Neutron Diagnostics
GSI, 15.12.2016

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CIVIDEC Instrumentation

Outline

- Neutron signatures in sCVD diamond
- Signal analysis in real-time
- Applications

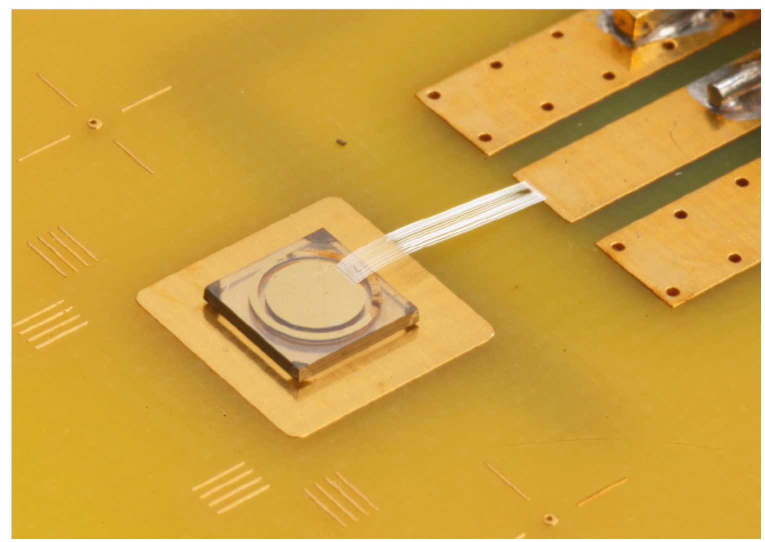
cividec Instrumentation

Diamond Detectors

Synthetic chemical vapor deposition diamond:

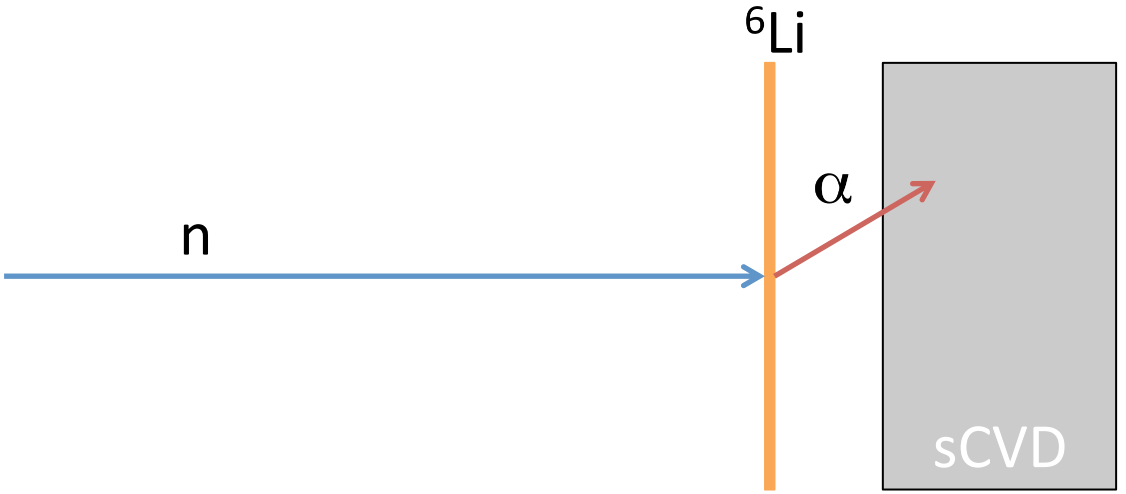
- Solid-state detector.
- Little impurities (N < 5 ppb, B < 3 ppb).
- Thermal robust.
- Radiation hard.

Uniquely suited for diagnostics in rough environments like fission and fusion reactors.



Detecting neutrons with diamond detectors

Thermal neutrons



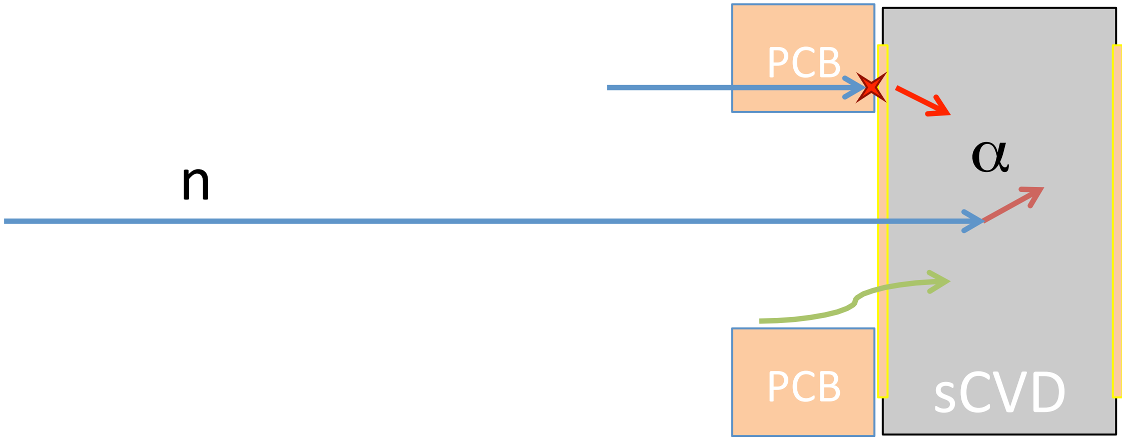
External converter needed: ^{6}Li, ^{10}B, ^{235}U, …

Fast neutrons

Diamond sensor serves as neutron converter.

Background considerations

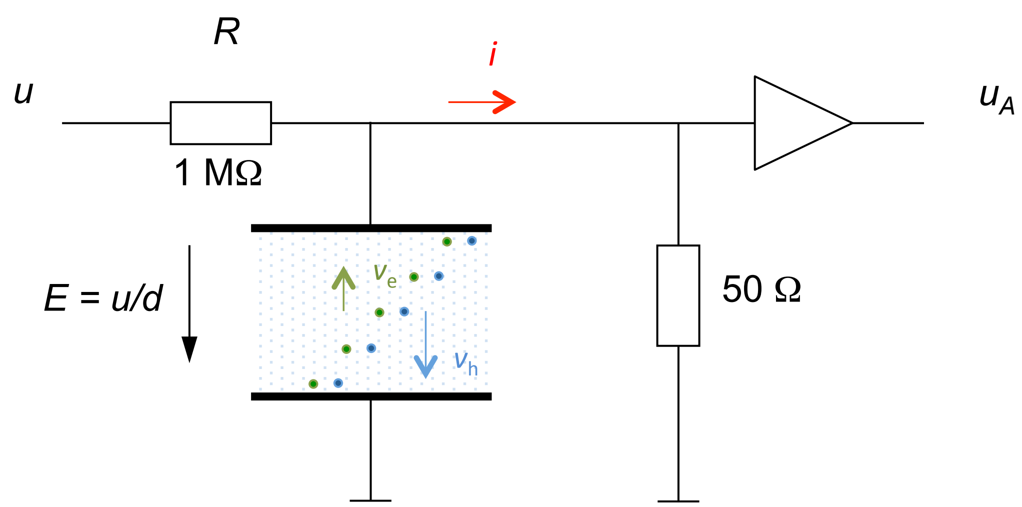
- Neutron interactions in surrounding materials (n,γ), (n,p), (n,a), …
- In-beam γ from the neutron source.
- …



Background often dominating -> should be minimized or even rejected!

Current signals in sCVD diamond

Equivalent circuit diagram

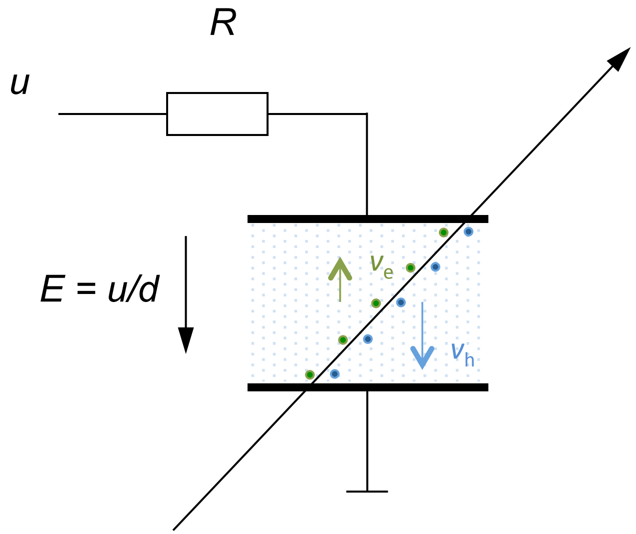


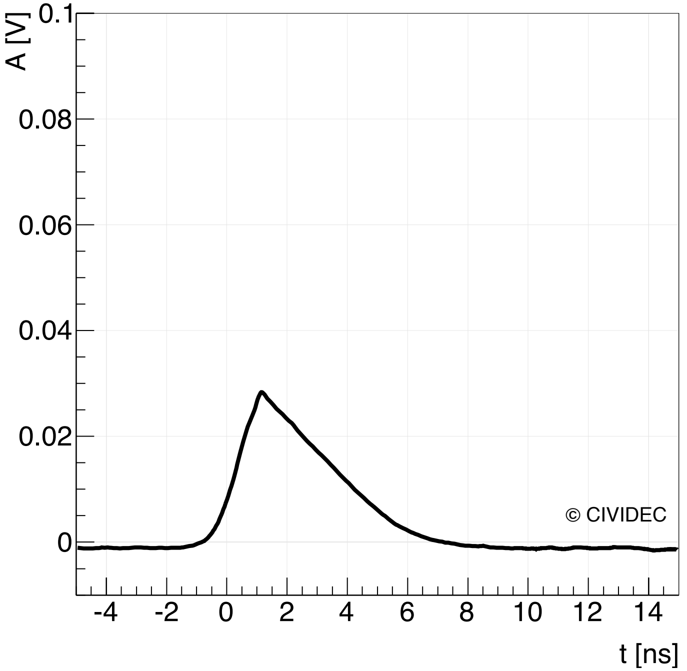
Schockley-Ramo Theorem

$$I = q \cdot \frac{v_{drift}}{d}$$

Signal shapes in sCVD

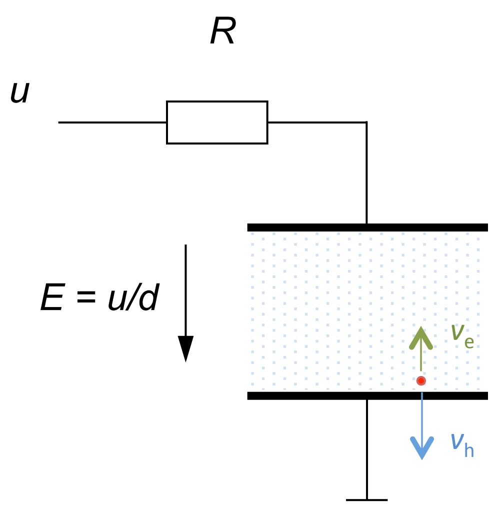
Homogeneous ionization (MIP, γ):

