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EXOTICS WITH CYCLOTRON AND TANDEM: THE EXCYT FACILITY, STATUS AND PERSPECTIVES

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The EXCYT (Exotics with Cyclotron and Tandem) facility at the INFN-LNS is based on a K-800 superconducting cyclotron (CS) injecting stable ions into a Target Ion Source (TIS) assembly to produce the required radioactive nuclear species, and on a 15 MV Tandem for post-accelerating the radioactive beams.

The CS features have been widely improved during the last years to obtain a steady primary beam, moreover a dedicated beam diagnostics was developed to detect and transport the low intensity radioactive ion beam from the TIS to the users experimental apparatus. The commissioning of the facility was completed on July 2006 by delivering a ^{8}Li beam to the users. For some ion beams such as for Li, the extraction efficiency from the TIS is suitable only after a charge exchange to obtain negative ions.

In this work we present the status of the project along with the first production data of ^{8,9}Li. The production of the radioactive beam was performed by injecting a $^{13}C^{4+}$ primary beam of 45 MeV/u on a graphite target. The maximum primary beam power was 147W (1 eμA) with a a ^{8}Li production of about 1 10^{7} pps. The ionisation of the TIS reaction products were achieved by a Tungsten positive surface ioniser. To perform the conversion from positive to negative ions, a Charge Exchange Cell (CEC), containing Cs vapours, was employed.

The CEC efficiency for a ^{8}Li was 3.4%, very close to the expected theoretical value. This result also confirms the isotopic shift effect previously observed for a ^{6,7}Li on the CEC efficiency. The extraction voltage was 10 kV while the injection energy to the tandem was 100 kV. The maximum post-accelerated a ^{8}Li yield was about 9200 pps with a starting production of about 3.7 10^{6} pps.

EXCYT FACILITY: EXOTIC BEAM PRODUCTION, DETECTION AND CHARGE EXCHANGE

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Abstract

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1 INTRODUCTION

The aim of the EXotics with CYclotron and Tandem (EXCYT) [1] facility is the production and acceleration of radioactive ions (see figure 1). It is based on the two-accelerator method (ISOL technique): a K-800 Superconducting Cyclotron (CS) is used as a driver to provide the stable heavy ion primary beam (up to 80 MeV/u, 1 pμA). The radioactive elements are produced in a target-ion source assembly (TIS), then after extraction, conversion (if needed) into negative ions by a Charge exchange Cell (CEC) and separation from isobaric contaminations (see figure 2), they are post-accelerated by a 15 MV Tandem. The first beams already produced are ^{8,9}Li, some others among fluorine, chlorine, oxygen and aluminium are planned in the future, with an intensity ranging between $10^{4}\div10^{6}$ pps and at the typical energies of our Tandem.

The first ^{8,9}Li production at EXCYT was obtained on June 2005 while the entire facility was preliminary commissioned with stable ^{6,7}Li beams on December 2005 [2] using a dedicated ion-source assembly where the target was replaced with an oven filled with BrLi salt. The first post-acceleration was conducted on March 2006. The final commissioning of the facility was completed on July 2006 by delivering a ^{8}Li beam to the users. We also started an R&D programme to increase the RIB production developing new target materials and geometries. Preliminary promising results are here reported.

2 EXCYT COMMISSIONING WITH STABLE BEAMS AND FIRST RIBS PRODUCTION

The completion of the facility was achieved at the fall of 2004. The first months of 2005 were mainly devoted to the control system debugging with particular care to the safety and radioprotection systems. At the beginning we focused our attention in the commissioning with positive stable $^{6,7}Li^{+}$ beams over the two High Voltage (HV) platforms postponing in a second time the commissioning of the 2^{nd} stage separator and the coupling line with the Tandem.

The HV platforms system consists of two platforms working at the same voltage (250 kV maximum) in separated rooms and connected through a high voltage conduit. Most of the radioactivity is generated and confined in the first platform area (platform A in fig.2). This platform hosts the target-ion source (TIS) assembly (fig.4) [3], the pre-separator [4] and is contained in a shielded pit. The radioactivity level in the second platform area (platform B in fig.2) is much lower, this platform hosts the charge exchange cell [5] and the first stage of the isobaric mass separator. [4].

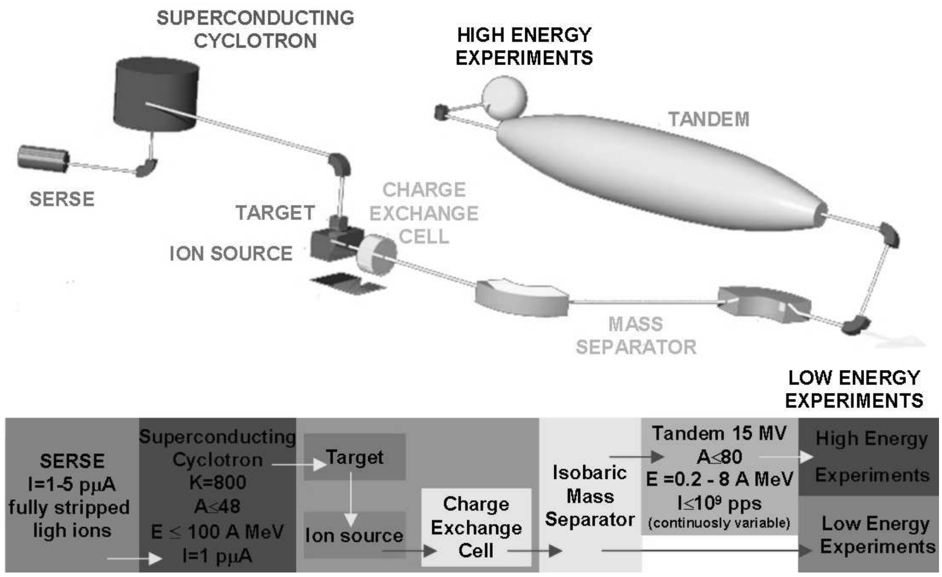

Fig. 1 – The EXCYT facility scheme

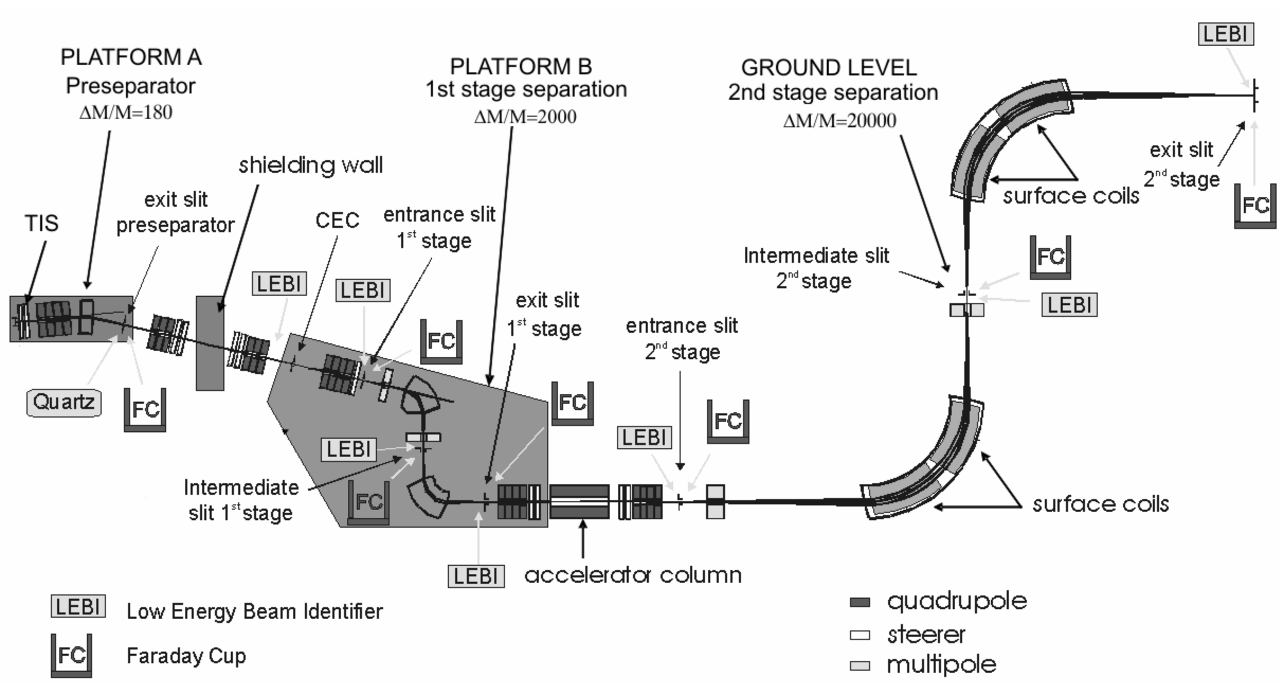

Fig. 2 – The layout of the isobaric mass separator

After some preliminary operation, aimed to find the correct setting of the electrostatic elements and of the dipoles, on June 2005 the first $^{8}Li^{+}$ beam was successfully produced and extracted. The primary beam of $^{13}C^{4+}$ (45MeV/amu) was provided by the K-800 Superconducting Cyclotron. A beam power of 18 W was delivered and focused on the Target Ion Source Assembly (TIS) to produce the radioactive atoms.

The TIS consisted on a 8.5 mm thick graphite (^{12}C) Target (see figure 5) on a tantalum container and a Positive Ion Source (PIS) both heated up to 2100 °C. The PIS, being a surface ionisation source, is highly selective and efficient for alkaline atoms.

The ^{8}Li beam was extracted at 25 keV from the TIS and transported through the two HV platforms, it was measured by mean of a LEBI device [6] which detects the ^{8}Li beta decay emission. Taking into account the LEBI detection efficiency and subtracting the background, the ^{8}Li production yield was of 3×10^{4} atoms/s. ^{8}Li beam was characterized stopping the beam by means of a valve. The LEBI counts have been then fitted with an exponential decay equation which half-live time resulted to be 0.84 s in perfect agreement with the expected value for ^{8}Li.

At the end of 2005 a similar procedure was followed to find the optimal settings for the 2nd stage separator (fig.2) and for the coupling line with the Tandem. A ^{7}Li beam generated locally in the EXCYT Target-Ion-Source assembly as positive ion and transformed in negative ion in the charge exchange cell was successfully injected and accelerated by the LNS 15 MV Tandem.

Different operating conditions of CEC have been explored, the charge exchange efficiency for the 25 keV Lithium beam was of 0.72 % as expected from the test at Oak Ridge Laboratory [5].

After the acceleration of the negative Lithium ions up to 150 KeV at the exit of the low activity platform, they was transported up to the Tandem entrance with an efficiency of 50%.

The first successful exotic beam production even with low yield and the commissioning of the whole facility with stable beams, permitted to focus our efforts in the maximization of the transport efficiency through the three stages of separation and through the coupling line with the tandem.

Moreover, since the CEC showed an increase of efficiency by decreasing the lithium beam energy (see figure 8), we decided to lower the TIS extraction voltage. The best operating point was found experimentally at 10 kV permitting to obtain higher CEC efficiency with negligible beam losses over the HV platforms with respect to higher Li beam energy. In these condition, on March 2006, we increased the ^{8}Li production measured on LEBI1 up to $5.5\cdot10^{5}$ pps.

Finally, in the last months, the increase of beam diagnostic reliability especially for the high energy ^{8}Li detectors (scintillating fibres and Si detectors), together with a meticulous campaign of debugging and checking of the electrostatic elements of the secondary beam transport devices with stable beams, permitted a strong increase of transmission efficiency as resumed by table 1.

There are still losses in the pre-separator and in the coupling line to the tandem which we are confident to still decrease matching the design calculations. The tandem transmission efficiency of 33% is strongly affected by the acceleration voltage. In this case we operated at the value of 7MV, lower values will strongly reduce the efficiency while higher operating voltage may increase this value up to 50-60%.

Table 1 – 7Li transport, charge exchange and post-acceleration efficiencies

From TIS to CEC $^{7}Li^{+}$	**CEC effic.** $^{7}Li^{+}\rightarrow{}^{7}Li^{-}$	**Through 1st stage sep.** $^{7}Li^{-}$	**Through 2nd stage sep.** $^{7}Li^{-}$	**Through Tandem coupling line** $^{7}Li^{-}$	**Through tandem** $^{7}Li^{3+}$
62%	2.7%	100%	100%	75%	33%

3 LOW ENERGY BEAM IMAGER/IDENTIFIER

LEBI (Low Energy Beam Imager/Identifier) is the diagnostic device designed in order to work in the EXCYT low energy (5-300 keV) beam line. It is able to visualize the 2D transversal profile of the beam and to measure its intensity down to the few particle regime. It can also identify the nuclear species composing the radioactive beam, by means of decay curve reconstruction, beta and gamma spectroscopy. LEBI is substantially composed of two components, that are used for the beam imaging and for the beam counting/ identification.

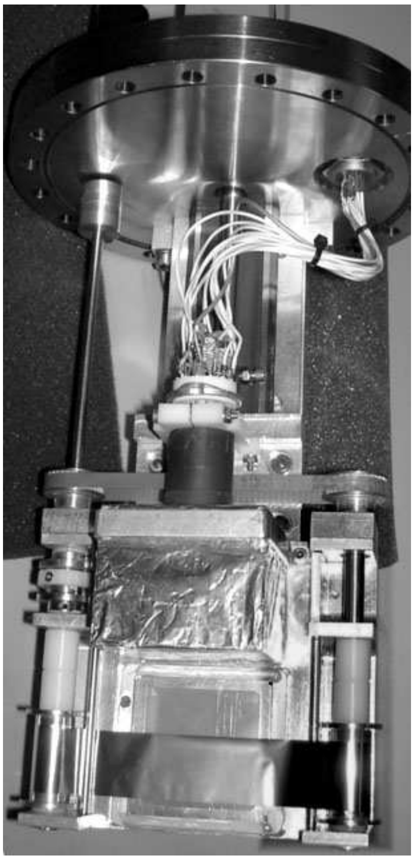

Fig. 3: The LEBI device

The first component is a thin scintillating screen made of CsI(Tl) watched by a high sensitivity CCD camera, the second is a plastic scintillator BC408 coupled with a small photomultiplier placed also inside the vacuum chamber and powered with an active voltage divider mounted outside. Moreover a couple of germanium detectors can be positioned at a relative angle of 90°, to detect possible gamma rays cascades bound to the radioactive decays. When LEBI has to be used for beam imaging, the CsI(Tl) screen is put along the beam line by means of a pneumatic actuator, in order to intercept the beam and thus producing a related light spot representing the 2D transversal profile. In order to avoid troubles due to the charge up on the surface of the screen that can alter the beam profile (because of the low kinetic energy of the incoming particles, the range of such beam is of the order of hundreds of nanometers), a grounded grid composed of very thin metallic wires is put in front of the screen itself. Contaminations due to the implantation of radioactive particles inside the screen, is prevented by using a very thin (6 μm) aluminized mylar tape covering a fraction of the screen surface, so that it can be wound by means of a step motor. The imaging of the stable beams is therefore performed when the beam hits directly the screen surface, while to visualize radioactive beams the screen is placed at a different height, so that the beam hits the mylar tape implanting inside it. In the latter case, the light spot is produced by the radiation emitted from the decay of the implanted radioactive ions (mainly β and γ rays), that cross the scintillating screen. The large plastic scintillator coupled to the photomultiplier is placed in the same holder containing the CsI(Tl) screen, so that to intercept the beam it is sufficient to change the position of the holder. It allows to measure the radioactive beam intensity and to identify the nuclear species, by means of beta spectroscopy and decay curve reconstruction, suitable to determine the end-point energy of the beta particles and the half-life time of the radioisotopes [6], [7]. Six LEBIs are installed along the low energy beam line (see figure 3).

4 TARGET ION SOURCE ASSEMBLY

Due to our beam line configuration the primary beam is impinging vertically to the TIS assembly, as described in the figure 4 The target is graphite made, it is supported in Ta container and it is heated by Joule effect by a surrounding heater.

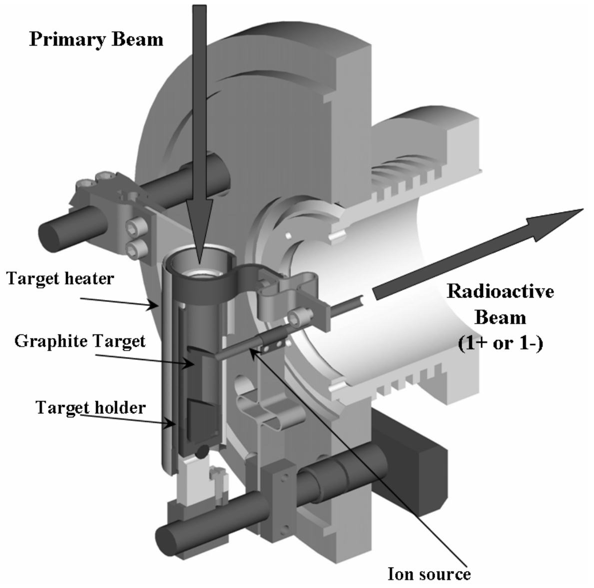

Fig. 4 : The TIS assembly.

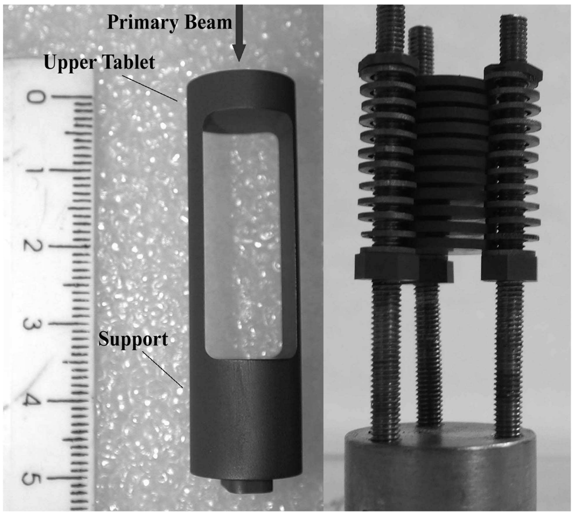

Fig. 5 : Targets, old version (left, MAR'06), new version (right, JUL'06).

The $^{8,\ 9}$Li particles collected from the target will effuse through the transfer tube to the ionizer, where they are ionized by a Positive Ion Source (PIS) and then extracted by an acceleration voltage of 10 kV. The beam is injected at 100 keV to the tandem after the isobaric mass separation. PIS is particularly suitable for alkaline ions for which it is highly selective and efficient. Our PIS off-line measurements indicate that Li^+ can be obtained with high ionization efficiency (> 70%) by means of a tungsten ionization tube.

The results of several ^{8}Li diffusion simulations, performed on the target structure suggest that only the ^{8}Li particles produced within the first hundreds of microns from the target surface are able to reach the surface before their decay, ^{8}Li atoms produced deeper will decay during their path inside the target never being collected. These considerations have triggered the decision to modify the target design by employing ten, uniformly spaced, 1 mm-thick, graphite disks (see fig. 5). An increase of a factor 6 on the ^{8}Li production yield was then expected.

Different type of ion sources can be chosen for the RNB ionization, they have been characterized off-line in terms of ionization efficiency. The most used are certainly the surface ionization sources whose main features are the high selectivity and efficiency. In these sources the atoms from the target get ionized hitting a hot surface. In this case the valence band is broadened overlapping the Fermi level, therefore electrons can move from the atom to the metal or vice versa depending on the electropositive or electronegative nature of the atom in relation with the work function of the metal surface. This means that:

- for positive ionization higher efficiencies can be obtained for species with low ionization potentials and high work function materials.
- for negative ionization high efficiencies are obtained for species with high electron affinity and low work function material [8].

