Overview of the US ATLAS Program

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ATLAS EXPERIMENT

Status: March 2021

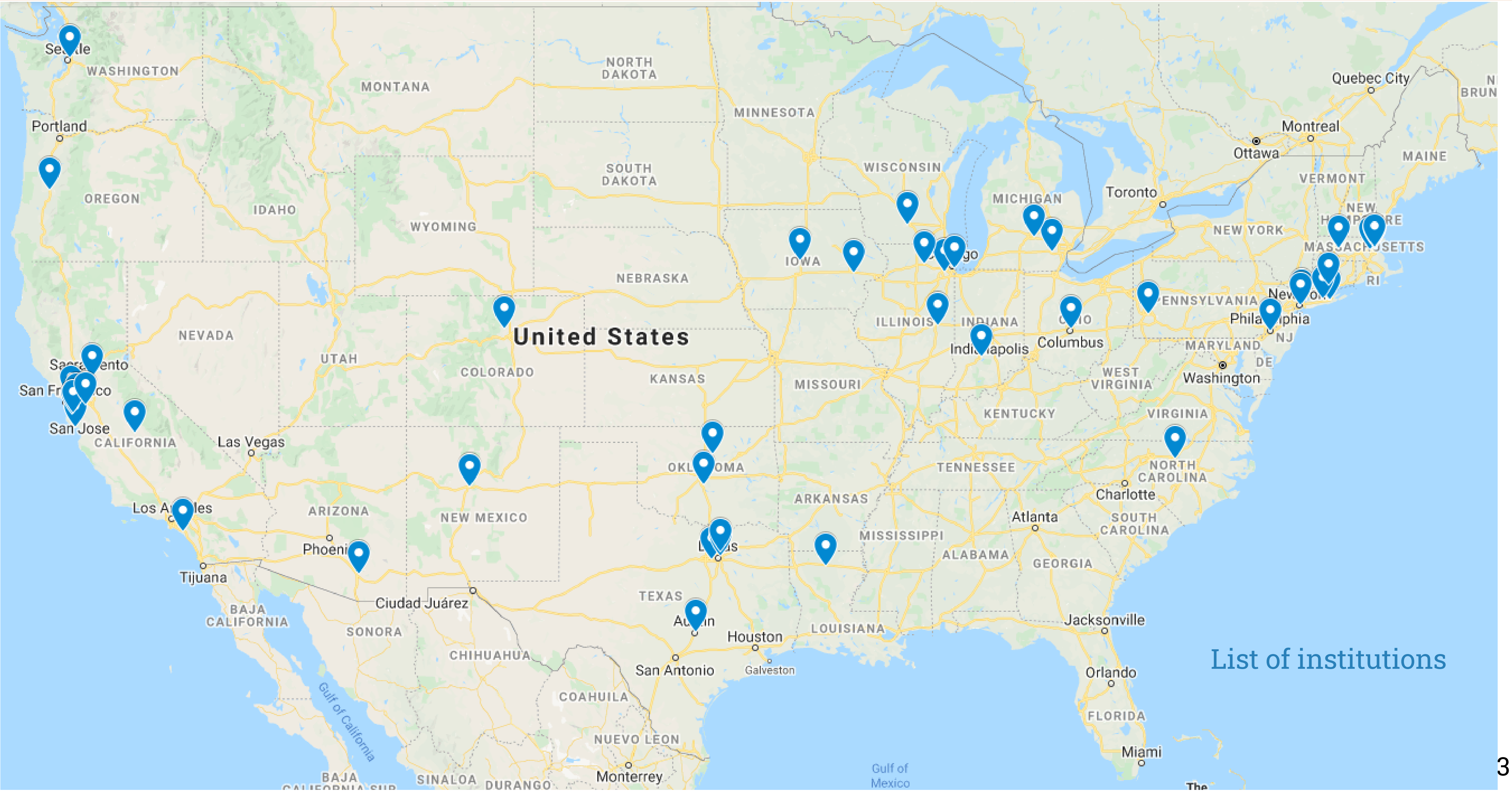
- Argentina
- Armenia
- Australia
- Austria
- Azerbaijan
- Belarus
- Brazil
- Canada
- Chile
- China
- Colombia
- Czech Republic
- Denmark
- France
- Georgia
- Germany
- Greece
- Israel
- Italy
- Japan
- Mongolia
- Morocco
- Netherlands
- Norway
- Philippines
- Poland
- Portugal
- Romania
- Russia
- Serbia
- Slovakia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- Taiwan
- Turkey
- UK
- USA
- CERN
- JINR

