# POLCA2 (POLarimetry with CZT Arrays): experimental set-up, calibration procedures and results.

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# 1. Aims and summary

This document describes the experimental set-up and the preliminary results of the measurements performed with an X-Ray detection system based on a 16x16 pixel CdZnTe detector from Imarad coupled to a Front-End readout based on ASICs from eV products. The experimental activity main goal is to extract evaluations of the polarization detection capability of the CZT detector induced in the crystal by primary polarized 100 keV÷1MeV photons at the European Synchrotron Radiation Facility (ERSF) in Grenoble, France. Preliminary tests shall also be performed at Ferrara University with the 10÷100 keV polarized beam able to qualify a Laue X-Ray focalizing lens prototype.

There have been very few developments in the field of polarimetry in hard X- and soft γ-ray astronomy, indeed not one dedicate polarimeter has ever been launched either as a satellite or balloon borne experiment.

The collaboration developed between the Physics Department of the University of Coimbra, Portugal and the IASF/INAF–Dept. of Bologna (*Istituto di Astrofisica Spaziale e Fisica Cosmica*), Italy, have recently proposed an instrument devoted to polarimetric measurements for hard X-ray and soft gamma ray (100 keV – 10 MeV) astrophysical measurements. The proposed telescope, using four 32 × 32 matrices of thick CdTe micro-spectrometers (2 mm × 2 mm × 10 mm) as the detection plane will allow this type of measurement to be performed for the first time by a dedicated instrument whose detection plane is optimised for the detection of Compton scattered events.

As part of the design process, a sophisticated Monte Carlo simulation code based on the GEANT4 program was developed, and an extensive polarimetric study was performed in order to evaluate the response and performance of the detection plane to the type of linearly polarised radiation expected to be produced by physical processes inherent to celestial sources.

In order to compare the results already obtained from detection plane Monte Carlo simulations with experimental data, a first experimental run (POLCA1) has been performed by using a CdTe prototype matrix (4 × 4 pixels) detector. The data extracted in the first run (POLCA1) encouraged to develop a second experimental set-up (POLCA2) based on a CZT 16x16 pixel detector.

The system should provide coded data able to perform spectroscopic analysis on one or two CZT pixels coincident within a selectable acceptance time (about 1 μsec).

The detection system is implemented with:

- a front-end (FE) electronics able to analogically process up to 122 channels;
- a conventional wired red out electronics (Takes) with 128 channel capability, coincidence circuitry and digital-to-analog converter (10-bit ADC);
- a data collecting system (PC) operating under user written SW in LabView environment.

The report should provide a technical tool both to arrange the experiment preparation and provide the user with the documentation useful to inspect for fault search or to modify the existing set-up.

## 2. The CZT detector

The Imarad CZT detector is organized in 16x16 pixel array; each square pixel having dimensions of 2mmx2mm with an interpixel gap of 0.5 mm. The pixel (anods) CZT are presented at the output user through the connectors J1, J2, J3 (0.5 mm interpin gap, Matsushita/Panasonic) wired on the anode side. J1 and J2 are 50+50 pin, J3 is 70 pin. Since 128 pixels as a maximum can be read out, the connector J3 is not used.

A schematic view of CZT detector and the I/O harness is shown in Fig. 1.

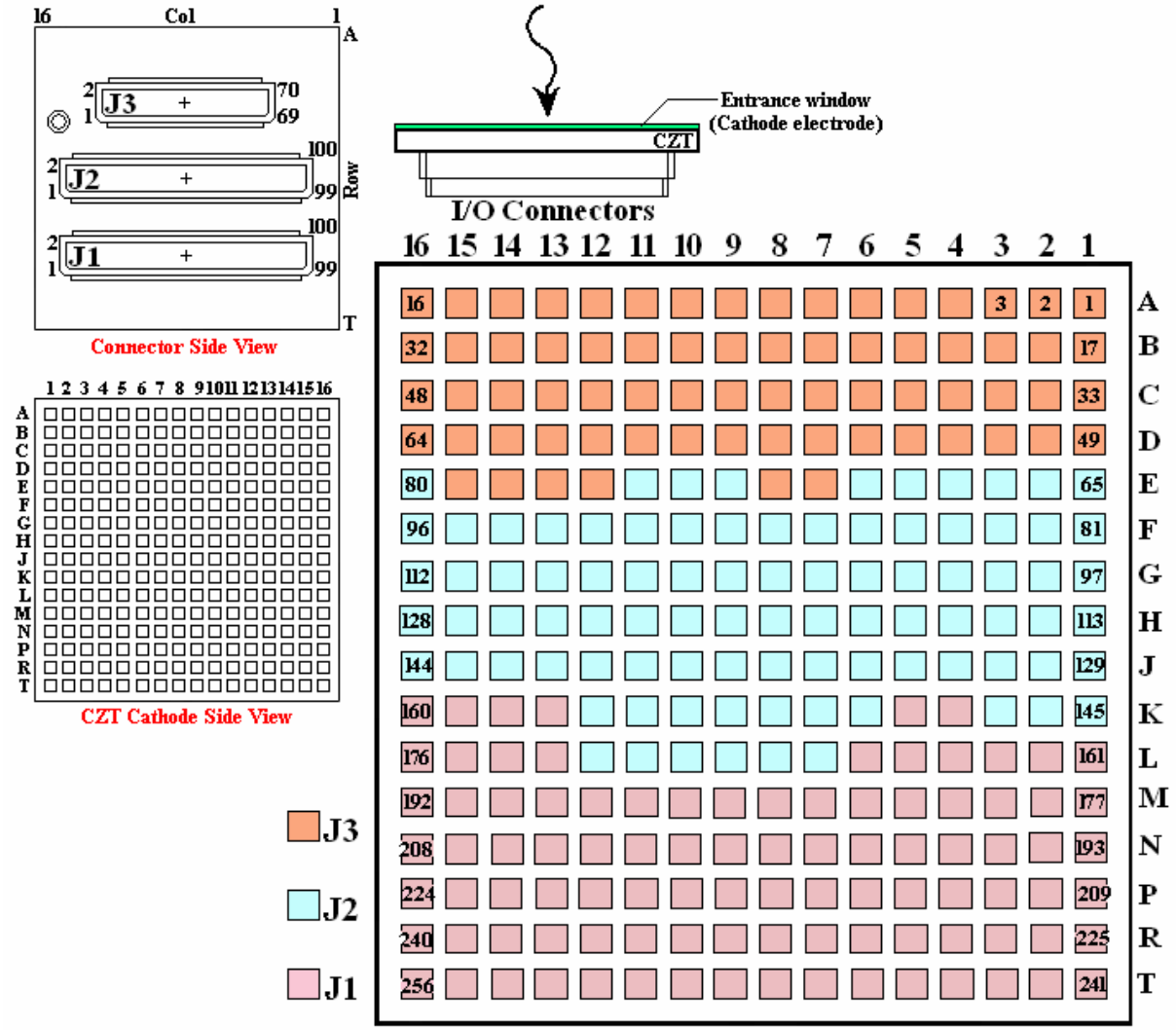



Fig.1. Organization of the 16x16 Imarad CZT detector and I/O connectors.

The following three lists give the pin function of the output connectors J1, J2, J3 both in the Imarad coding (alphanumeric) and in the pixel numbering (purely numeric ranging from 1 to 128).

**Connector J1-100 pin**

| Pin # | | Pixel # | Pin # | | Pixel # |
|---|---|---|---|---|---|
| 1 | P16 | 224 | 2 | K15 | 159 |
| 3 | P15 | 223 | 4 | K16 | 160 |
| 5 | T16 | 256 | 6 | K14 | 158 |
| 7 | T15 | 255 | 8 | K13 | 157 |
| 9 | R16 | 240 | 10 | L16 | 176 |
| 11 | R15 | 239 | 12 | M16 | 192 |
| 13 | R14 | 238 | 14 | L15 | 175 |
| 15 | R13 | 237 | 16 | N16 | 208 |
| 17 | P14 | 222 | 18 | M15 | 191 |
| 19 | P13 | 221 | 20 | N15 | 207 |
| 21 | T14 | 254 | 22 | L14 (?) | 174 |
| 23 | T13 | 253 | 24 | M14 | 190 |
| 25 | P12 | 220 | 26 | L13 | 173 |
| 27 | R12 | 236 | 28 | N14 | 206 |
| 29 | T12 | 252 | 30 | M13 | 189 |
| 31 | P11 | 219 | 32 | N13 | 205 |
| 33 | R11 | 235 | 34 | M11 | 187 |
| 35 | T11 | 251 | 36 | M12 | 188 |
| 37 | P10 | 218 | 38 | N12 | 204 |
| 39 | R10 | 234 | 40 | M10 | 186 |
| 41 | T10 | 250 | 42 | M9 | 185 |
| 43 | T9 | 249 | 44 | N11 | 203 |
| 45 | R9 | 233 | 46 | N10 | 202 |
| 47 | P9 | 217 | 48 | N9 | 201 |
| 49 | T8 | 248 | 50 | N8 | 200 |
| 51 | R8 | 232 | 52 | M8 | 184 |
| 53 | P8 | 216 | 54 | N7 | 199 |
| 55 | T7 | 247 | 56 | N6 | 198 |
| 57 | R7 | 231 | 58 | M7 | 183 |
| 59 | P7 | 215 | 60 | M6 | 182 |
| 61 | T6 | 246 | 62 | K5 | 149 |
| 63 | R6 | 230 | 64 | M5 | 181 |
| 65 | P6 | 214 | 66 | K4 | 148 |
| 67 | T5 | 245 | 68 | N5 | 197 |
| 69 | R5 | 229 | 70 | L6 | 166 |
| 71 | P5 | 213 | 72 | N4 | 196 |
| 73 | T4 | 244 | 74 | L5 | 165 |
| 75 | R4 | 228 | 76 | M4 | 180 |
| 77 | P4 | 212 | 78 | L4 | 164 |
| 79 | T3 | 243 | 80 | $AV_{DD}$ | Not used |
| 81 | R3 | 227 | 82 | ID1 | Not used |
| 83 | P3 | 211 | 84 | ID2 | Not used |
| 85 | T2 | 242 | 86 | ID3 | Not used |
| 87 | R2 | 226 | 88 | N3 | 195 |
| 89 | P2 | 210 | 90 | L3 | 163 |
| 91 | T1 | 241 | 92 | M3 | 179 |
| 93 | R1 | 225 | 94 | N2 | 194 |
| 95 | P1 | 209 | 96 | M2 | 178 |
| 97 | N1 | 193 | 98 | L2 | 162 |
| 99 | M1 | 177 | 100 | L1 | 161 |

**Connector J2-100 pin**

| Pin # | | Pixel # | Pin # | | Pixel # |
|---|---|---|---|---|---|
| 1 | J15 | 143 | 2 | G16 | 112 |
| 3 | H15 | 127 | 4 | F16 | 96 |
| 5 | J14 | 142 | 6 | E16 | 80 |
| 7 | H16 | 128 | 8 | G14 | 110 |
| 9 | H14 | 126 | 10 | F14 | 94 |
| 11 | J16 | 144 | 12 | J13 | 141 |
| 13 | K12 | 156 | 14 | J12 | 140 |
| 15 | K11 | 155 | 16 | F15 | 95 |
| 17 | K10 | 154 | 18 | G15 | 111 |
| 19 | L12 | 172 | 20 | J11 | 139 |
| 21 | | | 22 | H11 | 123 |
| 23 | L11 | 171 | 24 | H13 | 125 |
| 25 | F10 | 90 | 26 | G13 | 109 |
| 27 | H7 | 119 | 28 | J10 | 138 |
| 29 | K8 | 152 | 30 | H10 | 122 |
| 31 | L10 | 170 | 32 | H9 | 121 |
| 33 | G8 | 104 | 34 | J9 | 137 |
| 35 | K9 | 153 | 36 | H12 | 124 |
| 37 | H8 | 120 | 38 | J8 | 136 |
| 39 | F7 | 87 | 40 | G12 | 108 |
| 41 | L9 | 169 | 42 | F13 | 93 |
| 43 | | | 44 | F12 | 92 |
| 45 | L8 | 168 | 46 | G9 | 105 |
| 47 | K7 | 151 | 48 | G11 | 107 |
| 49 | H5 | 117 | 50 | F11 | 91 |
| 51 | G7 | 103 | 52 | G10 | 106 |
| 53 | K6 | 150 | 54 | E11 | 75 |
| 55 | L7 | 167 | 56 | F8 | 88 |
| 57 | J5 | 133 | 58 | E10 | 74 |
| 59 | J4 | 132 | 60 | G5 | 101 |
| 61 | J7 | 135 | 62 | F9 | 89 |
| 63 | H6 | 118 | 64 | E9 | 73 |
| 65 | CGND | Shield | 66 | G4 | 100 |
| 67 | CGND | Shield | 68 | J6 | 134 |
| 69 | CGND | Shield | 70 | F2 | 82 |
| 71 | CGND | Shield | 72 | H4 | 116 |
| 73 | CGND | Shield | 74 | G6 | 102 |
| 75 | CGND | Shield | 76 | G3 | 99 |
| 77 | ID4 | Not used | 78 | F6 | 86 |
| 79 | H3 | 115 | 80 | E2 | 66 |
| 81 | J3 | 131 | 82 | E6 | 70 |
| 83 | AGND | Not used | 84 | J2 | 130 |
| 85 | K3 | 147 | 86 | F5 | 85 |
| 87 | H2 | 114 | 88 | E5 | 69 |
| 89 | H1 | 113 | 90 | E4 | 68 |
| 91 | K1 | 145 | 92 | F4 | 84 |
| 93 | J1 | 129 | 94 | G2 | 98 |
| 95 | K2 | 146 | 96 | E3 | 67 |
| 97 | F1 | 81 | 98 | F3 | 83 |
| 99 | G1 | 97 | 100 | E1 | 65 |

**Connector J3-70 pin**

| Pin # | | Pixel # | Pin # | | Pixel # |
|---|---|---|---|---|---|
| 1 | C16 | 48 | 2 | A16 | 16 |
| 3 | B15 | 31 | 4 | A15 | 15 |
| 5 | C15 | 47 | 6 | A14 | 14 |
| 7 | C14 | 46 | 8 | B16 | 32 |
| 9 | D16 | 64 | 10 | C13 | 45 |
| 11 | D15 | 63 | 12 | B13 | 29 |
| 13 | D14 | 62 | 14 | B14 | 30 |
| 15 | E14 | 78 | 16 | A12 | 12 |
| 17 | E15 | 79 | 18 | B12 | 28 |
| 19 | D13 | 61 | 20 | A11 | 11 |
| 21 | C12 | 44 | 22 | A13 | 13 |
| 23 | E13 | 77 | 24 | C9 | 41 |
| 25 | E12 | 76 | 26 | D9 | 57 |
| 27 | D12 | 60 | 28 | A10 | 10 |
| 29 | C11 | 43 | 30 | A9 | 9 |
| 31 | B11 | 27 | 32 | C8 | 40 |
| 33 | D11 | 59 | 34 | B9 | 25 |
| 35 | D10 | 58 | 36 | B8 | 24 |
| 37 | C10 | 42 | 38 | A8 | 8 |
| 39 | B10 | 26 | 40 | C7 | 39 |
| 41 | D8 | 56 | 42 | A7 | 7 |
| 43 | D7 | 55 | 44 | A6 | 6 |
| 45 | B6 | 22 | 46 | B5 | 21 |
| 47 | C3 | 35 | 48 | A5 | 5 |
| 49 | C6 | 38 | 50 | A4 | 4 |
| 51 | B7 | 23 | 52 | B3 | 19 |
| 53 | D6 | 54 | 54 | A3 | 3 |
| 55 | C5 | 37 | 56 | B2 | 18 |
| 57 | D5 | 53 | 58 | A2 | 2 |
| 59 | E8 | 72 | 60 | C4 | 36 |
| 61 | E7 | 71 | 62 | C2 | 34 |
| 63 | B4 | 20 | 64 | A1 | 1 |
| 65 | D3 | 51 | 66 | B1 | 17 |
| 67 | D4 | 52 | 68 | C1 | 33 |
| 69 | D2 | 50 | 70 | D1 | 49 |

The distribution of the CZT pixels in the I/O connectors is shown in Fig 2. The connector J1 outputs 96 pixels, J2 90, J3 70. The combination of J1 and J2 permits to read up to 186 pixels. As already told, the Takes processing electronics permits to read out up to 128 pixel; since the main constraint dictates a square (11x11) CZT pixel subset is considered, it is required that:

- it is mandatory to connected J2 because it permits to wire the internal CZT detector shieldings to the analog GND of the front-end electronics;
- the couple J2-J3 does not permits to read a 11x11 adjacent pixel subset:
- the couple J1-J2 is chosen for the read out of the detector;
- the connector J3 is left unused.

