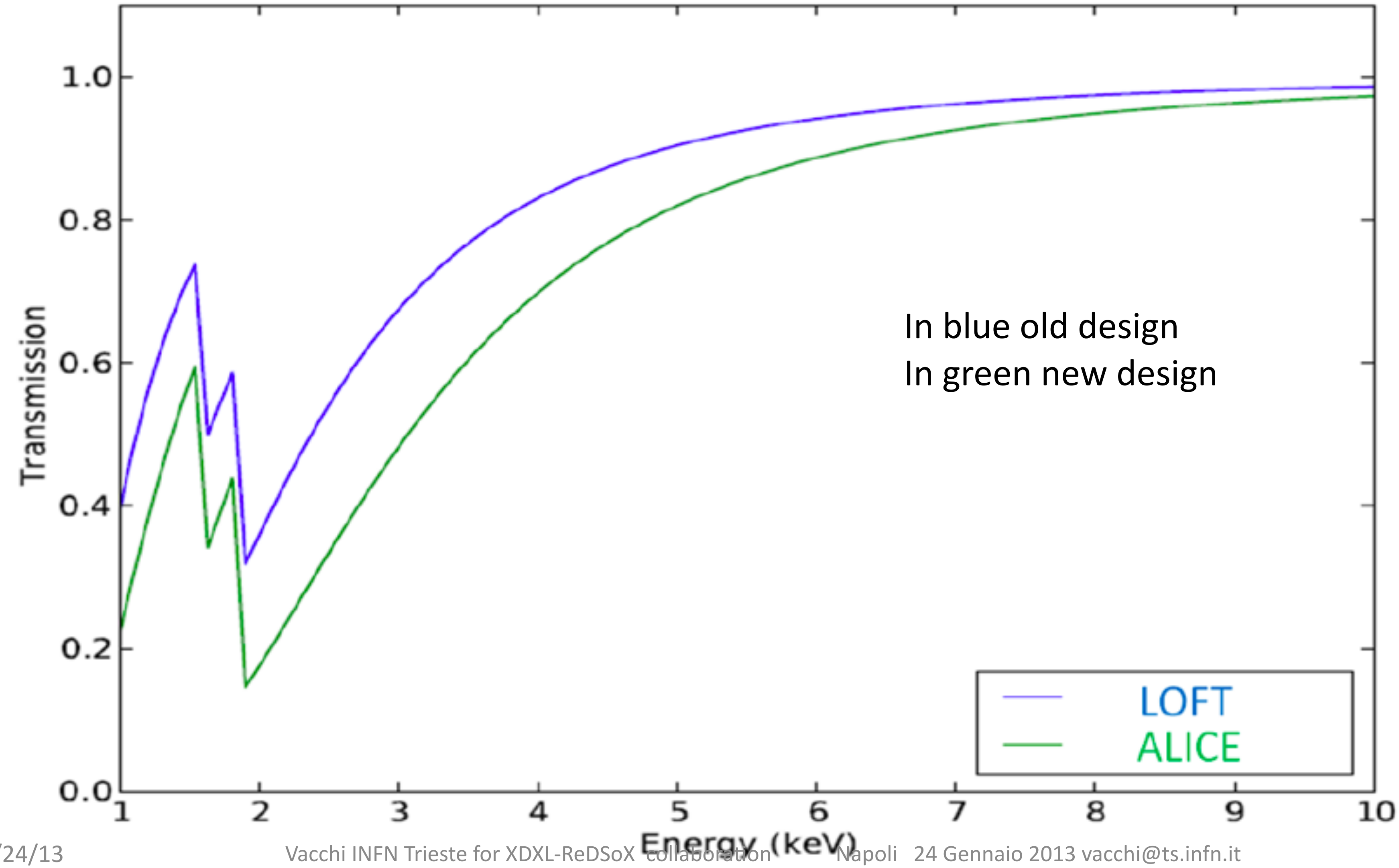


Efficiency modulation @ 4.5 keV, 200 µm spot size: ottimizzazione della risposta alle basse energie (FBK-1 vs Alice)



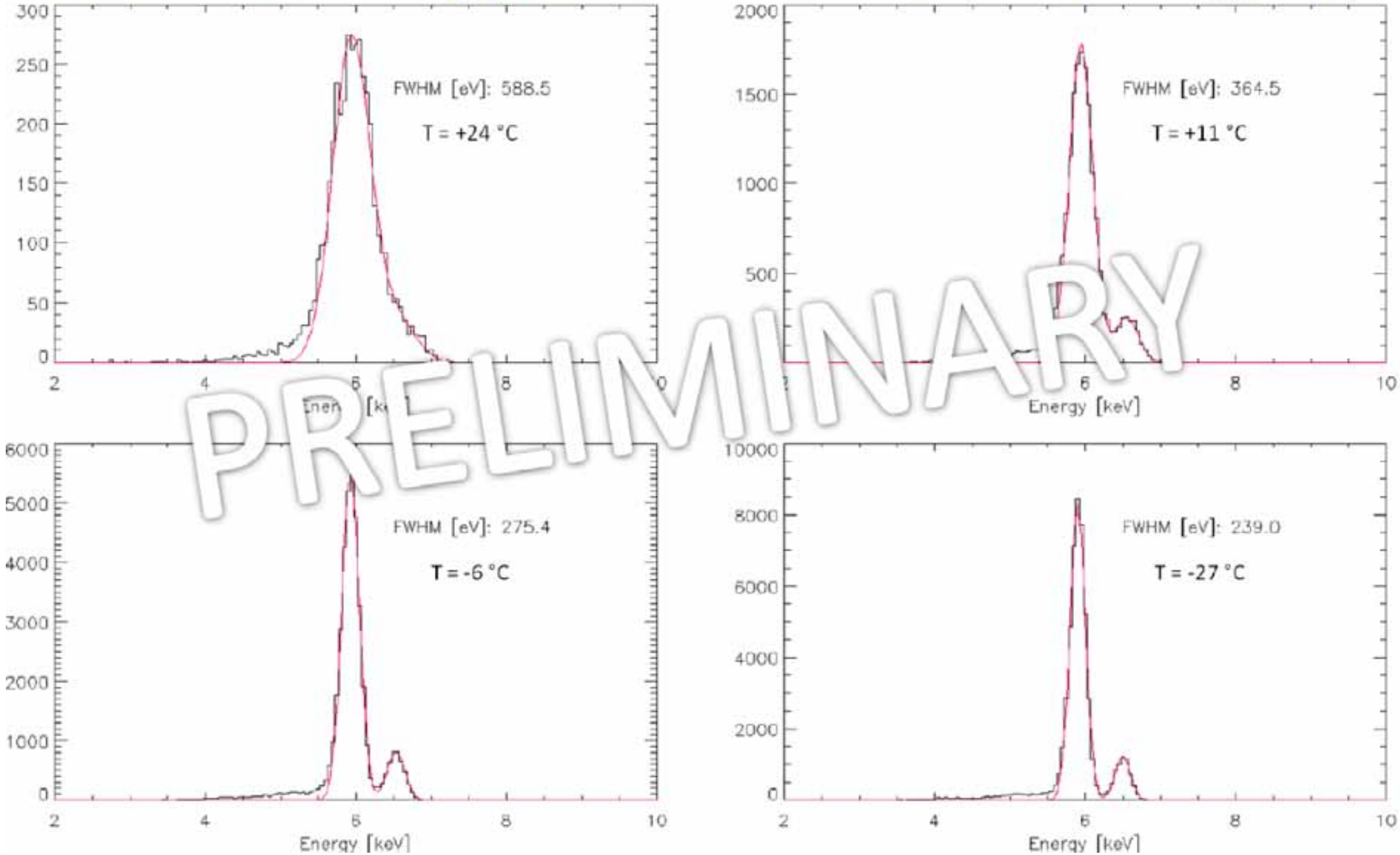
In red old design
In black new design

Stessi dati, che mostrano l'aumento dell'efficienza quantica alle basse energie.



In blue old design
In green new design

FBK 2 - W4 energy resolution vs Temperature (t_{SH} = 1μs)



Nuclear Instruments and Methods in Physics Research A 633 (2011) 15–21

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Room-temperature spectroscopic performance of a very-large area silicon drift detector

G. Zampa [a,*], R. Campana [b,c,**], M. Feroci [b,c], A. Vacchi [a], V. Bonvicini [a], E. Del Monte [b,c], Y. Evangelista [b,c], F. Fuschino [d], C. Labanti [d], M. Marisaldi [d], F. Muleri [b], L. Pacciani [b,c], M. Rapisarda [b,c,f], A. Rashevsky [a], A. Rubini [b,c], P. Soffitta [b], N. Zampa [a], G. Baldazzi [e], E. Costa [b], I. Donnarumma [b], M. Grassi [g], F. Lazzarotto [b], P. Malcovati [g], M. Mastropietro [h], E. Morelli [d], L. Picolli [g]

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

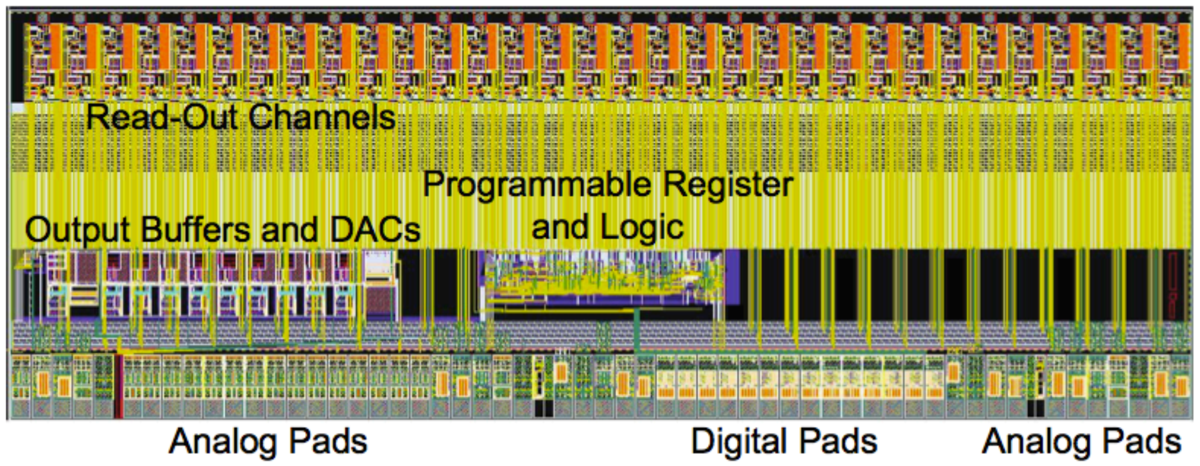
journal homepage: www.elsevier.com/locate/nima

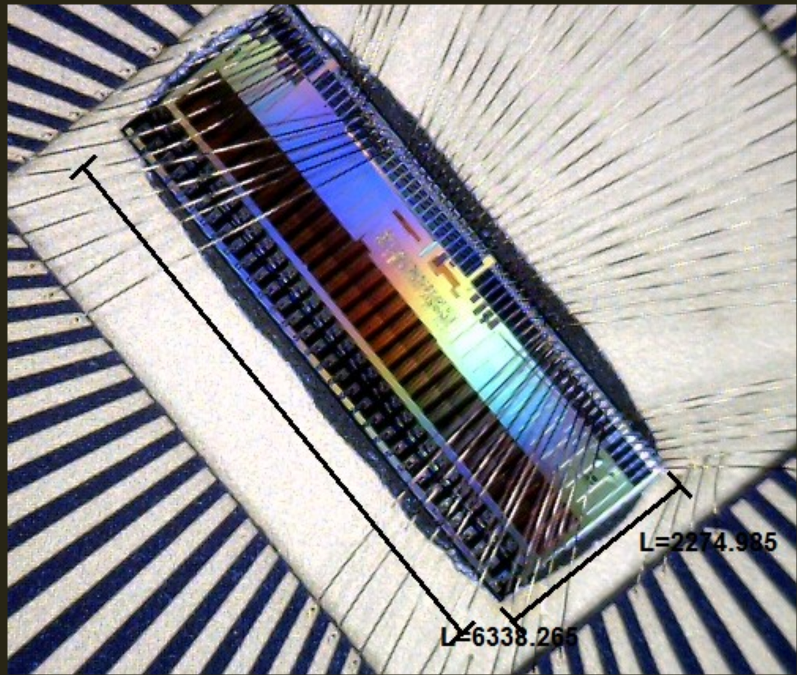
Imaging performance of a large-area Silicon Drift Detector for X-ray astronomy

R. Campana [a,b,*], G. Zampa [c], M. Feroci [a,b], A. Vacchi [c], V. Bonvicini [c], E. Del Monte [a,b], Y. Evangelista [a,b], F. Fuschino [d], C. Labanti [d], M. Marisaldi [d], F. Muleri [a], L. Pacciani [a,b], M. Rapisarda [a,b,e], A. Rashevsky [c], A. Rubini [a,b], P. Soffitta [a], N. Zampa [c], G. Baldazzi [f], E. Costa [a], I. Donnarumma [a], M. Grassi [g], F. Lazzarotto [a], P. Malcovati [g], M. Mastropietro [h], E. Morelli [d], L. Picolli [g]

[a] INAF/IASF-Roma, Via Fosso del Cavaliere 100, I-00133 Roma, Italy

The ASIC for SDDs





Packaged ASIC 32 ch (200 mm pitch) dimension in mm


LOFT
Large Observatory For x-ray Timing
A mission proposal selected by ESA
as a candidate Cosmic Vision M3 mission
devoted to X-ray timing
and designed to investigate
the space-time around collapsed objects
http://www.isdc.unige.ch/loft/index.php
show

The LOFT Mission

LOFT is specifically designed to exploit the diagnostics of very rapid X-ray flux and spectral variability that directly probe the motion of matter down to distances very close to black holes and neutron stars, as well as the physical state of ultradense matter.

