Excitations Nucléaires par Laser
-ENL-

Nuclear physics with high power lasers

Magurele (Romania), 31th of January 2017
LIA COSMA Workshop

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Outline

1. **What can we do with high power lasers?**

   Plasma target

   Projectiles

2. **What kind of nuclear physics?**

   Double beam experiments

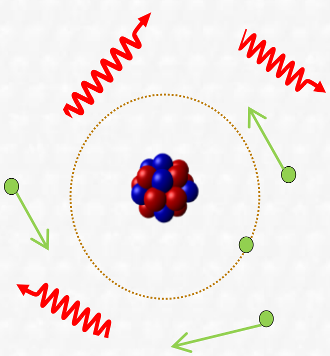
   Nuclei in extreme environment

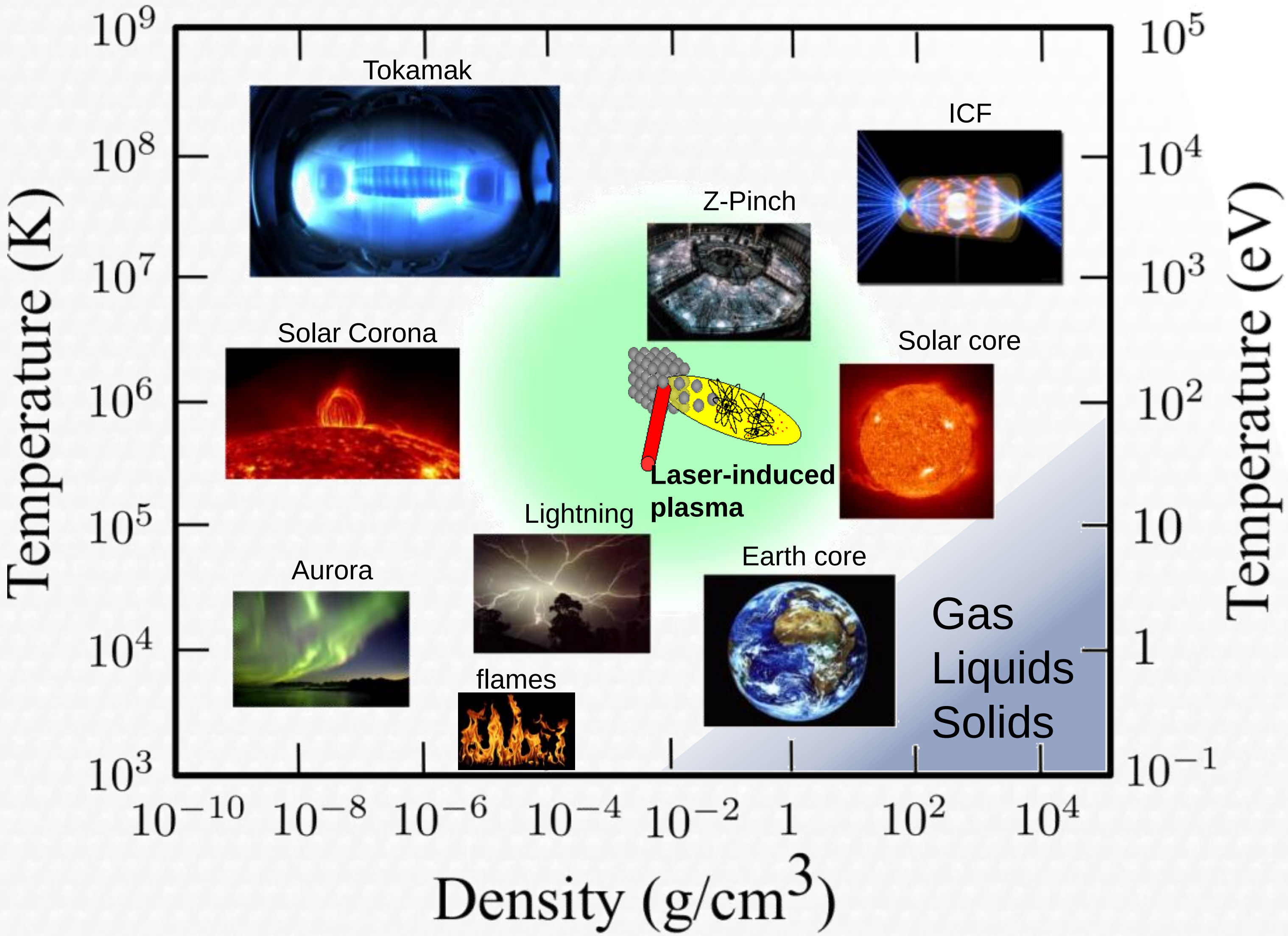
3. **Challenges to overcome**

Laser-induced plasma

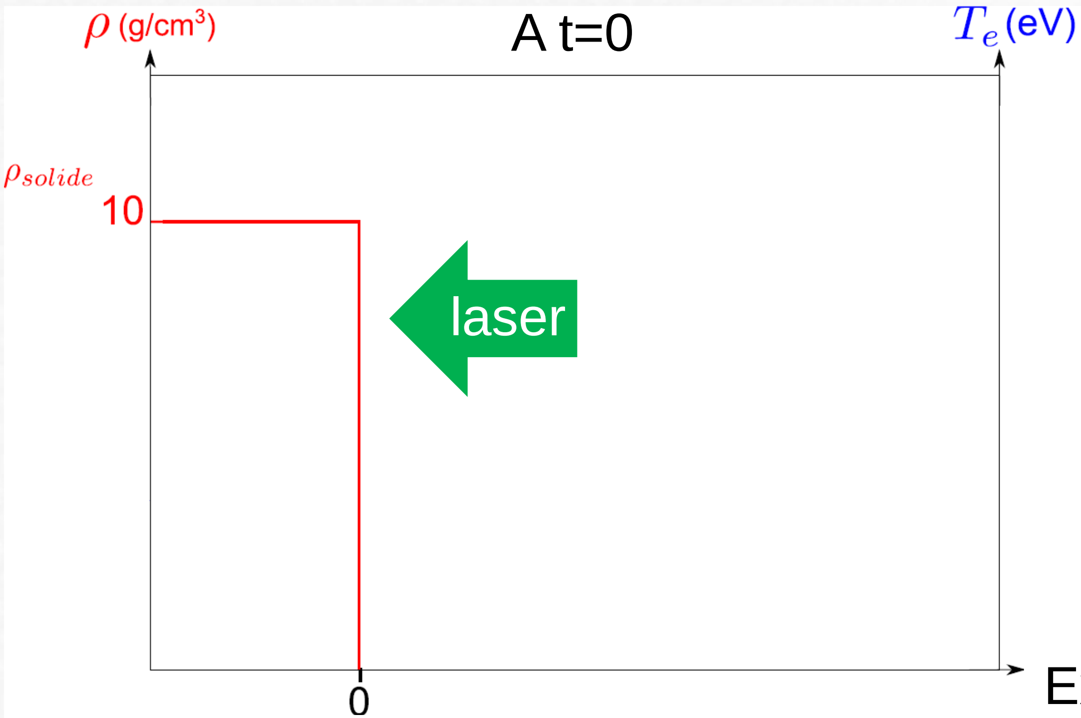
The 4th state of matter (99.9% visible matter)

Plasma =
ions
+ free electrons
+ photons





Laser-induced plasma

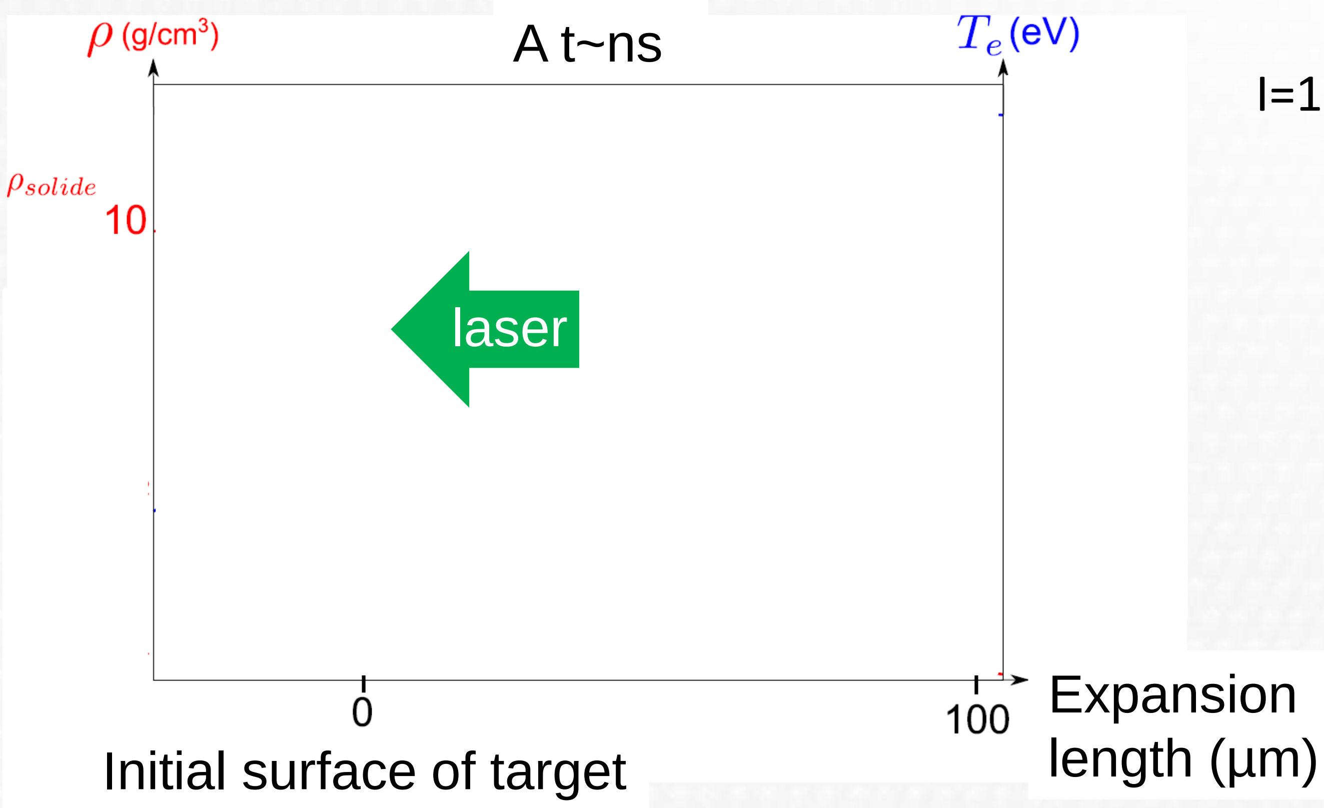


Initial surface of target

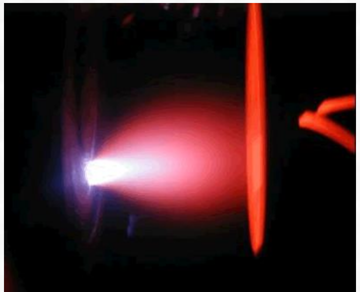
Expansion length (µm)

