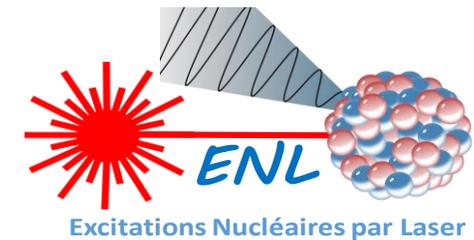


GAMMA SPECTROSCOPY IN A HIGH POWER LASER ENVIRONMENT

Emmanuel Atukpor

Excitations Nucléaires par Laser: ENL

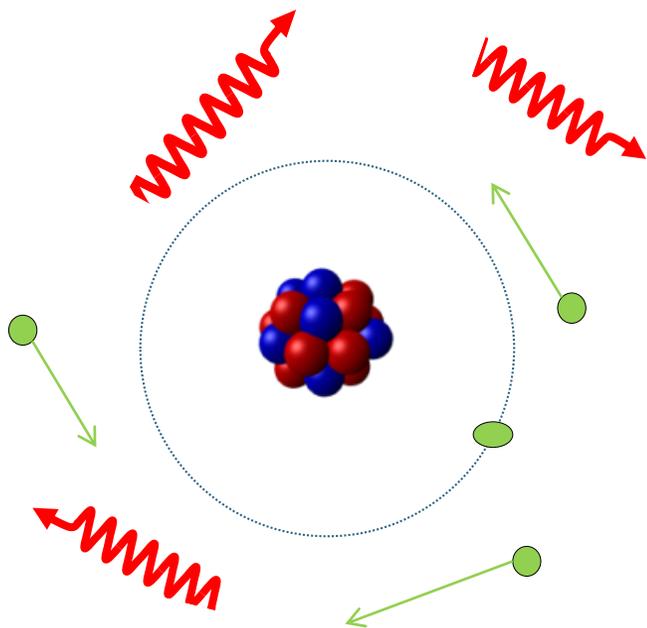


- ❖ Context: Nuclear Physics in Laser Plasma
- ❖ PhD work: Gamma Spectroscopy in Laser environment
 - Scintillators
 - Semiconductors
- ❖ Conclusions and Perspective

LASER-PRODUCED PLASMA

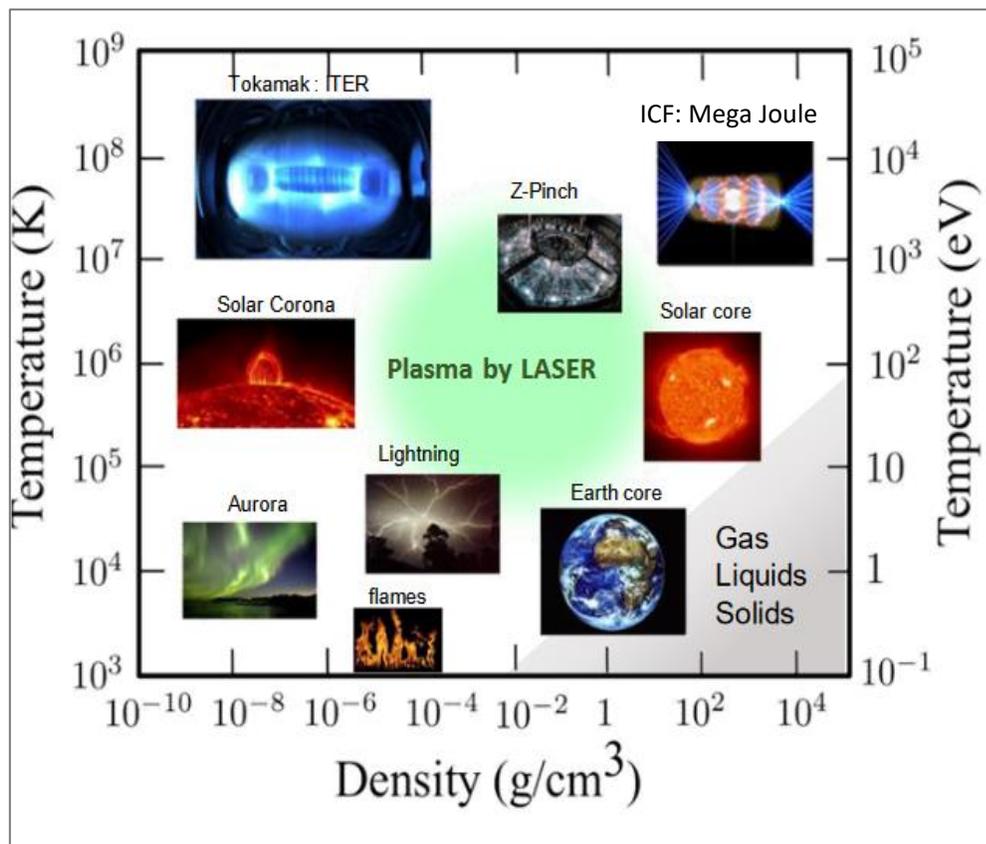
PLASMA

- Multi-charged ions
- Free Electrons
- Photons



The visible Universe is plasma

Laser-plasma is similar to plasma in the stars

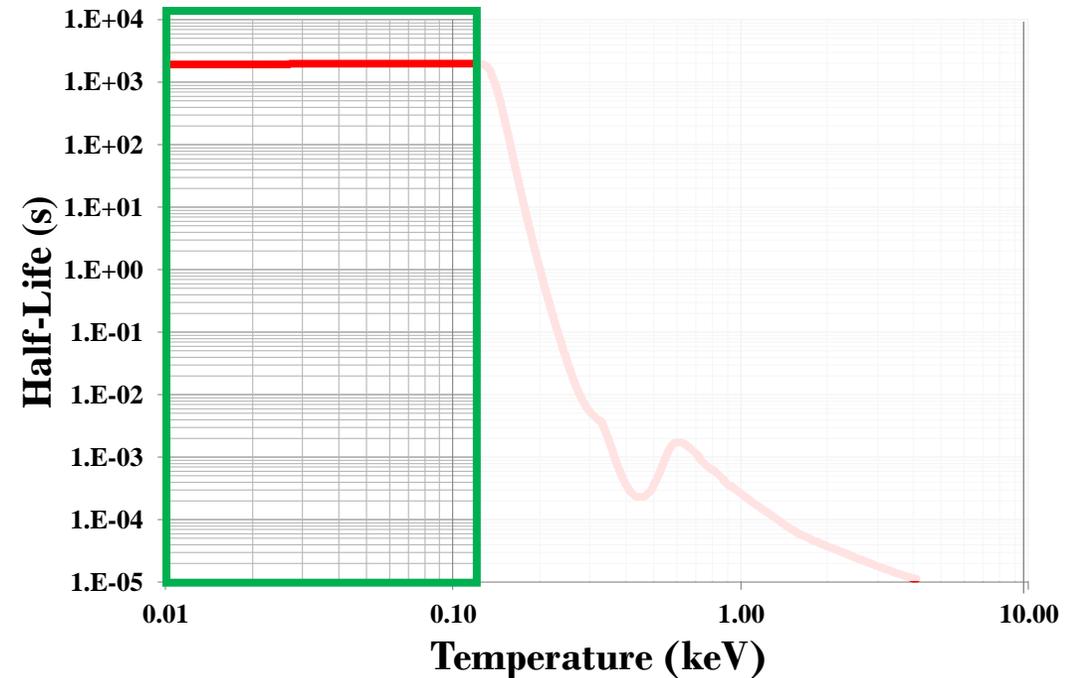
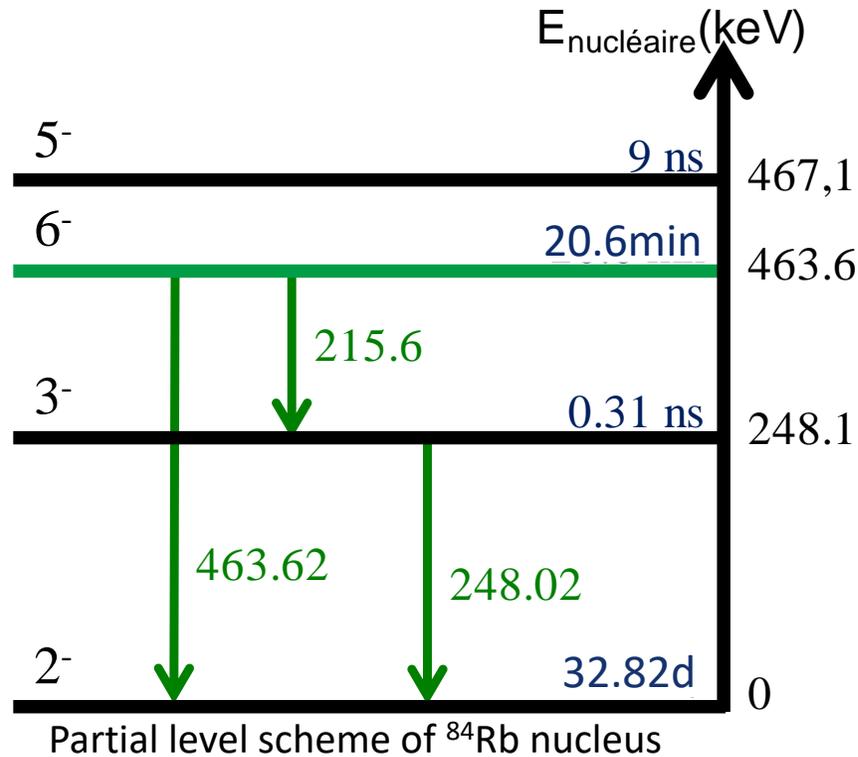


- Astrophysical plasma possible in the lab
- Possibility of Nuclear Astrophysical studies in stellar-like environment

NUCLEAR PHYSICS IN PLASMA: SIMULATION STUDY

Modification of nuclei apparent lifetime in plasma: Case of ^{84}Rb

$$T_{1/2} = \frac{\ln(2)}{\lambda_\gamma} \approx 20\text{mins}$$



Simulation study by:

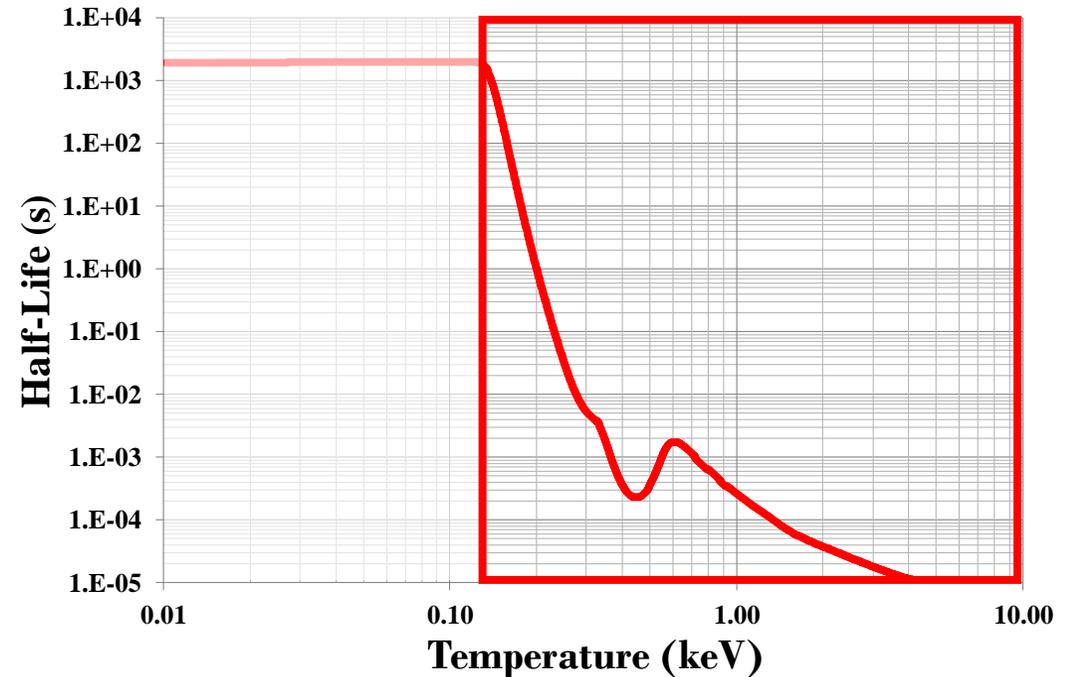
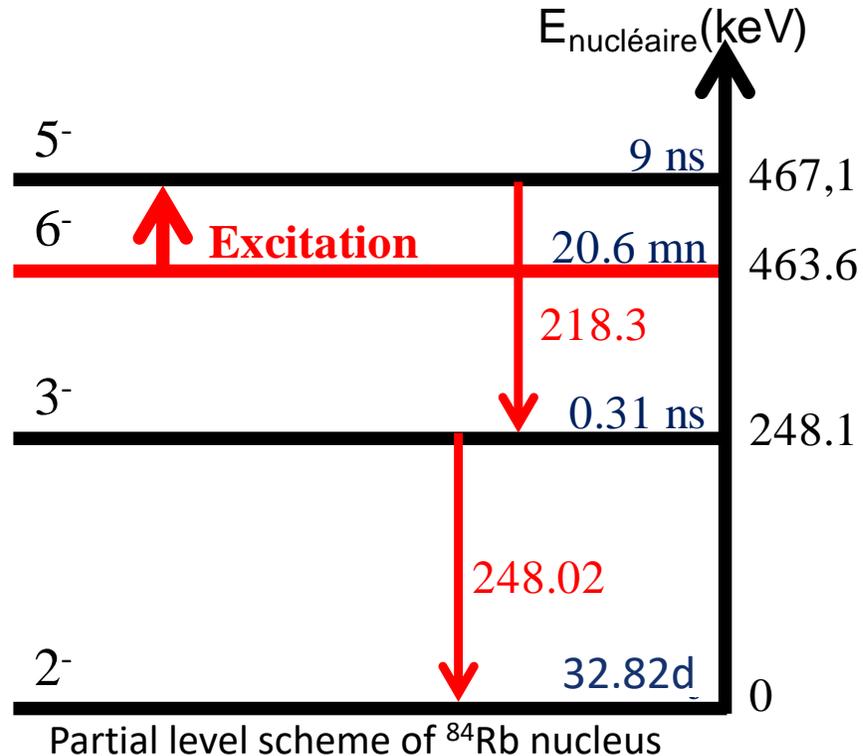
D.Denis-Petit et al. Ch.21, Applications of Laser-Driven Particle Acceleration, Eds. Parodi, Bolton, Schreiber, CRC press, ISBN 9781498766418 (2018)

