# ATLAS upgrade plans and Potential

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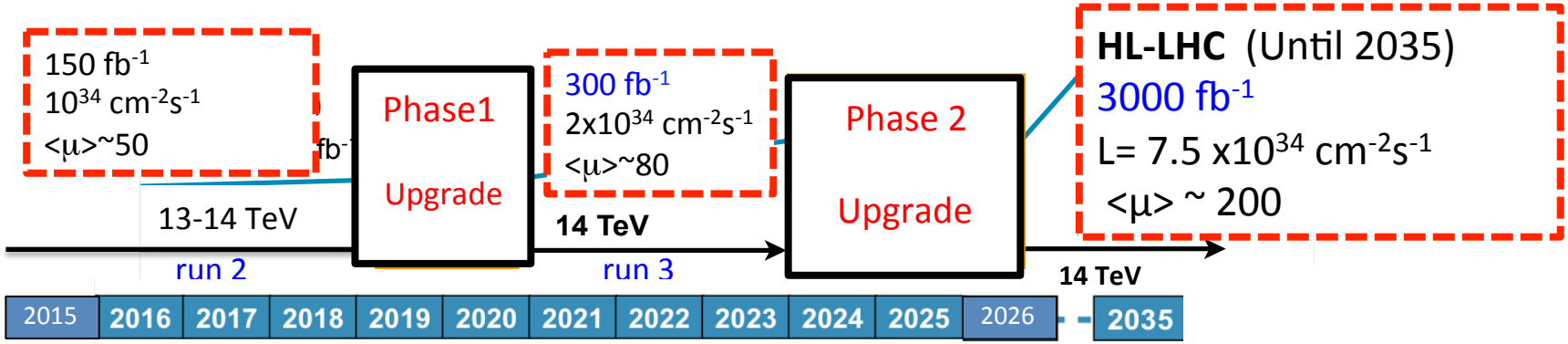
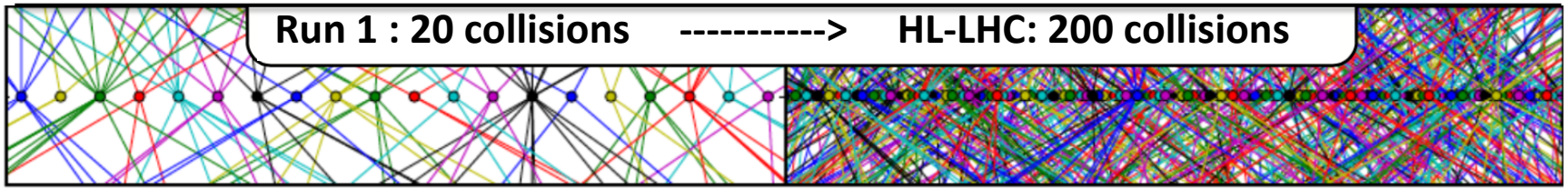
On behalf of the ATLAS collaboration

Lund LHCP2016 June 2016

# LHC and ATLAS upgrades road map




## Detector challenges:

- x 10 more radiation (~ $10^{16}$neq/cm$^2$ ; 10 MGy )
- x 10 more pile-up

**- Run1:** <μ>=20 ;<$n_{PU\ jets\ pT>30GeV}$> ~ 0.04

**- HL-LHC:** <μ>=200 ;<$n_{PU\ jets\ pT>30GeV}$> ~ 7.4

x10 x185

**ATLAS Upgrades needed to:**

- keep performance (tracking, b-tag, jet/Etmiss,...)
- Trigger rates acceptable with low $P_T$ thresholds

Pile-up mitigation up to large η is needed !

# Physics motivation at HL-LHC

## Electroweak symmetry Breaking

- **Higgs precision measurements** (coupling and spin-CP quantum numbers)
- **Higgs rare and invisible decays (H->μμ , H->Zγ,…)**
- **Top Yukawa coupling (ttH)**
- **Higgs self coupling**

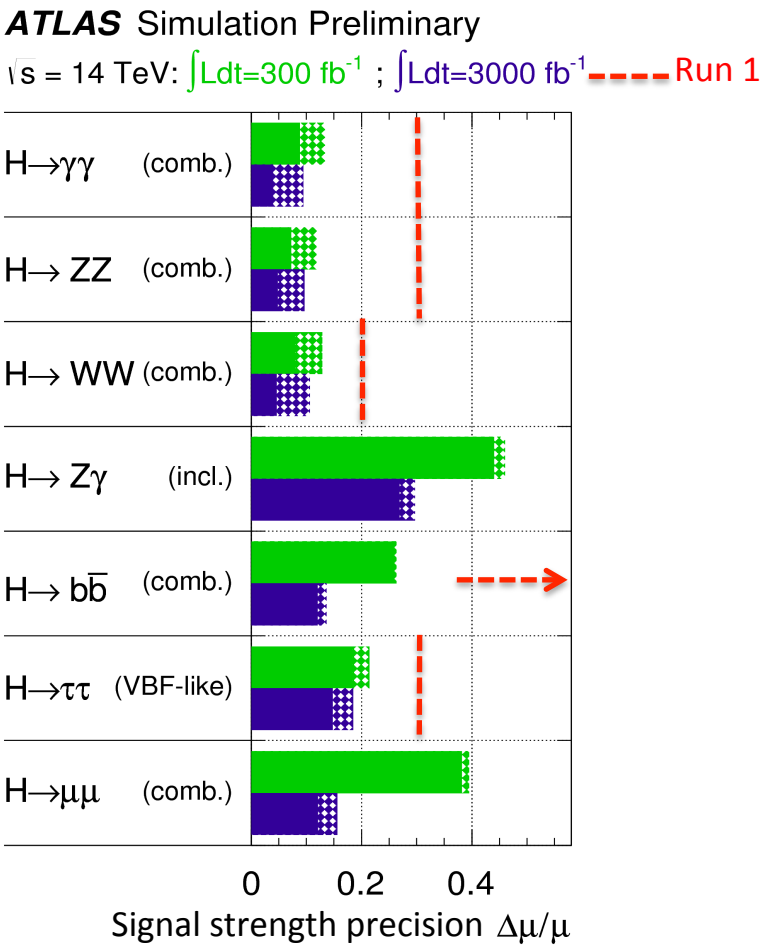
## Beyond the Standard Model

- **Higgs sector** (search for deviations from SM)
- **Dark matter**
- **SUSY**
- **Exotics**

Many dedicated ATLAS talks presented during this week

# Higgs precision measurements

ATL-PHYS-PUB-2014-016




| Signal strength precision Δμ/μ * | | | | |
|---|---|---|---|---|
| H→ | L = 300 fb-1 (run 3) | | L = 3000 fb-1 (LH-LHC) | |
| | w/o theory Δ (%) | w/ theory Δ (%) | w/o theory Δ (%) | w/ theory Δ (%) |
| γγ | 9 | 13 | 4 | 9 |
| WW | 8 | 13 | 5 | 11 |
| ZZ | 7 | 11 | 4 | 9 |
| bb | 26 | 26 | 12 | 14 |
| ττ | 18 | 21 | 15 | 19 |
| Zγ | 44 | 46 | 27 | 30 |
| μμ | 38 | 39 | 12 | 16 |

* $\mu = \sigma x BR_{obs} / \sigma x BR_{SM}$

## At HL-LHC:

- **~ 100 million SM Higgs bosons**
- **~4-5% precision for main channels, ~10-20% for rare modes**
- **Will be able to quantify small deviations from the SM**
- **3-4 x more sensitivity in direct searches for additional Higgs bosons than at LHC**

ATL-PHYS-PUB-2013-003, 2014-007

## ATLAS Mass reach for Exotic signatures

| ATLAS @14 TeV | Z' → ee SSM 95% CL limit | $g_{KK}$ → t t RS 95% CL limit | Dark matter M* 5σ discovery |
|---|---|---|---|
| 300 $fb^{-1}$ | 6.5 TeV | 4.3 TeV | 2.2 TeV |
| 3000 $fb^{-1}$ | 7.8 TeV | 6.7 TeV | 2.6 TeV |

