The ATLAS Upgrade Program

-Zvi Citron for ATLAS
HL-LHC Schedule

LHC / HL-LHC Plan

LHC

Run 1
Run 2
Run 3
Run 4 - 5...

LS1

13 TeV


splice consolidation button collimators R2E project

75% nominal Lumi

30 fb⁻¹

nominal Lumi

130 fb⁻¹

EYETS

cryoimist interaction regions

140 fb⁻¹

LS2

13 - 14 TeV

2019 2020 2021 2022 2023 2024

Diodes Consolidation LIU Installation Civil Eng. P1-P5

inner triplet radiation limit

2 x nominal Lumi

350 fb⁻¹

LS3

14 TeV

2027 2028 2029 2030 2031

HL-LHC installation

5 to 7.5 x nominal Lumi

3000 fb⁻¹

4000 fb⁻¹

HL-LHC TECHNICAL EQUIPMENT:

DESIGN STUDY

PROTOTYPES

INSTALLATION & COMM.

PbPb:~7 nb⁻¹

pPb:~0.5 pb⁻¹

OO:~0.5 nb⁻¹

Already pushed back ...

ATLAS - CMS HL upgrade

ALICE - LHCb upgrade

ATLAS - CMS

upgrade phase 3

HiLumi LHC

At the Large Hadron Collider

2027

2040

PbPb:~7 nb⁻¹

pPb:~0.5 pb⁻¹

OO, other:?
**ATLAS HL-LHC Upgrades**

**New Muon Chambers**
- Inner barrel region with new RPCs, sMDTs, and TGCs
- Improved trigger efficiency/momentum resolution, reduced fake rate

**New Inner Tracking Detector (ITk)**
- All silicon with at least 9 layers up to $|\eta| = 4$
- Less material, finer segmentation

**Upgraded Trigger and Data Acquisition System**
- Single Level Trigger with 1 MHz output
- Improved 10 kHz Event Farm

**Electronics Upgrades**
- On-detector/off-detector electronics upgrades of LAr Calorimeter, Tile Calorimeter & Muon Detectors
- 40 MHz continuous readout with finer segmentation to trigger

**High Granularity Timing Detector (HGTD)**
- Precision time recon. (30 ps) with Low-Gain Avalanche Detectors (LGAD)
- Improved pile-up separation and bunch-by-bunch luminosity

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**Zvi Citron**

Quark Matter – 6 April 2022
This section presents the design of the ZDC in Run 4 and the studies carried out as basis for the specific choices made for it. The primary features of the design have been finalized. However, in several cases more R&D is required before final design decisions can be made.

In this document, a right-handed reference system will be used, with the $z$ axis along the beam-line and the $x$ axis parallel to the tunnel floor and pointing to the center of the LHC.

3.1 TAXN absorber area

During heavy ion operation in LHC Runs 1-3, the ZDC is installed inside the Target Absorbers for Neutrals (TAN). This absorber is designed to protect the nearby superconducting magnets from the forward neutral radiation coming out from the interaction region. The TAN is located at $\pm 140$ m from the interaction point, at the place where the long straight-section of the beam-pipe branches back into two independent beam-pipes (see Fig. 8). For this reason, this is the only possible location to measure forward-going neutral particles that are produced in $A+A$, $p+A$, or $pp$ collisions. During LS3, the TANs will be moved 13 meters closer to the ATLAS IPs, and upgraded to cope with the increase in the number of collisions and integrated luminosity per year planned for the HL LHC. All the details about the design of the new absorber, the TAXN, are discussed in Chap. 5.

Based on the experience gained with the Run 2 ZDC, the design of the Run 4 ZDCs for ATLAS and CMS has been optimized to accomplish the integration of the detector with the TAXN.

The TAXN design has been coordinated through collaboration with the members of HL-LHC Work Package 8 (WP8 “Collider-Experiment Interface”), with the goal to accommodate all requests from the different stakeholders in its design: machine, ZDC, BRAN, and the transport group (see Sec. 7.6 for details). The envelope for the available space inside the TAXN reserved for the ZDC is shown in Fig. 9. The floor of this region is located 110 mm below the center of the two beam pipes.

In addition to the geometrical constraints from the available space in the TAXN slot, several other factors have been examined and taken into account when designing the Run 4 ZDC:
ATLAS Run 3 Upgrades

New Muon Chambers
• New Small wheels Installed!

TDAQ Upgrades
• Many upgrades for Run 3 on the way to HL-LHC
• L1 and HLT improvements

LAr Calorimeter Upgrades
• Segmented Super Cells replace coarse trigger towers
• Shower shape discrimination at trigger level

Beam splash from 2021!

Zvi Citron
יואל בנגי סיפר
אוניברסיטת ניוניב

Zero Degree Calorimeters in ATLAS

- Located at ± 140 m from IP in Target Absorber for Neutrals, ZDC measure spectator neutrons from AA collisions
- Crucial for triggering in HI collisions
- Crucial for event selection, especially UPC
- High radiation environment
- Limited space and far away

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What’s New For ZDC Run 3 - Instrumentation

• Run 1/2 ZDC used quartz rods for Cherenkov photons

• Suffered from severe instantaneous and integrated luminosity dependent light output due to **radiation damage** of the quartz rods
  • Run 2 Pb+Pb totalled ~ 10 MRad
  • Even run to run, O(hr), damage required PMT gain adjustments.

