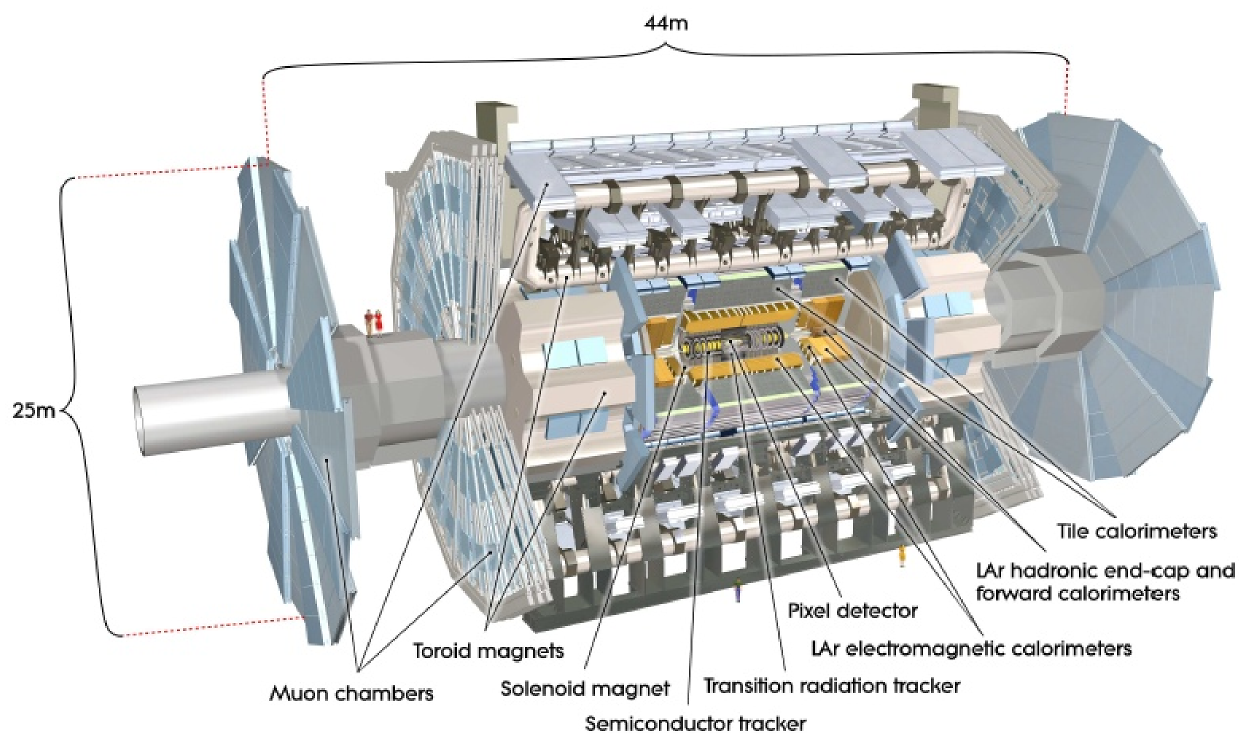
ATLAS UPGRADES

ATLAS Upgrades for the HL-LHC: meeting the challenges of a five-fold increase in collision rate.

Gerald Oakham, Carleton University
For the ATLAS Collaboration

Introduction

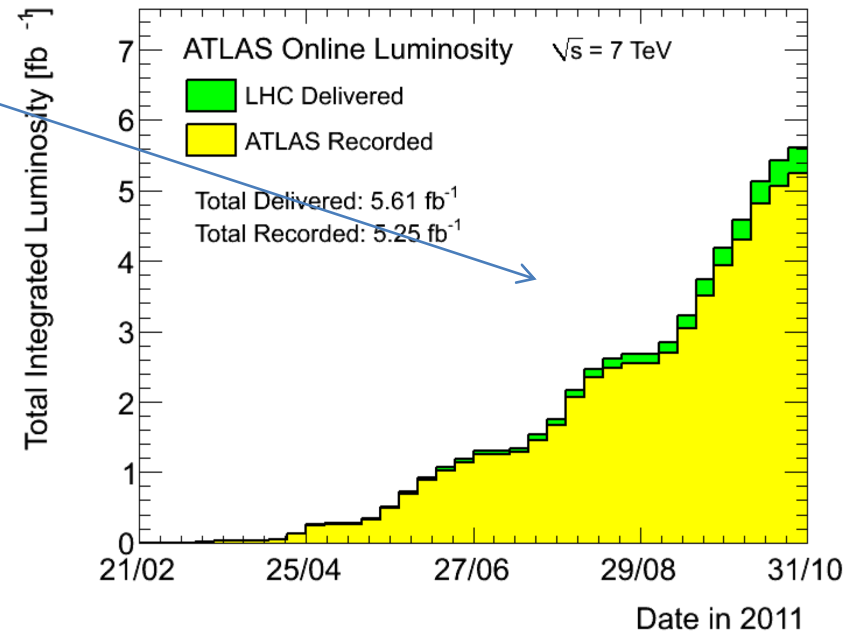
- Current status of the ATLAS detector
- Motivation for ATLAS upgrades
- Upgrades to the LHC and expected performance and timelines
- Multiphase upgrade plan for ATLAS
  - Phase 0 , Phase 1 and Phase2
- Upgrade details
- Outlook



The ATLAS Detector

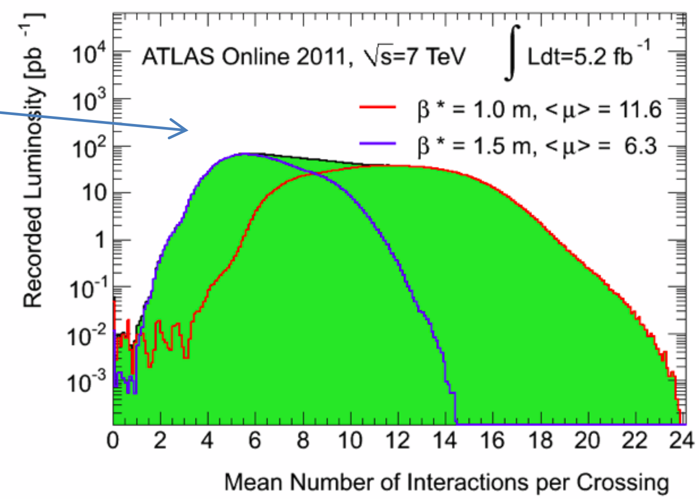
Current ATLAS performance

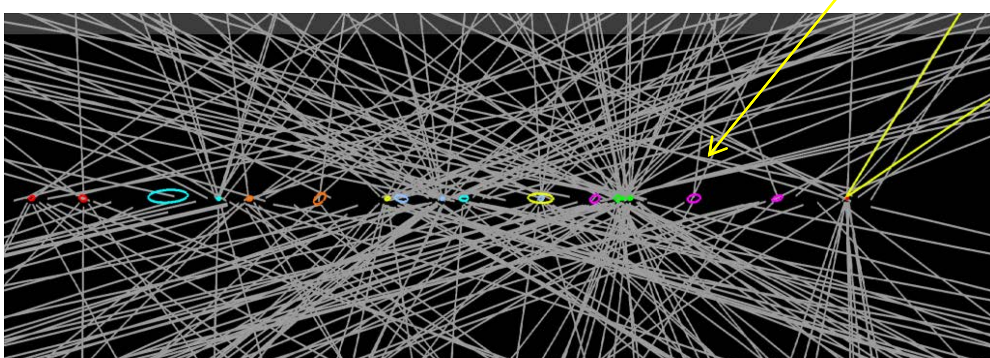
- Highly efficient data taking
- Detectors working very well
- High percentage of operational channels
- 5.25 fb^{-1} recorded



- Excellent physics results published
- Discussed in other talks at this conference.

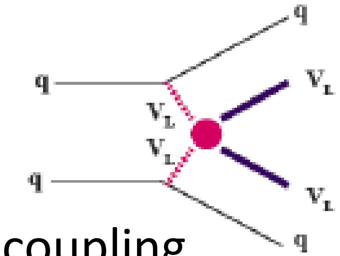
- 2011 is the first year with significant pile up.





