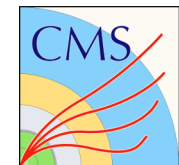




# BRIL Software at the CMS experiment

Zhen Xie (Princeton University)

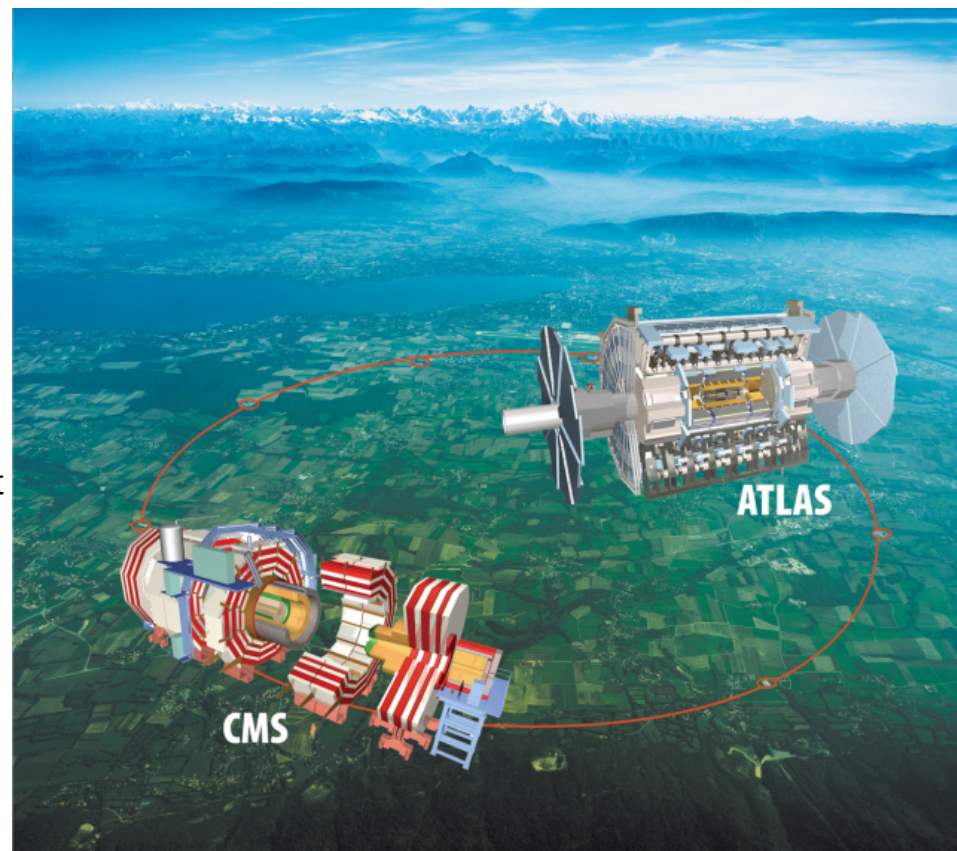


# Overview



- Introduction to CMS-BRIL
  - What we do and its importance
- LHC long term schedule
- BRIL Online 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

