The CMS Outer Tracker Upgrade for the High Luminosity LHC

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Toward the HL-LHC Upgrade

LHC / HL-LHC Plan

Run 1 | Run 2 | Run 3 | Run 4 - 5...
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7 TeV | 8 TeV | 13 TeV | 14 TeV

- **LS1**
  - splice consolidation
  - button collimators
  - R2E project
- **EYETS**
- **LS2**
  - injector upgrade
  - Cryo RF P4
  - P7 11 T dip. coll.
  - Civil Eng, P1-P6
- **ALICE - LHCb upgrade**
- **HL-LHC installation**

- **ATLAS - CMS upgrade phase 1**
- **ATLAS - CMS upgrade phase 2**

- 75% nominal luminosity
- 2 x nominal luminosity
- 2.5 x nominal luminosity
- Radiation damage
- Cryo limit interaction regions

- 30 fb⁻¹
- 150 fb⁻¹
- 300 fb⁻¹
- 3000 fb⁻¹

⟨Pile-up⟩ ~ 20
⟨Pile-up⟩ ~ 40-50
⟨Pile-up⟩ ~ 140-200
The $p_T$-module concept

Thanks to its 3.8T magnetic field, CMS capable of selecting tracks with $p_T>1$ at L1-trigger.

Stubs processed in the back-end electronics to build L1 track primitives at 40 MHz.

The CMS HL-LHC outer tracker will be equipped with two $p_T$ module versions

- **PS** (pixel + strip) modules $r < 60$ cm
- **2S** (strip + strip) modules $r > 60$ cm.
PS and 2S Modules

**PS modules: Macro Pixel + Strip**
- Macro Pixel: 1.5 mm × 100 μm
- Strip: 2.4 cm × 100 μm
- Module area: ~5 × 10 cm²

**2S modules: Strip + Strip**
- Strip: 5 cm × 90 μm (both sides)
- Module area: ~10 × 10 cm²
Status of the upgrade - PS prototypes

First MPA prototypes produced and mini-pixel-modules (3x2) MPAs assembled and their functionalities tested on beam.

- Two MPAs stacked to validate the stubs.
- Track $p_T$ simulated by tilting the module with respect to the beam.

Efficiency vs clock delay in agreement with the simulations.
Status of the upgrade - 2S prototypes

- Mini-modules equipped with two CBCs and two small strip sensors stacked.
- Various beam test campaigns before and after irradiation carried out.
- Efficiency and resolution in agreement with the expectations.

Efficiency > 99%
Status of the upgrade - 2S prototypes

- $p_T$ cut is tuned by varying the matching window size.
- Prototype irradiated to $6 \times 10^{14} \text{n}_{\text{eq}}/\text{cm}^2$, twice the expected fluence for the full HL-LHC data taking.

After irradiation the efficiency is still very high and the threshold in $p_T$ remains steep.

Correlation window:
- 4 strips
- 5 strips
- 6 strips

Rotation Angle:
- $24.0^\circ$
- $15.8^\circ$
- $11.8^\circ$
- $9.4^\circ$
- $7.8^\circ$
Status of the upgrade - 2S prototypes

- The mechanical aspect of large complexity, critical detector handling and assembly alignment.
- Full modules assembled in the various production centers to validate the procedures and gaining experience.
- Prototypes tested in laboratory and with beam showed good results.

Specs noise = 1000 e⁻

Average efficiency > 97 %
Conclusions

• The LHC will be upgraded in 2024 for the High-Luminosity data taking with great opportunities for physics but harsh challenges for the experiments.

• The CMS Outer Tracker will provide L1 tracking capabilities thanks to the $p_T$-modules.

• First MPA mini-modules (the “P” of PS) showed results compatible with the specs.

• 2S mini-modules showed excellent results in terms of efficiency, resolution and stub building functionalities.

• Full 2S modules assembled to validate the procedures with good results.

• Getting ready for pre-production!
  – Construction of 2250 modules plus 5% pre-production and 10% spare modules at Sidet
  – Design, module fabrication, and assembly of the Flat Barrel at Sidet
  – Construction of all macro-pixel-assemblies or MaPSAs
Backup - Tracker layout for HL-LHC

Phase 1 tracker

Phase 2 tracker
Expected performances