eXTP Large Area Detector: qualification procedure of the mass production

A. Rachevski[1*], M. Antonelli[1], P. Bellutti[2,6], V. Bonvicini[1], G. Borghi[2,6], R. Campana[7], F. Ceraudo[4], D. Cirrincione[3,1], E. Del Monte[4,5], Y. Evangelista[4,5], M. Feroci[4,5], F. Ficorella[2,6], G. Orzan[1], G. Pepponi[2,6], A. Picciotto[2,6], I. Rashevskaya[6], G. Zampa[1], N. Zampa[1], N. Zorzi[2,6] and A. Vacchi[3]

*) corresponding authour, 1) INFN Trieste, Padriciano 99, I-34149, Trieste, Italy, 2) Fondazione Bruno Kessler, Via Sommarive 18, I-38123, Trento, Italy, 3) Dipartimento di Matematica ed Informatica, Università di Udine, Via delle Scienze 206, I-33100, Udine, Italy, 4) INAF-IAPS, Via del Fosso del Cavaliere 100, I-00133, Roma, Italy, 5) INFN Roma Tor Vergata, Via della Ricerca Scientifica 1, I-00133, Roma, Italy, 6) TIFPA – INFN, Via Sommarive 14, I-38123, Trento, Italy, 7) INAF-OAS, Via Piero Gobetti 93/3, I-40129, Bologna, Italy

ABSTRACT

A 7.24 x 12.03 cm^2 sensor, Silicon Drift Detector (SDD), has been developed for the enhanced X-Ray Timing and Polarimetry (eXTP) mission of the Chinese Academy of Science, with a large contribution by a European consortium inherited from the ESA-M3 LOFT mission study. In the frame of the project X-Ray Observatories (XRO), active in the National Scientific Commission 2 of the INFN, we report the details of the qualification procedure to select from the mass production the 640 sensors that will equip the Large Area Detector (the eXTP instrument dedicated to the X-ray spectroscopy in the range 2-30 keV), with energy resolution below 240 eV FWHM at 6 keV during the entire mission duration of at least 5 years. This stringent requirement dictates the need to thoroughly verify the characteristics of each single sensor before integration in the final layout. We describe the dedicated testing facilities that have been developed. We report on the detector selection criteria and test results obtained in the pre-series production.