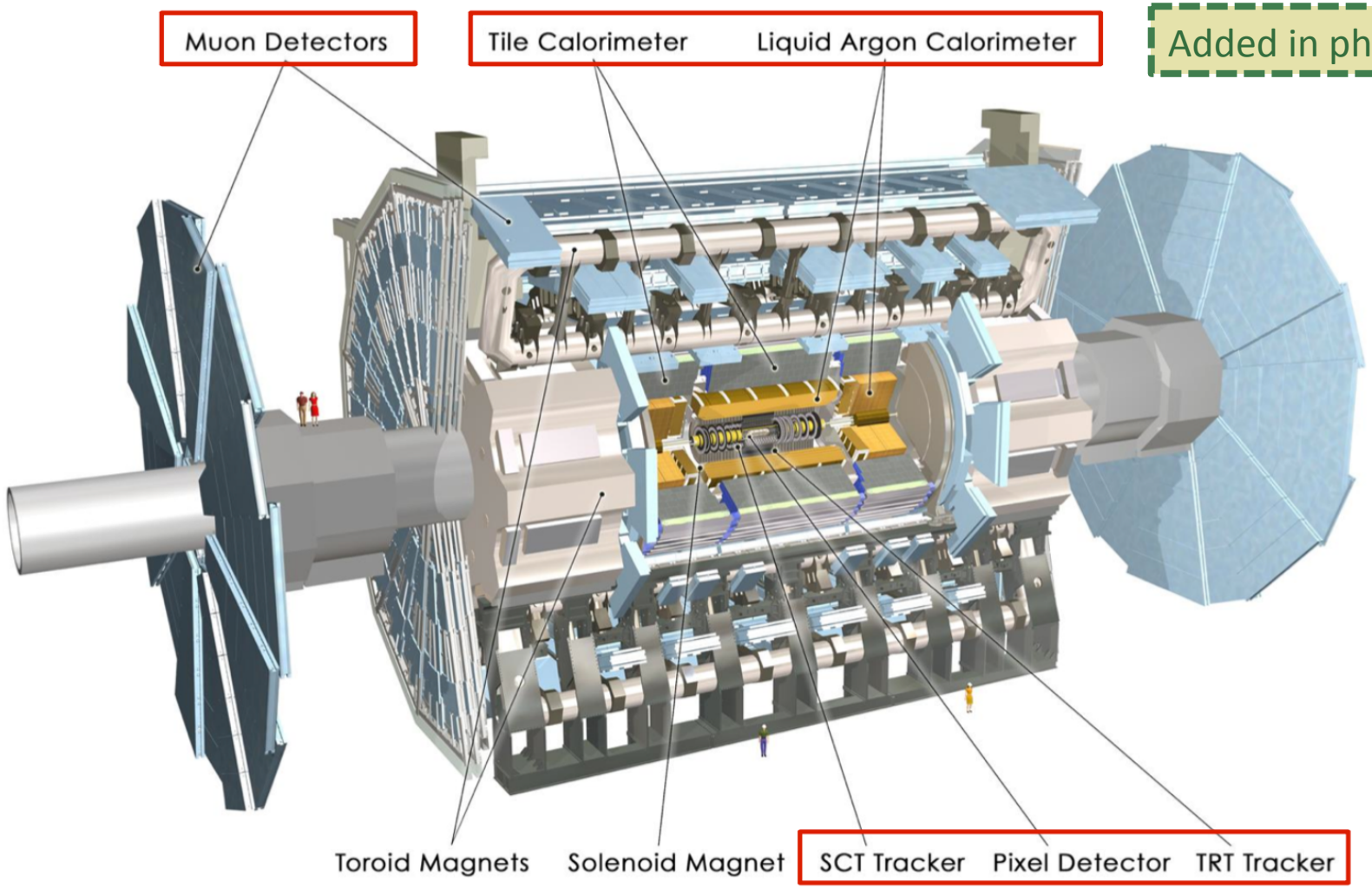
ATL-PHYS-PUB-2014-010 , 2013-011, 2015-032

## ATLAS Mass reach for SUSY particles

| ATLAS projection | gluino mass | squark mass | stop mass | sbottom mass | $\chi_1^+$ mass WZ mode | $\chi_1^+$ mass WH mode |
|---|---|---|---|---|---|---|
| 300 $fb^{-1}$ | 2.0 TeV | 2.6 TeV | 1.0 TeV | 1.1 TeV | 560 GeV | None |
| 3000 $fb^{-1}$ | 2.4 TeV | 3.1 TeV | 1.2 TeV | 1.3 TeV | 820 GeV | 650 GeV |

Significant increase in mass reach for Exotics and SUSY signatures at HL-LHC (3000 $fb^{-1}$)

# ATLAS Phase 0 upgrades (2013-2014)

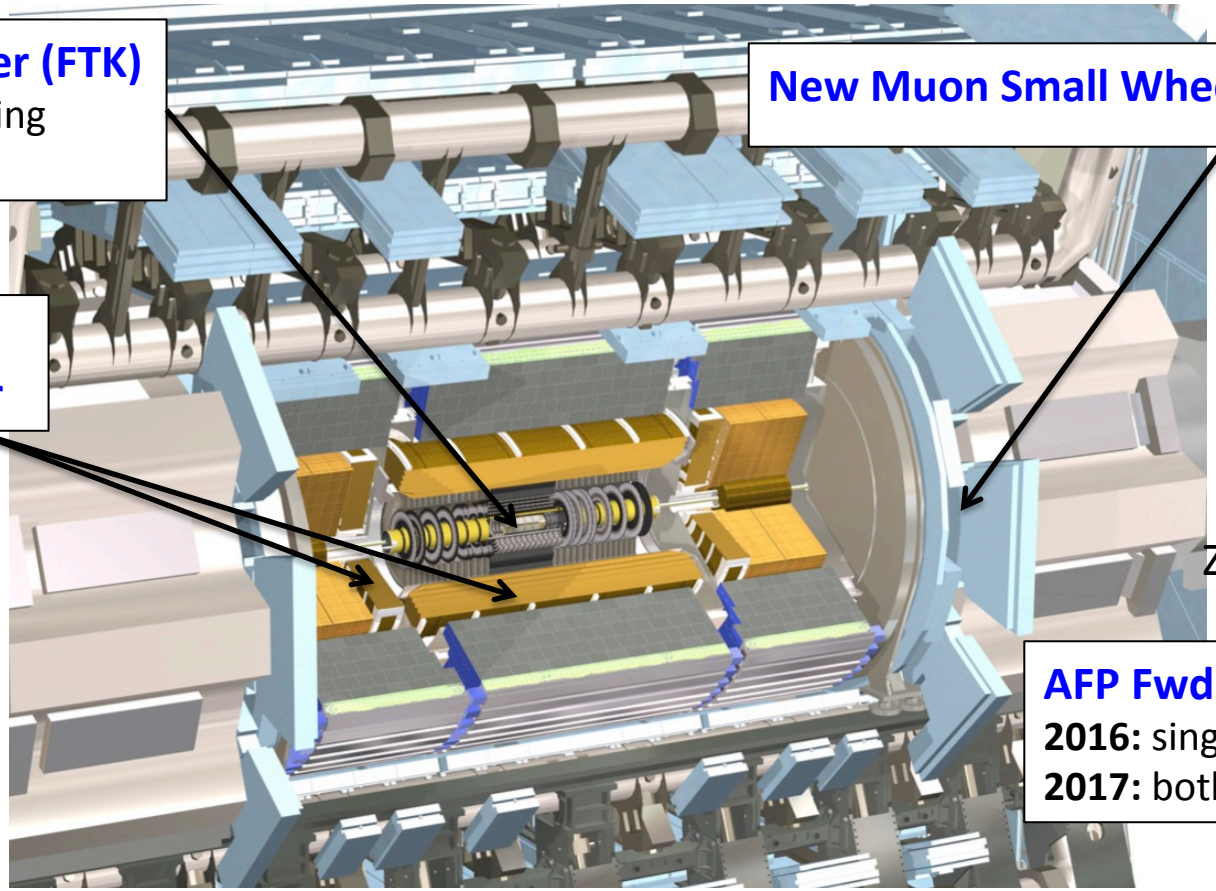



**Muon spectrometer:**
**+ RPC** in barrel feet
**+ MDT** in $|\eta|$ ~1.1-1.3

**Pixel:**
**+ IBL**

**trigger (run1→run2):**
**L1 (HW):** 2.5 μs latency ; **70 KHz→ 100KHz**
**HLT/Event Filter** (software): **600Hz→ 1KHz**

# ATLAS Phase 1 upgrades (2019-2020)




**Fast Track Trigger (FTK)**
**2016:** commissioning
**2017:** operation

**New Muon Small Wheel (NSW)**

**High Granular L1 calorimeter trigger**

**Trigger/DAQ**
**L1:** 100KHz
**HLT:** 1KHz

**AFP Fwd detector**
**2016:** single arm
**2017:** both arms

## Main target:

- Better trigger capabilities (efficiency, fake rejection)
- Maintain same acceptance/$p_T$ thresholds at higher pileup

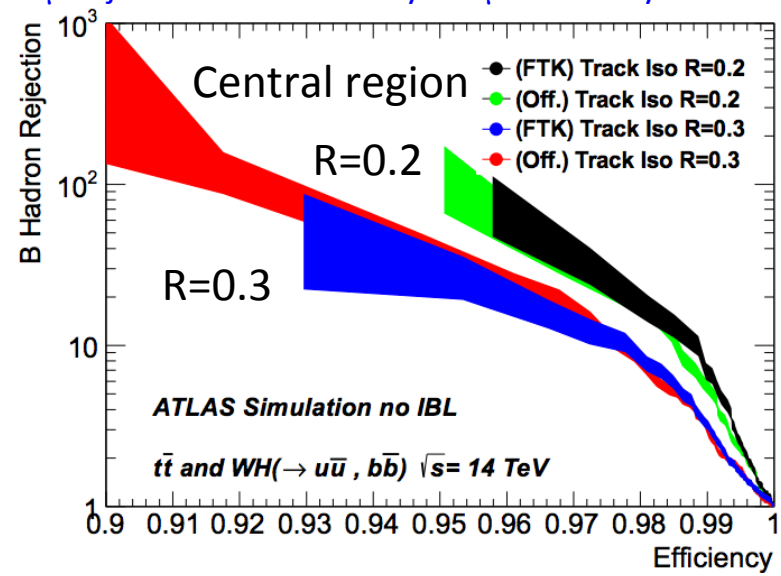
# Fast TracK Trigger (FTK)

