Report on the benchmarking of the event generator for heavy ion induced reaction

Event generator for heavy-ion induced reaction is based on the GSI nuclear-reaction model ABRABLA07. ABRABLA07 is a two-stage abrasion-ablation model developed for the modelling of the heavy-ion reactions at relativistic energies. The first stage model ABRA is based on the geometrical abrasion picture of the heavy-ion reactions. The abrasion picture is based on the clean cut of the target nucleons by the interacting projectile (and vice versa). The number of nucleons, which are removed during the abrasion, depends only on the collision impact parameter. From the number and 'type' of nucleons removed the excitation energy and the isotopic composition of the primary pre-fragment may be determined. For more details, see [1,2]. De-excitation of pre-fragments produced during the abrasion stage is followed by the ablation model ABLA07. ABLA07 is a dynamical code that describes the de-excitation of the thermalised system by simultaneous break-up, particle emission and fission. Simultaneous break-up is considered as the cracking of the hot nucleus into several fragments due to thermal instabilities, see [3]. The description of particle evaporation is based on the extended Weißkopf-Ewing formalism where the change of angular momentum in the evaporation process due to particle emission is included. The fission decay width is calculated taking into account dynamical effects. The basic ingredients of the ABLA07 model are:

1. Emission of neutrons, light charged particles (^{1,2,3}H, ^{3,4,6}He), intermediate-mass fragments IMF (Z>2) and gamma rays is considered.

2. In calculating the particle decay widths the following effects are considered:
• Energy dependent inverse cross sections based on nuclear potential using the ingoing-wave boundary condition model.
• Nuclear-structure effects – pairing, shell effects, collective enhancement are taken into account.
• Thermal expansion of the source is taken into account.
• Change of angular momentum due to particle emission is considered.

3. The fission decay width is described by including:
• An analytical time-dependent approach to the solution of the Fokker-Planck equation.
• The influence of the initial deformation on the fission decay width.
• The double-humped structure in the fission barriers of actinides.
• Symmetry classes in low-energy fission.

4. Particle emission on different stages, i.e. between ground state and saddle point, between the saddle and scission point, and from two separate fission fragments, of the fission process is calculated separately.

5. Kinetic-energy spectra of the emitted particles are directly calculated from the inverse cross sections. Kinetic energy of heavy residues is calculated from the momentum conservation.

6. A stage of simultaneous break-up in the decay of hot excited systems is explicitly treated.

Please note, that when coupled with an adequate first-stage model the de-excitation code ABLA07 can be used also in other energy regimes, e.g. fusion reactions. More details about ABLA07 can be found in [4].

Several outputs of the ABRABLA07 code are available:

- Tables with isotopic production cross sections of all residues.
- Tables with isobaric and isotonic production cross sections of all resides.
- List-mode file where all relevant information are given on even-wise base: For each event, (A,Z,p_x,p_y,p_z,L) of pre-fragments and all final fragments created in this event are given. Also, information on the production mechanism of a given final fragment, i.e. light-particle emission, IMF emission or fission, is given.

In the following results of the ABRABLA07 will be compared with different experimental data measured in heavy-ion reactions at relativistic energies. The following systems will be considered: ^{86}Kr(500*A*MeV)+Be, ^{56}Fe(1000*A*MeV)+Ti, ^{136}Xe(1000*A*MeV)+Pb, ^{208}Pb(1000*A*MeV)+Cu, and ^{238}U(1000*A*MeV)+Pb.

- System ^{86}Kr(500*A*MeV)+Be

Experimental data are taken from: Weber et al. Nucl. Phys. A578 (1994) 659.

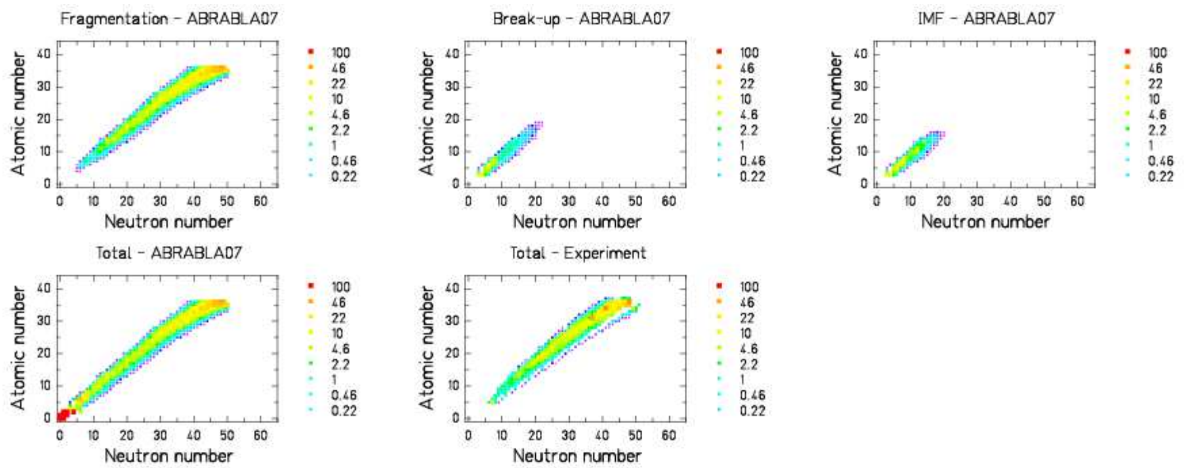


Fig. 1: Calculated and measured cross sections for the reaction ^{86}Kr(500AMeV)+Be shown on the nuclide chart. Up – different contributions to the total production cross section as predicted by ABRABLA07 (fragmentation, simultaneous break-up, intermediate-mass fragment evaporation). Down – total production cross sections: left are shown ABRABLA07 predictions, right are shown experimental data.

