Progetto PRIN 2020

Congresso SIF, 11-15 September 2023

AS Be ST

A 7-Beryllium electron capture STudy for nuclear and solid state physics

Maria Lucia Mitsou, PhD Student
DMF, Università degli Studi della Campania, *Luigi Vanvitelli*

R.Buompane (1)(5), L.Gialanella (1)(5),C.Santonastaso (1)(5), G.Porzio (1)(5),N.Itaco (1)(5), M.Canino (2),M.Pierruccini (2),C.Bidini (2),N.Casali (6),H.C.Neitzert(3), M.Laubenstein (7), A. Di Leva (4)(5), A. Formicola (6), L. Di Benedetto (3), A. Rubino (3), M.Bellettato (2), C. Degli Esposti Boschi (2)

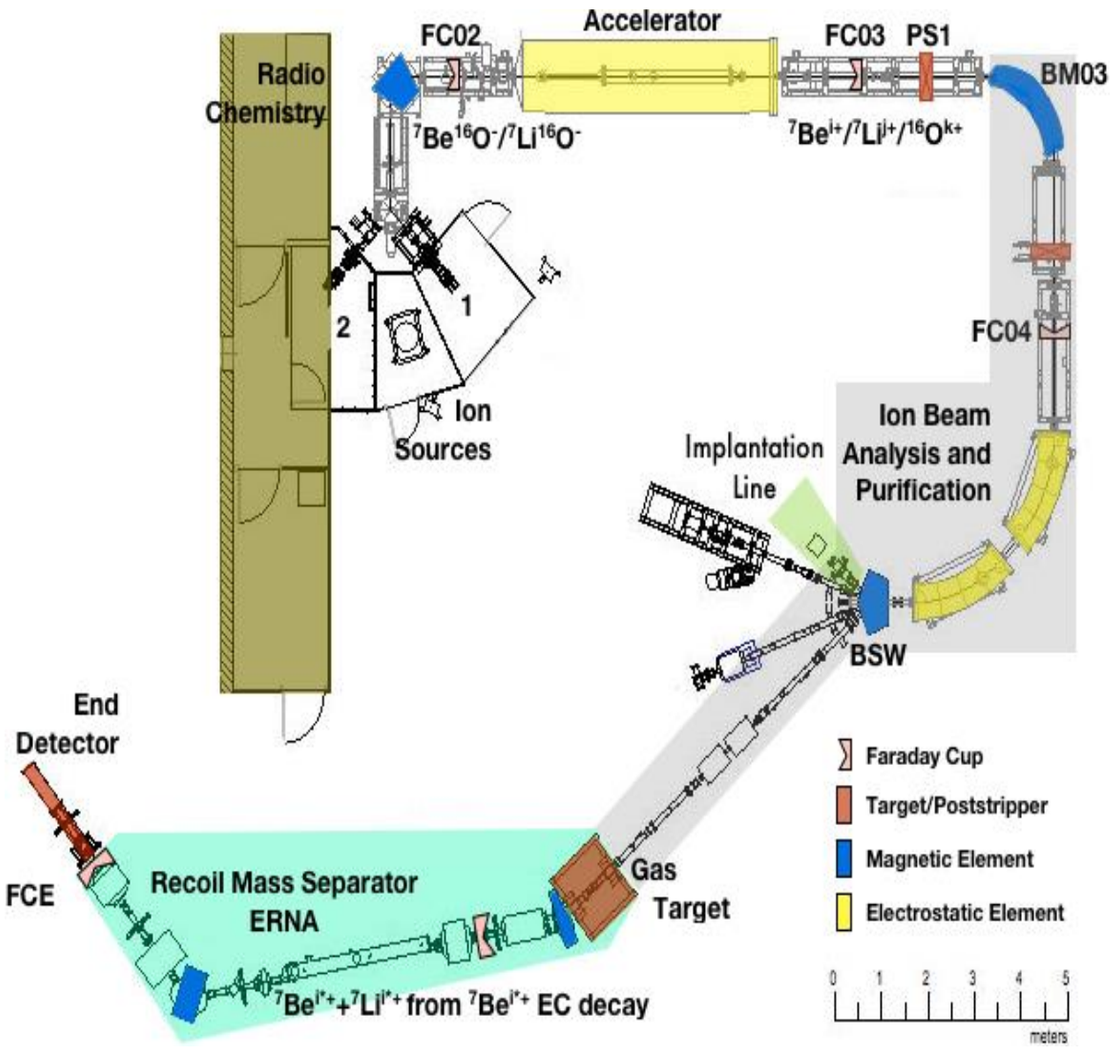
(1) DMF-Università degli studi della Campania , Luigi Vanvitelli
(2) CNR-IMM BO
(3) DII, Università degli studi di Salerno
(4) Università degli studi di Napoli, Federico II
(5) INFN, Sezione di Napoli
(6) INFN, Sezione di Roma
(7) INFN-LNGS

