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^{222}Rn daughters in liquid nitrogen

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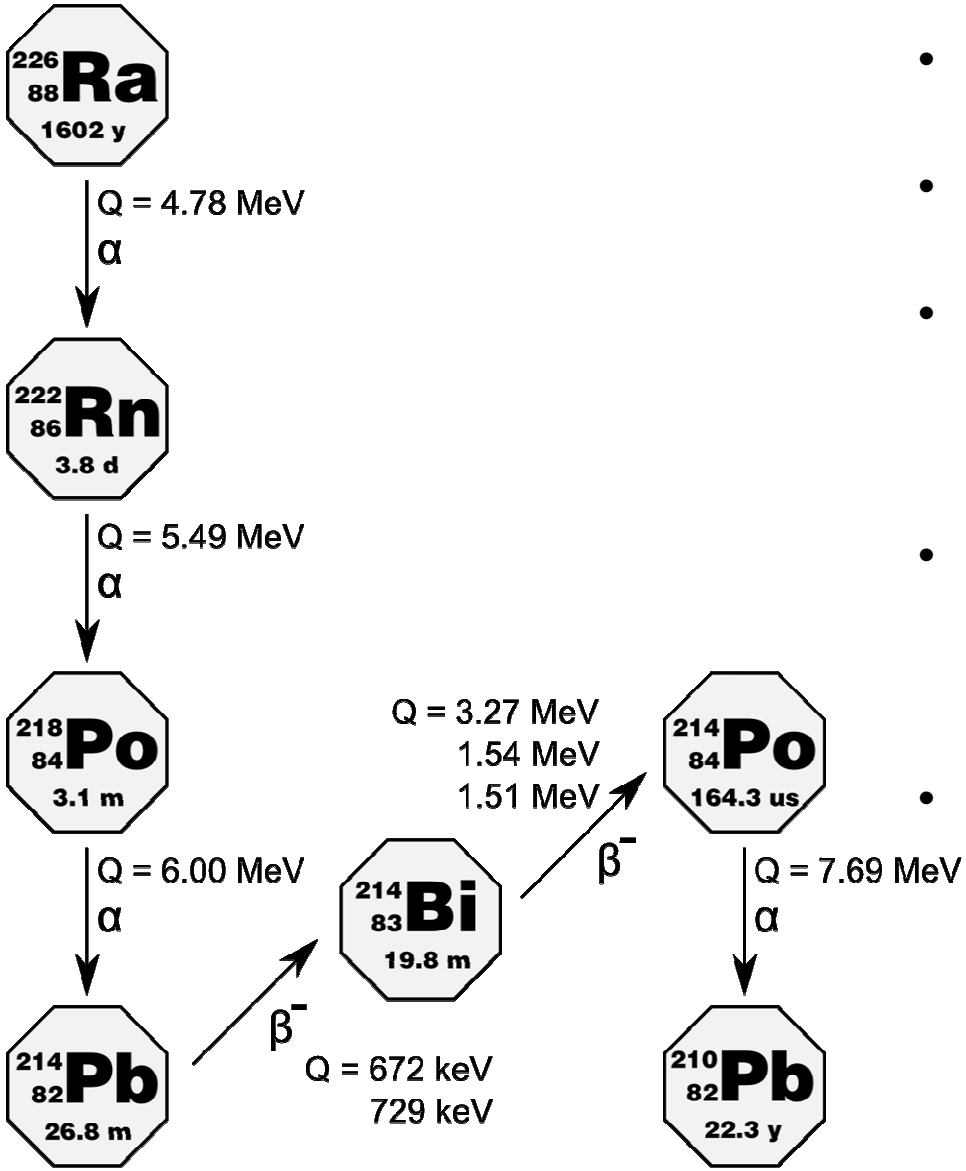
Outline

