CMS Experience with Adoption of the Community-supported DD4hep Toolkit

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on behalf of the CMS Collaboration

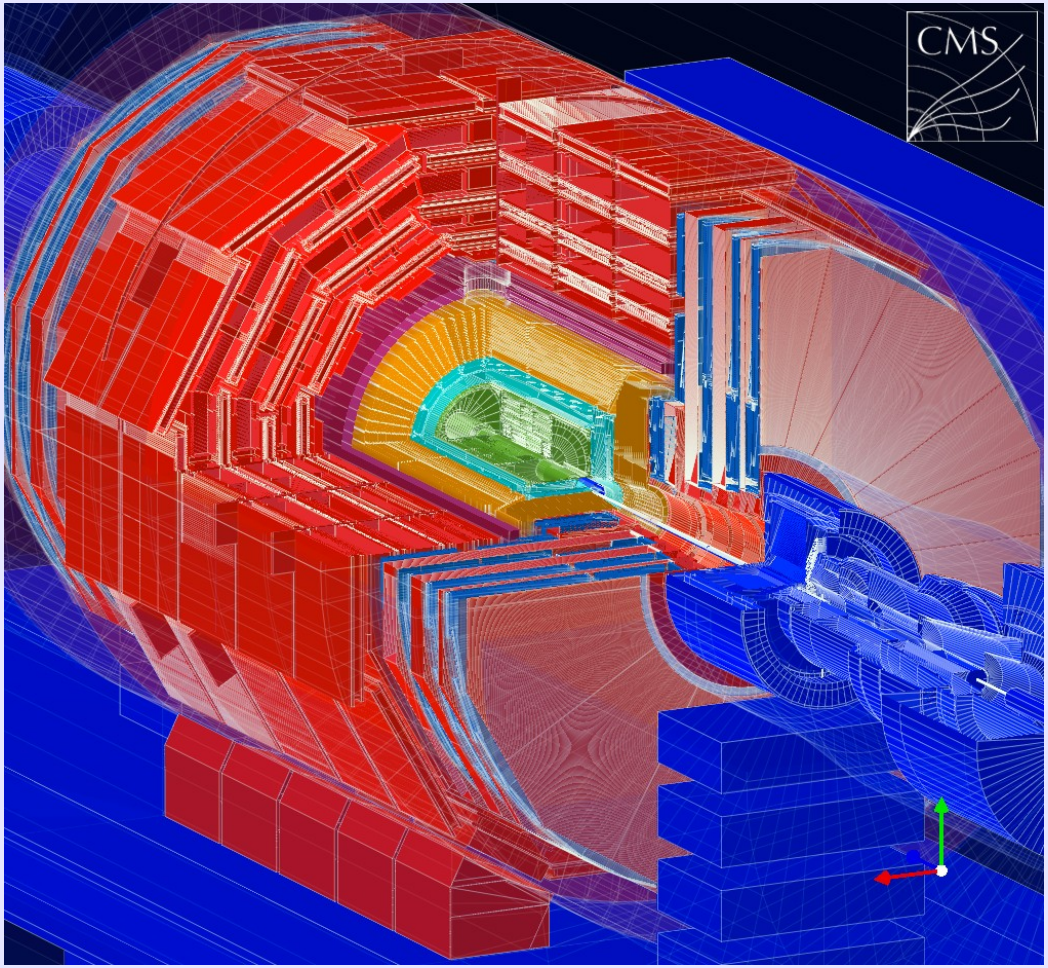
Outline

- Motivation to adopt DD4hep
- Migration process and scope
- Code migration techniques
- Migration challenges
- Good practices for migration
- Summary

