Diamond detectors characterization for ^{235}U fission fragments detection at LOHENGRIN

ML Gallin-Martel LPSC Grenoble France

Collaboration LPSC / ILL / Krakow / INFN Milano

mlgallin@lpsc.in2p3.fr

OUTLINES

- **Context : induced fission of Uranium-235**
- **Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection**
- **Spectroscopic measurement**
    - Alpha and tritons data analysis
    - Fission Fragment (FF) data analysis
    - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- **Timing resolution with FF**
- **Conclusion**

OUTLINES

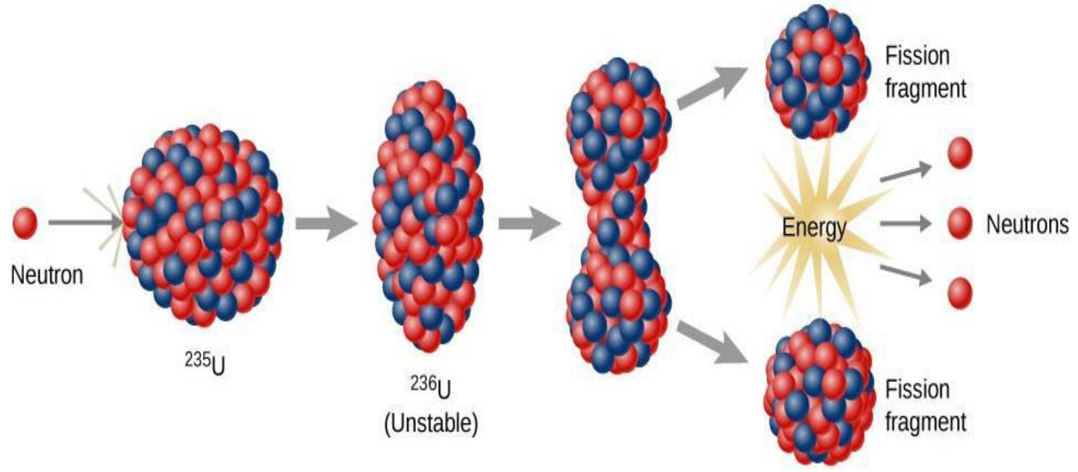
- **Context : induced fission of Uranium-235**
- **Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection**
- **Spectroscopic measurement**
  - Alpha and tritons data analysis
  - Fission Fragment (FF) data analysis
  - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- **Timing resolution with FF**
- **Conclusion**

Context

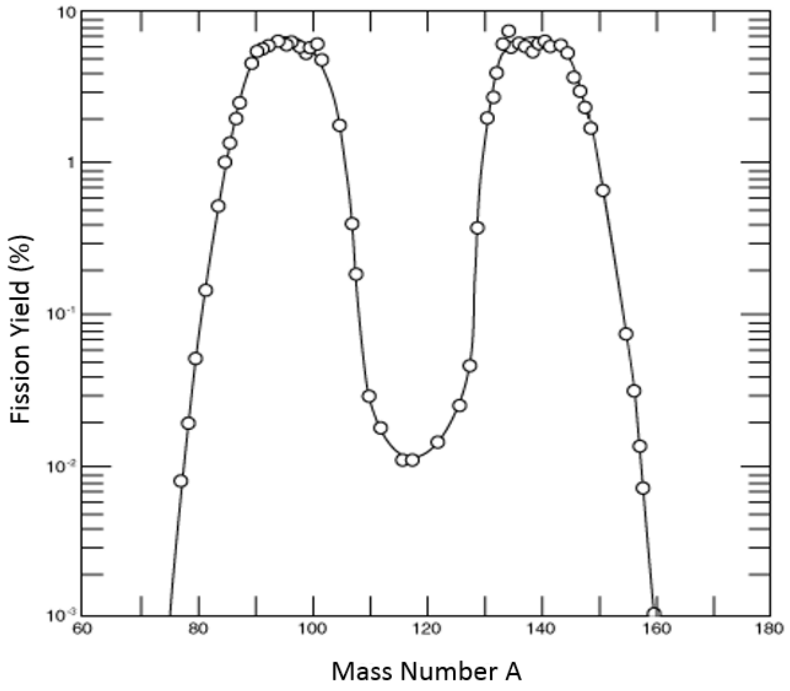
$${}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \rightarrow \mathrm{X} + \mathrm{Y} + \lambda\,{}^{1}_{0}n$$

X,Y : Fission Fragments.

λ : number of neutrons.



Induced fission of Uranium-235



Mass distribution of fission fragments

Why it is important to study nuclear fission ?

- key data for nuclear reactor studies,
  =>linked to the estimation of **decay heat**, **criticality** or **radiotoxicity of spentfuel**

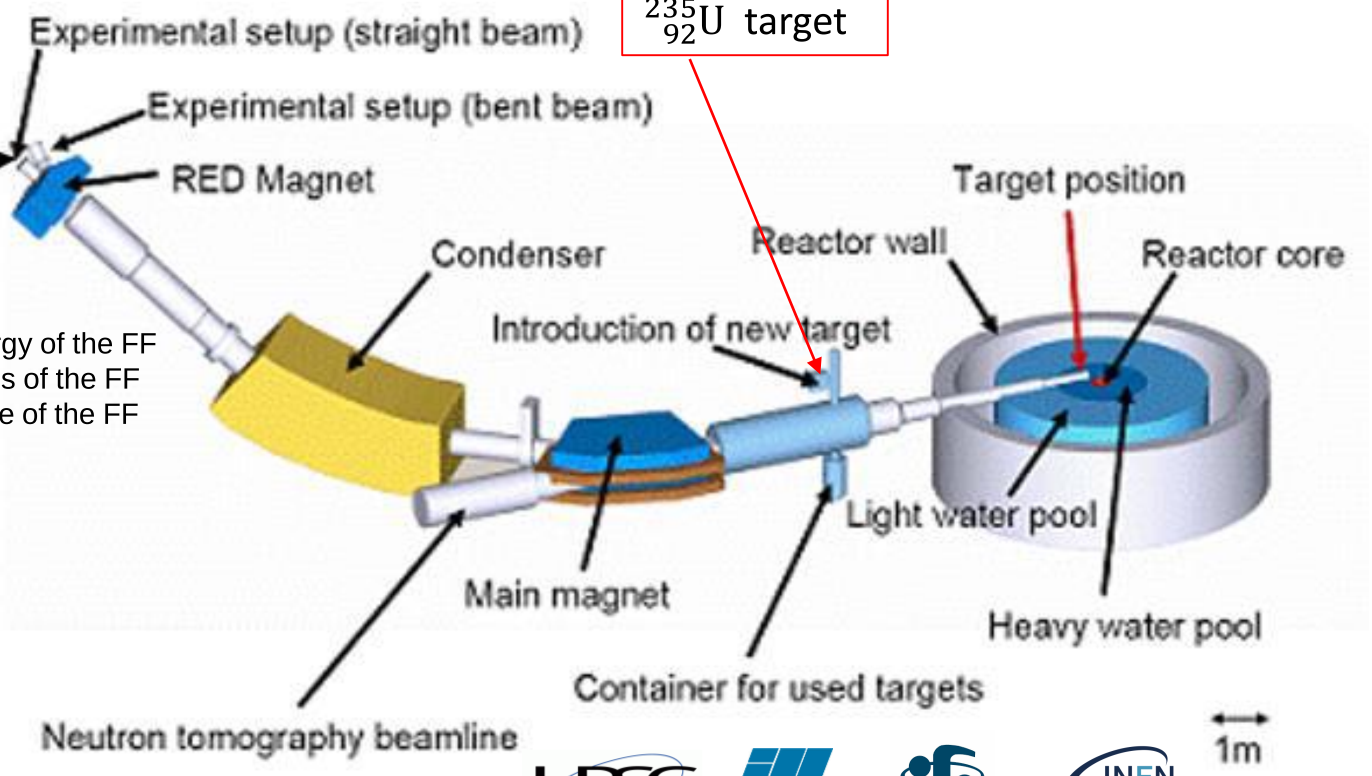
- important for the understanding of the **fission process itself.**

OUTLINES

- Context : induced fission of Uranium-235
- **Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection**
- Spectroscopic measurement
  - Alpha and tritons data analysis
  - Fission Fragment (FF) data analysis
  - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- Timing resolution with FF
- Conclusion

Experimental apparatus

LOHENGRIN spectrometer at the Laue-Langevin Institut Grenoble



$^{235}_{92}\mathrm{U}$ target

- **A magnetic field** deflects vertically the FF according to their $\frac{E}{q}$
- **An electric field** deflects horizontally the FF according to their $\frac{A}{q}$

- E: kinetic energy of the FF
- A: atomic mass of the FF
- q : ionic charge of the FF

➔ **Collaboration LPSC / ILL / Krakow / INFN Milano**

Objectives :

- **test diamond sensors for fission fragment detection**

Diamond Assets :