The election of the couple of connectors J1-J2 permits to read out a square CZT subset of 11x11 pixels arranged as depicted in Fig. 3.


Fig. 2. CZT pixel distribution in the output connectors J1, J2, J3.

| | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | A |
| B | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | B |
| C | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | C |
| D | 64 | 63 | 62 | 61 | 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 | 49 | D |
| E | 80 | 79 | 78 | 77 | 76 | 75 | 74 | 73 | 72 | 71 | 70 | 69 | 68 | 67 | 66 | 65 | E |
| F | 96 J2/4 | 95 J2/16 | 94 J2/10 | 93 J2/42 | 92 J2/44 | 91 J2/50 | 90 J2/25 | 89 J2/62 | 88 J2/56 | 87 J2/39 | 86 J2/78 | 85 J2/86 | 84 | 83 | 82 | 81 | F |
| G | 112 J2/2 | 111 J2/18 | 110 J2/8 | 109 J2/26 | 108 J2/40 | 107 J2/48 | 106 J2/52 | 105 J2/46 | 104 J2/33 | 103 J2/51 | 102 J2/74 | 101 J2/60 | 100 | 99 | 98 | 97 | G |
| H | 128 J2/7 | 127 J2/3 | 126 J2/9 | 125 J2/24 | 124 J2/36 | 123 J2/22 | 122 J2/30 | 121 J2/32 | 120 J2/37 | 119 J2/27 | 118 J2/63 | 117 J2/49 | 116 | 115 | 114 | 113 | H |
| J | 144 J2/11 | 143 J2/1 | 142 J2/5 | 141 J2/12 | 140 J2/14 | 139 J2/20 | 138 J2/28 | 137 J2/34 | 136 J2/38 | 135 J2/61 | 134 J2/68 | 133 J2/57 | 132 | 131 | 130 | 129 | J |
| K | 160 J1/4 | 159 J1/2 | 158 J1/6 | 157 J1/8 | 156 J2/13 | 155 J2/15 | 154 J2/17 | 153 J2/35 | 152 J2/29 | 151 J2/47 | 150 J2/53 | 149 J1/62 | 148 | 147 | 146 | 145 | K |
| L | 176 J1/10 | 175 J1/14 | 174 J1/22 | 173 J1/26 | 172 J2/19 | 171 J2/23 | 170 J2/31 | 169 J2/41 | 168 J2/45 | 167 J2/55 | 166 J1/70 | 165 J1/74 | 164 | 163 | 162 | 161 | L |
| M | 192 J1/12 | 191 J1/18 | 190 J1/24 | 189 J1/30 | 188 J1/36 | 187 J1/34 | 186 J1/40 | 185 J1/42 | 184 J1/52 | 183 J1/58 | 182 J1/60 | 181 J1/64 | 180 | 179 | 178 | 177 | M |
| N | 208 J1/16 | 207 J1/20 | 206 J1/28 | 205 J1/32 | 204 J1/38 | 203 J1/44 | 202 J1/46 | 201 J1/48 | 200 J1/50 | 199 J1/54 | 198 J1/56 | 197 J1/68 | 196 | 195 | 194 | 193 | N |
| P | 224 J1/1 | 223 J1/3 | 222 J1/17 | 221 J1/19 | 220 J1/25 | 219 J1/31 | 218 J1/37 | 217 J1/47 | 216 J1/53 | 215 J1/59 | 214 J1/65 | 213 J1/71 | 212 | 211 | 210 | 209 | P |
| R | 240 J1/9 | 239 J1/11 | 238 J1/13 | 237 J1/15 | 236 J1/27 | 235 J1/33 | 234 J1/39 | 233 J1/45 | 232 J1/51 | 231 J1/57 | 230 J1/63 | 229 J1/69 | 228 | 227 | 226 | 225 | R |
| T | 256 J1/5 | 255 J1/7 | 254 J1/21 | 253 J1/23 | 252 J1/29 | 251 J1/35 | 250 J1/41 | 249 J1/43 | 248 J1/49 | 247 J1/55 | 246 J1/61 | 245 J1/67 | 244 | 243 | 242 | 241 | T |

Fig.3. CZT Pixel subset (low left hand corner) selected for the experiment.
Pixels are also related to the J1-J2 output pin number.

Fig. 4 shows the details of the J1-J2 output pin connection assembled at the factory, the association with the pixel numbering (Fig. 2&3) and the grouping of the pixel signals relative to the destination FE ASICs (8, 16 channel eV ASICs are used).

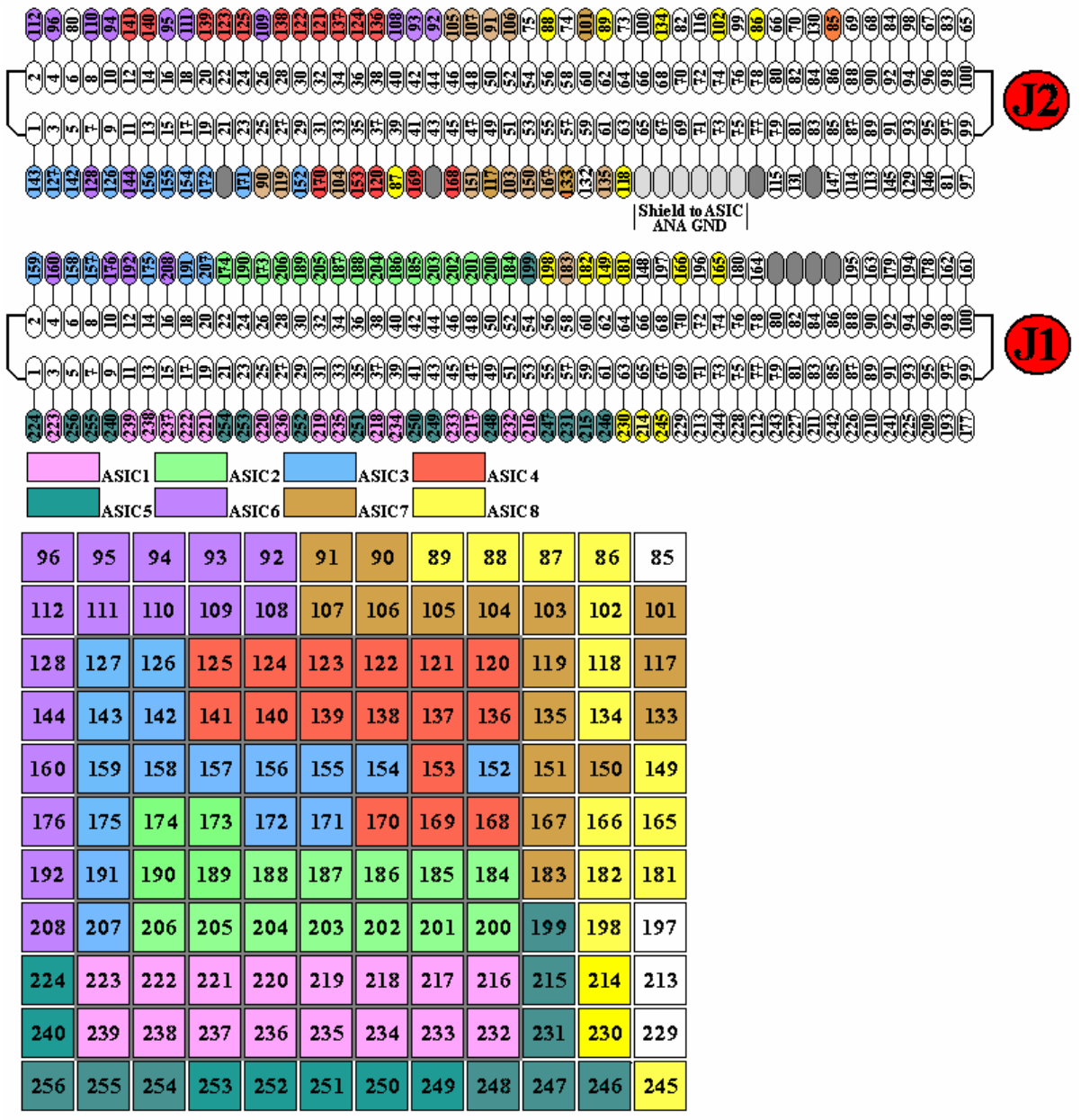



Fig. 4. CZT subset chosen for the read out and pixel association with the 8 eV ASICs.

The use of the eV ASICs, each of which analogically processes 16 CZT channels, permits-in combination with the associated Takes electronics and the acquisition system-to accumulate two

coded events coincident within the acceptance time. So, even if somewhat pletoric and expensive, the experimental set-up permits both photon-by-photon spectroscopy and polarimetric studies.

## 3. The Front-End electronics

A dedicated PCB has been designed and developed for the FE electronics (8, 16 channel ASICs from eV products) by simply reproducing a PCB design constructed for another application requiring the use of a single eV ASIC (16 analog channels). The implementation (Fig. 5) was been found reliable and has been also adopted as basic active component for the present application.

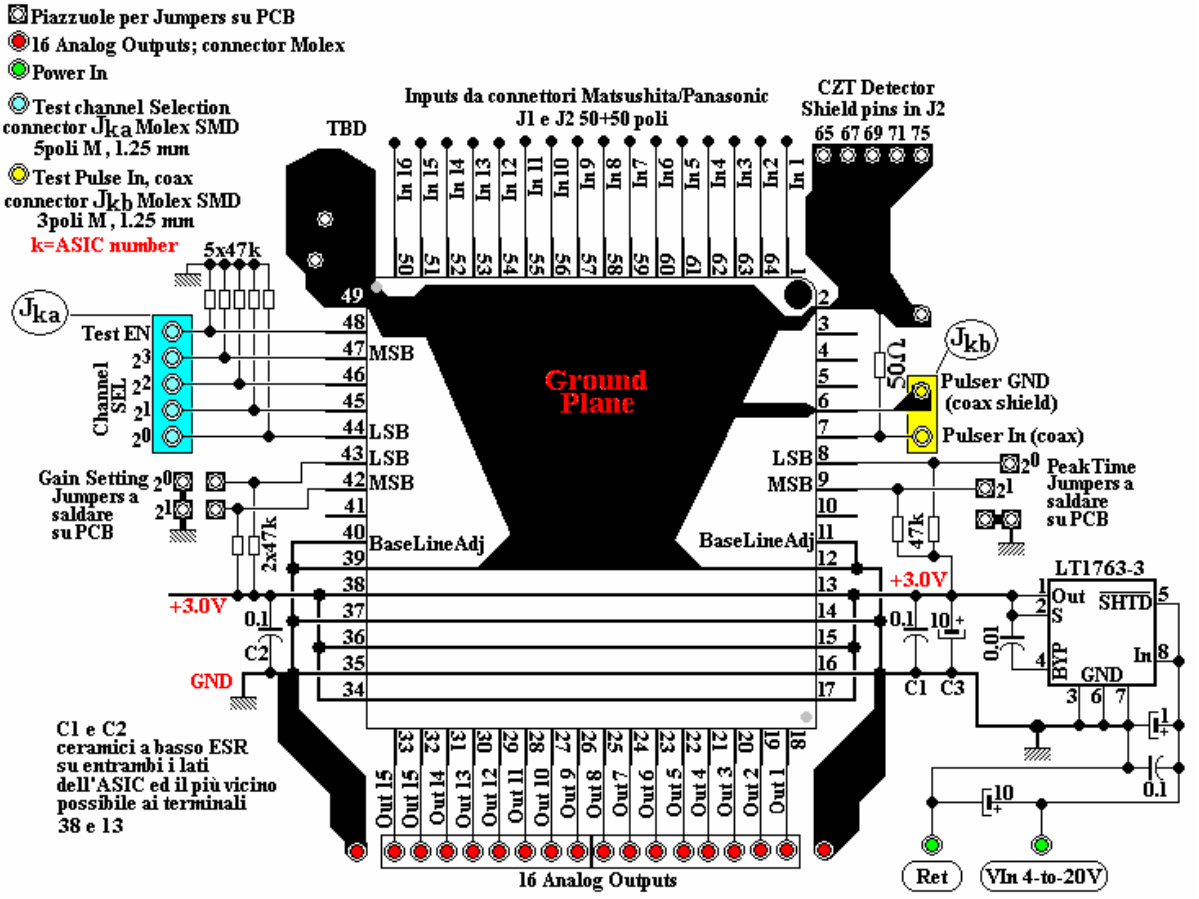



Fig. 5. Basic electric configuration for an eV, 16-chs ASIC. A LT1763 LDO regulator is used to bias two ASICs, which means that in the final PCB there are 4 regulators.

In Appendix I are reported the electrical schemes of the 4 couples of ASICs, each couple being powered by an LT-1763 regulator.