INTRODUCTION

- The ^{7}Be isotope decays in ^{7}Li through electron capture (EC). There is a growning interest in the investigations of half-life variations induced by environmental conditions.

- The study of the ^{7}Be half-life variation has an impact in astrophysics, in the fundamental physics and in the solid state physics.

- In the CIRCE facility we will study the variation in the decay rate of ^{7}Be with two approaches. The first approach is based on a dose of ^{7}Be atoms implanted in SiC diode depletion region polarized with an intense electric field (MV/cm). The second is the measurement of in-flight decay rate of a pure ^{7}Be beam in 3+ charge state studied with recoil mass separator ERNA.



M.L. Mitsou

The scientific motivation.

- In fundamental physics, the study of the ^{7}Be decay rate in ionized state would provide information on beta-decay matrix element. For instance, the triple ionized state of the ^{7}Be is an hydrogenoid atom with a well know electronic wavefunction.
- The measurement may set constraints for the nuclear term in the electroweak matrix element .
- The nuclear term is included in the universal Hamiltonian density in the form of the hadronic current.

$$\lambda = \frac{2\pi}{\hbar}\left|M_{fi}\right|^{2}\varrho$$ **Fermi Golden Rule**

According to QED , the matrix element depends on the coupling between hadronic and leptonic currents

$$\boldsymbol{M_{fi} = \langle n\nu_e | G_{EC} \int dx^4 \left(J_\mu(x) L_\mu(x) + h.c\right) | pe \rangle}$$

$\boldsymbol{G_{EC} = G_C cos\theta}$ **Coupling costant**

$$\begin{cases} \boldsymbol{J_\mu(x) = i\bar{\psi}_p(x)\gamma_\mu(1+\lambda\gamma_5)\psi_n(x)} \\ \boldsymbol{L_\mu(x) = i\psi_{\nu_e}(x)\gamma_\mu(1+\gamma_5)\psi_e(x)} \end{cases}$$

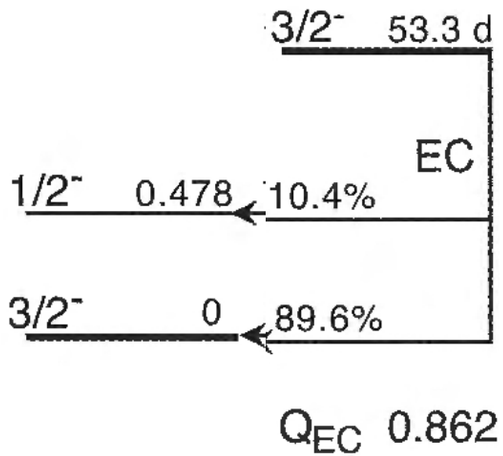
Manipulating the matrix element and the Golden Rule we obtain that the decay constant is :

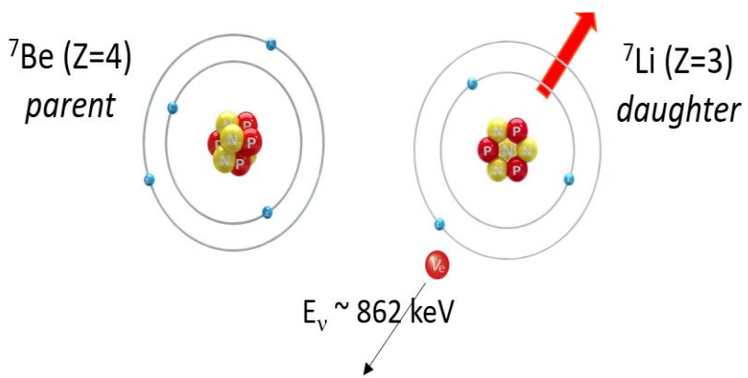
$$\boldsymbol{\lambda \propto |\psi_e(0)|^2}$$