- 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

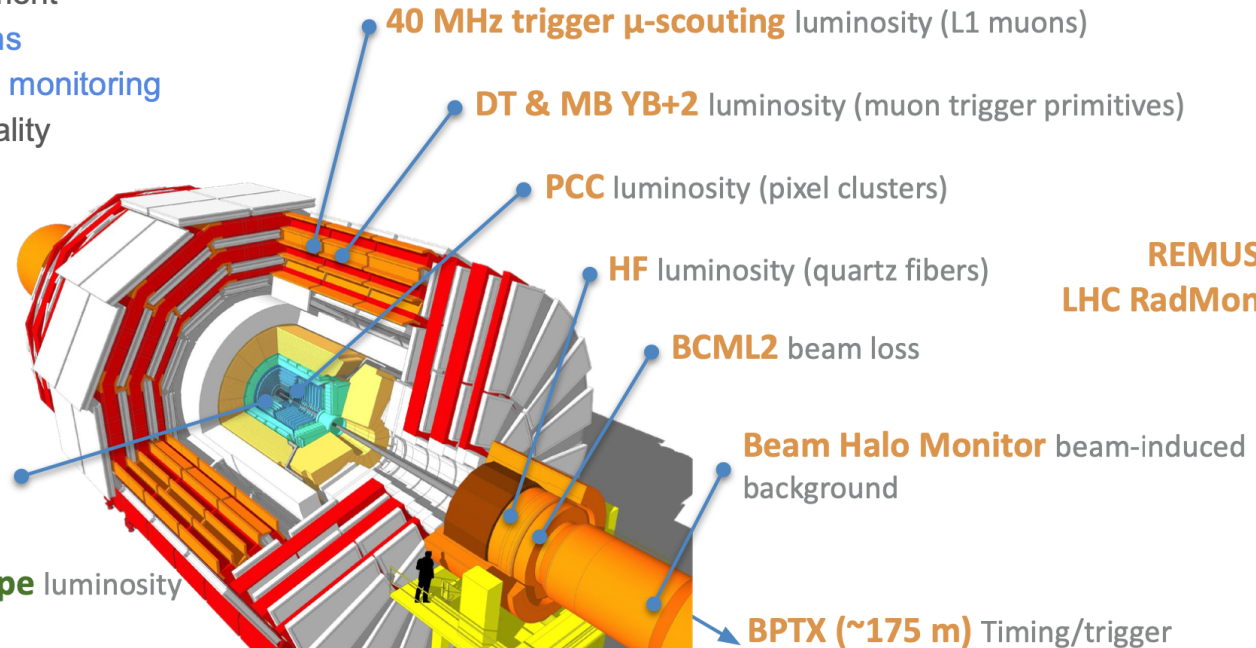
Many Run-2 systems upgraded with new components:

Completely rebuilt and optimised for Run-3:

**BCM1F** luminosity, beam-induced background

**BCML1** beam loss

**Pixel Luminosity Telescope** luminosity

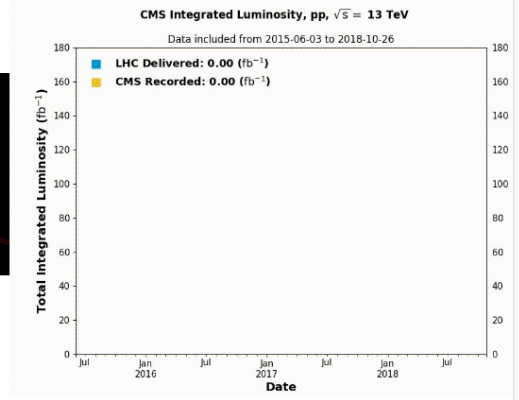
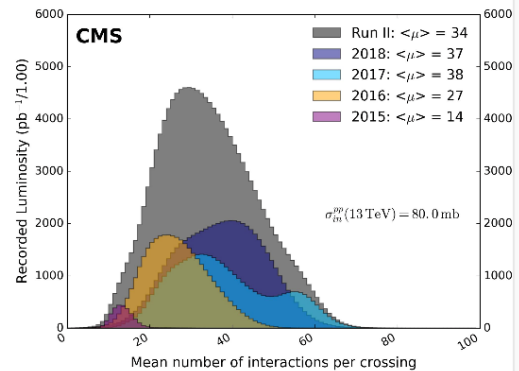
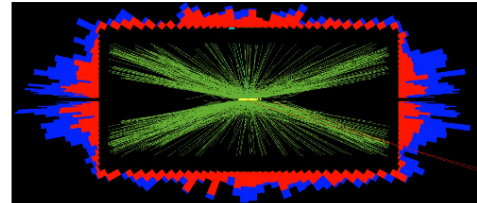


## ● What is luminosity?

- Proportional to **expected number of interactions** when bunches of protons cross
  - At the LHC, groups of  $\approx 100$  billion protons collide as often as 40MHz
  - On average,  $\approx 35$  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.  $\dot{N}_{Higgs} = \mathcal{L} \cdot \sigma_{Higgs} \approx (0.02 \text{ pb/s})(50 \text{ pb}) = 1 \text{ Hz}$
- **Instantaneous** luminosity is aggregated into **integrated** luminosity
  - **Amount of data** produced in a certain period of time