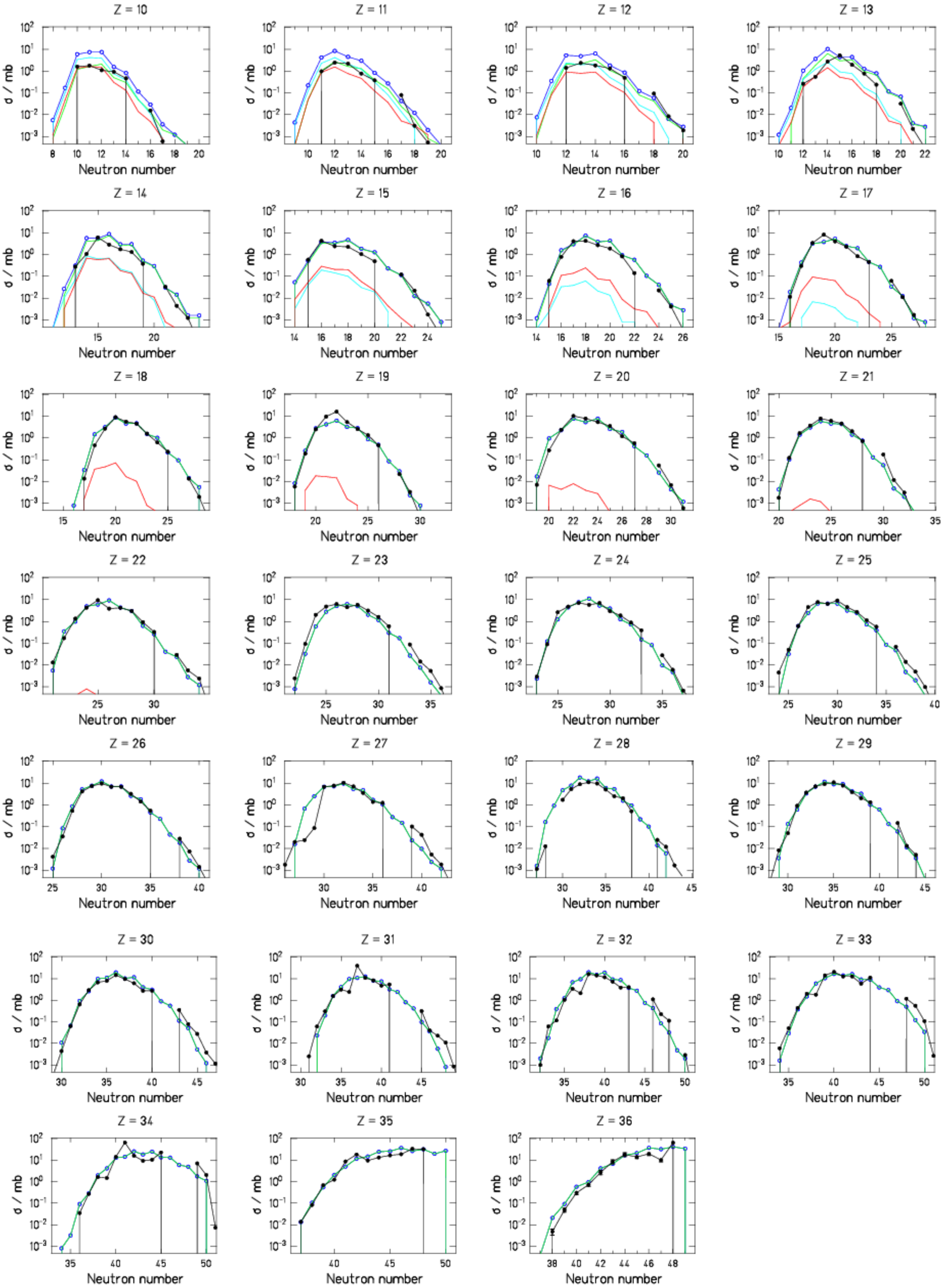


Fig. 2: Isotopic production cross sections for the reaction ^{86}Kr(500AMeV)+Be: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), IMF evaporation (light blue line), fragmentation (green line).

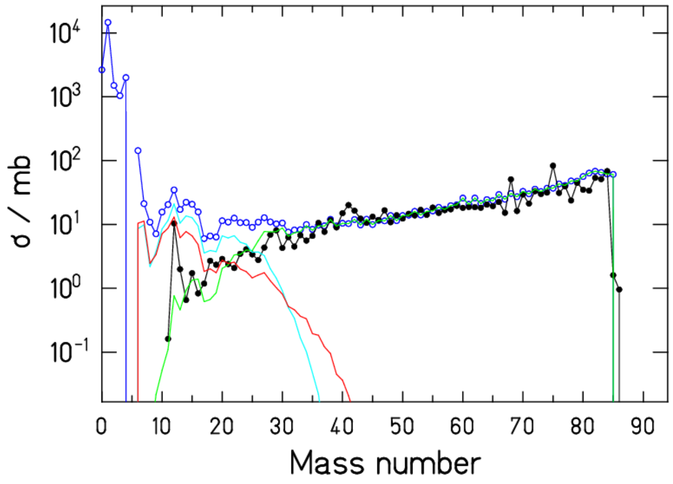


Fig. 3: Mass distribution for the reaction ^{86}Kr(500AMeV)+Be: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), IMF evaporation (light blue line), fragmentation (green line).

