New method of (human) body imaging with PET based on 3g/2g annihilation.

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OUTLINE:

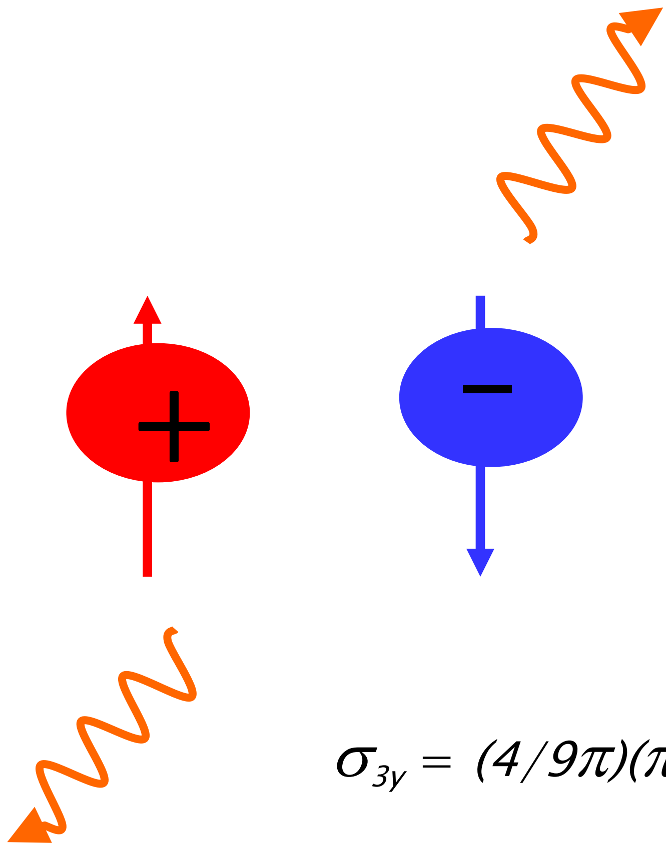
1. Processes leading to 3γ and 2γ annihilation

2. Determination of 3γ fraction from PALS and J-PET

3. Preliminary measurements of tissues towards medical imiging

Processes of positron annihilation

1. Free annihilation

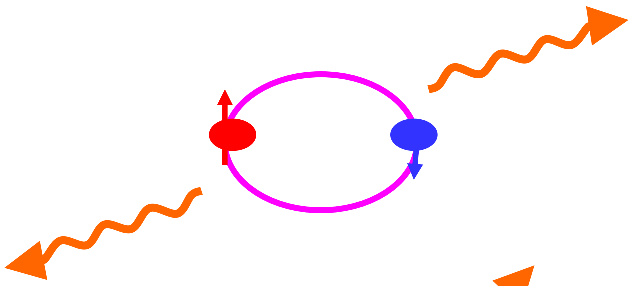


$$e^+ + e^- \rightarrow n\gamma$$

$$\sigma_{3\gamma} = (4/9\pi)(\pi^2 - 9)\alpha\sigma_{2\gamma} = (1/372)\,\sigma_{2\gamma}$$

