BRIL Software at the CMS experiment

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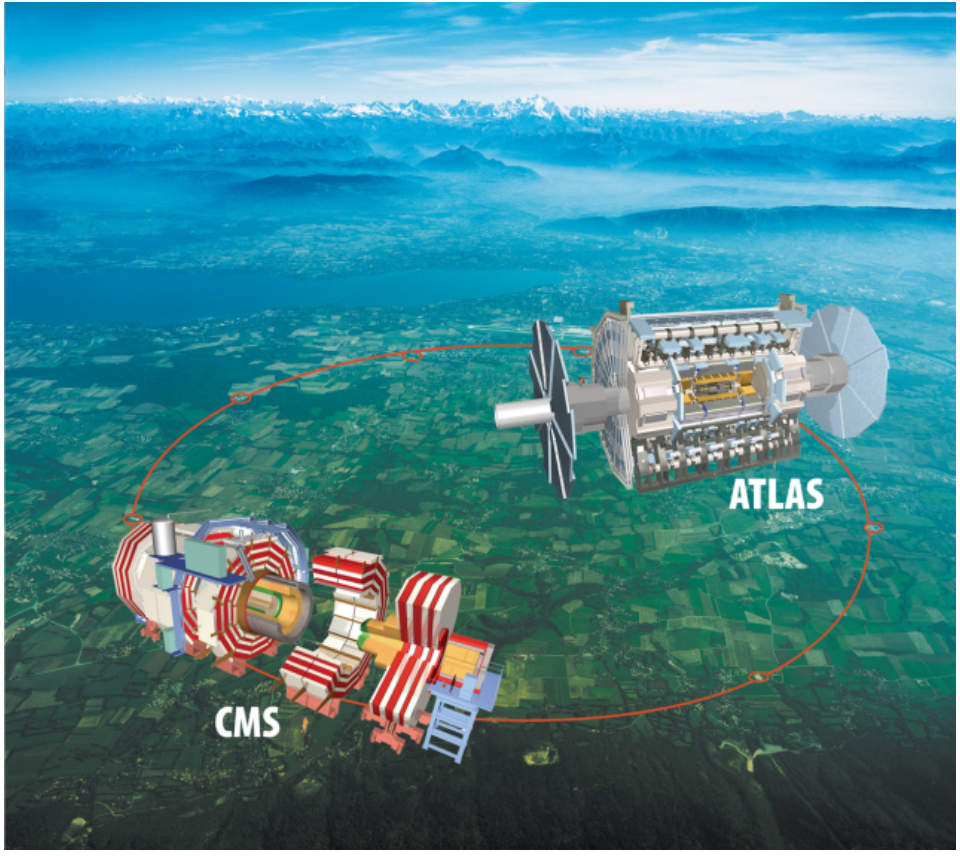
Overview

- Introduction to CMS-BRIL
  - What we do and its importance
- LHC long term schedule
- BRIL Onine core software
  - Run 3 software architecture and area of development
  - Area of development in Phase-2
- BRIL Offline core software
  - Run 3 software architecture and area of development
  - Area of development in Phase-2
- BRIL core software upgrade schedule
- Benefits of contributing to BRIL core software upgrade effort

LHC & CMS-BRIL

- Large Hadron Collider (LHC)
  - Largest and highest-energy particle collider
  - At CERN, beneath the France-Switzerland border near Geneva
  - Proton and heavy-ion collision program producing record-setting center-of-mass energies and luminosities
- Compact Muon Solenoid (CMS)
  - One of the two general-purpose detectors at LHC
- CMS Beam Radiation,Instrumentation, and Luminosity (BRIL) project
  - Responsible for a number of detector systems that measures luminosity, beam conditions and radiation products produced by the LHC at the CMS detector



BRIL Sub-detectors

BRIL encompasses several subsystems to provide:

- luminosity measurement
- operational conditions and cavern radiation monitoring
- beam abort functionality
- beam timing

Many Run-2 systems upgraded with new components:

40 MHz trigger µ-scouting luminosity (L1 muons)

DT & MB YB+2 luminosity (muon trigger primitives)

PCC luminosity (pixel clusters)

