

10/03/2025

Réunion imXgam

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PhD student (DT & CPPM)

Supervisors:

Elena Gaboriau-Borissenko, DT

Christian Morel, CPPM

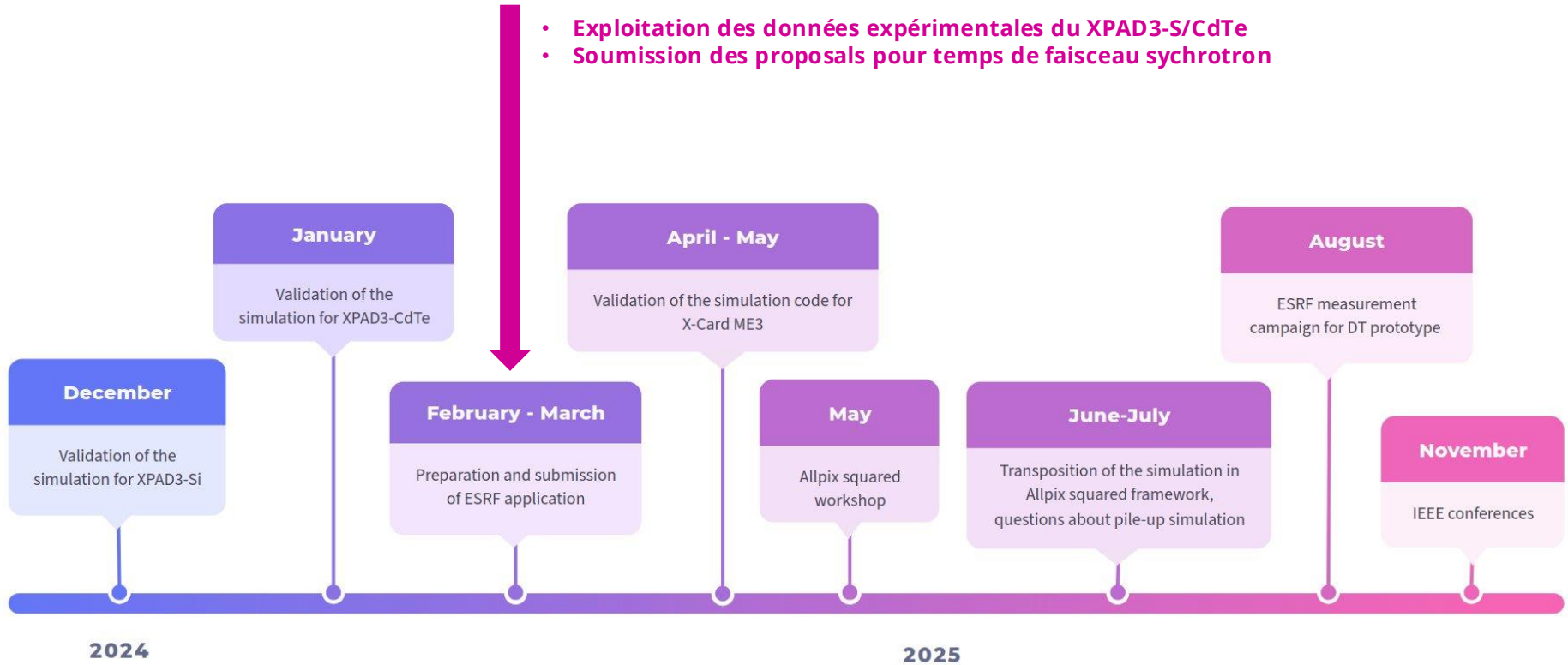
Yannick Boursier, CPPM



1. Rappel des objectifs / plan

On est ici !

- Exploitation des données expérimentales du XPAD3-S/CdTe
- Soumission des proposals pour temps de faisceau synchrotron



2. Proposals pour temps de faisceau en synchrotron

- SOLEIL
 - Date de dépôt: 17 février
 - Ligne: PSICHE
 - Proposal review decision : ~ **1er mai**
- ESRF
 - Date de dépôt: 28 février
 - Ligne: ID11
 - Proposal review decision : ~ **1er juin**



4. Exploitation des données de threshold scan XPAD3-S/CdTe

- Etude du pixel 46 62 : Modèle deux gaussiennes + constante

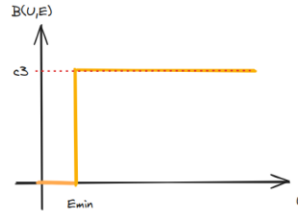
$$F(U, E, E_{\min}, E_e, \sigma_1, c_1, \sigma_2, c_2, c_3) = c_1 \left(\frac{1}{\sqrt{2\pi}} \exp \left(-\frac{\left(\frac{U-E}{\sigma_1}\right)^2}{2} \right) + c_2 \frac{1}{\sqrt{2\pi}} \exp \left(-\frac{\left(\frac{U-(E-E_e)}{\sigma_2}\right)^2}{2} \right) + B(U, E, E_{\min}, c_3) \right)$$

Où

$$B(U, E, E_{\min}, c_3) = \begin{cases} 0, & \text{si } E_{\min} \leq U \\ c_3, & \text{sinon} \end{cases}$$

Avec

- E : Energie du faisceau incident
- E_e : Energie des photons de fluorescence (~ 25 keV pour du CdTe)
- σ_1, σ_2 : Ecart-types respectivement de la première et seconde gaussienne
- c_1, c_2, c_3 : Amplitudes



4. Exploitation des données de threshold scan XPAD3-S/CdTe

- Etude du pixel 46 62 : Modèle deux gaussiennes + constante

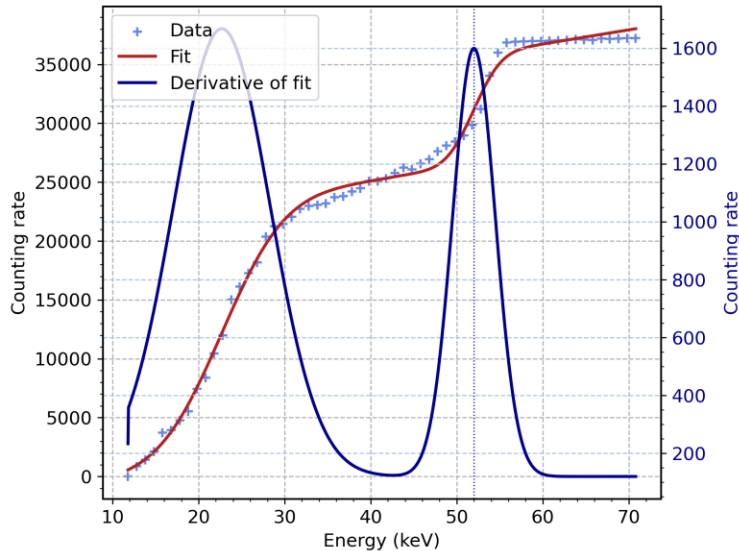
$$F(U, E, E_{\min}, E_e, \sigma_1, c_1, \sigma_2, c_2, c_3) = c_1 \left(\frac{1}{\sqrt{2\pi}} \exp\left(-\frac{(U-E)^2}{2\sigma_1^2}\right) + c_2 \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{(U-(E-E_e))^2}{2\sigma_2^2}\right) + B(U, E, E_{\min}, c_3) \right)$$

Où

$$B(U, E, E_{\min}, c_3) = \begin{cases} 0, & \text{si } E_{\min} \leq U \\ c_3, & \text{sinon} \end{cases}$$

Threshold scan of pixel 46 62 from ROOT file Mod0_Chip3.root, $E_{inc} = 52.0$ keV

Data of threshold scan, model fit and its derivative



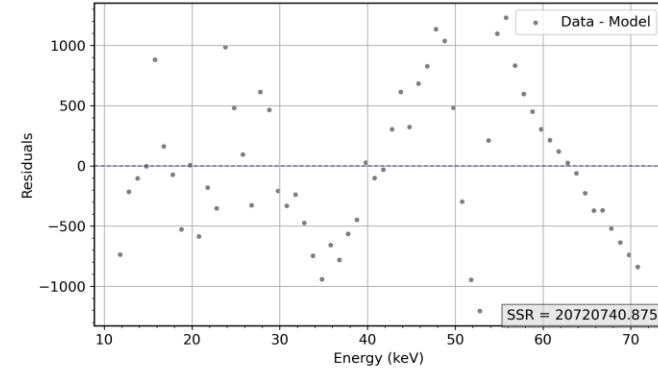
Fitted parameters:

$E = 52.00$ keV
 $E_{\min} = 11.79$ keV
 $E_e = 29.31$ keV
 $\sigma_1 = 2.48$ keV
 $c_1 = 9210.67$
 $\sigma_2 = 5.61$ keV
 $c_2 = 2.36$
 $c_3 = 0.01$

