EINGEGANGEN 22. Mai 2000

Date of Receipt: ______ GSI Exp. No. S244

Proposal for an Experiment at GSI, Darmstadt

1. Title of Proposal: **The GSI FRS γ-Ray Spectroscopy Campaign**

x New Proposal

x Continuation of Previous Experiment (Exp. No.:..S210................)

2. Spokesperson:	Full Address:	Telephone/Fax:	email:
P.H. Regan	Univ. Surrey		p.regan@surrey.ac.uk
M. Hellström	Univ. Lund		hellstr@beta.kosufy.lu.se
J. Gerl	GSI		j.gerl@gsi.de
M. Pfützner	Univ. Warsaw		pfutzner@minuv.edu.pl

Participants:	Address:	Telephone:	email:
FRS γ-campaign Collaboration	(see overview document)		

3. GSI Contact Person: J. Gerl

UNILAC: ☐ SIS: x ESR: ☐

Requested Beam Properties and Experimental Equipment:

a) Ion Species (Charge State): ^{48}Ca/^{50}Ti, ^{58}Ni, ^{96}Ru, ^{136}Xe, ^{208}Pb, ^{238}U
b) Intensity (Particle nA): $10^7 - 10^9$ /s
c) Energy (MeV/u): 500 - 1000
d) Target Station: FRS
e) Special Requests on Beam Properties: ______
f) Special Target Requirements: ______
g) Electronic Pool: ______
h) GSI Computers: ______
i) Further Assistance Requested from GSI: ______

For Safety Aspects of the Proposal please fill in the Extra Form.

Requested Beam Time (in Shifts of 8 Hours each)

Total: 213 Number of Runs: 2-3

Prefered Dates: 12.2000 – 2.2001 Dates when you cannot run: ______

Detailed description of the Proposal: Please attach an experiment description (max. 10 pages including figures) which should summarize the scientific justification and relevant technical details for the proposed experiment. For a continuation request, a brief status report of the previous as well as an outline of the future experiments should be given.

Date:______________ (Do not fill in) GSI Exp.No.:______________

SUPPLEMENTARY FORM FOR SAFETY ASPECTS OF A PROPOSAL

Title:__**The GSI FRS γ-Ray Spectroscopy Campaign**

Spokesperson: P.H. Regan, M. Hellström, J. Gerl, M. Pfützner GSI-Contact Person:__J. Gerl

1. General Safety

   a. Do you use combustible or hazardous gases within your experiment (e.g. gas target, gas detectors)? Music chamber at FRS — Yes x No ☐
   What sort of gases?
   Which quantities or flow rates? ______________

   b. Do you use other dangerous (e.g. toxic, inflammable, biologically hazardous etc.) materials within your experiment? — Yes ☐ No x
   What sort of materials? ______________
   Which quantities? ______________

   c. Is your vacuum set-up equipped with fragile parts like thin glass or foil windows etc. (danger of implosion)? — Yes ☐ No x
   Brief description of the construction: ______________
   ____

   d. Is it intended to move heavy parts for setting-up your experiment or during the experiment? — Yes ☐ No x
   Brief description of the equipment and working procedure: ______________
   ____

2. Radiation Safety

   a. Do you use radioactive sources or materials on-site? — Yes x No ☐
   What sources? 152Eu, 60Co
   Which activities? 370kBq each

   b. Is it intended to direct the beam through air or other gases? — Yes x No ☐
   Beam sort, energy, intensity: FRS fragments
   Distance through air or gas: 5 m

3. Electrical/Laser Safety

   a. Do you use electrical instruments on-site? — Yes ☐ No ☐
   Max. Voltage/max. current: ______________

   b. Do you use high-intensity radio frequency (RF) sources on-site? — Yes ☐ No x
   Frequency region/power: ______________

   c. Do you use lasers in your experiment? — Yes ☐ No x
   Laser-type, max. power: ______________

4. Is there any other special safety aspect to be considered in connection with your proposal ? ______________ — Yes ☐ No x

Date:
19.5.2000

Spokesperson of the experiment:

The GSI Fragmentation Gamma-Ray Spectroscopy Campaign: New Vistas in Discrete Line Nuclear Structure Studies

Co-spokespersons P.H. Regan[1], M. Hellström[2], J. Gerl[3] and M. Pfützner[4]

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[2] *Div. of Cosmic and Subatomic Physics, Lund University, SE-22100, Sweden*
[3]*GSI, Planckstrasse 1, D-64291 Darmstadt, Germany*
[4]*Institute of Experimental Physics, Warsaw University, Pl-00861 Warsaw, Poland*

On behalf of an international collaboration including, GSI (Germany), Surrey, Liverpool, York, Brighton, Manchester, Daresbury (UK), Saclay, GANIL, Bordeaux, IPN Orsay, Grenoble (France), Lund, Uppsala (Sweden), Leuven (Belgium), Oak Ridge, Uni. Tennesse Knoxville, Notre Dame (USA), Jyväskylä (Finland), ANU Canberra (Australia), Universita Frederica II, Napoli (Italy), Santiago De Compostella (Spain), NBI-Copenhagen (Denmark), Warsaw University (Poland)

Abstract:
A unique opportunity has arisen whereby a highly efficient and versatile, modular array of germanium detectors is available for nuclear structure studies using secondary beams from the GSI Fragment Separator. The aim of this proposal is to present a variety of different experiments using this array in a coherent and time efficient manner. The overall physics aims of this 'campaign' are the elucidation of the structure of highly exotic nuclei using a combination of high-resolution gamma-ray spectroscopic techniques including isomer spectroscopy and relativistic Coulomb excitation. We hope to make the most efficient use of this equipment by having a 'dedicated' set-up which should reduce the time spent on particle identification calibrations and detector mounting and maximise the effort spent on studying new physics vistas.

Overview of Campaign.

Over the last decade many highly successful experiments performed at GSI have highlighted the broad range of exotic nuclear species which can be accessed using projectile fragmentation (eg. [1, 2, 3, 4, 5]) and projectile-fission (eg. [6, 7, 8]). In these experiments, the secondary reaction products were separated and identified using the GSI Fragment Separator [9]. This work has opened up previously inaccessible regions of the nuclear chart for study, in particular the study of nuclei with highly exotic neutron to proton ratios. The study of the internal structure of these nuclei poses many topical questions to nuclear physicists, including the possible re-arrangement of 'usual' shell model orbitals due to perturbations in the mean field and the effect of the structure of these nuclei on nucleosynthesis via the *rp* and *r*-process. The measured production yields of exotic nuclei in these experiments have provided data points to test predictions of production cross-sections using the EPAX parameterisation [10] and in some cases, entrance spin distributions using the abrasion/ablation model [11, 12]. In this project, we propose to utilise this clean and efficient mode of exotic nuclei production, coupled to a high efficiency gamma-ray detection set-up to perform spectroscopy measurements in a wide range of otherwise inaccessible systems.

A number of novel methods for investigating the internal structure of the exotic proton or neutron-rich nuclei produced in projectile fragmentation or projectile fission have recently been developed. The current collaboration represents a collection of 'world experts' in this evolving field, who have pioneered experiments coupling projectile fragmentation/fission reactions with gamma-ray spectroscopic techniques. For example, measurements of isomeric decays with lifetimes in the nanosecond to millisecond regime have been performed over a wide range of nuclei at GANIL using the projectile fragmentation technique with beams lighter than A=100 [13, 14, 15, 16, 17, 18, 19]. Many new physics results have arisen as a result of this work, including studies of isospin symmetry on the N=Z line [15, 18]; the effect of the N=40 and N=50 shell closures in neutron rich nuclei [19, 20]; identification of single particle states and shell model effective charges in nuclei around the doubly magic $^{100}_{50}\mathrm{Sn}_{50}$ core [16]; and high deformation prolate-oblate shape-coexistence [14, 15].

The combination of much higher velocities (allowing thicker targets and increased overall yield) plus the stronger magnets of the FRS compared to LISE, currently makes the SIS+FRS combination superior for the study of more neutron rich or heavier systems. In 1996, pioneering work performed at GSI using a 1 GeV per nucleon ^{238}U beam revealed isomeric decays in very neutron rich lead systems [21]. This initial experiment used a rather modest gamma-ray detection set-up, but clearly revealed the potential for such work in heavy nuclei. This experiment also highlighted (see fig. 1) the power of the technique in synthesising very exotic nuclei, by identifying the neutron rich species, ^{219,220}Po, some ninety years after the discovery of ^{218}Po [21]! A later experiment was performed in April 1999, using a 1 GeV/nucleon ^{208}Pb with a higher efficiency 4 clover set-up. Using K-isomeric states [22] as experimental tags, the results clearly demonstrated the power of this 'isomer spectroscopy' technique for the study of medium to high spin states in exotic, heavy nuclei. Highlights of this work included the identification of high-spin, $K = \frac{35}{2}\hbar$ isomeric decays in three nuclei in the A$\sim$180 region [23, 24, 25, 26] (see fig.2). This work clearly demonstrated that discrete line spectroscopy of the decay from high-spin states in exotic, neutron rich systems is experimentally viable using this technique. Additional exciting results from the ^{208}Pb run were the identification of gamma-cascades in otherwise spectroscopically inaccessible neutron rich tungsten nuclei (^{190}W, see fig.3), the tentative results of which indicate a new sub-shell effect in heavy neutron rich nuclei [24]. Highlights of the work based on the projectile fission of ^{238}U beams includes the identification of the doubly magic $^{78}_{28}\mathrm{Ni}_{50}$ [6, 7] and new spectroscopic information on effective charges and single particle energies in highly neutron-rich systems. At the end of 1999, an experiment using the projectile fission of a ^{238}U beam to study very neutron rich systems around the $^{132}_{50}$Sn$_{82}$ doubly magic core resulted in the first, tentative spectroscopic information in a number of experimentally challenging nuclei [27] (see fig.4).

A number of successful 'in-beam' studies have been performed on the spectroscopy of neutron rich light nuclei centred on the N=20 and N=28 shell gaps by groups at MSU [28, 29], RIKEN [30] and GANIL [31]. The gamma-group at GSI has also contributed significantly in this new area with the development of 'relativistic in-beam' spectroscopy [32] of e.g. ^{44}Ar and the recently performed experiment on the study of N=Z systems using relativistic Coulomb excitation [33].

In all of these efforts, the success depended on a combination of sufficient primary beam intensity, the consistent performance of the ion source, SIS accelerator and FRS, and a high efficiency, high resolution gamma-ray detection array. The exotic nature of many of the nuclei under study means that a significant portion of the allocated beam time is often required to carefully calibrate the energy loss and time of flight characterstics of the FRS. This is required in order to obtain correct identification spectra and also to 'de-bug' the specialist electronics and data acquisition set-up for these experiments. The purpose of this proposal is to maximise the efficiency of work by presenting a coordinated 'campaign' of nuclear structure based experiments using the FRS with a combination of a high efficiency and versatile gamma-ray set-up.

The specific physics aims of the campaign are listed in the next section and in the appendices. We believe that such a coordinated effort has the advantage of maximising the beam time associated with collecting the gamma-ray data by combining the beam time required for several FRS experiments for the particle identification calibration. We envisage a total running time for the entire campaign of approximately two months, for a series of both 'isomer' and 'in-beam' type experiments. (see table 1 below). We request that the EA judges each physics case and award beam time on its own merit, but we choose to present them as a collection of related experiments which would benefit from a dedicated set-up. It is envisaged that once the decision of the EA with regards to beam time has been made, the collaboration will plan the man-power requirements for the successful implementation of the campaign so as to manage this project in the most efficient manner possible. To this end, it is envisaged that a Surrey post-doc (Dr. Zsolt Podolyak) will join the 'in-house' GSI team for a period of approximately four months and act as a liaison physicist with the other, outside members of the collaboration.

We believe that in addition to the interesting physics opportunities which such a coordinated campaign will realise, it is also timely, in that most of these experiments can ONLY currently be performed at GSI. While the upgrade at MSU and the low-energy beams associated with SPIRAL may make these laboratories competitive in the proposed areas of physics over the next five years, at the current time GSI has a distinct advantage in this field.

Below is a summary of the proposed experiments and a brief summary of the main physics objectives. The specific details can be found in the individual two page physics cases in the attached appendices.

Main Physics Aims.

After an initial discussion meeting held in Novermber 1999 in Warsaw by some members of the collaboration, a list of physics objectives was drawn up which could be addressed as part of a coherent campaign of gamma-ray spectroscopy experiments using secondary fragmentation/fission beams transmitted by the FRS. This list is given below.

- N$\sim$Z, isospin symmetry studies with isomers.
- 'In-beam' collectivity measurements of very neutron rich systems with N$\approx$20,28.

- Isomer studies around the doubly magic $^{78}_{28}\mathrm{Ni}_{50}$ and $^{132}_{50}\mathrm{Sn}_{82}$.
- Deformed isomers at the proton drip line (around $^{140}_{66}\mathrm{Dy}_{74}$)
- g-factor measurements with radioactive ions.
- Studies of shape coexistence in neutron rich N=74 systems (across the Z=50 shell).
- Studies of the high deformation region around the 'doubly mid-shell' nucleus $^{170}_{66}\mathrm{Dy}_{104}$.
- K-isomers to study the shape evolution of neutron rich nuclei with A$\sim$ 170 → 200.
- Triple shape coexistence around the very neutron deficient (N$\sim$104) Z$\sim$82 nuclei.
- High spin shape coexistence and isomer spectroscopy of neutron-rich Po→U nuclei.

Each specific interest group within the collaboration was called upon to prepare a brief, two page physics case summary for specific experiments related to the major aims listed above. These 'sub-experiments' are summarised in the table below. The specific two page physics cases for each experiment are given in the appendices at the end of this overview document.