$I=10^{14}$ W/cm^2

Laser-induced plasma



I=10^{14} W/cm^2



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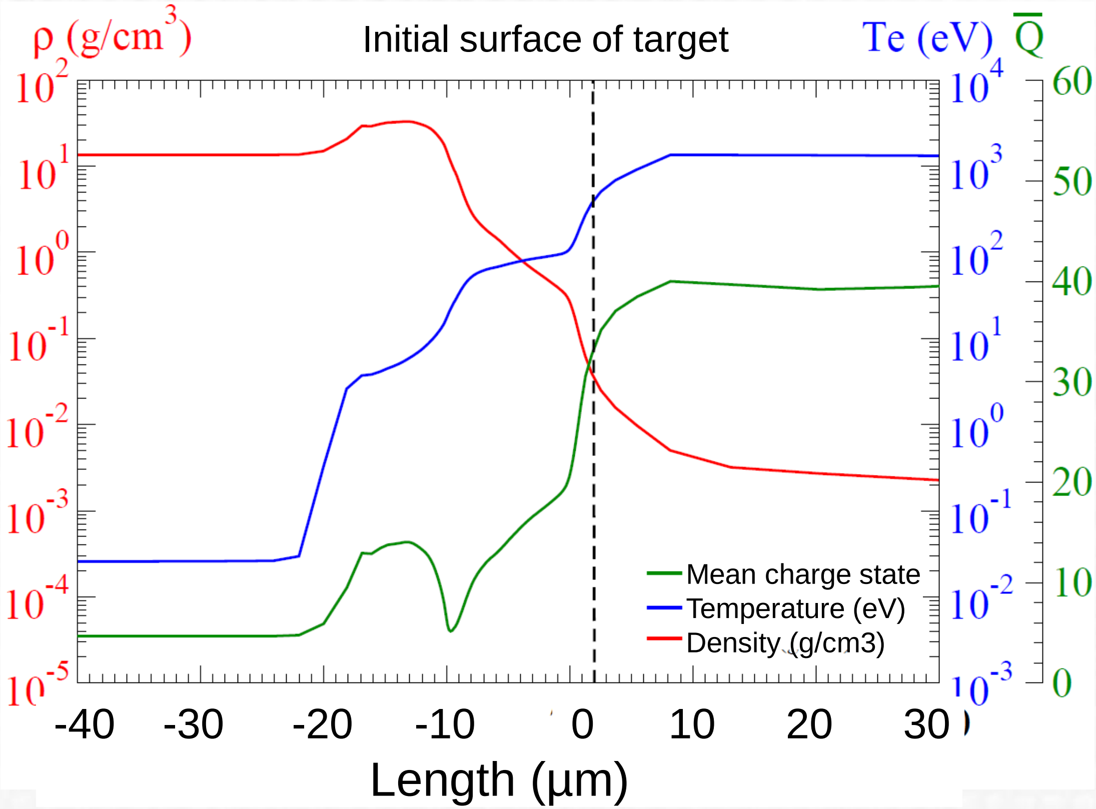
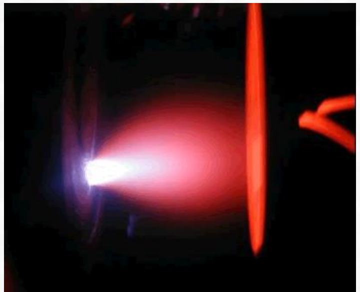


