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Determination and Monte Carlo Simulations of Neutron Flux Inside Spallation Target QUINTA

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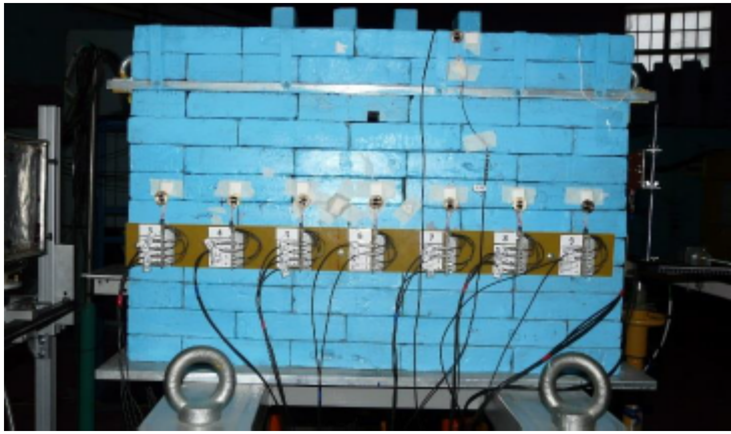
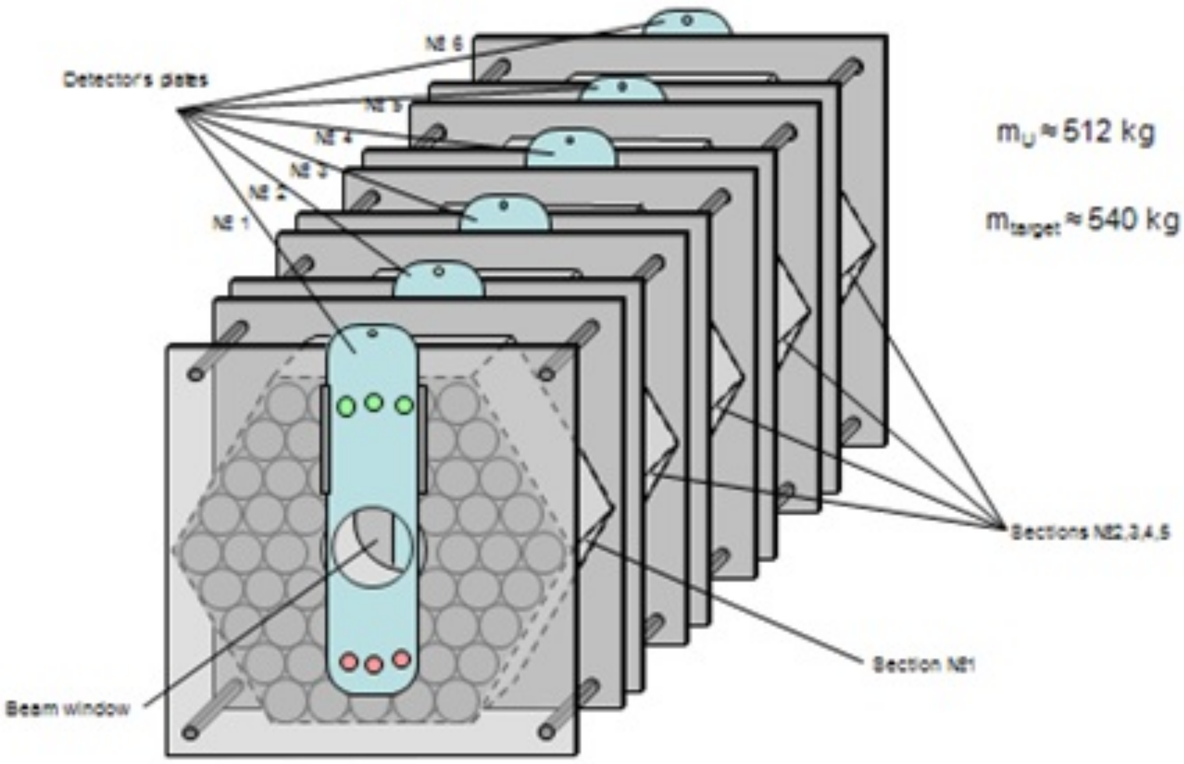
Subcritical setup QUINTA

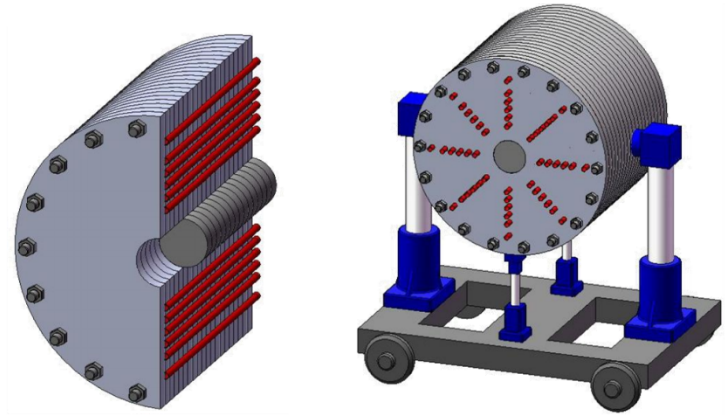
- Accelerator Driven Systems research
- Testing of quality of simulation programs
- The QUINTA dimensions are 700 x 350 x 350 mm and the weight is about 540 kg
- 5 sections (composed of natural uranium rods)
- 6 aluminium plates (holders) for placement of activation samples
- Irradiation by relativistic proton or deuteron beams from Phasotron or Nuclotron accelerators
- Production of huge neutron field inside the setup by spallation and fission reactions
- Neutron flux is measured by activation detectors and evaluated by activation techniques

