Gamma spectrometry in the highly disturbed environment of a high power laser

E. Atukpor , M. Tarisien

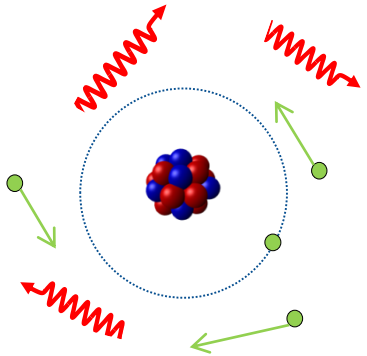
The High power Laser

[0.1 – 10] PW

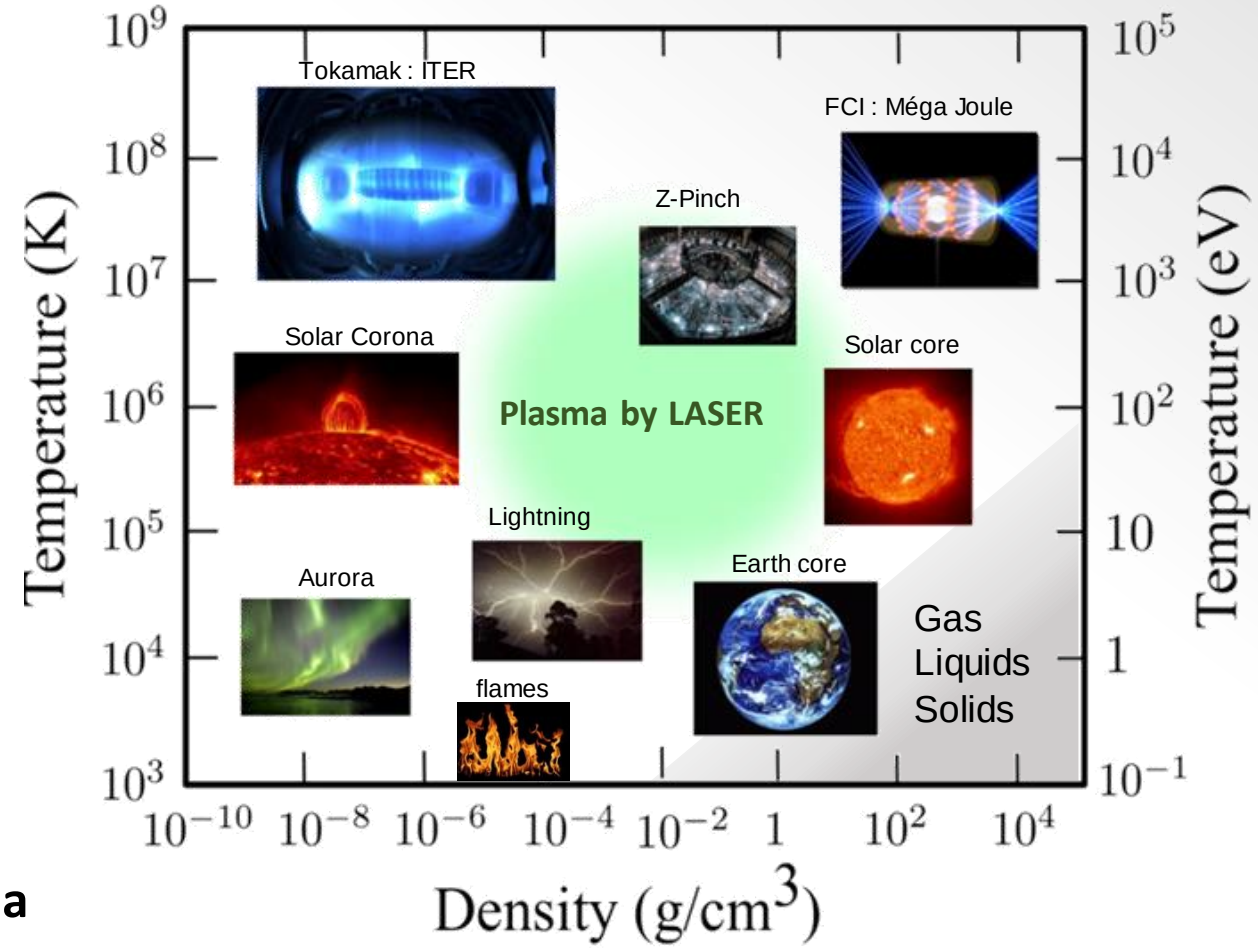
Power density
(Intensity)
$10^{18\text{-}22}$ W.cm^{-2}

Are nuclear reactions the same in a star as in a solid?

The plasma is the 4th state of matter (99.9% of the visible matter)



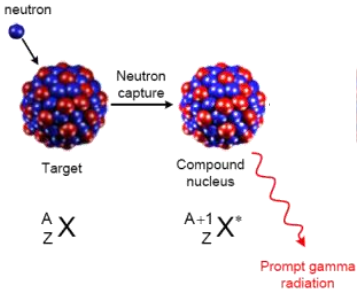
- Multicharged ions
- Free electrons
- Photons



→Huge population of excited nuclei in a plasma

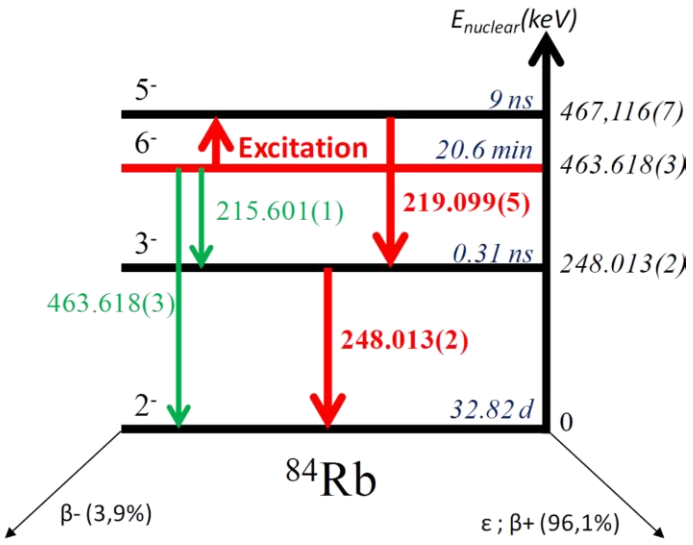
Do the nuclei have the same properties in plasma as in a solid?

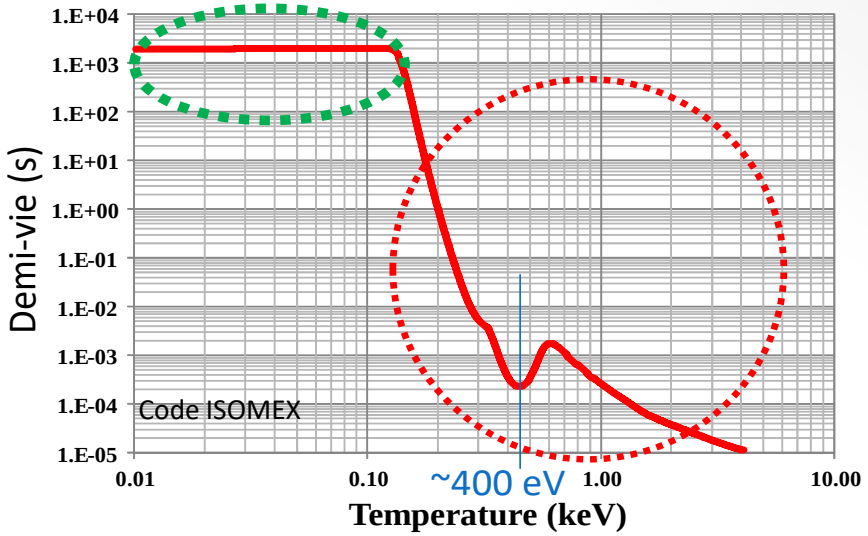
- Nuclear reaction Cross section modifications on excited state



Neutron energy	$^{177m}Lu(n,\gamma)^{178m}Lu$ / $^{177}Lu(n,\gamma)^{178m}Lu$
< 25 meV	0,47 +/- 0,07

