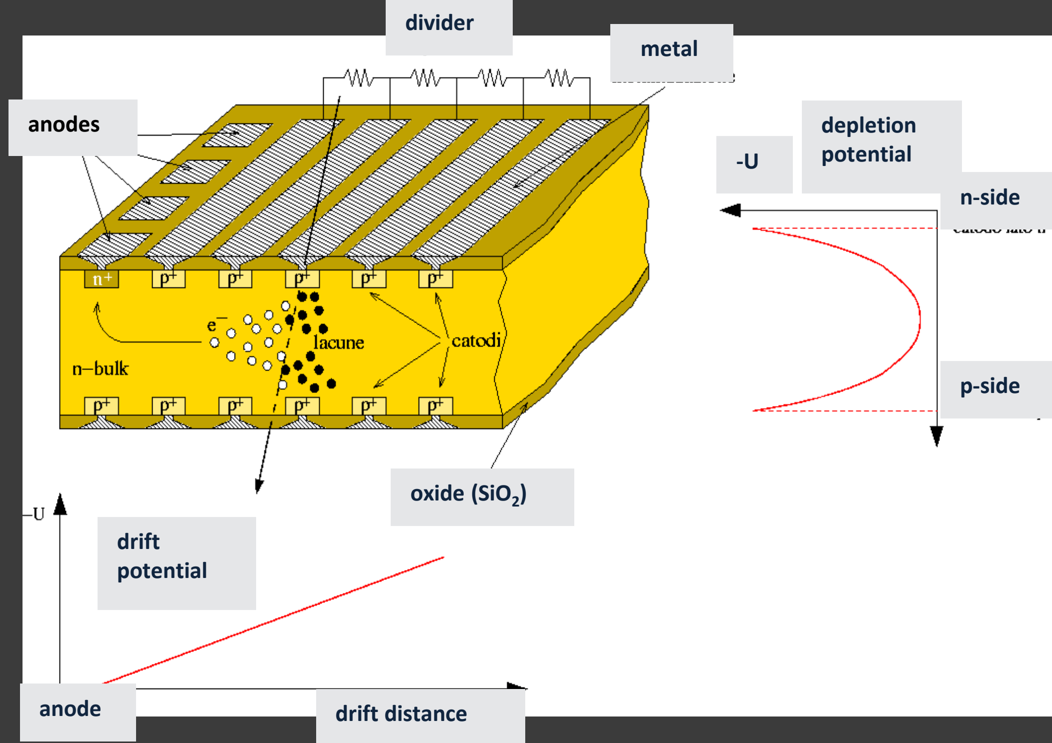
Development of Advanced Silicon Drift Detectors and Electronics for Synchrotron Radiation and X-ray Astronomy and Astrophysics

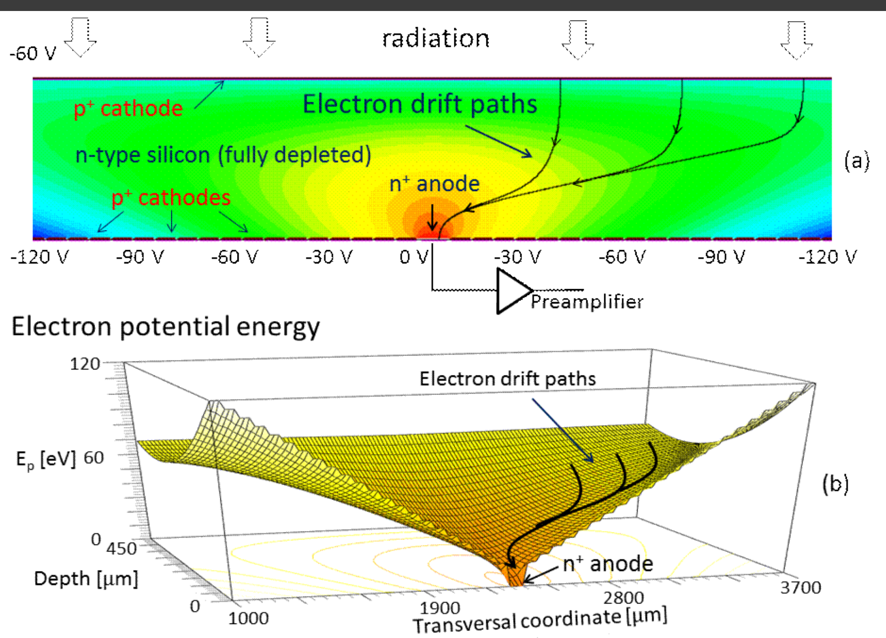
Andrea Vacchi INFN Trieste
for the REDSOX collaboration

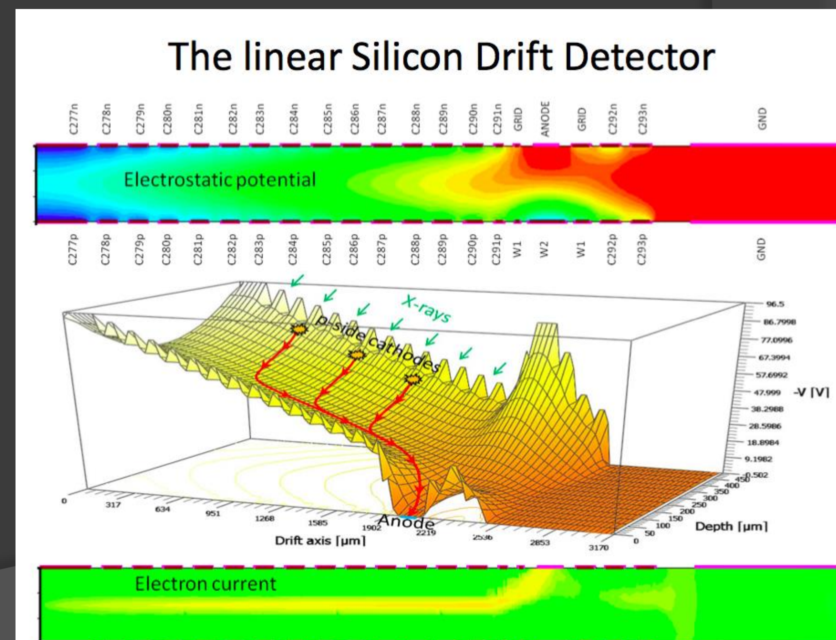
2nd ATTRACT TWD Symposium in Detection and Imaging (Strasbourg)

SDD

working principle







The First Large-area Silicon Drift Detector (1991)

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

187

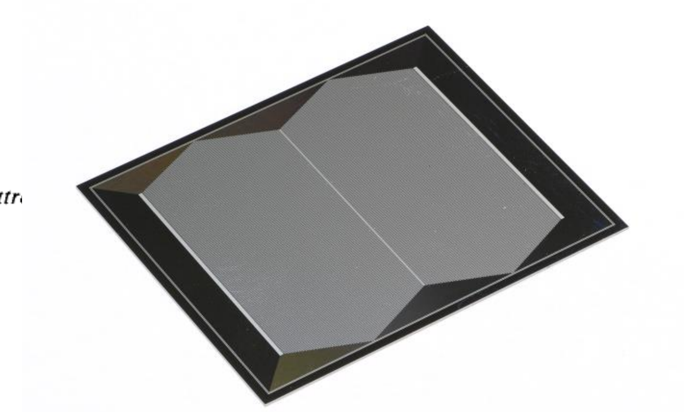
Performance of the UA6 large-area silicon drift chamber prototype

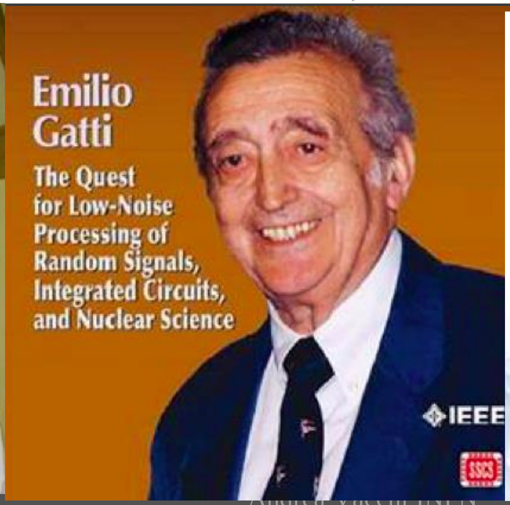
A. Vacchi
The Rockefeller University, New York, NY, USA

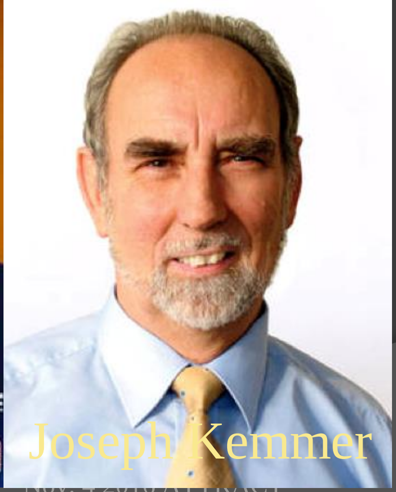
A. Castoldi, S. Chinnici, E. Gatti, A. Longoni, F. Palma and M. Sampietro
Politecnico di Milano, Dipartimento di Elettronica and Centro di Elettronica Quantistica e Strumentazione Elettr

