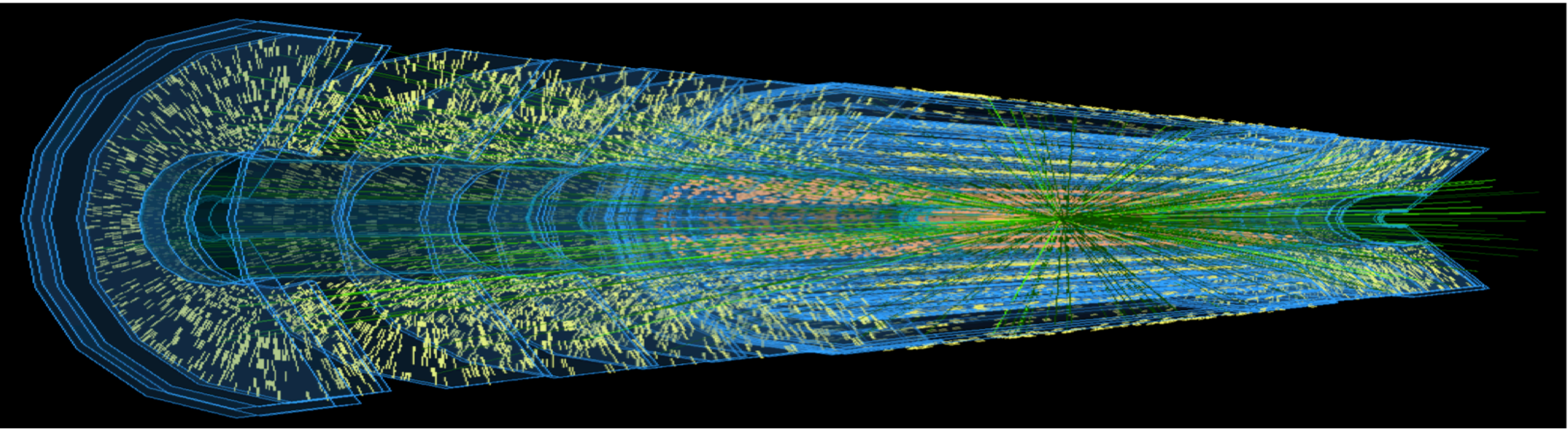
ATLAS Upgrades Towards the High Luminosity LHC



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for the ATLAS Collaboration

IHEP-LHC, 20-22 November 2012, Protvino, Russia

HELMHOLTZ | ASSOCIATION

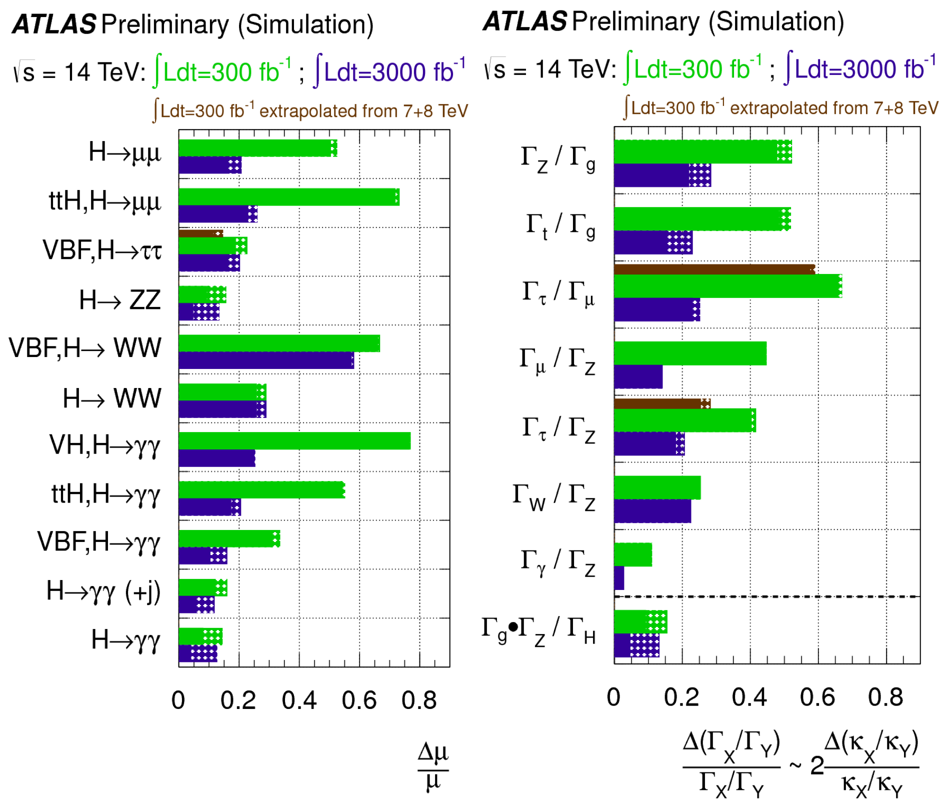
DESY

Outline

- ☞ Motivation for upgrades
- ☞ LHC upgrade timeline
- ☞ Challenges
- ☞ ATLAS upgrades
  - ✍ Phase-0
  - ✍ Phase-1
  - ✍ Phase-2
- ☞ Summary

Motivation for Upgrades

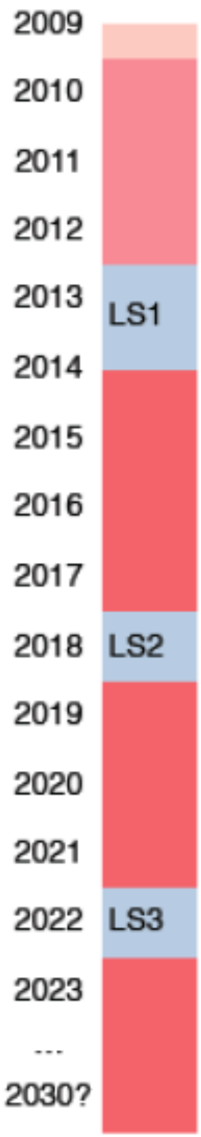
- ☞ Measure the properties of the recently observed Higgs-like boson at the LHC: Yukawa and self-couplings, spin and CP quantum numbers etc.
- ☞ Continue and extend the searches for physics beyond the Standard Model: SUSY, extra-dimensions …
- ☞ LHC, with all upgrades, expected to deliver around 3000 fb^{-1} in total to perform these tasks



(a) (b)

Expected measurement precision on (a) the signal strength; (b) ratios of Higgs partial widths, taken from ATL-PHYS-PUB-2012-001

Preliminary LHC Upgrade Timeline



LHC startup, √s= 900 GeV

√s=7~8 TeV, L=6×10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

Go to design energy, nominal luminosity

√s = 13~14 TeV, L ~ 1×10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

ATLAS detector upgrade: **Phase-0**

Injector and LHC Phase-1 upgrade to full design luminosity

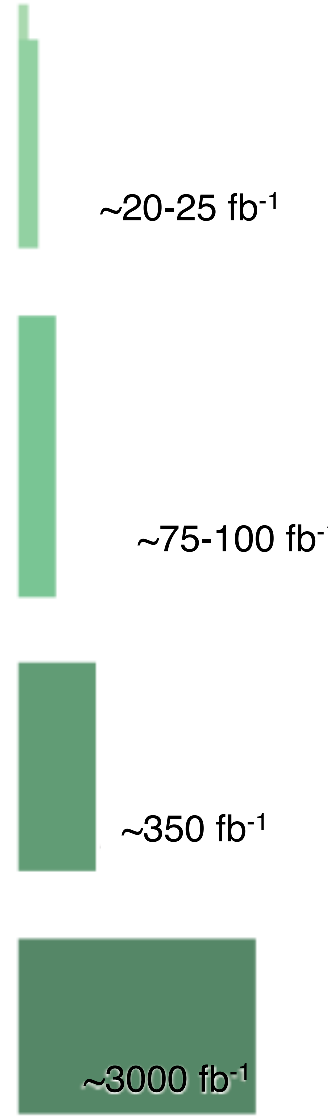
√s = 14 TeV, L ~ 2×10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

Phase-1

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

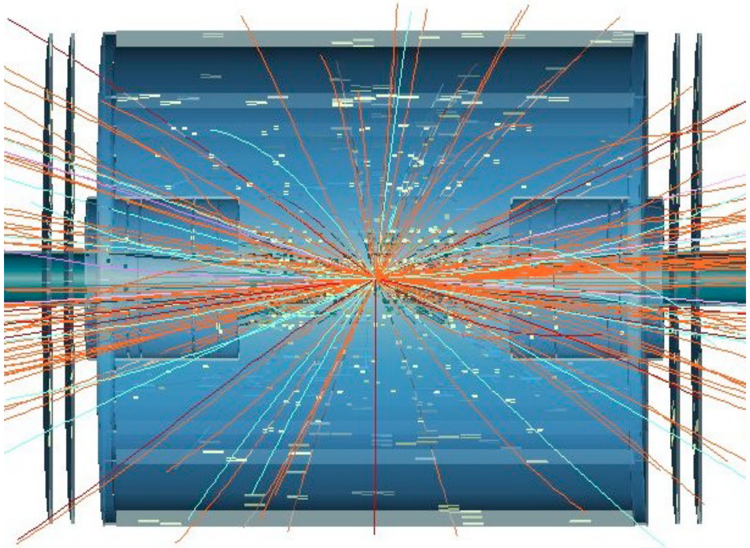
√s = 14 TeV, L = 5×10^{34} cm^{-2} s^{-1}, luminosity levelling

Phase-2

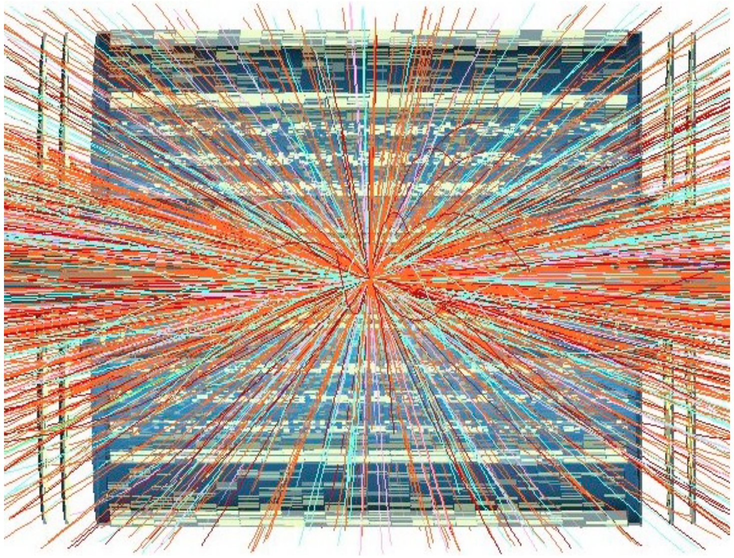


As shown at "Chamonix 2012"

