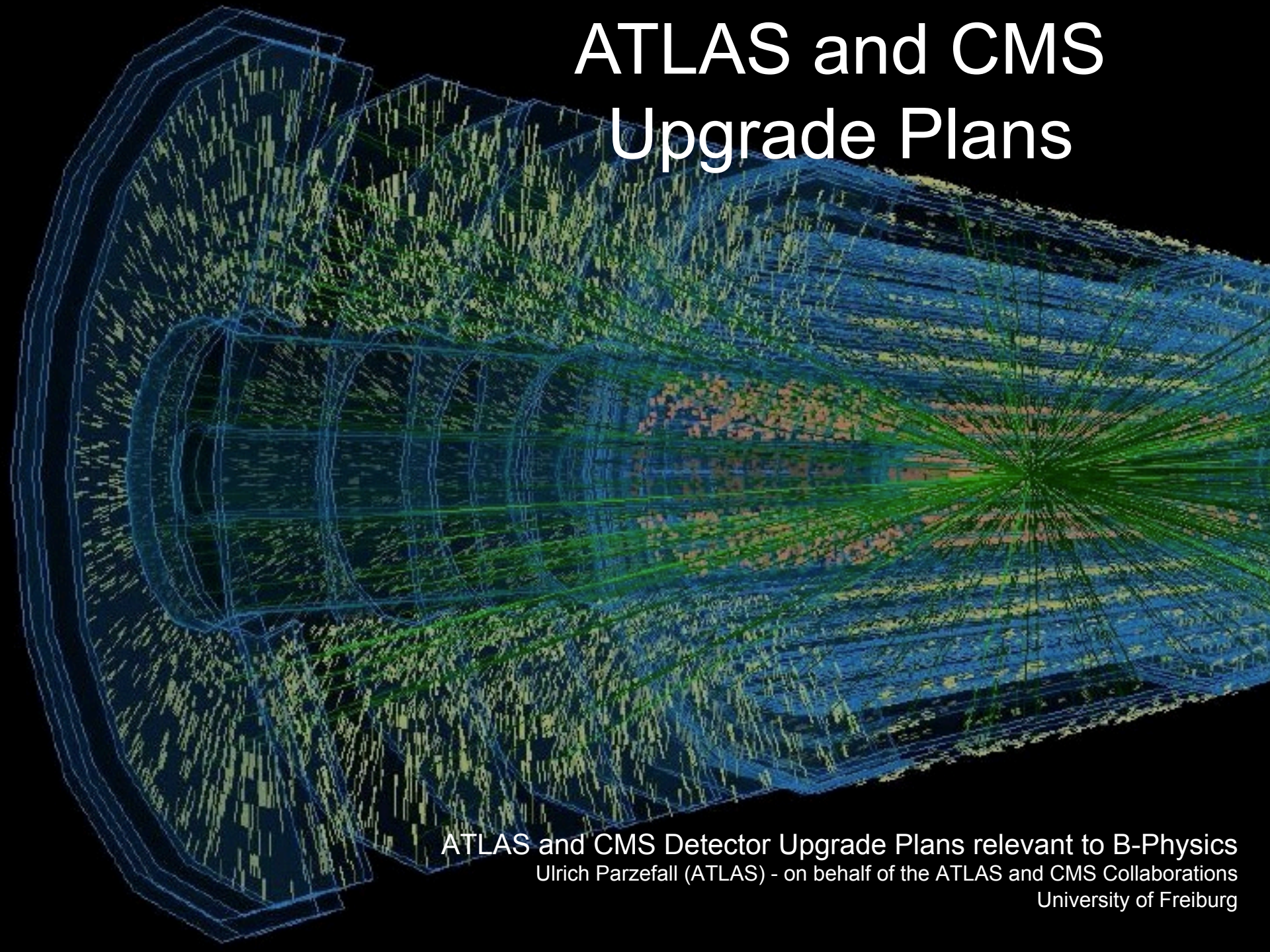
ATLAS and CMS Upgrade Plans

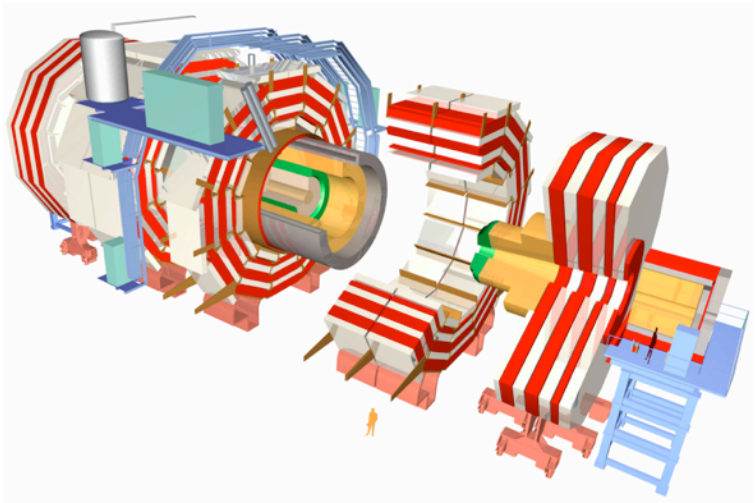


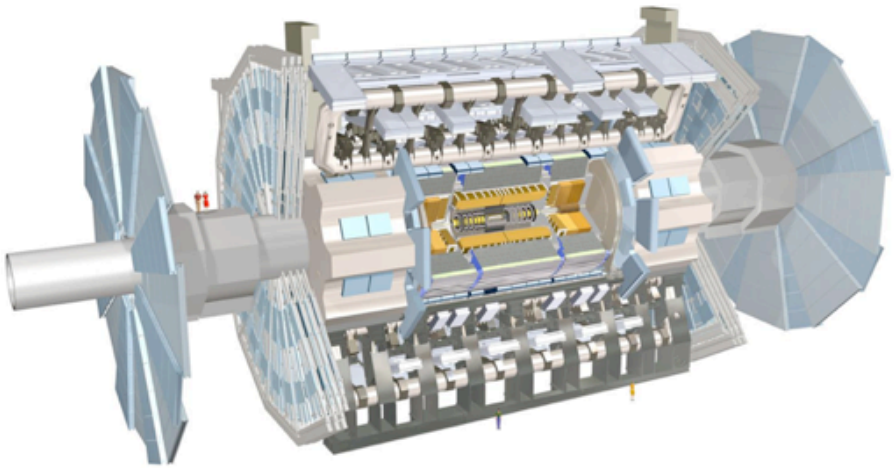
ATLAS and CMS Detector Upgrade Plans relevant to B-Physics

Ulrich Parzefall (ATLAS) - on behalf of the ATLAS and CMS Collaborations
University of Freiburg

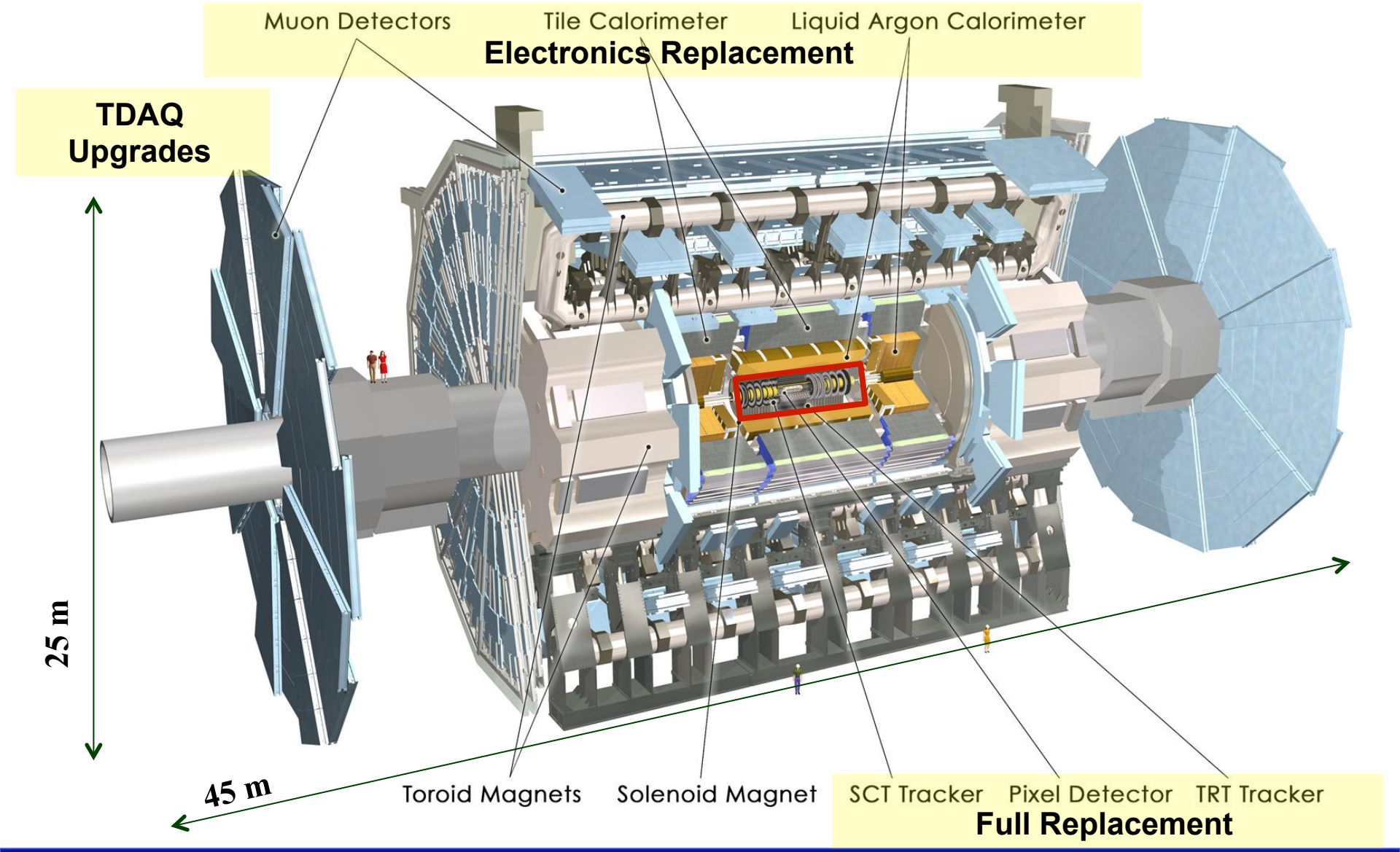
Outline

- ATLAS & CMS (and why we need to upgrade)
- Time line & individual detector upgrades
  - 3 Phases, major one Phase 2 or HL-LHC
- Summary & Outlook

