5 Performance benchmarks and validation of results

In this chapter we will perform validation tests of Vulkan Spirit on standard set of micromagnetic problems provided by µMag modeling group and compare them with the provided solutions[3]. After that we will discuss the performance results of VkFFT library and Vulkan Spirit in general. The VkFFT library will be compared in performance to Nvidia cuFFT library, which presents a modern general approach to calculating FFTs on GPU. The Spirit Vulkan implementation will be compared to MuMax3 package, which is also a GPU solver for micromagnetism, however it is based on proprietary Nvidia CUDA technology[6].

5.1 Spirit Vulkan validation

In this section, solutions to the standard set of micromagnetic problems #1-4 are given[3].

5.1.1 Standard problem #1

The first problem consist of measuring the hysteresis loop of a permalloy rectangle. The geometry parameters are: $1\mu m \times 2\mu m \times 20nm$ rectangle, $A_{\mathrm{ex}} = 1.3 \times 10^{-11} \frac{J}{m}$, $M_{\mathrm{s}} = 8 \times 10^{5} \frac{A}{m}$, $K_{\mathrm{u}} = 5 \times 10^{2} \frac{J}{m^3}$, with uniaxial anisotropy parallel to the long edge. The simulation discretization is $512 \times 256 \times 1$. The initial configuration is obtained by relaxing circular magnetization. The hysteresis loops are measured for fields applied parallel to the long and short edge of the rectangle. Relaxation method is LBFGS-OSO. The results are in consent with the majority of the solutions and show that the switch between +1 and -1 magnetization happens at approximately 0.01T for field parallel to the long edge (Fig. 5.1) and at approximately 0.02T for field parallel to the short edge (Fig. 5.2).

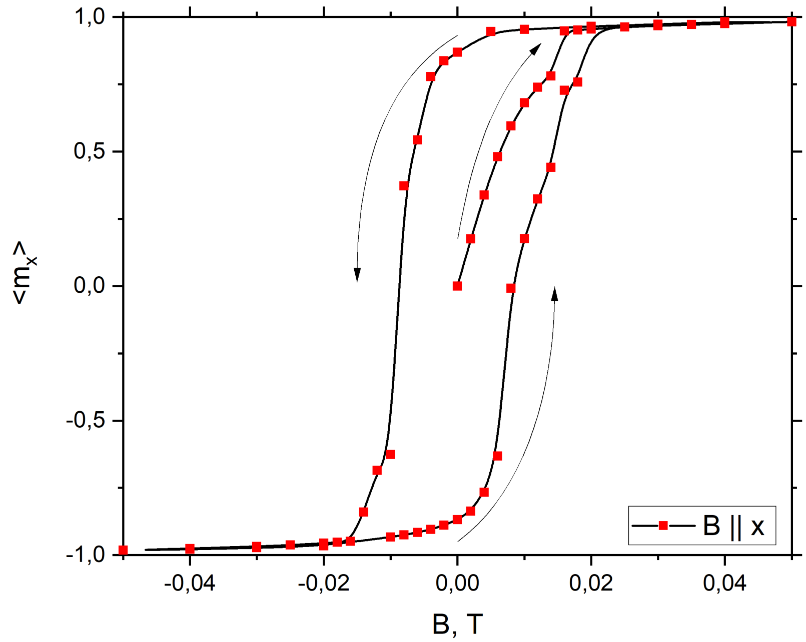


Figure 5.1: Hysteresis loop for $< m_x >$ when field is parallel to the long edge