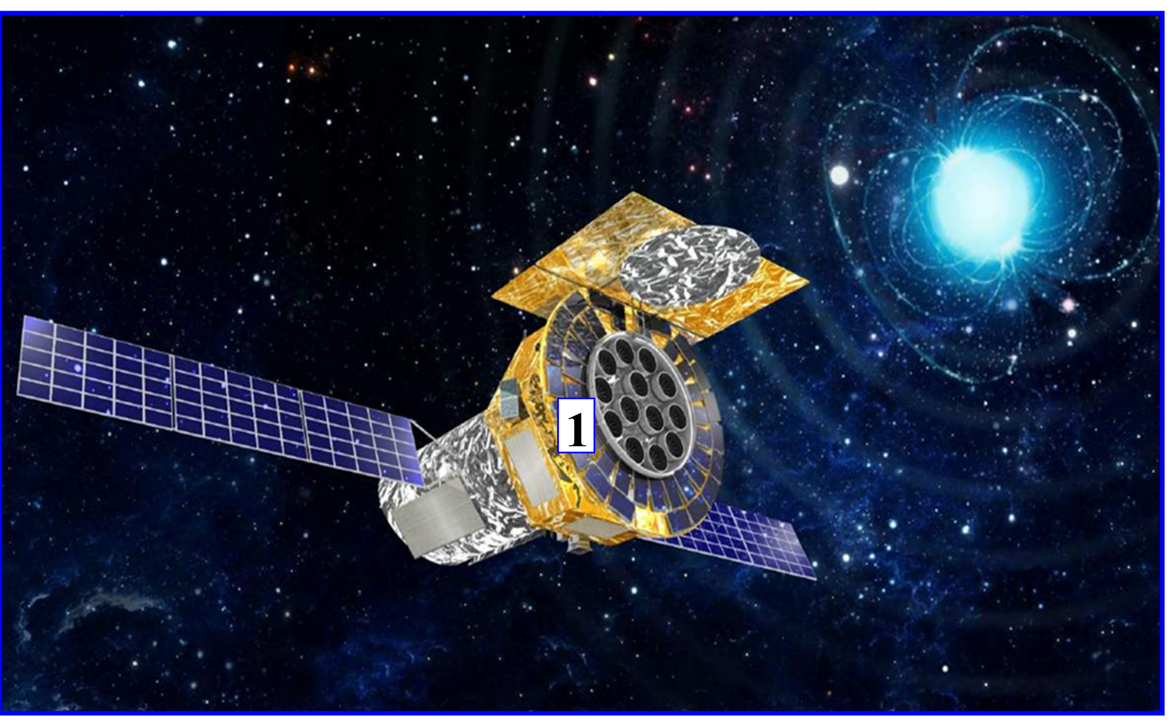

Fig. 1 enhanced X-ray Timing and Polarimetry (eXTP) space mission. 640 sensors (SDDs) of the Large Area Detector (LAD) are organized in 40 modules (1). Each module is composed of a set of 16 SDDs and 16 capillary plate collimators.

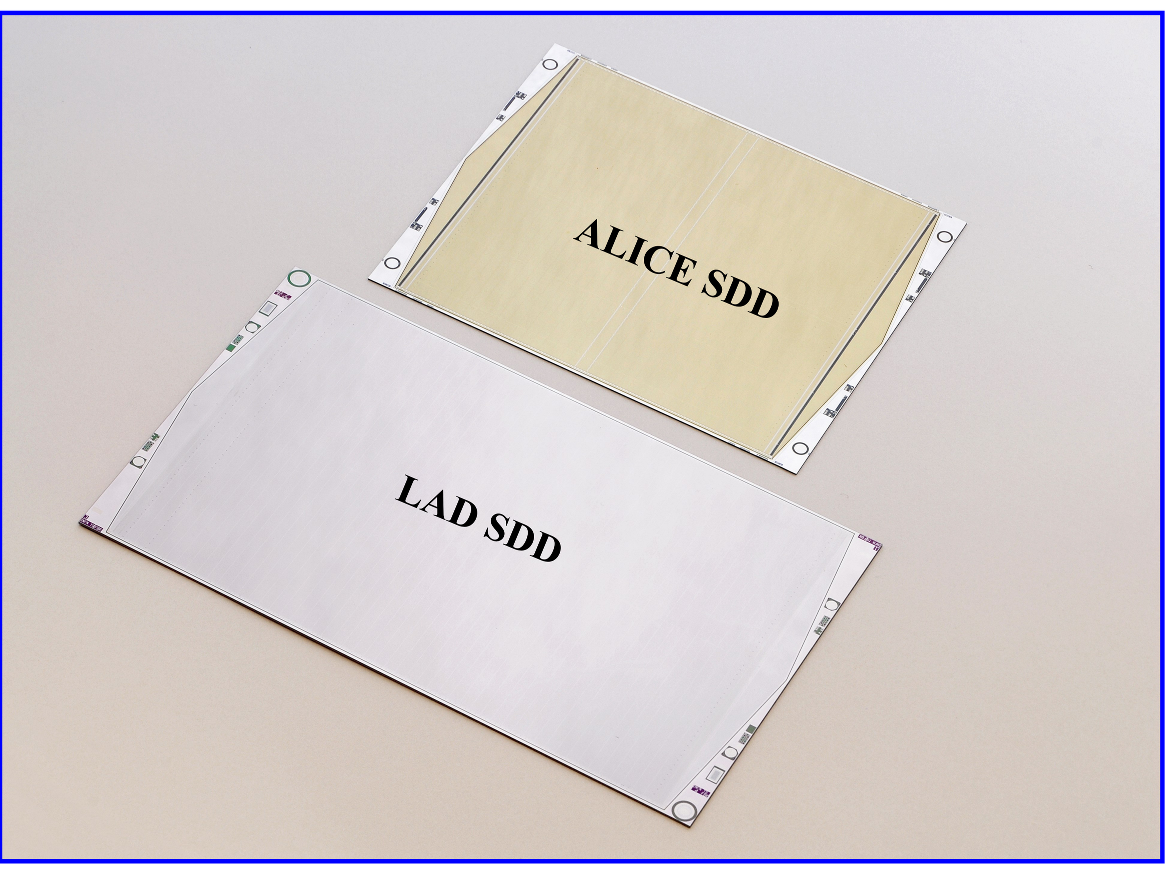

Fig. 2 Comparison between ALICE SDD (active area 7.53 x 7.00 cm^2) and LAD SDD (active area 10.86 x 7.00 cm^2)