^{7}Be electron capture decay

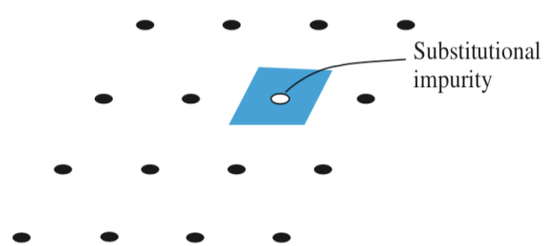
- The electron capture process:

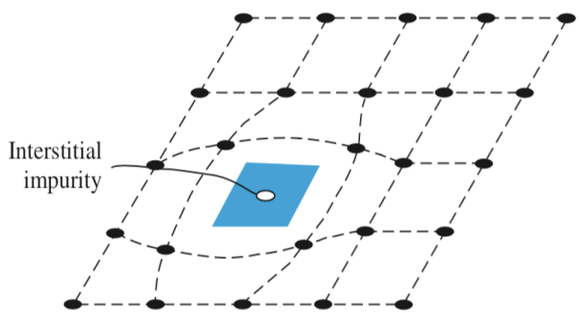
$$^{A}_{Z}X + e^{-} \rightarrow {}^{A}_{Z-1}X' + \nu_e$$



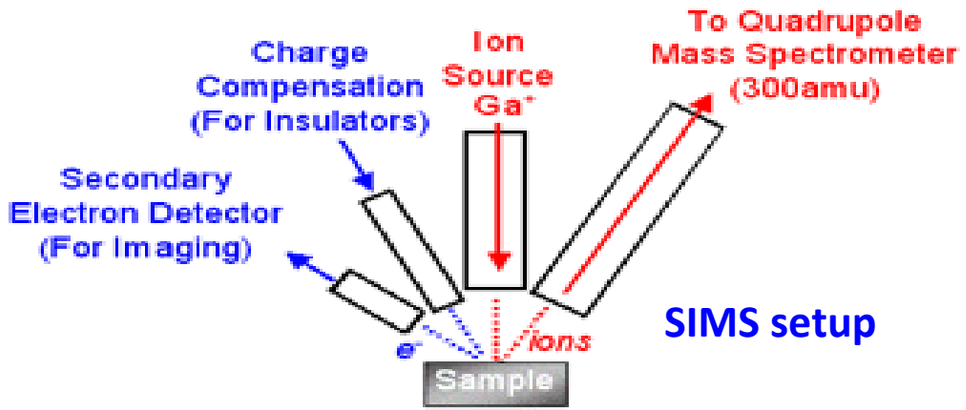


- $T_{1/2} = (53{,}22 \pm 0{,}06)d$
- The shells *K* or *L* are involved in the capture. The electronic wavefunction and the density of electrons in the nucleus can be perturbate by the application of an electric field (Stark effect).
- The implantation of ^{7}Be atoms inside the depletion region of a SiC diode is motivated by the expectation of a variation of half-life due an intense electric field.