$$\sigma_{3\gamma} < 0.3\%\,\sigma_{2\gamma}$$

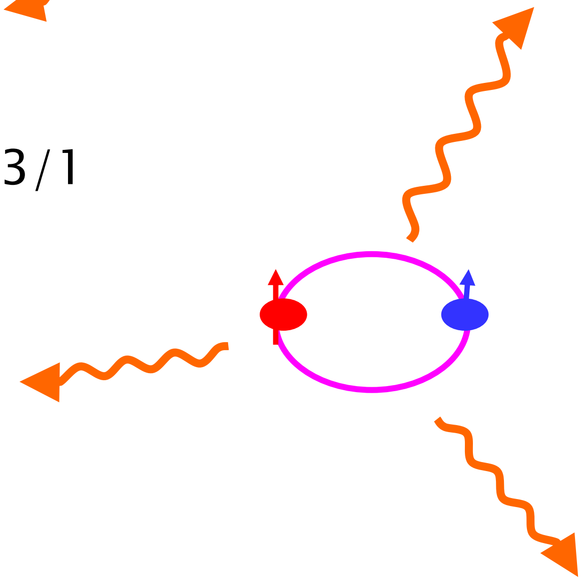
2. Positronium decay *in the vacuum*



τ = 125 ps

$\lambda_{p\text{-}Ps} = (7{,}98950 \pm 0{,}00002)\ ns^{-1}$

$P(o\text{-}Ps)/P(p\text{-}Ps) = 3/1$

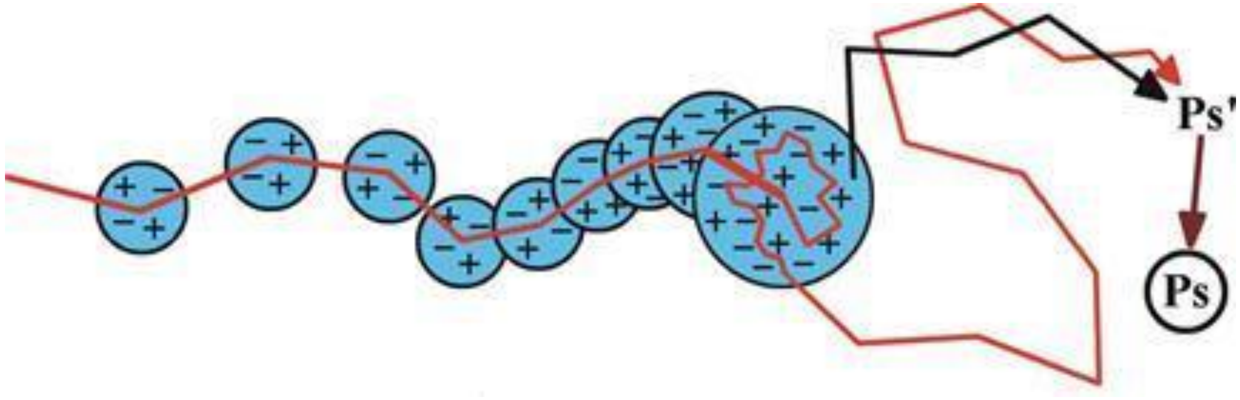


τ = 142 ns

$\lambda_{o\text{-}Ps} = (7{,}03993 \pm 0{,}00001)\ ms^{-1}$

3. **Positronium** ***in the condensed matter***

Thermallization

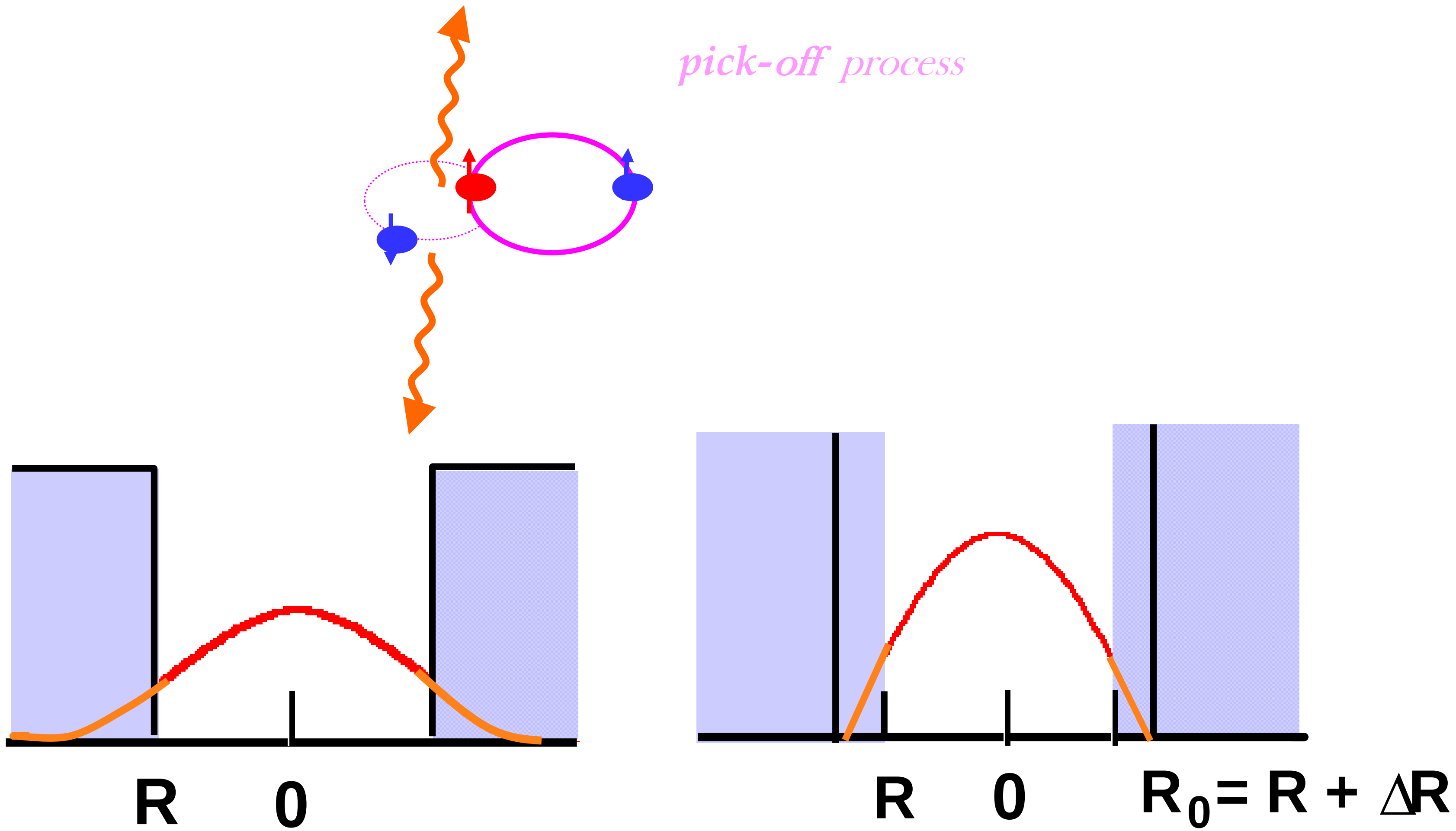


Positronium – trapping in the free volumes existing in the material

Lifetime value shortening due to:

- ortho-para conversion
- chemical and magnetic quenching
- pick-off

3. Positronium *in the condensed matter*



L.O. Roelig "Positron Annihilation" (1967) 127
A.P. Buchikhin et al. ZETF 60 (1971) 1136

S.J. Tao, J.Chem.Phys. 56 (1972) 5499
M. Eldrup et al. Chem.Phys. 63 (1981) 51

3. Positronium *in the condensed matter*

$$\lambda_{o-Ps} = 1/\tau_{o-Ps} = \lambda_{po} + \lambda_t$$

$$\lambda_{po} = P\lambda_b,$$

$$\lambda_t = 0.007\,\mathrm{ns}^{-1}$$

$$\lambda_b = \frac{1}{4}\lambda_s + \frac{3}{4}\lambda_t = 2\,\mathrm{ns}^{-1}$$

$$P = \int_R^{\infty} |\Psi(r)|^2 r^2 dr$$

(For sphere)

$\tau \in (0.7 - 142)$ ns

3. Positronium *in the condensed matter*

Decay constanst for pick-off process (averaged over all populated states) :

$$\lambda_{po} = \sum_{i=1}^{N} \lambda_i(R) g_i \exp\left[-\frac{E_i(R)}{kT}\right] \Big/ \sum_{i=1}^{N} g_i \exp\left[-\frac{E_i(R)}{kT}\right].$$

Decay constant for nl-th state, spherical shape:

$$\lambda_{po}^{nl} = \lambda_b \int_{X_{nl}R/R_0}^{X_{nl}} j_l^2(r) r^2 dr \Big/ \int_0^{X_{nl}} j_l^2(r) r^2 dr$$

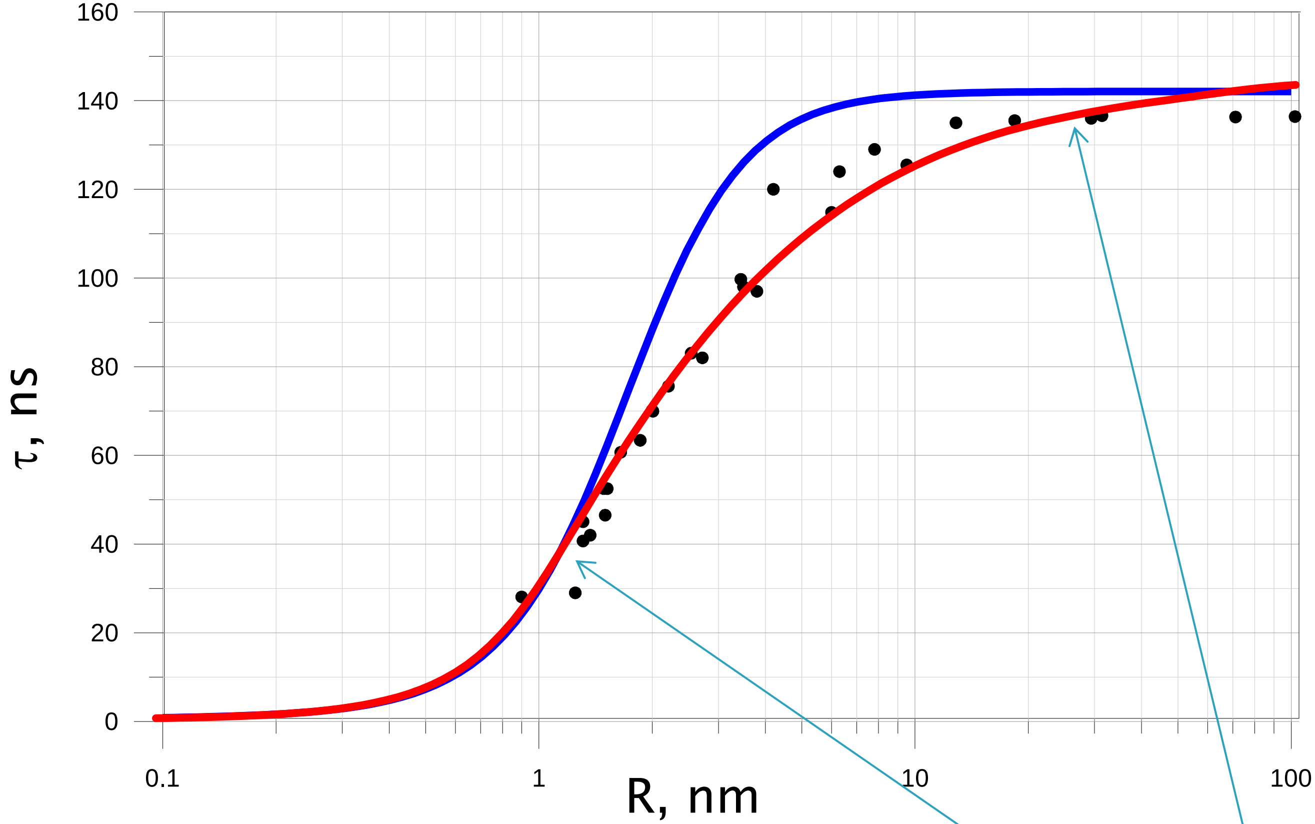
Decay constant for nm-th state, cyllindrical shape:

$$\lambda_{po}^{nl} = \lambda_b \int_{X_{nl}R/R_0}^{X_{nl}} j_l^2(r) r^2 dr \Big/ \int_0^{X_{nl}} j_l^2(r) r^2 dr$$