ATLAS-TDR-021-2013

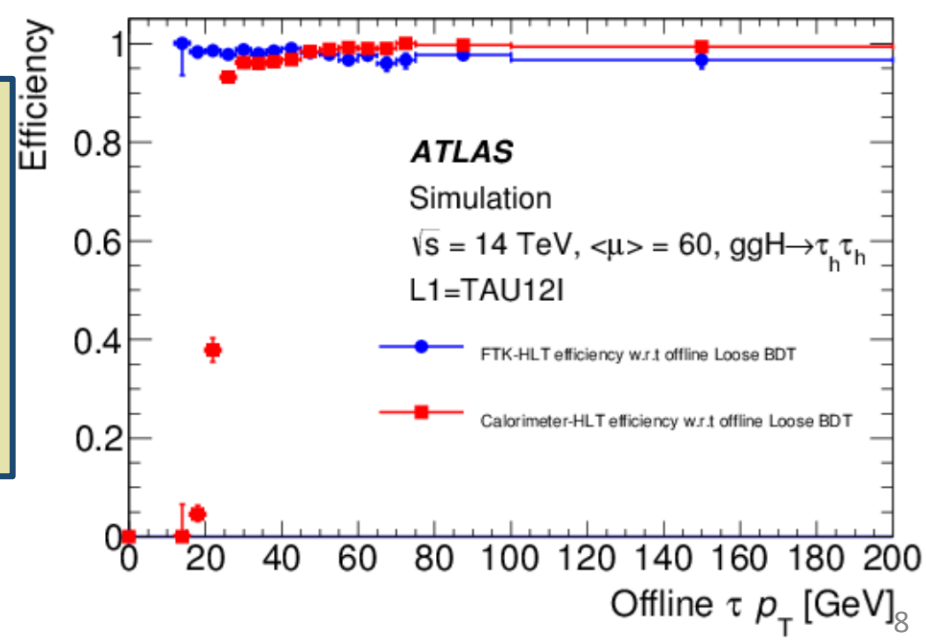
- Hardware based tracking of Si-tracking layers at "Level 1.5"
- Provides tracking information to L2 in ~25 μs
- Two steps
  - Pattern recognition
  - Track fitting

**performance ~ to offline up to L= $3 \cdot 10^{34}$ $cm^{-2}s^{-1}$**

μ rejection from B-decays vs μ efficiency from W




τ Trigger efficiency improvement using FTK tracks

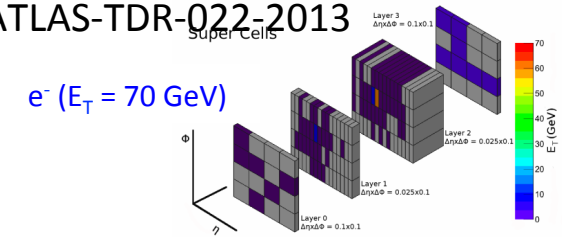



**Status/Plans:**

- Installed hardware/software infrastructure
- **July 2016:** expect full slice test
- **Fall** 2016: barrel commissioning
- **2017:** full coverage operation

# L1 granular calorimeter trigger

ATLAS-TDR-022-2013

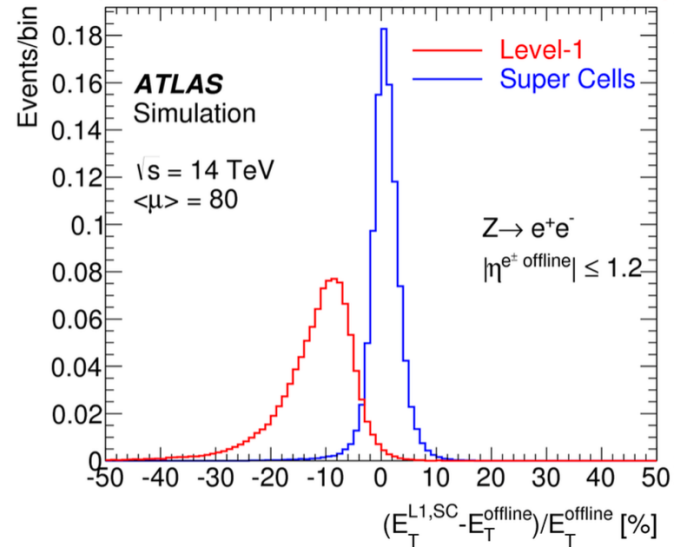



(b) Upgraded: 10 SCs in 0.1 × 0.1

- Expect ~270 kHz @ $3x10^{34}cm^{-2}s^{-1}$ with current layout and run1 thresholds (>> total L1 rate of 100kHz)

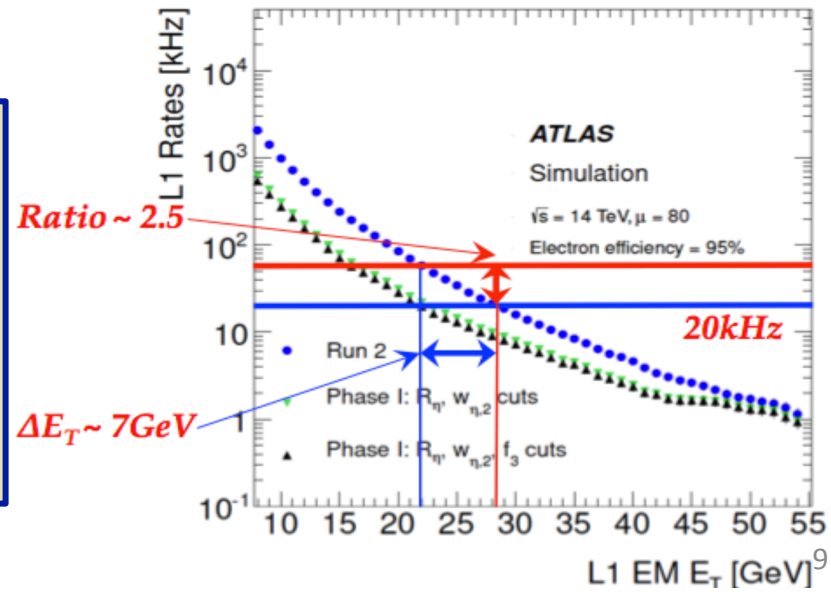
- Will have 10 x more granularity in η/depth (towers-> super-cells)
- New readout electronics feed 40 MHz digitized data to L1
- Apply offline reconstruction algorithms at L1

  → **better jet rejection, lepton isolation/reconstruction**
  → **Improved energy resolution**
  → **keep low threshold for lepton trigger**



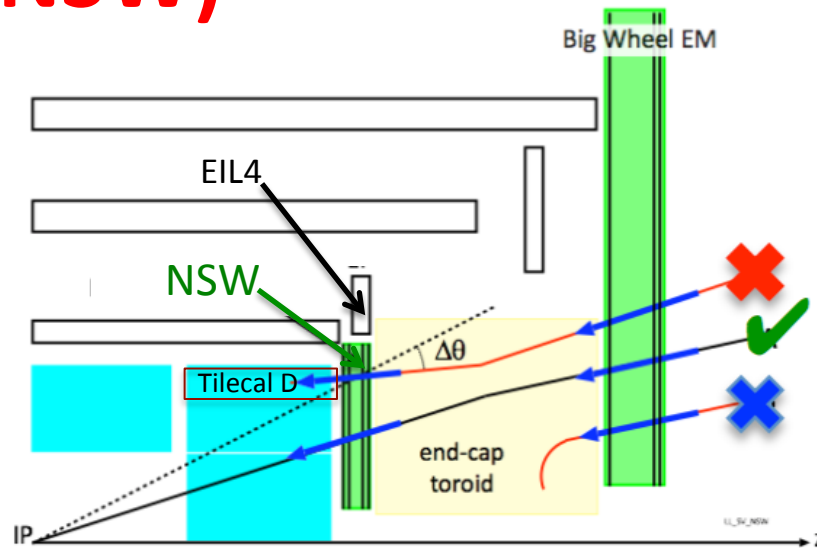

## Status/Plans:

- **Summer 2014:** Installed FE elect. Demonstrator
- **2015:** Successful data taking
- **On-going:** FE and BE prototype and production
- **2019:** Installation