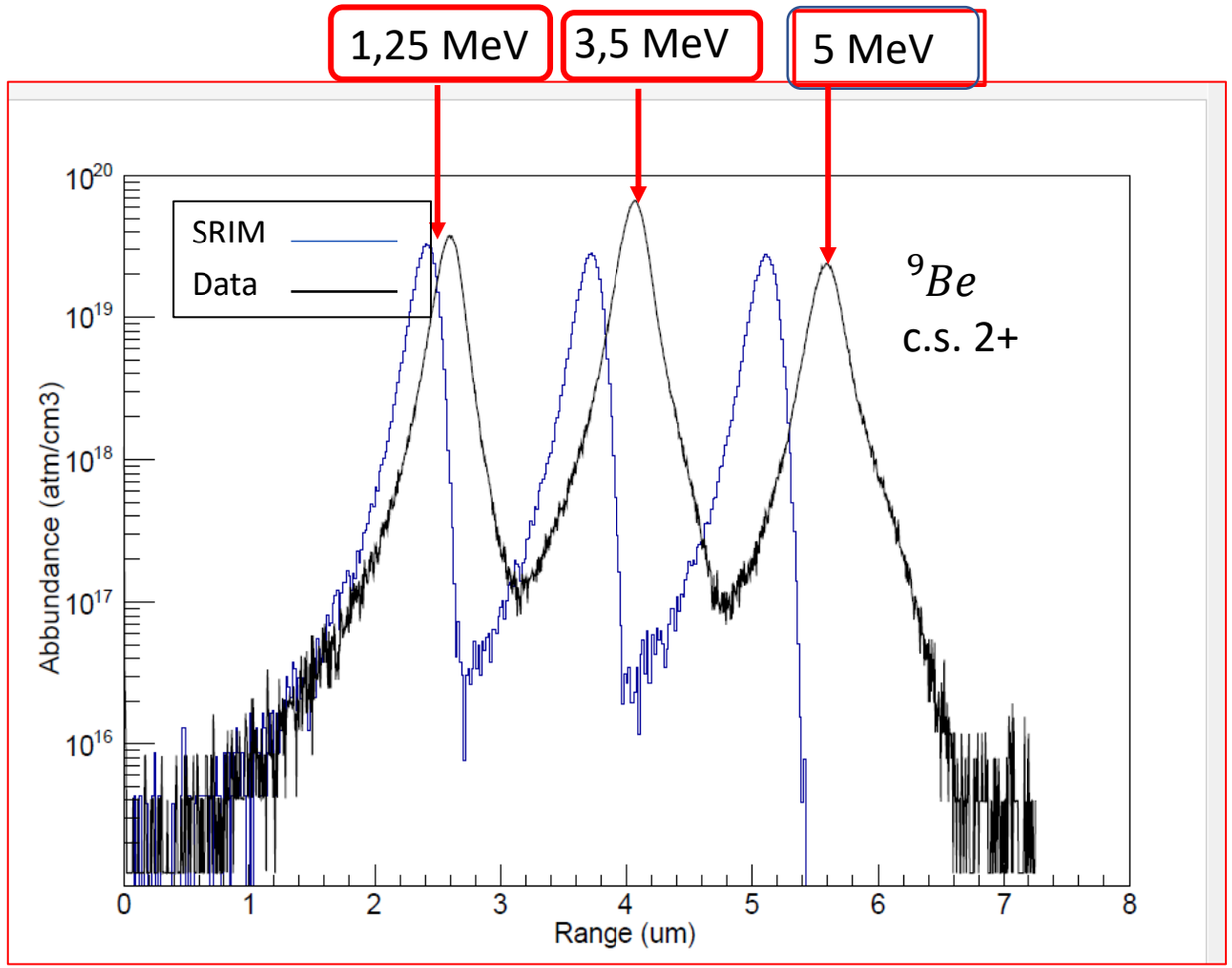


First approach:implantation test with ^{9}Be atoms



SIMS setup

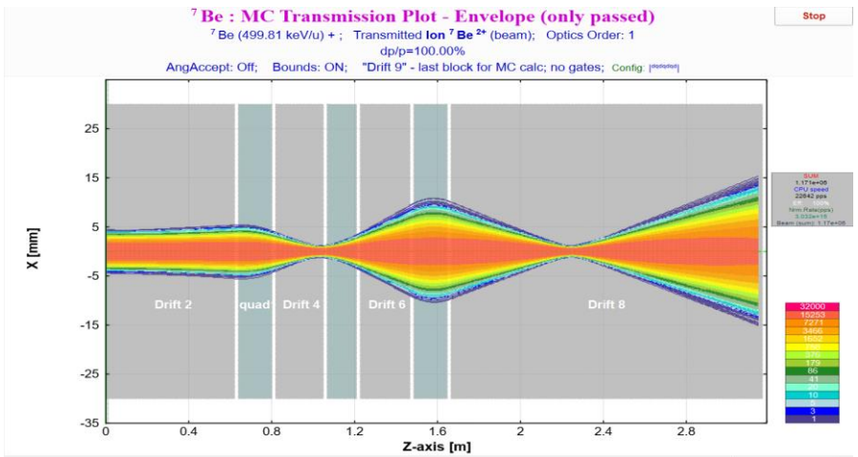
- At the CIRCE Laboratory we are developing a line for materials analysis (RBS, channeling, NRA…).
- To have information about the substitutional and interstitial ^{7}Be impurities, we will perform channeling/RBS on the implanted sample. For this purpose, we are developing a 5-axis manipulator.
- On test diodes we have performed ^{9}Be implantation to explore the possibility of damage recovery through annealing and the behavior of the interstitial atoms. The implanted substrates were explored with SIMS depth profile measurement (Probion).

