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Strukturforschung

SF7 ab Okt. 2007 geschlossen

Nukleare Messtechnik

SF7

Arbeitsgruppenleiter: [Prof. Wolfram von Oertzen \(emeritiert\)](#)[Projekte/
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In der Arbeitsgruppe "Nukleare Meßtechnik" werden Entwicklungsarbeiten zu kernphysikalischen Meßmethoden und kernspektroskopische Untersuchungen durchgeführt.

Am Q3D-Magnetspektrometer können mit Hilfe der [Elastic Recoil Detection Analysis \(ERDA\)](#) sehr dünne Schichten leichter Elemente ($Z < 20$) mit hoher Tiefenauflösung von wenigen Nanometern untersucht werden.

Eine neue Methode der ladungsselektiven Messung von Energieverlusten und Umladungsprozessen wurde etabliert und wird systematisch weiterentwickelt. Diese Arbeiten werden in Zusammenarbeit mit SF4, der GSI und der TU-Darmstadt durchgeführt; für letztere ist die Bestimmung von Energieverlusten in verdünnten Medien und heißen Plasmen von Interesse, in denen ähnliche Effekte auftreten.

In der Kernspektroskopie konzentrieren sich die Arbeiten auf die Untersuchung extrem deformierter Kerne. In einer Reihe experimenteller und theoretischer Arbeiten konnten wir zeigen, daß alpha-Teilchen und ^{16}O -Cluster durch kovalente Neutronen in Kernmolekülen insbesondere in Be-Isotopen gebunden werden. Diese Konfigurationen erscheinen als angeregte isomere Zustände in leichten neutronreichen Kernen z.B. als Polymerketten in ^{13}C bis ^{16}C . Gegenwärtig werden auch asymmetrische Moleküle basierend auf der ^{16}O -alpha-Bindung untersucht. Hierzu werden Experimente mit den Magnetspektrometern Q3D durchgeführt und neue Möglichkeiten der gamma-Spektroskopie mit Teilchen-gamma-Koinzidenzen entwickelt. Ein Triggerdetektorsystem zum Nachweis binärer Reaktionsfragmente ([BRS](#)) für den europäischen gamma-Detektor-Ball [EUROBALL](#) wurde entwickelt und wird in einer europäischen Kollaboration am Beschleuniger [VIVITRON \(IReS Strasbourg\)](#) zum Einsatz gebracht.

Basierend auf der kernphysikalischen Nachweisteknik für geladene Teilchen wurde die [Entwicklung von großflächigen Micro-pattern Detektoren für thermische Neutronen](#) (Reaktorneutronen und Spallationsquellen) begonnen. Der

Detektor arbeitet mit einem ^{157}Gd Konverter. Die Ortsinformation wird durch Verwendung von Mikrostreifen-Niederdruck-Gasdetektoren erhalten. Dieses Projekt ist eingebunden in ein europäisches Netzwerk (DETNI - Detectors for Neutron Instrumentation), welches von SF7 koordiniert wird.

Letzte Änderung: 14.11.2007 Verantwortlich: [Webmaster SF7](#)



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Strukturforschung

SF7 ab Okt. 2007 geschlossen

Nukleare Messtechnik

SF7

Arbeitsgebiete

weiterführende Texte in englisch

[25 years of the Q3D spectrometer.](#)[High Resolution ERDA at the Q3D Magnetspectrometer.](#)[Nuclear Spectroscopy of Neutron rich light isotopes](#)[Nuclear Rainbows](#)[Nuclear Spectroscopy with Binary Reactions](#)

- [The Binary Reaction Spectrometer](#)

[Large-area micro-pattern detectors for thermal neutron imaging](#)[EU joint research activity on neutron detectors \(DETNI\)](#)

Letzte Änderung: 31.01.2005 Verantwortlich: Webmaster SF7

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Nuclear Methods and Instrumentation

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Nuclear Molecules

- [Dao T. Khoa, W. von Oertzen, H.G. Bohlen and S. Ohkubo](#),
Nuclear rainbow scattering and nucleus-nucleus potential
[J. Phys. G34 \(2007\) R111-164](#)
[PDF\(3.5 MB\)](#)
- [W. von Oertzen, Martin Freer and Yoshiko Kanada-En'yo](#),
Nuclear clusters and nuclear molecules
[Phys. Rep. 432 \(2006\) 43-113](#)
[PDF\(2.8 MB\)](#)

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Structural Research

Nuclear Methods and Instrumentation



25 years of the Q3D spectrometer

[25 years: an overview of the Q3D spectrometer](#)

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25 Years Q3D Magnetic Spectrometer: Publications

1. Results obtained at the Q3D Magnetic Spectrometer at VICKSI-ISL, HMI

[1.1.-1.100. Publications](#)

2. Work at Magnetic Spectrometers of other Laboratories

2.1 Germany: GSI-Darmstadt

[2.1.1.-2.1.18 Publications](#)

2.2 France: ISN-Grenoble and SPEG-GANIL-Caen

[2.2.1. - 2.2.8. Publications ISN - Grenoble](#)

[2.2.9. - 2.2.20. Publications SPEG-GANIL](#)

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Themes:

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High Resolution ERDA at the Q3D Magnetspectrometer

Contact: [Abel Blazevic](#)

Elastic Recoil Detection Analysis ERDA

Suppose, you have a sample with thin layers (1 - 100 nm) and you would like to know, of which elements does the sample consist and how are they distributed in depth. Hence you need the stoichiometry and the depth profiles of the constituents. There are two methods for the analysis, the Rutherford Back Scattering RBS, and the Elastic Recoil Detection Analysis ERDA.

In ERDA one bombards the sample with fast ($E = 0.5 - 3 \text{ MeV/u}$) heavy ions. Fig. 1 illustrates the principal of the method.

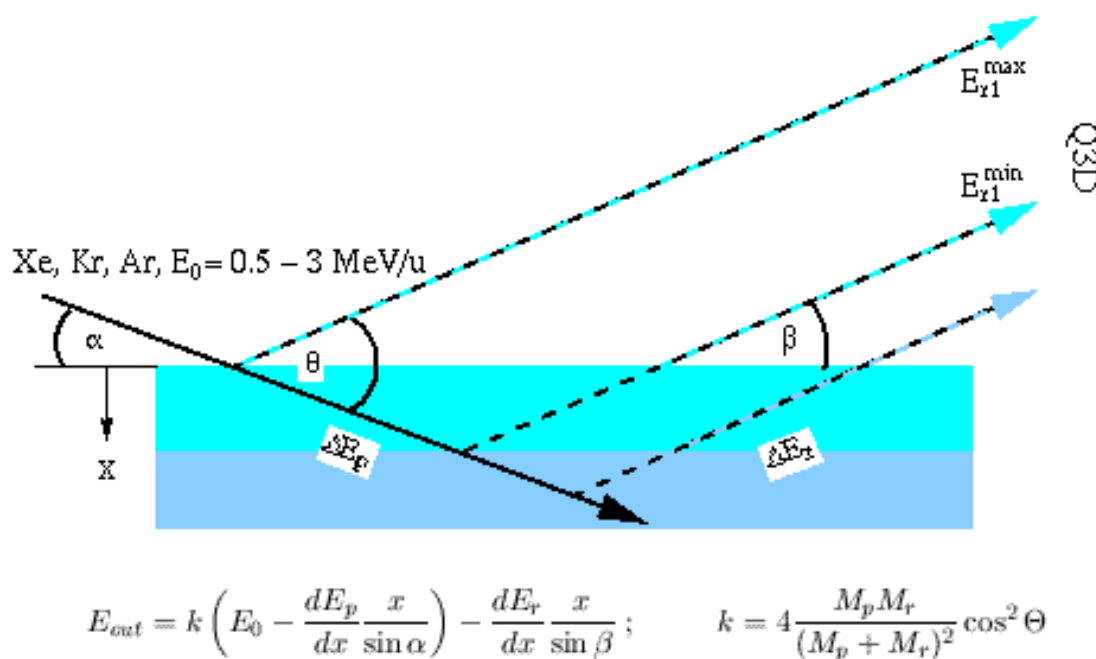


Fig. 1: The principal of ERDA

The projectiles penetrate the sample with a flat incident angle $[\alpha]$ ($3^\circ - 10^\circ$). Some of them are scattered on sample atoms. Several of the recoiled sample atoms leave the probe as ions and can be detected. Ions scattered from the surface have a greater energy than ions coming from the depth, because the projectiles as well as the recoiled atoms lose energy on their way through the probe due to interaction with the sample electrons and atoms (electronic stopping). For known stopping powers dE/dx (energy loss dE of a projectile after passage of a material of thickness dx) of the projectile and recoil it is possible to estimate the depth x , where from the recoiled ion is scattered by measuring its energy.

At the HMI we have combined ERDA with the high resolution magnetic

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spectrometer Q3D. Fig.2 shows the way we obtain the depth profiles.

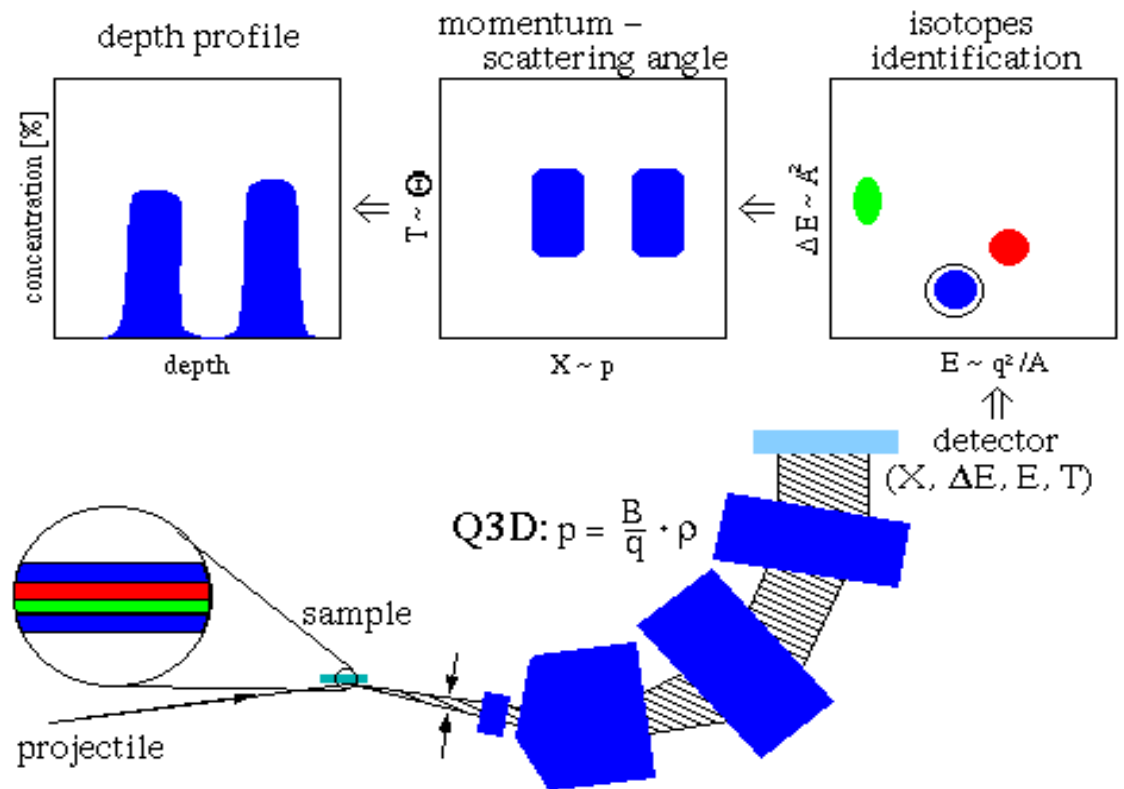


Fig. 2: ERDA combined with the magnetic spectrometer Q3D.

The sample, in this example consisting of four layers, the topmost and lowest of the same material, is bombarded by heavy projectiles. The recoiled ions, coming from all four layers, reach the magnetic spectrometer through an entrance slit (arrows). In the magnetic field of the Q3D the ions are separated in their momentum. The high dispersion of the spectrometer, $dp/p = 95 \text{ mm}/\%p$, leads to an excellent energy resolution of $dE/E = 2 \cdot 10^{-4}$. In the detector, situated in the focal plane of the Q3D, four quantities of each ion are measured, the position X in the focal plane, an energy loss $[\Delta E]$ in a gas filled drift chamber, the residual energy E in a scintillator and the time of flight T through the Q3D. In the first step of the analysis the different isotopes are identified in a plot $[\Delta E]-E$, where every isotope forms a separated spot. By gating individual spots (blue spot in Fig.2) it is possible to extract only one isotope for the further analysis. In the next step one projects the spectrum $X-T$ on the X -axis, which is proportional to the momentum of the ion and which can be transformed in an energy scale. Considering the energy loss of the projectile, the energy transferred to the recoil in the scattering process and the energy loss of the recoil, this energy scale finally can be transformed in a depth scale.