Fig. 6 shows the component side view of the 8-ASICs PCB. By acting on couples of on-board jumpers (JPi, JPi+1), any ASIC's gain and peaking time can be independently regulated: possible values are listed in Table I.

Table I: ASIC's gain and peaking time values for setting

| Gain (mV/fC) | JPi | | Peaking Time (μsec) | JPi+1 | |
|---|---|---|---|---|---|
| | LSB | MSB | | LSB | MSB |
| 200 | 0 | 0 | 0.6 | 0 | 0 |
| 100 | 1 | 0 | 1.2 | 1 | 0 |
| 50 | 0 | 1 | 2.4 | 0 | 1 |
| 33 | 1 | 1 | 4 | 1 | 1 |

Jumpers JPi and JPi+1 open select Gain=33 mV/fC, Peaking Time=4 μsec, respectively.
Furthermore, by acting on the channel address (on board connectors Ji) and feeding an input pulse to the correspondent connectors Ji+1, there is the possibility to individually test anyone of the 128 ASICs' channels, one at a time.

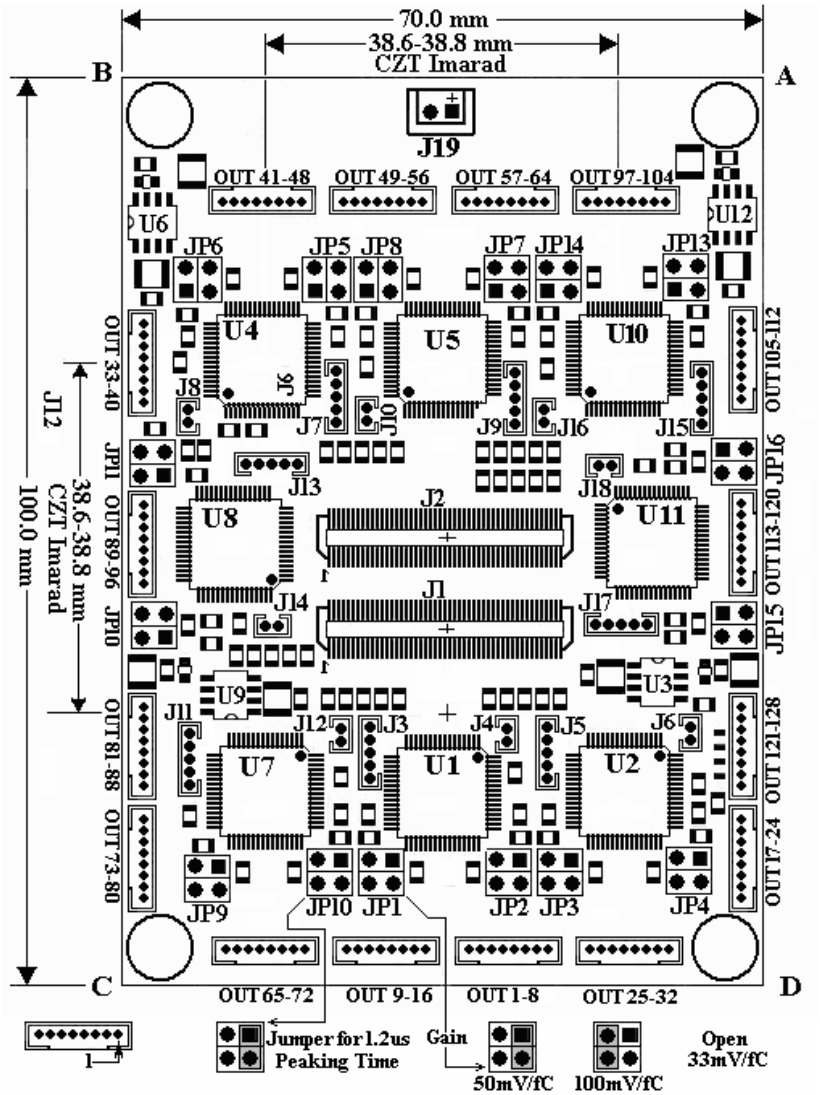



Fig. 6-a. Component side view of the ASIC PCB, together with the on-board connectors. The connectors coupling the PCB with the CZT detector output multipin connectors (J1 & J2) are soldered on the opposite side.

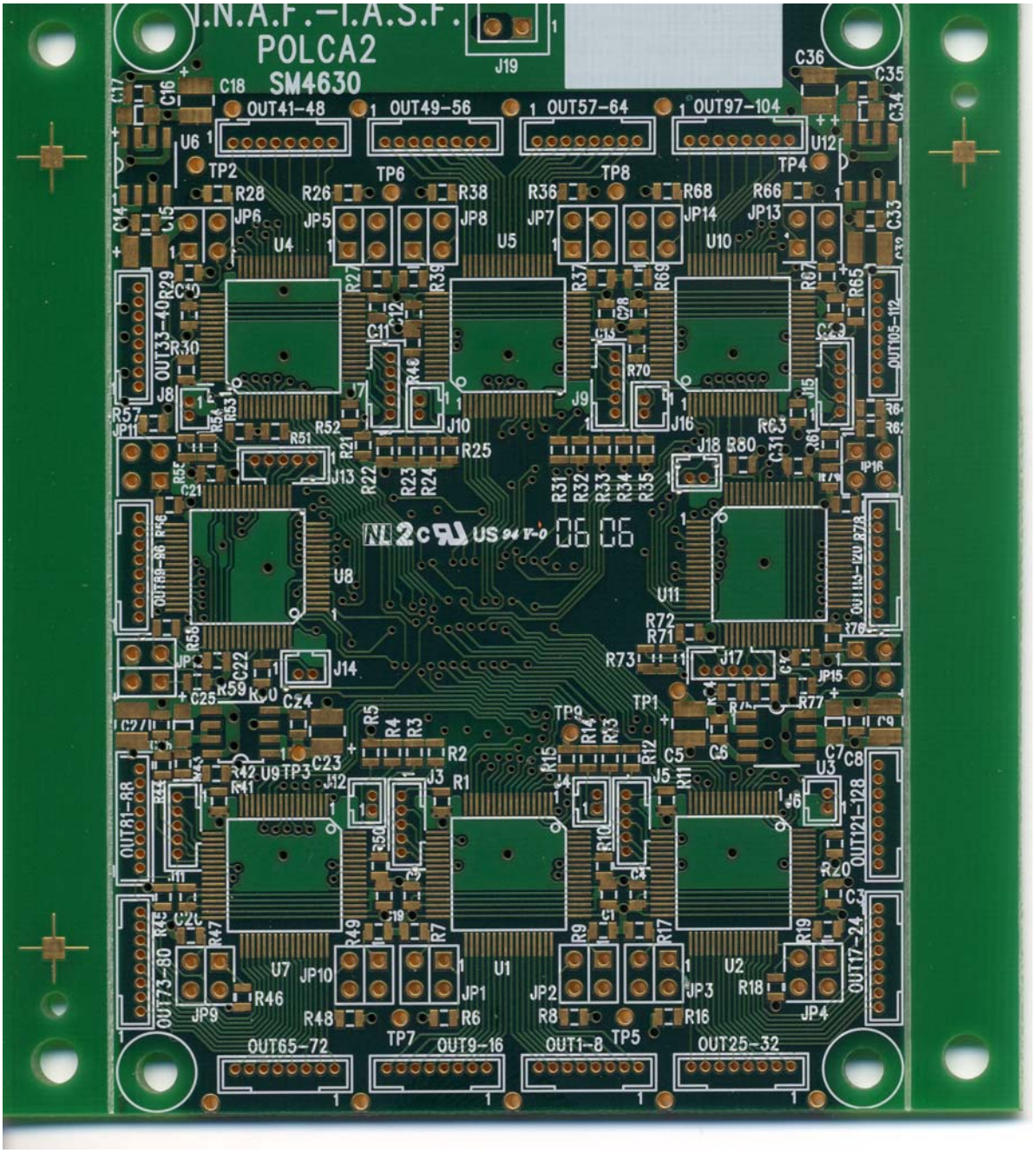



Fig. 6-b. Picture of the ASIC side in the POLCA2 interface board. The pads labelled *Tp1*, *Tp2*, *Tp3*, *Tp4* are test points for regulated + 3V (independent checks for outputs provided by four LT1763-3 regulators), while the ones labelled *Tp5*, *Tp6*, *Tp7*, *Tp8*, *TP9* are test points for GND.

## 3.1. The FE mechanical arrangement

In the original design the FE (CZT detector, ASIC PCB, HV DC-DC converter, Voltage pre-regulators) should have been included in the same container. However, due to the 3.5 Watt power consumption of the ASIC PCB and the tight proximity with the CZT detector, the system temperature tend to rise up 30-35°C with an ambient kept at about 24°C. Since the rise in detector temperature tends to increase the leakage current, so degrading the overall noise performance, it was decided to separate the ASIC PCB container from the CZT detector box, trying to reduce a tight thermal coupling. This led to the arrangement schematically shown in Fig. 7.

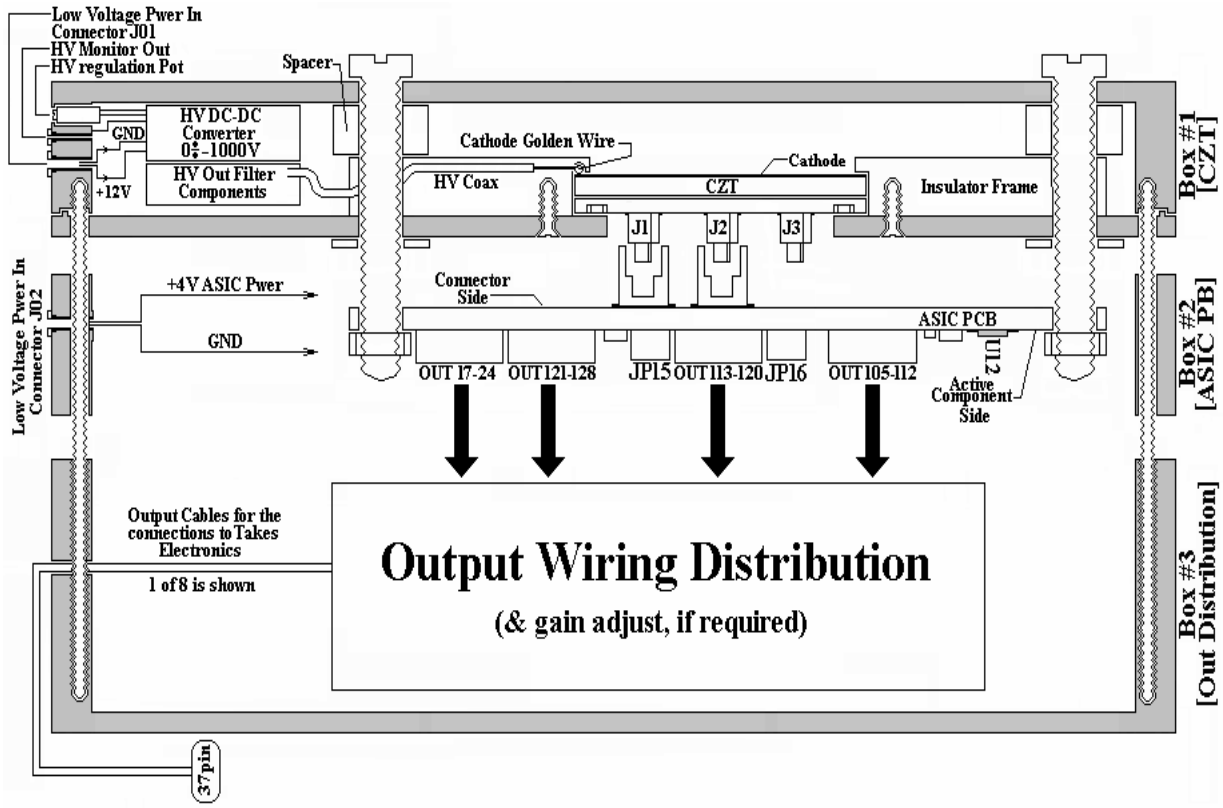



Fig. 7. Mechanical assembly of POLCA2 experiment: three boxes, mechanically and electrically connected, provide EMI protection and thermal insulation of the CZT detector with respect to the other FE subsystems. Lateral view from the higher ASIC PCB dimension. The ASIC PCB dimensions are 10cmx7cm, the dimensions of the containers are 15cmx8cm (height is different for the three boxes).

## 3.2. The ASIC PCB electrical harness

The ASIC PCB electrical Input connectors and the related functions are listed in Table II. Except for the connectors J1&J2 coupling the CZT detector to the ASIC PCB, all the connectors are card-edge type and are wired on the PCB component side.

Table II: ASIC PCB Input connectors.

| Connector | Function | ASIC # | IC | Notes | Connector Type |
|---|---|---|---|---|---|
| J1 | Inputs from CZT | | | Solder Side | 100 pin Panasonic |
| J2 | Inputs from CZT | | | Solder Side | 100 pin Panasonic |
| J3 | Ch SEL ASIC # 1 | 1 | U1 | Component Side | Molex 5 pin |
| J4 | Pulser In ASIC # 1 | 1 | U1 | Component Side | Molex 2 pin |
| JP1 | Gain Setting ASIC # 1 | 1 | U1 | Component Side | Jumper 2 positions |
| JP2 | Peak Time ASIC # 1 | 1 | U1 | Component Side | Jumper 2 positions |
| J5 | Ch SEL ASIC # 2 | 2 | U2 | Component Side | Molex 5 pin |
| J6 | Pulser In ASIC # 2 | 2 | U2 | Component Side | Molex 2 pin |
| JP3 | Gain Setting ASIC # 2 | 2 | U2 | Component Side | Jumper 2 positions |
| JP4 | Peak Time ASIC # 2 | 2 | U2 | Component Side | Jumper 2 positions |
| J7 | Ch SEL ASIC # 3 | 3 | U4 | Component Side | Molex 5 pin |
| J8 | Pulser In ASIC # 3 | 3 | U4 | Component Side | Molex 2 pin |
| JP5 | Gain Setting ASIC # 3 | 3 | U4 | Component Side | Jumper 2 positions |
| JP6 | Peak Time ASIC # 3 | 3 | U4 | Component Side | Jumper 2 positions |
| J9 | Ch SEL ASIC # 4 | 4 | U5 | Component Side | Molex 5 pin |
| J10 | Pulser In ASIC # 4 | 4 | U5 | Component Side | Molex 2 pin |
| JP7 | Gain Setting ASIC # 4 | 4 | U5 | Component Side | Jumper 2 positions |
| JP8 | Peak Time ASIC # 4 | 4 | U5 | Component Side | Jumper 2 positions |
| J11 | Ch SEL ASIC # 5 | 5 | U7 | Component Side | Molex 5 pin |
| J12 | Pulser In ASIC # 5 | 5 | U7 | Component Side | Molex 2 pin |
| JP9 | Gain Setting ASIC # 5 | 5 | U7 | Component Side | Jumper 2 positions |
| JP10 | Peak Time ASIC # 5 | 5 | U7 | Component Side | Jumper 2 positions |
| J13 | Ch SEL ASIC # 6 | 6 | U8 | Component Side | Molex 5 pin |
| J14 | Pulser In ASIC # 6 | 6 | U8 | Component Side | Molex 2 pin |
| JP10 | Gain Setting ASIC # 6 | 6 | U8 | Component Side | Jumper 2 positions |
| JP11 | Peak Time ASIC # 6 | 6 | U8 | Component Side | Jumper 2 positions |
| J15 | Ch SEL ASIC # 7 | 7 | U10 | Component Side | Molex 5 pin |
| J16 | Pulser In ASIC # 7 | 7 | U10 | Component Side | Molex 2 pin |
| JP13 | Gain Setting ASIC # 7 | 7 | U10 | Component Side | Jumper 2 positions |
| JP14 | Peak Time ASIC # 7 | 7 | U10 | Component Side | Jumper 2 positions |
| JP17 | Ch SEL ASIC # 8 | 8 | U11 | Component Side | Molex 5 pin |
| J18 | Pulser In ASIC # 8 | 8 | U11 | Component Side | Molex 2 pin |
| JP15 | Gain Setting ASIC # 8 | 8 | U11 | Component Side | Jumper 2 positions |
| JP16 | Peak Time ASIC # 8 | 8 | U11 | Component Side | Jumper 2 positions |
| J19 | Power In (+4V) | | | Component Side | Amphenol 2 pin |

Any Output connector groups 8 ASIC Channels, for a total of 16 8-pin Molex connectors wired on the four peripheral sides of the ASIC PCB Component surface. The Output connectors are labelled as Out(1-8), Out(9-16),……, Out(113-120), Out(121-128).