ATLAS Collaboration

180 institutions (236 institutes) from 40 countries

ATLAS EXPERIMENT

US ATLAS: Where Are We?

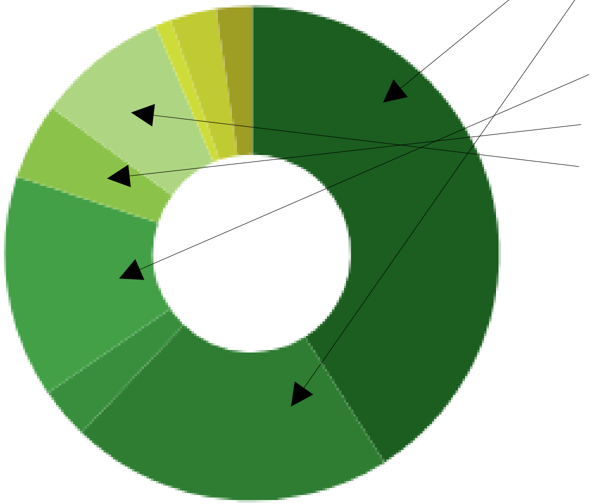


List of institutions

US ATLAS: Who Are We?

- US collaborators are around 20% of the total number of people on ATLAS (we're the largest single country)

Professional Status (US collaborators only)



- 476 Physicist "with PhD": faculty, postdocs, research scientists
- 245 Physics PhD student
- 39 Physics masters/diploma student
- 169 Undergraduate/summer student
- 58 Engineer with PhD
- 100 Engineer without PhD
- 12 Engineering student
- 35 Technician or equivalent
- 27 Administrator/other

How Do We Organize?

- It's all about collaboration
- We are all members of ATLAS, but we are also members of subcommunities which form around specific issues
  - each subdetector has a sort of international sub-collaboration dedicated to building & running it
- "US ATLAS" as an organization handles issues common to US institutions
  - interaction with funding agencies
  - following through on US commitments to the experiment
  - providing community building, training, development opportunities for US collaborators
  - forum to discuss professional standards

Types of US ATLAS Institutions

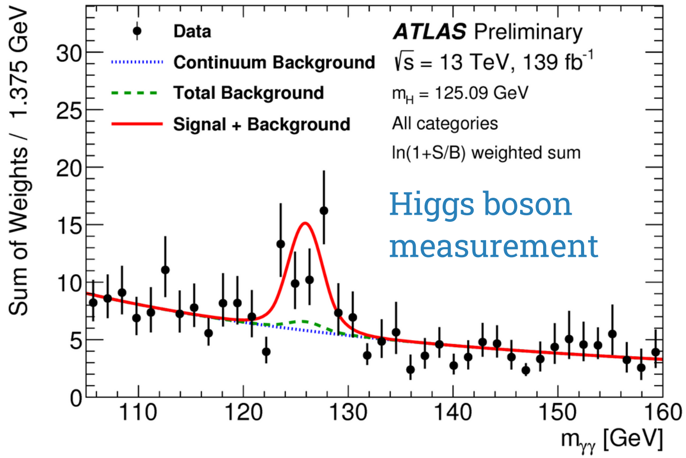
- National Laboratories: these are organizations that do research on behalf of the Department of Energy.
  - Permanent physicist staff are PhD-level
  - Tend to take leading role where large-scale engineering effort is needed
  - US ATLAS has four: Brookhaven [NY], Argonne [IL], Lawrence Berkeley [CA], SLAC [CA]. Brookhaven is the national "host laboratory."
- Universities: these do research and teaching. Almost all have PhD programs, most also have some undergrad involvement in research.
  - some universities run official "Research Experiences for Undergraduates" programs which are open to students beyond their institution
  - many faculty have more informal ways of involving younger students
- There are programs to make it easier to bring students & faculty from universities to national labs for collaboration

