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Toolbox for HEP and the sustainability of HEP event generators

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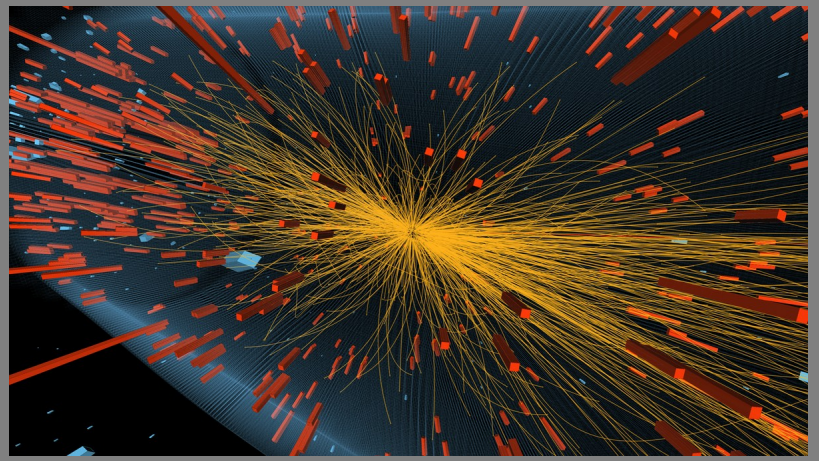
Docker

- Open source platform for containerization.
- Docker containers bundle an app with everything it needs (code, runtime, libraries).
- Containers share the host OS kernel, starting in seconds and using far fewer resources than virtual machines. ⇨ Lightweight and fast
- Each container runs independently, avoiding dependency conflicts. ⇨ Isolated environments
- Build images from simple Dockerfiles, ensuring consistent setups across dev, test, and production. ⇨ Declarative & reproducible
- Docker Hub for sharing images, Docker Compose for multi-service apps, and native integration with Kubernetes.

Monte Carlo event generators & HIJING ++

- MC event generators simulate the complete evolution of particle collisions, proton-proton, proton-heavy ion and heavy ion-heavy ion.
- HIJING++ (Heavy Ion Jet INteraction Generator), written in C++ and has built in parallelization (CPU)
- MC event generators generate a large amount of data, require lot of resources to run
- The need for computational power is growing ⇨ Optimization is important
- Tuning of MC event generators is required (e.g. Monash tune of Pythia8)



