ATLAS Detector Upgrades, Impact to Medical Physics

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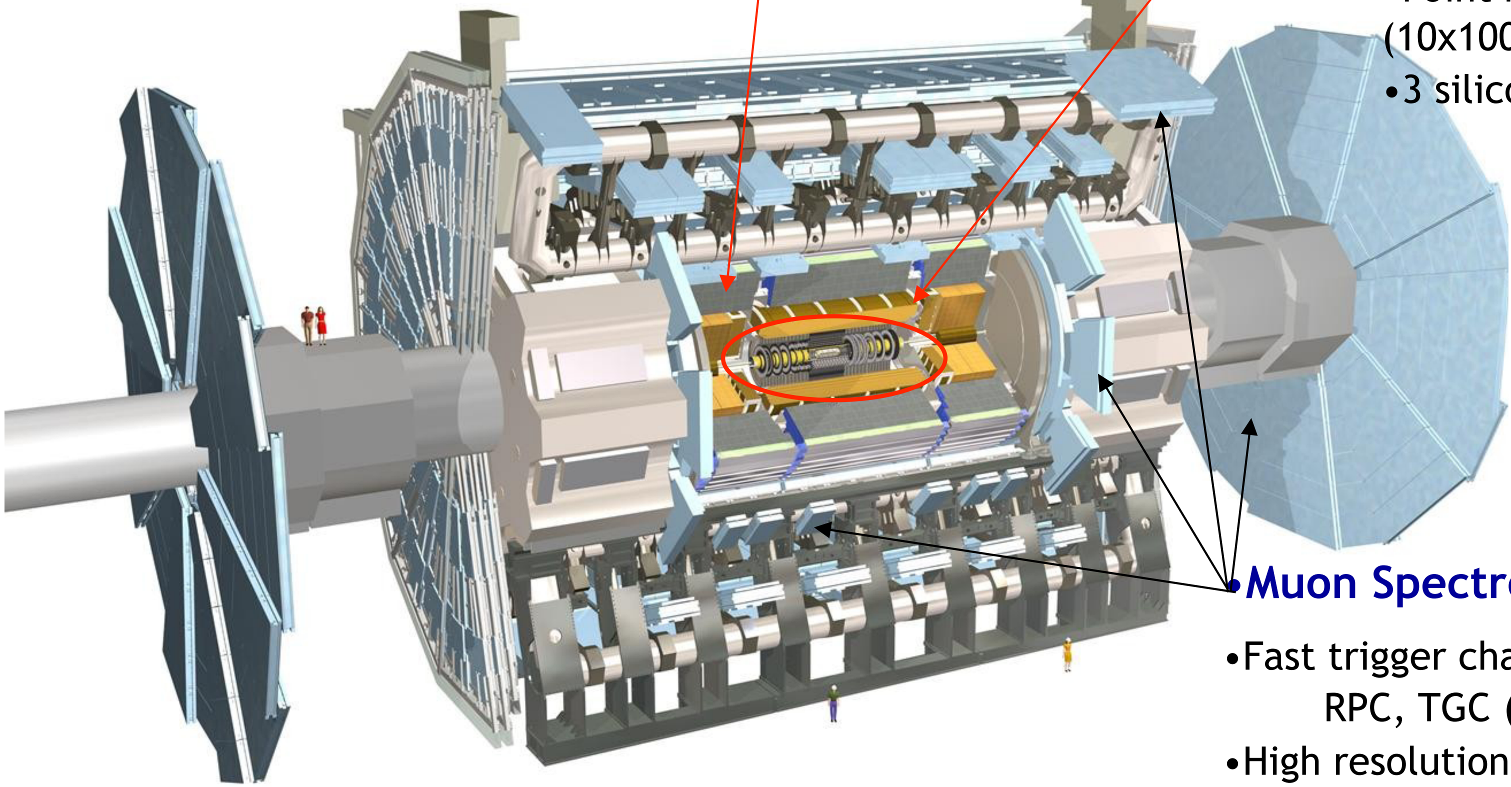
Outline

- Introduction: LHC & ATLAS Upgrade Roadmap
- LHC Upgrade Schedule
- ATLAS Upgrades; few different levels of phases; Phase0, I, II
- Medical applications
- Summary

General purpose detector at the LHC



•Inner Detector
(High granularity, tracking coverage: $|\eta|<2.5$)
- •Si pixel detector
- •SCT (strip detector)
- •TRT (transition radiation)

•Point resolution of Pixel Detector ~ (10x100)μm (φ-z)
•3 silicon layers, innermost @ 5cm

•Muon Spectrometer
•Fast trigger chambers
RPC, TGC (<10 ns time resol)
•High resolution tracking detectors:
MDT, CSC (40 μm spatial resolution)

The ATLAS Upgrade Roadmap

The present ATLAS detector was designed for a nominal luminosity of 10^{34} cm^{-2} s^{-1} and a expected lifetime/period of operation of 10 years.

Discovery of a Higgs particle 2012; new interesting physics results:

LHC planned to run until at least 2028-2030, with a substantial luminosity upgrade. The High Luminosity LHC (HL-LHC)

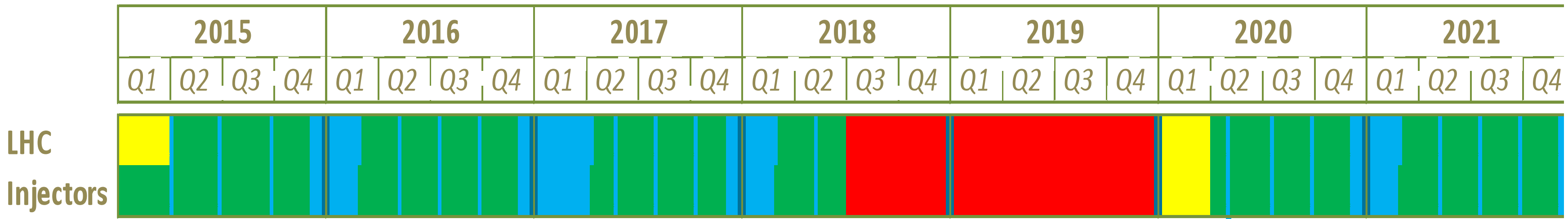
European Strategy Update

European Strategy for Particle Physics
(autumn 2012)

"The discovery of the Higgs boson is the start of a major program of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this program."

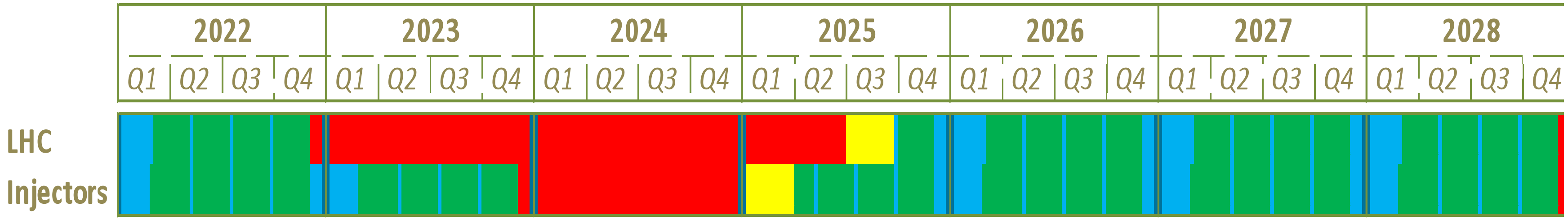
LHC schedule beyond LS1

LS2 starting in 2018 (July) 18 months + 3 months BC (Beam Commissioning)
LS3 LHC: starting in 2023 => 30 months + 3 BC
injectors: in 2024 => 13 months + 3 BC

