ATLAS Upgrade plans

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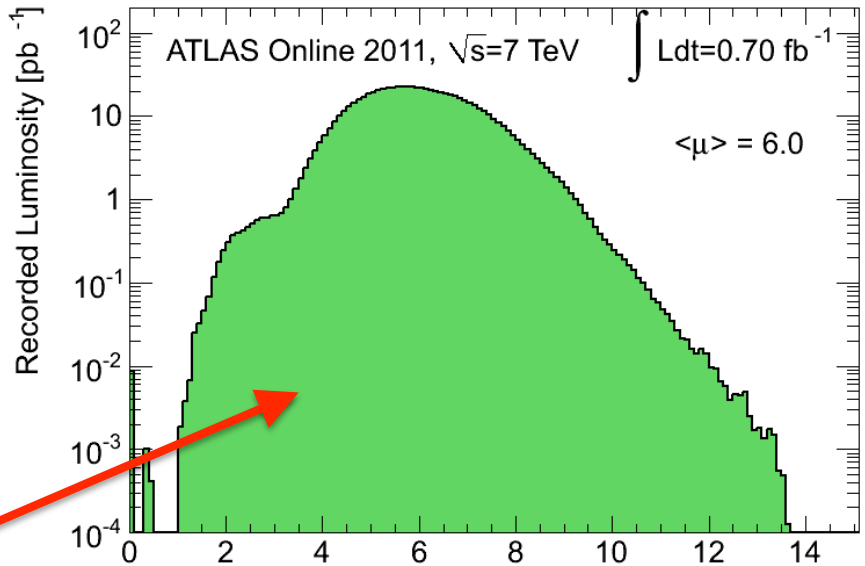
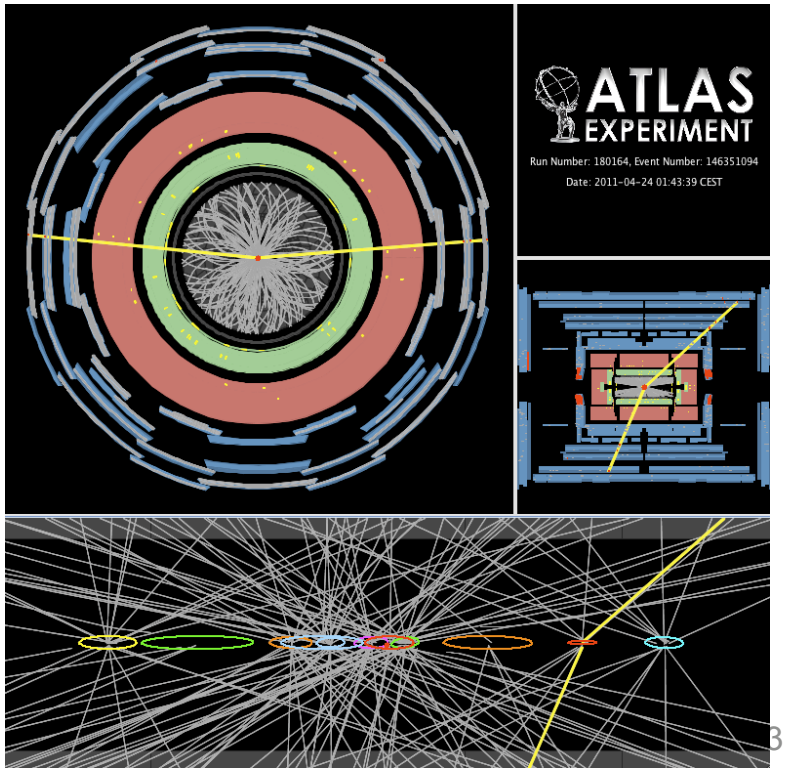
Outline

- Current status of ATLAS
- LHC upgrade for High Luminosity (HL-LHC)
  - Physics motivation, targets, timelines
- ATLAS upgrade plans & UK role/activities
- Summary & Outlook

Current status of ATLAS

- Recorded ~1.2fb^{-1}, efficiency > 95%, most good for physics
  - Peak luminosity ~2e33cm^{-2}s^{-1}
  - ~6 interactions per crossing
  - Many results at EPS with more than 1fb^{-1}
  - More than 40 collision results submitted for publication, many more made public as preliminary (conference notes), publications will follow





ATLAS-UK roles

- ATLAS-UK holds key positions in ATLAS at the senior management level, in data taking, and in Physics Coordination, among which:
  - Deputy spokesperson: Dave Charlton (Birmingham)
  - Higgs convener: Bill Murray (RAL/STFC)
  - Standard Model convener: Jon Butterworth (UCL)
  - Exotics convener: Cigdem Issever (Oxford)
  - B physics convener: James Catmore (Lancaster)
  - MC generators convener: Claire Gwenlan (Oxford)
  - Simulation coordinator: Phil Clark (Edinburgh)
  - SCT Project Leader: Steve McMahon (RAL/STFC)
  - Upgrade coordinator: Phil Allport (Liverpool)

Expectations for 2011-2012

- LHC set to continue increasing the peak lumi
  - Likely to see luminosities close to 1e34 in 2011, with ~20-30 pile-up interactions on average

- Expecting ~3-4fb^{-1} in 2011 and possibly another ~10fb^{-1} in 2012

- Very exciting times for all discovery physics at the LHC!

The HL-LHC project

HL-LHC: idea

- Upgrade the LHC to deliver O(3000fb^{-1}) per experiment in the 2020-30s (x10 the LHC)
  - O(300fb^{-1}) per year, at peak luminosity 5e34
- Physics motivation:
  - Increased discovery potential
    - multi-TeV region, explore more of SUSY parameter space…
  - Detailed studies of discoveries made with 300fb^{-1}
    - e.g. Higgs properties, SUSY parameters etc
  - Probe the gauge structure of the SM
    - Vector Boson Fusion at 1TeV, triple gauge couplings…

Need to trigger on/do physics with objects at the electroweak scale as in current LHC, but in a more difficult environment!!!