The Positive Ion Source (PIS) is particularly suitable for alkaline ions, while the Negative Ion Source (NIS) is indicated for halogens with exception of fluorine. Other available ion-sources are the Hot Plasma Ion Source (HPIS), which is suitable to ionize positively many elements, included noble gases, with an efficiency of about 1%, and the Kinetic Ejection Negative Ion Source (KENIS) which is especially designed for fluorine ions for which an efficiency of about 5% is expected. The PIS has been employed for the EXCYT commissioning because our off-line measurements indicate that Li^+ can be obtained by means of this ioniser with very high ionisation efficiency (> 70%). Our PIS simply consisted of a tungsten tube. The ionization efficiency primarily depends on the work function of the metallic surface (4.5 eV for W). Rhenium and particularly iridium exhibit a higher work function (4.8 eV and 5.4 eV respectively) therefore they are good candidate to replace the W ionization tube. Since oxidized tungsten exhibit a very high work function (about 6.0 eV), a O_2 flow into the ioniser could be an excellent solution to improve the efficiency. A new ion-source prototype is ready for a test, where a tantalum ionization tube can be internally lined with a W, Re or Ir foil. We expect higher ionization efficiency from these tests.

5 FIRST BEAM DELIVERED TO USERS

The design of a new target assembly (see figure 5), together with an increase of primary beam power and the mentioned improvement of beam optics, made possible an increase of ^{8}Li production yield of more than one order of magnitude in a couple of months.

In table 2 a comparison of the results obtained is reported: all the production yields are measured by LEBI1.

These values are strongly satisfactory, the TIS extraction voltage employed was 10kV while the injection energy to the tandem was 100keV.

Table 2 – $^{8,9}Li$ production yields on LEBI1 (** ^{9}Li yield on July was measured while the yield efficiency was not at the maximum).

	Beam Energy	Beam Power	Target Temperature	8Li Production yield	9Li Production yield
March '06	45 MeV/u	75 W	2600 K	**5.5 10^5 pps**	**1.8 10^4 pps**
July '06	45 MeV/u	100 W	2600 K	**5.0 10^6 pps**	**6.2 10^4 pps ****
July '06	45 MeV/u	147 W	~2700 K	**9.0 10^6 pps**	not measured

Table 3 – ^{8}Li transport transport, charge exchange and post-acceleration efficiencies

CEC effic. $^{8}Li^{+}\rightarrow^{8}Li^{-}$	**Through 1st stage sep. $^{8}Li^{-}$**	**Through 2nd stage sep. $^{8}Li^{-}$**	**Through Tandem coupling line $^{8}Li^{-}$**	**Through tandem $^{8}Li^{3+}$**
3.4%	100%	90%	80%	10%

The CEC efficiency for ^{8}Li was 3.4%, very close to the expected theoretical value of 3.6% at 10keV. Table 3 reports the transmission efficiency for ^{8}Li beam up to the tandem entrance which are in good agreement with the ones obtained for ^{7}Li (see table 1).

The only remarkable difference was the anomalous decrease of the tandem acceleration efficiency with respect to stable beam operations down to 10%.

We believe that these beam losses are due to misalignments in the final part of tandem coupling line or in a not well tuned lens or steerer inside the accelerator itself. Further test are planned to overcome the problem and a new quadrupole quadruplets could be also installed just before the tandem to achieve a better focusing of the RIBs at terminal location.

The maximum ^{13}C primary beam intensity was 1 eμA which corresponds to a beam power of 147W leading to a production yield of 9×10^6 pps of ^{8}Li, after the CEC the yield was 3.2×10^5 pps.

During the operational days we experienced a continuous increasing of the production efficiency, probably due to the target-ioniser conditioning and loss of impurities from the target.

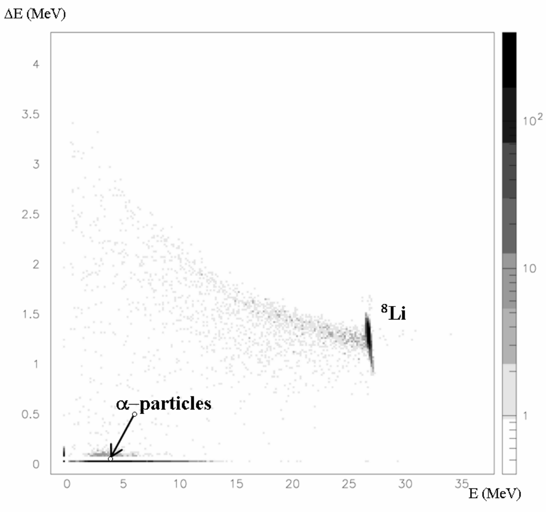

Fig. 6. ΔE-E matrix of ^{8}Li at E_{lab}= 28.1 MeV

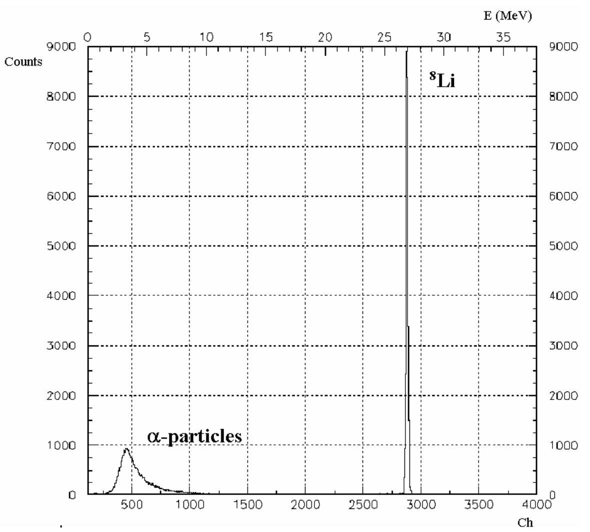

Fig. 7. Energy spectrum of E detector

Finally, on July 2006 the first EXCYT radioactive beam (^{8}Li) was injected in the 80° beam line of Laboratori Nazionali del Sud and there characterized in terms of purity and intensity. The secondary $^8Li^{1-}$ beam was post-accelerated by the Tandem to a final energy E_{lab}=28.1 MeV ($^8Li^{3+}$). The maximum ^{8}Li yield was about 9200 pps with a starting production of about 3.7 10^6 pps, the acceleration efficiency was even in this case about 10%. However, the users test required a maximum beam flux of 10^3 pps, therefore during the test the delivered beam intensity to the experimental cave was reduced to 800 pps.

The beam was analysed by using a *ΔE-E* silicon telescope (*ΔE* stage 7.9 μm, *E* stage 500 μm). Its energy was such that alpha particles coming from the decay of ^{8}Li, after implantation on the *E*-stage, could not escape from the detector. Fig. 6 shows the calibrated *ΔE-E* 2d-spectrum. No beam contamination shows up from the spectrum.

Energy spectrum recorded on the *E* detector (Fig. 7) clearly shows the two contributions coming from the ^{8}Li beam and the alpha particles produced by the decay of the implanted ions. Integrated yield and average energy of the alpha particle contribution are fully consistent with ^{8}Li decay properties.

6 CHARGE EXCHANGE CELL

The charge exchange cell (CEC) consists of a vacuum chamber containing cesium vapours at a variable temperature, in which Li^+ ions, extracted from the ion source, are transformed into negative ones by interaction with the Cs atoms. The CEC device and the efficiency measurement procedure have already been described [5]. The charge exchange consists on a two step process, the first of which is energetically supported (exothermic) while the second is not (endothermic), as described by the following formulae, where $E_i(X)$ is the ionization energy and $E_a(X)$ is the electron affinity of the X element.

$$Li^+ + Cs \rightarrow Li + Cs^+$$

$$\Delta E = E_i\,(Cs) - E_i\,(Li) = \\ = 3.89\ eV - 5.39\ eV = -1.5\ eV$$

$$Li + Cs \rightarrow Li^- + Cs^+$$

$$\Delta E = E_i\,(Cs) - E_a\,(Li) = \\ = 3.89\ eV - 0.62\ eV = 3.27\ eV$$

Cesium was chosen because of its low ionization energy, other elements, even alkalines, exhibit bigger values reducing the CEC efficiency. The CEC efficiency strongly depends on the energy of the Li^+ extracted from the TIS: the lower the Li energy the higher the CEC efficiency. It is foreseen a maximum by the adiabatic mass criterion [9] that in this case lies at about 5 keV.

The beam optics elements have been originally designed to operate at a minimum extraction energy of 15-20 keV. First beam transmission tests were performed at 25 keV, at this energy the CEC efficiency for ^{7}Li was very low: 0.72%. Strong effort was dedicated to improve the beam transmission at the lowest suitable RNB extraction energy. This value was fixed at 10 keV as a good compromise between a good transmission and CEC efficiency. The measure of the CEC efficiencies versus different ^{6,7}Li energies are reported in figure 8. Measurements were performed off-line at the HRBIF of the Oak Ridge National Laboratory [5]. Since the CEC efficiency depends on the ion velocity rather than on the ion energy in this figure 8 an isotopic shift effect is observable.

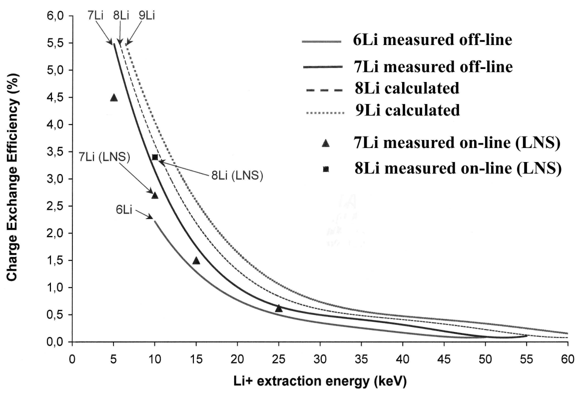

Figure 8 : Charge Exchange efficiency versus Li extraction energy

From these data it is possible to estimate the CEC efficiency for ^{8,9}Li ions. On-line measurements, during July '06, confirm the expectations. The CEC efficiency for ^{8}Li at 10 keV is 3.4%, very close to the expected value of 3.6%.

7 FUTURE DEVELOPMENTS

Due to the successful production and post-acceleration of ^{8}Li, the commissioning of the EXCYT facility is concluded. Further tests will be carried out to optimise the transport efficiencies in the pre-separator and mainly in the tandem coupling line, nevertheless we can start the experimental program already approved by the LNS PAC with ^{8}Li. The intensity will not be a limiting factor for these first experiments, however an R&D programme on TIS and ion sources is under way at LNS to enhance the production yields for Lithium, Oxygen, Chlorine and Fluorine. The increase of the primary beam power up to 500 W will also permit a further increase of the secondary beam.

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Questions:

?????: How are you going to improve transmission through the Pelletron?

Maurizio: We have several problems. Coupling the separator which has transmission of 70% at the moment, then we have this coupling line to the tandem and the tandem itself. We need to align better the last magnet of the coupling line. This is very critical because we don't have any detector here. We want to add some quadrupoles to focus better to the tandem.

David Weisser (ANU): Could you remind me what the injection energy is into the tandem?

Maurizio: The injection energy is 10 keV from the target ion source plus 100 keV from the platform.

Weisser: For sputter sources using tantalum ionizers, when the surface becomes contaminated, using platinum improves the performance substantially. Platinum has a very high electron affinity so I wonder if that might be another candidate for you to investigate.

Maurizio: But the problem with platinum is that it has a relatively low melting temperature. We operate the target ion source at 2600 Kelvin and the ionizer is really close to the target container. The temperature of the ionizer is about 1800 degrees centigrade. At this temperature, platinum will melt. Even iridium will be quite difficult.

Weisser: The Massey criterion that you talked about; that is some kind of a chemical calculation based on based on binding energy of electrons. If you use the lithium charge exchange with a lithium beam, wouldn't it cancel that and give you a higher cross section?

Maurizio: You mean with a lithium charge exchange with a lithium beam? If you go to the Massey criterion, then this value should be zero. We can not go lower than ten keV so it is better to have a material which has a maximum around ten keV. This is one answer. The other answer is that in this reaction, this is exothermic anyway. You have to put in the ionization energy of the lithium which is higher than that of caesium so this reaction has a maximum that goes in this direction but probably the efficiency at the end is lower. We didn't do any experiments with other materials but I hope that in the future we will be able to do some experiments with rubidium. According to the literature, if you use rubidium or sodium instead of caesium, you have a maximum that lies in this zone, but the efficiency is lower. But this is just theory. Did any of you do any experiments to show that rubidium is better that caesium? Maybe it's better for helium. Is there any theoretical reason why rubidium should work better, or is it just experimental evidence?

Greg Norton (NEC): The reason we use rubidium is strictly for the helium beam. In the helium beam, the helium minus is in a metastable state and I think that it is an entirely different situation than with the lithium. This is based on experimental evidence done at the University of Wisconsin back in 1980 and there is a paper that was published, I think, in IEEE that gives the charge state fraction for converting neutral helium to helium minus at various energies. It turns out that from a duoplasmatron, with a twenty keV helium beam, lithium is your best choice, but with an rf source at five keV, rubidium is your best choice. It depends on the energy of the beam coming into the charge exchange cell, what exchange medium you use. But this is all work for helium.

Martha Meigs(Oak Ridge National Laboratory): Do you have plans for a hot plasma ion source so that you could also provide low energy, positive ion beams?

Maurizio: We have tested once, but we have never coupled on-line to our ion source. Our next beam will probably be aluminum so in that case we cannot use a positive ion source so we will have to use a hot plasma source. In that case it is interesting to use that beam not only for nuclear physics, but also at one or two hundred keV using just the platform energy to do some solid state physics experiments. We will accelerate the aluminum beams as aluminum fluoride.

End of questions

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

EXCYT (EXotics with Cyclotron and Tandem): Exotic beam production, detection and charge exchange

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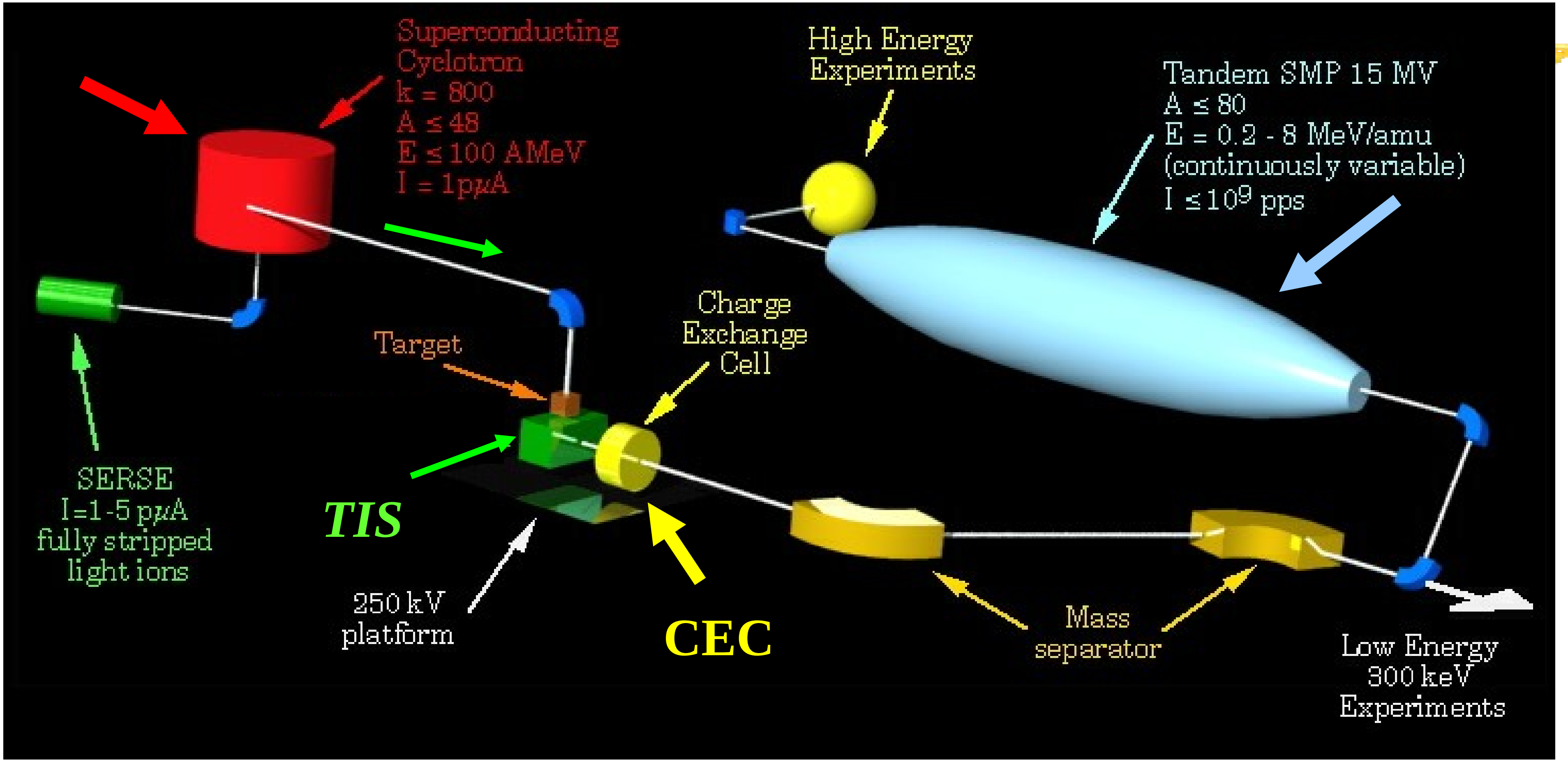
Facility Layout



Maximun Energy: 2.5 ÷ 150 MeV (***preacceleration energy up to 300 keV***)

Low emittance (<0.5 π mm.mrad): clear-cut beam spot e low angular spread

Easy variable beam energy (excitation function study)

***Low energy spread:* ΔE/E = 10^{-4}.**

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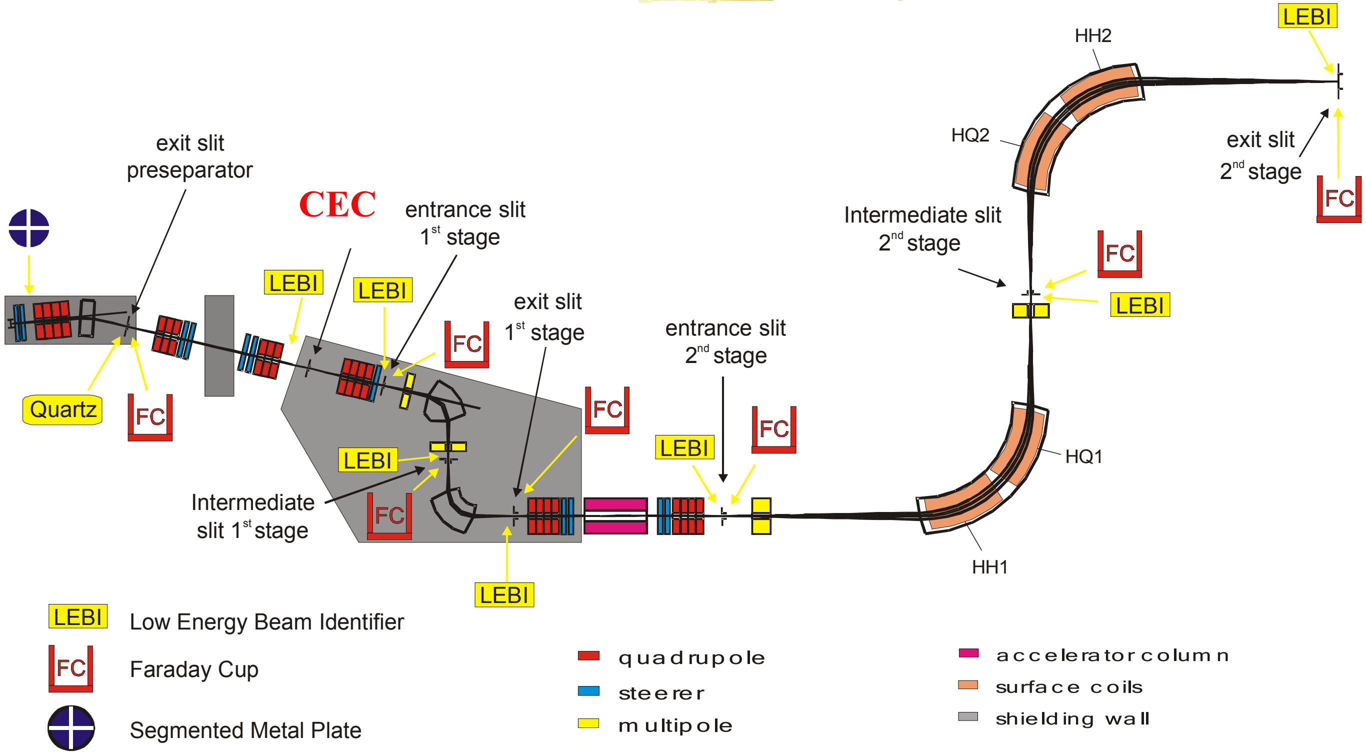
Isobaric mass separator



The mass separator system consists on 2 stages, the first stage on two platforms at High Voltage (up to 250 kV).
The design transmision efficiency is ~ 100% with a beam of $\varepsilon_x=\varepsilon_y=4\pi$ mm mrad ($x_0=y_0=\pm0.2$ mm, $a_0=b_0=\pm0.2$ mm).

