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# Enhancement of X-ray emission by double-pulse target ablation in a laser produced plasma

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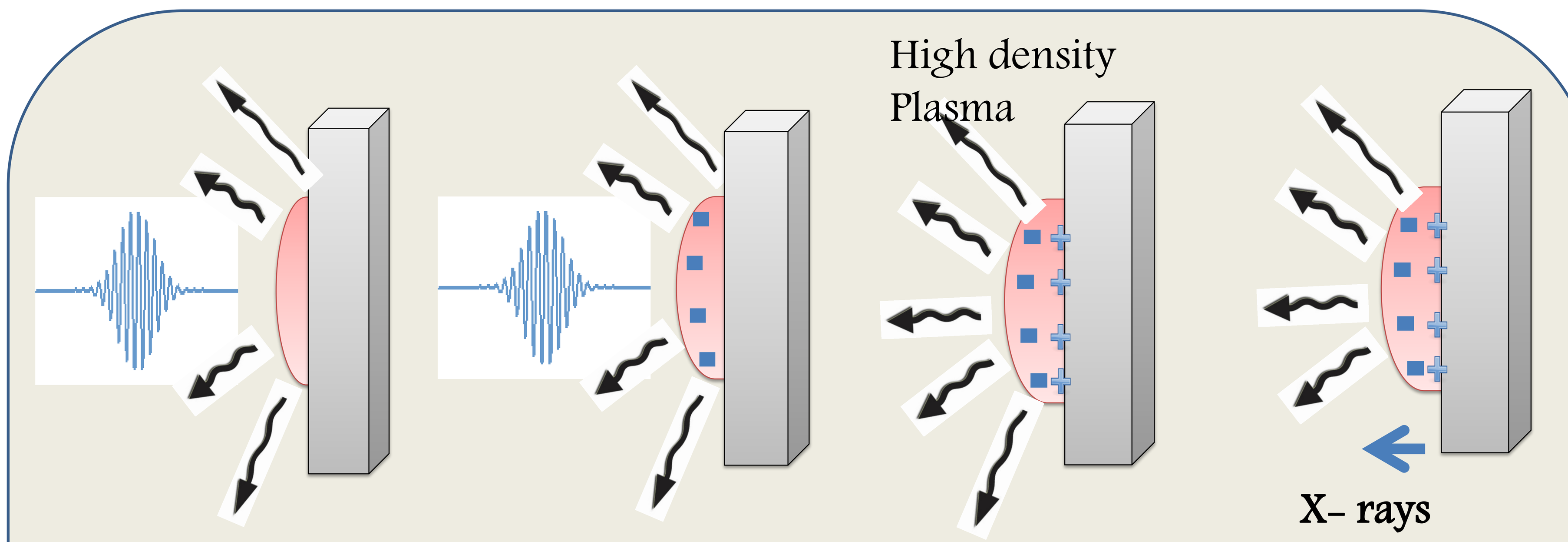
## Introduction

Owing to its various applications, the generation of X-rays from intense laser-matter interaction has received substantial research attention in the last decade. The high densities and temperatures possible with laser plasmas is ideal for obtaining efficient X-ray emission.

Here we investigate X-ray emission in the energy range of 10 keV to 150 keV from plasmas produced by ablating an Aluminium target using single and double ultrafast laser pulses (100 fs, 800 nm) of $10^{14}$ to $10^{15}$ W/cm$^2$ intensity. A substantial enhancement in X-ray emission was observed with double pulse (DP) ablation geometry.