NUCLEAR PHYSICS IN PLASMA: SIMULATION STUDY

Modification of nuclei apparent lifetime in plasma: Case of ^{84}Rb

- Population of 5^- from the 6^-
- Reduction in the lifetime of ^{84}Rb to few μs

$$T_{1/2} = \frac{\ln(2)}{\lambda_\gamma + \lambda_{\text{excitation}}} \approx \text{some } \mu\text{s}$$



Simulation study by:

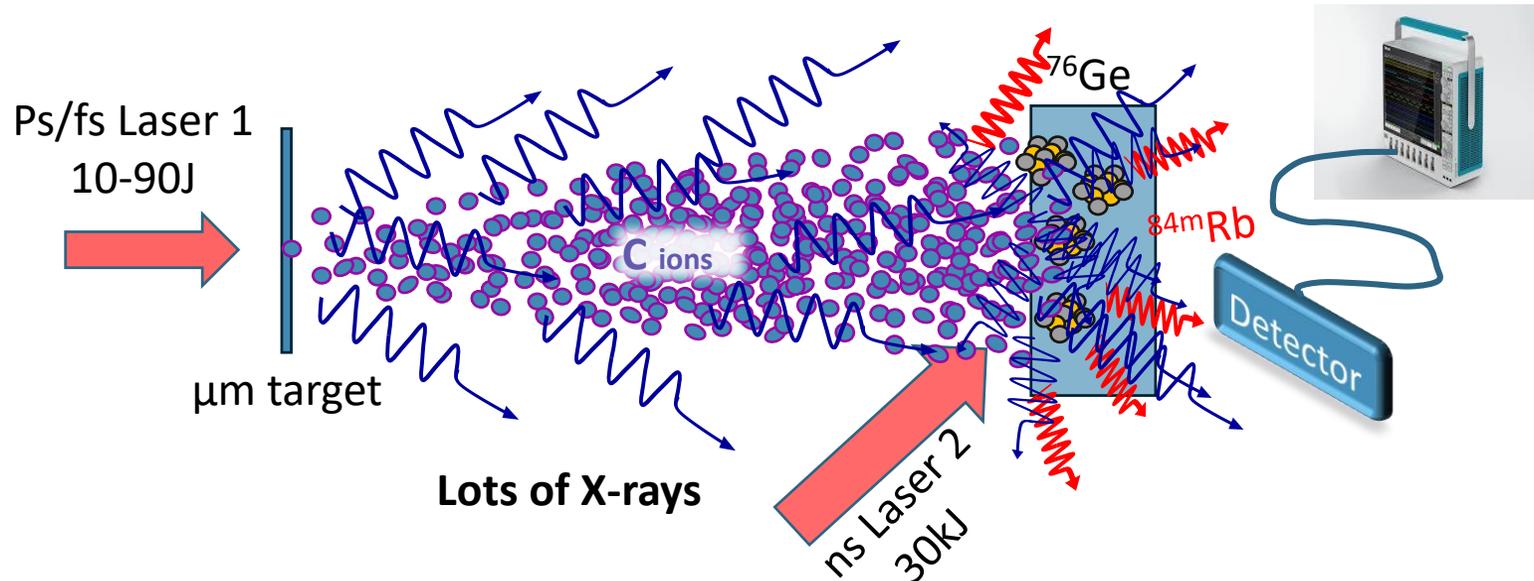
D.Denis-Petit et al. Ch.21, Applications of Laser-Driven Particle Acceleration, Eds. Parodi, Bolton, Schreiber, CRC press, ISBN 9781498766418 (2018)

**Can we perform this study in the lab?
With $^{84\text{m}}\text{Rb}$?**

NUCLEAR PHYSICS IN PLASMA: EXPERIMENTAL STUDY

Modification of nuclei apparent lifetime in plasma: $^{76}\text{Ge}(^{12}\text{C},p+3n)^{84\text{m}}\text{Rb}$

- We need carbon ions for this reaction
- High power lasers can also accelerate ions and produces Plasma



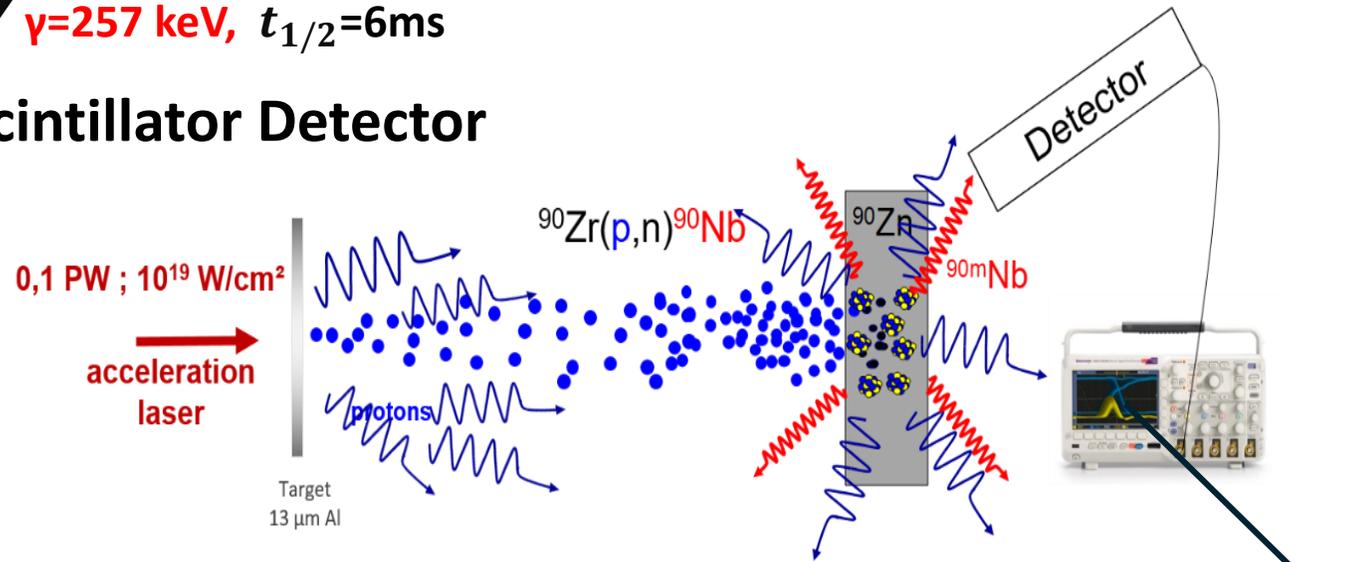
- Huge quantities of X-rays!!!
- Our detectors will be blind

NUCLEAR PHYSICS IN PLASMA: EXPERIMENTAL STUDY

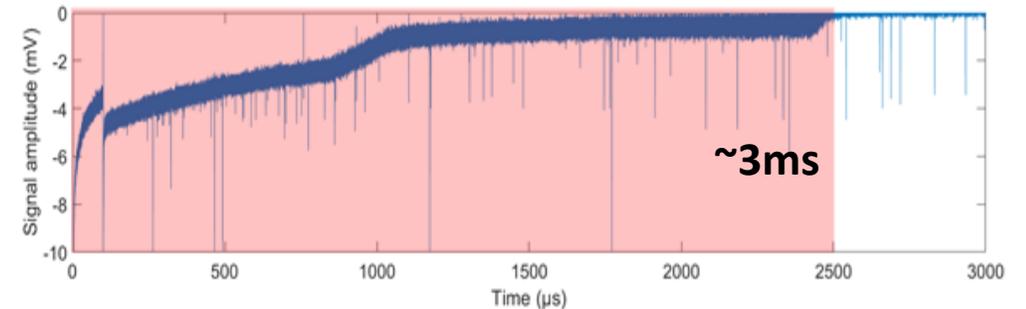
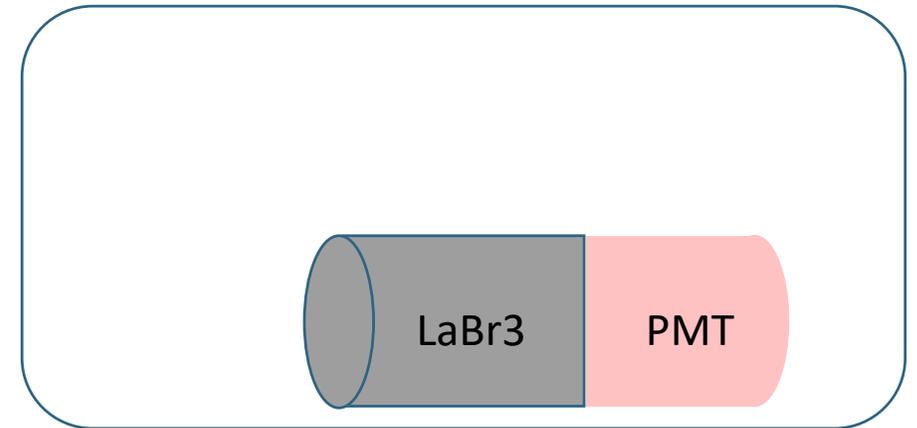
DETECTOR TEST in high power Laser environment: $^{90}\text{Zr}(p,n)^{90\text{m}}\text{Nb}$

➔ $\gamma=122\text{ keV}$, $t_{1/2}=63\ \mu\text{s}$,
 $\gamma=257\text{ keV}$, $t_{1/2}=6\text{ms}$