The combination of ERDA and a magnetic spectrometer results in some advantages:

- The energy resolution of the Q3D, $dE/E = 2 \cdot 10^{-4}$, is one of the best, one order of magnitude better than conventional silicon detectors.
- The kinematic effects (recoil energy dependence from the scattering angle) can be eliminated with magnetic elements (multipoles) for all recoiled ions at once.
- The kinematic corrections allow to use a great solid angle, max 10.4 sr, without losing the good energy resolution. Hence low beam intensities and short measuring times are needed, which takes care of the sample.

All those advantages allows to estimate the depth profile of a sample with a depth resolution of less then 1 nm in a short time without destroying the sample.

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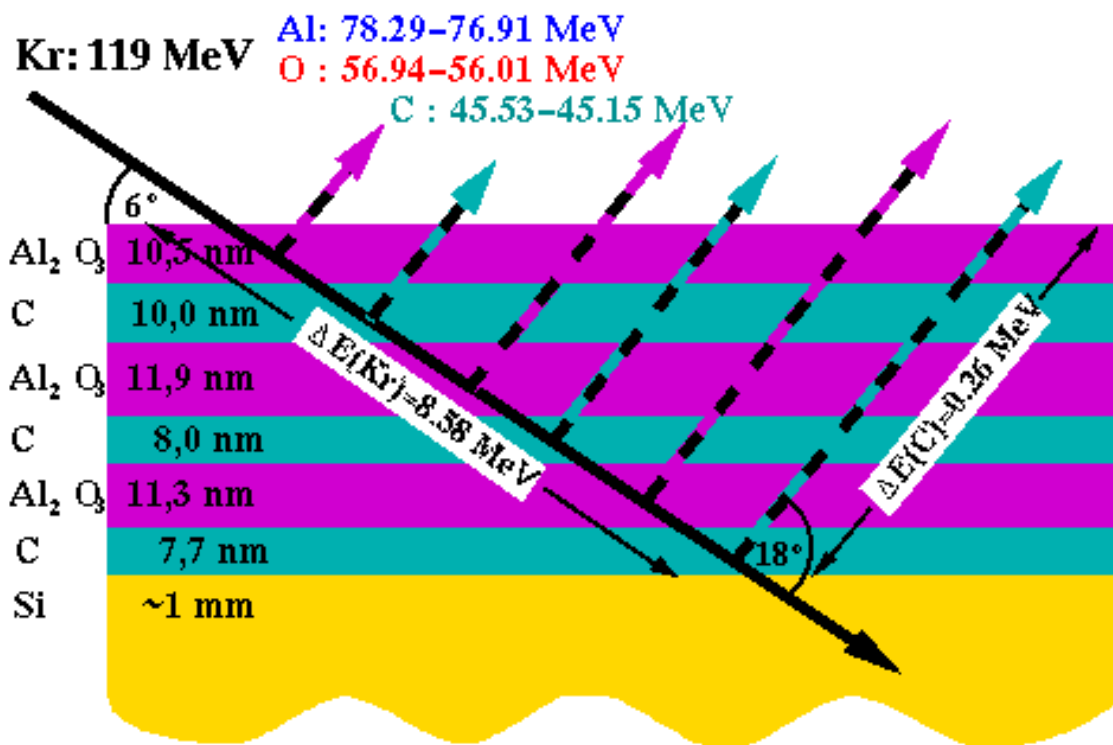
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ERDA: Some examples

Fig.3: The structure of the Al₂O₃-C-multilayer-sample.

The energy intervals of the ions recoiling from the first two layers are written on top of the layer. Further there is the energy loss of the Kr-projectile and a C-recoil from the last layer entered which shows the advantage of using heavy ions as projectiles because of their great stopping power.

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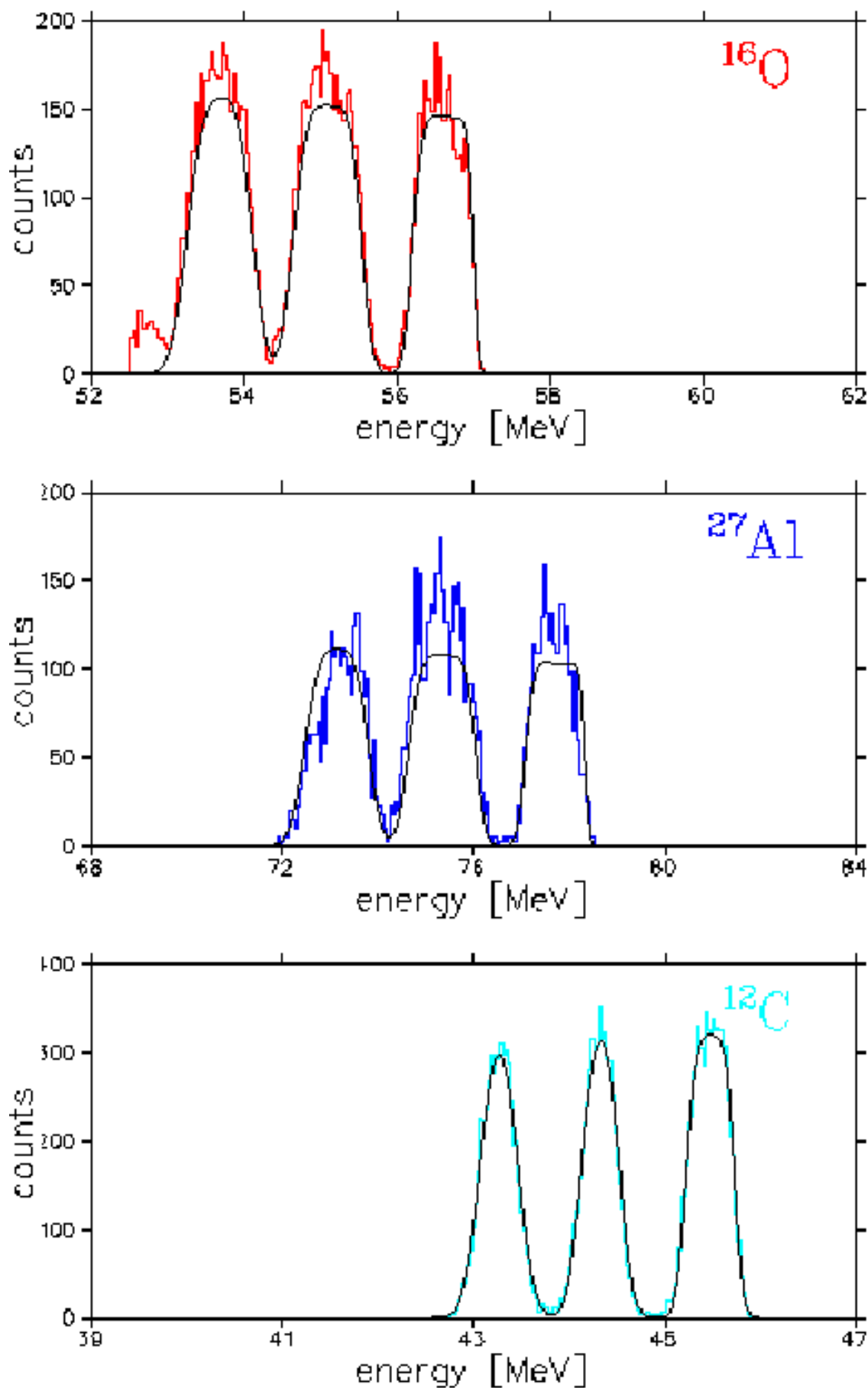


Fig.4: A simulation of the measured spectra, assuming the layer thicknesses as marked in Fig.3.

The depth distribution was supposed to be boy-shaped and was folded with a depth resolution function including the detector resolution, energy and angular straggling. With the slope of the first O-layer we estimated the experimental depth resolution to 1.3 nm.

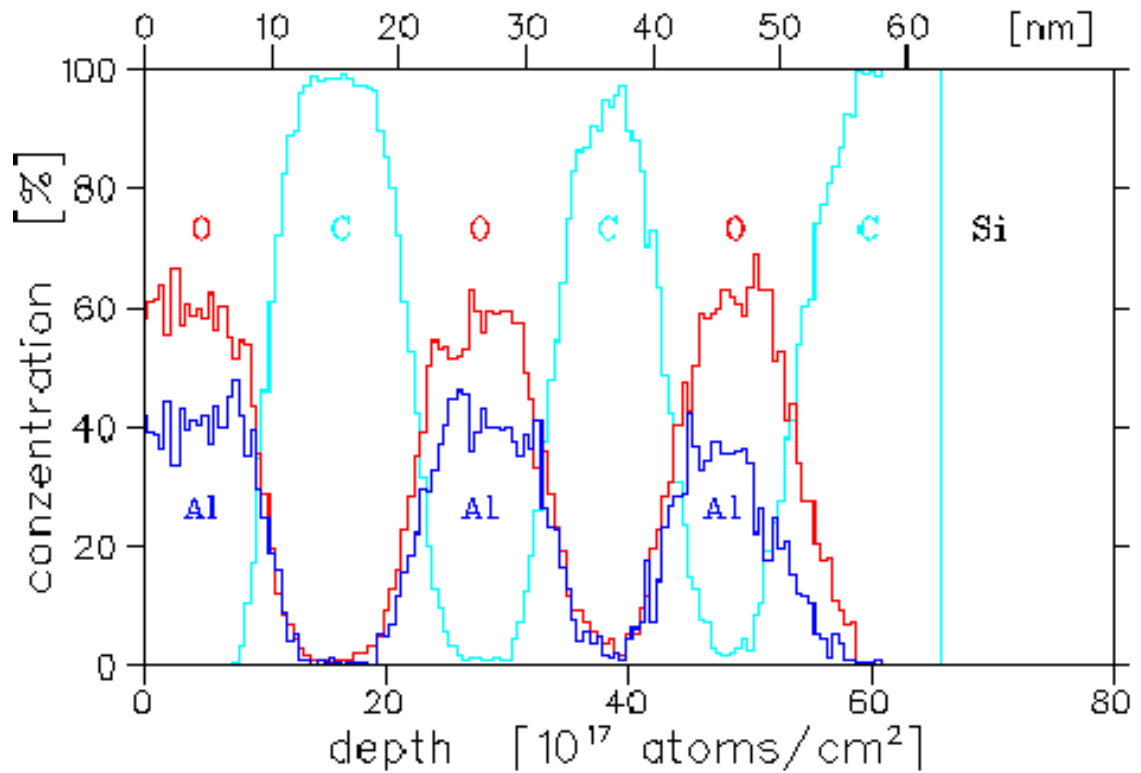


Fig.5: Depth distribution of the layer constituents obtained with an iterative method and the measured spectra. There is no depth resolution considered.

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ERDA on thin layers

The evolution of the charge state distribution

There is a problem of estimating the depth of the first layer with high resolution ERDA, caused by a changing stopping power S of the projectile in the 'non-equilibrium' region near the surface.

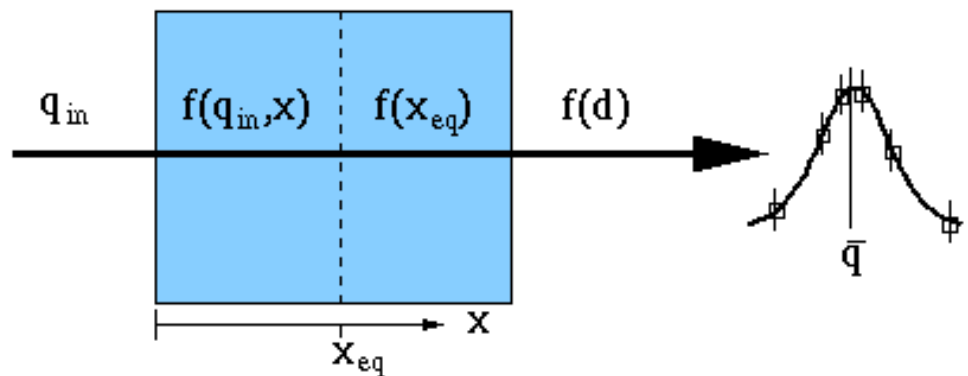


Fig.6: The passage of ions through matter.

Ions with an incident charge q_i change their charge state when penetrating into matter. There are several processes like electron capture, ionisation, excitation, radiative and Auger decay, which result in an evolution of a charge state distribution $f(q_i, x)$. A dynamic equilibrium is reached after a certain depth x_{eq} resulting in a stable charge state distribution $f(x_{eq})$ for $x \geq x_{eq}$ at this energy. The energy loss in this region can be calculated by the methods of Biersack & Ziegler or Northcliff & Schilling with an effective charge in the formula for the stopping power S . For $x < x_{eq}$, however, S changes with the evolution of the charge state distribution. Thus we developed a new method to investigate this dependence and the energy loss of ions in specific charge states under non-equilibrium conditions.

