Event Reconstruction and Analysis in the R3BRoot Framework

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Abstract. The R^3B experiment (Reaction studies with Relativistic Radioactive Beams) will be built within the future FAIR / GSI (Facility for Antiproton and Ion Research) in Darmstadt, Germany. The international collaboration R^3B has a scientific program devoted to the physics of stable and radioactive beams at energies between 150 MeV and 1.5 GeV per nucleon. In preparation for the experiment, the R3BRoot software framework is under development, it deliver detector simulation, reconstruction and data analysis. The basic functionalities of the framework are handled by the FairRoot framework which is used also by the other FAIR experiments (CBM, PANDA, ASYEOS, etc) while the R^3B detector specifics and reconstruction code are implemented inside R3BRoot. In this contribution first results of data analysis from the detector prototype test in November 2012 will be reported, moreover, comparison of the tracker performance versus experimental data, will be presented.

1. Introduction

The future R^3B (Reactions with Rare Radioactive Beams) experiment is one of the scientific pillars of the FAIR facility to be built in Darmstadt, Germany. It is organised as an international collaboration including about 50 institutes from all over the world. Series of experiments will perform reaction studies with exotic nuclei far off the stability region with the focus on nuclear structure and dynamics. Also astrophysical aspects and technical applications are considered as part of the scientific program.

The NeuLAND (New Large Area Neutron Detector) will be used in the R^3B setup for detection of fast neutrons, in particular for the classification of multi-neutron events ($\leq$6) with precise identification of a first interaction and determination of neutron momenta (in the range from 50 - 1000 MeV) by measurement of position and time of flight. For the summary on the detector concept of NeuLAND see [1, 2].

The aim of the work presented here was to achieve a high performance of the reconstruction algorithm with respect to efficiency, purity and resolution of the identification of such physics observable as, e.g., the so-called tetra-neutron (4 neutrons with a narrow distribution in space and time). The test beam experiment, performed at GSI in November 2012, has delivered first data taken with the full-size NeuLAND prototype. These results were compared to the simulation, leading to improvements in the reconstruction algorithm.

2. Simulation environment

The R^3B experiment is currently in the preparation phase, in which the detector prototypes are being tested. Thus the simulations of the detector performance and comparison versus experimental data is of a high priority. The R3BRoot software package is a branch of the FairRoot framework developed at GSI starting from 2004, which supports all future FAIR experiments with the simulation, reconstruction and data analysis infrastructure ([3]). It is based on ROOT ([4]) and VMC (Virtual Monte Carlo) interface, allowing easy switching between Geant3 [5] and Geant4 [6] transport engines. The task mechanism, inherited from ROOT, provides the possibility for user-friendly steering macros. The framework consists out of 1050 source files, containing 135000 lines of C++ code.

Figure 1 shows the visualisation of several R^3B modules, top-right corner - NeuLAND detector for the neutron measurement. Other detectors from left to right: CALIFA (gamma spectroscopy) with the target inside, super conducting GLAD magnet, Drift Chambers, and ToF wall.