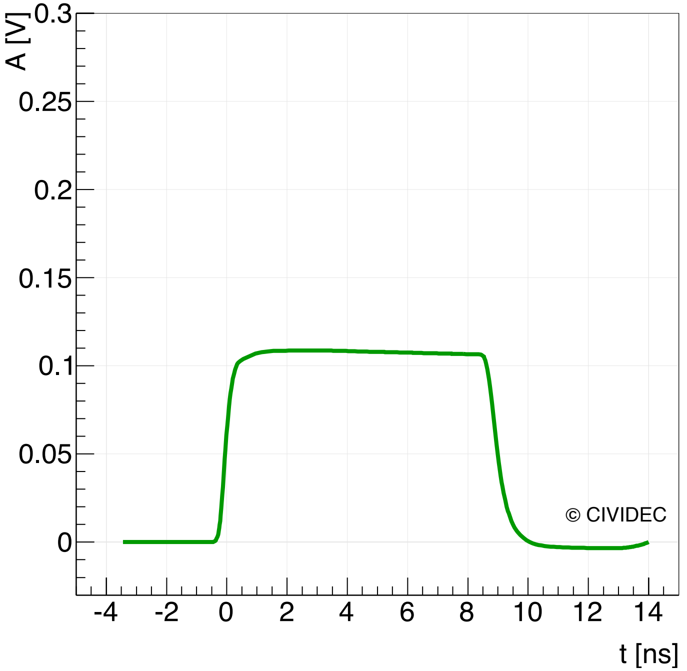




Signal shapes in sCVD

Point-like ionization:





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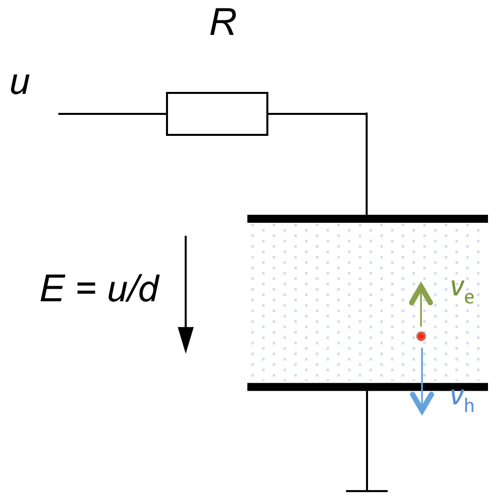

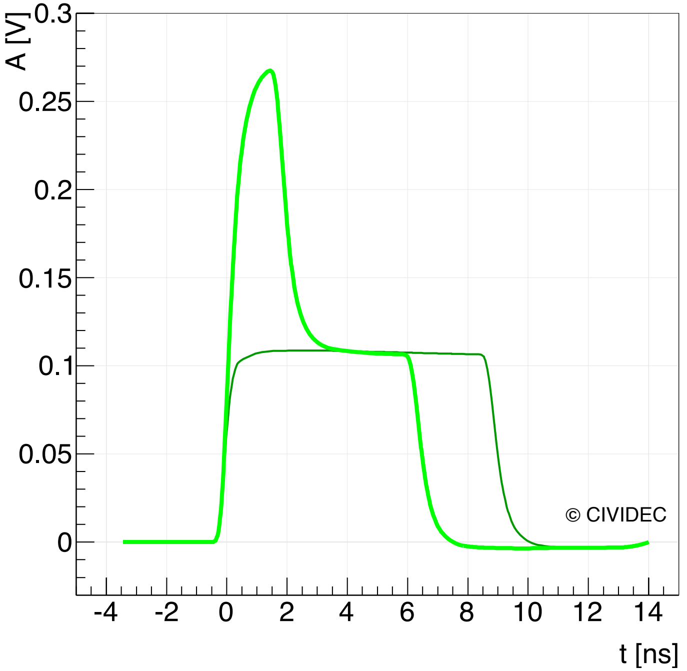

Signal shapes in sCVD

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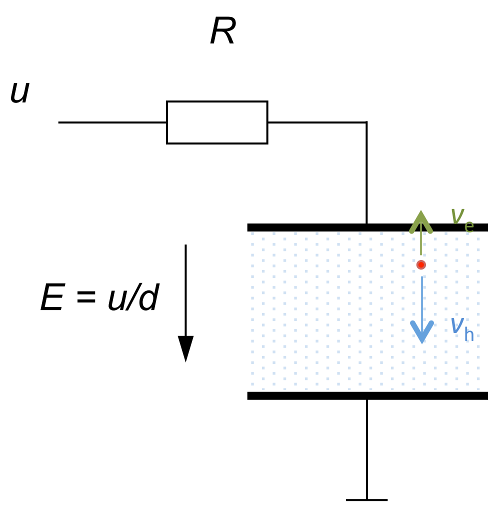
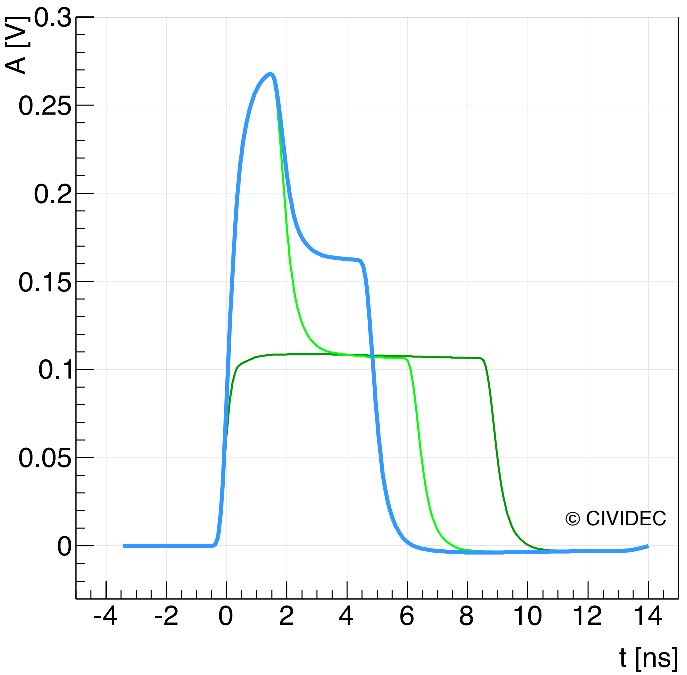
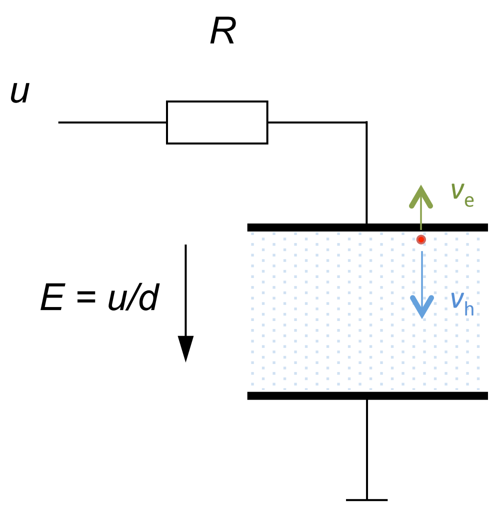
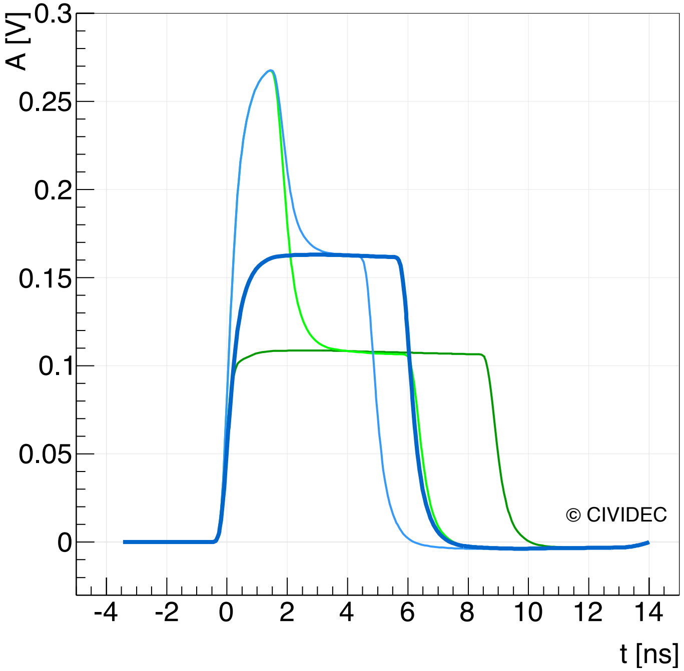




Signal shapes in sCVD

Point-like ionization:





Signal shapes in sCVD

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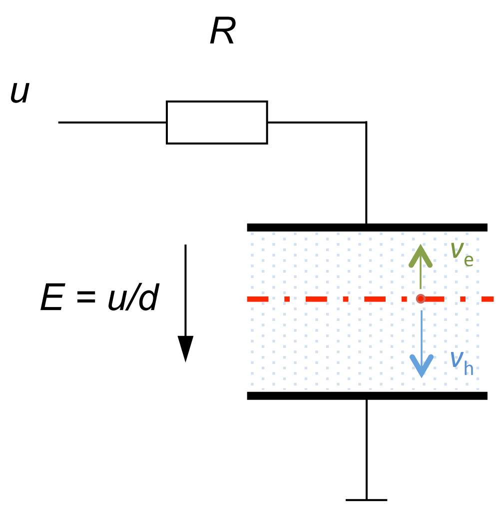
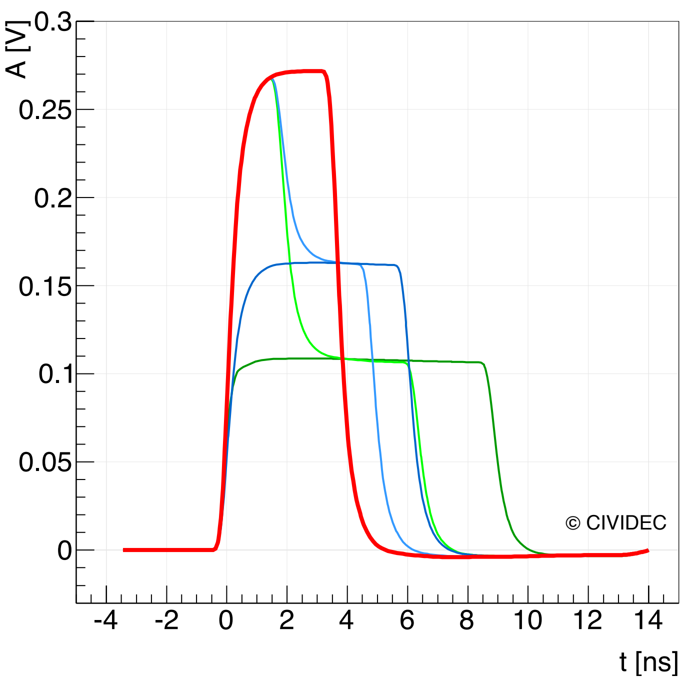
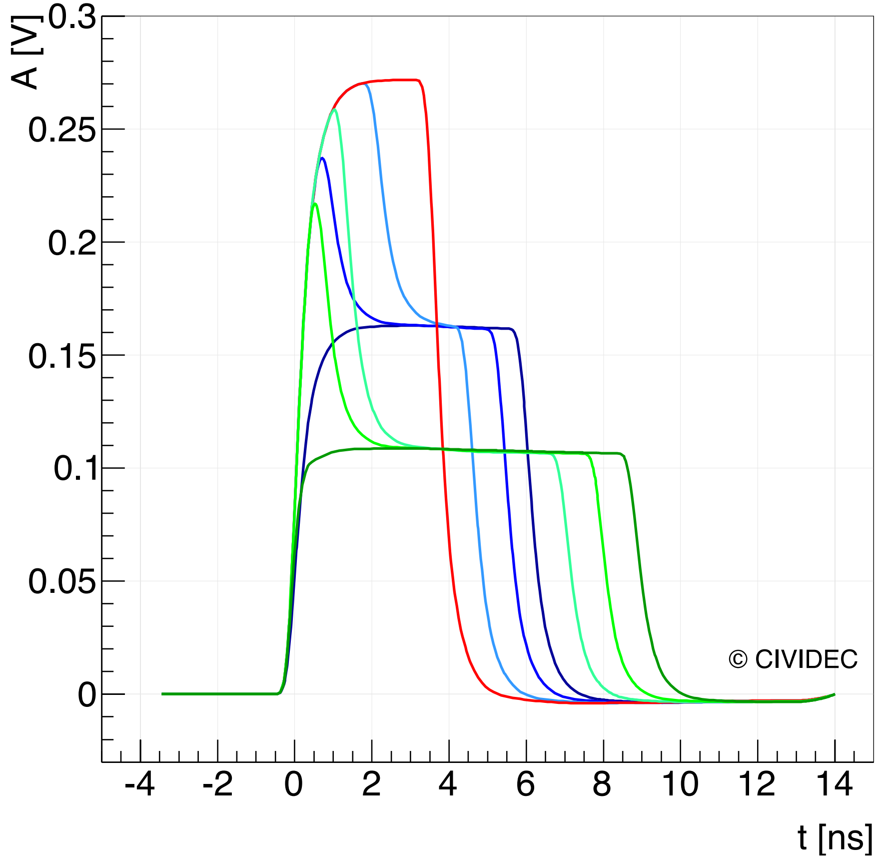


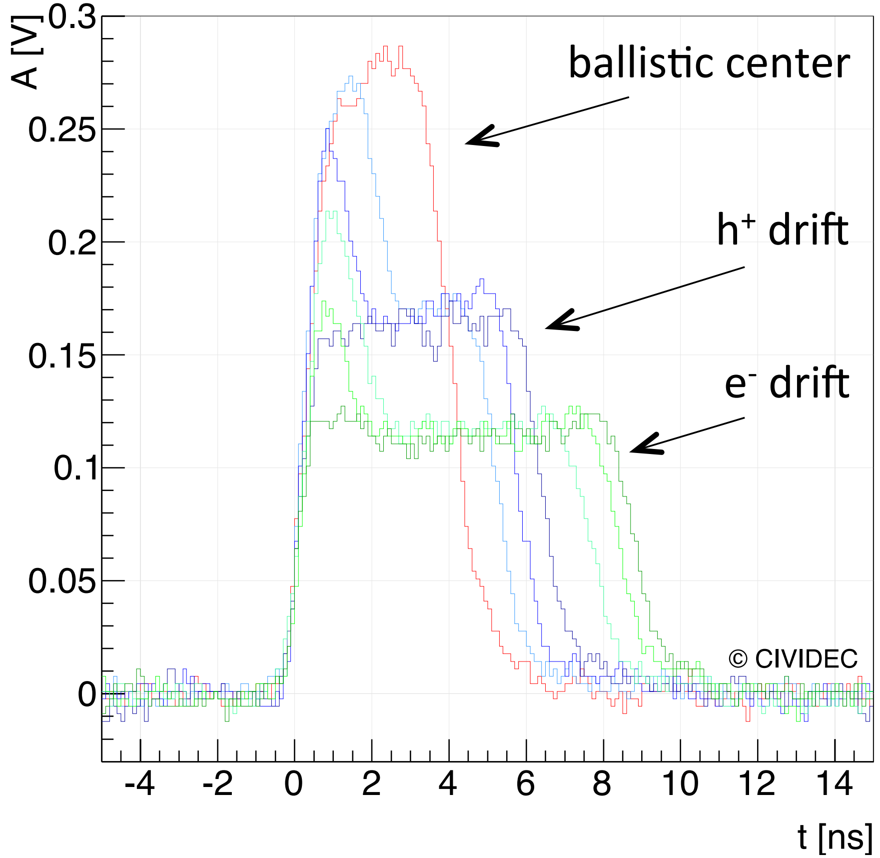


New definition:
Ballistic Centre
$t_{d,h} = t_{d,e}$

Simulation: point-like ionization



Experiment: point-like ionization



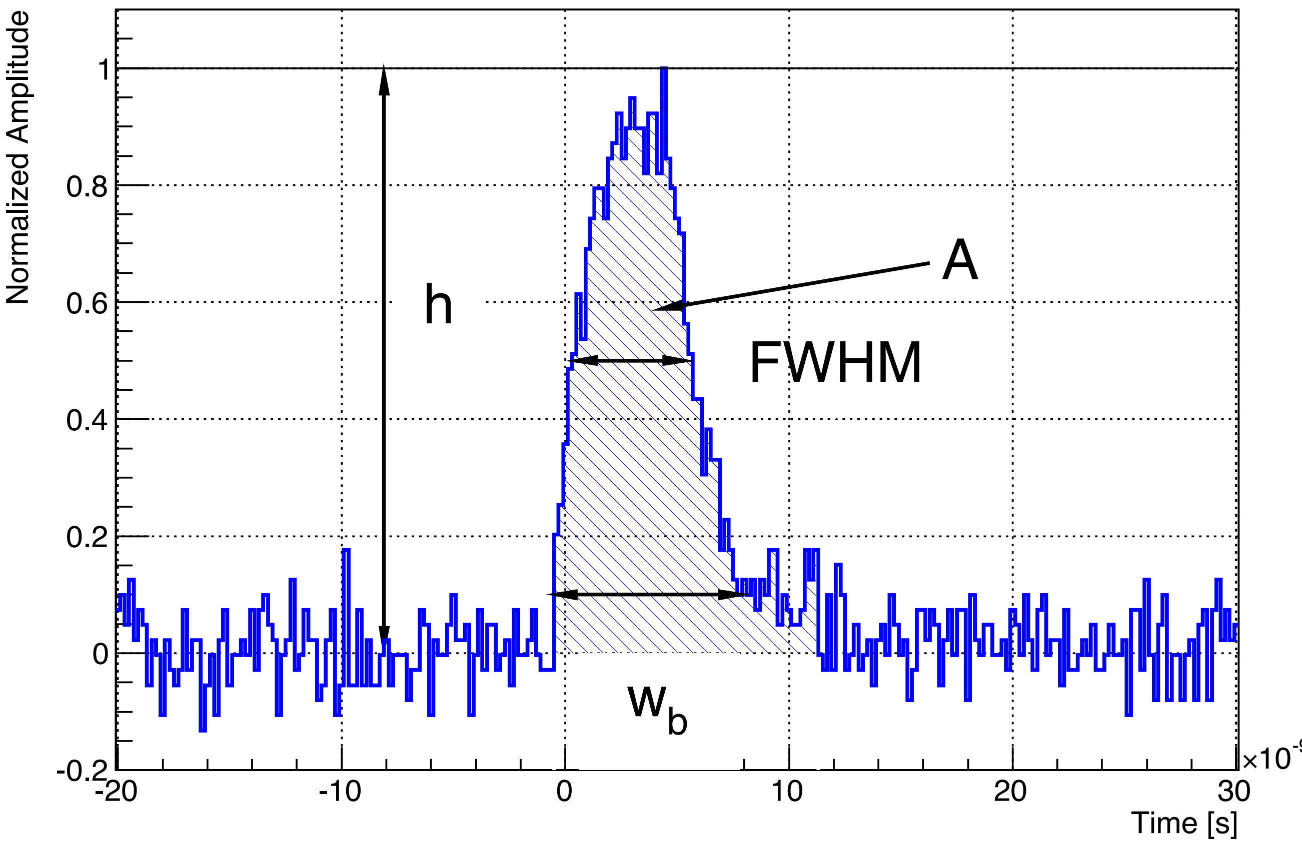
Requirements

1. sCVD diamond sensor.
2. RF-shielded detector design.
3. Low detector capacitance (RC time constant).
4. 2 GHz Broadband Amplifier.
5. Real-time data acquisition and analysis.

With these ingredients, background reactions to neutron measurements can be rejected.

