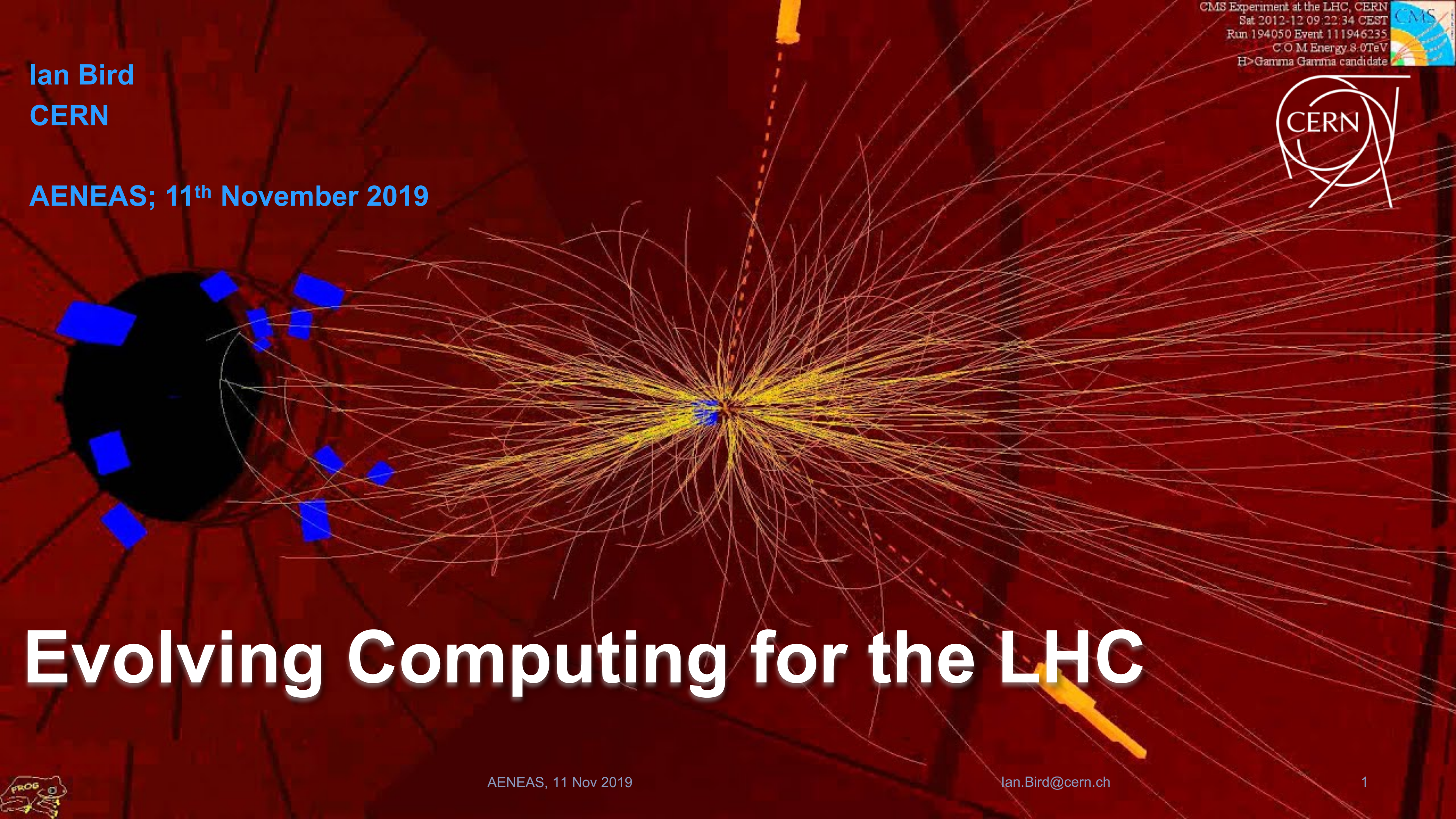
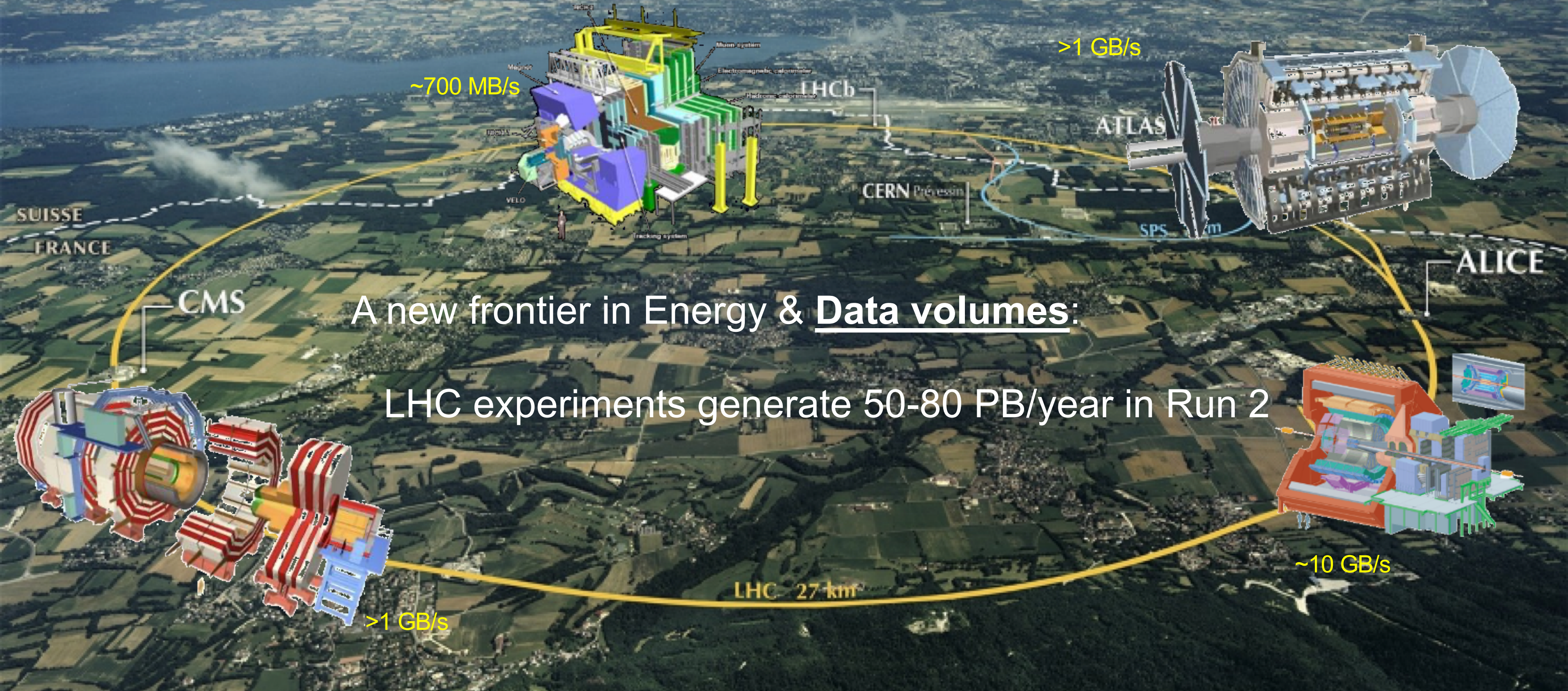
Ian Bird
CERN

AENEAS; 11th November 2019

Evolving Computing for the LHC



The Large Hadron Collider (LHC)