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A new method for study of energy loss in pre-equilibrium

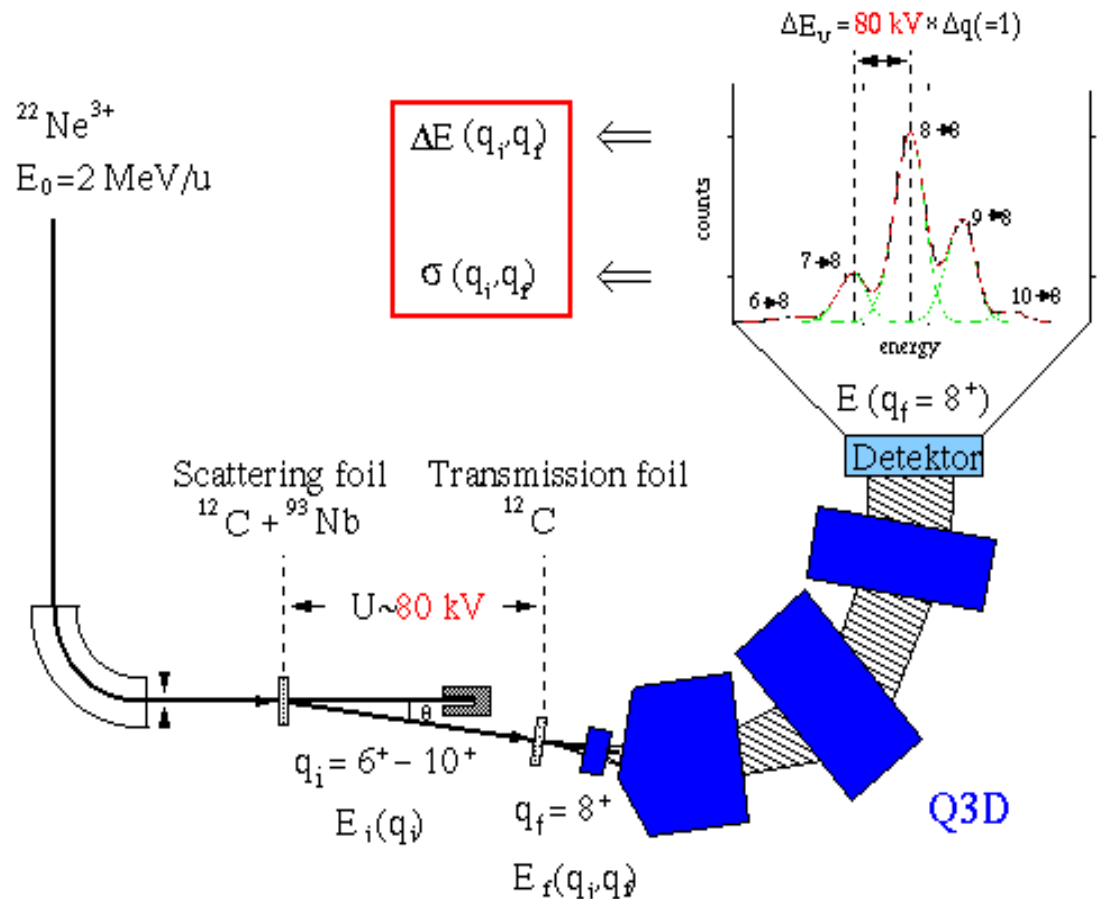


Fig.7: The principal of the novel method.

Ions coming from the accelerator are scattered at first in a thin foil (scattering foil) to reduce the beam intensity for the detector and to create different charge states q_i , which are then incident on a second foil (transmission foil). A high voltage with opposite polarity is applied to both foils so that the energy of the ion is shifted according to its charge state. If the ion changes its charge state q_i to q_f during the passage of the transmission foil, its energy has changed by

$$\Delta E_U(q_i - q_f) + \Delta E(q_i, q_f, x),$$

where ΔE_U is the energy shift due to the potential U and ΔE is the energy loss in the foil. Ions with the final charge state q_f are detected in the focal plane of the magnetic spectrometer Q3D ($q_f = 8^+$ in Fig. 1). There their energy is measured with high resolution ($dE/E = 4 \cdot 10^{-4}$). In the spectrum we observe several peaks corresponding to different q_i ($6^+ - 10^+$ in Fig. 1), which are separated due to the applied voltage. From the exact peak positions we deduce the energy loss $\Delta E(q_i, q_f, x)$ for varying foil thickness x (see Fig. 2), whereas the peak integrals serve for the

determination of the charge changing cross sections $[\sigma](q_i, q_f)$.

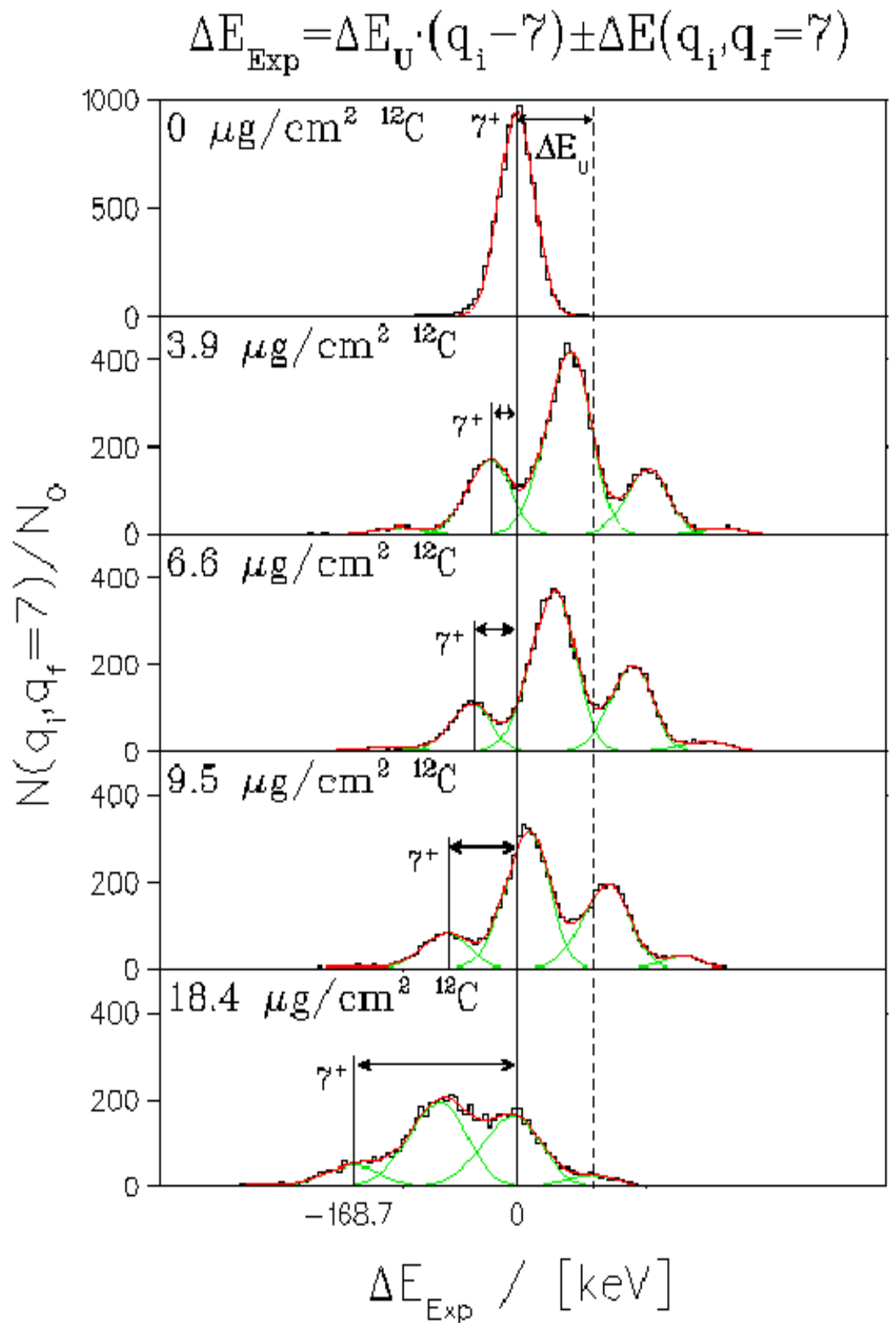


Fig.8: A set of spectra with $q_f = 7+$ and varying foil thickness.

The first spectrum was measured without a transmission foil. The peak serves as reference for the energy loss determination. With increasing thickness the peaks broaden due to straggling effects and the corresponding peaks are shifted to lower energy due to increasing energy loss. By shifting the reference position by ΔE_U it is possible to estimate the energy loss for varying q_i and q_f .

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The charge state distributions

Fig. 9 shows the charge state distributions for Ne ions with different incident charge states q_i ($6^+ - 10^+$) in dependence on the thickness of the second foil. The symbols represent our data, whereas the lines show a theoretical description [1] by solving the rate equations:

$$\frac{dY_i}{dx} = \sum_j Y_j(x) \cdot \sigma_{ji} - Y_i(x) \sum_j \sigma_{ij}$$

Y_i : fraction of the ions with an electronic configuration i (e.g. $1s^22p$),

$[\sigma]_{ij}$: cross section for a process changing the configuration from i to j .

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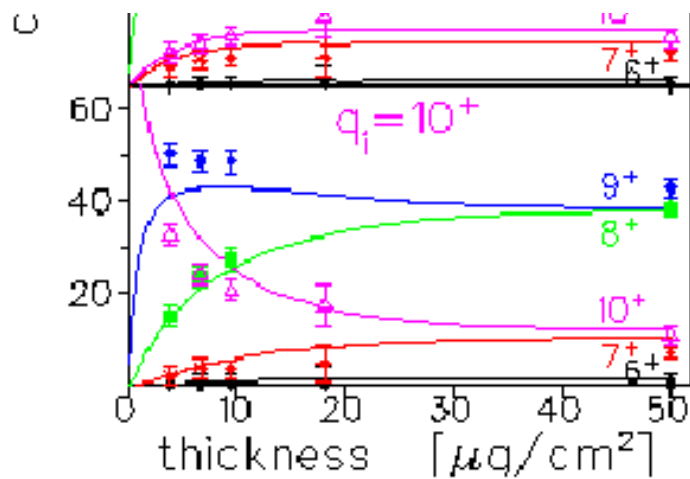


Fig.9: The charge state distributions for Ne ions ($E_0 = 2 \text{ MeV/u}$) in carbon for varying incident charge states q_i .

The cross sections $[\sigma]_{ij}$ for each relevant electronic configuration as well as for each transition were calculated with quantum mechanical methods (PWBA, CDW, see Tab. 1) or were taken from the literature (radiative and Auger decay).

Tab. 1 shows the cross sections for Ne ions at an energy of 2 MeV/u (in carbon), calculated with quantum mechanical methods and used in the rate equations, $[\sigma]_c$: electron capture (CDW), $[\sigma]_{ion}$: ionisation (PWBA) and $[\sigma]_{ex}$: excitation (PWBA). The values were calculated for a H-like Ne and then scaled to the configurations involving the effects of the bound target and projectile electrons.

σ	Ne H-like.	scaled for				
		6 ⁺	7 ⁺	8 ⁺	9 ⁺	10 ⁺
$\sigma_c(1s)$	221	-	-	-	115	221
$\sigma_c(2s)$	160	-	46.7	106	135	160
$\sigma_c(2p)$	298	152	174	197	251	298
$\sigma_c(3s)$	72.0	11.0	19.1	30.5	48.8	72.0
$\sigma_c(3p)$	121	18.5	32.1	51.4	81.9	121
$\sigma_c(3d)$	48.0	7.3	12.8	20.4	32.5	48.0
$\sigma_{ion}(1s)$	50.1	143	135	126	50.1	-
$\sigma_{ion}(2s)$	757	2370	1060	907*	757*	-
$\sigma_{ion}(2p)$	838	1370*	1200*	1000*	838*	-
$\sigma_{ion}(3s)$	2330	3150*	2890*	2620*	2330*	-
$\sigma_{ion}(3p)$	2430	3260*	3000*	2720*	2430*	-
$\sigma_{ion}(3d)$	2450	3300*	2980*	2700*	2450*	-
$\sigma_{ex}(1s \rightarrow 2s)$	6.1	-	6.9	13.5	6.1	-
$\sigma_{ex}(1s \rightarrow 2p)$	28.3	75.5	72.0	68.4	28.3	-
$\sigma_{ex}(1s \rightarrow 3s)$	1.3	2.9	2.8	2.8	1.3	-
$\sigma_{ex}(1s \rightarrow 3p)$	5.3	14.4	13.7	12.9	5.3	-
$\sigma_{ex}(1s \rightarrow 3d)$	0.5	1.4	1.3	1.3	0.5	-
$\sigma_{ex}(2s \rightarrow 2p)$	1030	2070	1030	1030*	1030*	-
$\sigma_{ex}(2s \rightarrow 3s)$	56	151	72	66*	56*	-
$\sigma_{ex}(2s \rightarrow 3p)$	81	206	99	93*	81*	-
$\sigma_{ex}(2s \rightarrow 3d)$	210	598	279	253*	210*	-
$\sigma_{ex}(2p \rightarrow 3s)$	26	40*	35*	30*	26*	-

$\sigma_{ex}(2s \rightarrow 3d)$	210	330	210	200	210	-
$\sigma_{ex}(2p \rightarrow 3s)$	26	40*	35*	30*	26*	-
$\sigma_{ex}(2p \rightarrow 3p)$	81	92*	85*	77*	81*	-
$\sigma_{ex}(2p \rightarrow 3d)$	210	362*	343*	317*	210*	-

*: excited state

 σ [10^{-20} cm²]

Tab.1: Cross sections for Ne ions in carbon.

