Reduced Formats at Belle II.

Michel Hernandez Villanueva
DESY

Analysis Ecosystems Workshop II
May 23 - 25, 2022

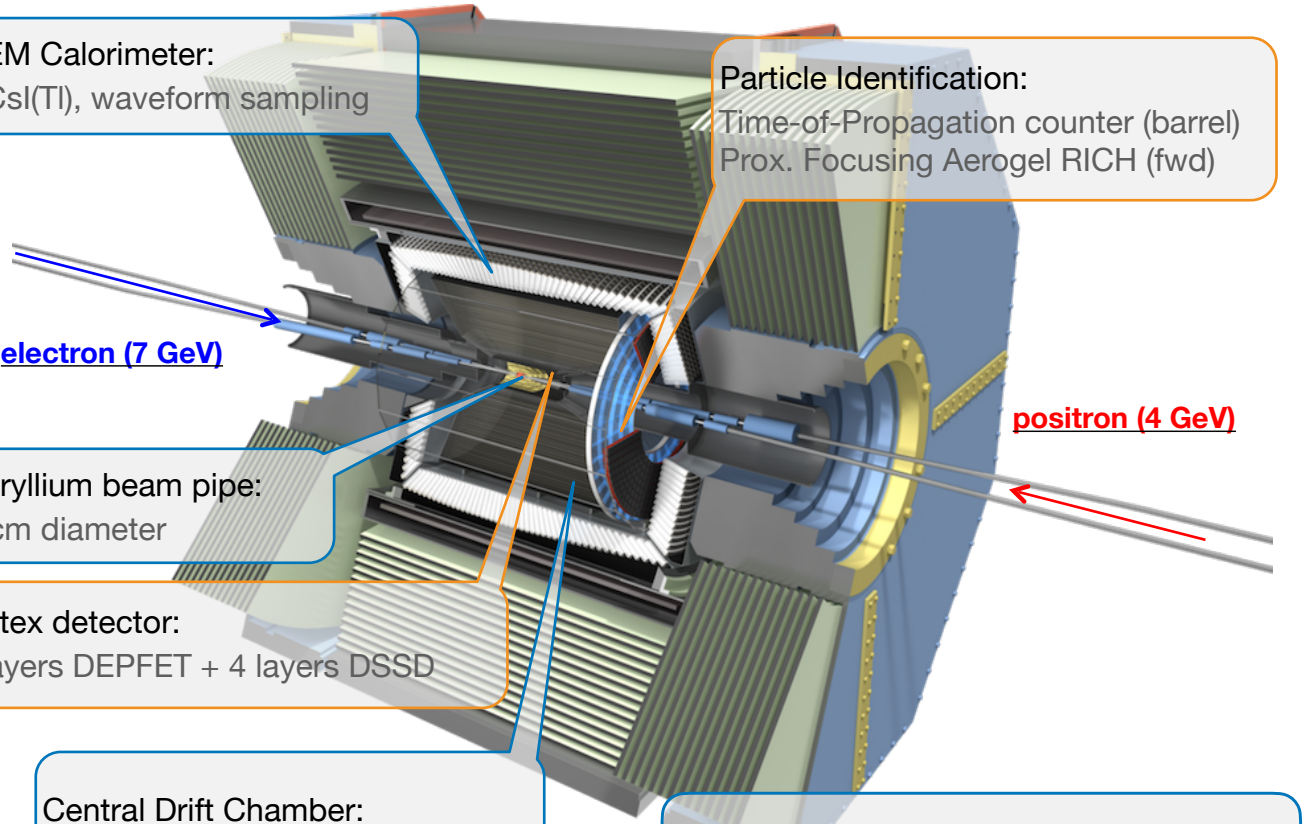
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Belle II

DESY.

The Belle II Experiment

Hardware, Software and Computing in a Nutshell



EM Calorimeter:
CsI(Tl), waveform sampling

Particle Identification:
Time-of-Propagation counter (barrel)
Prox. Focusing Aerogel RICH (fwd)

electron (7 GeV)

positron (4 GeV)

Beryllium beam pipe:
2 cm diameter

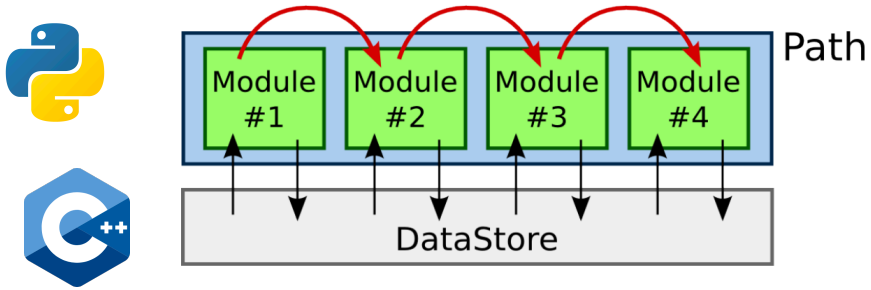
Vertex detector:
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber:
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