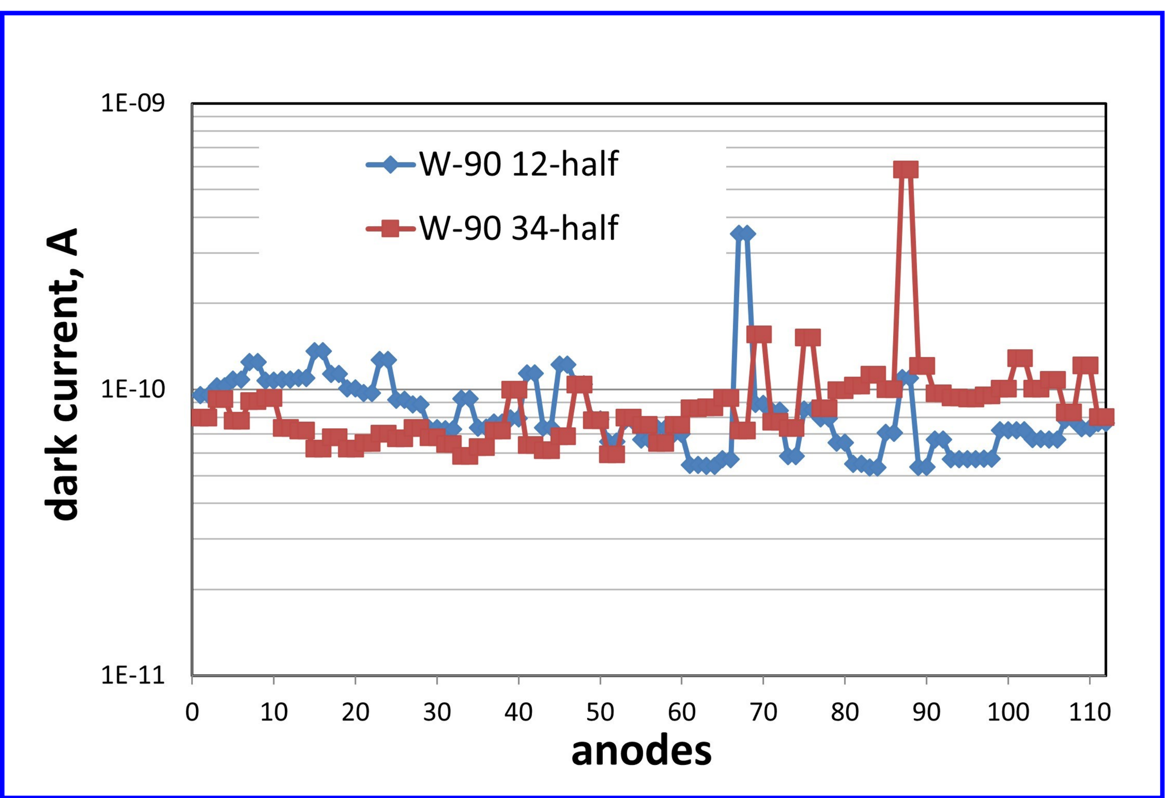

Fig. 6 Dark currents measured in two halves of the SDD

SPACE MISSION CONCEPT

The enhanced X-ray Timing and Polarimetry (eXTP) space mission (Figure 1) is a flagship space astronomy mission developed by a Sino-European scientific consortium [1], led by the Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS). eXTP completed its extended Phase A study in 2018, currently it continues with the Phase B to be accomplished in 2023. Presently the target launch date is 2027, for a minimum mission lifetime of 5 years (goal 8 years). The scientific program aims to study matter under extreme conditions of gravity, density and magnetism. For the first time simultaneous, high-throughput spectral, timing and polarimetry observations are foreseen. The European contribution consists of two instruments, the Large Area Detector (LAD) and the Wide Field Monitor (WFM).

SENSOR SELECTION CRITERIA

To equip LAD with 640 SDDs with characteristics that would ensure success to the mission scientific program we have to elaborate in detail the qualification procedures that sensors coming from the mass production must undergo. First, under nominal bias conditions we measure one by one the dark current at each collection anode due to its influence on energy resolution characteristics. According to computer simulations performed for the whole array of LAD sensors on-board of the satellite, their temperature will be below –30 °C. This allows us to release the requirements on the currents measured at room temperature. Based on updated analysis, SDDs with a number of "hot" anodes (i.e. having a current higher than 600 pA/cm^2 at 20 °C) less than 1% of a total number of 224 anodes, would pass the selection. Second, we measure the potential distribution on the drift cathodes of both SDD sides. The maximum potential unbalance between corresponding cathodes has to be less than 35 V, otherwise there is a risk to partially lose the signal charge drifting towards the anodes from the interaction point.

