



X-ray fluorescence setup and measurements of CMOS sensors

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Outline



- Idea of x-ray fluorescence measurements
- Details on the setup
- Details on the CMOS TowerJazz Investigator chip
- Measurements
- Summary

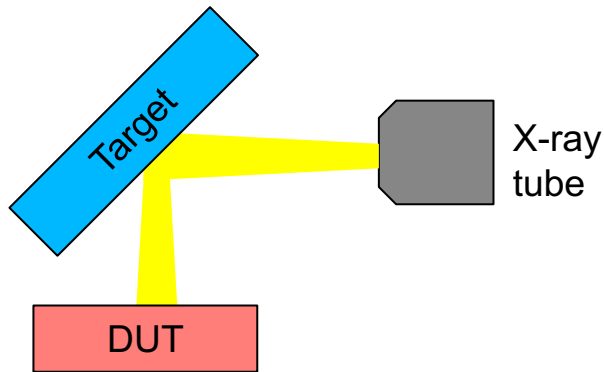
X-ray fluorescence method

Many new pixel CMOS sensors to evaluate

Method to calibrate and study the linearity of response of new sensors in the lab

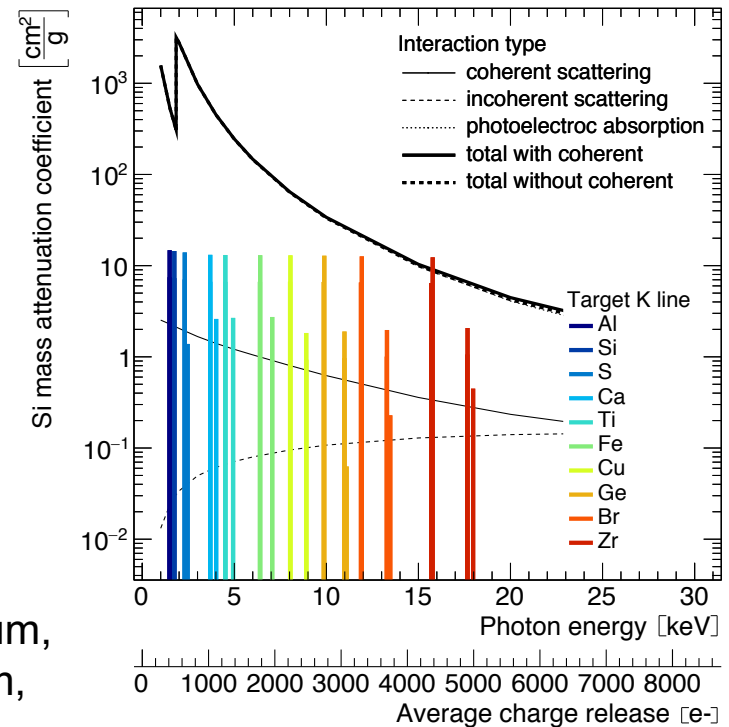
→ X-ray fluorescence method

- X-ray from tube induces K_α - and K_β emission lines of target materials and gives access to a dense set of **monochromatic** lines in the keV-100 keV range measurements



- Typical **target materials**: Al, Tin, Titanium, Molybdenum, Zinc, Manganese, Iron, Copper, Germanium, Zirconium,
- Plus allows **measurements of charge spectra and energy resolution**

