ARCADIA at Fermilab

21st March 2024

Contributors:

Davide Chiappara, Piero Giubilato, Caterina Pantouvakis, Michele Rignanese, Sabrina Ciarlantini

Updates:

Fe55 measurement – X-ray fluorescence

INFN PADOVA Istituto Nazionale di Fisica Nucleare Sezione di Padova

Università degli Studi di Padova

Padova GRIT

Dipartimento di Fisica e Astronomia Galileo Galilei

Outline

1) To better understand **frontside-backside discrepancies in terms of shift of the S-curve:**

- Measurements with higher statistics and control over temperature with ^{55}Fe source;
- Improved MC simulation: randomly generated electrons cloud width, possibility to simulate a N x N pixel matrix, etc … ;

2) To **calibrate the sensor threshold range**, more energies are required:

- Measurements with monochromatic source at a different energies → X-rays fluorescence

X-ray s-curve fit model: recap

$$N(t) = \mathrm{N}_0\left(1 + \frac{C_S}{\sigma}(t_0 - t)\right)\left(1 + erf\left(\frac{(t_0 - t)}{\sigma}\right)\right)$$

C_S → Charge sharing contribution

σ → Electronic noise

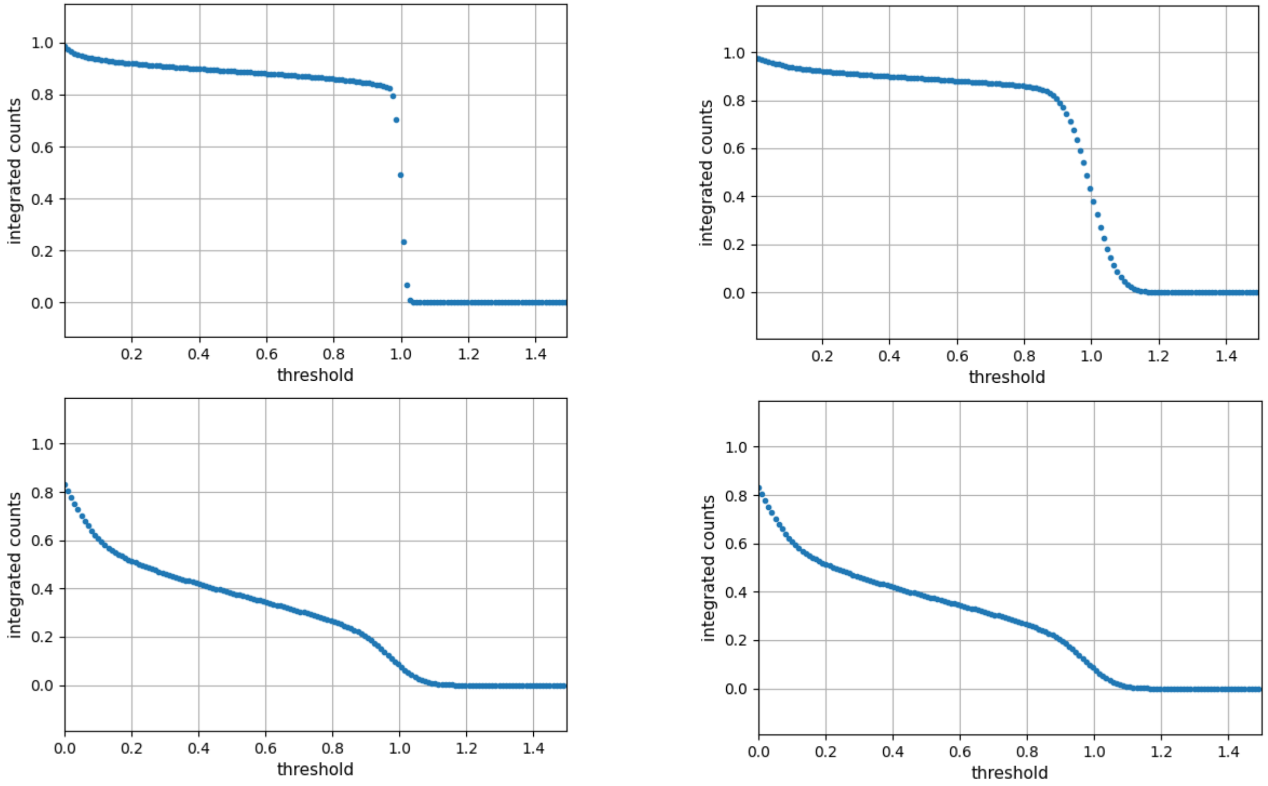
t : threshold

t_0: threshold at which the s-curve inflection point is found

Small σ | Large σ

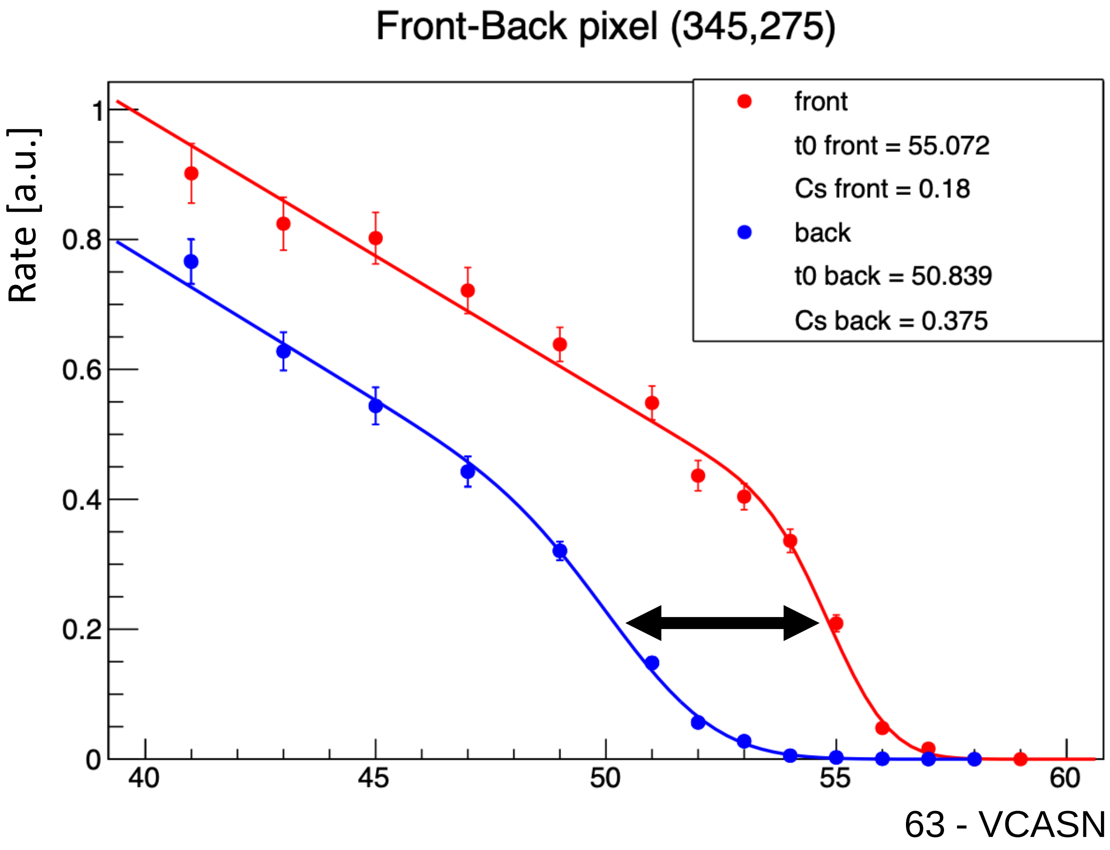
Small C_S

Large C_S



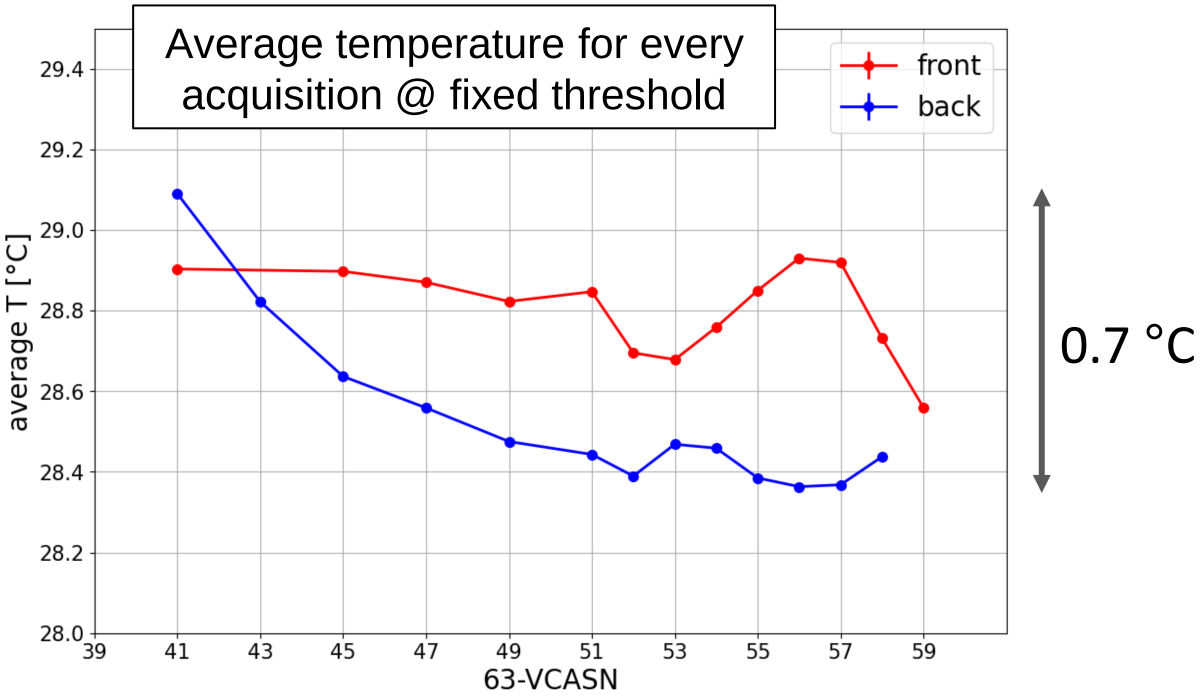
^{55}Fe measurements at fixed temperature

Measurements with ^{55}Fe source @ T = 29 °C



The shift is clearly still evident

Temperature was measured every 30 seconds with a probe placed on ARCADIA Front-End Board



Charge sharing effects

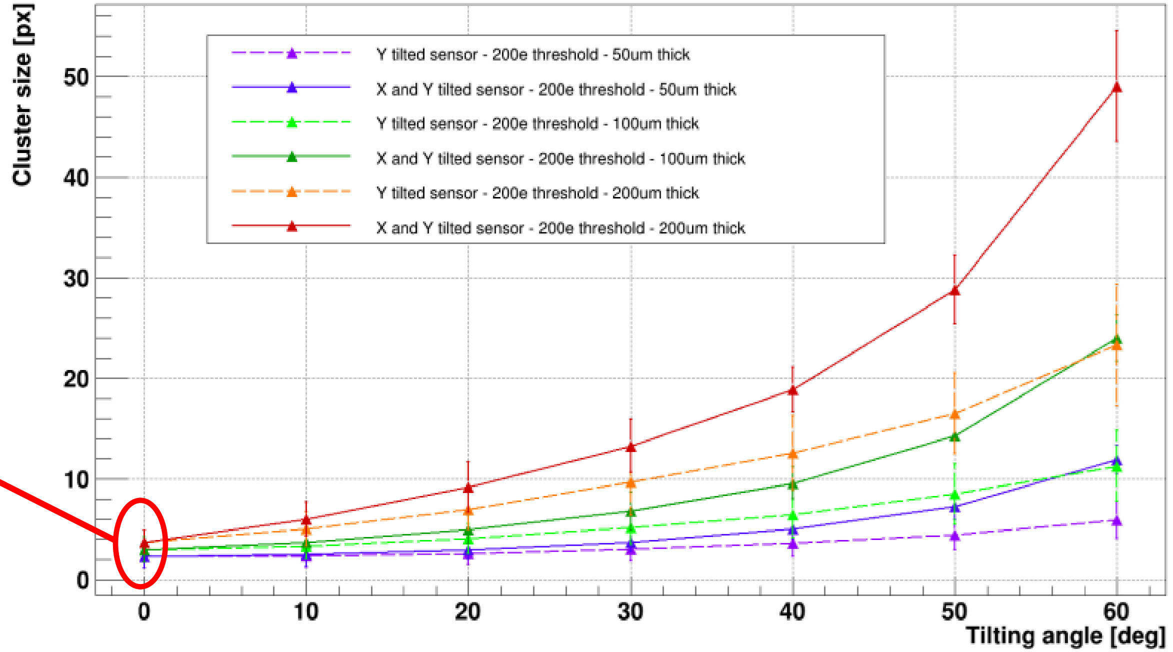
How do we explain the S-curves shift?

Main hypothesis: charge sharing effects among neighbour pixels. In the backside configuration charges diffuse more because they are generated far from the collection electrodes.

Longer drift path → Higher diffusion

Hint: even with a simulated MIP-like charge release (200 MeV μ^-), the average cluster size is of about 4 pixels.