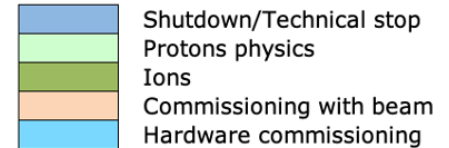
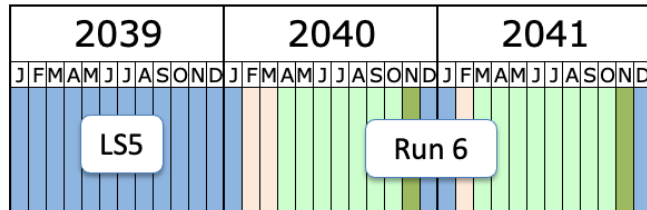
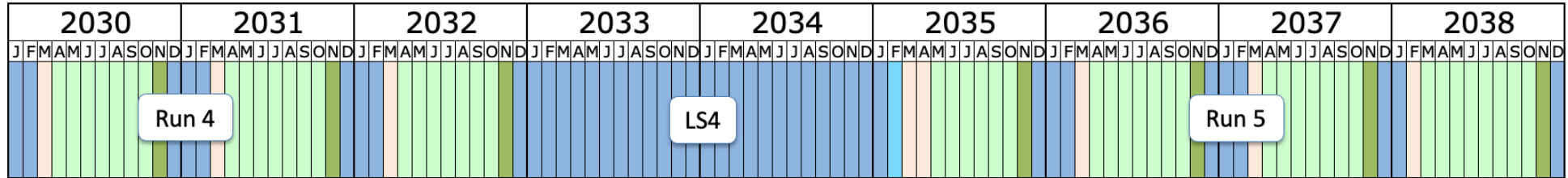
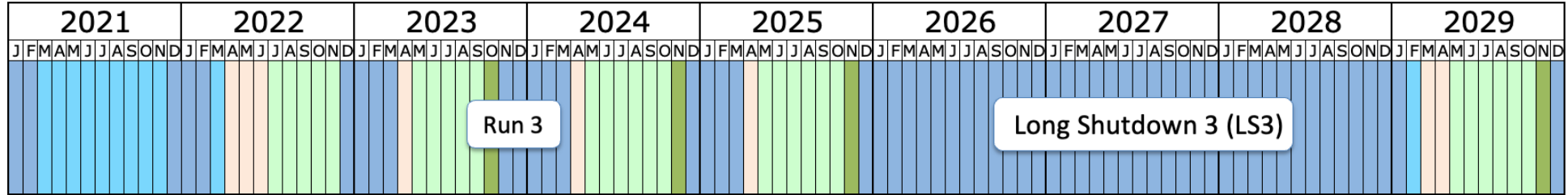
## ● Why is it important?

- 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.  $N_{Higgs} = \sigma_{Higgs} \int_{24hr} \mathcal{L} dt \approx (700 \text{ pb}^{-1})(50 \text{ pb}) = 35E3$
  - Particularly important for **cross-section measurements**



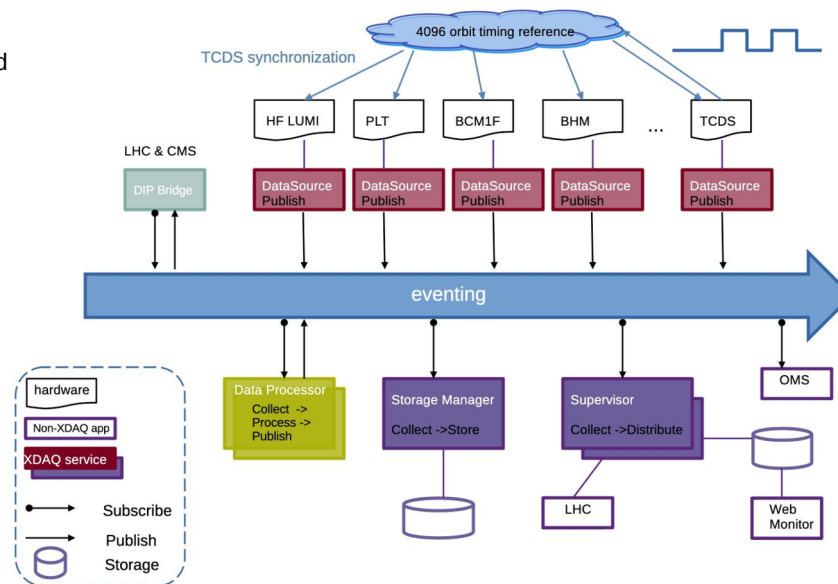


# LHC long-term schedule



Last update: April 2023

- 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)