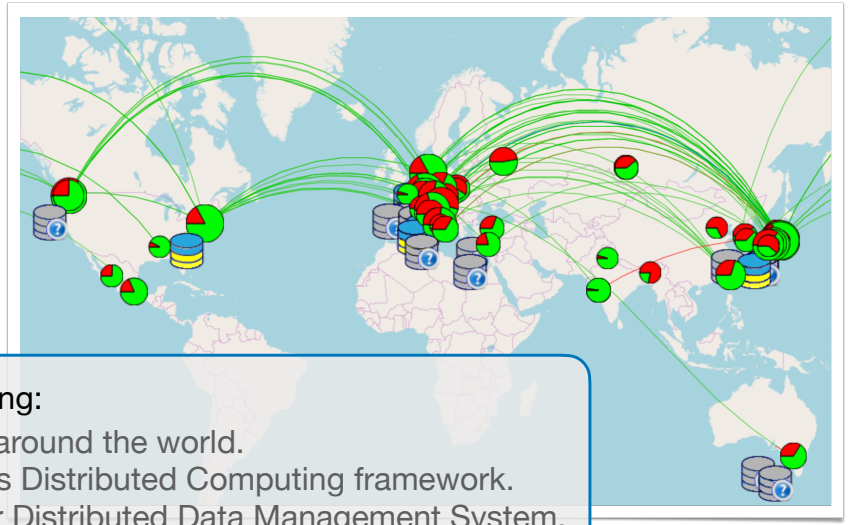
Readout (TRG, DAQ):
Max. 30kHz L1 trigger
~100% efficient for hadronic events.
1MB (PXD) + 100kB (others) per event
Over 30 GB/sec to process

arXiv:1011.0352 [physics.ins-det]

Software:
Open-source algorithms for simulation, reconstruction, visualization, and analysis.



Comput. Softw. Big Sci. 3 1 (2019)



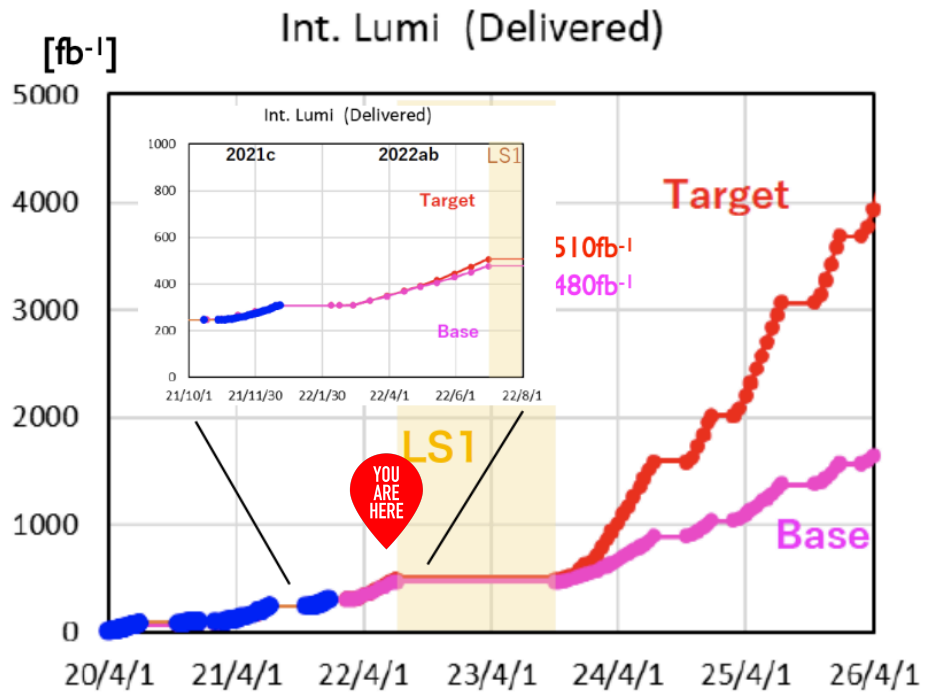
Computing:
55 sites around the world.
DIRAC as Distributed Computing framework.
Rucio for Distributed Data Management System.

EPJ Web Conf., 245 (2020) 11007

DESY.