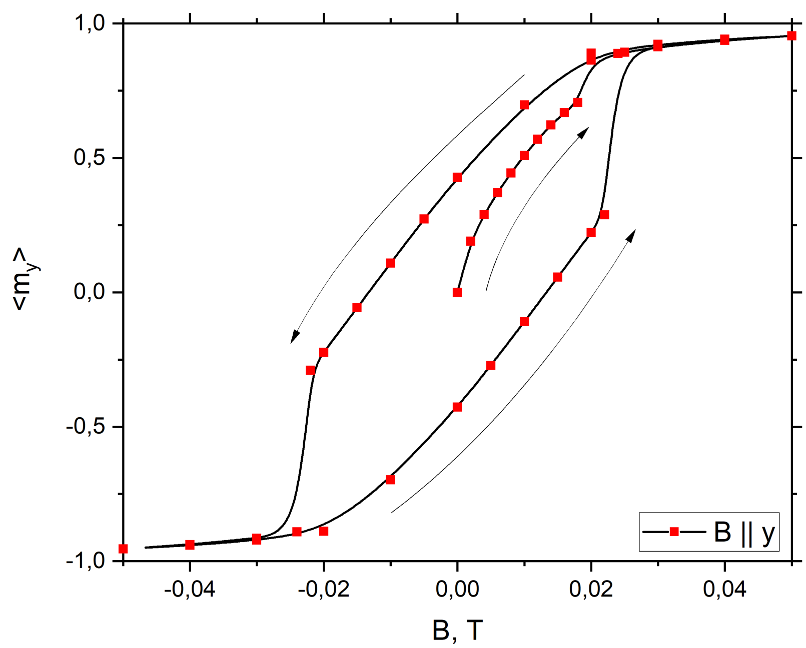


Figure 5.2: Hysteresis loop for $< m_y >$ when field is parallel to the short edge

5.1.2 Standard problem #2

In this problem the coercivity and remanence of thin strip is studied. The strip has fixed shape, such as it's length $L = 5d$ and thickness $t = 0.1d$, where d is sample width. The geometry parameters are calculated in terms of intrinsic length scale $l_{\mathrm{ex}} = \sqrt{\frac{A_{\mathrm{ex}}}{K_{\mathrm{m}}}}$, where K_{m} is a magnetostatic energy density coefficient $K_{\mathrm{m}} = \frac{\mu_0 M_{\mathrm{s}}^2}{2}$. To get remanence, we magnetize the strip in the $(1, 1, 1)$ direction and let it relax. After that, we apply field in the direction $(1, 1, 1)$ to get coercivity - in this case it will correspond to the field value when $M_{\mathrm{x}} + M_{\mathrm{y}} + M_{\mathrm{z}} = 0$. On Fig. 5.3 and Fig. 5.4 results for strips with width from l_{ex} to $30l_{\mathrm{ex}}$ are given. The discretization is chosen to be $256 \times 64 \times 1$, which satisfies the requirement for cell sizes to be under l_{ex}. Relaxation method is LBFGS-OSO. This result matches with the result obtained by R. D. McMichael, M. J. Donahue, and D. G. Porter in [46].