Motivation for high luminosity running

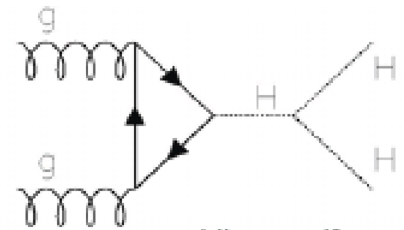
- Higgs Boson
  - Determine properties (assuming it is found)
- SUSY
  - Squarks and gluinos 1-1.5 TeV
  - SUSY particle properties
- 3-5 TeV W' and Z' properties?
- Look for strongly coupled scalars



- Gauge Boson self coupling
- Quark sub-structure
- Other phenomena

For example if Higgs Boson is found at LHC

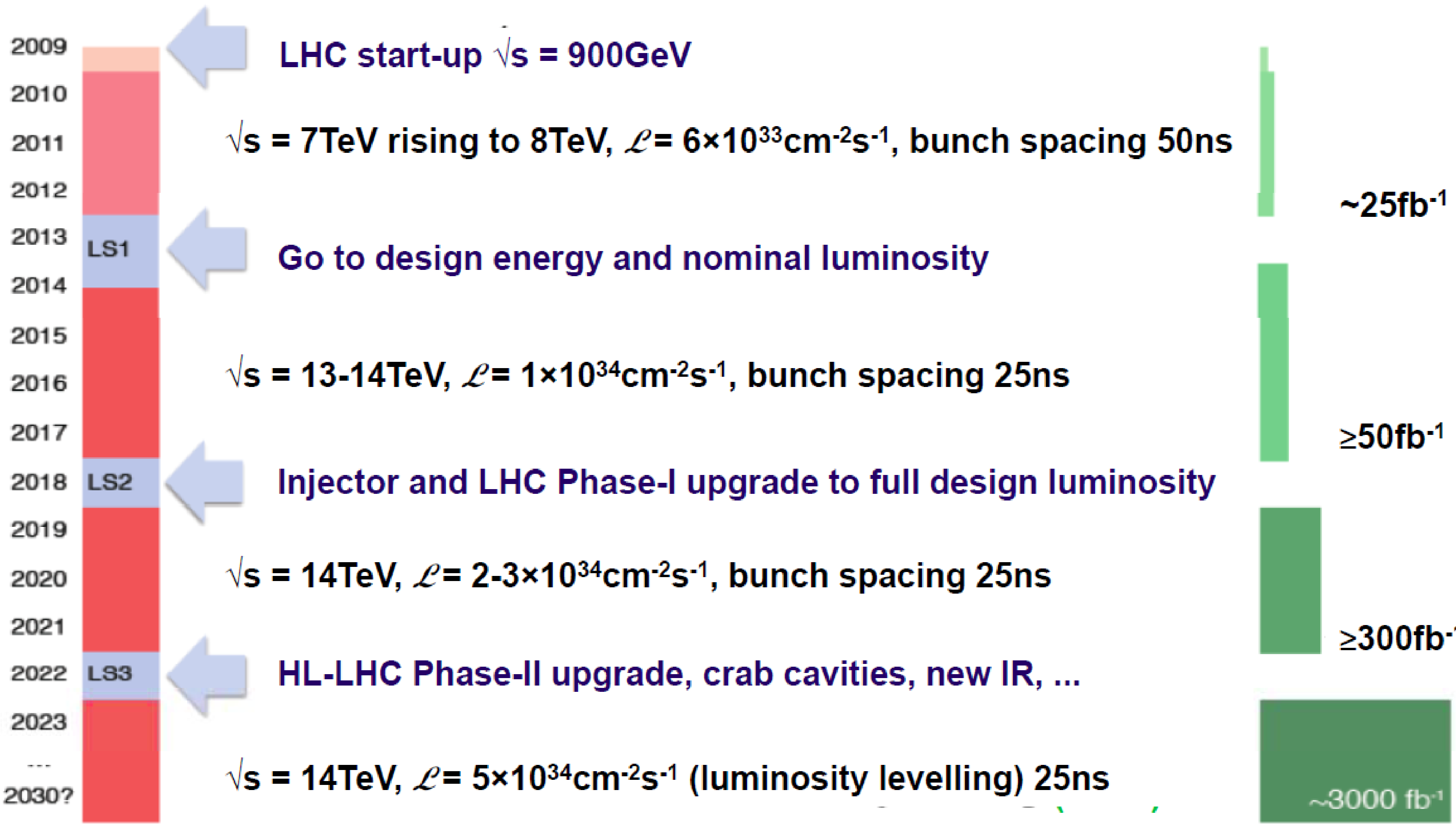
- Measure σ.B
- Ratio of H couplings to fermions
- Low rate Higgs couplings
- Spin (and CP)
- Self-couplings
- Dynamics of EWSB



Higgs self-coupling

To explore this physics require 3000 fb^{-1}

LHC plans


2009
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2020
2021
2022
2023
...
2030?
LS1
LS2
LS3
LHC start-up √s = 900GeV
√s = 7TeV rising to 8TeV, ℒ= 6×10^33 cm^-2 s^-1, bunch spacing 50ns
~25fb^-1
Go to design energy and nominal luminosity
√s = 13-14TeV, ℒ= 1×10^34 cm^-2 s^-1, bunch spacing 25ns
≥50fb^-1
Injector and LHC Phase-I upgrade to full design luminosity
√s = 14TeV, ℒ= 2-3×10^34 cm^-2 s^-1, bunch spacing 25ns
≥300fb^-1
HL-LHC Phase-II upgrade, crab cavities, new IR, ...
√s = 14TeV, ℒ= 5×10^34 cm^-2 s^-1 (luminosity levelling) 25ns
~3000 fb^-1

Possible ATLAS Upgrade time-line

Phase 0 Upgrade 2013-2014

New inner pixel layer (IBL) : *Possible new Diamond Beam Monitor (DBM)*
Muon system completion
New neutron shielding
Potential replacement of Minimum Bias Trigger scintillators

Phase I Upgrade 2018

New Muon small wheels
Improved Granularity of Calorimeter trigger at level 1
Trigger and Data Acquisition upgrades including Fast Track Trigger
Under consideration: new pixel detector based on IBL experience

Phase II Upgrade 2022

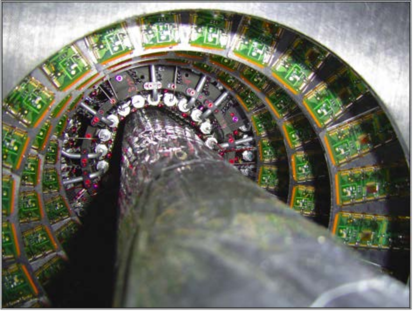
All new Tracking Detector
New Trigger and Data Acquisition system including Calorimeter electronics upgrades
New detectors for parts of Muon system + more neutron shielding
Possible upgrades for Forward and Hadronic EndCap Calorimeters

Phase 0

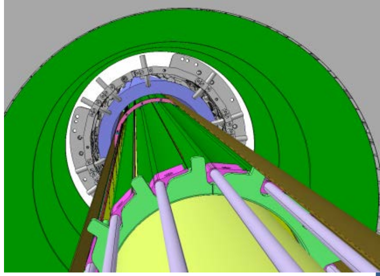
- **LHC** consolidation –repairs to magnet interconnections
- Complete Quench protection system
- Shutdown 18 months –then to design energy and luminosity
- Consolidation of existing detector
  - New calorimeter Power Supplies, Inner Detector cooling, power network magnet cryogenics etc
  - Completion of Muon System
  - New neutron shielding in toroid end-cap
- New components
  - New innermost pixel detector, new beam pipes
  - *Possible new Pixel Service quarter panels*
  - *Possible Diamond beam monitor*

Note need to maintain compatibility with subsequent upgrades

PHASE 0 Upgrades 2013-2014 Running 2014-2018

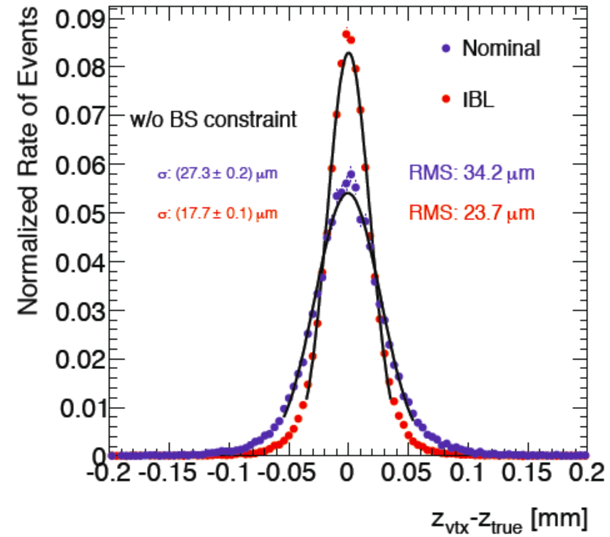


New inner pixel layer: Insertable B Layer (IBL)

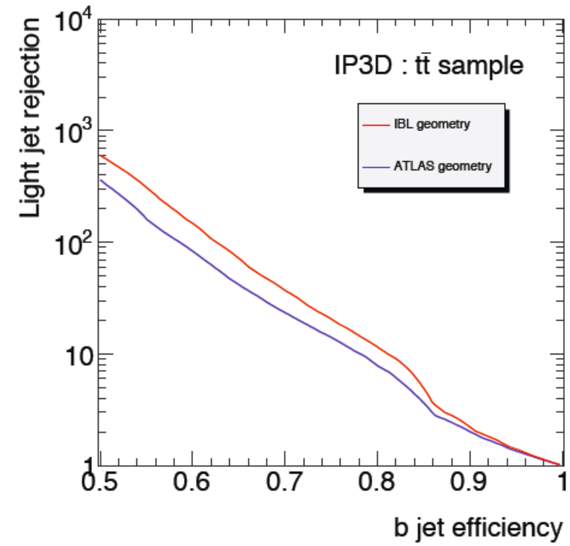


PHASE 0 Upgrades 2013-2014 Running 2014-2018

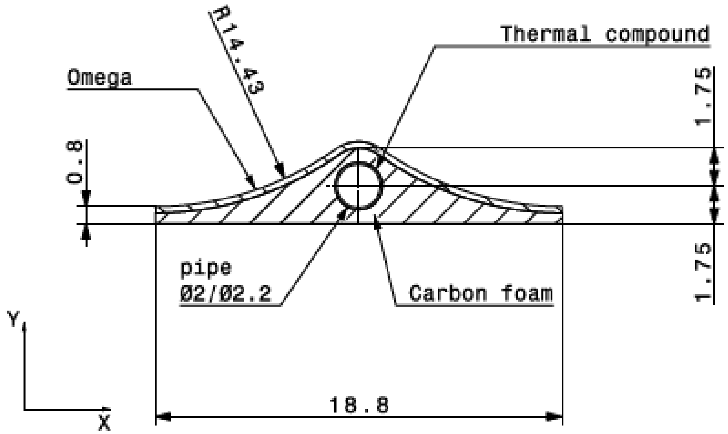
- Additional layer will boost tracking performance
  - Vertex resolution
  - B / light jet separation
- Adds redundancy in high rate area (radiation damage)

