TOWARDS MULTI-PHOTON IONIZATION OF POSITRONIUM

- PS FORMATION IN POROUS SILICA

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THE POSITRON BEAM LINE

The positron source and trap located in Aarhus was aquired from First Point Scientific in 2008 by the ASACUSA collaboration. It consists of a 50mCi ^{22}Na source located in a focusing Helmholtz configuration, encapsuled by lead, and radiating positrons with energies up to the Q-value. The first thing for the positrons to see is a solid neon moderator at a temperature of 6.8K and shaped as a cone. When passing the moderator, the positrons loose energy by collisions inside the solid, and they continue through the beam tube with an energy ~1eV into a Surko type trap [1].

The trap is composed of a set of electrodes surrounded by a solenoide, and it creates a potential well along the axis of the beam line, where the positrons can be trapped. By colliding with a buffer gas inside the potential well, the positrons loose kinetic energy within the trap, and by applying a rotating wall potential, the non-neutral positron plasma can be compressed in the radial direction.

As an extention to the beam line, different kinds of experiments can be attached, and the positron energy and time composition can be controlled very accurately.

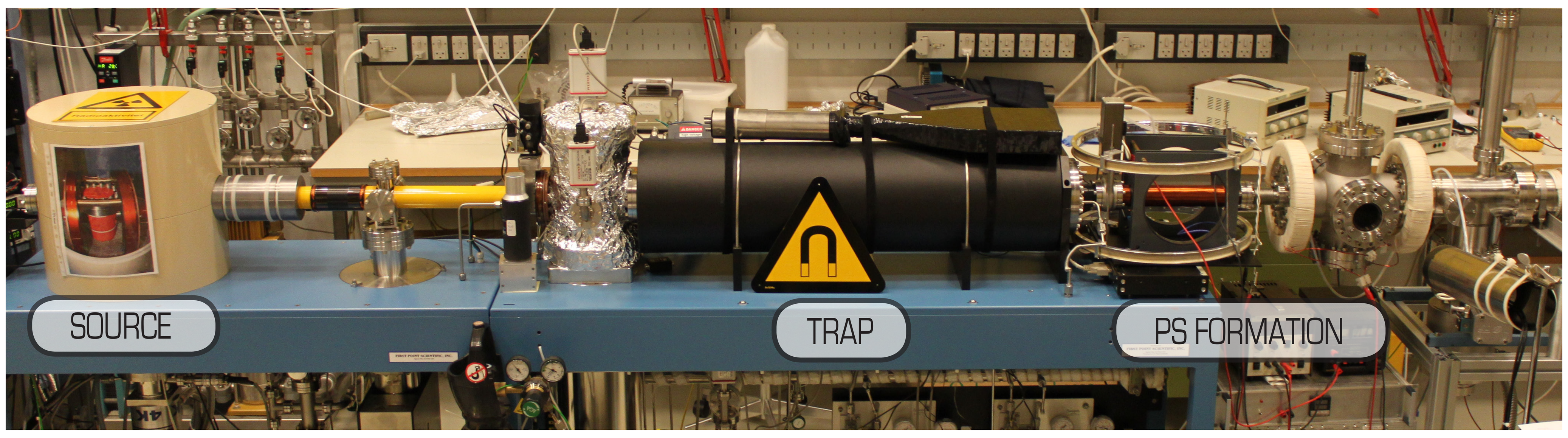


Figure 1: The positron beam line in Aarhus consists of two parts; the source and the trap (see text). In this setup an experiment to measure the Positronium formation in different kinds of porous silica is attached.

PS FORMATION IN POROUS SILICA

It is of great interest to optimize the ratio of ortho-positronium (o-Ps) created when positrons collide with a given target. The ratio of o-Ps formed pr. incomming positron depends on the energy and the structure of the target, and the porosity of the surface plays an important role in this aspect. Because the photons in the annihilation of o-Ps share the total energy of the electron-positron pair in the positronium atom, a photon originating from 3γ annihilation will have an energy below the photo peak energy, and the shape of the spectrum tells us how many ortho-positronium atoms there are created. Along the lines of [2] we define the ratio

$$R = \frac{T-P}{P}$$

for a given fraction of Ps formation, f. The Ps formation fraction is measured relative to the fraction of a Germanium (111) crystal at 1000K (f=100%) and mica, which is assumed to be a very poor positron to Ps converter. By means of the reference values the fraction, f is given by

$$f_{3\gamma} = \left[1 + \left(\frac{R_1 - R}{R - R_0}\right)\left(\frac{P_1}{P_0}\right)\right]^{-1}$$