Funding

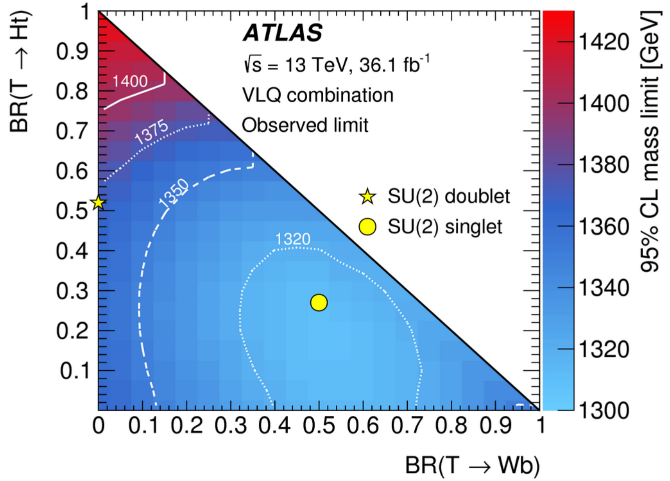
- Researchers on ATLAS in the US are funded by the Department of Energy and the National Science Foundation.
- “Research” grants – the ones individual institutions apply for in a competitive process – mostly go to salaries of researchers (students, postdocs, engineers, research scientists, faculty) & things like travel
- Funding for certain operations of the experiment and construction of detector upgrades is handled collaboratively across the US ATLAS institutions
  - and lots of operations/upgrade work is funded by the research grants

Physics Analysis

- Analysis = using the data collected by the experiment to test a hypothesis or measure a quantity
  - only one part of an experimental physicist's job – the data need to be collected in the first place!
- Activity is organized at the ATLAS level
  - ~ 400 different analyses in progress right now
  - most analyses are complex enough (or have enough interest) to have many people working on them; even so individual contributions are critical and noticed
- There are US collaborators working in every area of ATLAS physics analysis
  - direct searches for new particles and interactions
  - precision measurement of properties of known particles
  - behavior of hot and compressed nuclear matter
- That said, any particular physicist has preferred topics!



