

## **<sup>100</sup>Sn and neighbouring nuclei**

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We have produced <sup>100</sup>Sn and nuclei in its neighbourhood by fragmentation of <sup>124</sup>Xe ions with an energy of 1 A·GeV from the SIS at GSI, Darmstadt. The fragments of interest were separated in-flight in the fragment separator (FRS) with the B $\rho$ - $\delta$ E-B $\rho$  method using two stages of degraders. Redundant measurements of energy loss, magnetic rigidity, and flight time in the second half of the FRS allowed a unique identification of the fragments. In addition to 250 nuclei of <sup>100</sup>Sn we identified for the first time the T<sub>z</sub> = -1/2 nuclei <sup>95</sup>Cd, <sup>97</sup>In and <sup>99</sup>Sn. Although we see some events at the location of <sup>103</sup>Sb, its half-life must be at least 3 times shorter than the flight time through the FRS of 200 ns in contrast to the lower limit of 1.5  $\mu$ s given in the literature. This proves proton radioactivity to be the dominant decay channel for <sup>103</sup>Sb. The fragments were stopped in a stack of Si detectors. For the correlation of implantation position and time with subsequent decays we used three large area position sensitive Si strip detectors with a total of 7200 pixels. Ten 1mm thick Si detectors in front and behind this implantation zone served as calorimeter to measure the  $\beta$ -spectrum and to determine its endpoint. The implantation detector was surrounded by the 105 Ge detectors of the RISING array in the stopped beam configuration to observe isomeric decays as well as the  $\gamma$ -deexcitation following  $\beta$ -decays. A number of isomeric states was observed. In <sup>102</sup>Sn we find a new isomeric  $\gamma$ -line which we attribute to the 6<sup>+</sup> - 4<sup>+</sup> transition. In <sup>98</sup>Cd we also observe an unknown transition, shedding light on core excited states. For the decay of <sup>100</sup>Sn we can deduce a much more precise value of the half-life and of the decay energy to the excited 1<sup>+</sup> state in <sup>100</sup>In. That gives us the Gamov-Teller strength of the decay which is the largest ever seen. For the first time we observe the  $\gamma$ -cascade depopulating that 1<sup>+</sup> state.

# Evidence of proton-neutron correlations close to the drip line

Roberto Liotta

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Proton-neutron correlations in nuclei above the  $Z=50$  shell closure are investigated with the aim of understanding why the states  $2_1^+$  and  $4_1^+$  in Te and Xe isotopes remain at a rather constant energy as one approaches  $N = 50$ . Our calculations reveal that standard QRPA calculations, involving a quadrupole-quadrupole interaction with *constant strengths*, cannot explain this feature. It is found that in order to reproduce experimental data one has to include a non vanishing proton-neutron pairing strength. The proton and neutron orbitals are common in the  $N \approx Z$  region and therefore it is likely that the isoscalar proton-neutronpairing interaction is responsible for this behaviour.

# Probing nuclear structure at the proton drip-line using the RDT technique

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The Recoil-Decay-Tagging (RDT) technique have been used extensively over the last several years to investigate many aspects of nuclear structure. Today, the RDT technique is very refined, and includes several different tagging modes. At the JYFL lab in Jyväskylä, the combined powers of the RITU recoil separator, the GREAT focal plane detector array, and the JUROGAM germanium array, have been utilized to probe the nuclear structure at reaction cross sections down to  $\approx 10$  nb. In this talk, the RDT-technique will be presented with a focus on experiments to study nuclear structure at or beyond the proton drip-line. A number of examples from experiments are used to demonstrate the high selectivity of the technique. Plans for future experiments and some of the future technical challenges will be discussed.

# **ESS - A new European centre for neutron physics and more**

Mats Lindroos  
Lund University

In May 2009 at a ministerial meeting in Brussels it was decided to site the European Spallation source in Lund in Sweden. Since then the first steering committee for ESS has been held and the ESS team in Lund has been mandated to lead a design update for the facility. The objective is to arrive at a final cost-to-completion for the end of 2012 and start prototyping for key components so that first protons can be delivered in 2018-2019. The possibility for nuclear and particle physics at ESS (and medical applications) is presently being explored and a workshop on this is being organised for 2-4 December 2009 in Lund. I will in my talk present the status of ESS, the plans for the design update with some focus on the linac activities and discuss the nuclear and particle physics programme.