It is clear that there is a natural division between the experiments into what might be considered *isomer* experiments and other, *in-beam* experiments, the latter of which would require modifed set-ups. We propose to keep a standard set-up for the isomer spectroscopy experiments, a significant number of which require a ^{238}U beam. We also ask that all of the 'isomer' proposals (including those which require ruthenium, lead and nickel beams) be ran as contiguously as possible to maximise the efficiency of time taken for the mechanical and electronics/data acquisition set-up, together with the energy losses and time of flight etc. calibrations through the FRS.

Germanium Detectors and Associated Electronics

We propose to use a high efficiency gamma-ray array consisting of at least six CLOVER style germanium detectors [34]. These will comprise two VEGA, large clovers and 4 EXOGAM clover detectors. In addition, we anticipate the use of at least one LEPS detector supplied by the University of Surrey for increased low energy detection efficiency (which is often important in the study of isomeric decays) in the array. Additional, highly segmented germanium detectors for in-beam experiments are also likely to be available from the Surrey/Liverpool/Daresbury Gamma-Ray Tracking collaboration. The first 'window of opportunity' for the availability of the EXOGAM detectors is due to the GANIL shutdown in January and February of 2001.

Our previous experience on isomer studies at the FRS has revealed a loss of effective efficiency due to the phenomenon of the 'radiation-flash' whereby a significant fraction of the germanium detectors are 'blinded' due to prompt radiation emitted when the ion of interest comes to rest in the stopper. A possible solution to this problem is to use the new DGF (digital gamma finder) modules [35] which time stamp each individual gamma event with a 25 ns (40 MHz) clock. This means that once a detector which has been blinded by the prompt flash has recovered (the order of 1 μs), it can still be used to detect delayed events for the rest of the master trigger time window. (Note that the use of DGF modules also fits in well with the plans of a future 'total data readout' (TDR) system as envisaged for use with the GREAT spectrometer at GSI).

Nuclei of Interest	Primary Beam	Proposers	Experiment Type	Request
IN-BEAM EXPTS.				
^{132}Te	^{236}Xe-frag.	Ch. Schlegel	Low-E Coulex	6 days
^{36}Mg, N$\geq$20	^{48}Ca($\rightarrow^{38}$Si) or ^{50}Ti($\rightarrow^{36}$Si)	J. Gerl	2 step frag.+ in-beam	7 days
^{80}Zr, N$\sim$Z	^{96}Ru-frag.	S. Mandal	Coulex + g-factors	7 days
ISOMER EXPTS.				
^{54}Ni, $T_z = -1$	^{58}Ni-frag.	D. Rudolph	μs-isomer	4 days
^{82}Nb, ^{86}Tc	^{96}Ru-frag.	P.H. Regan B. Blank	μs-isomer	5 days
^{76}Ni	^{238}U-fiss.	M. Bernas H. Grawe	μs-isomer	7 days
N=74, ^{124}Sn	^{136}Xe-frag.	A.M. Bruce D.M. Cullen	μs-isomer	4 days
^{132}Sn	^{238}U-fiss.	M. Hellström M. Mineva	μs-isomer	4 days
N=74, ^{140}Dy	^{208}Pb-frag.	D.M. Cullen A.M. Bruce	μs-isomer	5 days
N$\leq$104 Pb,Po,Rn	^{238}U-frag.	R.D. Page R. Wadsworth	μs-isomer	5 days
A$\sim$170-200 ν-rich	^{238}U-frag.	P.M. Walker P.H. Regan	μs-isomer	5 days
A$\sim$180-200 ν-rich	^{238}U-frag.	Ch. Schlegel	ms-s isomer isomer	7 days
A$\sim$230, Po-Th	^{238}U-frag.	Zs. Podolyak	μs-isomer	5 days

Table 1: Summary of physics cases which have been submitted under the 'campaign' umbrella. The projects naturally separate into 'isomer' and 'in-beam' type experiments. Note we envisage similar mechanical and electronics set-up for all of the 'isomer'-type experiments.

Relevance to Future Work and Plans

This work is a natural pre-cursor to the GREAT spectrometer, which is being planned at Jyväskylä and will ultimately also be used at GSI. GSI is also a member of the EXOTAG collaboration and has received EU Framework V funding for this project. This campaign is a natural starting point for such work.

Beam Time Request and Counting Rate Estimates

As table 1 shows, we require a total of 33 days for ^{238}U beam for a variety of isomer experiments. We also require an additional 18 days for the ^{58}Ni, ^{96}Ru, ^{136}Xe and ^{208}Pb beams, making a total of 51 days for the 'isomer' part of the campaign. The specific breakdown for each 'physics' request is outlined in the relevant two page summary given in the appendices. Each beam change will also require an extra day to retune the FRS and to check the energy loss and time of flight calibrations for the new beam(s).

The 20 days requested for the in-beam experiments will require separate set-ups for each experiment and therefore are to also be treated individually.

References

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Institution	Individuals
Surrey	P.H. Regan, Zs. Podolyak, C.J. Pearson, W.N. Catford, P.M. Walker, W. Gelletly, M. Caamano *et al.*
GSI	J. Gerl, Ch. Schlegel, H. Grawe, H. Geissel, S. Mandal, H.J. Wollersheim, P. Armbruster *et al.*
Lund	M. Hellström , M.Mineva, D. Rudolph, C. Fahlander *et al.*
Warsaw	M. Pfützner, Z. Janas, M. Sawicka *et al.*
Liverpool	R.D. Page, T. Enqvist, P.J. Nolan, P.A. Butler *et al.*
York	R. Wadsworth *et al.*
Brighton	A.M. Bruce *et al.*
Staffordshire	M.A. Bentley *et al.*
Manchester	D.M. Cullen, S.J. Freeman, J. Durell *et al.*
CEA-Saclay	W. Korten, M. Rejmund, K. Hauschild, R. Lucas *et al.*
IPN-Orsay	M. Bernas, F. Azaiez *et al.*
Daresbury	R.C. Lemmon, J. Simpson, D.D. Warner
CENBG-Bordeaux	B. Blank, J. Giovinazzo, M. Chartier *et al.*
ANU-Canberra	G.D. Dracoulis
Leuven	G. Neyens *et al.*
GANIL	M. Lewitowicz *et al.*
Oak Ridge	K. Rykaczewski *et al.*
U. Tennessee	R. Grzywacz *et al.*
Notre Dame	M. Wiescher, A. Aprahamian, S.M. Vincent
Jyväskylä	R.Julin *et al.*
Santiago de Compostella	J. Benlliure *et al.*
NBI Copenhagen	G. Sletten *et al.*
Grenoble	J.A. Pinston, J. Genevey *et al.*

Table 2: Members and Institutions associated with the various experimental proposals of the Campaign.

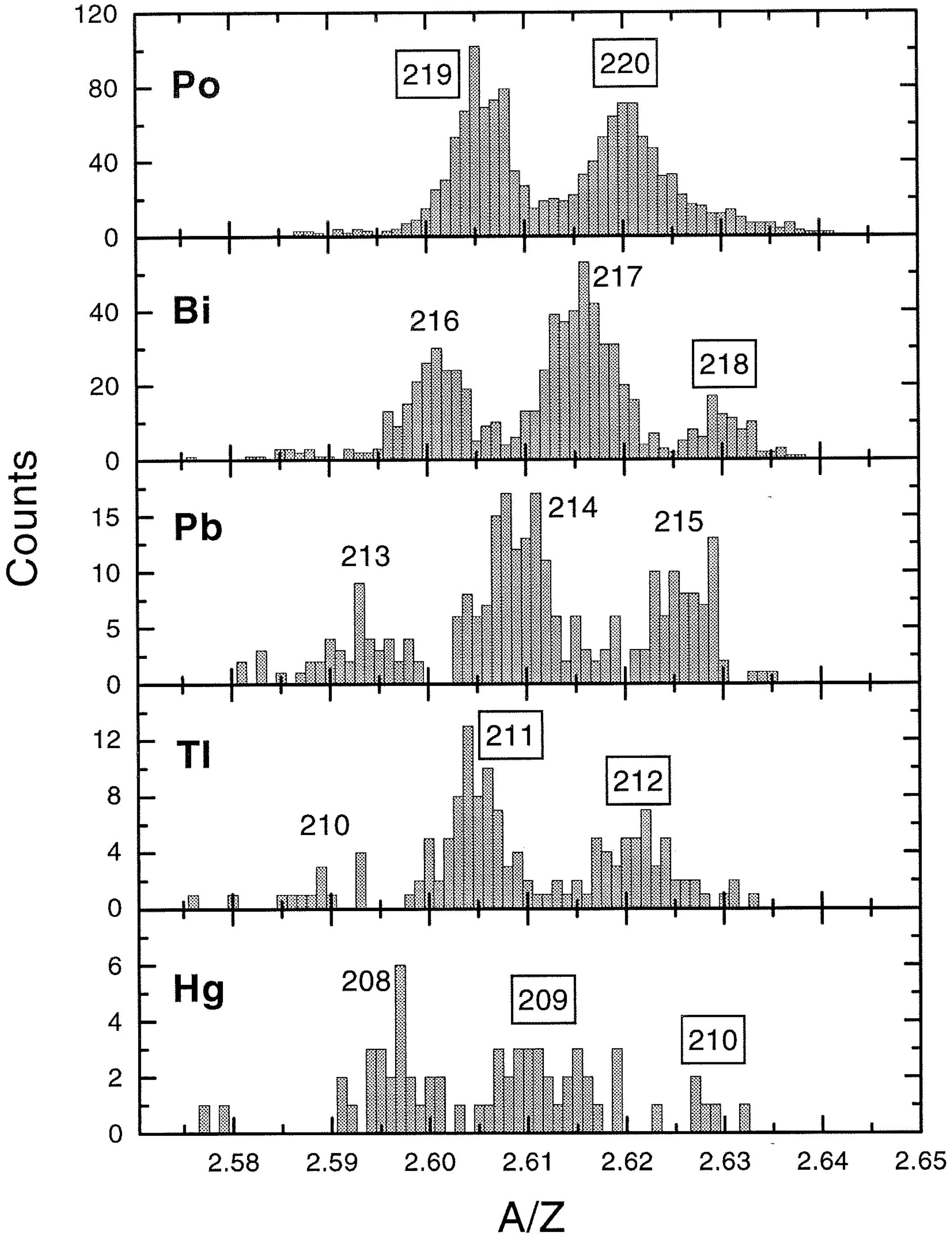

Figure 1: Identification spectra for neutron rich nuclei identified in the fragmentation of ^{238}U [21], including the identification of ^{219,220}Po.

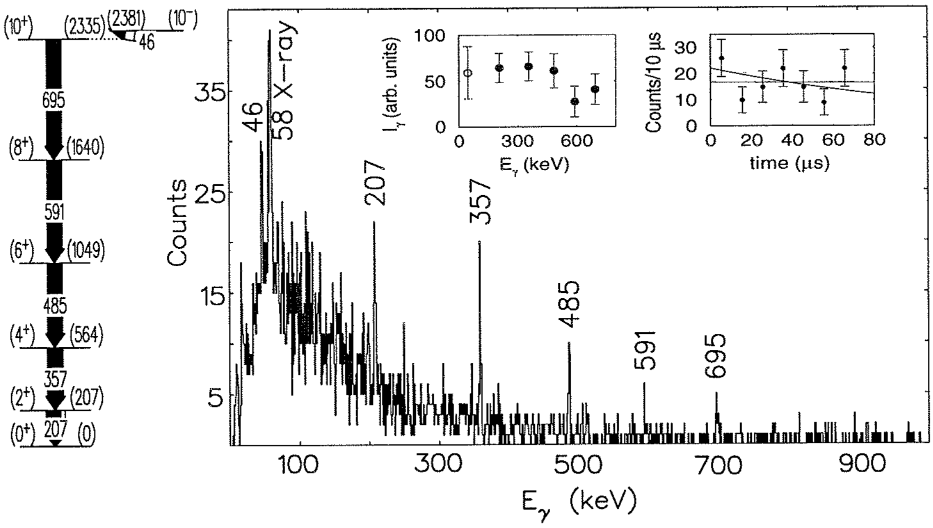

Figure 2: Proposed decay scheme and delayed γ-ray spectra for ^{190}W observed in the fragmentation of a 1 GeV/nucleon ^{208}Pb beam at GSI [24].

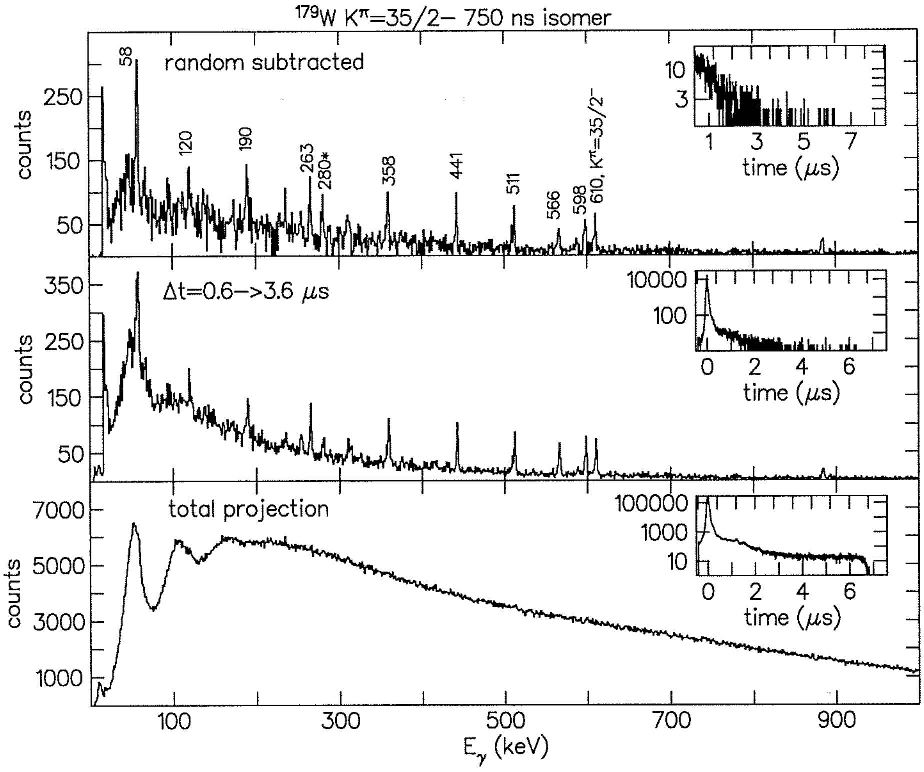

Figure 3: Delayed gamma-ray and time spectra, showing the decay of the $K^\pi = \frac{35}{2}^-$ isomer in ^{179}W as observed following the fragmentation of a ^{208}Pb beam [23].

