Investigation of the possibility to use ion beams for ADS through simulation in GEANT4

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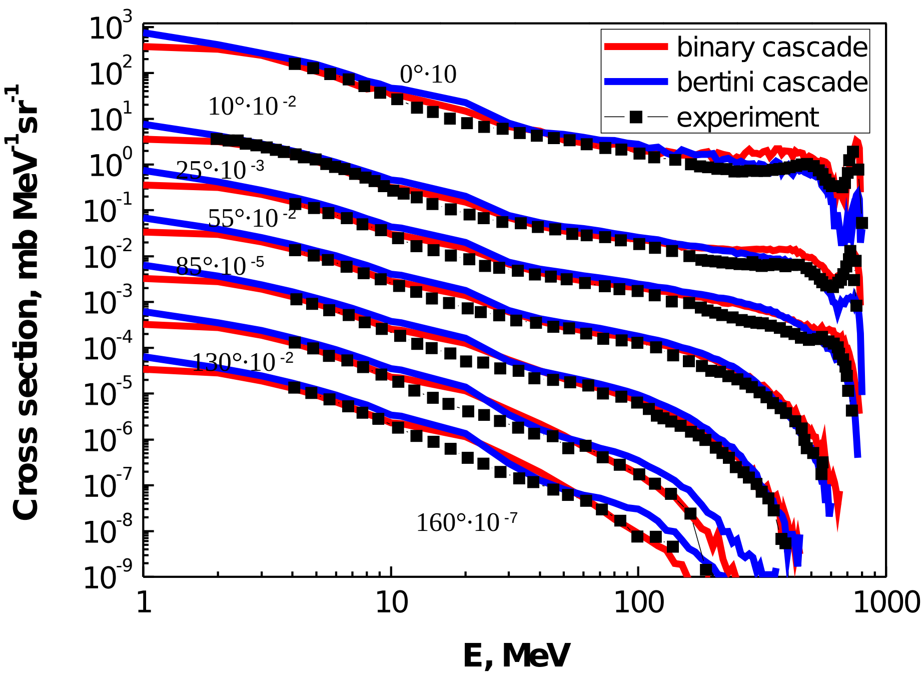
Available models and their performances

- In the range of energy 1-10 GeV two models for hadron inelastic interaction were investigated: binary cascade and bertini cascade
- Interaction of protons in thin targets



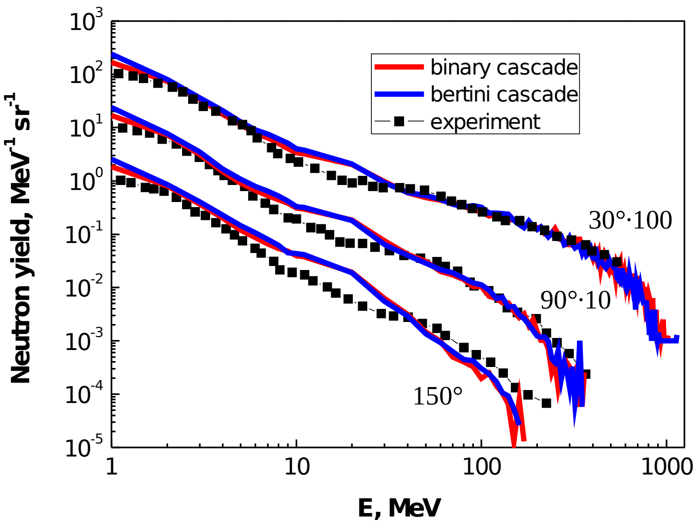
Proton 0.8 GeV in thin Pb target (experimental data from ref [1])

Neutrons with energy > 5 MeV

Ang	BC	BERT	Exp
0	$1.1{\cdot}10^{-4}$	$1.{\cdot}10^{-4}$	$8.7{\cdot}10^{-5}$
10	$2.1{\cdot}10^{-3}$	$2.{\cdot}10^{-3}$	$1.6{\cdot}10^{-3}$
25	$3.6{\cdot}10^{-3}$	$4.3{\cdot}10^{-3}$	$3.{\cdot}10^{-3}$
55	$4.9{\cdot}10^{-3}$	$6.2{\cdot}10^{-3}$	$4.5{\cdot}10^{-3}$
85	$4.5{\cdot}10^{-3}$	$5.8{\cdot}10^{-3}$	$3.9{\cdot}10^{-3}$
130	$2.8{\cdot}10^{-3}$	$3.6{\cdot}10^{-3}$	$2.5{\cdot}10^{-3}$
160	$1.2{\cdot}10^{-3}$	$1.5{\cdot}10^{-3}$	$1.1{\cdot}10^{-3}$
total	$1.9{\cdot}10^{-2}$	$2.36{\cdot}10^{-2}$	$1.68{\cdot}10^{-2}$