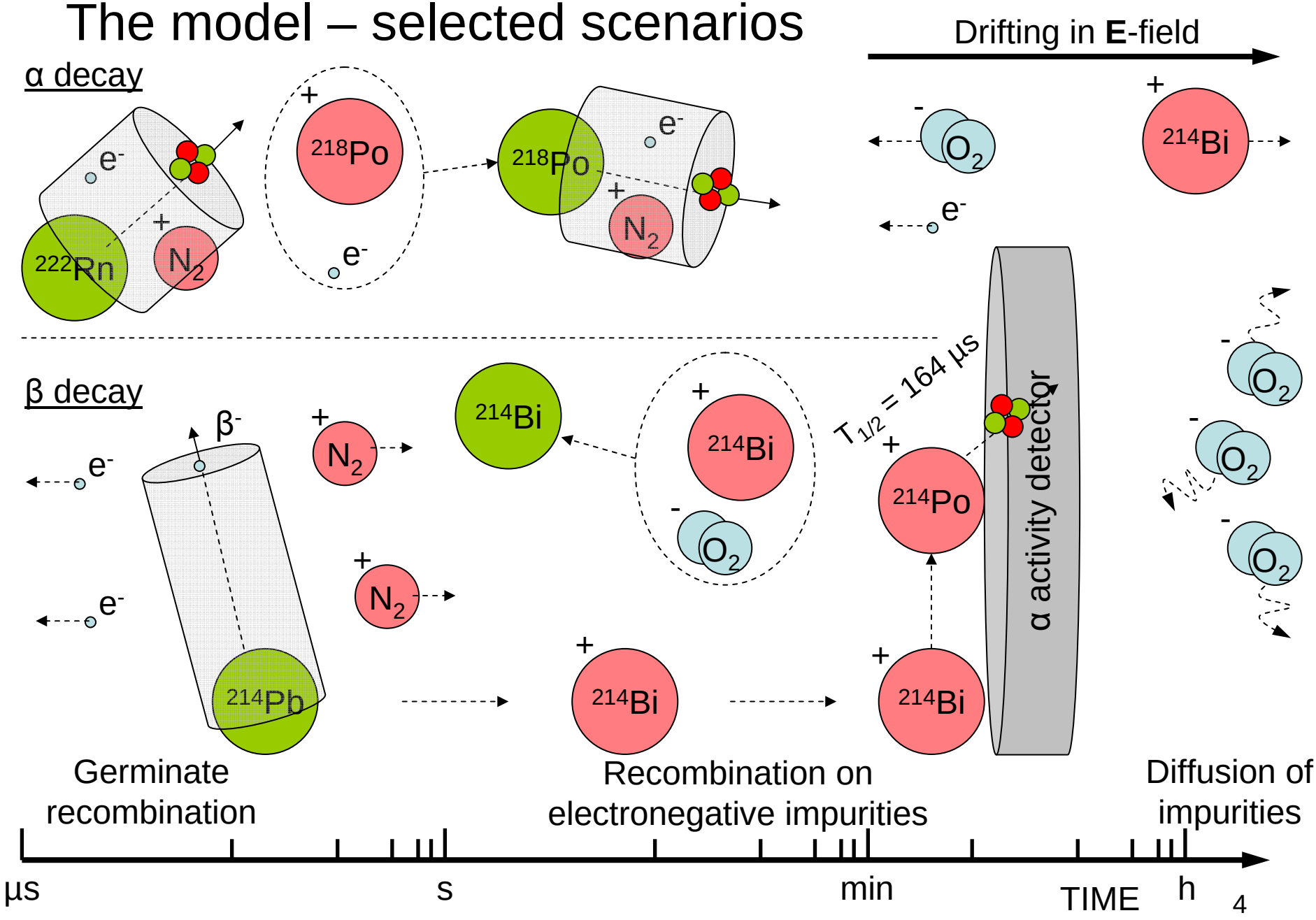
- Motivation – ^{222}Rn induced background in cryoliquids
- Proposed model
- Experimental setup
- Results of α-activity measurements
- Summary

^{222}Rn induced background in cryoliquids



- ^{226}Ra present in most of the construction materials;
- Gaseous ^{222}Rn emanation dissolves into the cryoliquids;
- Ionized decay products are subject to electric field, induced in the cryoliquid (e.g. drift chambers);
- Energy released in alpha, beta and gamma decays in ^{226}Ra decay chain are above e.g. $Q_{\beta\beta}$ (neutrinoless double beta decay);
- Natural intrinsic source of background in majority of the low background experiments.