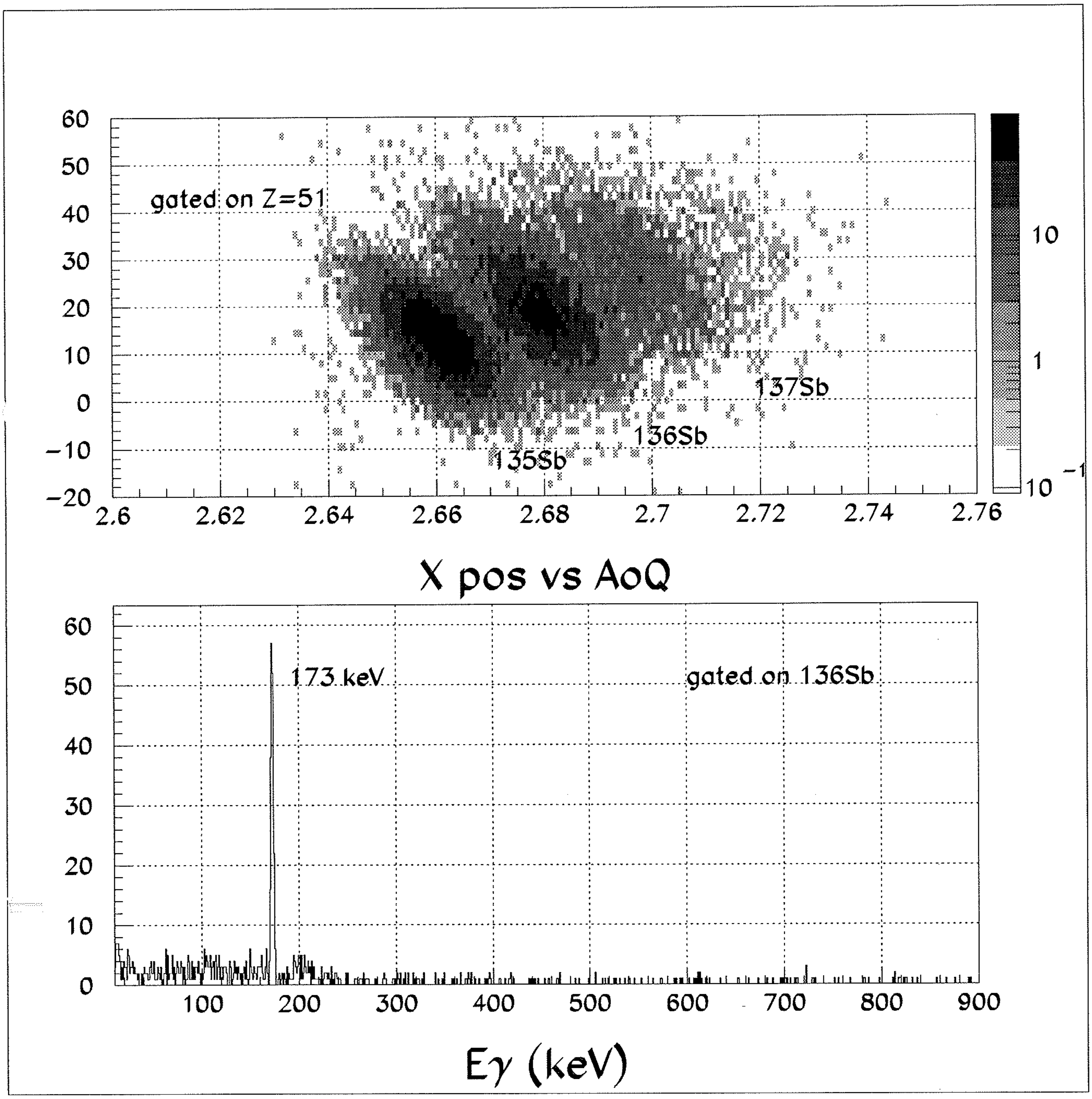

Figure 4: Particle identifiication and delayed gamma-ray spectrum showing the isomeric decay in $^{136}_{51}\mathrm{Sb}_{85}$, following the projectile fission of ^{238}U [27].

Measurement of B(E2)-values by Coulomb excitation of secondary beams slowed down to the Coulomb barrier

Ch. Schlegel[1], J. Gerl[1], K. Hauschildt[2], I. Kojouharov[1], W. Korten[2], Y. Kopach[1], S. Mandal[1], P. Mayet[1], M. Rejmund[2], H. Schaffner, H.J. Wollersheim[1] and the FRS γ-campaign collaboration

[1]GSI, [2]CEA Saclay, Paris, France

We propose to measure the B(E2)-values of n-rich nuclei around ^{132}Te produced in projectile fragmentation of a ^{136}Xe beam by Coulomb excitation on a Te-target. Due to comparatively high expected fragment intensities slowing down of the fragments to the Coulomb barrier will still result in reasonable Coulomb excitation yields with a secondary target. Thus ambiguities in the B(E2)-values caused by nuclear excitation can be avoided.

Besides enlarging the systematics of B(E2) values into the n-rich region the experiment serves as a test case for the use of slowed-down secondary beams for low energy nuclear structure experiments.

The experiment should take place behind the final focus of the FRS, see figure 1.

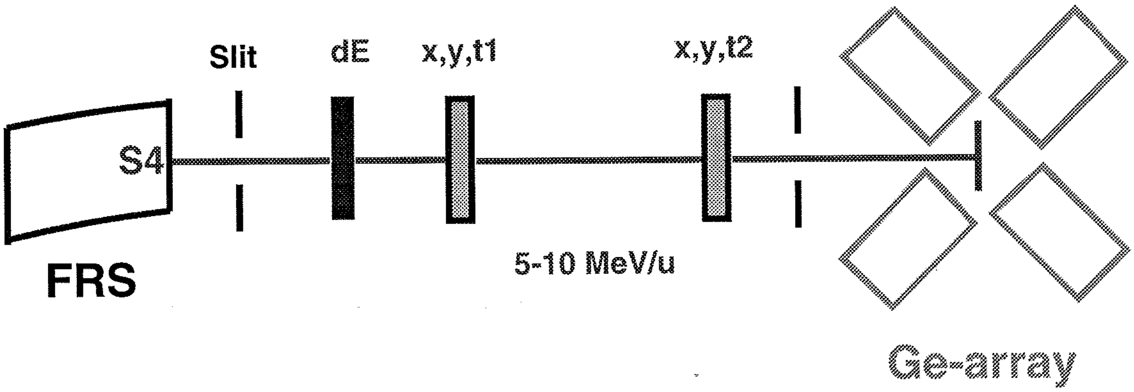

Figure 1: Experimental set-up to perform Coulomb excitation experiments at projectile energies around the Coulomb barrier behind the final focus of the FRS.

To perform an ΔE isotope selection we will use a silicon detector, whereas the beam position is measured by gas avalanche counters. The beam must be guided behind the final focus of the FRS (S4) to the secondary target in vacuum. In order to optimally perform the experiment at the Coulomb barrier an energy at S4 of around 40-50 AMeV is needed. Slowing down to the Coulomb barrier is achieved by the tracking detectors between S4 and the Coulex target without additional degrader. A higher energy of e.g. 100 AMeV at S4 should not be taken, because slowing down of such an energy to the few AMeV-region would result in excessive energy spread. Operation of the second dipol stage of the FRS at the required low rigidities of 2.3-2.6 Tm should be possible but has to be tested. According to our simulation calculations the selected Te-beam will have an energy spread of 5 AMeV at 5 AMeV before reaching the secondary target, see figure 2. The save energy for Coulomb excitation of ^{132}Te on a ^{130}Te target is ≤ 4.2 AMeV. To select the right energy range for Coulomb excitation it is necessary to measure the energy of the projectiles in front of the secondary target. The energy measurement will be done via TOF with fast gas avalanche counters. The angle spread of the beam will be reduced by slits in front of the secondary target. Finally the beam will be stopped in a thick Coulex-target. ^{128}Te/^{130}Te is chosen as target because the B(E2)-values of their first excited states are well known. The most probable processes are either the

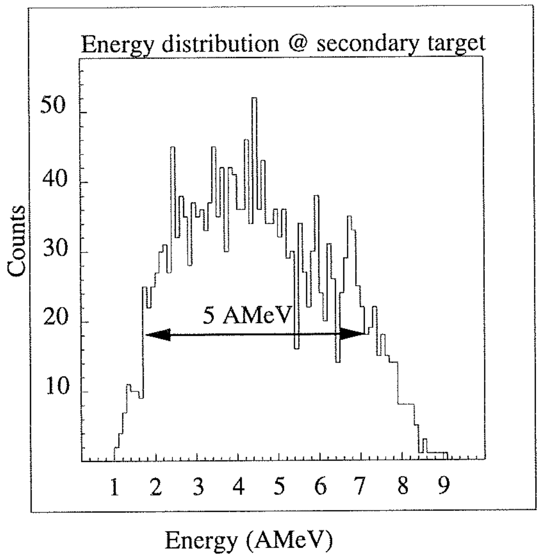

Figure 2: Monte Carlo simulation of the energy spectrum in front of the secondary target.

Coulomb excitation of the target nuclei or the excitation of the beam particle, that is why it is possible to determine unknown B(E2)-values relative to the known one by intensity comparisn. The emitted γ-rays will be measured with Ge-detectors placed in a compact arrangement around the secondary target.
A Monte Carlo simulation using the code MOCADI [1] was performed to estimate the transmission through the FRS and the tracking detectors. Taking into account the production cross section of 2 mb for ^{132}Te using a ^{136}Xe beam with a primary intensity of 10^9 particles/spill one can obtain finally in front of the secondary target a yield of $6{\cdot}10^4$ particles (^{132}Te)/spill. There are impurities in the beam which are separated in space resp. energy or have much less intensities as the selected fragment. To get a count rate estimate the known B(E2)-values of the even Te-isotopes were extrapolated to ^{132}Te resulting in a Coulomb excitation cross section, which is 6.3 b at 550 MeV. In a thick target experiment the cross section has to be integrated over the target thickness which leads finally to an effective yield which is $\approx$4 times higher. Using an effective target thickness of 10 mg/cm^2, an absolute efficiency of 5%, of the 974 keV 2^+ line and taking 20% of the energy-spectrum (Fig. 2) as 'useful' events results in 1 count/min in the 2^+ line of ^{132}Te.
In addition, the experiment serves a test case for γ-spectroscopy using slowed down beams. Therefore background radiation, beam quality and beam contamination caused by reactions in the tracking materials will be investigated. We request 6 shifts of beam time for the experiment and 12 shifts for setting up the FRS at these low energies.

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Shape evolution in light n-rich nuclei

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The light n-rich isotopes between the N=20 and N=28 shell closures provide an interesting testing ground for the shell model where drastic shape changes and co-existence of deformed and spherical structures are expected. One example is ^{32}Mg with a prolate deformation of the 2^+ state of $\beta \approx 0.5$ [1]. Recent theoretical work [2] predicts an even stronger deformation for ^{34}Mg and reduced deformation for ^{36}Mg. The aim of the proposed experiment is to study the level structure of nuclei in this mass region and, in particular, to determine for the first time lifetimes of excited states. B(E2)-values obtained from the lifetimes will be a measure of the deformation of the nuclei in their excited states.

Beam cocktails of excited nuclei with A/Z ratios between 2.5 and 3.0 can be well produced either by primary fragmentation [3] of a ^{48}Ca beam or by secondary fragmentation [4] of e.g. a ^{38}Si beam derived from fragmentation of the primary ^{48}Ca beam. The advantage of a two step process is that the intermediate beam produces in the second step the isotopes to be studied with a relative abundance in the cocktail which is 3 to 6 orders of magnitude higher than the production in one step. Thus detector load and background from unwanted channels is strongly reduced. The number of useful intermediate beams is of course limited since they have to be produced with a yield of 10^3 to 10^5 ions/s to be efficient.

The intermediate (respectively primary) beam will be selected by the first two sections of the FRS. The final fragmentation will take place with a target at the middle focus S2. The final fragments will be selected and identified by the further FRS sections and the standard S4 tracking detectors. The γ-decay of low energy low and medium spin states of the excited secondary fragments will be detected by segmented Clover detectors at forward and backward angles around the secondary target. The target-detector distance will be chosen to obtain an energy resolution of about 1% for a fragment energy of about 100 MeV/u. To determine lifetimes the target will be composed of a stack of three 0.3 g/cm^2 ^{197}Au foils, separated by 0.7 mm and 2.1 mm from each other. This arrangement results in specific γ-line shapes for lifetimes between about 0.1 ps and 20 ps covering the range expected for the nuclei of interest.

To reach the very n-rich nucleus ^{36}Mg a ^{48}Ca primary beam is necessary producing ^{38}Si as intermediate fragment. If this beam is available two settings of the FRS are planned. The first one employs the ^{48}Ca directly with an intensity of 10^5/s... 10^6/s (depending on the rate capability of the tracking and γ-detectors at S2). In the second setting a ^{38}Si intensity of $\approx 10^3$/s is expected for a primary intensity of 10^9/s ^{48}Ca. With these two settings the whole range of Mg nuclei with A=28.. 36 will be reachable in the experiment. If a ^{48}Ca beam would not be available ^{50}Ti could be used instead. However, in that case the selected secondary beam would be ^{36}Si and ^{34}Mg would be the heaviest isotope. Beside the Mg isotopes the neighbouring isotopic chains is present in the fragmentation cocktail with similar intensities. Therefore the whole region of the nuclidic chart will be investigated with the two settings.