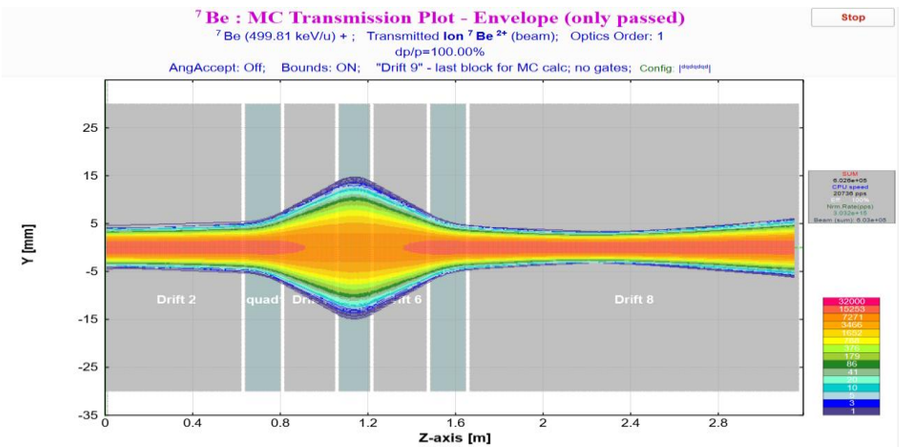


M.L. Mitsou

First approach: implantation test with ^{7}Be

Simulations with LISECute++ code





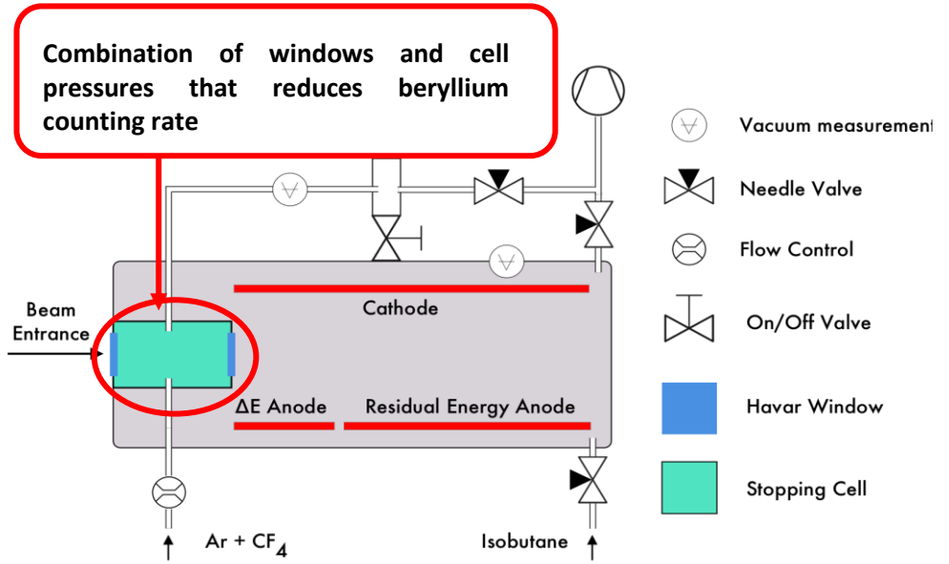
- The samples have been implanted in a spot of circular area thanks to the magnetic triplet quadrupoles.
- Stopping test on photoresist (P2-PR) and P3-LTO layers:
- Implantation on SiC1009M without electric contacts for activity measurements ai LNGS with HpGe detector.