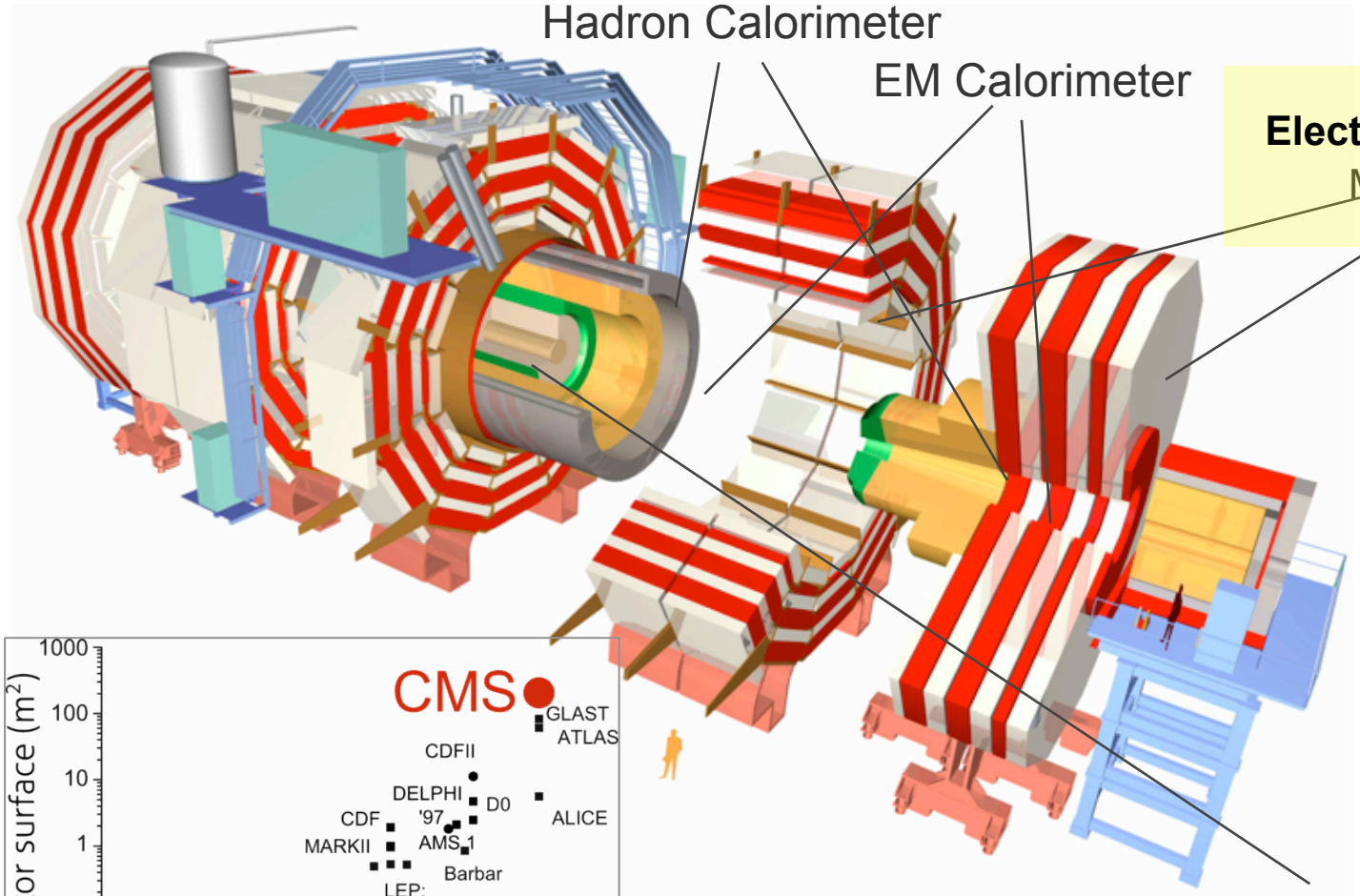




The ATLAS Detector



The CMS Detector



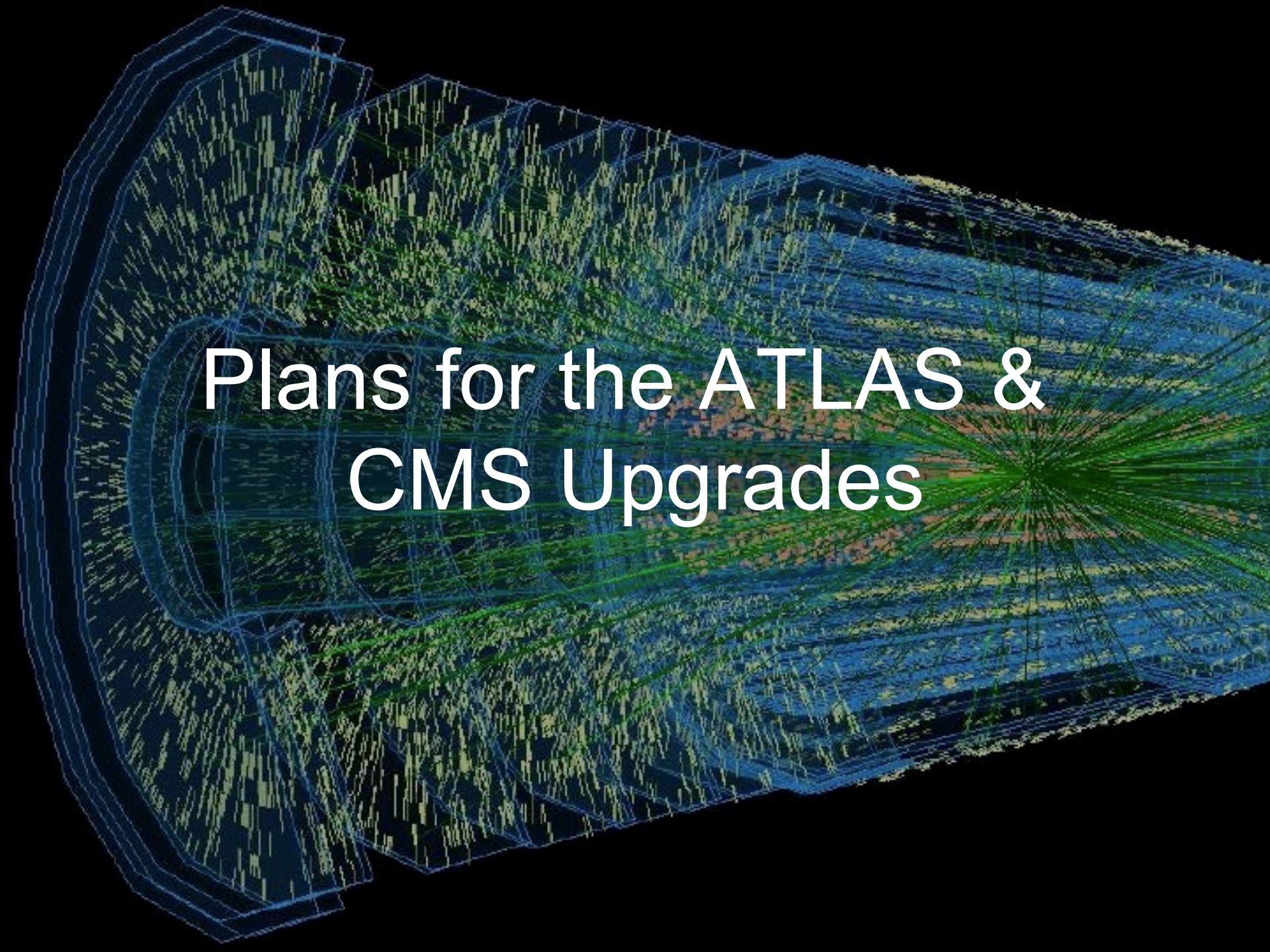
Electronics Replacement
Muon Chambers

Pixel & Strip Tracker
Full Replacement

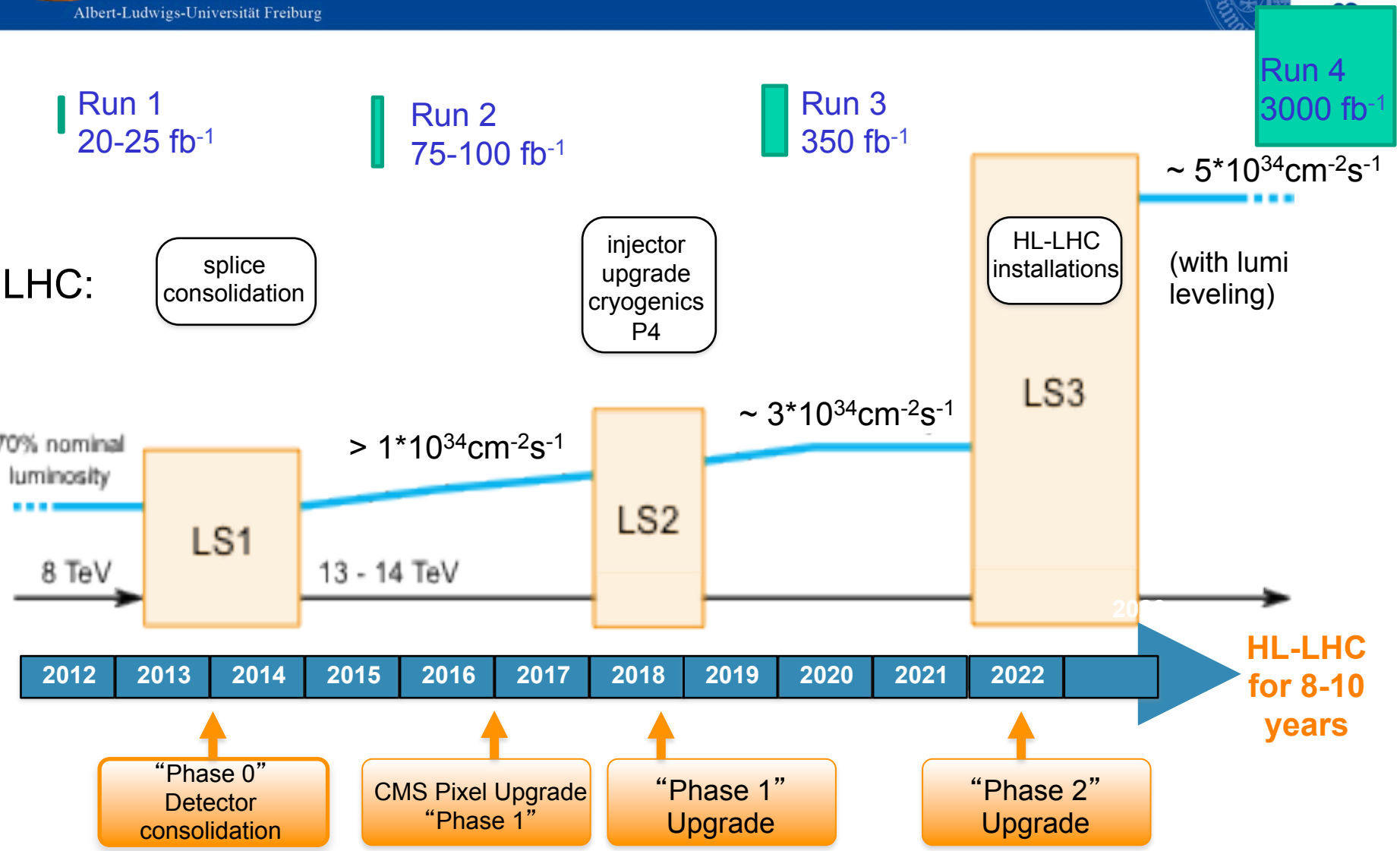
Upgrade Motivation

- Fully exploit Physics potential of LHC machine: collect maximal Luminosity at LHC design energy
- Probing the Higgs sector
  - Fermion and weak gauge boson couplings
  - Spin & CP
  - Measure self coupling
- Observe and measure rare processes that occur at rates below the current sensitivity (within or beyond the SM)
- ESWG: “Europe’s top priority should be exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030” https://indico.cern.ch/getFile.py/access?resId=0&materialId=0&confId=217656

- Designing and building the new ATLAS/CMS detector components is a project of 10++ years
- This talk largely concentrates on upgrades in the silicon trackers


Plans for the ATLAS &
CMS Upgrades

Preliminary LHC Upgrade Timeline

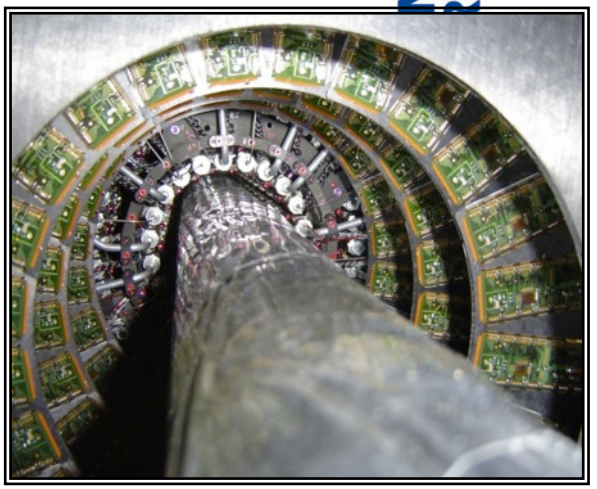


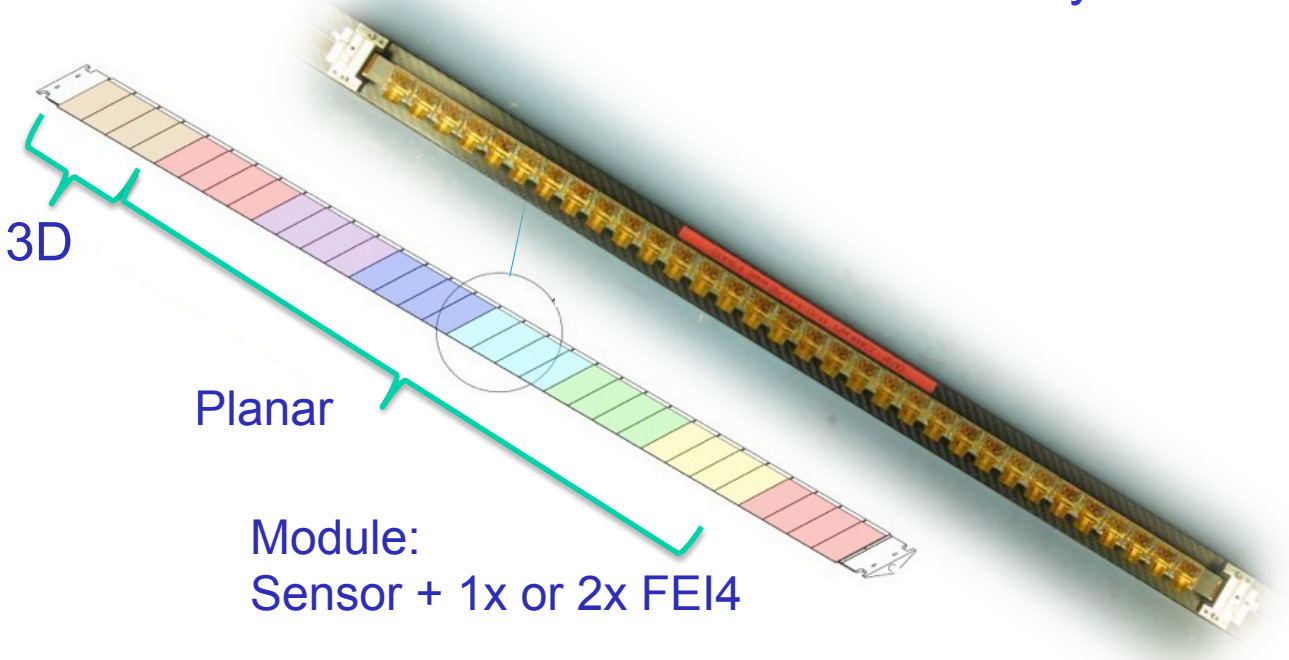
See also CERN DG New Year Presentation on 6th Jan 2013

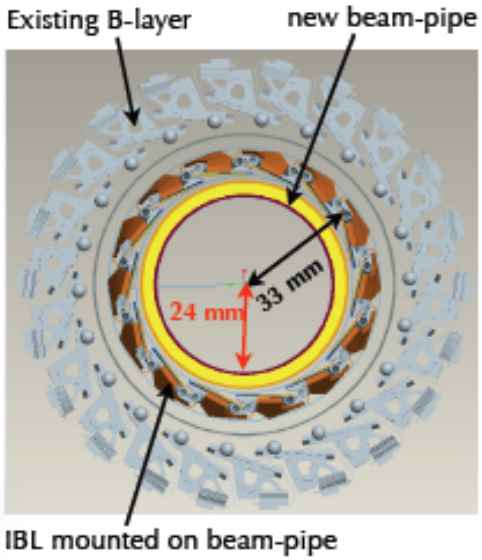
https://indico.cern.ch/getFile.py/access?resId=0&materialId=slides&confId=219327

Phase 0 ATLAS IBL

- New pixel layer around smaller beam pipe
- Current pixel package to be brought to surface
- FE-I4 Pixel Chip in 130nm CMOS
  (26880 channels at 50 x 250 μm^2)
- Per Stave 12 double chip planar + 8 single chip 3D
- 12 M Pixels per stave
- Effects shown in Jiri Masik's talk on Wednesday



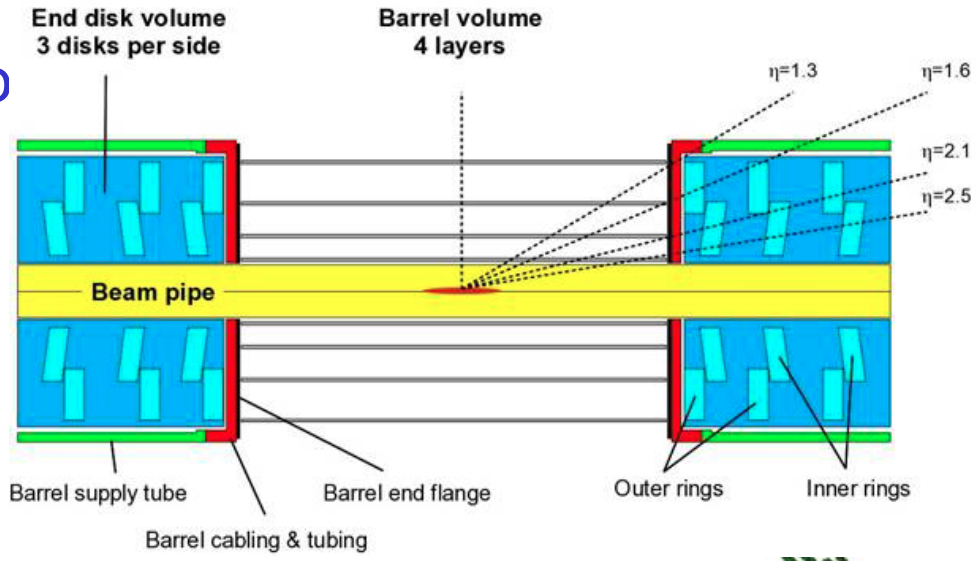


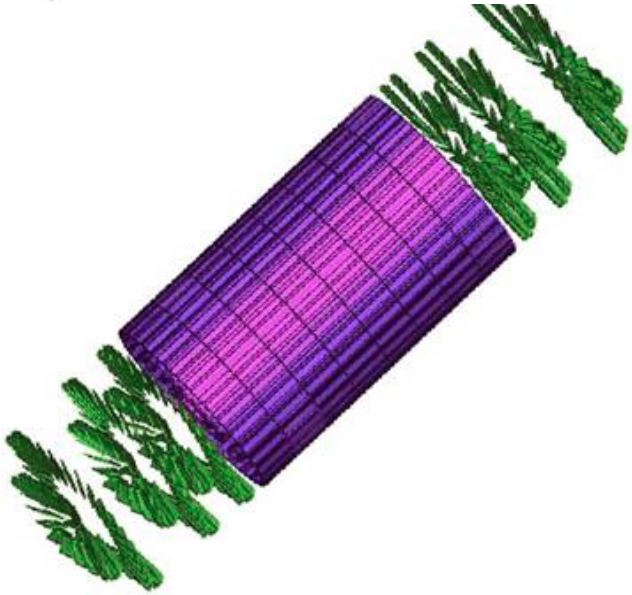


Phase-0, 100 fb^{-1}

Phase 1 CMS Pixel

- All-new Silicon pixel system to be installed 2016/17
  - **BPIX**: 4 Layers (3 now), 81 M Pix (increased by 1.6)
  - **BPIX:** Innermost layer at 29.5mm (now 39mm)
  - **FPIX**: 3x2 Disks (2x2 now), 44 M Pix (increased by 2.5)
  - New read-out ASIC (lower threshold, less dead time)
  - Less material than present now
  - Pixel size remains 100x150μm^2