Scintillator Detector



Lanthinum Bromide+ PMT



F. Negoita et al., AIP Conference Proceedings vol. 1645, p. 228, 2015

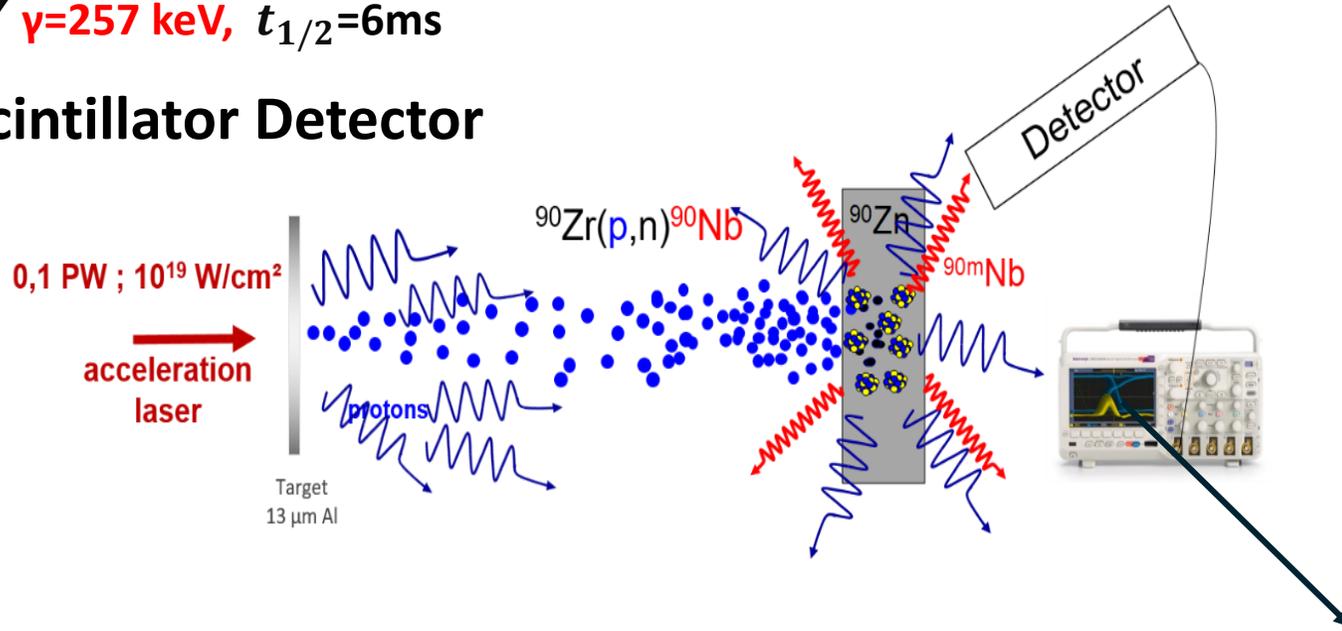
M.Tarisien, et al., IEEE Transactions on Nuclear Science, Vol 65, issue 8, p.2216-2219 (2018)

NUCLEAR PHYSICS IN PLASMA: EXPERIMENTAL STUDY

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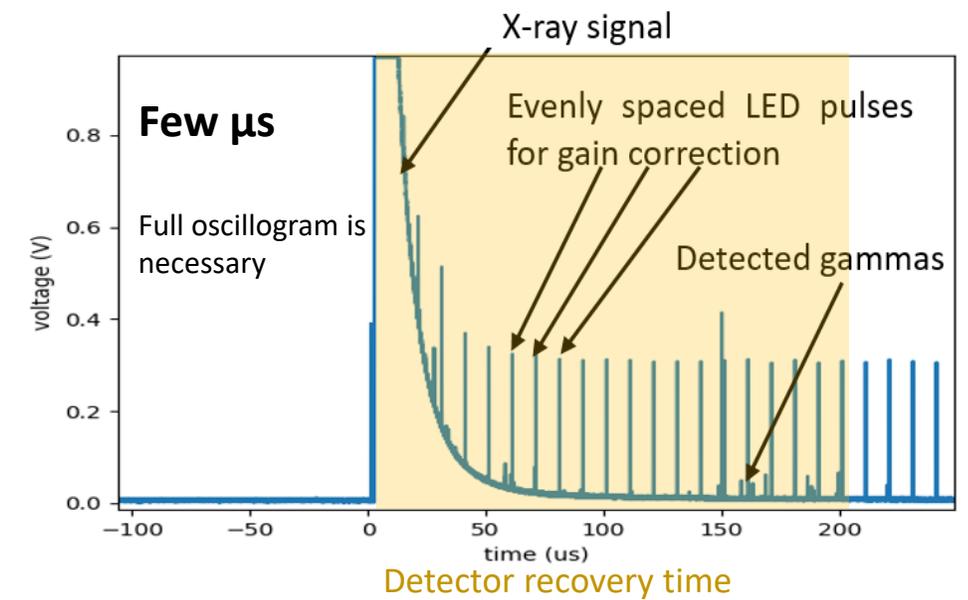
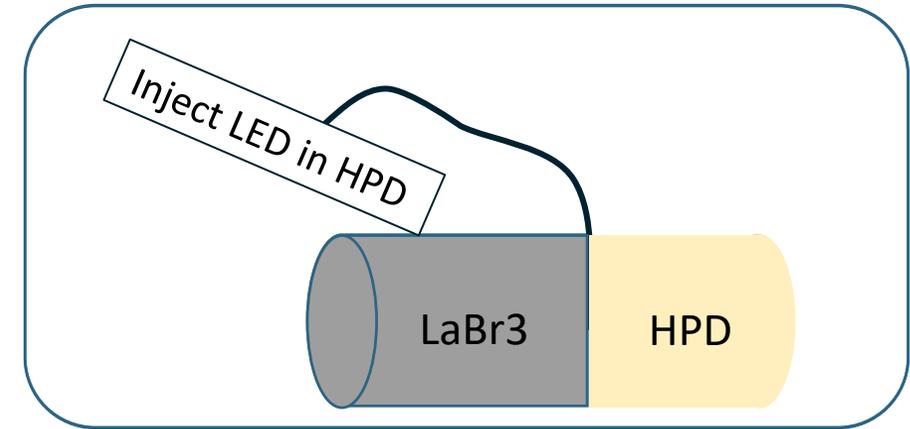
$\gamma=122\text{ keV}$, $t_{1/2}=63\ \mu\text{s}$,
 $\gamma=257\text{ keV}$, $t_{1/2}=6\text{ms}$

Scintillator Detector



It is necessary to perform offline treatment and analysis

Lanthinum Bromide+ Hybride Photodiode

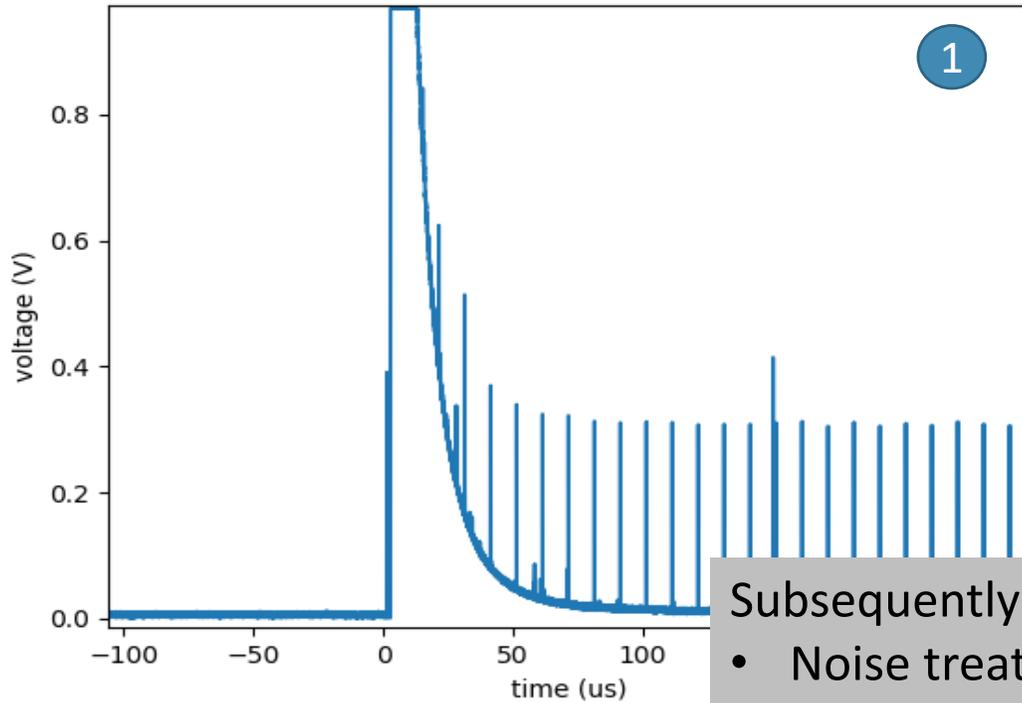


F. Negoita et al., AIP Conference Proceedings vol. 1645, p. 228, 2015

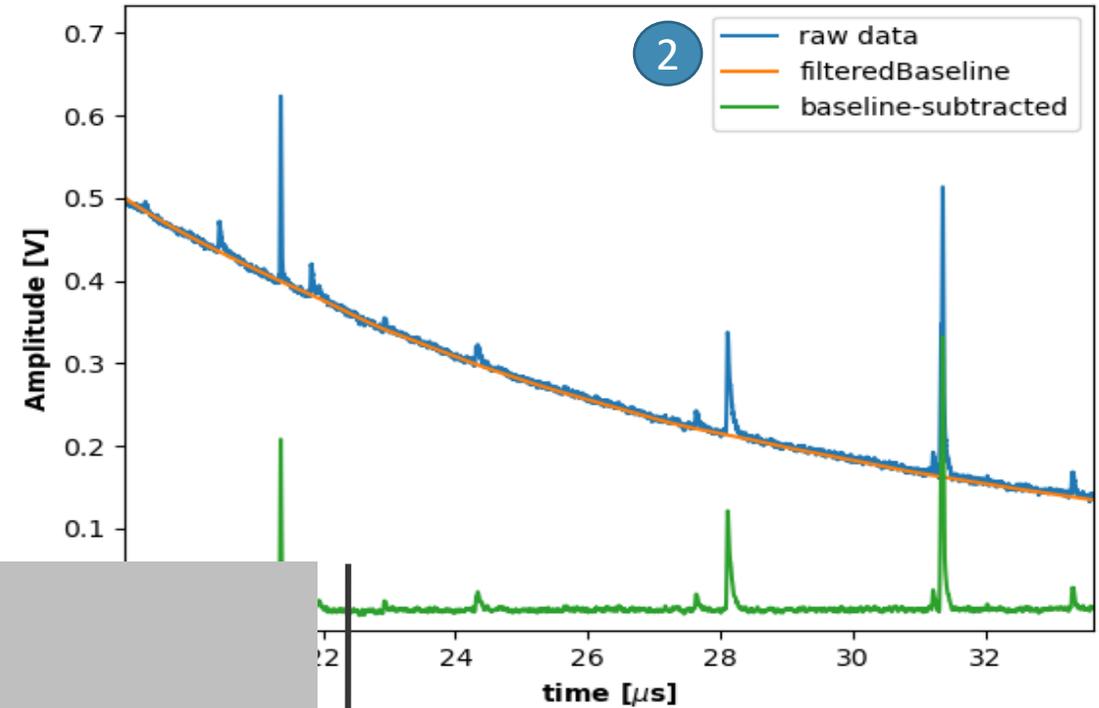
M.Tarisien, et al., IEEE Transactions on Nuclear Science, Vol 65, issue 8, p.2216-2219 (2018)