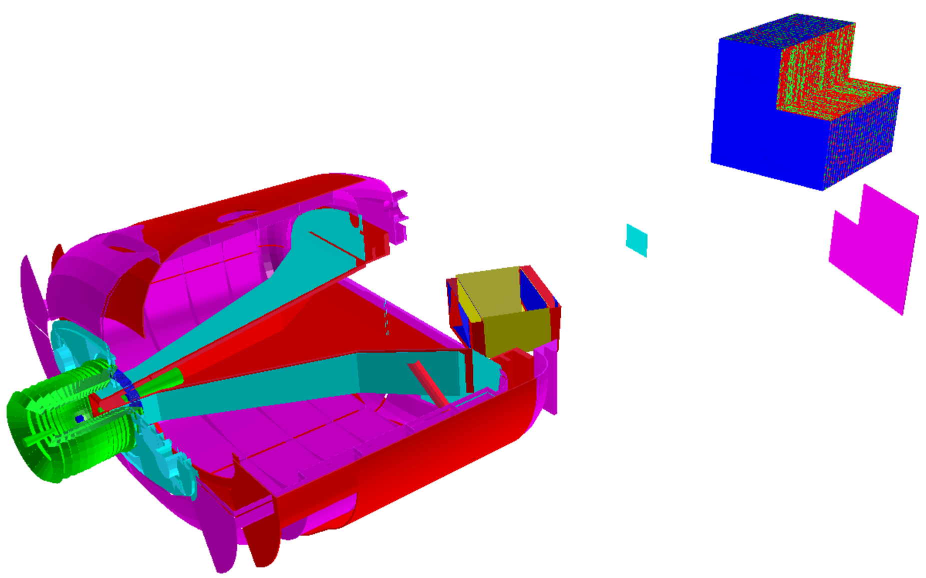

Figure 1. Visualisation of the R^3B detector geometry implemented in R3BRoot.

2.1. NeuLAND geometry

The neutron detector in R^3B will be constructed out of 3000 plastic scintillator bars (read-out from both ends with a single-channel photo-multiplier), organised in 30 double-planes (horizontal and vertical directions iteratively) implementing in this way a fully-active scintillator concept. The dimensions are 2.5 x 2.5 meters with a depth of 3 m. Depending on the specific requirements of the experiment with respect to acceptance and resolution, NeuLAND will be placed at different distances downstream of the target from 14 to 35 m. As input we have used reaction products of ^{132}Sn on hydrogen with stripping of 1 to 4 neutrons having relative energy of 100 and 500 keV. The transport of particles and light in the detector volume by Geant3 (using the GEANT-CALOR interface for neutron transport) was extended by applying light quenching. In the reconstruction we have considered 150 ps time resolution (experimental result from single bar tests), light attenuation and time decay.

3. Simulation results

The reconstruction procedure implies two steps: first the hit producer (digitiser) and second the neutron tracking. The hit producer task is taking Monte Carlo Points (results of transport calculations) as input and creates digis (the same data level as in the real experiment), applying light attenuation in the detector material and a light read-out from the two far ends of a scintillator bar by photomultipliers. The created digis contain information about time, charge and position and serve as input for the second task of the reconstruction algorithm.

3.1. Calorimetric properties

Before finding the first hits of the incident neutrons, the decision on the event class (amount of neutrons) has to be taken. It is done, by applying a set of pre-calibrated 2-D cuts on the values of the number of clusters (groups of digis representing the track of a charged particle, which are created by analysing digi pattern in an event with respect to position and time) and total energy deposit in the detector volume (see Figure 2).