Challenges

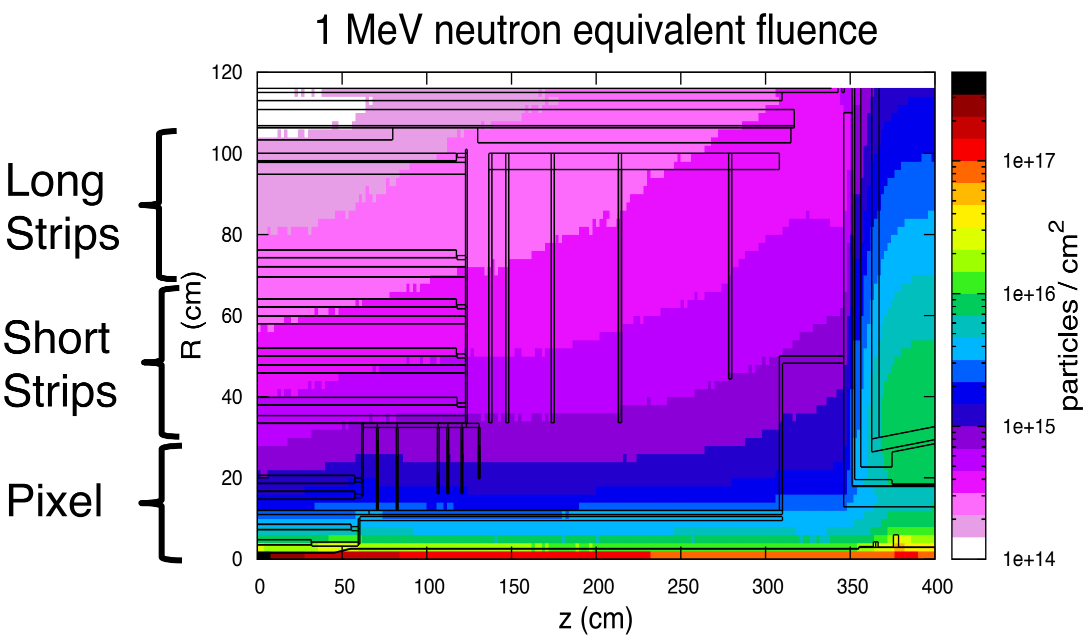


LHC in 2011: 1×10^{33} cm^{-2} s^{-1}

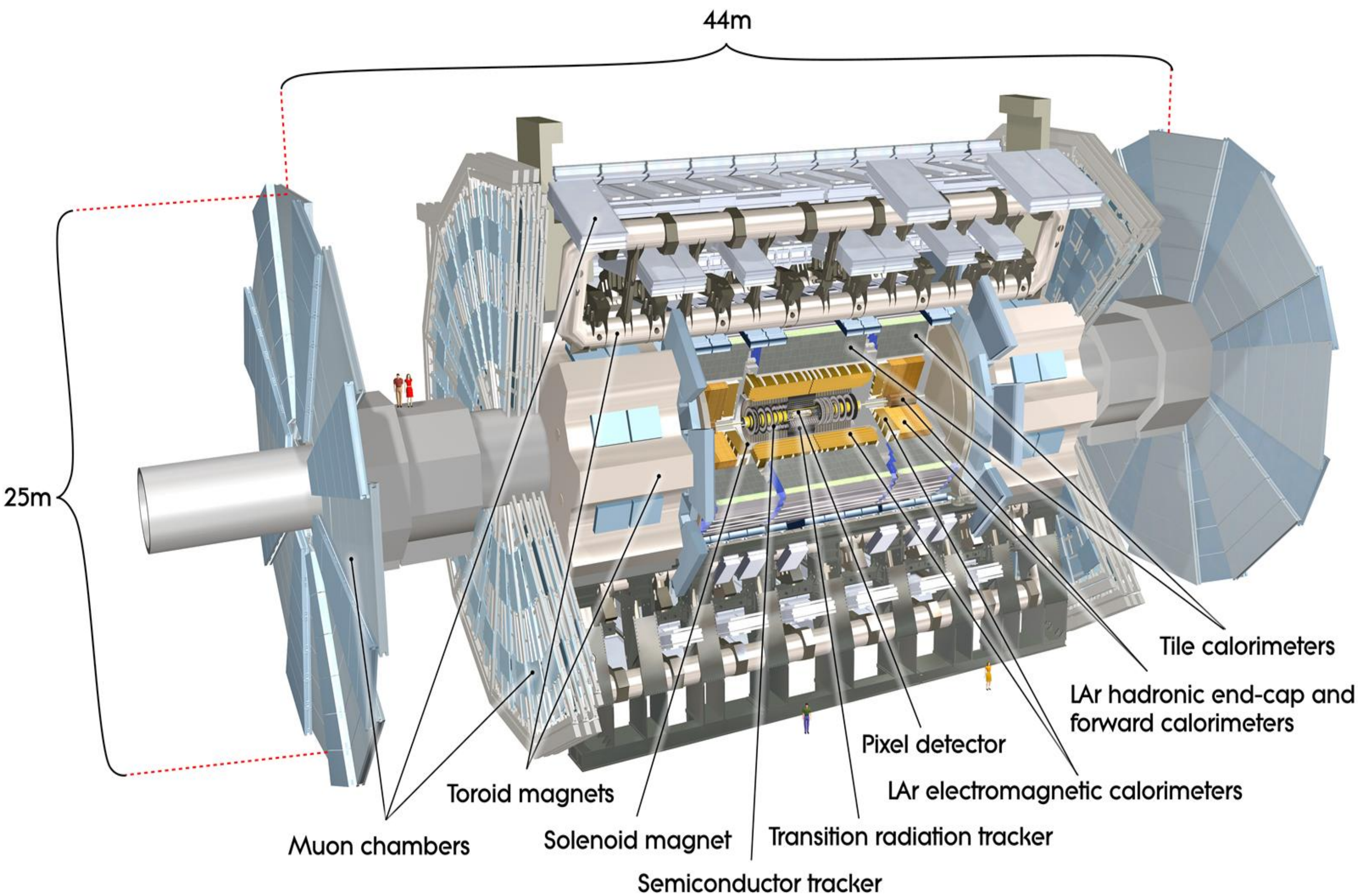


HL-LHC : 5×10^{34} cm^{-2} s^{-1}

- ☞ Higher instantaneous luminosity
  - ✍ Increased pileup collisions
  - ✍ Higher detector occupancy
- ☞ Higher integrated luminosity
  - ✍ Increased radiation damage
- ☞ Preserve and improve physics performance to fully benefit from the increasing luminosity



The ATLAS Experiment



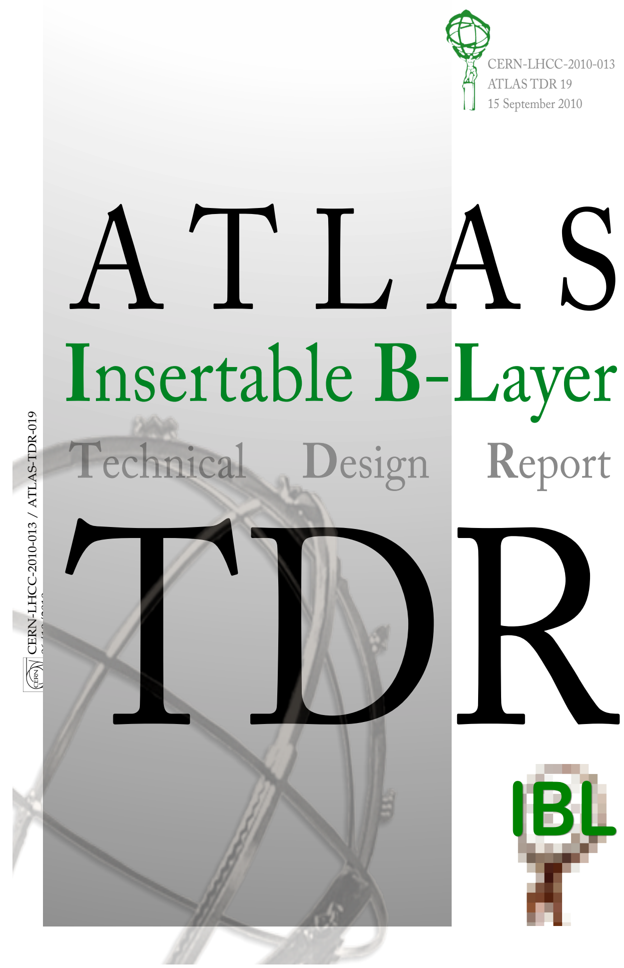
Phase-0: 2013/14 (LS1)

☞ LHC

- ✍ Shutdown 18 months
- ✍ Consolidation of the superconducting circuits
- ✍ Design luminosity 10^{34} cm^{-2} s^{-1} / integrated luminosity 100 fb^{-1} @ 13 TeV