For this reaction, there is very good overall agreement between data and ABRABLA07 predictions. Only for the lightest residues contributions from break-up and IMF evaporation are somewhat over-predicted. For the residues with Z>13 (A>30) agreement between data and calculations is very good.

- System ^{56}Fe(1000*A*MeV)+Ti

Experimental data are taken from: P. Napolitani et al., Phys. Rev. C70 (2004) 054607.

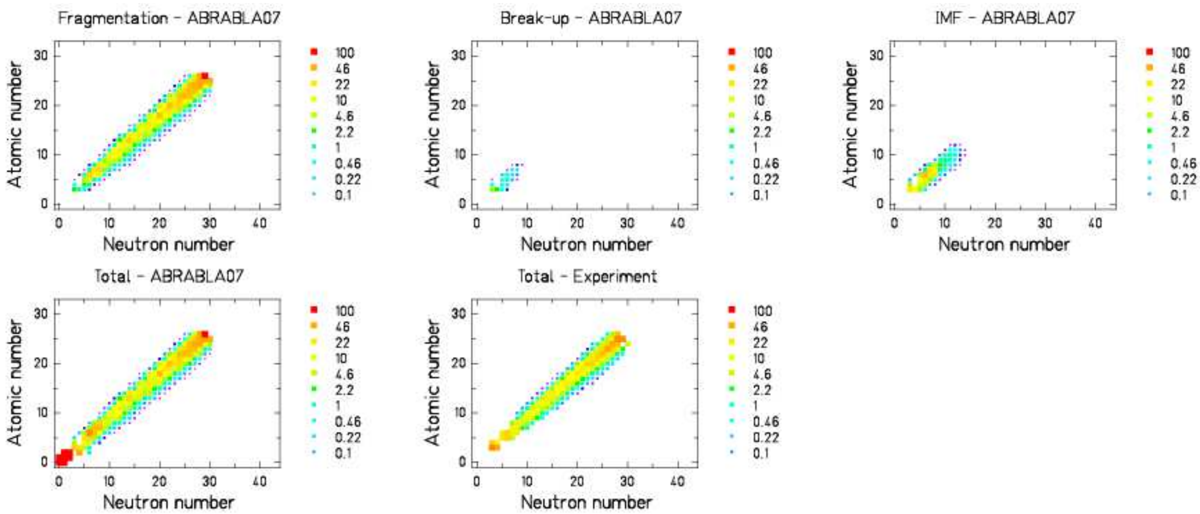


Fig. 4: Calculated and measured cross sections for the reaction ^{56}Fe(1000AMeV)+Ti shown on the nuclide chart. Up – different contributions to the total production cross section as predicted by ABRABLA07 (fragmentation, simultaneous break-up, intermediate-mass fragment evaporation). Down – total production cross sections: left are shown ABRABLA07 predictions, right are shown experimental data.

