Stage International Masterclass - Physics in the 21st Century

X ray data analysis in physics

Diana Laura Sirghi

INFN-LNF

30 January - 02 February 2011
Frascati, Italy

LNF - DAFNE accelerator

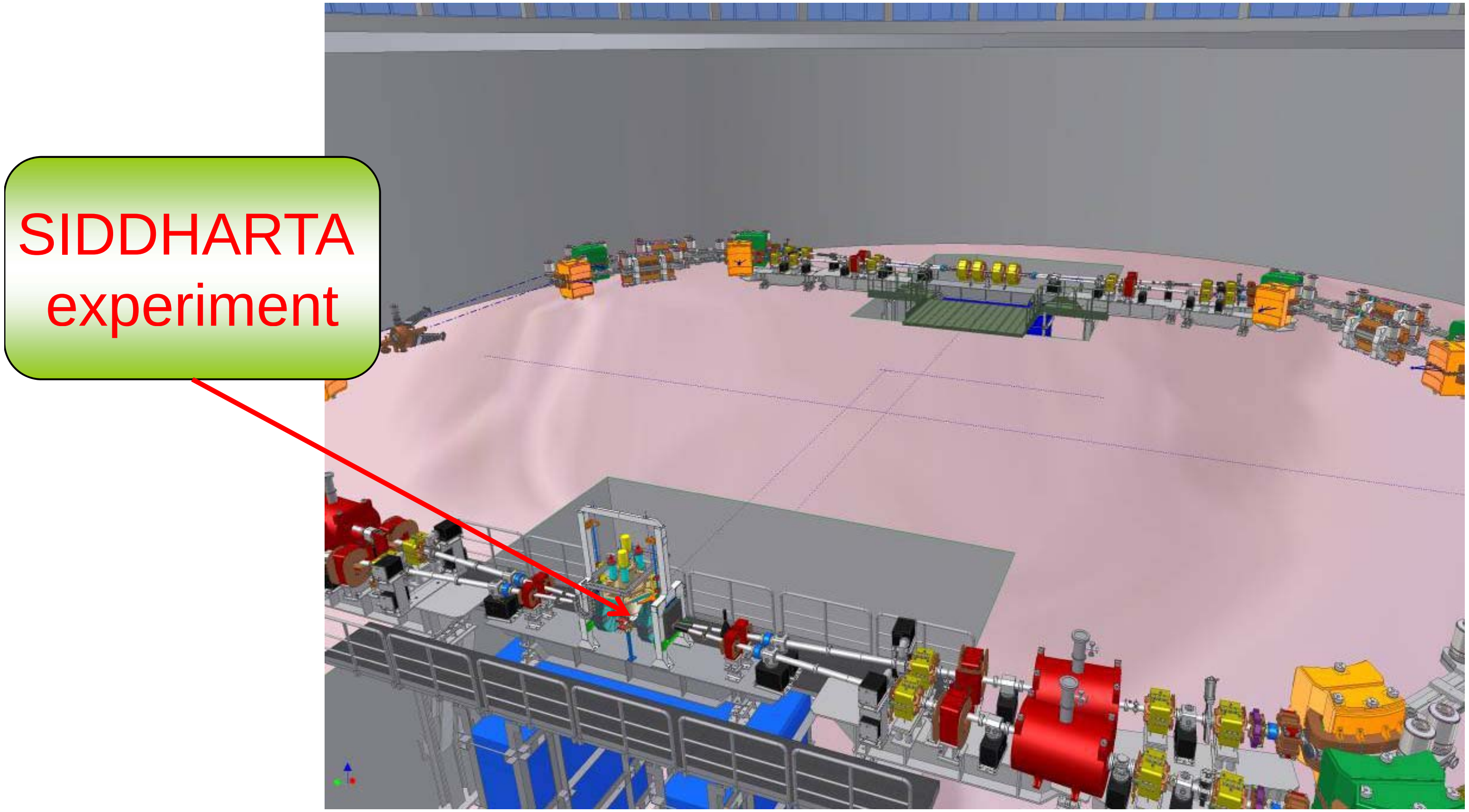
SIDDHARTA

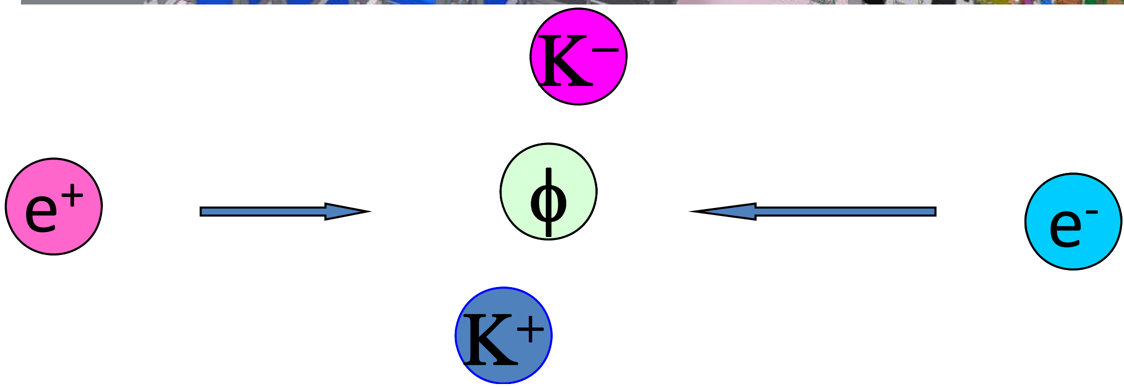
SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

- LNF- INFN, Frascati, Italy
- SMI- ÖAW, Vienna, Austria
- IFIN – HH, Bucharest, Romania
- Politecnico, Milano, Italy
- MPE, Garching, Germany
- PNSensors, Munich, Germany
- RIKEN, Japan
- Univ. Tokyo, Japan
- Victoria Univ., Canada

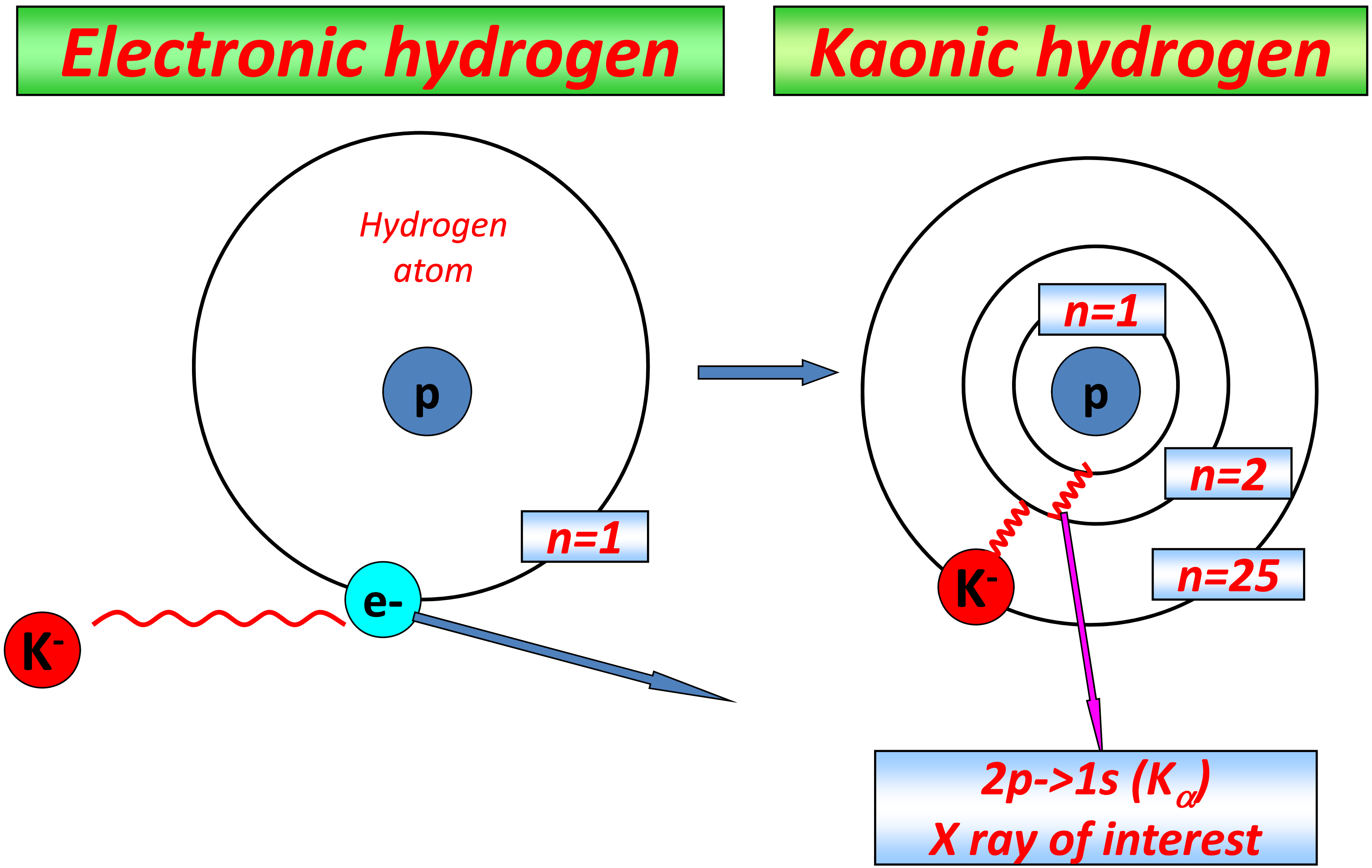
EU Fundings: JRA10 – FP6 - I3HP
Network WP9 – LEANNIS – FP7- I3HP2

SIDDHARTA experiment





SIDDHARTA experiment



What we are measuring in the SIDDHARTA experiment are **the X-rays** coming from the exotic atoms

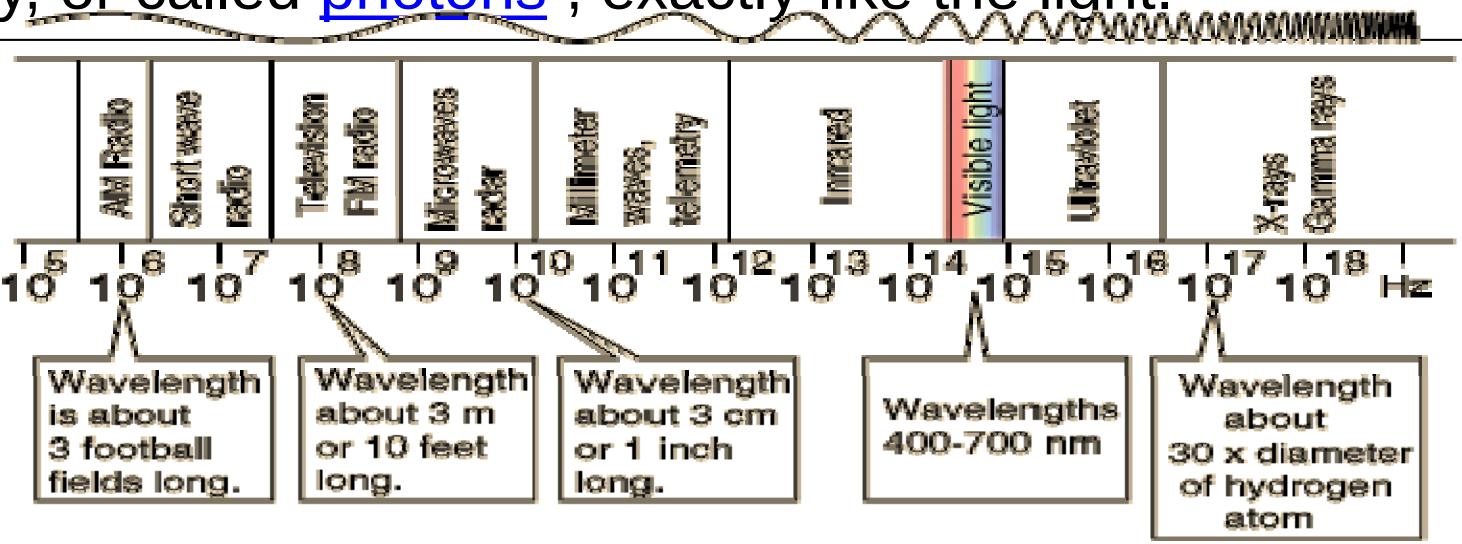
Let's see **what means the X ray** and **how we can analyze** the signal given by the X ray

About X-rays

X-rays are a form of electromagnetic radiation with short-wavelength (of 0.01 to 10 nanometers) (hence, high frequency ((3×10^{16} Hz to 3×10^{19} Hz), and hence, relatively high energy (120 eV to 120 keV)).

For example, the **X-rays are shorter in wavelength** than visible light rays.

The X-rays are similar with the other types of electromagnetic radiation, are emitted and absorbed as discrete packets of energy, or called photons , exactly like the light.



About X-rays

X-rays are created, in principle, by **two different atomic processes**:

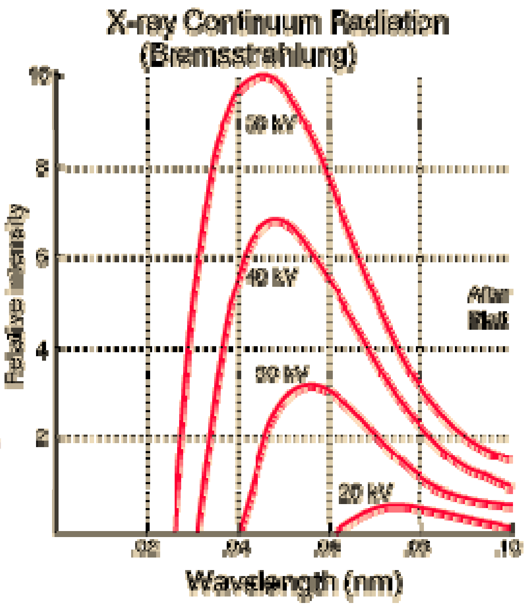
1. X-rays creates by the deceleration of high-energy electrons in collisions with the atomic nucleus (this type of X –rays are cooled **Bremsstrahlung**;
   Bremsstrahlung is a german word, from *bremsen* "to brake" and *Strahlung* "radiation", which means "**braking radiation"** or **"deceleration radiation"**)

2. X-rays produced by the transitions of the electrons in the orbital of the atoms (this type of X-rays are cooled **“characteristics X-rays” or “X-rays fluorescence”)**

1. Bremsstrahlung X rays – ”deceleration radiation”

X-rays creates by the deceleration of high-energy electrons in collisions with the atomic nucleus (this type of X –rays are cooled Bremsstrahlung;
Bremsstrahlung is a german word, from *bremsen* "to brake" and *Strahlung* "radiation", which means "**braking radiation"** or **"deceleration radiation"**)

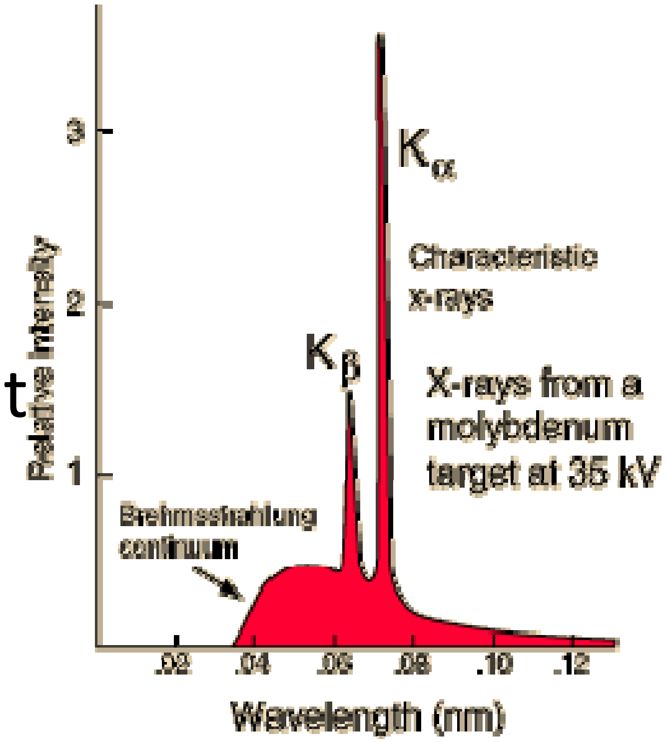
Bremsstrahlung has a continuous spectrum. The intensity of the X-rays increases linearly with decreasing frequency, from zero at the energy of the incident electrons.



