TRIUMF - RESEARCH PROPOSAL	**Experiment no.**	**Sheet** 1 **of** 5

Title of proposed experiment

High accuracy mass measurements for superallowed nuclear β-decay emitters

Name of group

TITAN

Spokesperson for group

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Members of group (name, institution, status)

(For each member, include percentage of research time to be devoted to this experiment over the time frame of the experiment)

J. Dilling	TRIUMF	Scientist	80 %
P. Delheij	TRIUMF	Scientist	80 %
G. Ball	TRIUMF	Scientist	20 %
P. Bricault	TRIUMF	Scientist	20 %
J. Caggiano	TRIUMF	Scientist	30 %
J. Lee	McGill University	Professor	30%
J.Crawford	McGill University	Professor	30%
F. Buchinger	McGill University	Lecturer	30%
B. Moore	McGill University	Professor	30%
G. Gwinner	U. Of Manitoba	Professor	40%
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V. Ryjkov	TRIUMF	Post-doc	100%
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Date for start of preparations:

Date ready: Summer 2006

Completion date: date

Beam time requested:

12-hr shifts	**Beam line/channel**	**Polarized primary beam?**
See table		

SUMMARY	Sheet 2 of 5

Precise measurements of the intensities for superallowed Fermi $0^+ \rightarrow 0^+$ β decays between analog states provide demanding and fundamental tests of the properties of the weak interaction. In particular, since the axial vector decay strength is zero for such decays the intensities are directly related to the weak vector coupling constant, G_V. Firstly, bremsstrahlung and related processes must be accounted for through calculated radiative corrections and secondly, Coulomb and other charge-dependent forces break isospin symmetry resulting in a small and calculable shift in the nuclear matrix element. Thus the test of the CVC hypothesis becomes modified to read:

$$ft\,(1 + \delta_R)\,(1 - \delta_C) \equiv Ft = K/[2G^2_V(1 + \Delta_R)] = \text{constant} \quad ,$$

where K is a constant, f is the statistical rate function, t is the partial half-life for the transition, Δ_R and δ_R are the nucleus-independent and nucleus-dependent parts of the radiative correction; and δ_C is the isospin symmetry-breaking (Coulomb) correction. The ft value that characterizes any β transition depends on three measured quantities: the total transition-energy, the half-life of the parent state and the branching ratio for the particular transition of interest. The Q_{EC} value is required to determine the statistical rate function while the half-life and branching ratio combine to yield the partial half-life. Presently nine transitions have been determined with sufficient accuracy to confirm CVC at the level of $3 \cdot 10^{-4}$. The average value of Ft is 3072.7 ± 0.8, with a corresponding chi square per degree of freedom of 0.42 [Har05].
These data together with the muon lifetime also provide the most accurate value for the up-down quark mixing matrix element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, V_{ud}. The unitarity test as it relates to the elements in the first row of the CKM matrix

$$V^2_{ud} + V^2_{us} + V^2_{ub} = 1$$

can be examined using the recommended Particle Data Group [PDG04] values for V_{us} and V_{ub} (i.e. 0.2200 ±0.0026 determined from K_{e3} decay and 0.0036 ± 0.0007, respectively). The result becomes:

$$\sum V^2_{ui} = 0.9965 \pm 0.0014 \quad ,$$

which fails to meet unity by 2.2 standard deviations.

Here we propose to carry out high accuracy mass measurements on superallowed beta-decay emitters. The motivation is two-fold. Firstly measurements are proposed on isotopes, where the TITAN experiments will improve significantly the accuracy, and secondly, re-measurements are proposed on isotopes where non-direct mass measurements have been carried out to determine the Q_{EC} value. The latter motivation stems from a recent investigation by the CPT group, which found 5 cases of Q_{EC} determination to be erroneous by up to 5 sigma. This was only discovered by carrying out an accurate re-measurement.

This proposal is a summary proposal for 15 different cases, and represents an extension of E966, the mass determination of ^{74}Rb.

BEAM and SUPPORT REQUIREMENTS

Experimental area

ISAC I TITAN

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

Secondary channel

Radioactive beam of the requested isotope at 30-60 keV.

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emittance, intensity, beam purity, target, special characteristics)

TRIUMF SUPPORT:
Summarize all equipment and technical support to be provided by TRIUMF. If new equipment is required, provide cost estimates.

NOTE: Technical Review Forms must also be provided before allocation of beam time.

NON-TRIUMF SUPPORT:
Summarize the expected sources of funding for the experiment.
Identify major capital items and their costs that will be provided from these funds.

NSERC

SAFETY

Summarize possible hazards associated with the experimental apparatus, precautions to be taken, and other matters that should be brought to the notice of the Safety Officer. Details must be provided separately in a safety report to be prepared by the spokesperson under the guidance of the Safety Report Guide available from the Science Division Office.

The TITAN facility will operate with low levels of radioactive beam. Radioactive hazards are not envisaged during the experimental runs. When the beam line has to be opened standard ISAC procedure will be followed to check for contamination. Other potential hazards areas include the charge breeding EBIT (X-rays) and the high voltage operation of the RFQ and the EBIT. All three areas will have been safety commissioned by the time the experiments will be carried out. Local shielding for the x-rays and a lock-out procedure for the HV Farraday cages will be in place.

The following information should be included:

(a) **Scientific value of the experiment**: Describe the importance of the experiment and its relation to previous work and to theory. All competitive measurements at other laboratories should be mentioned. Include examples of the best available theoretical calculations with which the data will be compared.

(b) **Description of the experiment**: Techniques to be used, scale drawing of the apparatus, measurements to be made, data rates and background expected, sources of systematic error, results and precision anticipated. Compare this precision with that obtained in previous work and discuss its significance in regard to constraining theory. Give a precise list of targets to be used in order of their priority.