OFFLINE ANALYSIS 1/2

Oscillogram



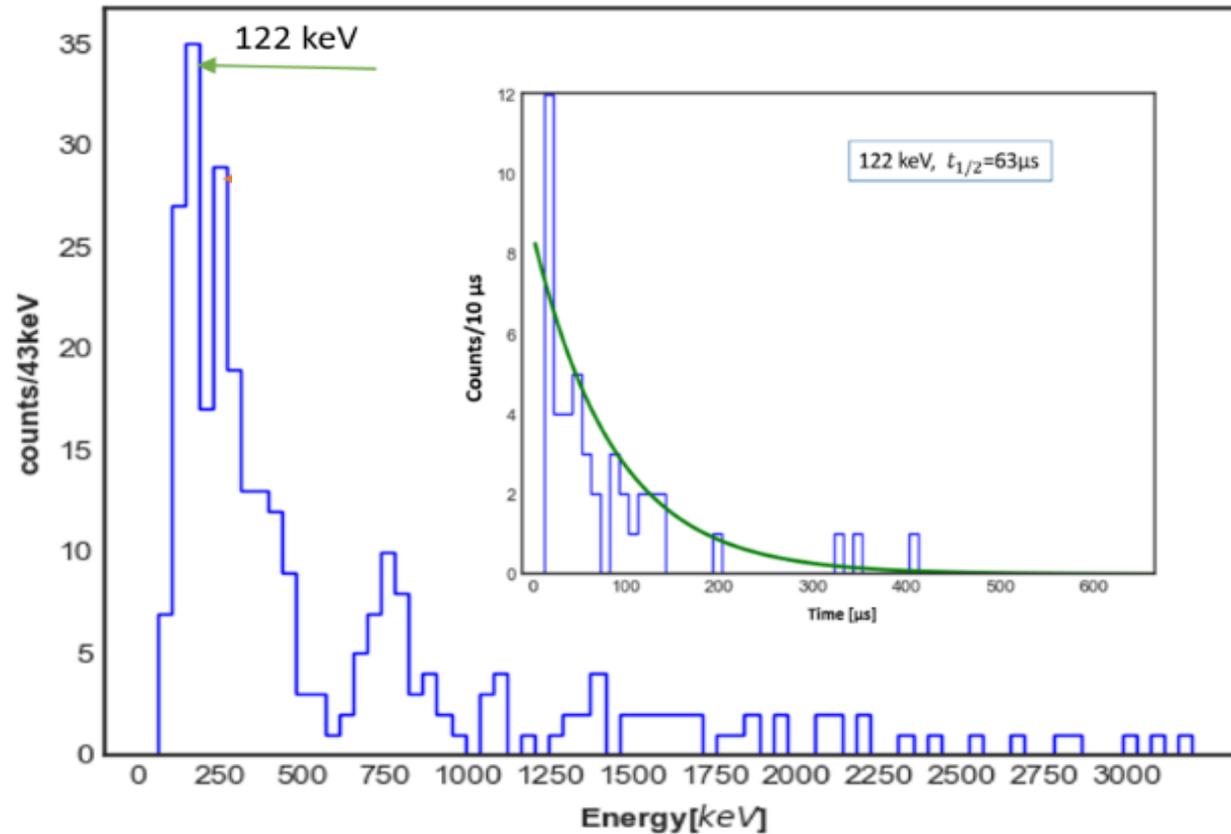
X-ray signal baseline subtraction



Subsequently:

- Noise treatment
- Gain correction
- Peak detection
- Histogramming

OFFLINE ANALYSIS 2/2

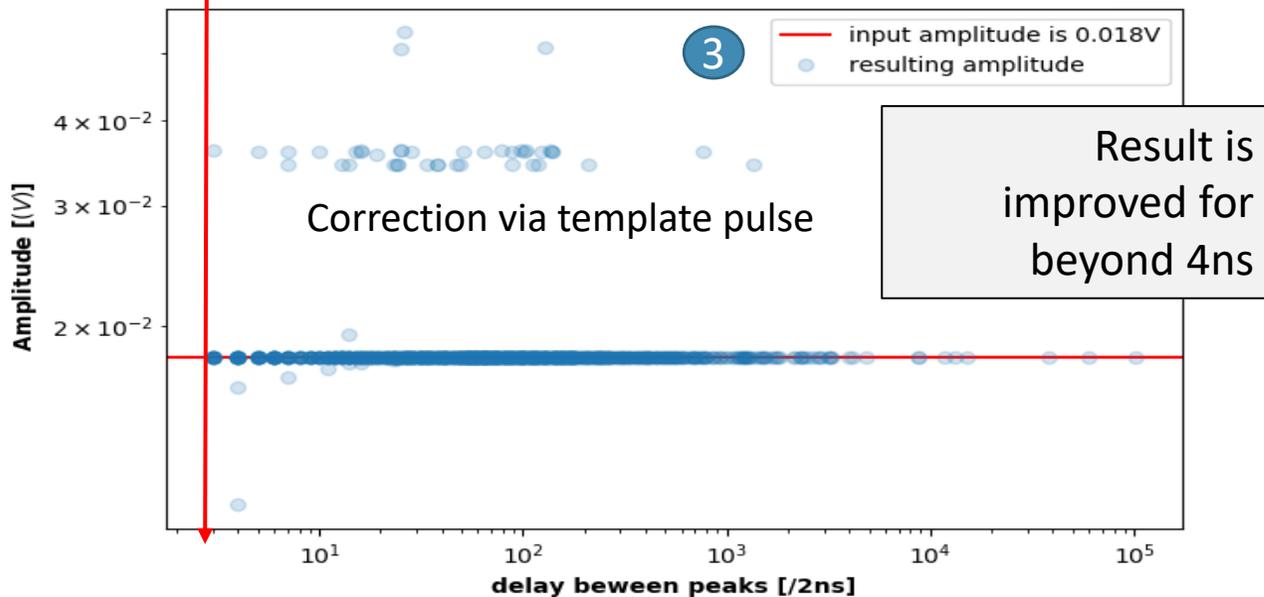
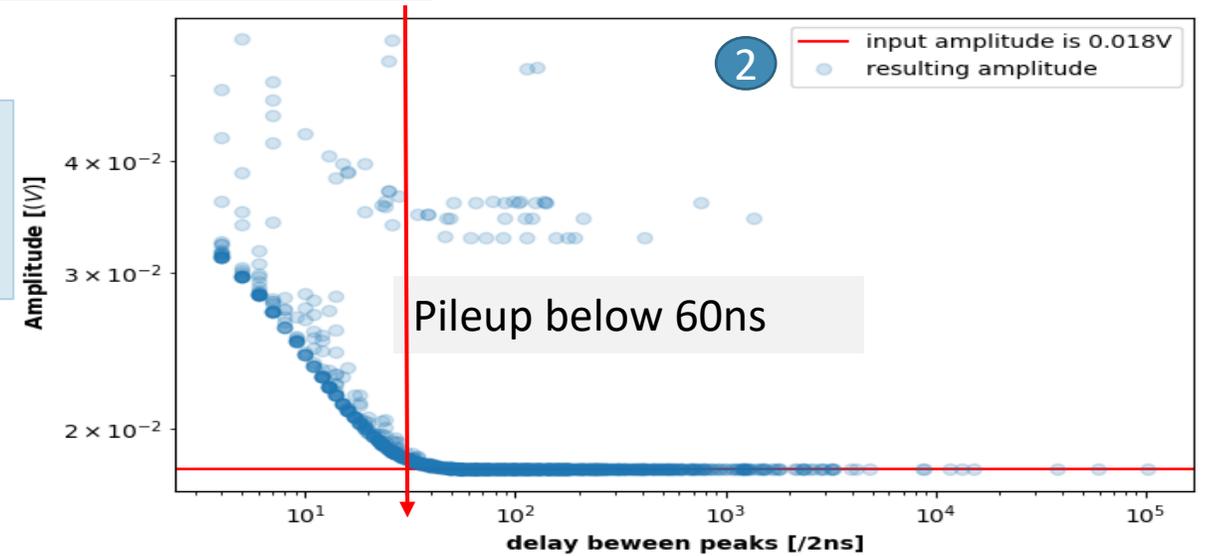
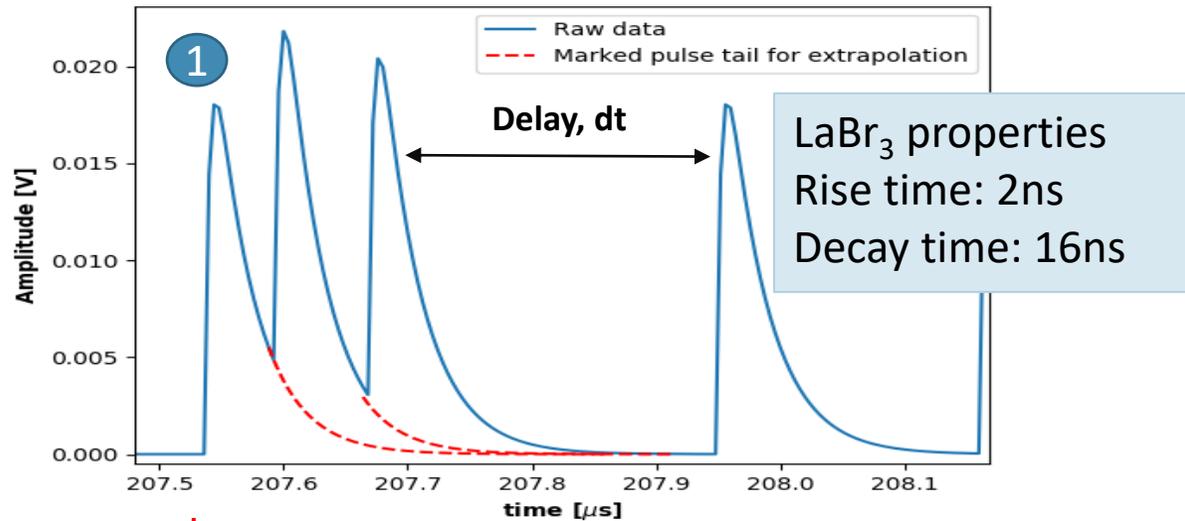


- **122 keV detected**
- **More statistics** are needed
- New generation of lasers **>1Hz**
- **optimised detection**

=> Pileup

MANAGE PILEUP OCCURRENCES OFFLINE

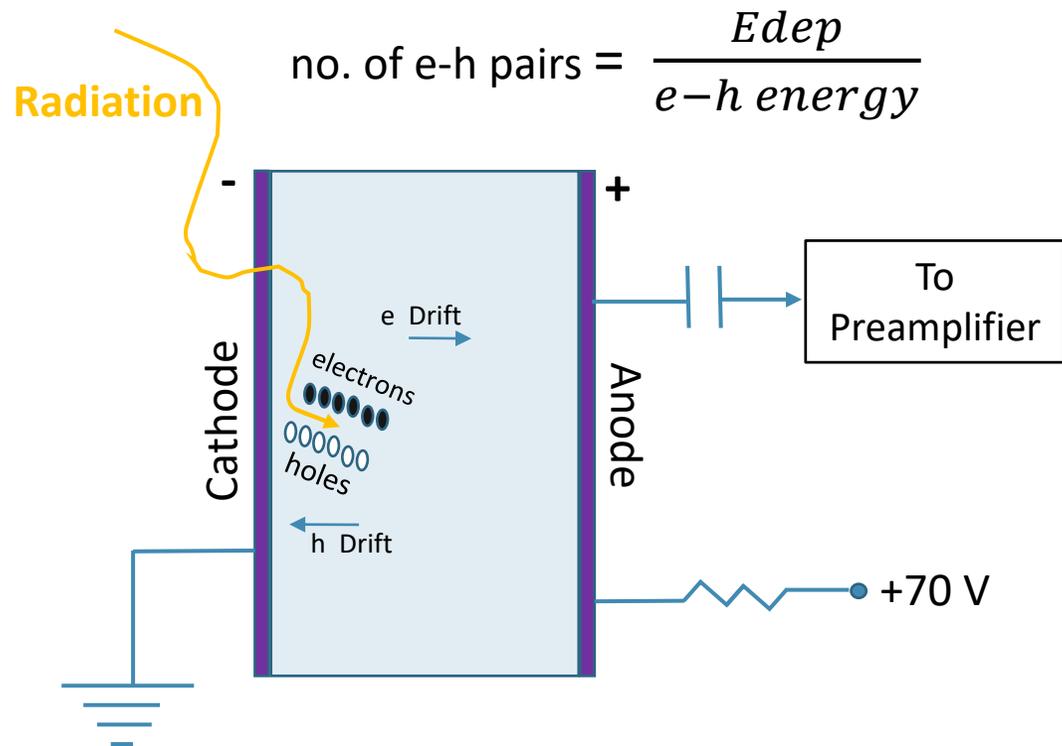
PILEUP SIMULATION: From LaBr₃ Scintillator Captured By An Oscilloscope



- analysis after detection is ready!
- Currently at some μ s with scintillators
- **Semiconductors could help improve the time of detection?**