P. Rehak
Brookhaven National Laboratory, Upton, NY, USA

J. Kemmer
Facultät für Physik der Technischen Universität, Munich, Germany







SDD for LHC-ALICE experiment

Wafer type:

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

Area:

- Sensitive: 7.02 × 7.53 ≈ 53 cm^2, <u>divided in 2 drift regions</u>
- total: 7.25 × 8.76 cm^2, (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:

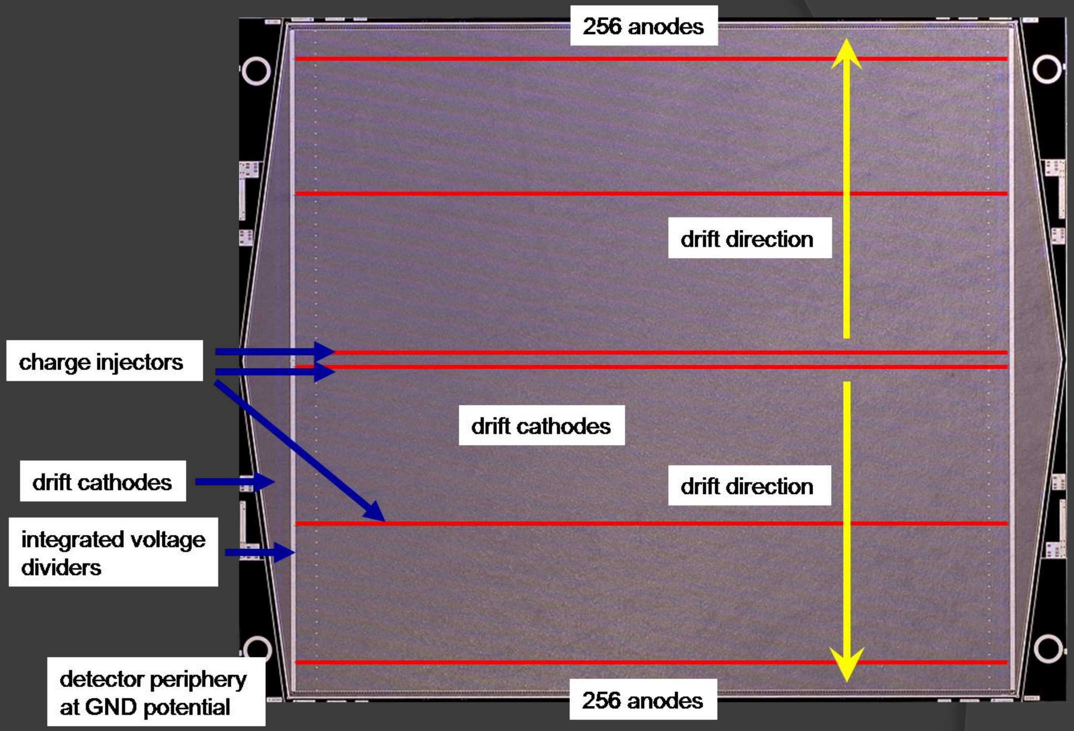
- independent voltage dividers

Integrated dividers:

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

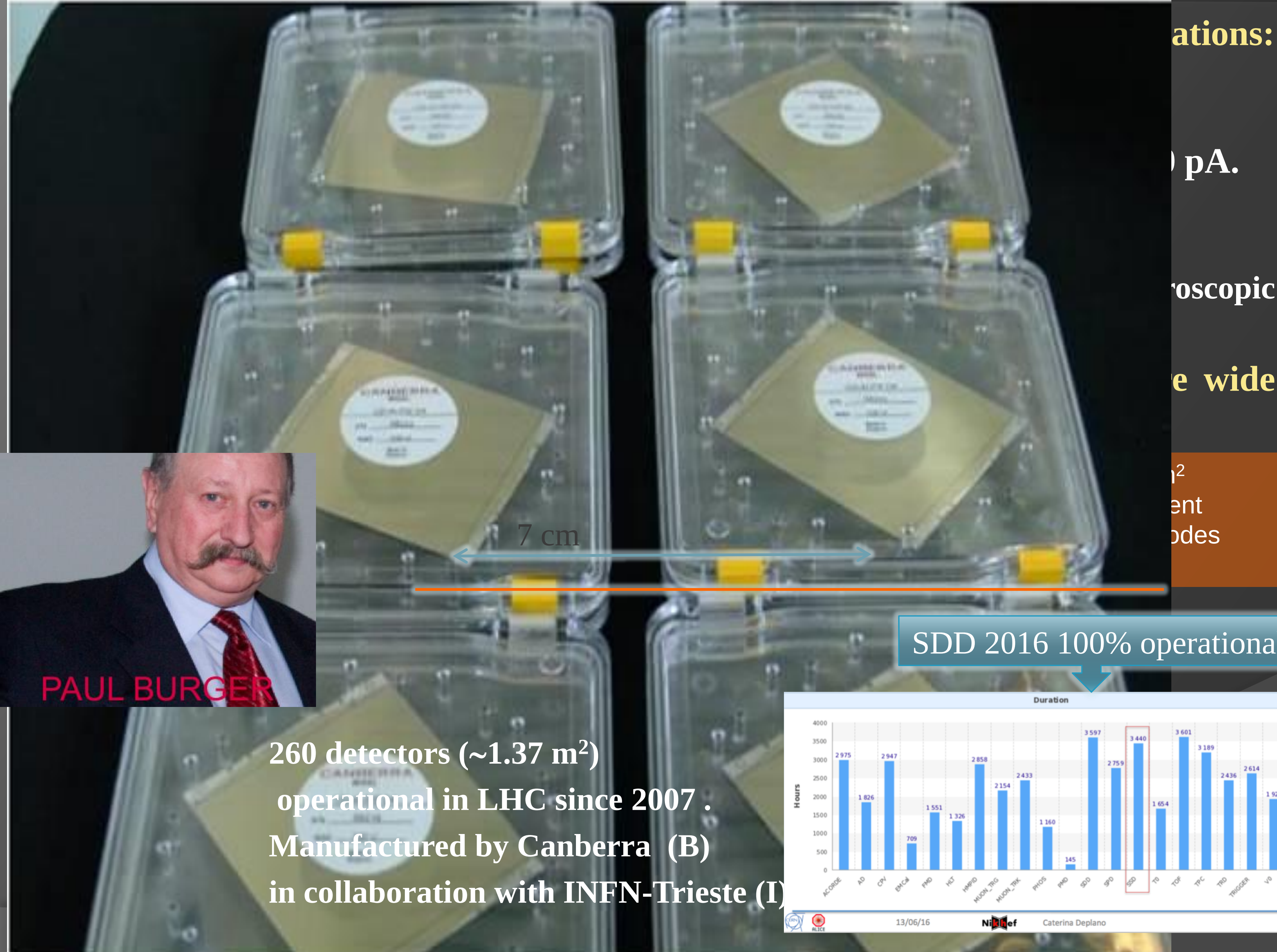
Each anode:

- has a very small capacitance of ~100 f F
- reads an area of 10 mm^2



Specs for the detector :

- HV bias: -2.4 kV, 8V/cathode E = 670 V/cm
- 35mm in 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



ations:

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odes

260 detectors (~1.37 m^2)

operational in LHC since 2007 .

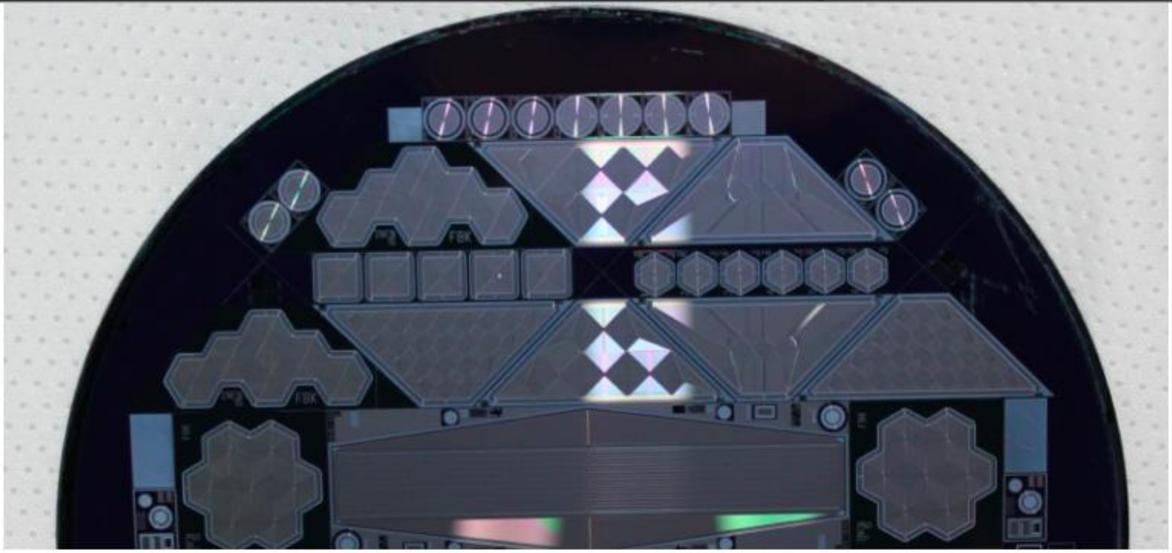
Manufactured by Canberra (B)

in collaboration with INFN-Trieste (I)

