ATLAS Detector : Performance and Upgrades

Denis Oliveira Damazio (Brookhaven National Laboratory) on behalf of the ATLAS experiment.

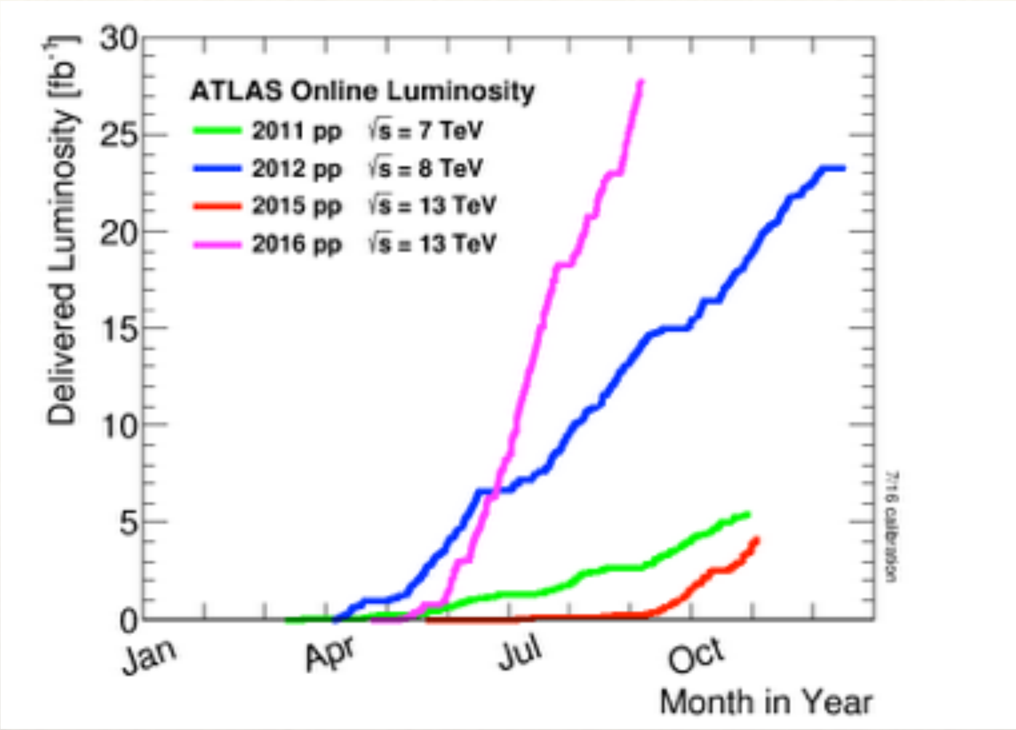
Obvious disclaimer : impossible to cover the wide range of activities in the detector, performance, physics and upgrade groups in one talk

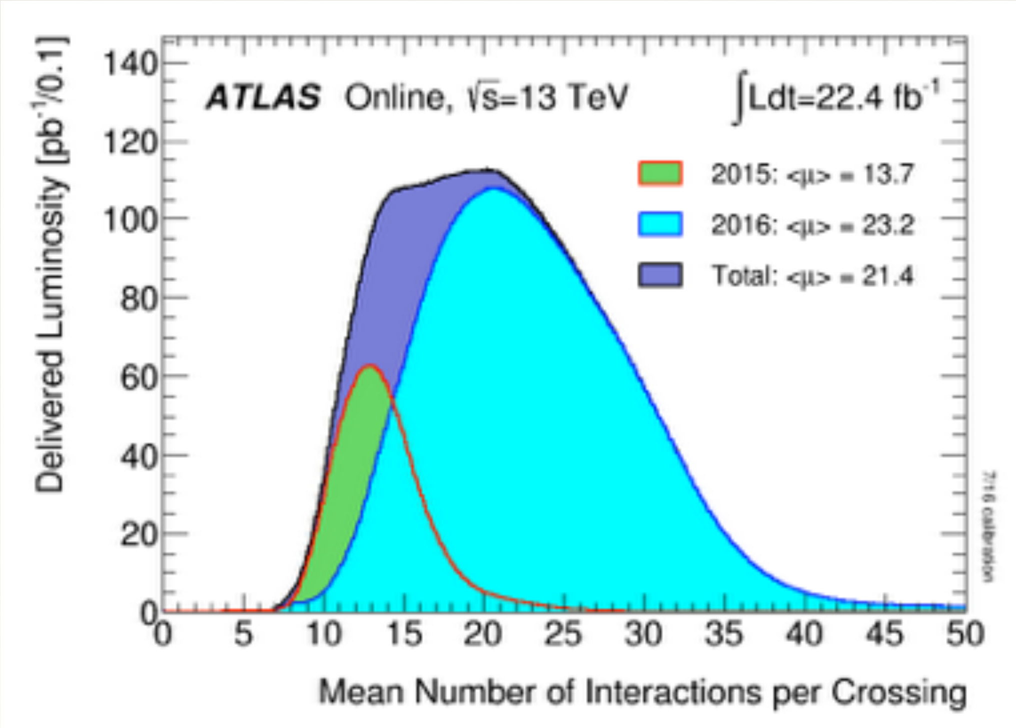
Outline :

- detector presentation.
- Run 1 -> Run 2 upgrades.
- Run 2 initial performance.
- Higher luminosity upgrades.

LHC performance

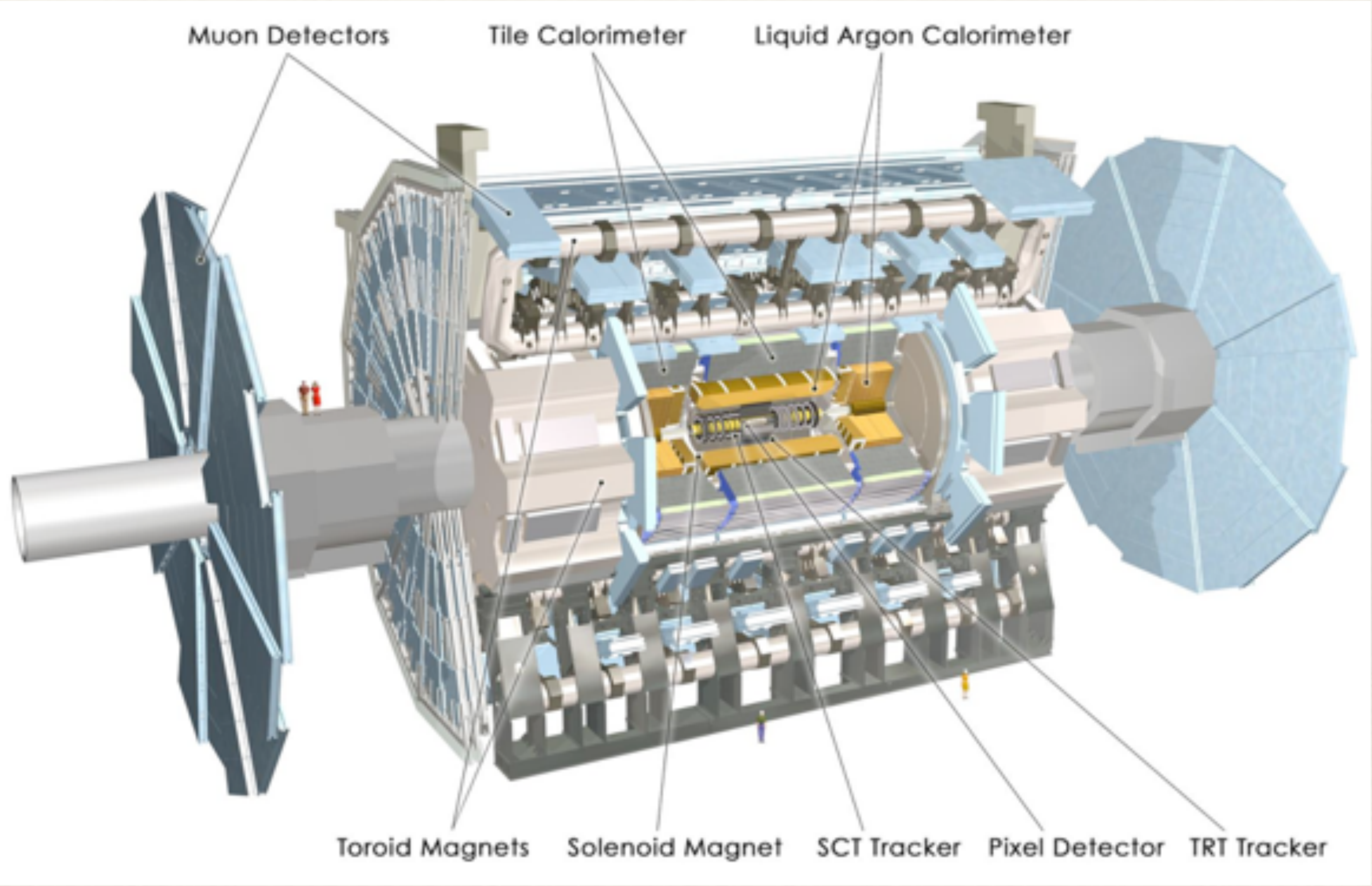
- After a quite calm 2015, LHC provided much more intense beams in 2016 so far.
- Amazing and very stable operations at $\sqrt{s}$=13 TeV colliding at 25 ns with more than 2000 bunches per ring. The goal is to go beyond 100 fb^{-1} with total data from 2015-2018.





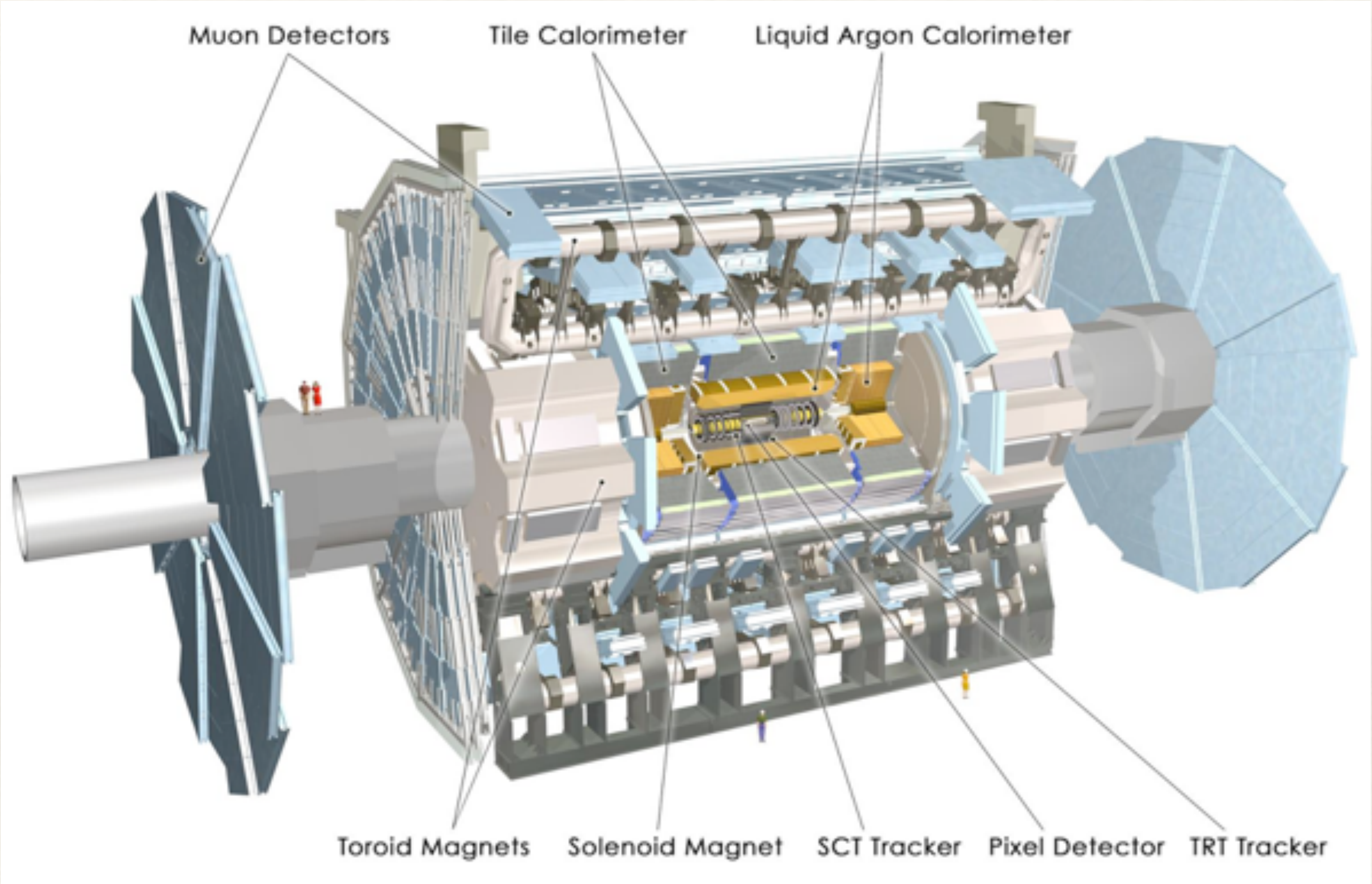
ATLAS detector

- Complex set of detectors operating with excellency since the beginning of the LHC data taking.
- Capable of coupling with a wide range of operating conditions (25ns / 50ns; 900GeV, 7TeV, 8TeV, 13TeV; Heavy Ions, Cosmic Rays, beam splashes).