Large charge sharing!



from C. Ferrero, C. Neubüser, L. Pancheri and A. Rivetti, "Monte Carlo simulations of Fully Depleted CMOS pixel sensors for radiation detection applications," *2023 18th Conference on Ph.D Research in Microelectronics and Electronics (PRIME)*, Valencia, Spain, 2023, pp. 101-104, doi: 10.1109/PRIME58259.2023.10161878.

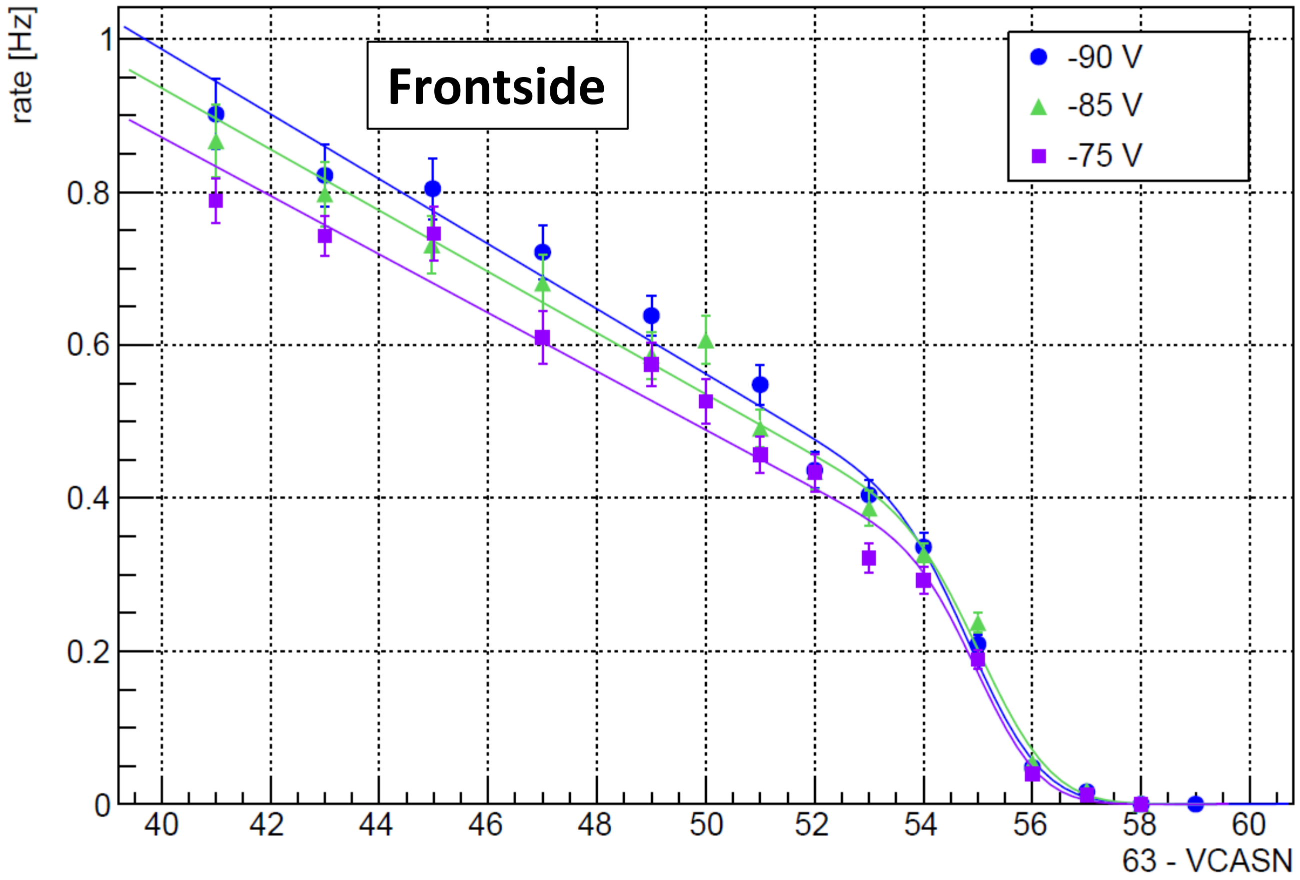
Fig. 7. Average cluster size as function of the tilting angle for three different sensor thicknesses with a fixed threshold of 200 e^-. The double tilting technique is shown in solid line, while the y-tilting is displayed in dashed line.

Measurements varying the backside bias

Università degli Studi di Padova
Dipartimento di Fisica e Astronomia Galileo Galilei

Nominal working backside V_{bias} = - 90 V

Idea: decreasing V_{bias} the electric field is modified, and the diffusion should be enhanced



from fit

Bias (V)	t_0 (63-VCASN)	Cs
-90	55.1 ± 0.1	0.18 ± 0.03
-85	55.3 ± 0.1	0.18 ± 0.03
-75	55.2 ± 0.1	0.17 ± 0.02