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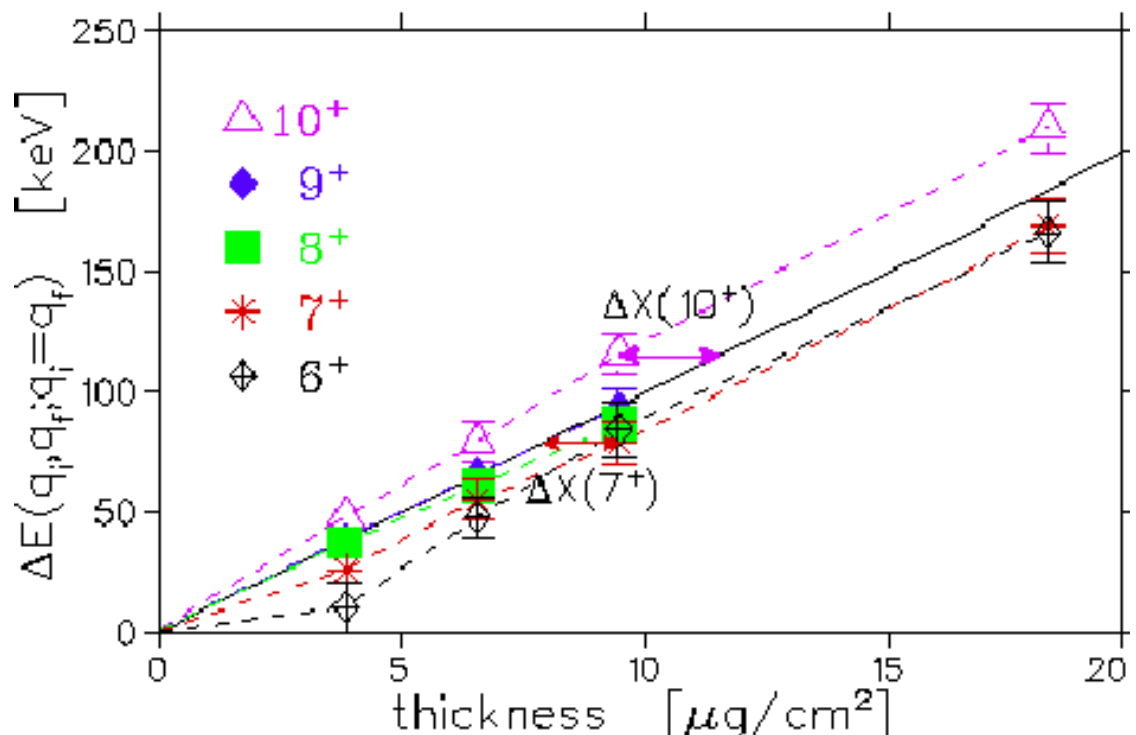
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Energy loss in thin layers

Fig. 10 shows the measured energy losses for Ne ions in Carbon with $q_i = q_f$. The solid line represents the energy loss calculated with the equilibrium values of the stopping power by the method of Biersack & Ziegler. Thus the horizontal deviation of the measured points to the line, marked with arrows in Fig. 10 for two examples, is the error $[\Delta x]$ one would get by calculating the carbon thickness with the equilibrium values. It is, e.g., for $q_i = q_f$ and a thickness of 9.5 $[\mu\text{g}/\text{cm}^2]$ $[\Delta x](10^+) = 1.15 [\mu\text{g}/\text{cm}^2]$ and $[\Delta x](7^+) = -1.0 [\mu\text{g}/\text{cm}^2]$.

Our aim was to extract stopping powers $S(q)$ for 'frozen' charge states from this data. Therefore we had to eliminate those contributions to the energy loss, where the ion had changed its charge state during the penetration through the foil and hence suffered a different energy loss as long it stayed in a different charge state than q_i .

Fig.10: Energy loss for $q_i = q_f$.

The first step was a Monte-Carlo simulation (MCS) of the charge state distributions. Fig. 11 shows the result of a simulation for $q_i = 10^+$. We have marked in red the number of ions leaving the foil with $q_f = 10^+$. One can see, that 43 % of those ions penetrate the foil without changing their charge state. Their energy loss is the one we want to determine, but the measured energy loss includes the contributions also of all the ions, which have been temporarily in a lower charge state and hence have lost less energy.

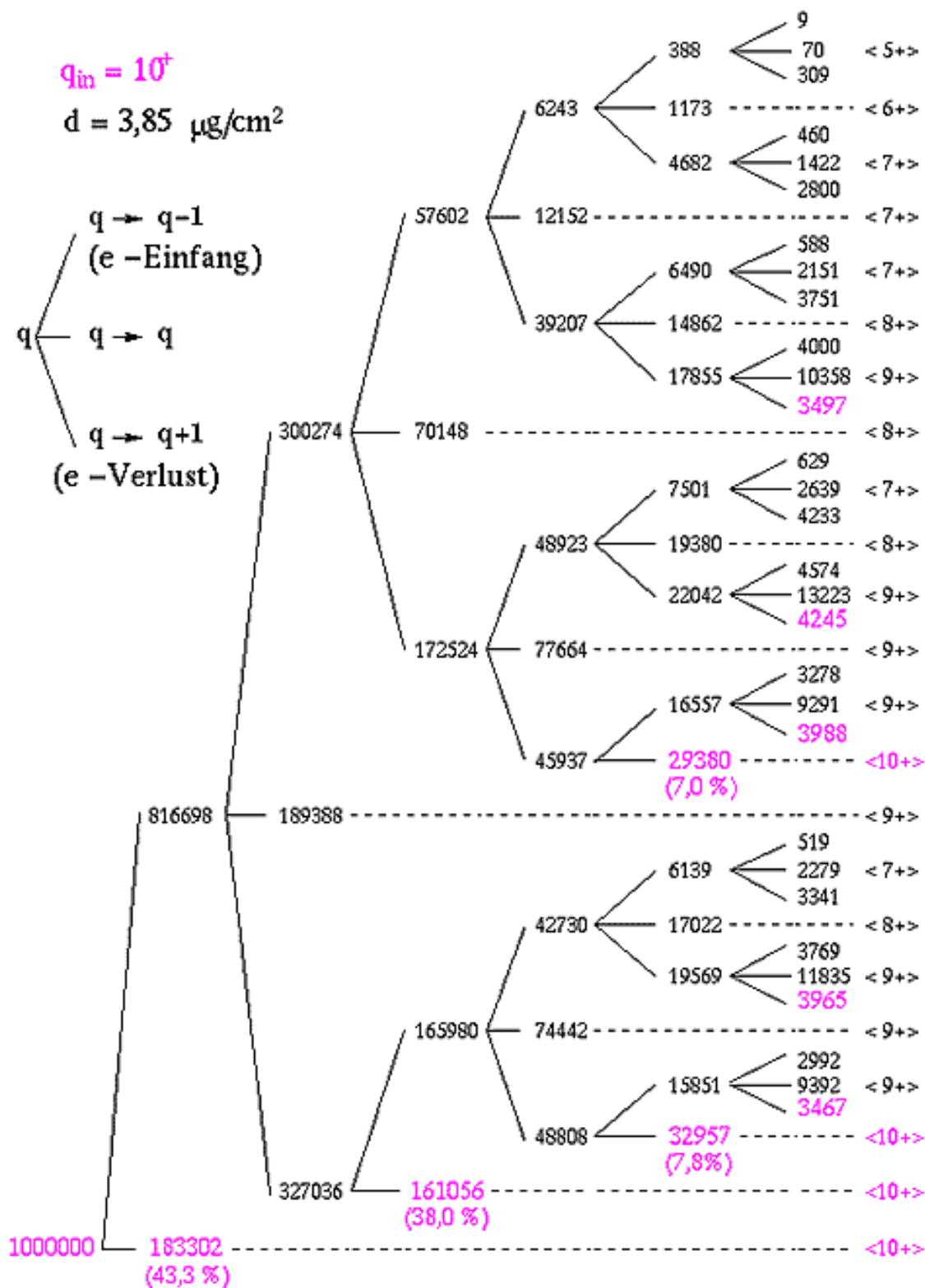


Fig. 11: Monte Carlo Simulation of the charge state distribution for $q_i = 10^+$. Ions leaving the foil with $q_f = 10^+$ are marked red.

To eliminate their contribution to the energy loss we combined the MCS with a charge dependent stopping power. As initial values we used $S(q) = (S_{eq}/q_{eff}^2) \cdot q^2$ where S_{eq} and q_{eff} were taken from the tables of Northcliff & Schilling. The simulated energy spectra of the Ne-ions with $q_i = q_f$ are shown in Fig. 12.

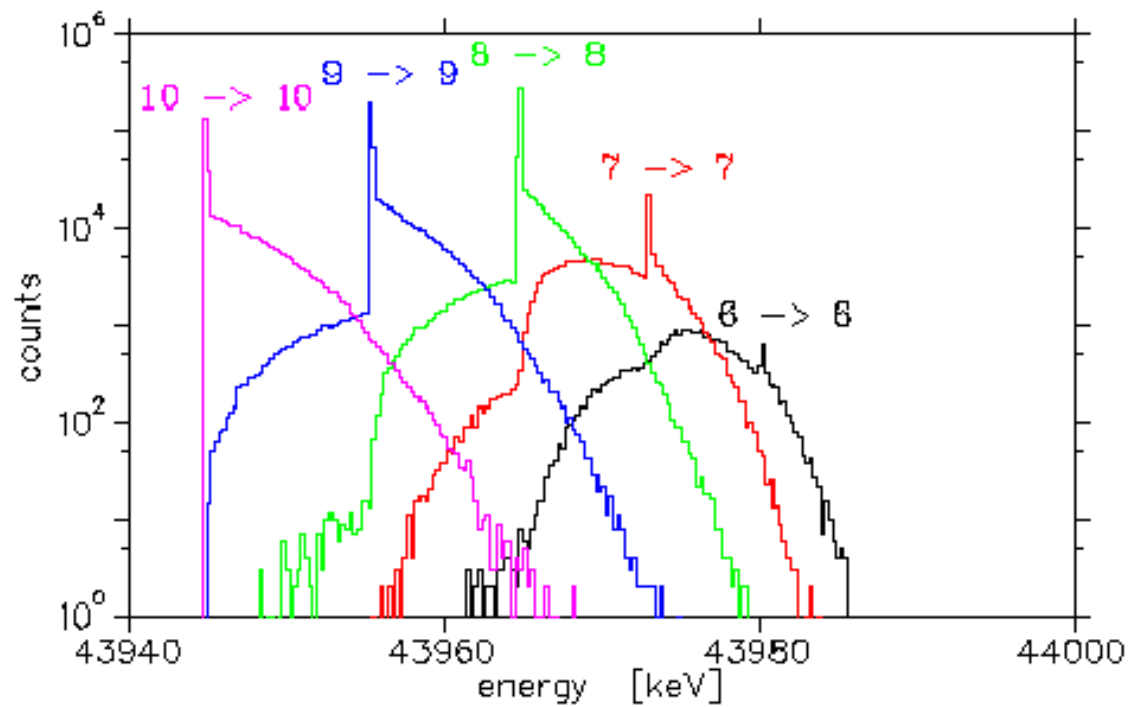
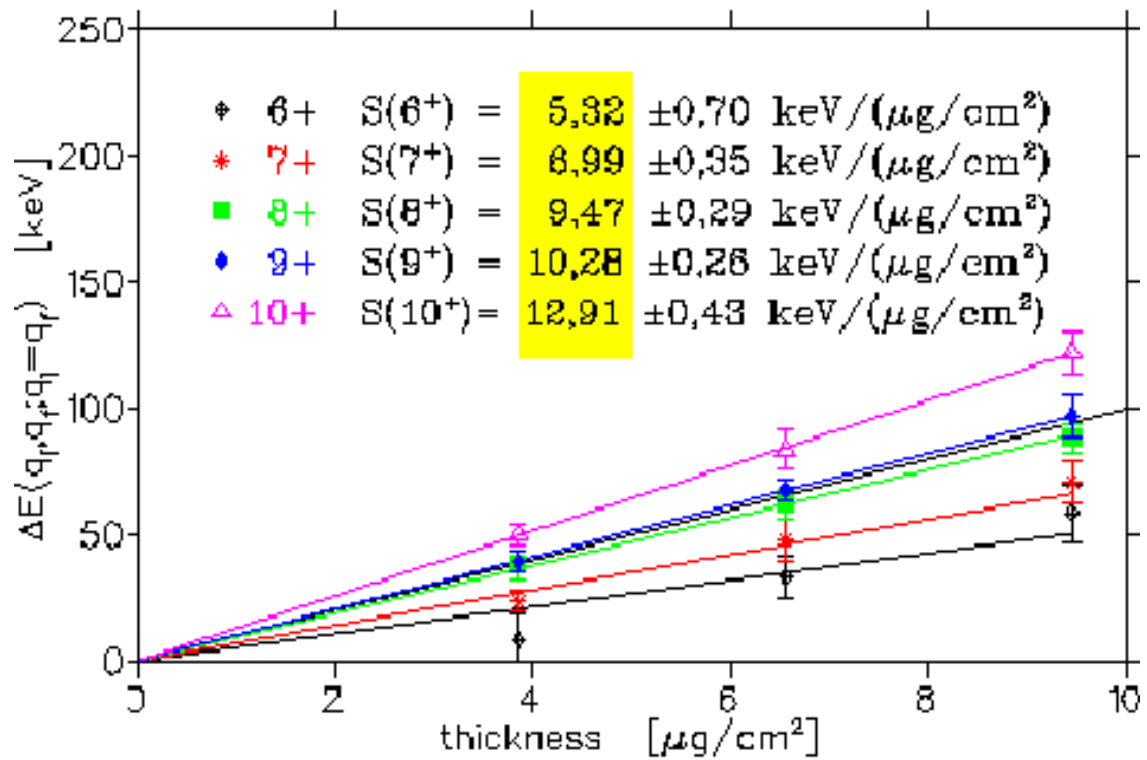


Fig. 12: Monte Carlo Simulation of energy spectra for $q_i = q_f$ and foil thickness $d = 3.9 \text{ [}\mu\text{g/cm}^2$ ($E_0 = 44 \text{ MeV}$).