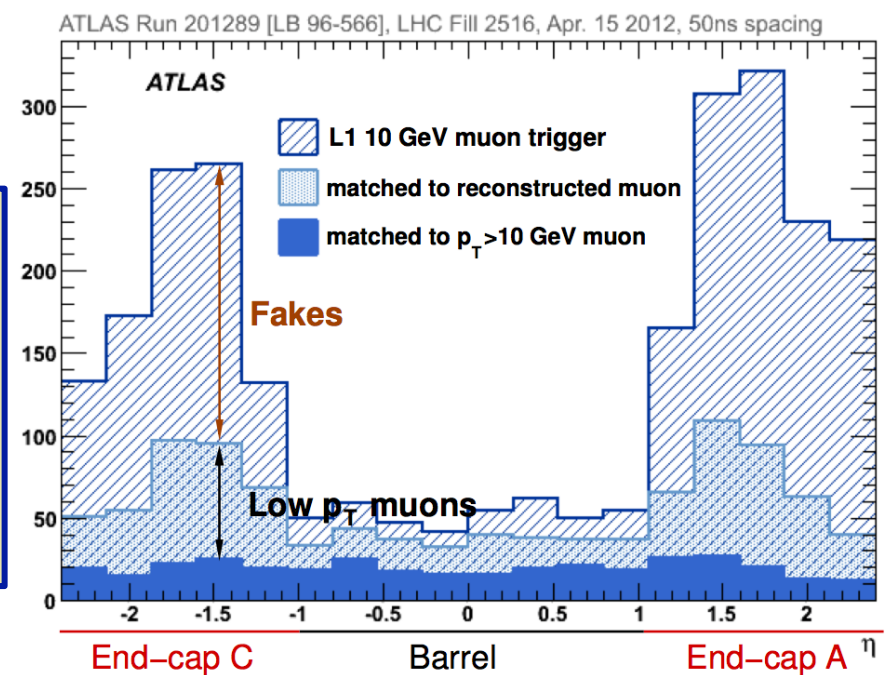


# New muon Small Wheels (NSW)

ATLAS-TDR-020-2013




- At present μ L1 dominated by fakes in 1.3<η<2.7
- NSW w/ high-rate capability for L1:
  - **sTGC**+MicroMegas for trigger/precise tracking
- L1 μ ($p_T$>20GeV)~ 60KHz
  - →22 KHz w/ NSW
  - →17 KHz w/ NSW+EIL4
  - →13 KHZ w/ NSW+EIL+Tilecal D




**Status/Plans:**

- **Now:** Modules 0 construction in various sites
- **2016:** Final Design Review and PRR for all sites
- **2017/2018:** Production
- **2019:** Installation

# Trigger/DAQ phase 1 upgrade

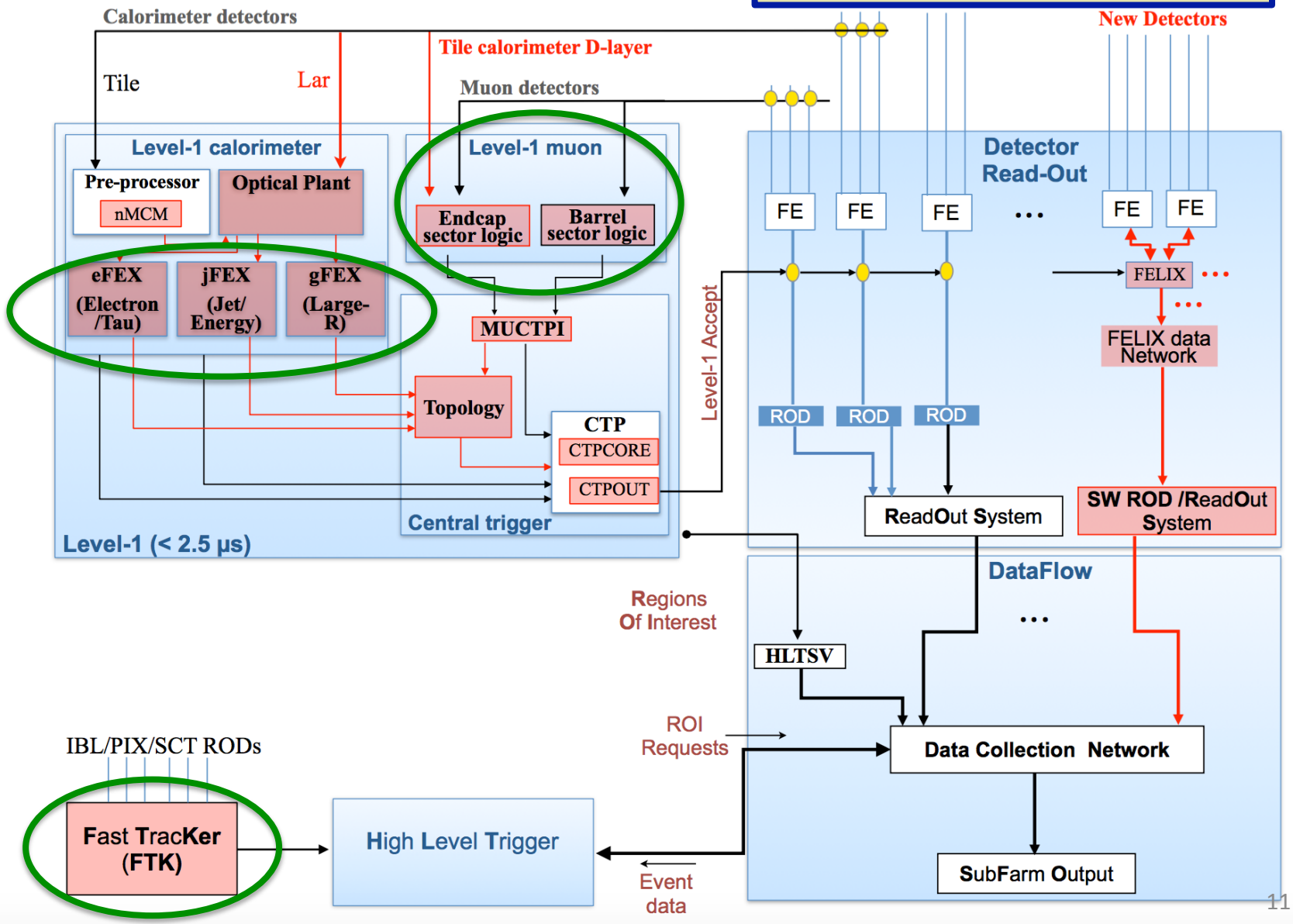
ATLAS-TDR-023-2013

**Trigger/DAQ**
**L1 (HW):** 2.5 μs latency ; 100KHz
**HLT/Event Filter** (software): 1KHz

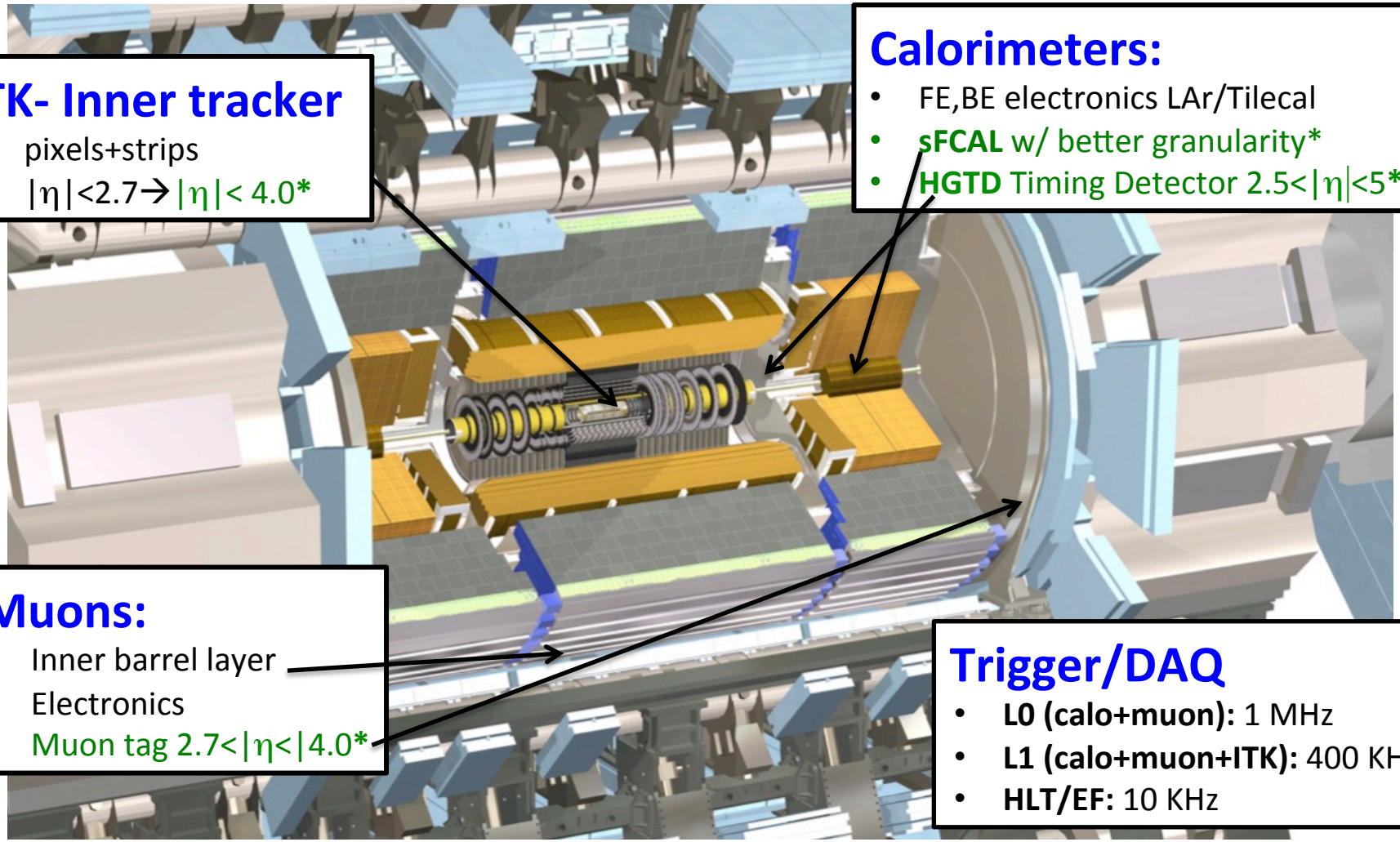
L1 Muon

L1 Calo

FTK



# ATLAS phase 2 Upgrades for HL-LHC (2024-2026)



## ITK- Inner tracker

- pixels+strips
- $|\eta|<2.7 \rightarrow |\eta|< 4.0$*

## Calorimeters:

- FE,BE electronics LAr/Tilecal
- **sFCAL** w/ better granularity*
- **HGTD** Timing Detector $2.5<|\eta|<5$*