$I = 10^{14}$ W/cm^2

E=35J,
τ=4 ns
ϕ=100 µm
λ=1.06 µm

$_{80}$Hg target

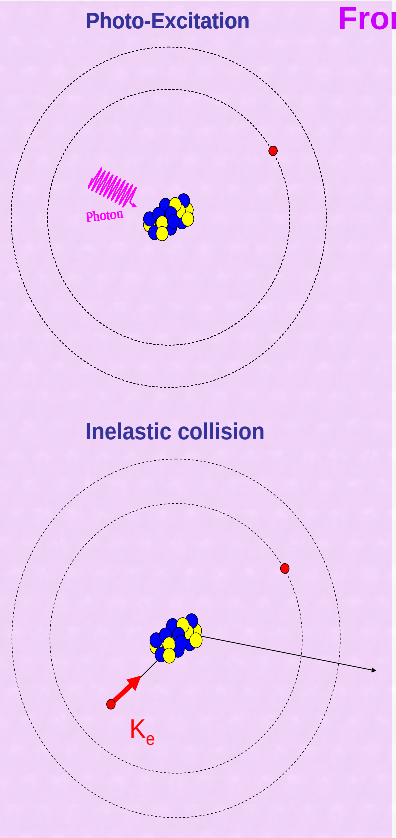
Profiles at the end of laser pulse

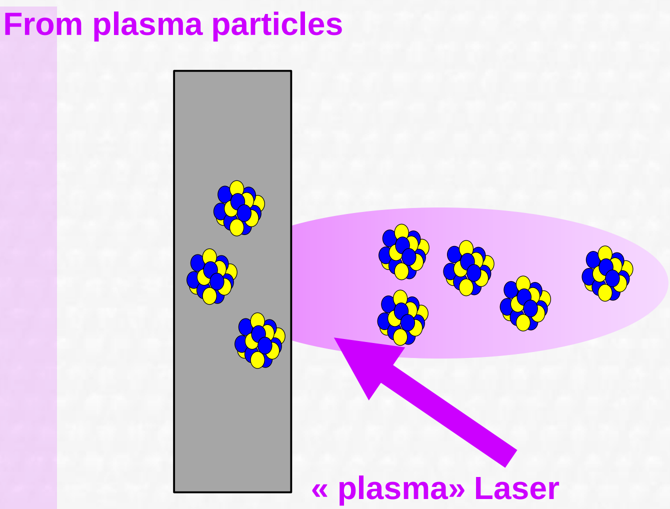


Temperature ⬄ Charge state
→nuclear processes modifications

Laser-induced plasma

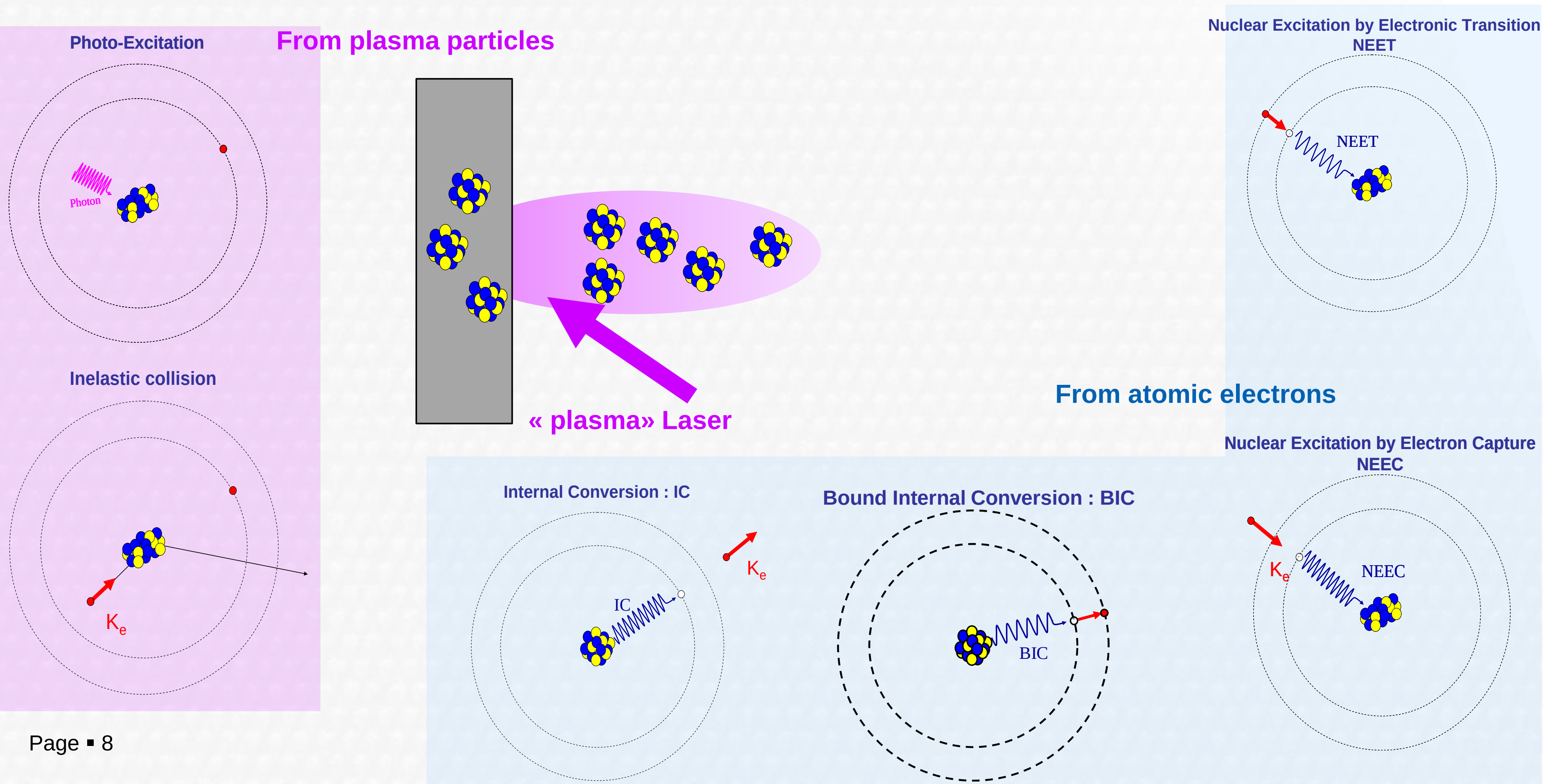
- **Nuclear processes in a plasma**





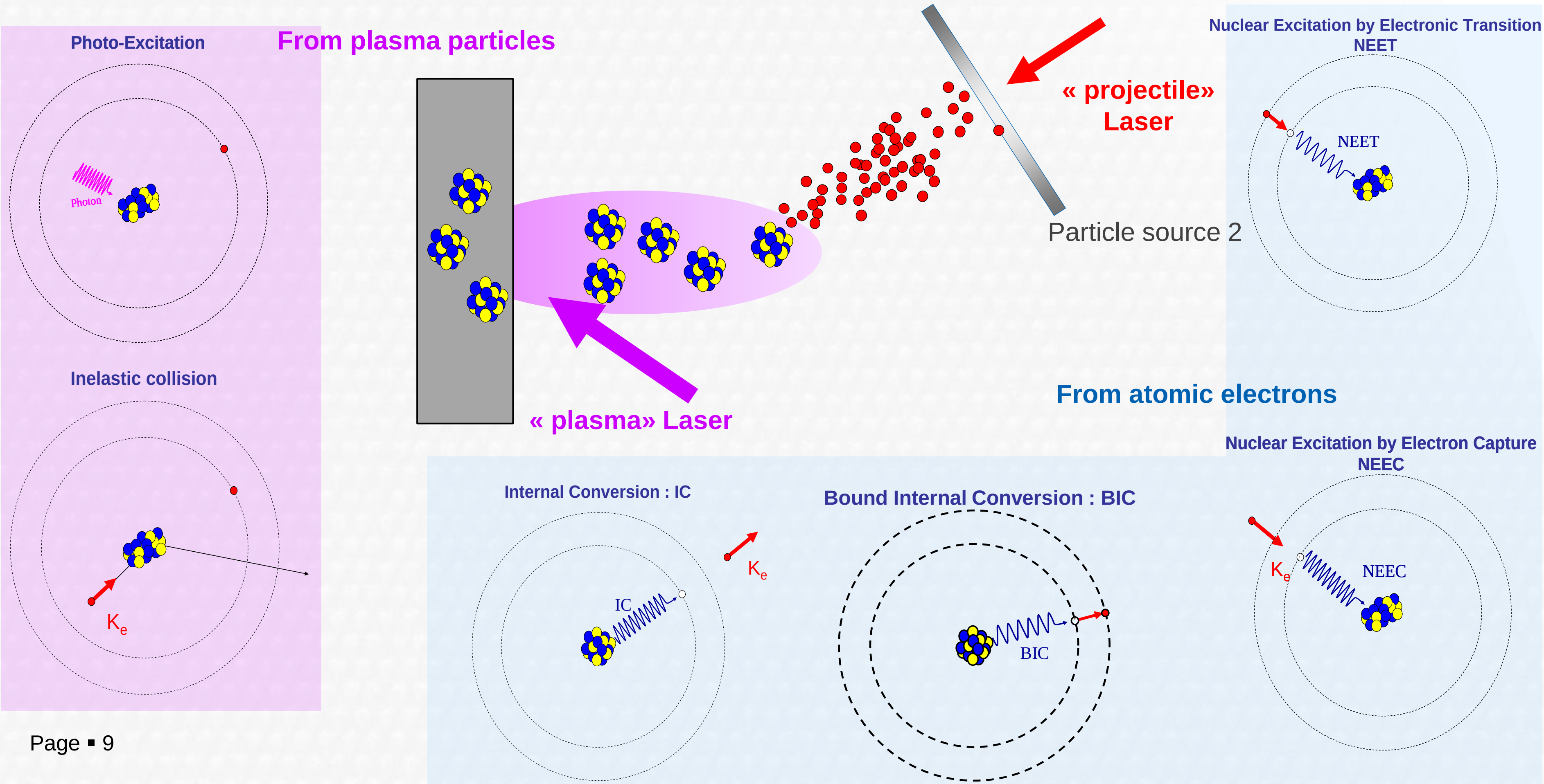
Laser-induced plasma

- **Nuclear processes in a plasma**

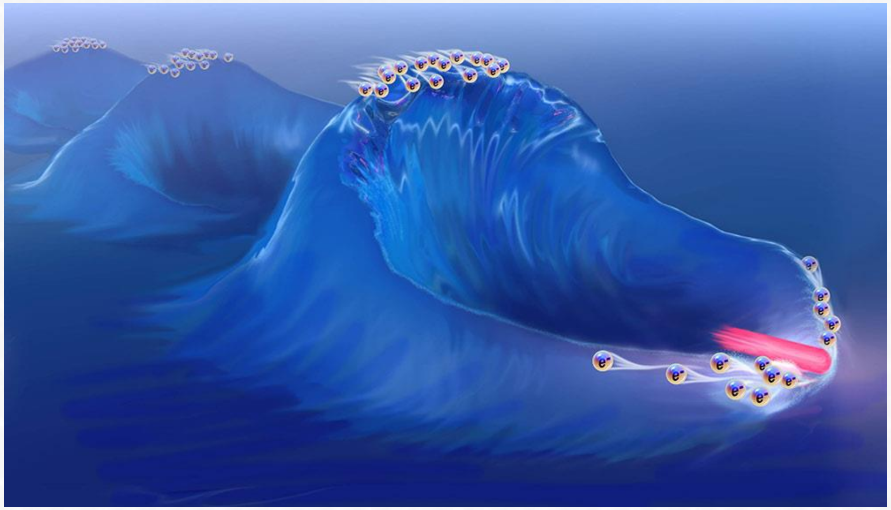


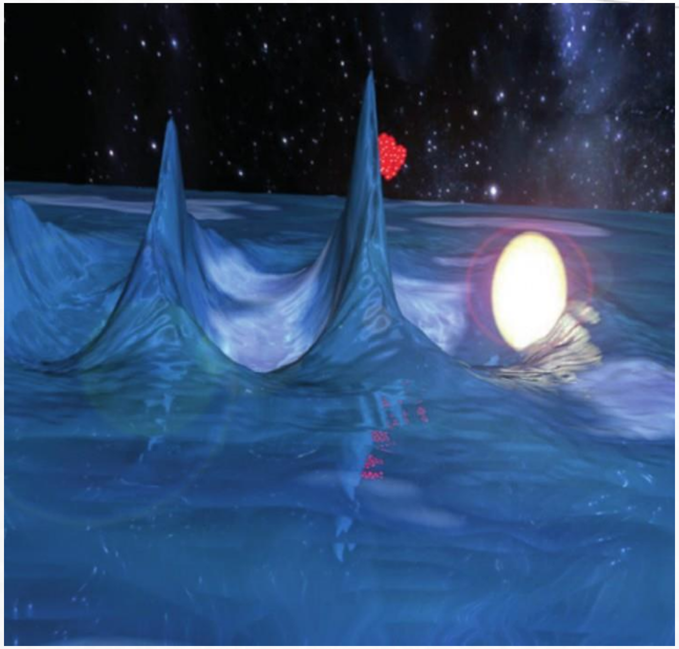
Nuclear physics with lasers

– **Plasma targets and plasma environment**



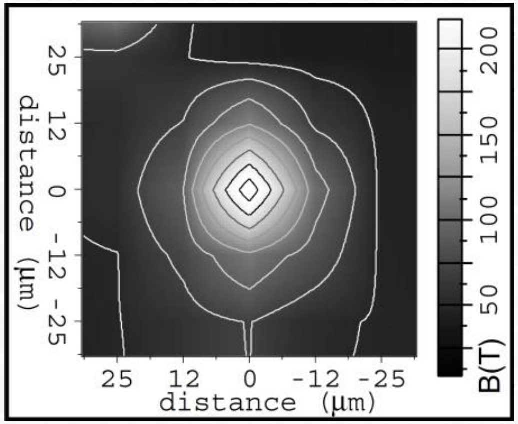
Laser-induced Electrons and γ ray sources





Very high fields created

Measurement :
Z. Najmudin et al,
Phys. Rev. Lett.
87, 215004 (2001)