☞ ATLAS

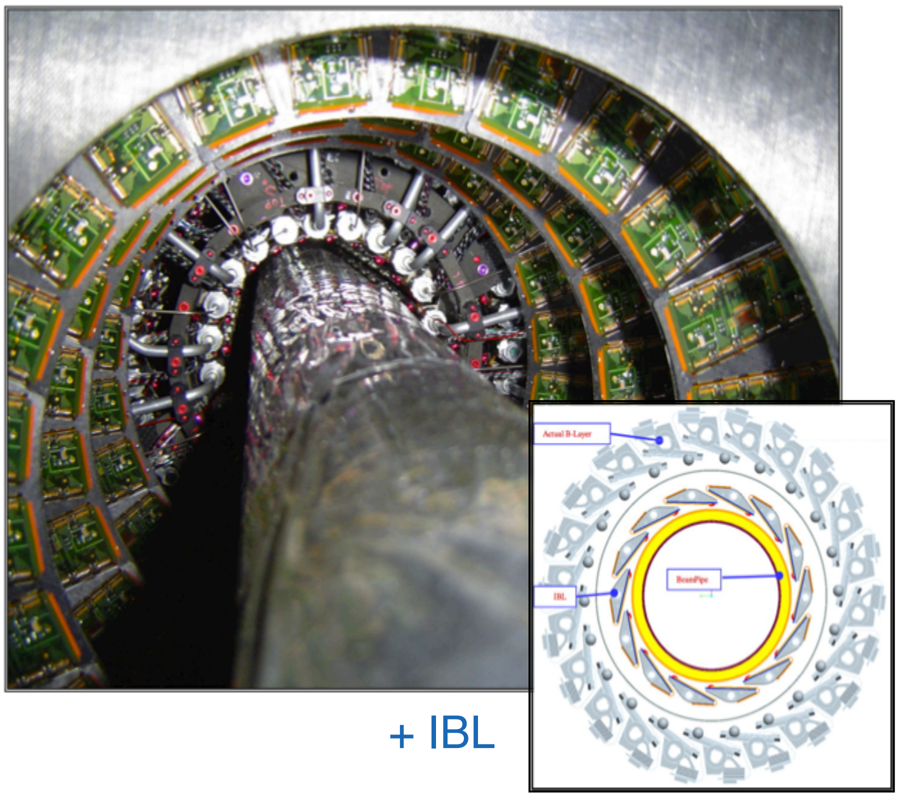
- ✍ Detector consolidation
  - New calorimeter power supplies, Inner Detector cooling, power network magnet cryogenics …
  - Completion of the Muon system
  - New neutron shielding
- ✍ Detector upgrades:
  - Insertable B-Layer (IBL)
  - *Possible* Pixel Service Quarter Panels
  - *Possible* Diamond beam monitor



Insertable B-Layer

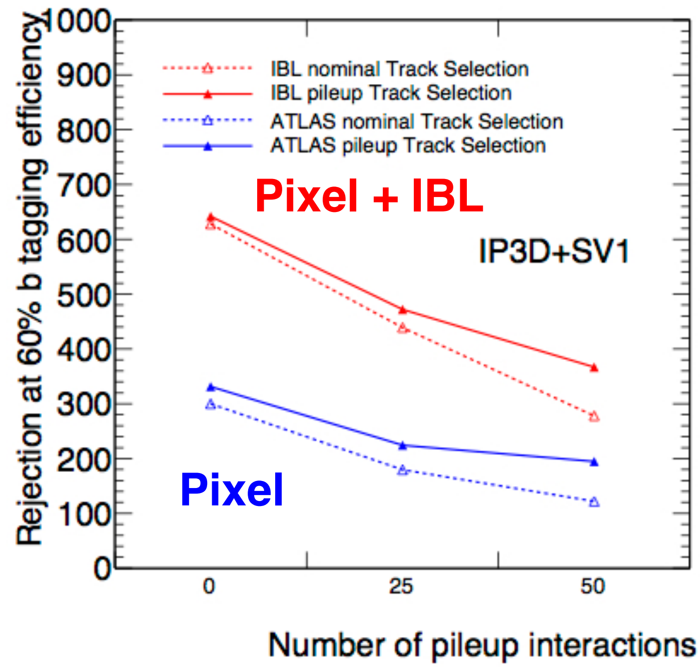
- Improve performance, 4th low mass pixel layer with small pixel size closer to the beam
  - Tracking, vertexing, *b*-tagging and τ-reconstruction
- Technology step towards HL-LHC

Present beam pipe & B-Layer



+ IBL

Impact on *b*-tagging



- Mounted on the new beam pipe
  - Installation options to be decided
  - May extract and repair the pixel detector on the surface → new Service Quarter Panels (nSQP) and diamond beam monitor attached to the SQP

Pixel Sensors: Planar & 3D

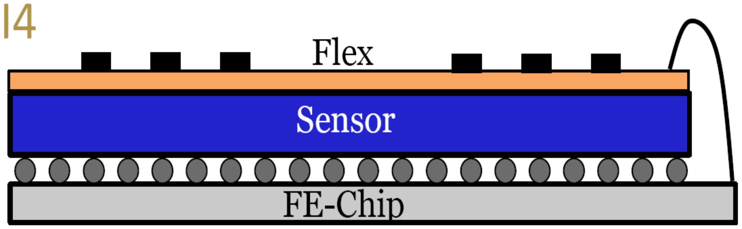
☞ Planar sensor

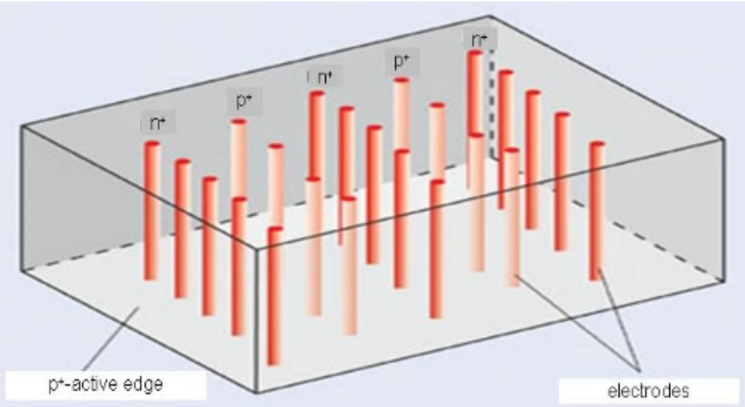
- ✍ "classic" sensor design
- ✍ Oxygenated n-in-n
- ✍ 200 µm thick
- ✍ Minimize inactive edge by shifting guard-ring underneath pixels
- ✍ Radiation hardness proven up to $2.4 \times 10^{16}\ n_{eq}/cm^2$
- ✍ Problem: HV might exceed 1000 V

Hybrid Pixel Chip Assembly

- Sensor and FE chip produced separately
- Connected via bump bonding

FE-I4





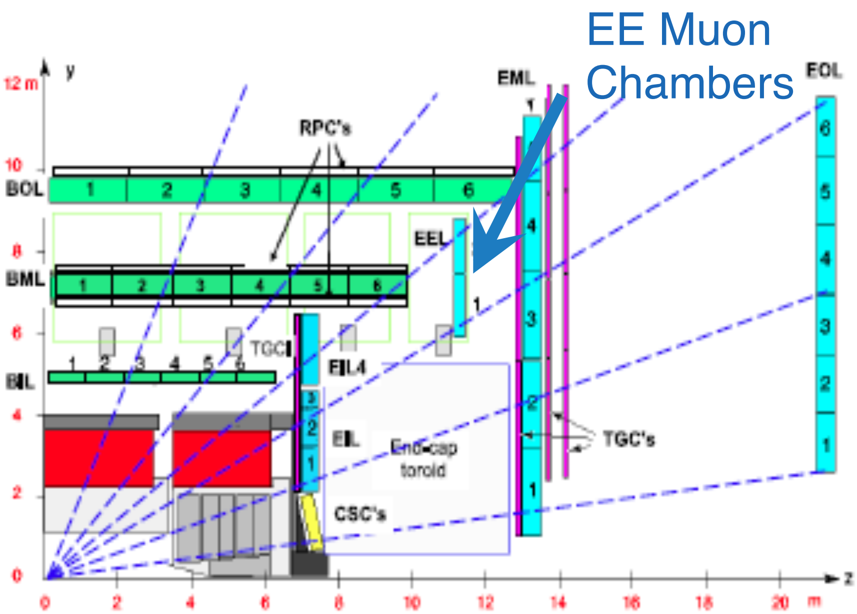
☞ 3D sensor

- ✍ Both electrode types are processed inside the detector bulk
- ✍ Maximum drift and depletion distance set by electrode spacing
- ✍ Reduced collection time and depletion voltage
- ✍ Low charge sharing

IBL baseline:

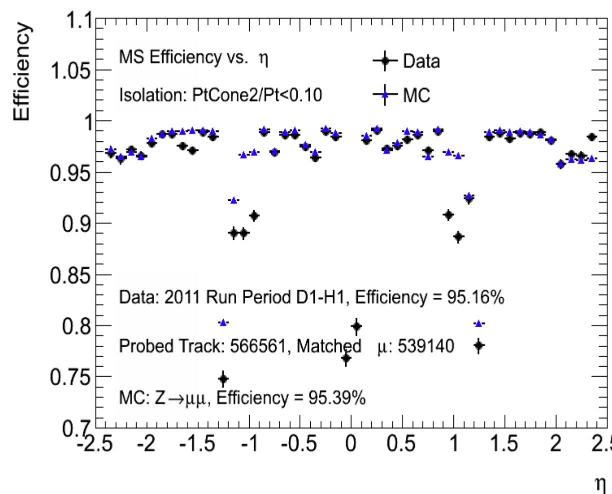
- 75% planar sensors
- 25% 3D sensors (in the forward region)

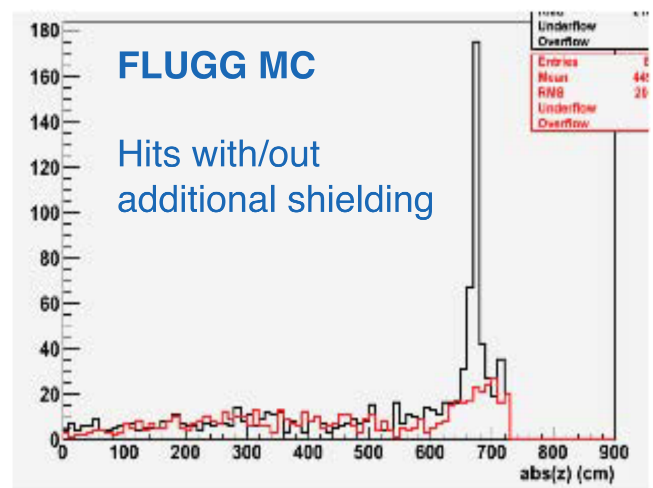
Muon system



- ☞ End-cap Extension (EE) Chambers
  - ✍ Improve coverage in 1.0 <|η|<1.3
  - ✍ Install missing 52 of 62 chambers
  - ✍ Address low tracking efficiency in the region
- ☞ Corresponding L1 trigger updates
- ☞ New shielding @ 7 m
  - ✍ Gap between forward calorimeter and shielding disk
  - ✍ Reduce hit occupancy in the Muon Small Wheel region

