Direct measurement of the n_TOF **NEAR** neutron fluence with **diamond detectors**

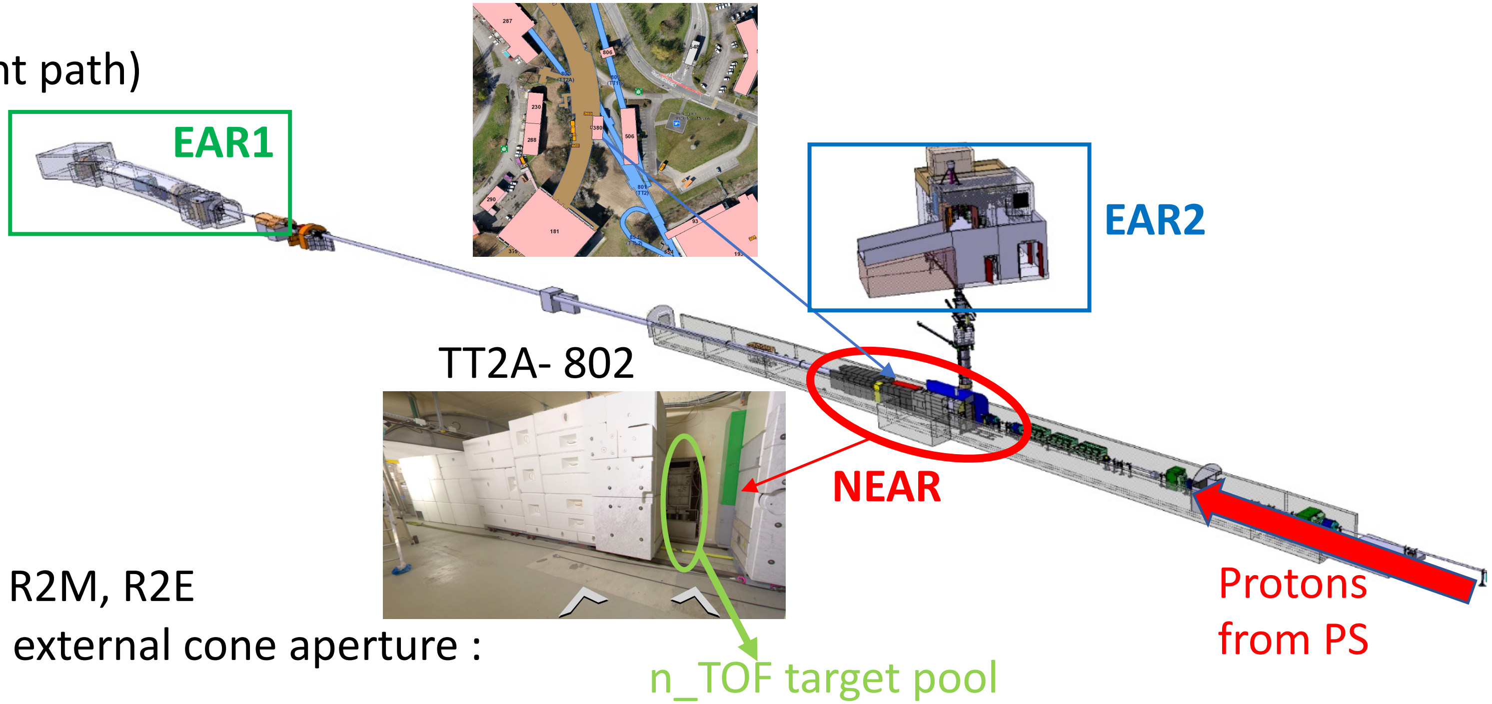
M. Diakaki[1], M. Bacak[2], C. Weiss[3,4], E. Griesmayer[3,4], C. Guerrero[5], E. Jericha[3], M. Kokkoris[1], A. Mengoni[6,7], N. Patronis[7], E. Stamati[2,7], R. Vlastou[1] +++

and the n TOF Collaboration[8]

[1]National Technical University of Athens, Greece
[2]European Organization for Nuclear Research (CERN), Switzerland
[3]TU Wien, Atominstitut, Stadionallee 2, 1020 Wien, Austria
[4] www.cividec.at
[5]Universidad de Sevilla, Spain
[6]Agenzia Nazionale per le nuove tecnologie (ENEA), Bologna, Italy
[7]University of Ioannina, Greece
[8]www.cern.ch/n_TOF

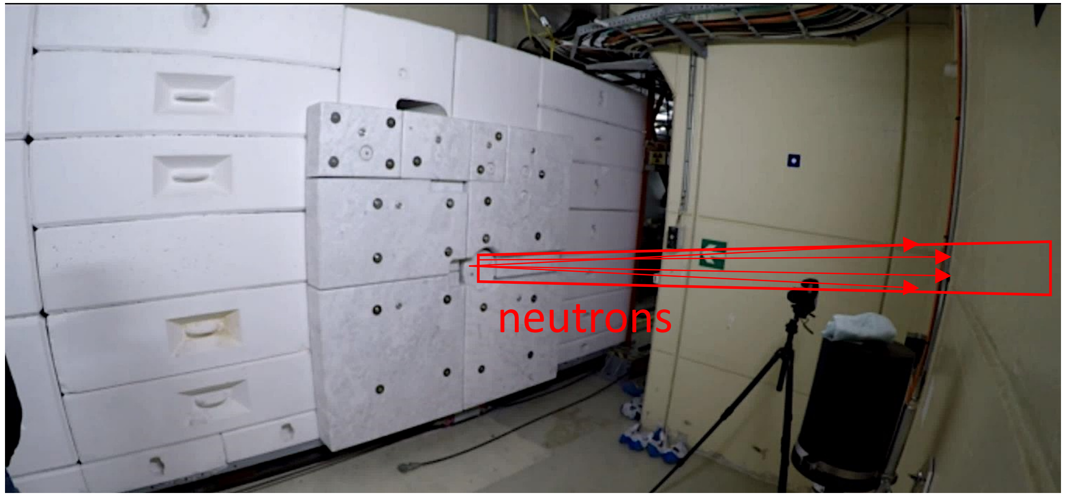
The n_TOF NEAR station

- Very close to the Pb spallation target (~3m flight path)
- Commissioned in 2021