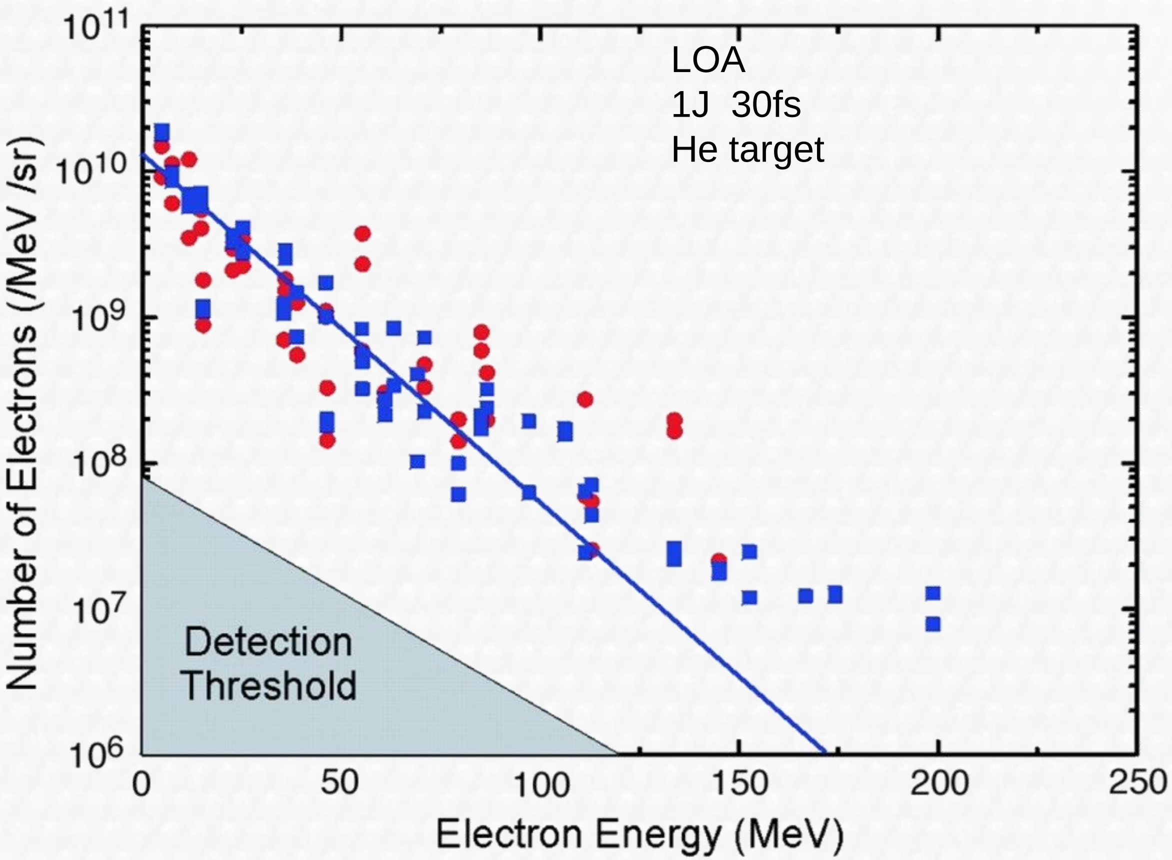


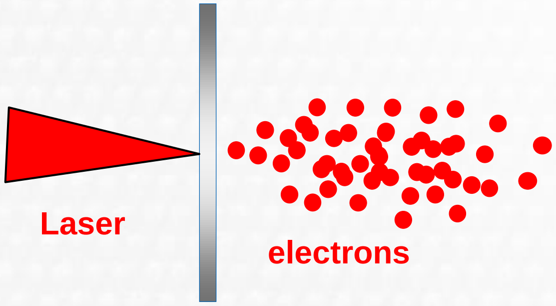
$\not\!E \sim 10^9$ V/cm

UHI laser :
$I \sim 10^{18-20}$ W/cm²
Δt = ~10s fs

=> Extreme environment

Laser-induced Electrons and γ ray sources





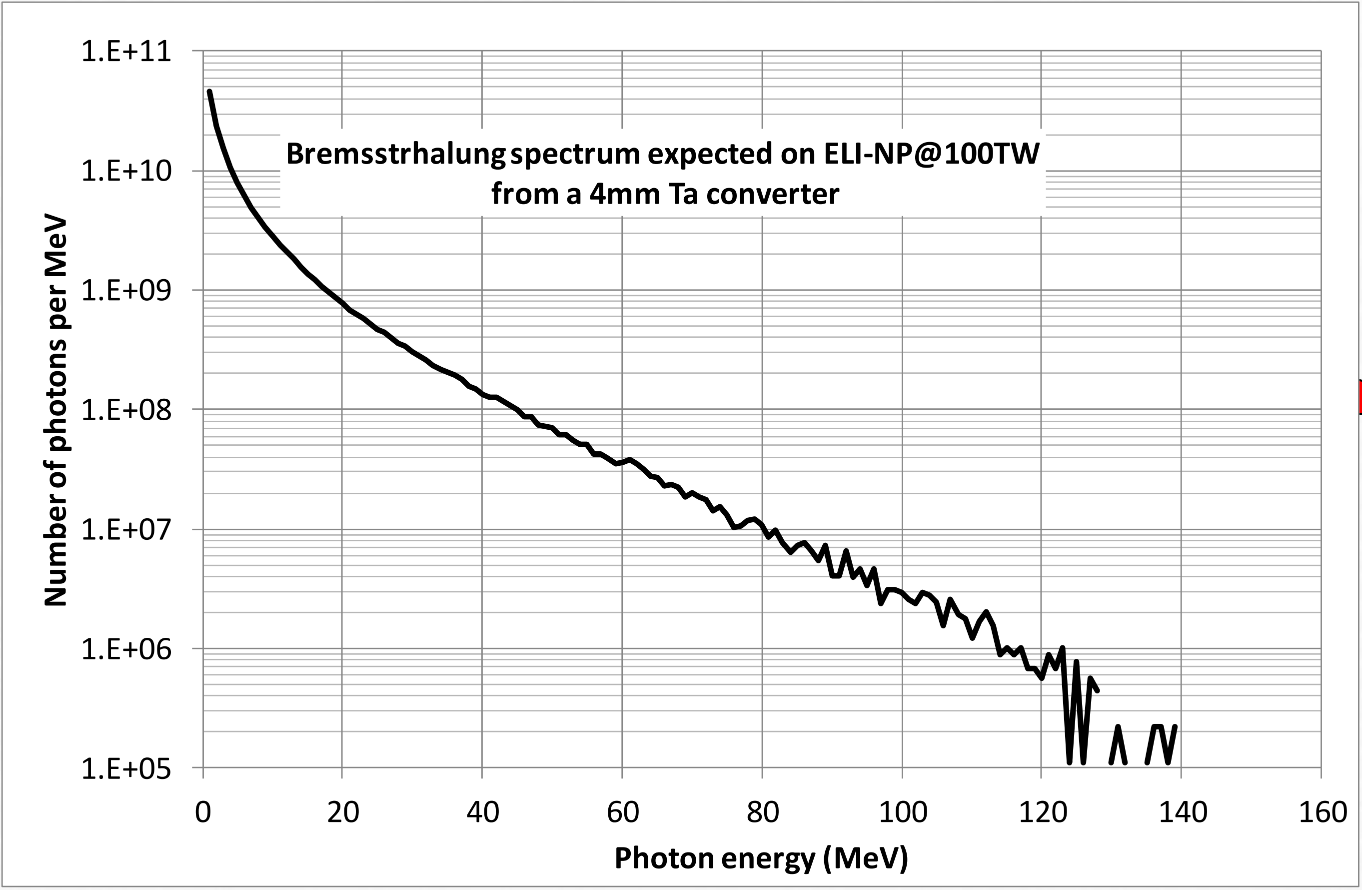
Salle Jaune of LOA :

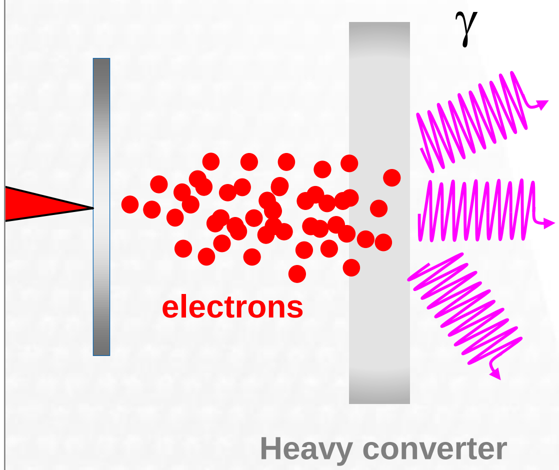
Laser 1 J ; 30-fs ; He supersonic gas jet ; 3×10^{18}W/cm²

*V. Malka et al. Science, **298**, 1596 (2002)*

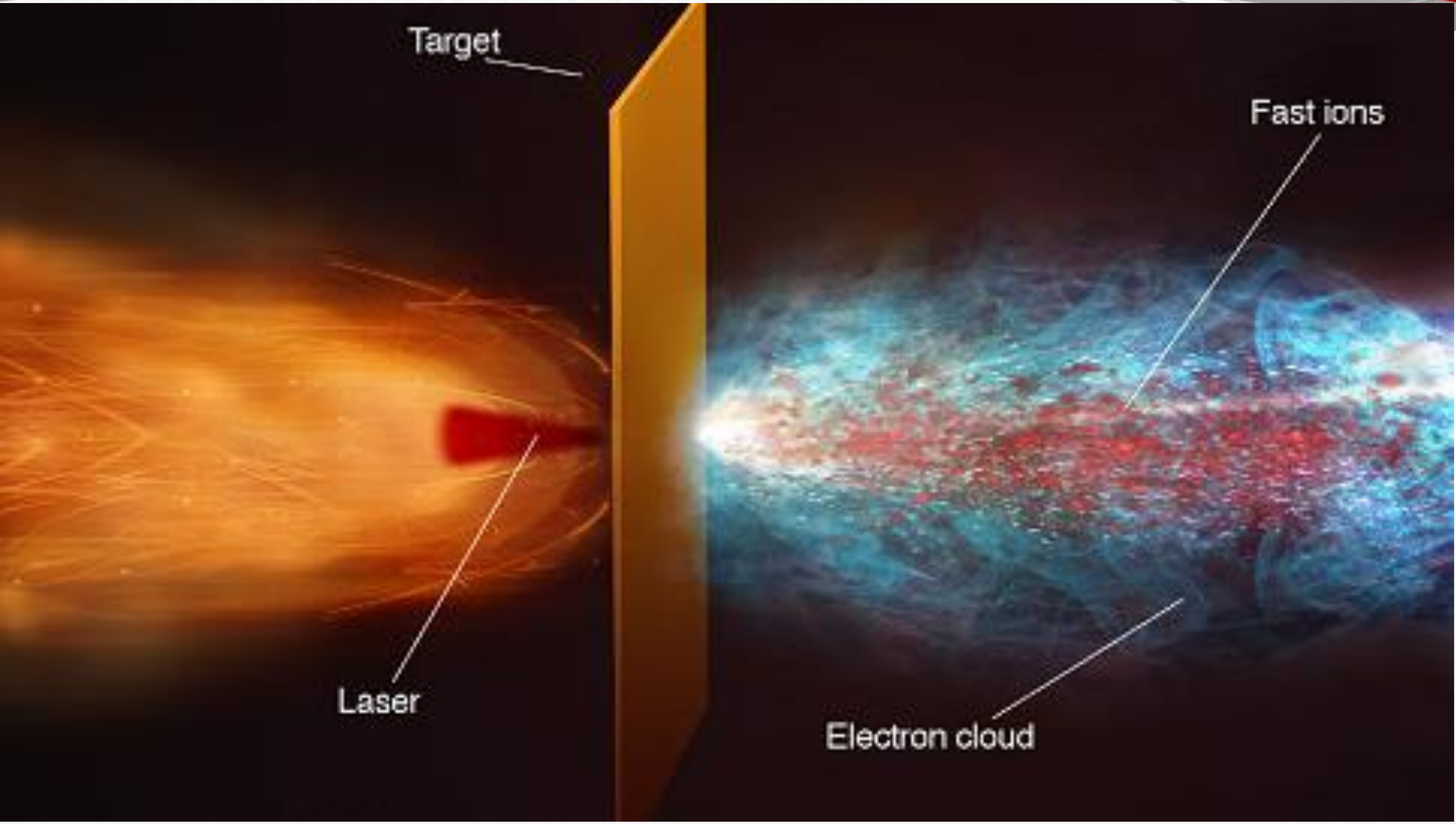
Laser-induced Electrons and γ ray sources

Bremsstrahlung γ rays





Laser-induced ion acceleration

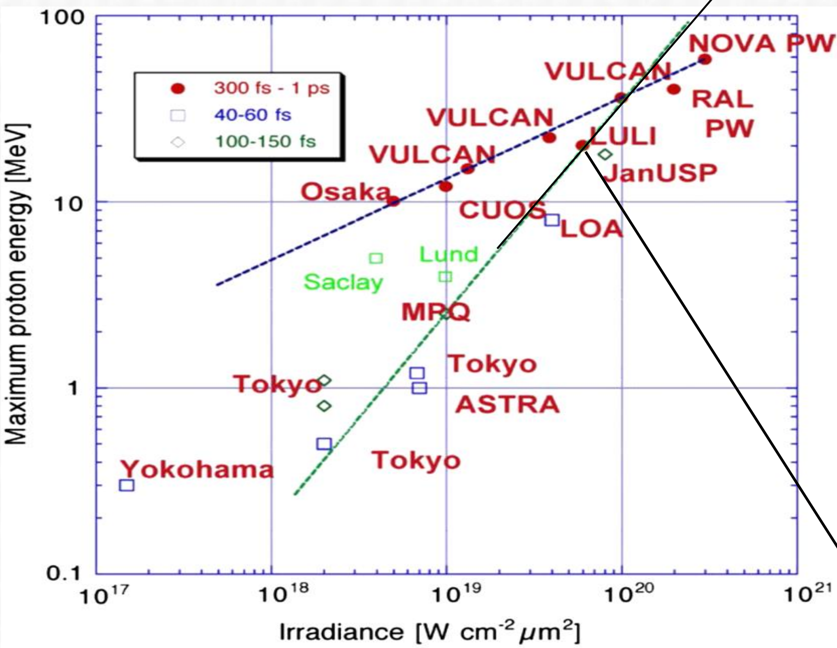


Target Normal Sheath Acceleration (TNSA)