2. Characteristics X rays

X-rays produced by the transitions of the electrons in the orbital of the atoms (this type of X-rays are cooled "characteristics X-rays" or "X-rays fluorescence")

- X-Ray fluorescence of elements
  - sharp peaks, independent of incident energy
  - uniquely characterizes an element

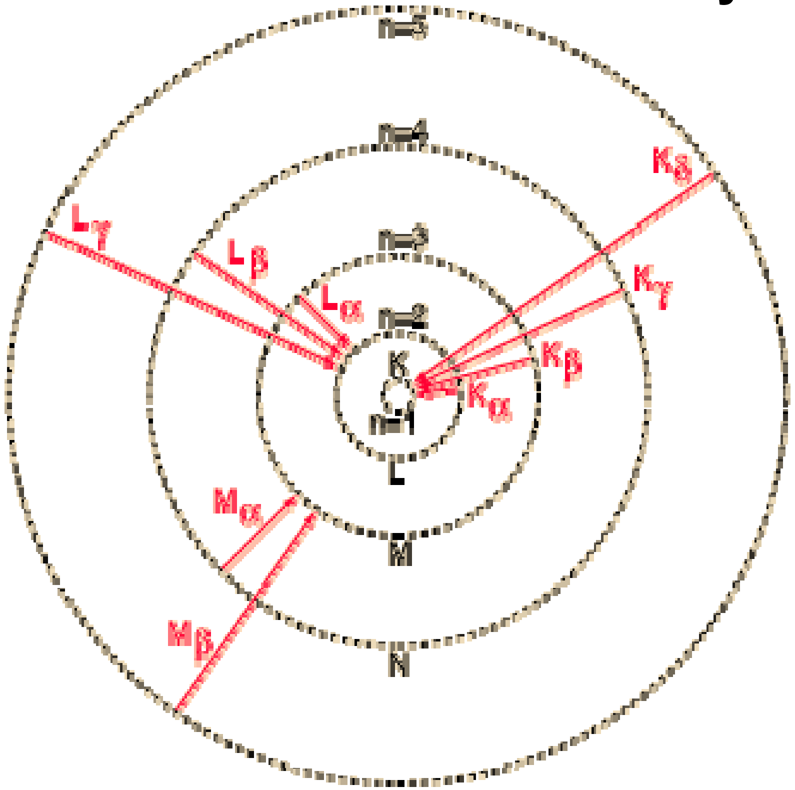


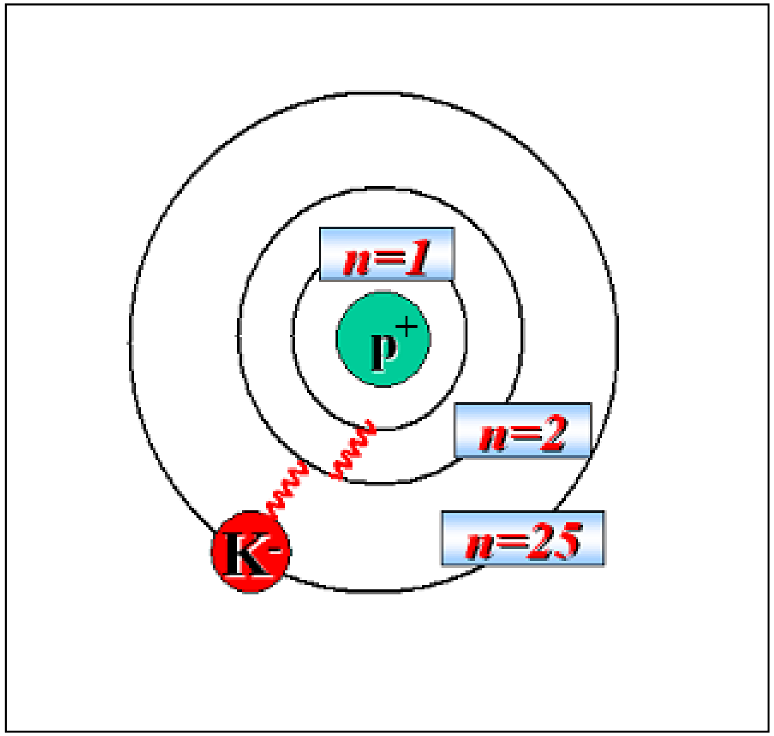
- How are they produced?
- What is the relation?

ATOMIC STRUCTURE!

Transitions of the characteristics   X rays

In this image are shown the transitions of characteristics X-rays into an atom





Each atomic atomic orbital corresponds to a particular energy level of the electrons -> the transitions of the electrons between levels with different n will determine the emission of the X ray characteristics.

Table 7a. X-ray Energies and Intensities (per 100 K-Shell Vacancies)

	$_{5}$B	$_{6}$C	$_{7}$N	$_{8}$O	$_{9}$F	$_{10}$Ne	$_{11}$Na	$_{12}$Mg	$_{13}$Al	$_{14}$Si	$_{15}$P	$_{16}$S	$_{17}$Cl	$_{18}$Ar	$_{19}$K
$K_{\alpha 1}$	**0.183** 0.11 *5*	**0.277** 0.19 *8*	**0.392** 0.35 *14*	**0.525** 0.55 *22*	**0.677** 0.9 *4*	**0.849** 1.20 *12*	**1.041** 1.53 *16*	**1.254** 2.0 *2*	**1.487** 2.6 *3*	**1.740** 3.3 *3*	**2.010** 4.1 *4*	**2.308** 5.0 *5*	**2.622** 6.1 *6*	**2.957** 7.3 *7*	**3.314** 8.5 *9*
$K_{\alpha 2}$	**0.183** 0.056 *23*	**0.277** 0.09 *4*	**0.392** 0.17 *7*	**0.525** 0.28 *11*	**0.677** 0.43 *17*	**0.848** 0.60 *6*	**1.041** 0.77 *8*	**1.254** 1.00 *10*	**1.486** 1.29 *13*	**1.739** 1.64 *17*	**2.009** 2.04 *21*	**2.307** 2.49 *25*	**2.621** 3.0 *3*	**2.955** 3.6 *4*	**3.311** 4.3 *4*
$K_{\beta 1}$									**1.554** 0.0155 *16*	**1.836** 0.056 *6*	**2.136** 0.122 *12*	**2.464** 0.229 *23*	**2.816** 0.38 *4*	**3.190** 0.58 *6*	**3.590** 0.79 *8*
$K_{\beta 3}$									**1.554** 0.0079 *8*	**1.836** 0.028 *3*	**2.136** 0.062 *6*	**2.464** 0.116 *12*	**2.816** 0.192 *20*	**3.190** 0.30 *3*	**3.590** 0.40 *4*
$L_{\beta 1}$														**0.251** 0.011 *3*	**0.296** 0.013 *4*
$L_{\beta 3}$														**0.310** 0.0038 *13*	**0.359** 0.0050 *17*
$L_{\beta 4}$														**0.310** 0.0024 *9*	**0.359** 0.0010 *5*

	$_{20}$Ca	$_{21}$Sc	$_{22}$Ti	$_{23}$V	$_{24}$Cr	$_{25}$Mn	$_{26}$Fe	$_{27}$Co	$_{28}$Ni	$_{29}$Cu	$_{30}$Zn	$_{31}$Ga	$_{32}$Ge	$_{33}$As	$_{34}$Se
$K_{\alpha 1}$	**3.692** 9.8 *4*	**4.091** 11.3 *5*	**4.511** 12.8 *6*	**4.952** 14.5 *7*	**5.415** 16.4 *7*	**5.899** 18.3 *8*	**6.404** 20.2 *9*	**6.930** 22.1 *10*	**7.478** 24.0 *11*	**8.048** 26.0 *12*	**8.639** 28.0 *10*	**9.252** 29.8 *11*	**9.886** 31.3 *11*	**10.544** 32.7 *12*	**11.222** 34.1 *12*
$K_{\alpha 2}$	**3.688** 4.93 *22*	**4.086** 5.68 *25*	**4.505** 6.4 *3*	**4.945** 7.3 *3*	**5.405** 8.3 *4*	**5.888** 9.3 *4*	**6.391** 10.2 *5*	**6.915** 11.2 *5*	**7.461** 12.2 *6*	**8.028** 13.3 *6*	**8.616** 14.3 *5*	**9.225** 15.2 *6*	**9.855** 16.1 *6*	**10.508** 16.8 *6*	**11.182** 17.6 *6*
$K_{\beta 1}$	**4.013** 1.02 *5*	**4.461** 1.22 *6*	**4.932** 1.42 *6*	**5.427** 1.64 *7*	**5.947** 1.84 *8*	**6.490** 2.14 *10*	**7.058** 2.40 *11*	**7.649** 2.65 *12*	**8.265** 2.88 *13*	**8.905** 3.10 *14*	**9.572** 3.39 *12*	**10.264** 3.70 *13*	**10.982** 3.98 *14*	**11.726** 4.25 *15*	**12.496** 4.54 *16*
$K_{\beta 2}$												**10.366** 0.0314 *11*	**11.101** 0.097 *4*	**11.864** 0.194 *7*	**12.652** 0.323 *12*
$K_{\beta 3}$	**4.013** 0.519 *23*	**4.461** 0.62 *3*	**4.932** 0.72 *3*	**5.427** 0.84 *4*	**5.947** 0.94 *4*	**6.490** 1.09 *5*	**7.058** 1.23 *6*	**7.649** 1.36 *6*	**8.265** 1.48 *7*	**8.905** 1.59 *7*	**9.572** 1.74 *6*	**10.260** 1.90 *7*	**10.975** 2.05 *7*	**11.720** 2.19 *8*	**12.490** 2.34 *8*
$K_{\beta 5}$							**7.108** 0.00127 *7*	**7.706** 0.00188 *11*	**8.329** 0.00264 *15*	**8.977** 0.00365 *21*	**9.651** 0.00504 *25*	**10.350** 0.0063 *3*	**11.074** 0.0078 *4*	**11.826** 0.0095 *5*	**12.601** 0.0116 *6*
$L_{\alpha 1}$		**0.396** 0.026 *7*	**0.452** 0.063 *16*	**0.511** 0.12 *3*	**0.572** 0.19 *5*	**0.637** 0.26 *7*	**0.704** 0.33 *8*	**0.776** 0.41 *10*	**0.851** 0.50 *13*	**0.929** 0.60 *15*	**1.012** 0.65 *13*	**1.098** 0.70 *14*	**1.188** 0.81 *16*	**1.282** 0.87 *17*	**1.379** 0.98 *20*
$L_{\alpha 2}$		**0.396** 0.0028 *7*	**0.452** 0.0070 *18*	**0.511** 0.013 *3*	**0.572** 0.021 *5*	**0.637** 0.029 *7*	**0.704** 0.037 *9*	**0.776** 0.045 *11*	**0.851** 0.056 *14*	**0.929** 0.066 *17*	**1.012** 0.072 *15*	**1.098** 0.077 *16*	**1.188** 0.090 *18*	**1.282** 0.096 *19*	**1.379** 0.108 *22*
$L_{\beta 1}$	**0.350** 0.016 *4*	**0.400** 0.020 *5*	**0.458** 0.050 *12*	**0.518** 0.096 *24*	**0.581** 0.15 *4*	**0.648** 0.20 *5*	**0.717** 0.25 *6*	**0.791** 0.31 *8*	**0.868** 0.34 *9*	**0.949** 0.39 *10*	**1.035** 0.42 *11*	**1.125** 0.46 *12*	**1.219** 0.49 *12*	**1.317** 0.52 *13*	**1.420** 0.58 *15*
$L_{\beta 3}$	**0.412** 0.0062 *19*	**0.468** 0.0075 *23*	**0.529** 0.009 *3*	**0.590** 0.010 *3*	**0.652** 0.012 *4*	**0.720** 0.014 *4*	**0.792** 0.016 *5*	**0.866** 0.018 *5*	**0.940** 0.020 *6*	**1.022** 0.021 *6*	**1.107** 0.023 *7*	**1.195** 0.024 *7*	**1.294** 0.025 *7*	**1.386** 0.027 *8*	**1.492** 0.029 *9*
$L_{\beta 4}$	**0.412** 0.0039 *12*	**0.468** 0.0048 *15*	**0.529** 0.0056 *17*	**0.590** 0.0067 *20*	**0.652** 0.0079 *24*	**0.720** 0.009 *3*	**0.792** 0.010 *3*	**0.866** 0.012 *4*	**0.940** 0.013 *4*	**1.022** 0.014 *4*	**1.107** 0.015 *5*	**1.191** 0.016 *5*	**1.286** 0.016 *5*	**1.380** 0.018 *5*	**1.486** 0.019 *6*
$L_{\beta 6}$		**0.402** 0.0017 *4*	**0.456** 0.0018 *5*	**0.513** 0.0022 *6*		**0.640** 0.0023 *6*	**0.708** 0.0022 *6*	**0.779** 0.0022 *6*	**0.855** 0.0022 *6*		**1.020** 0.0021 *4*	**1.114** 0.0027 *5*	**1.212** 0.0033 *7*	**1.315** 0.0038 *8*	**1.424** 0.0045 *9*
$L_{\gamma 3}$												**1.297** 0.0012 *4*	**1.412** 0.0042 *13*	**1.524** 0.0047 *15*	**1.648** 0.0051 *16*
L_{η}		**0.353** 0.020 *5*	**0.401** 0.022 *6*	**0.454** 0.026 *7*	**0.510** 0.025 *6*	**0.568** 0.026 *7*	**0.628** 0.028 *7*	**0.693** 0.028 *7*	**0.760** 0.026 *7*	**0.831** 0.028 *7*	**0.907** 0.029 *7*	**0.984** 0.030 *8*	**1.068** 0.031 *8*	**1.155** 0.031 *8*	**1.245** 0.034 *9*
L_{l}		**0.348** 0.026 *7*	**0.395** 0.029 *8*	**0.446** 0.034 *9*	**0.500** 0.033 *9*	**0.556** 0.038 *10*	**0.615** 0.040 *11*	**0.678** 0.043 *11*	**0.743** 0.045 *12*	**0.811** 0.048 *13*	**0.884** 0.047 *10*	**0.957** 0.048 *10*	**1.037** 0.052 *11*	**1.120** 0.053 *11*	**1.204** 0.056 *12*