## Muons:

- Inner barrel layer
- Electronics
- Muon tag $2.7<|\eta<|4.0$*

## Trigger/DAQ

- **L0 (calo+muon):** 1 MHz
- **L1 (calo+muon+ITK):** 400 KHz
- **HLT/EF:** 10 KHz

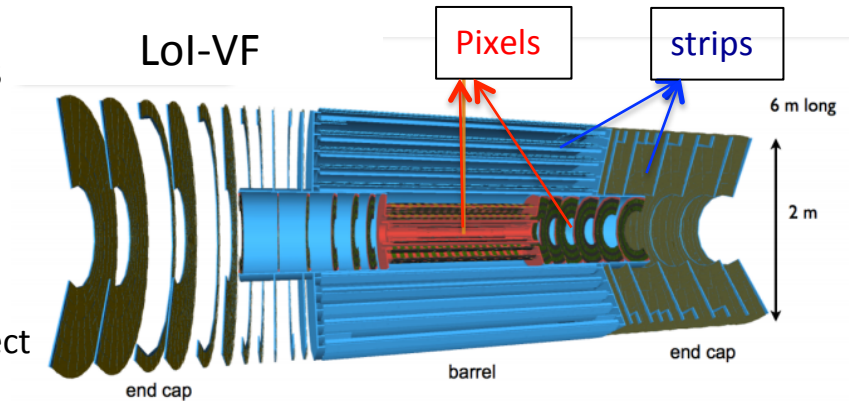
*** Large eta scenarios (part of the reference detector layout)**

ATLAS References:

- Phase II LoI CERN-LHCC-2012-022
- Scoping doc. CERN-LHCC-2015-020 (Impact of different cost scenarios on physics/perf.)
- All Initial Design Reports-IDRs until end 2016 → Technical Design Reports-TDRs until end 2017

# ITK for HL-LHC

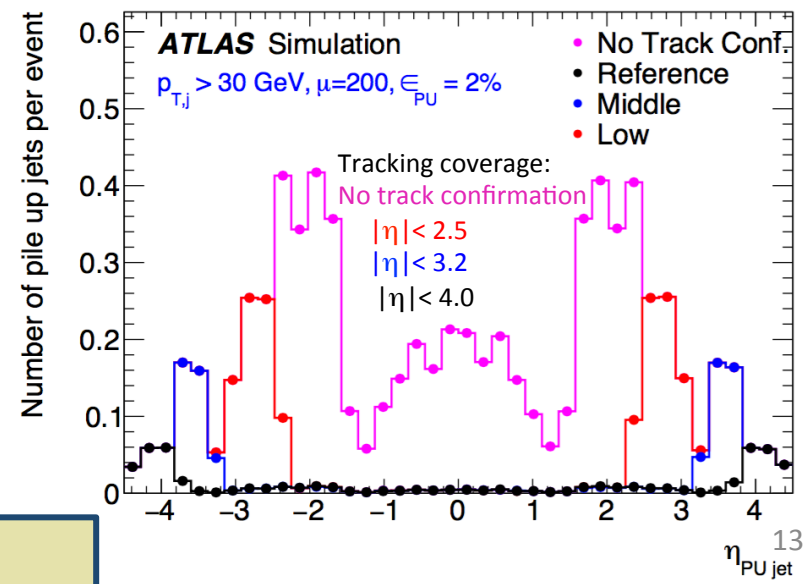
- **Goal:** keep good tracking/vertex perf. + b-tag capabilities
- Pile-up and Rad. levels ($10^{16}$n/cm$^2$) is a big challenge.
- Reference layout (LoI-VF) up to $|\eta|<4$:
  - 4 pixel layers (~ 9-18m$^2$) :
    - Pixel sensors: Planar,3D, HV/HR CMOS
    - hybrid module w/ pixel sensors +FE chip + Interconnect
  - 2x5 Strip layers (~ 190 m$^2$) : n-in p , HV/HR CMOS
- ~ 8x more channels and 2-3x less material than current ID
- Occupancy < 1%
- ~ 14 hits up to $|\eta|=2.5$




**ITK performance in HL-LHC ~ or better (ID+IBL) in run 2**

- Collaboration w/ RD42, RD50, RD53
- Optimizing layout to $|\eta|=4.0$, to be frozen by 2017 TDR.

Number PU jets vs $\eta$ (for PU jets rejection =98%)

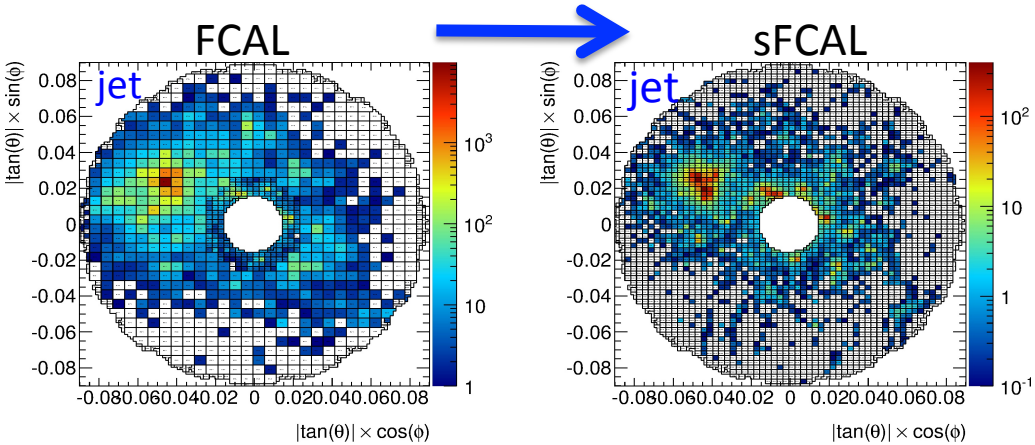



**Status/Plans:**

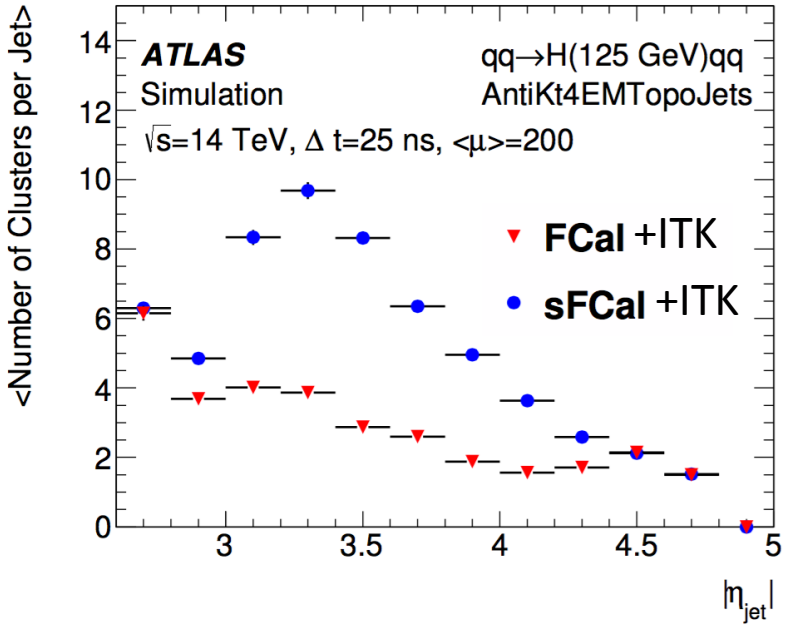
- **Ongoing:** layout and prototypes optimization/tests
- **TDR:** Q4 2016 (strips) and Q4 2017 (pixels)
- **Construction:** 2018-2023
- **Installation:** 2024-2025

# Calorimeter (LAr and Tilecal) at HL-LHC

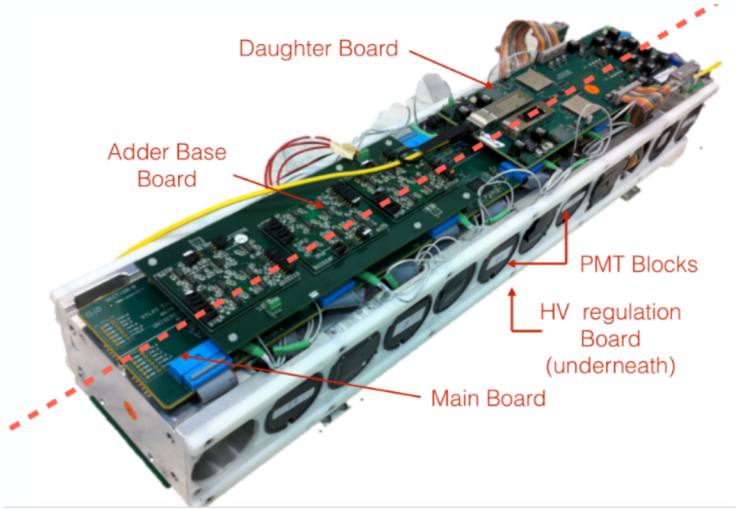
- Replace only FE/BE electronics in (Tile/LAr) barrel+EC
  - Ageing/Irradiation
  - Compatible w/ L0 trigger (rate/latency)
- New fwd calorimeter (sFCAL):
  - 4x better transversal granularity
  - narrower LAr gaps (100 μm)