Phase-1, 350 fb^{-1}

Phase 1 CMS Pixel

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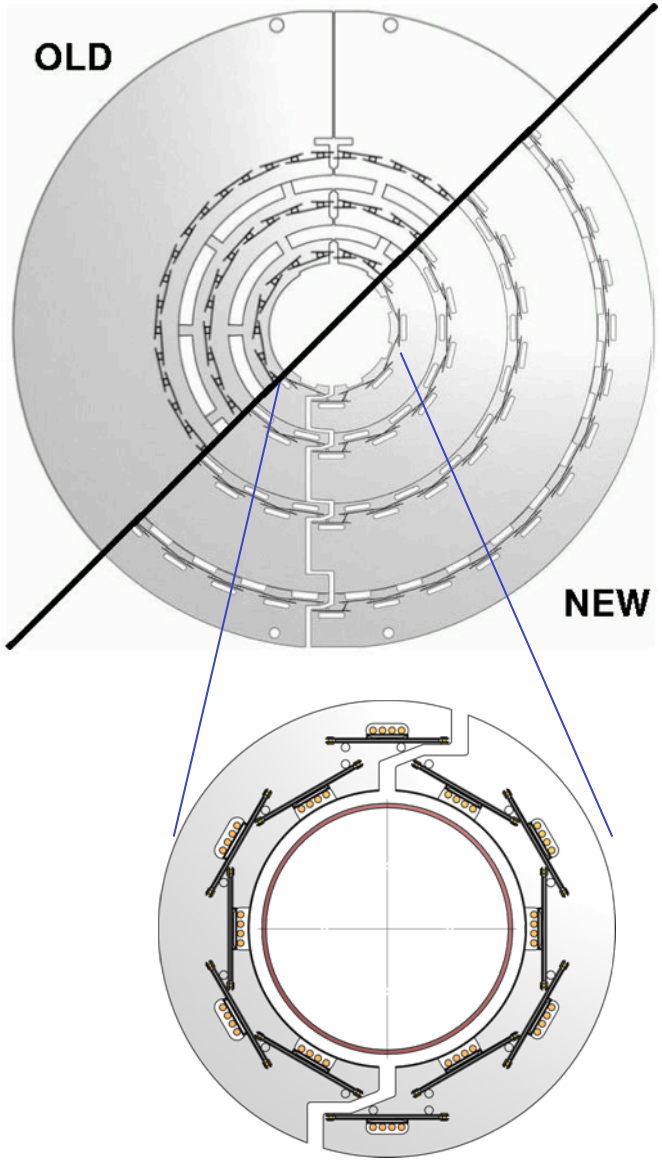
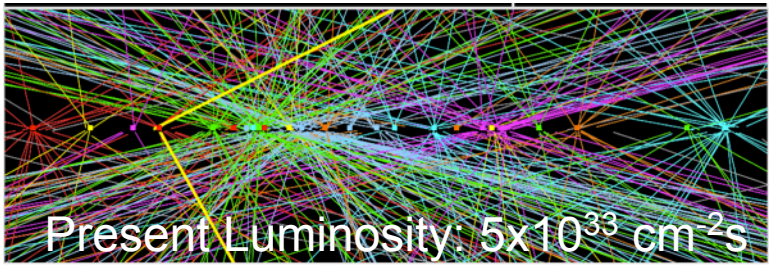


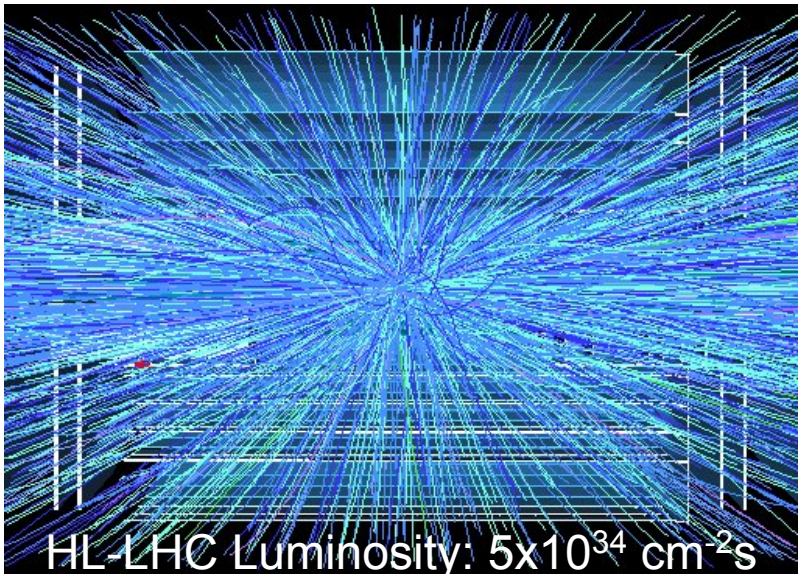
Phase-1, 350 fb^{-1}

The HL-LHC Challenge

- Higher instantaneous luminosity
  → more protons collide in one event
  - Pile up of up to 200 collisions per bunch crossing → increased occupancy
  - Higher trigger level (L1) rates must be roughly kept
  - Need more selective triggers rather than simply raising thresholds globally
- Higher integrated luminosity means higher total particle flux through detector
  - Increased radiation damage (inner layers!) **increased radiation hardness required**
- Goal is to achieve **the same (or better) performance (resolution etc.)** at the HL-LHC as at the LHC, despite the large increase in event rate

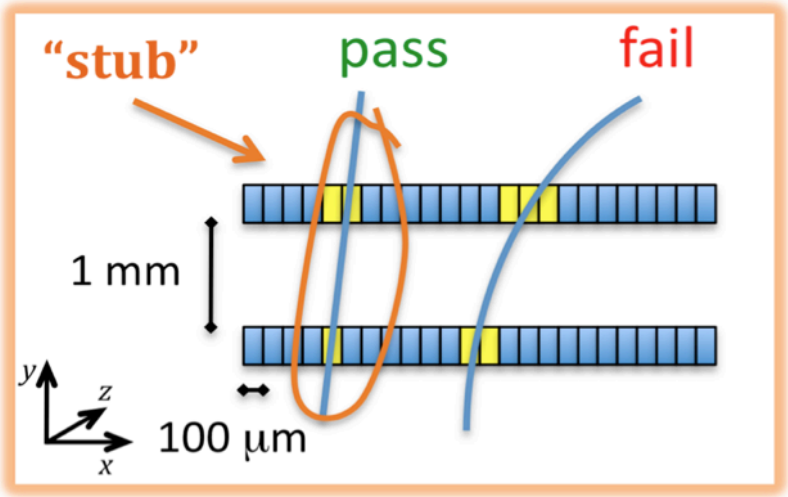


Z -> μμ event with 25 other vertices



CMS: T/DAQ Upgrades

- At present, Silicon Strip Tracker only in High-Level Trigger
- Plan to use it in Level-1 Trigger after tracker replacement
- Aim for higher tracker pipeline latency (3.2 ➔ ~6 μs)
- Tracker info available as “seeds” to High-Level Trigger
- Idea: select high-momentum tracks at local level
- look for low bending (close azimuth in adjacent modules)
- Very similar ideas pursued in ATLAS (see backup slides)



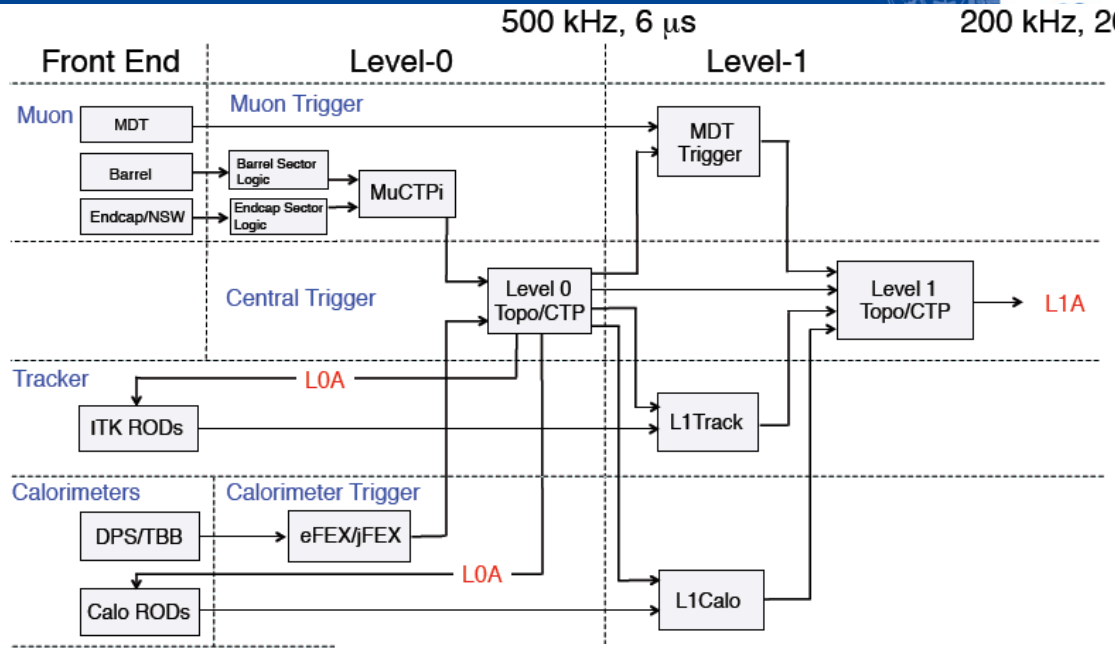
Phase-2, 3000 fb^{-1}

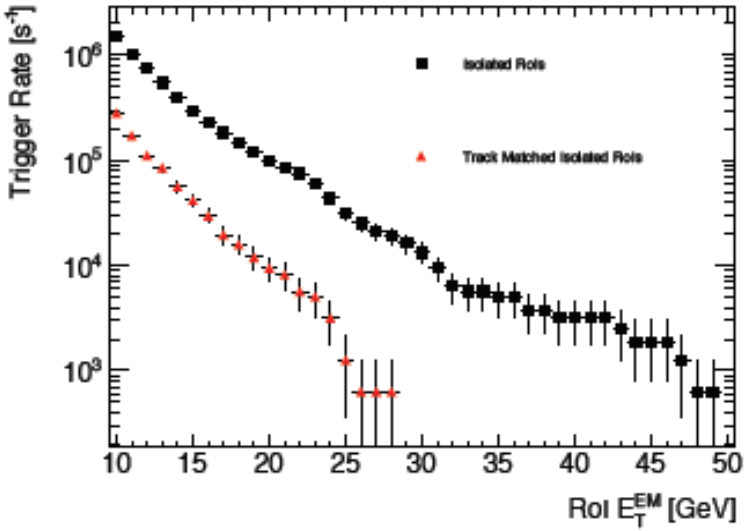
ATLAS: Split TDAQ L1 Scheme

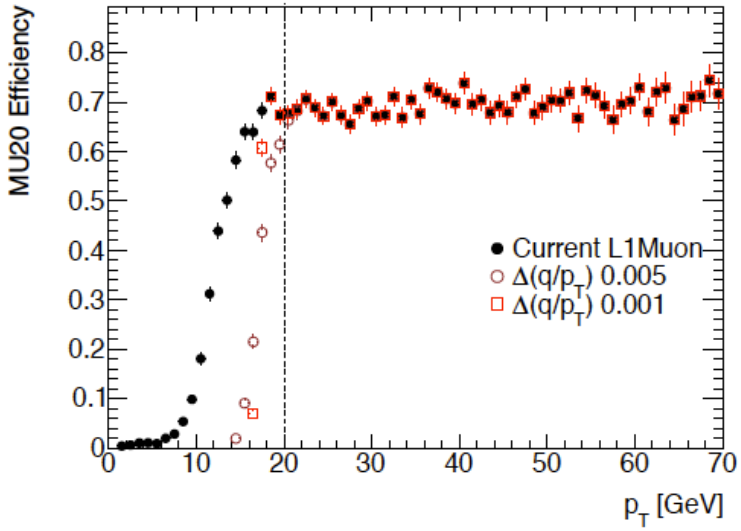
Simulation studies show that including a track trigger complements muon and EM triggers