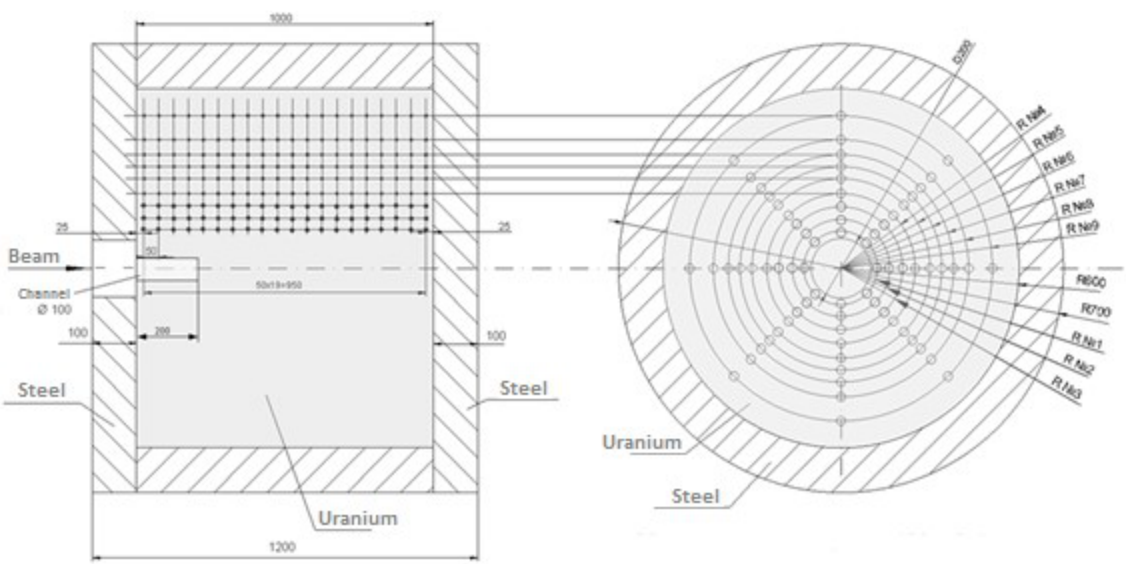




Subcritical setup BURAN

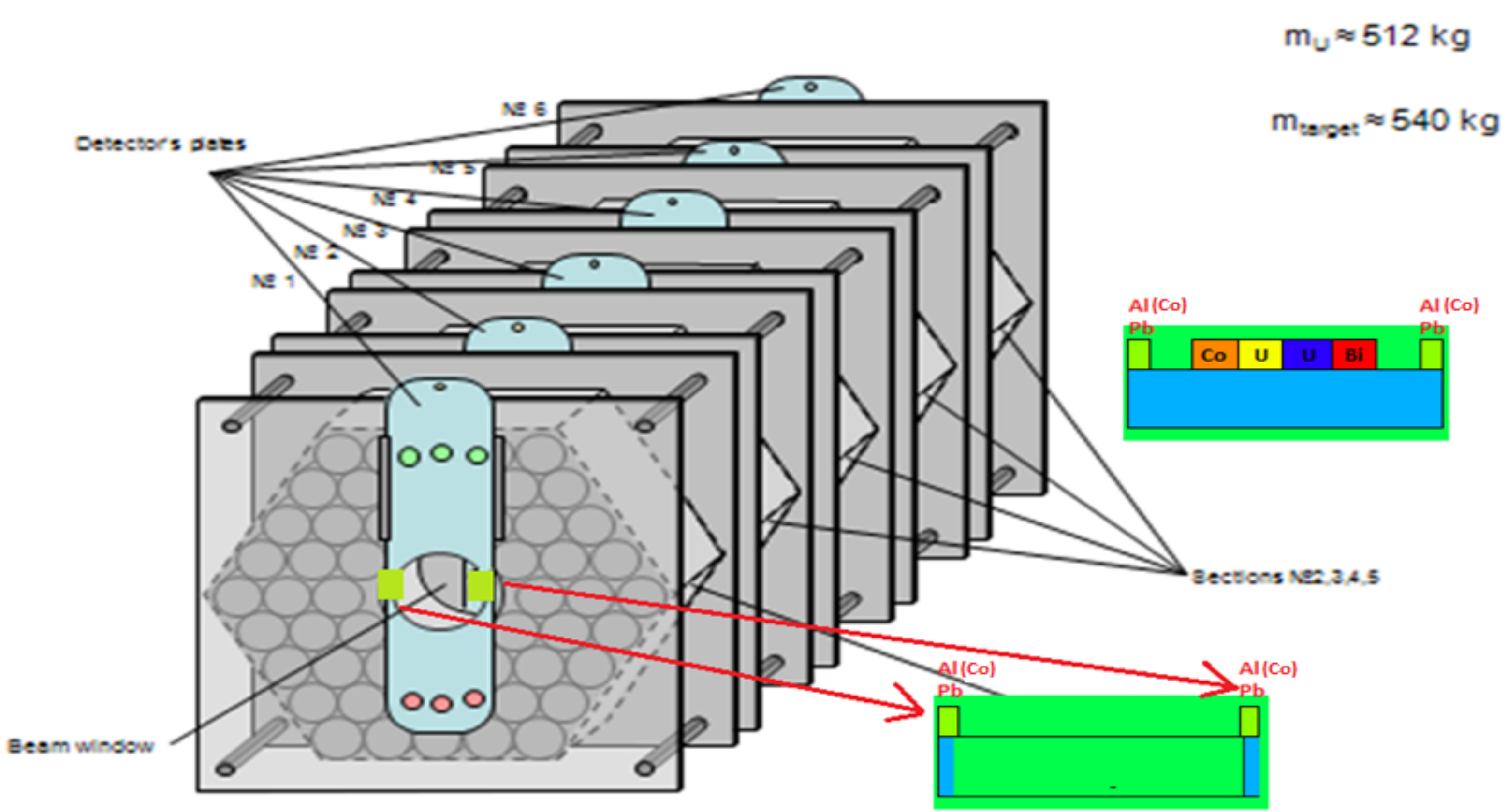
- Experiments with a new subcritical setup called BURAN should start soon in the Joint Institute for Nuclear Research
- Basic part of the Buran setup is a huge cylinder made from 20 tons of depleted uranium (0.3 % 235U) with longitudinal distance of 1000 mm and 1200 mm in diameter
- The cylinder is surrounded by 100 mm steel covering
- In the blanket there are 72 channels for placement of samples
- BURAN is considered as quasi-infinite target with almost no neutron leakage (neutron leakage from QUINTA is more than 80 %)





Positions of aluminiun and lead detectors

- Irradiation by 4GeV and 8GeV deuteron beam on Nuclotron in November 2013 and December 2013 and by 660MeV proton beam on Phasotron in November 2015
- Marking of aluminium plates: the first one = 0, the last one = 5
- Aluminium, cobalt and lead activation samples placed on x-axis edges of each aluminium plate
- Reaction rates of Na-24, Co-57, Co-58, Bi-205 and Bi-206 were investigated (evaluated by neutron activation techniques) and compared to Monte Carlo simulations
- Reaction rate = total number of nuclei created in an activation sample normalised to one source particle and one atom of the sample
- It is expected that reactions on aluminium and cobalt samples provide us with an information about sum of neutron +proton+deuteron flux $^{27}Al(n,\alpha)^{24}Na$ $^{27}Al(p,n3p)^{24}Na$ $^{27}Al(d,2n3p)^{24}Na$, $^{59}Co(n,3n)^{57}Co$, $^{59}Co(p,p2n)^{57}Co$, $^{59}Co(d,p3n)^{57}Co$
- Reactions on lead samples -> proton+deuteron flux $^{nat}Pb(p,x)^{206}Bi$ $^{nat}Pb(d,x)^{206}Bi$



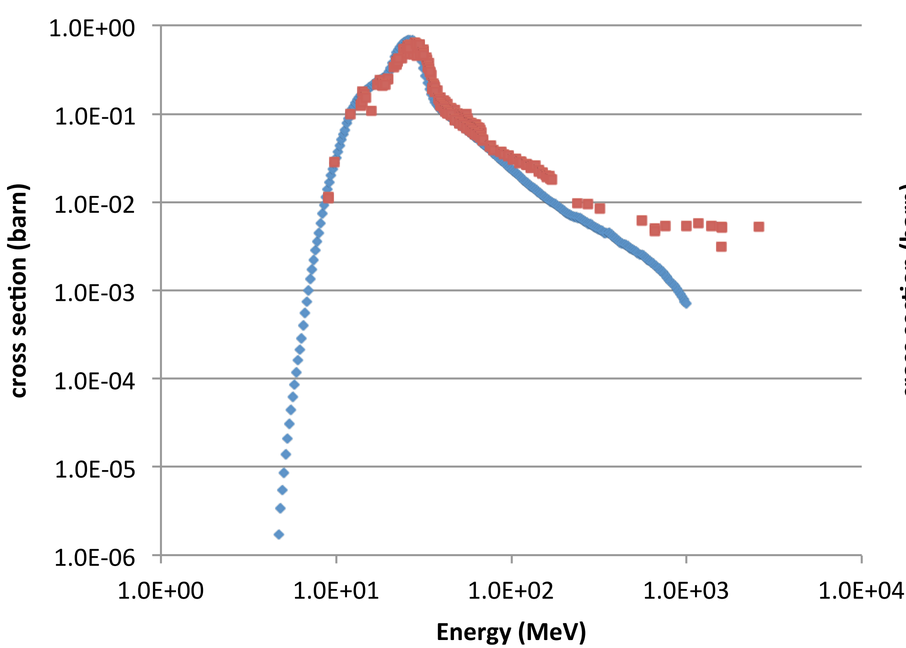
Simulations

- Simulations were performed in Monte Carlo code MCNPX 2.7 (physical models used INCL4+ABLA)
- Flux of neutrons, protons and deuterons were simulated
- Cross sections of Na-24, Co-57, Co-58, Bi-205 and Bi-206 production were calculated in TALYS 1.6
- Reaction rates were calculated by convolution of the simulated flux and the calculated cross sections