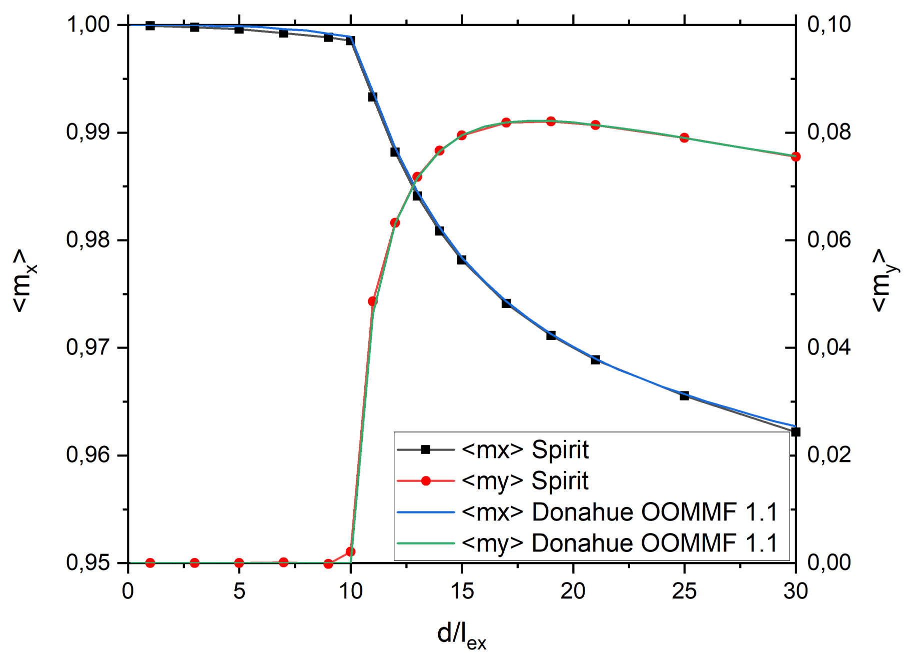


Figure 5.3: Remanence for standard problem #2

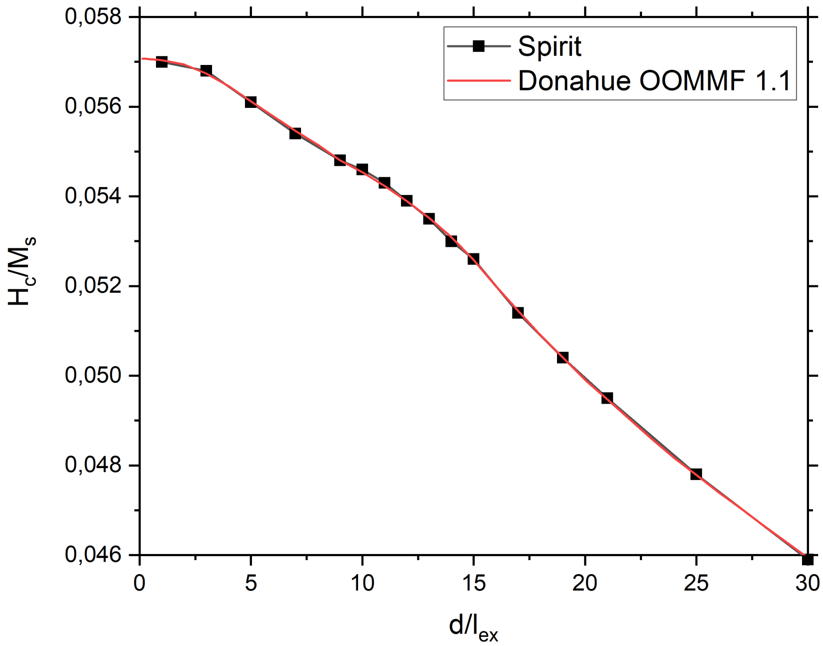
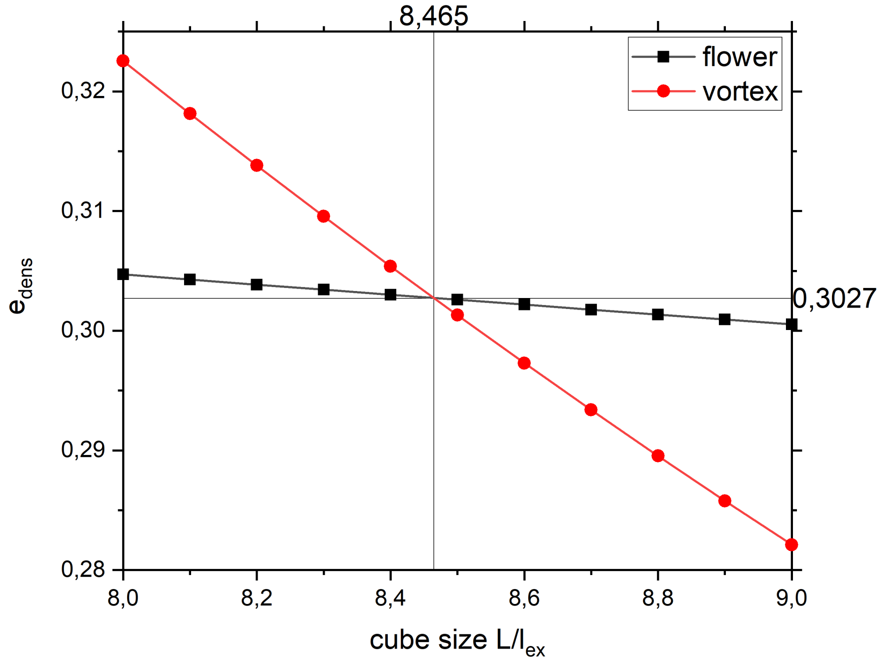


