Offline Data Processing Software for the Super Tau Charm Facility

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on behalf of the STCF offline software team

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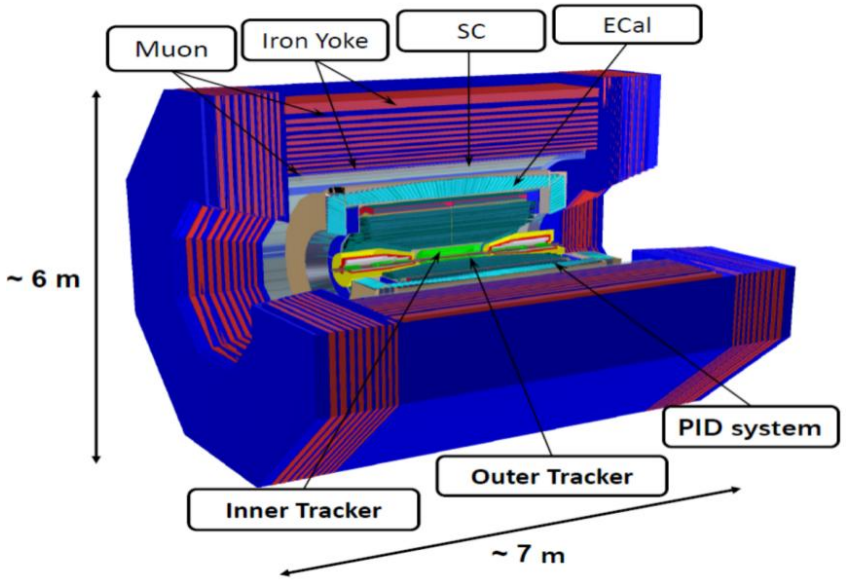
Super Tau Charm Facility (STCF)

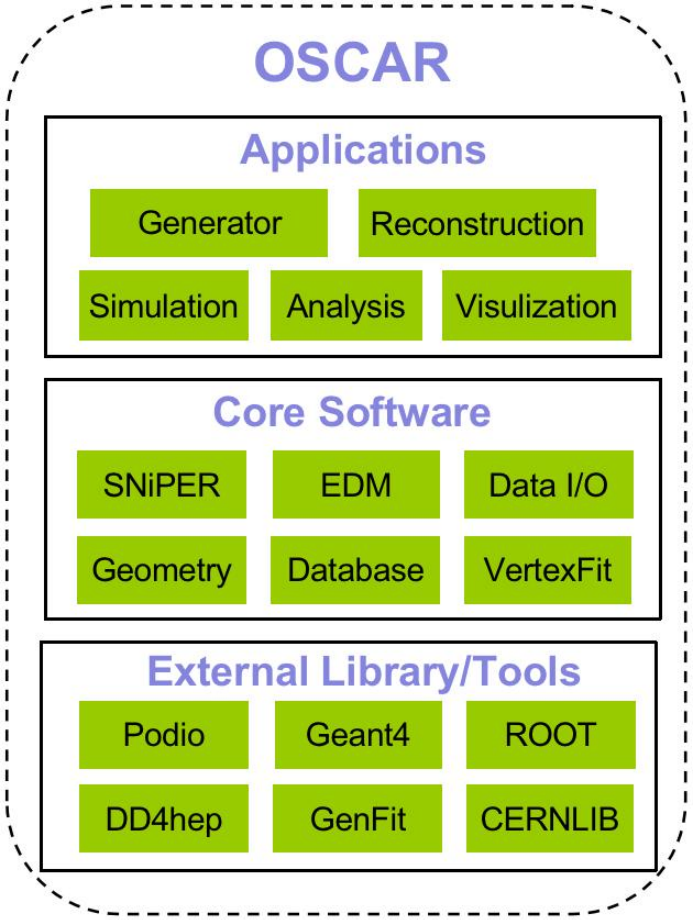
- STCF is proposed for next Tau-Charm factory in China
  - CME: $2 - 7\ GeV$
  - Luminosity: $> 0.5 \times 10^{35} cm^{-2} s^{-1}$ (100 times of its predecessor, BESIII)
  - Potential to further improve the luminosity and realize polarized beam
  - Composed of ITK, MDC, RICH, DTOF, ECAL and MUD sub-system



CDR: arXiv:2303.15790

Overview of STCF Offline Software System

- The Offline Software of Super Tau-Charm Facility (OSCAR) is designed for detector design, MC data production and physics analysis
- OSCAR is partially based on Key4hep
  - Reuse some components. Extend others for STCF
- Core software are developed for common functionalities
  - Event loop control (sequently or concurrently)
  - Detector data and event data management
  - Common tools for data analysis
  - Other common services
- Some applications are migrated from BESIII



