ATLAS Upgrades

Ben Smart
for the LAPP and LPSC ATLAS groups

Laboratoire d'Annecy-le-Vieux de Physique des Particules

We want to understand the universe in which we live

We use the LHC and the ATLAS detector to study the most fundamental components of the universe

With the LHC, and ATLAS and CMS detectors, we recently discovered the Higgs boson!

The Higgs boson is predicted by the BEH mechanism for electroweak symmetry breaking

The BEH mechanism describes the origin of mass!

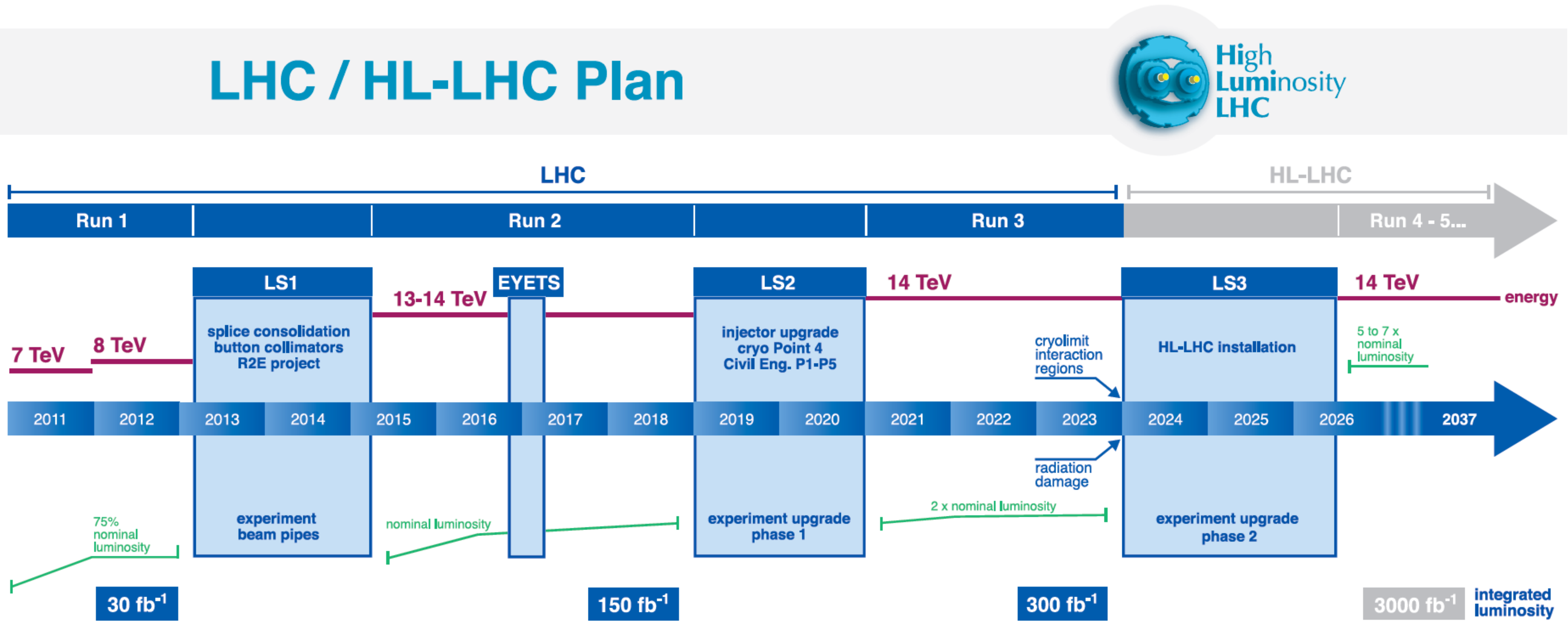
- The Standard Model of particle physics is currently humanity's best description of the fundamental nature of the universe.

- We want to study and test the Standard Model. For example, to see if the Higgs boson is exactly as the Standard Model predicts, or if new physics beyond the Standard Model awaits us.

- For this, and other searches for new physics, we want to...
  - Precisely measure Higgs boson mass and couplings to other particles.
  - Search for rare Higgs decays.
  - Measure (for the first time) Higgs-Higgs self-coupling.
  - Search for other (different) Higgs bosons.
  - Search for Supersymmetry (SUSY).
  - Search for new particles, such as heavy vector bosons: W' and Z'.
  - Search for any other new physics.

The Plan For The Future: LHC

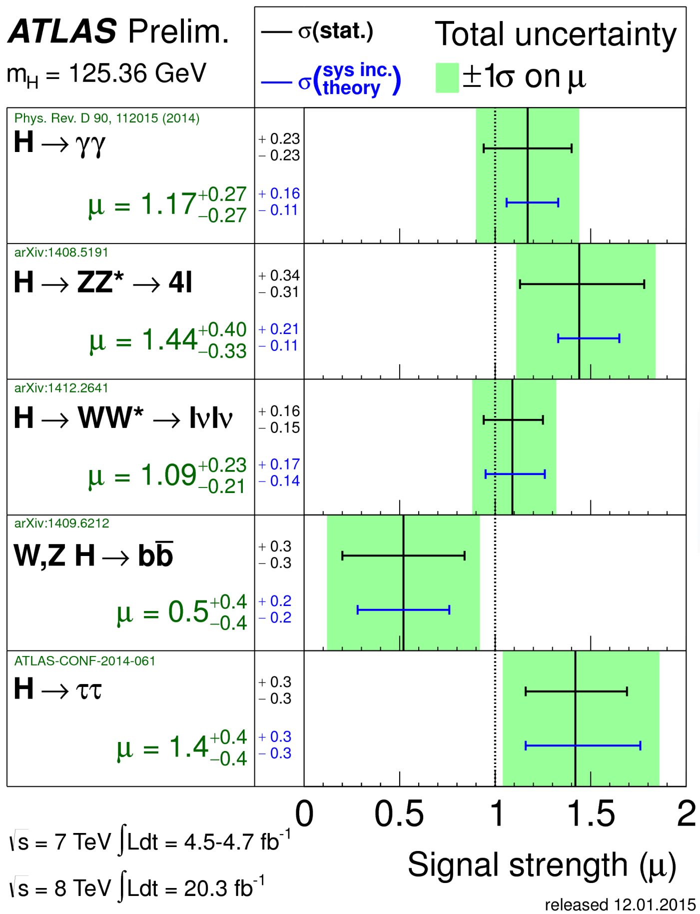
- To improve our measurements and searches, the LHC and ATLAS will be upgraded:



- The LHC will become the High-Luminosity-LHC, to produce 3000 fb^{-1} of integrated luminosity in 2035.
  Higher Energy → benefits searches for new particles.
  Higher integrated luminosity → benefits precision measurements and studies of rare processes.

- These upgrades will improve our measurements and searches:

Run 1



$\Delta\mu/\mu = 0.23$

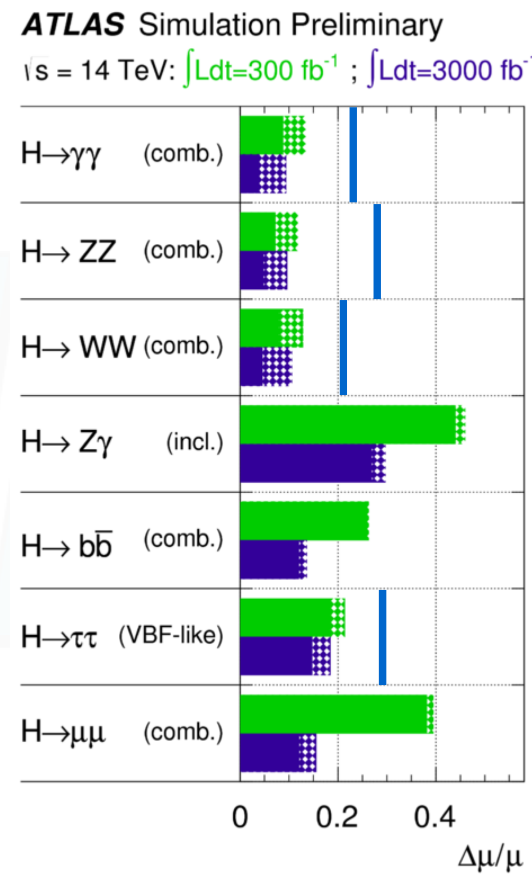
$\Delta\mu/\mu = 0.28$

$\Delta\mu/\mu = 0.21$

$\Delta\mu/\mu = 0.8$

$\Delta\mu/\mu = 0.29$

Run 3 and HL-LHC

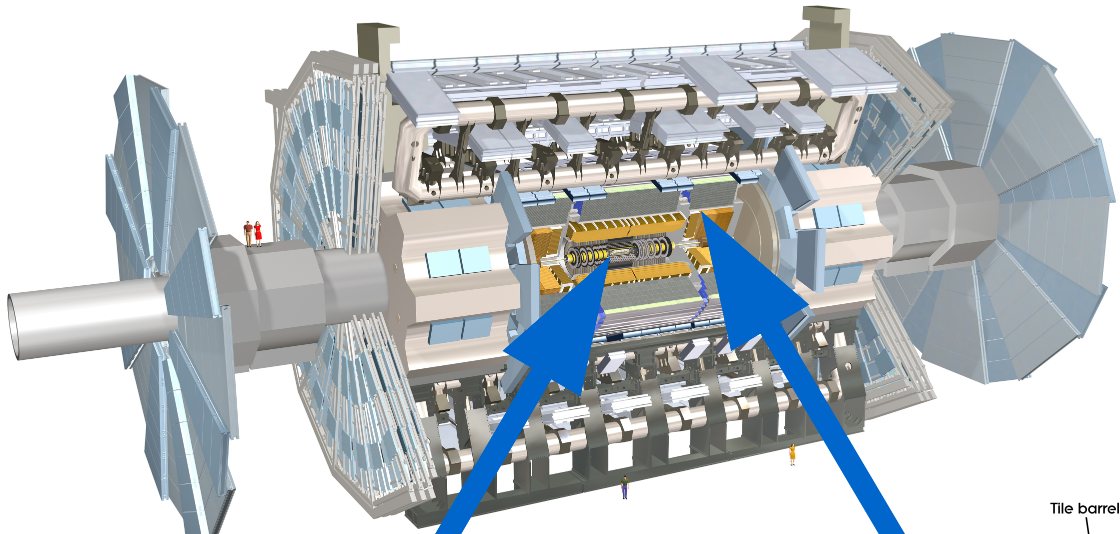


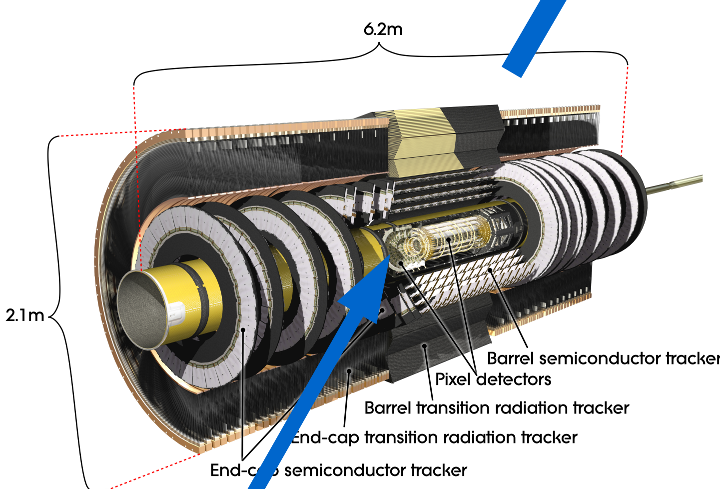
Dashed areas indicate $\Delta\mu/\mu$ with current theory uncertainties.

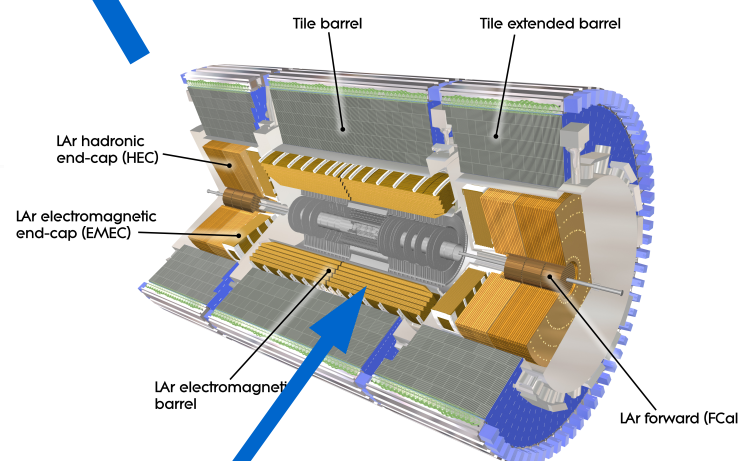
Vertical blue lines are Run 1 values.

The Plan For The Future: ATLAS

- Upgrades required for ATLAS:



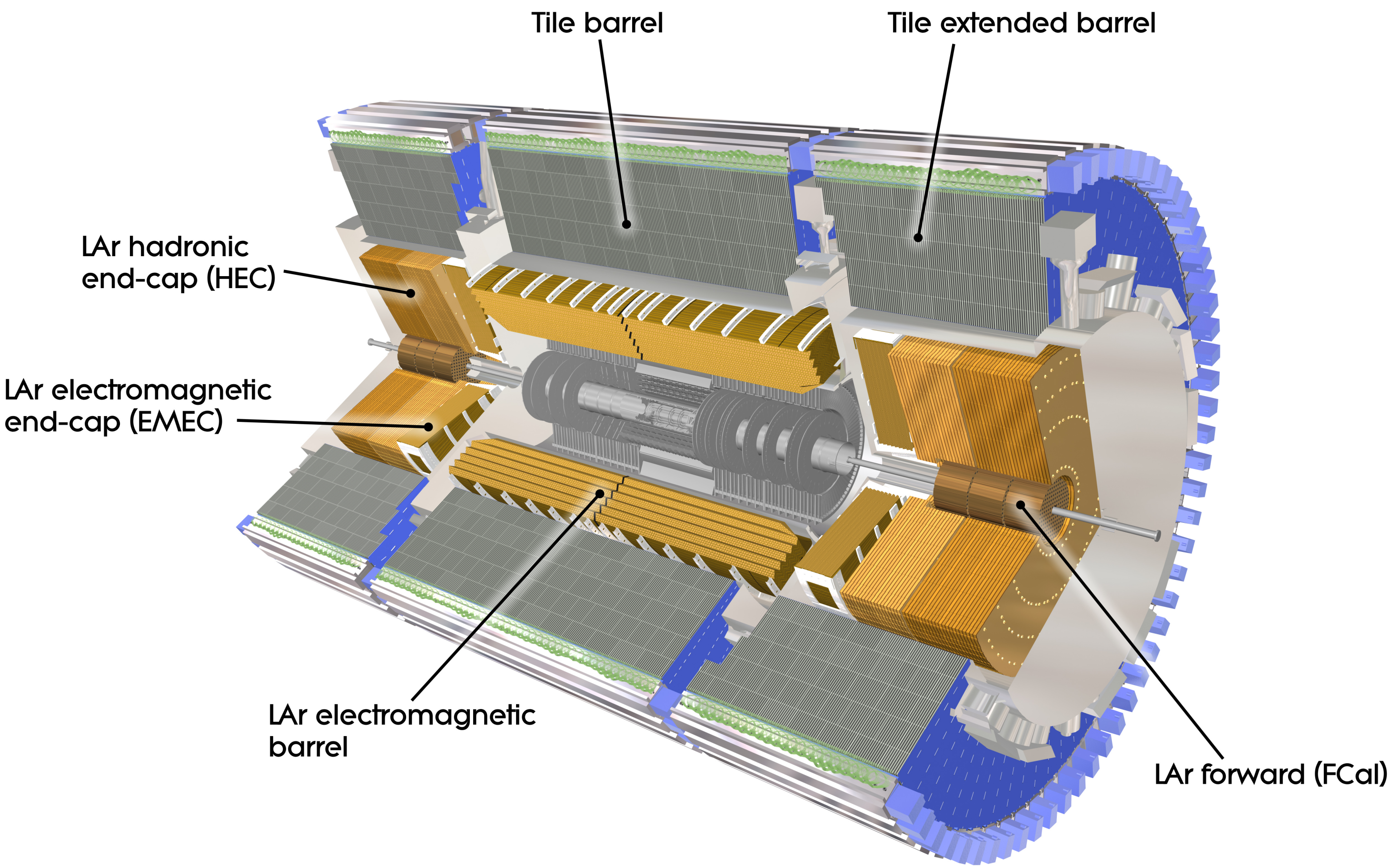




Pixel Detector: in LS3
LAPP, LPSC

Electromagnetic Calorimeters:
in LS2 and LS3
LAPP, LPSC

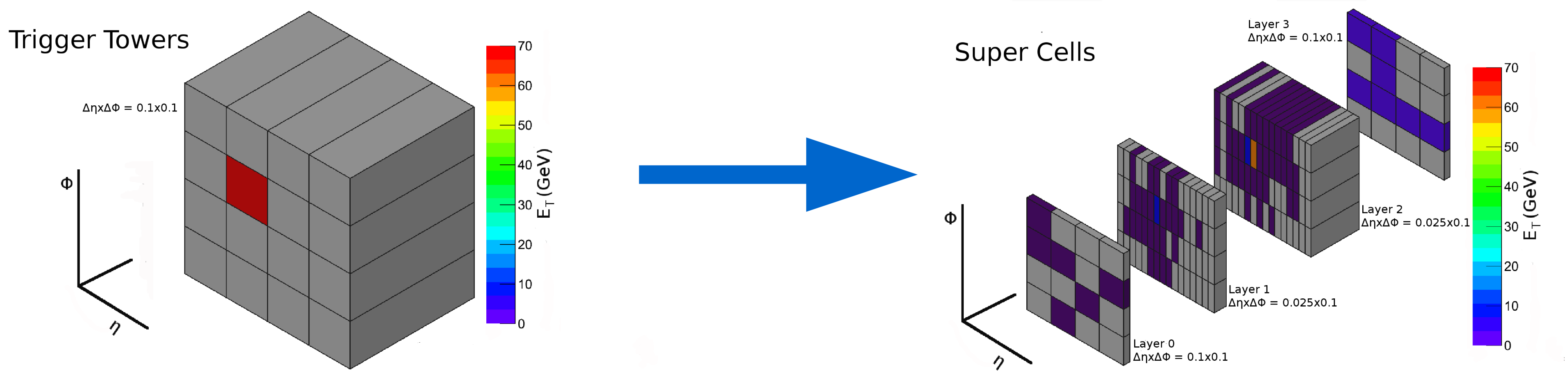
- First, we look at Electromagnetic Calorimeter (liquid Argon) upgrades...



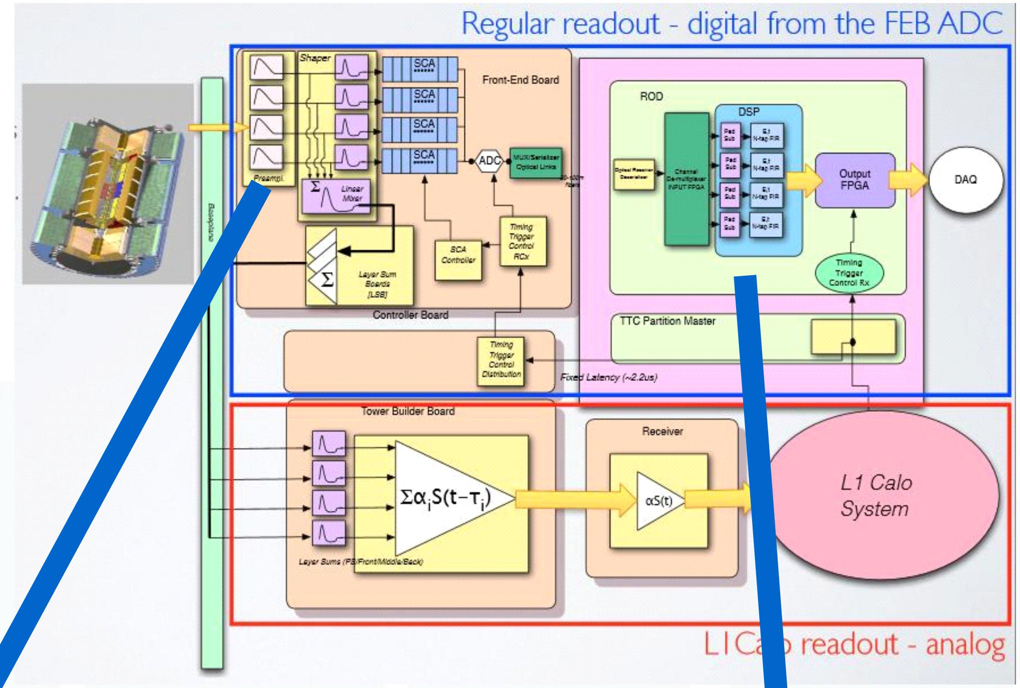
- Total ATLAS Level1 (hardware) trigger rate is limited to 100 kHz.
  - As LHC instantaneous luminosity is increased, too many Electromagnetic (EM) Level1 trigger cells will each receive more energy than the trigger energy thresholds.

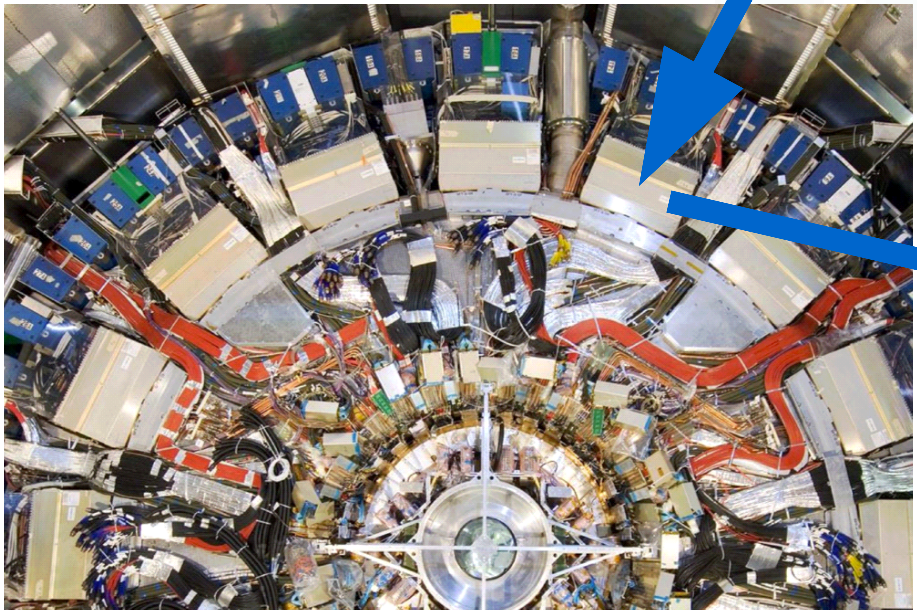
- Two possible solutions:
  - Increase trigger thresholds → Leads to lower trigger efficiencies.
  - Increase EM Level1 trigger granularity → individual EM Level1 trigger cells each receive less energy.