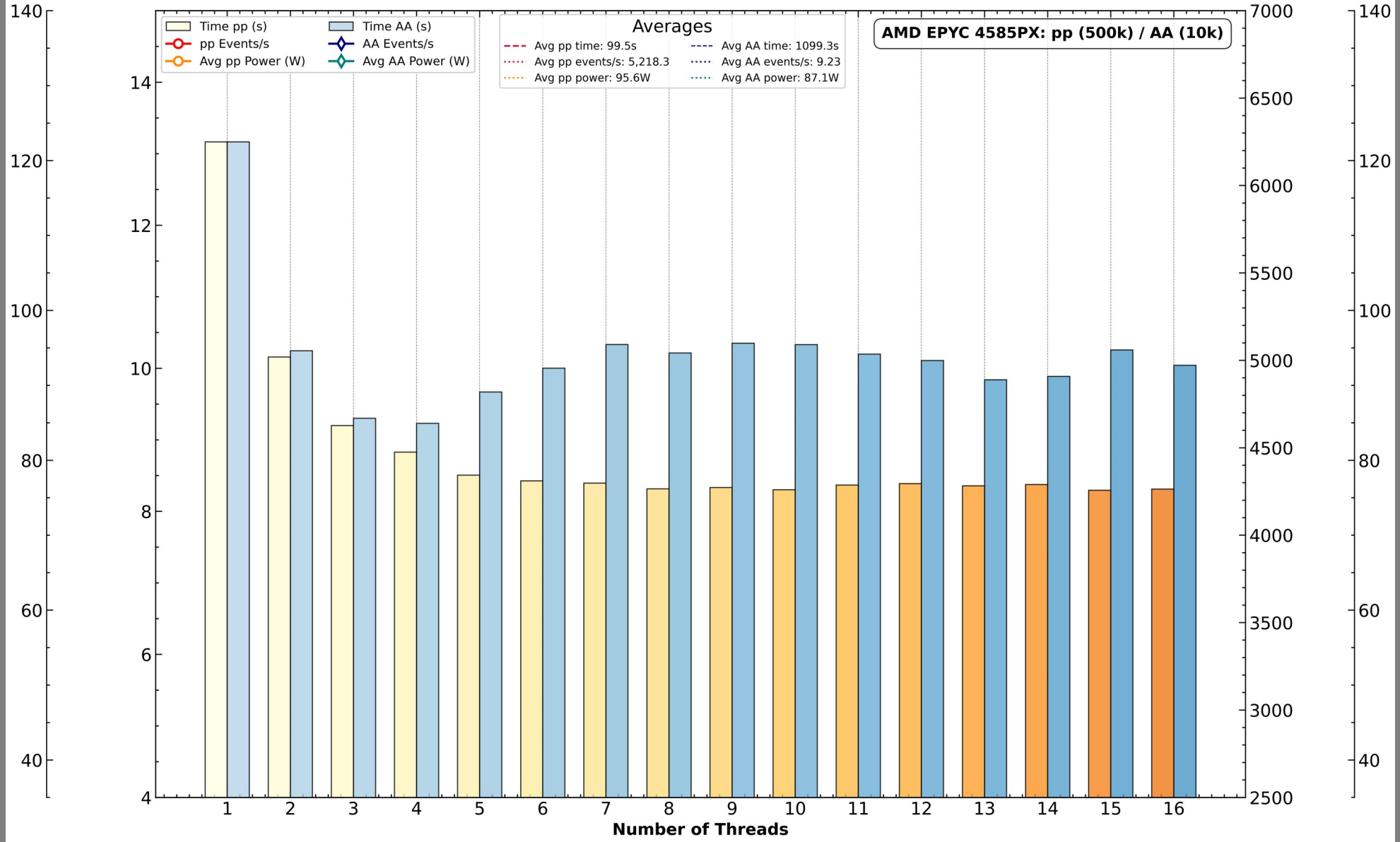
HEP Toolbox

- Professor, Rivet, Pythia ⇨proripy
- Based on Ubuntu 22 LTS (for now), 100% open source
- Future plans to create a version with 

base, rolling release image version
- Image includes: Pythia8, Rivet, Professor, ROOT, YODA, HepMC3, FastJet3, HighFive, LHAPDF6
- Code debuggers included: C/C++, Python3, Go, Ruby, Rust (+ GNU Debugger as extra)
- Image has an SSH version for VSCode integration
- Latest version: 77rev/proripy:4.4
- It was initially created to make the tuning and debugging of HIJING++ more convenient but now has over 1300 downloads.