How it works: Drift current

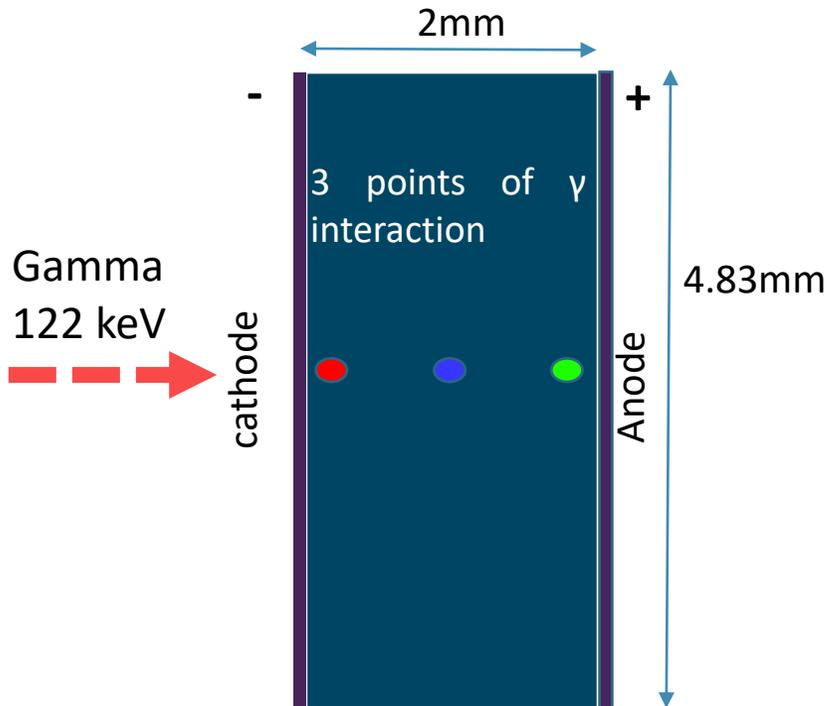
- CdTe is efficient around 100 keV of gamma
- Poor mobility of holes **10 times less** than electrons; $\mu_h=100 \text{ cm}^2/Vs$, $\mu_e=1100 \text{ cm}^2/Vs$



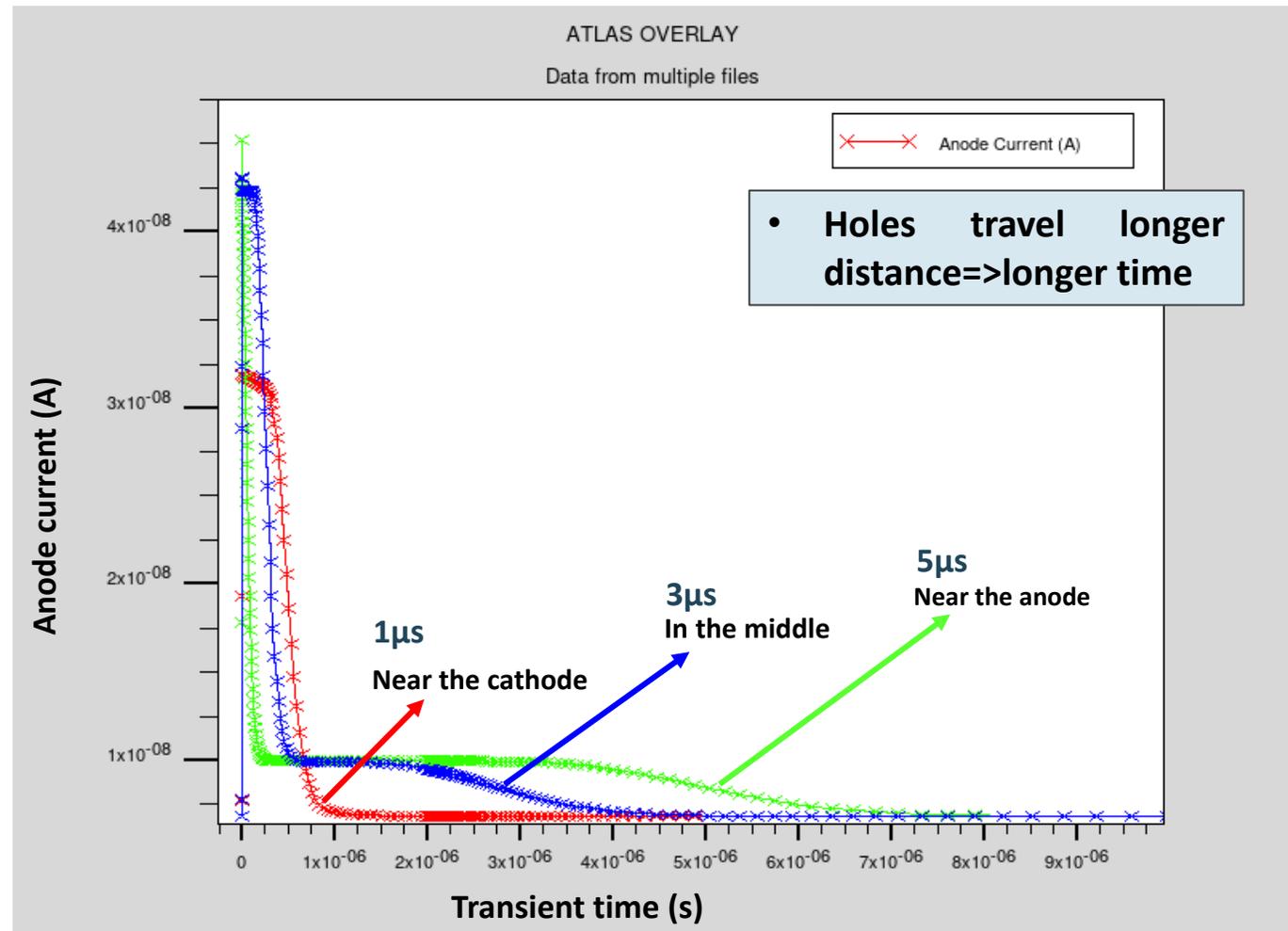
- e-h pairs are created when particle interact in detectors
- Under an Electric field, they drift to their respective electrodes
- Current is induced in the process =>Ramo-shockley: $I \propto v(e,h)$

EXPLORING SEMICONDUCTOR: Cadmium telluride (CdTe)

With ATLAS SILVACO: CdTe+ γ (different positions in Crystal)



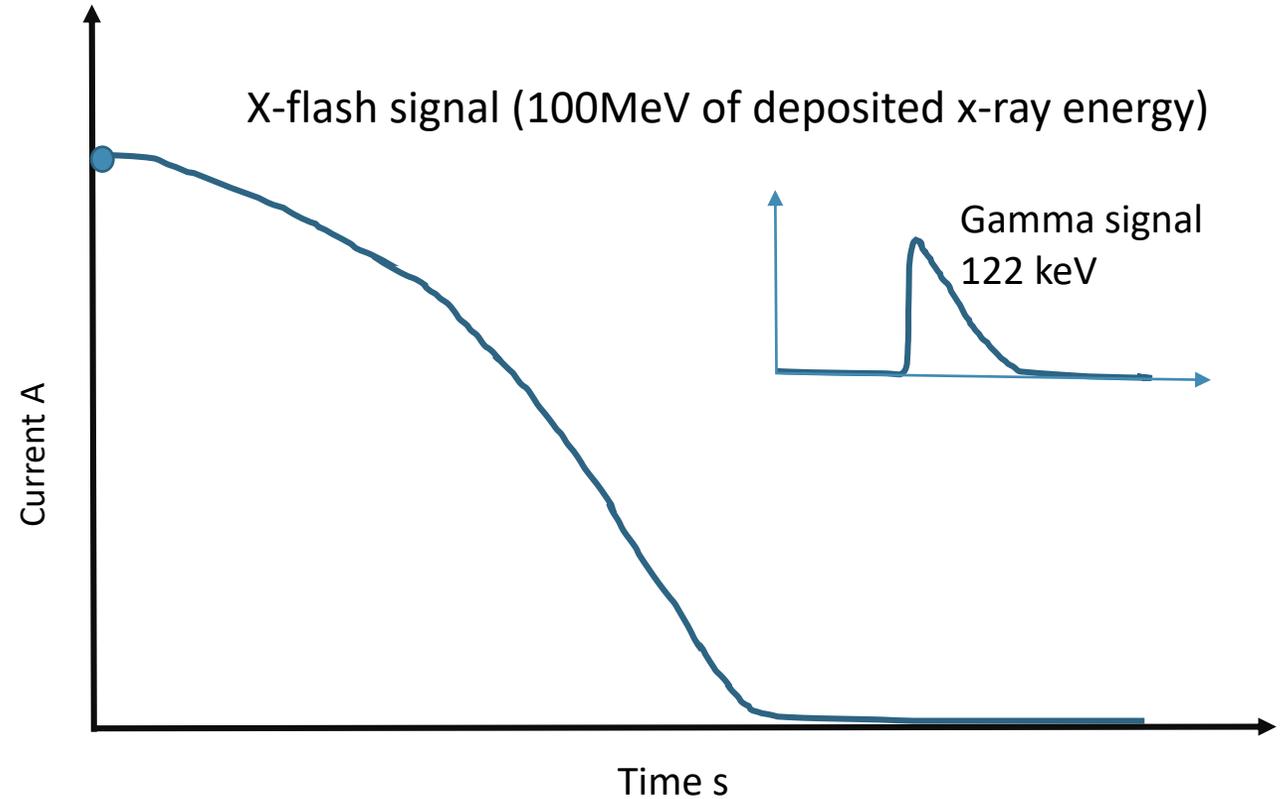
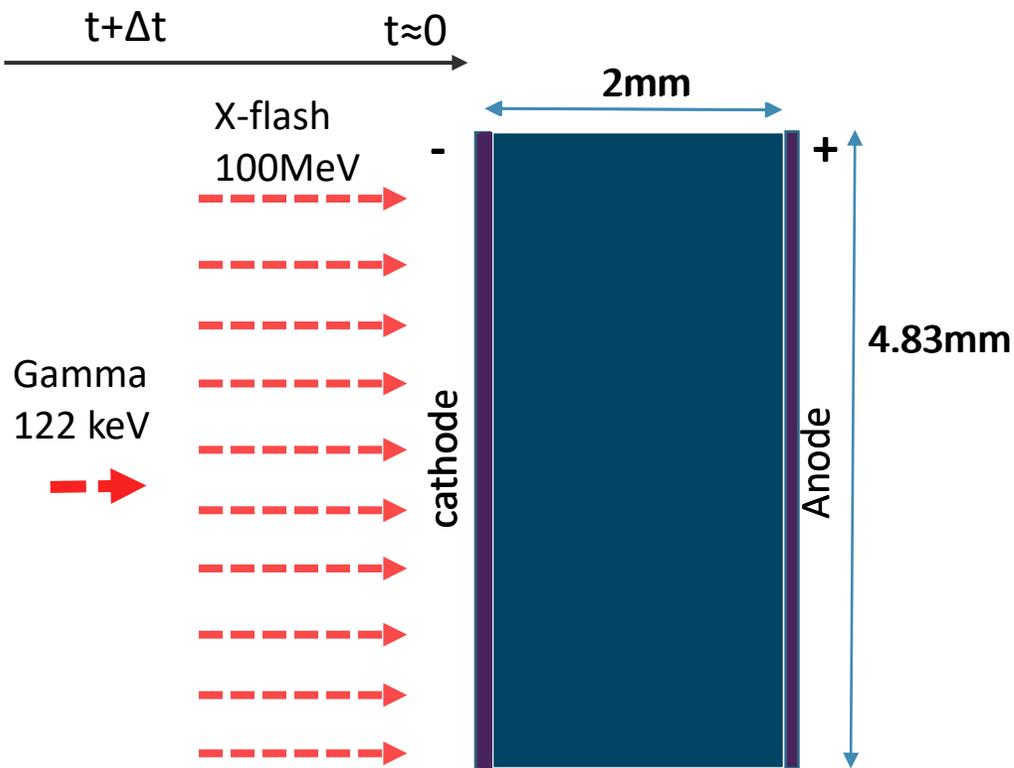
Exposing the Cathode electrode will help reduce signal duration



PILEUP CONCERNS!!!

