Upgrade and future of ATLAS

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for the ATLAS Collaboration

LHC Days 2012

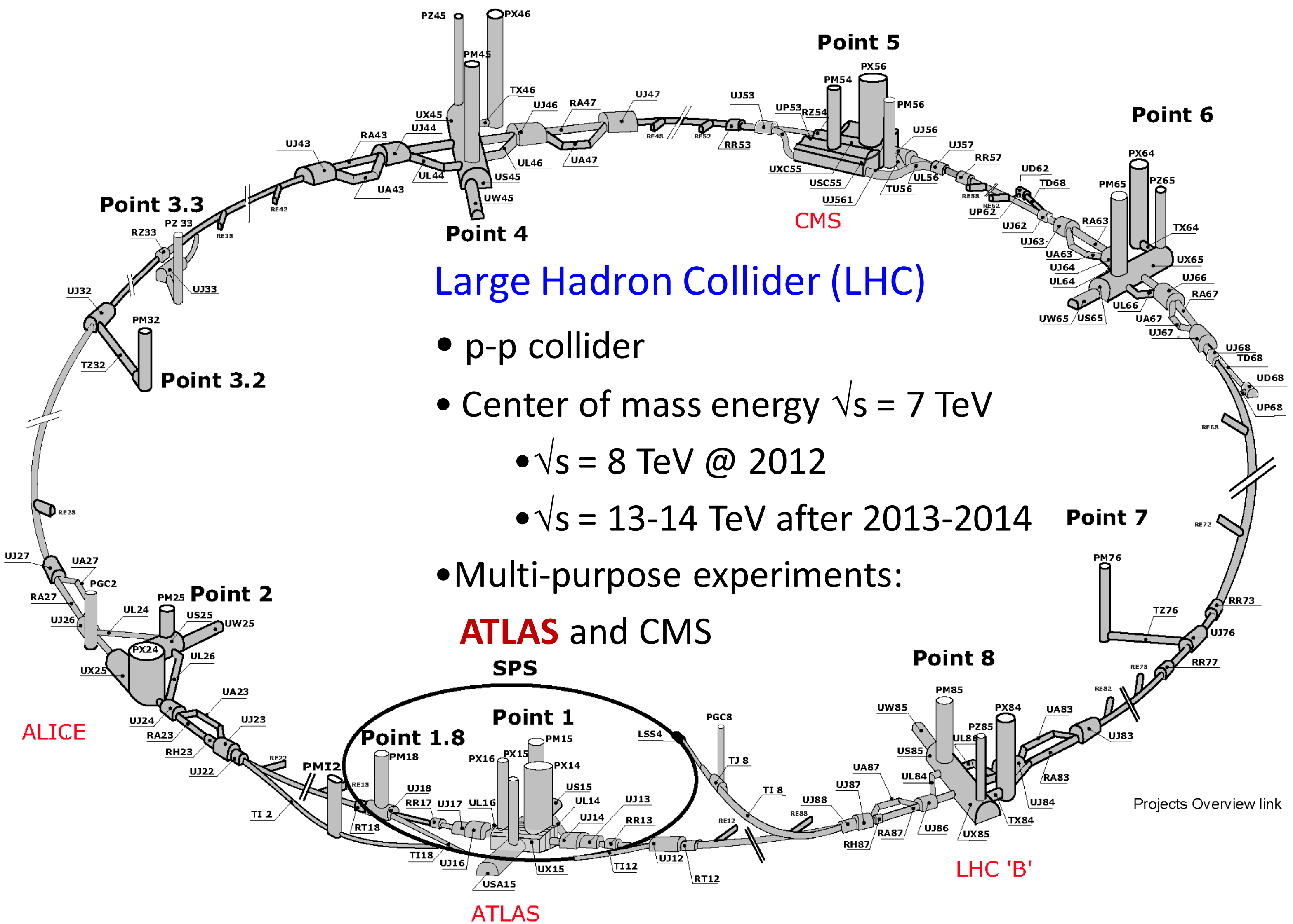
1-6 October 2012

Split, Croatia

Outline

- ATLAS
- Historical perspectives
- Motivation for the upgrade
- Timeline
  - Phase-0
  - Phase-1
  - Phase-2
- Conclusion

LHC



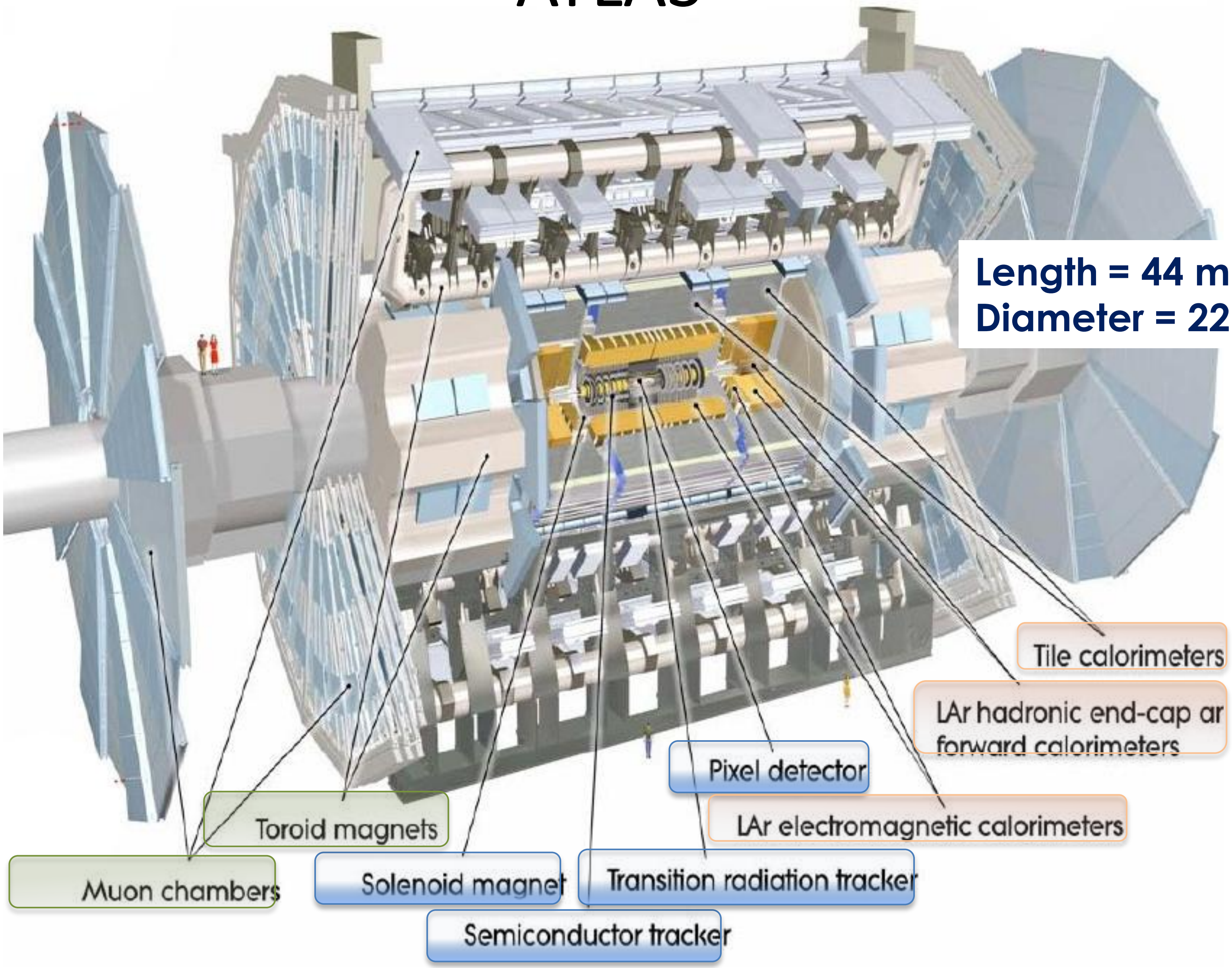
Large Hadron Collider (LHC)

- p-p collider
- Center of mass energy √s = 7 TeV
    - √s = 8 TeV @ 2012
    - √s = 13-14 TeV after 2013-2014
- Multi-purpose experiments:

  ATLAS and CMS

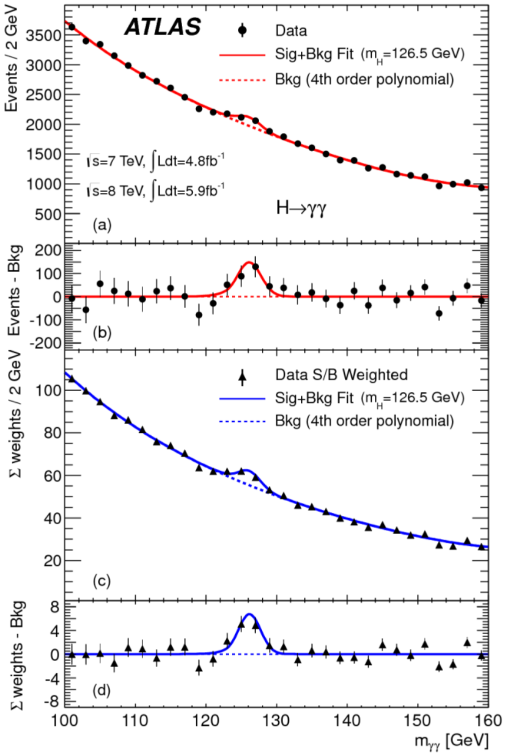
Projects Overview link

ATLAS



Length = 44 m
Diameter = 22 m

Historical Perspectives



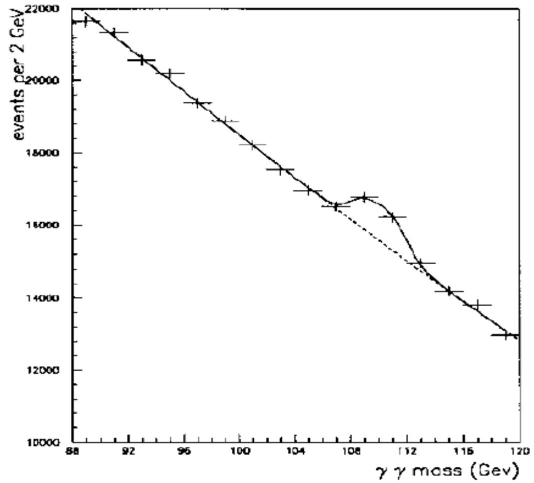


Figure 8.1: *Expected* $m_{\gamma\gamma}$ *spectrum for* $H \to \gamma\gamma$ *signal above irreducible* $\gamma\gamma$ *background for* $m_H = 110$ *GeV and* 10^5 pb^{-1}

CERN/LHCC/92-4
LHCC/I 2
1 October 1992

ATLAS

Letter of Intent
for a
General-Purpose pp Experiment
at the
Large Hadron Collider at CERN

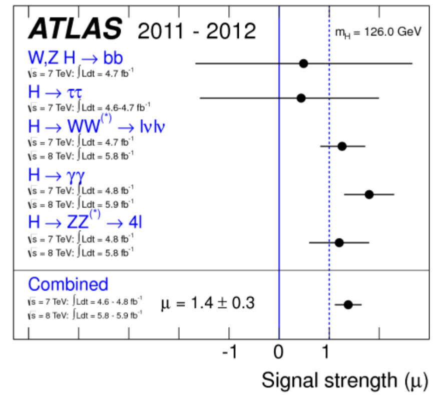
Abstract

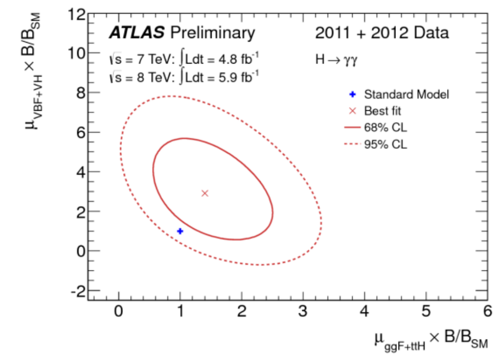
The ATLAS collaboration proposes to build a general purpose proton-proton detector for the Large Hadron Collider, capable of exploring the new energy regime which will become accessible. The detector would be fully operational at the startup of the new accelerator. The detector concept, the research and development work under way to optimize the detector design, and its proposed implementation are described, together with examples of its discovery potential.