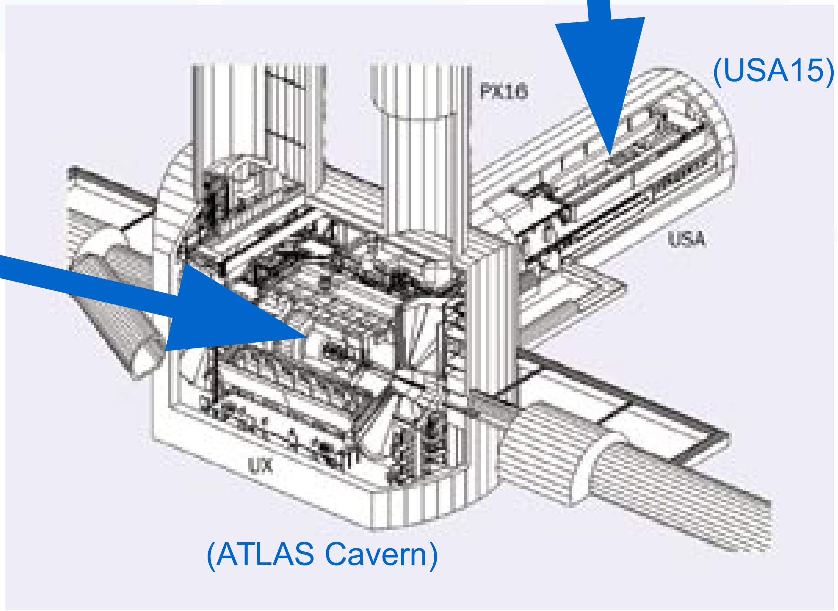
- Trigger read-out electronics in electromagnetic calorimeters will be upgraded.



- Current ATLAS EM Calorimeter Level1 trigger read-out is analogue at the detector.
- Analogue signal is converted to digital in USA15 cavern, ~30m from detector.
- Analogue signals more susceptible to electrical noise.





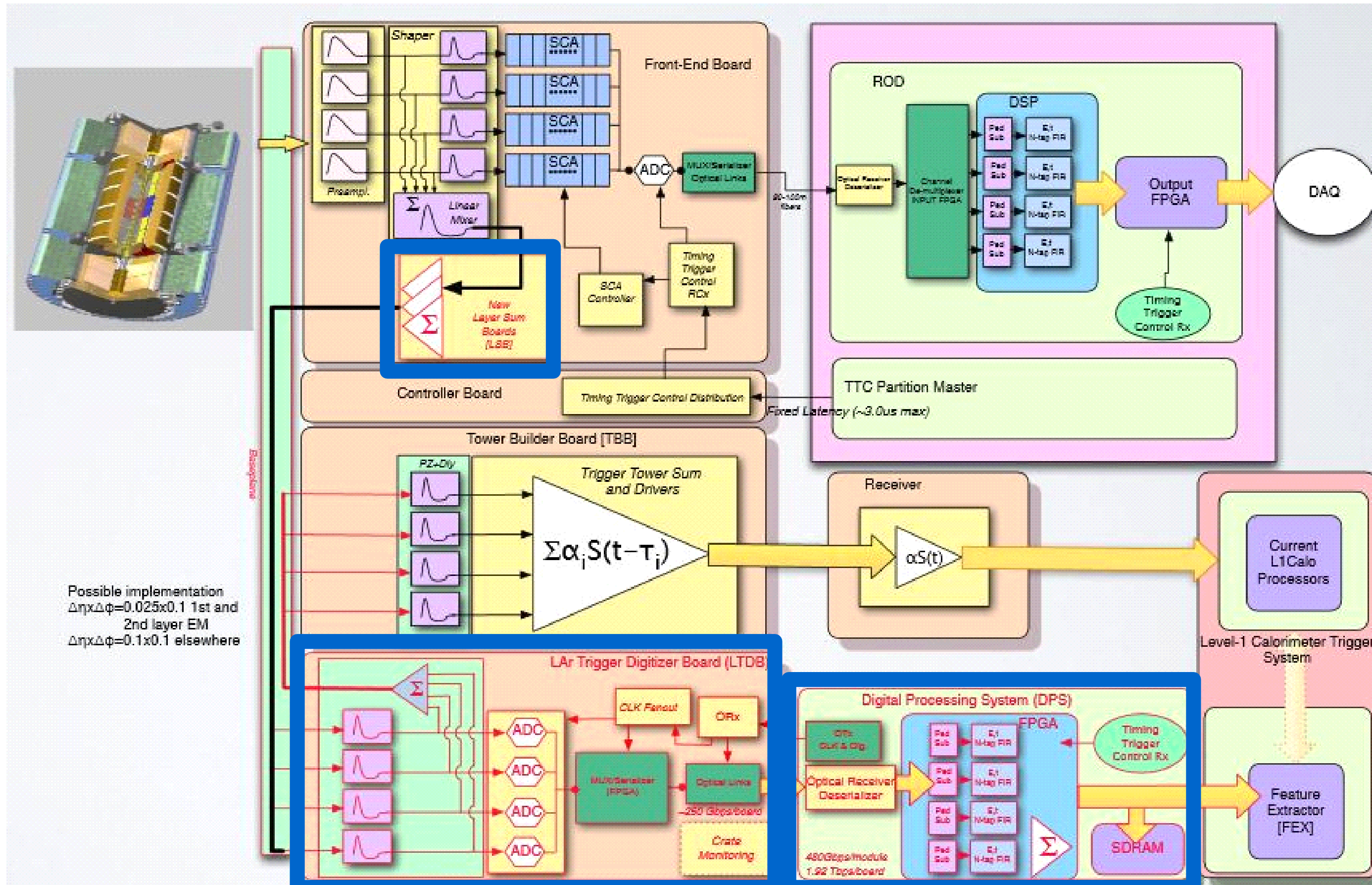


- Future setup: new components highlighted in blue.

- Analogue to digital conversion done close to detector.

- New components provide higher EM Level1 trigger granularity.

- Possible to switch between old and new systems.



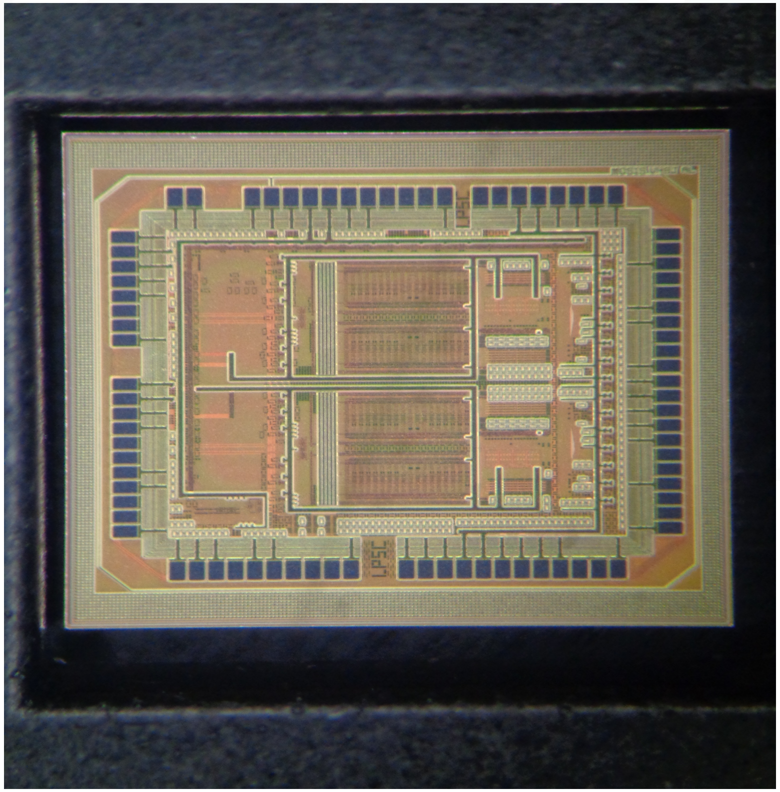
LPSC performing R&D for Phase 2 upgrade

LAPP currently completing Phase 1 upgrade developments.
Next will start Phase 2 developments.