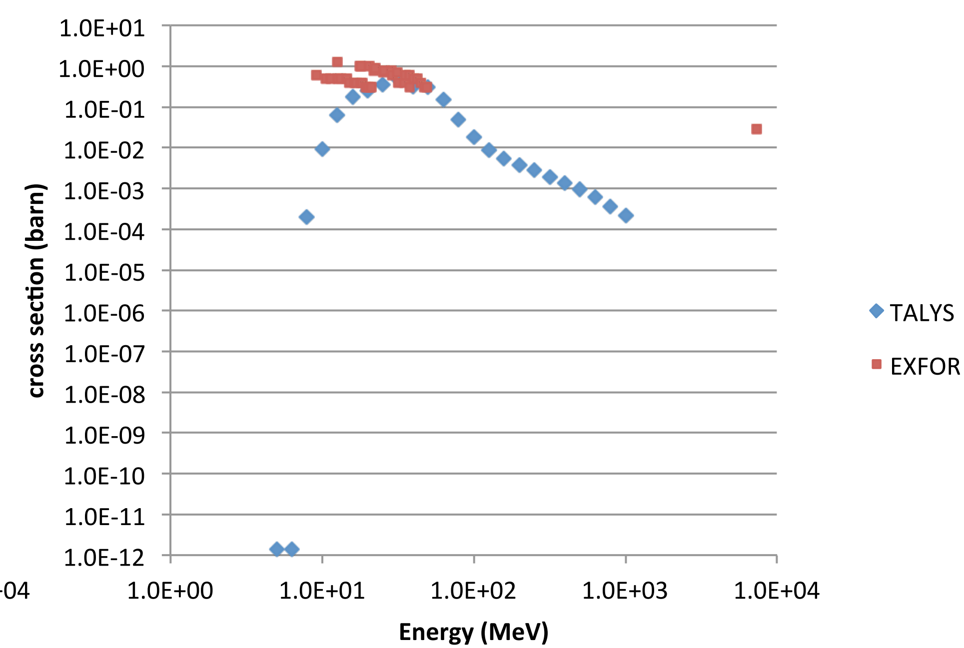
Cross sections

- Comparison of cross sections calculated by TALYS 1.6 with data from cross section database EXFOR
- Good agreement for reactions with protons

cross section $^{nat}Pb(p,x)^{206}Bi$



cross section $^{nat}Pb(d,x)^{206}Bi$

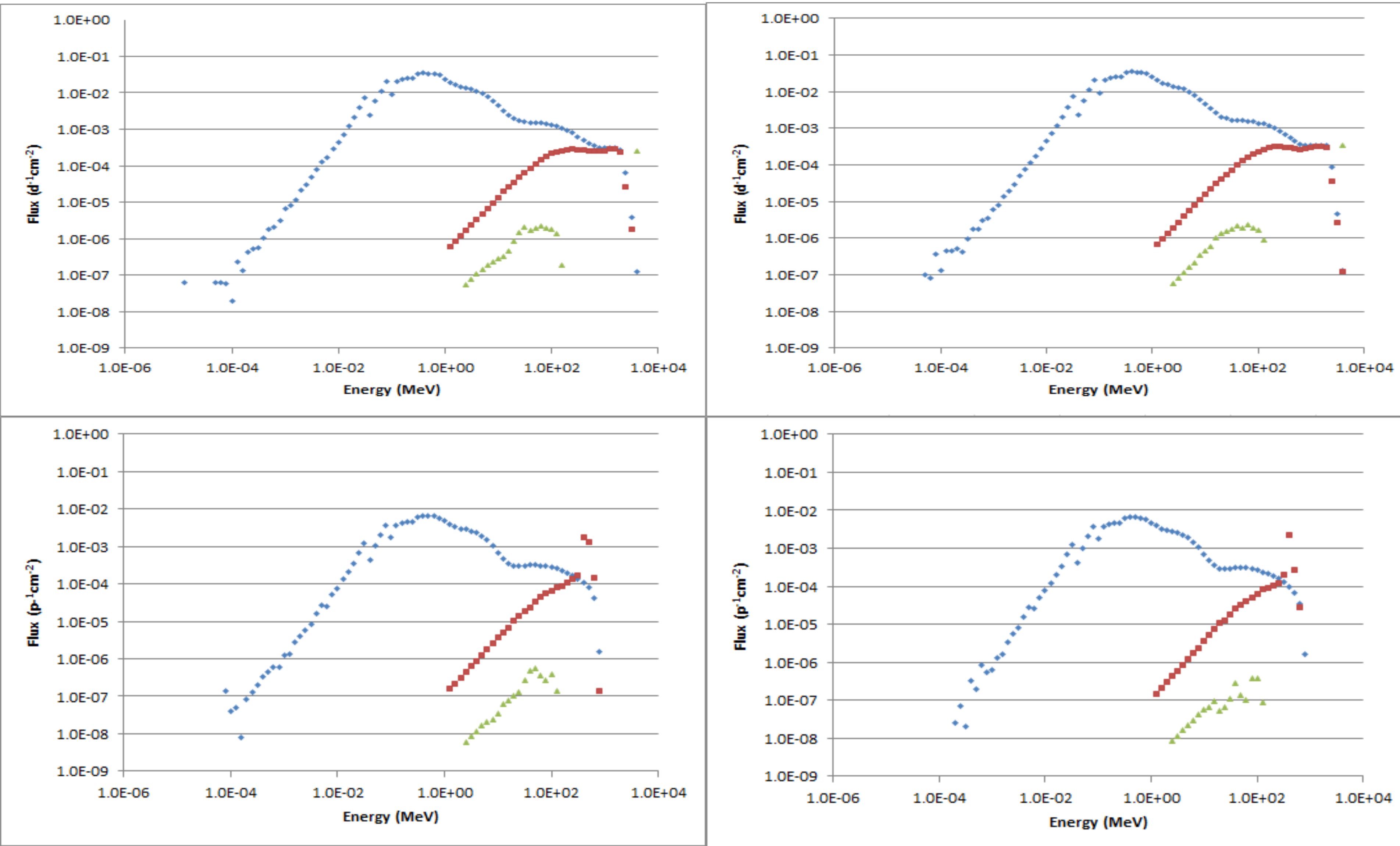


Simulations of neutron(blue line), proton(red) and deuteron(green) fluxes on 2nd Al-plate (upper figures for d4GeV, lower for p660MeV)