- Modifications of apparent half-lives





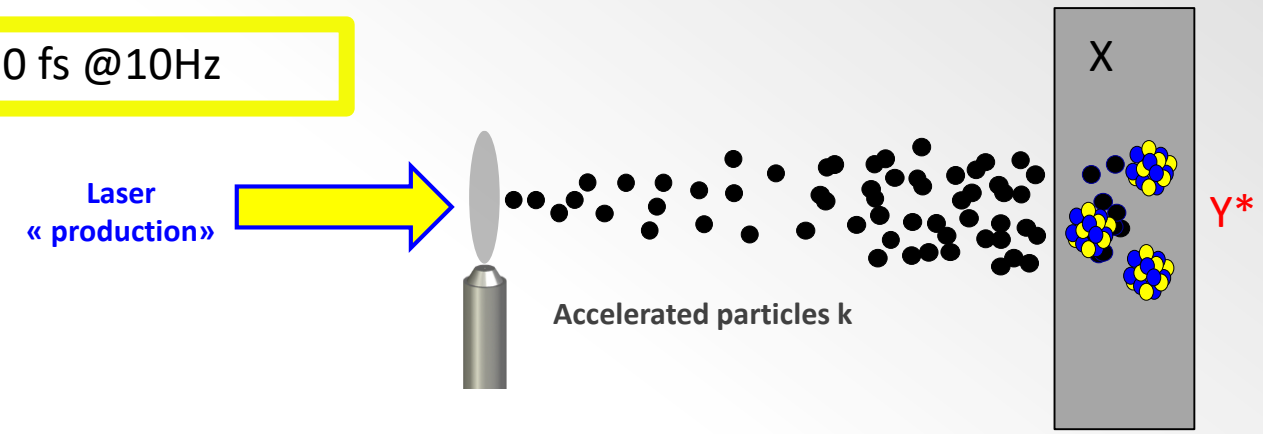
D. Denis-Petit, et al. Phys. Rev. C 96, 024604 (2017)

Apparent half-life modification experiment

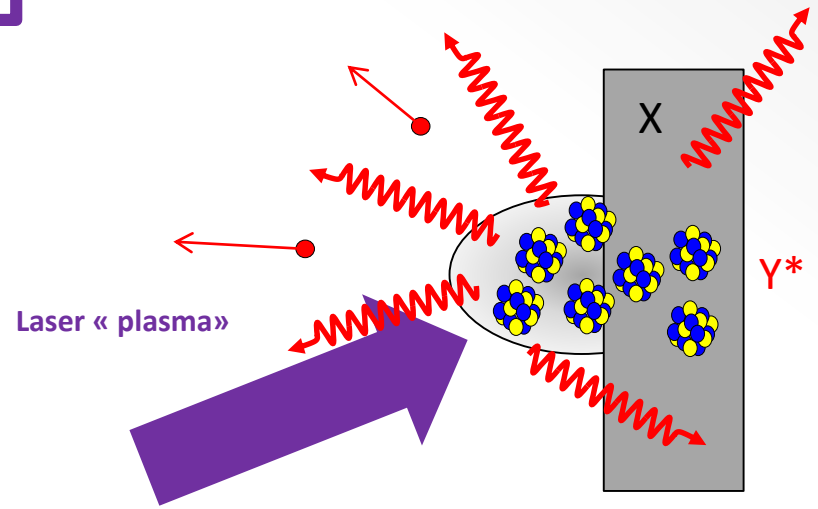
Par exemple sur

ELI-Beamlines, Prague

30J ; 30 fs @10Hz



1.5 kJ ; 1 ns @ 1 tir/min



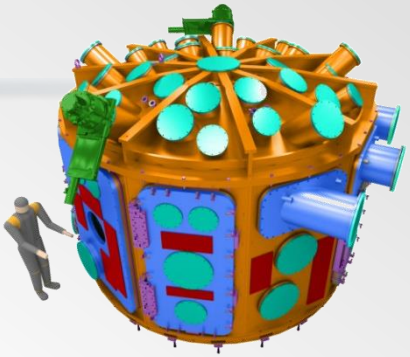
✓ Lifetime studies in astrophysical plasma

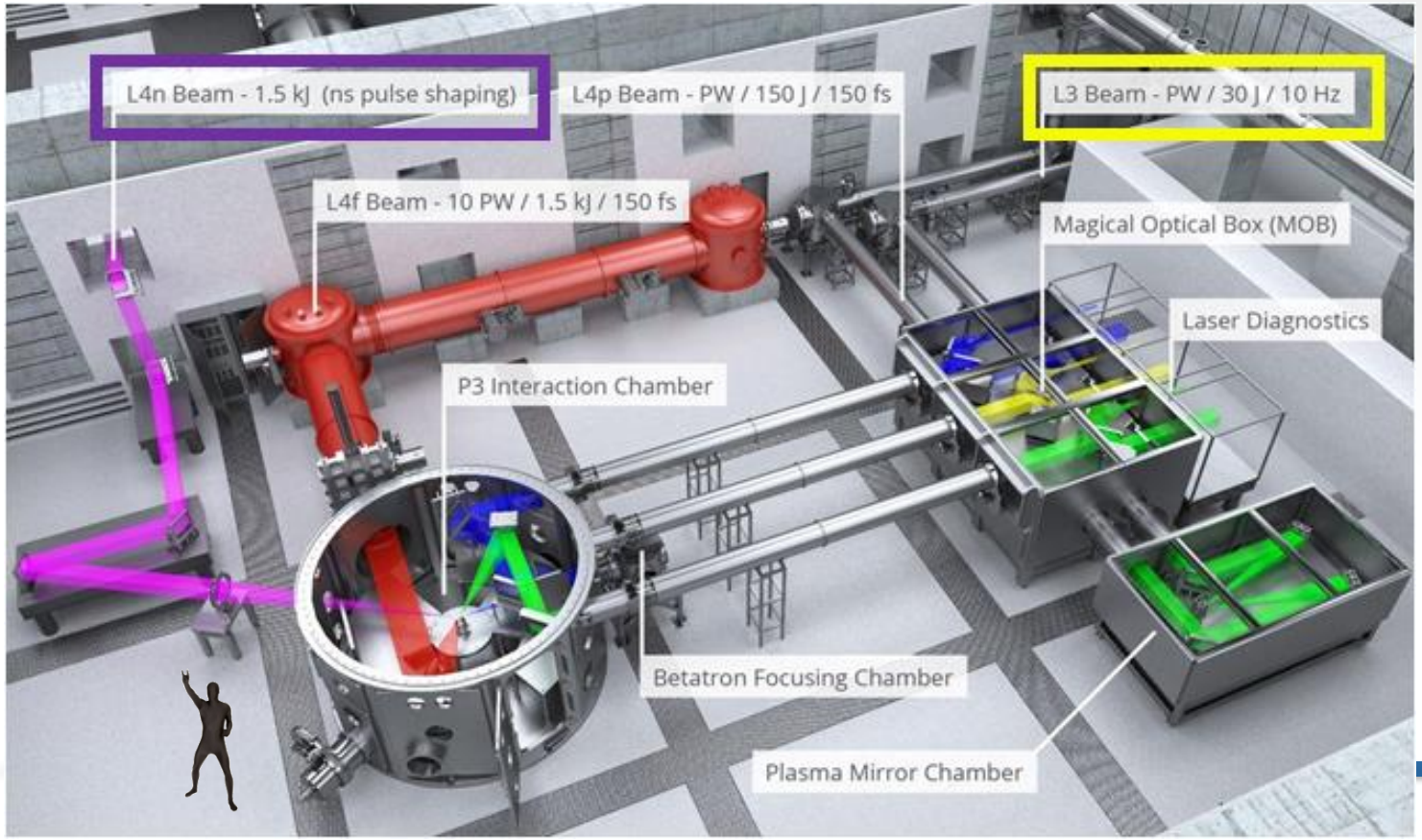
Apparent half-life modification experiment