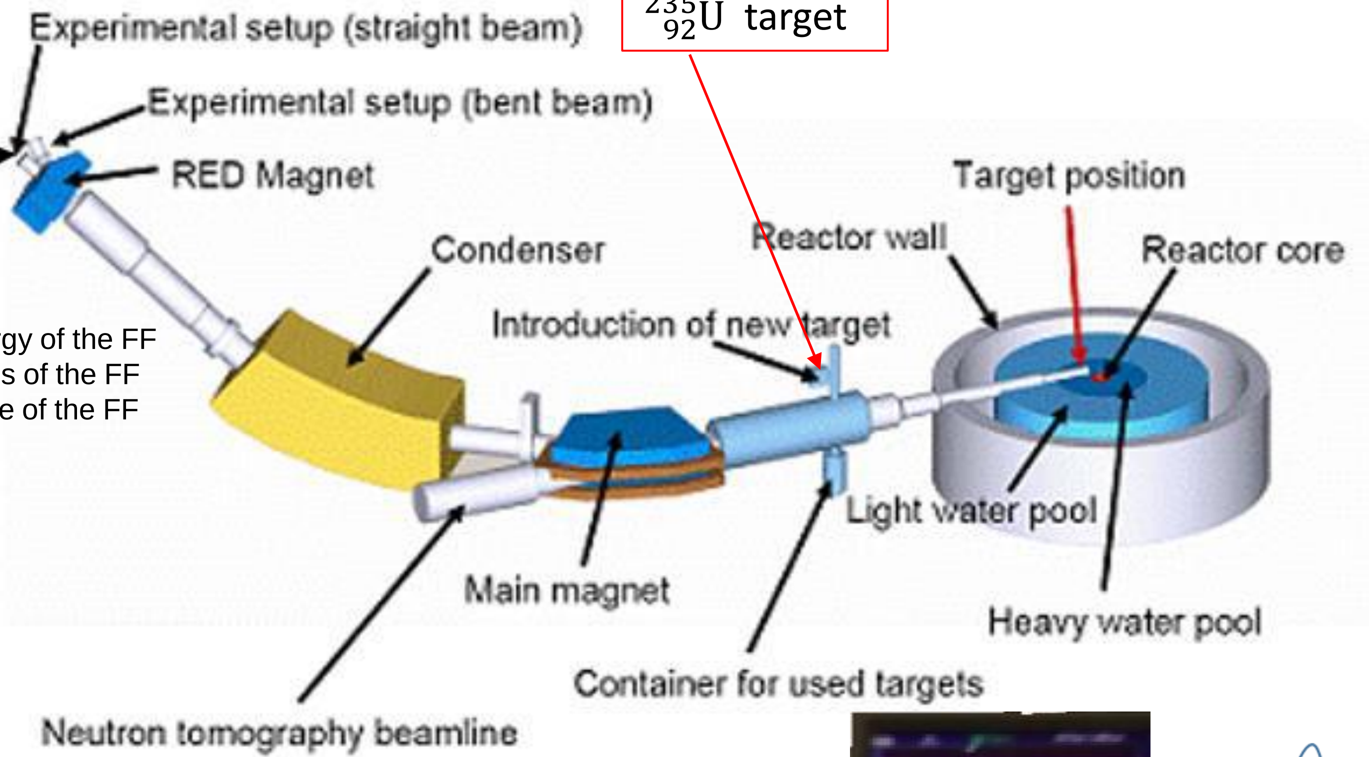
- Intrinsic radiation hardness
- Fast signal risetime enables timing precision of a few tens of ps
- Low noise

Experimental apparatus

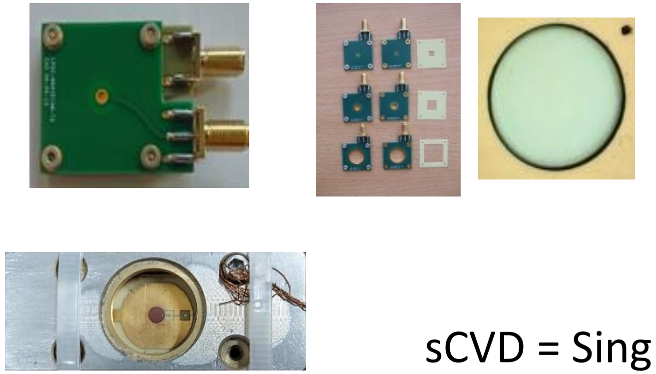
LOHENGRIN spectrometer at the Laue-Langevin Institut Grenoble

- **A magnetic field** deflects vertically the FF according to their $\frac{E}{q}$
- **An electric field** deflects horizontally the FF according to their $\frac{A}{q}$

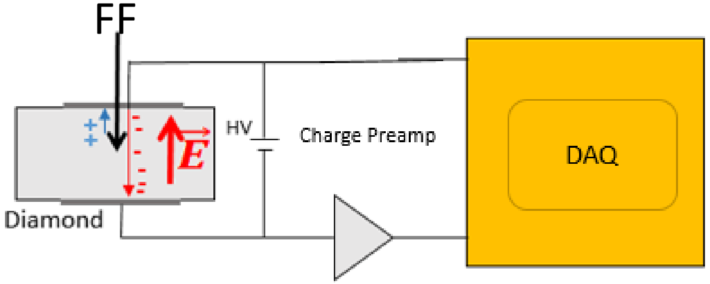
- E: kinetic energy of the FF
- A: atomic mass of the FF
- q : ionic charge of the FF



Diamond detector



Diamond detector + support



sCVD = Single Crystal Chemical Vapour Deposition

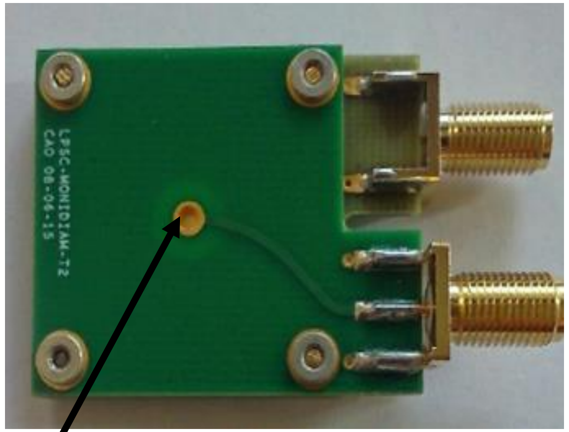
Schematic of the test bench set-up

The signal observed on the oscilloscope

The displayed spectrum of FFs on PC

Comparison of LPSC and Krakow diamond

sCVD diamond detectors
517 um thickness
(4,5x4,5mm^2)

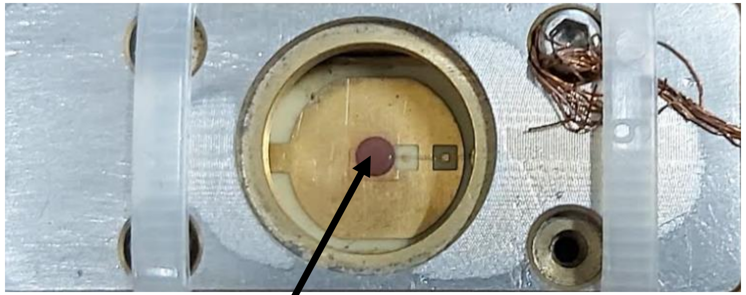


LPSC

2 mm in diameter

VS

sCVD diamond detectors
50um thickness
(2mm in diameter)



Krakow

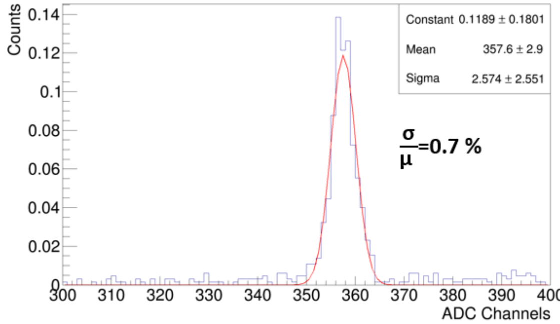
2 mm in diameter

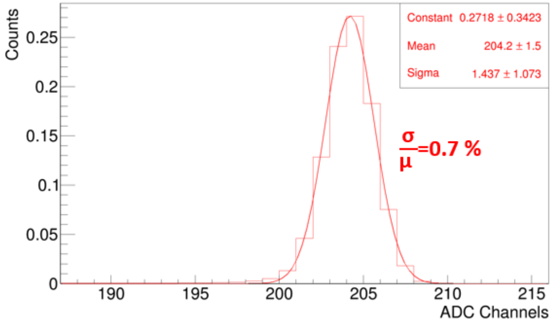
OUTLINES

- Context : induced fission of Uranium-235
- Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection
- **Spectroscopic measurement**
  - Alpha and tritons data analysis
  - Fission Fragment (FF) data analysis
  - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- Timing resolution with FF
- Conclusion

Alpha and triton data analysis

sCVD diamond detectors
500um thickness
(2mm in diameter)

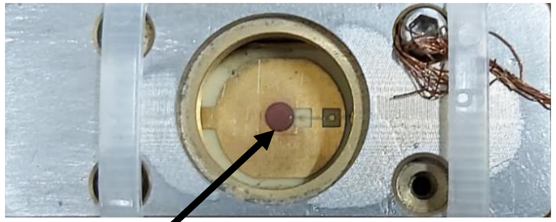




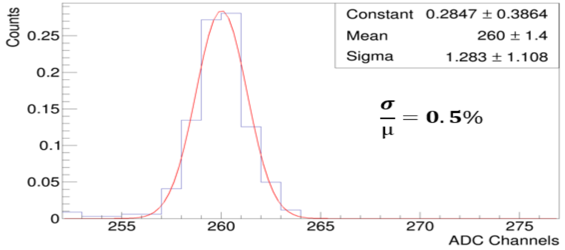
α 4.75 MeV

T 2.7 MeV

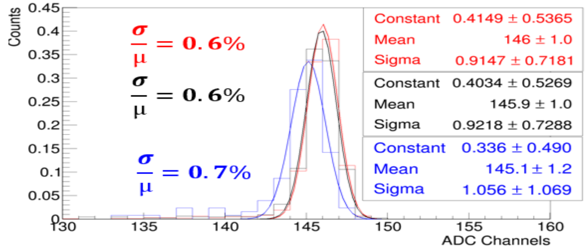
sCVD diamond detectors
50um thickness
(2mm in diameter)