The mass resolution of each step is:

$(\Delta M/M)_{Pre} \approx 180$ (**Pre-separator** : 18° magnet and a set of 4 electrostatic quadrupoles)

$(\Delta M/M)_{1st} \approx 2000$ (**I stage**: 2 magnets (77° e 90°) and 2 sets of 4 electrostatic quadrupoles)

$(\Delta M/M)_{2nd} \approx 20000$ (**II stage**: 2 magnets (90°, ρ=2.6 m) and a set of 4 electrostatic quadrupoles)

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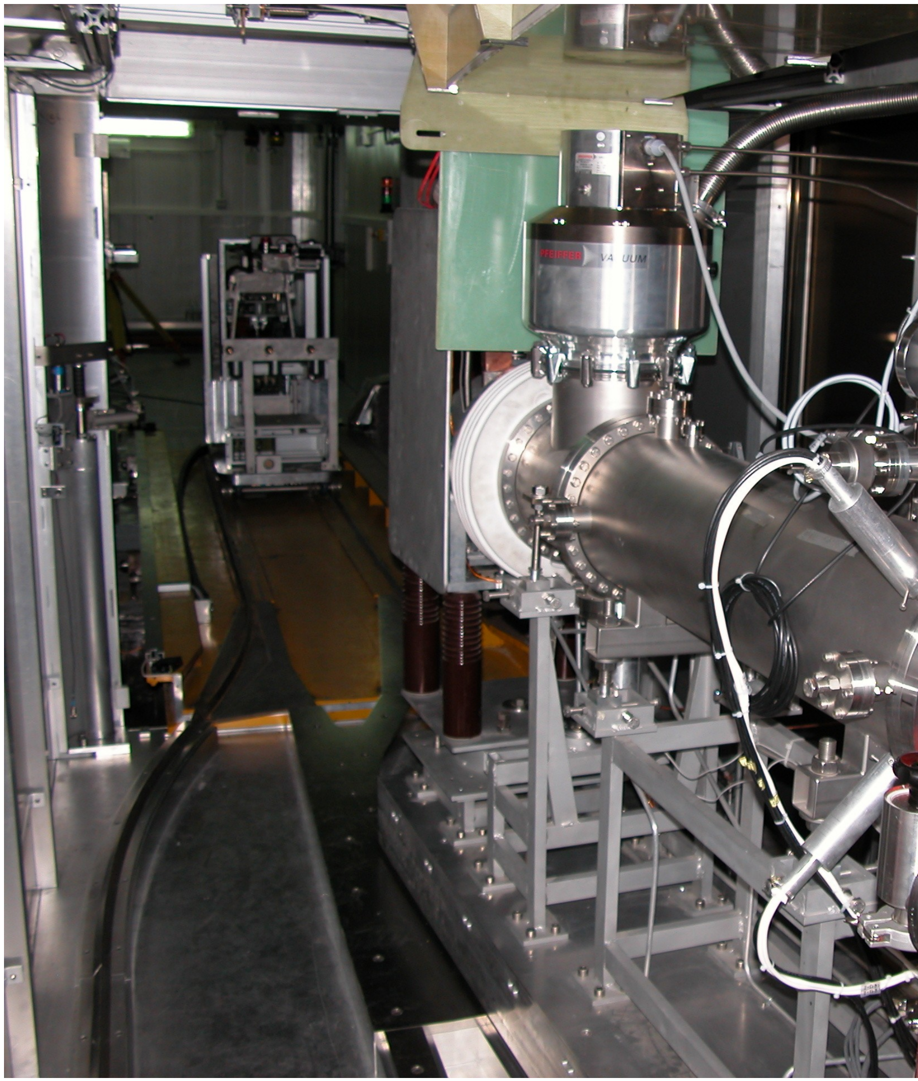
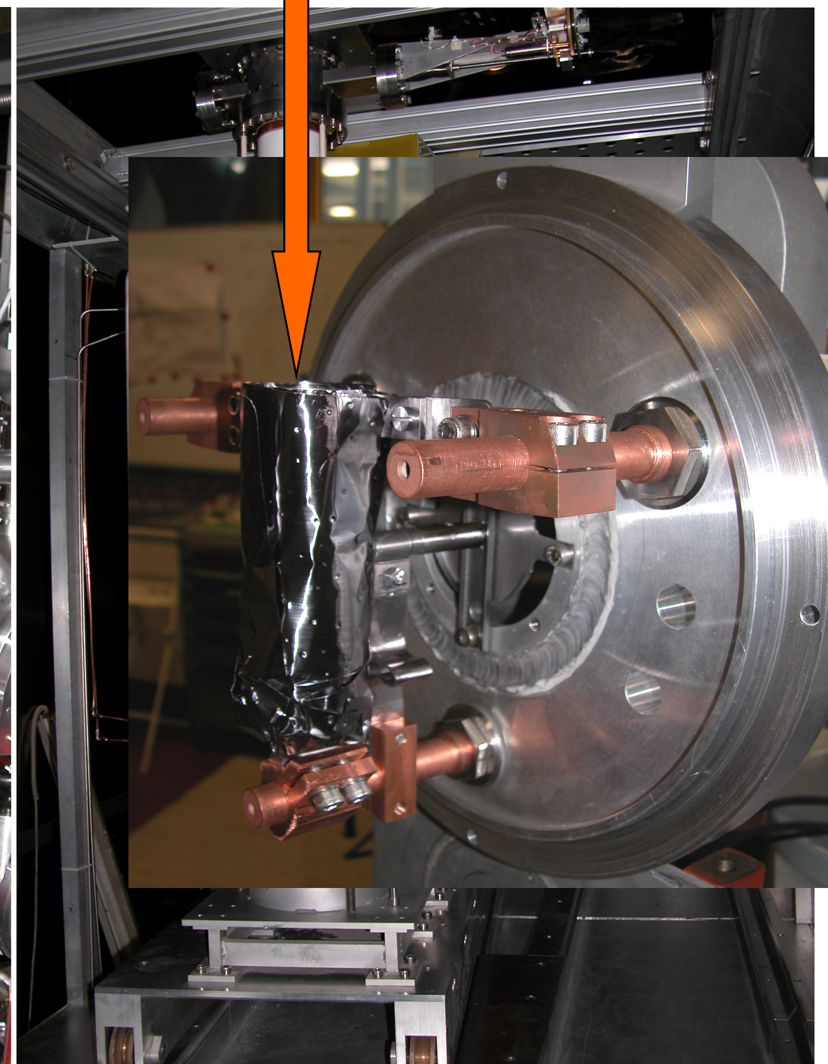
Pre-separator





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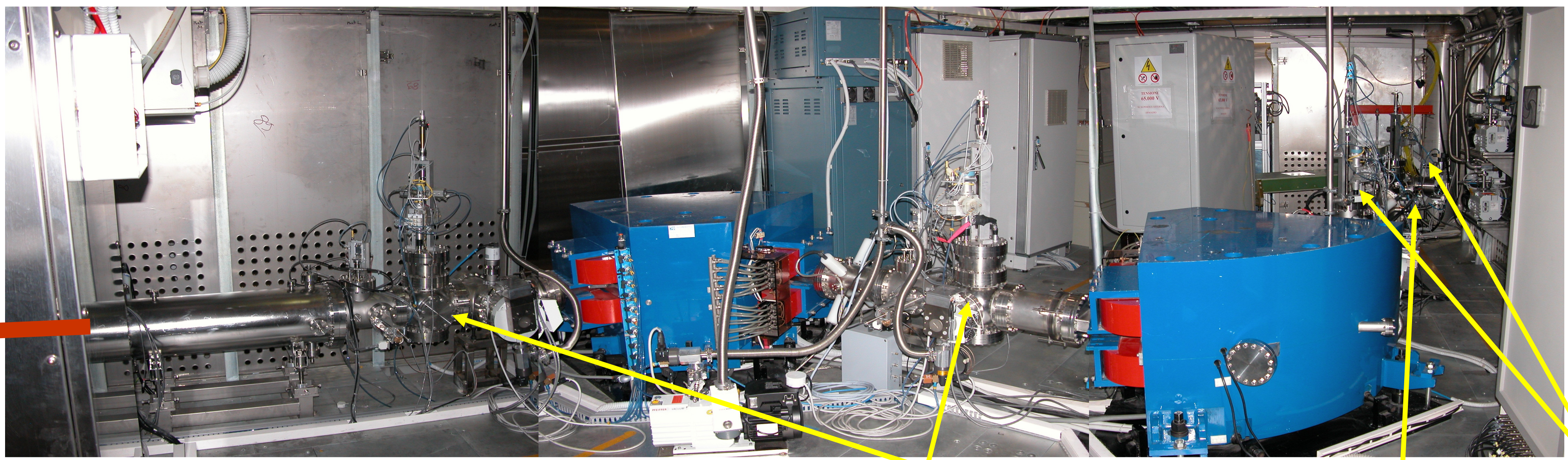
First stage of the isobaric mass separator (platform B)



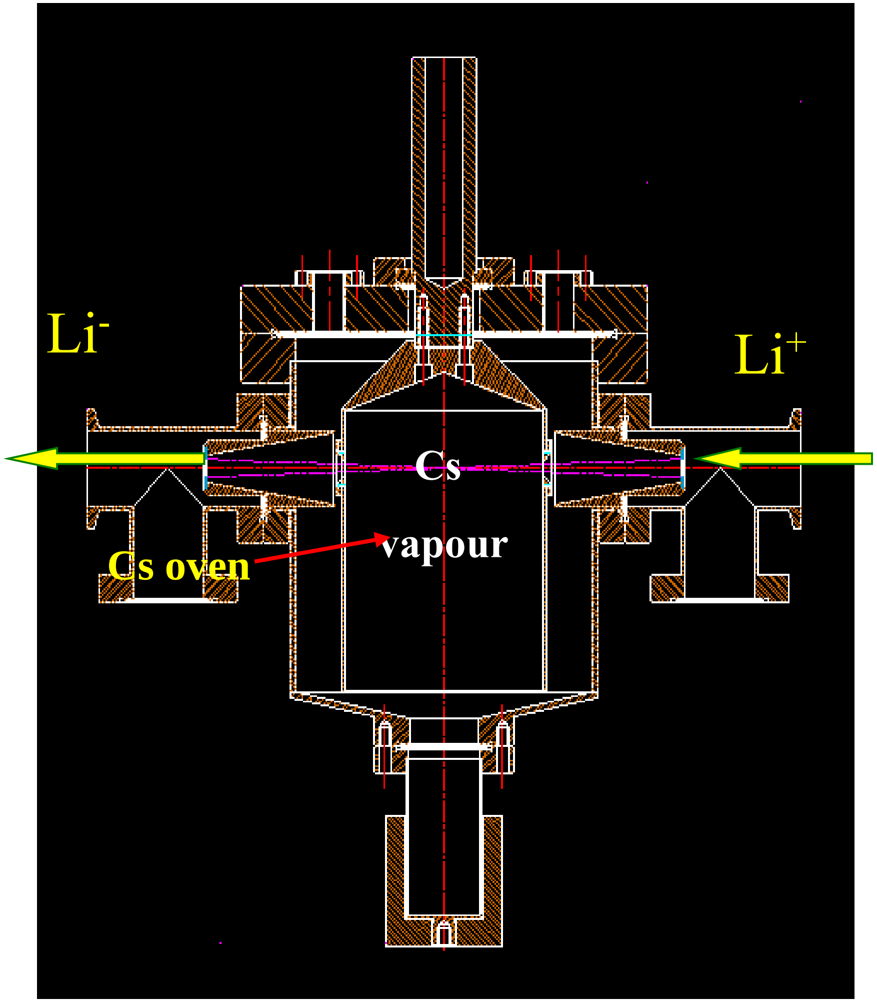
To second stage separator

LEBI

CEC

LEBI

Charge-exchange cell



@10 keV 7Li- Eff=2.7%
@10 keV 8Li- Eff=3.4%

@5 keV 7Li- Eff=4.5%
@5 keV 8Li- Eff=5.5%

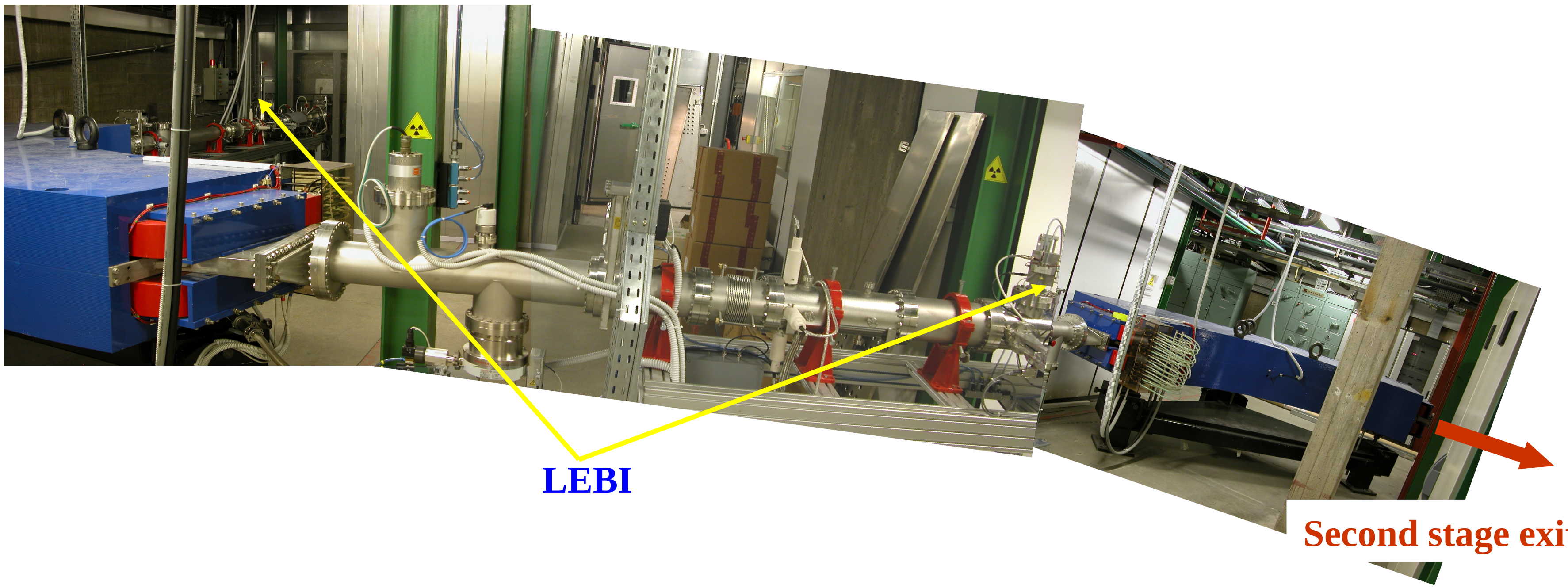
$$Li^{+} + Cs \rightarrow Li + Cs^{+}$$

$$\Delta E = E_i(Cs) - E_i(Li) = 3.89eV - 5.39eV = -1.5eV$$

$$Li + Cs \rightarrow Li^{-} + Cs^{+}$$

$$\Delta E = E_i(Cs) - E_a(Li) = 3.89eV - 0.62eV = 3.27eV$$

Second stage of the isobaric mass separator (at ground)



Beam lines to the Tandem

TANDEM

Experimental rooms

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Commissioning of the facility

Phase 1: Preliminary commissioning of magnetic and electrostatic elements over the two HV platforms with stable positive 6Li+ , 7Li+ beams (JAN'05)

Phase 2: First production of 8Li+, 9Li+ (JUN'05).

Phase 3: Commissioning of the whole facility with stable Li beam (DEC'05).

Phase 4: Transport of 8Li- through the mass separator, injection and acceleration at the Tandem (MAR'06)

Phase 5: First 8Li delivered to experimental apparatus (JUL'06) + Current experiment (OCT '06)

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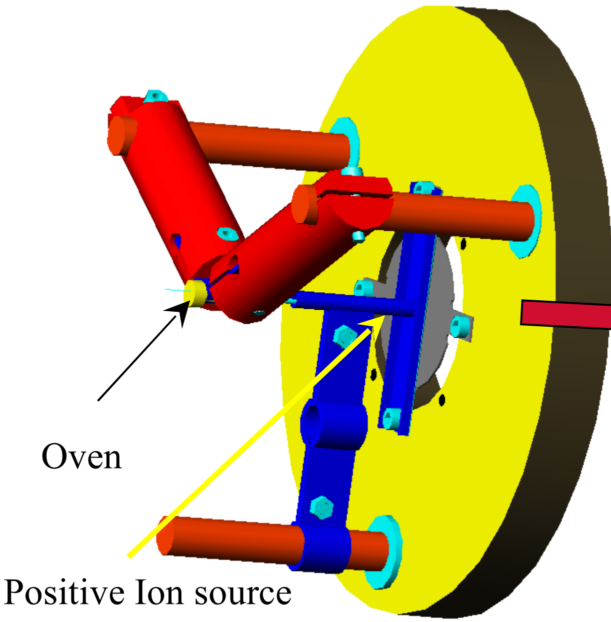
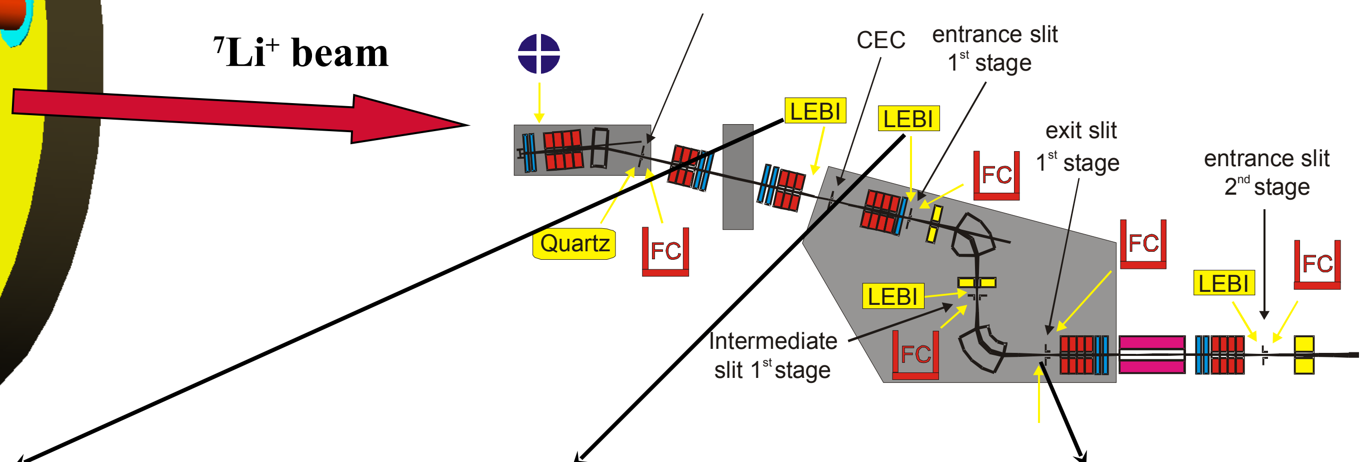
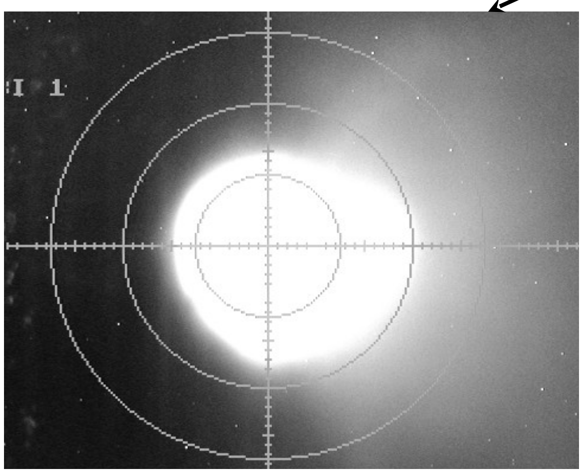
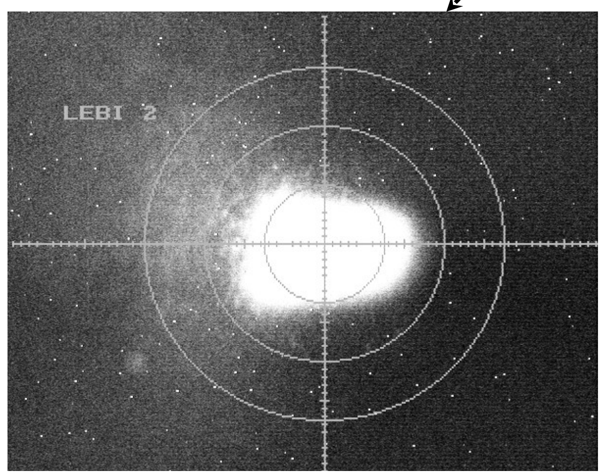
Platforms Commissioning with stable beam (May '05)

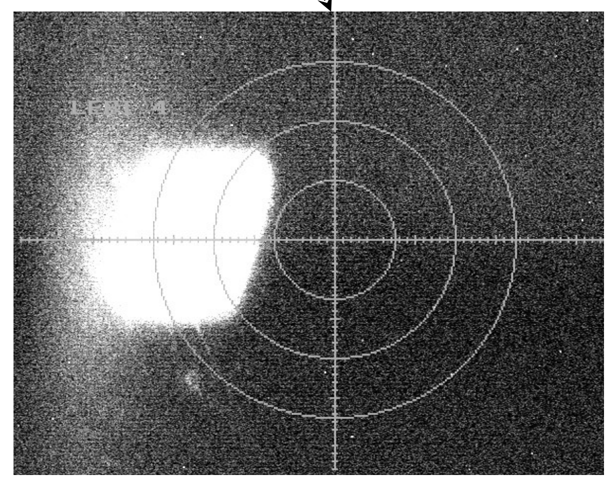
$^7Li^+$ generated onto the TIS, transported @25 keV through the platforms with high transmission efficiency (87%).











