Enhaced Gamma-Photon Generation Through Laser-Solid Interaction in the Relativistic λ^3 Regime

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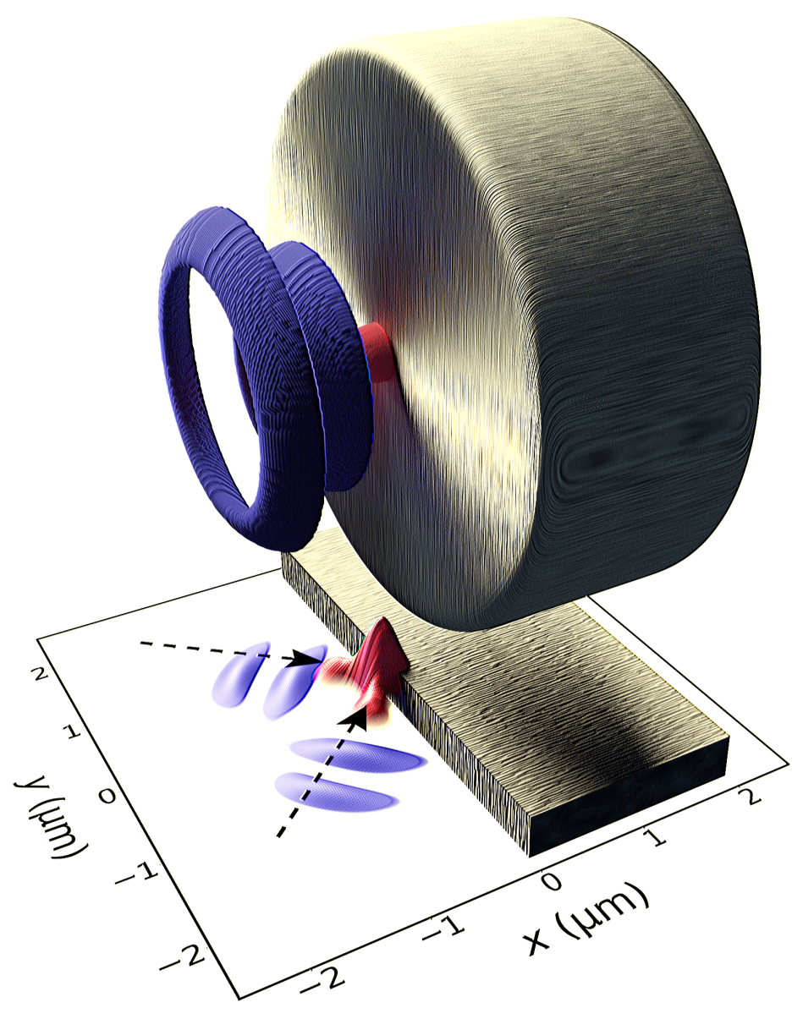
INTRODUCTION

A **tightly focused single cycle** laser results in the highest achievable intensity on the expense of the least energy for a fixed laser power, being in the so called **λ^3 regime** [1].



Simulation Setup.

Interaction of an intense λ^3-laser with a foil results in **high** laser to **γ-photon** energy conversion efficiency, κ_γ [2].

This work performs a parametric study of the λ^3-laser-target interaction, where the variables include the laser **polarisation** mode (radial, linear and azimuthal), the target **thickness** and electron number **density**.

The results are obtained via 3D QED PIC simulations [3].

The laser ($\lambda = 1$ μm) energy is 280 J, contained within **3.4 fs** FWHM duration, corresponding to an 80 PW laser. The laser is focused on a **$\sim\lambda/2$** spot, at an intensity of 10^{25} Wcm^{-2}.