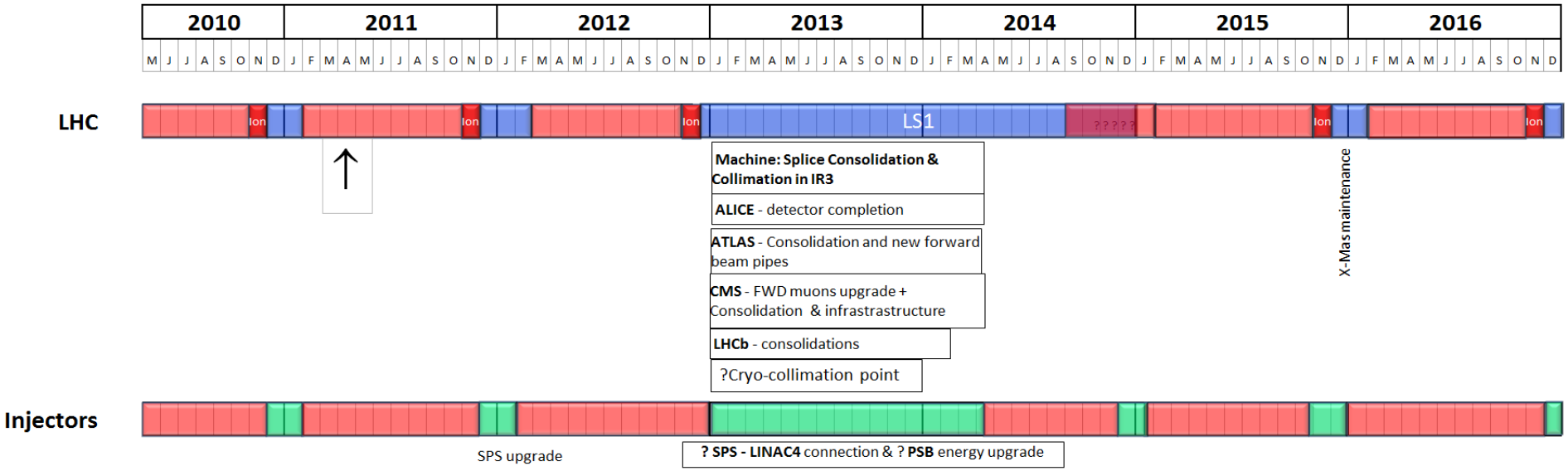
Timelines for HL-LHC

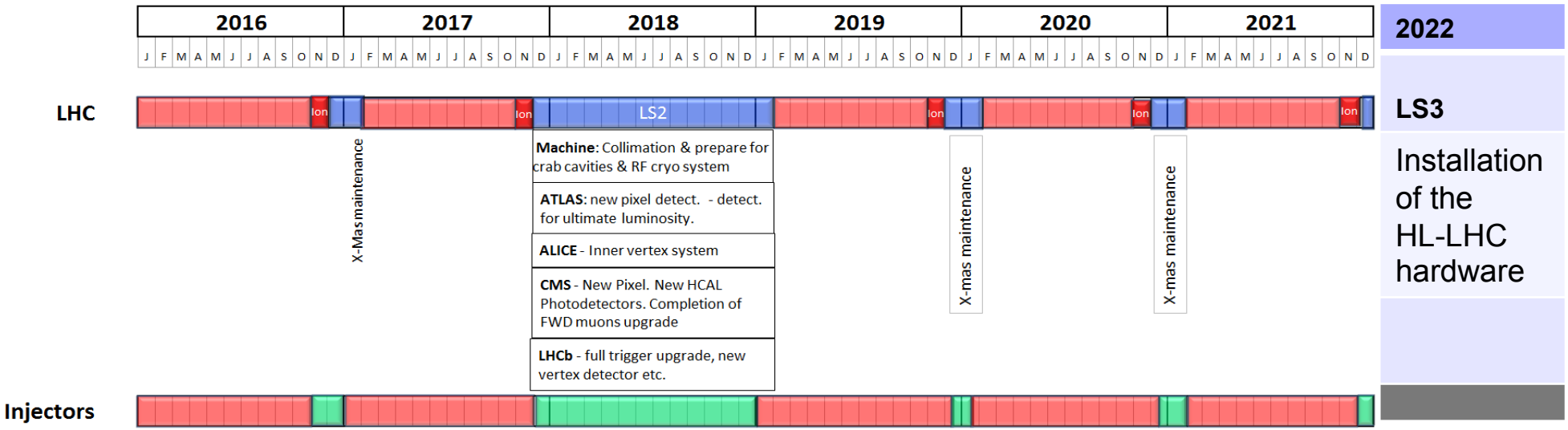
- Three Long Shutdowns (LS):
  - LS1 (2013-14) Phase-0: prepare for 14TeV & 1e34
    - LHC will have delivered 10-20fb^{-1} at 7TeV
  - LS2 (2018) Phase-I: upgrades for lumi ~2.5e34
    - LHC will have delivered 50-100fb^{-1} at 14TeV
  - LS3 (2022-23) Phase-II: upgrades for 5e34 & 3000fb^{-1}
    - Up to ~200 pp interactions per crossing at 50ns bunch spacing

- Dates driven by:
  - Integrated lumi "saturation"
  - Radiation damage of accelerator components
  - R&D and construction for the required accelerator upgrades

New rough draft 10 year plan

Not yet approved!

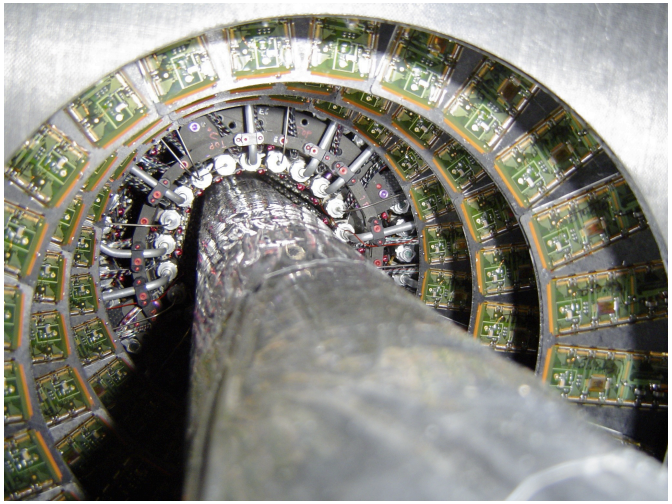


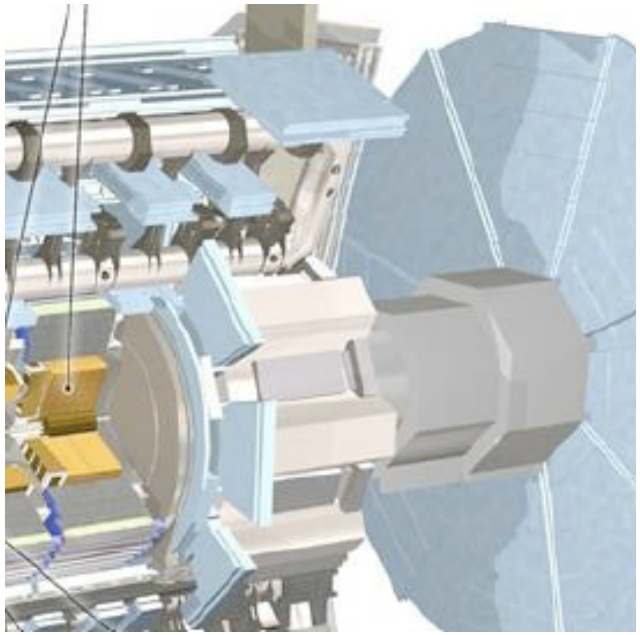


ATLAS Upgrades for HL-LHC

ATLAS Upgrades this decade

- At Phase-0 (2013-2014)
  - New Pixel Insertable Barrel Layer (IBL) very close to the beam
    - The readout of current innermost Pixel layer becomes inefficient above 1e34
- At Phase-I (2018)
  - New Muon inner endcap Wheels
    - Too high occupancy in existing chambers above 1e34, would give inefficiencies
    - New wheels will give sharper L1 muon thresholds and better rejection of fake L1 muon triggers in forward region
  - Trigger upgrades
    - L1 topological processor
    - Hardware track finder after L1 (FTK)
  - Under consideration to replace non-IBL pixel layers: x2 less material and better resolution for improved b-tagging