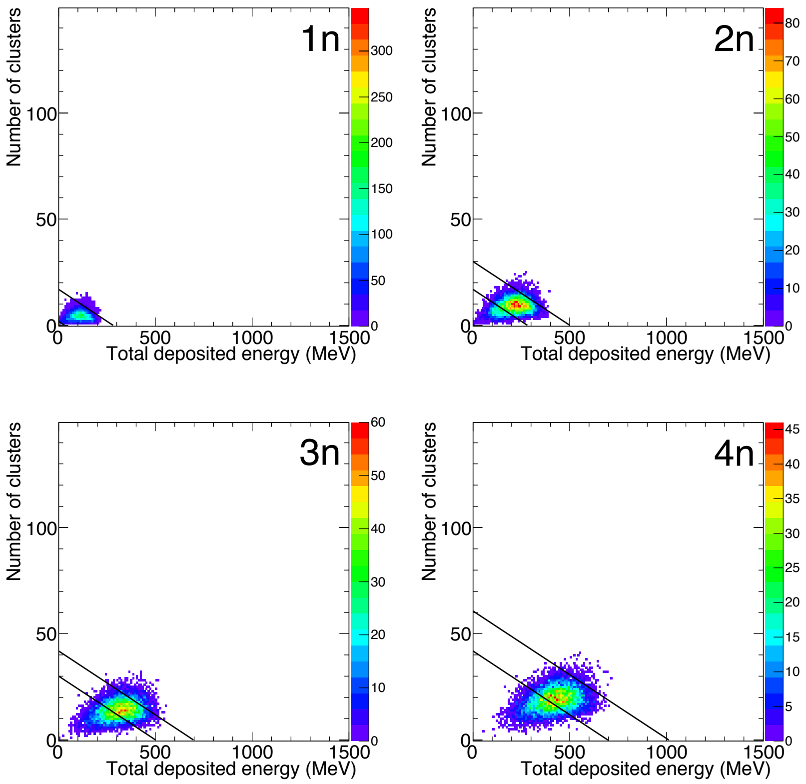

Figure 2. Distribution of number of clusters versus total deposited energy.

Simulation results in an anti-correlation between N_{CL} (vertical axis) and E_{TOT} (horisontal axis), which allows deriving number of impact neutrons with higher efficiency and purity than in case of 1-D cut on total energy only (efficiency for 4n case was increased from 40 to 60%, and contamination by 3n was dropped from 30 to 10%).

3.2. Neutron identification matrices

Table 1 lists the values for the multi-neutron recognition probabilities in %. Columns show generated number of neutrons, rows - detected by the reconstruction explained above. Diagonal elements in the table stand for efficiency, non-diagonal - for misidentification probabilities. Achieved values are in the region of the design goal and are typical for an astrophysical experiment.
These results were obtained for ^{132}Sn at 600 AMeV beam energy with 500 keV relative energy and NeuLAND detector placed at 14 m downstream the target.

Table 1. Neutron identification matrix for beam energy of 600 AMeV, and E_{rel}=500 keV, see subsection 3.2.

	1n	2n	3n	4n
1n	**92**	22	2	0
2n	2	**71**	32	7
3n	0	6	**55**	32
4n	0	0	10	**57**

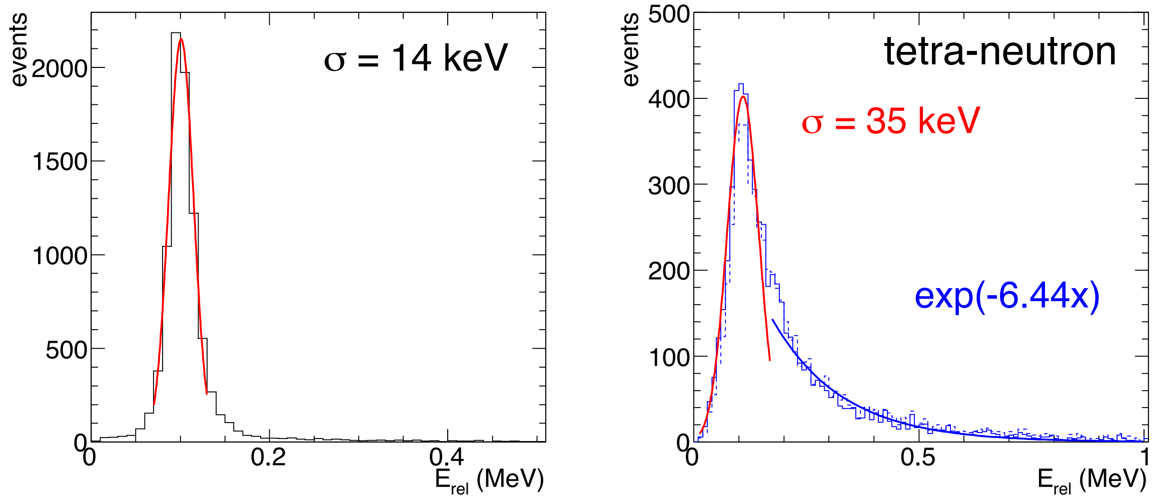

Figure 3. Astro-physics: 1 incident neutron. Tetra-neutron: 4 incident neutrons (beam energy 600 AMeV, E_{rel}=100 keV).