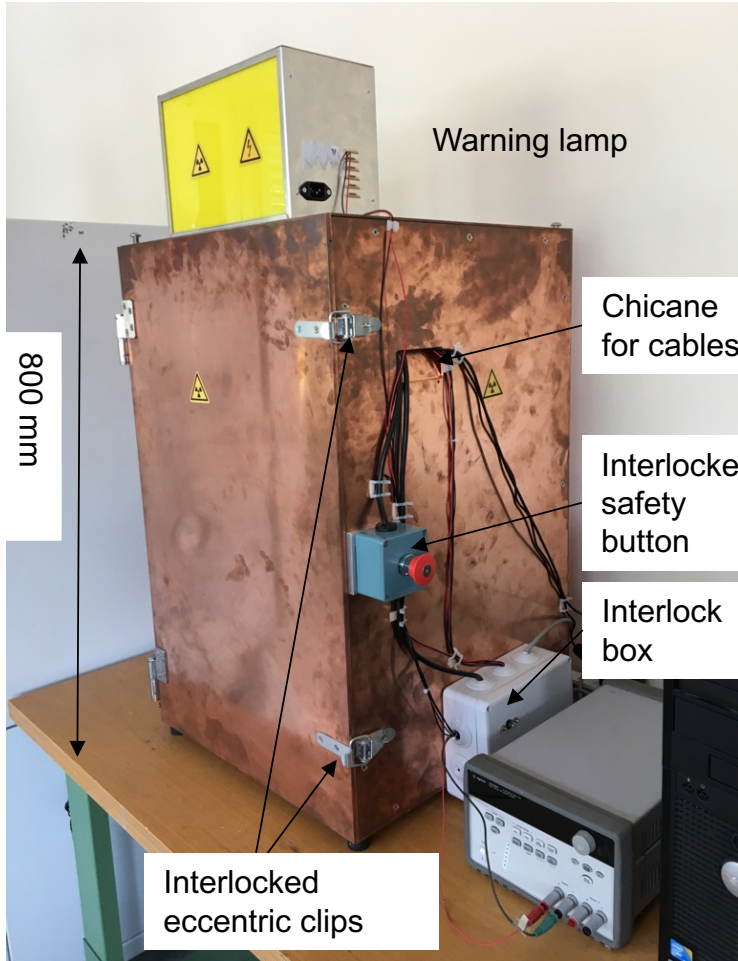
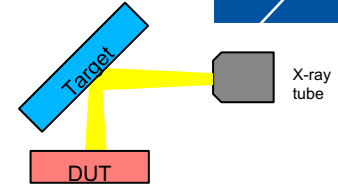
L.-D. Pohl et al., Obtaining spectroscopic information with the ATLAS FE-14 pixel readout chip, Nuclear Instrum. Meth. A788 (2015), 49
D. Maneuski, Fluorescence X-ray measurements