(c) **Experimental equipment**: Describe the purpose of all major equipment to be used.
Details of all equipment and services to be supplied by TRIUMF must be provided separately on the Technical Review Form available from the Science Division Office.

(d) **Readiness**: Provide a schedule for assembly, construction and testing of equipment. Include equipment to be provided by TRIUMF.

(e) **Beam time required**: State in terms of number of 12-hour shifts. Show details of the beam time estimates, indicate whether prime-user or parasitic time is involved, and distinguish time required for test and adjustment of apparatus.

(f) **Data analysis**: Give details and state what data processing facilities are to be provided by TRIUMF.

(A) Scientific Motivation:

Precise measurements of the intensities for superallowed Fermi $0^+ \rightarrow 0^+$ β decays between analog states provide demanding and fundamental tests of the properties of the weak interaction. In particular, since the axial vector decay strength is zero for such decays the intensities are directly related to the weak vector coupling constant, G_V. Indeed the conserved vector current (CVC) hypothesis implies that G_V is an absolute constant with the consequence that the measured *ft* values for Fermi decays between isospin T = 1 states should all be the same irrespective of the nucleus studied. A practical demonstration of this, however, is thwarted by a couple of complications. Firstly, bremsstrahlung and related processes must be accounted for through calculated radiative corrections and secondly, Coulomb and other charge-dependent forces break isospin symmetry resulting in a small and calculable shift in the nuclear matrix element. Thus the test of the CVC hypothesis becomes modified to read:

$$ft\,(1 + \delta_R)\,(1 - \delta_C) \equiv \mathcal{F}t = K/[2G^2_V(1 + \Delta_R)] = \text{constant} \quad ,$$

where K is a constant, *f* is the statistical rate function, *t* is the partial half-life for the transition, Δ_R and δ_R are the nucleus-independent and nucleus-dependent parts of the radiative correction; and δ_C is the isospin symmetry-breaking (Coulomb) correction. The *ft* value that characterizes any β transition depends on three measured quantities: the total transition-energy, the half-life of the parent state and the branching ratio for the particular transition of interest. The transition energy Q_{EC} is required to determine the statistical rate function while the half-life and branching ratio combine to yield the partial half-life. Presently nine transitions have been determined with sufficient accuracy to confirm CVC at the level of $3 \cdot 10^{-4}$. The average value of $\mathcal{F}t$ is 3072.7 ± 0.8, with a corresponding chi square per degree of freedom of 0.42 [Har05].

These data together with the muon lifetime also provide the most accurate value for the up-down quark mixing matrix element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, V_{ud}. The current status of V_{ud} is reviewed by Hardy and Towner in ref. [Har05]. In particular the value of V_{ud} is given by

$$V^2_{ud} = K/[2G^2_F\,(1 + \Delta_R)\mathcal{F}t] \quad ,$$

where G_F is the weak coupling constant from muon decay; $G_V = G_F\,V_{ud}$. The result obtained is $|V_{ud}|$ = 0.9738 ± 0.0004. It is important to note that the error associated with $|V_{ud}|$ is not predominantly experimental in origin, the largest uncertainties being in Δ_R (± 0.0004) and δ_C (± 0.0003). The unitarity test as it relates to the elements in the first row of the CKM matrix

$$V^2_{ud} + V^2_{us} + V^2_{ub} = 1$$

can be examined using the recommended Particle Data Group [PDG04] values for V_{us} and V_{ub} (i.e. 0.2200 ±0.0026 determined from K_{e3} decay and 0.0036 ± 0.0007, respectively). The result becomes:

$$\sum V^2_{ui} = 0.9965 \pm 0.0014 \quad ,$$

which fails to meet unity by 2.2 standard deviations
Recently, attention has focused on the value of V_{us} which can be obtained from the semileptonic decay of neutral and charged kaons resulting in four independent determinations i.e. from the K^+_{e3}, $K^+_{\mu3}$, K^0_{e3} and $K^0_{\mu3}$ branching ratios. In these measurements it is necessary to determine not only the decay rate but also the momentum dependence of two form factors as well as theoretical estimates of isospin and SU(3) symmetry breaking effects. The E865 experiment at Brookhaven recently reported [She03] a new value of V_{us} from a high statistics measurement of K^+_{e3}. The result 0.2272 ± 0.0023_{stat} ± 0.0019_f would eliminate the unitarity 'problem', however it is inconsistent with preliminary results from the KLOE experiment which is able to measure all four decay branches [Dur03]. Recently [Ale04], the KTeV(E832) experiment at Fermilab reported a value for V_{us} = 0.2252(22). Further, Cabibbo [Cab04] from a reanalysis of semileptonic hyperon decays neglecting SU(3) symmetry breaking effects obtained a value for V_{us} =0.2250(27). In contrast, the NA48 collaboration at CERN found a value of V_{us} = 0.2187(22) [Lai04], in agreement with previous measurements. In this case the uncertainty was dominated by the theoretical uncertainty in the form factor $f_+(0)$. With a number of new experiments in progress (E865, KLOE, NA48/2 and CMD2) [Dur03] the present uncertainty in the value of V_{us} is expected to be resolved in the coming years.

Nevertheless, continued effort to reduce the uncertainty in V_{ud} remains a high priority since the unitarity test of the elements in the first row of the CKM matrix is, at the present time, the most precise unitarity test that can be applied to the CKM matrix.