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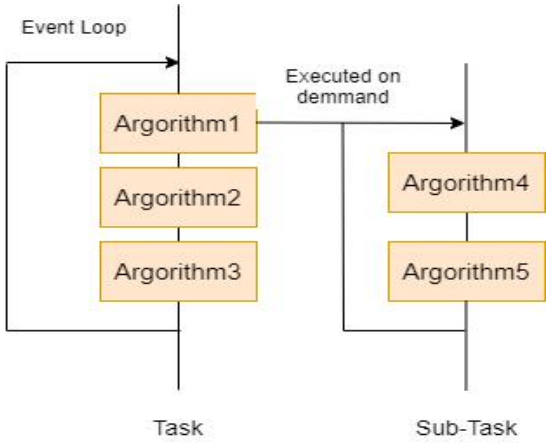
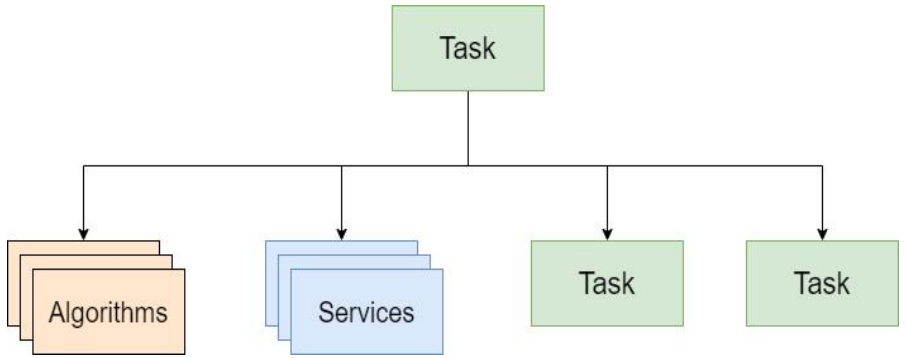
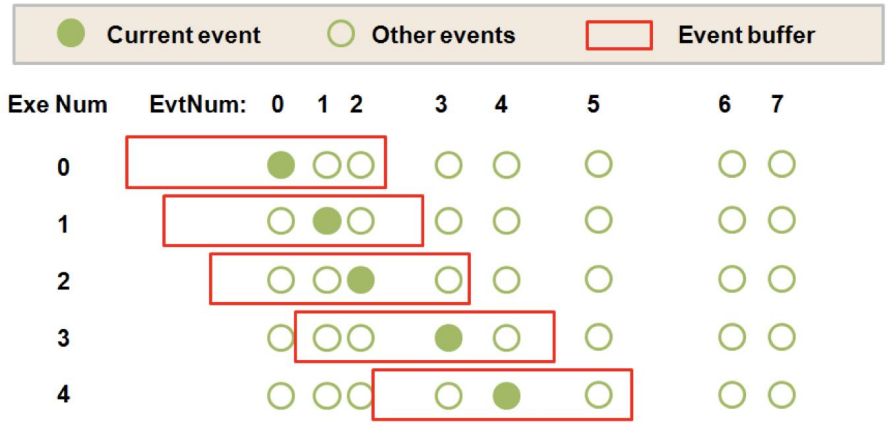
Underlying Framework: SNiPER

- Lightweighted, precisely aimed at small-scaled HEP experiments
- Adopted by JUNO (neutrino), LHAASO (cosmic ray), nEXO (neutrinoless double beta decay) and HERD (dark matter)
  - Provide basic functionalities of event loop control, application interface, job configuration, logging etc.
- Advantages of SNiPER
  - Lightweighted, efficient, highly extendable. Flexible event loop control. Flexible to be integrated with other software, e. g. podio, ROOT, ...
  - C++/Python hybrid programing, highly configurable. Efficient multithreading.



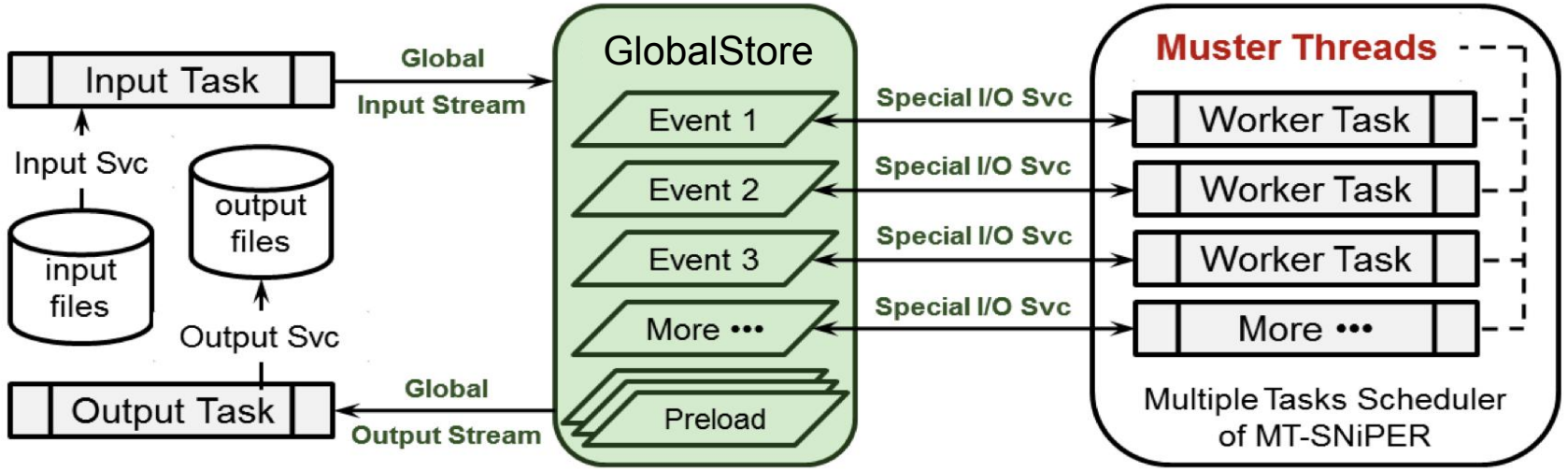




reference: J. H. Zou et al J. Phys.: Conf. Ser. 664 (2015) 072053
J. H. Zou et al EPJ Web Conf. 214 (2019) 05026