EXPLORING SEMICONDUCTOR: Cadmium telluride (CdTe)

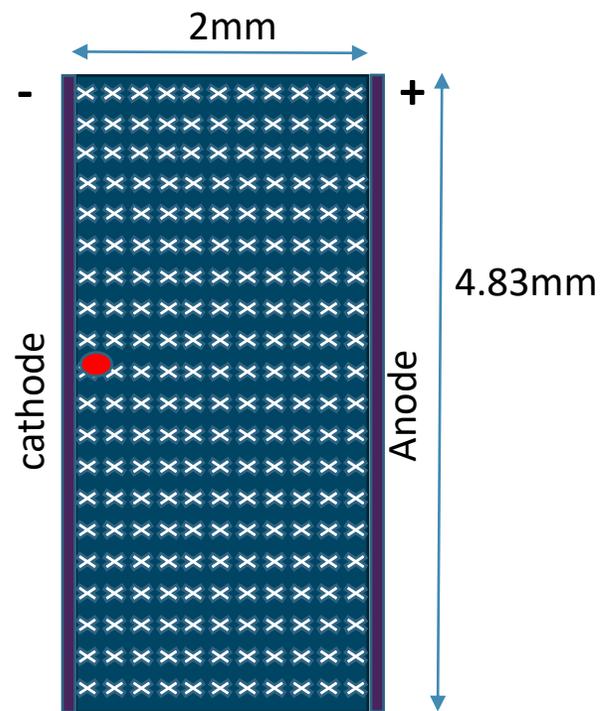
Ideal case: CdTe+X-flash+ γ



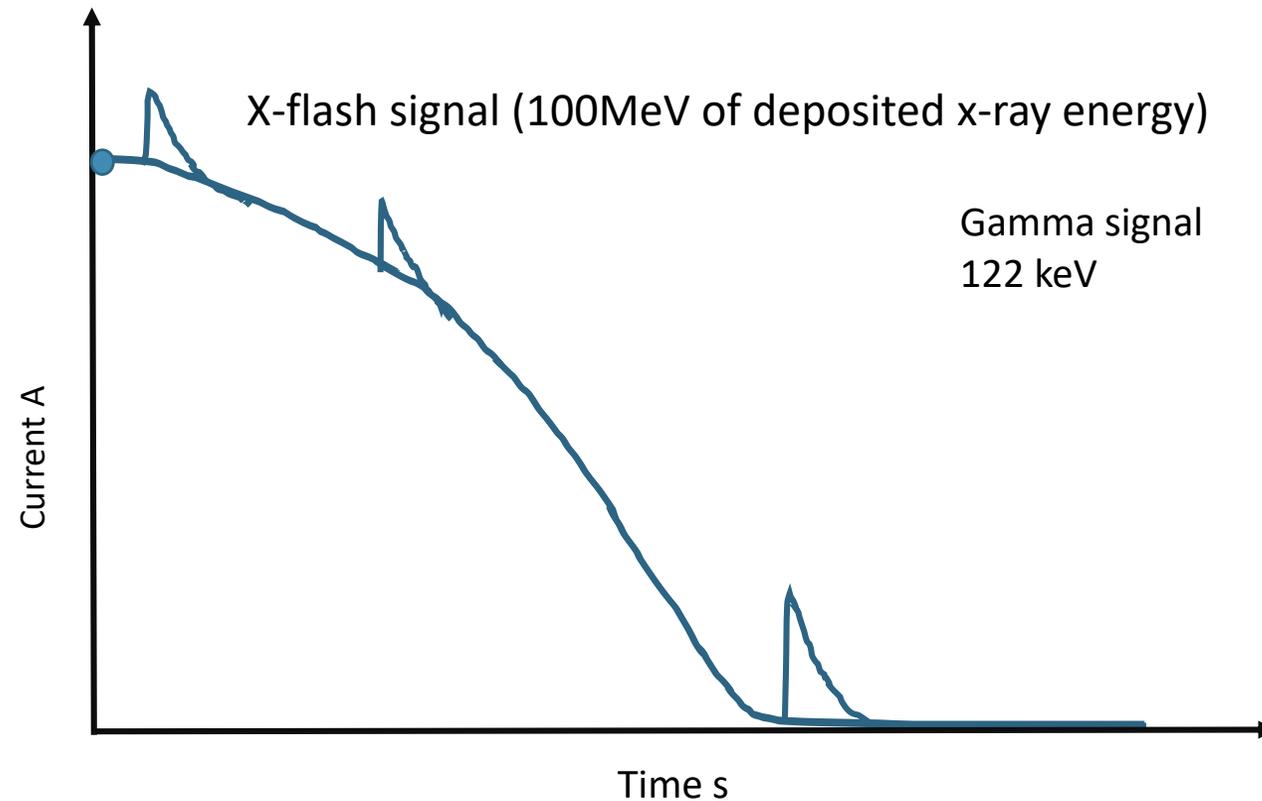
When can the 122 keV signal be found on the flash signal if it arrives after the flash?

EXPLORING SEMICONDUCTOR: Cadmium telluride (CdTe)

Ideal case: CdTe+X-flash+ γ

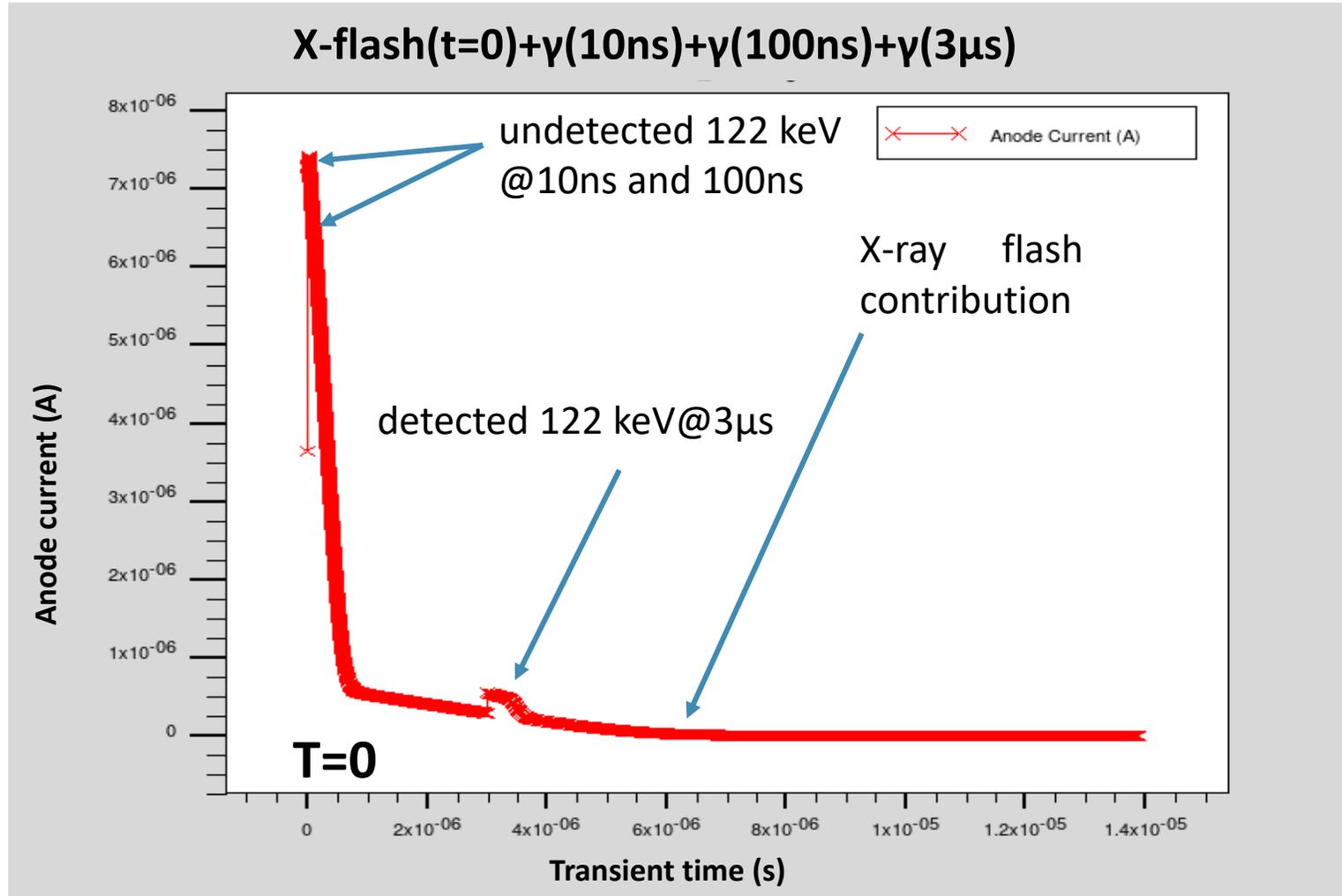


Homogeneous distribution of charges from X-ray flash



When can the 122 keV signal be found on the flash signal if it arrives after the flash?

Real case: CdTe+X-flash+ γ



- Long duration=>Hole drift and electron diffusion current
- Within some μ s for detection (for 100MeV)

CONCLUSIONS AND PERSPECTIVE

- Large Quantities of Xrays => A major limitation of γ spectroscopy in Laser Plasma
- With scintillators => limited in 10s of μ s
- CdTe considered:
 - ⇒ detection possible within few μ s
 - ⇒ Pileup concerns ❌

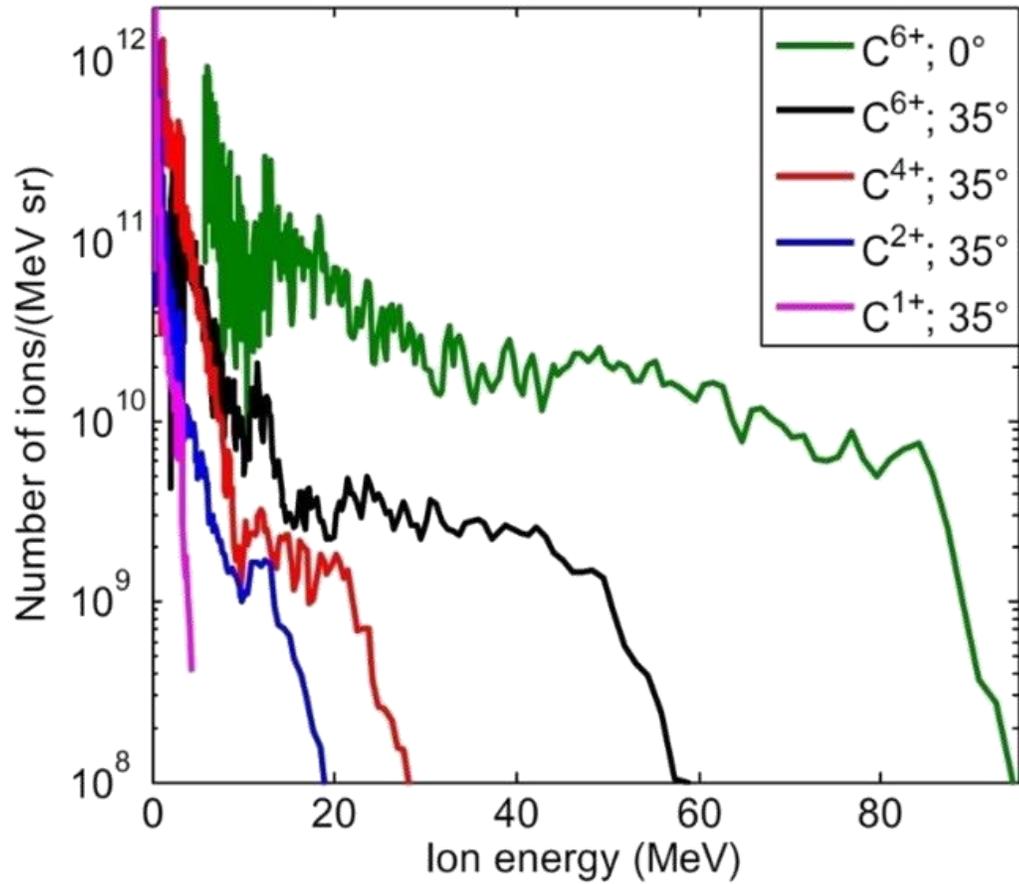
- Back to scintillators=> Filter bands of interest from Scintillator
- Try silicon=> with more thickness (Good hole and electron mobility)
- Further test experiments next year
- Suggestions are welcomed