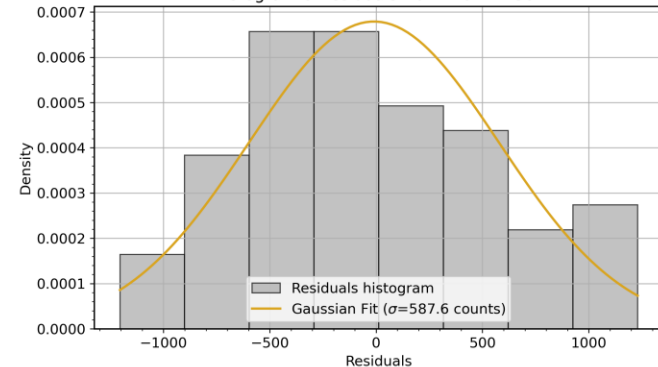
$FWHM_1 = 2.35 \cdot \sigma_1 = 5.84$ keV
 $Resolution = FWHM_1/E = 0.11$

Residual Analysis - pixel 46 62

Residuals vs. Energy



Histogram of residuals - bin width = 304



4. Exploitation des données de threshold scan XPAD3-S/CdTe

- Modèle de Philips

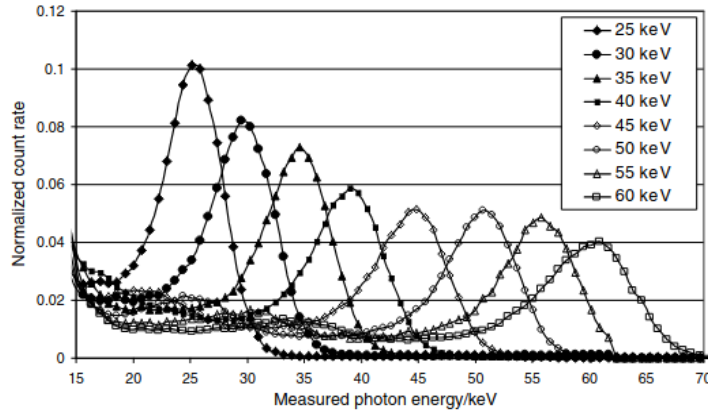


Figure 2. Spectral response of one threshold in one detector pixel resulting from monochromatic illumination with photon energies ranging from 25 keV to 60 keV. The count rate in the detector was about 10^5 photons pixel⁻¹ s⁻¹. The data are normalized to an integrated count rate of 1 cts s⁻¹ above 20 keV.

The observation of the shape of the spectral response motivated the phenomenological model described in the appendix. Since the shapes of the spectral responses of the individual pixels and bins did not vary strongly, we used only one function for the description of all pixels.

A.2. Response function model

The phenomenological model for the response function was motivated by the analysis of the response function measurements (see section 4.1). The model function consists of two Gaussian peaks, one at the incident energy and one at an energy reduced by the average energy of K-escape photons. Furthermore, a constant background for energies below the incident energy is present in the model. This results in the following formula:

$$R(U, E) = c_1(E) \left(\frac{1}{\sqrt{2\pi}\sigma_1(E)} \exp\left(-\frac{1}{2} \frac{(U-E)^2}{\sigma_1(E)^2}\right) + c_2(E) \frac{1}{\sqrt{2\pi}\sigma_2(E)} \exp\left(-\frac{1}{2} \frac{(U-E_e-E)^2}{\sigma_2(E)^2}\right) + B(U, E) \right). \quad (A.2)$$

The background $B(U, E)$ has a constant value on the U -scale of c_3 for $U < (E - 3\sigma_1)$ and is then linearly ramped down to zero within a width of $6\sigma_1$. E_e is the average energy of an

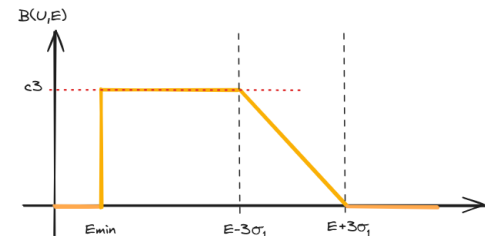
J.P. Schlomka and al, Experimental feasibility of multi-energy photon-counting K-edge imaging in pre-clinical computed tomography, Phys. Med. Biol. 53 (2008) 4031-4047 <http://dx.doi.org/10.1088/0031-9155/53/15/002>

$$R(U, E, E_{\min}, E_e, \sigma_1, c_1, \sigma_2, c_2, c_3) = c_1 \left(\frac{1}{\sqrt{2\pi}} \exp\left(-\frac{(U-E)^2}{2\sigma_1^2}\right) + c_2 \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{(U-(E-E_e))^2}{2\sigma_2^2}\right) + B(U, E, E_{\min}, \sigma_1, c_3) \right)$$

$$\text{Où } B(U, E, E_{\min}, \sigma_1, c_3) = \begin{cases} c_3, & \text{si } E_{\min} \leq U < E - 3\sigma_1 \\ \frac{(E+3\sigma_1-U)c_3}{6\sigma_1}, & \text{si } E - 3\sigma_1 \leq U < E + 3\sigma_1 \\ 0, & \text{sinon} \end{cases}$$

Avec

- E : Energie du faisceau incident
- E_e : Energie des photons de fluorescence (~ 25 keV pour du CdTe)
- σ_1, σ_2 : Ecart-type respectivement de la première et seconde gaussienne
- c_1, c_2, c_3 : Amplitudes



4. Exploitation des données de threshold scan XPAD3-S/CdTe

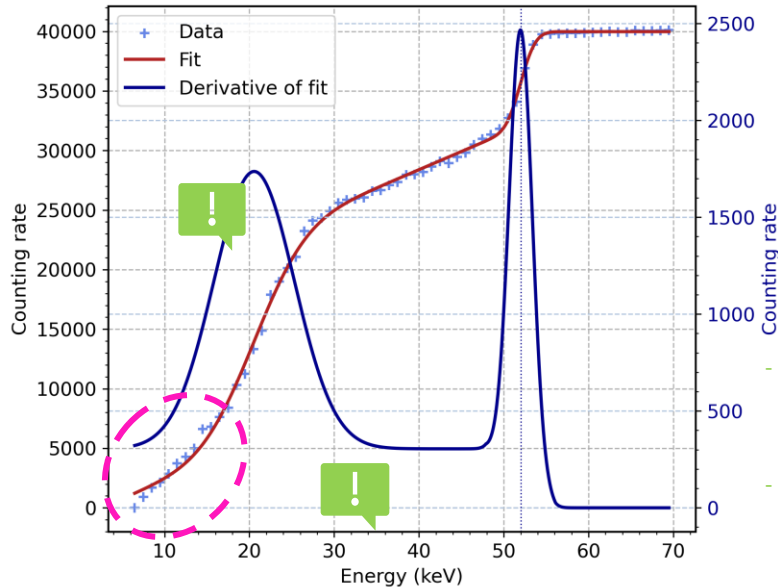
- Etude du pixel 46 62 : Modèle de Philips

$$R(U, E, E_{\min}, E_e, \sigma_1, c_1, \sigma_2, c_2, c_3) = c_1 \left(\frac{1}{\sqrt{2\pi}} \exp \left(-\frac{(U-E)^2}{2\sigma_1^2} \right) + c_2 \frac{1}{\sqrt{2\pi}} \exp \left(-\frac{(U-(E-E_e))^2}{2\sigma_2^2} \right) + B(U, E, E_{\min}, \sigma_1, c_3) \right)$$

$$\text{Où } B(U, E, E_{\min}, \sigma_1, c_3) = \begin{cases} c_3, & \text{si } E_{\min} \leq U < E - 3\sigma_1 \\ \frac{(E+3\sigma_1-U)}{6\sigma_1}, & \text{si } E - 3\sigma_1 \leq U < E + 3\sigma_1 \\ 0, & \text{sinon} \end{cases}$$

Threshold scan of pixel 46 62 from ROOT file Mod0_Chip3.root, $E_{inc} = 52.0$ keV

Data of threshold scan, model fit and its derivative

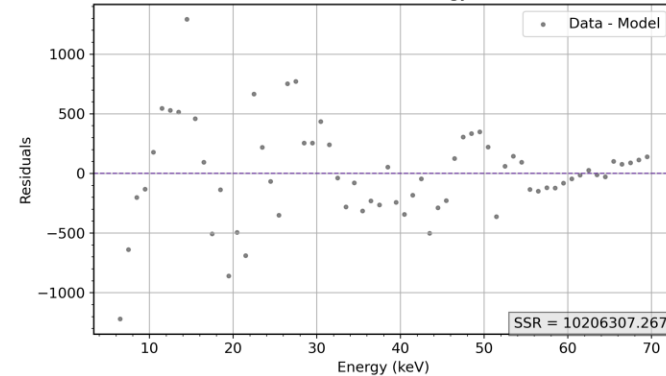


Fitted parameters:
 $E = 52.00$ keV
 $E_{\min} = 2.55$ keV
 $E_e = 31.44$ keV
 $\sigma_1 = 1.37$ keV
 $c_1 = 7938.00$
 $\sigma_2 = 4.73$ keV
 $c_2 = 2.14$
 $c_3 = 0.04$