Parallelism in MT-SNiPER

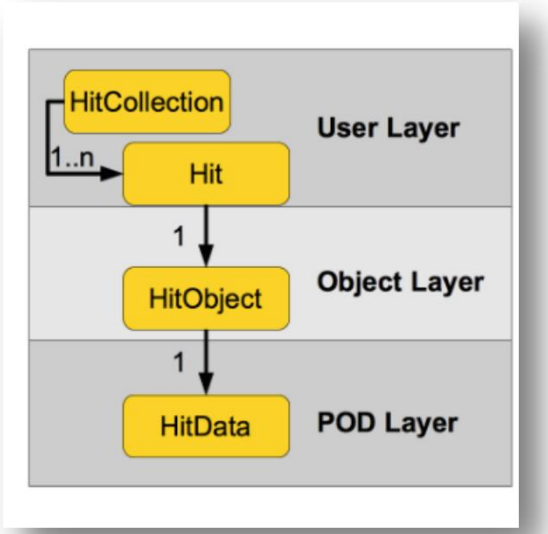
- SNiPER provides simple interfaces for building multithreaded applications
  - Based on Intel TBB
  - SNiPER Muster (Multiple SNiPER Task Scheduler) works as a thread pool/scheduler
  - Data I/O is binded to dedicated I/O thread for flexibility
  - A Global Store is developed to support multithreaded event data management
  - Application code is mostly consistent for serially and parallelly execution



Event Data Model Based on Podio

- Event Data Model (EDM) lies at the heart of OSCAR
  - Define the structure of event data in memory and in data files
  - Implement relationship between data objects (hit-track-MC particle)
  - Handle schema evolution
- EDM is defined based on podio (Key4hep, adopted by FCC CEPC, ILC, ...)
  - Generate C++ code based on YAML definition
  - Support both C++ and Python
  - Good multithreading support
  - Powerful and flexible relationshop between data objects
  - Support multiple data file format