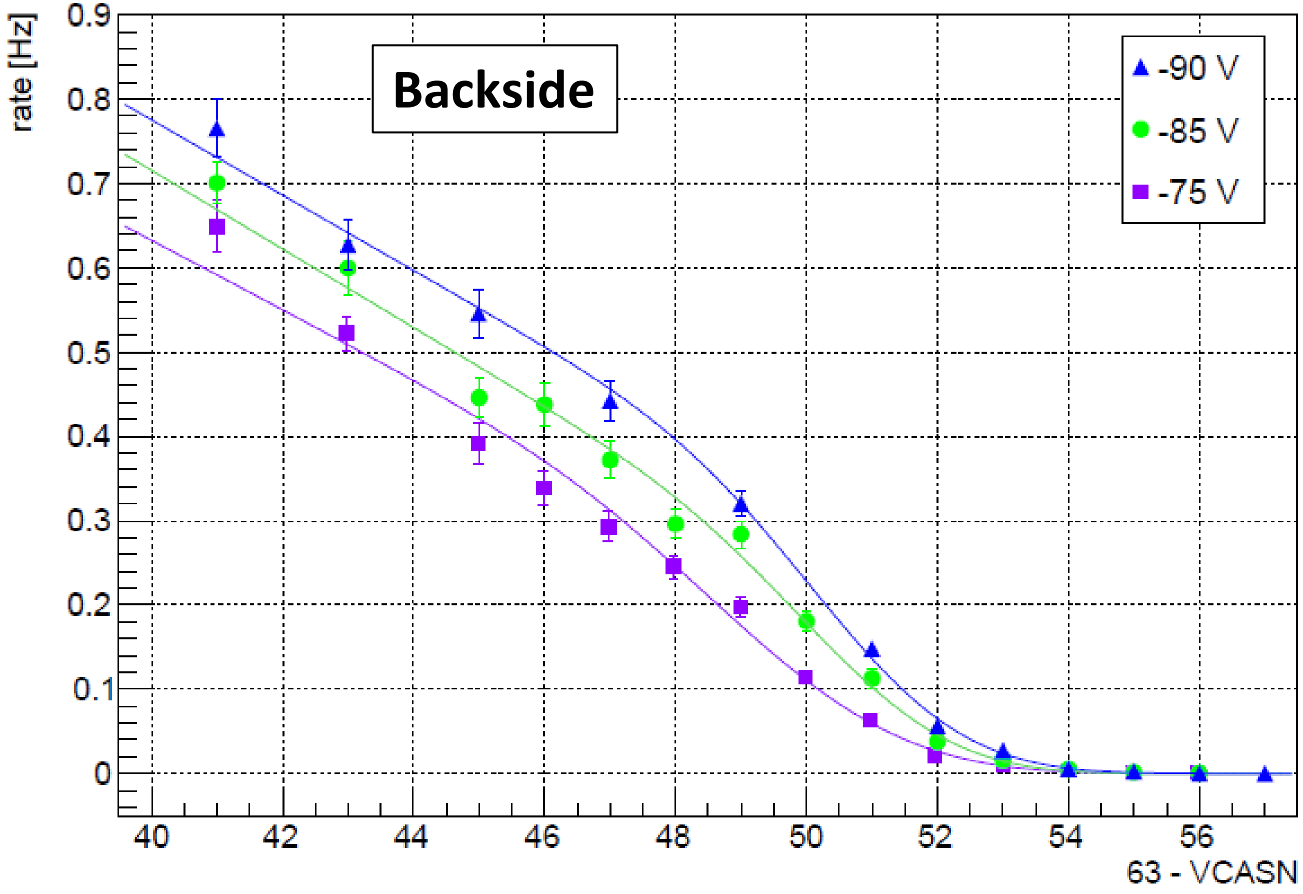
Measurements varying the backside bias

Università degli Studi di Padova

Dipartimento di Fisica e Astronomia Galileo Galilei

Nominal working backside V_{bias} = - 90 V

Idea: decreasing V_{bias} the electric field is modified, and the diffusion should be enhanced

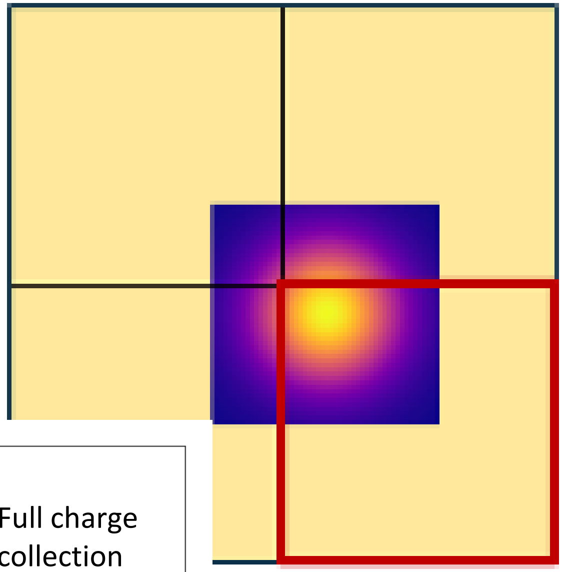


from fit

Bias (V)	t_0 (63-VCASN)	Cs
-90	50.9 ± 0.3	0.4 ± 0.1
-85	51.0 ± 0.2	0.6 ± 0.1
-75	50.0 ± 0.3	0.6 ± 0.1

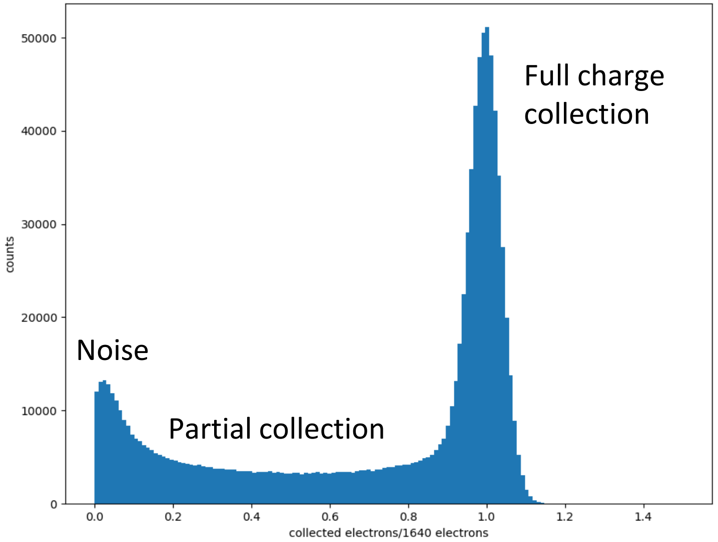
Single pixel MC simulation: recap

Single pixel Monte Carlo simulation to study geometrical charge sharing effects in both frontside and backside configuration



Simulation is performed using the following steps:

- Generate hit coordinates **(x, y)**
- Build a 2D gaussian with μ = **(x, y)** and fixed ***w***
- Calculate numerical integral in pixel area + electronic noise contribution
- Fill analog histogram → S-curve



Charge cloud: Model 1.0

Università degli Studi di Padova

Dipartimento di Fisica e Astronomia Galileo Galilei

Single pixel Monte Carlo simulation to study geometrical charge sharing effects in both frontside and backside configuration

Simulation is performed using the following **steps**:

- Generate hit coordinates **(x, y)**
- Build a 2D gaussian with μ = **(x, y)** and **w**
- Calculate numerical integral in pixel area + electronic noise contribution
- Fill analog histogram → S-curve

Charge cloud width randomization:

1. Generate the X-ray interaction depth z:
   Front: $N(z) = N_0 \exp(-\mu\, z)$
   Back: $N(z) = N_0 \exp(-\mu\, (200 - z))$
   with 200 μm = ARCADIA thickness.

