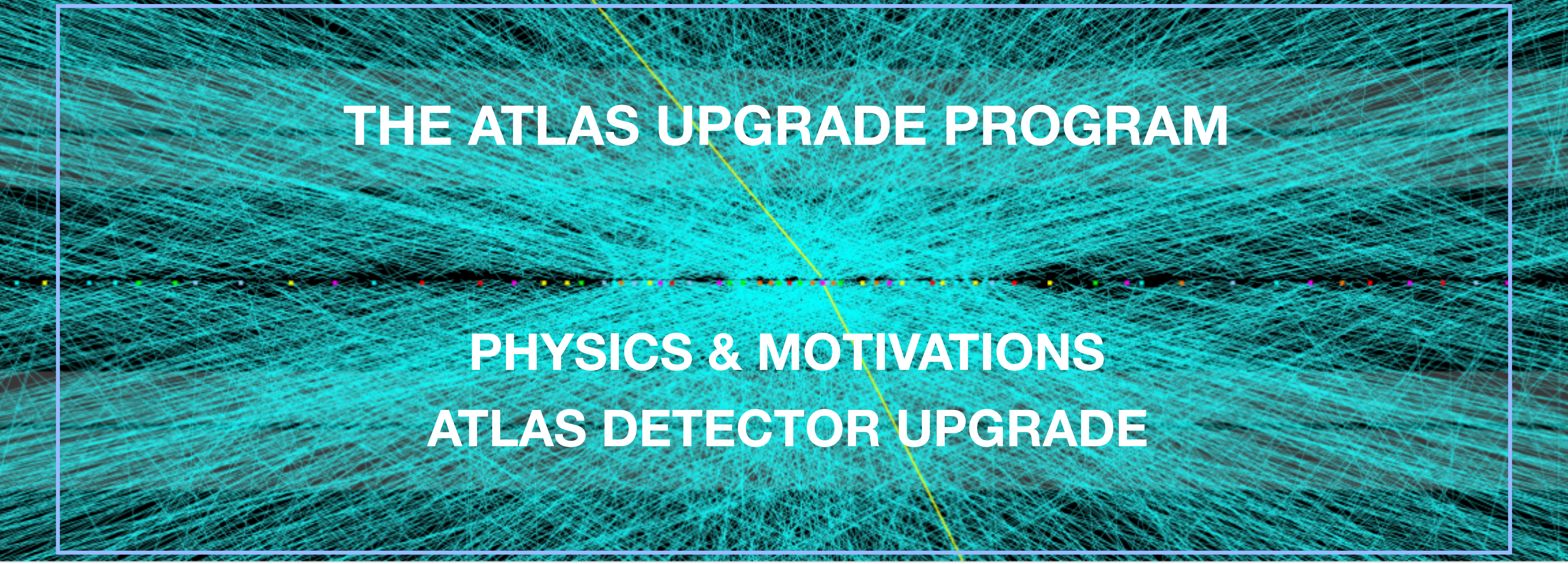
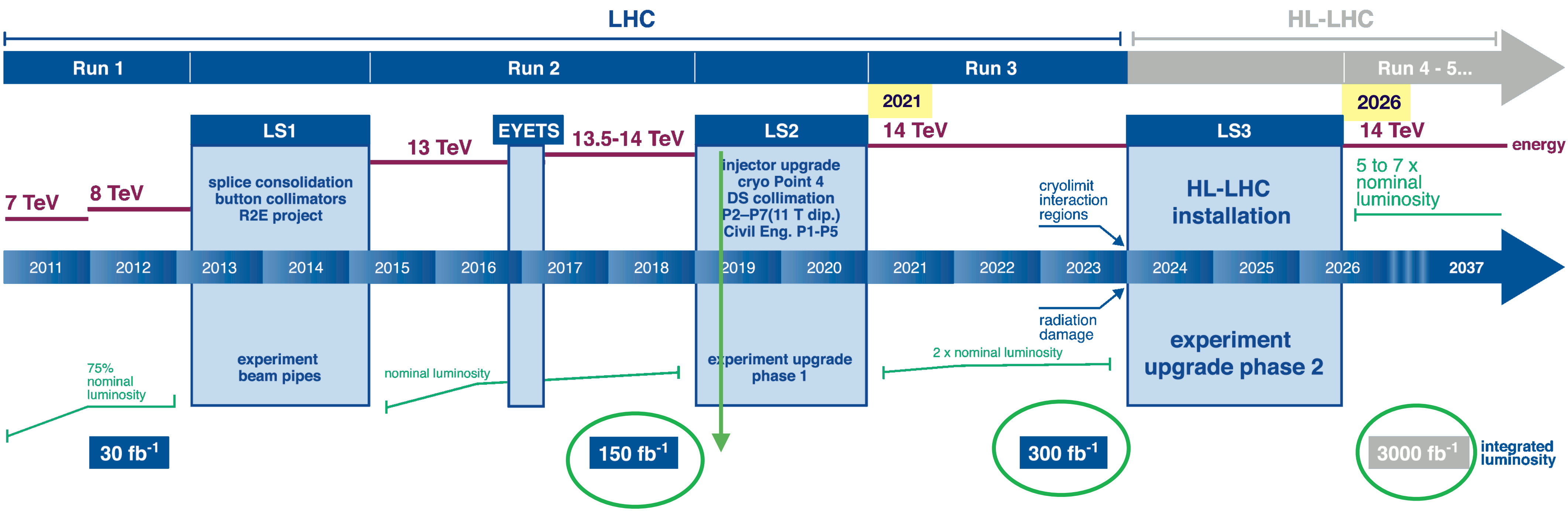


THE ATLAS UPGRADE PROGRAM

PHYSICS & MOTIVATIONS

ATLAS DETECTOR UPGRADE

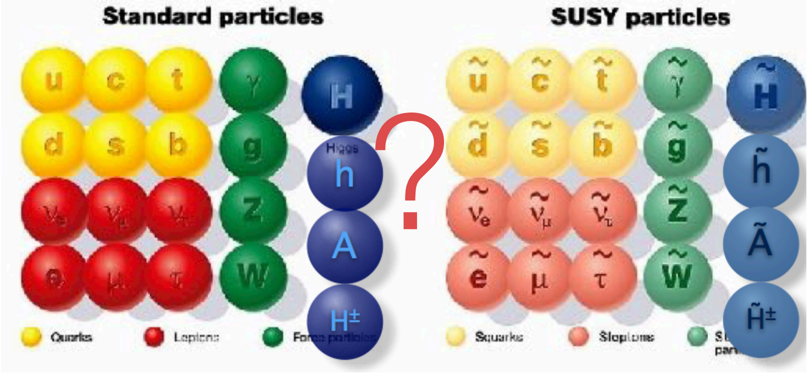


THE MISSION of the LHC

LHC Explore the TeV energy range

Direct searches for Physics Beyond

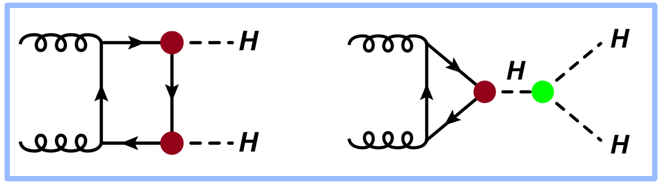
the Standard Model at the highest energies



Exploration of the Higgs sector

- Precision measurements of the Higgs boson properties
  - Higgs boson couplings
  - Self coupling
  - New Higgs bosons ?

σ_{HH} ~40 fb

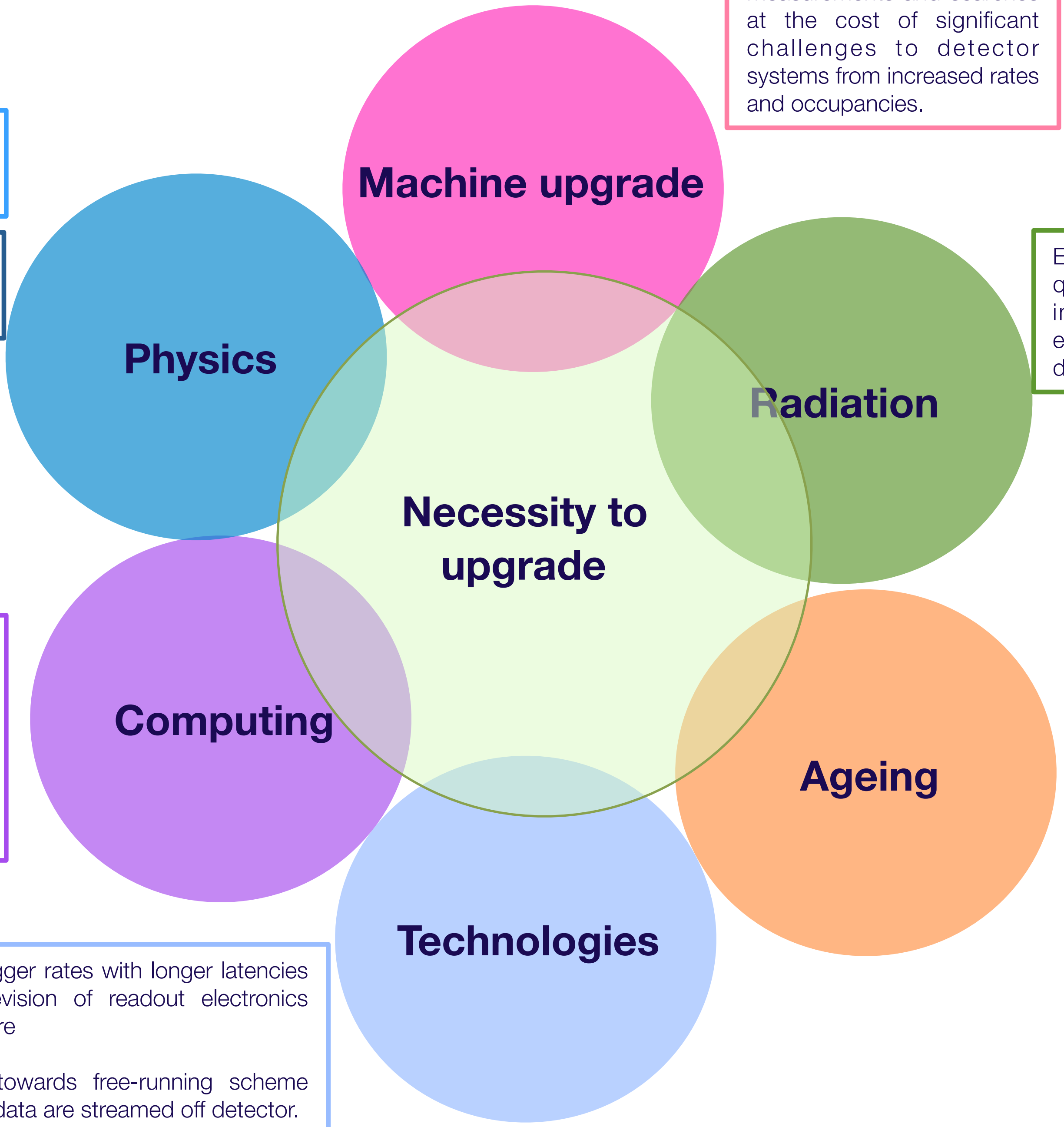


Precision measurements

SMALL CROSS SECTIONS

HIGH LUMINOSITY

MOTIVATION for HL-LHC upgrade



Necessity to upgrade

Machine upgrade

HL-LHC offers large luminosity needed to cover a wide range of physics measurements and searches at the cost of significant challenges to detector systems from increased rates and occupancies.

Physics

Keep detector performance for physics at least as good as in run 1 and run 2

Keep acceptable trigger rate with low-p_T thresholds and suppress pile-up up to high $|\eta|$

Radiation

Exiting front-end electronics not qualified for operation at HL-LHC integrated luminosity of 3000 events/fb and needs to be replaced due to radiation exposure.

1 MeV neutron equivalent fluences $1.5\ 10^{16}$ cm^2
Absorbed radiation dose: 11.4 MGy

Computing

Benefit from **high performance components** such as larger and faster FPGAs, higher bandwidth transmission links, backplane, network and storage technologies, advance computing.

Ageing

System will be in **operation for more than 20 years** in harsh radiation environnement. Mitigation strategies needed for inaccessible/irreplaceable detector components, e.g. adding new sensitive layers to maintain required performance

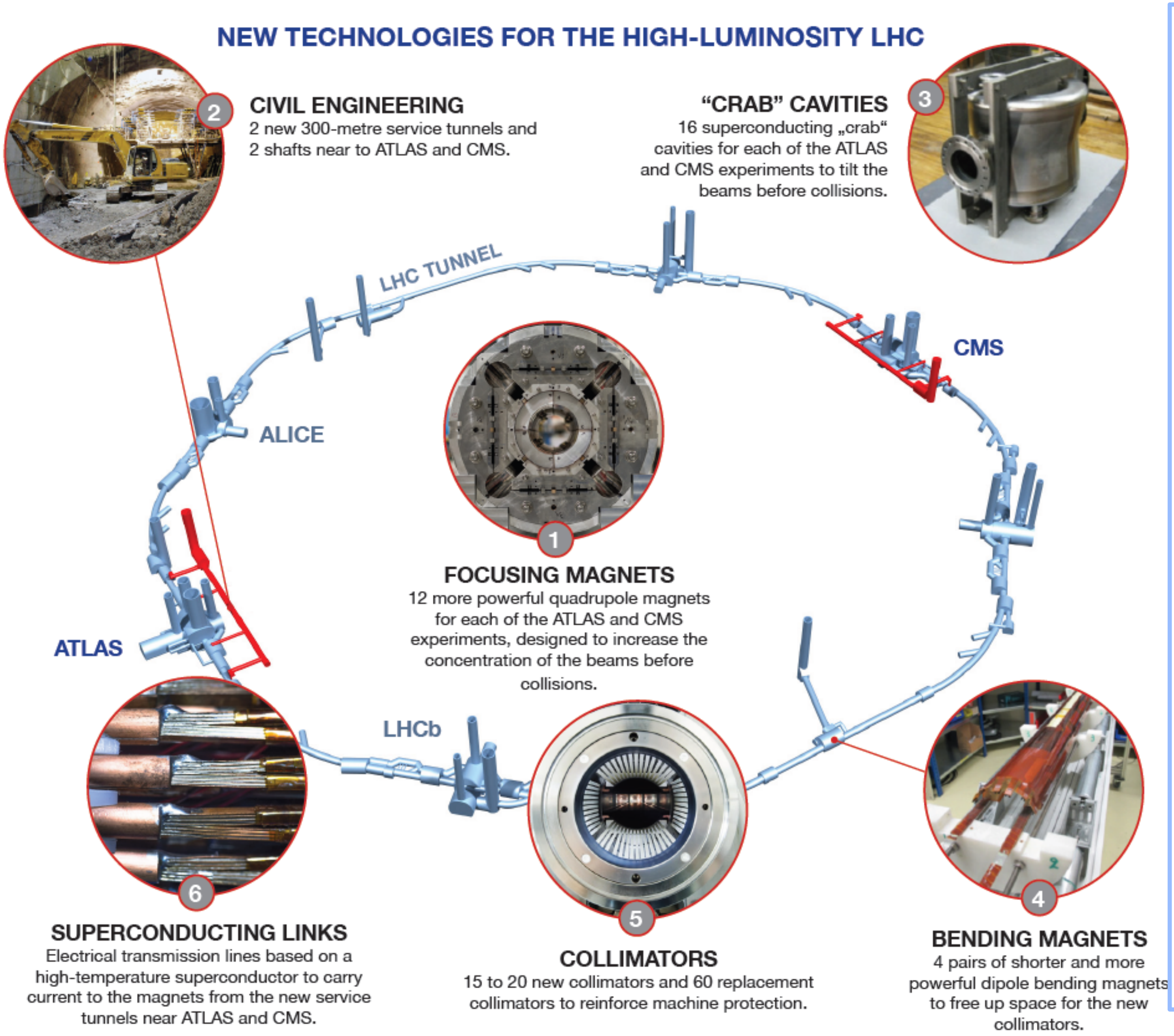
Technologies

Higher trigger rates with longer latencies require revision of readout electronics architecture

Evolving towards free-running scheme where all data are streamed off detector.

This allows for further upgrade for trigger with new off-detector electronics.

The High Luminosity LHC



NEW TECHNOLOGIES FOR THE HIGH-LUMINOSITY LHC

CIVIL ENGINEERING
2 new 300-metre service tunnels and 2 shafts near to ATLAS and CMS.

“CRAB” CAVITIES
16 superconducting „crab“ cavities for each of the ATLAS and CMS experiments to tilt the beams before collisions.

FOCUSING MAGNETS
12 more powerful quadrupole magnets for each of the ATLAS and CMS experiments, designed to increase the concentration of the beams before collisions.

SUPERCONDUCTING LINKS
Electrical transmission lines based on a high-temperature superconductor to carry current to the magnets from the new service tunnels near ATLAS and CMS.

COLLIMATORS
15 to 20 new collimators and 60 replacement collimators to reinforce machine protection.

BENDING MAGNETS
4 pairs of shorter and more powerful dipole bending magnets to free up space for the new collimators.

Innovative technologies

Superconducting magnets materials

niobium-titanium (NbTi) up to 9-10 Tesla → niobium-tin (Nb_3Sn) reaching 12-13 Tesla → double magnet aperture of dipoles and quadrupoles

Crab cavities

rotation of the beam by providing a transverse deflection of the bunches → to increase luminosity at collision points and to reduce beam-beam parasitic effects

New magnesium-diboride-based (MbB_2) **superconding cables**

from 20 to 100 kA → move power converters from the LHC tunnel to new service gallery

>1.2 km (~5%) of current ring to be replaced with new components

From LHC to HL-LHC

$$L = \frac{1}{4\pi}\underbrace{\left(f_{rev} n_b N_b\right)}_{\text{maximize total beam current}} \underbrace{\frac{N_b}{\varepsilon_N}}_{\text{maximize brightness (injectors \& beam-beam limit)}} \frac{\gamma}{\beta^*} R(\theta_c, \varepsilon, \beta^*, \sigma_z)$$

compensate reduction factor *R*

crossing angle
hourglass effect

maximize energy & minimize β*

Parameter	Nominal LHC	Nominal HL-LHC 25ns		
	[Design Report]	[standard]	[BCMS]	[8b4e]
Beam energy in collision [TeV]	7	7	7	7
Number of protons per bunch [$\times 10^{11}$]	1.15	2.2	2.2	2.3
n_b	2808	2748	2604	1968
Number of collisions in IP1 and IP5	2808	2736	2592	1960
Beam current [A]	0.58	1.09	1.03	0.82
crossing angle [μrad]	285	590	590	554
beam separation [σ]	9.4	12.5	12.5	12.5
$\beta*$ [m]	0.55	0.15	0.15	0.15
ϵ_n [μm]	3.75	2.50	2.50	2.2
ϵ_L [eVs]	2.5	2.5	2.5	2.5
Levelled luminosity [$\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	-	5.32	5.02	5.03
Events / crossing	27	140	140	140
Levelling time [hours]	-	8.3	7.6	9.5

Configuration	$\mathcal{L}_{\text{inst}}$ [$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	$\langle\mu\rangle$	$\int\mathcal{L}$ per year [fb^{-1}]
Baseline	5	140	250
Ultimate	7.5	200	>300

Upgrade of several components of the LHC and injector

New super-conducting triplet: **lower β***

Injector upgrade

Increased **beam charge**

Luminosity levelling

High availability

Aim at 3000 events/fb (4000 events/fb)

Increased pile-up

from **20** (LHC nominal) via **60** (LHC today)

to **140** (HL-LHC baseline) or even **200** (HL-LHC ultimate) with L=7.10^{34}Hz/cm^2

Triggering on low-p_T objects for precision physics

Low occupancy detectors, highly segmented

The PILE-UP CHALLENGE

ATLAS was designed to handle a level of pile-up with <μ>=20.

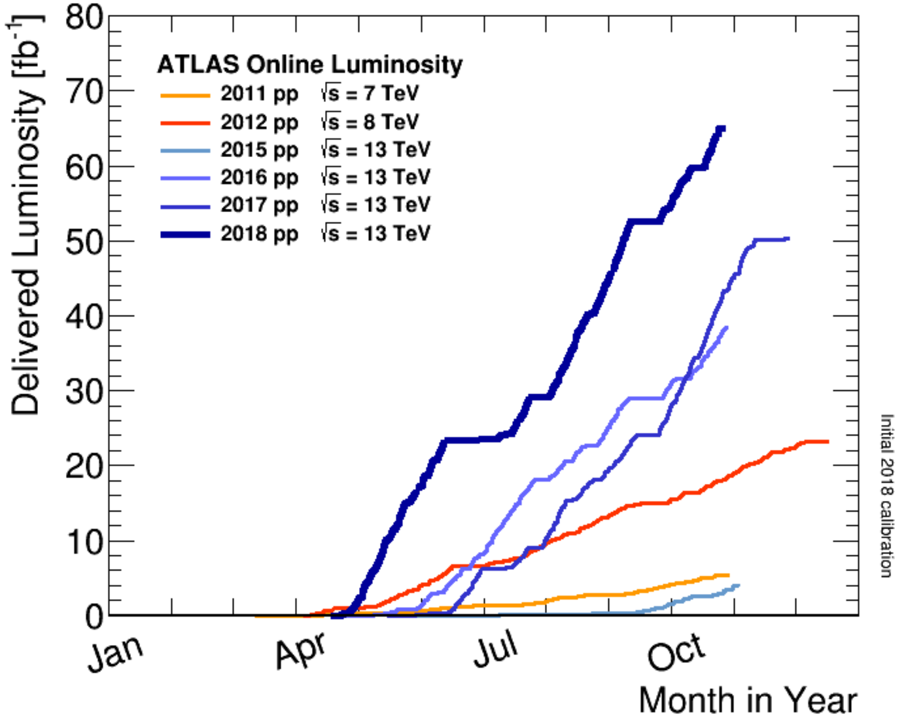
Since 2017, the level of pile-up largely exceeded the design value

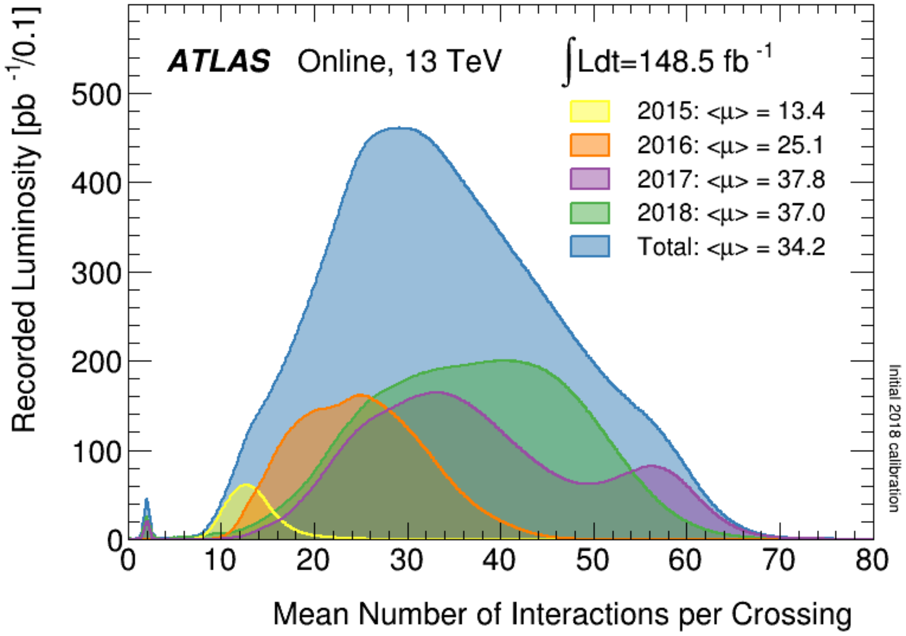
<μ>=37.8 events/BC

μ_{max}~70 events/BC

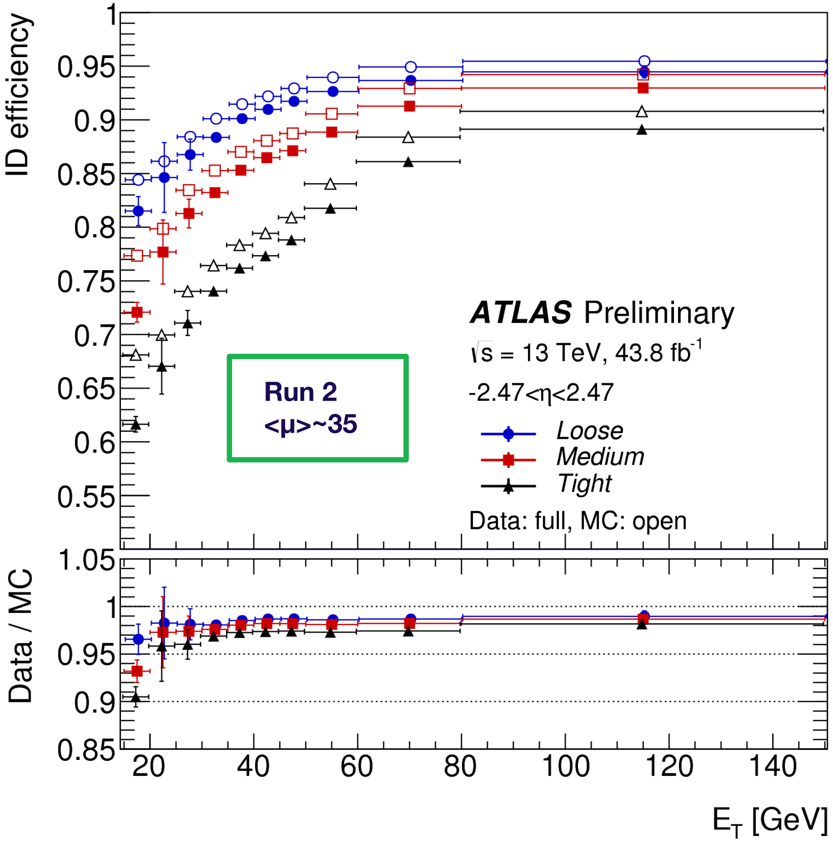
ATLAS has developed an efficient strategy to mitigate the impact of pile-up in event reconstruction and physics analysis.

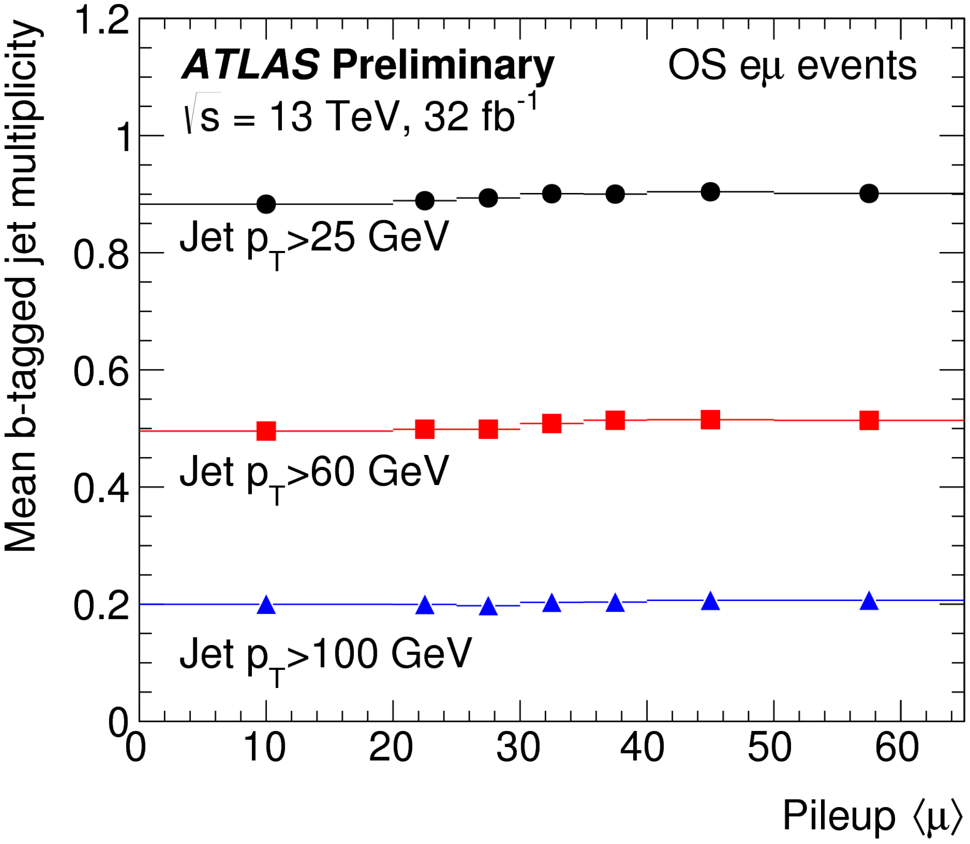
Essential expertise towards detector design for HL-LHC.





The PILE-UP CHALLENGE: PERFORMANCE at HIGH PILE-UP





Electron reconstruction

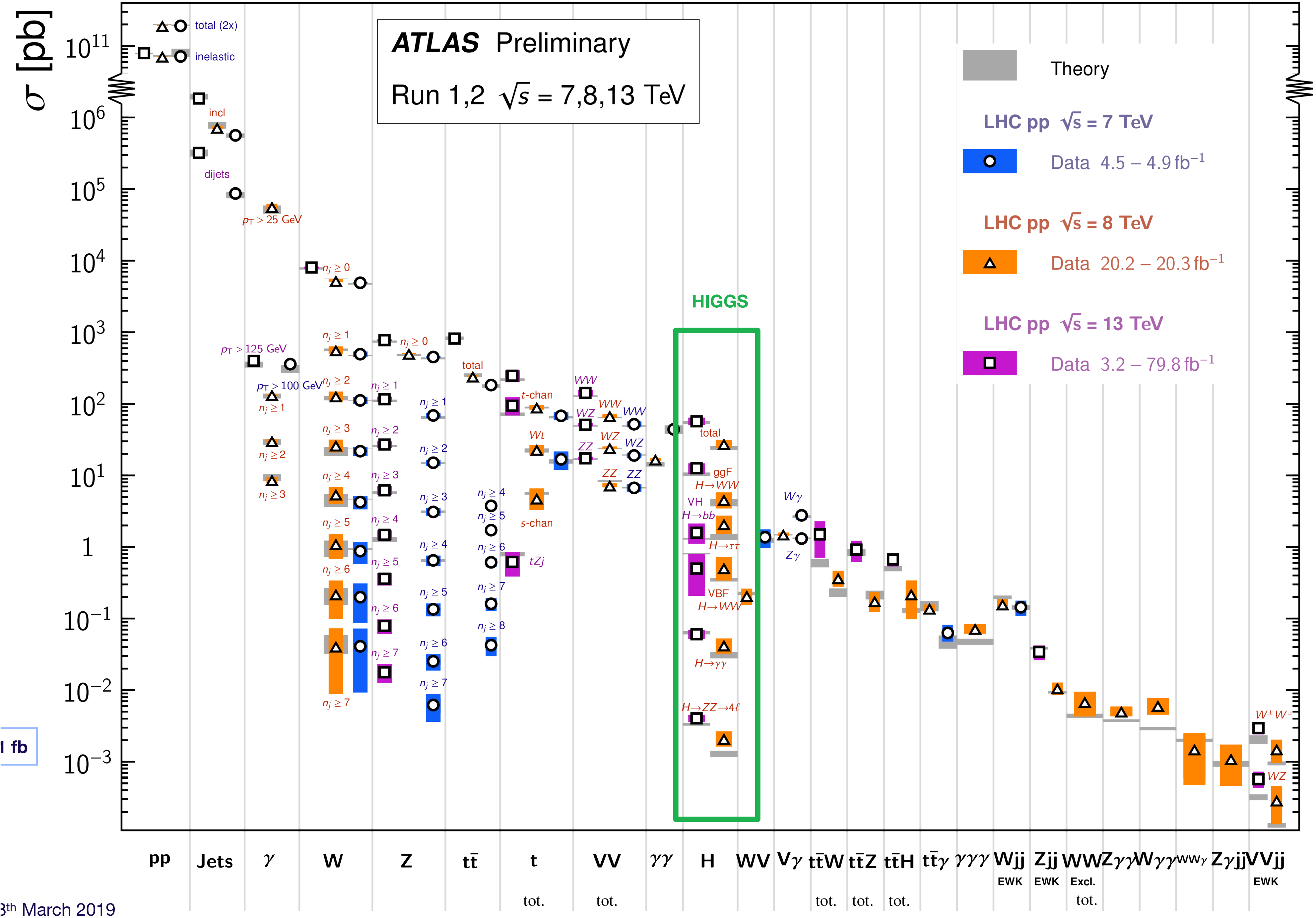
- p_T dependence tracked by Monte Carlo
- Lower efficiency in data w.r.t MC
  - known mis-modelling, differences in shower shapes

Flavour tagging

- Mean number of b-tagged jets on opposite-sign eμ events not affected by pileup

Standard Model Production Cross Section Measurements

Status: July 2018



1 fb

1 fb

The main proton–proton physics goals in a nutshell

Run 1 (8 TeV)

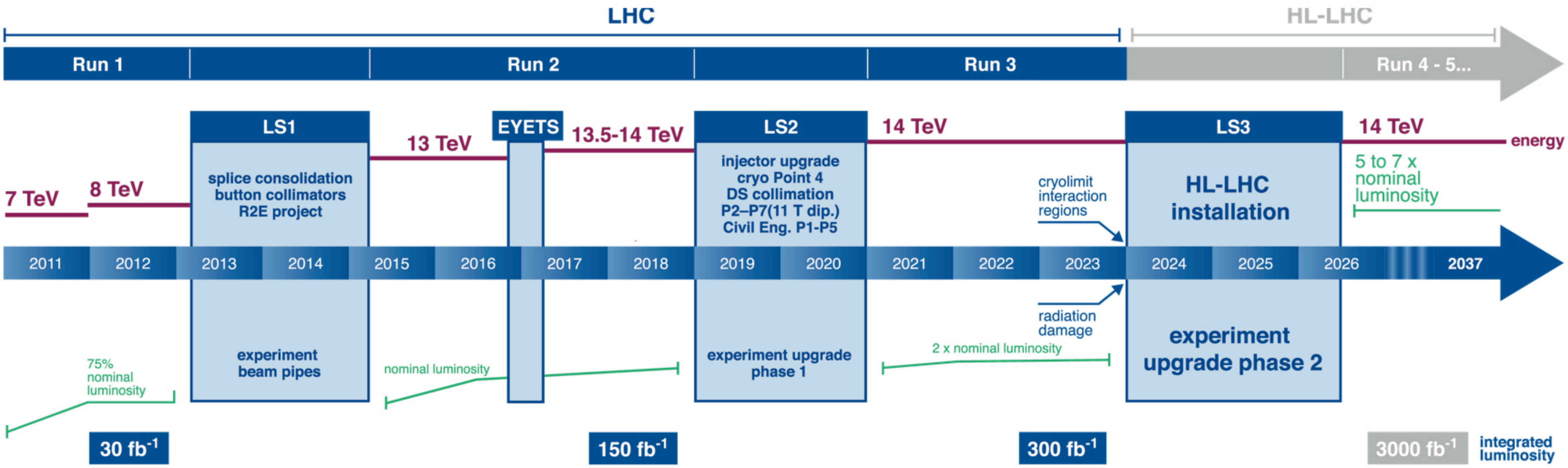
- Discovery of Higgs boson
- Searches for additional new physics (negative)
- Observation of rare processes, such as $B_s \to \mu\mu$
- Precision measurements of Standard Model processes
- Study of *CP* asymmetries in B_s sector

Run 2 & 3 (13–14 TeV)

- Searches for new physics
- Improved measurements of Higgs couplings in main channels
- Consolidation / observation of Higgs channels
- Measurement of rare Standard Model processes & more precision
- Improved measurements of rare *B* decays and *CP* asymmetries

HL-LHC (14 TeV)

- Precision measurements of Higgs couplings
- Observation of very rare Higgs modes
- Ultimate new physics search reach (on mass & forbidden decays, eg, FCNC)
- Ultimate SM & HF physics precision for rare processes



A few points

In the context of the preparation of the European Strategy for Particle Physics;

Consider option at **High Luminosity** LHC: 3000 fb^{-1}

Consider option at High Luminosity and **High Energy** LHC: 27 TeV (15 ab^{-1})

This option is probably not very realistic as requires high gradient magnets which are not available.