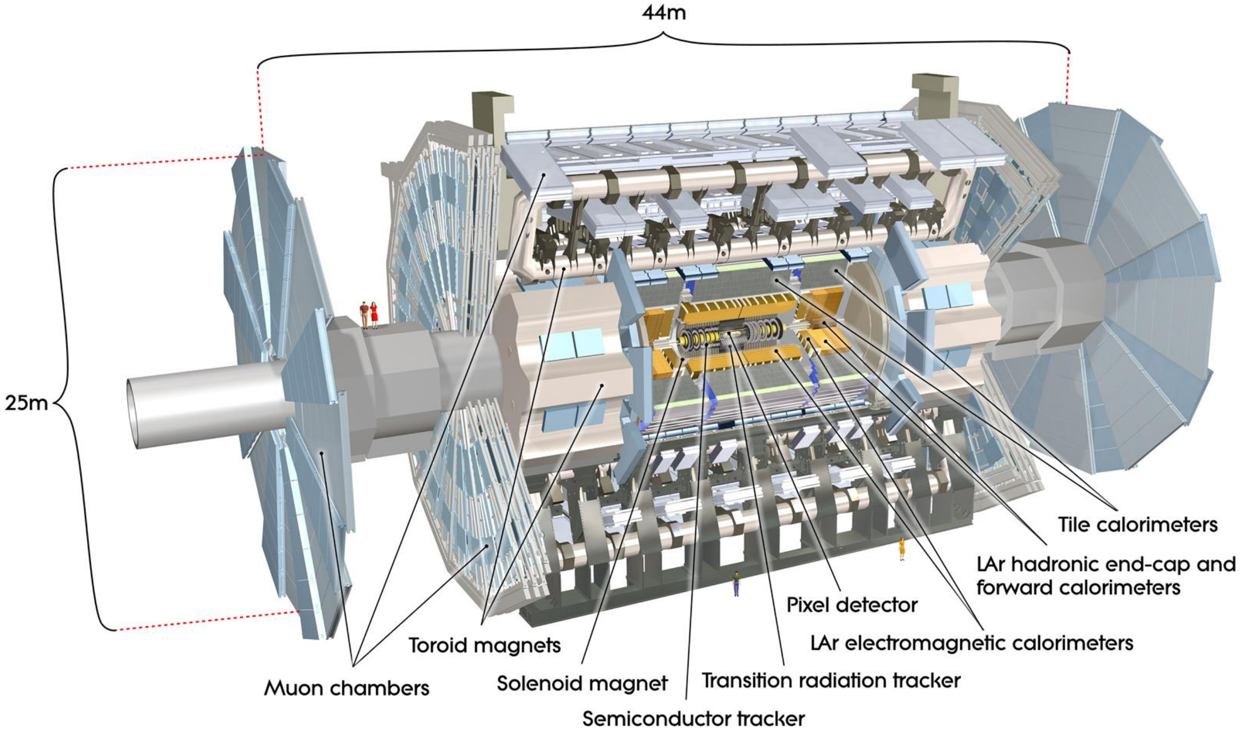
Higgs boson measurement



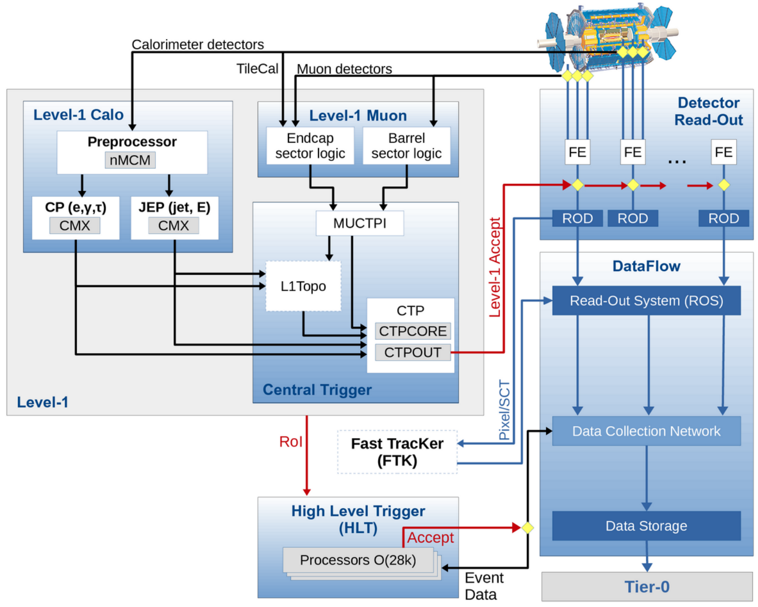
Search for a new particle

Building & Running a Detector

- Experiments like ATLAS need to be designed, constructed, installed, and operated
  - this includes mechanical parts, but also the electronics to read data out of the detector and to decide which collisions to record, and the software to make sense of the raw data
  - planning for ATLAS spans decades, but there are always many things to do in the short term
- The US has had a part in building & operating essentially every part of the detector



