Dynamics of positronium emission from mesoporous silica

A.Deller §, A. Munoz Alonso, B.S. Cooper, T.E. Wall, and D.B. Cassidy

Department of Physics and Astronomy, University College London,
Gower Street, London, WC1E 6BT, United Kingdom

§ a.deller@ucl.ac.uk

Introduction

Mesoporous silica is an excellent material for efficiently converting positrons to cool (<1000 K) positronium (Ps) [1], with applications ranging from Ps gravity measurements [2] to antihydrogen production [3]. Time-of-flight (TOF) is a well-established technique often used to study the dynamics of Ps and to characterise converter materials (e.g. [4]). We report laser-enhanced Ps TOF (LEPTOF) [5] measurements of o-Ps emitted from mesoporous SiO_2.

Technique

A 5 ns bunch of ~10^5 positrons ejected from a two-stage Surko-type positron trap (Fig. 1) [6] are implanted into a mesoporous SiO_2 film to produce Ps atoms. These cool within the pores before being emitted to vacuum with near thermal energies. A UV laser pulse (λ = 243 nm, E = 1 mJ, Δt = 6 ns) intersects the emitted Ps distribution at time τ, driving 1S-2P transitions inside a ~1 mm wide region at a distance z from the film's surface (Fig. 2); a coincident green laser pulse (λ = 532 nm, E = 20 mJ) photoionises the excited atoms. Ionisation typically precipitates rapid annihilation of the positron, resulting in an excess of gamma-rays at a time correlated with the laser delay (Figs. 3 & 4); these are detected with a $PbWO_4$ scintillator + PMT via single-shot positron annihilation lifetime spectroscopy (SSPALS) [7].

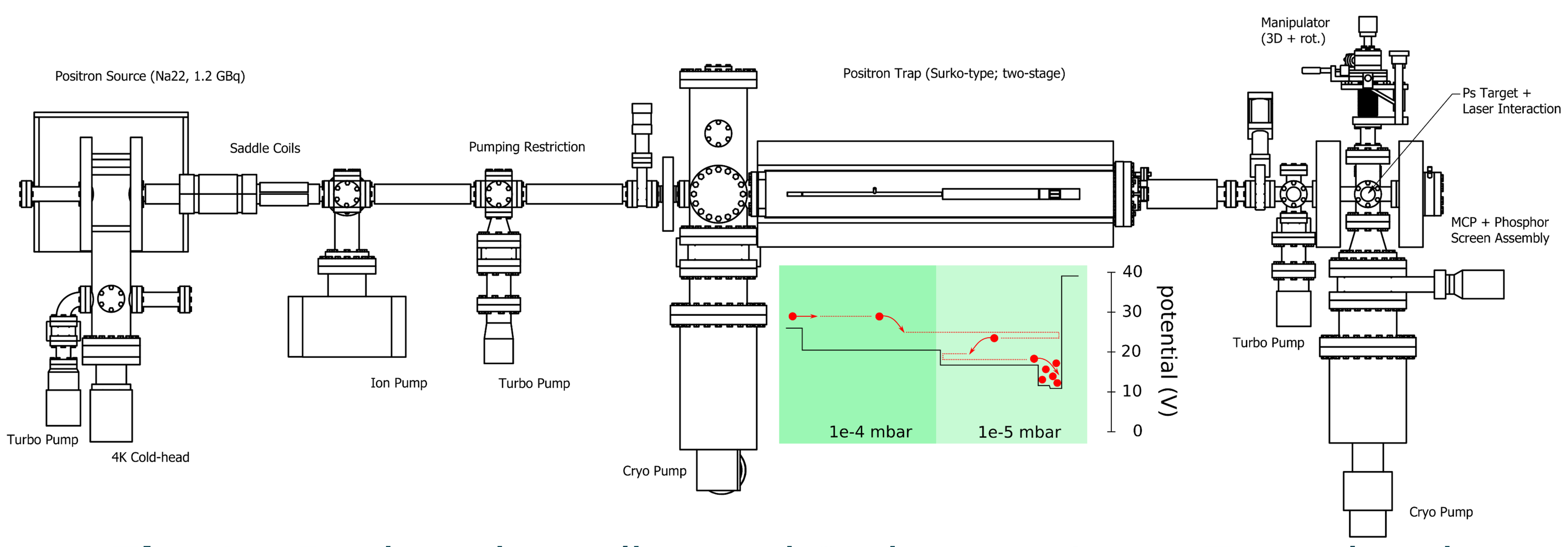

Fig. 1 – Positron beamline and Surko trap. Inset: Trap electric potential and buffer-gas (N_2) pressure.