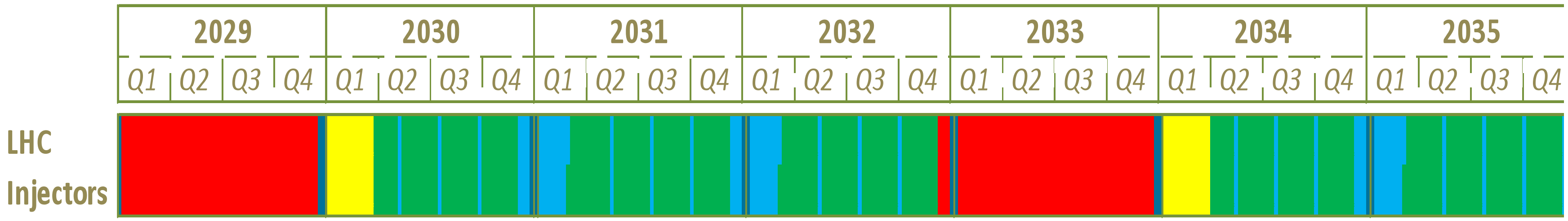


Phase-0 Upgrades (now)

Phase-I Upgrades



Phase-II Upgrades



LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators, 2nd December 2013

LHC Upgrade Roadmap in Details

Phase	Years	Shutdown	Description	Integrated luminosity	Run
	2009		LHC startup, 900 GeV		
	2010, 2011, 2012		7 + 8 TeV, $L=6 \times 10^{33}/cm^2s$, Bunch spacing 50 ns	~25 1/fb	RUN I
now Phase-0	2013, 2014	LS1	Go to design energy, nominal luminosity		
	2015, 2016, 2017		13 - 14 TeV, $L \sim 1 \times 10^{34}/cm^2s$, bunch spacing 25 ns	75 - 100 1/fb	RUN II
Phase-1	2018, 2019	LS2	Injector + LHC Phase-1 upgrade to ultimate design luminosity		
	2020, 2021, 2022		14 TeV, $L \sim 2 \times 10^{34}/cm^2s$, bunch spacing 25 ns	~300 1/fb	RUN III
Phase-2	2023, 2024, 2025	LS3	HL-LHC Phase-2 upgrade: Interaction region, crab cavities?		
	2026, ..., 2030?		14 TeV, $L=5 \times 10^{34}/cm^2s$, luminosity levelling	~3000 1/fb	RUN IV

Pileup might increase well above 50

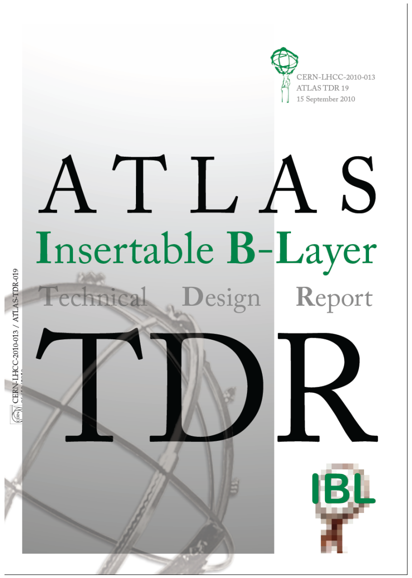
The experiments were constructed for a pileup around 23 !

Trigger upgrades

- The high pileup degrades the performance of current trigger algorithms
  - If nothing is done the rates exceed by far 100 kHz
- The new “Higgs-like” boson is relatively light (125GeV)
  - The future physics program foresees to investigate this boson with enhanced precision.
    - This means trigger efficiencies need to stay at least as good as they are.
    - Trigger thresholds cannot be increased without “cutting into the physics”
- The experiments need to find ways to cope with the higher pileup without loosing efficiency for physics
- General solutions:
  - Increase resolution for trigger object: Energy, Momentum, Spacial
    - Finer grain input data to trigger
  - More input data to the trigger
  - Enhance detectors in critical high multiplicity regions (forward region)
  - More complex algorithms
    - To be implemented in modern FPGAs
    - e.g. topological triggers, calculation of invariant mass, subtraction of pileup, ...
  - Include tracking in Lvl1 Trigger

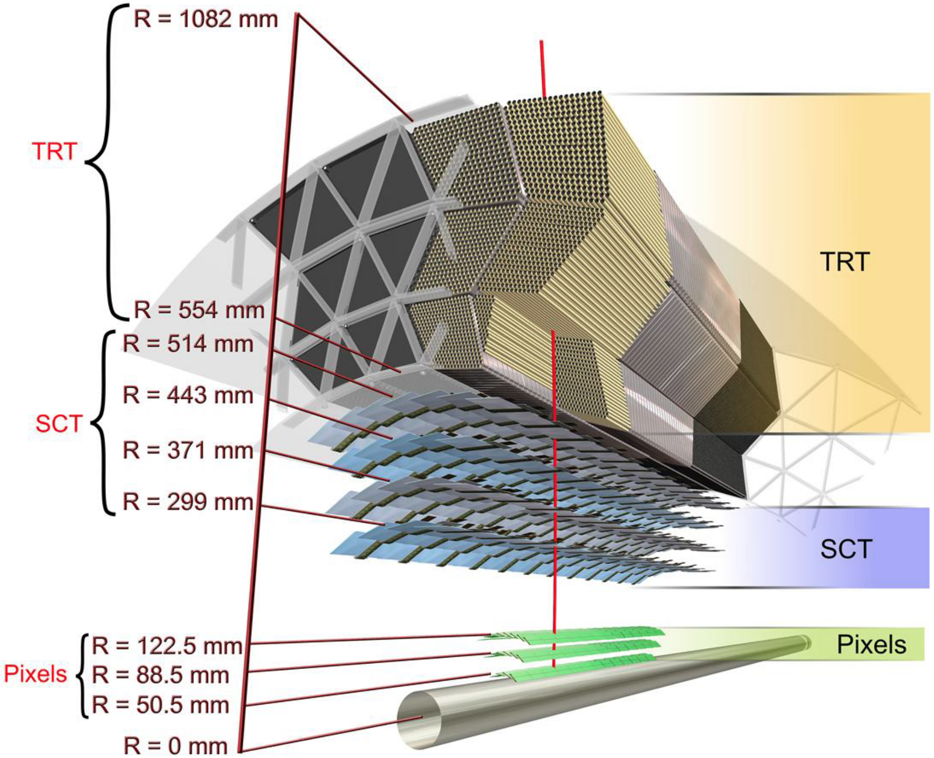
Phase-0 Upgrades

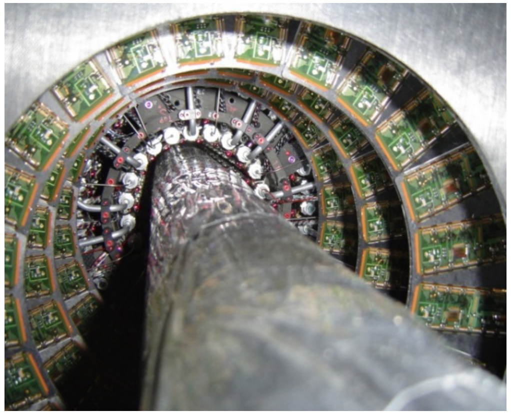
- New Insertable pixel B-Layer (IBL) + new pixel services (nSQP) + new small Be pipe
- DAQ/services upgrades to cope with high(er) pileup running in Run2. Many systems have added new hardware to overcome existing bandwidth limitations present in Run1
- Detector consolidation
- Replace all calorimeter Low Voltage Power Supplies
- Finish the installation of the EE muon chambers staged in 2003 + additional chambers in the feet and elevators region + RPC gas consolidation
- Upgrade the magnets cryogenics and decouple toroid and solenoid cryogenics
- ……construction ongoing……