Run 2 trigger system

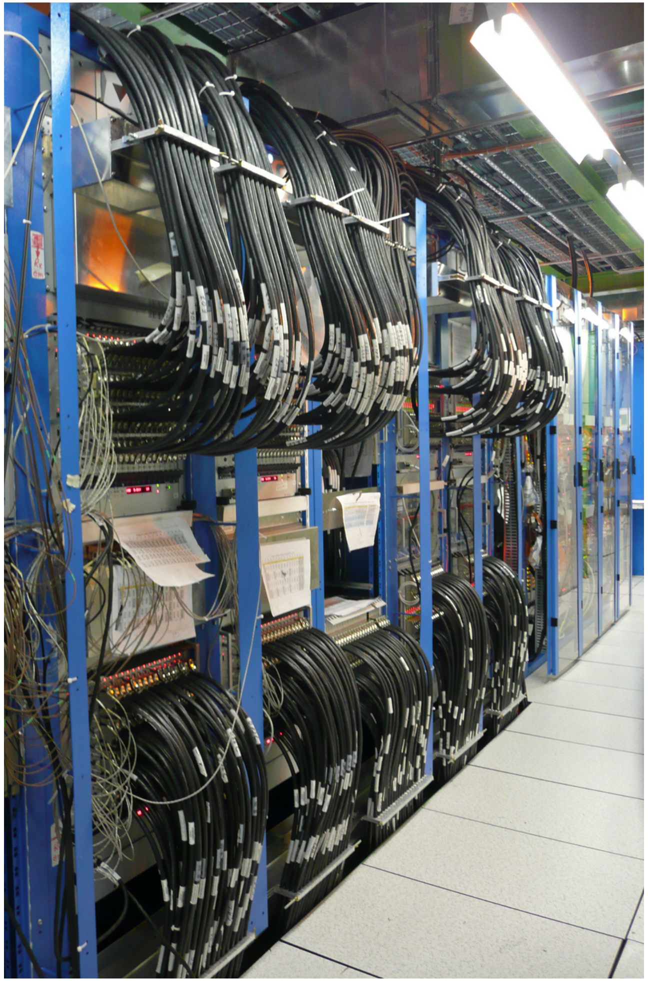


Trigger

- The vast majority of proton-proton collisions are not very interesting; what we want to study is generally quite rare
- As collisions happen, we make an immediate decision as to whether we even want to record the event at all, using the "trigger"
  - if we didn't do this, we'd need to write out over fifty terabytes of data a second...

Collisions 40 MHz → Hardware trigger 100 kHz output decision in 2.5 μs → Software trigger 1 kHz output decision in 0.2 s

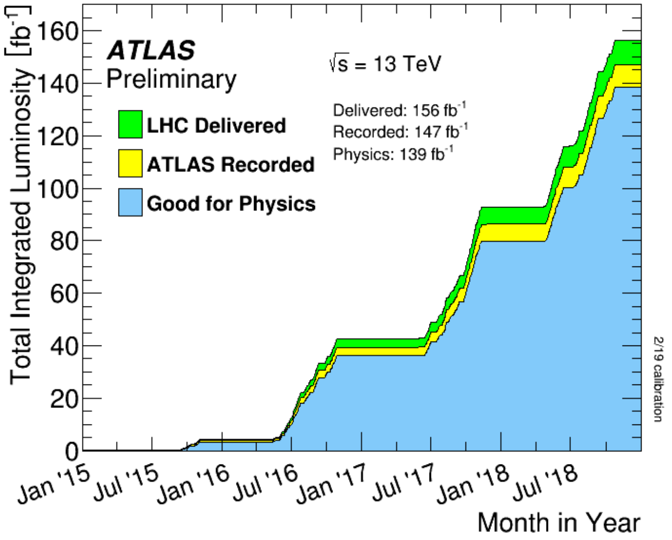
- The US has a very strong involvement in both the hardware and software triggers – hardware, software framework, software algorithm design, and real-world operations



What Does It Take To Operate a Detector?