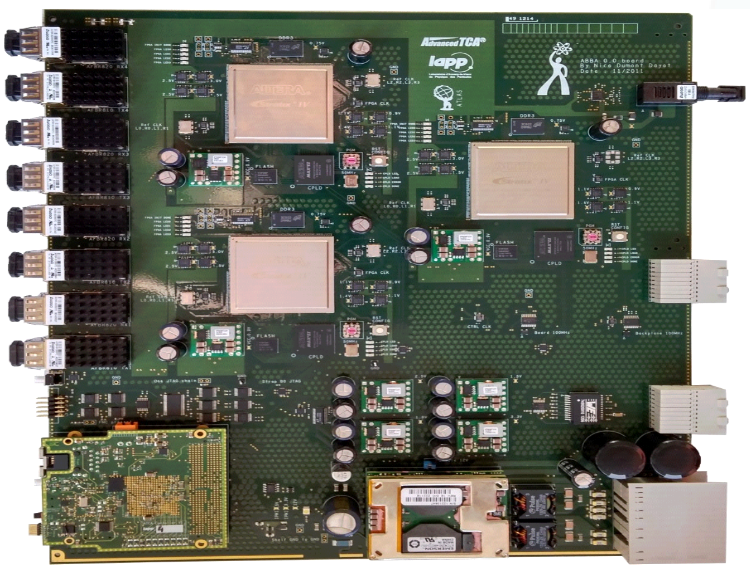
Carolina Gabaldon – LPSC

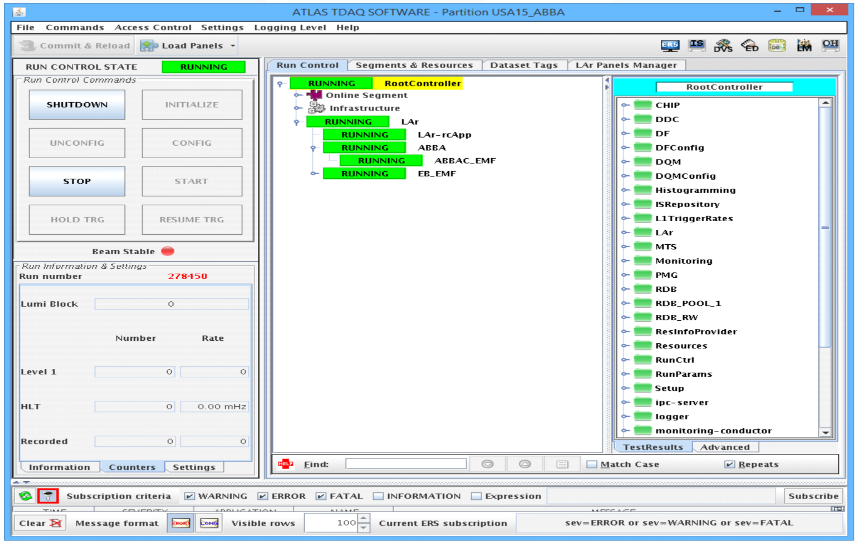
- LPSC are developing Analogue to Digital Conversion (ADC) chips for the Liquid Argon Trigger Digitiser Boards (LTDB).

- Research and development ongoing for Phase 2 upgrades.
  - Boards have been developed
  - Now validating design and measuring performance (Results expected soon!)



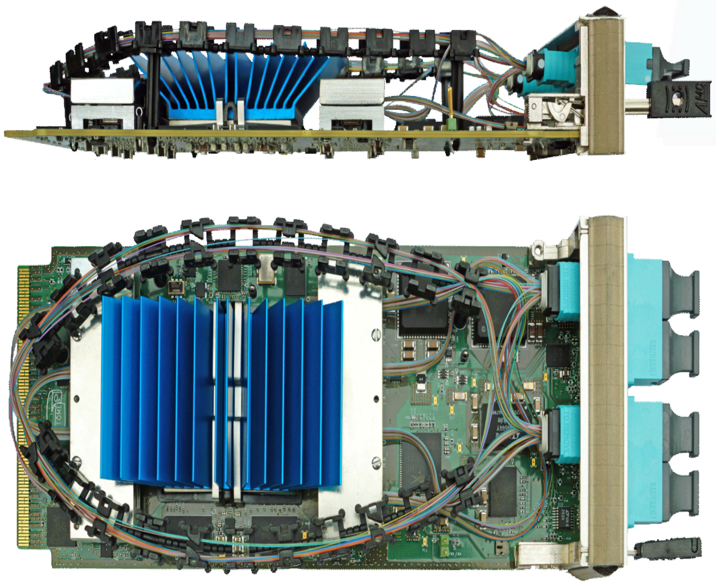
- LAPP is developing Digital Processing Systems (DPS)
  - Designed to receive digital data, compute energy, and then transfer results to triggering system.
- Two demonstration boards (ABBA card) installed in ATLAS counting room (USA15 cavern), and tested during data 2015 taking, with successful results.
- LAPP has also developed control and DAQ software for use in ATLAS control room.

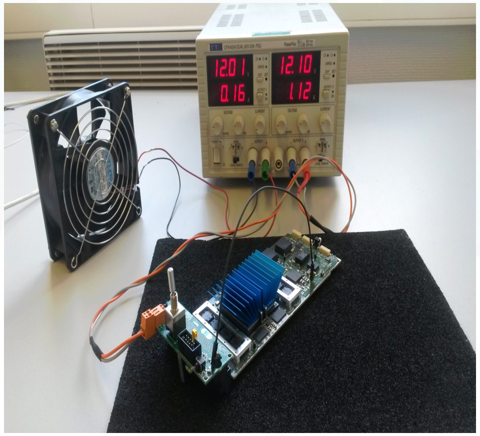


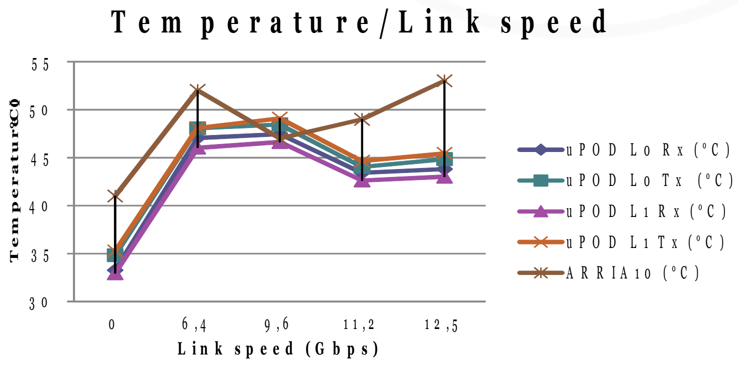


- LAPP is also developing next-generation Digital Processing Systems (DPS) as future replacements for the ABBA cards:

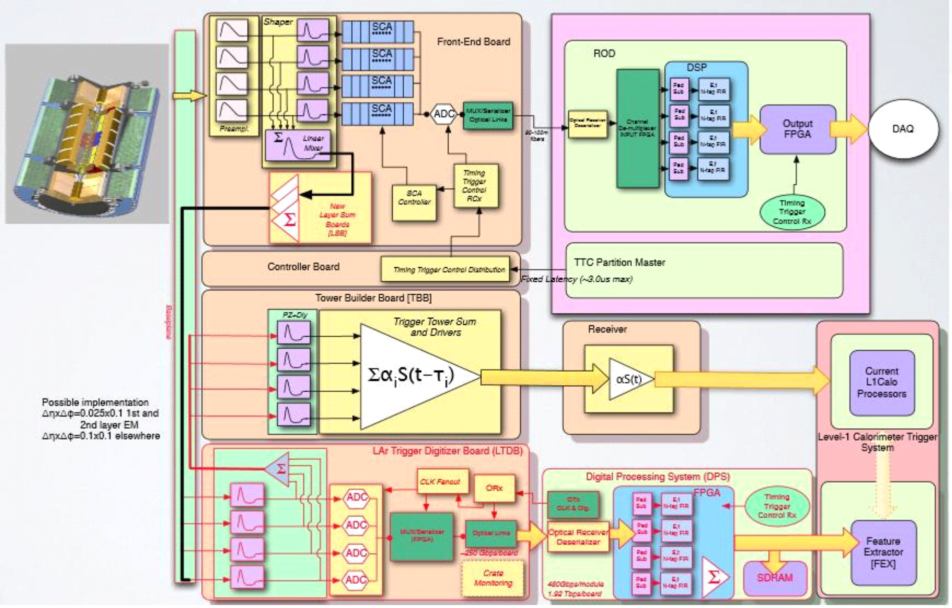
- LATOME cards.
  - Aim to integrate more circuits together on the boards
  - Increased density of data-processing circuitry
  - Cooling of boards is a major factor