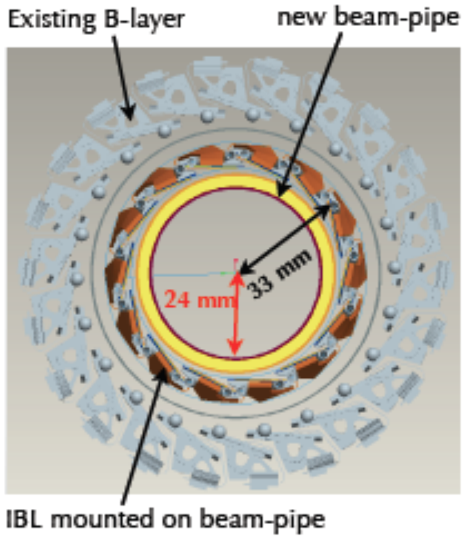


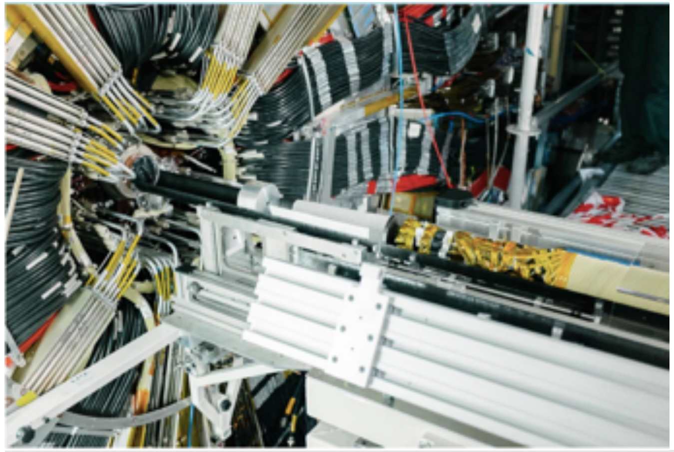
Work Responsibility	
Barcelona	Prototype: 3D, Planar; Production: contribution
Bonn	Prototype: 3D, Planar, Diamond; Production: contribution
CERN	Prototype: 3D, Planar, Diamond; Production: contribution
Dortmund (/MPI)	Prototype: Planar; production: wafer QC
KEK	Prototype: Planar; Production: contribution
Liverpool	Prototype: Planar; Production: contribution
Ljubljana	Prototype: Diamond
LPNHE/Orsay	Prototype: Planar; Production: contribution
Manchester/Glasgow	Prototype: 3D; Production: contribution; QC supervision (Manchester)
New Mexico	Prototype: 3D, Planar, Diamond; Production (silicon): contribution
Ohio SU	Prototype: Diamond
Oslo/Bergen	Prototype: 3D; Production: contribution
Prague AS	Prototype: Planar; Production: contribution
Santa Cruz	Prototype: Planar, (3D); Production: contribution
SLAC/Stony Brook	Prototype: 3D; Production: contribution
Toronto(/Carleton)	Prototype: Diamond
Udine(/Trento)	Prototype: 3D, Planar; Production: contribution

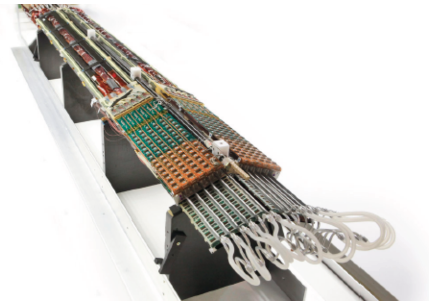
Phase-0 Upgrades - Insertable B-Layer (IBL)











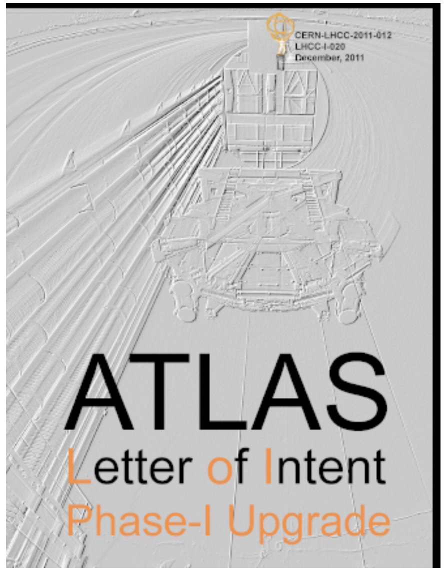
- IBL was inserted into ATLAS on 07.05.2014
- New diamond beam monitor with new rad-hard 2cmx2cm FE-14 pixel chip, 130nm CMOS process
- Will be operational until Phase-II

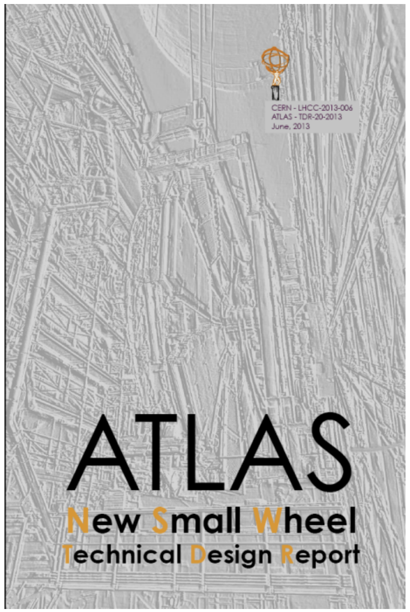
Future Upgrades for LS-2 *(Long Shutdown-2)*

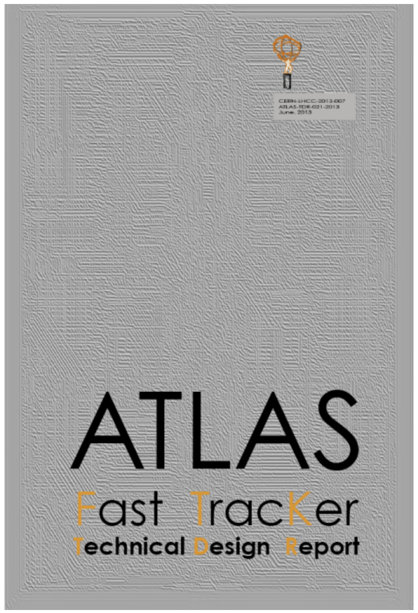
Phase-I Upgrade:

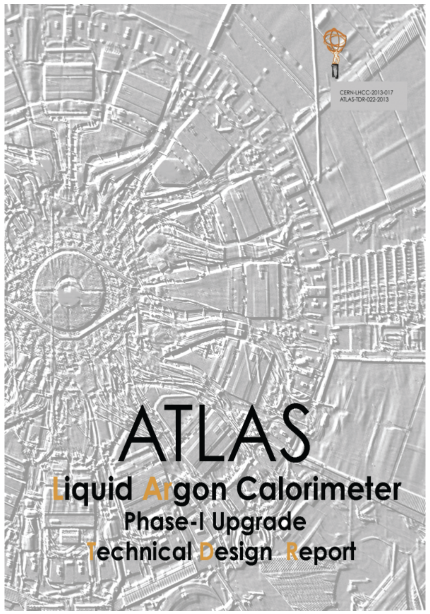
in 2013 four Technical Design reports were prepared & approved by CERN LHC Committee:

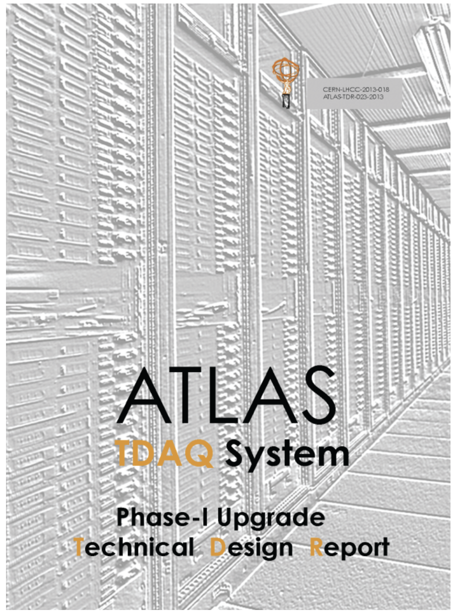
- New Small Wheel
- Fast Tracker
- Liquid Argon Colorimeter
- TDAQ System