Fig. 8 shows the correspondence required to relate any CZT Pixel to the ASIC processing Channel: i.e. CZT(Out-J1&J2)- PixelCZT#- ASIC#- ASICCh#-ChannelOutLabelling

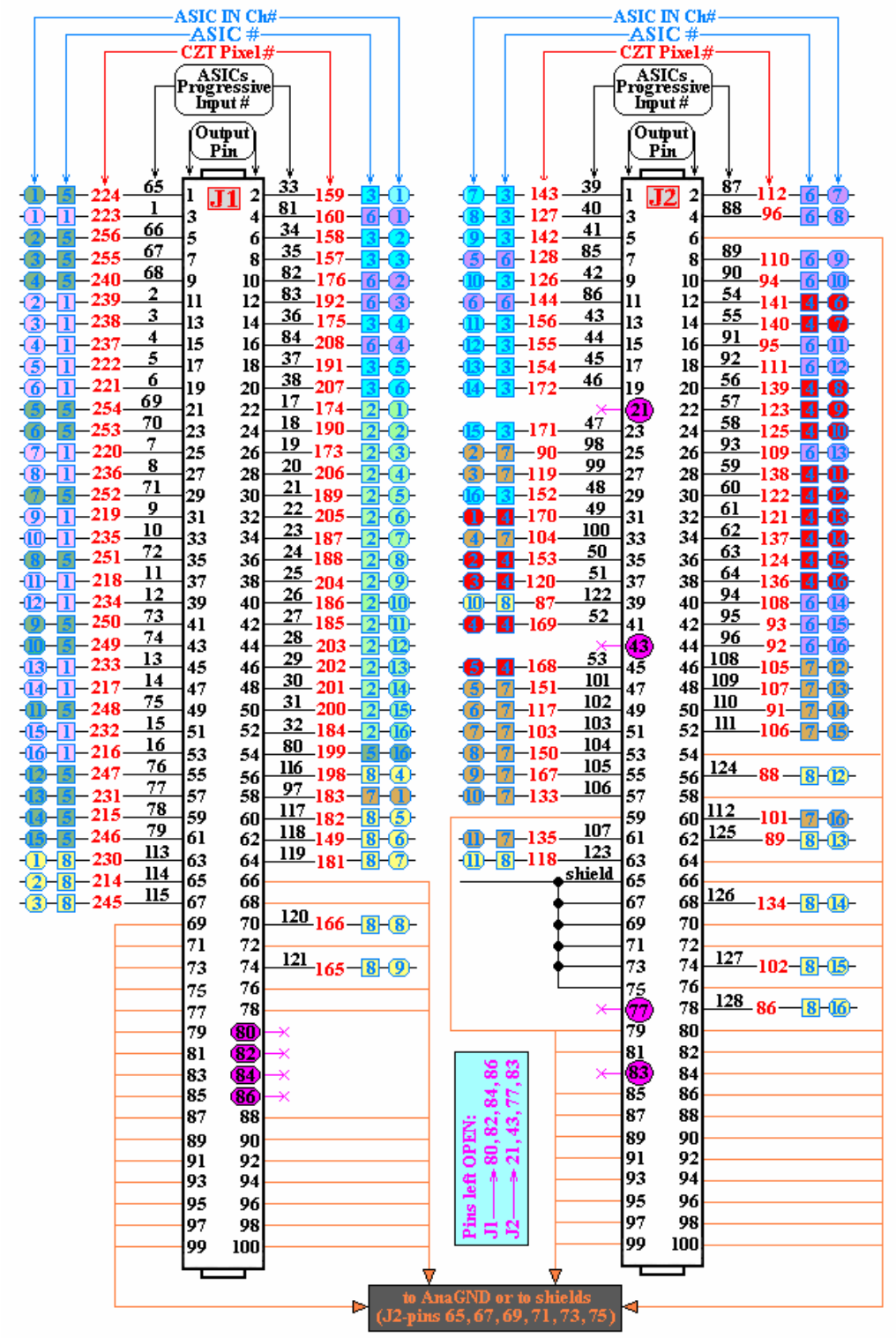



Fig. 8. Correspondence map between J1-J2 CZT pin function and ASIC user defined channels. Unused CZT outputs are tied to GND to limit the electrical field distortion.

## 3.3. The electrical diagrams of the FE containers

Simple electronics provide interface with the subsystems mounted in the three containers (Box#1, Box#2, Box#3). They are considered in details.

### 3.3.1. Electronics inside Box#1

The elecronics wired inside Box#1 simply has to:

- provide low voltage supply to power the EMCO high voltage DC-DC converter;
- provide the output voltage monitor (low-voltage, 0-5V) able to control the HV supply;
- permit the high voltage regulation by action on a potentiometer accessible from the external.

The electrical diagram is shown in Fig. 9.

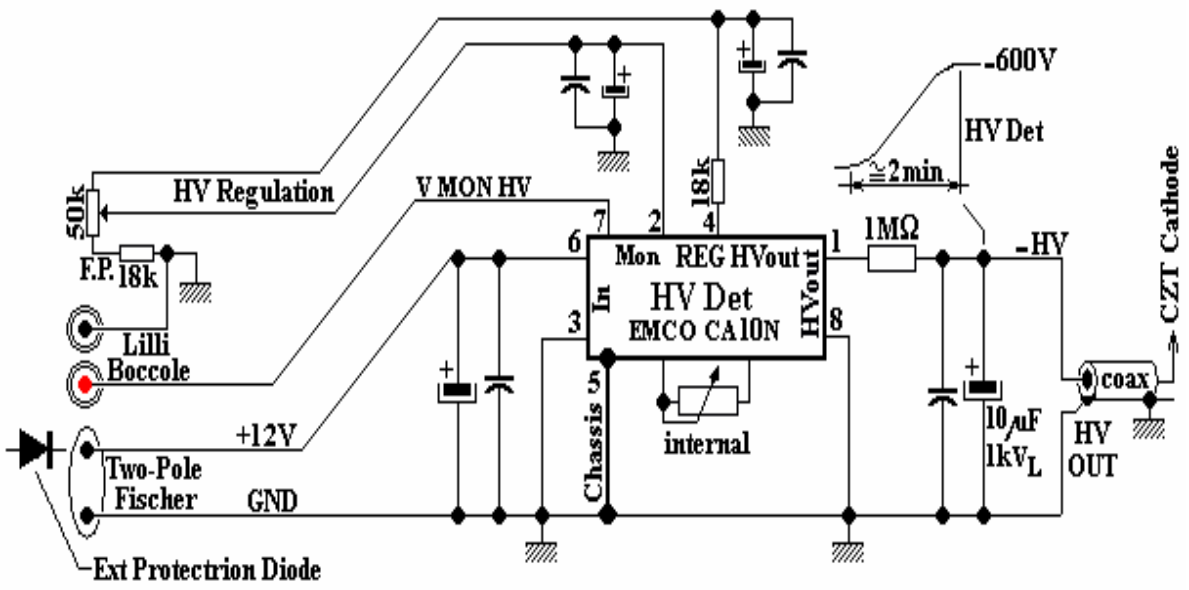



Fig. 9. Components wired inside the Box#1 to give HV Bias to the CZT detector and make possible external control.

The High Voltage monitor value as a function of the High Voltage applied to the CZT detector is given below in Table III. Minimum (– 216 V) and maximum (– 822 V) high voltage are due to the series resistors in the regulation network. The Imarad CZT typical bias voltage is – 600 V.

The sensitivity of the HV monitor is of the order of 4.05 mV(out)/1V(HV).

Table III. The relation between the HV bias voltages and the HV monitor values.

| HV (Volt) | HV Monitor (Volt) |
|---|---|
| – 216 | 0.878 |
| – 300 | 1.219 |
| – 400 | 1.618 |
| – 500 | 2.023 |
| – 600 | 2.430 |
| – 700 | 2.835 |
| – 800 | 3.242 |
| – 822 | 3.332 |

### 3.3.2. Electronics inside Box#2

No additional electronics is wired inside Box#2, except for the ASIC PCB. The input power connector (+4Volt DC) is J02 and outside remotely protection diode is to be used to prevent from reverse supply polarity. J02 is connected to the on-board 2-pin connector Amphenol J19.

### 3.3.3. Electronics inside Box#3

No electronic component is wired inside Box#3, unless the Takes electronics require a reduction in any channel gain. If it is needed to reduce the channel gains, in the Box#3 16 DIP sockets are provided permitting to reduce the overall signal gains by placing in series to any channel a resistor in accordance with the Takes electronics requirements. If no gain reduction is required, jumpers will transfer the ASIC outputs directly to Takes electronics inputs. The Box#3 simply accepts the ASIC outputs from the 16-8-pin organized Molex outputs and adapt them to the standard inputs of the Takes electronics (DB 37 pin).

Fig. 10-a shows the overall wiring schematics relative to the Front-End subsystems.

If required to use the test facility for the ASICs, the Box#3 should be removed and connectors for the channel selection (address) and test pulse placed in the position to test the desired ASIC. Channel selection is simply performed by facing the wanted 4-bit configuration in the appropriate channel selection connector (Molex, 5 pin, 1 for pulser enable, 4 for the channel addressing).

### 3.3.4. Power requirements

Two power supplies are required by the FE:

- +12V (connector J01) for the EMCO HV DC-DC converter. The power drain is ≈ 15 mA at the power-on, lowering to about 5 mA after the burn-in (3 minutes).
- +4V (connector J02) for the ASIC PCB. The power drain is ≈ 850 mA at the power-on, lowering to about 800 mA after the burn-in (5 minutes).

As power sources a double series regulated-high stability-low ripple/noise laboratory power supplies is used.

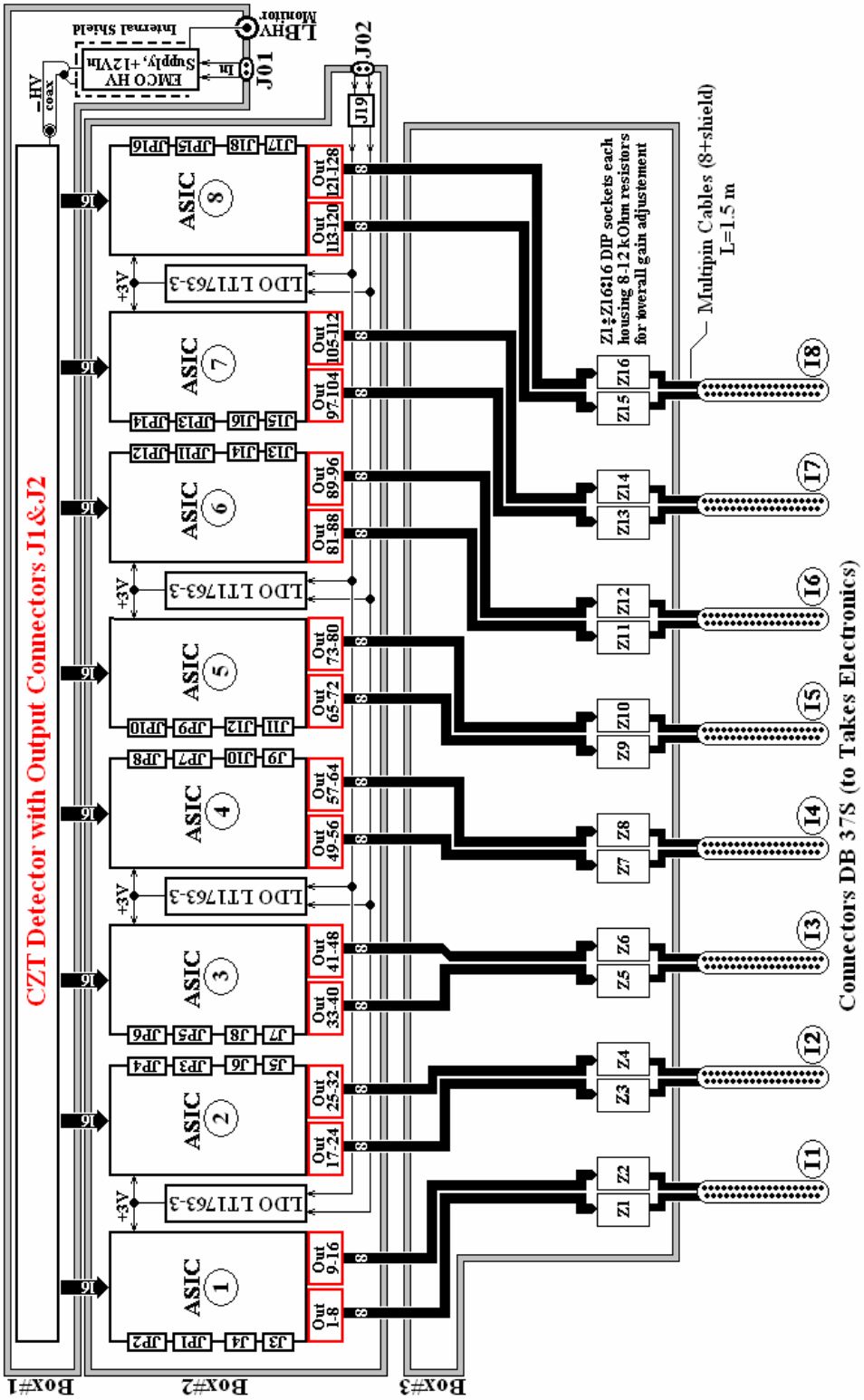
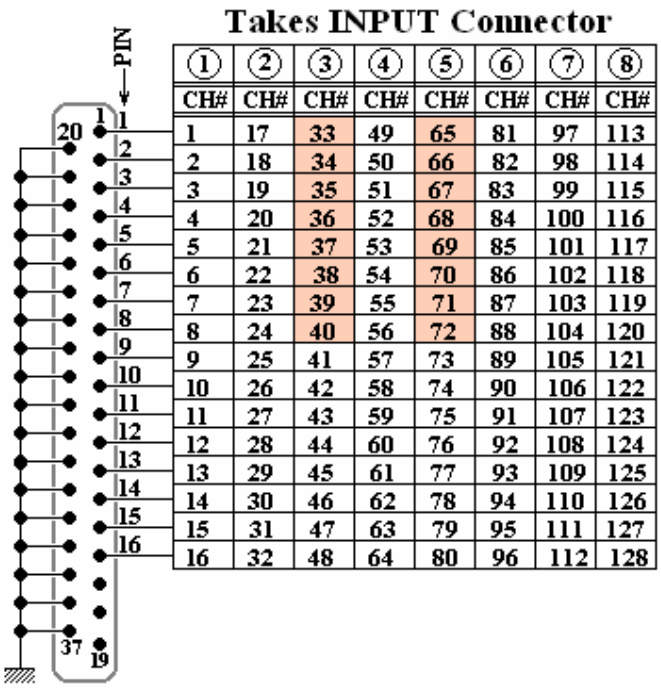



Fig. 10-a. Wiring distribution of the POLCA2 Front-End electronics.

