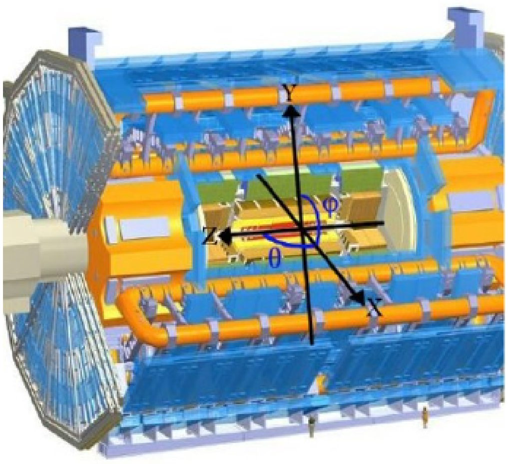
Bence Tanko-Bartalis

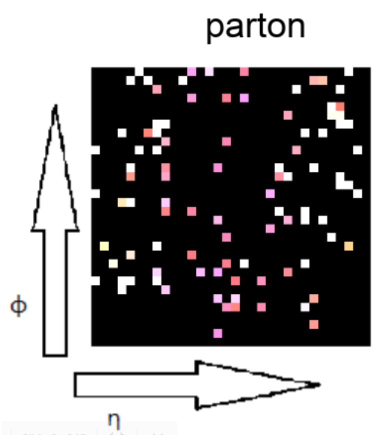
Wigner Research Centre for Physics

During the summer of 2021, I participated in research at the Wigner Research Center for Physics of the Hungarian Academy of Sciences in Budapest. The research centre is working with high energy physics. Here, I was part of a theoretical physics research group which tried to use Artificial Intelligence to replicate hadronization. During the eight weeks long internship, we have achieved some results which we hope to publicise soon.

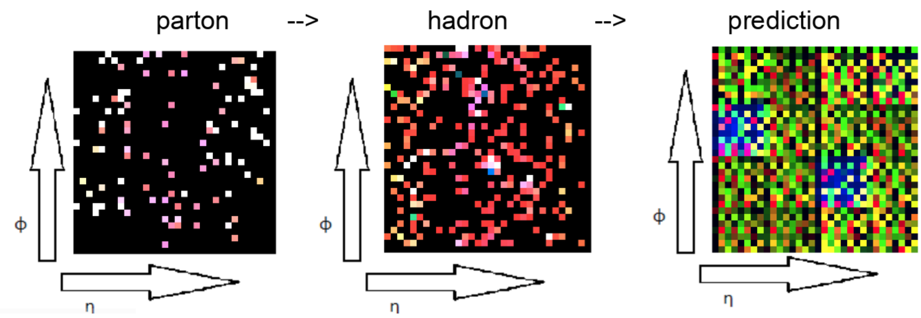
I have started my work by getting to know the most current research papers on the topic. This was my first time to really read through dozens of scientific articles and it was quite challenging. I have had a lot of things that I had to learn because my knowledge on hadronization was very limited. If I had to describe it the easiest way, it is a process when partons (like quarks that build up for example protons) combine into hadrons such as protons or neutrons. The exact method of hadronization is still unknown to mankind, but it is one of the million-dollar questions in physics. Since there is no mathematical method to describe hadronization, AI is a great tool to look at it because AI might realise patterns that we cannot.

After getting to know most of the papers, we found the most appealing to be J. W. Monk's Deep Learning as a Parton Shower. His idea was to try to replicate the parton shower, which is part of the hadronization process. He read in the pTs (impulse in the x-y plane) of each particle in the event. If two particles coincided to be in the same space he just added the pT value to the pixel, so he got a brighter pixel. He got a similar 2D picture like the one on the right below just in black and white. He did this both before and after (which is the input and output of the AI) the parton shower and he has got promising results, which has been published.



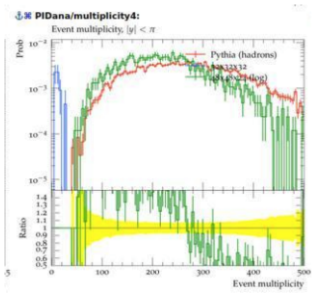


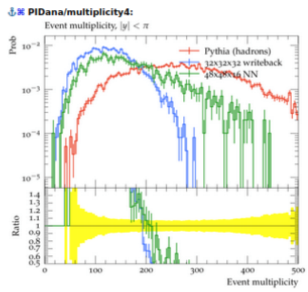
From his idea we thought a bit further and we tried to create a RGB hypercube. This hyper cube had the same dimensions in the x-y coordinate system with an extra z direction which made it possible for us to account for each particle individually. The RGB colors helped us further to get more information. The colors had their meaning: red is pT, green is energy and blue is mass. The first two quantities can have 10^{13}



magnitude difference so we took the logarithm of all the values before we passed it into the AI. First we tried a very basic Variational Autoencoder that did not produce an output that was desired (see above). Parton is the input of the data and hadron is the output (that it is trained on), and prediction is the output of the Convolutional Neural Network (CNN) that is the AI. After trying to improve this result and failing, we tried to use an Auto Encoder similarly to what J.W. Monk used. After this, we got way better results. He used something called active Loss which inspired our gauss Loss that helped the AI to learn about the information that is inside the picture 50-500 pixels compared to the empty ones that are 35 000 - 70 000 pixels. After that, we were able to start to look at the physics behind what is happening using rivet analysis and statistics.

The pictures to the right are rivet analysis. The target is to get the blue line as close to the green one as possible. The red line shows us what would be the "the ideal" output meaning the output of green would be the same as the red if we had infinitely large computational power (hence no information loss when putting the data into a hypercube). The picture on the left is one of the first rivet analyses that we have done and the right one is after tuning some hyper parameters.





Other than learning the direct skills that are needed to do the research, I have gained experience in using AI and many other tasks that are part of a research in general. I have learned to summarise and present all my week's achievements in a short presentation. I have learned how important documentation is. I also had a chance to use Linux and a powerful computer inside a GPU laboratory provided by the institute. This was also my first time when I had to run things on a remote computer through SSH which was a new and exciting experience. This is very useful for AI research as people usually do not have computers that have 64 GB of RAM or 8 GPU for fast calculations. (Even on this machine the calculations took several hours.) These are all needed in the research that we have done because we have read in hyper cubes that are 48x48x16x3 pixels per event and we have read in at least 10 000 events to get a meaningful result, but we have also used 20-30 thousand data to get more accurate results. The code was written in python using Tensorflow and Keras. We shared the code between each other using GitLab which is most often used when people work together on codes.

In summary, I was able to join a research group for eight weeks at the Wigner Research Center for Physics of the Hungarian Academy of Sciences. For this opportunity, I would like to thank Dr. Levai Peter, Dr. Barnafoldi Gergely and Dr. Biro Gabor. We have made advances in hadronization using CNN-s and getting inspiration from J.W. Monk's article. This is a hot topic currently in high energy physics and is heavily researched. There are still a lot of improvements that can be made to move physics forward in this direction.