On the necessity for systematic study of Kα emission in non-refluxing conditions

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Motivation

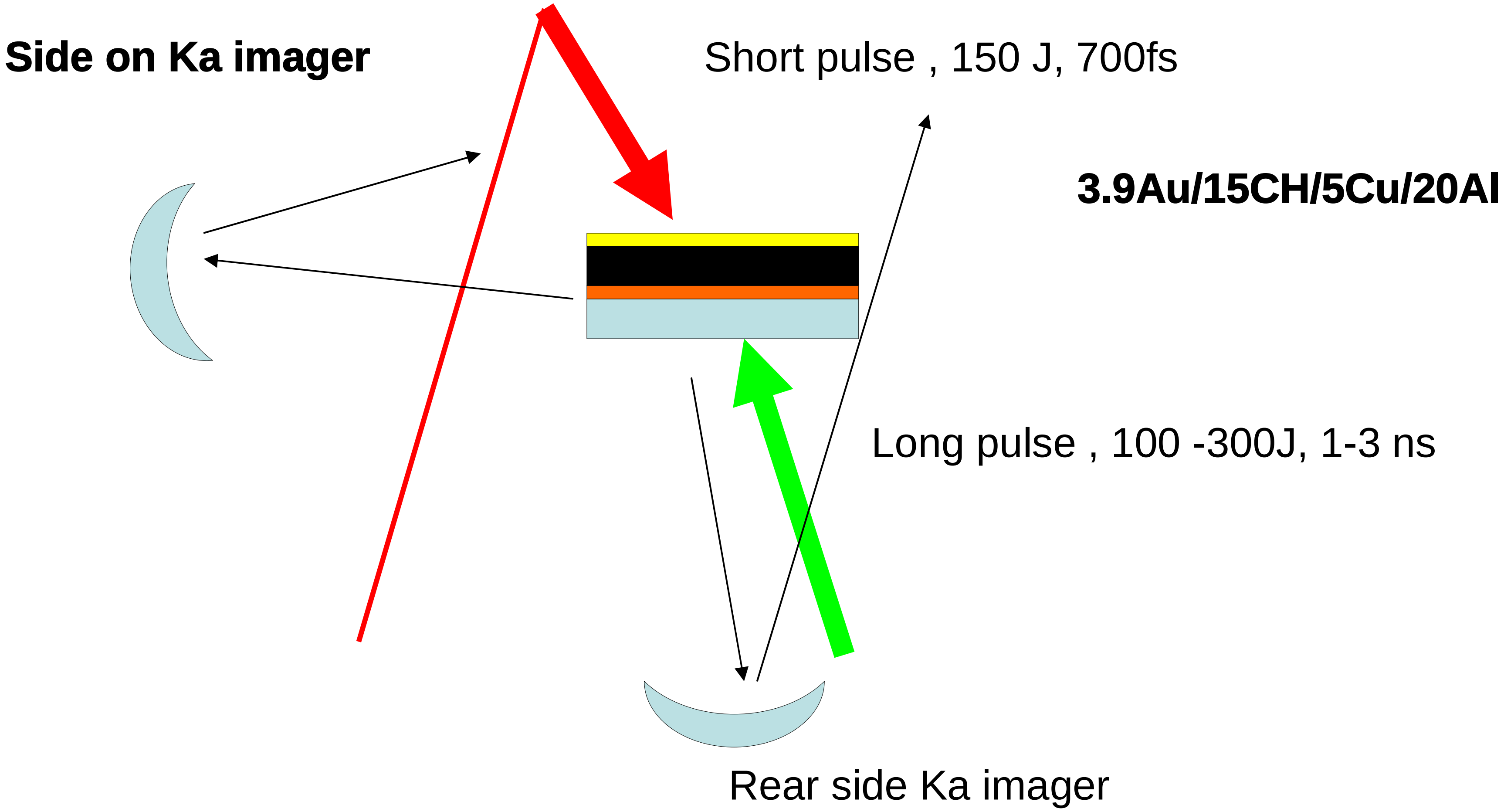
The Ka emission is a widely used diagnostic to track the fast electron beam transport in target material.

It can give information on fast electron penetration depth, spreading angle and laser to electron conversion efficiency.

As proved experimentally, Kα emission depends on plasma parameters, more specifically on the plasma gradients at the target interface, that determine the fast electron refluxing. There's a need for a more detailed study of Kα emission in non relfuxing condition to better understand the details of fast electron transport in target material.

Titan data at Livermore

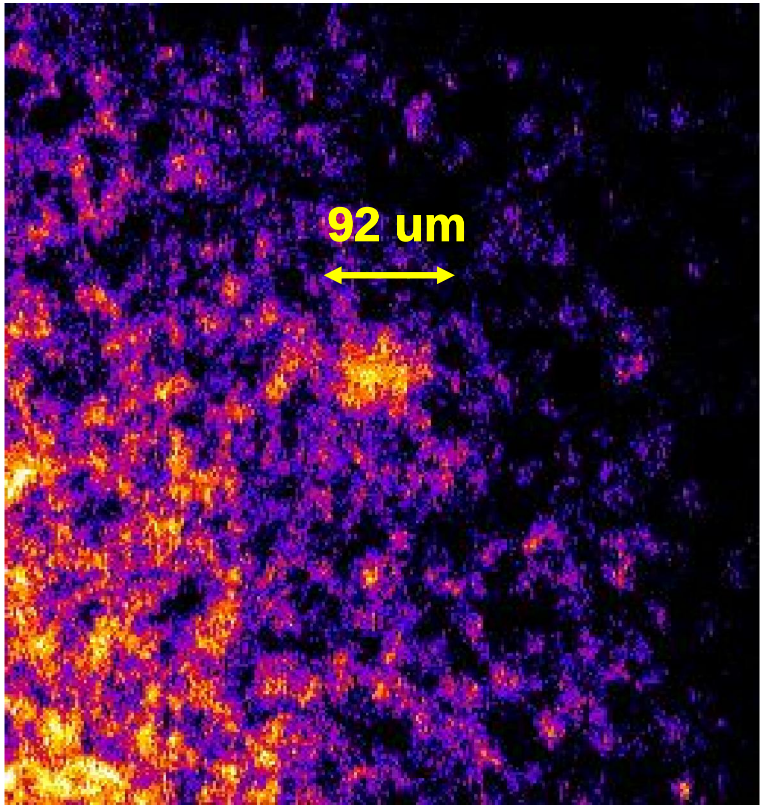
The experimental setup was composed by many diagnostic, for our purpose we will show only the K-alpha imaging diagnostics