The sharp lines contain all the ions penetrating the foil without changing their charge state, whereas the shoulders to the left and right are formed by the ions, which were temporarily in a higher or lower charge state, respectively, and which have suffered during that time a greater or smaller energy loss. By folding these spectra with the experimental resolution the energy shift between the sharp peak and the center of the folded curves was determined. The contributions due to charge state fluctuations were thus obtained. We used these energy shifts to correct the values in Fig. 10 and obtained from their slopes new $S(q)$ -values for the second step of the MCS. With this iteration we succeed to eliminate the influence of the charge state fluctuations.

The slopes of the corrected energy losses in Fig. 13 result in the stopping power $S(q)$ of the frozen charge state q (yellow box).

Fig. 13: Corrected energy loss values for $q_i = q_f$.

These $S(q)$ values are shown in Fig. 14 as a function of q^2 . The solid line represents a $S(q) \sim q^2$ dependence as expected from first order perturbation theory. Its slope was determined with $S_{\text{eq}}/q_{\text{eff}}^2$. For $q_i \leq 8^+$ there is a good agreement with the equilibrium conditions, but for higher charge states there is a clear discrepancy. A possible realistic dependence is pictured by the dashed line.

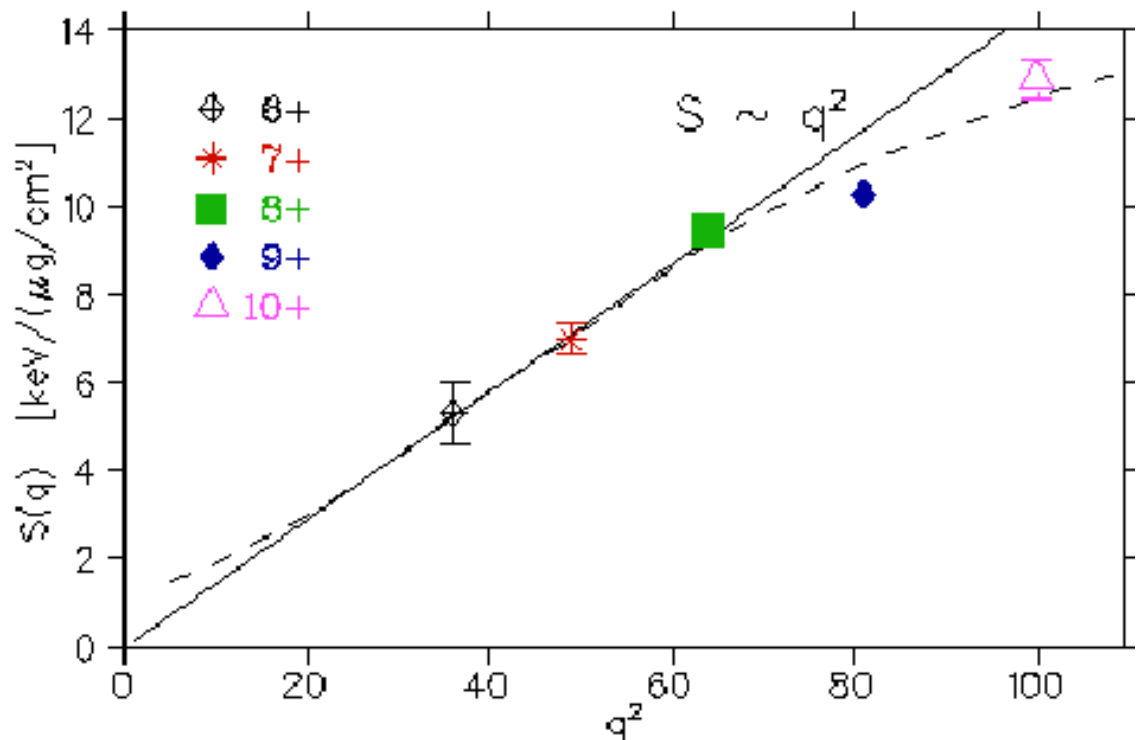


Fig. 14: Charge state dependent stopping power.

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- *H.G. Bohlen, R. Kalpakchieva, W. von Oertzen, T.N. Massey, B. Gebauer, T. Kokalova, A.A. Ogloblin, Ch. Schulz, S. Thummerer*

Structures of neutron-rich Beryllium and Carbon isotopes

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Particle-hole structures of neutron-rich Be- and C-isotopes

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- *H.G. Bohlen, R. Kalpakchieva, B. Gebauer, S.M. Grimes, H. Lenske K.P. Lieb, T.N. Massey, M. Milin, W. von Oertzen, Ch. Schulz, T. Kokalova, S. Torilov, S. Thummerer*

Spectroscopy of particle-hole states of ^{16}C [Phys.Rev. C 68, 054606, p. 1-10 \(2003\)](#)

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Structure Studies of Neutron-rich Beryllium and Carbon Isotopes

Proc. of the Symposium on Nuclear Clusters: From Light Exotic to Superheavy Nuclei, Rauischholzhausen, Germany, August 2002, Eds. R. Jolos and W. Scheid, EP Systema, Debrecen, Hungary, p. 53-58 (2003)

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- *W. von Oertzen, H.G. Bohlen*

Covalently bound molecular states in beryllium and carbon isotopes

[Comptes Rendus Physique 4, 465-474 \(2003\)](#)

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- *H.G. Bohlen, W. von Oertzen, R. Kalpakchieva, B. Gebauer, S.M. Grimes, A. Lenz, T.N. Massey, M. Milin, Ch. Schulz, Tz. Kokalova, S. Torilov, S. Thummerer*

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Spectroscopy of ^7He states using the $(^{15}\text{N}, ^{17}\text{F})$ reaction on ^9Be

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Nuclear Structure Studies of Bound and Unbound States in Drip-Line Nuclei

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Spectroscopy of the Unbound Nucleus ^{11}N by the $^{12}\text{C}(^{14}\text{N},^{15}\text{C})^{11}\text{N}$ Transfer Reaction

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Spectroscopy of Excited States of ^8He

[Z.Phys. A356, 233 \(1996\)](#)

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- *W. von Oertzen, H.G. Bohlen, D.T. Khoa*

Nuclear rainbow and the EOS of cold nuclear matter

Proc. of the Int. Symposium on Physics of Unstable Nuclei (ISPUN02),
Halong Bay, Vietnam, 20-25 Nov. 2002,
Eds. Dao Tien Khoa, Nguyen Dinh Dang and Shigeru Kubono,

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Int.Conf. on Clustering Phenomena in Nuclear Physics, St.Petersburg
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- *K.A. Gridnev, V.B. Soubotin, W. von Oertzen, H.G. Bohlen, X.Vinas*

Double-folding Model Including the Pauli Exclusion Principle

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The Equation of State for Cold Nuclear Matter as Seen in Nucleus-Nucleus Scattering

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Large-area micro-pattern detectors for thermal neutron imaging

Head of R&D work on micro-pattern gas detectors at HMI:

[Dr. Burckhard Gebauer](#)



Current R&D work on the ESS Project at HMI Berlin Large-area micro-pattern detectors for thermal neutron imaging

R&D on very high resolution and fast, large-area, hybrid micro-strip and other micro-pattern gas detectors for thermal neutrons

The pulsed high-flux neutron source [ESS](#), in synergy with advanced focussing neutron optics and spectrometers, will require novel imaging detectors with better resolutions and faster response, necessary for exploiting the improved beam emittance, flux density and time structure.

As a first generation of very high resolution and fast gas detectors utilising composite foil converters, at HMI novel robust large-area multilayer micro-strip gas chamber (MSGC) detectors are being developed, which are optimised for a low-pressure two-stage gas amplification mode. The limitations with respect to time and position resolutions caused by the widely used gaseous neutron converter ^3He , in particular due to the range of the p ions emitted in the reaction $n + ^3\text{He} \rightarrow p (573 \text{ keV}) + t (191 \text{ keV})$ and due to parallax errors in the deep gas gap necessary for good detection efficiency, are avoided by using a composite foil converter of $^{157}\text{Gd}/\text{CsI}$ in the central detector plane (cf. [Fig.1](#)). After neutron capture and subsequent emission of at least one fast (29-182 keV) conversion electron with $87.3 \pm 2.5 \%$ efficiency, a detectable cluster of low-energy electrons is emitted by the fast electron from one of the converter surfaces which are coated by about $1 \mu\text{m}$ thick layers of columnar CsI. In the two adjacent low-pressure gas gaps, sandwiched between MSGC plates, the clusters are amplified exponentially in a two-stage gas multiplication mode, beginning without parallax at the converter surface in parallel-plate mode and further in the strong alternating fields between the micro-strips. This mode delivers safe operation with high gains and low gamma-ray background by restricting the sensitive detector volume to the converter surfaces.

Along with other major requirements (60% thermal neutron detection efficiency, low

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gamma-ray background, long-term stability, reliability and design flexibility) the following properties are expected to be achieved:

- Two-dimensional position resolutions of ~ 0.1 mm FWHM for detector areas <100 cm² (for neutron radiography, tomography and reflectometry applications), which deteriorate with cost-effective readout modes to a few tenths of a mm for large-area detectors and detector arrays (e.g. for single crystal diffraction of tiny biological samples).
- Time-of-flight resolutions of a few ns for thermal neutrons.
- A count rate capacity which is intrinsically $>10^6$ mm⁻² s⁻¹, however, with economical readout modes limited by the data acquisition system developed presently to $2 \cdot 10^6$ s⁻¹ per detector segment.
- Large-area detector segments with sensitive areas of up to 1000 cm², which can economically be concatenated to detector arrays.

The R&D work relies on preceding comprehensive modelling and optimisation of the detector functionality. Experimental progress has been achieved in converter, multilayer MSGC, readout and data acquisition technology and prototype development. The project is partner in the EU-funded [DETNI](#) (Detectors for Neutron Instrumentation) Joint Research Activity, which is coordinated by Dr. B. Gebauer. The R&D is further performed in collaborations with [Frank Laboratory of Neutron Physics](#), Joint Institute for Nuclear Research, Dubna, Russia; [Institute for Physics of Microstructures](#), Russian Academy of Sciences, Nizhny Novgorod, Russia; the firm [IMT Masken und Teilungen AG](#), Greifensee, Switzerland, and [German Fraunhofer-Institutes](#).