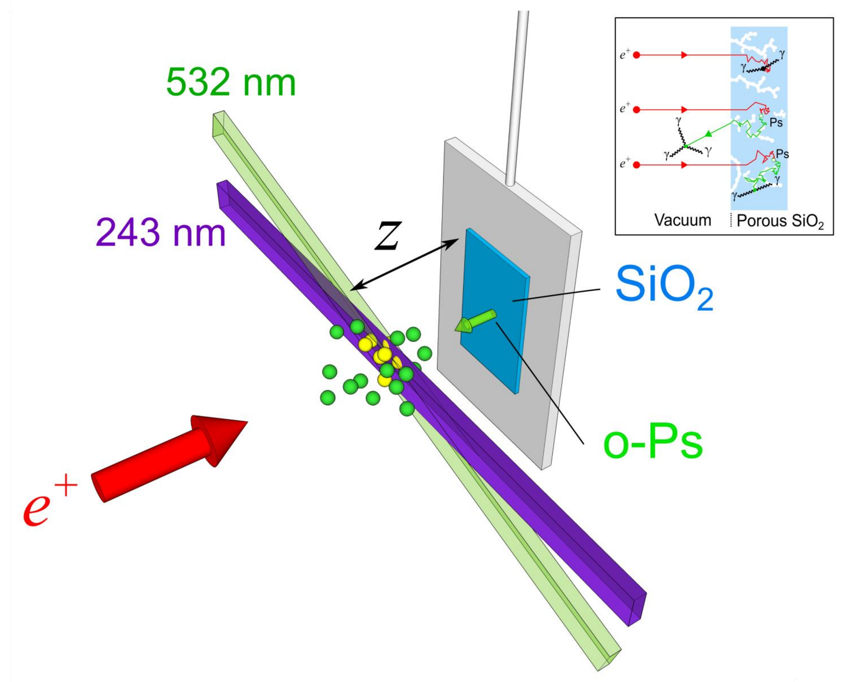

Fig. 2 –Ps formation region and laser paths

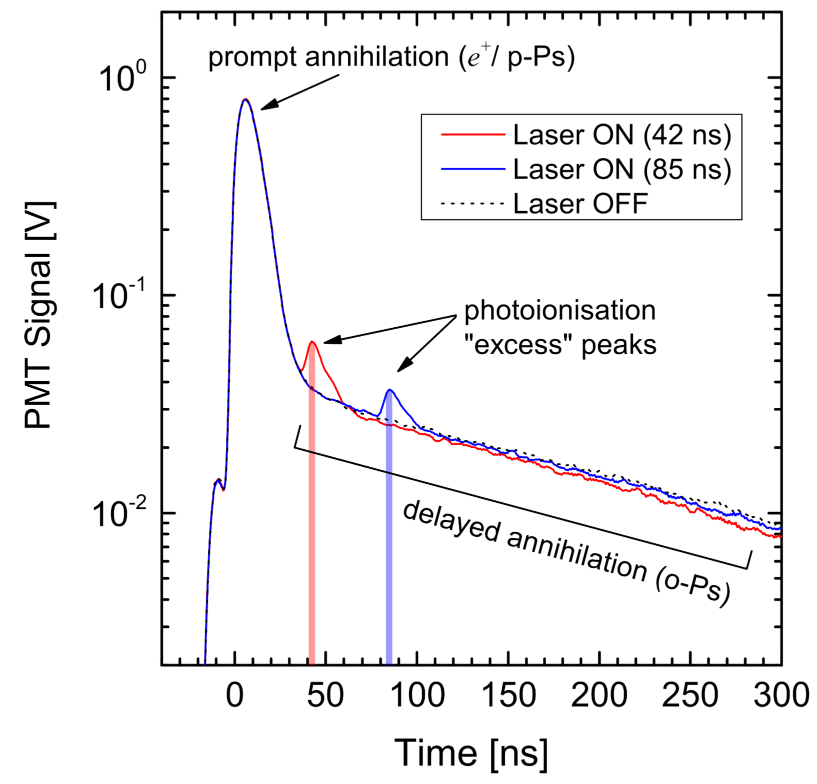

Fig. 3 – Positron annihilation