HEP Toolbox

- Available on hub.docker.com but also on its own gitlab project
- Custom benchmarking script included from version 4.4
- Benchmarking script can be used to measure MC event generator run time, CPU power consumption and test the impact of parallelization on runtime and power consumption
- HIJING++ ran with 500,000 pp events and 10,000 AA events
- We investigated 5 different CPUs
  - Intel Xeon E5-2650 | 8C/16T @ 2.6GHz | 2012 | 95 W
  - AMD EPYC 7302 | 16C/32T @ 3.35GHz | 2019 | 155 W
  - AMD EPYC 7502P | 32C/64T @ 3.35GHz | 2019 | 180 W
  - AMD Ryzen 7 8845HS | 8C/16T @ 5.14GHz | 2023 | 54 W
  - AMD EPYC 4585PX | 16C/32T @ 5.76GHz | 2025 | 170 W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pp Events/s
Avg pp Power (W)
Time AA (s)
AA Events/s
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Averages
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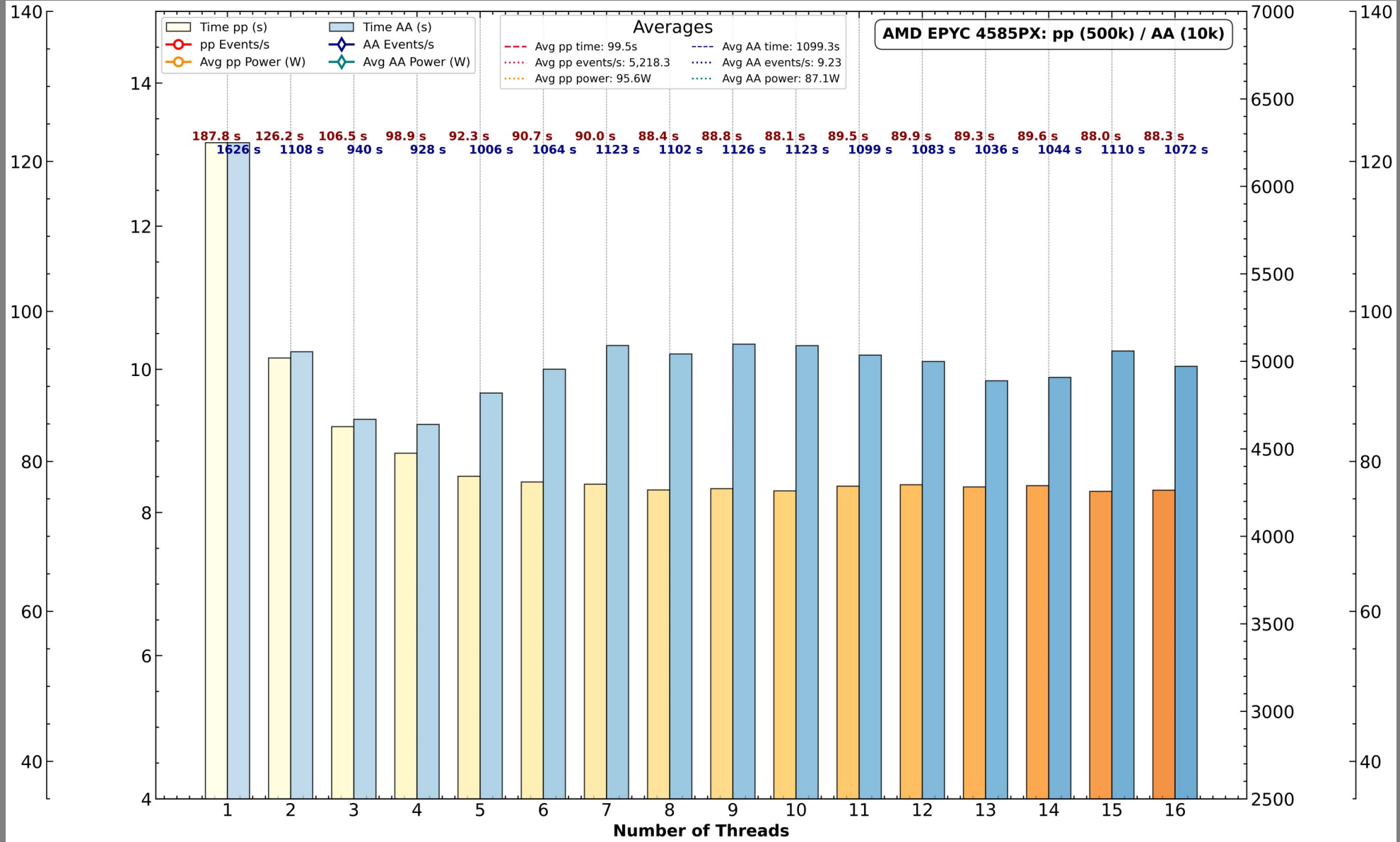
Avg pp events/s: 5,218.3
Avg pp power: 95.6W
Avg AA time: 1099.3s
Avg AA events/s: 9.23
Avg AA power: 87.1W
AMD EPYC 4585PX: pp (500k) / AA (10k)
Number of Threads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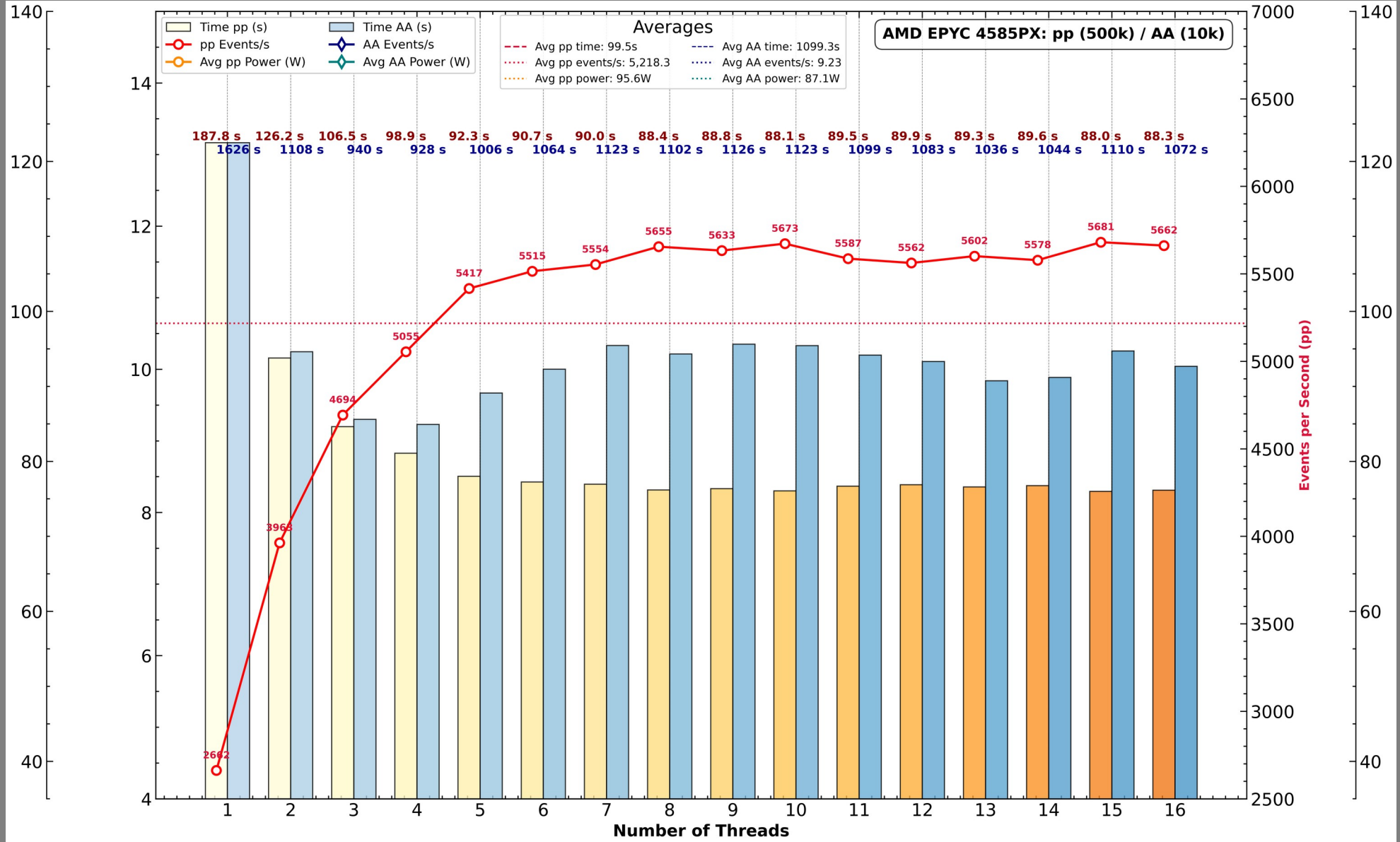
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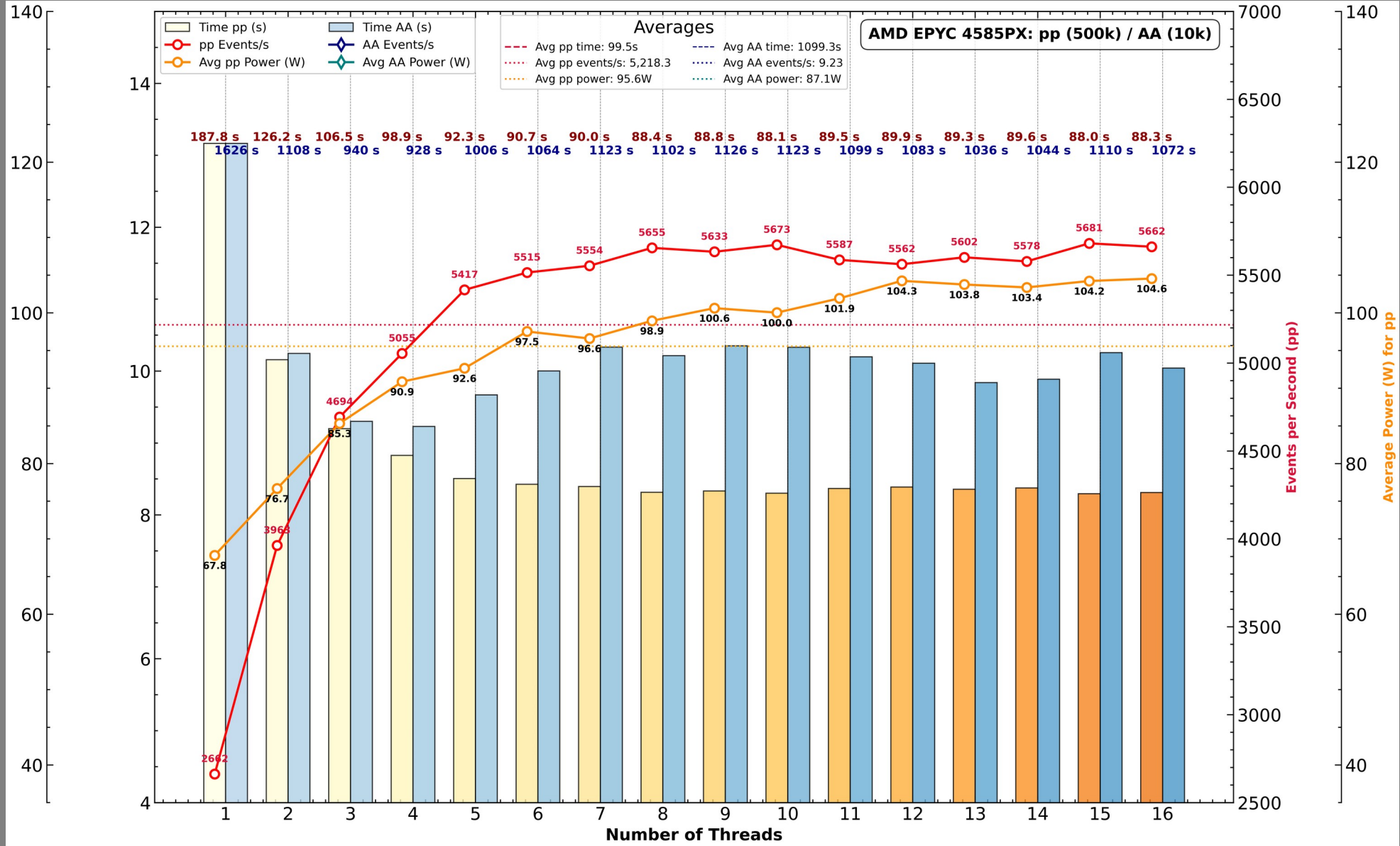