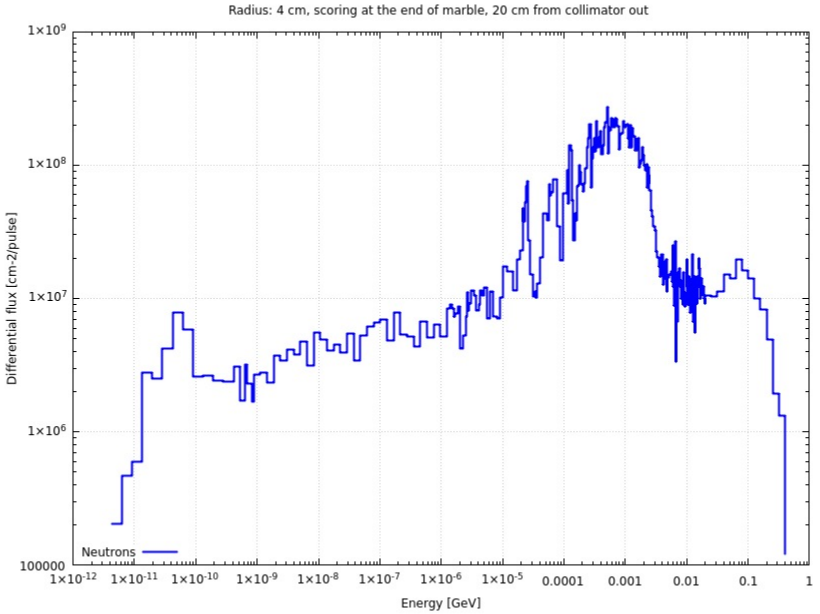
- n_TOF mixed field irradiation places for n_TOF, R2M, R2E

collaboration applications, along the center of the external cone aperture :

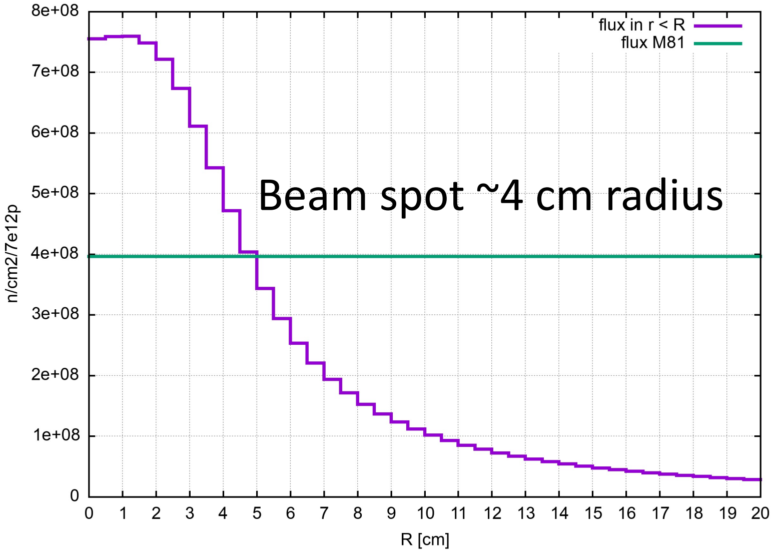


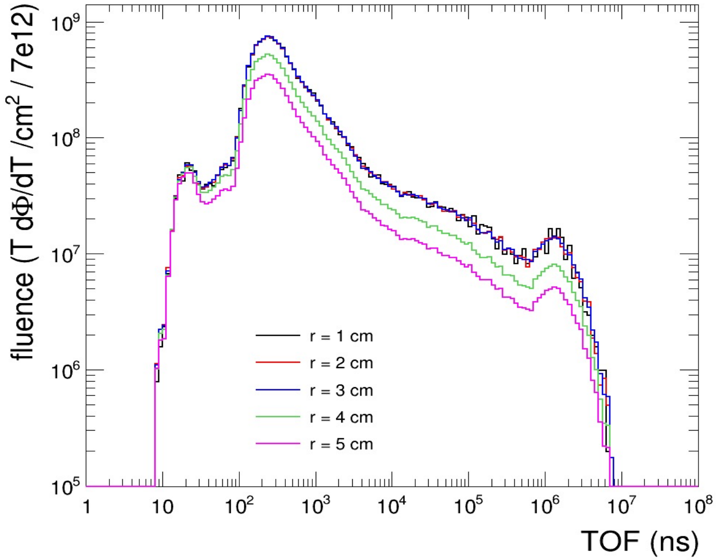
Photos from A.P. Bernardes presentation, n_TOF meeting 25/11/2021

NEUTRON FLUENCE CHARACTERISATION at NEAR (simulations)



Radial dependence of neutron fluence:

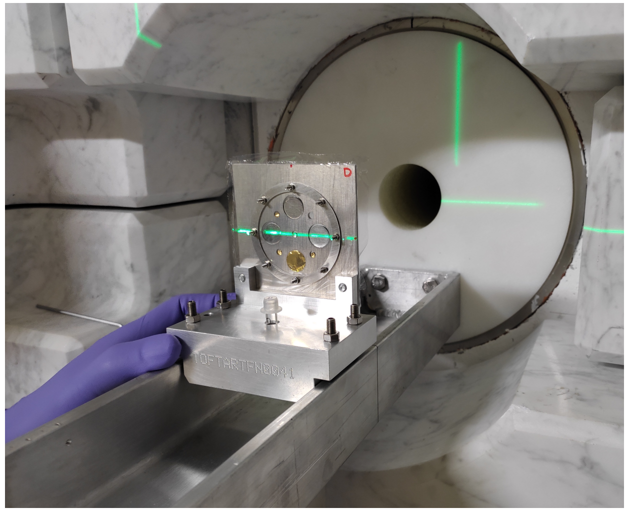




NEUTRON FLUENCE CHARACTERISATION at NEAR (experimental)

To-date:

- Based on the **Multiple Foil Activation Analysis (MAM1 and MAM2 configurations)** and the **Moderation-Absorption technique (ANTILOPE).**
- **Successful experimental campaigns in 2021, analysis ongoing.**



MAM1

MAM2

ANTILOPE

- The above mentioned techniques are based on neutron ACTIVATION, **no active detector yet at NEAR.**

With the present LoI we **propose to measure the neutron fluence at NEAR with an active detector, based on the diamond technology**. Detector development will be implemented in order to cope with the extremely high neutron fluence.

Why diamond sensors??

