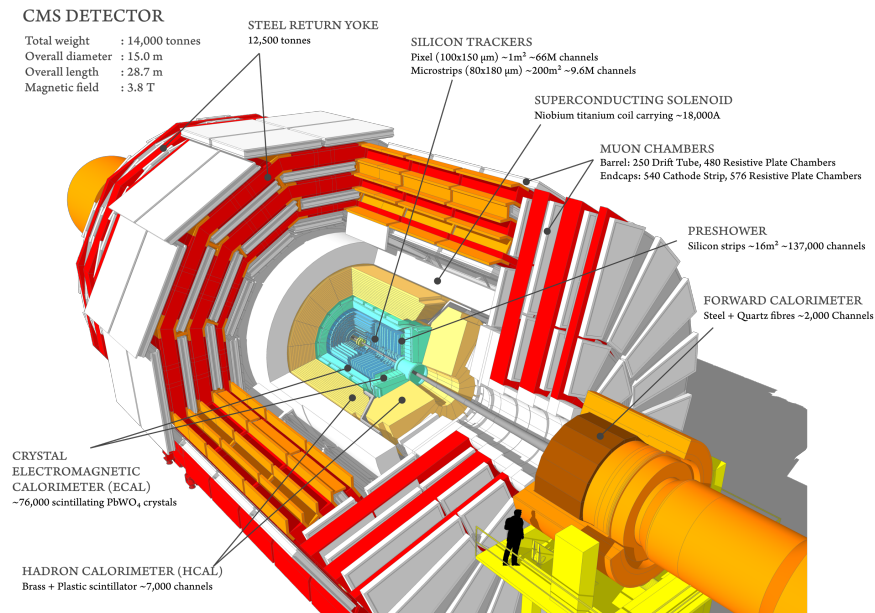# Development of the CMS Phase2 Outer Tracker Analyzer Of Test Outputs (POTATO) software

Matteo Marchisio Caprioglio

Italian Summer Students Midterm Reports 2024

22 August 2024

The CMS Experiment @ CERN

CMS DETECTOR
Total weight   : 14,000 tonnes
Overall diameter : 15.0 m
Overall length   : 28.7 m
Magnetic field   : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 µm) ~1m² ~66M channels
Microstrips (80x180 µm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
~76,000 scintillating PbWO$_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

General purpose detector looking for new physics, made of several layers:

- Layer "zero": pixel detectors (vertex)
- Layer 1: silicon tracker (inner&outer) -> no trigger
- Layer 2: ECAL -> L1 trigger
- Layer 3: HCAL -> L1 trigger
- Layer 4: superconducting magnet
- Layer 5: muon detectors -> L1 trigger

🔷 Fermilab

The High-Luminosity LHC upgrade

During Long Shutdown 2 the LHC will be upgraded with the High Luminosity project, which will increase its instantaneous luminosity to $\sim 7.5 \times 10^{34}$ cm^{-2} s^{-1}, requiring an extensive program of upgrades to all of the collider experiments, including CMS.
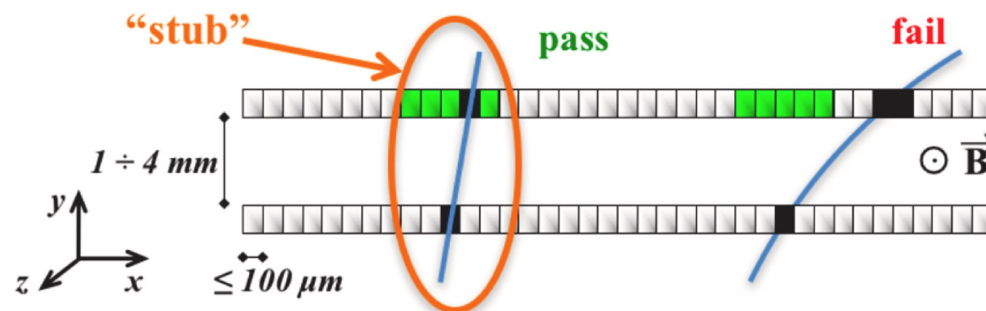
New operating conditions include:

- High radiation levels
- Pileup of many interactions (140-200 p-p collisions per bunch crossing)
    -> necessity of augmented granularity
- High data throughput
    -> necessity of data reduction to look for "interesting" events
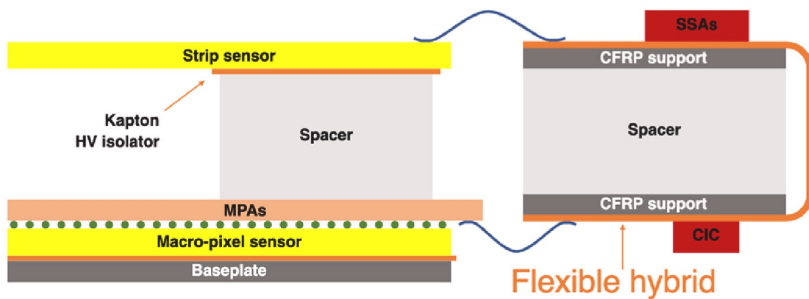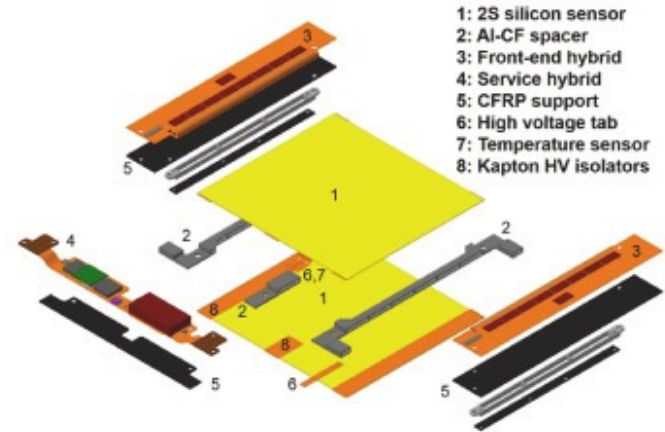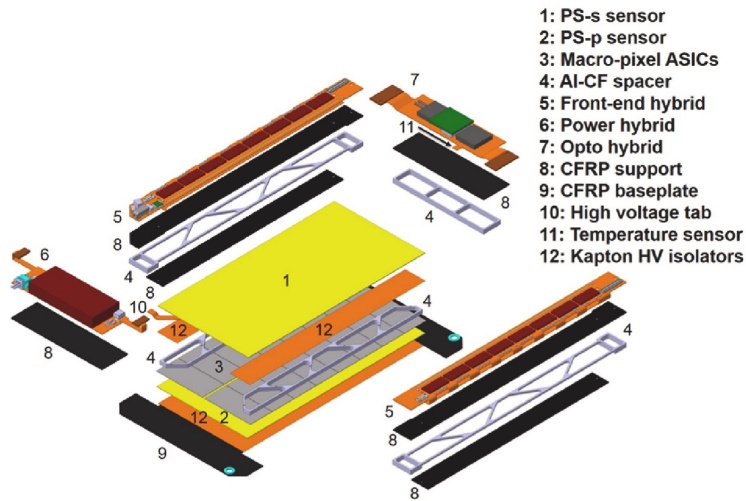   -> new L1 trigger inputs to maintain reconstruction capability

The Phase2 Outer Tracker Upgrade tackles all of these requirements.

🟦 **Fermilab**

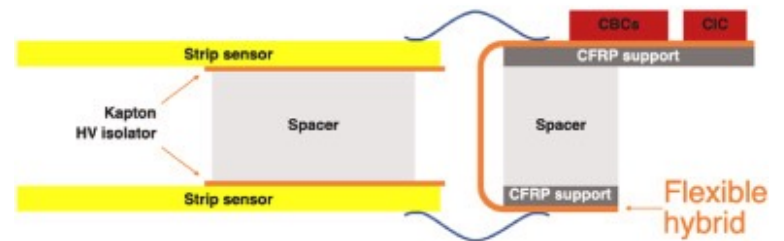# The CMS Phase 2 Outer Tracker Upgrade – Overview