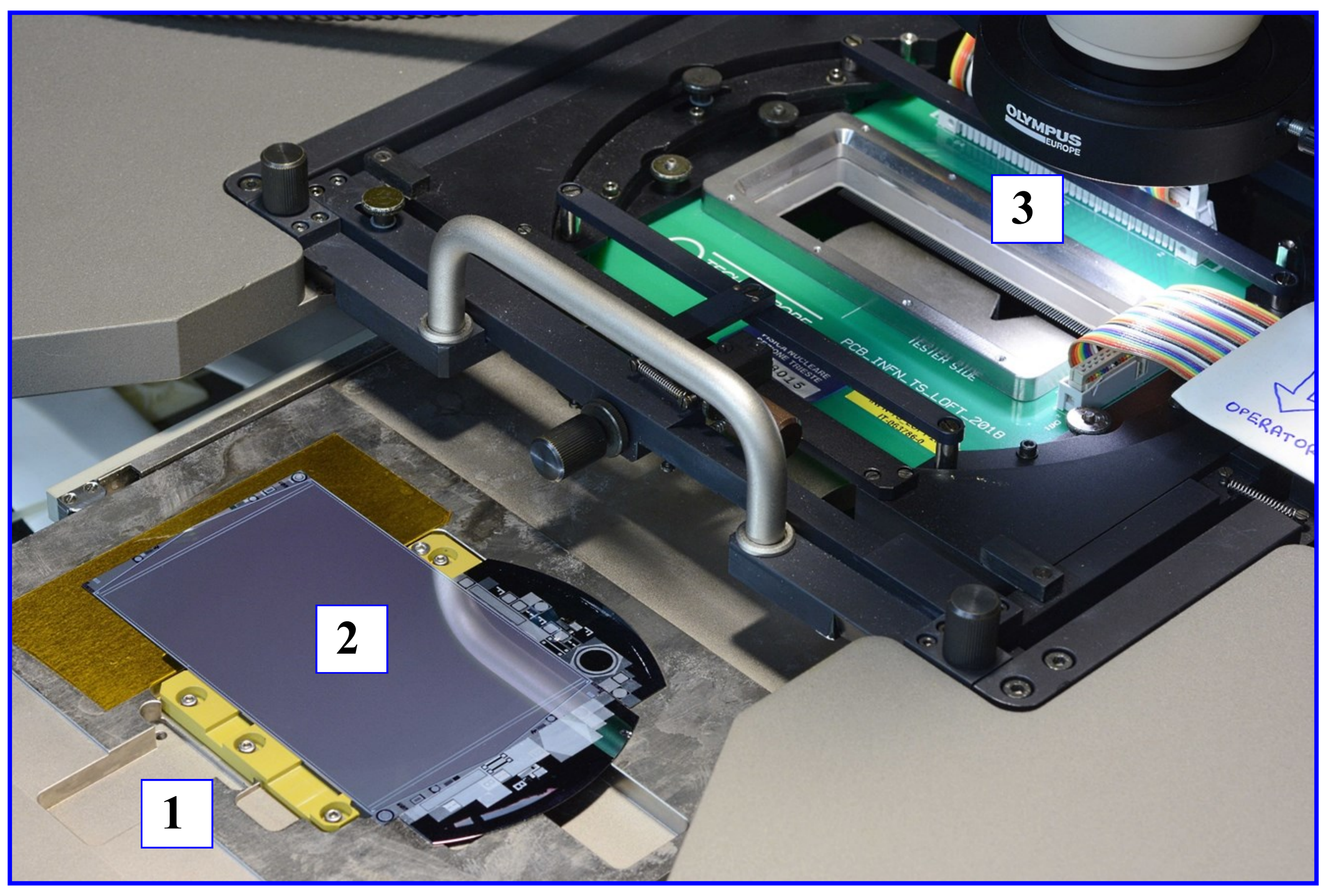

Fig. 3 Karl-Suss PM8-DSP double side probe-station
1: withdrawable chuck;
2: LAD SDD;
3: "anode" probe card