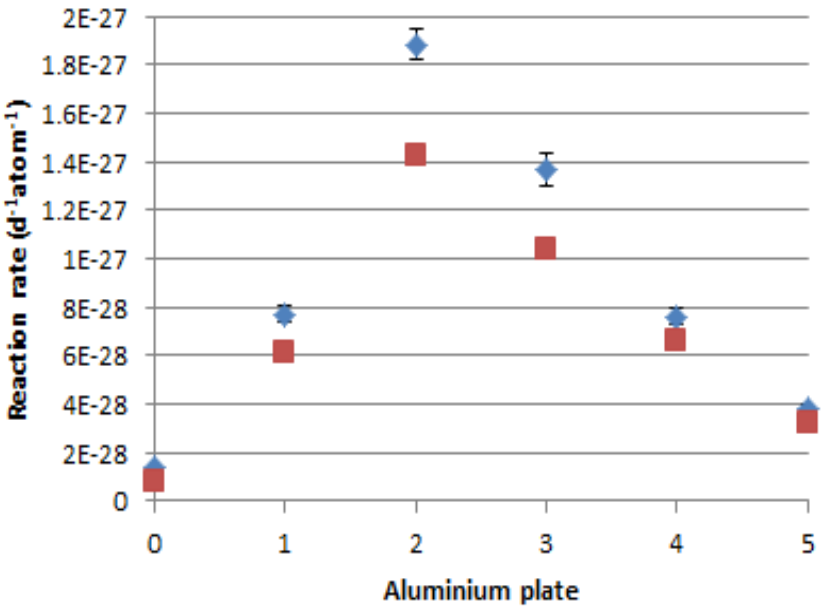
Figures on the left = left side of Quinta

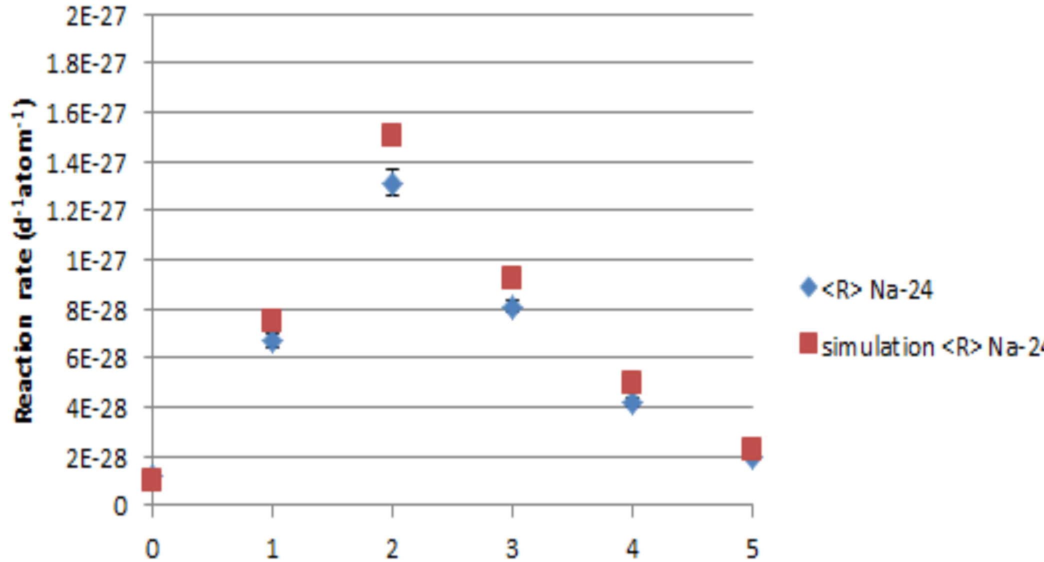
Figures on the right = right side of Quinta

- Values on the left and right side are supposed to slightly differ because of incident beam inclination (about 2 degrees)