- Good radiation hardness
- High granularity
- L1 trigger input with the "p_T modules" method: a signal ("stub") is produced when a particle hits the second detector layer within a certain window
  - selection of high p_T particles
  - formation of short tracks to be used together with calorimeter and muon info for L1
- Improved jet p_T resolution at trigger level
- Reduced material budget
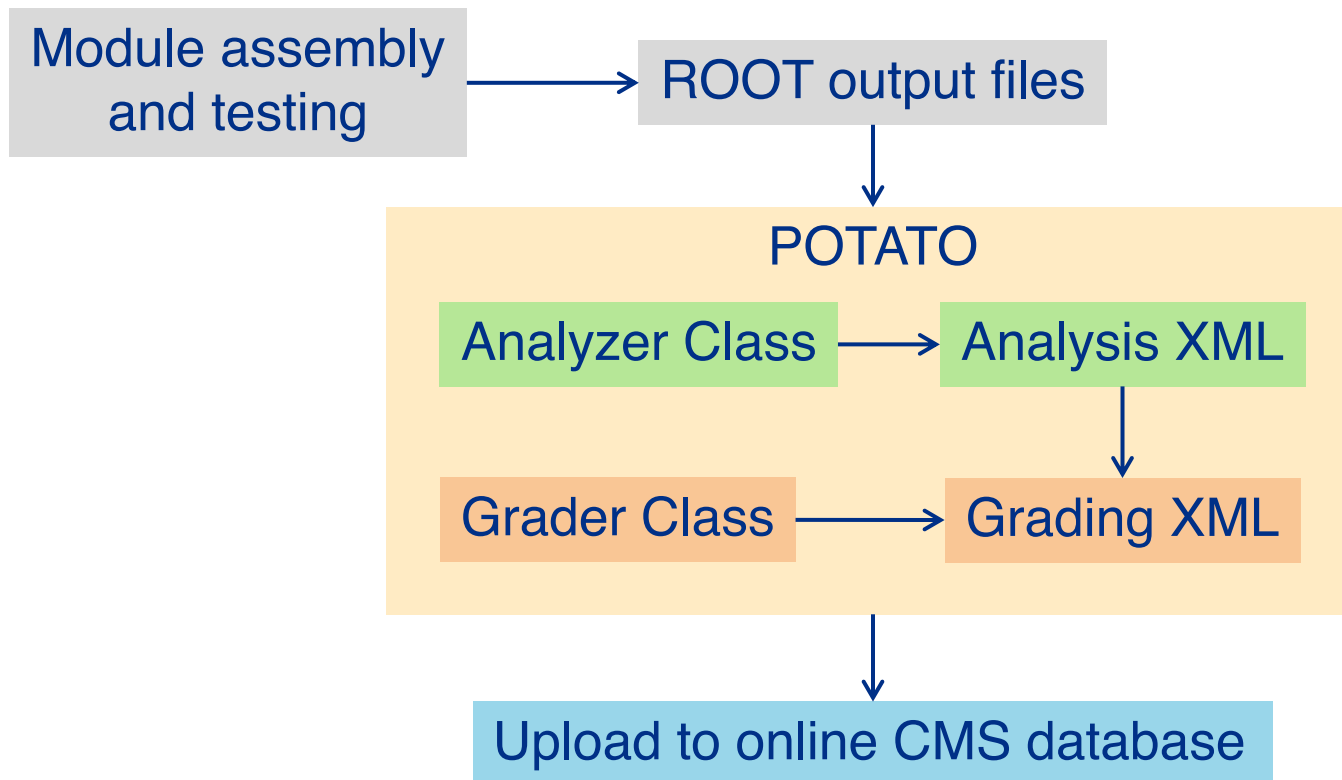
The CMS Phase 2 Outer Tracker Upgrade – Modules

1: PS-s sensor
2: PS-p sensor
3: Macro-pixel ASICs
4: Al-CF spacer
5: Front-end hybrid
6: Power hybrid
7: Opto hybrid
8: CFRP support
9: CFRP baseplate
10: High voltage tab
11: Temperature sensor
12: Kapton HV isolators

1: 2S silicon sensor
2: Al-CF spacer
3: Front-end hybrid
4: Service hybrid
5: CFRP support
6: High voltage tab
7: Temperature sensor
8: Kapton HV isolators

PS (pixel-strip) Module
Near the beam line (higher granularity)

2S (strip-strip) Module
Far from the beam line (lesser granularity)