Since the failure in the unitarity of the CKM matrix would imply physics beyond the minimal Standard Model it is important to eliminate all possible trivial explanations for the apparent discrepancy. To restore unitarity, the calculated radiative corrections for all nine nuclear transitions would have to shift downwards by 0.3% (as much as one-quarter of their current value), or the calculated isospin symmetry-breaking corrections shift upwards by 0.3% (over one-half of their value), or some combination of the two. However, because the leading terms in the radiative corrections are so well founded, attention has focused more on the Coulomb corrections. Although smaller than the radiative corrections, the Coulomb corrections are clearly sensitive to nuclear structure because the Coulomb and charge dependent nuclear forces destroy isospin symmetry between the initial and final analog states in superallowed beta decay. As a result, there are different degrees of configuration mixing in the two states and the radial wave functions of the converting proton and the corresponding neutron differ because their binding energies are not identical. We accommodate both effects by writing $\delta_C = \delta_{C1} + \delta_{C2}$.
Methods to calculate δ_C have been developed by Towner *et al* [Tow77] and Ormand and Brown [Orm95]. Both methods employ the shell model to calculate δ_{C1} but derive δ_{C2} by two different methods: 1) from full-parentage expansions in terms of Woods-Saxon radial wave functions, and 2) from a self-consistent Hartree-Fock calculation. The values of δ_C predicted by the two methods are in reasonable relative

agreement for the nine well-known transitions with A ≤ 54 but differ absolutely by ~0.07%. This difference is much less than the 0.3% required to resolve the unitarity discrepancy.

As mentioned previously the present error in *Ft* determined from the nine well-known superallowed transitions is not dominated by experimental uncertainties. However, if we accept the premise that it is valuable for experiments to be at least a factor of two more precise than theory then an examination of the world data shows that the Q_{EC}-values and half-lives for several of the nine well-known superallowed transitions can all bear improvement. Such improvements are now feasible. The Q_{EC}-values are reaching the required level as mass measurements with new on-line Penning traps such as ISOLTRAP [Kel04, Muk04] and the CPT [Sav04, Sav05] become possible. In particular, the recent determination of the Q_{EC} value for decay of the superallowed β-emitter ^{46}V obtained by measuring the difference in the masses of ^{46}V and its decay daughter ^{46}Ti with the CPT [Sav05], not only improved the precision of this quantity but also revealed a systematic error in a set of 7 measurements that affected previous evaluations of V_{ud} by 0.02%.

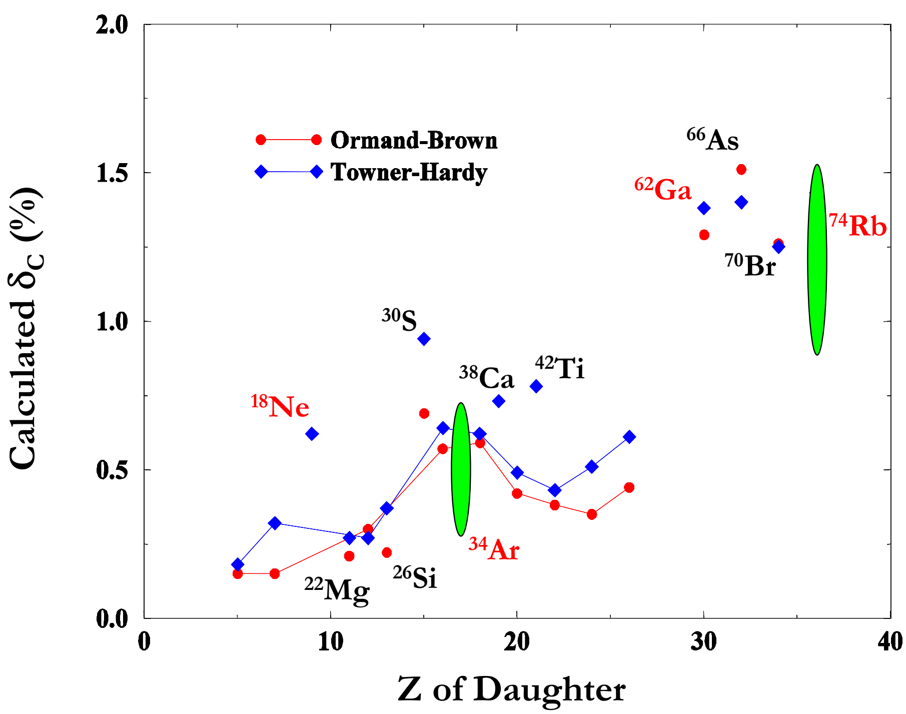


Fig. 3: Values of δ_C derived from two calculations for selected superallowed Fermi β decays. The values for the nine most precisely measured cases are drawn connected by lines. Where data exists, the two calculations give similar results, in other cases, like ^{74}Rb and ^{34}Ar, there can be large differences.

Precision decay measurements for one of the nine well-known superallowed β-emitters ^{26m}Al has also been approved by the TRIUMF EEC (E1028). Since the calculated nuclear structure dependent correction for ^{26m}Al (δ_C - δ_{NS} = 0.261(24)% [Tow02]) is smaller by nearly a factor of two than those for the other eight well-known superallowed β-emitters it is an ideal case to pursue a reduction in the experimental errors for all three relevant quantities. The ultimate goal is to reduce the experimental uncertainty in *ft* for ^{26m}Al by a factor of three.

Improvements will also come as we increase the number of superallowed emitters accessible to high accuracy measurements. In particular, the δ_C corrections are predicted to be much larger for the heavier *fp*-shell nuclei [Orm95]. The lifetime and branching ratio measurements for ^{74}Rb and ^{62}Ga obtained during the first five years of operation of ISAC [Bal01,Pie03,Bro05] demonstrate the potential of this new second-generation radioactive beam facility to deliver the beams required to extend high-accuracy superallowed β-decay studies to heavier $T_z = 0$ emitters. However, for these short-lived isotopes only the TITAN facility has the capability to determine the Q_{EC} values with sufficient precision to provide a critical test of CVC. With the development of suitable ion sources (e.g. surface, negative, FEBIAD, ECR and the TRIUMF Resonant Laser Ion Sources (TRILIS)) and the capability of handling proton beam intensities on target of up to 100 μA, it should be possible to study the complete series of $T_Z = 0$ nuclei from ^{62}Ga to ^{86}Tc.