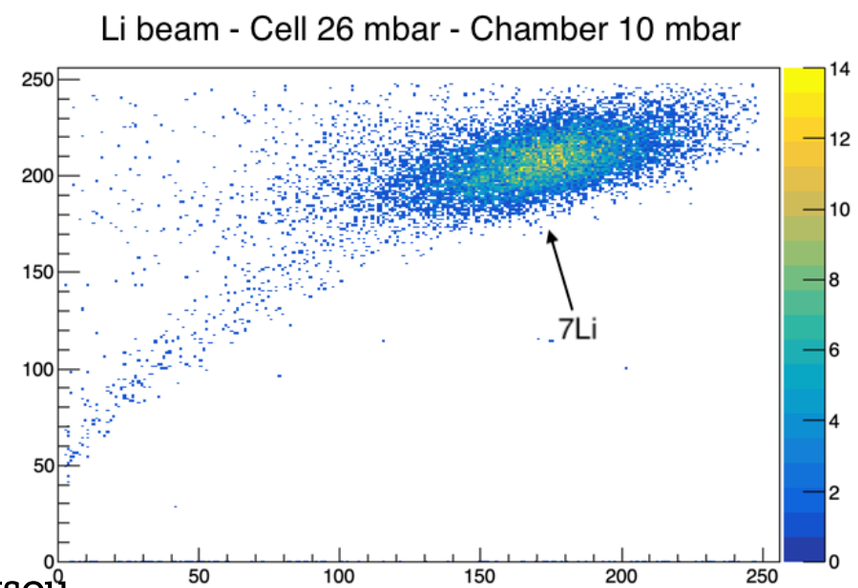
	depth	**time**	**Concentration** $(\frac{atoms}{cm^3})$	**Activity**
P2-PR	$0{,}25\ \mu m$	$2040\ s$	$5{,}2 \times 10^{16}$	$(14{,}40 \pm 0{,}21)\ kBq$
P3-LTO	$0{,}25\ \mu m$	$1800\ s$	$4{,}8 \times 10^{16}$	$(13{,}50 \pm 0{,}22)\ kBq$
SiC1009M	$0{,}25\ \mu m$	$140\ s$	$6{,}35 \times 10^{16}$	$(1{,}80 \pm 0{,}13)\ Bq$

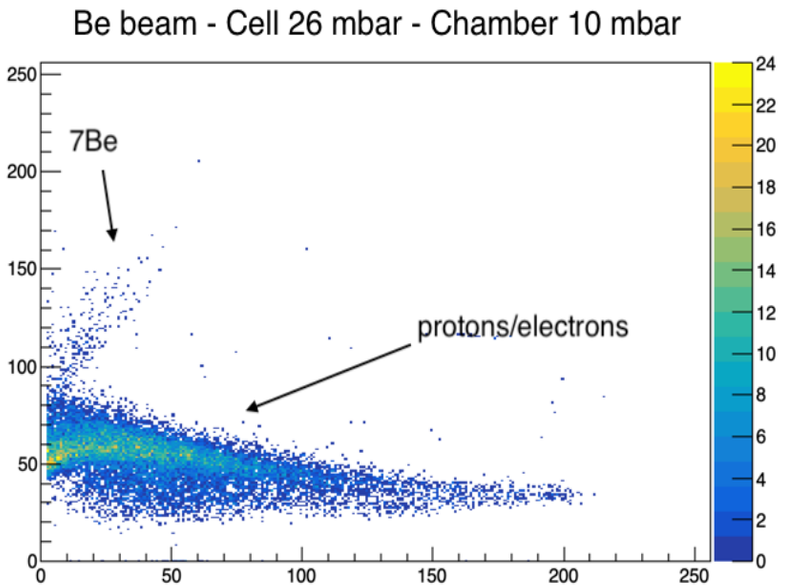
M.L. Mitsou

Second approach: IC test

- The in-flight decay is studied with ERNA where can be reached an excellent suppression of ^{7}Li leaky .
- The aim of the experiment is to detect the ^{7}Li producted by the decay during the flight. For this scope is used the ionization chamber of ERNA.
- The IC optimization is motivated by the use of gas without hydrogen and by the stopping beryllium atoms before the active region of the detector.
- The combination of the signals from the two anodes gives a matrix plot (ΔE vs E_{res}).







Conclusion

- The residual activity of 2 cps on the P2-PR layer after the washing reveals that we need a photoresist thicker than 10 µm to implant only in the device with a diameter of 500 µm. These steps are necessaries for the the diode build -up. The diode is now in production and the masks have been completed.

- In the previous in-flight decay experiment the count rate of event expeted was about 1 $^{event}/_{day}$ according to the ^{7}Be current beam. Improvements for reaching higher beam current are required. For these scope, we are designing new cathodes and we are studying an optimization of the chemical preparation of the process.

THANK YOU FOR YOUR ATTENTION!