Courtesy: E. Jr. Schioppa

X-ray fluorescence setup at CERN

4 mm thick copper wall box with interlock system and x-y-z source mount



Warning lamp

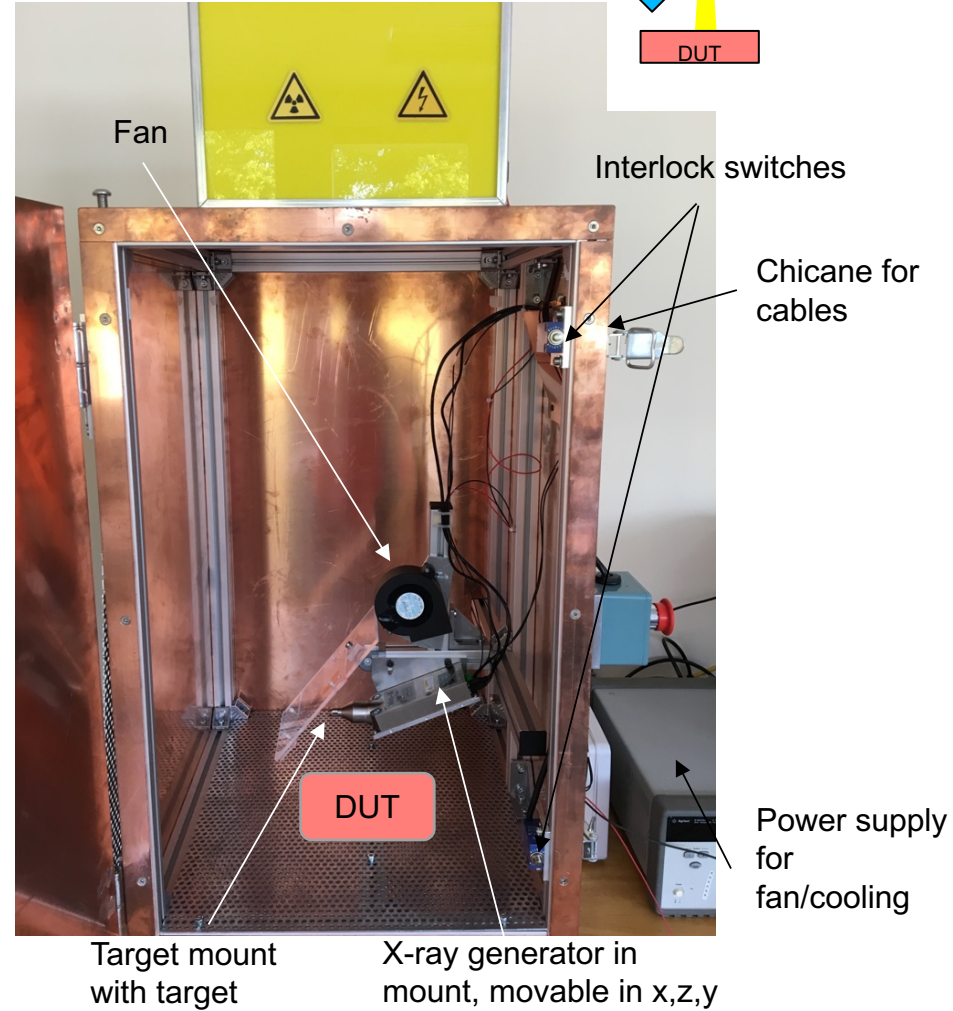
800 mm

Chicane for cables

Interlocked safety button

Interlock box

Interlocked eccentric clips



Fan

Interlock switches

Chicane for cables

DUT

Power supply for fan/cooling

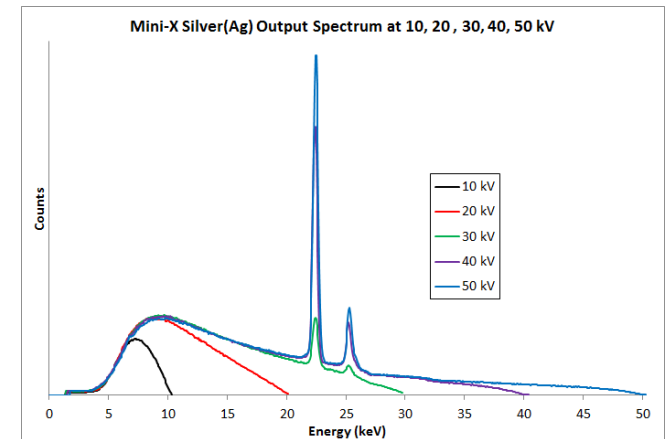
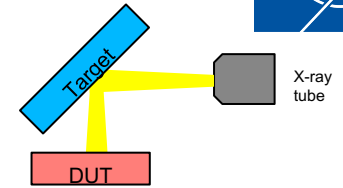
Target mount with target

X-ray generator in mount, movable in x,z,y

With support from L. Tluosos, J. Alozy, M. Abbas and CERN EP-DT-EO

X-ray fluorescence setup at CERN ctd'

- Portable X-ray source: AMPTEK Mini-X with Ag transmission target
 - Max. 4 W (HV:10 kV to 50 kV, current: 5 μ A to 200 μ A), controlled via USB
 - 10^6 counts per s/mm² (30 cm distance)
- Target materials: potentially two calibration energies per target