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Recent Publications

- Detector requirements for the European spallation neutron source ESS ([pdf](#))
 B. Gebauer
 Proceedings of SPIE's 47th Annual Meeting, Seattle, USA, July 7-11, 2002
- Development of hybrid MSGC detectors with high position and time-of-flight resolution for neutron scattering experiments at ESS ([pdf](#))
 Ch. Schulz, B. Gebauer, G. Richter, B. Namaschk, L.N. Balykov, F.V. Levchanovski, A. Nikiforov, V.I. Shashkin, A.Yu. Klimov and V.V. Rogov
 Proceedings of SPIE's 47th Annual Meeting, Seattle, USA, July 7-11, 2002
- Neutron Scattering Instrumentation - Detector Requirements - Comprehensive summary session 1 ([pdf](#))
 B. Gebauer
 Proc. Int. Workshop on Position-Sensitive Neutron Detectors (PSND) - Status and Perspectives, Berlin, June 28-30, 2001
- High-resolution Hybrid Micro-pattern Detectors - Comprehensive summary session 4 ([pdf](#))
 B. Gebauer
 Proc. Int. Workshop on Position-Sensitive Neutron Detectors (PSND) - Status and Perspectives, Berlin, June 28-30, 2001
- Development of a hybrid MSGC detector for thermal neutron imaging with a MHz data acquisition and histogramming system ([pdf](#))
 B. Gebauer, Ch. Schulz, G. Richter, F.V. Levchanovsky, A. Nikiforov
 Proceedings of the Imaging 2000 Conference, Stockholm, Sweden, June 28 - July 1, 2000; [Nucl. Instr. and Meth. A 471 \(2001\) 249-253](#)
- Novel microstrip detectors and data acquisition strategies for thermal neutron imaging at the next generation pulsed neutron sources ([pdf](#))
 B. Gebauer
 Invited Review, Proceedings of the 2nd Int. Workshop on Data Acquisition Systems for Neutron Experimental Facilities (DANEF-2000), Dubna, Russia, June 5-7, 2000, JINR E10-2001-11, pp. 28-43.
- A PCI DAQ board for a two-dimensional high-resolution delay line detector ([pdf](#))
 F.V. Levchanovsky, B. Gebauer, Ch. Schulz
 Proceedings of the 2nd Int. Workshop on Data Acquisition Systems for Neutron Experimental Facilities (DANEF-2000), Dubna, Russia, June 5-7,

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- Application of DSPs in Data Acquisition Systems for Neutron Scattering Experiments at the IBR-2 Pulsed Reactor
V. Butenko, V. Drozdov, B. Gebauer, F.V. Levchanovski, A. Nikiforov, V. Prikhodko
Proc. of the Int. Conf. on Computing in High Energy and Nuclear Physics (CHEP'2001), Sept. 3-7, 2001, Beijing, China, pp. 560-561.
- Development of large-area hybrid low-pressure 2D-MSGC detectors for thermal neutron imaging ([pdf](#))
N. Chkhalo, B. Gebauer, Ch. Schulz, G. Richter, M. Wilhelm, Th. Wilpert, F. V. Levchanovsky
Proceedings of the Int. Workshop on Micro-pattern Gas Detectors, Orsay, France, June 28-30, 1999, eds. M. Lemonnier and F. Sauli, p. 47.
- Working Group Report on Hybrid and Other Detector Technologies
B. Gebauer
Proceedings of the Workshop on Neutron Detectors for Spallation Sources, Brookhaven National Laboratory, USA, Sept. 24-26, 1998, eds. J. Hastings, G. Smith, B. Yu.
- Novel large-area, low-pressure MSGCs for thermal neutron imaging using composite $^{157}\text{Gd}/\text{CsI}$ converters
B. Gebauer, Ch. Schulz, Th. Wilpert
Proceedings of the German-Russian User Meeting on Condensed Matter Physics with Neutrons at IBR-2, April 2-4, 1998, JINR Dubna, Russia, eds G. Klose, H. Lauter and A. Belushkin, ISBN 5-85165-499-6, p. 105.
- Large-area low-pressure micro-strip gas chambers for thermal neutron imaging
B. Gebauer, Ch. Schulz, Th. Wilpert, S.F. Biagi
[Nucl. Instr. and Meth. A 409 \(1998\) 56.](#)
- Novel large-area thermal neutron imaging detectors comprising $^{157}\text{Gd}/\text{CsI}$ -converters and micro-strip gas chambers with low-pressure, two-stage amplification and delay line readout
B. Gebauer, Ch. Schulz, Th. Wilpert
[Nucl. Instr. and Meth. A 392 \(1997\) 68.](#)

Recent Conference Contributions (without written contributions)

- Development of high-resolution and fast hybrid micropattern detectors for the next generation pulsed neutron sources
B. Gebauer
Int. Workshop on Position-Sensitive Neutron Detectors (PSND), Berlin, June 28-30, 2001, Book of Abstracts, pp. 49-51
- A large-area hybrid multi-layer micro-strip gas chamber (MSGC) detector for thermal neutron imaging

B. Gebauer, Ch. Schulz, F.V. Levchanovski, A. Nikiforov, L.N. Balykov, G. Richter, B. Namaschk, A.Yu. Klimov, V.V. Rogov, V.I. Shashkin
2nd German-Russian User Meeting, Dubna, April 21-25, 2001.

- A novel large-area, low-pressure detector with high position and time-of-flight resolution for thermal neutron imaging
Ch. Schulz, B. Gebauer, F.V. Levchanovski, A. Nikiforov, G. Richter, L.N. Balykov, V.I. Shashkin, A.Yu. Klimov, V.V. Rogov
Int. Conf. on Neutron Scattering (ICNS 2001), München, Sept. 9-13, 2001;
Book of Abstracts, p. 30 (T-98)
- Development of high-resolution, large-area hybrid MSGC detectors for thermal neutron imaging
Ch. Schulz, B. Gebauer, L.N. Balykov, G. Richter, F.V. Levchanovski, A. Nikiforov
Int. Workshop on Position-Sensitive Neutron Detectors (PSND), Berlin, June 28-30, 2001, Book of Abstracts, pp. 74-76
- Development of very high resolution and fast hybrid 2D-micro-strip gas chamber detectors for the next generation pulsed neutron sources
B. Gebauer
4th TECHNI Meeting, Paul Scherrer Institut, Villigen, Switzerland, October 18-19, 2001
- Very high resolution and fast large-area hybrid low-pressure MSGC detector for thermal neutron imaging
B. Gebauer
3rd TECHNI Meeting, Univ. Milano-Bicocca, Milan, Italy, May 3-4, 2001
- Very high resolution and fast large-area hybrid low-pressure 2D-MSGC detectors for thermal neutron imaging
B. Gebauer
Second TECHNI Meeting, Grenoble, France, October 12-13, 2000
- Entwicklung eines hochauflösenden Niederdruck-Mikrostreifen-Neutronendetektors mit Folienkonverter für ESS
B. Gebauer
Herbsttagung der Studiengruppe für Elektronische Instrumentierung, Hahn-Meitner-Institut, Berlin, 25-27. September 2000
- Very high resolution large-area MSGC detectors
B. Gebauer
First TECHNI Meeting, Abingdon, U.K., March 30-31, 2000
- Development of large-area hybrid low-pressure 2D-MSGC detectors for thermal neutron imaging
B. Gebauer, N. Chkhalo, Ch. Schulz, G. Richter, Th. Wilpert, F.V. Levchanovsky
6th ESS General Meeting, Ancona, Italy, Sept. 20-23, 1999
- Das Neutronendetektorprojekt am HMI Berlin
Th. Wilpert
Workshop über Intrakristalline Strain/Stress-Messungen mit

Beugungsverfahren, Geoforschungszentrum Universität Potsdam,
10.11.1998

- Novel large-area, low-pressure MSGCs for thermal neutron imaging using composite $^{157}\text{Gd}/\text{CsI}$ converters
Ch. Schulz, N. Chkhalo, B. Gebauer, Th. Wilpert
European Workshop on thermal neutron detectors for the European Spallation Source, Delft, The Netherlands, Oct. 27-28, 1998
- Novel large-area, low-pressure MSGCs for thermal neutron imaging using $^{157}\text{Gd}/\text{CsI}$ converters
B. Gebauer
Workshop on neutron detectors for spallation sources, Brookhaven National Laboratory, USA, Sept. 24-26, 1998
- Novel large-area, low-pressure MSGC detectors for thermal neutron imaging
Ch. Schulz, B. Gebauer, Th. Wilpert
DPG Frühjahrstagung Hadronen und Kerne, Bochum, 16-20.3.1998
- Novel large-area, low-pressure MSGCs for thermal neutron imaging using composite $^{157}\text{Gd}/\text{CsI}$ -converters
B. Gebauer, Ch. Schulz, Th. Wilpert
8th Int. Wire Chamber Conf., Vienna, Austria, Feb. 23-27, 1998
- Thermal neutron imaging using large-area, low-pressure MSGCs and $^{157}\text{Gd}/\text{CsI}$ -converters
B. Gebauer
XENNI Meeting, Genova, Italy, Nov. 24-25, 1997
- A novel concept for large-area neutron detectors with high position resolution
Ch. Schulz, B. Gebauer, Th. Wilpert
5th Summer School on Neutron Scattering, Zuoz, Switzerland, Aug. 9-15, 1997

Recent Talks at other Institutes

- Entwicklung eines hochauflösenden Niederdruck-Mikrostreifen-Gas-Neutronendetektors mit Folienkonverter für ESS
B. Gebauer
Zentrallabor für Elektronik, Forschungszentrum Jülich, Jülich, 11. Dezember 2000
- Novel hybrid low-pressure Microstrip Gas Chamber Detectors for high resolution thermal neutron imaging
B. Gebauer
Institute for Physics of Microstructures, Russian Academy of Sciences, Nizhny Novgorod, Russia, June 13, 2000
- Thermal neutron imaging gas detectors and the Berlin

detector concept

B. Gebauer

Frank Laboratory of Neutron Physics, JINR Dubna, Russia, Jan. 16, 1997

Theses

- [Entwicklung eines neuartigen Niederdruck-Detektors mit hoher Orts- und Flugzeitauflösung zum Nachweis thermischer Neutronen \(postscript version, 8.6 MB\)](#)

Ch. Schulz

Freie Universität Berlin, Dezember 1999

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Collaborations

- [TECHNI](#) (Technology for Neutron Instrumentation) RTD network
- [Frank Laboratory of Neutron Physics](#), Joint Institute for Nuclear Research, Dubna, Russia
- [Institute for Physics of Microstructures](#), Russian Academy of Sciences, Nizhny Novgorod, Russia
- The firm [IMT Masken und Teilungen AG](#), Greifensee, Switzerland
- [Fraunhofer-Institut für Schicht- und Oberflächentechnik](#), Braunschweig, Germany

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Projects / Cooperations

Cooperations

- GSI -Darmstadt: energy loss in non-equilibrium
- IReS-Straßburg: spectroscopy of extreme deformations in nuclei
- University of Birmingham, UK: spektroskopy of molecular structures
- LNL-Legnaro/Universität Padua: spektroskopy of extreme nuclear shapes
- Universität St. Petersburg: nuclear-nuclear interactions and reaction mechanism
- Flerov Laboratory, JINR Dubna, Rußland, und Universität -Ohio, USA: neutron rich nuclei
- Fraunhofer-Institut FhG-IST Braunschweig: MSGC neutron detector technology
- Firma IMT Zürich: MSGC neutron detector technology
- Akademie-Institut für Mikrostrukturphysik, Nischni Nowgorod, Rußland: MSGC neutron detector technology
- Frank Laboratory, JINR Dubna, Rußland: data acquisition for the neutron detector

Third-party funds

- BMBF - Verbundforschung (EUROBALL)
- EUROBALL-Kooperation (D, Dk, F, I, UK, S)
- A. v. Humboldt Stiftung
- FU-Stipendien
- TMR-LSF-Programme EU-TMR-LSF programs
- DAAD
- 5th EU program, Network: TECHNI
- 6th EU program, EU joint research activity on neutron detectors (DETNI)
- BMBF - german collaboration with JINR Dubna

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Structural Research

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Head: [Prof. Wolfram von Oertzen](#) (emeritus)[Projects/
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In the group "Nuclear Measurements" experimental methods and instrumentation are developed for nuclear physics experiments as well as for applications of nuclear methods.

With the Q3D magnetic spectrometer the thickness and stoichiometry of light elements in very thin layers can be investigated by using the [Elastic Recoil Detection analysis \(ERDA\)](#) with a resolution of a few nanometers. Investigations to the detection of hydrogen were started. A new method of the charge-selective measurement of the energy loss and charge changing processes in non-equilibrium in very thin layers has been developed, systematic investigation for Oxygen, Neon and Argon ions have been started. This work is done in cooperation with SF4, the GSI and the TU Darmstadt; in the latter case the determination of the energy loss in diluted media and hot plasmas are of interest.

In nuclear spectroscopy the work concentrates on the investigation of extremely deformed nuclei. In experimental and theoretical work we could show that alpha particles and ^{16}O -clusters can be bound by covalent neutrons to form nuclear molecules. These configurations appear as isomeric states in light neutron rich nuclei. For example as excited dimers (Beryllium) and Polymers (Carbon, Oxygen). Asymmetric molecules based on the ^{16}O +alpha-system are currently investigated. For this investigation experiments with the magnetic spectrometers Q3D (HMI) are performed and new possibilities of gamma spectroscopy on the gamma-detector arrays [EUROBALL](#) and [GASP](#) with particle-gamma coincidence are developed. A detector system for the detection of binary reaction fragments ([BRS](#)) for the European gamma-detector ball [EUROBALL](#) is built and will be used in an European collaboration at the accelerator [VIVITRON](#) at the [IReS laboratory \(Strasbourg\)](#) in the future.

Based on experimental techniques from nuclear physics for the detection of charged particles the [development of large-area micro-pattern detectors for thermal neutrons](#) (reactor neutrons and spallation source neutrons) was started. It will operate with ^{157}Gd CsI converters. The position information is obtained using a low-pressure

micro-strip gas chamber detector. This project is embedded in the Joint Research Activity DETNI (Detectors for Neutron Instrumentation) coordinated from SF7.