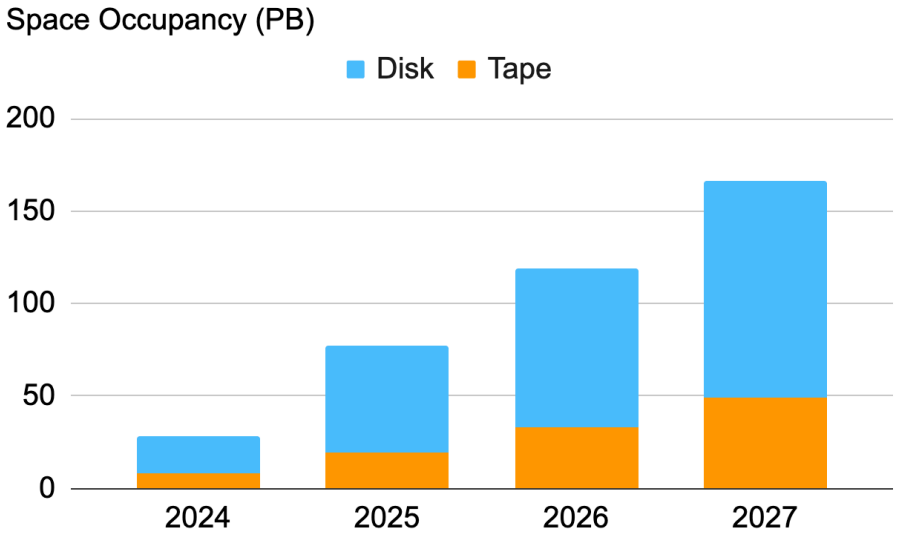
Data Taking at Belle II

Let's talk about numbers



- Integrated luminosity expected by the end of the experiment: 50 ab^{-1}
  (x50 than the previous B factories)

- The estimated size of the dataset collected by the experiment is O(10) PB/year.



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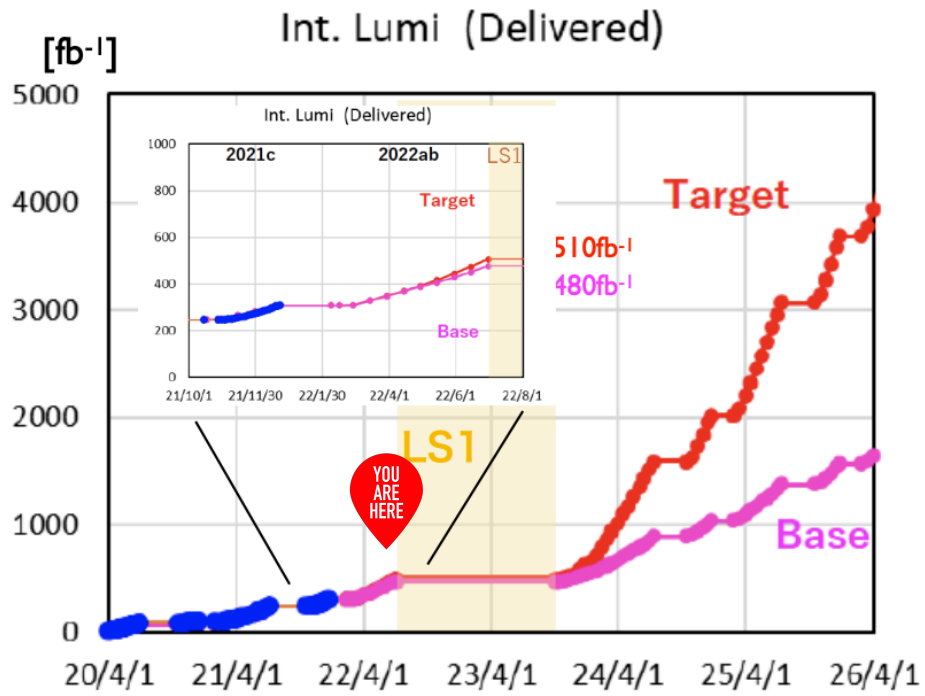

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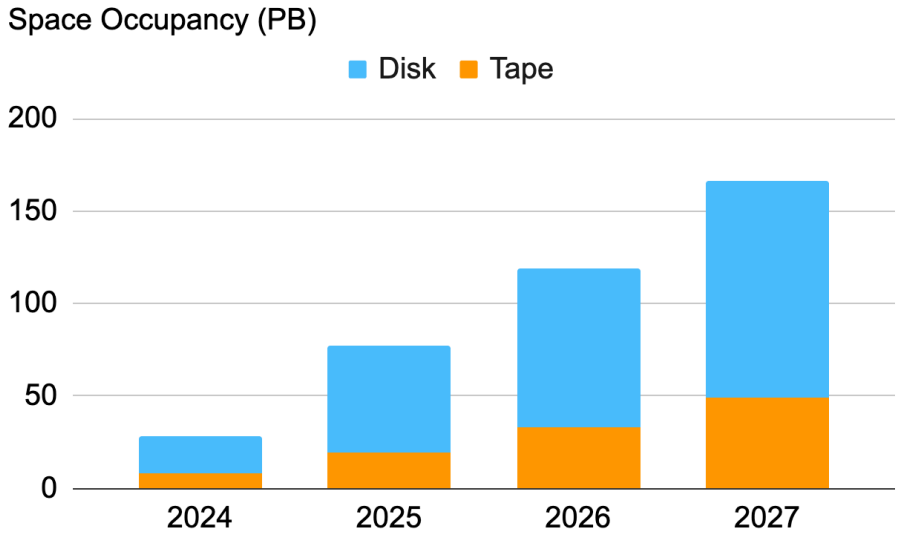
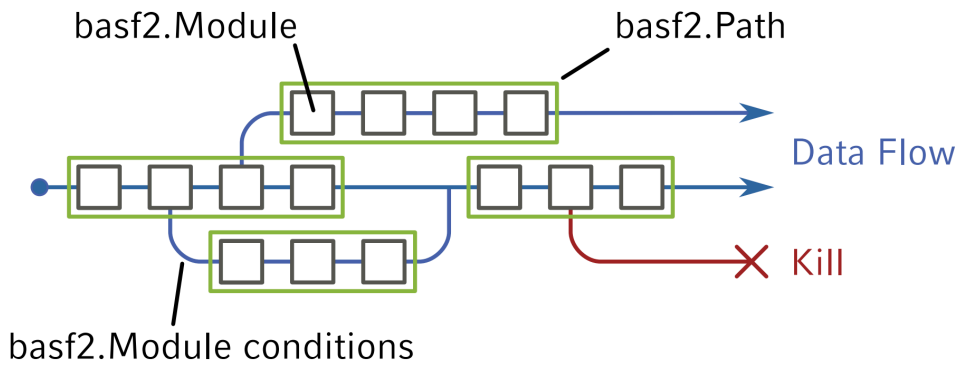