	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In

The X-ray spectrum

In the X-ray data analysis we are refrying to the **SPECTRUM of the X ray**

The distribution of the number of particles which are forming the radiation in function of the energy is called <u>energy spectrum</u>

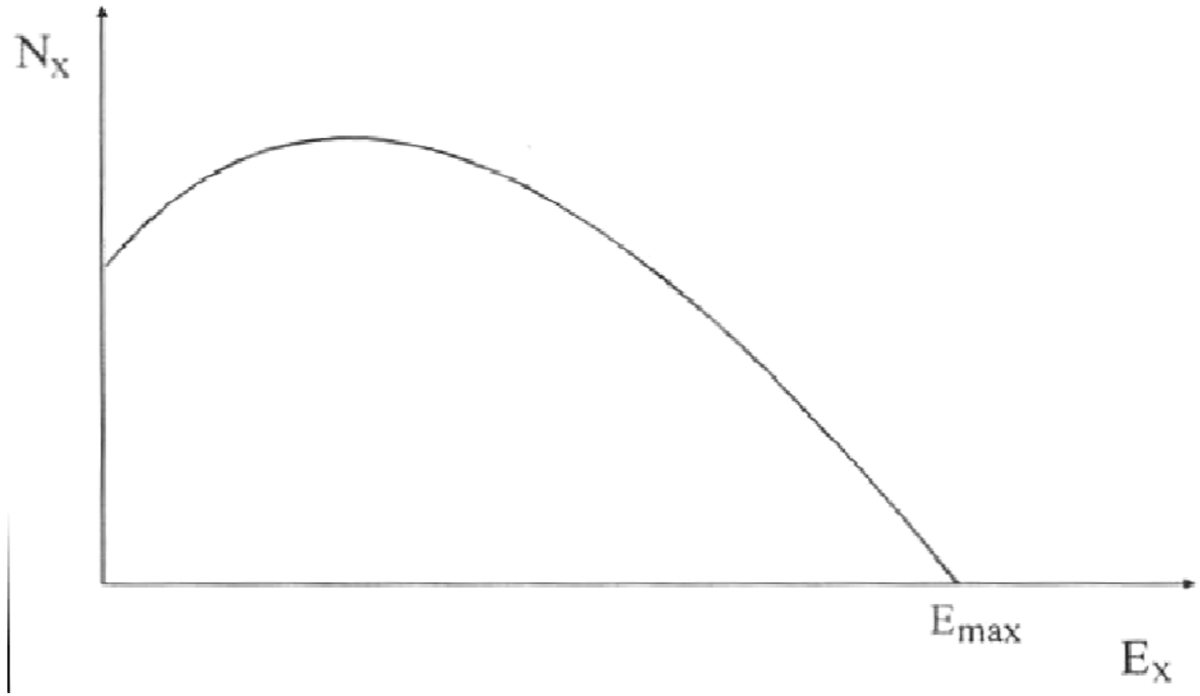
They are 3 spectra types:

1. Continuous X-ray spectrum
2. Discreet X-ray spectrum
3. Mixed X-ray spectrum

The X-ray continuous spectrum

The **continues X-ray spectrum** is produced by the particles with the energy limited to an interval Emin, Emax.

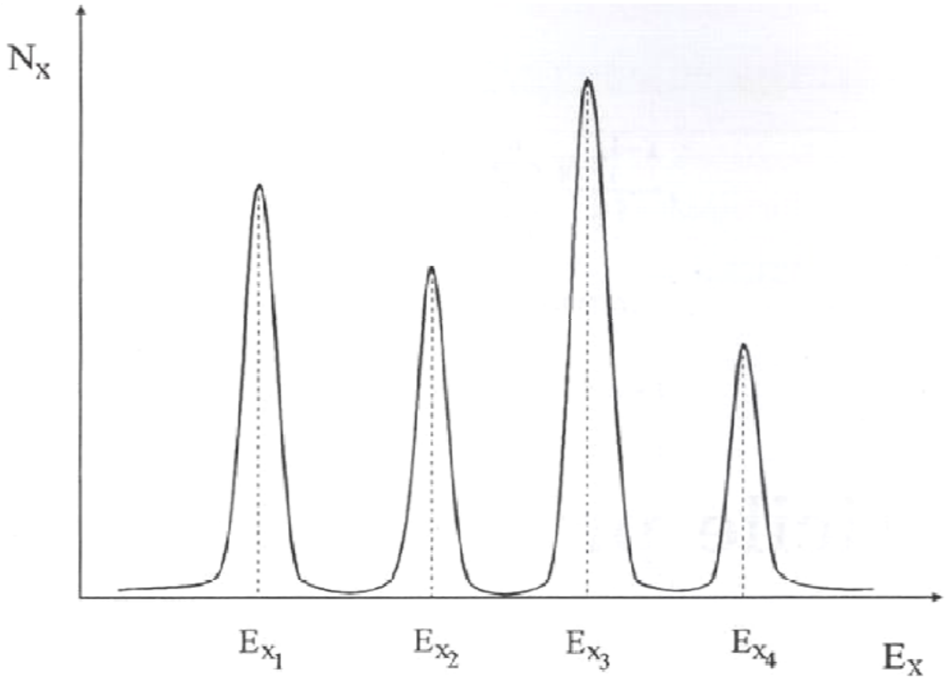
The **X-ray continuous spectrum** can be associated to the **Bremsstrahlung X rays.**



The X-ray discreet spectrum

The **X-ray discreet spectrum** is produced by the X-rays with the energy well defined Ei (i=1,n)).

The **X-ray discreet spectrum** is formed by the fluorescence lines and can be associated to the **characteristics (fluorescence) X rays**.

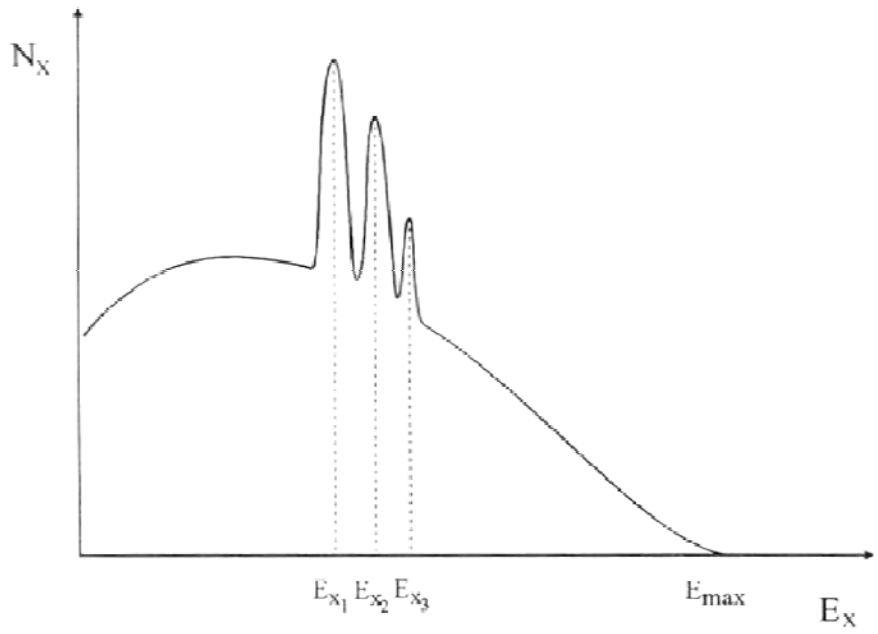


The X-ray mixed spectrum

The **mixed X-ray spectrum** is formed by one discret componet and one continous component

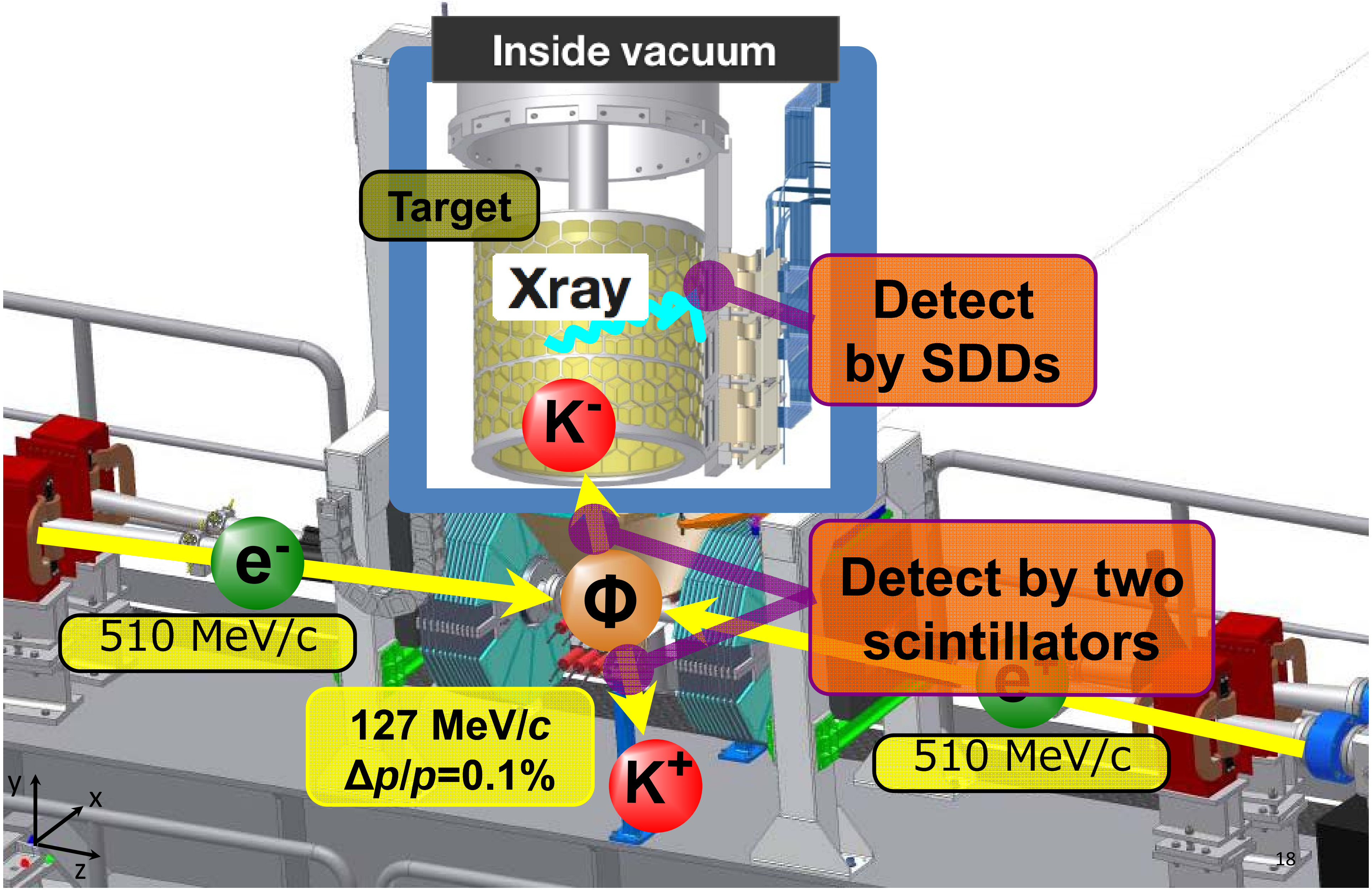
One example for the mixed spectrum is the **real X-ray spectrum** .

Discret component: characteristics (fluorescence) X-rays
Continuous component :X-rays produced like "deceleration radiation“ (Bremsstrahlung X-rays)

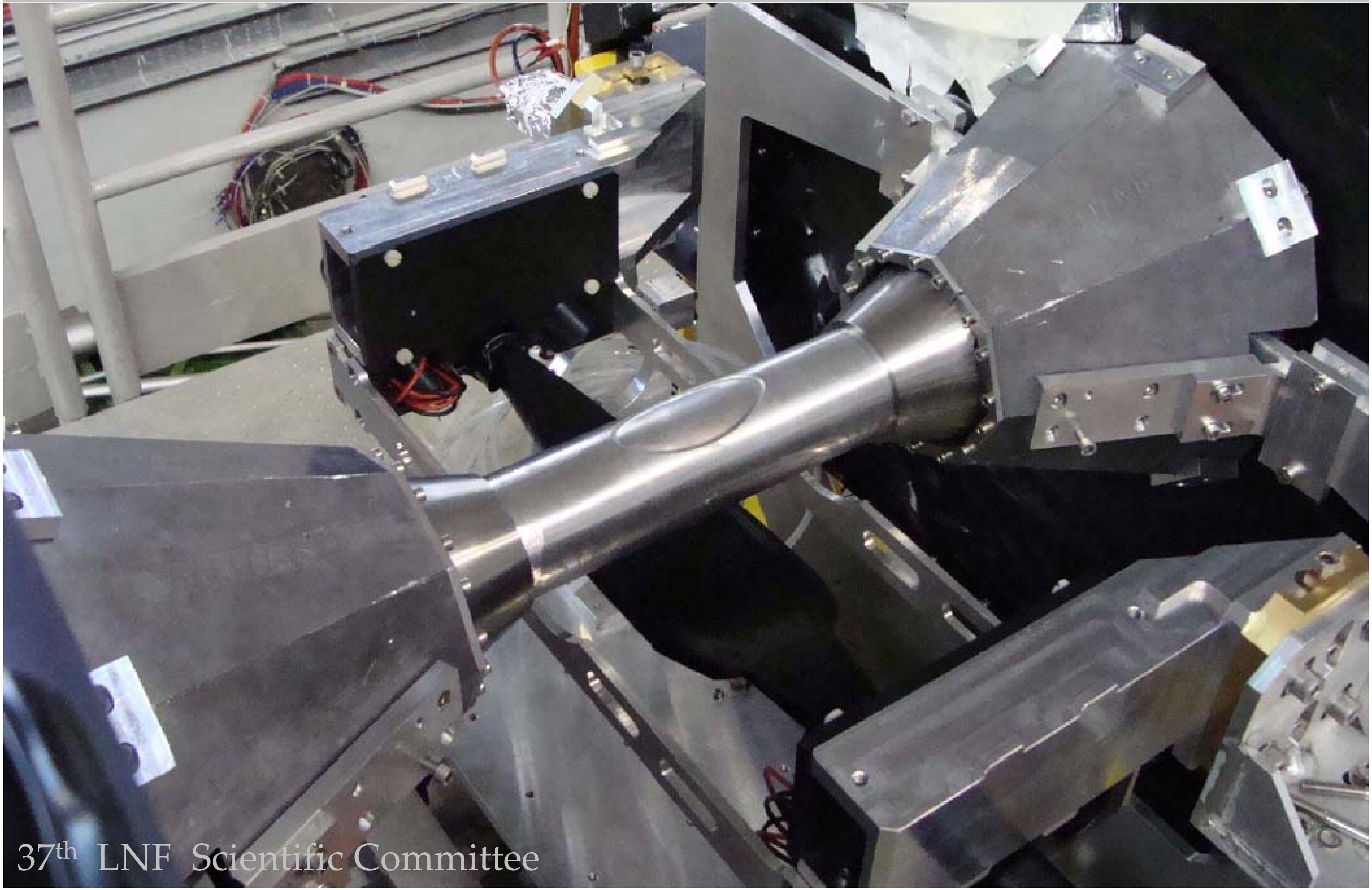


We will used all the presented information in order **to analyze one real X-ray spectrum** obtained during the data taking with the Silicon Drift Detector (SDD) in the **SIDDHARTA experiment**