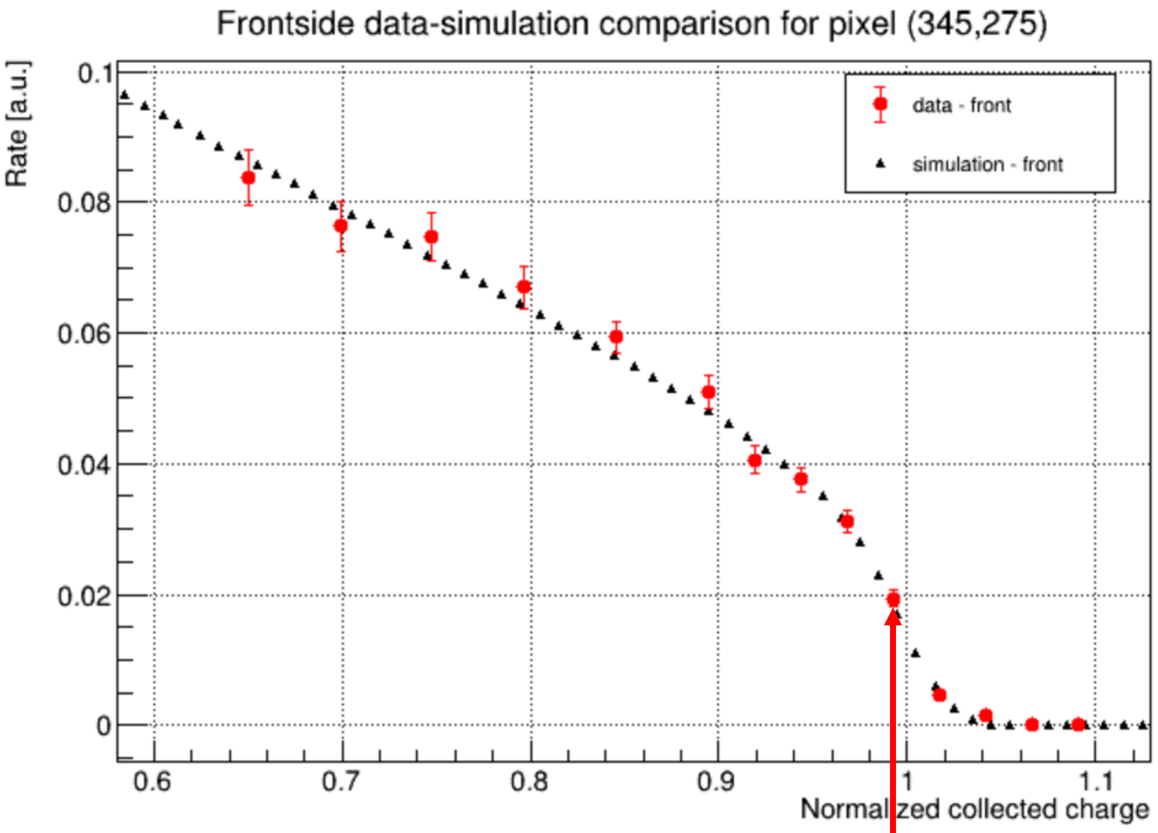
2. From the interaction depth z, the charge cloud width *w* is computed assuming a simplified model:

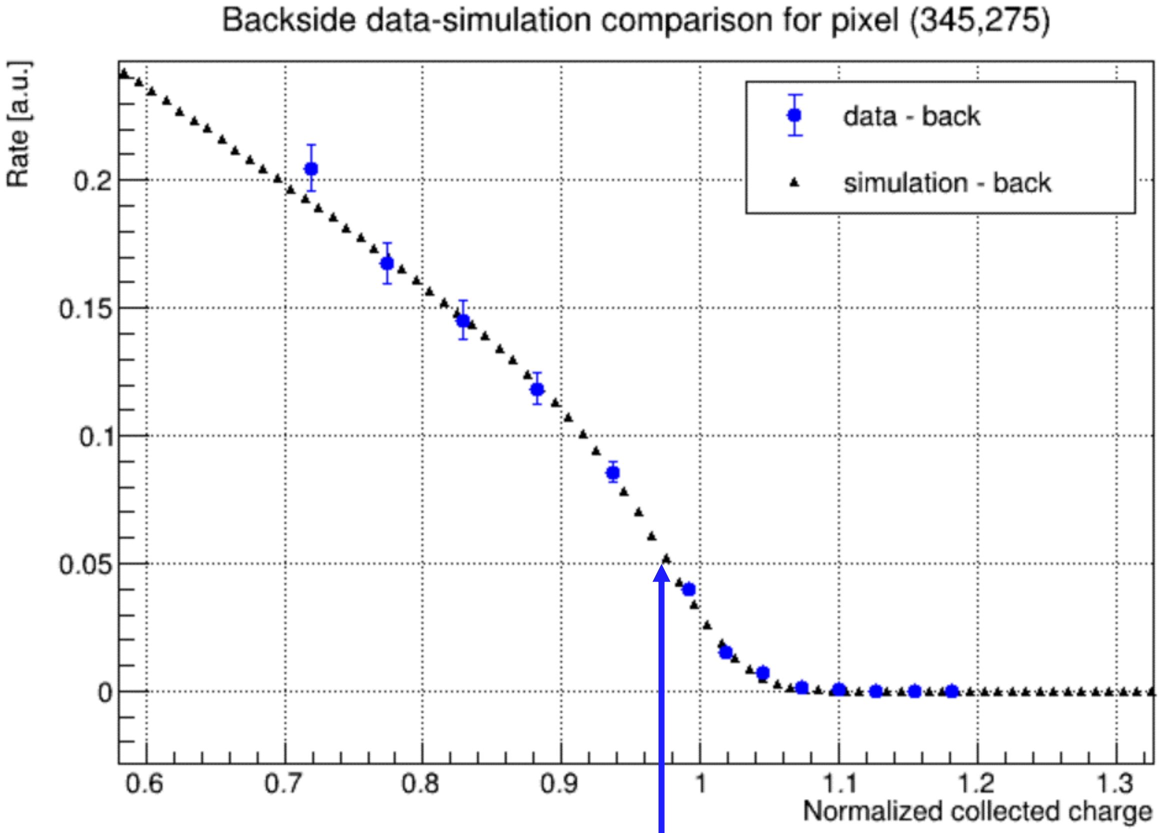
$$w = \boldsymbol{\Delta} + \boldsymbol{k}\sqrt{z}$$

Simulation-data comparison

Università degli Studi di Padova
Dipartimento di Fisica e Astronomia Galileo Galilei

With this model, we can simulate both backside and frontside measurements tuning properly the the two parameters. We obtain a pair (**Δ**, **k**) that reproduces well both s-curve **shapes** .





data are rescaled to have $t_0^{data} = t_0^{sim}$

Model 1.0: MC-data comparison

Università degli Studi di Padova
Dipartimento di Fisica e Astronomia Galileo Galilei