- Taking shifts in the control room!
- Calibrating and aligning detectors
- Monitoring detector status, anticipating & preventing problems
- Repairing broken hardware & electronics
- Preparing small scale updates to software & firmware to cope with unexpected conditions
- Updating the trigger to select events more efficiently
- Checking the data output to verify the detectors are running OK
- Deducing and keeping track of the number of collisions delivered by the LHC
- … and so on …

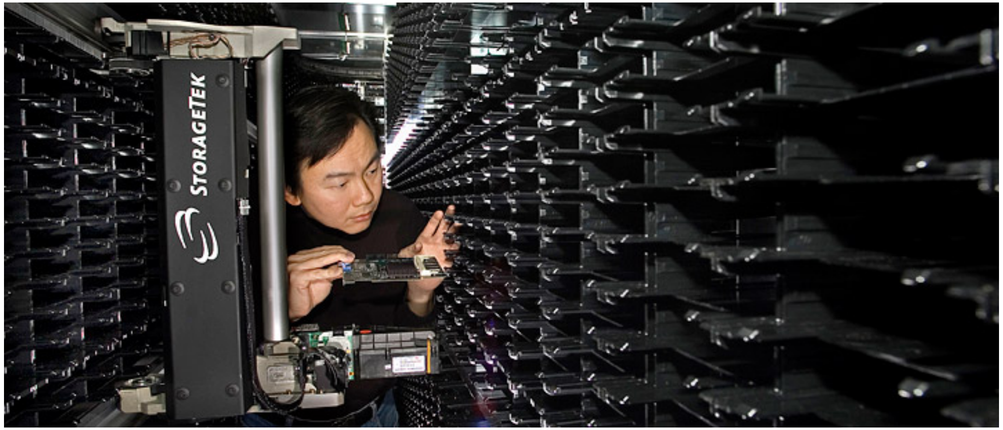
Many tasks can be done from the US



Computing – Hardware

- ATLAS depends on a worldwide "grid" of computing sites to provide processing power and storage: ~ 350,000 CPU cores
  - The US provides around 20% of the ATLAS computing needs, including the largest "Tier-1" site (which keeps a partial copy of the raw ATLAS data)
  - The US has four "Tier-2" sites, which all involve resources at multiple institutions (e.g. Southwest Tier-2, with facilities at UT-Arlington, Oklahoma, and Langston)
  - The Tier-1 and 2s are primarily used for "production" jobs to reconstruct raw data or simulate the way the detector responds various possible collisions
  - Sites generally use commodity hardware and are often shared with non-ATLAS (and non-particle physics) communities. Software advances make adding a generic university computing cluster almost "plug and play".
  - Increasing use of "opportunistic" resources like high performance supercomputer facilities (which pose specific challenges).
- US also provides resources to analyze data via "shared Tier-3" facilities