REDSOX: collaboration

Dedicated specialized development poles within the collaboration network take care of the various aspects of the realization

- detector modeling,
- dedicated electronics
- prototyping,
- testing,
- production iteration
- system integration
- test beam



REDSOX – REsearch Drift for SOft X-rays

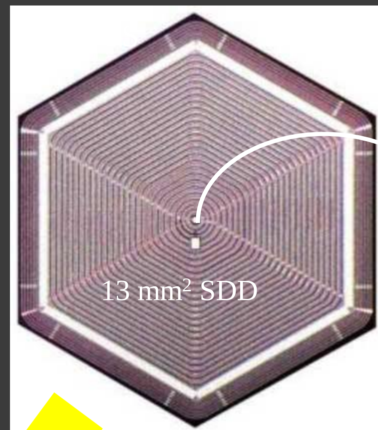
- **development of high energy resolution SDD for soft X-rays**
- **evolution of SDD technology in collaboration with FBK CMM Trento**
- **Evolution of SDD FE electronics in collaboration with PoliMI**
- **develement of large surface SDD for X-ray astrophysics**
- **development of SDD detection systems for Advanced Light Sources**

Know-how diffusion; parallel developments ; efficiency & optimization;

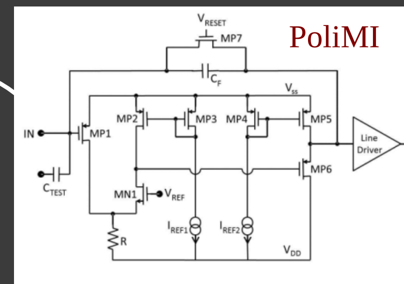
Starting point: state-of-the-art technology

Very-low leakage current production process was developed at FBK

- Typical: < 150 pA/cm^2
- Minimum: 25 pA/cm^2

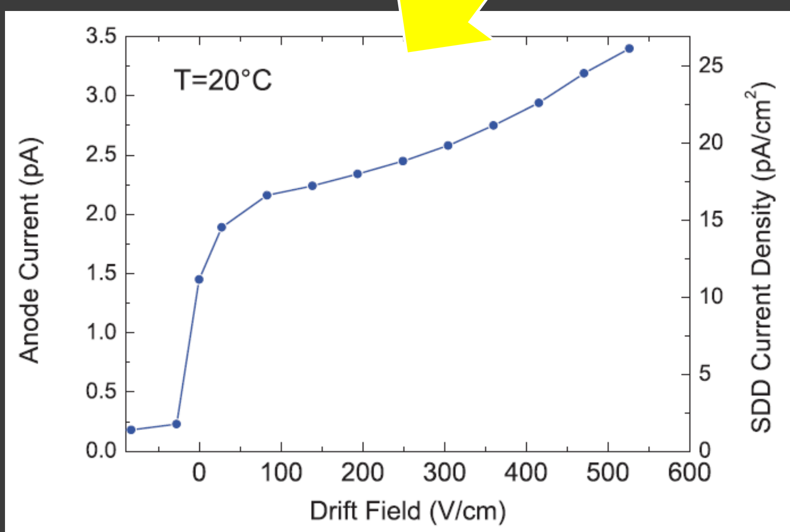


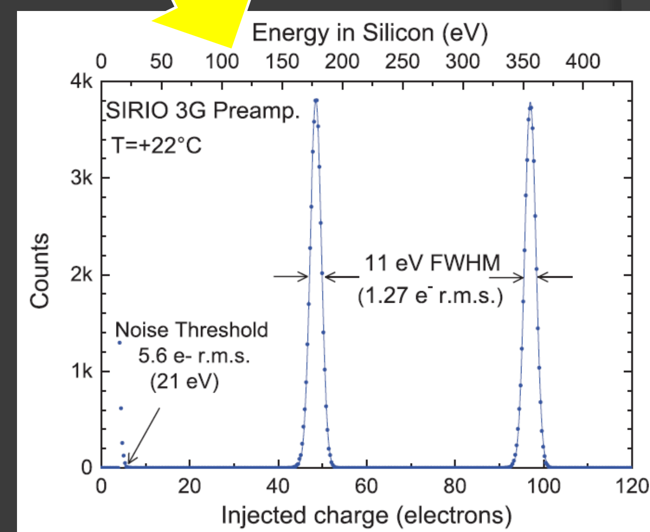
SIRIO preamplifier



Low-power and very-low noise optimized preampl. in sub-micron technology **PoliMI**

- Power: 10 mW including the output buffer
- ENC of 1.27 e$^-$ r.m.s. at 22 ° C
- 0.9 e- r.m.s. at -30° C

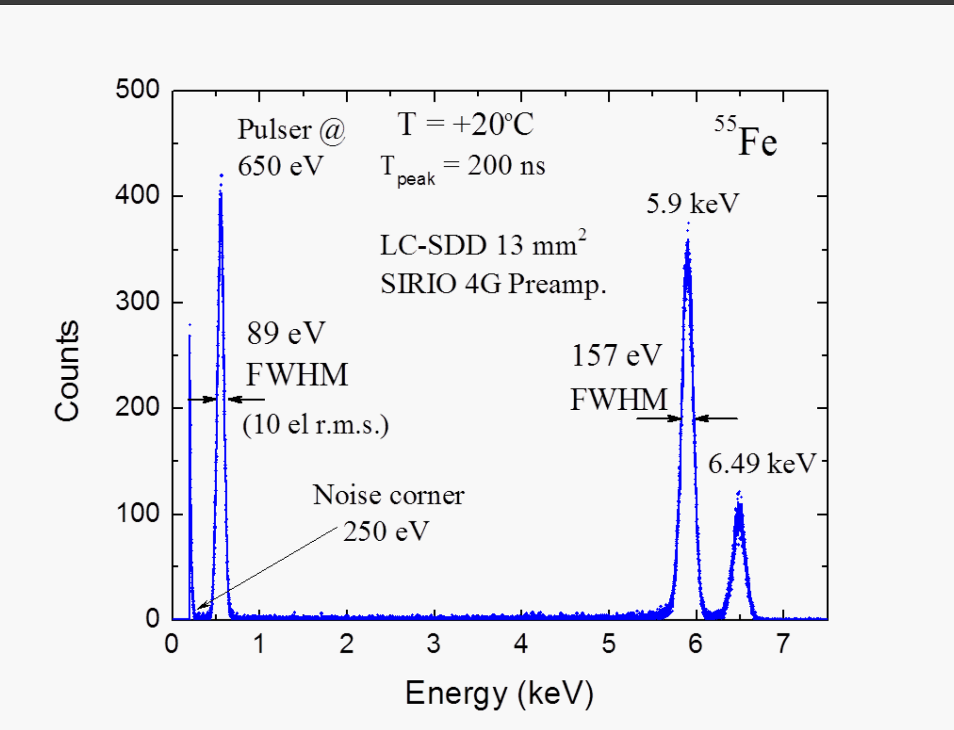




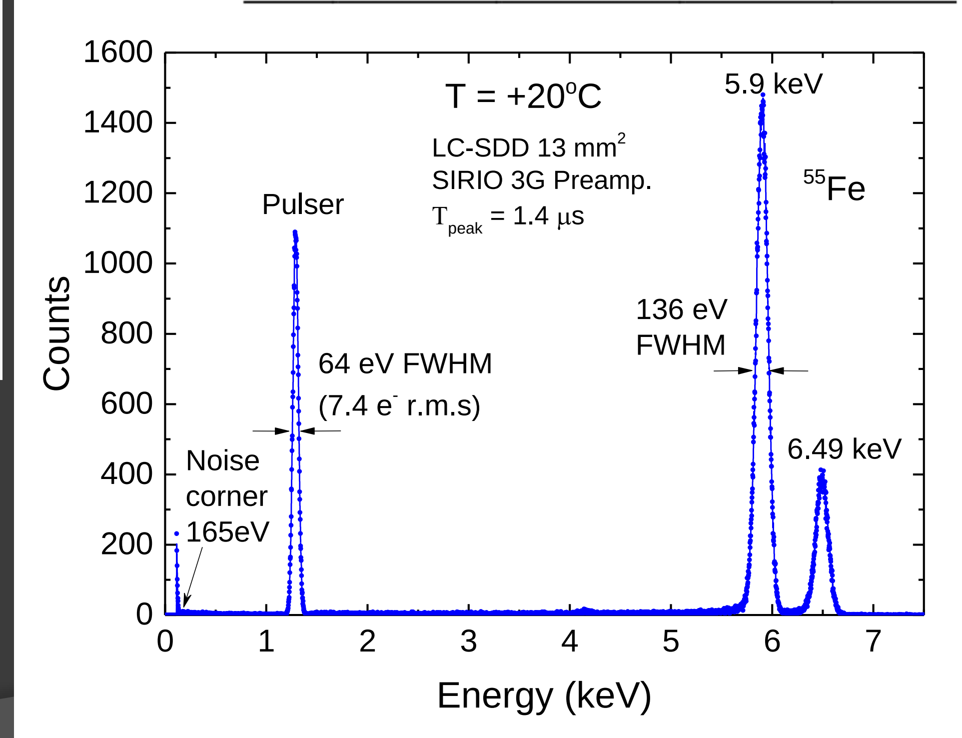
G. Bertuccio, et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 63, NO. 1, FEBRUARY 2016