Need to bring the Muon Small Wheel to the surface





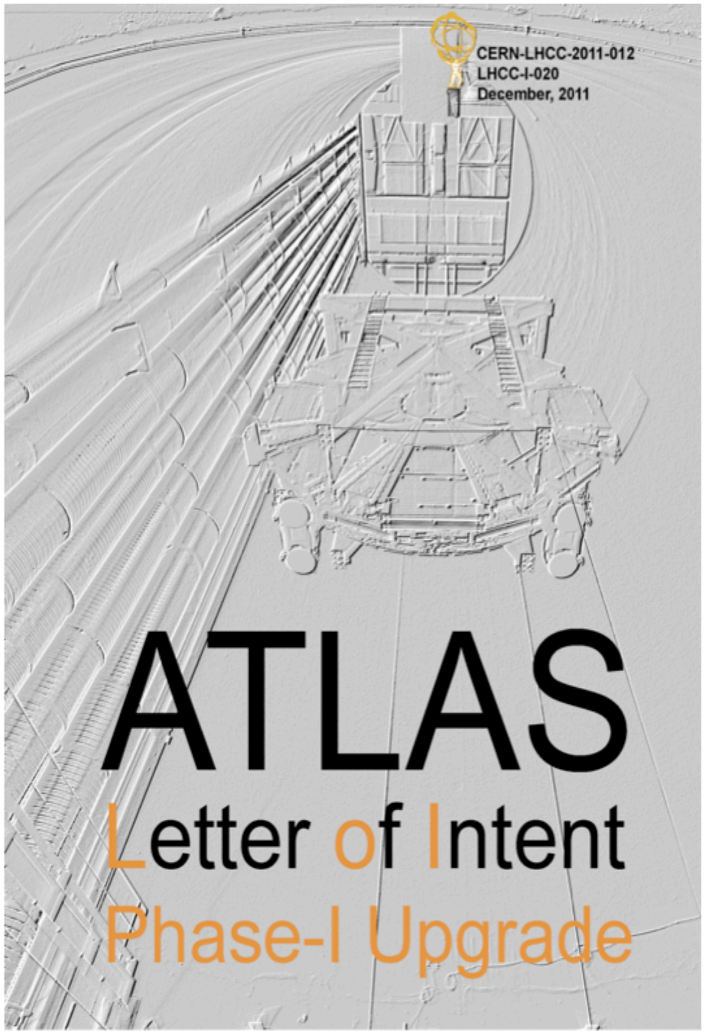
Phase-1: 2017/18

☞ LHC

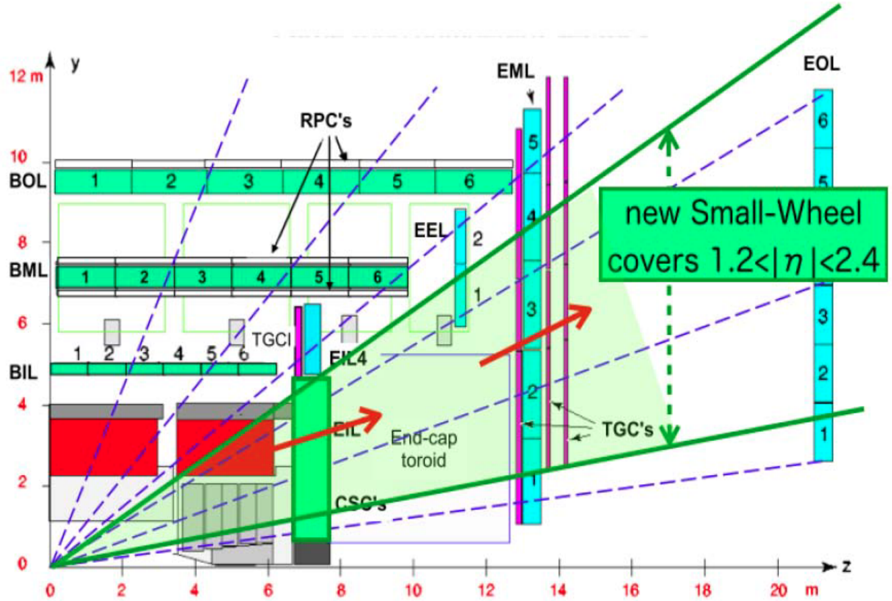
- ✍ Shutdown 14 months
- ✍ Consolidation of injector chain and collimators
- ✍ Peak luminosity 2×10^{34} cm^{-2} s^{-1}/ integrated luminosity 350 fb^{-1}@14 TeV

☞ ATLAS

- ✍ New Muon Small Wheels
- ✍ L1 calorimeter trigger
- ✍ Fast track trigger
- ✍ Forward physics system
- ✍ All upgrades to be compatible with Phase-2



New Muon Small Wheels



☞ Detector technologies

✍ Small Muon Drift tube (sMDT): 15 mm diameter, much shorter drift time

✍ Thin Gap Chambers (sTGC): reduced cathode resistivity → rate capability increased up to 30 kHz/cm^2

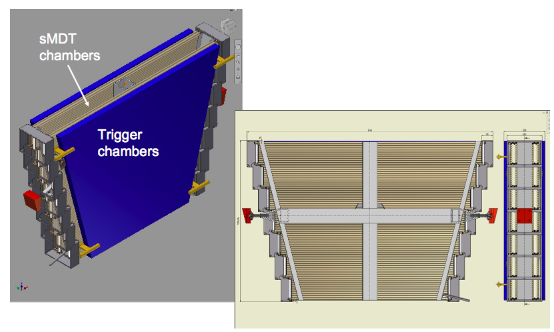
✍ Resistive Plate Chambers (RPC)

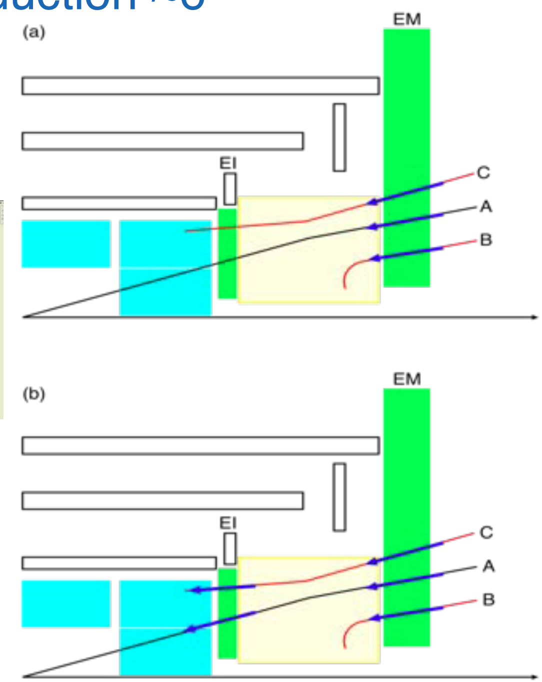
✍ Micromegas (MM)

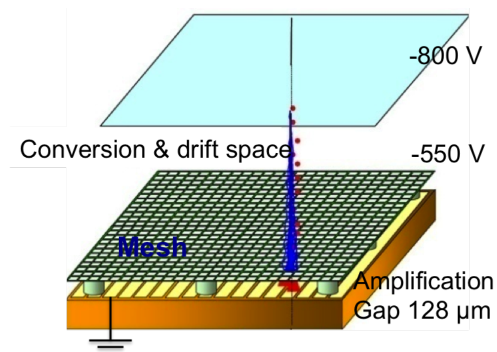
☞ New Muon Small Wheel (nMSW)

✍ Equipped with precision tracker that works up to the ultimate luminosity $5\times10^{34}\ cm^{-2}\ s^{-1}$

✍ Kill fake triggers by requiring IP pointing segments in the inner station → trigger rate reduction ~6