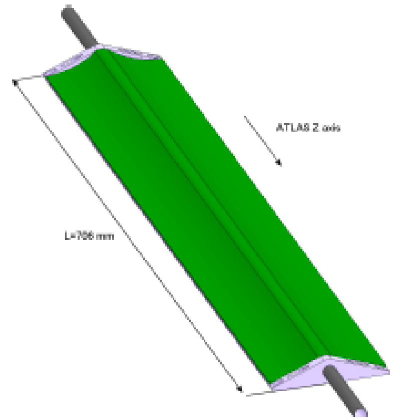


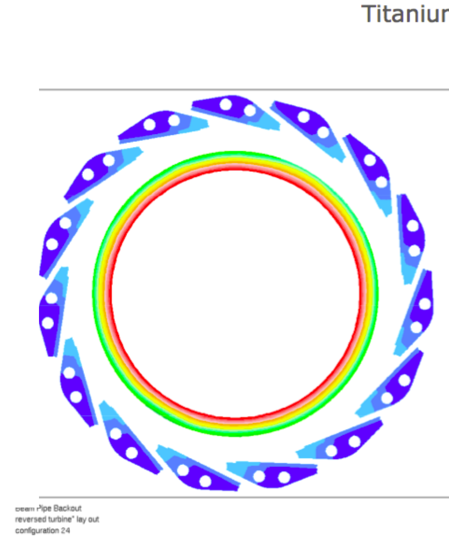
- Challenging environment
  - Requires removal of existing beam pipe
  - New beam pipe and IBL installed at same time



IBL and new beam pipe

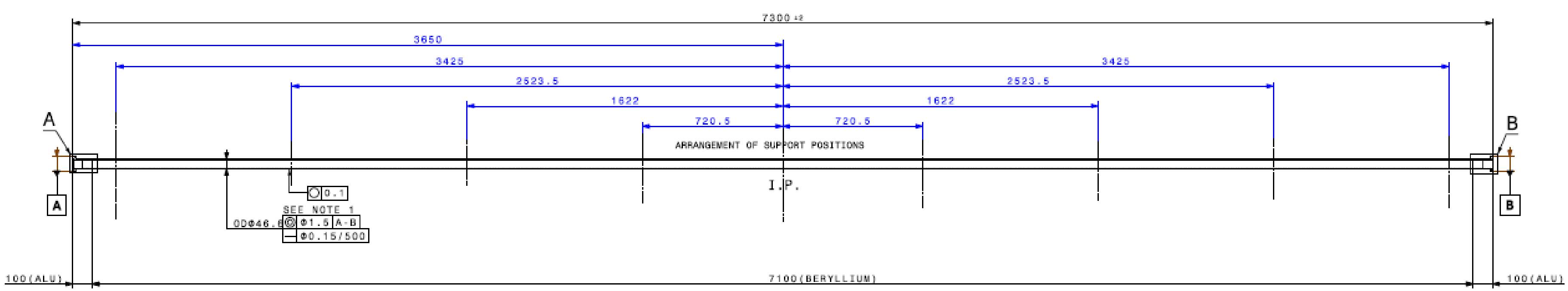






- New stave design (Pixel support structure)
- Carbon foam – light with good heat conduction

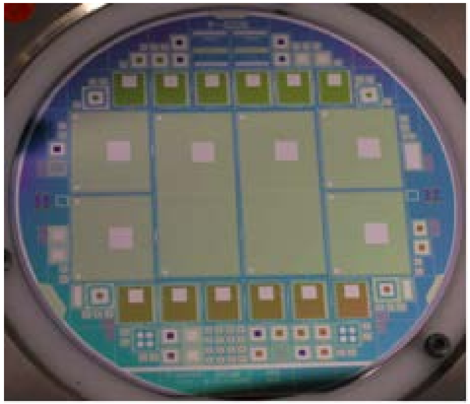
- Beam pipe central - 0.8 mm thick Beryllium outer parts Aluminum



PHASE 0 Upgrades 2013-2014 Running 2014-2018

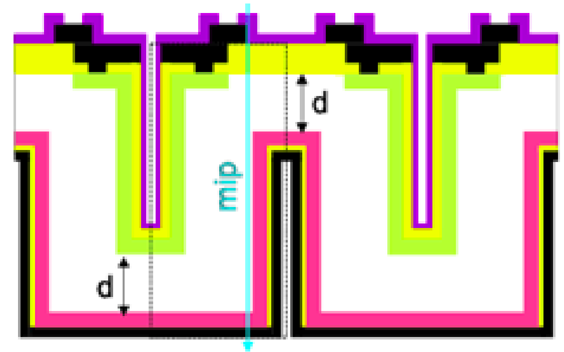
IBL Sensor and readout technology

Planar pixel sensors



- Prototypes with 150-250 μm thickness, delivered and being tested
- 50 x 250 μm pixel size
- Tested to 2 x 10^{16} n/cm^2

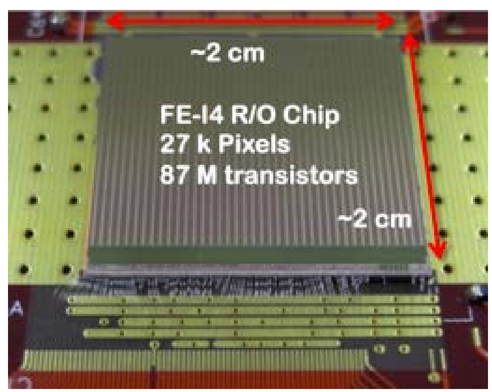
3D sensors



- Double sided with 230 μm thick; 200 μm guard has demonstrated good radiation hardness
- Operates at low voltage even after irradiation

New readout chip (FE-I4)

- Performing well



PHASE 0 Upgrades 2013-2014 Running 2014-2018

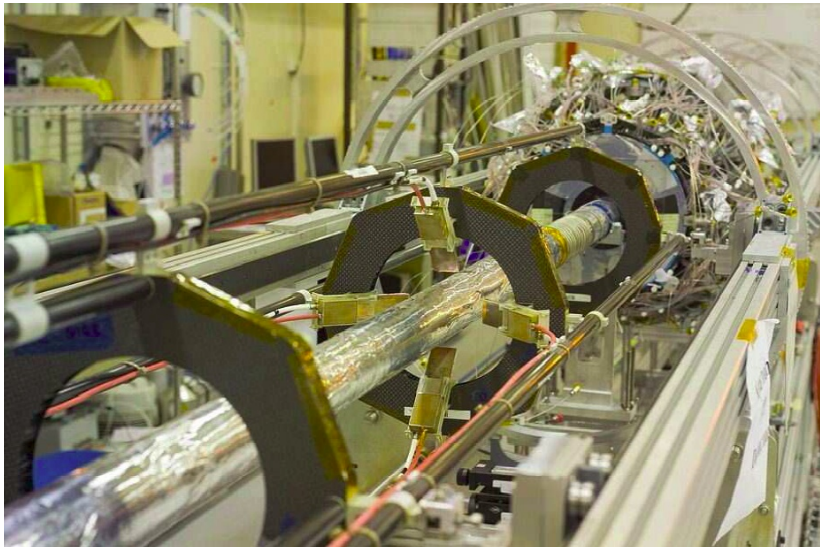
New pixel quarter panels and DBM

Pixel Service Quarter Panels (SQP)

- Transfer services from outside world to pixel detectors
- Problematic opto-couplers on SQP
- To replace these need new infra-structure and electronics.
- New electronics will allow greater readout bandwidth for > 10^{34} operation
- Work is underway on this project
- Needs to be proven prior to installation

Diamond Beam Monitor

- Uses Diamond detectors produced for IBL trials
- Attached to pixel SQP
- Will provide very fast monitoring of beam in high rate environment
- Installation only possible if SQP are replaced



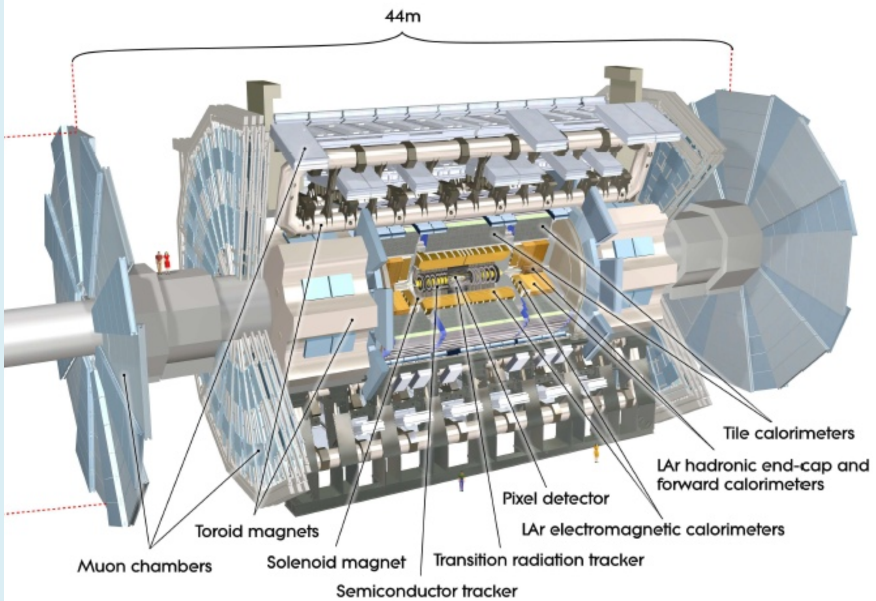
PHASE 0 Upgrades 2013-2014 Running 2014-2018