ATLAS upgrades for 2021-22

- Upgrades are necessary to retain performance at 5e34 and to withstand irradiation up to ~3000fb^{-1}
  - New, all-silicon tracker (pixels + strips)
  - New calorimeter readout to provide higher granularity information for the L1 Calo trigger
  - Major redesign of the L1 Trigger hardware and other upgrades to Trigger-DAQ system
  - Changes in the very forward calorimeters
- Present Calorimeters, Muon Chambers and Magnets don't change

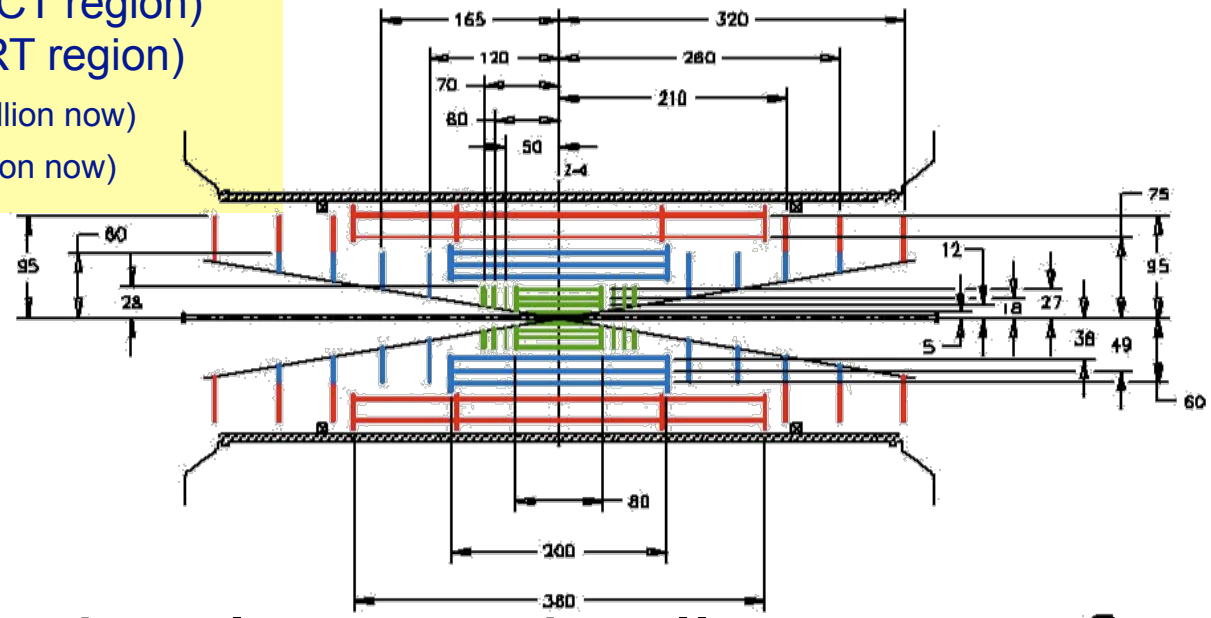
ATLAS-UK Upgrade project

- Funded via PPRP (04/2010-03/2013)

- Work packages on
  - Tracker upgrade (Strips + Pixels)
  - Trigger upgrades (L1Calo, L1Track, HLT)
  - Computing and simulation studies

Tracker Upgrade

4 layers of pixels to larger radius than now
3 double-layers of short strips (SCT region)
2 double-layers of long strips (TRT region)
Approx. 400 Million pixels (cf 80 Million now)
Approx. 45 Million strips (cf 6.3 Million now)



To be ready on the surface by early 2021

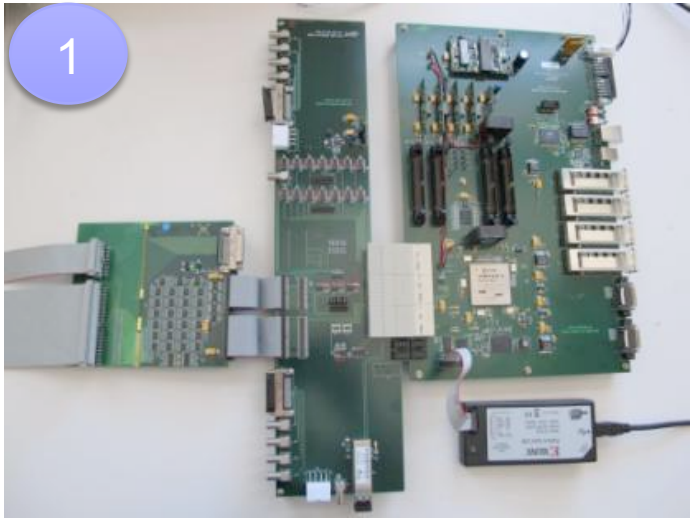
- The UK has a major involvement in all aspects of the project
  - Sensors (Pixel and Strips), on-detector electronics, powering, DAQ, mechanics, integration…
  - Simulation studies for radiation levels and layout optimization