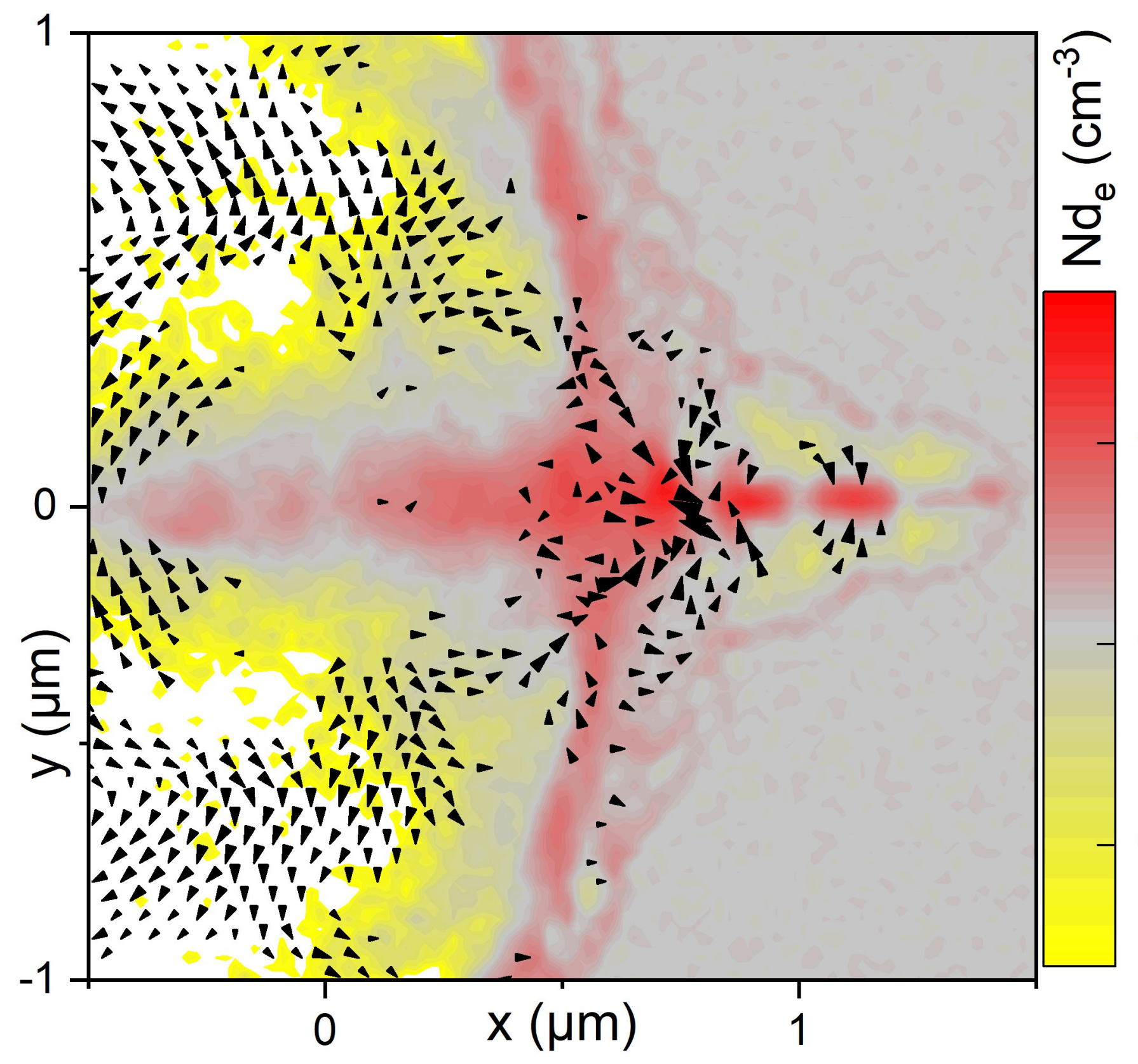
A practical advantage of our result is the elimination of the need of a preplasma in front of the target [4,5] for maximising κ_γ.

OVERVIEW OF THE RESULTS

Our multi-parametric study reveals that κ_γ is enhanced by a **radially polarised laser**, reaching **$\sim$50 %**, compared to $\sim$40 % for linearly and $\sim$30 % for azimuthally polarised lasers.

For the radially polarised laser, optimum κ_γ occurs for a 2 μm thick foil having an electron number density of 1.2×10^{24} cm^{-3}, corresponding to **titanium**.