K. Ciesielski, A.L. Dawidowicz, T. Goworek, B. Jasińska and J. Wawryszczuk, *Chem. Phys. Lett.* 41, (1998).

3. Positronium *in the condensed matter*

PALS *vs* LN



3γ fraction $f = \tau_{o\text{-}Ps}/\tau_{T.}$

$\tau \in (0.7 - 142)$ ns

From PALS experiment:

3γ fraction of o-Ps decay

$$f_{(o-Ps)3\gamma} = \tau_{o-Ps} / \tau_{o-Ps-vacuum}$$

In total lifetime spectrum (number of annihilations)

$$f_{3\gamma} = \frac{\left(1 - \sum_i P_i\right)}{372} + \frac{3}{4} \sum_i \frac{\tau_i(o-Ps)}{\tau_T} P_i$$

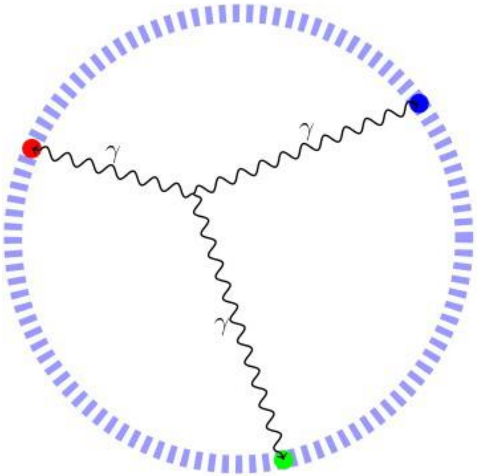
$P = 4/3 I_i$ – Ps i-th component Formation probability (calculated from o-Ps intensity)

τ_T = 142 ns

In living organisms expected $f_{3\gamma} \sim 1\%$

Application of 3γ/2γ in medical imaging

Competitive method to o-Ps lifetime determination



A. Gajos et al. Nucl.Instrum. Meth. A 819 (2016) 54
D. Kamińska et al. European Physical Journal C 76(8) (2016)
P. Moskal et al., Patent application P 405185 (2013), PCT/EP2014/068374

Number of rejestered 3γ events during PET investigation in the body depends on:
- tissues porosity
- radionuclide concentration

From experiment one can determine the rate:

$$f_{3\gamma 2\gamma} = N_{3\gamma}/N_{2\gamma}$$

$$f_{3\gamma 2\gamma} = \frac{f_{3\gamma}}{1 - f_{3\gamma}}$$

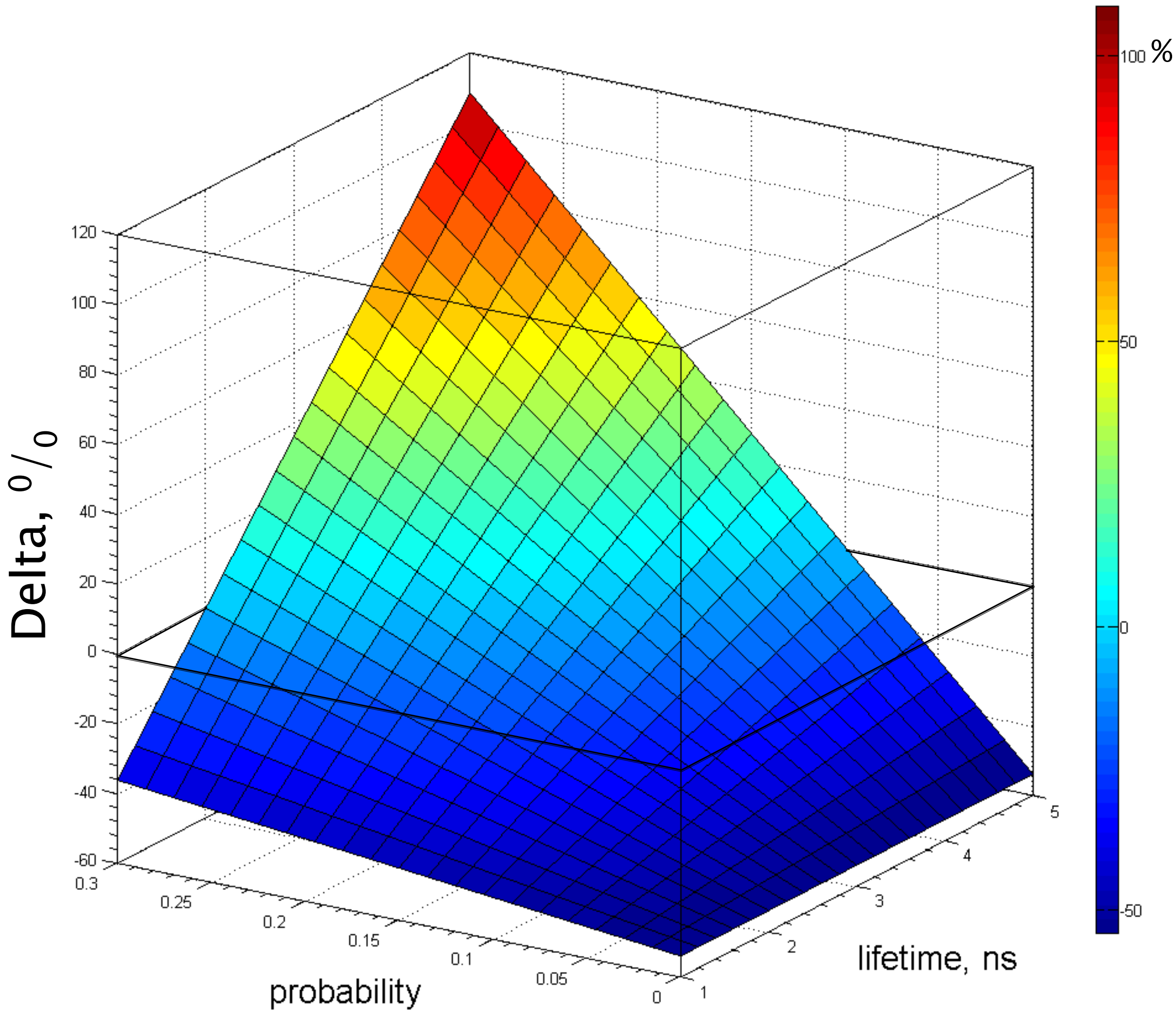
$$\delta_{3\gamma} = \frac{\left(f_{3\gamma 2\gamma}\right)_t - \left(f_{3\gamma 2\gamma}\right)_r}{\left(f_{3\gamma 2\gamma}\right)_r} \times 1000 \, ‰$$

$(f_{3\gamma 2\gamma})_t$ –in the investigated object
$(f_{3\gamma 2\gamma})_r$ –in the reference substance