- Not as large when compared to HL-LHC scales, but **corresponds to 10^{12} events,** representing a significant data management challenge.

Belle II analysis software framework

A high-level analysis software

- **Basf2**: Belle II Analysis Software Framework.
  - More of a software framework than an “analysis framework”.
    (It also performs the unpacking of raw data, tracking, clustering, …)
- The executable is a wrapper for IPython 3.
  - Controls the sequence in which modules are executed.



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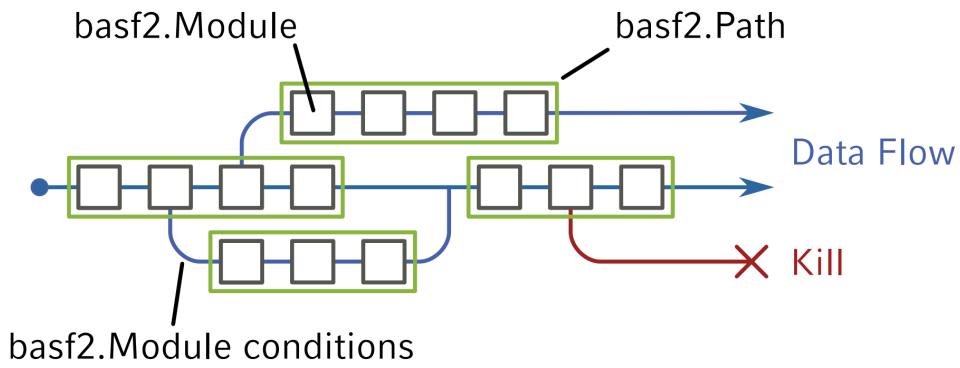
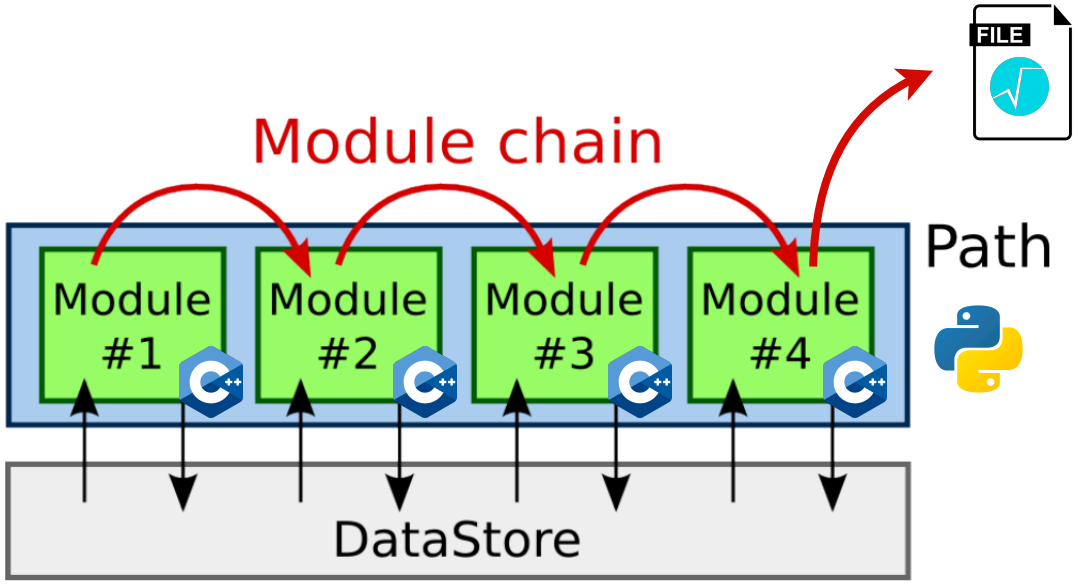
- The executable is a wrapper for IPython 3.
  - Controls the sequence in which modules are executed.
- Modules are blocks of code that perform a specific task.
  - C++ under the hood.
  - They exchange data via the **DataStore**, a globally accessible interface to mutable objects.
- ROOT is used for persistency.
  - Output modules write the content of the DataStore to TTrees.
  - Permanent and event-durability objects are stored separated.