Using two Vega and four Exogam clover detectors at forward and backward angles a γ-detection efficiency of about 1% (at 1.3 MeV) can be achieved. Thus to obtain a minimum of 100 counts in the 2^+ γ-line 6 shifts of beam time are required for the direct fragmentation setting and 15 shifts for the secondary fragmentation setting.

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Measurements of Nuclear Moments by using Relativistic Heavy Ions

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1 Experimental Method

We propose to measure the g-factors of the first excited state in Sr and Zr nuclei around mass 80 (viz. ^{78,80,82}Sr and ^{80,82,84}Zr) after Coulomb excitation using Transient magnetic Field technique (TF). Secondary beams of said nuclei will be produced via projectile fragmentation of a 500 MeV/u ^{96}Ru primary beam using a ^{27}Al primary target of thickness 4 g/cm^2. Fragments will be transported to the S4 focus of FRS after passing through an achromatic ^{27}Al wedge of variable thickness ($\sim$ 1.5-2 g/cm^2) to produce different energy secondary beams from 50-100 MeV/u. The beam velocity corresponds to the 1s electron Bohr velocity ($v_1 s$) of said nuclei (e.g 50 MeV/u corresponds to $v_{1s} \sim$ 0.3c for ^{80}Sr) At the final focal plane at S4 we will place a multilayer target composed of ^{208}Pb ($\sim$ 0.3 g/cm^2) and ferromagnetic Gd. For the reasons of magnetism it will be cooled to liquid nitrogen temperature where by the good thermal conductivity of the different layers help to avoid beam heating effects. The whole target set-up will be placed inside a weak magnetic field to align the spins of the scattered nuclei along the magnetic field direction.

The isotopes of interest, separated by FRS, will be identified with the standard FRS detector set-up. Combined measurements of magnetic rigidity Bρ, energy loss and time of flight will provide an identification of ion species event-by-event impinging on the secondary target along with their position and angle. The identification of reaction products behind the secondary target will be accomplished by a position sensitive ΔE-E telescope placed at zero degree with an angular coverage of $\pm$ 10°.

The precession of the angular correlation of gamma rays deexciting low-lying discrete levels will be measured with high efficiency segmented Clover Ge detectors arranged at angles where the angular correlation has its maximum logarithmic slopes in the center of mass frame. To avoid the problem of feeding of different high lying states a BaF_2/NaI array may be useful to add around the secondary target. The precession angle will be measured for different atomic charge states of the excited projectile by selecting H-like or He-like ions from FRS. From these measurement the magnitude of spin the exchange cross section from various electronic configurations and an empirical calibration of the velocity and Z-dependence of the transient magnetic fields will be obtained. Also it will be interesting to perform these measurements with different ion velocities at and above the 1s electron Bohr velocity to extract the effect on transient fields.

2 Precession and Count rate estimation

To estimate the count rate for an excited state we have been calculating the Coulomb excitation cross section $\sigma(E\lambda)$ of different nuclei using the relativistic Coulomb excitation theory of Winther and Alder [1]. The B(Eλ) values were taken from the literature [2, 3]. The Monte Carlo ray-tracing simulation code MOCADI has been used to simulate the beam transport and transmission through the FRS to the final (S4) focal plane and to calculate the secondary beam production rate. The optimal yield for the different proposed nuclei to be studied are given in Table 1. In all the cases we have been assuming a primary beam intensity of $2\mathrm{x}10^9$ per 4 sec spill at 500 MeV/u. A Coulomb excitation reaction target of thickness $\sim$ 300 mg/cm^2 was considered. The secondary beam is incident on this reaction target at $\sim$ 80 MeV/u which corresponds to 50 $\sim$ 55 MeV/u (i.e, $\sim$ 0.3c) on the Gd-foil. We farther assumed (based on previous expt.) the absolute efficiency of individual crystals of the segmented Clover to be around 1% for $E_\gamma \sim$ 700 keV. The resultant count rates $N_r(2^+)$ after correction of each γ-ray detector efficiency and solid angle (detector at 20° with an acceptance of each crystal $\sim$ 1.5° (25 mrad)) are shown in Table 1.

The precession angle Φ_{TF} has been calculated from the formula given below [4],

$$\Phi_{TF} = g\tfrac{\mu_n}{\hbar} B_{TF} t_{eff}$$

where μ_n is the Bohr magneton, g is the g-factor to be measured. B_{TF} is the Transient magnetic Field acting on the nucleus for a time t_{eff} and can be expressed as [5],

$$B_{TF} = p_{1s}(Z, host) q_{1s}(v_{ion}, Z, host) B_{1s}(Z)$$

where p_{1s} is the degree of polarization of the 1s electron, q_{1s} is the ion fraction with a single 1s electron (H-like ion) and B_{1s} its Fermi contact field. The latter can be expressed as,

$$B_{1s} = 16.7 K(Z) Z^3 \text{ [Tesla]}$$

where $K(Z)$ is a relativistic correction factor [6]. Both p_{1s} and q_{1s} have been estimated for a Gd host by extrapolating the value given in literature [7] for low Z-nuclei. t_{eff} has been calculated from the known mean entrance and exit time of the ions in a Gd foil of thickness 50 mg/cm^2 by using the formula given below,

$$t_{eff} = \int_{tin}^{t_{out}} e^{t/\tau} dt$$

where τ is the mean life time of the nuclear state. Estimated values of the precession angle along with the expected transient magnetic field are given in Table 2.

3 Beam Time Request

On the basis of the count rate estimation we ask for following beam time. For each of the nuclei ^{82}Zr and ^{78}Sr we request 6 shifts which allow a statistical precision in the measurement better then 2%. For the other nuclei we request 6 shifts to achieve the same precision. A further 3 shifts are requested for tuning the FRS and gamma detector setup. The total requested beam time therefore amounts to 21 shifts or 7 days.

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Table 1: Count rate estimation

Nuclei	Sec. Beam Rate (P.P.P)	E_γ keV	σ_{E2} mb	$N_r(2^+)$ counts/hr
^{78}Sr	2.9e+4	278.5	692	19
^{80}Sr	6.8e+5	385.7	611	453
^{82}Sr	5.1e+5	577.5	352	197
^{82}Zr	3.0e+4	407.9	580	22
^{84}Zr	8.0e+5	540.0	1319*	1159

$*$ B(E2) estimated from prescription of Ref. [8].

Table 2: Precession angle estimations (g-factor=1.0)

Nuclei	B_{TF} (MG)	$t_{eff}(fs)$	Φ_{TF} (mrad)
^{78}Sr	266	34	43
^{80}Sr	266	30	38
^{82}Sr	266	37	47
^{82}Zr	322	32	50
^{84}Zr	322	28	43

Effective charges near ^{56}Ni

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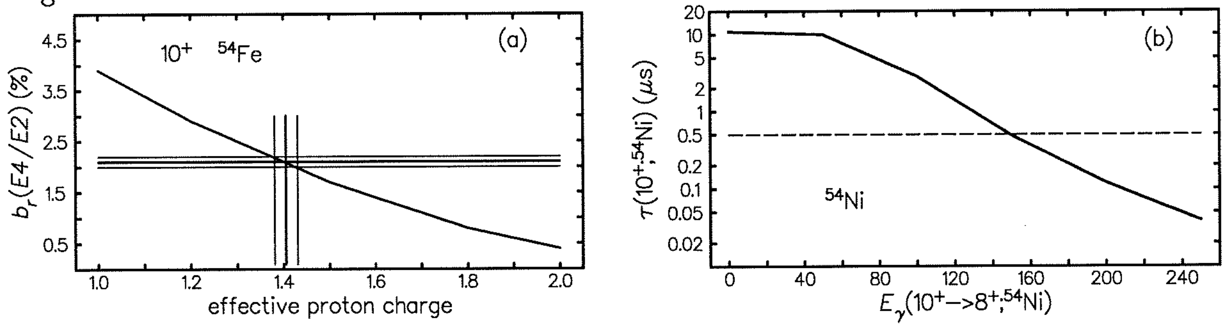
Spectroscopic data from doubly magic nuclei and their nearest neighbours serve as sources for and act as constraints on the parameter sets of the nuclear shell model, and, consequently, define the effective nuclear interactions. The nuclei near ^{56}Ni are of particular interest as they are amenable to different microscopic theoretical treatments. The most distinctive observables to compare and relate different nuclear models are transition probabilities. Their prediction commonly implies the use of effective charges and effective g-factors, which, e.g., for the spherical shell model, may depend very much on the model space. It is proposed to provide a benchmark test for the effective charges near ^{56}Ni using the known lifetime [τ = 525(10) ns] and the branching ratio [b_r=2.2(1)%] of the 3578 keV $E4$ and 146 keV $E2$ γ-decays of the 10^+ isomer in ^{54}Fe [1], and the corresponding properties of the so far unknown mirror state in ^{54}Ni.

To illustrate the idea, relatively simple shell-model calculations have been performed within the full fp shell, but limited to two-particle two-hole excitations across the magic gap at particle number 28 [2]. Figure 1(a) shows the dependence of b_r on the effective proton charge e_p, with $e_p + e_n = 2.0$ fixed (an overall scaling can for once account for the absolute strengths). The horizontal lines indicate the experimental error, the vertical lines the inferred effective proton charge *for this given calculation.* Performing the calculation with identical parameters for ^{54}Ni, the $B(E4; 10^+ \rightarrow 6^+)$ and $B(E2; 10^+ \rightarrow 8^+)$ transition strengths and, subsequently, the lifetime of the 10^+ state can be predicted. Together with the experimental branching ratio b_r, if measured to some 5% precision, the determination of this lifetime should allow for a stringent test of the predicted wave functions of the two $A = 54$ mirror nuclei *and* the effective charges used — not only for this relatively simple approach, but for *any* shell-model calculation in the ^{56}Ni region.

Figure 1:



The lifetime of the 10^+ state in ^{54}Ni strongly depends on the energy of the $10^+ \rightarrow 8^+$ $E2$ transition [see Fig. 1(b)], but the five-step γ-ray cascades (known in ^{54}Fe, expected in ^{54}Ni) following the isomeric decays are unique fingerprints. The beam time estimate is based on the 'worst case' we consider feasible for the experiment at GSI, i.e., $\tau(10^+;^{54}\mathrm{Ni}) = 0.5$ μs which implies $b_{r;\mathrm{calc}} = 4\%$. For even shorter lifetimes, i.e., $E_\gamma(10^+ \rightarrow 8^+) > 150$ keV [see Fig. 1(b)], in-beam studies such as fusion-evaporation reactions become applicable.

MOCADI simulations [3] have been performed to estimate the best possible FRS setting for the experiment. The slits at S1 can be used to reduce the rate at S2, and slits at S2 and S4 will be narrowed to significantly suppress unwanted isotopes of higher cross-section than ^{54}Ni ($\sim$ 10 μb,[4]), such that the rate for the focal plane detectors is less

than 3000/s during extraction, with a large fraction of the rate ($\sim$ 50%) arising from ^{54}Ni nuclei. A beam cycle involves eight seconds of accelaration and stacking, and four seconds of extraction, i.e., there will be five spills per minute. $5 \cdot 10^9$ 650 AMeV ^{58}Ni beam particles per spill impinging on 4g/cm^2 ^{9}Be then provide some 10000 particles per spill at S4, i.e., $5 \times 10000 \times 50\%$/min=25000/min ^{54}Ni nuclei at the focal plane. The total flight time amounts to 500 ns. Together with an estimated 300 ns recover time for the Ge-detectors after implantation, the clock for the measurement of isomeric decays starts 800 ns after their production in the target, which for the 'worst case' scenario implies that only some 20% of isomeric ^{54}Ni nuclei are accessible to the measurement. An isomeric ratio of 5% is estimated based on the 13% measured for the 8^+ isomer in ^{70}Ni [5]. A somewhat heavier beam, e.g., ^{64}Zn, may enhance the isomeric ratio, but on the cost of primary beam intensity and cross section (factor of about four [6]).
We further assume the γ-ray efficiency at 3.5 MeV to be 1%, and we need to register 400 counts (=5% uncertainty) in the peak of the $E4$ transition (b_r = 4%) in ^{54}Ni. Folding in these factors, one obtains 25000/min$\times$20%$\times$5%$\times$1%$\times$4%=0.1/min events, i.e., eight eight-hour *production* shifts are needed. Additional four shifts shall be devoted to (*i*) find the optimum FRS setting, and (*ii*) run in-beam calibrations using the known ^{54}Fe case as a benchmark. In total, we ask for 12 shifts, i.e., 4 days of beam time.

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Isomer Spectroscopy of the odd-odd T_z=0 Nuclei ^{82}Nb and ^{86}Tc.

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PHYSICS MOTIVATION

The study of self-conjugate nuclei and proton-neutron pair correlations are major thrusts of current nuclear structure research. The pioneering in-beam work done at the Daresbury laboratory [1] identifying the first excited states in even-even N=Z nuclei from $^{64}_{32}$Ge upto $^{84}_{42}$Mo highlighted the sudden changes in nuclear structure which can occur with small changes in nucleon number within these *fpg* shell systems. The rather proton-rich nature (compared to the line of stability) of these nuclei meant that a subtle experimental technique was required. In these formative experiments, the population of the $N = Z$ systems was achieved via two-neutron evaporation from compound nuclei formed at beam energies close to the Coulomb barrier. However, resticting the choice to stable beam-target combinations means that for N=Z nuclei heavier than $^{78}_{39}$Y [2], at least three neutrons must be evaporated to populate such systems. This makes the study of heavy $N = Z$ nuclei using stable-beam induced fusion-evaporation reactions extremely difficult, and to date ^{84}Mo remains the heaviest $N = Z$ nucleus whose internal decays have been probed using this type of reaction. In this proposal, we aim to identify the low-lying excited states of the $N = Z = 41$ and $N = Z = 43$ systems ^{82}Nb and ^{86}Tc, using the projectile fragmentation of a ^{96}Ru beam and the 'isomer-spectroscopy' technique. These would correspond to a new experimental 'benchmark' regarding the structure of (odd-odd) self-conjugate nuclei and as such would allow a comparison of the relative strengths of the $T = 1$ and $T = 0$ neutron-proton pairing modes [2,3,4] for increasing proton number.