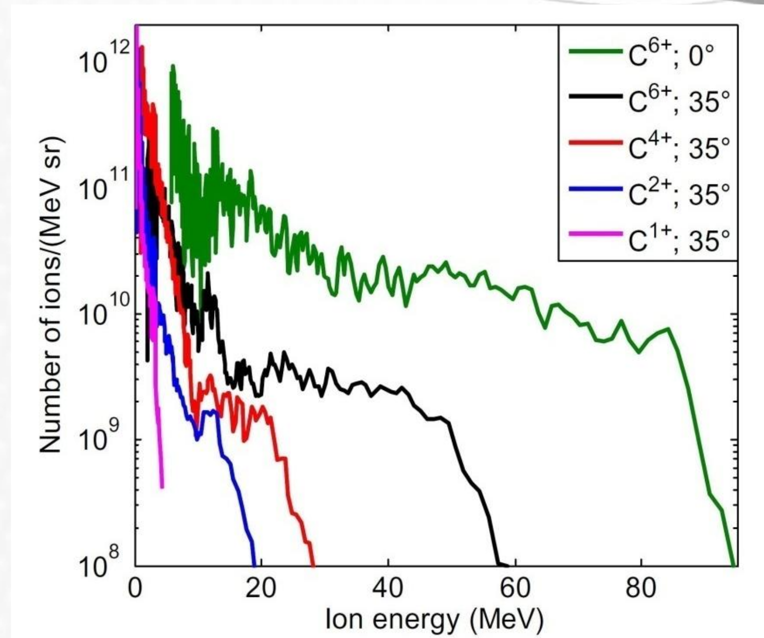
Laser-induced ion acceleration

Apollon /
ELI-NP

Laser-accelerated protons
in the world



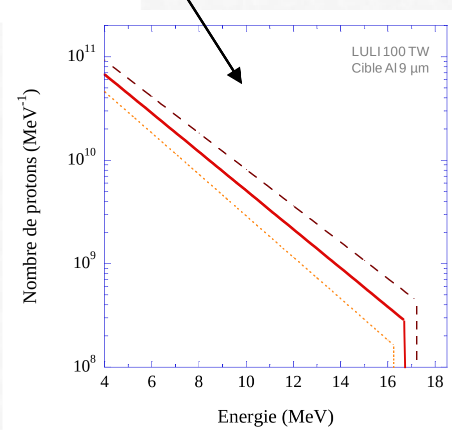
Macchi et al. Rev. Mod. Phys, ***85****, 751 (2013)*



New Journal of Physics **12** (2010) 045020 (15pp)

Astra-Gemini Laser : 115 TW ; 6 J ; 50 fs
=> 7×10^{20}Wcm^{-2}

Laser-accelerated
protons at LULI 100TW

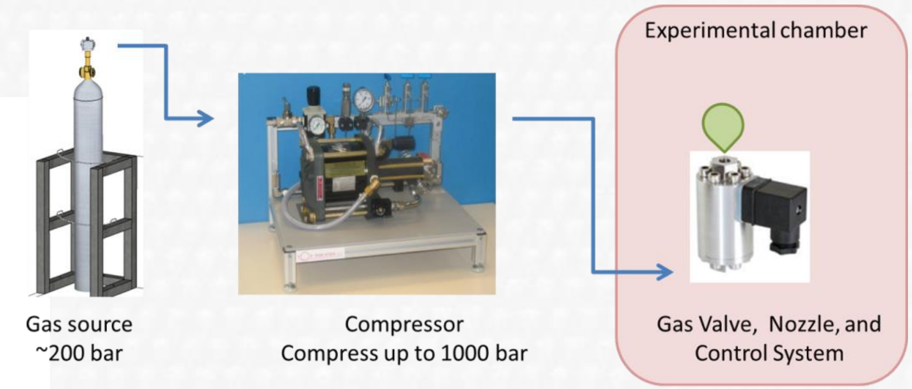


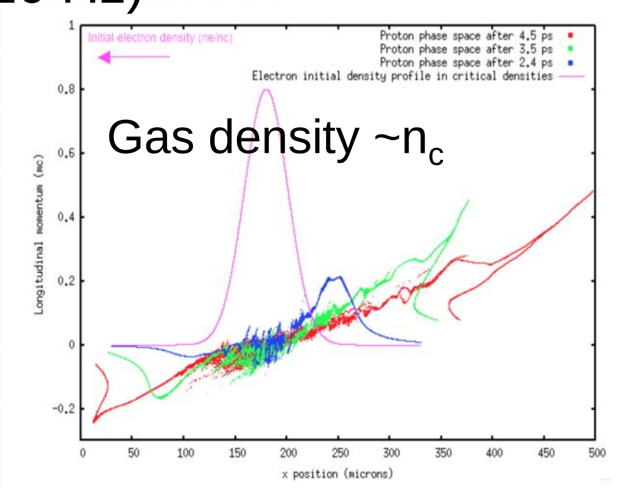
10^{13} protons in a ~1ns
bunch ⬄ 1,6 kA beam

Laser-induced ion acceleration

✓TNSA able to accelerate >10^{13} ions [1-200] MeV

✓Gas jet advantages : Few debris at high repetition (10 Hz)





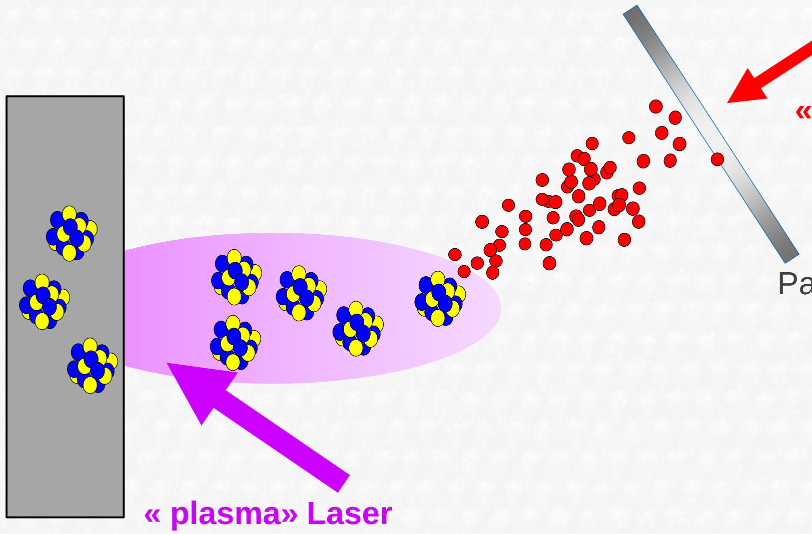
New process : Collisionless Shock Acceleration (CSA)

*2D PIC simulations ; with ELI-NP : **~75 MeV** protons*

✓possibility to accelerate different ions
✓acceleration in volume : large number of ions expected
✓ CSA studies on Apollon : Working group ELI-NP/LULI/LIDYL/CELIA/CENBG
experiment on PICO2000 in October 2017

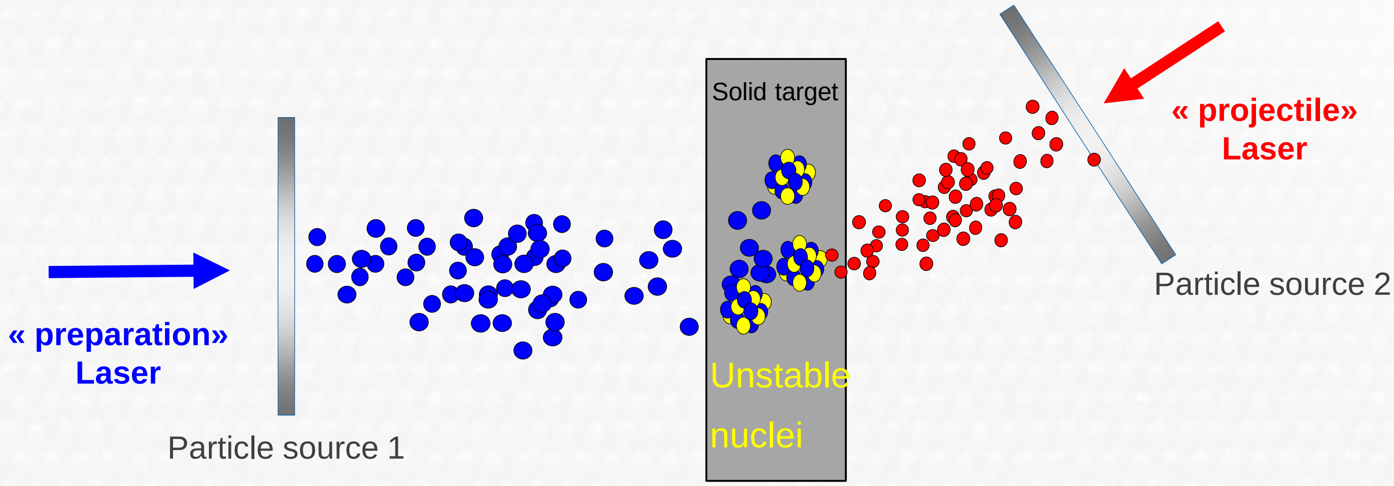
Nuclear physics with lasers

- **New possibilities with high power lasers**
  - **Plasma targets and plasma environment**



Nuclear physics with lasers

- **New possibilities with high power lasers**
  - **« Simultaneous » use of several beams : target preparation + projectile**

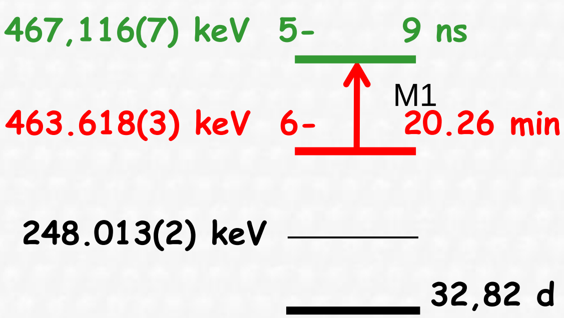


Target : 10^{21} nuclei/cm² ; Projectile : 10^{13} particles on Ø 100µm spot ; Cross section : 0,1 barn
→ 10^{13} /cm² secondary targets × 10^{13} particles → 10 reactions/shot
1 shot / min → ~14 400 reactions /day