SIDDHARTA overview

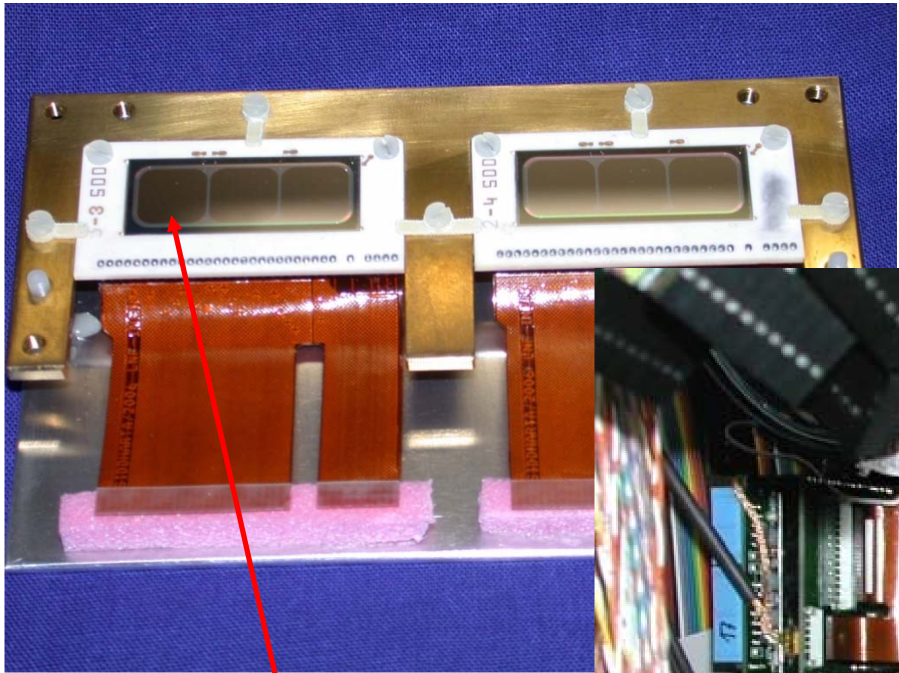


SIDDHARTA interaction region



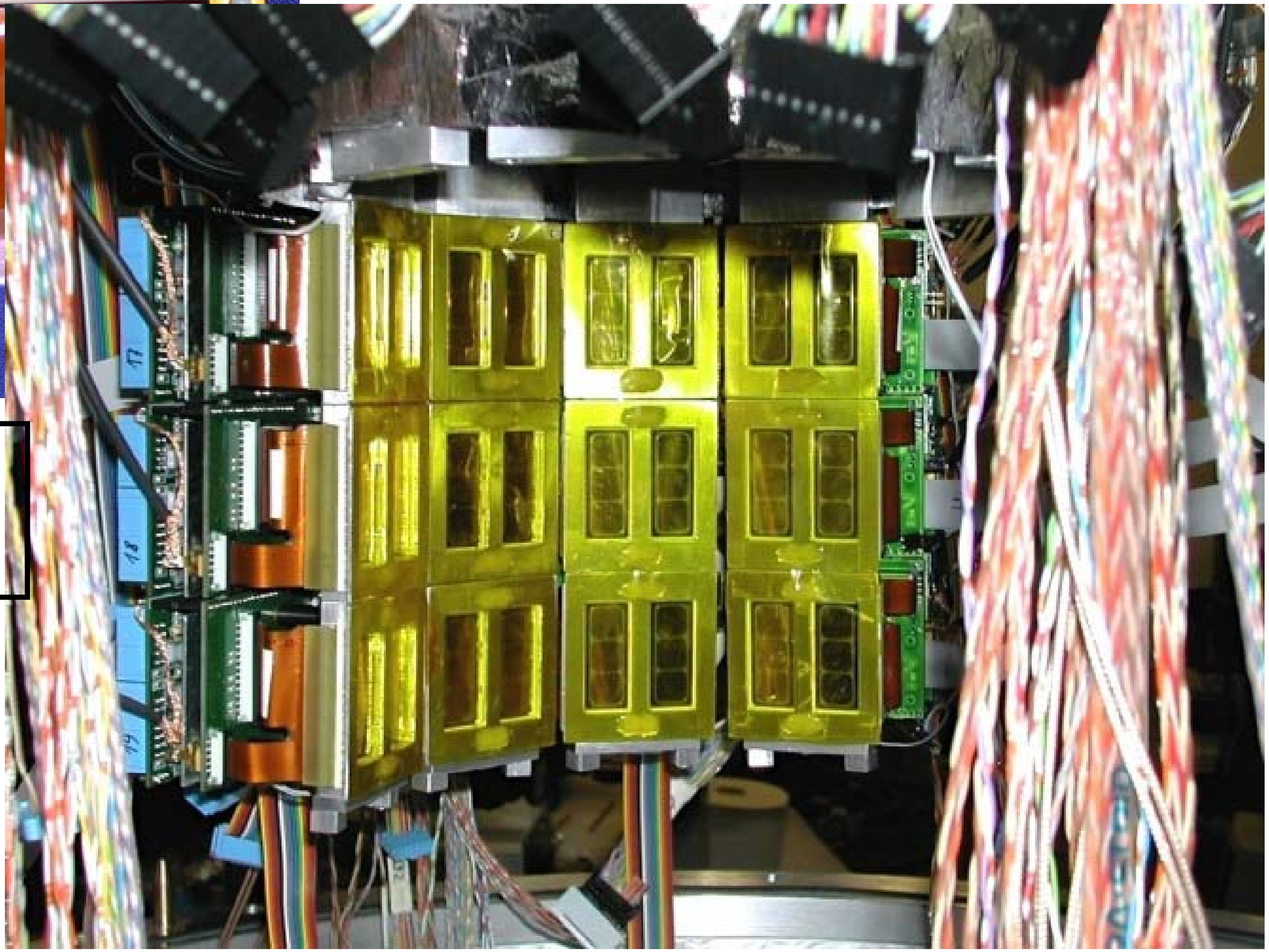

SDDs & Target
(inside vacuum)
Kaon detector

Silicon Drift Detector - SDD

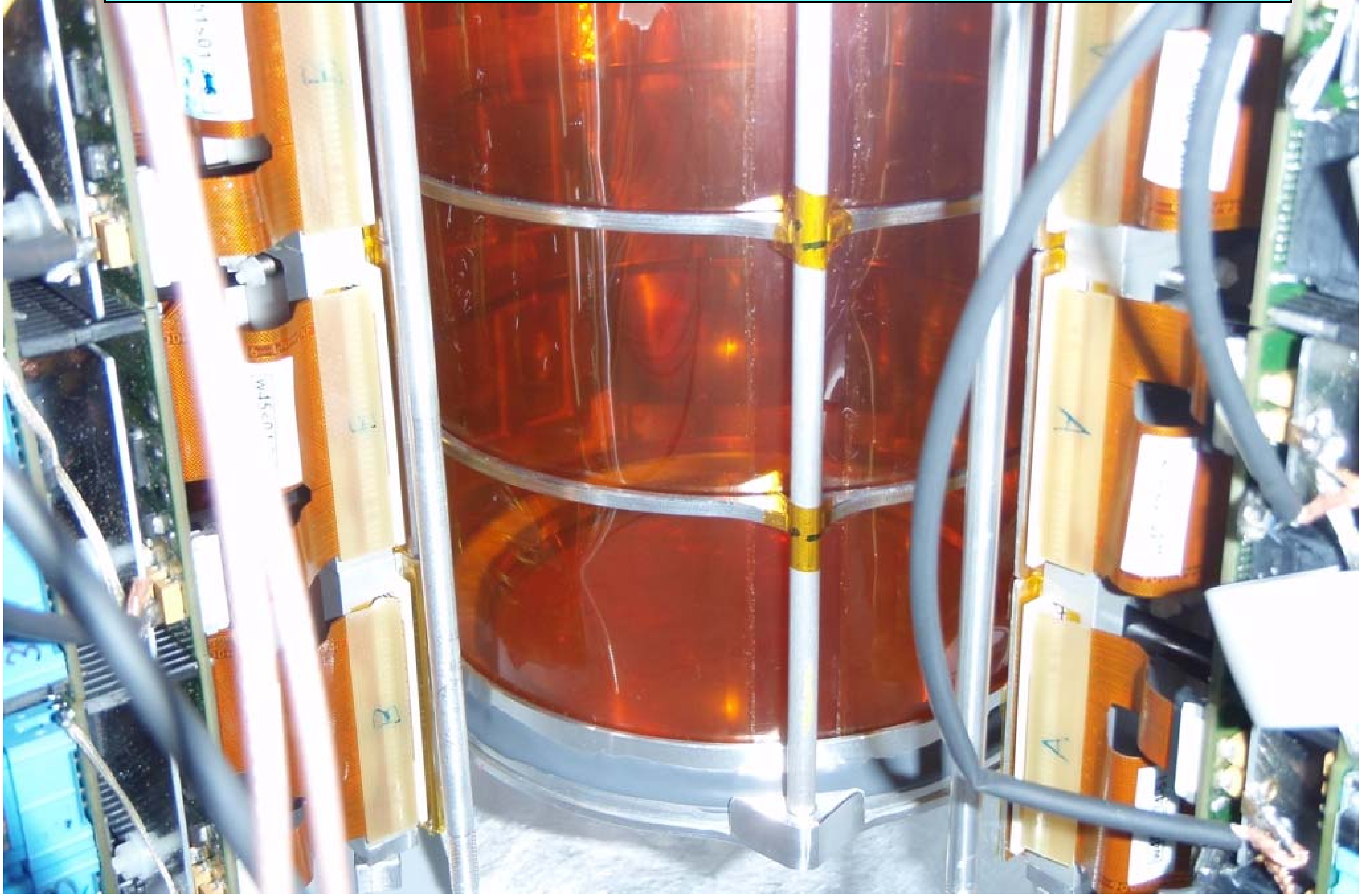


1 SDS: 1 cm^2 active detector area

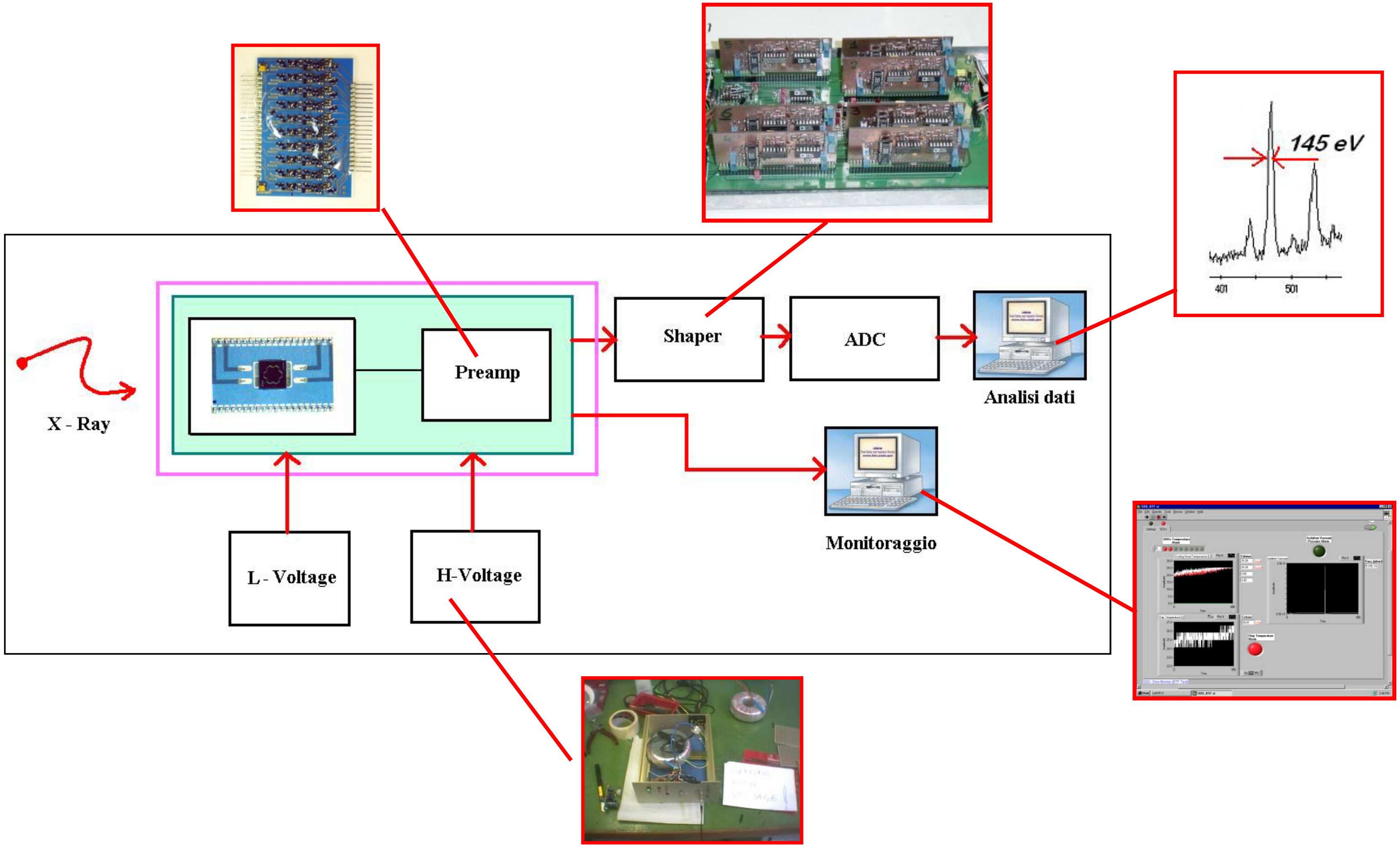
TOTAL: 144 cm^2 active detector area



Target cell



SIDDHARTA data acquisition

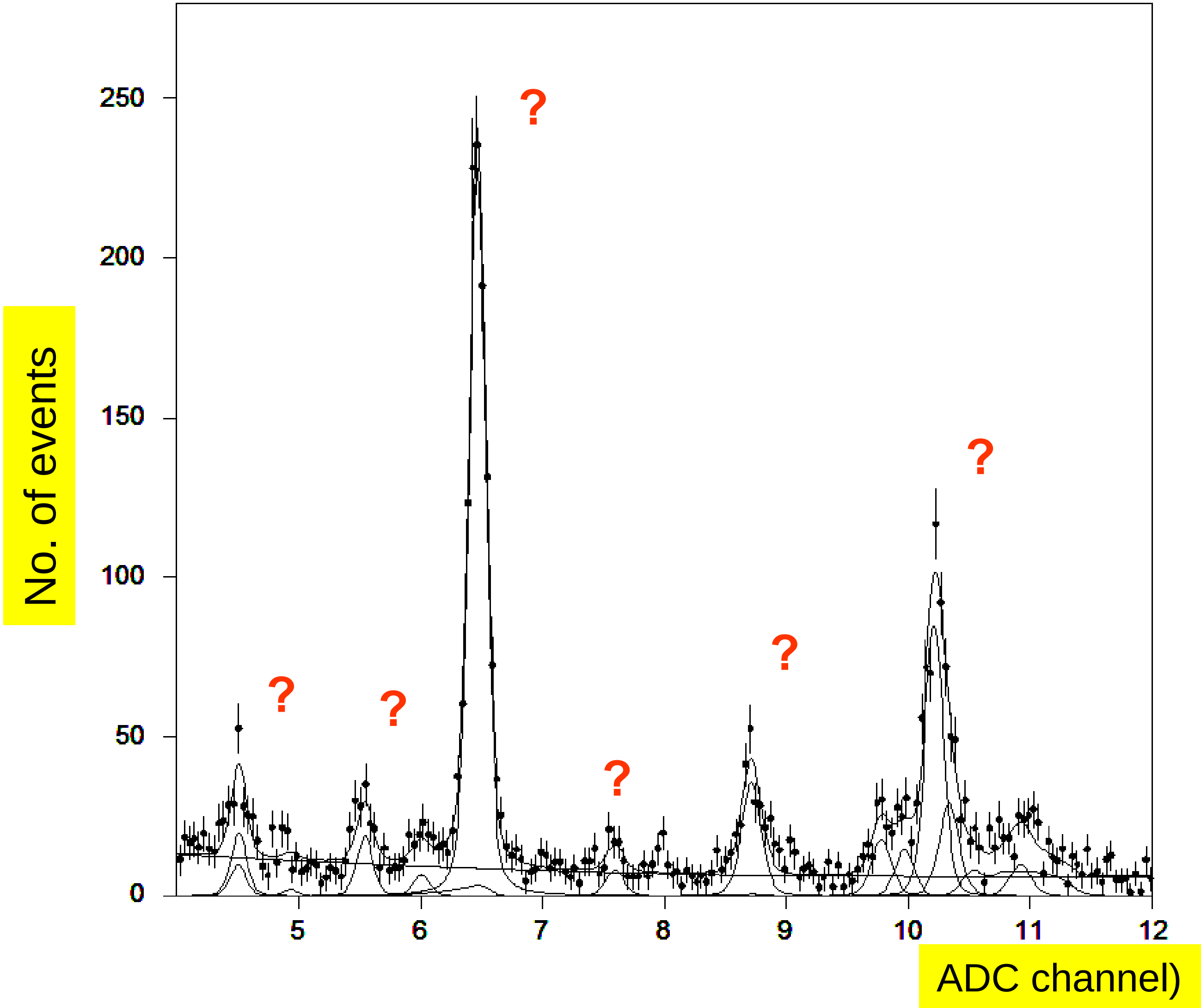


SIDDHARTA data aquistion

The data coming from the interaction of the X rays with the SDD, are written in one PC in format like files *.txt (the simplest way)

SSD1	SSD2	SSD3	SSD4	SSD5	SSD6	SSD7	
12	10	5	344	19	18	23	4
11	378	1	1	17	16	19	4
6	3	385	1	18	19	26	5
4	0	0	0	23	364	18	5
9	0	1	337	1	18	19	5
11	1	0	1	7	15	18	5

Data analysis



The spectrum obtained after the data taking with SIDDHARTA.

How we can interpret it?