Tape robot for data storage at Brookhaven Tier-1

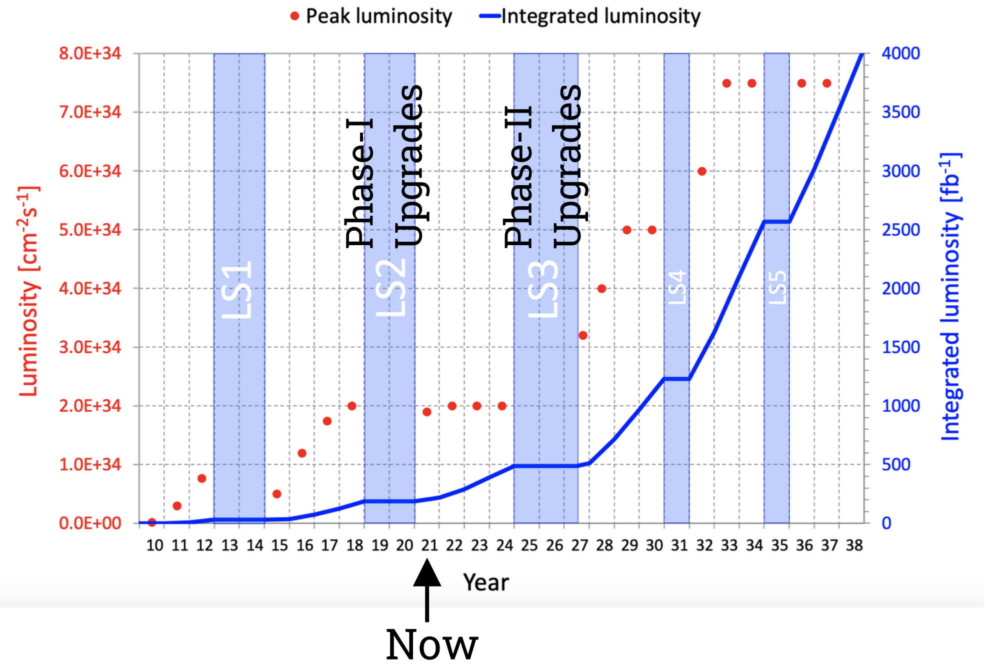


Computing – Software

- US collaborators provide much of the core software used in ATLAS
  - to reconstruct data
  - to simulate collisions
  - to coordinate distributed processing across the Grid
  - to allow physicists to analyze and visualize data
- Maintain the testing environment that permits software to be developed while ensuring it works and bugs aren't introduced
  - an ATLAS software release is ~ 5 million lines of code, needs to run on data recorded over ten years ago! Extensive testing of proposed changes needed
- Need to use computing resources (and researcher time) in the most efficient way, and to train researchers in best practices
- Use forefront technologies: high overlap with developments in industry
  - machine learning, containerization, orchestrated & reproducible workflows, …

The HL-LHC Challenge

- Quantum mechanics is a statistical process. Certain things we want to observe occur really rarely, so we need to produce as many total collisions as possible.
- The High Luminosity LHC (HL-LHC) will involve sustained collision rates ~ 4x higher than the maximum we have currently achieved
  - achieved by increasing the number of simultaneous collisions
  - overstresses electronics & detectors which were not designed for this rate
  - produces messier collisions which are harder to reconstruct
- Need to upgrade various parts of the detector to handle this

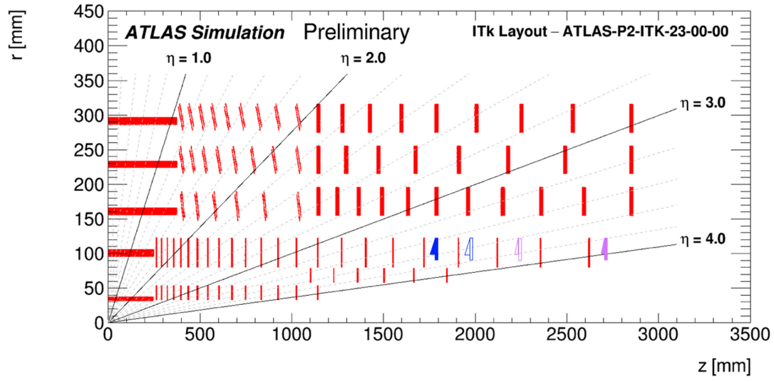


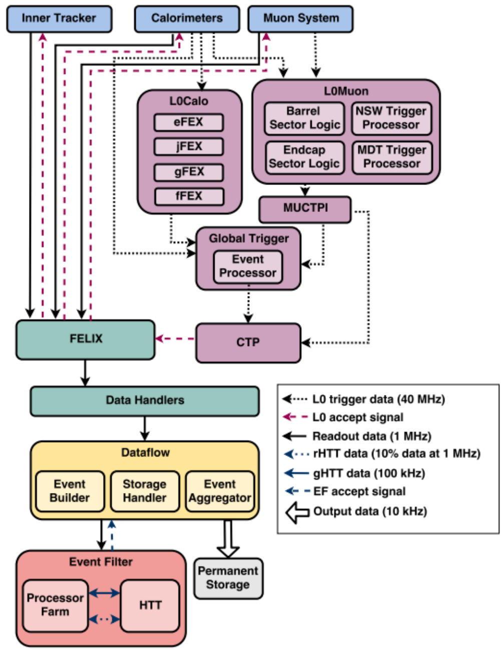
A New Detector: the New Small Wheel(s)

- Biggest "Phase-I" upgrade, being installed now: replacement of some older muon detectors (the "small wheels") with newer devices
- Challenges: new technology, custom electronics, integration of components built across the world (all during COVID!)