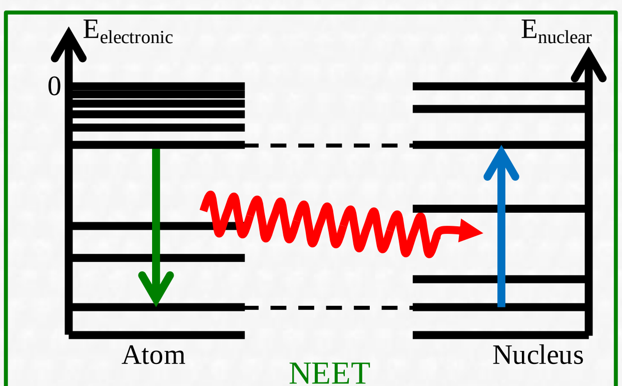
✓Nuclear reactions on very short-lived radioactive nuclei (down to few ns)
✓ Nuclear reactions on excited nuclei

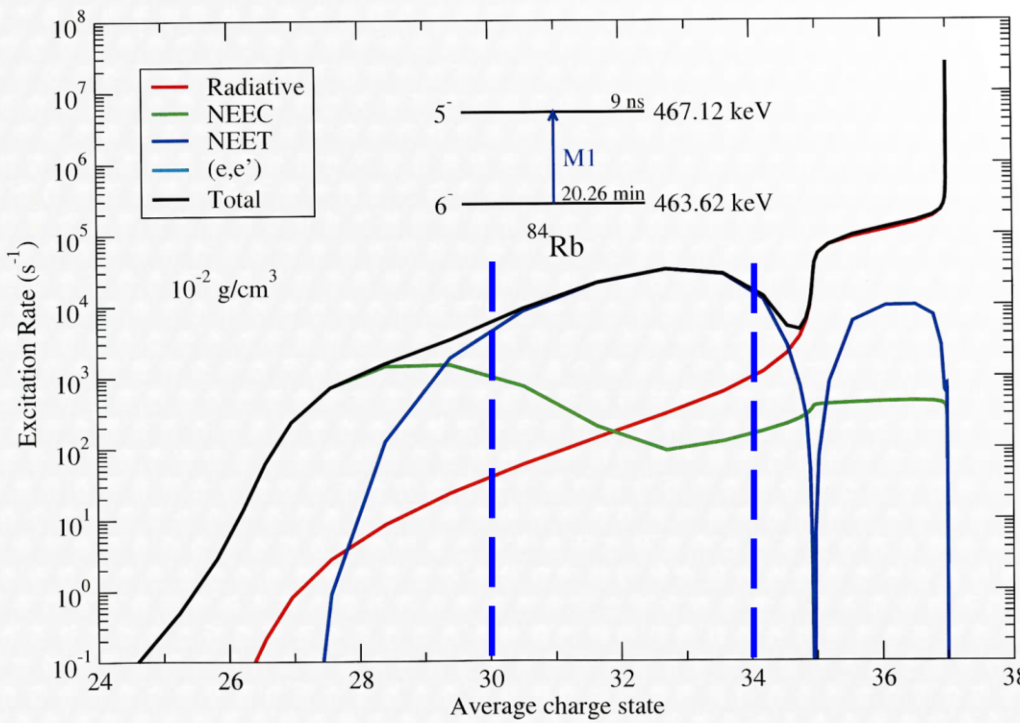
Nuclear physics with lasers

$$\Delta E^{nucl} = 3{,}498 \text{ keV}$$



$^{84}_{37}Rb$



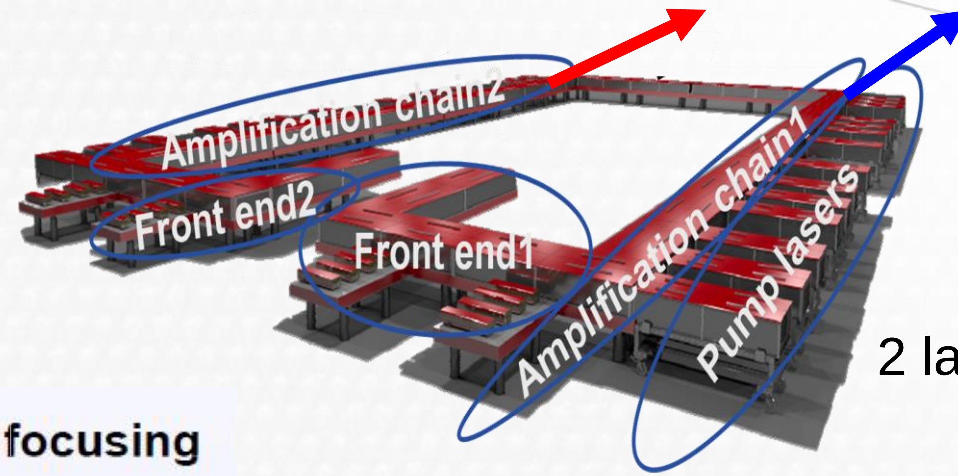


ISOMEX calculations of excitation rates of ^{84m}Rb in a plasma, as functions of the mean charge state of the plasma

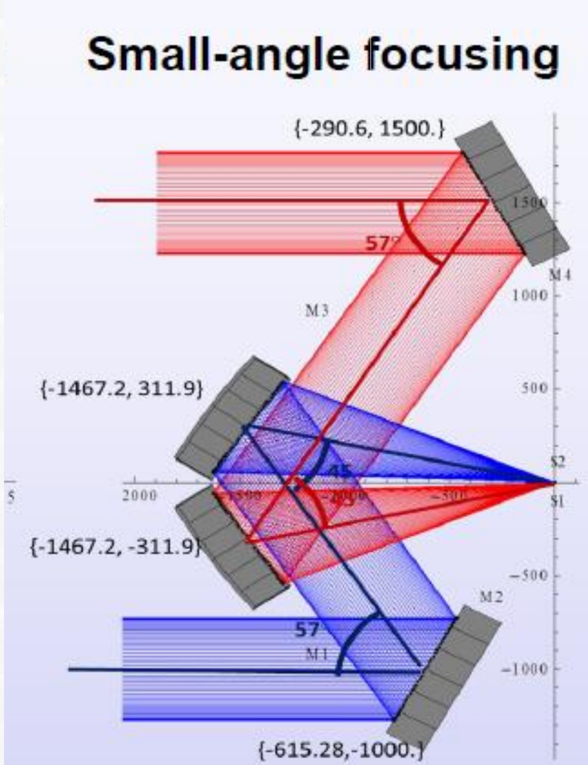
D. Denis-Petit, PhD thesis, University of Bordeaux , 2014

→Apparent half-live modification

^{84}Rb experiment at ELI-NP



2 lasers of the HPLS



Production Laser : 0,1 PW / 0,1s
3J – 30fs

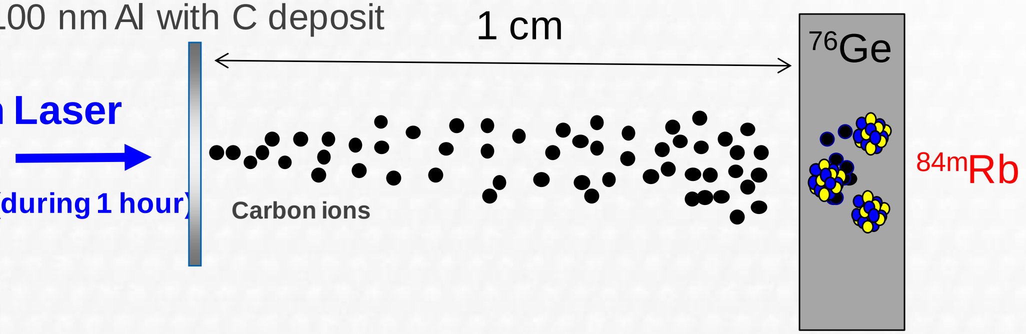
Plasma Laser : 10 PW / 60s
250 J - 0,5 ns

^{84}Rb experiment at ELI-NP

^{76}Ge(^{12}C,p+3n)^{84m}Rb

Target
100 nm Al with C deposit

Production Laser

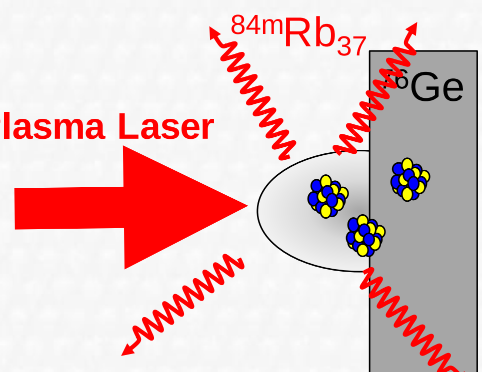


0,1 PW @10Hz (during 1 hour)
3J – 30 fs
$8.\ 10^{20}$ W/cm

30µm thick target

10^{15} W/cm²
10 PW /min (10 consecutive shots)
250 J – 0,5 ns

Plasma Laser



Assuming a plasma with :

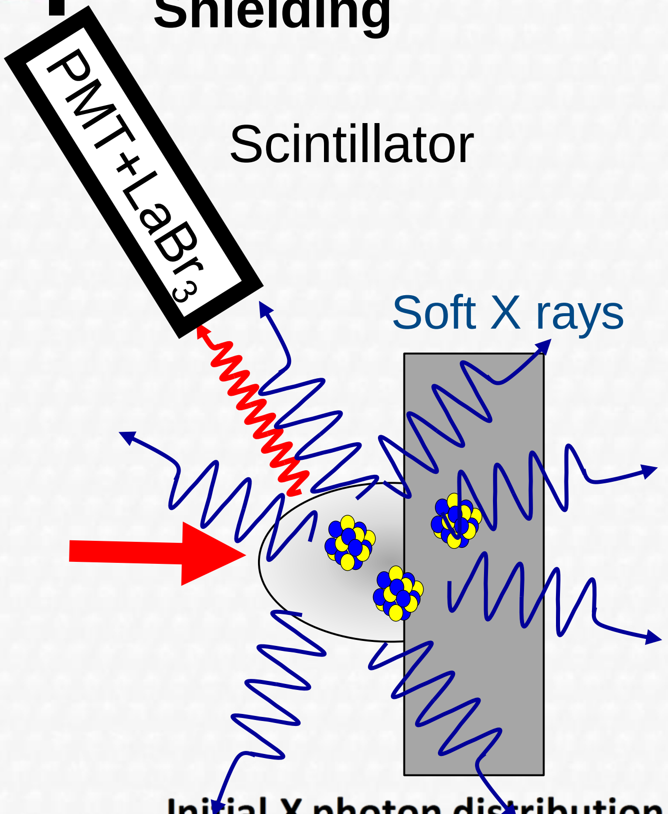
30 µm depth
250 µm diameter
$Q=29^{+}$ to 34^{+}
$\rho=10^{-2}$ g/cm^{3}

