

CERN/PSCC/85-31
PSCC/P84
19 April 1985

PROPOSAL TO THE PSCC

HIGH-PRECISION DIRECT MASS DETERMINATION
OF UNSTABLE ISOTOPES

CERN¹ - Mainz² - Montreal³ - Collaboration

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Geneva 1985

1. SCIENTIFIC MOTIVATION

The extension of systematic high-precision measurements of the nuclear mass to nuclei far away from the valley of β stability is demanded for by nuclear physics and astrophysics: the mass or binding energy represents as a fundamental gross property a key input parameter for nuclear matter calculations. Precise mass data are needed for calculations of the nucleosynthesis or to test mass formulas, which, e.g., are again needed for these astrophysical means. The test is especially decisive in case of very unusual proton-to-neutron ratios, i.e., in case of nuclei far away from β -stability. Further interesting aspects are the observation of shell structure effects like shell closures or subshell closures, new regions of deformation or the study of pairing energies in exotic regions of the chart of nuclei.

The great interest in precise mass data became evident at the international conference on "Atomic Masses and Fundamental Constants 7" which took place last year in Seeheim¹⁾. Until now, precise mass measurements are restricted to the valley of stability of the chart of nuclei or its direct neighbourhood. Far away from this valley, nuclear binding energies are measured indirectly by means of mass differences obtained as Q values from nuclear decays or reactions (the only exception until now are the mass measurements of the ORSAY group on the alkali isotopes performed at CERN²⁾). The unknown mass of the unstable isotope under investigation has to be linked via many mass differences to the known mass of a (generally) stable isotope. It is inherent in this procedure, that the errors of the different connecting Q values are summing up and large uncertainties are to be expected for nuclei far away from stability. It can furthermore be expected that many masses quoted in the literature are wrong, since the determination of Q values requires generally a very detailed knowledge of the level schemes of the nuclei involved. However, the level schemes are very complex far away from stability and in many cases not sufficiently known.

In order to avoid these drawbacks of the indirect mass measurements, new methods for on-line mass-determinations were investigated by several groups. The Orsay group³⁾ developed (after experiments taking place at the PS) a double-focusing mass spectrometer for on-line measurements at ISOLDE, with a precision of around 10^{-6} at a resolution of 10^{-4} . They carried out mass-measurements in extremely long isotopic chains of alkalis without being limited as to the precision by the rather unknown nuclear level schemes. Already in these first systematic measurements, a number of surprising results were obtained, as e.g.

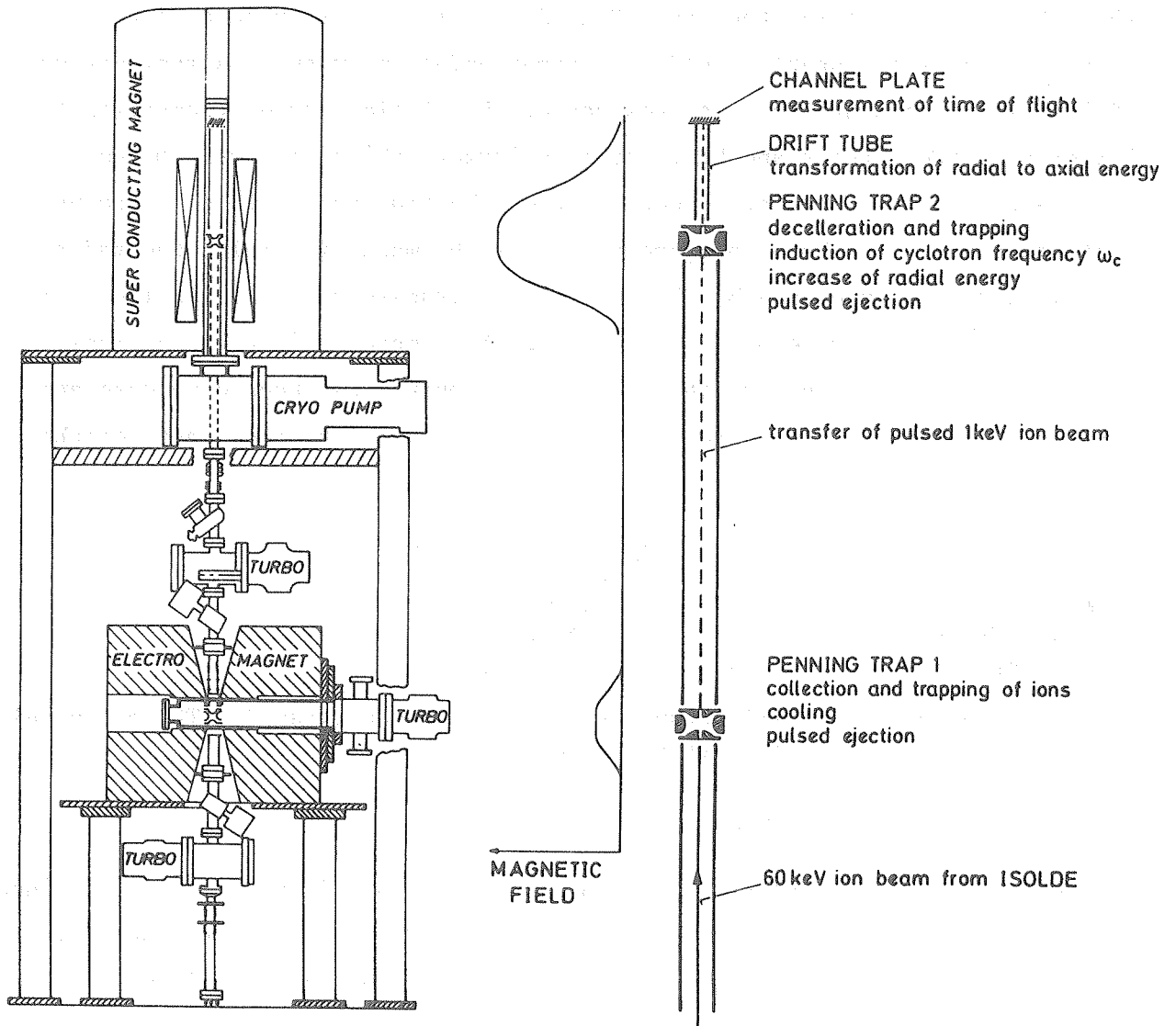


Fig. 1: Principle (right) and experimental set up (left) for high-precision mass measurements.

