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

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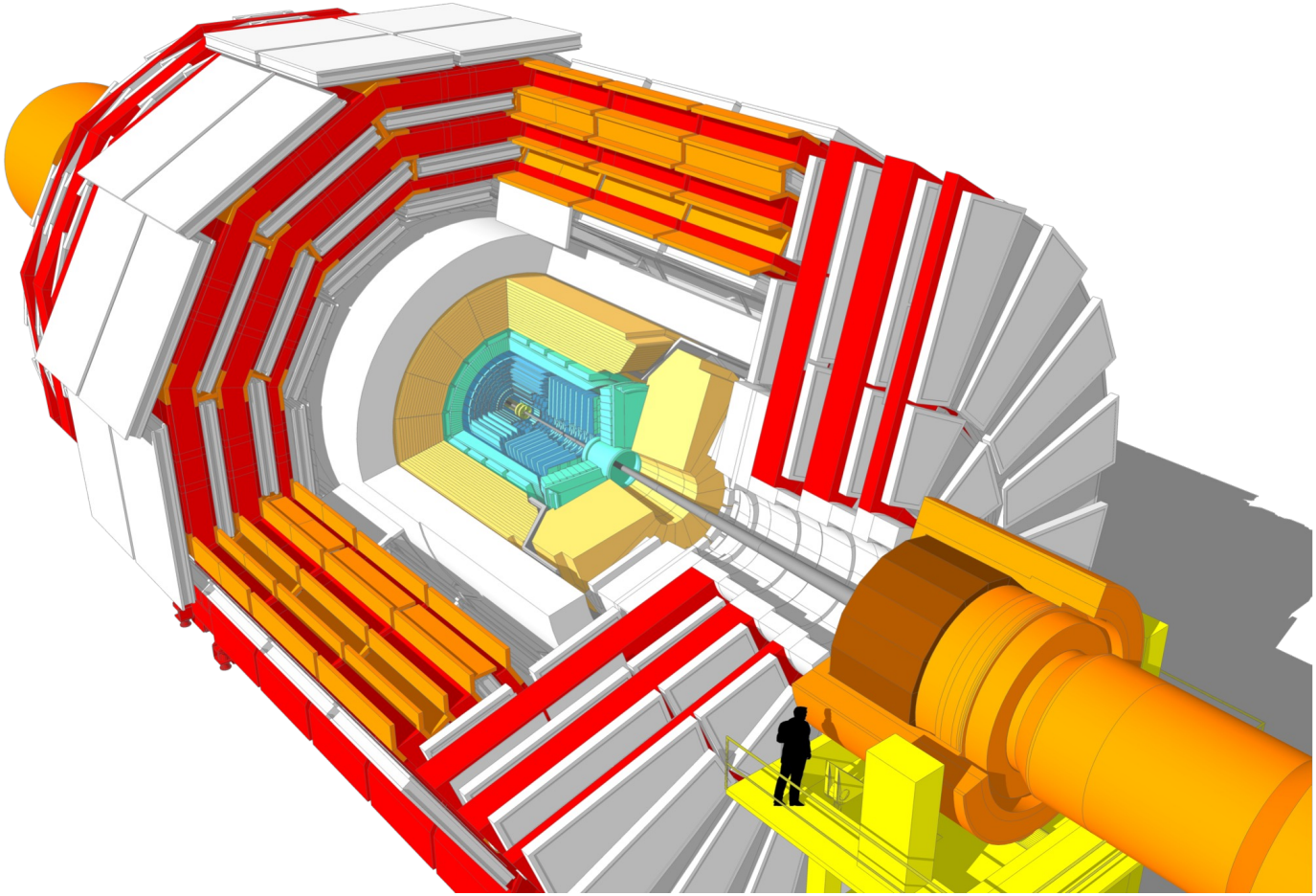
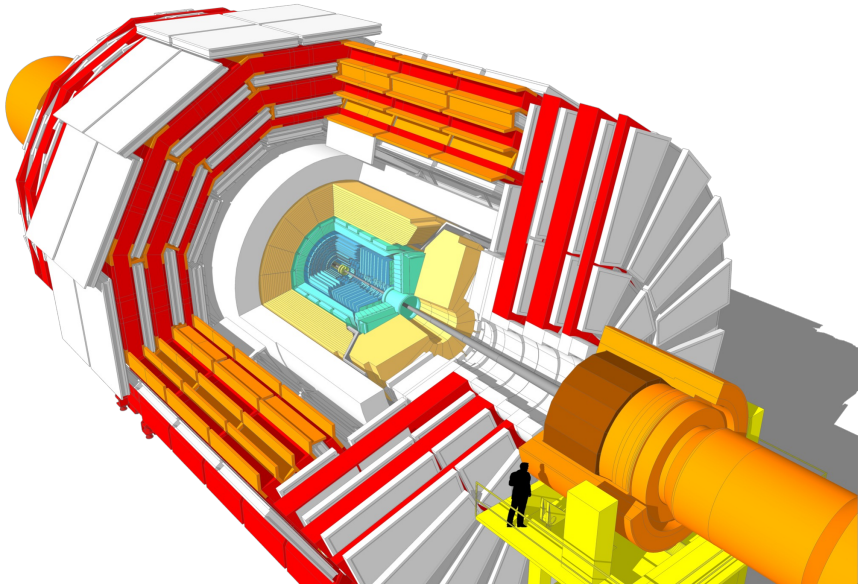
The CMS Experiment @ CERN