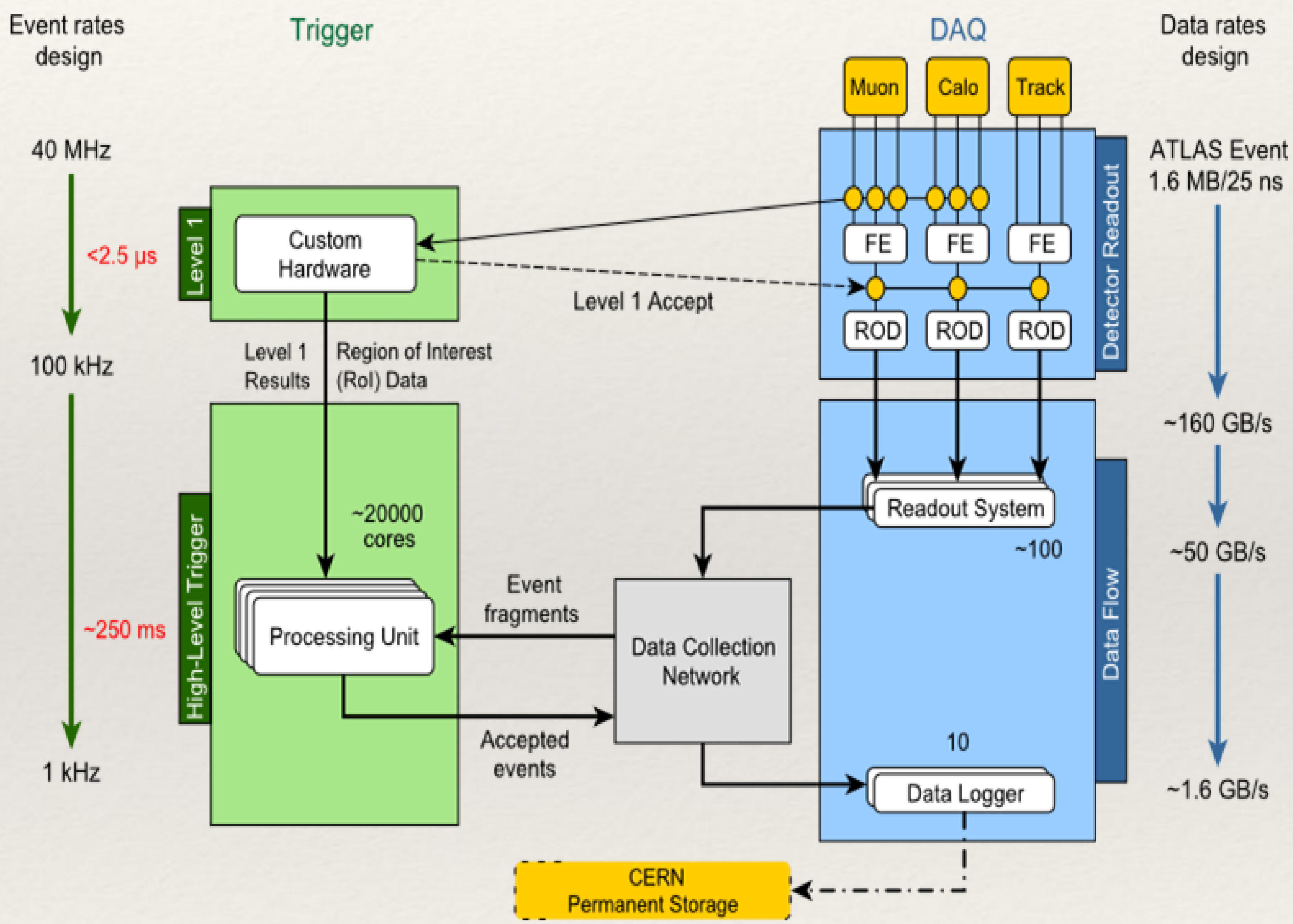
ATLAS detector

- 3 Tracking detectors with large number of channels (Pixels, Semi-Conductor Tracker and Transition Radiation Tracker with particle discrimination capability).
- 4 Sampling Calorimeters covering different detector regions (EM : lead/ liquid Argon, Tile Hadronic : iron/ scintillators, Hadronic EndCaps : copper/liquid Argon, Forward : copper-tungsten/ liquid Argon).
- 4 Muon detectors with complementary measuring and triggering capabilities.
- Solenoid and toroid magnetics for charge and momentum measurement.
- Forward detectors not show in the picture (far down the accelerator tunnel).



ATLAS Trigger

- The ATLAS trigger in Run 2 is divided in a hardware and a software level.
- The Level 1 (L1 - custom hardware based) reduces the collision rate from the bunch crossing frequency (40 MHz) to 100 kHz compatible with the detector read-out system. Only the calorimeter and the Muon detectors are used.
- Detector data "pre-digested" by the Read-out drivers (RODs) is stored temporally in buffers in the Read-Out System and used in the High-Level Trigger (HLT) Processing Units (software based). The algorithms can use L1 information (for instance, (η,φ) coordinates of electron candidates) and run specialised or offline-like algorithms, combining data from all detectors necessary.
- Final recording "budget" is 1kHz on average.



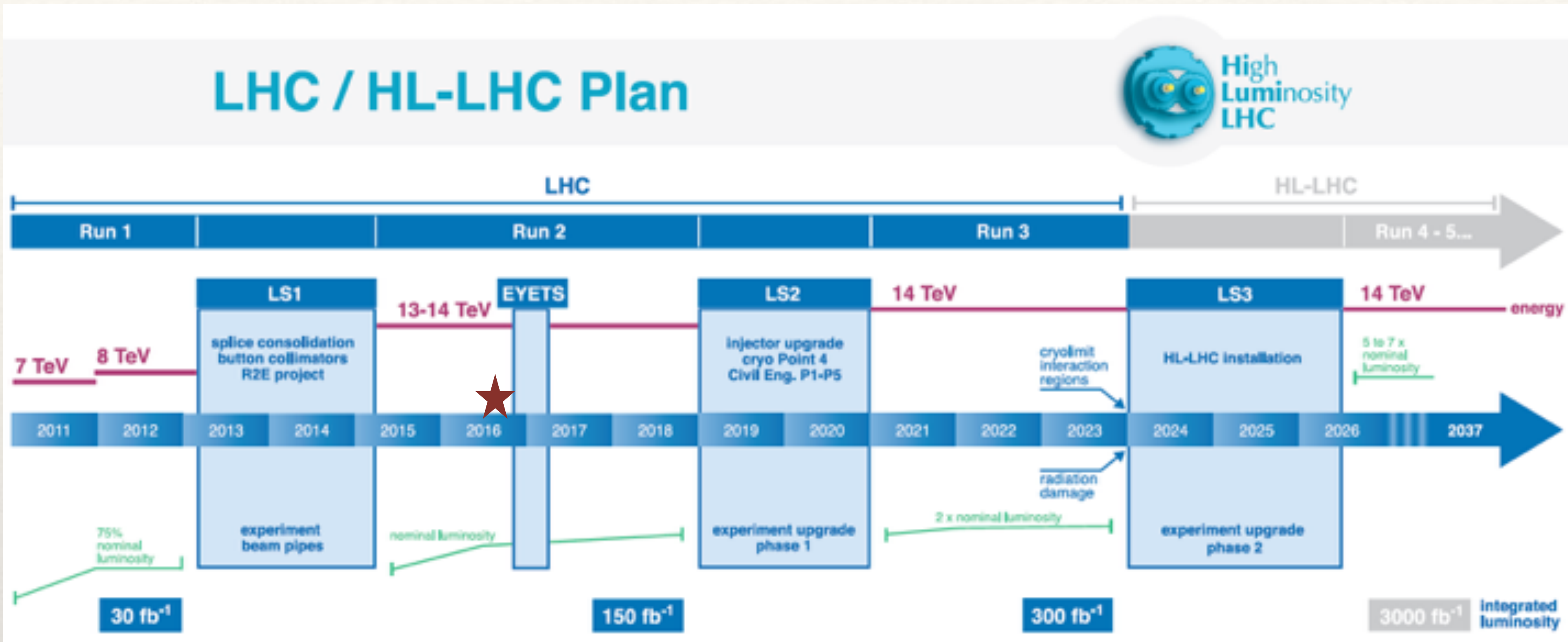
ATLAS status - Run 2

- All different detectors working with high efficiency.
- Pixels here include our newly installed 12 M Insertable B-layer (see next slide).

Detector efficiency in May, 2016

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	98.2%
SCT Silicon Strips	6.3 M	98.7%
TRT Transition Radiation Tracker	350 k	97.2%
LAr EM Calorimeter	170 k	100%
Tile calorimeter	5200	100%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.7%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	383 k	99.8%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	357 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Chambers	383 k	96.6%
TGC Endcap Muon Chambers	320 k	99.6%
ALFA	10 k	99.9 %
AFP	188 k	98.8 %

Time Line of LHC operation

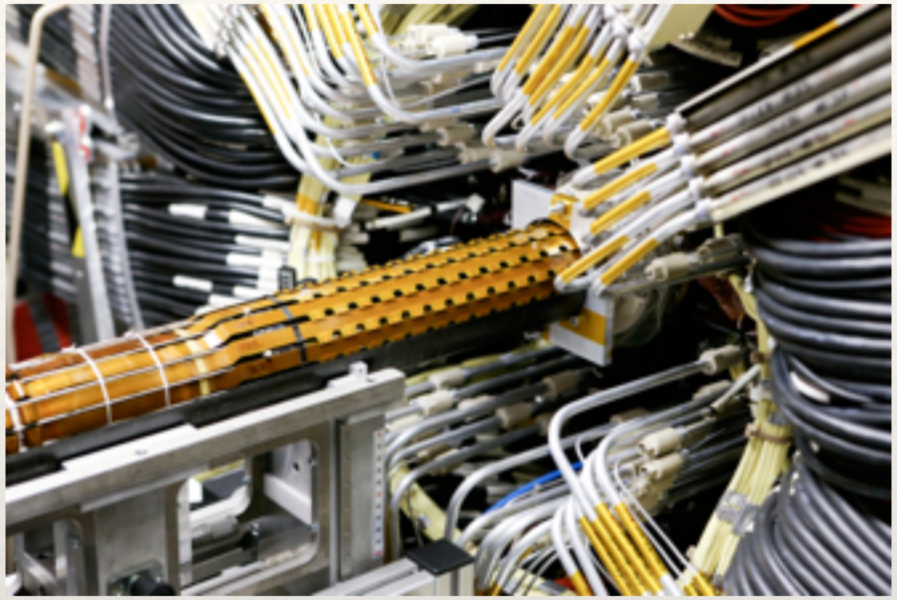


- LHC energy (13 TeV) is already close to the nominal limit (14 TeV).
- luminosity-wise, LHC is already beyond the nominal value (<μ>=27.5). Will probably be beyond the double by 2019 (<μ>=55) and maybe more than 5 times in 2024 (<μ> > 140). <μ>=200 could be reachable.
- Complexity of the events is even larger : challenge, in particular for the trigger. To protect the electroweak sector, single lepton thresholds must be preserved below half of Z or W mass with as high efficiency as possible.
- Some detectors won't survive the particle flux.
- Experience with present detector helps to define main concerns in upgrade.

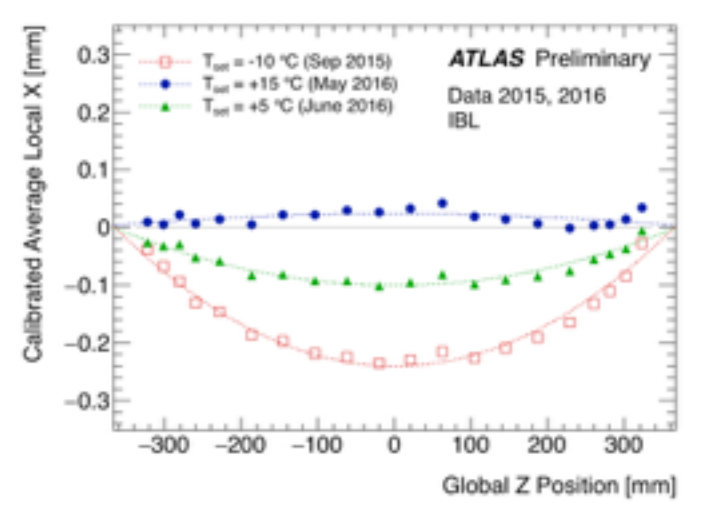
Run 2 - IBL performance

- Insertable B-Layer installed at mere 33 mm from collision center (as well as new beam-pipe).
- Alignment procedure showed clear dependency with temperature (online alignment necessary).
- Major improvement (up to 4 times) in impact parameter resolution, early conversions identification and B-tagging.