Our recent study of the ground state decays of heavy $N = Z$ nuclei following the projectile fragmentation of an intermediate-energy (70 MeV/nucleon) ^{92}Mo beam at GANIL [5], established T=1, $J^{\pi}=0^+$ ground states for the heavy odd-odd systems, $^{78}_{39}$Y, $^{82}_{41}$Nb and $^{86}_{43}$Tc. In a related experiment at GANIL, we also discovered [6] the presence of a γ-decaying isomeric state in ^{86}Tc together with tentative evidence for an isomeric decay in the micro-second time regime in $^{82}_{41}$Nb. The γ-ray energy and time spectra which provide the experimental evidence from reference [6] for the ^{86}Tc isomer are shown in figure 1. Although the statistics from this GANIL experiment represent work at the observable limit, the most likely interpretation of the 595 keV γ-ray transition present in this spectrum is as the $2^+ \rightarrow 0^+$ decay in $^{86}_{43}$Tc, built upon the T=1, $I^{\pi} = 0^+$ ground state. Note that the energy is close to that of the analog 567 keV, $2^+_1 \rightarrow 0^+_1$ decay in the T_z=1 isobar, ^{86}Mo [7]. The GANIL experiment used a ^{92}Mo beam, which relied on a 'fragmentation plus proton-pickup' for the Z=42 molybdenum beam to populate $^{86}_{43}$Tc. In the current proposal, we aim to use the heavier ^{96}Ru beam at relativistic energies to populate the ^{86}Tc system with a significantly higher cross-section compared to the GANIL work. This, added to the thicker targets available due to the significantly higher primary beam energies at GSI suggest a large increase in the final transmitted yield for the ^{86}Tc (and ^{82}Nb) nuclei at the end of the FRS.

PROPOSED EXPERIMENT AND ESTIMATED YIELDS

We propose to use the fragmentation of a 500 MeV/nucleon energy ^{96}Ru beam on a 4 g/cm^2 thick ^{9}Be target to populate the isomeric states in ^{82}Nb and ^{86}Tc using the 'standard'

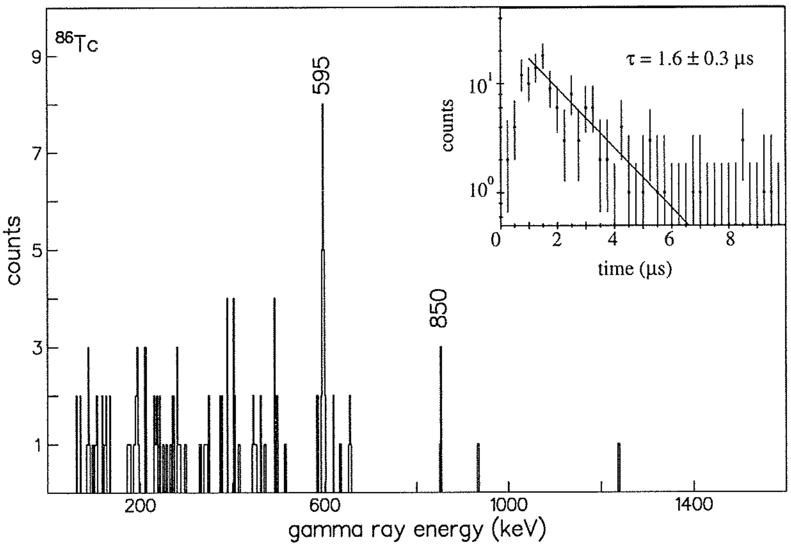

Figure 1: ^{86}Tc isomer spectrum from the ^{92}Mo GANIL data [6].

campaign isomer set-up.

The production cross-sections of the nuclei of interest following the fragmentation of ^{96}Ru is estimated using the EPAX parameterisation to be 3×10^{-8}b and 4×10^{-7}b, respectively (see also [8]). For a setting optimized for ^{86}Tc, the FRS transmission is calculated to be 30% for ^{86}Tc. ^{82}Nb can be transmitted in the same setting with a similar efficiency. Assuming a primary beam current of 10^9 particles per spill and 6 spills per minute, this corresponds to an expected rate reaching the end of the FRS of approximately 12 per minute for the setting on ^{86}Tc and of 120 per minute for ^{82}Nb. Assuming an isomeric ratio of approximately 20% and a γ-ray detection efficiency of approximately 5% for energies between 200 and 600 keV, this would correspond to 1700 and 170 unambiguously assigned isomeric decay transition obeserved in ^{82}Nb and ^{86}Tc per day, respectively. Note, the spectrum obtained in the GANIL work for ^{86}Tc as shown in figure 1 was obtained with approximately 300 identified ^{86}Tc ions. We aim to improve this by at least by an order of magnitude in the current work, and possibly to establish coincidence relationships below the isomers using $\gamma - \gamma$ data.

The FRS setting will be centred between ^{86}Tc and ^{82}Nb, with the aim of establishing the decay scheme below the 1.6μs ^{86}Tc isomer and of searching for the ^{82}Nb isomeric decay.

As a part of a campaign, with fully operational and calibrated FRS, five full days of beam time are required including tuning time for the FRS.

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Isomer spectroscopy of fission fragments close to ^{78}Ni

SIS/FRS proposal

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Abstract

It is proposed to identify the γ-decay of the $I^{\pi}=8^{+}$ and related isomers in ^{74,76}Ni and their neighbours, populated in fission of 750 A MeV ^{238}U. A total of 21 shifts is requested.

Spokesperson: M. Bernas; **GSI contact person:** H. Grawe

1 Physics motivation

The doubly magic nucleus ^{78}Ni with N/Z=1.78 is the most neutron rich shell closure accessible in the region of neutron excessive nuclei of the Segré chart. Shell structure and residual interactions at this keypoint are intimately related to heavily discussed issues as shell quenching, low-lying intruder deformed states, development of new shell structure and the astrophysical r-process. The need for experimental information about nuclei in this region is accentuated by differing predictions from various theoretical calculations. While HFB mean field and shell model calculations suggest a significant shell closure for ^{78}Ni [1, 2] a recent HFB calculation [3] and relativistic mean field calculations [4] indicate that nuclei with large neutron excess approaching the dripline by coupling of bound neutron states to the continuum above the Fermi surface will quench the shell gap.

The study of the isomeric γ-decay of long lived (>100 ns) states offers an efficient probe of the evolution of shell structure and nuclear mean field of very neutron-rich nuclei. Such isomers occur abundantly near shell closures with single particles occupying high spin orbitals at the Fermi surface. From the isomeric decay pattern and the strengths of the expected E2 and M2 transitions, single particle energies, residual interaction, shell occupation and development of collectivity, leading eventually to disappearance of the isomerism, can be extracted.

The double shell closure at Z=28, N=50 is a waiting point for the r-process and close to this region a quenching of the N=50 shell gap is predicted in relativistic mean field calculations [4]. The structure of the neutron-rich Ni isotopes beyond ^{68}Ni is governed by the $\nu g_{9/2}$ orbital giving rise to $I^{\pi}=8^{+}$ and $21/2^{+}$ seniority v=2 and 3 isomers. Coupling of these states to $p_{3/2}$ and $f_{5/2}$ protons will give rise to high spin isomers in odd-even Cu and Ni isotopes. In odd-neutron nuclei the coupling of $\nu g_{9/2}^{2} p_{1/2}$ produces similar isomers and the $\nu g_{9/2} \rightarrow f_{5/2}$ M2 isomeric transition fixes the relative positions of these single particle orbits.

The heaviest Ni isotopes studied sofar in fragmentation of ^{86}Kr and ^{76}Ge beams are ^{70}Ni [2, 5] and ^{72}Ni, besides their one - particle (hole) neighbours ^{67,69}Ni and ^{71}Cu [5]. In ^{70}Ni a $\nu(g_{9/2})^2_{8+}$ was identified, which has its counterparts in 69Ni and ^{71}Cu. The closest approach to ^{78}Ni are its 2p2h neighbour ^{78}Zn [2] with a $\nu(g_{9/2})^2$ dominated 8^+ isomer as in the heavier N=48 isotones [6], and the 4p isotone ^{82}Ge [7]. While this is an "a fortiori" argument for the existence of an 8^+ isomer in ^{76}Ni and hence the persistence of a N=50 shell gap, it is at variance with the disappearance of the 8^+ isomer in ^{72}Ni within a time range of 20 ns - 1 ms. Sample decay schemes are shown in Fig. 1.

Therefore it is proposed to identify the 8^+ isomer in ^{76}Ni and in ^{74}Ni (if it exists), to enlighten the drastic change in structure in the middle of the $\nu g_{9/2}$ shell, which is in contrast to the N=50 valence mirror nuclei $^{90}_{40}$Zr$_{50}$ - $^{98}_{48}$Cd$_{50}$ [8].

2 Experiment

As shown in previous GSI experiments, relativistic fission of uranium provides a unique possibility to produce nuclei around ^{78}Ni. The production rates of very n-rich isotopes, including isomers, produced in fission of 750 A MeV ^{238}U on a Be target (1 g/cm^2) have already been investigated [9, 10]. The standard experimental setup of the isomer campaign is used. Details on the exploratory test experiment are given in proposal S210 by M. Hellström et al.

3 Count rates and beam request

Based on the following cross sections and efficiencies

$\sigma = 16$ nb	production cross section ^{76}Ni [9]
$\epsilon_{acc} = 1.6$ %	FRS transmission for fission products
$\epsilon_{iso} = 15$ %	isomeric ratio
$\epsilon_{\gamma} = 6$ %	γ photopeak efficiency at 1.33 MeV

we expect about 8 cts. in the photopeak of the $2^+ \rightarrow 0^+$ transition in ^{76}Ni in a 6 days run. We arrive at the same estimate, when extrapolating the results for ^{70}Ni from the exploratary experiment [10]. There we implanted 200 ^{70}Ni ions/h. Using the measured cross sections for ^{76}Ni (16 nb) and ^{70}Ni (0.03 mb) [9] and the efficiencies from above this translates into 9 cts. in a 6 days run for the above mentioned transition. This requires a beam intensity of **7** $\times 10^8$ ^{238}**U** /s, i.e. optimum performance of the ion-source – accelerator – FRS ensemble. This would also allow to detect a 8^+ isomer in ^{74}Ni, even if as short lived as 100 ns.

Therefore a total beam time of **21 shifts** including **3 shifts** for FRS tuning is requested.

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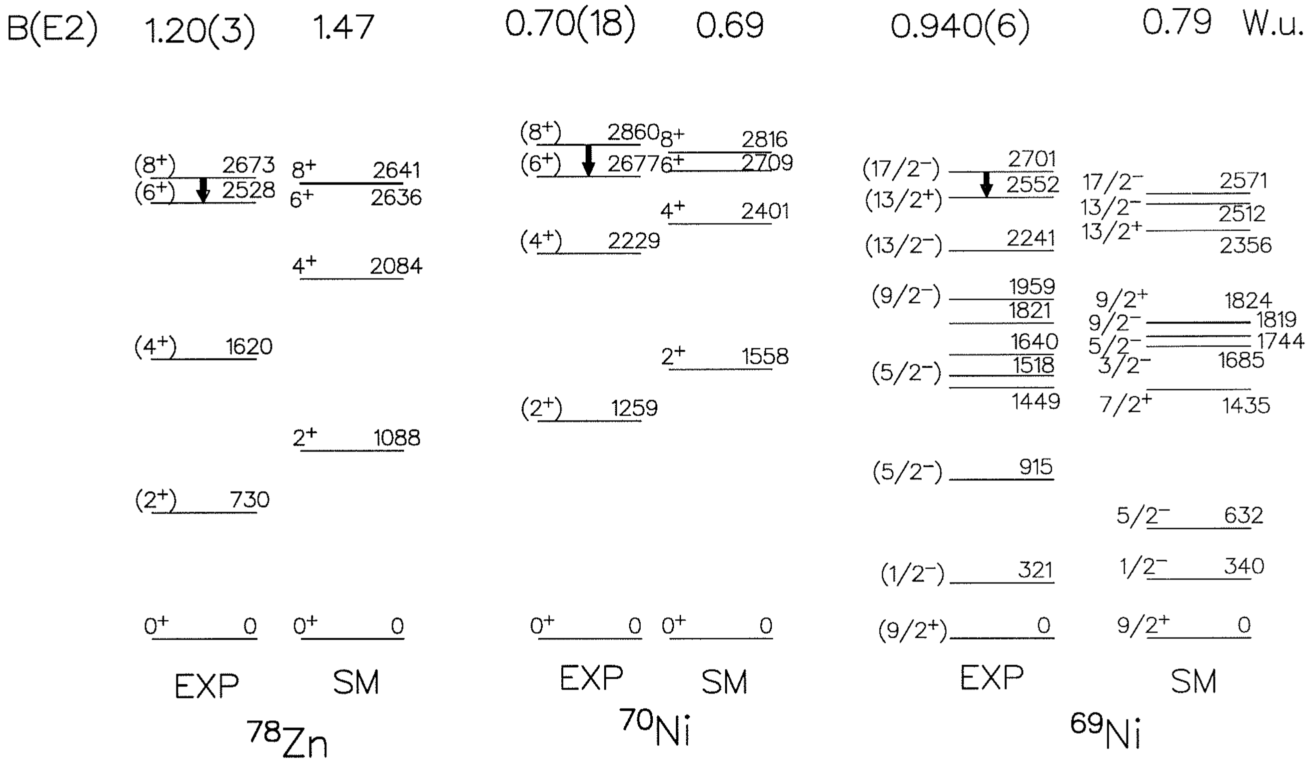

Figure 1: γ-decay of the $17/2^-$ resp. 8^+ isomers in ^{69,70}Ni and ^{78}Zn in comparison to shell model predictions

The survival of *K*-Isomers against the onset of the Z=50 closed shell.