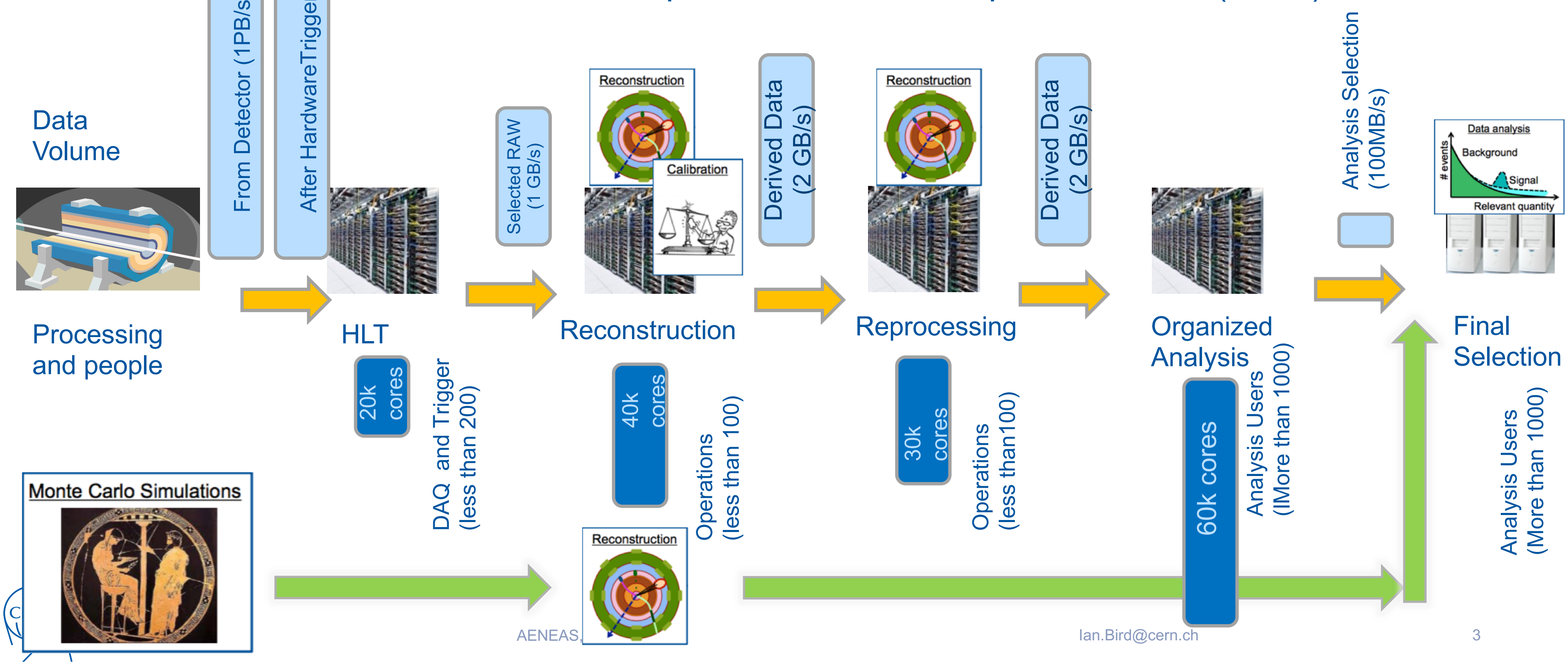
A new frontier in Energy & **Data volumes**:

LHC experiments generate 50-80 PB/year in Run 2

Data Analysis at the LHC

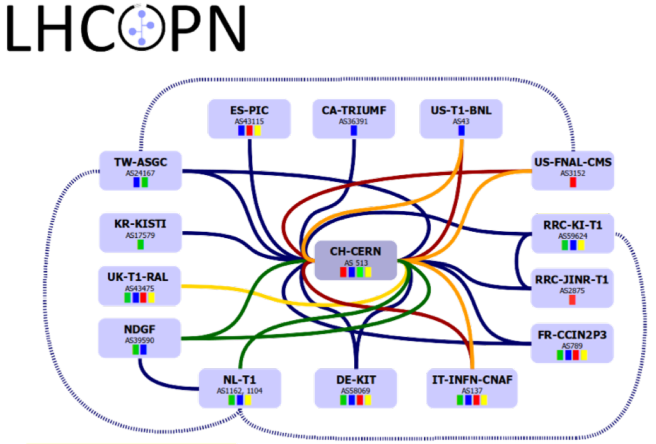
The process to transform raw data into useful physics datasets

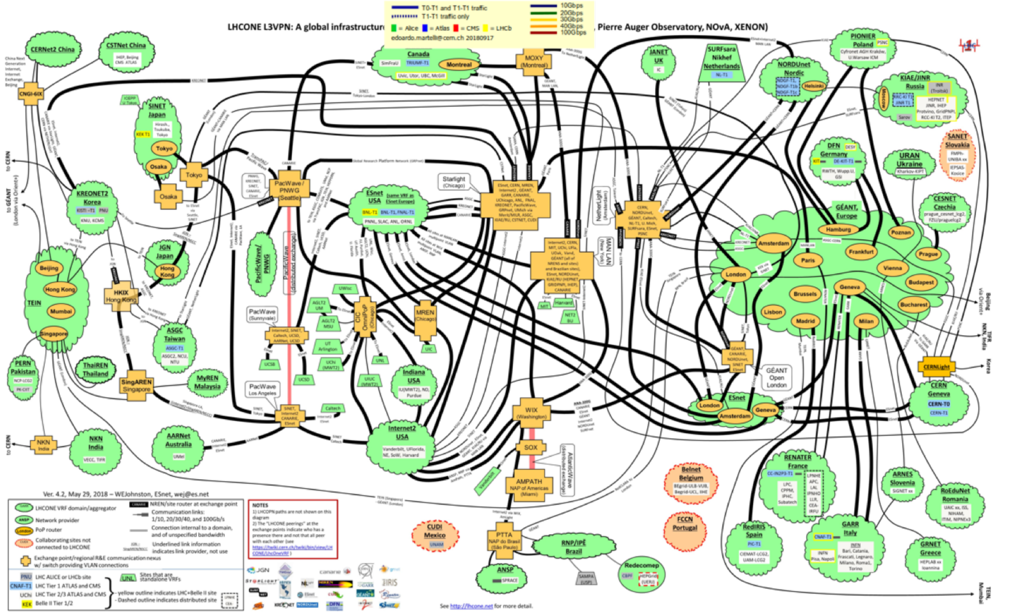
- This is a complicated series of steps at the LHC (Run2)

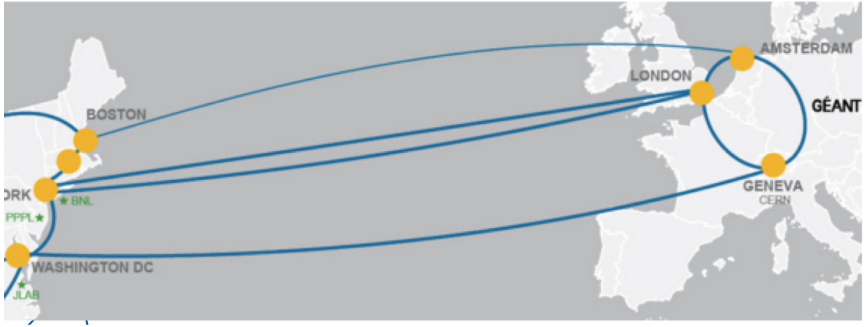


Scale of computing needs

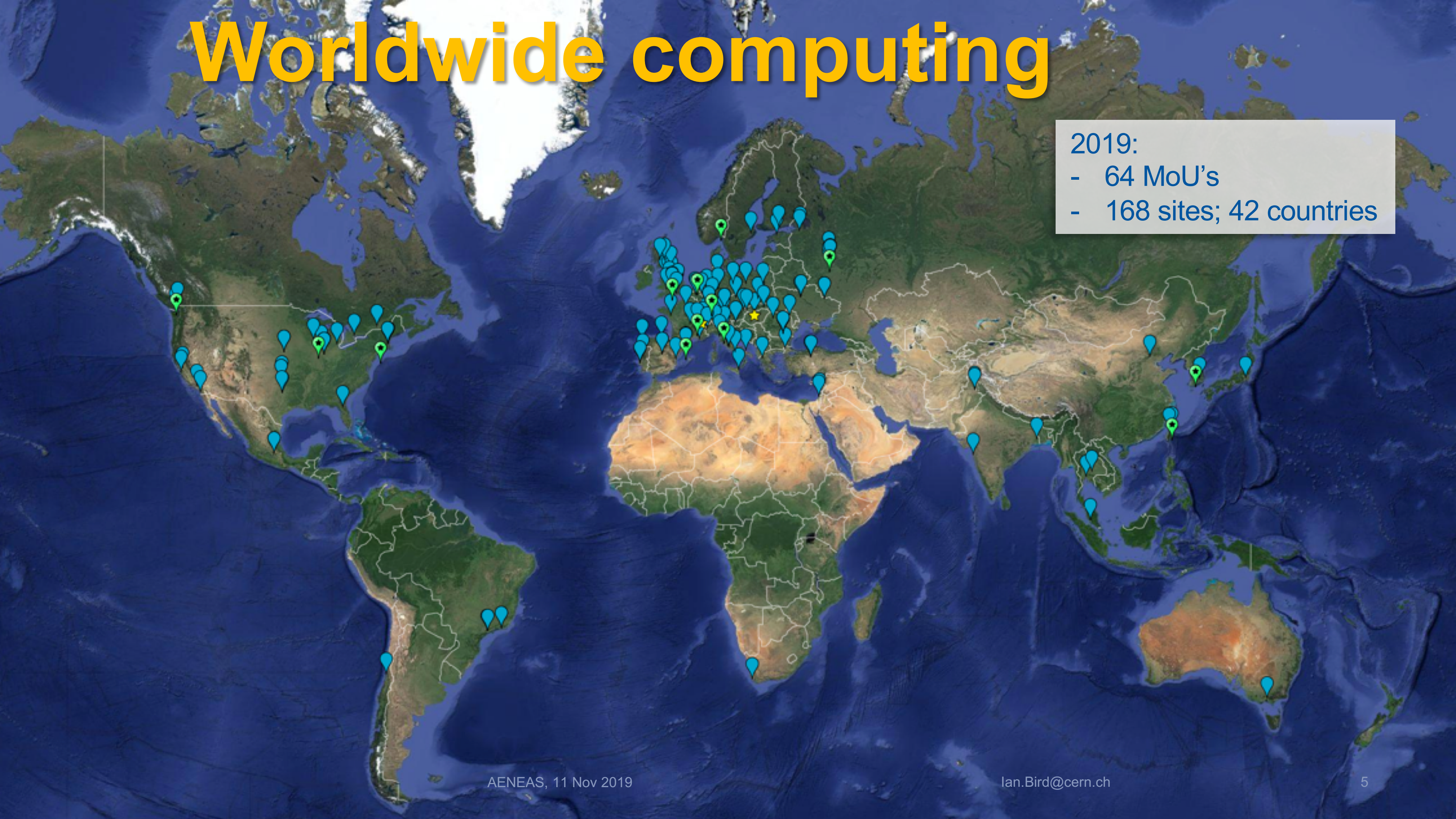
- CPU:
  - ~ 1 million cores fully occupied ("x86")
- Storage
  - ~ 1 EB (~500 PB disk, >500 PB tape)
- Global networking
  - Some private 10-100 Gbps
  - LHCOne – overlay