Need for DD4hep

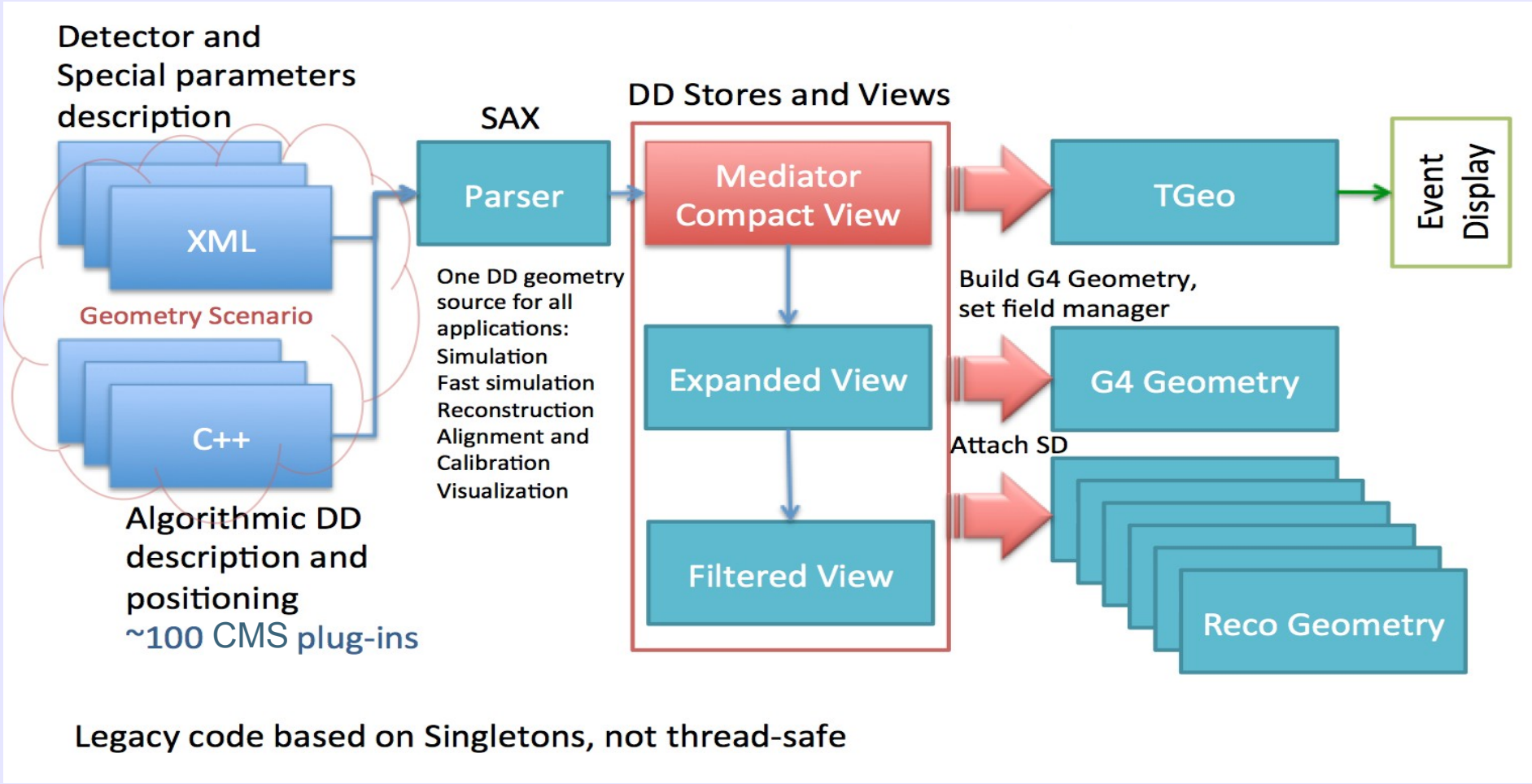
- The Compact Muon Solenoid (CMS) collaboration developed and maintained for many years its own custom detector description (DD) for detector geometry
- CMS DD disadvantages:
  - It is a singleton that doesn't support multi-threading
    - CMS software uses advanced parallelization techniques for improved performance that are blocked by singletons
      - See CMS poster “Concurrent Conditions Access across Validity Intervals in CMSSW” by Chris Jones for parallelization example
  - Old code that is costly to maintain and enhance
    - Accumulated defects and obsolete sections over many years
    - No easy path to adopt innovations and new technology