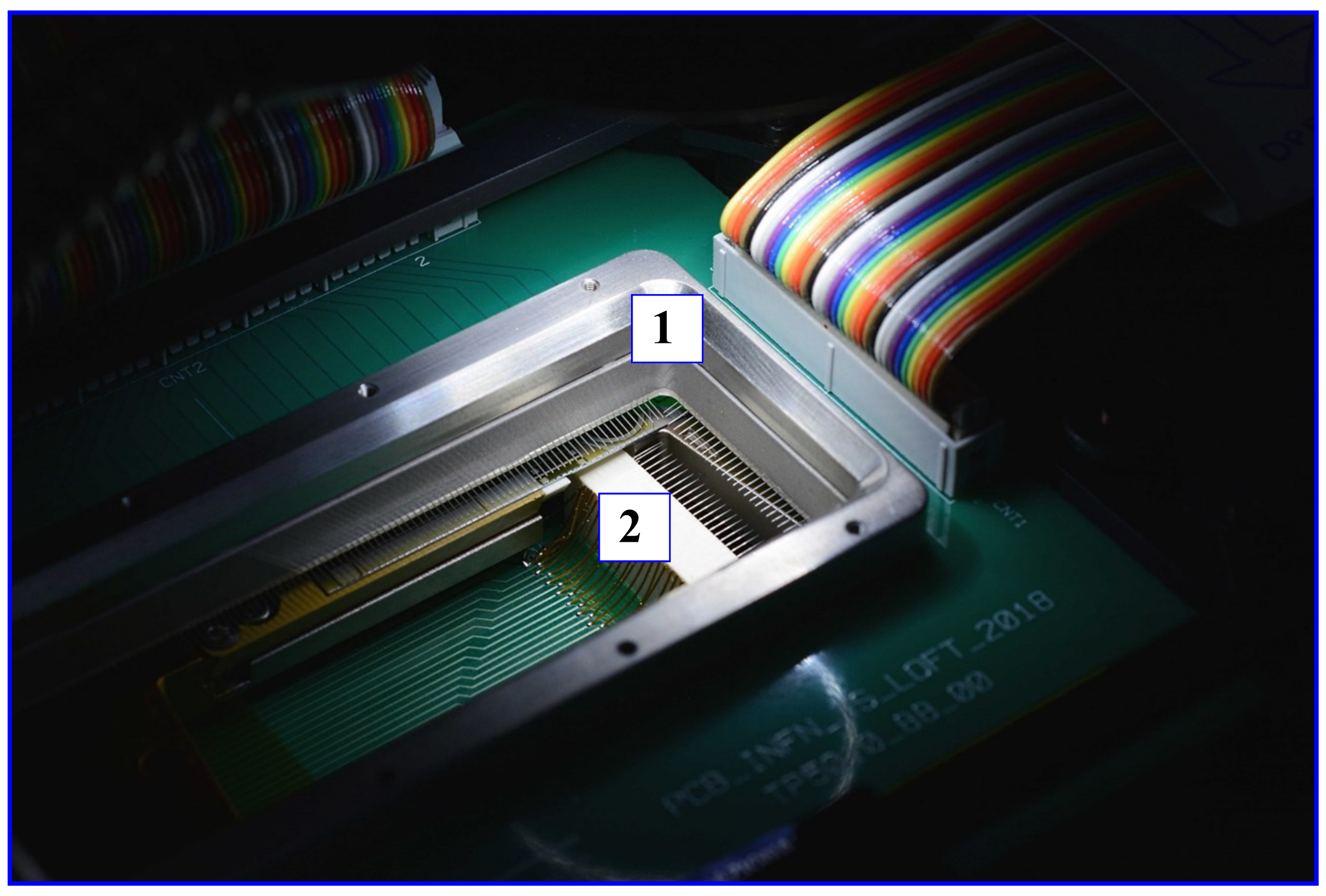

Fig. 4 "anode" probe card with 144 tungsten-rhenium pins (1) and "bottom" probe card with 32 tungsten-rhenium pins (2). N.B. In the picture the withdrawable chuck is NOT inserted.