The model – selected scenarios



The model highlights

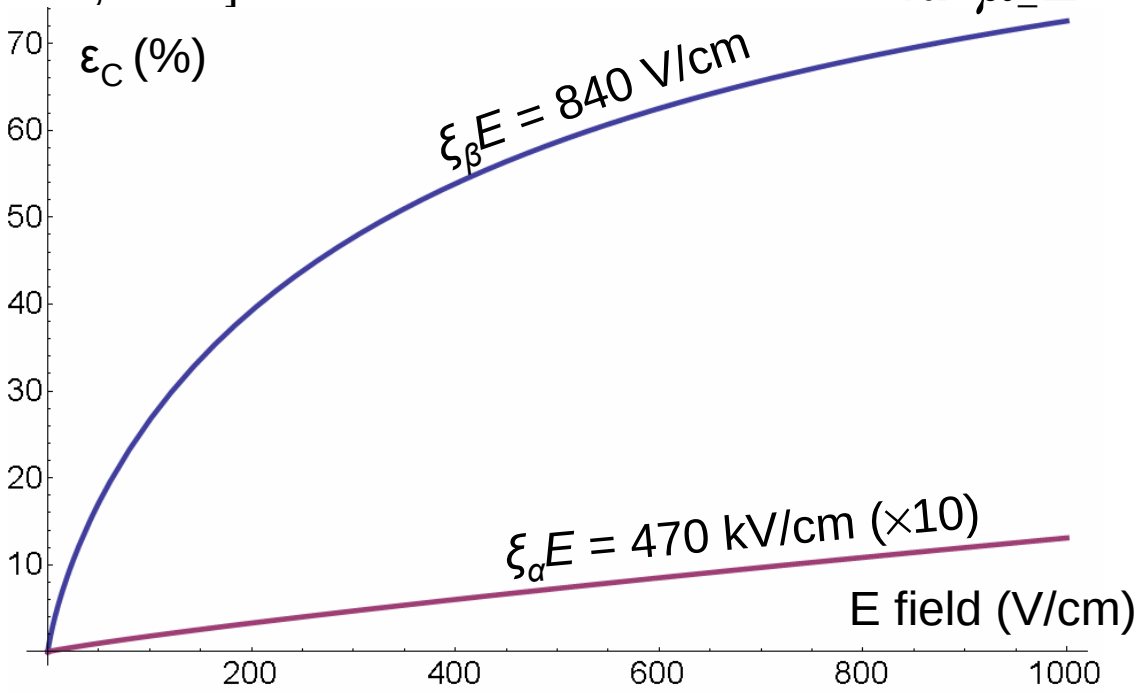
- Box model of germinate neutralization

$$\varepsilon_C = \frac{C}{C_0} = \frac{\ln(1+\xi)}{\xi}$$

  - Probability ε_C of the initial C_0 charge survival is a function of external electric field strength E and type of ionizing decay
  - N_i is the number of electron-cation pairs produced within a box of dimensions a, α is the recombination coefficient, μ_- is the electron mobility