ELI-Beamlines, Prague

30J ; 30 fs @10Hz

1.5 kJ ; 1 ns @ 1 tir/min

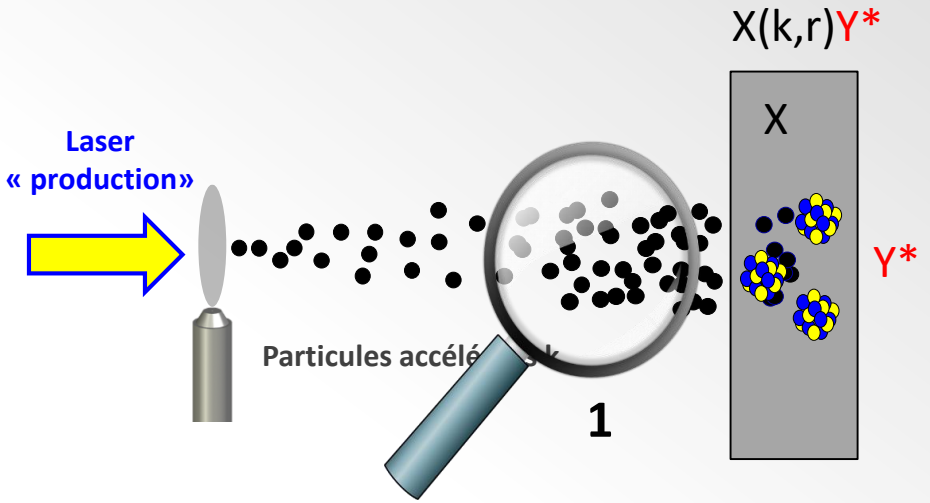


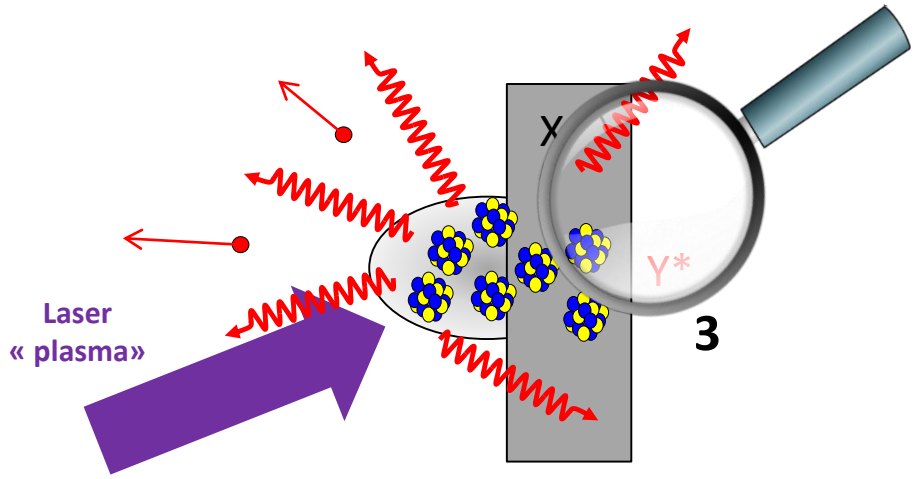


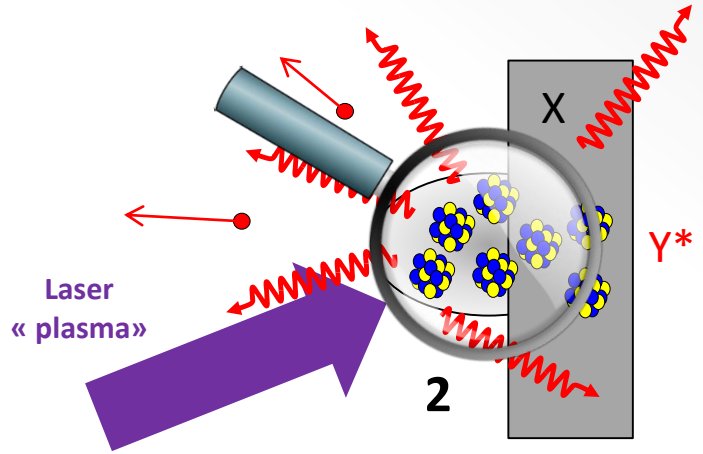
Apparent half-life modification experiment

Requires :

1. Laser-Plasma Acceleration **of projectiles**, Production and **Characterisation**
2. Producing astrophysical plasmas
3. **Detection of nuclear observables near a laser shot**

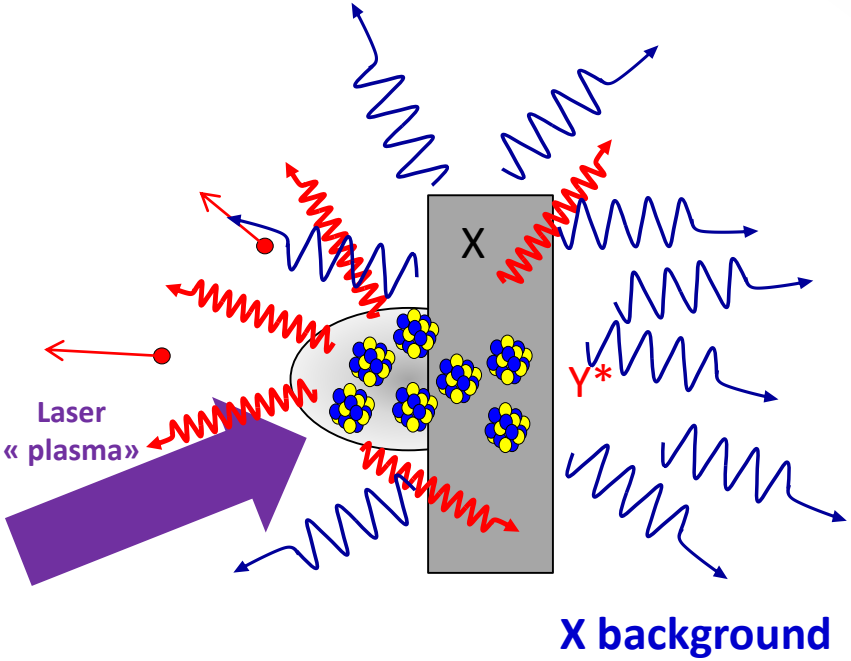






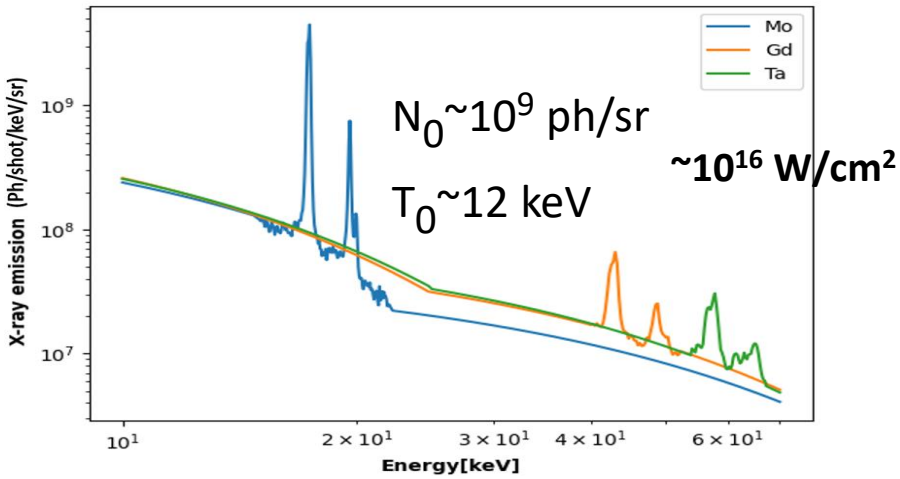
X ray flash makes detector blind

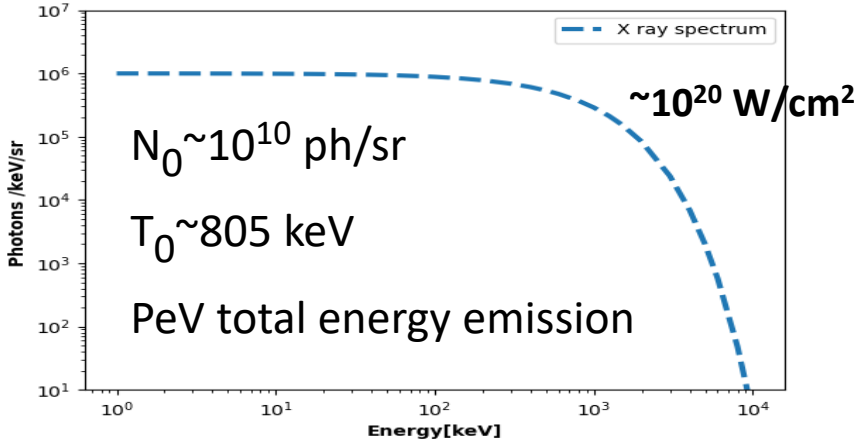
BUT : generation of X background



X background

X-ray spectrum measured at CELIA (ECLIPSE)