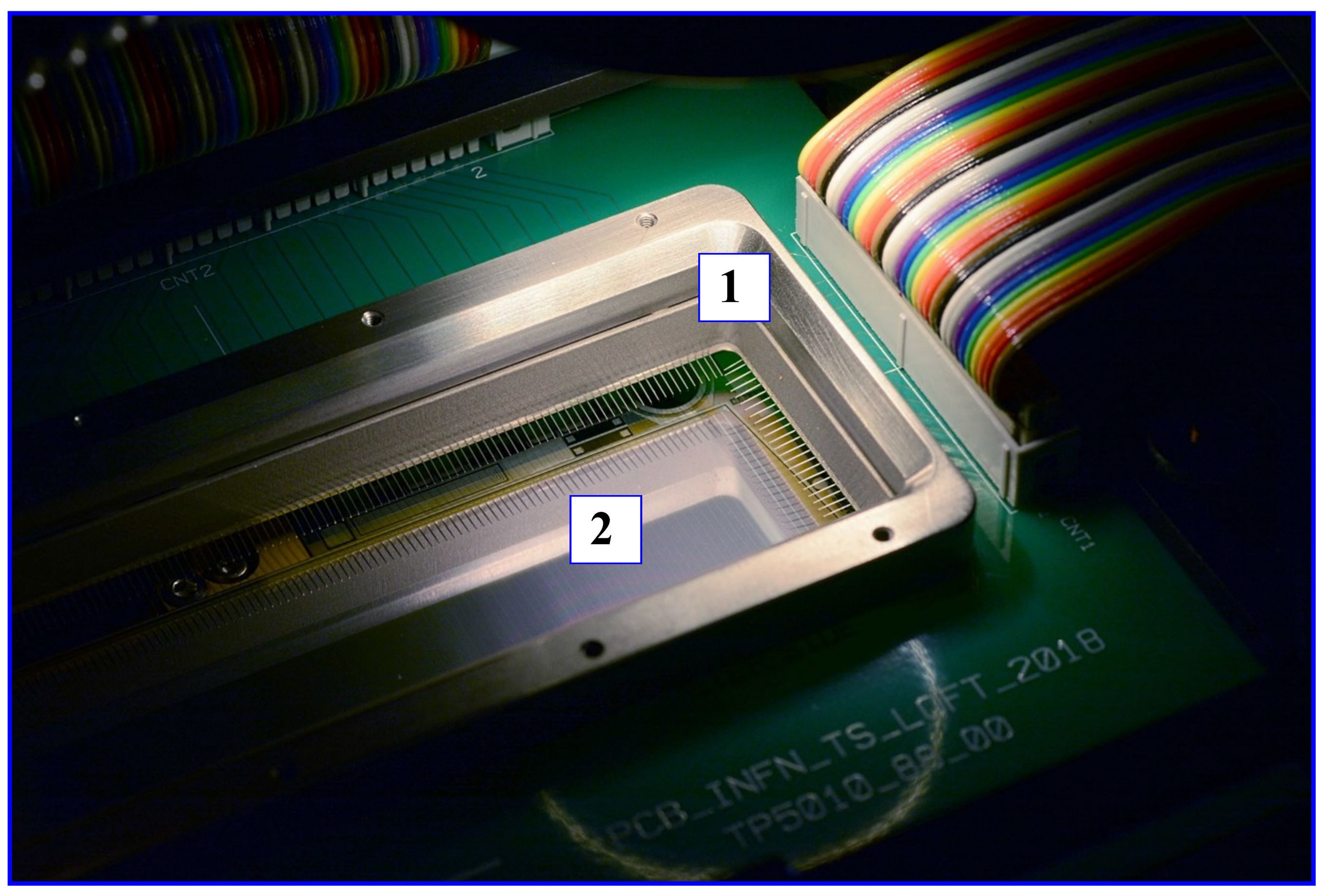

Fig. 5 "anode" probe card with 144 tungsten-rhenium pins (1) and LAD SDD (2).
In the picture the probe card is NOT in contact with the SDD, it is in the loading position above it.

SENSOR

The sensor, designed by INFN-Ts and fabricated by FBK (Trento), on n-type 450 µm thick, 6-inch diameter, n-type silicon wafers with a resistivity of 9 kΩ·cm, is a linear Silicon Drift Detector (SDD). It has a total area of 87.1 cm^2, with a sensitive-to-total area ratio of about 87% (Figure 2). Technology and design are both a significant heritage of a long term activity carried out first for the ALICE experiment at CERN [2, 3, 4], and then for the LOFT M3 mission candidate [5, 6]. It meets the requirements specific for a modern space-borne X-ray detecting system: 2−30 keV energy range with a spectral resolution ≤ 240 eV FWHM at 6 keV, power consumption ≤ 0.5 mW/cm^2 (sensor only) of sensitive area at room temperature, enhanced quantum efficiency at the low end of the energy range, and the capability of X-ray spectral timing on a ten microseconds scale. The sensor geometry is conceived as a two-halves SDD, each one defined by 292 implanted cathode strips with a pitch of 120 µm. They are named "12-half " and "34-half ", in accordance with symbols 1, 2, 3, 4 imprinted via the metallization mask at the sensor corners. On both sides, they are connected to implanted resistive voltage dividers, located along the vertical edges of the sensitive area. Thus, when a bias voltage of 1.3 kV is applied to the central cathode, the divider current flows through the cathode chain, creating a linear potential distribution on the cathode strips. It generates an electric drift field of 360 V/cm in the sensor depleted volume. For each half the drift field is directed towards 112 collection anodes placed with a pitch of 970 µm along the top and the bottom edges of the sensitive area. In this way the signal charge from X-rays impinging the sensor will be distributed on 1 to 3 anodes at most, depending on the drift distance.