lifetime spectrum, $V(t)$. Laser times shaded.

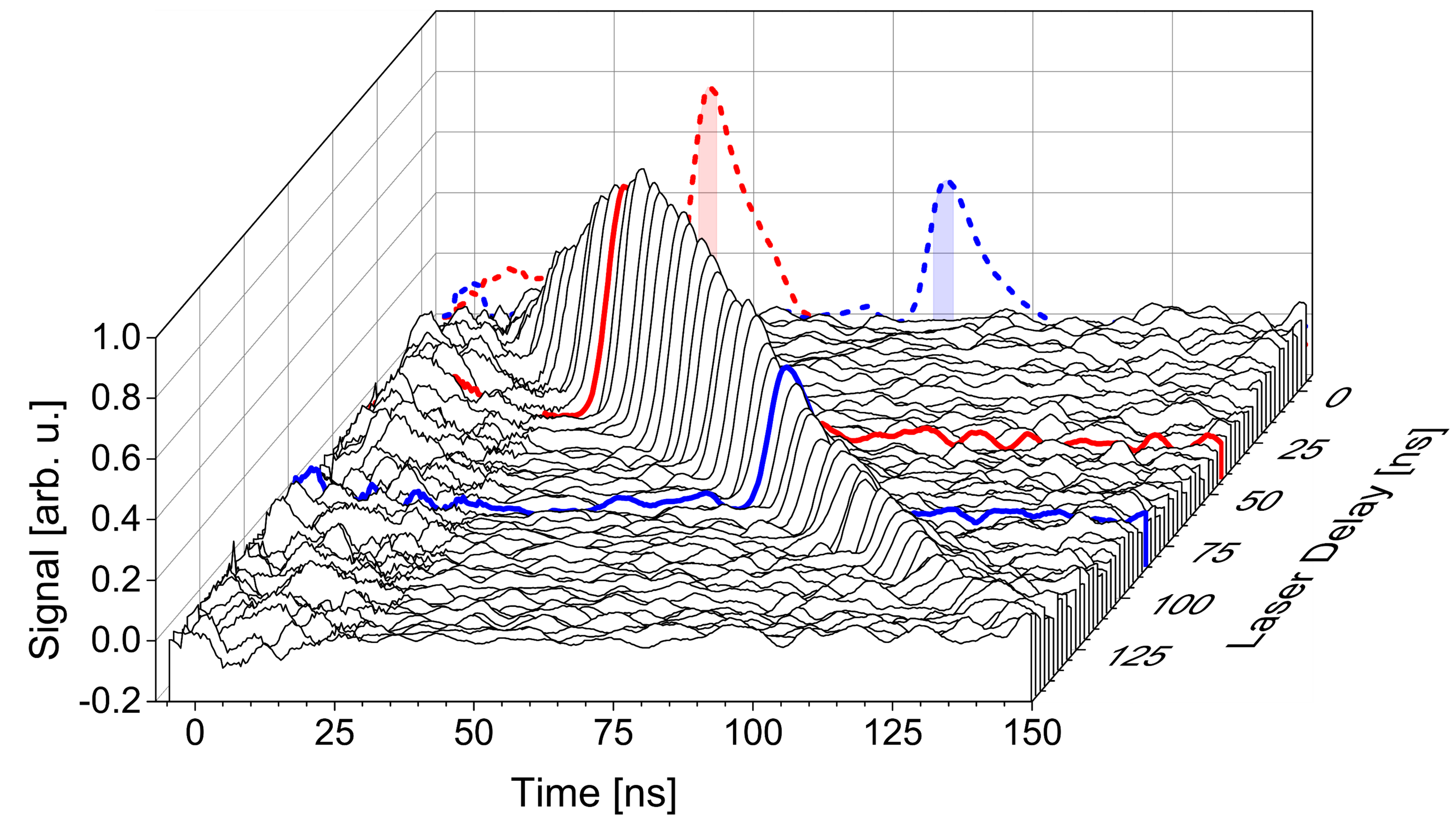

Fig. 4 – Background subtracted and o-Ps decay corrected SSPALS spectra.