Some TeV to PeV total energy emission

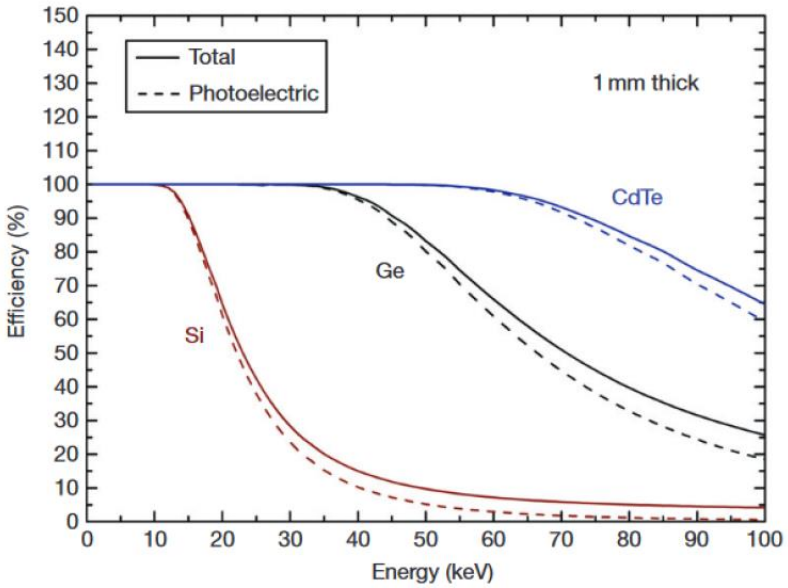
This background make blind the detectors for long periods (**up to ms**)

CdTe for gamma spectroscopy

(~< 1 MeV)

Cadmium Telluride

- ✓ Good for detecting few hundred keV gamma



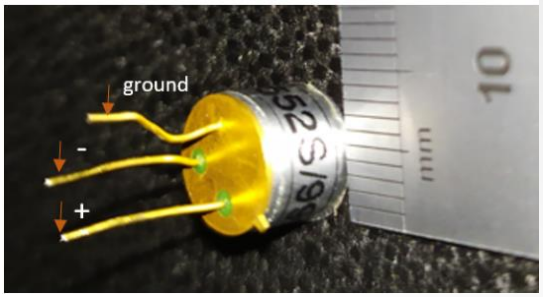
μ_e ~1100 cm^2/V.s

μ_h ~ 100 cm^2/V.s

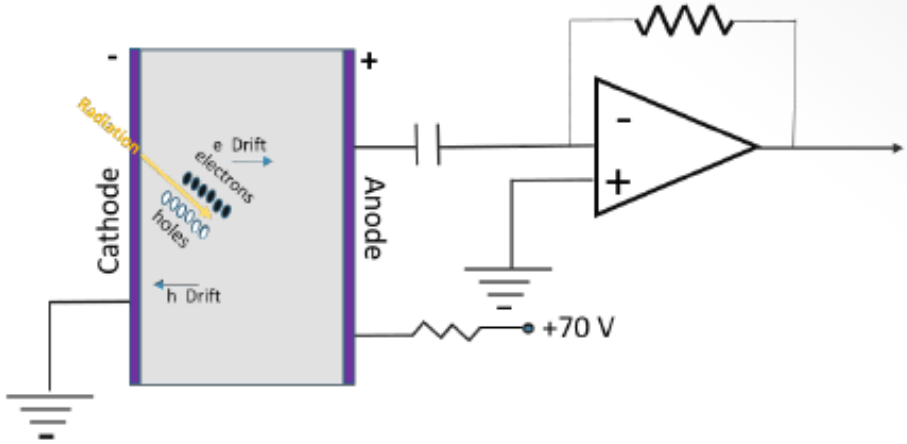
Main problem

- ✓ Bought CdTe in Aluminium Cylinder

Eurorad Company

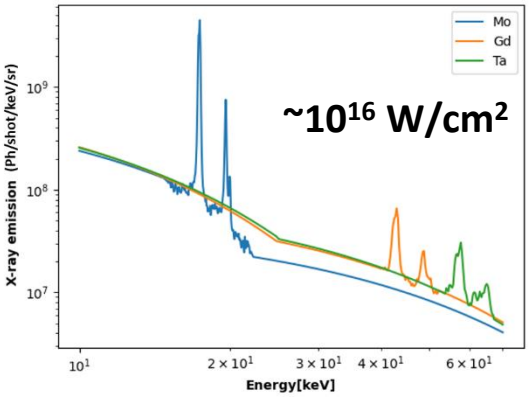


4.83 x 4.83 x 2 mm^3

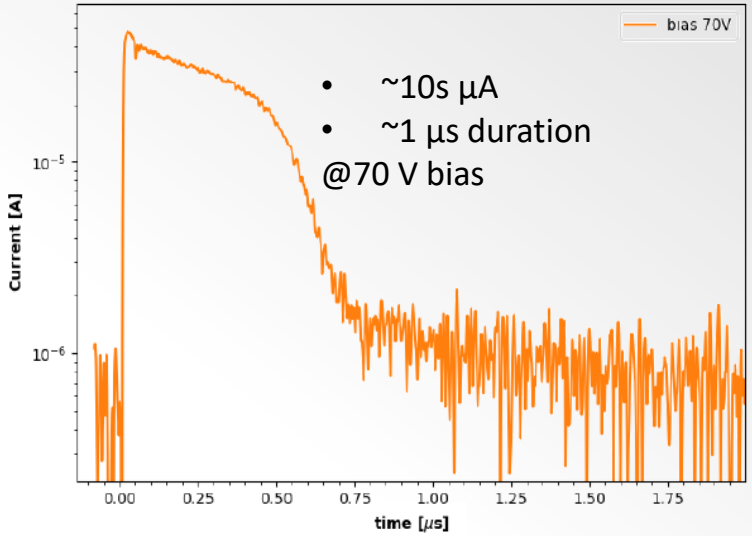


CdTe for gamma spectroscopy

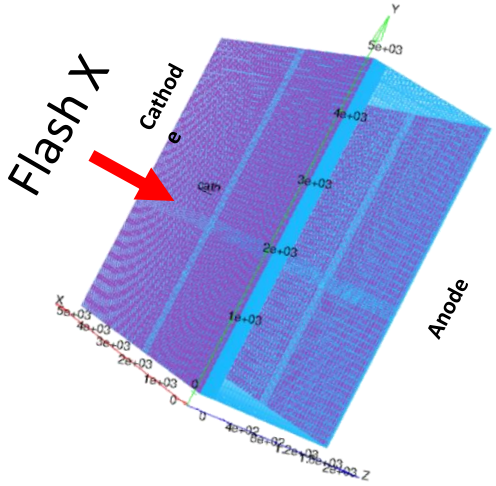
(~< 1 MeV)