The CMS Experiment @ CERN



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

1. pixel detector (vertex)
2. silicon tracker (inner&outer)
   -> no trigger
3. ECAL -> L1 trigger
4. HCAL -> L1 trigger
5. (superconducting magnet)
6. muon detector -> L1 trigger

The High-Luminosity LHC Upgrade

During Long Shutdown 3 the High-Luminosity Project will be completed, increasing the LHC's instantaneous luminosity to ~7.5 × 10^{34} cm^{-2} s^{-1} (fivefold wrt the current value): all the collider experiments, including CMS, will need to be upgraded.

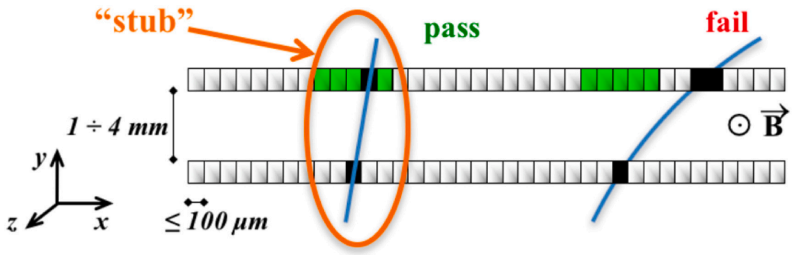
New operating conditions include:

- High radiation levels (up to a fluence of $10^{15} \div 10^{16}$ n_{eq} cm^{-2} in the inner regions)
- Pileup of many interactions (up to 200 p-p collisions per bunch crossing)
  - > necessity of augmented granularity
- High data throughput
  - > necessity of increased data reduction to look for "interesting" events for offline analysis
  - > necessity of new L1 trigger inputs to maintain reconstruction capability