Results

Time-of-flight

The mean value (W) within 4 ns windows coincident with the laser pulses, of the background subtracted and o-Ps decay corrected spectra (i.e. $[V(t) - V_{bk}(t)]\ exp(\Gamma\ t)$, where Γ = 1/ 142 ns), are plotted in Fig. 5. The expectation value of the TOF is shown in Fig 6; a correction function that takes into account the variation in ionisation probability with Ps speed and the corresponding average locations of ionisation were found by simulation [5]. Linear fits to the data-sets are used to find the mean speed of the Ps distributions, and by extrapolation to zero distance, the emission times.

Ps Cooling and Emission

The target bias determines the implantation energy of the e^+, thus the depth at which Ps forms, the mean time for Ps to diffuse from the porous network to vacuum, and ultimately the temperature of the emitted atoms. Accordingly, the emission time is found to increase with the target bias, whereas the speed correspondingly decreases [4, 8] (Fig. 7: the blue vertical bars represent an estimate of the scope for systematic uncertainty; uncorrected estimates are shown in grey; the RMS speed associated with the Doppler width of the 1S-2P transition is shown in red).

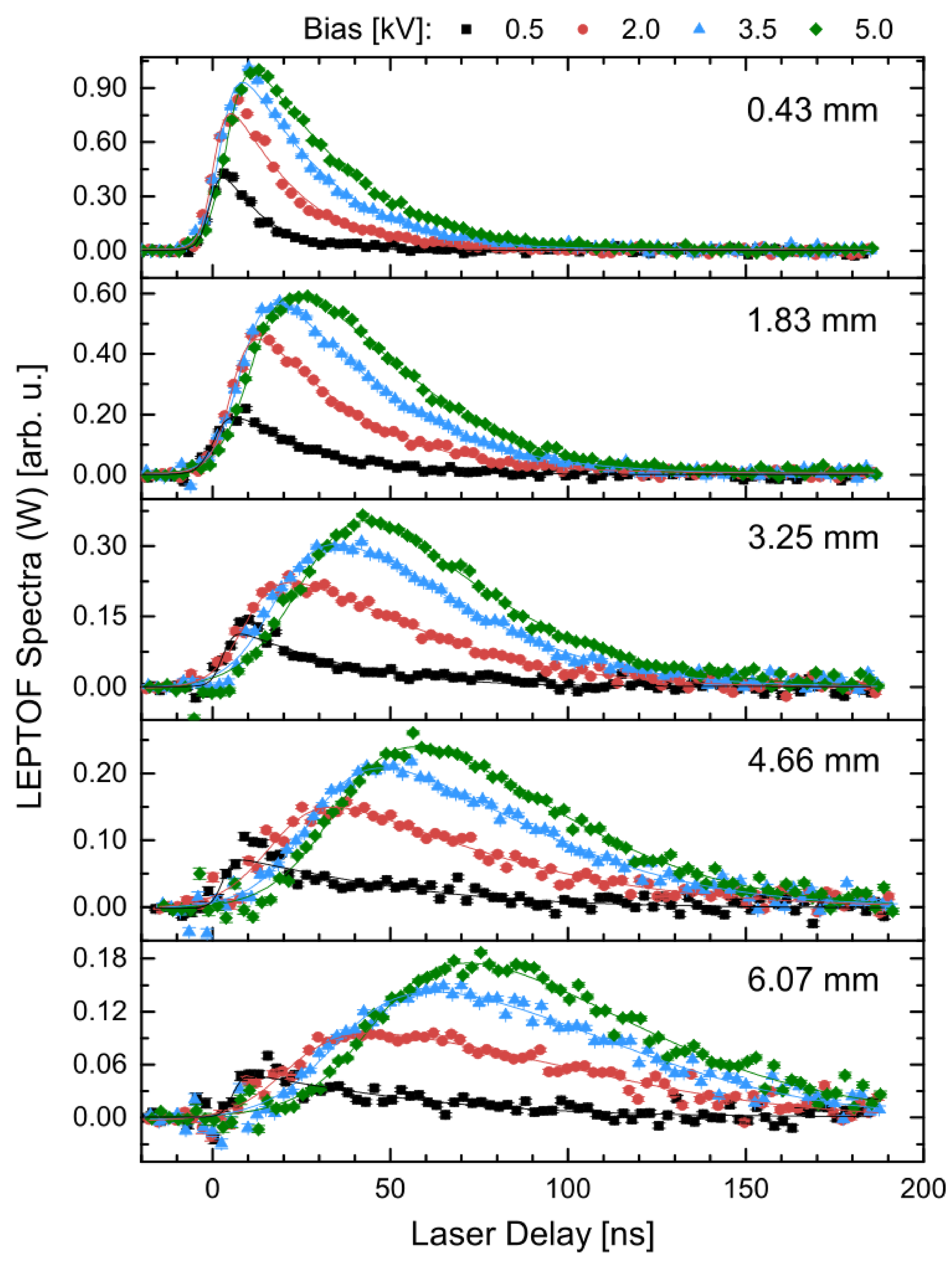

Fig. 5 – Ps ionisation signal at various measurement positions *(z)*

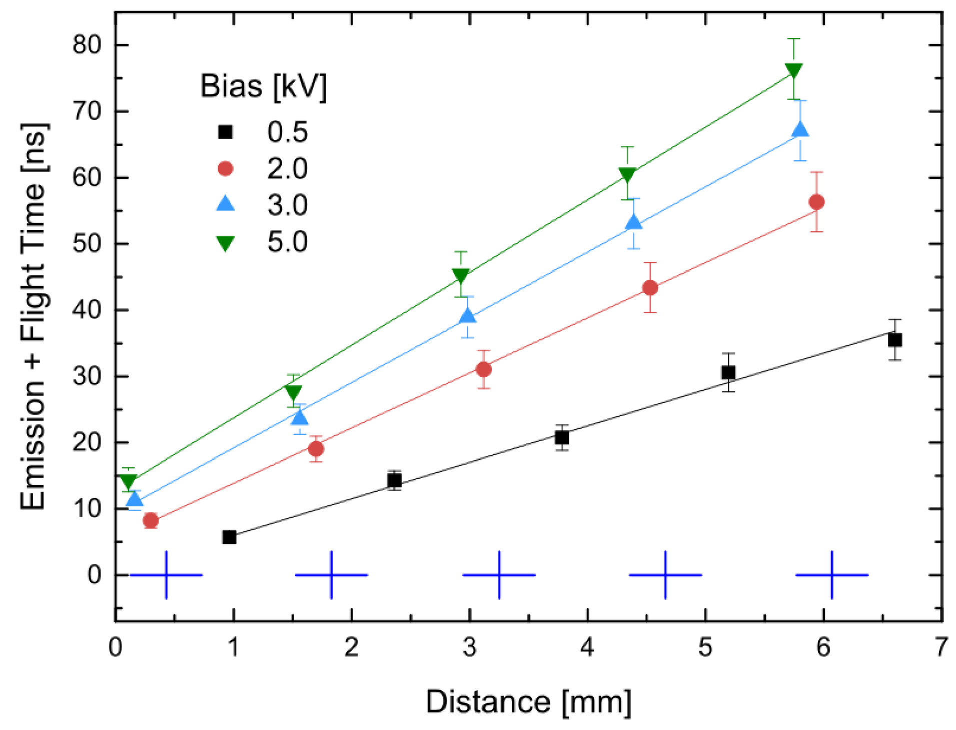

Fig. 6 – Expectation value of the Ps TOF. The blue crosses mark each laser location.