Figure 5.4: Coercivity for standard problem #2

5.1.3 Standard problem #3

In this problem the single domain limit of a cubic magnetic particle is studied. The task is to find the size of a cube at which the flower state energy is equal to the vortex state energy. The geometry parameters are calculated in terms of intrinsic length scale $l_{\mathrm{ex}} = \sqrt{\frac{A_{\mathrm{ex}}}{K_{\mathrm{m}}}}$, where K_{m} is a magnetostatic energy density coefficient $K_{\mathrm{m}} = \frac{\mu_0 M_{\mathrm{s}}^2}{2}$. For simulations, permalloy parameters are used: $A_{\mathrm{ex}} = 1.3 \times 10^{-11} \frac{J}{m}$, $M_{\mathrm{s}} = 8 \times 10^5 \frac{A}{m}$ with anisotropy parallel to the principal axis of the cube and equal to $K_{\mathrm{u}} = 0.1 K_{\mathrm{m}}$. In this case $K_{\mathrm{m}} = 4 \times 10^5 \frac{J}{m^3}$ and $l_{\mathrm{ex}} = 5.7nm$. The cube size L is given in l_{ex} and as the transition is expected near $L = 8.5 l_{\mathrm{ex}}$, cubes of sizes from $8 l_{\mathrm{ex}}$ to $9 l_{\mathrm{ex}}$ are studied. The simulation grid is $32 \times 32 \times 32$. The flower and vortex states are obtained after relaxation from random magnetization. After that, for different cube sizes relaxation is performed from these states. All relaxations use LBFGS-OSO method. The obtained result (Fig. 5.5) shows that transition happen at $L = 8.465 l_{\mathrm{ex}}$, the corresponding reduced energy (in units of K_{m}) is $e = 0.3027$. This result matches with the result obtained by Alex Hubert, Karl Fabian and Wolfgang Rave in [47].



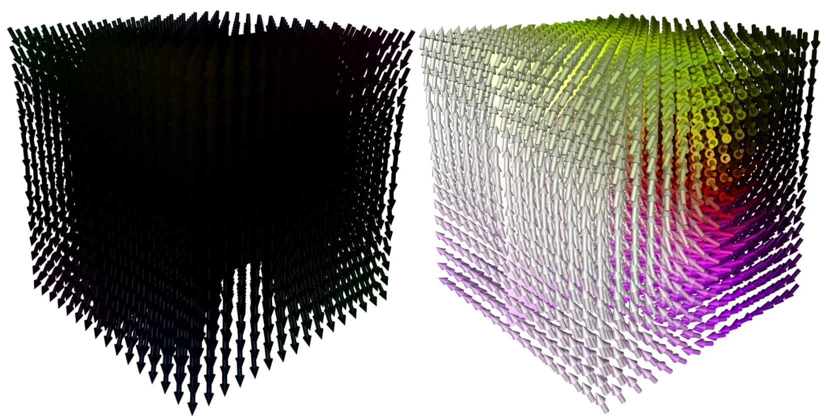


Figure 5.5: Energy densities of flower (left) and vortex (right) states as a function of cube size L