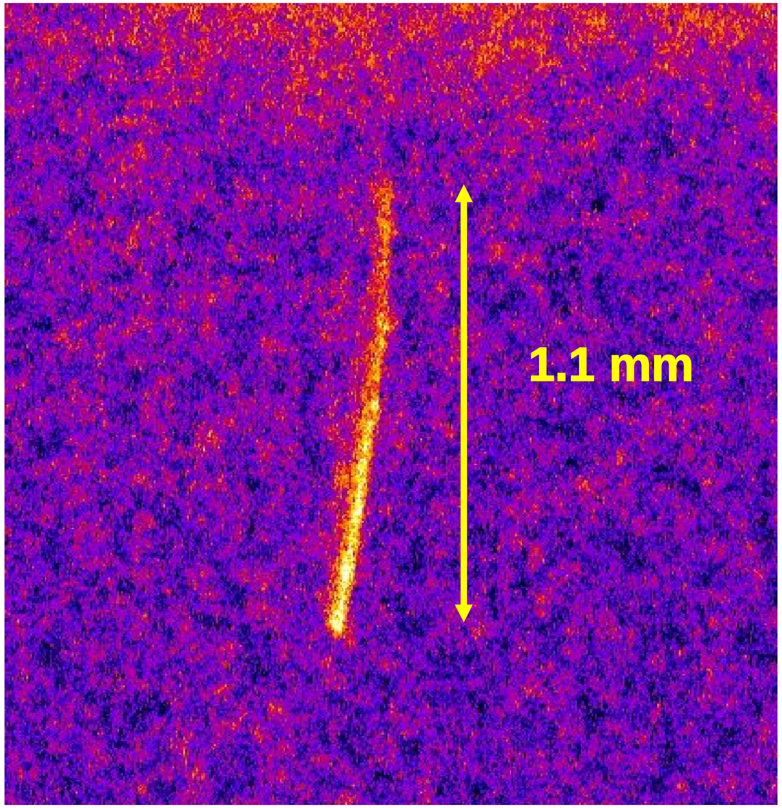
Titan data at Livermore

Shot for 3.9Au/15CH/5Cu/20Al in refluxing conditions

Kα back



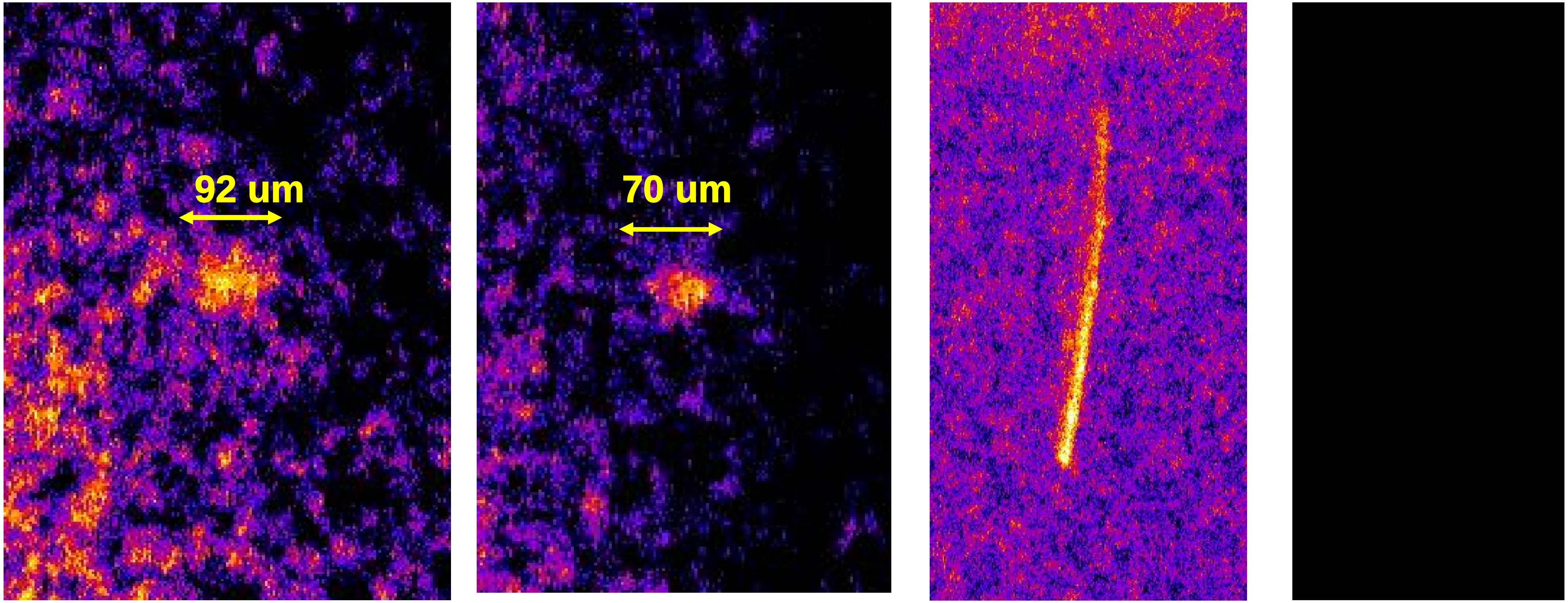
Side on Kα



Titan data at Livermore

Shot for 3.9Au/15CH/5Cu/20Al with get lost layer

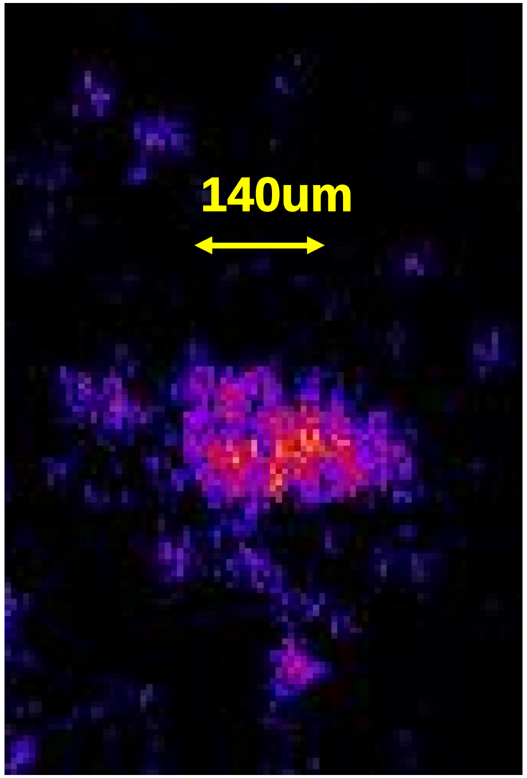
Only SP   With LP   Only SP   With LP



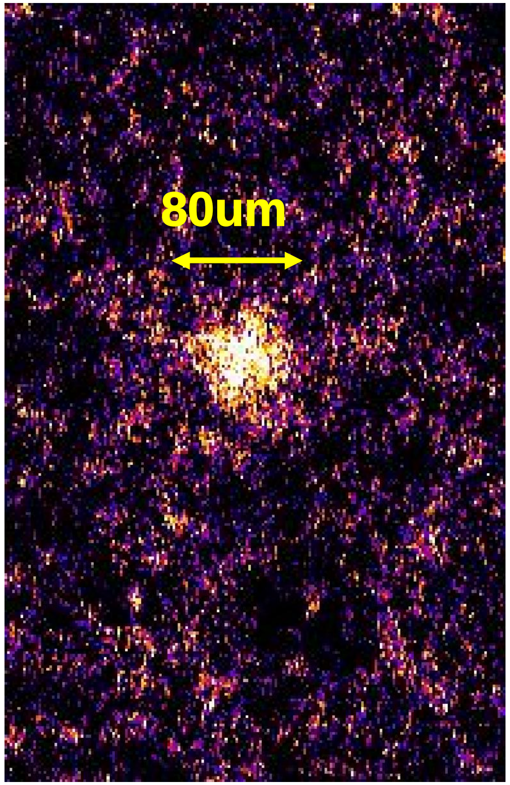
Titan data at Livermore

Shot for 0.1Al/25CH/5Cu/12.5Au