Table IV: list of the I/O connectors of the POLCA2 FE.

| Connector | Function | Type | | |
|---|---|---|---|---|
| J01 | +12V power In (HV) | 2-pole Fischer | Box#1 | |
| LB | HV Monitor Out | Mini sockets | Box#1 | |
| J02 | +4V power In (ASIC PCB) | | Box#2 | |
| 1 | Out 1-16/In Takes | DB37S | Box#3 | Cable + flying connector |
| 2 | Out 17-32/In Takes | DB37S | Box#3 | Cable + flying connector |
| 3 | Out 33-48/In Takes | DB37S | Box#3 | Cable + flying connector |
| 4 | Out 49-64/In Takes | DB37S | Box#3 | Cable + flying connector |
| 5 | Out 65-80/In Takes | DB37S | Box#3 | Cable + flying connector |
| 6 | Out 81-96/In Takes | DB37S | Box#3 | Cable + flying connector |
| 7 | Out 97-112/In Takes | DB37S | Box#3 | Cable + flying connector |
| 8 | Out 113-128/In Takes | DB37S | Box#3 | Cable + flying connector |




| ① CH# | ② CH# | ③ CH# | ④ CH# | ⑤ CH# | ⑥ CH# | ⑦ CH# | ⑧ CH# |
|---|---|---|---|---|---|---|---|
| 1 | 17 | 33 | 49 | 65 | 81 | 97 | 113 |
| 2 | 18 | 34 | 50 | 66 | 82 | 98 | 114 |
| 3 | 19 | 35 | 51 | 67 | 83 | 99 | 115 |
| 4 | 20 | 36 | 52 | 68 | 84 | 100 | 116 |
| 5 | 21 | 37 | 53 | 69 | 85 | 101 | 117 |
| 6 | 22 | 38 | 54 | 70 | 86 | 102 | 118 |
| 7 | 23 | 39 | 55 | 71 | 87 | 103 | 119 |
| 8 | 24 | 40 | 56 | 72 | 88 | 104 | 120 |
| 9 | 25 | 41 | 57 | 73 | 89 | 105 | 121 |
| 10 | 26 | 42 | 58 | 74 | 90 | 106 | 122 |
| 11 | 27 | 43 | 59 | 75 | 91 | 107 | 123 |
| 12 | 28 | 44 | 60 | 76 | 92 | 108 | 124 |
| 13 | 29 | 45 | 61 | 77 | 93 | 109 | 125 |
| 14 | 30 | 46 | 62 | 78 | 94 | 110 | 126 |
| 15 | 31 | 47 | 63 | 79 | 95 | 111 | 127 |
| 16 | 32 | 48 | 64 | 80 | 96 | 112 | 128 |

Fig. 10-b. Correspondence between the physical pins in the Takes connector and the electronics channels in the multi-parametric system.

# 4. The POLCA2 Read out and Acquisition system

The POLCA2 experiment is represented by the block diagram of Fig. 11. As desribed above (section 2 & 3), the FE detection system and Electronics provide 128 analog signals to the Read-Out Electronics (Takes). Any CZT channel, independently amplified and shaped by active semi-gaussian filters inside the ASIC to which it is connected, is separately presented to the Takes electronics at an input to which a unique address is associated.

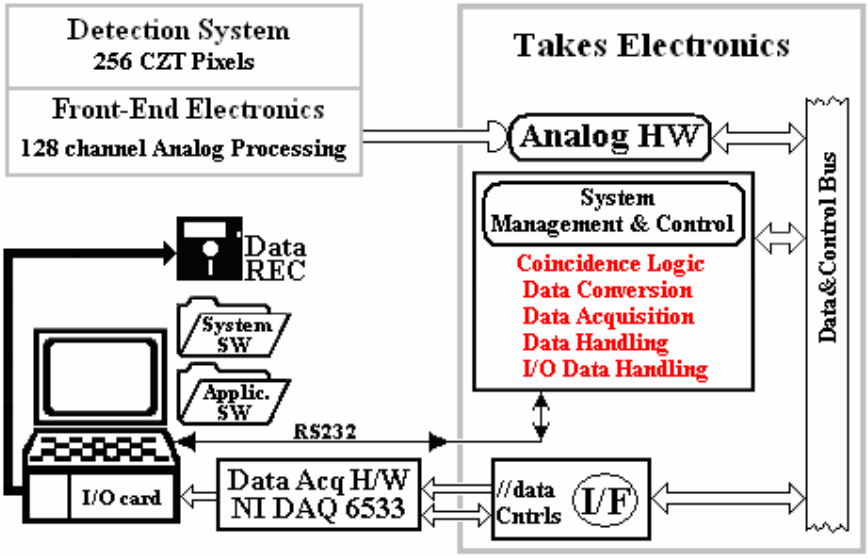



Fig. 11. The POLCA2 experiment with subsystems set in evidence together with the overall control CPU.

Both the HW and SW have been described in detail (IntRep-Polca1: **Ref. d**). It should be underlined the main features of the Takes Electronics. Any signal is presented to a peak stretcher (**PPS**) and to a voltage comparator (minimum energy threshold $\mathbf{E_{min}}$). The peak voltage of any analog signal overcoming $\mathbf{E_{min}}$ is pre-stretched for a time of the order of the input pulse rise time (≈ 0.7 μsec). For the 128 pixel signals configuration, if within the coincidence window time, selectable among 1, 2, 4, 8, 16 μsec, one or two digitized outputs coming from the energy thresholds $\mathbf{E_{min}}$ occur, a post stretching action is issued and the analog data are enabled to be converted in digital by the analog-to-digital converter (ADC). The coincidence criterion is simply based on the fact that single or double events detected within the coincidence time (usually 1 or 2 μsec) are accepted as valid and then post-stretched to be converted in digital by the 12 bit flash ADC. The energy of any event (single or double overcoming $\mathbf{E_{min}}$) is coded with 10 significant bits and to any channel an address code is associated depending on its physical input wiring. Takes also adds a coded field which allows to detect if a single or double event has occurred within the selected coincidence time.

Takes reserves a word of 32 bit to any single event, two 32 bit pattern for any double event. Furthermore, for design reasons, Takes provides output coded data in serial form.

Since the address associated by Takes to any input does not correspond to the real pixel number (Fig. 3), the POLCA2 SW has to convert the Takes address into the true pixel address in order to reconstruct the square subset read (Fig. 4). The trans-coding is performed by using a look-up table constructed by means of the correspondence listed in Appendix II.

## 5. The POLCA2 calibration program

The calibration procedure has the main following purposes:

- to inspect for the presence of “dead” pixels;
- to have quantitative evaluations on the channel-to-channel non-uniformity (pixel efficiency combined with the ASIC channel gain);

- to verify the linearity of the detection system, i.e. the response at various Gamma-ray energies;
- to evaluate the noise level of each active pixel in order to set the minimum energy threshold;
- to extract the energy resolution of each living pixel at different Gamma-ray energies.

The calibration set-up is shown in Fig. 12 and permits to test any analog channel output provided by the FE electronics by sequentially selecting groups of 8 ASIC channel outputs.

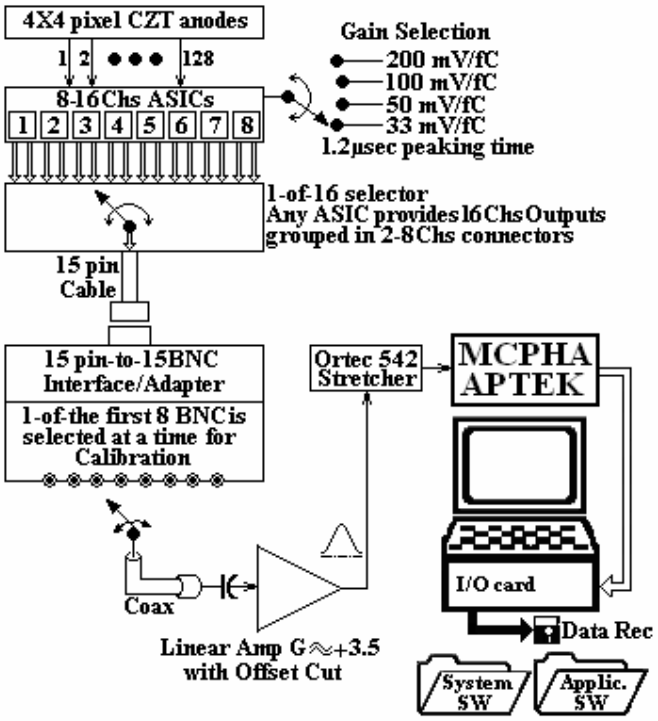



Fig. 11. Calibration set-up to test any individual channel separately.

### 5.1.1. CZT working ability inspection

The tests on any CZT pixel have been performed with the basic set-up shown in Fig. 11 by using two $^{137}$Cs and $^{57}$Co radioactive sources which gave the possibility to both inspect for dead/faulty channels and verify the CZT capability to cover the desired energy range [100keV÷1MeV]. The use of a unique external amplification chain and the same stretcher ensures for the inspection on non-uniformities limited only to the CZT-ASIC cannel combination. The ASICs' selected gain is 50 mV/fC and, taking into account the external amplification factor of about 3.5, the detection system permits to cover the desired range, even with an ASIC gain of 100 mV/fC, used with $^{57}$Co. Two totally dead pixel were found over 128 which led to a useful CZT area of about 98.5%. The dead pixels are #172 (amplification channel 46) and #176 (amplification channel 82). As expected, some pixels were found to be more noisy than others and thus almost unusable: typical spectra of a good working pixel and a "poor" one are shown in comparison in Fig. 12.

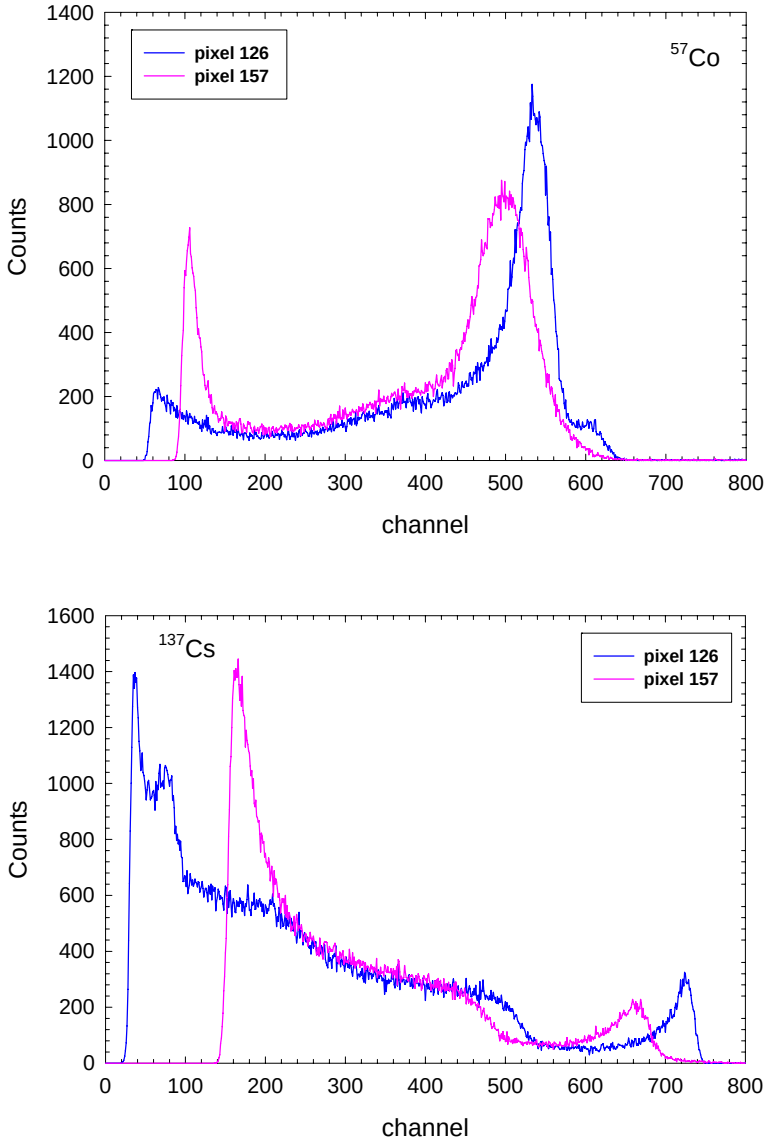



Fig. 12. Energy spectrum of a good pixel (blue) as compared with that of a noisy pixel (pink), acquired with $^{57}$Co (above) and $^{137}$Cs (bottom).