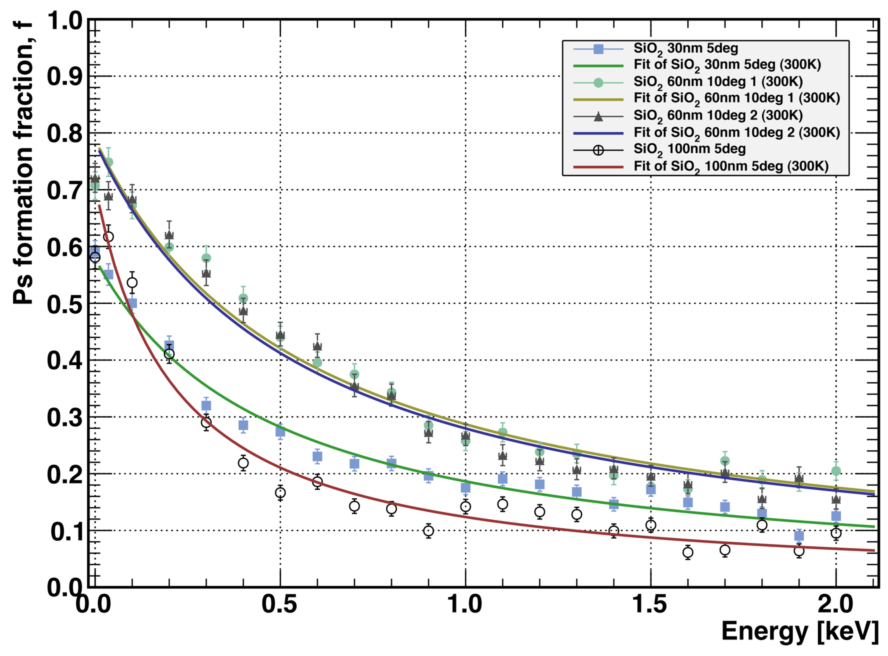
and is plotted as a function of energy. The data are fitted by the least square method to the function

$$f_{3\gamma} = f0(E/E_0 + 1)^{-1}$$

and we expect to see a high fraction, f, for a target of high porosity. The increased emission of o-Ps into the surrounding vacuum being a consequence of an increased effective surface area, and less positronium atoms are trapped in the target.

The targets in our experiment is created by vaporizing the silica onto a thin film of carbon, held at a specific angle and rotated. The expected structure of the targets is shown in figure 3(d)-(e) as SEM images. However, the angle was not well defined because of an unexpected roughness in the samples, and the structure became as seen in figure 3 (a)-(c).

Preliminary data from the targets with the not so well defined structure is shown in figure 2, and as seen we get a Ps formation fraction as high as 80% compared to the standard references of Ge(111) at 1000K and mica at 300K.



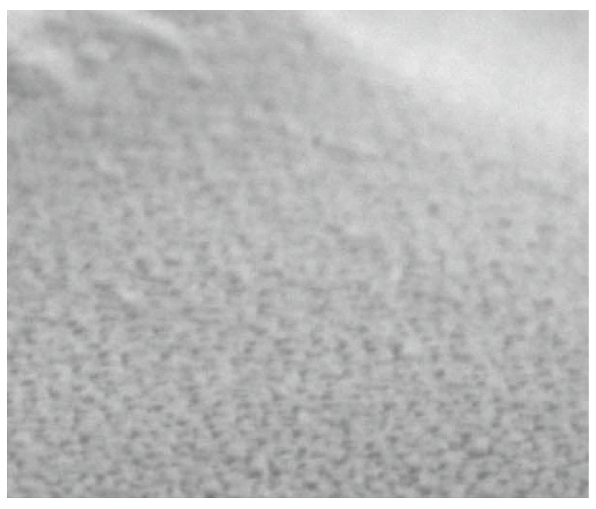


Figure 3(a): SiO_2 surface manufactured with a tilt of 5 deg and 100nm orthogonal thickness (magnification: 240000).