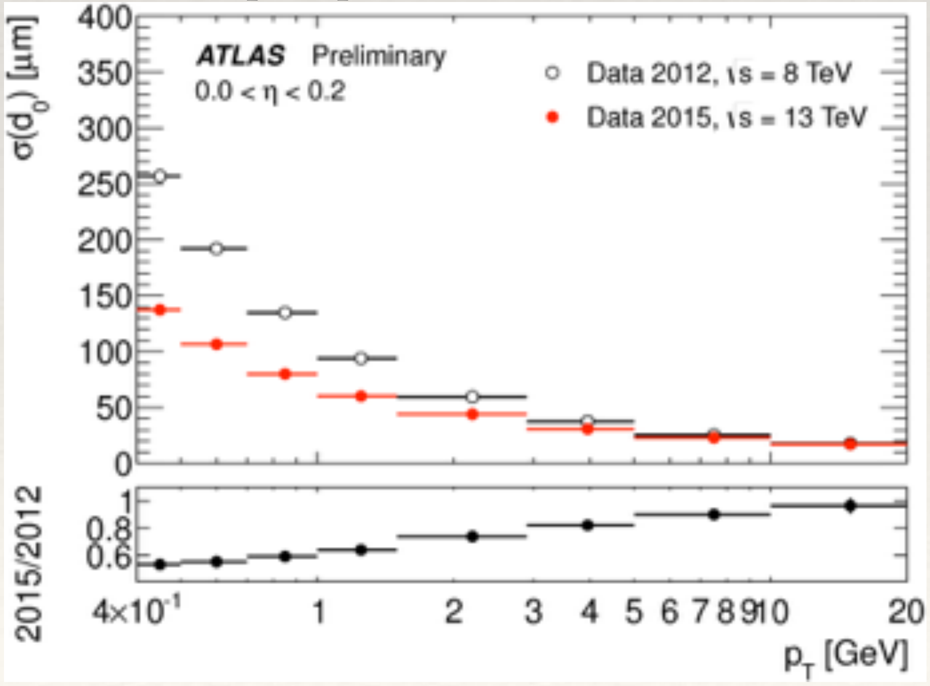
IBL installation



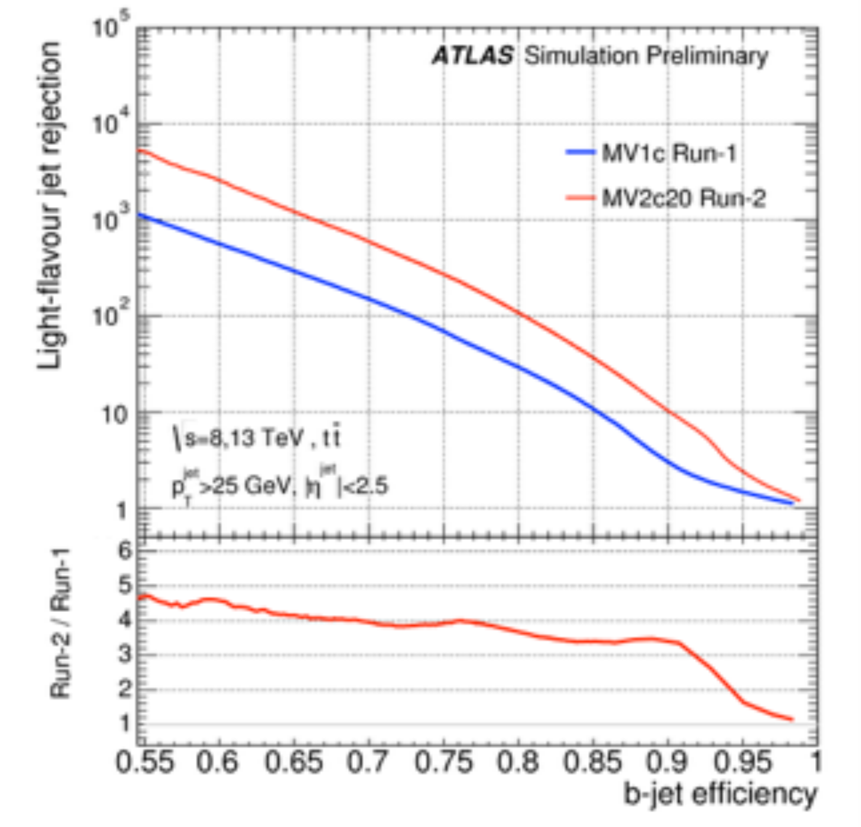
temperature dependent IBL alignment



impact parameter resolution

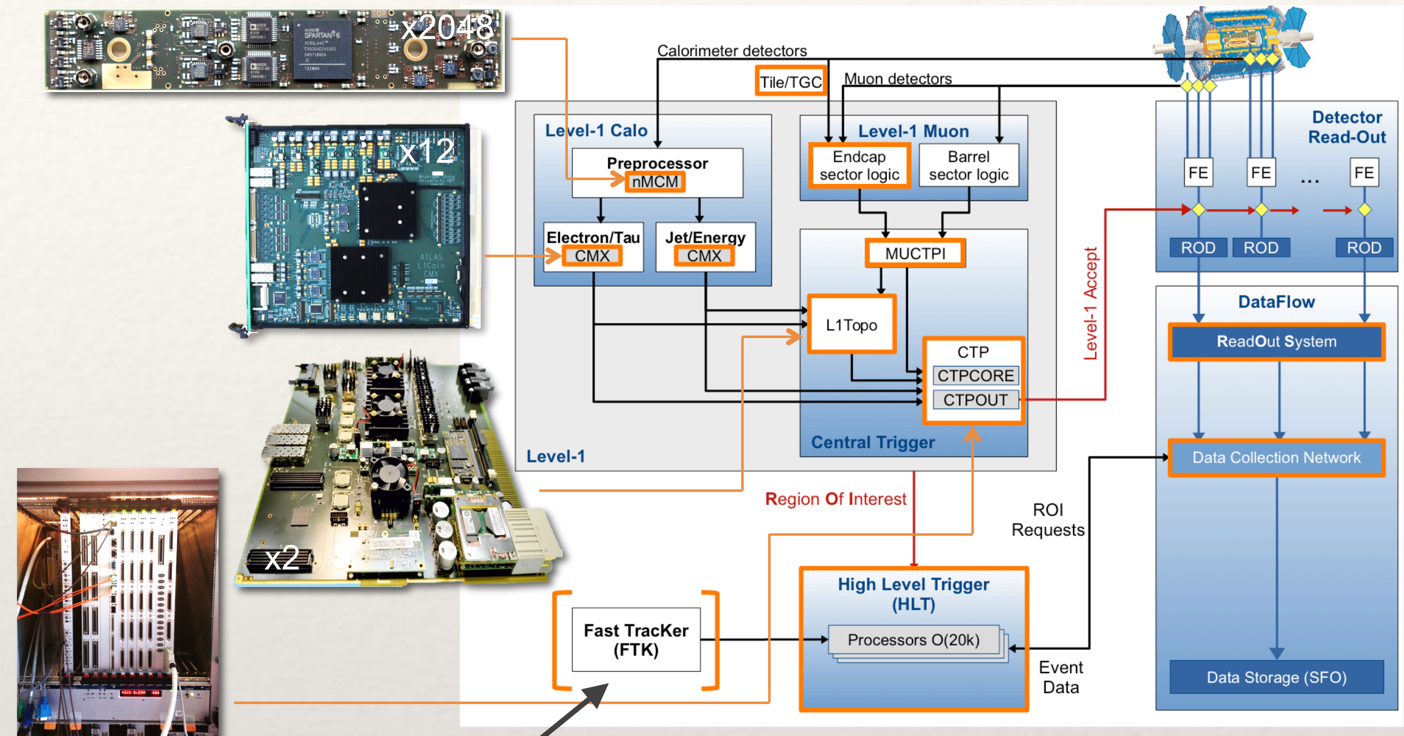


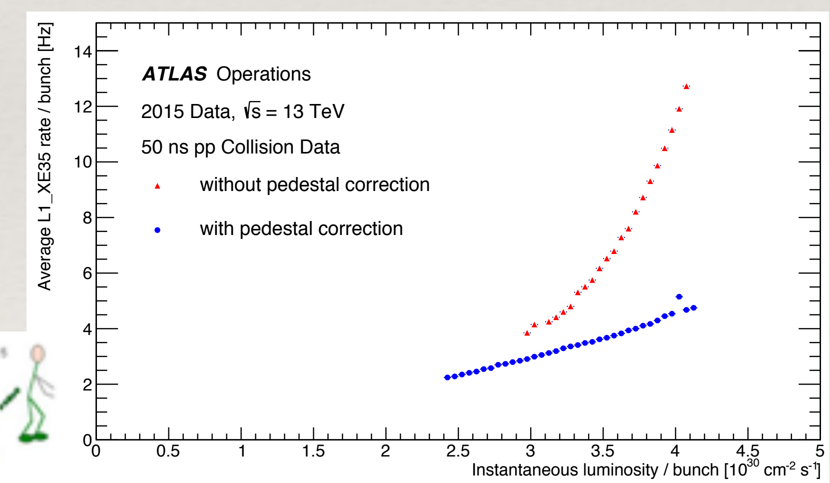
B-jet tagging highly improved



Run 2 - Trigger updates

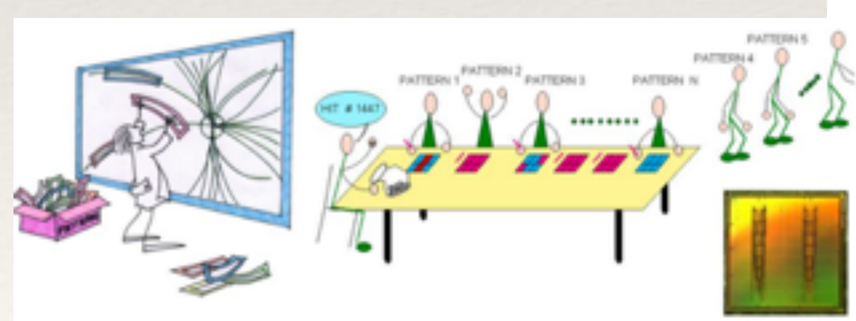
- High pile-up and long calorimeter pulse : bunch-crossing structure effects in energy measurement.
- New L1 hardware sample calorimeter analog signals at 80 MHz (was 40 MHz). Flexibility (ASIC versus FPGA) allows to perform bunch crossing dependent pedestal suppression on the fly : Very relevant for MET rates.
- More integrated HLT farm allows for higher rate access to the detectors (including full detector access at tens of kHz) : challenge to adapt offline algorithms in HLT.
- Track finding performed with pattern matching technique via content addressable associative memory (Fast TracKer - FTK) to speed up HLT processing being installed / tested.





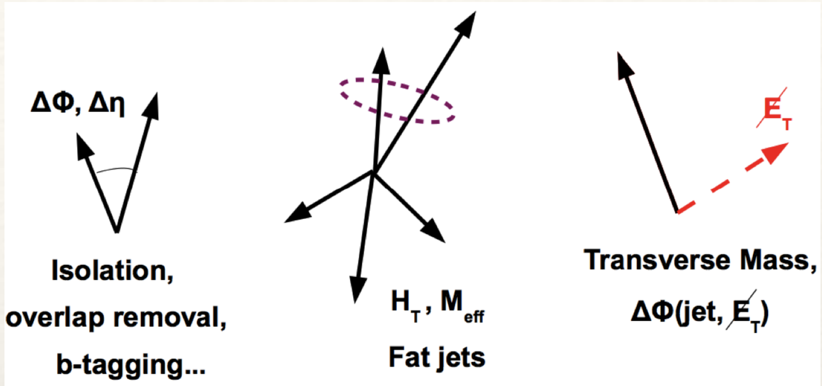
L1 rates reduced

Pattern matching performed in hardware

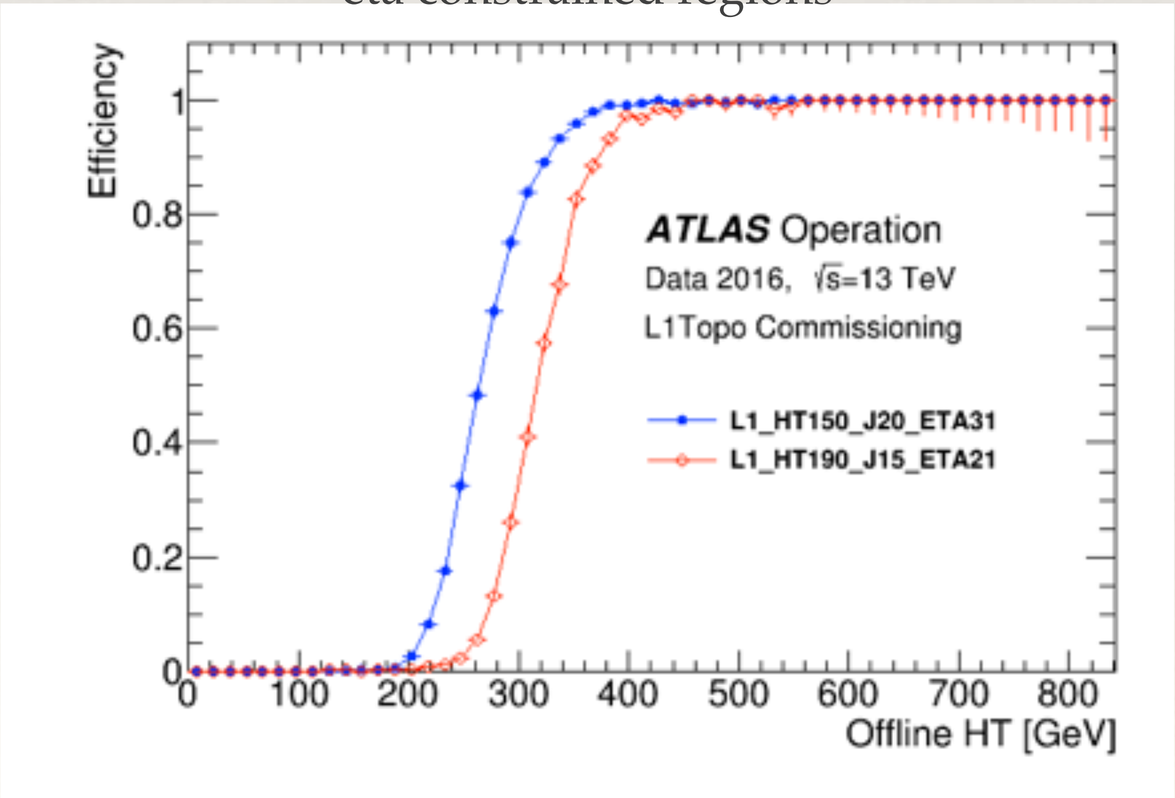


Run 2 - L1 Topological trigger

- Some objects like Z's and W could be better selected at early trigger stages if operation on multiple L1 Trigger OBjects (TOBs) were possible.
- L1 Topological trigger (FPGA based processor) can perform mass cuts on electron, muons, jets or taus and missing ET phi direction, Some isolation and Large Jets also possible.
- separate jet triggers based on detector regions (central/forward) helps to keep rates under control.
- Being commissioned/tested and helping to test some other upgrade hardware.