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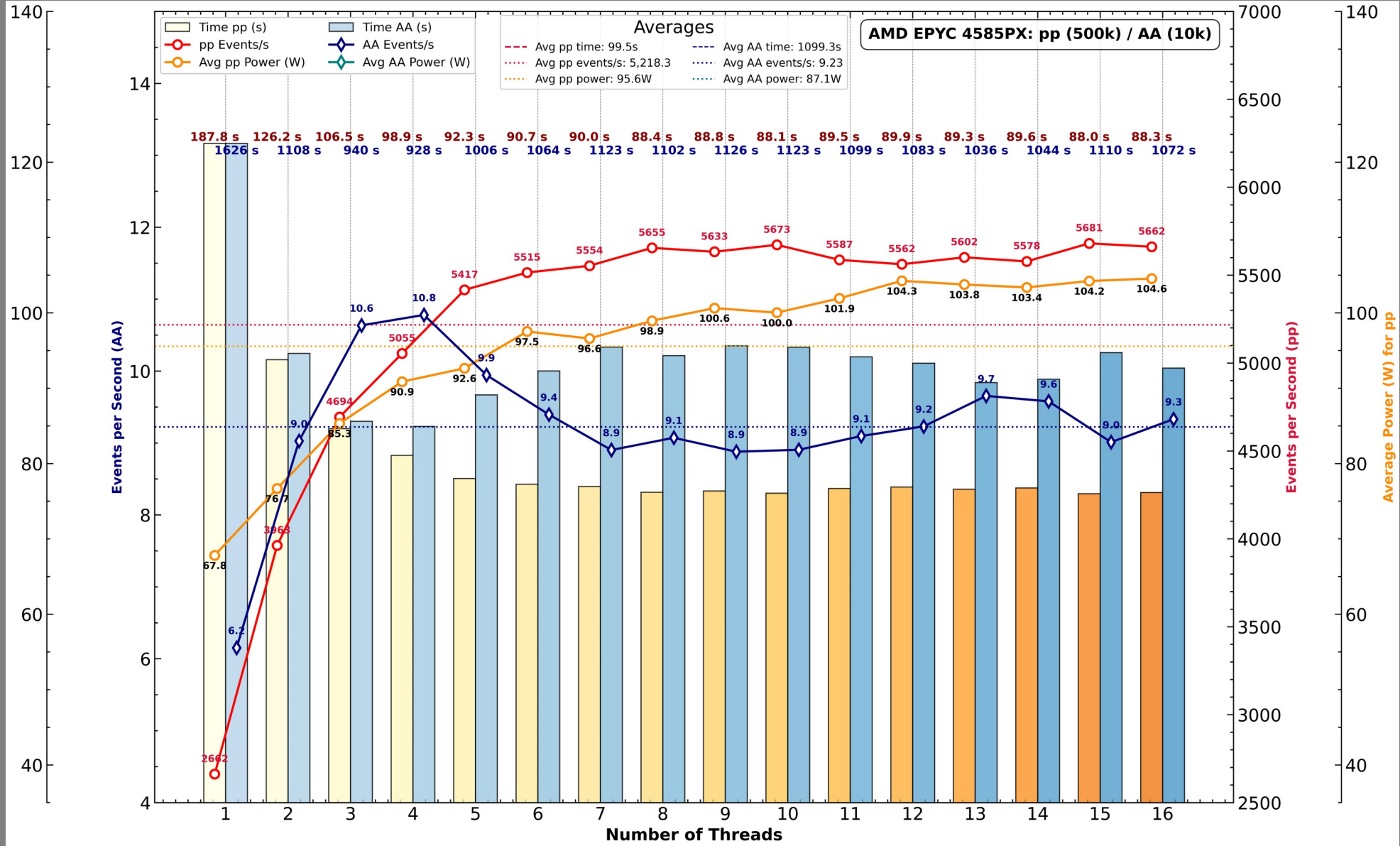
Number of Threads
Events per Second (pp)
Average Power (W) for pp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6.2 9.0 10.6 10.8 9.9 9.4 8.9 9.1 8.9 8.9 9.1 9.2 9.7 9.6 9.0 9.3
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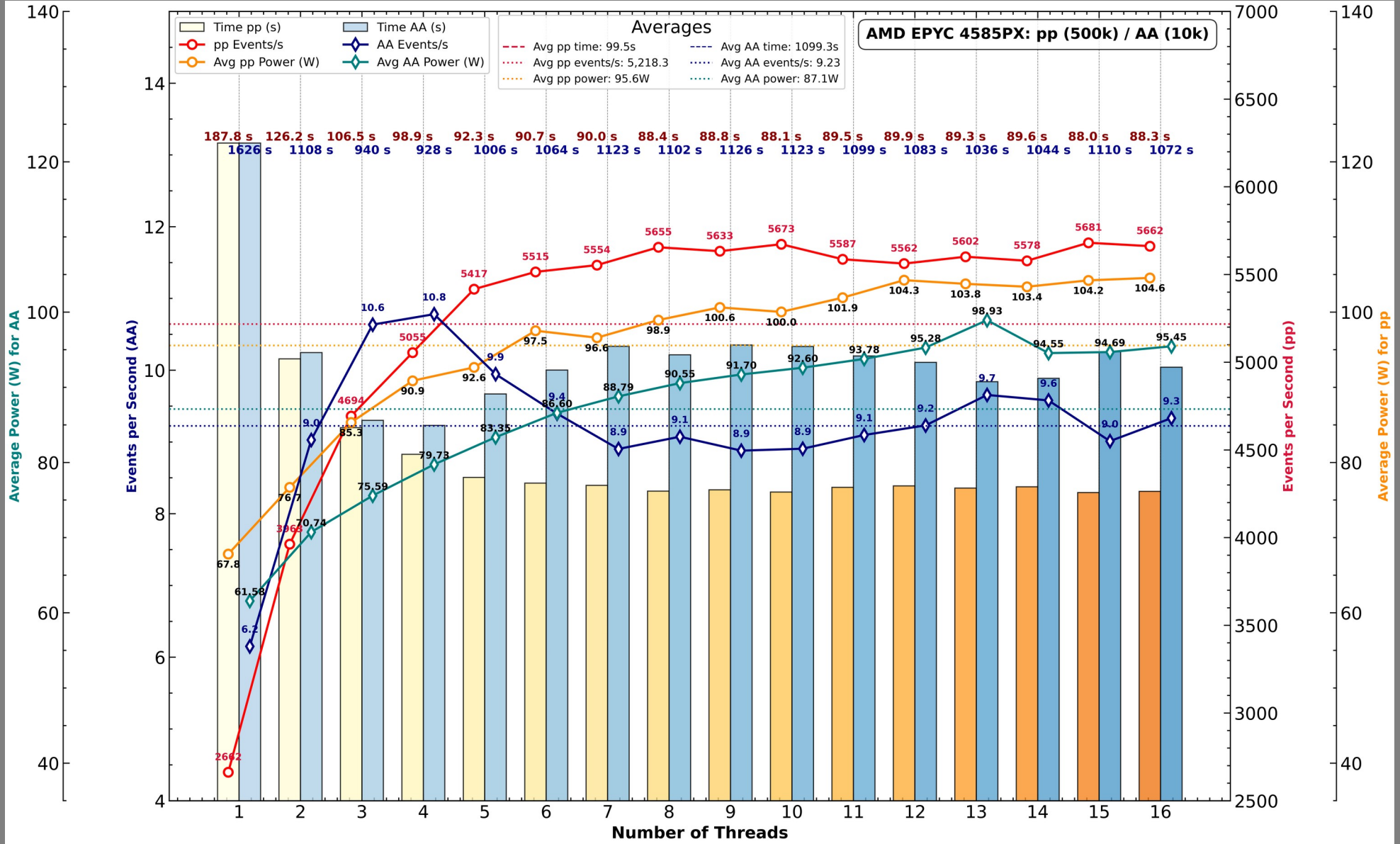
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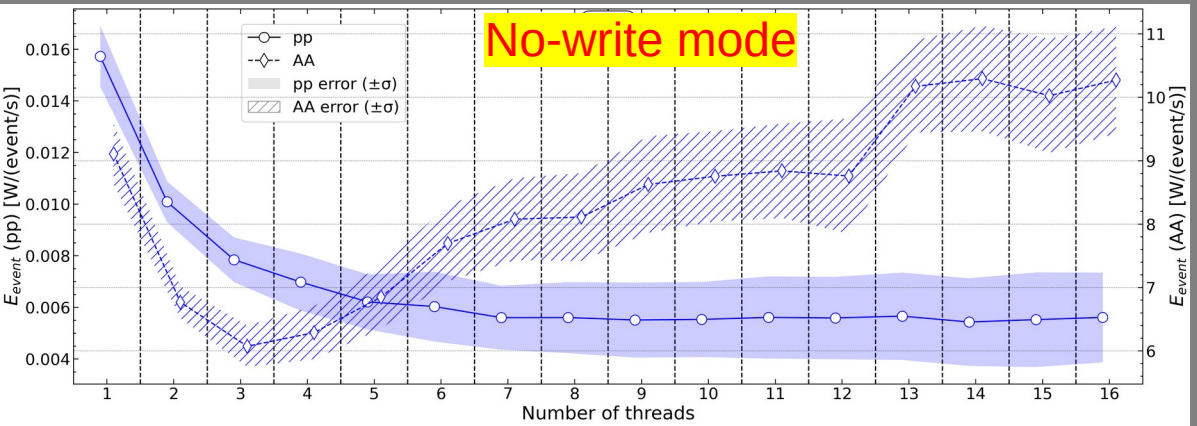
Sustainability