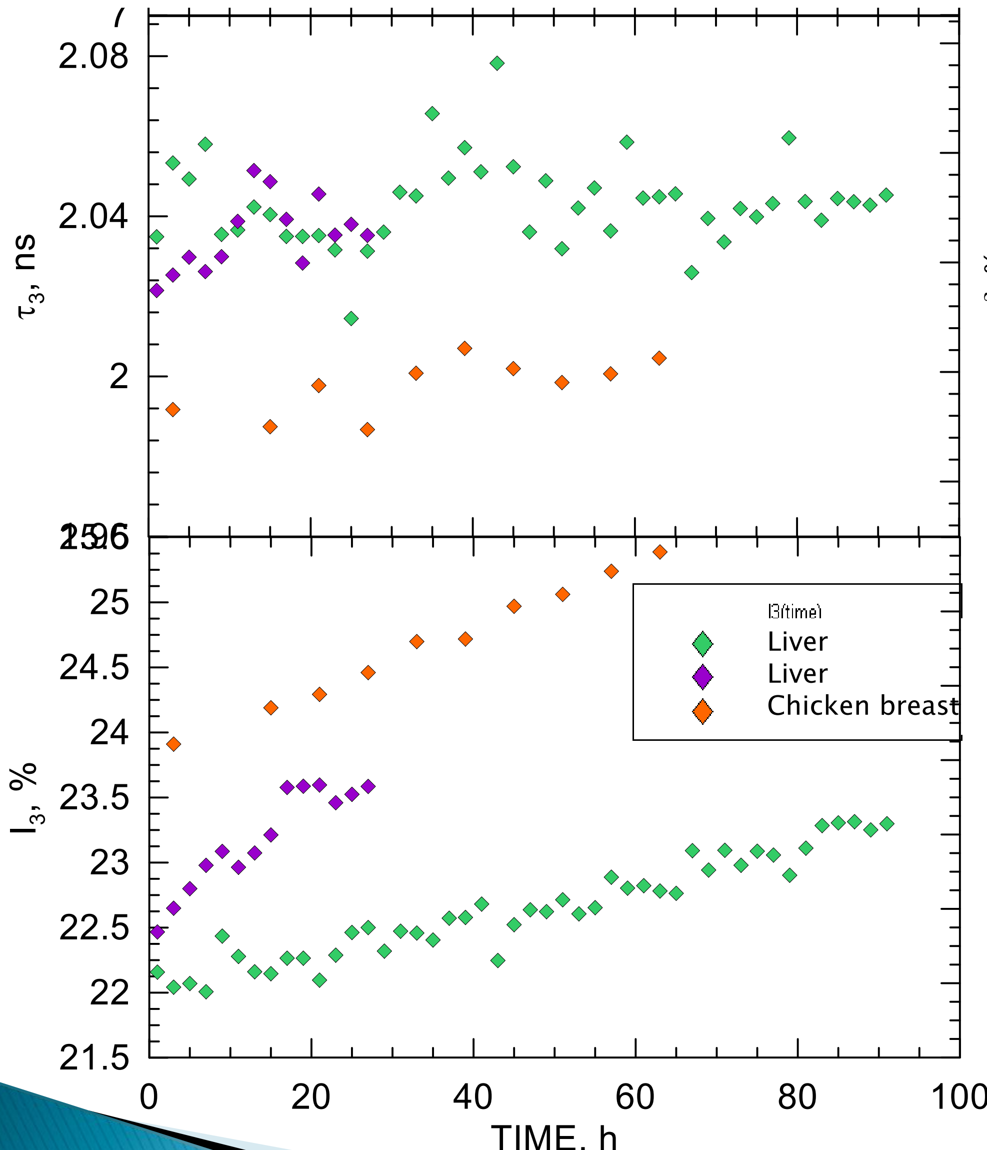
Aqueous solutions:
$\tau_{o-Ps} = 2.0$ ns, $P_{o-Ps} = 30\%$

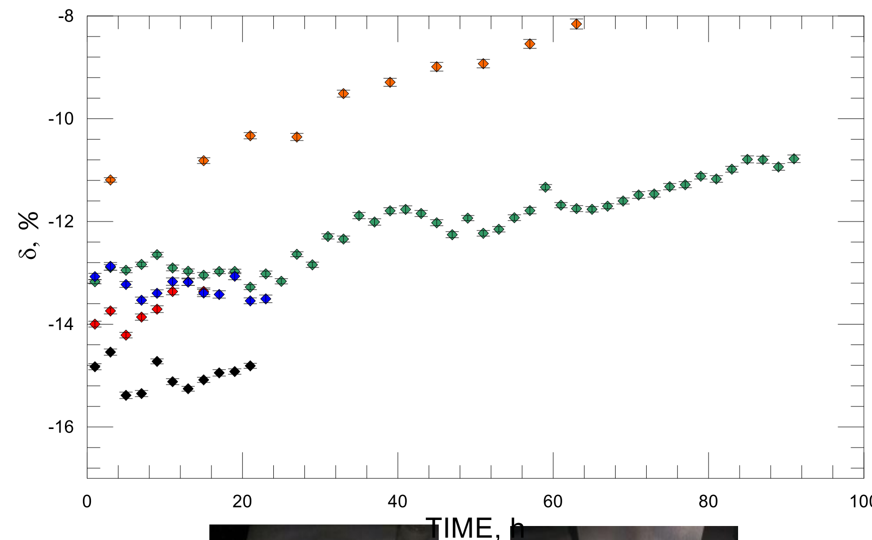
B. Jasinska, P. Moskal, P 418689 (2016)
Stepanov – Mater. Sci. Forum, Vol. 666, 109-114 (2010)