3.3. Reconstruction algorithm
After the number of incident neutrons is determined as explained above, the tracking procedure starts. First of all, the cluster pattern of an event is analysed with respect to the kinematical topology of elastic scattering of neutrons on hydrogen. The secondary hits of elastically scattered neutrons are eliminated from the further analysis. The remaining clusters are sorted according to the values of absolute deviation of potential neutron velocity from the beam velocity (smaller deviation has higher priority) and to the energy deposit in the cluster (higher energy deposit has higher priority). Additional requirement on the sorting of clusters, is that the very first cluster in time stays first. The primary interactions of the known number of incident neutrons are then taken from the list of sorted clusters.

3.4. Relative energy spectra
The reconstruction algorithm is finalised by calculating the neutron momenta (using distance to the target and ToF) and relative energy. Figure 3 shows in this way reconstructed spectrum for 2 different physics cases. The design goal resolution of better than 20 keV is achieved. We have concluded from the detailed analysis of single neutron momentum resolution, that the tail towards higher values on the right plot stems from the higher probability of misidentification in case of 4 incoming neutrons.

4. Prototype test experiment
The full-size NeuLAND prototype detector was tested at GSI in November 2012 with a deuteron beam at various energies from 200 AMeV - 1,5 AGeV. The aim of the experiment was to test the whole read-out chain in the integrated system with other detectors, estimate the total efficiency of neutron measurements, and to obtain the value of time resolution. In addition, one can study quasi free scattering of deuteron on hydrogen by analysing data also from Crystal ball and Silicon trackers. This work is currently ongoing.

Figure 4 shows the technical drawing of the experimental setup in cave "C" at GSI. In the middle - Crystal Ball, the Silicon Tracker and the Target, further downstream - the ALADIN magnet and the NeuLAND prototype.

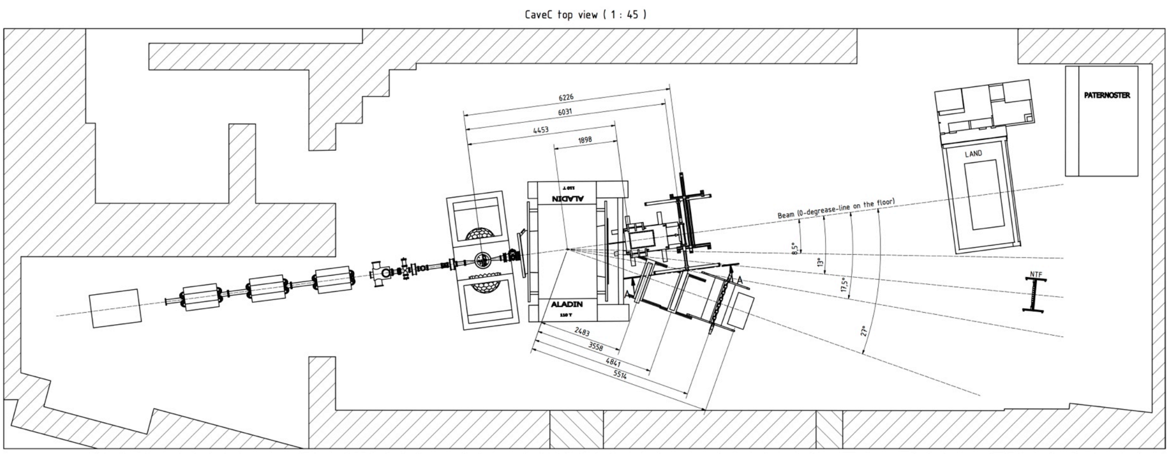

Figure 4. Sketch of the prototype test setup.

The detector was built out of 146 modules with 15 single planes only in vertical direction, total depth is 1,5 m. In this work we focus on the first-level comparison of the simulation results and the experimental data, namely single channel response and total energy deposit.

The old LAND data and R3BRoot simulation results have been conducted which helped in understanding important detector effects. In order to reproduce the measured energy deposit per paddle, one has additionally to introduce individual low charge thresholds, resolution and such effect as photo-multiplier saturation.