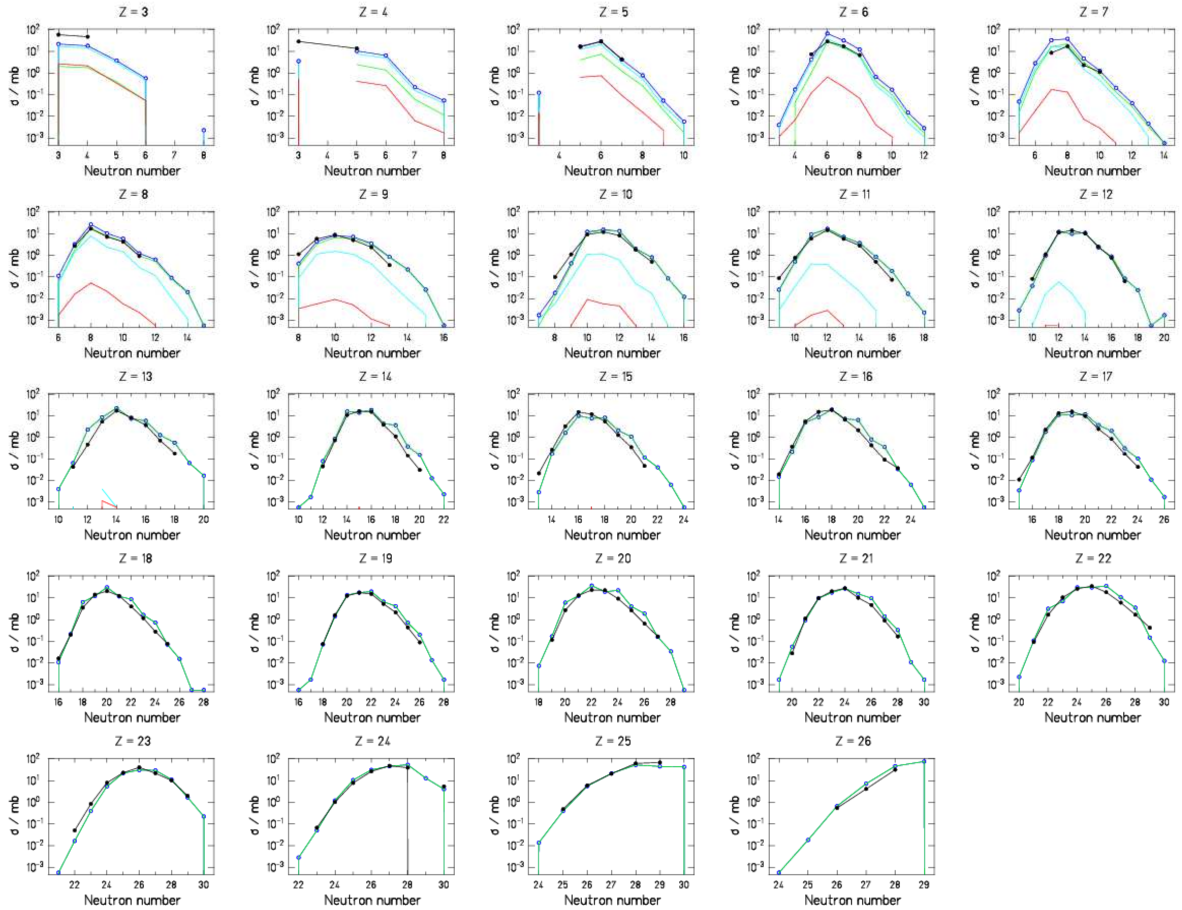


Fig. 5: Isotopic production cross sections for the reaction ^{56}Fe(1000AMeV)+Ti: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), IMF evaporation (light blue line), fragmentation (green line).

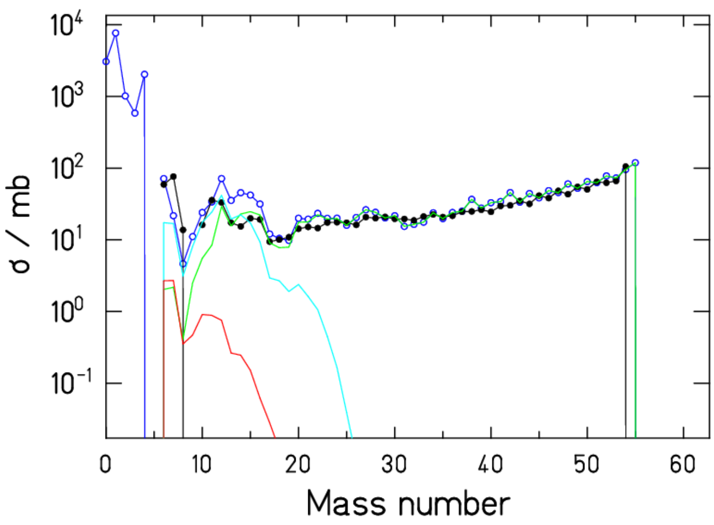


Fig. 6: Mass distribution for the reaction ^{56}Fe(1000AMeV)+Ti: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), IMF evaporation (light blue line), fragmentation (green line).

For the reaction ^{56}Fe(1000*A*MeV)+Ti an excellent agreement between experiment and ABRABLA07 predictions over the whole range of A and *Z* has been achieved.

- System ^{136}Xe(1000*A*MeV)+Pb

Experimental data are taken from: D. Henzlova et al, Phys. Rev. C 78 (2008) 044616.

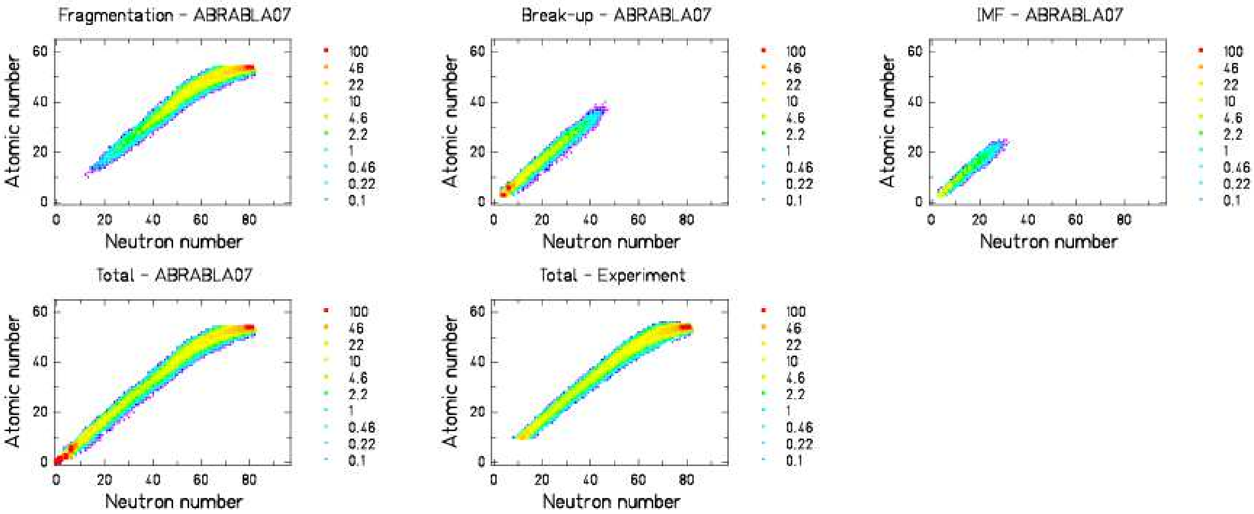


Fig. 7: Calculated and measured cross sections for the reaction ^{136}Xe(1000AMeV)+Pb shown on the nuclide chart. Up – different contributions to the total production cross section as predicted by ABRABLA07 (fragmentation, simultaneous break-up, intermediate-mass fragment evaporation). Down- total production cross sections: left are shown ABRABLA07 predictions, right are shown experimental data.