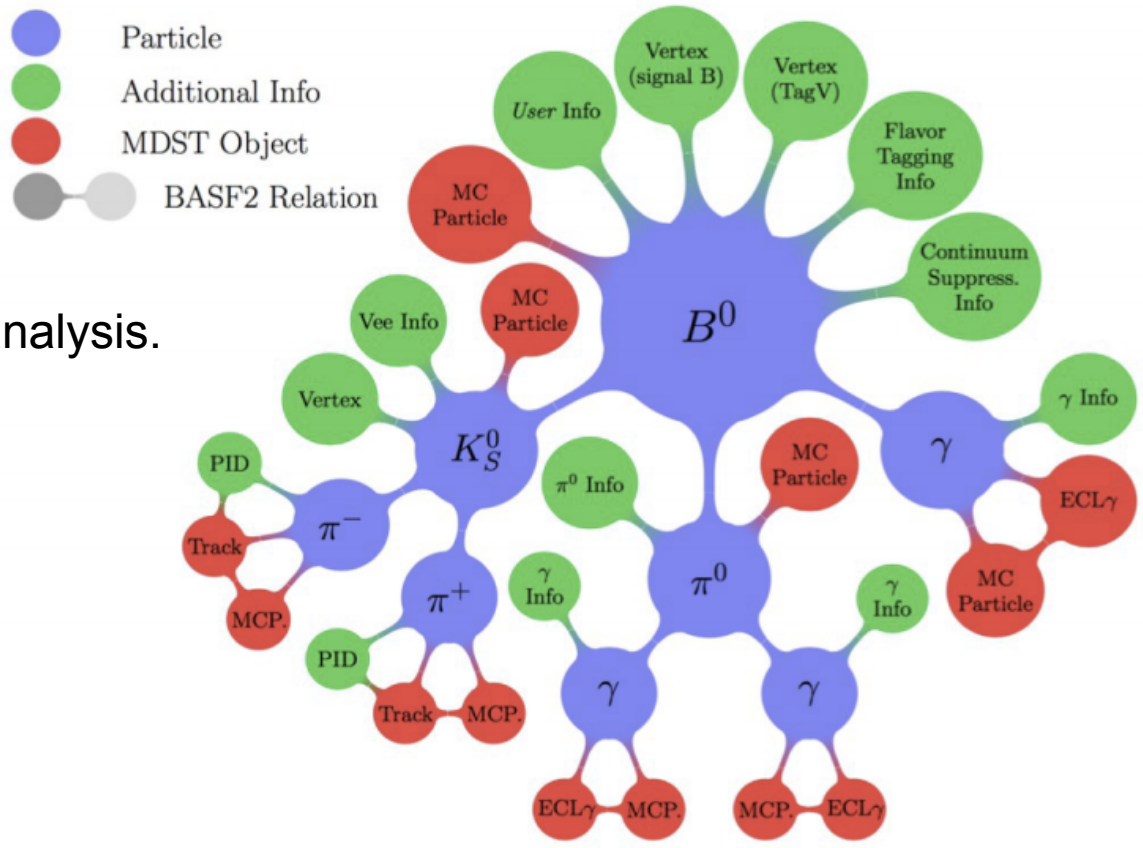
Data Formats

ROOT files containing subsets of objects

- **Raw**:
  - ~70 kB/event
  - Defined by the detector readout.