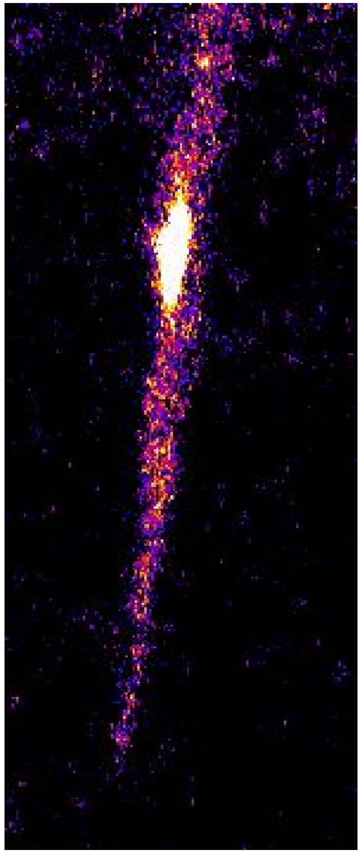
Only SP



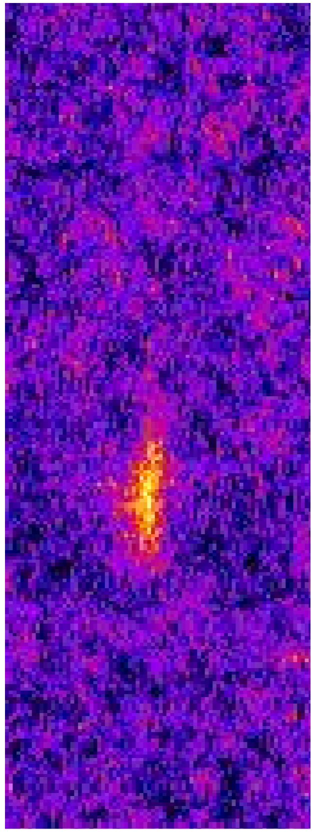
With LP



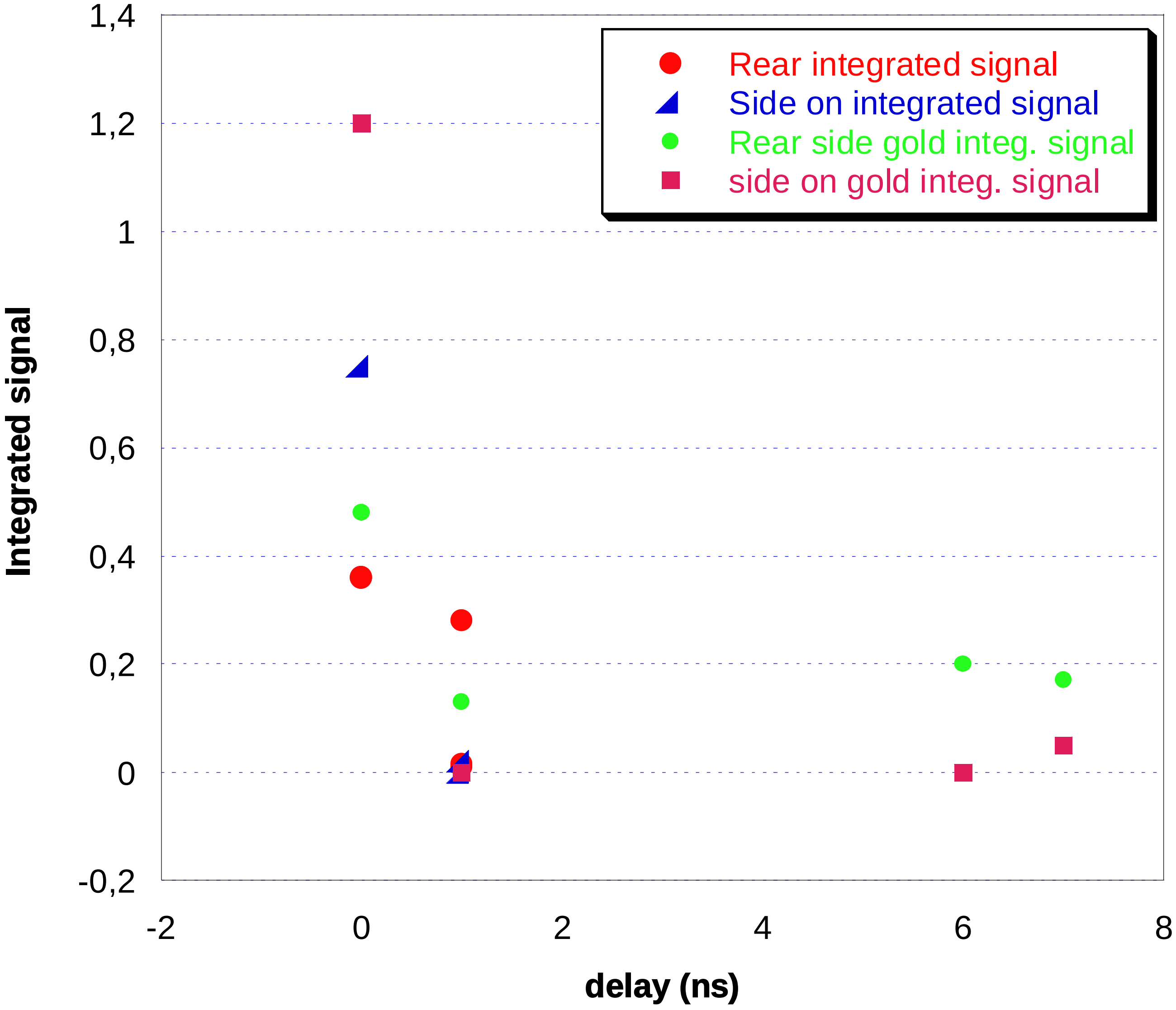
Only SP



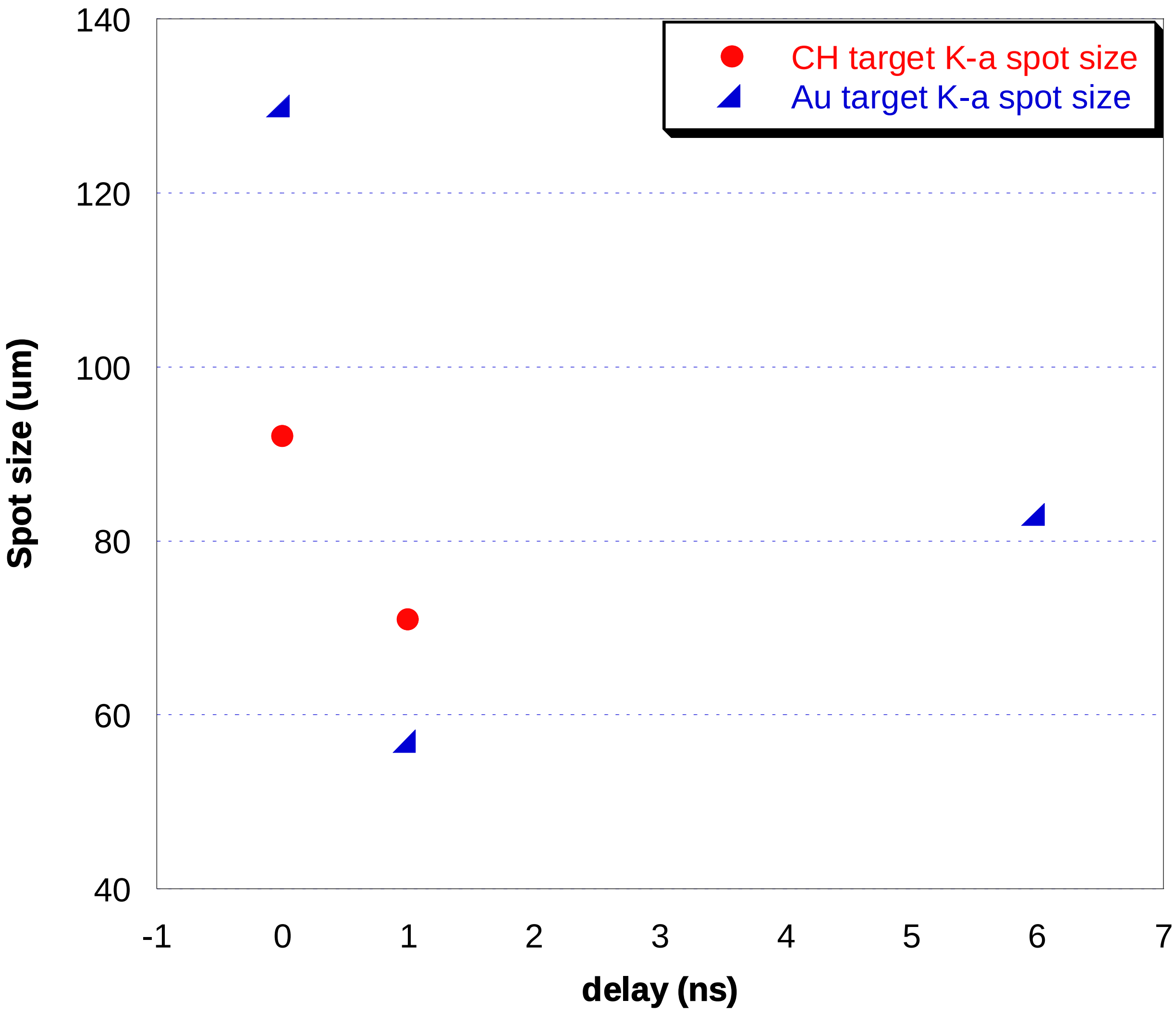
With LP



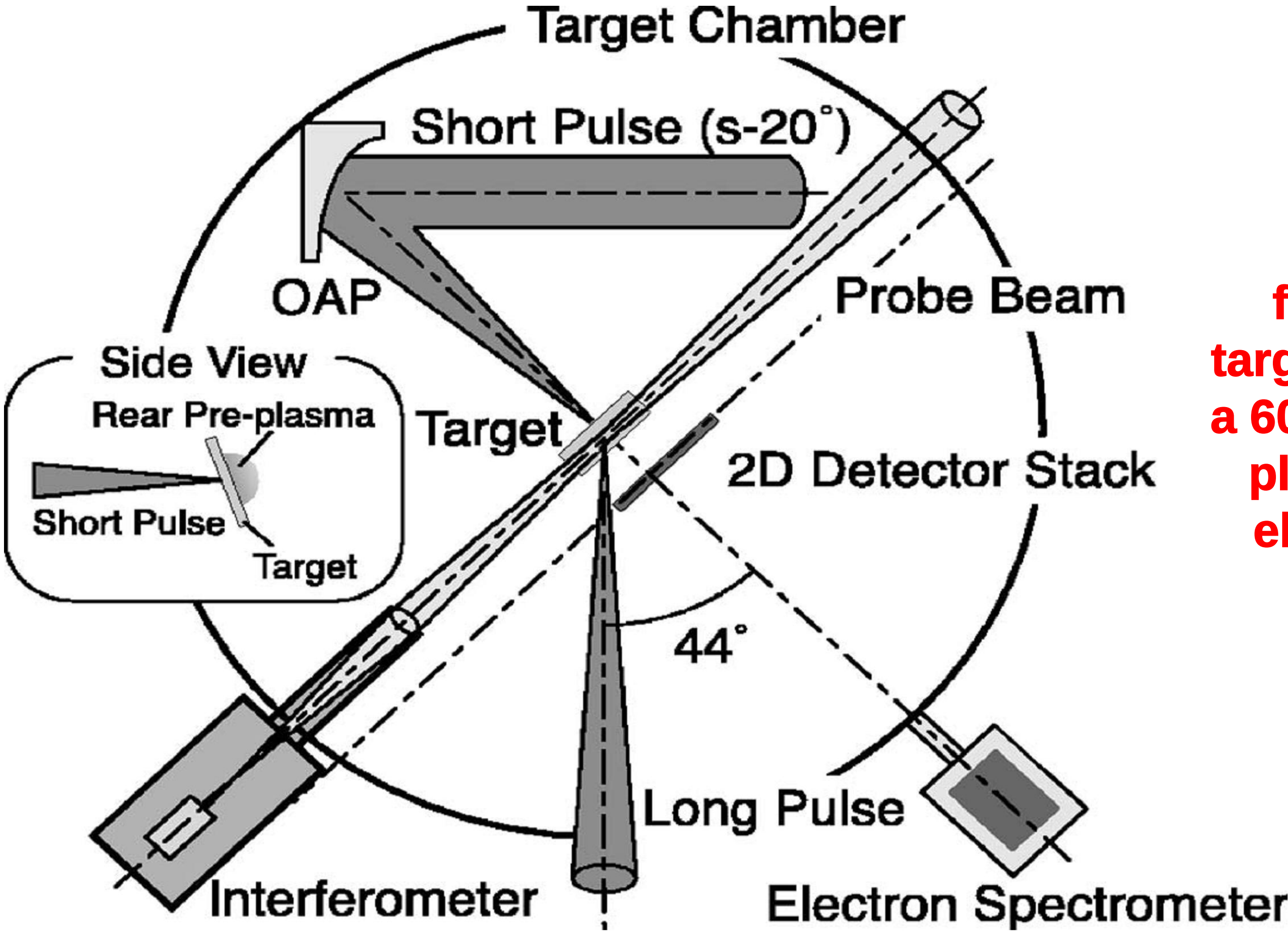
Titan data at Livermore



Titan data at Livermore



Other works



A long pulse focused on the target rear produces a 60 µm scale lenght plasma, 10^{19} cm^{-3} electron density.