TESTING FACILITIES

Dedicated testing facilities already successfully used during the mass production of SDDs for the Inner Tracking System of the ALICE experiment, have been adopted to select 640 sensors that will equip the LAD. We use a Karl-Suss PM8-DSP double side probe-station designed and realized ad hoc (Figures 3, 4, 5). It allows having a simultaneous access with probes to both sensor sides, which is necessary to bias properly the SDD and to perform the qualification procedures. On the upper side containing the anodes we use an epoxy-ring type "anode" probe card with 144 tungsten-rhenium pins: 112 pins for the anodes and 32 pins for drift cathodes. The second epoxy-ring type "bottom" probe card with 32 tungsten-rhenium pins faces the lower side of the SDD and contacts the corresponding drift cathodes. To measure pA range dark currents on the anodes we use a Keithley 617 Programmable Electrometer together with a Keithley 7002 Switch System. The potentials on every 10th drift cathode are measured with a Keithley 237 High Voltage Source Measure Unit together with a Keithley 6103C High Voltage Probe. To complete the qualification procedures for one sensor we need to repeat twice, one for each half, the following sequence: sensor positioning on the probe station withdrawable chuck, put in contact "anode" probe card with SDD upper side, put in contact the "bottom" probe card with SDD lower side, switch on SDD bias, scan the 112 anodes dark currents, measure potentials on every 10th drift cathode of upper and lower sides, switch off SDD bias, move away the probe cards from the SDD. This procedure takes about 1 hour to complete.

Preliminary on-wafer testing can be performed in FBK with a general purpose automatic prober. Total sensor current can be evaluated at different points of the voltage divider at the upper side. An early identification will allow to exclude "bad" sensors from subsequent dicing and characterization steps.

SENSOR QUALIFICATION PLOTS

As an example we give qualification results obtained for the SDD W-90 from the 2016 pre-series production. Figure 6 presents dark currents measured in two halves and normalized to 20 °C temperature. Figure 7 presents the linear potential distribution on drift cathodes of upper and lower sides measured at a bias voltage of 1.3 kV, whereas the potential unbalance between corresponding cathodes of the two sides is shown in Figure 8. W-90 sensor would successfully pass the qualification procedure (see "Sensor Selection Criteria").