5.1.4 Standard problem #4

In this problem dynamical capabilities and precision of the code are studied. Here a dynamic magnetization reversal of permalloy rectangle in the presence of external field is performed. The geometry parameters are: $500nm \times 125nm \times 3nm$ rectangle, $A_{\text{ex}} = 1.3 \times 10^{-11} \frac{J}{m}$, $M_{\text{s}} = 8 \times 10^{5} \frac{A}{m}$. The simulation discretization is $256 \times 64 \times 1$. The initial configuration is an S-state obtained by relaxing uniformly magnetized in the direction $(1, 1, 1)$ rectangle. The relaxation is performed using LBFGS-OSO method. After relaxation we apply uniform external magnetic field defined according specification as: (a): $(-24.6, 4.3, 0)$mT on Fig. 5.6 and (b): $(-35.5, -6.3, 0)\, mT$ on Fig. 5.7, which corresponds to the direction of (a): 170 and (b): 190 degrees counterclockwise from the positive x axis. For dynamics both Depondt and RK45 solvers are tested with a time step of $0.01ps$. Below evolution in time of the average magnetization is given, as well as the system image when $< m_{\text{x}} >$ first crosses zero. Evolution is compared to the results of MuMax3 package[5].

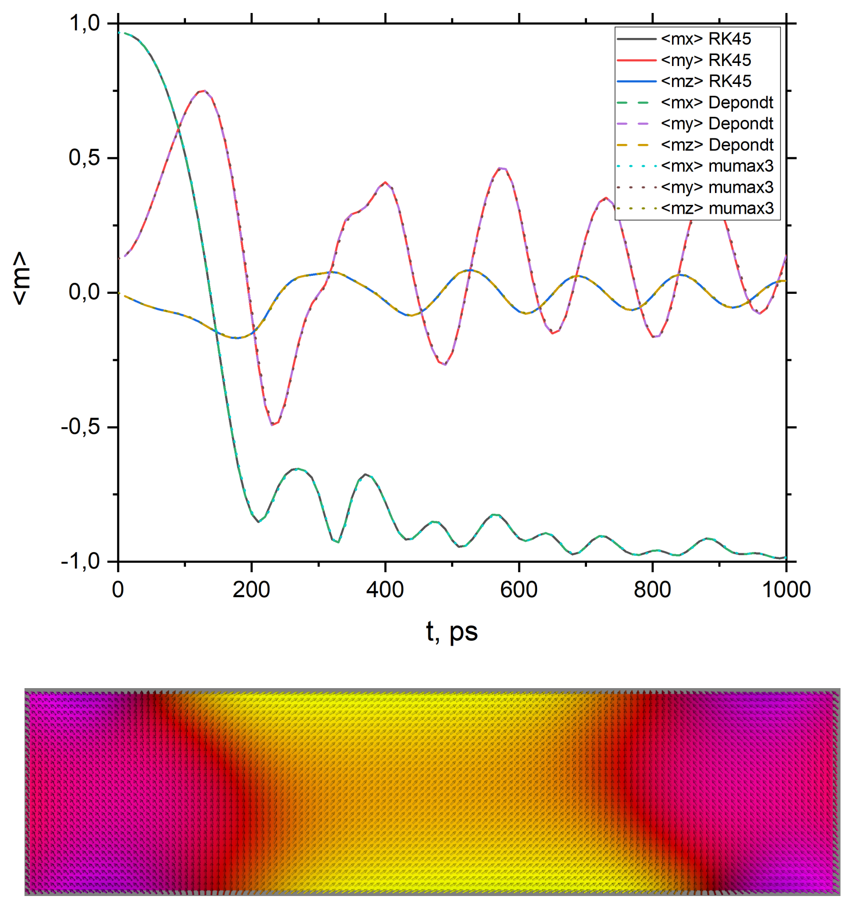
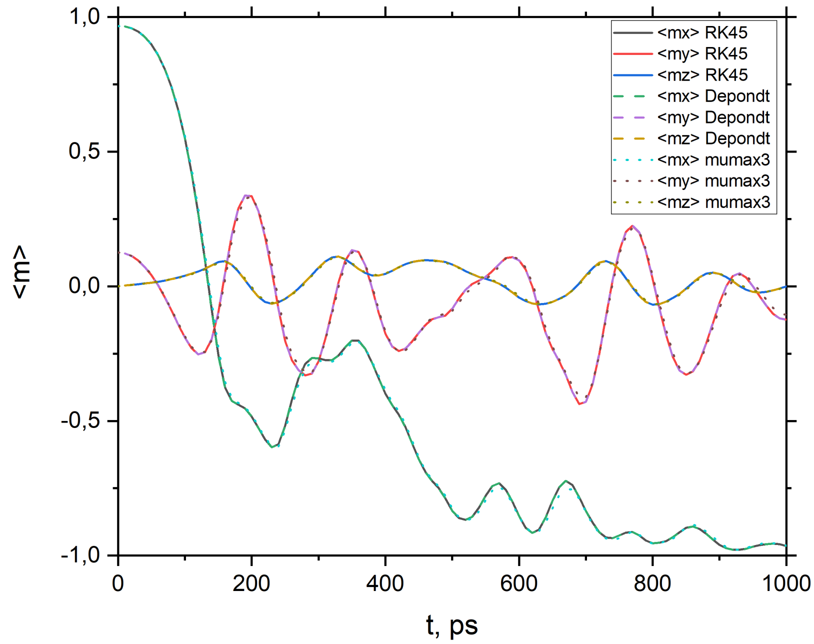