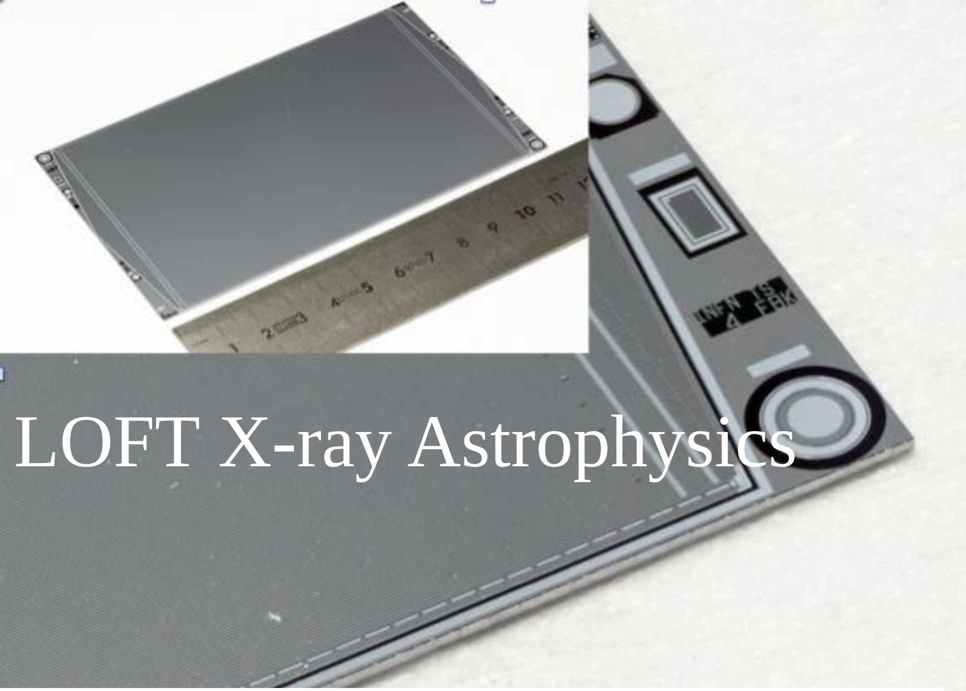
G. Bertuccio, et al.
X-Ray Silicon Drift Detector–CMOS Front-End System with High Energy Resolution at Room Temperature
IEEE Transactions on Nuclear Science
Year: 2016, Volume: 63, Issue: 1Pages: 400 - 406,
DOI: 10.1109/TNS.2015.2513602

T (°C)	^{55}Fe 5.9 keV LINE WIDTH (eV FWHM)	PULSER LINE WIDTH (eV FWHM)	ENC (e- r.m.s.)	Peaking Time (µs)
+30	148	82	9.4	0.8
+20	136	64	7.4	1.4
+10	133	53	6.1	2.4
0	129	44	5.0	4.8
-10	129	41	4.7	9.6
-30	123.7	29	3.3	19.2
READOUT ELECTRONICS				
+22	--	11	1.27	51.2
-30	--	8.7	1.0	102.4



T +20 ^{0}C





LOFT X-ray Astrophysics

SDD development for the LOFT mission

During the M3 LOFT assessment study R&D activities were carried out to reach the required readiness level:

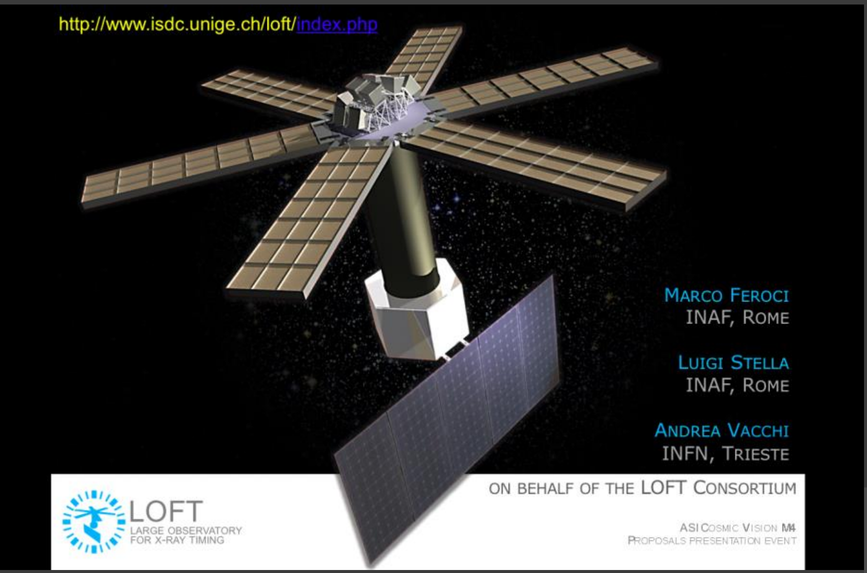
- Detector optimizations:
  - ✓ Reduced power consumption
  - ✓ Sensitivity to environment (humidity)
  - ✓ Improved quantum efficiency
  - ✓ Anode pitch optimization to improve spectroscopy and imaging performance
- SDD production process
  - LOFT-LAD real size prototypes (4” → 6” wafers)
  - ✓ Leakage current reduction
- Space qualification
  - ✓ Vacuum operation
  - ✓ Radiation environment (total dose, NIEL)
  - ✓ Orbital debris and micrometeoroids

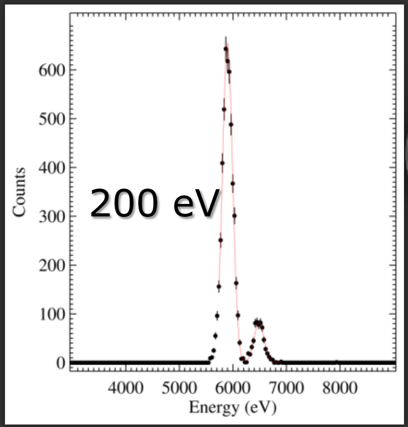
Synchrotron et. ....

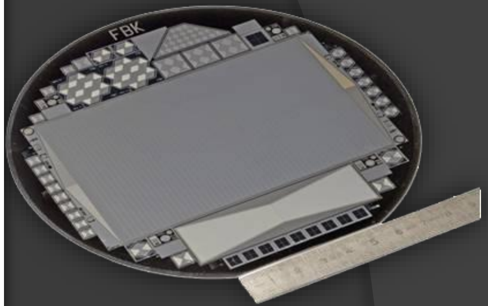
Systems for the TwinMic and XAFS beamlines of Elettra synchrotron (Trieste, Italy) Fluorescence Spectroscopy and Flux measurement in the soft X-ray regime

- **increase the count-rate** by up to an order of magnitude.
- **very versatile architecture** adapt to any setup
- **high energy resolution at** T > 0 °C E_{RES} < 150 eV FWHM @ 5.9 keV
- **cope with large fluxes of photons**
- **large geometric acceptance** reduce the measurement time
- reduce damage to the sample
- good sensitivity in the whole energy range of the beamline
- acquire larger maps

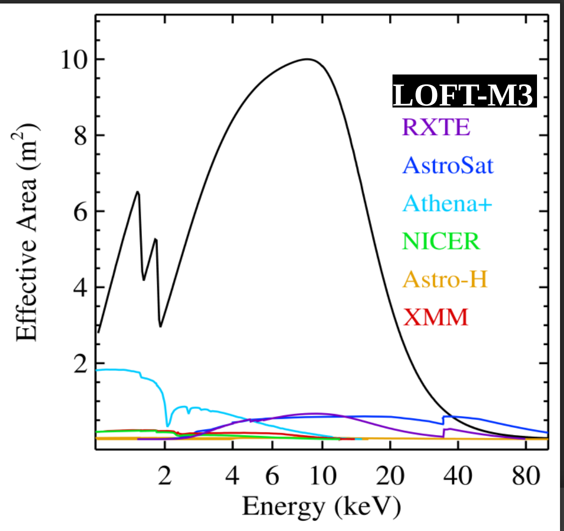
LOFT concept **revolutionary solid-state design** of the LOFT/LAD combines for the first time a huge effective area >15 times larger than that of any previously flown X-ray experiment