Proton and alpha in medium thick targets

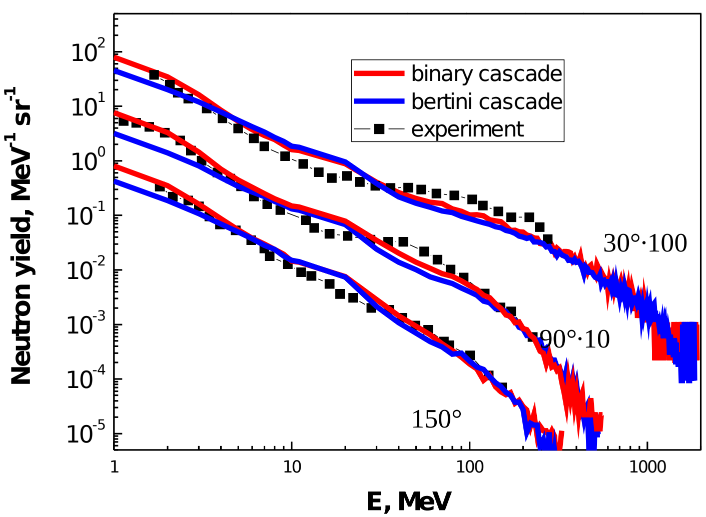
Target cylinder of Pb with diameter 20 cm and length 20 cm



Alpha 1 AGeV (experimental data from Ref. [2])

Neutrons with energy > 2 MeV

Ang	BC	Bert	Exp
30	0.146	0.156	0.131
90	0.215	0.231	0.177
150	0.114	0.124	0.081
Total	0.476	0.511	0.39



Proton 2.55 GeV (experimental data from Ref. [2])

Neutrons with energy > 2 MeV

Ang	BC	Bert	Exp
30	$6.57\cdot10^{-2}$	$5.36\cdot10^{-2}$	$5.76\cdot10^{-2}$
90	$9.99\cdot10^{-2}$	$6.23\cdot10^{-2}$	$9.37\cdot10^{-2}$
150	$5.04\cdot10^{-2}$	$3.64\cdot10^{-2}$	$4.23\cdot10^{-2}$
Total	0.216	0.152	0.193

Very thick targets

Cylinder of Pb with diameter 20 cm and length 60 cm

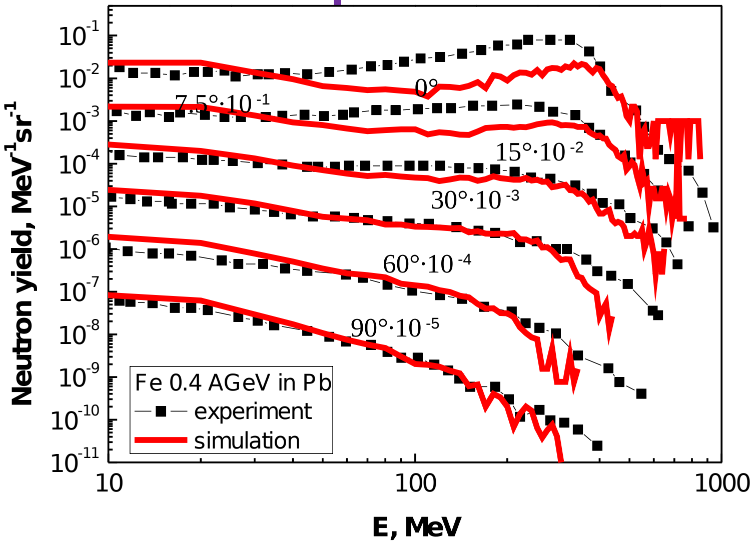
(experimental data from [2])

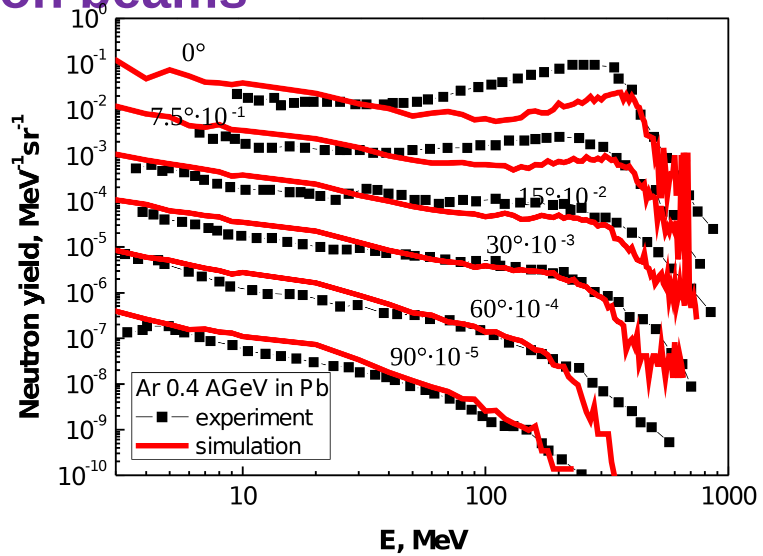
Ep, GeV	Ntotal			E>20MeV		
	exp	bc	bert	exp	bc	bert
1	24.1±2.9	21.2	26.7	2.1±0.4	1.3	1.4
2.55	63.5±7.6	44.6	64.5	5.8±1.0	3.38	4.2
3.65	80.6±9.7	57.6	87.1	8.5±1.5	4.5	6.1

In thin and medium thick targets both models give predictions close to the experimental data.

