



Computing Challenges for LHC

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The Particle Physics Challenge

- **CERN Science is Data Intensive Science**
 - All experiments:
 - Our combined data storage now totals 376 PB
 - LHC experiments
 - Run 1 (2009-2013) we stored 65 PB
 - Run 2 (2015-2018) we stored 209 PB
 - Run 3 (2022-2026) we expect to store 600 PB
- **That needs the combined power of all our computing centres to analyse:**
 - CERN Data Centre
 - 450k CPU cores, 320 PB of storage
 - WorldWide LHC Computing Grid
 - 170 data centres in more than 42 countries
 - 1.4M CPU cores, 1.5 Exabytes of storage

The WLCG in action

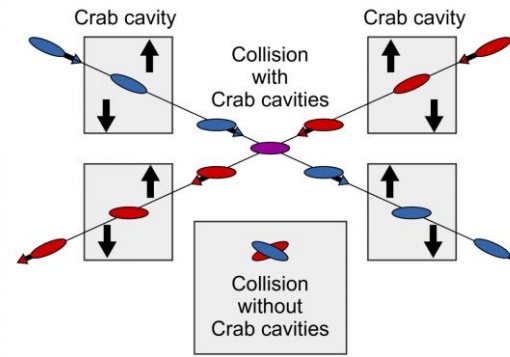


The HL-LHC Challenge

Higher luminosity equates to more data for the experiments, giving them greater precision and more potential for new discoveries

- **More luminosity = more resources needed!**

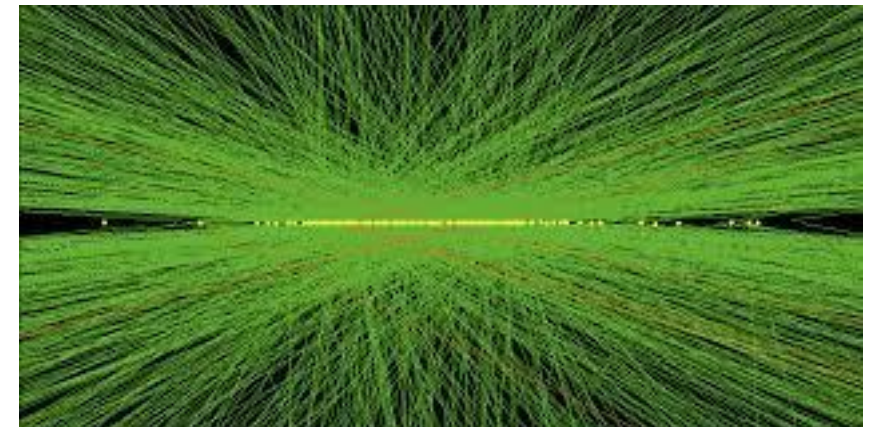
- $\times 10$ increase
- More than Moore's law and we have flat budget
- Will still be $\times 3$ too low



Crab cavities, more powerful focusing quadrupole magnets

- **More pile-up = more complex events**

- 40 per bunch-crossing at Run 2
- 200 expected at Run 4



Strategies to Face the HL-LHC Challenge

Addressing conventionally:

- Hardware efficiency
- Refactoring, modernising, optimising code
- Building a new energy efficient data centre - PCC

Leveraging innovations:

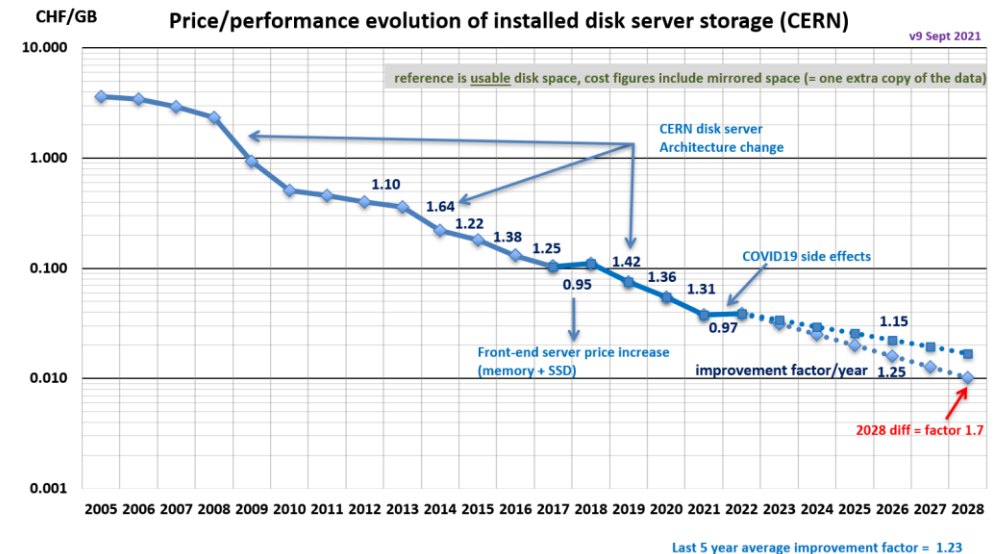
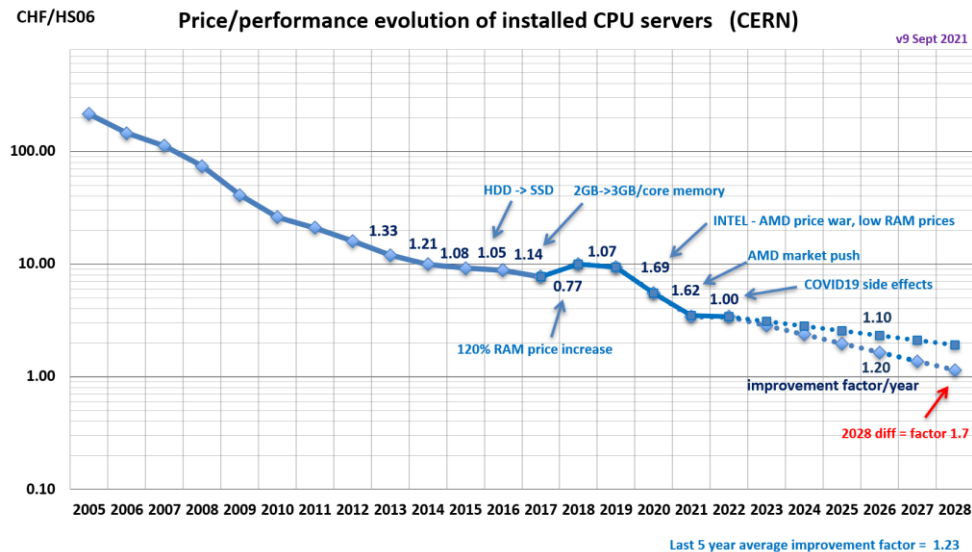
- Accelerators like GPUs and TPUs (and FPGAs) in readout chain
- ML and DL (deep learning) applied to all stages of readout/analysis
- Data Lakes (Pooled research centres; with streaming and caches)
- Utilise HPC centres

Helping to drive paradigm shifts

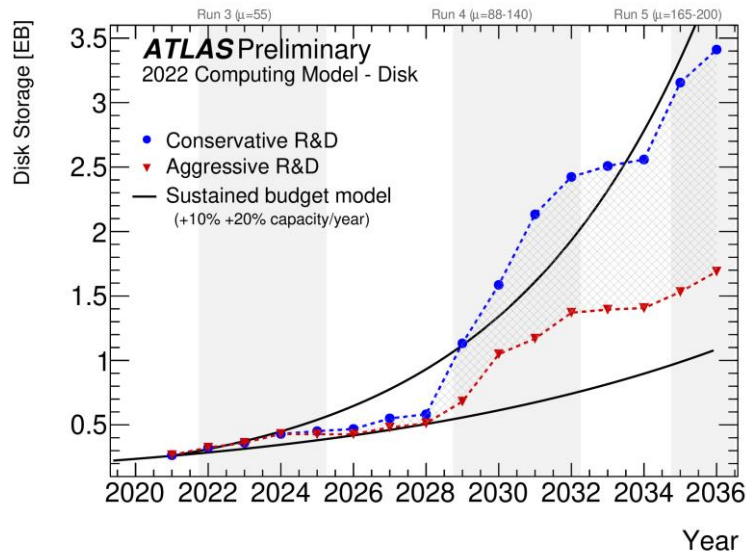
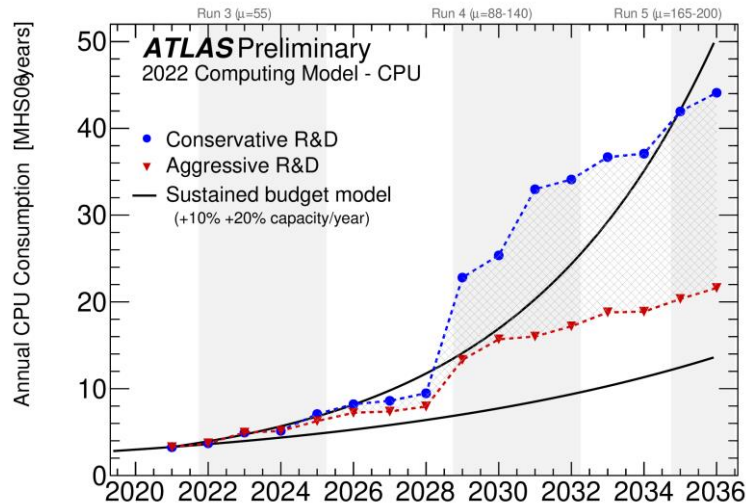
- Quantum Technology Initiative