The radially polarised λ^3-laser is characterised by a dominant **longitudinal** electric field. This field component benefits the formation of a **conical hole** within the foil volume, enhancing the coupling of the laser field to the electrons. For a linearly polarised laser the cavity is asymmetric, suppressing its formation.



Electron density during the interaction of an 80 PW λ^3 focused laser with a titanium foil. The arrows represent the electric field vectors.

Interference of the tightly focused fields results in uneven contribution to the parameter χ_e (that governs γ-photon formation) by the electric and magnetic terms, with **non-cancelling** contribution even for electrons co-propagating the laser pulse.

The high χ_e values result in high κ_γ, which in turn creates copious pairs, with **positrons** obtaining $\sim$10 % of the laser energy.

REFERENCES

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[4] T. Nakamura et al. *Phys. Rev. Lett.* **108** 195001 (2012)
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γ-PHOTON OPTIMUM, AND POWER SCALING

The dependency of κ_γ on the laser **power** was examined in the range 1−300 PW for a 2 μm thick titanium foil and for a radial polarisation mode.

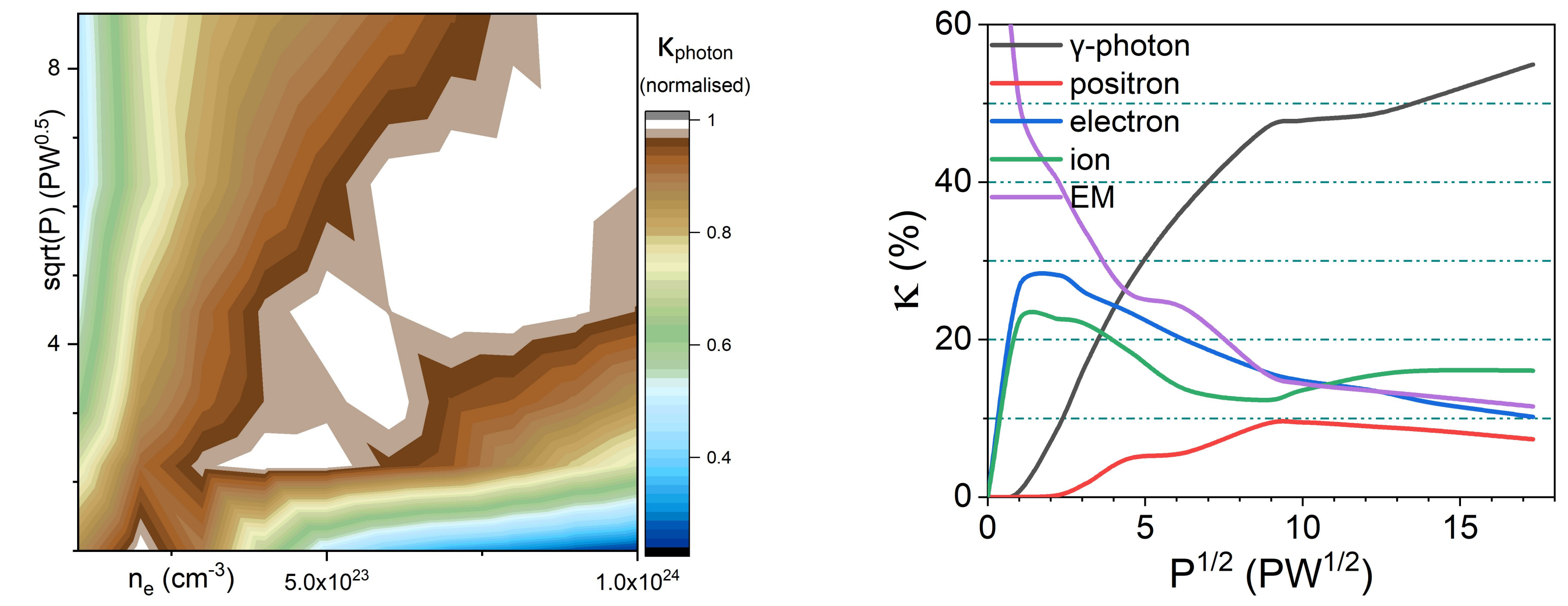
The κ_γ **increases by increasing the power**. The other particles saturate at a conversion efficiency of $\sim$10 %, indicating that κ_γ should saturate at $\sim$60 %.