2 mm in diameter



0°
-45°
45°



α 4.75 MeV

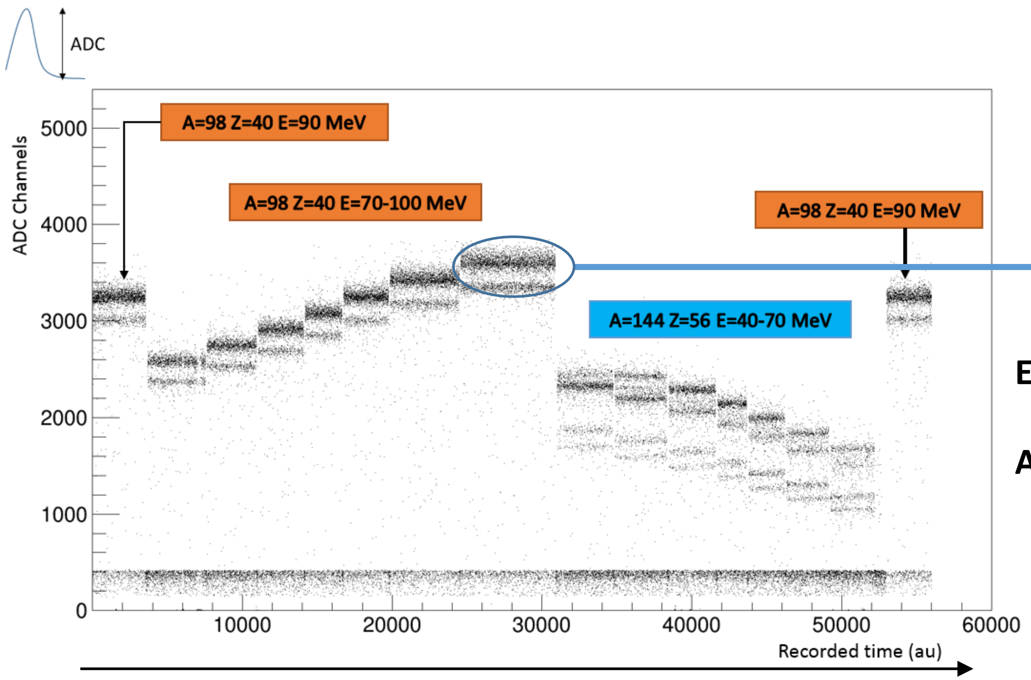
ADC = 55.3 x E -3.4

T 2.7 MeV

OUTLINES

- **Context : induced fission of Uranium-235**
- **Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection**
- **Spectroscopic measurement**
    - Alpha and tritons data analysis
    - Fission Fragment (FF) data analysis
    - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- **Timing resolution with FF**
- **Conclusion**

Energy resolution analysis with Fission Fragments (FF)

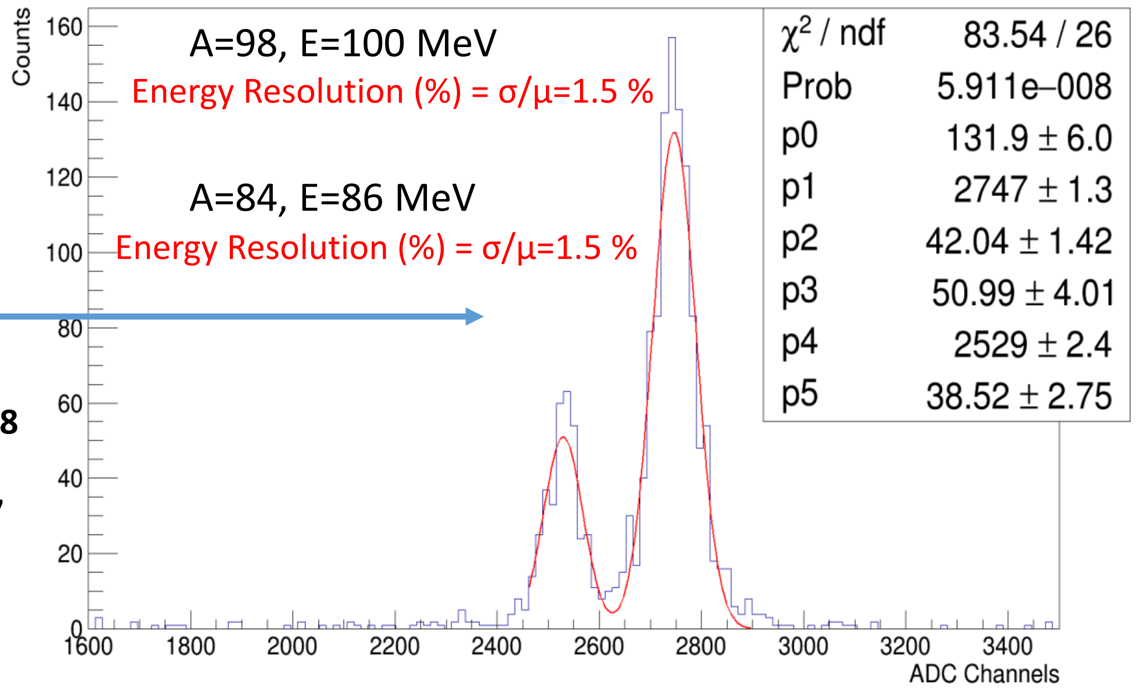


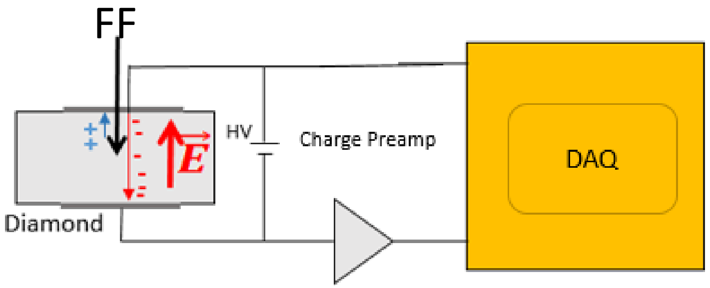
Time of experiment (au)