Signal analysis

Parameters

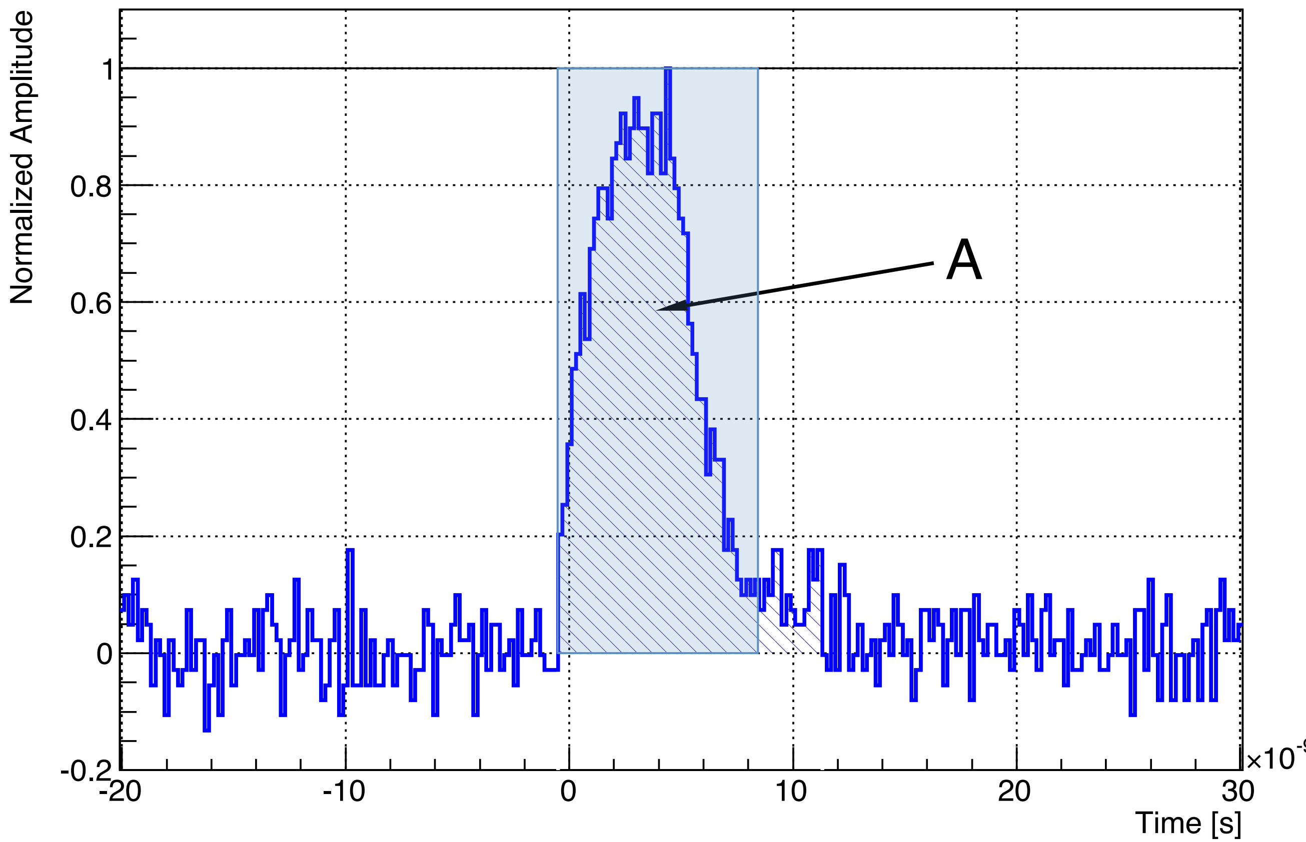


Normalized Amplitude
1
0.8
0.6
0.4
0.2
0
-0.2
-20
-10
0
10
20
30
×10-9
Time [s]
h
A
FWHM
w_b

Selection criteria

Parameter	***Information***
Area A	Deposited energy in the detector
Base width w_b	Drift time
FWHM	Signal shape and drift time (if no high-energy neutrons)
Form factor F	Signal shape

Form-factor



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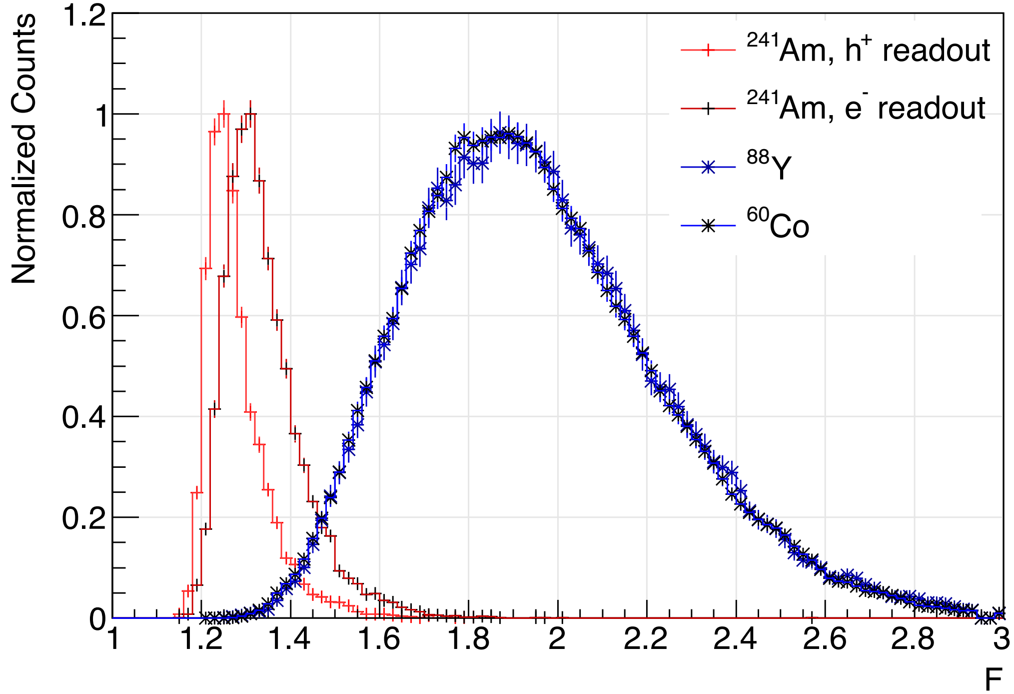
-10
0
10
20
30
×10-9
Time [s]
A

Distinguishing by shape

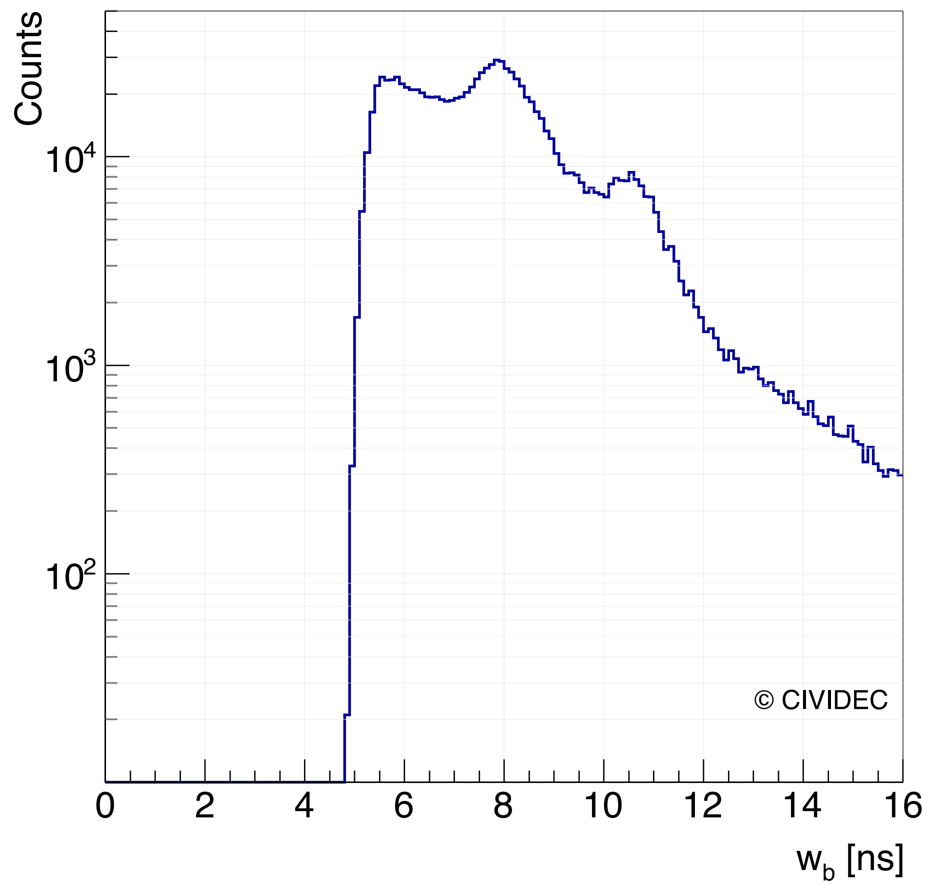
- Form-factor $$F = \frac{calculated\ area}{measured\ area} = \frac{h \cdot w_b}{A}$$

Rectangles: $F = 1$

Triangles: $F = 2$

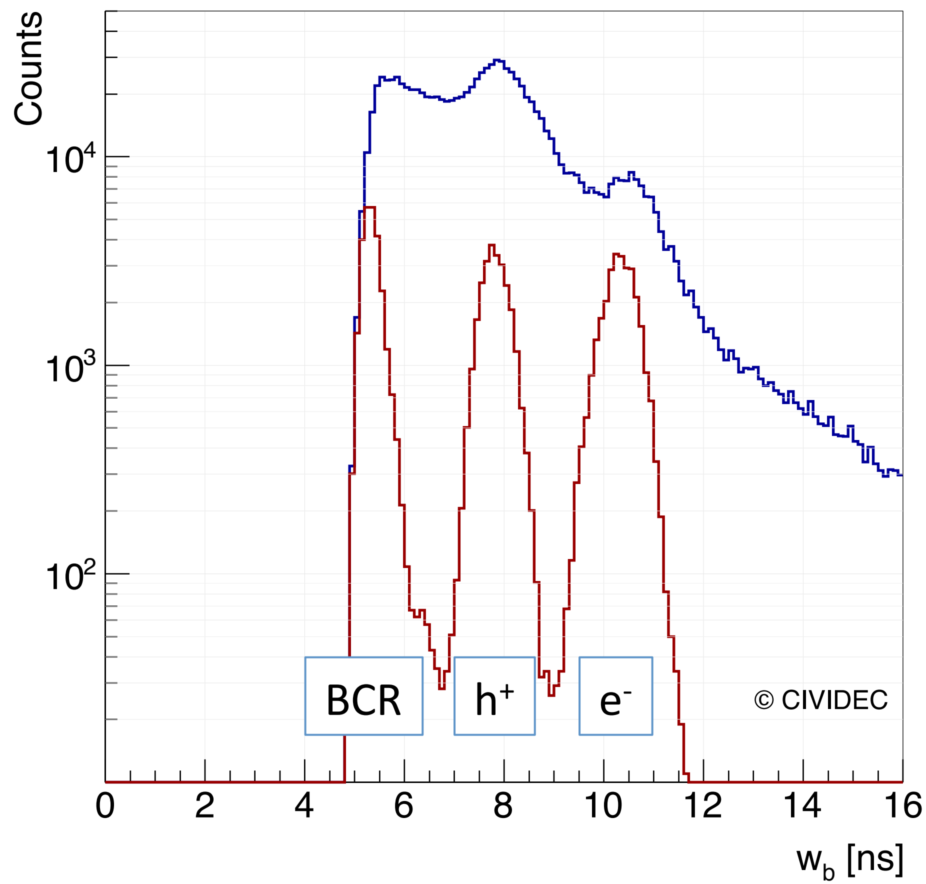


Distinguishing by drift time



- Measurement with 14 MeV neutrons

Distinguishing by drift time



- Measurement with 14 MeV neutrons
- Selection criteria F < 1.4

Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)