Expected range of δ parameter calculated from lifetime values



Experiment – chicken meat aging





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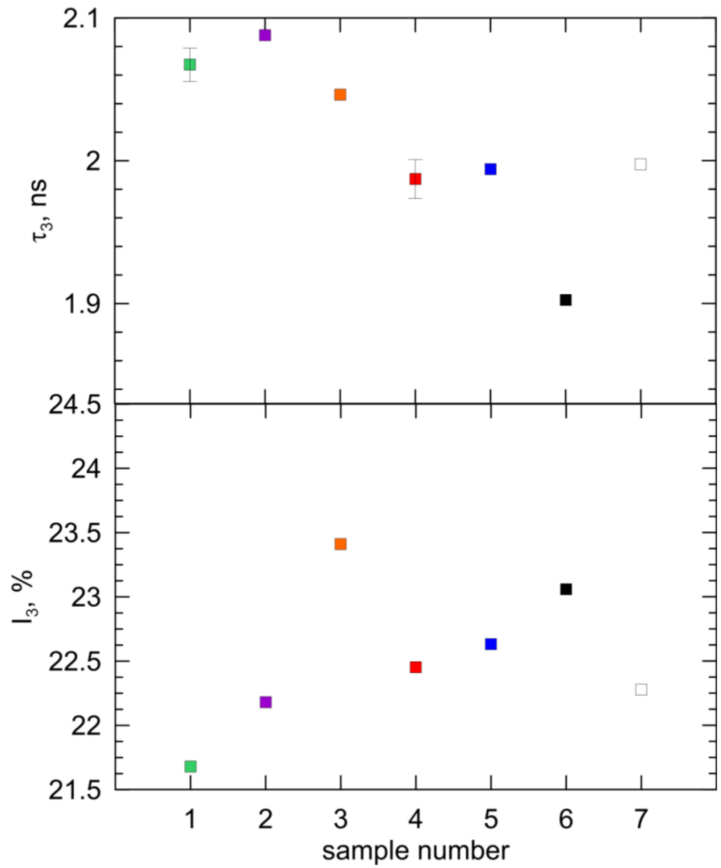
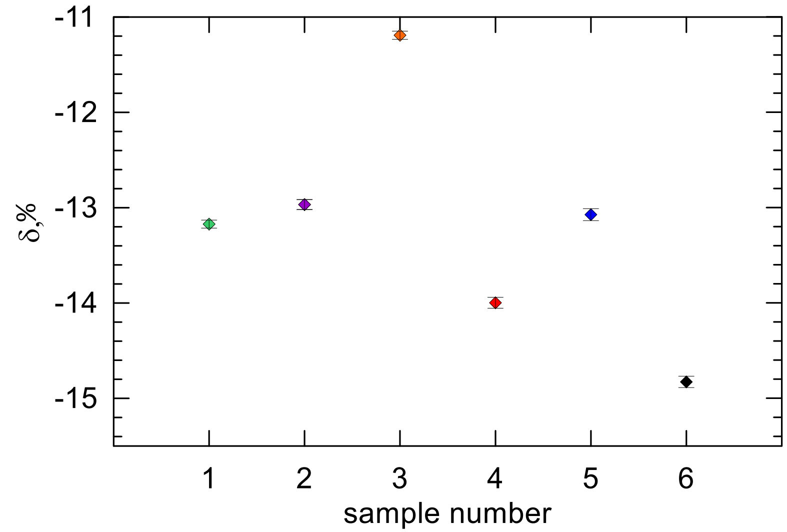
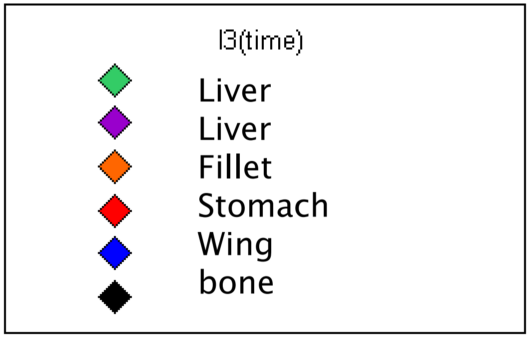
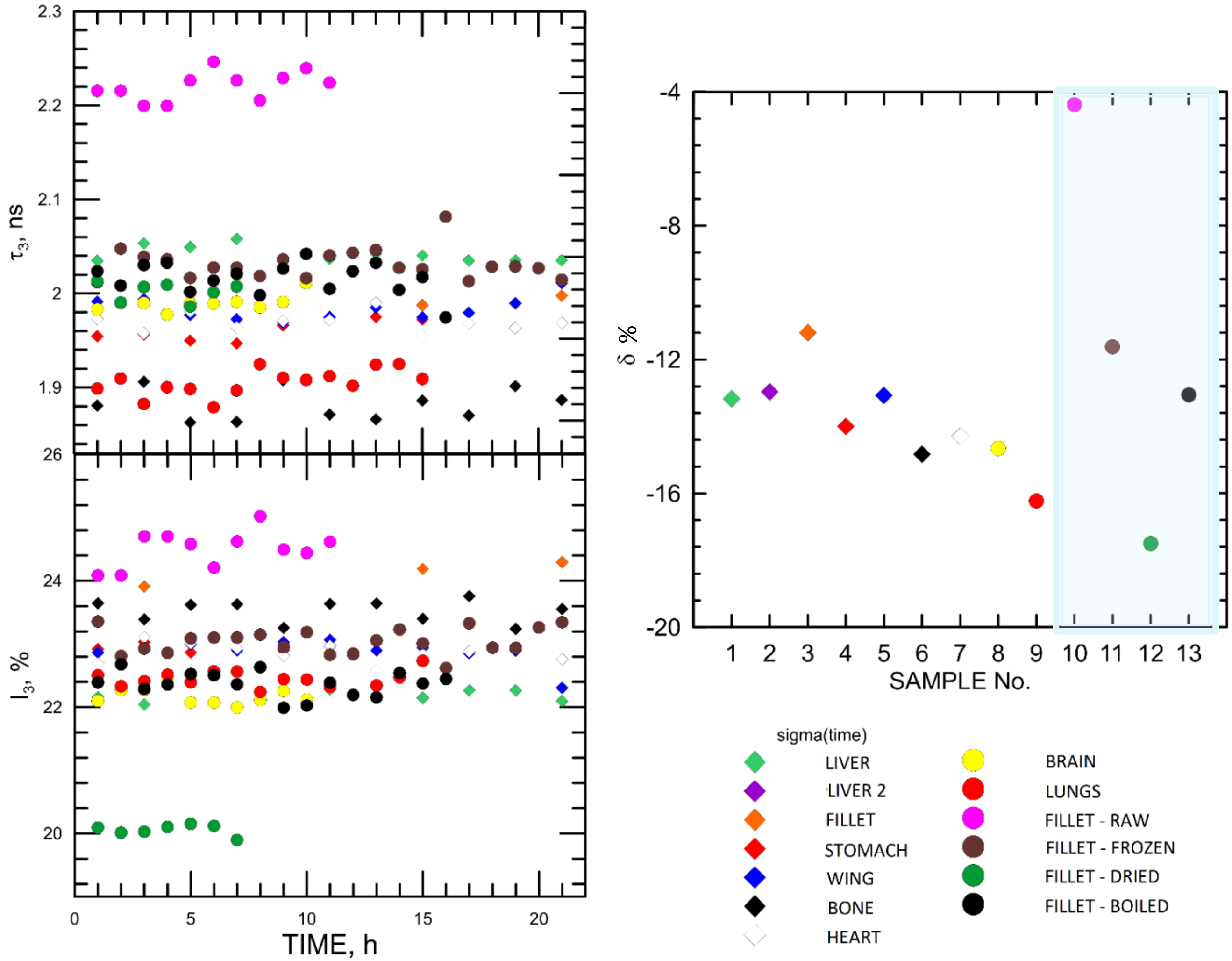