The noisy pixels are the following: channel #39 (pixel# 143), #41 (pixel# 142), #45 (pixel# 154), #46 (pixel# 172), channel #83 (pixel# 192), channel #94 (pixel# 108), channel #118 (pixel# 149).

## 5.2. Channel-to-channel non-uniformity

By considering the individual pixels' responses at the 122 keV $^{57}$Co and $^{109}$Cd energy peak with an ASIC gain of 100 mV/fC, the channel-to-channel non-uniformity has been evaluated by calculating the peak centroid and the deviation from the mean for any pixel (Fig. 13).

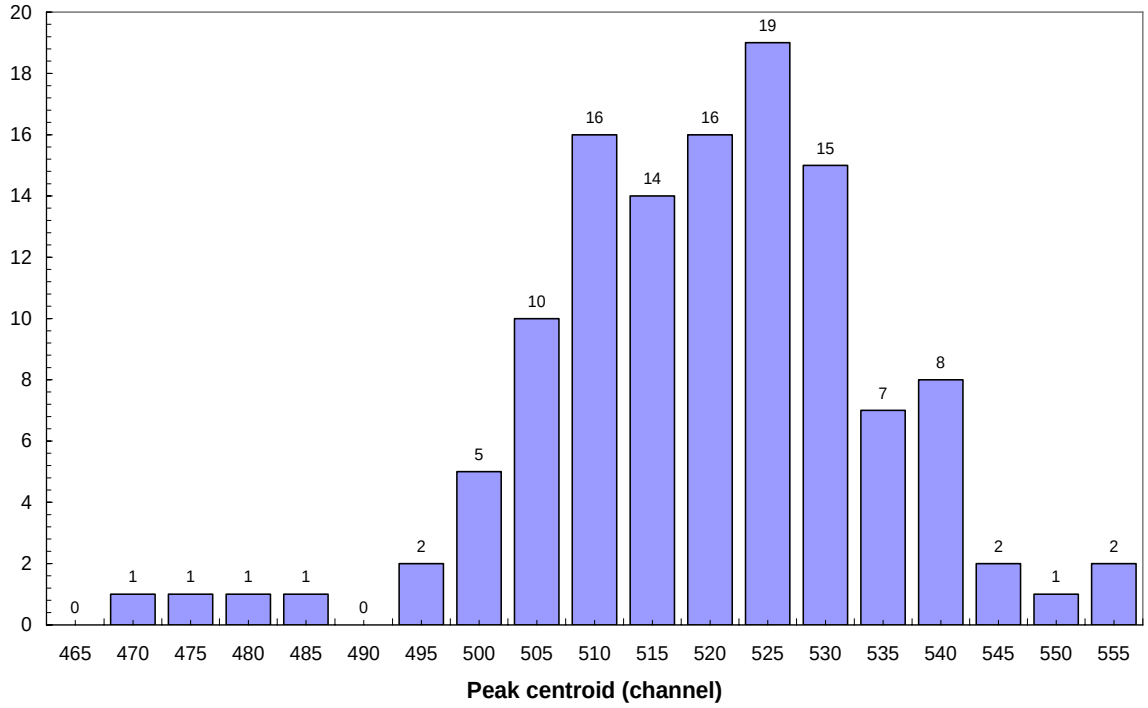



Fig. 13. Distribution of the centroid values calculated at 122 keV. The inset reports the statistical parameters of the distribution.

## 5.3. POLCA2 linearity

Linearity was tested by using $^{109}$Cd (22keV and 88keV), $^{57}$Co (122keV), $^{137}$Cs (662keV) radioactive sources with an ASIC gain of 50 mV/fC ($^{137}$Cs) and 100mV/fC ($^{109}$Cd, $^{57}$Co). The spectra of $^{57}$Co and $^{109}$Cd, obtained irradiating a good pixel, are shown in Fig. 14.

| Energy (keV) | Centroid Channel | | | Linear Fit (*) | |
|---|---|---|---|---|---|
| | Pixel 121 | Pixel 123 | Mean Value | a | b |
| 22 | 93.73 | 96.58 | 95.16 | -3.65 ± 0.10 | 4.490 ± 0.001 |
| 88 | 396.64 | 386.18 | 391.41 | | |
| 122 | 553.59 | 534.77 | 544.18 | | |
| 662 | 733.52 | 721.66 | | | |

**(*) Centroid channel=a+b energy**

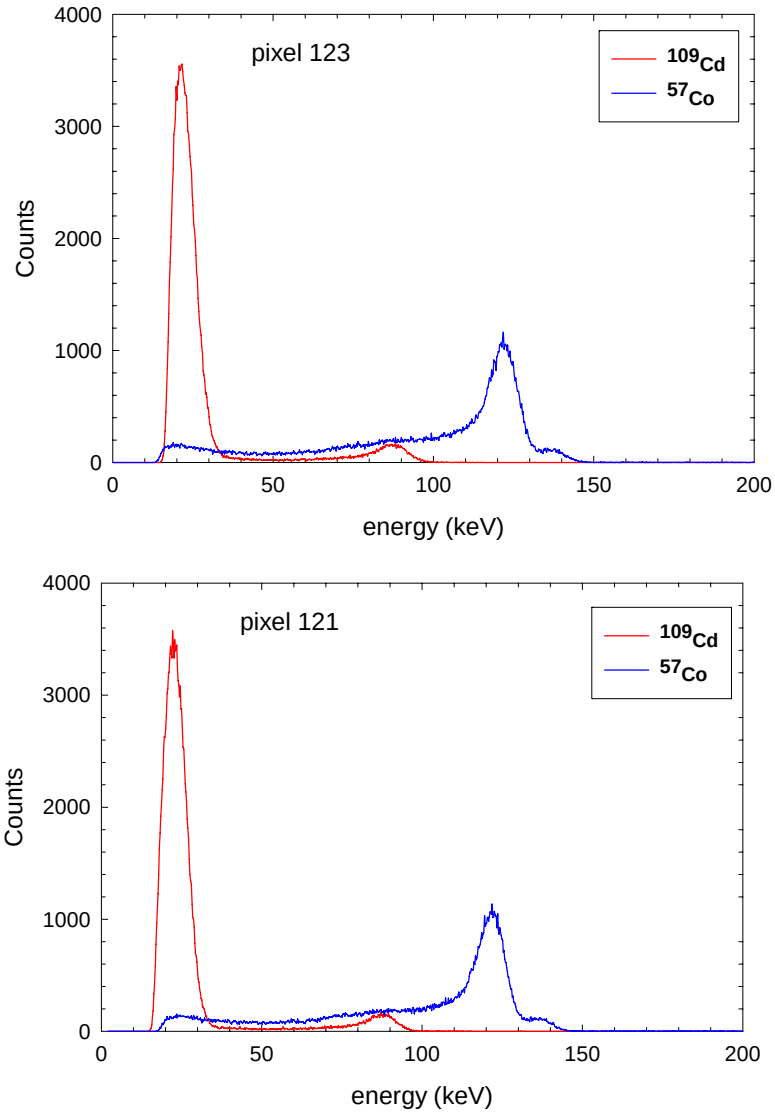



Fig. 14. a) Energy spectrum of $^{57}$Co (blue) and $^{109}$Cd (red); b) Zoom of the peak at 88 keV.

## 5.4. Energy resolution

The same set of data collected for the paragraph 5.4 has been used to calculate the energy resolution of any CZT detection channel (Fig. 15).

## 5.5. Threshold evaluation

To better evaluate the low energy threshold, the ASICs' gain has been raised to 200mV/fC and low peak energies of $^{57}$Co were considered.

In Fig. 16 the distribution of the threshold values in channel are shown. The mean value corresponds to about 19.9 keV.

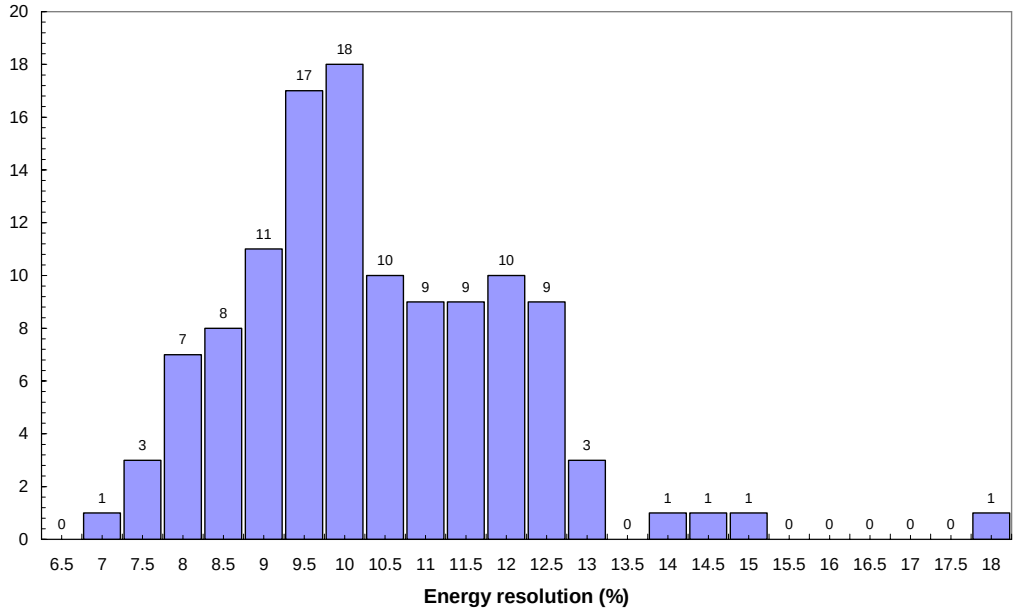



Fig. 15. Distribution of the energy resolutions calculated at 122 keV. The inset reports the statistical parameters of the distribution.

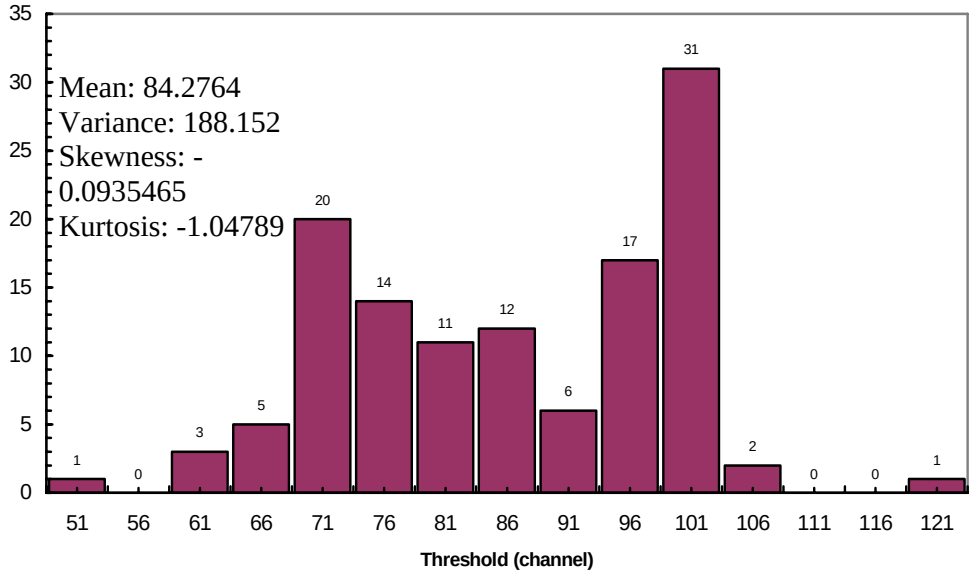



Fig. 16. Distribution of the thresholds values. The inset reports the statistical parameters of the distribution.

### 5.5. Overall noise evaluation

The measurements have shown that the performance of the POLCA2 detection system is worst than expected from the datasheet of IMARAD (now Orbotech) that, for example, give a resolution of ~5% (FWHM) in average at 122 keV.

The IMARAD value have been obtained with their standard system that use as FEE 2 ASIC's (128 channels each) from IDEAS mounted directly on the backside (anode side) of the detector without employing connectors: from noise level point of view, this configuration is of course better than the POLCA2 one in which the detector is connected to the readout electronics (16 channel eV products ASIC) through three high density connectors and there are longer fan out between the pixel and the input stage of the corresponding ASIC channel.

On other hand the performance of the 16 channels ASIC from eV product have very good noise figure as demonstrated by the performance of 4x4 pixel eV product CZT detector with the same thickness and almost the same pixel pitch of the POLCA2 detection system and the same bias condition: ~3 % (FWHM) at 122 keV, ~8 keV low energy threshold.

Therefore we can infer that the degradation in the spectroscopic performance we observe in the POLCA2 detection system is mainly due to the electrical interface between the detector and the ASIC readout: i.e. increase in parasistic capacitances due to the connectors and the detector fan-out layout.

In order to confirm this hypothesis some more tests will be performed injecting directly in the connectors on the I/F ASIC board known charge pulses corresponding to various energies and evaluating the ASIC output signal FWHM.

## 6. Conclusions

The functional tests described in this report confirm that the POLCA2 detection system is almost ready to be used for performance tests in different experimental conditions using the TAKES multiparametric back-end electronics to obtain spectroscopic images for single and multiple events.

The POLCA2 will be used as soon as possible in three different experiments:

- Experiment at ESRF (beam line ID15): to evaluate the performance as hard X ray polarimeter of a CZT pixel detector between 100 and 1000 keV.
- Experiment with the X-ray facility at the Ferrara University: to evaluate the response of a CZT pixel detector as a Laue lens focal plane prototype.
- Experiment at the SDof the Leicester University (UK): to assess the performance of an hybrid detector (CCD+pixel CZT detector) as focal plane for coaxial grazing incidence and multilayer mirror for X-ray astronomy (e.g. 0.1/1-100 keV)

# 7. References

**a.** E. Caroli, G. Bertuccio, A. Cola, R. M. Curado da Silva, A. Donati, W. Dusi, G. Landini, P. Siffert, M. Sampietro and J. B. Stephen, "**Hard X-ray polarimetry with a thick CdTe position sensitive spectrometer** *" SPIE Proceedings on X-ray and Gamma-ray instrumentation for Astronomy XI*, vol. 4140, pp. 573-583, 2000.

**b.** R. M. Curado da Silva, E. Caroli, J. B. Stephen, and P. Siffert, "**Monte Carlo polarimetric simulations of a hard X-ray energy telescope**" *SPIE Proceedings on X-ray and Gamma-ray instrumentation for Astronomy XII*, vol. 4497, pp. 70-78, 2002.

**c.** R. M. Curado da Silva, E. Caroli, J. B. Stephen, and P. Siffert, "**Monte Carlo Simulations of the design of a Hard X-ray Telescope optimised for polarimetry**" accepted for publication in *SPIE Proceedings on Astronomical Telescopes and Instrumentation*, presented in Hawaii, USA, 29 July 2002.