Table 1. List of isotopes to be measured at TITAN; Given is the isotope, half-life, present mass uncertainty from [AME03], uncertainty that can be achieved with TITAN. In addition the production method, yield, and production year (or expected) are given. Isotopes in bold are already available at ISAC and # indicates that the mass value is estimated from systematic trends. TRILIS is resonant laser ion source. The mass measurement of ^{74}Rb is already approved by the EEC (E966) with high priority.

Isotope	***Half-live***	***Present Δm***	***TITAN Δm***	***(Expected)Yield***	***Ion source***
^{26m}Al	6 s	0.06 keV	57 eV	$9 \cdot 10^5$	TRILIS
^{38m}K	923 ms	0.4 keV	53 eV	$7 \cdot 10^7$	Surface
^{62}Ga	116 ms	28 keV	160 eV	$2 \cdot 10^3$	TRILIS
^{62}Zn	9.1 h	10 keV	100 eV	$5 \cdot 10^3$	TRILIS
^{66}As	96 ms	200 # keV	120 eV	$1 \cdot 10^4$	ECR
^{66}Ge	2.3 h	30 keV	170 eV	$1 \cdot 10^4$	Febiad
^{70}Br	79 ms	360 keV	196 eV	$5 \cdot 10^5$	Febiad
^{70}Se	41 min	60 keV	112 eV	$1 \cdot 10^4$	Febiad
^{74}Rb	65 ms	4 keV	285 eV	$5 \cdot 10^3$	Surface
^{10}C	19.3 s	0.4 keV	20 eV	$5 \cdot 10^6$	ECR
^{14}O	70 s	0.4 keV	22 eV	$1 \cdot 10^5$	ECR
^{26}Si	2.21 s	1 keV	52 eV	$1 \cdot 10^3$	ECR
^{30}S	1.18 s	3 keV	60 eV	$1 \cdot 10^3$	ECR
^{38}Ca	439 ms	4 keV	87 eV	$2 \cdot 10^3$	ECR
^{42}Ti	200 ms	5 keV	147 eV	$1 \cdot 10^2$	Surface

The $T_Z = -1$ superallowed emitters with $18 \leq A \leq 38$ are also amenable to high-accuracy measurements using the radioactive beams from ISAC. Some of these, e.g. ^{18}Ne, ^{30}S and ^{42}Ti are predicted to have large nuclear-structure-dependent corrections. The challenge presented by these decays is to measure large (≥ 5%) branches to non-analogue states.

Overall, the field of high precision and high accuracy experiments will have an enormous impact. Cases as found in [Sav05] showed that the reliability of the previously measured data needs to be checked. Deviations of up to 5 sigma were found for those measurements, which point to thorough re-measurements. The recent compellation [Har05] in particular points out that previously accepted Q_{EC} values need re-confirmation. Penning trap mass spectrometer in general and TITAN in particular are well suited for this task. Table 1 shows the identified cases for the measurement program of superallowed β-emitters that can be produced and ionized now or for which plans exist at ISAC, and hence can be measured with TITAN. The list comprises isotopes, where clear improvement with TITAN can be made, but also isotopes, where a re-measuring with TITAN is desired.

(B) Experimental description:

The experiment will be carried out with the TITAN facility. The isotopes from ISAC will be delivered to the experiment located in the low-energy area of ISAC I. The continuous beam will be brought into the linear cooler and buncher RFQ (RFCT), where it will be cooled via interactions with buffer gas, followed by bunched extraction. The kinetic energy of the beam extracted from this device can be adjusted and will be ~ 2-4 keV.

The ion bunch is transferred to the Electron Beam Ion Trap (EBIT) for charge breeding. The ions will be stored and charge bred for a specific time and the electron beam energy can be adjusted. Then the ion bunch is mass-to-charge selected employing two Wien filters (WIFI 1&2). This provides a beam of only one charge state, and eliminates possible isobaric contamination. The next step is the cooler Penning trap (CPET) where the then highly charged ions are cooled with either electrons or protons. The final step is the mass measurement in a Penning trap (MPET) employing a time-of-flight method. A description of the system can be found in [Dil03,Ryj05] and a schematic is shown in figure 1.