Target-Ion Source

Total RIB Production yield :

-Primary ion beam intensity and energy

-Cross-section of production

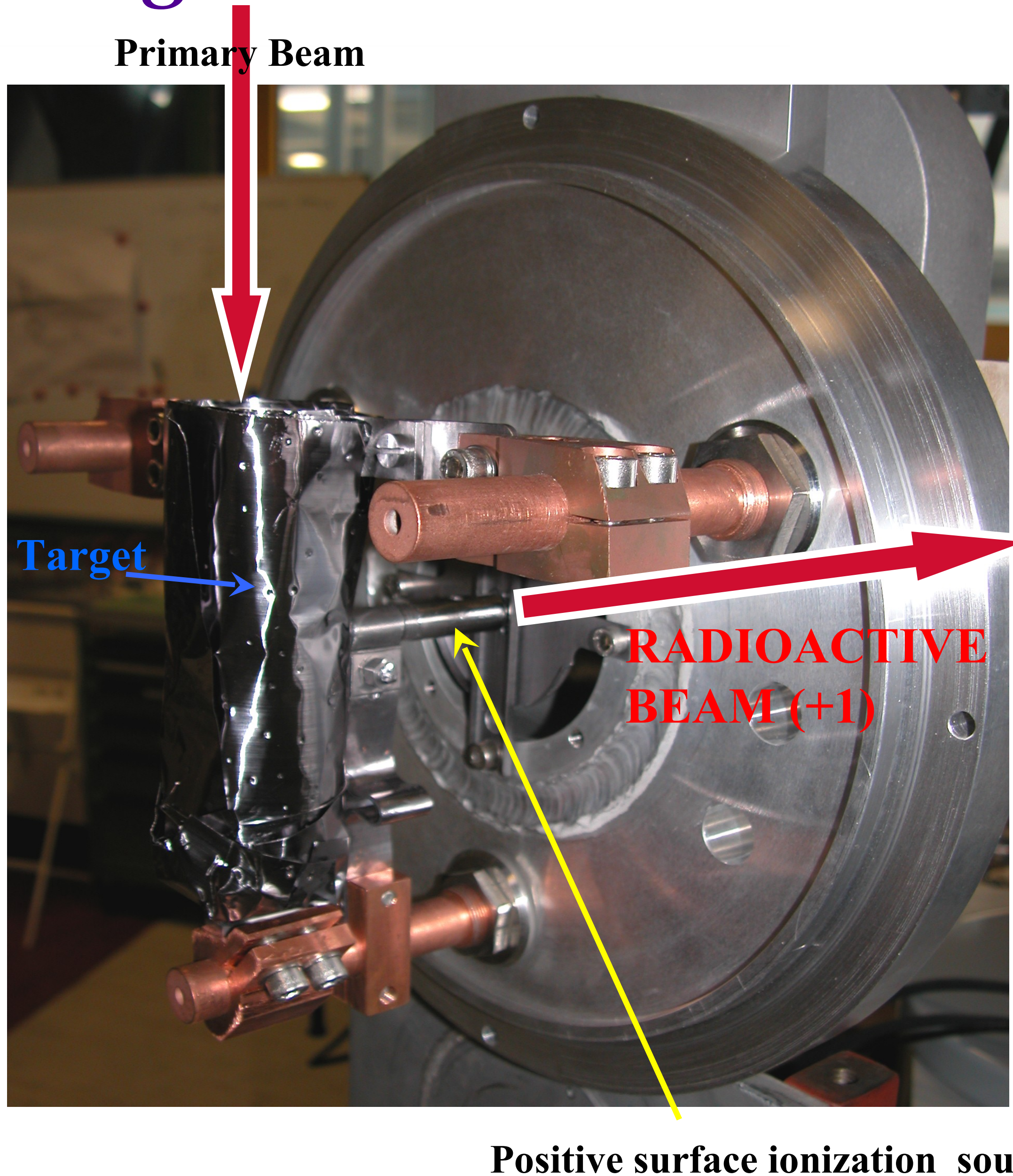
-Diffusion through the target bulk

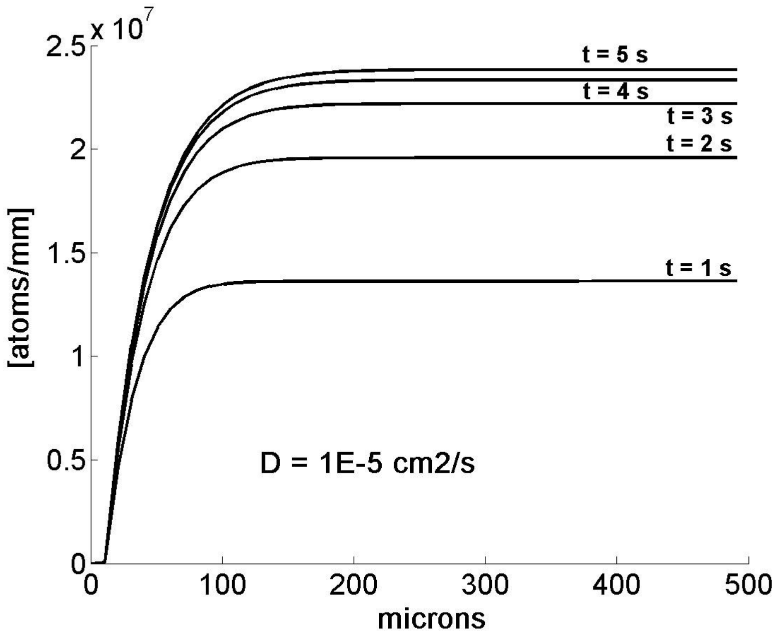
-Effusion to ionizer

-Ionisation efficiency

-Charge exchange efficiency

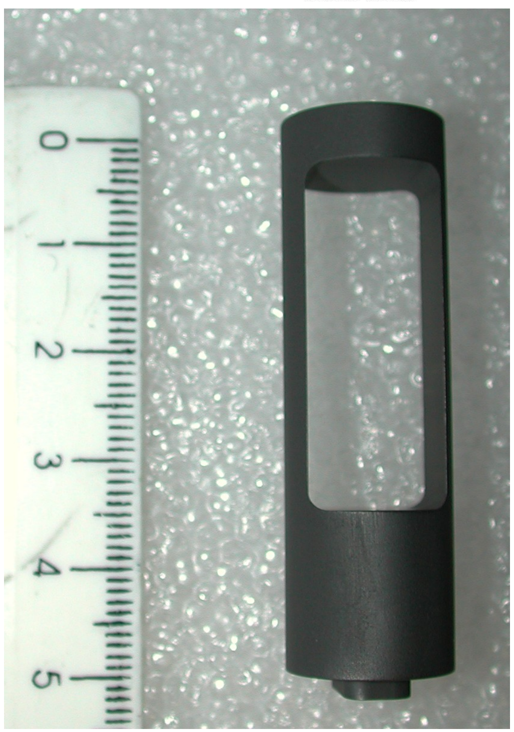
-Transport, Separation and Post-acceleration efficiency

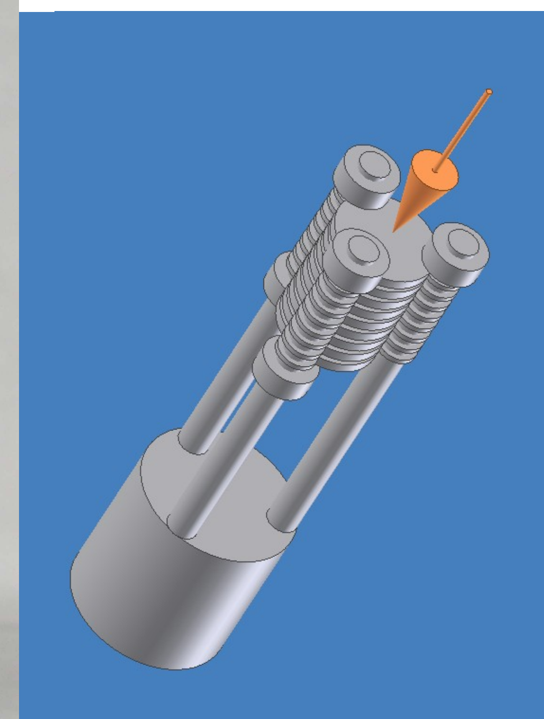




8Li concentration plot versus time, near the target surface

TARGET material UTR146 graphite





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Beam Production Yields

Beam Energy	Beam Power	Max Target Temperature	8Li Production yield	8Li production efficiency	9Li Production yield	9Li production efficiency
LNS $^{8,9}Li^{+}$ production (MARCH 06)						
45 MeV/u	75 W	2600 K	**$5.5\ 10^{5}$ pps**	**0.22%**	**$1.8\ 10^{4}$ pps**	**0.05%**
LNS $^{8,9}Li^{+}$ p Factor 7.3 **n (JULY 06)**						
45 MeV/u	100 W	2600 K	**$5.0\ 10^{6}$ pps**	**1.6%**	**$6.2\ 10^{4}$ pps**	**0.15%**

Beam transport enhancement : factor 2

New target contribution : factor 3.6

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Ion sources

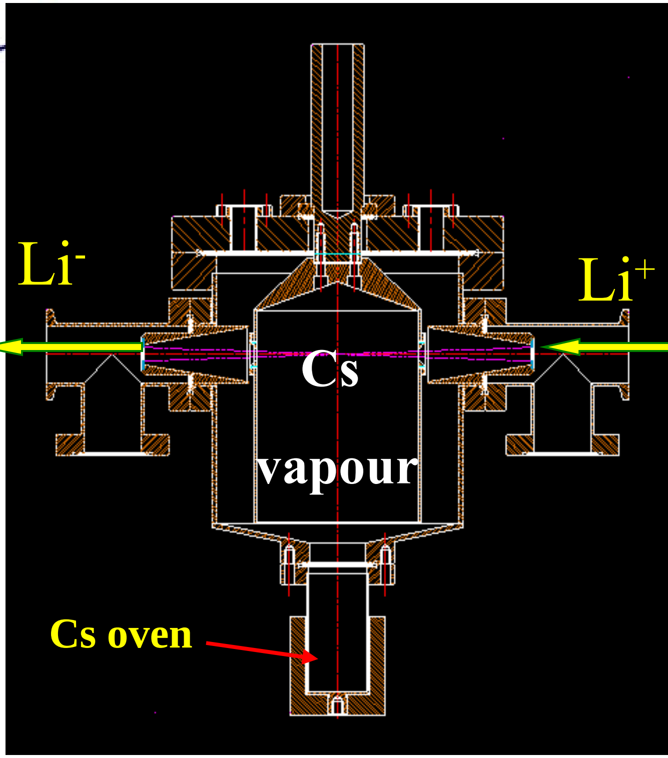
- PIS : Positive Ion Source by surface ionisation.
  Off-line measured efficiency for ^{7}Li: 70-75%.
  Suitable for alcalines (Li, Na, K …).
  Now in operation Tungsten. Next : Rhenium or Iridium

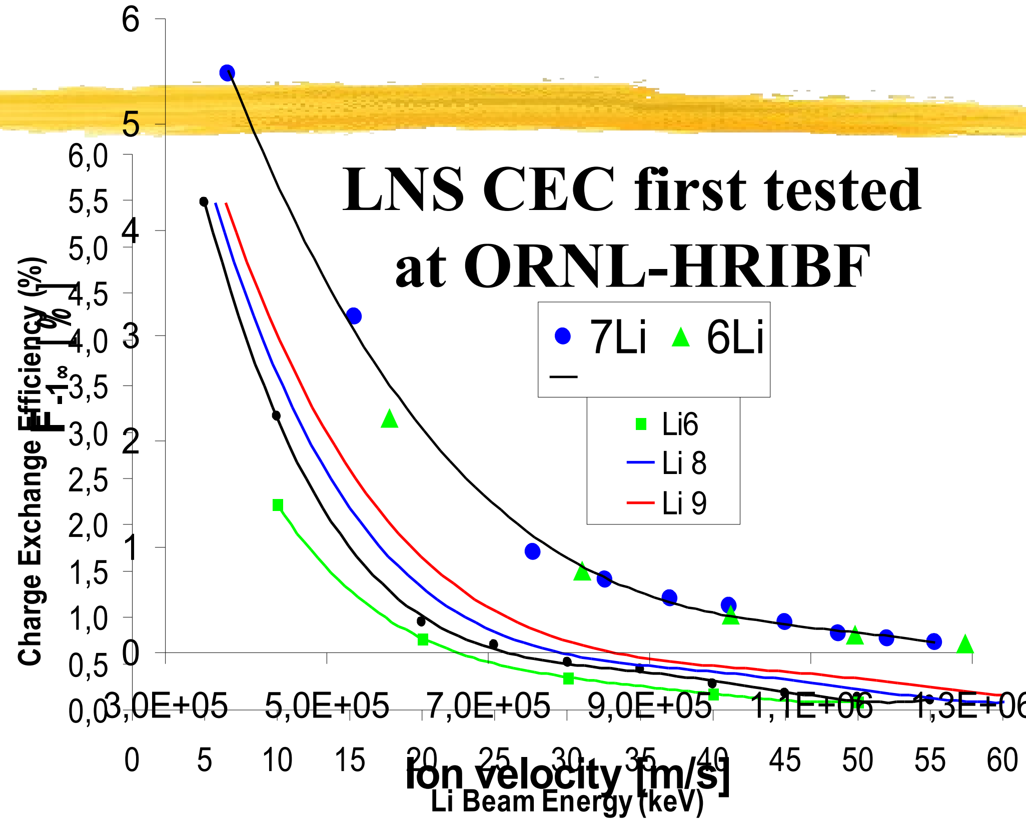
- HPIS : Hot Plasma Ion Source.
  Measured efficiency for ^{22}Ne and ^{40}Ar: ~ 1%
  Suitable for noble gas or any other element

- NIS : Negative Ion Source by surface ionisation.
  Expected efficiency: 40%
  Suitable for halogens (Cl , Br ..) with the exception of F

- KENIS: Kinetic Ejection Negative Ion Source
  Expected efficiency 5%
  Alternative to NIS for F

Charge-exchange cell





$$Li^{+} + Cs \rightarrow Li + Cs^{+}$$

$$\Delta E = E_i(Cs) - E_i(Li) = 3.89eV - 5.39eV = -1.5eV$$

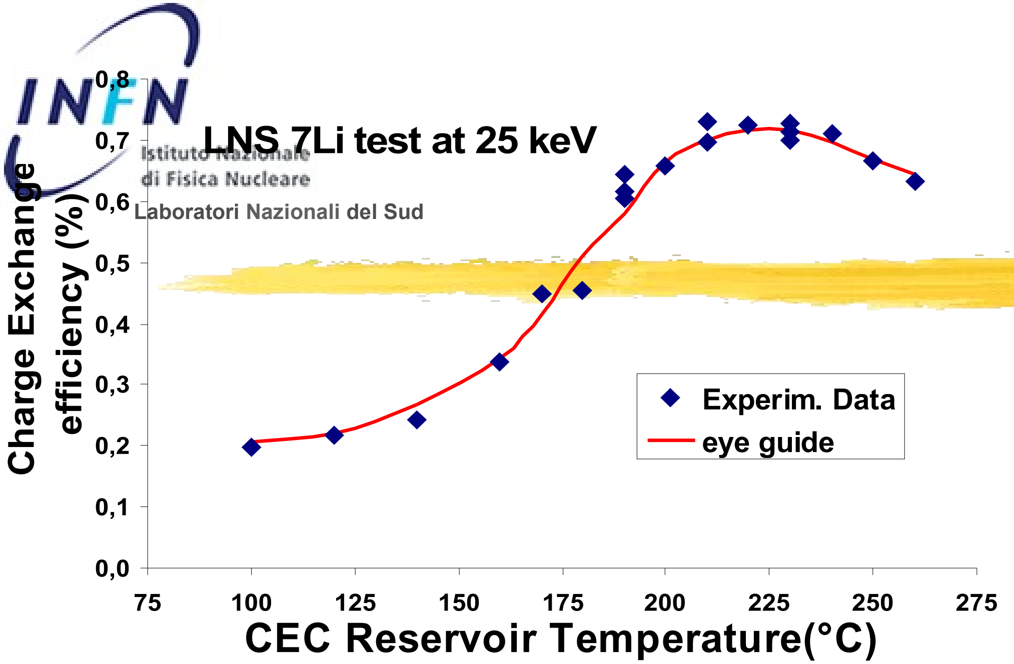
$$Li + Cs \rightarrow Li^{-} + Cs^{+}$$

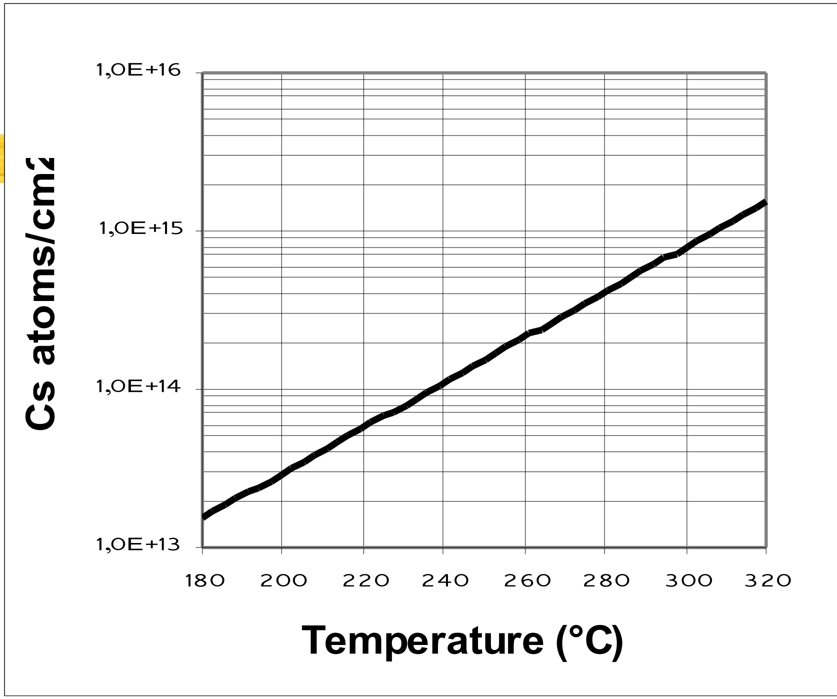
$$\Delta E = E_i(Cs) - E_a(Li) = 3.89eV - 0.62eV = 3.27eV$$