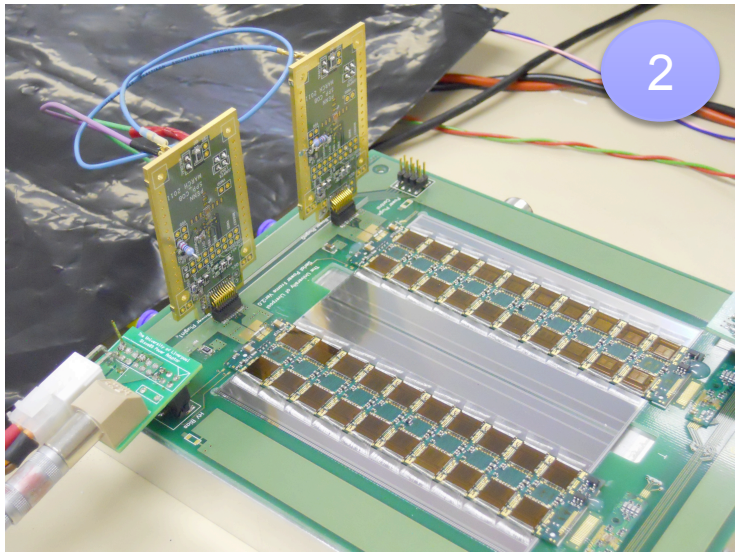
UK Tracker upgrade project

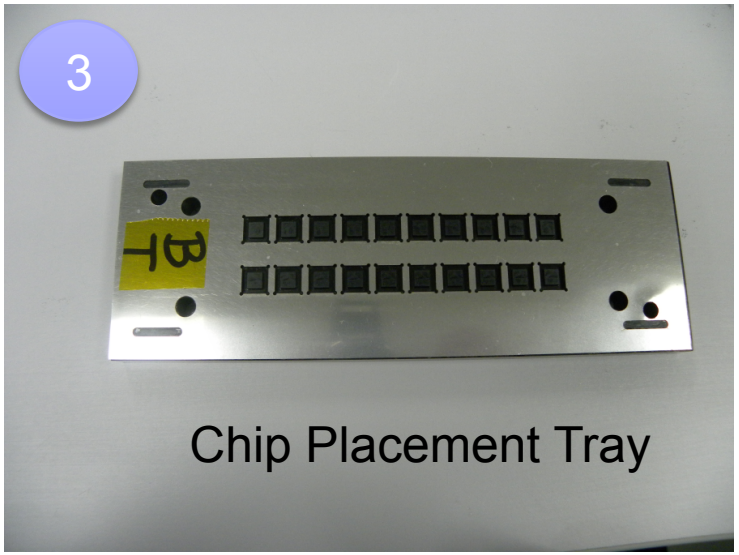
- Top level deliverables by 2013
  - Fully tested, fully populated, full-size stave using 250nm chipset
  - Advanced, full-size thermo-mechanical stave for the 130nm chipset
  - Electrical Stavelet for 130nm chipset with a 130nm module.
  - 4-chip pixel module using FEI-4 chipset

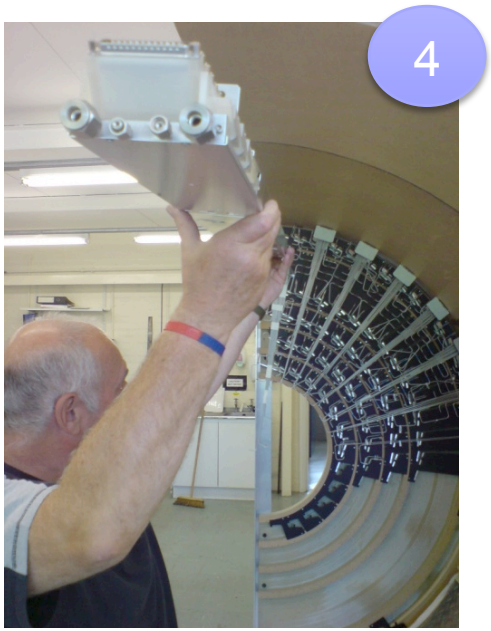
Highlights – Strips

1. HSIO-based platform for hybrid-module-stave(let) DAQ
2. New prototype serial power protection chips in 130nm technology currently being tested on module
3. Novel Hybrid and Module assembly techniques developed at Liverpool now being rolled out elsewhere - Cambridge has already bonded & tested hybrids
4. A fully integrated service assembly being developed. Initial prototype tested on the service mock up at RAL.





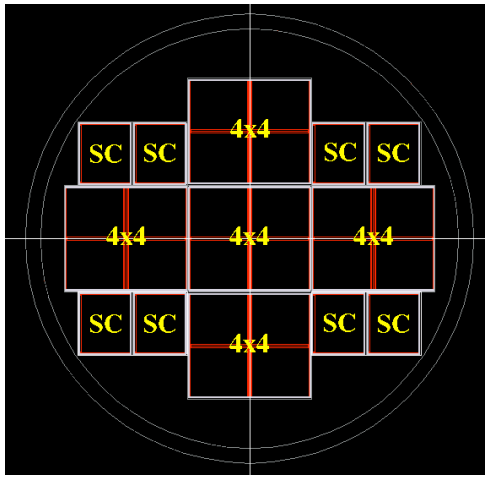




Manual Fitting of SM

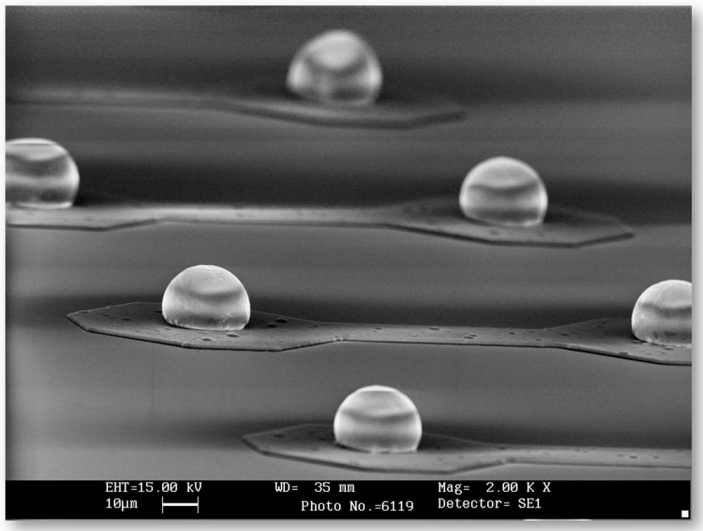
Highlights – Pixels

- IBL: evaluation of planar vs. 3D sensors in test beams
- Construction of quad-sensor modules for outer pixel layers
  - Optimize gaps between modules
- Developing bump-bonding capabilities for prototyping studies
  - In parallel working with established suppliers (IZM, VTT)
- Layout studies and mechanical prototypes



Planar quad module

22micron bumps grown using evaporator and formed using reflow oven at RAL



Trigger upgrades for 5e34

- Physics at the HL-LHC will require triggering on signatures at the electroweak scale (W/Z/H)
  - Raising the p_T thresholds partially cancels the benefits of upgrading the LHC luminosity!
- Greatest challenge is for the L1 Trigger
  - Has to achieve ~5 times higher rejection in a much more complex environment
- Reading out the tracker at ~500kHz not an option
  - Doable, but costly and introduces a lot of material