- By introducing a way to measure the cost of each event, E = P/T, we can plot this as a function of the number of threads and find the most optimal level of paralleliaztion.
- Tuning a MC event generator is a computationally intensive task, requiring many runs and thus a lot of power
- Nowadays, especially with the High-Luminosity LHC era, the required scale of simulated data is expected to increase significantly
- By optimizing the simulations, one can find a ‘carbon-aware’ way to run MC event generators, leading to more sustainable efficiency

AMD EPYC 4585PX



- Power consumption was measured every second and the average was considered.
- The error comes from how the power consumption was measured.
- Most optimal doesn’t mean the fastest
- Little difference between the runtimes of SSD and HDD.
- No-write included as reference, no files were created, pure speed test of the CPU

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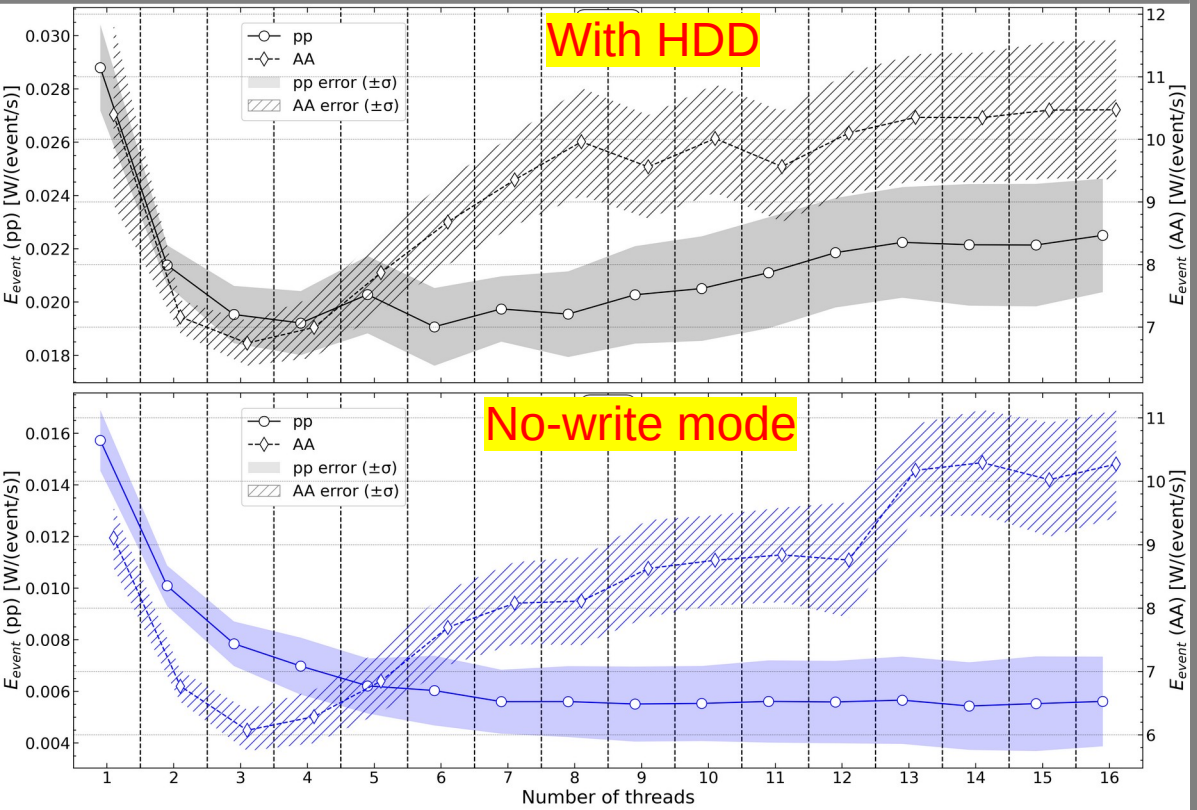

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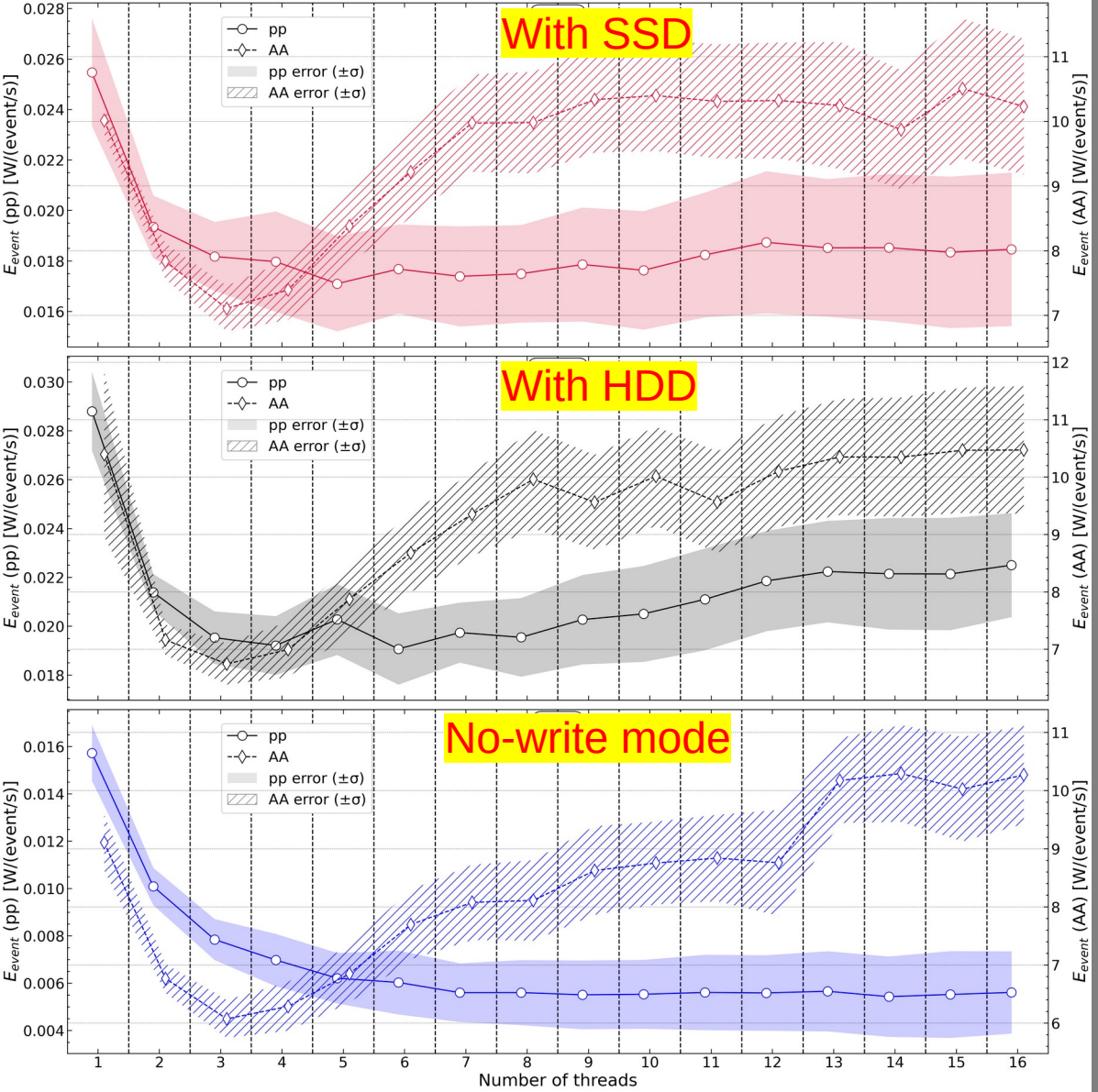