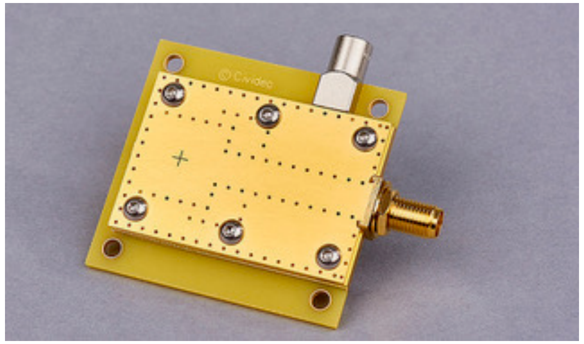
- Diamond sensor (allotrope of carbon) is characterised by
  - high radiation resistance,
  - high thermal conductivity /low thermal expansion coefficient
  - fast response time
  - high rigidity, biological and chemical inertia.
  - Good energy resolution (sub 1% for 5.5 MeV alpha particles)

Successfully used in
- neutron induced reaction studies
- neutron fluence measurements,

even in **harsh radiation environments** [1,2]

- Diamond sensor will be **especially developed by CIVIDEC Instrumentation [3]** for the flux measurement at NEAR:

Single crystalline sensor fabricated via the CVD (Chemical Vapour Deposition) technology.



Proposed characteristics: 50 um thickness, 4x4 mm^2 active surface, ^6LiF converter

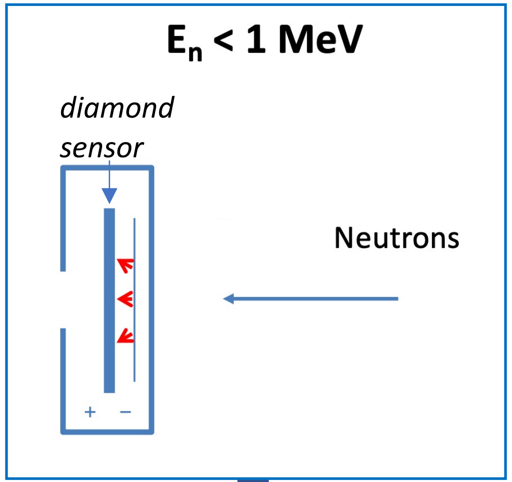
cividec Instrumentation

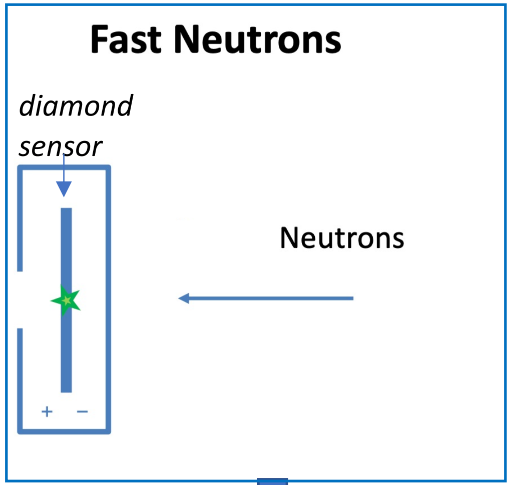
[1] E. Griesmayer et al., A novel neutron flux monitor at the Vienna TRIGA Mark II reactor, IAEA-CN-231-A.17, 2015

[2] M. Angelone and C. Verona, Review-Properties of Diamond-Based Neutron Detectors Operated in Harsh Environments, J. Nucl. Eng. 2021, 2, 422–470

[3] https://cividec.at/

Neutron detection principle





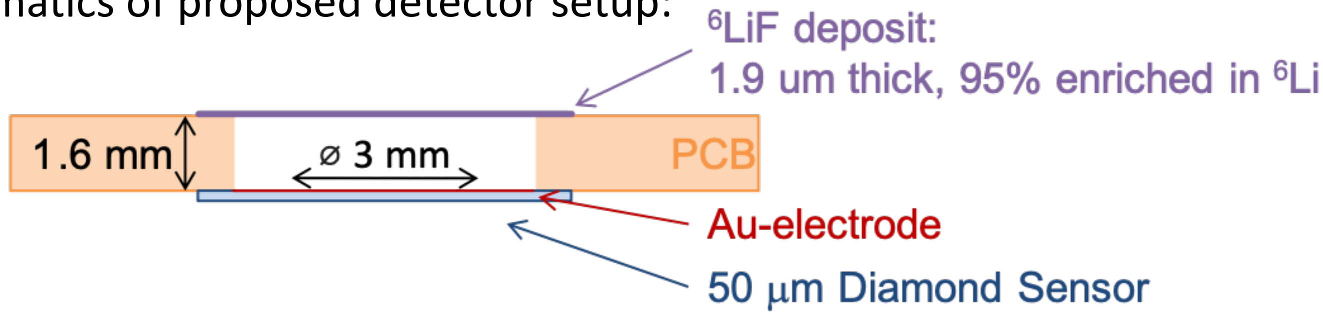
based on a secondary reaction:
^{6}Li(n,t)
Diamond sensor measures the secondary t and α particles

based on neutron interactions in the diamond:
^{12}C(n,el) and **^{12}C(n,inl)**
For E_n > 6MeV also **^{12,13}C(n,xα/p)**

Nuclear reaction	E_{th} [MeV]	Q [MeV]
^{12}C(n,el)^{12}C	0.0	0.0
^{12}C(n,α)^{9}Be	6.2	-5.7
^{12}C(n,3α)	7.9	-7.3
^{12}C(n,p)^{12}B	13.6	-12.6
^{12}C(n,d)^{11}B	14.9	-13.7
^{13}C(n,α)^{10}Be	4.1	-3.8

This principle already used in fission reactors and fusion tokamaks [1]

- Schematics of proposed detector setup:

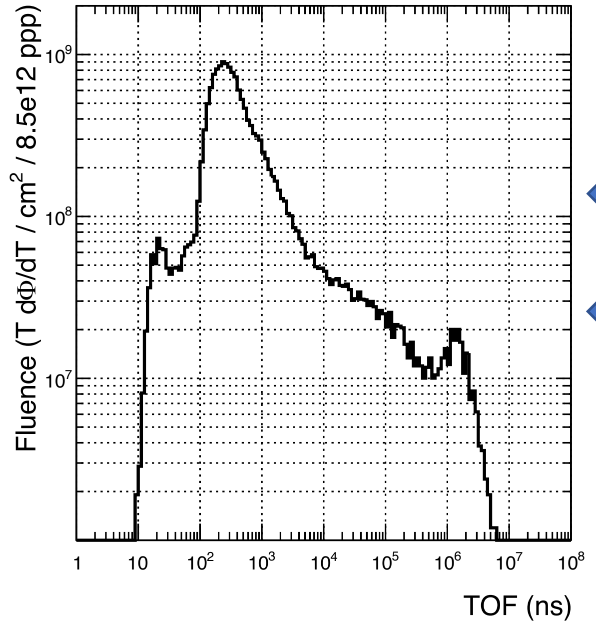


[1] M. Angelone and C. Verona, J. Nucl. Eng. 2021, 2, 422–470

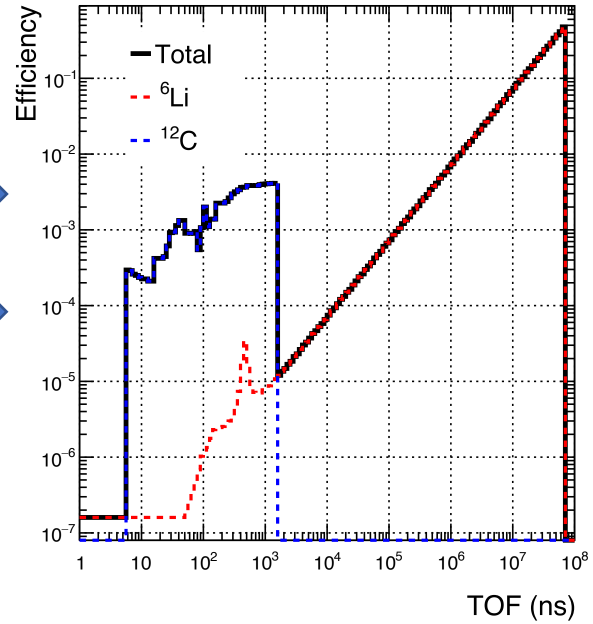
Estimated diamond det. response at NEAR (I)

Expected Counting Rate estimation, based on:

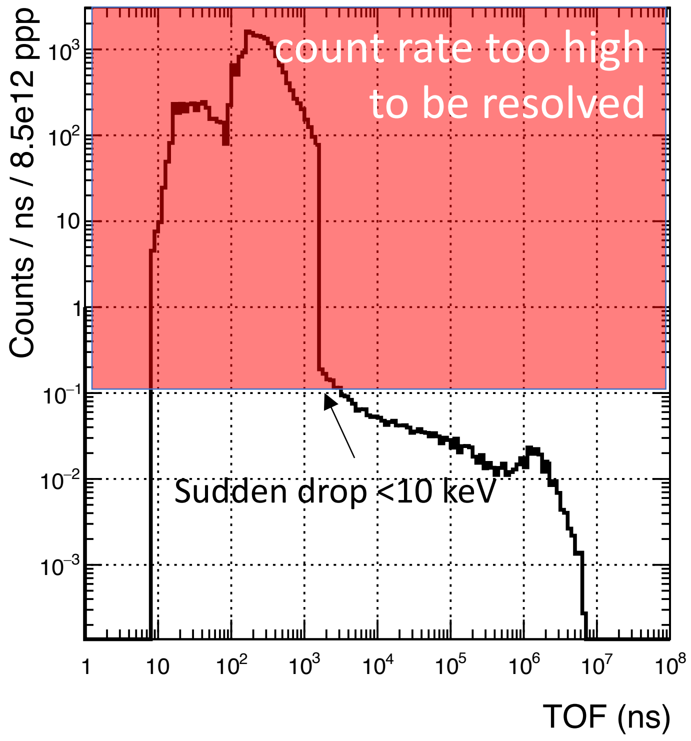
FLUKA simulations
of neutron flux
(scaled to detector area and
number of protons on target,
converted to neutron rate)



Efficiency vs neutron energy
(simulations)



Counting Rate:



Calculation performed by Christina Weiss

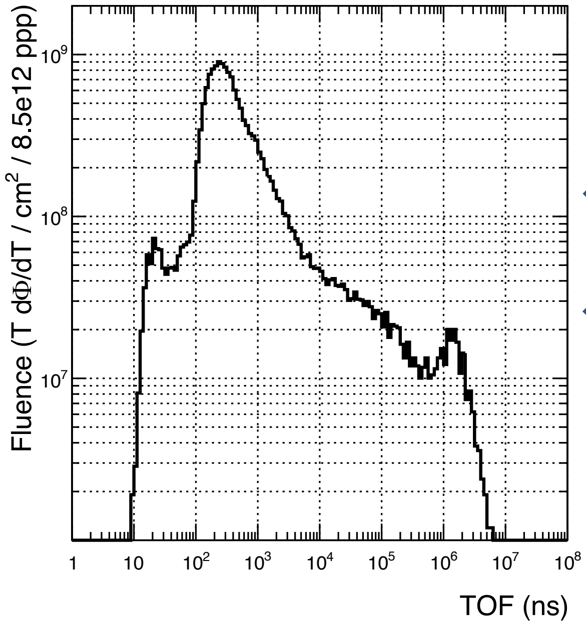
Detector current will be measured to extract the neutron fluence

cividec
Instrumentation

Estimated diamond det. response at NEAR (II)

Expected Counting Rate estimation, based on:

FLUKA simulations
of neutron flux
(scaled to detector area and number of protons on target, converted to neutron rate)

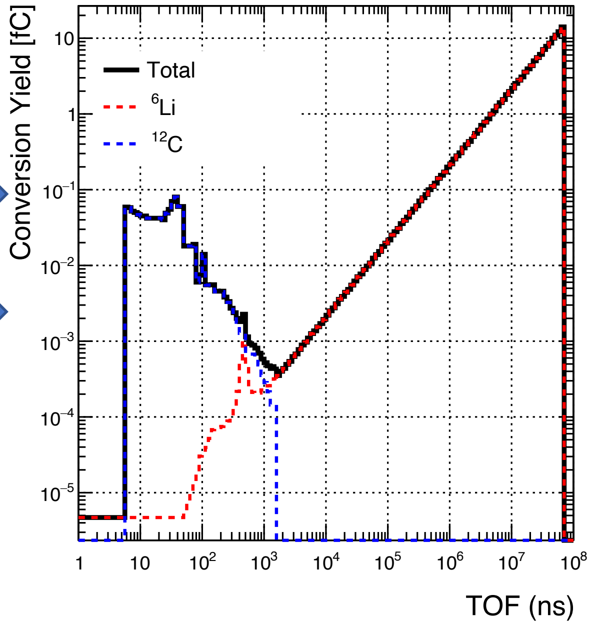


Conversion Yield (Y):