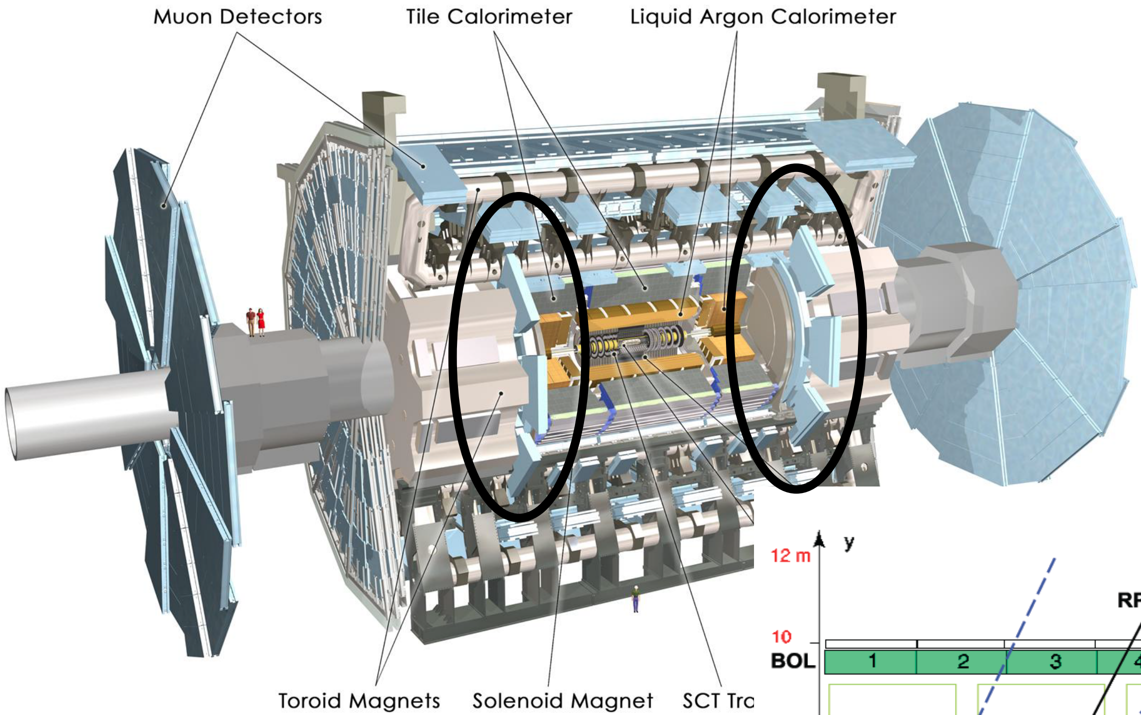




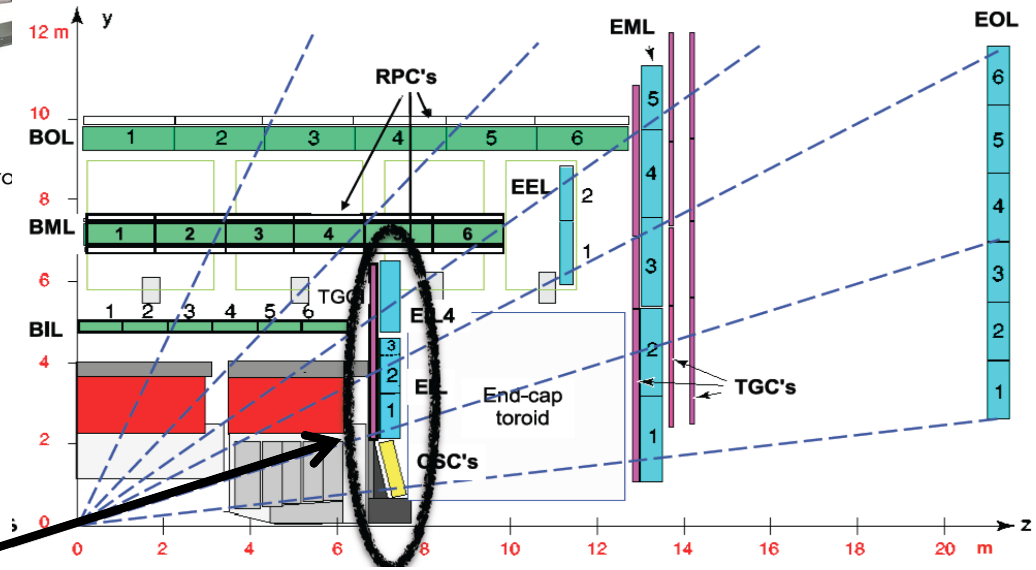




New Small Wheel (NSW)



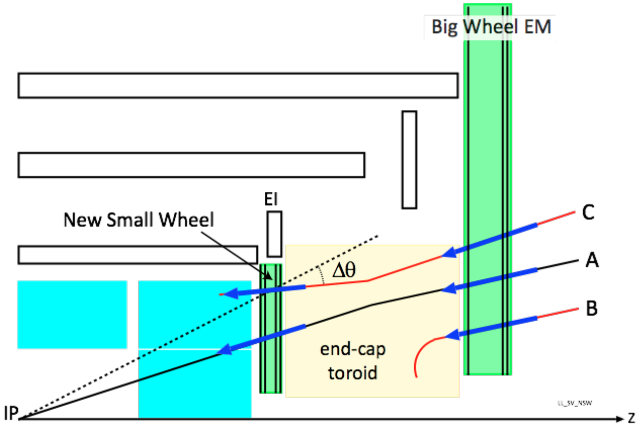
- NSW will replace the innermost endcap station of the Muon Spectrometer
- Located between end-cap calorimeter and end-cap toroid
- Is not so small; 10 m in diameter



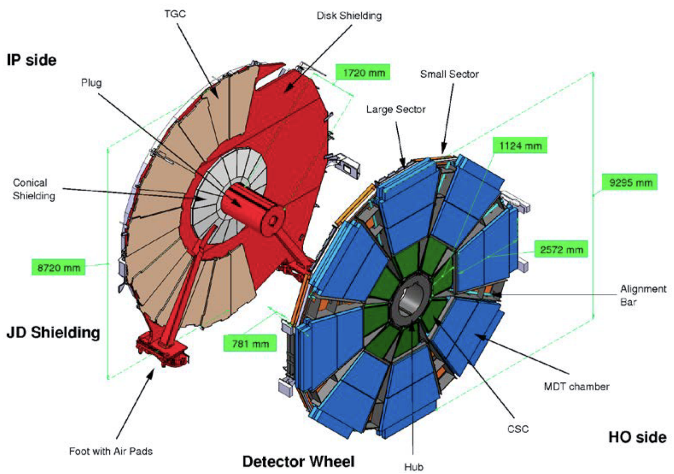
Existing SW Problems & NSW Technology

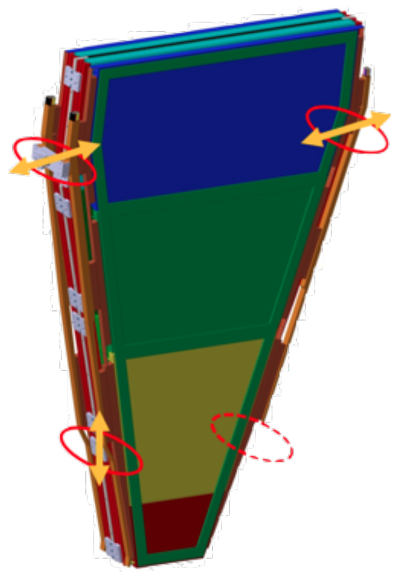
•The ATLAS upgrade is motivated primarily by the pile-up rate (<n>=55 interactions per 25 ns bunch crossing) that are expected at $L=2\times10^{34}$ $cm^{-2}s^{-1}$. This will lead to an increased particle flux (rate) which the present detectors (MDT + CSC) cannot handle efficiently. Also, added trigger capability.