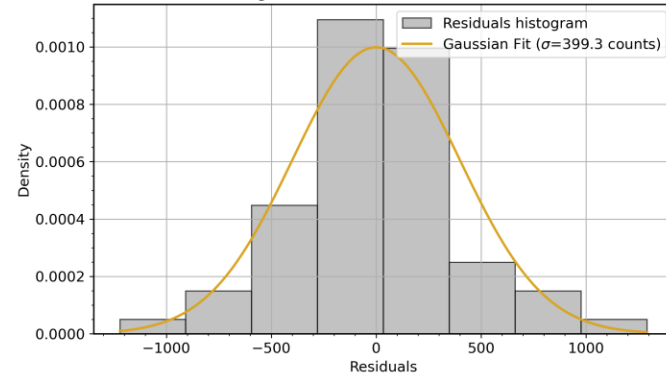
$FWHM_1 = 2.35 \cdot \sigma_1 = 3.22$ keV
 Resolution = $FWHM_1/E = 0.06$

- Superposition du pic du aux photons d'échappement + pic des photons qui s'échappent des pixels voisins
- Ici DACL= 1keV. S'assurer de la conversion en comparant E-Ee pour différentes énergies

Residual Analysis - pixel 46 62
Residuals vs. Energy



Histogram of residuals - bin width = 314



4. Exploitation des données de threshold scan XPAD3-S/CdTe

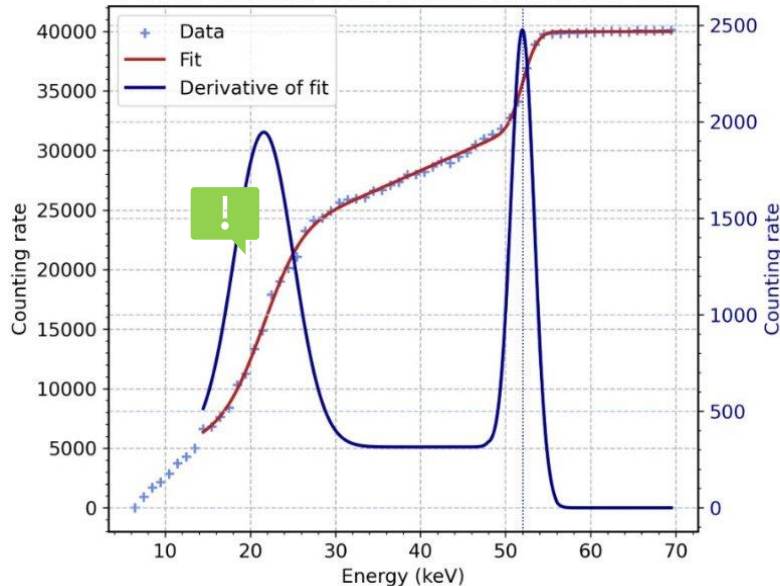
- Etude du pixel 46 62 : Modèle de Philips

$$R(U, E, E_{\min}, E_e, \sigma_1, c_1, \sigma_2, c_2, c_3) = c_1 \left(\frac{1}{\sqrt{2\pi}} \exp \left(-\frac{(U-E)^2}{2\sigma_1^2} \right) + c_2 \frac{1}{\sqrt{2\pi}} \exp \left(-\frac{(U-(E-E_e))^2}{2\sigma_2^2} \right) + B(U, E, E_{\min}, \sigma_1, c_3) \right)$$

$$\text{Où } B(U, E, E_{\min}, \sigma_1, c_3) = \begin{cases} c_3, & \text{si } E_{\min} \leq U < E - 3\sigma_1 \\ \frac{(E+3\sigma_1-U)}{6\sigma_1}, & \text{si } E - 3\sigma_1 \leq U < E + 3\sigma_1 \\ 0, & \text{sinon} \end{cases}$$

Threshold scan of pixel 46 62 from ROOT file Mod0_Chip3.root, $E_{inc} = 52.0$ keV

Data of threshold scan, model fit and its derivative

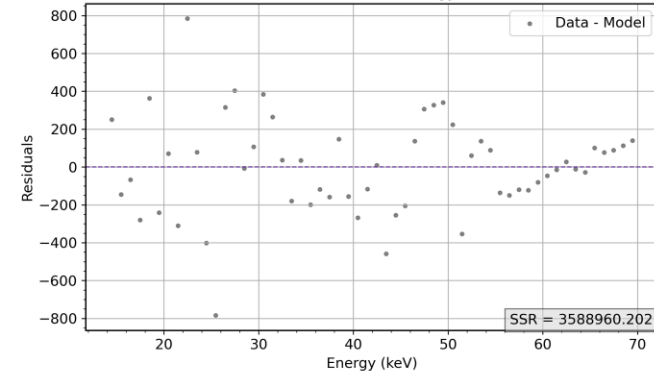


Fitted parameters:
 $E = 52.00$ keV
 $E_{\min} = -4.81$ keV
 $E_e = 30.41$ keV
 $\sigma_1 = 1.36$ keV
 $c_1 = 7888.43$
 $\sigma_2 = 3.47$ keV
 $c_2 = 1.80$
 $c_3 = 0.04$

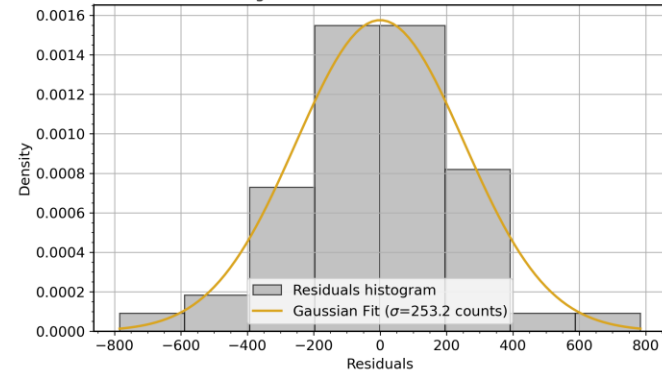
$FWHM_1 = 2.35 \cdot \sigma_1 = 3.19$ keV
 Resolution = $FWHM_1/E = 0.06$

Analyser l'énergie
 ~40 keV pour
 essayer de voir la
 séparation des deux
 pics

Residual Analysis - pixel 46 62
 Residuals vs. Energy



Histogram of residuals - bin width = 196



4. Exploitation des données de threshold scan XPAD3-S/CdTe



$$R(U, E, E_{\min}, E_e, \sigma_1, c_1, \sigma_2, c_2, c_3) = c_1 \left(\frac{1}{\sqrt{2\pi}} \exp \left(-\frac{\left(\frac{U-E}{\sigma_1}\right)^2}{2} \right) \right) + c_2 \frac{1}{\sqrt{2\pi}} \exp \left(-\frac{\left(\frac{U-(E-E_e)}{\sigma_2}\right)^2}{2} \right) + B(U, E, E_{\min}, \sigma_1, c_3)$$

$$\text{Où } B(U, E, E_{\min}, \sigma_1, c_3) = \begin{cases} c_3, & \text{si } E_{\min} \leq U < E - 3\sigma_1 \\ \frac{(E+3\sigma_1-U)}{6\sigma_1}, & \text{si } E - 3\sigma_1 \leq U < E + 3\sigma_1 \\ 0, & \text{sinon} \end{cases}$$

Avec

- E : Energie du faisceau incident
- E_e : Energie des photons de fluorescence (~ 25 keV pour du CdTe)
- σ_1, σ_2 : Ecart-type respectivement de la première et seconde gaussienne
- c_1, c_2, c_3 : Amplitudes