CMS Detector Geometry



2021 model built with DD4hep

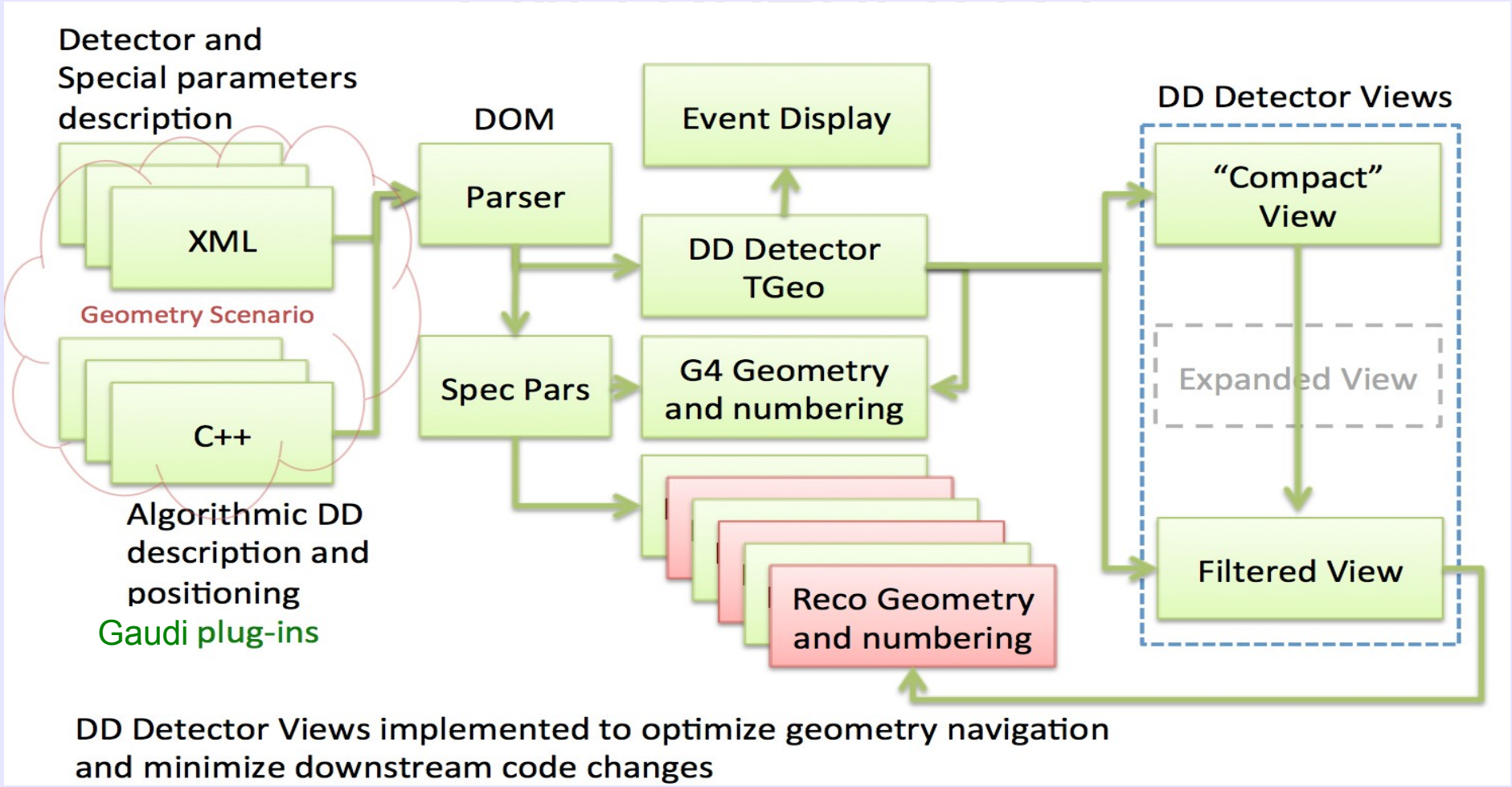
Old CMS DD


Detector and
Special parameters
description
XML
Geometry Scenario
C++
Algorithmic DD
description and
positioning
~100 CMS plug-ins
SAX
Parser
One DD geometry
source for all
applications:
Simulation
Fast simulation
Reconstruction
Alignment and
Calibration
Visualization
DD Stores and Views
Mediator
Compact View
Expanded View
Filtered View
TGeo
Event
Display
Build G4 Geometry,
set field manager
G4 Geometry
Attach SD
Reco Geometry
Legacy code based on Singletons, not thread-safe

Benefits of DD4hep

- Supports multi-threading
- Fully featured
- Community-supported toolkit
  - Widely used in HEP by CALICE, FCC, ILC, LHCb, etc.
  - Benefits from innovations and contributions from across HEP community
- Will continue to evolve with advancing technology
- Commitment for years of maintenance and enhancement
- Development based at CERN
- DD4hep team very responsive to users' needs