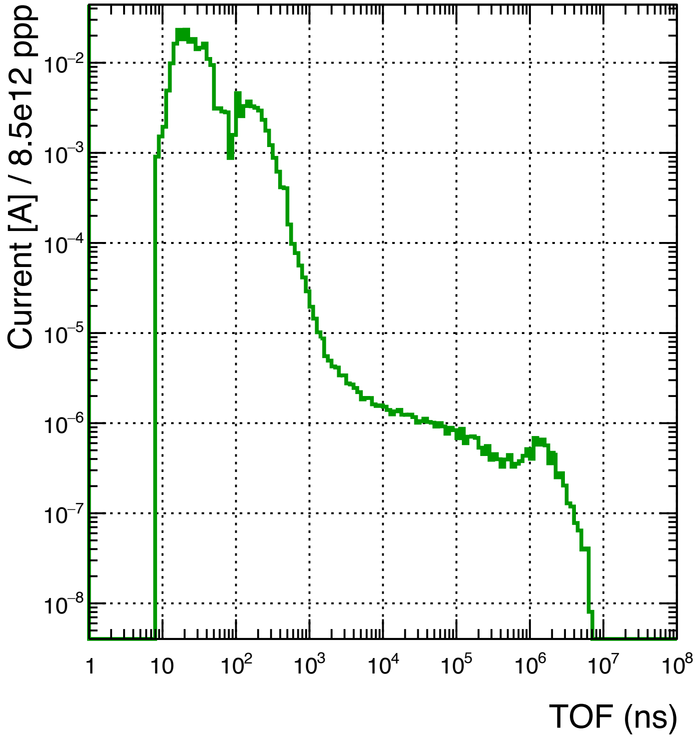
Y = Q_m * e

Q_μ = Mean charge / neutron interaction

ε = Neutron detection efficiency



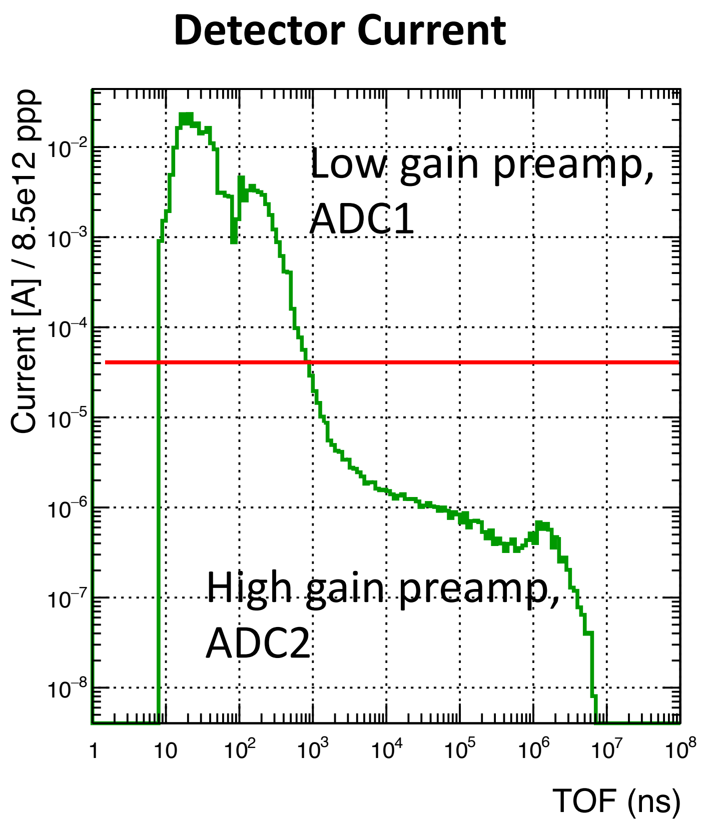
Detector Current:



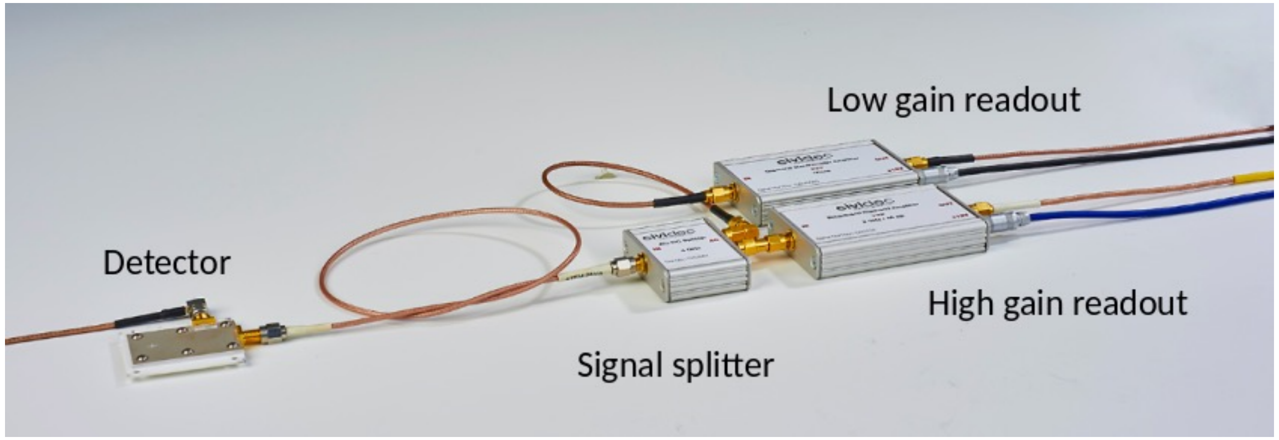
Calculation performed by Christina Weiss

cividec Instrumentation

Estimated diamond det. response at NEAR (III)