- Improves muon P_T resolution
- Improves EM identification by matching to track

Implemented as 2-level scheme reusing Phase-I L1 trigger improvements for new L0

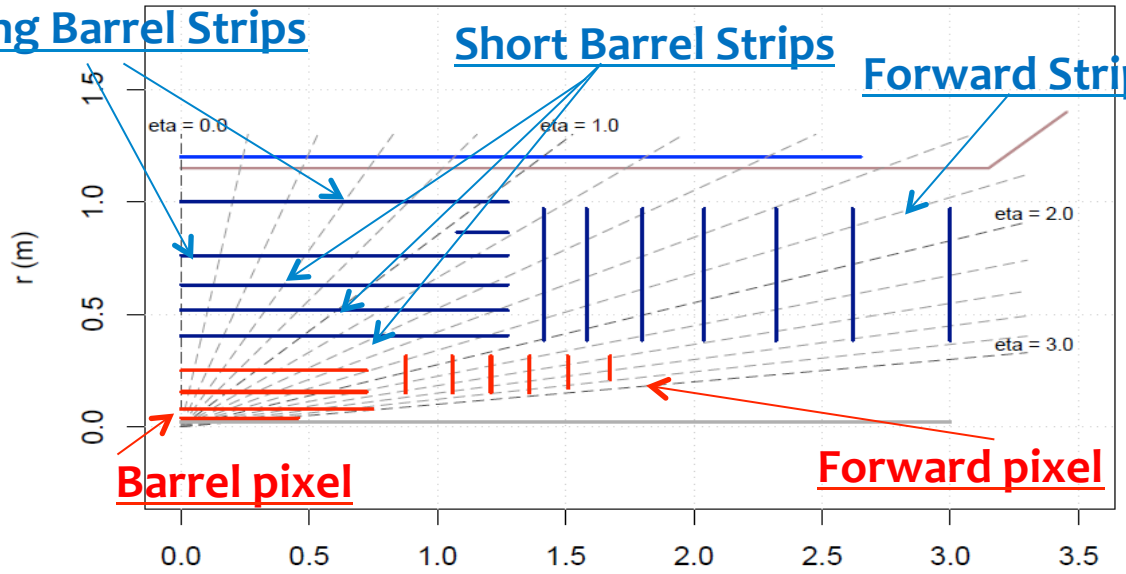




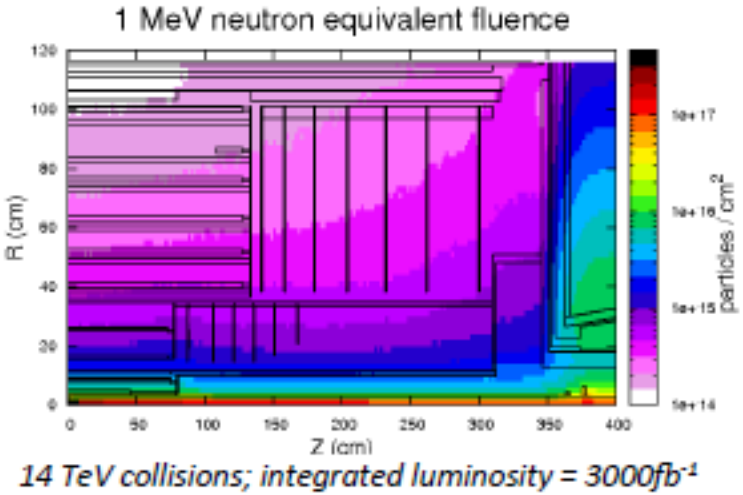


Phase-2, 3000 fb^{-1}

ATLAS HL-LHC Tracker

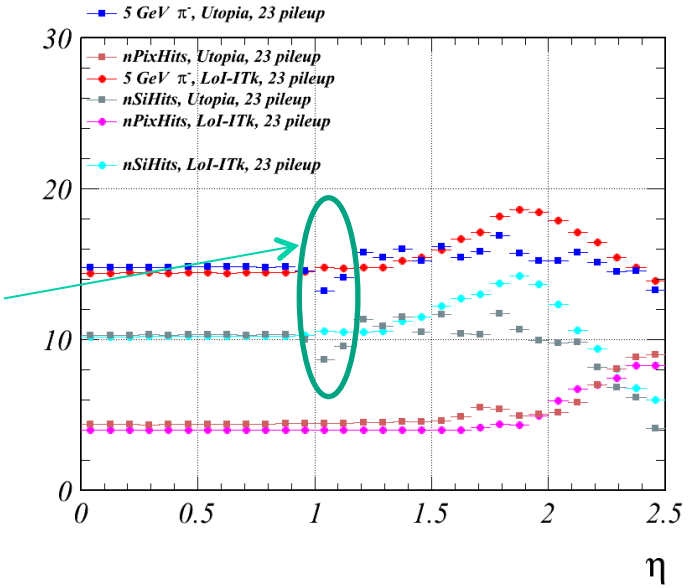


- Layout of new ATLAS Inner Tracker for HL-LHC
- Have at least 14 silicon hits within acceptance (robust tracking)



Phase-2, 3000 fb^{-1}

Effect of stub layer



HL-LHC Pixel Plans

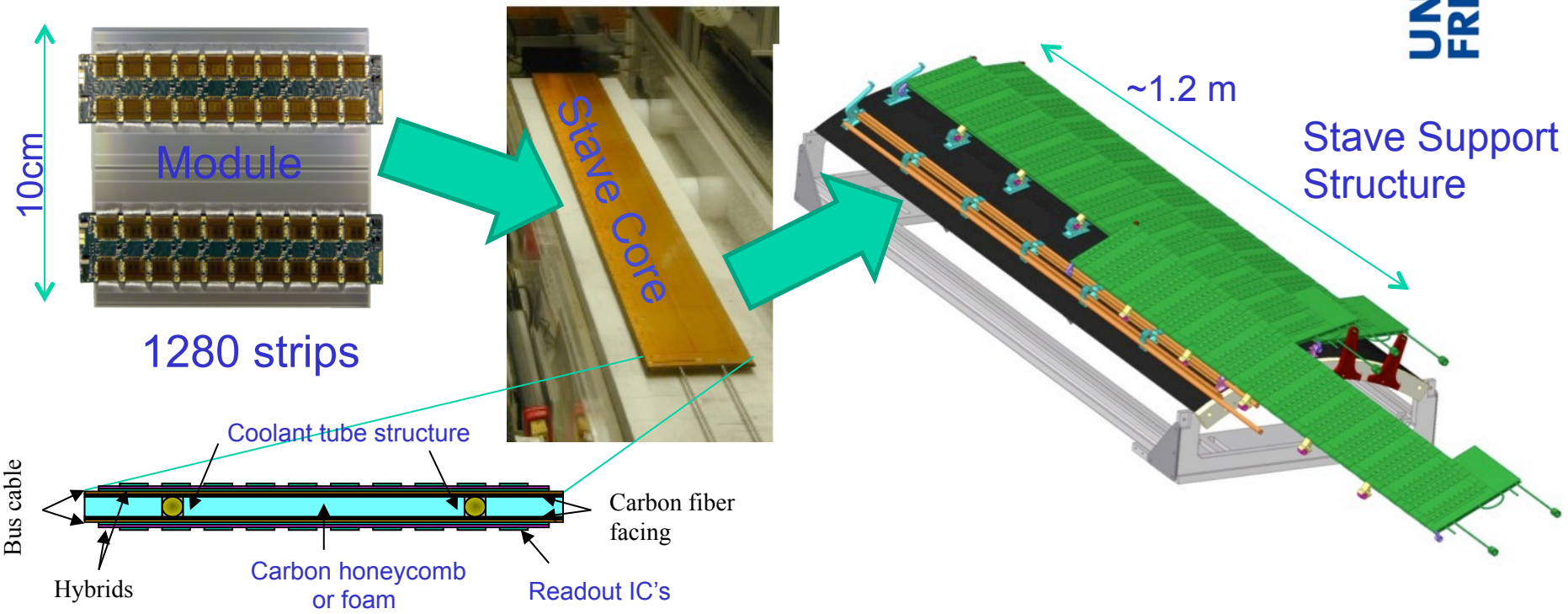
- Pixel upgrades ongoing or in the pipeline
  - ATLAS: New Innermost Pixel Layer (IBL) under installation
  - CMS: New pixel system for Phase 1
  - Both need new pixels in Phase 2, with developments less advanced than for strip systems
  - Options: Thin sensors (e.g. 150μm) in planar and/or 3D technologies, 65nm CMOS ASICs, diamond also studied

- ATLAS (4 barrels, 6 EC disks)
- Pixels: 50×250μm^2 (considering 25×125 μm^2 for inner layers)
- 8.2 m^2 with 638M channels
- Different layouts and sensor geometries under study

- CMS (4 barrels, 3 disks)
- Aim: significantly smaller pixel size. Options down to 30×100 μm^2
- Considering to cover up to η≈4

Phase-2, 3000 fb^{-1}

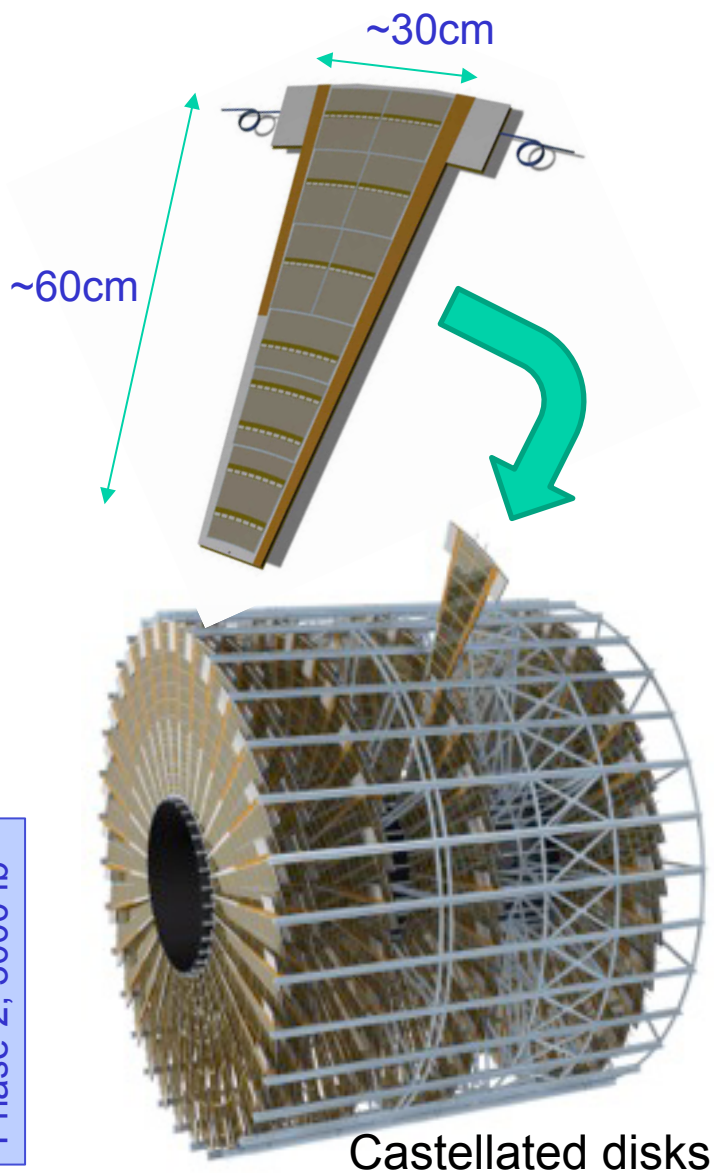
ATLAS Strips: Barrel Stave Concept



Phase-2, 3000 fb^{-1}

- Stave Modules
  - 2 short (23.8mm) + 3 long (47.6mm) layers
  - Hybrid: ASICS glued to kapton-flex and wire-bonded
  - Populated hybrid directly glued to silicon sensor, strips connected via wire bonds
  - Prototyping with Hamamatsu 6" sensor and ABCn ASIC (250nm technology)
- Double-sided Stave
  - 48 modules glued to core structure
  - Carbon fibre laminated to foam filler
  - Embedded cooling pipes (CO_2)
  - Co-cured bus tape for data and power
- Attached to global support structure
  - Carbon fibre support structure with brackets for attachment
  - End insertion for easy assembly and access

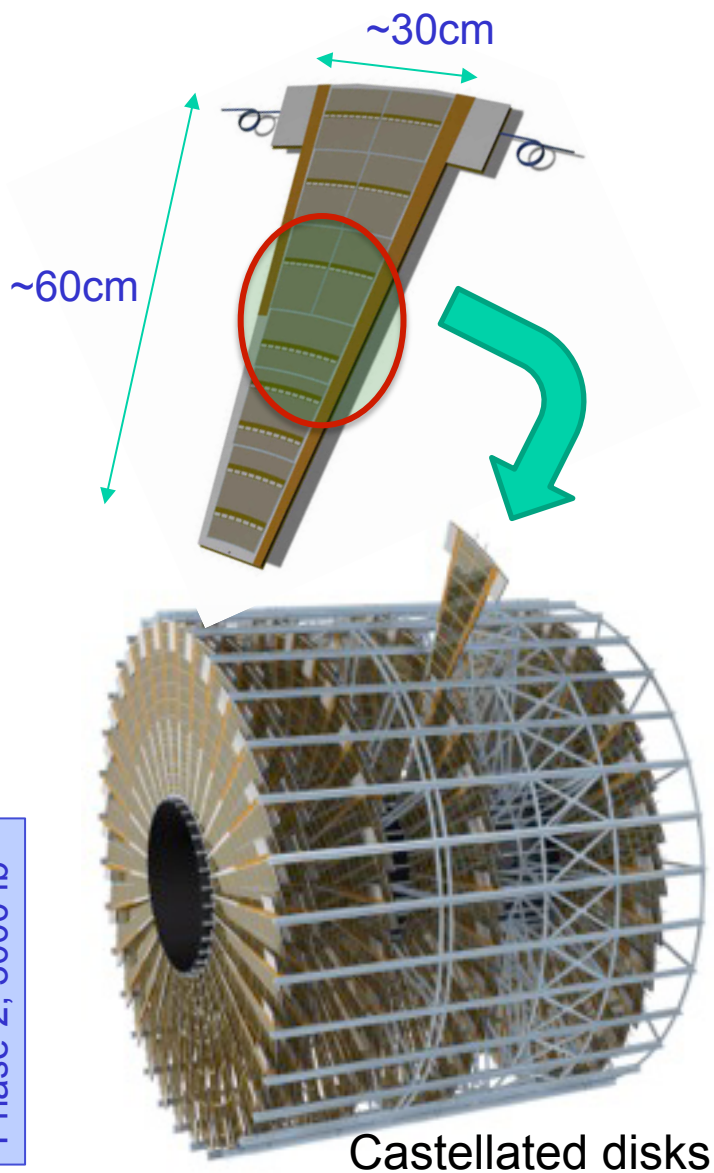
ATLAS Strips: Stave End-cap = Petal



- 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
- ***Petalet*** Programme underway
  - Double-sided, six-sensor prototype
  - Explore many options
  - Prototypes sensors & hybrids available
  - First modules produced successfully

Phase-2, 3000 fb^{-1}

ATLAS Strips: Stave End-cap = Petal



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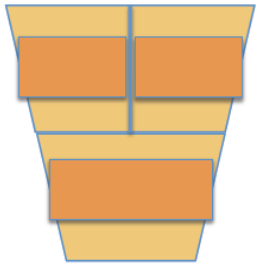
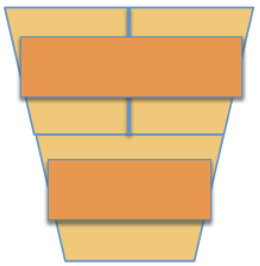
Phase-2, 3000 fb^{-1}



Petalet: use 4" wafers to produce sensors and build a small petal

Allows to test petal specific issues, like how to configure the bus tapes.