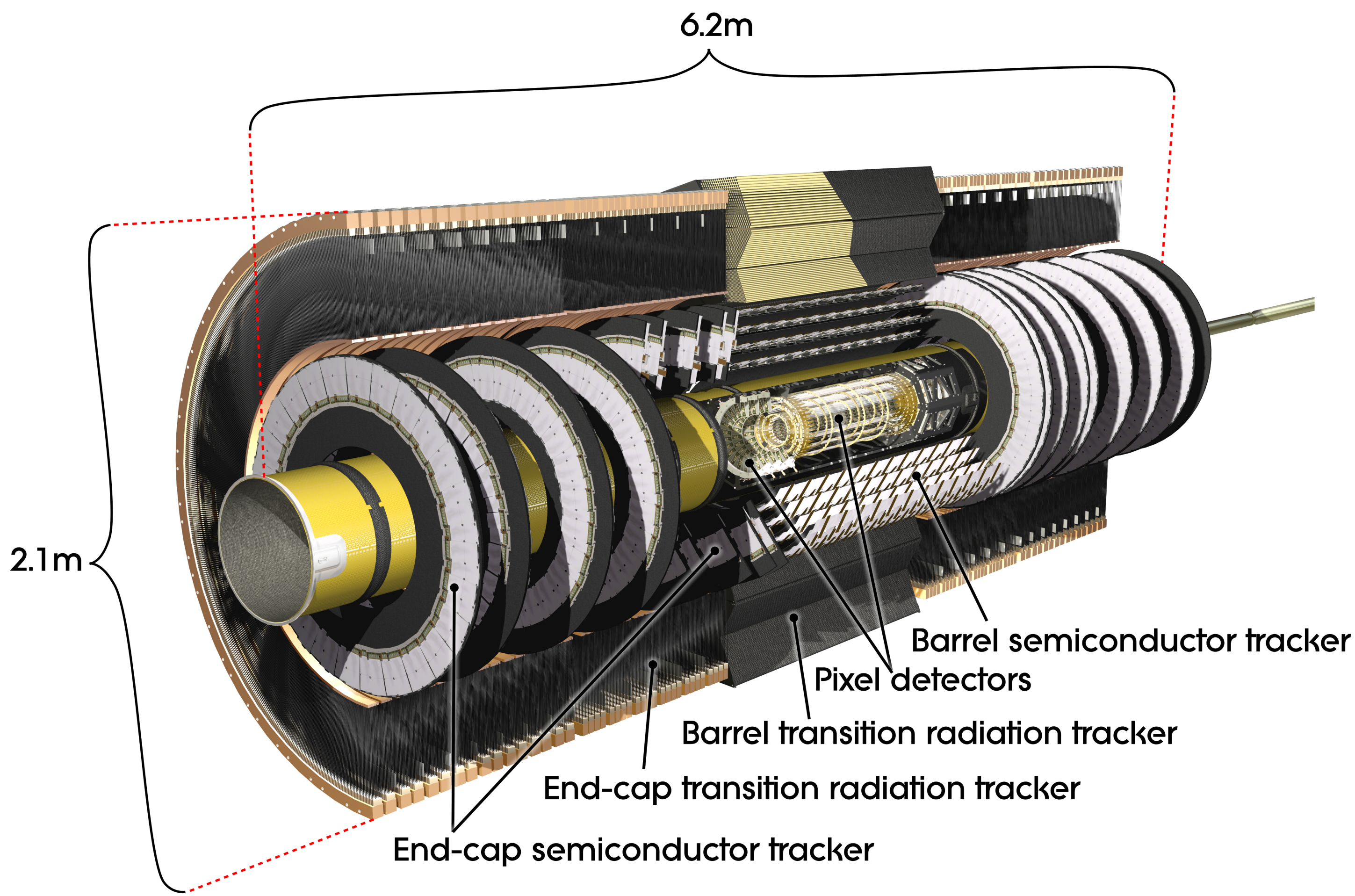




- LAPP and LPSC are making significant contributions to the ATLAS electromagnetic calorimeter upgrades, utilising strong existing expertise.
- Through post-doc funding, Enigmass has contributed to the development of this expertise.
- LAPP and LPSC contributions and responsibilities primarily in read-out electronics for high-speed triggering, for both Phase1 and Phase 2 upgrades.



- And now for something completely different...
  Inner Detector (Silicon pixel) upgrades...

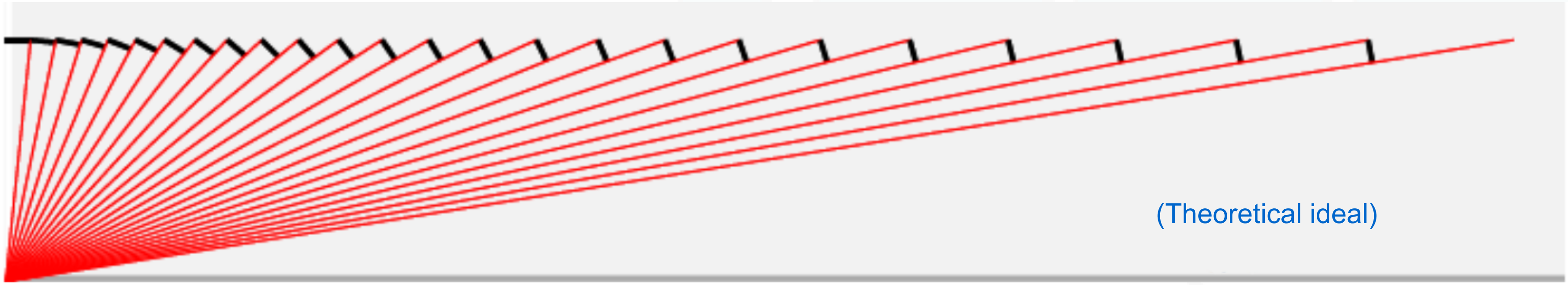


2012 ATLAS event, with 25 reconstructed vertices (μ=25)

~5cm

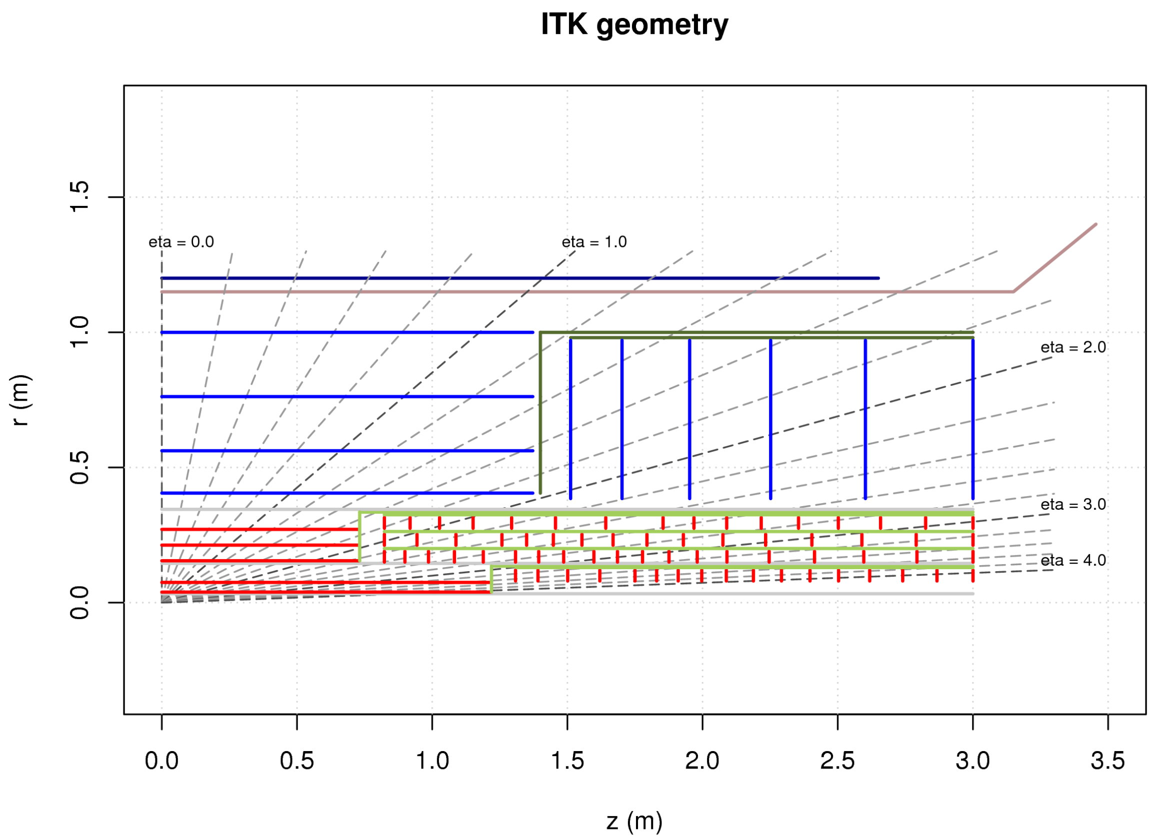
- At the HL-LHC (upgrade phase 2) we expect μ=200 within a similar or shorter space.
- Higher track density requires a better Inner Detector to maintain tracking and b-tagging performances.
- We will also increase η coverage to 3.2 or 4.0 (currently 2.5) to increase acceptance and reconstruct forward jets for VBF and VBS.
- Existing components will be heavily radiation-damaged by LS3.