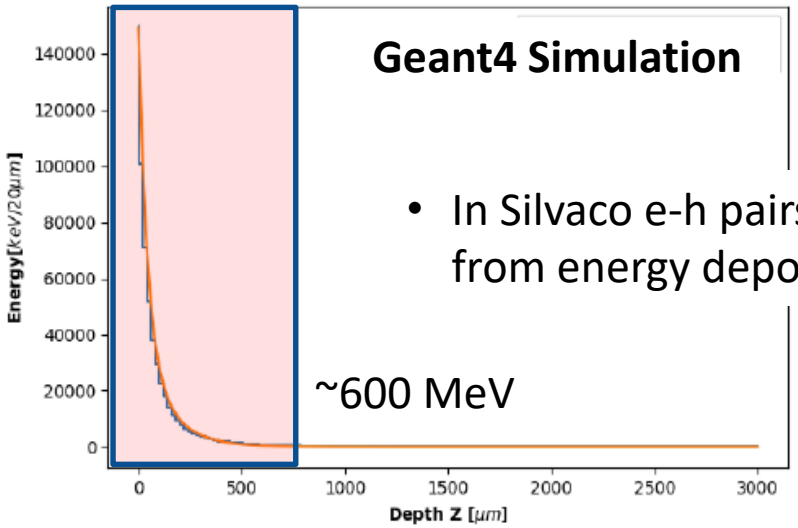


CELIA Experiment



Silvaco Simulation

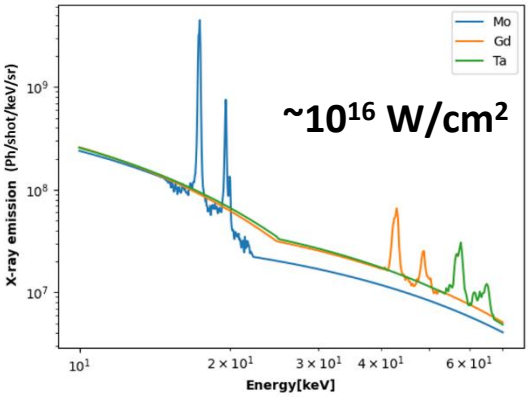




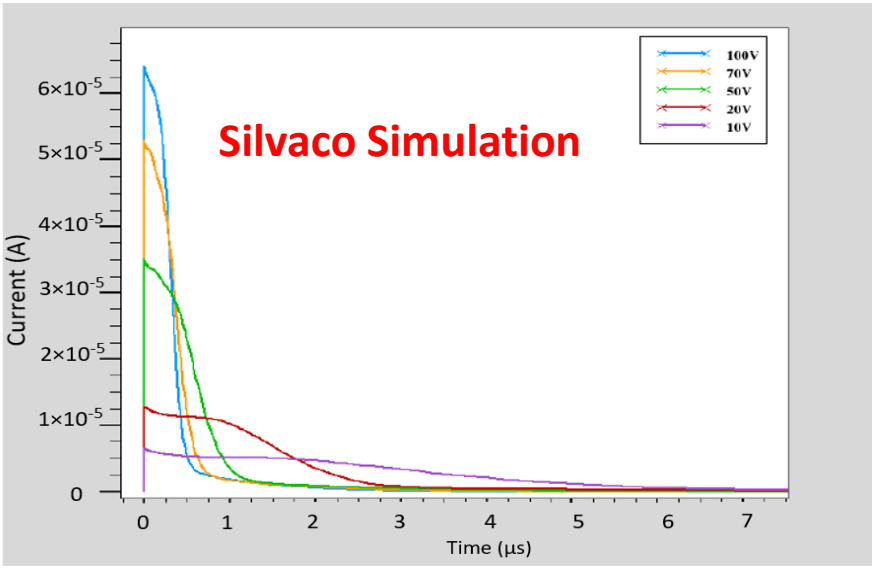
- In Silvaco e-h pairs are generated from energy deposition distribution

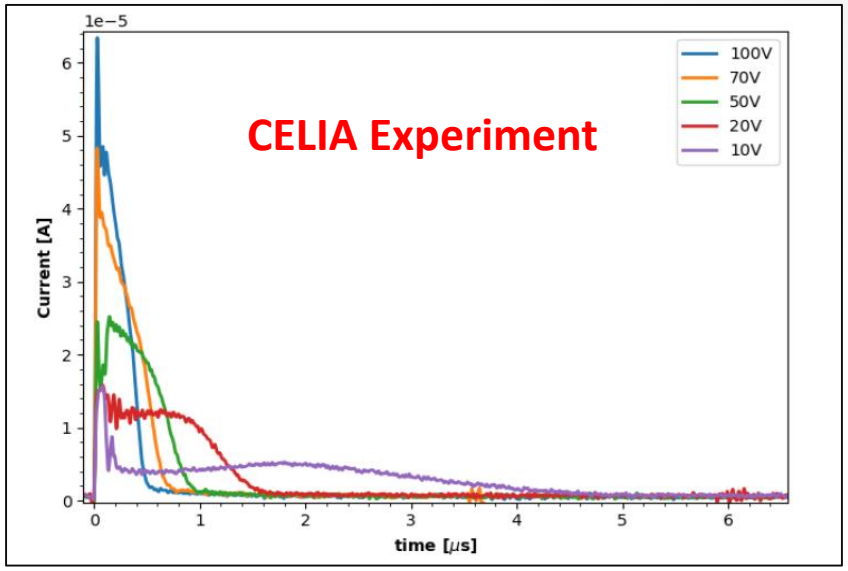
CdTe for gamma spectroscopy

(~< 1 MeV)



- Good matching between simulation and experiment
- We can put confidence in the simulation



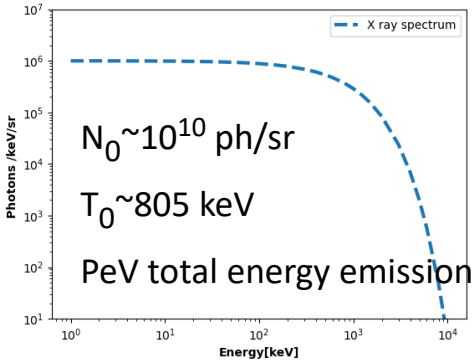


CdTe for gamma spectroscopy

(~< 1 MeV)

CdTe in X flash from Higher intensity laser: Simulation

Experimental data
(one of the worst conditions)

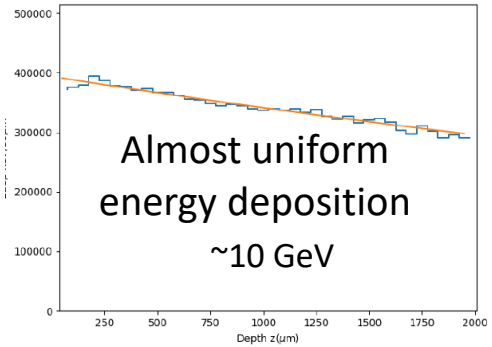


N_0~10^{10} ph/sr

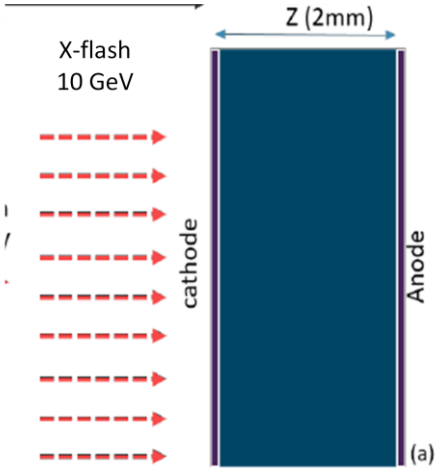
T_0~805 keV

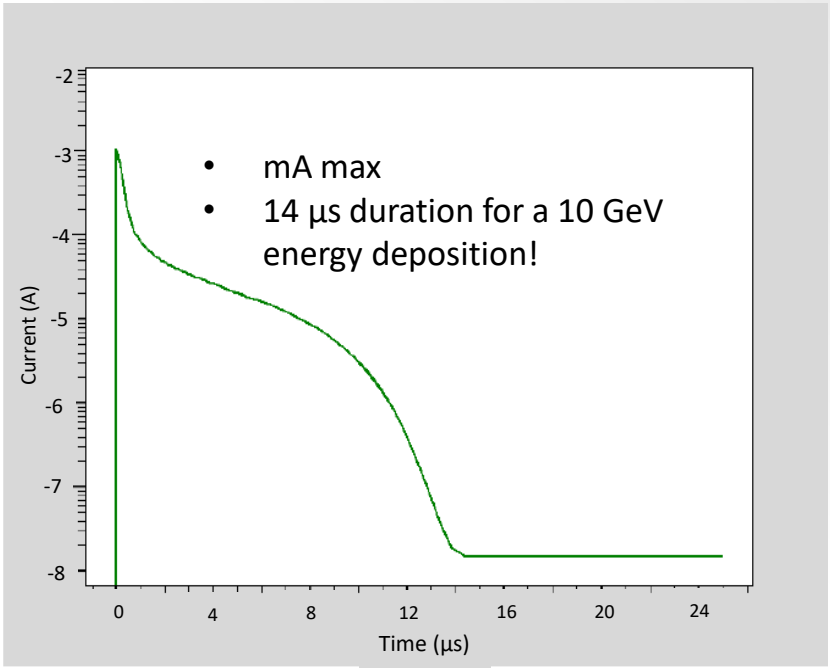
PeV total energy emission

Geant4 Simulation



Almost uniform
energy deposition
~10 GeV





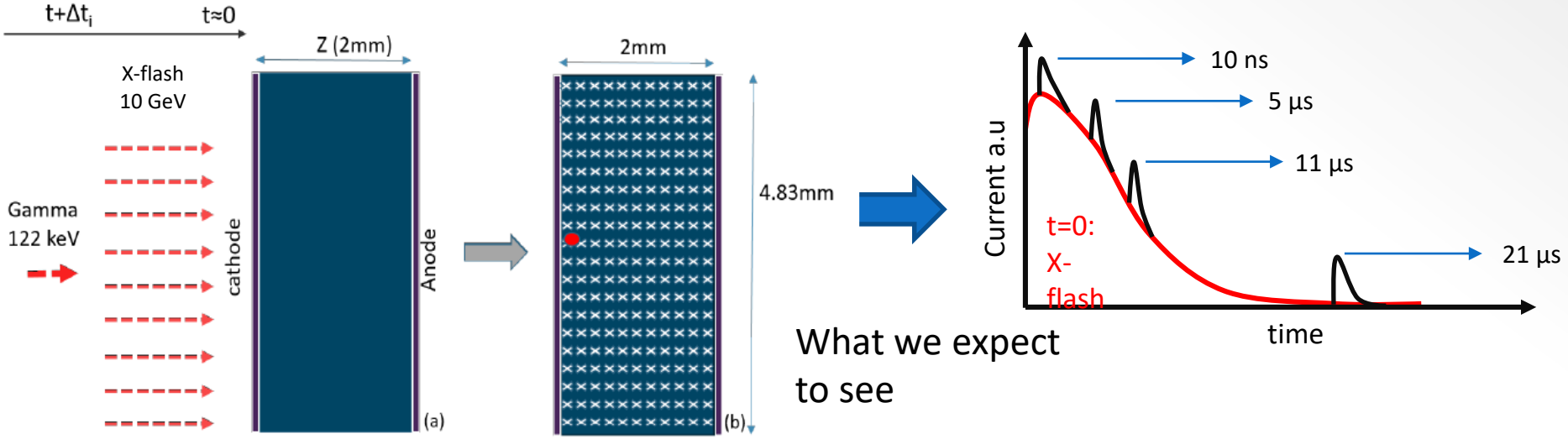
When can a gamma be detected after the X flash?