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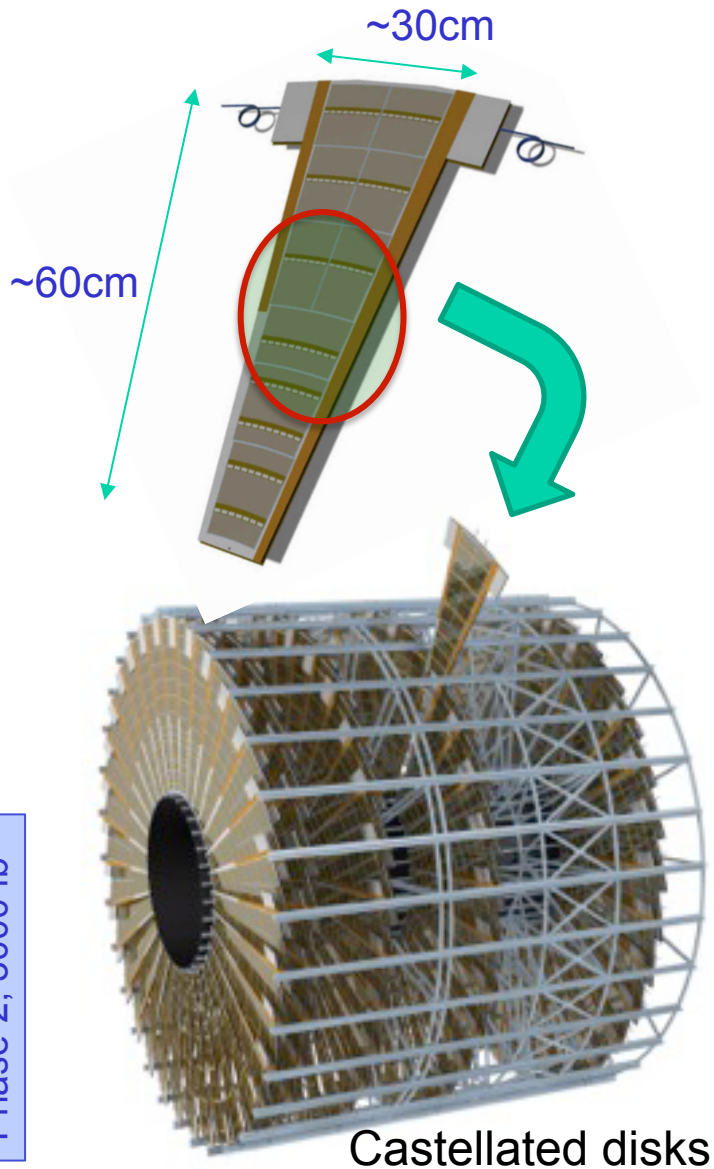

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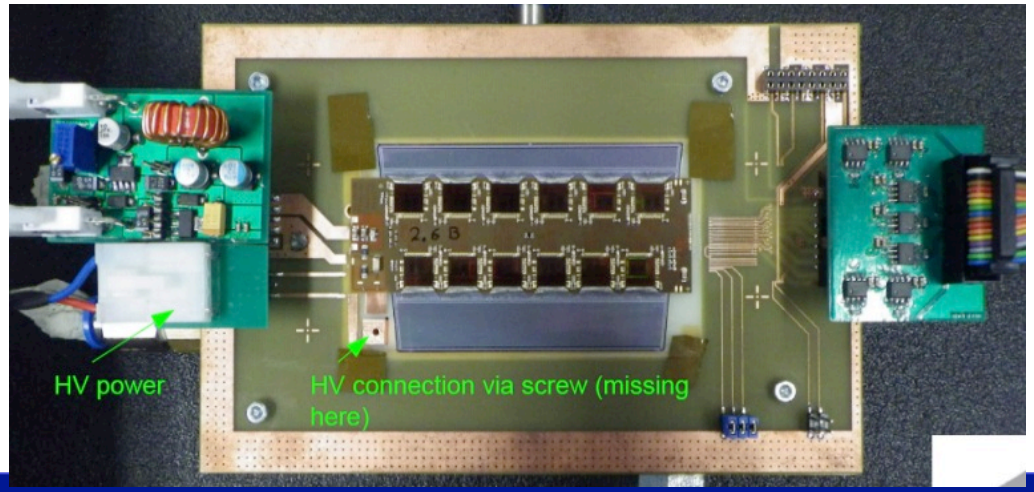
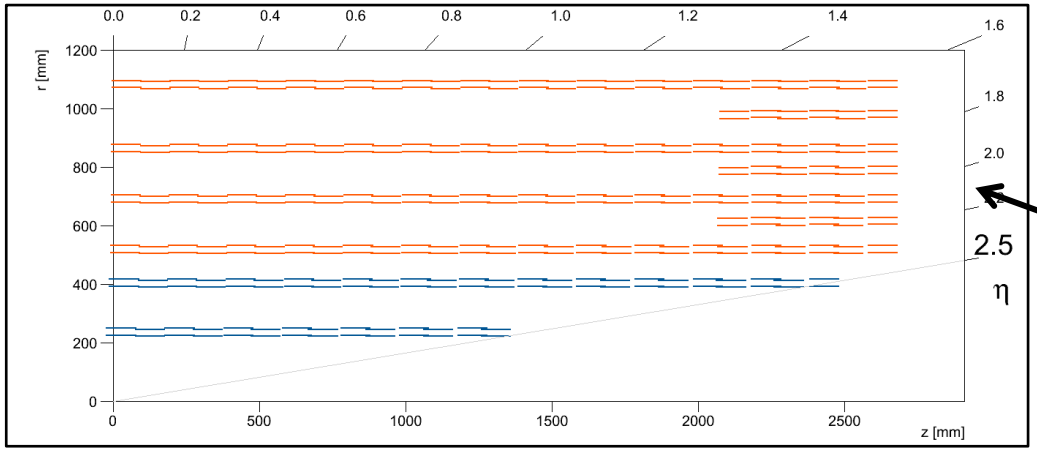
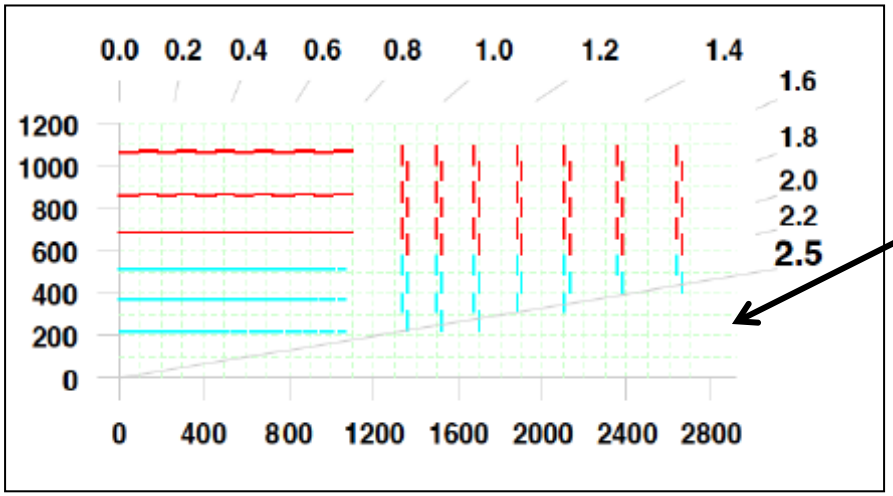


Phase-2, 3000 fb^{-1}

CMS HL-LHC "Strip" Tracker



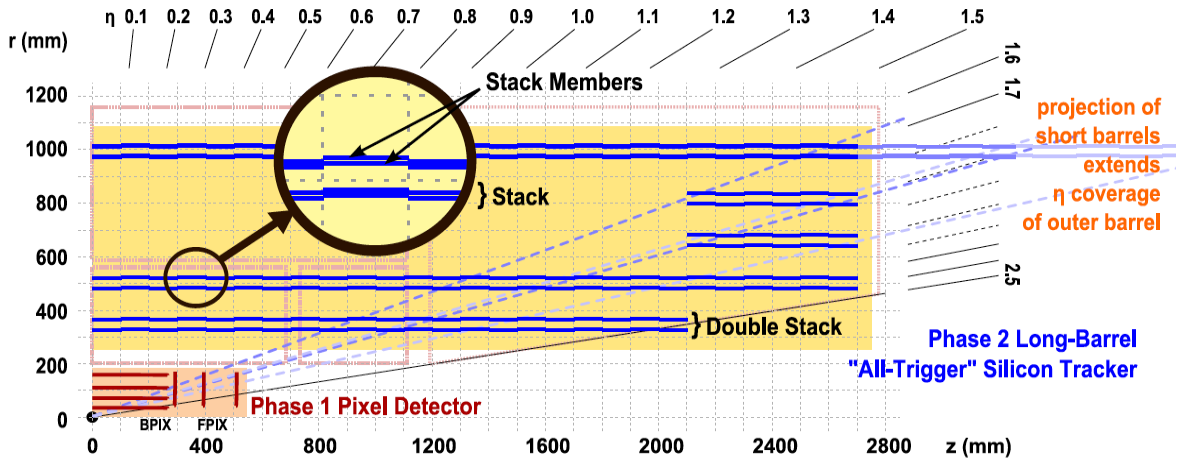
- Several options under discussion, two main ideas being followed up.
- Option 1: ***Long barrel***
  - 10 layers of "stacks"
  - 5 double stacks with 4 cm separation
  - 100 μm x 1mm pixels (not really a strip tracker)
  - Designed for local track trigger
- Option 2: ***Barrel + end cap***
  - Inner strip layers use pixels + strips (*PS Modules)*
  - Outer layers use strips *(2S Modules)*
  - Designed for tracking performance



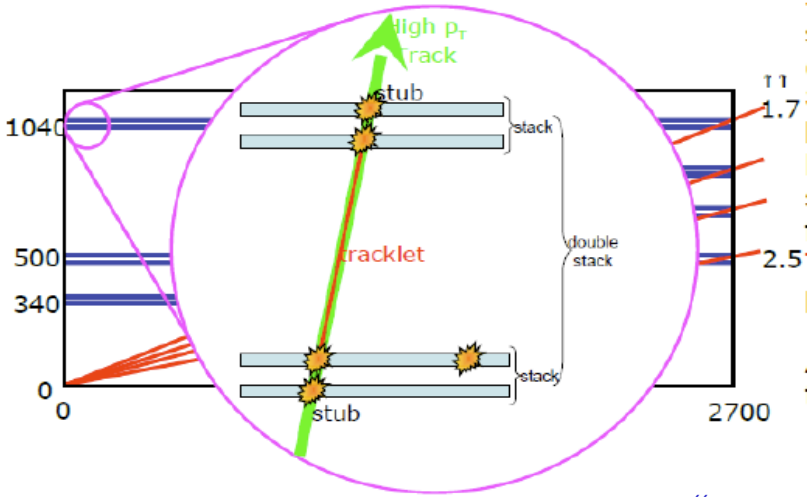
+ pixel system
(4 barrel layers and 3 disks)

Phase-2, 3000 fb^{-1}

CMS "Long-Barrel" Double-Stack Concept

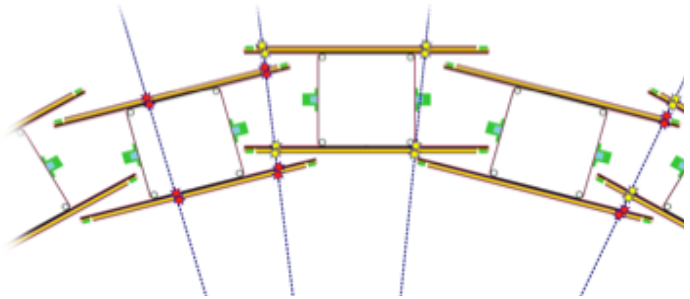


6 long layers = 3 Super layers



Pairs of stubs are combined to form "tracklets"

ϕ arrangement within double-stack layer

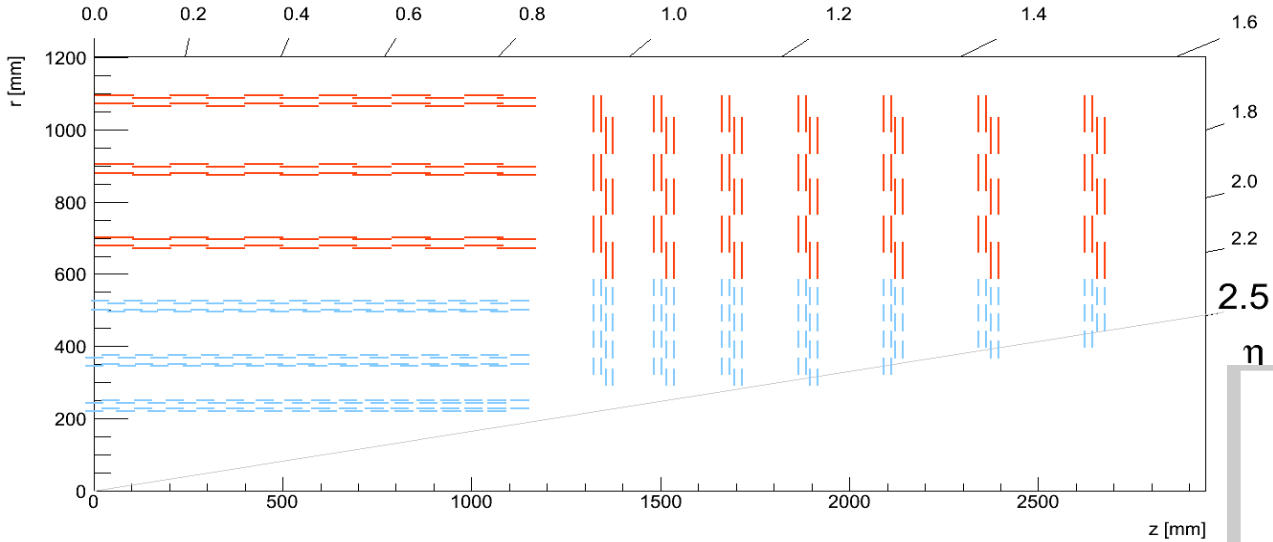


Common supporting mechanics

Phase-2, 3000 fb^{-1}

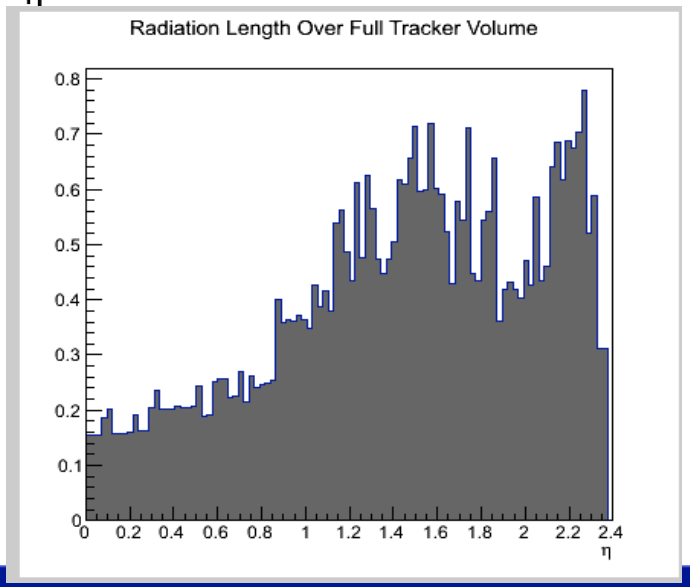
CMS: Barrel & End Cap concept

- "Long-Barrel" optimised for local track trigger. "Barrel & End Cap" driven by tracking performance and low mass
- Needs generic approach for L1 track finding