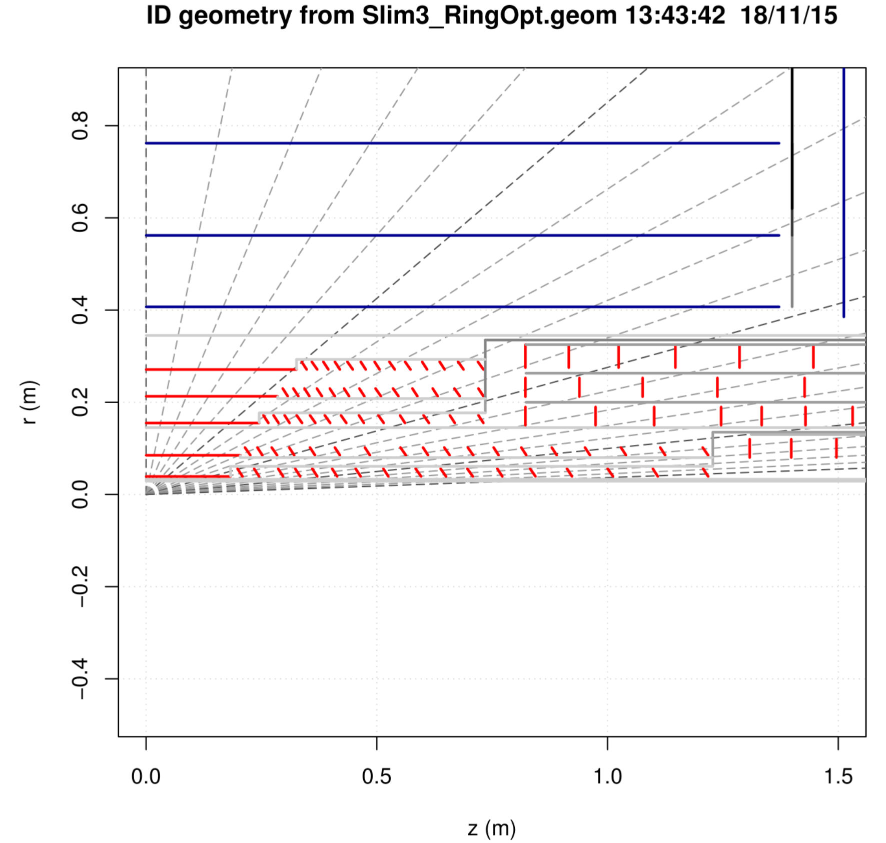
- New Inner Detector will be called the 'Inner Tracker' (ITk).
- Several designs for pixel detector are being considered.
  We are performing studies to determine which one will be best for physics results – Final layout to be decided by mid 2016.
- The 'inclined' sensor layout is one such proposal:



  - First performance studies and realistic inclined layout originated at LAPP (Teddy Todorov)
  - Initial studies suggest improvements over non-inclined designs
  - Gaining interest (LPSC, Uni Geneva, CERN, Saclay)
  - ATLAS collaboration now convinced this option is worth pursuing

Inner Detector Upgrades: Inclined layout





Non-inclined layout → Inclined layout (zoomed)

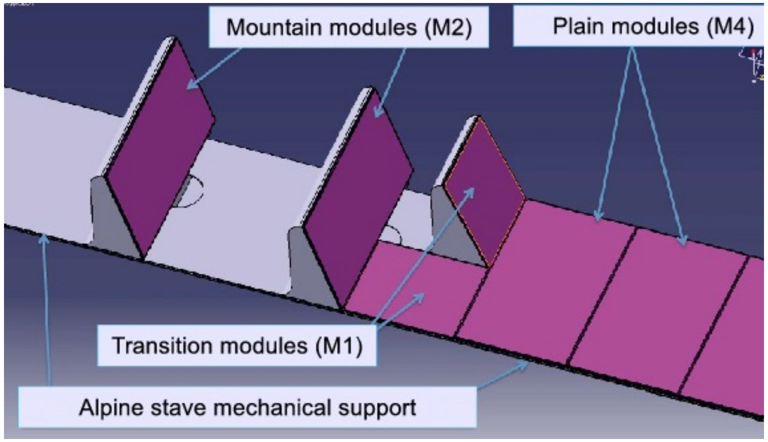
Non-inclined layouts have non-optimal transition region between parallel-to-beamline and perpendicular-to-beamline sensor regions.

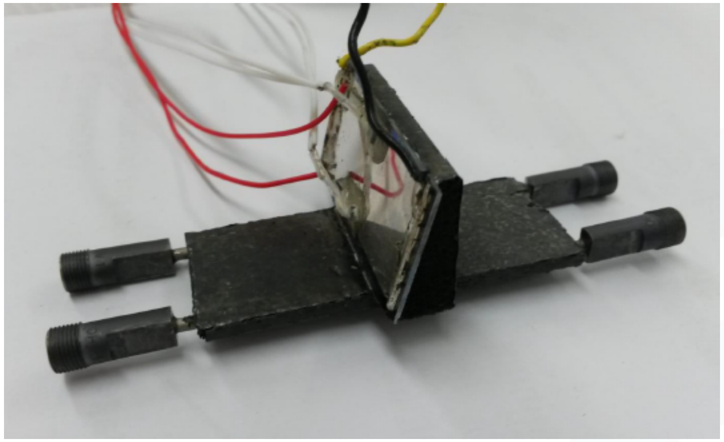
Inclined layouts attempt to solve this by inclining sensors towards interaction point in this transition region.

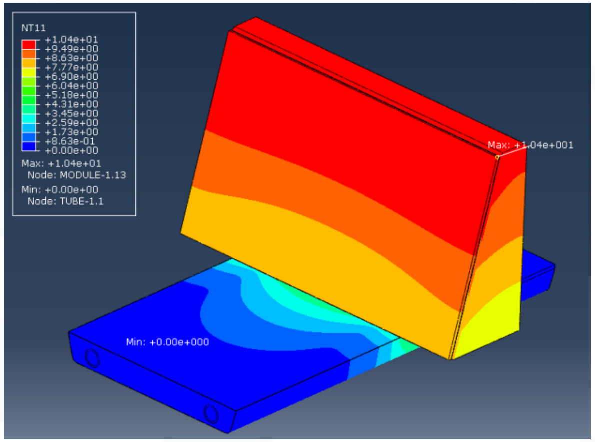
Ben Smart – LAPP

- Design challenge: cooling inclined sensors.