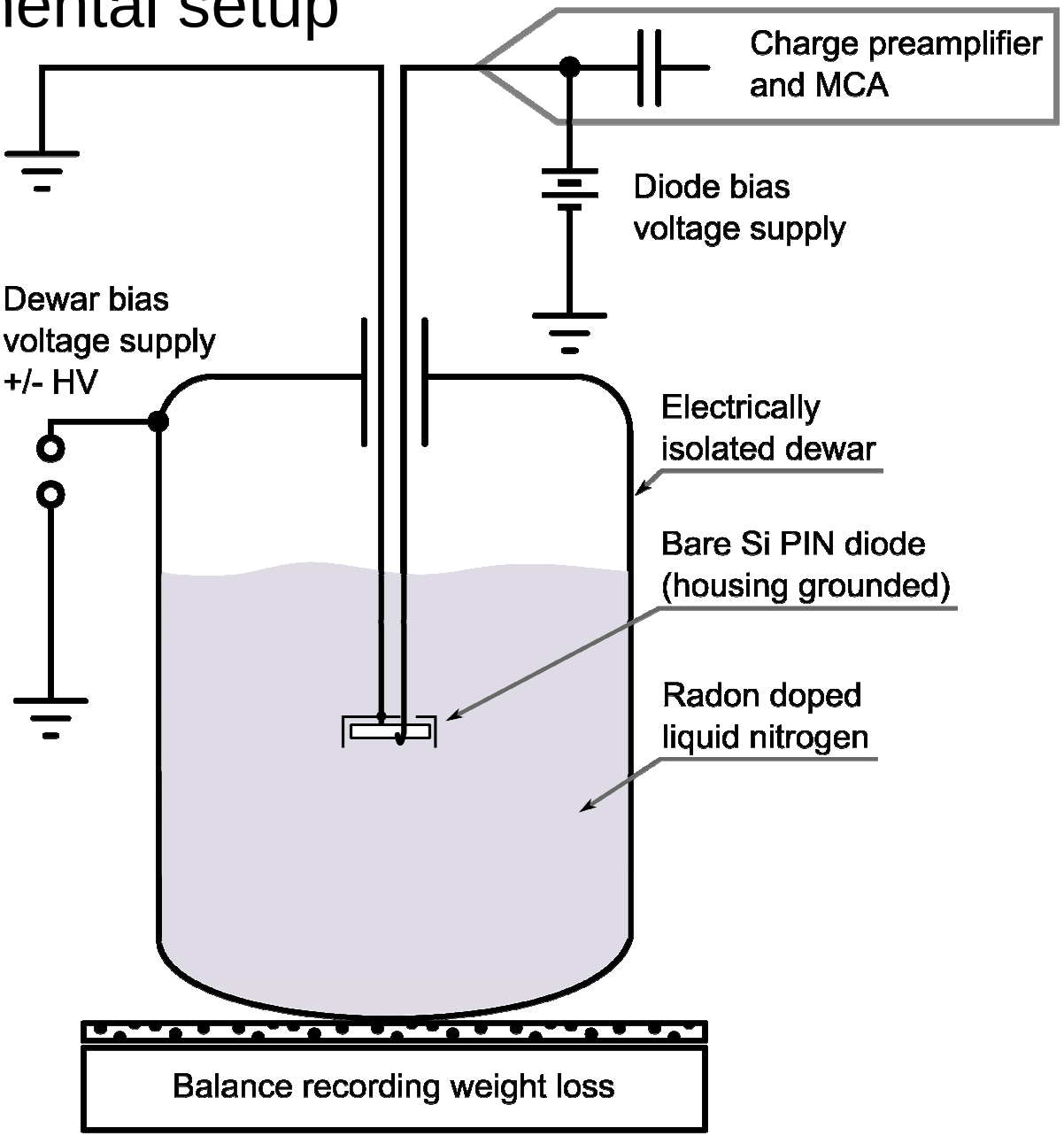
$$\xi = \frac{N_i \alpha}{4a^2 \mu_- E}$$

  - Values of ξ known from fits [J. Thomas et.al., Phys. Rev. A, 1987]:
    - $\xi_\beta E$ = 840 V/cm for 364 keV electrons
    - $\xi_\alpha E$ = 470 kV/cm (5.64 MeV alpha-decays)