Figure 5.6: Time evolution for problem 4a and system image when $< m_{\text{x}} >$ first crosses zero



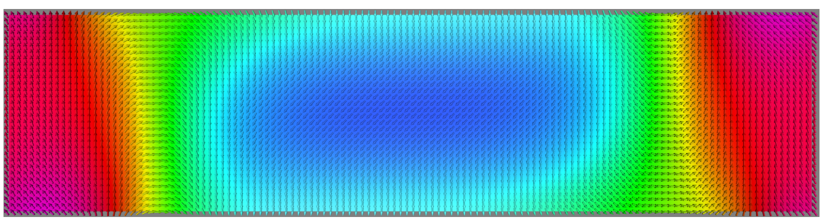


Figure 5.7: Time evolution for problem 4b and system image when $< m_x >$ first crosses zero

5.2 VkFFT performance

To measure how VkFFT implementation works in comparison to cuFFT[4], we will perform a number of 2D and 3D tests that correspond to systems with sizes that are usually used in micromagnetics and atomistic spin dynamics. The test will consist of performing FFT and inverse FFT consecutively multiple times to calculate average time required. The results obtained on Nvidia 1660 Ti graphics card are given in the comparison chart on Fig. 5.8. As we can see, VkFFT outperforms cuFFT in multidimensional FFT test, being up to four times faster on small systems (due to the scheduling multiple transforms consequtively in one dispatch) and getting 5-20% performance increase on average for bigger systems, which are excellent results for a custom FFT library.