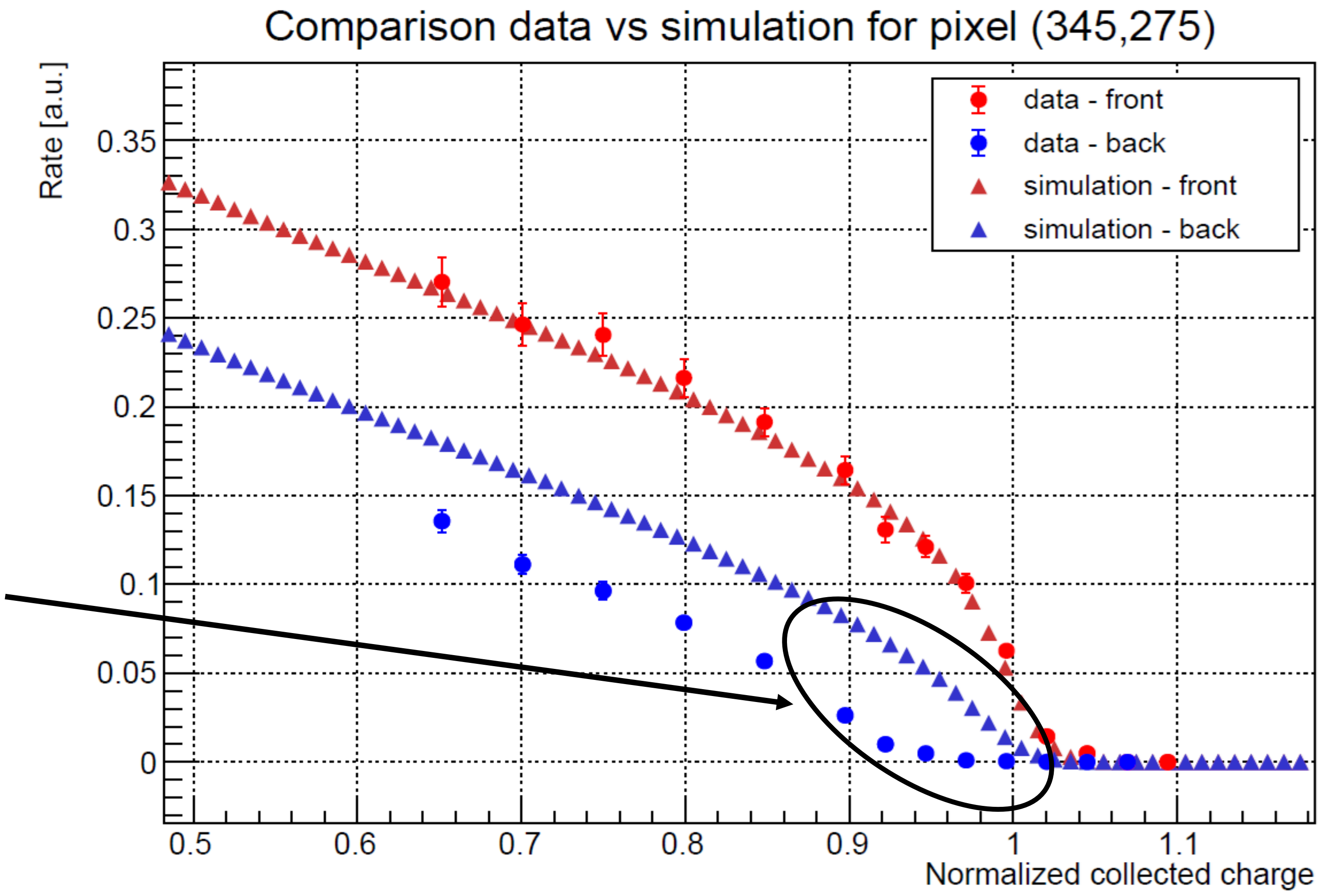
A good model should reproduce both backside and frontside measurements with the same calibrated x-axis (threshold calibration is only dependent on the pixel front-end).

However, this model is not able to reproduce the shift in t_0 we see in data.

Model: $w = \boldsymbol{\Delta} + \boldsymbol{k}\sqrt{z}$

shape ✓

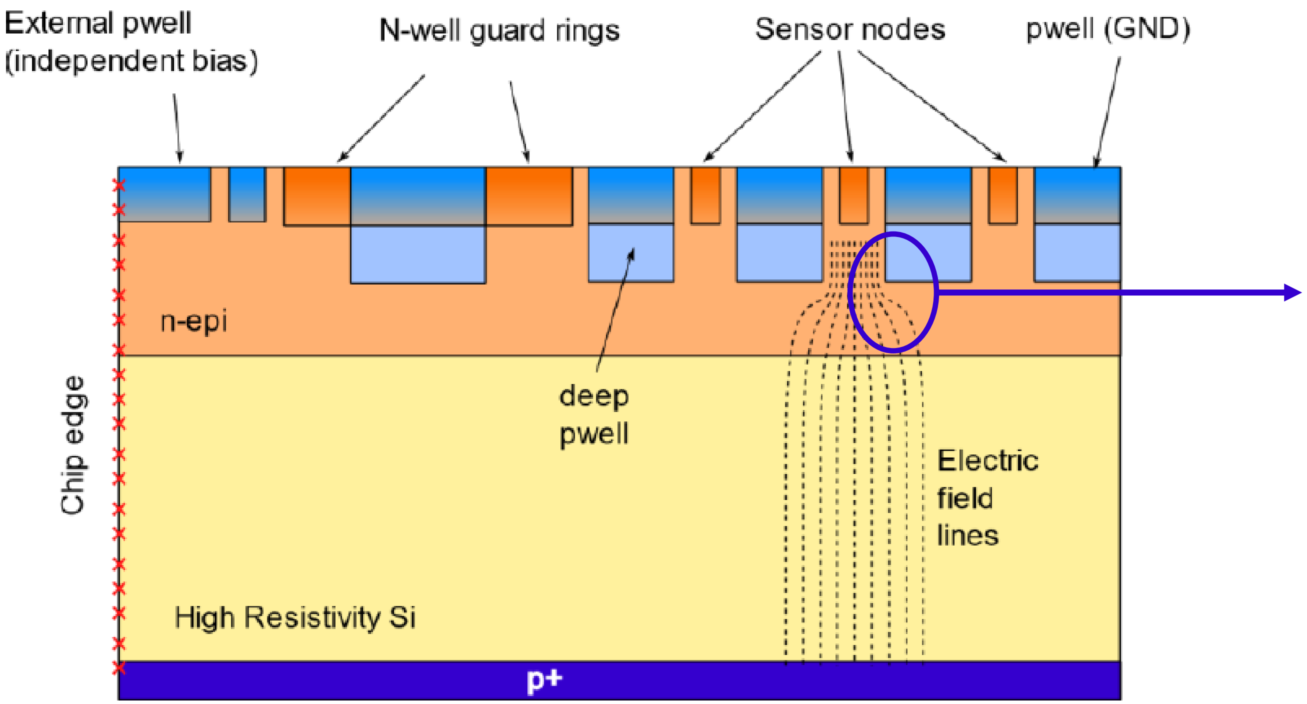
t_0 position ✗



Charge cloud: Model 2.0

Correction added to take into account the hit distance from the pixel center

$$w = \boldsymbol{\Delta} + \boldsymbol{k}\sqrt{z \cdot (1 + \boldsymbol{c} \cdot d(x,y))}$$



From TCAD simulation:
non homogeneous electric field

t_{99} @ center (ns) for 100 µm thickness	t_{99} @ corner (ns) for 100 µm thickness
6.6	22.9