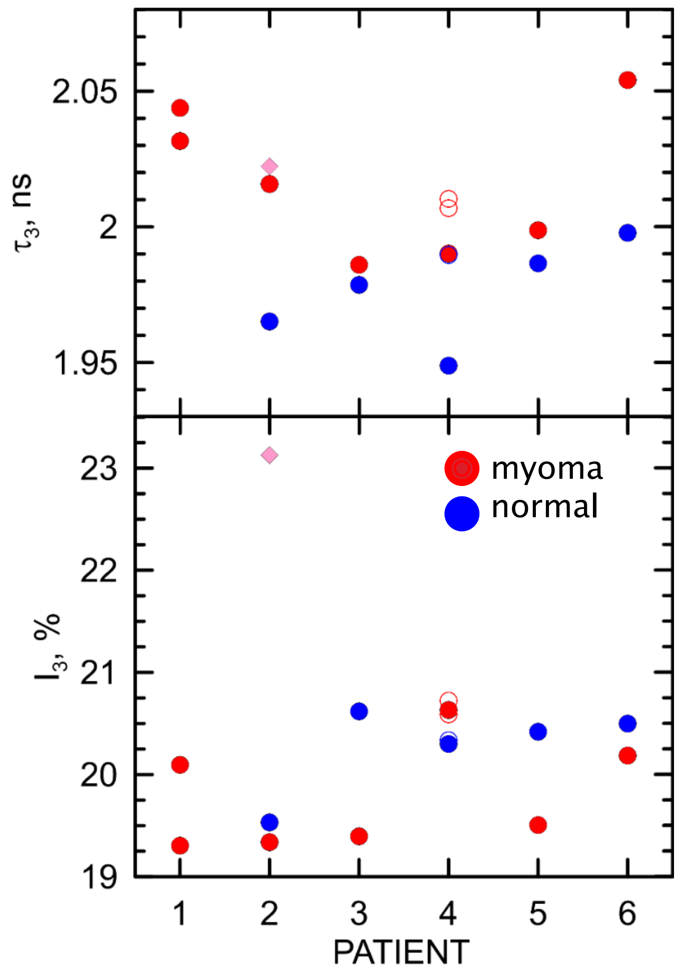


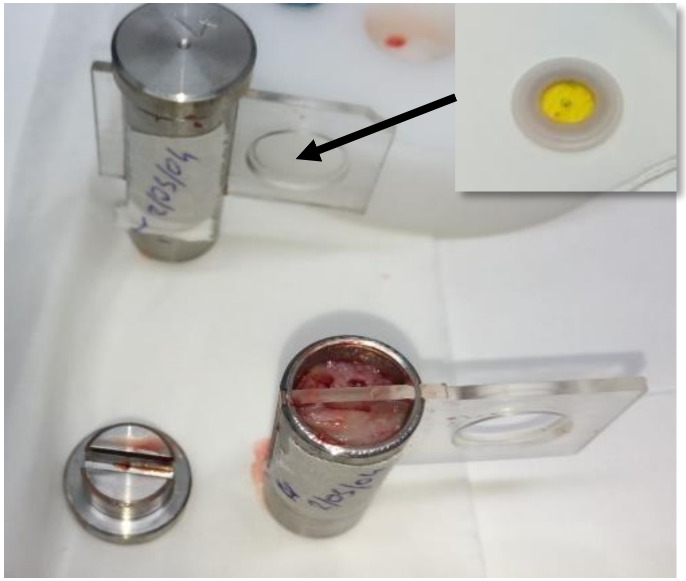


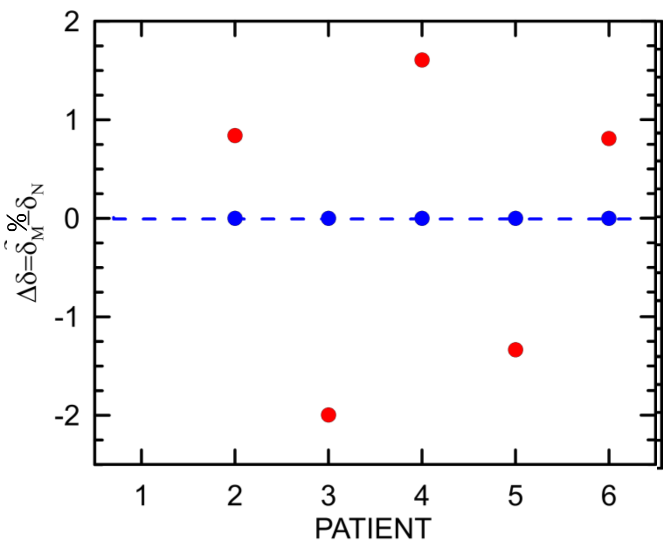
With δ parameter one possible to differentiate between tissues kind.

Human tissues

Comparison of normal uterus and myoma muscles







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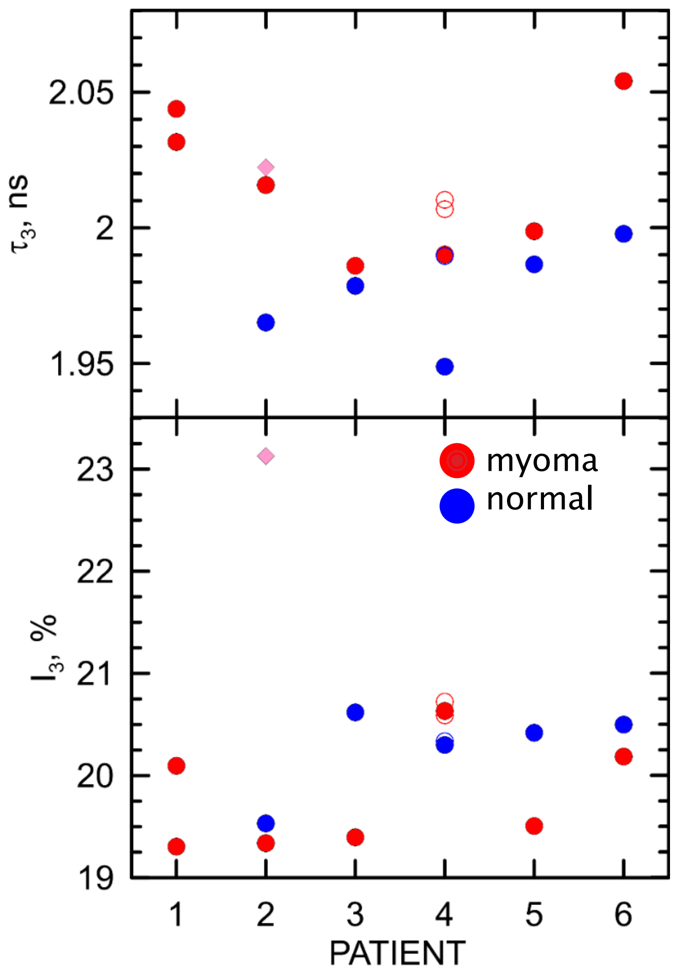
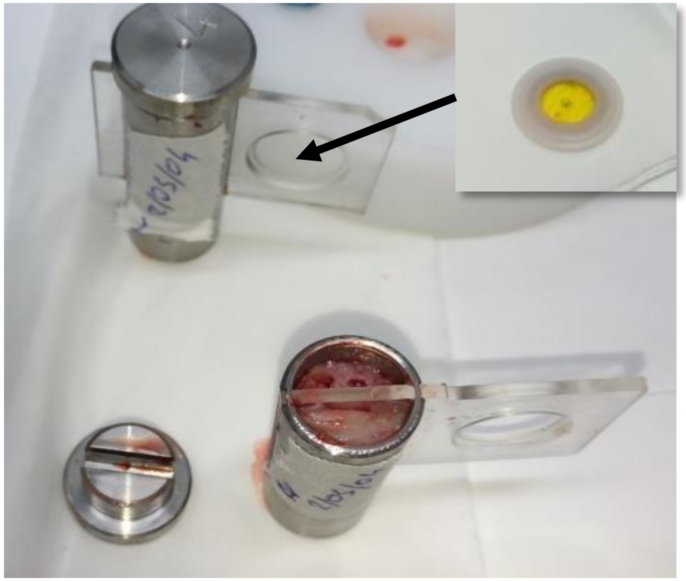
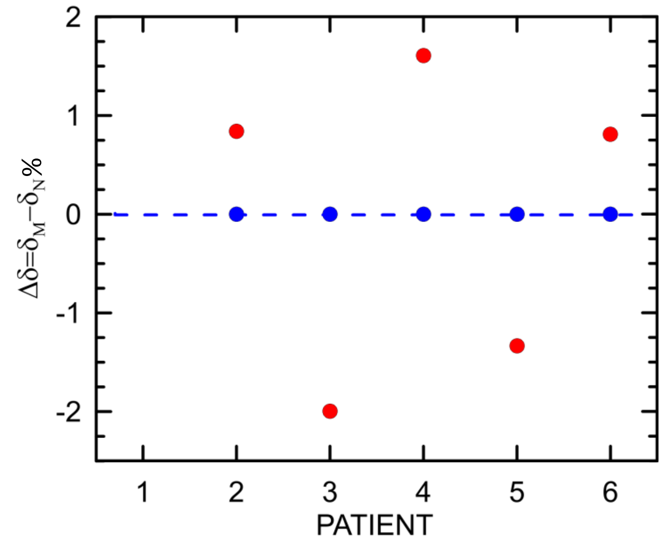