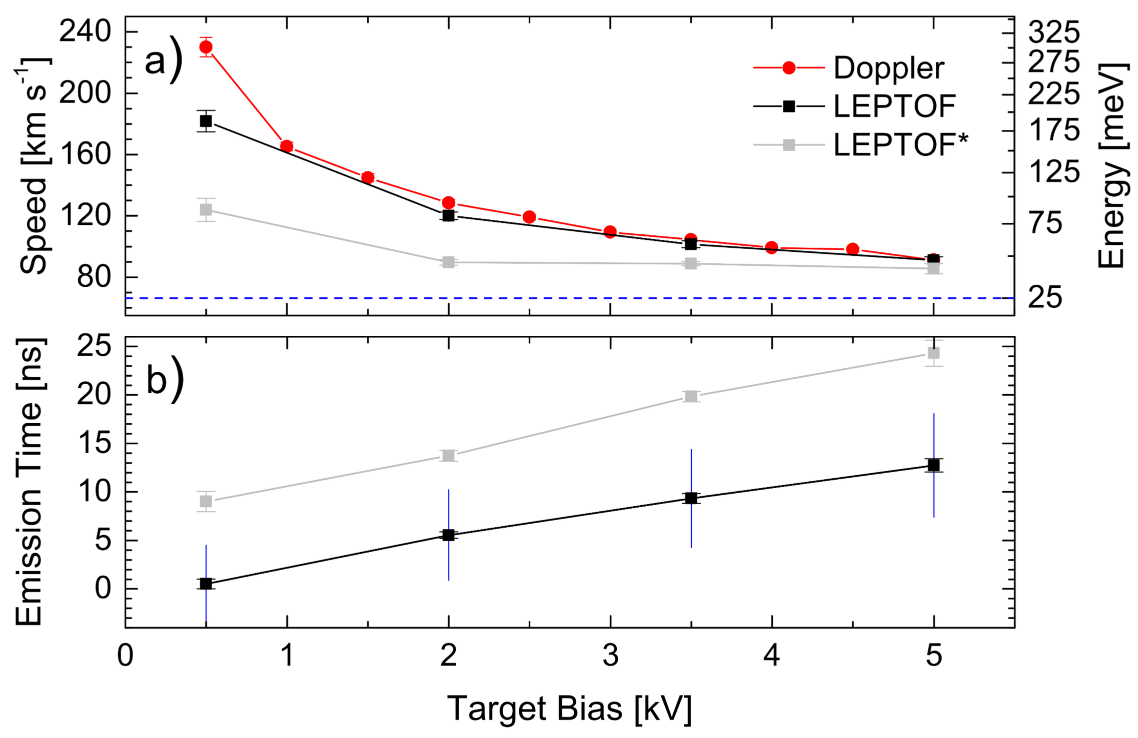

Fig. 7 – LEPTOF measured Ps speed and emission time from porous SiO_2

Summary

LEPTOF spectroscopy [5] has some advantages over conventional TOF methods, including the ability to be easily extended for Doppler spectroscopy [8], however, a correction function is needed to account for the variable laser-Ps interaction strength. For cold distributions and intense laser fields this effect becomes negligible, thus LEPTOF could prove crucial for precise measurements of ultra-cold Ps sources.

References

1. Liszkay L *et al* (2012) *New J. Phys.* **14**, 065009
2. Cassidy DB and Hogan SB (2014) *Int. J. Mod. Phys. Conf. Ser.* **30**, 1460259
3. Kellerbauer A *et al* (2008) *Nucl. Instrum. Meth. B* **266**, 351
4. Crivelli P *et al* (2010) *Phys. Rev. A* **81,** 052703
5. Deller A *et al* (2015) *New J. Phys.* **14**, 065009
6. Danielson JR *et al* (2015) *Rev. Mod. Phys.* **87**, 247
7. Cassidy DB *et al* (2006) *Appl. Phys. Lett.* **88**, 194105
8. Cassidy DB *et al* (2010) *Phys. Rev. A* **81** 012715

Figures 3-7 adapted from [5] doi:10.1088/1367-2630/17/4/043059