Energy sums performed in eta constrained regions

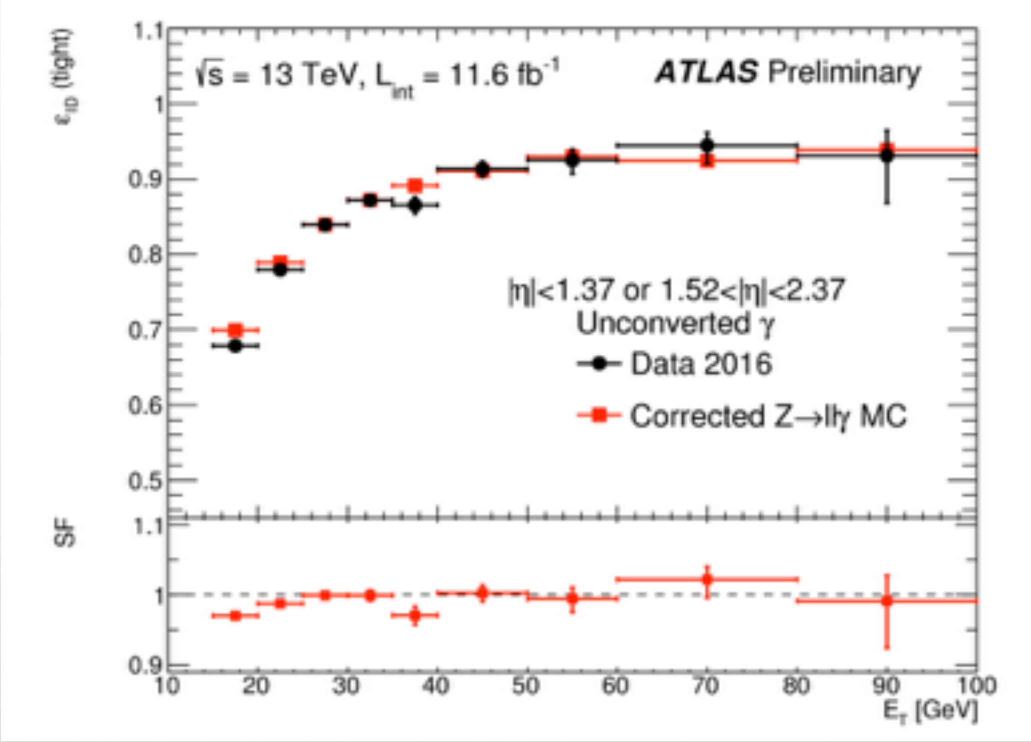


Electrons/photons performance

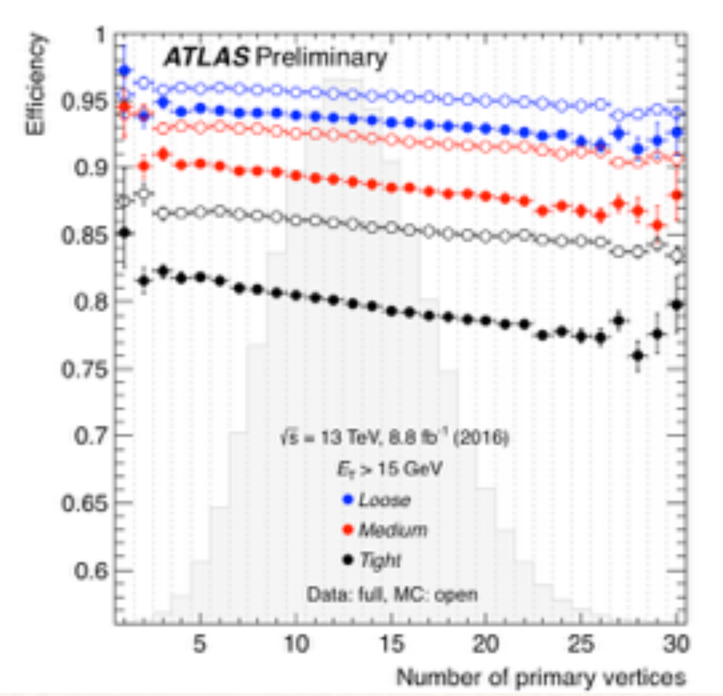
- Likelihood for electrons based on Shower Shapes and tracks properties. Cut based for photons.
- New TRT Likelihood variable capable to work with new TRT gas mixture (argon instead of Xenon).
- Calorimeter and track based isolation (isolation cone ΔR variable with object P_T).
- MVA-based calibration (BDT) for electrons and photons (converted and unconverted treated separately).
- Tag & Probe (J/ψ, Z and W) used for efficiency estimation based on data only : stable operation in 3 operation points with respect to luminosity. Photons use radiative Z and more complicated matrix method (see perf. note) for performance evaluation.

Much more details in the 3 performance notes about :
2015 electron ID; 2015 photon ID; calibration

Photon efficiency using radiative Z boson decays



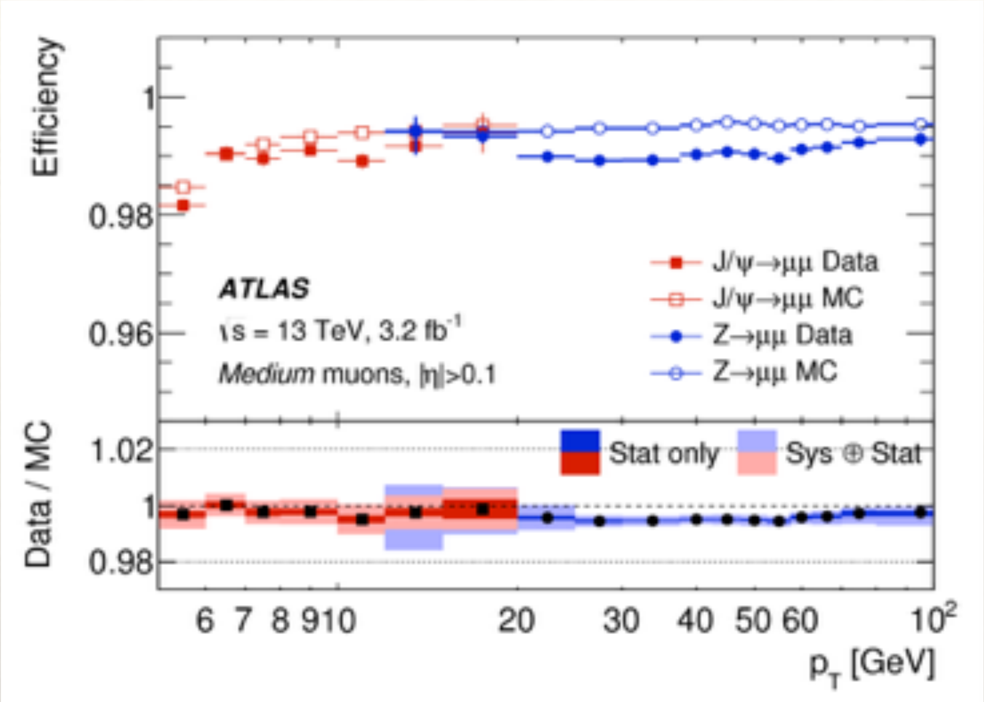
electron efficiency dependency with respect Number of Vertices

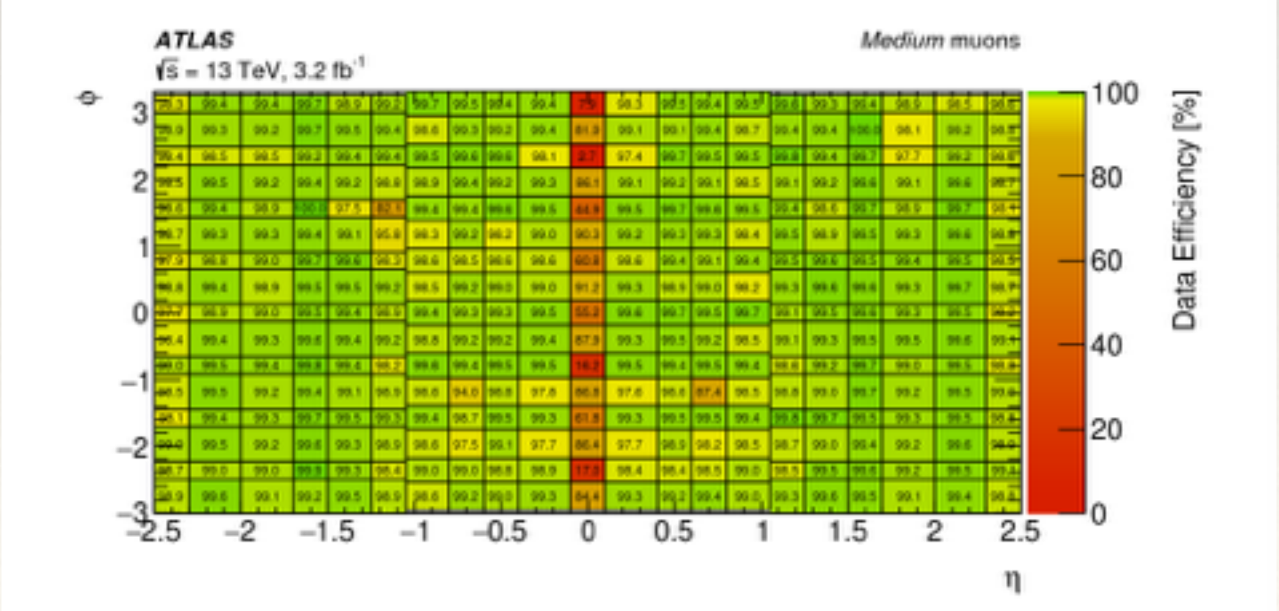


Muons performance

- Specific muon chambers or Tracking failures reduce efficiency in well located regions. Otherwise excellent performance.
- Efficiency maps prepared for offline analysis.
- Calorimeter and track based isolation (isolation cone ΔR variable with object P_T) also available.
- Also using Tag & Probe with J/ψ and Z's for efficiency measurement.

Reconstructed muons efficiency with 2016 data

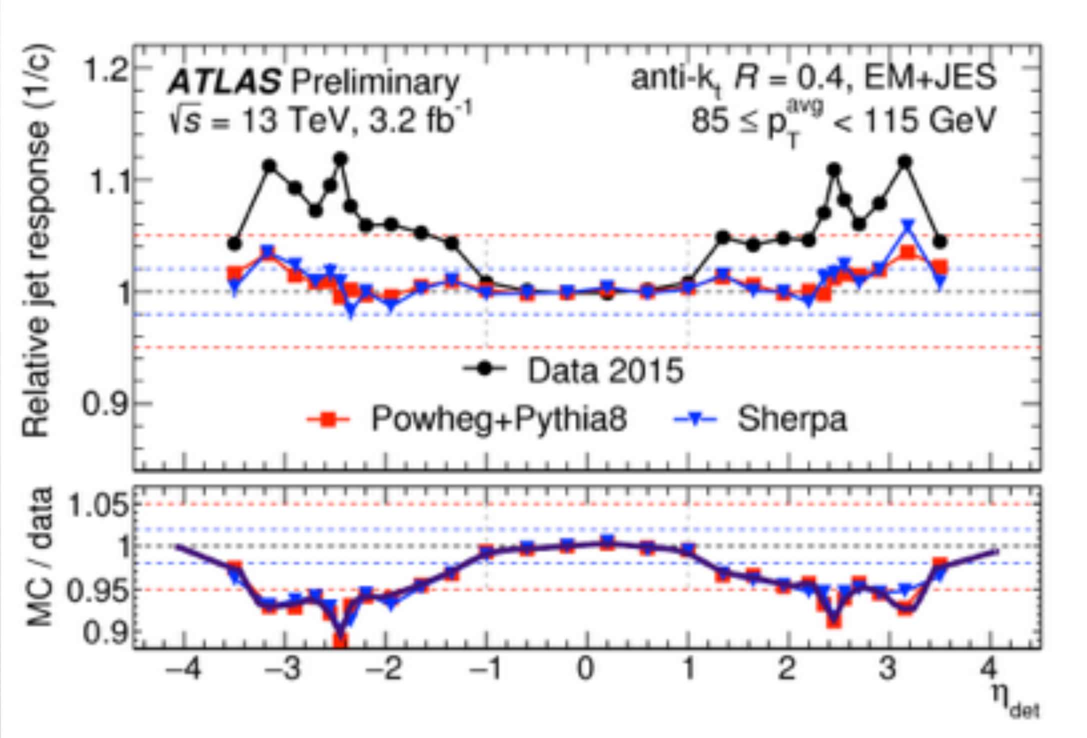


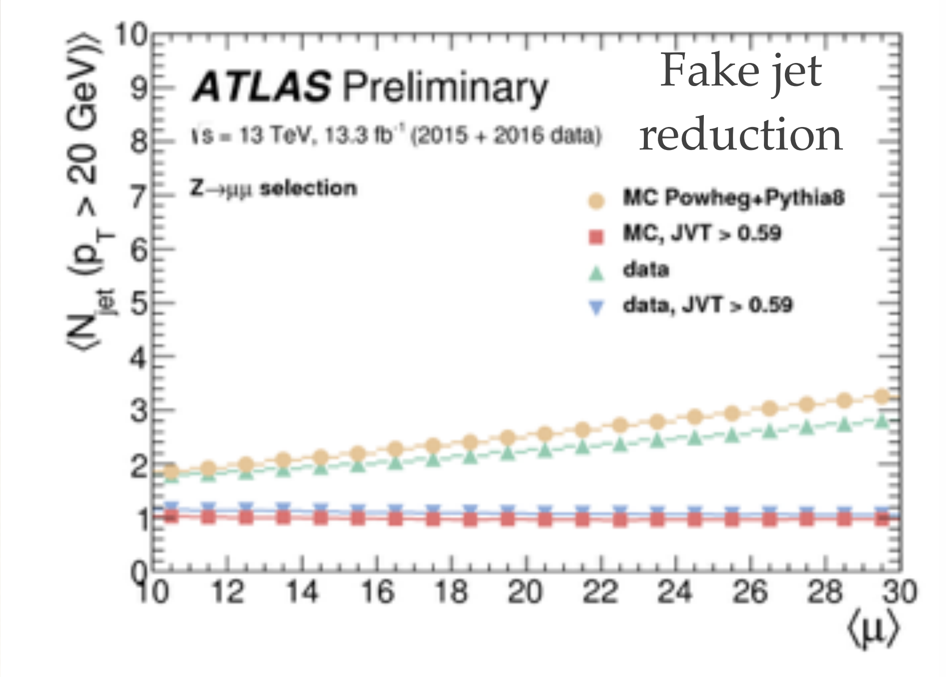


Jets performance

- Jets reconstruction starts from topological calorimeter clustering (no predefined cluster shape, cluster grows as cells touching it have significance) which are later used in anti-Kt (R=0.4).
- Cleaning from detector noise is also used. Jet quality cuts.
- Jet suffers a lot from pile-up (soft jets like) despite the topological clustering.
- Event-wide or track based variables (Jet Vertex Fraction - JVF) also used to mitigate pile-up effects.
- Jet Energy Scale (JES) used to combine EM and non-compensating calorimeter response to form final Jet energy.
- Recent addition of Larger Jet areas to cover the cases when multiple jets are coming from similar source (boosted).