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P.H. Regan[4] P.M. Walker[4], Z. Podolyak[4], J. Gerl[5], & the FRS Collaboration.

[1] *Manchester,* [2] *Liverpool,* [3] *Brighton,* [4] *Surrey,* [5] *GSI.*

This experiment will test the effect of the proximity of the Z=50 closed shell on the stability/existence of *K*-isomers in the *even-even* N=74 isotones $^{126}_{52}$Te, $^{124}_{50}$Sn, $^{122}_{48}$Cd and $^{120}_{46}$Pd. The approach towards closed shell (and region of lower deformation) around $^{126}_{52}$Te, $^{124}_{50}$Sn might be expected to be accompanied by the breakdown of the *K* quantum number. This proposal will test the predictive power of Woods-Saxon configuration-constrained shape polarisation calculations [1] in a low deformation regime. This experiment forms part of a systematic study at GSI of isomeric states in the N=74 isotones (see the proposal "*K*-Isomer survival at the proton-drip line; ^{140}Dy").

Investigation of the effect of the Z=50 closed shell on N=74 *K*-isomers existence.

As the proton number decreases along the N=74 isotone chain from Z=56 (^{130}Ba), through Z=52 (^{126}Te), to Z=50 (^{124}Sn) and through the closed shell to Z=48 (^{122}Cd) and Z=46 (^{120}Pd), the ground state nuclear shapes become rather soft and less deformed. Figure 1 shows the excitation energy of the lowest 2^+ state across the N=74 chain. Low-spin shape coexistence is a well established effect in the Pt, Hg and Pb nuclei as the Z=82 closed shell is approached [2]. In a low spin spherical limit *K* might *not*, therefore, be expected to be a good quantum number. At higher spins and excitation energies, however, some of these nuclei become deformed. (The deformation results from a single-proton excitation from the oblate driving $g_{9/2}$ orbit into the prolate deformation driving $h_{11/2}$ orbit.) Recently, in the mass 180 region, a candidate $K^{\pi} = 8^-$ isomeric state was identified in the Z=82 nucleus, ^{188}Pb, [3]. The associated intruding collective well was found to compete with the coexisting oblate and spherical minima allowing a prolate deformation and therefore, the *K* isomer to be defined. In this experiment we shall test the predictions [1] that an excited nucleus in the proton deficient N=74 isotones, for example ^{124}Sn, can form a prolate deformed minimum, allowing *K* to be defined and $K^{\pi} = 8^-$ and higher-*K* isomers to exist.

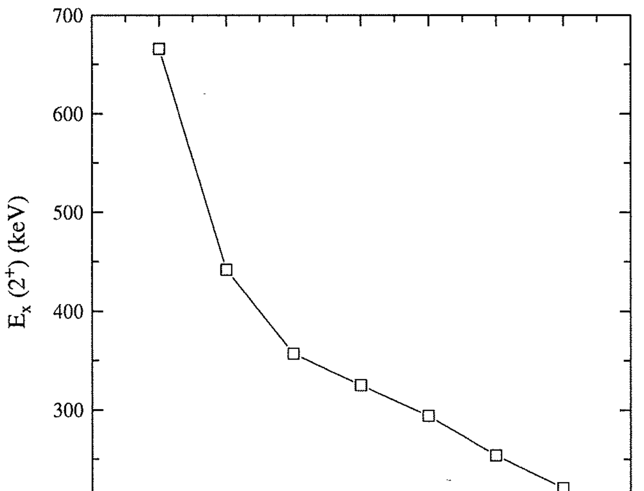

FIG. 1. The excitation energy of the lowest 2^+ state across the N=74 chain. As the closed shell is approached, the nuclei become less deformed and rather soft.

We propose to analyse the products of a fragmentation reaction of a 1 GeV/A $^{132}_{54}$Xe beam incident on a 1.6g/cm^2 natural $^{9}_{4}$Be target at the entrance to the FRS to search for $K^{\pi} = 8^-$ isomeric states in the N=74 neutron-rich nuclei around ^{124}Sn. The FRS will be used in standard achromatic mode with an aluminium wedge-shape degrader of thickness 2 g/cm^2 at the intermediate focal plane. Reaction products will be identified by combining the measurements of energy loss (ΔE) and time of flight (TOF) with information from position-sensitive multi-wire counters and the magnetic field readings. From these measurements of the magnetic rigidity together with position and TOF, the atomic number Z, and the mass-to-charge ratio (A/Q) will be determined for the ions reaching the final focal plane. These procedures rely on the fact that the ions will be fully stripped at these energies. The identified ions will be slowed down in a variable-thickness aluminium degrader and after passing through a 3mm thick plastic scintillator will be implanted into a few cm thick aluminium catcher plate. This final aluminium catcher will be set between a high-efficiency closed-packed array of segmented Ge detectors which will be used to to identify delayed γ rays in the 100 ns - 1 ms time range with respect to an ion passing through the MUSIC chamber, i.e. a clock will be started by a heavy ion which is detected at the focal plane, and subsequently stopped by the arrival of a γ-ray within a few hundred μs window. Such a setup will greatly reduce the background. The half-life of the delayed γ-ray transitions can be measured by time-to-amplitude converters between these signals. Data will be taken with an identified recoil, a delayed γ-ray transition, and also delayed $\gamma - \gamma$ coincidences which will help in unravelling the decay pattern of these isomers. Some of the known isomeric states in the neighbouring nuclei will be used as an internal calibration in the lifetime procedure.

Beam time requests.

The cross sections for the formation of these neutron-rich mass 120–130 nuclei have been estimated from the EPAX and Benesh prescriptions and have been cross checked with the LISE program from GANIL and the LIESCHEN code from GSI. The EPAX production rates were as follows, $^{126}_{52}$Te 50 mb, $^{124}_{50}$Sn 20 mb, $^{122}_{48}$Cd 0.8 mb and $^{120}_{46}$Pd 1.2 μb. The transmission losses have been calculated with the LIESCHEN code with the FRS setup to transmit $^{124}_{50}$Sn, assuming that approximately 45-50% of the secondary fragments will survive the optical transmission path through the FRS due to reactions which take place in the degrader and that only approximately 70-80% of the $^{124}_{50}$Sn recoils will remain fully stripped. With these assumptions the LIESCHEN code predicts that approximately 7×10^{-6} ^{124}Sn nuclei will be implanted into the aluminium plate per incident beam particle. Therefore, with an incident ^{132}Xe beam of 5×10^8 particles per pulse every second (with 3 spills/min) then we should get on average approximately 50 ^{124}Sn nuclei per second at the focal plane. We will run at this ^{124}Sn setting for 1 shift ($\approx 10^6$ counts) and then on ^{122}Cd for 3 shifts ($\approx 10^5$ counts) and finally for 2 days on the ^{120}Pd setting ($\approx 10^3$ counts). A recent experiment which successfully observed the 6μs isomer in ^{138}Gd was recently run with similar conditions [4].

We expect to take 2 shifts to set up and optimise the FRS and in total request 4 days of beam time.

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Evolution of shell structure ‘outside’ doubly magic ^{132}Sn

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Introduction

The doubly magic nucleus ^{132}Sn (Z=50, N=82), besides ^{78}Ni (Z=28, N=50), marks the only double shell closure now accessible in the very neutron rich (N/Z>1.6) region of the nuclear chart. The shell structure and residual interaction at these fix-points are intimately related to many important issues, such as the proposed quenching of shell-closure strength for extremely neutron-rich nuclei, the development of low-lying deformed intruder configurations, and the astrophysical r-process.

That the detailed understanding of neutron-rich systems far from stability is far from complete is illustrated by the different predictions of e.g. shell evolution obtained by various theoretical approaches. Calculations do indicate that a new interaction needs to be developed, along the Skyrme approach, to correctly take into account energy densities and therefore increase the predictive power for more exotic systems, where the coupling of bound neutron states with unbound continuum states above the Fermi level will soften (or "quench") the shell gaps [1]. To fine-tune the interaction, experimental data on both global nuclear properties as well as spin-dependent ones are needed for neutron-rich systems.

Recent r-process calculations [2, 3] indicate that the situation close to the ^{132}Sn region is not at all clear. Whereas ^{132}Sn itself is clearly doubly magic, a comparison of observed r-process mass-abundances with those calculated with the QRPA using masses from the Möller formula (FRDM) show that by using masses obtained under the assumption of attenuated shell effects, the fit to the mass abundance curve in the regions of A=115 and 140 can be greatly improved [2,4]. Nuclei along the N=82 shell closure below Z=50 form an important r-process waiting point [5]. The N=82 shell gap has been predicted to be considerably reduced for Z=46 [6], but up to now there is little experimental evidence for this effect.

The properties of excited states originating from proton $g_{9/2}$ holes relative to the ^{132}Sn core and the neutron $f_{7/2}$, $h_{9/2}$ and $i_{13/2}$ particles in Sn isotopes with N>82, will give information on the shell structure in this region. Especially in the case of the N=82 isotones, a direct comparison of the $I=8^+$ E2 strength with the N=50 proton-rich isotonic chain is possible. The decay of isomers provide a unique and quite selective method to probe not only transition rates but also level energies. Previous investigations of the tin region isomers include studies of fission product β-decay after ISOL mass separation (limited by the availability of high-spin β-decay parents) [7], measurements of prompt γ-decay of fission products, either on-line [8] or off-line with EUROGAM (limited by low production yields to the Z>50, N>82 region) [9,10], and now also experiments at the GSI fragment separator.

These experiments have opened access to single particle (hole) states for protons (neutrons) above (below) Z=50 (N=82). Most of the single neutron states beyond N=82 are known by now [10] and empirical two-body matrix elements (TBME) for a few key configurations and spins in particle-particle and particle-hole neighbours of ^{132}Sn [11]. The results show a remarkable resemblance of the ^{132}Sn structure to that of ^{208}Pb. On the other hand, going deeper into the neutron particle shell for N>82 Sn isotopes and into the proton hole shell for N=82, Z<50 isotones, dramatic changes with respect to deformation and/or shell quenching are expected.

Previous experiment

In December 1999, experiment S210 [12] was performed aimed at searching for new isomers in the region around ^{132}Sn. The nuclides of interest were produced in the fission of 750 MeV/nucleon ^{238}U beam with a 1 g/cm^2 beryllium target and subsequently separated in the FRS, identified in-flight by the standard Bρ-ΔE-TOF method, and finally implanted into a catcher at the final focus of the FRS. The catcher was viewed by 5 segmented Clover germanium γ-ray detectors, one of which was the GSI SuperClover and four of the so-called EXOGAM type. Isomeric decays were detected by requiring a slow correlation of the detected γ-radiation with the heavy ion identified in-flight. Two different time ranges, 0-8 μs and 0-80 μs were investigated in parallel using TDCs and TACs/scalers. In three different settings centered on nuclei ranging from ^{131}Sn to ^{134}Sn to ^{130}Cd, several previously observed isomers with half-lives in the 100 ns – 10 μs region were observed, and one isomer in ^{136}Sb was observed for the first time. The most ex-

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[*] Spokesperson of the proposal. The GSI contact person is H. Grawe, KP2.

otic setting, centered on ^{130}Cd, also encompassed ^{136}Sn. The data analysis is still in progress, but preliminary results indicate that the statistics for these two isotopes are too low (about 300 ions implanted in 24 hours) to allow the detection of isomeric γ-rays. In the case of ^{130}Cd, a microsecond isomer is indeed expected in analogy with the one observed in ^{98}Cd [13] (both nuclei are two proton holes with respect to the doubly magic ^{100}Sn and ^{132}Sn, respectively, and the same proton orbitals are involved.)

It is important to stress that the overall "background" rate of other reaction products reaching the final focus is very low at the high-rigidity separator settings required for the very neutron-rich fission fragments. For this reason, high-quality spectroscopic information can be obtained even for isomers with quite low production rates. In the December 1999 run, the total count rate at the second intermediate focal plane was low enough as to allow good time-of-flight resolution up to the final focus, where the overall rate was less than 10 events per second at the most exotic setting. The experiment was therefore in no way rate limited, and at least a factor of 30 higher primary beam intensity on the production target could have been tolerated. In fact, it should be noted that during this most exotic setting, the primary beam intensity was on average 3×10^{8} ^{238}U/spill which with a 15 second overall cycle (1 s extraction, 14 s stacking, cooling and acceleration) corresponds to a lower average intensity (2×10^{7} per second) than was achieved previously with the old (pre-cooler) ion source/injector/acceleration scheme! (A maximum of 10^{9} ^{238}U/spill was achieved for a very short period during the initial phase of the Sn-region experiment.)

In March 2000, another experiment (Schatz *et al.*, E040) was performed using ^{238}U fission to investigate nuclei east and north-east of ^{132}Sn. The on-line analysis of this measurement suggests that a number of new isotopes were observed for the first time. The experimental setup used in this run (aimed at detecting β-delayed neutron radiation) did not allow for isomer spectroscopy. It is hoped that further investigations of these new nuclei, including γ-spectroscopy, could reveal information about excited states from the depopulation of isomeric levels – if these are not situated above the neutron separation energy.