## **Isotope-selective gamma-ray spectroscopy at GSI: PreSPEC, TISISPEC, TRAPSPEC**

Dirk Rudolph  
Lund University

In-beam and decay spectroscopy of nuclei far from the line of stability are and are going to be in the focus of experimental nuclear structure studies in the years to come. Incentives to do so range from finding the mere limits of nuclear existence, the isospin dependence of the nuclear force, and the origin of the heavy elements, to name but a few.

By providing the highest resolving power on characterizing bound or quasi-bound nuclear quantum states, gamma-ray spectroscopy plays a vital role in this "NUSTAR" context. However, it is of utmost importance to relate the observed rare (gamma-ray) decays to a given isotope, let it be for nuclei moving with relativistic energies or being at rest. At GSI-Darmstadt this is possible within international frameworks at either the SIS-FRS facility (named PreSPEC) as well as with a newly developed spectroscopy set-up suited for the focal plane of the gas-filled separator TASCA (TISISPEC) or the ion trap SHIPTRAP (SHIPTRAP), both using stable beams from the UNILAC accelerator.

# Characterisation of Superdeformed Bands in $^{62}\text{Zn}$

Jnaneswari Gellanki  
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The combined data from four fusion-evaporation reaction experiments have been utilized to investigate deformed and superdeformed structures in  $^{62}_{30}\text{Zn}_{32}$ . Together with the efficient GAMMASPHERE  $\gamma$ -ray spectrometer and ancillary particle detection systems, this approach allowed to define the connection of rotational bands to well-known, low-lying excited states in  $^{62}\text{Zn}$ , and the spectroscopy of record-high high-spin states:  $I^\pi = (35^-)$  at  $E_x = 42.5$  MeV. Four superdeformed bands in  $^{62}\text{Zn}$  are characterized and described by means of cranked Nilsson-Strutinsky calculations.

# The Near-Threshold Pion Production Program at MAX-lab

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## Abstract

Near-threshold pion photoproduction is an elementary process involving an explicit rearrangement of the quarks in the nucleon. It is thus a direct probe of the quark structure of the nucleon. At energies below the Delta resonance, pion photoproduction also provides a stringent test of chiral symmetry as a result of accurate predictions from chiral effective field theory.

Precision sub-Delta measurements of the angular distribution and the total cross section for pion photoproduction are thus of fundamental importance. Surprisingly, aside from the  $(\gamma + p \rightarrow p + \pi^0)$  channel which has been thoroughly studied at MAMI-B and SAL, few data exist in this crucial near-threshold region.

MAX-lab is the one photonuclear facility worldwide whose energy range is perfectly tuned to such experiments. As such, a comprehensive program of near-threshold pion photoproduction experiments has recently been initiated. These experiments include measurements of the angular distribution for  $\pi^+$  photoproduction in the p-wave energy region for both the proton and heavier targets and the total cross section for  $\pi^-$  photoproduction close to threshold using a deuterium target. In this presentation, an overview of the pion photoproduction program at MAX-lab will be presented. This overview will include preliminary results from recent production & commissioning runs together with a look at future plans.

## **Information from Vetenskapsrådet: what is it and what happens to your application**

Johan Bijmens  
Lund University

I will give a short overview of the Swedish Research Council (Vetenskapsrådet), how it is built up and how the process from application submitted to refused/granted money works.

## **$^{14}\text{C}$ from atmospheric nuclear weapons testing – a versatile tracer still sticking around**

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Atmospheric nuclear weapons testing in the late 1950's and early 1960's almost doubled the amount of  $^{14}\text{C}$  in the atmosphere. The resulting  $^{14}\text{C}$  "bomb pulse" can provide useful age information in many scientific areas, *e.g.* forensics, environmental sciences, geosciences and medicine. This talk will present the concept of bomb-pulse dating, as well as some recent applications, focussing on studies concerning processes in the human body. Possibilities and limitations of the technique will also be discussed.