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On-line Dissertations / Theses: PhD theses

- [Abel Blazevic: High-resolution thin layer analysis with energetic heavy ions](#)
- [Ingo Peter: Enhanced neutron-pair transfer between superfluid heavy nuclei](#)
- [Severin Thummerer: Gamma-spectroscopy of deformed nuclei with binary reactions](#)
- [Christian Schulz: Development of a novel low-pressure detector with](#)

[high position and time-of-flight resolution for thermal neutron detection](#)

- [Tzany Kokalova: Gamma-ray spectroscopy of deformed states in light nuclei and cluster emission](#)
- [Sergey Torilov: Investigation of quasi-molecular states in \$^{40,42}\text{Ca}\$ by gamma-ray spectroscopy](#)

Digital Diploma theses

- [Ramin Torabi: Investigation of cluster states in light, neutron-rich nuclei using multi-nucleon-transfer reactions](#)

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Strukturforschung

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Nukleare Messtechnik

SF7

Publications 2006

SF7.01

Tz. Kokalova, N. Itagaki, W. von Oertzen, C. WheldonSignatures for Multi- α -Condensed States.
Phys. Rev. Lett. 96 (2006) 192502

SF7.01

M. Avrigeanu, W. von Oertzen, V. AvrigeanuOn Temperature dependence of the optical potential for alpha-particles at low energies.
Nucl. Phys. A 764 (2006) 246-260

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M. Avrigeanu and W. von OertzenOn the α -particle semi-microscopic optical potential at low energies.
Proceedings of Science, June 2006

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A. Blazevic, H.G. Bohlen, W. von Oertzen, V.V. Balashov, A.V. StysinCharge-state resolved energy spectra of swift ^{22}Ne ions passing through thin carbon foils.
Nucl. Instrum. and Meth. in Phys. Res. B 245 (2006) 41-43

SF7.01

W. von Oertzen, M. Freer, Y. Kanada-En'yoNuclear clusters and nuclear molecules.
Phys. Rep. 432 (2006) 43-113

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H.G. BohlenDas beste Molekül der Kernphysik.
Physik Journal 5 (3) (2006) 20-22

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C. Wheldon, J.J. Valiente-Dobón, P.H. Regan, C.J. Pearson, C.Y. Wu, J.F. Smith, A.O. Macchiavelli, D. Cline, R.S. Chakrawarthy, R. Chapman, M. Cromaz, P. Fallon, S.J. Freeman, W. Gelletly, A. Görgen, A.B. Hayes, H. Hua, S.D. Langdown, I.Y. Lee, X. Liang, Zs. Podolyák, G. Sletten, R. Teng, D. Ward, D.D. Warner and A. D. YamamotoObservation of an isomeric state in ^{197}Au .
Phys. Rev. C 74 (2006) 027303, p.1-4

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Wolfram von OertzenDynamics of Alpha-clusters in N=Z nuclei.
Eur. Phys. J. A 29 (2006) 133-139[Structural Research](#)[Nuclear Methods...](#)

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Publications 2005

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Nucl. Phys. A 759 (2005) 327-341

SF7.01

Dao T. Khoa, H.G. Bohlen, W. von Oertzen, G. Bartnitzky, A. Blazevic, F. Nuoffer, B. Gebauer, W. Mittig, P. Roussel-ChomazStudy of refractive structure in the inelastic ${}^{16}\text{O}+{}^{16}\text{O}$ scattering at the incident energies of 250 to 1120 MeV.

Nucl. Phys. A 759 (2005) 3-22

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H.G. Bohlen, R. Kalpakchieva, W. von Oertzen, T.N. Massey, A.A. Ogloblin, G. de Angelis, Ch. Schulz, Tz. Kokalova, C. WheldonStructure studies of excited states of ${}^{17}\text{C}$ and ${}^{16}\text{C}$.

J. Phys. G 31 (2005) S1461-S1464

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P. McEwan, M. Freer, N. Curtis, D. Price, V. Ziman, H.G. Bohlen, Tz. Kokalova, Ch. Schulz, R. Torabi, W. von Oertzen, C. Wheldon, T.N. Massey, R. Kalpakchieva, W. CatfordInvestigation into the structure of ${}^{14}\text{C}$ using recoil coincidence techniques

J. Phys. G 31 (2005) S1921-S1925

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Tz. Kokalova, W. von Oertzen, S. Torilov, S. Thummerer, M. Milin, A. Tumino, G. de Angelis, E. Farnea, A. Gadea, D.R. Napoli, N. Marginean, T. Martinez, M. Axiotis, S.M. Lenzi, C. Ur, P. Papka, M. RousseauEmission of unbound ${}^8\text{Be}$ and ${}^{12}\text{C}^*(0^+_2)$ clusters in compound nucleus reactions.

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K.L. Keyes, A. Papenberg, R. Chapman, J. Ollier, X. Liang, M.J. Burns, M. Labiche, K.-M. Spohr, N. Amzal, C. Beck, P. Bednarczyk, F. Haas, G. Duchene, P. Papka, B. Gebauer, Tz. Kokalova, S. Thummerer, W. von Oertzen, C. Wheldon

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Spectroscopy of Ne, Na and Mg isotopes approaching the Island of Inversion.

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Octupole-deformed molecular bands in ^{21}Ne .

Eur. Phys. J. A 26 (2005) 321-326

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I. Sanchez i Zafra, C. Beck, F. Haas, P. Papka, V. Rauch, M. Rousseau, F. Azaiez, P. Bednarczyk, S. Courtin, D. Curien, O. Dorvaux, A. Nourreddine, J. Robin, M.-D. Salsac, W. von Oertzen, B. Gebauer, Tz. Kokalova, S. Thummerer, C. Wheldon, G. de Angelis, A. Gadea, S.M. Lenzi, D.R. Napoli, S. Szilner, W.N. Catford, D. Jenkins

Study of binary reaction channels in the $^{24}\text{Mg}+^{12}\text{C}$ collisions.

Ricerca Scientifica ed Educazione Permanente, Supplemento 124 (2005) 224-231

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A. Bürger, T.R. Saito, A. Al-Khatib, A. Banu, T. Beck, F. Becker, P. Bednarczyk, G. Benzoni, A. Bracco, P. Bringel, F. Camera, E. Clement, P. Doornenbal, H. Geissel, J. Gerl, M. Górska, A. Görngen, H. Grawe, J. Gr̄bosz, G. Hammond, M. Hellström, H. Hübel, M. Kavatsyuk, O. Kavatsyuk, M. Kmiecik, I. Kojouharov, N. Kurz, R. Lozeva, A. Maj, S. Mandal, W. M̄czȳski, D. Mehta, B. Million, S. Muralithar, A. Neusser, Zs. Podolyák, T.S. Reddy, P. Reiter, N. Saito, H. Schaffner, A.K. Singh, H. Weick, O. Wieland, C. Wheldon, M. Winkler and H.J. Wollersheim

Relativistic Coulomb excitation of $^{54,56,58}\text{Cr}$.

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A. Bürger, T.R. Saito, H. Grawe, H. Hübel, P. Reiter, J. Gerl, M. Górska, H.J. Wollersheim, A. Al-Khatiba, A. Banu, T. Beck, F. Becker, P. Bednarczyk, G. Benzoni, A. Bracco, S. Brambilla, P. Bringel, F. Camera, E. Clément, P. Doornenbal, H. Geissel, A. Görngen, J. Gr̄bosz, G. Hammond, M. Hellström, M. Honma, M. Kavatsyuk, O. Kavatsyuk, M. Kmiecik, I. Kojouharov, W. Korten, N. Kurz, R. Lozeva, A. Maj, S. Mandal, B. Million, S. Muralithar, A. Neußer, F. Nowacki, T. Otsuka, Zs. Podolyák, N. Saito, A.K. Singh, H. Weick, C. Wheldon, O. Wieland, M. Winkler and RISING Collaboration

Relativistic Coulomb excitation of neutron-rich $^{54,56,58}\text{Cr}$: On the pathway of magicity from $N=40$ to $N=32$.

Phys. Lett. B 622 (2005) 29-34

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High- K states in the odd-odd nuclide ^{180}Re .

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Saito, H. Schaffner, J. Simpson, D.D. Warner, H. Weick, C. Wheldon, M. Winkler and H.J. Wollersheim

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Proceedings of the 21st Winter Workshop on Nuclear Dynamics,
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Gamma-ray spectroscopy of the doubly-odd nuclide ^{184}Re .

Nucl. Phys. A 763 (2005) 1-30

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Selection of cold transfer and enhanced neutron-pair transfer in the $^{206}\text{Pb}+^{118}\text{Sn}$ reaction.
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Wolfram von Oertzen

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 Structural Research
Nuclear Methods and Instrumentation

SF7

Gamma Spectroscopy with Binary Nuclear Reactions

Overview

With the presently available powerful gamma-detector arrays fusion evaporation reactions will remain the main tool for nuclear in-beam gamma-ray spectroscopy. However, binary fusion-fission, deep-inelastic and multi-nucleon transfer reactions bear the potential to extend the range of the accessible nuclei, to reach extremes of nuclear configurations and observational limits considerably.

1) New regions of the nuclear chart can be studied (e.g. very neutron-rich nuclei, whereas fusion-evaporation reactions with stable beam and target nuclides populate predominantly neutron-deficient nuclei).

2) Specific configurations (e.g. hyperdeformed states in alpha-cluster nuclei) can be excited very selectively.

3) By detection of both heavy ejectiles of binary exit channels in two large-area position imaging and particle identifying trigger detectors in kinematic coincidence by means of the Z, A, energy, scattering angle and momentum correlations and the binary Q-value measured, the reaction channel and the dynamics of the gamma emitting nuclei can be identified with unprecedented selectivity and the Doppler-shifts of the gamma-rays can be determined. Thus, very weak binary channels can be triggered in the particle detectors and non-binary events are suppressed effectively. The resolving power for gamma-ray detection is improved and very low fractions of the total cross sections become accessible in the gamma spectra.

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Nuclear Methods and Instrumentation

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The Binary Reaction Spectrometer

Contact : [Dr. Burckhard Gebauer](#)

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Range of Applications of the Trigger Spectrometer

Compared to fusion-evaporation reactions using stable projectile and target nuclides binary reaction channels bear the potential to open up new regions of the nuclear chart for gamma-ray spectroscopy. For instance, nuclei on the neutron-rich side of the valley of stability can be studied by multiple-alpha transfer, deeply inelastic and fusion fission reactions. Specific high-spin states, e.g. belonging to hyperdeformed configurations in alpha-cluster nuclei, can be populated and detected very selectively by the choice of specific alpha-transfer and fusion-fission entrance and exit channels. In addition, nuclear reaction studies can gain qualitatively new insights from separation of individual transitions. However, because of the spread of intensity over many exit channels, separation of concurrent reaction channels should be achieved by particle separation; using thin targets and powerful particle detection trigger systems, complete reaction channel separation can be obtained for lighter ejectiles ($M < 40$) in addition to a selection of the entry points of gamma-ray cascades and to optimal Doppler-shift correction. These points summarise the scientific objectives for the Binary Reaction Trigger Spectrometer (BRS) for EUROBALL (cf. Fig. 1).