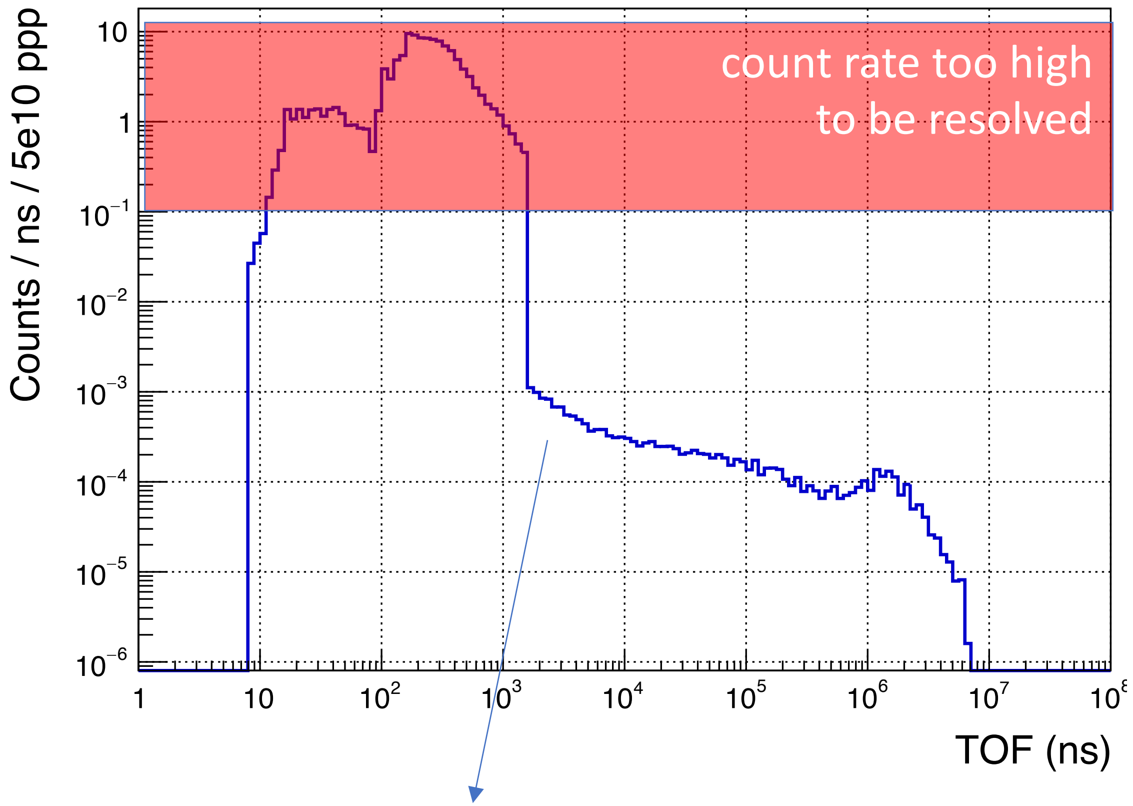
Strong fluctuation of detector current=>
Detector signal will be splitted and treated with 2 different preamplifier gains + 2 ADC channels . Development ongoing in Vienna.

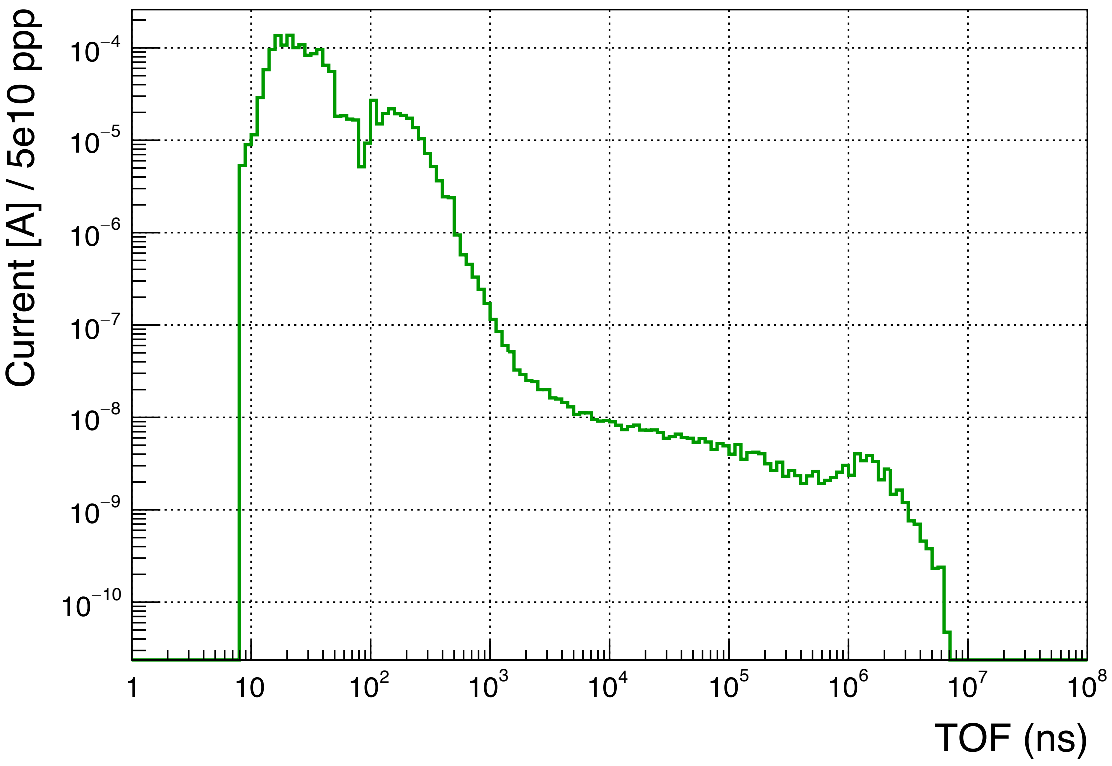


Storage of waveforms at 10-12 bit oscilloscopes for consequent offline analysis.