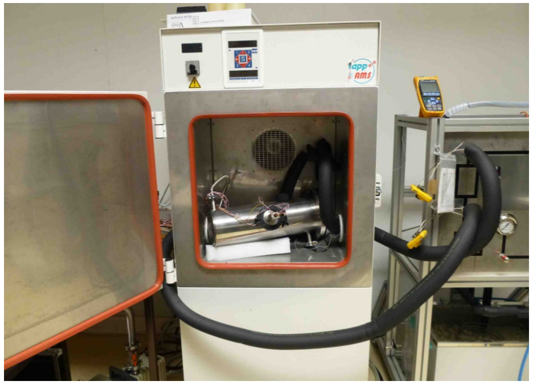
- Insufficient cooling leads to 'thermal runaway' → sensor failure.
- Low thermal gradient over sensor is also desired.

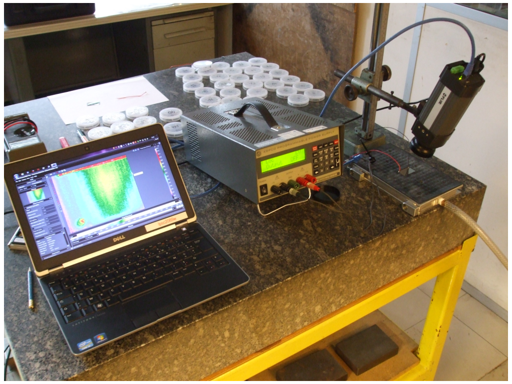






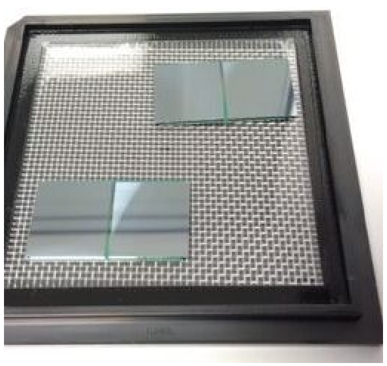
- Thermal studies are being performed by LAPP and LPSC.
  - Mockup and heater production at LPSC

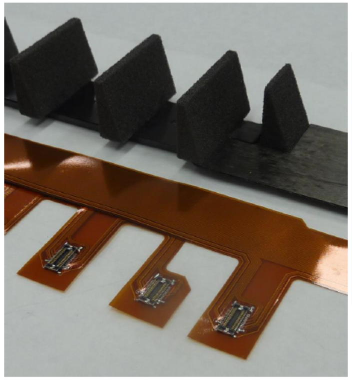


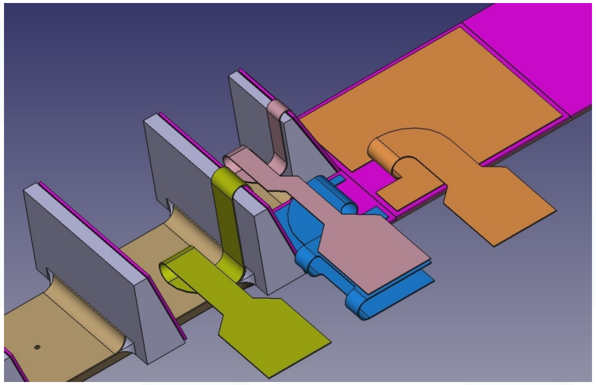


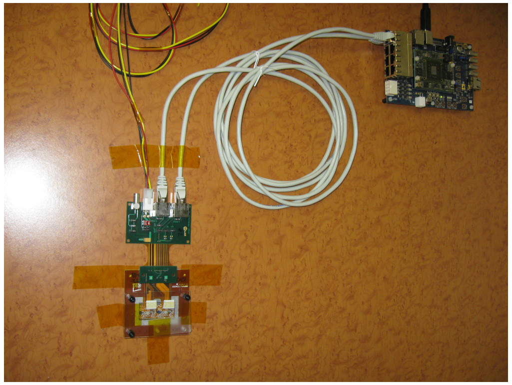
André Rummler – LAPP

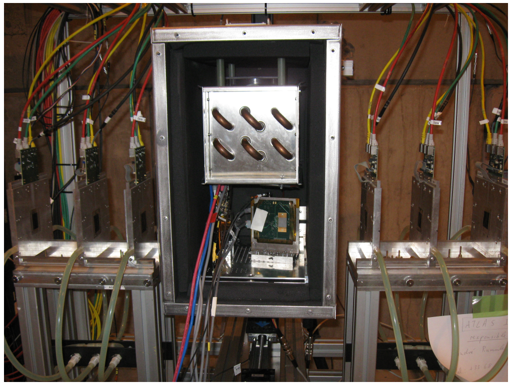
- First pixel sensors adapted to inclined layout produced with LPNHE.
- Read-out circuitry (stave flexes) being designed and produced at LAPP.
- Sensors and read-out electronics being tested in testbeam at CERN.









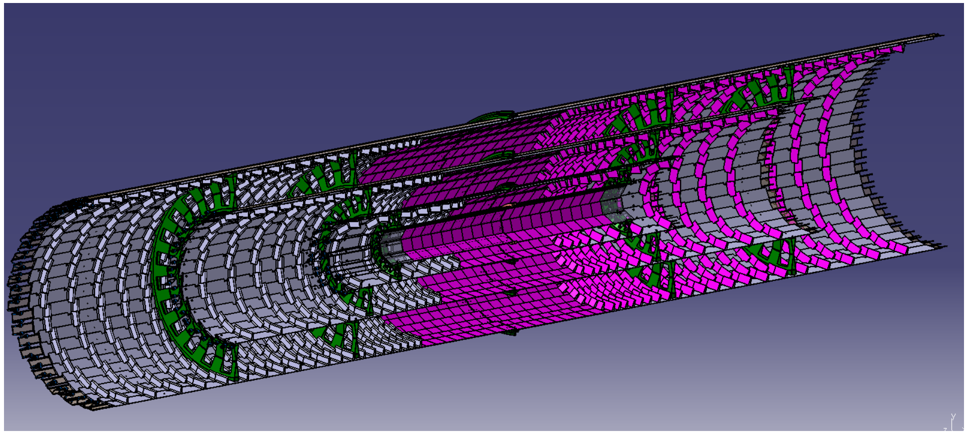


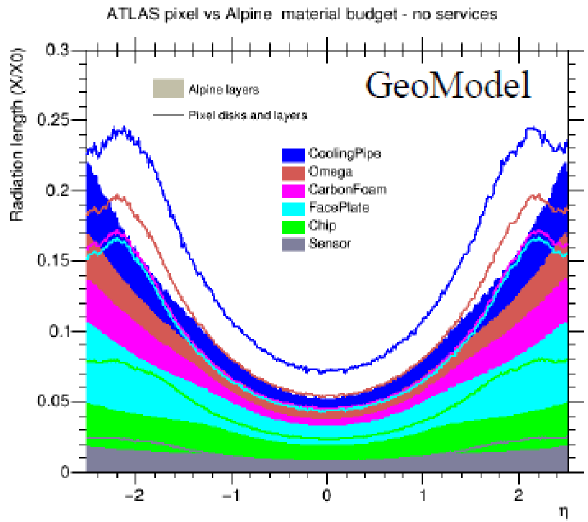
Ben Smart – LAPP, Agni Bethani - LPSC

- Inclined-specific software developed by LAPP and LPSC.
  - Detector geometry description (including services)
  - Tracking geometry description
  - Simulation studies being performed
  - Trigger performance studies

- Test different layouts - determine best layout for physics results.

- Optimisation of layouts:
  - Minimal material required: less material → better physics results
  - Determine best sensor layout for particle track resolution





- LAPP and LPSC collaboration has increased over the last year:
  - Common meeting and budgets requests
  - Together making significant contributions towards pixel detector upgrades
  - Active in multiple areas of upgrade design and testing

- Inclined layout now being considered by ATLAS collaboration as possible final design.

- Enigmass funding is critical to reach upgrade goals:
  - Teams bolstered by Enigmass-funded staff
  - If application for hardware funding selected
    – will speed up realisation of key demonstrations
    – crucial for achieving ATLAS deadlines.

Conclusion

We are developing new technology to upgrade the ATLAS detector

We will use the upgraded ATLAS detector and LHC to perform improved measurements and searches for new physics

These will include new studies of the Higgs boson, the BEH mechanism, and the origin of mass!

These improved measurements and searches will shed new light on the fundamental nature of the universe

This will help us better understand the universe in which we live!