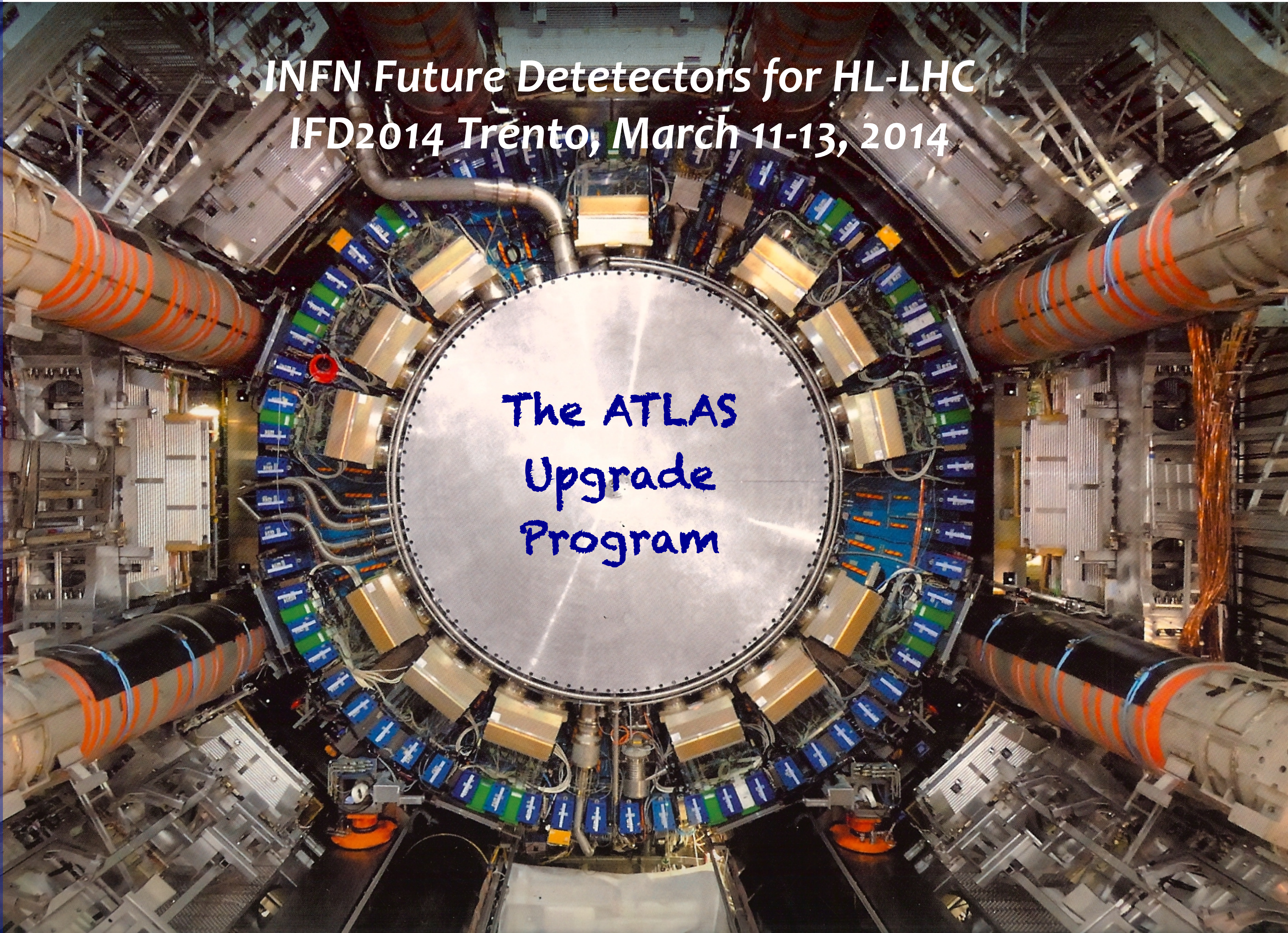
INFN Future Detetectors for HL-LHC
IFD2014 Trento, March 11-13, 2014



The ATLAS Upgrade Program

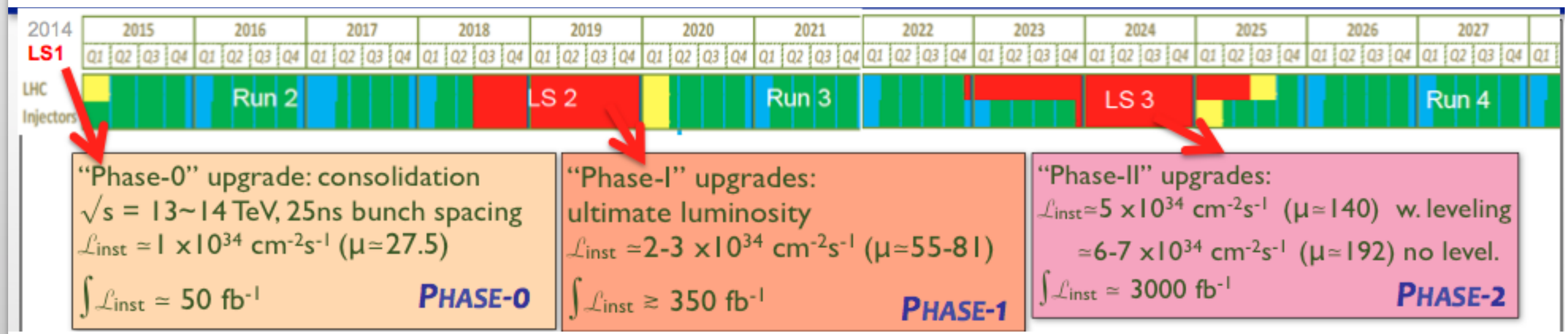
Mauro Iodice – INFN Sezione di Roma Tre

Upgrade Program of the ATLAS experiment at LHC

- The ATLAS Detector and main motivations for the upgrades
- Overview of ATLAS Phase-1(*) Upgrade
- Proposals for ATLAS Phase-2 upgrade (*)

(*) CMS Phase-1 (LS1 + LS2) = ATLAS Phase-0 (LS1) + Phase-1(LS2)

CMS Phase-2 = ATLAS Phase-2 (LS3)



THE ATLAS DETECTOR

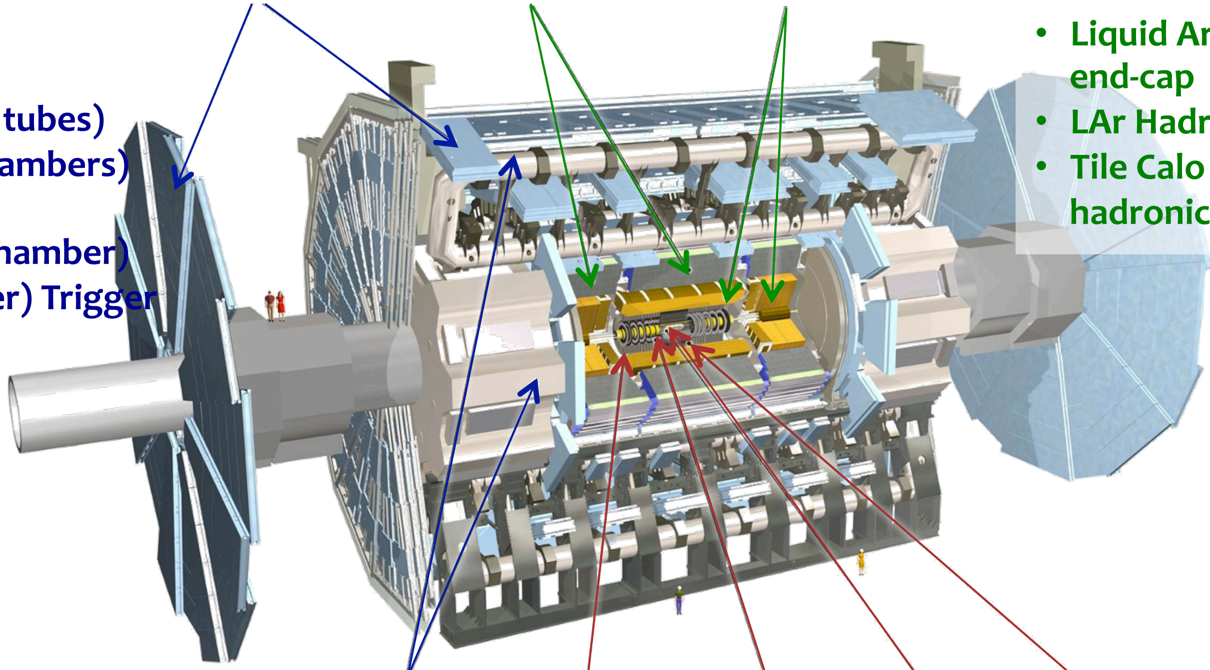
Muon spectrometer
μ Tracking
Toroid Magnet

Precision Tracking:
- MDT (Monitored drift tubes)
- CSC (Cathode Strip Chambers)

Trigger:
- RPC (Resistive Plate Chamber)
- TGC (Thin Gas Chamber) Trigger

Calorimeter system
EM and Hadronic energy

- Liquid Ar (LAr) EM barrel and end-cap
- LAr Hadronic end-cap
- Tile Calo (Fe–scintillator) hadronic barrel