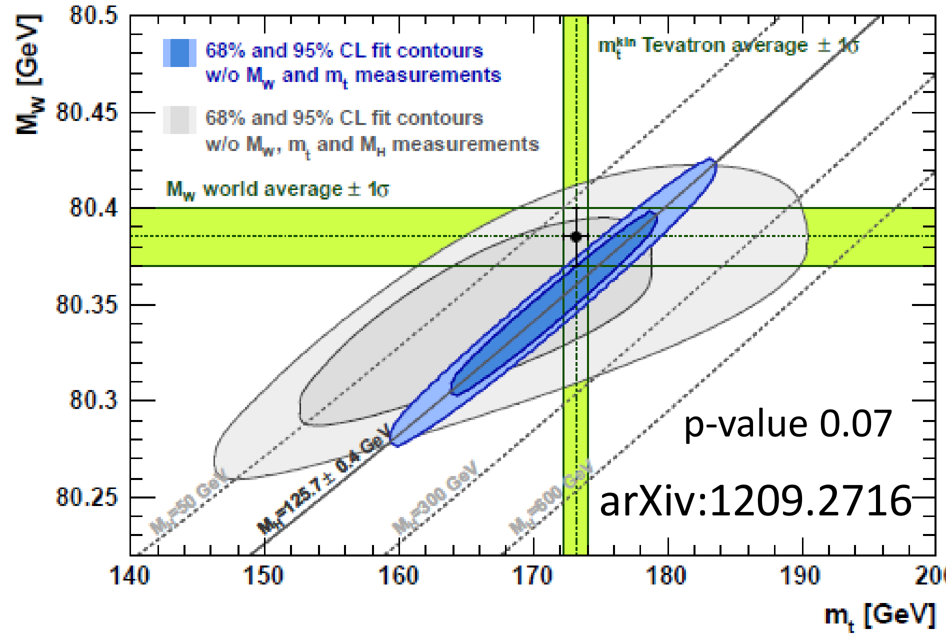
- The Higgs(-like) boson was discovered with ½ of the nominal energy, more severe pileup than expected and 1/3 of the integrated luminosity than considered to be necessary.
- Utilising major innovations in analysis, technology and computing techniques.
- Hope for similar surprises in the future!

Motivation for the Upgrade

- Most likely the Higgs boson is found. What is the next?
- Is this the Standard Model Higgs?
- Is there anything else?
- Due to its nature the Higgs boson couples to all the (massive) particles and therefore we have the tool to search physics Beyond the Standard Model.

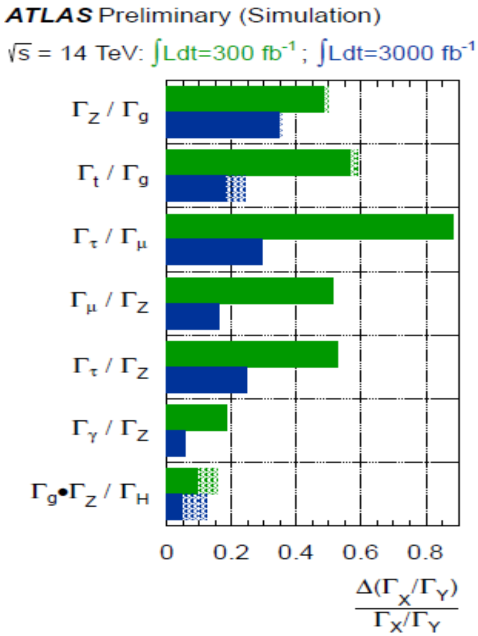


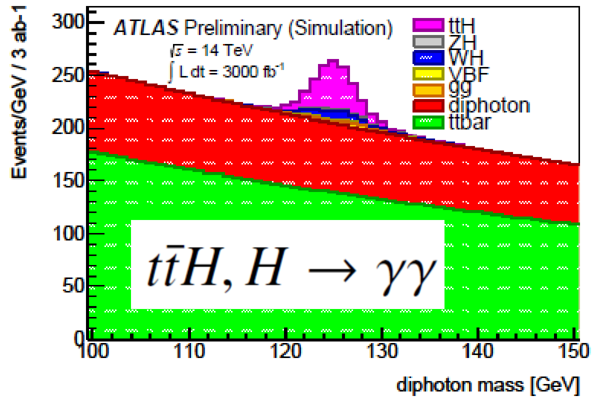


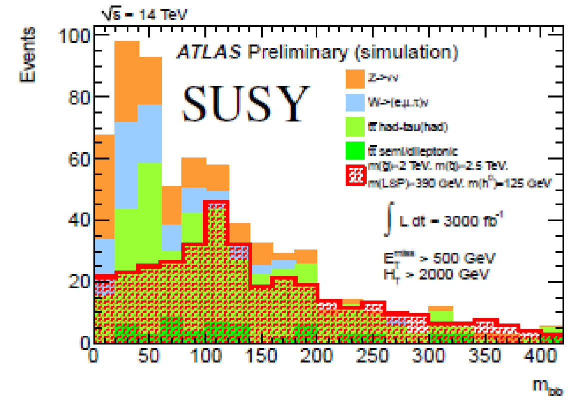


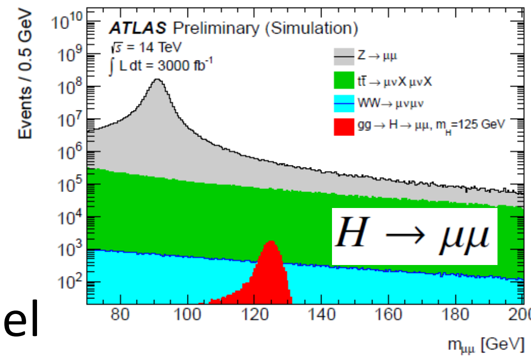
"In the absence of any direct evidence of new physics, the Higgs will be (one of?) the best source of information about possible new physics..." *Christophe Grojean*

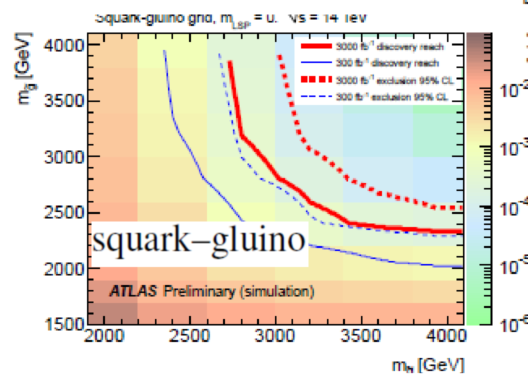
Future Physics @ ATLAS



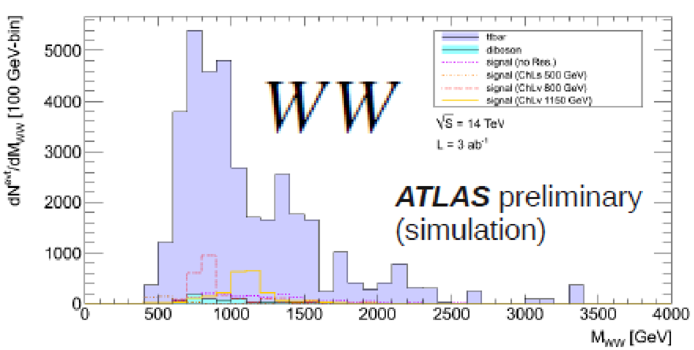


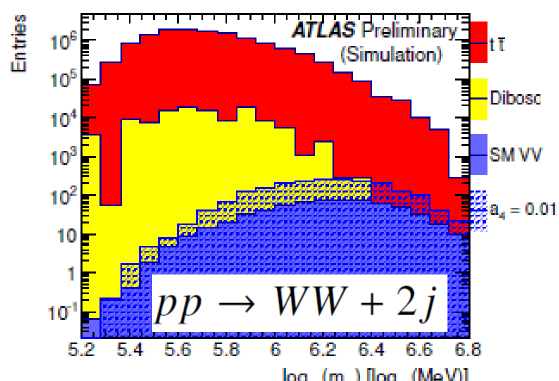


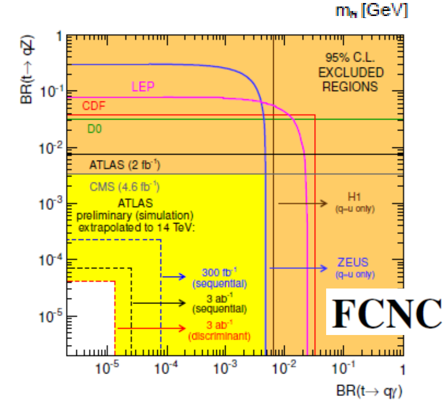




- Higgs self-coupling
  – ~3σ in $HH \to b\bar{b}\gamma\gamma$ channel

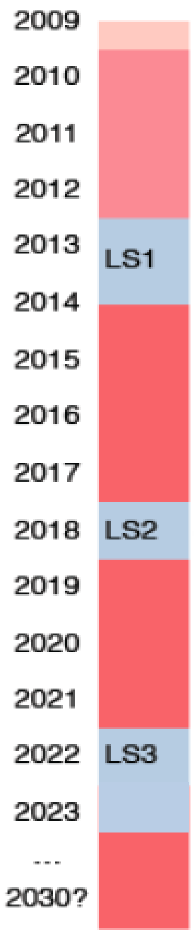






LHC Upgrade Schedule

as shown in Chamonix 2012



✧ LHC startup, √ s = 900 GeV

$\sqrt{s}$=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

Go to design energy, nominal luminosity (**Phase-0**)

~20 months

$\sqrt{s}$=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

Injector and LHC **Phase-1** upgrade to full design luminosity

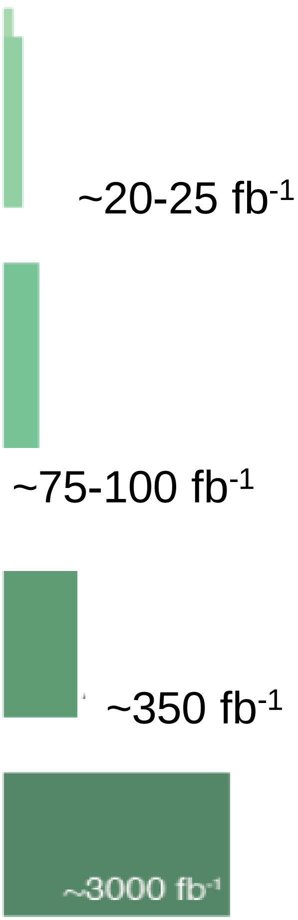
~14 months

$\sqrt{s}$=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

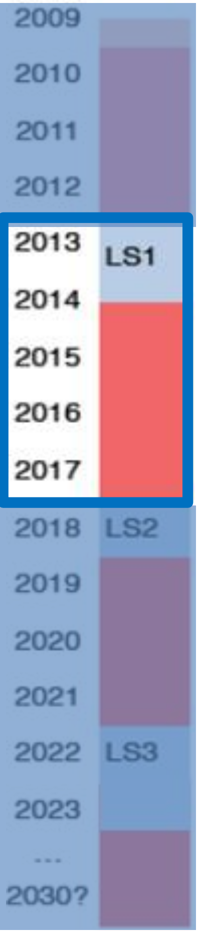
HL-LHC **Phase-2** upgrade, IR, crab cavities?