Jet response

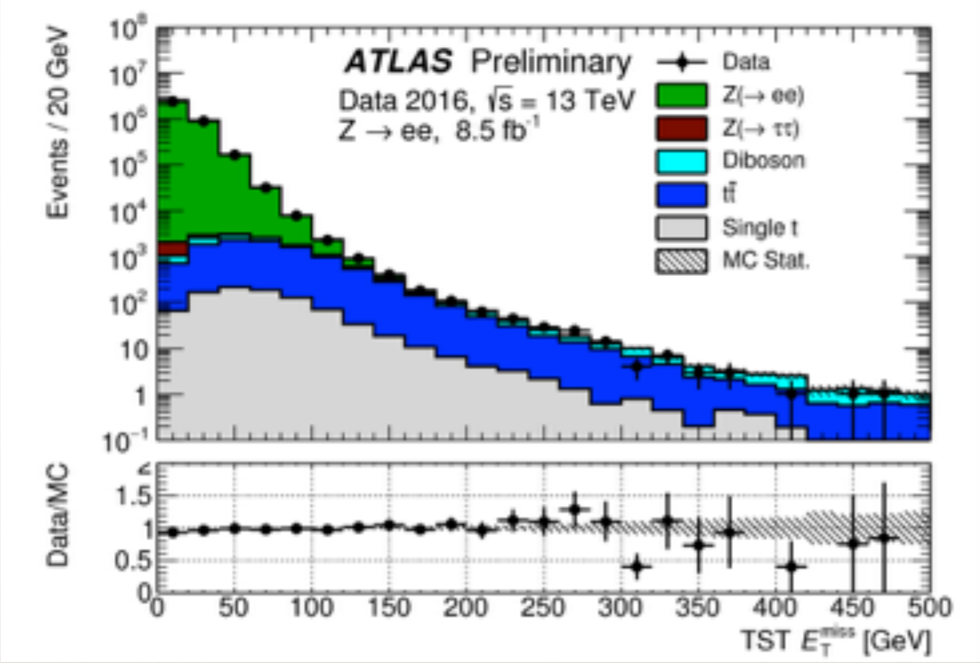


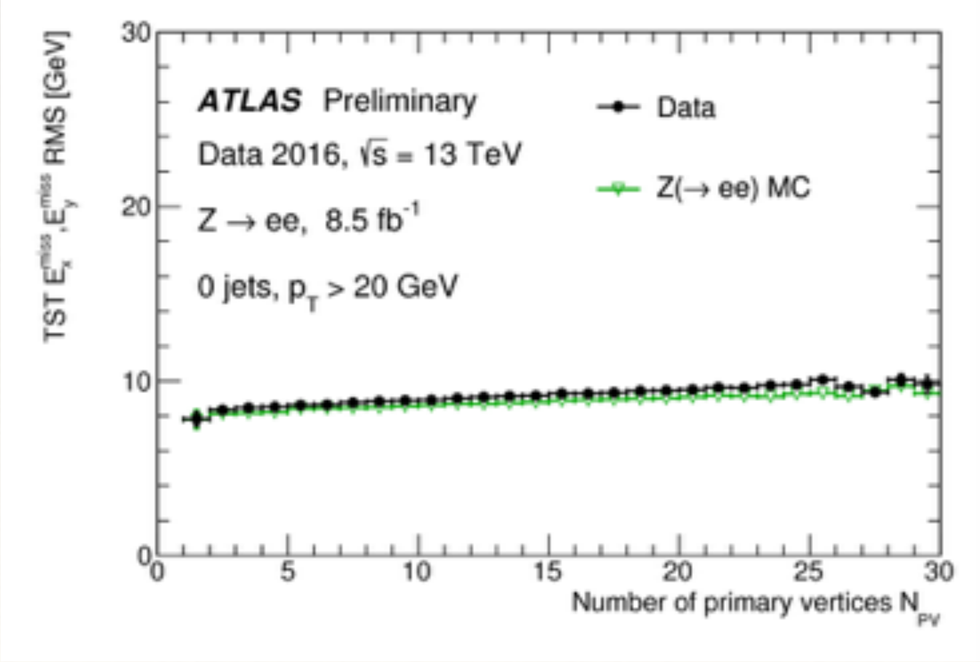


Missing Transverse Energy

- Reconstruction algorithm uses all identified objects to calculate MET.
- Calorimeter and Tracking information (Soft-Terms) are included to increase resilience to underlying events and pile-up : stable resolution.
- Results including 2015/2016 data sets. Comparison of MET selection with MC events (good modelling).

missing transverse energy

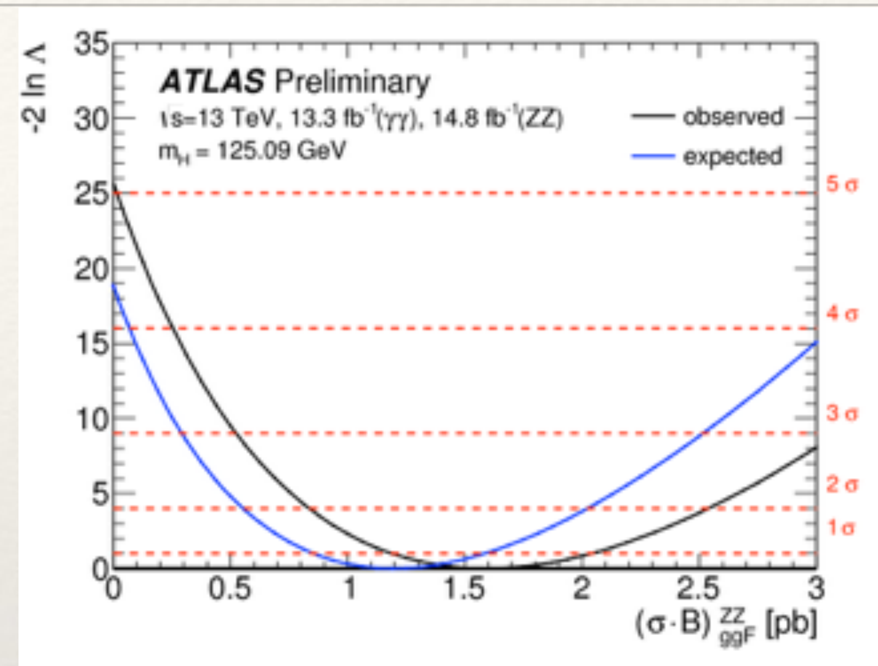


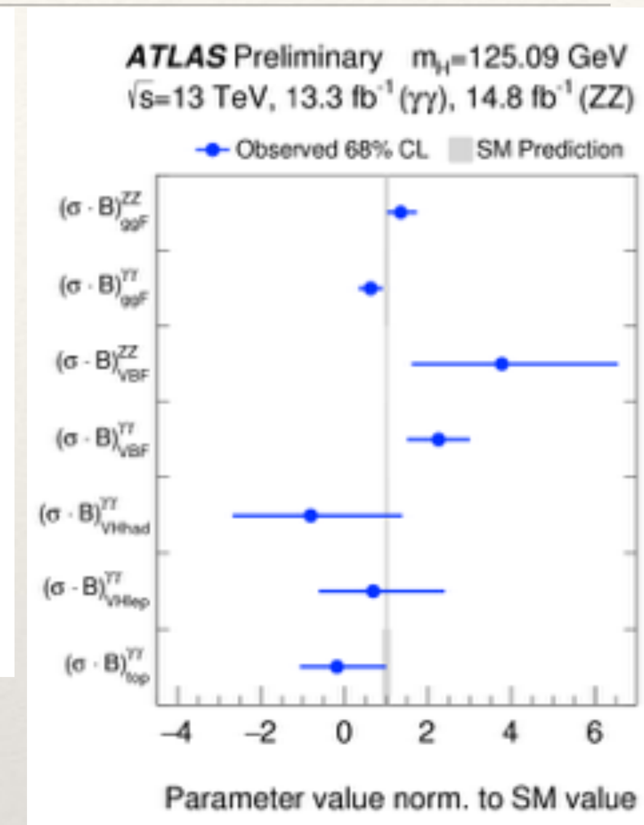


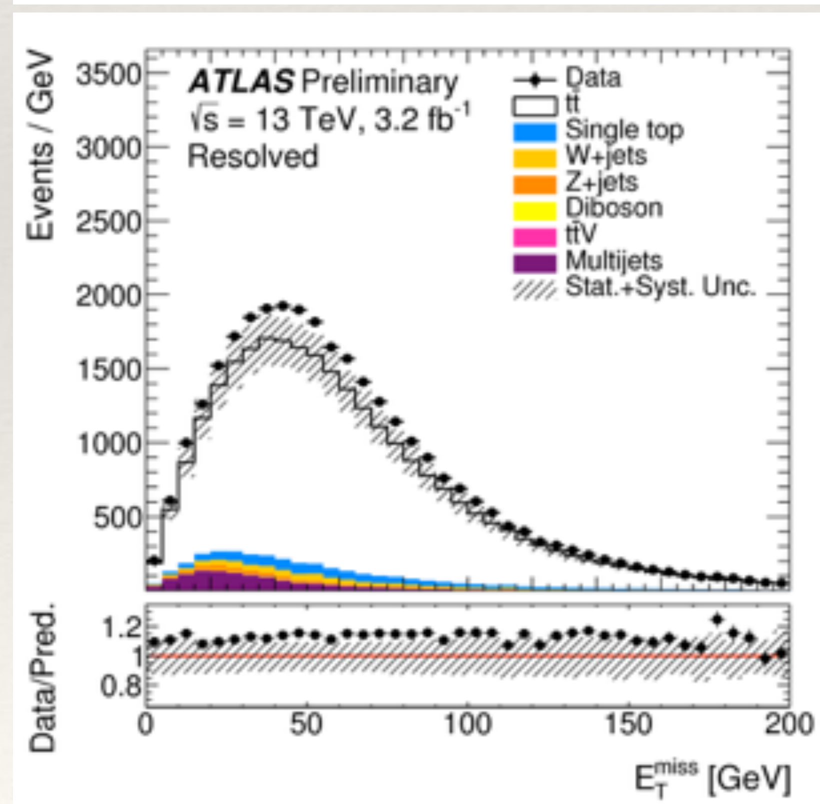
Some description about TST MET : http://cds.cern.ch/record/2037700/files/ATL-PHYS-PUB-2015-023.pdf

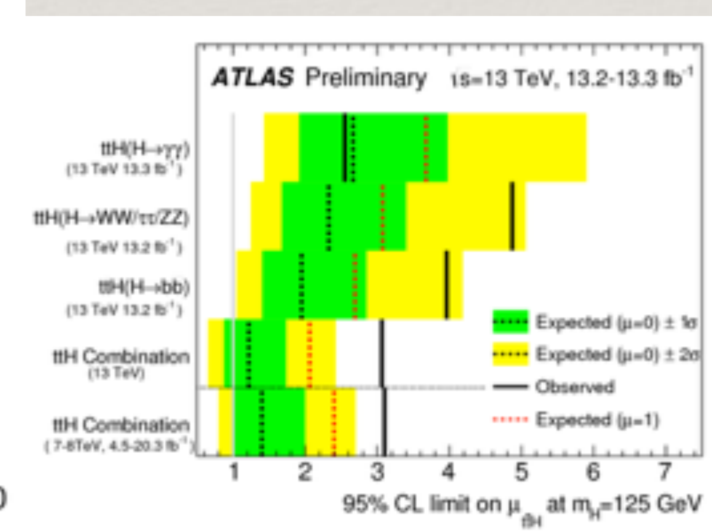
On going Analysis

- Many preliminary results already including 2016 data available.
- Multiple Higgs and Top analysis and measurements started with 13 TeV data (2015/2016). Significance, coupling being studied.
- Since this will be further explored during this conference, I will refrain from detailing too much here.

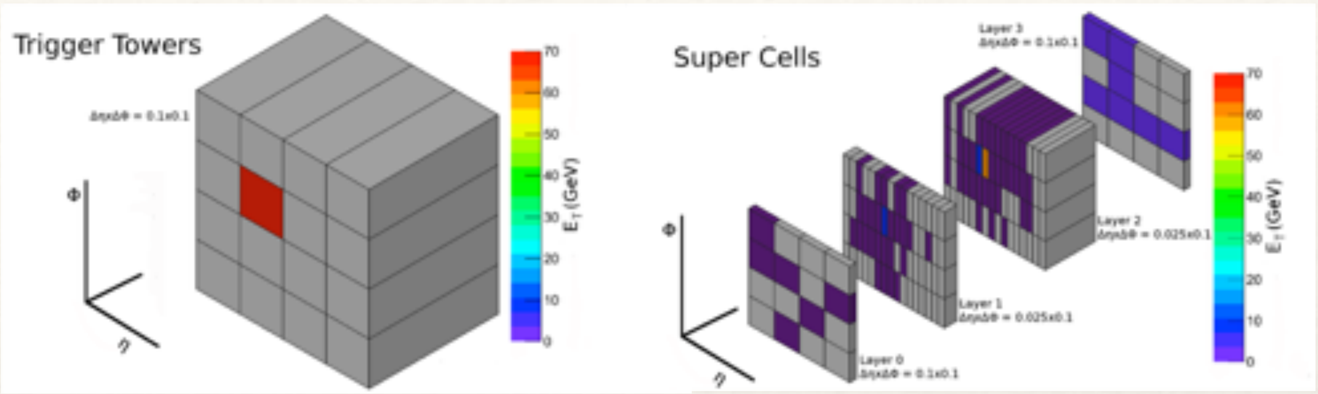






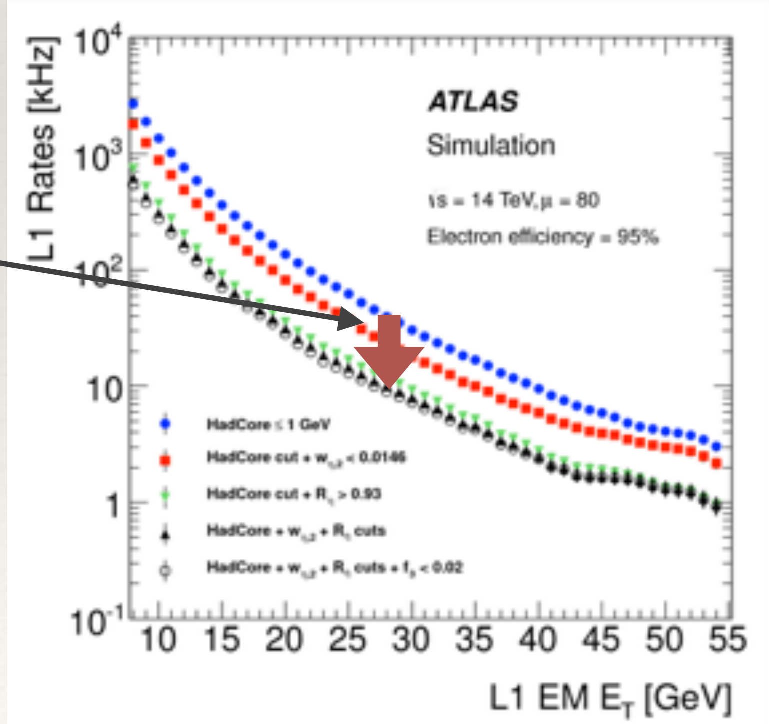


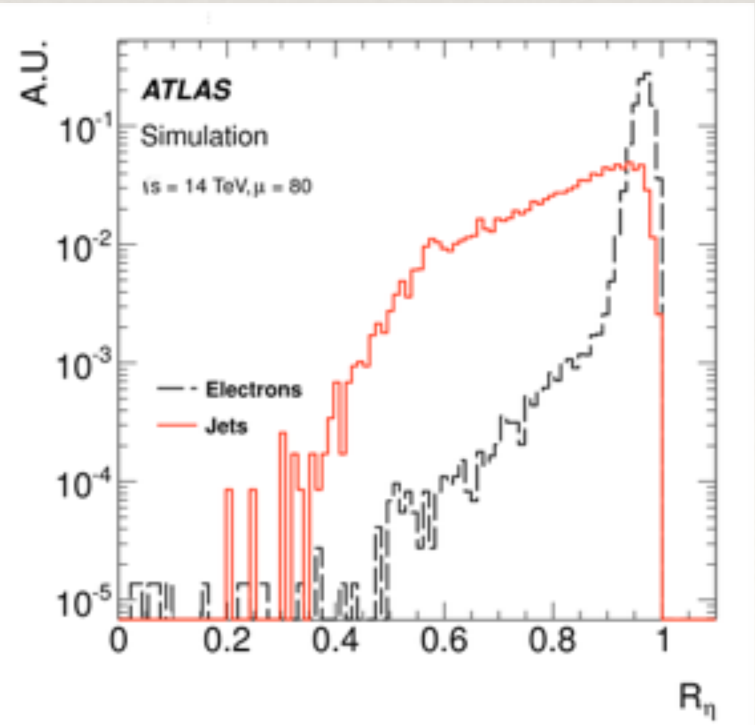
Phase 1- Lar Calorimeter upgrades



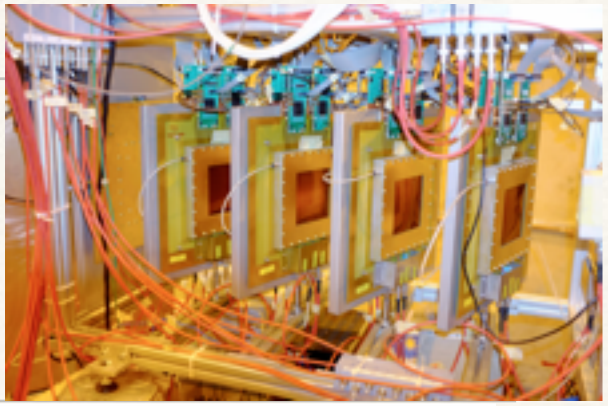
- L1 EM rates will go well beyond experiment capability with increased pile-up scenario : limited in shower shape definition with present hardware primitives (δηxδϕ=0.1x0.1) : Trigger Towers to the Level 1 system.
- Proposed increase granularity, longitudinal granularity to become exactly as at the cell level. Lateral granularity also improved.
- rate reduction helps to keep similar E_T thresholds with increased luminosity.
- Demonstrator already installed in a small detector wedge. Production of new electronics going on.