In very thick targets binary cascade model underestimates the neutron yield, and the underestimation is accentuated with the increase in energy.

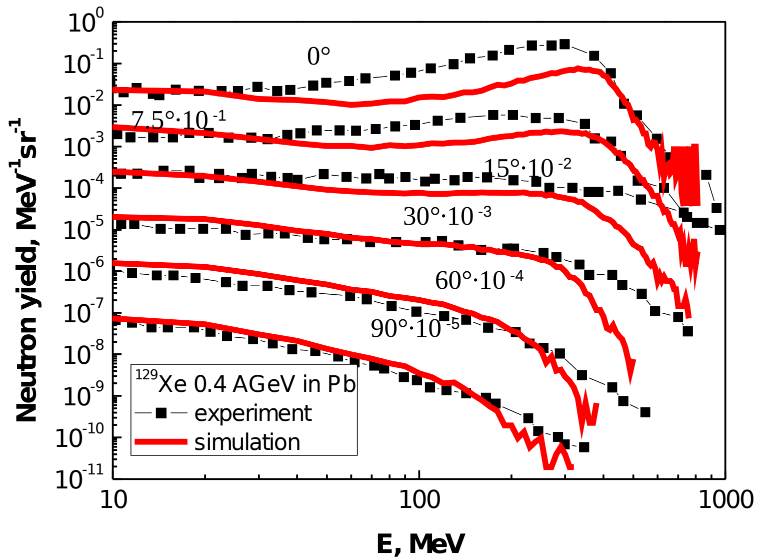
Neutron production with ion beams





Neutrons with energy > 5 MeV

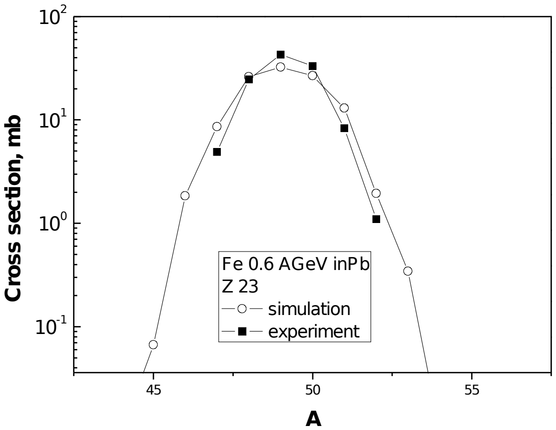
Ion	Exp	Sim
Ar	0.37	0.30
Fe	0.34	0.27
Xe	0.55	0.47

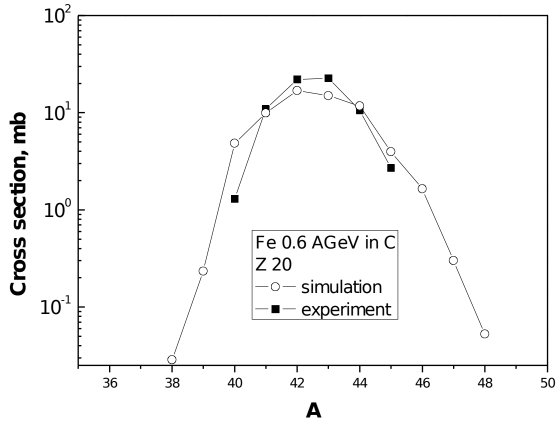


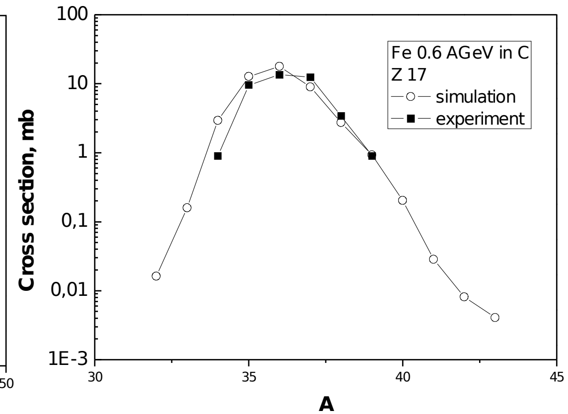
Experimental data from [3,4]