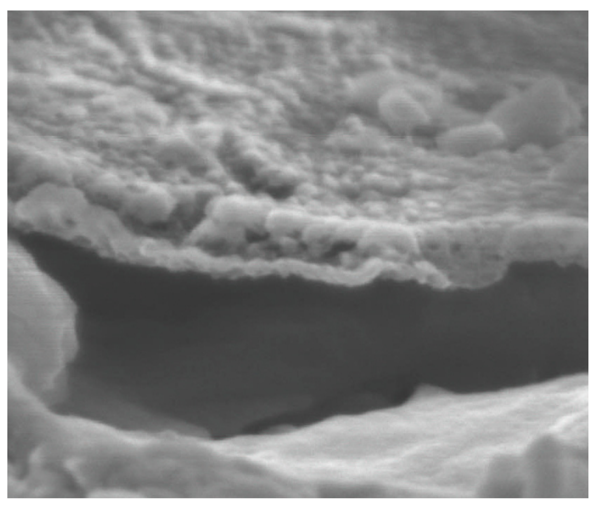


Figure 3(b): Si surface manufactured with a tilt of 5 deg and 100nm orthogonal thickness (magnification: 400000).

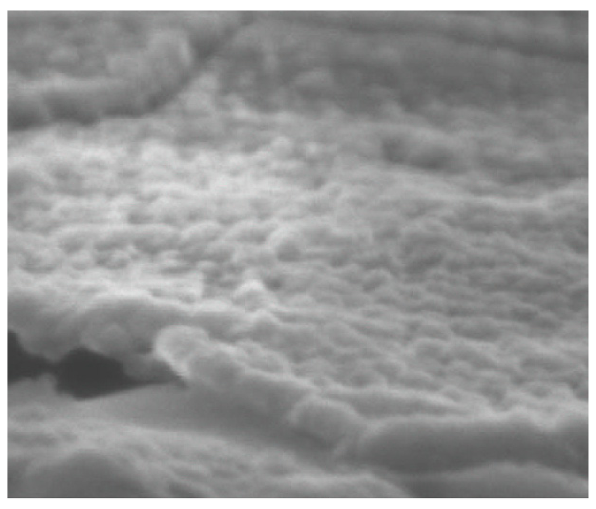


Figure 3(c): Si surface manufactured with a tilt of 5 deg and 100nm orthogonal thickness (magnification: 400000).

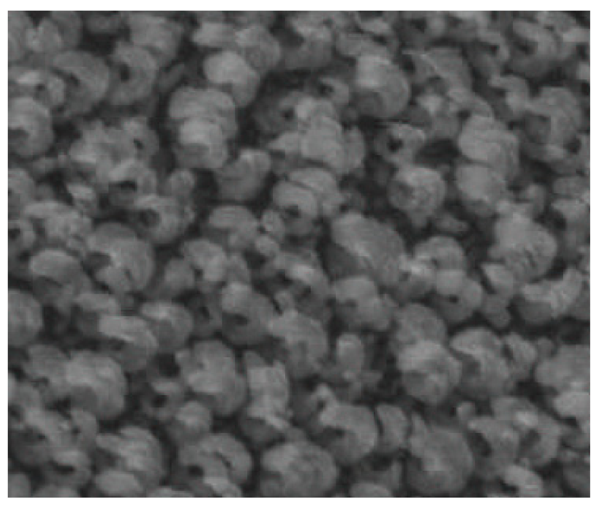


Figure 3(d): Homogeneous Si surface with helix structure grown on a Si wafer (no measurement). Magnification:100000.

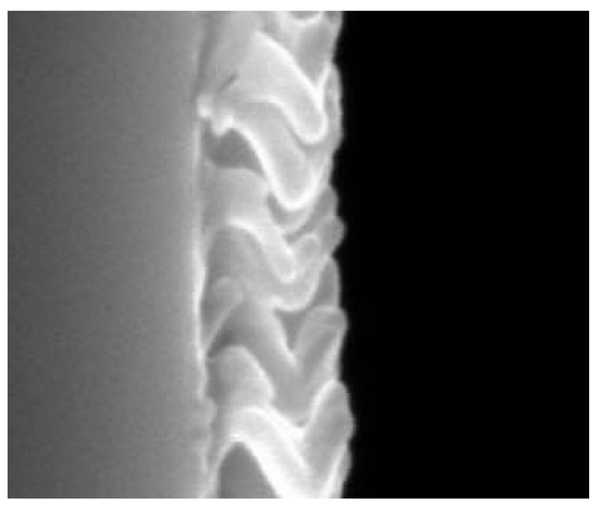


Figure 3(e): Cross section of homogeneous porous Si target on a Si wafer (no measurement). Magnification: 200000.

