ATLAS Software and Computing and its evolution towards High-Luminosity LHC

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on behalf of the ATLAS S&C activity
The ATLAS Collaboration

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181 institutions (247 institutes) from 42 countries
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ATLAS Collaboration member nationalities
Over 5900 members of 163 nationalities
The ATLAS detector now

Phase-I upgrade

- New LAr L1 trigger
- Muons: New Small Wheels
- New software: Athena Multi-Threaded
The ATLAS detector in HL-LHC

Phase-II upgrade

New Inner Tracking detector (ITk)

High Granularity Timing Detector (HGTGD)

New muon chambers (new RPC and sMDT)

Upgraded Trigger and Data Acquisition system
● We just finished the second year of Run 3
  ○ Run 3 will end in 2025
● HL-LHC will start in 2029
The Physics challenge: Run 3

Our “interesting” data set size is measured in fb\(^{-1}\)

- Trigger rate (incl. delayed) ~3.5 kHz
- RAW size ~1.3 MB/ev
- Pile-up ~60
- ~10B real events/year
- ~30B MC events/year
The Physics challenge: HL-LHC (Run 4)

Our “interesting” data set size is measured in fb\(^{-1}\):

- Trigger rate \(\sim 10\) kHz
- RAW size \(\sim 4\) MB/ev
- Pile-up \(\sim 140\)
- \(~50B\) real events/year
- \(~150B\) MC events/year
The Computing Challenges

- Needs in terms of CPU power, disk and tape storage grow exponentially
  - Model updated in 2023 — no significant change to these projections
- Need for major R&D (and/or budgetary) effort to achieve HL-LHC physics potential
  - We have defined **Conservative R&D** and **Aggressive R&D** scenarios
    - N.B.: some projects for which we were/are not able to estimate the concrete impact are not (yet) included (e.g. GPU usage, FastChain simulation)
  - The black lines indicate the “flat budget” of 10% (lower line) and 20% (upper line)
Getting There from Here

- **ATLAS S&C HL-LHC Roadmap**
- Defines milestones and deliverables to get to the HL-LHC successfully
- R&D is ongoing
  - We’ve just spent some time discussing and reviewing “demonstrator” prototype projects for the HL-LHC
  - We see already lot of engagement!
- Integration and validation will require **time**
  - Late arriving R&D is risky
- In 2025 we expect to have in the TDR a detailed path to HL-LHC data taking
  - For example, accelerators: Yes or No
  - This is also the timeline for a decision from our trigger group on accelerators
Attention Points (Processing / CPU)

● No single application dominates CPU in 2031
● That’s good news and bad news for us
  ○ No silver bullet to “solving” our resource crunch
  ○ Also not fatal if one workflow isn’t improved
  ○ Can diversify our R&D — lots of interesting projects!
● Lots of ideas around these problems
  ○ Ideas need to be supported by active effort
● Biggest (by some metric) “CPU” efforts currently in:
  ○ Faster simulation (Geant4 optimization / on GPU, better fast simulation, FastChain…)
  ○ ML/accelerator-based charged particle tracking
  ○ New approaches to analysis
● Effort spread around reasonably well
  ○ Other ML/accelerator approaches to reconstruction, event generation, etc
  ○ Cleaning up “waste” (e.g. unused / failed production)
Attention Points (Storage)

- Several ongoing disk efforts as well
  - RNTuple (of course)
  - Lossy compression: difficulty is not the infrastructure but the physics validation
  - Augmentation to support sparse additional data
  - Constant revision / review of file contents
  - Alternative compression/settings — delicate balance
  - More aggressive deletion / recreation

- Anticipating our PHYSLITE format will serve a wide variety of analyses in Run 4
  - The disk model is driven by “remnants”: how many analyses don’t use PHYSLITE, and what they use instead. This is where the hard work goes!

- Very successful model for data distribution
  - Our “data carousel” uses tape effectively as a warm storage medium, reducing disk needs
  - Already have a mechanism for replication of popular datasets, and expecting to continue this way
High-Performance Computing

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- We have a mixture of “transparent” and “complex” HPCs today
  - Transparent: Mare Nostrum (ES), ND-T1 (NO/SE), Vega (SI), Karolina (CZ), CSCS (CH), (Leonardo (IT)), …
  - Complex: Cori/Perlmutter, Toubkal, …
HPC and Heterogeneity Philosophy

- We need more compute for the HL-LHC
- We need to keep our resources diverse
  - Expect HPCs to be an important component
- We do not need to run everywhere!!
  - Even a small HPC today could deliver a huge fraction of our required cycles
  - Vega is barely top 100 and is easily our #1 site — and we only use the CPU partition
  - This means we can find the most friendly HPC machines to use
- Corollary: we don’t need to run on all hardware
  - We are validating at scale ARM now (simulation and reconstruction already validated for physics) and have some GPU developments in the pipeline
  - It appears likely that ARM+CPU might already be sufficient for us
  - Portability languages will be key for us to port to other hardware
Some caveats: lots of “business as usual”

● **We have to keep on running the experiment while we are planning for major upgrades**
  ○ We are building a new ATLAS while we are running ATLAS
  ○ Failing is not an option

● **Lot of efforts that need to go into non-R&D work (or at the boundaries)**
  ○ Maintaining our current software - need to be able to process and analyse all existing data
  ○ Updates to database infrastructure
  ○ Improvements in metadata handling
  ○ Upgrade geometry and digitization
  ○ SW performance improvements
  ○ Re-tuning of Fast and G4 simulation for Run 4 new detector, and re-tuning reco
  ○ Distributed computing: lots of fundamental stuff, building blocks (tokens, OS, network, storage technologies)

● **R&D projects are on top of this:**
  ○ Balance (between R&D and “business as usual”) is key
  ○ And we need to have a strong focus on “impact”
Interesting & useful discussion of energy consumption during WLCG Workshop
  ○ Discussions dominated up to now by ATLAS members + sites

Happy to engage further on energy consumption, power, C02, etc

Various positive steps in terms of energy reduction
  ○ ATLAS full (Geant4) simulation fully validated on ARM (and now working on evgen+reco)
  ○ Clearly defined list of priorities for sites in case of power-shedding needs (switching off disk should be the last resort)
Summary

● ATLAS is facing interesting, difficult, but solvable software and computing challenges for the HL-LHC
  ○ One of the biggest challenges not mentioned here is supporting and retaining skilled developers

● Now is a great time for R&D, demonstrators, prototypes, and pilot projects!
  ○ From experience we know how long and painful integration in our frameworks and full physics validation are: we should take this into consideration to manage our expectations!

● Focusing our efforts on common, shared objectives is paramount
  ○ The way in which we work can make the difference between success and failure!
  ○ Fragmented efforts are lethal — and ineffective

● This was a “quick” overview of some of the challenges
  ○ Much more in our HL-LHC Roadmap, and we are happy to discuss further with anyone interested in contributing!
Thank you!
CERN Hardware cost