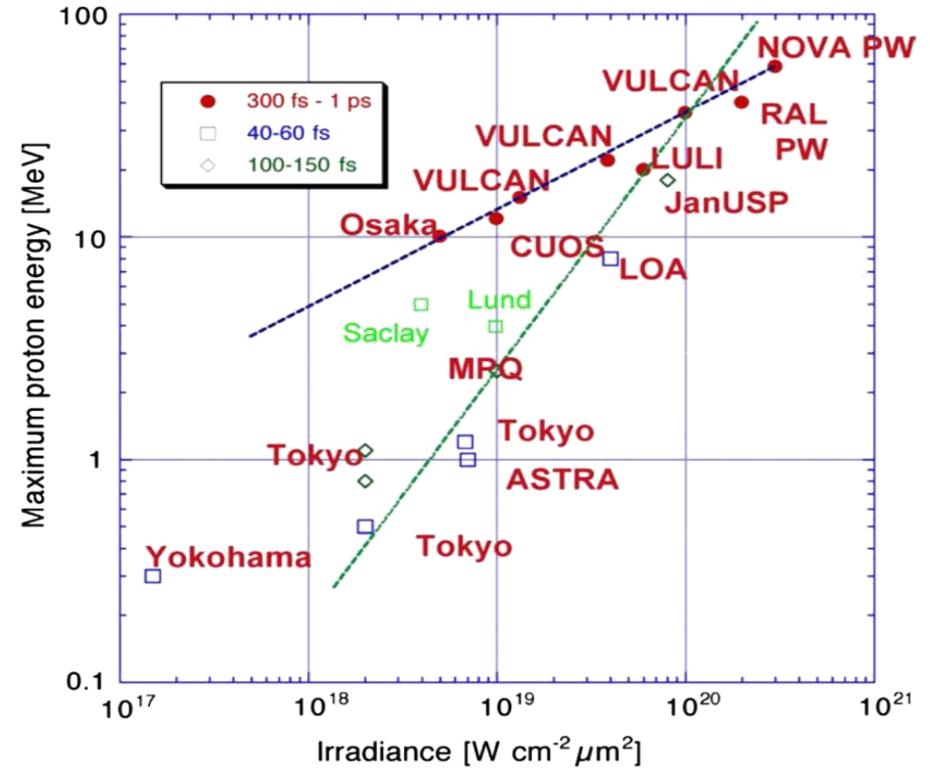
THANK YOU FOR LISTENING

Backup slides

Energies reached for C and H ions



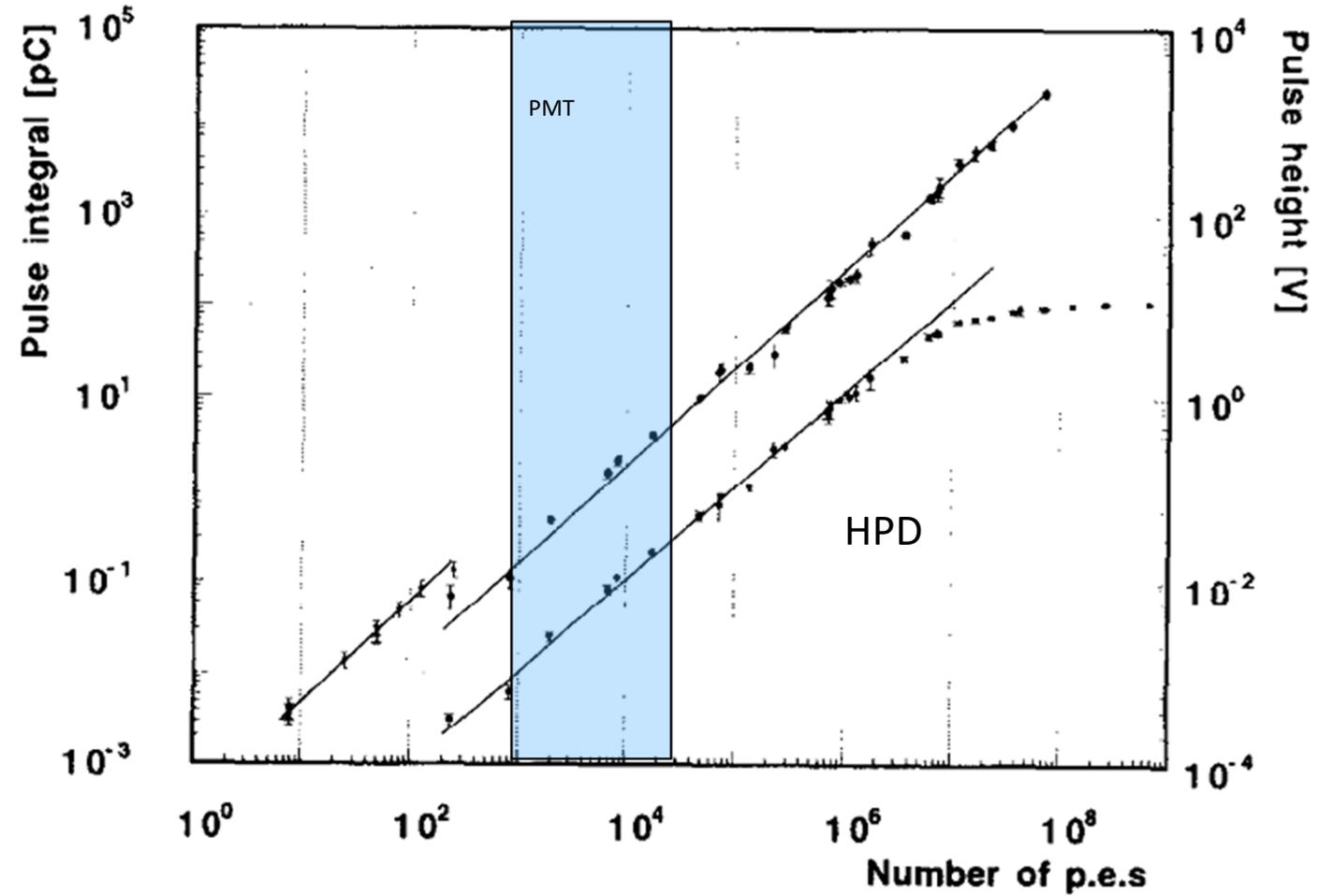
Carroll, D. C et al., *New Journal of Physics* **12** (2010) 045020 (15pp)



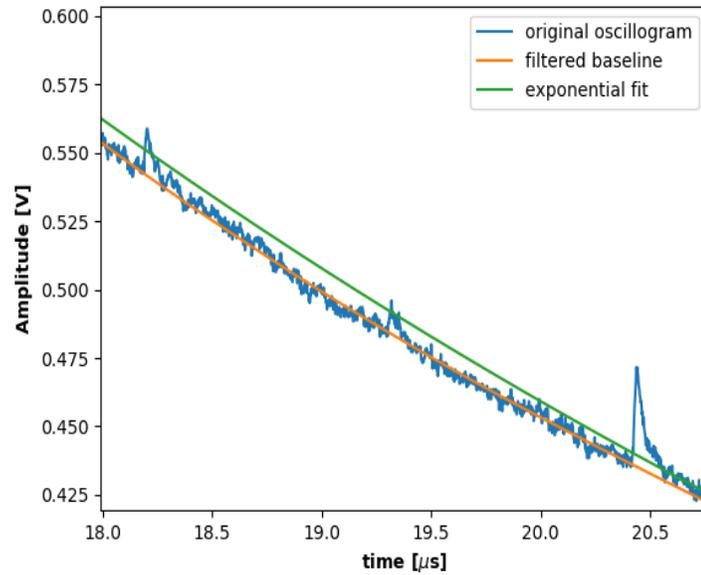
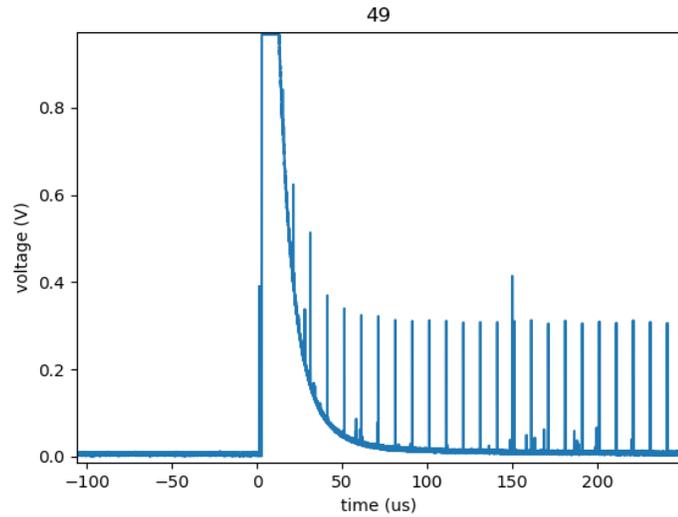
Macchi et al. *Rev. Mod. Phys.*, **85**, 751 (2013)