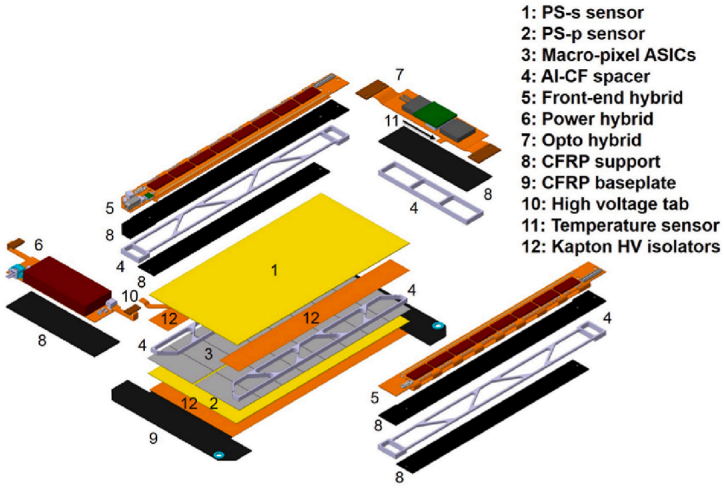
The CMS Phase 2 Outer Tracker Upgrade – Overview

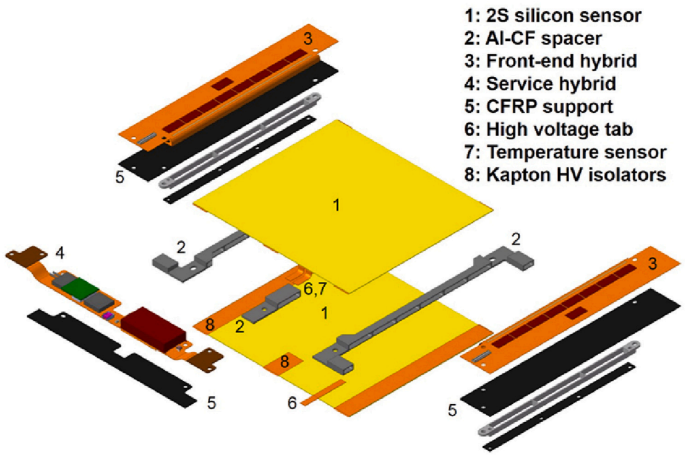
The Phase 2 Outer Tracker Upgrade tackles all of the HL-LHC requirements, and its main characteristics are the following:

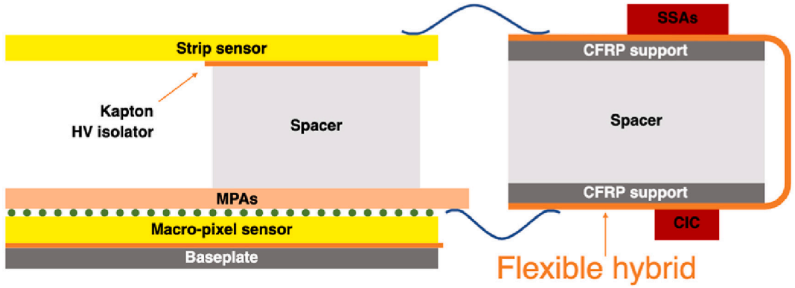
- Good radiation hardness to withstand radiation levels
- Reduced material budget wrt current setup
- High granularity
- "p_T modules" concept:
  - > a signal (called "stub") is produced when a charged particle hits the second sensor of the module within a certain (programmable) window wrt to a hit on the first sensor
  - > in the 3.8 T magnetic field present inside the CMS detector this results in a high transverse momentum (p_T) discrimination of incoming particles
  - > the stub is provided as L1 trigger input at bunch crossing rate (40 MHz) with E/HCAL and muon info
- Improved jet p_T resolution at trigger level