# Measurements of the fission fragment properties of $^{234}\text{U}$ as a function of incident neutron energy

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## Abstract

The reaction  $^{234}\text{U}(n, f)$  is relevant for nuclear reactor applications since it is the compound nucleus formed after second chance fission of  $^{235}\text{U}(n, f)$  the main constituent in the reactor fuel. Full information on the fission fragment properties like fission fragment mass and total kinetic energy are rather scarce for this nucleus and as a function of incident neutron energy. For theoretical calculations of the reaction cross sections for Uranium isotopes this information is a crucial input parameter. Hence the interest in the investigation of fission fragment properties. Furthermore,  $^{234}\text{U}$  is also relevant for the Thorium cycle. Fluctuations in the fragment properties have been observed in the threshold region where vibrational resonances are present [1]. One of the goals of the present study is to verify these fluctuations and to stimulate an improved modeling of the fission process.

The measurements of the neutron induced fission of  $^{234}\text{U}$  have been performed at the Joint Research Centre, Institute for Reference Materials and Measurements, JRC-IRMM, in Geel Belgium. The neutron production was performed at the 7MV Van De Graaff accelerator through the reactions  $^7\text{Li}(p, n)$  and  $^3\text{H}(p, n)$ . Fission fragment properties are studied as a function of incident neutron energy, by means of a double Frisch Grid Ionization Chamber. Measurements were performed so far at neutron energies:  $E_n = 0.64, 0.77, 0.9, 1.0, 1.5, 2.0, 2.5$  and  $3.0$  MeV. A strong anisotropy of the angular distribution is observed around the vibrational resonance at  $E_n \approx 0.77$  MeV. Preliminary results concerning mainly the angular distributions will be presented. Further analysis of the other fission fragment observables measured in this experiment is ongoing.

## References

- [1] A.A. Goverdovskii and B.D. Kuz'minov. The effect of a vibrational state in the second potential well on the average kinetic energy of fragments in the neutron-induced fission of  $^{234}\text{U}$ . *Soviet Journal of Nuclear physics*, 44:179–180, 1986.

# Neutron induced light-ion production from iron and bismuth at 175 MeV

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Light ion (p, d, t, He-3 and alpha) production in the interaction of 175 MeV neutrons with Iron and Bismuth has been measured with low-energy thresholds and for a wide angular range using the MEDLEY setup. A successful campaign at 96 MeV has been recently completed and published (Phys. Rev. C 79, 064611 (2009)) and now higher energy region is under investigation.

MEDLEY is a conventional spectrometer system consisting in eight telescopes placed at angles from 20° to 160°, in steps of 20°. Each telescope is composed of two silicon surface barrier detectors, to perform particle identification, and a CsI(Tl) scintillator to fully stop the produced light-ions and to measure their kinetic energy.

Measurements have been performed at The Svedberg Laboratory, Uppsala (Sweden), where a quasi mono-energetic neutron beam is available and well characterized. Time of flight was measured and used to select light-ion events induced by neutrons in the main peak of the source neutron spectrum. Experimental techniques are presented as well as procedures for data taking and data reduction. Preliminary double-differential (energy and angle) production cross sections for protons, deuterons, tritons are reported and compared with theoretical reaction model calculations.

## **WASA at CELSIUS**

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WASA at CELSIUS is now history but luckily the WASA detector has got a second life at COSY. At CELSIUS it started with letters of intent in 1984 that led to the development and operation of a unique experimental setup with some quite remarkable innovative features. The data taking ended in June 2005 and still there are new results emerging from analysis work. I will give a brief overview of the WASA project at CELSIUS and point at some main achievements.

## The $pd \rightarrow {}^3\text{He} \eta \pi^0$ reaction

The  $pd \rightarrow {}^3\text{He} \eta \pi^0$  reaction has been studied at a beam energy of  $T_p = 1450$  MeV using the WASA detector at the former CELSIUS storage ring at the The Svedberg Laboratory.

Events with one  ${}^3\text{He}$  and four photons were considered and the  $\eta$  and  $\pi^0$  mesons were identified *via* their decay to  $\gamma\gamma$ -pairs. The total cross section was measured and invariant mass distributions of the  ${}^3\text{He}\pi^0$ -system, the  ${}^3\text{He}\eta$ -system and the  $\eta\pi^0$ -system were reconstructed. The data indicate that the production mechanism involves the formation of the  $\Delta(1232)$  isobar. Although the beam energy does not allow the full peak of the resonance to be seen, the invariant masses of all three pairs of final state particles are well reproduced by a phase space Monte Carlo simulation weighted with a  $p$ -wave factor of the  $\pi^0$  momentum in the  ${}^3\text{He}\pi^0$  rest system.