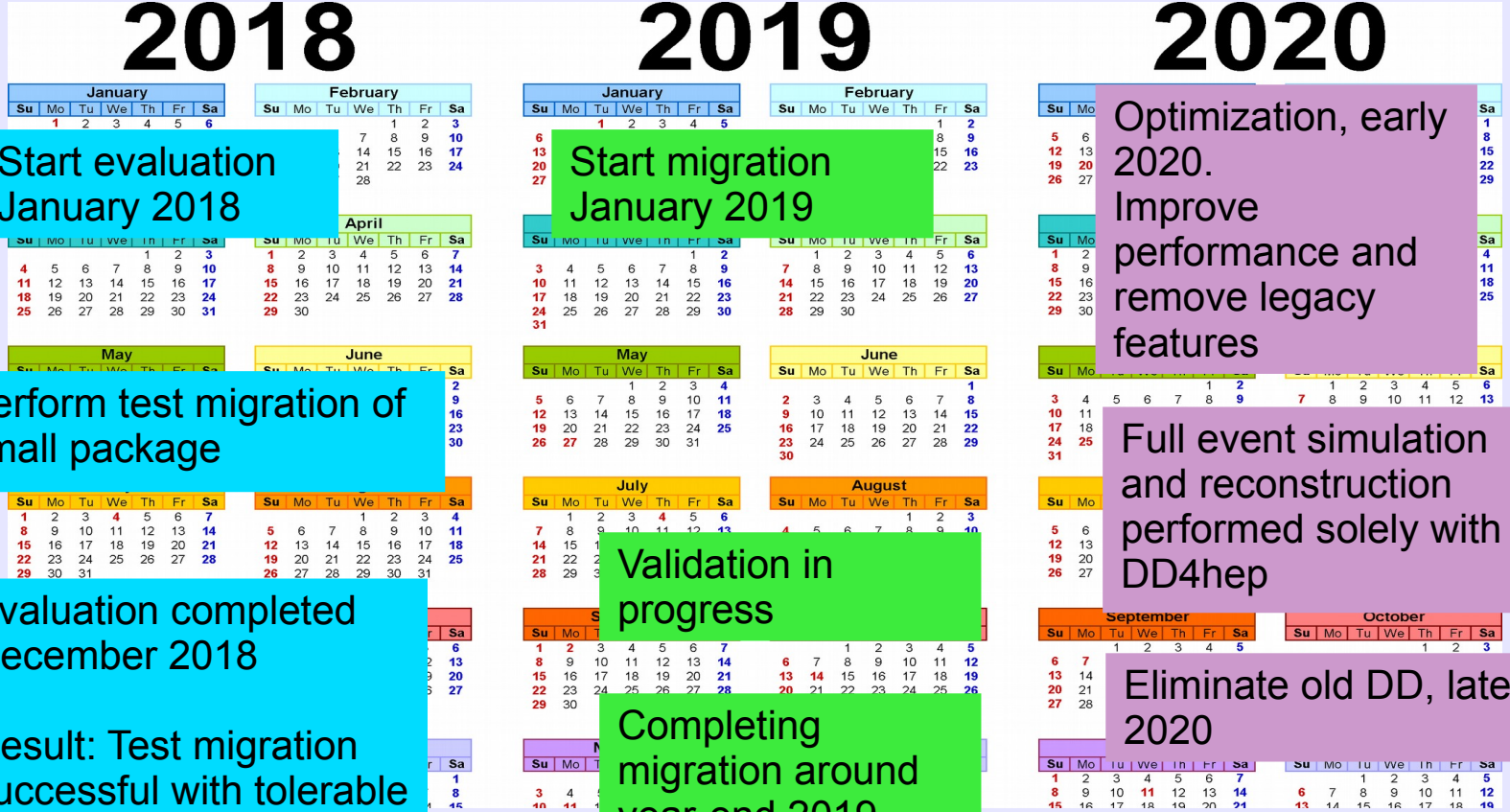
CMS Using DD4hep



Additional Benefits of Migration

- Migration provides opportunity to improve code base
  - Drop unused shapes, features, and obsolete code
  - Fix previously undetected overlaps of geometric volumes
  - Refine geometry and enhance testing and validation
- Motivates improvement of DD4hep to meet CMS requirements
- Builds expertise among developers doing migration
- Demonstrates value of community-supported software
- HEP community faces huge upcoming computing challenges like HL-LHC
  - Will need to pool efforts to meet these challenges