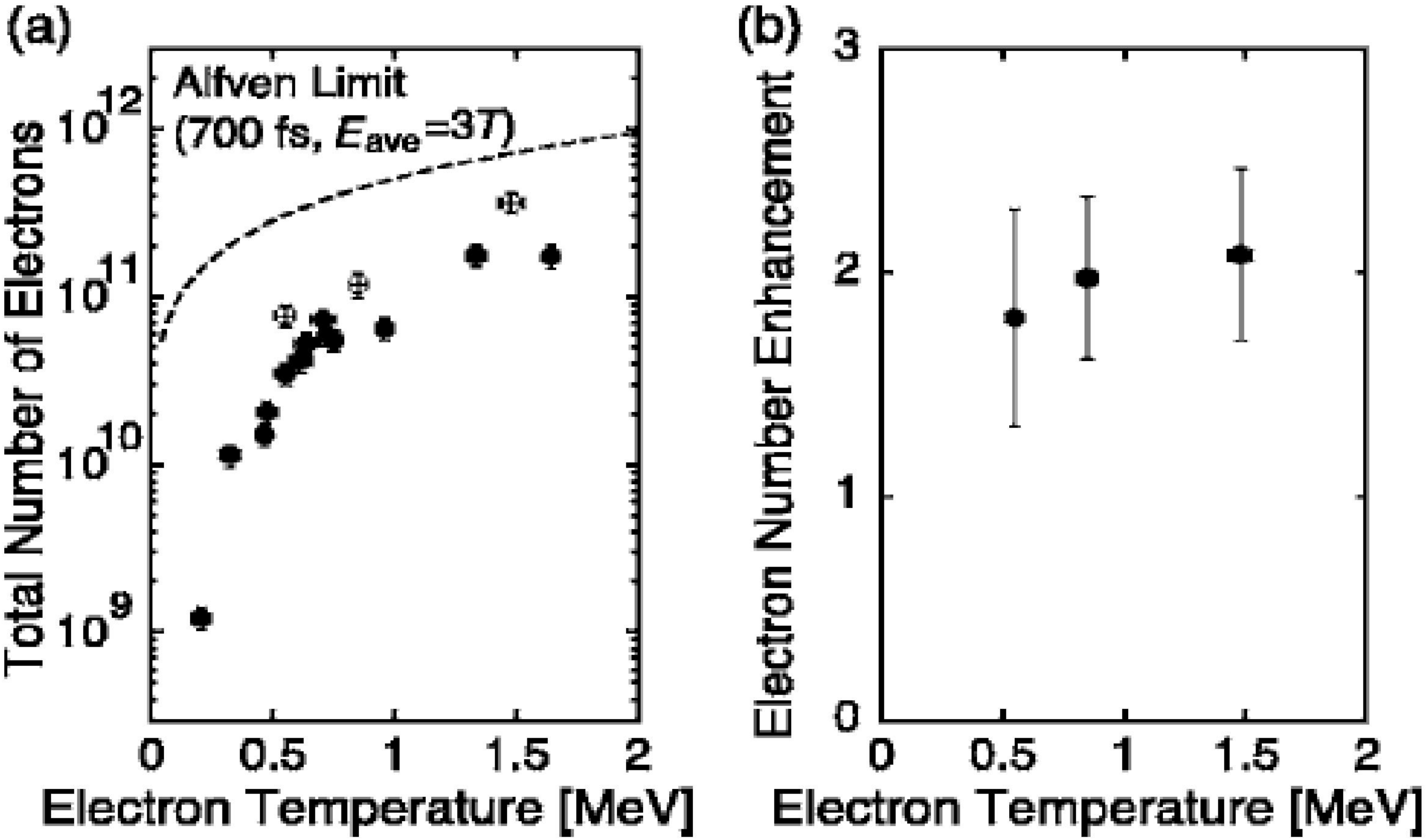
Yabuuchi et al, Phys. Plasmas **14**, 040706 2007

Other works

Rear plasma case

No rear plasma case

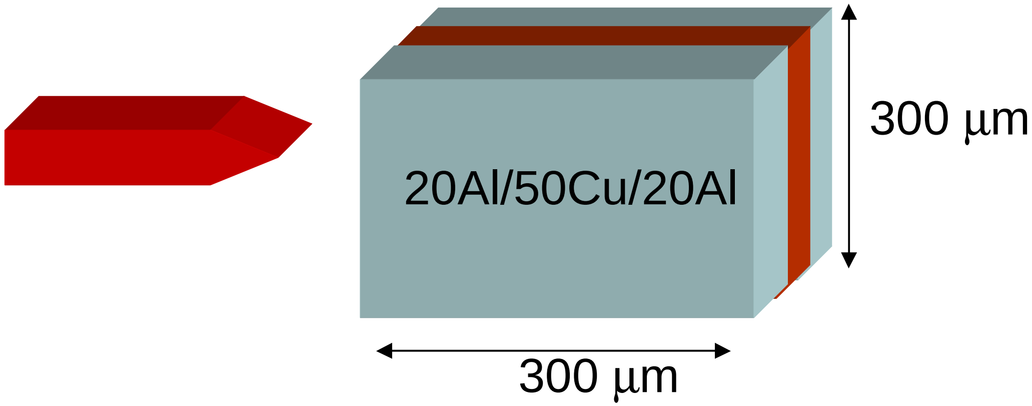
Introducing a get lost layer, the electron number collected by the e-spec increases by 2

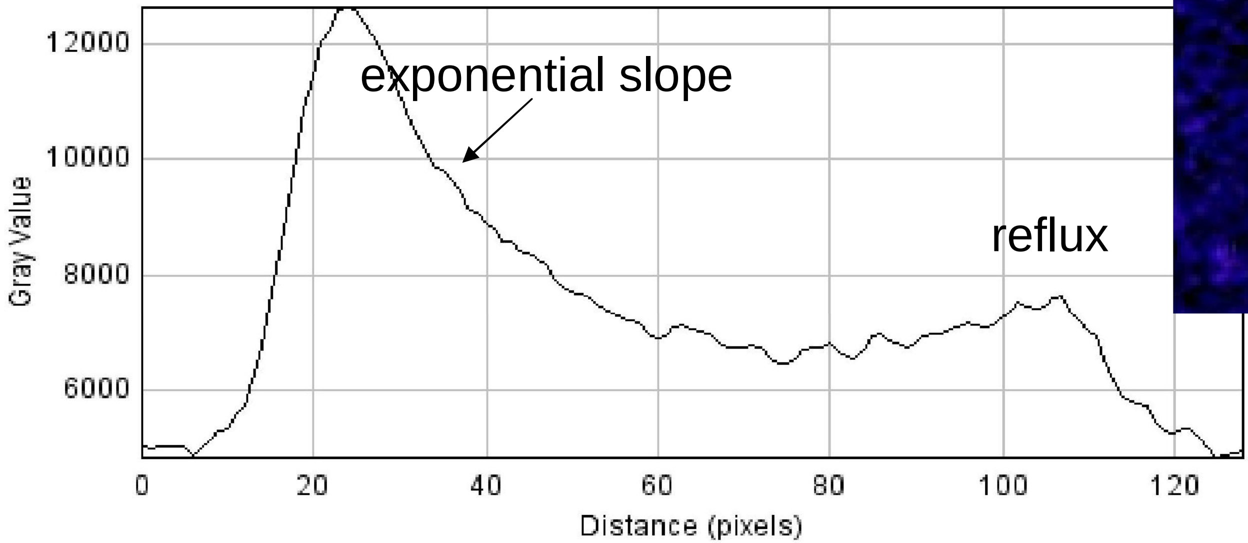


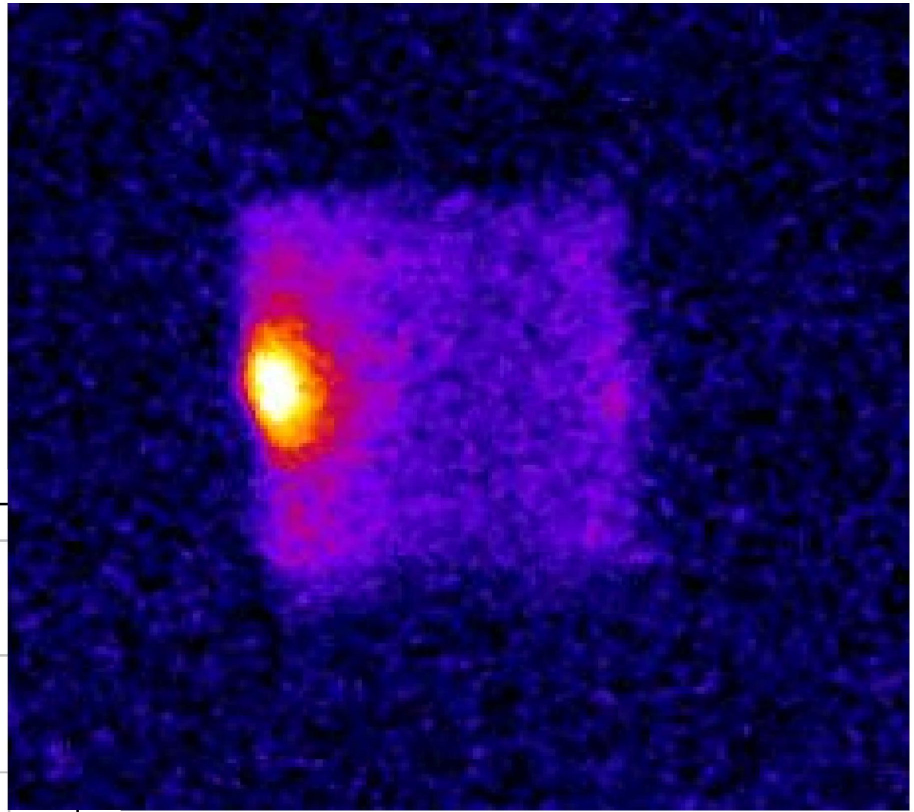
Yabuuchi et al, Phys. Plasmas **14**, 040706 2007