Inner Detector (ID)
Tracking
2T Solenoid Magnet

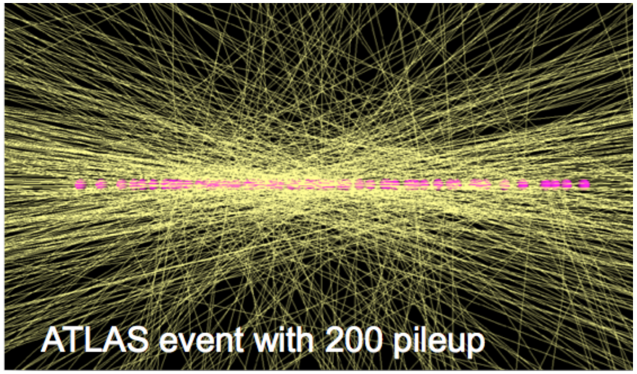
- Silicon Pixels 50 x 400 μm^2
- Silicon Strips (SCT)
  80 μm stereo
- Transition Radiation Tracker (TRT) up to 36 points/track

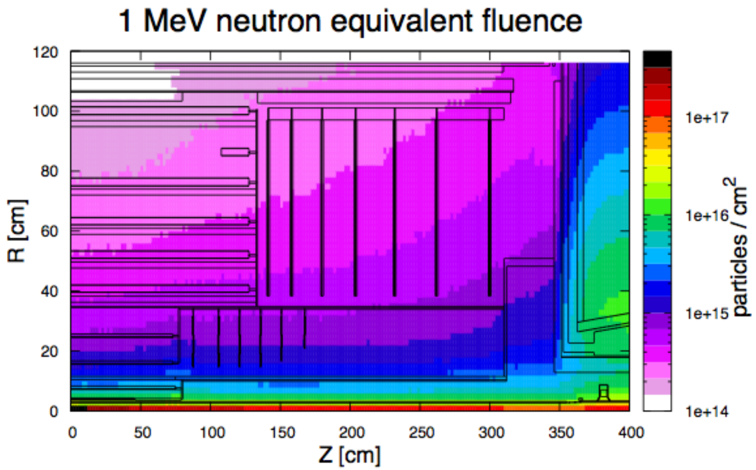
3 Level Trigger system

- L1 – hardware – 100 kHz 2.5 μs latency
- L2 – software – 3-4 kHz 10 ms latency
- EF – software – 100 Hz 1-2 s latency

MAIN MOTIVATIONS FOR THE UPGRADES OF THE DETECTORS

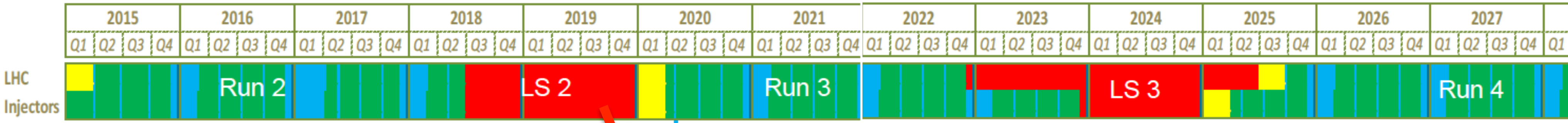
- Mantain and possibly improve performance with the increase in luminosity: **from 1x10^{34} to >5x10^{34} cm^{-2}s^{-1}**
- High pile-up up to **<μ>~200**
  A challenge for L1 Trigger and HLT
- High occupancy – read-out links saturation
- Aging, especially for detectors close to the beam-pipe. **Fluence up to 10^{16} n_{eq}/cm^2**

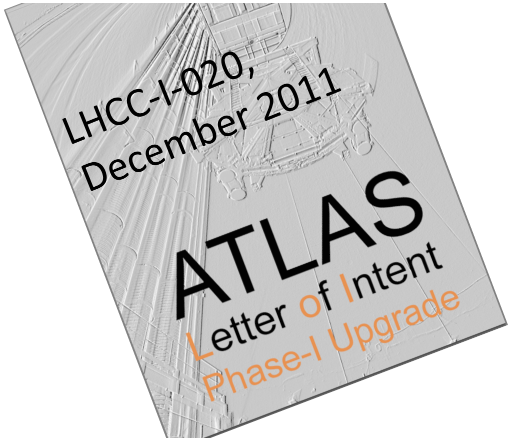




Maximum 1MeV-neq fluence and ionising dose for 3000 fb^{-1} in the pixel system is 1.4×10^{16}cm^{-2} and 7.7 MGy at the centre of the innermost barrel layer

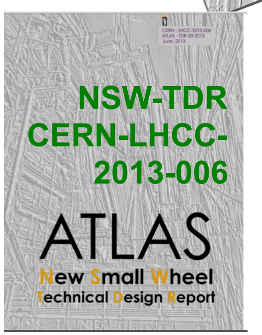
ATLAS UPGRADES FOR PHASE-1 (LONG SHUTDOWN 2)





“Phase-I” upgrades:
ultimate luminosity
$\mathcal{L}_{inst} \approx 2\text{-}3 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \approx 55\text{-}81$)
$\int \mathcal{L}_{inst} \gtrsim 350\ fb^{-1}$

PHASE-1



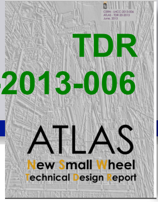
- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter Trigger at Level-1
- Fast TracKing (FTK) for the Level-2 trigger
- Topological Level-1 trigger processors
- New forward diffractive physics detectors (AFP)

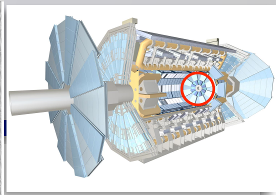
Compatibility with Phase-2
An example: Operation condition of NSW

- In operation from 2017 to >2032
- Instantaneous luminosity up to $5\text{-}7\ 10^{34}\ cm^{-2}s^{-1}$
- Average number of interactions per bunch-crossing ~140
- Bckgrnd hit rate up to 14 kHz/cm^2
- Total dose expected in the hottest regions in 15 years ~1Coulomb/cm^2
- Total Ionizing Dose (TID) in 10 years at large η: about 0.5 Mrad

NEW SMALL WHEEL - OVERVIEW

TDR
CERN-LHCC-2013-006

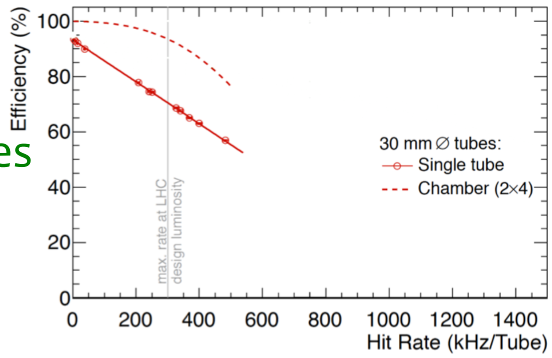




Two main motivations for the NSW

1) *Cavern Background*

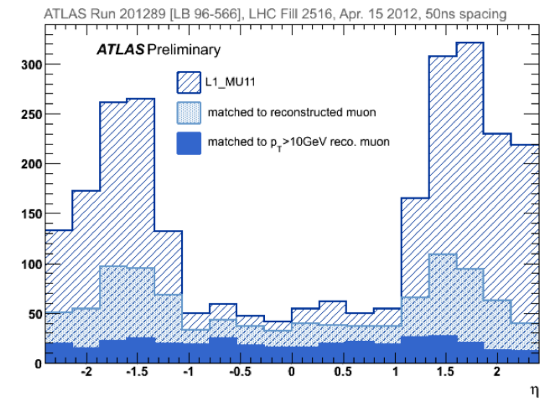
The MDT efficiency drops for tube-hit rates > 300 kHz/tube (tube hit and segment tracking inefficiency)



At 7x10³⁴ (luminosity of phase2) the rate estimate is (safety factor 1.5) 14 kHz/cm² (>5 MHz/MDTtube)

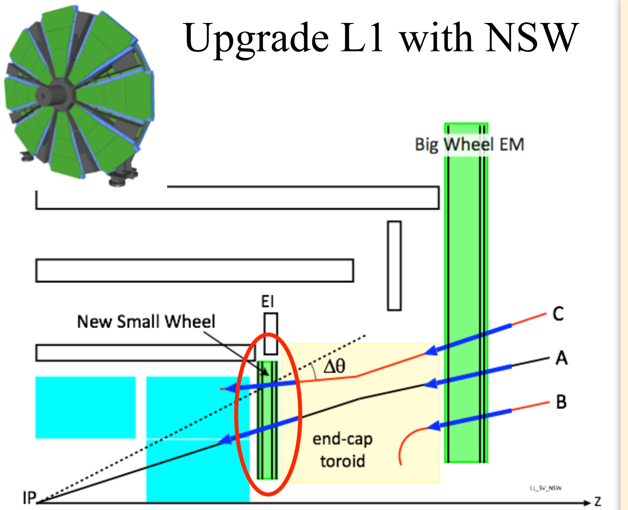
2) *TRIGGER*

L1 muon trigger rate in the end-cap (based on Big Wheel) dominated by fake triggers.