The expected physics performance have been documented in a **CERN yellow report**:

Volume 1 which documents combined results (e.g. ATLAS & CMS)

Standard Model & top, Higgs, SUSY & exotics, Flavour physics, Heavy ions

Volume 2 which includes PUBlic notes from the ATLAS & CMS experiments: link

Expected performance and results were presented in the HL/HE-LHC jamboree on 1st March at CERN: link

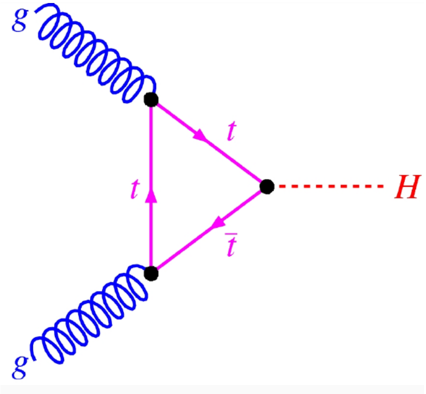
Higgs boson production and decays

Four main production channels at the LHC

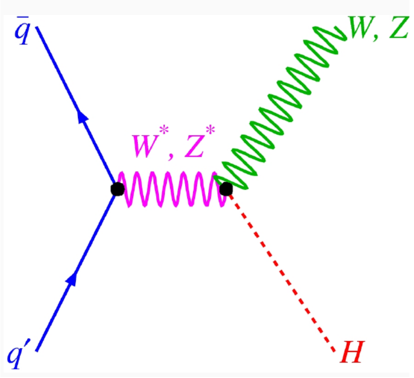
σ_H = 56 pb at $\sqrt{s}$=13 TeV

~200 millions Higgs bosons produced in ATLAS by end of HL-LHC

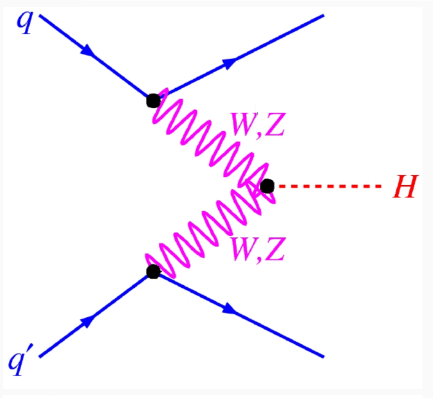
Large number of decay channels



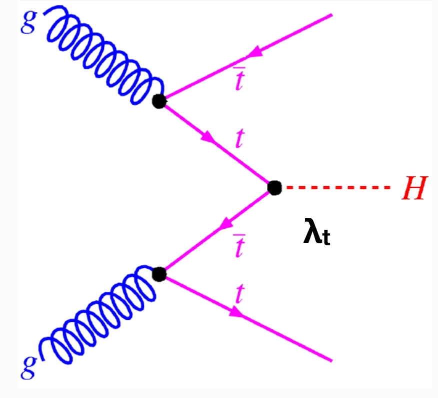
Gluon-gluon fusion (ggF)
dominant - 88% of the total



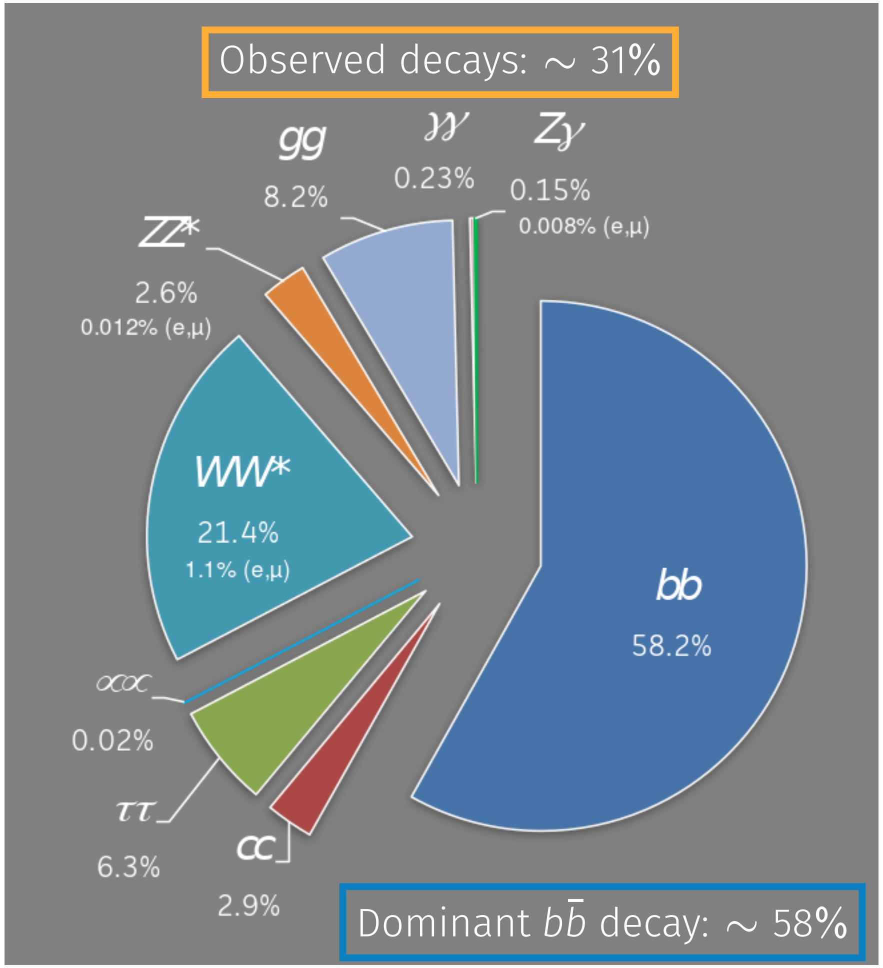
VH - WH/ZH
3% of the total



Vector boson fusion (VBF)
7% of the total



ttH
1% of the total



Observed decays: ~ 31%

Dominant $b\bar{b}$ decay: ~ 58%

HIGGS BOSON COUPLINGS at HL-LHC

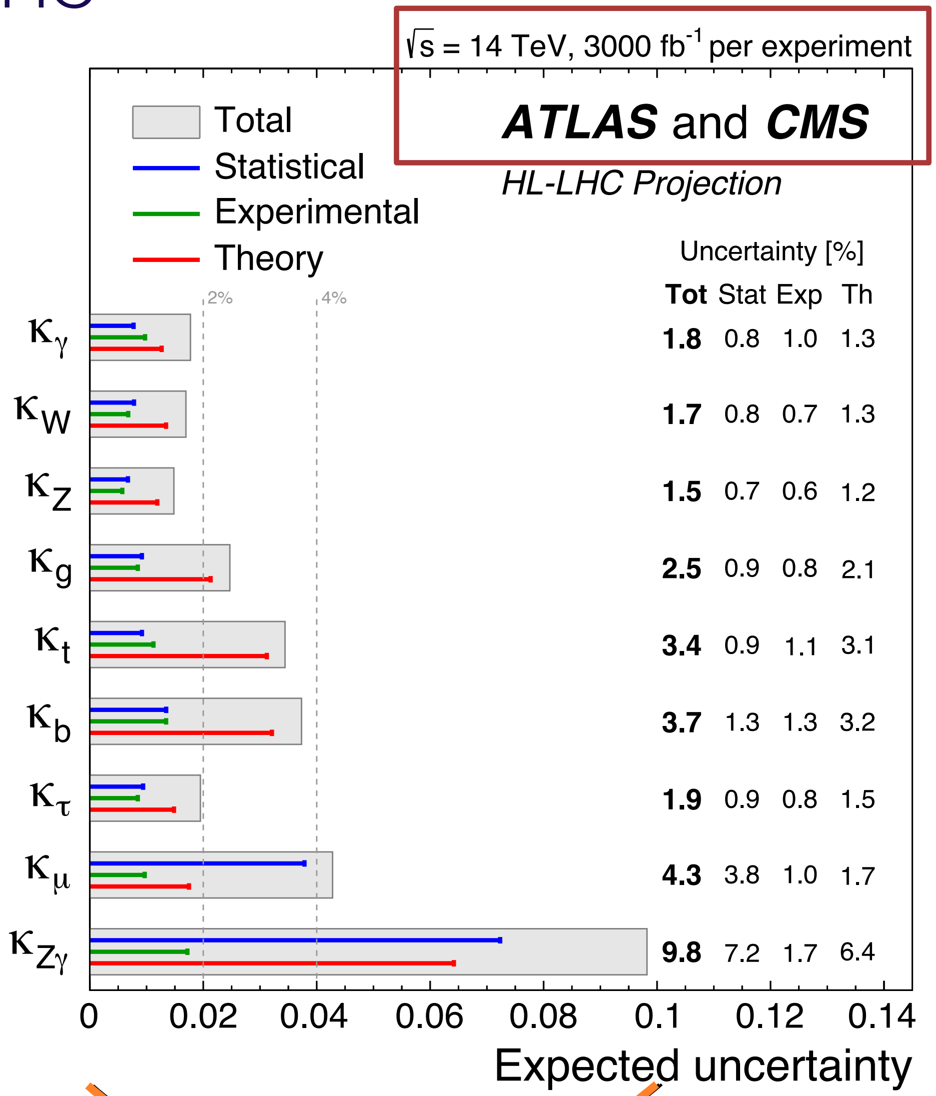
arXiv:1902.00134 [hep-ph]

$$\kappa_j^2 = \sigma_j/\sigma_j^{\mathrm{SM}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j/\Gamma^j_{\mathrm{SM}}$$

In the Standard Model, $K_j = 1$.
Six coupling modifiers are defined corresponding to tree level Higgs boson couplings.
In addition, three are introduced to describe ggH, H→γγ and H→Zγ.

$$\kappa_{\mathrm{W}},\ \kappa_{\mathrm{Z}},\ \kappa_{\mathrm{t}},\ \kappa_{\mathrm{b}},\ \kappa_{\tau} \text{ and } \kappa_{\mu}$$

$$\kappa_{\mathrm{g}},\ \kappa_{\gamma} \text{ and } \kappa_{\mathrm{Z}\gamma}$$

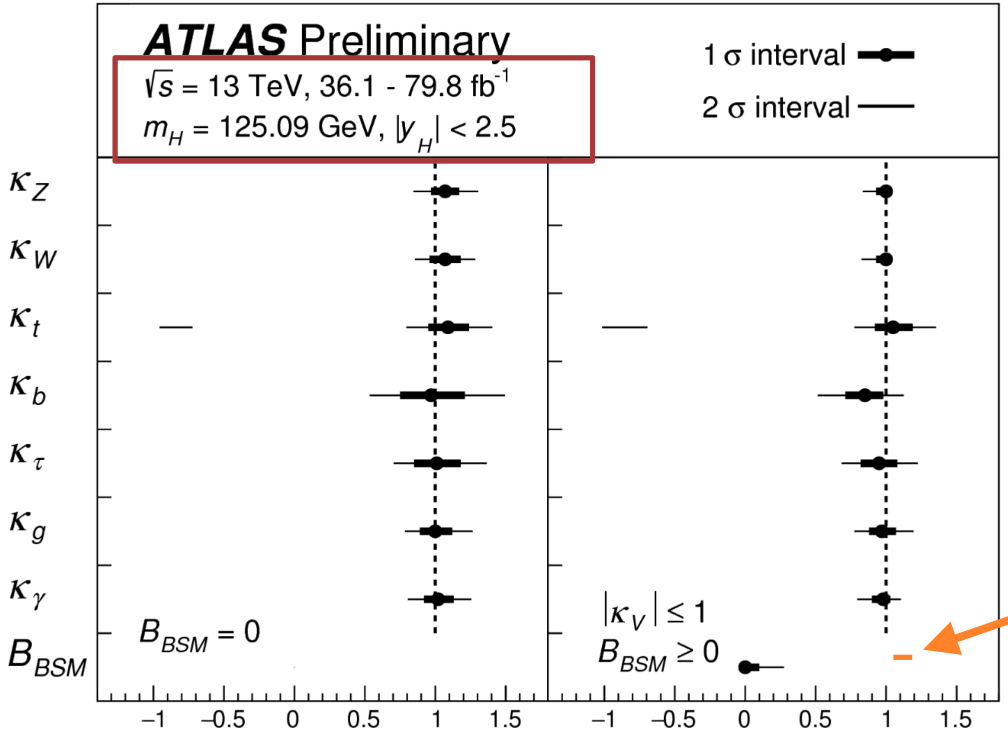


Uncertainty [%]

	Tot	Stat	Exp	Th
κ_γ	**1.8**	0.8	1.0	1.3
κ_W	**1.7**	0.8	0.7	1.3
κ_Z	**1.5**	0.7	0.6	1.2
κ_g	**2.5**	0.9	0.8	2.1
κ_t	**3.4**	0.9	1.1	3.1
κ_b	**3.7**	1.3	1.3	3.2
κ_τ	**1.9**	0.9	0.8	1.5
κ_μ	**4.3**	3.8	1.0	1.7
$\kappa_{Z\gamma}$	**9.8**	7.2	1.7	6.4

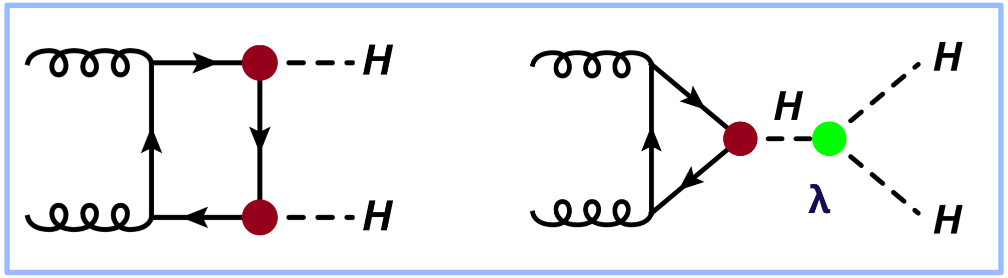
0.1

ATLAS-CONF-2018-031

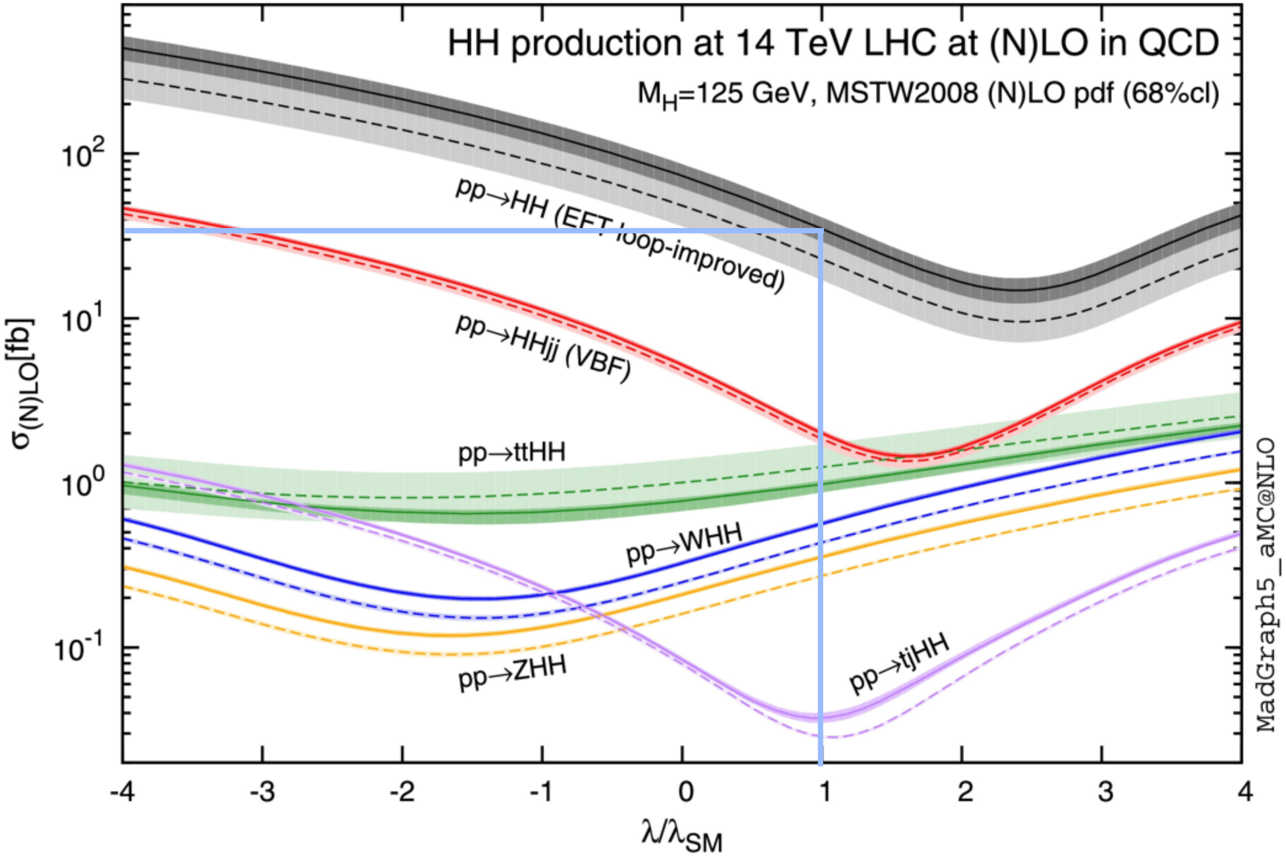


DI-HIGGS PRODUCTION at HL-LHC

Phys.Lett.B732(2014) 1420-149



σ_{HH} ~40 fb

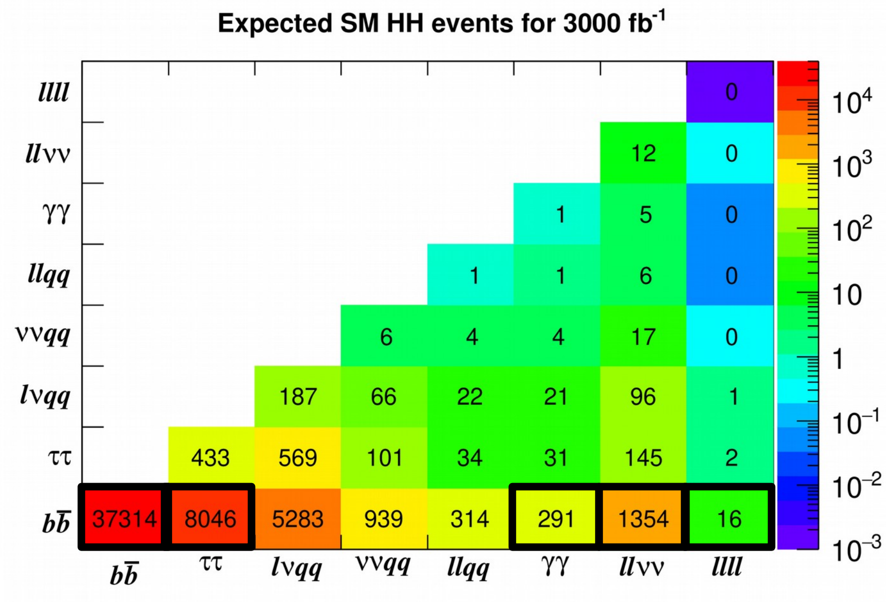


Probe the nature of the Higgs Boson Self Coupling

HH analysis: some numbers and remarks

In the context of the preparation for the European strategy of Particle Physics - Yellow Report

	ATLAS	CMS	
bbbb	extrapolation	parametric	Largest BR ☺ Large multijet and tt bkg ☹
bbττ	extrapolation	parametric	Sizeable BR ☺ Relatively small bkg ☺
bbγγ	smearing	parametric	Small BR ☹ Good diphoton resolution ☺ Relatively small bkg ☺
bbVV (→lνlν)		parametric	Large BR ☺ Large bkg ☹
bbZZ (→4l)		parametric	Very small BR ☹ Very small bkg ☺



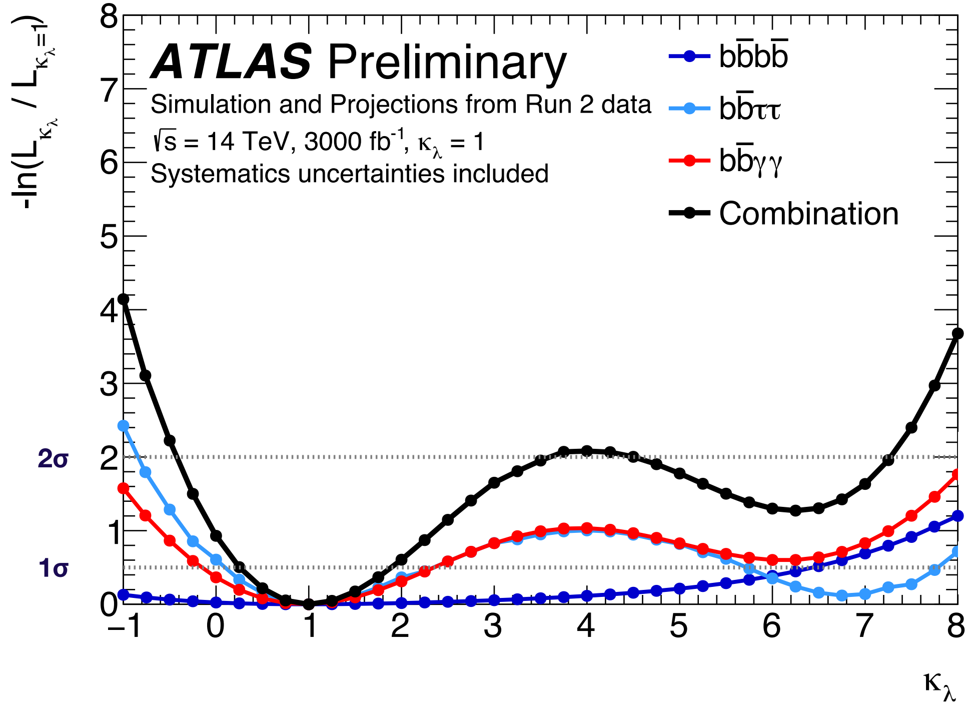
Expected SM HH events for 3000 fb^{-1}

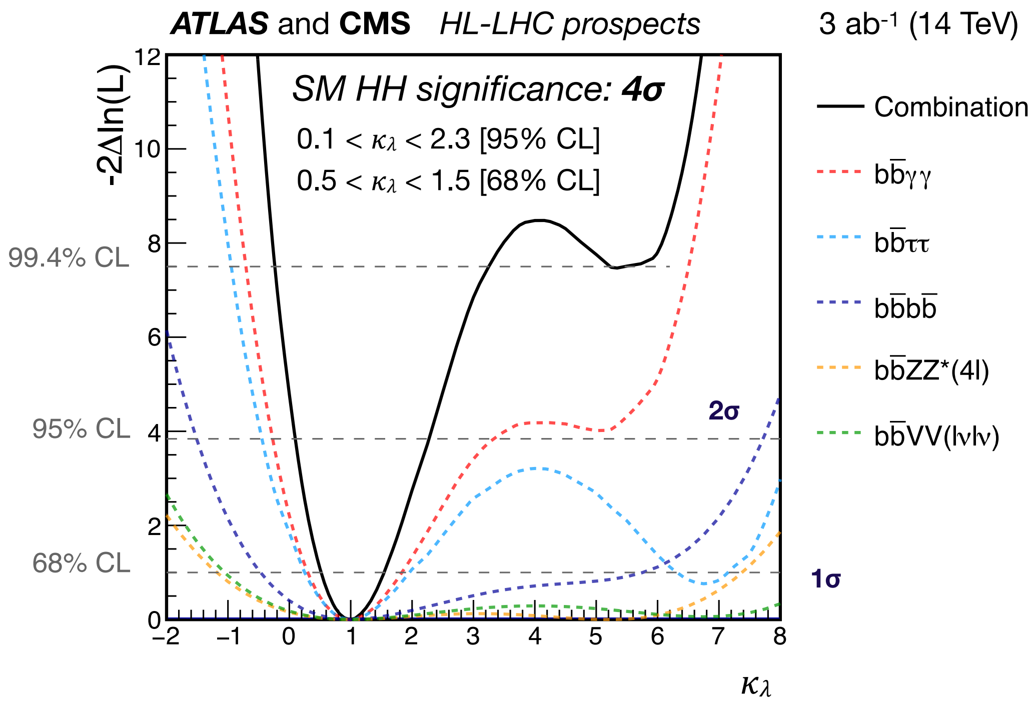
	$b\bar{b}$	ττ	lνqq	ννqq	llqq	γγ	llνν	llll
llll								0
llνν							12	0
γγ						1	5	0
llqq					1	1	6	0
ννqq				6	4	4	17	0
lνqq			187	66	22	21	96	1
ττ		433	569	101	34	31	145	2
$b\bar{b}$	37314	8046	5283	939	314	291	1354	16

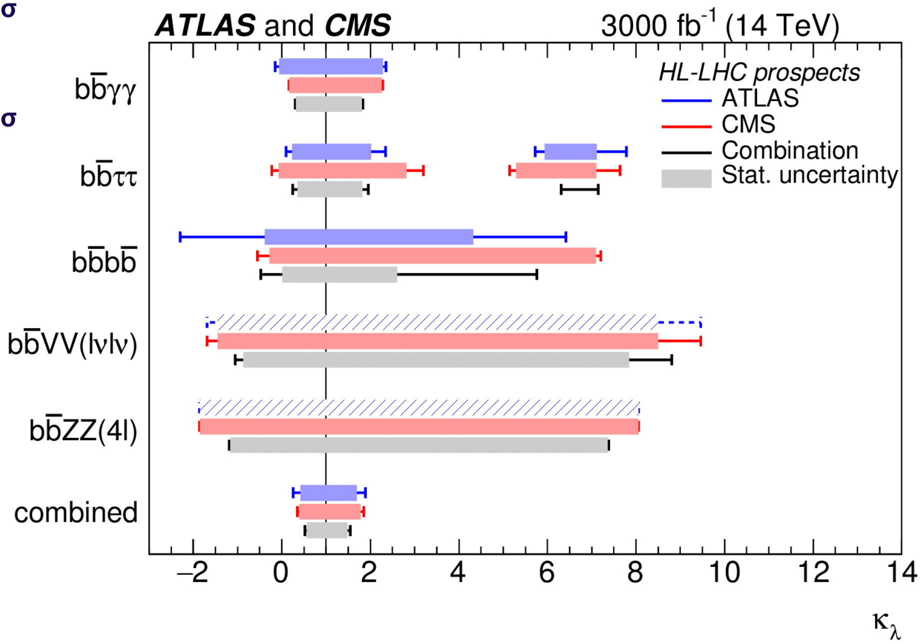
E. Petit at HL/HE-LHC jamboree - 1st March 2019

DI-HIGGS PRODUCTION at HL-LHC: HH→bbbb, bbγγ, bbττ

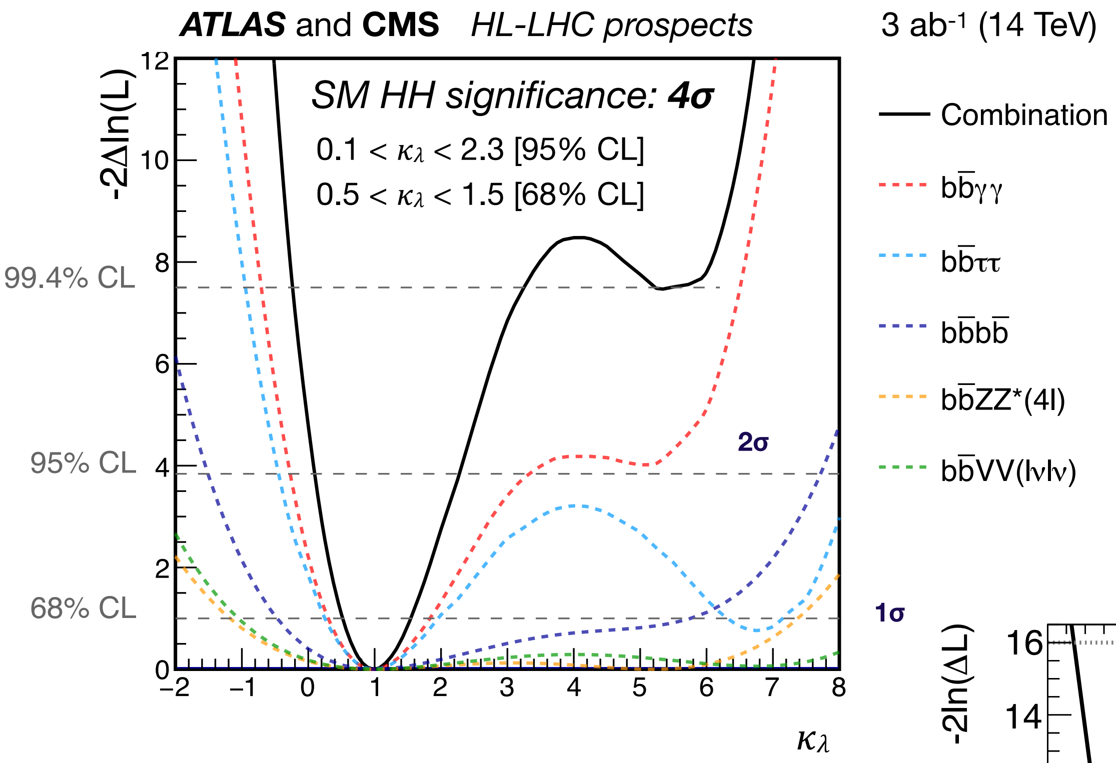
arXiv:1902.00134 [hep-ph]