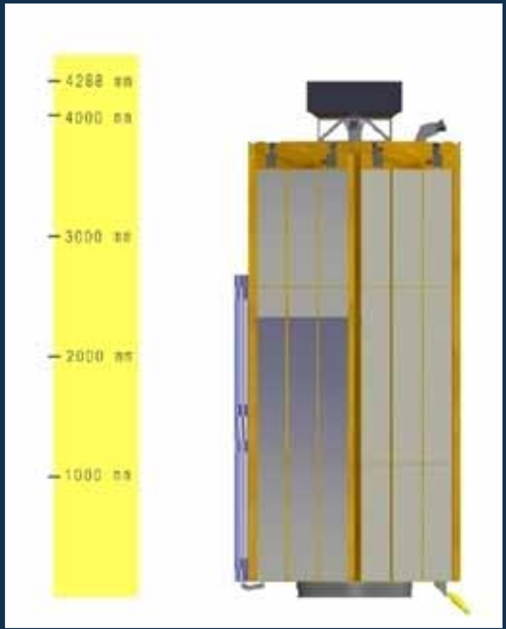
LOFT will investigate variability from submillisecond QPO's to years long transient outbursts.

The LOFT LAD has an effective area ~20 times larger than its largest predecessor (the Proportional Counter Array onboard RossiXTE) and a much improved energy resolution.

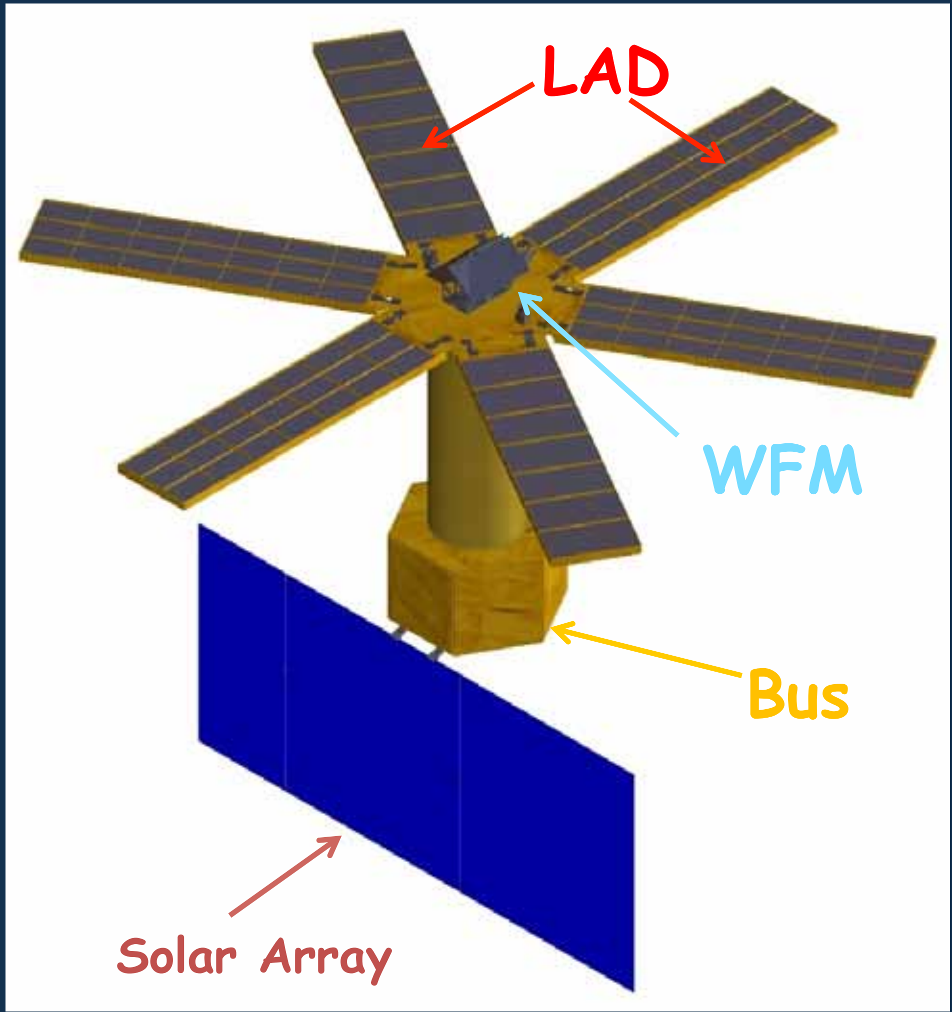
The LOFT WFM will discover and localise X-ray transients and impulsive events and monitor spectral state changes, triggering follow-up observations and providing important science in its own.

The LOFT satellite (from proposal)

Industrial study by Thales Alenia Space – Italia (design confirmed by ESA-CDF)

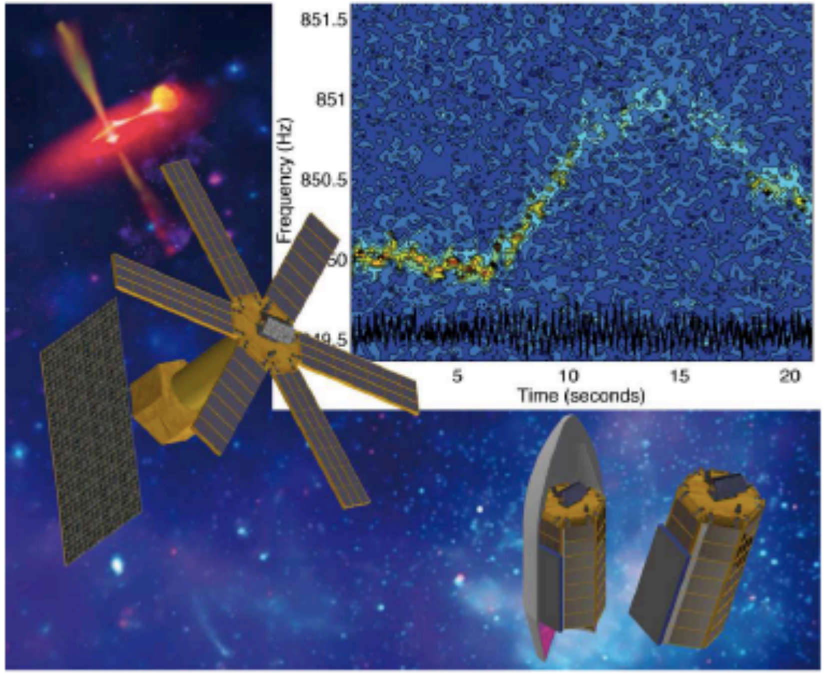


folded



LOFT

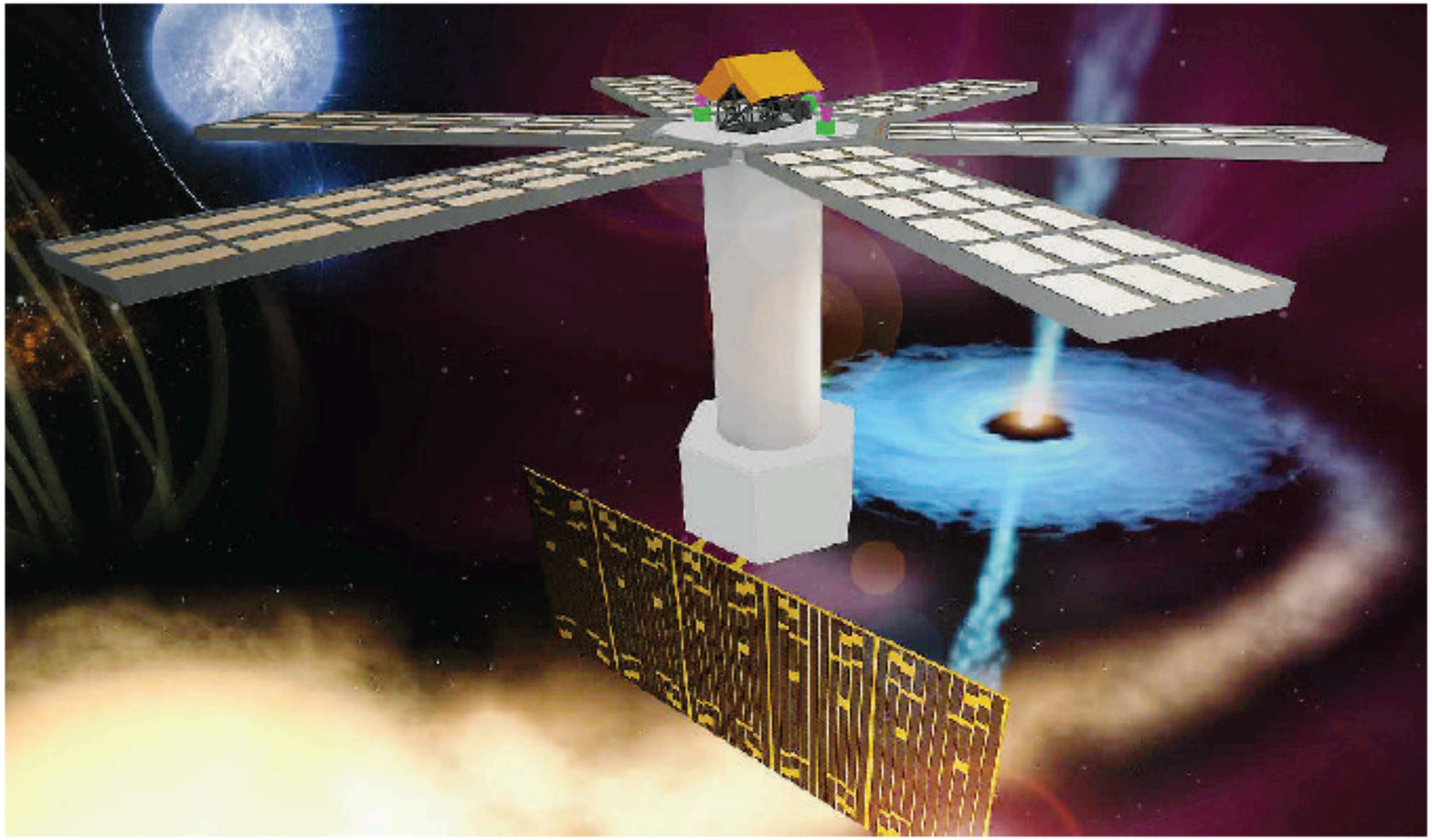
Large Observatory For x-ray Timing



Brazil, Canada, Czech Republic, Germany, Greece, Ireland, Israel, Italy, Japan, the Netherlands, Poland, Spain, Switzerland, Turkey, United Kingdom, USA;

INAF (IASF-Rome, IASF-Bologna, IASF-Milan, IASF-Palermo, HeadQuarters Rome, OA Rome, OA Padua, OA Palermo, OA Cagliari); INFN (Trieste, Bologna, Milan, Rome); ASDC Frascati; CBK Poland; CfA Cambridge; MPE Garching; IEEC-CSIC Barcelona; INPE S.J. dos Campos; ISAS/JAXA, Nakagawa; ISDC Geneve; ISSI Bern; MIT Cambridge; MSSL London; NASA/MSFC, Huntsville, NRL Washington; N. Copernicus Warsaw; Polytechnic Milan; Prague Astronomical Institute; University of: Alberta, Amsterdam, Arizona, Bologna, Cagliari, Calgary, Cornell, Crete, Durham, Ferrara, Galway, Geneve, Groningen, Jerusalem, John Hopkins, Maryland, Opava, Padua, Palermo, Pavia, Prague Technical, Sabanci, Stony Brook, Southampton, Thessaloniki, Tuebingen.

LA STAMPA
MERCOLEDÌ 23 MARZO 2011



Una promessa
«Loft» è un progetto guidato da ricercatori italiani dell'Istituto Nazionale di Astrofisica insieme con numerosi altri enti di ricerca italiani ed esteri: la sigla è l'acronimo di «Large Observatory For x-ray Timing»

Il super-occhio è italiano

Astrofisica. Il progetto per spiare i buchi neri: l'Esa l'ha scelto tra 47 arrivati da tutta Europa
Battezzato «Loft», il satellite verificherà le implicazioni della teoria della Relatività di Einstein

A LOFT in the sky could be not the weirdest idea that man conceived

Federer and Agassi playing at the Jumeirah Hotel in Dubai

LOFT (Large area Observatory For x-ray Timing) is an innovative mission concept for the next generation of X-ray timing experiments. Recent developments in the field of Silicon detectors allowed to design a realistic observatory devoted to X-ray timing studies with an effective area around 13 m2, in the energy range 2–30 keV

Key properties of the detectors, demonstrated in our laboratory includes an energy resolution better than 500 eV at room temperature with a time resolution better than 10 μs,

LOFT will allow unprecedented fast and accurate time variability studies related to accreting collapsed objects

A timing observatory in the 10 m2 class has important diagnostic potential for open problems in fundamental physics, such as strong gravity effects, the measurement of the mass of black holes and neutron stars, the equation of state of ultradense matter.