Need ~2 years

$\sqrt{s}$=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling



Phase-0

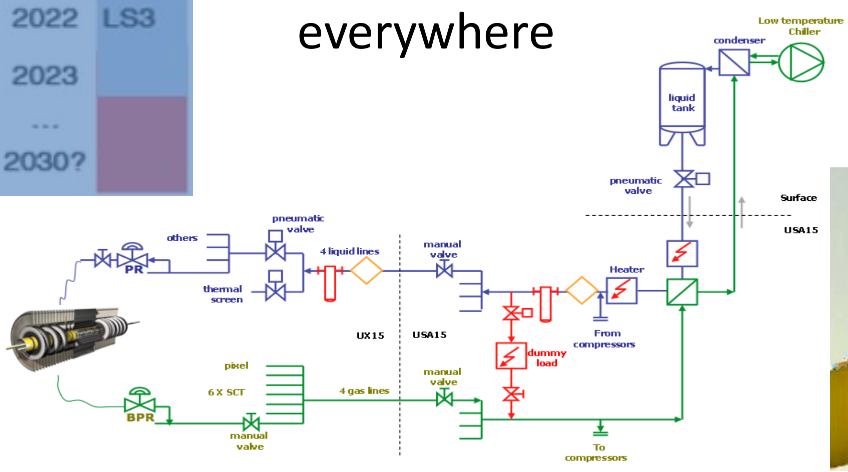


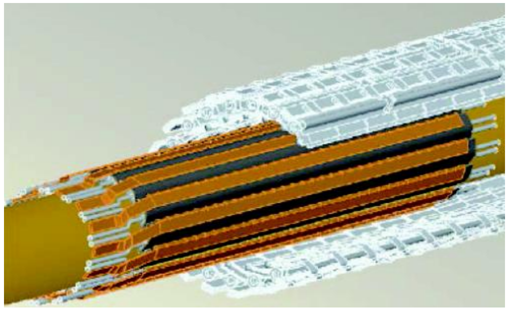
Detector consolidation:

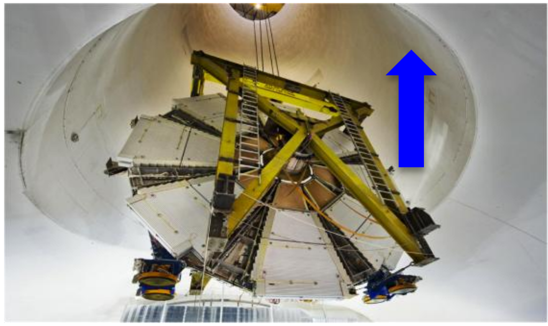
- New ID evaporative cooling plant
- New Calorimeters LV power
- Magnets cryogenics consolidation
- Muon spectrometer consolidation
- Infrastructure consolidation
- Maintenance and repairs everywhere

Detector upgrade:

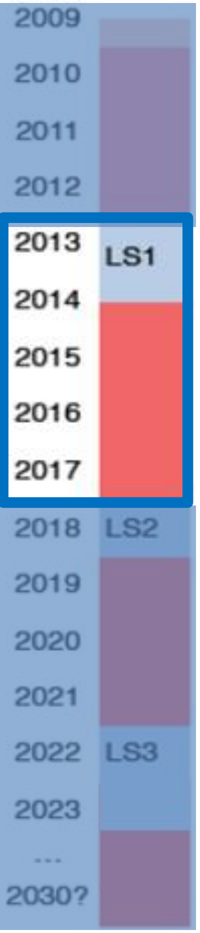
- New Aluminum beam pipes
- New small radius central Be pipe
- IBL: 4th pixel layer
- Improved pixel services (decision in December 2012)
- New chambers in the muon spectrometer to improve geometrical coverage

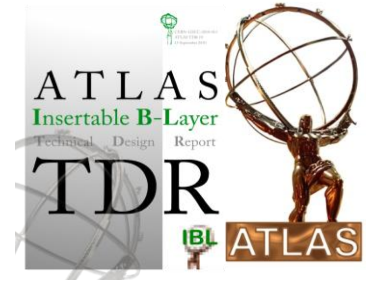




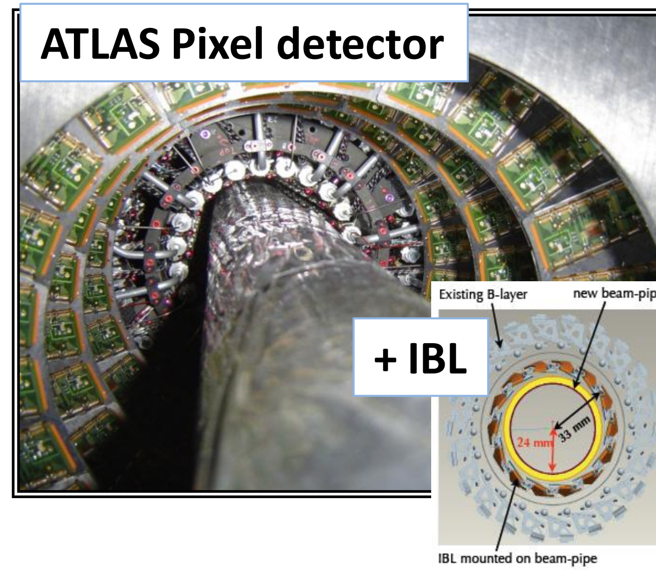


Insertable B-Layer

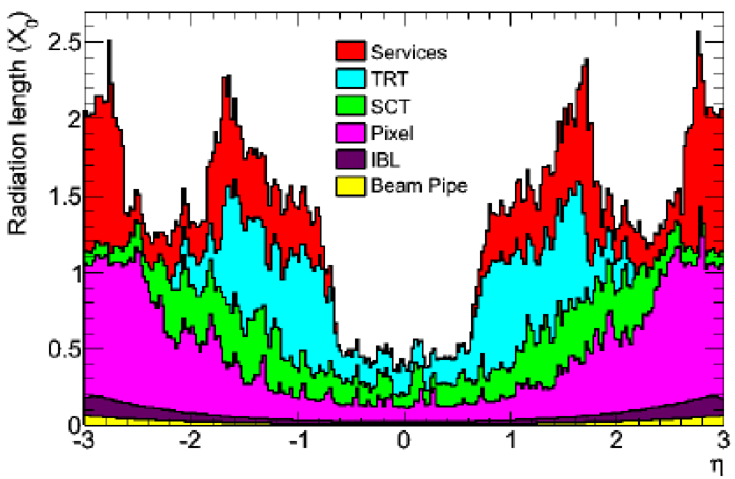




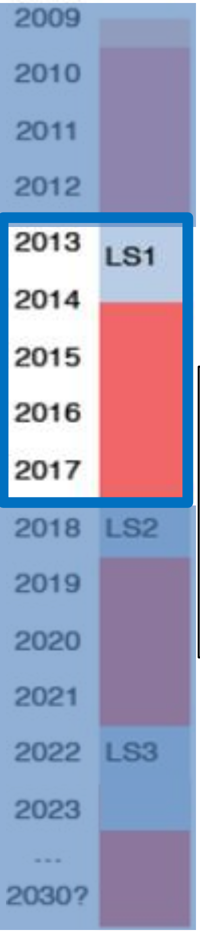
- Improve performance of the pixel detector
  - tracking, vertexing, b-tagging for high pile-up
- Technology step towards HL-LHC



- **Option A**: build around a new Be beam pipe and slip inside the present detector in situ
- **Option B**: if the pixel package is removed to replace the services, this operation can be carried out on the surface

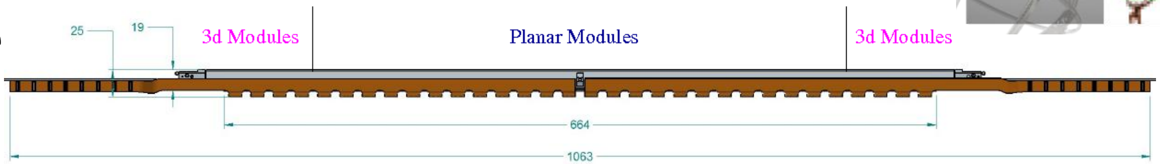


- Material budget: **$0.015\ X_0$ / layer**
  - in the current detector: 0.03 X_0 /layer
- Coverage: **z = 60cm, |η| < 2.5**
- First hit **@33mm** (now @50.5mm)
  => smaller beam pipe (29 -> **25mm**)
- Pixel size **100x250µm** (now 100x400µm)
- No eta overlap due to clearance
  => minimize edges of the modules

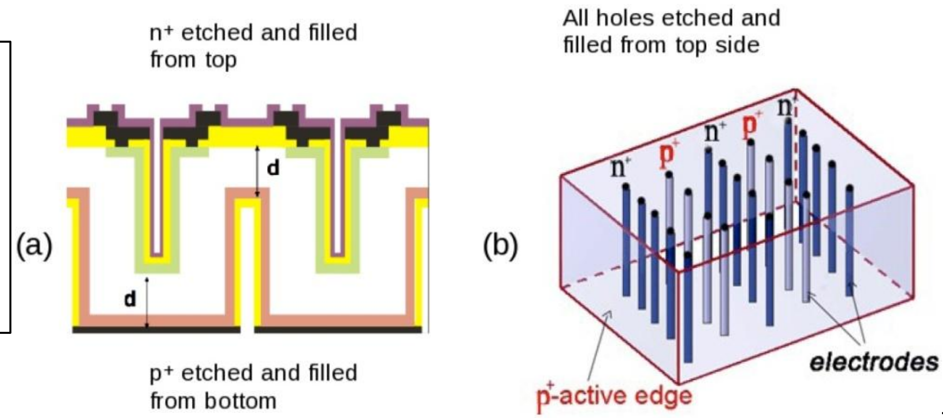


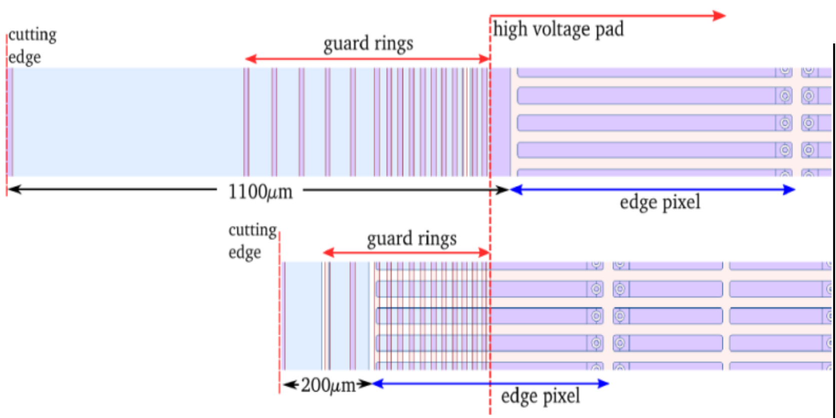
Insertable B-Layer

- IBL baseline
  - 75 % planar
  - 25 % (3D sensors @ large eta)



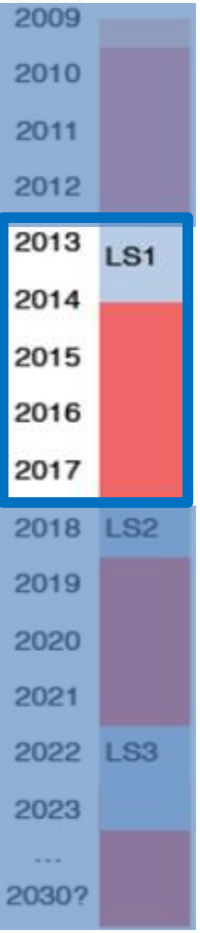
Planar (slim edge):
- **200 µm** thickness
- Inactive edge **<250 µm** (was 1100 µm)
- Low charge generated after irradiation -> low threshold operation and high HV

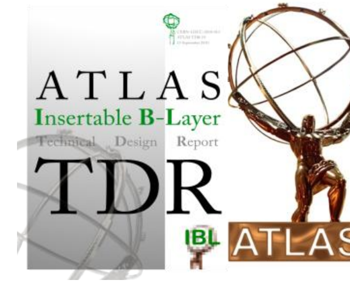




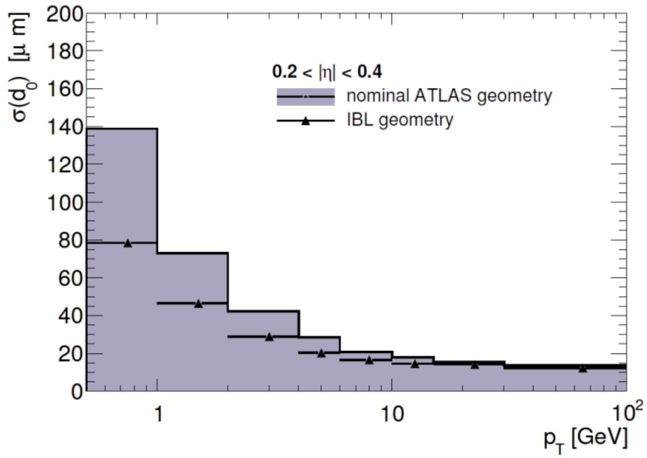
Double-sided 3D (forward region):
- **230 µm** thickness
- Inactive edge **200 µm**
- Low depletion voltage **(<180V)**
- Medium operating temperature
- More complex process => Higher cost