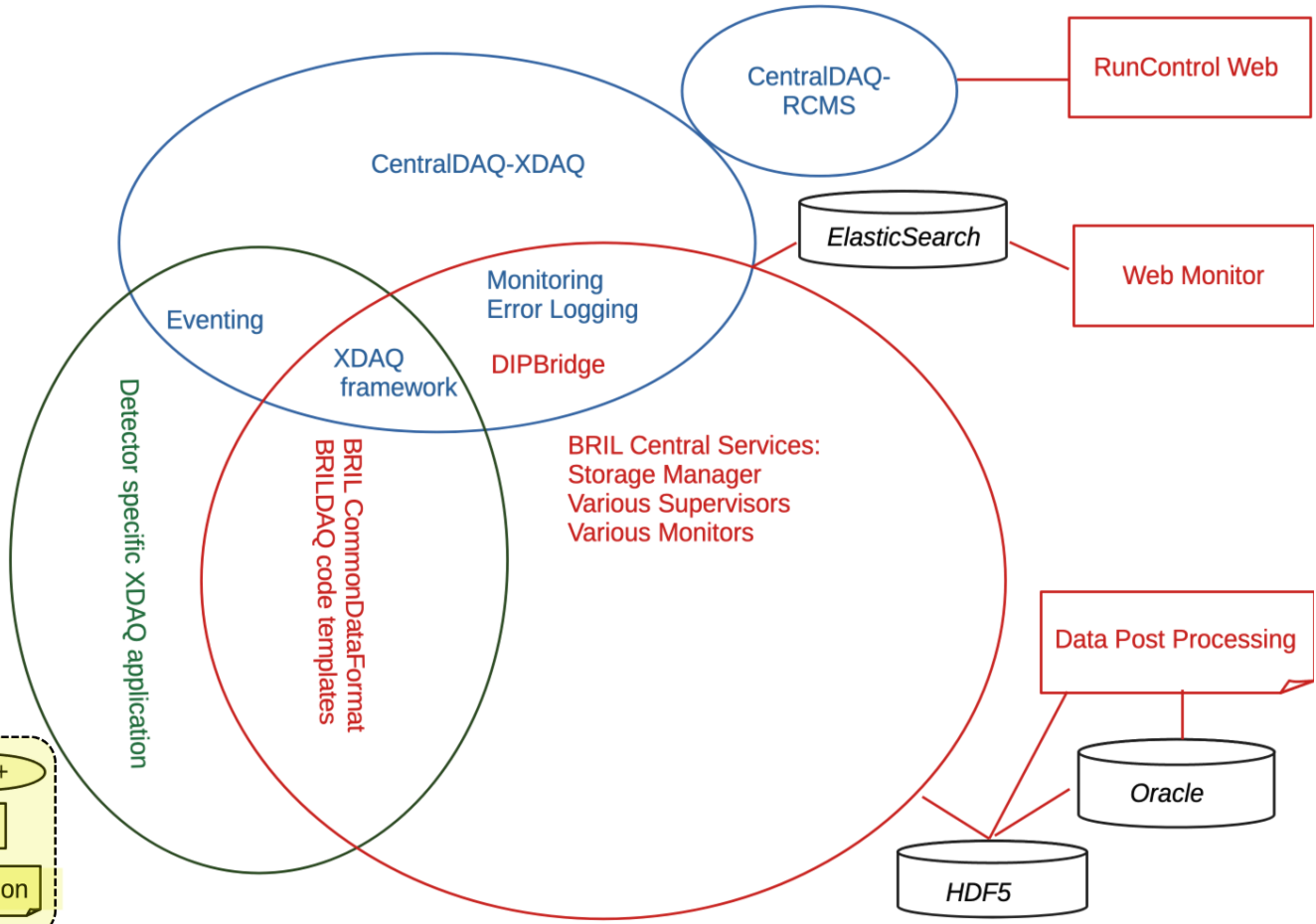


BRILDAQ-Core

BRILDAQ-Subsystem

Central DAQ

3<sup>rd</sup> party product



Programming Languages:

- C++
- JS
- Python

10/24/23





# BRILDAQ Web Monitor





# BRILDAQ Run Control Web

BRILDAQ controls lumipro

Links

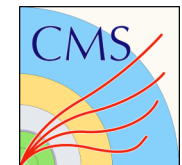
## Configuration tree

- central
  - global
    - BunchPatternProcessor
    - LuminosityMonitor
    - VDMScan
    - bestLumiProcessor
    - lumistore
    - newVDMMonitor
    - timesource\_hwclock
    - timesource\_selfclock
    - timesource\_tcdsclock
    - vdmstore
  - local
    - VDMMonitor
    - VDMScan
    - fakVDMSource
- dip
  - global
    - BCMFAnalyzer
    - BRILAlarms
    - LumiLevelling
    - commondataexchange
    - dipprocessor
    - lumidippublisher
- bcmf
  - global
    - bcmfprocessor
    - bcmfsource
    - lumistore
  - local
    - bcmfprocessor
    - bcmfsource
- bcmfputca
  - global
    - bcmfputcaprocessor
    - bcmfputcasource
    - localstore
    - timing\_processor
  - local
    - bcmfputcaprocessor
    - bcmfputcasource
- bcm1
  - global
    - bcm1
    - bcm1\_nostore
- bhm
  - global
    - bhmprocessor
    - bhmprocessor\_nostore
    - bhmsource
    - bhmsource\_nostore
    - lumistore

## Active configurations

/global/

/lumipro/central/global /LuminosityMonitor Host: srv-s2d16-15-01.cms Port: 6868 Lumi topics: pitlumizero,bcm1fumi,hfoculumi,hfeti utumi,dtumi,pitslinklumi,remuslumi,bcm1futcalumi	/lumipro/central/global/VDMScan Host: srv-s2d16-15-01.cms Port: 2987	/lumipro/central/global/bestLumiProcessor Host: srv-s2d16-21-01.cms Port: 9236 Bestlumi priority: bcm1fumi,bcm1futcalumi,hfeti utumi,pitlumizero,hfoculumi Minbias: 60000 InTopics: tcds,beam,pitlumizero,hfetlumi,hfoculumi,bcm1fumi,bcm1futcalumi	/lumipro/central/global/newVDMMonitor Host: srv-s2d16-15-01.cms Port: 1787	/lumipro/central/global/timesource_hwclock Host: srv-s2d16-21-01.cms Port: 4100	/lumipro/central/global/vdmstore Host: srv-s2d16-15-01.cms Port: 59000	/lumipro/dip/global/BRILAlarms Host: srv-s2d16-31-01.cms Port: 50427
/lumipro/dip/global/ /commondataexchange Host: srv-s2d16-21-01.cms Port: 50023 amodetag: PROTPHYS targetev: 0 flashlists: brlsummary,beam,vachisto,pitcurrents	/lumipro/dip/global/dipprocessor Host: srv-s2d16-31-01.cms Port: 50018	/lumipro/dip/global/lumidippublisher Host: srv-s2d16-31-01.cms Port: 50211	/lumipro/bcmf/global/bcmfprocessor Host: srv-s2d16-28-01.cms Port: 9010 calltag: 2022_09_Protons sigmavis: 0.33.0 SBILcalib: 0 Nonlinearity: 0 Excluded channels (Lumi): 1,10,27,40,41,42,43,45,46,47,16,6,7,9,28,29,21,17,30,31,22,15,23,24,25,0 Excluded channels (Bkgd): 1,10,15,23,24,25,27,40,41,42,43,45,46,47,16,6,7,9,28,29,21,17,30,31,22,0	/lumipro/bcmf/global/bcmfsource Host: srv-s2d16-28-01.cms Port: 50007	/lumipro/bcmf/global/lumistore Host: srv-s2d16-28-01.cms Port: 60025 Comisioning Mode: false File path: /localdata/2023	/lumipro/bcmfputca/global/bcmfputcaprocessor Host: srv-s2d16-16-01.cms Port: 9015
/lumipro/bcmfputca/global/bcmfputcasource Host: srv-s2d16-16-01.cms Port: 7070	/lumipro/bcm1/global/bcm1 Host: srv-s2d16-31-01.cms Port: 50073	/lumipro/bhm/global/bhmprocessor Host: srv-s2d16-13-01.cms Port: 9110 backgroundalgo: normalize: true bkgidbn: 1 class: SimpleBackground	/lumipro/bhm/global/bhmsource_nostore Host: srv-s2d16-13-01.cms Port: 9210 Z plus orbitphase: 0.50 Z minus orbitphase: 0.55 amplitude: true calenabile: false	/lumipro/bptx/global/bptxScopeProcessor Host: vmepc-s2d16-08-01.cms Port: 58008 Atolfactor_B1: 0.50 Atolfactor_B2: 0.50	/lumipro/dt/global/dtprocessor Host: srv-s2d16-25-01.cms Port: 4868 sigmavis: 0.50	/lumipro/hf/global/hfetprocessor Host: srv-s2d16-14-01.cms Port: 7115 sigmavis: 0.50
/lumipro/hf/global/hfocprocessor Host: srv-s2d16-14-01.cms Port: 7110 sigmavis: 0.83.0	/lumipro/hf/global/hfsource Host: srv-s2d16-14-01.cms Port: 6210	/lumipro/hf/global/lumistore Host: srv-s2d16-14-01.cms Port: 60025 bus: hf filepath: /localdata/hfdata001	/lumipro/plt/global/pltprocessor Host: vmepc-s2d16-06-01.cms Port: 9203 calltag: pit_MagnetOn_2021Test calibrzerotag: pitzero_MagnetOn_2021Test use mask: 0 excludechannels: 4,5,6,7,8,9 accidentalspzero: 0 accidentalspnone: 0.0	/lumipro/plt/global/pitsinkprocessor Host: vmepc-s2d16-06-01.cms Port: 9233	/lumipro/plt/global/pltsource Host: vmepc-s2d16-06-01.cms Port: 9213	/lumipro/remus/global/remusprocessor Host: srv-s2d16-15-01.cms Port: 5078 InTopics: dip/REMUS/CMS/PMIL5514,dip/REMUS/CMS/PMIL5515,dip/REMUS/CMS/PMIL5516,dip/REMUS/CMS/PMIL5517 bestTopic: dip/REMUS/CMS/PMIL5515 inCalibrations: 9,2995,9,8215,34,1823,32,4344