F. Gaede, etc. , CHEP2019

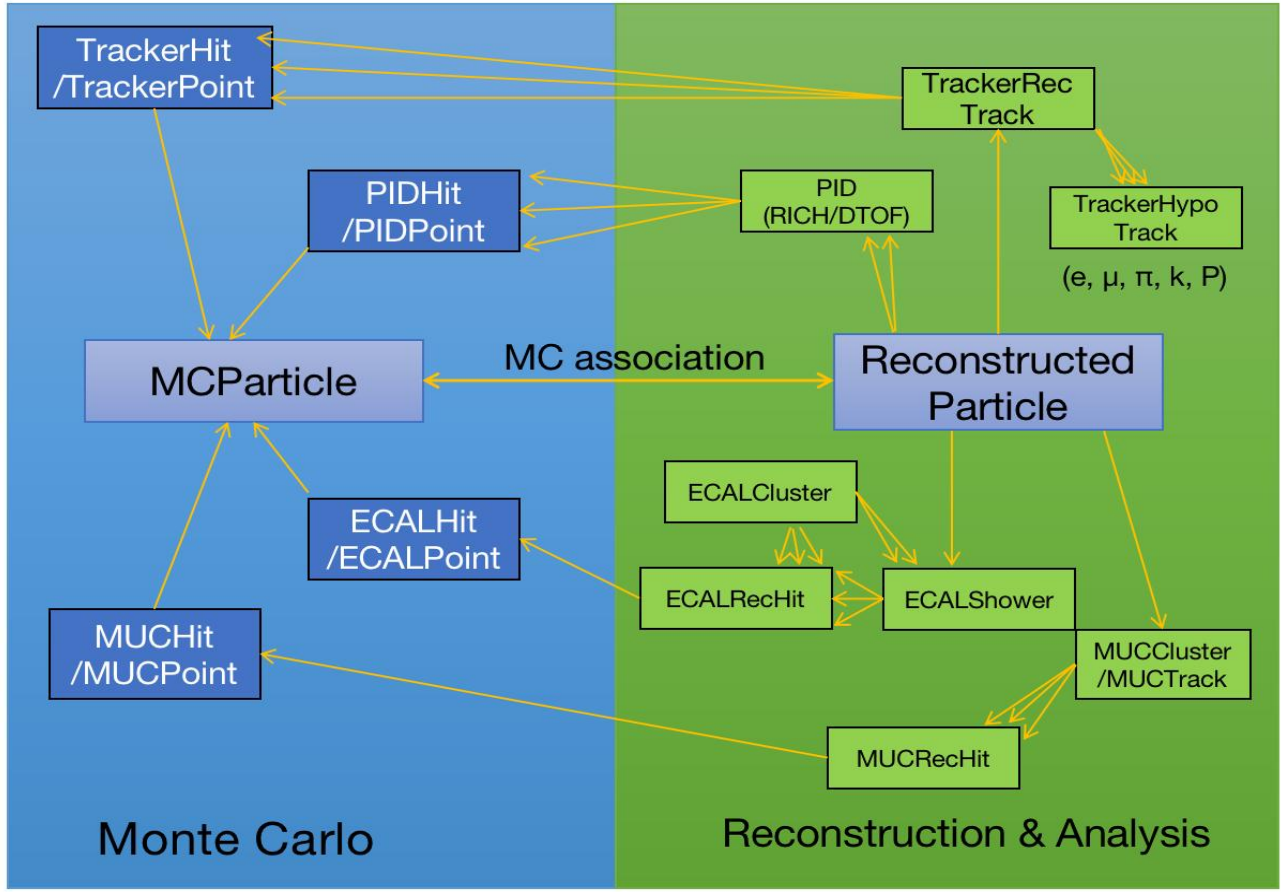


https://github.com/AIDASoft/podio

Event Data Model Based on Podio

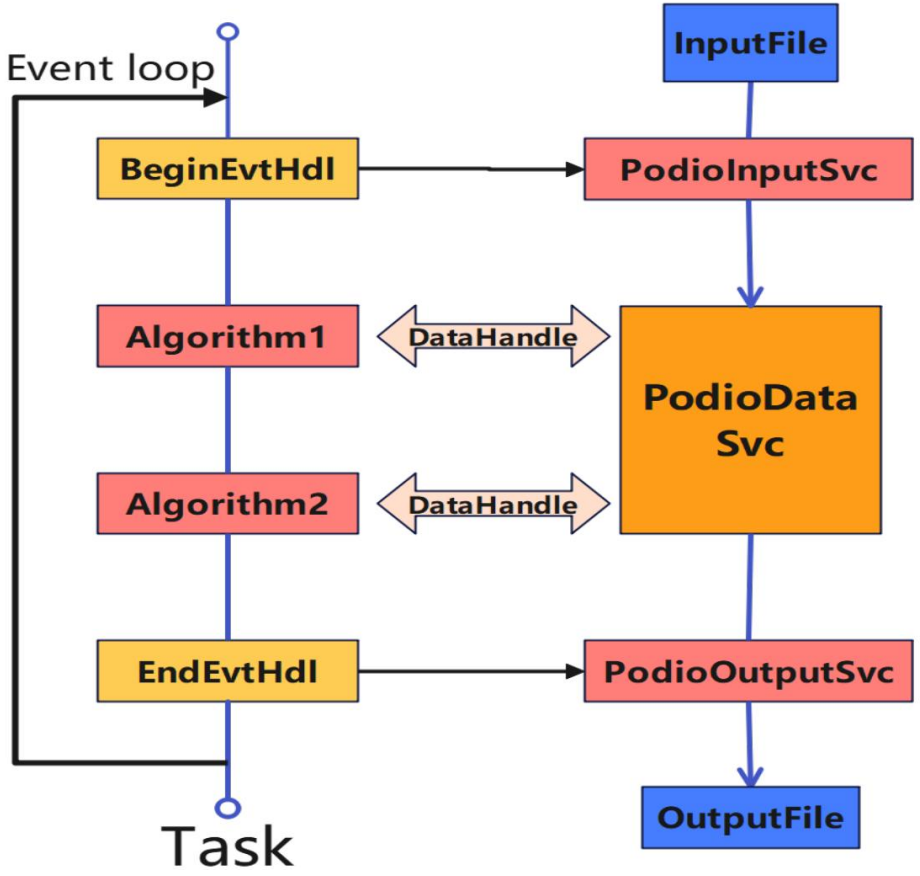
- Due to the specific requirements of STCF, EDM4hep is not directly used
- Design EDM classes based on Podio and reuse some EDM4hep classes

- Re-use MCParticle and ReconstructedParticle in EDM4hep as the core index
- Design EDM classes specificly for STCF simulation and reconstruction (for the PID system, and contains more information for detector optimization and physics analysis)
- MCParticle and ReconstructedParticle are correlated based on track matching algorithm, bridging MC and reconstructed data



Event Data Management

- Event data management system manages event data in memory, provides interfaces for user applications and handles data I/O
- Extend SNiPER DM system based on Podio
  - PodioDataSvc: memory management
  - PodioInputSvc: data input
  - PodioOutputSvc: data output
  - DataHandle: interface
- Event data and user application are completely decoupled