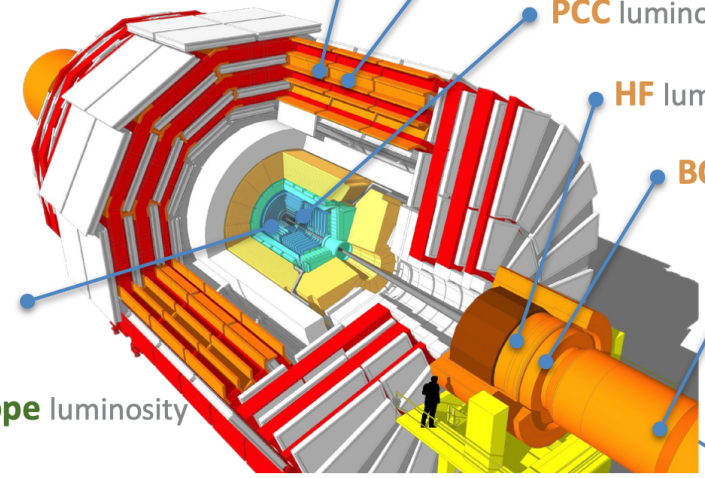
HF luminosity (quartz fibers)

REMUS
LHC RadMon

BCML2 beam loss

Beam Halo Monitor beam-induced background

BPTX (~175 m) Timing/trigger



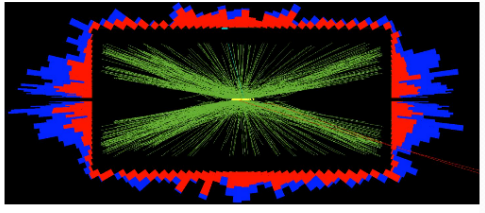
Completely rebuilt and optimised for Run-3:

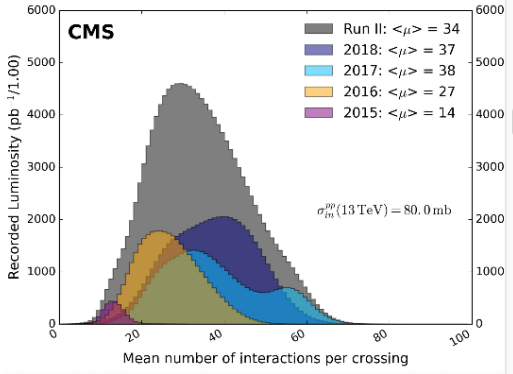
BCM1F luminosity, beam-induced background

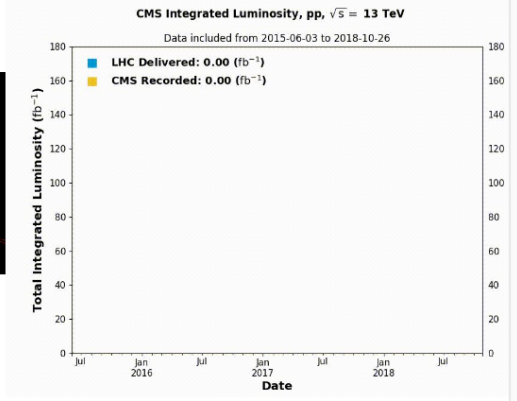
BCML1 beam loss

Pixel Luminosity Telescope luminosity

- # What is luminosity?
  - Proportional to expected number of interactions when bunches of protons cross
    - At the LHC, groups of ≈100 billion protons collide as often as 40MHz
    - On average, ≈35 proton interactions for each crossing (“pileup”)
  - Quantifies the ability to produce a certain number of interactions
    - Proportionality factor between rate of interactions and cross-section
    - e.g. $\dot{N}_{Higgs} = \mathcal{L} \cdot \sigma_{Higgs} \approx$ (0.02 pb/s)(50 pb) = 1 Hz
  - *Instantaneous* luminosity is aggregated into *integrated* luminosity
    - Amount of data produced in a certain period of time
- # Why is it important?
  - Monitoring of accelerator performance
    - Optimization of beam parameters
  - Detector operation during data-taking
    - Instantaneous luminosity informs trigger “selectiveness”
  - Final deliverable: integrated luminosity for physics analyses
    - Yields expected frequency of each type of interaction
      - e.g. $N_{Higgs} = \sigma_{Higgs} \int_{24hr} \mathcal{L}\, dt \approx$ (700 pb^{-1})(50 pb) = 35E3
    - Particularly important for cross-section measurements