A : fixed
E : fixed

E/q= 100/21= 86/18=4.8

A/q= 98/21= 84/18=4.7

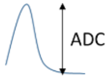


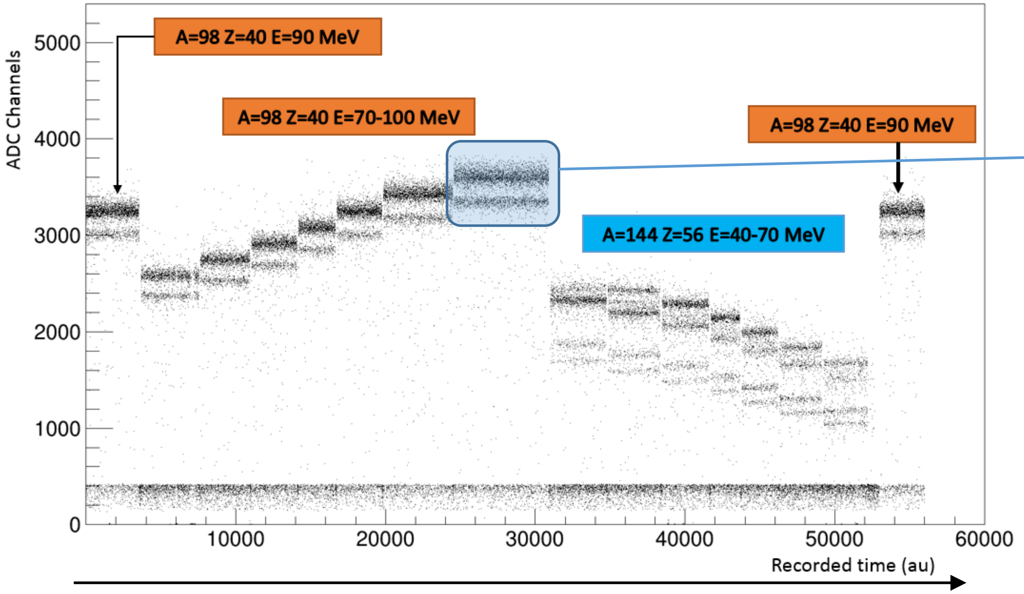


Schematic of the test bench set-up

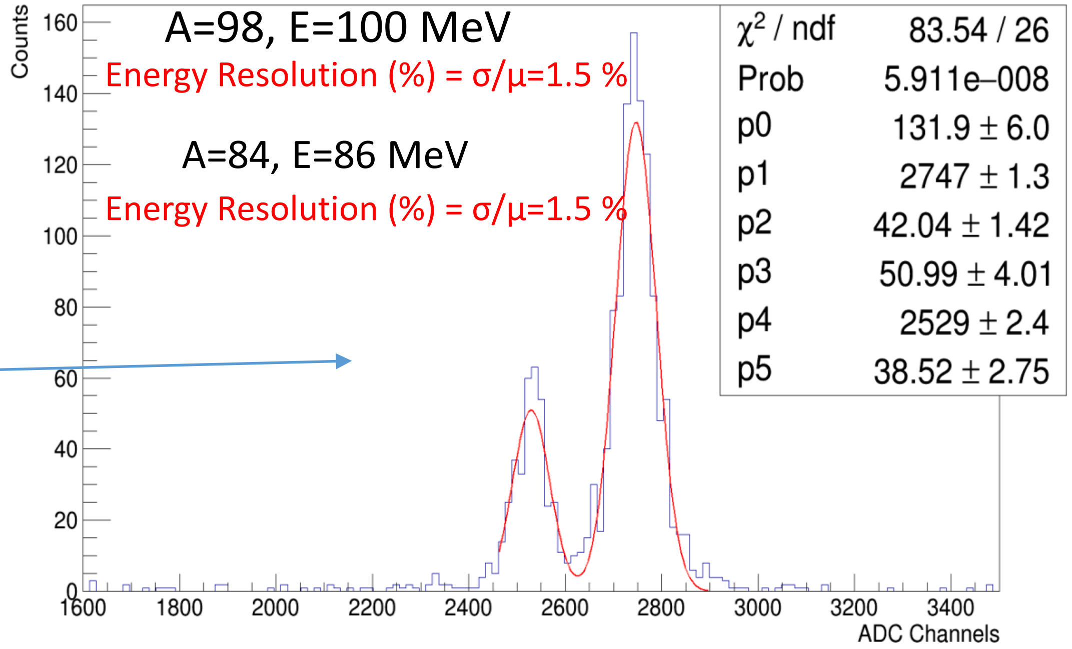
The displayed spectrum of FFs on PC

Energy resolution analysis with FF

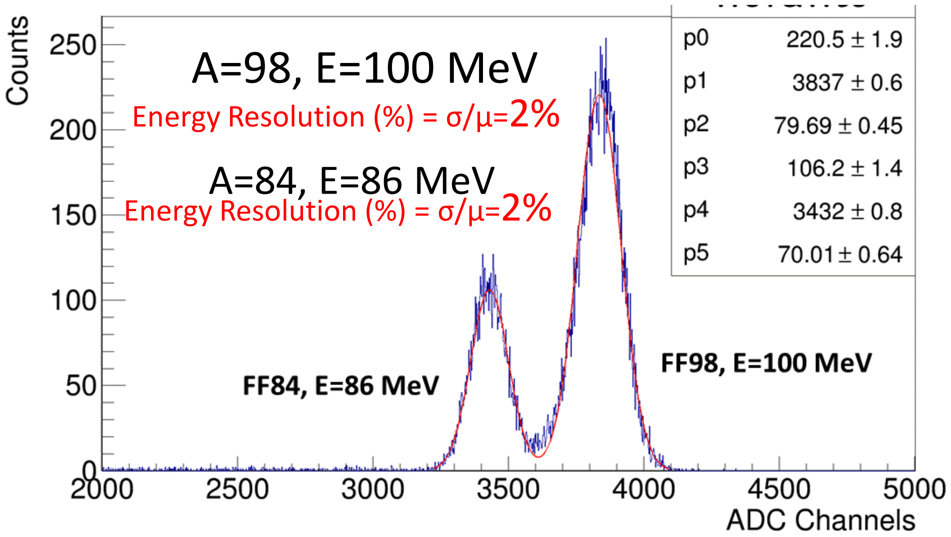




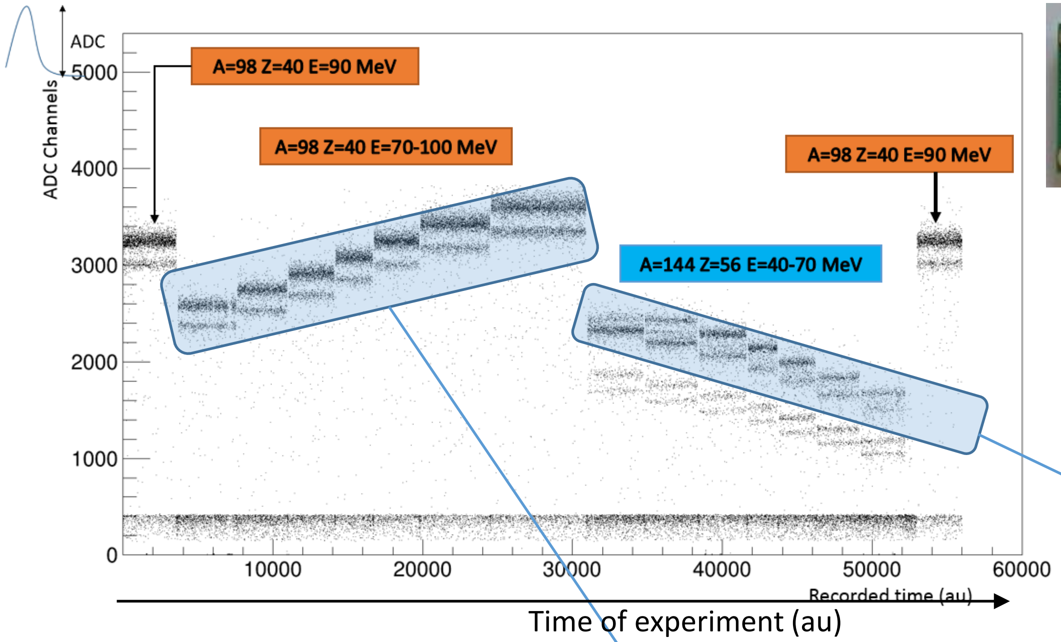
Time of experiment (au)



In comparison to the **gaseous ionization chamber**

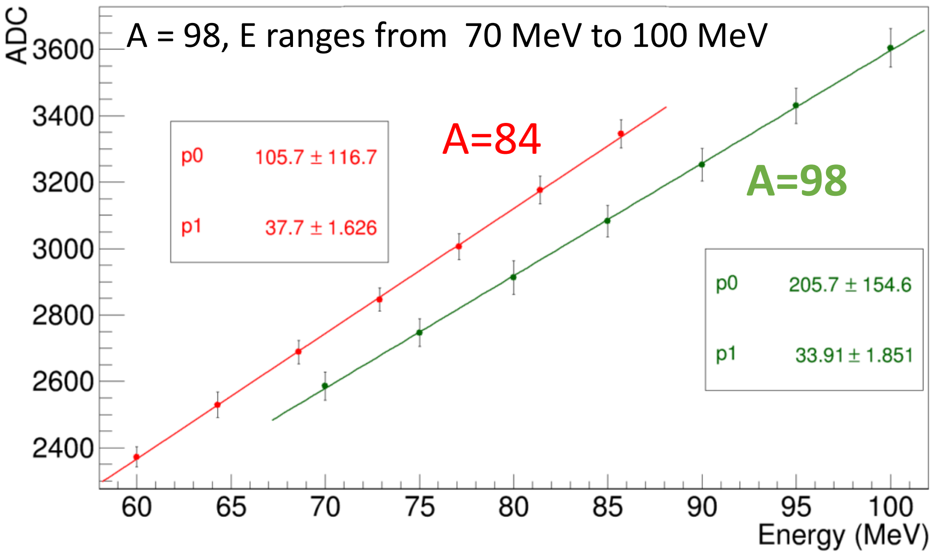


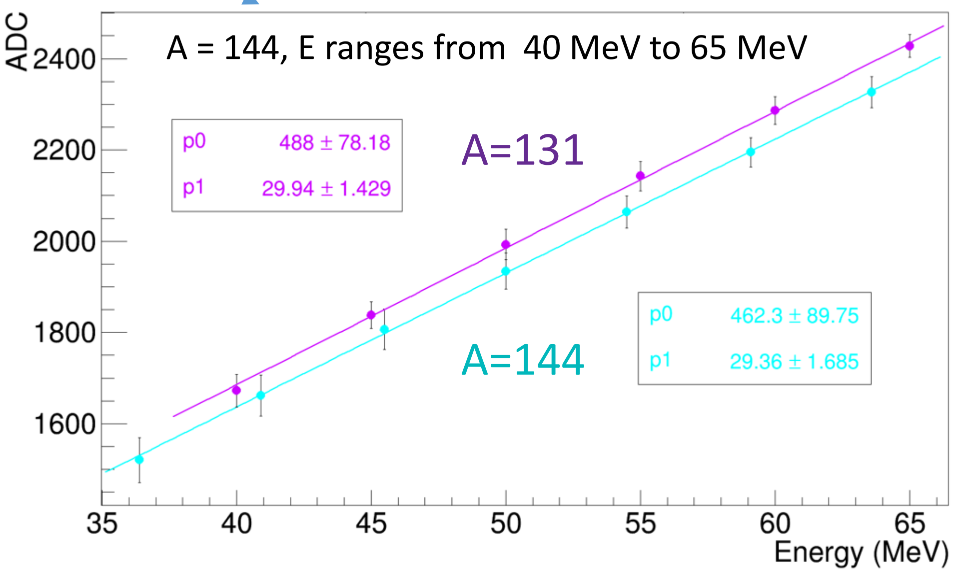
Detector response analysis with FF



ADC = P0+P1xE

P0 and P1 fit parameters



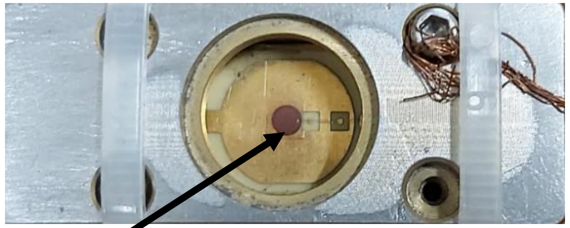


OUTLINES

- Context : induced fission of Uranium-235
- Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection
- Spectroscopic measurement
    - Alpha and tritons data analysis
    - Fission Fragment (FF) data analysis
    - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- Timing resolution with FF
- Conclusion