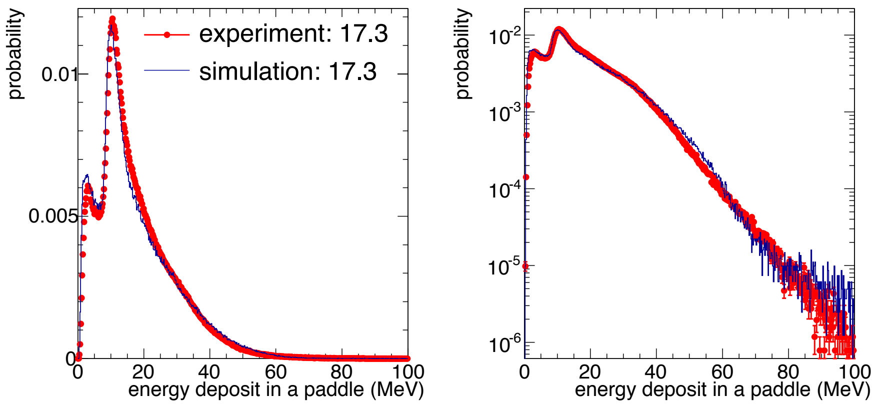

Figure 5. Energy per paddle distribution. Points - experimental data, histogram - simulation.

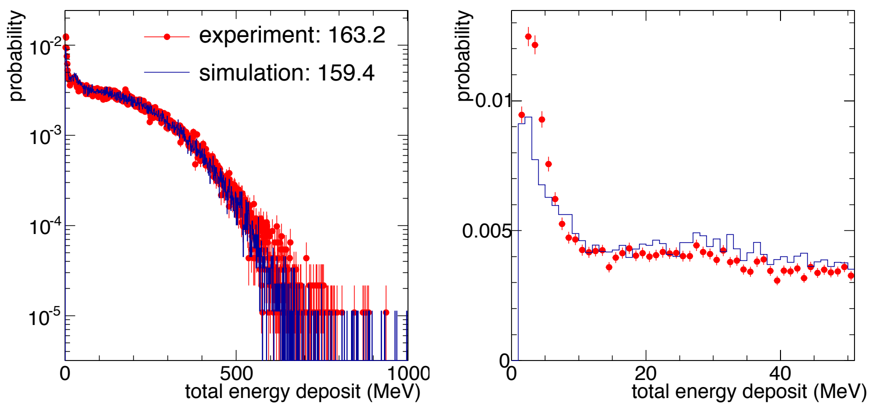

Figure 6. Total energy deposited in the NeuLAND prototype. Points - experimental data, histogram - simulation.

The comparison is presented in Figure 5 for single paddle spectra, and in Figure 6 for the energy deposit in entire detector volume. We conclude very good agreement in the shape, the mean values, and the most probable values of the distribution.

5. Summary

The future R^3B experiment at FAIR is fully supported with the simulation software by the R3BRoot framework and work is ongoing to provide the tools for data analysis and online monitoring. With respect to the NeuLAND detector, the performance of the ToF spectrometer was significantly improved. These studies and results were included in the Technical Design Report (TDR) for the subsystem, which was approved beginning 2013. In addition, the TDR for the subsystem CALIFA (gamma spectrometer), which is based on R3BRoot simulation results, was also approved by FAIR.

The main direction of the algorithm development within the R3BRoot framework is the possibility to use the same code for both simulation and future data analysis (offline and online). That is why the issue with the verification and validation of the reconstruction task is of a big importance. We conclude overall good agreement of simulated and measured detector performance in the particular case of the NeuLAND prototype. With respect to the timing of the algorithm, we observe most of the calculation time spent on input / output of data, being in the order of $\approx$100 ms per event, i.e. processing speed of 5.7 events/s for the simulation and 22 events/s for the analysis (on 2.8 GHz Intel Xeon CPU). An additional constraint on the size of transferred data objects should improve the timing performance. Taking into account maximum beam intensity of the R3B experiment 10^3 - 10^5 beam particles per second and moderate reaction products multiplicity, we conclude that the online data reconstruction with deployment on a cluster with $\approx$ 100 cores will be possible.

References

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