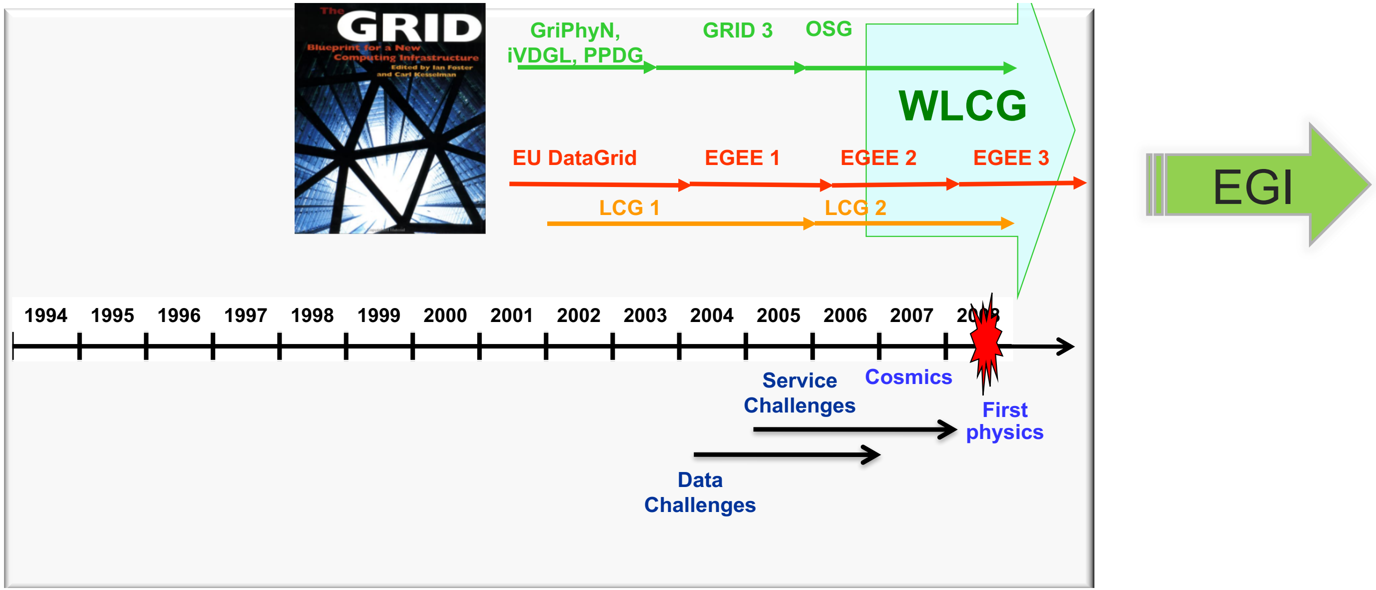




Worldwide computing

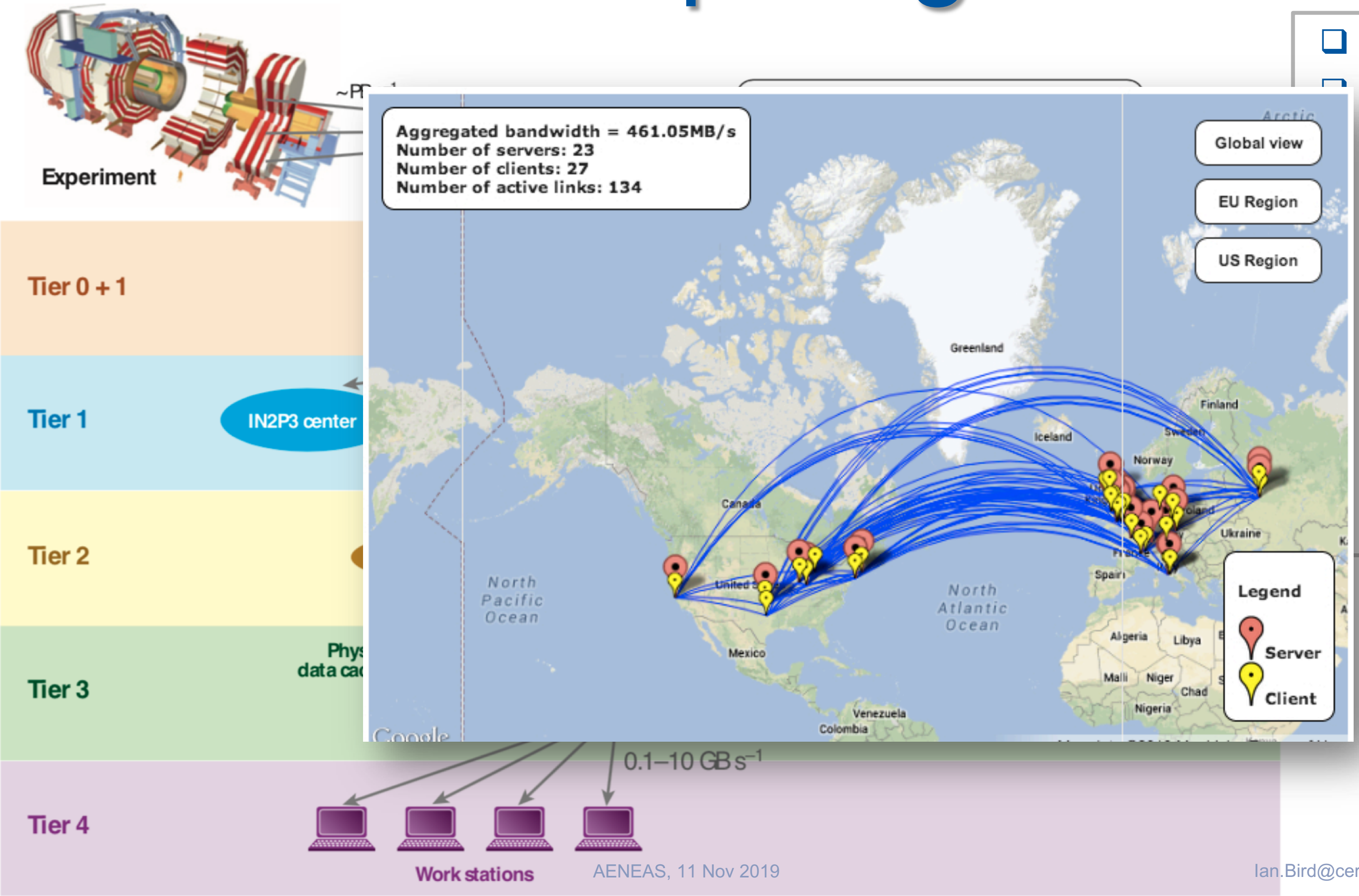


2019:
- 64 MoU's
- 168 sites; 42 countries



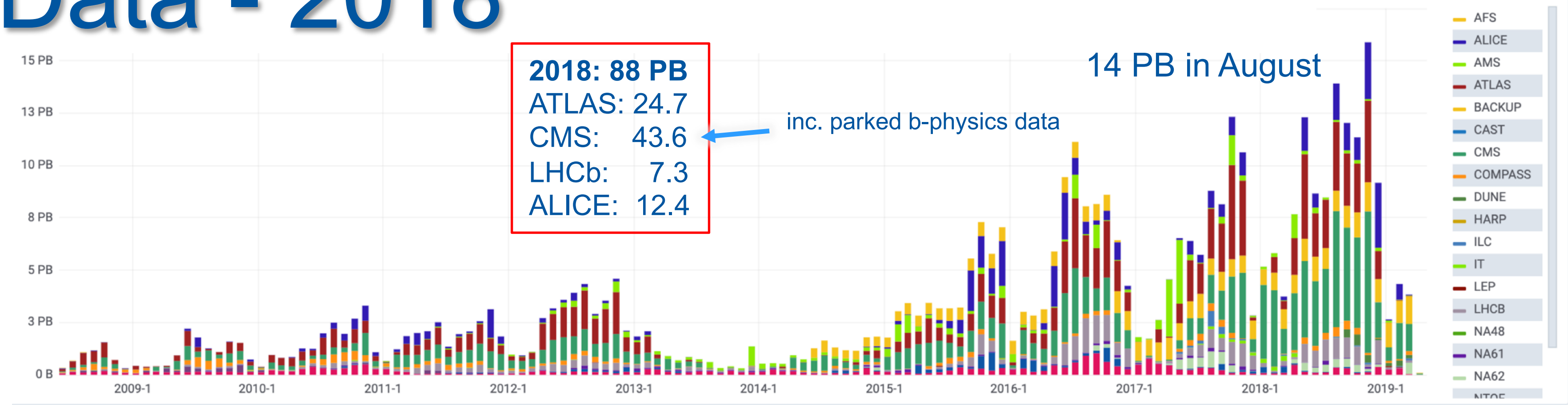
- When we started LHC computing (~2001)
  - There were no internet companies, no cloud computing – Google was a search engine, Amazon, etc. did not exist
- We had to invent all of the tools from scratch
  - At CERN we had no tools to manage a data centre at the scale we thought was needed (no commercial or OS tools existed)
    - Initial tools developed through EU Data Grid
- Grid ideas from computer science did not work in the real world at any reasonable scale
  - We (EU, US, LHC grid projects) had to make them work at scale
  - We had to invent trust networks to convince funding agencies to open their resources to federated users
- Our users were not convinced that any of this was needed ;-)

Evolved computing model



- Model from 1999
- Uncertainty over network performance, reliability