At $3 \cdot 10^{34}$ $cm^{-2}s^{-1}$ rate L1MU20 (p_T>20 GeV) ~60 kHz exceed the available bandwidth for L1Mu (~15kHz)

Upgrade L1 with NSW



"New Small Wheels"

Reduce fake muon triggers requiring:

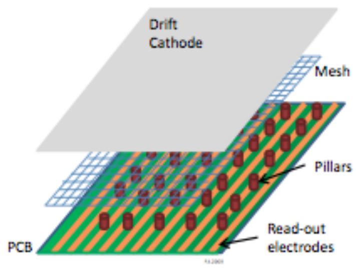
- Segments with High precision IP pointing (σ_θ~ 1mrad)
- Matching BigWheel segments

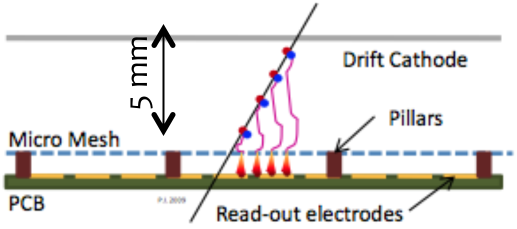
*sTGC + **A New detector: MicroMegas (MM)***

primary detector for precision tracking in the NSW

sTGC+MM for the NSW. Operate from 2017 until 2032

→ROBUSTNESS and REDUNDANCY





EM LIQUID ARGON -- OVERVIEW

TDR
CERN-LHCC-2013-017

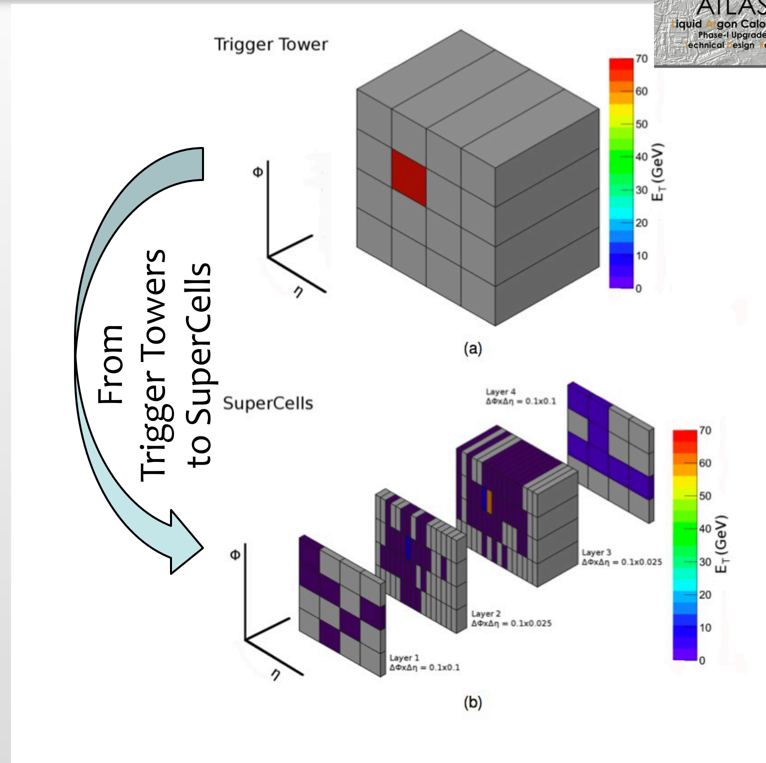
- *Maintain Trig-L1 high efficiency for low PT EM objects*
- *Imrove e/jet discrimination*
  - At $\mathcal{L}$ ~ 3×10^{34} $cm^{-2}\,s^{-1}$
  - pile-up uo to <μ> = 80

Modify Electronics:

More information on shower development at L1

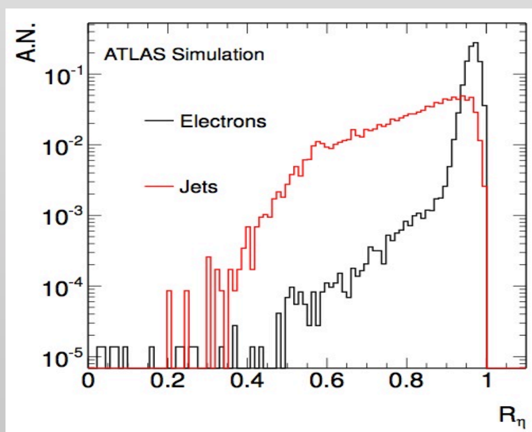
Apply rejection criteria similar to those used offline

- More segmentation in η
- Information on Layers (depth information)
- Information on energy deposit with finer energy scale quantization

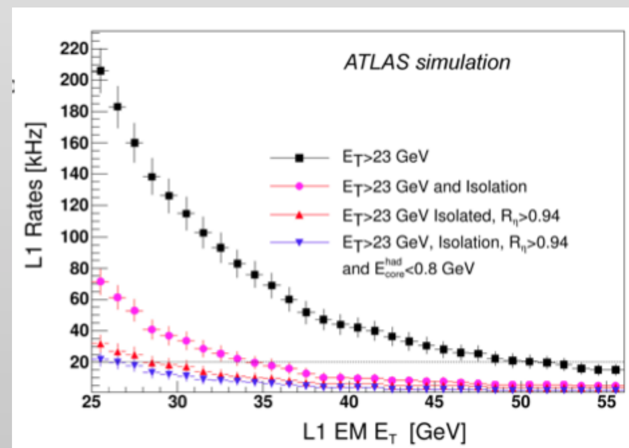


Selection e/jet

- Exploit greater segmentation to build selective variables L1Calo (shower shapes algorithms)
- An example: $R_\eta = \dfrac{\sum_{3x2} E_T}{\sum_{7x2} E_T}$



Rη allows to maintain trig. rate of 20 kHz with a 25 GeV Threshold



FAST TRACKER (FTK) - OVERVIEW

TDR
CERN-LHCC-2013-007

- Fast reconstruction of charged particles in the Inner Detector
- Make use of data from PIXEL detector, SemiConductor Tracker (SCT) and from the new Insertable B-Layer (IBL) pixel detector
- "hardware based" tracking system. For each L1 trigger provides input to L2 with high precision track parameters for b-tagging, tau, lepton isolation
- Foreseen to evolve in Phase-2 for L1 trigger (in the L0/L1 scheme)

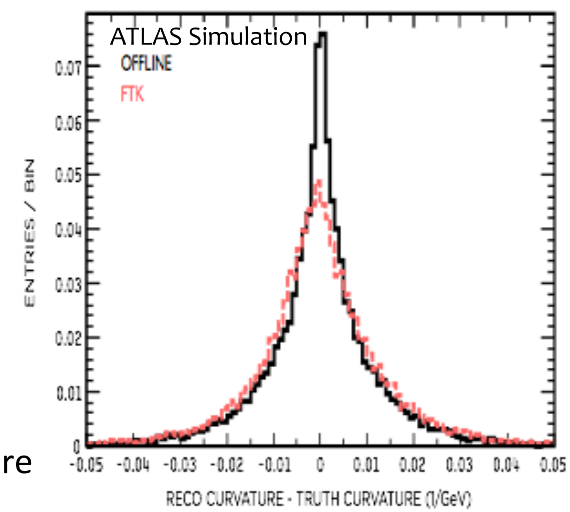
Pattern recognition:

Based on Associative memories

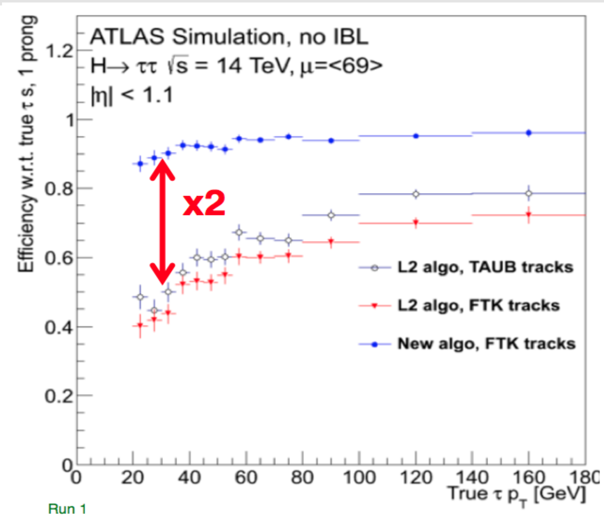
Match hits to 10^9 predefined patterns

Track Fitting:

Second stage of track-fitting provides track parameter close to offline (**FPGA**)