Number of clusters/VBF tag-jet vs η




Tile FE electronics demonstrator




**Status/Plans:**

- **Ongoing:** demonstrator/prototypes tests (Tile)
- **June 2016:** sFCAL decision
- **Q3 2017:** Tile and LAR TDR
- **Construction:** 2018-2023
- **Installation:** 2024-2025

# HGTD-High Granular Timing Detector at HL-LHC (2.5<η<5)

## Goal:

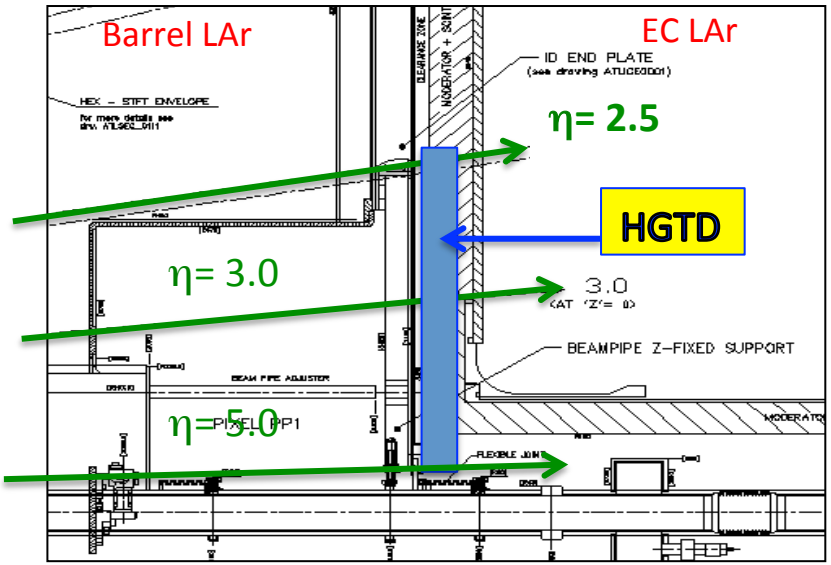
- Pile-up mitigation in forward
  - **Offline:** Improve e/g and jet/ETmiss perf.
  - **Online:** L0 Trigger time info

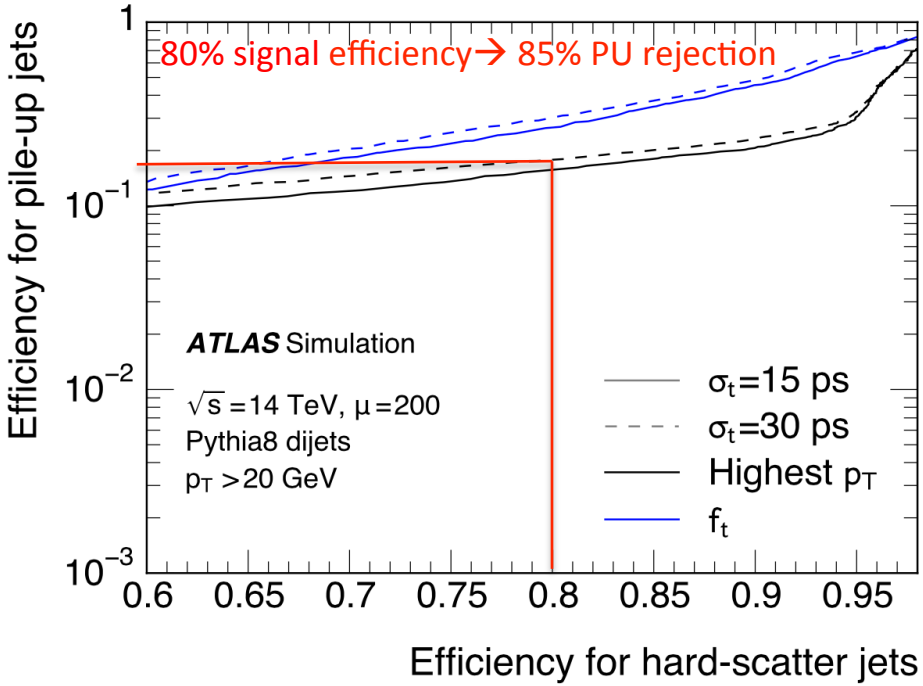
→ Keep lower trigger thresholds

→ Increase VBF physics acceptance

## Layout:

- 4 Si layers in front of LAr EMEC+FCAL
  - Δt ~30 ps ; < 5x5mm2
  - Option: Pre-shower 3Xo W in 2.5<|η|< 3.2




**Status/Plans:**

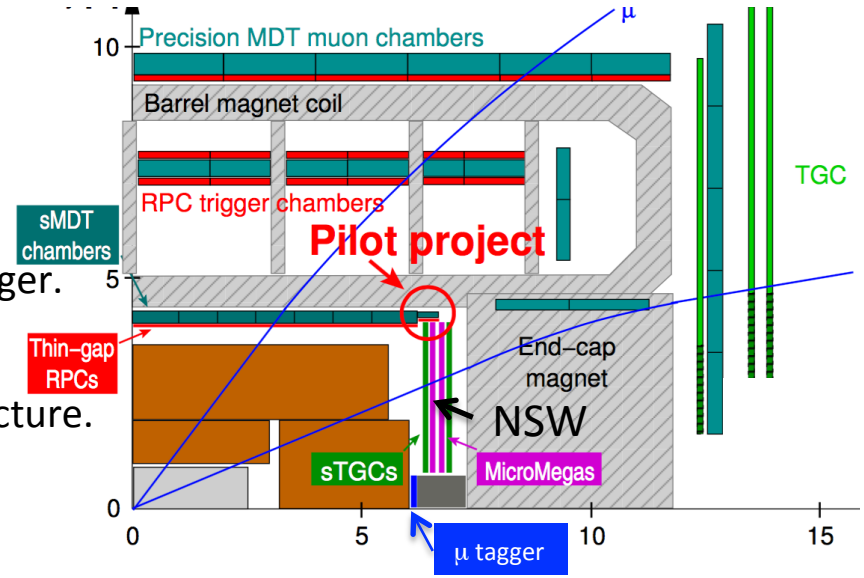
- **Ongoing:**
  - Si sensors R&D (LGAD, pin diode) for speed and radiation hardness needs
  - Study L0 trigger/perf./physics gains
- **Fall 2016:** Test beams (LGAD, pin diodes)
- **Installation:** 2024-2025

# Muon spectrometer at the HL-LHC

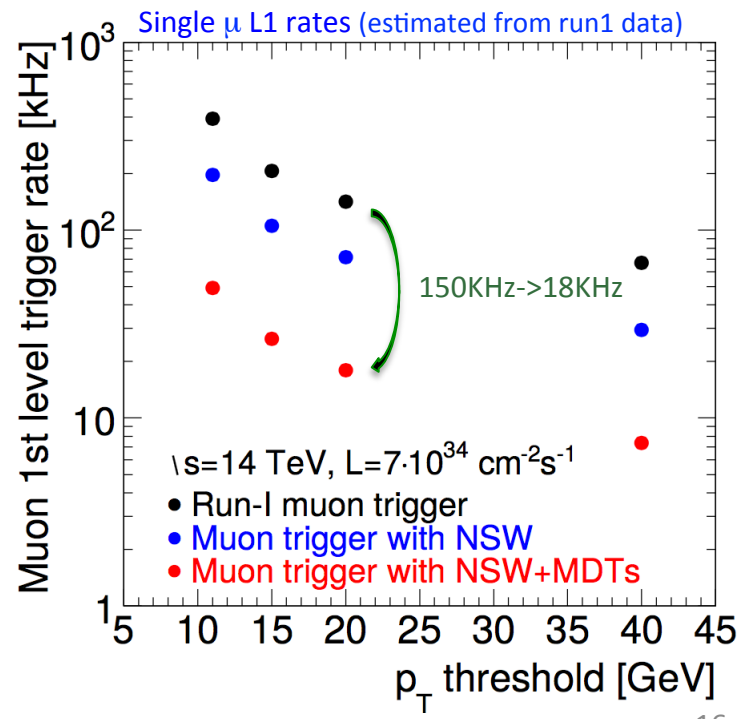
## New μ chambers:

✓ NSW (**sTGCs**+**MM**) : remove fakes (2019-2020)

- **Thin-gap RPCs** in barrel : better acceptance and $\sigma_{PT}$ μ trigger.
- **sMDTs** in barrel: to free space for Thin-gap RPCs
- New **electronics** in RPC/TGC/MDT for new trigger architecture.
- μ tagger: to identify muons up to |η| = 4.0.