At $\sim$100 PW the electron-positron pair generation is maximised relatively to the γ-photon generation.

The optimum κ_γ strongly depends on the electron density at lower laser intensities. The density dependency faints as power increases.

At optimum density, a 1 PW gives a κ_γ of $\sim$3 %.

As power increases, the same does the number of times an electron/positron emits a γ-photon, with the dependency being approximately linear with the dimensionless amplitude.



(a) *The κ_γ (normalised) at each power and for different electron densities.*

(b) *Laser (radial) energy conversion efficiency as a function of the root of power for all particle species.*

γ-FLASH INTERACTION WITH HIGH-Z TARGET

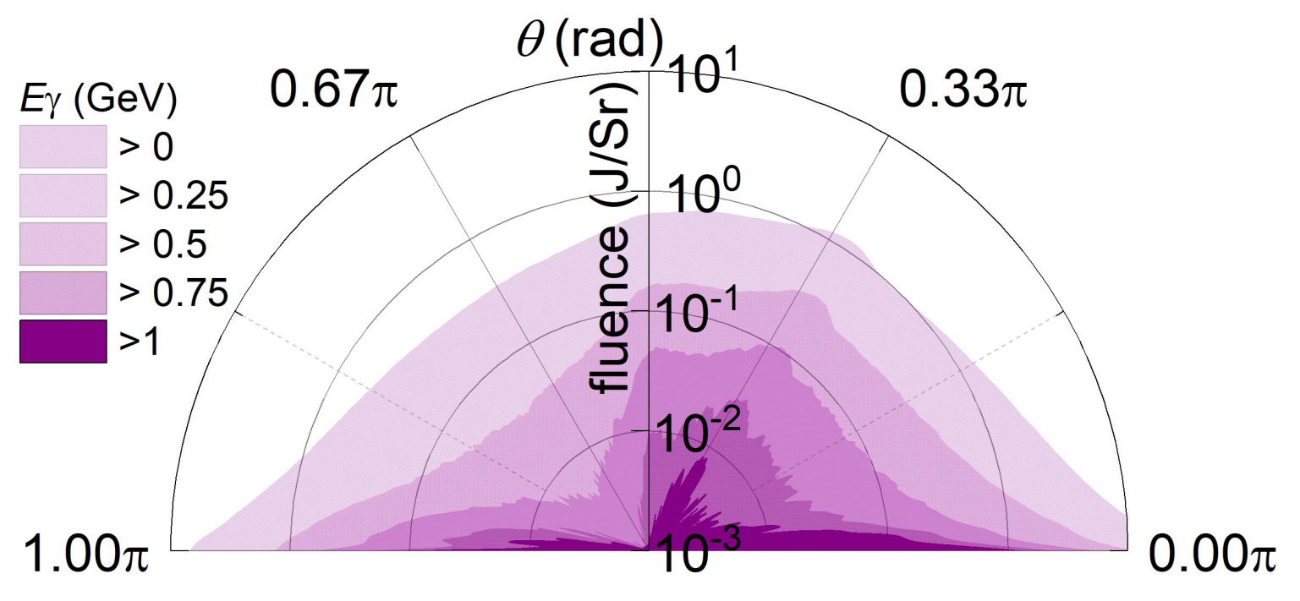
Most energetic γ-photons are generated within one laser period. During that time, γ-photon loss to pairs also occurs.

High energy γ-photons form an almost collimated beam in the **forward/backward** direction and at 60°.