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1. Thermal neutrons
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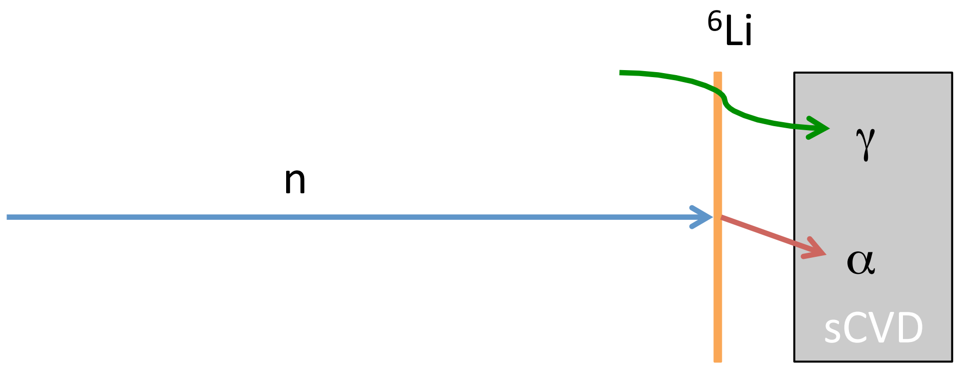
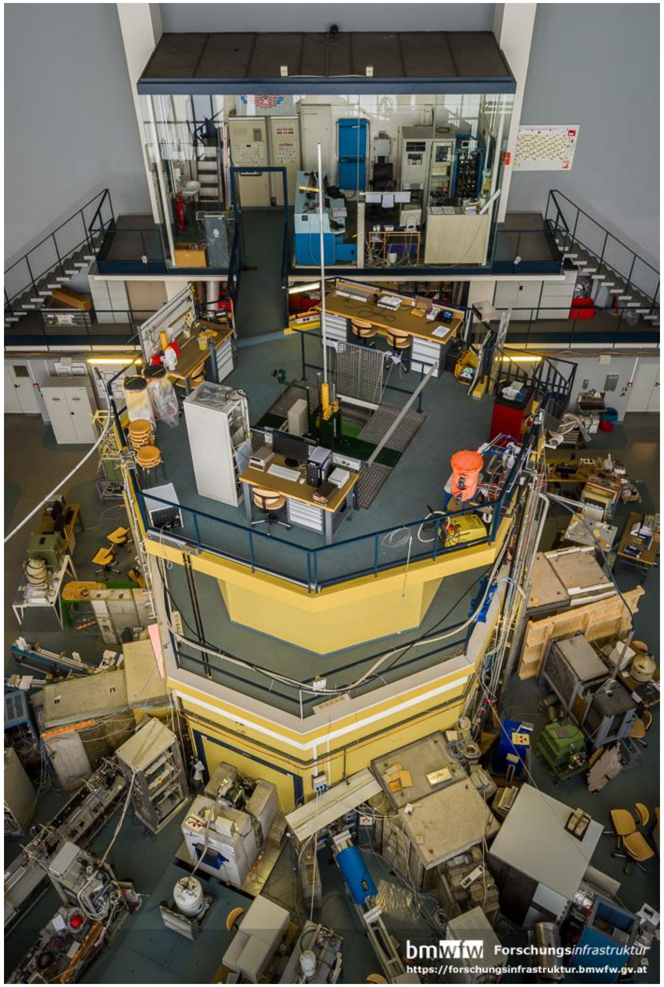
ATI, Vienna, Austria

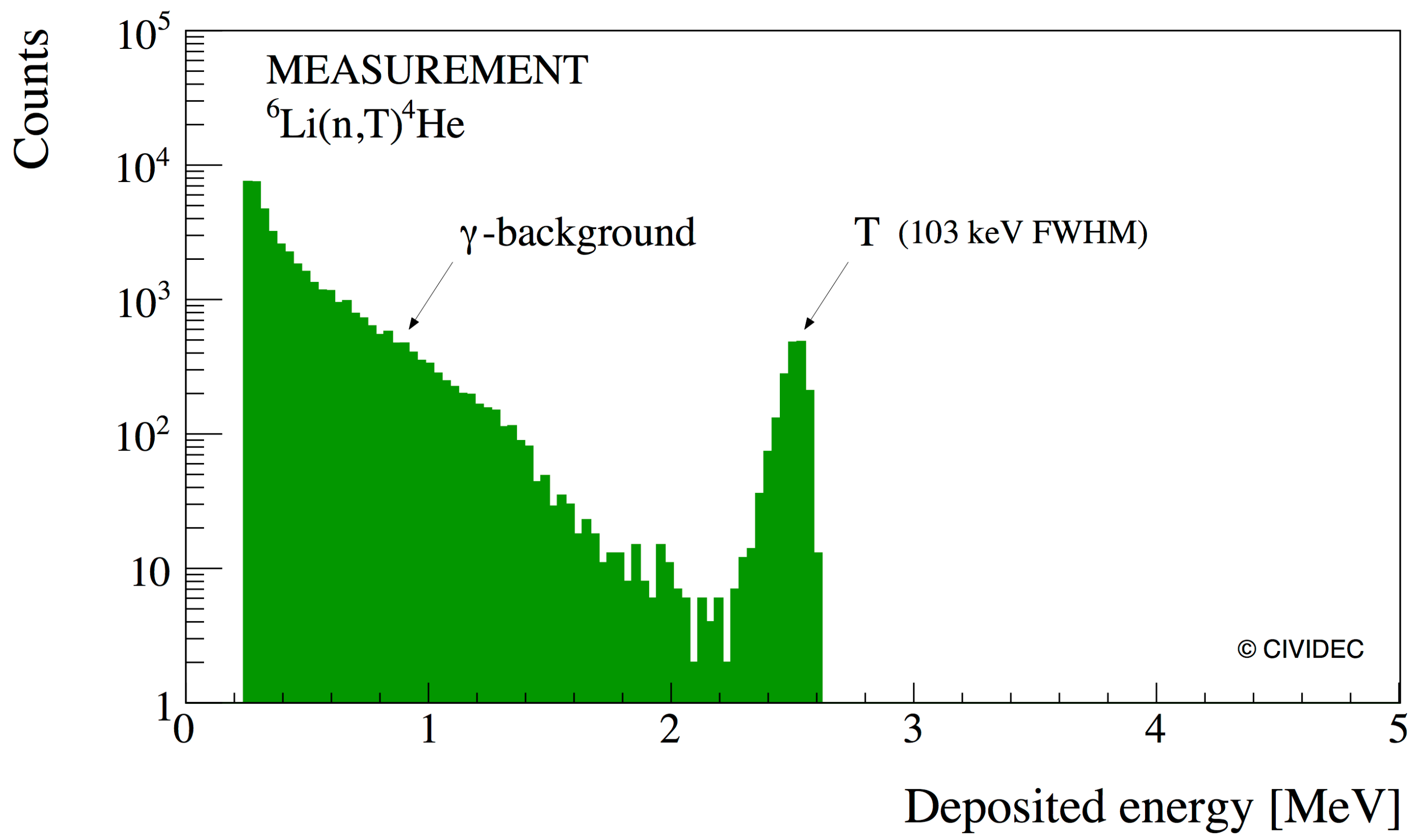
- Measurement at a thermal neutron beam line at the TRIGA Mark-II reaction.
- ^{6}Li converter for thermal neutron conversion.
- High γ-background.





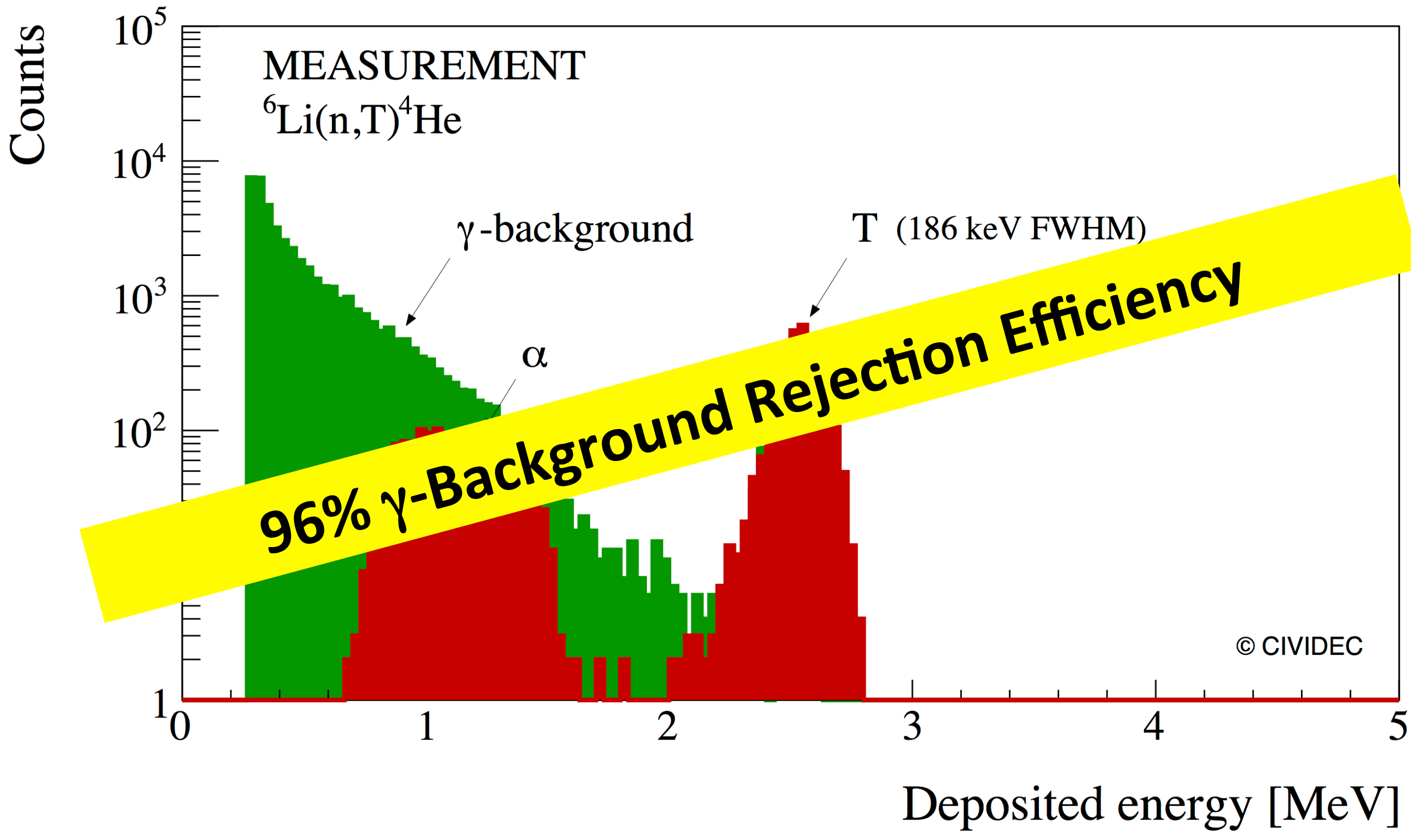
Recorded spectrum without PSA

Ref: P. Kavrigin et al., NIMA 795, 88-91 (2015).



Selecting the relevant signals

Ref: P. Kavrigin et al., NIMA 795, 88-91 (2015).