Fermilab

Phase2 Outer Tracker Analyzer Of Test Outputs (POTATO) – Overview

- Meant to be used worldwide for Outer Tracker modules analysis and grading during production (the Outer Tracker cannot be easily disassembled)

- Built in C++, QT and ROOT, capable of uploading results to online CMS database

```
Module assembly
and testing          ──►   ROOT output files
                                   │
                                   ▼
                              POTATO
         Analyzer Class  ──►  Analysis XML
                                   │
                                   ▼
         Grader Class    ──►  Grading XML
                                   │
                                   ▼
         Upload to online CMS database
```

🔅 Fermilab

POTATO Software – My Work

- Reimplementation in OOP approach of grading procedure (generic Grader class with specific Grader2S and GraderPS inherited classes)

- Help in adding new ROOT histograms to the analysis procedure and thus new fields to the grading procedure

- Versioning system implementation and improvement for grading procedure (mismatch between local XML documents and online CMS database):

  - v1-00 successful upload, some XML fields not yet implemented

  - v1-0x no upload, test of new XML fields

- Code readability improvement
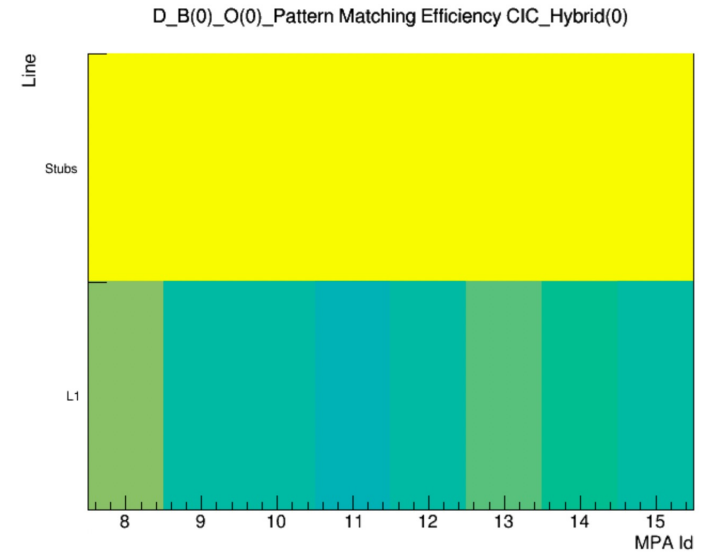
One of the histograms added

```
<VERSION>v1-01</VERSION>
<PART>
 <KIND_OF_PART>PS Module</KIND_OF_PART>
 <SERIAL_NUMBER>PS_26_FNL-00101</SERIAL_NUMBER>
</PART>
<DATA>
 <OVERALL>A</OVERALL>
 <LV_CURR_AMP>N/A</LV_CURR_AMP>
 <IV_CURR_MAMP>N/A</IV_CURR_MAMP>
 <IV_RATIO>N/A</IV_RATIO>
 <IV_BREAKDOWN>N/A</IV_BREAKDOWN>
 <HV_CURRENT_600></HV_CURRENT_600>
 <LV_POWER_CONSUMPTION></LV_POWER_CONSUMPTION>
 <NOISE_AVG>A</NOISE_AVG>
 <NOISE_RMS>A</NOISE_RMS>
 <NOISE_NOUTL_LOW>A</NOISE_NOUTL_LOW>
 <NOISE_NOUTL_HIGH>A</NOISE_NOUTL_HIGH>
 <SCURVE>N/A</SCURVE>
 <FEHR_OVERALL>A</FEHR_OVERALL>
 <FEHR_NOISE_AVG>C</FEHR_NOISE_AVG>
 <FEHR_NOISE_RMS>A</FEHR_NOISE_RMS>
```

Example of grading XML document

🔷 **Fermilab**

POTATO Software – Next Weeks

- OOP approach extension to analysis procedure (generic Analyzer class with specific Analyzer2S and AnalyzerPS inherited classes)

- Versioning system implementation and improvement for the analysis procedure in a similar way to grading procedure

- Addition of new ROOT histograms and XML fields (including temperature and humidity) to analysis and grading procedures

- Differentiation of grading procedure based on test temperature

- Request of new XML fields to be added to the online CMS database

Fermilab

Thanks for your attention!

🧬 Fermilab