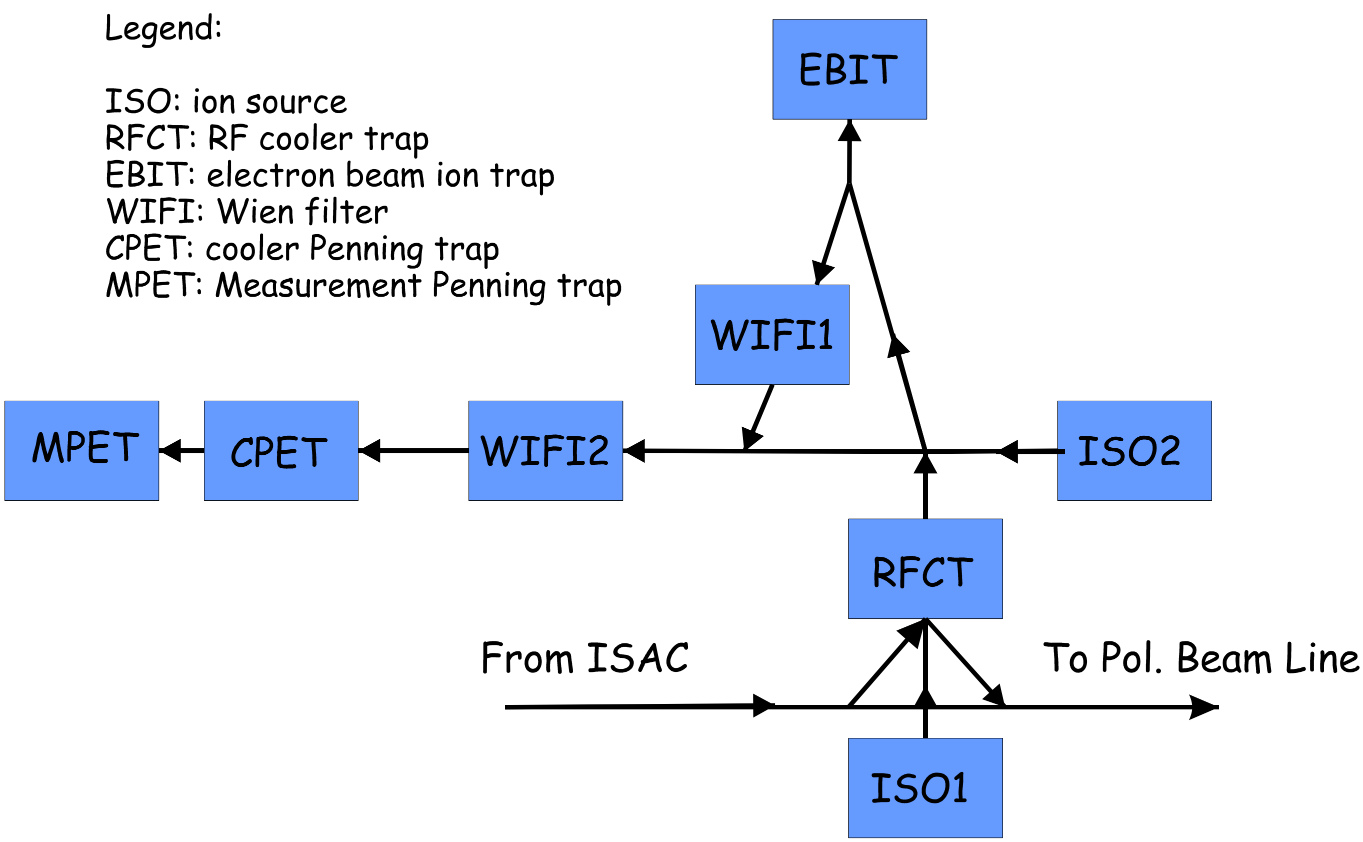


Fig. 1 Schematic of TITAN.

The actual mass measurement is done in the following way using the Penning trap mass spectrometer. Penning traps are the most precise devices to measure masses and our system is designed to carry

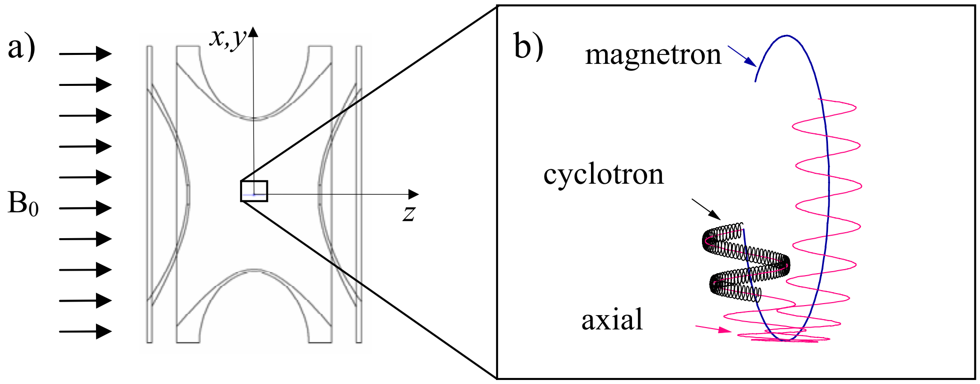


Figure 2. Typical Penning trap a) the geometry and coordinate system; the hyperbolic electrodes create harmonic potential of the form $V(x,y,z) = A(z^2 - (x^2+y^2)/2)$; uniform magnetic field is directed along z-axis $\vec{B} = B_0\hat{z}$. b) ion motion inside the Penning trap consists of three characteristic modes. Along z-axis ion oscillates with axial frequency ω_z. In the x,y-plane the ion motion is a combination of two circular motions with fast modified cyclotron frequency ω_+ and slow magnetron frequency ω_-.

out measurements of atomic masses with an accuracy of $\delta m/m<1\bullet10^{-8}$, even for radioactive isotopes with half-lives well below 100 ms. In the center of such a spectrometer is the set of hyperbolic electrodes placed in the strong magnetic field, schematically shown in figure 2.

The measurement consists of the following steps.

1. Ion injection. The electrostatic potential is removed and a few ions are allowed to drift into the trap. When the ions are in the trap, the potential is raised to confine them. The closing time should be optimized so that the energy of the resulting axial oscillations is minimal. The ion motion after injection is mostly magnetron and axial oscillation, with minimal cyclotron motion.