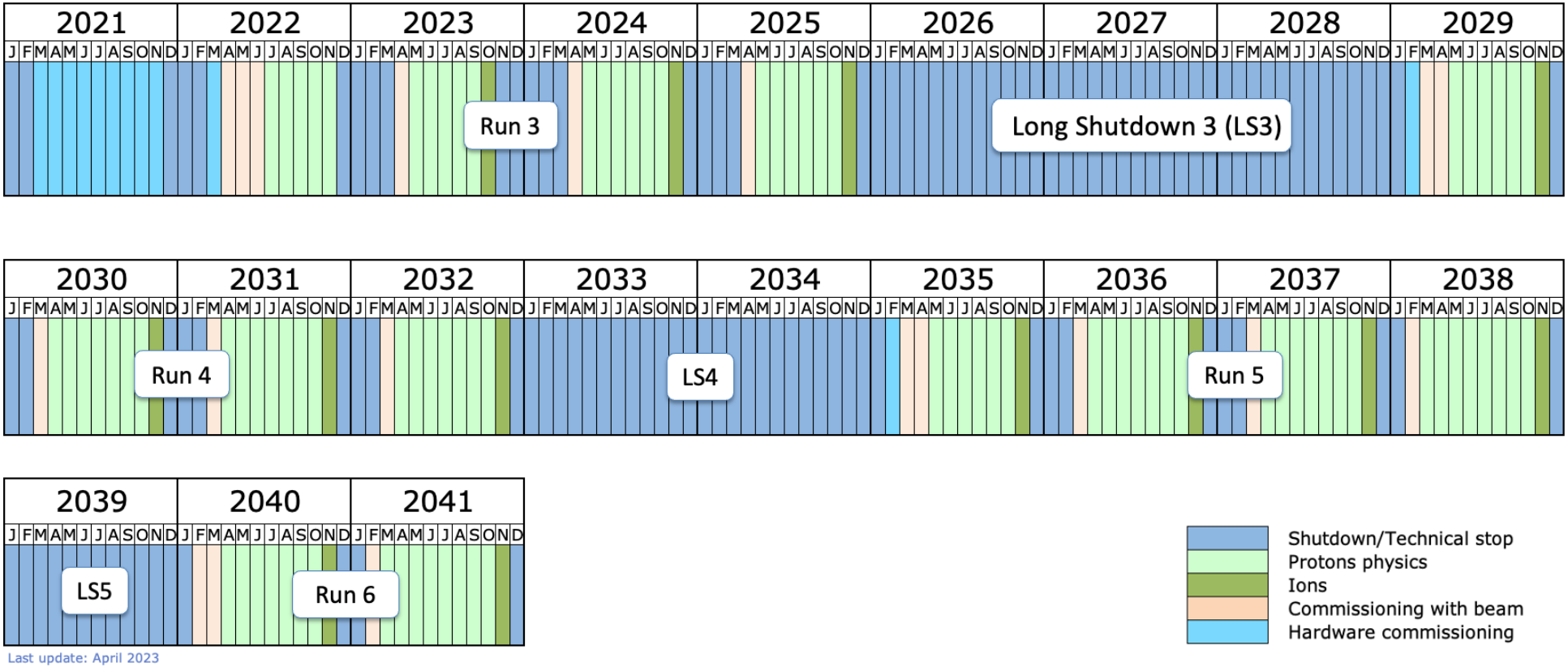






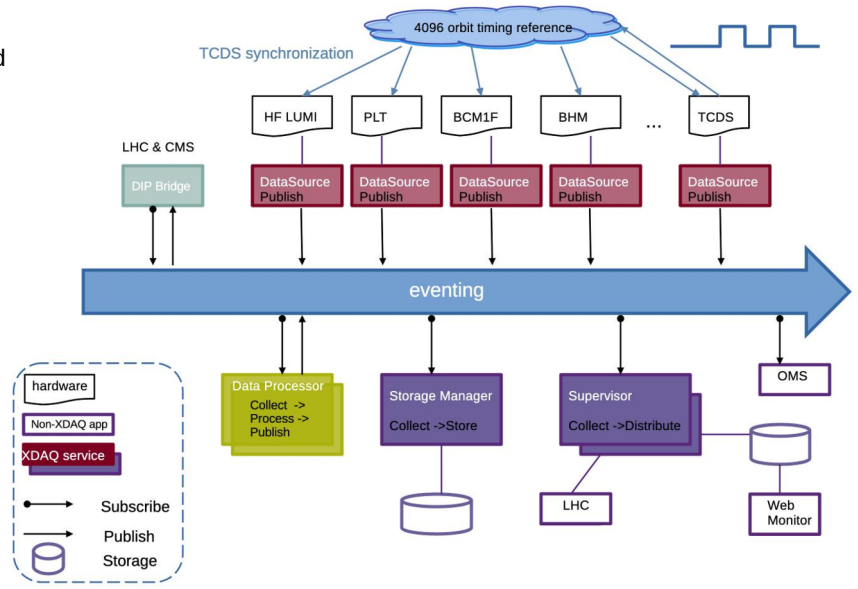
CMS Luminosity - Public Results

LHC long-term schedule



BRIDAQ: Data Acquisition System in Run 3

- Realtime data acquisition and monitoring of heterogenous subsystems
- Unique, independent non-event data acquisition and handling system in CMS
  - Continuous running with LHC beam at the same time is aware of CMS run parameters and clock
  - Data are immediately analysable: no fragment reassembly
  - Complex physics quantities are monitored as charts in realtime
- Architecture:
  - Service-oriented with Publisher-Subscriber message exchange for component decoupling
  - Asynchronous Event-driven for speed
  - Common data format for heterogenous subsystems
  - Hierarchical binary format file (HDF5) and Relational summary database guarantee all data can be used by detector and physics communities directly without multi-tier reprocessing, complex bookkeeping and transportation
- ~20TB/year raw data (after compression) + summary data, monitoring data, calibration data of less amount



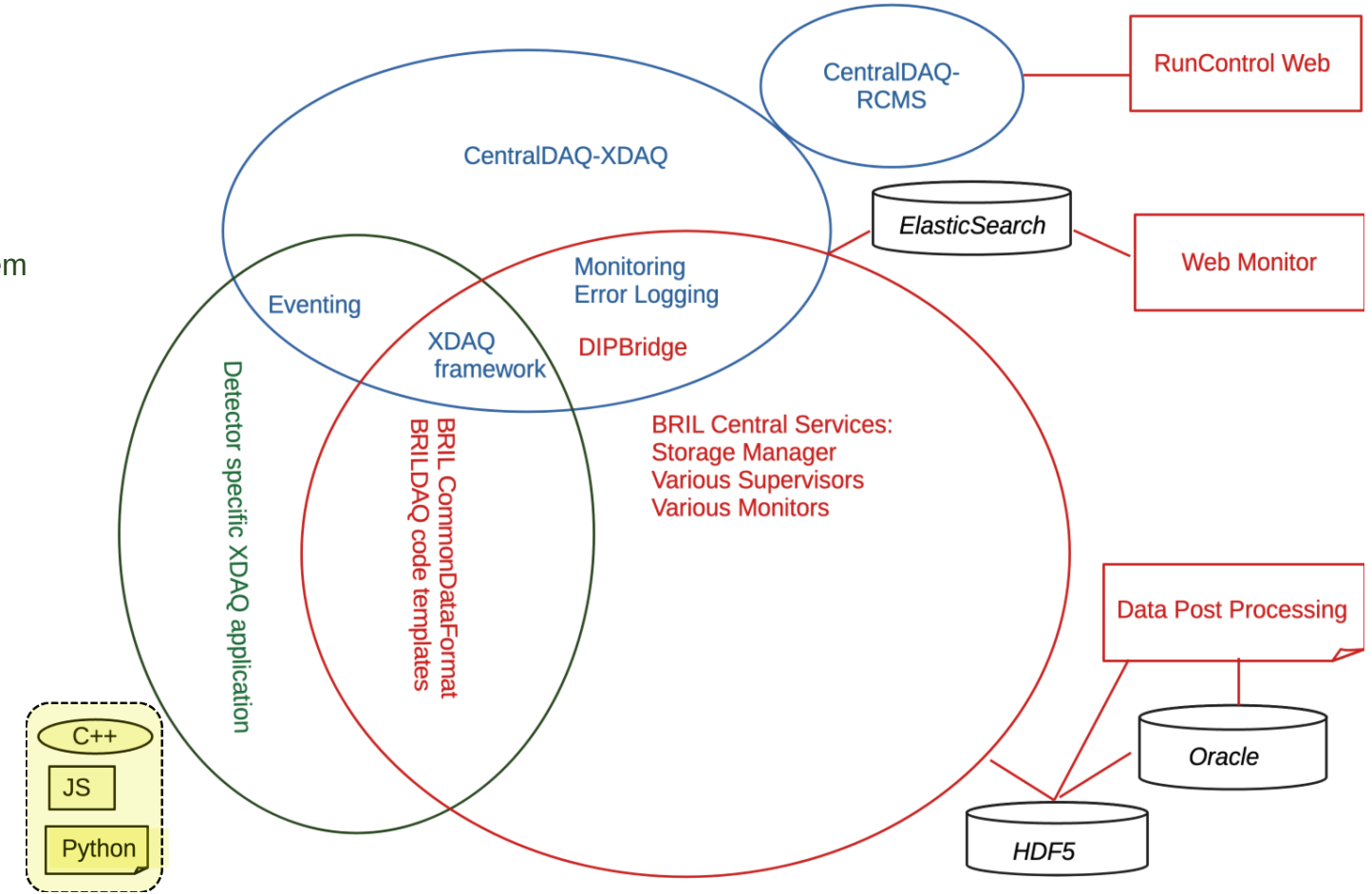
BRILDAQ-Core: area of development (Run3)