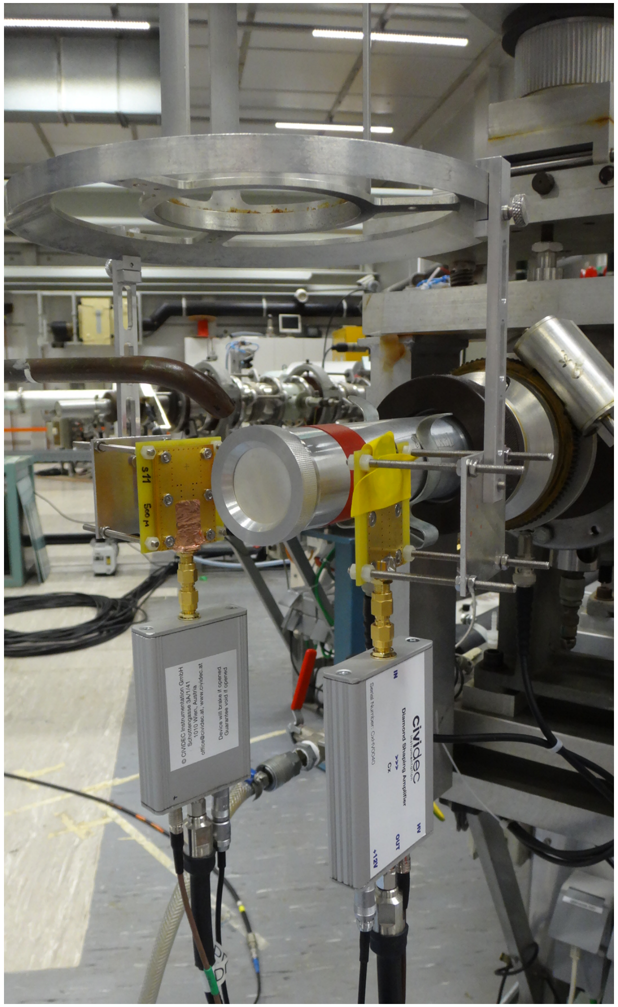


Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)

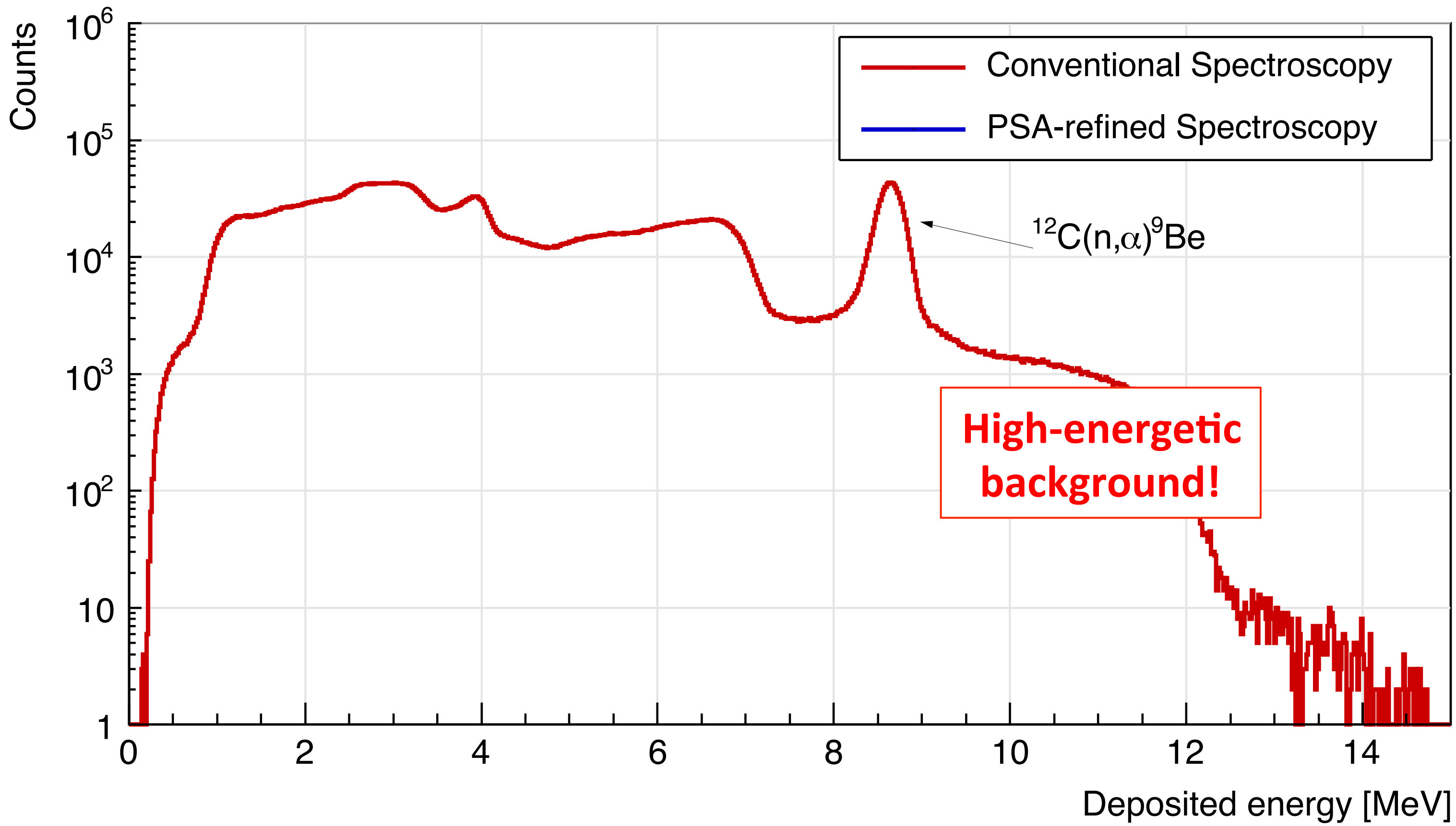
EC-JRC, Geel, Belgium

- Measurement at the Van de Graaff accelerator of EC-JRC in mono-energetic neutron beam.
- sCVD sensor used as converter.
- Proton recoil background.



Measurement of 14.3 MeV neutrons

Ref: P. Kavrigin et al., Eur. Phys. J. A 52, 179 (2016).



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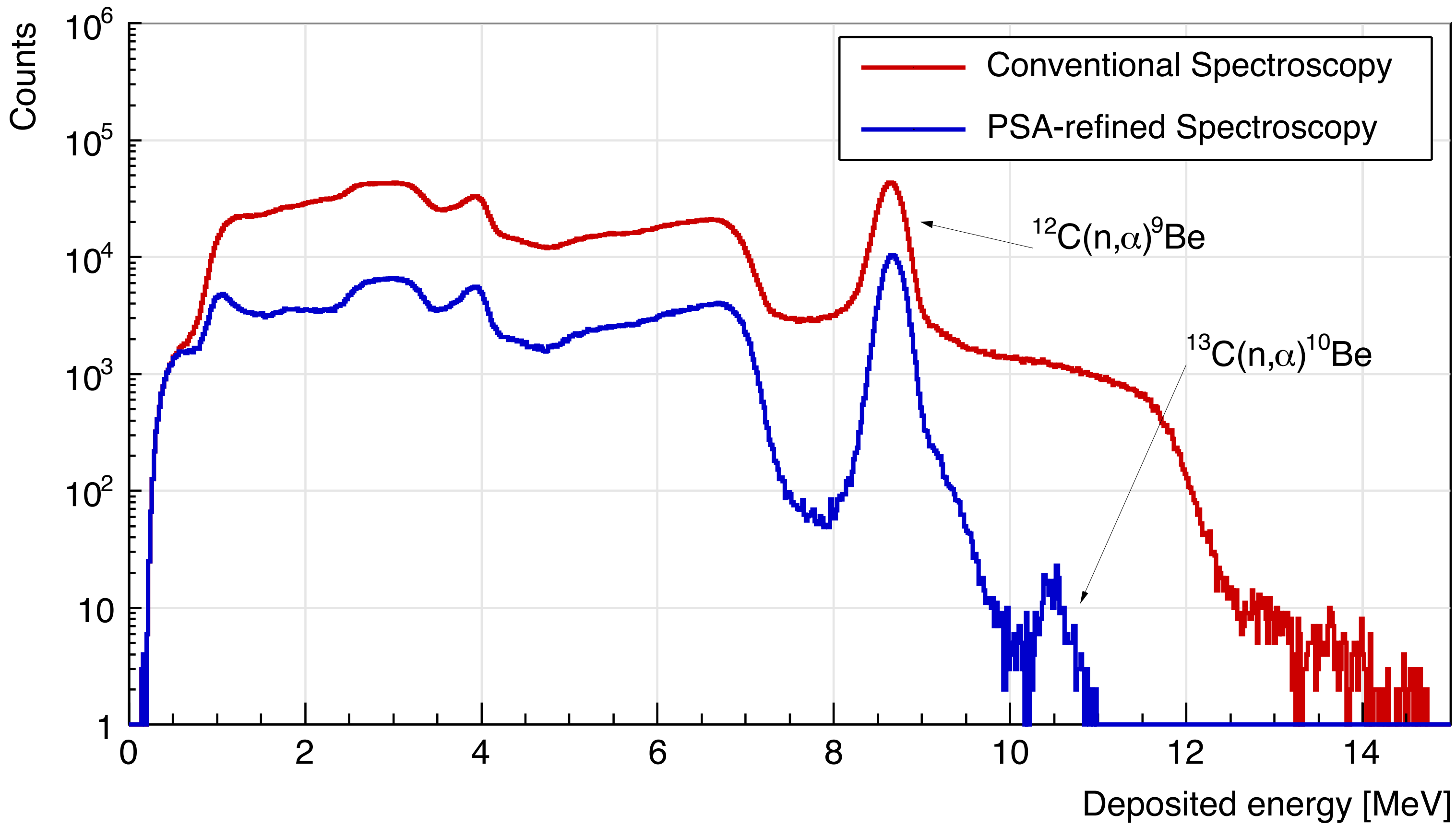