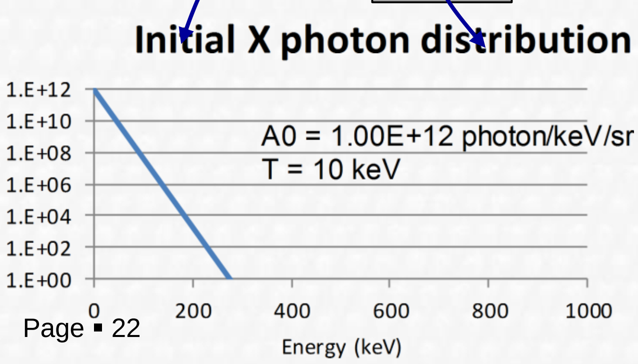
During 30 ps

per shot : $0.1 < N_{de\text{-}ex} < 80$
per cycle : $0.9 < N_{de\text{-}ex} < 710$
per day : $18 < N_{de\text{-}ex} < 14200$
Assuming 20 cycles /day

Detector in laser environment

- **Shielding**





Detector in laser environment

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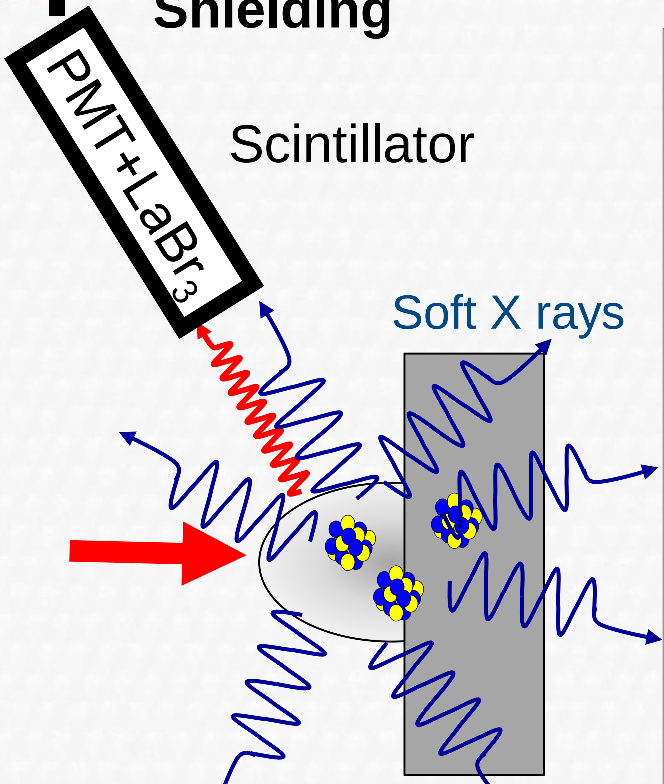
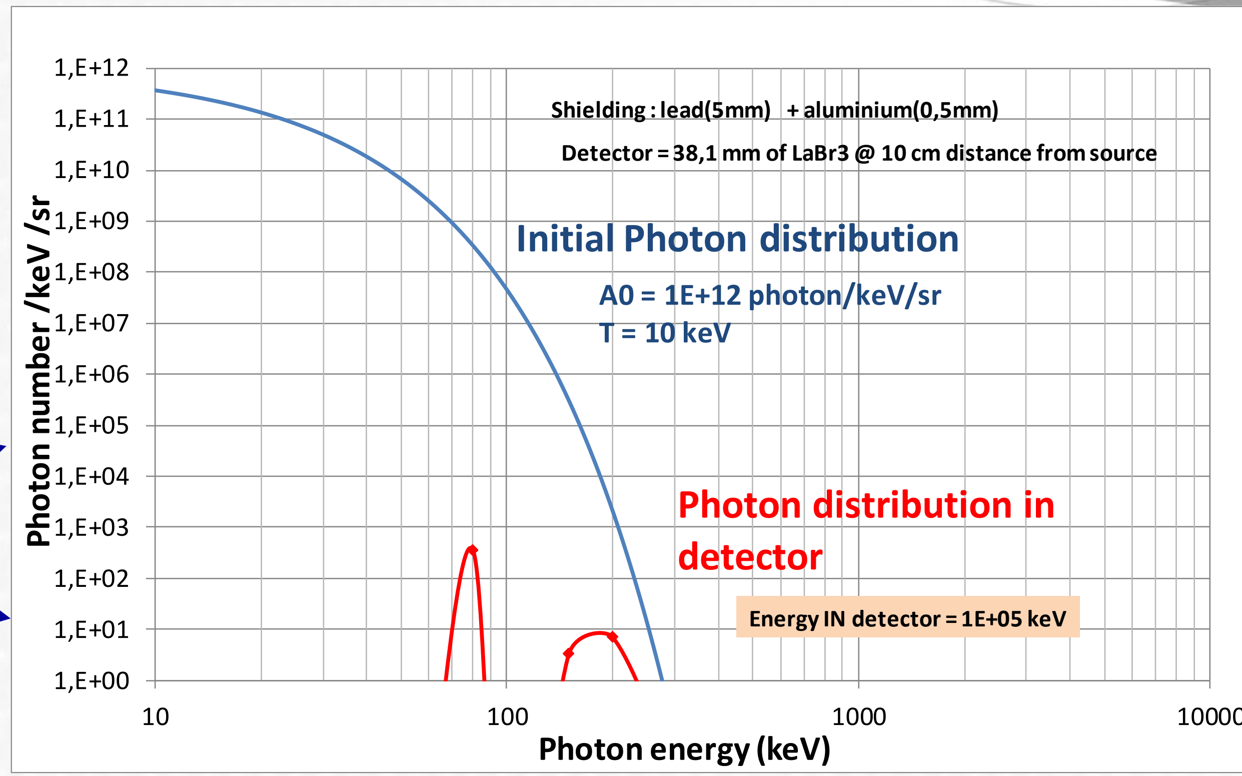
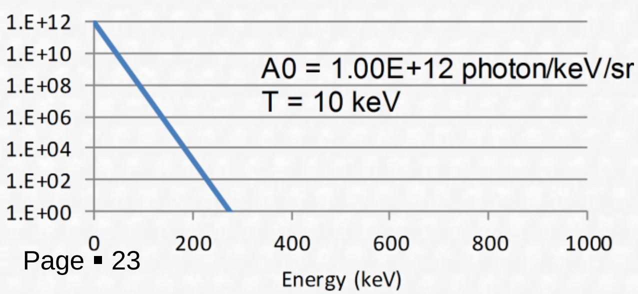




Initial X photon distribution



100 MeV deposited energy in detector through the shielding

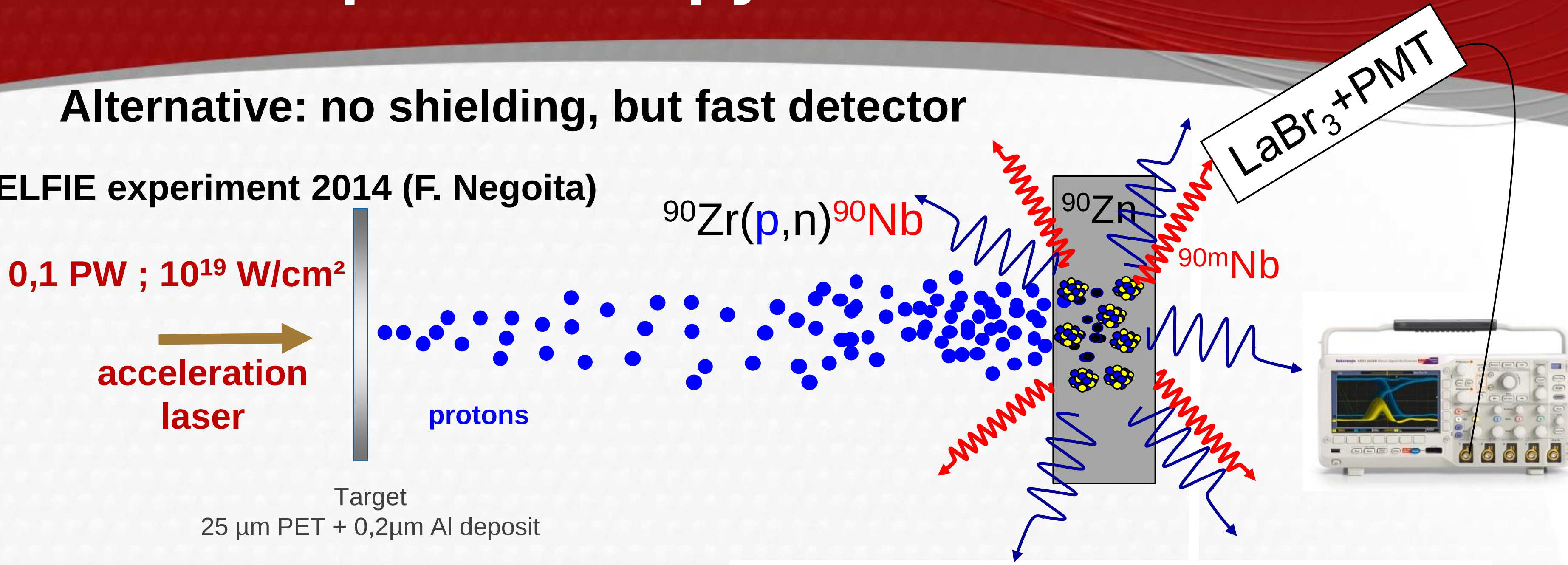
A10µm diameter hole @10 cm → 800 MeV deposited energy