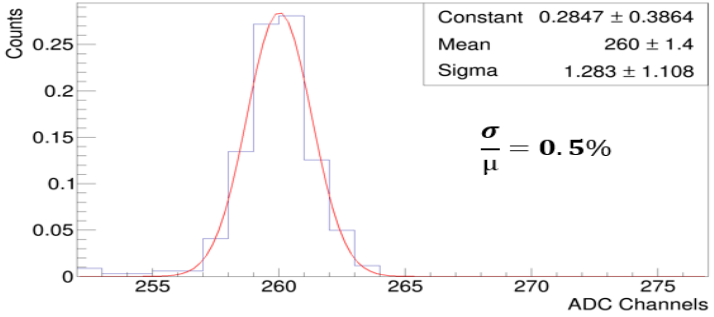
Pulse Height Defect observation

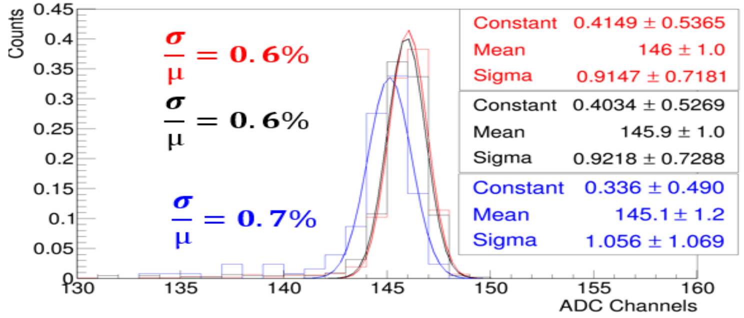
sCVD diamond detectors
50um thickness
(2mm in diameter)



2 mm in diameter

Krakow





α 4.75 MeV

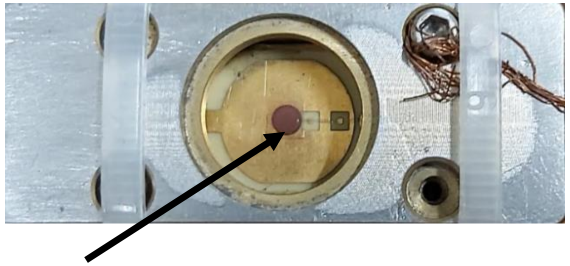
Alpha and triton data analysis

T 2.7 MeV

ADC = 55.3 x E(MeV) -3.4

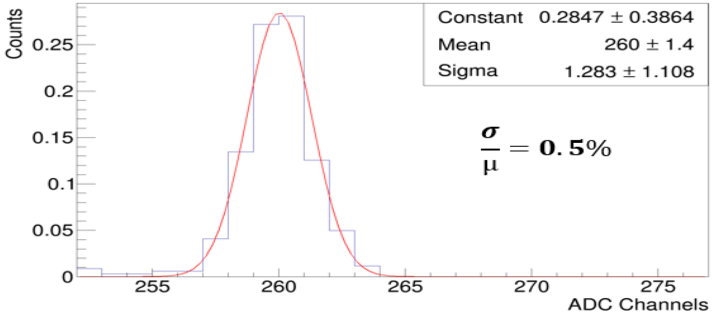
Pulse Height Defect observation

sCVD diamond detectors
50um thickness
(2mm in diameter)



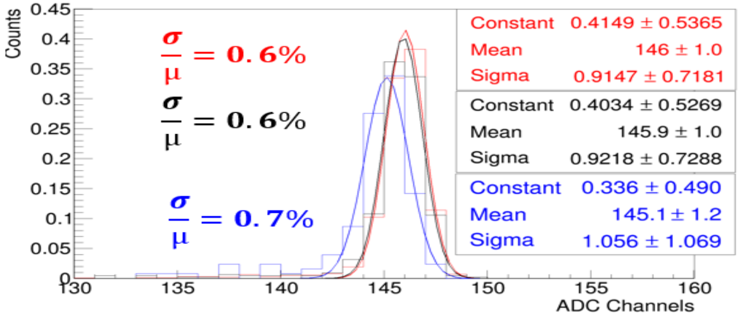
2 mm in diameter

Krakow



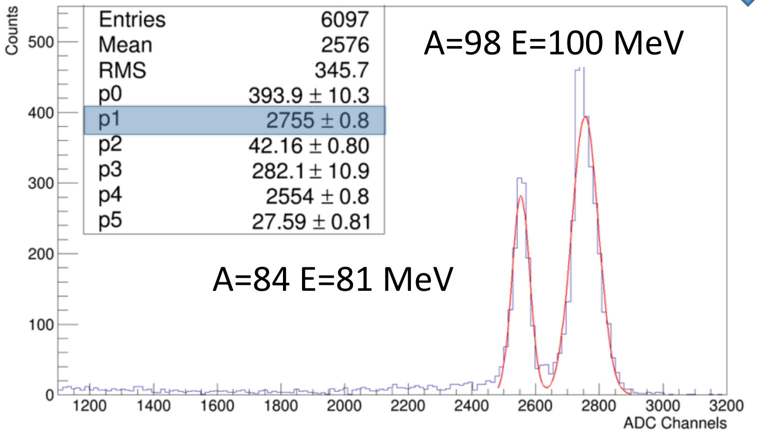
α 4.75 MeV

Alpha and triton data analysis



T 2.7 MeV

Detector response analysis with FF



ADC = 55.3 x E(MeV) -3.4

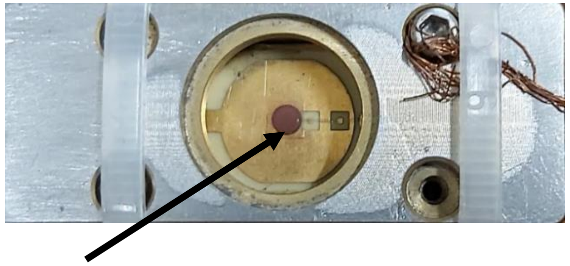
=> one should expect that the FF98 peak at the energy of 100 MeV is at ADC = 5527

BUT : observed at the channel 2755 !!!!

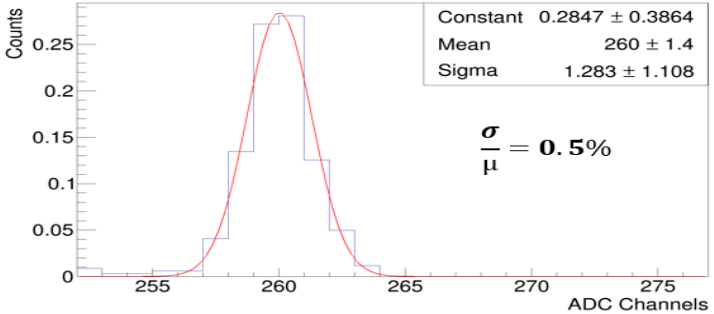
50 % of the kinetic energy is not reconstructed:

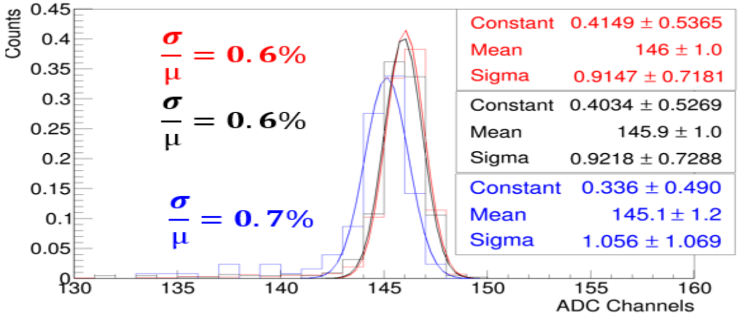
Pulse Height Defect observation

sCVD diamond detectors
50um thickness
(2mm in diameter)



2 mm in diameter Krakow





α 4.75 MeV

Alpha and triton data analysis

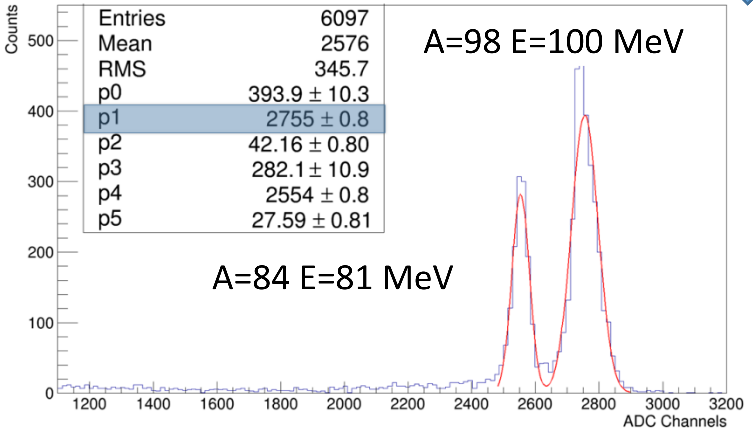
T 2.7 MeV

The Pulse Height Defect (PHD) :

$$\Delta E = E_k - E_{DD}.$$

E_k : The kinetic energy of an incident ion.

E_{DD} : The energy derived from the measured electric signal.