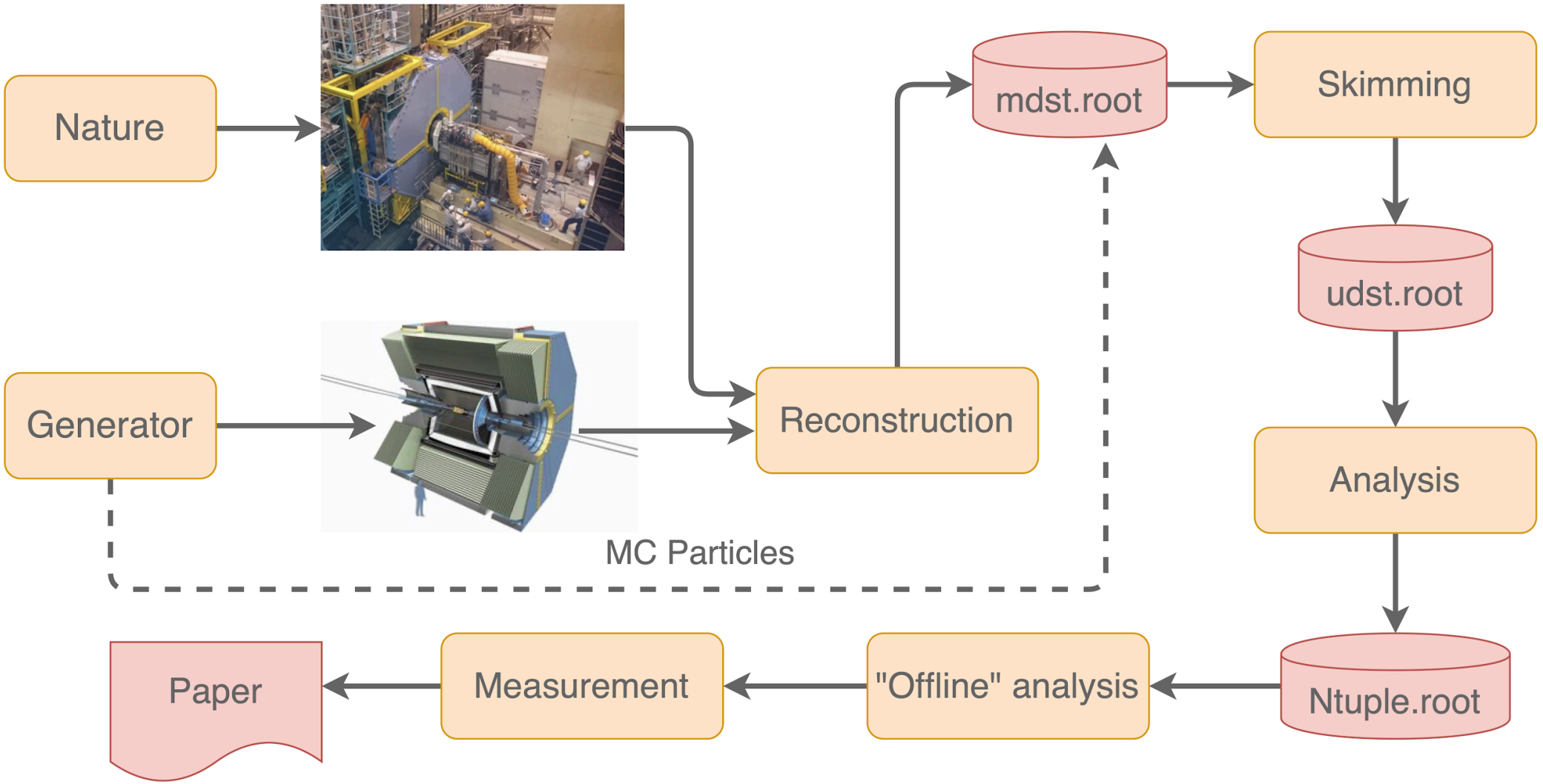
- **mDST**: mini Data Summary Table
  - ~15 kB/event
  - Strictly controlled subset of objects necessary for analysis.
    - Tracks, clusters, MC information, etc.
  - No ‘raw’ data information is stored.

- **uDST**: user data summary table
  - ~20 kB/event
  - mDST objects + analysis objects (**ParticleLists**).
  - Contains a subset of the events stored in mDSTs.
  - Intended for end-user physics analysis.