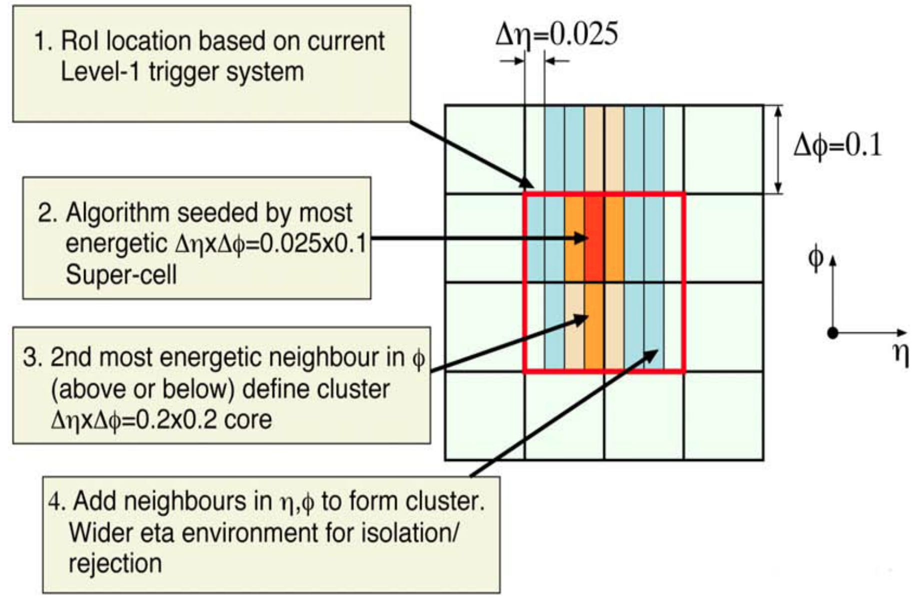


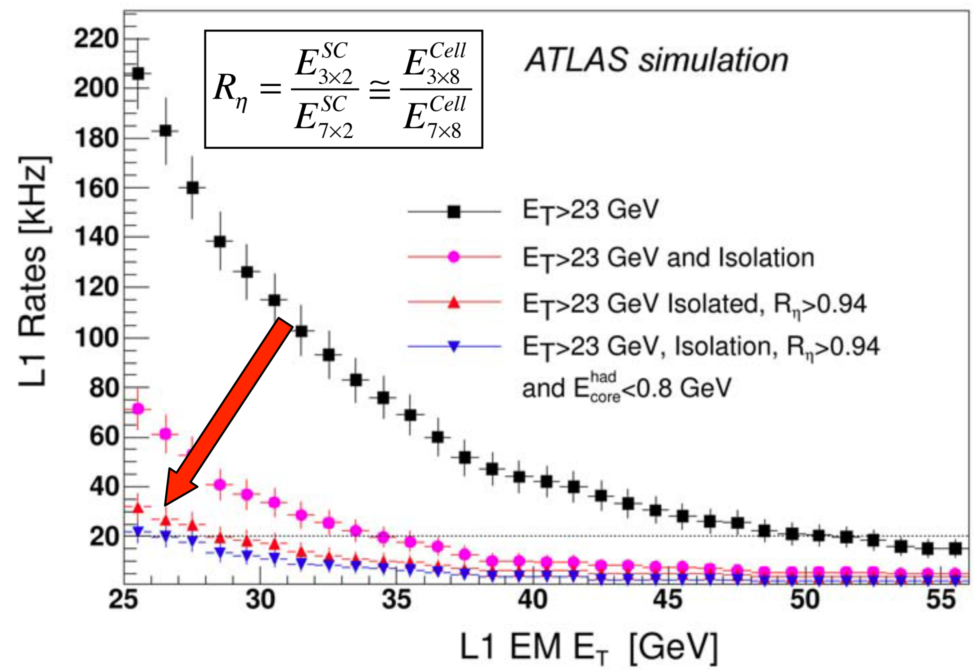




Granularity L1 Calorimeter Trigger

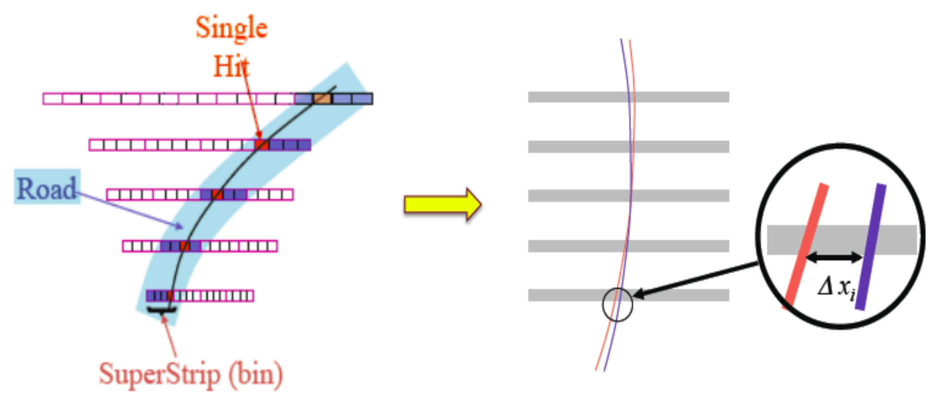
- Improve granularity of L1 for better e-jets discrimination
  - Explore the lateral shower shapes
  - Reduce L1 trigger rate and preserve un-prescaled threshold at ~25 GeV
- Partial upgrade of calorimeter front-end architecture, part of the input stage of the L1 and the interface among the two systems
- Require new front-end digital chain
  - Super-cells with higher granularity are formed in the front-end shaper sum ASIC and individually digitized
  - L1 uses ratio of energies of different size clusters





Fast Track Trigger (FTK)

- Current trigger system
  - Level-1: hardware based (~50 kHz)
  - Level-2: software based with RoI access to full granularity data (~5 kHz)
  - Event Filter (EF): software trigger (~500 Hz)
- FTK hardware based track trigger (Level-“1.5”)
  - Inspired by the CDF Silicon Vertex Trigger (SVT)
  - Inputs from Pixel and SCT, data in parallel to normal read-out
  - Two step reconstruction: pattern recognition & linearized track fit
  - Provides inputs to L2 in ~25μs
- Major Level-2 improvement for
  - b-tagging, τ-reconstruction
  - Lepton isolation
  - Primary & pileup vertex reconstruction

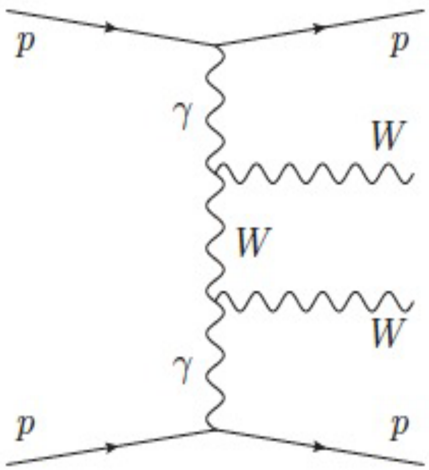


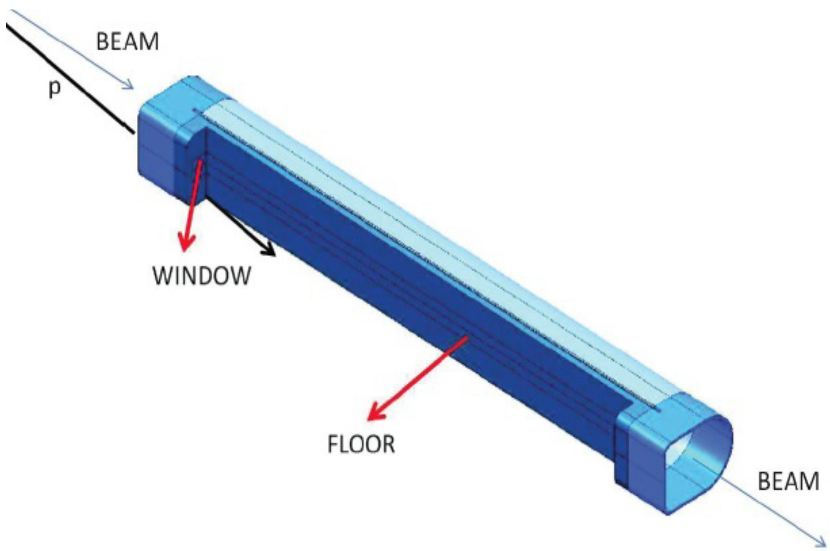
Pattern recognition in coarse resolution (superstrip→road)

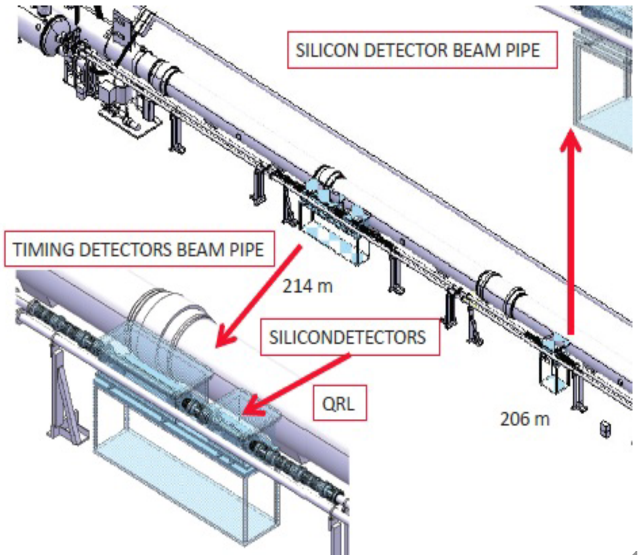
Track fit in full resolution (hits in a road)
$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$

Forward Physics System

- ☞ ATLAS Forward Proton (AFP) detectors
- ☞ Physics motivation: anomalous couplings between W/Z and γ, QCD diffractive physics
- ☞ Hardware
  - ✍ Silicon position detectors at small scattering angles (206m and 214m from IP), use technology from IBL
  - ✍ Movable beam pipe (thin walls, few 100 μm)
  - ✍ Picosecond timing detectors (fast Cerenkov timing detectors < 10ps time resolution)
  - ✍ Movable beam pipe, cables, other infrastructure need to be installed @ Phase-0







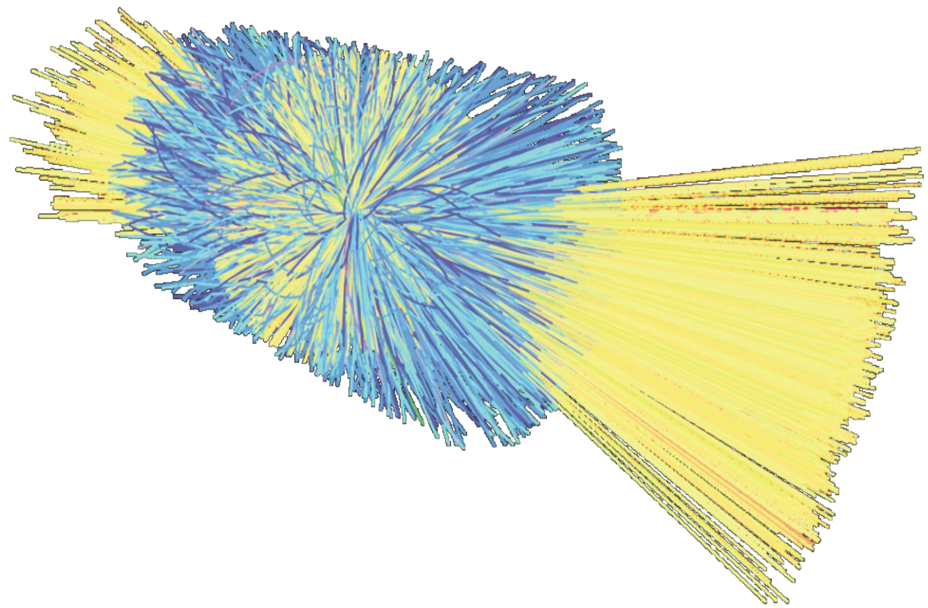
Phase-2: 2022/23

☞ HL-LHC

- ✍ Shutdown 18 months
- ✍ Prepare for luminosity levelling
- ✍ Peak luminosity 5×10^{34} cm^{-2} s^{-1} / integrated luminosity 3000 fb^{-1}

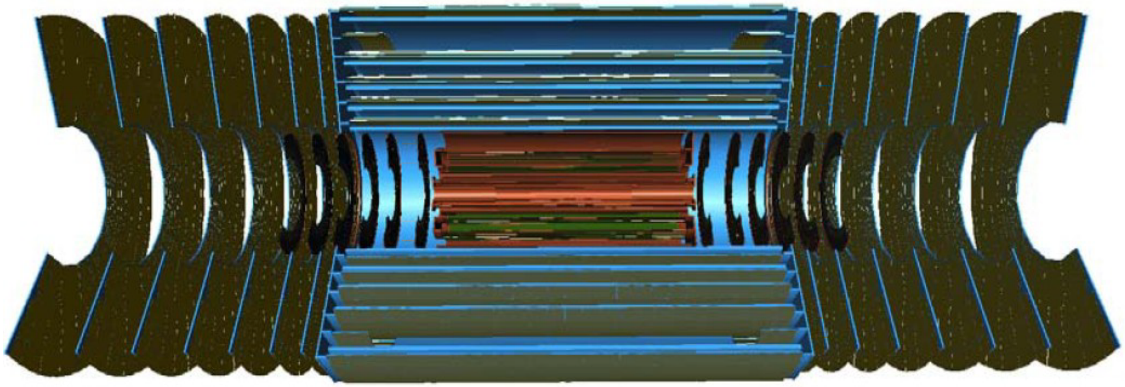
☞ ATLAS

- ✍ Inner Detector upgrade (full replacement)
- ✍ Upgrade of Muon system
- ✍ Upgrade of Forward Calorimeters & new LAr calorimeter electronics