Which is the meaning of the peaks which appears in the spectrum?

Gauss distribution

The shape of the peaks can be described by one function called Gauss distribution ("bell"-shape)

$$P_g(x;\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

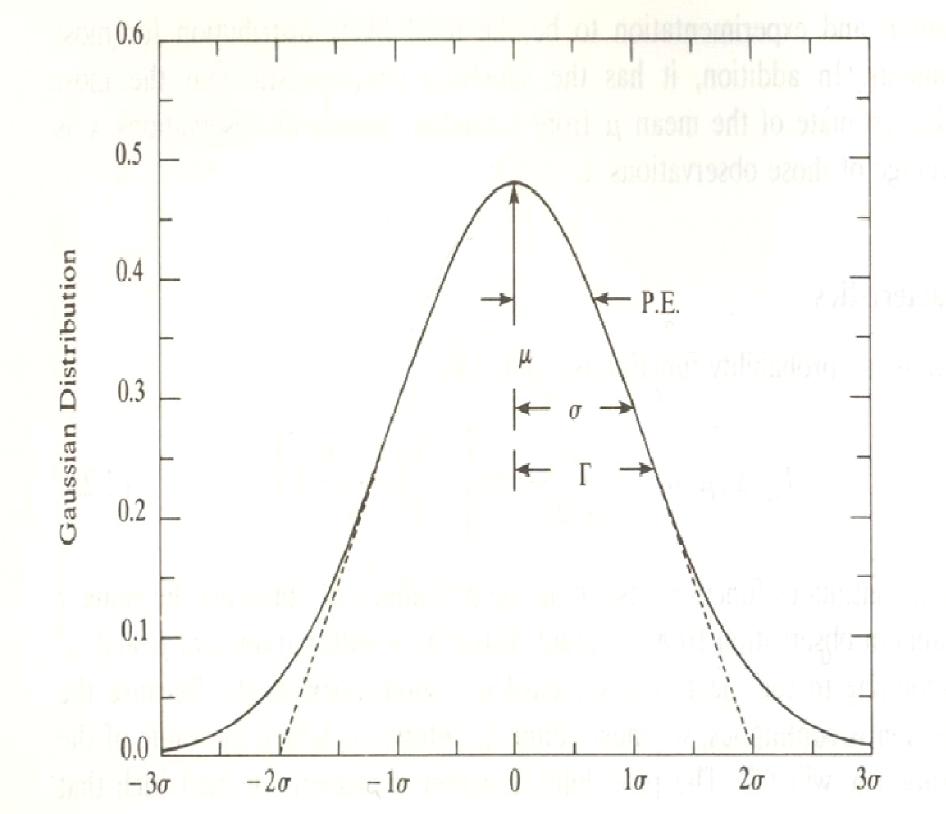
μ = average (give the position of the peak)

σ = standard deviation

Γ = full-width at half maximum: FWHM

$$\Gamma = 2.354 \times \sigma$$

Γ = the resolution of the detectors

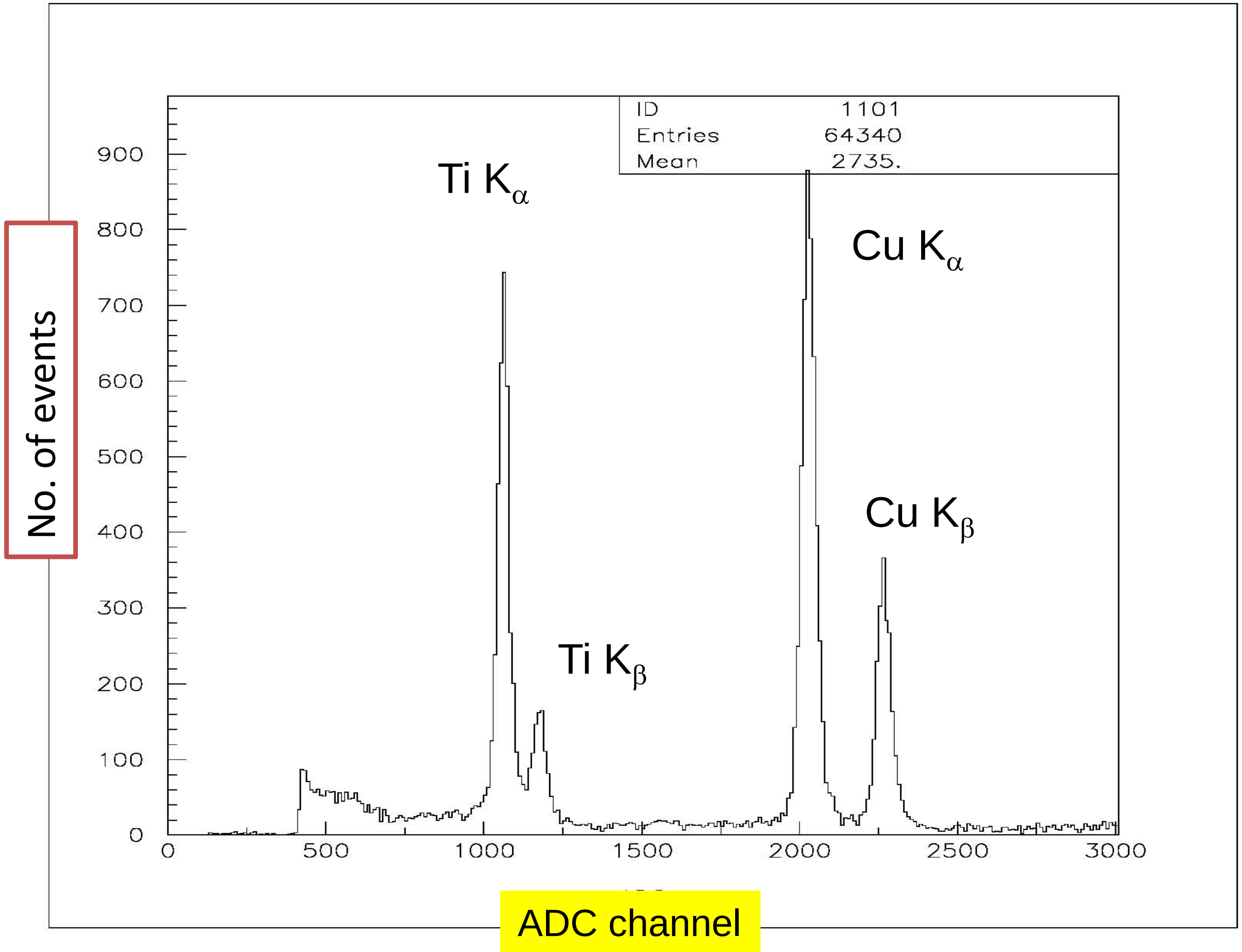


In order to identify the elements which appear in the spectrum, we have to create a spectrum, in which we know which elements appear.

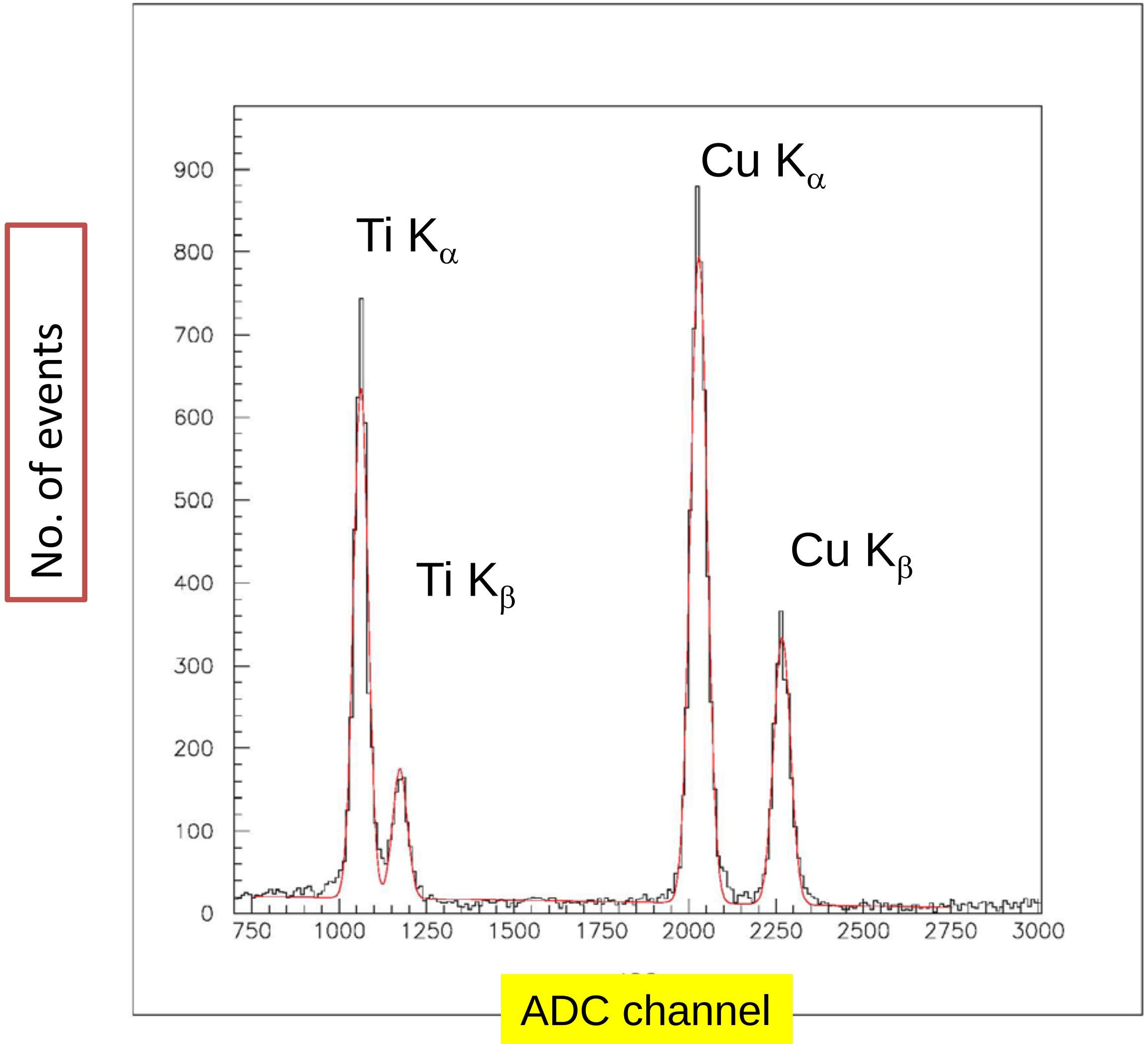
For this reason, we put in the front of the SDD foils of a known materials (like Ti, Cu), which, will be activate the beam and will emit the X-rays characteristics with the energy well known.