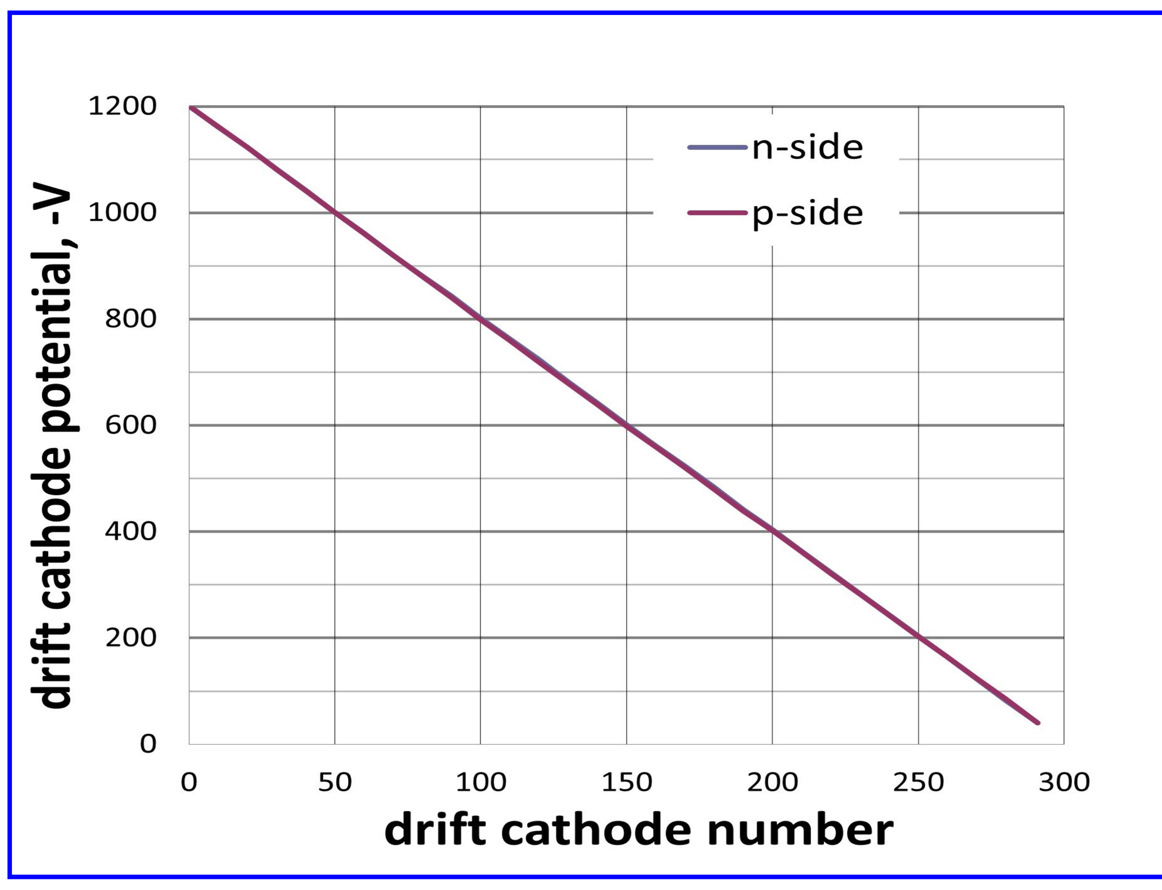

Fig. 7 Potential distribution on drift cathodes

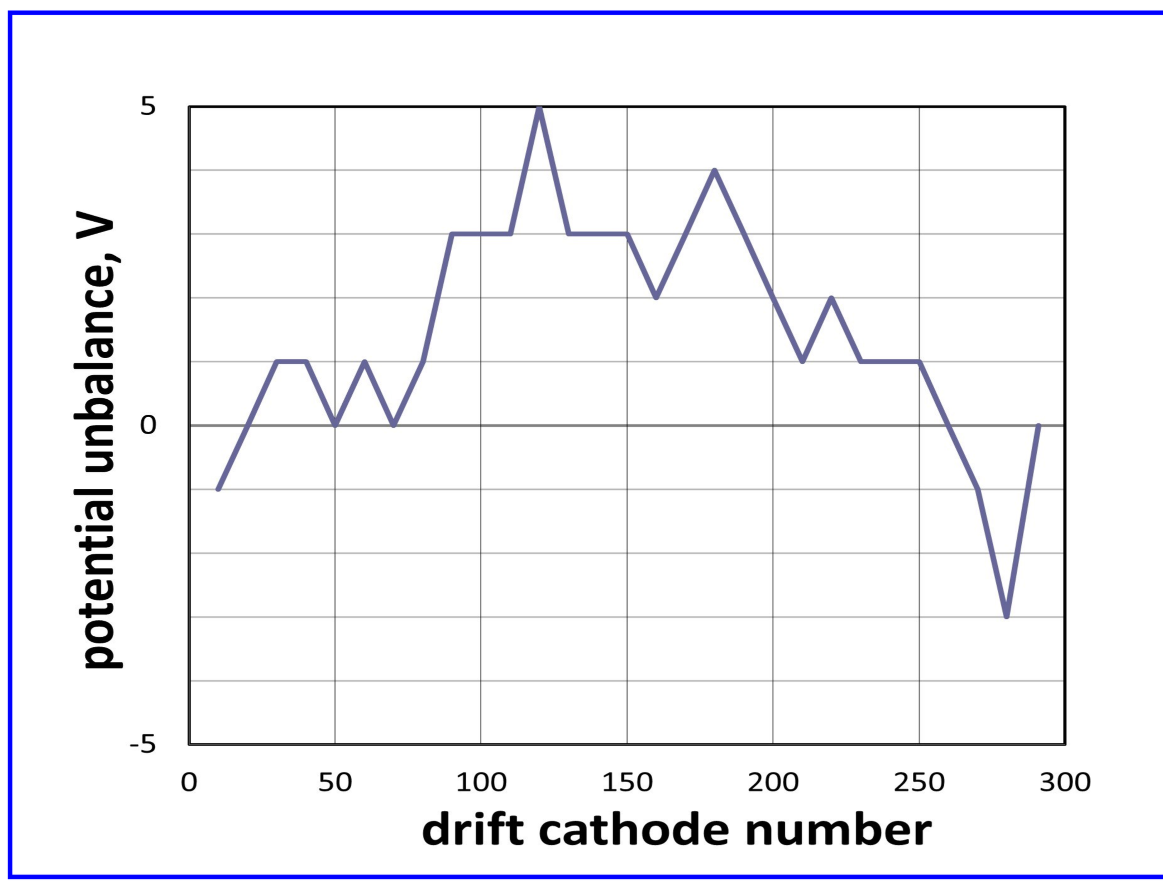

Fig. 8 Potential unbalance between drift cathodes of 2 sides

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