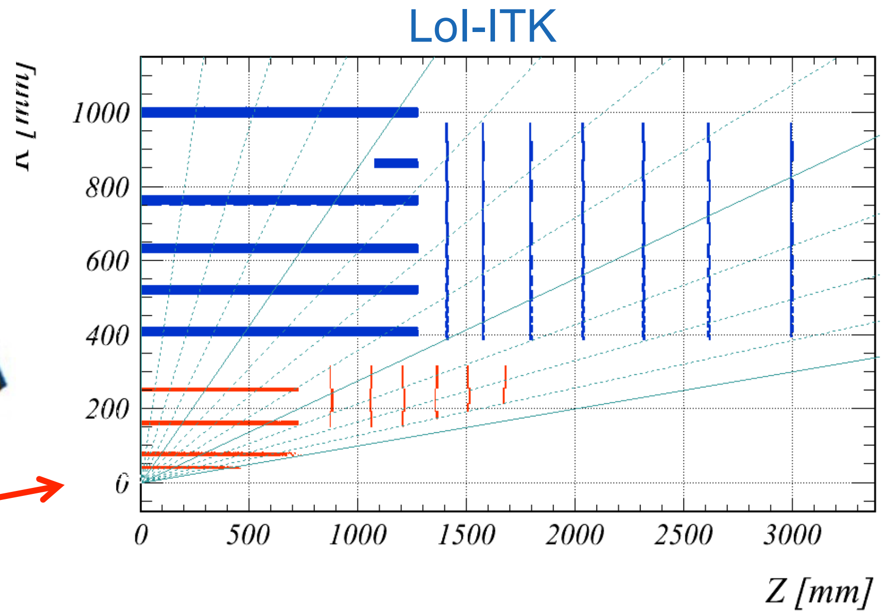


Letter of Intent for Phase-2 being produced

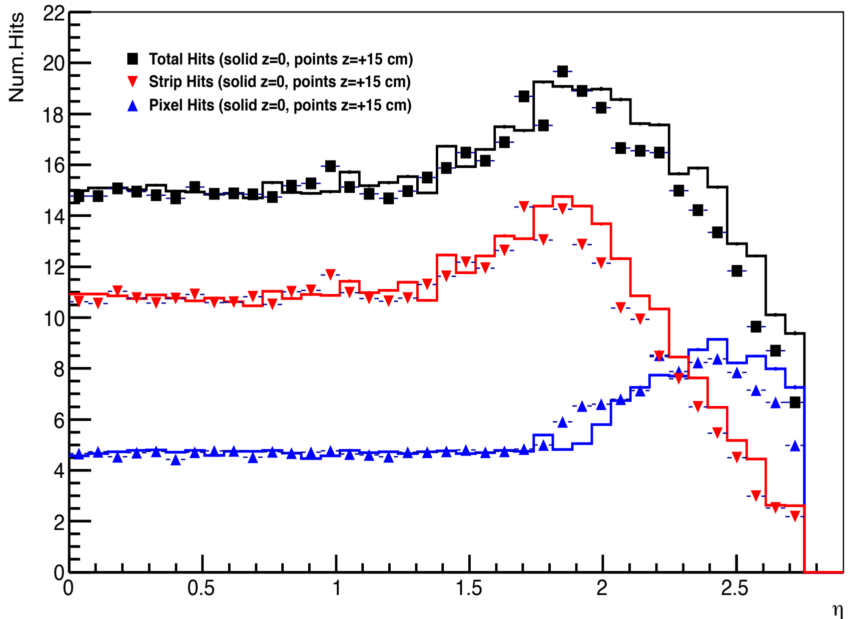
Tracker Layout



Full silicon detector

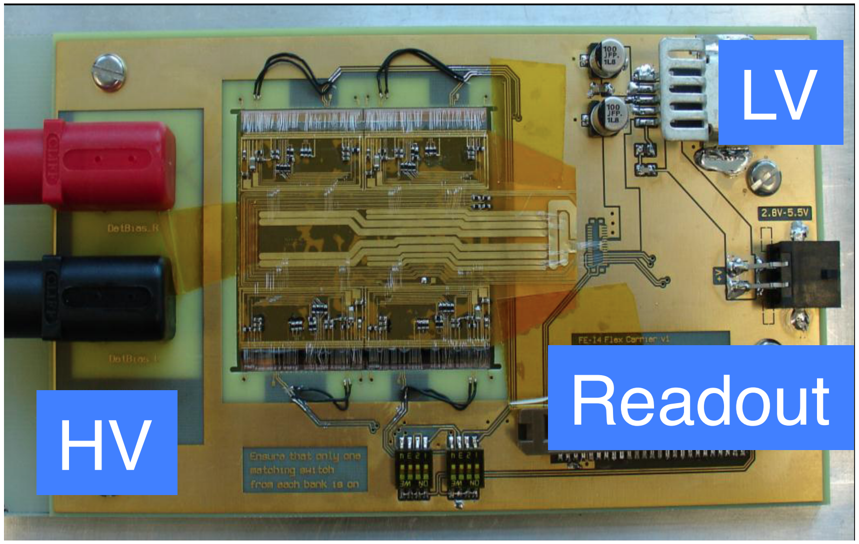


- Baseline layout
  - Full coverage up to |η| < 2.5 (providing ~14 hits-per-track), pixel extended to |η| = 2.7 (forward muon ID)
  - Pixel: 4 barrel layers (r=39-250 mm) and 6×2 end-cap disks
  - Strips: 3 short-strip + 2 long-strip barrel layers (r=405-1000 mm) and 7×2 end-cap disks
- Alternative layouts also being investigated



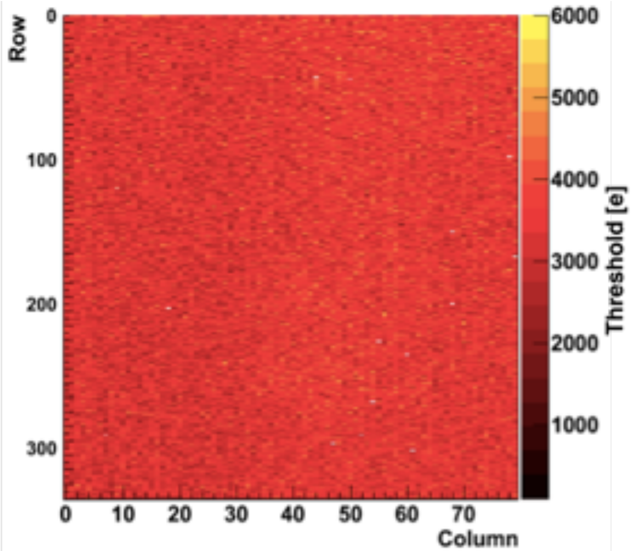
Pixel System

- ☞ Large area (7 m^2)
  - ✍ Cost effectiveness
- ☞ Reduce cost of interconnects
  - ✍ Connect single large sensor to 4/6 ASICs
- ☞ New Front-End ASIC FE-I5
  - ✍ 130 nm CMOS: lower power
  - ✍ More space: increased radiation hardness
- ☞ Cost effective sensors
  - ✍ n-in-p or n-in-n



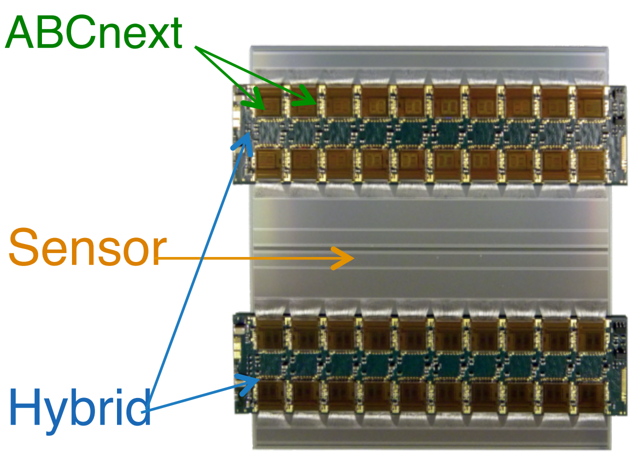
Quad module: 2 sensors + 4 chips

	Inner 2 Barrels	Outer 2 Barrels/Disk
Sensor Types	All materials possible 150 μm silicon or thinner	Planar n-in-p 150 μm
Pixel Size	25 μm × 150 μm	50 μm × 250 μm
Time over Threshold	0-8 bits	4 bits
Modules	2×1 and 2×2 chips	2×2 (quad), 2×3 (hex) chips
Data rate per module	Up to 2 Gbit/s	640 Mbit/s