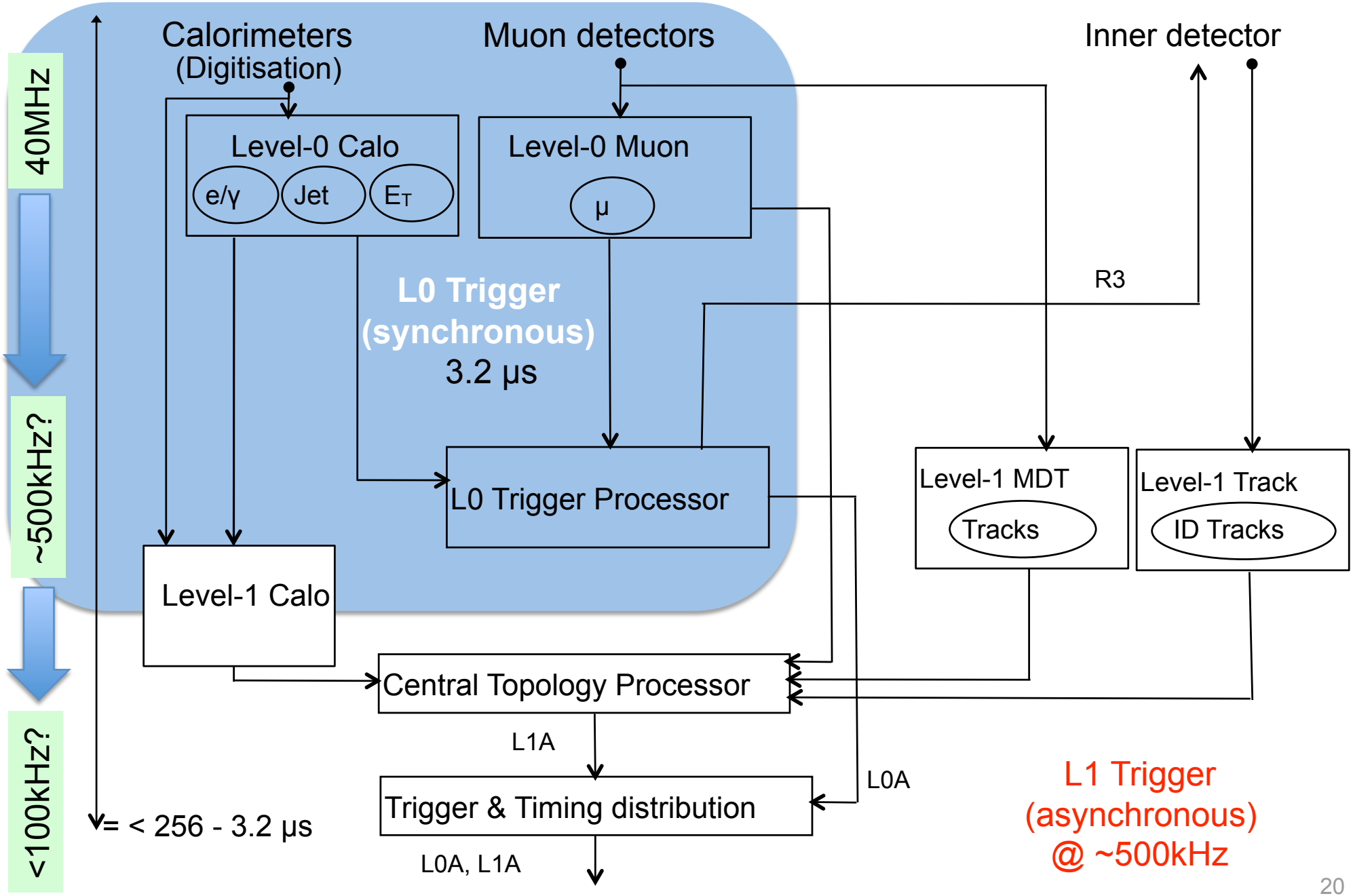
L1 Trigger upgrade work in UK

- Phase-I topological processor
  - Reject L1 muons inside L1 jets
  - Disambiguate jets from electrons
  - Reject back-to-back topologies (QCD)

- L1Calo for Phase-II
  - Full Calo granularity available: ongoing work to evaluate how much of this is needed and how best to use it

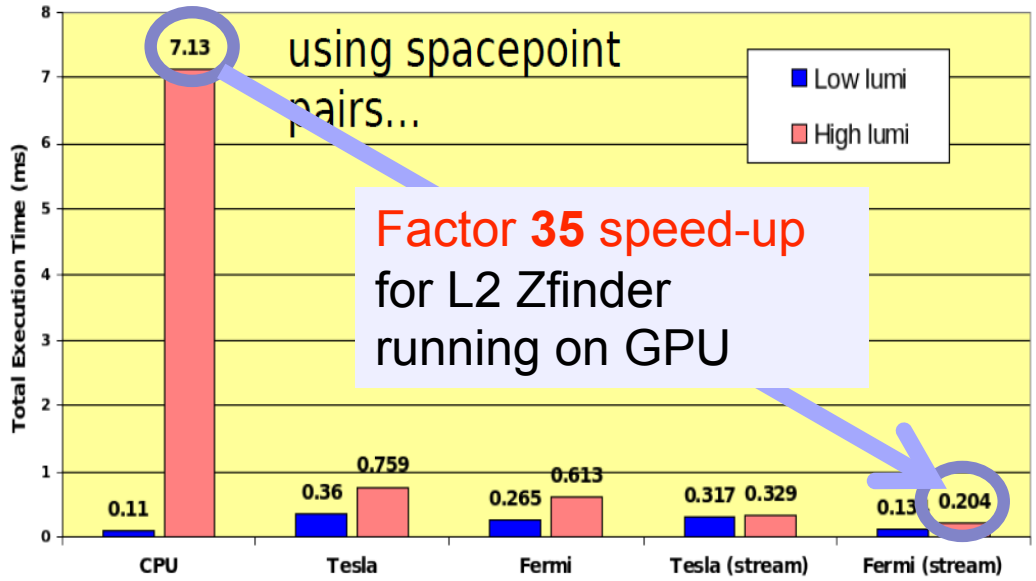
- L1 Track Trigger
  - Ongoing work to establish its necessity for ATLAS and determine the optimal design
  - Exploring L0/L1 architecture: regional tracker readout seeded by L0Calo/L0Muon

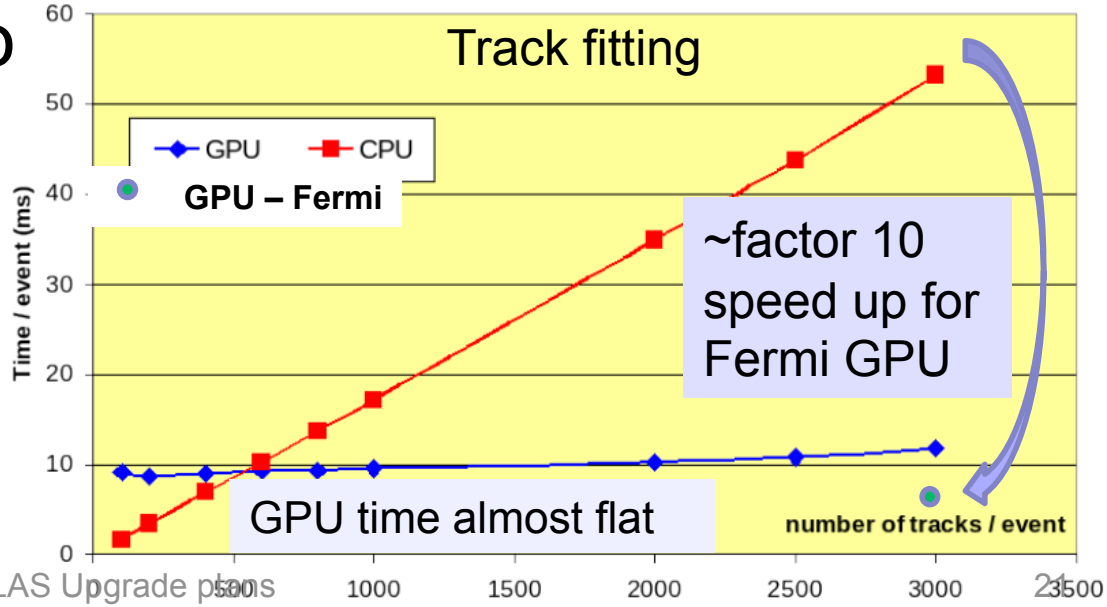
A possible Phase-II architecture: L0/L1



HLT upgrade work in UK

- Optimize the event selection for higher luminosities
- Incorporate new Pixel layer in tracking
- Integrate FTK inputs to HLT event selection
- Explore the use of GPUs to speed up pattern recognition