ADC = 55.3 x E(MeV) -3.4

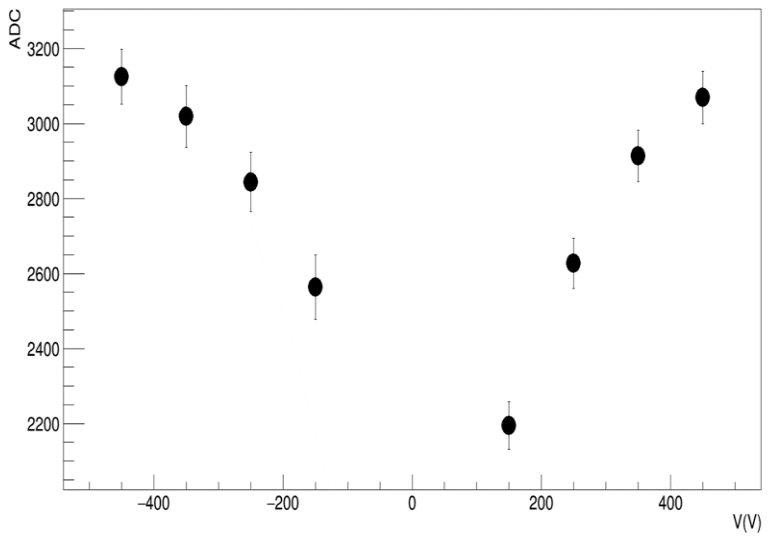
=> one should expect that the FF98 peak at the energy of 100 MeV is at ADC = 5527

BUT : observed at the channel 2755 !!!!

50 % of the kinetic energy is not reconstructed: Pulse Height defect !

Data analysis

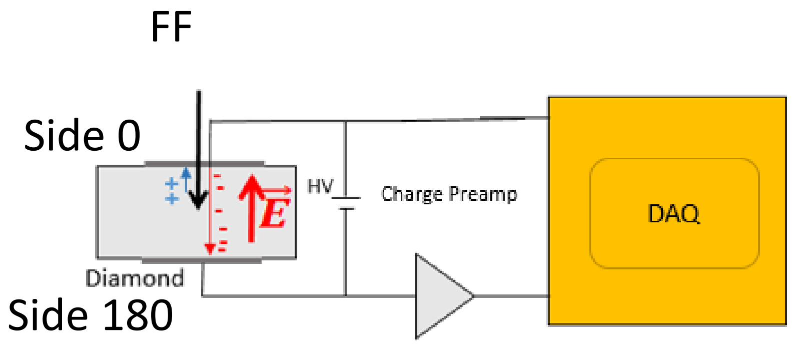
searched for optimal combinations of diamond side exposed to FF versus applied bias voltage to diamond.



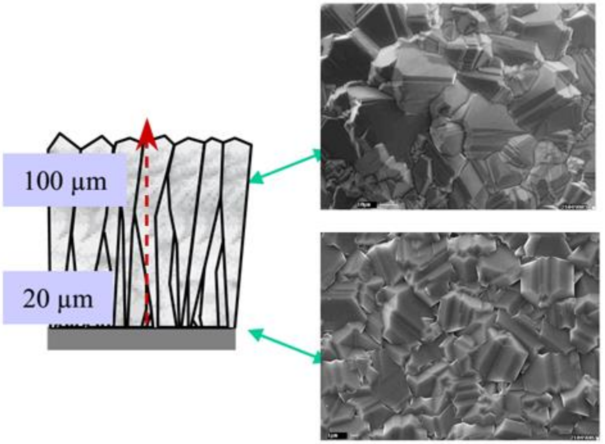
- **An optimum voltage of -450 V corresponds to side 0° and +450 V to side 180° for LPSC = 0.9 V/ µm.**
- **An optimum voltage of 200 V for Krakow = 4 V/µm.**

Diamond detector

LPSC detector

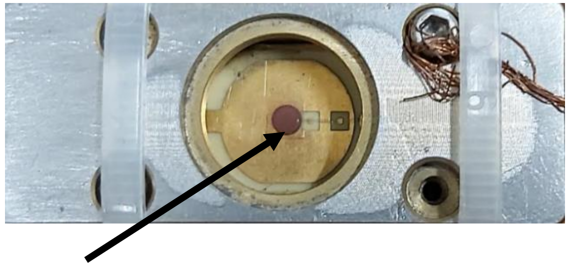


Schematic of the test bench set-up

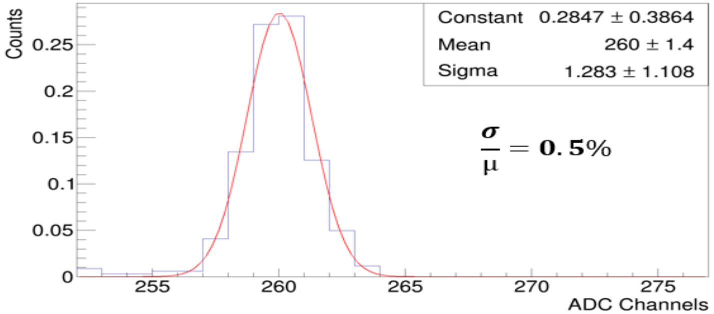


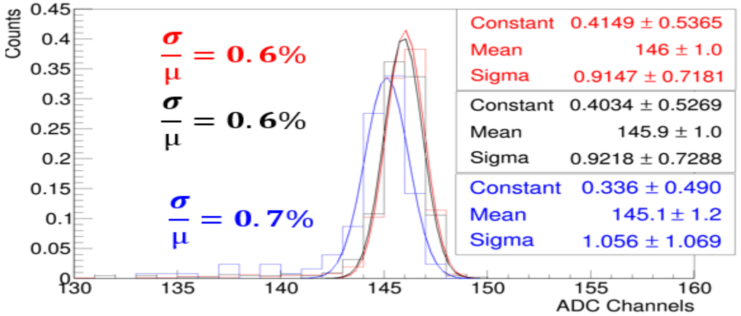
Pulse Height Defect observation

sCVD diamond detectors
50um thickness
(2mm in diameter)



2 mm in diameter   Krakow

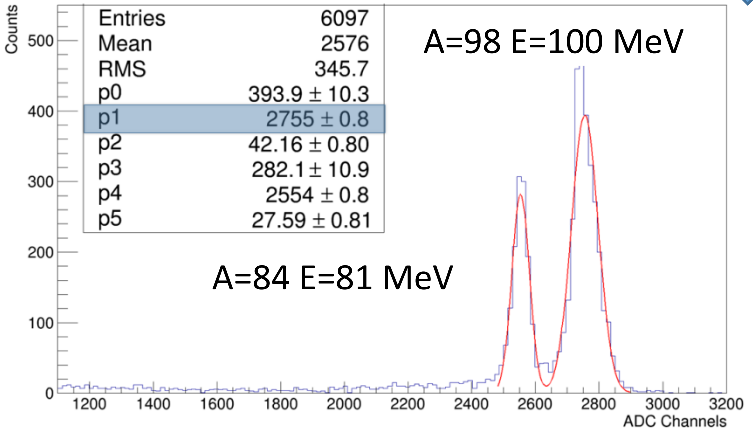




α 4.75 MeV

Alpha and triton data analysis

T 2.7 MeV



ADC = 55.3 x E(MeV) -3.4

=> one should expect that the FF98 peak at the energy of 100 MeV is at ADC = 5527

BUT : observed at the channel 2755 !!!!

The Pulse Height Defect (PHD) :

$$\Delta E = E_k - E_{DD}.$$

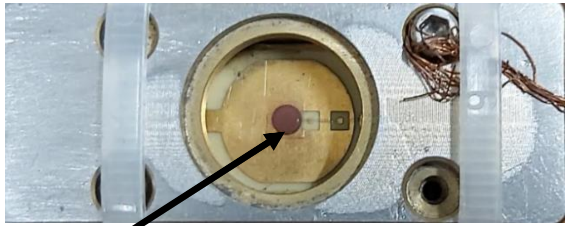
E_k : The kinetic energy of an incident ion.

E_{DD} : The energy derived from the measured electric signal.

50 % of the kinetic energy is not reconstructed: Pulse Height defect !

Pulse Height Defect observation

sCVD diamond detectors
50um thickness
(2mm in diameter)



2 mm in diameter Krakow

The Pulse Height Defect (PHD) :

$$\Delta E = E_k - E_{DD}.$$

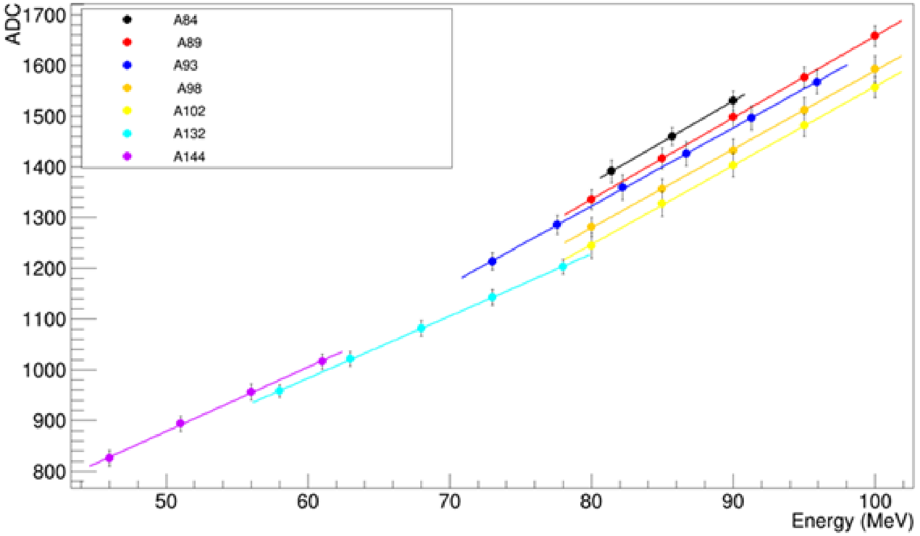
E_k : The kinetic energy of an incident ion.

E_{DD} : The energy derived from the measured electric signal.