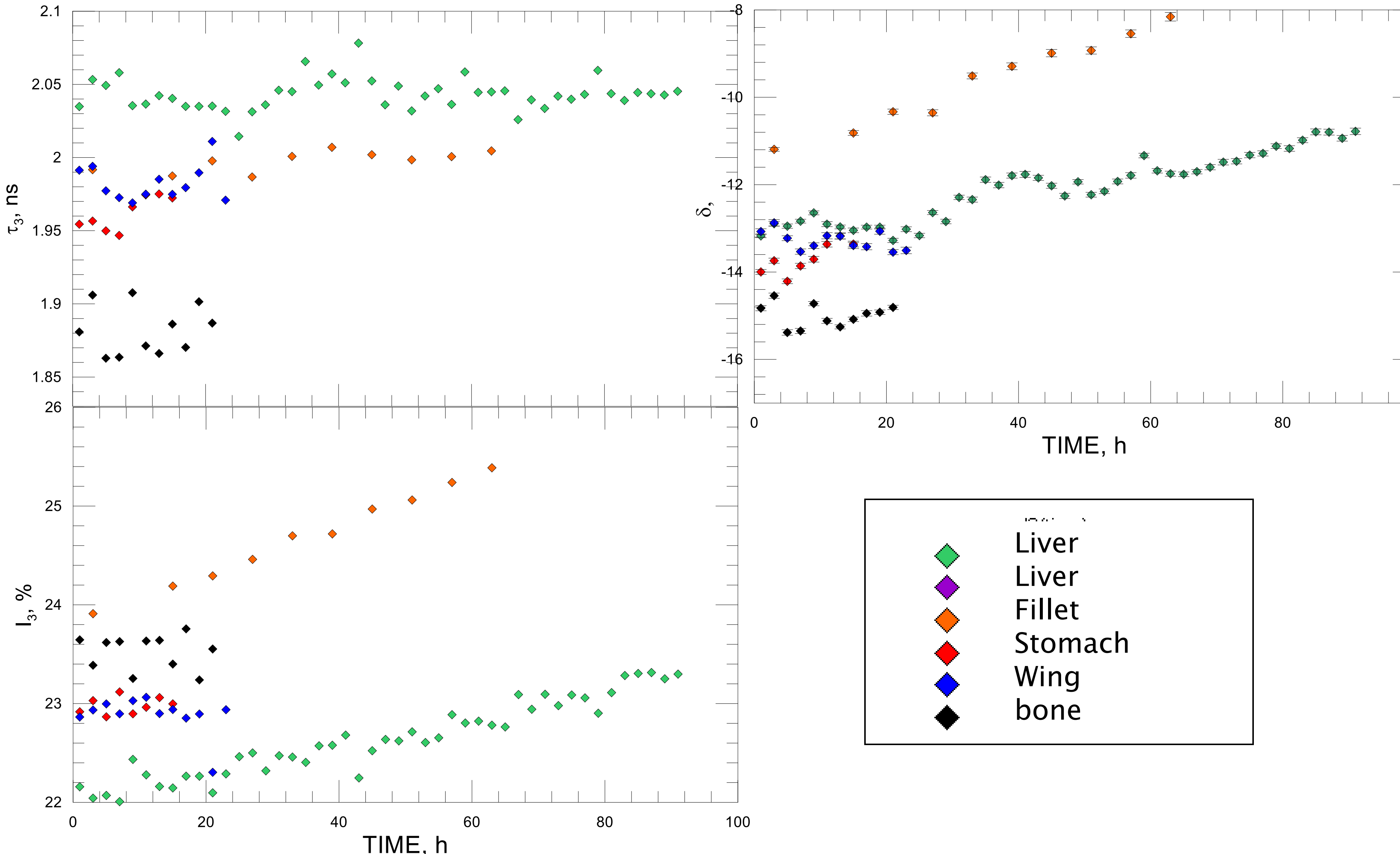


Conclusions

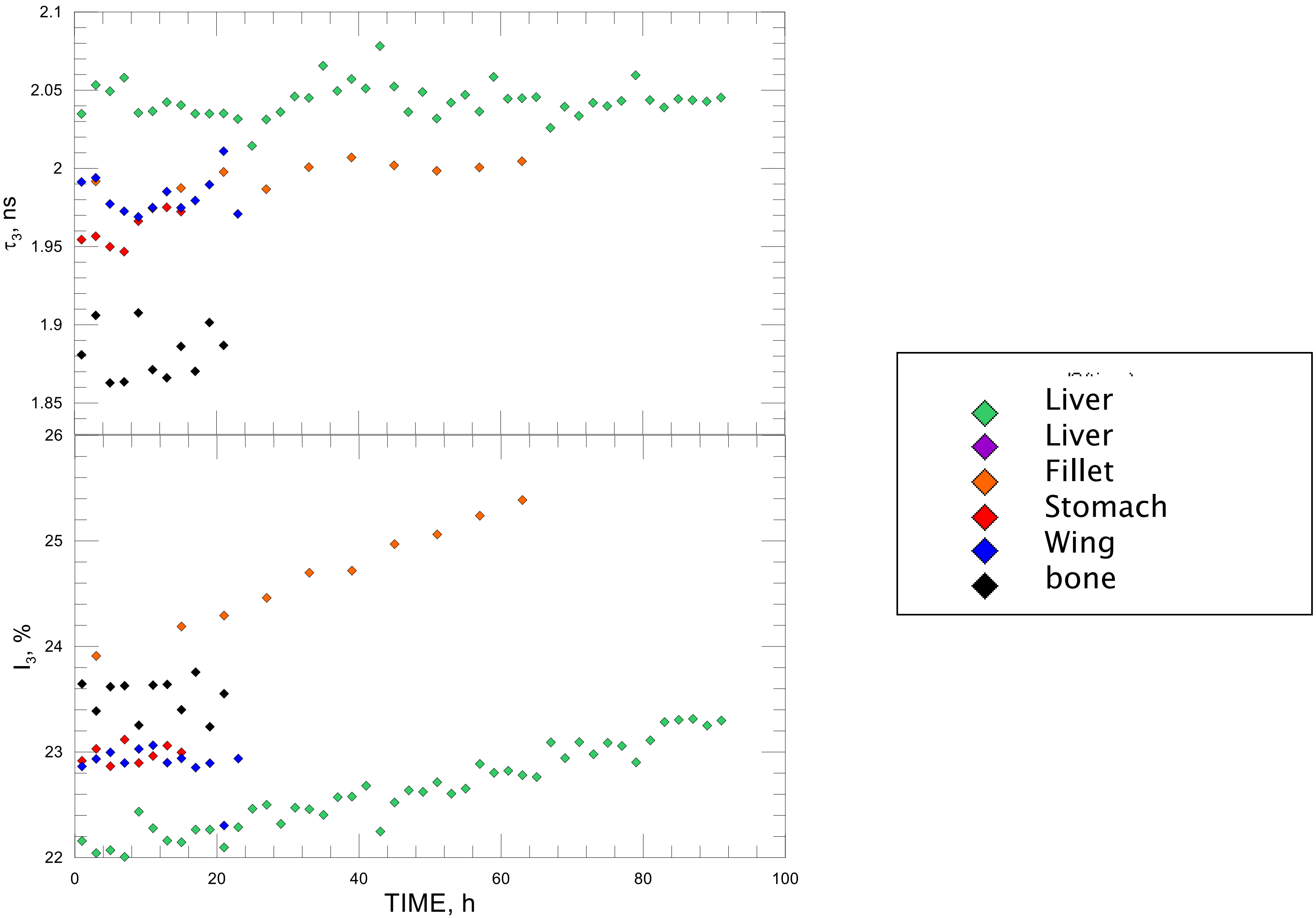
1. With δ parameter it is possible to differentiate between tissues kind.

2. With δ parameter it is possible to observe material aging.

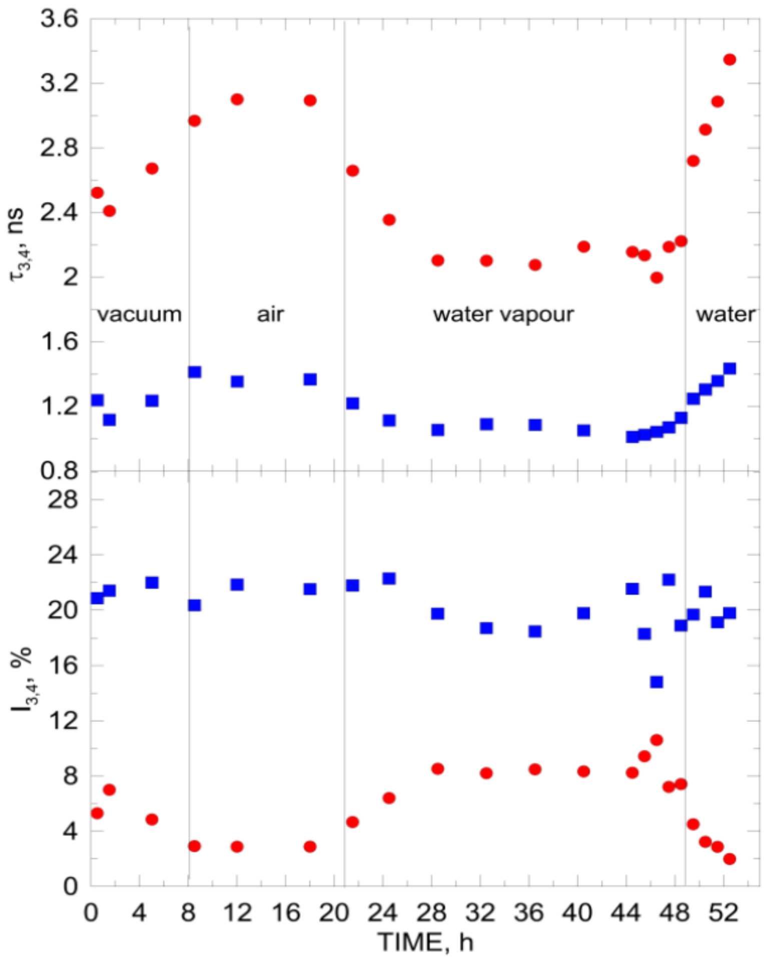
3. Result of measurements for human tissues are promising but not conclusive (at this stage of investigations).