Hardware Efficiency

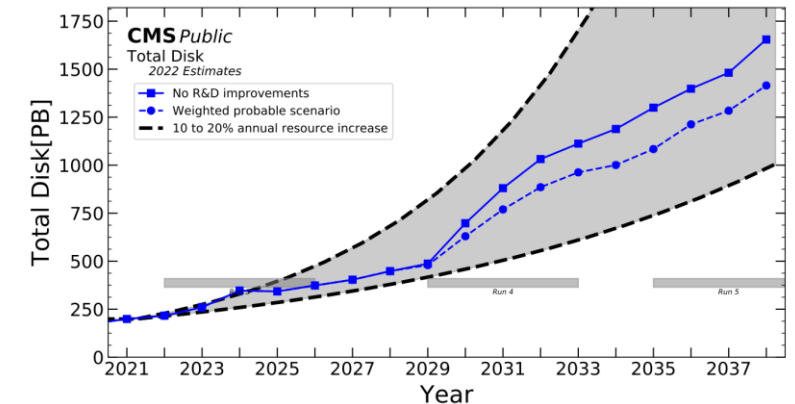
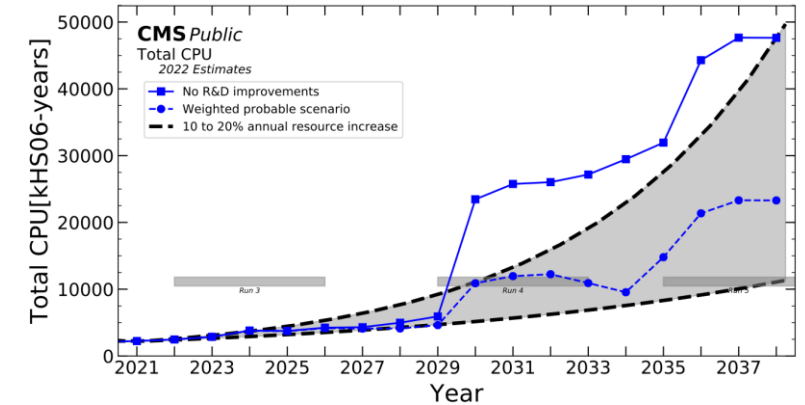
- Hardware cost is more and more dominated by market trends rather than technology
- The assumption of +20%/year in storage and CPU for the same budget is still holding, but with large fluctuations (see plots below and notice the log scale)
- It is not wise to expect better than this ...



ATLAS and CMS needs for HL-LHC



- The gap between available and needed resources is filling up, assuming the main R&D activities are successful
- Investing in further (identified) R&D activities would fill this gap further. Need more effort
- There are still large uncertainties



Optimising Software

Analysed the efficiencies of the main workloads of the experiments

- Developed a tool to automate the process of low-level analysis of CPU use
- Event Generation and Detector Simulation are the most CPU intensive workloads on the WLCG

Organise frequent C++ courses with a focus on efficiency

- Organised from within the community and free of charge – 250 trained in 4 courses
- [Next one](#) 11-13th October

Using accelerators to improve efficiency of Event Generation

- Re-engineering Monte Carlo event generator (Madgraph5_aMC@NLO) for GPU and vector instructions for CPUs
- Observe speedups close to the theoretical maximum for CPU vector instructions

Using accelerators to improve efficiency of Detector Simulation

- Collaboration with software dev group focussing on software performance and efficient computing