- ➔ Reasons of the appearance of PHD were investigated mainly for Si detectors in the past
- ➔ PHD already observed for CVD diamonds : O.Beliuskina et al., Eur. Phys. J A (2017) **53:** 32 and Y. Sato et al., 2013 EPL **104** 22003
- ➔ The main process leading to a pulse-height defect is the incomplete charge collection in the detector.
- ➔ This may arise from various sources, but for heavy ions the main source appears to be the recombination of electron-hole pairs in the plasma bulk produced by the heavily-ionizing particle

Pulse Height Defect analysis

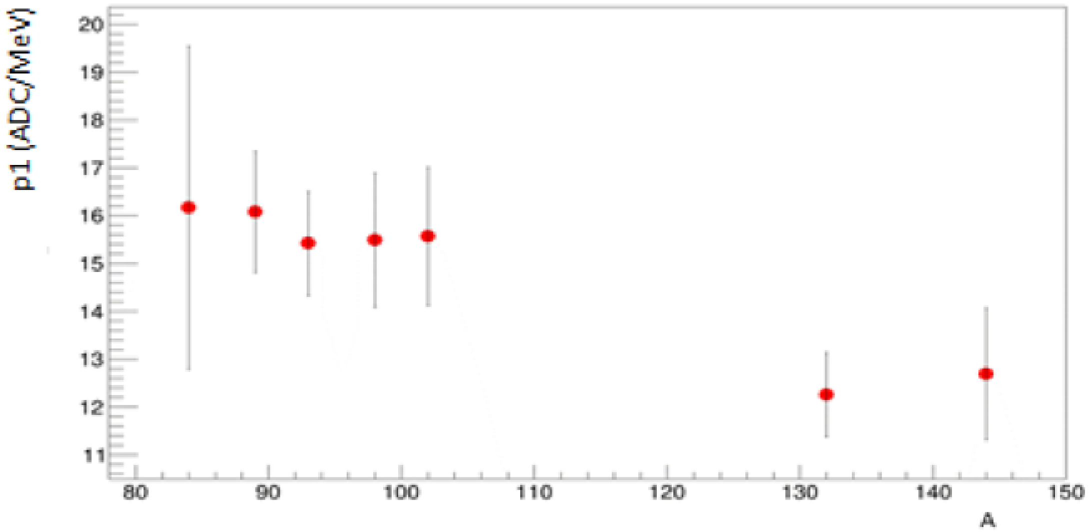
ADC = **P0**+**P1**xE **P0 and P1** fit parameters

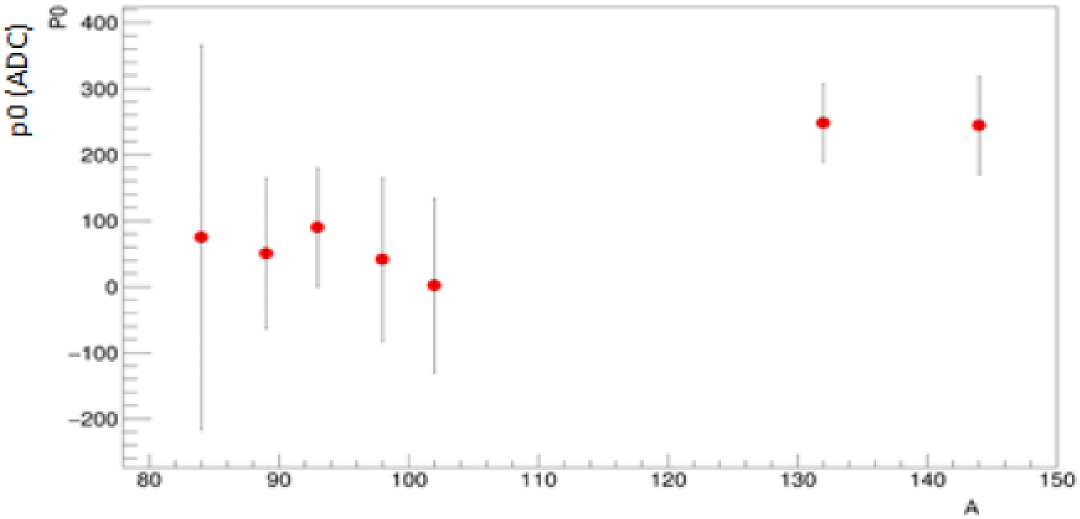


- **P0 and P1** values can be considered as constant values for light FF (respectively heavy FF)

- a difference of a factor of about ~1.2 (measured on p_1) araised between light FF and heavy FF

The ionic mass A (ionic charge Z) of incident FF influences PHD.



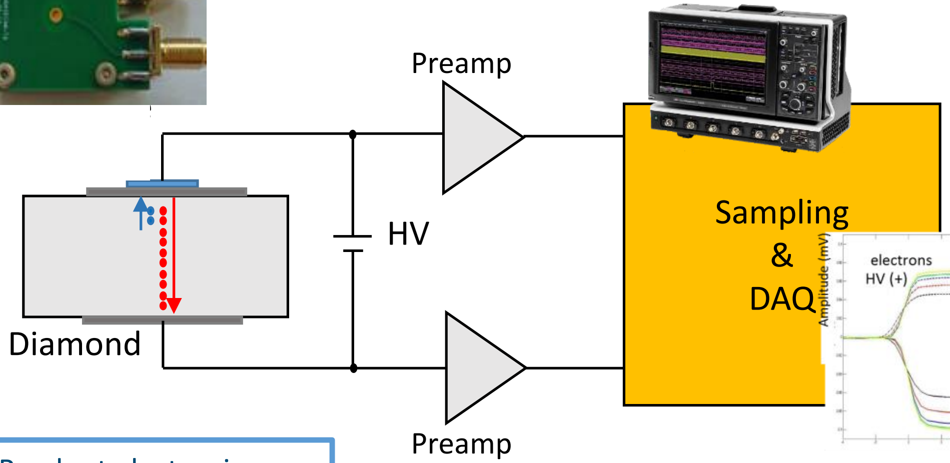


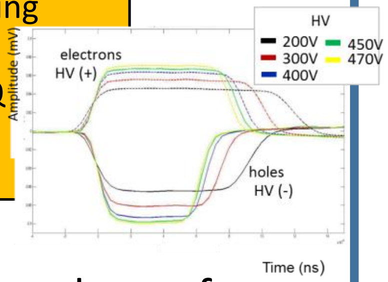
OUTLINES

- **Context : induced fission of Uranium-235**
- **Experimental apparatus : tests of diamond sensors at LOHENGRIN for fission fragment detection**
- **Spectroscopic measurement**
  - Alpha and tritons data analysis
  - Fission Fragment (FF) data analysis
  - Observation of the Pulse Heigh Defect : alpha and triton versus FF data analysis
- **Timing resolution with FF**
- **Conclusion**

Time resolution analysis

WaveRunner Lecroy
2 GHz; 10 or 20 GS/s





signal waveforms

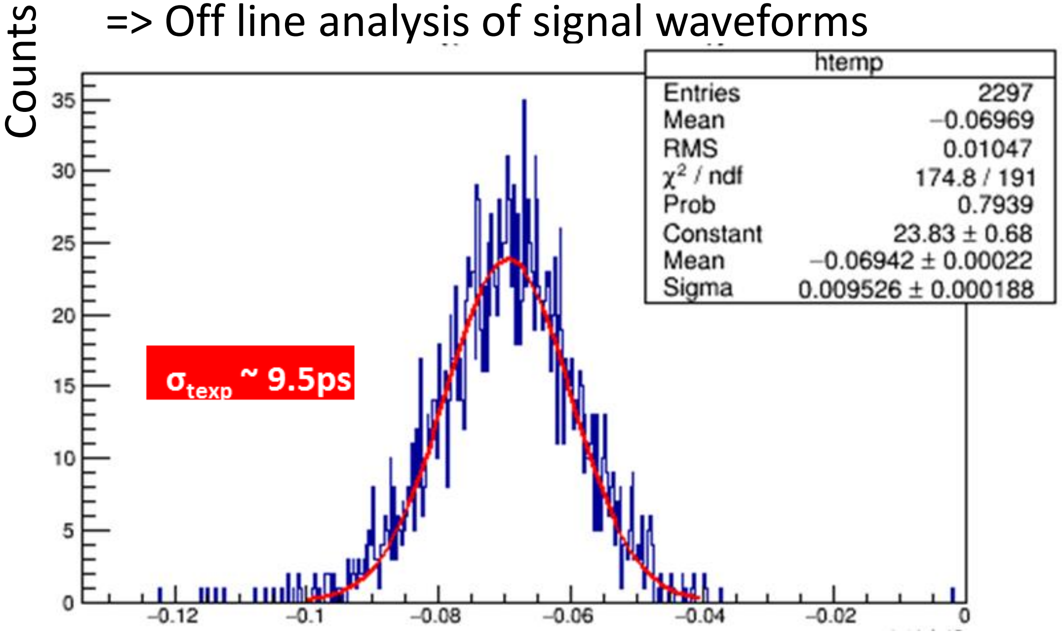
Readout electronics :

2 CIVIDEC current preamplifier

Band Width:	**2 GHz**
Gain:	**40 dB**
Impedance:	**50 Ω**
Dynamic range:	**~ +/- 1 V**
Power Supply:	**12 V / 100 mA**

Difference of the timing of both surface signals

=> Off line analysis of signal waveforms



Time (ns)

Excellent time resolution measured on 90MeV $^{98}_{40}Zr$!