Estimated diamond det. response at NEAR (IV)

- Very low intensity pulses (5e10 ppp):





Measurement of the AC detector signal will be possible

Proposed planning of measurements

➢ ***7×10^{17} protons are requested in total, for the following planning:***

- 2×10^{17} – debugging + intensity ramp
- 2×10^{17} – **central position neutron fluence measurement**
- 1×10^{17} – **beam homogeneity scan** of the NEAR collimator 10×10 cm^2 in 0.5 cm steps (detector mounted on special XY-table that can be moved remotely)
- 1×10^{17} – **neutron fluence measurement** with B_4C filter, useful for activation measurements [1]
- 1×10^{17} – **neutron fluence measurement** without ^{6}Li converter, central position (elastic ^{12}C + delayed photons estimation)

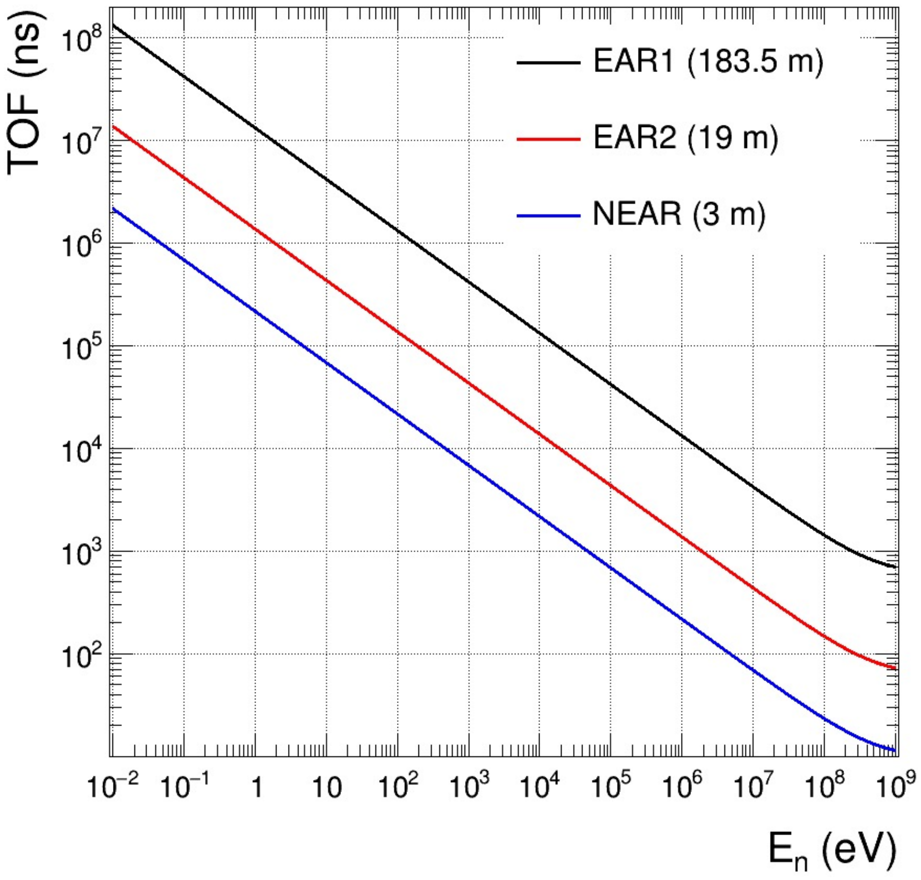
➢ The number/splitting of protons is indicative and will highly depend on the performance of the detector and includes contingency for parallel detector and electronic chain development, which in consequence might require splitting the measurement in two time periods to leave time for detection system adaptation (for example one run in 2022 and one run in 2023).

➢ Any suggestions, remarks, propositions, new members at the “DEAR” collaboration are more than welcome !

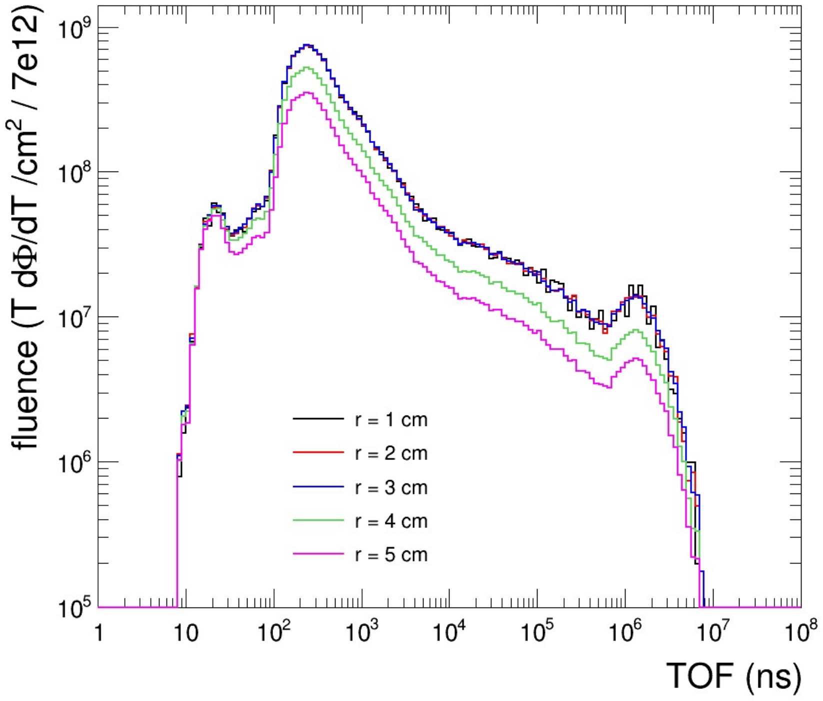
Thank you!

[1] E. Stamati et al., CERN-INTC-2022-008; INTC-P-623 (2022)

Extra slides



TOF (ns)
EAR1 (183.5 m)
EAR2 (19 m)
NEAR (3 m)
E_n (eV)



fluence (T dΦ/dT /cm^2 / 7e12)
r = 1 cm
r = 2 cm
r = 3 cm
r = 4 cm
r = 5 cm
TOF (ns)