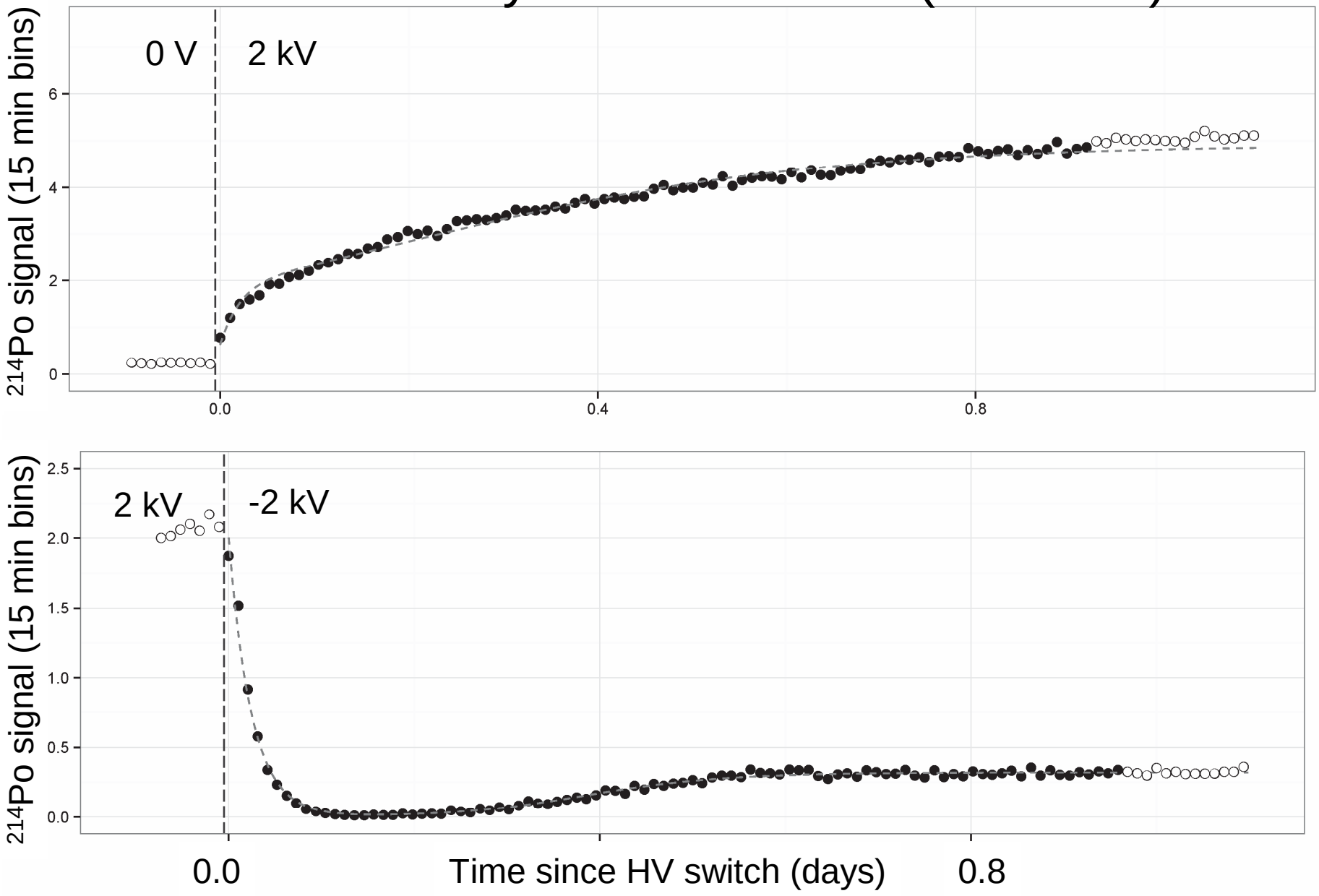


- Bulk recombination on electronegative impurities;
- Changes of impurity concentration in time (in a long timescale) due to diffusion and adsorption.

The experimental setup



Results of α-activity measurements (selection)



Experimental results (preliminary)

- The ion lifetime parameters (T_{max} for negative ions fixed to ^{214}Bi lifetime – fit results were always divergent);
- Systematical errors originate from the ^{222}Rn doping uncertainties. They are not discussed.