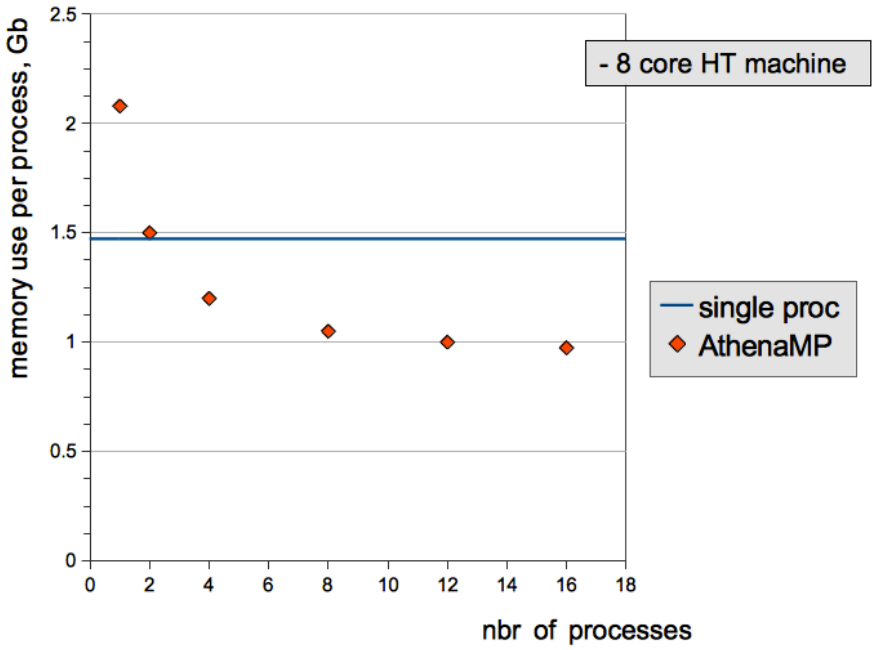




Computing for HL-LHC

- May have to revise computing model to handle the significant increase in event size/complexity

- Ongoing UK work
  - Developing/testing high-performance, parallelized code for Grid usage
  - Exploring the use of GPUs in offline computing



Conclusions – Outlook

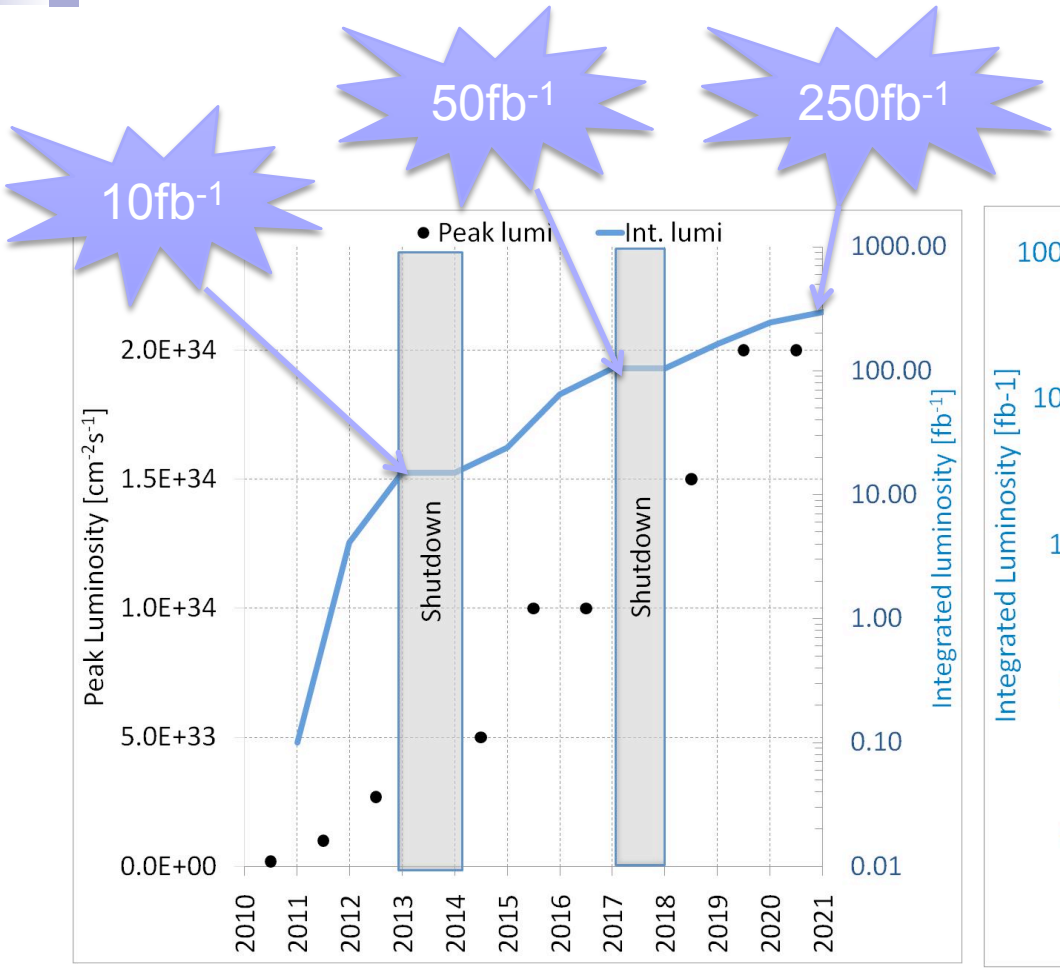
- The LHC and its luminosity upgrade will dominate the high energy discovery frontier in the next two decades
  - Plan to deliver a legacy dataset of 3000fb^{-1}