# Symmetries and Hadron Spectroscopy with WASA-at-COSY

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The experiments with the WASA detector at COSY Jülich focus both on studies of symmetries and symmetry breaking mechanisms in hadronic systems as well as hadron spectroscopy. The purpose is to investigate the properties of QCD in the non-perturbative regime, where confinement and chiral symmetry breaking are the characteristic phenomena.

Isospin violation and tests of conservation of the fundamental C, P, and T invariances and combinations thereof are the key physics issues in studies of  $\eta$  decays. Results on the Dalitz plot distribution for the isospin violating  $\eta \rightarrow 3\pi^0$  decay have been obtained from the very first production run in 2007. In 2008 and 2009, high statistics data samples of neutral and charged  $\eta$  decays have been recorded unbiased with respect to the decay by tagging on the  ${}^3\text{He}$  in the  $pd \rightarrow {}^3\text{He}\eta$  reaction.

Low-mass enhancements in isoscalar  $\pi\pi$  mass distributions in two-pion production processes involving the fusion of nucleons or few-nucleon systems, like  $pn \rightarrow d\pi\pi$ ,  $pd \rightarrow {}^3\text{He}\pi\pi$ , or  $dd \rightarrow {}^4\text{He}\pi\pi$ , are a long-standing puzzle known as the ABC effect. In first exclusive data this effect has already been observed using the WASA detector at CELSIUS. Further exclusive and kinematically complete data have recently been measured with WASA-at-COSY, with orders of magnitude higher statistics. For the most basic reaction  $pn \rightarrow d\pi\pi$ , preliminary results confirm the interpretation that the low-mass enhancement is correlated with a  $\Delta\Delta$  excitation of an isoscalar proton-neutron pair. However, the energy dependence of the total cross section exhibits a huge resonance structure with a maximum below the  $\Delta\Delta$  mass.

Selected results obtained so far with WASA-at-COSY will be presented and the next steps within the physics program will be outlined.

# $\eta \rightarrow \pi^+ \pi^- \pi^0$ decay with WASA-at-COSY

Patrik Adlarson

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In 2008 and 2009 twelve weeks of beam time was used in an experiment at WASA-at-COSY with the purpose to study  $\eta$ - decays. The  $\eta$ 's were produced in the  $pd \rightarrow {}^3\text{He} \eta$  reaction at a beam energy of 1 GeV. The total amount of  $\eta$  events on disk is about  $3 \cdot 10^7$ . This data will, among other things, be used to study the  $\eta \rightarrow \pi^+ \pi^- \pi^0$  decay which proceeds mainly via isospin violation. The decay width is proportional to the quark mass difference squared,  $(m_d - m_u)^2$ . Preliminary results of the analysis are presented.

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## Study of cusp effects in the $\eta \rightarrow 3\pi^0$ decay

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The hadronic eta to three pion decays provide possibility to measure some basic quantities of the Strong interaction. Pion scattering length and u - d quark mass ratio is parameters that are sensitive to this decay. Previously this decay was described by CHPT or dispersive framework. Recently a new framework to describe this has been available. By treating pion's instead of quarks as a perturbation an improvement of the possibility to measure the pion scattering length has been available. The cusp that occur where the available energy of creating a charge pion pair are sensitive to the scattering length of two pion scattering. becomes zero in the neutral channel This has already been done in Kaon decay to find the scattering length's  $a_0$  and  $a_2$  with high statistics. The same method could be used in hadronic eta decay with lower accuracy.

# Experimental Studies on Actinides for Novel Nuclear Applications

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More than a decade ago Nuclear Physics was established as research area at Örebro University. Together with co-workers from both within Sweden and abroad one major purpose of these activities has been and still is the collection of precise data most relevant for novel nuclear applications. We give an overview of the most important results obtained so far, describe the current status and present future projects.