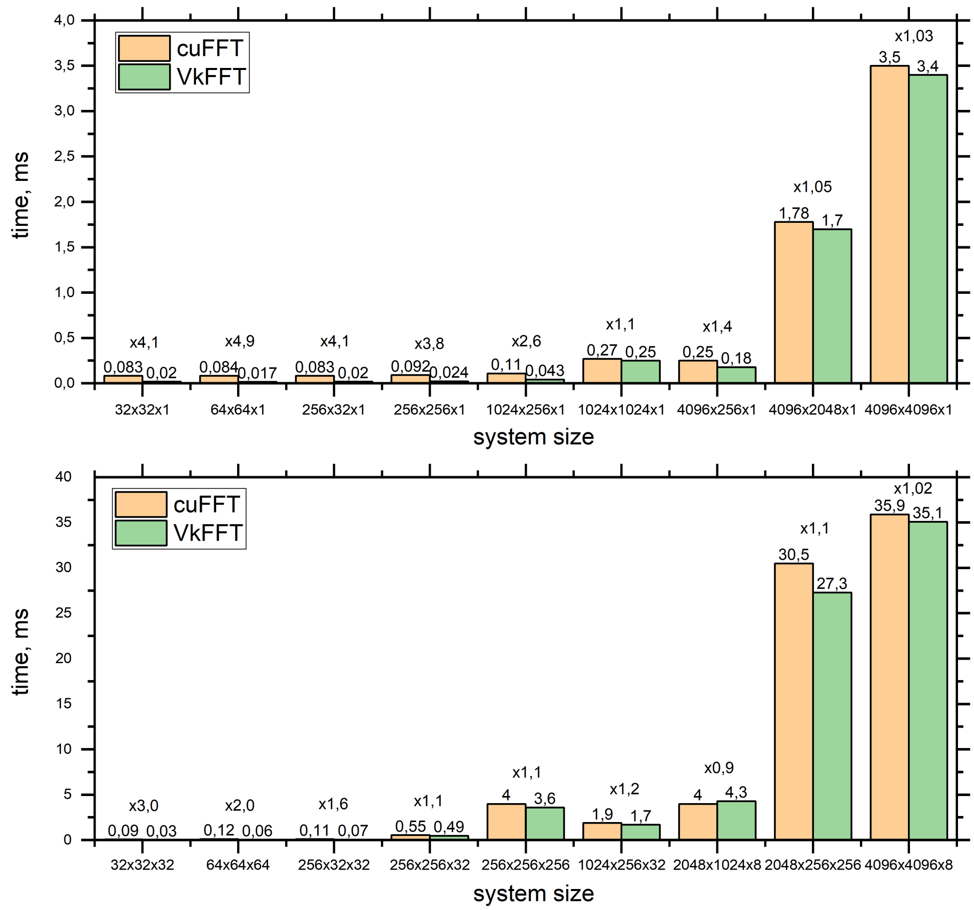


Figure 5.8: Comparison of test results for Nvidia cuFFT and new VkFFT

5.3 Vulkan Spirit overall performance comparison

In this section raw performance comparison between Vulkan Spirit and MuMax3 GPU software is given[5]. The standard problem four is chosen as the test system with RK4 solvers used in both software packages. Performance is measured in terms of time taken to complete $1ns$ ($0.1ns$ for big systems) of simulation on open-boundary system with DDI. The fixed timestep is chosen to be $0.01ps$, which results in the total amount of 100000 (10000) iterations. All runs are performed multiple times on one machine, equipped with Nvidia 1660Ti GPU. On Fig. 5.9 test results for multiple system sizes are given. As we can see, optimizations and possibilities opened up by using Vulkan and VkFFT library result in 100% computational speed increase for large systems and 200% increase for smaller systems.

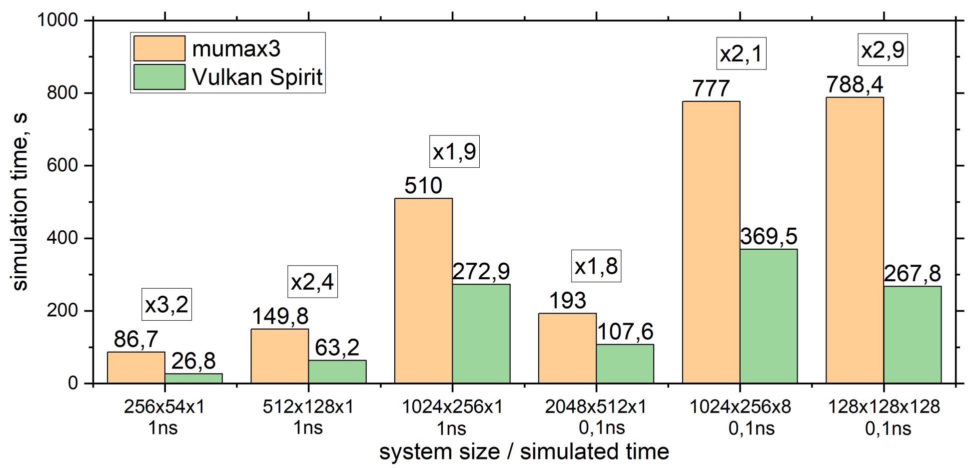


Figure 5.9: Comparison of test results for MuMax3 and new Vulkan Spirit. In boxes, speedup scaling factor is given