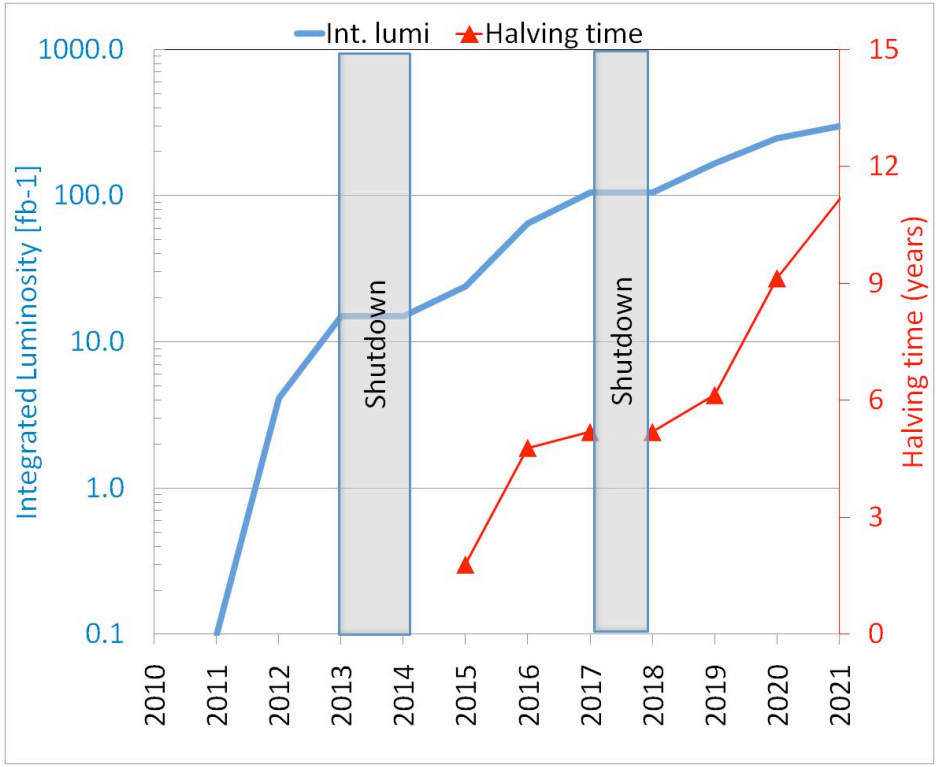
- Major upgrades of the detectors required to cope with the high instantaneous and integrated luminosity
  - Up to 200 pp collisions / bunch crossing

- UK has a leading role in the R&D for the ATLAS Tracker and Trigger upgrades, and in coordination & planning of the overall ATLAS upgrade programme

Extras

LHC int. luminosity evolution



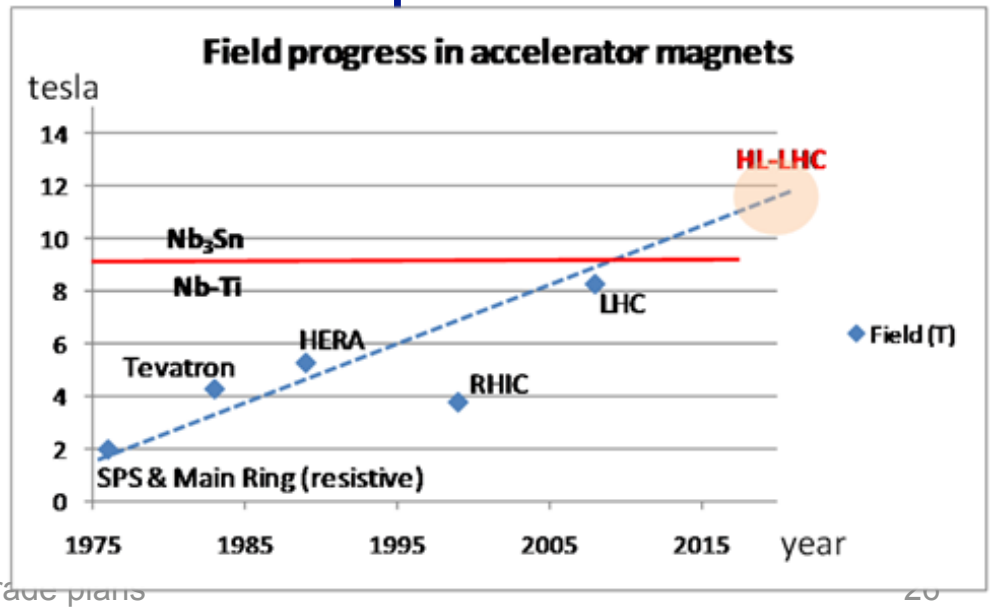


If it takes many (>10) years to deliver integrated luminosity that halves statistical errors, then it is not cost-effective.

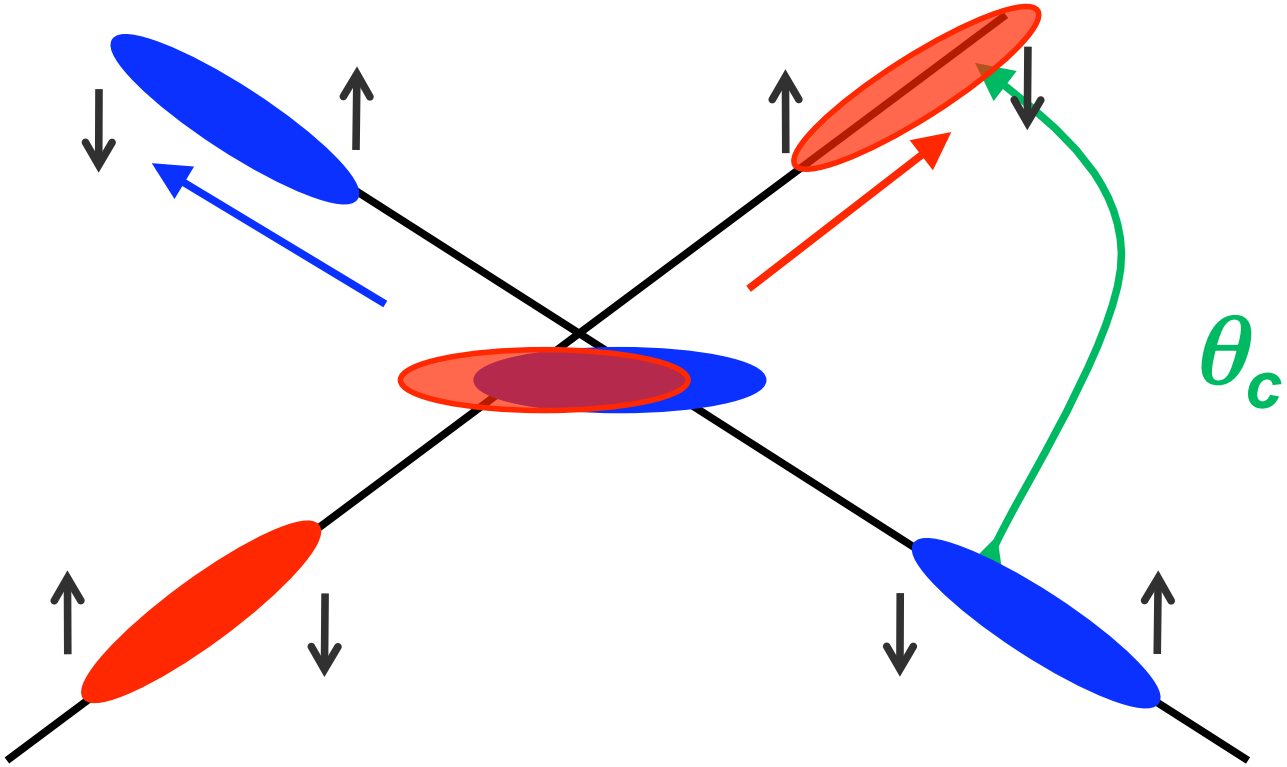
How to deliver 300fb^{-1}/year

- Upgrade the machine to deliver 10e34 (5e34 with luminosity leveling
  - Higher current per bunch
  - Higher field magnets for stronger focusing
  - Superconducting crab cavities for lumi leveling
  - Extreme collimation in the collision points
  - …