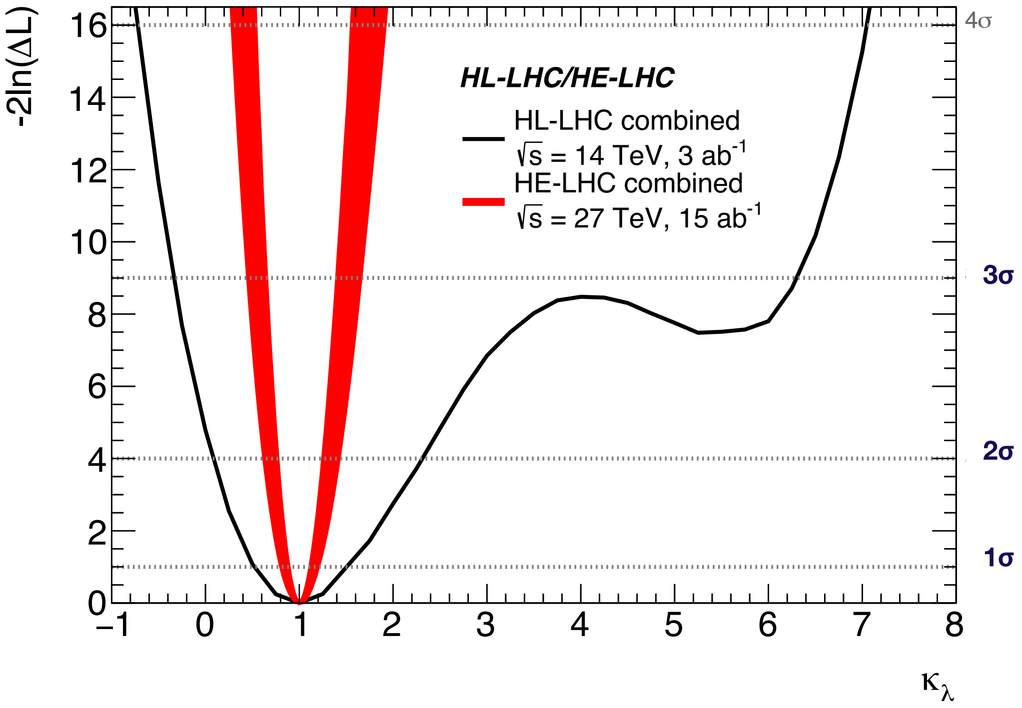




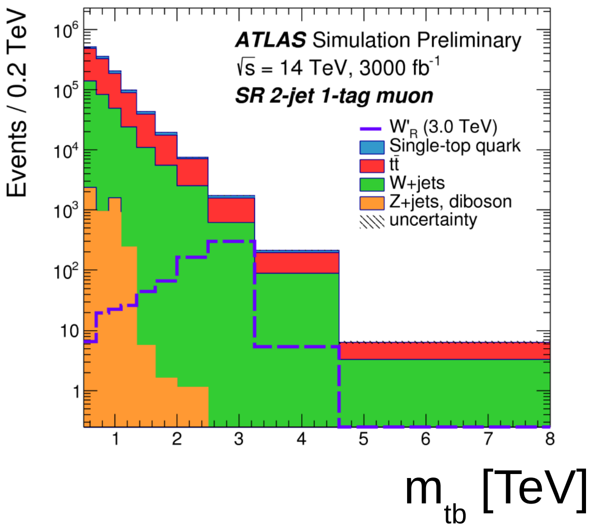


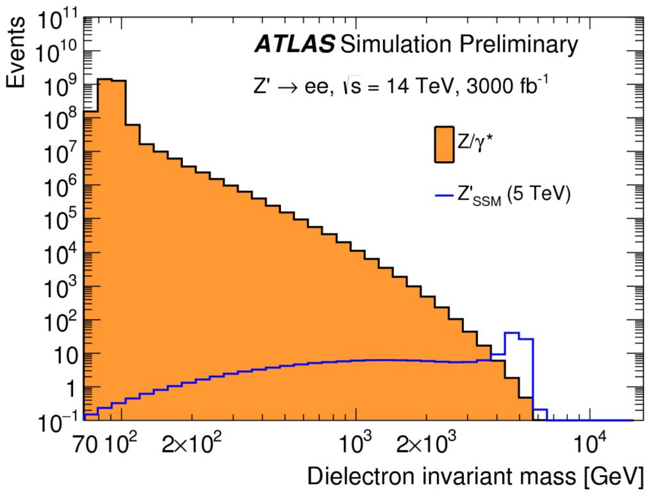
HH at HL and HE LHC





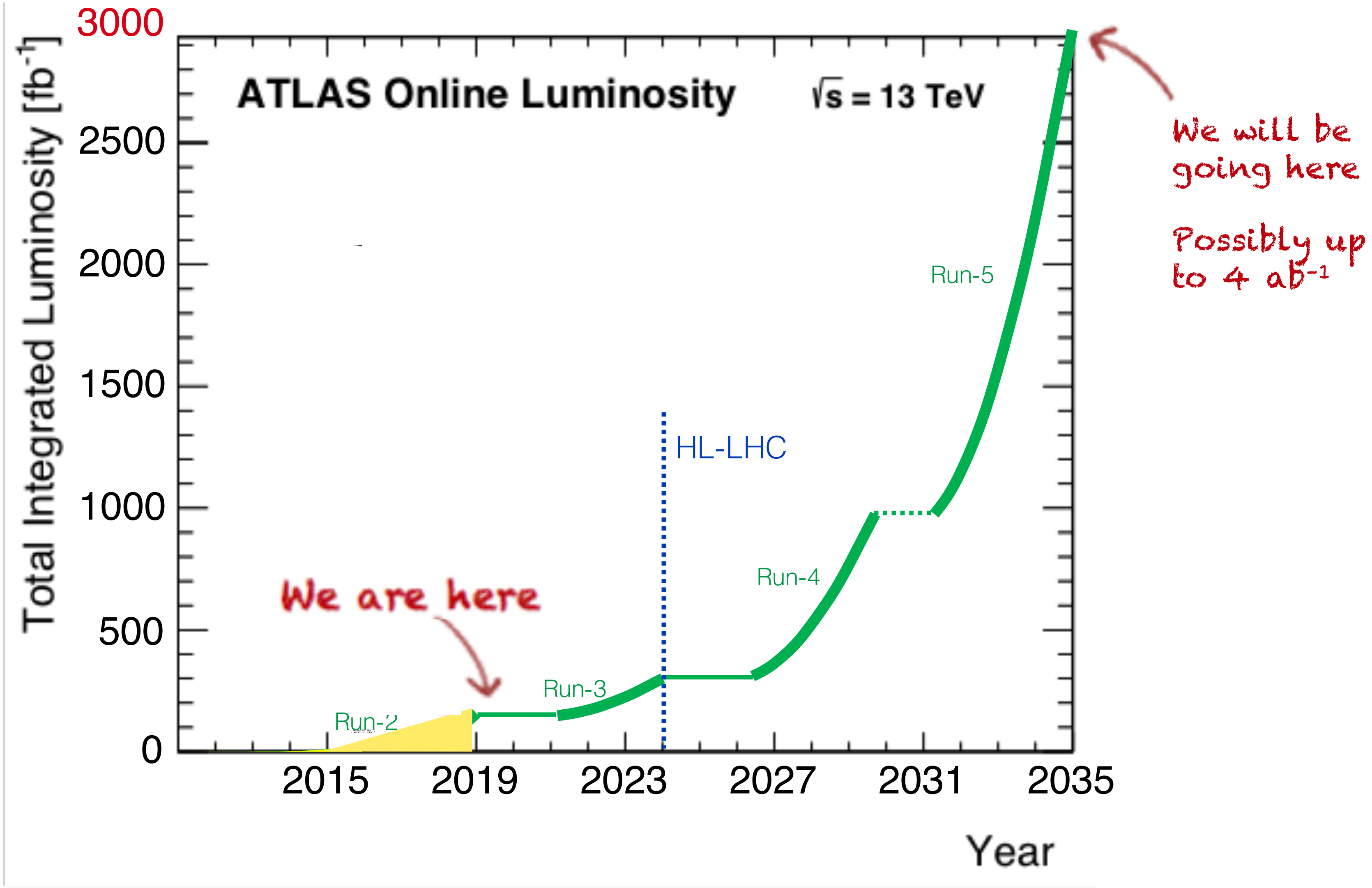
Heavy resonances





	Exclusion limit (95 % C.L.)		
	Run-2	HL-LHC	HE-LHC
$Z'_{SSM} \to \ell\ell$	4.5 TeV (36 fb-1)	6.5 TeV	12.8 TeV
$W'_{SSM} \to \ell\nu$	5.5 TeV (79.8 fb-1)	7.9 TeV	-
$Z'_{\psi} \to \ell\ell$	3.8 TeV (36 fb-1)	5.8 TeV	11.4 TeV
$W'_{R} \to tb$	3.2 TeV (36 fb-1)	4.9 TeV	

Luminosity increase



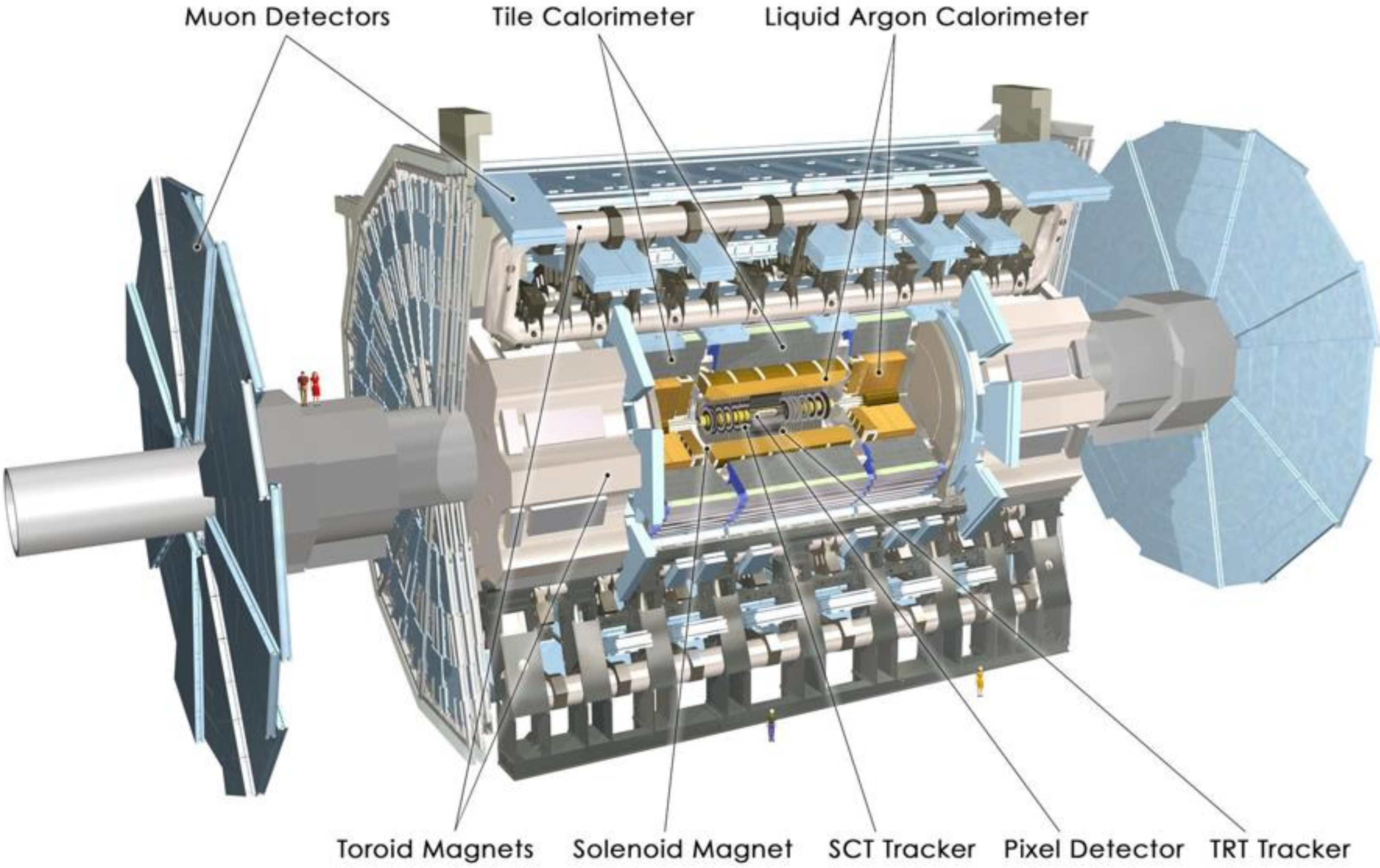
We will be going here

Possibly up to 4 ab^{-1}

© P. Ferreira da Silva at Moriond EW, 2016

TODAY: ~150/fb: ~5% of the expected HL-LHC sample

The ATLAS detector

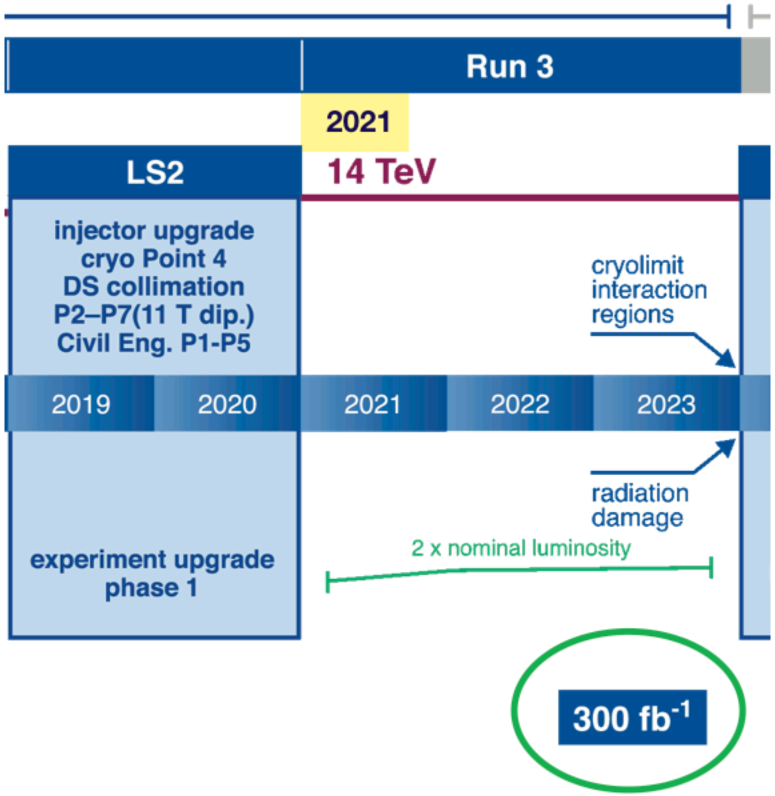


PHASE-I UPGRADE

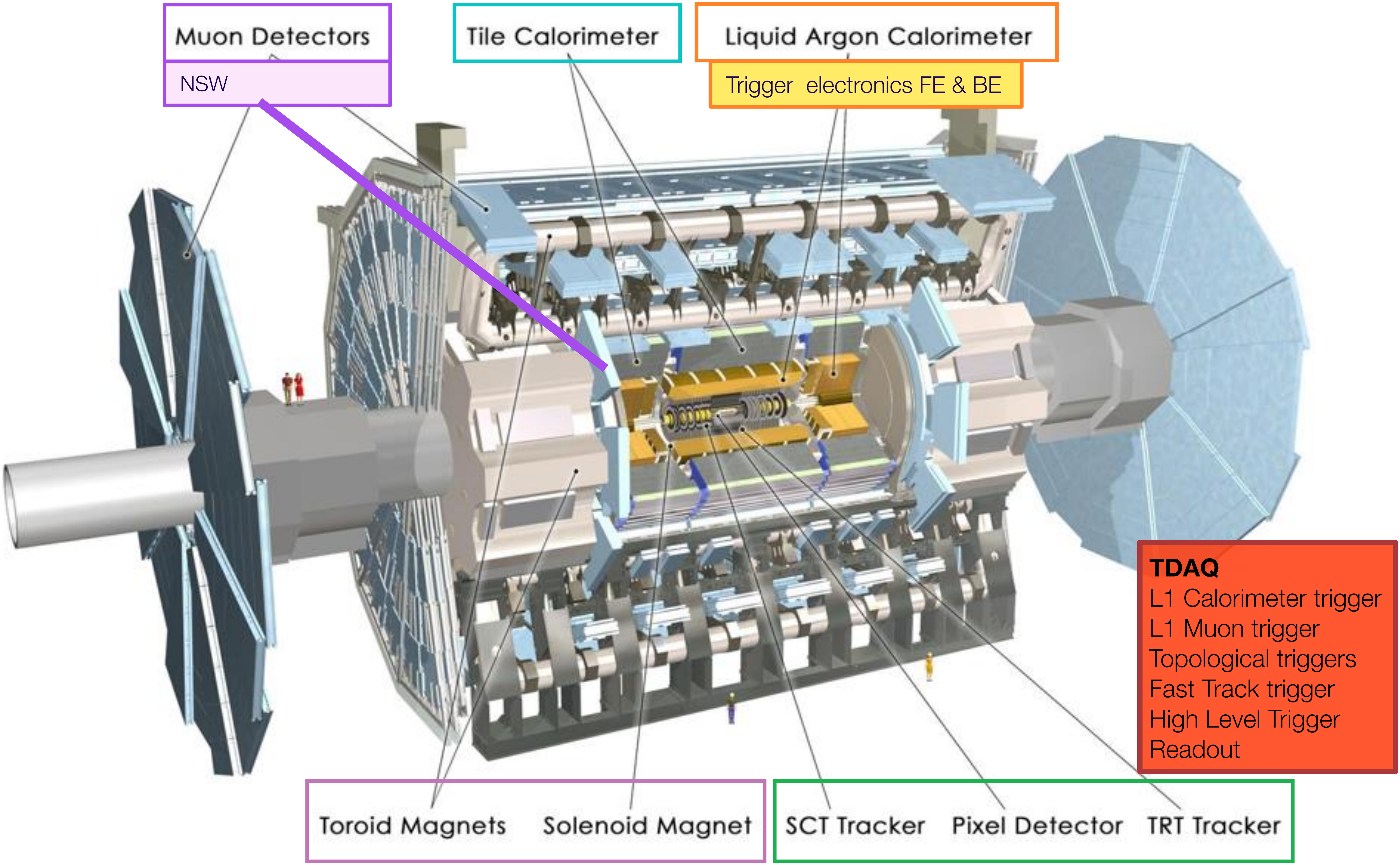
Liquid argon calorimeter

Muons - New Small Wheel

Trigger & Data acquisition



The ATLAS detector: Phase-I upgrades



Muon Detectors

NSW

Tile Calorimeter

Liquid Argon Calorimeter

Trigger electronics FE & BE

TDAQ
L1 Calorimeter trigger
L1 Muon trigger
Topological triggers
Fast Track trigger
High Level Trigger
Readout

Toroid Magnets

Solenoid Magnet

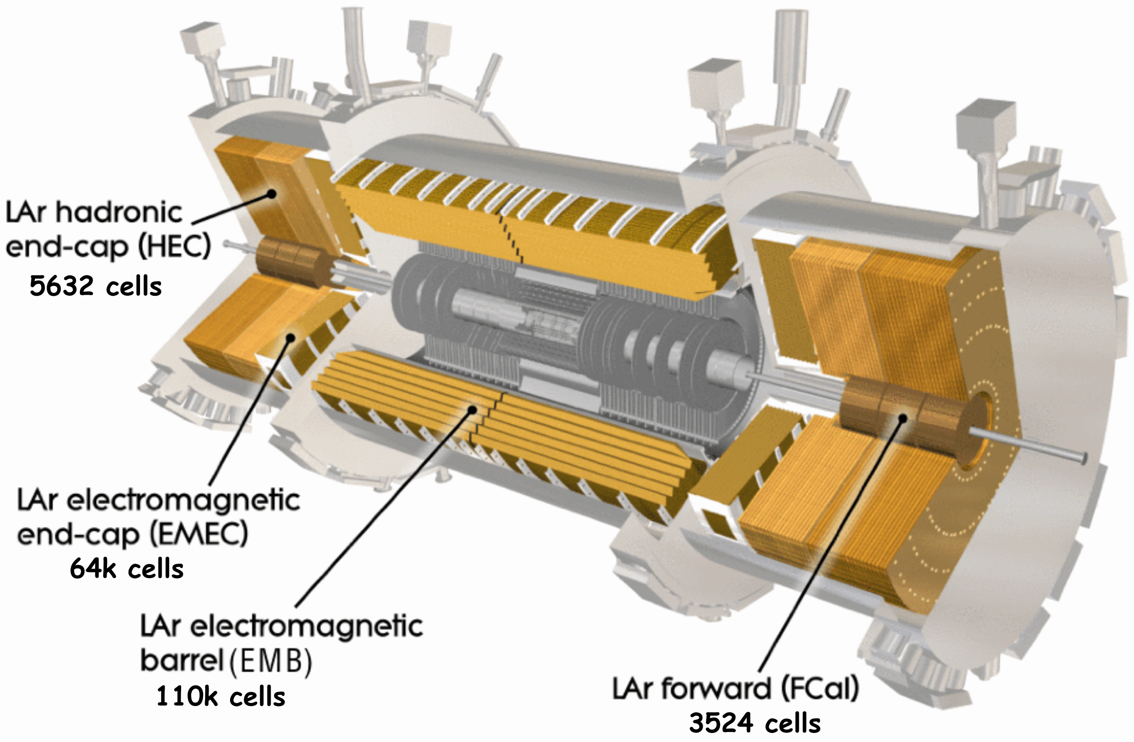
SCT Tracker

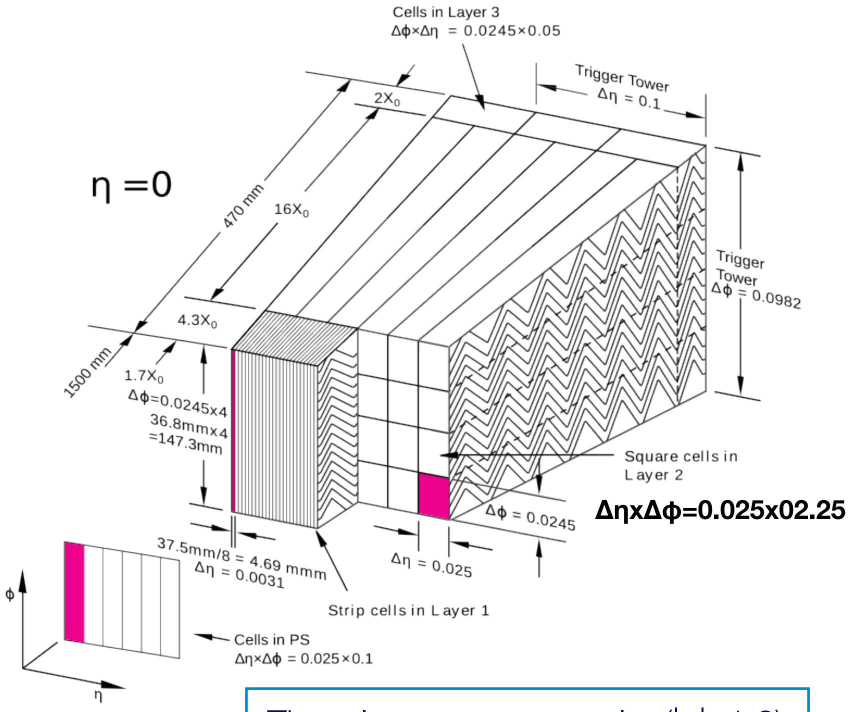
Pixel Detector

TRT Tracker

The ATLAS Liquid Argon Calorimeter

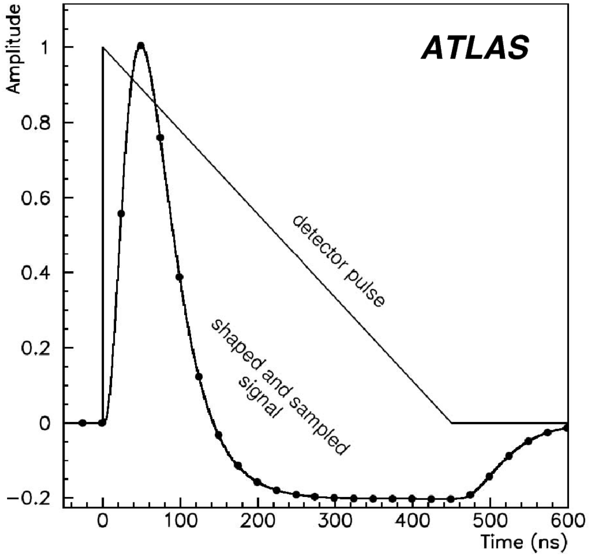
LAr calorimeters are expected to continue to operate reliably during the HL-LHC data taking period





Three layers + presampler (|η|<1.8)

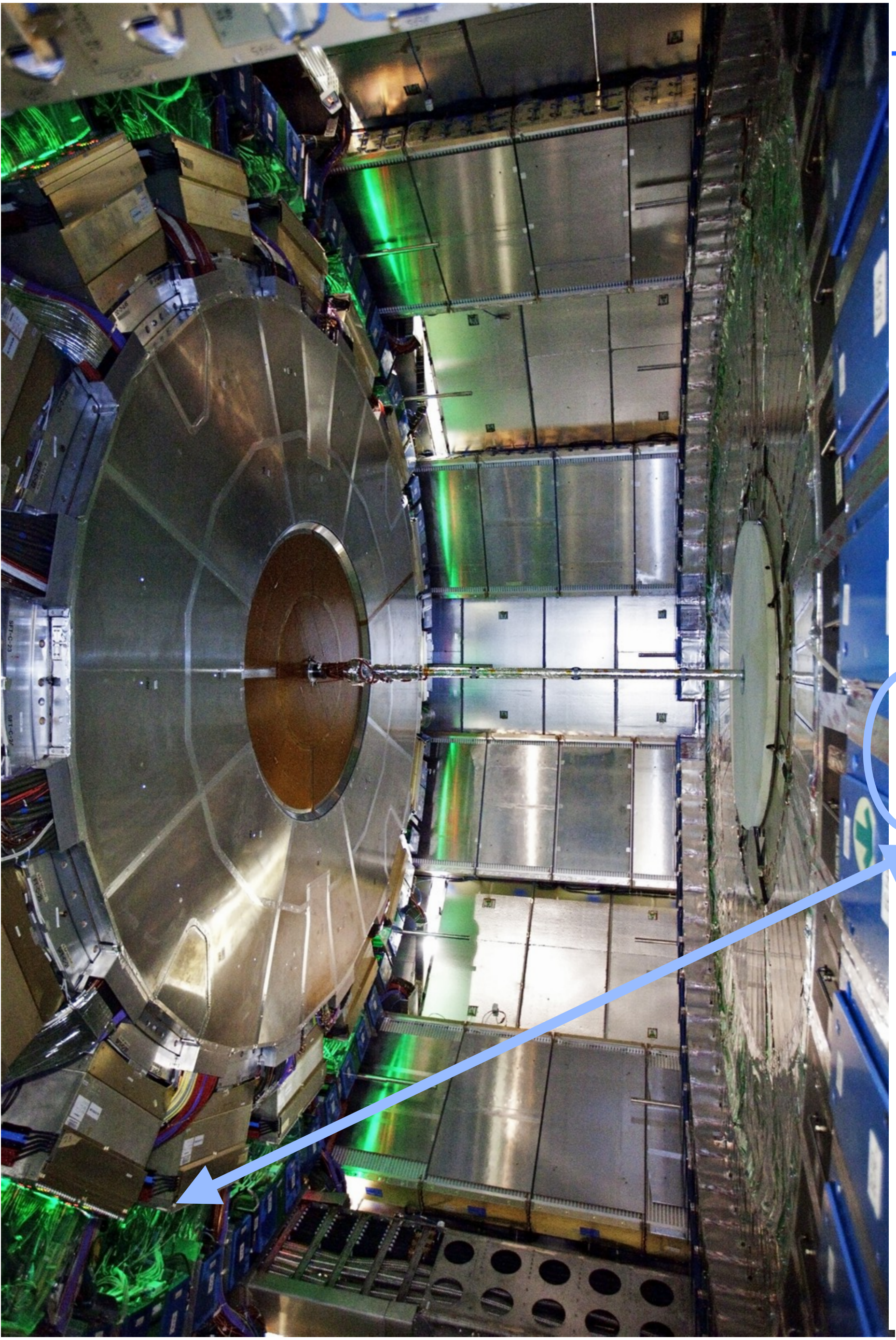
Fine grained LAr sampling calorimeter: 182468 cells
Dynamic range **~50 MeV to 3 TeV**

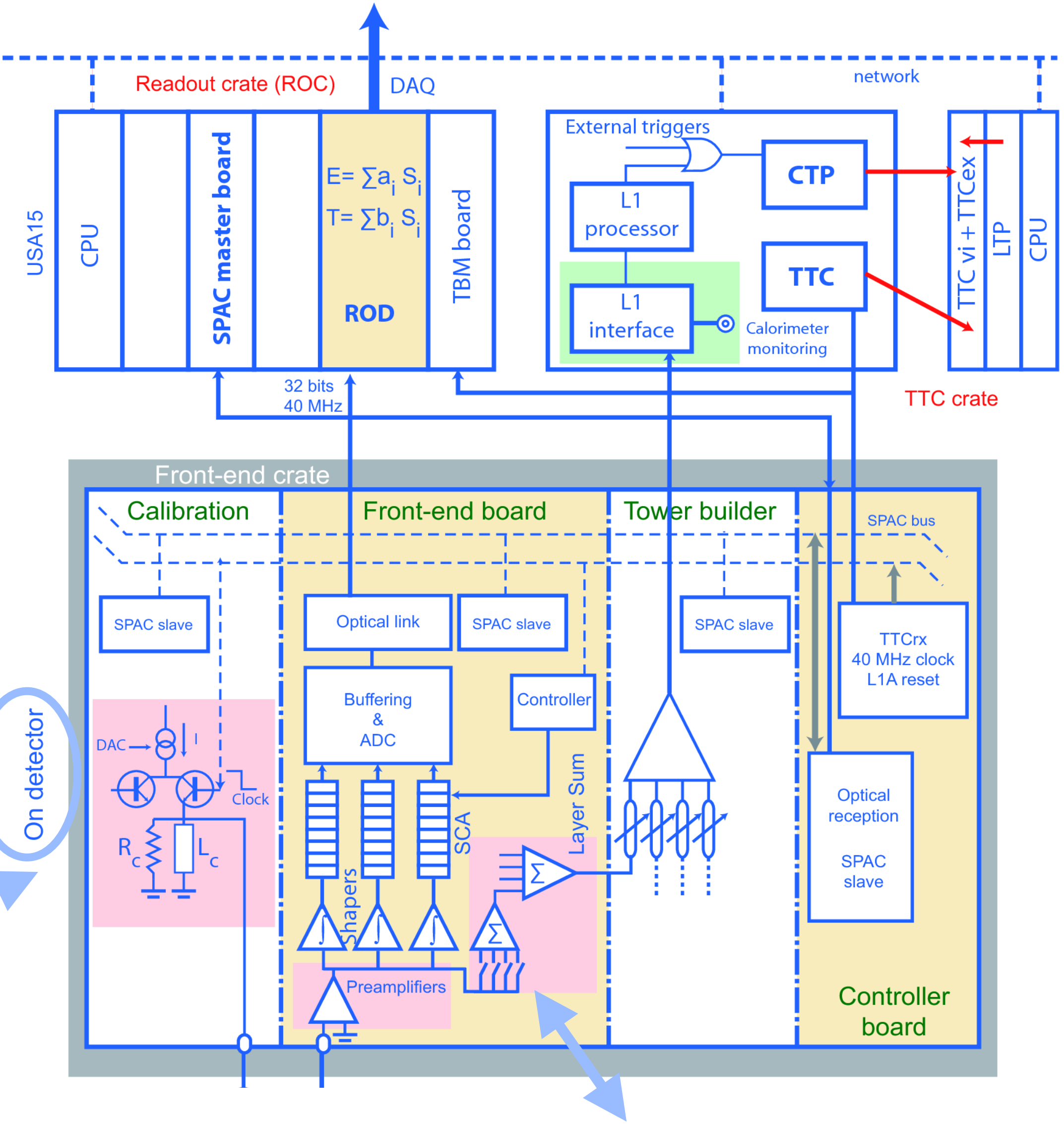


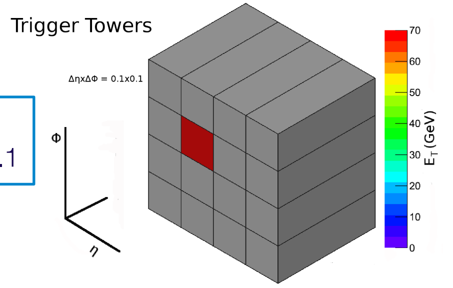
Triangular ionisation pulse amplified, shaped and sampled at **40 MHz**
Trigger sums built on frontend boards and Trigger board
Three gain scales
4 samples digitised by **12-bit ADC** upon L1 accept