Hardware already being tested and partially installed in ATLAS for testing

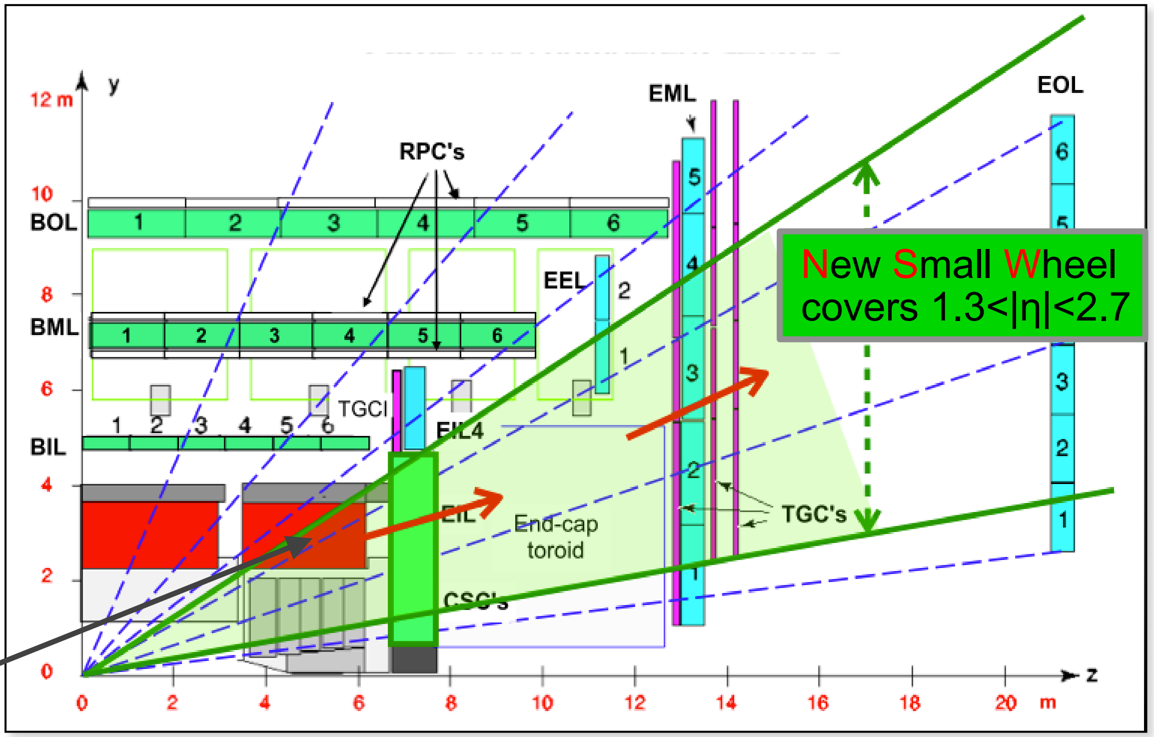


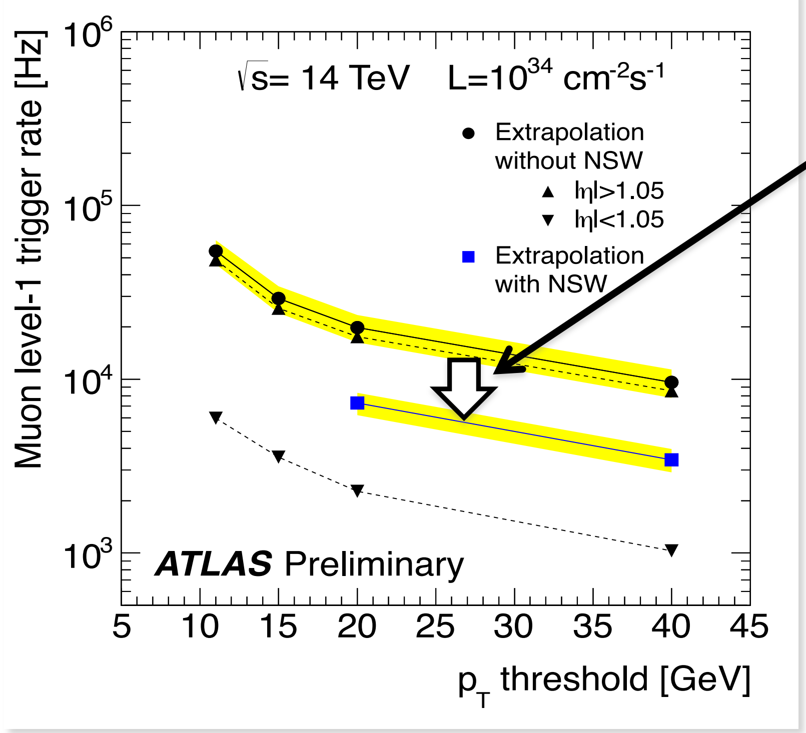


Phase 1 - New Muon Wheel



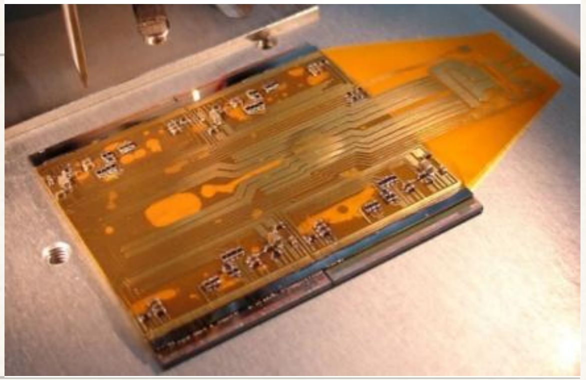
- L1 muons rates also extremely high, specially in forward direction.
- Only two wheels in the forward region instead of 3 in the central region. So, new solutions have to be found (eg: Tile Calorimeter being used in muon triggers). But it is not enough.
- Using MicroMegas and sTGCs. Improved tracking and trigger capability. Compatibility with luminosity up to <μ>=200.