CdTe for gamma spectroscopy

(~< 1 MeV)

CdTe gamma spectroscopy in X flash from Higher intensity laser: Simulation

✓ X flash + 122 keV gammas



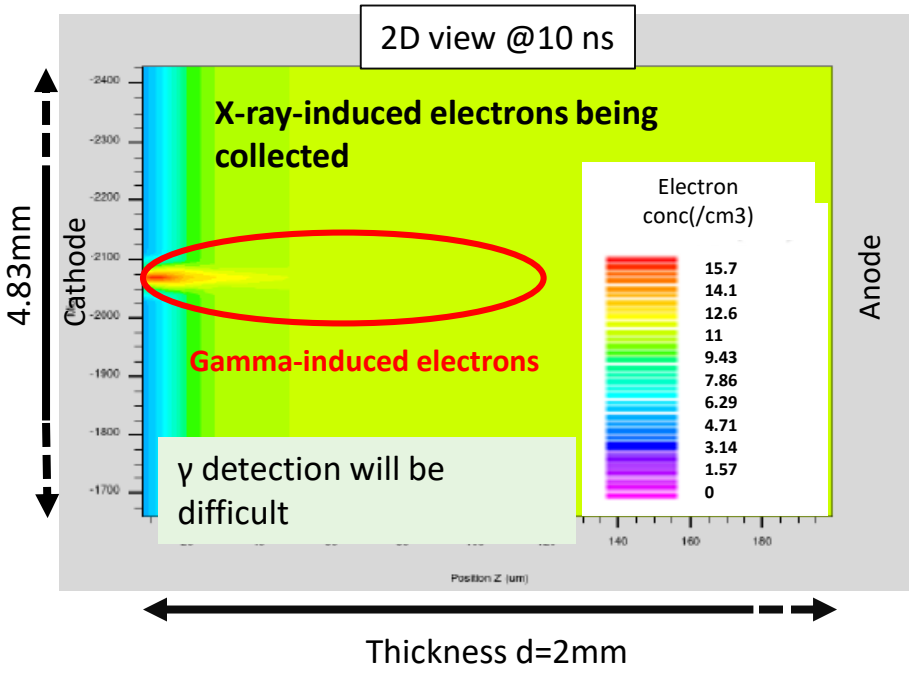
What we expect to see

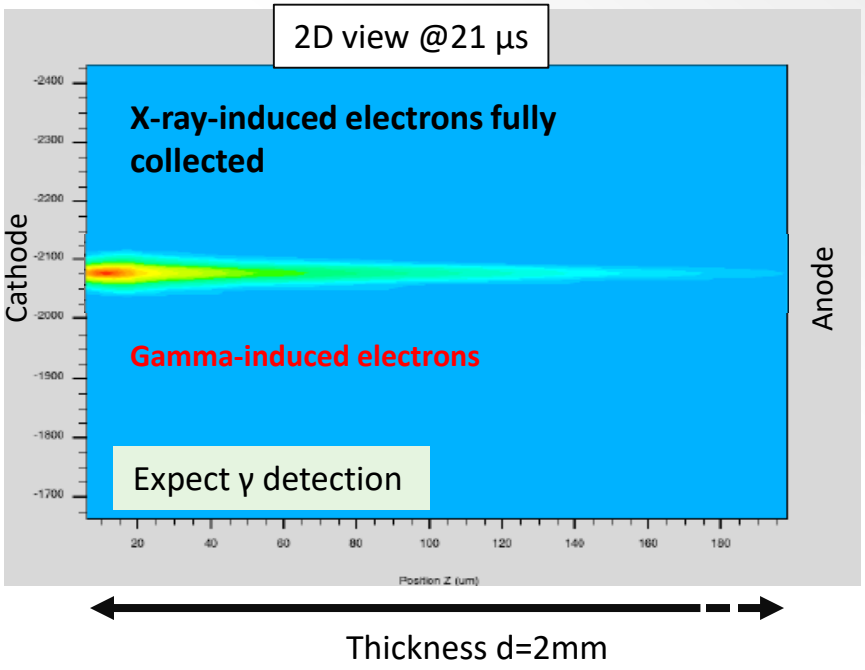
CdTe for gamma spectroscopy

(~< 1 MeV)

CdTe gamma spectroscopy in X flash from Higher intensity laser: Simulation

✓ X flash + 122 keV gammas

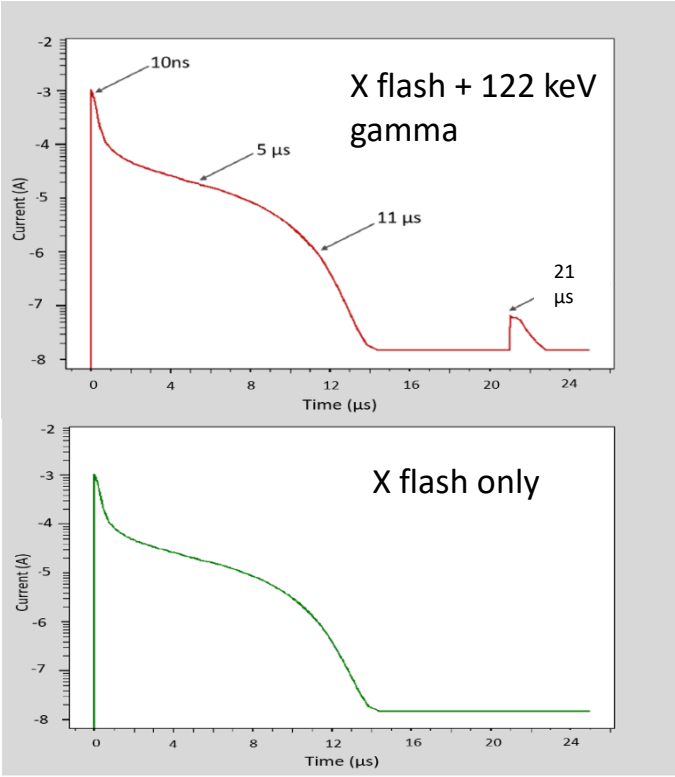




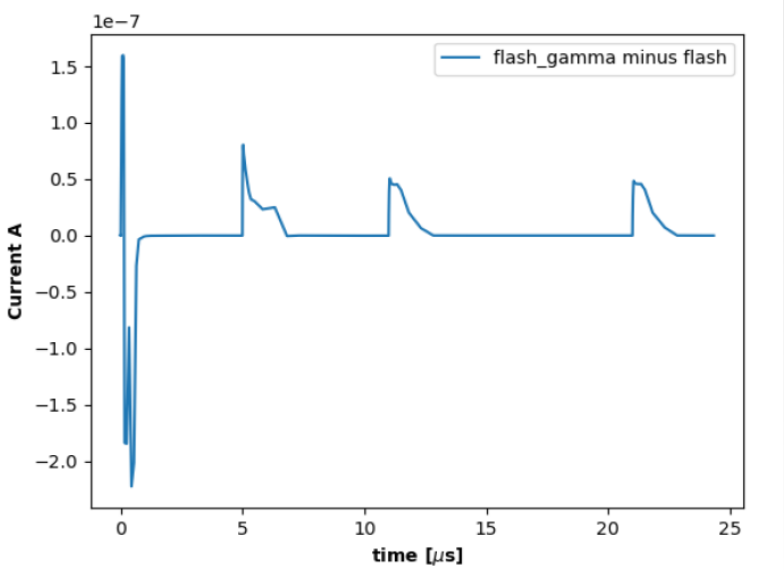
CdTe for gamma spectroscopy

(~< 1 MeV)