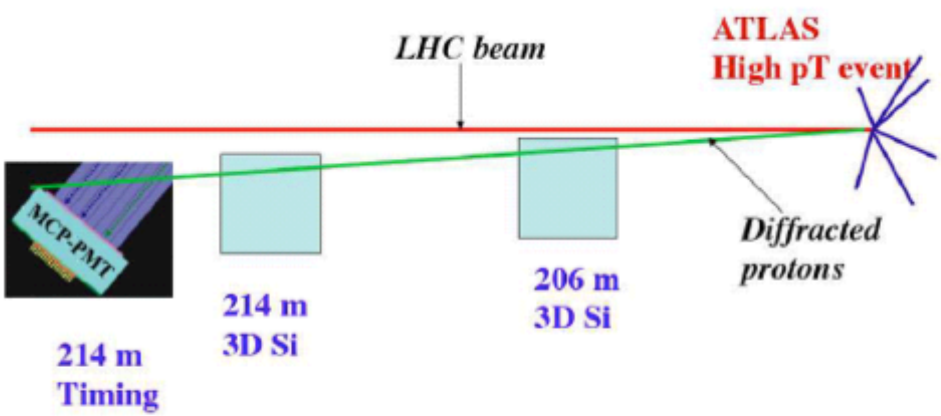


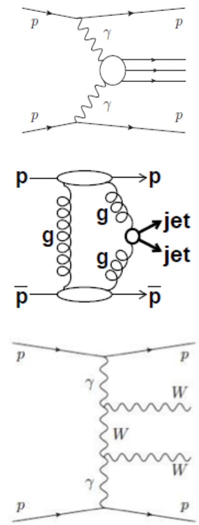
Resolution curvature
Vs offline tracking



τ trigger efficiency improves by x2 using track info

ATLAS FORWARD PHYSICS (AFP) - OVERVIEW



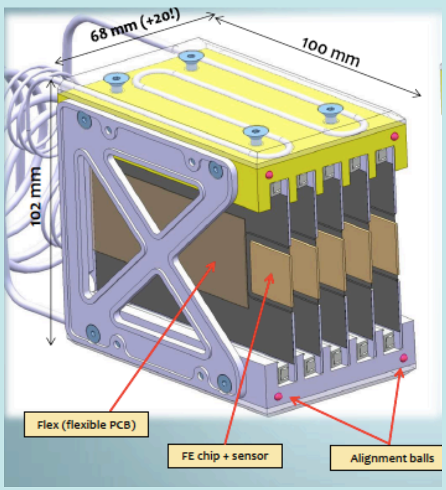


AFP is one of the ATLAS upgrade project of the LoI Phase-1

- Goal: tag diffractive events with protons at very forward angle (in the beam pipe)
- Physics: Anomalous coupling of γ with W and Z, esotic physics, QCD (Double Pomeron Exchange)

Two branchs of detectors. Each consisting of:

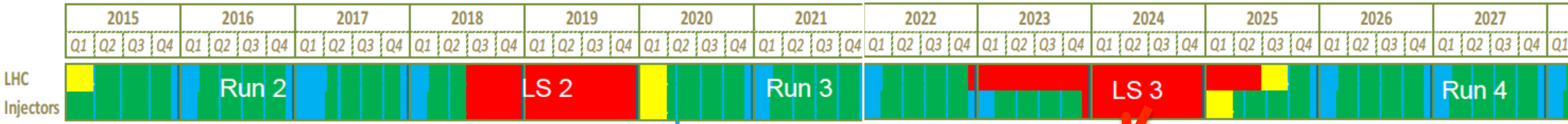
- 5+5 pixel tracking stations (3D same technology of IBL; angular resol. ~ 1 μrad)
- 1 timing station (time resolution ~ 10 ps → ~2 mm on the vertex of interaction)
- The detectors are contained in two station of interface to the beam: RomanPot (±206m and ±214m)



Approval steps

- Approval delayed wrt other phase-1 projects. Not yet approved by ATLAS
- AFP Physics Review held Jan. 24th (Impressive progress, approved physics in Run-2 – few days dedicated run)
- Next steps: Resources and Technical Reviews

ATLAS UPGRADES FOR PHASE-2 (2022-2023)



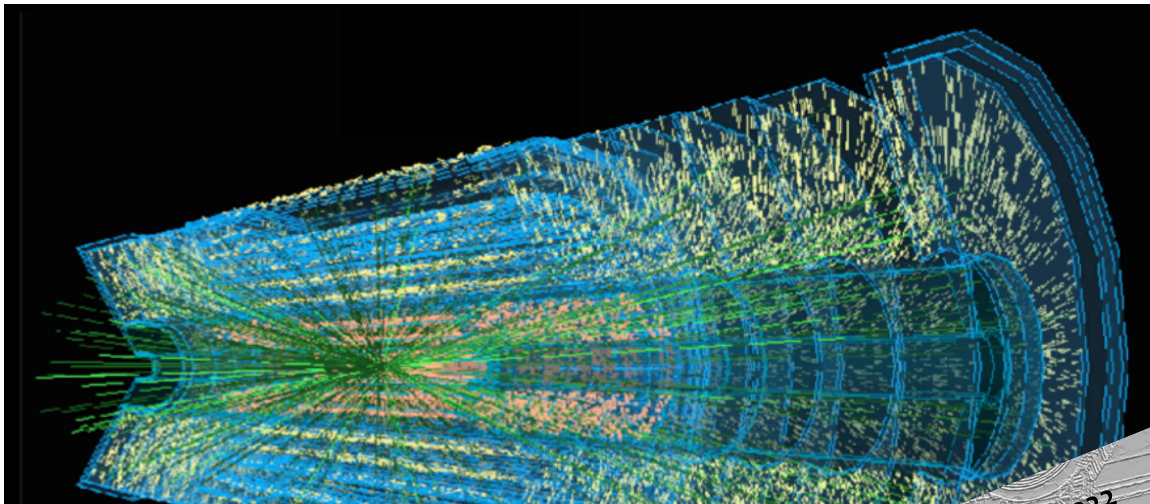
"Phase-II" upgrades:

$\mathcal{L}_{inst} \simeq 5 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 140$) w. leveling

$\simeq 6\text{-}7 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 192$) no level.

$\int \mathcal{L}_{inst} \simeq 3000\ fb^{-1}$

FASE-2



- The current tracker will be damaged in Phase-2 by radiation and affected by high occupancy → Full replacement
- New trigger scheme L0(500kHz)/L1, based on L1 track trigger
- calo/muon upgrades di Phase-1 are compatible with Phase-2, but in some cases read-out electronics upgrade is needed
- Computing & software upgrades

- All new Tracking Detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible Level-1 track trigger
- Possible changes to the forward calorimeters

Motivations for the Upgrade of the Trigger and Data-Flow Systems

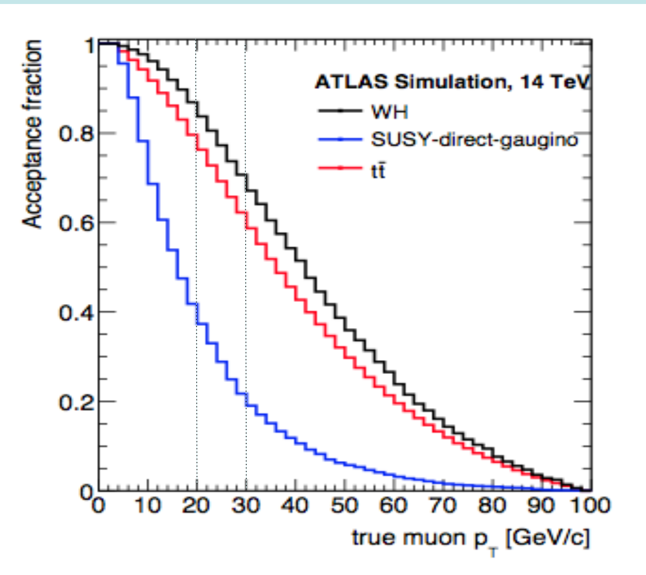
Present (Phase-1) L1 trigger:

- L1Calo and L1Muon → L1Accept in 2.5 μs (after combination of triggers and RoI in the Topological Processor and CTP)
- Rate limited to <100 kHz by read-out detector capability

PHASE-2

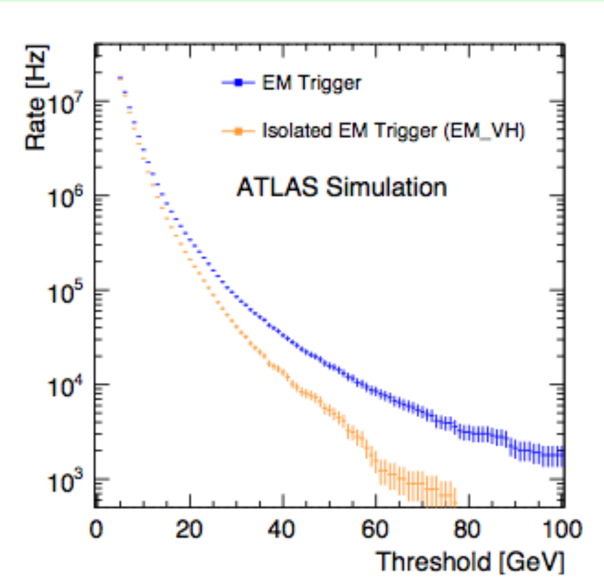
- Maintain efficient triggers for isolated electrons and muons with **thresholds ~20 GeV**
- **Flexibility** to adapt to any new physics discoveries and changes in bckgnd conditions
- Compatible with the **constraints imposed by the detector** →