BRILDAQ-Core

BRILDAQ-Subsystem

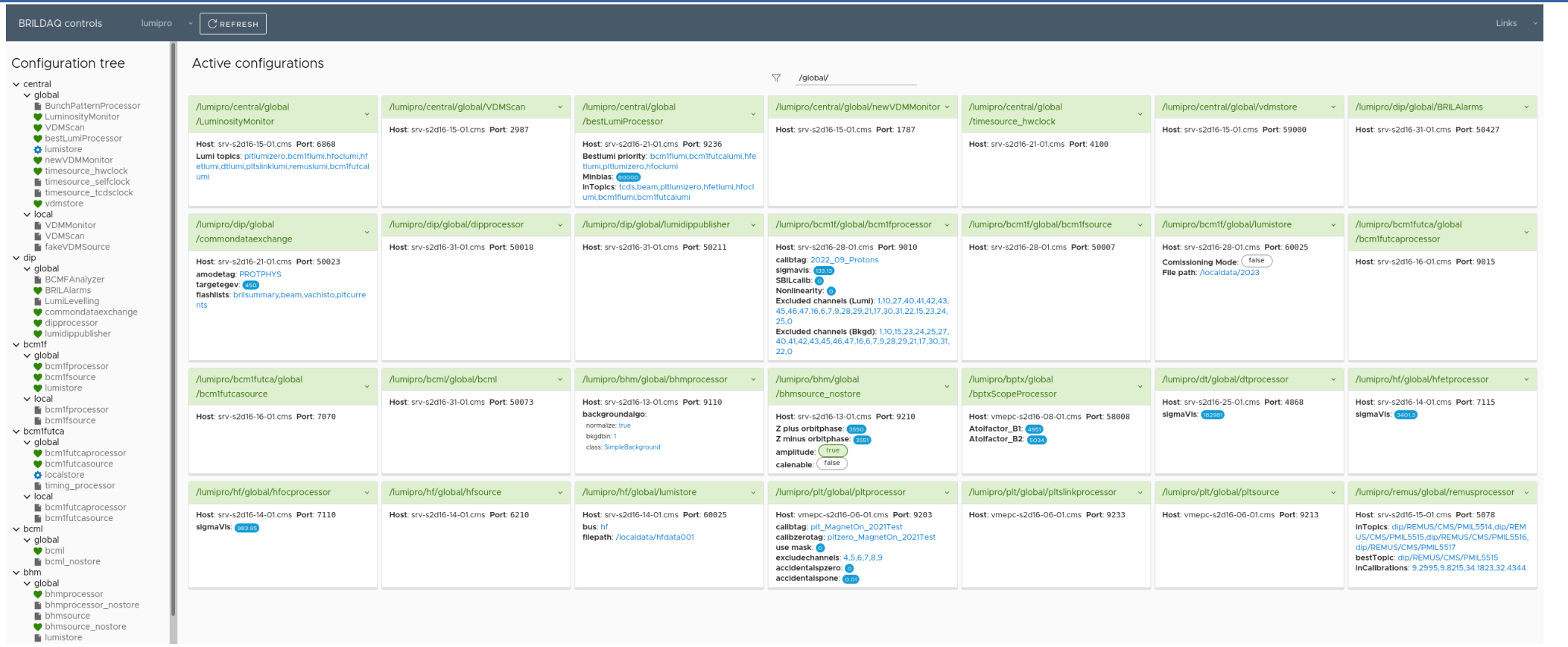
Central DAQ

3rd party product



BRILDAQ Web Monitor

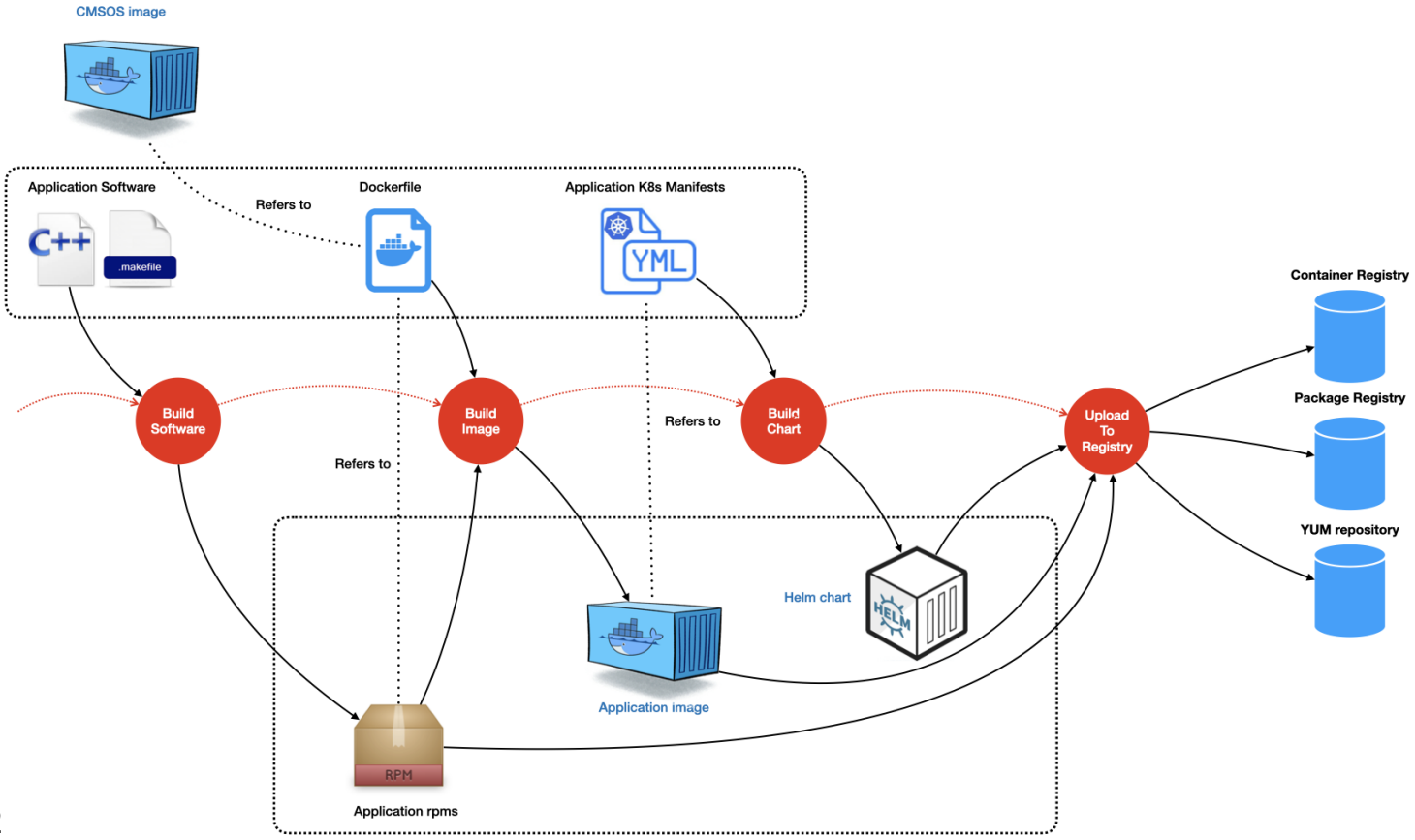
BRILDAQ Run Control Web



BRILDAQ-Core: Area of Development (Phase-2)

- Keep the general architecture : Event-driven, message-oriented, service-oriented, loosely-coupled heterogeneous system
- Replace out-of-date technologies e.g.
  - XML → YAML as configuration language
- Replace in-house and custom solutions with off-the-shelf products. e.g.
  - In-house “eventing” → MQTT protocal + EMQX broker or ?
  - Monitoring matrix “flashlist”→ Prometheus+InfluxDB or ?
  - Monitoring database “Elasticsearch” → Opensearch or ?
  - Data Serialisation protocol → ?
  - LHC “DIP” messaging protocol→ ?
- Look for better solutions
  - Monitoring database Elasticsearch → EMQX+fluentd+Opensearch or ?
  - Storage “HDF5”+Oracle → a file based analytical database?
  - Logging and Error database , Oracle → ?
- Replace the development+release RPM workflow to containerization workflow: Docker, Kubernetes, HELM...