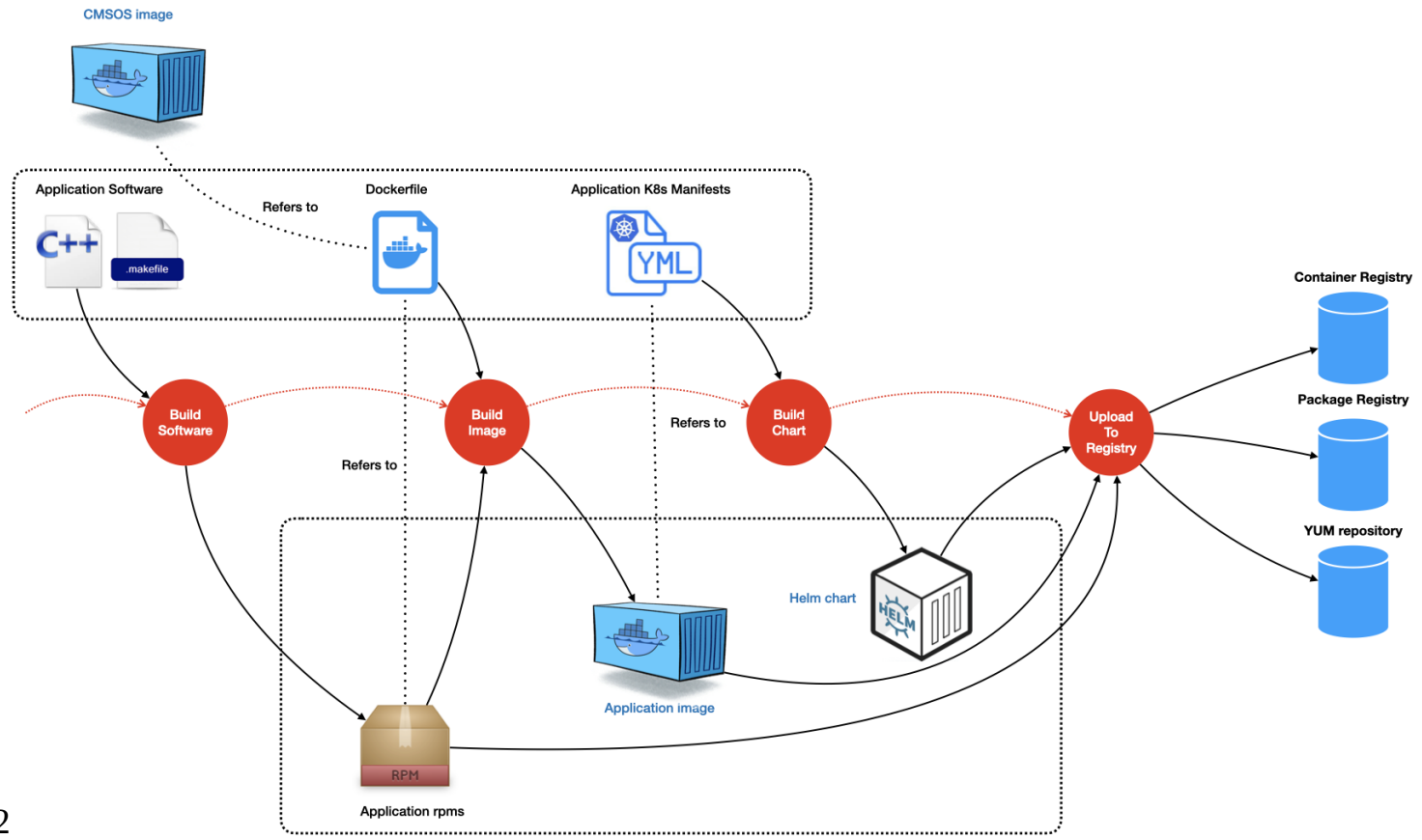


# BRILDAQ-Core: Area of Development (Phase-2)



- 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 protocol + 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



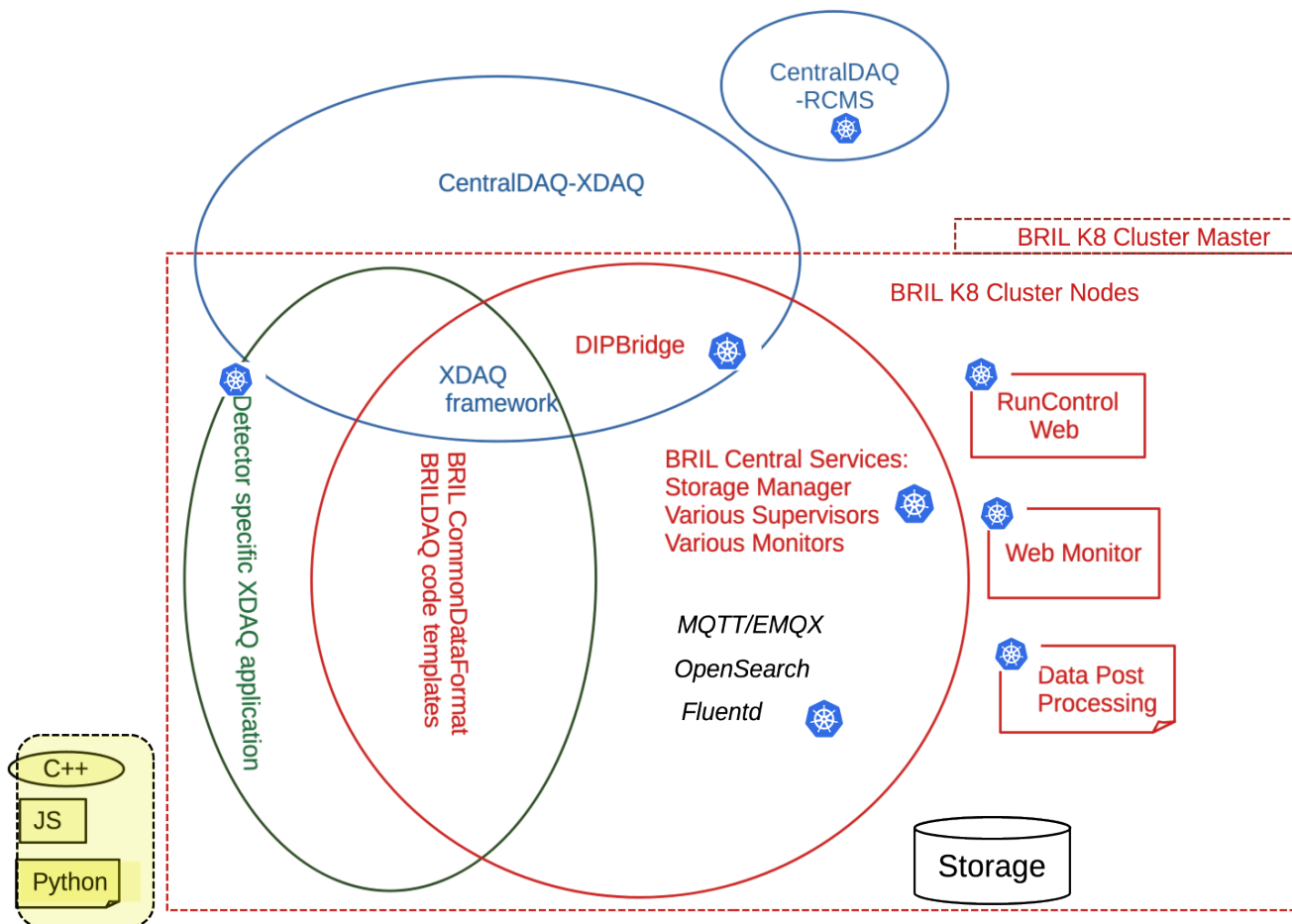
# A mental image of BRILDAQ development areas in Phase-2