CIPEA proposal to compare electrical power consumption of HEP workflows on CPU/GPU

Quantum Technology Initiative



- Assess the **areas of potential quantum advantage** in HEP applications (QML, classification, anomaly detection, tracking)
- Develop **common libraries of algorithms, methods, tools**; benchmark as technology evolves
- Collaborate to the development of shared, **hybrid classic-quantum infrastructures**

Computing & Algorithms



- Identify and develop techniques for **quantum simulation** in collider physics, QCD, cosmology within and beyond the SM
- Co-develop quantum computing and sensing approaches by providing **theoretical foundations** to the identifications of the areas of interest

Simulation & Theory



- Develop and promote **expertise in quantum sensing** in low- and high-energy physics applications
- Develop quantum sensing approaches with emphasis on **low-energy particle physics measurements**
- Assess **novel technologies and materials** for HEP applications

Sensing, Metrology & Materials

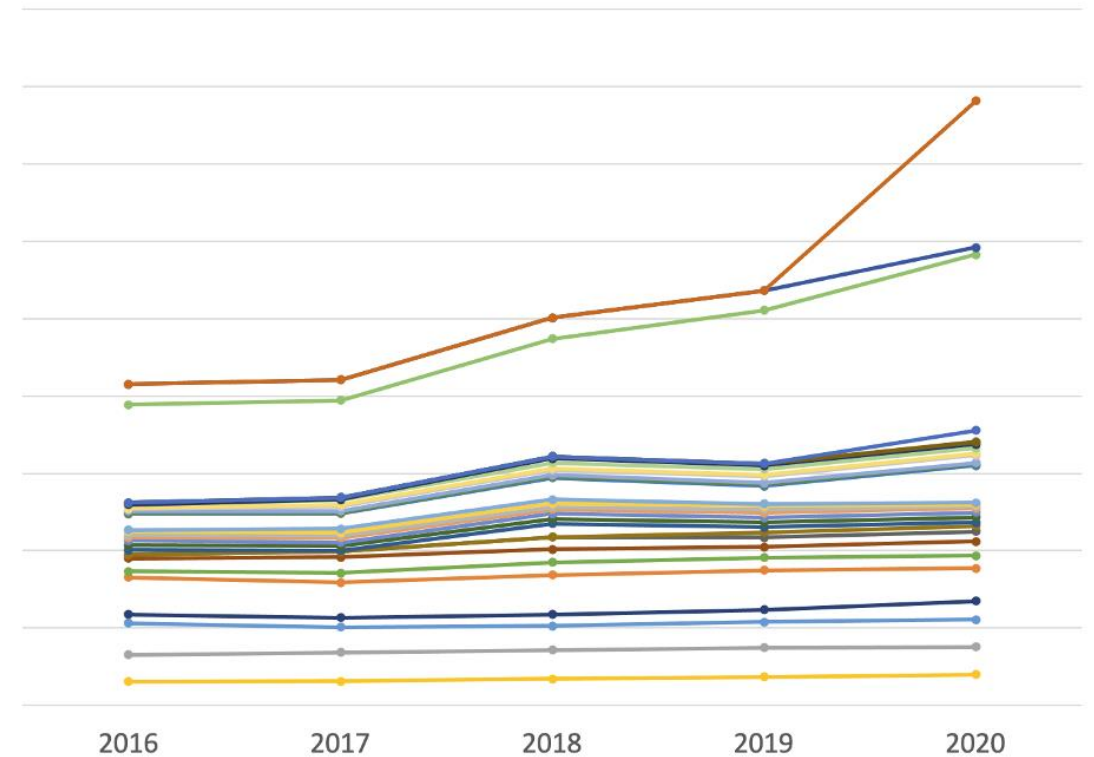


- **Co-develop CERN technologies relevant to quantum infrastructures** (time synch, frequency distribution, lasers)
- Contribute to the **deployment and validation of quantum infrastructures**
- Assess requirements and **impact of quantum communication on computing applications** (security, privacy)

Communications & Networks

The added challenge

- **Licences Cost growing at 3-6% per year!**
 - With some large step functions!



Opportunity

- **This school helps work on this together!**
 - Data Science, data management, data visualisation, data technologies, security, software design, machine learning

....and shape the future

On behalf of the management of the IT department at CERN, welcome and enjoy the two weeks with the great CSC team.