SDDs & Target
(inside vacuum)
Kaon detector

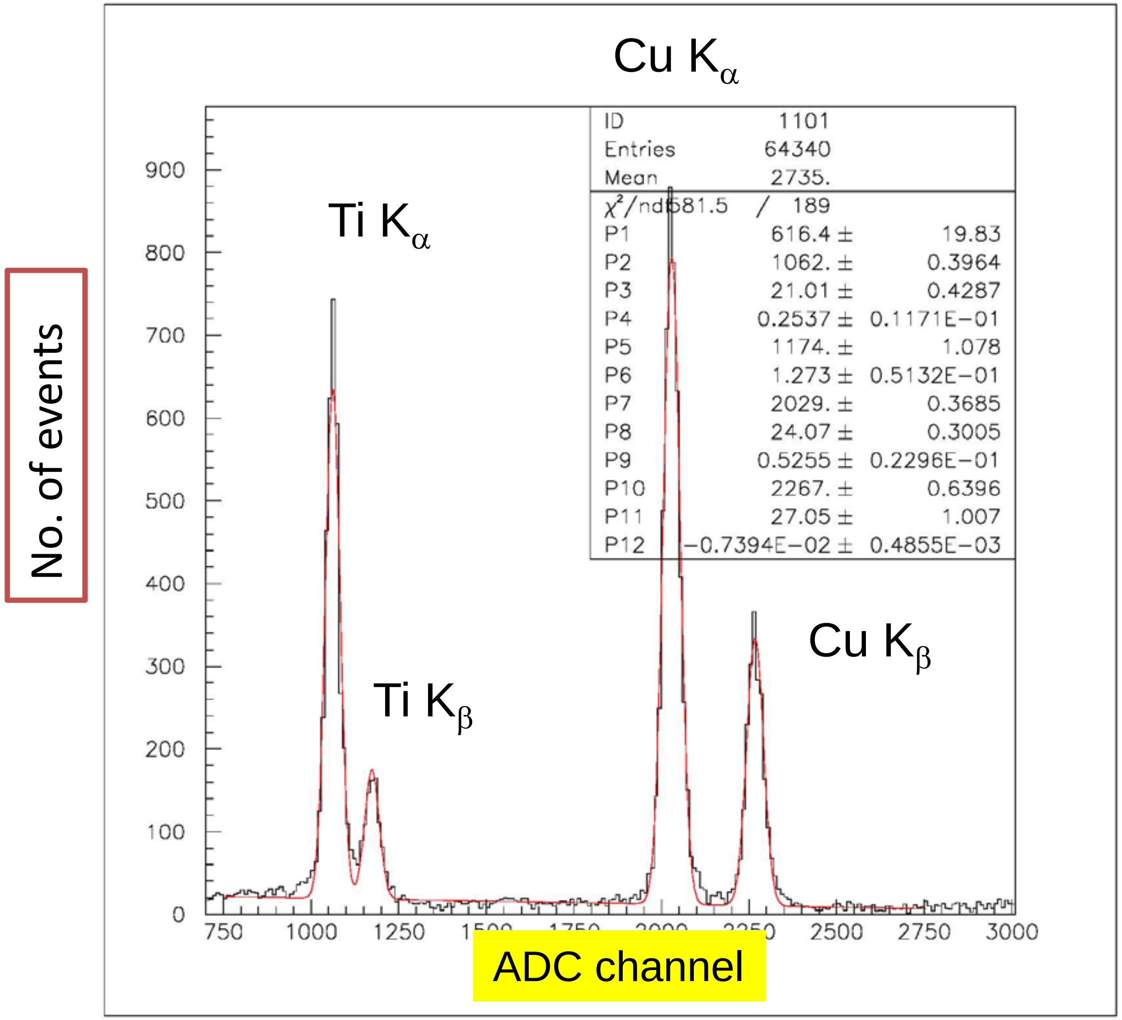
X-ray spectrum obtained by activating the Ti and Cu foils



The Gaussian fit of the X-ray spectrum obtained by activating the Ti and Cu foils



Results of the Gaussian fit of the X-ray spectrum obtained by activating the Ti and Cu foils



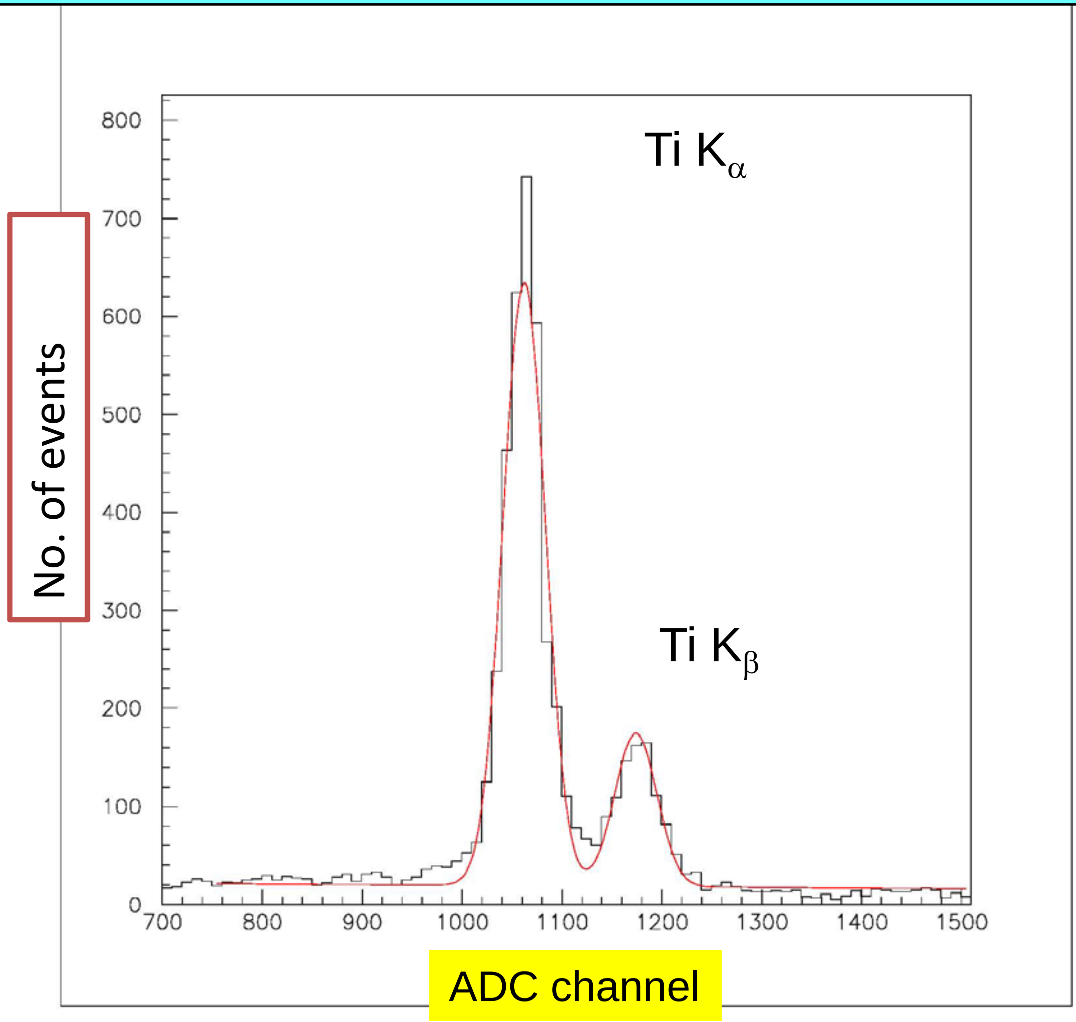
Results of the Gaussian fit of the Ti peak

The parameters of the fit are:

P1= 616.4 -> the height of the Ti Ka peak

P2 = 1062 -> the position of Ti Ka peak (in ADC channels)

P3 = 21.01 -> standard deviation (in ADC channels)



Energy calibration

The energy calibration means to calculate how many energy corresponds to each ADC channel in the X ray spectrum

We will pass from one spectrum which in the ADC channel (no physical meaning) to another spectrum which is in energy.

In this way, we can identify the all the elements which give X rays in our spectrum.

From the tables (very well known):

$$E_{TiK_\alpha} = 4.511 keV$$

The energy corresponding to each ADC channel is:

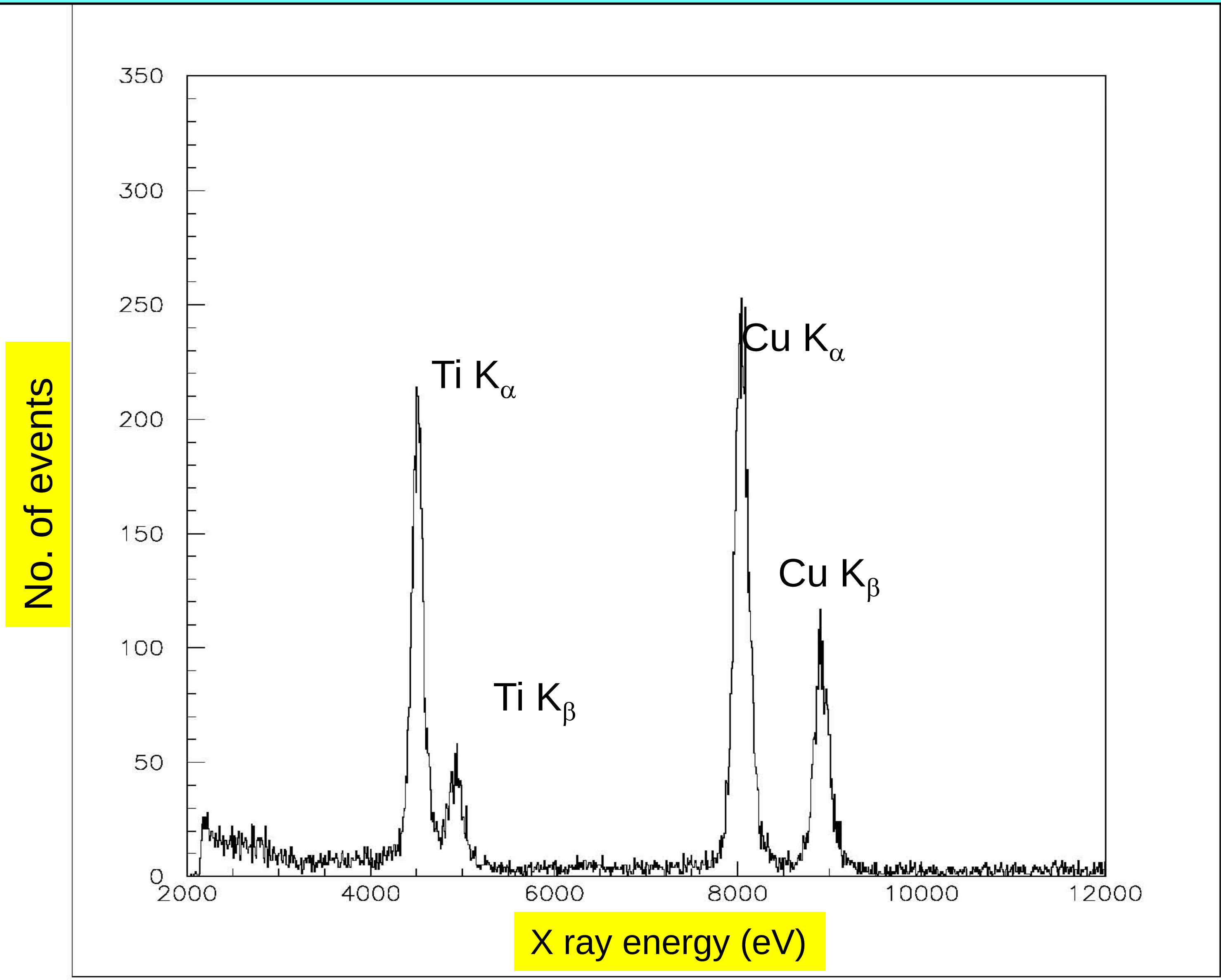
$$\frac{E_{MnK_\alpha}}{Channel} = \frac{4511(eV)}{1062(channel)} = 4.25\text{eV/canale}$$

Table 7a. X-ray Energies and Intensities (per 100 K-Shell Vacancies)