- Focus on distributing data *globally* to compute resources
- No concept of data remote from compute
- Quickly evolved

Data - 2018



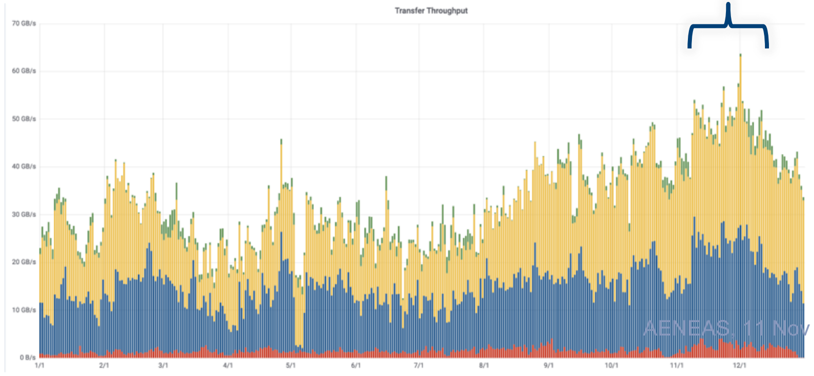
2018: 88 PB
ATLAS: 24.7
CMS: 43.6
LHCb: 7.3
ALICE: 12.4

inc. parked b-physics data

14 PB in August

Data transfers

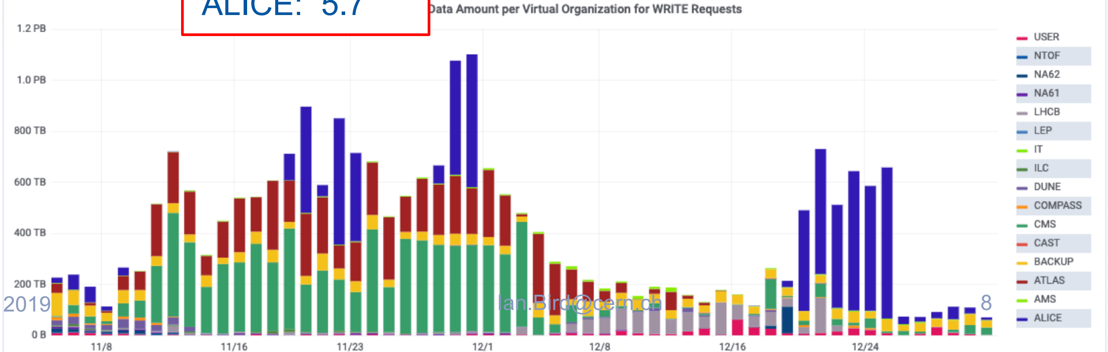
HI Run



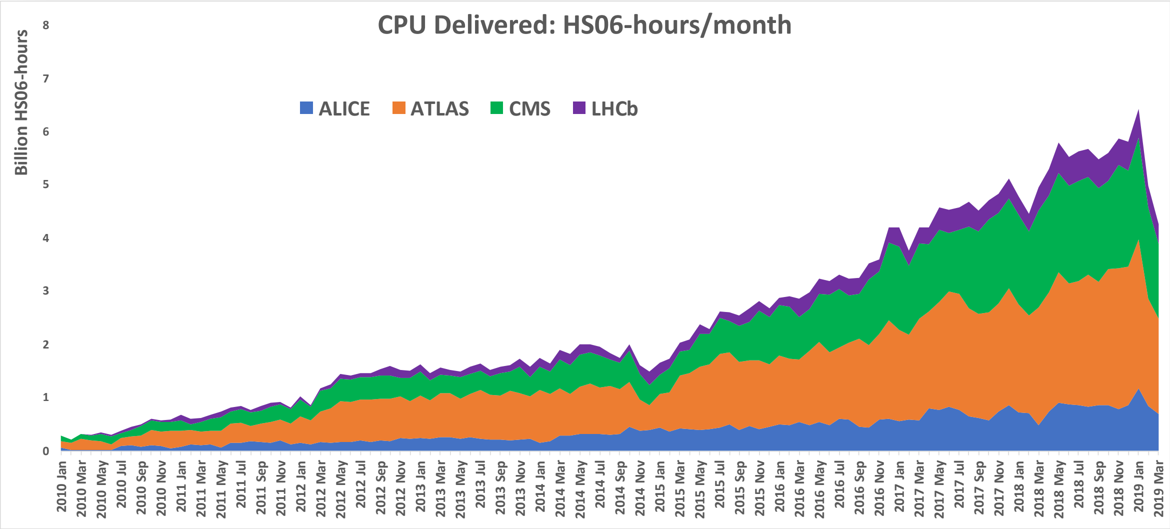
2018: 19.8 PB
ATLAS: 5.2
CMS: 7.7
LHCb: 1.2
ALICE: 5.7

HI Run

18.6 PB in November

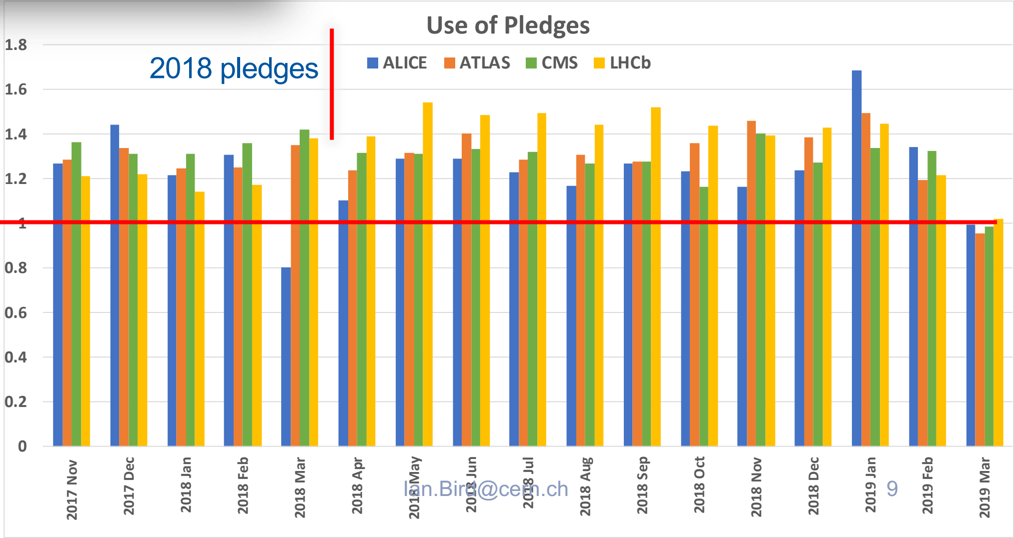


CPU Delivered



New peak: ~270 M HS06-days/month

~ 860 k cores continuous



Some lessons and comments

- A federated infrastructure is of tremendous value and importance
  - This is the *key* feature that identifies our collaborative distributed infrastructure
  - Even though the X.509 model was difficult to use and manage
  - Security coordination; policies, incident response, vulnerability & threat intelligence is of huge value
  - Sociological – inclusivity