Tight shield is needed … but we need to detect

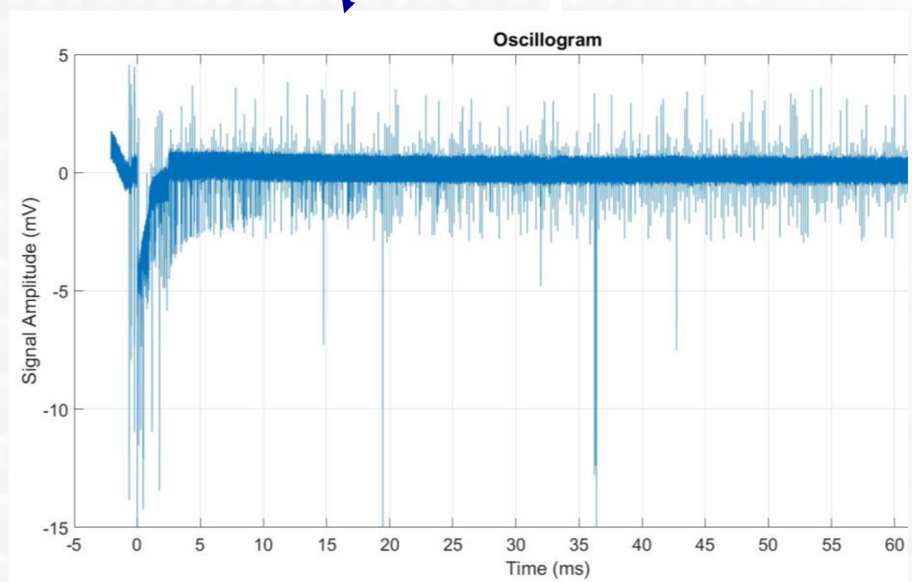
Gamma spectroscopy in laser environment

- **Alternative: no shielding, but fast detector**

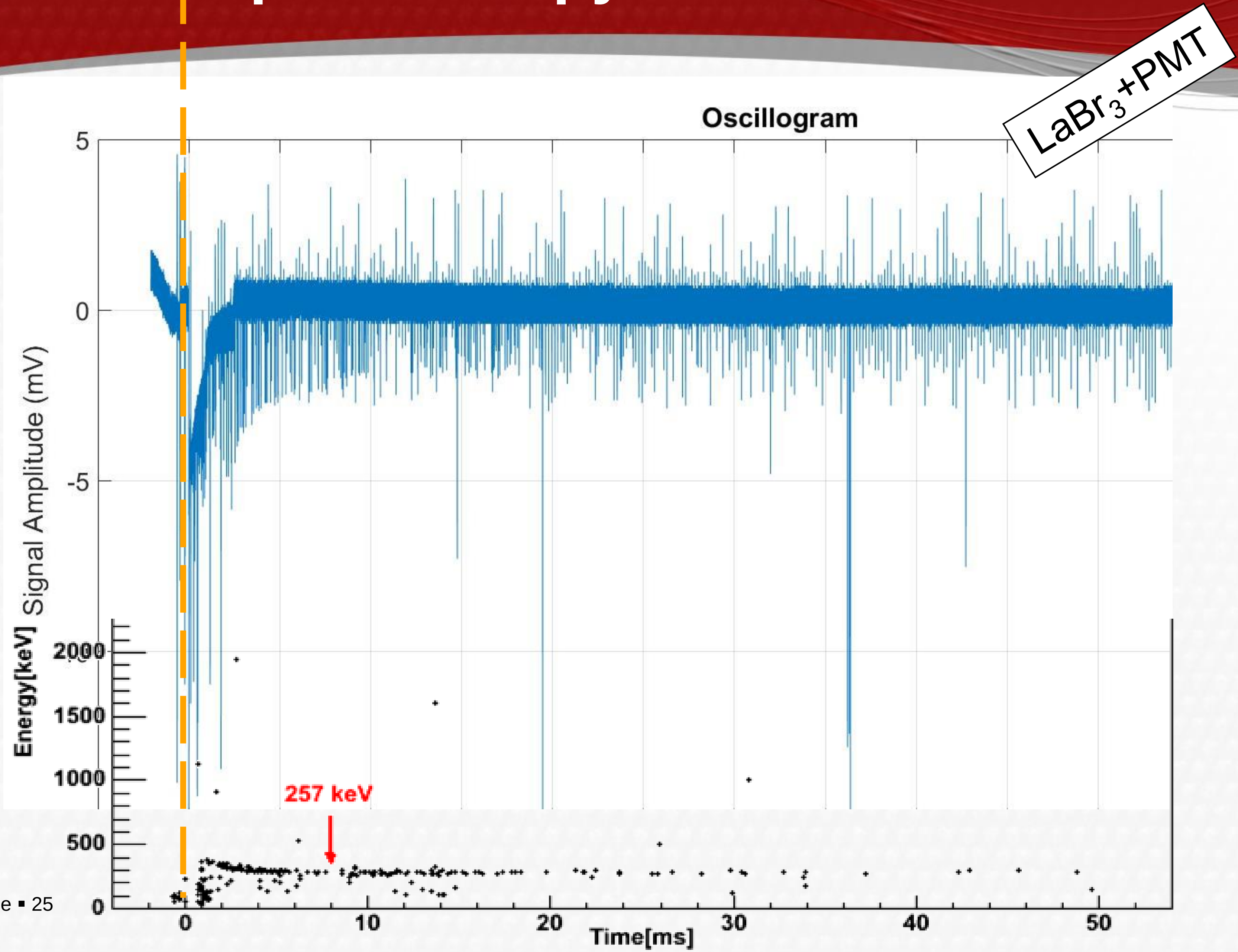
ELFIE experiment 2014 (F. Negoita)



Isomeric state Energy and spin	Half life	Emitted gamma ray energy
122.37 keV	63 µs	122.37 keV
382.01 keV ; 1+	6.19 ms	257.34 keV

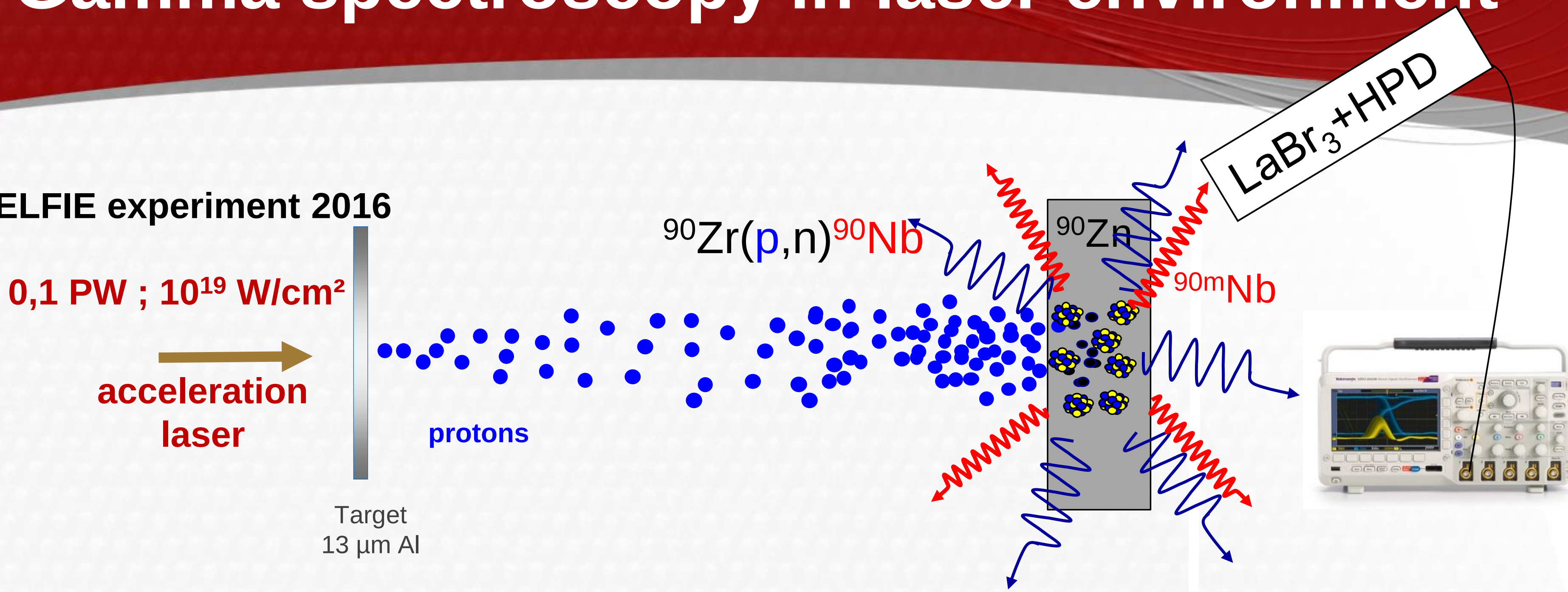


Gamma spectroscopy in laser environment



Gamma spectroscopy in laser environment

ELFIE experiment 2016



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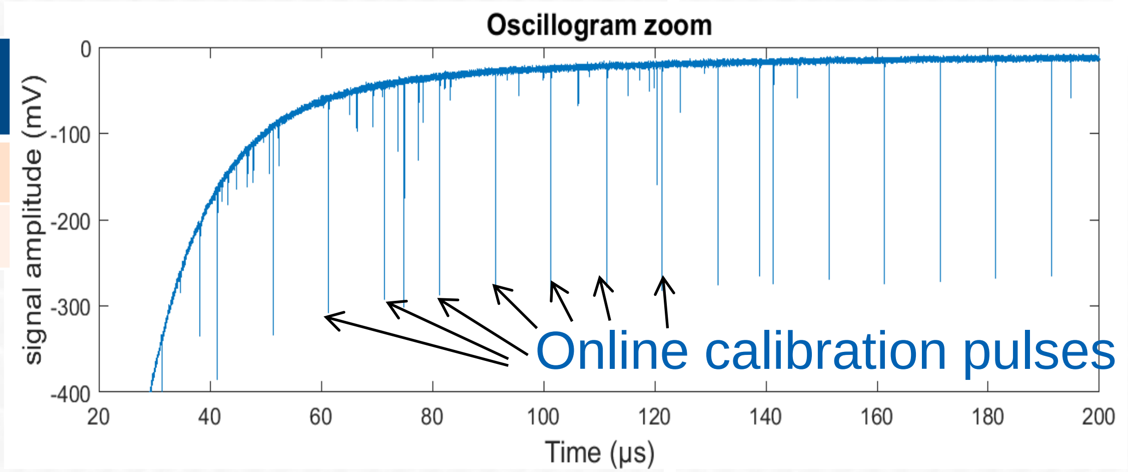

- γ Spectroscopy should be possible ~50µs after laser pulse
- γ Detection rate Possible up to 100MHz

Conclusion

- **Nuclear physics with high power lasers :**
  - **Nuclear excitation in extreme environment**
  - **Production and reactions on unstable nuclei**
  - **Nuclear reactions on excited nuclei**

- **Challenges for next years**
  - **Produce high flux of ions with gas jets (CSA)**
  - **Improve nuclear observable detection in laser environment**

➲ **Nuclear physics with high power lasers will be possible thanks to multi laser beam facilities and high repetition rates lasers**