LHC ALICE SDD Detectors Heritage



LOFT Science

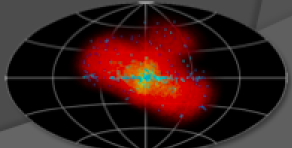
"Matter Under Extreme Conditions"

fast and violently variable X-ray Universe

Probe the state of matter at supra nuclear densities in Neutron Stars ("**Dense Matter**")

Probe gravity theory in the very strong field environment of Black Holes ("**Strong Gravity**")

Probe physics of hundreds of galactic and bright extragalactic cosmic sources ("**Observatory Science**")



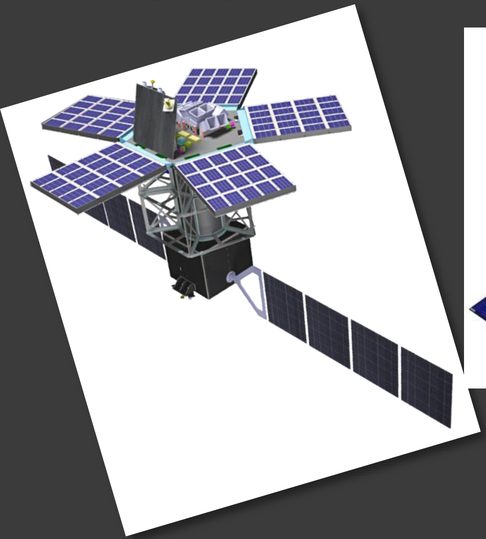
POSSIBLE MISSION APPROACHES

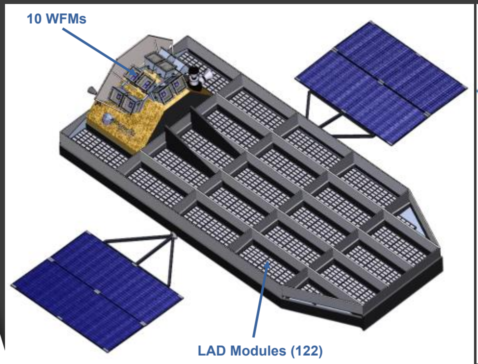
LOFT
Large Observatory
For x-ray Timing
(ESA)

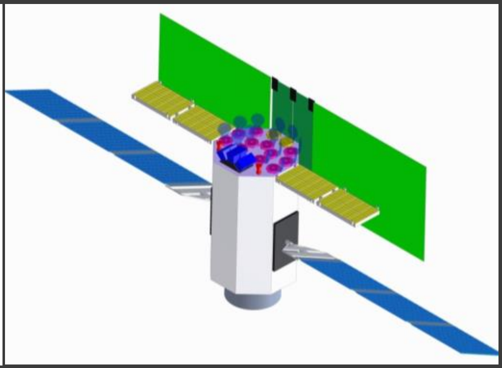
LOFT-P
STROBE X
LOFT-Probe
(NASA)

eXTP
enhanced X-ray Timing and
Polarization mission (CAS)

1-m^2 on ISS study



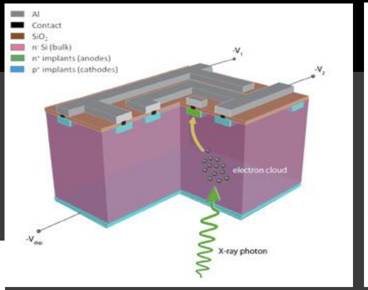


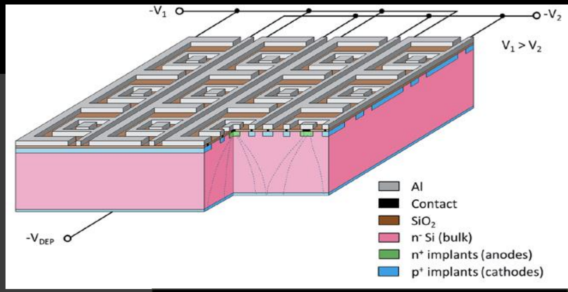


Weak/soft sources:
Collimated Area +
Telescopes.
And Polarimeter

Bright sources: Large Collimated Area

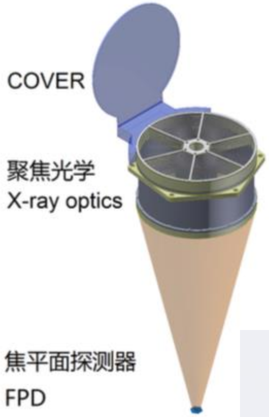
Pixel Drift Detector
focal plane of X-ray optics
in the 0.5-10 KeV band

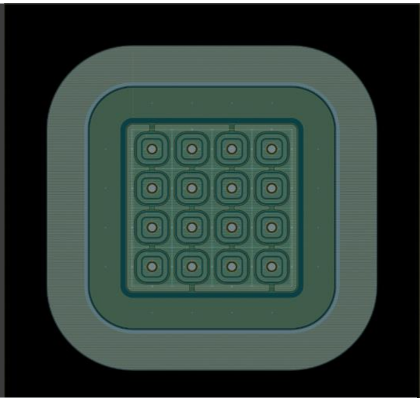


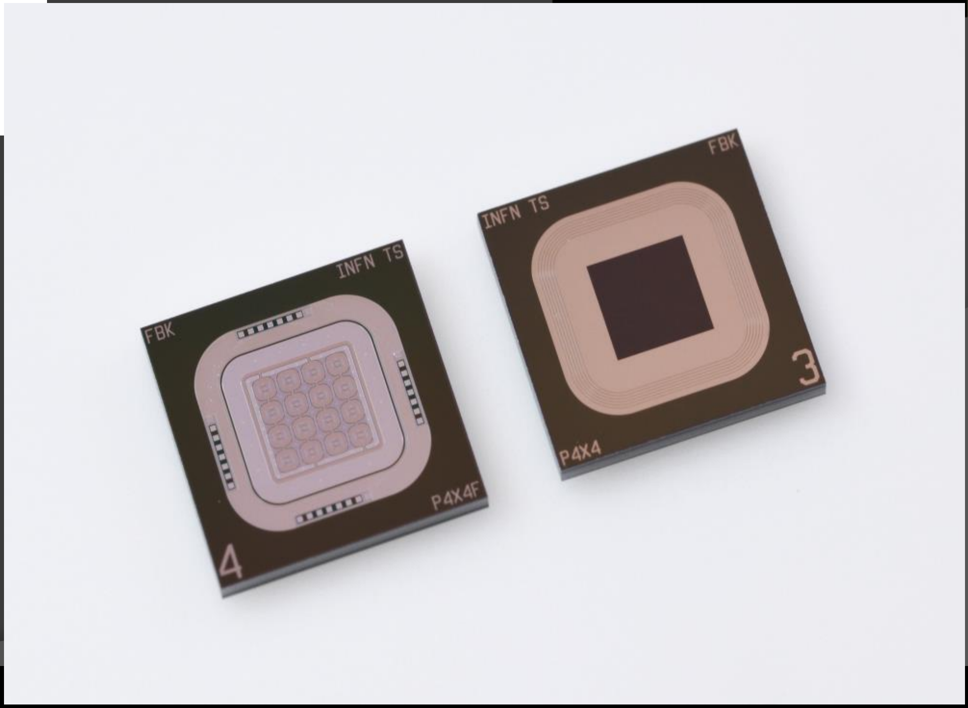


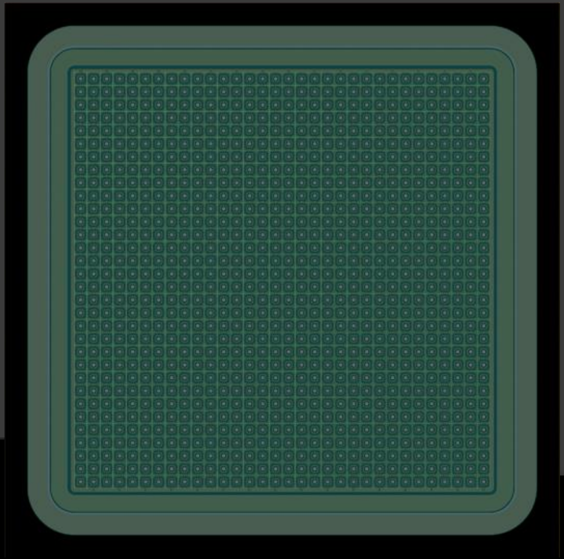
- SFA for spectroscopic and timing measurement with imaging capability.