Insertable B-Layer



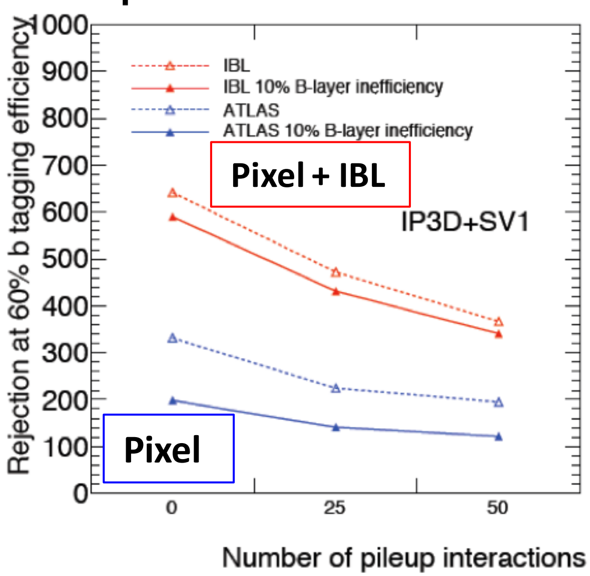


- Improvements in tracking and vertexing



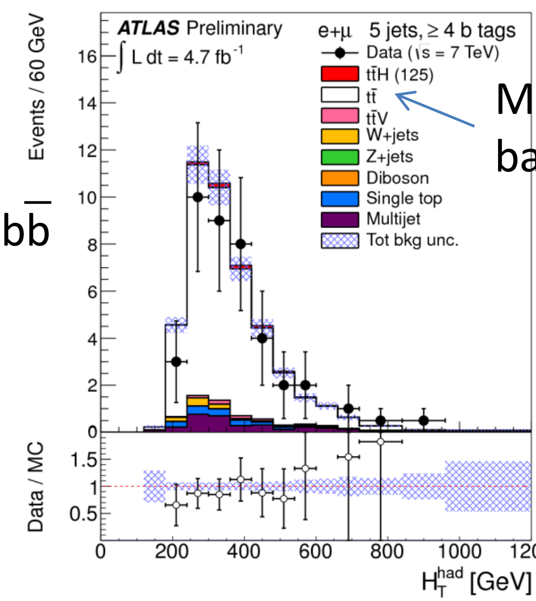
Impact parameter in $t\bar{t}$ events

- Improvements in b-tagging



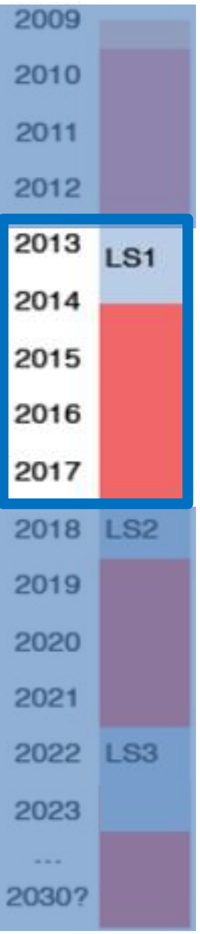
Essential for $H \rightarrow b\bar{b}$ and top physics

$t\bar{t}H$

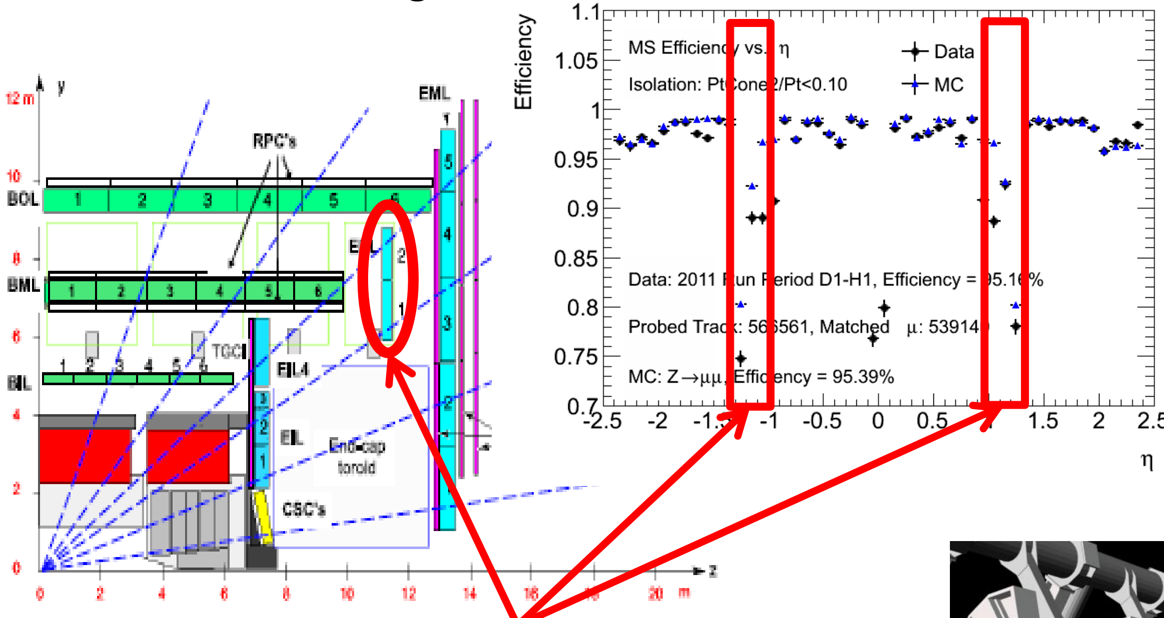


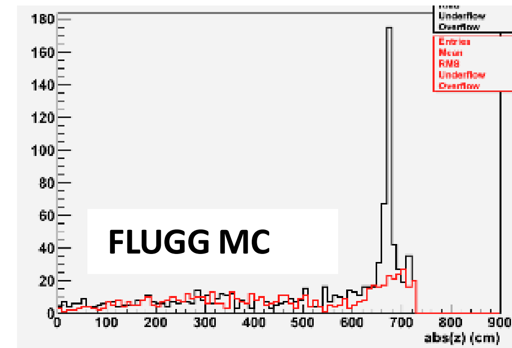
Major background

Muon System



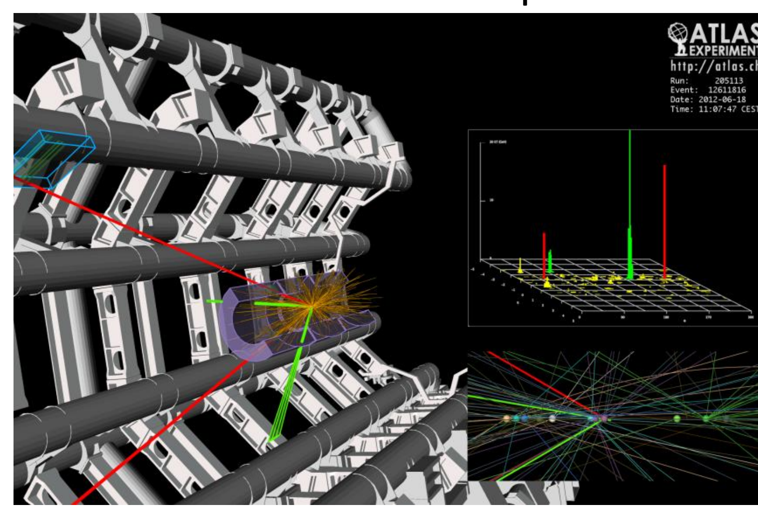
- Gap between forward calorimeter & shielding disk
  - New shielding will be installed @ 7m





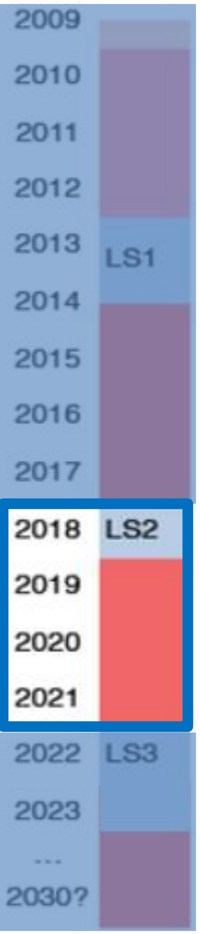
Beam Interaction hits
with & without shielding

H→ZZ^*→2e2μ candidate



- **Endcap Extension (EE) Muon Chambers** (1.0<|η|<1.3) will be installed (52 of 62) to address low efficiency in the region
- Need to bring Muon Small Wheel (9m diameter) on the surface
  - out of the way of the IBL
- Corresponding L1 trigger updates

Phase-1



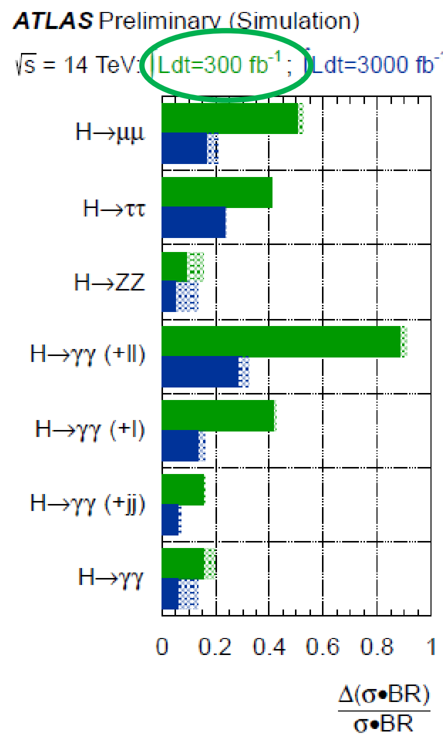
- *LOI presented in December 2011*
- *Approved by the ATLAS CB in January 2012*
- *Endorsed by LHCC in March 2012*

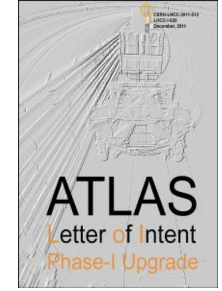
Four upgrade projects:

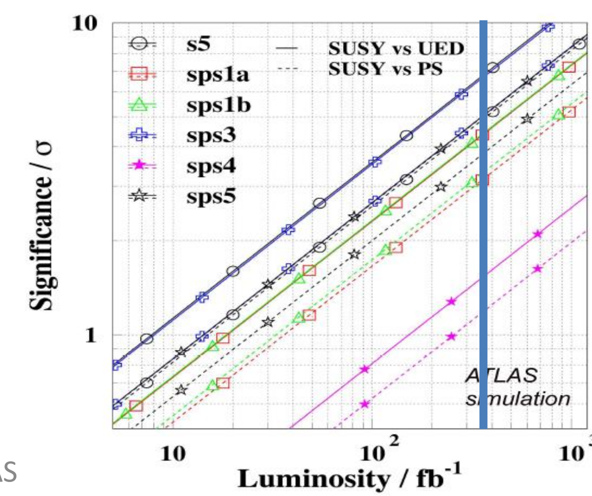
- New muon small wheels
- Fast tracking trigger (input to LVL2 trigger)
- High granularity and high precision calorimeter trigger (LVL1 calo trigger)
- Various trigger/DAQ upgrades

One new project:

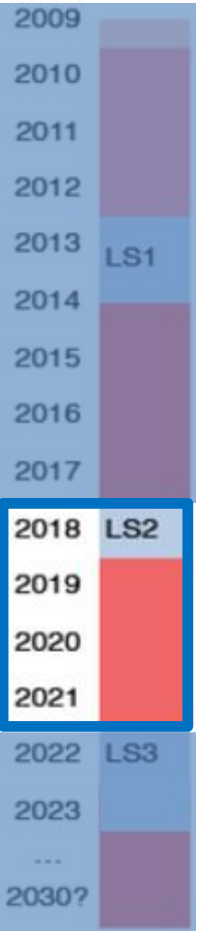
- AFP : New forward detectors at ±210m



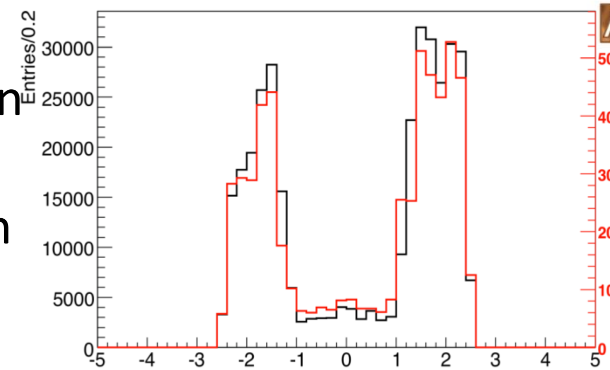




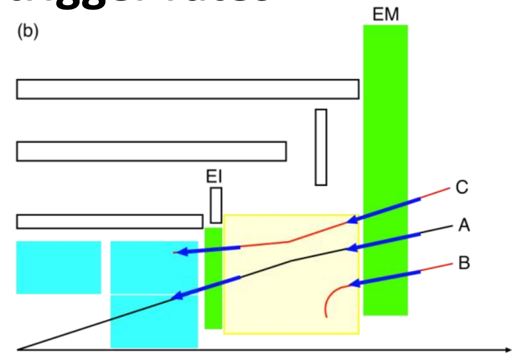
New Muon Small Wheel (nMSW)



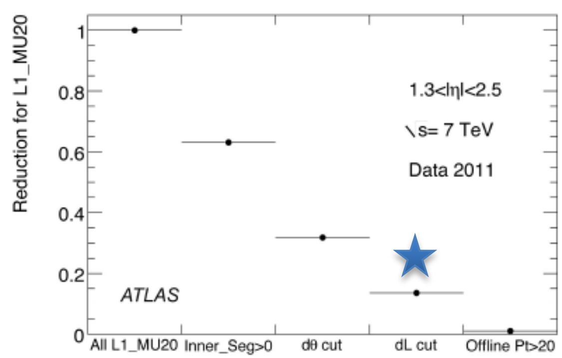
- Trigger on low Pt leptons, but…
  – High rates in muon system from cavern background (low energy photons and neutrons), especially in forward region
- New Small Wheel
  – Equipped with precision tracker that works up to the ultimate luminosity (5-7)x10^{34} cm^{-2}s^{-1} with some safety margins
  – Suppress the fake triggers by requiring IP pointing segment in EI (small wheel)

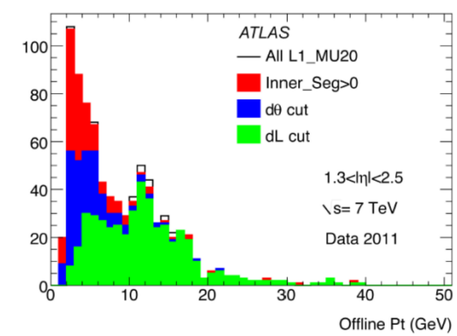


MU20 trigger rates

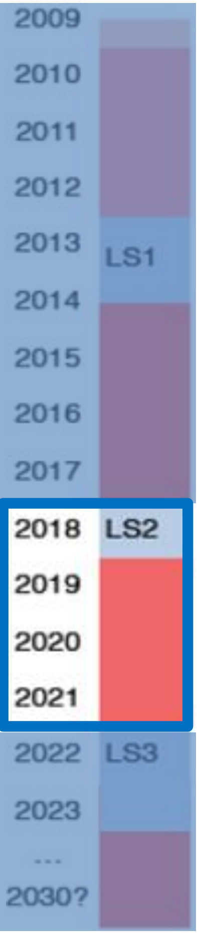


★ the nMSW segment matches in (η−ϕ) to the triggering segment => **order of magnitude rate reduction**





nMSW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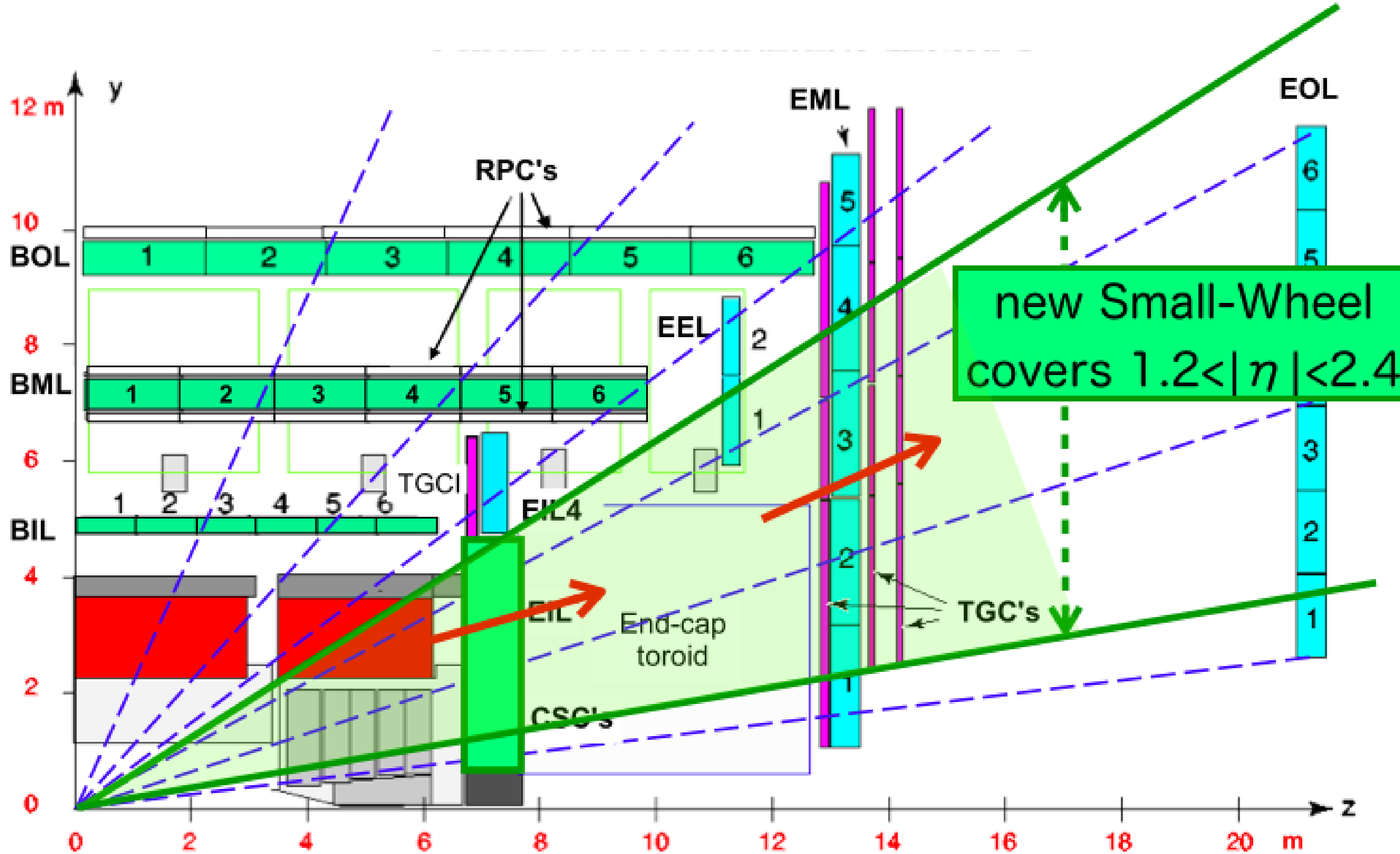
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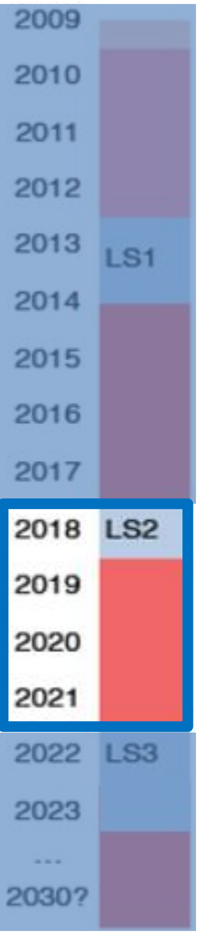
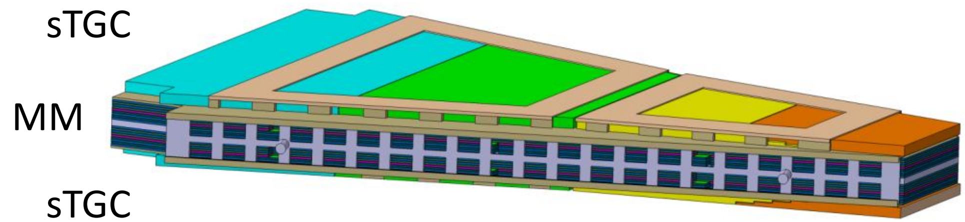
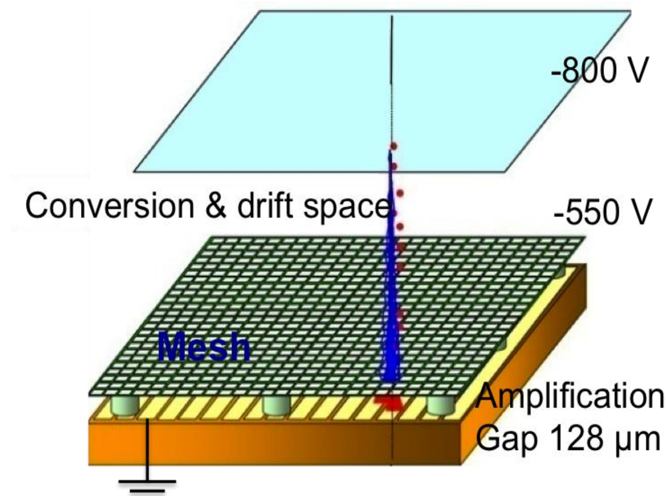
nMSW detectors

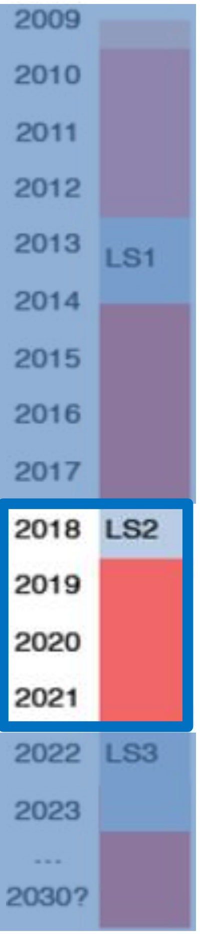


- **sTGC (**Thin Gap Chambers): reduced cathode resistivity of 100kΩ/square => **rate capability has been increased** substantially up to 30kHz/cm^2
- **MicroMegas** (MM)
  - MM consists of a planar drift electrode, a gas gap of a few mm thickness, acting as ionization and drift region, and a thin metallic mesh at ~100 µm distance from the read-out electrode, creating the gas amplification region