Online **energy reconstruction** at **100 kHz** in DSP based backend electronics

Liquid Argon Calorimeter Readout Electronics





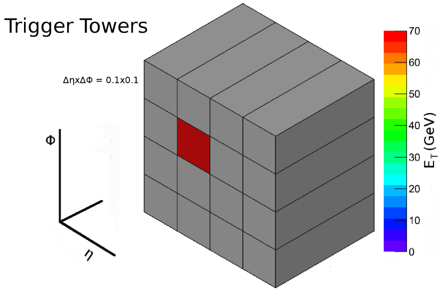


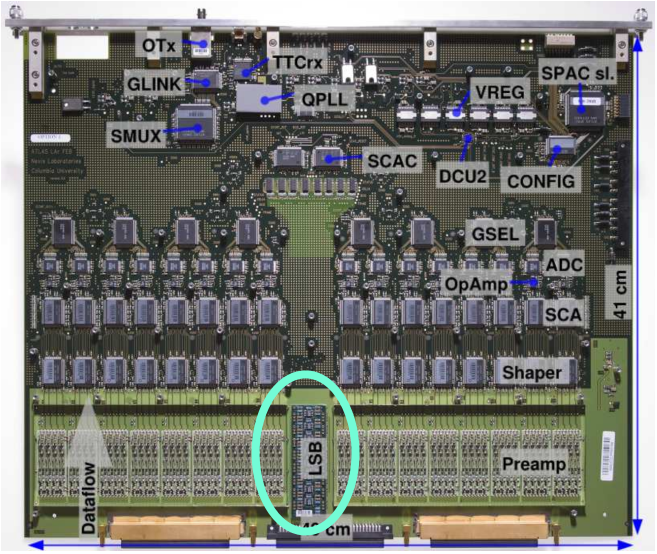
Trigger Towers
Δη x Δφ = 0.1x0.1

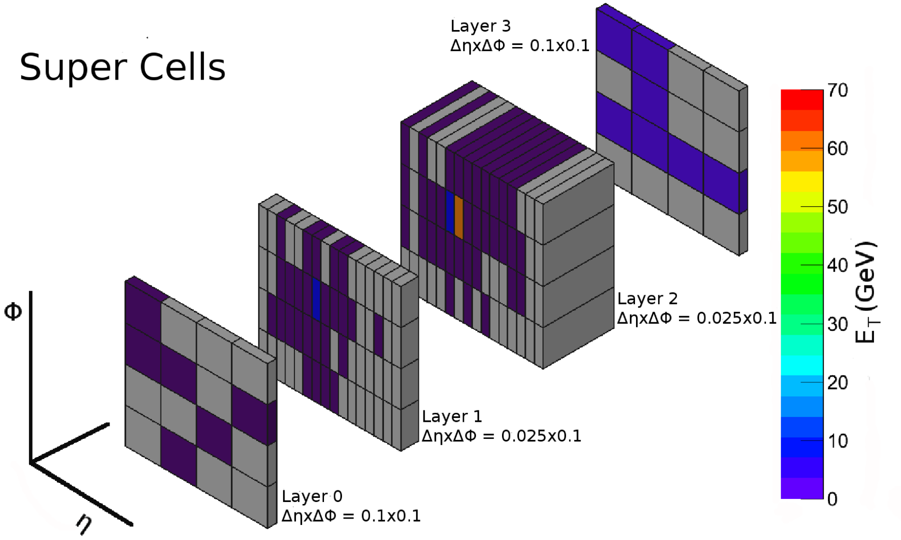
Liquid Argon Phase-I Upgrade: improved trigger

N J Buchanan et al 2008 JINST 3 P03004 (Fig. 17)

ATLAS Liquid Argon Calorimeter Phase-I Upgrade TDR



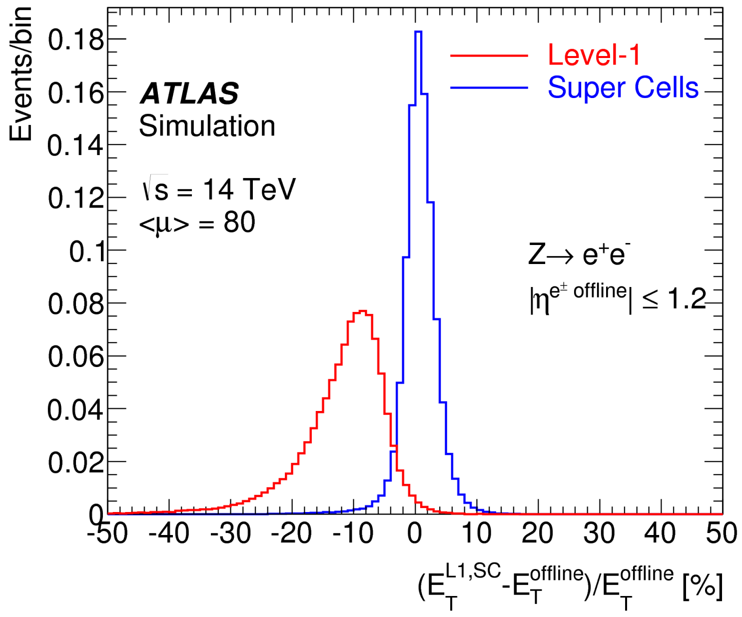


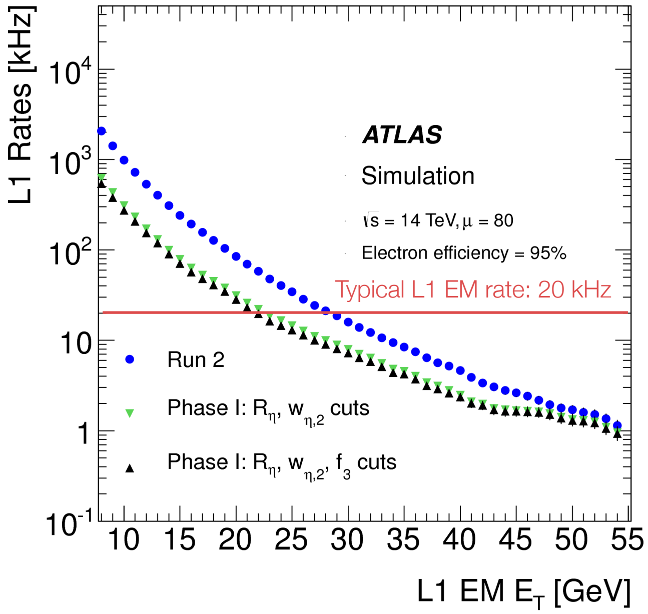


~3000 Trigger Towers

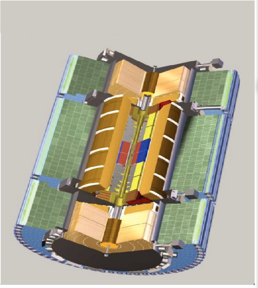
Increase granularity on the trigger path by removing some sums on frontend board.

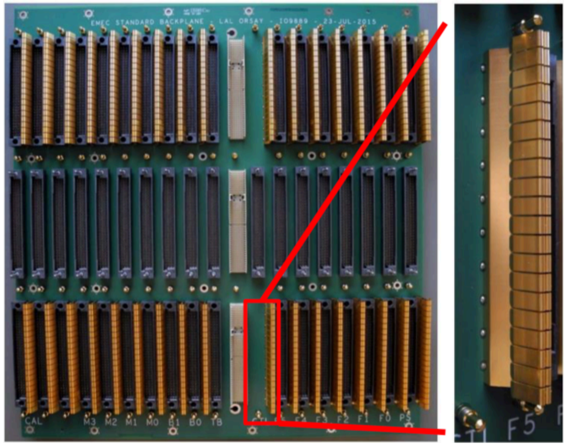
~34000 Super Cells



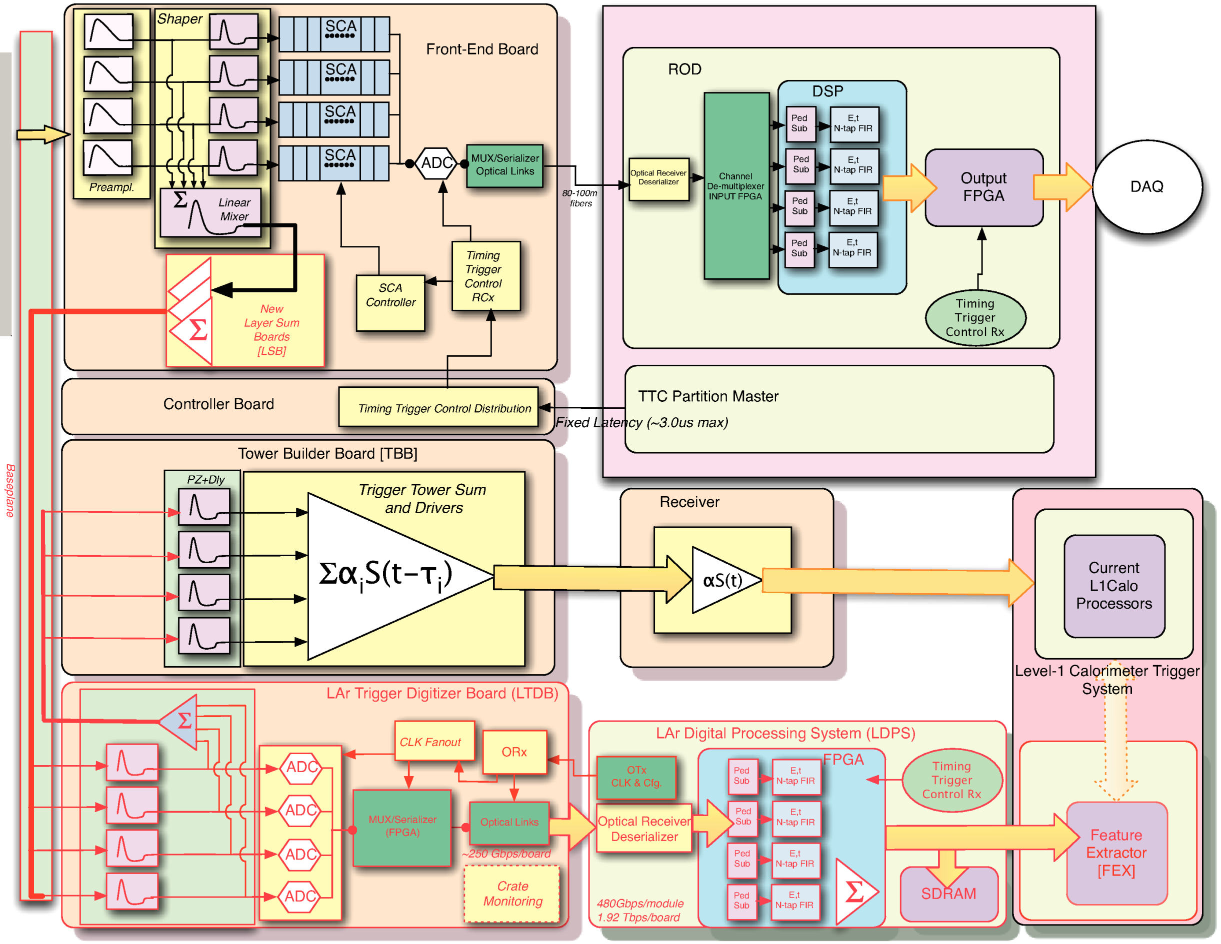


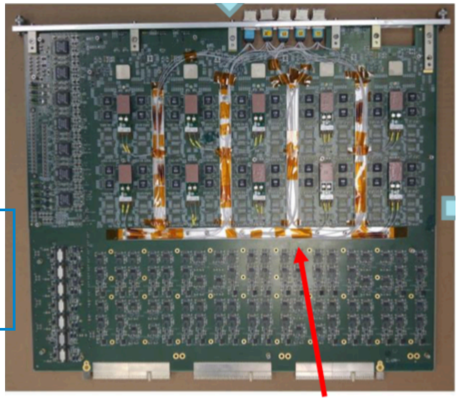
Liquid Argon Phase-I Upgrade: improved trigger





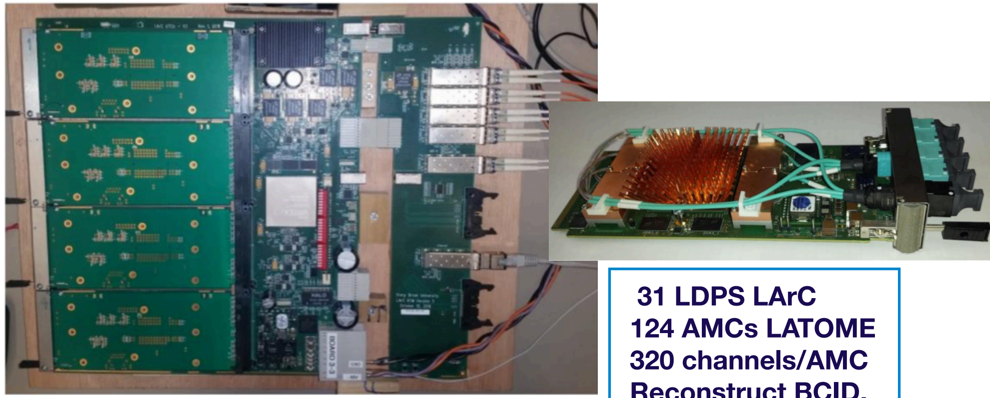
56 baseplanes





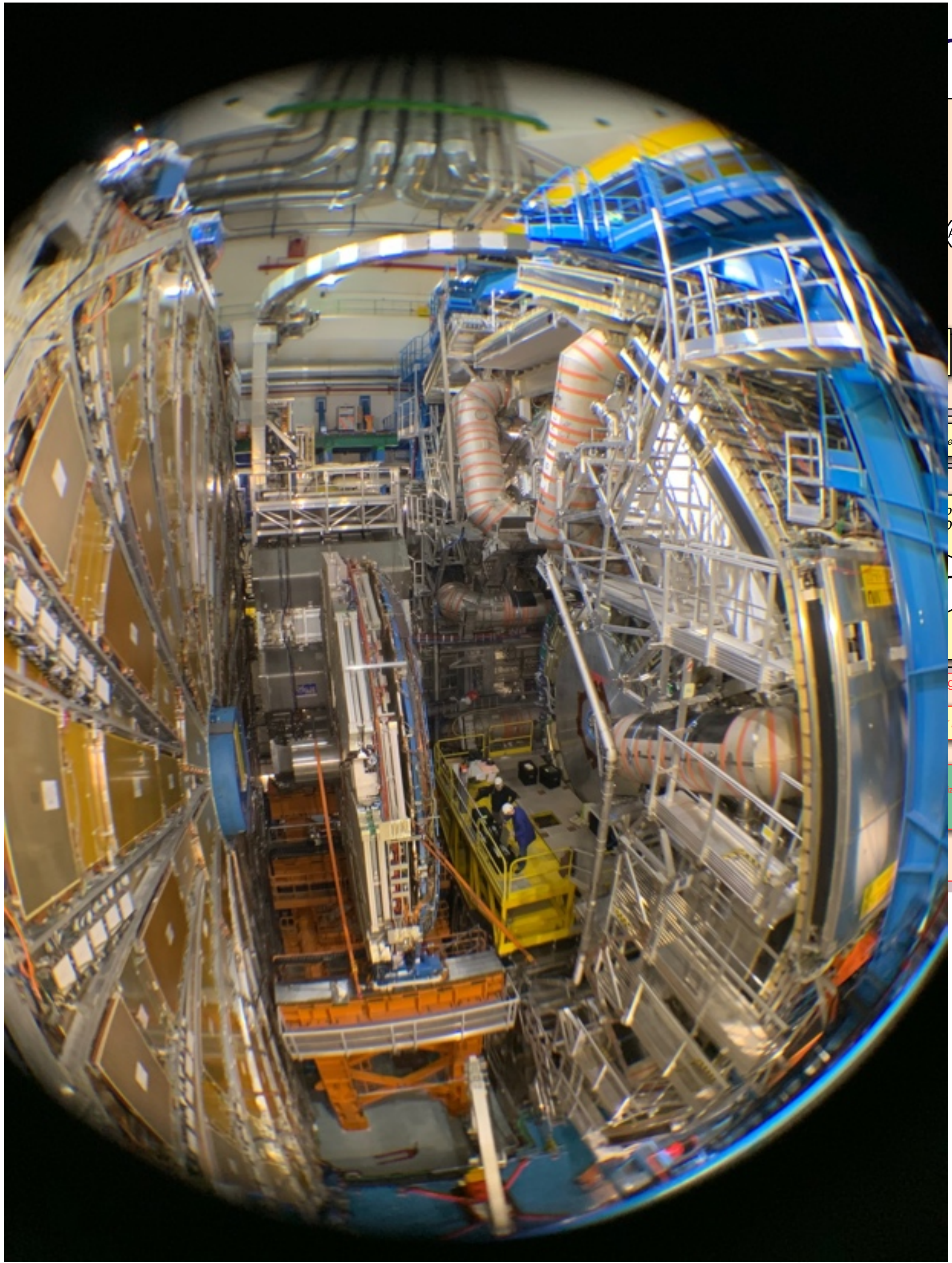
Pre-production LTDB with fiber trough

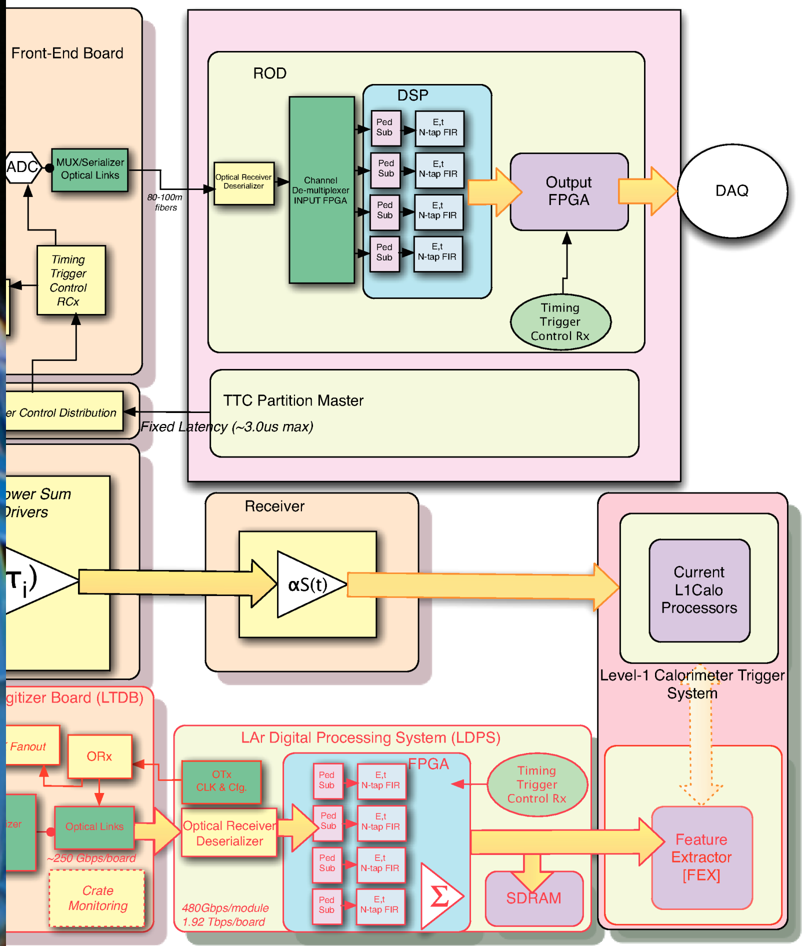
124 LTDB
320 channels/board
Digitise signals at 40 MHz

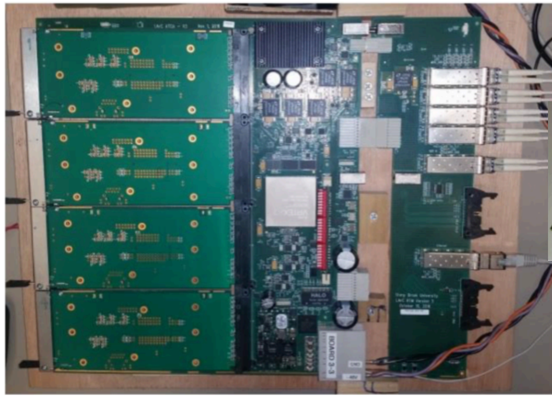


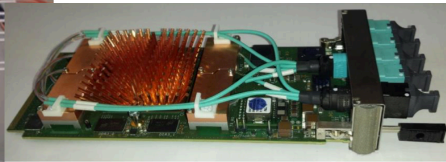
31 LDPS LArC
124 AMCs LATOME
320 channels/AMC
Reconstruct BCID, E_T at 40 MHz

oved trigger





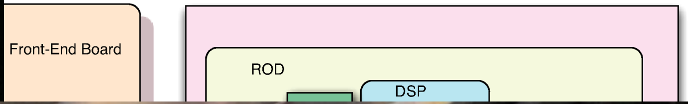


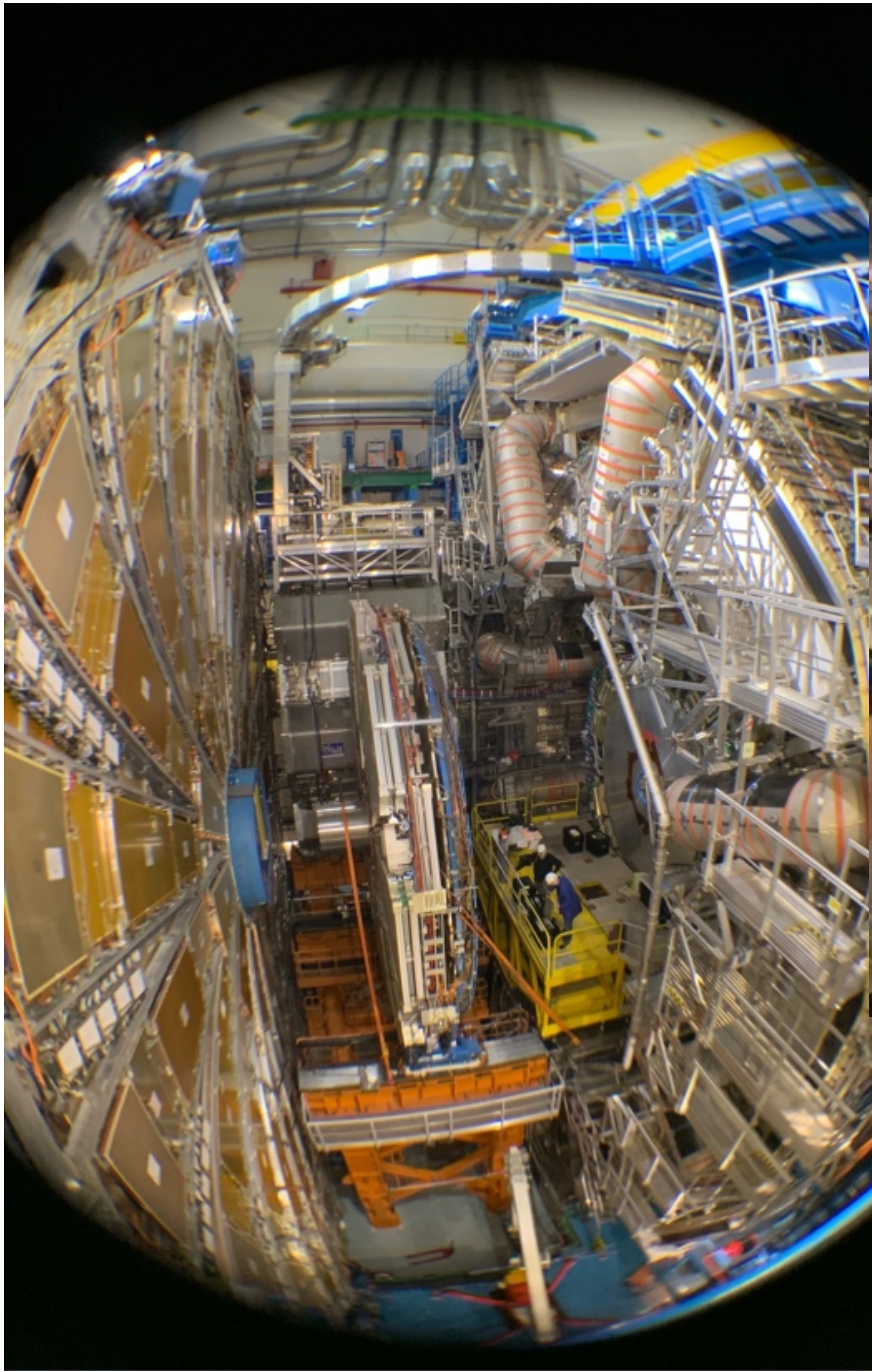


Pre-production LTDB with fiber trough

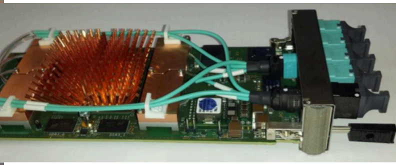
31 LDPS LArC
124 AMCs LATOME
320 channels/AMC
Reconstruct BCID,
E_T at 40 MHz

roved trigger



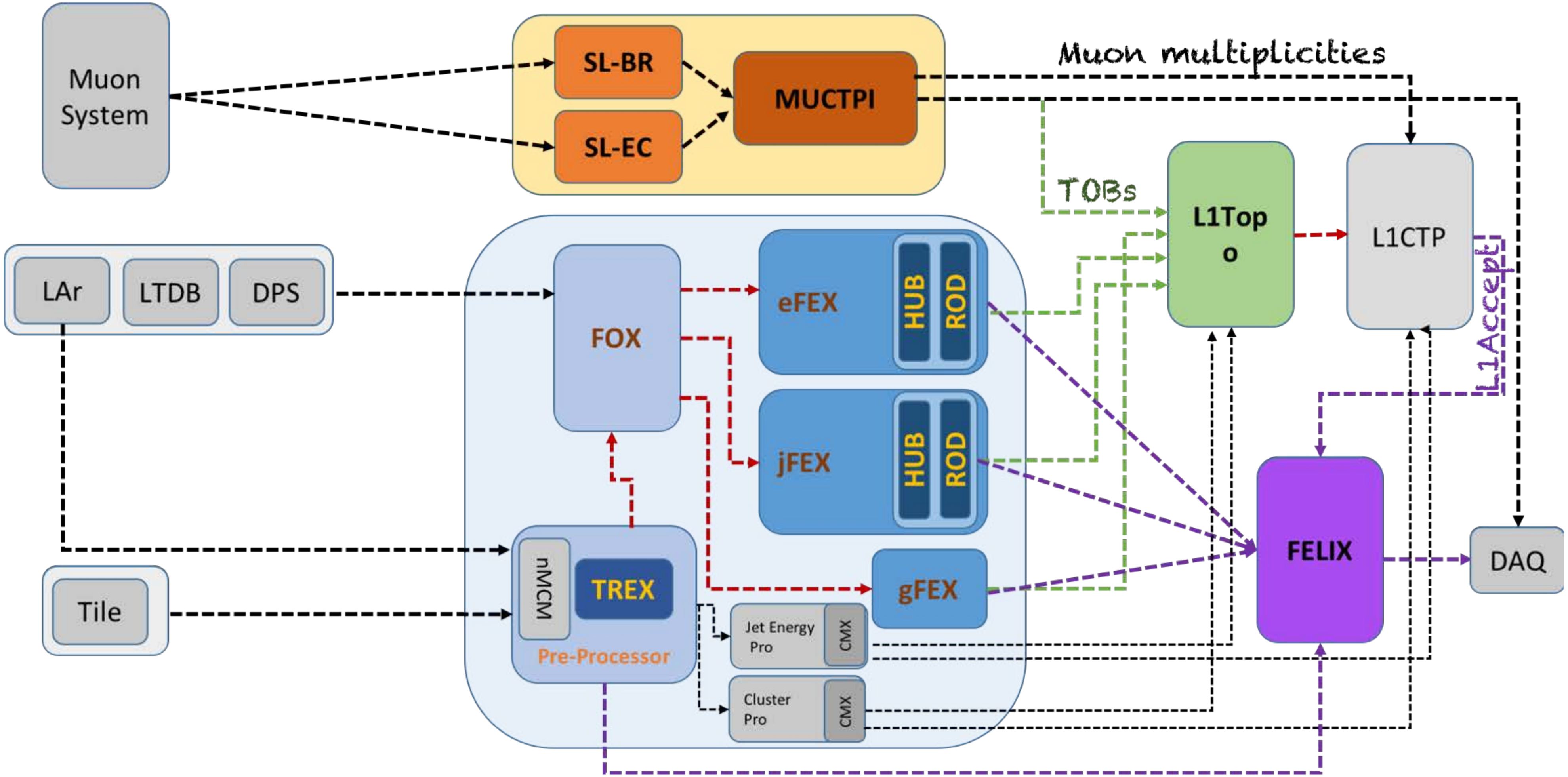


Pre-production LTDB with fiber trough

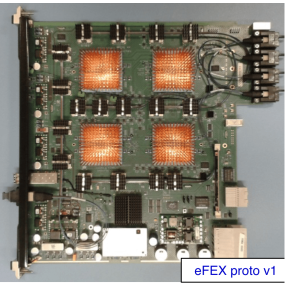


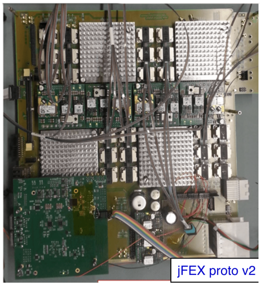
31 LDPS LArC
124 AMCs LATOME
320 channels/AMC
Reconstruct BCID,
E_T at 40 MHz

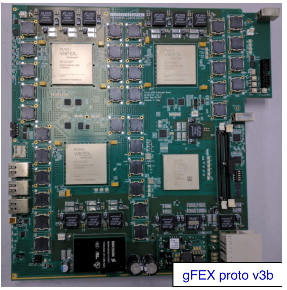
TDAQ upgrade

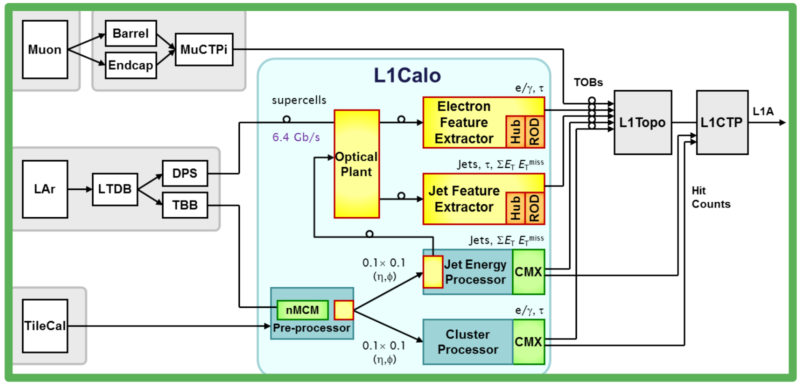


Trigger-DAQ Phase-I Upgrade


eFEX proto v1

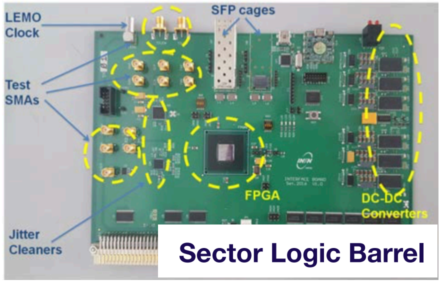

jFEX proto v2


gFEX proto v3b

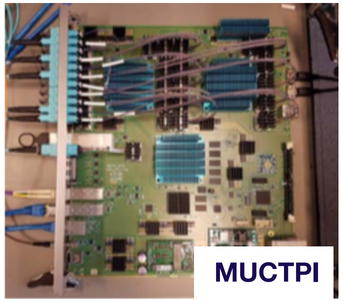


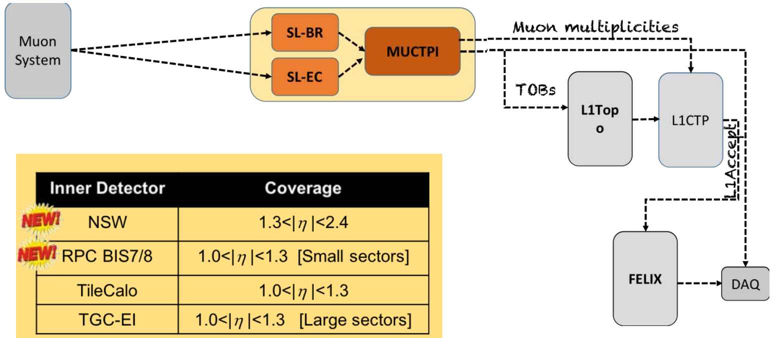
Improved LAr calorimeter segmentation for L1

eFex, jFex, gFex….