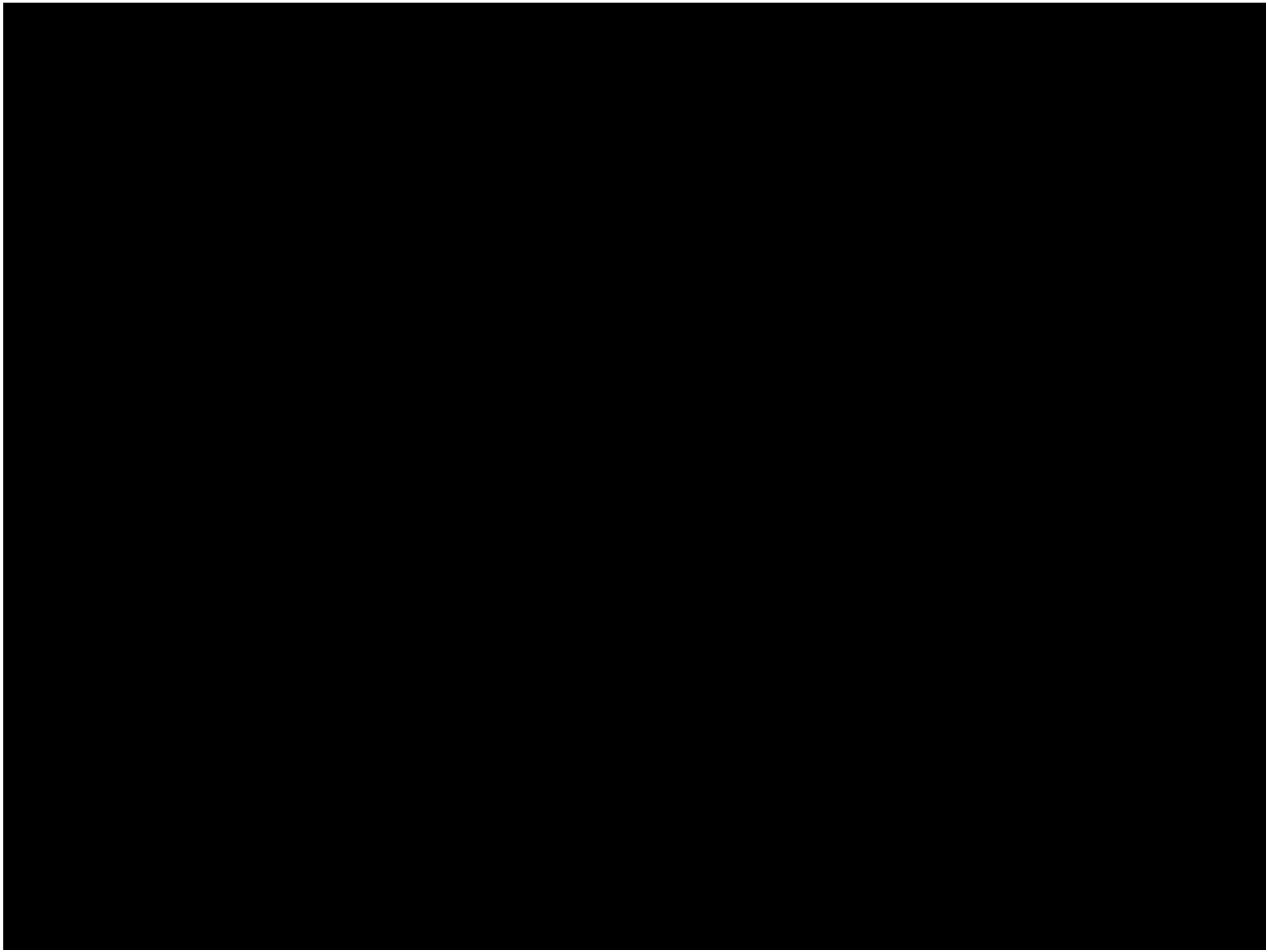
	0→2 kV	2→-2 kV	-2→2 kV
ε_C (%)	47.1 ± 0.5	0.65 ± 0.02	55.6 ± 0.3
T_0 (s)	5.9 ± 0.1	0.4 ± 0.1	0.098 ± 0.008
T_{max} (s)	21.6 ± 0.3	**1188**	9.56 ± 0.06
r (d^{-1})	4.4 ± 0.2	11.8 ± 1.0	10.4 ± 0.2
Ions	positive	neg.-like	positive

- Abundances [a.u.] of ^{222}Rn daughters on the surface of the Si-PIN detector;
- Amount of ^{218}Po is consistent with 0.