- All these require a lot of R&D



Lumi leveling with crab cavities

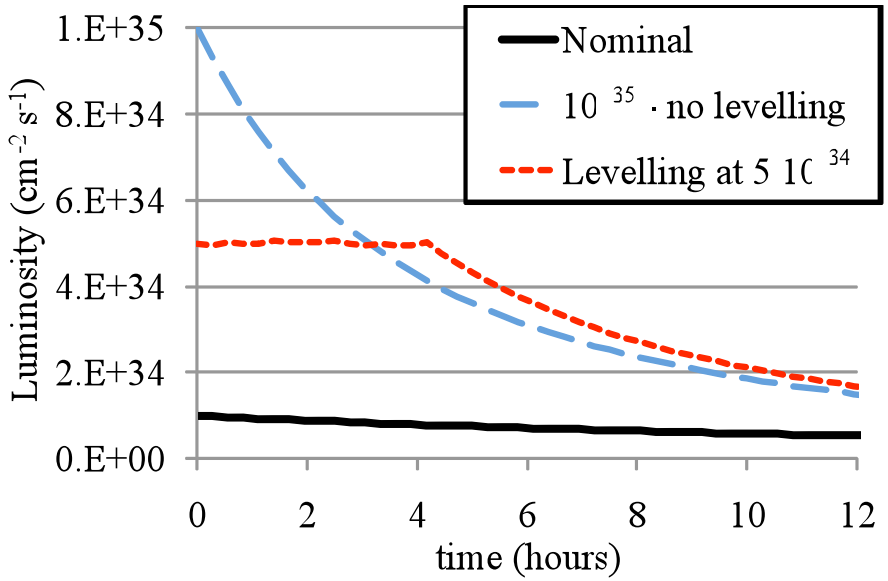


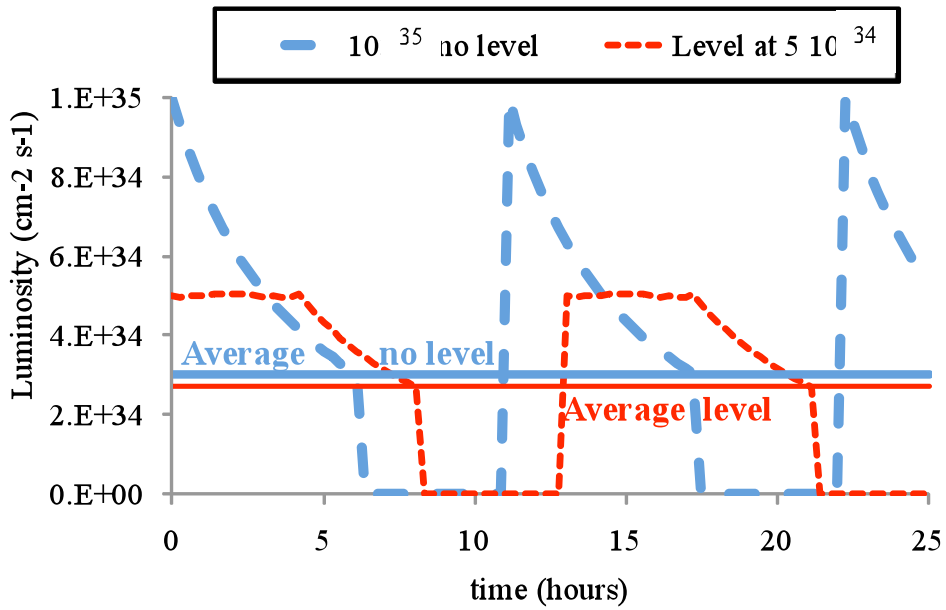
- RF crab cavity deflects head and tail in opposite direction so that collision is effectively “head on” for luminosity and tune shift
- bunch centroids still cross at an angle (easy separation)
- First proposed in 1988, in operation at KEKB since 2007

→ *world record luminosity!*

Lumi profile with leveling

- Much more manageable for the detectors
  - ~100 vs. ~200 pp collisions per bunch crossing
- Also better for LHC
  - Reduced peak heat deposition in critical cold regions of the machine





Example HL-LHC parameters

parameter	symbol	nom.	nom.*	HL crab	HL sb + lrc	HL 50+lrc
protons per bunch	N_b [10^{11}]	1.15	1.7	1.78	2.16	3.77
bunch spacing	Δt [ns]	25	50	25	25	50
beam current	I [A]	0.58	0.43	0.91	1.09	0.95
longitudinal profile		Gauss	Gauss	Gauss	Gauss	Gauss
rms bunch length	σ_z [cm]	7.55	7.55	7.55	5.0	7.55
beta* at IP1&5	β^* [m]	0.55	0.55	0.15	0.15	0.15
full crossing angle	θ_c [μrad]	285	285	(508-622)	508	508
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0.65	0.65	0.0	1.42	2.14
tune shift	ΔQ_{tot}	0.009	0.0136	0.011	0.008	0.010
potential pk luminosity	L [10^{34} cm^{-2}s^{-1}]	1	1.1	10.6	9.0	10.1
events per #ing		19	40	95	95	189
effective lifetime	τ_{eff} [h]	44.9	30	13.9	16.8	14.7
run or level time	$t_{run,level}$ [h]	15.2	12.2	4.35	4.29	4.34
e-c heat SEY=1.2	P [W/m]	0.2	0.1	0.4	0.6	0.3
SR+IC heat 4.6-20 K	P_{SR+IC} [W/m]	0.32	0.30	0.62	1.30	1.08
IBS ε rise time (*z, x*)	$\tau_{IBS,z/x}$ [h]	59, 102	40, 69	38, 66	8, 33	18, 31
annual luminosity	L_{int}[fb^{-1}]	57	58	300	300	300

Current TDAQ architecture

keyfacts®

- L1 uses only Calo/Muon
- 40MHz ➔L1➔75kHz
  - Unlikely to change hugely, given material constraints
- L2 accesses only ~10% of event data (in RoIs)
- Rate to disk ~200Hz
  - Unlikely to change hugely, given increased event size