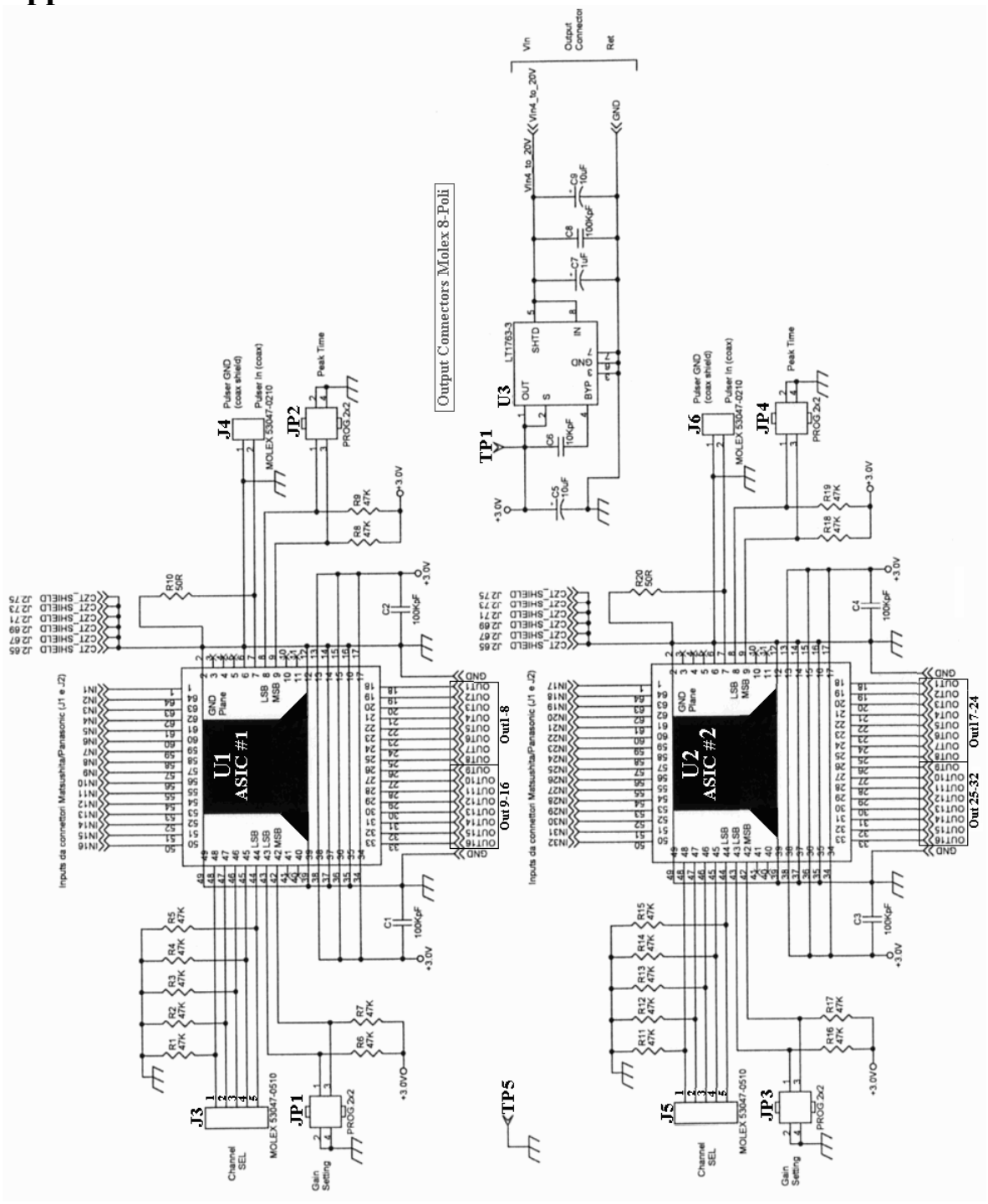
**d.** Caroli, R.M. Curado da Silva, A. Donati, M. Hage-Alì, F. Schiavone, J.B. Stephen, G.F.Taiocchi, G. Ventura, **PolCA (POLarimetria con CdTe Aarrays)**, *IASF/CNR Internal Report N. 345*, August 2002

**e.** E. Caroli, N. Auricchio, A. Donati, F. Schiavone, John B. Stephen, G. Ventura, R. M. Curado da Silva, P. Siffert, M. Hage-Ali and G. F. Taiocchi, "**A study of prototype CdTe hard X and gamma-ray detector**", *Nucl. Instrum. and Methodes in Phys. Res.*, Vol A513, pp. 350-356, 2003.

**f.** R. M. Curado da Silva, Ezio Caroli, M. Hage-Ali, J. B. Stephen, M. Ayoub, A. Donati, F. Schiavone, G. Ventura and P. Siffert, "**Experimental polarimetric study of an hard X-ray energy telescope prototype**", *IEEE Trans. Nucl. Sci.*, Vol. 50, nº 4, pag. 1198-1203 (2003).

**g.** R. M. Curado da Silva, N. Auricchio, E. Caroli, A. Donati, M. Hage-Ali, F. Schiavone, P. Siffert, J. B. Stephen, G. Ventura, **Hard X an Soft Gamma-Ray Polarimetry with CdTe Pototypes**, *IEEE Transactions on Nuclear Science*, Vol. 51, N. 5, p. 2478 October 2004

# Appendix I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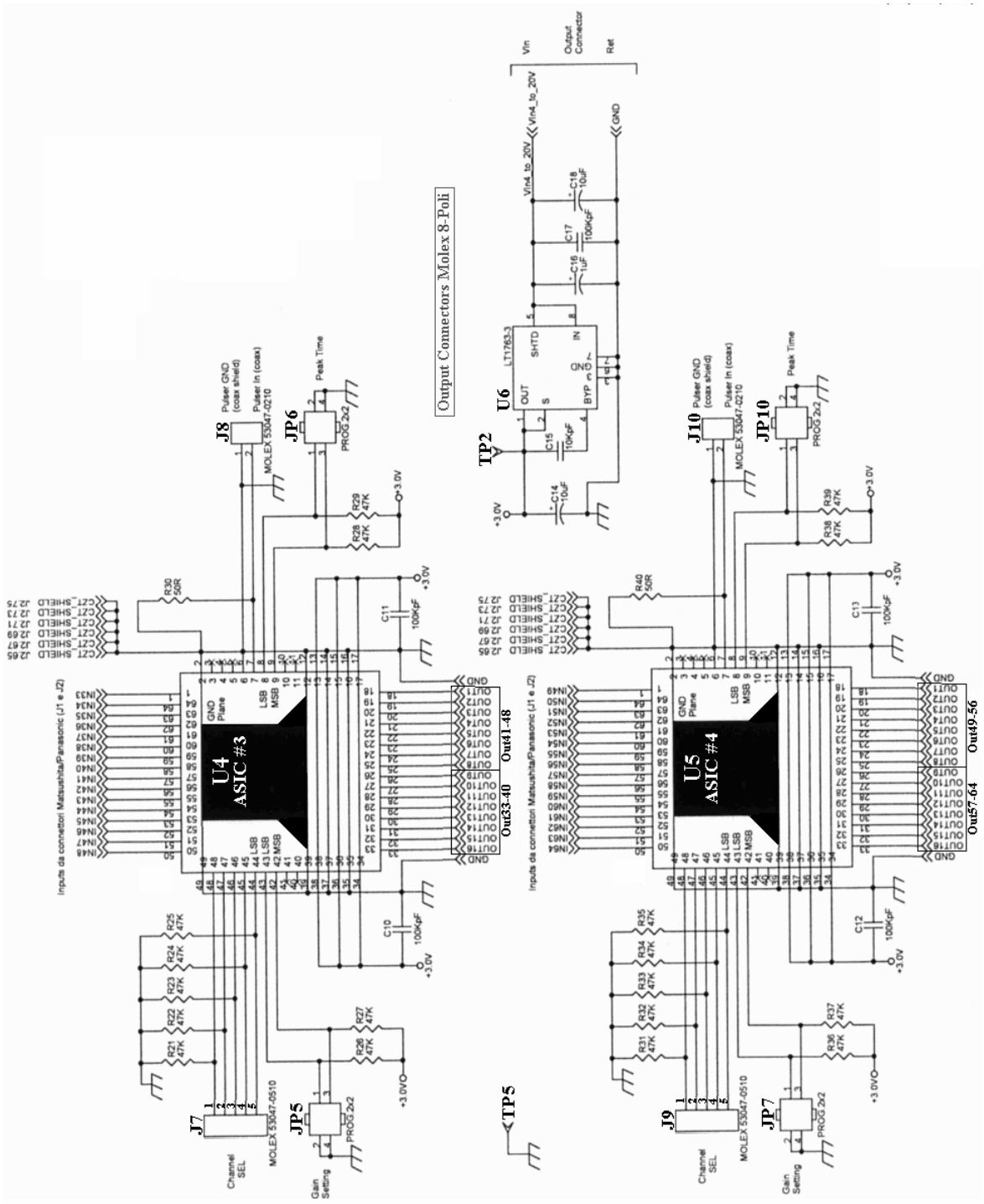
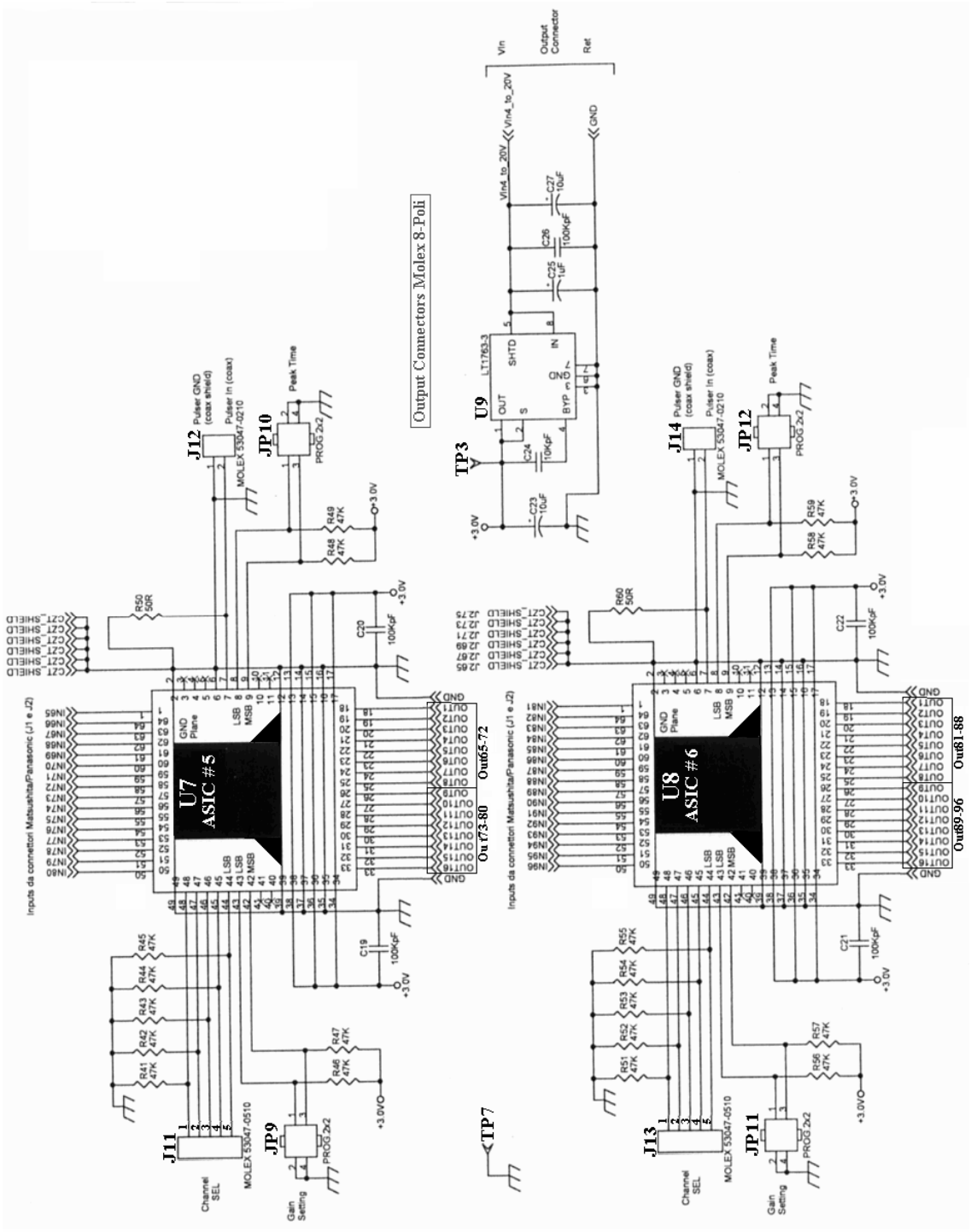
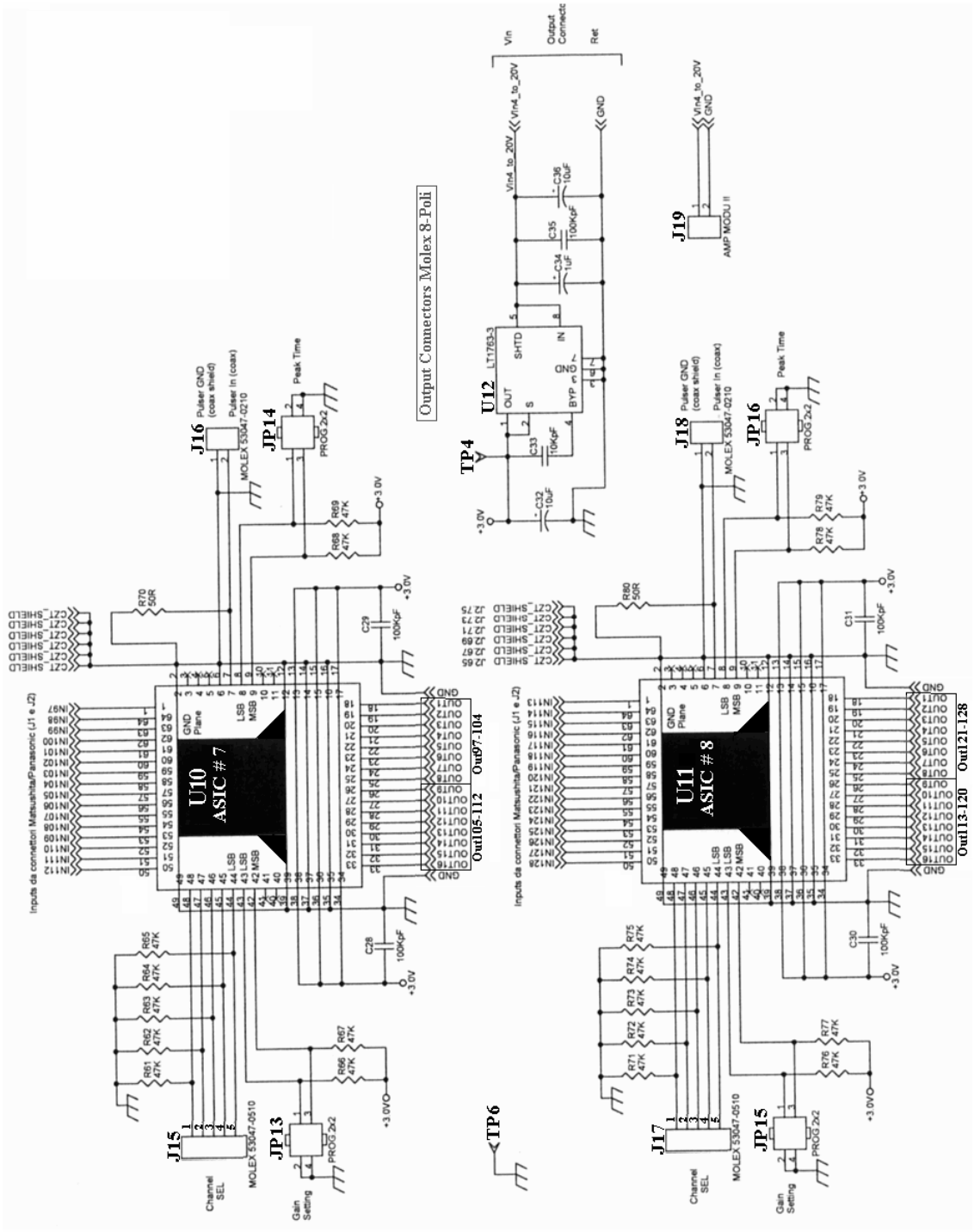
U1 ASIC #1
U2 ASIC #2
U3
J1
J2
J3
J4
J5
J6
JP1
JP2
JP3
JP4
TP1
TP5
Out1-8
Out9-16
Out17-24
Out25-32
Inputs da connettori Matsushita/Panasonic (J1 e J2)
Output Connector
Vin
Ret
GND
Vin4_to_20V
Peak Time
Pulser GND (coax shield)
Pulser In (coax)
Channel SEL
Gain Setting
+3.0V