## The nELBE neutron source

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**Abstract:** The neutron time-of-flight facility nELBE at the radiation source ELBE (Electron Linear accelerator with high Brilliance and low Emittance) of the Forschungszentrum Dresden-Rossendorf operates a liquid lead circuit as a neutron radiator. It has been operational since November 2007. The measurements of energy resolved neutron cross sections by a time-of-flight arrangement are performed with a flight path of only 6 meters. The electron beam has a pulse width less than 10 ps and the volume of the irradiated lead is only 1 cm<sup>3</sup> resulting in a sharp temporal distribution without moderation of the neutrons. Cross section measurement of the inelastic neutron scattering on <sup>56</sup>Fe as well as total cross section measurements on <sup>181</sup>Ta, <sup>27</sup>Al, <sup>nat</sup>C, H and polyethylene will be reported.

## Suitability of LaCl<sub>3</sub> detectors for prompt fission $\gamma$ -ray measurements

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A challenging task within the modelling of new generation reactor neutron kinetics is the calculation of the  $\gamma$ -heat deposition e. g. in steel and ceramics reflectors without UO<sub>2</sub> blankets, which is required to be known with an uncertainty as low as 7.5%. A major difficulty in measuring the competition between neutron and  $\gamma$ -ray emission during fission fragment deexcitation is the suppression of background  $\gamma$ -rays induced by prompt fission neutrons in the  $\gamma$ -detector. A common method is to distinguish between  $\gamma$ -rays and neutrons by their respective different time-of-flight, which however is limited by the timing resolution of the detector (not better than 5 ns for NaI). A promising approach seems to be the use of recently developed cerium-doped lanthanum halide crystal scintillation detectors.

Prior to an experiment at the 10 MW research reactor at IKI in Budapest, dedicated to the measurements of the fission-fragment mass and kinetic energy distribution as well as prompt fission  $\gamma$ -rays from thermal (cold) neutrons on <sup>235</sup>U and scheduled for the beginning of the year 2010, we have performed several preparatory studies. First we have characterized three coaxial 1.5" x 1.5" LaCl<sub>3</sub>:Ce detectors in terms of energy conversion and resolution, linearity, dynamical range, intrinsic efficiency, timing resolution and intrinsic radioactivity. These detectors were then recently tested in a fast-neutron environment with the 4 MV Van de Graaff accelerator at CEA/DAM Ile de France, in order to investigate neutron-gamma separation by means of the time-of-flight technique and a possible built-up of background components in the detector material due to neutron capture. We intend to report on the results obtained so far.

## VERDI – a double (v, E) fission-fragment spectrometer

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The investigation of neutron-induced fission characteristics, like fragment mass- and energy-distributions, is usually based on the double-energy technique using twin Frisch-grid ionisation chambers (IC). The main feature of an IC is its insensitivity to radiation damage, which makes it most suitable for measurements in a strong neutron environment. Providing the existence of prompt neutron emission data, the pre-neutron fission fragment mass and energy distributions may be obtained in an iterative process. However, those input data do exist only for the main isotopes of uranium and plutonium with sufficient precision and extrapolation methods have to be applied when analysing neighbouring compound nuclear systems.

With the construction of the double (v, E) spectrometer VERDI we aim at the measuring pre- and post-neutron masses directly and simultaneously, avoiding prompt neutron corrections. In order to achieve a mass resolving power  $A/\Delta A \geq 100$ , ultra-fast time pick-up detectors based on artificial diamond material are under investigation. From the simultaneous measurement of pre- and post-neutron fission-fragment data prompt neutron multiplicity may then be inferred as a function of fragment mass and total kinetic energy

This contribution aims at presenting the VERDI spectrometer and the implementation of novel radiation hard time pick-up detectors for low-energy heavy ions.

## Photo-fission at the S-DALINAC

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The fission of  $^{238}\text{U}$  and  $^{234}\text{U}$  induced by bremsstrahlung with endpoint energies between 6 MeV and 9 MeV has been investigated at the superconducting Darmstadt electron linear accelerator S-DALINAC. The experiment is a step in preparing for an experimental investigation of parity violation in photo-fission. A twin Frisch grid ionization chamber has been used to determine fission fragment energy and mass distributions via the double kinetic energy technique. The fission fragment emission angle, which is used to correct for energy loss in the target and backing material for a correct determination of fragment energy and mass, is deduced from the electron drift time. The research program and results of the first experimental studies will be presented.