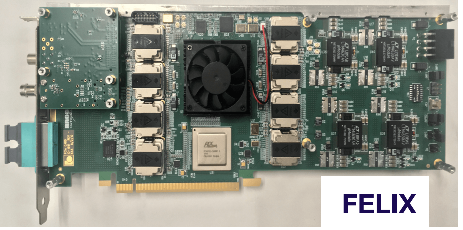
Sector Logic Barrel

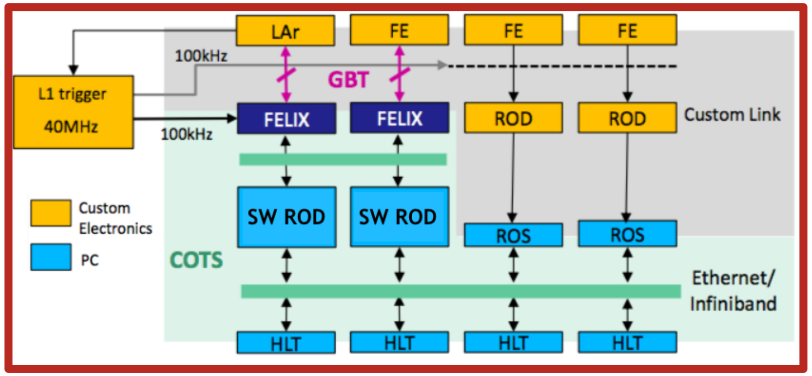

MUCTPI



Inner Detector	Coverage
NEW! NSW	1.3<|η|<2.4
NEW! RPC BIS7/8	1.0<|η|<1.3 [Small sectors]
TileCalo	1.0<|η|<1.3
TGC-EI	1.0<|η|<1.3 [Large sectors]

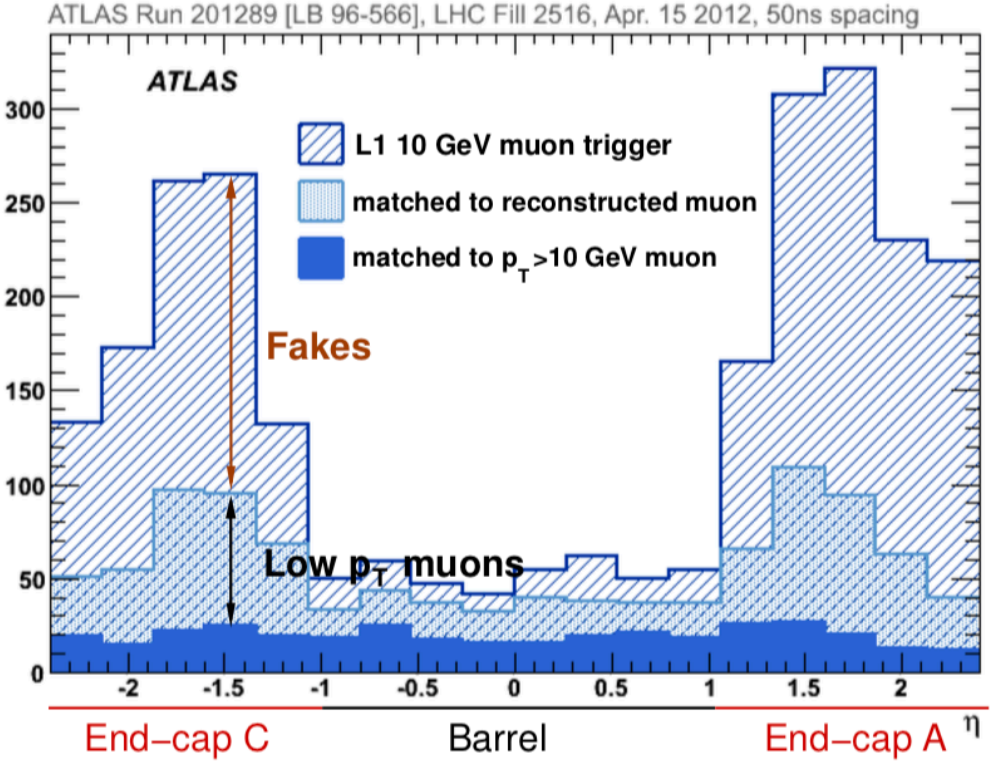
New Small Wheel for improvement background rejection at L1

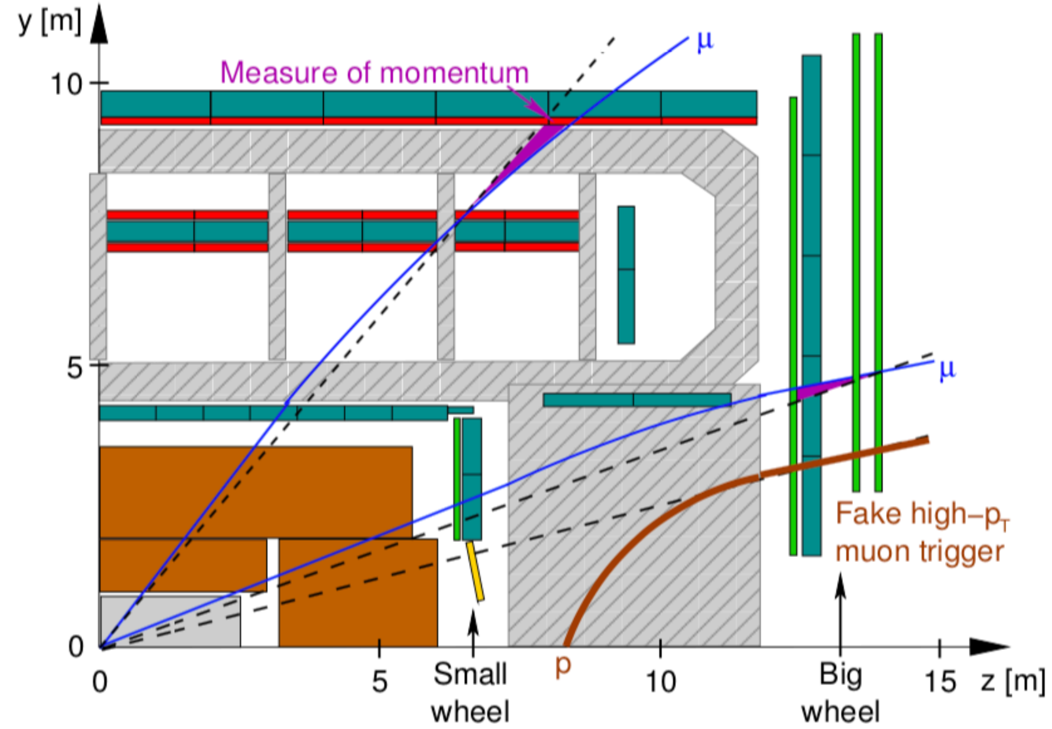

FELIX



FELIX board

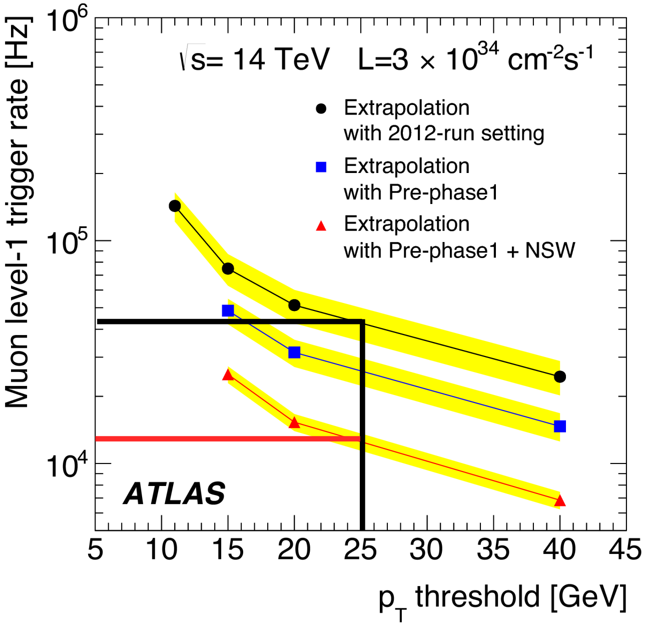
Sources of Level 1 muon trigger at LHC



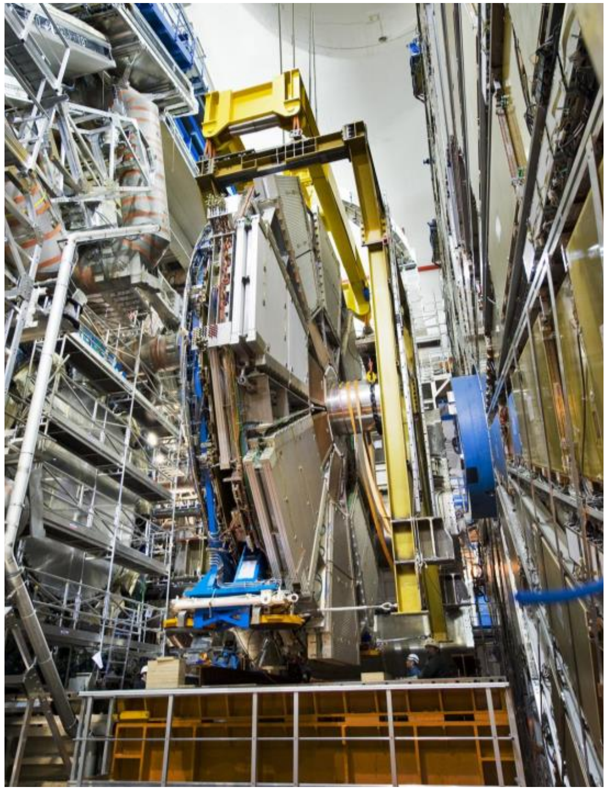


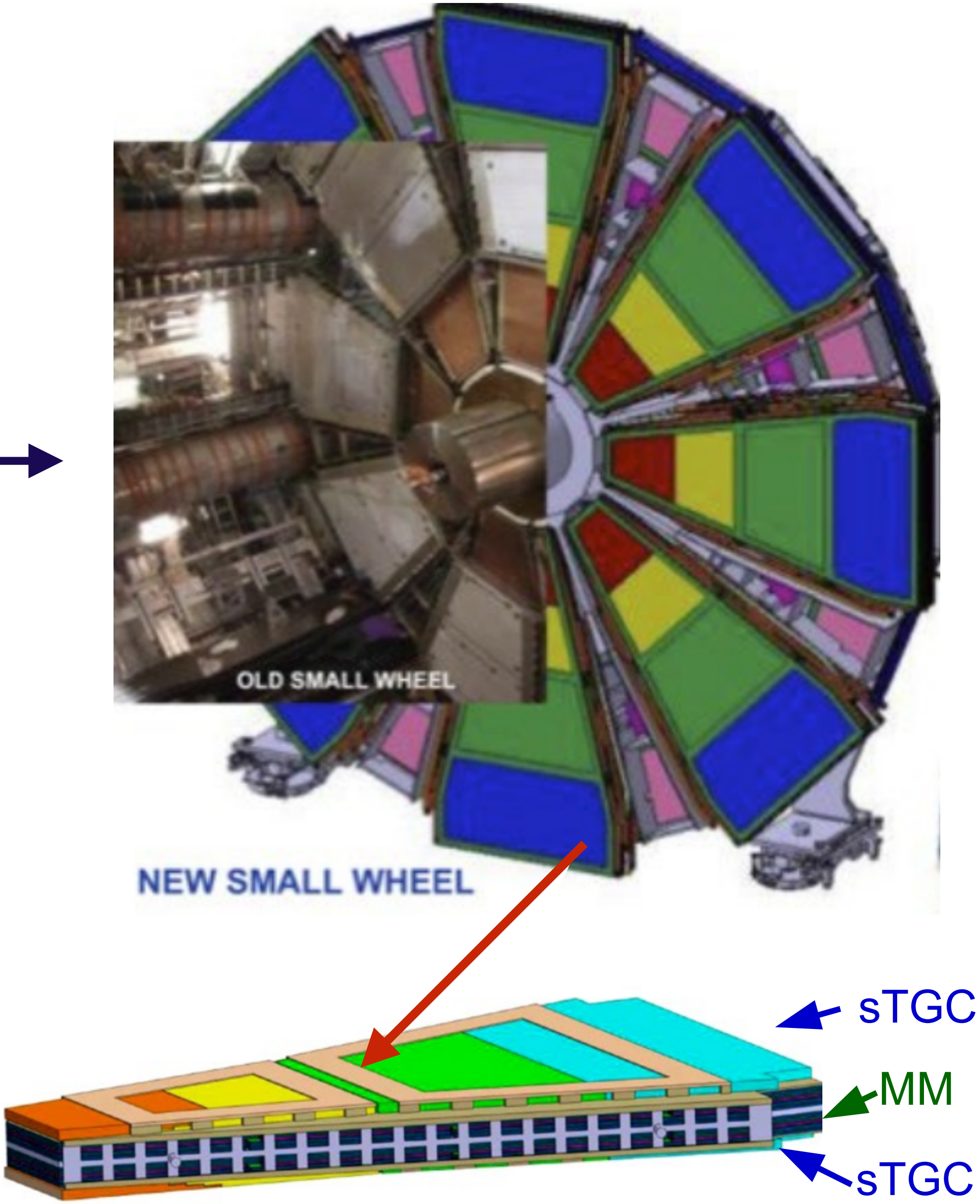
Muon trigger rate dominated by **fake** triggers in the endcaps caused by **charged particles not emerging from the interaction point.**

Real muon triggers contaminated with sub-pT-threshold muon due to the reduced momentum resolution caused by the moderate spatial resolution of the trigger chambers,



New Small Wheel



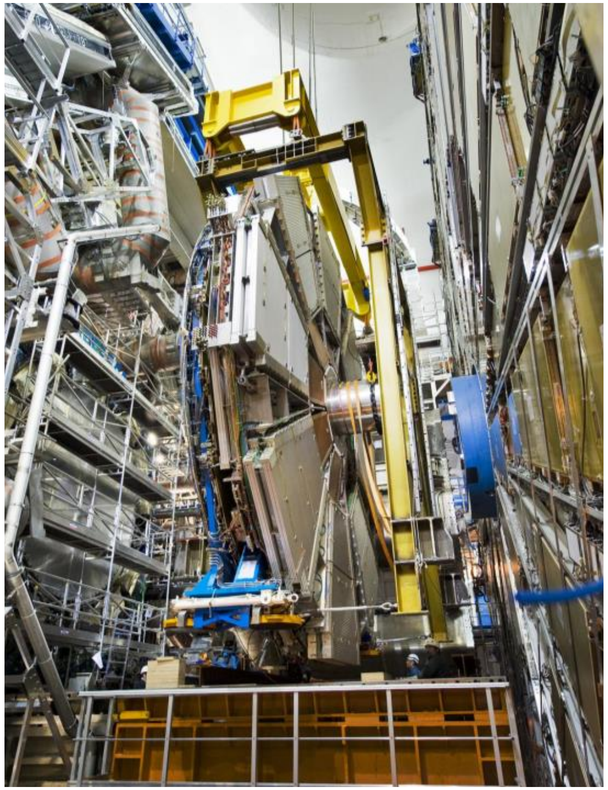


Replace muon small wheels with improved trigger capability: **<1mrad** angular resolution and associated trigger vector capability

2 sTGC quadruplets for trigger, bunch id and vector tracking with **<1mrad** resolution

2 MicroMegas for quadruplets for tracking with resolution **<100µm**

New Small Wheel

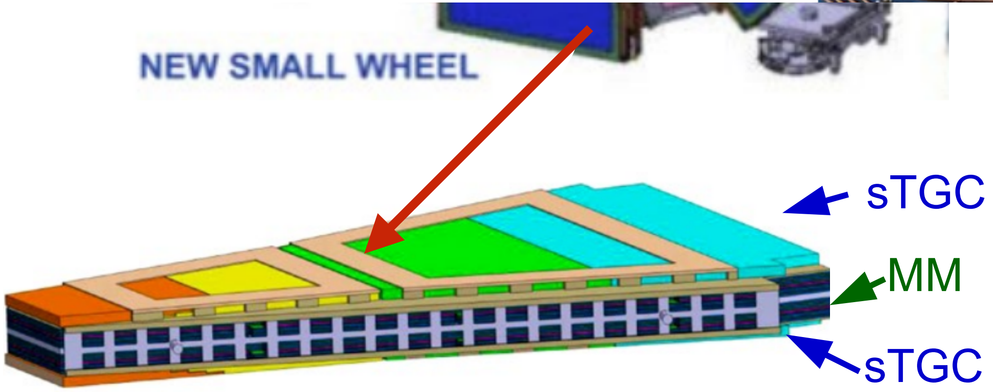


From B191, before Xmas

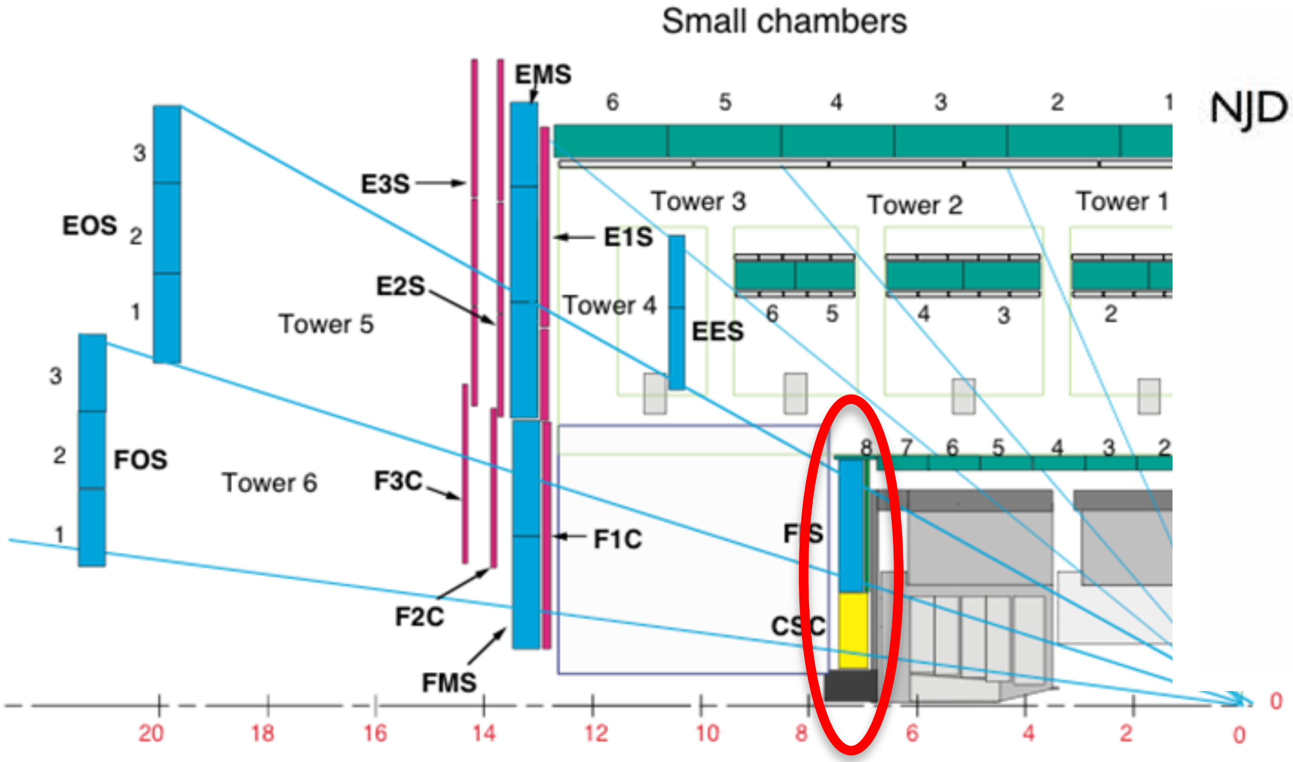
Replace muon small wheels with improved trigger capability: **<1mrad** angular resolution and associated trigger vector capability

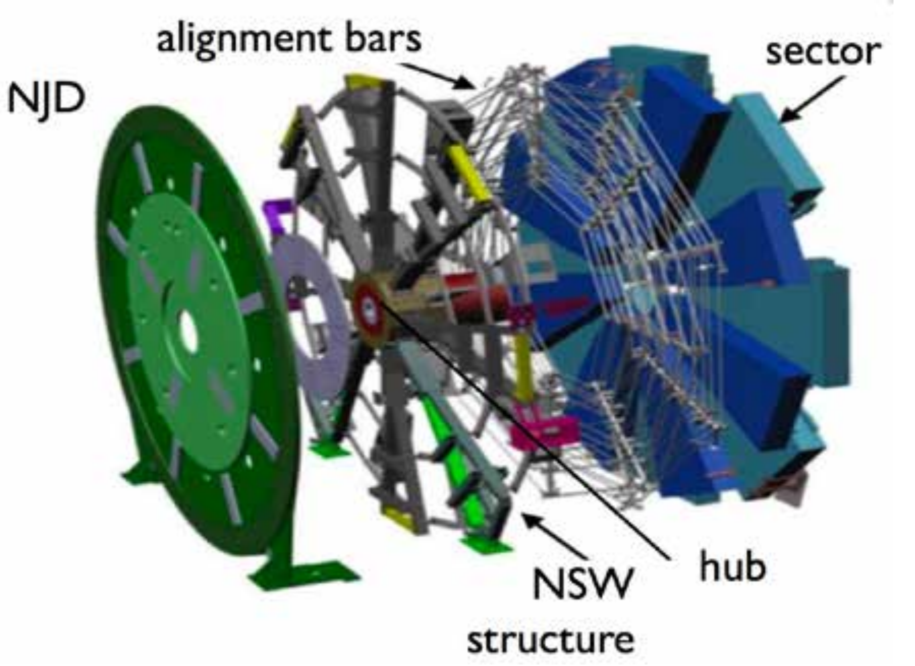
2 sTGC quadruplets for trigger, bunch id and vector tracking with **<1mrad** resolution

2 MicroMegas for quadruplets for tracking with resolution **<100µm**

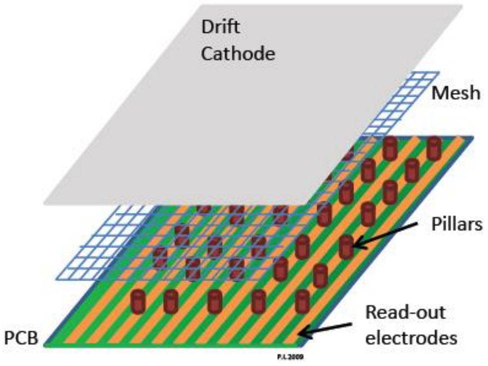


New Small Wheel in construction

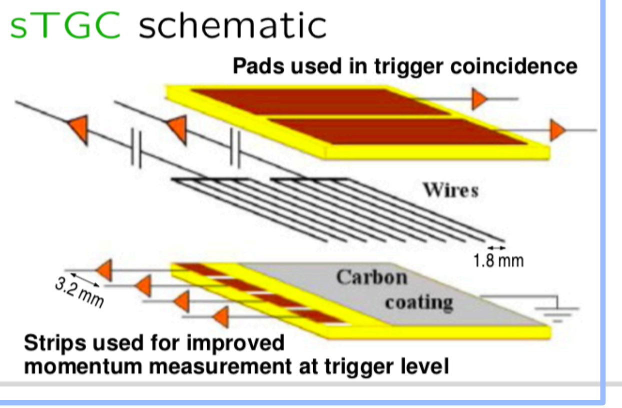




Micromegas



small Thin Gap Chambers (sTGC)



FINAL ADJUSTMENTS for PRODUCTION - VERY INTENSE CONSTRUCTION PERIOD AHEAD of US for INSTALLATION DURING LS2

PHASE-II UPGRADE

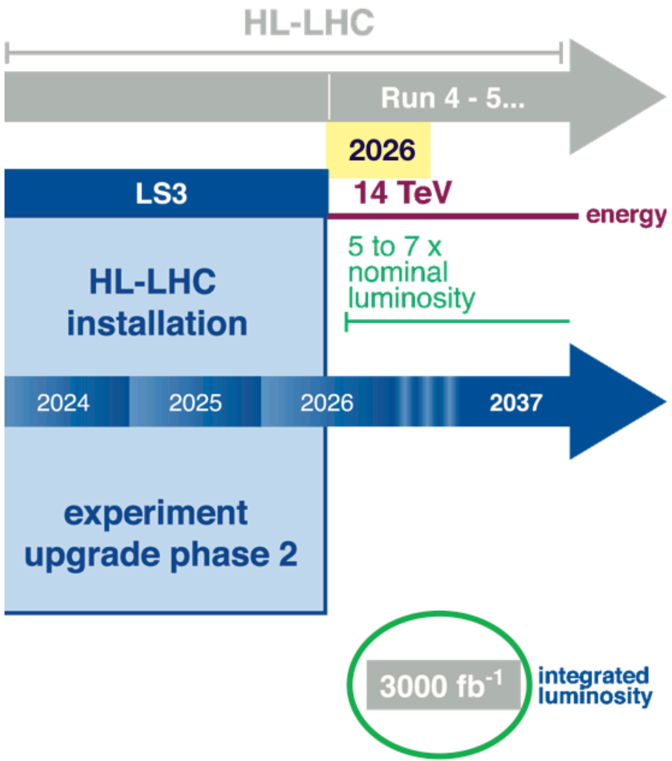
Inner Tracker

Calorimeters

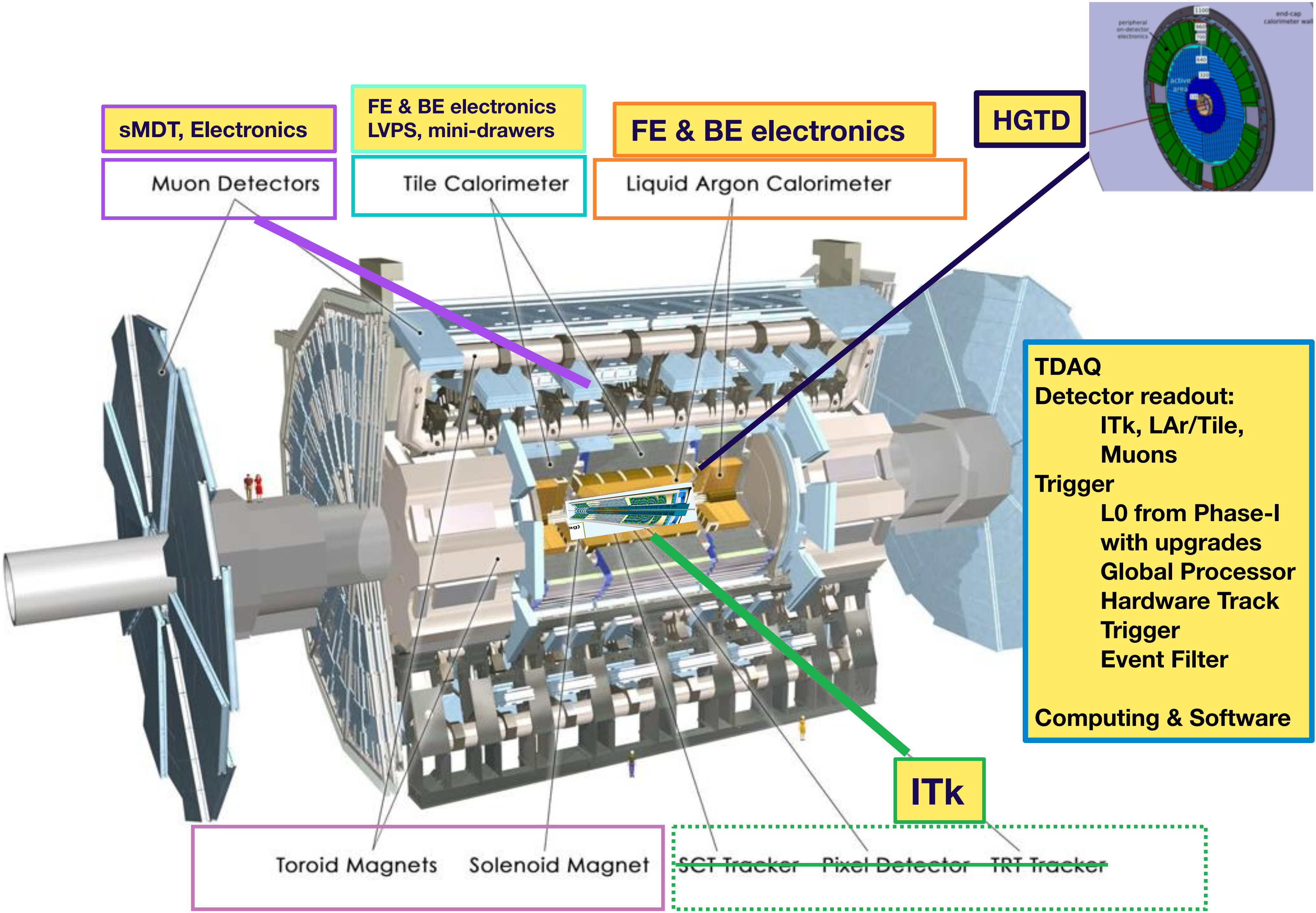
Muon System

TDAQ

High Granularity Timing Detector



The ATLAS detector: Phase-II upgrades



sMDT, Electronics

FE & BE electronics
LVPS, mini-drawers

FE & BE electronics

HGTD

TDAQ
Detector readout:
- **ITk, LAr/Tile, Muons**

Trigger
- **L0 from Phase-I with upgrades**
- **Global Processor**
- **Hardware Track Trigger**
- **Event Filter**

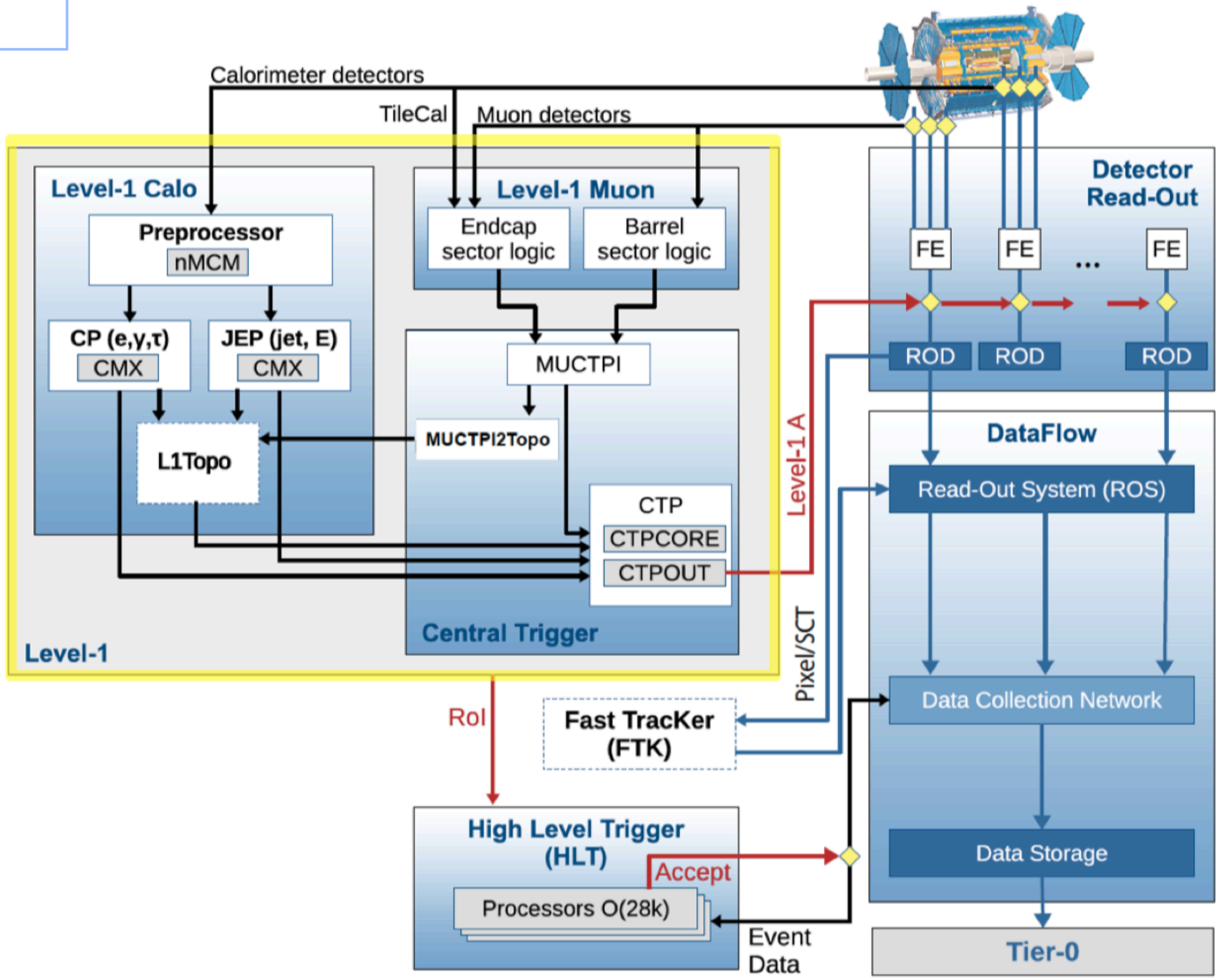
Computing & Software

ITk

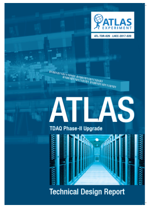
Trigger/DAQ upgrade for HL-LHC

Changes in the readout system have strong implications in the upgrade detector and electronics design.