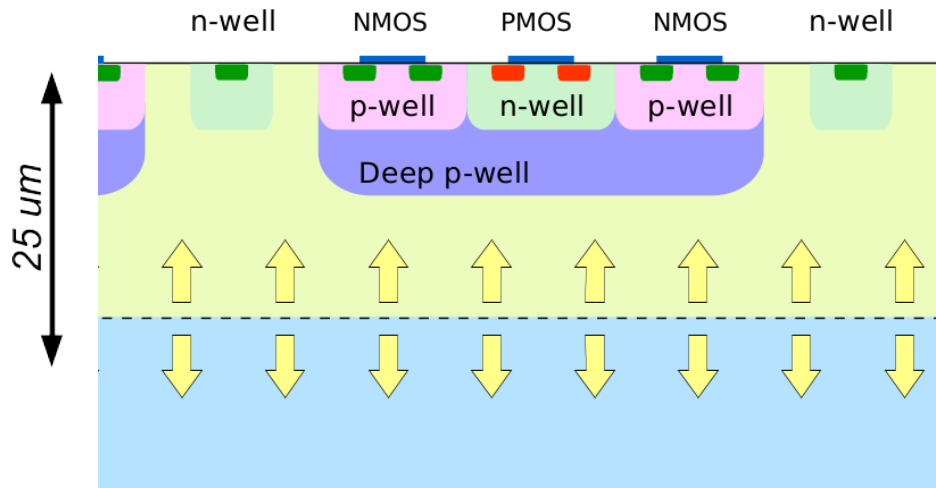


Periodic Table of the Elements

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 52.00	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.69	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.906	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.36	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 La-Lu Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.222	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222
87 Fr Francium 223	88 Ra Radium 226	89-103 Ac-Lr Actinides	104 Rf Rutherfordium 261	105 Db Dubnium 262	106 Sg Seaborgium 263	107 Bh Bohrium 264	108 Hs Hassium 265	109 Mt Meitnerium 266	110 Ds Darmstadtium 267	111 Rg Roentgenium 268	112 Cn Copernicium 269	113 Nh Nihonium 270	114 Fl Flerovium 271	115 Mc Moscovium 272	116 Lv Livermorium 273	117 Ts Tennessine 274	118 Og Oganesson 276
89 La Lanthanum 138.905	90 Ce Cerium 140.12	91 Pr Praseodymium 140.908	92 Nd Neodymium 144.24	93 Pm Promethium 144.913	94 Sm Samarium 150.36	95 Eu Europium 151.964	96 Gd Gadolinium 157.25	97 Tb Terbium 158.925	98 Dy Dysprosium 162.50	99 Ho Holmium 164.930	100 Er Erbium 167.259	101 Tm Thulium 168.930	102 Yb Ytterbium 173.054	103 Lu Lutetium 174.967			
90 Ac Actinium 227	91 Th Thorium 232.038	92 Pa Protactinium 231.036	93 U Uranium 238.029	94 Np Neptunium 237.048	95 Pu Plutonium 244.064	96 Am Americium 243.061	97 Cm Curium 247.070	98 Bk Berkelium 247.070	99 Cf Californium 251.080	100 Es Einsteinium 252.083	101 Fm Fermium 257.103	102 Md Mendelevium 258.106	103 No Nobelium 259.108	104 Lr Lawrencium 260.109			

CMOS Sensor: TowerJazz 180nm technology

- The modified process with high efficiency after irradiation

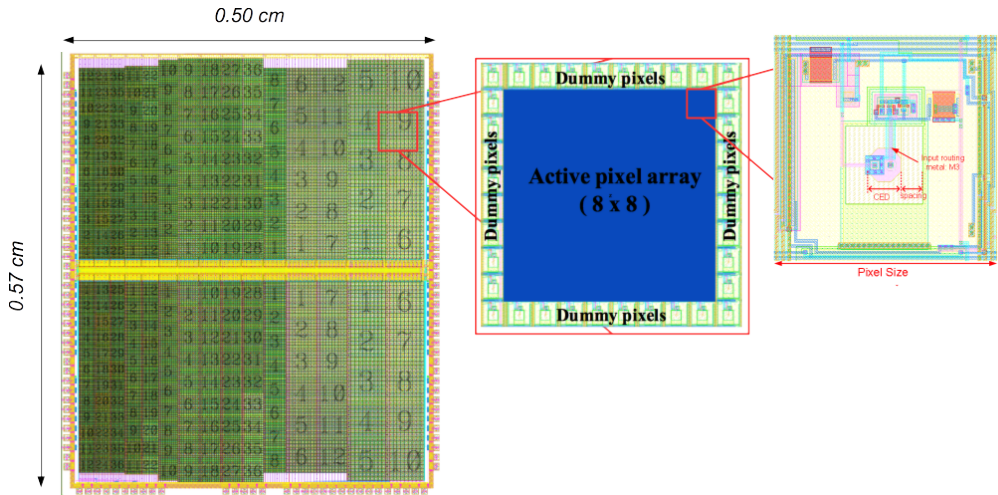


Courtesy: E. Jr. Schioppa

- Low input capacitance (\sim fF) at the collection electrode
- Large S/N ratio can be achieved
- Fast signals
- A planar junction extends across the full pixel surface
- Charge collected in depleted volume

H. Pernegger et al., First tests of a novel radiation hard CMOS sensor process for depleted monolithic active pixel sensors, JINST 12 (2017) P06008