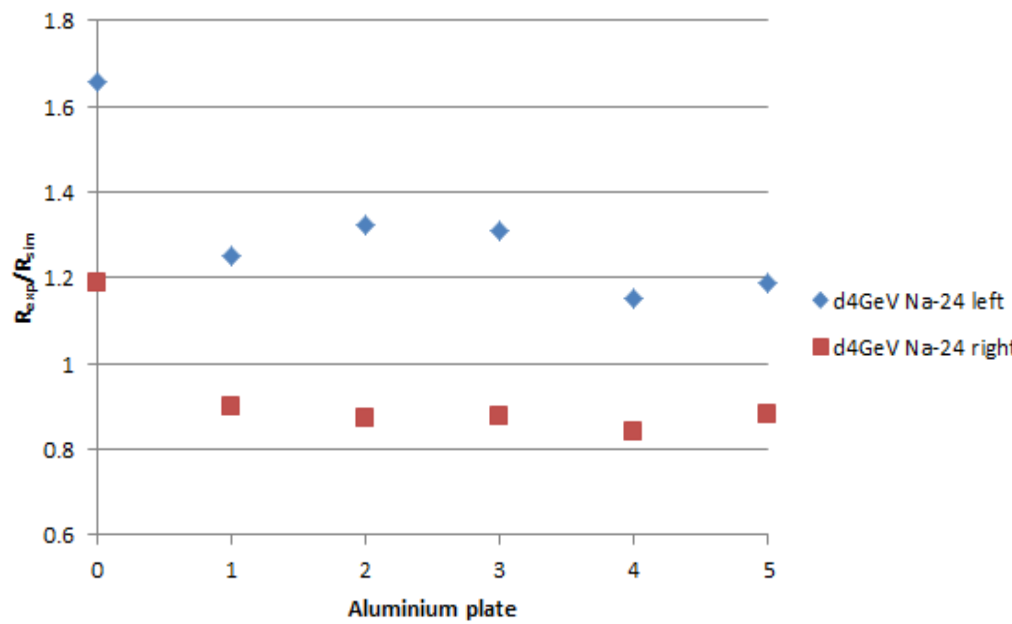


Reaction rates of Na-24
November 2013, 4GeV deuteron



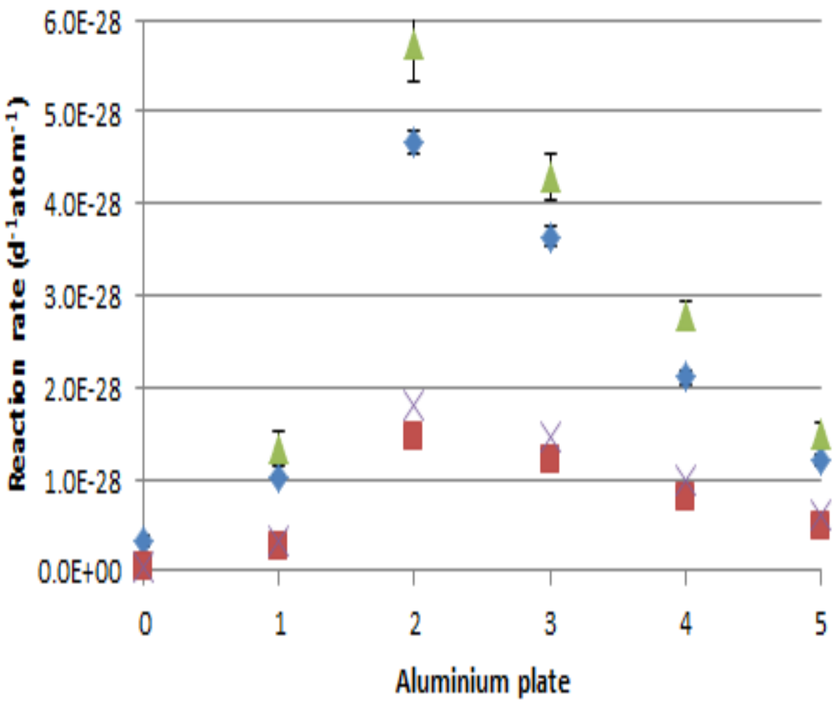


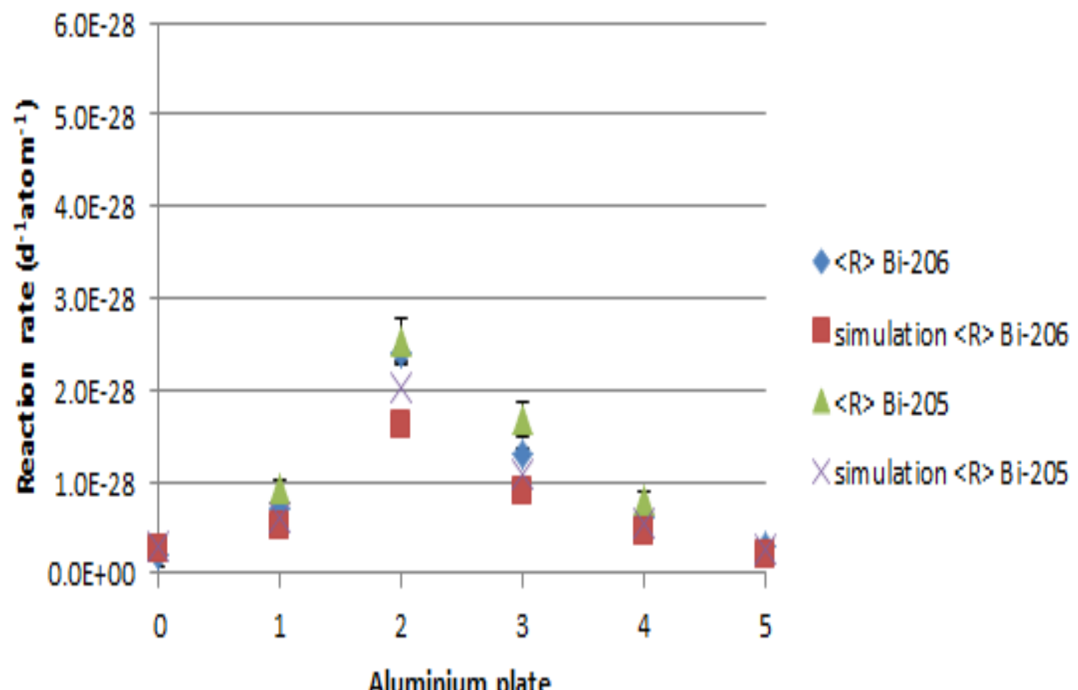
- Statistical uncertainties of experimental reaction rates visible in the graphs
- Experiment – greater values of reaction rates on left side
- Simulated reaction rates of Na-24 = neutrons+protons+deuterons
- Dominant contribution from neutrons (for protons < 5%, for deuterons < 0.1%)
- Good agreement of experiment and simulation



Reaction rates of Bi-206 and Bi-205 November 2013, 4GeV deuteron

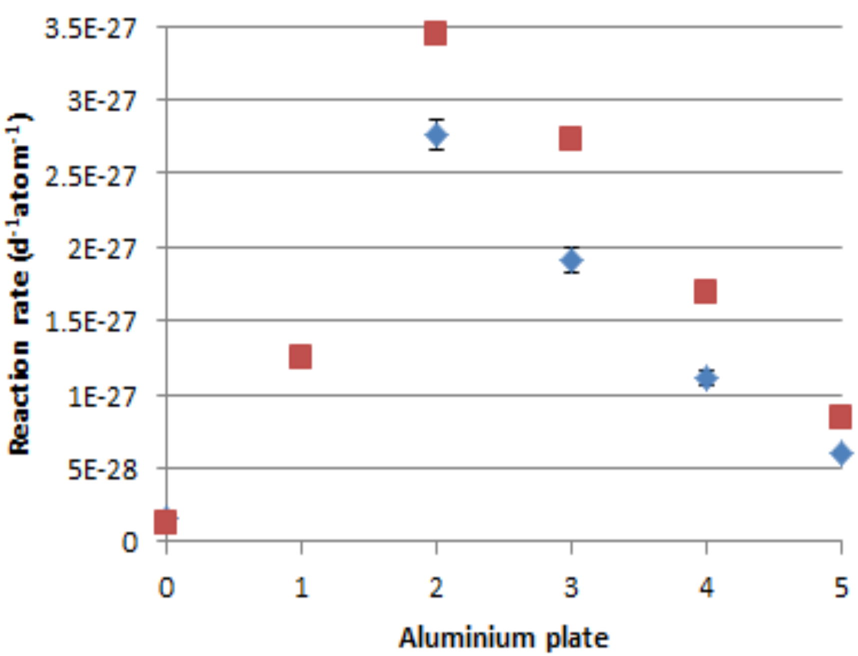
- Simulated reaction rates are underestimated compared to experimental reaction rates on the left side
- The biggest discrepancy is on aluminium plate 2 where the greatest particle flux was reached
- The discrepancy decreases with decreasing flux
- Contributions to reaction rates from deuterons were usually < 5%