“Transverse” targets

It is possible to see the “exponential” decay of Ka radiation followed by a rise up due to fast electron refluxing at the rear surface



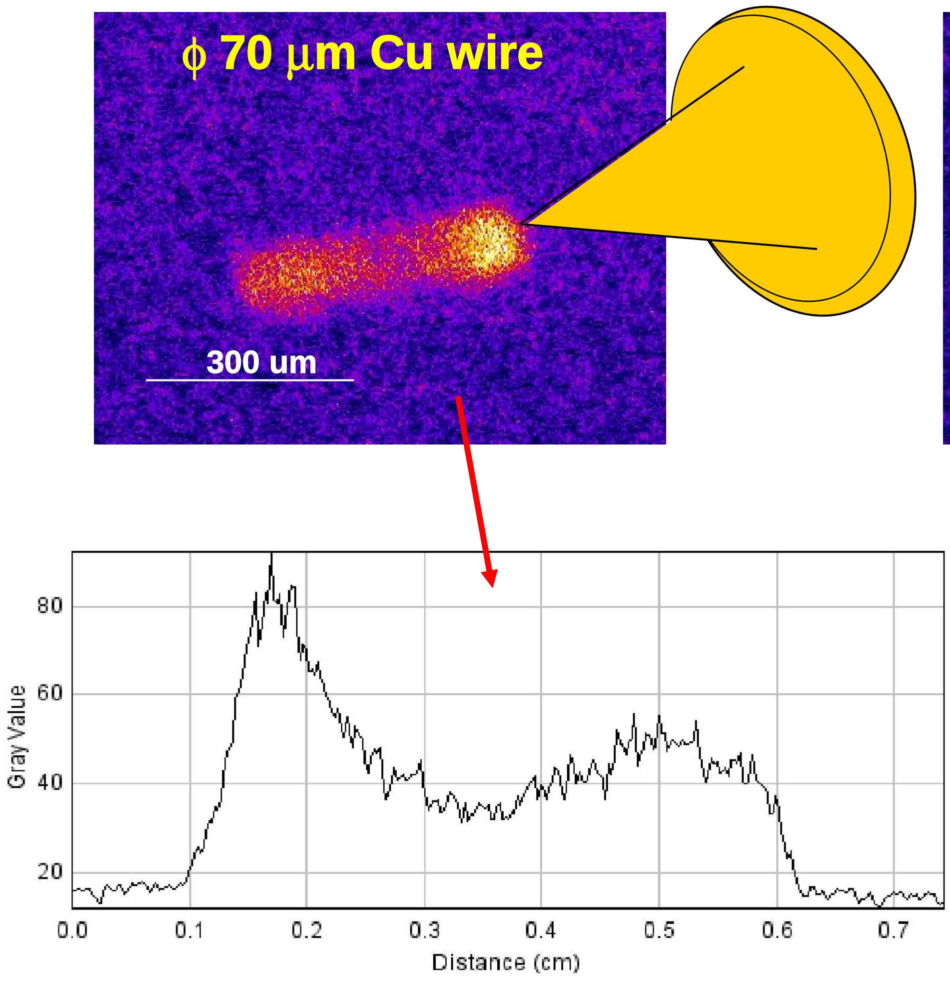


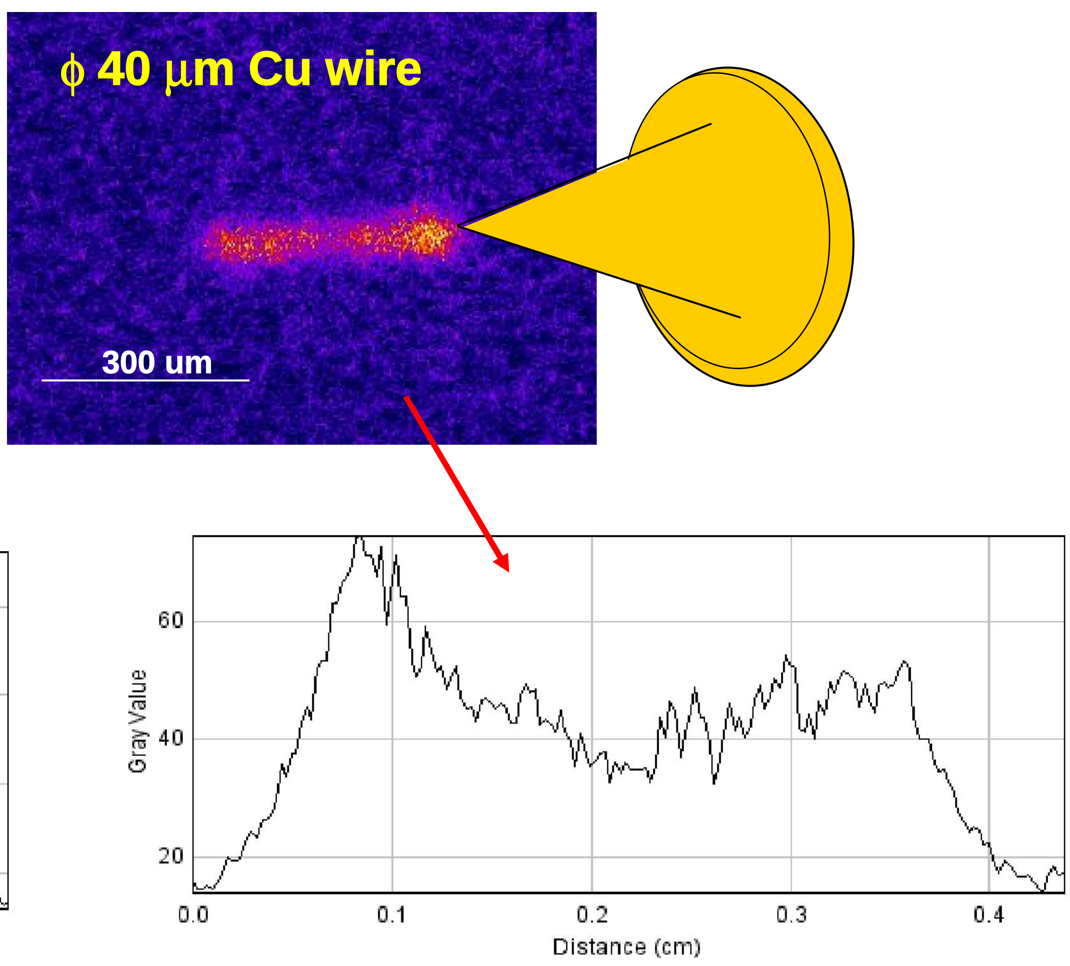


Cone-wire targets

Cone-wire targets from "fast electron transport" experiment at TAP

The wires are 400 μm long





Analytical Model

The total number of Ka photons produced in a single passage in the tracer layer is given by

$$N_K = \int_{E_K}^{\infty} \sigma(E) f(E,x) \omega_K n_{Cu} \lambda \left(1 - e^{-L_{Cu}/\lambda}\right) dE$$

where σ(E) is the relativistic cross section for K-shell ionization

$$\sigma_{K,\mathrm{Rel}}(E)(cm^2) = 7.92\times10^{-14} \frac{1}{EE_K} R(E) \ln\frac{E}{E_K}$$

and R(E) is the relativistic correction factor

$$R(E) = \left(\frac{2+E_K}{2+E}\right)\left(\frac{1+E}{1+E_K}\right)^2 \left(\frac{(E_K+E)(2+E)(1+E_K)^2}{E(2+E)(1+E_K)^2 + E_K(2+E_K)}\right)^{3/2}$$

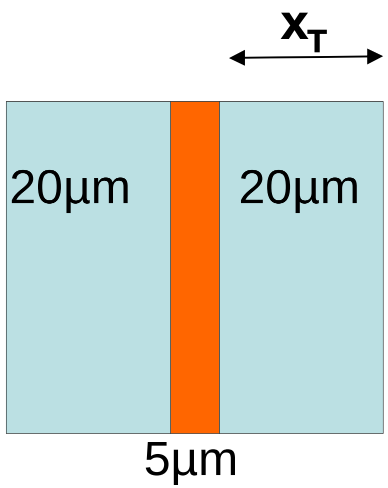
Analytical Model

The fast electron distribution function has been chosen so that

$$f(E,x) = f(E) N_{e0} e^{-x/\lambda}$$

where f(E) is a relativistic Maxwellian, assumed to do not vary in shape but only in number of particles during the transport

x_T is the tracer layer depth in the target, for simplicity, the target is assumed symmetrical with respect to the tracer layer, but the model is applicable to different target designs .