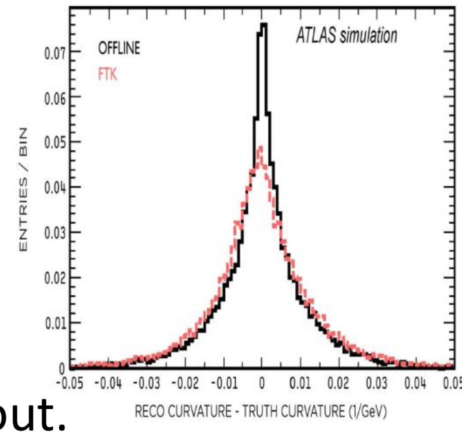


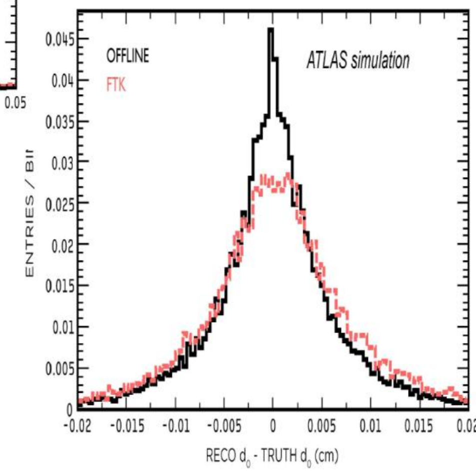


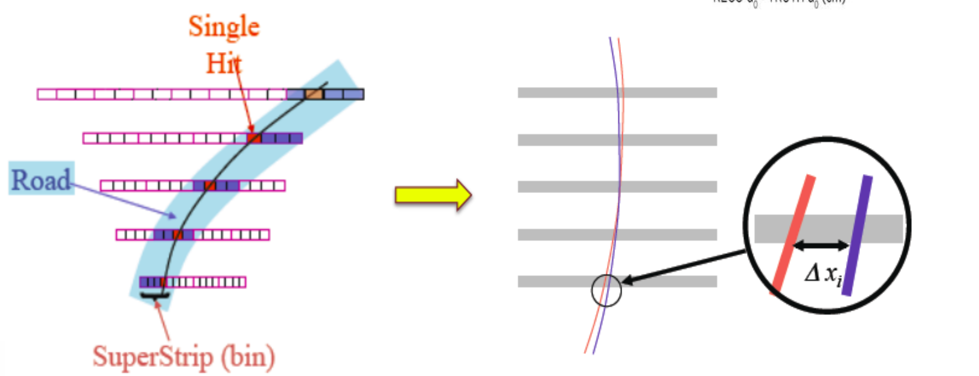
Fast TracKer (FTK)



- FTK: Global hardware based tracking at "Level 1.5"
  - Descendent of the CDF Silicon Vertex Trigger (SVT)
  - Inputs from Pixel and SCT detectors.
  - Data in parallel to normal read-out.
  - Provides inputs to L2 in ~25 μs. Track parameters at ~offline precision
  - Two phases:
    - Pattern recognition (10^9)
    - Track fitting
  - Major improvement for
    - b-tagging
    - tau ID
    - lepton isolation



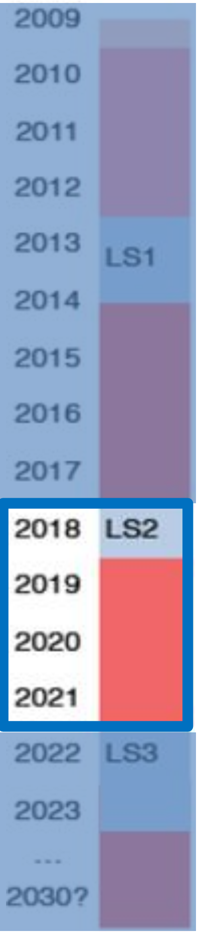




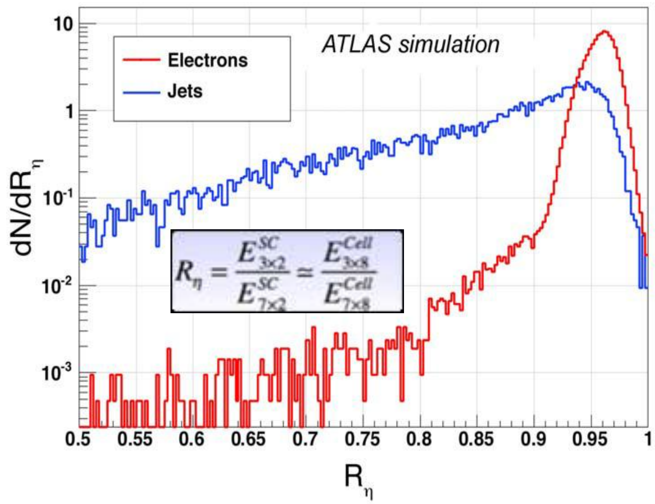
Pattern recognition in coarse resolution (superstrip→road)

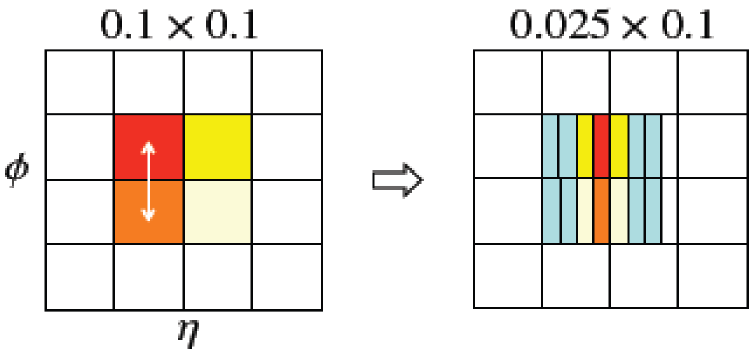
Track fit in full resolution (hits in a road)
$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$

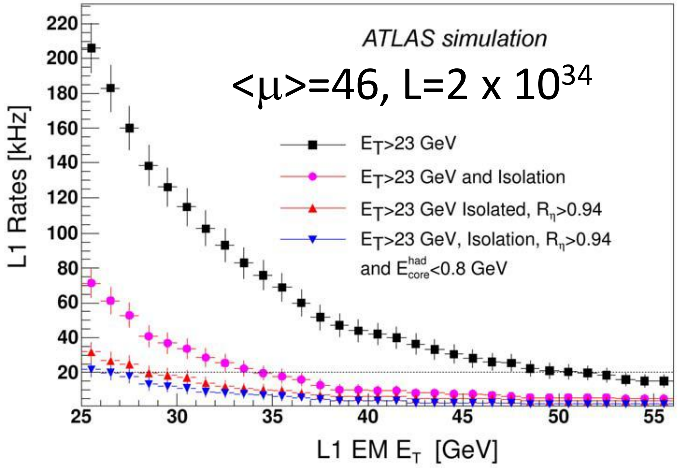
Calorimeter L1 Trigger



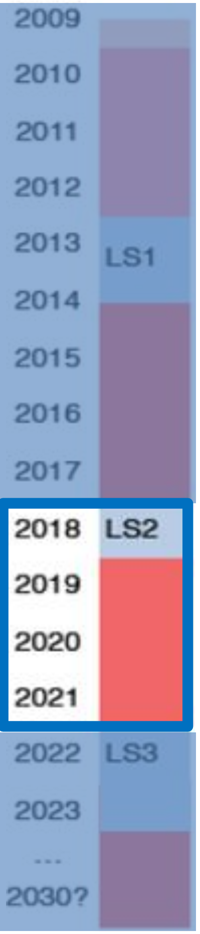
- Goal: Improve granularity of L1 for better e/jets discrimination
  - Shower shape algorithms
  - Partial upgrade of the calorimeter front-end read-out architecture, part of the input stage of the L1 and the interfaces among the two systems
  - The upgrades must be compatible with Phase 2
  - The proposed architecture will be validated by an **in-beam system test** planned for **installation in ATLAS during the Phase-0 shutdown**



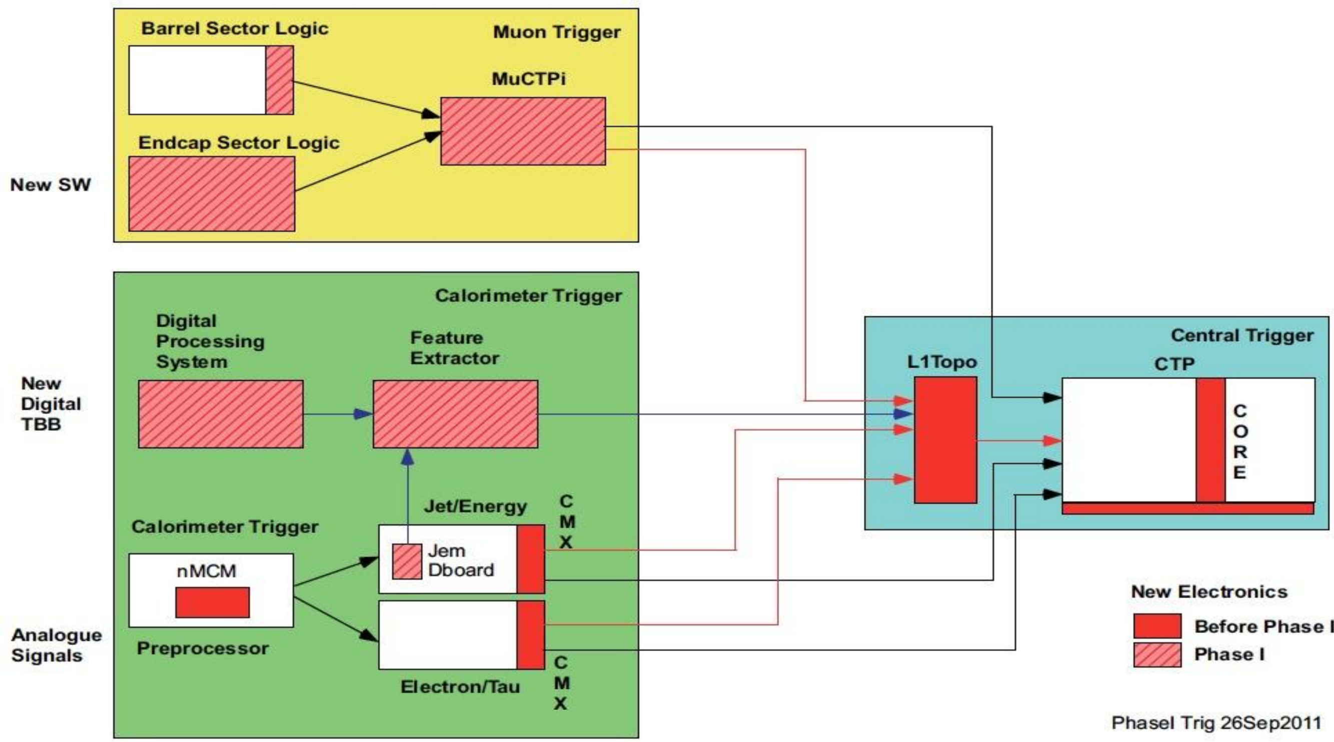




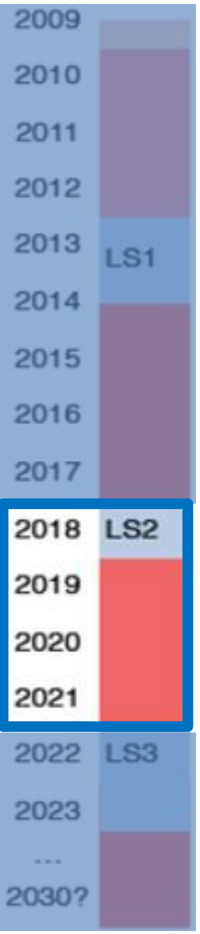
Trigger & DAQ



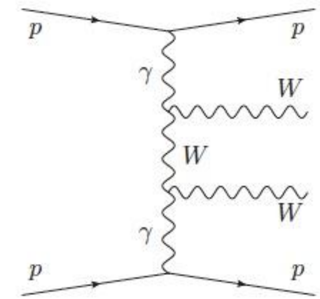
- Incorporate Muon Small Wheels, L1Calo higher granularity, FTK
- L1 (including topological trigger) -> FTK -> L2 & EF
  - Greater integration of Level-2 and Event Filter selections + Event Builder