CdTe gamma spectroscopy in X flash from Higher intensity laser: Simulation

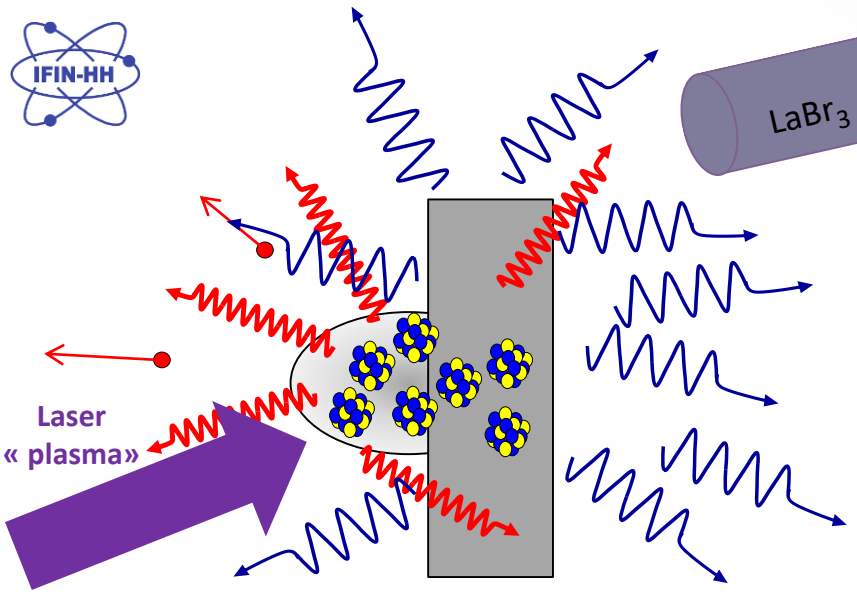


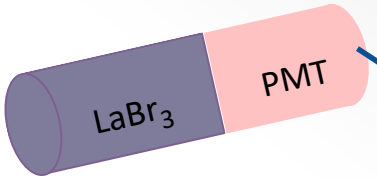
Subtraction



- Detection at the instant of the laser short is not possible
- The earliest detection without deformation of the pulse is about 10 µs

Scintillator in high power laser environment

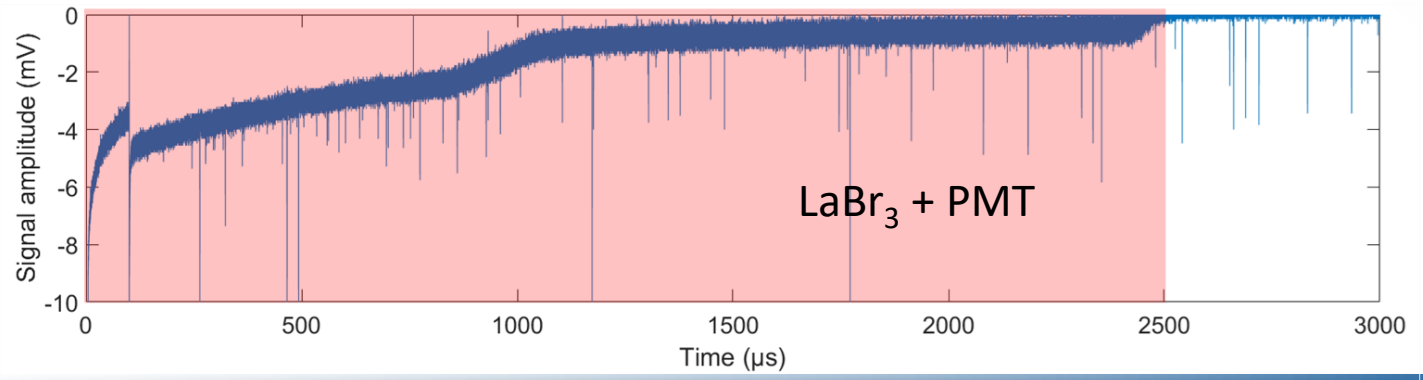




Half life	γ transition Energy
63 μs	122.37 keV
6.19 ms	257.34 keV

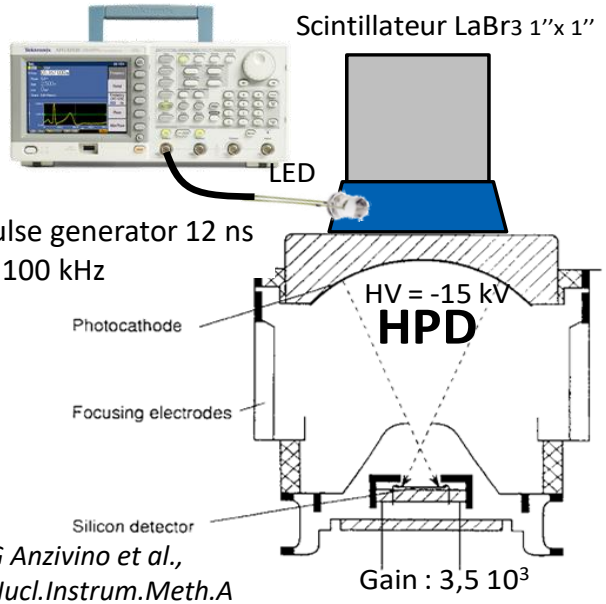
^{90m}Nb

^{90m}Nb **X background**

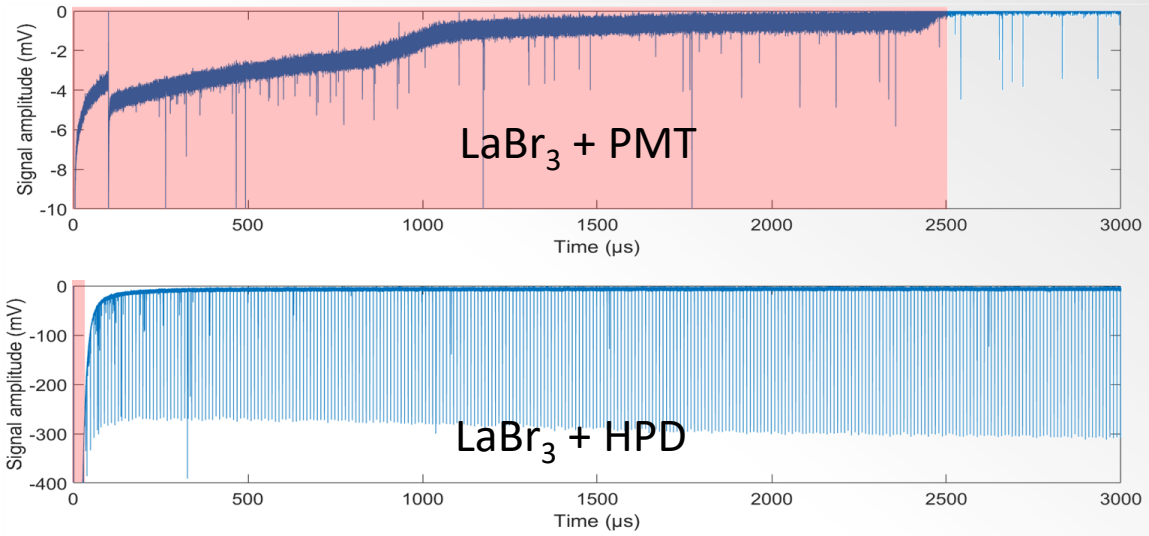


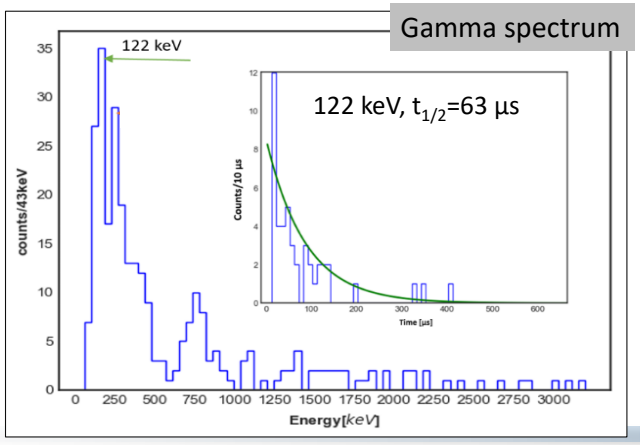
F. Negoita et al., AIP Conference Proceedings 1645, 228 (2015)