Model 2.0: MC-data comparison

Università degli Studi di Padova

Dipartimento di Fisica e Astronomia Galileo Galilei

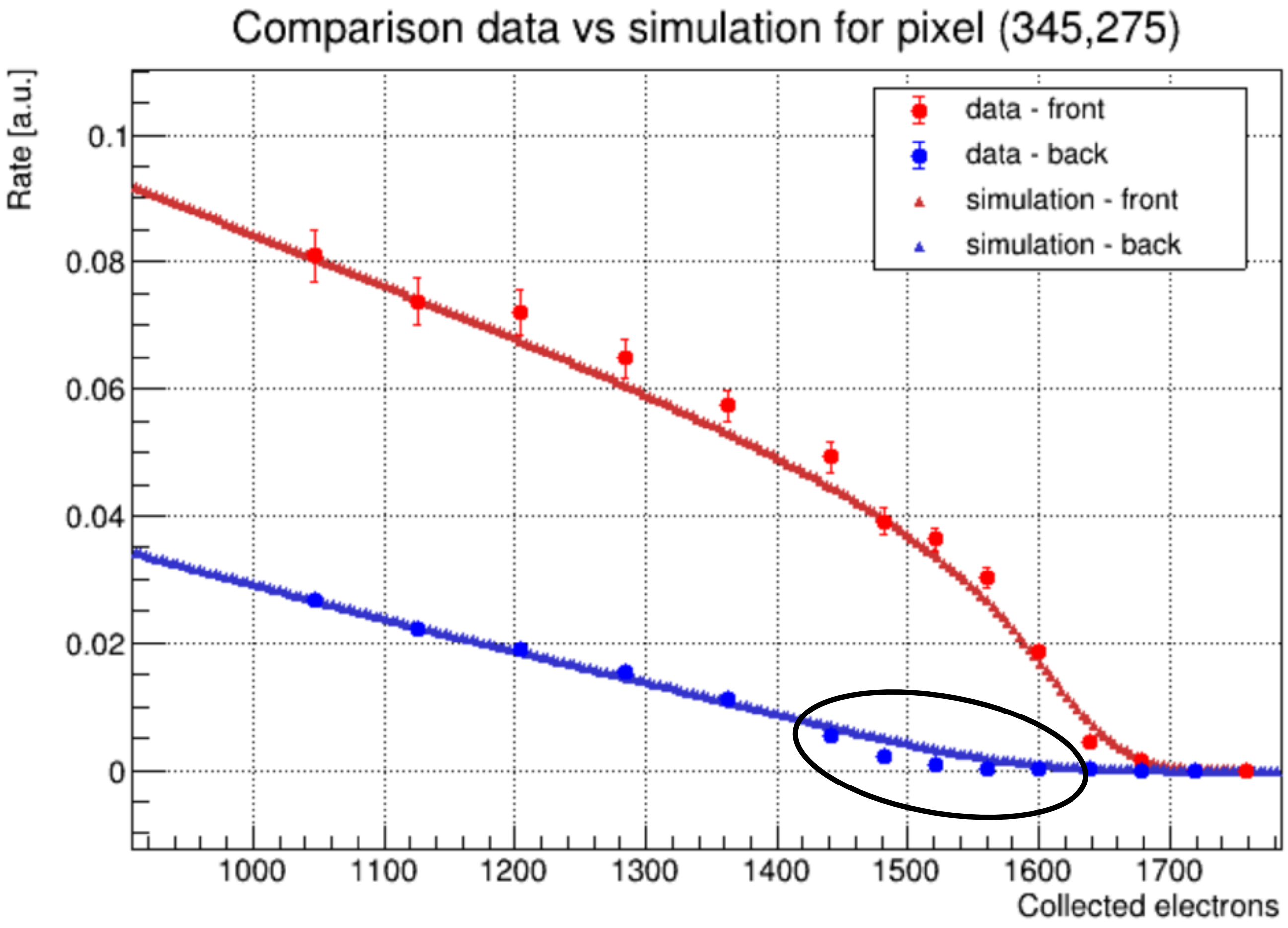
Modified model works better, but there are three parameters to be tuned to reproduce data.

Model: $w = \boldsymbol{\Delta} + \boldsymbol{k}\sqrt{z \cdot (1 + \boldsymbol{c} \cdot d(x, y))}$