Rate Latency	Run 2	Run 3 Phase I	Run4 Phase II
Level 0	-	-	1-4 MHz 6-10 µs
Level 1	100 kHz 2.5 µs	100 kHz 2.5 µs	400-800 kHz 35 µs
HLT	1kHz	1kHz	10 kHz



Trigger and Data Acquisition



Trigger/DAQ

Level-0 Trigger System 10 μs

Identify physics objects

Compute event level quantities

Send L0A to sub-systems

Data transmitted at 1MHz to FELIX

DAQ system

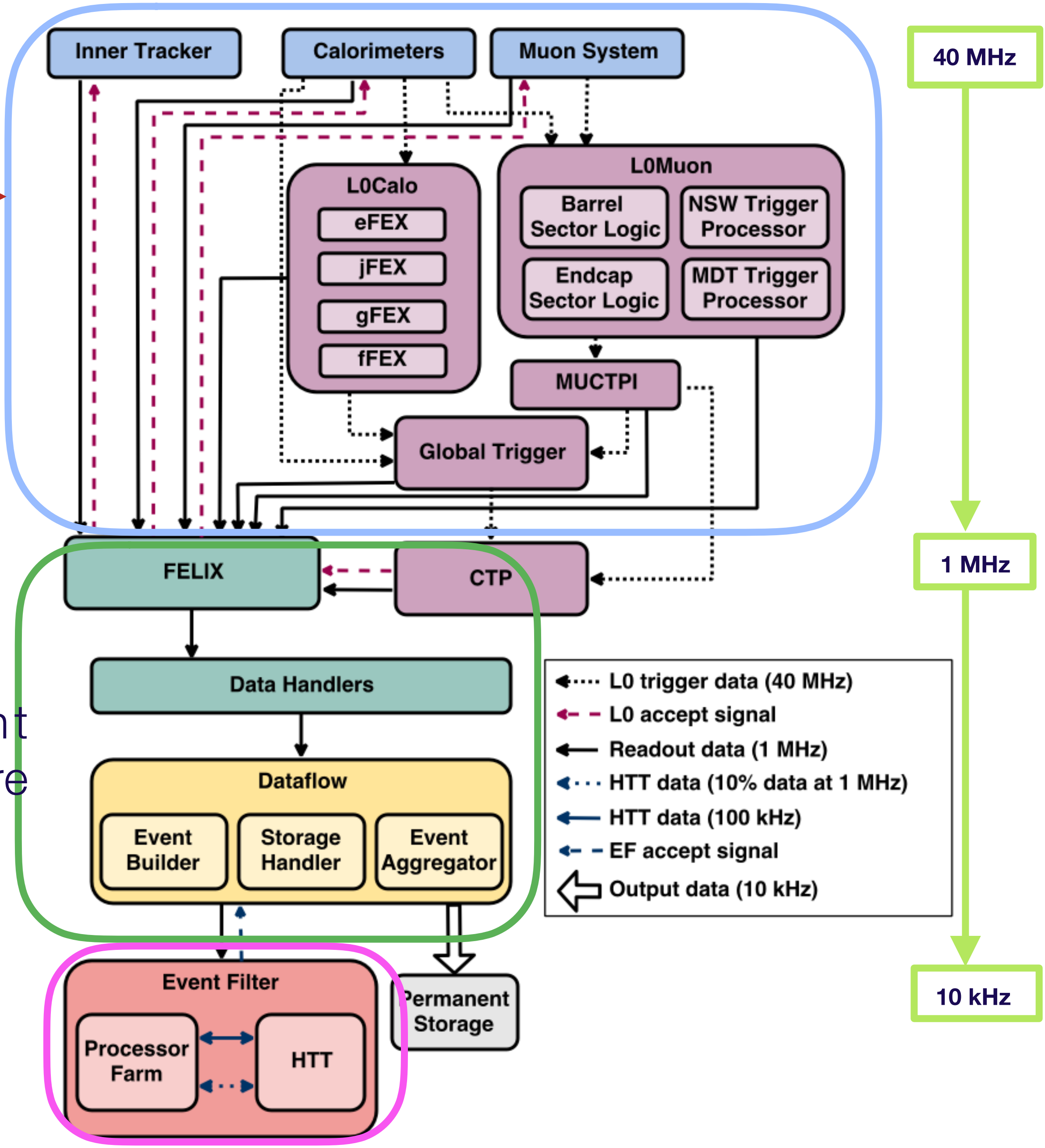
Event builder

Transmit events to

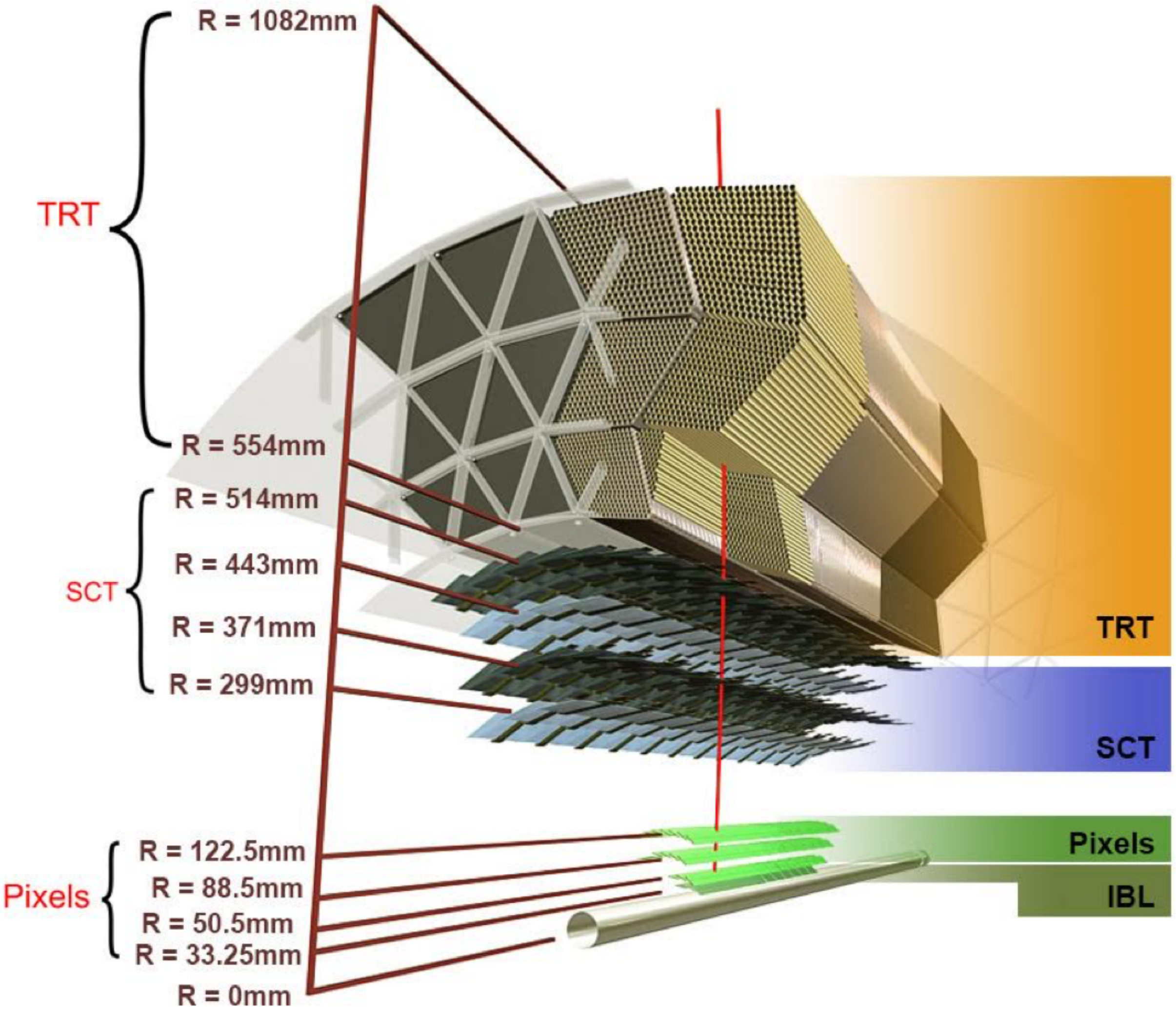
Event Filter System

Decision based on event reconstruction and Hardware Track Trigger

Output to storage at 10 kHz



The ATLAS INNER DETECTOR



Pixels 90
Strips 6
TRT 0.3
} 10^6 channels

$|\eta|<2.5$

pixel

IBL 50x250 μm^2

σ_{hit}=10/70 μm Rϕ/z

pixels 50x400 μm^2

σ_{hit}=10/115 μm Rϕ/z

SCT

pitch 60-80 μm; length ~ 6cm

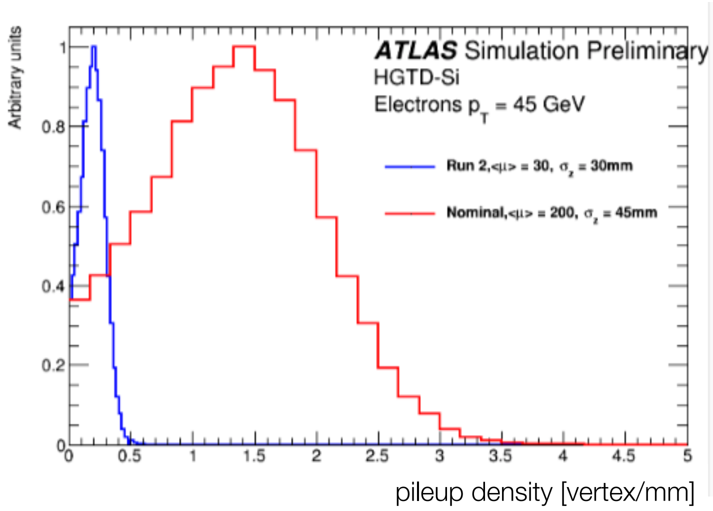
σ_{hit}=17/580 μm Rϕ/z

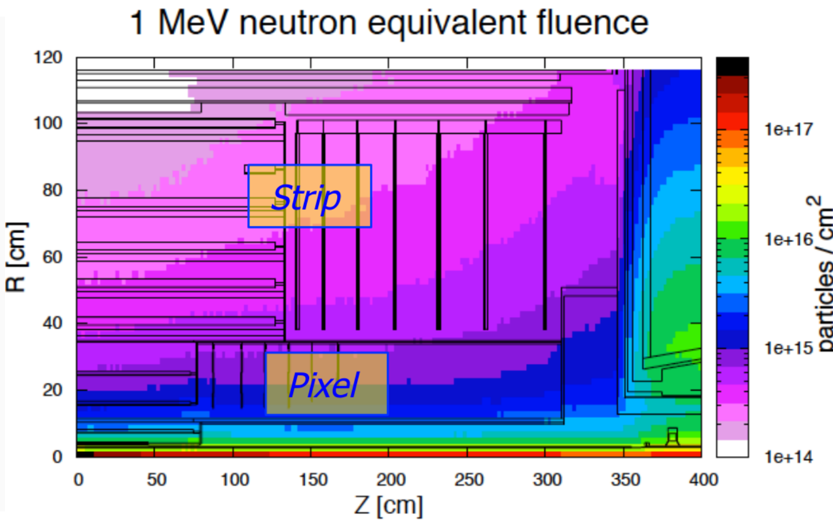
TRT

σ_{hit}=130 μm

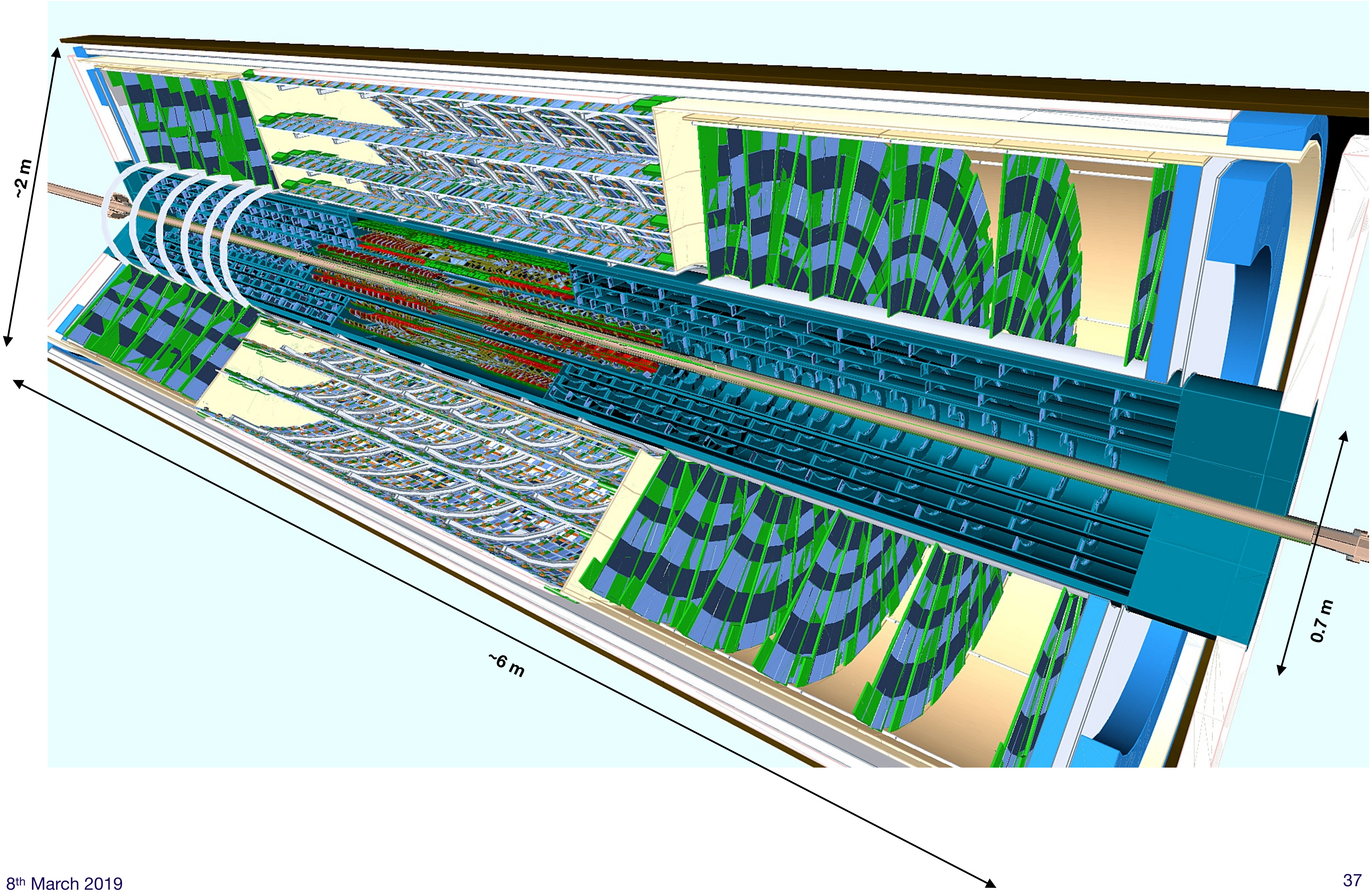
ATLAS Inner Tracker -ITk- for HL-LHC

200 pile-up events	occupancy	high granularity, material
10^{16} neq/cm^2, 10 MGy	conception, tests	modularity
3000 events/fb	2026-2037	robust
VBF/VBS	Increased η coverage	|η|<4





ATLAS Inner Tracker -ITk- for HL-LHC



ITk HOME

ITk: The new ATLAS Inner Tracker

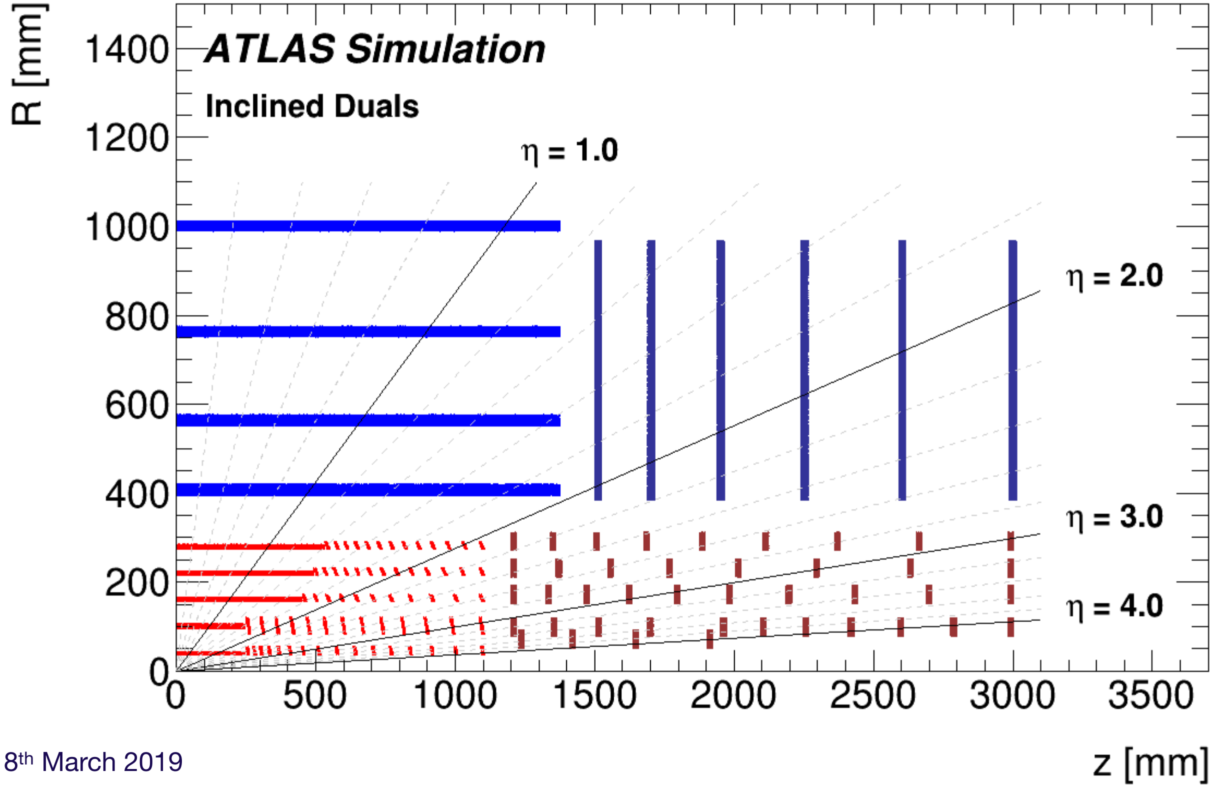
Motivation

Replacement of the central tracking detector in ATLAS.

Essential to manage the higher track densities at the anticipated luminosities. Essential to adapt the detector technologies to the higher radiation levels

Layout has converged on a **silicon pixel** (5 layers in the barrel, confined to a cylinder of R=34.5 cm around the beam pipe) + a **silicon strip** system (4 oute layers in the barrel).

Extension of η coverage to 4.0: requires novel technical advances



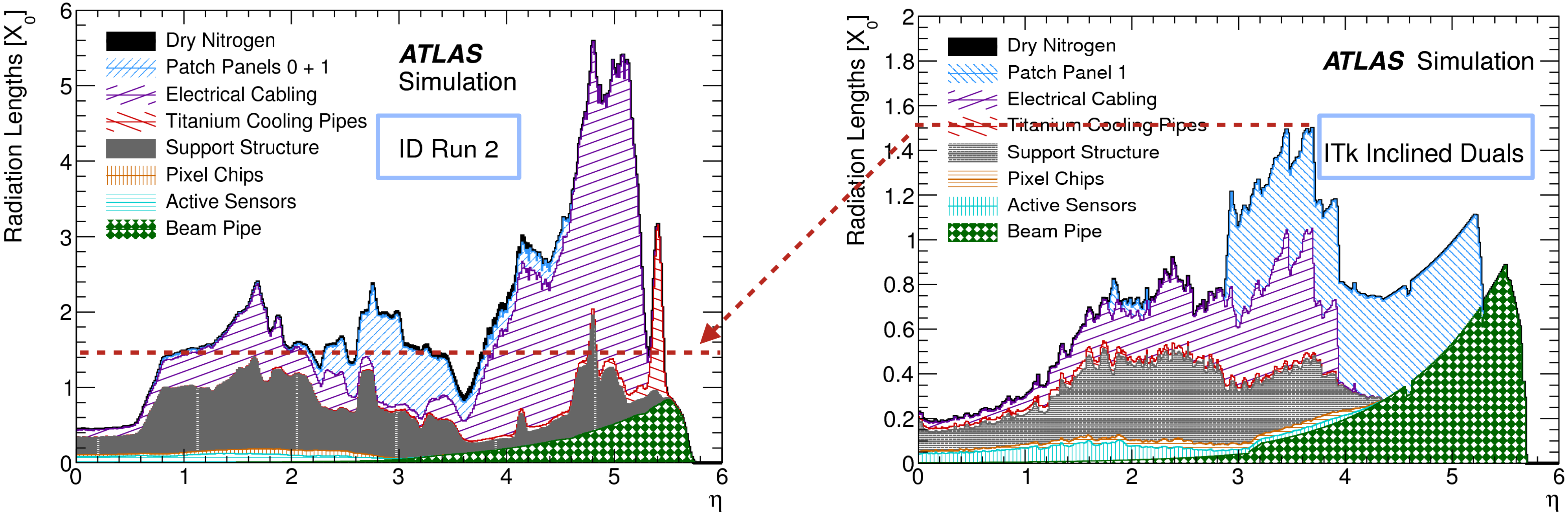
Pixels 600 }
Strips 70 }
10^6 channels

|η|<4.0

Pixel 25x100 or 50x50 μm^2

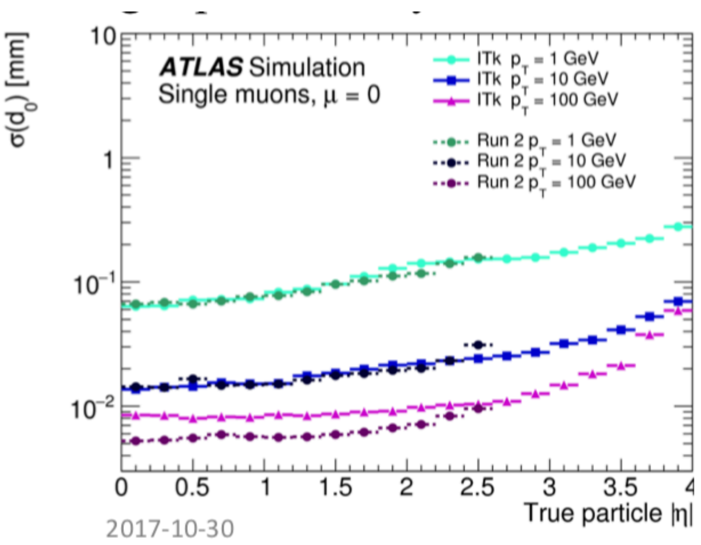
Strips 75μm pitch; length ~10 cm

ITk - MATERIAL

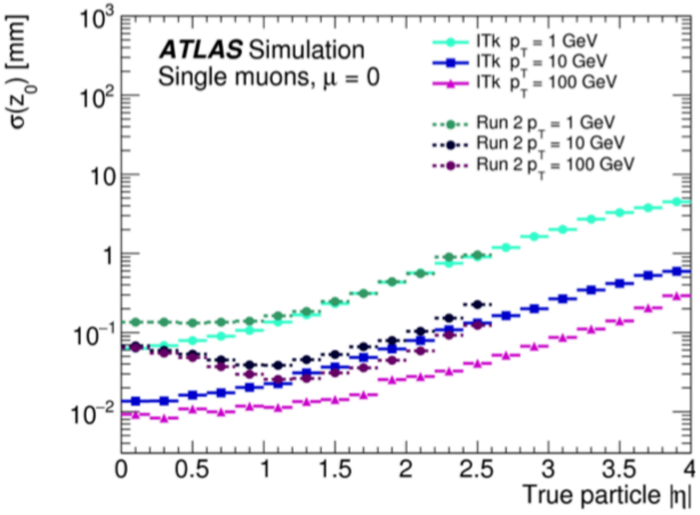


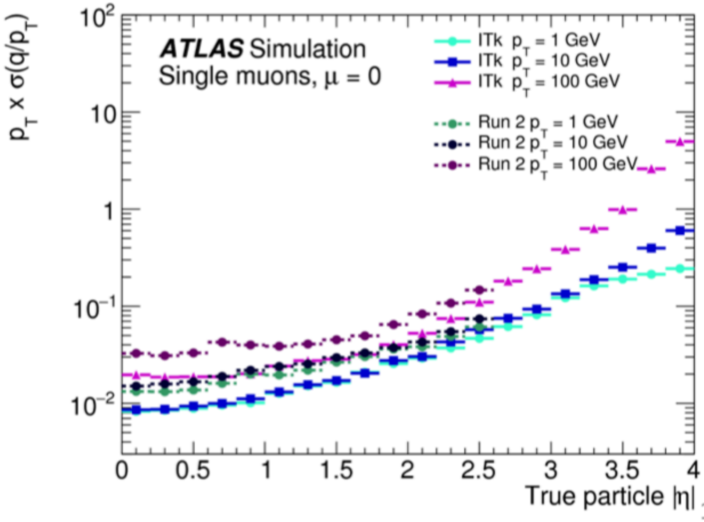
Thinner sensors
Improved (modern) material structure
Titanium tubes for cooling
Sensors inclined in extended barrel section

ITk - PERFORMANCE



2017-10-30





Excellent capability to resolve the position and momentum

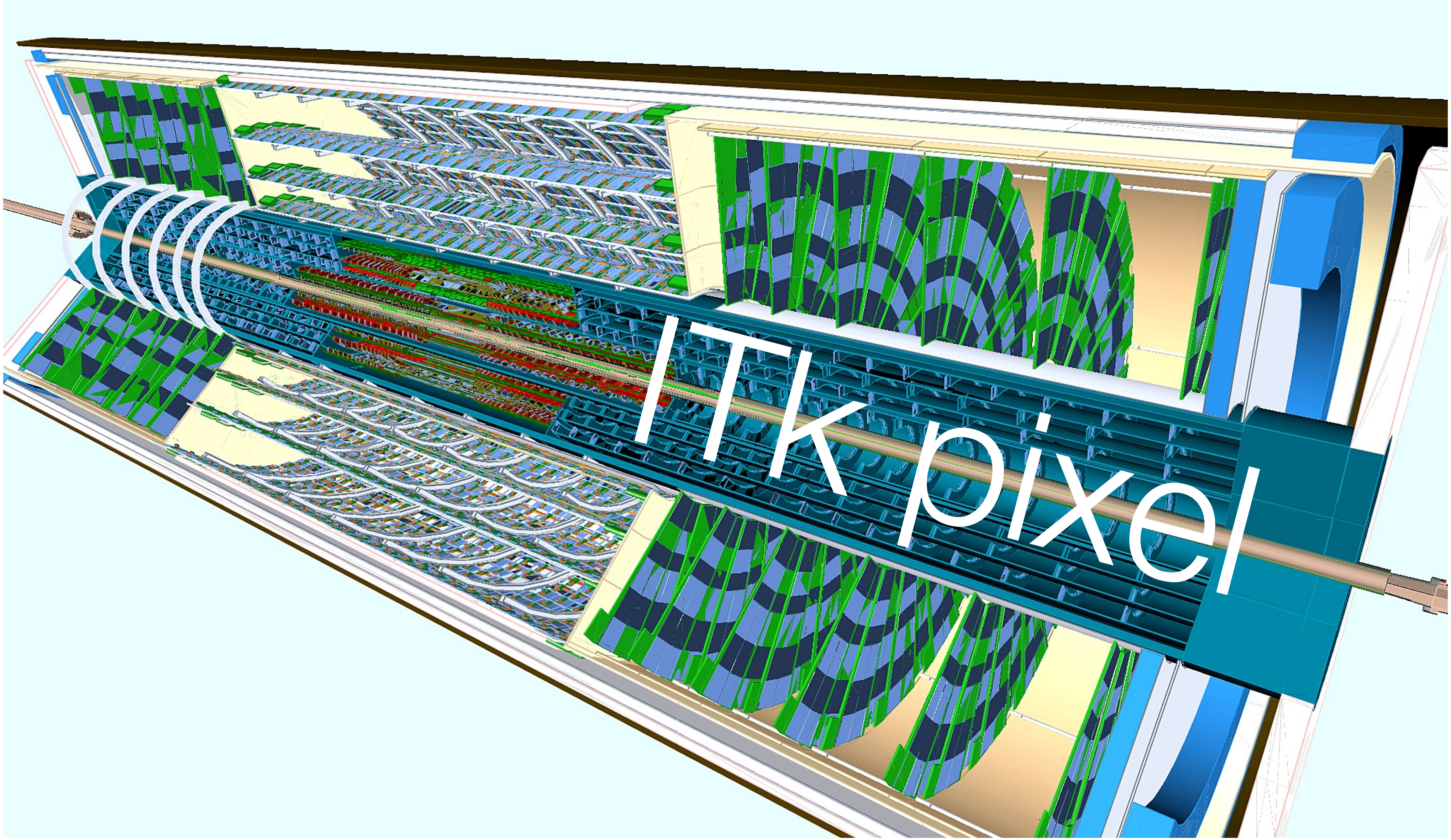
Transverse impact parameter (IP) resolution d_0 similar to current ID

- Run-2 performance better at very high momentum due to analog clustering calibration while such calibrations are not yet ready for ITk
  - ITk with analogue clustering expected to provide similar resolution as for the current ID

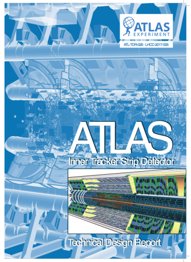
Significant improvements in the longitudinal IP resolution z_0.

- Reduction of pixel pitches from 250/400 μm to 50 μm for ITk.