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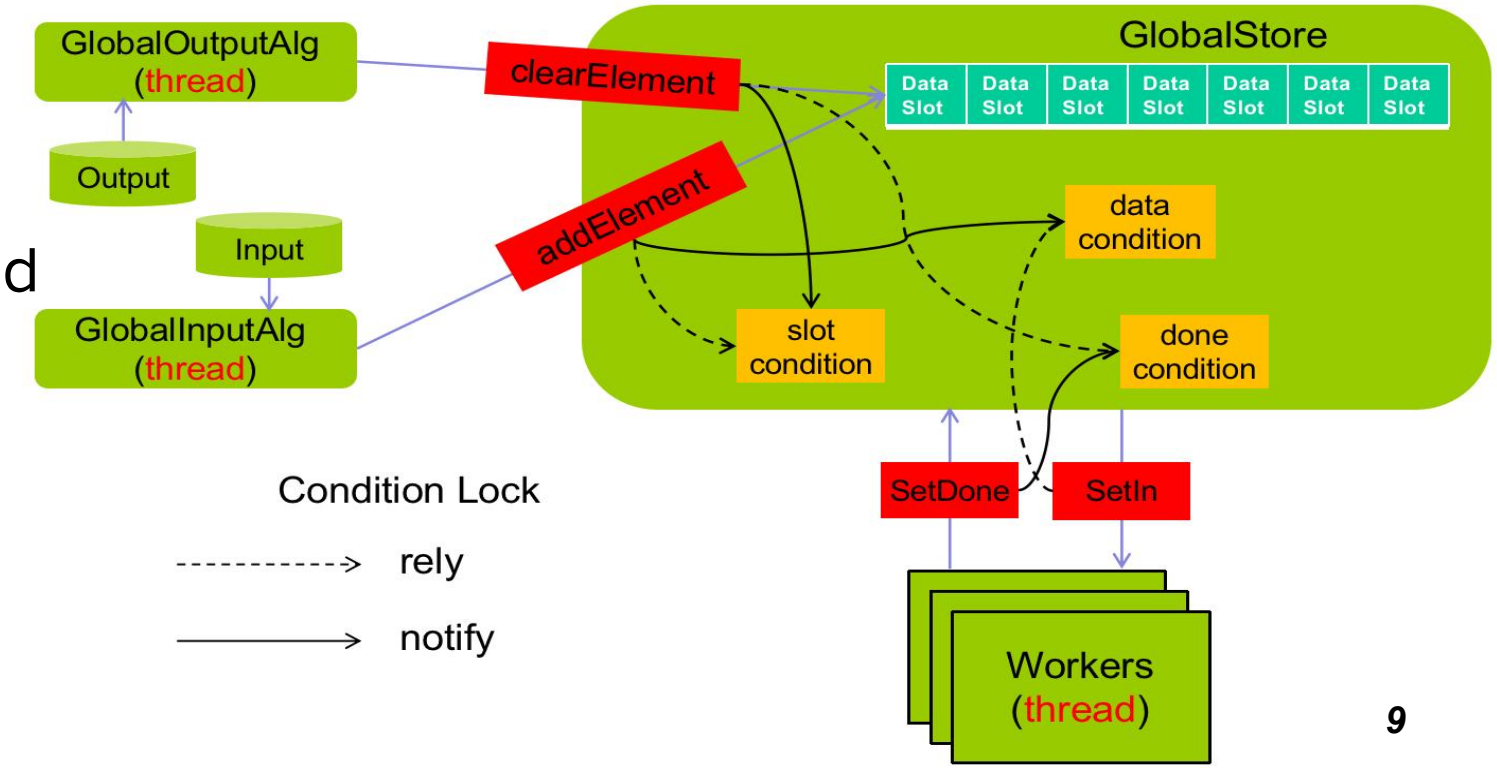
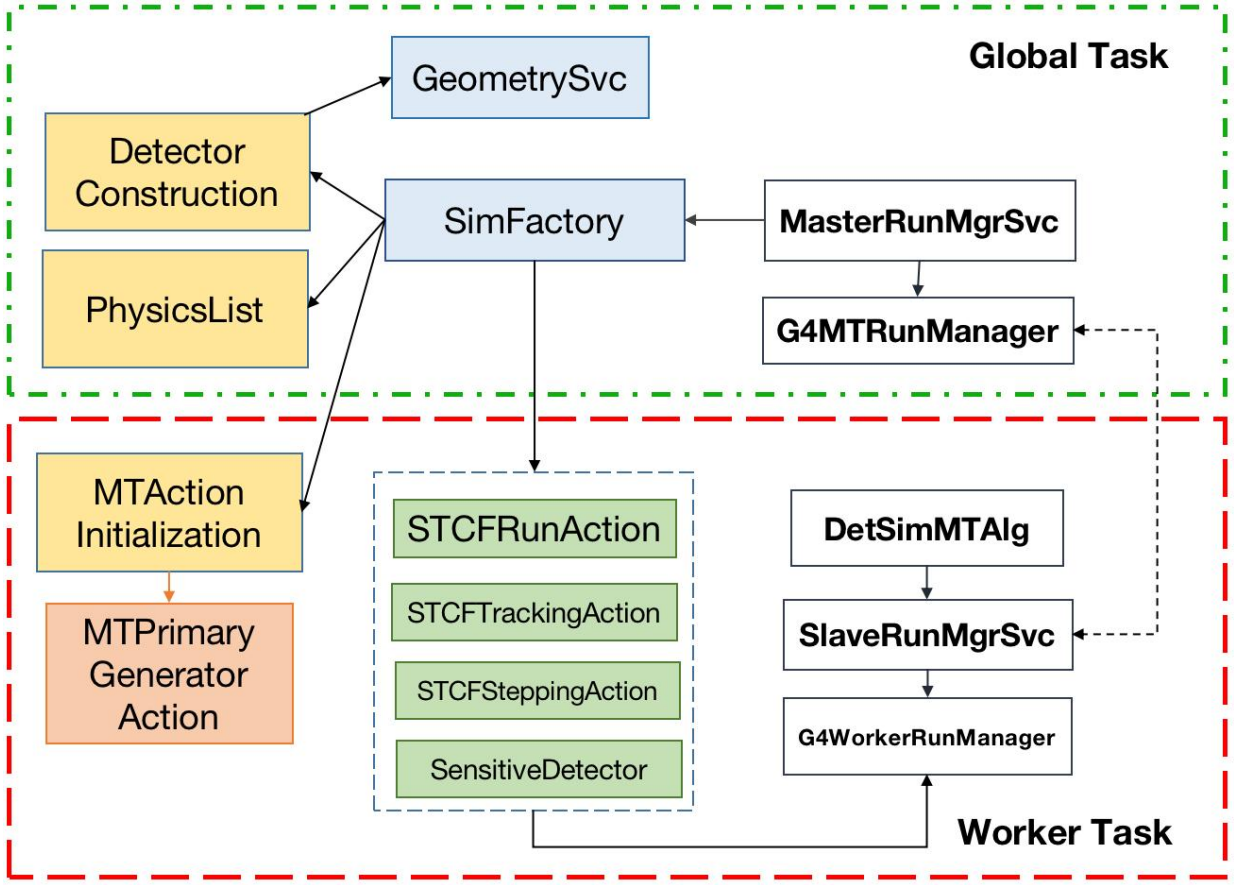
Parallelized Event Data Management