7416 PS modules

9784 2S modules



p_T resolution @ 100 GeV (offline)	1.1% – 2.7%
p_T resolution potential @ 100 GeV (L1)	1.9% – 2.7%
z_o resolution potential @ 100 GeV (L1)	0.079 – 0.086

CMS: Strip Module Types

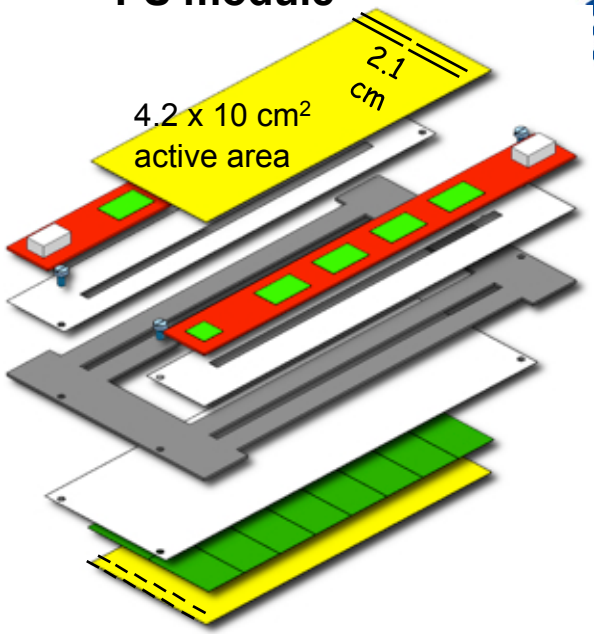
- Only two module types used in 2S/PS tracker layout (compared to 27 in current tracker)
- In both designs distance between sensors adjustable (during design phase) to adjust search window for radius
- **PS module:** sandwich of **P**ixel and **S**trip sensor for inner part of tracker (<50 cm radius)
  - 21 mm long strips on top sensor (100 µm pitch)
  - 0.1 x 1.5 mm^2 pixels on bottom sensor
- two tiers of front-end chips
  - data from strip FE chips transferred to pixel chips
  - correlation and stub formation performed in pixel chip periphery

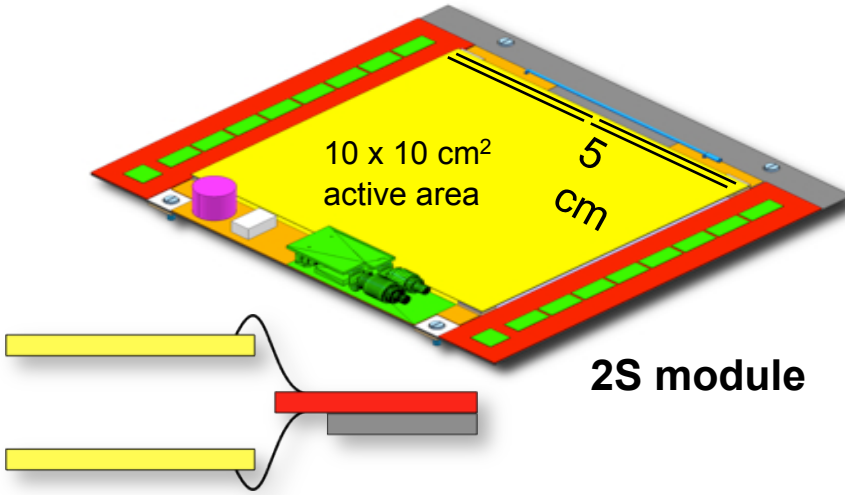
2S module: 2 Strip sensors for outer region

- No Z information
- Hybrid bonded to both sensors

Phase-2, 3000 fb^{-1}

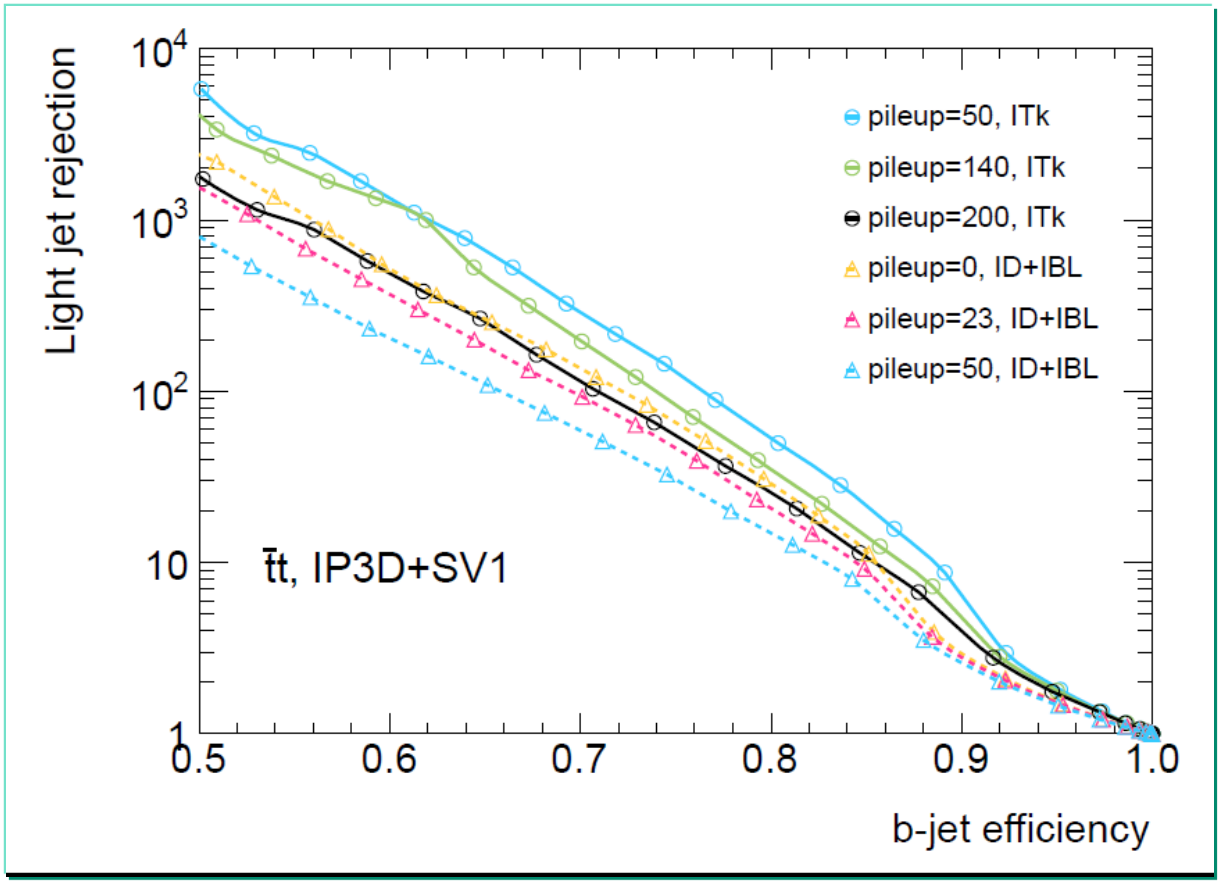
PS module





2S module

Performance after Upgrades



- ATLAS b-jet efficiency summary for Phase 1 (“ID+IBL”) and HL-LHC (“ITk”) shows that performance will be roughly kept

Summary & Outlook

- **ATLAS & CMS** need to undergo series of upgrades
  - Fully exploit LHC physics potential (Higgs couplings, spin,…)
  - Adapt to increasing LHC luminosity
  - Keep up detector performance in adverse conditions
- Phase-0 (2013/2014 shutdown) :
  - Insertable B-Layer installation
  - No new silicon installations (reduce temp of pixel and strip system)
- Phase-1 (2016/2017 shutdown) :
  - Complete new pixel system
  - Fast Track Trigger
  - No pixel or strip installations foreseen
- Phase-2 or HL-LHC (2022/23 shutdown):
  - Inner Detectors challenged by high radiation & occupancy
  - CMS & ATLAS build completely new all-silicon ID (pixel and strips)
  - Prepare the detector for HL-LHC and 8-10 more years

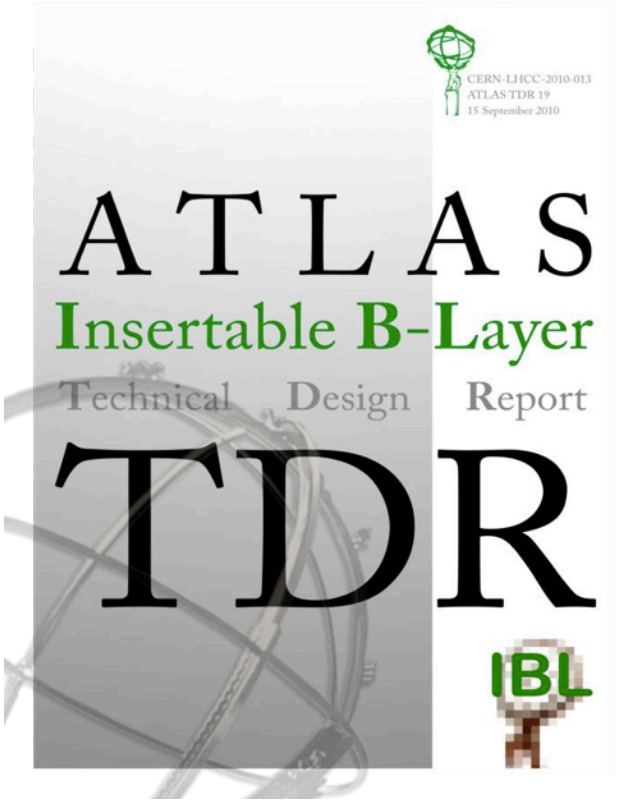
Credits

- Based on material from and/or discussions with a large number of ATLAS and CMS colleagues
- Duccio Abbaneo, Tony Affolder, Phil Allport, Tom Barber, Didier Contardo, Ingrid Gregor, Marc Hauser, Roland Horisberger, Manfred Jeitler, Katja Klein, Susanne Kühn, Carlos Lacasta, Jeff Spalding et al

BACKUP only after this slide

Phase-0

- LHC:
  - Shutdown **18 months** (foreseen to end Sep 2014)
  - Consolidate the superconducting splices for (almost) design energy (**13 TeV**) and nominal (**10^{34} cm^{-2}s^{-1}**) luminosity ➔ **50 fb^{-1}**
- ATLAS:
  - **New inner pixel layer** (IBL)
  - **Muon system upgrades**
  - Trigger
  - Consolidation & Upgrades