Migration Timeline

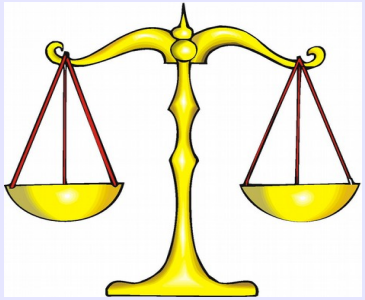


Scope of Migration

- CMSSW, the CMS software system, has about 6.5 million lines of code
  - Mostly C++ code, some Python and XML
  - Only small fraction needs to be migrated
- Detector geometry used for event simulation and reconstruction
- Roughly 150,000 lines of C++/Python code require migration
  - Several hundred files
  - Not all lines of code have to be changed, but they must at least be reviewed
  - 1.5 million lines of XML detector geometry description
    - XML requires only minor fixes, no major changes
    - 61 C++ algorithms called from XML require migration
- Half dozen developers performing migration

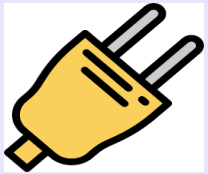
Techniques for Migrating Code

- Evaluation phase
  - Separate package for migrated code
  - Leave old code untouched
- Migration phase combines various approaches
  - Put migrated code into mainline development branch (“integration build”)
  - Parallel migrated versions of some files put in `dd4hep` directories or given names starting with `DD4hep_`
    - Python script loads desired version
  - Some sections of migrated code activated by `fromDD4hep` flag
  - Some classes templated to provide old and migrated versions
  - Try to balance:
    - Preserving old behavior for validation of migrated code
    - Minimizing code duplication



Integration of DD4hep

- DD4hep handled as external tool in CMSSW
  - DD4hep built by CMS build system
  - CMS keeps up with DD4hep releases
  - Recent issue: DD4hep revised its cmake configuration
    - Required CMSSW fix to build new version of DD4hep
- DD4hep uses Gaudi plug-in format



  - CMS has its own plug-in format
  - CMS added rule to build system to support Gaudi plug-ins
- CMSSW uses both dynamic and static libraries
  - DD4hep added support for static libraries

Migration Challenges

- DD4hep lacked seven special features required by CMS geometry code
  - These features include special shapes and use of a left-handed coordinate system
  - DD4hep team enhanced DD4hep to include these features
- CMS XML geometry files have improperly defined shapes and undefined object references
  - Fixes made or in progress
- Old, obscure code is difficult to migrate and test

Good Practices for Migration

- Perform evaluation and test migration to ensure toolkit will meet requirements
- Identify special exceptions in legacy code that will take most time to migrate
  - Assess whether special features can be dropped
  - If not, schedule sufficient resources for their migration
- Provide developers with migration examples and instructions to facilitate migration process
- Engage with toolkit developers to enhance toolkit
- Use migration as opportunity for overall software improvement

Acknowledgments

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  - Sergio Lo Meo, INFN & ENEA
  - Mircho Rodosov, Bulgarian Academy of Sciences

Summary

- DD4hep is a powerful toolkit for detector geometry
  - Fully featured
  - Committed to years of support and further innovation
  - Development team very responsive to user needs
- CMS adoption of DD4hep is a success story for community-supported software
  - DD4hep supports highly complex geometry of CMS detector
  - Migration process improved both CMS software and DD4hep itself
- Community-supported toolkits provide major benefits to HEP

Backup

Migration Challenges (1)

- TGeo used by DD4hep not thread-safe
  - ROOT fix made it thread-safe
- DD4hep required enhancement to become compatible with Geant 10.4
- Special shapes needed by CMS (cut tube, pseudo-trapezoid, and truncated tube)
  - DD4hep team added these shapes
- Incorrect polycone shapes in XML files have to be fixed
- Old, obscure code difficult to migrate and test

Migration Challenges (2)

- Reflection rotations used by CMS for sub-detectors with two mirror-image sides (left-handed coordinate system)
  - DD4hep implemented reflection rotations
- CMS uses both Geant4 and ROOT unit conventions (mm = 1 vs. cm = 1)
  - DD4hep enhanced to allow selection of units convention
- CMS DD allows reference to undefined geometric objects in XML
  - DD4hep requires all objects be defined before being referenced
  - CMS code required enhancement to safely process legacy XML files with undefined object references