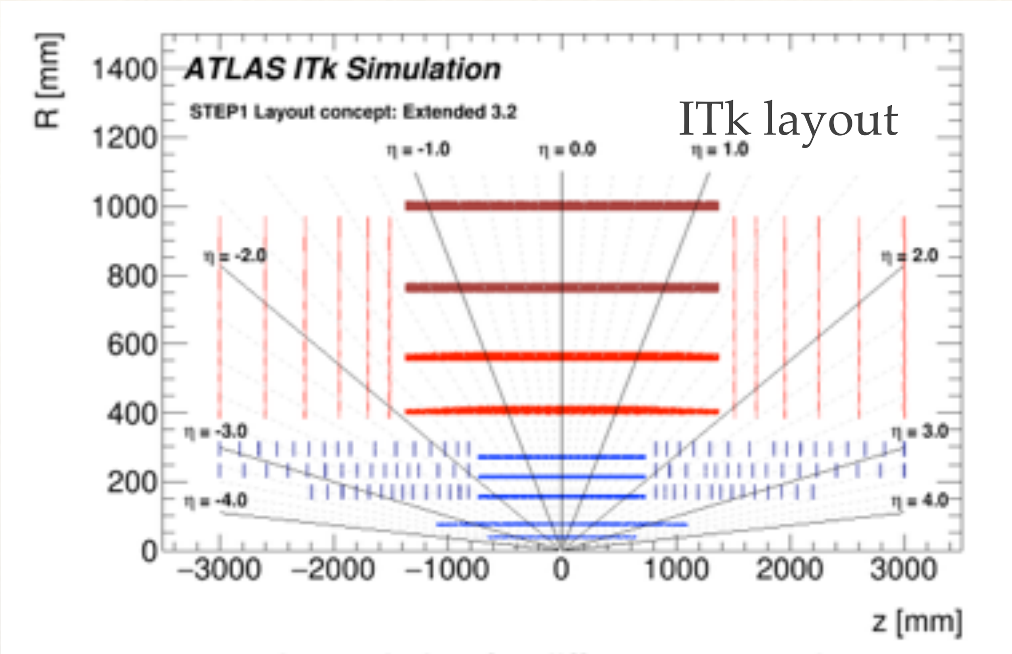
Rate Reduction

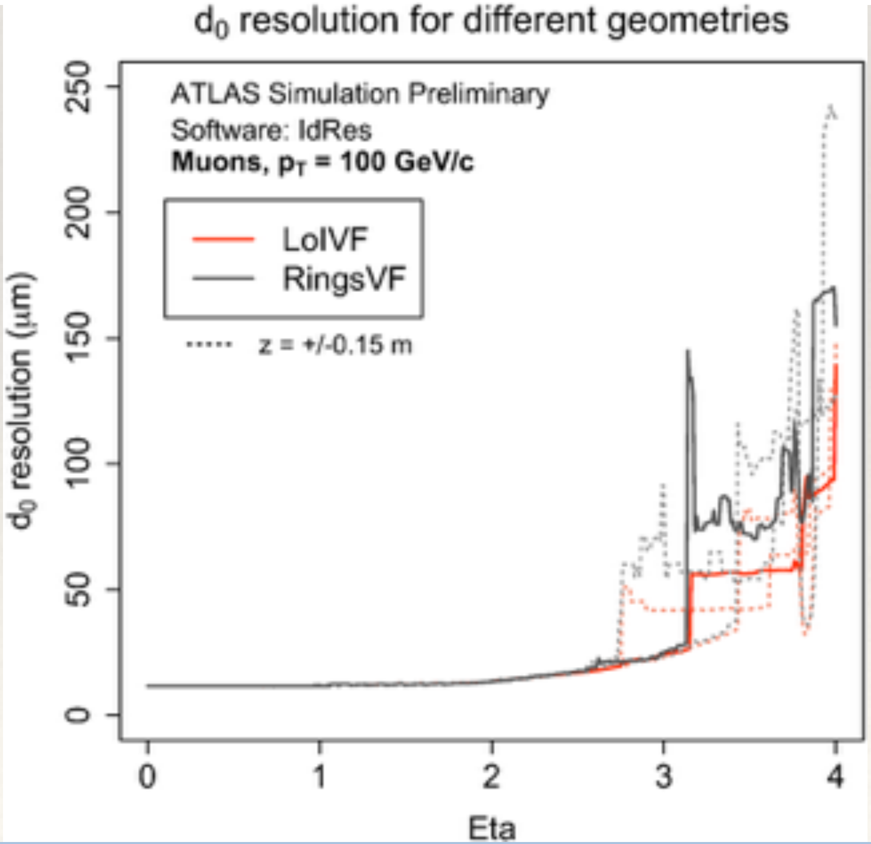
Quad Pixel Module Prototype



Phase 2 - ITk

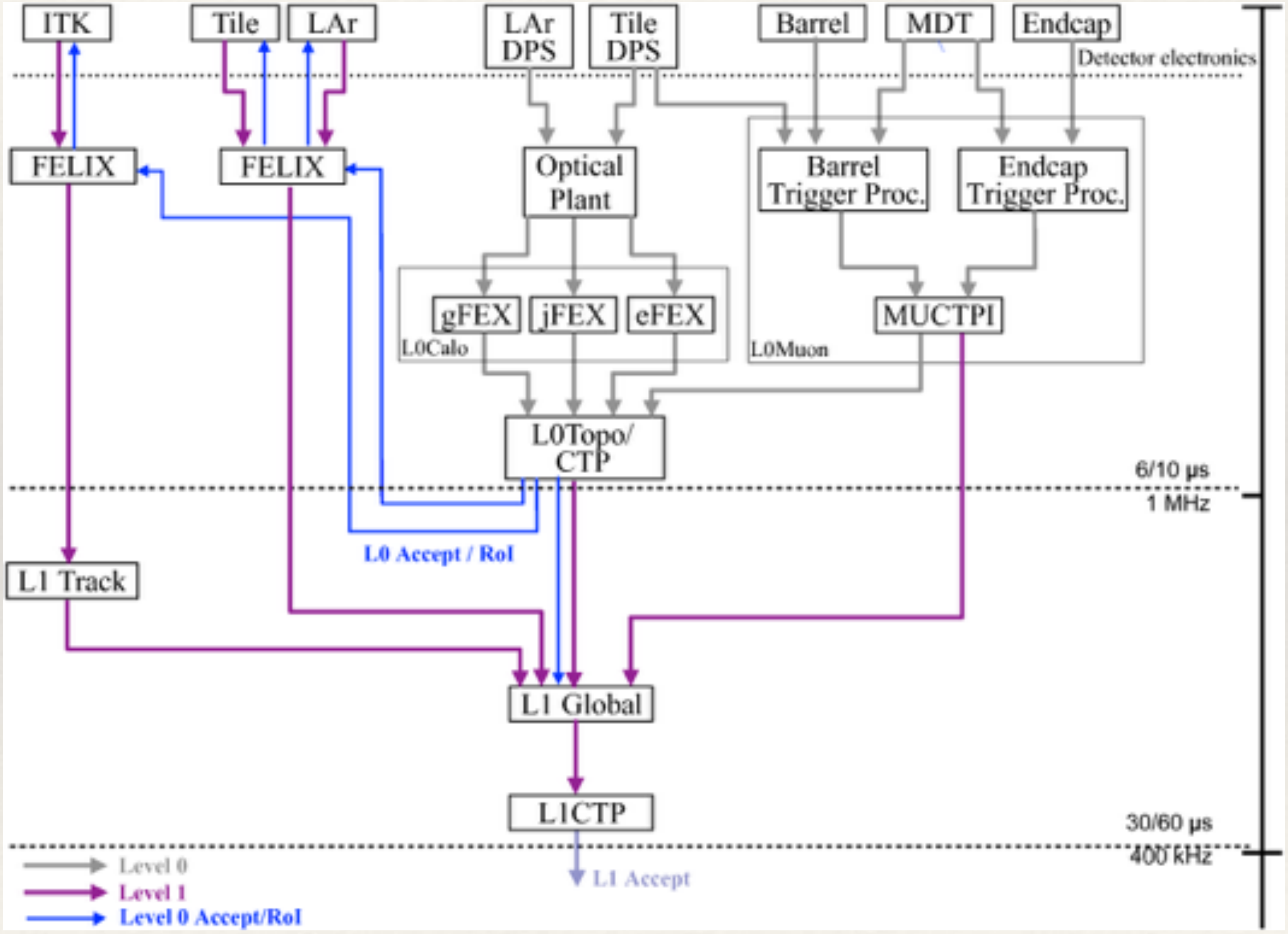
- Given the luminosity increase on phase 2, the present ATLAS Inner Detector electronics will not survive the radiation, so complete replacement is necessary.
- A completely new trajectory detector being designed/simulated, the Inner TracKer (ITk).
- Only silicon based, no more transition radiation detector (Pixels - blue points; strips - red points with double readout)
- Slightly reduced material, prototypes being tested and final layout still under discussion. Increased η range : resolution compatible with Run-2 values.





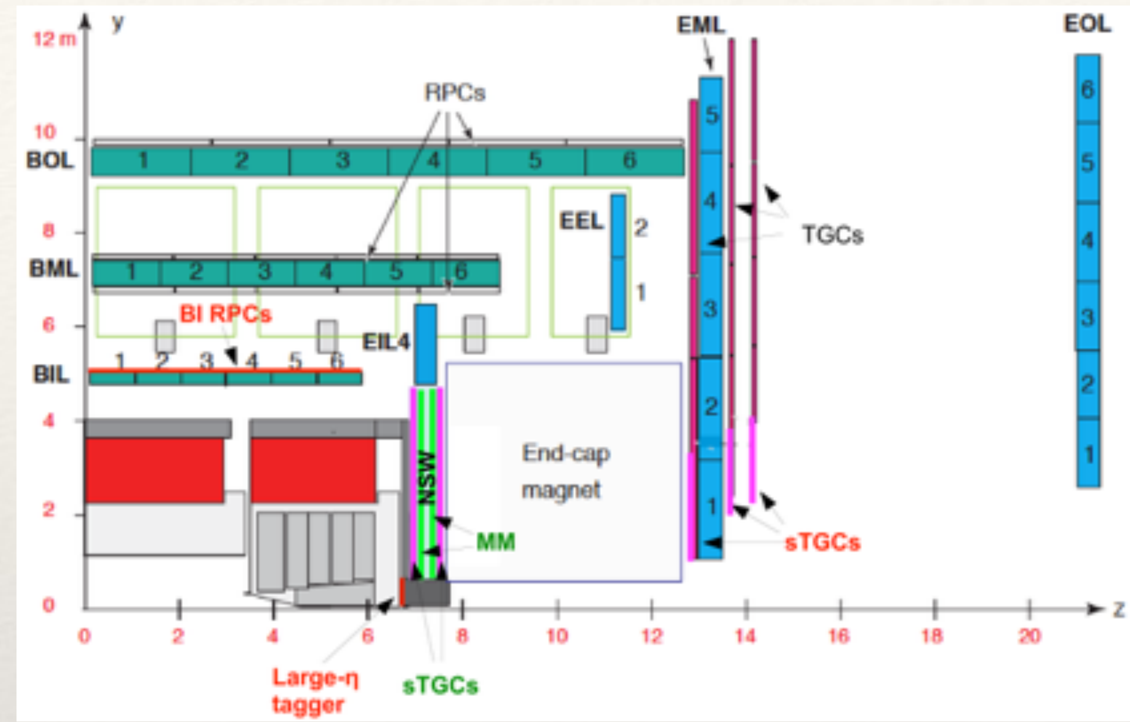
Phase 2 - DAQ restructuring

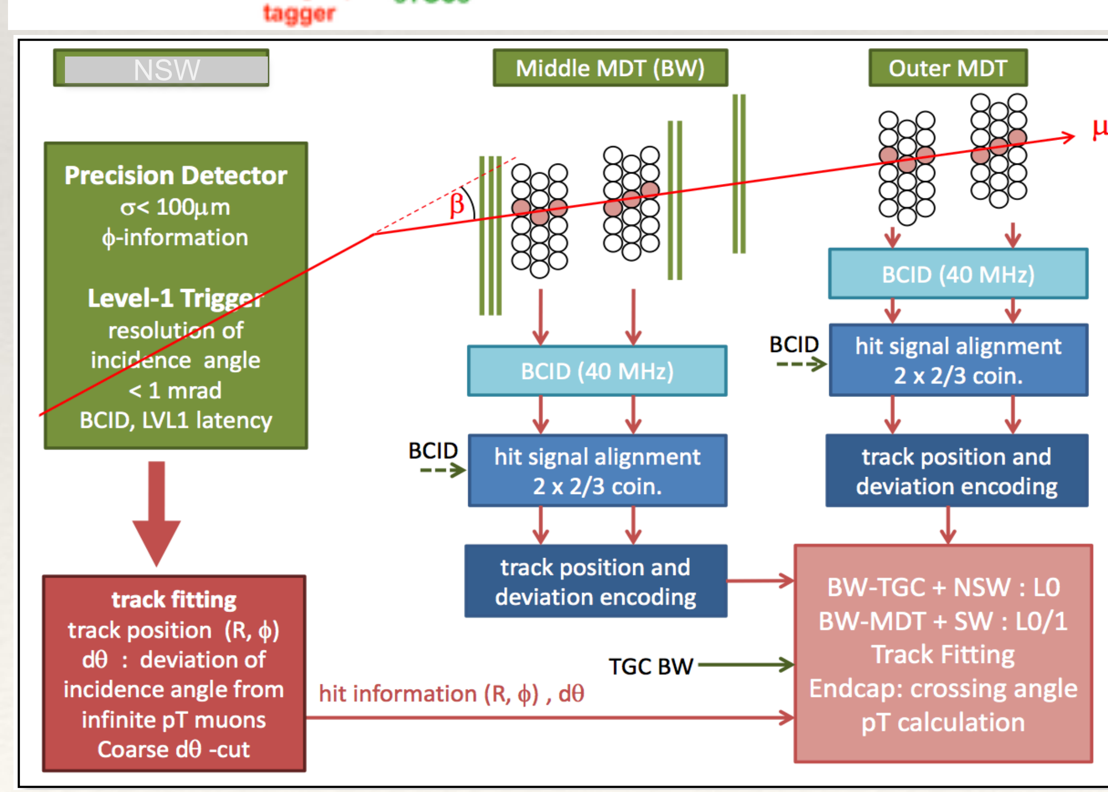
- In phase 2, phase 1 level 1 becomes level 0 with about 500 kHz of acceptance (Muon/Calo).
- ITk (tracking, see next slide) to be used together with digital readout of the full detectors (including precision muons chambers) in the new Level 1. Level 1 output rate (200 kHz) beyond present acceptance by readout electrons (100 kHz), whole detector Front-End to be re-designed.
- Present L1 phase 1 design will help build Front-End Readout in phase 2.
- More complex Level 1 algorithms will be possible (using Level 0 Regions of Interest).



Phase 2 - muon upgrades

- Additions of more muon walls with more trigger capabilities, and also integrated in the new L0/L1 framework.
- Use the detected trigger muon to extrapolate inside the precision detectors (MDTs) and refine muon measurement.