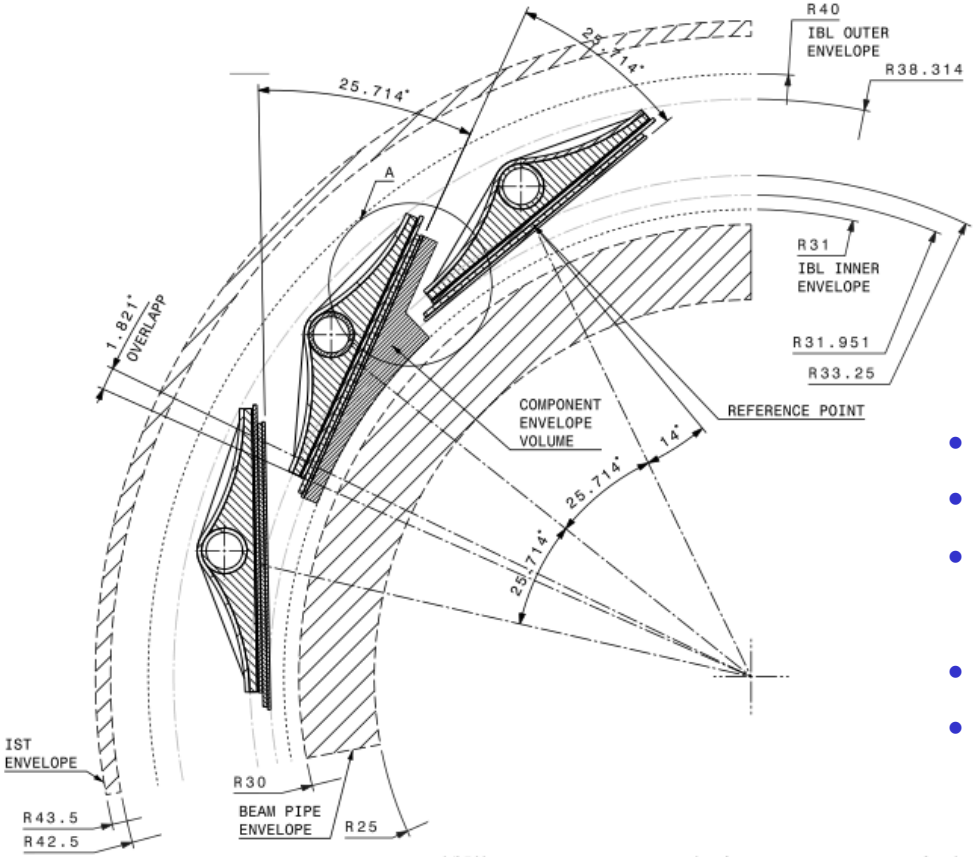
https://cdsweb.cern.ch/record/1291633

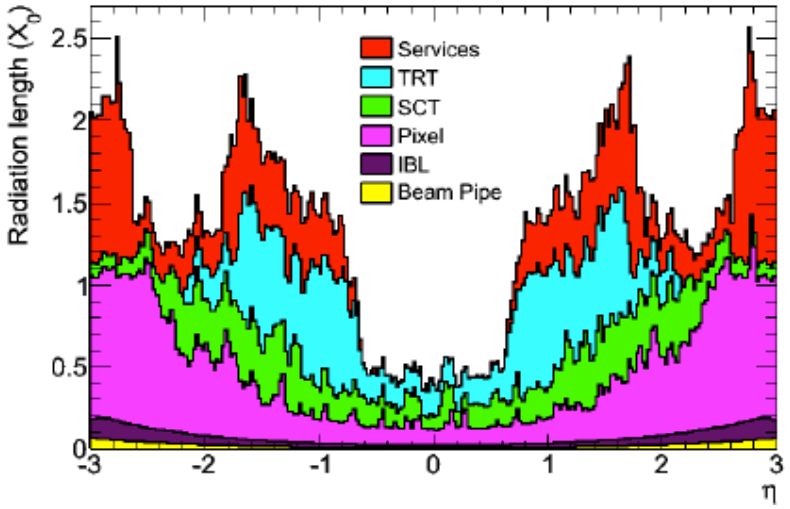
https://cdsweb.cern.ch/record/1451888

Phase-0, 100 fb^{-1}

Insertable B-Layer

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



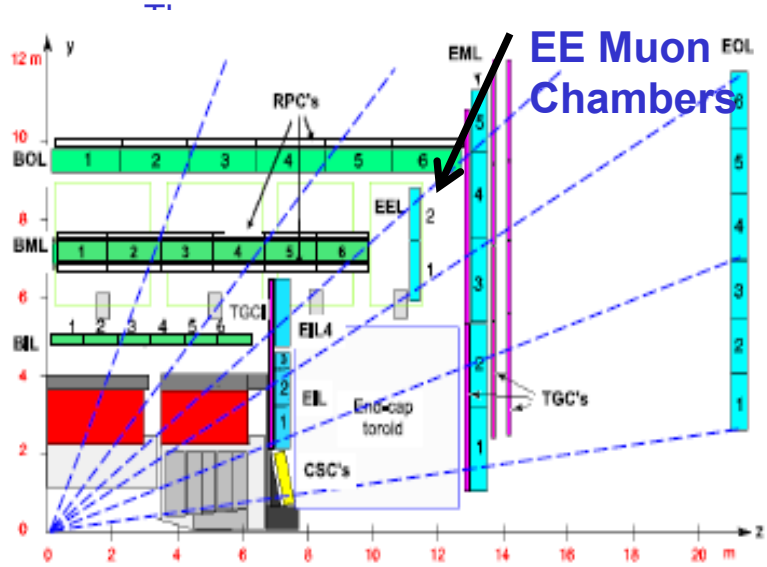


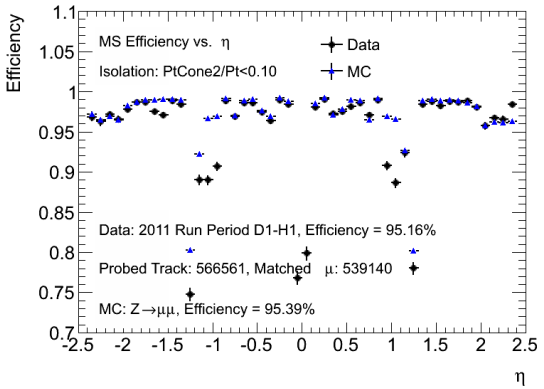
- Reduced material budget: **0.015 X_0**
- Coverage: z = 60cm, **|η| < 2.5**
- Sensors **@33mm** (now @50.5mm)
  ➔ smaller beam pipe (29 ➔ **25mm**)
- **14 staves** with Φ overlap
- No η overlap due to clearance
  ➔ minimize inactive edge region

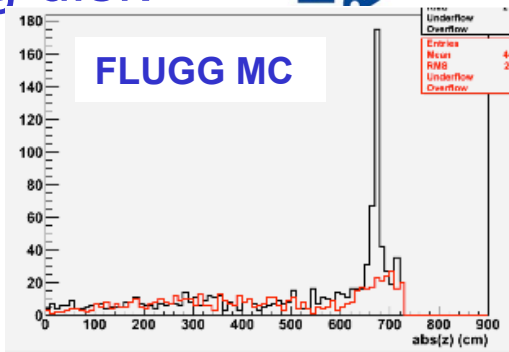
Phase-0, 100 fb^{-1}

Phase-0 Muon System

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







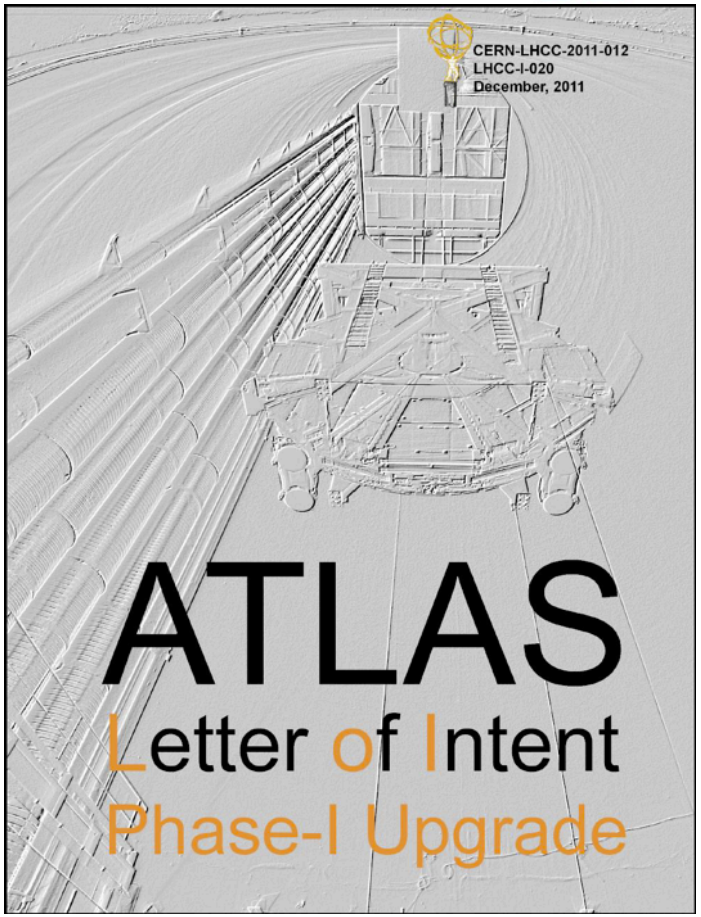
Beam Interaction hits
without & with shielding

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

Phase-0, 100 fb^{-1}

Phase-1

- **LHC**
  - **14 months** shutdown - consolidation of injector chain
  - Energy 14 TeV
  - Peak luminosity **2 x 10^{34} $cm^{-2}s^{-1}$**
- **ATLAS**
  - **New Muon Small Wheels**
  - **Fast track trigger at "Level-1.5"**
  - Higher granularity in Level-1 trigger
  - **New diffractive physics detector stations**
  - All upgrades to be **compatible with Phase 2**

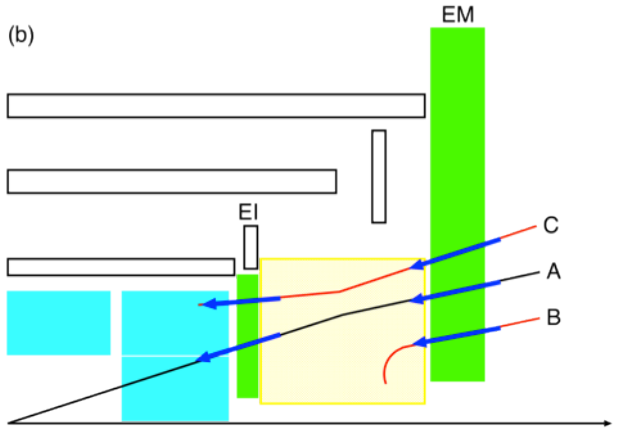


https://cdsweb.cern.ch/record/1402470/

Phase-1, 300 fb^{-1}

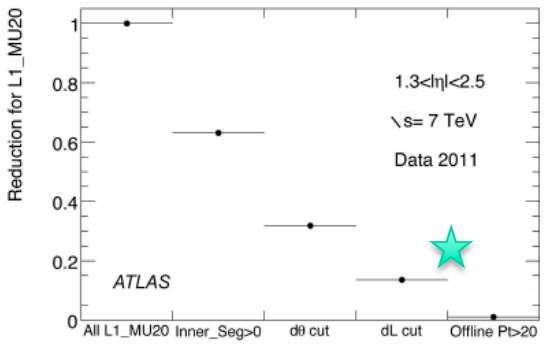
New Muon Small Wheels

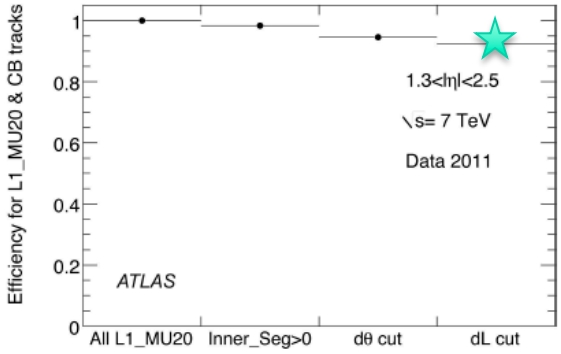
- Trigger on low P_t leptons, but…
  - High rates in muon system from cavern background, especially in forward region
- New Small Wheel (nMSW)
  - Equipped with precision tracker that works up to the ultimate luminosity $5x10^{34}$ $cm^{-2}s^{-1}$
  - Reduce fake triggers by large factor: require segment in small wheel (EI) pointing to interaction point



Phase-1, 300 fb^{-1}

★ the nMSW segment is matched in (η−φ) to triggering segment

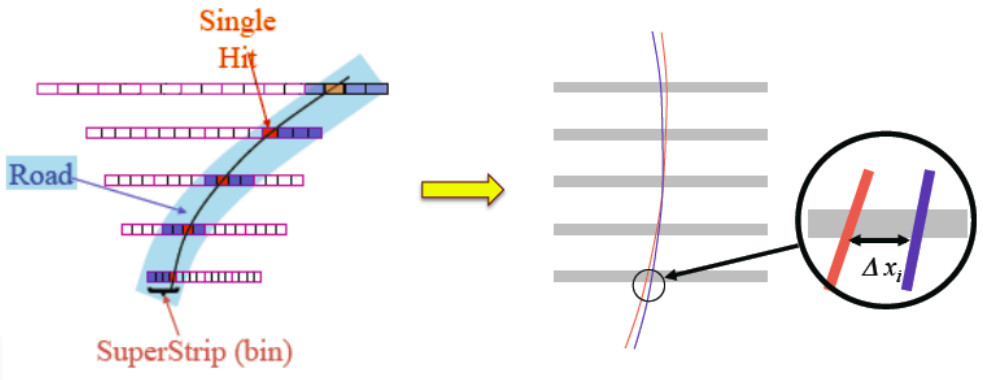




Trigger: FastTracKer FTK

- Current Trigger system
  - Level-1 (L1): hardware based (~50 kHz)
  - Level-2 (L2): software based, full granularity data (~5 kHz)
  - Event Filter: software trigger (~500 Hz)
- FTK: Global hardware based ("Level 1.5")
  - Derived from CDF Silicon Vertex Trigger (SVT)
  - Inputs from Pixel and Silicon Strips (SCT)
  - Data in parallel to normal read-out
  - Input 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

Phase-1, 300 fb^{-1}

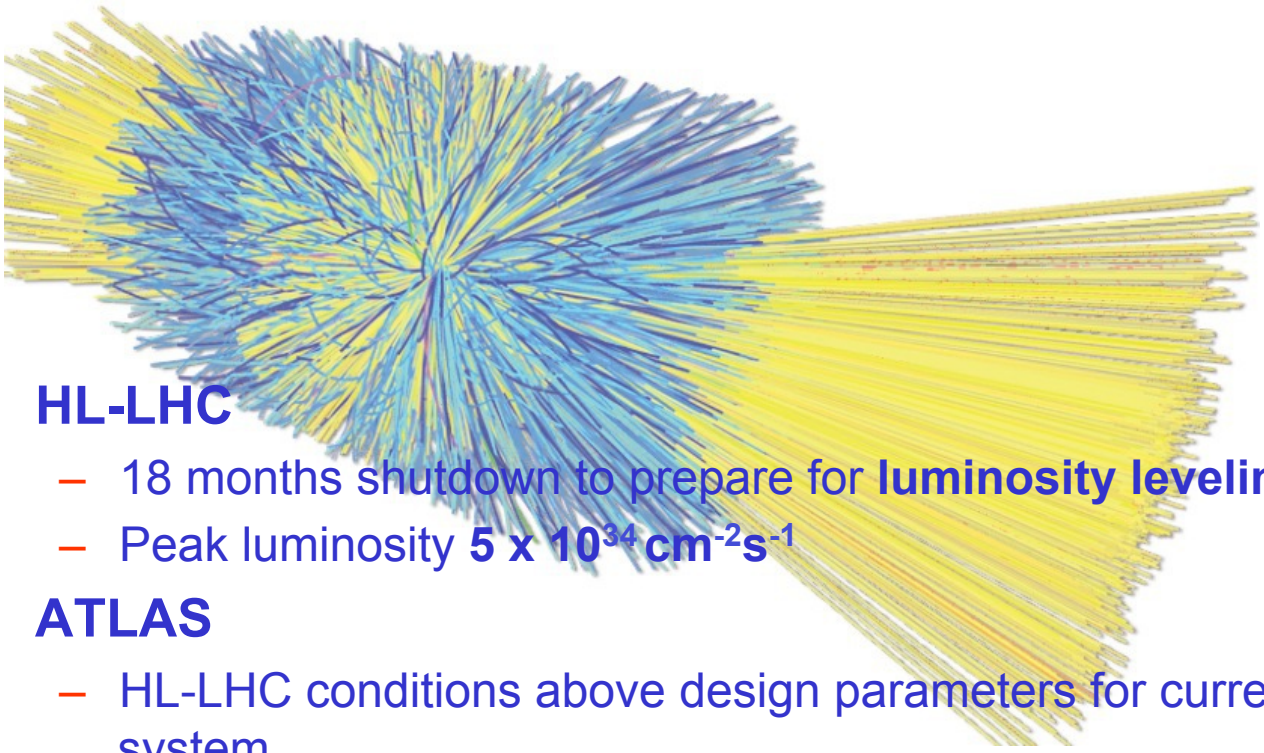


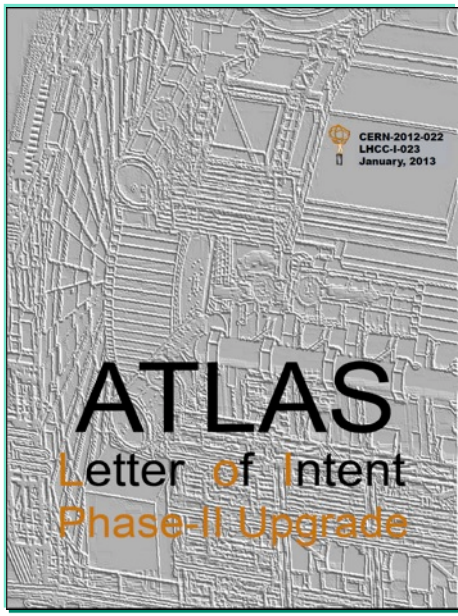
Pattern recognition in coarse resolution (superstrip➔road)