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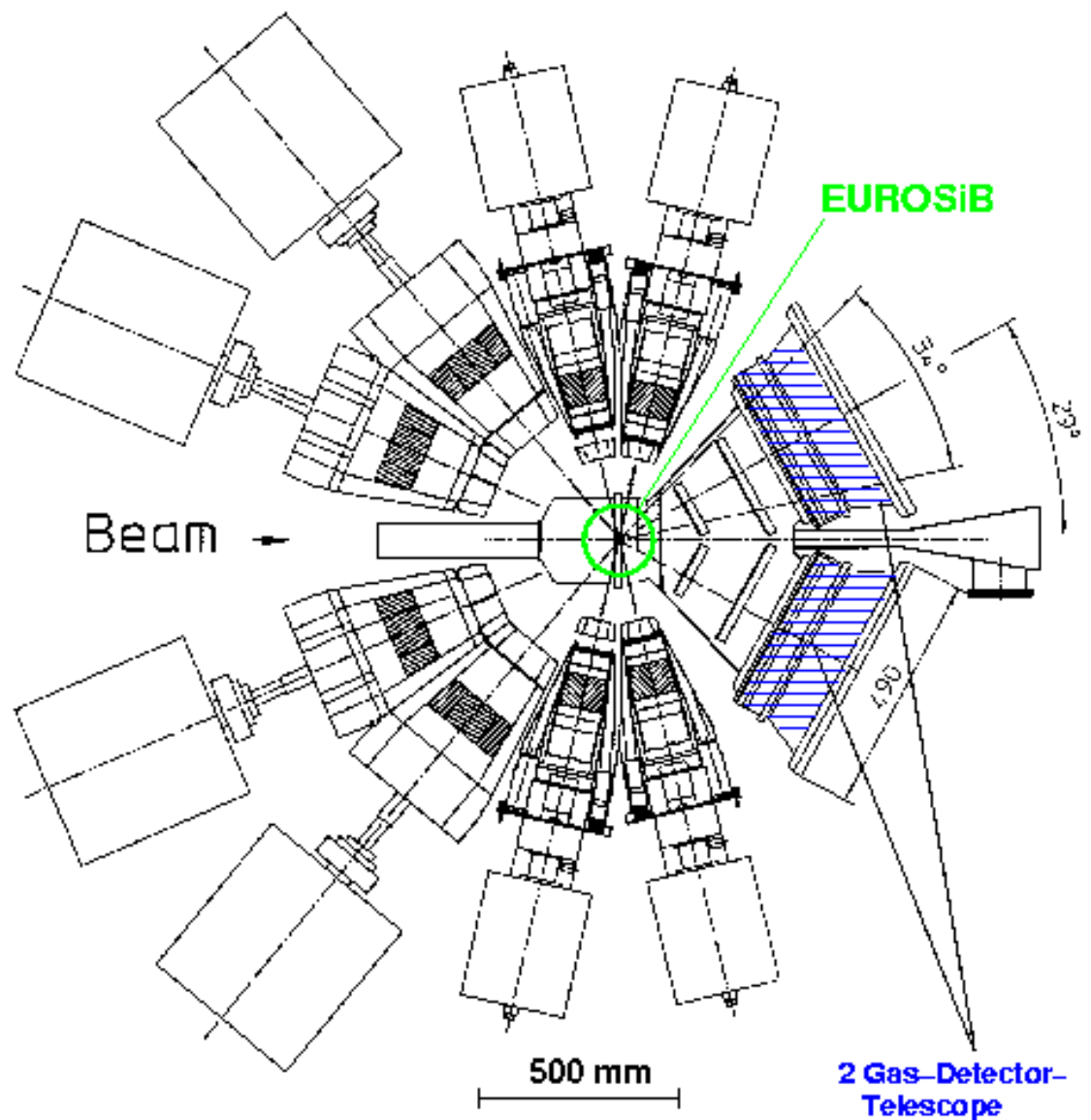


Fig. 1: Set-up of EUROBALL III with the BRS.

By obtaining unprecedented channel resolution in the BRS, the observational limits of EUROBALL can be considerably improved (cf. Fig. 2). Because unique channel separation can already be achieved in the trigger detector system in favourable cases, multifold gamma-ray detection is not needed for background reduction in the gamma-ray spectra. However, detection of two-fold gamma-ray coincidences will be used in order to identify gamma-bands.

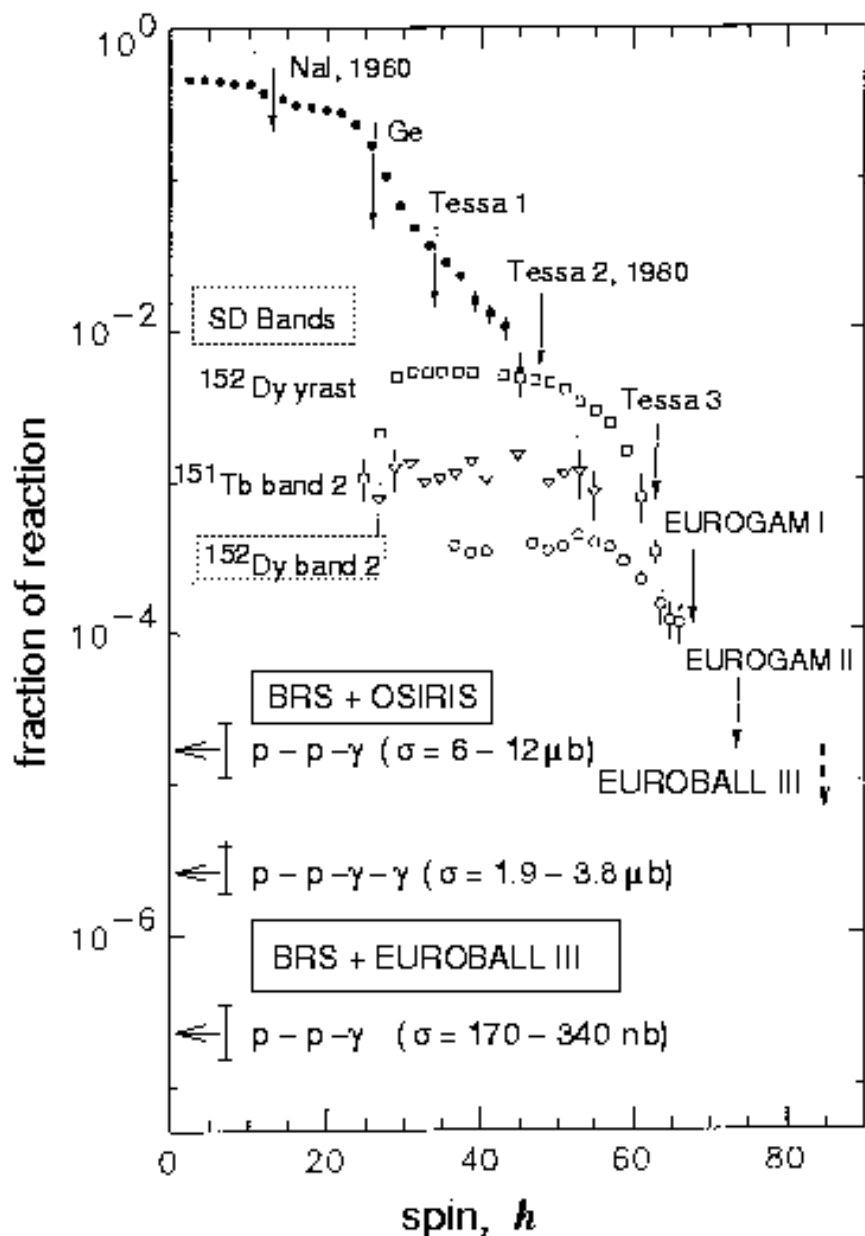


Fig. 2: Improvement of observational limits for gamma-ray detection (in comparison with various detection systems) predicted for BRS + EUROBALL III for the indicated reaction leading to hyperdeformed states in ^{40}Ca .

Features of the Trigger Spectrometer

The BRS for EUROBALL III combines in a kinematic coincidence set-up at forward angles two large-area logarithmic heavy-ion detector telescopes, comprising two-dimensional position-sensitive low-pressure multiwire chambers (MWCs) with subsequent Bragg-curve ionization chambers (BICs). All detection planes are fourfold segmented in order to increase the count rate capability. Thus, in a limited dynamic range (see below) correlations between two heavy ejectiles can be measured with high resolutions with respect to laboratory scattering angles (θ , ϕ) and time of flight (TOF) in the MWCs and rest energy (E), Range (R) and Bragg-Peak height (BP) in the BICs. BP delivers a nearly mass-independent Z signal.

In the EUROBALL III set-up both detector telescopes of the BRS span a vertical reaction plane and cover each forward scattering (polar) angles $\theta = 12\text{--}46$ deg on either side of the beam axis. Thus, in cases of inverse kinematics both ejectiles of binary reaction channels can be detected in exclusive kinematic coincidence measurements; this is the case if the projectiles are heavier than the targets and/or

the reaction Q-values are sufficiently negative, as in the investigation of highly excited strongly deformed states. In this case, linear momenta and masses can be determined as well as binary Q-values, specifying, e.g., the entry energies of gamma-ray cascades with 0.5-2 MeV (FWHM) energy resolution. In addition, using Z, R and E correlation measurements, unambiguous identification of binary reaction channels can be achieved and non-binary events are suppressed effectively. The latter can be further suppressed using the correlation for the coplanarity condition for the two ejectiles. For pulsed beams with absolute TOF measurements of two heavy ejectiles, even for the small flight paths used of ~400 mm, sufficient mass resolution for lighter nuclei can be reached, dependent on reaction kinematics. In combination with the unique Z resolutions and the resolutions in the E and R correlations, three-body channels can be separated. For exit channels with more than three emitted ejectiles, kinematics cannot be reconstructed uniquely without using an additional light charged particle (LCP) ball in coincidence. Thus, the BRS vacuum chamber allows to use a silicon detector setup like EUROSIB in coincidence. However, by measuring, TOF, E, R and Z for two heavy ejectiles, in most cases the reaction dynamics of quasi-elastic, deeply-inelastic and fusion-fission channels can be adequately determined in spite of light particle evaporation, and Doppler-shifts of gamma-rays can be corrected in many cases; by detecting only for one ejectile in one-arm experiments. In this mode of operation, normal kinematics can be used, detecting the lighter projectile-like nuclei for gamma-ray spectroscopy in the heavy recoil nuclei.

Dynamic Ranges

The most stringent restrictions in the dynamic ranges result from the fixed angle settings and the limited opening angles of the detector telescopes in applications where both ejectiles of binary exit channels are detected exclusively. The lightest particles which can be identified in the telescopes are alpha-particles. In the MWCs the low-energy thresholds are at < 0.1 MeV/u. In the BICs adequate Z resolution can be achieved for kinetic energies at or above the Bragg-maxima. In cases, where the correlation angles are too large for detection of two correlated ejectiles or the kinetic energy of one of the ejectiles is too low for detection, a measurement of the faster ejectile will often deliver a good trigger for gamma-ray spectroscopy. However, the ejectile must be stopped in the ionization chamber section.

With the BICs of 125 mm active depth this will be possible. for instance, at least for the following energies 6 MeV/u 16O, 7.5 MeV/u 28Si, 8.5 MeV/u 40Ca or 9 MeV/u 56Ni.

Mechanical Set-up

In the BRS set-up for EUROBALL III (see Fig. 1) both detector telescopes are positioned within the forward sector cone in a vertical plane and, therefore, the 30 phase I Ge detectors of EUROBALL III are taken out; thus, the total photopeak efficiency of the array is reduced by ~14%. The telescopes are centered at $\theta_L=29^\circ$ and cover each polar angular ranges of $\Delta\theta_L=34^\circ$ on either side of the beam axis; with their opening in azimuth $\Delta\phi_L=17.4^\circ$ they cover 21% of the full solid angle between $\theta_L=12^\circ$ - 46° . The basically inner target chamber with a spherical conical forward end cap is split into forward and back-angle parts along $\theta_L=90^\circ$. The back-angle part is connected to a flange of the target manipulator system of the standard target chamber. The gas detector telescopes, with the forward angle part of the target chamber connected to them, are supported from their rear side from a base plate which is positioned on a dedicated support table (80x110 cm²). The BRS set-up has its own vacuum pumping and control system and is completely assembled on its base plate, which also supports its gas regulation systems and front-end electronics.

Electronic Detection Schemes and Count Rate Capability

The gas detector telescopes are electronically segmented fourfold in each detection plane. The MWCs can be operated with count rates < 300 kcps. In the BICs the electrons' drift times extend up to ~ 2 micro sec in the fast counting gas CF₄, resulting in electronic dead times below 4 micro sec. Thus, for the fourfold segmented detector the count rate should be limited to ~ 100 kcps. The generation of all MWC and BIC signals can be gated externally. In the standard kinematic coincidence mode the GATE signal is derived from the coincidence of the fast MWC timing signals (OR'ed for the four segments) of both telescopes which is ready within 200 ns. This GATE signal is also made coincident with the accelerator beam pulse. In order to avoid signal deterioration of the fast timing and BIC signals and in order to obtain the GATE signal in time, the two racks of dedicated NIM electronics used are located close (6-8 m cable length) to the BRS trigger detectors.

Fast Trigger and Validation Signals for the Data Acquisition System

In the kinematic coincidence mode, in the fast trigger signal the following signals are mixed:

- The above defined GATE signal in coincidence with the EUROBALL multiplicity sumbus signals (Ge, BGO). Usually, the required escape-suppressed Ge multiplicity will be two.
- The prescaled GATE signal - without gamma-ray coincidence - or prescaled mixed timing signals of both individual telescopes. These triggers which are unbiased from gamma-ray emission are used for cross section normalization. Usually they include elastic scattering.
- A third trigger signal obtained solely from the EUROBALL multiplicity sumbuses without reference to the BRS will also be mixed in for higher gamma multiplicities.

Readout Scheme

For readout of the ~ 80 BRS channels dedicated CAMAC/Fera ADCs (Silena 4418/V) are available which will be located within one CAMAC crate; only ADCs are used. The average number of BRS parameters per event will be 18-20; the trigger rate will be reduced to few kcps if two heavy ejectiles and two gamma-rays are required in the trigger.

Data Acquisition and Monitoring Software

The EUROBALL data acquisition system will be usable without modifications; the parameter space will be enlarged by about 80 parameters for the BRS signals. For on-line data analysis a HMI monitoring program will be used in on-spy mode. After setting particle gates, using the monitoring program for channel selection, the gamma-rays in the events will be analyzed using the standard EUROBALL on-line analysis software. For data storage a DLT 7000 tape drive is used in compatibility mode with DLT 4000; the latter tape drive is available at HMI and used for off-line data analysis.

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