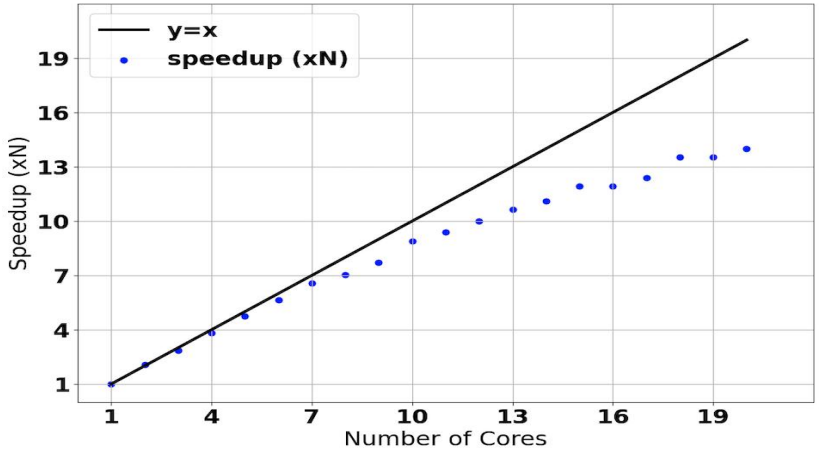
- To enable parallelized data processing, a GlobalStore is developed based on Podio
  - Re-implement podio::EventStore to cache multiple events (each within one data slot)
  - Use several condition lock to enable safety exchanging data between threads
  - I/O services are binded to dedicated I/O threads, to ensure performance and flexible post- or pre-processing
- Based on parallelized DM system, detector simulation and reconstruction are developed
- Users could switch serial/ parallel by just changing job configuration

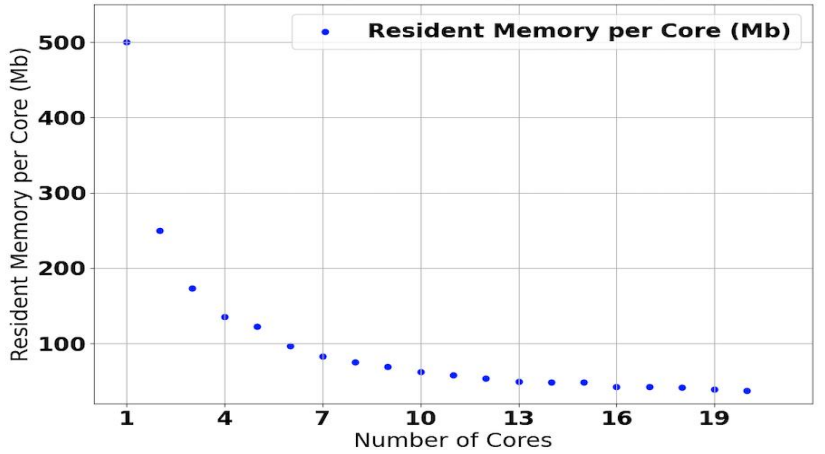


Parallelized Detector Simulation

- Based on the MT-SNiPER and parallelized DM system, parallelized detector simulation applications are developed
  - Basic performance tests show promising scalability