MULTI-PHOTON IONIZATION

In this experiment we place our positronium atoms in a pulsed laser beam from a Nd:YAG pulsed laser. Due to the high intensity the electron in Ps can simultaneously absorb multiple photons, ionizing the atom, this is known as multi-photon ionization (MPI). Positronium is especially suited for MPI experiments since calculations[3] show that the cross section is:

$$\sigma_{\mathrm{Ps}} = 2^{3N-1}\sigma_{\mathrm{H}}$$

where N is the number of ionizing photons and σ_{Ps} and σ_{H} is the ionization cross-section for positronium and hydrogen respectively. The Nd:YAG wavelength is 1064 nm making 6 photon absorption the lowest possible order. This means that σ_{Ps} is 2^{17} times higher than σ_{H} and the intensity threshold is approximately 2^4 times smaller than for hydrogen.

One would expect the electrons to emerge with energy $E = Nh\nu - E_0$, where E_0 is the binding energy, but this is not always the case. Experiments show electron peaks in the energy spectrum corresponding to N, N+1, N+2 etc photons, and a peak spacing of half the photon energy. We call these peaks channels and the process is known as above threshold ionization (ATI) and is due to absorption of a number of photons (S) above the ionization threshold, the energy of the electron is thus $E = (N+S)h\nu - E_0$. The reason this process is even possible, is because the electron is in the vicinity of the positron that acts as a momentum reservoir allowing the electron to absorb additional photons even after ionization.

In MPI the ionized electron is created in a strong EM field which forces the electron to oscillate with the frequency of the electric field. This additional motion means the electron will have extra kinetic energy which raises the ionization threshold. This is known as a ponderomotive shift, and can be expressed as

$$U_{\mathrm{Pond}} = \frac{e^2\lambda^2 I}{2\pi m_e c^3}$$

A high ponderomotive shift will lead to channel closing, meaning that the peaks in the energy spectrum corresponding to S=0, 1, 2 etc will disappear as we increase the intensity. This is something we hope to show experimentally.