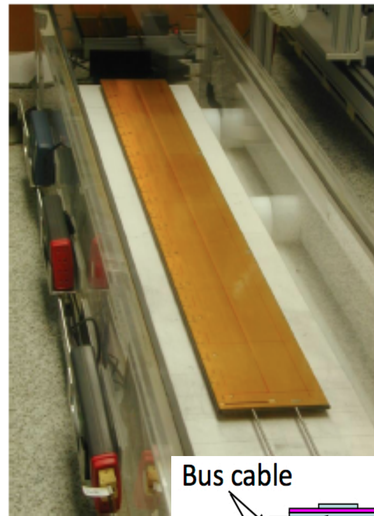


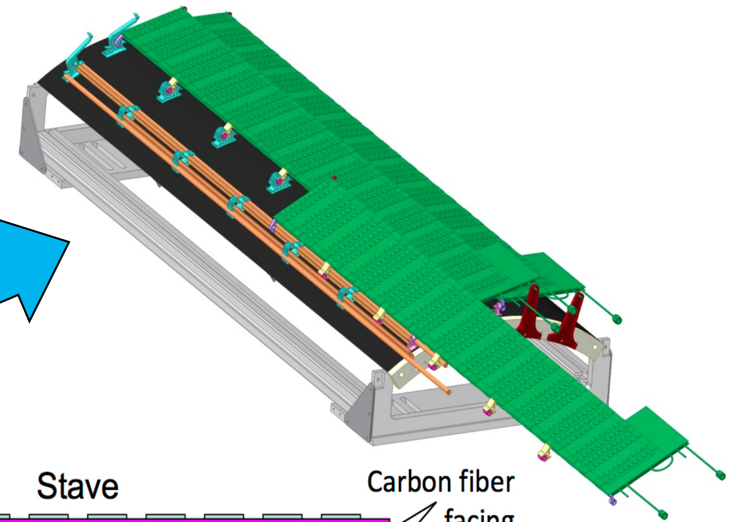
Prototype module readout test

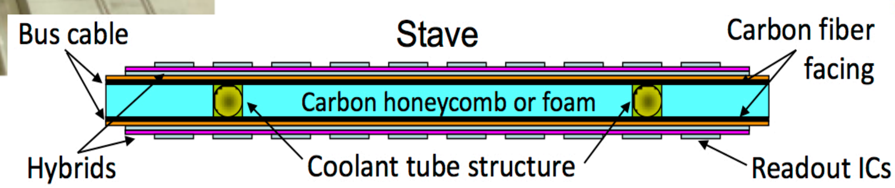
Strip System: Barrel Stave Concept



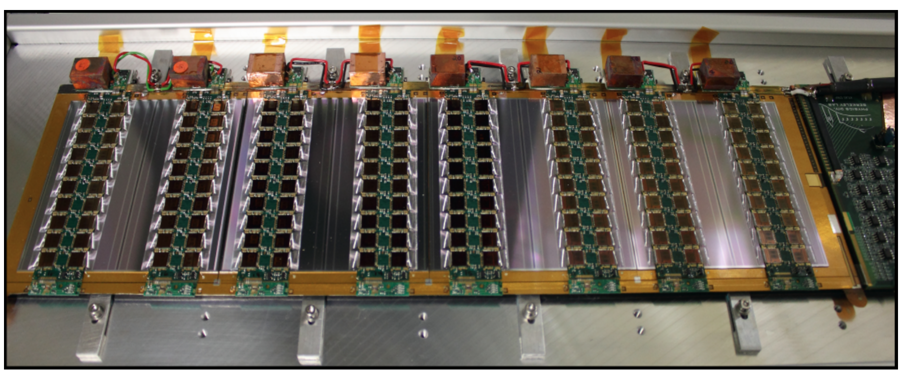
Module







- Stave Modules
  - Hybrid with 130nm ABCnext chips
  - Glued to kapton-flex and wire-bonded
  - Hybrid glued to silicon sensor, strips connected via wire bonds

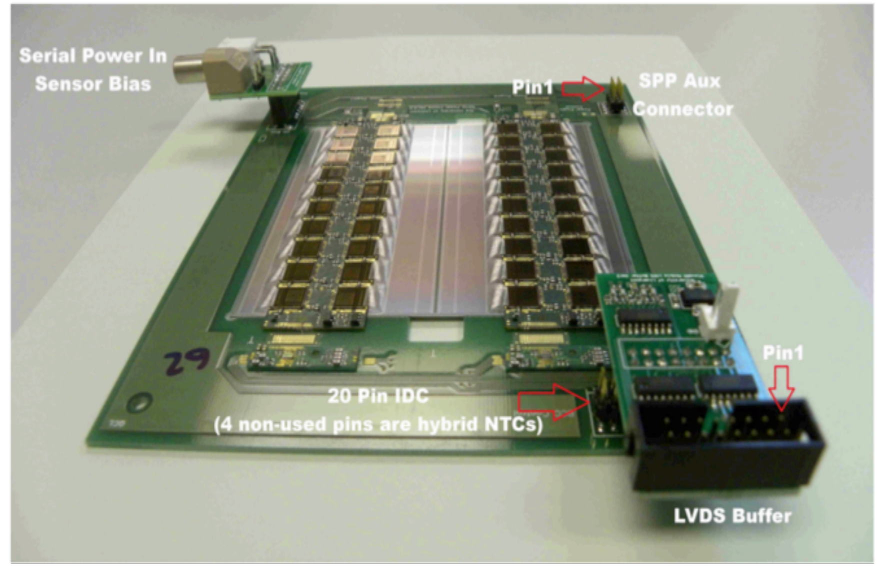


Small Stave: Stavelet

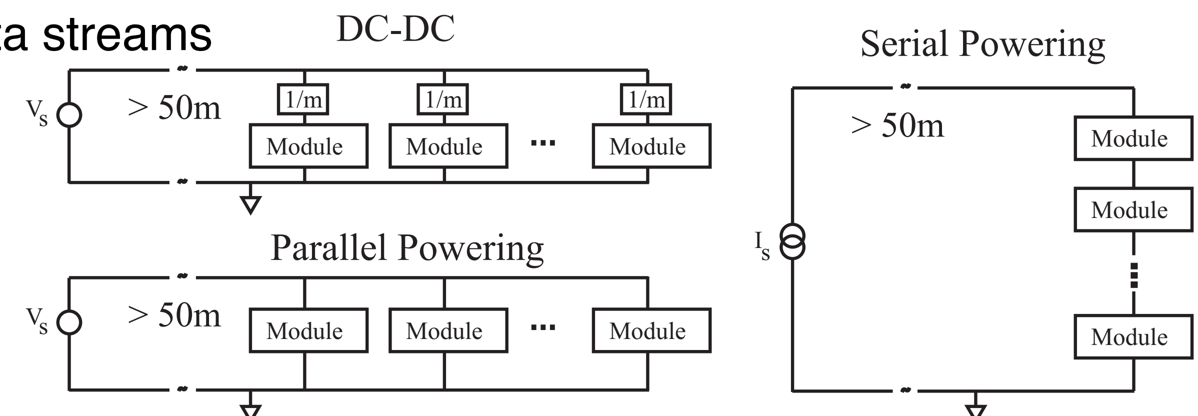
- Double-sided stave
  - 48 modules glued to core structure
  - Carbon fiber laminated to foam filler
  - Embedded cooling pipes (CO_2)
  - Co-cured bus tape for data and power
- Attached
  - Carbon fiber support structure with brackets for attachment
  - End insertion for easy assembly and access

Barrel Stave Module

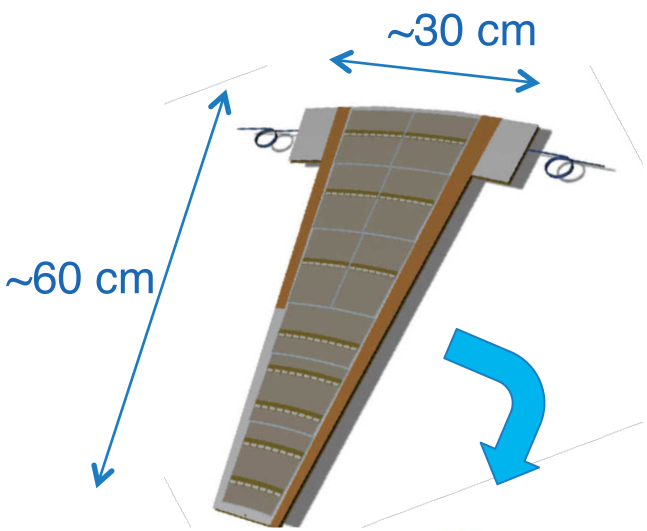
- Hamamatsu strip sensor
  - n-in-p: fast signal, reduced charge sharing
  - Depletes from the segmented side: good signal even not fully depleted (radiation damage)
  - Single-sided process: cheaper than n-in-n, more foundries
  - 9.75 × 9.75 cm^2 (6 inch wafer)
- ABCnext readout chip
  - 130nm CMOS with binary readout (250nm for the test module)
  - 256 readout channels
  - Controller chip to multiplex data streams
- Powering options
  - DC-DC power converters
  - Parallel power
  - Serial power
  - High voltage multiplexing