Detector	Max. Rate	Max. Latency
MDT	$\sim 200\,\mathrm{kHz}$	$\sim 20\,\mu s$
LAr	any	any
TileCal	$> 300\,\mathrm{kHz}$	any
ITK	$> 200\,\mathrm{kHz}$	$< 500\,\mu s$



An increase in threshold from 20 to 30 GeV results in a reduction in acceptance ~ 1.3 – 1.8

Acceptance of muons from $t\bar{t}$, WH and SUSY processes



For an electron trigger threshold of 25 GeV:

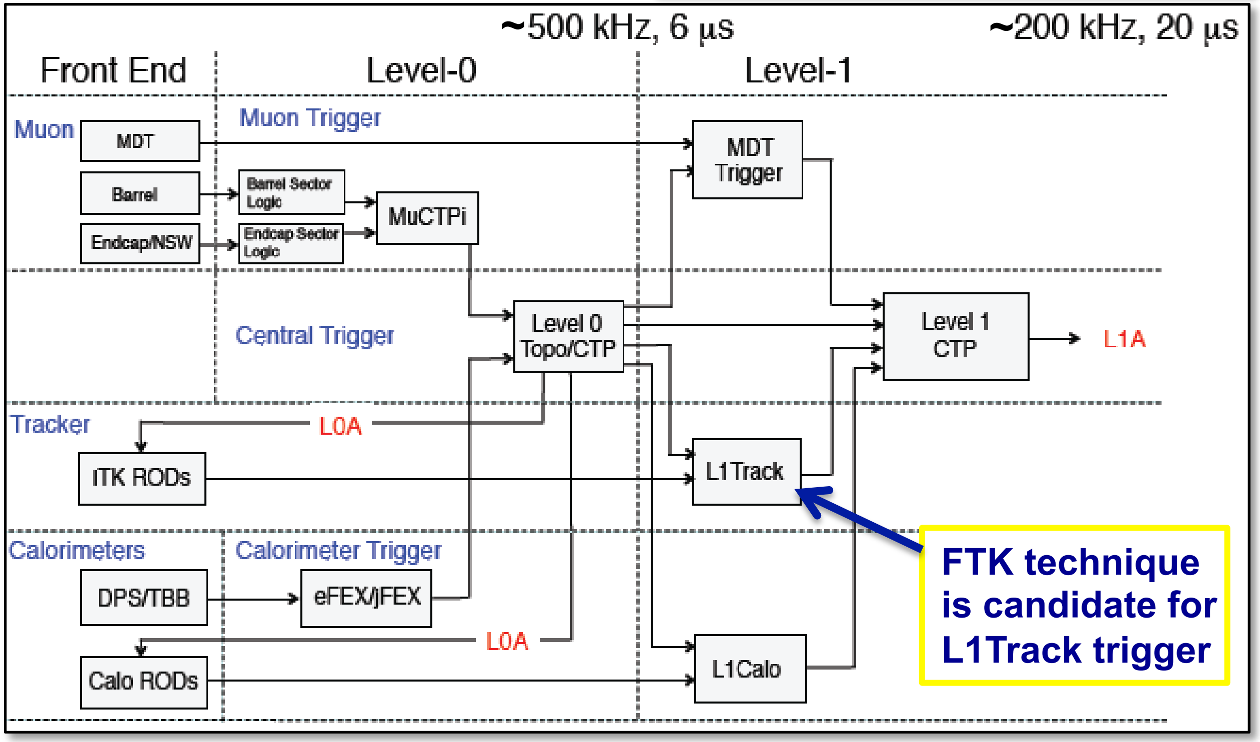
- **250 kHz** without hadronic isolation
- **125 kHz** with hadronic isolation (EM_VH)

Projected trigger rates for $<\mu> = 115$ (~ $4\times10^{34}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) Vs trigger threshold for isolated electron

TRIGGER AND DATA-FLOW SYSTEMS

- New design for Phase-2
  - 2-level system L0/L1: *Phase-1 L1 becomes Phase-2 L0 and new L1 includes tracking*
  - Make use of improvements made in Phase-1 (NSW, L1Calo) in L0
  - **Introduce precision muon and inner tracking information in L1**
    - **Better muon pT resolution**
    - **Track matching for electrons,…**
  - **Requires changes to detector FE electronics feeding trigger system**

Will also have new timing/control links and LHC interface system



Level-0 Muon + Calo
Rate ~ 500 kHz, Lat. ~6 μs

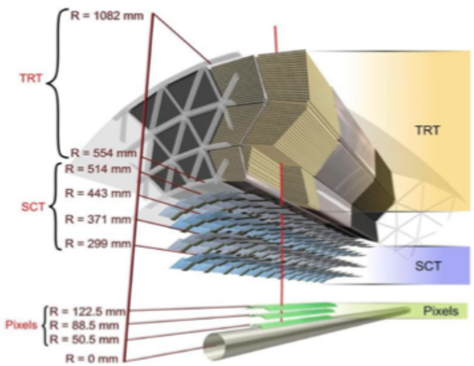
Level-1 *Muon + Calo + Tracks*
Rate ~ 200 kHz, Lat. ~20 μs

THE ATLAS INNER TRACKER FOR HL-LHC

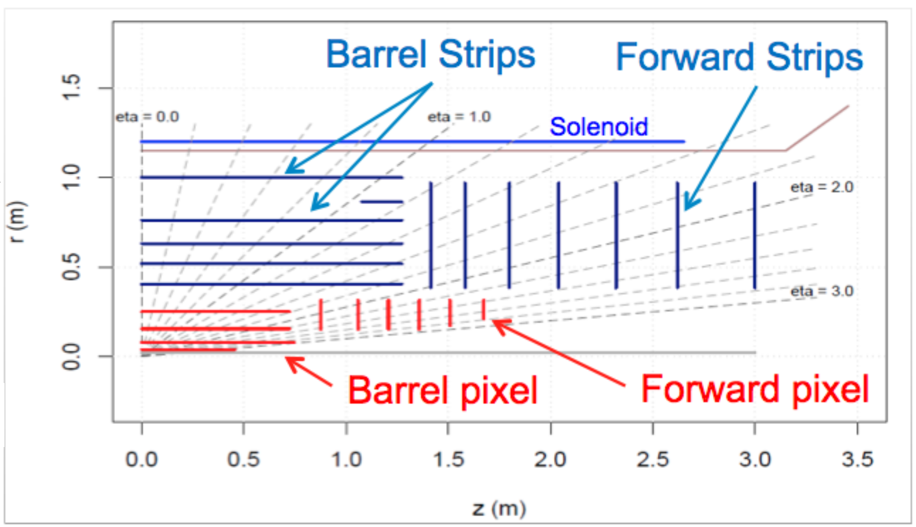
- Present Inner Detector: designed to operate 10 years at $1\text{x}10^{34}$ $cm^{-2}\,s^{-1}$ with μ=23, L1=100kHz
- Limiting factors at HL-LHC of the present tracker:
  - Bandwidth saturation (Pixel, SCT)
  - Occupancy (TRT, SCT)
  - Radiation damage (Pixel, SCT designed for 400 and 700 fb^{-1}, respectively)

➥ LoI layout : *New, All Si ATLAS **I**nner **T**rac**K**er*

- High granularity and bandwidth to operate at 5 x 10^{34} $cm^{-2}\,s^{-1}$ → high pile-up (μ~140)
- Proposed design 638Mpix + 74Mstrips for $|\eta| < 2.7$ → working on optimizations



present Inner Detector



Pixels (638M channels)

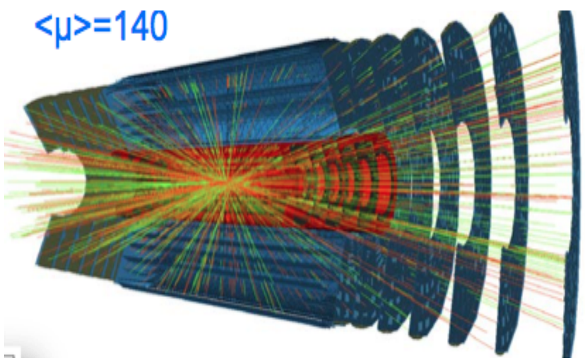
- 4 barrel layers + 6 fwd disks
- inner 2 layers replaceable: 25µm x 150µm
- outer Pixel: 50µm x 150µm
- sensors bump bonded to readout chip using 65nm CMOS

Strips (74M channels)

- 5 barrel layers + 7 fwd disks
- stub layer for overlap region
- 2 Si sensors at 40mrad

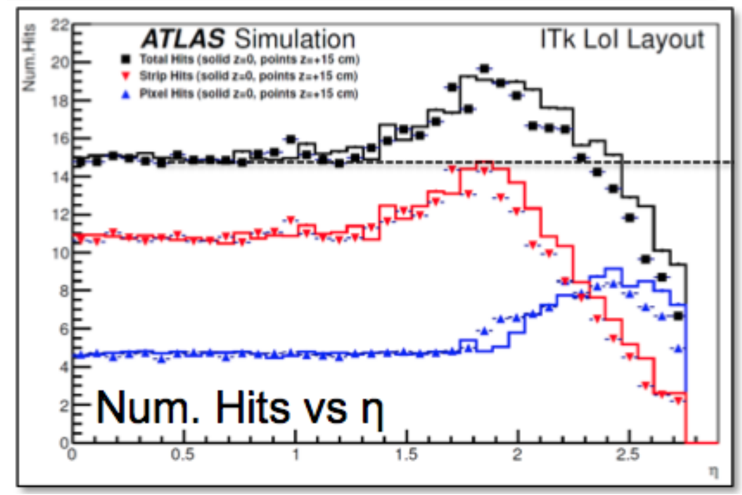
Alternative layouts being considered: include either a further pixel layer or inclined pixel