Scintillator in high power laser environment



G Anzivino et al., Nucl.Instrum.Meth.A 365 (1995) 76-82

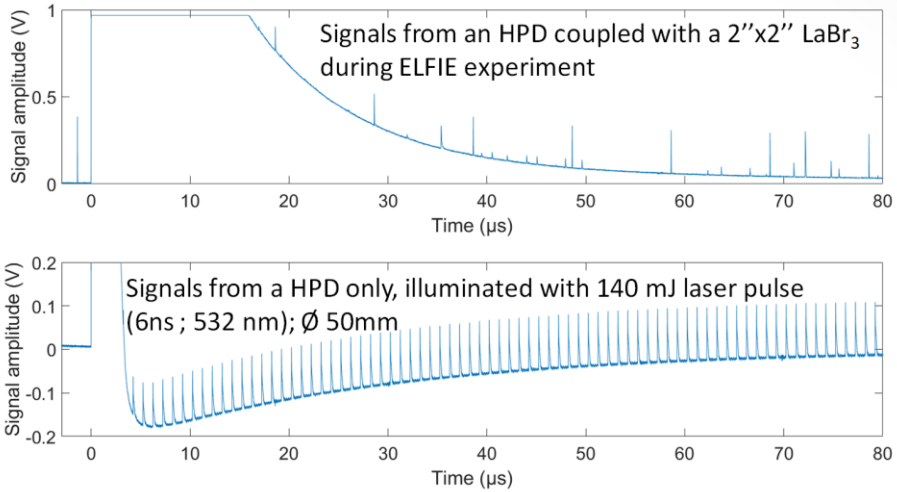




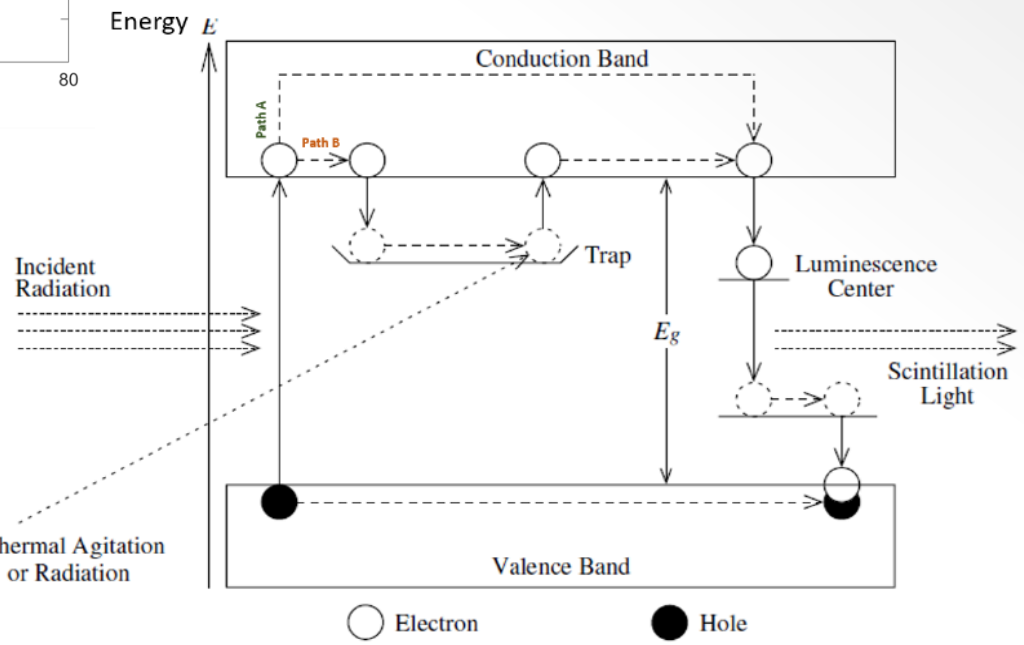
- ✓ Recovery time reduced to 15 µs with Hybrid Photo Diode (HPD) and data processing
- ✓ Photodetector or afterglow responsible for blinding time?

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

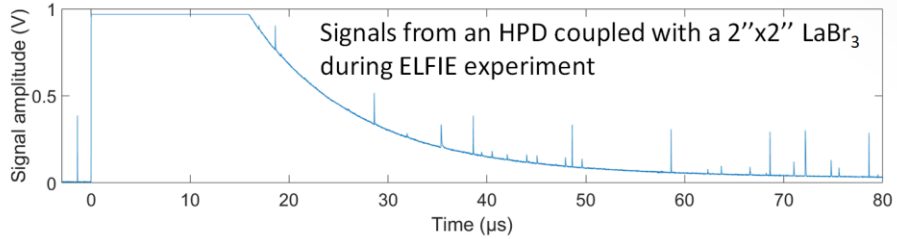
Scintillator in high power laser environment

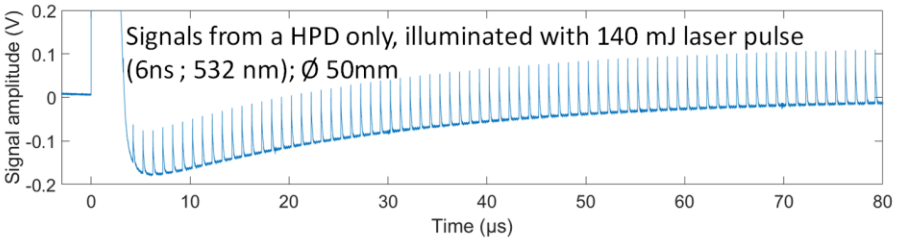


Afterglow is mainly responsible of long dead time



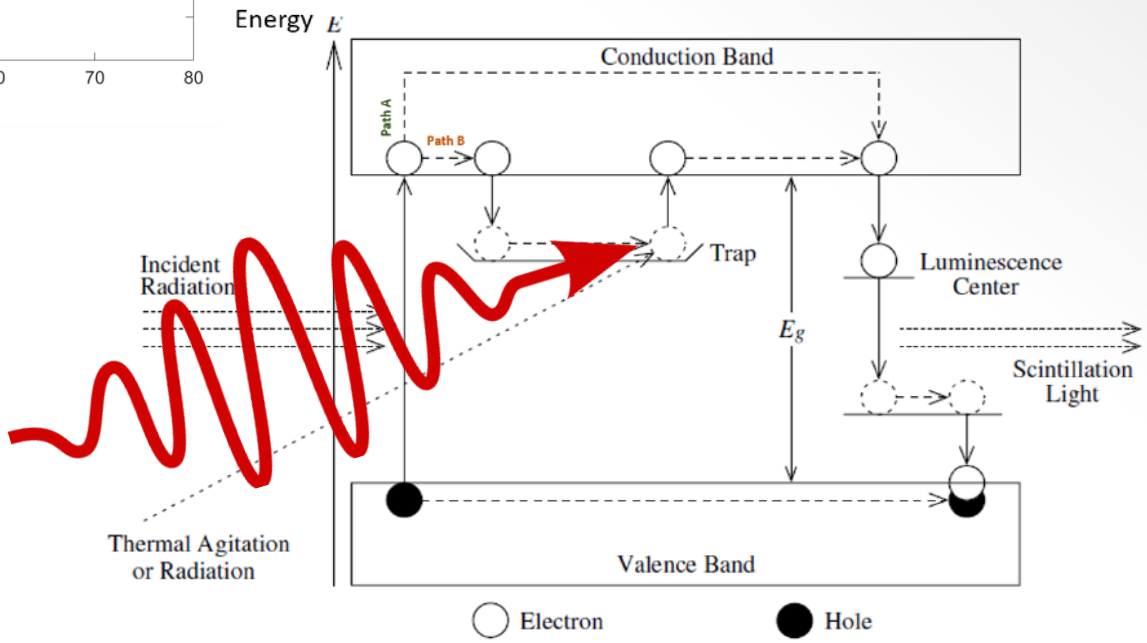
Scintillator in high power laser environment





Afterglow is mainly responsible of long dead time

Photonic stimulation with a laser



Conclusions

- Lasers: unique tools to study nuclear properties in astrophysical plasma : it creates both targets and projectiles

- The main issue remains the detection in such perturbed environment. We are looking for a detectors capable of recovering from a laser shot : Semiconductor and scintillators are considered.

- For the moment the lower limit of blindness duration is ~10µs
  - To be confirm experimentally for CdTe
  - To reduce afterglow with photo stimulation