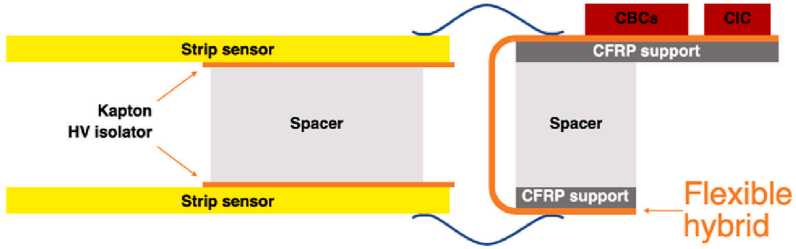


The CMS Phase 2 Outer Tracker Upgrade – Modules









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

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

Fermilab

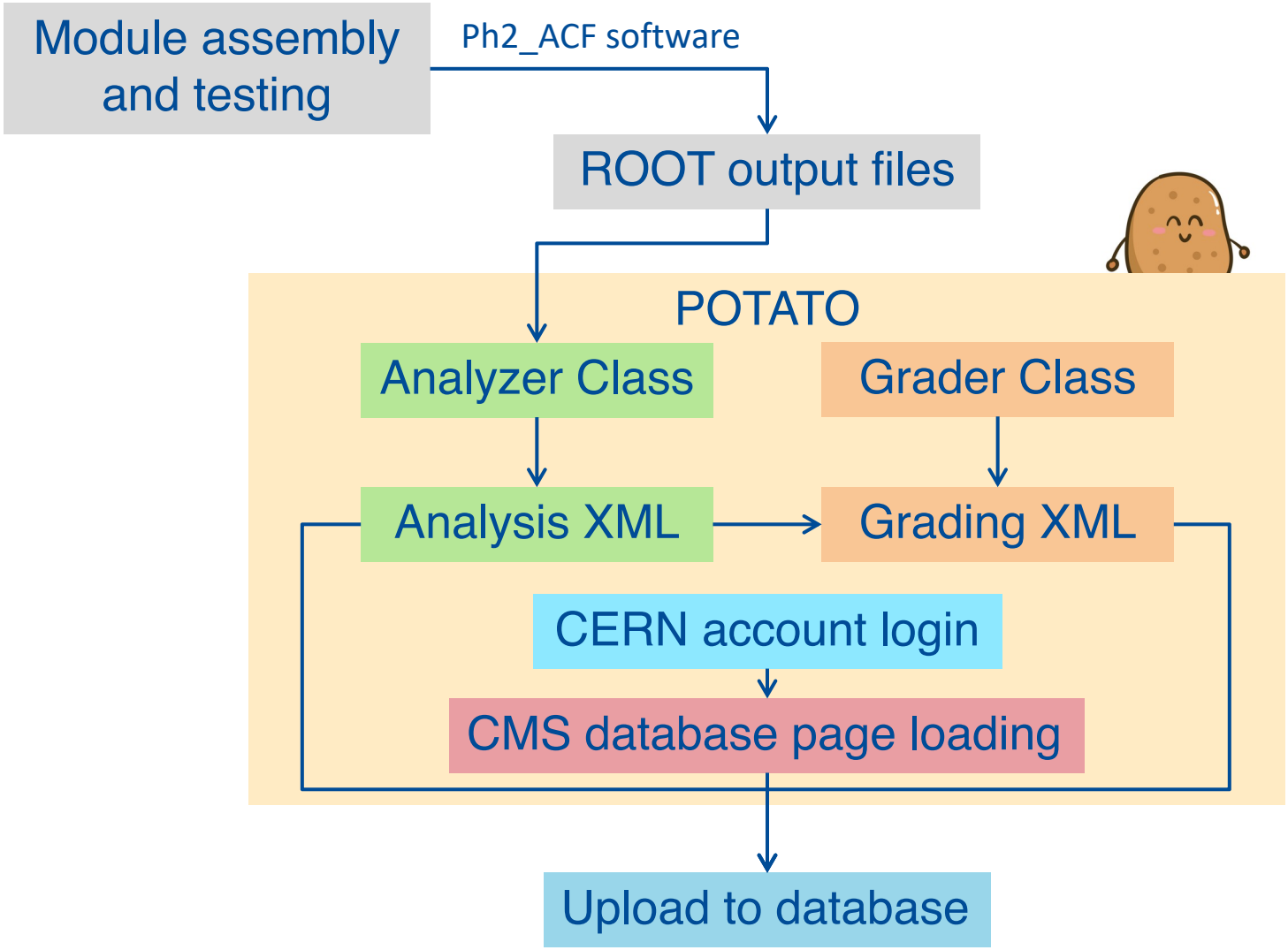
Phase2 Outer Tracker Analyzer Of Test Outputs – Overview

In many CMS institutions, including Fermilab, both 2S and PS modules will be assembled and tested to evaluate their performance before installation (the Outer Tracker cannot be disassembled), so a standardized approach is needed to analyze and grade them.