OFFLINE ANALYSIS

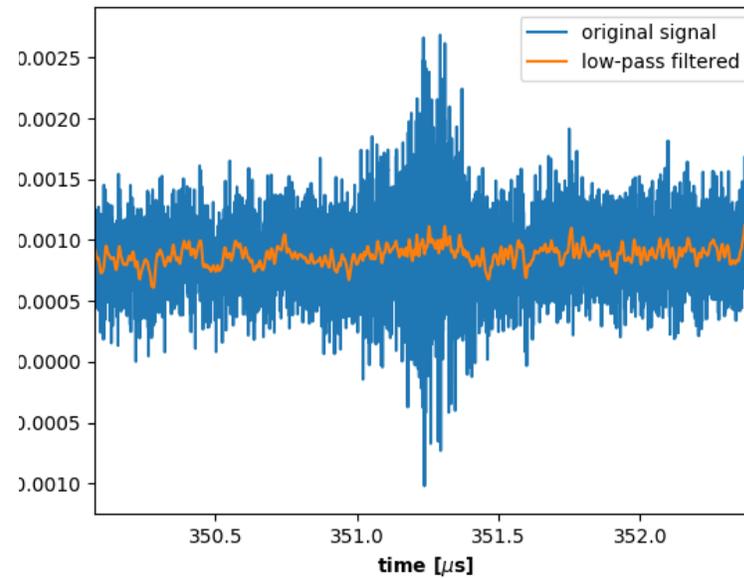
HPD has a wider range compared to PMT



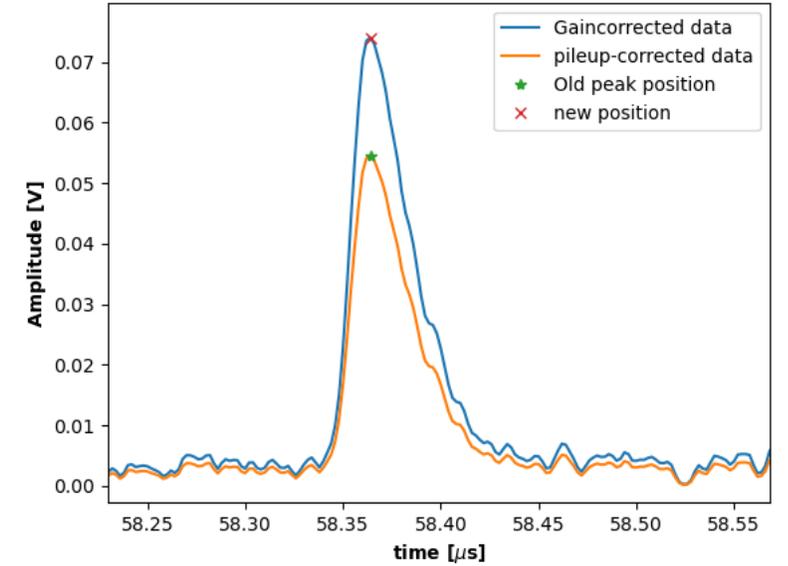
OFFLINE ANALYSIS



X-ray signal baseline subtraction



Noise and EMP perturbation treatment

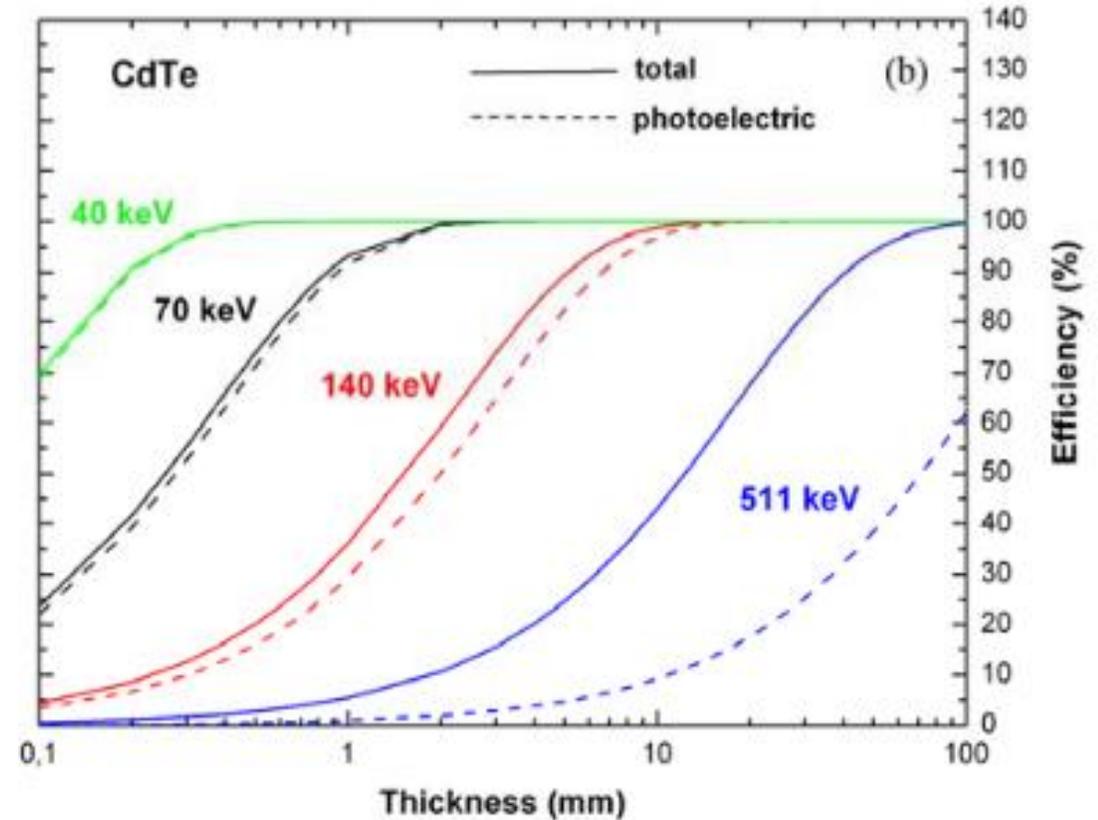
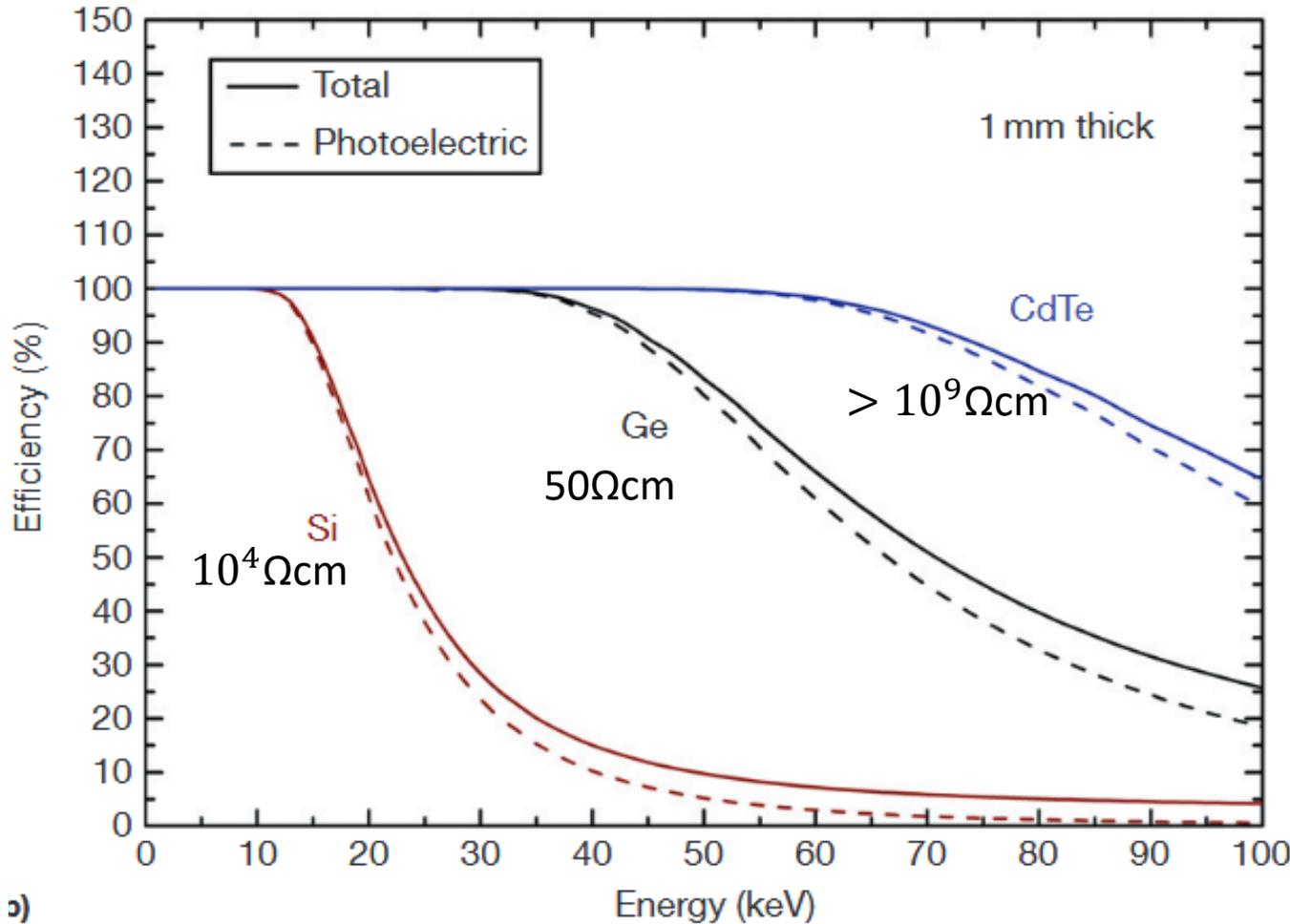


Gain correction

- Combining successive LEDs we can restore each gamma pulse to their original amplitudes

WITH SEMICONDUCTOR HOW CLOSE CAN WE GET FOR 122 keV?

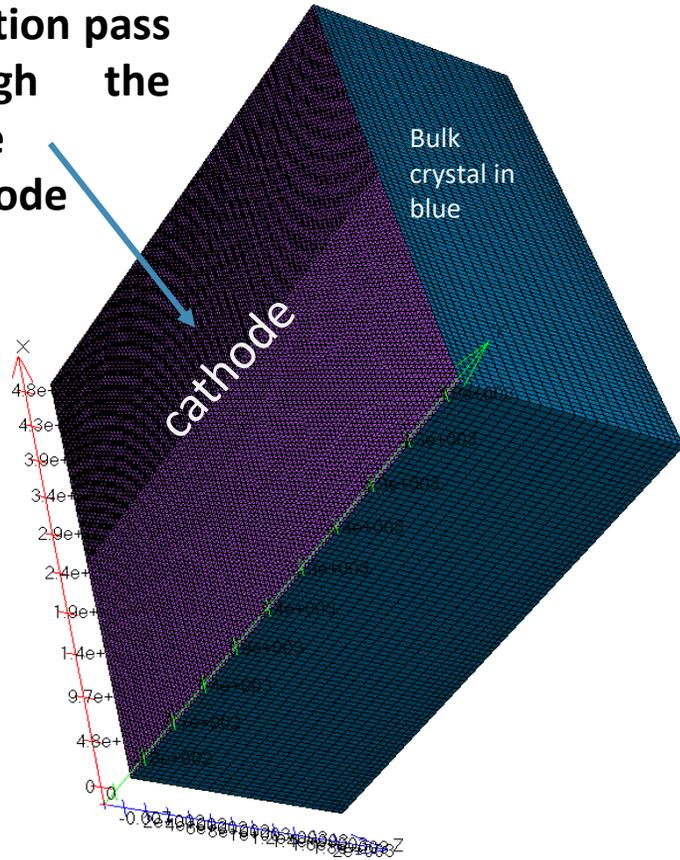
Exploring Cadmium telluride (CdTe) : $^{90}\text{Zr}(p,n)^{90}\text{Nb}$



SILVACO SOLVES THE FOLLOWING EQUATIONS

Modelling CdTe detector with SILVACO

Radiation pass through the anode
Electrode



$$\vec{E} = -\nabla\psi$$

$$\frac{\partial n}{\partial t} = \frac{1}{q} \text{div} \vec{J}_n + G_n - R_n$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q} \text{div} \vec{J}_p + G_p - R_p$$

$$\vec{J}_{dis} = \varepsilon \left(\frac{\partial \vec{E}}{\partial t} \right)$$

○ Electron current

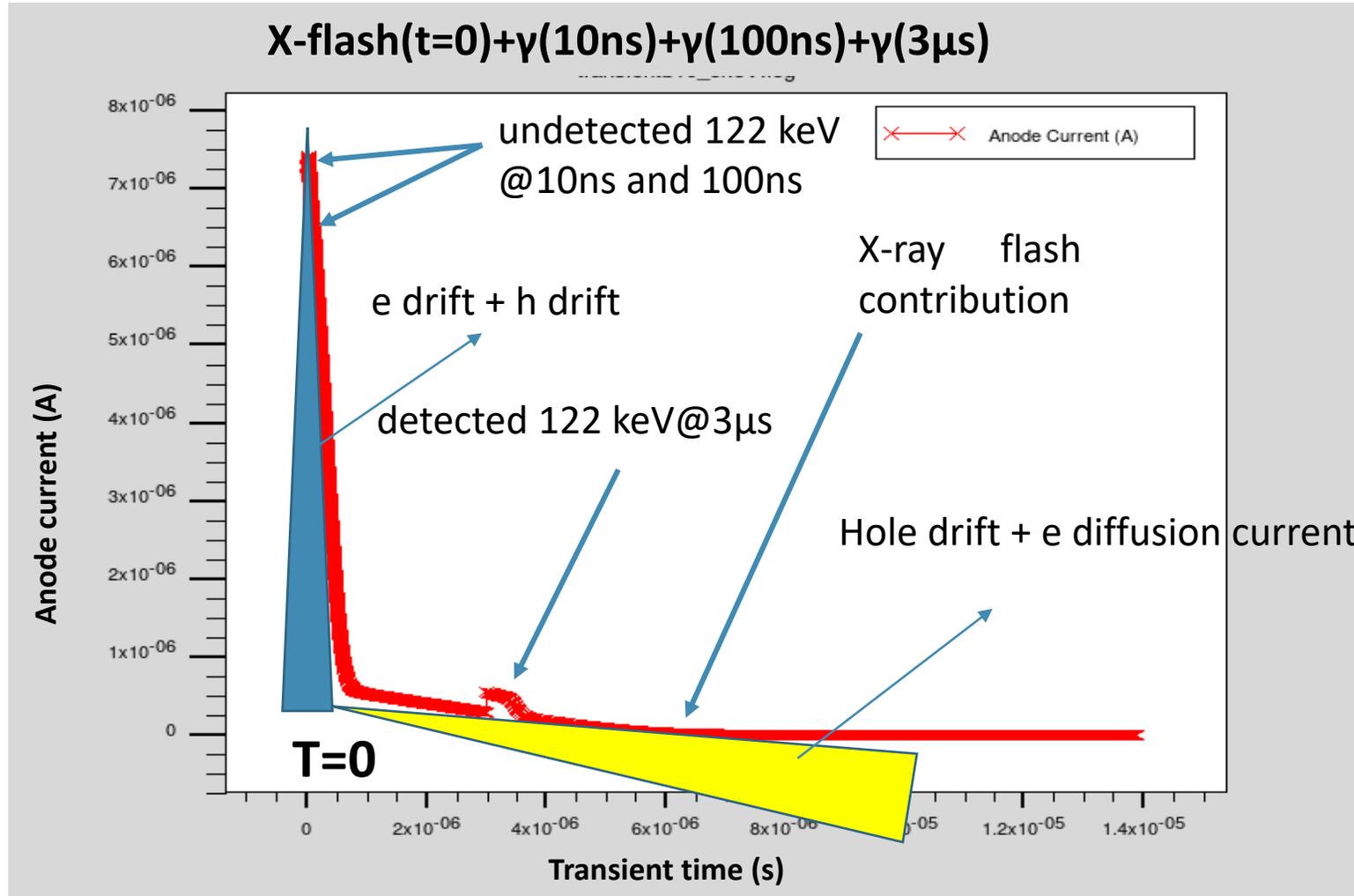
○ Hole current

○ Displacement current

$$\vec{J}_n = qn\mu_n \vec{E}_n + qD_n \nabla n$$

$$\vec{J}_p = qp\mu_p \vec{E}_p - qD_p \nabla p$$

Real case: CdTe+X-flash+ γ



- No detector saturation
- Long duration=>Hole drift and electron diffusion current