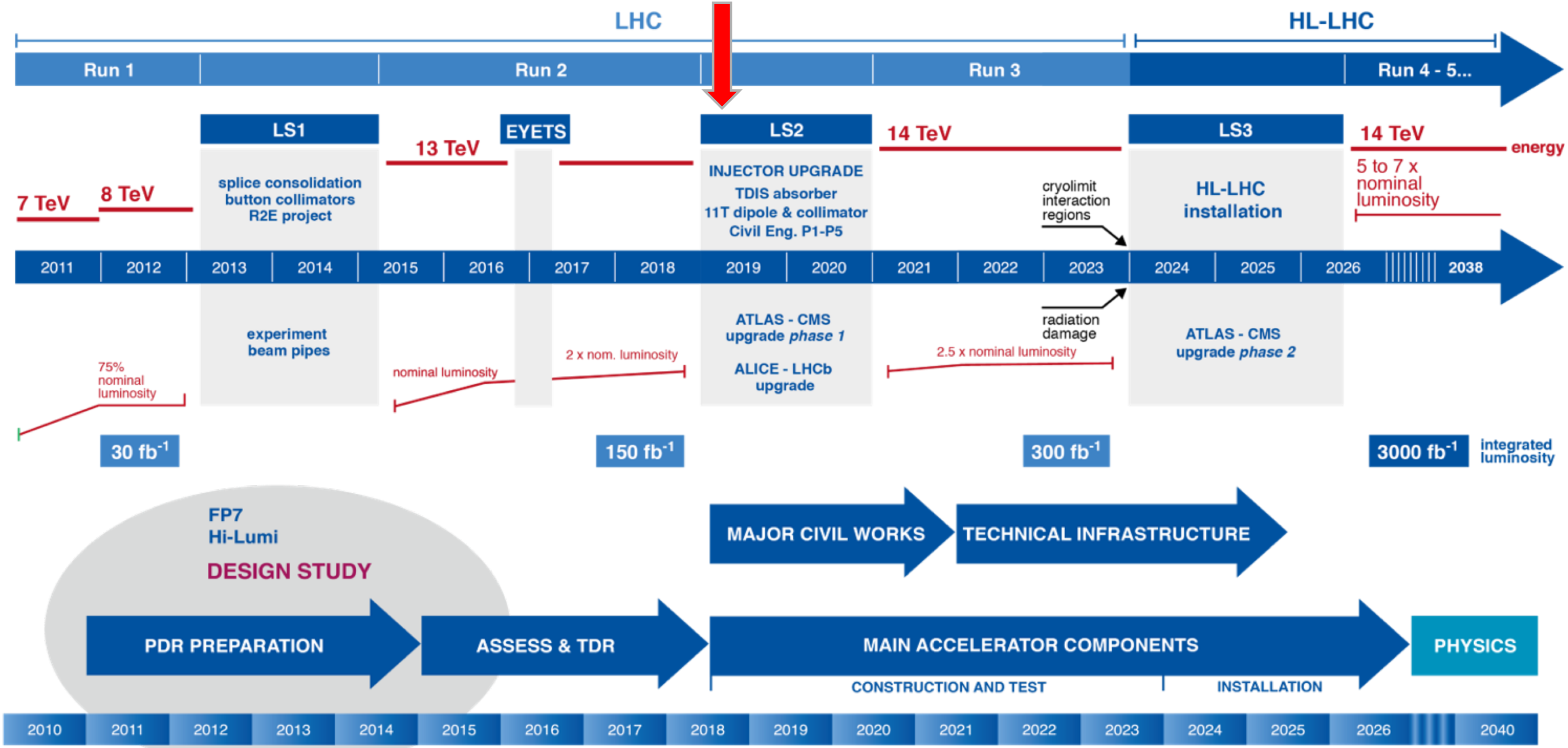
- The network is a fundamental resource and opportunity, not a problem to be solved
  - Redundancy and distribution of services as originally foreseen was unnecessary, complex, and expensive
  - Today service model is much simplified and streamlined

- Today's operational structure is very simple – coordination at a high level, no need for the heavyweight operations centres
  - Integrated global ticketing system was essential

- Distributed data management and storage is expensive – hardware and operations
  - Data pre-placement is not an optimal strategy (it is a complex problem)

- Hardware and cost evolution is becoming a serious concern –
  - "Moore's law" as we assumed it is broken
  - Future of storage technology is a concern – tape and disk
  - The future computational resources are very heterogenous

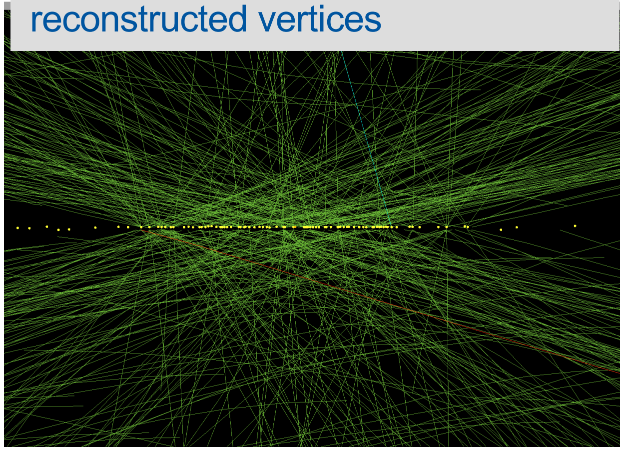
LHC / HL-LHC Plan



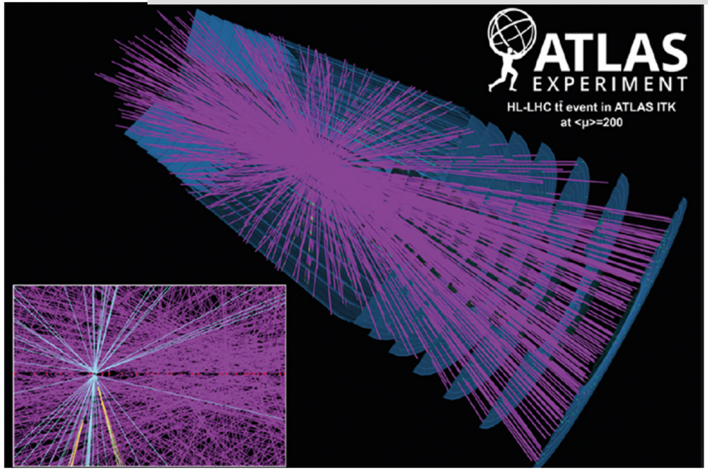
Events at HL-LHC

- Increased complexity due to much **higher pile-up** and higher trigger rates will bring several challenges to reconstruction algorithms

CMS: event from 2017 with 78 reconstructed vertices



ATLAS: simulation for HL-LHC with 200 vertices



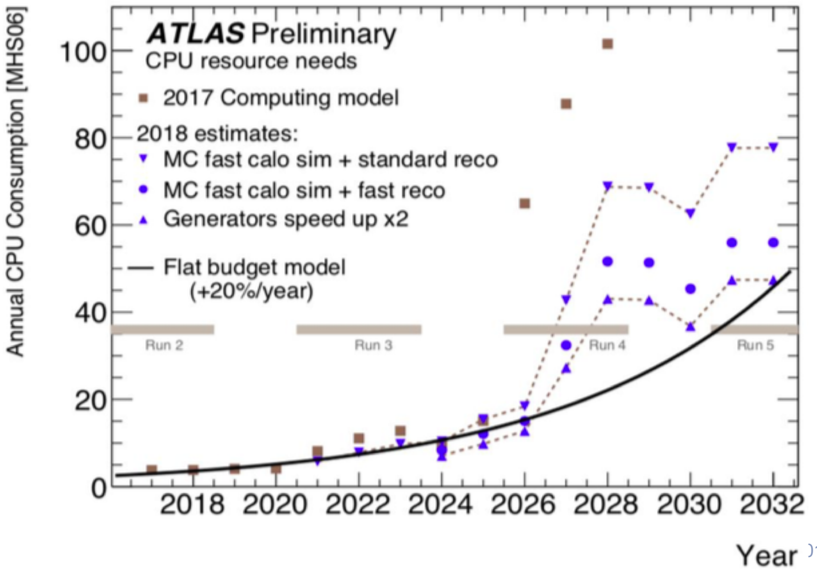
The HL-LHC computing challenge

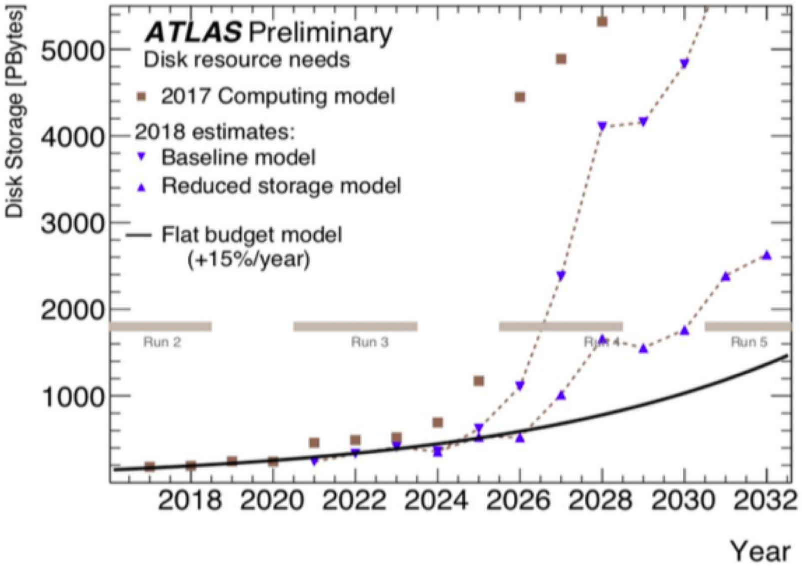
2017:

- HL-LHC needs for ATLAS and CMS are above the expected hardware technology evolution (15% to 20%/yr) and funding (flat)
- The main challenge is storage, but computing requirements grow 20-50x

2019:

Continually improving estimates – evolve computing model, software, infrastructure





Evolution of HEP computing

HSF-CWP-2017-01
December 15, 2017

arXiv:1712.06982v5 [physics.comp-ph] 19 Dec 2018

A Roadmap for HEP Software and Computing R&D for the 2020s

HEP Software Foundation[1]

ABSTRACT: Particle physics has an ambitious and broad experimental programme for the coming decades. This programme requires large investments in detector hardware, either to build new facilities and experiments, or to upgrade existing ones. Similarly, it requires commensurate investment in the R&D of software to acquire, manage, process, and analyse the shear amounts of data to be recorded. In planning for the HL-LHC in particular, it is critical that all of the collaborating stakeholders agree on the software goals and priorities, and that the efforts complement each other. In this spirit, this white paper describes the R&D activities required to prepare for this software upgrade.

[1] Authors are listed at the end of this report.

https://doi.org/10.1007/s41781-018-0018-8

WLCG-LHCC-2018-001
05 April 2018

WLCG Strategy towards HL-LHC

Executive Summary

The goal of this document is to set out the path towards computing for HL-LHC in 2026/7. Initial estimates of the data volumes and computing requirements show that this will be a major step up from the current needs, even those anticipated at the end of Run 3. There is a strong desire to maximise the physics possibilities with HL-LHC, while at the same time maintaining a realistic and affordable budget envelope. The past 15 years of WLCG operation, from initial prototyping through to the significant requirements of Run 2, show that the community is very capable of building an adaptable and performant service, building on and integrating national and international structures. The WLCG and its stakeholders have continually delivered to the needs of the LHC during that time, such that computing has not been a limiting factor. However, in the HL-LHC era that could be very different unless there are some significant changes that will help to moderate computing and storage needs, while maintaining physics goals. The aim of this document is to point out where we see the main opportunities for improvement and the work that will be necessary to achieve them.

During 2017, the global HEP community has produced a white paper - the Community White Paper (CWP), under the aegis of the HEP Software Foundation (HSF). The CWP is a ground-up gathering of input from the HEP community on opportunities for improving computing models, computing and storage infrastructures, software, and technologies. It covers the entire spectrum of activities that are part of HEP computing. While not specific to LHC, the WLCG gave a charge to the CWP activity to address the needs for HL-LHC along the lines noted above. The CWP is a compendium of ideas that can help to address the concerns for HL-LHC, but by construction the directions set out are not all mutually consistent, not are they prioritised. That is the role of the present document - to prioritise a program of work from the WLCG point of view, with a focus on HL-LHC, building on all of the background work provided in the CWP, and the experience of the past.

At a high level there are a few areas that clearly must be addressed, that we believe will improve the performance and cost effectiveness of the WLCG and experiments:

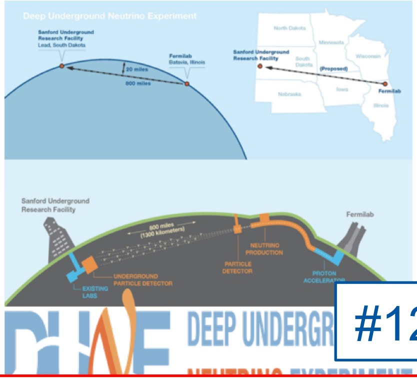
- **Software:** With today's code the performance is often very far from what modern CPUs can deliver. This is due to a number of factors, ranging from the construction of the code, not being able to use vector or other hardware units, layout of data in memory, and end-end I/O performance. With some level of code re-engineering, it might be expected to gain a moderate factor (x2) in overall performance. This activity was the driver behind setting up the HSF, and remains one of the highest priority activities. It also requires the appropriate support and tools, for example to satisfy the need to fully automate the ability to often perform physics validation of software. This is essential as we must be adaptable to many hardware types and frequent changes and optimisations to make the best use of opportunities. It also requires that the community develops a level of understanding of how to best write code for performance, again a function of the HSF.

1

https://cds.cern.ch/record/2621698

Synergies

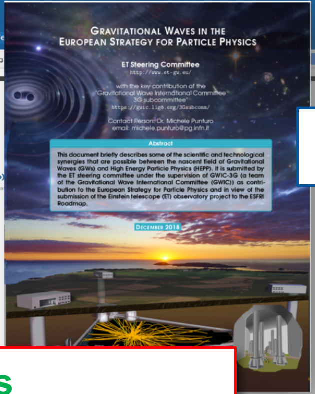
CERN COURIER
Aug 11, 2017
SKA and CERN co-operate on extreme computing



#126

Joint Gravitational Waves and CERN Meeting
Friday 1 Sep 2017, 09:00 → 20:00 Europe/Zurich
500-1-001 - Main Auditorium (CERN)
Federico Ferrini (INFN Sezione di Pisa (INFN)), Francesco Fide

09:00 → 09:20 Welcome and introduction to the meeting
Speakers: Eckhard Elsen (CERN), Federico Ferrini (EGO)
09:20 → 09:45 GW from a particle physics perspective
Speaker: Gian Giudice (CERN)
09:45 → 10:10 The New Era of Precision Gravitational-Wave (astro)
Speaker: Alessandra Buonanno
10:10 → 10:30 Discussion



#64

Recent European Strategy for Particle Physics

Common theme in many contributions is the desire to collaborate with LHC R&D work
➔ implies governance evolution

Physics European Consortium (APPEC)
APPEC Contribution to the European Particle Physics Strategy
December 17, 2018
Editorial Board:
S. Katsanevas, A. Masiero, T. Montaruli, J. de Kleuver, A. Haungs
Contact Person:
T. Montaruli (APPEC Chair from Jan. 1, 2019)
Email: teresa.montaruli@unige.ch
Website : http://www.appec.org
APPEC

#84

APS Division of Particles and Fields Response to European Strategy Group Call for White Papers:
Tools for Particle Physics
DPF Executive Committee and Strategy Whitepaper Editing Grou
dpfstrategy@fnal.gov
December 18, 2018
Abstract
The U.S. particle physics strategy process is summarized in a companion white paper that also describes U.S. activities related to the five P5 science drivers. Additional activities within the U.S. particle physics program that are critical to progress in our field are described here.

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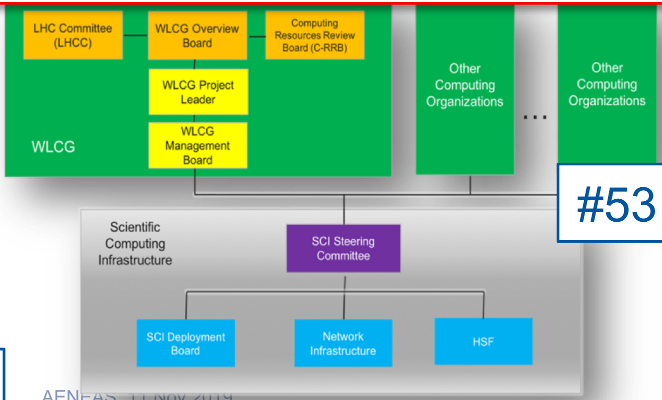

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#77
The International Linear Collider
A Global Project

Statement of the Pierre Auger Collaboration as input for the European Particle Physics Strategy Update 2018 – 2020
Ralph Engel (auger_spokespersons@fnal.gov),
on behalf of the Pierre Auger Collaboration