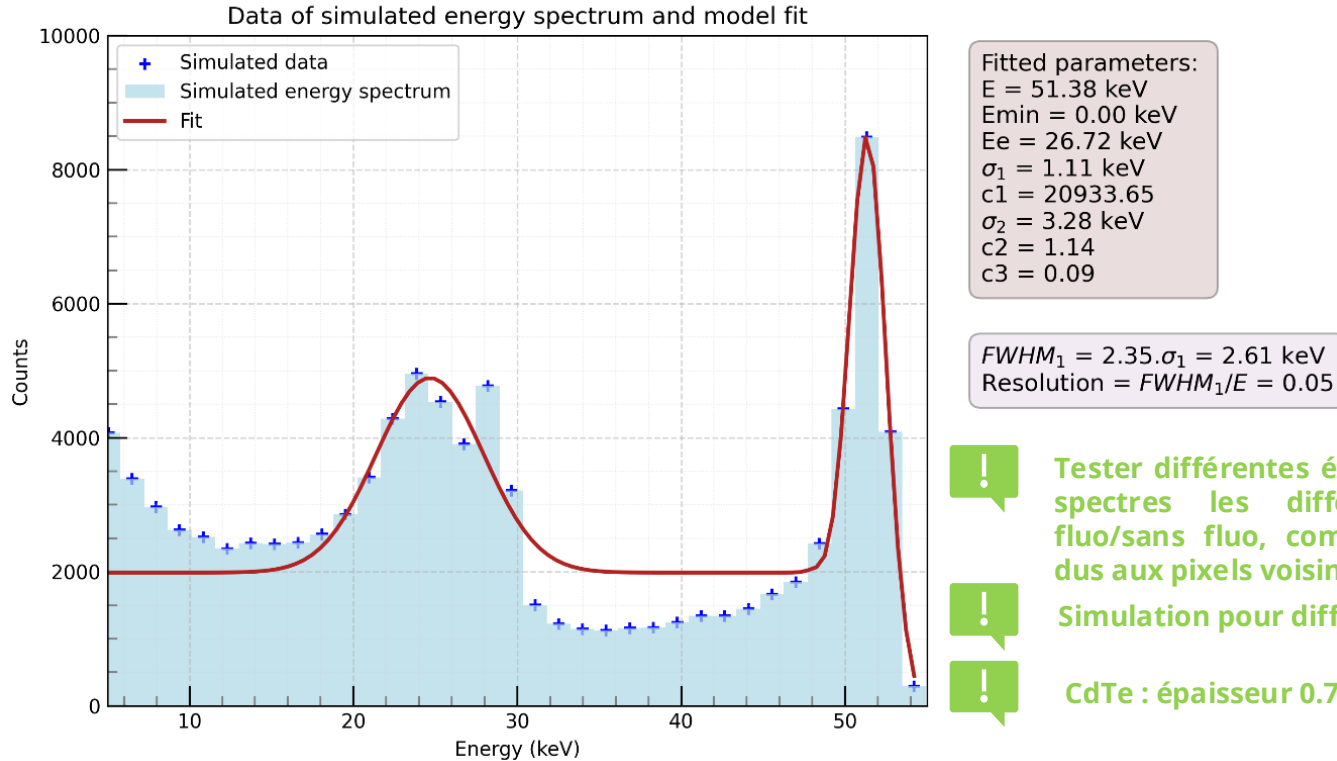
Sur 4 pixels étudiés

	46 62	47 70	48 52	49 68	$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i$	$\sigma = \sqrt{\frac{\sum_i^N x_i - \bar{x} ^2}{N-1}}$	$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{N}}$
offset	6.48	9.28	7.97	10.32	8.53	1.66	0.55
E	45.520	42.721	44.030	41.685	43.49	1.66	0.55
E _{min}	2.55	-1.15	1.35	-1.10	0.41	1.84	0.61
E _e	31.44	30.20	30.30	30.62	30.64	0.56	0.188
σ_1	1.37	1.01	1.26	1.35	1.25	0.17	0.06
c ₁	7938	8665.34	6898.01	5133.31	7158.67	1532.69	510.90
σ_2	4.73	6.55	11.32	6.89	7.37	2.80	0.93
c ₂	2.14	2.33	3.90	2.91	2.82	0.79	0.26
c ₃	0.04	0.04	0.01	0.03	0.03	0.01	0.00

4. Exploitation des données de threshold scan XPAD3-S/CdTe

- Simulation : Modèle de Philips

Simulation - Energy spectrum of 52 keV incident photons - 10^6 evts



! Tester différentes énergies et séparer dans le spectres les différentes contributions : fluo/sans fluo, compton, pic d'échappement dus aux pixels voisins

! Simulation pour différents bruits, énergies

! CdTe : épaisseur 0.750 mm

Planification



Autres infos

- Prochain déplacement à DTX:
24 au 28 mars
- Visite Elena CPPM:
17 mars

A faire

- Préparer le workshop Allpix squared : soumettre abstract (31 mars)

En cours

- Exploitation des résultats des simulations pour le CdTe

Terminé

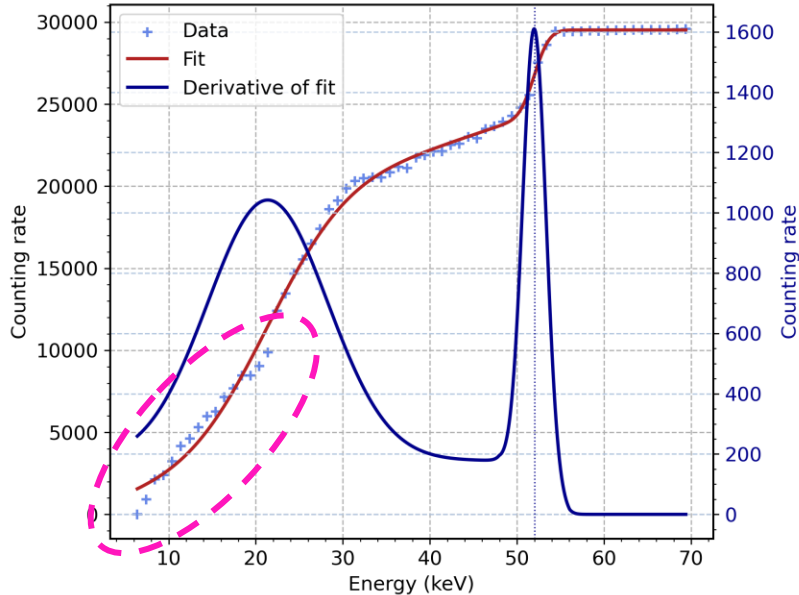
- Soumission des proposals ESRF/SOLEIL

4. Exploitation des données de threshold scan XPAD3-S/CdTe

- Etude du pixel 49 68 : Modèle de Philips

Threshold scan of pixel 49 68 from ROOT file Mod0_Chip3.root, $E_{inc} = 52.0$ keV

Data of threshold scan, model fit and its derivative

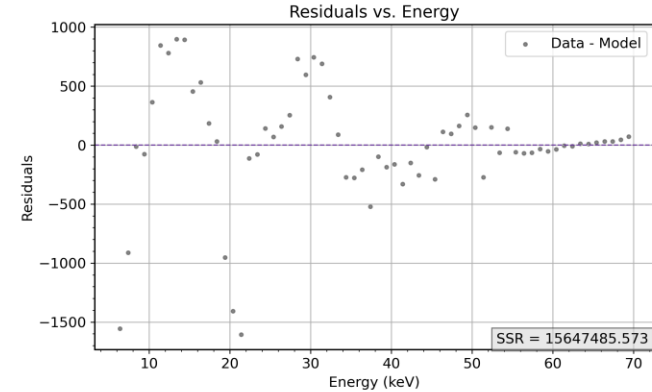


Fitted parameters:

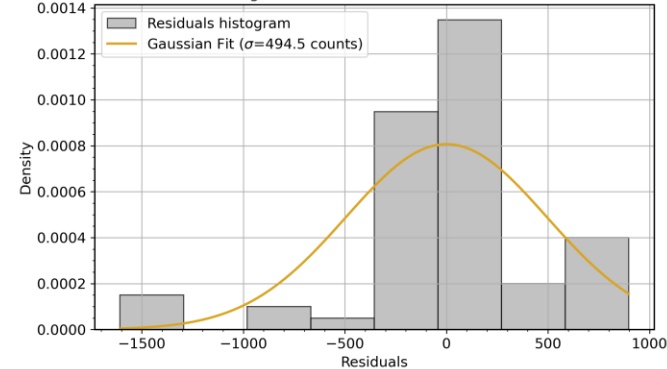
$E = 52.00$ keV
 $E_{min} = -1.10$ keV
 $E_e = 30.62$ keV
 $\sigma_1 = 1.35$ keV
 $c1 = 5133.31$
 $\sigma_2 = 6.89$ keV
 $c2 = 2.91$
 $c3 = 0.03$

$FWHM_1 = 2.35 \cdot \sigma_1 = 3.16$ keV
 $Resolution = FWHM_1/E = 0.06$

Residual Analysis - pixel 49 68



Histogram of residuals - bin width = 313

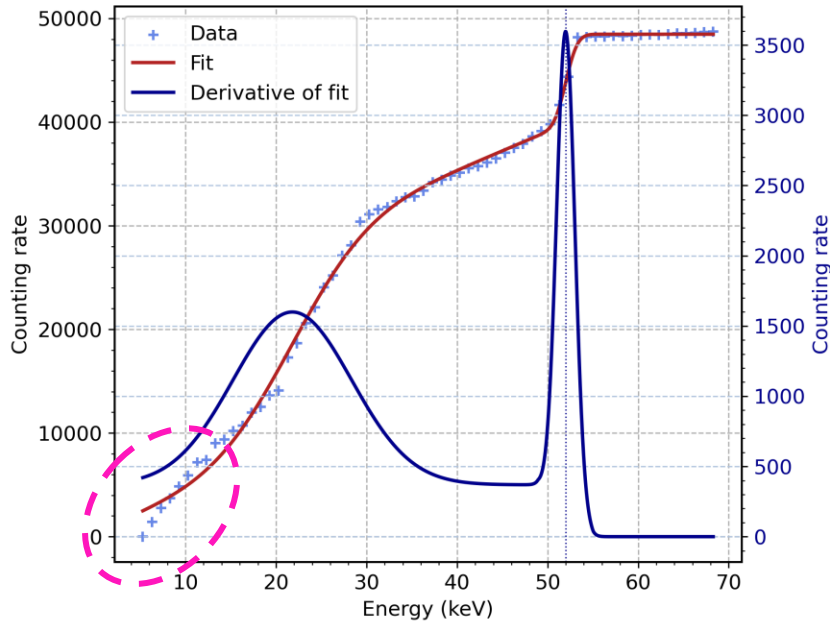


4. Exploitation des données de threshold scan XPAD3-S/CdTe

- Etude du pixel 47 70 : Modèle de Philips

Threshold scan of pixel 47 70 from ROOT file Mod0_Chip3.root, $E_{inc} = 52.0$ keV