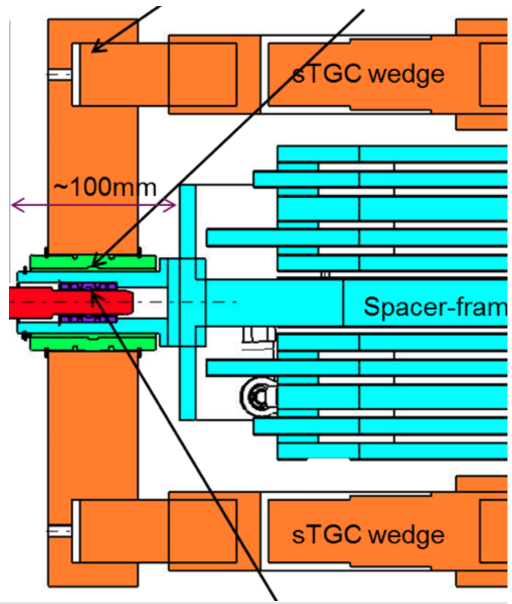
•Replacing the Small Wheels with a detector that can provide precise tracking and trigger segments will eliminate fake triggers without loss on physics acceptance.



- Two technologies: Both Micromegas & sTGC detectors will provide tracking and trigger data
- 16 Sectors per Wheel (8 large, 8 small)
- 2 Multiplets per Sector for Micromegas & 3 Multiplets per Sector for sTGC
- 8 Micromegas Layers & 8 sTGC Layers per Multilayer







Fast TracKer (FTK)

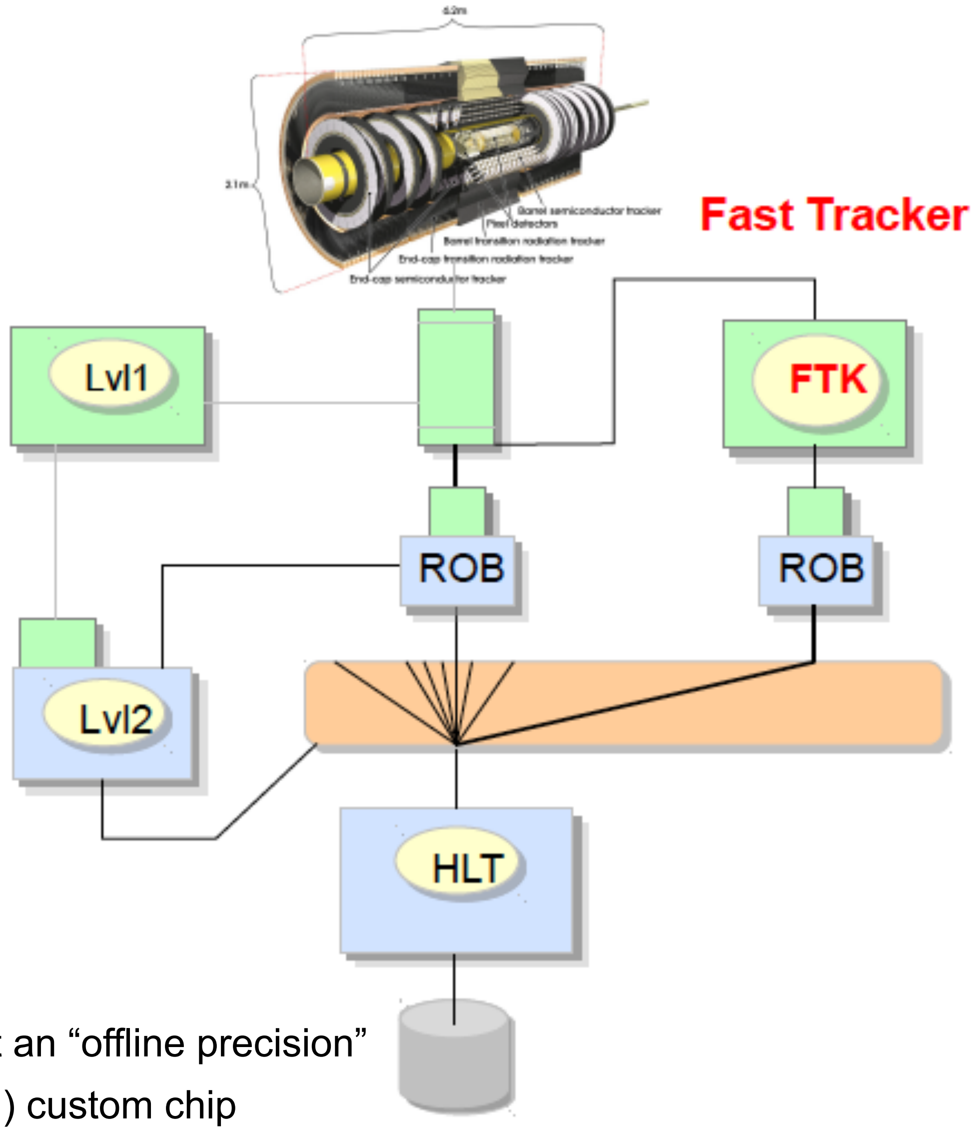
Track-finding is CPU intensive

– Especially in high pileup events the events the resources needed to do track finding increase other trigger algorithms.

Idea: Special highly parallel hardware processors should find tracks

– The output of the processor will be available at Lvl2 / Filter

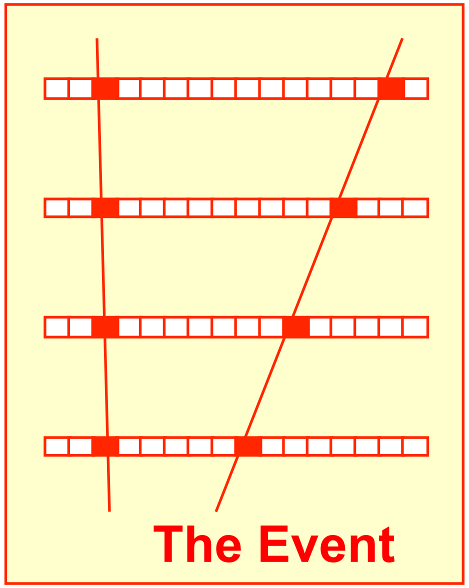
– The CPU time saved by not having to do tracking can be used for other trigger algorithms