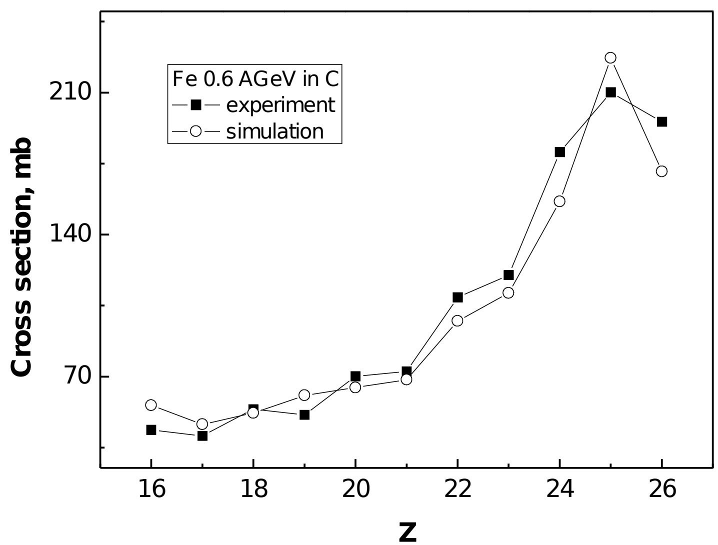
Nuclear fragmentation - spallation and fission reactions

Fragmentation of ^{56}Fe 0.6 AGeV in Pb (experimetal data from [5])

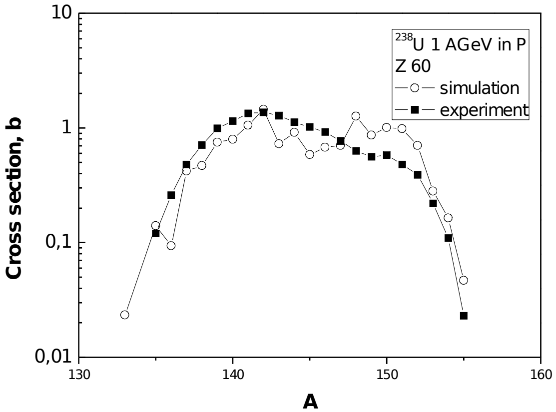


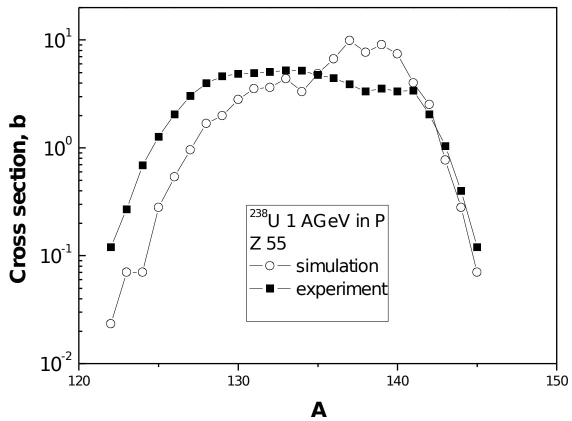


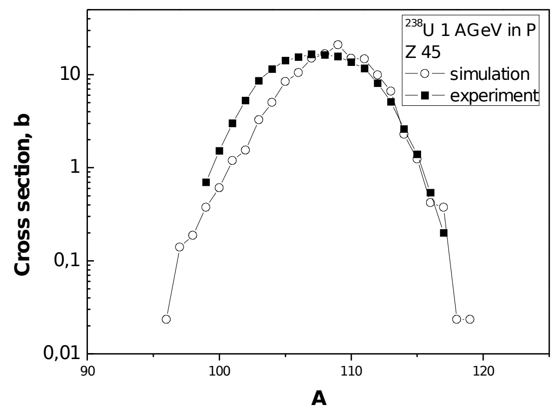


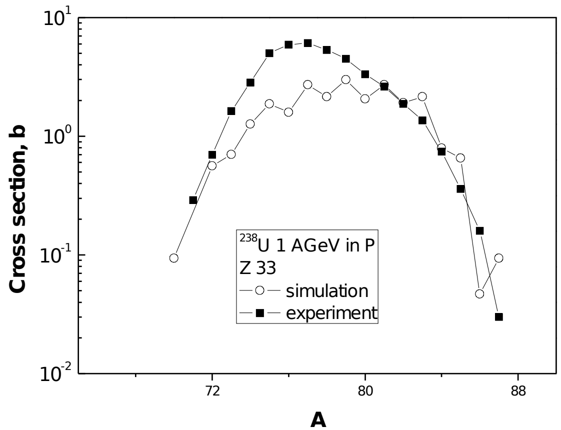


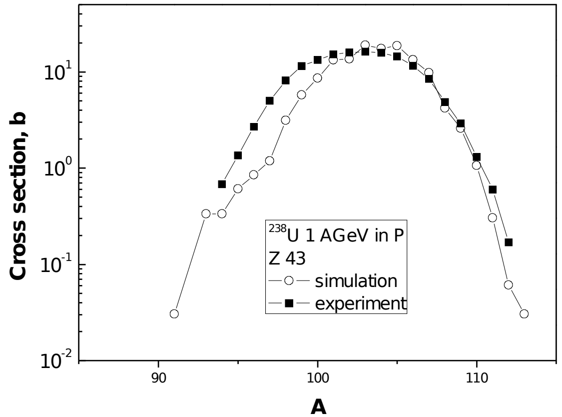
Fragmentation of ^{238}U 1 AGeV in H target (experimetal data from [6])