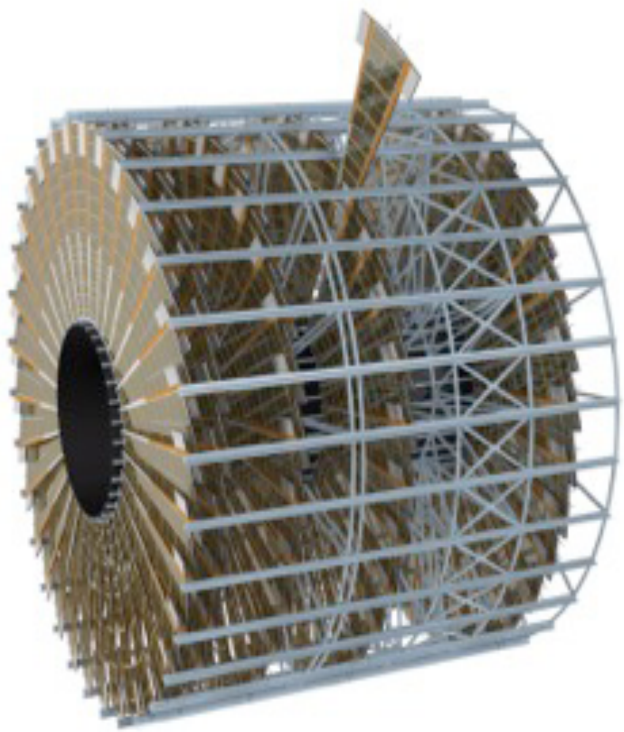


Low voltage powering



Strip System: Petal

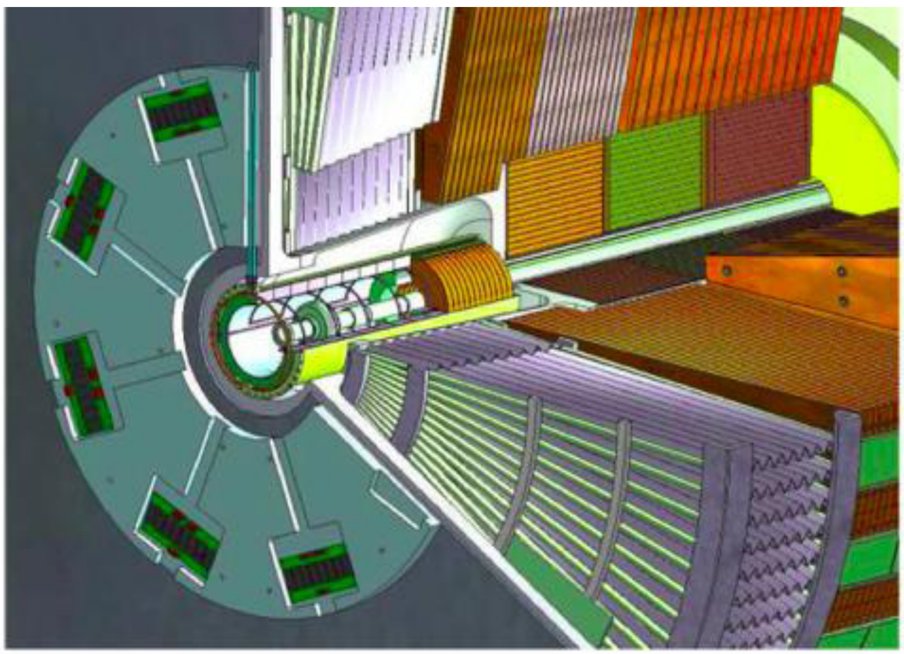




- ☞ Stave concept in end-cap: Petal
  - ✍ 7 disks per end-cap
  - ✍ Many different sensor sizes
  - ✍ Strip length 8.1mm to 58.3mm
- ☞ 32 petals per disk
  - ✍ 6 rings of sensors with radial strips
- ☞ First petal core produced
  - ✍ Flatness better than 100 µm
- ☞ Small Petal: Petalet
  - ✍ Double-sided, six sensor prototype
  - ✍ Explore many options
  - ✍ First sensors and hybrids produced

Calorimeter

- EM LAr Barrel & Calorimeter will work fine: no upgrade
- Full upgrade of front-end electronics (radiation, lifetime, performance …)
  - Both LAr and Tiles
- Hadronic End-cap electronics designed for 1000 fb^{-1} – possible replacement
- Forward Calorimeter @ HL-LHC instantaneous luminosity: overheating / ion build-up / HV-drop /signal loss …

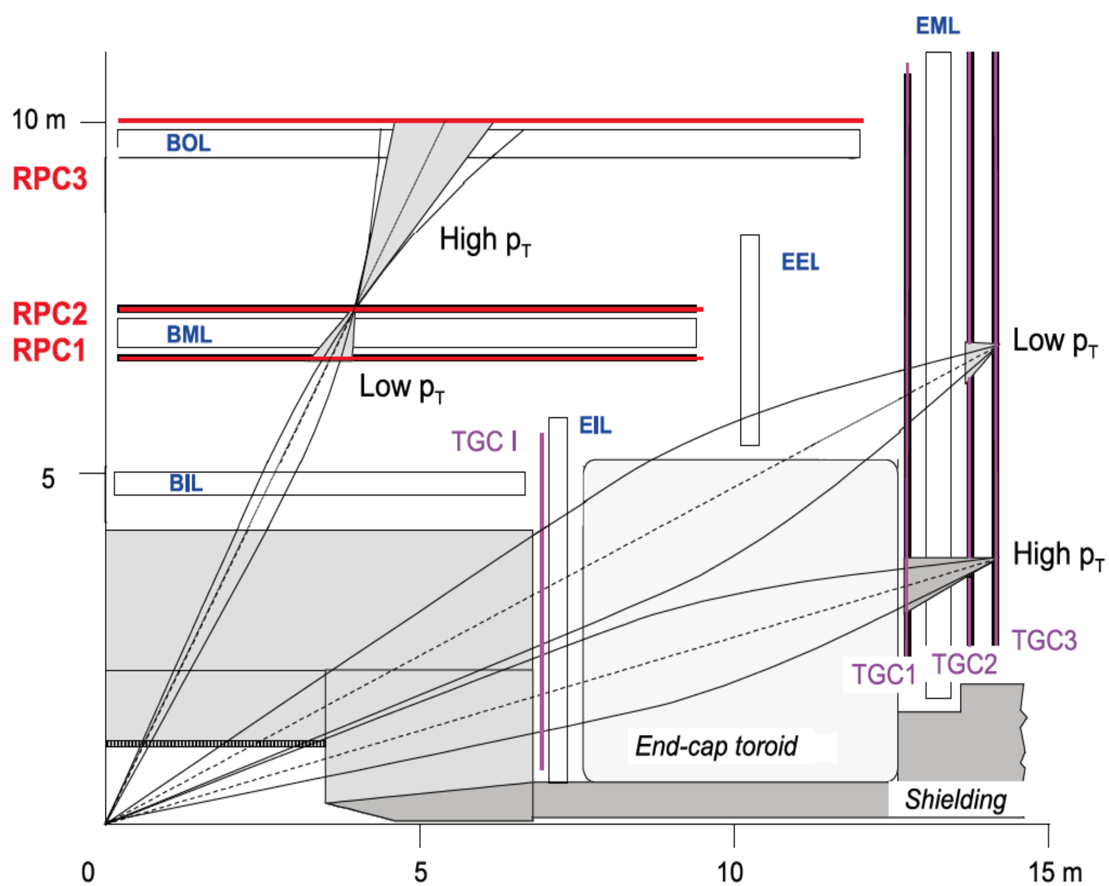


Option1:
Complete replacement of the FCAL
Smaller LAr gaps (to reduce ion build-up/ HV drop) + better cooling (avoid overheating)

Option2:
Installation of a small calorimeter in front of the current FCAL: Mini-FCAL → Reduce energy and ionization @ FCAL

Muon System

- High rates in the forward muon system – replacement needed
- Based on the experience from Phase-1 upgrade (nMSW)
- Upgrades in L1 trigger – “Muon Track Trigger”



Summary

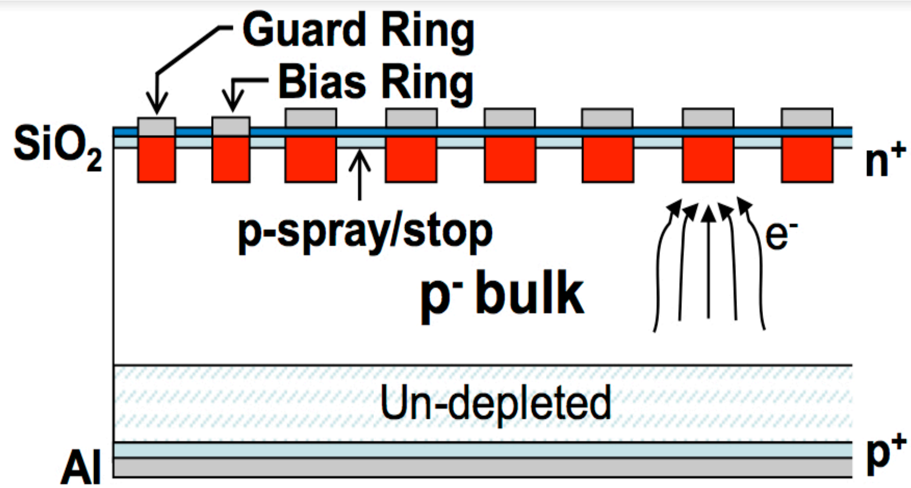
- Preserve excellent detector performance to take full benefit of increasing luminosity to fully exploit physics potential of the ATLAS experiment
  - Consolidation & upgrade of detector, electronics and TDAQ etc.
- Phase-0
  - Insertable B-Layer (TDR)
- Phase-1
  - Upgrades to cope with luminosity up to 2×10^{34} cm^{-2} s^{-1}
  - nMSW, FTK, L1 Calo …
  - Letter of Intent, TDR: 2014/2015
- Phase-2
  - Ensure ATLAS operation under the HL-HLC conditions and eventually collect 3000 fb^{-1} data
  - Full silicon tracker
  - LoI in preparation

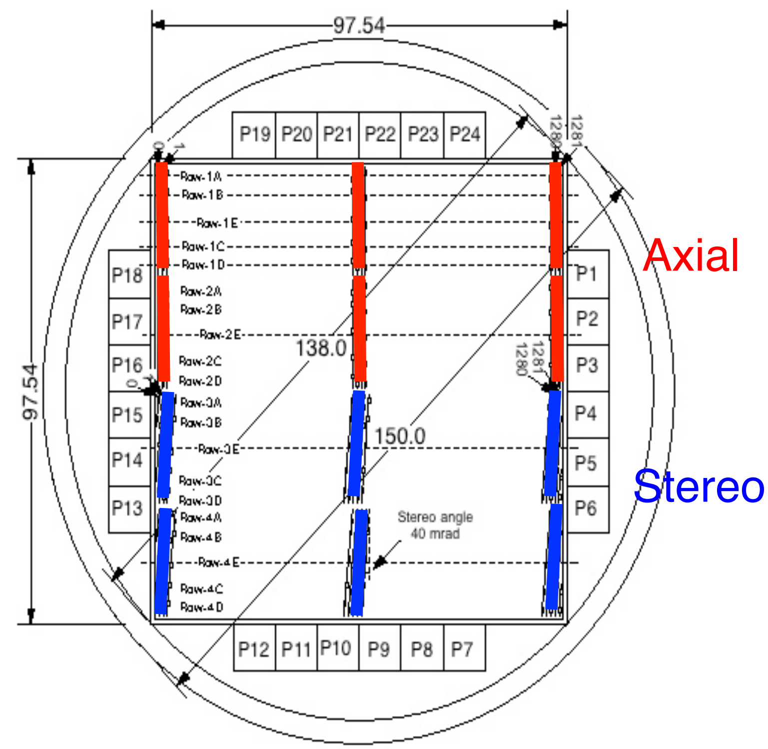
Backup slides

Radiation Hard Sensors

- n^+-strip in p-type substrate (n-in-p)
  - Collect electrons like current n-in-n pixels: faster signal, reduced charge trapping
  - Always depletes from the segmented side: good signal even not fully depleted (radiation damage)
  - Single-sided process: 50% cheaper than n-in-n and more foundries/available capacity world-wide
- Collaboration of ATLAS with Hamamatsu Photonics to develop 9.75×9.75 cm^2 devices (6 inch wafers)
  - 4 segments (2 axial + 2 stereo), 1280 strip each and 74.5 µm thick
  - FZ1 <100> and FZ2 <100> material studied
  - Miniature sensors (1×1 cm^2) for irradiation studies

N. Unno, et al., Nucl. Inst. Meth. A, Vol. 636 (2011) S24-S30





Axial-Stereo Sensor