2. Quadrupole RF excitation. An external RF field of the form $V_Q = V_Q^{(0)}\,(x^2 - y^2)\times\cos(\omega_Q t)$ is overlapped onto the electrostatic trapping potential for the measurement time interval T_{RF}. It converts the magnetron motion into the cyclotron motion of the same amplitude if the resonant condition

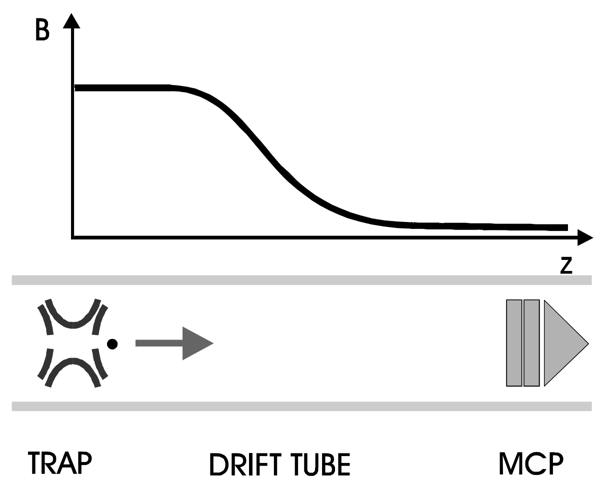
$$\omega_Q = \omega_+ + \omega_- = \omega_c = \frac{qB}{m}$$

is satisfied. The width of this resonance is given by the inverse of the excitation time T_{RF}, which determines the resolving power of this measurement method

$$\frac{m}{\delta m} \propto \omega_c T_{RF}\sqrt{N} = \frac{qB}{m} T_{RF}\sqrt{N} \quad ,$$

where N is the statistical improvement factor. Ideally one would try to increase the excitation time as much as possible. However, in the case of stable ions, this is limited by the storage time in the trap, and in our case of short-lived isotopes it is limited by the decay half-life of the ion.

3. Ejection and TOF measurement. After RF excitation the ions are released from the trap by gradually lowering the electrostatic potential along *z*-axis. The resonantly created cyclotron motion has the same amplitude as the initial magnetron motion. Since $\omega_+/\omega_- >>1$ (typically by several orders of magnitude) the energy and magnetic moment of the ion are drastically increased during the RF excitation. Upon ejection, the ion drifts outside the magnetic field region. On its way it passes through the region with the high gradient of the magnetic field. Here, the ions are accelerated proportionally to their magnetic moment. Thus the ions with high magnetic moment will have a shorter time-of-flight (TOF). This allows one to unambiguously detect the resonant conversion of the magnetron motion into the cyclotron motion, hence the resonant frequency, which is directly proportional to the mass. The schematic and an example is depicted in figure 3.



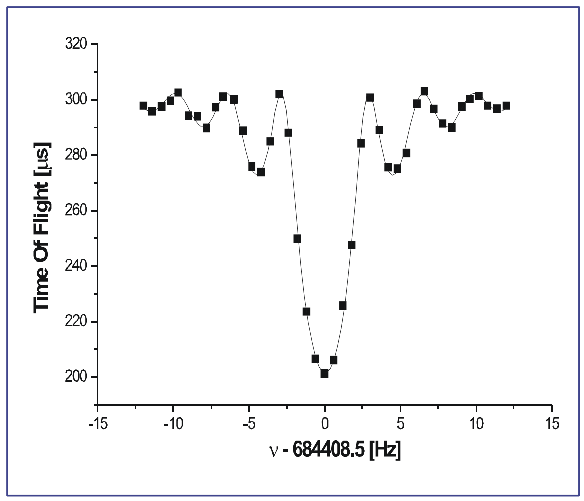


Fig. 3 Left: schematic of the TOF method, where the released ions move through the inhomogeneous magnetic field; right: TOF spectrum, shown is the excitation frequency versus the TOF. The minimum resonance corresponds to the cyclotron frequency, hence allows the mass determination.

Figure 4 shows the relative accuracy of Penning trap spectrometers as a function of measurement time, in sets of magnetic field strength *B* and charge state *q* of the ions. The TITAN system with a magnetic field of 4T will allow measurements with accuracies of better than $\delta m/m < 1 \cdot 10^{-8}$ on isotopes with half-lives as short as 20 ms, when ions with charge states of q = 20 are used.

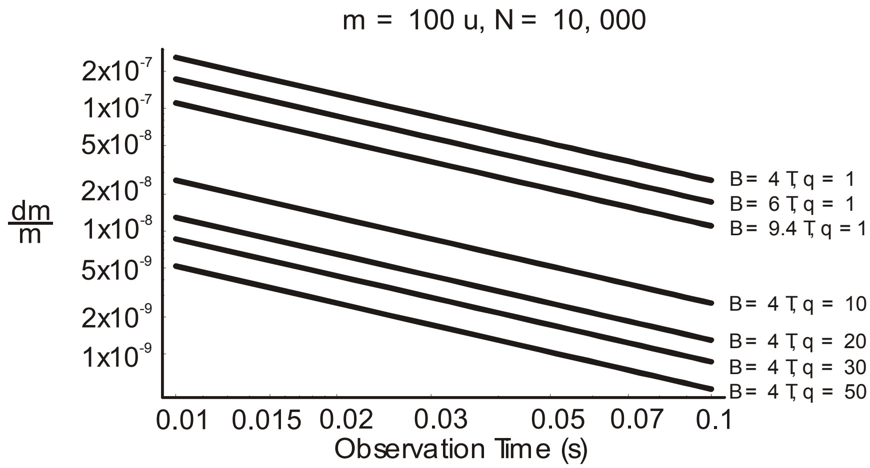


Fig.4 Relative accuracy of the Penning trap measurement as a function of observation time (typically two nuclear half-lives correspond to the applicable observation time). The different sets of graphs represent different charge states q and different magnetic field strength B. The case shown is for 10 000 ions at mass 100.

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TITAN is presently in the built-up phase and concrete efficiencies and performances are not known for all components. This proposal is based on the following assumptions and modifications to the requested beam time will be brought forward at the appropriate time.