Analytical Model

We define the integral as:

$$\int_{E_K}^{\infty} N_{e0}\sigma(E) f(E)\omega_K n_{Cu}\lambda\left(1-e^{-L_{Cu}/\lambda}\right)e^{-x_T/\lambda}dE = f_{e\to K}$$

The refluxing electron beam will produce:

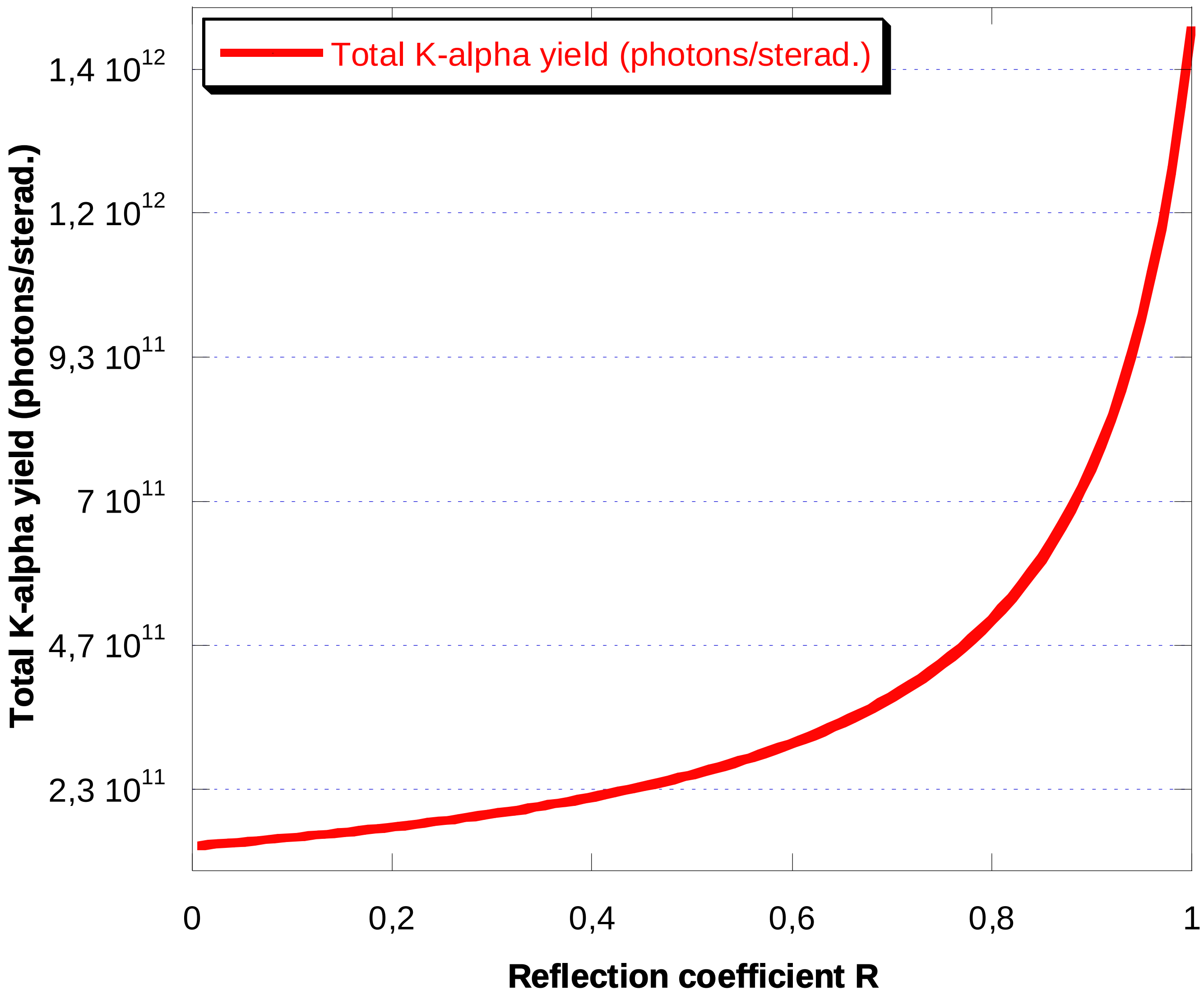
$$R\cdot e^{-(2x_T+L_{Cu})/\lambda} f_{e\to K} + R^2\cdot e^{-(4x_T+2L_{Cu})/\lambda} f_{e\to K} + \ldots \to$$

$$\to \sum_j \left(R\cdot e^{-(2x_T+L_{Cu})/\lambda}\right)^j f_{e\to K} = \frac{1}{1-R\cdot e^{-(2x_T+L_{Cu})/\lambda}} f_{e\to K}$$

Where R is the reflection coefficient, 0 ≤ R ≤ 1

Analytical Model

We can calculate the total Kα yield as function of the reflection coefficient R, for laser and target specs similar to the Titan laser conditions



Analytical Model

In the case of low contrast pulses -undriven target and high contrast -driven target, we have two different reflection coefficients for front and rear side, R and r. We need to consider four cases:

Undriven- High contrast SP

$$N_K = \frac{1}{1 - R \cdot e^{-\frac{2x_T - L_{Cu}}{\lambda}}} f_{e \to K}$$

Undriven- Low contrast SP

$$N_K = \frac{(1+R)}{1 - Rre^{-\frac{2x_T - L_{Cu}}{\lambda}}} f_{e \to K}$$

Driven- High contrast SP

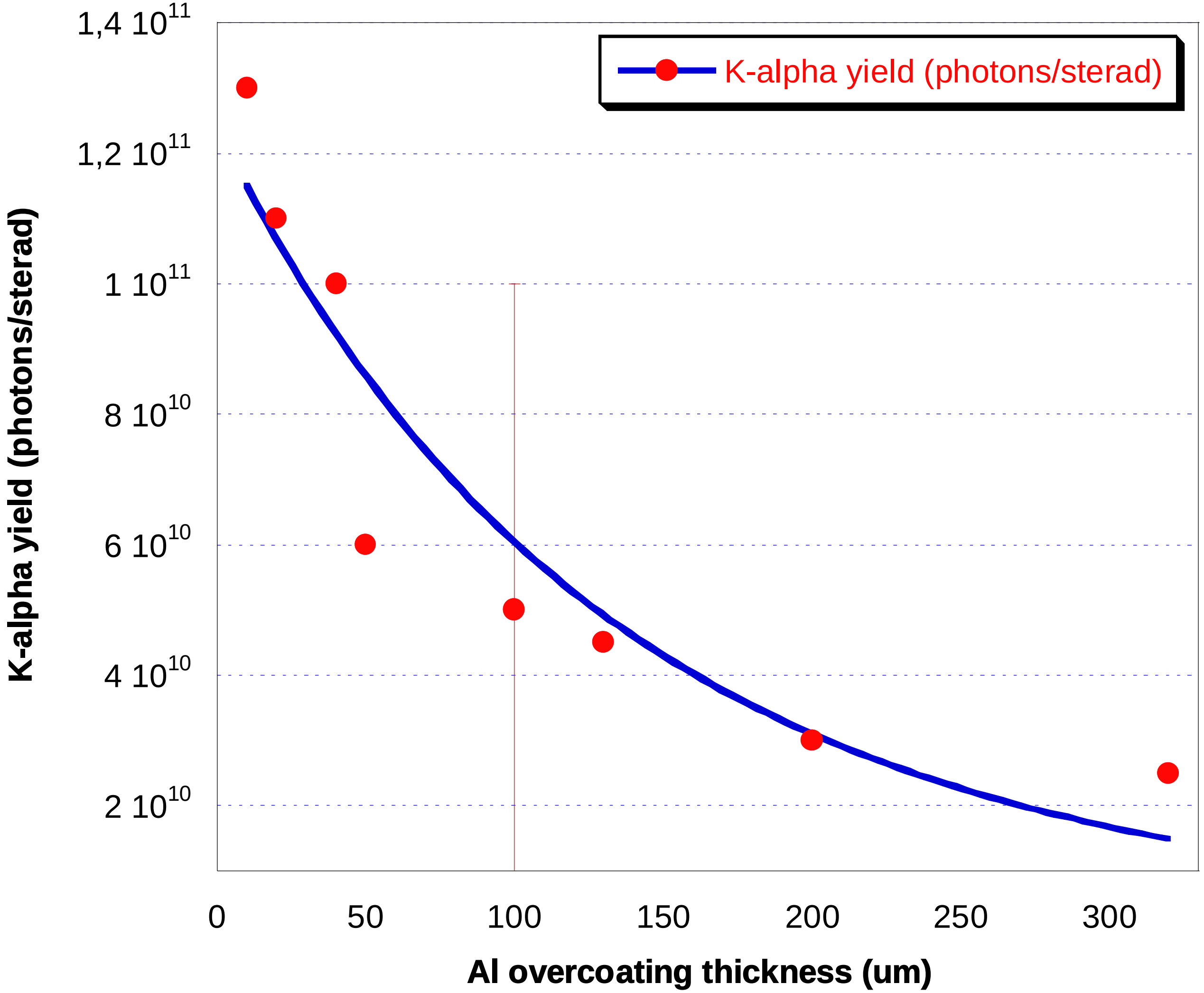
$$N_K = \frac{(1+r)}{1 - Rre^{-\frac{2x_T - L_{Cu}}{\lambda}}} f_{e \to K}$$

Driven- Low contrast SP

$$N_K = \frac{1}{1 - r \cdot e^{-\frac{2x_T - L_{Cu}}{\lambda}}} f_{e \to K}$$

Analytical Model

The reflection coefficient is determined only by plasma conditions at the interface.