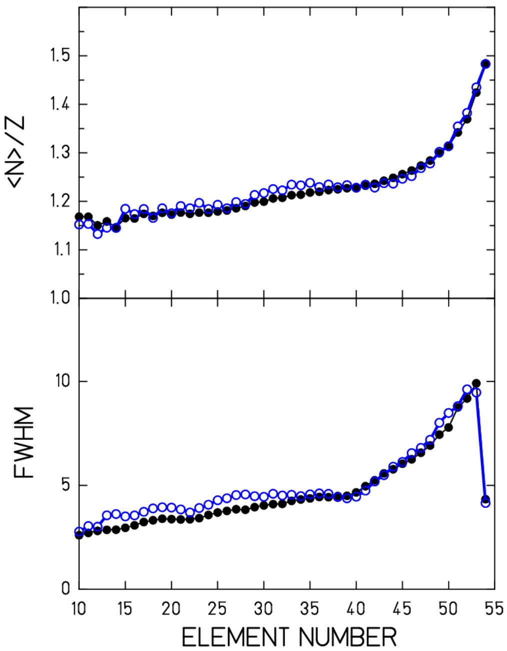


Fig. 8: Mean-neutron to proton ratio (up) and FWHM (down) of the isotopic distributions for the reaction ^{136}Xe(1000AMeV)+Pb: Experimental data (black dots), ABRABLA07 predictions: total (blue dots).

For the reaction ^{136}Xe(1000*A*MeV)+Pb we show first moments of the isotopic distributions (mean-neutron-to-proton ratio and FWHM) instead of isotopic distributions as in previous cases. This is only done due to limited space and large number of isotopic distributions (45 figures).

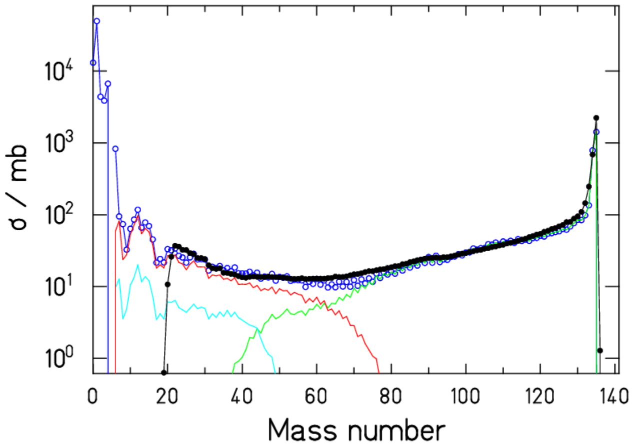
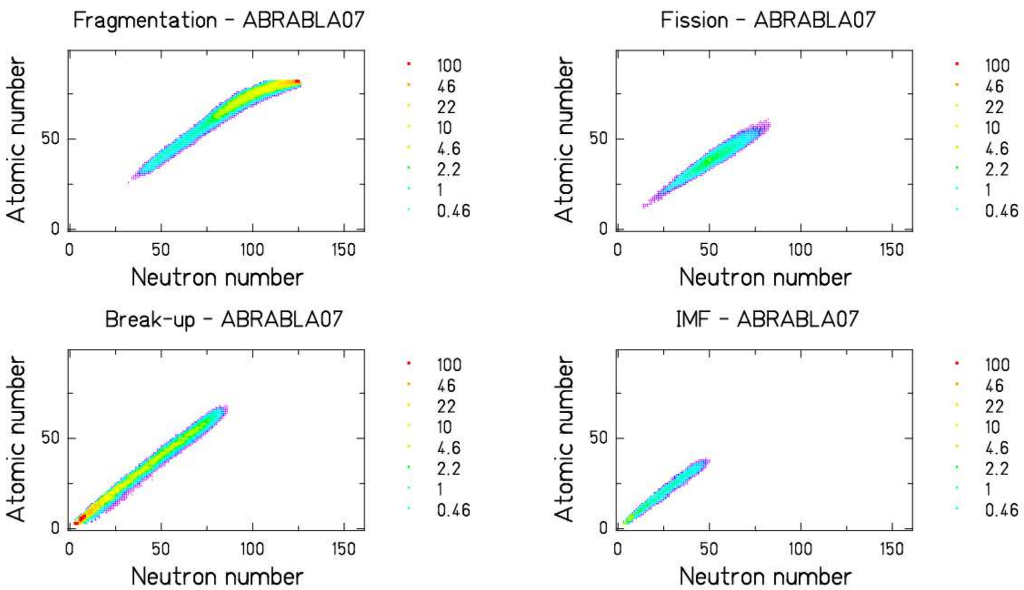


Fig. 9: Mass distribution for the reaction ^{136}Xe(1000AMeV)+Pb: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), IMF evaporation (light blue line), fragmentation (green line).

For the reaction ^{136}Xe(1000*A*MeV)+Pb an overall very good agreement between experimental data and ABRABLA07 predictions has been achieved.

- System ^{208}Pb(1000*A*MeV)+Cu

Experimental data are taken from: M. de Jong et al., Nucl. Phys. A 628 (1998) 479.
For this reaction only a part of the final residues has been measured in the experiment. Very good agreement between the measured data and ABRABLA07 has been achieved.



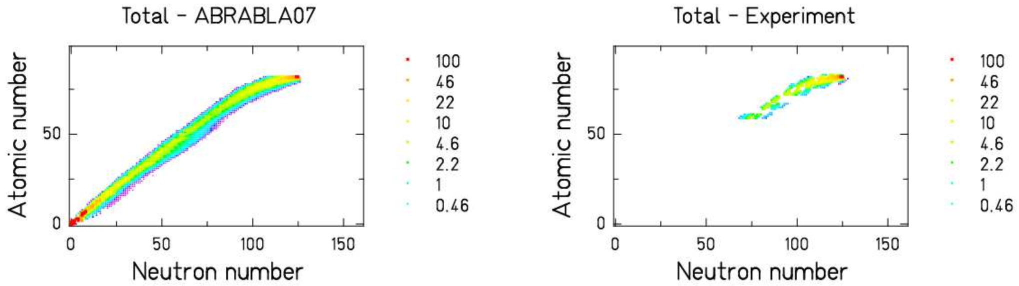


Fig. 10: Calculated and measured cross sections for the reaction ^{208}Pb(1000AMeV)+Cu shown on the nuclide chart. Up and middle – different contributions to the total production cross section as predicted by ABRABLA07 (fragmentation, fission, simultaneous break-up, intermediate-mass fragment evaporation). Down – total production cross sections: left are shown ABRABLA07 predictions, right are shown experimental data.