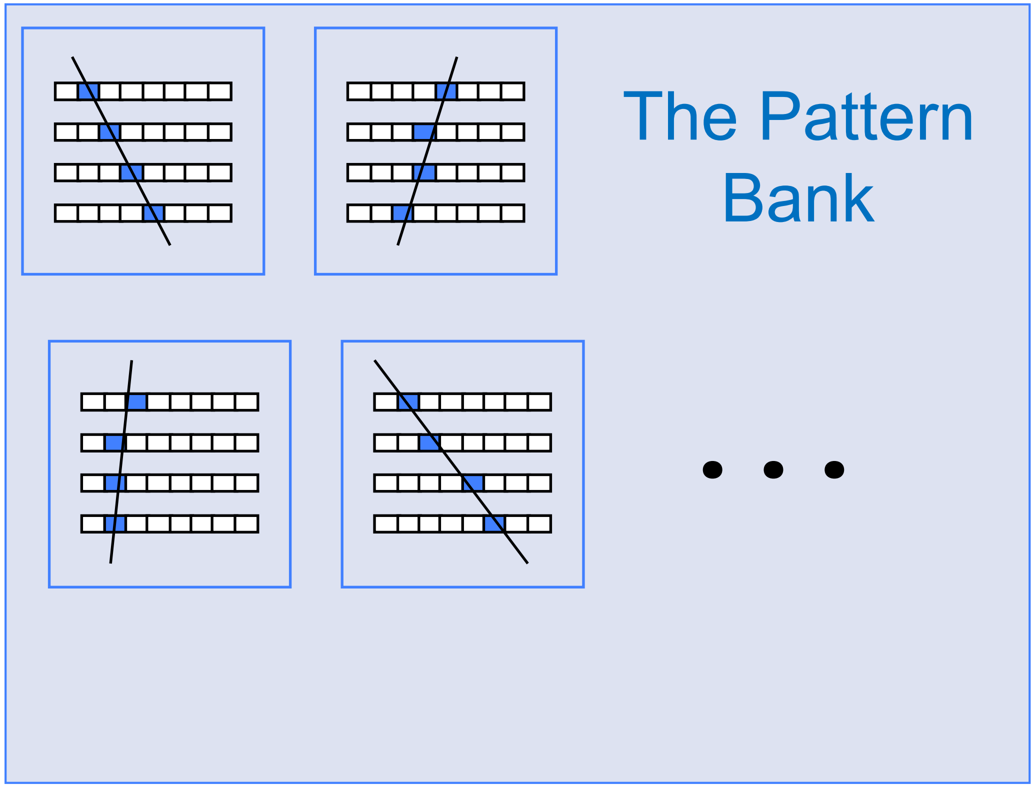


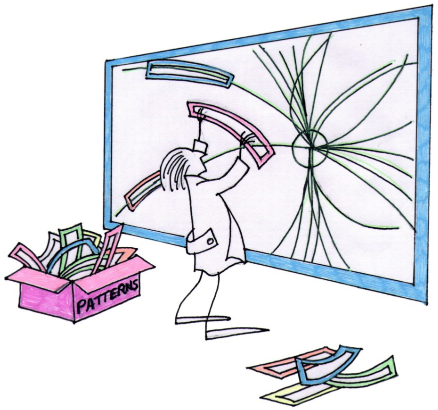
- Dedicated, hardware-based track finder
- Runs after L1, on duplicated Si-detector read-out links
- Finds and fits tracks (~ 25 μs) in the ID silicon layers at an “offline precision”
- Uses HEP-specific content addressable memory (CAM) custom chip
- Designed for installation before Phase-I to provide HLT with full tracking at start

Compare the Event Hit Pattern with many Stored patterns

– The comparison with all patterns has to be done in parallel!

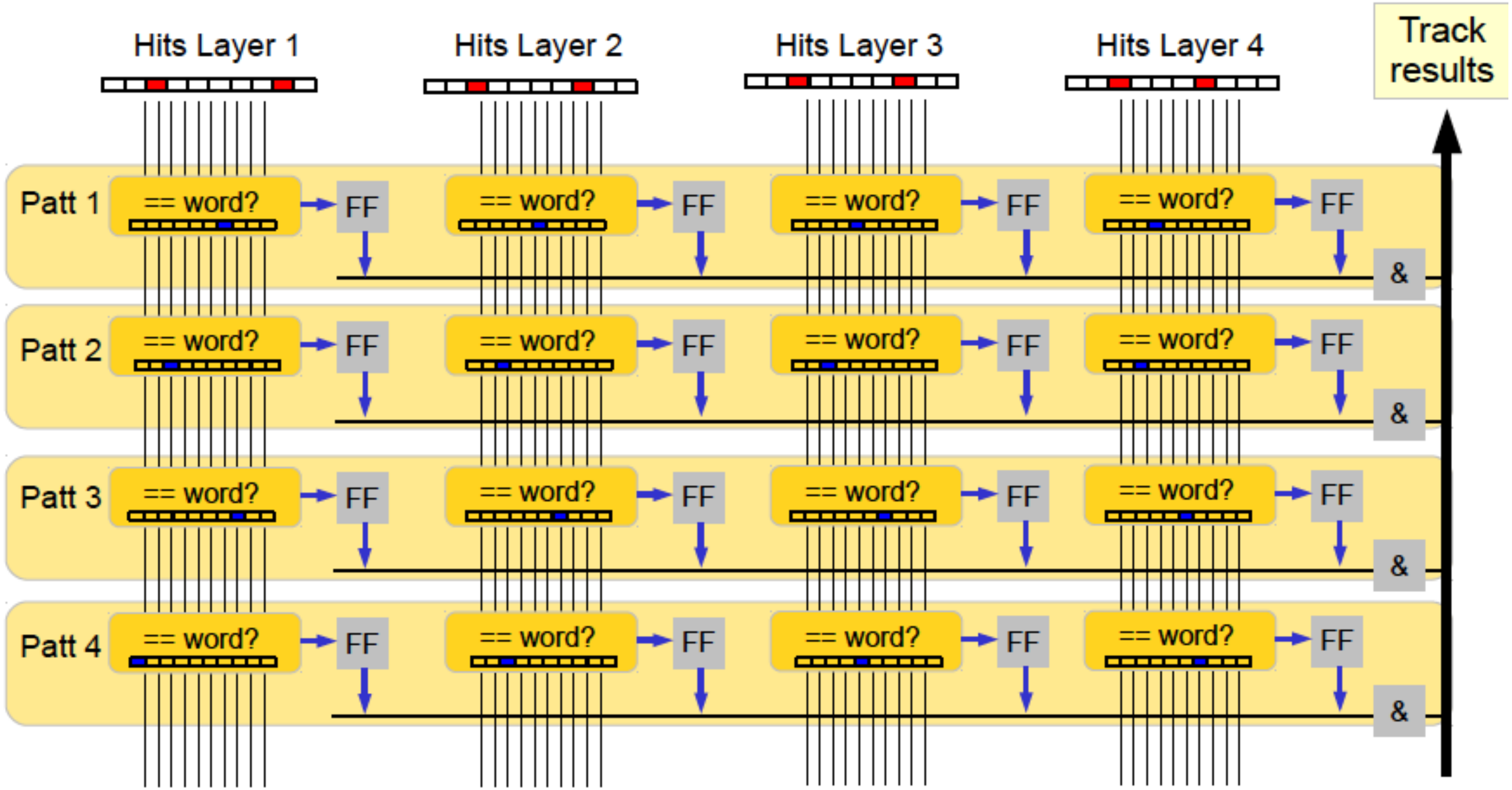






TRACKING WITH PATTERN MATCHING

Implementation of Hardware Track Trigger



Principle of a CAM: Content Addressable Memory

Liquid Argon Electronics Upgrade

• Radiation tolerance, natural ageing of the electronics and higher selectivity of the L1 calorimeter trigger to keep L1 rate below 100kHz are the driving motivations for an upgrade of the front- end electronics

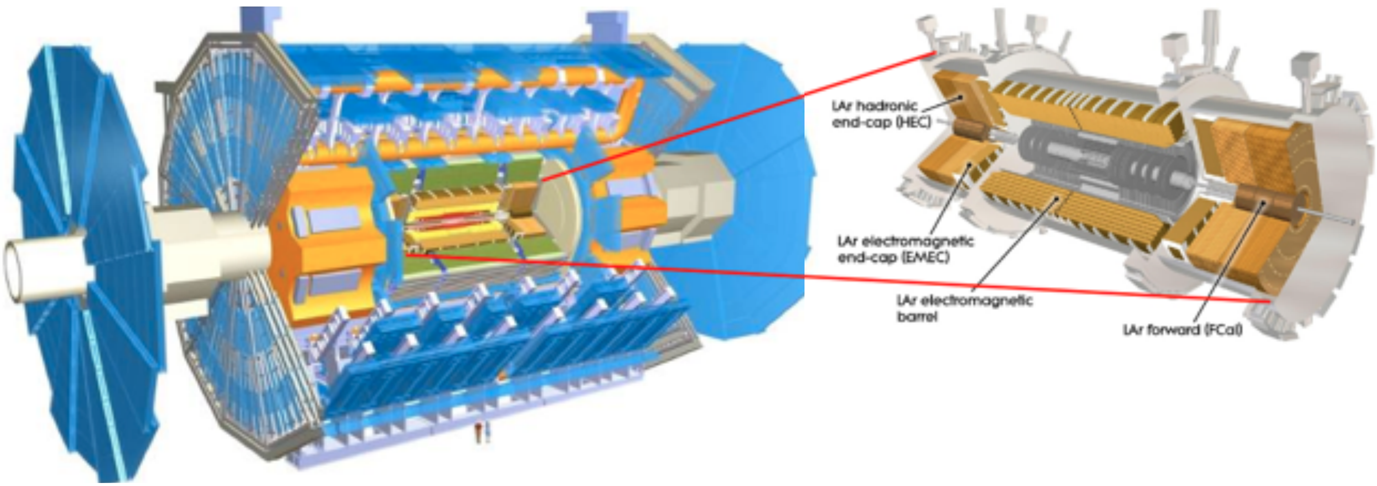
• Main purpose is to maintain high efficiency for Level-1 triggering on low PT objects (here electrons & photons)