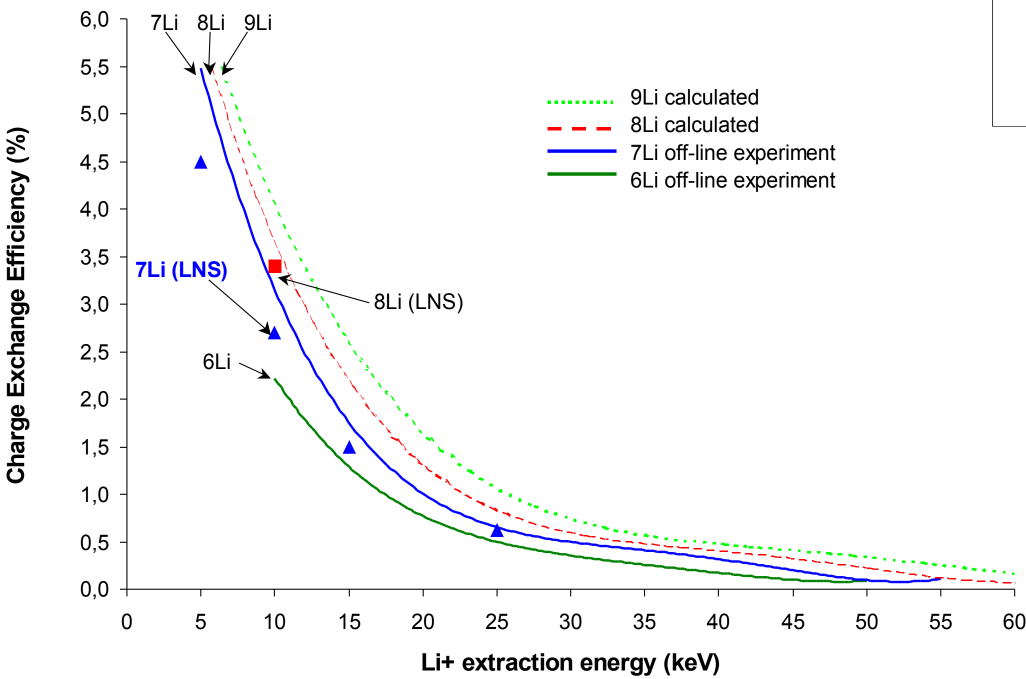
$$E_{MAX} = \frac{m}{2}\left(\frac{a \cdot \Delta E}{h}\right)^2$$

Adiabatic Massey criterion

Emax= 5keV







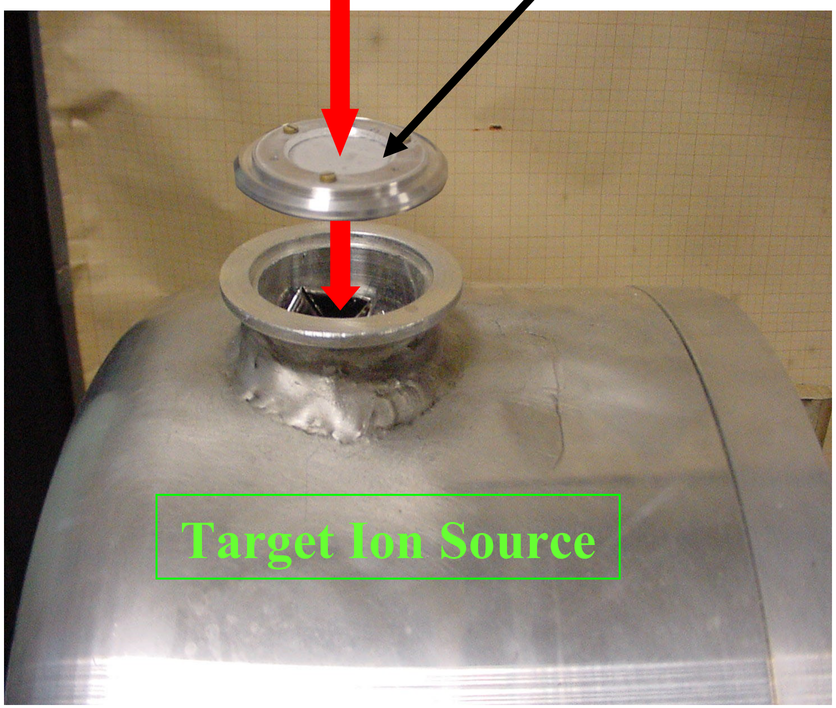
@10 keV 7Li- Eff=2.7%
@10 keV 8Li- Eff=3.4%

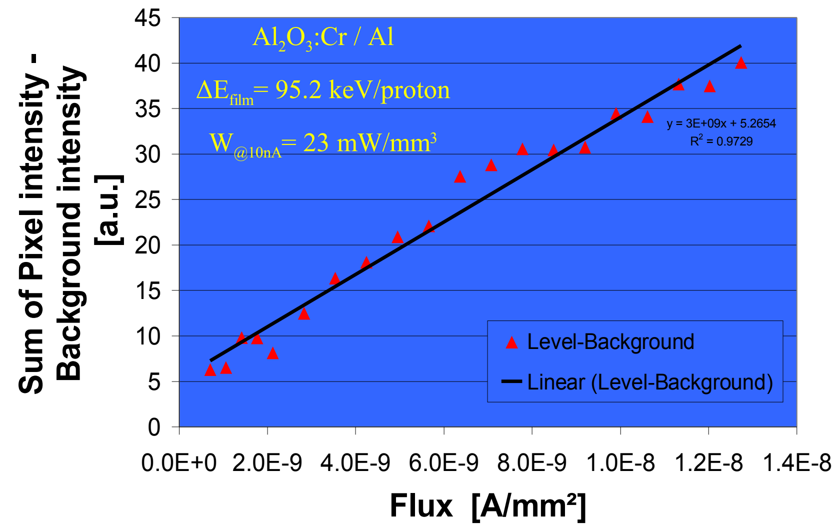
@5 keV 7Li- Eff=4.5%
@5 keV 8Li- Eff=5.5%

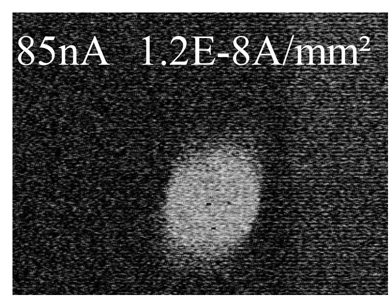
Primary Beam Detector

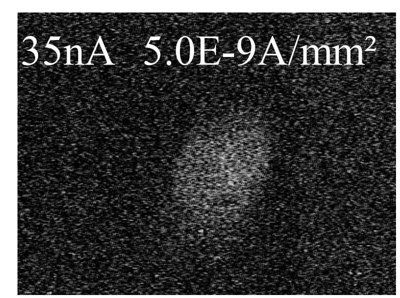
Primary BEAM

2µm Al_2O_3:Cr on a 6µm Al subtrate









Off-line test with 8.3 MeV protons

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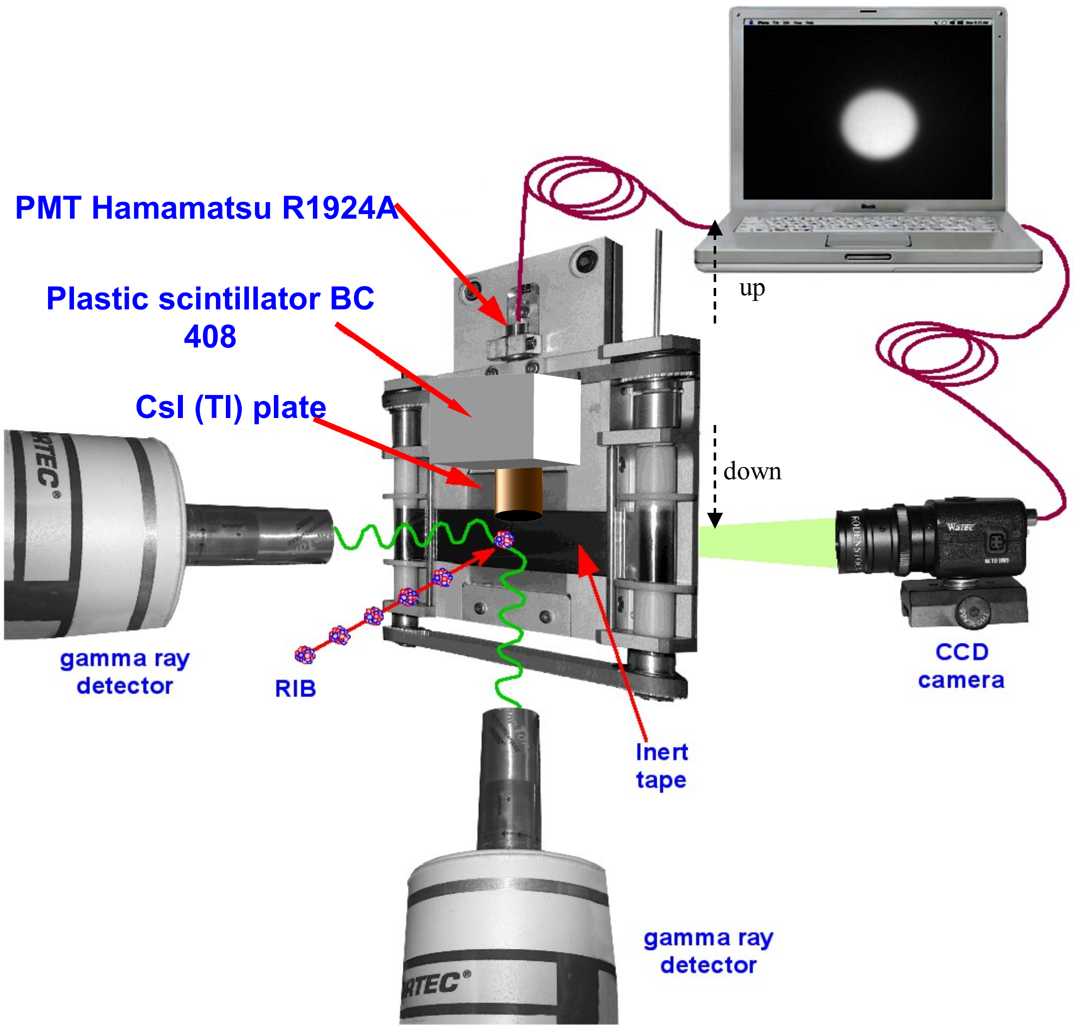
Diagnostics for Low Energy RIBs

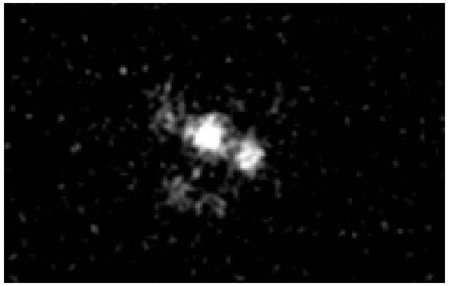
LEBI: Low Energy Beam Imager / Identifier



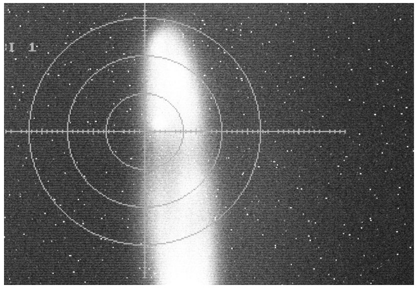
Based on a CsI(TI) 1÷2mm thick and on a plastic scintillator, LEBI is our solution for beam diagnostics of low energy radioactive beams (tens of keV).

LEBI: Low Energy Beam Imager / Identifier

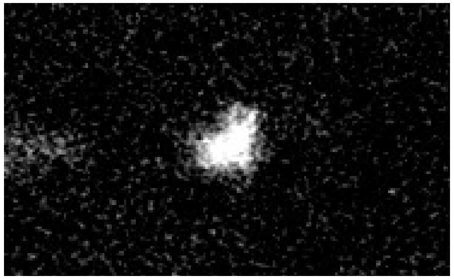
Protons
Current: 0.03 pA
Energy: 170 keV



Lithium
Current: ~ 1nA
Energy: 15 keV



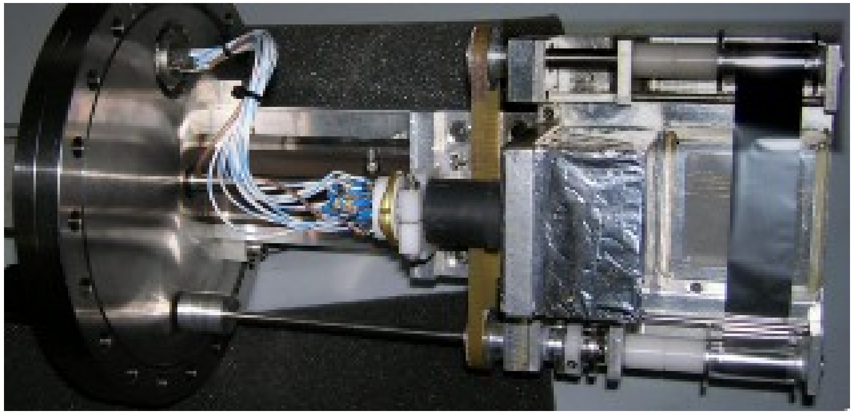
Oxigen
Current: a few pA
Energy: 50 keV

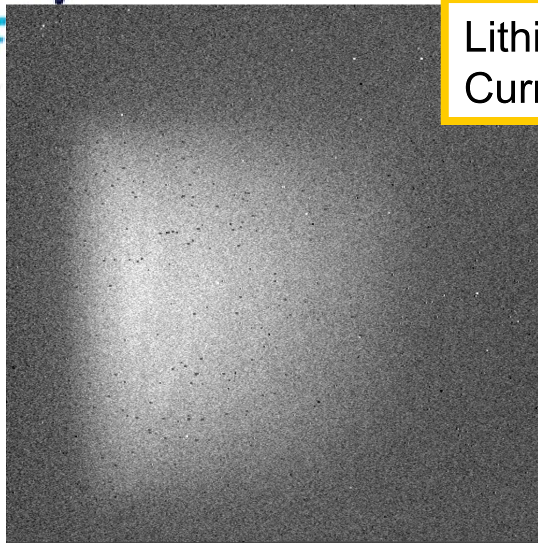


Stable beams

- **spatial resolution** is of the order of the plate thickness (about 1 mm)
- **minimum detected current** is $10^{4 \div 5}$ pps/mm^2

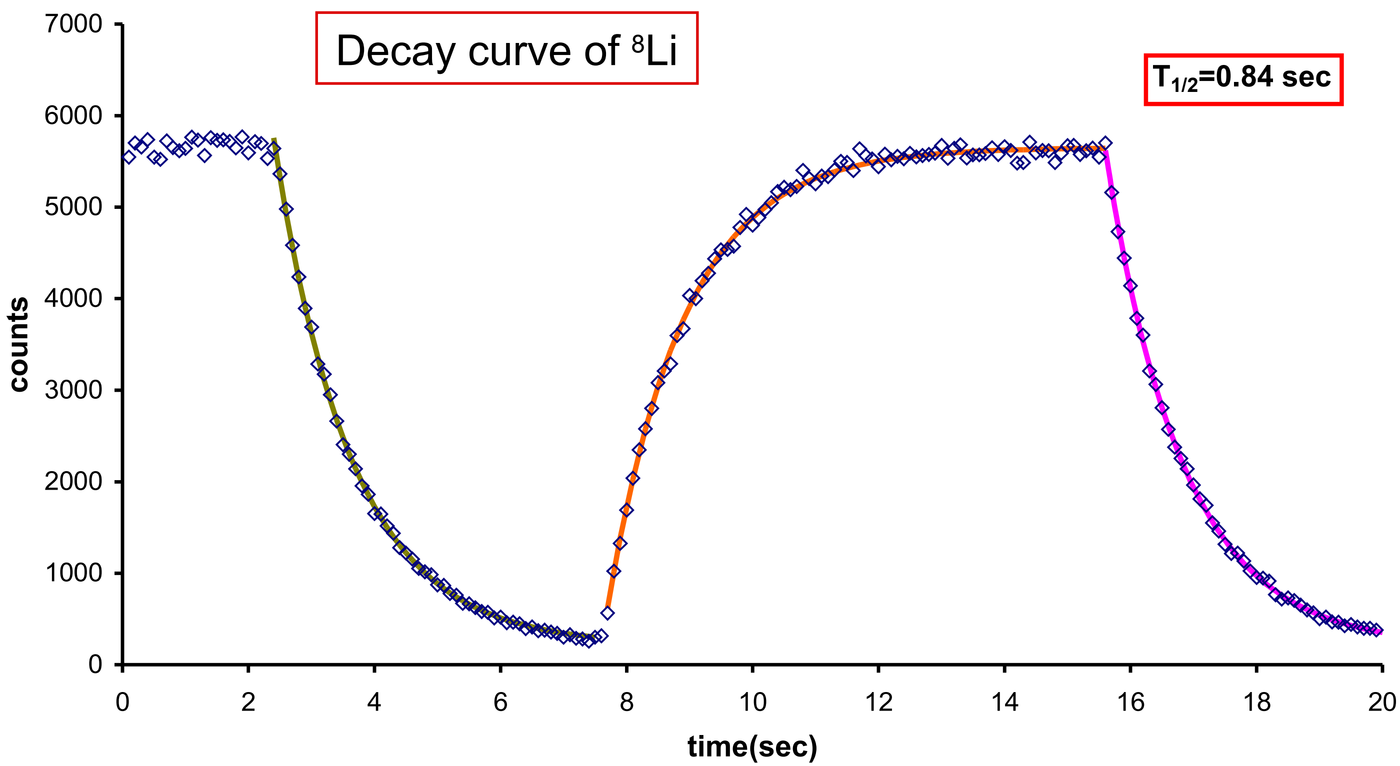
L.Cosentino, P.Finocchiaro, **NIM B 211 (2003)443-446**