Phase I

LHC - 14 month shutdown - consolidation of injector chain; collimators
Peak luminosity to increase to 2 x 10^{34} cm^{-2} s^{-1}
Collect total integrated luminosity 300 fb^{-1}

ATLAS Challenge of luminosity exceeding design luminosity

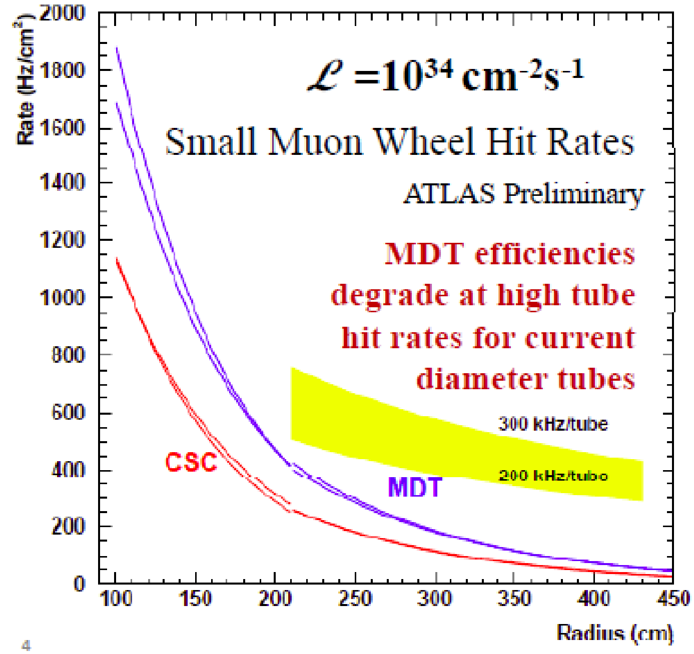
- Fast Track trigger for LVL2
- New Muon small wheels
- Higher granularity LVL1 trigger for Calorimeter
- Topological trigger processors for LVL1 information
- New diffractive physics detector stations (210m from ATLAS centre)
- (Upgrades to be compatible with Phase II)

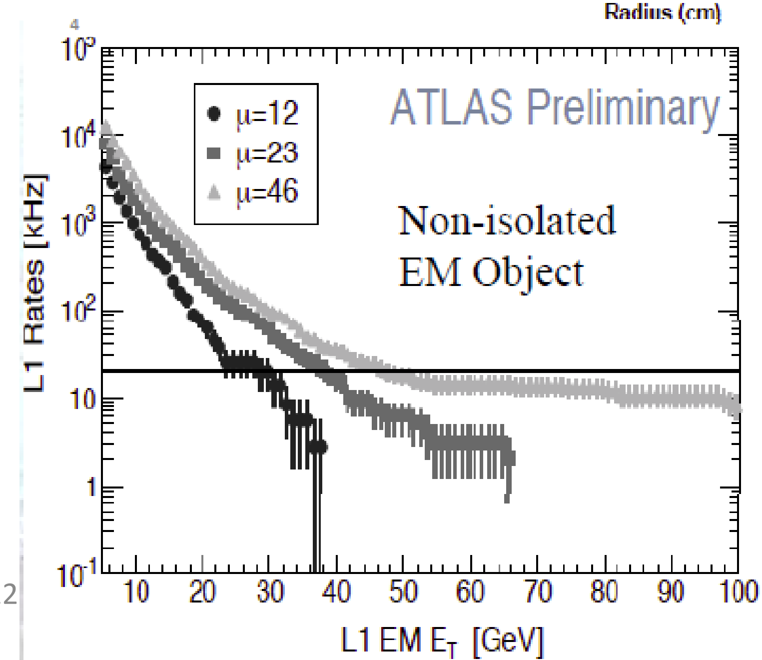


PHASE 1 Upgrades 2018 Running 2019-2021

Motivation for Phase 1 upgrades

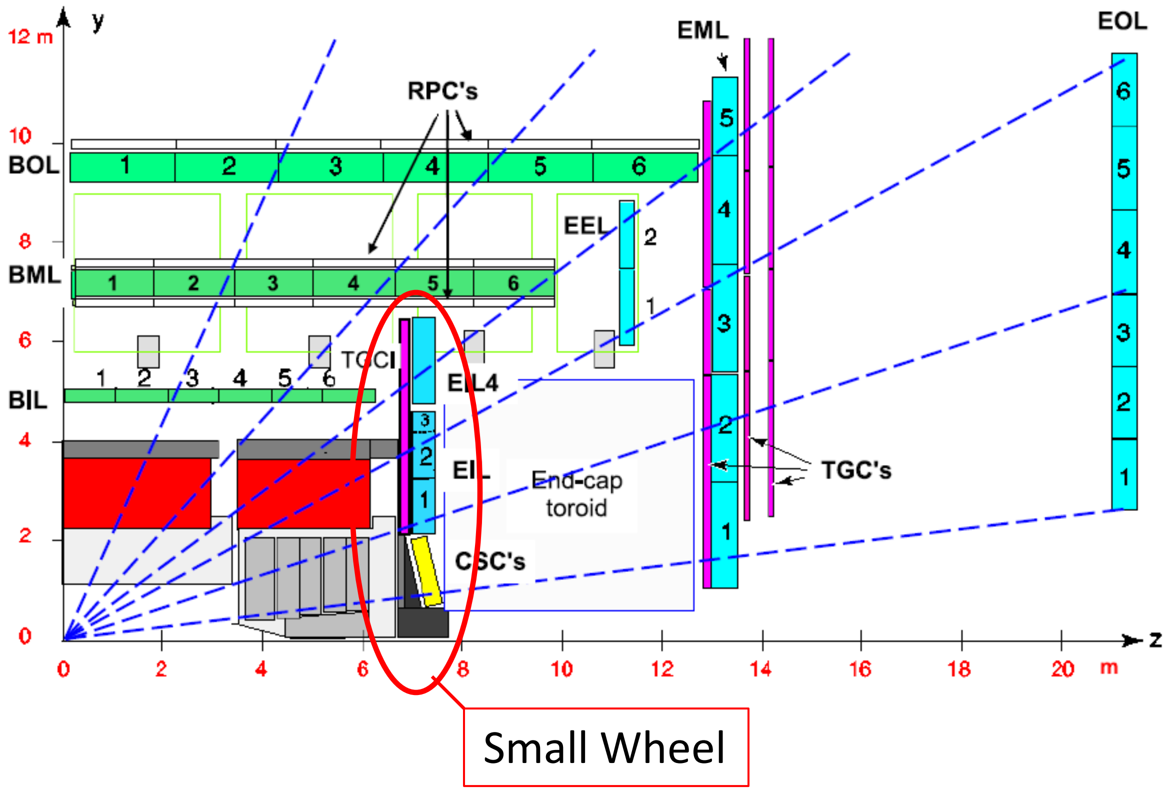
- Physics goals (Higgs SUSY etc) require ability to trigger on low P_T leptons –
- Low = 20 GeV in P_T
- Difficult with current ATLAS configuration at Phase I due to rates
- Forward trigger chambers limit trigger thresholds at high collision rates
- Similar limits for EM trigger as events have large number of vertices (high μ)

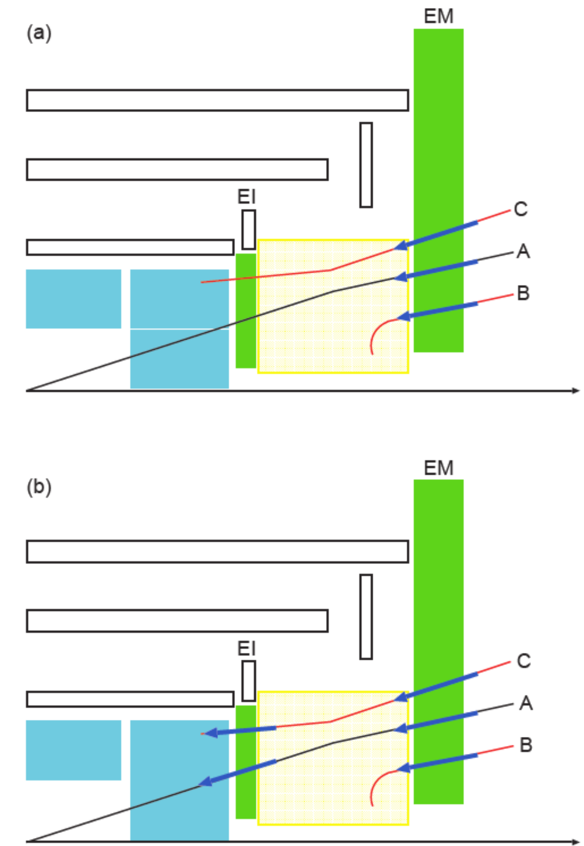




PHASE 1 Upgrades 2018 Running 2019-2021

New Small Muon Wheel



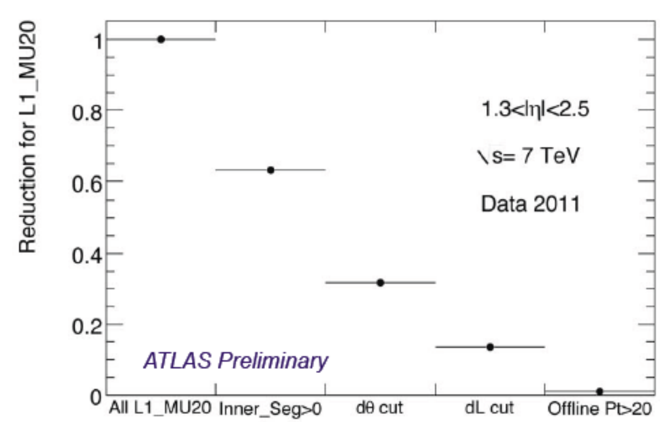


Function of new small wheel

Three options under consideration:

- Small drift tubes (size) and tracking Thin Gap Chambers
- Small drift tubes and Resistive Plate Chambers (Trigger)
- MicroMegas

Reduction in trigger rate to 20% with use of new small wheel
Only small change in efficiency



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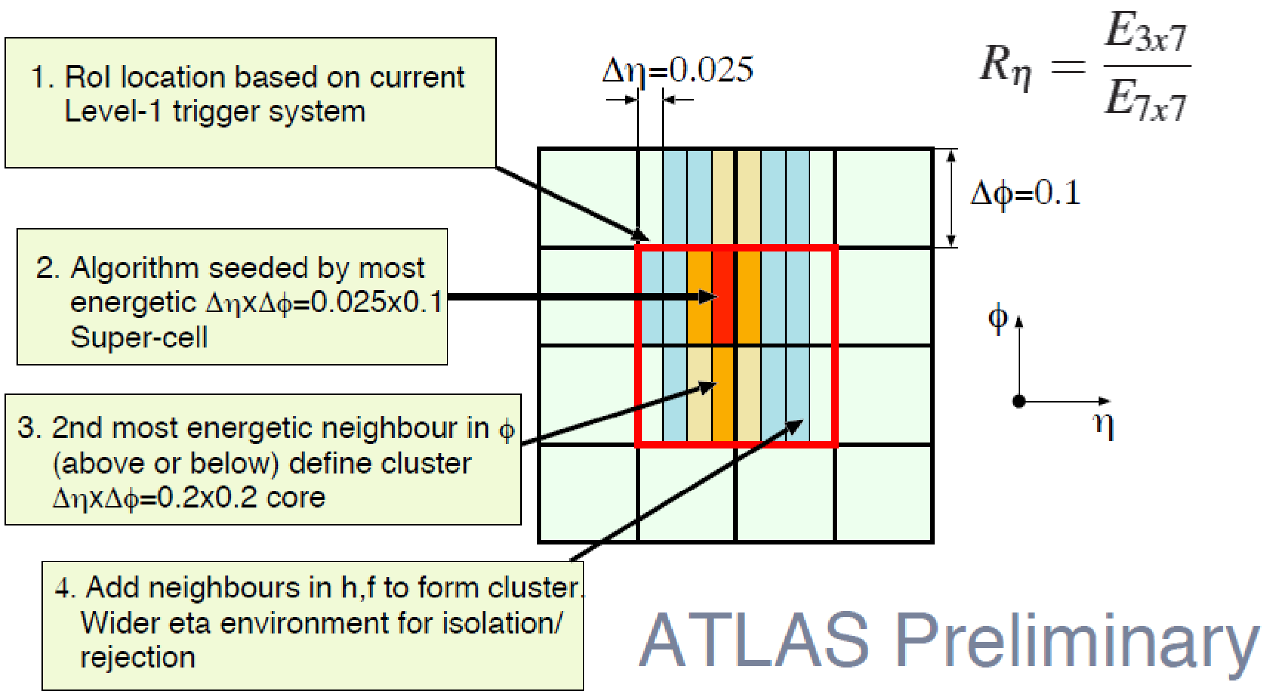
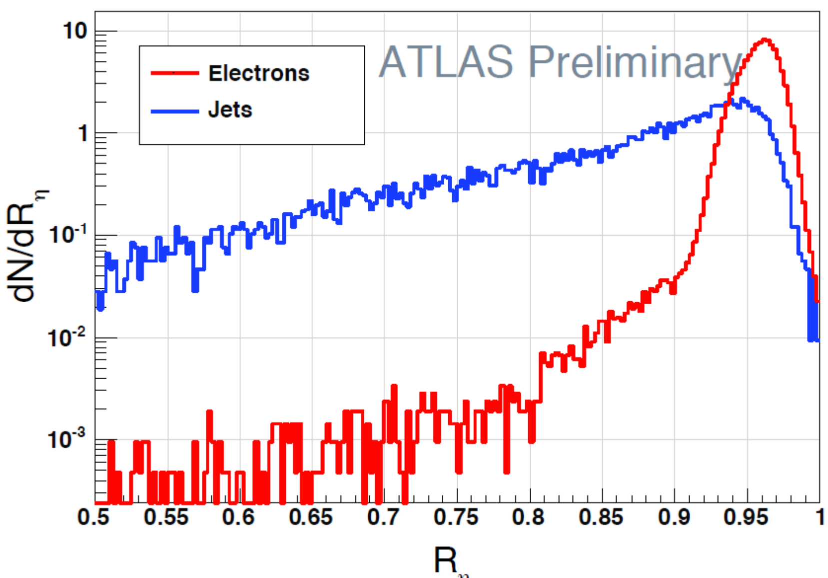
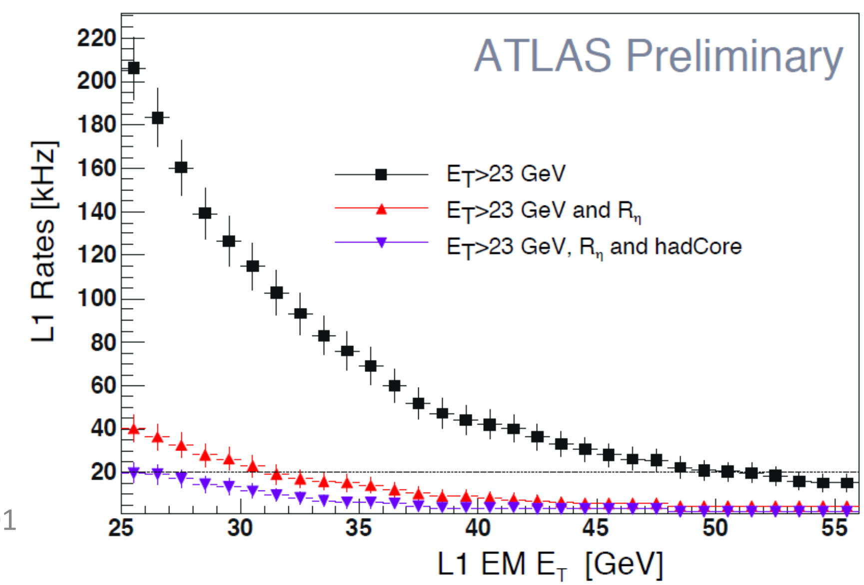
Calorimeter LVL1 trigger upgrade

- Improve granularity of trigger for better discrimination between electrons and jets
- Requires new trigger electronics located in replacement trigger daughter boards for the Front End boards.



Impact of upgrade on Calorimeter trigger rates





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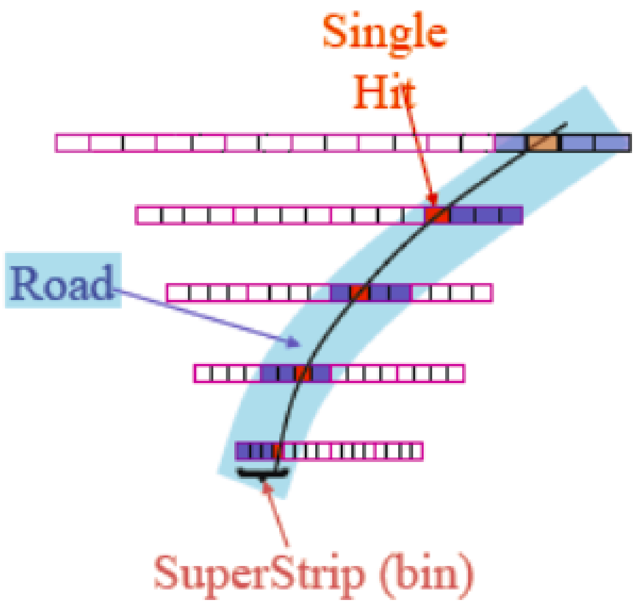
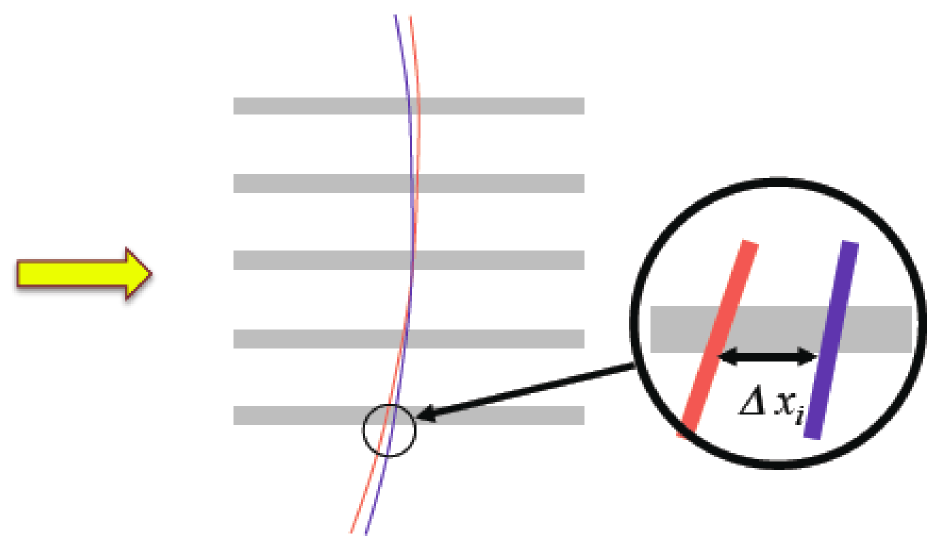
Fast TracKer project (FTK) for Level 2 trigger