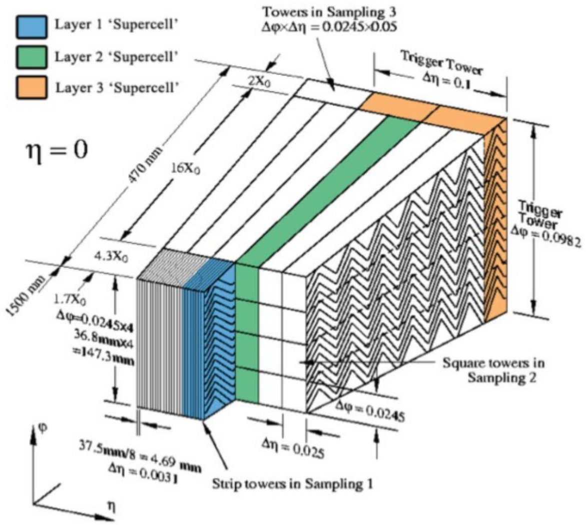
• Use higher granularity in trigger

• Improve energy resolution

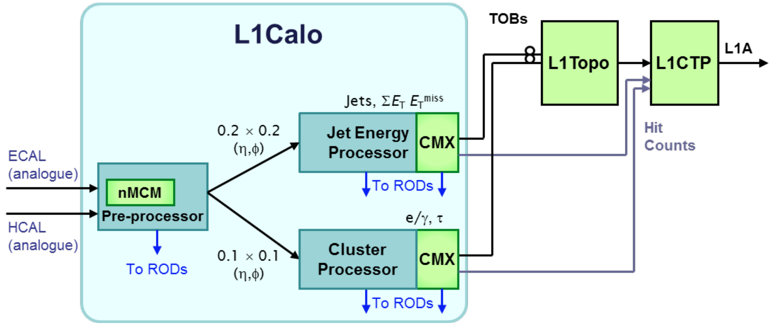
• Reduce electron, photon, tau, jet and missing Et trigger threshold

• In the LAr calorimeter this will be achieved by replacing the front-end electronics to allow finer granularity to be exploited at Level-1



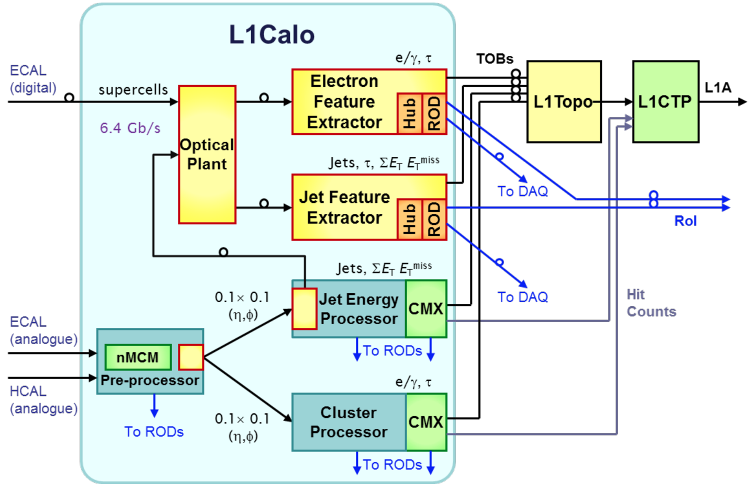


TDAQ Upgrades



Level-1

- Phase I: completely new L1 electron and jet triggers.
- Very complex ATCA modules. Requires mastery of 6-10 Gb/s signal handling. R&D with demonstrator to check simulations of distribution on boards

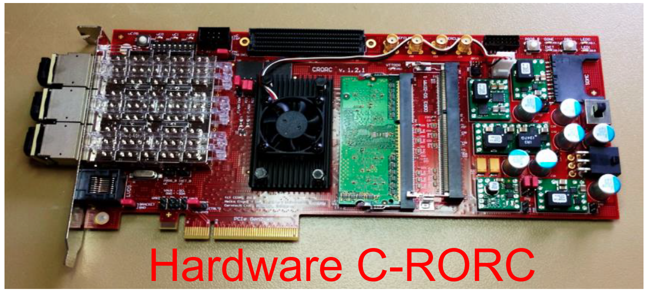


HLT

- Increase DataFlow throughput => higher request rates, more data per request
- Maintain rejection & limit rise of CPU times
- Provide for new detectors: FTK, IBL, NSW

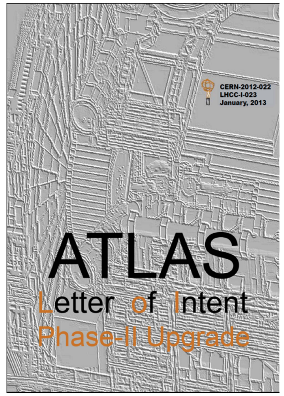
Dataflow

- New ROB being implemented on C_RORC (Combined Read Out Receiver Card)

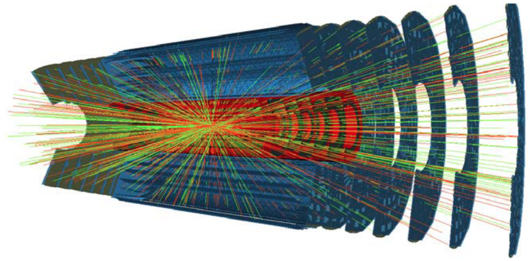


Phase-II Upgrade (LS3)

Starts end of 2022

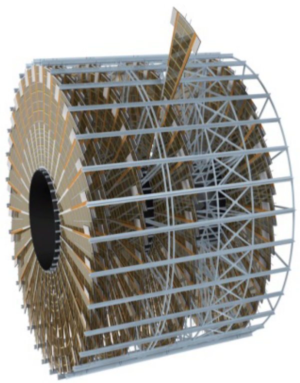


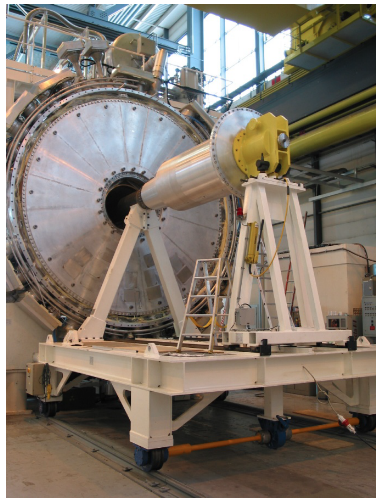
Integrated radiation levels (up to 2-3 x10^{16} n_{eq}/cm^2) and plan to cope with up to 200 interactions every 25 ns.



Implications of this include:

- New all-Si inner tracker (strips & pinels)
- L1 Track Trigger
- New LAr front-end and back-end electronics
- Possible upgrades of HEC and FCal
- Muon Barrel and Large Wheel trigger electronics
- Possible upgrades of TGCs in Inner Big Wheels
- TAS and shielding upgrade
- TDAQ, Software and Computing
- …..