Analysis Workflow

From data taking to physics results



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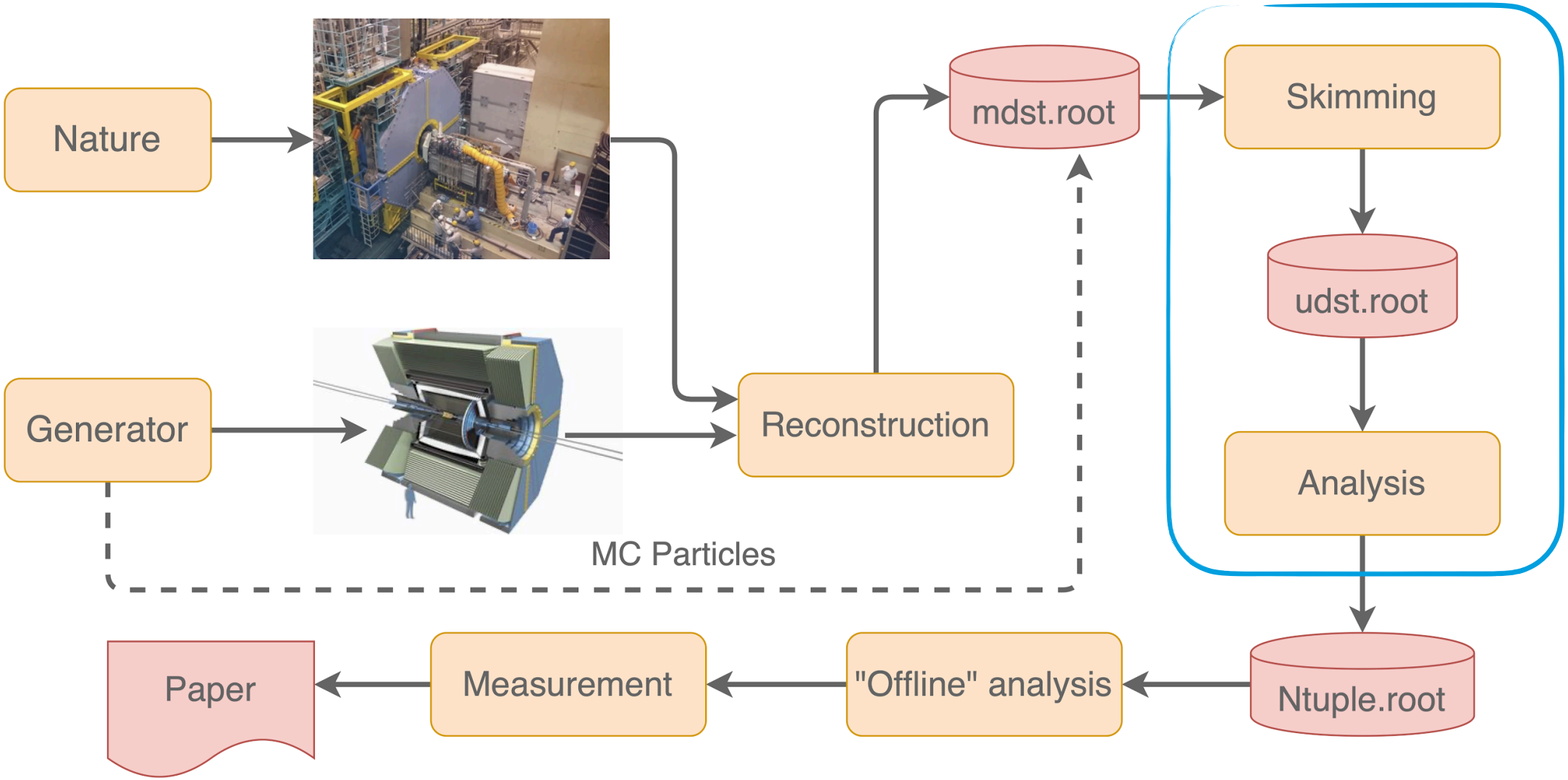

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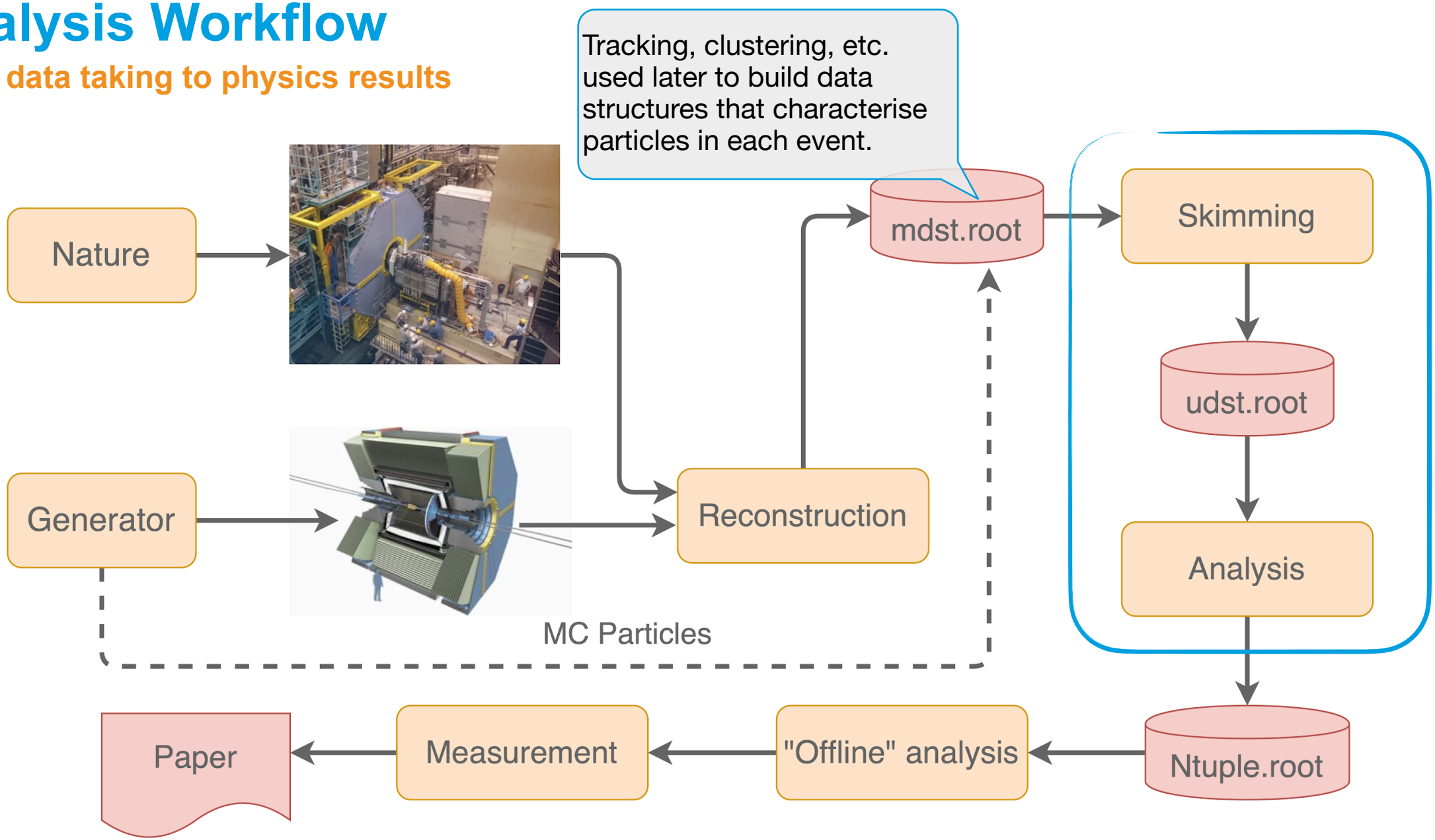