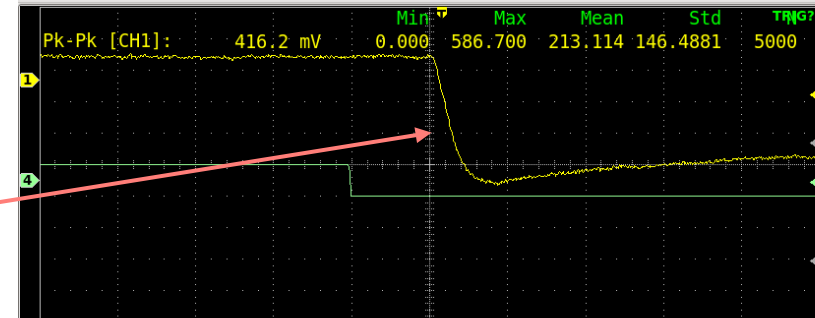
- TowerJazz Investigator 1 chip



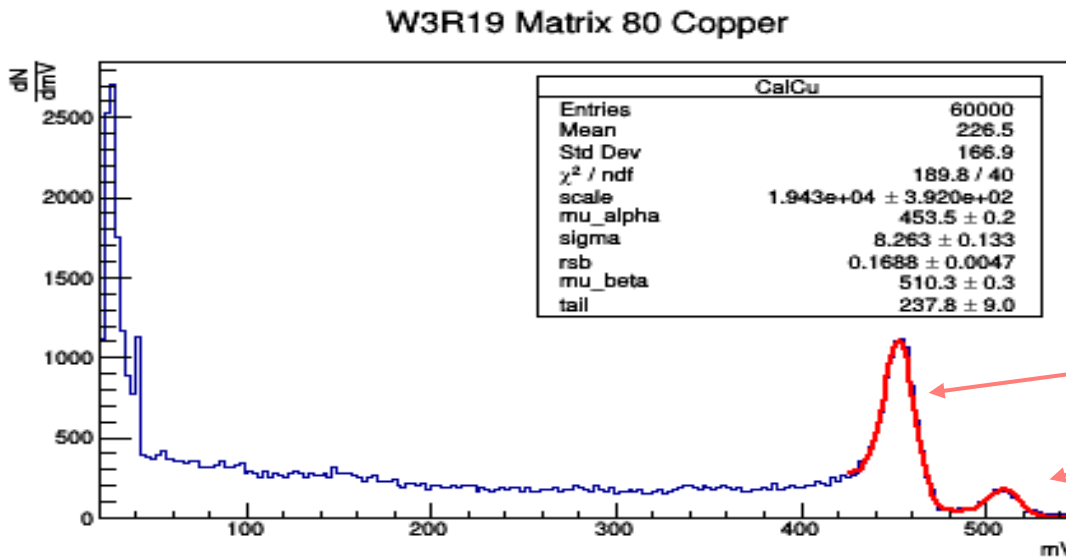
- Many different mini-matrices differing in geometry & front-end
- 4 matrices measured with pixel size of $28 \times 28 \mu\text{m}^2$ and $30 \times 30 \mu\text{m}^2$ and different depth of p-well

Measurements

- Test of 4 matrices with 3 target materials (unirradiated)
- Bias voltage 6 V
- Single pixel read out with Cividec C2HV amplifier, pulse amplitude proportional to charge
- 60000 events for each of the matrices for each of the target materials and wave-forms fitted



→ Charge spectra from X-ray emission



Materials	K_{α} [keV]	K_{β} [keV]
Titanium (Ti)	4.512	4.933
Iron (Fe)	6.405	7.059
Copper (Cu)	8.046	8.904

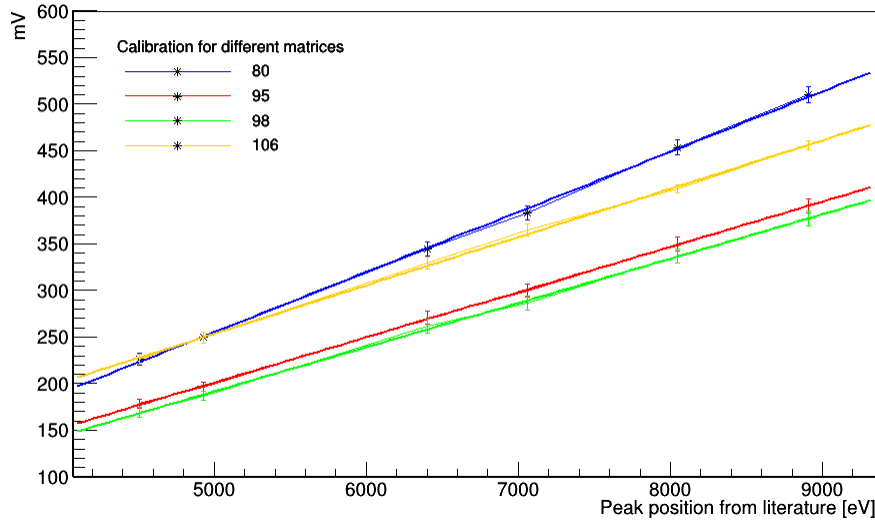
→ High resolution allows to see K_{α} - and K_{β} lines separately