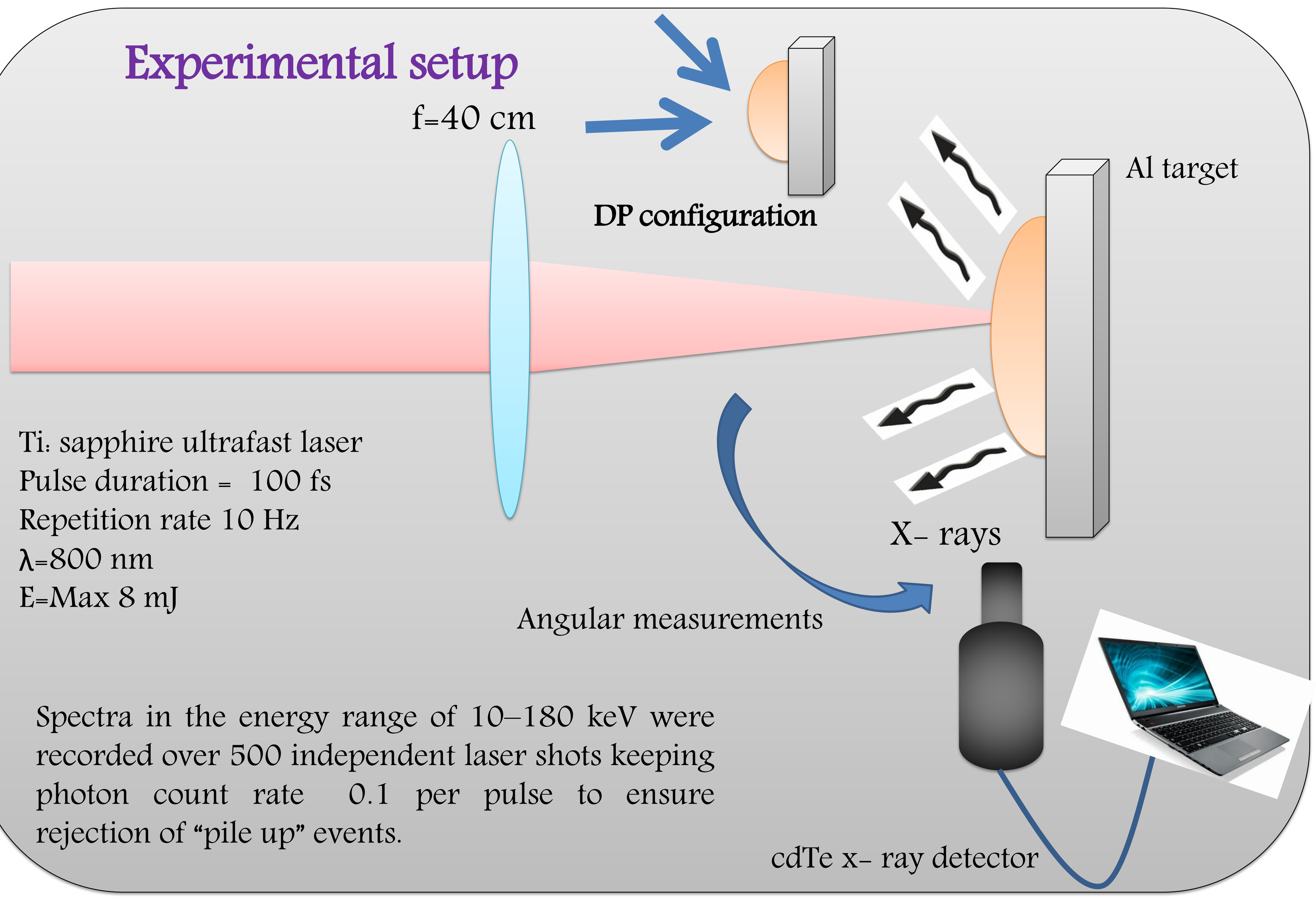

I ≈ $10^{14}$ to $10^{15}$ W/cm$^2$ Multi photon ionization

Electrons oscillate in the laser electric field

Bremsstrahlung emission takes place when this fast electron is decelerated in the Coulomb field of an ion.

The hot electrons generated in the laser plasma radiate via bremsstrahlung. Since the electrons are accelerated to very high energies ( 10–100 keV) the radiated bremsstrahlung photons also have a similar energy. This falls in the hard x-ray regime of the electromagnetic spectrum.

