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Addendum n°2 to the proposal P54 presented to the ISOLDE Experiment Committee

Mass measurement of very short half-lived nuclei

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After the presentation of the proposal P54, three technical questions were mentioned in the minutes of the 9th ISOLDE Committee (August 23-24, 1993) :
"a) whether low enough separator emittance can be achieved without sacrificing yield and timing, and b) whether the high resolution separator will be required or not and c) what the optimal voltage stepping will be". An answer to the last two questions was given in Addendum n°1 (CERN/ISC 93-36) : the GPS is better suited to feed the RF mass-spectrometer than the HRS and, consequently, the HRS is not required. A 5 seconds duration for the voltage stepping is satisfactory. Therefore, this new addendum will concentrate on the first question and will give an evaluation of the spectrometer transmission and of the lowest yield acceptable for mass measurement, resulting from the measured emittance of the ISOLDE beam.

In addition to the mass resolving power, the transmission is a crucial factor to determine the feasibility of accurate mass measurements of far from β-stability nuclei which are produced with low yields. The overall transmission is defined as the ratio of the beam current at the exit of the spectrometer tuned at the resonance frequency to the incoming ISOLDE beam current. The transmission factor is linked to the beam characteristics : emittance and kinetic energy spread, and to the spectrometer acceptance.

1. ISOLDE beam emittance measurements

⇒ Surface ionization source

The 60 keV beam of 205Tl$^+$ produced in a tungsten tube, 3 mm in diameter, has been measured[1] using a specific device lent by D. Habs (MPI - Heidelberg) and installed at the end of the GHM beam line of ISOLDE. It allows for direct emittance measurements with a moving slit upstream of a multi-wire current detector. The beam scanning is performed in 2 perpendicular planes shifted by 45 degrees from the horizontal plane. The source setting-up and optimization were performed as usual. The analysis of the data allows to plot the relationship between the emittance and the fraction of the beam intensity contained in this emittance (figure 1). The normalized emittance is found to be $\varepsilon_n = 6.9\ \pi\ \mathrm{mm\,mrad}\sqrt{\mathrm{MeV}}$ (un-normalized emittance $\varepsilon = 28\ \pi$ mm mrad at 60 keV) to keep 90 % of the intensity and $7.9\ \pi\ \mathrm{mm\,mrad}\sqrt{\mathrm{MeV}}$ for 95% (32 π mm mrad at 60 keV). The variance of the energy spread is estimated (probably over-estimated) from the source parameters, to be 2×10^{-4} (12 eV at 60 keV).

⇒ Plasma ionization source

A plasma ion source of the ISOLDE type, with an aperture of 1.5 mm in diameter, has been used to produced a xenon beam extracted at 20 keV. Using the same kind of emittance-meter in Oak Ridge (G. Alton, private communication) and the same data analysis procedure, the measured emittance is 38 π mm mrad for 95 % of intensity, corresponding to 22 π mm mrad at 60 keV, appears to be smaller than the former one probably because of the smaller aperture. The variance of the energy spread is estimated (probably over-estimated) from the source parameters to 5×10^{-4} (30 eV at 60 keV).

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[1] H. Schiebler and D. Habs, MPI Heidelberg, M. de Saint Simon, CSNSM Orsay, K. Janko, Bratislava, P. Van Duppen, G. Correia, M. Lindroos, CERN, private communication.

2. RF mass-spectrometer acceptance

The spectrometer makes three different cuts in the beam current : geometrical cuts in position and angle, kinetic energy cut and phase (time) cut due to the phase defining slit. Except for the last one, these cuts are due to four 0.4 x 10 mm^2 slits located along the trajectory. The spectrometer acceptance is as following :

- Horizontal plane : ± 0.2 mm, ± 10 mrad horizontal acceptance : $a_H = 2\pi$ mm mrad
- Vertical plane : ± 5.0 mm, ± 1.6 mrad vertical acceptance : $a_V = 8\pi$ mm mrad
- Kinetic energy spread acceptance : $\frac{\Delta E}{E} = \pm 4 \times 10^{-4}$ (48 V at 60 keV)
- Phase (time) acceptance : 1/3. This value corresponds to the regular setting leading to a half-amplitude cut.

3. Methods used for the transmission evaluation

The transmission evaluation has been performed using two methods :

- The various cuts are supposed to be independent from each other. The geometrical cuts are evaluated from the relationship between the measured emittance and the transmitted fraction of the beam (figure 1). The energy cut has been calculated assuming a gaussian distribution of the energy spread. An additional cut has been introduced to take into account the cut due to optical aberrations at each slit (90 %).
- In the second method, the transmission is evaluated using a multi-particle simulation of the whole spectrometer. The particle generation assumes gaussian distributions in location, angles and energy dispersion. Here, correlations between the cuts are implicitly taken into account, and there is no need to evaluate the spectrometer acceptance. Therefore, this method is certainly more realistic than the previous one.

4. Results of the transmission evaluation

The transmission is evaluated for the two types of ion source. The results appear in Table 1 where $\mathcal{T}_1$ and $\mathcal{T}_2$ are the overall transmissions obtained with the first and the second method respectively. E is the beam kinetic energy, sigma E the variance of the energy spread, $\mathcal{T}_H$, $\mathcal{T}_V$ and $\mathcal{T}_E$ are partial cuts due to horizontal, vertical and energy cuts. Because of a limitation of the intensity of the magnetic field, the ISOLDE high voltage has to be progressively decreased from 60 kV (for A = 100) down to 30 kV (for A = 250). The transmission is evaluated, in addition, for that borderline event.