Table 2: Assumptions for efficiencies for the various components, which are based on measurements from either individual components made off-line (RFCT) or from similar devices elsewhere:

RFCT	70 %
EBIT	50 %
Charge state	30 %
Cooler trap	50 %
Transfer beam line (incl. Wien filters)	10 %
Detection efficiency	80 %
SUM efficiency	0.4 %

With an overall efficiency of about 0.4 % the minimum requirement is 10^3 ions per second, since the actual TOF measurement is effectively carried out on single ions. The various cases will now be discussed in detail. The current mass values are taken from [Aud03].

1. **^{26m}Al, $T_{1/2}$= 6s, Z=N=13**

   Mass is presently known to 60 eV, however, that case is specifically pointed out in [Aud03] to be troublesome, and a new measurement is advised. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 170 eV. Here the measurement of a re-calibrated (p,n) reaction [Bri94] is used. With TITAN we could solve this and carry out a mass measurement yielding Δm = 60 eV.

   This would be done by producing the beam with a SiC target at ~ 70 µA and the TRILIS, and use suppression of contamination. A yield of $9 \cdot 10^5$ ions/sec has been measured. The measurement would be carried out by breeding the Al to charge state q=11 (breeding time ~ 3 ms), corresponding to the closed He-shell structure. With the two Wien filter as resolving power of R= 50 would be sufficient to provide an isobaric pure beam. The ground state and excited state will be resolved in the Penning trap. At a Penning trap excitation time of T_{rf} = 200ms and N=3000 a resolution of $\delta m/m = 2 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of Δm = 60 eV.

2. ^{38m}K, $T_{1/2}$= 923ms, Z=N=19

Mass of the isomer is presently known to 400 eV, derived by a measurement of the excitation energy (280 eV) and the ground state is known to 400eV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 110 eV. With TITAN we could carry out a mass measurement yielding Δm = 55 eV.

This would be done by producing the beam with a SiC target at ~ 1 µA and a surface source. A yield of $7 \cdot 10^7$ ions/sec has been measured. The measurement would be carried out by breeding the K to charge state q=17 (breeding time ~ 3.5 ms @ electron beam energy 400eV), corresponding to the closed He-shell structure. Possible contamination include Ca. For 400 eV the max. charge state $^{38}Ca^{18+}$ with m/q = 4.6 as for $^{38}K^{17+}$ m/q= 2.2. With the two Wien filter as resolving power of R= 50 would be sufficient to provide an isobaric pure beam. The ground state and excited state will be resolved in the Penning trap. At a Penning trap excitation time of T_{rf} = 500ms and N=3000 a resolution of $\delta m/m = 2 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 55 eV.

3. **^{62}Ga, $T_{1/2}$=116ms, Z=N=31**

Mass is presently known to 28 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 260 keV. With TITAN we could carry out a mass measurement yielding Δm = 161 eV.

This would be done by producing the beam with a ZrC target at ~ 40 µA and TRILIS. A yield of $1.5 \cdot 10^3$ ions/sec has been measured. The measurement would be carried out by breeding the Ga to charge state q=29 (breeding time ~ 25 ms), corresponding to the closed He-shell structure. At a Penning trap excitation time of T_{rf} = 150ms and N=3000 a resolution of $\delta m/m = 2.6 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 161 eV.

4. **^{10}C, $T_{1/2}$=19.3s, Z=6, N=4**

Mass is presently known to 400 eV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 11 eV. With TITAN we could carry out a mass measurement yielding Δm = 161 eV.

The highest yield observed @ TISOL (1991) was $1.4 \cdot 10^6$ ions/s as C and $1.4 \cdot 10^6$ ions/s as CO. The measurement would be carried out by breeding the C or CO to charge state q=6 (breeding time ~ 4 ms), which would be the first experiment with TITAN of fully stripped ions. The CO would be broken up in the EBIT and electron beam energy of 700 eV would be required. At a Penning trap excitation time of T_{rf} = 150ms and N=3000 a resolution of $\delta m/m = 2.0 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 20 eV.

5. **^{62}Zn, $T_{1/2}$=9.1h, Z=30, N=32**

Mass is presently known to 10 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 26 keV. With TITAN we could carry out a mass measurement yielding Δm = 100 eV.

The yield is presently unknown, and a target needs to be developed. (Off-line-batch mode production is to be considered). However, an excitation scheme for TRILIS exists and could be adapted quickly. The measurement would be carried out by breeding the Zn to charge state q=28 (breeding time ~ 27 ms). If the laser ion source is employed a clean be could be possible. At a Penning trap excitation time of T_{rf} = 250ms and N=3000 a resolution of $\delta m/m = 1.6 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 100 eV.

6. **^{66}As, $T_{1/2}$=96ms, Z=33, N=33**

Mass is presently not known at all and only extrapolations from systematic trends are available. The overall uncertainty in the Q_{ec} in [Har05] is given with 50 keV. With TITAN we could carry out a mass measurement yielding Δm = 118 eV.

A target and ion source needs to be developed (possibly the ECR). The measurement would be carried out by breeding the As to charge state q=23 (breeding time ~ 7 ms). An intermediate charge state would be chosen, since the half-life is short (with respect to the relative number of electrons to be removed.) At a Penning trap excitation time of T_{rf} = 150ms and N=10 000 a resolution of $\delta m/m = 2 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 118 eV.

7. **^{66}Ge, $T_{1/2}$=2.26h, Z=32, N=34**

Mass is presently known to 30 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 50 keV. With TITAN we could carry out a mass measurement yielding Δm = 171 eV.

A target and ion source needs to be developed (possibly the ECR). The measurement would be carried out by breeding the Ge to charge state q=30 (breeding time ~ 30 ms). At a Penning trap excitation time of T_{rf} = 150ms and N=3 000 a resolution of $\delta m/m = 2.6 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 171 eV.

8. **^{70}Br, $T_{1/2}$=79ms, Z=35, N=35**

Mass is presently known to 360 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 170 keV. With TITAN we could carry out a mass measurement yielding Δm = 196 eV.