Data of threshold scan, model fit and its derivative

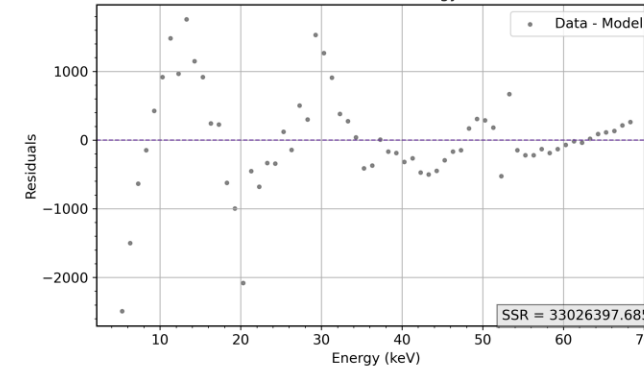


Fitted parameters:
 $E = 52.00$ keV
 $E_{min} = -1.15$ keV
 $E_e = 30.20$ keV
 $\sigma_1 = 1.01$ keV
 $c_1 = 8665.34$
 $\sigma_2 = 6.55$ keV
 $c_2 = 2.33$
 $c_3 = 0.04$

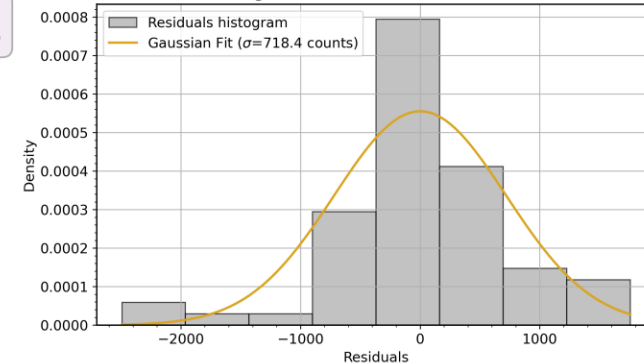
$FWHM_1 = 2.35 \cdot \sigma_1 = 2.38$ keV
Resolution = $FWHM_1/E = 0.05$

Residual Analysis - pixel 47 70

Residuals vs. Energy



Histogram of residuals - bin width = 531



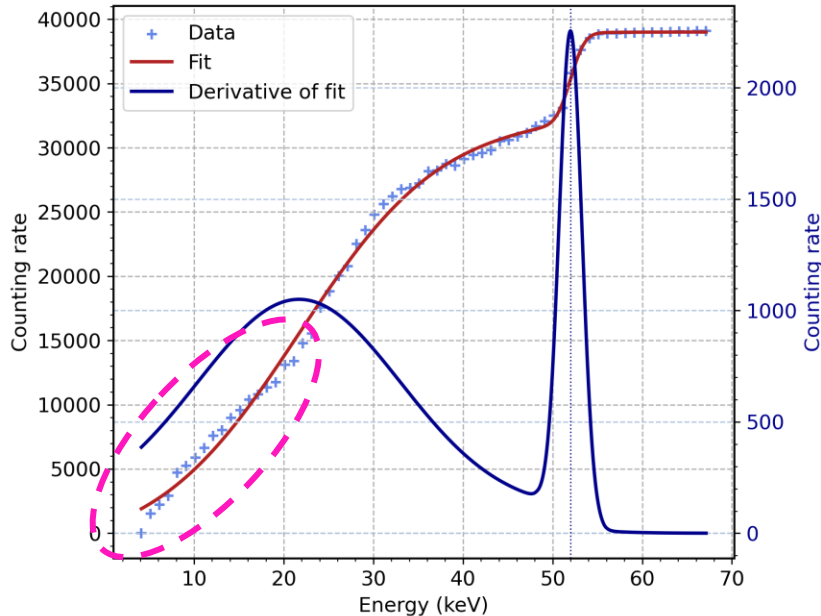
4. Exploitation des données de threshold scan XPAD3-S/CdTe



- Etude du pixel 48 52 : Modèle de Philips

Threshold scan of pixel 48 52 from ROOT file Mod0_Chip3.root, $E_{inc} = 52.0$ keV

Data of threshold scan, model fit and its derivative



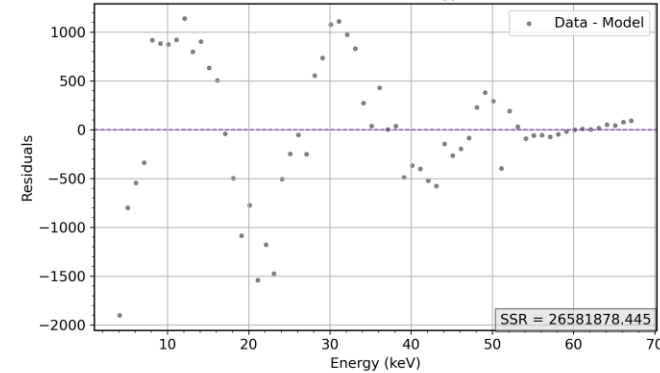
Fitted parameters:

$E = 52.00$ keV
 $E_{min} = 1.35$ keV
 $E_e = 30.30$ keV
 $\sigma_1 = 1.26$ keV
 $c_1 = 6898.01$
 $\sigma_2 = 11.32$ keV
 $c_2 = 3.90$
 $c_3 = 0.01$

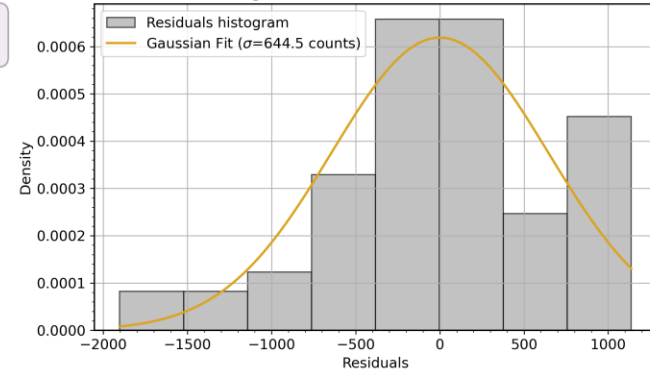
$FWHM_1 = 2.35 \cdot \sigma_1 = 2.97$ keV
 $Resolution = FWHM_1/E = 0.06$