- Complete global tracking at start of Level 2 trigger
  - Hardware based using DSP in an FPGA (~1 ns)
  - track finder + fast helical track fit
- Major improvement for b-tagging, τ-identification and lepton isolation





Pattern recognition in coarse resolution (superstrip→road)

Track fit in full resolution (hits in a road)

$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$

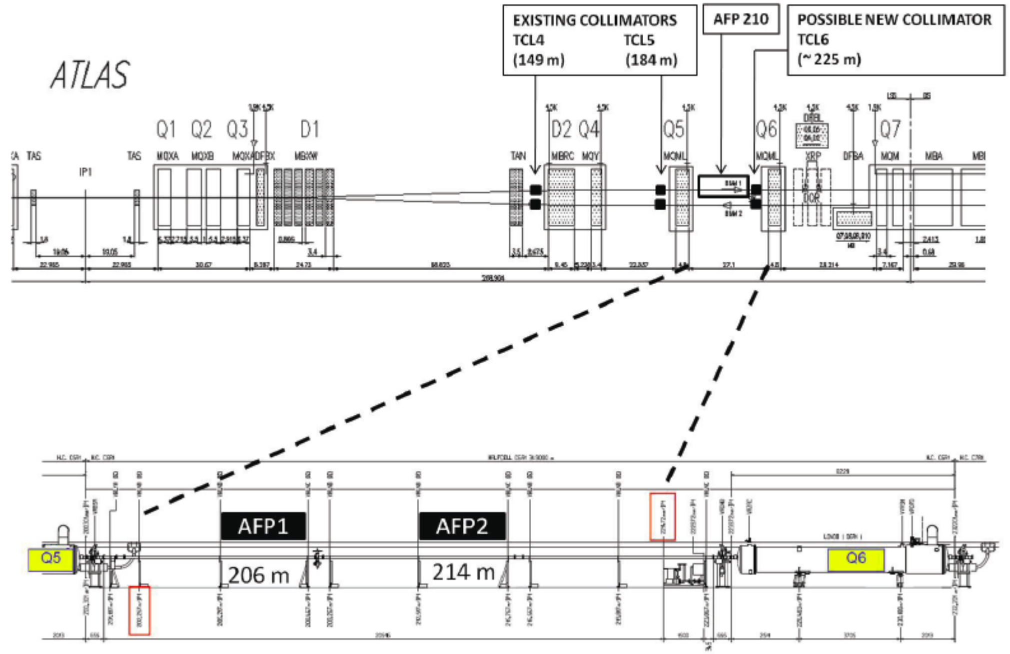
PHASE 1 Upgrades 2018 Running 2019-2021

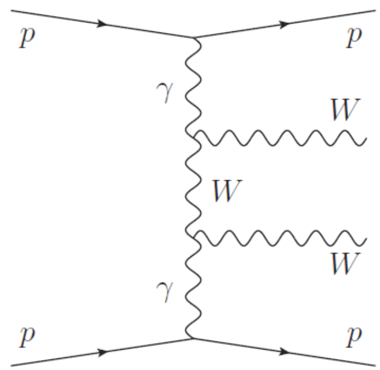
New Forward detectors

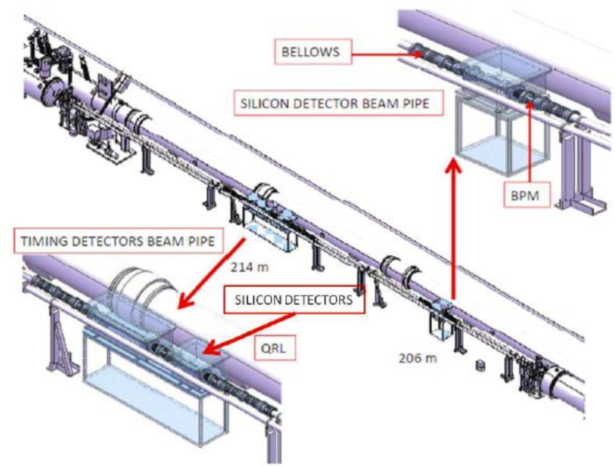
New timing detectors allow study of diffractive physics in presence of high pile-up – need high statistics for rare processes

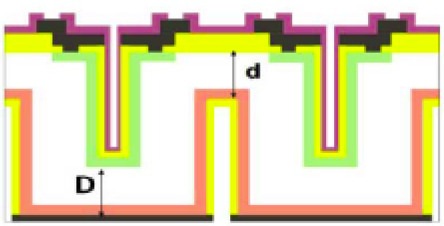
Look for:

- Anomalous quartic couplings
- Pomeron composition

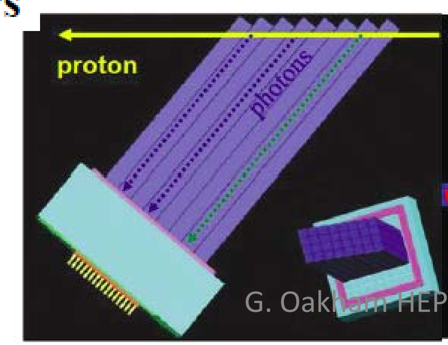


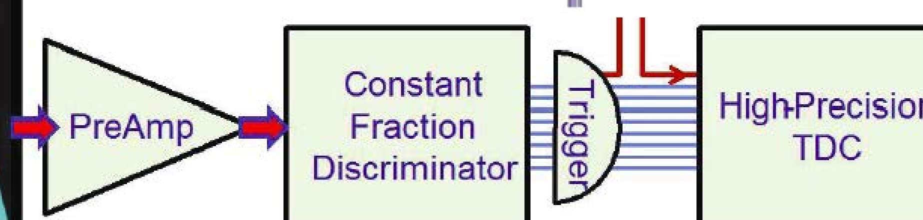






Edgeless 3D Sensors





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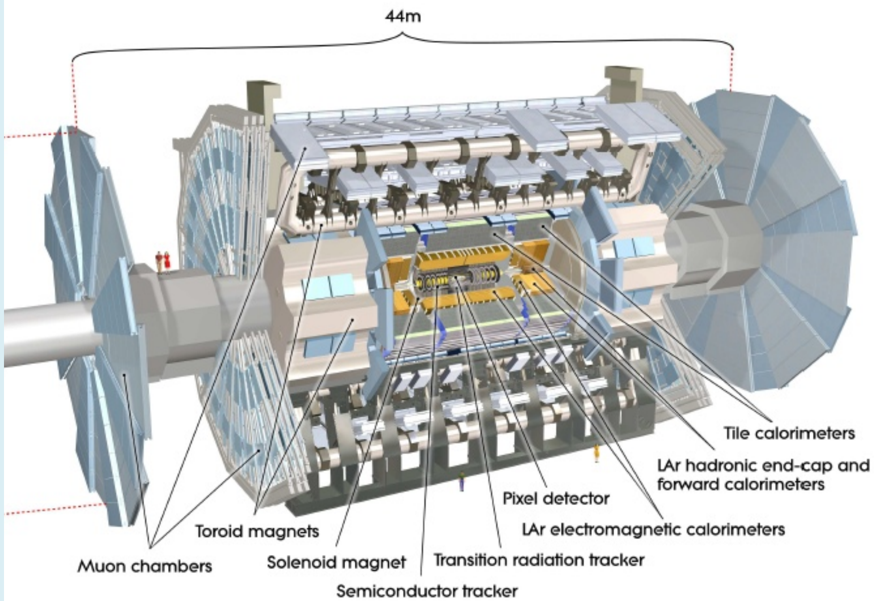
Phase II

LHC - 18 month shutdown - use of crab cavities for luminosity leveling
Peak luminosity to increase to 5 x 10^{34} cm^{-2} s^{-1}
Collect total integrated luminosity 3000 fb^{-1}

ATLAS Detectors must cope with both high instantaneous and high integrated luminosity