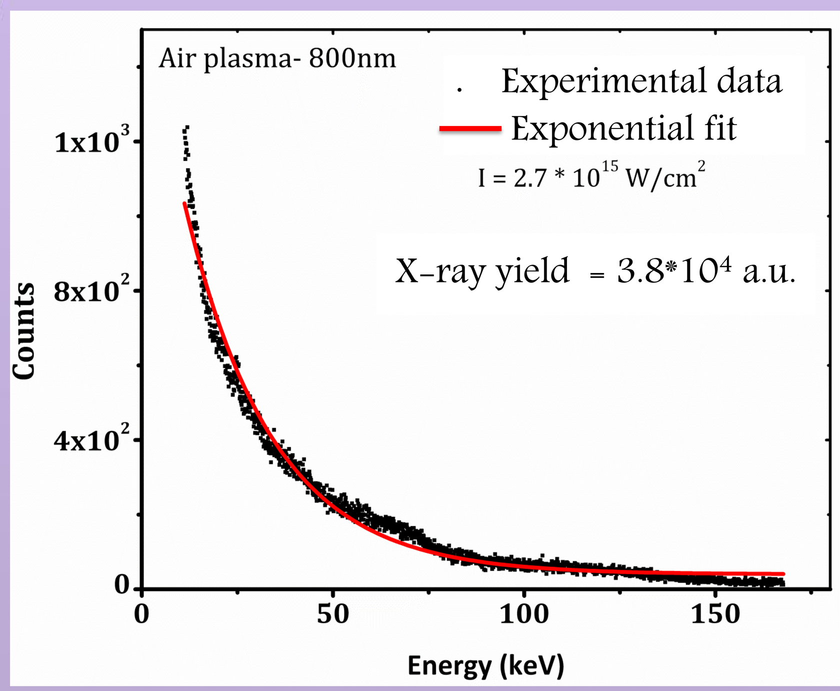
## Experimental setup

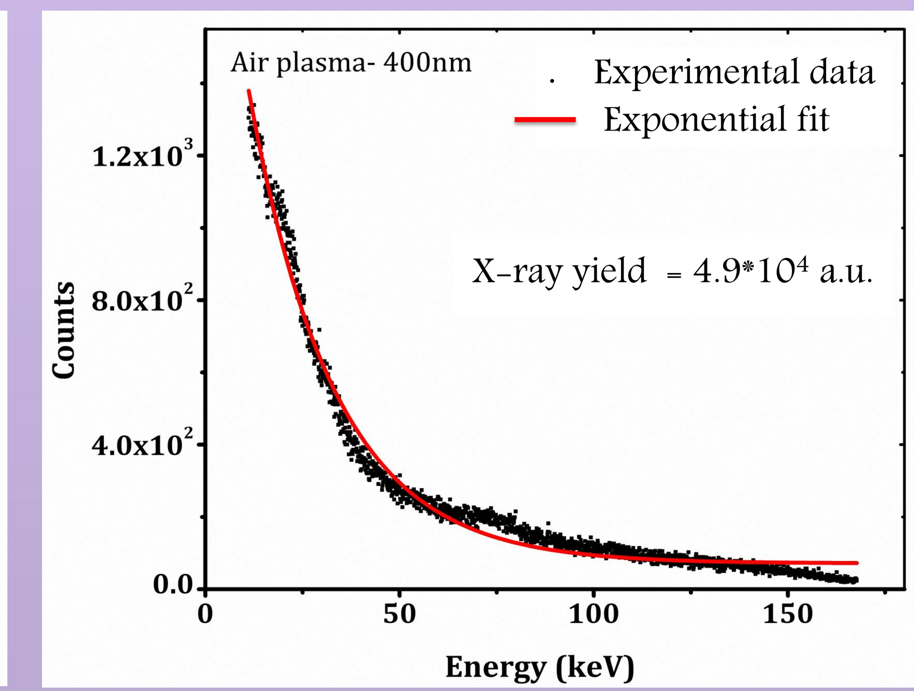



Ti: sapphire ultrafast laser
Pulse duration = 100 fs
Repetition rate 10 Hz
λ=800 nm
E=Max 8 mJ