THE ATLAS INNER TRACKER FOR HL-LHC



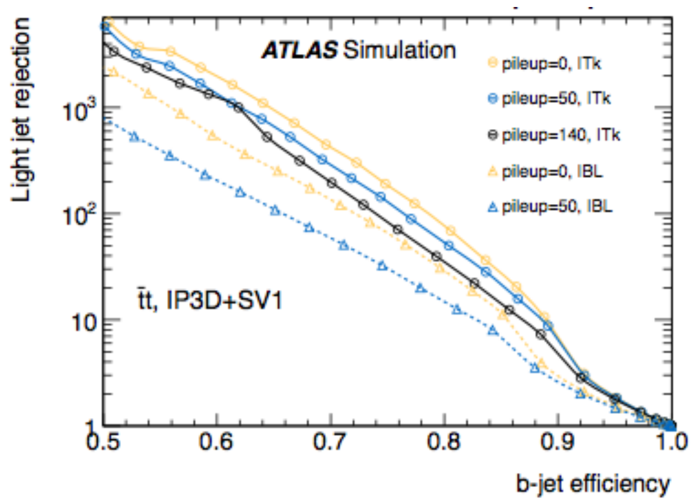
ITK from LoI layout:

- 14 points/track for |η| < 2.7
- Occupancy < 1% for <μ>=200
- Reduced material (factor 5 for |η| < 1) wrt ID

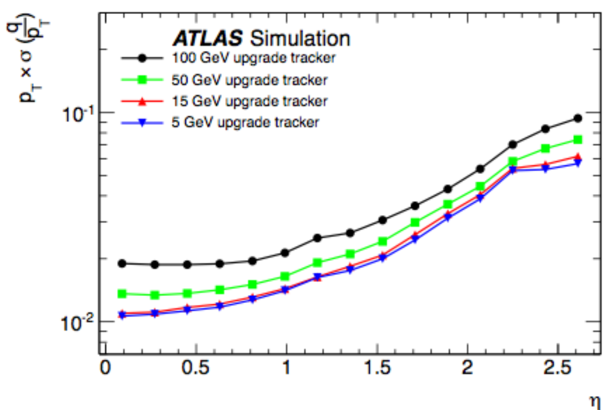


Simulations with ITK

- b-tagging in $t\bar{t}$ events for different pile-up.
- Better performance with ITK <μ>=140 compared to ID+IBL with <μ>= 0



Momentum Resolution Vs η



significant improvement due to the longer lever arm and more precise hit position

R&D ON SENSORS FOR THE ITK

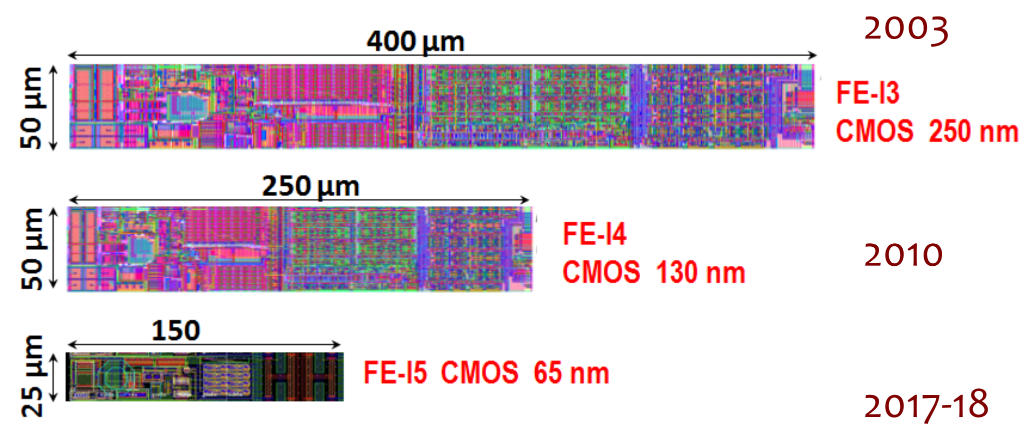
ITk Pixel Requirements

- 10÷20x TID/NIEL dose
- 6x event pile-up

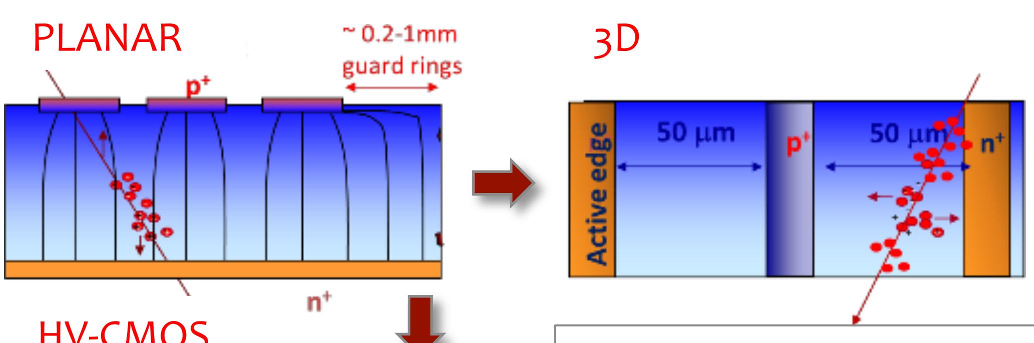
Enabling technologies

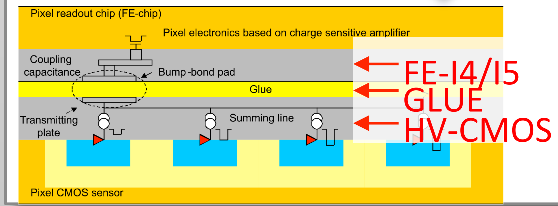
- *65 nm CMOS* → hi-dose, small pixel size → RD53
- 3D → low bias w.r.t. planar (<250 V from 1.5kV), larger collected charge per unit thickness (produced "here": by FBK)
- HighVoltage-CMOS → standard industrialized process (low-cost, large availability). No bump-bonding needed. Challenging, but very promising → ATLAS Task Force *(TF)*

ATLAS roadmap → Pixel Size



ATLAS roadmap → Sensor



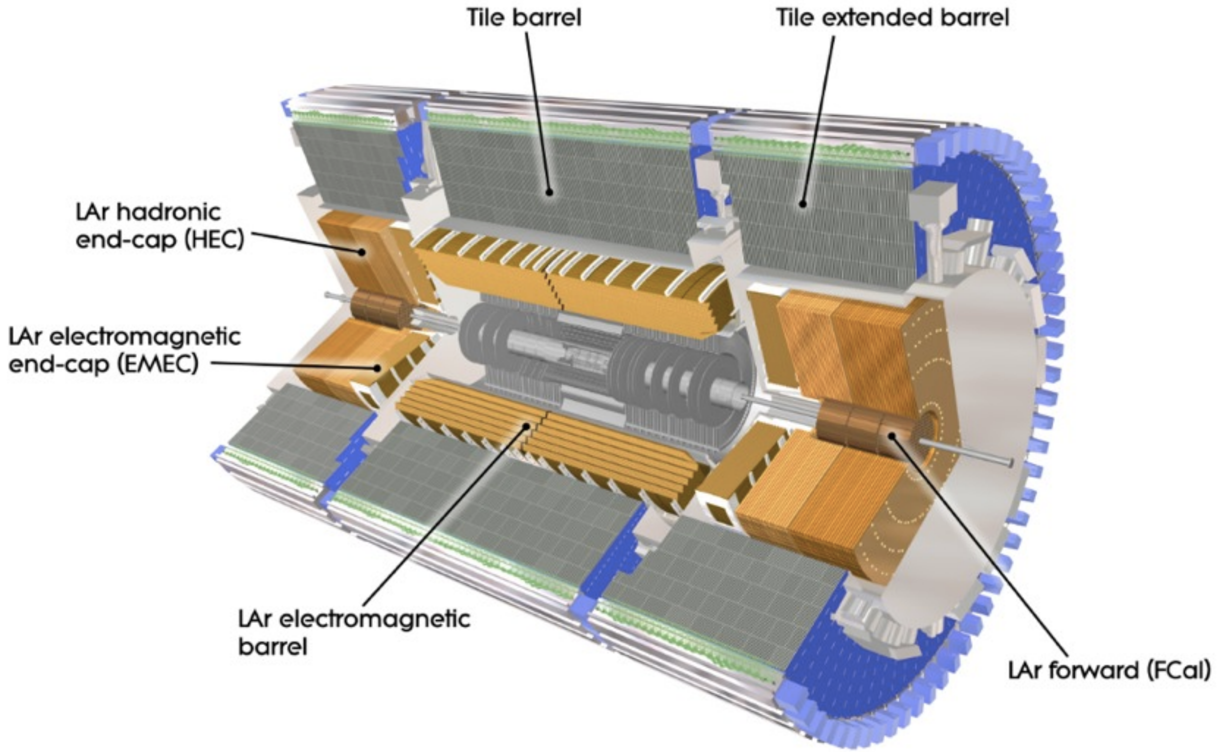


PLANAR → 3D
Extreme dose, inner pixels

PLANAR → HV/HR-CMOS
Low cost, moderate/(extreme?) dose, outer pixel radii /strip → ATLAS TF