Momentum resolution substantially improved by high precision measurements along the full track length provided by the full silicon tracker


ITk pixel

ITk- pixels



ITk pixel tracker

The TDR baseline design was defined aiming at

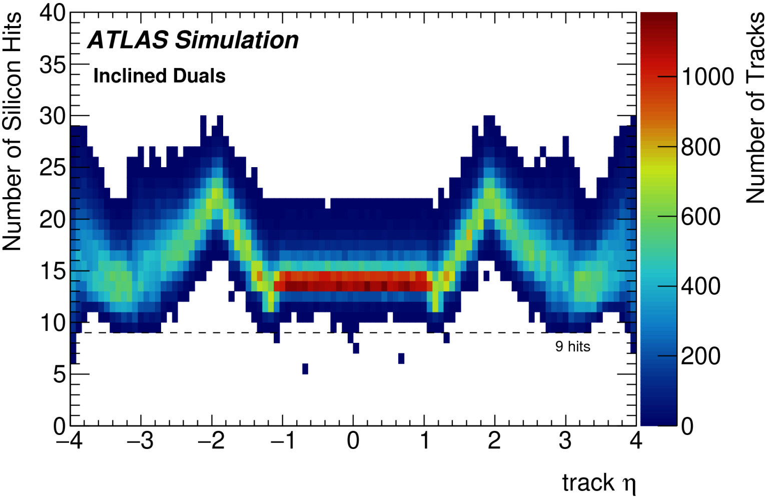
> **5 hits** close to the interaction point with high granularity and accuracy **~10 μm**

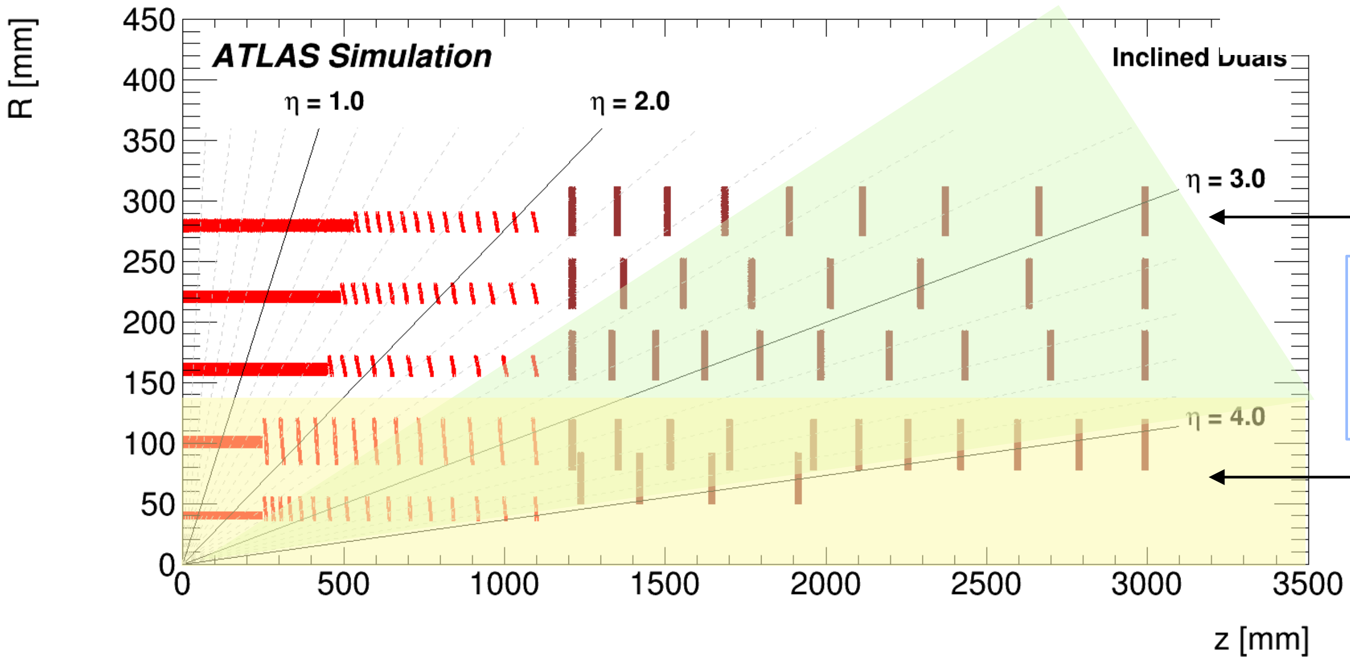
> **9 precision hits** over the full acceptance (-4<η<4) and up to R~1m

Minimisation of material over the full η acceptance

Best physics reach: good b-tagging, efficient reconstruction in dense jets and in high pile-up environnement, precise track & vertex measurements

Short barrel followed by inclined modules and the by disks (of different coverage: a measurement layer is not necessarily coplanar)





Additional η coverage

Active area: 12.7 m^2
pixel size: 50x50 (or 25x100) μm^2
Number of modules: 10276
Number of FE chips: 33184
Number of channels: ~500 10^6

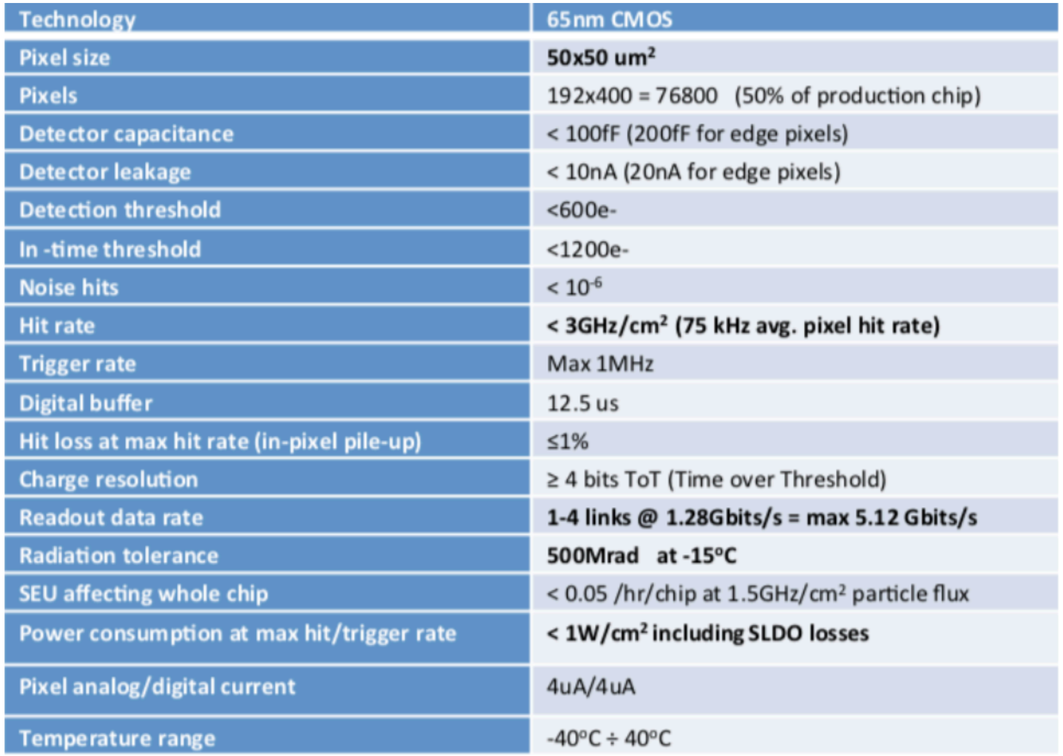
Insertable inner layers

ATLAS Inner Tracker -ITk- for HL-LHC - pixels frontend electronics

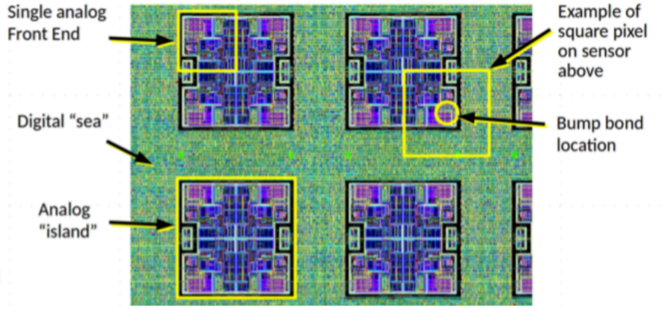
Synergic development with CMS (RD53) to design FE pixel ASIC for HL-LHC.

Main characteristics

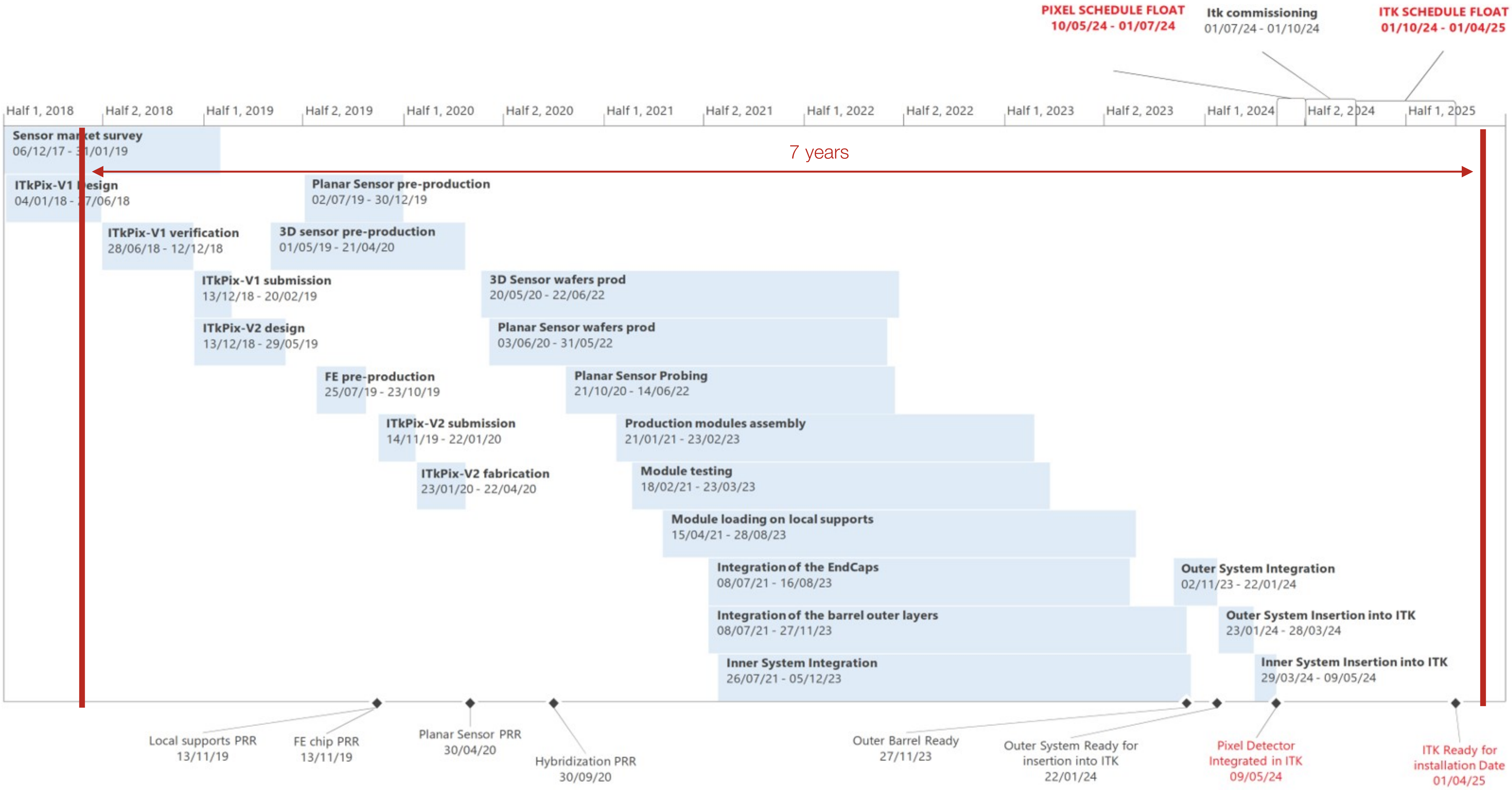
- Increased radiation hardness using 65nm technology in TSMC
- Smallest pitch for hybrid LHC application so far, 50x50 µm^2 (possibility for 25x100 µm^2)
- Highest data rate achievable per ASIC: 5Gbps

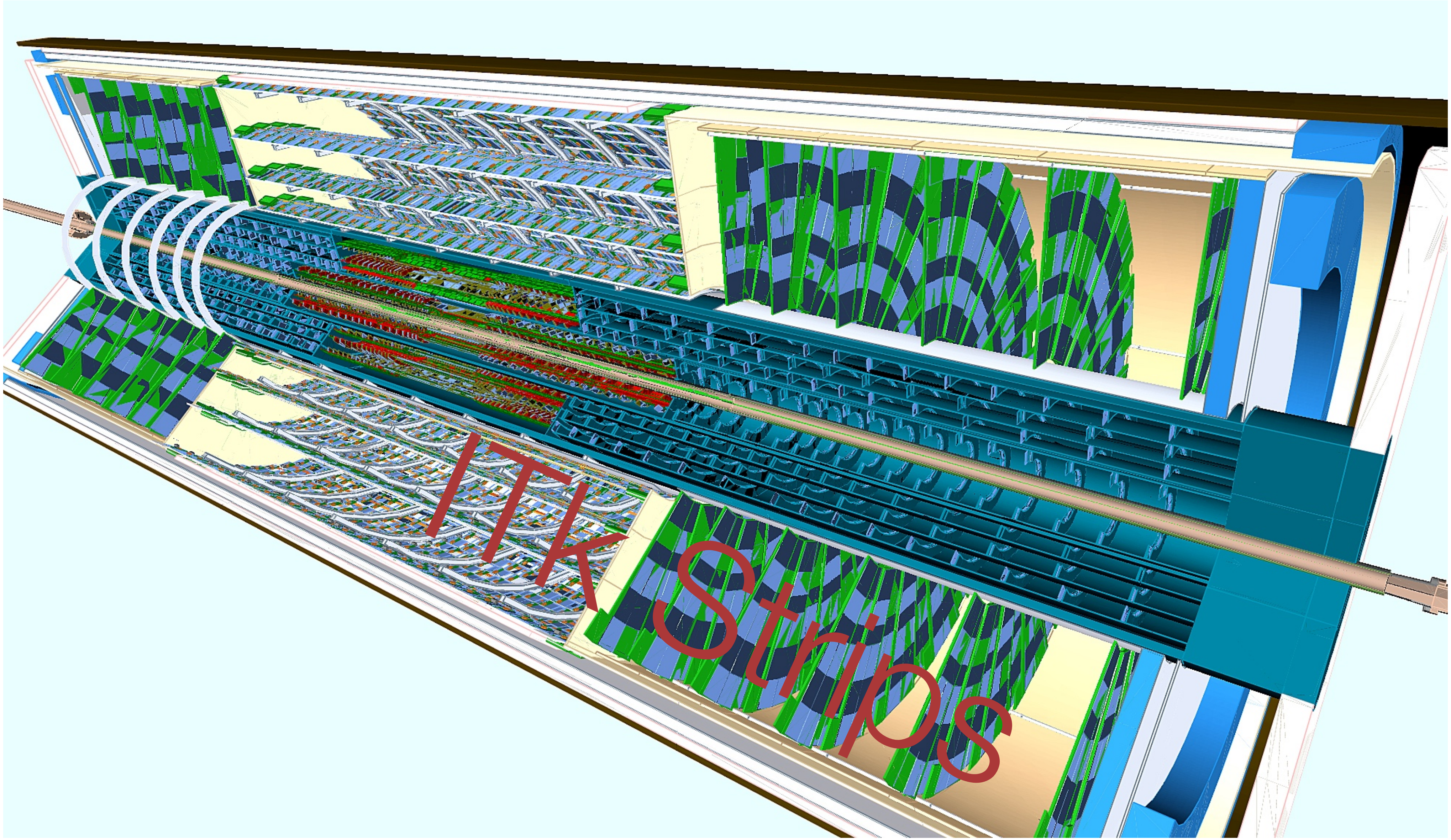


Technology	65nm CMOS
Pixel size	**50x50 um^2**
Pixels	192x400 = 76800 (50% of production chip)
Detector capacitance	< 100fF (200fF for edge pixels)
Detector leakage	< 10nA (20nA for edge pixels)
Detection threshold	<600e-
In -time threshold	<1200e-
Noise hits	< 10^{-6}
Hit rate	**< 3GHz/cm^2 (75 kHz avg. pixel hit rate)**
Trigger rate	Max 1MHz
Digital buffer	12.5 us
Hit loss at max hit rate (in-pixel pile-up)	≤1%
Charge resolution	≥ 4 bits ToT (Time over Threshold)
Readout data rate	**1-4 links @ 1.28Gbits/s = max 5.12 Gbits/s**
Radiation tolerance	**500Mrad at -15°C**
SEU affecting whole chip	< 0.05 /hr/chip at 1.5GHz/cm^2 particle flux
Power consumption at max hit/trigger rate	**< 1W/cm^2 including SLDO losses**
Pixel analog/digital current	4uA/4uA
Temperature range	-40°C ÷ 40°C

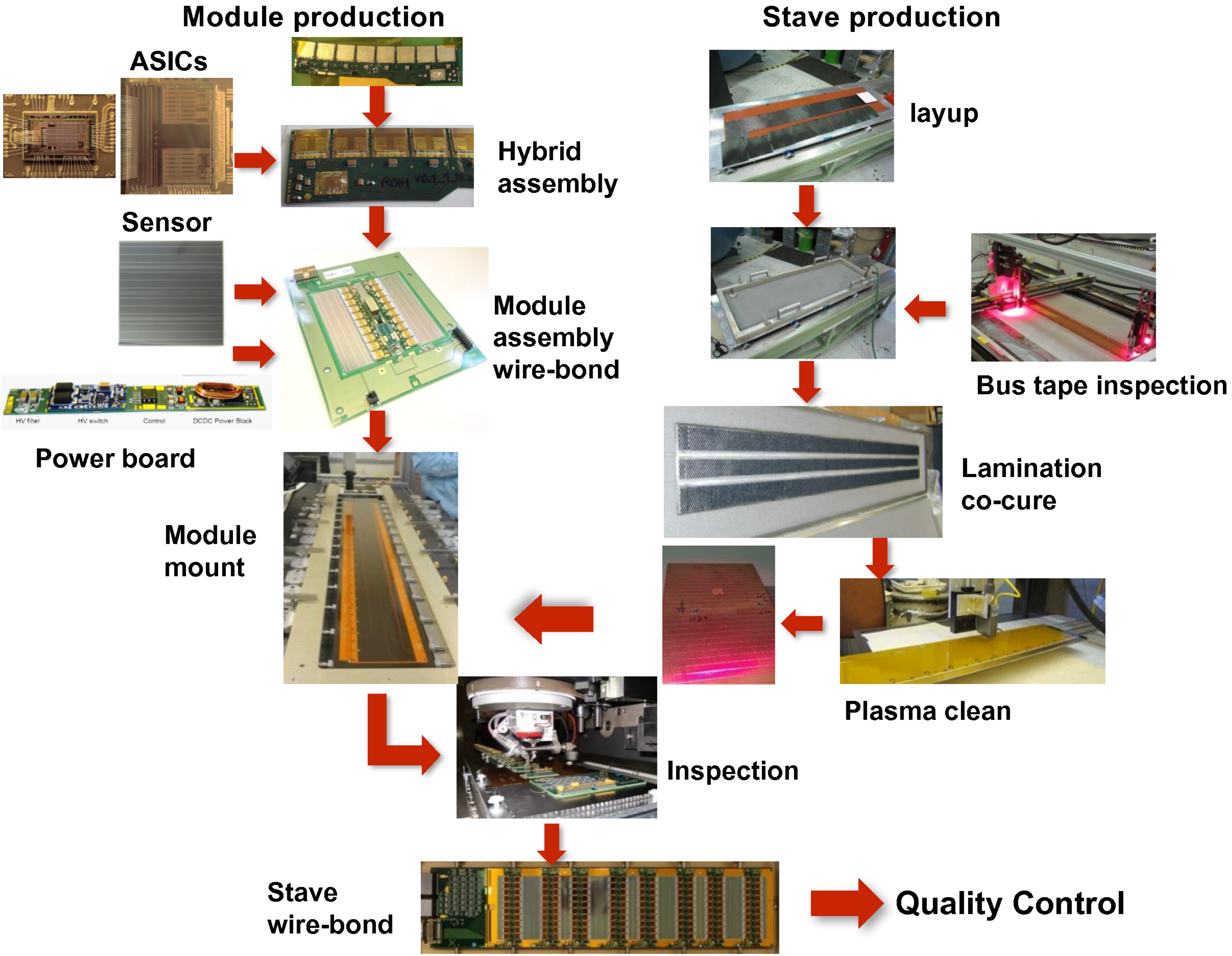


ATLAS Inner Tracker -ITk- for HL-LHC - pixel schedule




ITk Strips

ATLAS Inner Tracker -ITk- for HL-LHC - Strips Construction



Module production

ASICs

Hybrid assembly

Sensor

Module assembly wire-bond

Power board

Module mount

Stave production

layup

Bus tape inspection

Lamination co-cure

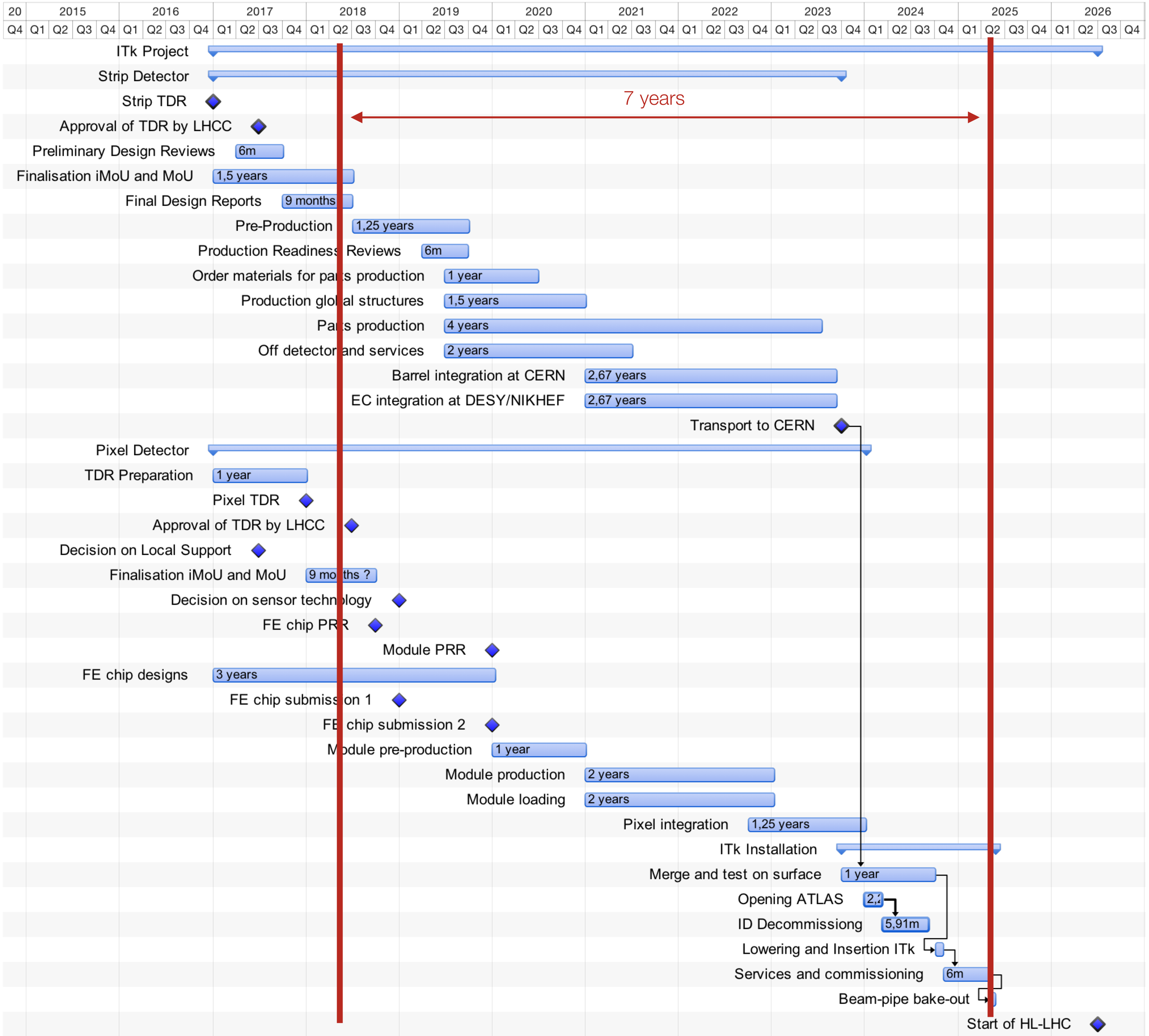
Plasma clean

Inspection

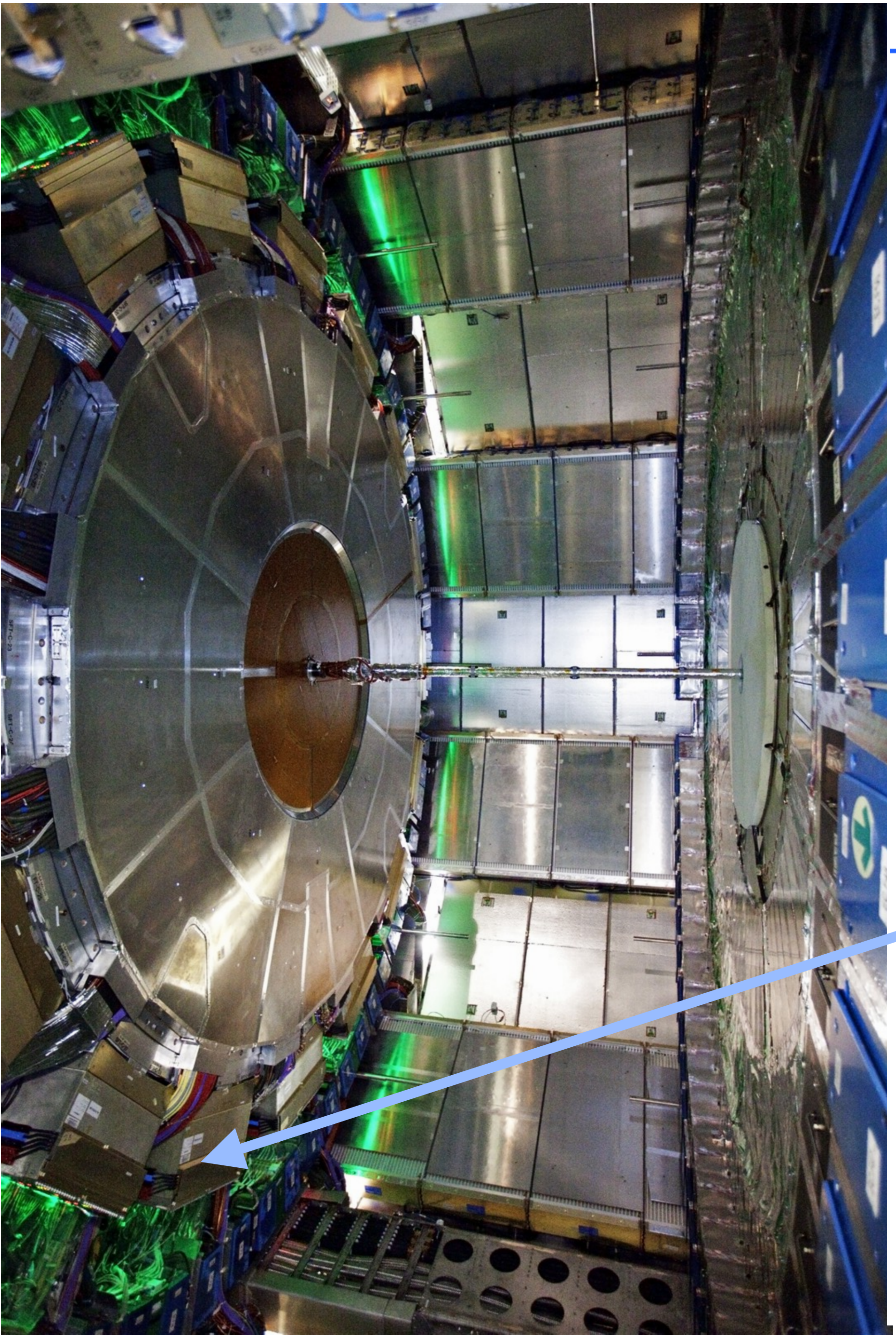
Stave wire-bond

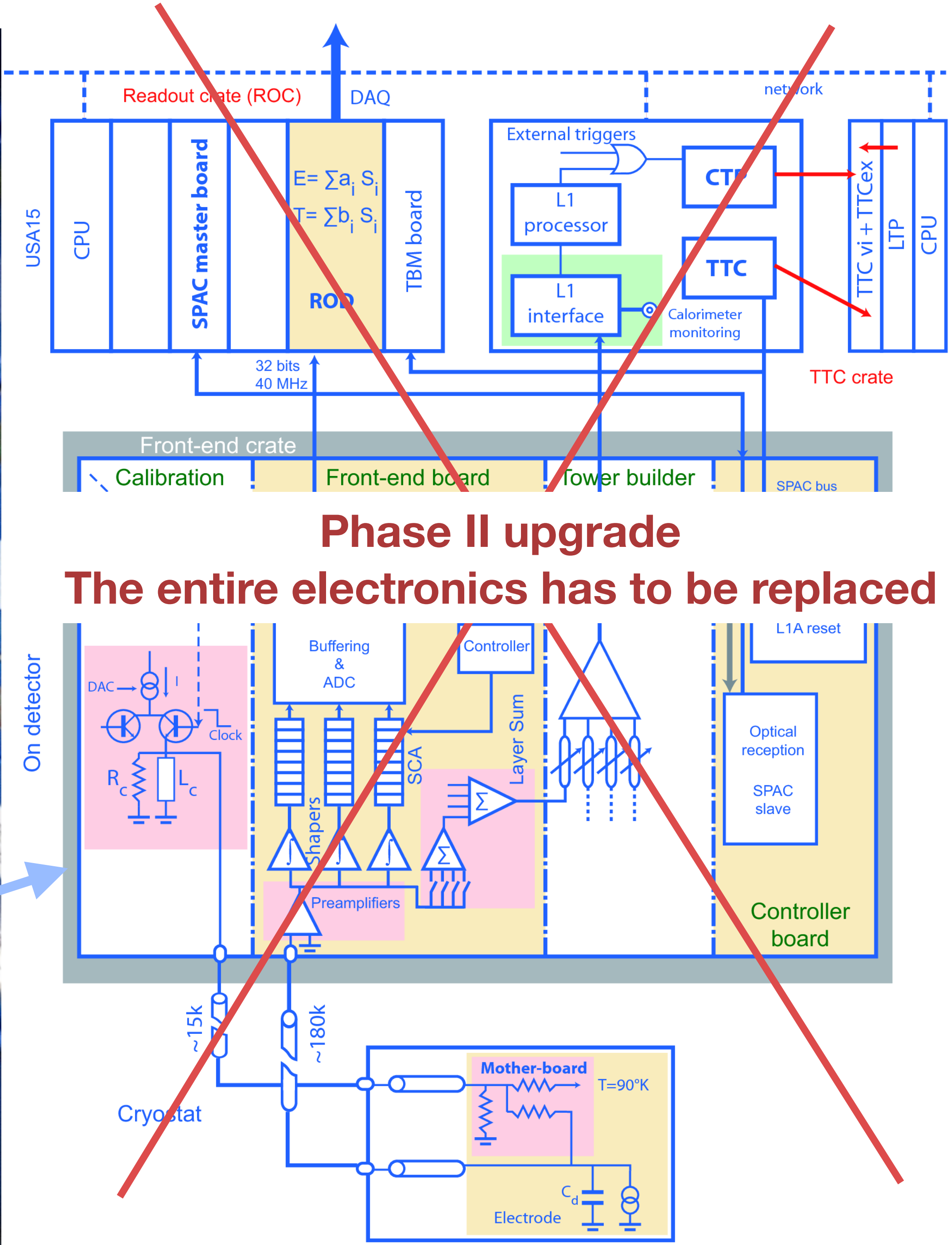
Quality Control

ATLAS Inner Tracker -ITk- for HL-LHC - Strips schedule



Liquid Argon Calorimeter Readout Electronics

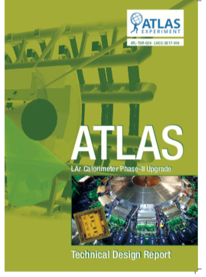




Phase II upgrade

The entire electronics has to be replaced

Liquid Argon calorimeter Phase-II electronics upgrade



Liquid Argon Calorimeter

Submission: Sep 2017
Approval: March 2018

Dynamic range

from MIP to multi-TeV: 16 bits

2-gain system, **14-bit** ADC

Linearity

~1‰ up to ~300 GeV

few % at high energies

TDAQ

Compatibility with 10/35 μs buffer

1.7 μs latency for L0 input

Noise: electronics + pile-up

electronics noise < MIP signal for calibration

reduction of out-of-time pile-up

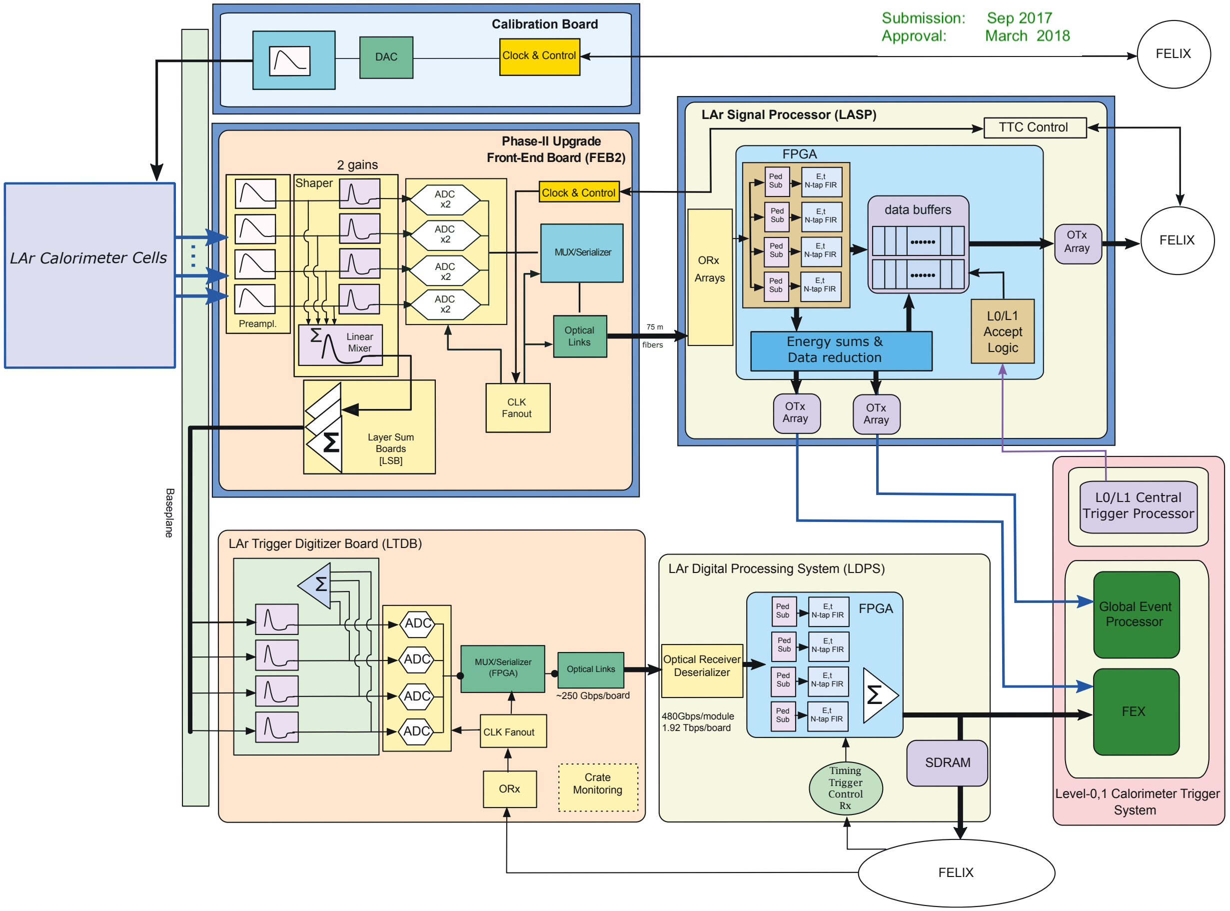
with complex digital filtering algorithms

optimise analog shaper characteristics

to minimise total noise deter digital filtering:

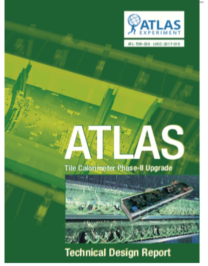
baseline CR-(RC)^2 shaping,

13 ns shaping time (programmable)



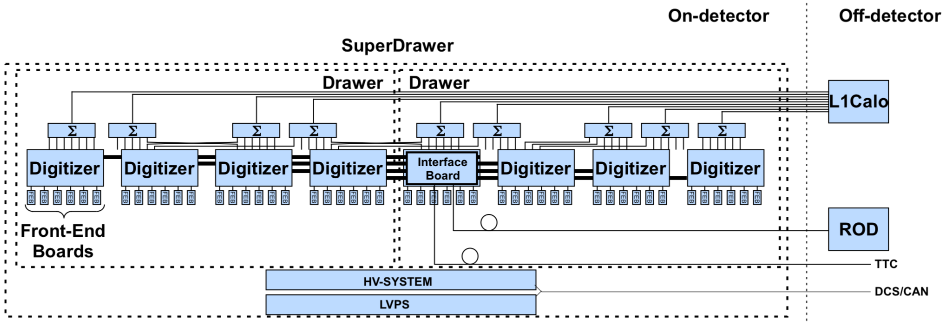
2 LV power systems
130 calibration boards
1524 frontend boards FEB2
372 LAr Signal processor units

Tiles calorimeter Phase-II electronics upgrade

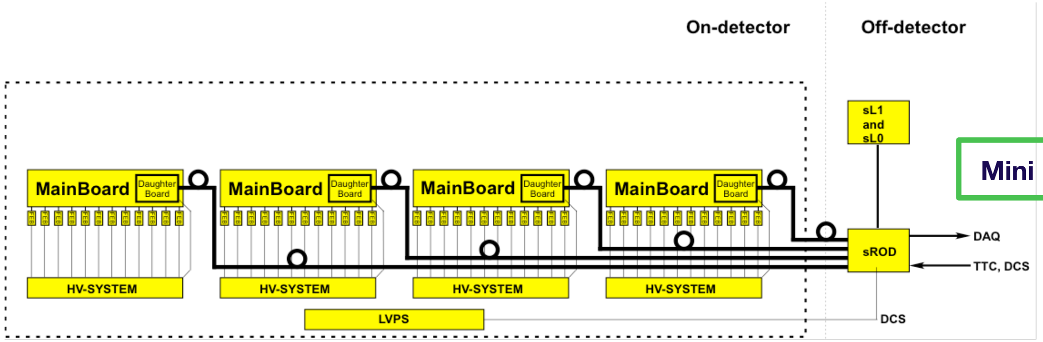


Tile Calorimeter

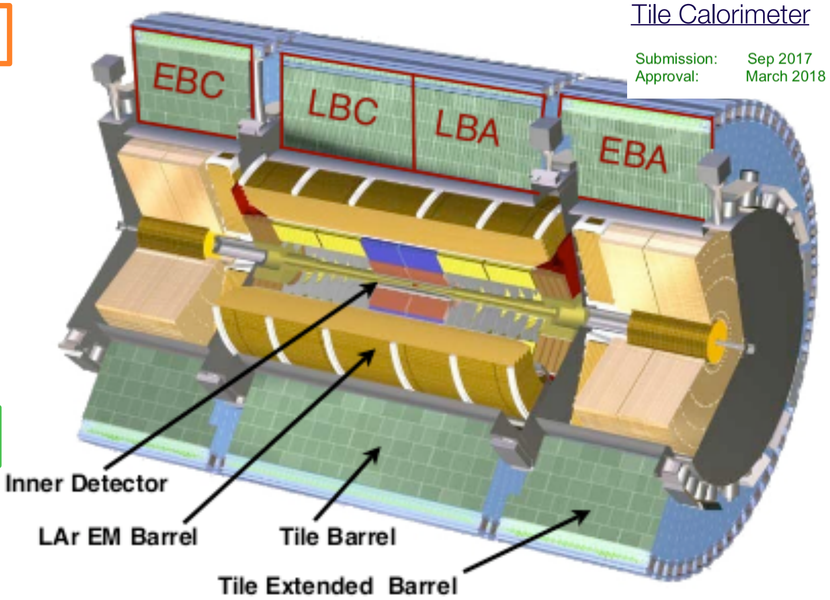
Submission: Sep 2017
Approval: March 2018



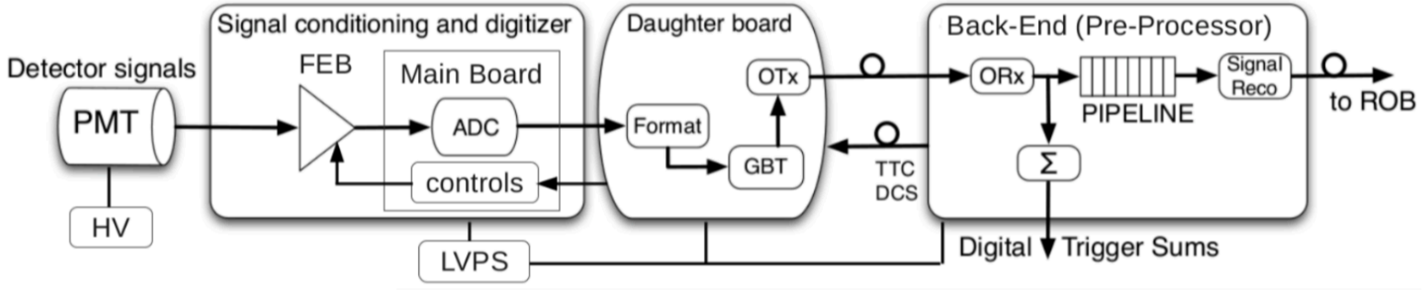
Super Drawers



Mini Drawers

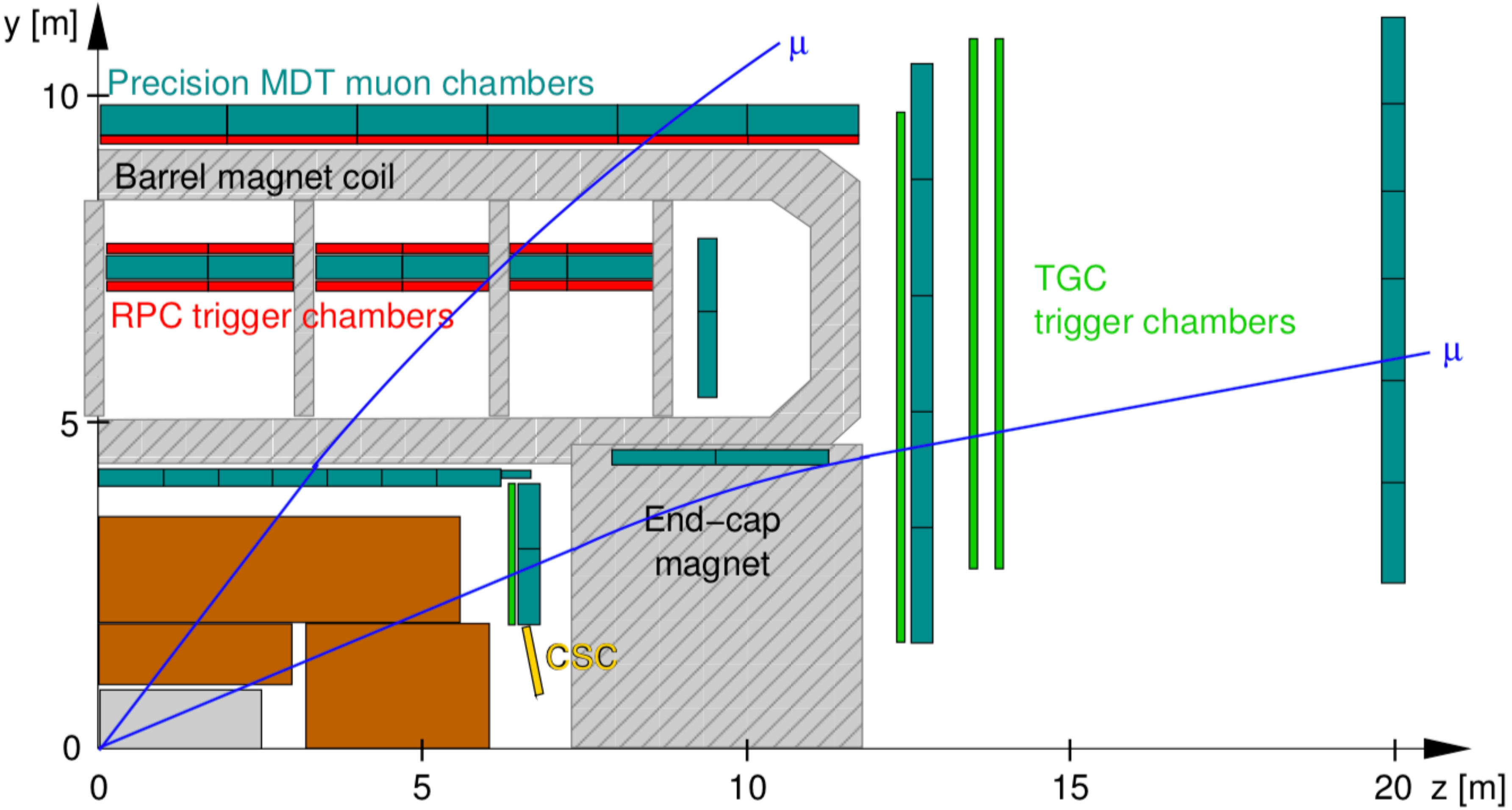


PMT at HL-LHC: some will be replaced
new FE electronics
LV power supplies moved to counting room
new BE electronics



Muon system

The ATLAS Muon system at LHC



Fast trigger chambers: RPC, TGC

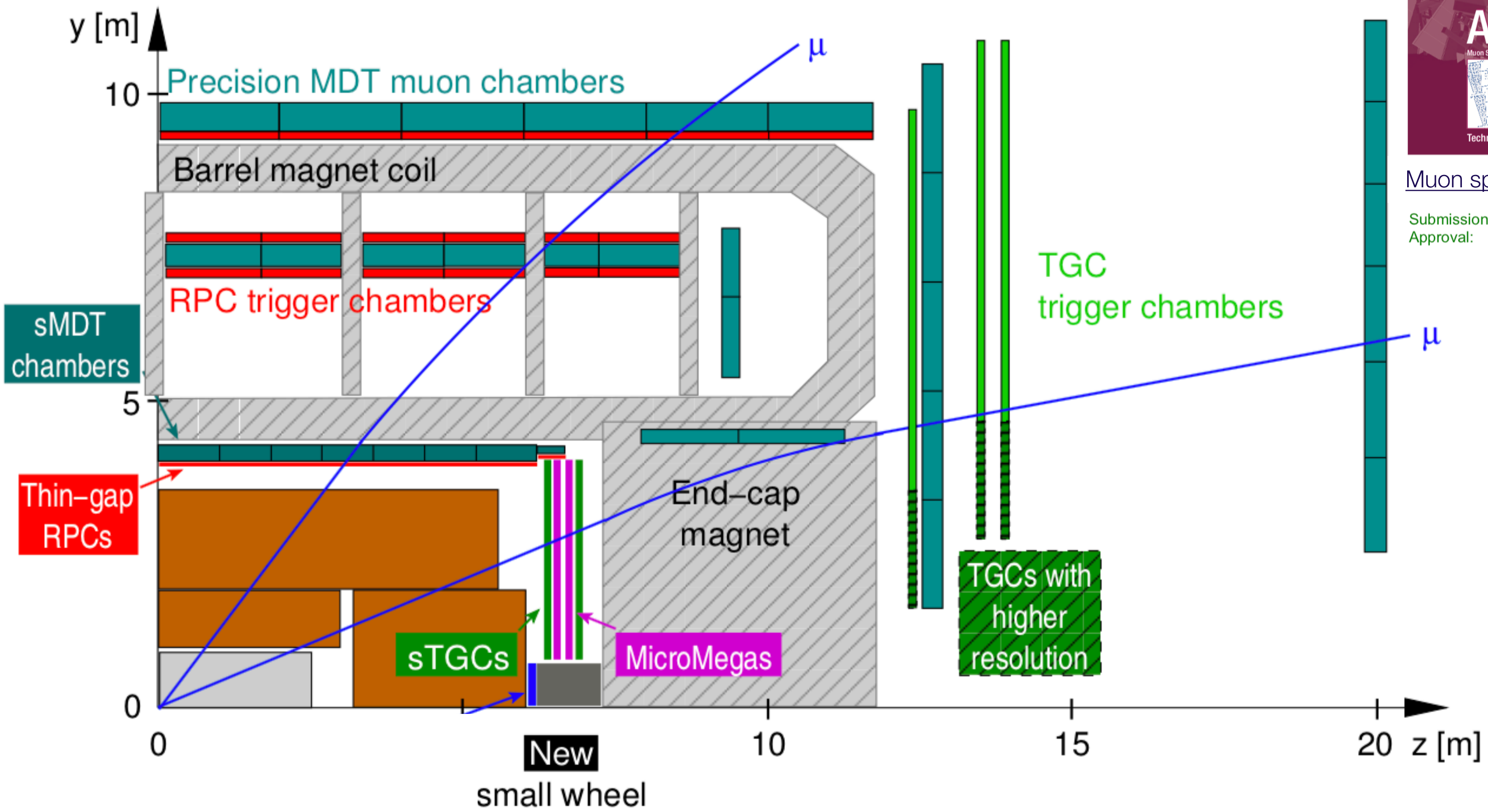
<10ns time resolution, moderate spatial resolution ~ mm-cm

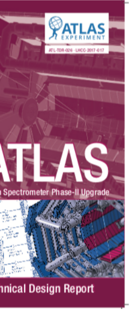
High-resolution tracking detectors: CSC, MDT (40 μm spatial resolution)

Optical alignement system with 50 μm resolution

$|\eta|<2.7$

The ATLAS muon system at the HL-LHC




ATLAS

Muon Spectrometer Phase-II Upgrade

Technical Design Report

Muon spectrometer

Submission: July 2017
Approval: Dec 2017

New Small Wheel

New TGCs with high resolution to cope with background at |η|~ 2.7

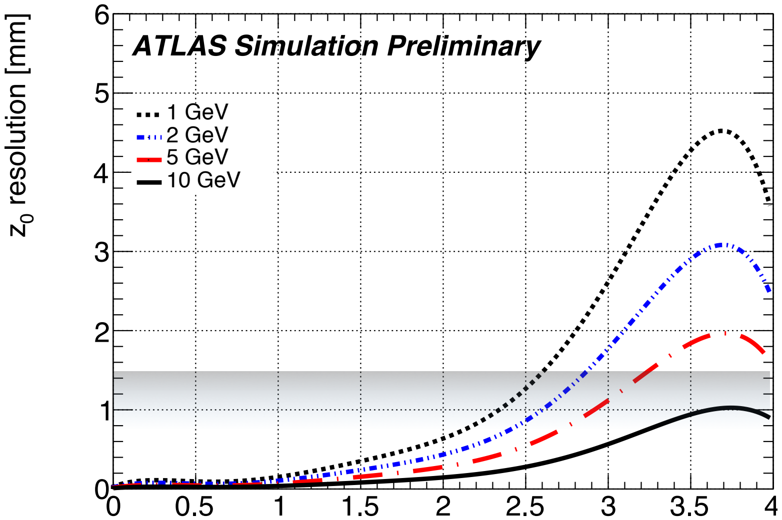
New thin-gap RPCs to close acceptance gaps of the barrel muon trigger

New sMDT chambers to free space for new RPCs

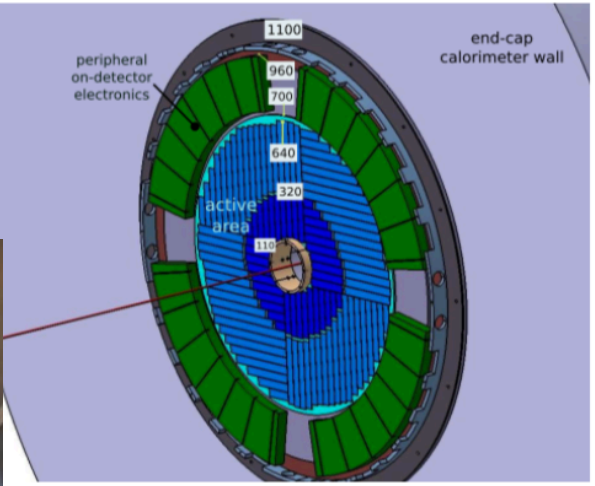
New on- and off-chamber electronics for new trigger architecture

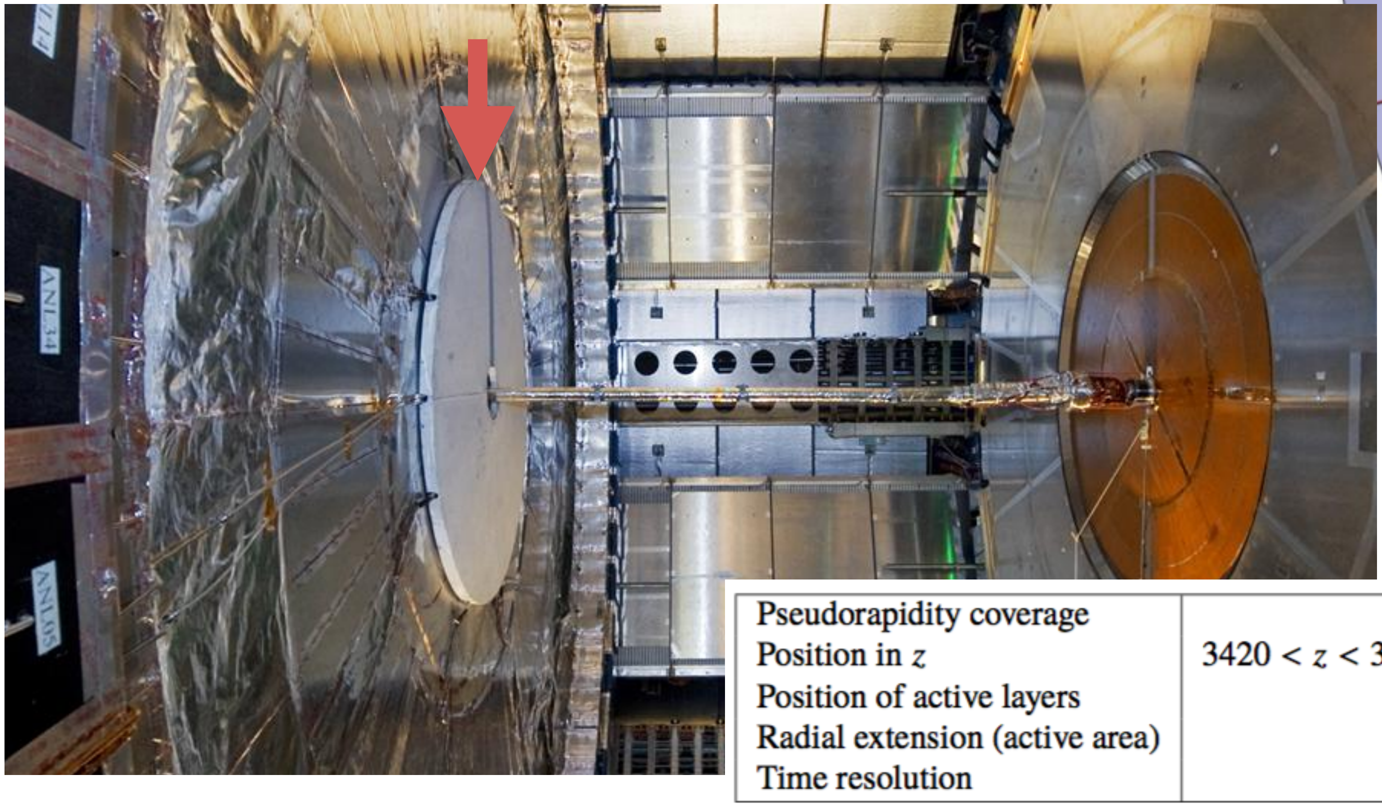
High Granularity Timing Detector

HGTD Technical Proposal
Submitted to LHHC



Z₀ resolution degrade with η
Including a high resolution time measurement allows to separate vertices
HGTD designed to have a time resolution of ~30 ps per track and resolve vertices inside the collision region (175 ps RMS)
New LGAD technology





Pseudorapidity coverage	$2.4 < \|\eta\| < 4.0$
Position in z	$3420 < z < 3545$ mm including 50 mm of moderator
Position of active layers	$3435 < z < 3485$ mm
Radial extension (active area)	110–1100 mm (120 mm–640 mm)
Time resolution	30 ps per track

25 years

1990 - ECFA Aachen meeting: Physics, detector, machine (H→ϒϒ ?)

1992 - ATLAS Letter of Intend

2 metre accordion module with fast readout

1994 - ATLAS Technical Proposal

Spanish fan - Endcap accordion prototype

1996 - 2000 - ATLAS Technical Design Reports

Modules Zero and R&Ds, testbeam, testbeam, testbeam

2000 ATLAS Memorendum of Understanding

Cavern & detector construction starts

2003-2004 ATLAS detector starts to go down

ATLAS combined testbeam

2006-2007 ATLAS continues installationFirst cosmic muons data taking

2008 - LHC incident / **2009** First collisions

More cosmic muons + 0.9 TeV + 2.76 TeV pp collisions

2010 ~35 evts/pb pp collisions at $\sqrt{s}=7$ TeV & Pb-Pb collisions

2011 ~ 5 evts/fb pp collisions at $\sqrt{s}=7$ TeV & Pb-Pb collisions

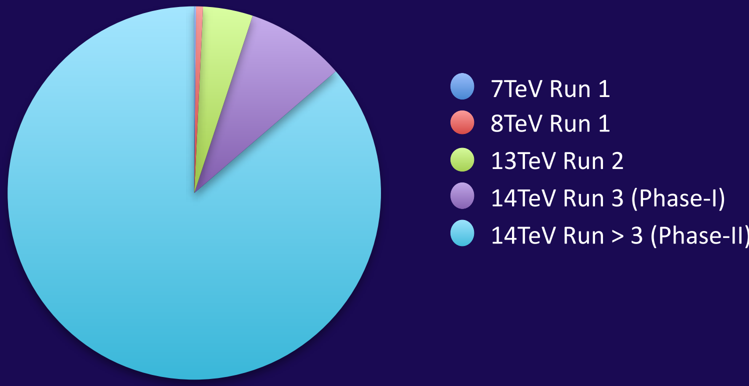
2012 ~ 20 evts/fb pp collisions at $\sqrt{s}=8$ TeV - The Higgs boson is discovered m_H ~125 GeV

2013 - p-Pb collisions and start of a two years Long Shutdown

2013-2014 Long Shutdown 1: **IBL installed**

2015-2018 LHC Run-2 ~80 evts/fb at $\sqrt{s}=13$ TeV so far

End 2018 Run 1 + Run 2 Towards **160/fb**



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20 years

2019-2020 Long shutdown 2: New Small Wheel, LAr trigger, TDAQ, FTK

2021-2023 LHC Run 3 +150 evts/fb for ~300 evts/fb total

2024-2026 Long shutdown 3: ITk, LAr electronics, Tiles, μ-system, TDAQ, HGTD

……. **2037** with 3000 evts/fb

CONCLUSIONS - OUTLOOK

A bright futur for ATLAS

ATLAS is engaged in several upgrades

Maintain trigger capability for **low p_T objects**

Replace detectors as pile-up and radiation increase, preserving or improving detector performance

Include new detector (e.g. HGTD) to improve pile-up rejection and gain redundancy

2019-2020 - LS2 Mainly trigger upgrade

- New Small Wheel
- LAr trigger upgrade
- TDAQ upgrade

2024-2025 - LS3 Replace detectors and electronics when necessary

- Inner tracker ITk
- LAr & Tiles electronics + Tiles mini-drawers
- Muon chambers improvement
- TDAQ

2026-2035 Run 4, Run 5, Run 6: 10 years of data taking 300 fb^{-1}/year .

And an exiting present in addition

BACKUP

TRIGGER at HL-LHC: example menu

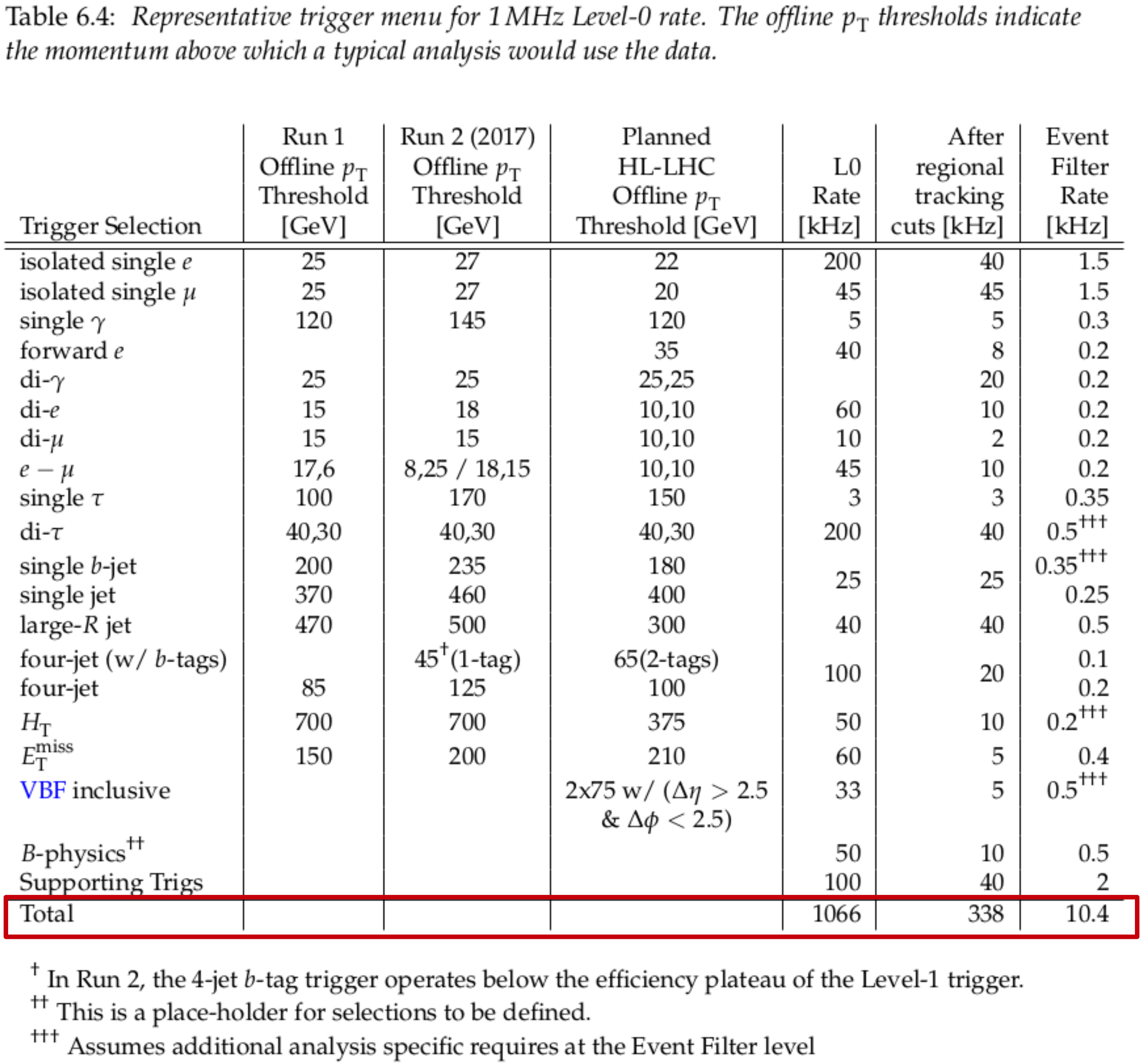

Table 6.4: *Representative trigger menu for 1 MHz Level-0 rate. The offline p_T thresholds indicate the momentum above which a typical analysis would use the data.*

Trigger Selection	Run 1 Offline p_T Threshold [GeV]	Run 2 (2017) Offline p_T Threshold [GeV]	Planned HL-LHC Offline p_T Threshold [GeV]	L0 Rate [kHz]	After regional tracking cuts [kHz]	Event Filter Rate [kHz]
isolated single e	25	27	22	200	40	1.5
isolated single μ	25	27	20	45	45	1.5
single γ	120	145	120	5	5	0.3
forward e			35	40	8	0.2
di-γ	25	25	25,25		20	0.2
di-e	15	18	10,10	60	10	0.2
di-μ	15	15	10,10	10	2	0.2
$e - \mu$	17,6	8,25 / 18,15	10,10	45	10	0.2
single τ	100	170	150	3	3	0.35
di-τ	40,30	40,30	40,30	200	40	$0.5^{\dagger\dagger\dagger}$
single b-jet	200	235	180	25	25	$0.35^{\dagger\dagger\dagger}$
single jet	370	460	400			0.25
large-R jet	470	500	300	40	40	0.5
four-jet (w/ b-tags)		$45^{\dagger}$(1-tag)	65(2-tags)	100	20	0.1
four-jet	85	125	100			0.2
H_T	700	700	375	50	10	$0.2^{\dagger\dagger\dagger}$
E_T^{miss}	150	200	210	60	5	0.4
VBF inclusive			2x75 w/ ($\Delta\eta > 2.5$ & $\Delta\phi < 2.5$)	33	5	$0.5^{\dagger\dagger\dagger}$
B-physics††				50	10	0.5
Supporting Trigs				100	40	2
Total				1066	338	10.4

[†] In Run 2, the 4-jet b-tag trigger operates below the efficiency plateau of the Level-1 trigger.

[††] This is a place-holder for selections to be defined.

[†††] Assumes additional analysis specific requires at the Event Filter level