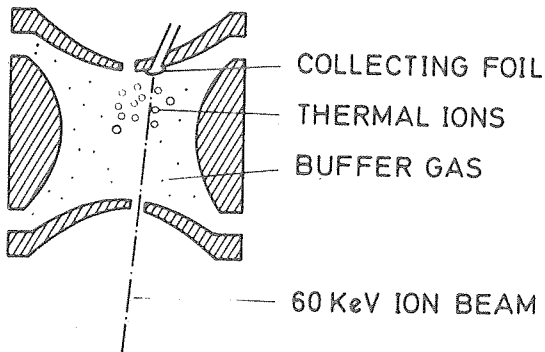


Fig. 2: Penning trap for storing and cooling of the ions obtained from the ion beam of an on-line mass separator (trap 1).

3.2 Calibration of the magnetic field: The stability of the superconducting magnet (drifts of the magnetic field $\leq 10^{-8}/\text{h}$) allows easy calibration of the magnetic field in long time intervals by means of a measurement of the cyclotron resonance of a stable isotope.

3.3 Sensitivity: The necessary intensity of the primary ion beam is estimated to be less than 10^6 ions/s for an isotope with $T_{1/2} \gtrsim 1\text{s}$. This number is calculated using a trapping efficiency of 10^{-3} to 10^{-4} in the first trap, assuming a transfer efficiency from trap 1 to trap 2 of about 1% - 10%, and requiring 10 ions in trap 2 as used in previous experiments. The ion beam intensity can be lower than 10^6 ions/s in case of a mass measurement of an isotope with longer half life, because the primary ions delivered by ISOLDE can be accumulated on the foil.

3.4 Applicability: The concept outlined above allows the measurement of isotopes of those elements which can be surface ionized. The extension to other elements is possible as discussed in section 5.

4. STATUS OF THE EXPERIMENT

All parts of the experimental set up are constructed and assembled. The superconducting magnet is powered and was tested to perform within the specifications (inhomogeneity $\leq 10^{-7}$, drift of the magnetic field $\leq 10^{-8}/\text{h}$). For the time being, trap 1 and trap 2 are disconnected and investigated separately with K, Cs, N and N_2 ions. The ratio of the number of ions, injected into trap 1 to those ejected as a bunch was measured to be 10^{-4} . In the precision trap (trap 2), a linewidth of 3 Hz was found in case of a $^{14}\text{N}_2$ measurement. This yields a resolution of 10^{-6} . Further tests will go on at Mainz during the next months and it can be expected that the figures given will still improve.

The only part of the system unchecked until now is the transfer of the bunched ions from trap 1 to trap 2. Extensive calculations of the ion optics for the transfer were performed¹¹⁾ and tests will start in early summer 1985.

5. FUTURE DEVELOPMENTS

First, the experimental set up will be applied for mass determination of isotopes of those elements which can be ionized at a hot surface. Candidates are the isotopes of the alkalis, the alkaline earth, and the rare earth elements.

With ion trap: Having the source as a collection of ions in an electromagnetic trap, rather than as a miniscule trace of atoms in the material of the source mount, would considerably enhance the capabilities of this apparatus. Scattering of betas from the mounting material would be avoided leading to much cleaner low energy regions for the observed spectra. Also, because the recoil energy of the nucleus in beta decay is usually much greater than the holding potential of the electromagnetic trap, it becomes feasible to do experiments in which this recoil is observed. Such experiments can remove ambiguities about the actual nuclei with which an observed beta decay is associated. Furthermore, by laser or r.f. techniques it would appear feasible to polarize the radioactive ions in an electromagnetic trap for angular correlation observations. Such observations relate to the Gamon-Teller versus Fermi components in beta decays and to possible tests of the CVC hypothesis.

6. ISOLDE REQUIREMENTS

The set-up is expected to be completely tested at Mainz and to be ready for installation at ISOLDE in the fall or end of 1985. It should be first placed at the extension of beamline 3 of ISOLDE-2 in UR10 in order to use the Uranium carbide target for the investigation of neutron-rich isotopes of the alkaline earths Ba and Ra. Later on it can also be installed at a beamline of ISOLDE-3.

Space

2.0 x 2.5 m² at beamline 3 in UR10. The space needed in the vertical direction is 3.90 m. A cable duct directly above beamline 3 has to be moved aside by about 1m. A place of similar size is needed in case of installation at IS-3. The beam has to be bent vertically.

4 x 3 m for electronics.

Liquid Helium

20 l/month, connection to recovery line.

EP Electronics pool: up to 50 kSFR.

Targets

Uranium carbide with tungsten-surface ionization (Ba,Ra) and molten Lanthanum with Tungsten-surface ionization (Ba). Eventually Tantalum foil target with Tungsten-surface ionization for the investigation in the rare earths elements.

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