LOFT - a Large Observatory For x-ray Timing

M. Feroci*[a,b], L. Stella[c], A. Vacchi[d], C. Labanti[e], M. Rapisarda[f,a,b], P. Attinà[g], T. Belloni[h], R. Campana[a,b], S. Campana[h], E. Costa[a], E. Del Monte[a,b], I. Donnarumma[a], Y. Evangelista[a,b], G.L. Israel[c], F. Muleri[a], P. Porta[g], A. Rashevsky[d], G. Zampa[d], N. Zampa[d], G. Baldazzi[i], G. Bertuccio[j], V. Bonvicini[d], E. Bozzo[k], L. Burderi[l], A. Corongiu[m], S. Covino[h], S. Dall'Osso[c], D. De Martino[n], S. Di Cosimo[a], G. Di Persio[a], T. Di Salvo[o], F. Fuschino[e], M. Grassi[p], F. Lazzarotto[a], P. Malcovati[p], M. Marisaldi[e], M. Mastropietro[a], S. Mereghetti[q], E. Morelli[e], M. Orio[r], A. Pellizzoni[m], L. Pacciani[a,b], A. Papitto[l,m], L. Picolli[p], A. Possenti[m], A. Rubini[a,b], P. Soffitta[a], R. Turolla[s], L. Zampieri[t]

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ABSTRACT

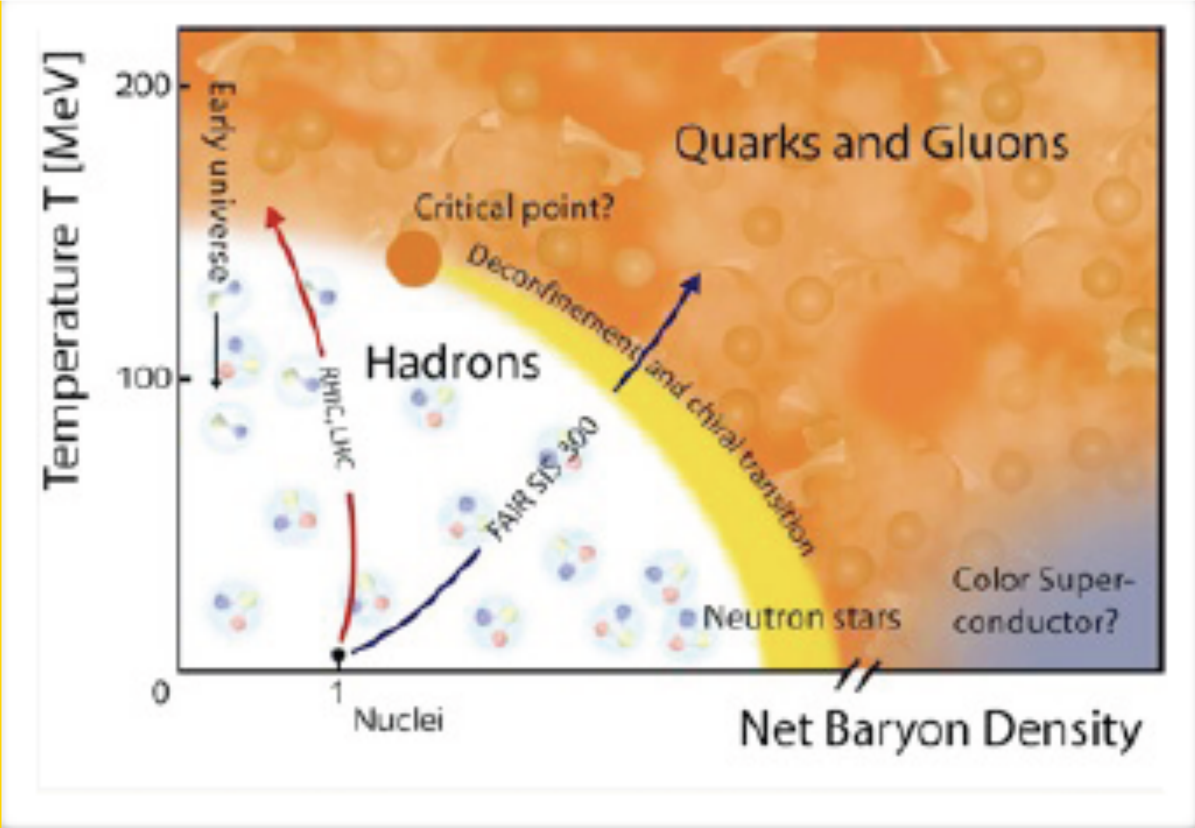
The X-ray sky in high time resolution holds the key to a number of observables related to fundamental physics, inaccessible to other types of investigations, such as imaging, spectroscopy and polarimetry. Strong gravity effects, the measurement of the mass of black holes and neutron stars, the equation of state of ultradense matter are among the

What are the fundamental physical laws of the Universe, physics of the matter in the innermost regions around compact objects (neutron stars and black holes) endowed with very strong gravitational fields

- -Matter under extreme conditions
- -Matter at supra-nuclear densities, making up the core of neutron stars
- -Matter under the strongest gravity fields generated by compact objects
- -Matter under the strongest magnetic fields (magnetars)
- Relevance to many fields of astrophysics: black hole evolution, stellar evolution, accretion processes, ...
- **Key technique**:

  Timing and spectroscopy of X-rays generated in the immediate vicinity of compact objects

Neutron stars



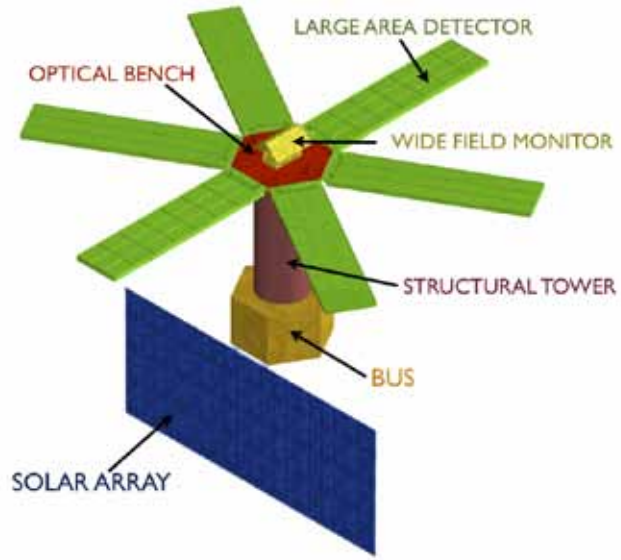
- Neutron stars probe the low temperature and large density region of the QCD phase diagram
  - This regime is expected to be marked by the appearance of exotic matter and phase transitions
  - **This regime can only be probed by astrophysical observations of**
  - **neutron stars**
  - key goal of modern physics well beyond astrophysics
  - Relevance also to the physics of supernovae, to short GRBs (NS mergers and GW emitter)

LOFT (Large Observatory For X-ray Timing)

http://www.isdc.unige.ch/loft/index.php/the-loft-mission

Why X-ray timing?

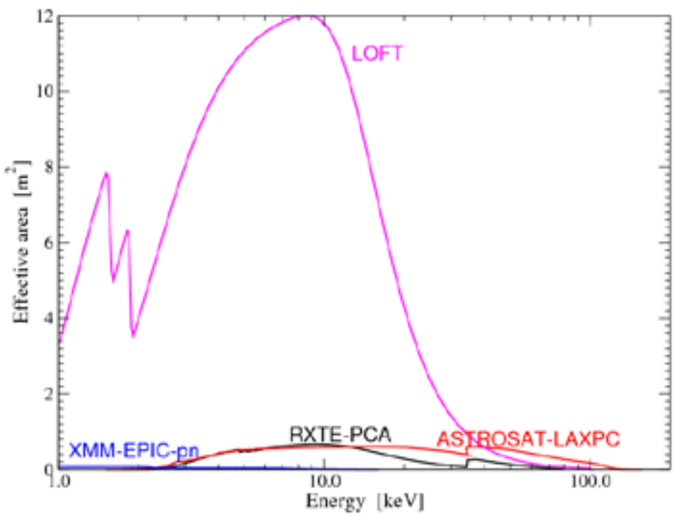
High-time-resolution X-ray observations of compact objects (as the Galactic and extra-Galactic neutron stars and black holes) provide a unique tool to investigate strong-field gravity, and give direct access to measurements of black hole masses and spins, and to the equation of state of ultra-dense matter.



Why LOFT?

A 10 m^2-class instrument in combination with good spectral resolution is required to exploit the relevant diagnostics and answer two fundamental questions of ESA's Cosmic Vision Theme *Matter under extreme conditions*, namely:

•**Does matter orbiting close to the event horizon follow the predictions of general relativity?**
•**What is the equation of state of matter in neutron stars?**



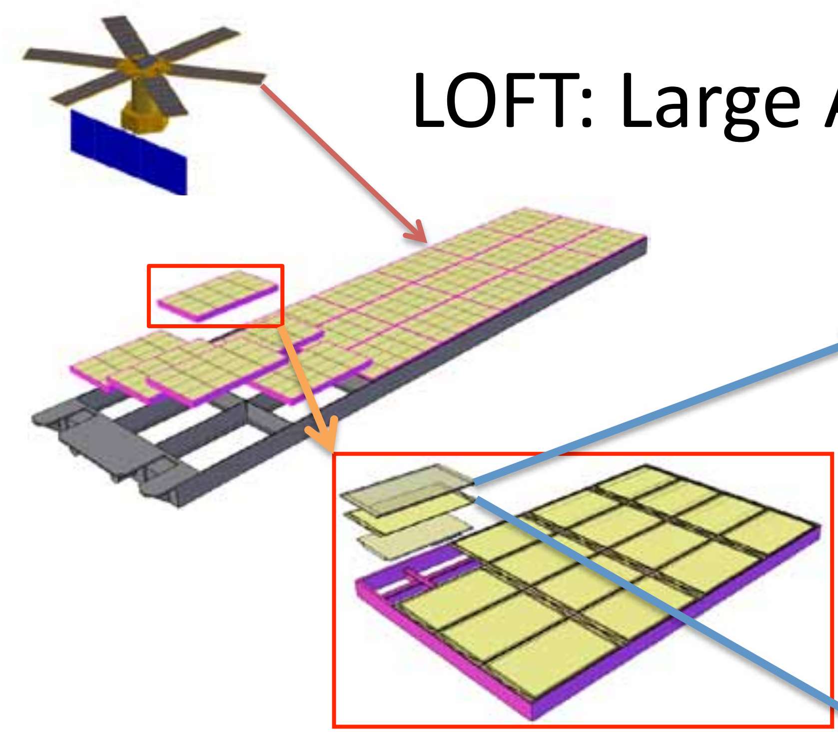
Thanks to an innovative design and the development of large monolithic silicon drift detectors, the Large Area Detector (LAD) on board of LOFT **achieves an effective area of ~12 m²** (more than an order of magnitude larger than current space-borne X-ray detectors) in the 2-30 keV range (up to 50 keV in expanded mode).

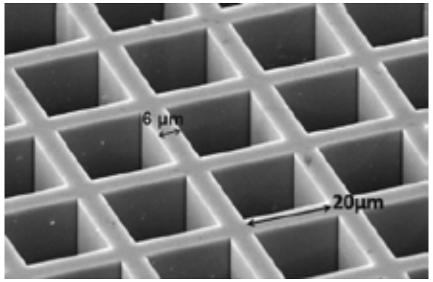
With this large area and a spectral resolution of <260 eV, **LOFT will revolutionize the study of collapsed objects in our galaxy and of the brightest super-massive black holes in active galactic nuclei**, yielding unprecedented information on strongly curved space-times and matter under extreme conditions of pressure and magnetic field strength.

The LOFT Baseline Overview

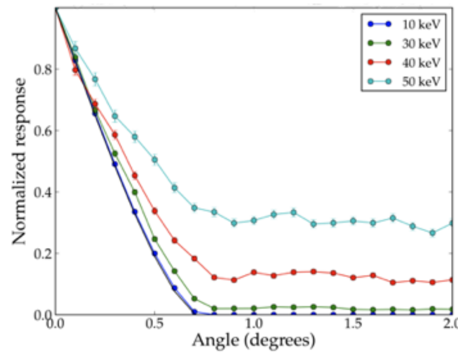
Detector	450 µm thick SDD
Energy Range	2-30 keV (2-50 keV extended range)
Field of View	<40 arcmin
Geometric Area	18 m^2
Effective area (@8 keV)	>10 m^2 (20x RXTE/PCA)
Energy Resolution	<260 eV (<200 eV for 40% of the area)
Time Resolution	5 µs
Crab Count Rate	3×10^5 cts/s
Deadtime	<0.5% for 1 Crab
Sensitivity	1 mCrab/1s
Supporting Experiment:	Wide Field Monitor (4 sr)
Satellite Mass	~2000 kg
Telemetry	~1 Mbps
Orbit	Low-Earth, equatorial

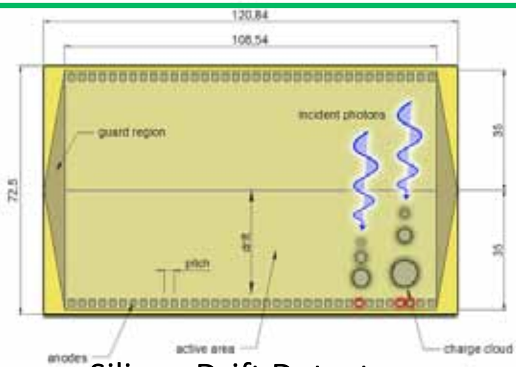
LOFT: Large Area Detector (LAD)



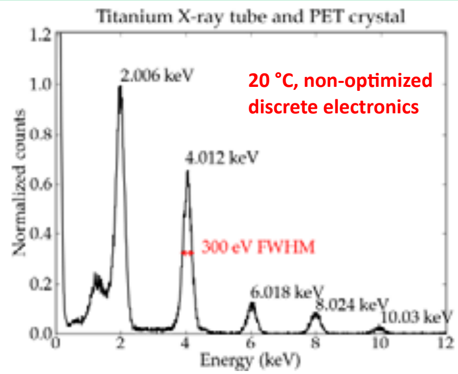


Micro-capillary plate





Silicon Drift Detector



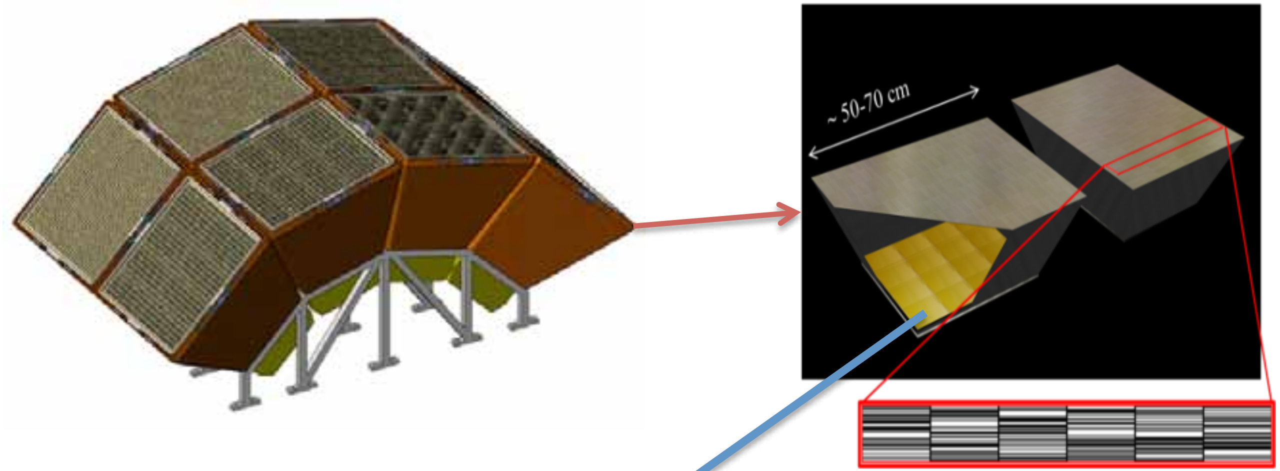
Caratteristiche dei rivelatori a deriva:

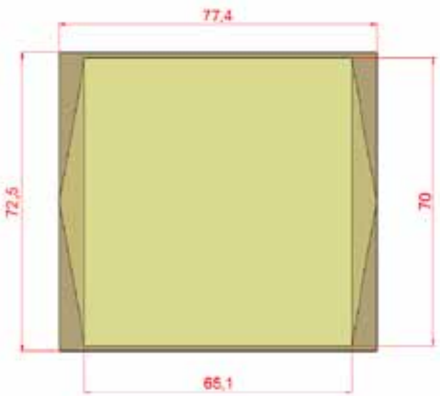
- Area sensibile di 76 cm^2, 46 % più grandi delle SDD di ALICE (FBK passarà ai 6” necessari per queste SDD entro metà 2013)
- Efficienza quantica ~ 17% più alta a 4.5 keV rispetto alle SDD di ALICE
- Passo anodico di 970 µm per limitare il numero di canali che integrano il segnale (max. 2)
- Consumo di potenza 1/10 rispetto alle SDD di ALICE
- Qualificate per lo spazio in orbita LEO, 600 km, 5° (SAA, Equatorial Soft Protons, Debris, Micro-meteorite)

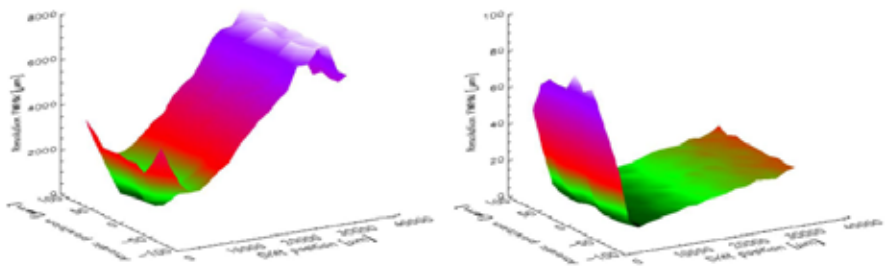
Frontend/Readout ASIC:

- Consumo di potenza di ~ 0.6 mW/canale
- Risoluzione energetica di 200 eV FWHM @ 5.9 keV sul singolo canale, massimo 260 eV per evento
- ADC 11 (12?) bit integrato

LOFT: Wide Field Monitor (WFM)





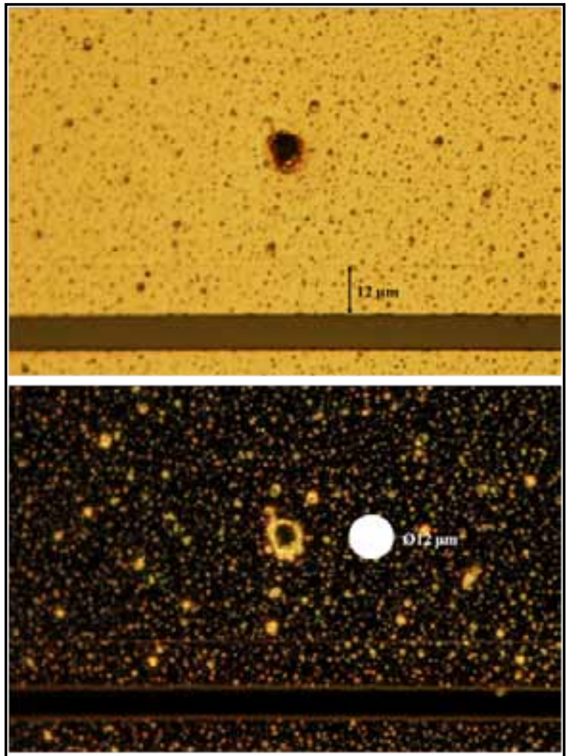


Drift (left) and **anodic** (right) spatial **resolution** (µm FWHM) for a **2 keV** photon and **145 µm pitch** at 253.15 K. The maps were obtained by segmenting the area read-out by a single anode in 200 sub-pixels (14.5 µm x 1.75 mm each one) and then generating 10^3 events in each pixel with a uniform spatial distribution.

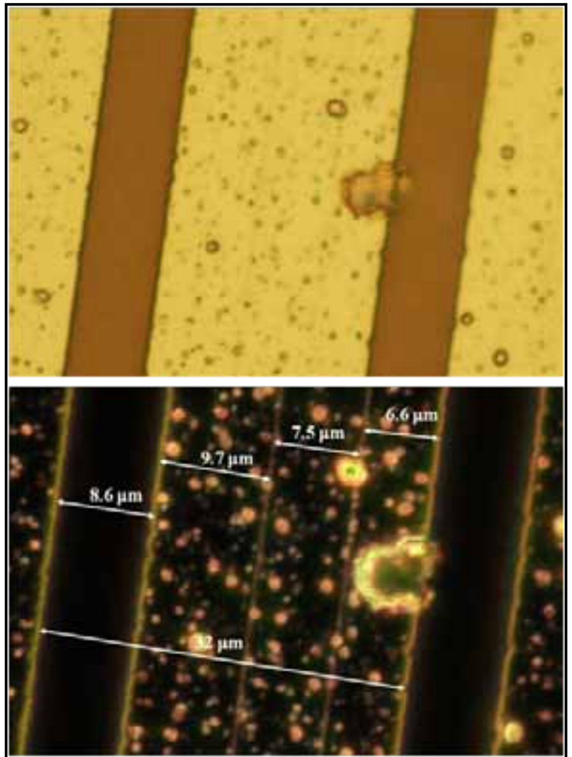
Caratteristiche dei rivelatori a deriva:

- Area sensibile di 45.6 cm^2
- Efficienza quantica ~ 17% più alta a 4.5 keV rispetto alle SDD di ALICE
- Passo anodico di 145 µm (294 µm in ALICE) per massimizzare la risoluzione spaziale lungo gli anodi
- Consumo di potenza 1/10 rispetto alle SDD di ALICE
- Qualificate per lo spazio in orbita LEO, 600 km, 5° (SAA, Equatorial Soft Protons, Debris, Micro-meteorite)

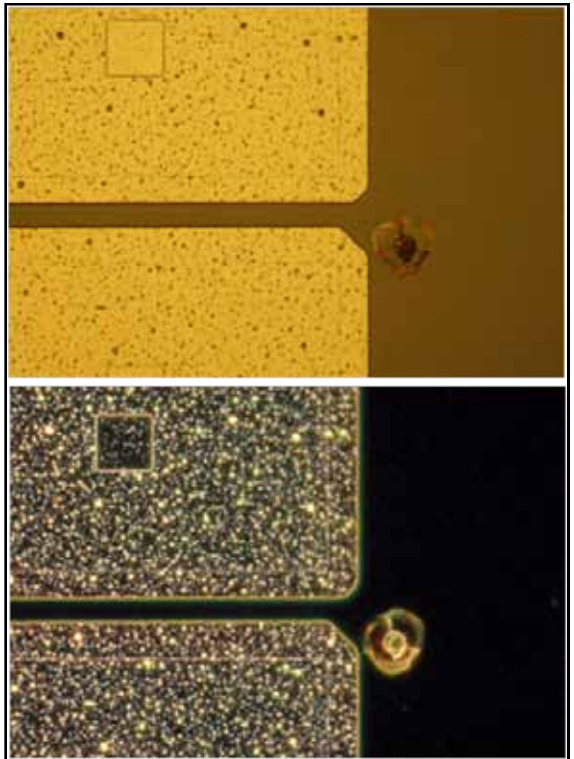
Space environment tests: debris



DRIFT REGION



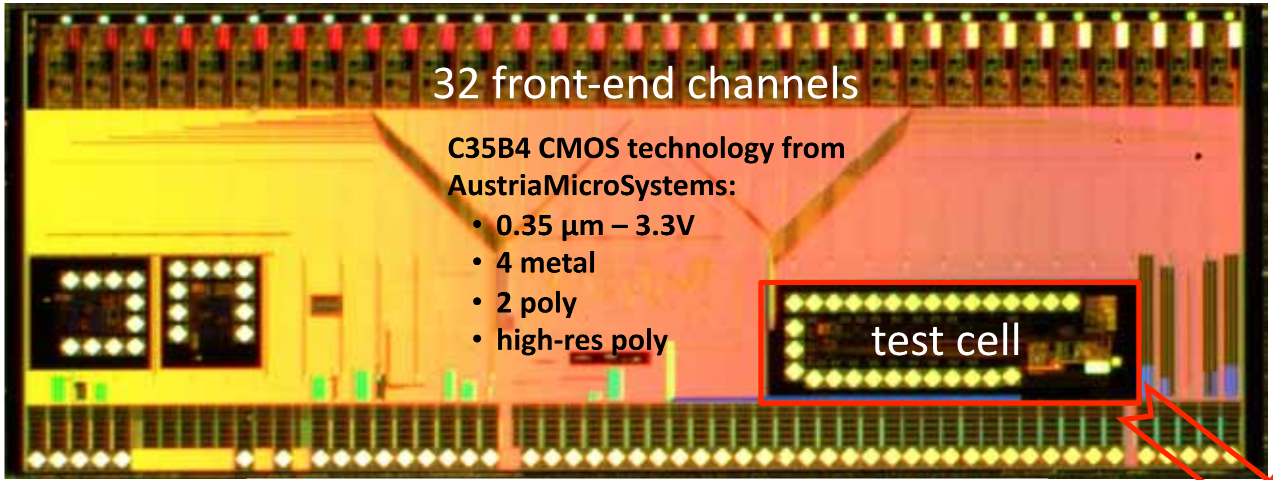
GUARD REGION

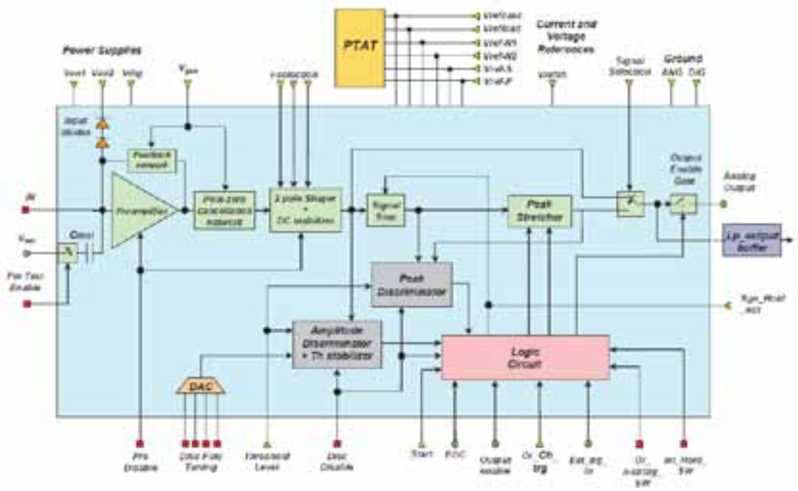


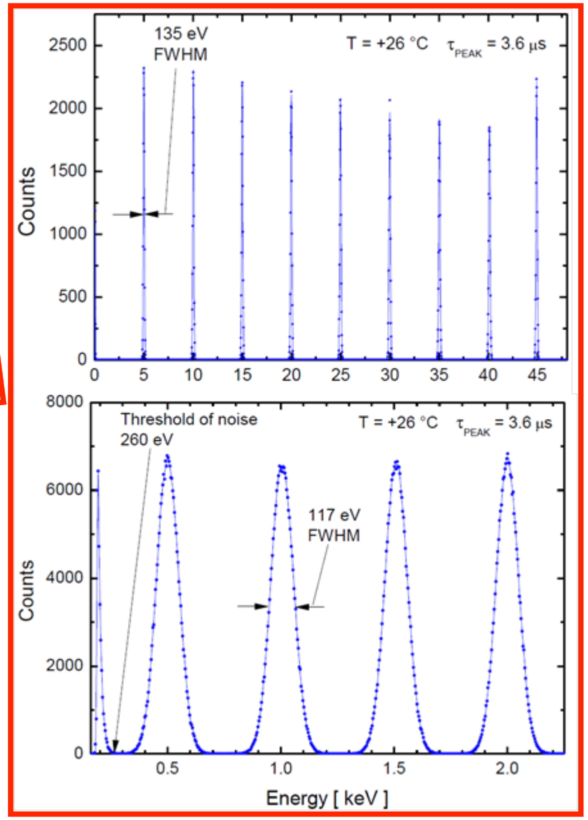
RESISTOR DIVIDER REGION

- Application of the SDDs to soft X-ray astrophysics experiments in space requires the devices to sustain severe environment conditions, e.g. it has to be able to survive orbital-debris and micrometeorite impacts without causing problems to the detector system (HV power supply is common to several detectors)
- A preliminary test at room temperature was carried out at the dust accelerator facility of the Max Planck Institute of Nuclear Physics in Heidelberg, Germany (July 18th, 2012)
- After shooting more than 100 aluminum particles (size between 0.1 and 4.2 µm, velocity in the range 1.1 ÷ 34 km/s, in inverse proportion to the size) an increase of 6 µA on the HV bias (17%) and of few nA in the total leakage current of the detector was observed, showing the sturdiness of the SDD
- Specific tests will be carried out to assess the impact of debris bombardment on the SDD performance