Forward Physics System

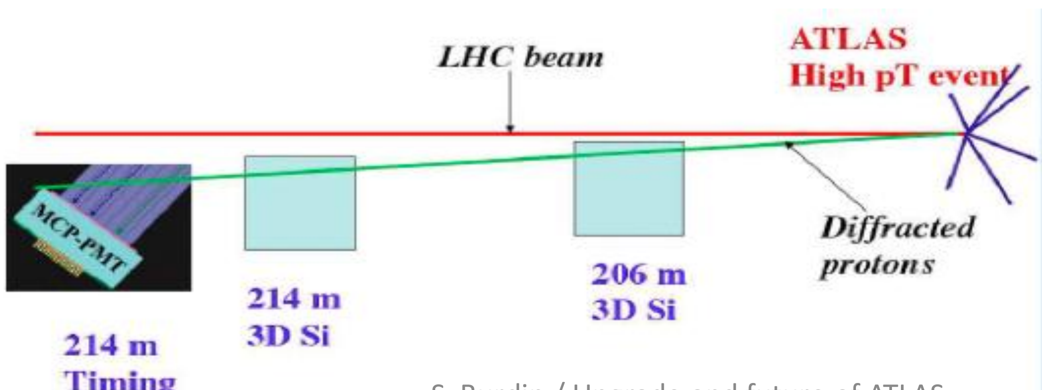


Diffractive Physics

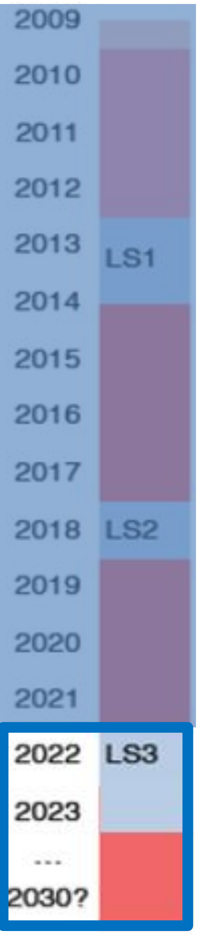


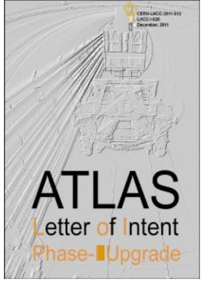
- ATLAS Forward Proton (AFP) detectors
  - Tag and measure scattered protons at ± 210m
- Hardware
  - Radiation-hard edgeless 3D silicon developed in IBL context
  - 10ps timing Cerenkov detector for association with high p_T primary vertex
  - Probe hard diffractive physics and central exclusive production of heavy particles

Acceptance	Tagged proton momentum loss ξ Typical di-photon mass acceptance	$0.02<\xi<0.2$ $300<\sqrt{(\xi_1\xi_2 s)}<1200$ (GeV)
Si Tracker	Spatial Resolution Angular Resolution Reconstructed Mass Resolution	$\sim 15\ \mu$m $\sim 1\ \mu$rad ~ 5 GeV
QUARTIC	Time resolution	<10 ps



Phase-2

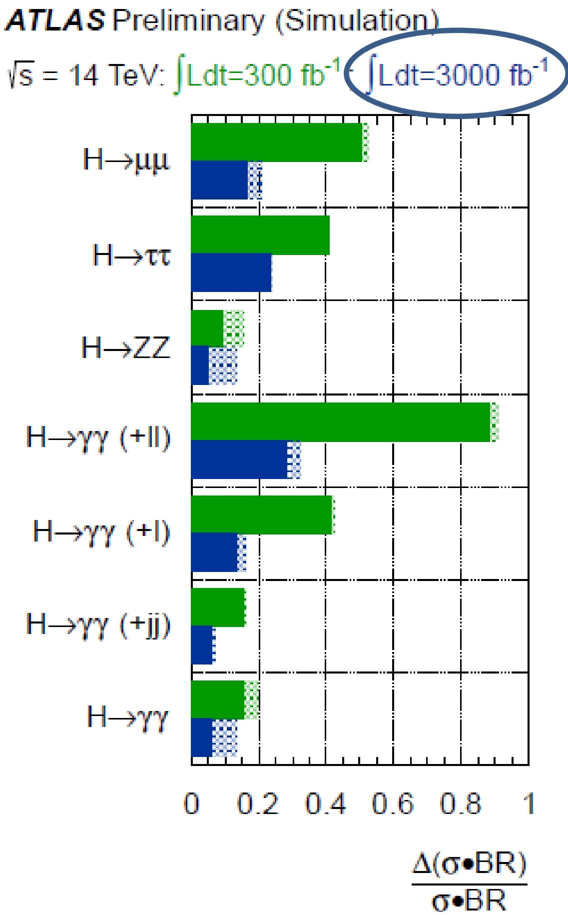




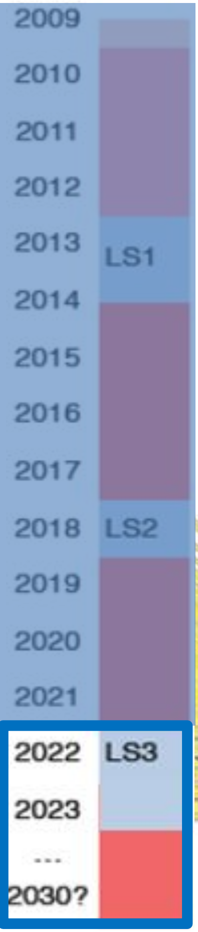
- *LOI to be presented in December 2012*
- *Approval by the ATLAS CB in January 2013*
- *Looking for endorsement by LHCC in March 2013*

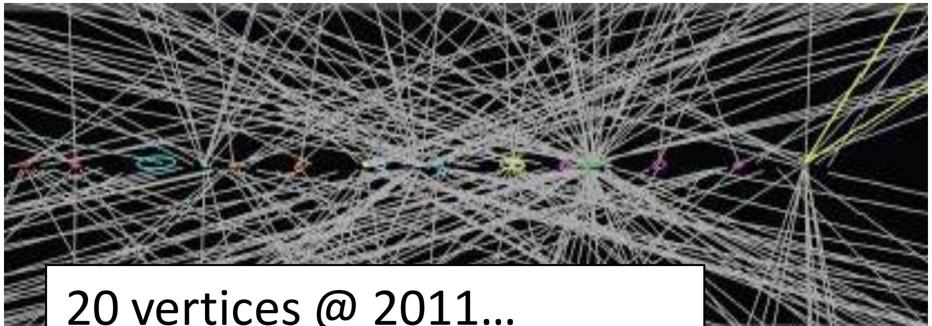
Upgrade projects:

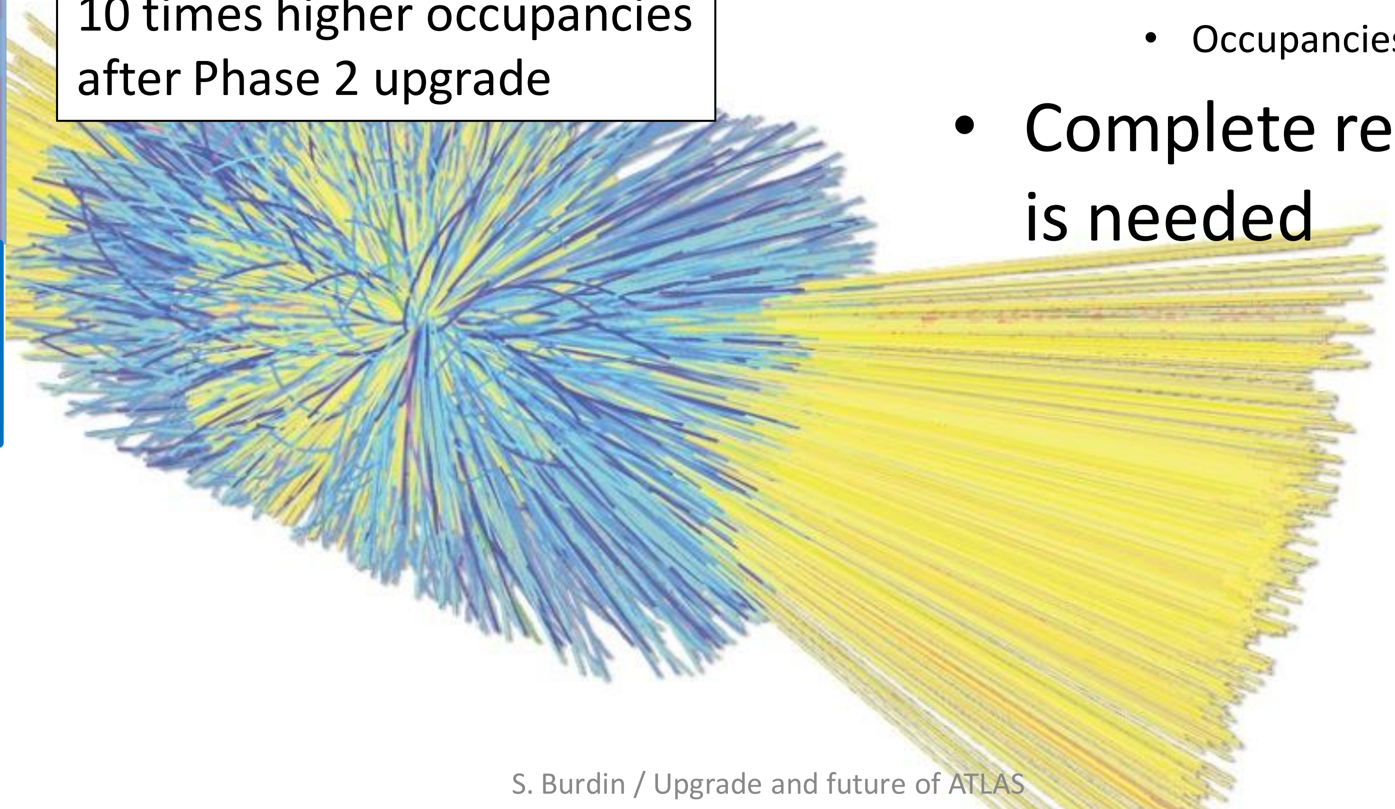
- **New Inner Detector (strips and pixels)**
  – very substantial progress in many R&D areas
- **New LAr front-end and back-end electronics**
- **New Tiles front-end and back-end electronics**
- **TDAQ upgrade**
- **TAS and shielding upgrade**
- **Various infrastructure upgrades**
- **Common activities (installation, safety, …)**
- **New FCAL (if conditions require it)?**
- **LAr HEC cold electronics consolidation (radiation hardness)?**
- **L1 track trigger (latency budget and physics case)?**
- **Muon Barrel and Large Wheel system electronics upgrade?**
- **Forward detectors upgrade?**



Inner Detector



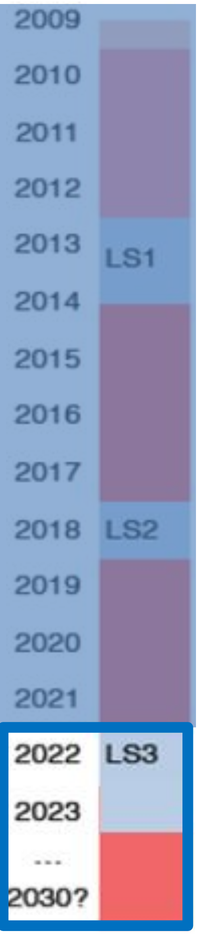




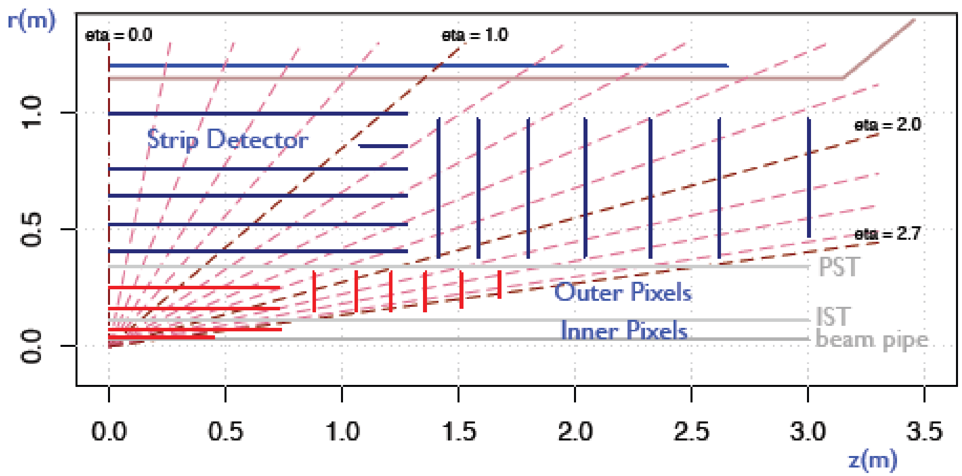
20 vertices @ 2011…
Will need to cope with
10 times higher occupancies
after Phase 2 upgrade