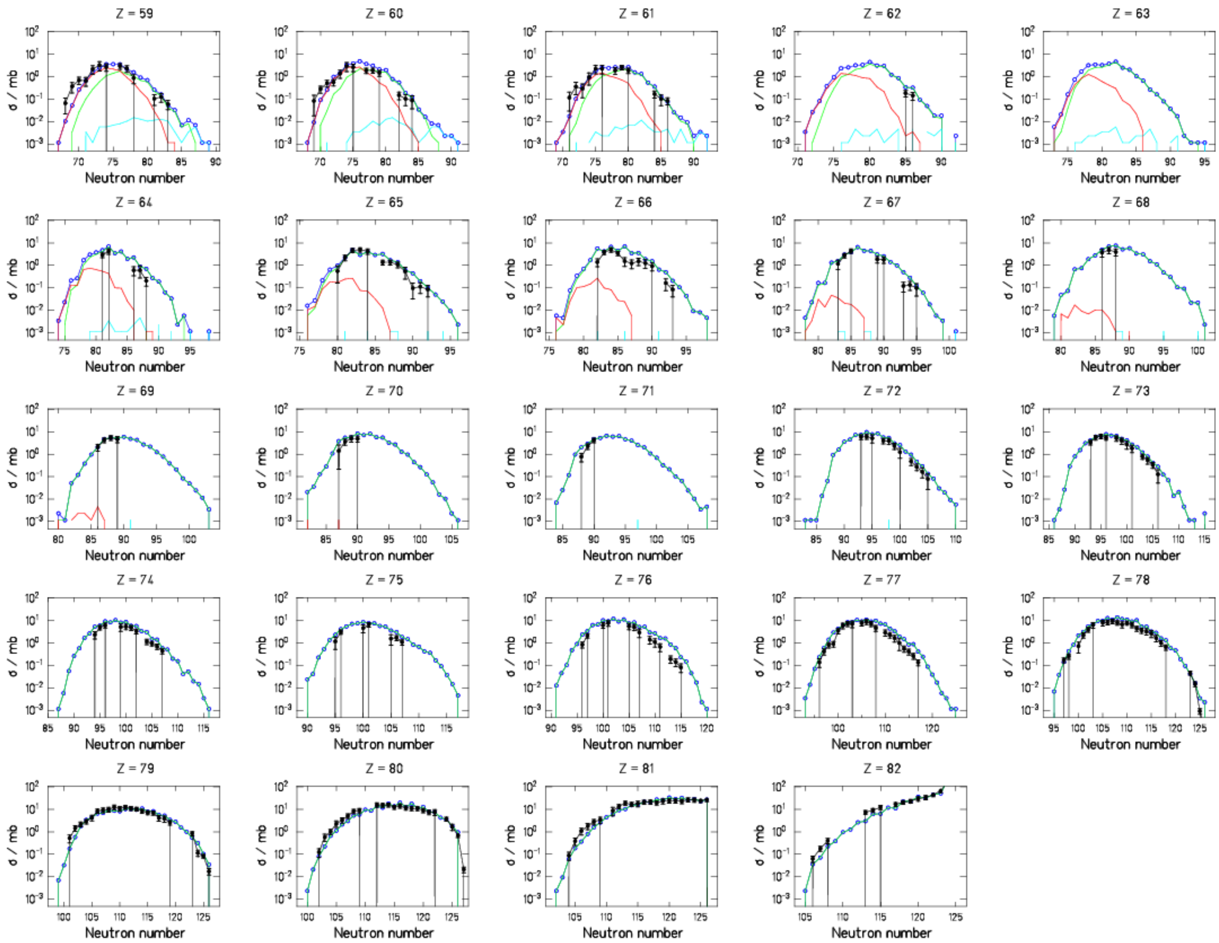


Fig. 11: Isotopic production cross sections for the reaction ^{208}Pb(1000AMeV)+Cu: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), fission (light blue line), fragmentation (green line).

- System $^{238}U(1000AMeV)+Pb$

Experimental data are taken from: T. Enqvist et al, Nucl. Phys. A 658 (1999) 47.
In the experiment only a part of the produced nuclei has been measured.