• Involved R&D to find better option than quartz
  • Valuable input from BRAN detector experience!

• Quartz rods replaced with radiation hard(er) fused silica rods
  • Run 3 anticipate ~130MRad
  • Expected to be robust to ~hundreds of MRad
What’s New For ZDC Run 3 - TDAQ

• All digital **readout** & trigger implemented with LUCROD board
  • 16 Channels: Analog inputs → Flash ADC → FPGA
  • On board baseline subtraction, pulse detection, signal summing
  • Trigger decisions – Multiple thresholds across both ZDC sides
• Improvement in cabling improves pile-up handling
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![Graphs showing Flash ADC value vs Time for HAD1, HAD2, and HAD3](image)
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ATLAS Preliminary  
pp 2021, 900 GeV, 0.8 nb⁻¹  
ZDC triggered events

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HAD1 Offline ADC_max  
Counts / (8×8)

HAD2 Offline ADC_max  
Counts / (8×8)

HAD3 Offline ADC_max  
Counts / (8×8)
What’s New For ZDC Run 3 – RPD

• Reaction Plane Detector measures transverse position of spectator neutrons

• Novel design with radiation hard fibers of varying lengths grouped into virtual tiles
RPD Performance Estimates

- Primary RPD use case is for determining reaction plane
- Quantify correction as
  \[ \langle \cos[k(\psi_0^{Sub} - \psi_0^{Truth})] \rangle = \sqrt{\langle \cos[k(\psi_0^A - \psi_0^C)] \rangle}, \]
  where \( k=1 \) (directed flow) and A&C are opposite side RPDs
- Prototype has been constructed and tested in beam, final detector being prepared for shipment to CERN
ATLAS ZDC → JZCaP HL-ZDC

• New detector for HL-LHC
  • The Joint Zdc Calorimeter Project (JZCaP) is a combined ATLAS-CMS effort to develop an improved ZDC
    • Currently joint R&D and design
    • “HL-ZDC” proposed for both experiments for HL-LHC
  • Accommodates Run 4 beam optics
    • TAN → TAXN at ± 127 m from IP (13 m closer)
    • Monolithic design (previously separate modules)
    • Narrower x-profile: 4.6 cm (previously twice as wide)
      • Energy containment remains comparable due to z length
  • Continues from Run 3 R&D
    • Radiation hardness
    • Light collection
    • TDAQ capabilities
    • Transverse measurement capabilities
ATLAS ZDC ➔ JZCaP HL-ZDC

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See S. Shenkar's poster on EM Module
New Inner Tracker (ITk) for HL-LHC

• New all-silicon inner tracker
• Extends $\eta$ acceptance to $\pm 4$ (from 2.5)
  • Improves flow measurements (where increased statistics of HL-LHC is less important)
New High Granularity Timing Detector (HGTD)

- Complements new ITk with timing information in 2.5<|\eta|<4
- Timing is key for pileup rejection at high multiplicity
- Replaces MBTS as baseline trigger for HI collisions
- Low Gain Avalanche Detectors
  - Next generation detectors are (almost) here

HGTD to be installed!
Summary

• Major upgrades to ATLAS for HL-LHC coming up, but fun has already started for Run-3

• ZDC are key detectors for the HI program, in ATLAS Run-3:
  • New fused silica is radiation hard(er)
  • All new digital read-out and triggering
  • New detector with transverse segmentation, RPD

• HL-ZDC will be built for ATLAS+CMS for HL-LHC

• New inner tracker (ITk) and timing detector (HGTD) crucial to HI program for HL-LHC
  • (And of course benefit from all upgrades)
Extras
THE JOINT ZERO DEGREE CALORIMETER PROJECT

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University of Maryland
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Alice Mignerey
Timothy Koeth

Quark Matter – 6 April 2022
Run 3 Installations Big and small

• Significant upgrades to the muon system
  • New small wheels installed!
• Zero Degree Calorimeter refurbished
Fused Quartz Radiation Hardness

Figure 28: Transmission of BRAN rods measured longitudinally. The uncertainty on each curve, not displayed for visualization sake, was estimated to be 5%.

Figure 29: Transmission of BRAN rods measured transversely at 240nm and correlated to dose given by FLUKA. The uncertainties on the dose values are obtained directly from FLUKA simulations.
Summed ZDC Trigger in Pilot Beams

**Graph**

- **Graph Title**: ATLAS Preliminary
- **Description**: pp 2021, 900 GeV, 0.8 nb^{-1}
- **Data**: ZDC triggered events
- **X-axis**: Offline $\Sigma ADC_{max}$
- **Y-axis**: Trigger $\Sigma ADC_{max}$
- **Legend**: Counts / (8x8)
- **Color Scale**: 1 to $10^3$

**Quark Matter – 6 April 2022**
HL-ZDC Performance

Figure of merit vs $\lambda_{\text{int}}$: Run 3 vs Run 4

![Graph showing figure of merit vs $\lambda_{\text{int}}$.]
RPD Beam Test

JZCaP HL-ZDC TestBeam 2021
Ongoing Analysis
PF-RPD Prototype

Counts/(5 [mV])

Σ PF-RPD Amplitudes [mV]

- e⁻ @ 200.0 GeV
- e⁻ @ 150.0 GeV
- e⁻ @ 100.0 GeV
- p @ 350.0 GeV