A target and ion source needs to be developed (possibly the ECR). The measurement would be carried out by breeding the Br to charge state q=25 (breeding time ~ 11 ms). Again, an intermediate charge state would be chosen, since the half-life is short with respect to the relative number of electrons to be removed. At a Penning trap excitation time of T_{rf} = 100ms and N=10 000 a resolution of $\delta m/m = 2.8 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 196 eV.

9. **^{70}Se, $T_{1/2}$=41 min, Z=34, N=36**

Mass is presently known to 60 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 170 keV. With TITAN we could carry out a mass measurement yielding Δm = 112 eV.

A target and ion source needs to be developed (possibly the FEBIAD could work). The measurement would be carried out by breeding the Se to charge state q=32 (breeding time ~ 30 ms). At a Penning trap excitation time of T_{rf} = 250ms and N=3 000 a resolution of $\delta m/m = 1.6 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 112 eV.

10. **^{14}O, $T_{1/2}$=70 s, Z=8, N=6**

Mass is presently known to 400 eV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 110 keV. With TITAN we could carry out a mass measurement yielding Δm = 22 eV.

The highest yield observed @ TISOL (1991) was $8 \cdot 10^4$ ions/s with the ECR source. The measurement would be carried out by breeding the O to charge state q=8 (breeding time ~ 4 ms, again fully stripped). At a Penning trap excitation time of T_{rf} = 200ms and N=3 000 a resolution of $\delta m/m = 1.6 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 22 eV.

11. **^{26}Si, $T_{1/2}$=2.2 s, Z=14, N=12**

Mass is presently known to 1 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 3 keV. With TITAN we could carry out a mass measurement yielding Δm = 52 eV.

A target and ion source needs to be developed (possibly the ECR). The measurement would be carried out by breeding the Si to charge state q=12 (breeding time ~ 5 ms). At a Penning trap excitation time of T_{rf} = 200 ms and N=3 000 a resolution of $\delta m/m = 2 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 52 eV.

12. **^{30}S, $T_{1/2}$=1.2 s, Z=16, N=14**

Mass is presently known to 3 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 3 keV. With TITAN we could carry out a mass measurement yielding Δm = 52 eV.

A target and ion source needs to be developed (possibly the ECR). The measurement would be carried out by breeding the Si to charge state q=12 (breeding time ~ 5 ms). At a Penning trap excitation time of T_{rf} = 200 ms and N=3 000 a resolution of $\delta m/m = 2 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 60 eV.

13. **^{38}Ca, $T_{1/2}$=439 ms, Z=20, N=18**

Mass is presently known to 4 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 5.9 keV. With TITAN we could carry out a mass measurement yielding Δm = 87 eV.

This would be done by producing the beam with a TiC target at ~ 40 µA and surface source. A yield of $2 \cdot 10^3$ ions/sec has been measured. A TRILIS scheme exists (has been used off-line), hence improvements, or purification could be applied. The measurement would be carried out by breeding the Ca to charge state q=19 (breeding time ~ 43 ms). The fully stripped system is needed for a sufficient suppression of K. At a Penning trap excitation time of T_{rf} = 150 ms and N=3 000 a resolution of $\delta m/m = 2.4 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 87 eV.

14. **^{42}Ti, $T_{1/2}$=200 ms, Z=22, N=20**

Mass is presently known to 5 keV. No direct mass measurement has been carried out. The overall uncertainty in the Q_{ec} in [Har05] is given with 5.4 keV. With TITAN we could carry out a mass measurement yielding Δm = 147 eV.

This would be done by producing the beam with a Ta target at ~ 50 µA and surface source. A yield of $1 \cdot 10^2$ ions/sec has been measured but in addition a TRILIS scheme exists, hence improvements, or purification could be applied. The measurement would be carried out by breeding the Ti to charge state q=22 (breeding time ~ 43 ms). The fully stripped system is needed for a sufficient suppression of contamination Ca, K etc. At a Penning trap excitation time of T_{rf} = 100 ms and N=3 000 a resolution of $\delta m/m = 2.4 \cdot 10^{-9}$ can be reached, corresponding to an absolute accuracy of about Δm = 147 eV.

(D) Readiness

The TITAN facility is presently being set up. First experiments with radioactive beam are planned for the second half of the year 2006. Tests will be carried out with the internal off-line ions sources and with the OLIS system prior to requesting on-line beam time being made available.

(E) Requested beam time:

The requested beam time is based on the assumed efficiency, a reasonable constant radioactive beam current, required time for magnetic field calibrations for the measurement magnet, and optimization procedures for the EBIT. **For all measurements a minimum yield of $1 \cdot 10^3$ ions/s is required**. For productions yields above 10^3 ions/s the experimental procedure is not faster, since the duty cycle is limited by the preparation time in the EBIT and the Penning trap. All measurements will be carried out with a very small number of ions (1-4 ions) per cycle in the measurement Penning trap. A conservative estimate is given, and could be adjusted if the performance is significantly better, or set-up and required optimization times are substantially shorter.

	Isotope	Requested # of 12h shifts	Comments
1.	^{26m}Al	4	Beam available
2.	^{38m}K	4	Beam available
3.	^{62}Ga	6	Beam available
4.	^{62}Zn	4	Development target & source
5.	^{66}As	8	Development target & source
6.	^{66}Ge	4	Development target & source
7.	^{70}Br	8	Development target & source
8.	^{70}Se	6	Development target & source
9.	^{10}C	4	Development source
10.	^{14}O	4	Development source
11.	^{26}Si	6	Development target & source
12.	^{30}S	6	Development target & source
13.	^{38}Ca	8	Beam available
15.	^{42}Ti	12	Improvement of source

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