Beam time request

The preliminary analysis of the December 99 experiments indicate that both ^{130}Cd and ^{136}Sn were transmitted (typical total transmission for fission fragments is $\approx$5%) to the final focus of the FRS at rates around 10^{-10} atoms per ^{238}U projectile incident on the production target. Because of losses due to secondary reactions and straggling during the slowing-down process, we estimate that only about 40% of the tin-region nuclides produced survive to be implanted. The isomeric ratios can be estimated to be 10-30%, and since the total flight time through the FRS is on the order of 550 ns, isomers with half-lives much shorter than this will suffer from in-flight decay losses. Assuming a similar Ge detector setup as used previously, the total photopeak detection efficiency for 1.3 MeV γ-rays is expected to be 6%. These considerations lead to the following beam time request:

- **3 shifts** for calibrating the particle identification procedure and the γ-ray detection setup using well-known isomeric decays (one setting including both ^{132}Sn and ^{135}Te).
- **9 shifts** of searching for new isomers, to be divided between one setting optimized for very n-rich cadmium-silver isotopes (centered on ^{130}Cd) and one for tin-antimony isotopes (^{136}Sn).

The total requested beam time amounts to **12 shifts**. This assumes that a ^{238}U primary beam intensity of at least 10^{9} ions/spill (15 second cycle) is available.

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K-Isomer survival at the proton-drip line; ^{140}Dy.

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P.H. Regan[5], R. Wadsworth[4] P.M. Walker[5], Z. Podolyak[5], J. Gerl[6], & the FRS Collaboration.

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This experiment will test how the proximity of the proton drip line and deformation stability affect the existence of isomeric states in $^{140}_{66}$Dy at the extreme end of the N=74 *even-even* isotone chain ($^{128}_{54}$Xe [1], $^{130}_{56}$Ba [2], $^{132}_{58}$Ce [3], $^{134}_{60}$Nd [4], $^{136}_{62}$Sm [5] to $^{138}_{64}$Gd [6]). Along with testing the predictive power of Woods-Saxon configuration-constrained shape polarisation calculations [7] at the proton drip line, several other physics issues will be addressed (see below). This experiment forms part of a systematic study at GSI of isomeric states in the N=74 isotones (see the proposal "The survival of *K*-Isomers against the onset of the Z=50 closed shell").

(i) Measuring the deformation of a drip-line nucleus

The ground state of the neutron deficient nucleus ^{140}Dy has only recently been established from the proton decay of ^{141}Ho [10]. This proposed experiment will identify transitions in the ^{140}Dy ground-state band from the delayed decay of the $K^\pi = 8^-$ isomeric state. Establishing the yrast ground-state band is of importance to determine the deformation stability of a nucleus through a measurement of its lowest excited states. ^{140}Dy is predicted by Moller and Nix to be well deformed ($\beta_2 = 0.276$) due to its valence protons and neutrons. Measurement of the ^{140}Dy deformation has repercussions for the WKB tunnelling lifetimes for proton decay in ^{141}Ho [10].

(ii) *K*-isomer stability; B(E1) strength and hindrance factors for their decays.

Once a new $K^\pi = 8^-$ isomer has been identified, at the FRS focal plane, the physics of its E1 γ-ray decay strength [B(E1)] and hindrance factor, for decay back to the ground state band, can be compared with the systematics of other *K*-isomer decays. There is current interest in understanding the large variation in $B(E1)$ strength observed across the N=74 chain [6]. These half-life variations have been suggested to be either due to a change in the underlying structure of the isomeric state itself or that of the yrast 8^+ state to which the isomer decays [6,7]. Despite these possible explanations, the general feature that the $B(E1)$ values *increase* as the nuclei become more stably deformed is counter intuitive. It might reasonably be expected that ^{140}Dy will reverse this trend and show greater robustness of the *K* quantum number. In addition, this larger deformation may allow the higher lying four-quasiparticle states to be observed. The $K^\pi = 8^-$ isomer in ^{140}Dy is predicted [7] to have a similar excitation energy to its isotone ^{138}Gd and its half life may be expected to be longer than that of ^{138}Gd ($6\mu s$).

(iii) Proton decay from the isomeric state?

If the lifetime of the $K^\pi = 8^-$ isomeric state in ^{140}Dy is sufficiently long, it might be possible to speculate on the possibility of observing proton decay from the isomer. The idea of two-proton decay from an isomeric state in a nucleus not lying beyond the proton-drip line should not be too readily dismissed since this was how the first example of one-proton radioactivity was serendipitously discovered [9]. The identification of two-proton decay, from the isomeric state in ^{140}Dy, would be from the observation of ^{138}Gd transitions in the ^{140}Dy FRS setting.

We propose to analyse the products of a fragmentation reaction of a 1 GeV/A $^{208}_{82}$Pb beam incident on a 1.6 g/cm^2 natural $^{9}_{4}$Be target at the entrance to the FRS to search for $K^\pi = 8^-$ isomeric states in ^{140}Dy. The FRS will be used in standard achromatic mode with an aluminium wedge-shape degrader of thickness 2 g/cm^2 at the intermediate focal plane. Reaction products will be identified by combining the measurements of energy loss (ΔE) and time of flight (TOF) with information from position-sensitive multi-wire counters and the magnetic field readings. From these measurements of the magnetic rigidity together with position and TOF, the atomic number Z, and the mass-to-charge ratio (A/Q) will be determined for the ions reaching the final focal plane. These procedures rely on the fact that the ions will be fully stripped at these energies. The identified ions will be slowed down in a variable-thickness aluminium degrader and after passing through a 3mm thick plastic scintillator will be implanted into a few cm thick aluminium catcher plate. This final aluminium catcher will be set between a high-efficiency closed-packed array of segmented Ge detectors which will be used to to identify delayed γ rays in the 100 ns - 1 ms time range with respect to an ion passing through the MUSIC chamber, i.e. a clock will be started by a heavy ion which is detected at the focal plane, and subsequently stopped by the arrival of a γ-ray within a few hundred μs window. Such a setup will greatly reduce the background. The half-life of the delayed γ-ray transitions can be measured by time-to-amplitude converters between these signals. Data will be taken with an identified recoil, a delayed γ-ray transition, and also delayed $\gamma - \gamma$ coincidences which will help in unravelling the decay pattern of these isomers. Some of the known isomeric states in the neighbouring nuclei will be used as an internal calibration in the lifetime procedure.

The cross sections for the formation of these nuclei have been estimated from the EPAX and Benesh prescriptions and have been cross checked with the LISE program from GANIL and the LIESCHEN code from GSI. In addition, this beam time request is based on previous fragmentation experience with a Pb beam [8] where the $K^\pi = 8^-$ isomer in ^{138}Gd was observed in 1 shift of beam time under the same experimental conditions, see Fig. 1. The cross section estimates show that ^{140}Dy will be produced at an approximately rate of 1/10th that of ^{138}Gd. In this case, we require to run for ≈12 shifts to be able to observe the isomer in ^{140}Dy with similar statistics.

We expect to take 3 shifts to set up and optimise the FRS and in total request 5 days of beam time.

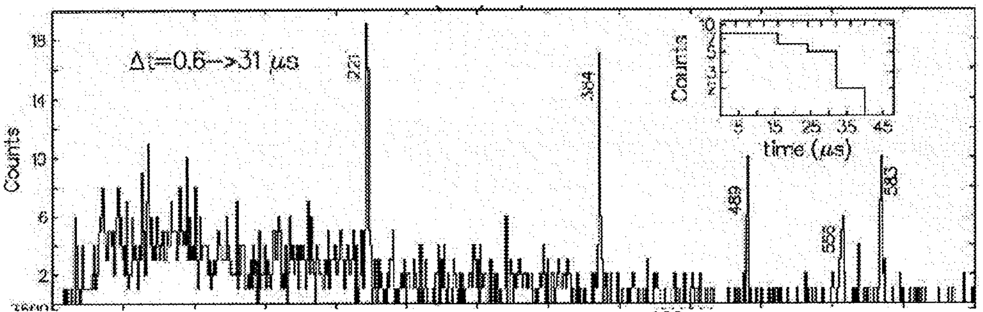

FIG. 1. The decay of the 6μs $K^\pi = 8^-$ isomeric state in ^{138}Gd produced from 1 shift of ^{208}Pb fragmentation data.

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Isomer Decay Probe of Shape Coexistence Lead Isotopes

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Neutron-deficient lead isotopes close to the neutron mid-shell near N=104 represent a particularly important example of the quantum mechanical mixing of nearly degenerate eigenstates characterised by different intrinsic shapes [1]. Calculations predict three different shape configurations at relatively low excitation energies, arising from the excitation of pairs of protons from the closed shell core [2,3]. The spherical ground states are associated with the Z=82 shell closure, while an oblate 2 particle-2 hole (2p2h) proton configuration has been observed in heavier lead isotopes. A more strongly deformed prolate configuration is also predicted for N≤106 and can be associated with both 4p4h and 6p6h excitations. New shapes, including a highly-deformed oblate configuration at an excitation energy of ~2.5 MeV, are also predicted for extremely light lead isotopes [3] (see figure 1).

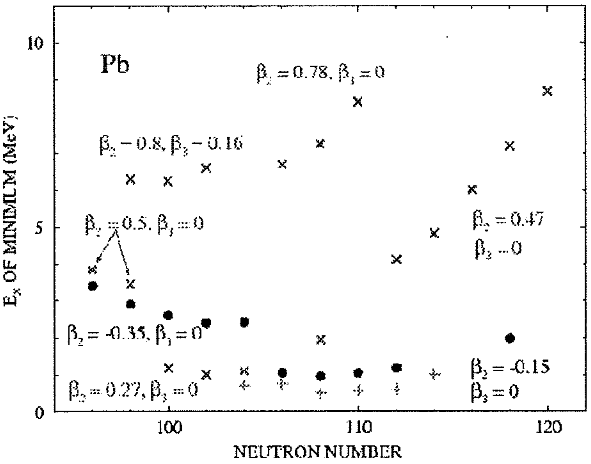

Figure 1 Calculated [3] excitation energies of coexisting oblate (dots) and prolate (crosses) configurations in even-even lead isotopes as a function of neutron number. Experimental values are indicated by the + symbols.

Recent in-beam γ-ray studies of the neutron-deficient lead isotopes ^{182,184,186,188}Pb [4-8] have provided evidence for the prolate configuration, which appears to become yrast at spins of around 2 - 4ħ in these nuclei. Complementary evidence from α decays of ^{192}Po feeding the 0^+ states of the spherical, normal deformed oblate and prolate configurations in ^{188}Pb was obtained in a RITU experiment in the first application of the α-particle/conversion electron coincidence technique [9]. The same technique was subsequently exploited in a successful SHIP experiment to study the α decay of ^{190}Po, in which the corresponding three 0^+ states in ^{186}Pb were all found to lie below the lowest 2^+ state [10].

The identification of these non-yrast 0^+ states is of particular significance since it provides a constraint on the unmixed band head energies and the mixing strengths between the structures in these nuclei. The identification of higher-spin, non-yrast states, especially from the normal deformed oblate configuration, would provide even more stringent constraints and allow information to be inferred about the bands' rotational properties. However, their feeding is such that they have not been observed in the in-beam or α-decay experiments. An alternative approach is to study the decay of μs isomers, the decays of which may cascade through the states of interest. Such isomers are known in ^{188,190}Pb, for example [8,11], and the intensity distributions of the yrast bands in lighter even-even isotopes are also suggestive of the existence of isomers.

The primary aim of the present proposal is therefore to study the γ-ray decays of μs isomers in neutron deficient lead isotopes, in order to search for the hitherto unobserved non-yrast transitions. The measurement of the decays of such isomers using conventional techniques becomes increasingly problematic as the cross sections plummet with decreasing neutron number. Highly selective techniques are therefore essential and the efficacy of the isomer tagging technique makes it ideally suited for this application.

The following table gives the cross sections and production rates estimated from EPAX calculations for lead isotopes in the region of interest. The estimates assume a beam of ^{238}U at 1 GeV/A, comprising 10^9 ions per spill and 3 spills per minute, and a 1 g/cm^2 thick Be target. Losses of 50% have been assumed at both the S2 degrader and stopping the ions at S4.

Nuclide	σ_{Be} (μb)	Target rate (s^{-1})	S4 rate (s^{-1})
^{182}Pb	0.006	0.019	0.003
^{183}Pb	0.054	0.18	0.045
^{184}Pb	0.41	1.4	0.34
^{185}Pb	2.5	8.5	2.1
^{186}Pb	13	43	11
^{187}Pb	54	181	45
^{188}Pb	188	628	157
^{189}Pb	542	1816	454
^{190}Pb	1309	4385	1096

Using the proposed germanium detector array to measure the γ rays emitted in the decays of the isomers, cross sections down to the level of ~100 nb should be accessible. This level of sensitivity should be sufficient to allow isotopes at least as far as ^{184}Pb to be investigated in a 5-day run forming part of this campaign. Identifying the non-yrast levels is vitally important for elucidating the nature of the configuration mixing in lead isotopes as they impose severe constraints on the band mixing calculations, which cannot be obtained from the yrast levels alone. Furthermore, these measurements will allow important questions to be addressed, such as whether the mixing interactions vary with spin and, if so, how.

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Search for high-spin K-isomers in neutron-rich rare earth nuclei

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INTRODUCTION and PHYSICS MOTIVATION

The structure of nuclei in the Yb-Hf-W-Os (Z=70-76) region is characterised by the presence of high-angular-momentum intrinsic, i.e. non-collective states. Such states are favoured over collective excitations because the proton and neutron Fermi levels are among quasiparticle orbitals with large angular-momentum projections (Ω) on the symmetry axis, allowing states with large values of $K = \Sigma\Omega$ to be formed. These states may be isomeric, one of the most famous being the $K^{\pi}=16^{+}$, 31 year isomer in ^{178}Hf [1].

Heavy rare earth nuclei around A$\sim$180 are a well established testing ground for a number of nuclear structure phenomena, including K-isomerism, configuration dependent pairing effects, gamma softness and hexadecapole deformation [2]. However, our current knowledge of the neutron rich isotopes of these elements is rather limited due to the difficulty in synthesising these species in an environment which allows detailed spectroscopy.