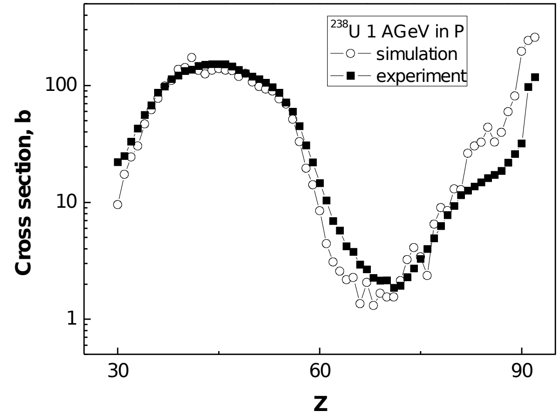




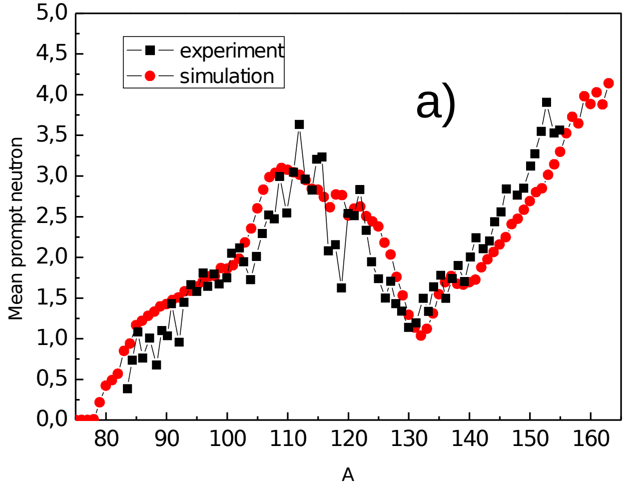


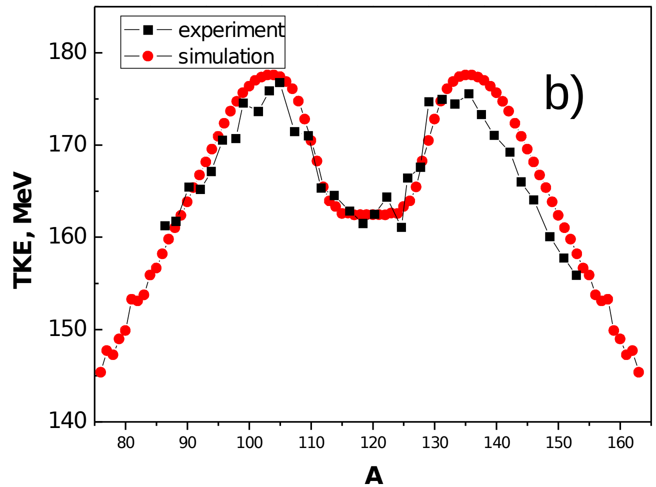


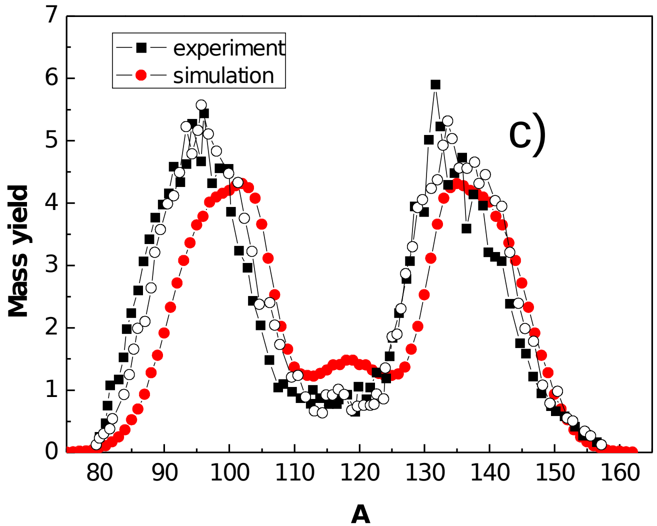




Fission model for neutrons with energy below 20 MeV

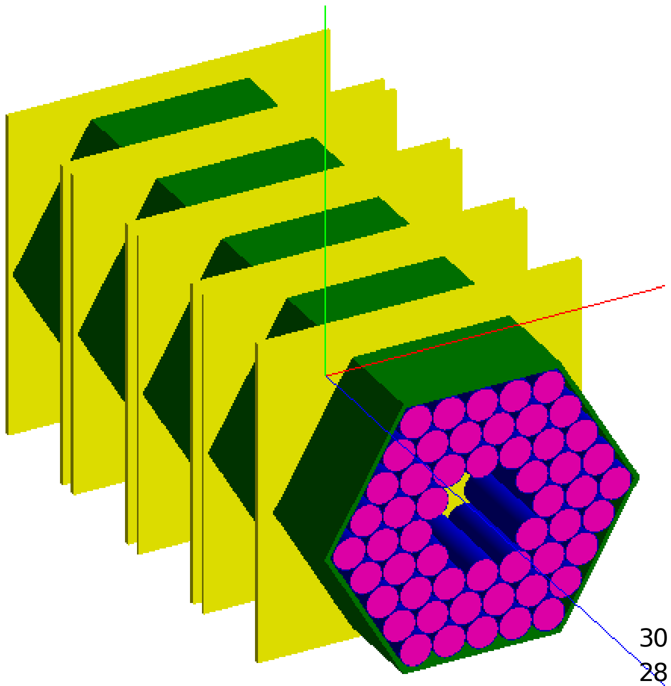


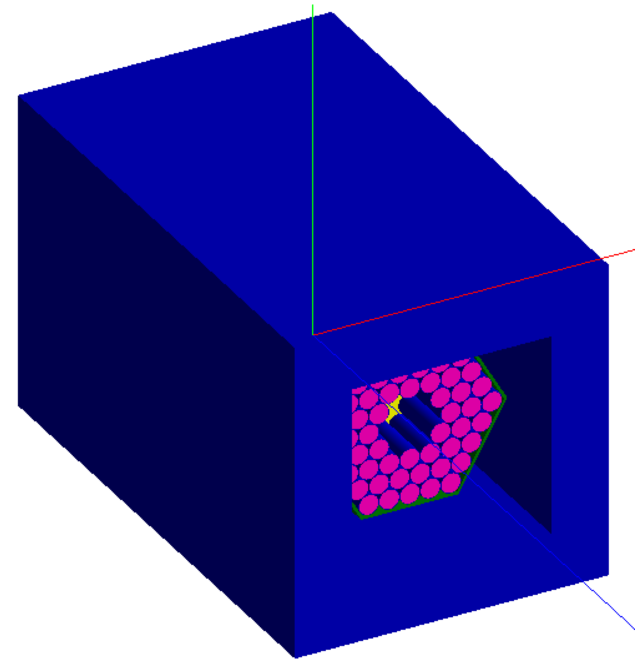




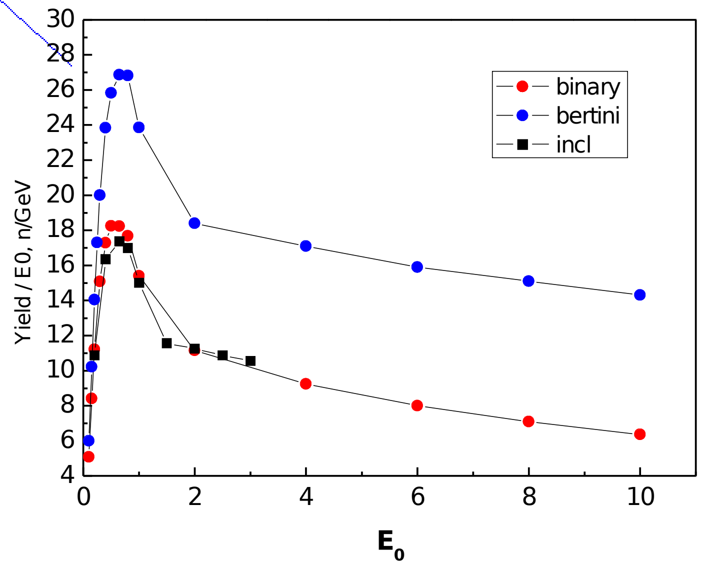
The dependence of the number of prompt neutrons on the fragment mass(a), the dependence of the total kinetic energy of the fragments on the fragment mass (b) and the mass distribution of the fragments (c) from the fission of ^{238}U with 14.5 MeV neutrons (experimetal data from [7]).

Simulation with “Quinta” setup





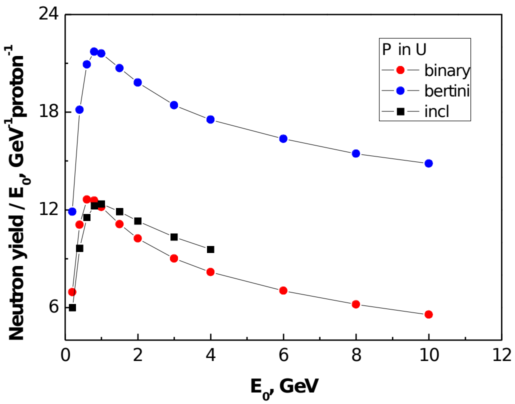
Neutron yield relative to the initial energy per nucleon of the deuteron beam