Calorimeter Systems -- Tile and Liquid Argon

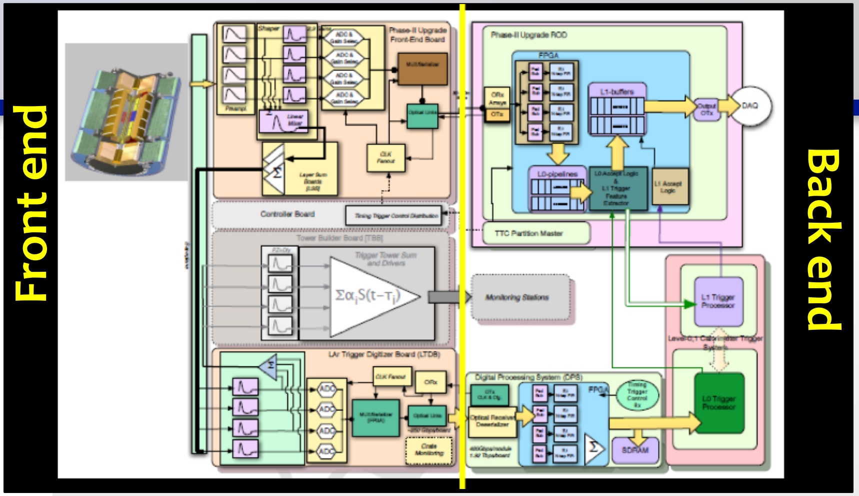
- **No change to detectors needed** -- The forward calorimeter (FCAL) is potentially the only exception.



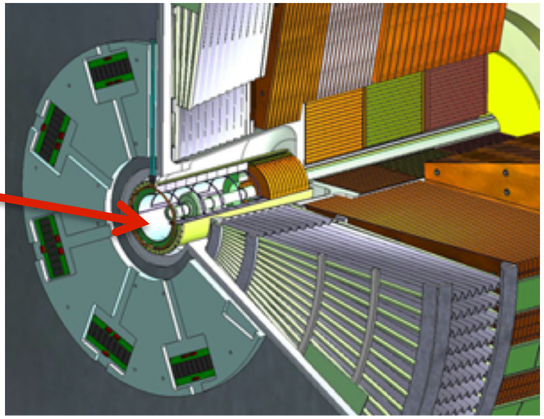
- New read-out architecture: Full digitisation and read-out of data at 40MHz and transmission to off-detector system, digital information to L1/L0 trigger
- Full replacement of Front-end and Back-end electronics

LAr CALORIMETER

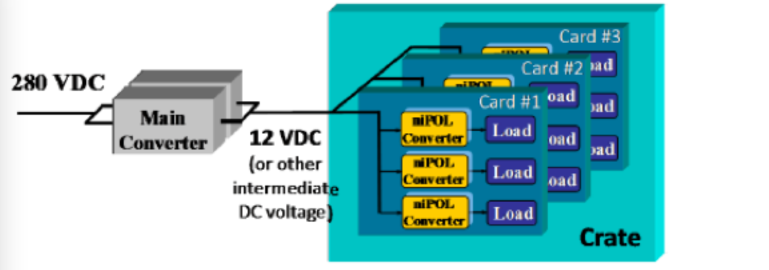
- Replace FE and BE electronics:
  send all data off detector for trigger and read-out at LHC bunch-crossing frequency of 40 MHz
  - -- Aging, radiation limits
  - -- 40 MHz digitisation, inputs to L0/L1
  - -- Improved and more complex trigger algorithms
  - -- Natural evolution of Phase-I trigger boards



- Replace Forward calorimeter (FCal) **if required**
  - -- Install new **sFCAL** in cryostat or **miniFCAL** in front of cryostat <u>if significant degradation in current FCAL</u>



- The power system
  - – All LVPS will be replaced with new units generating a single intermediate voltage (e.g. 12 V)
  - – Needed voltages for front-end generated by non-isolated Point of Load (POL) DC-DC converters located on board



. Proposed power supply distribution system (niPOL = non-isolated Point of Load).

MUON SYSTEM

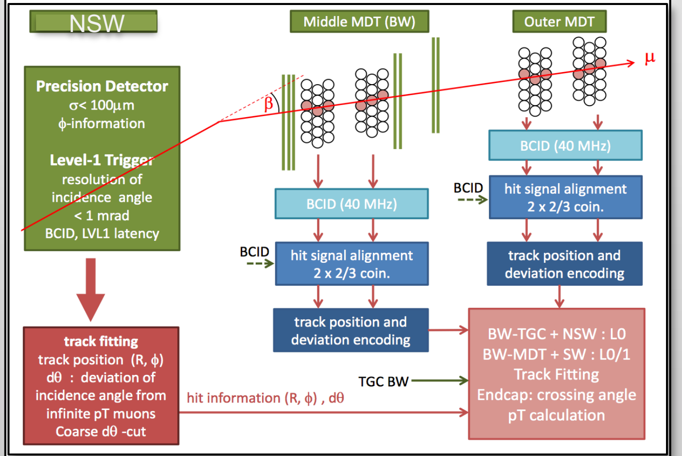
Trigger chambers: RPC (Barrel) and TGC (Endcap)

Upgrade od the electronics

- The present readout system of the RPC and TGC will not be able to cope with the new L0/L1 trigger scheme
- Present electronics designed for max latencies of 3.2 µs (TGC) and 6.4 µs (RPC), and for trigger rates up to 100 kHz.
- The **whole trigger electronics chain will have to be replaced**,
  → Opportunity to rebuild the readout chain *(improved spatial resolution with ToT in the bending direction)*

Endcap: Reduce fake trigger rates due to insufficient sharpness of the high-pT threshold

- Insufficient spatial resolution in the η coordinate of the TGCs in the Big Wheels
  - → Option: replace existing TGC with sTGC (technology of NSW) in the Big Wheel (Middle Layer)
  - → use of MDT coordinates for a better determination of the deflection angle (Outer layer)



Match angle measurement in end-cap MDTs to precision measurement in NSW

MUON SYSTEM

MDT Latency issue

- MDT limits the MAX latency to ~20 μs (at limit of operation for the MDTs) for the L0/L1 scheme
- Tracking at L1 would benefit from larger latencies (20 μs latency is non-trivial constraint for L1Track)

➥ REPLACEMENT of FE electronics (or different operation mode) currently under investigation

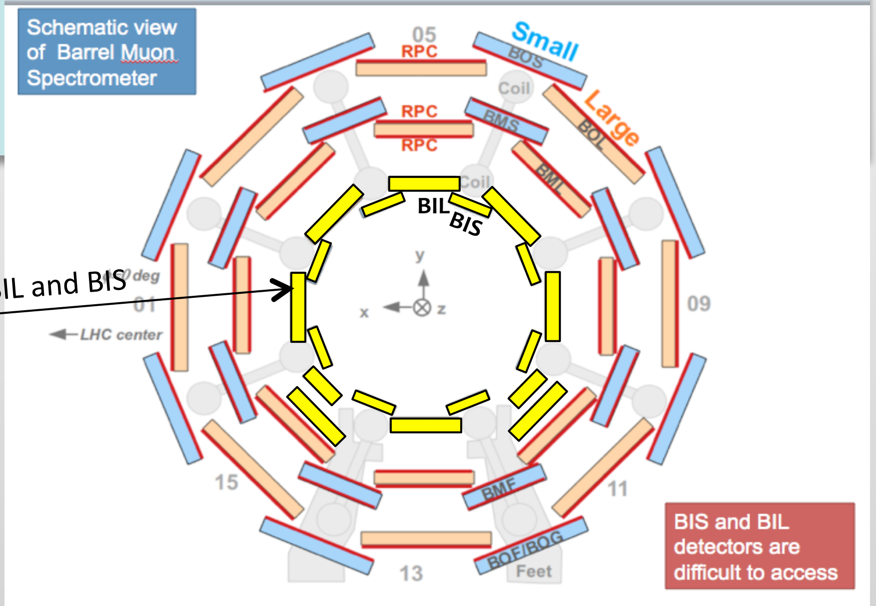
BENEFIT:

- **More flexibility to extend the Latency**
- **Use MDT precision hits for L1 trigger**

*Main issue is how to replace **MDT electronics** on all detectors*

- Some **Barrel** regions are inaccessible
- The **End Cap** region will need time for full replacement
- Estimates of time needed for different exchange scenarios.
- Evaluate reliably the maximum tolerable latency and trigger rate if we can't exchange all the electronics.