Conversion yield

Energy Interval	ε (ENDF/B-VIII.0)	Q_μ [fC]
$E_n < 10$ keV	$^6Li(n,a)t$	$Q\text{-value}/2/E_{ion}*q_{el} = 29.4$ fC
10 keV < E_n < 1 MeV	$^6Li(n,a)t$ $^{12}C(n,el)$	$Q\text{-value}/2/E_{ion}*q_{el} = 29.4$ fC $f_1(E_n)$, see below
$E_n > 1$ MeV	$^{12}C(n,tot)$	$f_2(E_n)$, Geant4 P. Kavrigin

ionisation energy of diamond

elementary charge

$$f_1(E_n) = E_n * 0.286 / E_{ion} * q_{el} * 0.5$$

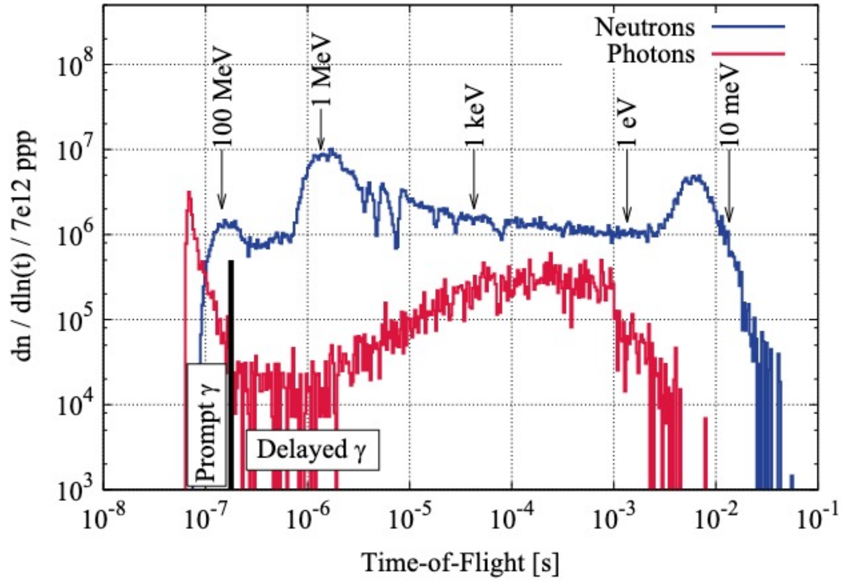
E_{max} for ^{12}C nucleus in $^{12}C(n,el)$

assuming isotropic scattering, we measure on average ½ of the total charge

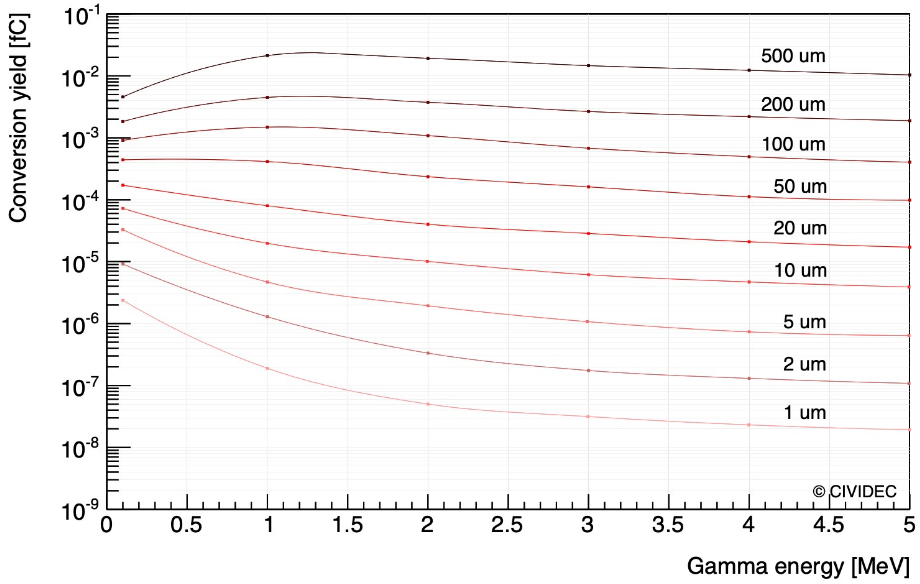
Table 1. Diamond parameters [1].

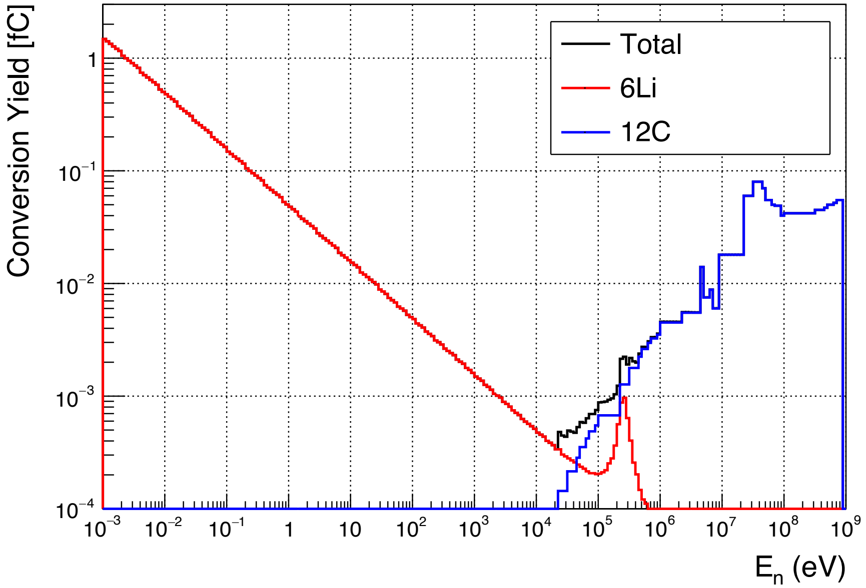
Parameter	Value
Atomic Number	6
E_g at 300 K (eV)	5.470
Density (g·cm^{-3})	3.515
ε_p (eV)	13
Fusion temperature (°C)	4100
Electron mobility (cm^{2}V^{-1}s^{-1}) at 300 K	1800–2200
Hole mobility (cm^{2}V^{-1}s^{-1}) at 300 K	1200–1600
Breakdown voltage (Vcm^{-1})	>10^7
Thermal conductivity σ_T (Wcm^{-1}K^{-1})	20
Saturation velocity v_{sat} (cm s^{-1})	2.7×10^7
Resistivity ρ (ohm cm)	>10^{13}
Intrinsic carrier density at 300 K (cm^{-3})	<10^3
Dielectric constant	5.7
Energy to displace an atom (eV) [1]	37.5–47.6

Gamma background, grossier estimation from EAR2 simulations



In Figure 3.17 the conversion yield of the γ interaction in diamond is shown.





Delayed gammas not expected to significantly influence the measurement