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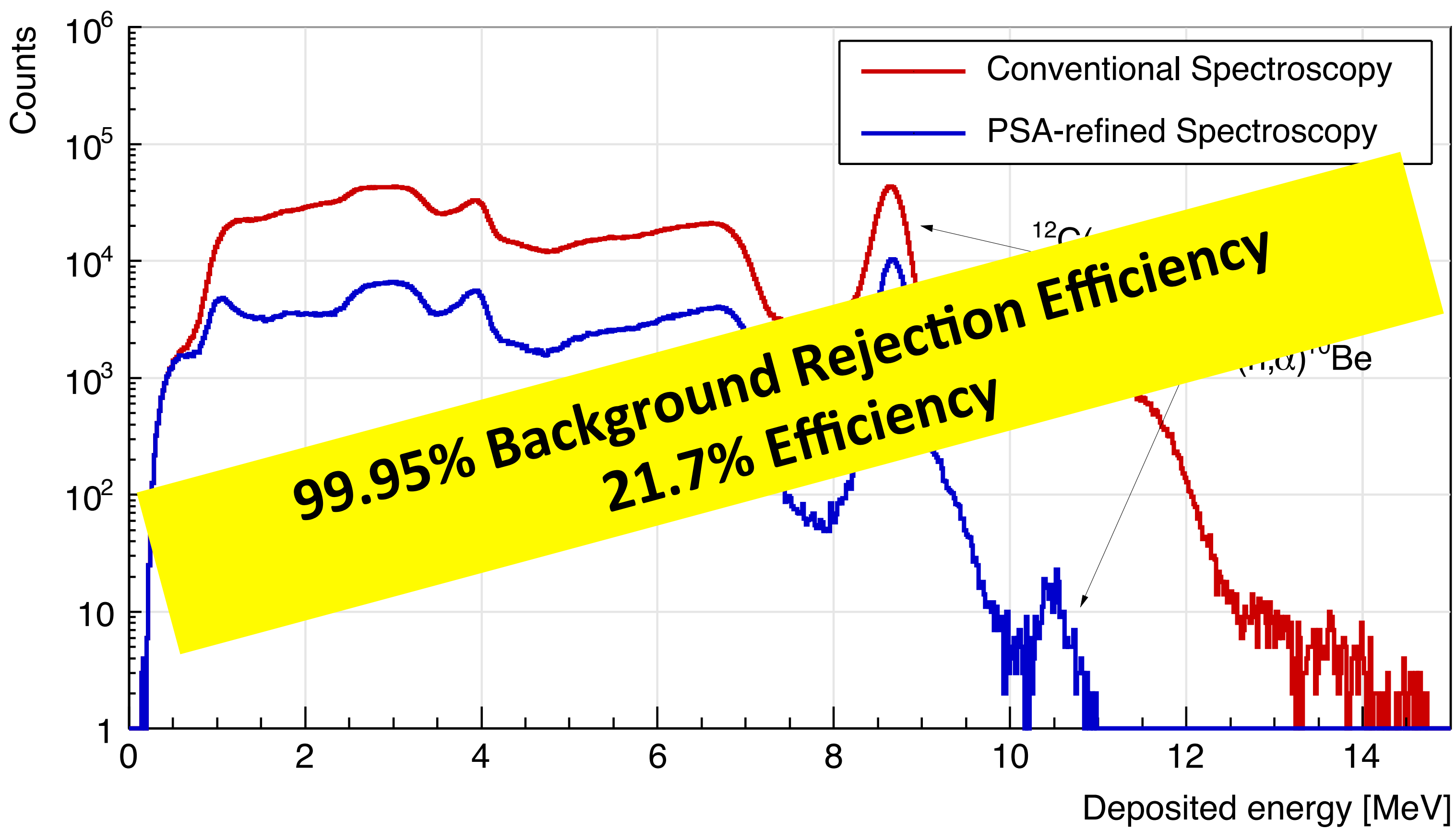


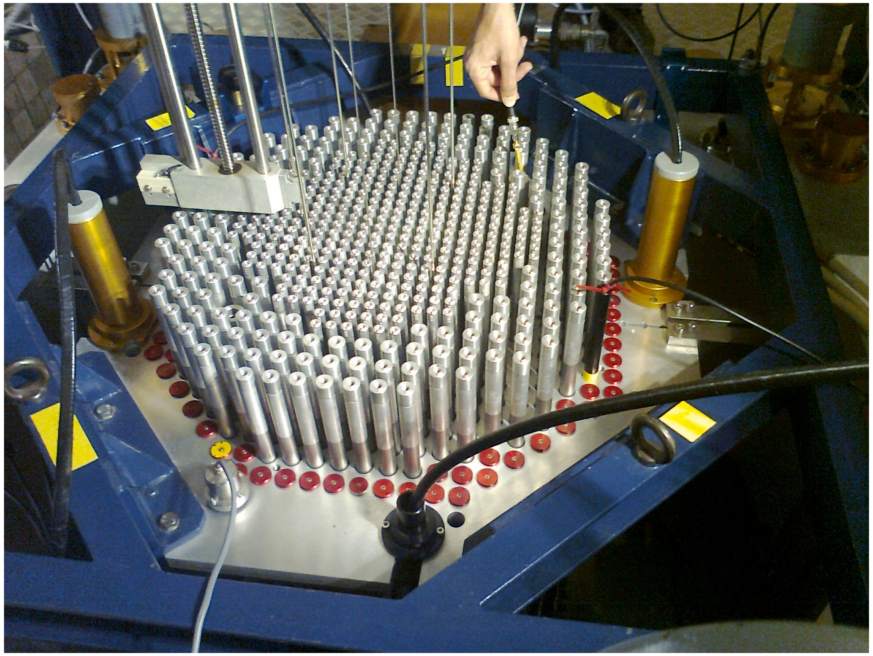
Three application examples:

1. Thermal neutrons
2. Fast neutrons
3. Mixed field (reactor core)

EPFL Lausanne, Switzerland

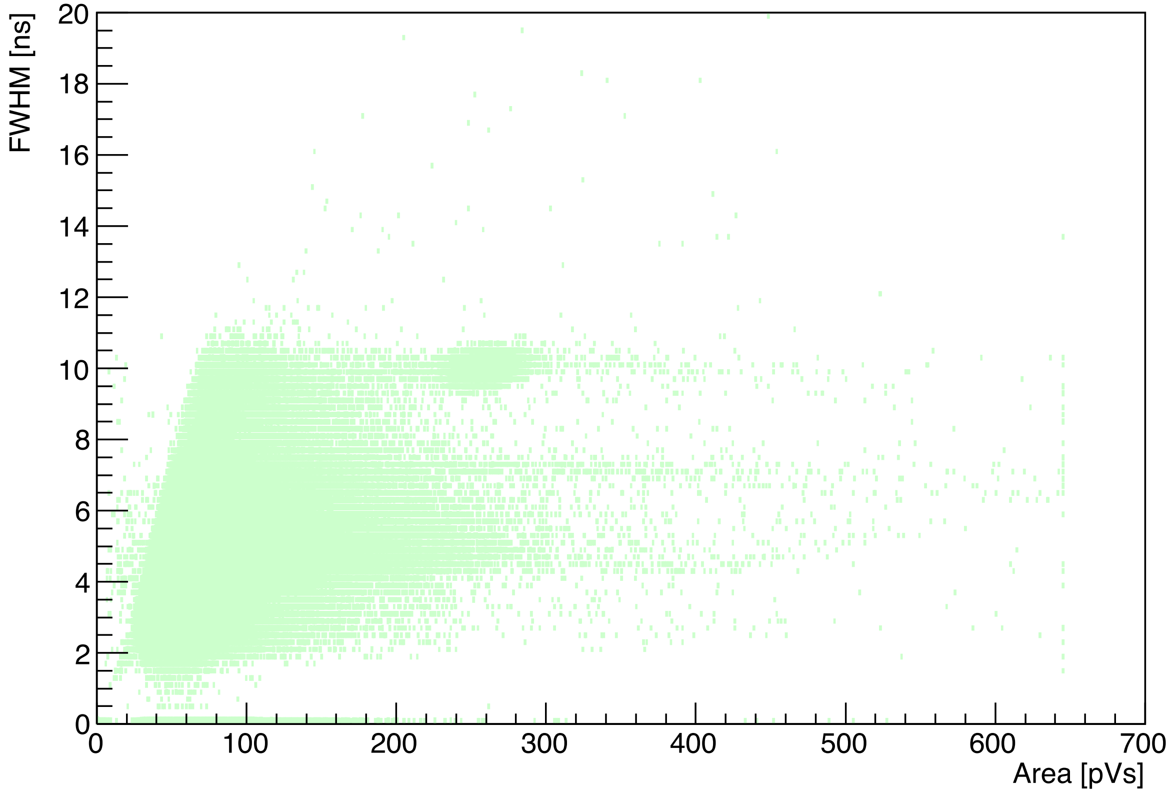
- sCVD Diamond + ^{6}Li neutron converter.
- In the core of the thermal reactor CROCUS.

- n-γ discrimination?
- Can the fast neutrons be identified?



Total Spectrum

Ref: M. Cerv, Ph.D. thesis, Vienna University of Technology (under preparation).



Photons

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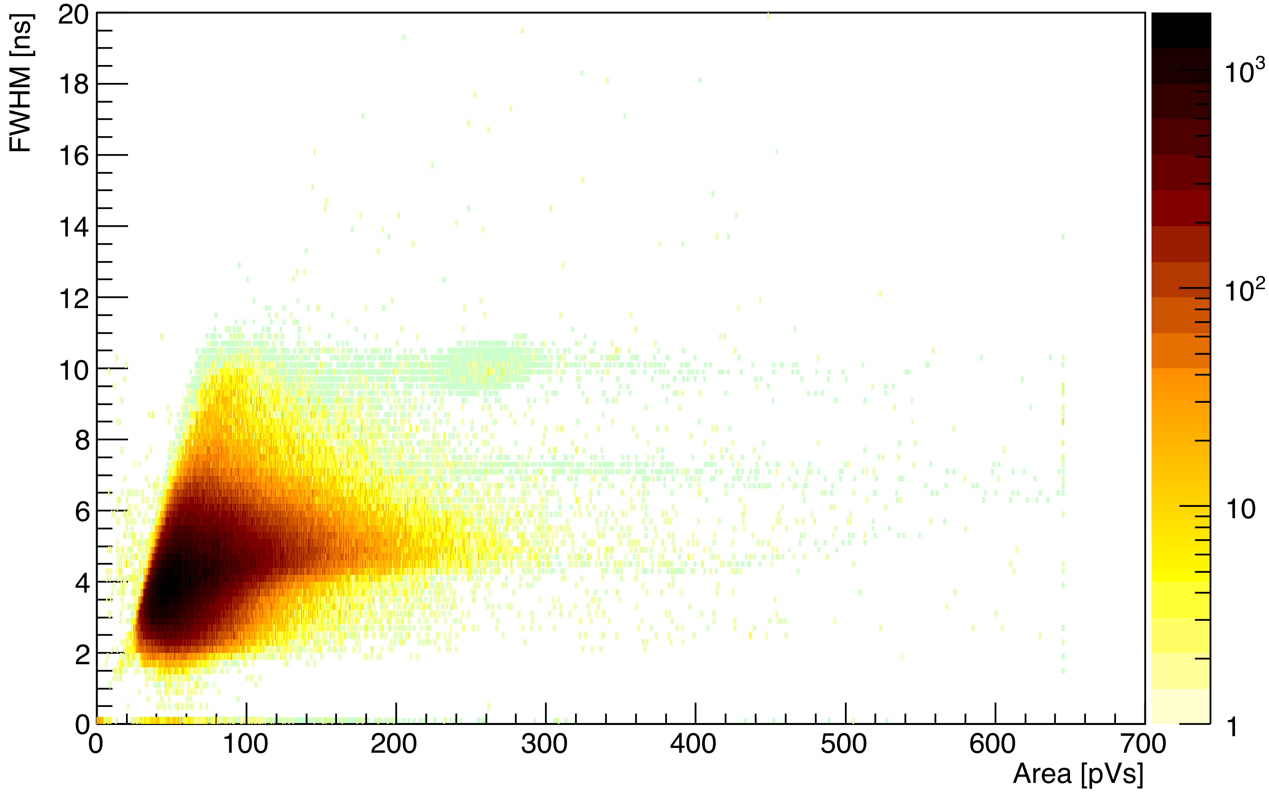