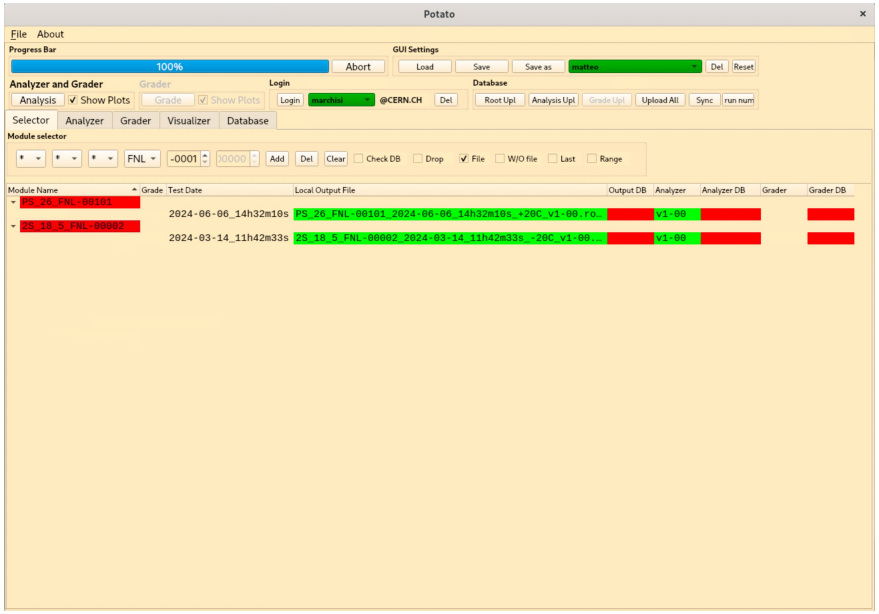
The Phase2 Outer Tracker Analyzer of Test Outputs (POTATO) software is being developed to serve this purpose:

- Meant to be used worldwide to assess module performance during production
- Built in C++, Python, ROOT and Qt
- Able to upload analysis and grading results to online CMS production database
- Easily expandable through the implementation of plugins

POTATO software – Functioning (1)



POTATO software – Functioning (2)