Still evaluating options required for Phase II detector upgrades

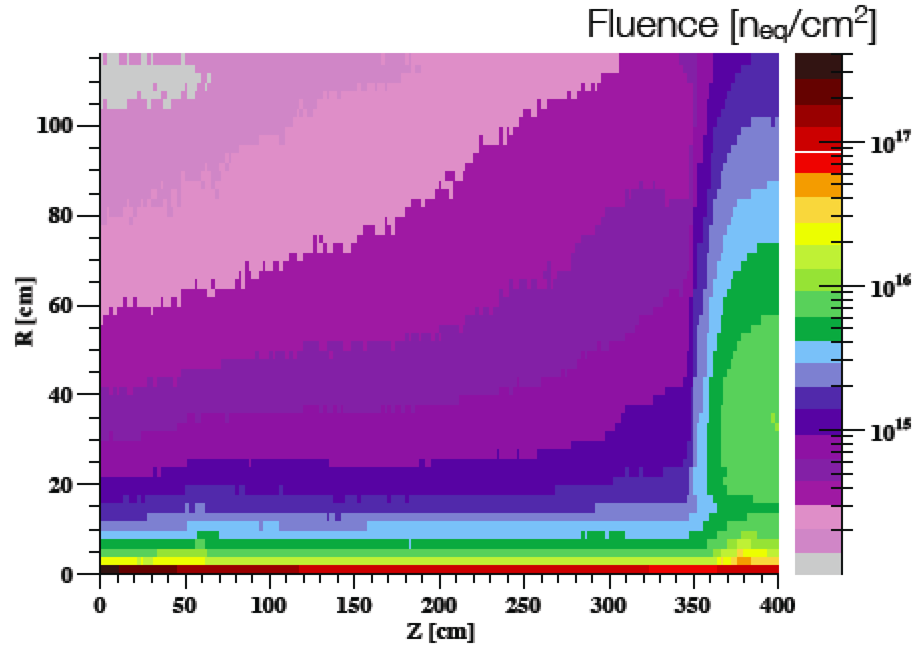
- New Inner detector
- Changes to the Forward Calorimeter
- New electronics for the Liquid Argon calorimeter
- Possible L1 track trigger
- Possible upgrade of Muon system

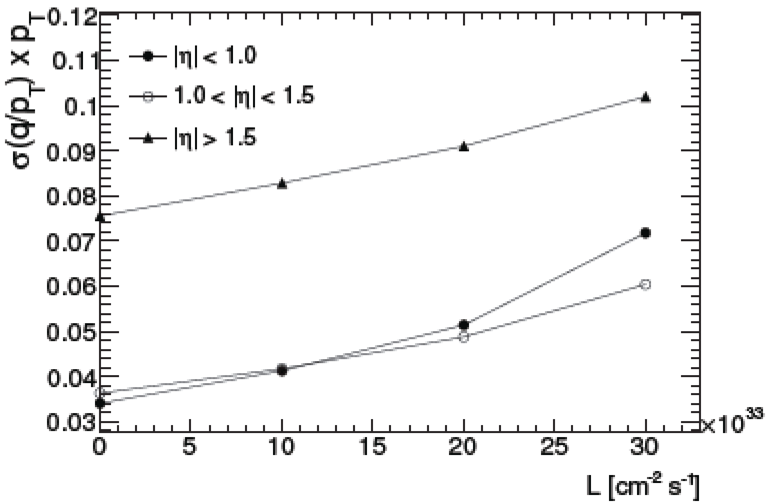


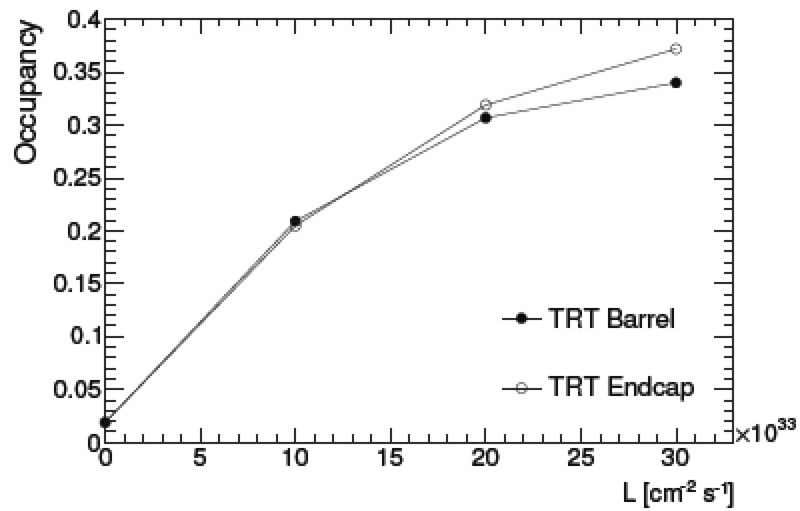
PHASE 2 Upgrades 2022 Running 2023 2030

Inner Tracker

- **Pixel** – b layer will suffer radiation damage
- **Silicon strip** detector –readout limitation above 2.5 * 10^{34} and radiation damage above 700 fb^{-1}
- **TRT** – high occupancy degrades momentum performance







Need complete replacement of inner tracking system with new pixel/strip system

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Possible new tracker layout

Classical barrel / end cap layout under consideration

4 layers of pixels

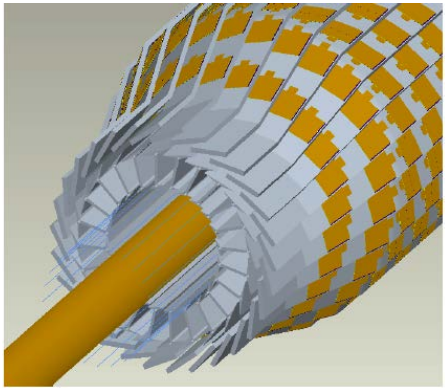
3 double layers of short strip silicon

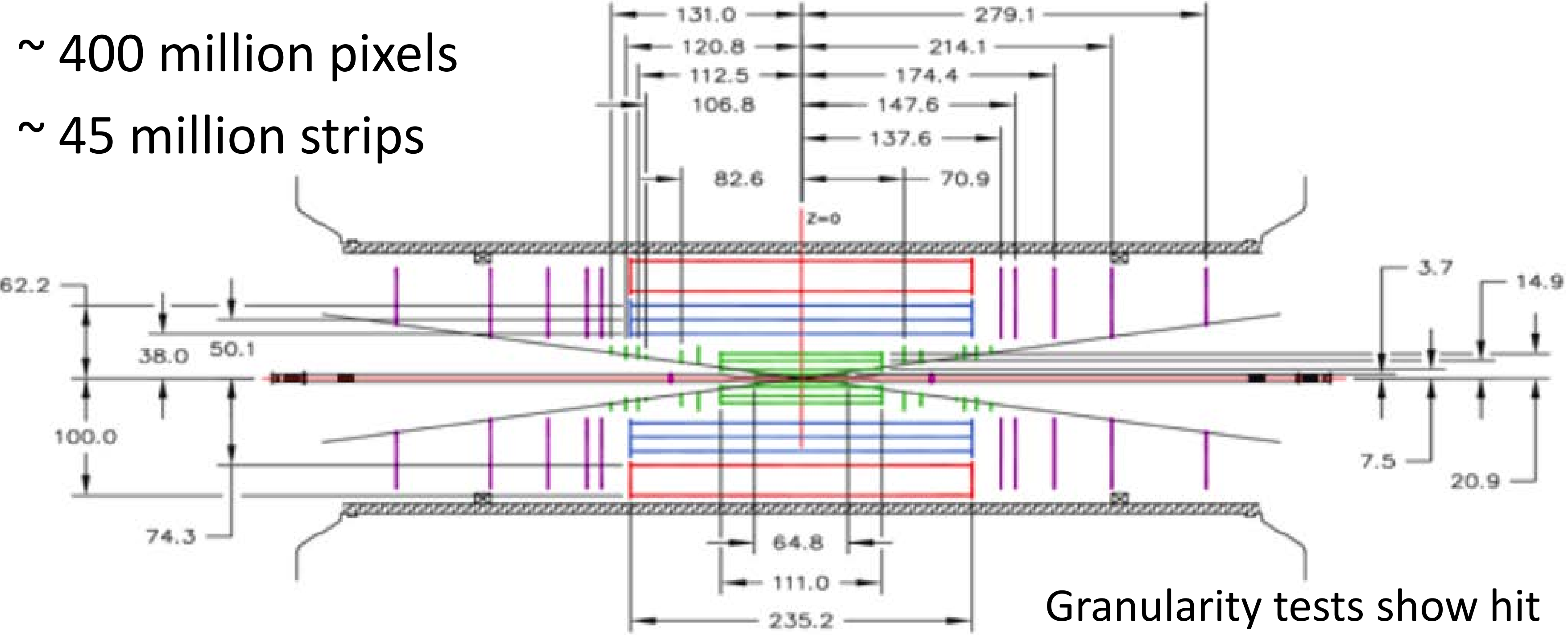
2 double layers of long strips

~ 400 million pixels

~ 45 million strips

Possible Pixel sensor arrangement





Granularity tests show hit occupancy OK

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Calorimetry upgrades

- **Readout electronics** – complete electronics upgrades. (for both Liquid Argon and Tile)
- **Integrated Luminosity** (3000 fb^{-1}) potential problems for Hadronic EndCap (**HEC**) electronics located in the cryostat. Designed for 1000 fb^{-1}.
- Requires plan for their possible replacement

- **Instantaneous luminosity** (5x 10^{34}): potential problems with overheating and signal loss in Forward Calorimeter (**FCal)**
- At high intensity beam heating could potentially cause Liquid Argon to boil
- In addition, ion build up and voltage drop across HV protection resistors in the cryostat will cause signal loss at the inner edge (high η) in the FCal