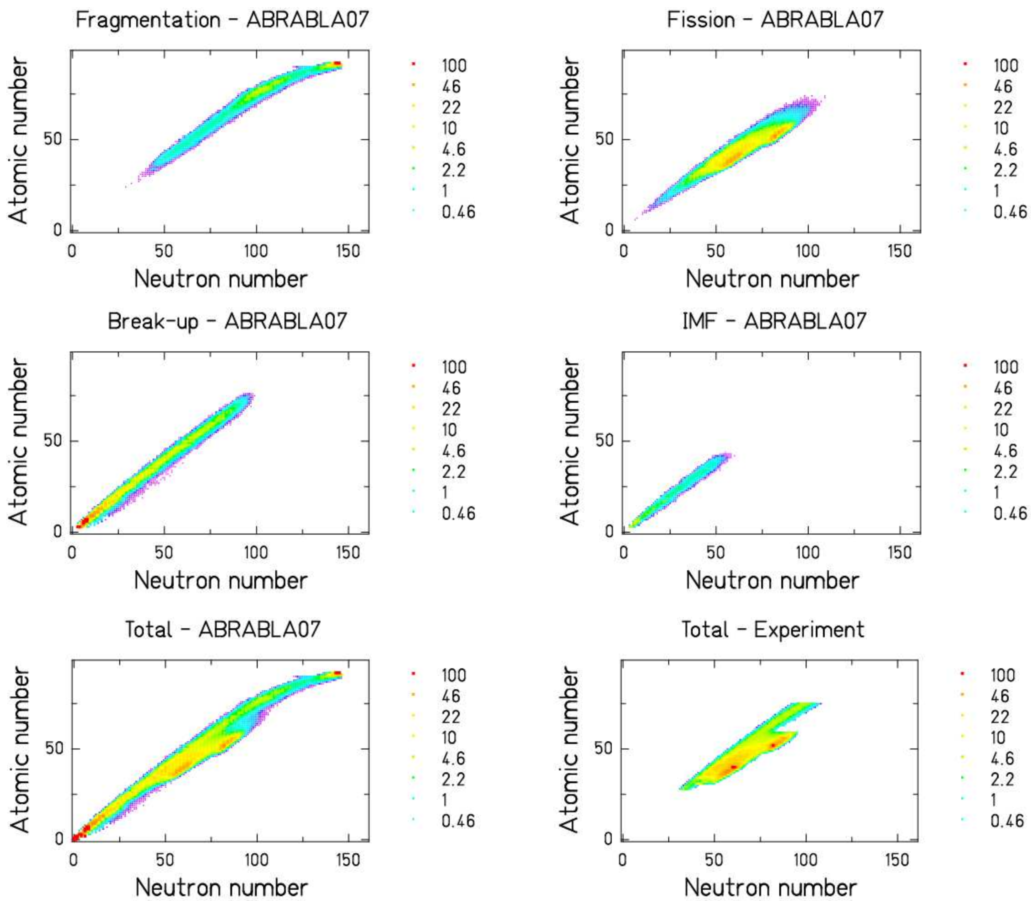


Fig. 12: Calculated and measured cross sections for the reaction $^{238}U(1000AMeV)+Pb$ shown on the nuclide chart. Up and middle – different contributions to the total production cross section as predicted by ABRABLA07 (fragmentation, fission, simultaneous break-up, intermediate-mass fragment evaporation). Down – total production cross sections: left are shown ABRABLA07 predictions, right are shown experimental data.

For the reaction $^{238}U(1000AMeV)+Pb$ an overall good agreement between experimental data and ABRABLA07 predictions has been achieved.