The POTATO GUI

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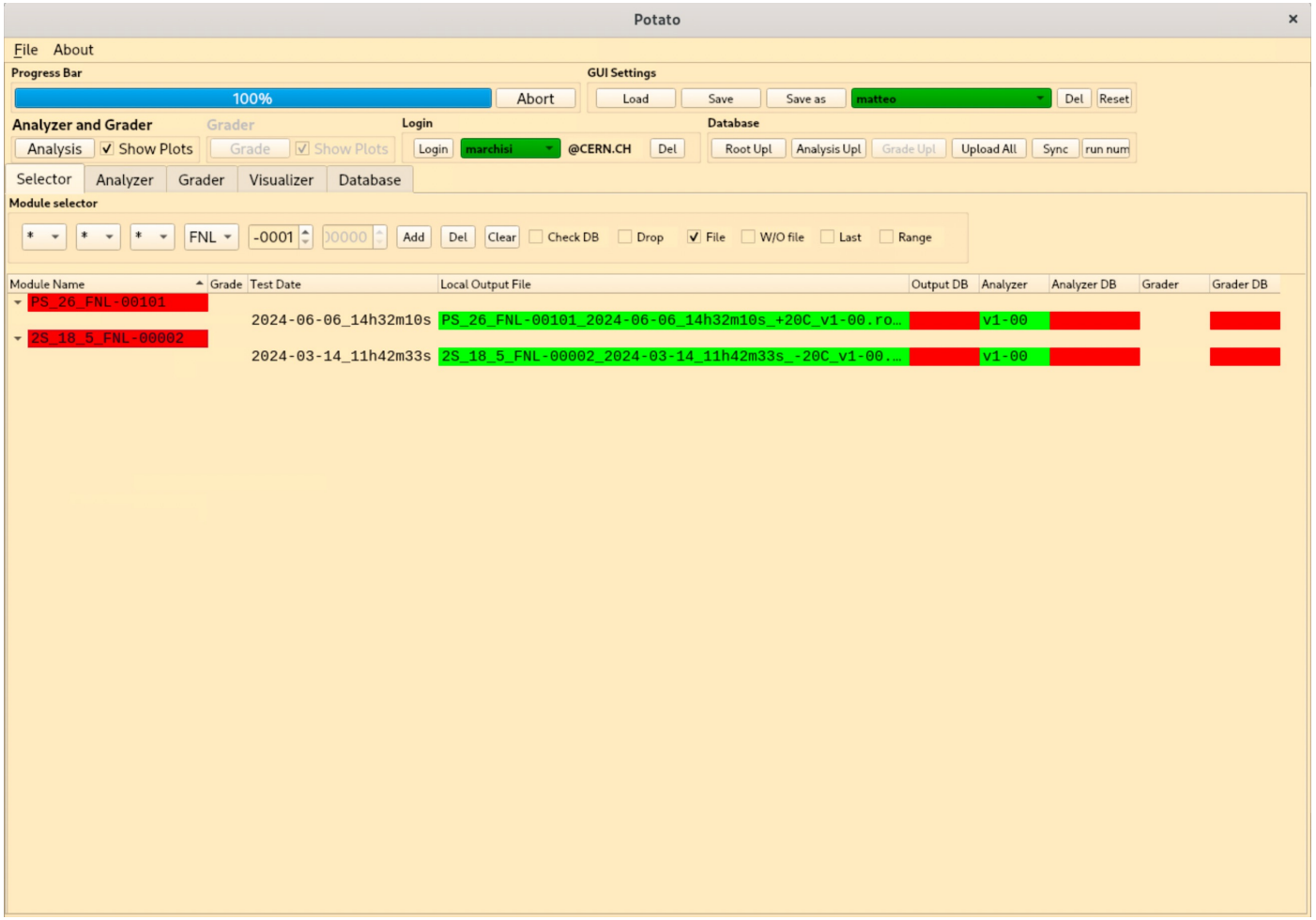
Example of Analysis XML

Fermilab

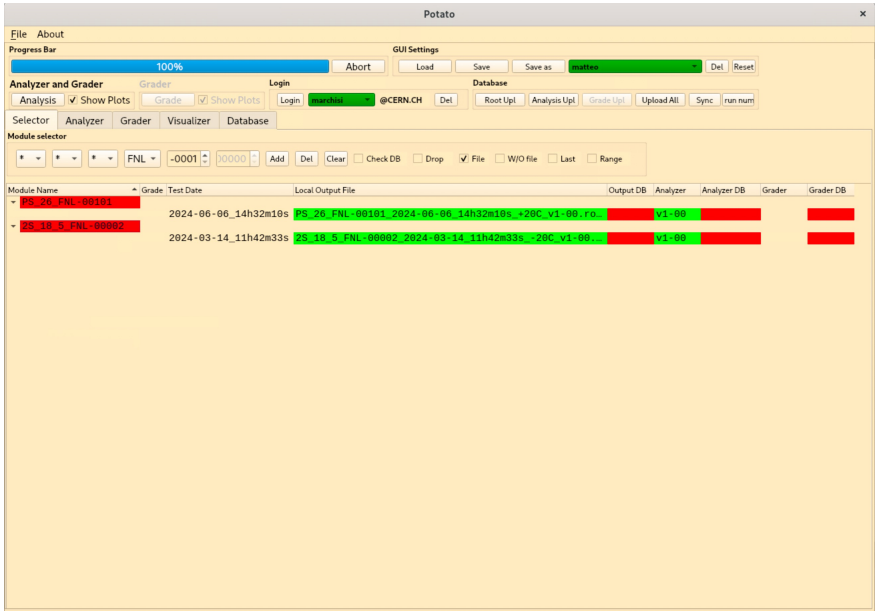
POTATO software – Functioning (2)