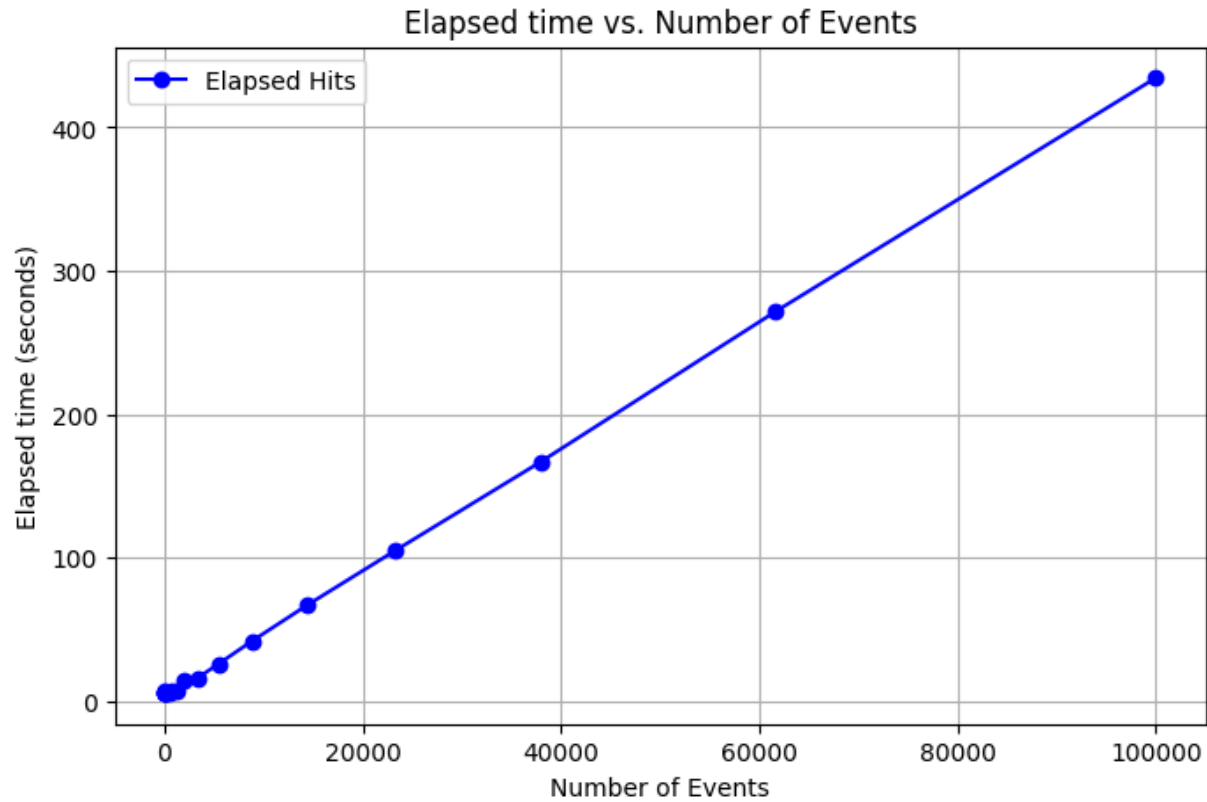
Residual Analysis - pixel 48 52

Residuals vs. Energy



Histogram of residuals - bin width = 380





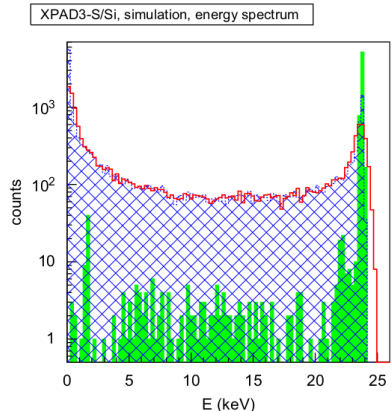
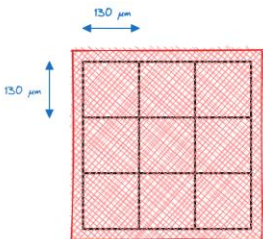
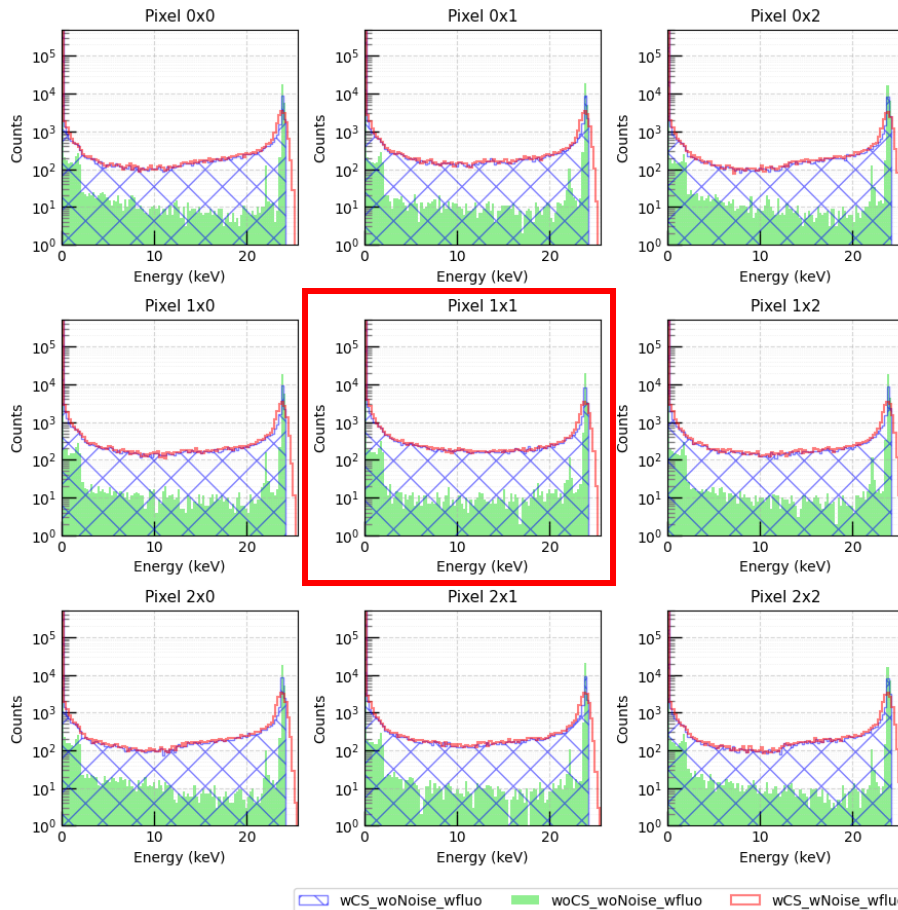


Fig. 1. Simulated spectrum as measured by XPAD3-S/Si for a monochromatic 24 keV beam. See the text for detailed explanations.

- Spectre vert : Désactivation du modèle de dynamique des charges (pas de diffusion, pas de répulsion). Pic de pleine énergie à 24keV. Fluorescence à 24keV – 1,8 keV (Kalpha du Si). Continuum Compton entre 0 et 2.06 keV.
- Spectre rouge -> Activation du modèle de dynamique des charges. Bruit électronique de 100e- (x3,62 keV pour le Silicium). Elargissement du pic de pleine énergie.
- Spectre bleu -> Activation du modèle de dynamique des charges. Partage de charges visible.

Simulation - energy spectrum - 24 keV - Irradiation of all pixels - 1000000 evts



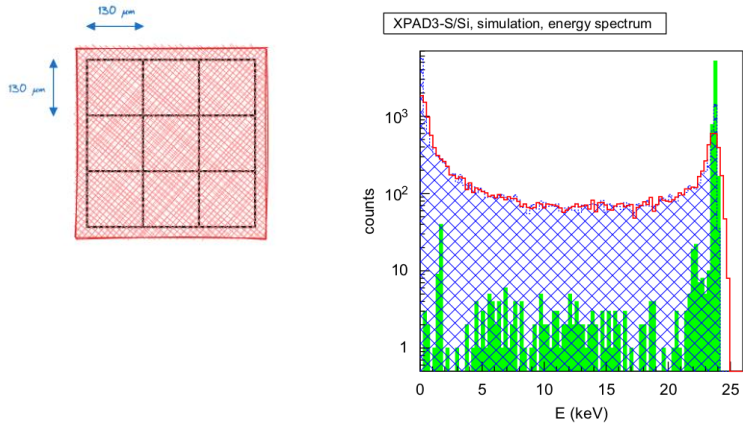
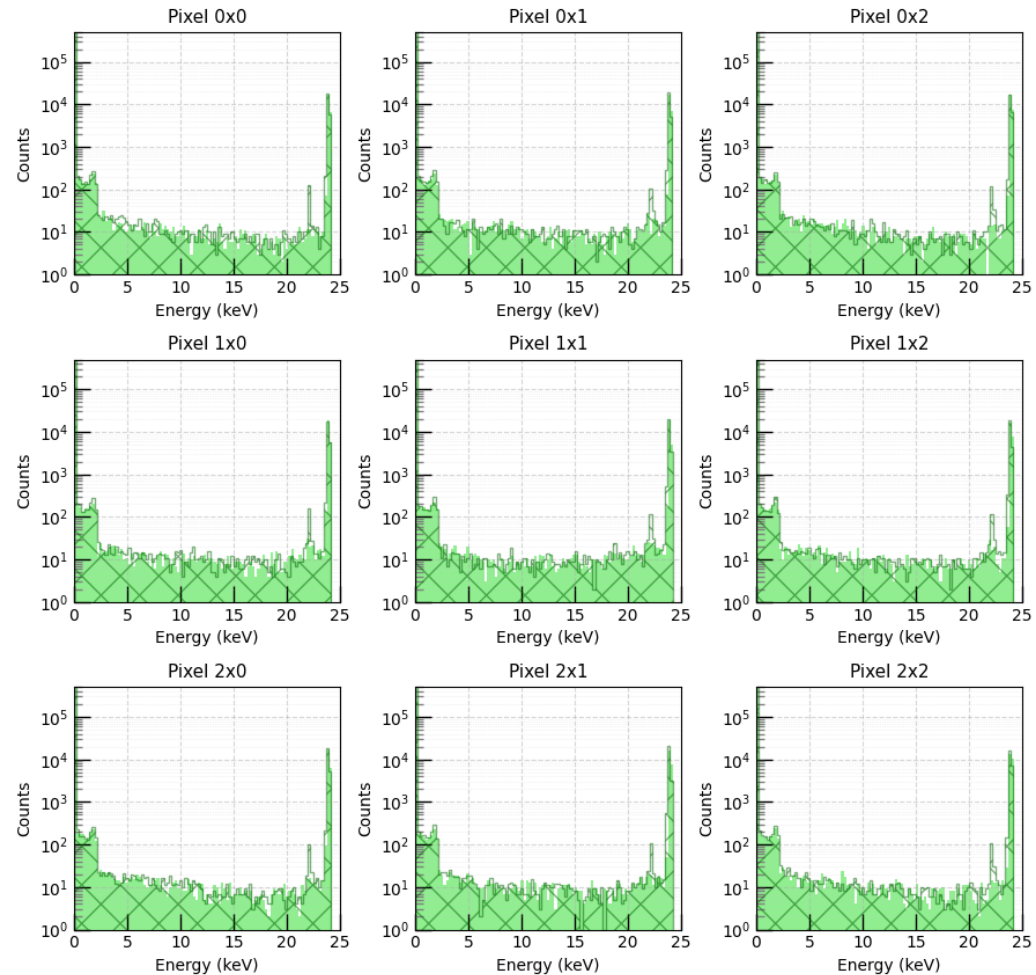
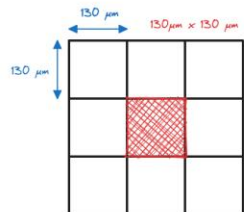