Output Connectors Molex 8-Poli
U4
ASIC #3
U5
ASIC #4
U6
LT1763-3
J8
J10
JP6
JP10
J7
J9
JP5
JP7
TP2
TP5
Out41-48
Out33-40
Out49-56
Out57-64
Channel SEL
Gain Setting
Peak Time
Pulser GND (coax shield)
Pulser In (coax)
Vin
Output Connector
Ret
Vin4_to_20V
GND
+3.0V


Output Connectors Molex 8-Poli
U7 ASIC #5
U8 ASIC #6
U9
J12
J14
JP10
JP12
JP9
JP11
J11
J13
TP3
TP7
Out73-80
Out65-72
Out81-88
Out89-96
Pulser GND (coax shield)
Pulser In (coax)
Peak Time
Channel SEL
Gain Setting
Vin
Output Connector
Ret
GND
+3.0V


Output Connectors Molex 8-Poli
U10 ASIC # 7
U11 ASIC # 8
U12 LT1763-3
J16
J14
J18
J16
J19
J15
J13
J17
J15
TP4
TP6
Out105-112
Out97-104
Out113-120
Out121-128
Channel SEL
Gain Setting
Pulser GND (coax shield)
Pulser In (coax)
Peak Time
MOLEX 53047-0210
MOLEX 53047-0510
PROG 2x2
AMP MODU II
Vin
Output Connector
Ret
Vin4_to_20V
GND
+3.0V
+3.0VO

# Appendix II

## General I/O correspondence: CZT pixels-Takes Electronics Input

| CZT IN Ch # | ASIC # | I.C. | IN Ch | CZT Pixel # | Takes IN Ch | Takes IN Connector | Pin |
|---|---|---|---|---|---|---|---|
| 1 | 1 | U1 | 1 | 223 | 1 | 1 | 1 |
| 2 | 1 | U1 | 2 | 239 | 2 | 1 | 2 |
| 3 | 1 | U1 | 3 | 238 | 3 | 1 | 3 |
| 4 | 1 | U1 | 4 | 237 | 4 | 1 | 4 |
| 5 | 1 | U1 | 5 | 222 | 5 | 1 | 5 |
| 6 | 1 | U1 | 6 | 221 | 6 | 1 | 6 |
| 7 | 1 | U1 | 7 | 220 | 7 | 1 | 7 |
| 8 | 1 | U1 | 8 | 236 | 8 | 1 | 8 |
| 9 | 1 | U1 | 9 | 219 | 9 | 1 | 9 |
| 10 | 1 | U1 | 10 | 235 | 10 | 1 | 10 |
| 11 | 1 | U1 | 11 | 218 | 11 | 1 | 11 |
| 12 | 1 | U1 | 12 | 234 | 12 | 1 | 12 |
| 13 | 1 | U1 | 13 | 233 | 13 | 1 | 13 |
| 14 | 1 | U1 | 14 | 217 | 14 | 1 | 14 |
| 15 | 1 | U1 | 15 | 232 | 15 | 1 | 15 |
| 16 | 1 | U1 | 16 | 216 | 16 | 1 | 16 |
| 17 | 2 | U2 | 1 | 174 | 17 | 2 | 1 |
| 18 | 2 | U2 | 2 | 190 | 18 | 2 | 2 |
| 19 | 2 | U2 | 3 | 173 | 19 | 2 | 3 |
| 20 | 2 | U2 | 4 | 206 | 20 | 2 | 4 |
| 21 | 2 | U2 | 5 | 189 | 21 | 2 | 5 |
| 22 | 2 | U2 | 6 | 205 | 22 | 2 | 6 |
| 23 | 2 | U2 | 7 | 187 | 23 | 2 | 7 |
| 24 | 2 | U2 | 8 | 188 | 24 | 2 | 8 |
| 25 | 2 | U2 | 9 | 204 | 25 | 2 | 9 |
| 26 | 2 | U2 | 10 | 186 | 26 | 2 | 10 |
| 27 | 2 | U2 | 11 | 185 | 27 | 2 | 11 |
| 28 | 2 | U2 | 12 | 203 | 28 | 2 | 12 |
| 29 | 2 | U2 | 13 | 202 | 29 | 2 | 13 |
| 30 | 2 | U2 | 14 | 201 | 30 | 2 | 14 |
| 31 | 2 | U2 | 15 | 200 | 31 | 2 | 15 |
| 32 | 2 | U2 | 16 | 184 | 32 | 2 | 16 |
| 33 | 3 | U4 | 1 | 159 | 33 | 3 | 1 |
| 34 | 3 | U4 | 2 | 158 | 34 | 3 | 2 |
| 35 | 3 | U4 | 3 | 157 | 35 | 3 | 3 |
| 36 | 3 | U4 | 4 | 175 | 36 | 3 | 4 |
| 37 | 3 | U4 | 5 | 191 | 37 | 3 | 5 |
| 38 | 3 | U4 | 6 | 207 | 38 | 3 | 6 |
| 39 | 3 | U4 | 7 | 143 | 39 | 3 | 7 |
| 40 | 3 | U4 | 8 | 127 | 40 | 3 | 8 |
| 41 | 3 | U4 | 9 | 142 | 41 | 3 | 9 |
| 42 | 3 | U4 | 10 | 126 | 42 | 3 | 10 |
| 43 | 3 | U4 | 11 | 156 | 43 | 3 | 11 |
| 44 | 3 | U4 | 12 | 155 | 44 | 3 | 12 |
| 45 | 3 | U4 | 13 | 154 | 45 | 3 | 13 |
| 46 | 3 | U4 | 14 | 172 | 46 | 3 | 14 |

| 47 | 3 | U4 | 15 | 171 | 47 | 3 | 15 |
|---|---|---|---|---|---|---|---|
| 48 | 3 | U4 | 16 | 152 | 48 | 3 | 16 |
| 49 | 4 | U5 | 1 | 170 | 49 | 4 | 1 |
| 50 | 4 | U5 | 2 | 153 | 50 | 4 | 2 |
| 51 | 4 | U5 | 3 | 120 | 51 | 4 | 3 |
| 52 | 4 | U5 | 4 | 169 | 52 | 4 | 4 |
| 53 | 4 | U5 | 5 | 168 | 53 | 4 | 5 |
| 54 | 4 | U5 | 6 | 141 | 54 | 4 | 6 |
| 55 | 4 | U5 | 7 | 140 | 55 | 4 | 7 |
| 56 | 4 | U5 | 8 | 139 | 56 | 4 | 8 |
| 57 | 4 | U5 | 9 | 123 | 57 | 4 | 9 |
| 58 | 4 | U5 | 10 | 125 | 58 | 4 | 10 |
| 59 | 4 | U5 | 11 | 138 | 59 | 4 | 11 |
| 60 | 4 | U5 | 12 | 122 | 60 | 4 | 12 |
| 61 | 4 | U5 | 13 | 121 | 61 | 4 | 13 |
| 62 | 4 | U5 | 14 | 137 | 62 | 4 | 14 |
| 63 | 4 | U5 | 15 | 124 | 63 | 4 | 15 |
| 64 | 4 | U5 | 16 | 136 | 64 | 4 | 16 |
| 65 | 5 | U7 | 1 | 224 | 65 | 5 | 1 |
| 66 | 5 | U7 | 2 | 256 | 66 | 5 | 2 |
| 67 | 5 | U7 | 3 | 255 | 67 | 5 | 3 |
| 68 | 5 | U7 | 4 | 240 | 68 | 5 | 4 |
| 69 | 5 | U7 | 5 | 254 | 69 | 5 | 5 |
| 70 | 5 | U7 | 6 | 253 | 70 | 5 | 6 |
| 71 | 5 | U7 | 7 | 252 | 71 | 5 | 7 |
| 72 | 5 | U7 | 8 | 251 | 72 | 5 | 8 |
| 73 | 5 | U7 | 9 | 250 | 73 | 5 | 9 |
| 74 | 5 | U7 | 10 | 249 | 74 | 5 | 10 |
| 75 | 5 | U7 | 11 | 248 | 75 | 5 | 11 |
| 76 | 5 | U7 | 12 | 247 | 76 | 5 | 12 |
| 77 | 5 | U7 | 13 | 231 | 77 | 5 | 13 |
| 78 | 5 | U7 | 14 | 215 | 78 | 5 | 14 |
| 79 | 5 | U7 | 15 | 246 | 79 | 5 | 15 |
| 80 | 5 | U7 | 16 | 199 | 80 | 5 | 16 |
| 81 | 6 | U8 | 1 | 160 | 81 | 6 | 1 |
| 82 | 6 | U8 | 2 | 176 | 82 | 6 | 2 |
| 83 | 6 | U8 | 3 | 192 | 83 | 6 | 3 |
| 84 | 6 | U8 | 4 | 208 | 84 | 6 | 4 |
| 85 | 6 | U8 | 5 | 128 | 85 | 6 | 5 |
| 86 | 6 | U8 | 6 | 144 | 86 | 6 | 6 |
| 87 | 6 | U8 | 7 | 112 | 87 | 6 | 7 |
| 88 | 6 | U8 | 8 | 96 | 88 | 6 | 8 |
| 89 | 6 | U8 | 9 | 110 | 89 | 6 | 9 |
| 90 | 6 | U8 | 10 | 94 | 90 | 6 | 10 |
| 91 | 6 | U8 | 11 | 95 | 91 | 6 | 11 |
| 92 | 6 | U8 | 12 | 111 | 92 | 6 | 12 |
| 93 | 6 | U8 | 13 | 109 | 93 | 6 | 13 |
| 94 | 6 | U8 | 14 | 108 | 94 | 6 | 14 |
| 95 | 6 | U8 | 15 | 93 | 95 | 6 | 15 |
| 96 | 6 | U8 | 16 | 92 | 96 | 6 | 16 |
| 97 | 7 | U10 | 1 | 183 | 97 | 7 | 1 |
| 98 | 7 | U10 | 2 | 90 | 98 | 7 | 2 |
| 99 | 7 | U10 | 3 | 119 | 99 | 7 | 3 |
| 100 | 7 | U10 | 4 | 104 | 100 | 7 | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 101 | 7 | U10 | 5 | 151 | 101 | 7 | 5 |
| 102 | 7 | U10 | 6 | 117 | 102 | 7 | 6 |
| 103 | 7 | U10 | 7 | 103 | 103 | 7 | 7 |
| 104 | 7 | U10 | 8 | 150 | 104 | 7 | 8 |
| 105 | 7 | U10 | 9 | 167 | 105 | 7 | 9 |
| 106 | 7 | U10 | 10 | 133 | 106 | 7 | 10 |
| 107 | 7 | U10 | 11 | 135 | 107 | 7 | 11 |
| 108 | 7 | U10 | 12 | 105 | 108 | 7 | 12 |
| 109 | 7 | U10 | 13 | 107 | 109 | 7 | 13 |
| 110 | 7 | U10 | 14 | 91 | 110 | 7 | 14 |
| 111 | 7 | U10 | 15 | 106 | 111 | 7 | 15 |
| 112 | 7 | U10 | 16 | 101 | 112 | 7 | 16 |
| 113 | 8 | U11 | 1 | 230 | 113 | 8 | 1 |
| 114 | 8 | U11 | 2 | 214 | 114 | 8 | 2 |
| 115 | 8 | U11 | 3 | 245 | 115 | 8 | 3 |
| 116 | 8 | U11 | 4 | 198 | 116 | 8 | 4 |
| 117 | 8 | U11 | 5 | 182 | 117 | 8 | 5 |
| 118 | 8 | U11 | 6 | 149 | 118 | 8 | 6 |
| 119 | 8 | U11 | 7 | 181 | 119 | 8 | 7 |
| 120 | 8 | U11 | 8 | 166 | 120 | 8 | 8 |
| 121 | 8 | U11 | 9 | 165 | 121 | 8 | 9 |
| 122 | 8 | U11 | 10 | 87 | 122 | 8 | 10 |
| 123 | 8 | U11 | 11 | 118 | 123 | 8 | 11 |
| 124 | 8 | U11 | 12 | 88 | 124 | 8 | 12 |
| 125 | 8 | U11 | 13 | 89 | 125 | 8 | 13 |
| 126 | 8 | U11 | 14 | 134 | 126 | 8 | 14 |
| 127 | 8 | U11 | 15 | 102 | 127 | 8 | 15 |
| 128 | 8 | U11 | 16 | 86 | 128 | 8 | 16 |