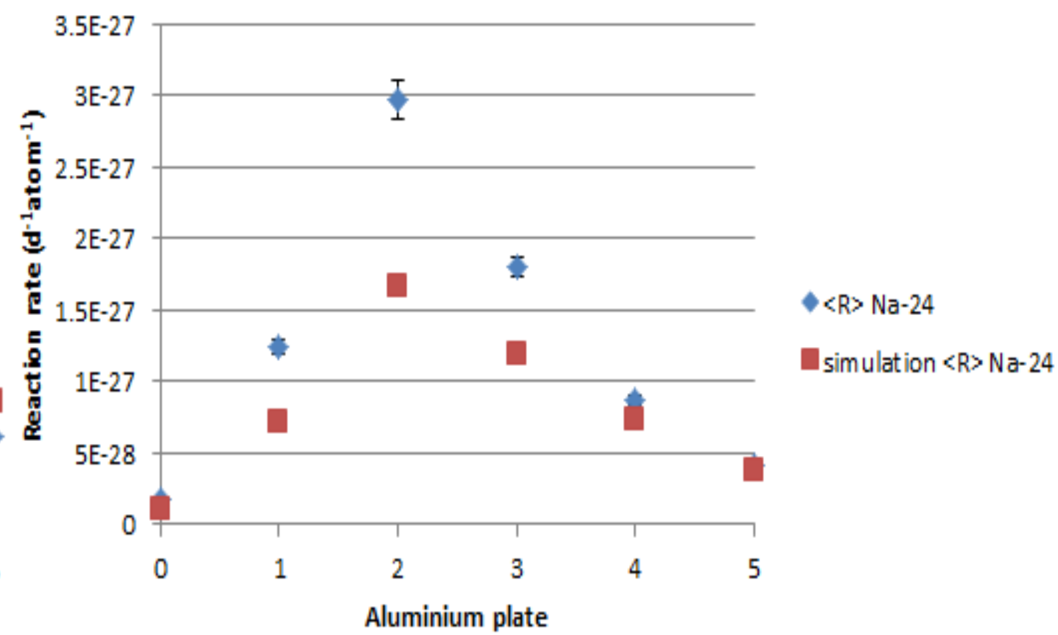




Reaction rates of Na-24 December 2013, 8GeV deuteron

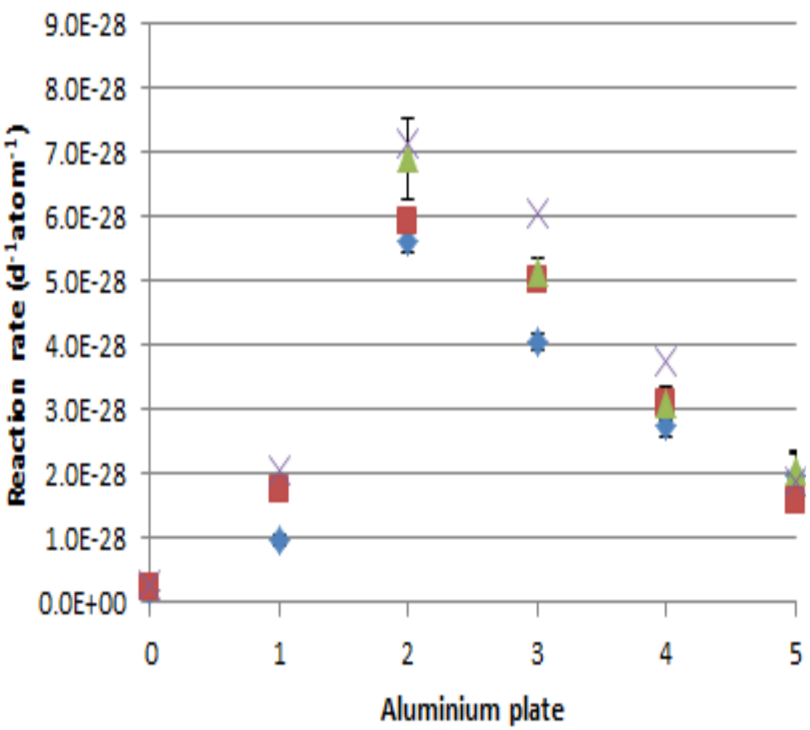
- Simulation does not fit conveniently the experiment – greater values on the left side
- The discrepancies on the left side does not seem to have the decreasing tendency with decreasing flux (aluminium plates 2, 3, 4) opposite to the right side
- Contributions to simulated reaction rates from protons and deuterons were similar to the 4GeV deuteron experiment

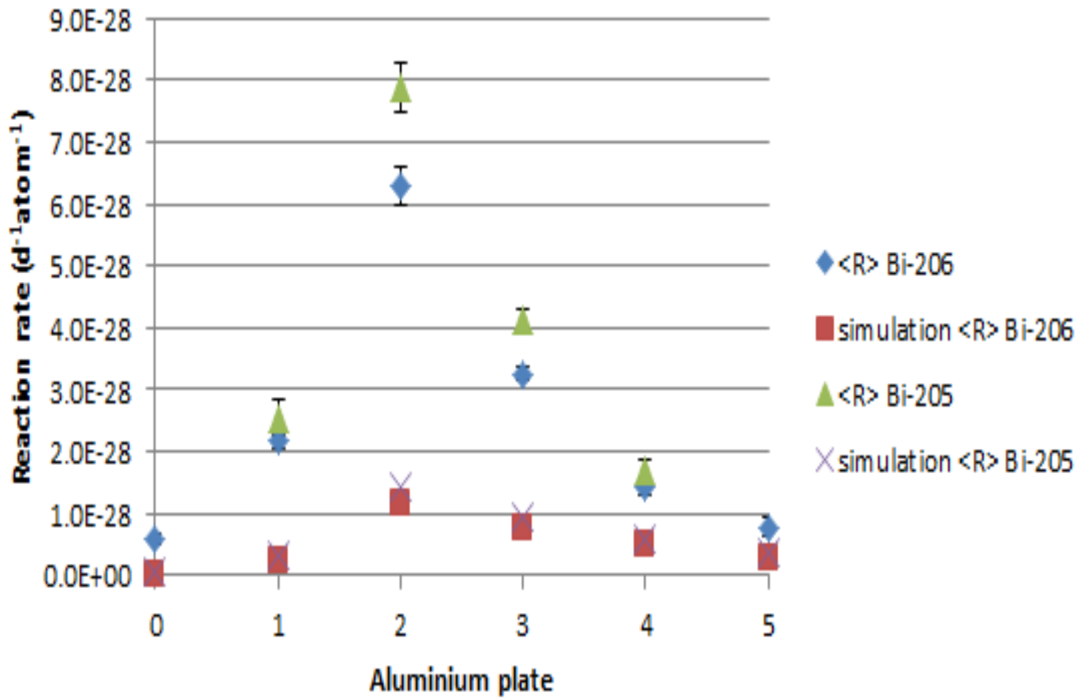




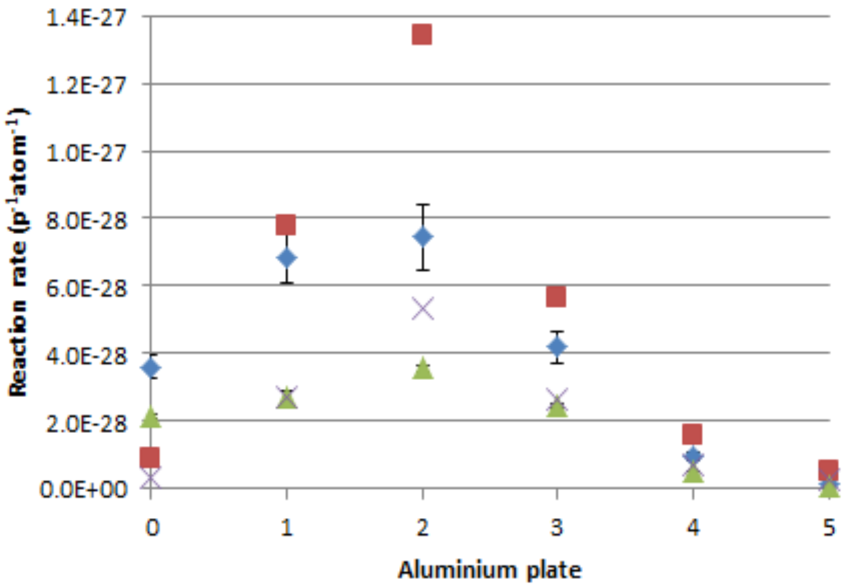
Reaction rates of Bi-206 and Bi-205 December 2013, 8GeV deuteron

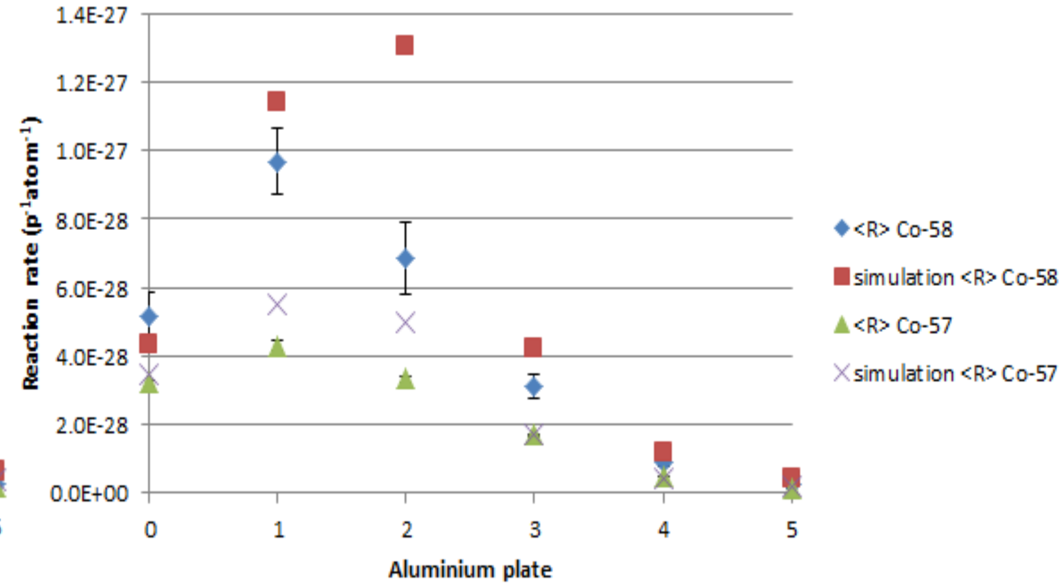
- Good agreement between experimental and simulated values on the left side
- Contributions to simulated reaction rates from deuterons were similar to the 4GeV deuteron experiment