Focal length	4.5 m
Area	>500 cm^2 @ 6 keV, 1 module >6000 cm^2 @ 2-6 keV, in total
Energy range	0.5~20 keV
Field of View	+/-6 arcmin
Angular res.	HEW≤1', W90≤3'
Energy res.	<180eV@6keV
Timing res.	10 us

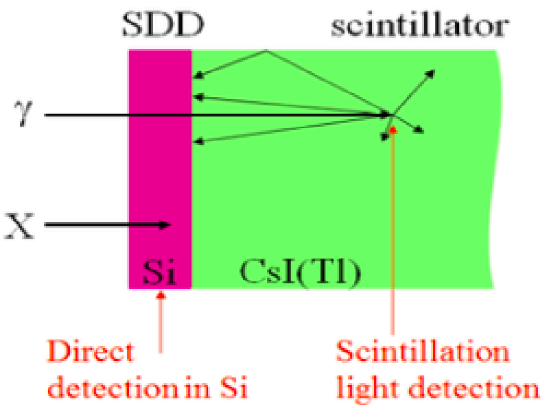


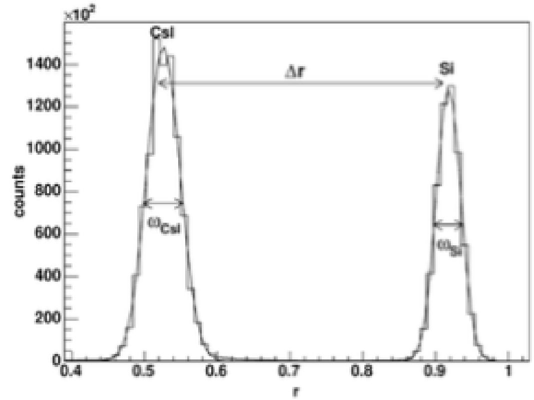


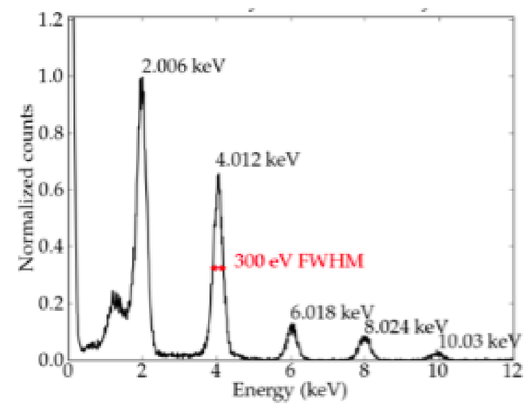


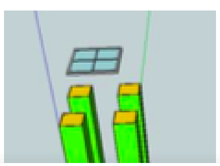


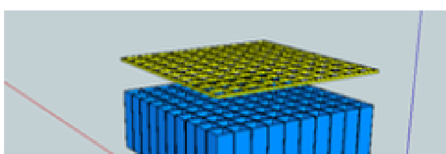
The X-Gamma-rays spectrometer (XGS)

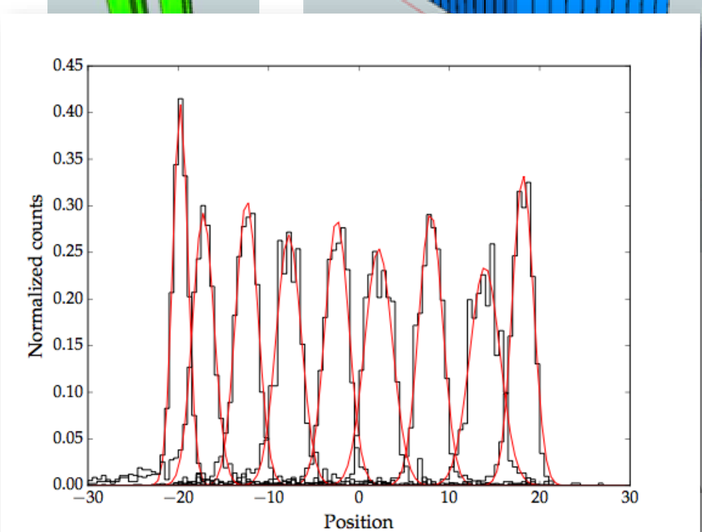




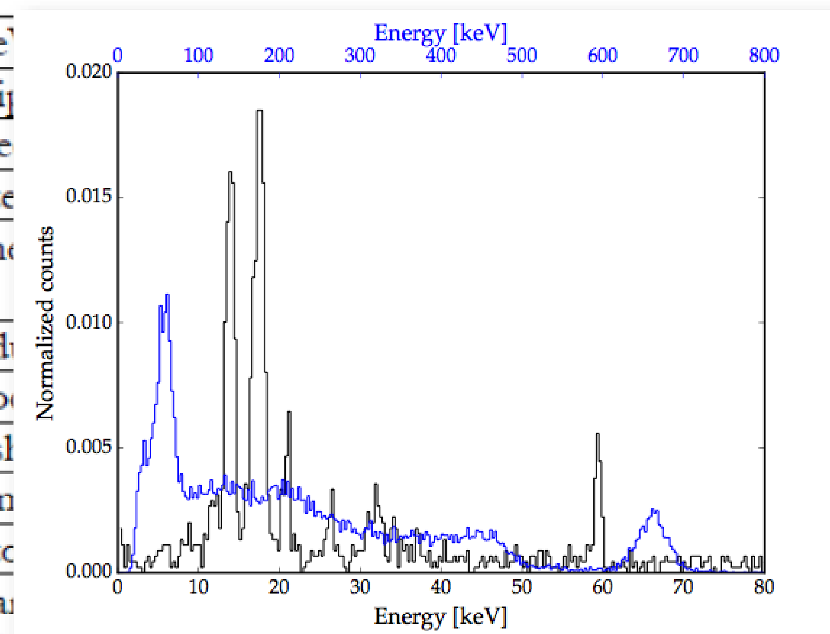




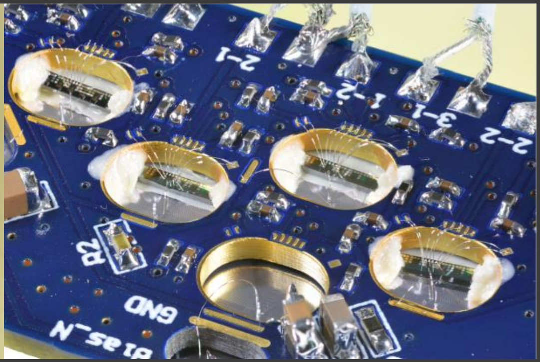


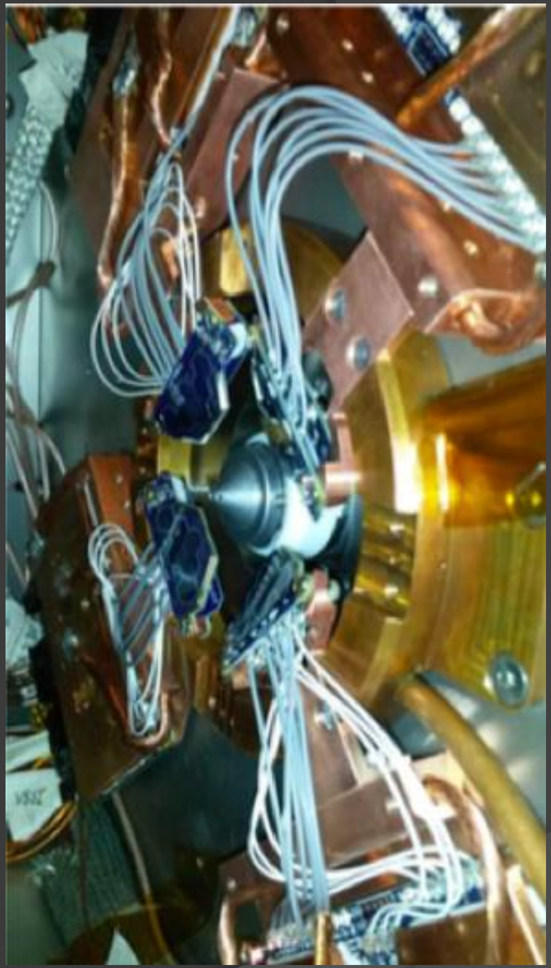


Energy band (ke
Detection princi
Low-energy dete
High energy dete
Separation of en CsI(Tl)
Number of mod
Size of each mo
Lateral passive sl
Slat collimator/n
Overall collimato
Average useful a in the SXI FOV (cm²)