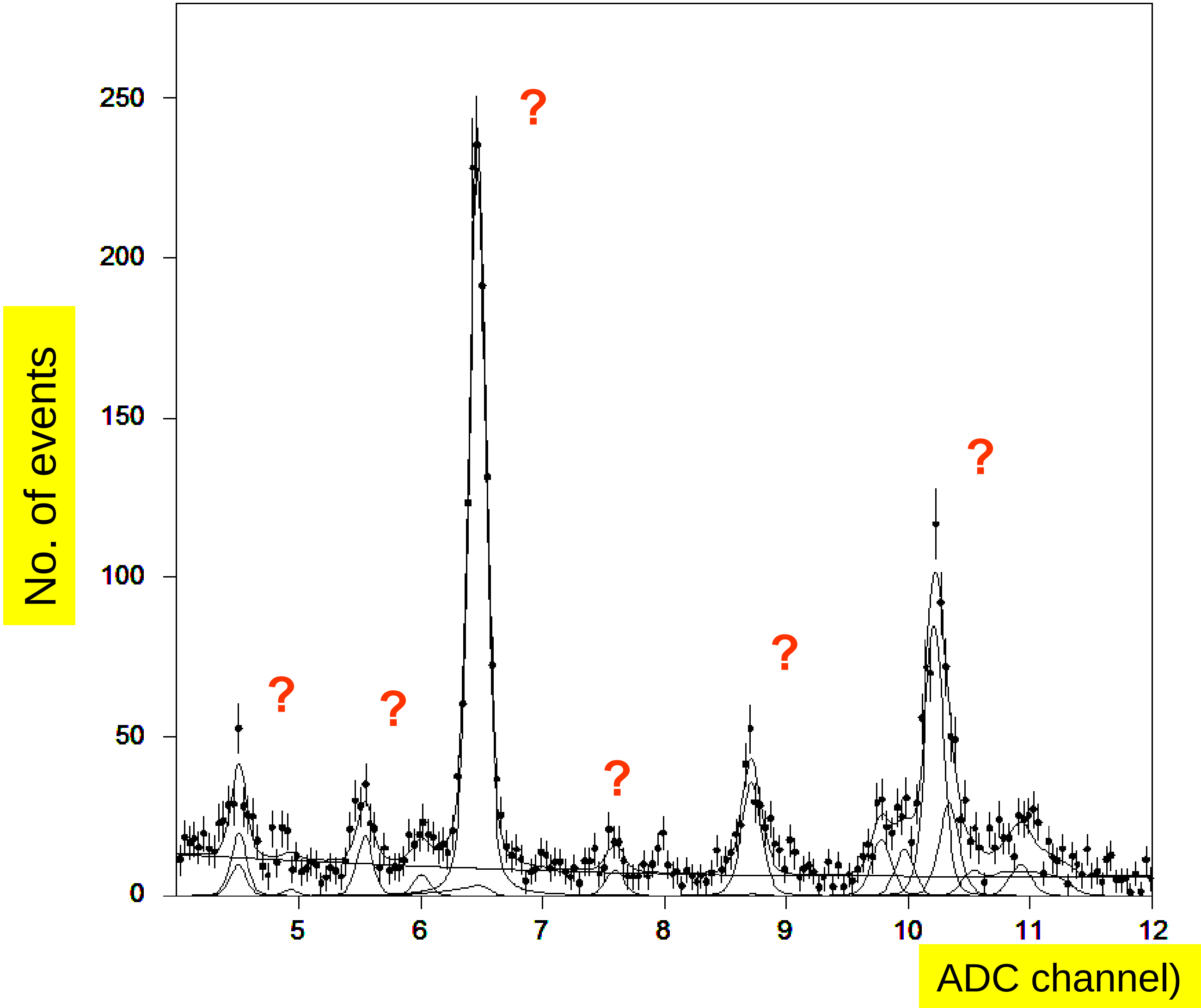
	$_{5}$B	$_{6}$C	$_{7}$N	$_{8}$O	$_{9}$F	$_{10}$Ne	$_{11}$Na	$_{12}$Mg	$_{13}$Al	$_{14}$Si	$_{15}$P	$_{16}$S	$_{17}$Cl	$_{18}$Ar	$_{19}$K
$K_{\alpha 1}$	**0.183** 0.11 *5*	**0.277** 0.19 *8*	**0.392** 0.35 *14*	**0.525** 0.55 *22*	**0.677** 0.9 *4*	**0.849** 1.20 *12*	**1.041** 1.53 *16*	**1.254** 2.0 *2*	**1.487** 2.6 *3*	**1.740** 3.3 *3*	**2.010** 4.1 *4*	**2.308** 5.0 *5*	**2.622** 6.1 *6*	**2.957** 7.3 *7*	**3.314** 8.5 *9*
$K_{\alpha 2}$	**0.183** 0.056 *23*	**0.277** 0.09 *4*	**0.392** 0.17 *7*	**0.525** 0.28 *11*	**0.677** 0.43 *17*	**0.848** 0.60 *6*	**1.041** 0.77 *8*	**1.254** 1.00 *10*	**1.486** 1.29 *13*	**1.739** 1.64 *17*	**2.009** 2.04 *21*	**2.307** 2.49 *25*	**2.621** 3.0 *3*	**2.955** 3.6 *4*	**3.311** 4.3 *4*
$K_{\beta 1}$									**1.554** 0.0155 *16*	**1.836** 0.056 *6*	**2.136** 0.122 *12*	**2.464** 0.229 *23*	**2.816** 0.38 *4*	**3.190** 0.58 *6*	**3.590** 0.79 *8*
$K_{\beta 3}$									**1.554** 0.0079 *8*	**1.836** 0.028 *3*	**2.136** 0.062 *6*	**2.464** 0.116 *12*	**2.816** 0.192 *20*	**3.190** 0.30 *3*	**3.590** 0.40 *4*
$L_{\beta 1}$														**0.251** 0.011 *3*	**0.296** 0.013 *4*
$L_{\beta 3}$														**0.310** 0.0038 *13*	**0.359** 0.0050 *17*
$L_{\beta 4}$														**0.310** 0.0024 *9*	**0.359** 0.0010 *5*

	$_{20}$Ca	$_{21}$Sc	$_{22}$Ti	$_{23}$V	$_{24}$Cr	$_{25}$Mn	$_{26}$Fe	$_{27}$Co	$_{28}$Ni	$_{29}$Cu	$_{30}$Zn	$_{31}$Ga	$_{32}$Ge	$_{33}$As	$_{34}$Se
$K_{\alpha 1}$	**3.692** 9.8 *4*	**4.091** 11.3 *5*	**4.511** 12.8 *6*	**4.952** 14.5 *7*	**5.415** 16.4 *7*	**5.899** 18.3 *8*	**6.404** 20.2 *9*	**6.930** 22.1 *10*	**7.478** 24.0 *11*	**8.048** 26.0 *12*	**8.639** 28.0 *10*	**9.252** 29.8 *11*	**9.886** 31.3 *11*	**10.544** 32.7 *12*	**11.222** 34.1 *12*
$K_{\alpha 2}$	**3.688** 4.93 *22*	**4.086** 5.68 *25*	**4.505** 6.4 *3*	**4.945** 7.3 *3*	**5.405** 8.3 *4*	**5.888** 9.3 *4*	**6.391** 10.2 *5*	**6.915** 11.2 *5*	**7.461** 12.2 *6*	**8.028** 13.3 *6*	**8.616** 14.3 *5*	**9.225** 15.2 *6*	**9.855** 16.1 *6*	**10.508** 16.8 *6*	**11.182** 17.6 *6*
$K_{\beta 1}$	**4.013** 1.02 *5*	**4.461** 1.22 *6*	**4.932** 1.42 *6*	**5.427** 1.64 *7*	**5.947** 1.84 *8*	**6.490** 2.14 *10*	**7.058** 2.40 *11*	**7.649** 2.65 *12*	**8.265** 2.88 *13*	**8.905** 3.10 *14*	**9.572** 3.39 *12*	**10.264** 3.70 *13*	**10.982** 3.98 *14*	**11.726** 4.25 *15*	**12.496** 4.54 *16*
$K_{\beta 2}$												**10.366** 0.0314 *11*	**11.101** 0.097 *4*	**11.864** 0.194 *7*	**12.652** 0.323 *12*
$K_{\beta 3}$	**4.013** 0.519 *23*	**4.461** 0.62 *3*	**4.932** 0.72 *3*	**5.427** 0.84 *4*	**5.947** 0.94 *4*	**6.490** 1.09 *5*	**7.058** 1.23 *6*	**7.649** 1.36 *6*	**8.265** 1.48 *7*	**8.905** 1.59 *7*	**9.572** 1.74 *6*	**10.260** 1.90 *7*	**10.975** 2.05 *7*	**11.720** 2.19 *8*	**12.490** 2.34 *8*
$K_{\beta 5}$							**7.108** 0.00127 *7*	**7.706** 0.00188 *11*	**8.329** 0.00264 *15*	**8.977** 0.00365 *21*	**9.651** 0.00504 *25*	**10.350** 0.0063 *3*	**11.074** 0.0078 *4*	**11.826** 0.0095 *5*	**12.601** 0.0116 *6*
$L_{\alpha 1}$		**0.396** 0.026 *7*	**0.452** 0.063 *16*	**0.511** 0.12 *3*	**0.572** 0.19 *5*	**0.637** 0.26 *7*	**0.704** 0.33 *8*	**0.776** 0.41 *10*	**0.851** 0.50 *13*	**0.929** 0.60 *15*	**1.012** 0.65 *13*	**1.098** 0.70 *14*	**1.188** 0.81 *16*	**1.282** 0.87 *17*	**1.379** 0.98 *20*
$L_{\alpha 2}$		**0.396** 0.0028 *7*	**0.452** 0.0070 *18*	**0.511** 0.013 *3*	**0.572** 0.021 *5*	**0.637** 0.029 *7*	**0.704** 0.037 *9*	**0.776** 0.045 *11*	**0.851** 0.056 *14*	**0.929** 0.066 *17*	**1.012** 0.072 *15*	**1.098** 0.077 *16*	**1.188** 0.090 *18*	**1.282** 0.096 *19*	**1.379** 0.108 *22*
$L_{\beta 1}$	**0.350** 0.016 *4*	**0.400** 0.020 *5*	**0.458** 0.050 *12*	**0.518** 0.096 *24*	**0.581** 0.15 *4*	**0.648** 0.20 *5*	**0.717** 0.25 *6*	**0.791** 0.31 *8*	**0.868** 0.34 *9*	**0.949** 0.39 *10*	**1.035** 0.42 *11*	**1.125** 0.46 *12*	**1.219** 0.49 *12*	**1.317** 0.52 *13*	**1.420** 0.58 *15*
$L_{\beta 3}$	**0.412** 0.0062 *19*	**0.468** 0.0075 *23*	**0.529** 0.009 *3*	**0.590** 0.010 *3*	**0.652** 0.012 *4*	**0.720** 0.014 *4*	**0.792** 0.016 *5*	**0.866** 0.018 *5*	**0.940** 0.020 *6*	**1.022** 0.021 *6*	**1.107** 0.023 *7*	**1.195** 0.024 *7*	**1.294** 0.025 *7*	**1.386** 0.027 *8*	**1.492** 0.029 *9*
$L_{\beta 4}$	**0.412** 0.0039 *12*	**0.468** 0.0048 *15*	**0.529** 0.0056 *17*	**0.590** 0.0067 *20*	**0.652** 0.0079 *24*	**0.720** 0.009 *3*	**0.792** 0.010 *3*	**0.866** 0.012 *4*	**0.940** 0.013 *4*	**1.022** 0.014 *4*	**1.107** 0.015 *5*	**1.191** 0.016 *5*	**1.286** 0.016 *5*	**1.380** 0.018 *5*	**1.486** 0.019 *6*
$L_{\beta 6}$		**0.402** 0.0017 *4*	**0.456** 0.0018 *5*	**0.513** 0.0022 *6*		**0.640** 0.0023 *6*	**0.708** 0.0022 *6*	**0.779** 0.0022 *6*	**0.855** 0.0022 *6*		**1.020** 0.0021 *4*	**1.114** 0.0027 *5*	**1.212** 0.0033 *7*	**1.315** 0.0038 *8*	**1.424** 0.0045 *9*
$L_{\gamma 8}$												**1.297** 0.0012 *4*	**1.412** 0.0042 *13*	**1.524** 0.0047 *15*	**1.648** 0.0051 *16*
L_{η}		**0.353** 0.020 *5*	**0.401** 0.022 *6*	**0.454** 0.026 *7*	**0.510** 0.025 *6*	**0.568** 0.026 *7*	**0.628** 0.028 *7*	**0.693** 0.028 *7*	**0.760** 0.026 *7*	**0.831** 0.028 *7*	**0.907** 0.029 *7*	**0.984** 0.030 *8*	**1.068** 0.031 *8*	**1.155** 0.031 *8*	**1.245** 0.034 *9*
L_{l}		**0.348** [illegible]	**0.395** [illegible]	**0.446** [illegible]	**0.500** [illegible]	**0.556** [illegible]	**0.615** [illegible]	**0.678** [illegible]	**0.743** [illegible]	**0.811** [illegible]	**0.884** [illegible]	**0.957** [illegible]	**1.037** [illegible]	**1.120** [illegible]	**1.204** [illegible]

The X-ray energy spectrum is:



Data analysis



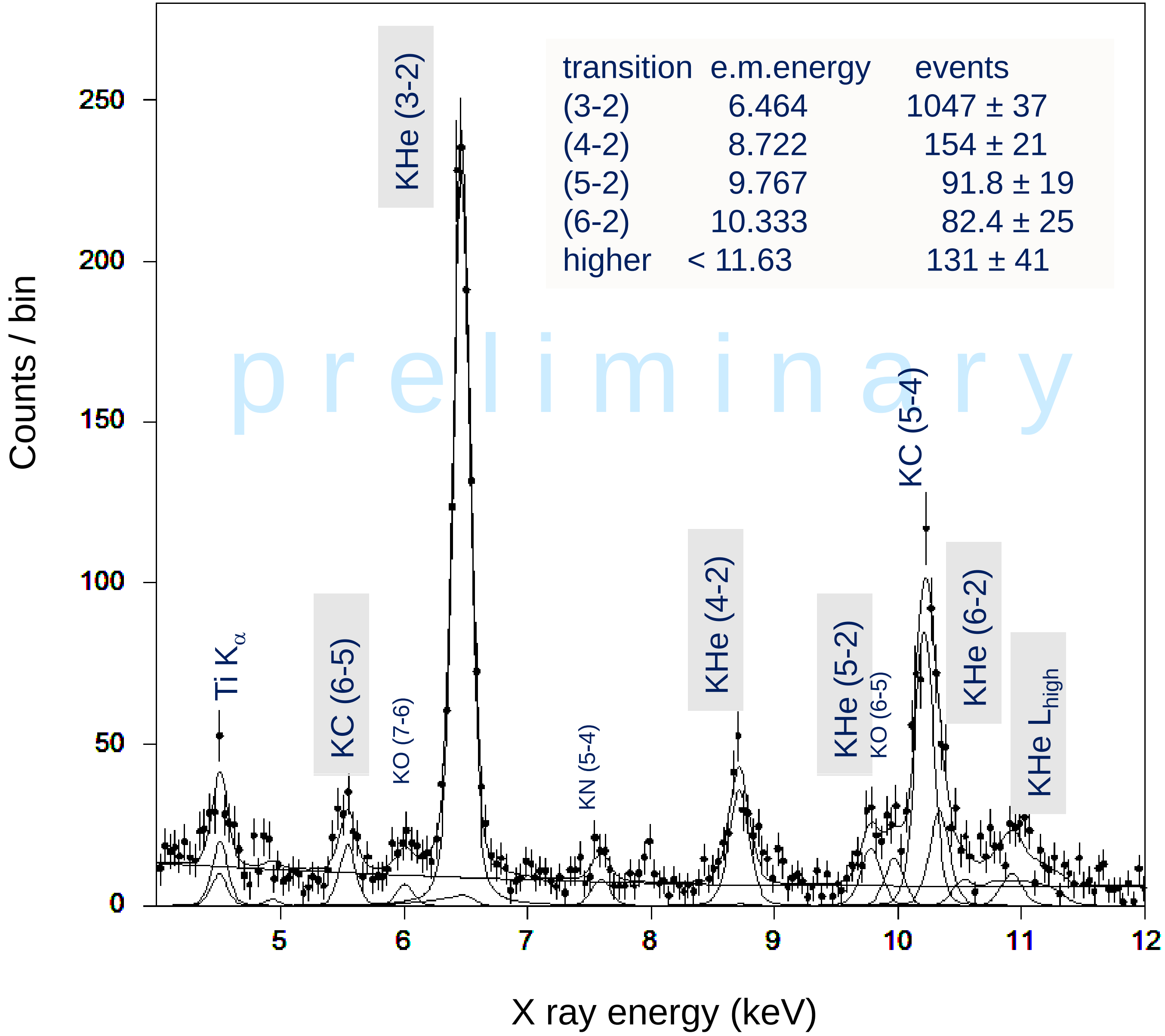
The spectrum obtained after the data taking with SIDDHARTA.