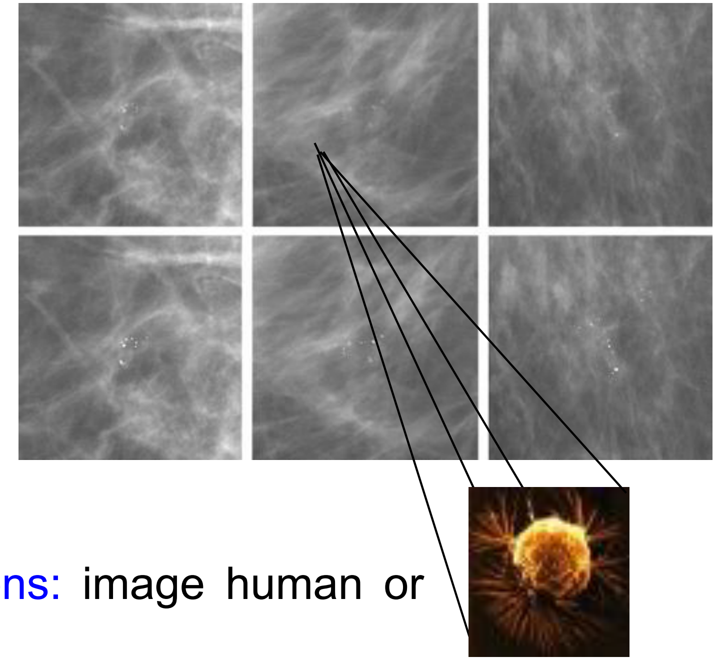


Impact to Medical Physics

Micromegas (Micro Pattern Gaseous Detectors)

Medical imaging

MPGD for breast cancer prevention: a high resolution and low dose radiation medical imaging, *R.M.Gutierrez, E.A.Cerquera and G.Manana, presented at 2nd INT. CONFERENCE ON MICRO PATTERN GASEOUS DETECTORS, 29 AUGUST – 1 SEPTEMBER 2011, KOBE, JAPAN*

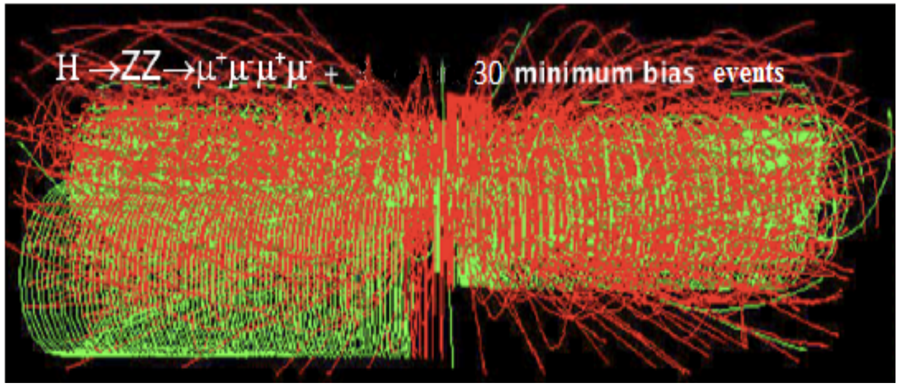


•Beta radiography in medical and biological investigations: image human or animal tissues labeled with beta-emitting radionucleides.

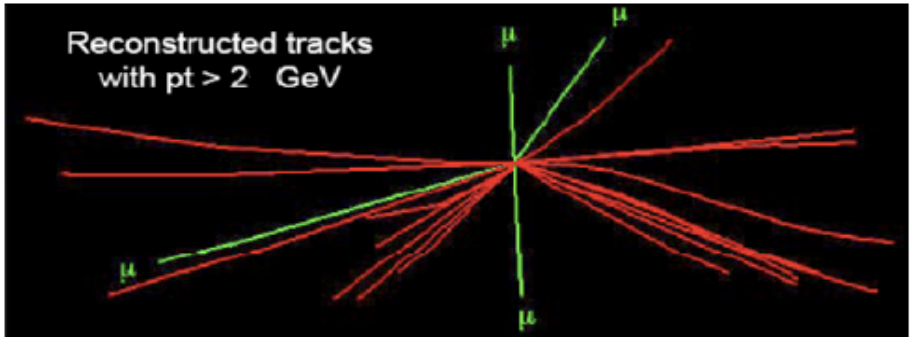
•Radiation monitor in radiotherapy and hadron therapy

Large field of possible applications → MICROMEGAS can simplify the construction and improve the performance in terms of accuracy and read-out speed.

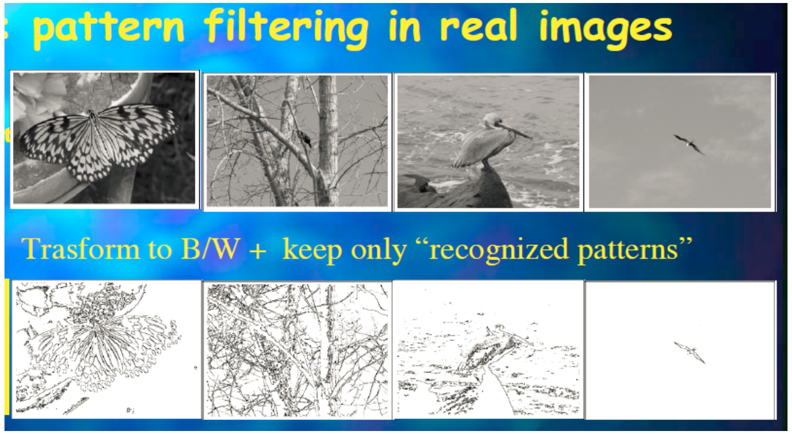
AM: a filter to detect the IMAGE relevant features



HEP



FILTERING NATURAL IMAGES:
edge detector
→ AM as neurons?
Filtered images are clear to human eyes



High-resolution medical image processing, → memory+computing power 3D in a limited time.

- R&D for **neurophysiologic** studies of the brain.

Summary

- LHC has worked flawlessly and ATLAS experiment has operated efficiently
- Higgs boson was discovered at M~125 GeV/c^2; higher precision needed
- The ATLAS Upgrade program will enable the experiment to retain its excellent performance also beyond design luminosity and for the HLLHC phase
- Exciting future prospects:
  - Run-2 probes new territory with many fb^{-1} of 13 TeV data
  - HL-LHC will perform precision Higgs physics
  - Significant upgrades are required to fully explore the future LHC runs

    — this is what we are doing!

- Thank you!

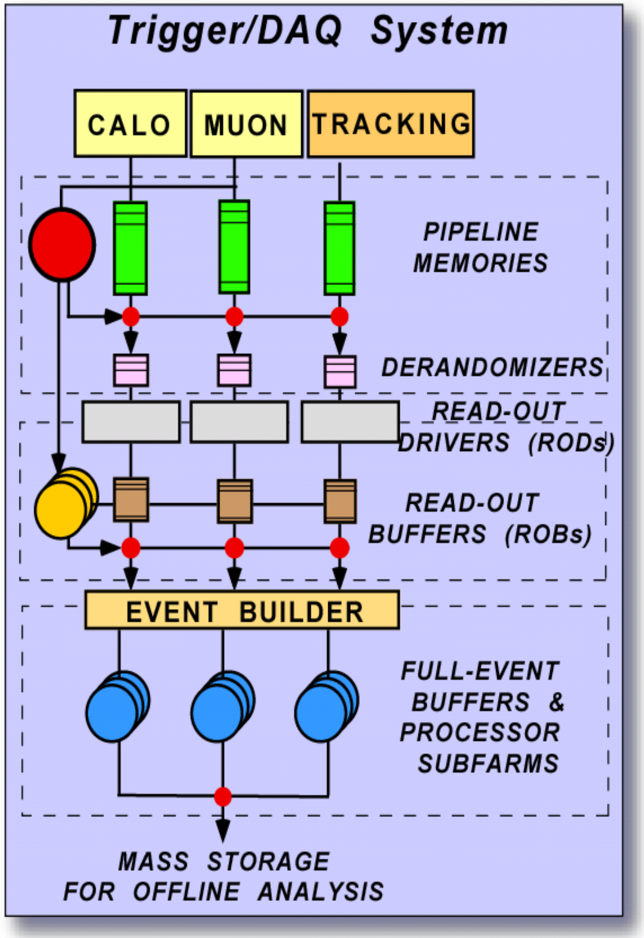
Backup Slides

The ATLAS trigger

Three stage system

Level1: Hardware,

High Level Trigger: (LVL2+EF) Software



- LVL1
  - hardware-based, identifies Regions of Interest (RoI) for further processing, Total rate 75 kHz
- LVL2
  - Confirmation of LVL1 data using precition detectors
  - Muon tracks extrapolation to inner detector
  - Track reconstruction in ROIs
  - Total rate 2 kHz
- EF
  - refines LVL2 selection using offline-like algorithms
  - Vertexing, transverse decay length cut, angular distribution cut, full event, alignment and calibration data available

hardware

software

Total rate 200 Hz ➔ to tape
(5-10% dedicated to B-Physics)