	2→0 kV	-2→2 kV	2→-2 kV
^{218}Po	0 ± 4	0 ± 0.7	0 ± 0.6
^{214}Pb	3 ± 5	0.1 ± 0.7	0.5 ± 0.7
^{214}Bi	9.4 ± 0.2	0.21 ± 0.05	2.00 ± 0.05
Bkg	0.11 ± 0.02	0 ± 0.009	0 ± 0.005

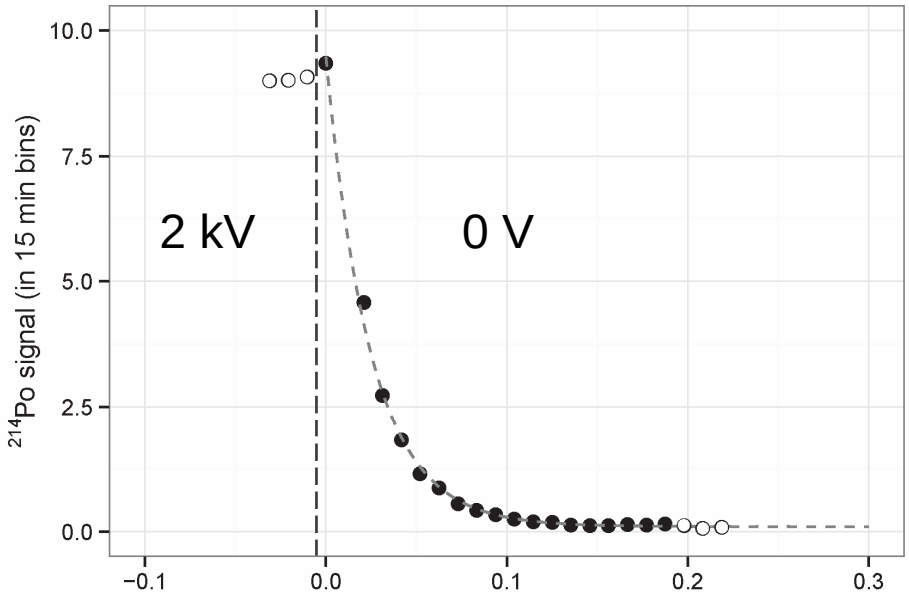
Summary

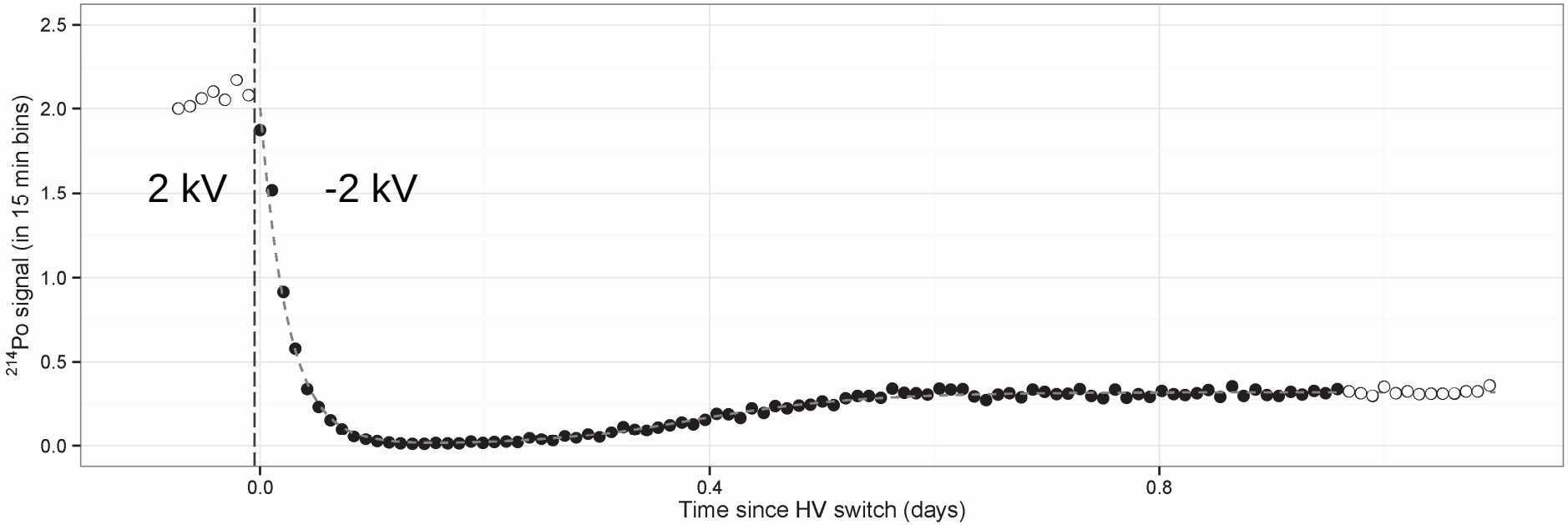
- We have observed positive and negative-like ions;
- Negative-like ions are probably formed as bigger compounds
  - Long ionic lifetime in technical grade cryoliquids;
- Positive ions exhibit long ionic lifetime – possible source of background;
- Proposed semi-empirical model well describes results
  - Mobility of the ions not known precisely (assumed)
  - Germinate neutralization depends on the type of decay and external electric field strength;
- Further improvements
  - Direct measurements of ^{218}Po
  - Electric field modeling
  - Measurements in different cryoliquids (liquid argon, xenon)
  - Controlled purity
  - Dedicated measurements of mobilities.
- Thanks to Nikodem Frodyma for providing the data.