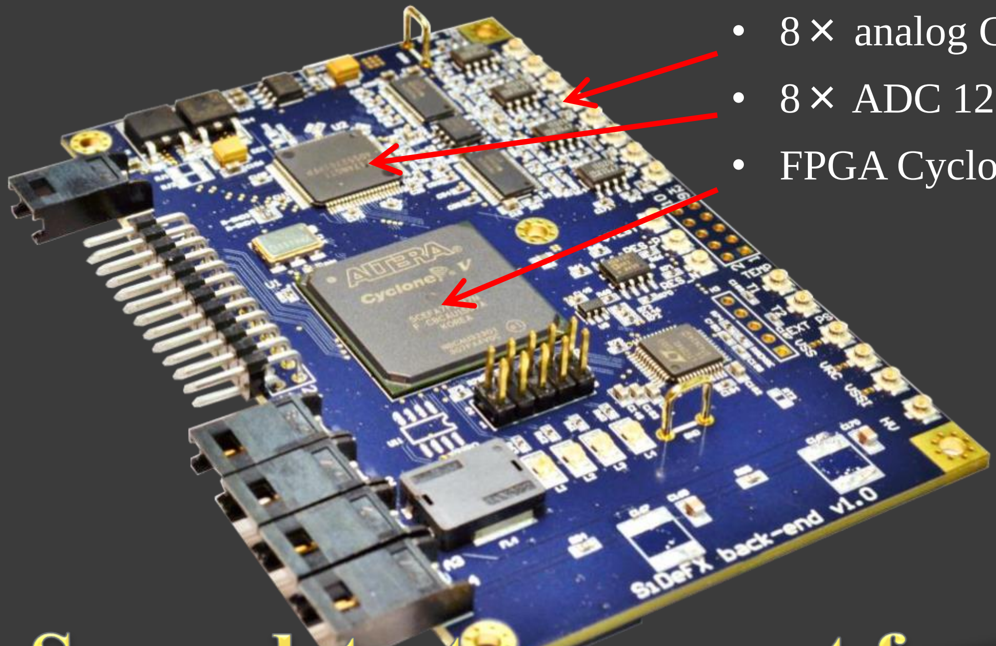


The new TwinMic detector system





- 6 not collimated hexagonal pixels (total area of 182 mm^2) read out by SIRIO preamplifiers

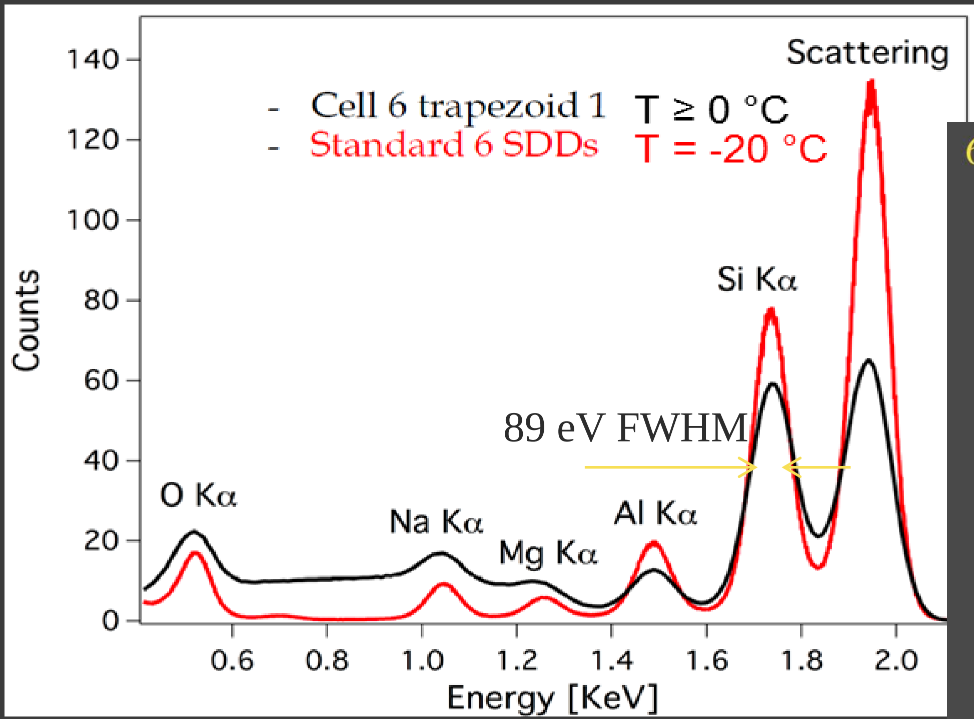


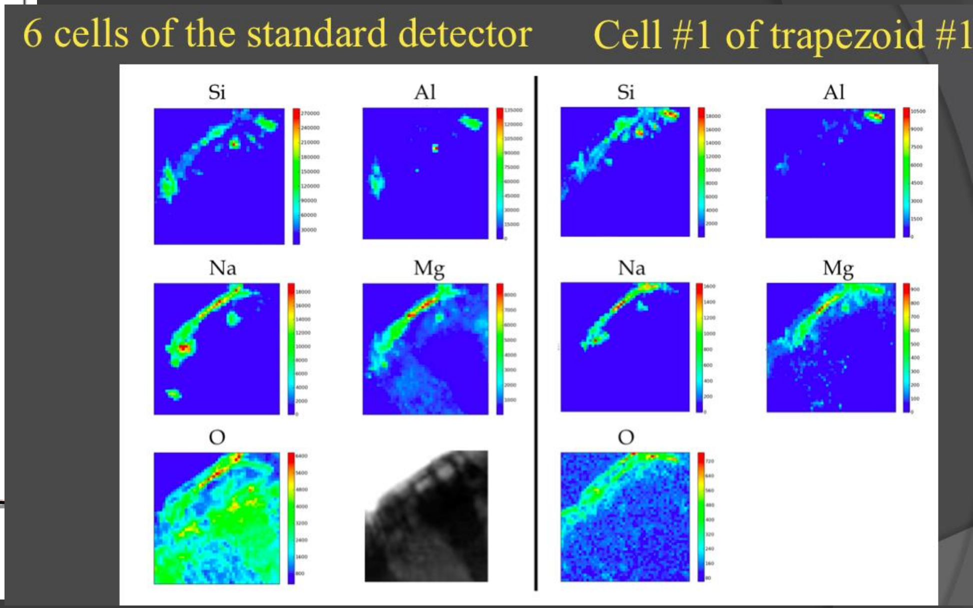
- 8 × analog CR-RC^2 filters
- 8 × ADC 12 bit 40 MSPS
- FPGA Cyclone 5

Four detectors mounted in the experimental chamber in vacuum conditions; for the test the distance from the sample was not yet optimal

Same detector concept for SESAME light source

TwinMic Beamline measurements



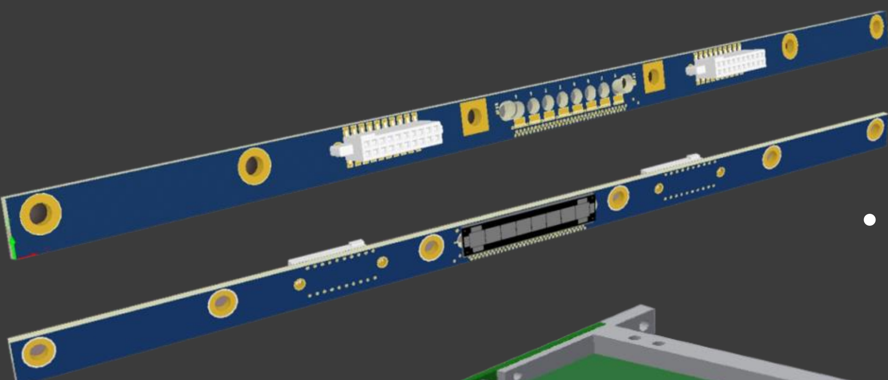


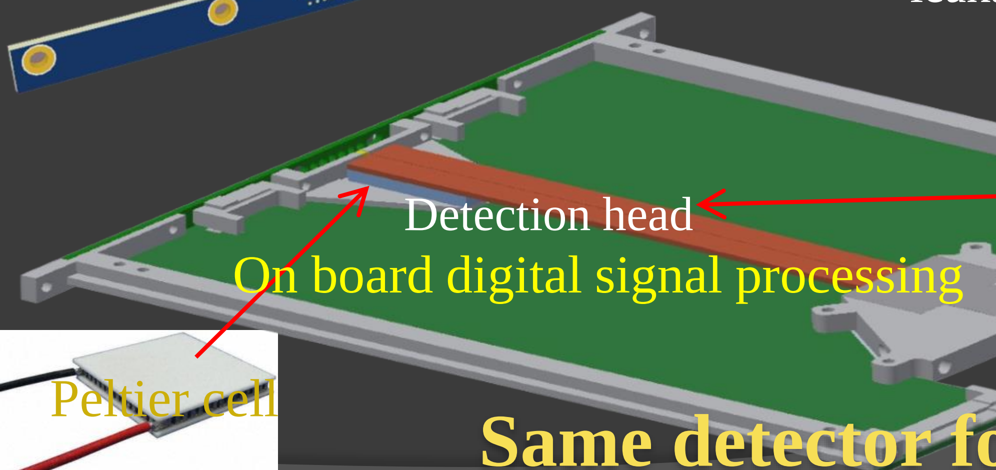
Si-Al-Mg-Na-O spectra of a *euphorbia pityusa* plant section acquired with one cell of the new TwinMic detector and with 6 SDDs of the standard system