Source	*method*	*E*	*ε95%*	*sigma E*	$\mathcal{T}_H$	$\mathcal{T}_V$	$\mathcal{T}_E$	$\mathcal{T}_1$	$\mathcal{T}_2$
type		*keV*	*pi mm mrad*	*eV*	*%*	*%*	*%*	*%*	*%*
Surface	1	60	32	12.0	12.0	41.0	99.0	**1.1**	
Surface	2	60		12.0	19.1	35.8	95.6		**2.0**
Surface	1	30	45	12.0	8.5	30.0	68.0	**0.38**	
Surface	2	30		12.0	14.2	27.5	68.0		**0.91**
Plasma	1	60	22	30.0	44.0	71.0	58.0	**4.0**	
Plasma	2	60		30.0	26.7	46.1	57.3		**2.4**
Plasma	1	30	32	30.0	30.0	63.0	31.0	**1.3**	
Plasma	2	30		30.0	19.1	35.8	30.7		**0.90**

The observed dispersion of the results is a consequence of evaluation procedures. Taking into account the uncertainties on emittance measurements and energy spread estimation, those numbers are compatible with an average transmission of 1 %, particularly considering the over-estimate of the energy spread.

5. Conclusion

Due to the background noise of the detector, close to 0.1 count per second, such a 1% transmission corresponds to a yield lower limit of 10 atoms/s. The proposal has shown that, taking into account such a sensitivity limit and the known yields of the SC-ISOLDE facility, a wide physics program could be carried out over more than 100 nuclei with half-lives shorter than 1 second. With the PS-Booster ISOLDE facility, we know that the yields are even higher, allowing for a wider program of accurate mass measurement spreading further from stability.

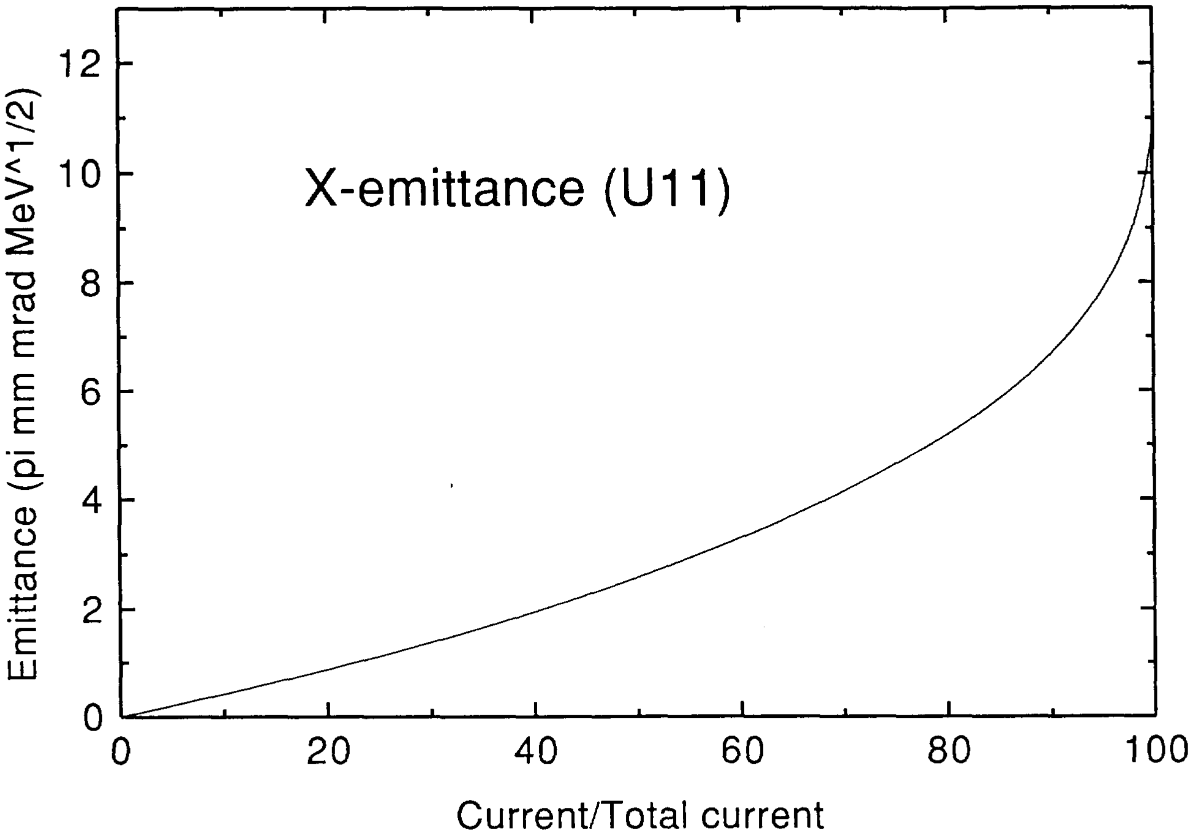

Figure 1. Normalized emittance versus percent of beam current for the surface ionization source. Beam : $^{205}Tl^{+}$, W-surface ionizer, internal diameter : 3 mm (from [1]).