BRIDAQ Phase-2: Containerization of workflow



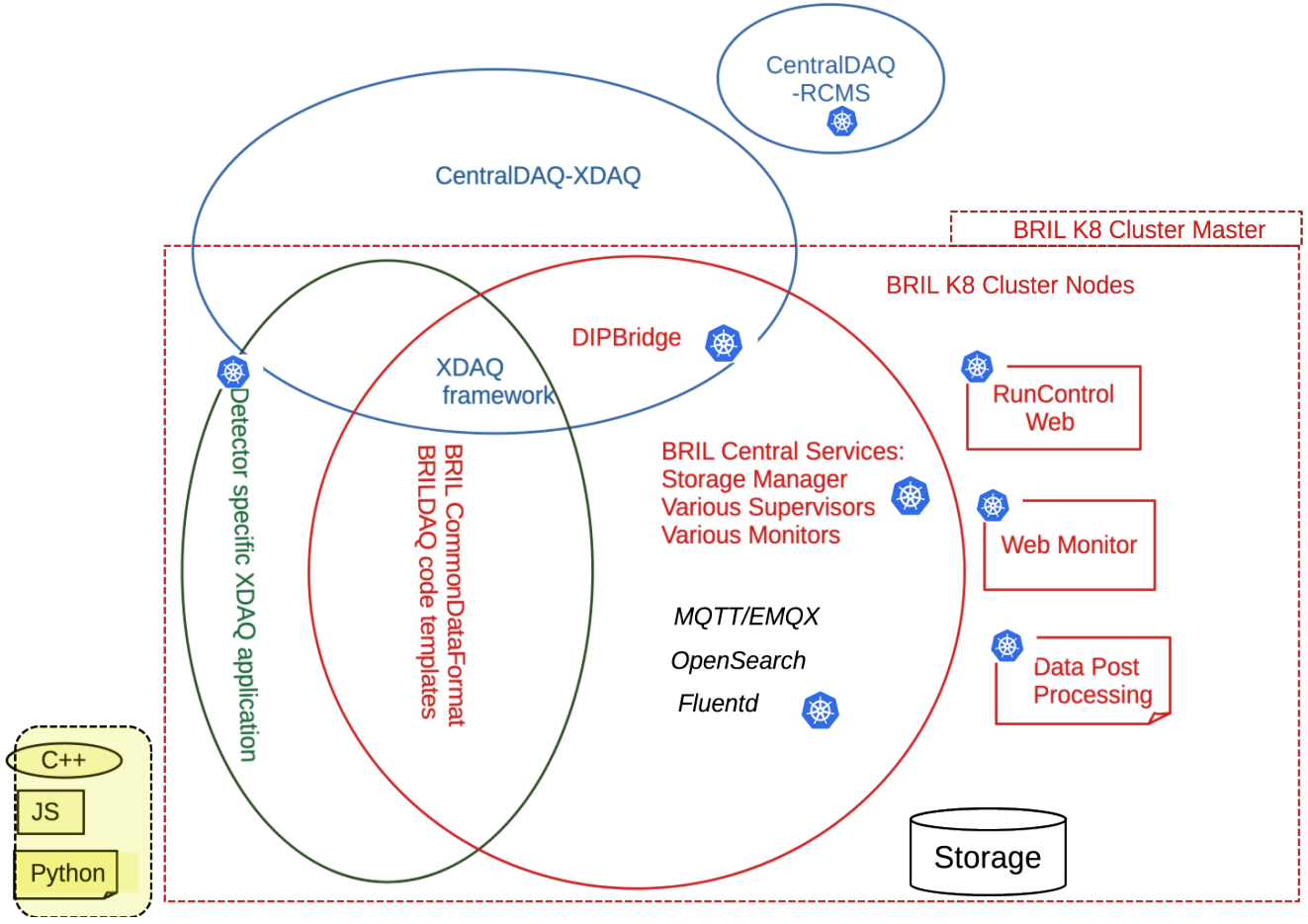
A mental image of BRILDAQ development areas in Phase-2