Lithium 8
Current: ~ 10^6 pps

Radioactive beam



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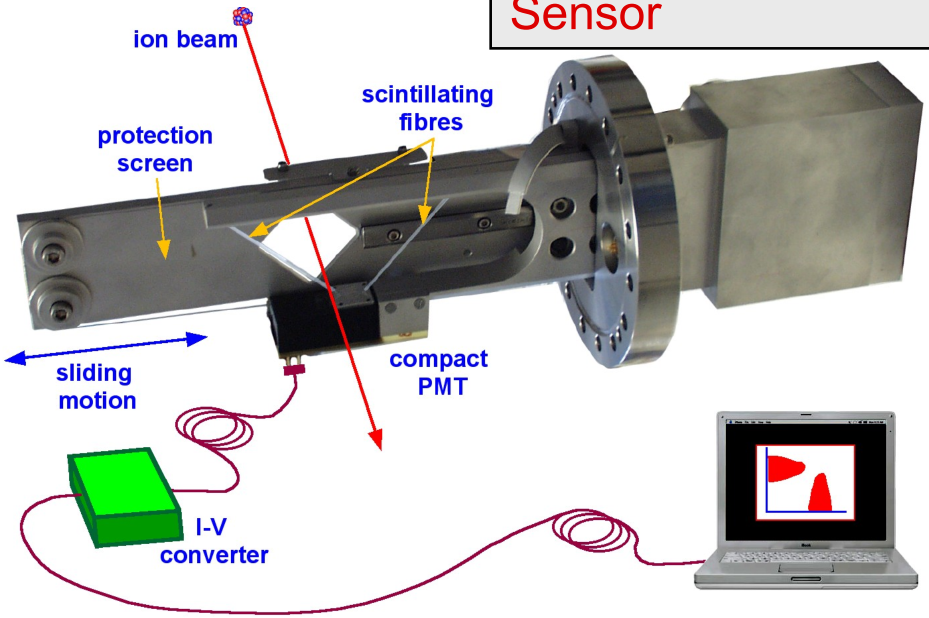
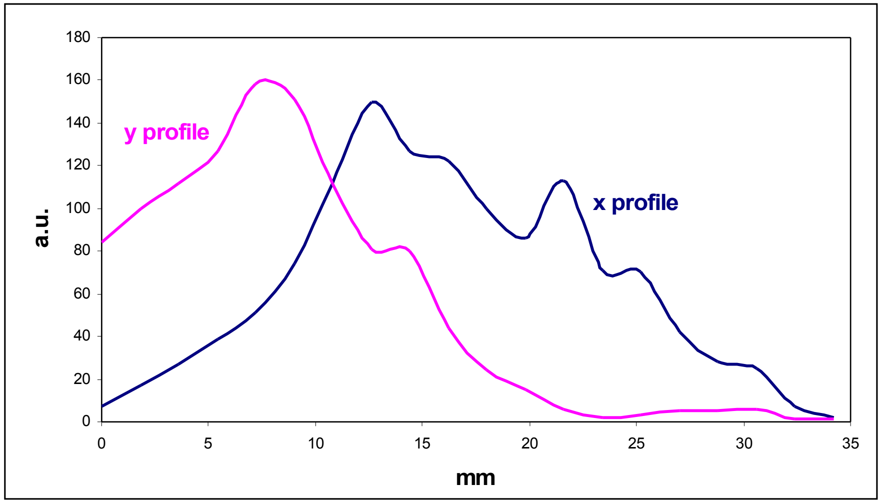
Diagnostics for High Energy RIBs

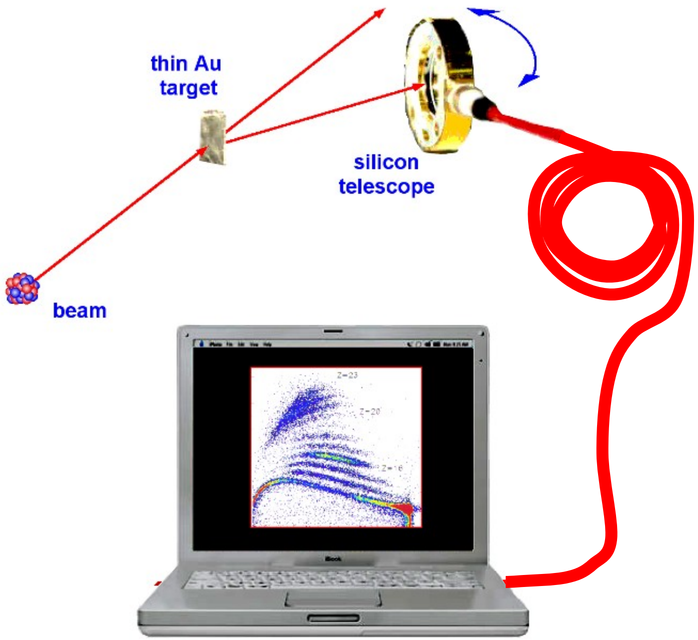
GFIBBS – Glass Fibre Based Beam Sensor





The Glass FIbre Based Beam Sensor (GFIBBS) represents our general solution for beam profiling, since we proved it is reliable, cheap and simple. It is based on a pair of glass or plastic scintillating fibres scanning the beam. The two fibres are mutually perpendicular and are readout by means of a single compact PMT. It allows to reconstruct the X and Y beam profiles in a single scan with high efficiency. Plastic fibres are used when counting of particles has to be performed. Lower detection limit is 1E3 pps

Diagnostics for High Energy RIBs



Accelerated ions identification is perfomed by means of a high resolution silicon telescope. The capability of this system to identify the nuclei with high efficiency, allows to determine the nuclear species present in the beam. The telescope can be accurately positioned around a target (typically gold), placed along the beam line, in order to intercept the scattered ions. The angle where the telescope must be placed is chosen as a function of the expected ions and of their energy, in order to have an intensity not larger than 10^4 particles per second on the telescope, thus preventing a quick detector damage.

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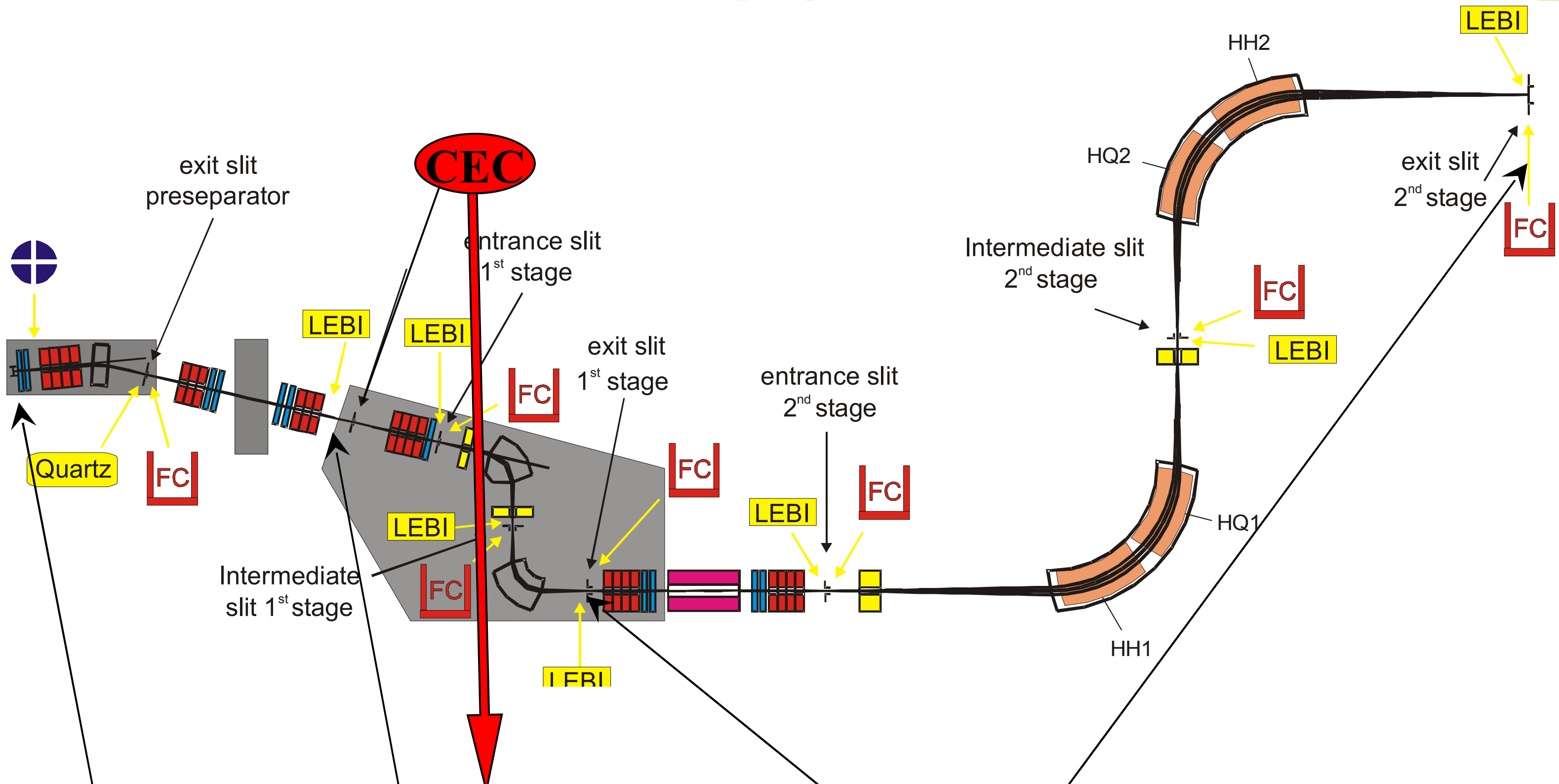
Transmission and CEC efficiencies for ^{8}Li beam



From TIS to CEC $^8Li^+$	CEC effic. $^8Li^+ \rightarrow {}^8Li^-$	Through 1st stage sep. $^8Li^-$	Through 2nd stage sep. $^8Li^-$	Through Tandem coupling line $^8Li^-$	Through tandem $^8Li^{3+}$
70%	3.4%	100%	90%	80%	10%

Operating parameters: V_{extr}= 10 kV, V_{acc}= 100 kV, V_0=7 MV

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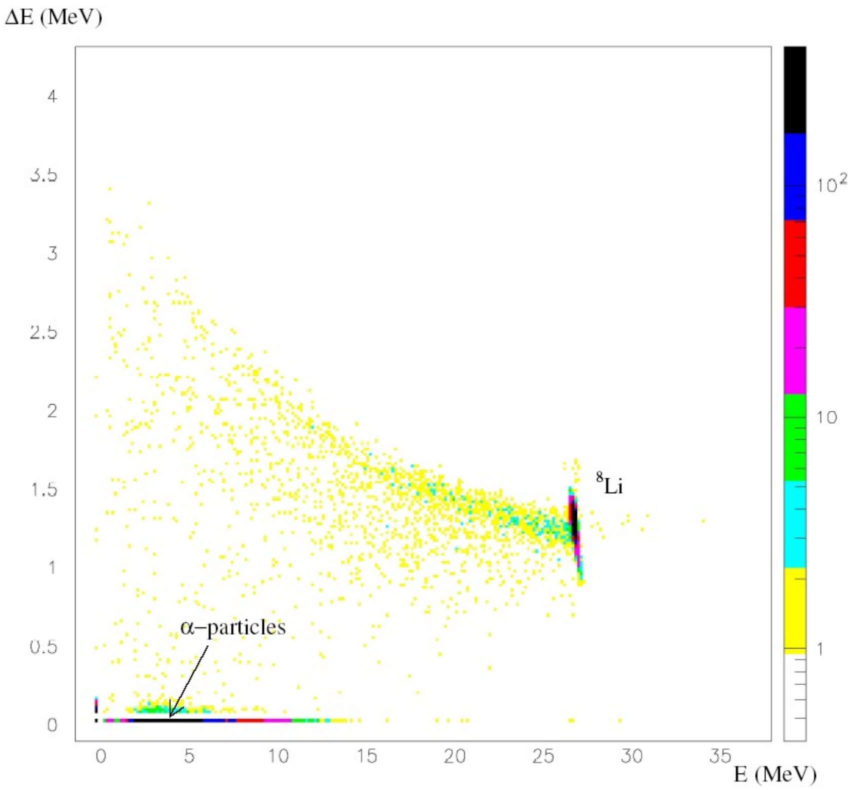
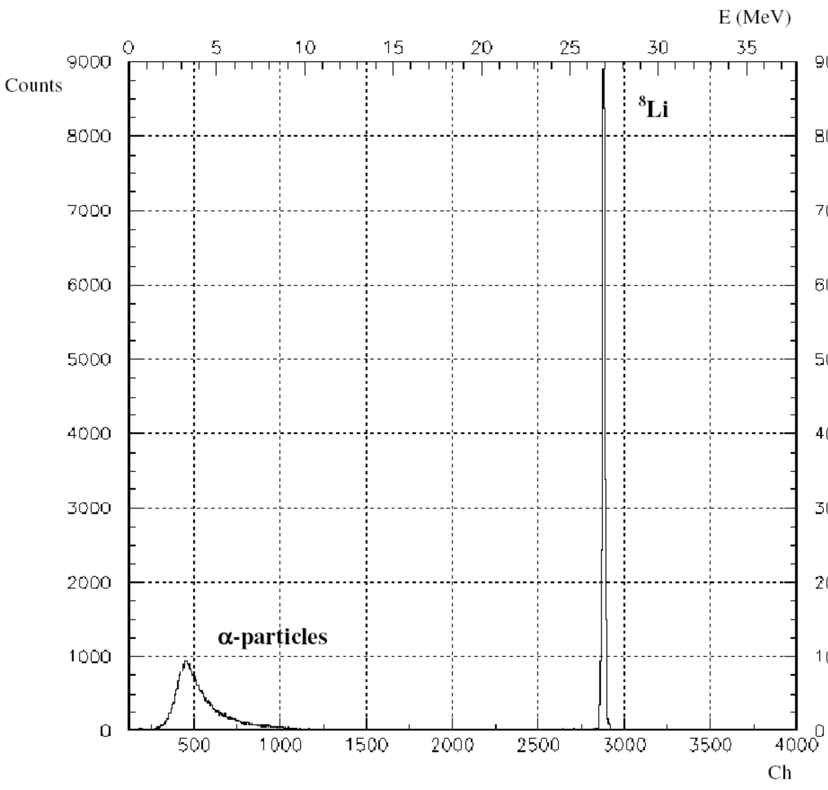
Commissioning Phase 4-5: 8Li- transport and post-acceleration with the Tandem

Primary beam power	Measuredon LEBI 1	CEC (10 keV)	Through the platforms	Through the 2^{nd} stage	At the Tandem entrance	Through the Tandem
		1.8% not optimised	95%	70%	50%	36%
75 watt	$5 \cdot 10^5$ $^8Li^+$	$9 \cdot 10^3$ $^8Li^-$	$8.6 \cdot 10^3$ pps	$6 \cdot 10^3$ pps	$3 \cdot 10^3$ pps	$1.1 \cdot 10^3$ pps
MAR '06	$1.8 \cdot 10^4$ $^9Li^+$					
		3.4%	100%	90%	80%	10%
101 watt	$5 \cdot 10^6$ $^8Li^+$	$1.7 \cdot 10^5$ $^8Li^-$	$1.7 \cdot 10^5$ pps	$1.5 \cdot 10^5$ pps	$1.2 \cdot 10^5$ pps	$1.2 \cdot 10^4$ pps
JUL '06	$6.2 \cdot 10^4$ $^9Li^+$					
147 watt	$9 \cdot 10^6$ $^8Li^+$	$3.2 \cdot 10^5$ $^8Li^-$	$3.2 \cdot 10^5$ pps	$2.7 \cdot 10^5$ pps	$2.1 \cdot 10^5$ pps	$2.1 \cdot 10^4$ pps

^9Li Production yield not at the maximum when measured

Commissioning Phase 5: $^8Li^-$ delivered to user





User test required max. flux of 10^3 pps.

R&D activities

- Better undestanding diffusion-effusion models (new target design)
- New target material (e.g. Foams, Fibers, Ta foils)
- New primary beam : ^{9}Be (proton transfer), new target design
- New container geometry to increase the transport efficiency (effusion) to the ioniser.
- New PIS surface materials : Re , Ir, W with O_2 flux.
- New negative source for Li ions.
- Higher primary beam power (500 W design value)

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EXCYT: Status and perspectives

- The entire facility has been commissioned and first beam delivered to user
- Further test to optimize transport efficiences in preseparator and tandem coupling line
- Beam transmission improvements through the Tandem.
- On 2007 is foreseen to carry out the experiments already scheduled by the PAC with 8Li (960 hours for 4 experiments: BIGBANG, RCS, RSM, MAGNEX-RIB).

Thanks for your attention!

e-mail : maurore@lns.infn.it

RESISTOR FAILURE AND RESISTOR SUPPORT BREAKDOWN AT LNL: PROBLEMS AND SOLUTIONS

D. Carlucci, A. Fasolato, A. Ferrara, S. Benvegnu, R. Bortolami, O. Carletto, F. Carletto, G. Muraro, R. Pagnin, G. Daniele, M. Contran, F. Nerva, G. Bisoffi, A. Dainese, M.F. Moisio, G. Bezzon, M. Poggi, L. Boscagli
INFN-LNL
Legnaro (Pd), Italy

During the last year operation, the XTU Tandem suffered severe problems concerning resistor failures. About 20 times the machine was opened for unscheduled maintenance and 18 times we were faced with column and tube resistor chain problems, like flashover on resistors, apparently inexplicable changes in resistor values, breach of the resistor springs and frame supports. In this report, we present the solution we adopted to solve the problem.

Questions:

?????(ANSTO): Those Nylatron bars, how do you secure them to the resistor supports?

Carluci: We have fixed the Nylatron bar... for each resistor support, there is one screw. There is no material inside the resistor support. There is only two mm. We use this space for to fix with the screw the Nylatron bar. But the Nylatron bar is very light. One of these is about one metre and about 150 grams. We have about sixty resistor supporters meaning that the weight isn't a problem. We are not sure about vibration. The main problem was the water but people from Strasbourg sent us some details about a Plexiglas bar from two dead sections. So we thought that a better solution for the breakdown of the resistor supports.

David Weisser (Australian National University): The thing that caused these to break off was the ear on the tube electrode. In those cases, what did you have to attached the repaired resistor holder to?

Carluci: Where the resistor connection is broken, we have put a vertical support. We have this kind of support in the dead section because the first resistor supporter isn't at 40 kV. There are about nine resistor supporters for forty kV and we use this kind of resistor supporter only in the dead section.

Weisser: With these blue bars in there, have you had many sparks of the machine yet? I'd be concerned about spark damage to the plastic where it is attached to the resistor support rings.

Carluci: We are arrived at 14 MV without any spark. We had some sparks over 14. For the moment, no damage. For the maintenance of July, we were inside the machine to check the first Nylatron bar in section number seven and we saw that it was okay.

Scott Daniel (Brigham Young University): Did megger the tube with resistors out? I saw what looked like some sputtering on the glass.

Carluci: I have never checked that but it is a good way to see trouble in the tube.

Chris Purcell (GNS New Zealand): Concerning your water problem, you made a lot of changes to your SF6 system. What do you think was the actual cause of the water problem?

Carluci: The problem was in the circuit of the SF6 system. Our old pump was made in 1950 and in the last period took more than ten litres of oil for each transfer of gas. The circuit of the gas was at six bar, but also went to a vacuum. So all the connections were stressed. There were many leaks and a lot of air and water came in during transfers.

????: What approximately was the contamination level of the water?

Carluci: The first information was 70 ppm or a dew-point of minus 20 degrees centigrade.

Weisser: If you had these leaks to air, wouldn't you have a significant air contamination of the SF6?

Carluci: It was about five or six years that our dew-point meter was broken. For a long period, the accelerator worked at 15 MV so it didn't matter. We think that the contamination increased for a long time and that at the end the leaks were probably bigger.

John McKay (retired): You mentioned that you were doing section-by-section conditioning. What voltages did you get on each section?

Carluci: In July we did section-by-section conditioning and the maximum voltage for each section was 3.2 to 3.4 MV.

Alistair Muirhead (ANU): You mentioned upgrades to your cyrogenic system. What was changed?

Carluci: We have put in a new compressor with a bigger capacity. In total it is about 180 grams/sec and it was 160.