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-2



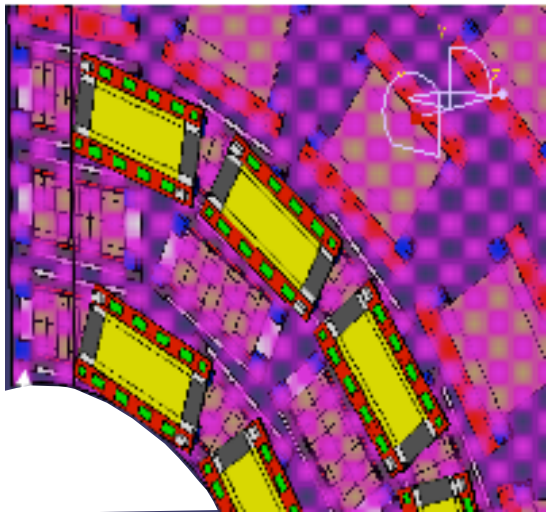


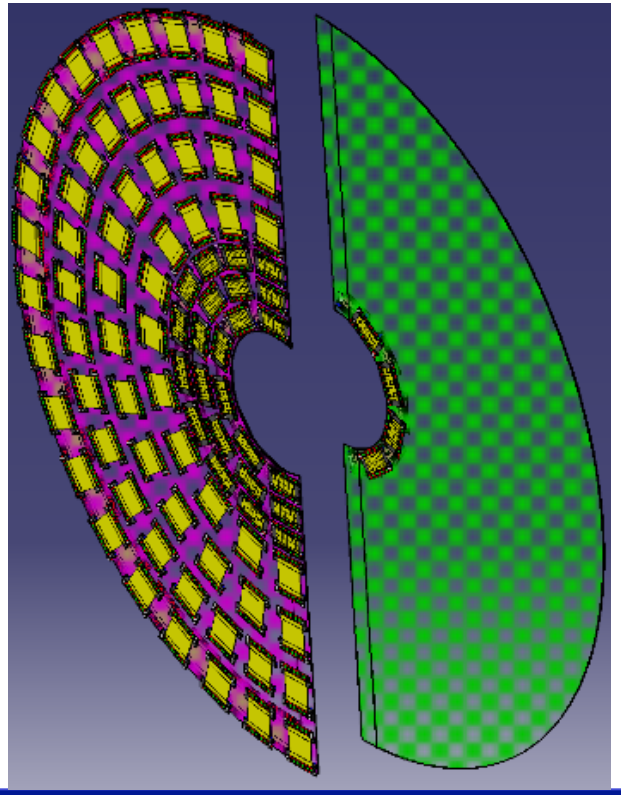
- **HL-LHC**
  - 18 months shutdown to prepare for **luminosity leveling**
  - Peak luminosity **5×10^{34} cm^{-2}s^{-1}**
- **ATLAS**
  - HL-LHC conditions above design parameters for current system
  - Inner Tracker LOI presented to LHCC few weeks ago
    - **Inner Detector upgrade (replacement of entire ID)**
    - Upgrade of Forward Calorimeters + New LAr calorimeter electronics
    - L1 track trigger
    - Upgrade of Muon system

Phase-2, 3000 fb^{-1}

CMS: Silicon Strip Endcaps

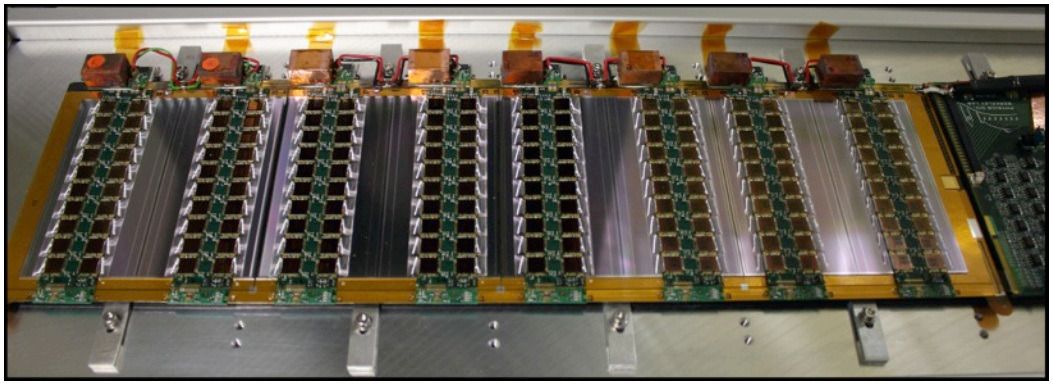
- End cap design based on barrel modules (with minimal modifications)
- Avoid multiple module types (as in present CMS end cap)
- Simplify production
- Price to pay is additional overlap:
  - More silicon than really needed (but aim to greatly reduce overall material budget)





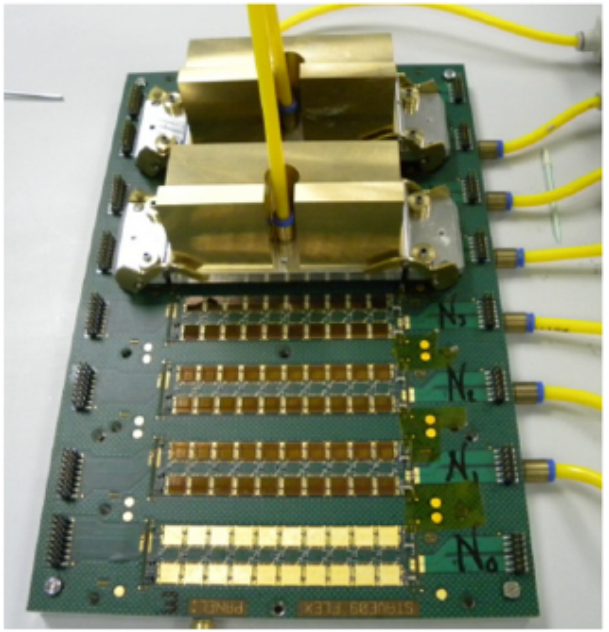
Phase-2, 3000 fb^{-1}

Strips: Stave Module Production



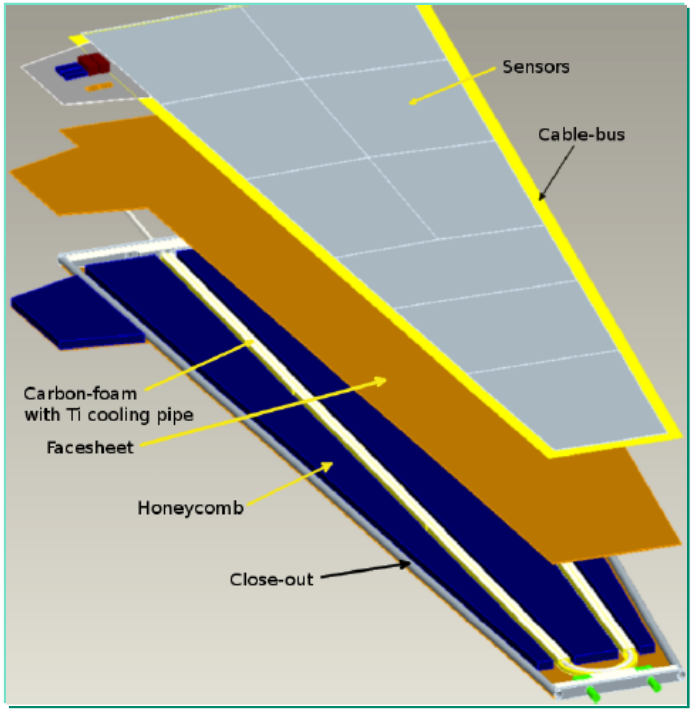
- Focus on mass-production
  - Hybrid panelisation for chip population
  - Testing on panel
  - Simple vacuum pickup tooling
- 8 production sites
  - ≈70 Modules produced

- *Stavelet* Program
  - Three single-sided 4-module "*Stavelets*"
    - DC-DC & serial powered
  - Allow testing of construction and powering options
  - Two full-length staves also in production, doubled-side *stavelets* planned
- Future Plans
  - 256 channel ASIC being designed (130nm)
  - Halve number of chips → lower power
  - New readout protocol

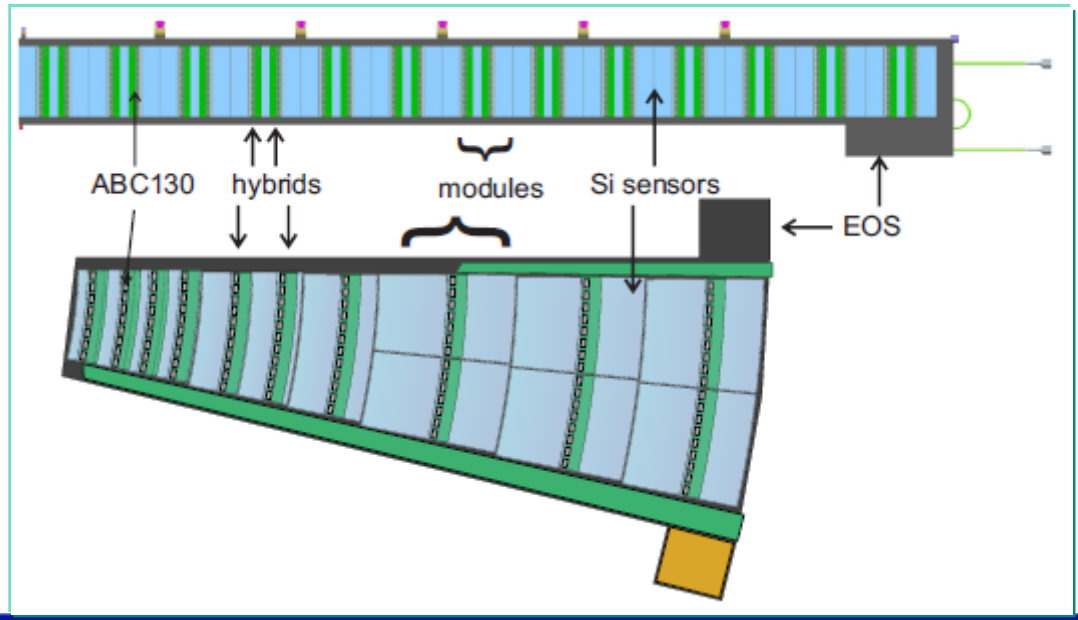


Phase-2, 3000 fb^{-1}

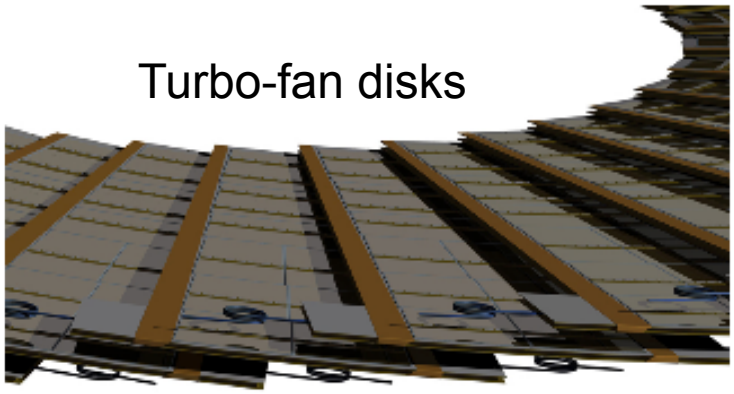
ATLAS Strips: Stave End-cap = Petal



- End-caps follow stave concept closely
- 6 rings of sensors with radial strips, glued onto bus tape, glued onto carbon core
- First petal cores produced

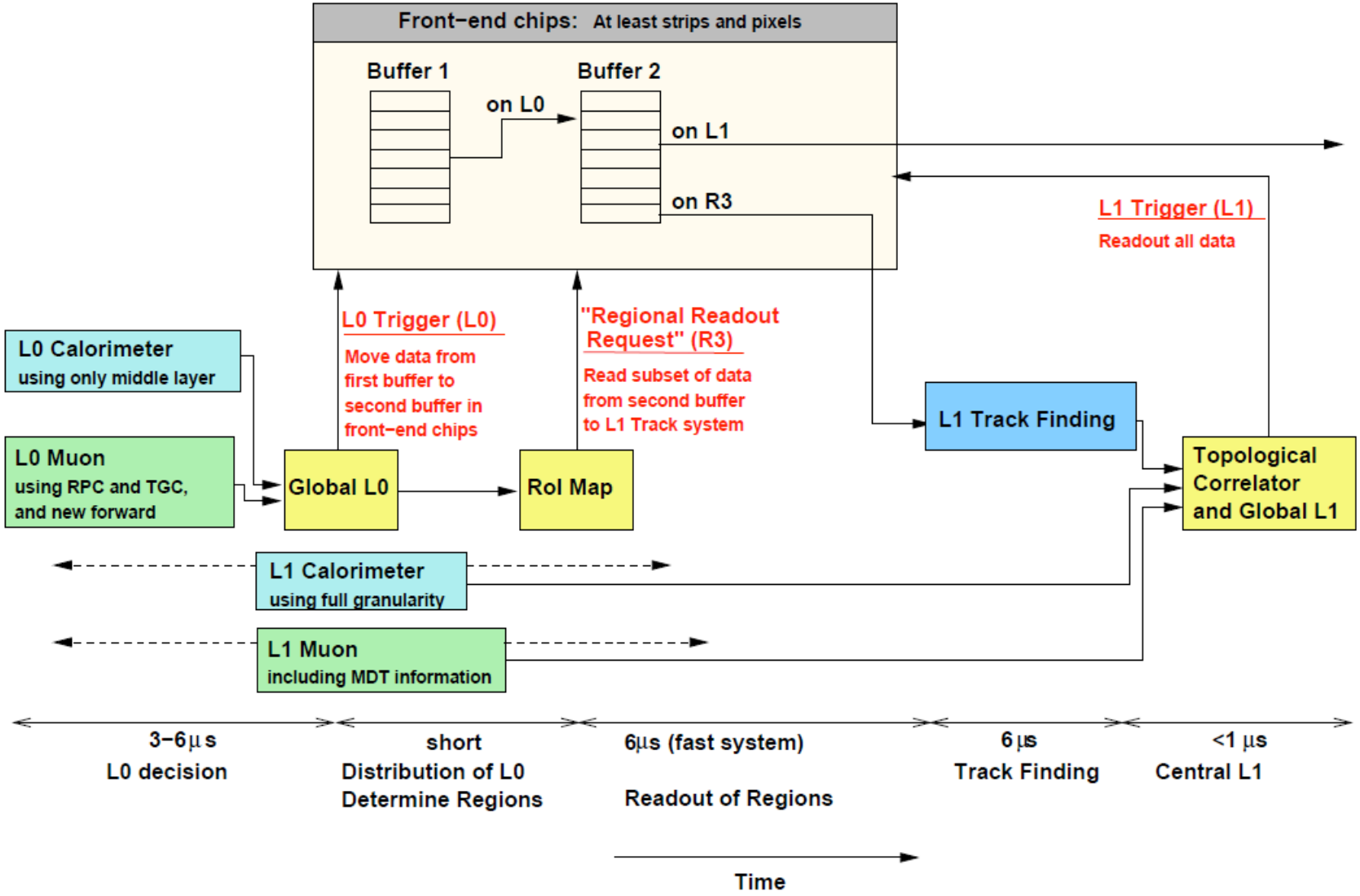


Turbo-fan disks



Phase-2, 3000 fb^{-1}

ATLAS: Split TDAQ L1 Scheme



Phase-2, 3000 fb^{-1}