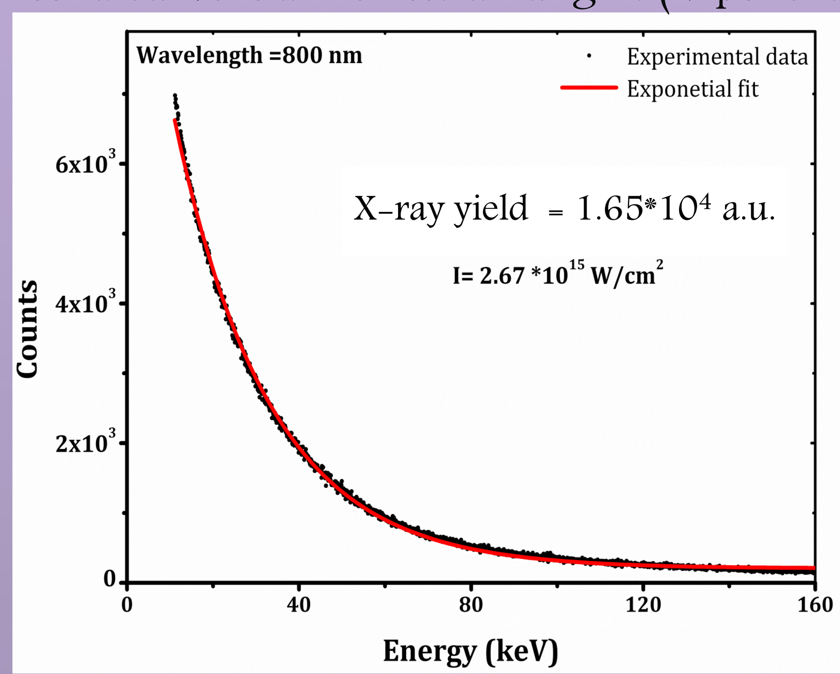
Spectra in the energy range of 10–180 keV were recorded over 500 independent laser shots keeping photon count rate 0.1 per pulse to ensure rejection of "pile up" events.