End of questions

Resistor Failure and support breakdown at LNL: Problems and solutions

D.Carlucci, G. Daniele, A. Fasolato, A. Ferrara, S. Benvegnù,
R. Bortolami, O. Carletto, F. Carletto,G. Muraro, R. Pagnin, M. Contran, F. Nerva,
A. Dainese, G. Bisoffi, M.F. Moisio, G. Bezzon, M. Poggi, L. Boscagli

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SNEAP 2006 Sydney-Camberra

LNL - INFN - Identity Card

MULTI TASK

MULTI DISCIPLINARY

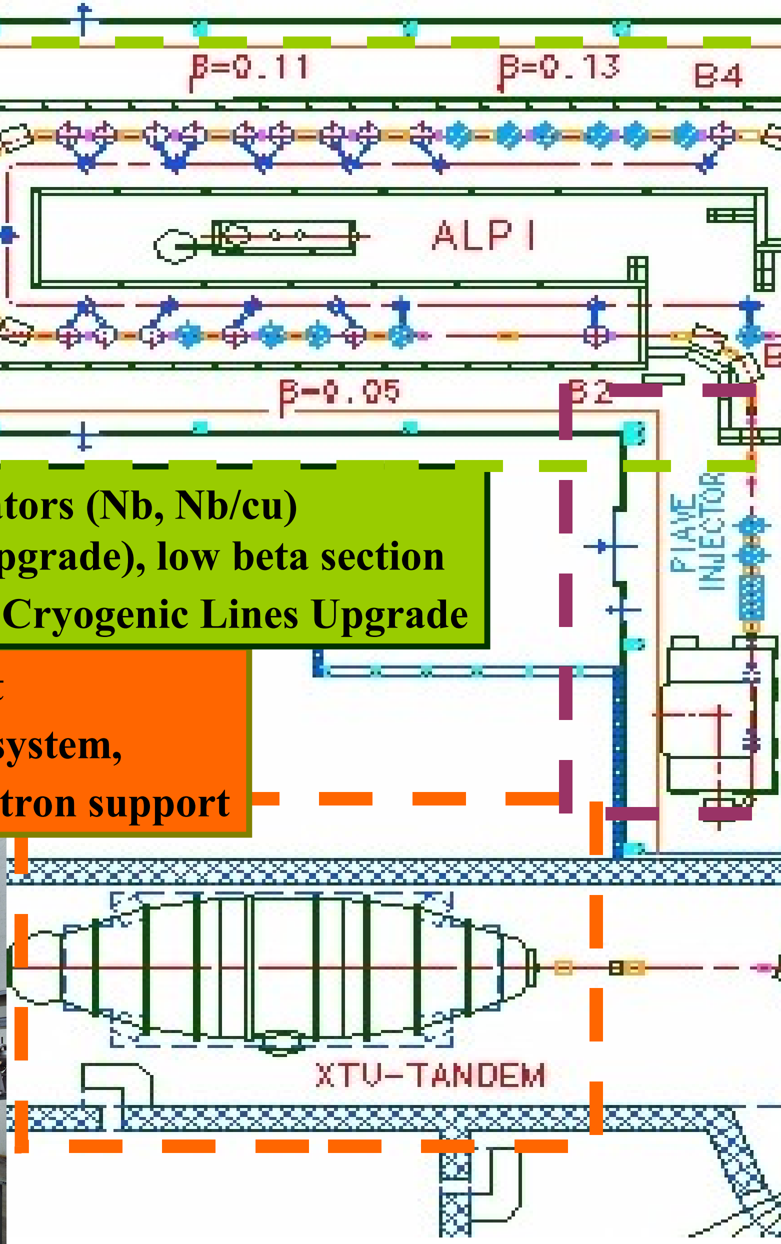
Nuclear Physics Based
User Oriented
Laboratories

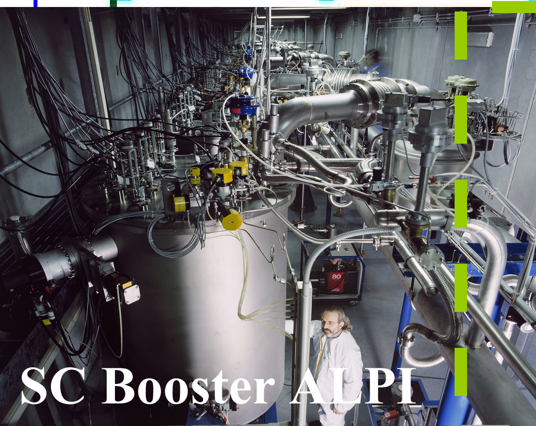
CORE RESEARCH ACTIVITIES

2. Nuclear Structure and Dynamics

4. Applications and Interdisciplinary use of ion beams and nuclear techniques and methods

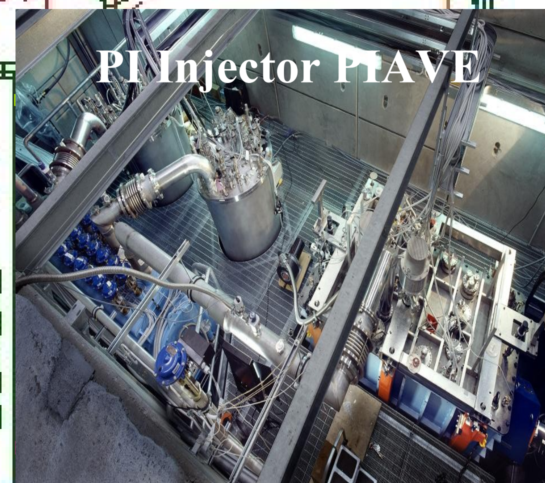
LNL - TANDEM PIAVE ALPI COMPLEX




SC Booster ALPI

68 SC Quarter Wave Resonators (Nb, Nb/cu)
V_{eq} ~ 40 MV (after '98-'02 Upgrade), low beta section operational at 3 MV/m after Cryogenic Lines Upgrade

V_T ~13.5÷13.8 MV at present
Special maintenance on SF_6 system,
Rs-holder mechanics & Nylatron support


PI Injector PIAVE

Commissioning completed
Test experiments performed
Noble gases + devpmt.s of Other ion beam species
New ECRIS purchased
Veq ~ 8 MV


XTU-Tandem

XTU:June 2005 – July 2005

- **June-July 2005**:(some problems)

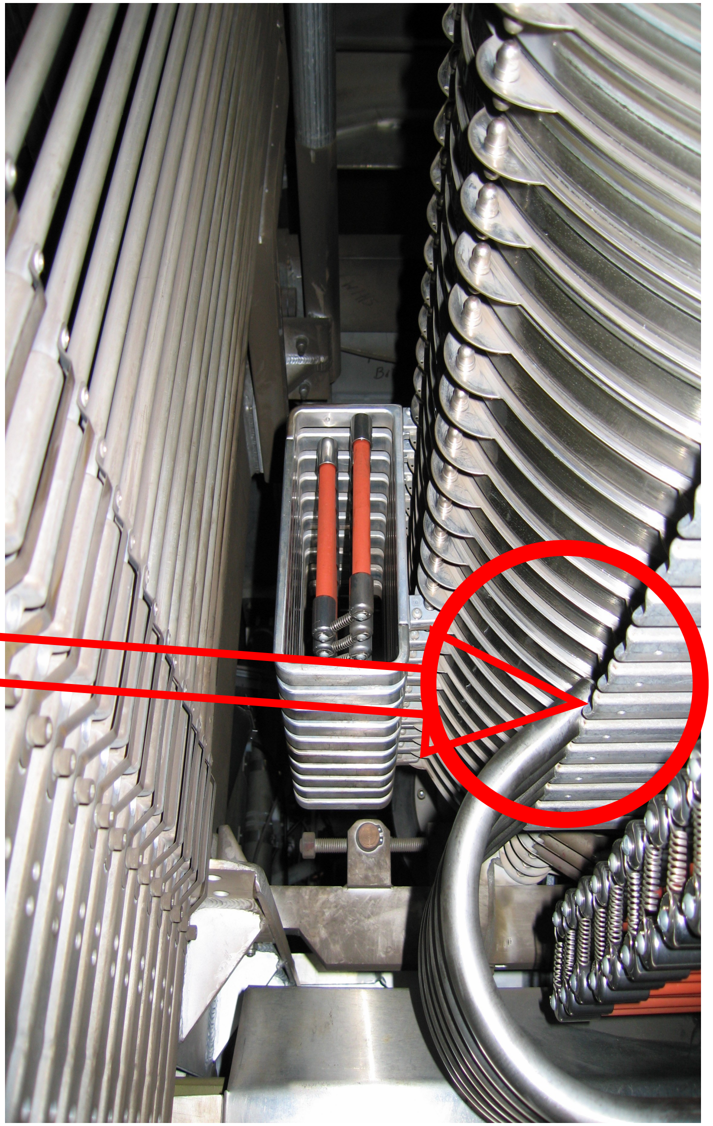
problem with resistors, value changed from ~500MΩ to ~340 MΩ

(particularly in sec.1 & sec.8).

Initially resistors support broke

➔ Bad trasmission

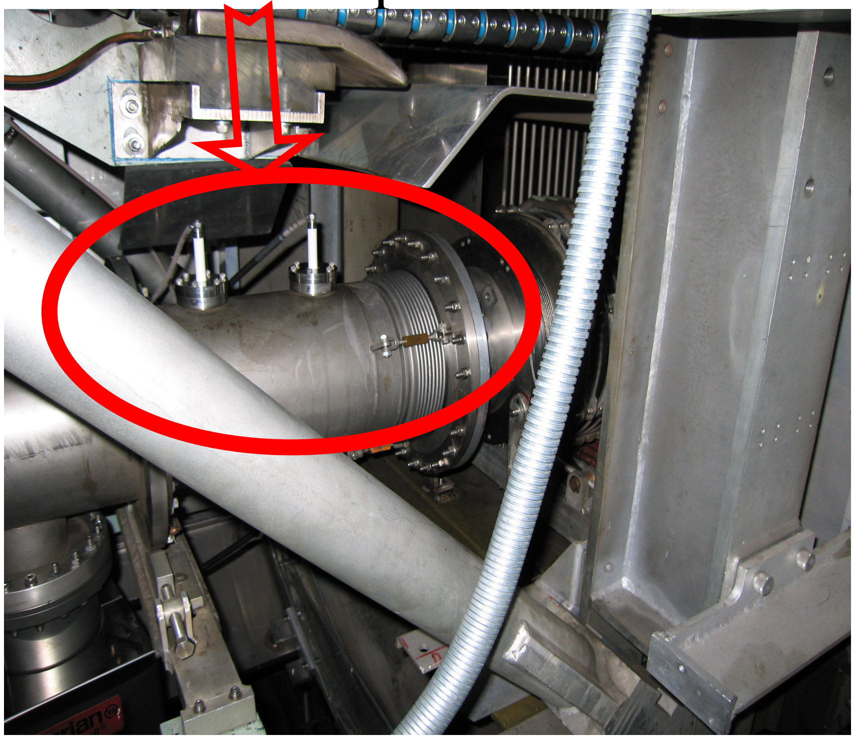
➔ Low T.V.(12-12.5)MV

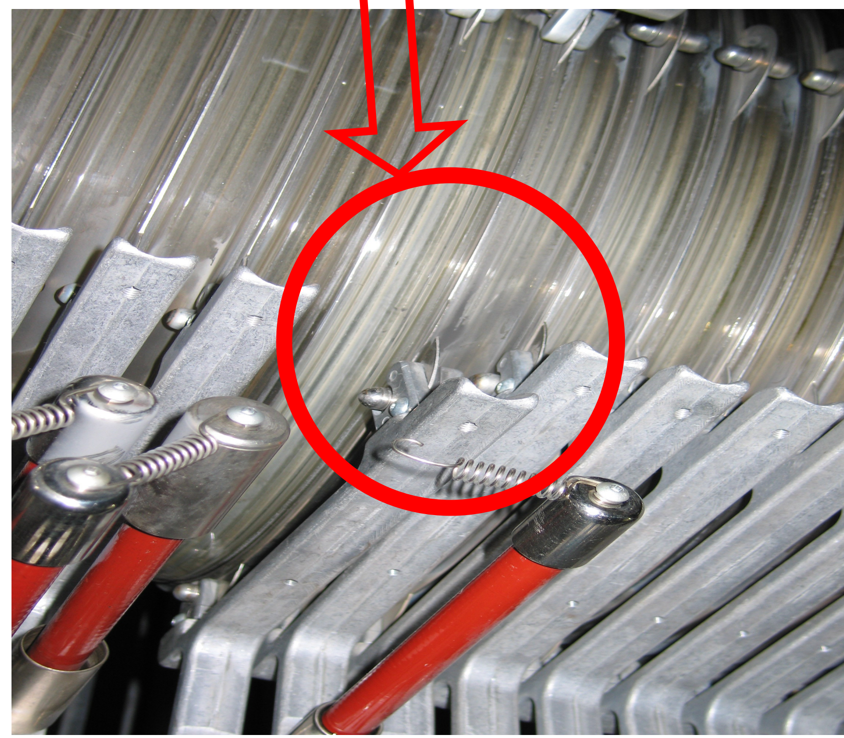


XTU:October 2005 – December 2005

- **Ocober-December 2005**: (Repeated problems with the Tandem)

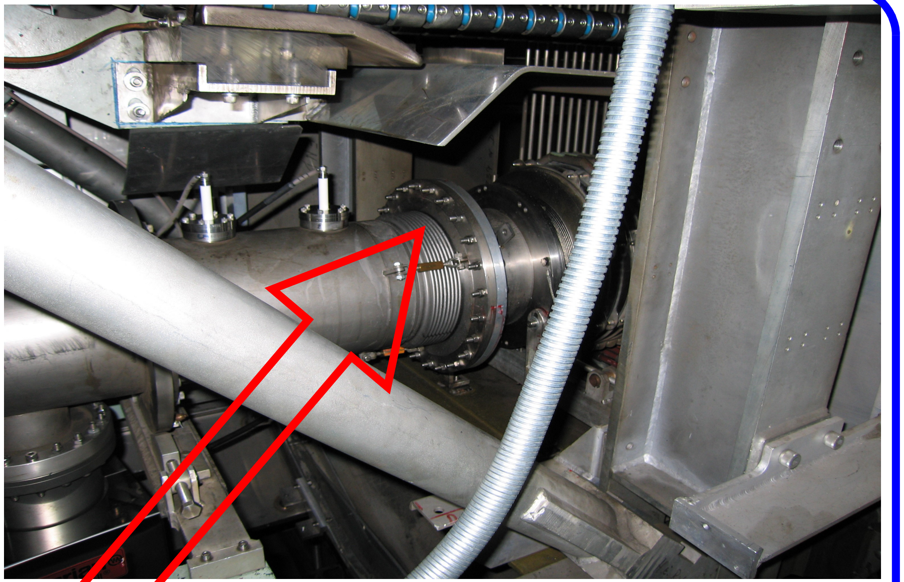
  10 unscheduled opening: 9 for broken resistor support and 1 for vacuum problem

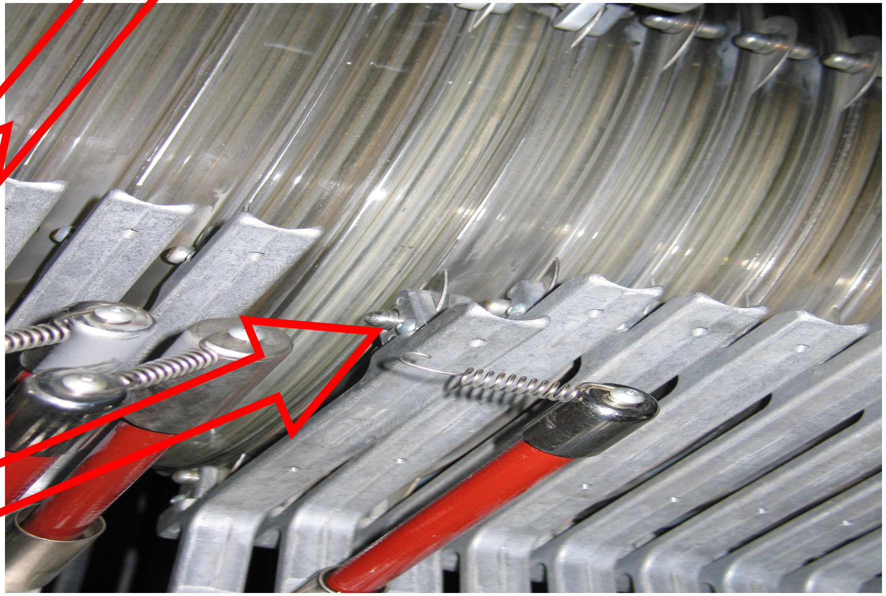




June- December 2005: **Max T.V. 12.5 MV**

September-December 2005 in summary: no experiments.





September 2005 - Regular maintenance main jobs were: Laddetron chain replaced, column resistors verified, terminal strippers changed

October 2005: bad beam transmission (resistors Sec.1 altered (changed), bad vacuum at the terminal (gaskets for lens feedthrough changed)

November 2005: repeated discharge problems at 12.5 MV (inter-R springs broken), accurate check of the whole machine

December 2005: Rs holder detached from tube (may be due to fatigue)

XTU:January 2006 – July 2006

- **January-July 2006**: (Total 2420 h beam on target) experiments with Tandem and Tandem+ALPI ($V_T \le 13$ MV). Repeated test experiments with PIAVE+ALPI were also done.

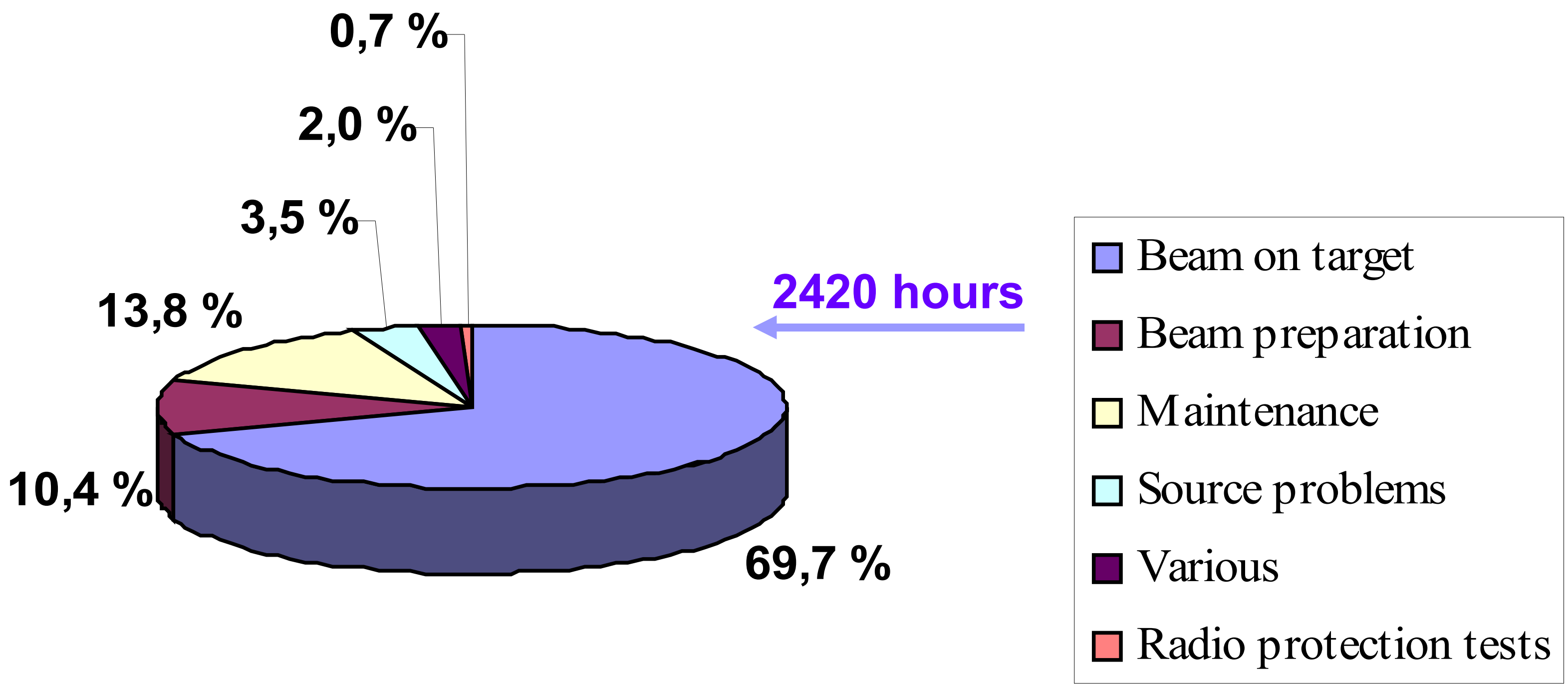
Apr.2006 maintenance carried out:

Contamination of SF6 gas by oil and water suspected (investigated)