Most of the MDT BIL and BIS

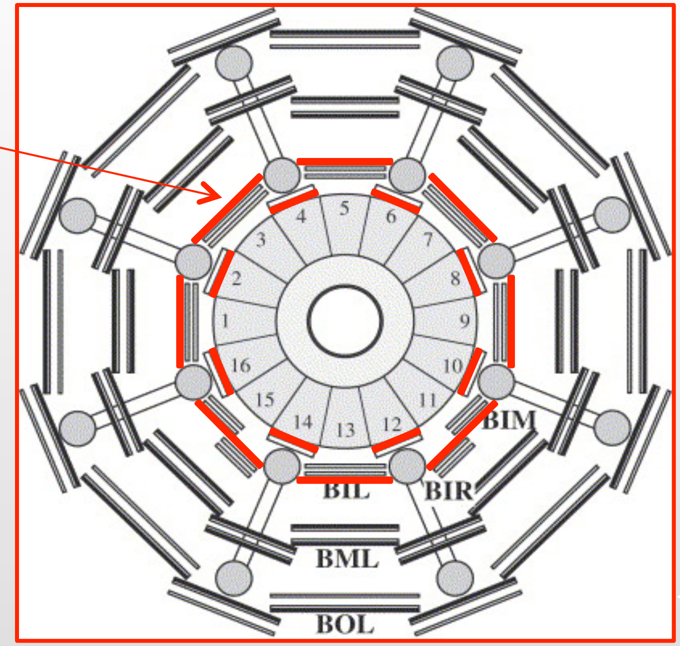


➥ NEW **RPC in the Inner layer**

- Improve pT resolution at L0 (complement MDT L1)
- Allow lowering the RPC working point (and increase the ageing capabilities)

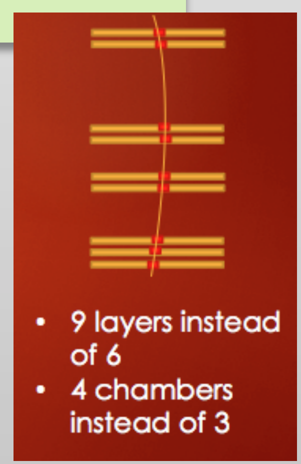
MUON SYSTEM – RPC INNER LAYER

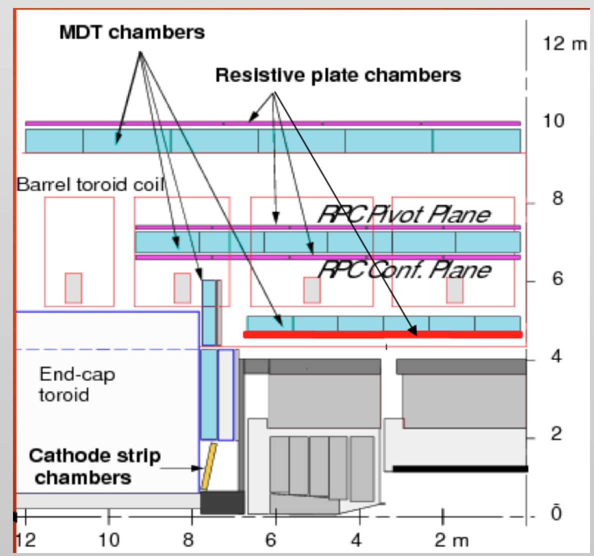
Increase the redundancy by adding the RPC inner layer (project not in the LoI)



- Thinner gas gap (<1mm); thinner electrodes (<1mm); new FE integrated with 100 pS TDCs; fast tracking capability at sub mm level
- Complementary to MDT L1 trigger whose electronics cannot be replaced in some of the inner chambers
- Provide redundancy and increase the lever arm of the RPC trigger for HL-LHC
- The 3rd station increase the lever arm → the momentum cut sharpness for the LVL1.

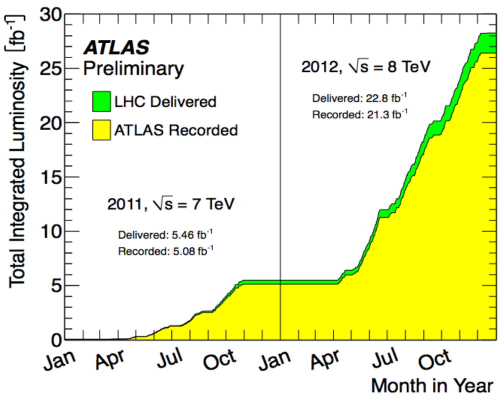
- Higher redundancy in the middle stations with a substantial improvement of the trigger robustness
- Increase (>10%) the LVL1 barrel acceptance (currently at 72%)

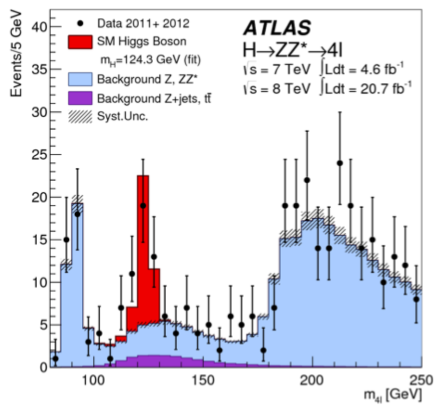




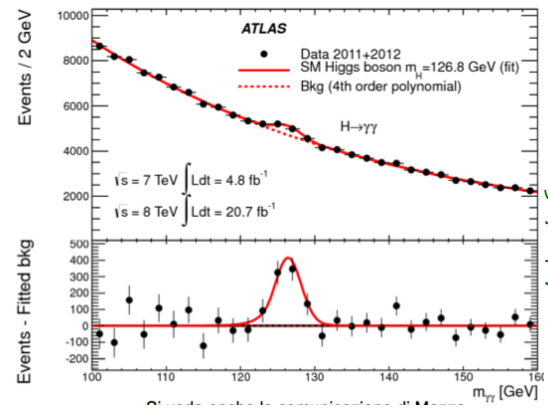
CONCLUSIONS

- **LHC RUN1 di LHC was a success of the machine, of the experiments and … of physics!**





arXiv:1307.1427



arXiv:1307.1427

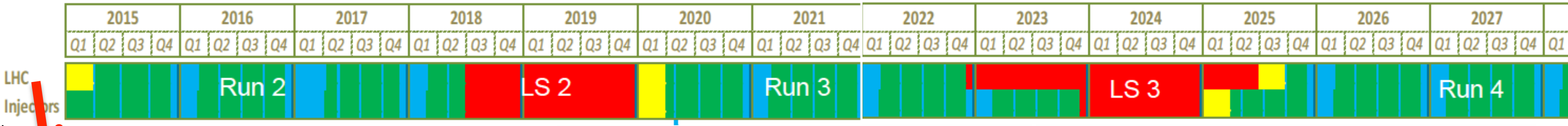
- **Today the european priority in the field of particle physics is to fully exploit the LHC potential, including the upgrade for high luminosity (HL-LHC)**

- HL-LHC ATLAS Upgrades (LongShutdown3 2023/2025) : New Tracker + TrigDAQ + electronics for Calorimeters and Muon System – New Muon detectors – extension to large η (ITK and Muon tag) under consideration

→ R&D for Phase-2 in all areas: Advanced for ITK (sensors, FE elx), Calo (r/o elx, power system), Muons (RPC and FE elx) and TDAQ (evolution of FTK, …)

BACKUP

ATLAS PHASE-0 UPGRADE (2013-2014)



"Phase-0" upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
$\mathcal{L}_{inst} \simeq 1 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 27.5$)
$\int \mathcal{L}_{inst} \simeq 50\ fb^{-1}$

FASE-0

- New Insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation of detector elements (e.g. calorimeter power supplies)
- Add specific neutron shielding
- Finish installation of EE muon chambers staged in 2003
- Upgrade magnet cryogenics

Phase-0 UPGRADE

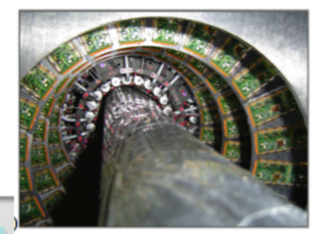
- Besides activities of "consolidation" of the detector, TWO main "upgrade":

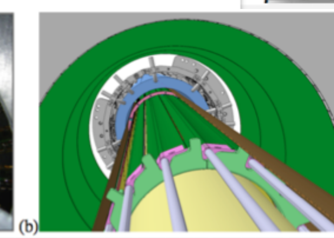
  → Completion of MDT EE (Endcap-Extension) installation in the region $1.0<\eta<1.3$

  → PIXEL: Insertable B-Layer

Insertable B-Layer: A new layer of pixel between the innermost layer of the pixel detector and the beam-pipe

- **New Beam-pipe (Beryllium) reduced radius: 29mm → 25mm**
- Smaller pixels: 50x400 μm → 50x250 μm
- Planar e 3D sensors
- New read-out chip (FE-I4)





Main motivations

- Compensate expected reduction of B-Layer efficiency caused by radiation
- Improve tracking, vertex resolution, b-tagging, reconstruction of τ

Light jet rejection in $t\bar{t}$ events for 60% b efficiency as a function of the average number of pileup