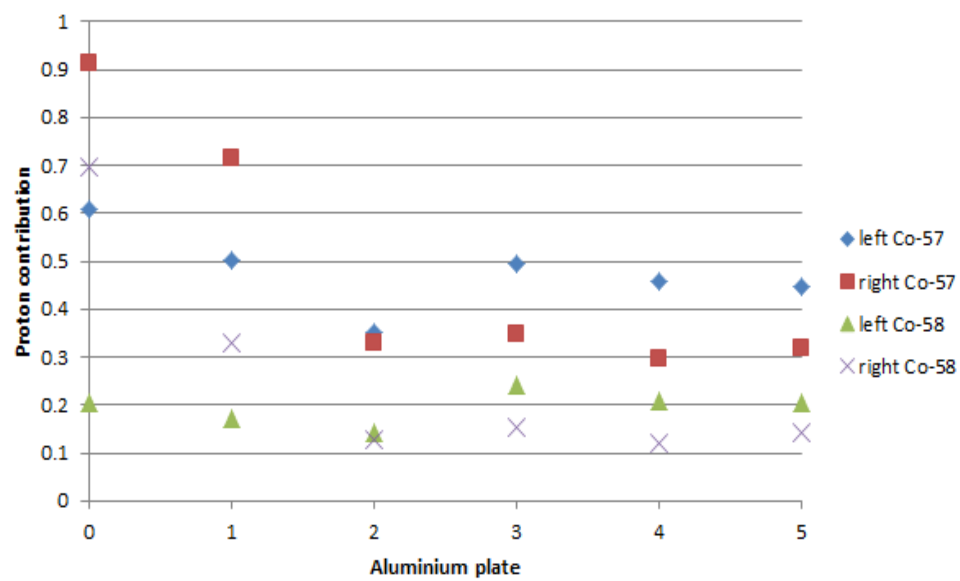


Reaction rates of Co-58 and Co-57 November 2015, 660MeV proton



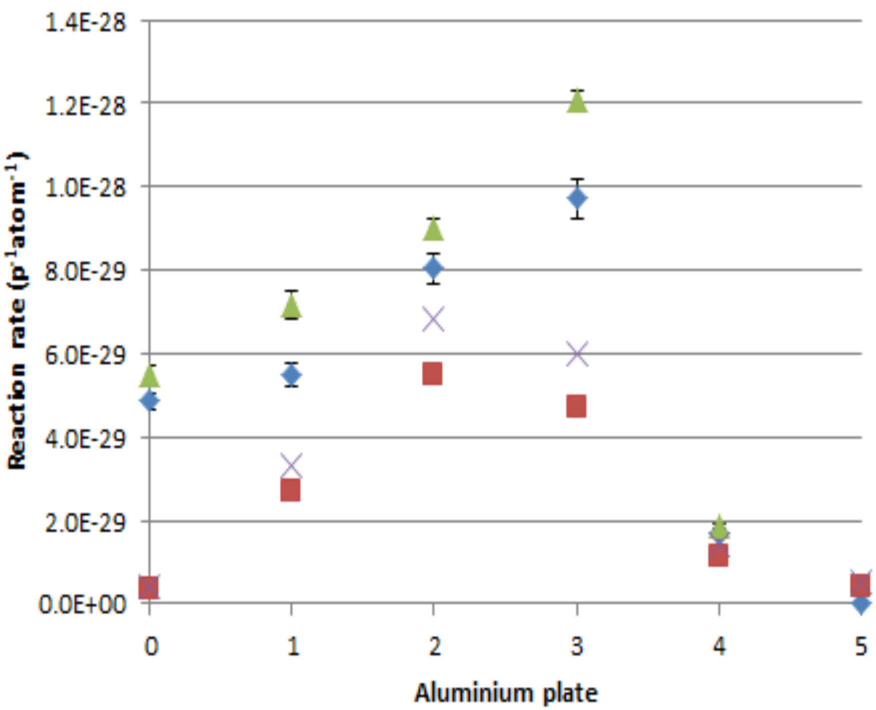


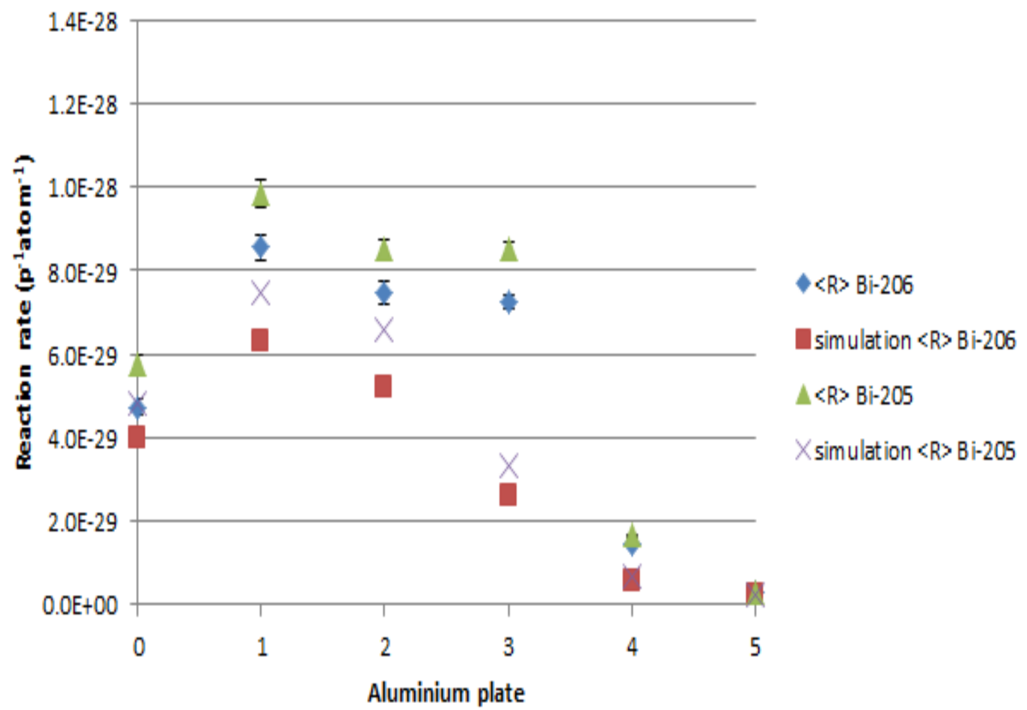
- The agreement between experiment and simulations is sufficient except for values on the 2nd alunimium plate for Co-58 production where the disagreement is a little over 50%
- Contribution to reaction rates of Co-57 and Co-58 production from reactions with protons are high compared to the proton contributions to Na-24 reaction rates at Nuclotron experiments (< 5%)
- Deuteron contributions are not more than 0.2%



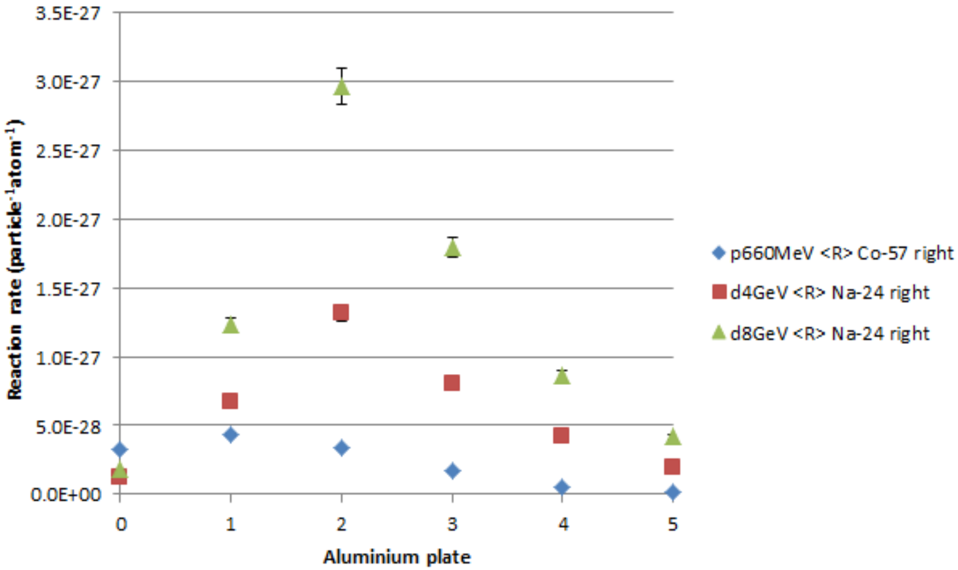
Reaction rates of Bi-206 and Bi-205 November 2015, 660MeV proton