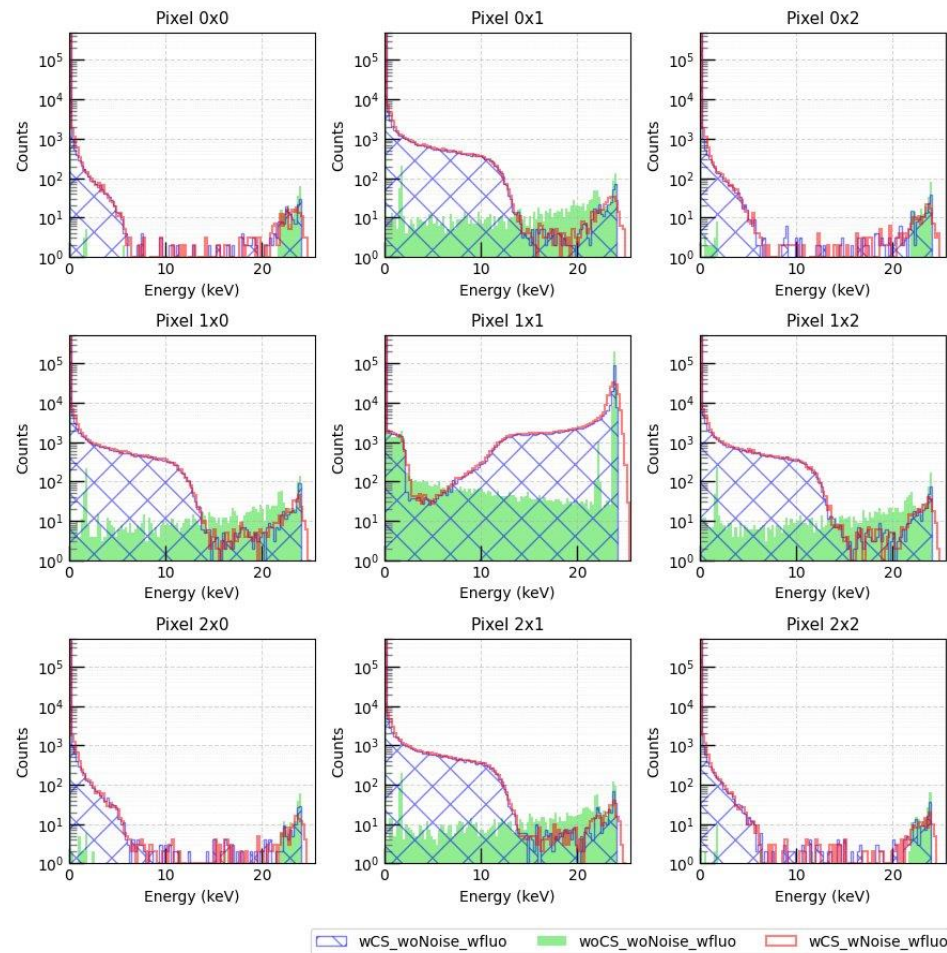
Fig. 1. Simulated spectrum as measured by XPAD3-S/Si for a monochromatic 24 keV beam. See the text for detailed explanations.

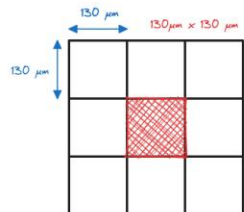
- Spectre vert -> Desactivation du modèle de dynamique des charges (pas de diffusion, pas de répulsion). Pic de pleine énergie à 24keV. Fluorescence à 24keV – 1,8 keV (K α du Si). Continuum Compton entre 0 et 2.06 keV.
- Spectre rouge -> Activation du modèle de dynamique des charges. Bruit électronique de 100e⁻ (x3,62 keV pour le Silicium). Elargissement du pic de pleine énergie.
- Spectre bleu -> Activation du modèle de dynamique des charges. Partage de charges visible.





- Spectre vert -> Desactivation du modèle de dynamique des charges (pas de diffusion, pas de répulsion). Pic de pleine énergie à 24keV. Fluorescence à 24keV – 1,8 keV (Kalpa du Si). Continuum Compton entre 0 et 2.06 keV.
- Spectre rouge -> Activation du modèle de dynamique des charges. Bruit électronique de 100e- (x3,62 keV pour le Silicium). Elargissement du pic de pleine énergie.
- Spectre bleu -> Activation du modèle de dynamique des charges. Partage de charges visible.
- Partage de charges en-dessous $\frac{1}{2}$ de l'énergie du photon incident.





$$E\gamma' = \frac{E\gamma}{1 + \alpha(1 - \cos(\theta))}$$

avec $\alpha = \frac{E\gamma}{m_e c^2}$ et $m_e c^2 = 511 \text{ keV}$

$$T_e = E\gamma \frac{\alpha(1 - \cos(\theta))}{1 + \alpha(1 - \cos(\theta))}$$

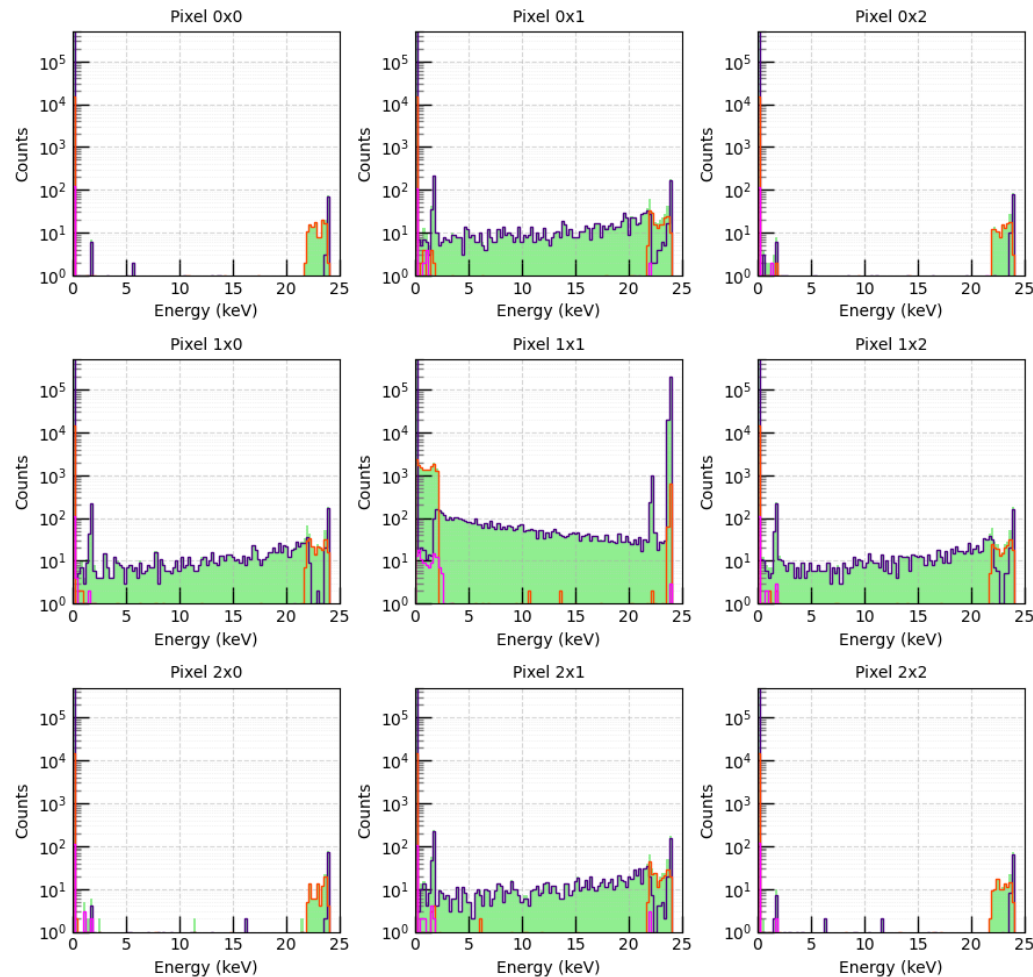
$T_{e \text{ max}}$ pour $\theta = 180^\circ$
 $T_{e \text{ min}}$ pour $\theta = 0^\circ$

$$T_{e \text{ max}} = 24 \frac{(24/511)(1 - \cos(180^\circ))}{1 + (24/511)(1 - \cos(180^\circ))}$$