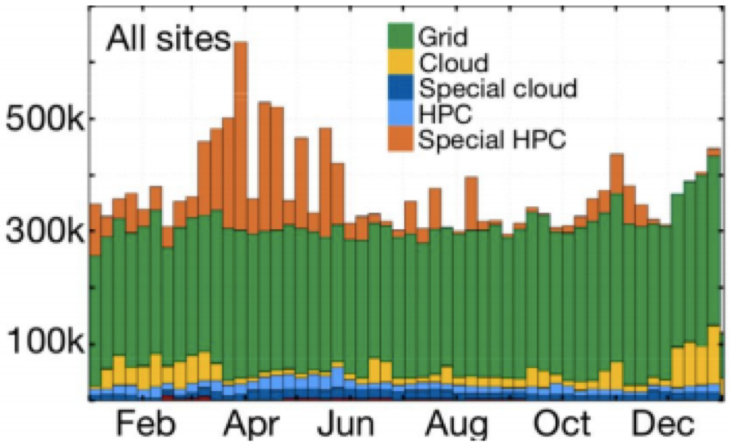
#117

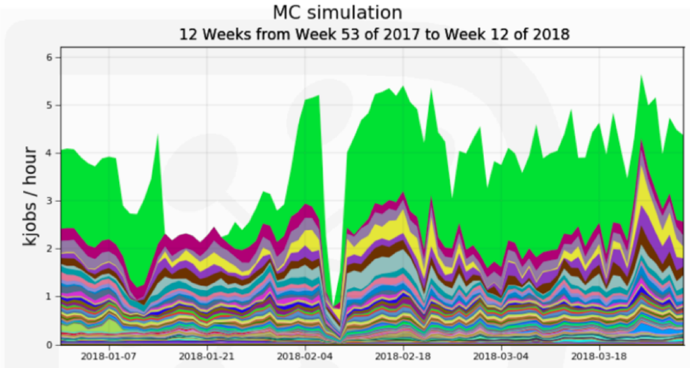
Common challenges

- Management of Exabyte- scale science data
  - And associated tools, networks, infrastructure
- Move from “simple” x86-like clusters to very heterogenous resources
  - Use of HPC and Exascale computing resources
- Infrastructures & centres likely to be common between HEP & Astronomy, Astroparticle, GW, etc.
- Software challenge – associated with the above
  - How to easily move code between various compute resources, validate correctness, adapt to new architectures, etc.
- Develop and retain skills in software and computing
  - In the scientific community – as well as with specialists
  - Issue of recognition in academic environments

Heterogenous computing

- Today get opportunistic use of many types of compute, in particular HPC systems, and HLT
- In future, this heterogeneity will expand; we must be able to make use of all types:
  - Non-x86 (esp GPU), HPC, clouds, HLT farms (inc FPGA?)





Use of HPC is challenging

- HPC are optimized for tightly coupled calculations, HEP applications are not designed to exploit those capabilities
    - HEP use cases require finer granularity than typical HPC applications
    - Hard to optimize: The software framework for each of the experiments is several million lines of C++ & Python and contributions from ~1000 people
- Each resource is huge but independent
    - Authorization, access, interfaces are all specific to the site
- Data access: HEP workflows often make heavy use of data and experiment specific services
    - Limitations in ingoing/outgoing access (policy) require rethinking
    - HEP data scale not suited to data distribution on an HPC
- Interfaces: Need for common interfaces for access, data handling and site services (connectivity, s/w distribution, containers, ..)
    - FNAL HEPCloud and CERN have similar approaches

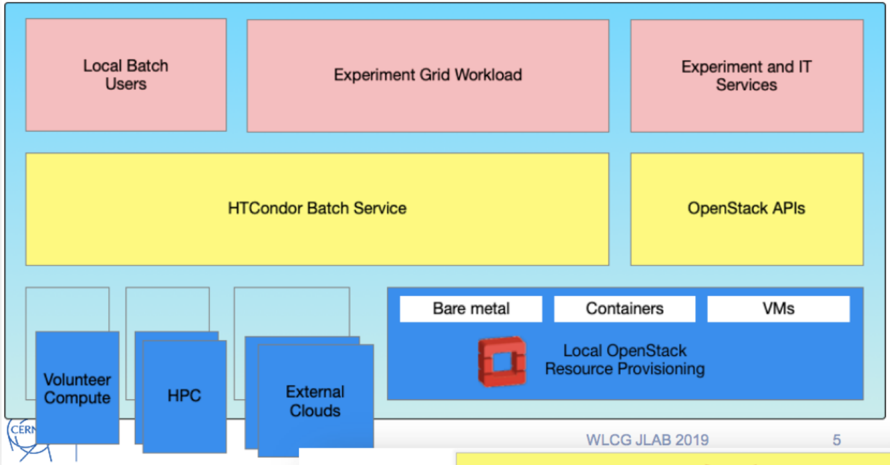
HEP engagement with DOE & NSF in USA and (together with SKA) with PRACE and EuroHPC in Europe and participating in BDEC2 workshops

EuroHPC
Joint Undertaking

BDEC2
BIG DATA AND EXTREME-SCALE COMPUTING 2

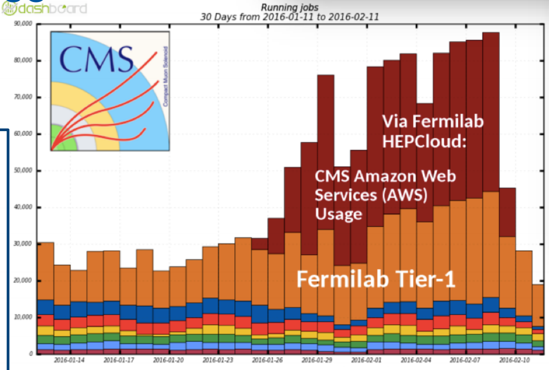
Heterogenous compute

- Requires:
  - Common provisioning mechanisms, transparent to users
  - Facilities able to control access (cost), appropriate use, etc
- HPC, Clouds, HLT will not have (affordable) local storage service (in the way we assume today)
  - Must be able to deliver data to them when they are in active use

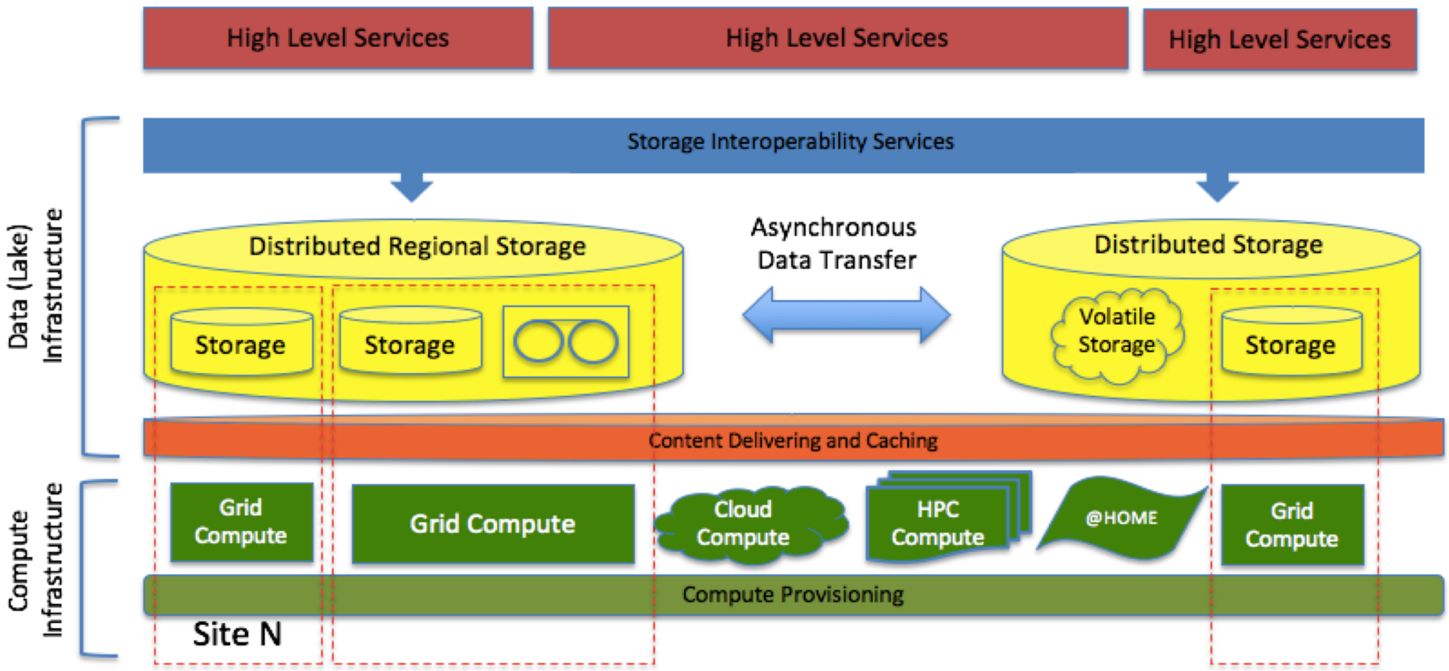


Deployed in a hybrid cloud mode:

- Procurers' data centres
- commercial cloud service providers
- GEANT network and EduGAIN Federated Identity Management



Data delivery "data lake (cloud)"



Idea is to localize bulk data in a cloud service (Tier 1's ➔ data lake): minimize replication, assure availability

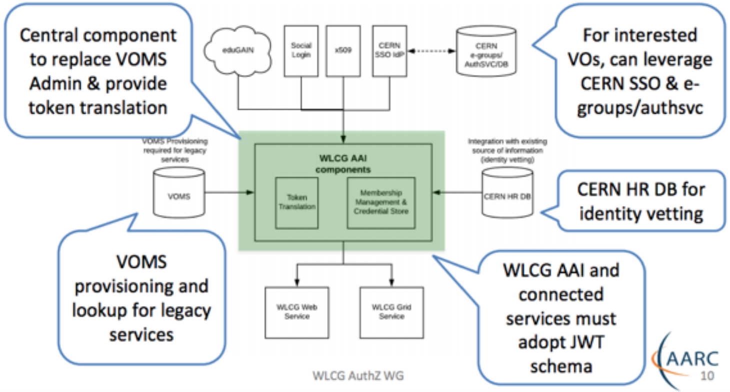
Serve data to remote (or local) compute – grid, cloud, HPC, ???