$^{6}Li(n,\alpha)^{3}H$

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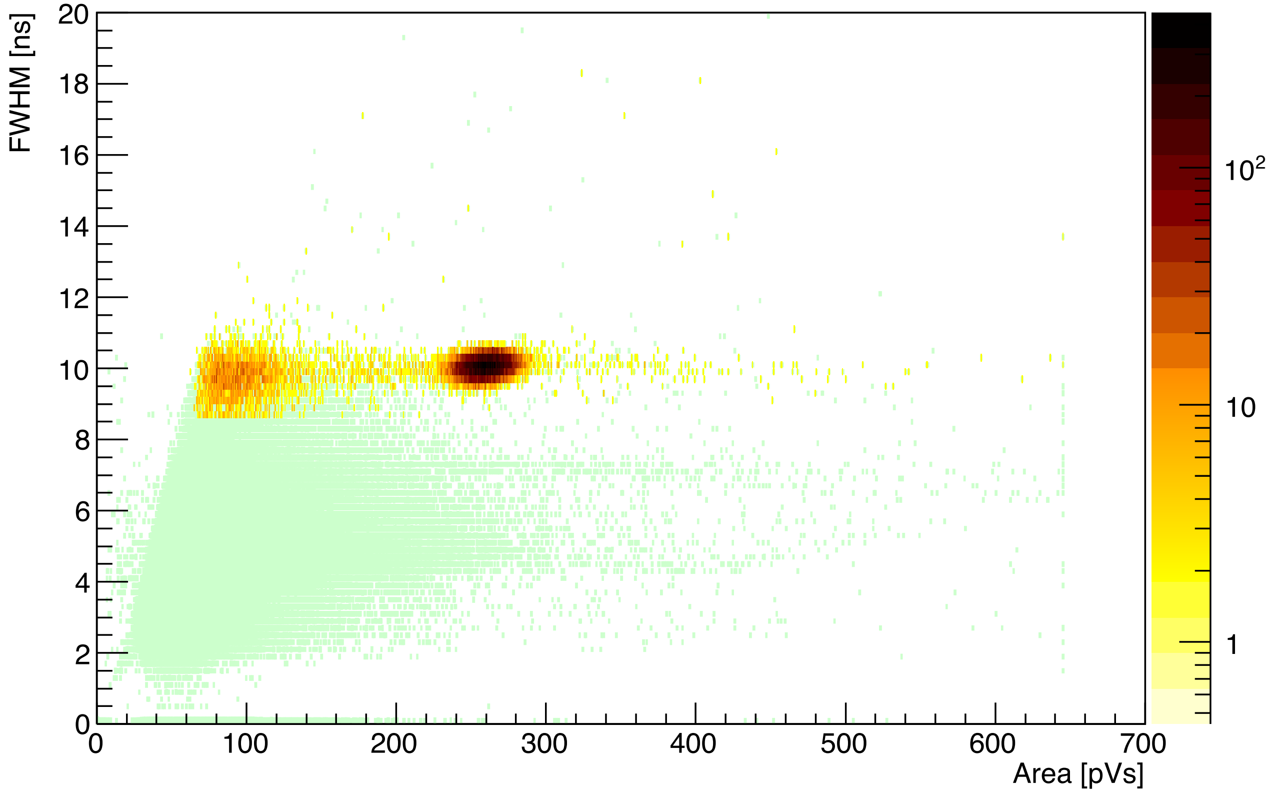

Fast Neutrons

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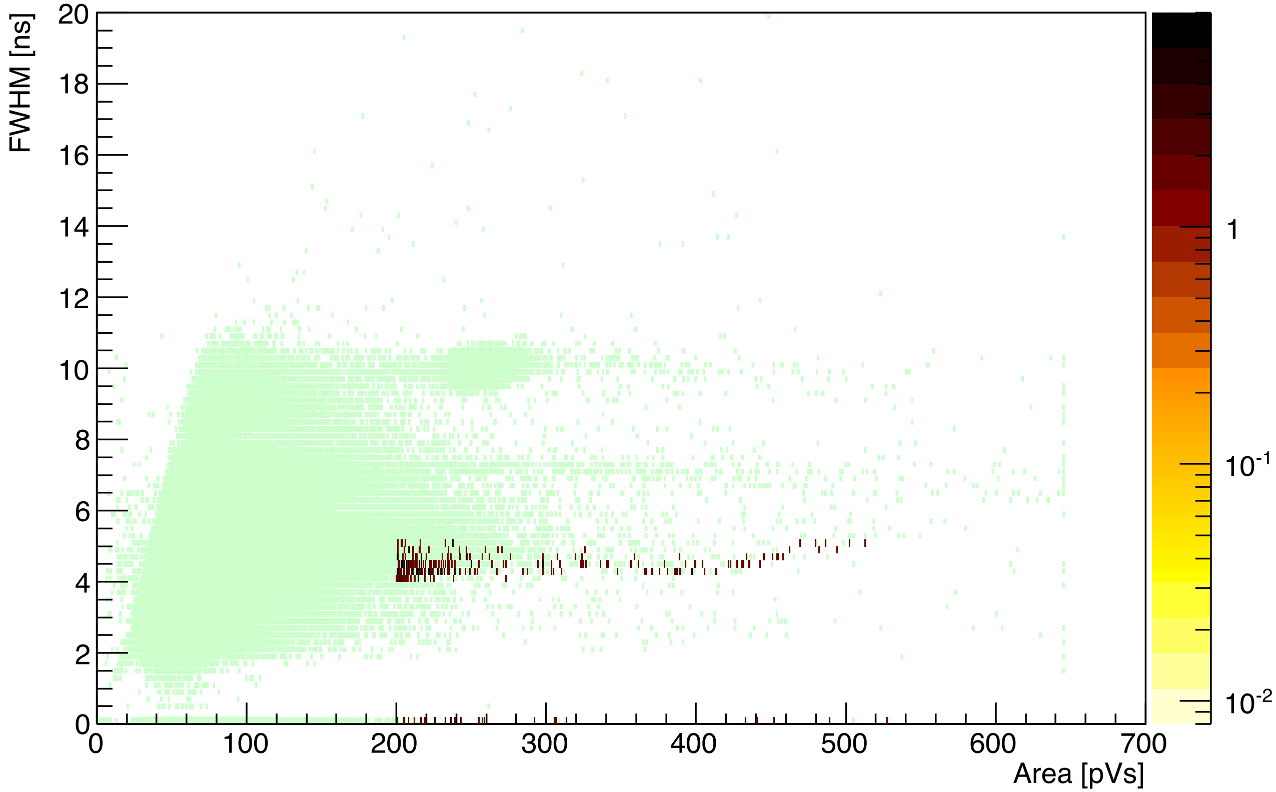

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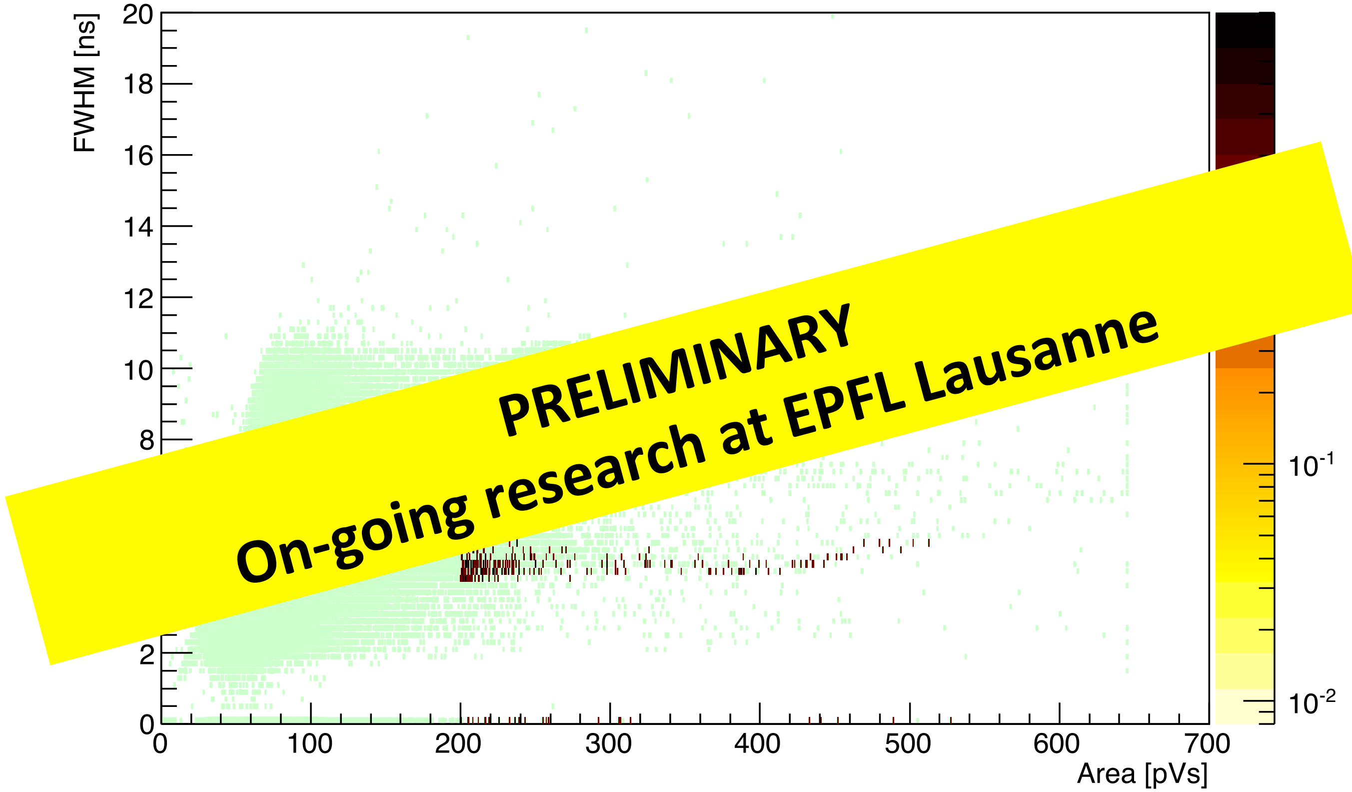

Conclusions

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- Current signals in diamond detectors reflect information on the initial charge-distribution profile in the diamond sensor.
- This allows to identify signals from different origins (MIP or cp entering the sensor, versus nuclear reactions inside the sensor).
- Via pulse-shape analysis the background in neutron measurements can be reduced significantly.
- This allows to extract the neutron interactions, even from measurements with significant background.

Thank you for your attention!

References:

1. C. Weiss et al., Eur. Phys. J. A (2016) 52: 269
2. P. Kavrigin et al., NIMA (2015) 795, 88.
3. P. Kavrigin et al., Eur. Phys. J. A (2016) 52: 179

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