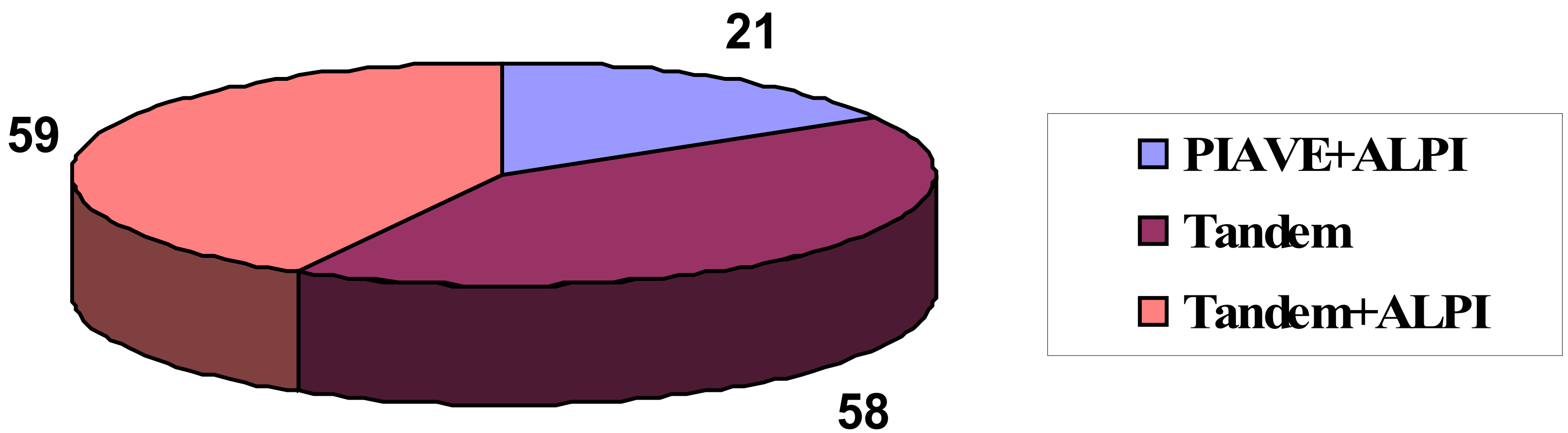
Oil: no; H_2O: yes; (Dew Point- 65 ppm)

- Al2O3 filter changed
- SF6 Dew Point meter repaired
- Spacer bar among Rs holders (mat.: nylatron mc 901, in sec.7) due to 19 nos. of mechanical breakdown of Rs holders
- First part of special maintenance on SF6 gas plant (cleaning, gasket change, new rupture disks)
- Dew Point brought down from 65ppm to 4 - 5 ppm (nominal value)

Percentage of Beam-on-target hours vs (...) in January-June 2006



Beam-on-target **days** Jan-Jul 2006 with PIAVE+ALPI, Tandem and Tandem+ALPI

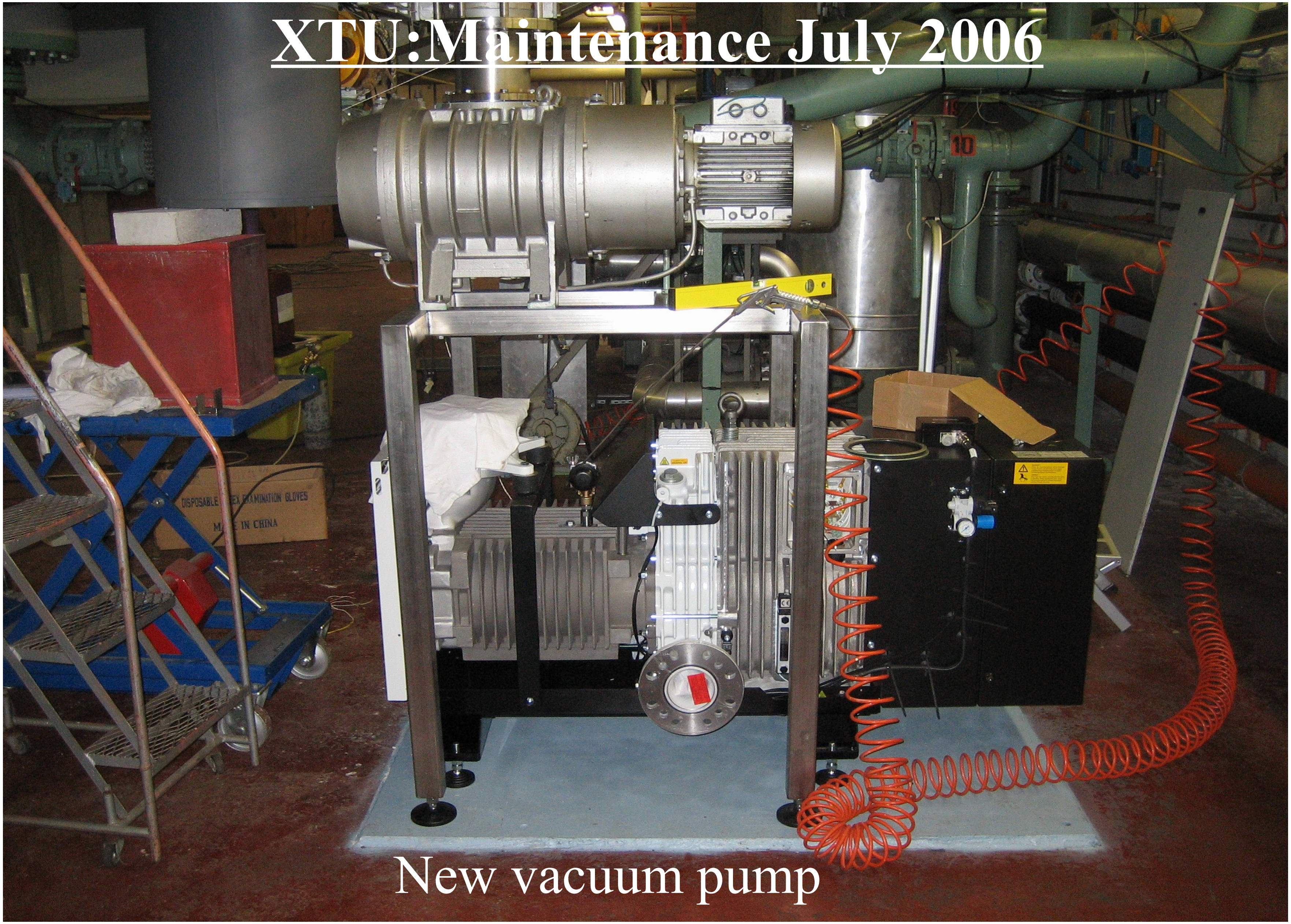


XTU:Maintenance July 2006

2. Separate section conditioning:
   (replacement of Rs voltage divider – accordingly)
2. Replacement of SF6 vacuum pump with a new one (oil-free)
5. Second part of special maintenance on SF6 gas plant (circuitry)
6. Spacer bar among Rs holders (mat.: nylatron mc 901, in sec.5)

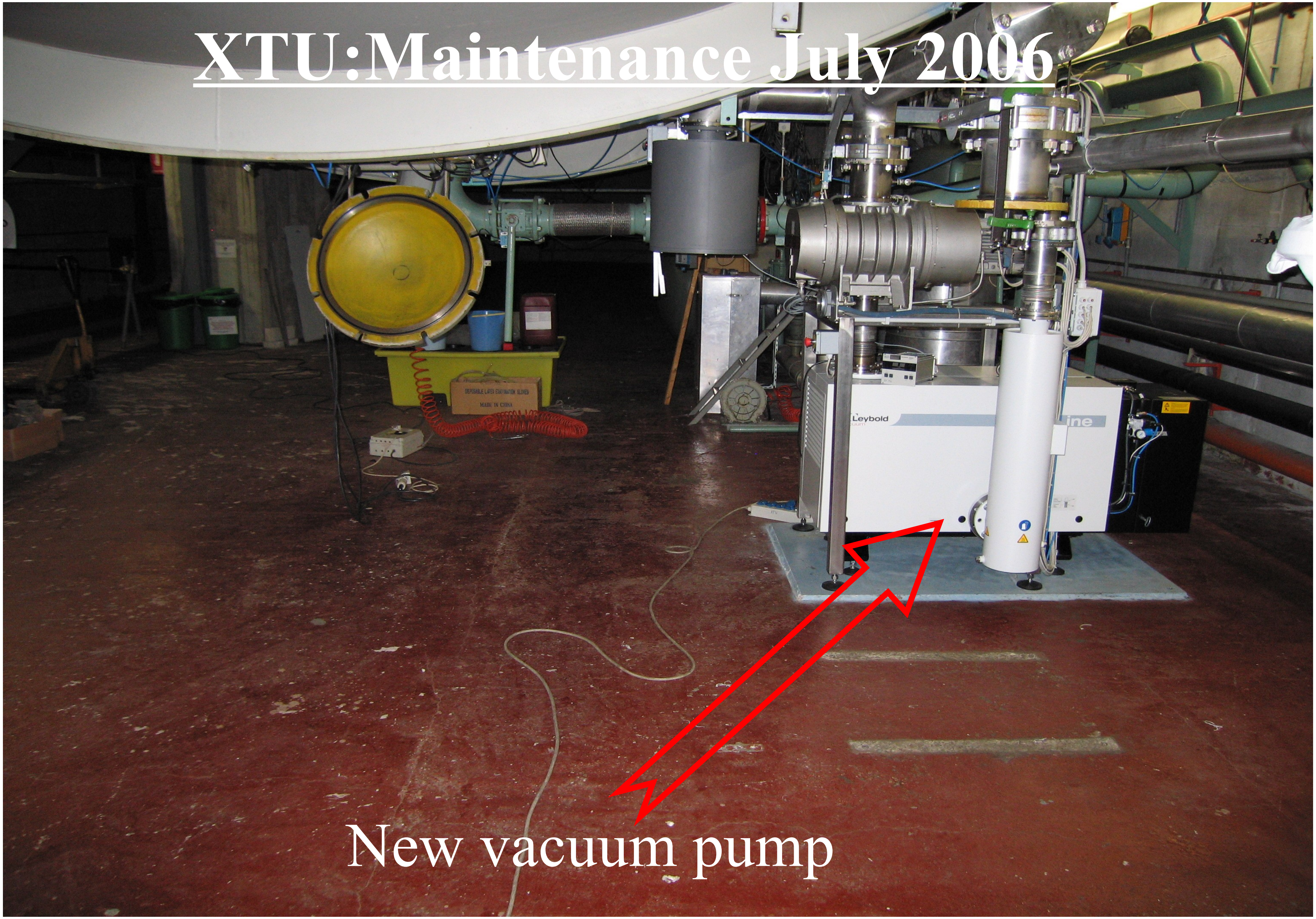
New vacuum pump

XTU:Maintenance July 2006



New vacuum pump

XTU:Maintenance July 2006



XTU:Maintenance July 2006

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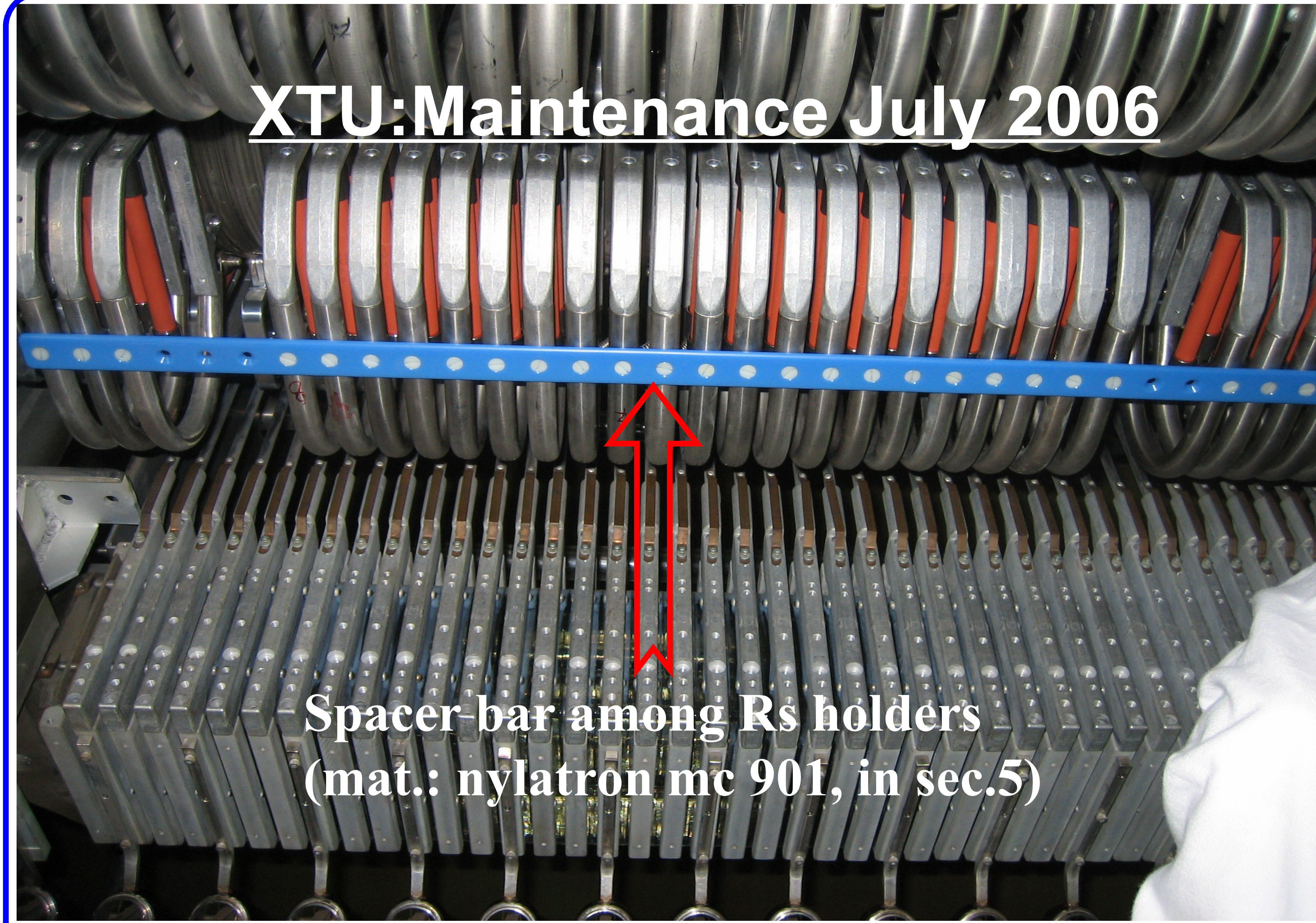

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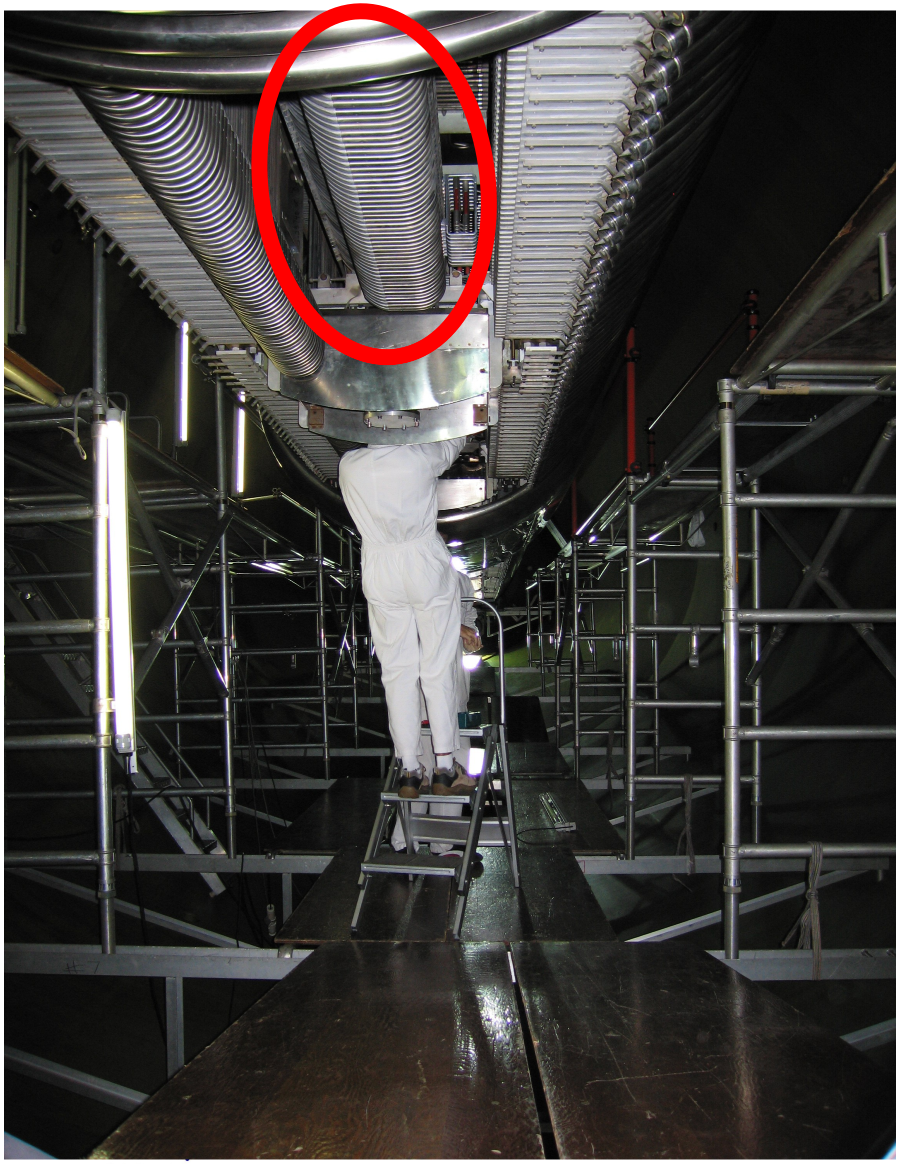

Found (2 - 3) mm difference from project position

XTU: September 2006

- During the last conditioning in September we reached 14 MV which was our targhet value with the actual resistence divider.
- The experiments already started last 7th october
- Operating voltage 13.5 MV (for safety reasons)
- Dew point - 65 °C ~ 4-5 ppm
- Riple, ok
- Charge positive & negative, ok
- Vacuum, ok
- No more mechanical breakdown of Rs holders

Conclusion

It is our opinion that resistor and support breakdown was mainly due to the water contaminant (60-70 ppm) in SF6 insulating gas.

We also believe that the introduction of the nylatron supports reduce the electro-mechanical stress and produce a more uniform electric field distribution up to a voltage of 13.5-14 MV mantaining a better mechanical stability and a constant gap betwin the support.

Further possible improvement ?


For now
just future

Thank you for your attention

General Discussion (SF6 purification)

????(inaudible): Question in regard to separating air from SF6.

John McKay (retired): As Jim Stark says, it is illegal to do now but you get a large oil drum, put a cylinder in there and surround it with liquid nitrogen and freeze out the SF6. Of course doing that to a steel cylinder at pressure is neither safe nor legal. I think that it may be possible to do it with an aluminum cylinder but I am not sure if that would be safer. It is a major job no matter how you do it. When we did it that way, it was a batch project. We froze out SF6 in the cylinder and while it was frozen, let the air blow off.

Greg Norton (NEC): There is a company called Dilo based in Germany but operates out of Florida. They make SF6 systems that liquify the SF6. You can store the SF6 back in the original cylinders. It seems to us that there is a company that you can rent something like this from. I don't recall if it is directly from Dilo or from somebody else.

???? (AVT Services): Regarding the SF6. We represent a company called Enervac who do SF6 recovery and they do liquify in one process. But the only problem is that it is all stored on board in one tank. As of yet, they don't have a method of separating it. We have thought of some ideas where we can pass the SF6 and air mixture past a CTI cryotrap, and freeze it out that way. Enervac is still working on that at the moment.

????: What percentage of air or oxygen in SF6 before you start to worry about it?

????: One of the first indicators is that the pressure in the storage vessel rises. As you pump more SF6 in, the pressure levels off as it liquifies. If you are pumping air in there, the pressure continues to rise and you'll lift the safety valve on the tank. A very practical way to know that you are in trouble.

End of discussion.