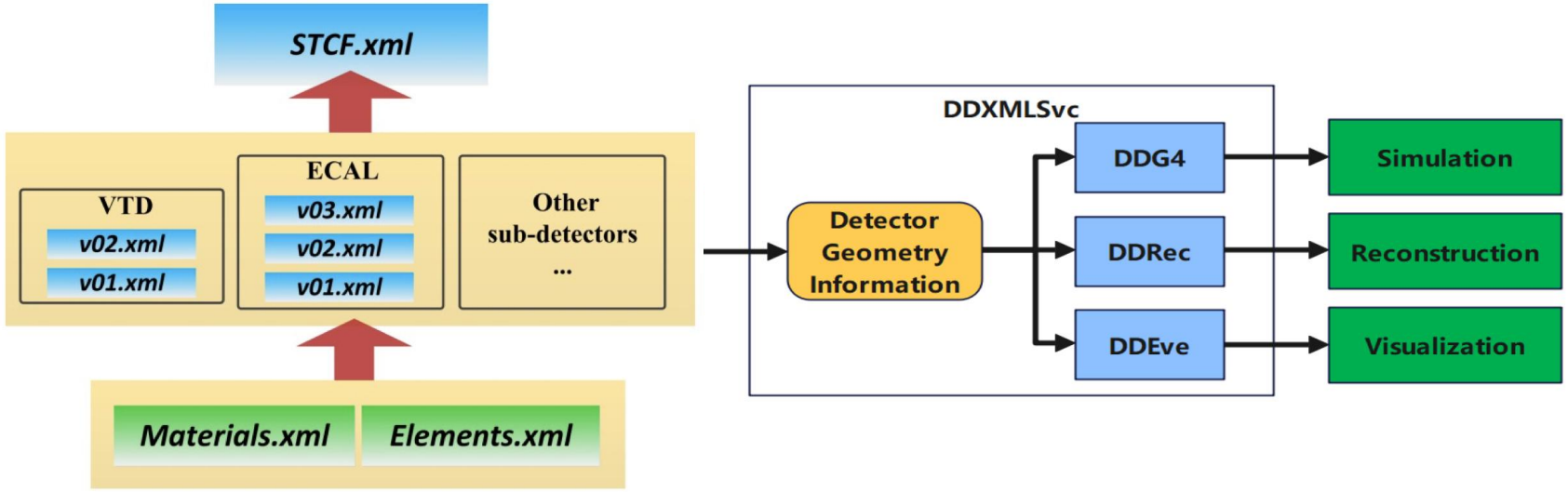




Geometry Management System

- Detector description in OSCAR is based on DD4hep
- Single source of detector information for detector description, simulation reconstruction and event display
  - DDG4 for delivering detector geometry to Geant4
  - DDRec for delivering detector geometry to reconstruction algorithms
  - DDXMLSvc: the unified interface to DD4hep, including DDG4 and DDRec

Flexible combinations of different versions of detector design, and combinations of sub-systems



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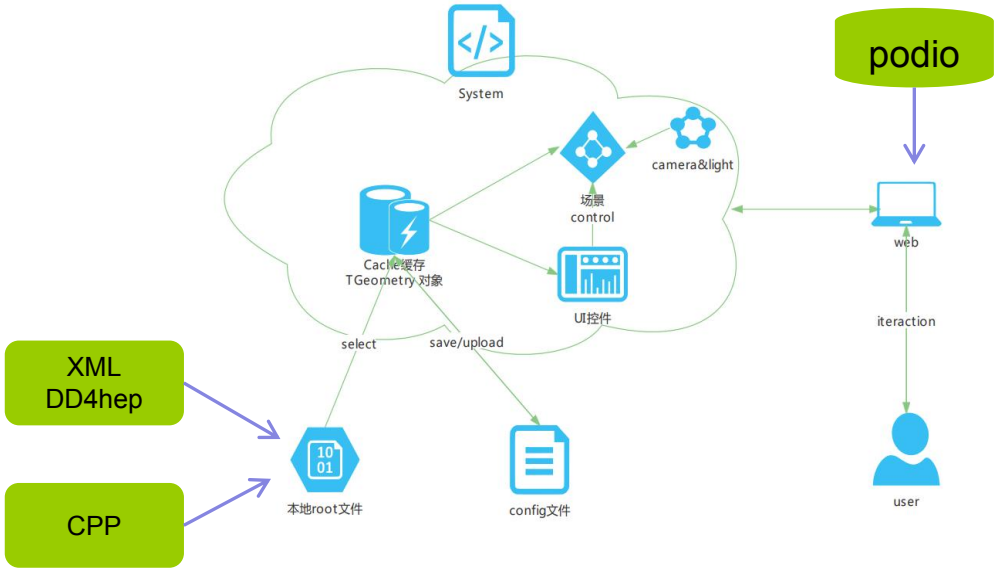
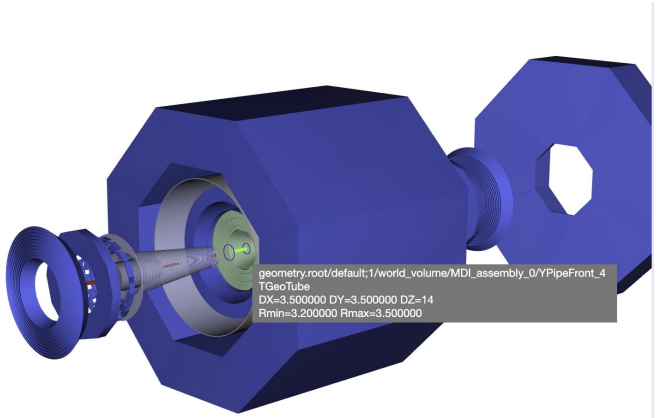
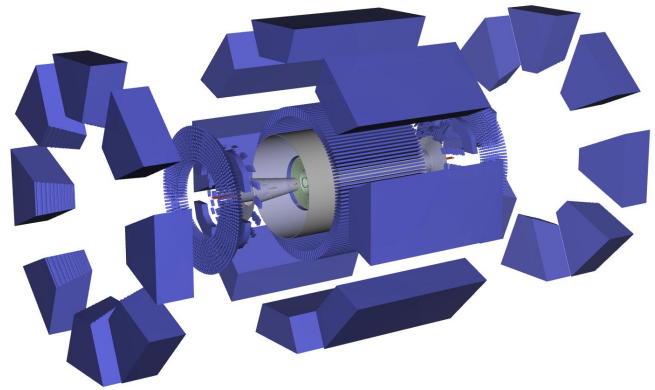
Geometry and Event Display

- A common geometry and event display system is being developed
  - User interface and 3D display based on WebGL
  - 3D engine and graphic libbrary based on Three.JS
  - Read geometry information from detector description based DD4hep (XML)
  - Event data read from Podio