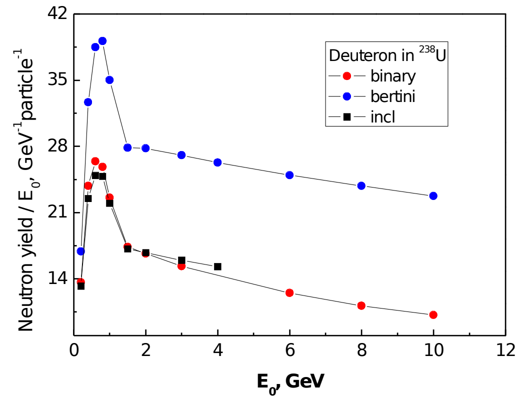


Verification of the influence of the geometry

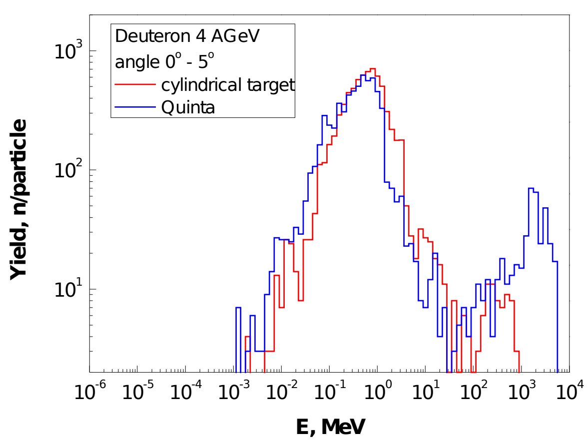
Cylindrical uranium target with radius 10 cm and length 52 cm

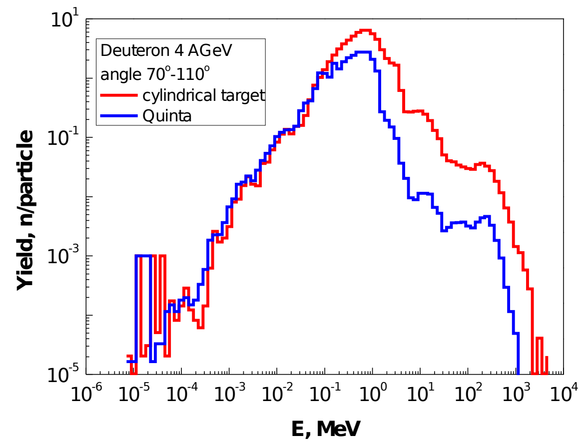
The dependence of the neutron yield on the energy per nucleon of the particle





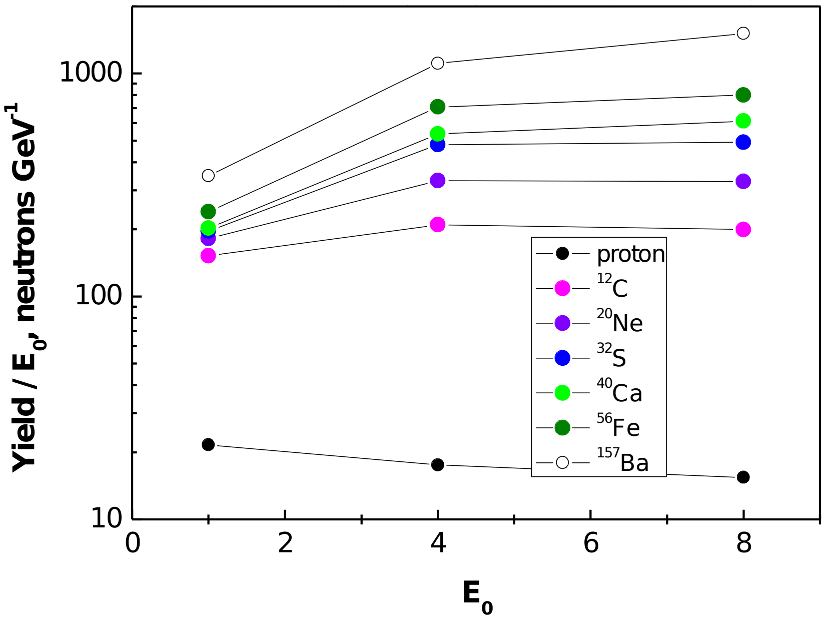
The geometry influence on the neutron spectra





Simulations with ions in uranium target

Ions with masses until ^{157}Ba and three energies: 1, 4 and 8 AGeV



The neutron yield reported to the initial energy per nucleon increases with the energy for ions.