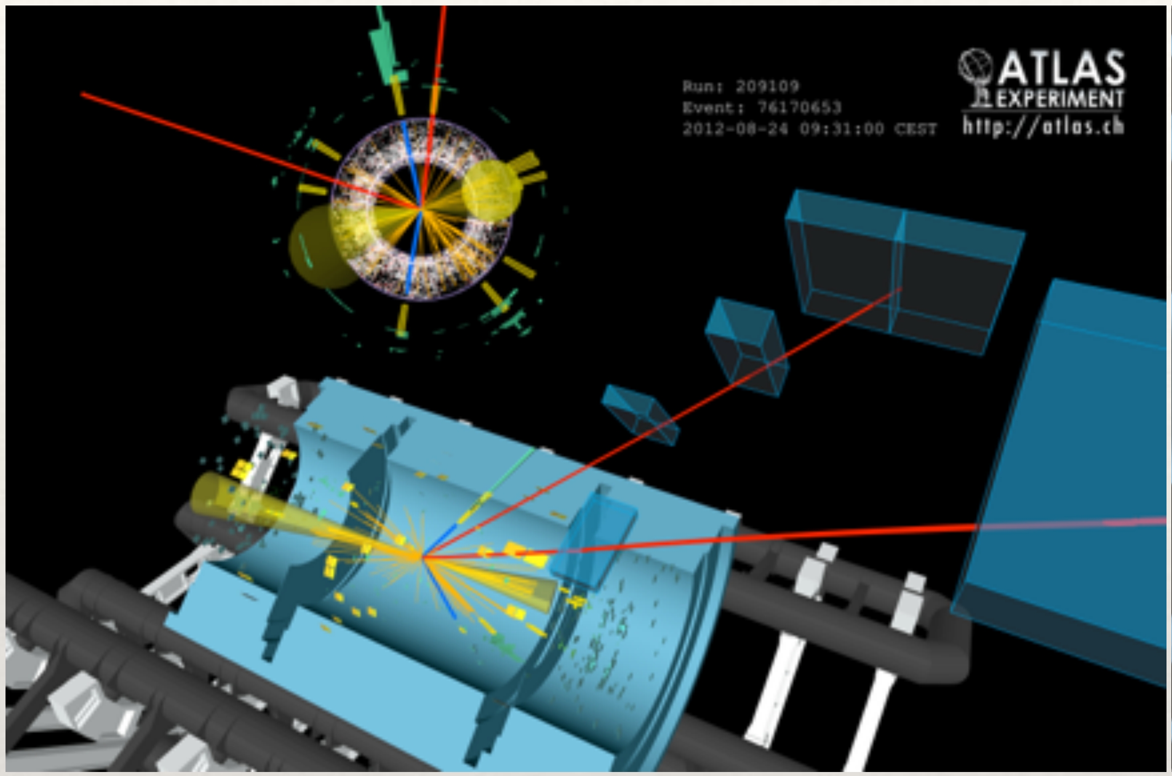


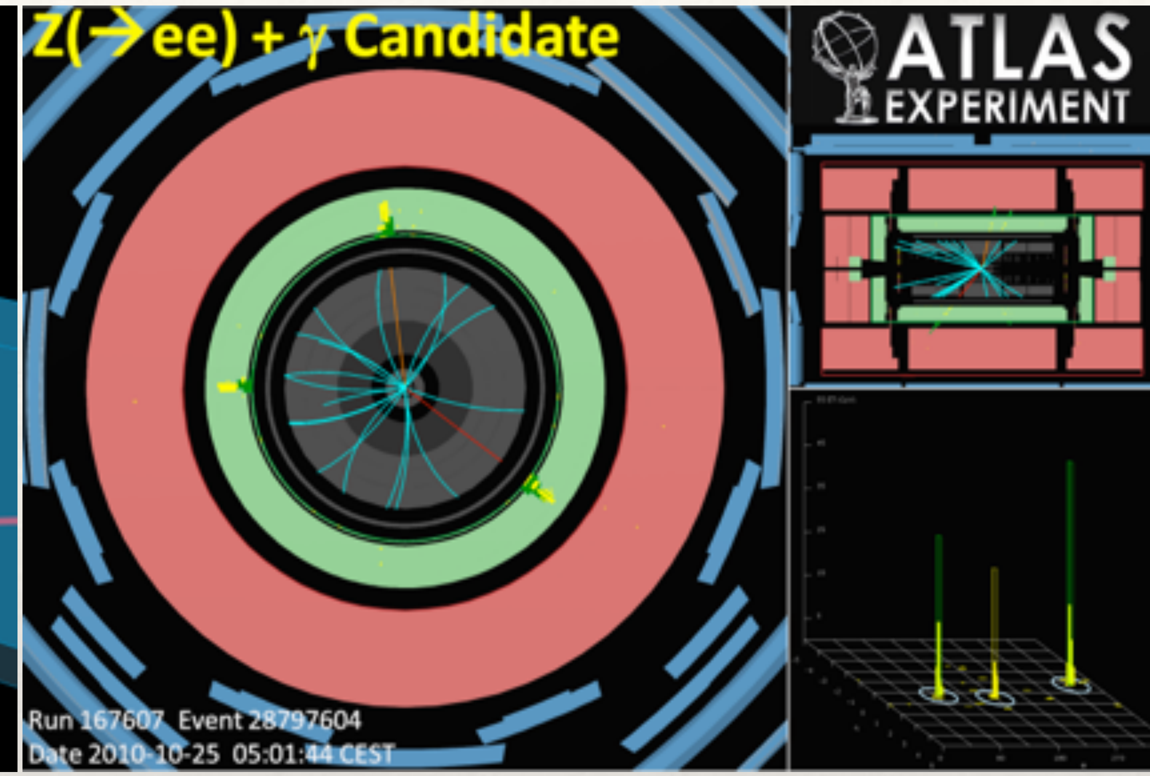


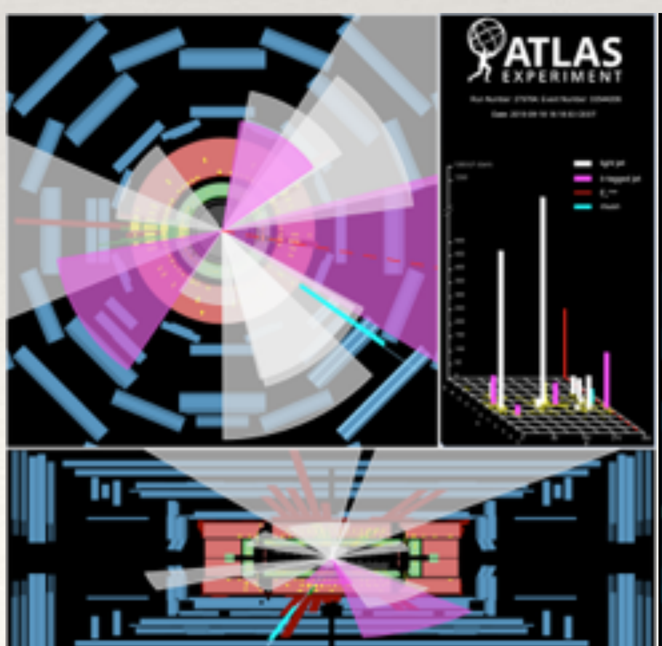
Conclusions

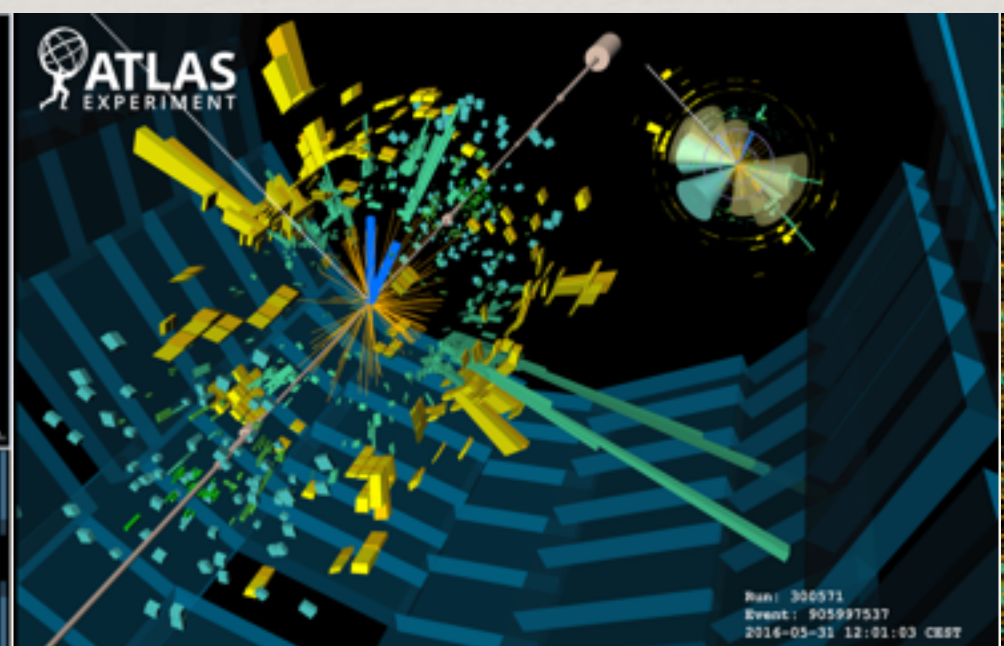
- ATLAS detector evolving continuously facing harsh LHC operating conditions. Run 2 already with special upgrades (IBL, L1 Topo, more muon chambers) to face LHC beyond the design luminosity.
- Detector performance evaluated over a wide range of luminosity scenarios and energy. Results usually rather stable with <μ> increase.
- Upgrade program well established with phase 1 under construction and phase 2 in prototyping stage. Some parts already integrated in the detector for testing.
- More integration between different sub-systems, specially for triggering purposes.
- Once more, this is NOT a complete description of the activities in ATLAS (no talking about HI results, Forward detectors, many different analysis or all upgrade plans). Also could talk about outreach, hardware developments, etc…
- Such rich development program still has a lot of work for students and new collaborators.

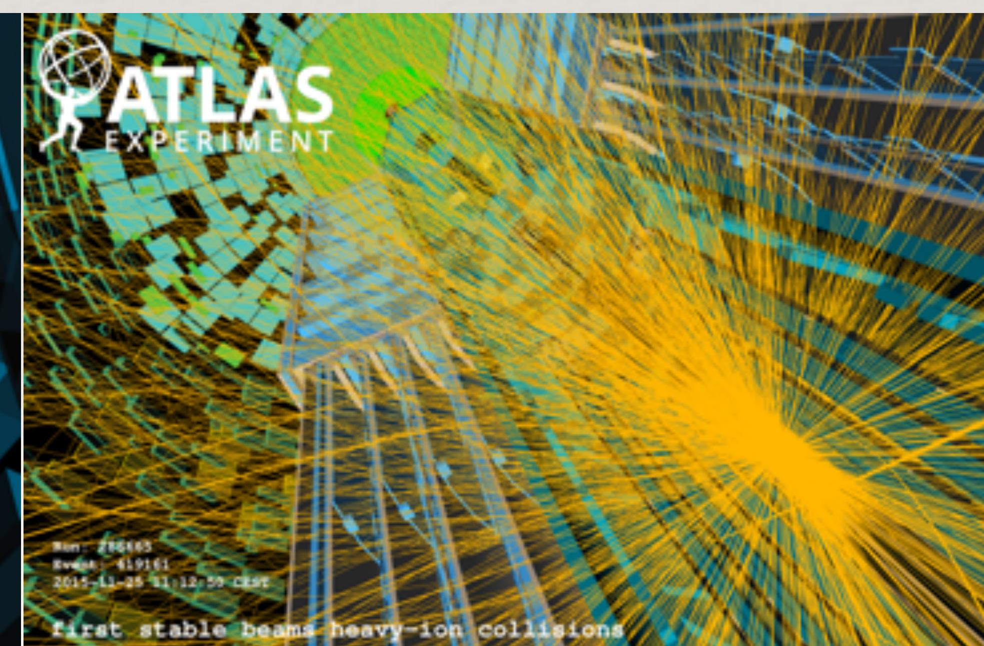
Events Displays











Still in this conference…

- "Neutrinos at LHC" by Toshi Sumida (Friday, Sep 23rd).
- "B-physics in ATLAS and CMS" by Dario Barberis (Thursday, Sep 22nd).
- "Top Physics in ATLAS and CMS" by José Enrique García Navarro (Thursday, Sep 22nd).
- "Recent highlights of hard QCD with W and Z bosons, jets and photons by ATLAS" by Bogdan Malaescu (Thursday, Sep 22nd).
- "Recent highlights of Electroweak Physics in ATLAS" by Manuella Vincter (Thursday, Sep 22nd).

Still in this conference…

- “Overview of ATLAS heavy ions results” by Brian Cole (Thursday, Sep 20th).
- “ttH measurements and combinations in ATLAS” by Antonio Baroncelli.
- “SM Higgs boson results ATLAS” by Dominik Duda (Monday, Sep 19th).
- “Higgs boson BSM ATLAS” by Anna Kaczmarska (Monday, Sep 19th).
- “Search for high mass resonances through 2 gamma channel in ATLAS” by Yee Chinn Yap (Tuesday, Sep 20th).

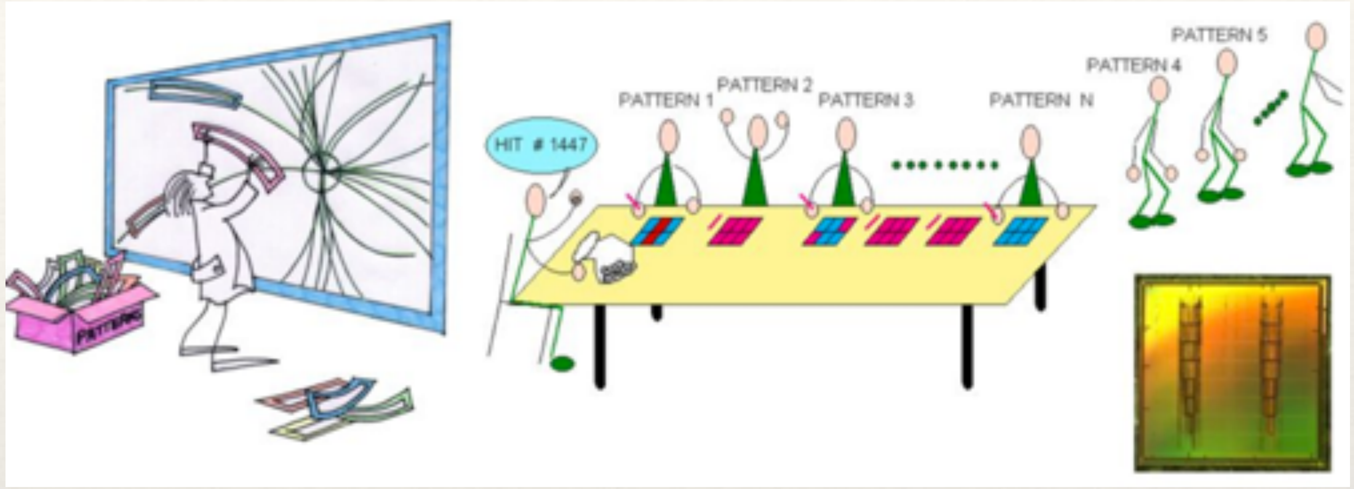
Still in this conference…

- “Heavy Higgs searches in diboson final states in ATLAS” by Zhiqing Zhang (Monday, Sep 19th).
- “Supersymmetry searches in ATLAS” by Edoardo Gorini (Tuesday, Sep 20th).
- “BSM physics in ATLAS and CMS” by Young-Kee Kim (Tuesday, Sep 20th).

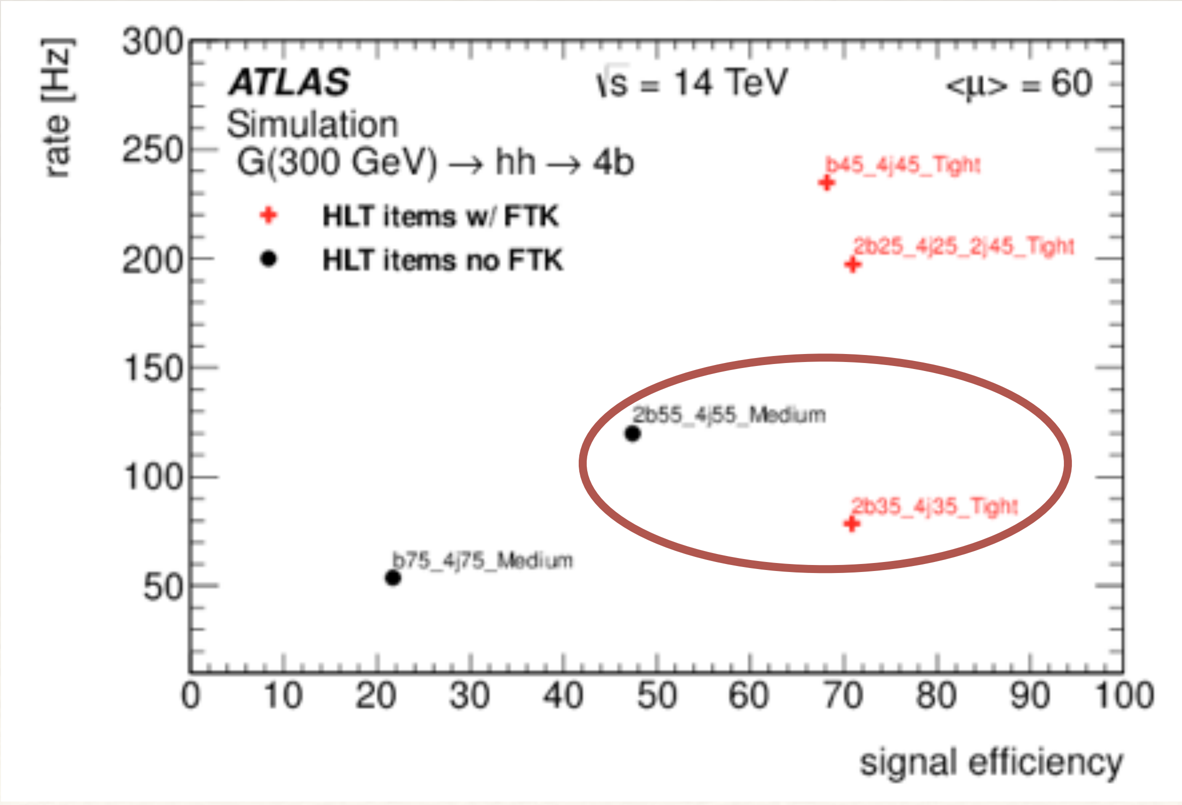
Back up

Run 2 - Fast TracKer

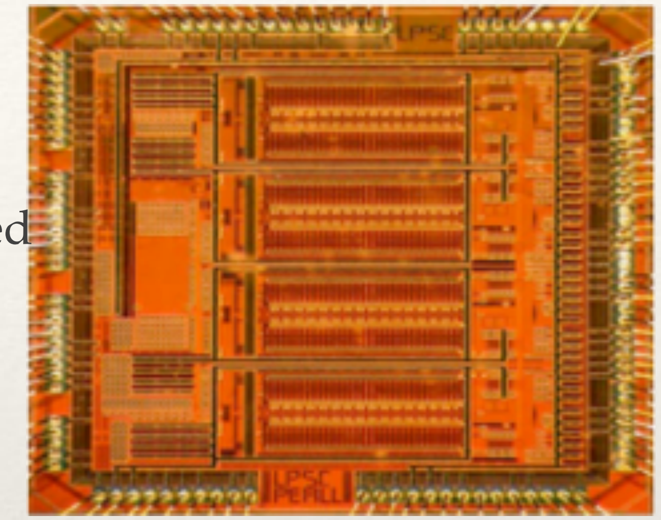
Pattern matching



- In the High-Level Trigger (HLT) finding a track is a very intense computational task.
- Processing time depends on the combinatorial search on space-points for tracks. This increases with luminosity.
- Using Associative Content Addressable Memories which accumulate all possible tracking patterns, tracks can be matched in 100 kHz and informed to the HLT.
- HLT tracking thresholds can be kept lower. Many HLT algorithms can benefit from a good number of vertices estimative as well. Being commissioned.



phase 2 - electronics upgrade



Radiation hard
Electronics to be used
in the Front-End

- Front-end upgrades