In our former study using the fragmentation of a relativistic ^{208}Pb beam several new isomers were identified in the neutron-rich Ta-Pt nuclei (see fig.1). In the case of the even-even nuclei two new isomers were observed with spin-parity of 10^{-} in ^{190}W and 5^{-} in ^{202}Pt, respectively. Both of these isomers are formed by breaking one quasiparticle pair. More isomeric decays are predicted in this region at higher spins, having multiquasiparticle configurations. However, using ^{208}Pb beam, these high spin decays were not observed. The induced angular momentum depends on the number of abraded nucleons and can be well explained by theory [3]. Generally speaking, states with higher spin can be populated by using heavier beams. Therefore we propose to use ^{238}U beam to populate the neutron-rich Ta-Pt nuclei. Our former experiment [4] proved that having a high number of ablated nucleons, high spin states can be reached. The observed high spin decays from the previously reported isomeric $K = \frac{35}{2}$ states in ^{175}Hf, ^{179}W and ^{181}Re [5-7] represent the highest discrete angular momenta observed in projectile fragmentation reactions so far. In addition to angular momentum considerations, the ^{238}U beam has the benefit of allowing the study of those nuclei which were in the 'shadow' of charge states of the primary ^{208}Pb beam.

THE EXPERIMENT

We propose to use the fragmentation of a 750 MeV/nucleon ^{238}U beam on a thick Be target to search for high spin isomeric states in the neutron-rich rare earth nuclei. The production cross-section of ^{190}W according to EPAX calculations (version 2 [8]) will be reduced by a factor of 7 compared to that with the ^{208}Pb beam (from 2.52 μbarn with ^{208}Pb beam to 0.37 μbarn with ^{238}U). However, with an incident beam of $\times10^{9}/12$ s spill (factor of 5 more than for the Pb beam) on 1.6 mg/cm^{2} Be target, assuming the same

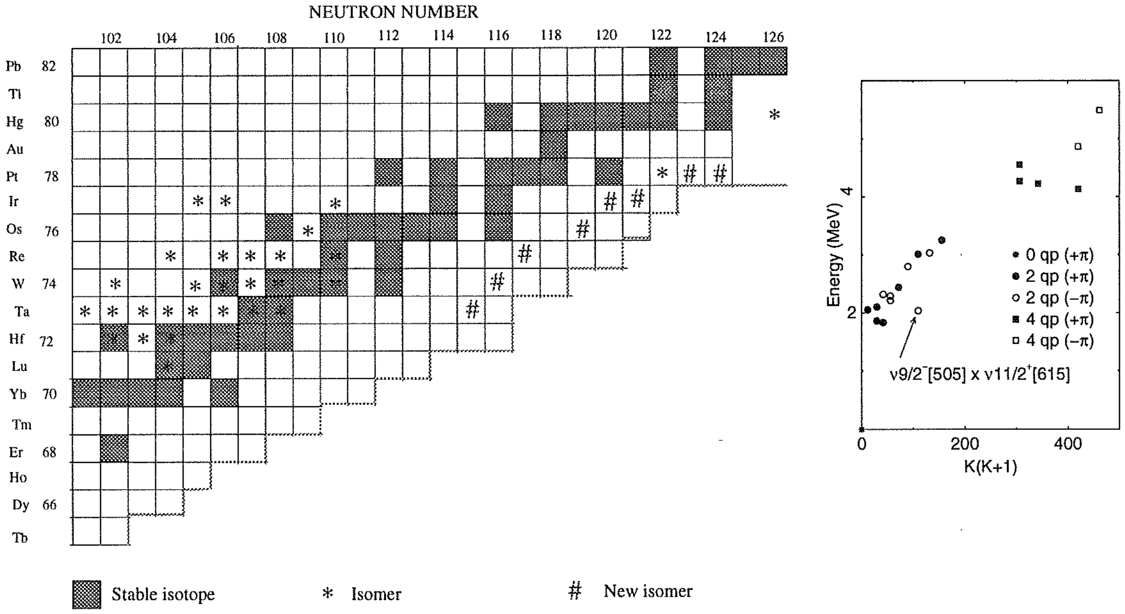

Figure 1: Isomeric states observed from the fragmentation of ^{208}Pb, and Blocked BCS calculatons for ^{190}W predictinting that some of the four-quasiparticle states may be isomeric.

transmission factor and charge-state losses, we will implant $\approx$500 ^{190}W ions/hour. This rate is similar to that of our previous experiment, and is suitable for discrete gamma-ray spectroscopy. With five days of beam time (compared to 62 hours of measurement with the ^{208}Pb beam) we expect to obtain some γ-γ coincidence data for the stronger channels. We note some differences compared to our previous experiment: the production of isomeric states should be more favourable (higher isomeric ratio), an increased γ-ray detection efficiency, and the fact that the lifetime of the formerly observed two-quasiparticle state in ^{190}W is on the edge of the sensitivity range ($\sim$ms) using this technique.

The experimental details are similar to those of the other experiments within the isomer part of the proposed FRS campaign.

As a part of a campaign, with fully operational and calibrated FRS, five days of beam time are required.

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Search for K-isomers in the ms-s time-range in neutron rich rare earth nuclei

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We propose to search for new isomers with half-lifes the a range from ms to s in neutron-rich nuclei with Z=72-76 using projectile fragmentation.
Theoretical work has for a long time [1] indicated that there are good prospects for finding new isomers in neutron-rich isotopes in the mass-180 region. Recent calculations [2, 3, 4, 5] support this view with quantitative predictions. Particularly at the neutron rich side the knowledge of isomeric states is very limited. Conventional methods like incomplete fusion or deep inelastic reactions are only able to populate isotopes close to the valley of stability, whereas projectile fragmentation with in flight separation turned out to be a powerful tool to produce exotic, n-rich isotopes in their isomeric states. A recent experiment searching for μs K-isomers at the FRS showed this to be very impressive [6]. Among other previously unknown K-isomers in this experiment the last known neutron rich isotope of the W chain, the nucleus ^{190}W, was produced and a decay-γ spectrum of the ground state rotational band was measured for the first time. The ground state band is fed by a ms-isomer at around 2.4 MeV excitation energy with a tentative spin assignment of $K^{\pi}=10^{-}$. An unambiguous determination of the excitation energy and spin of the isomer is not possible from this kind of measurement. However, the above given values are supported by BCS-model calculations.
These calculations predict higher lying isomers in this isotope which would have half-lifes longer than ms. By observing the decay of such a long lived isomer it will be possible to verify the previously proposed gs-rotational band and extend it to higher spin values.

The table below shows the experimental rates for isotope implantation behind the final focus of the FRS obtained with a primary beam intensity of $2{\cdot}10^{8}$ Pb-particles/spill.

Isotop	Z	A	Rate (p/s)
Os	76	194	0.3
Os	76	195	1.8
Os	76	196	0.5
Re	75	191	0.1
Re	75	192	0.5
Re	75	193	0.5
W	74	189	0.1
W	74	190	0.5
W	74	191	0.06
Ta	73	186	0.03
Ta	73	187	0.06

Compared to the previous experiment the isotope intensity will be improved due to the meanwhile finished intensity upgrade of the UNILAC. The experimental set-up will again consist of the standard FRS tracking detectors and the closed packed array of segmented Clover γ-detectors.
The time measurement will be done for each channel with special long range counters which can be started with the spill and stopped by individual γ-rays. The range clock frequency and thus the range of the counters can be adjusted to the spill structure of the beam.

The measurement of long lived isomers up to the second range will be influenced by background radiation. This background originates from isomer and β-decay of other isotopes implanted in the same time regime as the isotope of interest, room background and background from nuclear reactions in the stopper.
Taking the case of ^{190}W which was implanted with 0.5 p/s there was a total rate of the other isotopes of 4.0 p/s. Due to the fact that the γ-rays of the other isotopes will not have the energies e.g. of ^{190}W only Compton scattering of these events can contribute to the background under the γ-ray-lines of interest. According to an off beam measurement performed in the previous experiment [7] the mean multiplicity in a segmented Clover detector was 1.3, which indicates that the Compton scattering is low. On the other hand, there is the room-background with a continuous distribution with exponential slope and a few discrete γ-lines, which are well known. This kind of background can be subtracted. Background coming from nuclear reactions in the stopper will produce mainly prompt γ-rays. Possible longer lived activities can be reduced by changing the stopper from time to time.
In isotopes with already known levels of the gs-band the isotope selection can be verified, which well help to assign decays from new long lived isomers. For very exotic settings on the n-rich side we will have only total implantation rates $\leq 1/s$. Therefore for these yet unexplored isotopes correlation times of up to several seconds can be realized without excessive background.
To cover the region of interest on the n-rich side of the rare earth nuclei we need a setting on Hf, W and Os for which we request in total 20 shifts of beam time.

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Shape Coexistence Investigation in Neutron-Rich Po→Th Nuclei

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INTRODUCTION and PHYSICS MOTIVATION

Prior to the advent of fragmnetation reactions with ^{238}U beams, the study of the high and medium spin structure of the neutron-rich A≈230 nuclei was virtually impossible. Stable-beam induced fusion-evaporation reactions can not reach this part of the Segré chart, while β-decay studies populate only the very low spin states. The only medium to high-spin information available in the region comes from light particle reactions (using protons, neutrons and α-particles) and deep inelastic reactions on the naturally available ^{232}Th, ^{234,235,238}U targets [1]. However these cannot reach the neutron-rich isotopes. The limit of nuclei with available spectroscopic information together with the limit of identified isotopes [2] in this region are shown in fig. 1.

We propose to study the transitional region between the spherical ^{208}Pb and the deformed ^{238}U nuclei. The majority of this nuclei will be studied for the first time. The technique of isomer spectroscopy has proved to be a powerful method to study shape coexistence in other region of the Segré chart (see eg. ^{190}Pb [3]), and we expect that a similar phenomena also occurs in this region, namely competition between the deformed (K-isomers) and and spherical (seniority isomers) minima. The observation of new isomers will provide new information regarding the single-particle energies, the role of octupole and hexadecapole collectivity, and the persistence of the different shaped minima in the medium spin regime.

In the deformed even-even nuclei it is expected that the intrinsic 2,4,6 quasi-particle states might be isomeric. In ^{234}U for example, among others, bandheads with internal structure of ($\nu 7/2^-[743] \otimes 5/2^+[622]$), ($\nu 5/2^+[633] \otimes 5/2^+[622]$), and ($\nu 7/2^-[743] \otimes 5/2^+[622]$) have been observed [4]. These two-quasiparticle states with spin-parity of 6^-, 5^+ and 5^- lie at an energy around 1.5 MeV. The 6^- and 5^+ bandheads are isomeric with lifetimes of 33.5 μs and 2 ns, respectively. States with similar configurations are expected in a wide range of nuclei with neutron number of N=140-144, and some of them are expected to be isomeric. In the case of odd-mass nuclei the single-particle levels [5] could also be isomeric.

THE EXPERIMENT

We propose to use the fragmentation of a 750 MeV/nucleon ^{238}U beam on a Be target to search for isomeric states in the neutron-rich Po-Th nuclei. The main setting will be centred on ^{221,222}Po. According to the EPAX calculations (version 2 [6]) the production cross section of ^{222}Po is 0.34 μbarns. Assuming an incident beam of 10^9/12s spill on a 1.6 mg/cm^2 Be target and considering similar losses due to tranmission through the FRS, an implantation rate of 8-10/min ^{222}Po ions is expected. Formerly, we identified the yrast band of ^{190}W [7] under similar (12 ions/min) rate conditions.

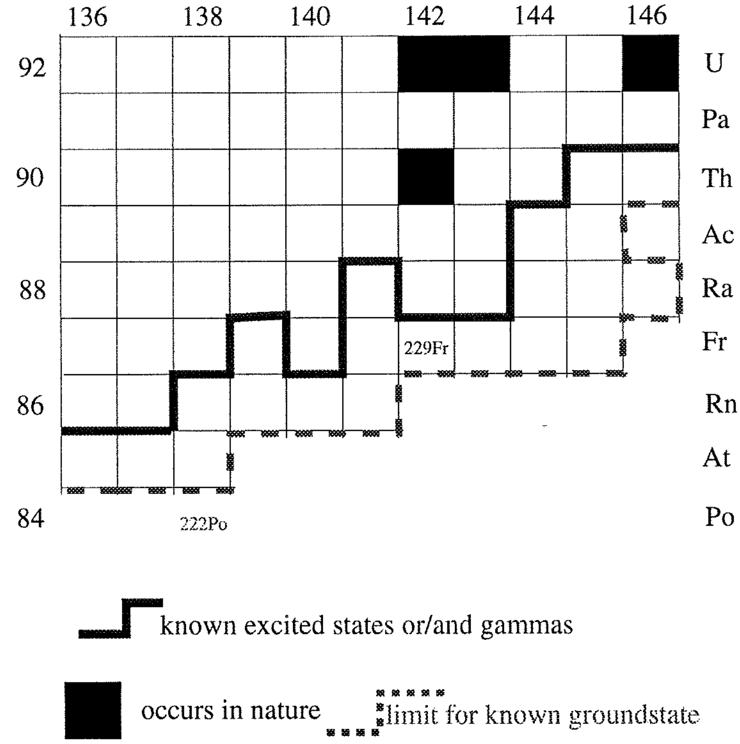

Figure 1: The region of neutron-rich Po-Th nuclei. The nuclei proposed to be studied lies on both sides of the line indicating the limit of previously synthetised [2] nuclei.

As our previous study, using the fragmentation of ^{208}Pb showed, a wide range of nuclei can be studied in the same setting (in this case from polonium to thorium). For the ions closer to the projectile the production cross section is much higher, for instance 2.1 μbarn for $^{229}_{87}$Fr, and they will be transmitted as H-like and He-like ions. We estimate that five days of beam time is needed to achieve the goal of the experiment (note that the effecting measurement time for ^{190}W was 62 hours).

The experimental details are similar to those of the other experiments within the proposed campaign.

As a part of the campaign, with fully operational and calibrated FRS, five days of beam time are required.

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