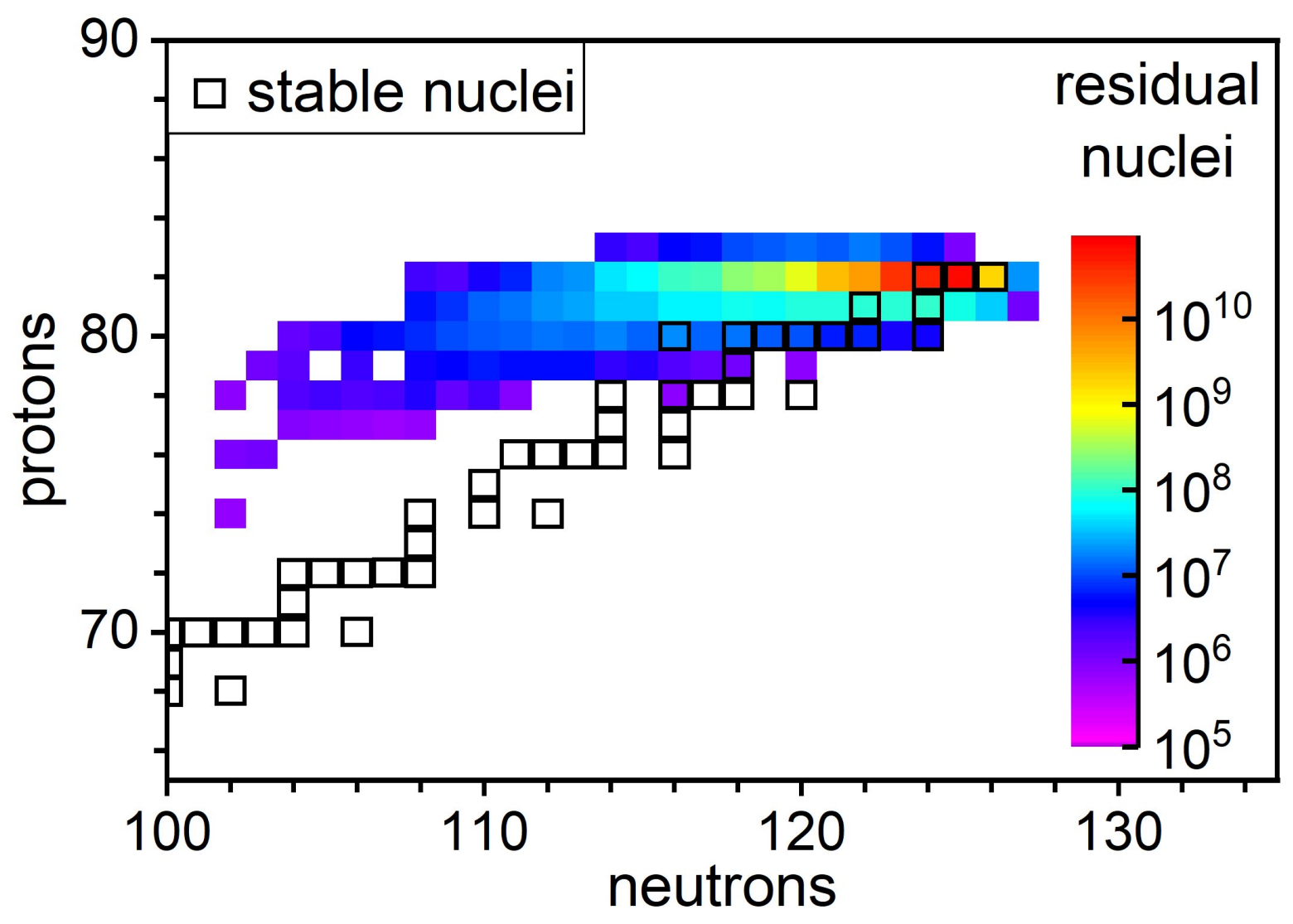
The γ-photons at 60° suffer geometrical dissipation due to their large solid angle compared to those on axis, resulting the latter having a significantly higher energy density.

The γ-photons form a $\sim$30 PW spherically expanding **γ-flash**.

The PIC γ-photons are transported with **FLUKA** [6] (Monte Carlo) to simulate their interactions with matter.



(a) *γ-photon angular distribution.*



(b) *Nuclide chart after importing PIC γ-photons in FLUKA (target 10 cm Pb).*

CONCLUSIONS

A single-cycle, tightly-focused 80 PW pulse leads to the ultraintense **λ^3 regime**.

The laser **polarisation**/power and target thickness/density strongly affect the γ-photon energy conversion efficiency.

Optimum κ_γ is obtained by a radial polarisation mode, resulting in a directional γ-flash.