Noise about 3.6 mV

Maximum deep PW, $28 \times 28 \mu\text{m}^2$

Results of unirradiated chip

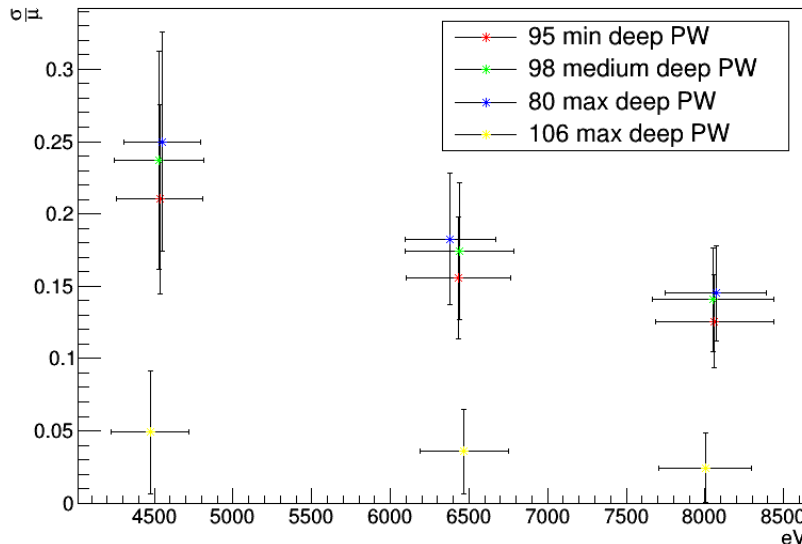
- Gamma peak positions versus literature values



- Matrix 80 (maximum deep PW),
- Matrix 95 (minimum deep PW) and
- Matrix 98 (medium deep PW) with $28 \times 28 \mu\text{m}^2$
- Matrix 106 (maximum deep PW) with $30 \times 30 \mu\text{m}^2$

- Linearity of gain
- Slightly higher gain for matrix 80 and also matrix 108 with maximum deep P-well

- Energy resolution for K_{α} -energies

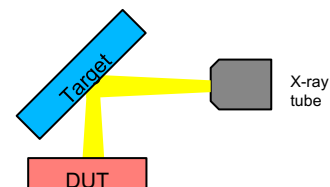


- Matrix 106 with larger pixel size has a better energy resolution (around 0.05 ± 0.04)
- Matrix 80 with maximum deep PW around 0.25 ± 0.08

Summary



- X-ray fluorescence setup installed and commissioned at CERN
- Ready to be used with new sensors
- Unirradiated CMOS Sensor Matrices from TowerJazz Investigator1 chip characterized with three target materials
 - Linear gain and good energy resolution measured
 - Matrix 80 has a higher gain (0.065 ± 0.002)
 - Matrix 106 has a better energy resolution (0.05 ± 0.04)
 - Low noise in the setup
- More measurements with several target materials ongoing
- Upgrade of setup for irradiated sensors in preparation



Thanky you!

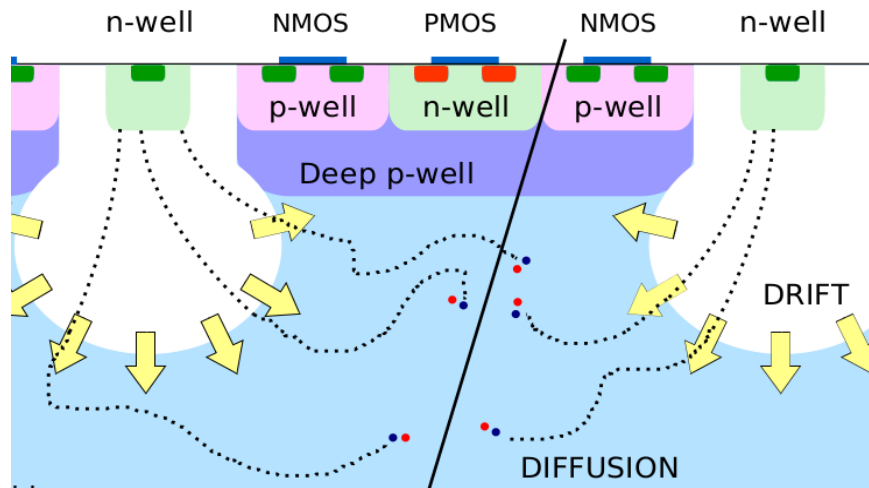
Thank you to Enrico and the Summer students Felipe and Michael!

Spare



TowerJazz 180nm CMOS technology

- The standard process



Difficult to obtain full lateral depletion
Not radiation hard