Front-end ASIC: preliminary results





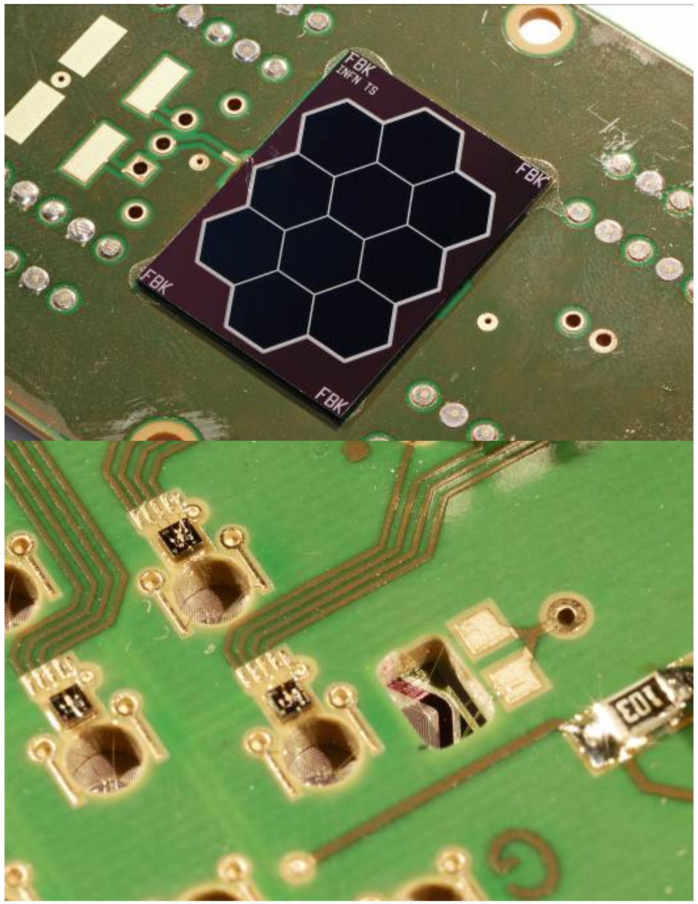


- Optimized for a 350 fF anode capacitance (LOFT-LAD pitch of ~1mm), and a maximum leakage current of 10 pA, with a power consumption of only 418 μW/ch
- The ASIC has a multiplexed analog output, the integration of the ADC is already being studied
- Measurements made with the single-channel test cell using the test input (no detector connected)
- Tests of the whole chip is under way

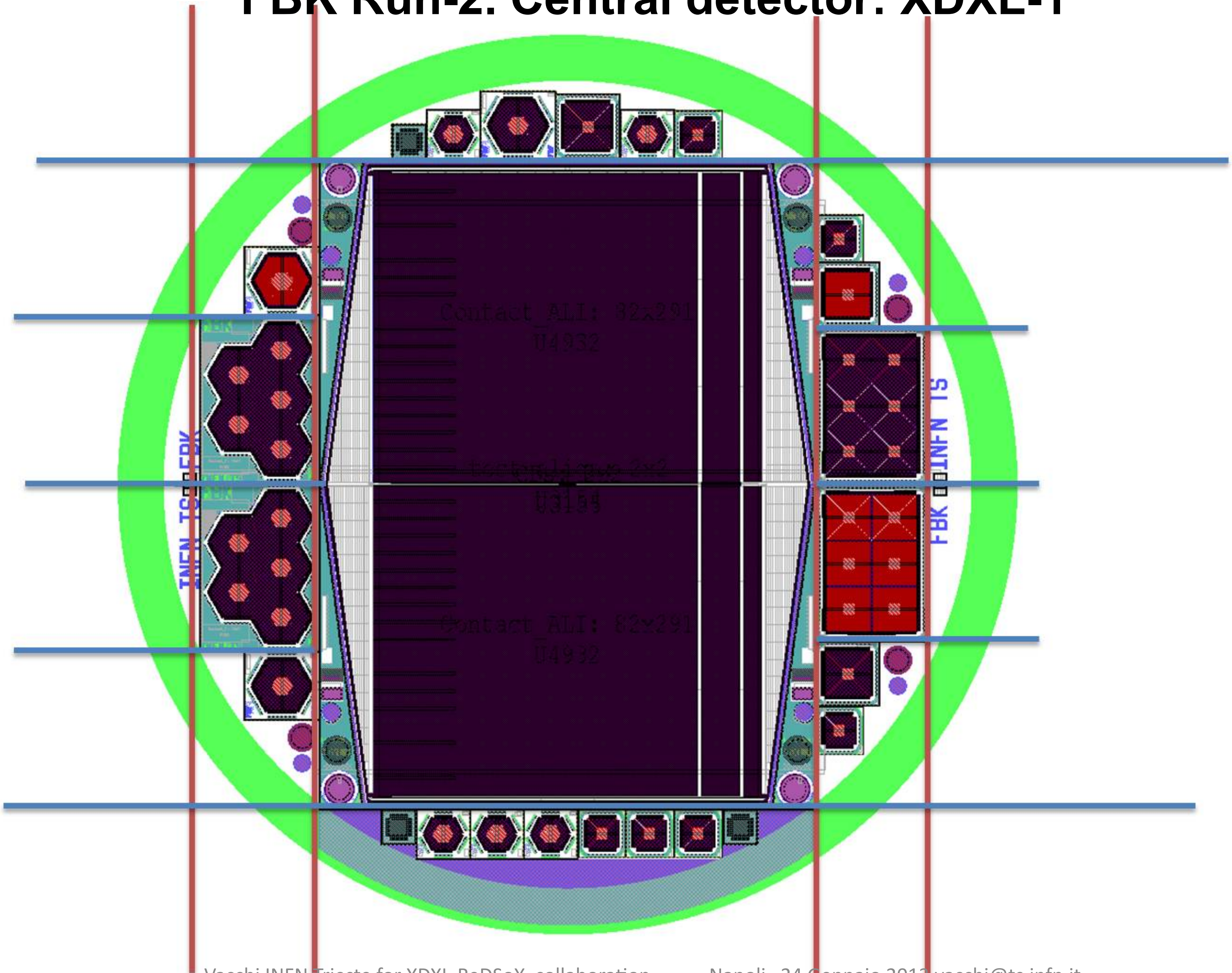
Hexagonal SDD array

Note da TS

- Discrete front-end electronics
- JFETs placed closer to the anodes than the ALICE-D4/ALI2 setup
- Plastic cover to protect the detector and the JFETs
- Very high leakage current: 23 pA at -10 °C but lower input capacitance
- The measurement show an excess noise at t_{sh} = 3 us (from the parallel and series noise extraction) probably coming from the 100 V power supply
- Bonding is very challenging

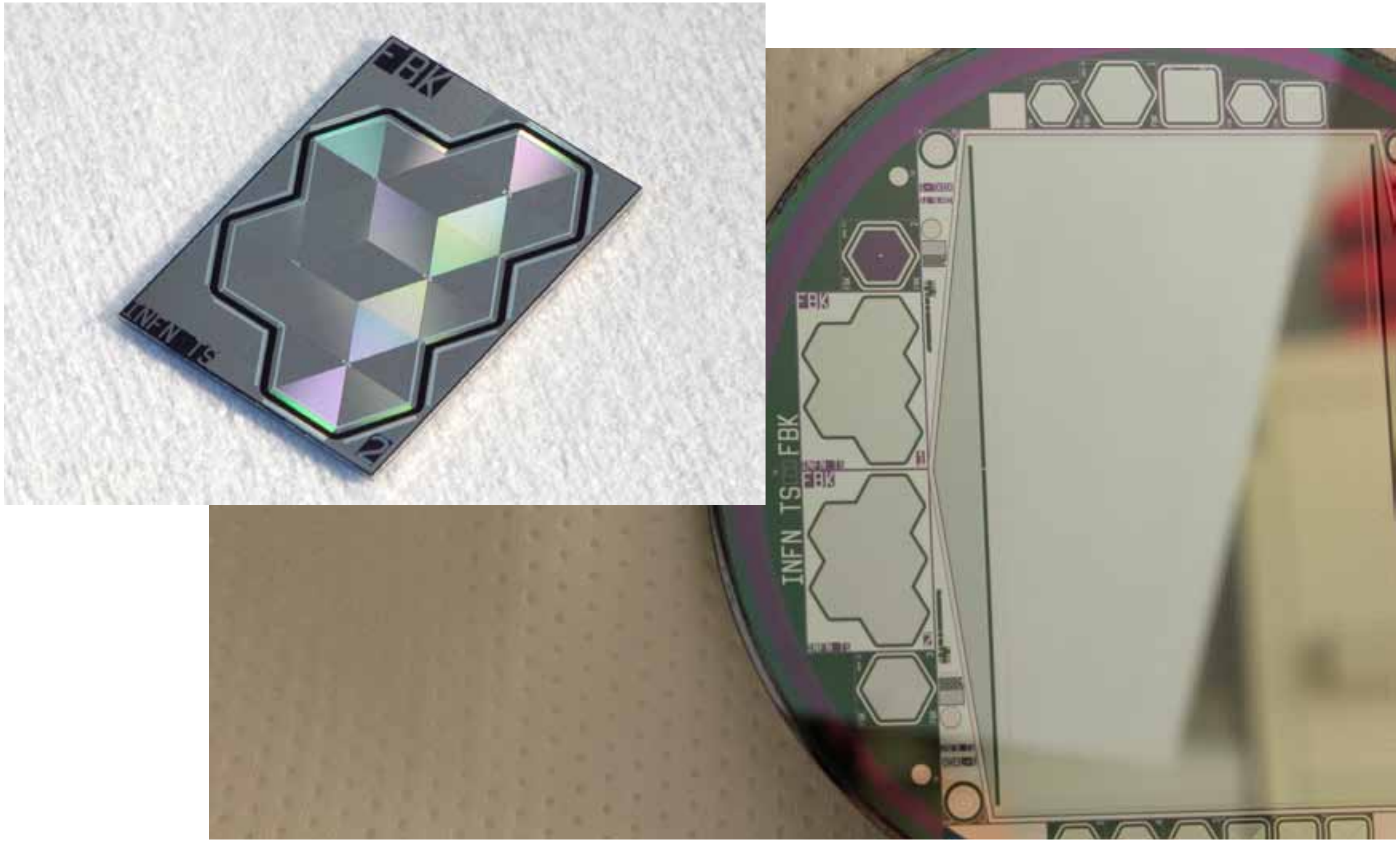


FBK Run-2. Central detector: XDXL-1

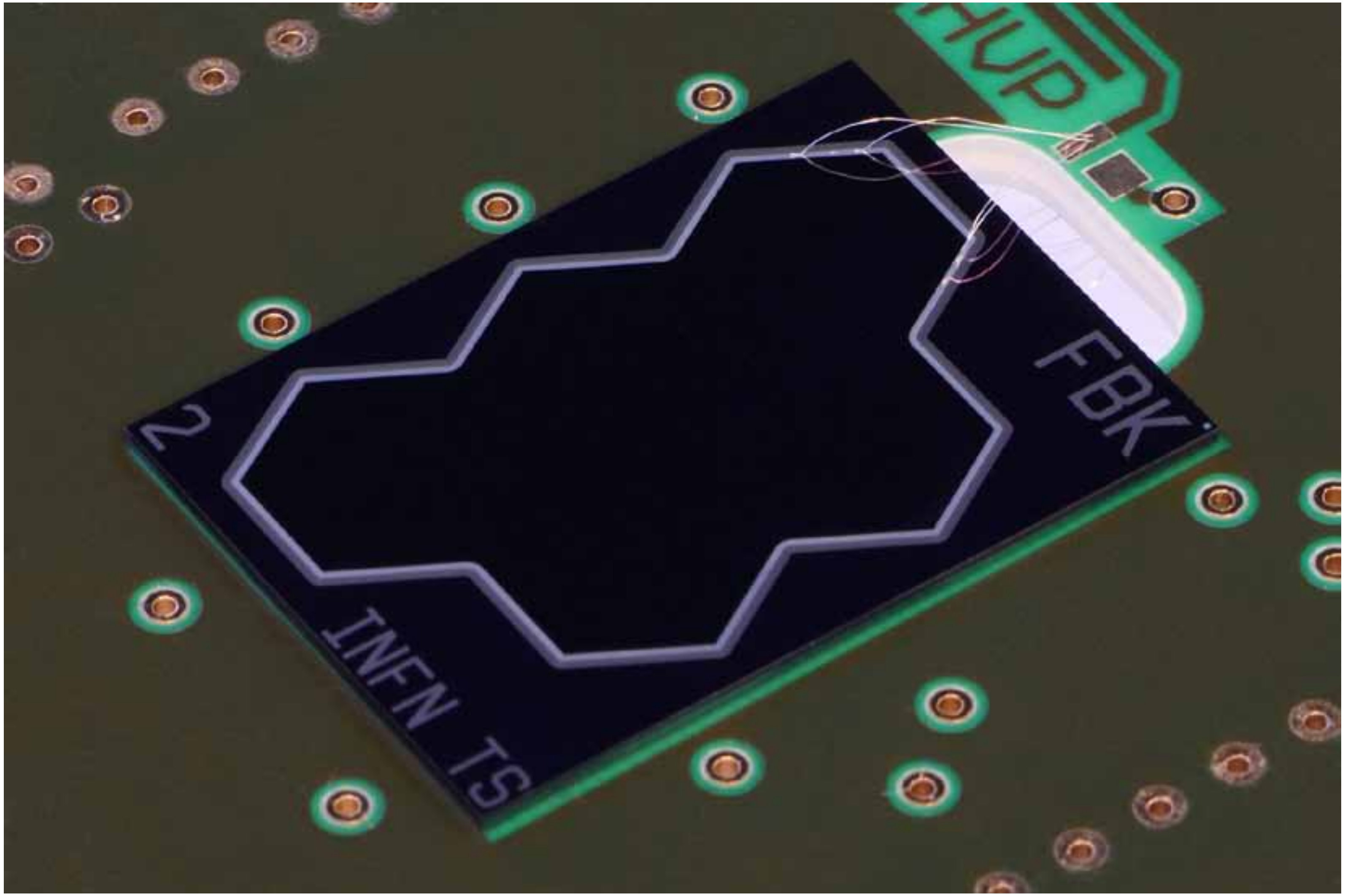


Detector back side (where n^+ readout anodes are placed)