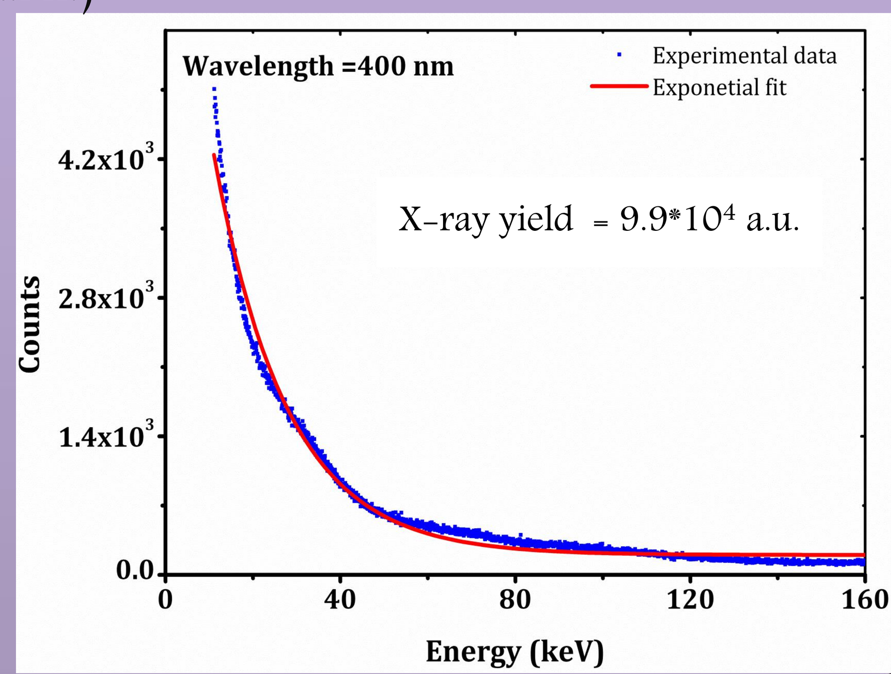
## Results



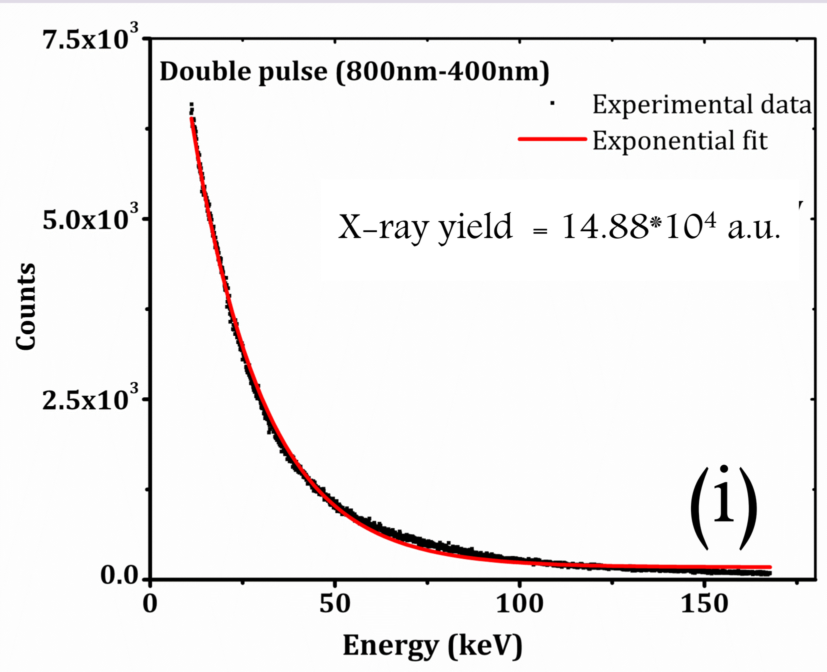

X-ray emission spectra from air breakdown with 800 nm, 400 nm respectively , 100 fs. The solid curve is a Bremsstrahlung fit (Exponential fit).