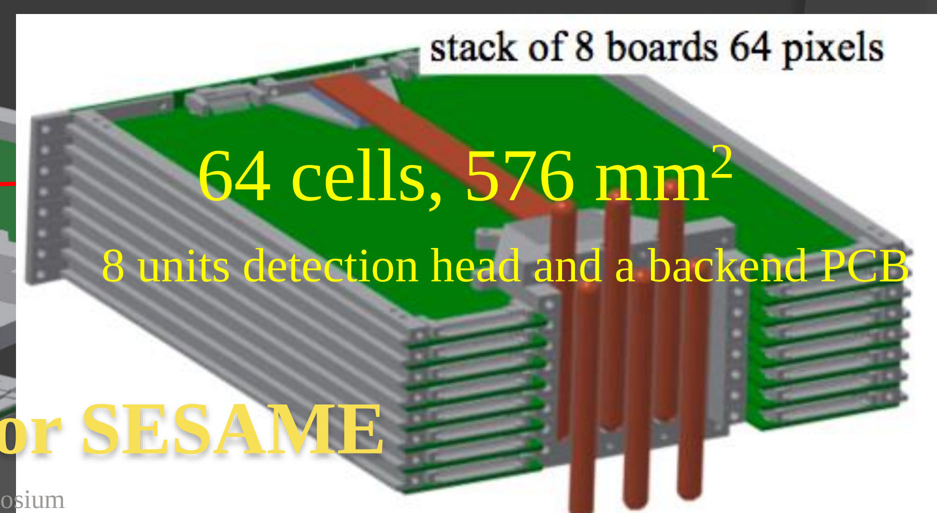
- Optimized digital filtering not yet available at that time, $t_R = 0.95$ µs
- Relevant background below 1.4 keV (electrons extracted from the sample?)
- Successive test with new mechanical support showed a doubling of the rate

XAFS Detection head design and the SESAME fluorescence detector

- Improved detector layout:
  - better defined sensitive area
  - on-board thermistors for temperature control
- Tungsten collimator to minimize "split" events
- New SIRIO preamplifier prototypes optimized for SESAME now under test at Politecnico di Milano
  - A low frontend PCB profile allows for compact stacking of detection heads
- Thermoelectric cooling is employed to reduce the leakage current

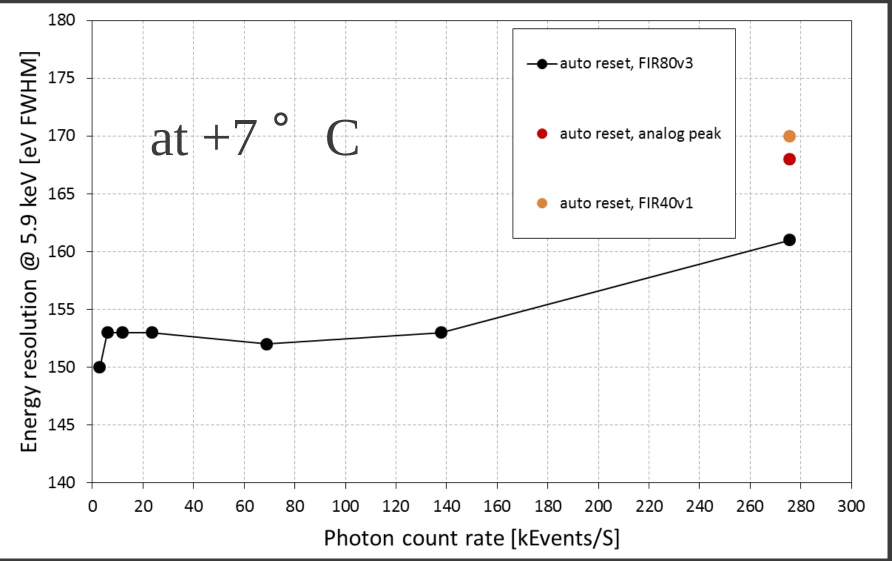


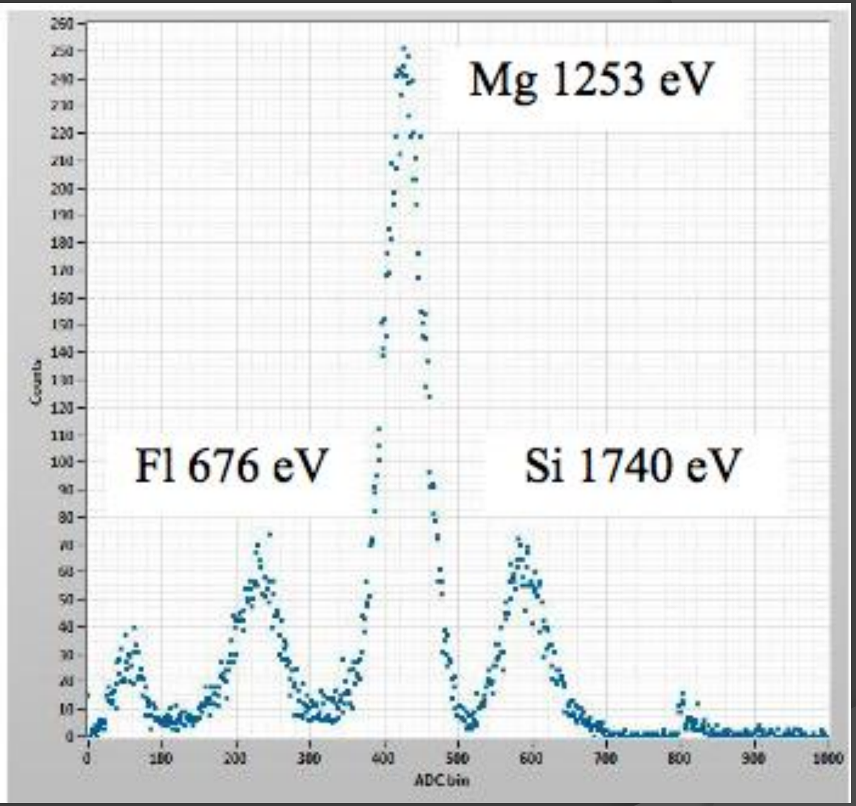


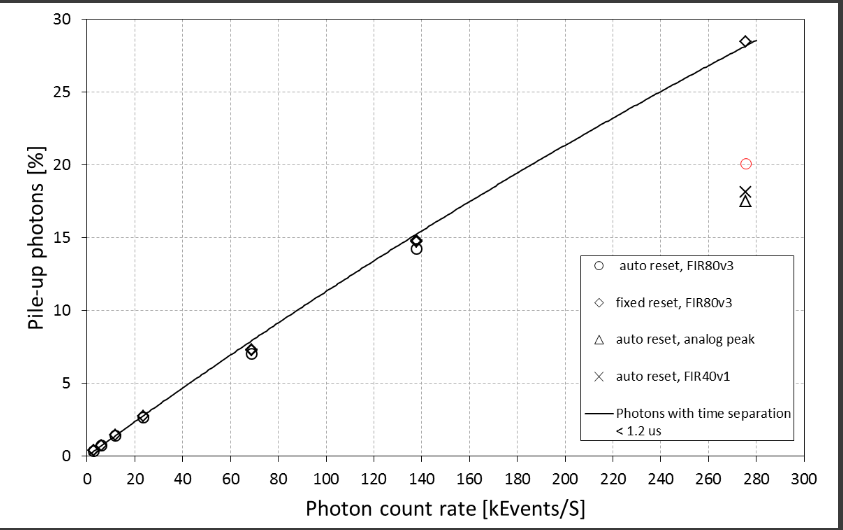


Same detector for SESAME

Energy resolution: auto reset







time resolution ?

- time resolution σ_t of a time of flight system rise time t_r divided by the signal to noise ratio (S/N).

$$\sigma_t = \frac{t_r}{S/N}$$

Let's take the existent SDD+SIRIO of 10 mm^2: x = thickness = 450 μm.
A MIP releases 33000 e-h pairs in 450 μm of Silicon, which gives

$$S = 33000\,pairs \times 3.6\frac{eV}{pair} = 120\,keV$$

- The charge collection time assuming:
- E = 500 V/cm, kT = 25 meV, q = 1.6E-19 C, μ = 1400 cm^2/Vs is:

$$t_r = \frac{6}{\mu E}\sqrt{\frac{2kTx}{qE}} = 40\,ns$$

- The optimal shaping time of the SIRIO is ~ 1 μs.
- With a lower shaping (100 ns), the series noise dominates and is ~ 50 eV.

Putting all together, S/N = 120000/50 = 2400, more than 2 order of magnitude larger compared to junction detectors.

$$\sigma_t = \frac{t_r}{S/N} = \frac{100\,ns}{2400} = 40\,ps$$

The REDSOX collaboration state of the art SDD

Summary

- Room temperature large scale application of high performance Silicon Drift Detectors in the low energy X-ray domain is made possible by the coordinated work of the REDSOX collaboration
  - The progress in simulation, design, production technology, front-end and readout electronics has allowed a progression of developments of SDD detectors and read out electronics for specific applications in some relevant direction
    - presented here front edge examples applications in X-ray astronomy/astrophysics and Synchrotron light

- There are possibilities for research fellowships within the REDSOX collaboration andrea.vacchi@ts.infn.it

- THANK YOU

2nd Meeting on Silicon Drift Detectors for Low Energy X-Ray Applications
9-11 May 2016, Palazzo Natta, COMO