The POTATO GUI

Fermilab

POTATO software – Functioning (2)



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   <ALIGNMENT_FEHR_L1>1</ALIGNMENT_FEHR_L1>
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Example of Analysis XML

Fermilab

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   <ALIGNMENT_FEHR_L1>1</ALIGNMENT_FEHR_L1>
```

Example of Analysis XML

POTATO Software – My Work (1)

The main focus of my work has been on optimizing both the analysis and grading procedures by adopting an Object Oriented Programming (OOP) approach and applying it to existing and new code.

The common modifications developed for both the analysis and grading procedures are the following:

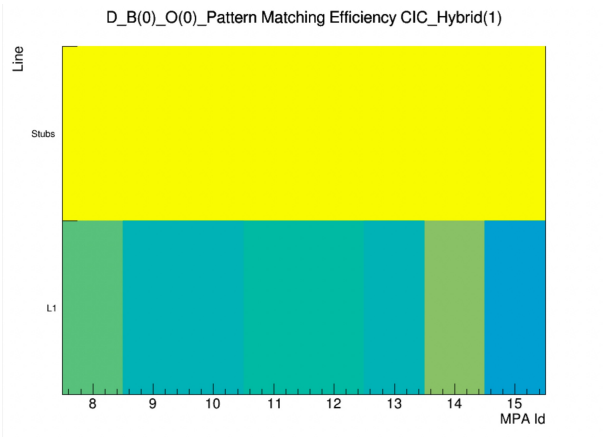
- Implementation of a base Analyzer/Grader class from which 2S or PS specific classes publicly inherit
- Complete itemization of the XML writing, with one method for each field (or group of strictly related fields):
  - Base class method if the process is the same for 2S and PS modules
  - Custom 2S/PS class method if there is a difference (from just different variables and cuts used to a completely specific process for each type of module)

POTATO Software – My Work (2)

- Implementation of a versioning system to account for mismatch between online database tables and local XML variables, for both the Analyzer and Grader classes (without it POTATO gave an error when trying to upload):
  - v1-00: XMLs created with this version can be uploaded to the database, new XML fields are simply not written in the local file
  - v1-0x: XMLs created with these versions are used to test the implementation of new fields and cannot be uploaded to the database until new fields are added
  - As of now Analyzer and Grader versions should always match
- Code readability improvement (automatic with OOP approach)
- Debugging of the CERN login process:
  - Migration to 2FA (mandatory from October 1st) broke POTATO functioning, now it only accepts accounts with single factor authentication
  - Creation of a CERN services account with single factor for Fermilab testing group, proposal to do the same for each Outer Tracker module testing site worldwide

POTATO Software – My Work (3)

I also helped adding the analysis and grading procedures for a new histogram which evaluates the pattern matching efficiency of the module under test.



Analysis

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Grade

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POTATO Software – Conclusions

During my internship at Fermilab I worked in close contact with CMS experts who greatly helped me in understanding the current stage of development and these are the main takeaways:

- POTATO is a powerful tool which will certainly help in the overall production and installation of the Phase2 Outer Tracker upgrade
- Some work still needs to be done on parts of the Analyzer classes:
  - new histograms are still being added to Ph2_ACF output files
  - not 100% OOP compliant
- The grade decisions (A, B, C, etc.) need to be fully defined and agreed upon by OT module testing sites:
  - A “missing grade” system needs to be implemented for full vs quick or old vs new tests
  - The overall module grade needs to be defined

Thanks for your attention!