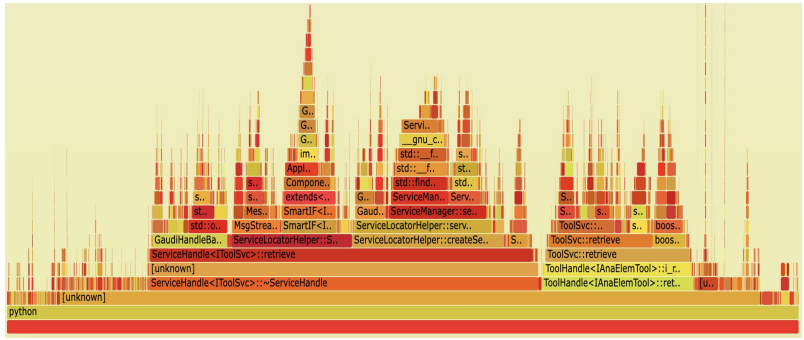


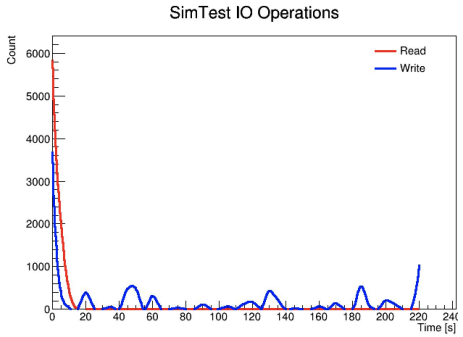


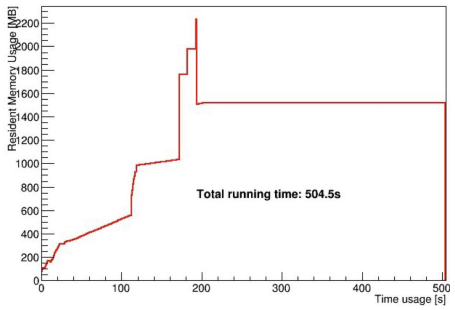


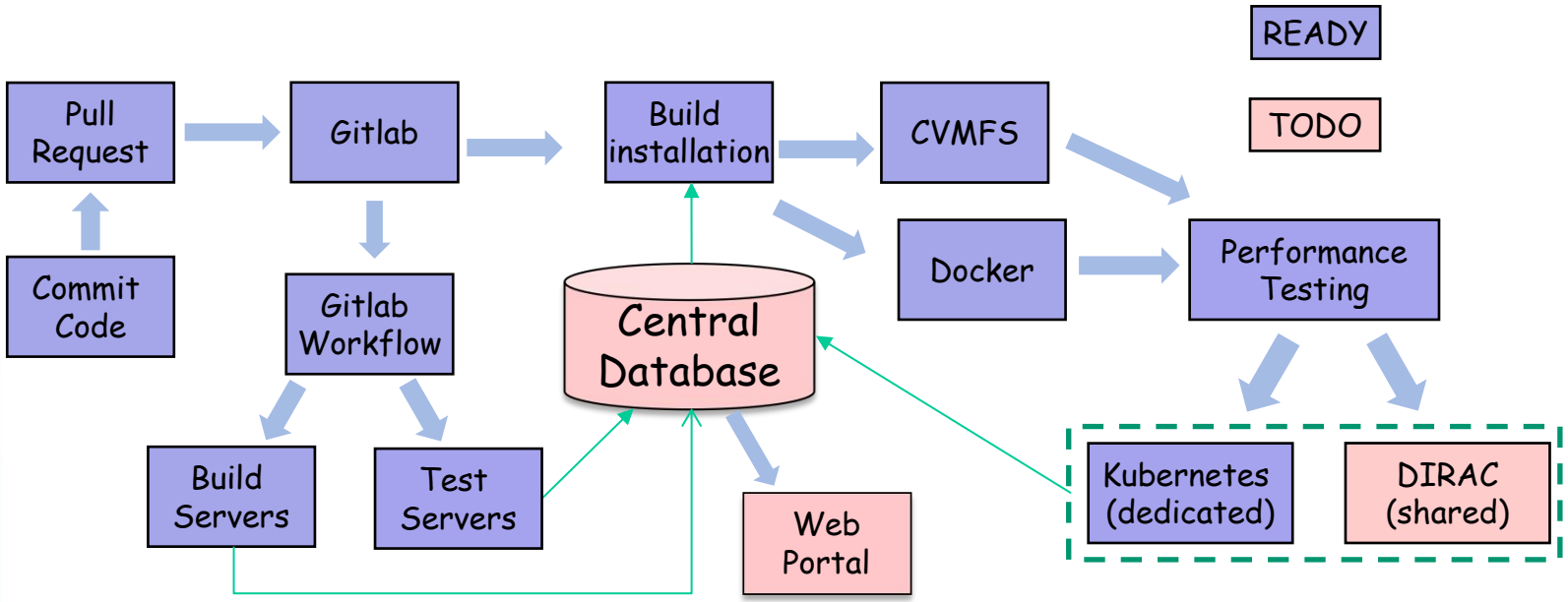
Automated Software Validation

- A software validation toolkit is developed, to support building software validation on different levels
  - Unit test, integrated test, software performance profiling and physics result validation
- Integrated with Gitlab Action system for automated validation
  - Trigger validation jobs on different levels on schedule/commits
  - Same system is being adopted by CEPC and Key4hep as well









Summary

- We introduced the basic design and functionalities of STCF offline software system (OSCAR), developed since 2019
  - Developed partially based on Key4hep. Many components are extended specificlly for STCF, but are also re-usable by other experiments
- Based on the core components, many STCF applications are (being) developed
  - Detector simulation, reconstruction algorithms, event display, analysis toolkit such as particle ID, VertexFit etc.
  - Now support preliminary physics analysis with MC data
- We have been continuously improving OSCAR based on new technologies
  - Many applications are being developed based on concurrent/heterogeneous computing, machine learning and quantum computing (#244 #439 #440 CHEP2023)