For experimental data and conditions found in Martinolli's paper, the measured reflection coefficient R is :

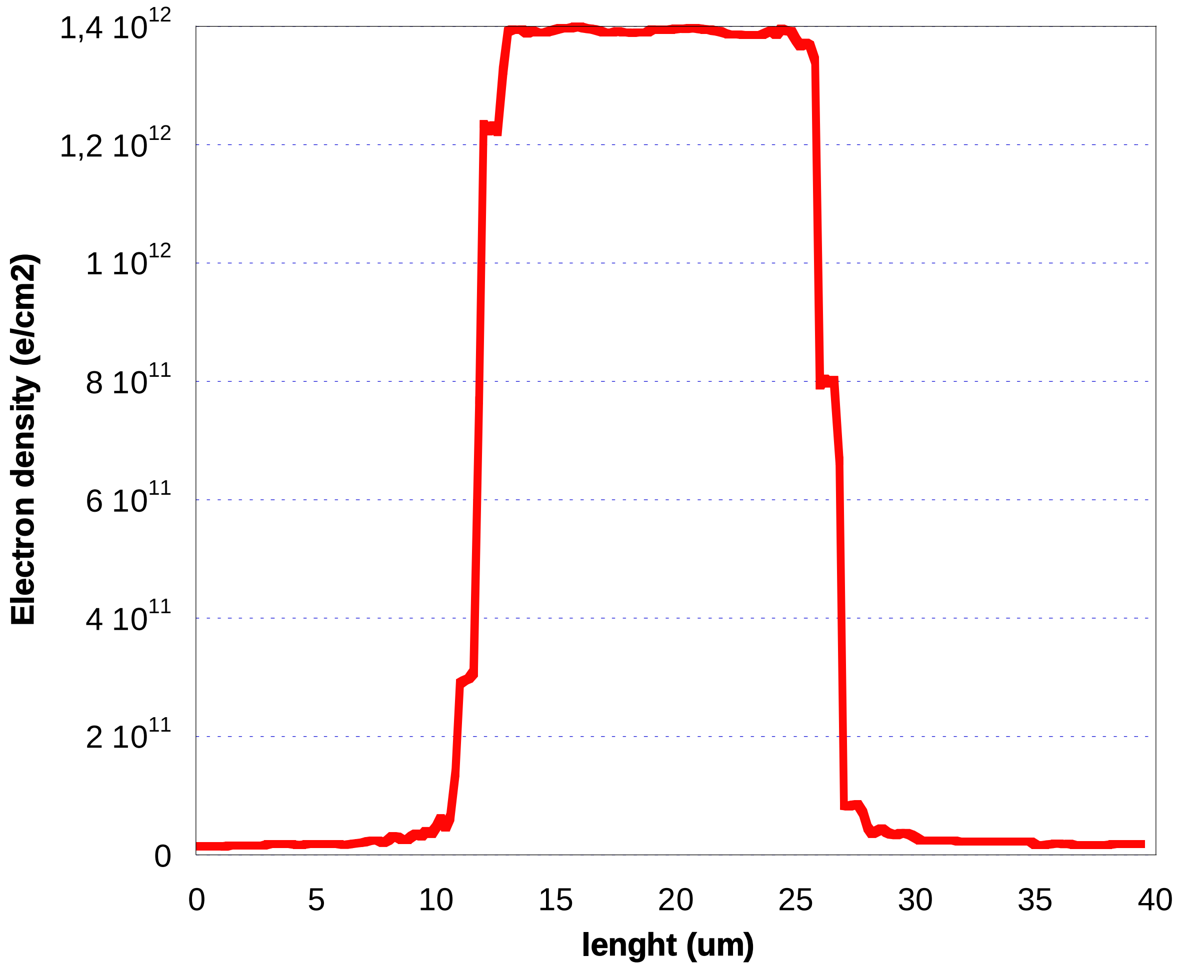
R=0.8 ± 0.04

Data from: Martinolli et al. PHYSICAL REVIEW E **73**, 046402 2006

Collisional Simulation

We performed a collisional simulation to verify the effective increment in the k-alpha yield in refluxing conditions. Propagation in a 20/5/20 um Al/Cu/Al target

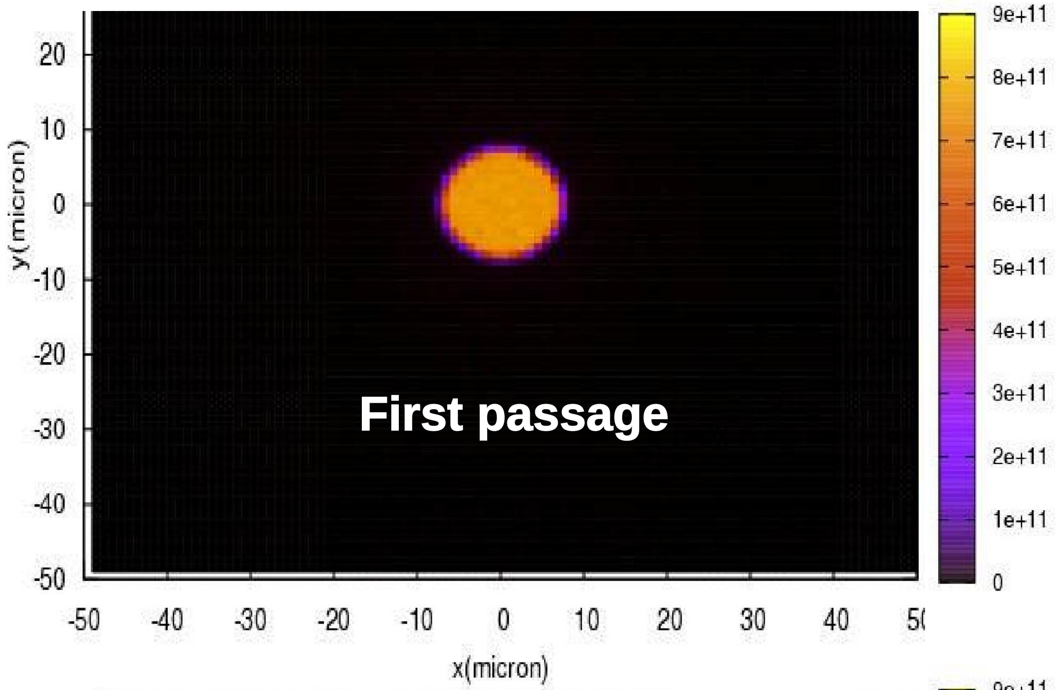
“Flat” fast electron distribution 1 MeV, 1.4 x 10^{11} e^{-}/cm^{2} and refluxing coef. R=0.85