The total sensitive area of the matrix is 135 mm^2, the wafer thickness is 450 µm

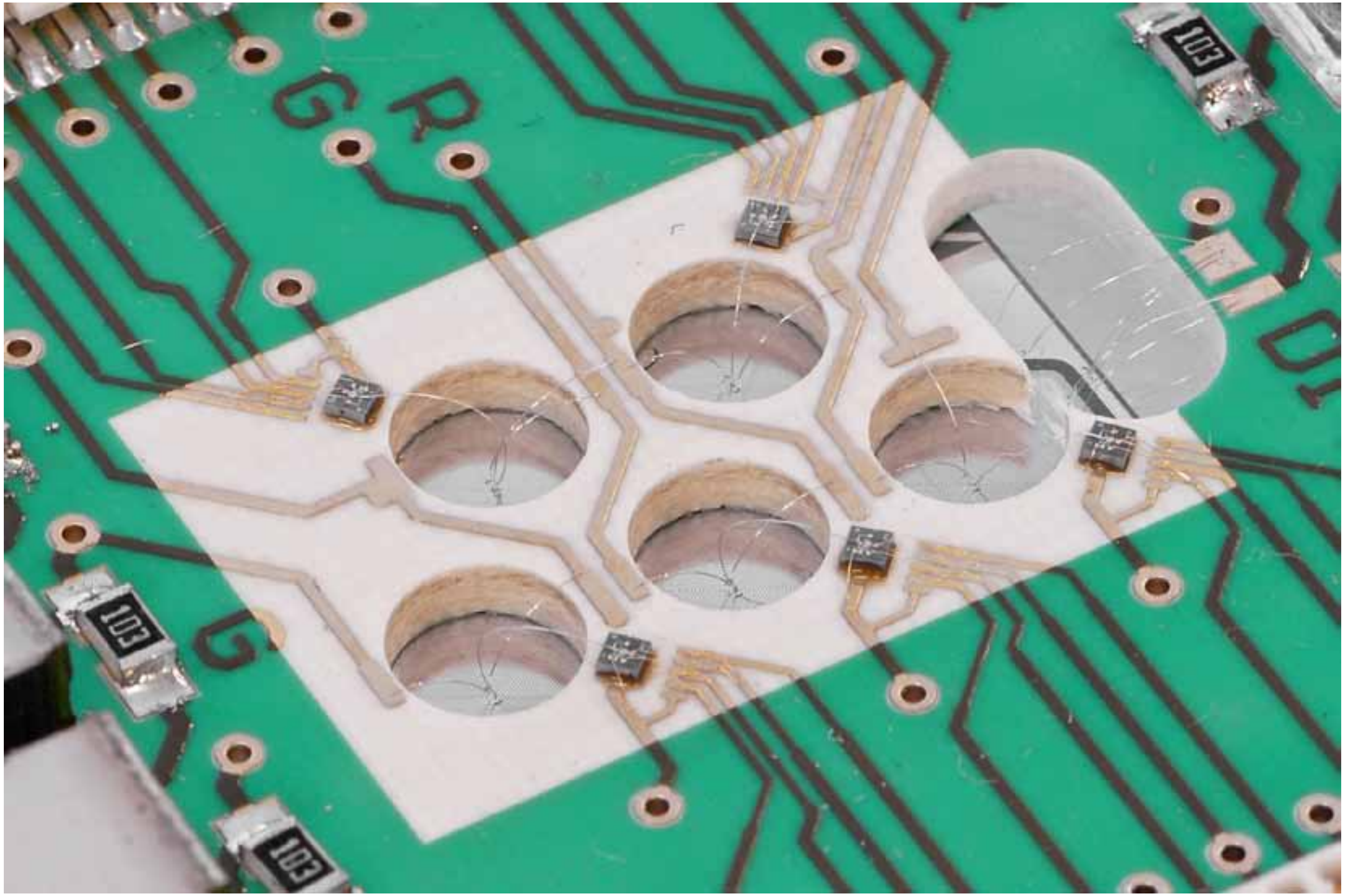


Detector front side (where X-rays enter the detector sensitive volume)



The total sensitive area of the matrix is 135 mm^2, the wafer thickness is 450 µm.

Mounted detector

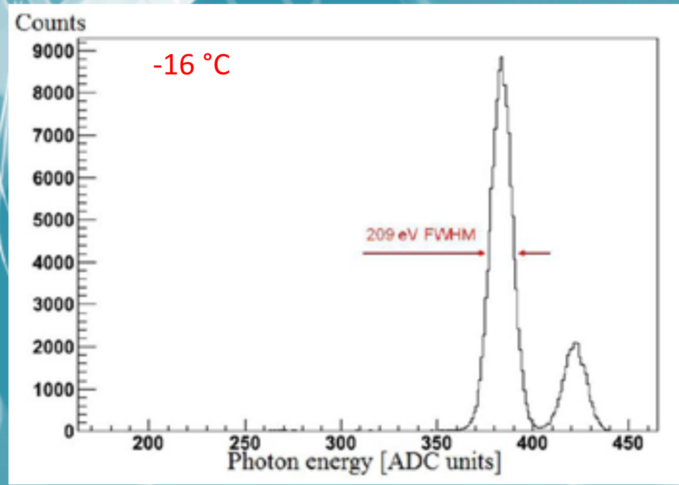


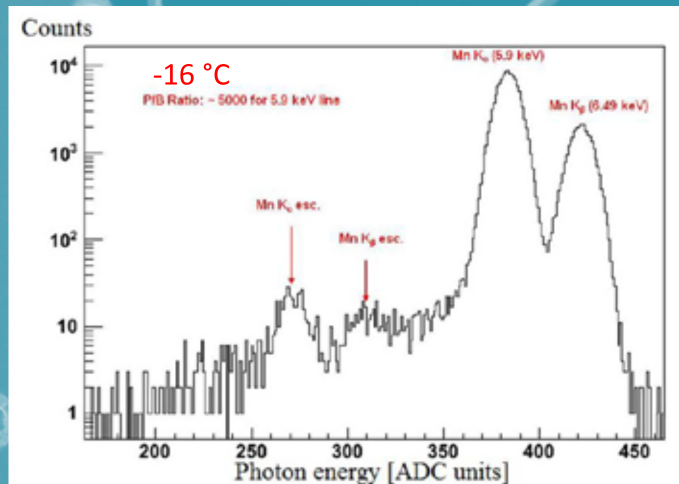
Spectroscopic SDD array (5 cells)

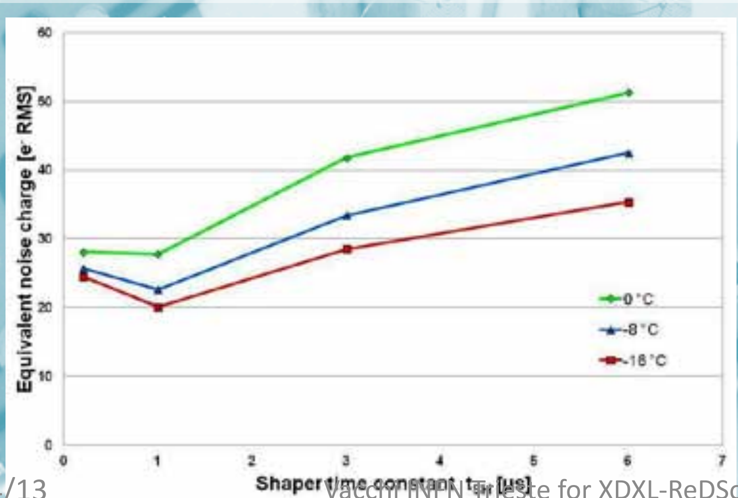
- Single-anode, spectroscopic SDDs deliver the maximum quantum efficiency due to their uniform, metal-free, entrance window: arrays of these are required to realize large sensitive areas
- ^{55}Fe measurements with prototypes produced at FBK using a discrete, non-optimized front-end electronics show good performance:

209 eV FWHM, P/B Ratio of ~5000 @ -16 °C
(Cell area = 27 mm^2, I_{DET} = 16 pA)

- Entrance window optimization is required to extend the sensitivity to X-ray energies as low as 200-300 eV
- ASIC front-end electronics is required to exploit the very low anode capacitance of the SDDs and satisfy the very stringent requirements of applications at Advanced Light Sources