BRILDAQ-Core

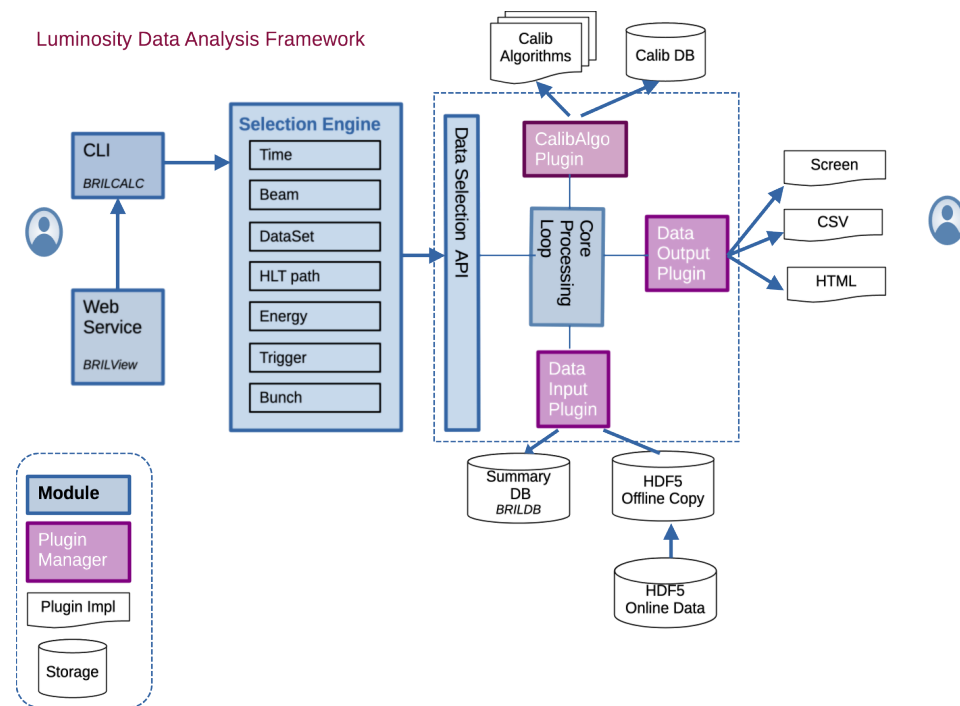
BRILDAQ-Subsystem

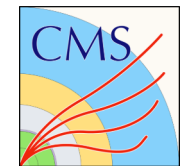
Central DAQ

3<sup>rd</sup> party product



- 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  $\sim 1$ sec in Phase-2. As consequence the data granularity will increase  $\sim 20$  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

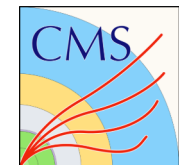


## Summary: direction of changes in BRIL Phase-2 software



- 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