Conclusion

- Single crystal diamond detector exhibit a good fission fragment peaks separation, a good energy resolution around 1.5% and an excellent time resolution ~9.5 ps

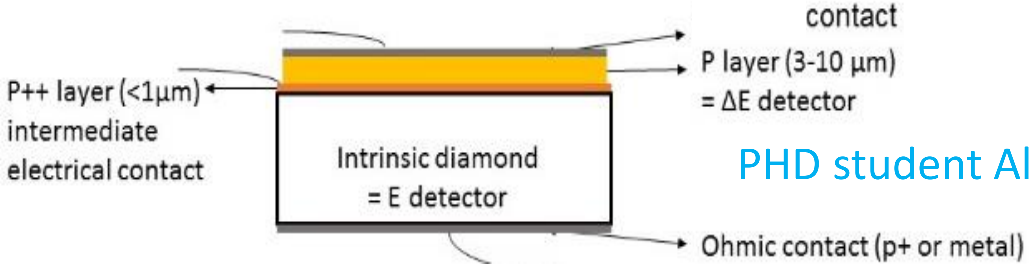
- Single crystal diamond detector can be a good alternative to ionization chamber in detecting fission fragment.

- Single crystal detector is affected by pulse height defect which lead to a loss of almost 50% of the initial signal and this is independent from the thickness but is dependent on the ionic mass A (or ionic charge Z) !

Perspectives

Design of a monolithic diamond ΔE-E telescope

Collaboration LPSC Grenoble**, Institut Néel** Grenoble , **Diamfab** Grenoble



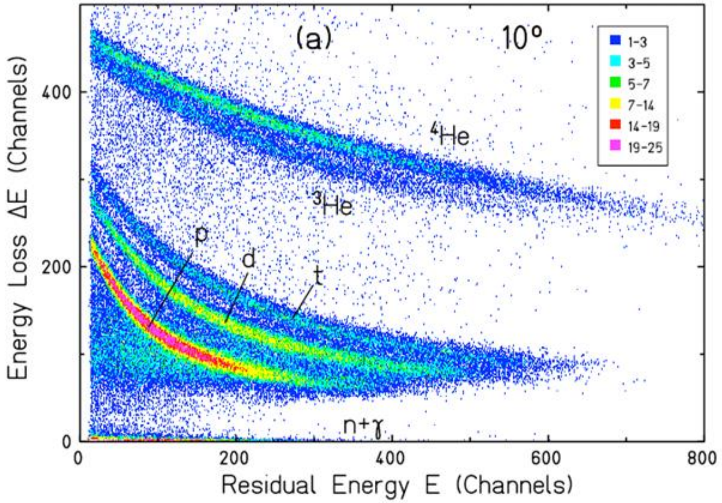
PHD student Alexandre Portier

DiamFab ➔ CVD process of a good quality epitaxial diamond layer with a good-controlled boron doping concentration

- This detector relies commercial diamond substrates.
- On the top side, a few µm-thick metal contact with a stack of highly doped layer (allowing metallic conduction)
- Lightly doped layer will be designed to collect charges induced by the incident particle with a good time resolution.
- On the back side, a second metallic contact will be deposited.

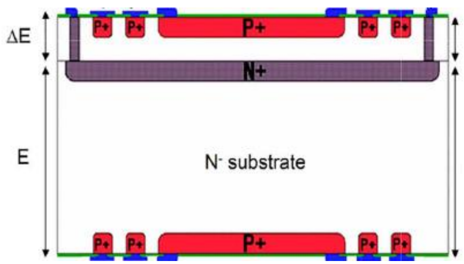
^{12}C 200 MeV/u ions Gunzert-Marx 2008

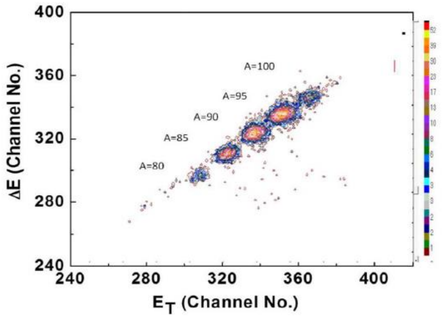
$\Delta E \sim Q^2/v^2$



E ~ A

Fission fragments (ILL-Lohengrin)
Singh 2014



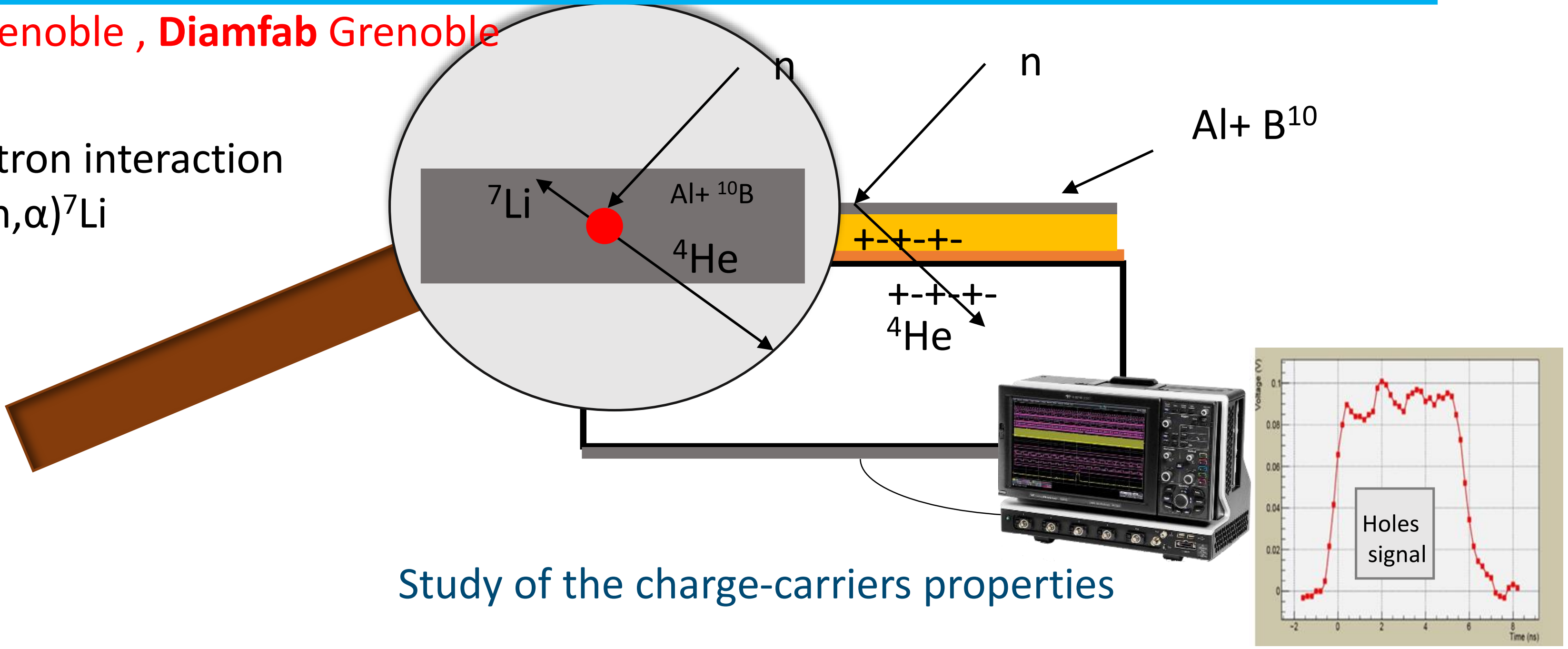


Foreseen application of the diamond ΔE-E telescope to particle detection

Collaboration LPSC Grenoble, **Institut Néel** Grenoble , **Diamfab** Grenoble

- neutron detection
  - → provided a converter layer like boron-10 be deposited on the top of the proposed ΔE–E detector

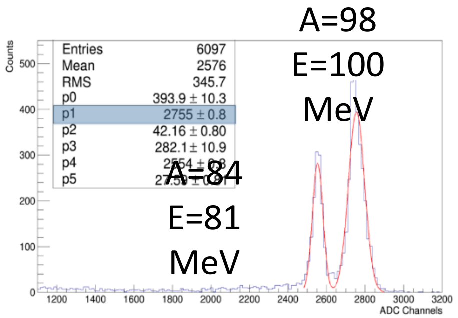
Neutron interaction
$^{10}B(n,\alpha)^{7}Li$

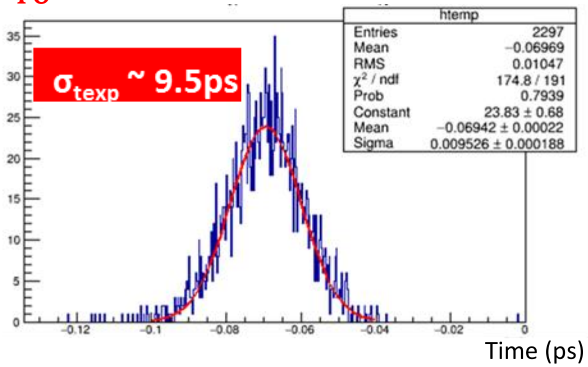


Study of the charge-carriers properties

- ILL fission fragments detection
  - → Identification and timing measurement of Fission Fragments with the Lohengrin mass spectrometer

90MeV $^{98}_{40}Zr$





Acknowledgements

NEUTRONS FOR SCIENCE

The authors would like to acknowledge the ILL for providing un access to the LOHENGRIN experiment

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

irfu

cea

saclay

Dominique Breton from the Laboratoire de l'Accélérateur Linéaire and **Eric Delagnes** from CEA Saclay are thanked for their implication in dedicated software development and technical support of the namely "wavecatcher" data acquisition system.