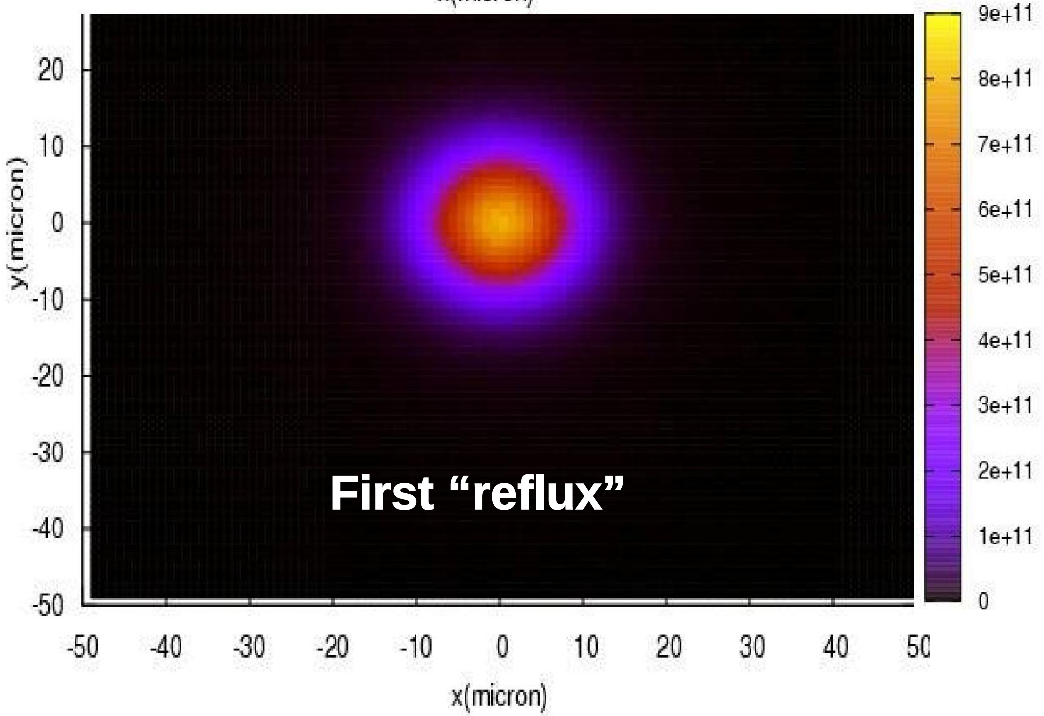


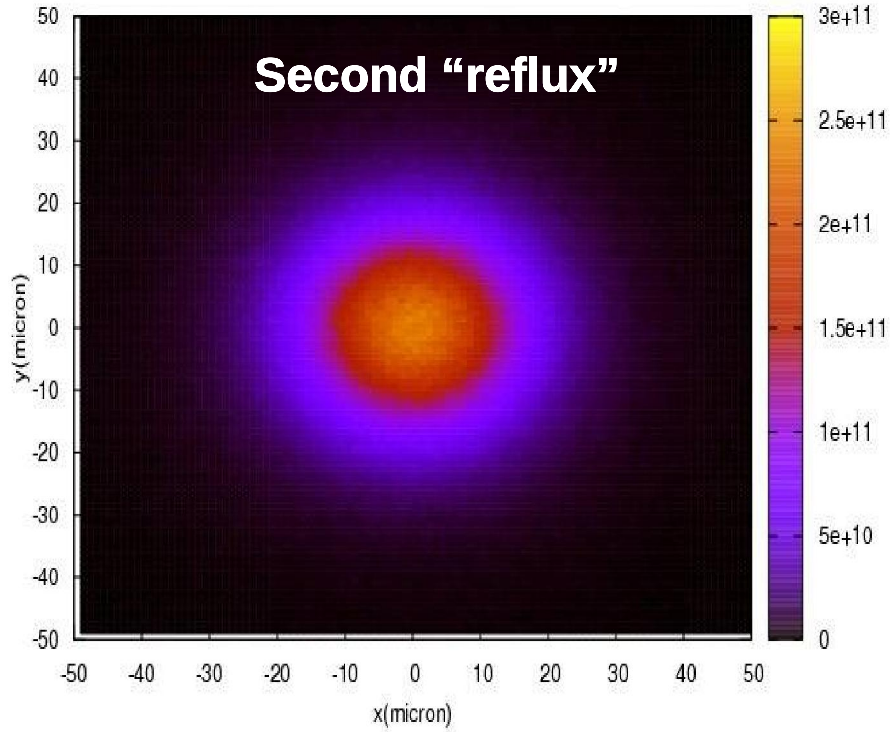
Collisional Simulation

Fast electron flux in the tracer layer.

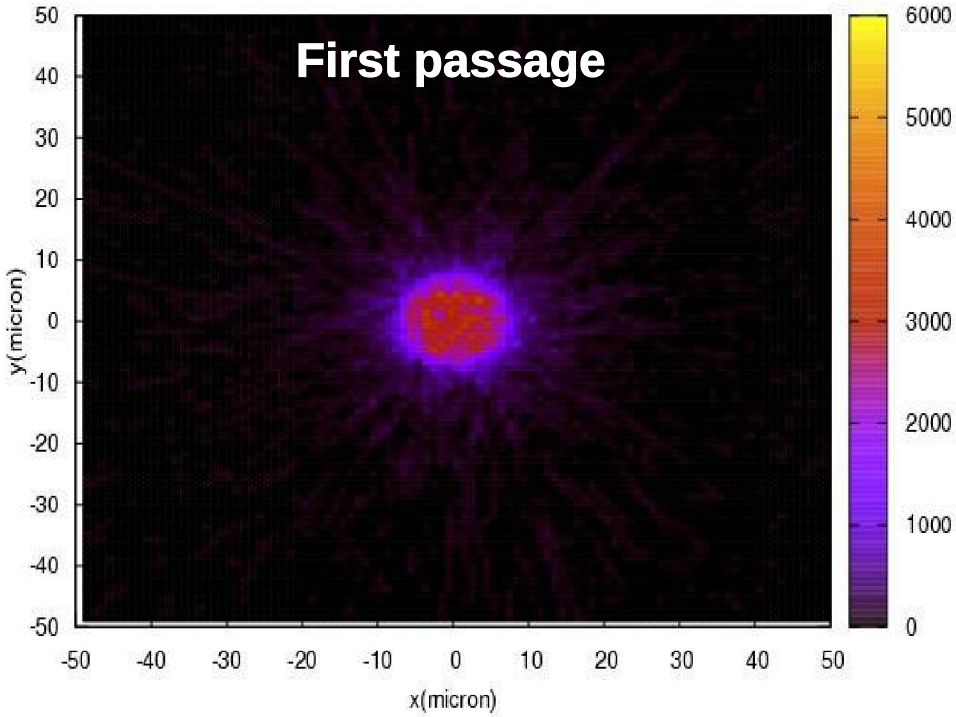
In the simulation we consider 2 refluxes





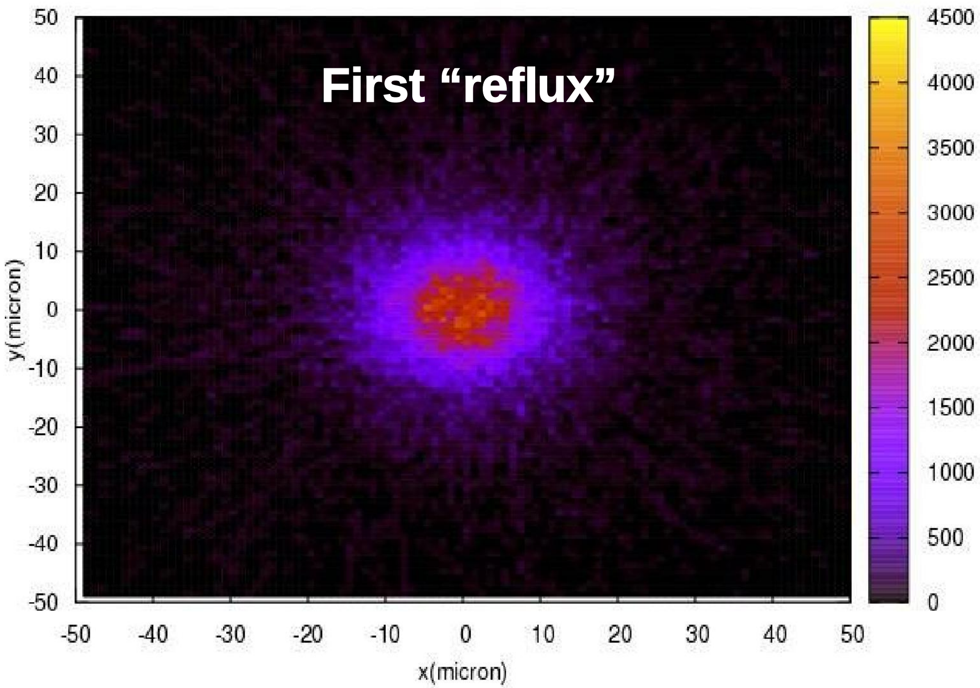


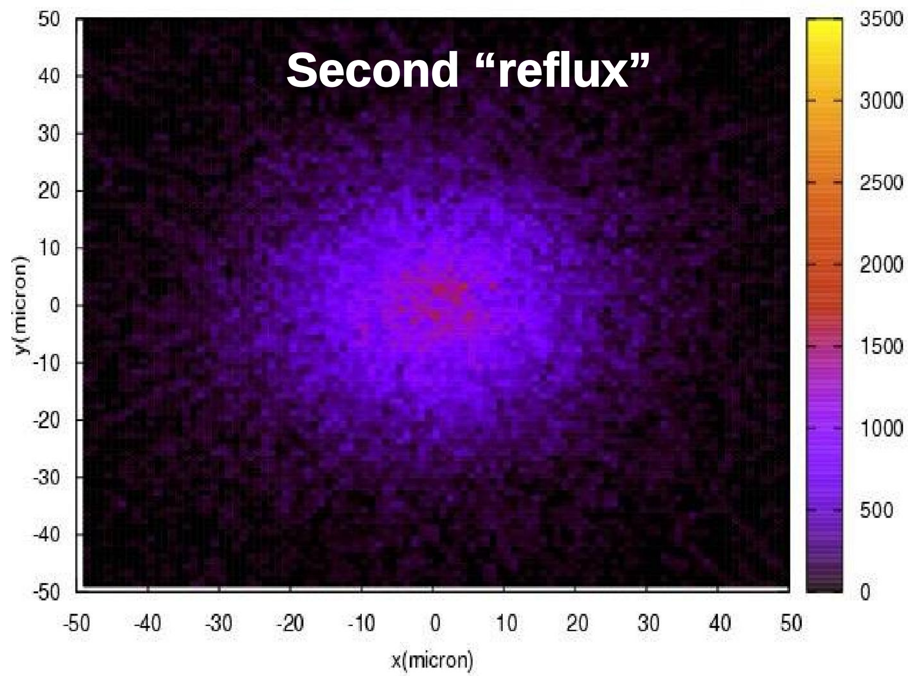
Collisional Simulation



Kα photon flux after the tracer layer.

These images are correspondent to those for electron fluxes





Conclusion

We developed a 1-D analytical model to describe the Ka yield with refluxing.

A reflection coefficient R , that contains the physics at the target plasma interface, has been introduced.

The measure of the reflection coefficient is important for the physics of electron guiding devices like cones or wires: what are the plasma conditions that “keep” the guiding properties of such devices?

We measured R for “classic” fast electron transport experiment finding R=0.8 in absence of get lost layer: need for absolute k-alpha yield measurements in non refluxing conditions to estimate R, coupled with interferometer diagnostic to characterize the plasma and associate R to the plasma gradients.