- Limitations of the current ID
  - Detectors designed for $1x10^{34}cm^{-2}s^{-1}$ and 700 fb^{-1}
    - Radiation damage
    - Bandwidth,
    - Occupancies…
- Complete replacement is needed

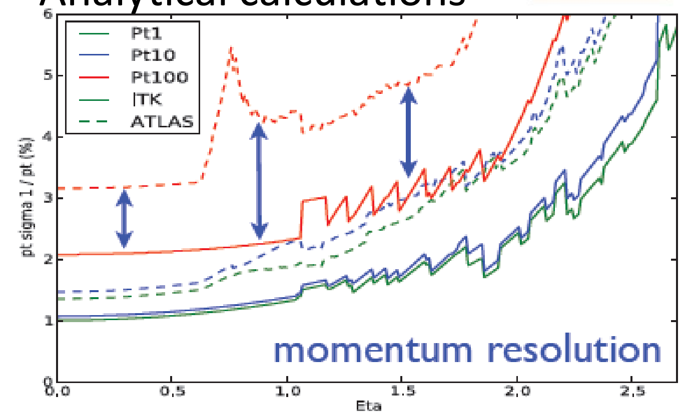
Inner Detector



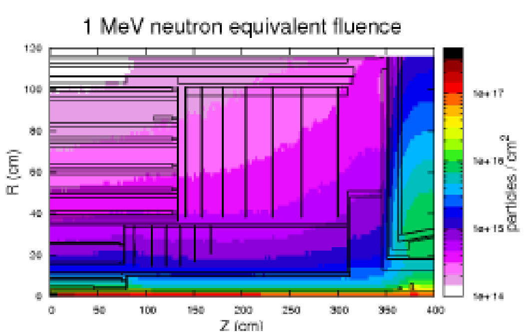
LOI Layout



Analytical calculations

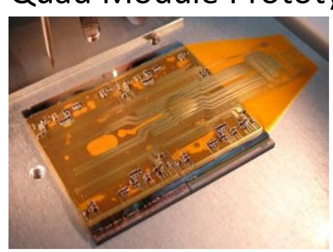


- 4 Pixel and 5 double sided Strip layers + 6 pixel and 7 strip disks
  - 14 hit system up to η=2.5
  - 80 -> **400 million pixels** (~7m^2), 6 -> **45 million strips** (~200m^2)
- full coverage for |η| < 2.5, Pixels cover |η| < 2.7 (forward muon identification)
- minimize hit gaps: Strip disk z_{max} = 3m, small layer in barrel-endcap gap
- increase radius of last Pixel layer to 25-30cm (better double track resolution)



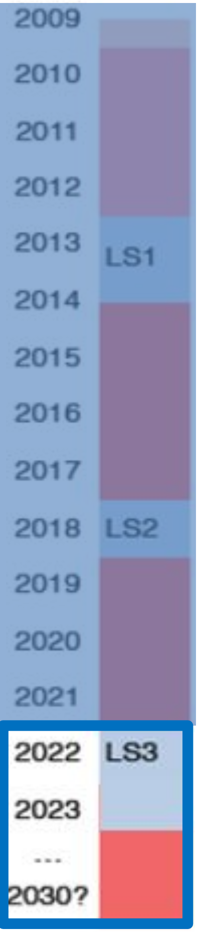
14 TeV collisions; integrated luminosity = 3000fb^{-1}

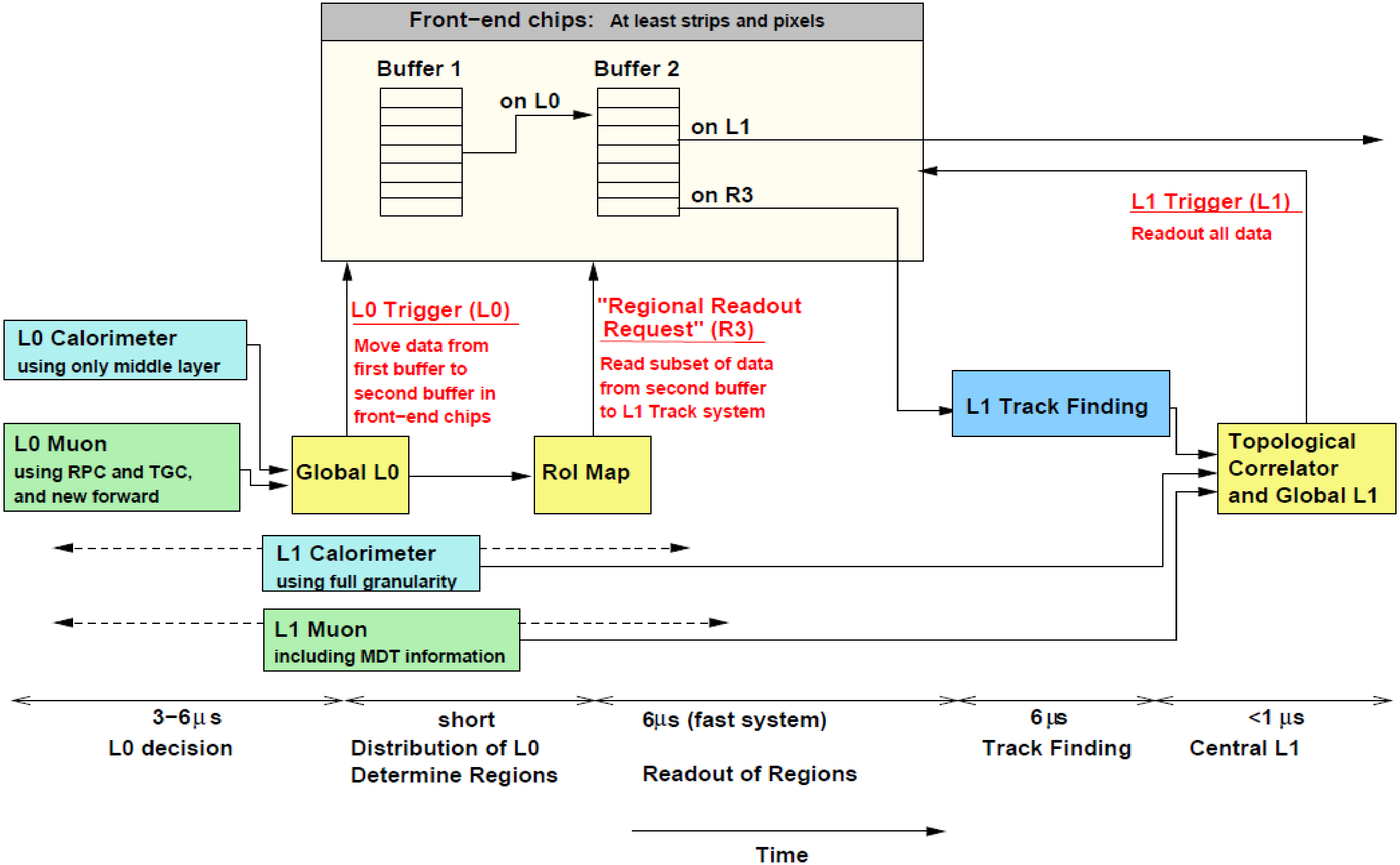
Pixel Quad Module Prototype



Microstrip Module Prototypes

Possible Trigger Scheme with L1 Track





Summary

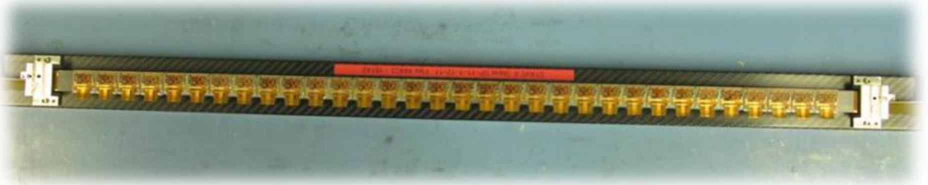
- Higgs discovery at the very beginning of the LHC running brings new opportunities for new physics
- Searches for SUSY, extra dimensions, etc. will continue as energy and luminosity increase further
  - Rich physics program with ATLAS detector at LHC for the next 20 years
- ATLAS Upgrade program aims at gradual improvement of the detector to fulfil this physics program
  - Phase-0: IBL and EE Muon Chambers
  - Phase-1: nMSW, FTK, Calorimeter Trigger, AFP
  - Phase-2: ID, calorimeter electronics, (FCAL, L1TT, Muon system)

Bright Future Ahead!

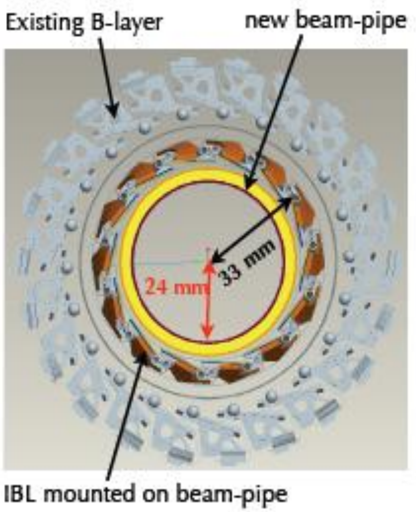
BACKUP

IBL Overview

- IBL Modules and staves
  - Sensors & Chips done, Bump-bonding: processing of sensor and electronic wafers completed - first batch of bare modules received, under assembly and qualification
  - Focus on systematic understanding of FEI4B modules in electrical tests
  - Several improvements implemented to module assembly and in stave assembly
  - Stave flex had production hick-up resulting in re-production of more Cu parts
  - First IBL stave assembled and systematically tested for 2 months now - stave works, some items remain to be understood



- Integration
  - Stave production testing ready and gear up now to prepare final test setups for full IBL
  - Integration tooling being finalized and SR1 area prepared for IBL integration
- Installation
  - Service design finalized and working on orders now
  - Installation tooling is tested in Bat 180, Beam pipe well on the way, IST assembly started
  - Prepare now detailed installation plan for LS1
- Off-detector
  - Final prototypes for ROD, BOC , opto available, first major FW released and under test now
  - Integrate now off-detector elements to system test with staves in SR1



ATLAS: Draft Target Specifications

LHC up to 2021		
		safer value
Peak Luminosity expected	$2 * 10^{34}$	$3 * 10^{34}$
Integrated Luminosity expected	300 fb^{-1}	400 fb^{-1}
μ = mean number of interactions per crossing (25nsec)	55 *	80
Safety factor to be used in the dose rate and integrated dose calculations	2?	2?
HL-LHC after 2022		
		safer value
Peak Luminosity expected	$5 * 10^{34}$	$7 * 10^{34}$
Integrated Luminosity expected	2500 fb^{-1}	3000 fb^{-1}
Int. Luminosity per year expected	250 fb^{-1}	300 fb^{-1}
μ = mean number of interactions per crossing (25 nsec)	140 *	200
Safety factor to be used in the dose rate and integrated dose calculations	2?	2?

Plan for occupancy numbers based on this (see μ values below)

Plan integrated dose figures based on this

μ values going with the peak luminosity figure if achieved with 25ns beam crossing

When we calculate the dose figures which are used to specify the radiation hardness of components which can be reliably tested for post-irradiation performance (eg ASICs, silicon sensors, diamond, ...) apply this safety factor to the dose calculations in setting the radiation survival specification

* https://indico.cern.ch/abstractDisplay.py/getAttachedFile?abstractId=153&resId=0&confId=175067