BRILDAQ-Core

BRILDAQ-Subsystem

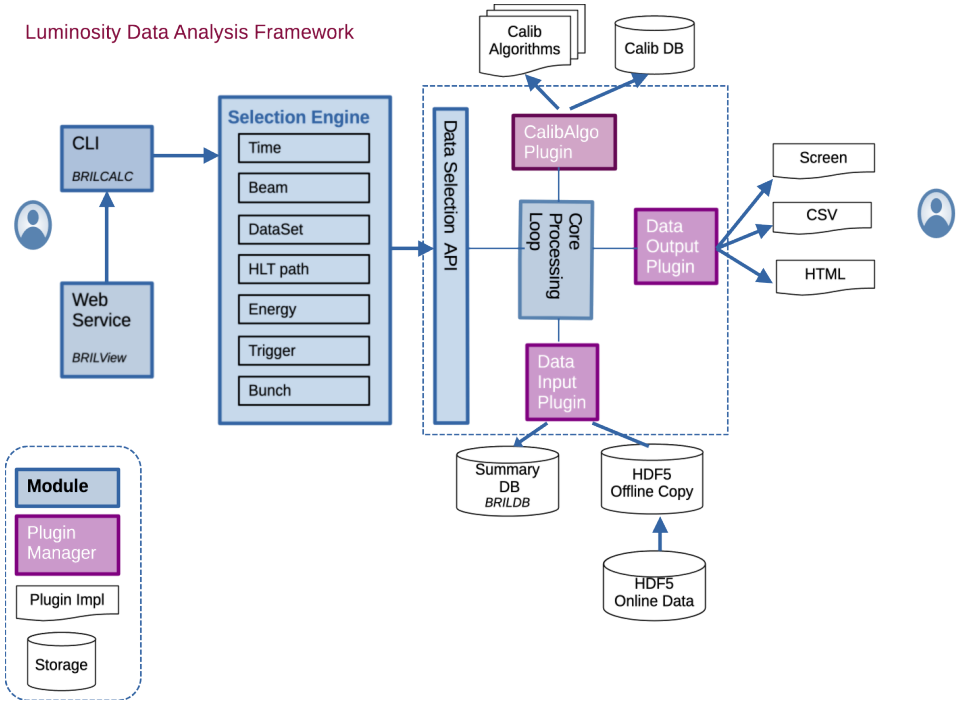
Central DAQ

3rd party product



BRILWS: BRIL offline data analysis work suite

- Plugin based modular design
- Aggregate data from BRIL summary database, L1 trigger and HLT database to calculate and deliver versioned luminosity results
  - For physics community
  - For BRIL detector performance study
  - For trigger performance study
- Delivered as both software releases and a central web service
- Support data access via CMS Grid



Development area in offline analysis worksuite

- Keep the CLI + Web tool format of the toolkit
- A lumisection will be shorted to ~1sec in Phase-2. As consequence the data granularity will increase ~20 times. Current database design and software are no more suitable.
  - Introduce parallel processing
  - Look for a more vector-friendly and fast Analytical Database System(OLAP) to replace Oracle
- Implement a more complex plugin manager system such that more sophisticated calibration algorithms can be added by power users.
- Interface to L1-Trigger and HLT data will change

Summary: direction of changes in BRIL Phase-2 software

- Software architecture will remain unchanged
- General “Look & Feel” of components will be kept
- Under the hood, all the components will have to be re-implemented
- Current online software deployment will be decentralized to a DevOps workflow.
  - Develop docker files, K8 manifest, debug pods...

BRIL software upgrade schedule

- 2024-2025 (parallel to run 3)
  - Collect requirements, define architecture, data model and deployment workflow of the BRIL online and offline software system at all levels
  - R&D and benchmark on candidate new technologies
- 2025-2026 (parallel to run 3)
  - Decide on detailed architecture and data model of the online and offline system
  - Implement a software system that can produce reasonable amount of fake online&offline data of
    - Raw histogram data, aggregated data, monitoring data, metadata for versioning and calibration systems
    - For all subsystems
    - At all data reduction/aggregation levels
- 2026-2028 (long shutdown period)
  - Implement the new online and offline software systems

Benefits of contributing to BRIL software upgrade effort

- Opportunity to contribute to a crucial part of the CMS experiment at LHC
- Opportunity to learn and put to use many cutting edge technologies
- Opportunity to participate in developing a complex software system almost from scratch
- Opportunity to get deep knowledge of the CMS online framework XDAQ
  - Close collaboration with XDAQ team: some XDAQ services, benchmark measurements etc are developed by BRIL
- A back-to-back non-event data management software system unique in CMS
  - Non-event data are essentially time-series data of large size. Many use cases can be found outside the physics field. The offline analysis toolkit is a data science framework.
  - The publisher-subscriber messaging and MQTT protocol in the data acquisition is widely used in the industry, e.g. smart parking system
- A software system not so big for a person to lose the global picture yet complex enough to see many programming paradigms and technologies working together
- A small team of a flat hierarchy insures everyones' work counts