- Better trigger performance
- L1 $\mu_{PT}$>20GeV:150KHz → 18KHz (w/ NSW+MDT)



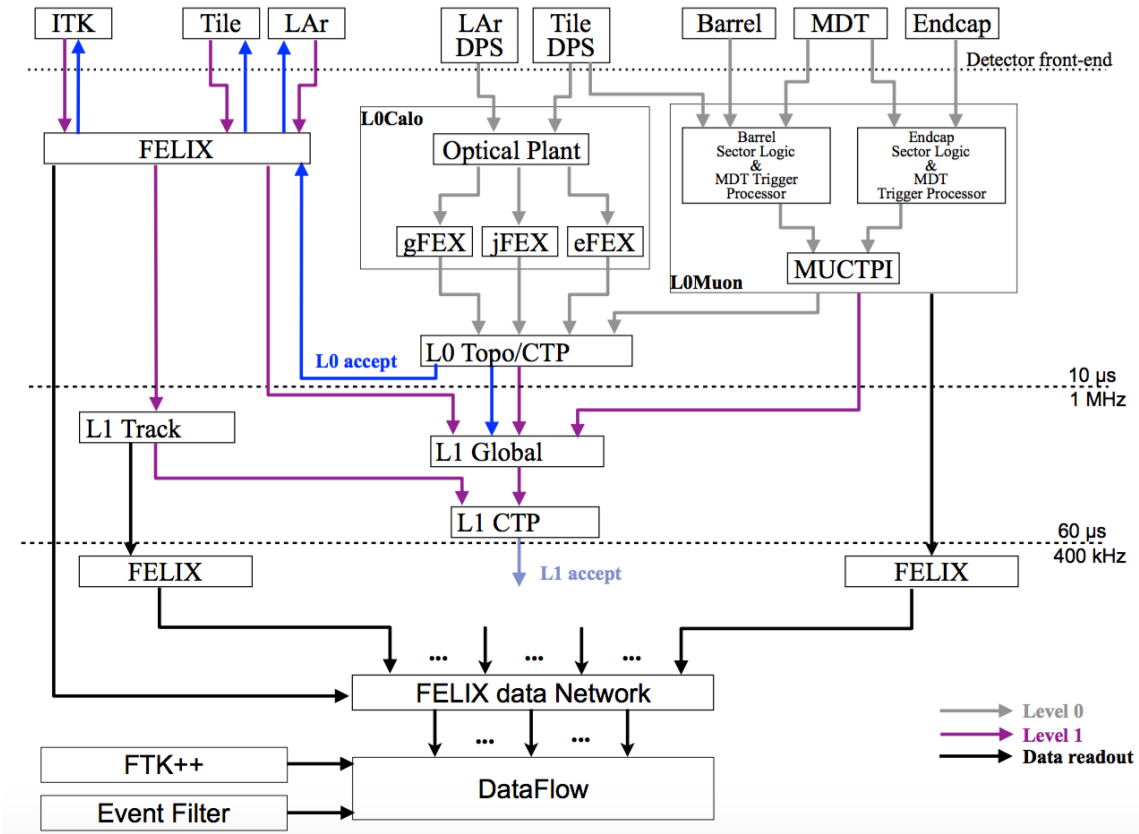

**Status/Plans:**

- **Ongoing:** maturing decisions on electronics and chambers proposals
- **Construction:** 2018-2023
- **Installation:** 2024-2026

# Trigger/DAQ at HL-LHC

- 2 hardware steps to maintain low $p_T$ thresholds.
  - **L0 (Calorimeters+Muon):** define RoI (profiting from phase 1 upgrades)
  - **L1 (ITK+calo+muon)** uses:
    - regional track info
    - regional full calorimeter (Lar+Tile) granularity
    - refined μ selection using μ precision MDT chambers
- **HLT/EF (software):** use offline-like algorithms

| | Out. Rate (KHz) | Latency (μs) |
|---|---|---|
| L0 | 1000 | 10 |
| L1 | 400 | 60 |
| HLT/EF | 5-10 | |

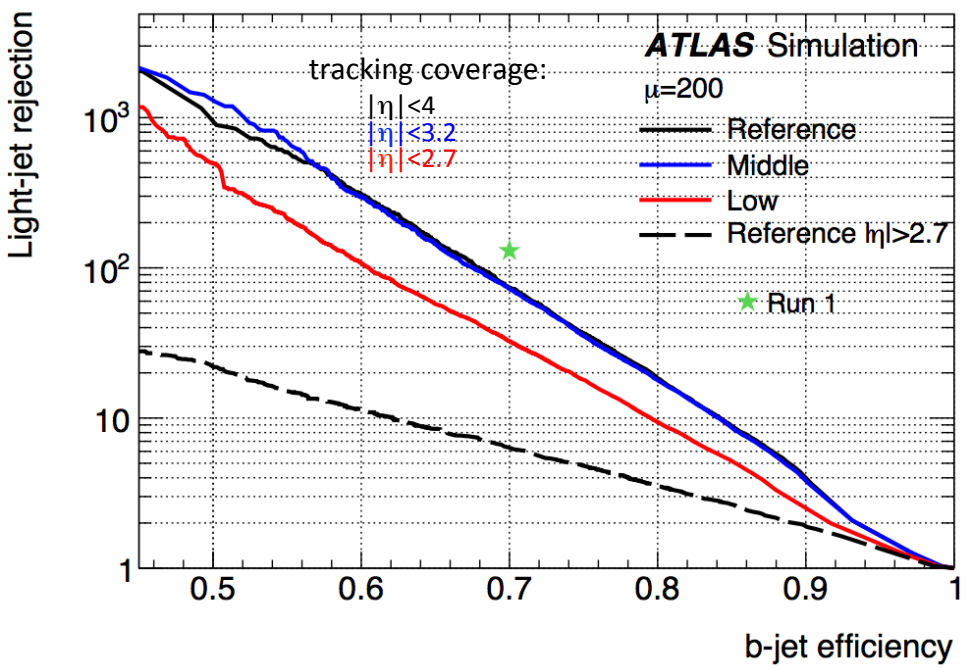


# B-tagging and vertexing performance at HL-LHC

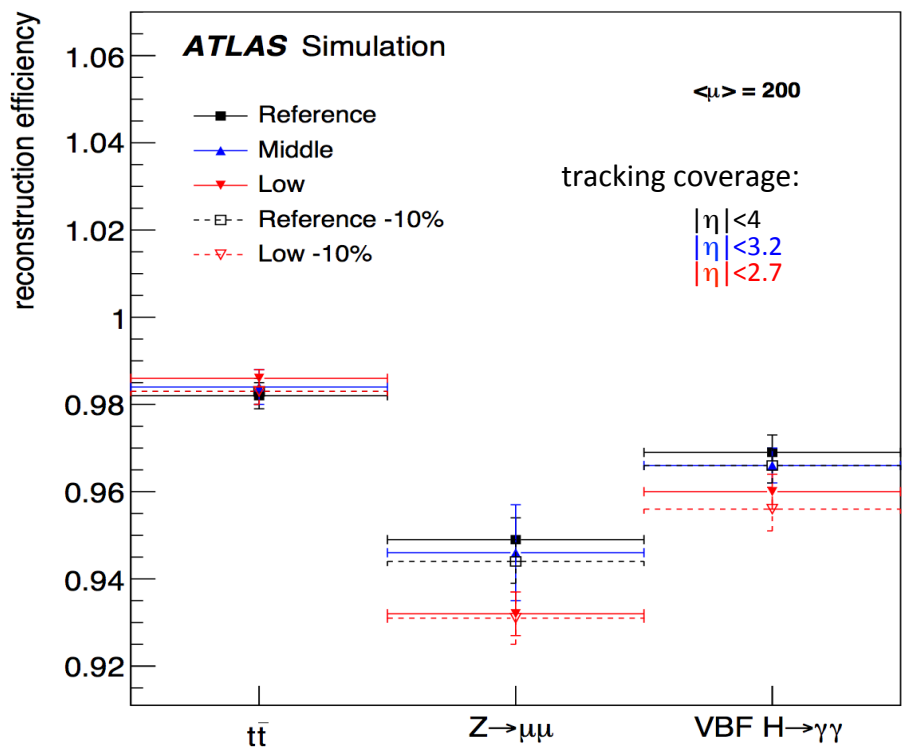
- b-tagging performance with VF-ITK similar to run1
- Improved hard scatter vertex selection efficiency including fwd tracks.