shape ✓

t_0 position ✓

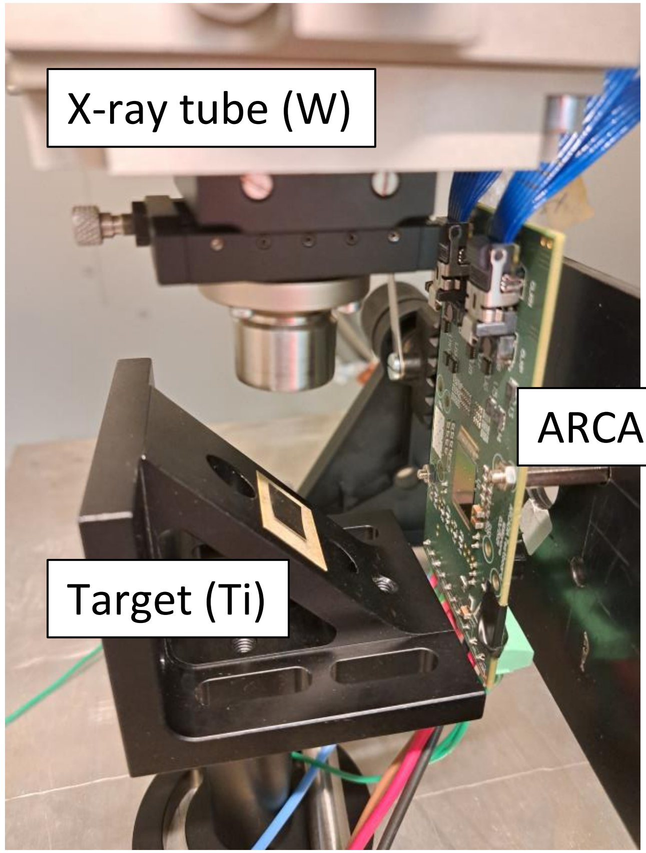
parameters ✗

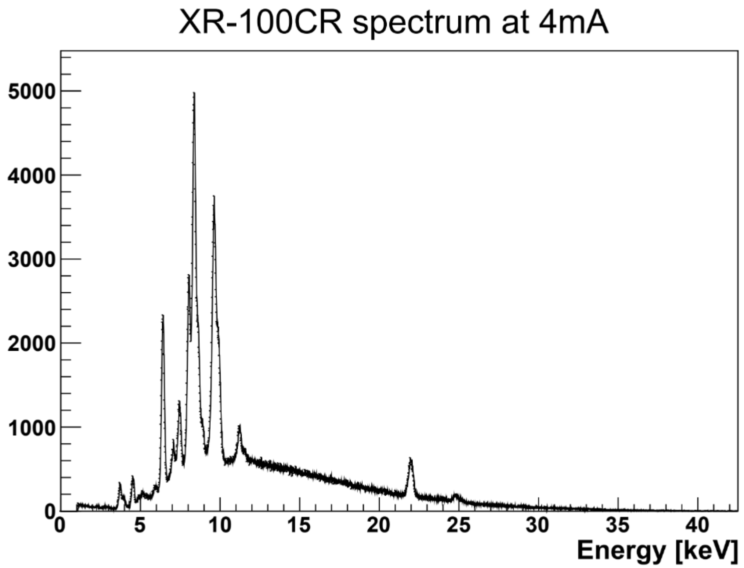


Next: AllPix2 to better simulate charge transport inside sensor

X-ray fluorescence measurements

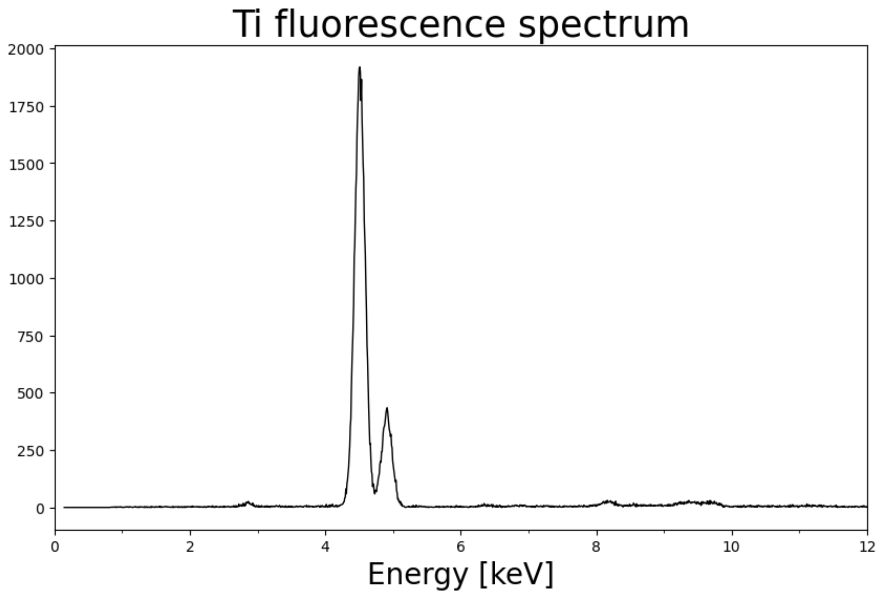
Tests at different energies → X-ray fluorescence setup with targets of different materials (Cu, Ti, Fe)



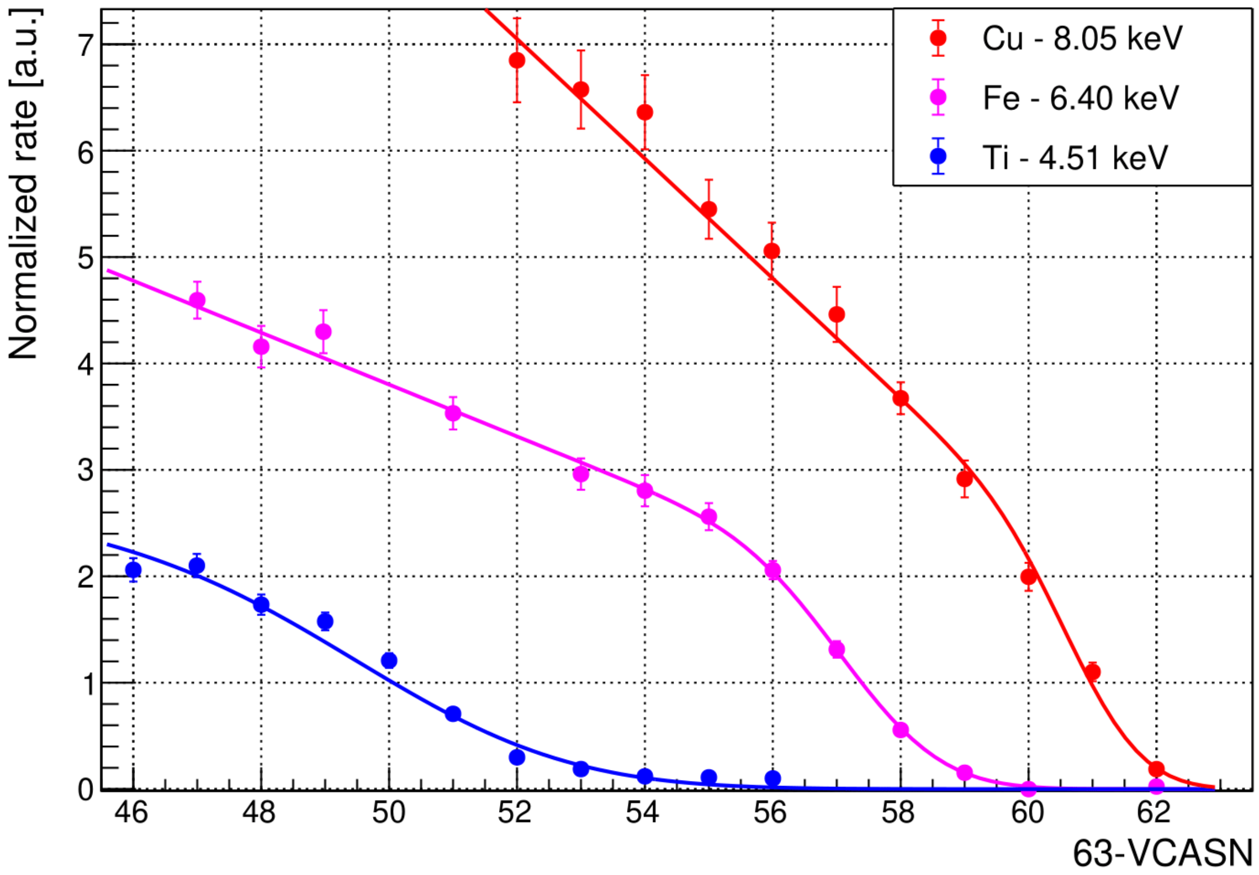


Target	E_{XRF} (keV)
Ti	4.51
Fe	6.40
Cu	8.05

From polychromatic X-ray tube spectrum to ~ monochromatic one impinging on ARCADIA



X-ray fluorescence S-curves



X-ray fluorescence setup

Pros:

- gives the possibility to obtain ~ monochromatic photons at different energies, both higher and lower than ^{55}Fe
- S-curves at different thresholds → possibility of calibration

Cons:

- Slow acquisition rate
- No control over temperature during the acquisitions
- Not feasible to use low energy X-rays (< 4.5 keV) because of their absorption in air