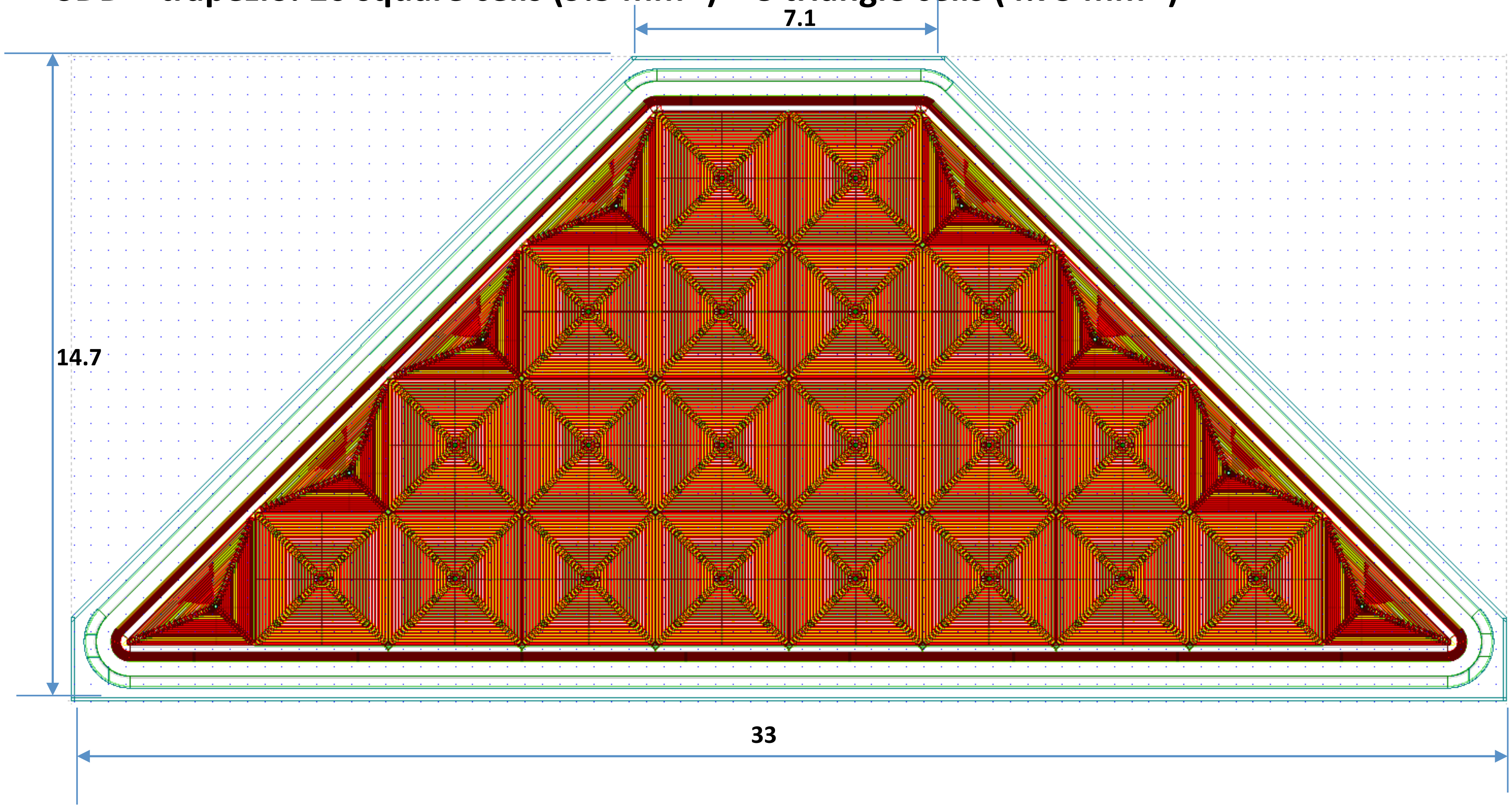




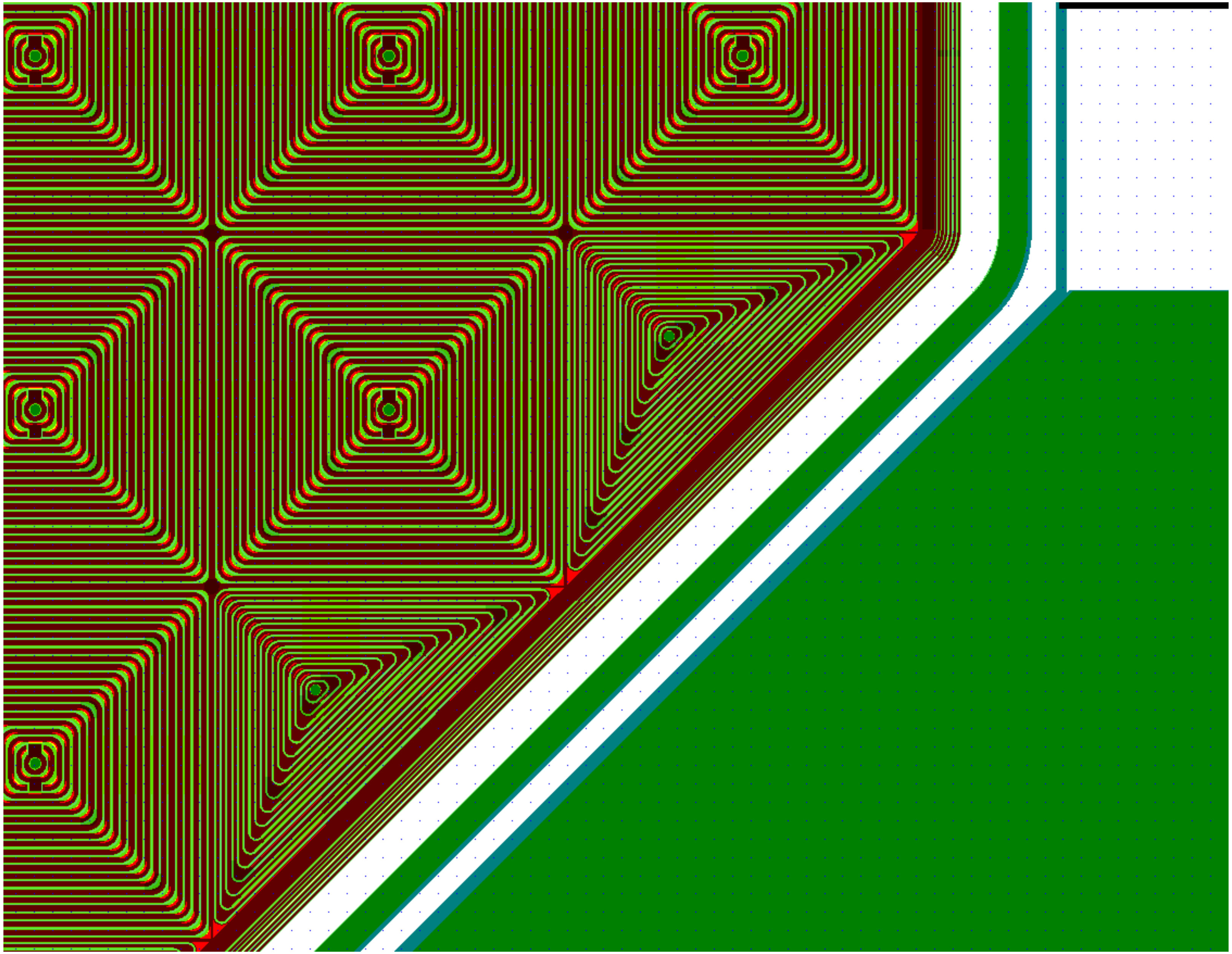
REDSOX

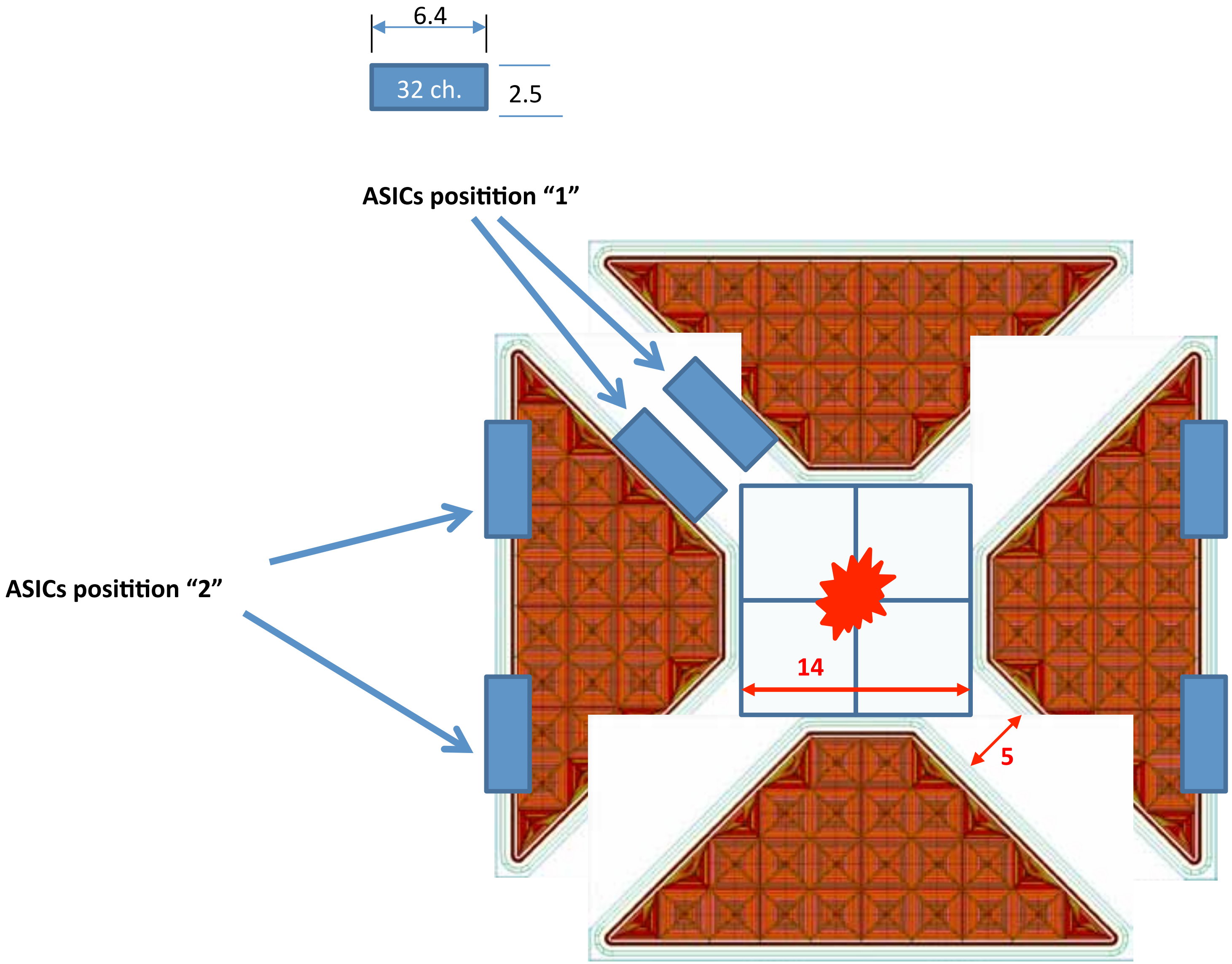
First approach: a structure optimized for fluorescence spectroscopy using syncrotron light radiation Pixels SDD

SDD – trapezio. 20 square cells (9.5 mm^2) + 8 triangle cells (4.75 mm^2)



Zoom on the detector back side




6.4
32 ch.
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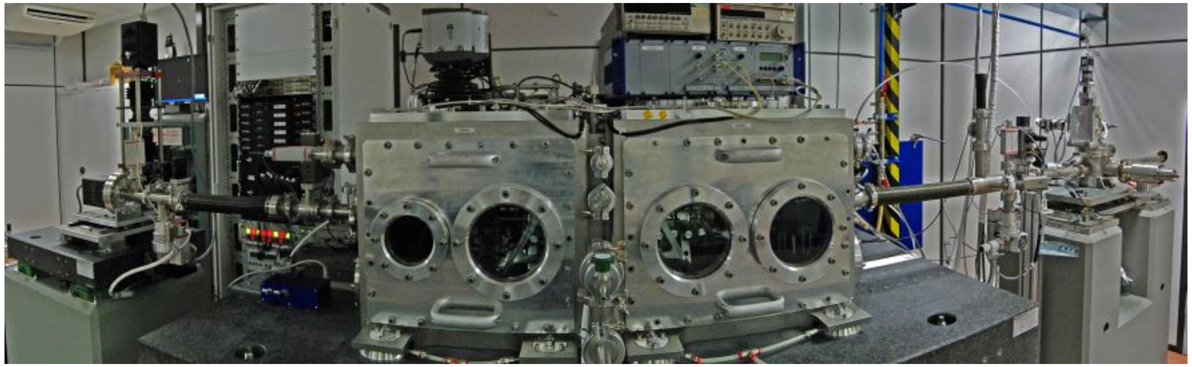
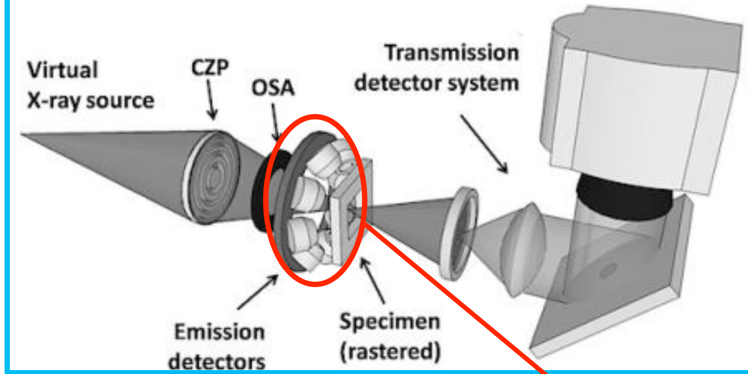
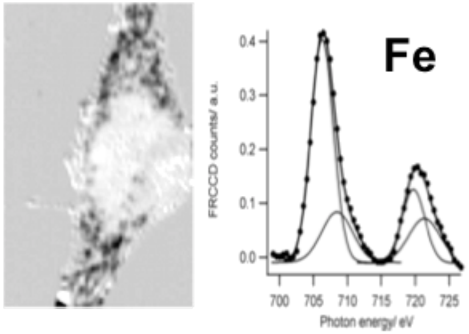
ASICs positition "2"
14
5

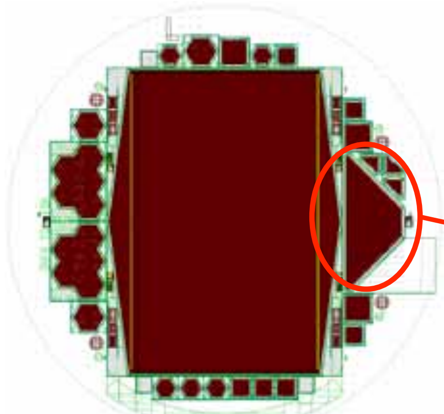
TwinMic @Elettra: Scanning Transm. X-ray Microscopy

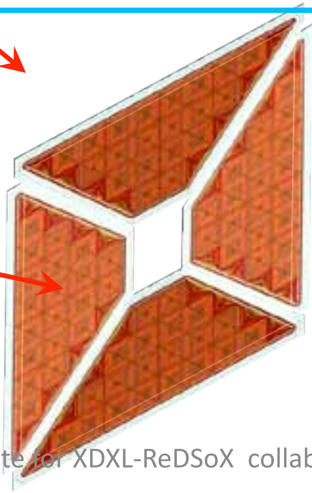


TwinMic is worldwide unique in combining transmission imaging, absorption spectroscopy and low-energy X-ray Fluorescence, which allows you analyzing simultaneously the morphology and elemental or chemical distribution of your specimen with sub-micron resolution. Scanning X-ray microscopy is non-static operation mode and lateral resolution is therefore limited by the specimen movement accuracy as well as the geometrical demagnification of the X-ray light source.







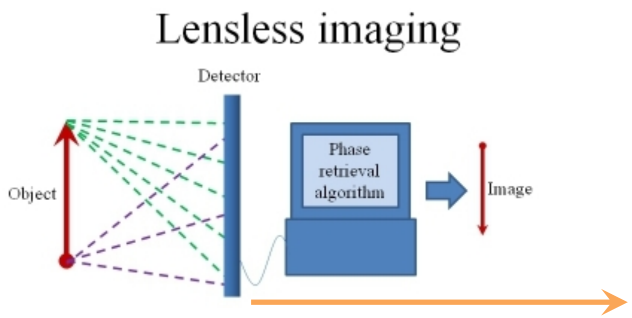


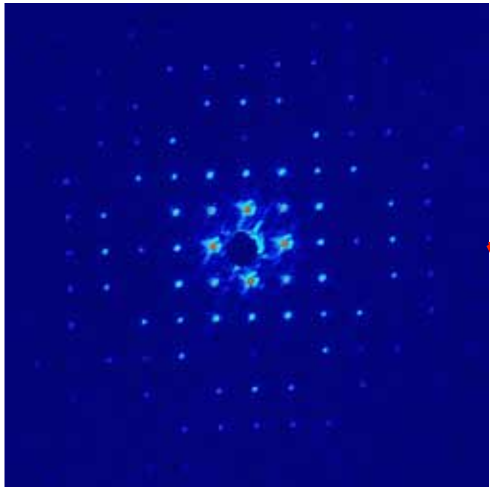
Sostituire gli attuali rivelatori (8 SDD PNSensor da 30 mm^2) con rivelatori più grandi (obiettivo: > 10x in area sensibile) per ridurre i tempi di acquisizione delle immagini.

Specifiche:

- Risoluzione energetica < 135 eV FWHM @ 5.9 keV
- Efficienza > 90% nell'intervallo 150 – 4000 eV
- Frequenza degli eventi fino a 1 Mcps sulla singola cella

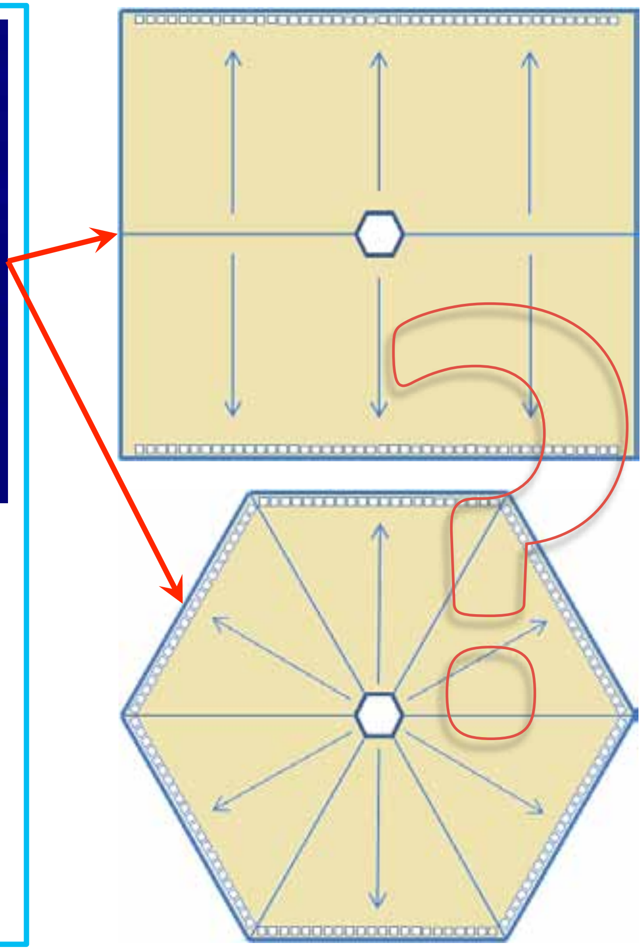
DiProl @ Fermi: diffraction and projection imaging





In Coherent Diffraction Imaging (CDI), when coherent **X-rays** impinge on the sample, the **magnitude** of the scattered radiation field is detected as a **diffraction pattern**; provided that the pattern is sufficiently "oversampled" to recover the radiation **phases**, it can be mathematically "inverted" to recover an image of the object's charge-density distribution.