CERN-LHCC-2015-020

light jet rejection vs b tagging efficiency




Vertex reconstruction efficiency



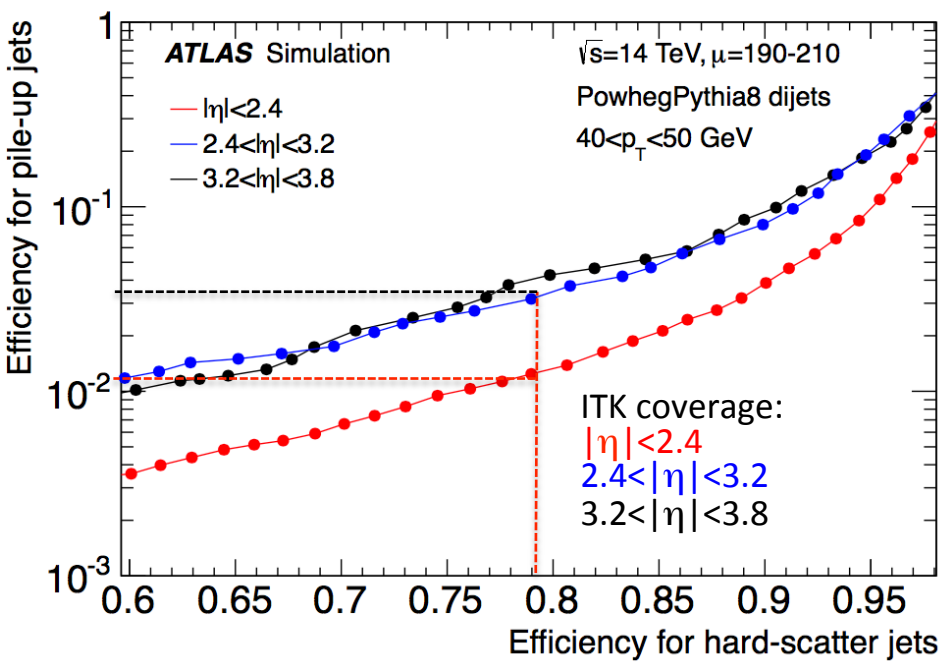
# Jet/Etmiss performance at HL-LHC

Tracker is very useful to discriminate Pile up jets from the hard scatter jets

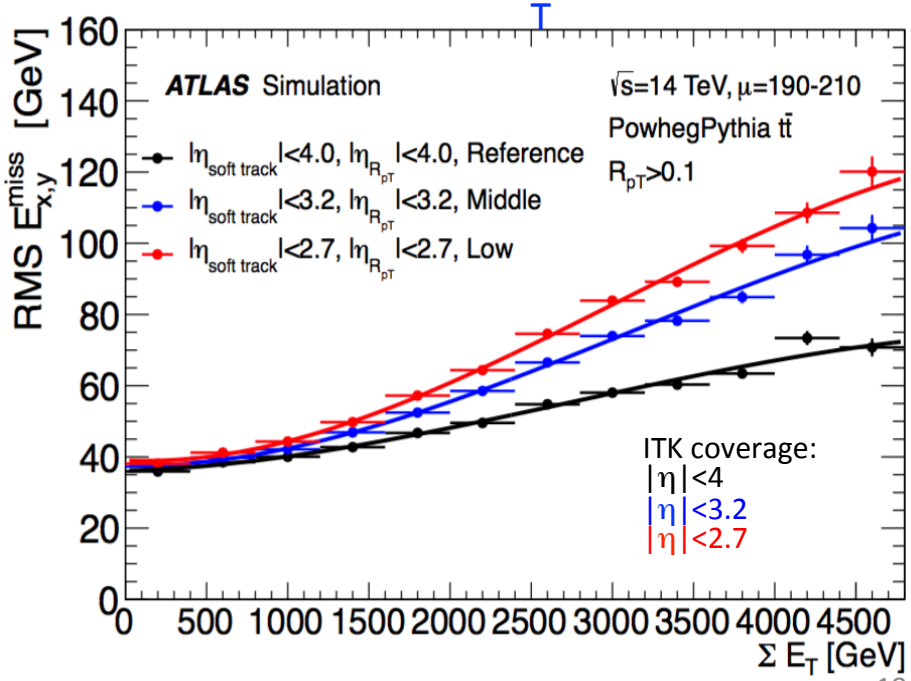
Improved jet/$E_{Tmiss}$ performance including tracker info up to $|\eta|$ =4

CERN-LHCC-2015-020

Efficiency of PU jets .vs. efficiency of HS jets




Etmiss resolution vs $\Sigma E_T$ in ttbar events



# Summary

- ATLAS upgrades allow to run efficiently at LHC and LH-LHC
- Three upgrade steps:
  - **Phase 0:** finished successfully in 2013
  - **Phase 1:**
    - FTK, NSW, L1Calo, TDAQ (TDRs approved in 2013)
    - Production starting/on-going for installation in 2019-2020
  - **Phase 2:**
    - All (ITK, LAR, Tile, Muon, TDAQ) TDRs until end 2017.
    - Final layouts (in particular at large $\eta$) to be finalised:
      - first step was the 2015 LHCC scoping exercise
      - TDRs and Internal ATLAS Design reviews for each option will conclude on the final ATLAS layout by end 2017

- Upgraded detector and improved algorithms provide the needed pileup mitigation and guarantees good performance to exploit fully the physics potential of the HL-LHC !

# BACK –UP

# ATLAS Phase 0 upgrades (2013-2014+Xmas breaks)

- ✓ **pixel IBL-layer + Smaller radius Be beam pipe**
  - First hit 33mm from IP (in run 1= 55mm)
  - pixel size: 100x250μm (in run1=100x400μm)
  - 75% planar/25% 3D sensors

  → **improve vertexing and b tagging.**
  → **~ x 1.5-2 better light jets rejection**
  → **important for H->bb**

- ✓ **New μ chambers**

-RPC "feet chambers" → **+ 4% μ trigger acceptance**
-MDT in $|\eta|$ ~1.1-1.3 → **improved $\sigma_{PT}$ by ~ factor 3**

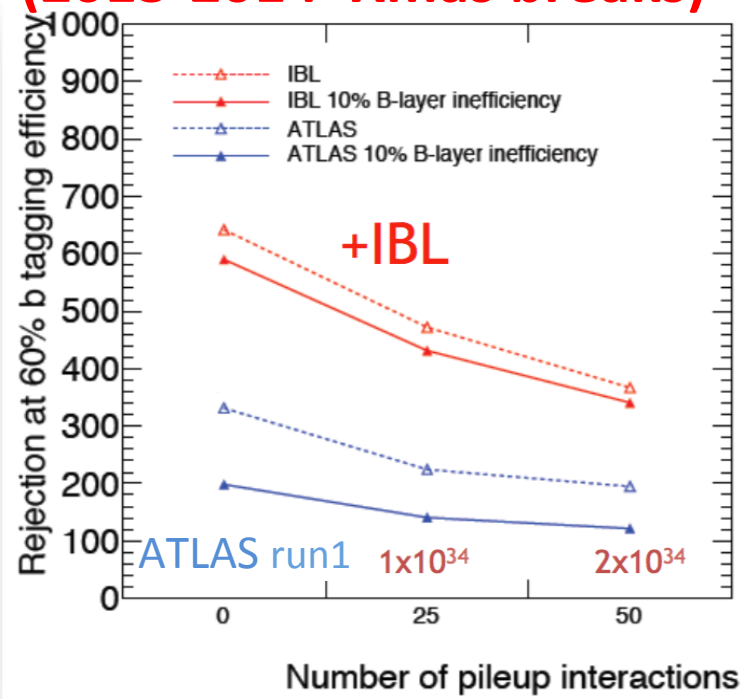
- ✓ **First ½ AFP detectors at Z= 200m from IP**

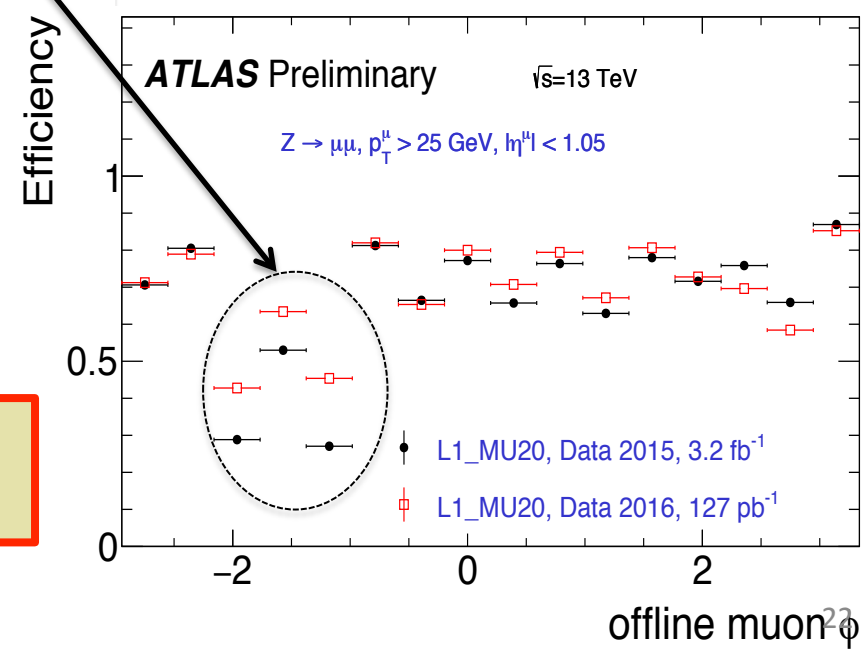
  → Atlas fwd Physics (rest ~2017)

- ✓ **new LUCID detector**

  → Luminosity measurements

**Improved performance for run2 and future**



# ATLAS Schedule for the phase 2 IDR and TDRs

| Upgrade project | Initial Design Review (IDR) | Technical Design Report (TDR) |
|---|---|---|
| ITk Strip<br>ITk Pixel | Q4 2014 | Q4 2016<br>Q4 2017 |
| LAr | Q4 2016 | Q3 2017 |
| TileCal | Q4 2016 | Q3 2017 |
| Muon | Q2 2016 | Q2 2017 |
| TDAQ | Q1 2016 | Q4 2017 |