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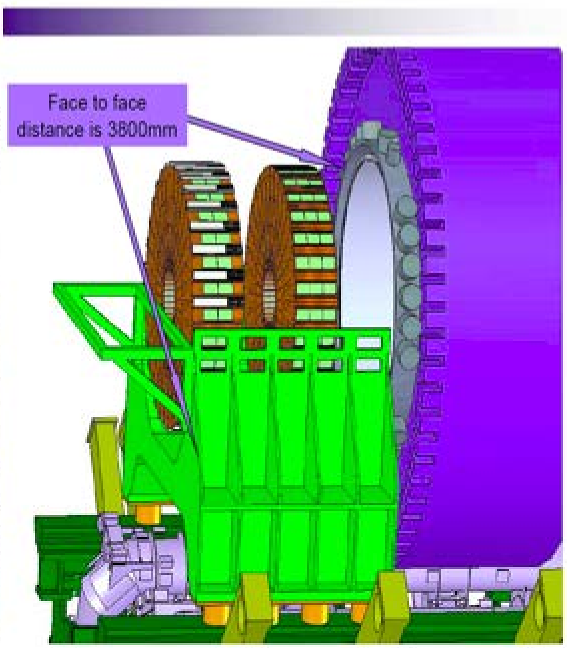
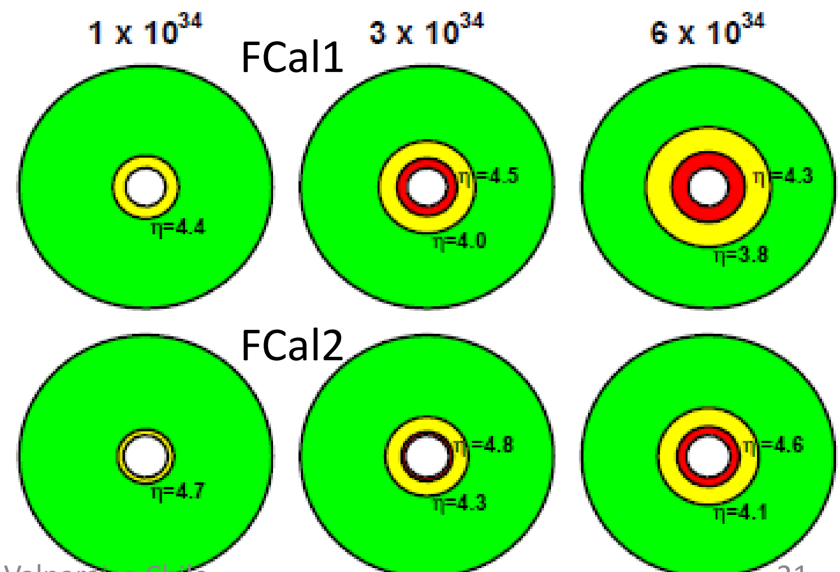
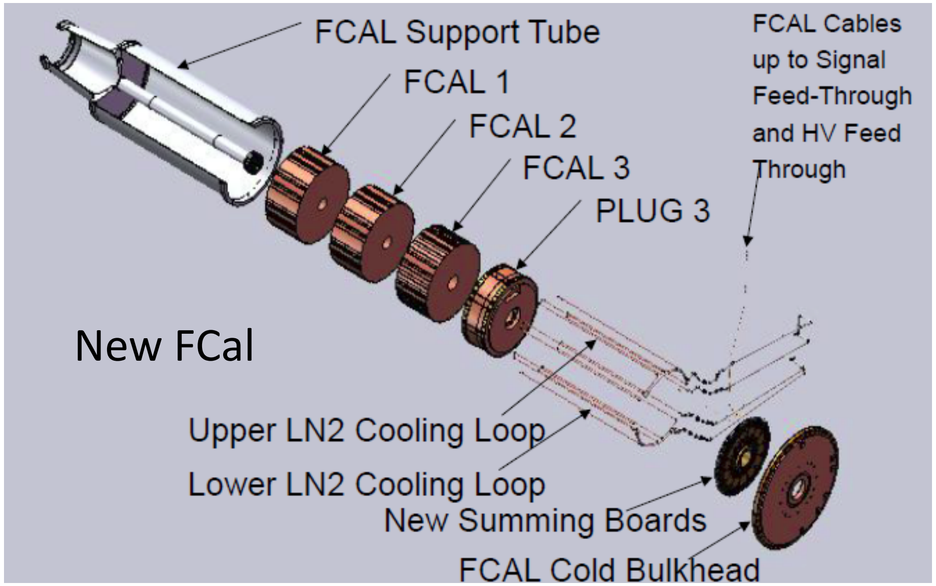


HEC electronics replacement requires opening of cryostat and removal of the HEC wheels from cryostat

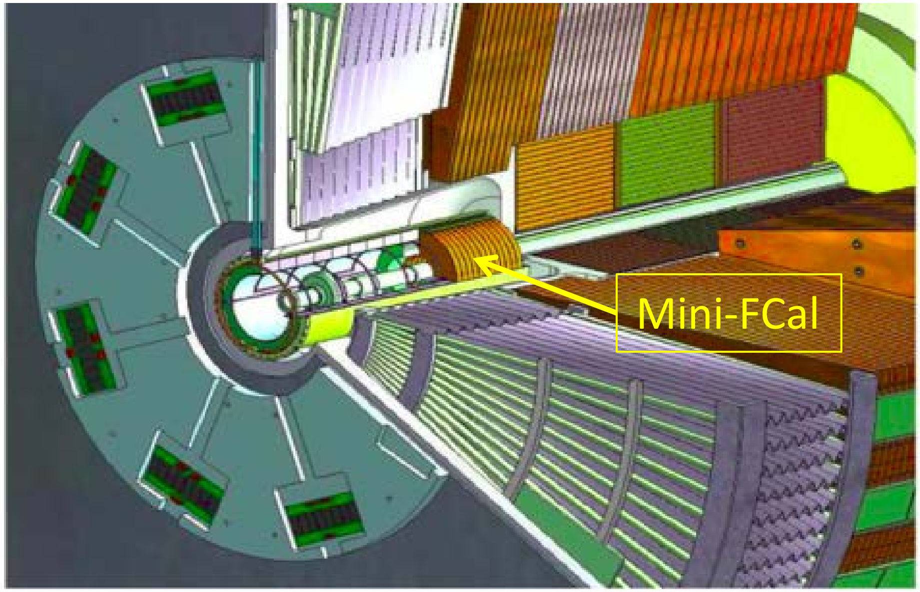


Solutions to FCal problem

- **Complete replacement of FCal.**
  - New detector with smaller gaps
  - New cold electronics for HV distribution
  - New cooling loops



- **Installation of a small calorimeter just in front of the current FCal: Mini-FCal**
  - Reduces energy and ionization in FCal to acceptable levels
  - Mini-FCal baseline is copper plate calorimeter with Diamond detector.
  - Also exploring use of detectors using High Pressure Xenon or Liquid Argon.



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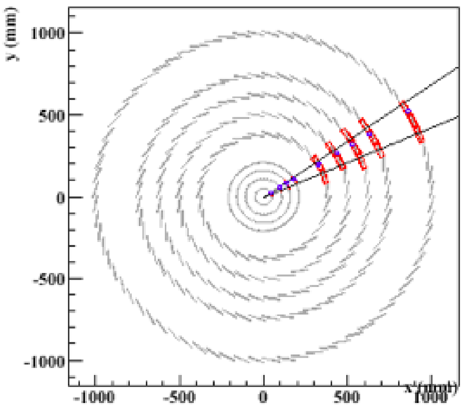
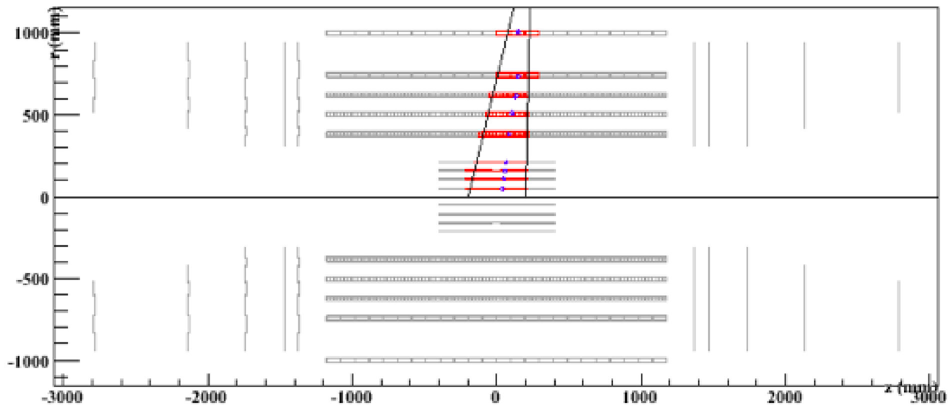
Track Trigger at Level 1

- Option 1: regional readout at L0 and L1
  - Calorimeter and Muons could provide region of interest (ROI)
  - Inner tracker is readout and hardware trigger confirms presence of a track candidate
  - Needs additional data stream in front end chip





- Option 2: Self seeded stand alone
  - Use paired modules (omit stereo placement)
  - Readout only coincident modules (high p_T)

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Outlook

- ATLAS detector working very well – good data taken in 2010 and 2011 with significant physics results
- Graduated upgrade program to build on experience to improve our detector and equip it to run at up to 5 times the design luminosity.
- These upgrades will impact all sub-systems of ATLAS
- Some interesting technical challenges to cope with the High Luminosity phase (HL-LHC) of CERN's TeV Hadron collider program