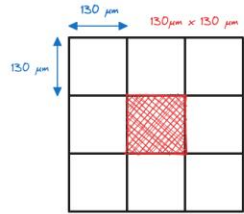
$$T_{e \text{ max}} = 2,06 \text{ keV} \quad E\gamma' = E\gamma - T_{e \text{ max}} = 21,94 \text{ keV}$$

$21,94 < E\gamma' < 24 \text{ keV}$
 $0 < T_{e \text{ max}} < 2,06 \text{ keV}$

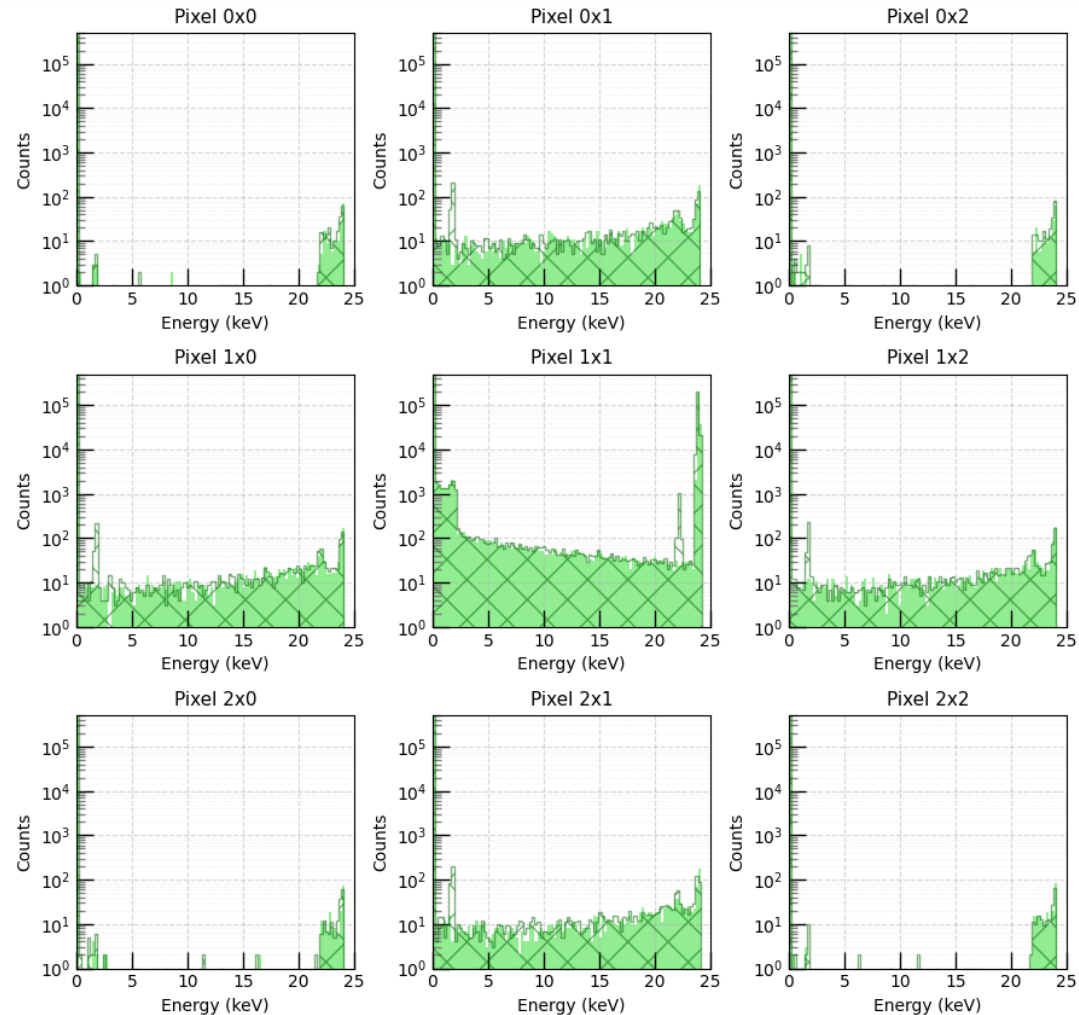
- Spectre vert -> Désactivation du modèle de dynamique des charges (pas de diffusion, pas de répulsion). Pic de pleine énergie à 24keV. Fluorescence à 24keV – 1,8 keV (Kalpa du Si). Continuum Compton entre 0 et 2.06 keV.
- Spectre rouge -> Activation du modèle de dynamique des charges. Bruit électronique de 100e- (x3,62 keV pour le Silicium). Elargissement du pic de pleine énergie.
- Spectre bleu -> Activation du modèle de dynamique des charges. Partage de charges visible.
- Partage de charges en-dessous ½ de l'énergie du photon incident.



■ full spectrum
 ■ compton = 0
 ■ compton = 1
 ■ compton > 1



- Spectre vert -> Desactivation du modèle de dynamique des charges (pas de diffusion, pas de répulsion). Pic de pleine énergie à 24keV. Fluorescence à 24keV – 1,8 keV (Kalpha du Si). Continuum Compton entre 0 et 2.06 keV.
- Spectre rouge -> Activation du modèle de dynamique des charges. Bruit électronique de 100e- (x3,62 keV pour le Silicium). Elargissement du pic de pleine énergie.
- Spectre bleu -> Activation du modèle de dynamique des charges. Partage de charges visible.
- Partage de charges en-dessous $\frac{1}{2}$ de l'énergie du photon incident.



3. Modèle / simulation pour le Silicium 20 keV

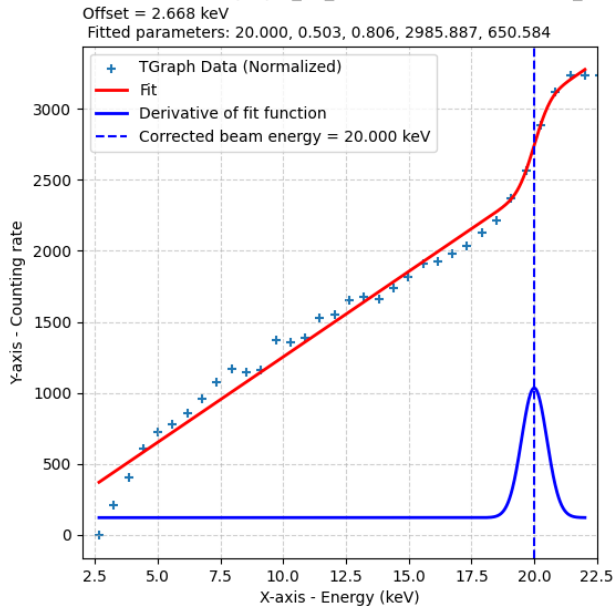
- Simulation – Silicium – 20 keV

3.1. Charge sharing estimation

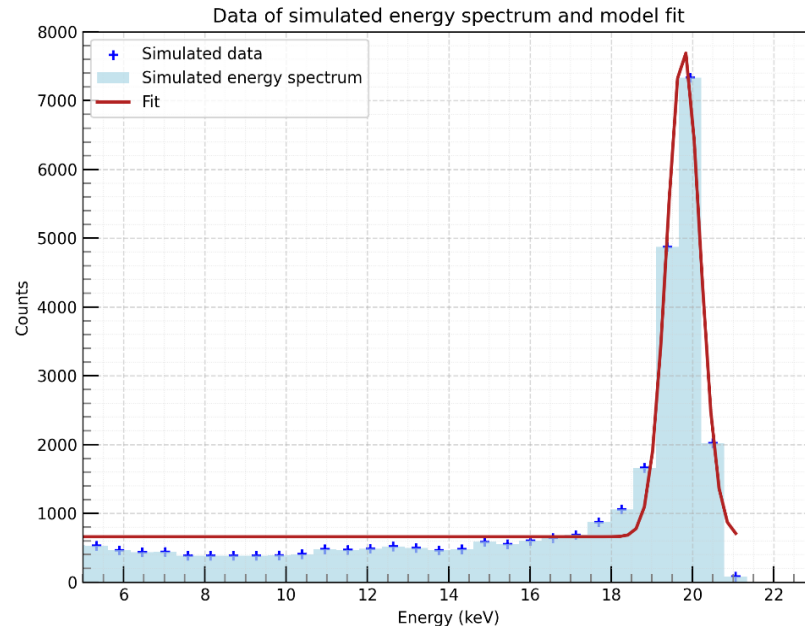
We estimate the charge sharing probability in the XPAD3-S detector, following the formulation proposed in Ref. [6]. The measured spectrum, for an incident energy E_0 , is the sum of an unsplit charge component $n_p(E, E_0)$ and of a charge sharing component $n_{cs}(E, E_0)$

$$n(E, E_0) = (1 - k)n_p(E, E_0) + kn_{cs}(E, E_0) \tag{1}$$

Fit and its derivative - TGraph pix_35_96;1 from ROOT file Mod0_Chip4.root



Simulation - Energy spectrum of 20 keV incident photons - 10^6 evts



Fitted parameters:
 $E = 19.78$ keV
 $w = 0.41$
 $k = 0.82$
 $c2 = 16010.62$