Backup slides

- The positive high voltage bias repels positive ions towards the Si-PIN detector, close to the ground potential
- The negative bias repels negative-like ions towards the detector





Backup slides – persistence of ions in cryoliquids

- In dense environments (liquefied gases used in low background experiments) the differences in energies required to free a bound electron ensures persistence of the ions.
- High purity of the liquids enhances the ionic lifetime and probably reduces chances to form negative-like compounds.

Atom	1st IP [eV]	2nd IP [eV]
Rn	11	-
Po	8.4	-
Pb	7.4	15
Bi	7.3	17
Gap energy [eV]		
Ar	16	-
N_2	15	-
Kr	14	-
Xe	12	-

- IP – ionization potential

Backup slides – mobilities of ions in cryoliquids

- Mobilities of ^{222}Rn daughters not known
  - A typical value of ^{226}Th mobility in liquid argon (NBP) is $2.4 \cdot 10^{-2}$ $mm^2V^{-1}s^{-1}$
    [K. Wamba et. al., NIMA, 555 (2005), 205-210]
- Mobilities of impurities well known
  - Oxygen ions in liquid argon (NBP) – $2.5 \cdot 10^{-1}$ $mm^2V^{-1}s^{-1}$
    [B. Henson, Phys. Rev., 135, 4A (1964), 1002-1008]

Backup slides – impurities concentration

- Bulk recombination on electronegative impurities
  - $[Y^+]$ is the time dependant concentration of the ions.
- Concentration of impurities changes in time. Concentration [Z] is related to the ionic half-lifetime *T* via attachment rate k_Z: $T(t) = \ln 2\, k_Z [Z](t)$;
- Changes of impurity concentration [Z] in time (in a long timescale) as a limited growth function
  - Solution to a differential equation, where $x(t) \equiv T(t)/T_{max}$;
- The maximum concentration is limited by the total amount of ions dissolved in the liquid volume – minimum ionic lifetime T_0;
- The minimum concentration is limited by the diffusion and convection flows (mixing) – maximum ionic lifetime T_{max};
- Change rate *r* is related to the diffusion of the impurities – timescale order of hours;

$$[Y^+](t) = [Y^+]_0 \, \mathrm{e}^{-k_Z [Z](t)t}$$

$$\frac{dx}{dt} = rx(1-x)$$

$$T(t) = \frac{T_0 T_{\max} \, \mathrm{e}^{rt}}{T_{\max} + T_0 \left(e^{rt} - 1\right)}$$