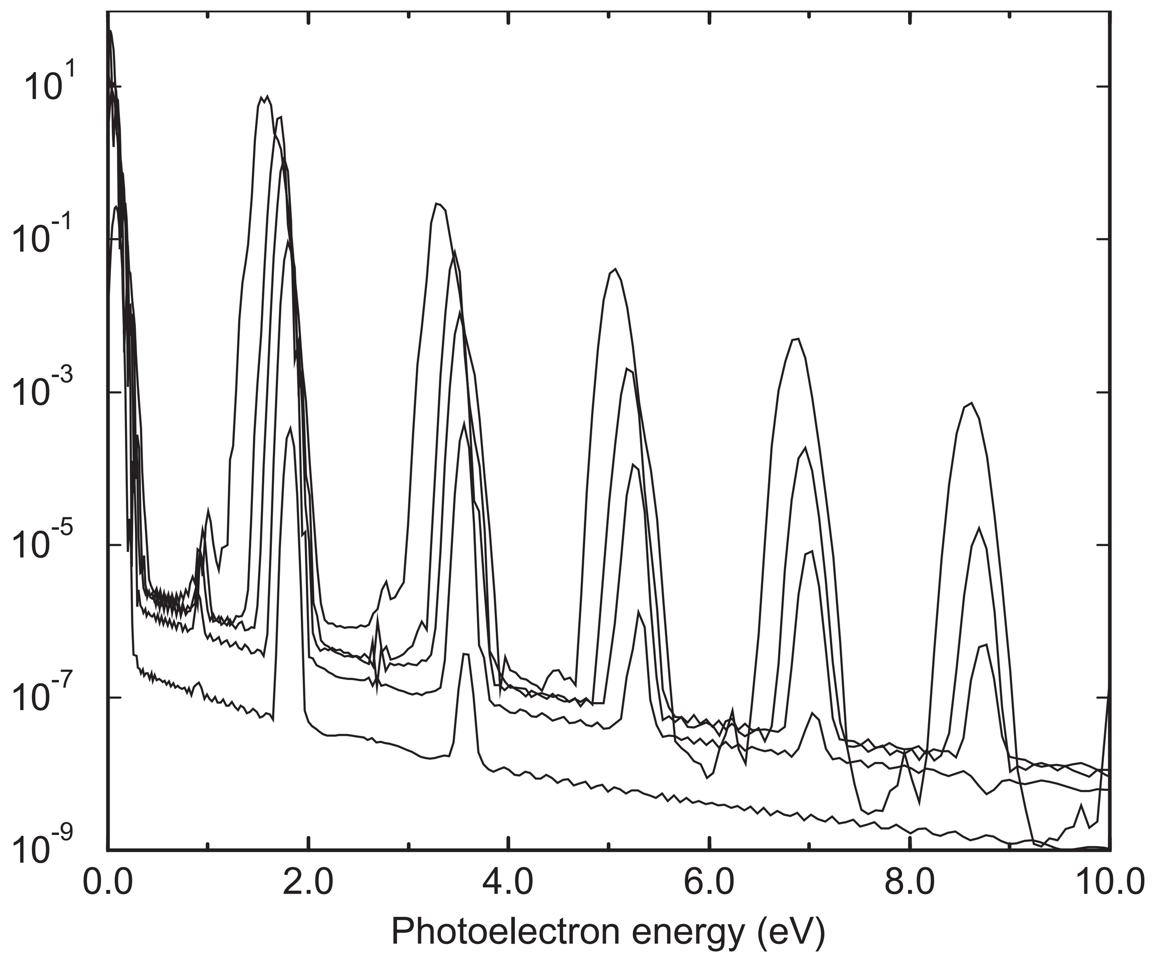


Figure 4: Simulated Photoelectron energy spectrum of Ps for a 50 fs pulse at 355 nm (2-photon ionization regime). The intensities are $3*10^{11}$, $2*10^{12}$, $5*10^{12}$, $9*10^{12}$ and $2*10^{13}$ W/cm^2 from lower to upper curve. Channel closing can be observed. [3]

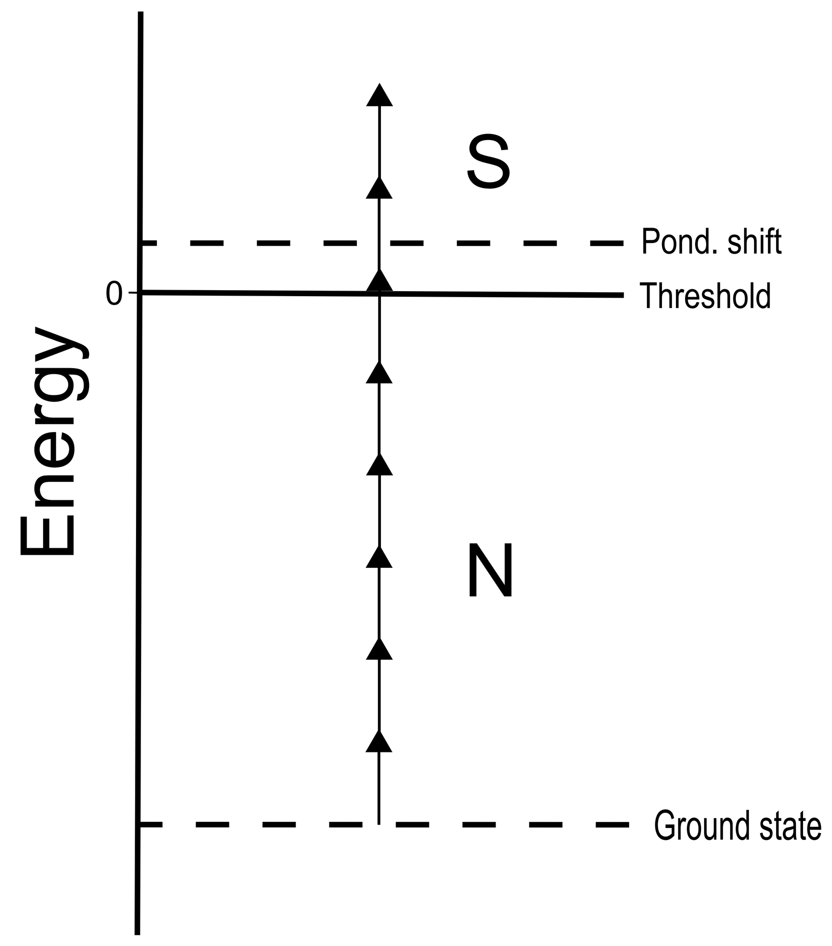


Figure 5: Schematic overview of Multi Photon Ionization (MPI). 6 photons are absorbed to excite the electron from the ground state to above threshold. All extra photon absorption is refered to as above threshold ionization (ATI). For high laser field intensities, the threshold may shift upwards because the leptons are born in a strong oscillating electric field, increasing the kinetic energy. This is the so-called ponderomotive shift.

REFERENCES

[1] Greaves, R. G. and Surko, C. M., *Phys. Rev. Lett.*, 2000, 85, 1883.
[2] Mills, A. P. Jr., *Phys. Rev. Lett.*, 1978, 41, 1828.
[3] Madsen, L. B., *Nucl. Instr. and Meth. in Phys. Res. B*, 2004, 221, 174

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