Massive uranium target

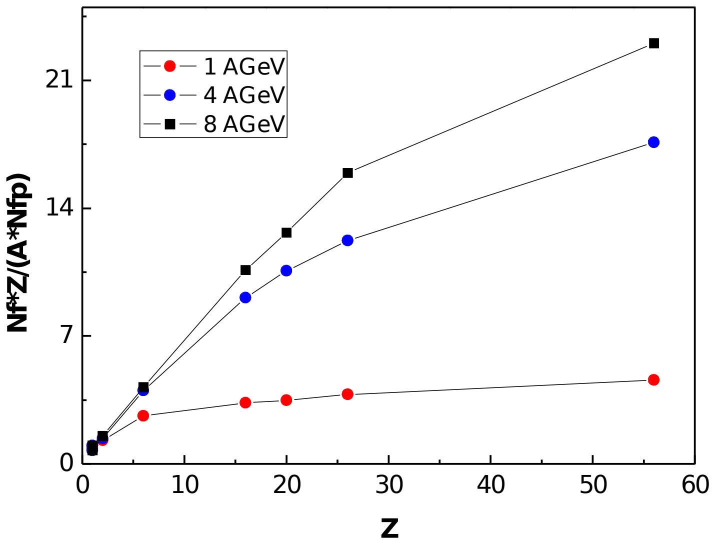
Uranium target with radius 20 cm and 200 cm length
The energy deposited, the number and the spatial distribution of the fission acts were registered

Particle	***1 AGeV***		***4 AGeV***		***8 AGeV***	
	Nfis	Edep [MeV]	Nfis	Edep [MeV]	Nfis	Edep [MeV]
proton	11.75	$2.652 \cdot 10^3$	40.68	$9.701 \cdot 10^3$	75.56	$1.841 \cdot 10^4$
deuteron	18.82	$4.475 \cdot 10^3$	59.37	$1.487 \cdot 10^4$	113.28	$2.966 \cdot 10^4$
alpha	28.74	$8.352 \cdot 10^3$	113.17	$3.305 \cdot 10^4$	231.34	$6.449 \cdot 10^4$

Particle	***1 AGeV***		***4 AGeV***		***8 AGeV***	
	Nfis	Edep [Mev]	Nfis	Edep [Mev]	Nfis	Edep [Mev]
^{12}C	58.64	$2.263 \cdot 10^4$	326.93	$1.112 \cdot 10^5$	634.19	$2.457 \cdot 10^5$
^{32}S	74.72	$4.978 \cdot 10^4$	739.73	$2.829 \cdot 10^5$	1403.76	$6.537 \cdot 10^5$
^{40}Ca	77.73	$6.021 \cdot 10^4$	859.61	$3.451 \cdot 10^5$	1914.18	$8.052 \cdot 10^5$
^{56}Fe	91.58	$8.204 \cdot 10^4$	1071.16	$4.649 \cdot 10^5$	2592.46	$1.117 \cdot 10^6$
^{137}Ba	125.5	$1.878 \cdot 10^5$	1751.95	$1.031 \cdot 10^6$	4257.23	$2.505 \cdot 10^6$

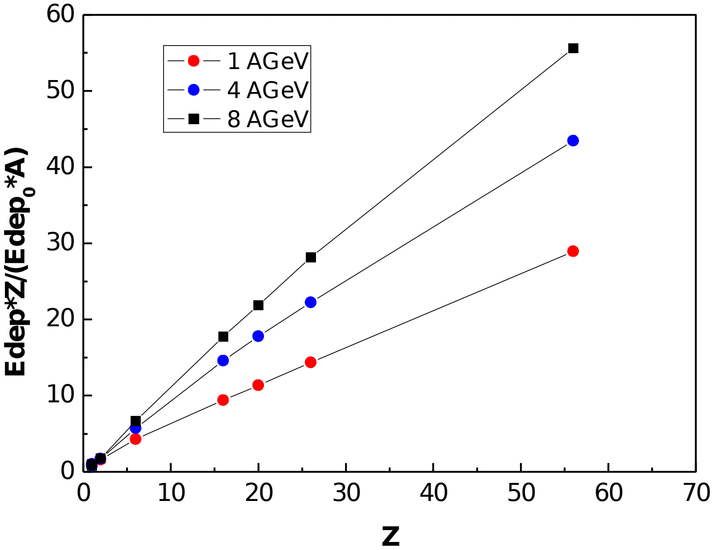
The ratio between the total number of fission acts and the energy consumed for the acceleration of the charged particles (proportional with A/Z) and reported to the number of fissions obtained with protons with the same energy on nucleon rises with the mass of the projectile.

The same is for the energy deposited.



The number of fission acts

Energy deposited



Conclusions

1. In thin and medium thick targets binary cascade and bertini models produce similar results with respect to the neutron production in the interaction of hadrons with targets.
2. In very thick targets binary cascade underestimate the yield of secondary neutrons with about 40 %.

3.The ratio between the neutron yield and the initial energy on nucleon decreases with the rise of the energy for protons and deuteron, but increase in the case of ions . The rise is faster for energies between 1 and 4 AGeV, and slower for energies from 4 to 8 AGeV.

4.The ratio between the total number of fission acts (respective the energy deposited in the target) and the energy spent to accelerate the particle compared with the ratio for protons with the same energy per nucleon rise with the ion mass, faster for ions until the region of Ca and Fe, and continues to rise slowly until Ba. This behavior suggests a possible optimum for the use of ions in ADS in the region around Fe.

References

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