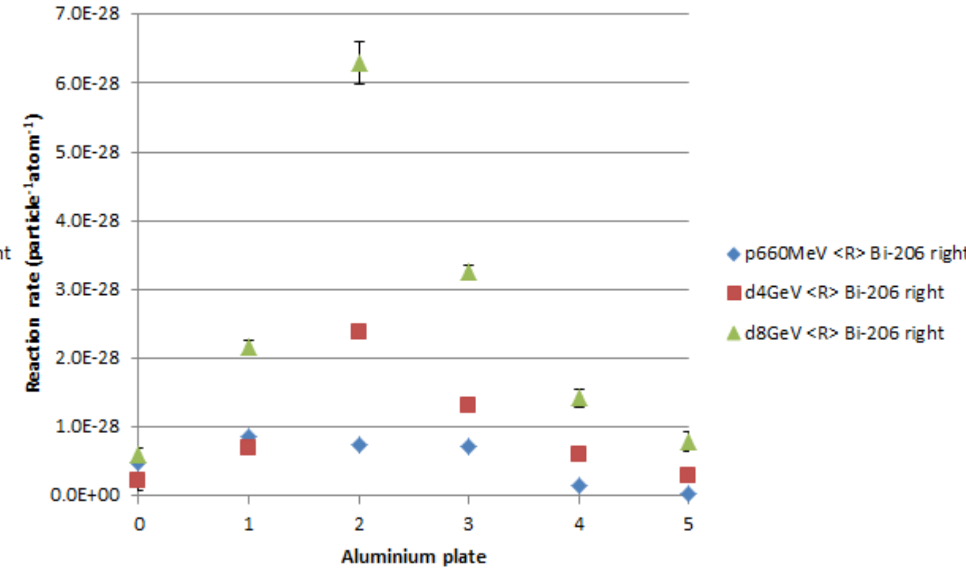
- On the left side the differences between experimental and simulated values are not small - at aluminium plates 4 and 5 the experimental and simulated values are in a good agreement
- On the right side the agreement is a little better than on the left side
- The greatest discrepancies can be found at aluminium plate 3
- However, the simulations follow the increasing and decreasing tendency of the experimental results (except for the values at aluminium plate 3 on the left side)
- The deuteron contributions to reaction rates of Bi-205 and Bi-206 production were less than 1.3 %

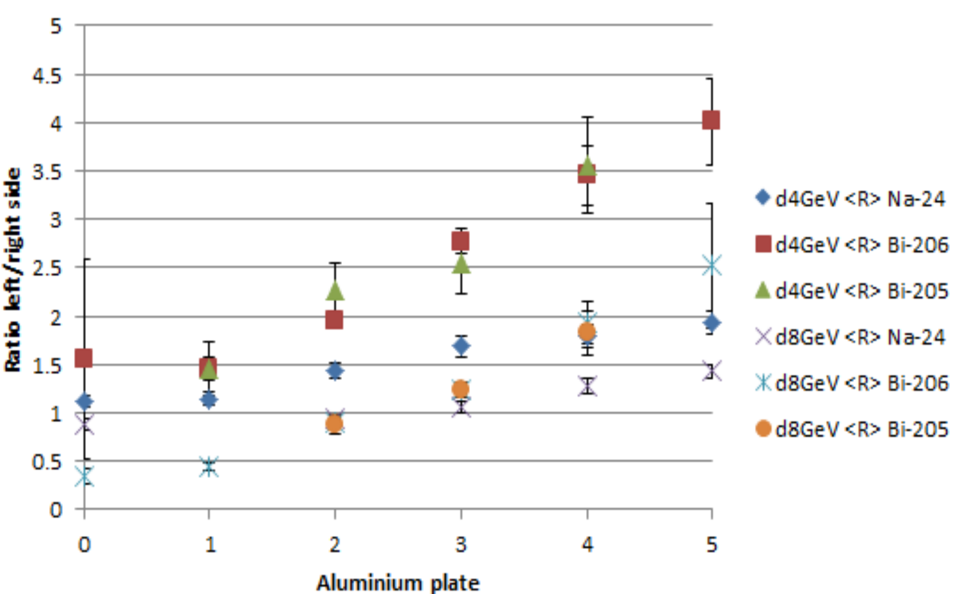


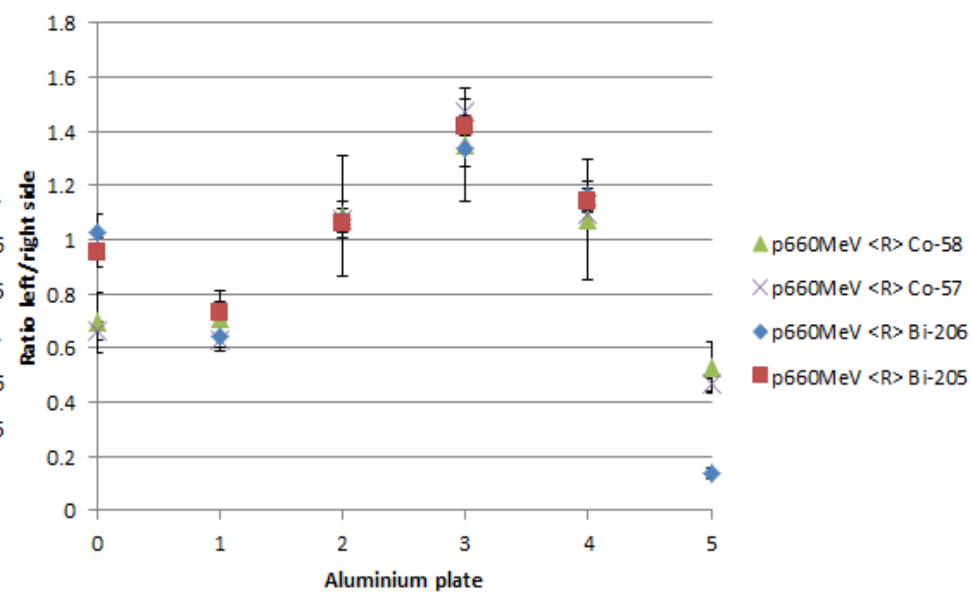


Reaction rates comparison and left/right side ratios of the experiments









Conclusions

- Reaction rates of Na-24, Co-57, Co-58, Bi-205 and Bi-206 from QUINTA experiments on Nuclotron and Phasotron were evaluated
- Simulations in MCNPX 2.7 were performed and compared to the experimental data
- The best agreement between experimental and simulated reaction rates was for Na-24 production for the 4GeV Nuclotron experiment and for Co-57 and Co-58 production for the Phasotron experiment
- Contribution to reaction rates of Co-57 and Co-58 production from reactions with protons are high compared to the proton contributions to Na-24 reaction rates

Thank you for attention

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