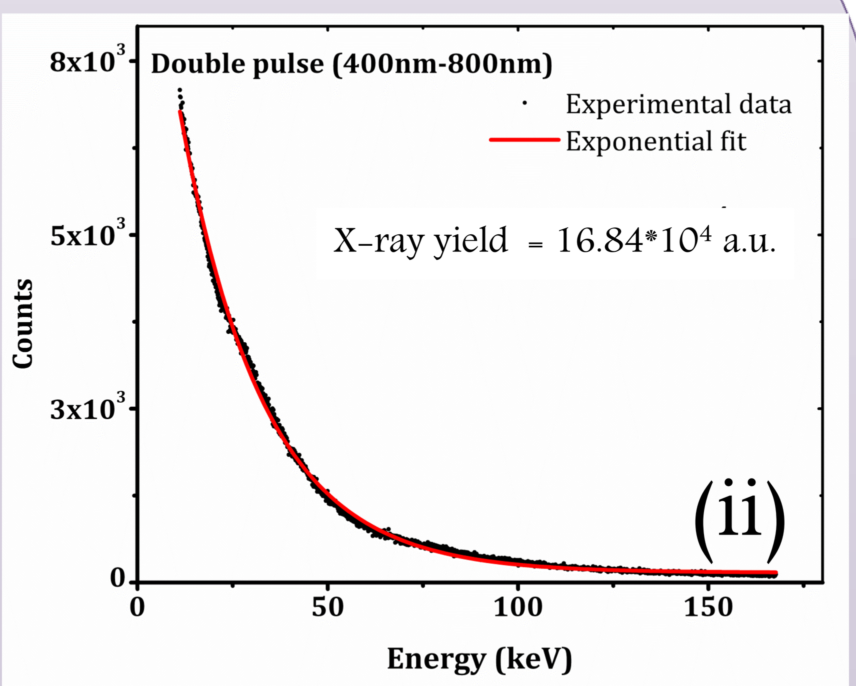


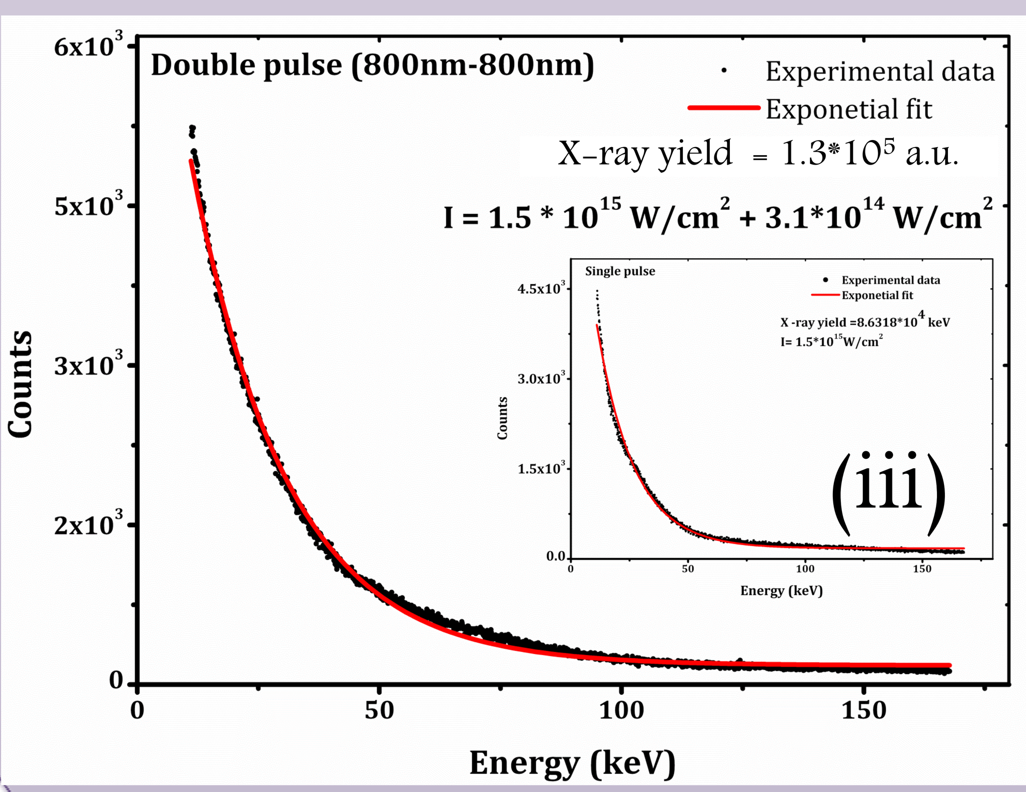

X-ray emission spectra from aluminium with 800 nm, 400 nm respectively, 100fs. The solid curve is a Bremsstrahlung fit .

## Results




X-ray emission spectra from aluminium in different cross beam double pulse configurations with a 3ns delay bet ween the pulses i) 800nm I$^{st}$ pulse -400nm 2$^{nd}$ pulse ii) 400nm I$^{st}$ pulse -800nm 2$^{nd}$ pulse iii) 800nm I$^{st}$ pulse -800nm 2$^{nd}$ pulse




| configuration | Hot electron temperature |
|---|---|
| Air breakdown 800nm | 22.90±0.01 keV |
| Air breakdown 400 nm | 21.98±0.01 keV |
| Single pulse 800nm | 22.05± 0.05 keV |
| Single pulse 400 nm | 16.72±0.09 keV |
| Double pulse 800nm-400nm | 19.506±0.04 keV |
| Double pulse 400nm-800nm | 21.98±0.04 keV |
| Double pulse 800nm-800nm | 19.76±0.06 keV |

- Resonance absorption (RA) plays an important role in the coupling of laser energy to plasma
- The "hot" electrons generated by collisional as well as collisionless processes (resonance absorption) are able to break through this coulomb barrier of the plasma because of their high energy.
- These hot electrons can then release energy in the form of bremsstrahlung or characteristic X-rays. The excitation of plasma wave is strongly dependent on the input laser intensity and the hot electron temperature generated by RA can be expressed by the well known scaling law

$$T_{hot} = 14(T_c I\lambda^2)^{0.33}$$

$T_{hot}$ and $T_c$ are the hot electron temperature and bulk plasma electron temperature expressed in keV, I is the input laser intensity expressed in units of $10^{15}$ W cm$^{-2}$, and the λ laser wavelength expressed in micrometres.

- In double pulse configuration initial plasma formation allows generating more electrons which can absorb more laser energy from laser and further heats up the plasma via collisional and collisionless processes. This excess "hot" electron generation helps in efficient coupling of laser energy.
- The enhanced X-ray yields because of the increased "hot" electron population, clearly validates the enhanced laser absorption by the plasma.
- Also, Surface modulations by the first pulse can give as much as 90% coupling of laser energy leading to generation of 'hotter' electrons manifested in terms of 'harder' X-rays.

## Summary

In summary, the double pulse configuration can enhance the X-ray yields compared to the single pulse configuration. This study clearly points out that the 800nm-800nm double pulse configuration couple more laser energy into the plasma via laser plasma interaction and surface modulation thus producing hotter plasma .

*References : 1. Teubner, U., et al, Physical review letters 70.6 ,794 (1993).*
*2. Kodama, R., et al. Applied physics letters 50.12 720-722 (1987).*