How we can interpret it?

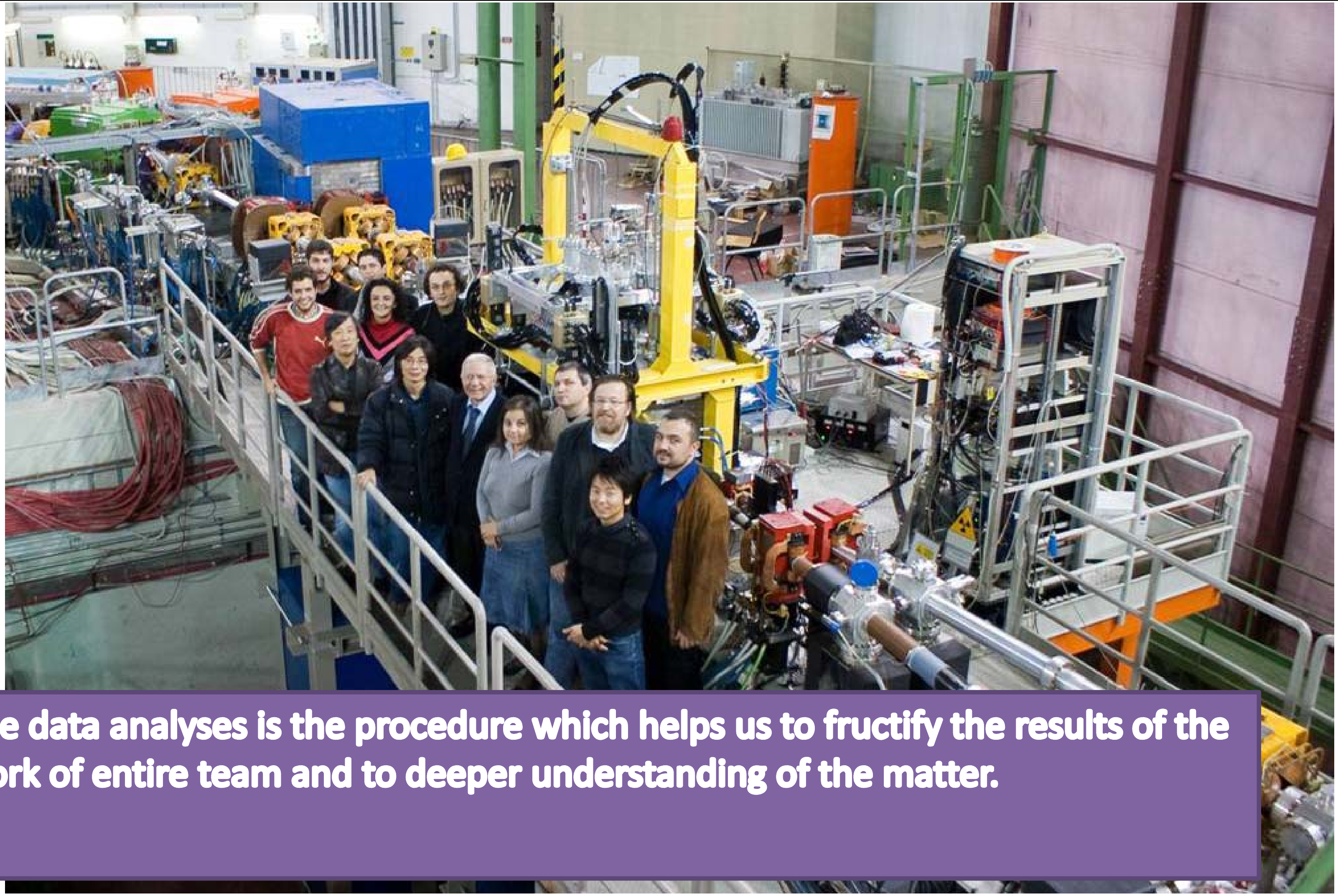
Which is the meaning of the peaks which appears in the spectrum?

$K\text{-}^4He$ spectrum

After the calibration procedure we can identify all the peaks which appear in the SIDDHARTA X-ray spectrum



Conclusion

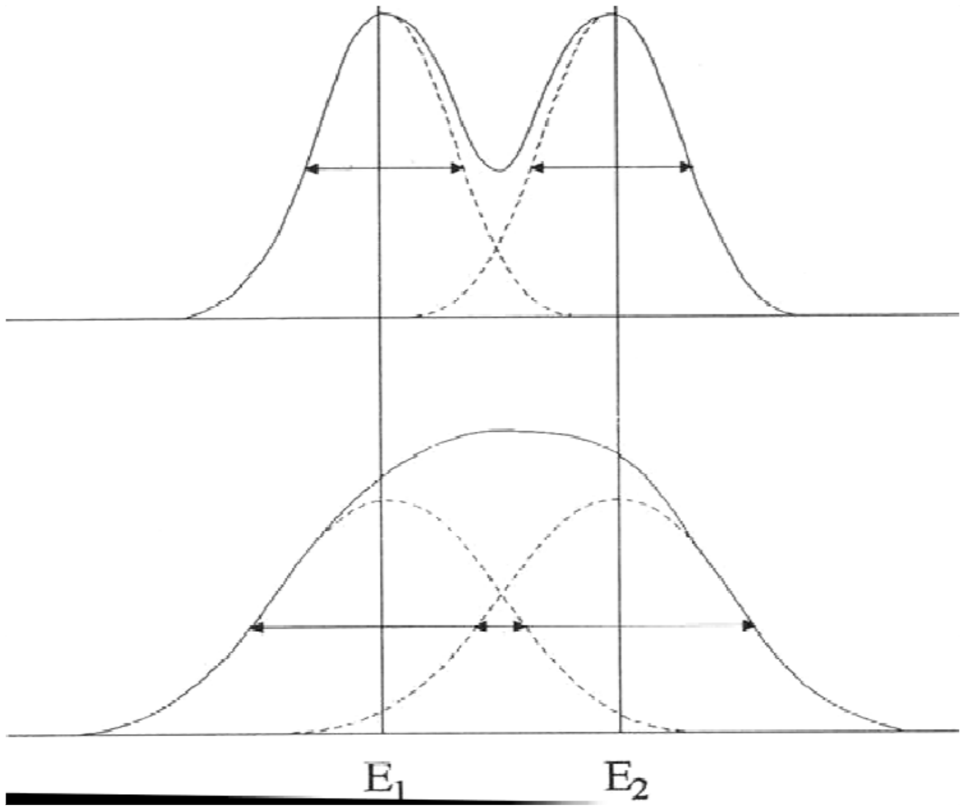


The data analyses is the procedure which helps us to fructify the results of the work of entire team and to deeper understanding of the matter.

Detector rezolution

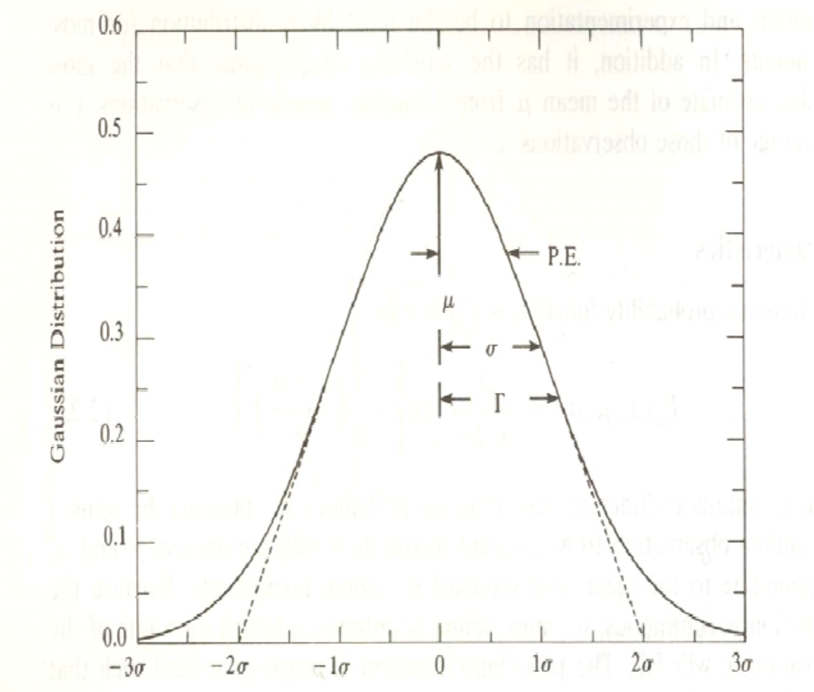
Another element which can be extracted from the X ray spectrum is the detector resolution.

The detector resolution represents the power of the detector to distinguish between two radiations with the energy very close to each other.



How to calculate the detector rezolution

The most common figure used to express detector resolution is full width at half maximum (FWHM). This is the width of the gamma ray peak at half of the highest point on the peak distribution .



From the Gauss distribution:

$$P_g(x;\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

σ = standard deviation

Γ = the resolution of the detectors

$$\Gamma = 2.354 \times \sigma$$

From our case:

$$\Gamma = 2.35 \times \sigma = 2.35 \times 21.01 \times 4.25 = 209.83 eV$$

About X-rays

X-rays are created, in principle, by **two different atomic processes**:

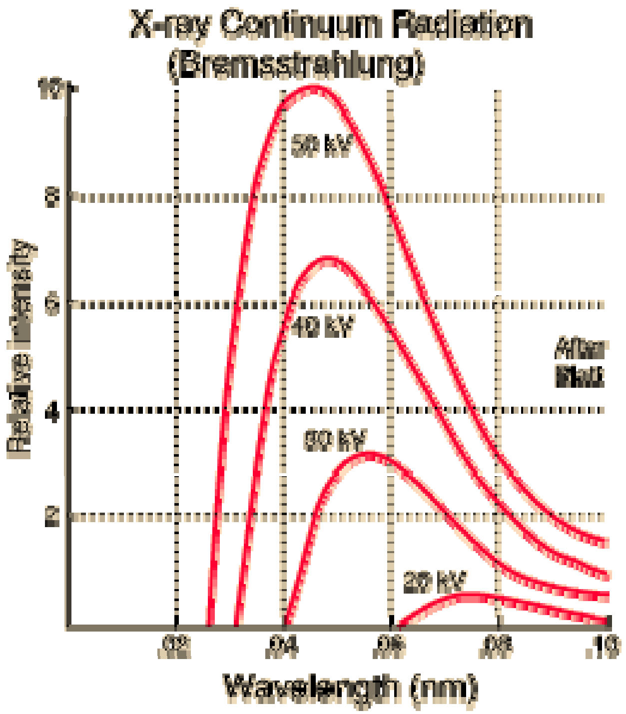
1. X-rays creates by the deceleration of high-energy electrons in collisions with the atomic nucleus (this type of X –rays are cooled **Bremsstrahlung**;
   Bremsstrahlung is a german word, from *bremsen* "to brake" and *Strahlung* "radiation", which means "**braking radiation"** or **"deceleration radiation"**)

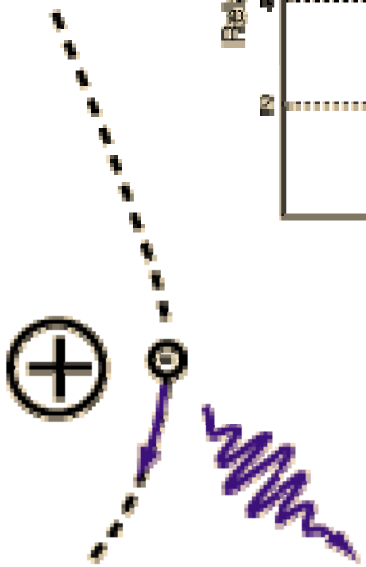
2. X-rays produced by the transitions of the electrons in the orbital of the atoms (this type of X-rays are cooled **“characteristics X-rays” or “X-rays fluorescence”)**

Bremsstrahlung X rays – "deceleration radiation"

"Bremsstrahlung" means **"braking radiation"** and is retained from the original German to describe the electromagnetic radiation produced by the acceleration of a charged particle, such as an electron, when deflected by another charged particle, such as an atomic nucleus.

Bremsstrahlung has a continuous spectrum, The intensity of the X-rays increases linearly with decreasing frequency, from zero at the energy of the incident electrons.



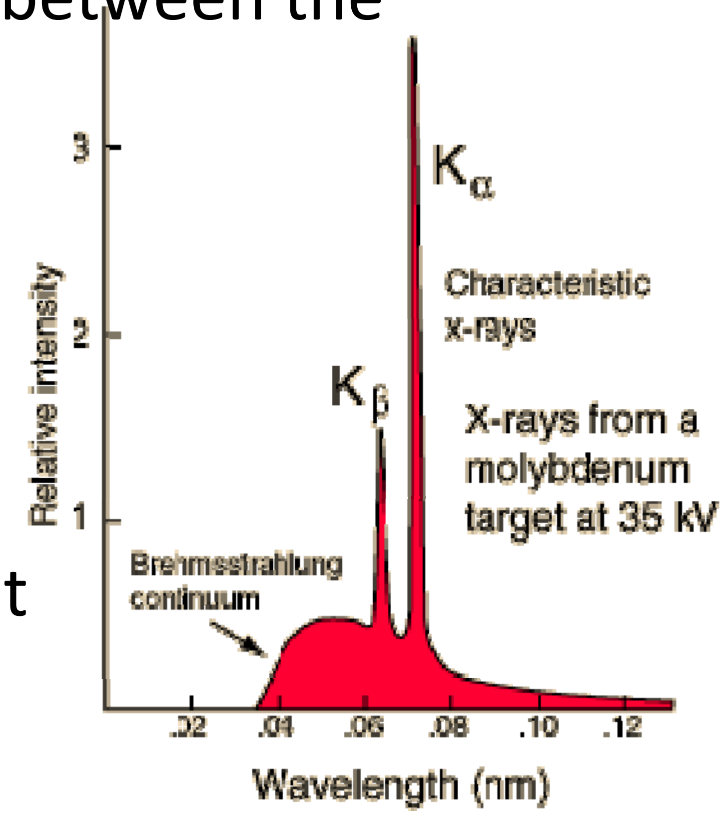


Accelerated electron emits radiation

Characteristics X rays

Characteristic x-rays are emitted from heavy elements when their electrons make transitions between the lower atomic energy levels

- X-Ray fluorescence of elements
  - sharp peaks, independent of incident energy
  - uniquely characterizes an element



- How are they produced?
- What is the relation?

ATOMIC STRUCTURE!

For analytical purpose,
X-rays are generated in three ways

1) Bombardment of target material with high-energy electron beam

2) Exposure of target material to primary X-ray beam to create a *secondary* beam of *X-ray fluorescence*

3) Use of radioactive materials whose decay patterns include X-ray emission