Simple caching is all that is needed at compute site

Works at national, regional, global scales

Data management and storage

- Set of R&D projects to prototype such a data management infrastructure – and associated tools
- Aims:
  - Reduce the global cost of storage (hw and operations)
  - Enable a more effective use of existing storage
  - Be able to efficiently and scalably deliver data to large, remote, heterogenous, compute resources (LHC Tier centres or HPC, clouds, other opportunistic)
  - Build a common set of DM tools that can be used by a broad set of scientific experiments
    - Today LHC, DUNE, SKA, Belle-II, GW-3G, and others are all looking at a common set of identified tools
- Also collaboratively (LHC+SKA with GEANT) looking at underlying data transfer and network tools (replace gridftp, network protocols, etc.)
- Evolution of the AAI solutions from X.509 towards token-based systems
  - Following AARC, AARC2 models
  - In line with most modern network services



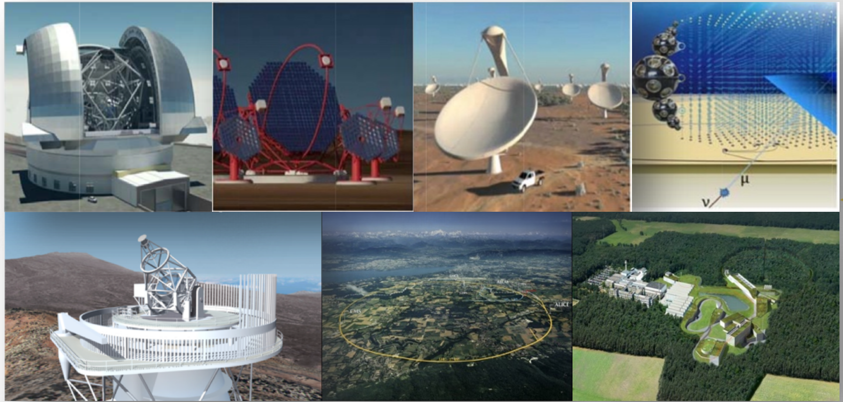
ESFRI Science Projects

HL-LHC	SKA
FAIR	CTA
KM3Net	JIVE-ERIC
ELT	EST
EURO-VO	EGO-VIRGO
(LSST)	(CERN,ESO)

ESCAPE

European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures

Horizon 2020 funded project



EUROPEAN OPEN SCIENCE CLOUD

Goals:

Prototype an infrastructure for the EOSC that is adapted to the Exabyte-scale needs of the large ESFRI science projects.

Ensure that the science communities drive the development of the EOSC.

Has to address *FAIR* data management, long term preservation, open access, open science, and contribute to the EOSC catalogue of services.

Work Packages

WP2 – Data Infrastructure for Open Science

WP3 – Open-source scientific Software and Service Repository

WP4 – Connecting ESFRI projects to EOSC through VO framework

WP5 – ESFRI Science Analysis Platform

Data centres (funded in WP2)

CERN, INFN, DESY, GSI, Nikhef, SURFSara, RUG, CCIN2P3, PIC, LAPP, INAF

Task 2.2 Content Delivering and Caching

Task 2.2 Storage Orchestration Service

Task 2.1 Storage Services

Task 2.1 Data transfer services

Task 2.3 Efficient Access to Compute

HTC/Grid

HPC

Cloud/ commercial

citizen

Task 2.4 Networking

Task 2.5 AAI

Software

HSF Set up in response to recognition that software will be key to success for HL-LHC and the future

HEP Software Foundation

The HEP Software Foundation (HSF) facilitates coordination and common efforts in high energy physics (HEP) software and computing internationally.

The HSF is now beginning community process to develop a consensus roadmap for HEP Software and Computing R&D for the 2020s. More infomation about this can be found on the Community White Paper (CWP) page on the HSF site.

Meetings

All our activities and ideas are discussed weekly in our HSF meeting. Feel free to participate!

- HSF Weekly Meeting #71, November 3, 2016
- HSF Weekly Meeting #69, September 15, 2016
- HSF Weekly Meeting #68, September 8, 2016

Full list of meetings »

Newsletter

If you would like to stay updated, please subscribe to our newsletter:

- Third HSF Workshop
- Sharing ideas and code
- HSF Newsletter - Logo Contest and Packaging Working Group

Older newsletters »

Activities

Our plenty of activities span from our working groups, organizing events to supporting projects as HSF projects, and channeling communication within the community with discussion forums, technical notes and a knowledge base.

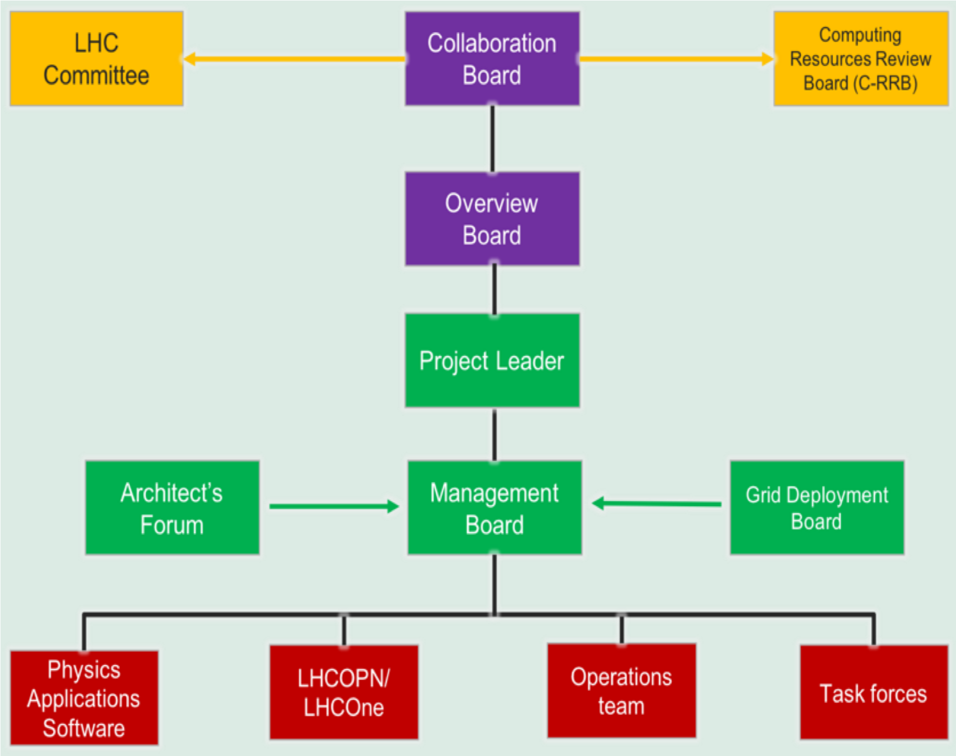
How to get involved »

We have discussed this problem with SKA and PRACE

Some national initiatives have started

Much more is needed

Governance / organization



LHCC: Scientific Review (4x/year)
RRB: Funding Agency Review (2x/year)

Overview Board: Strategic Advice of full collaboration

Resource Process (in MoU)

- The physics programme is reviewed and approved by the LHCC
  - Also assumptions that affect compute needs: e.g. how much simulation is required
- C-RRB meets twice a year
  - Informed by Scrutiny Group of computing experts
- Review use of pledged resources
  - Efficiency, usage levels, etc.
- Review Experiment Requests for resources
  - 2 year outlook: in Year N requests for N+2 are presented
  - Pledges from FA's are made for year N+1
  - Requests should be realistic in light of approved physics programme
- Generally the FA's pledge their "share"
  - Usually informed by the fraction of scientific authors from that country
  - Usually pledges are within 10-20% of requests (uncertainty level)
  - Occasionally funding may fail in a given year – experiments work around
  - FA's give guidance on what are realistic expectations
    - E.g. we are in a regime of "flat budgets" for the foreseeable future

Conclusions

- Distributed, federated, computing and data analysis is now a proven technology
- HL-LHC brings us Exabyte scale data and computing challenges
  - Many synergies with astronomy, astroparticle, and other HEP experiments
- A strong willingness to develop common infrastructure and tools is already apparent
  - Based on 15 years of development and attrition
- Investment in and recognition of software skills is essential
- Prototypes, like ESCAPE, give a real opportunity to bring science-led infrastructure and tools to the EOSC
- Science is now global – infrastructures must be too