HL-LHC Upgrade – Detector

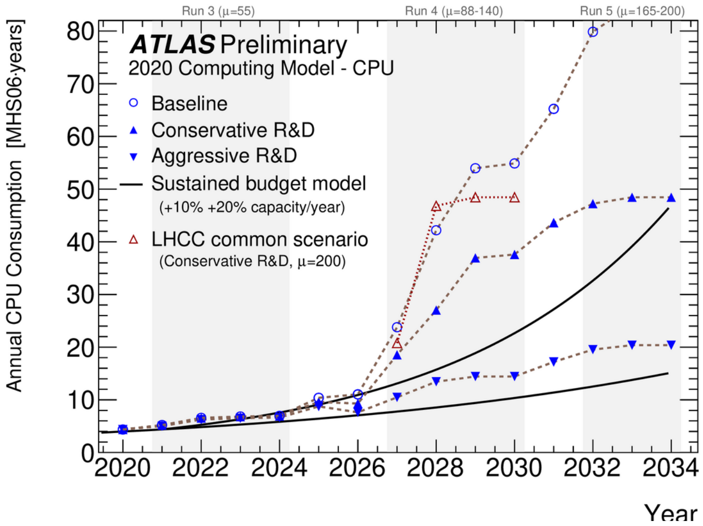
- Biggest detector change for HL-LHC: inner system for tracking the trajectories of charged particles will be replaced with a new system ("ITk") using 100% silicon sensors
  - smaller detection elements to reduce ambiguities between different particles; improve resilience to radiation damage
- Significant changes in the data readout and trigger architectures to handle increased rates
  - both detector-specific and general electronics & software

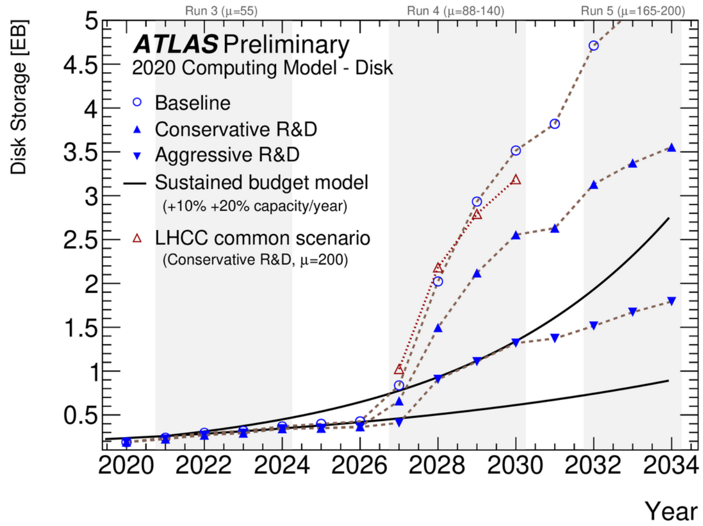




HL-LHC Computing

- More collisions & more data → larger computing requirements
  - current processing patterns would require more than we can afford
- A lot of work in the US dedicated to reducing our needs without sacrificing quality
  - more efficient use of CPUs & data storage resources
  - utilize new types of computing power, e.g. GPUs, and new providers, e.g. clouds, high performance computing centers
  - use machine learning to replace slow algorithms
  - figure out how to let physicists access data in reasonable time





Summary

- US collaborators form an essential part of the international ATLAS collaboration
- We're involved in all aspects of building, operating, and upgrading the detector, and analyzing the data to understand the fundamental nature of the universe
- US ATLAS provides a mechanism for American institutions to work together, both on practical matters and to improve as a community