τ3, ns
I3, %
δ,
TIME, h
TIME, h
Liver
Liver
Fillet
Stomach
Wing
bone


2.1
2.05
2
1.95
1.9
1.85
τ3, ns
26
25
24
23
22
I3, %
0
20
40
60
80
100
TIME, h
Liver
Liver
Fillet
Stomach
Wing
bone

WATER PRESENCE IN THE HUMAN BODY
YEAST



The o-Ps lifetime and intensity values as a function of the water vapour sorption time, index 3 denotes shorter-lived component (squares), 4 – longer-lived (circles). Measurement stages:

1) in vacuum ,

2) in dried air,

3) with presence of water vapour,

4) with drop of water placed in the chamber containing yeast.

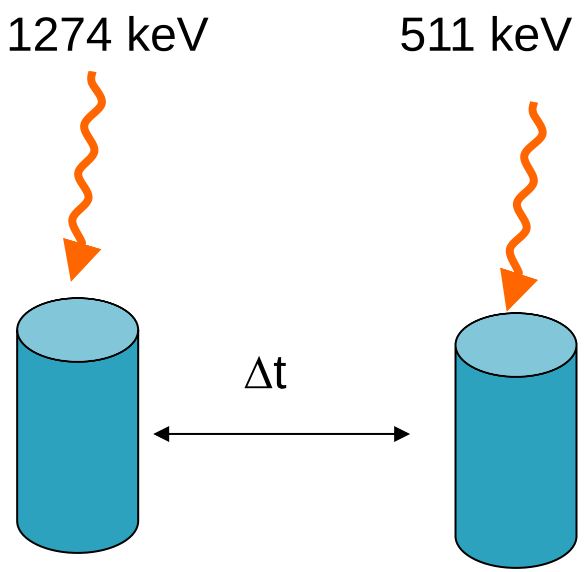
Plans of tests with J-PET

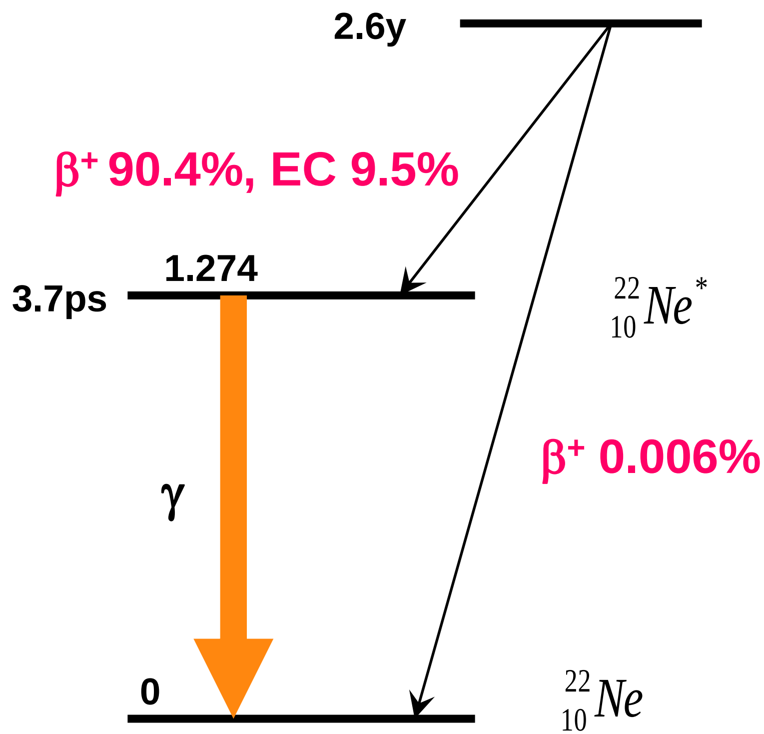
1. Determination of the experimental uncertainity
   (statistics of measurements/human body examination),
   repitibility of the results for one tissue

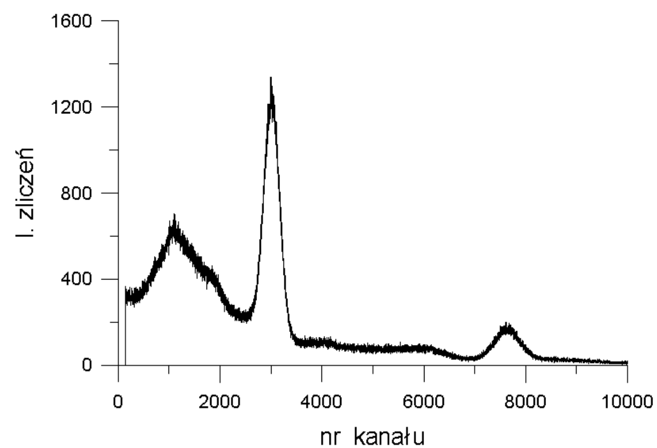
2. Preliminary determination of the range of del values for various tissues

PALS

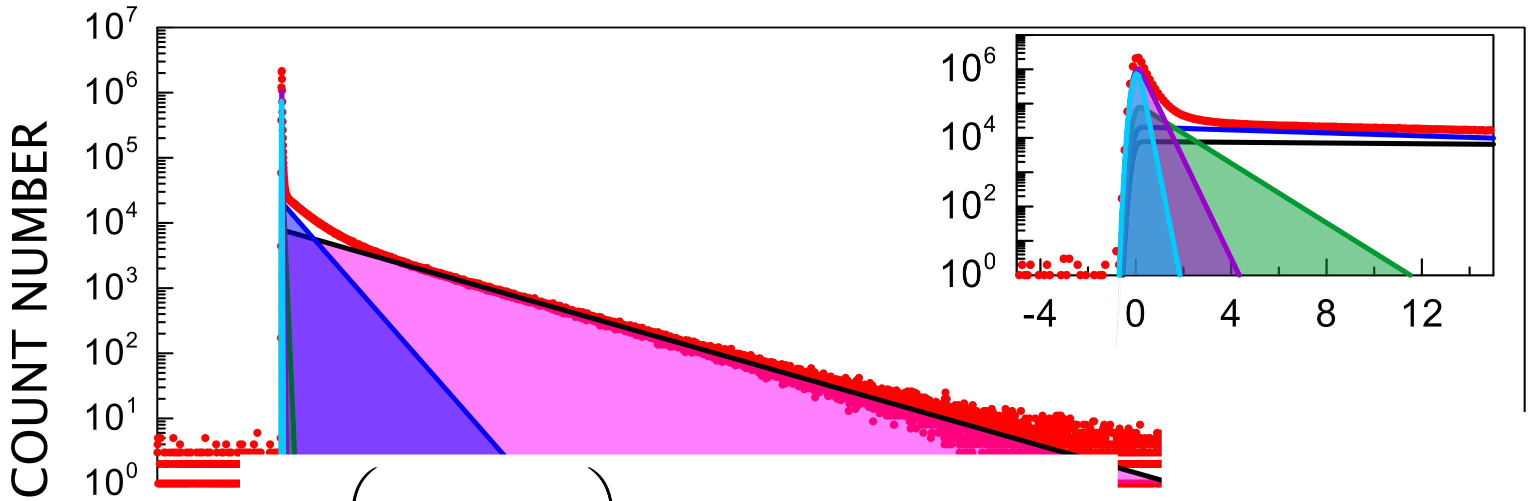
Positron Annihilation Lifetime Spectroscopy







3γ fraction – LT spectrum



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