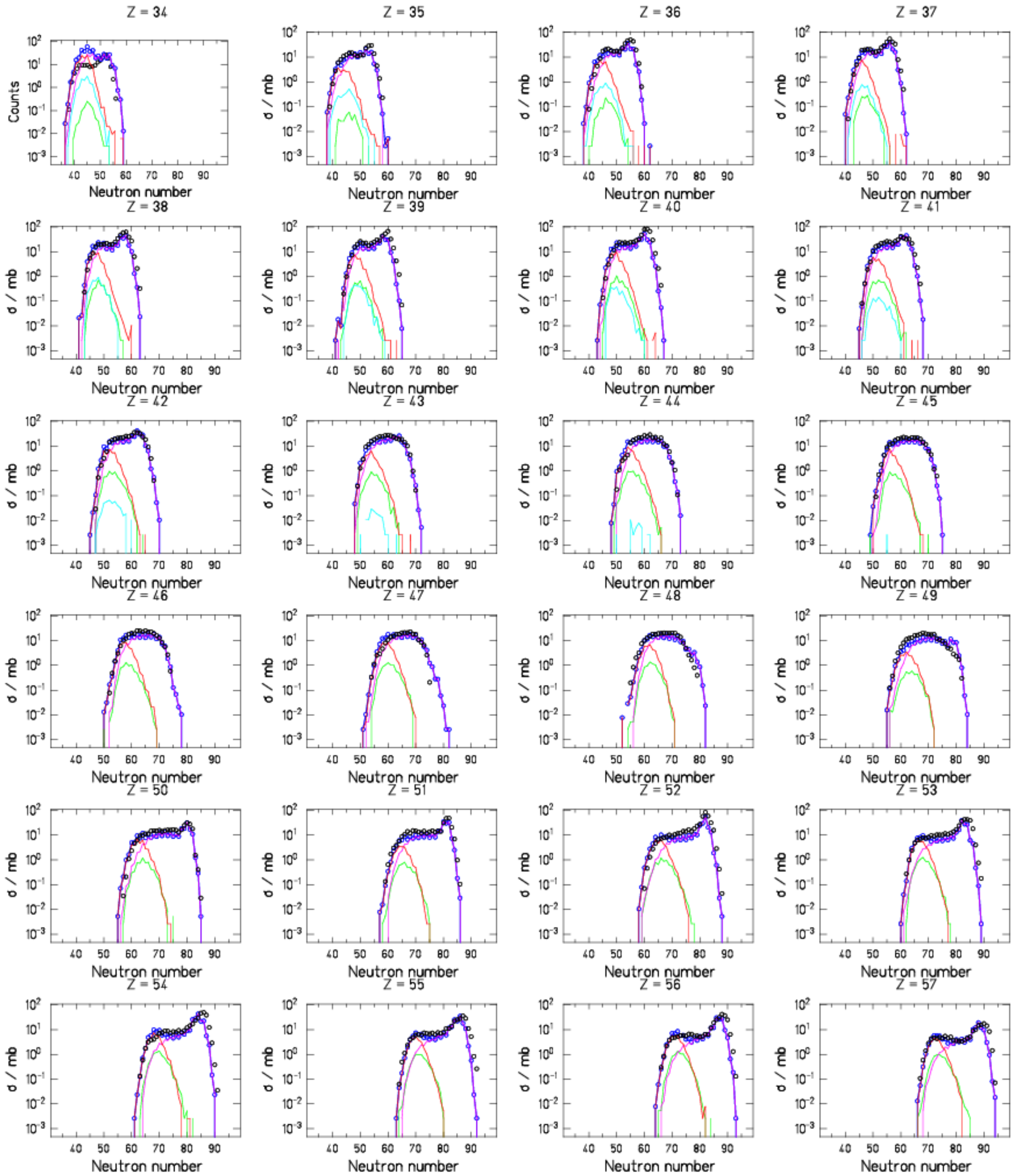


Fig. 13: Isotopic production cross sections for the reaction ^{238}U(1000AMeV)+Pb: Experimental data (black dots), ABRABLA07 predictions: total (blue dots), break-up (red line), fission (mangenta line), fragmentation (green line), IMF evaporation (light blue line).

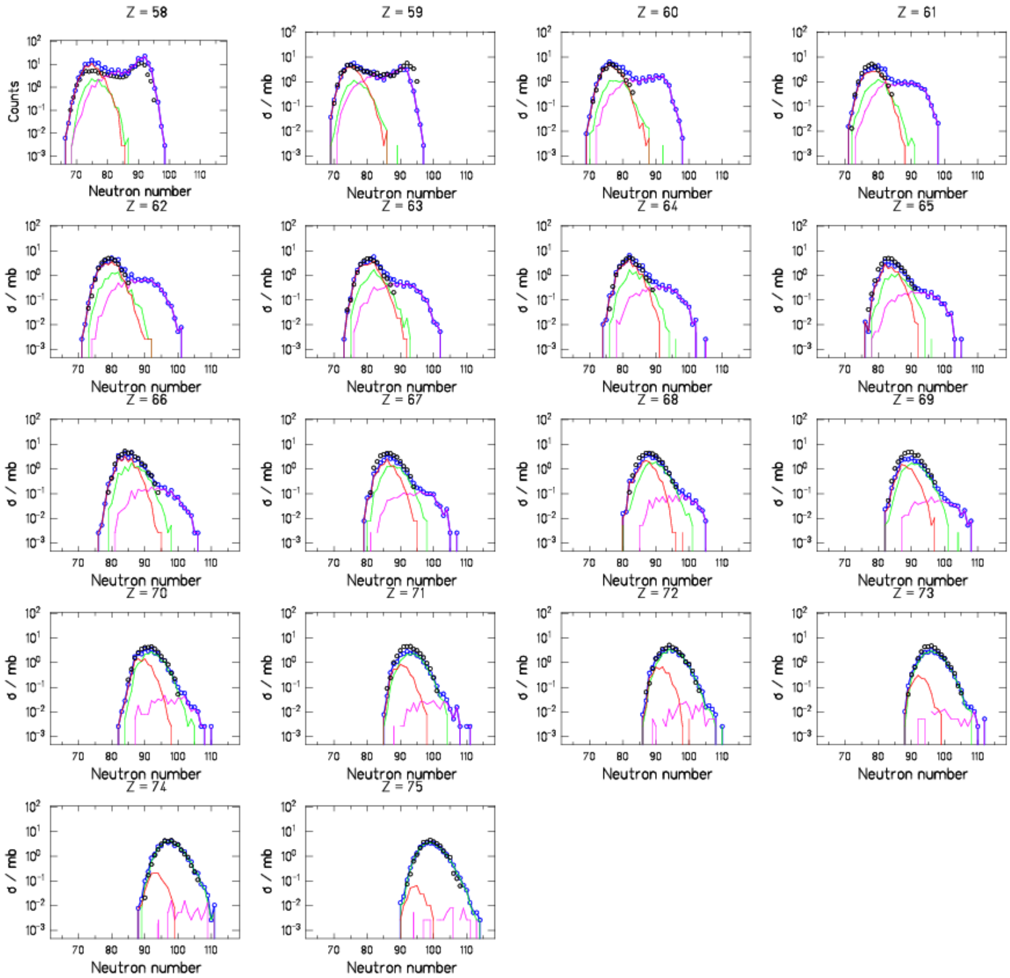


Fig. 13: Continuation.

Conclusions

In this report a benchmark of the GSI abrasion-ablation code ABRABLA07 has been presented. An overall good agreement between experimental data and ABRABLA07 predictions has been achieved for a large variety of target-projectile-energy combination. Thus, different processes through which the final resides are produced are properly described in the code. Only at low beam energies and for light projectile contributions from break-up and IMF emission are somewhat over-estimated, resulting in larger calculated cross section for residues with $Z_{resid}<Z_{proj}/3$; for heavier residues even at lower energies and for light projectiles agreement between data and calculations is very good.

References:

[1] J.-J. Gaimard, K.-H. Schmidt, Nucl. Phys. A 531 (1991) 709
[2] K.-H. Schmidt et al., Phys. Lett. B 300 (1993) 313
[3] K.-H. Schmidt et al., Nucl. Phys. A 710 (2002) 157
[4] A. Kelić et al., Proc. of Joint ICTP-IAEA Adv. Workshop on Model Codes for Spallation Reactions, ICTP Trieste, Italy, 4-8 Feb 2008. IAEA INDC(NDS)-530, p. 181, Vienna, Aug 2008