In this **lensless** microscopy technique, a **phase retrieval algorithm** applied to the acquired diffraction pattern replaces the image-forming optics, used in classical X-ray microscopes, making CDI free of the resolution limitations imposed by optics aberrations and efficiency. Using FELs, CDI is approaching the theoretical spatial resolution, determined only by the FEL wavelength, in the **nanometer** range, the degree of beam coherence and the angle to which the speckle pattern is detected.



Imaging con le SDD lineari?

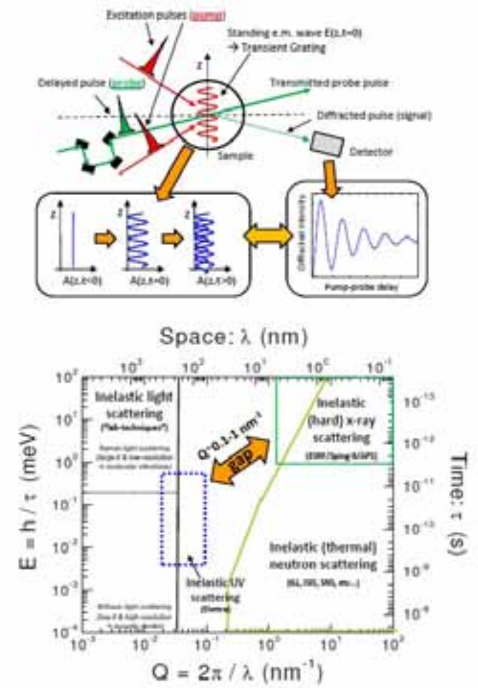
PROs

- In pochi µs l'immagine è fuori dal rivelatore che è pronto per acquisirne una nuova → necessita di buffer esterni (ASIC) ed elettronica di frontend simile ad ALICE
- Cooling moderato (probabilmente solo per termostatare il rivelatore) per via della formatura veloce del segnale

CONs

- HV ≈ 2 kV → potenza sul rivelatore
- Formatura veloce (decine di ns) →risoluzione dipende da elettronica di frontend (rumore serie) → potenza FE
- Efficienza modesta sotto il keV, quanto si può migliorare?
- Diffusione degli elettroni durante la deriva

Eis-Timer @ Fermi: Four-wave Mixing



EIS-TIMER end-station is a **FEL-based Four-Wave-Mixing instrument** that will exploit the time structure, harmonic content and coherence properties of the FERMI@Elettra source. In this case two non-collinear coherent FEL pulses (pump) are overlapped, in time and space, at the sample. Their interference originates a transient standing electromagnetic wave, called the transient grating (TG), with a spatial periodicity in the 1-100 nm range. The TG imposes a nanoscale modulation of sample parameters, whose time evolution can be monitored by measuring the diffraction of a third time-delayed coherent pulse (probe), which inpinges into the sample at the Bragg angle. The time-dependent diffracted signal encodes relevant information on several kinds of dynamics, ranging from slow (>ns scale) diffusion processes to fast (sub-fs scale) electron dynamics. The implementation of this experimental scheme, nowadays used only with optical lasers, to the VUV range would be extremely useful for the physics of disordered systems, since it will make accessible the mesoscopic kinematic region (**wavevectors in the 0.1-1 nm^{-1} range**) that cannot be explored by available instruments. Nanoscale TG experiments could also allow sensitive probing of thin films/interfaces, transport properties and correlations in nanostructured materials.

Le caratteristiche dell'impulso di luce FEL sono:

- Lunghezza d'onda (energia): 20 – 3 nm (60 – 400 eV)
- Durata dell'impulso: 100 – 20 fs
- Dimensione del fascio stimata sul rivelatore: 1 – 0.1 mm
- Numero di fotoni per impulso: 1 – 10000

~17 e$^-$

Range dinamico > 70000:1

- Al rivelatore è richiesta la capacità di misurare con una risoluzione migliore del 2% il numero di fotoni che lo raggiungono: single-photon counting quando il numero di fotoni è inferiore a 50
- In prima approssimazione il segnale FEL non trasporta informazioni spaziali, quindi una singola cella è sufficiente; l'opzione di un array lineare oppure di un rivelatore con risoluzione 1D è prospettata per gli sviluppi futuri

SDD

concludendo

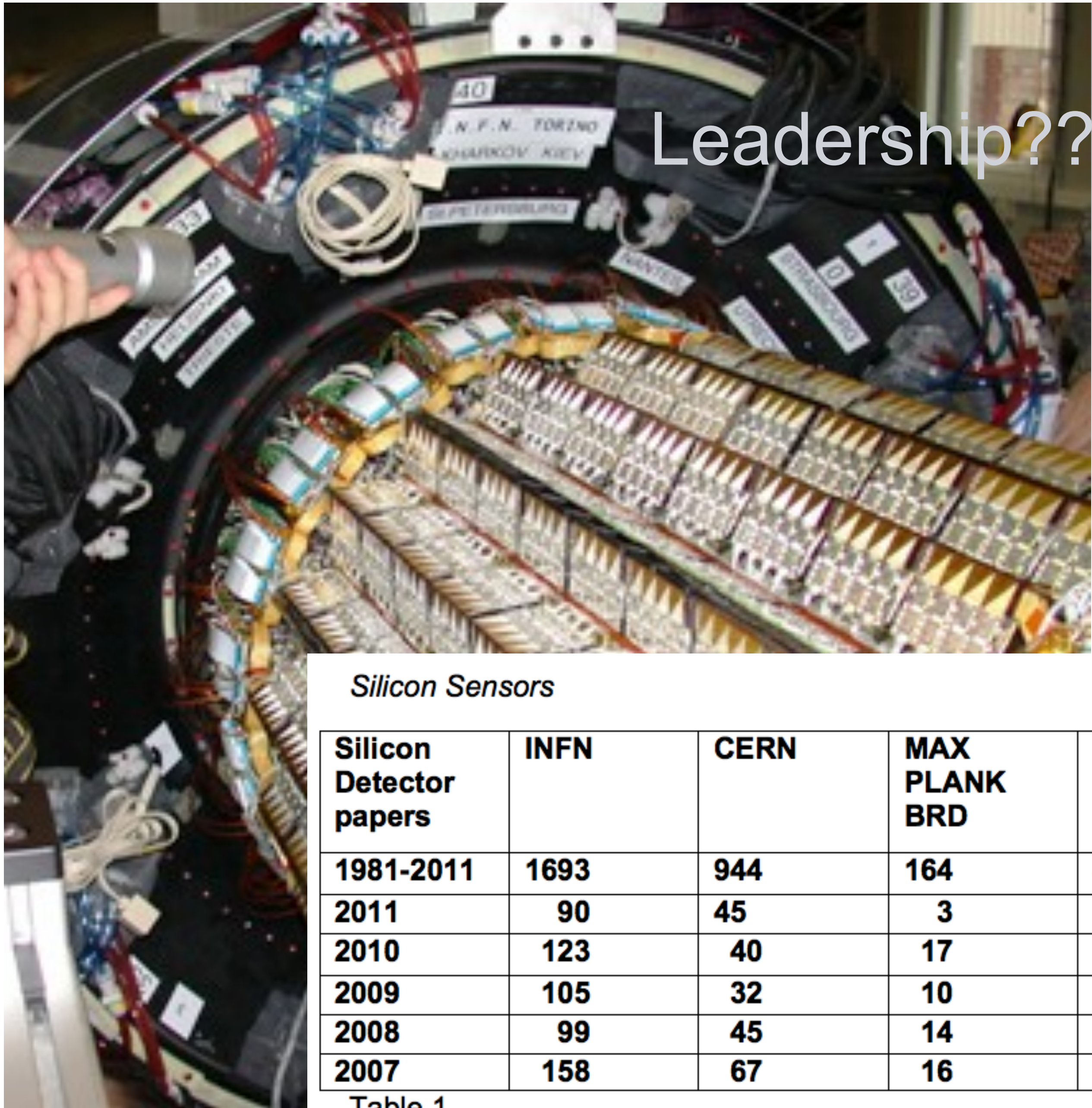
$S_{ilicon}D_{rift}D_{etectors}$

INFN Development

FBK Technology

- Large area
- Unmatched (by other Large Area detectors) X ray energy resolution
- High efficiency (thickness of silicon slab up to 1 mm)
- High quantum efficiency at low energy (thin entrance window)
- Custom design
- Ability to design ad hoc ASICS

Leadership??



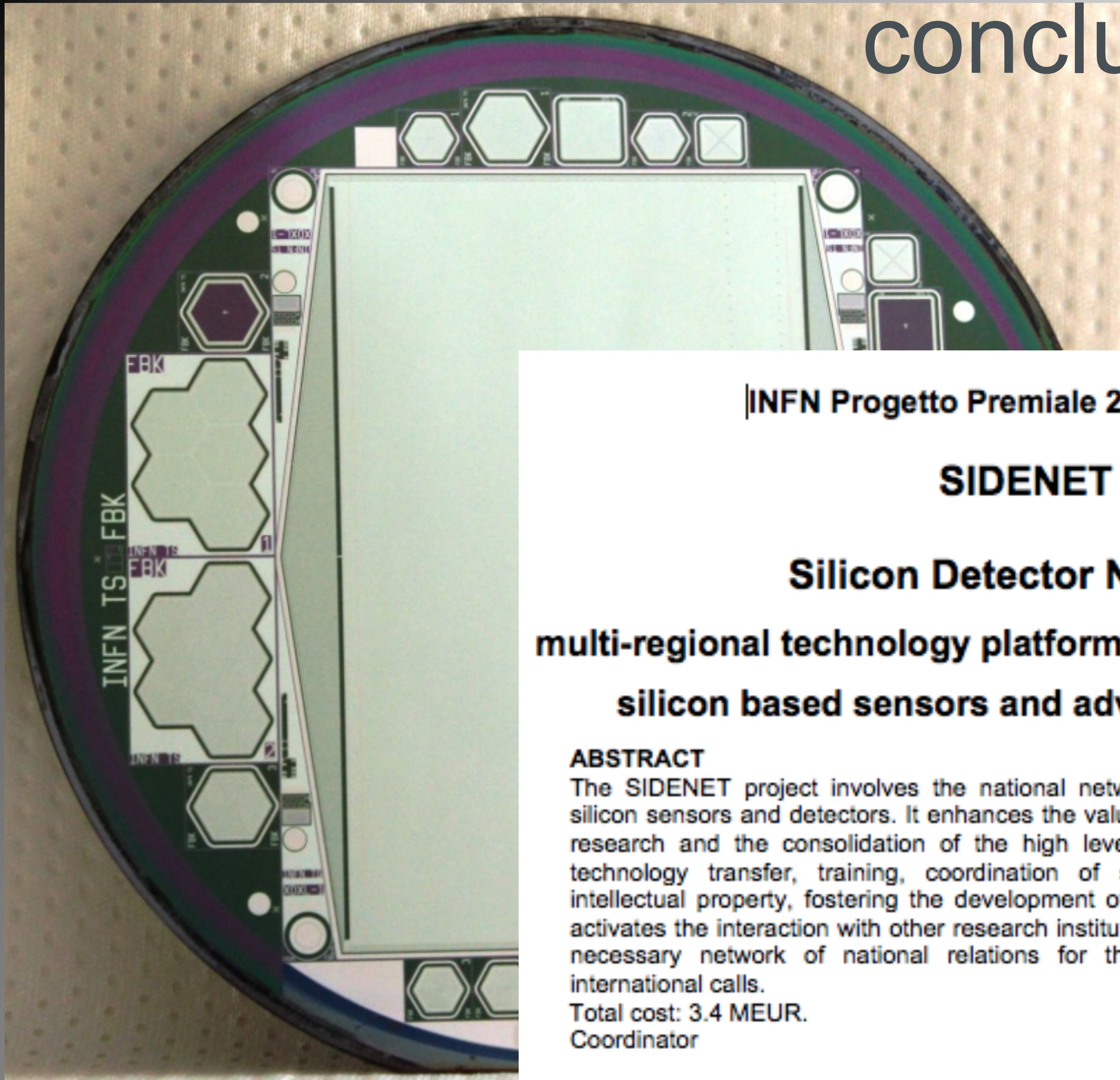
Silicon Sensors

Silicon Detector papers	INFN	CERN	MAX PLANK BRD	CNRS F	IN2P3 F	RIKEN J
1981-2011	1693	944	164	425	218	122
2011	90	45	3	45	20	9
2010	123	40	17	57	16	12
2009	105	32	10	39	20	8
2008	99	45	14	42	11	4
2007	158	67	16	20	13	10

Table 1

The data (Jan.2012) in table 1 also indicates the efficacy of the INFN in optimising the resources.while developing detectors which are then applied in different research fields. .

concluding



INFN Progetto Premiale 2013 DRAFT

SIDENET

Silicon Detector Network

multi-regional technology platform for the development of silicon based sensors and advanced electronics

ABSTRACT
The SIDENET project involves the national network of INFN structures which develop silicon sensors and detectors. It enhances the value of their activity through the support to research and the consolidation of the high level developed technologies. It promotes technology transfer, training, coordination of scientific infrastructures, protection of intellectual property, fostering the development of new companies. Moreover the project activates the interaction with other research institutions and private entities, developing the necessary network of national relations for the perspective of the participation to international calls.
Total cost: 3.4 MEUR.
Coordinator