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Results

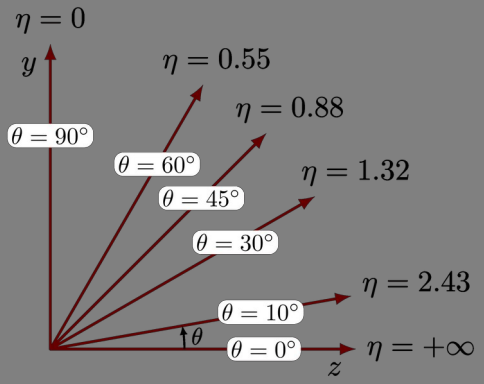
- Significant improvement over single thread mode in the case of HIJING++ at both the fastest and most optimal thread counts (25-51 %)

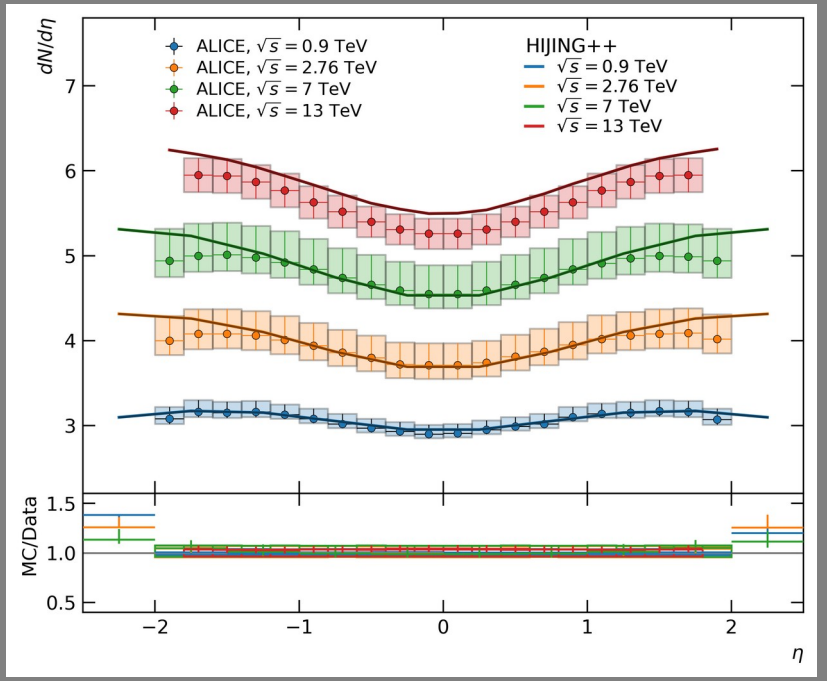
- Overall power consumption was calculated from:
  - 1024 configs
  - 5 million events each
  - 10 iterations
  - 6 energies
- In the case of AA collisions it would be 140-180 times more costly
- Simplified estimates, no Rivet analysis or Professor usage included

- AMD EPYC 4585PX (pp case)
  - Fastest: 1566 kWh – 15 threads
  - Optimal: 1458 kWh – 5 threads
  - Reduction: 6.8 %

Recent tuning results of HIJING++

- The HEP Toolbox was used which made the process convenient
- Preliminary results for pseudorapidity distribution at 4 different energies
- Pseudorapidity is used to measure the angle of the particles' trajectory relative to the beam, η=-ln(tan(θ/2))
- 6 parameters were used in the tuning: 0.9 TeV, 2.76 TeV, 7 TeV, 13 TeV





Usage of the Toolbox

- Tutorial available on the gitlab*
- Downloading the image: **docker pull 77rev/proripy:4.4**
  or ssh at the end if you need that verison.
- Run:
  docker run -it -v $HOME/Work:/home/devuser/Work 77rev/proripy:4.4
- It gives you a terminal inside the docker container, to run the same container again: **docker start *[container name]***
- Then to get the interactive terminal:
  docker exec -it --user root *[container name]* bash
- To start the ssh version:
  docker run -it -p 1779 77rev/proripy:ssh
  it will be accessible on the 1779 port and you can get the IP via the docker inspect command.

Conclusion

- Toolbox (Docker image) with Pythia8, Rivet, ROOT, etc. that work out-of-the-box.
- MC Event generators require optimization for sustainability ⇨ CPU Benchmarking required.
- Newer CPUs are a lot more efficient for these tasks, optimizable via parallelism.
- Tuning of MC event generators is convenient via the Toolbox.
- Gitlab page will be available shortly as well as publication on arXiv and EPJC.

Thank you for your attention!

Acknowledgments
- Team: Gábor Bíró, Gergely Gábor Barnaföldi, Gábor Papp
- Grants:
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  - 2025-1.1.5-NEMZ_KI-2025-00005
  - 2025-1.1.5-NEMZ_KI-2025-00013
  - 2024-1.2.5-TÉT-2024-00022

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NTT DATA

Check out the Docker Hub

This presentation is uploaded to Indico.