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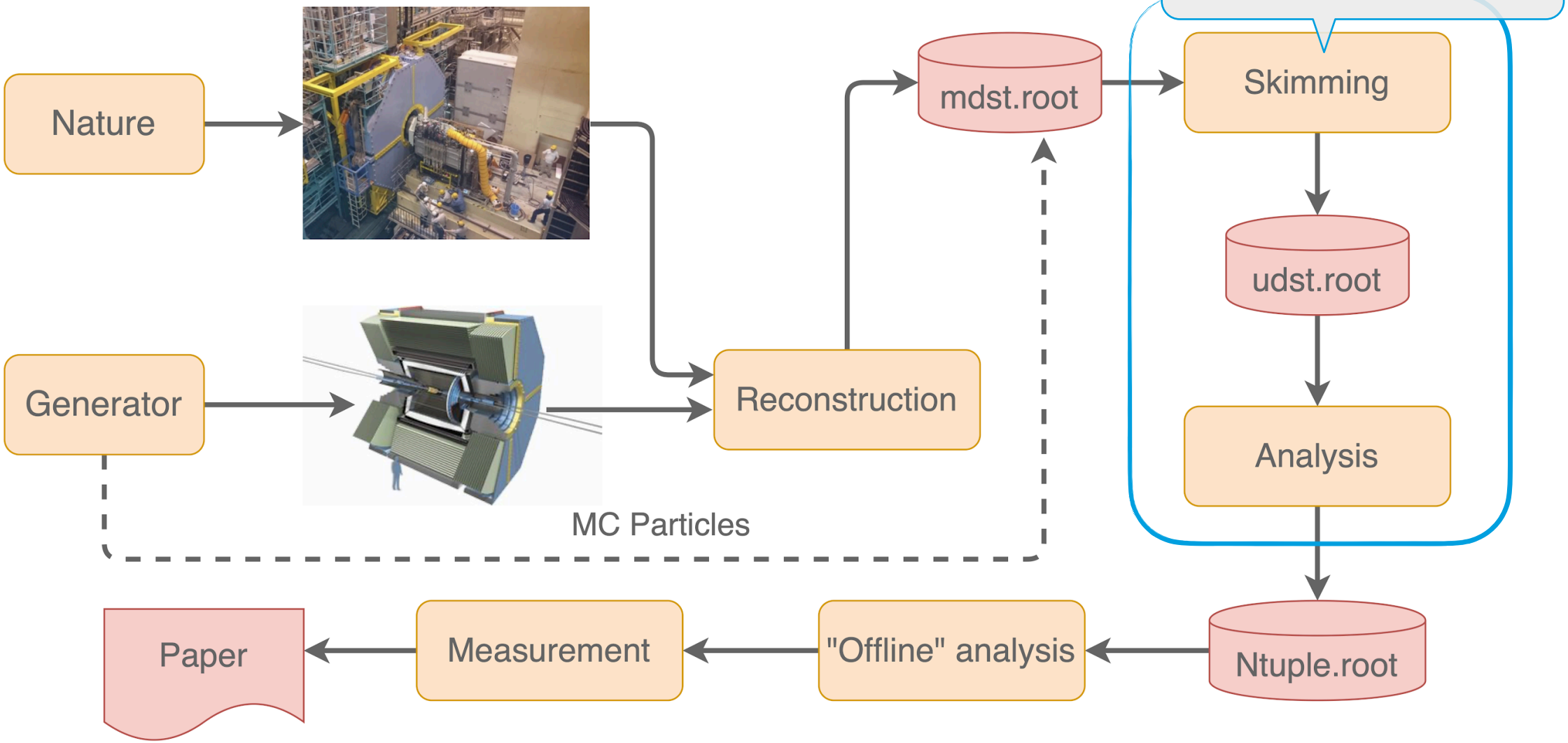

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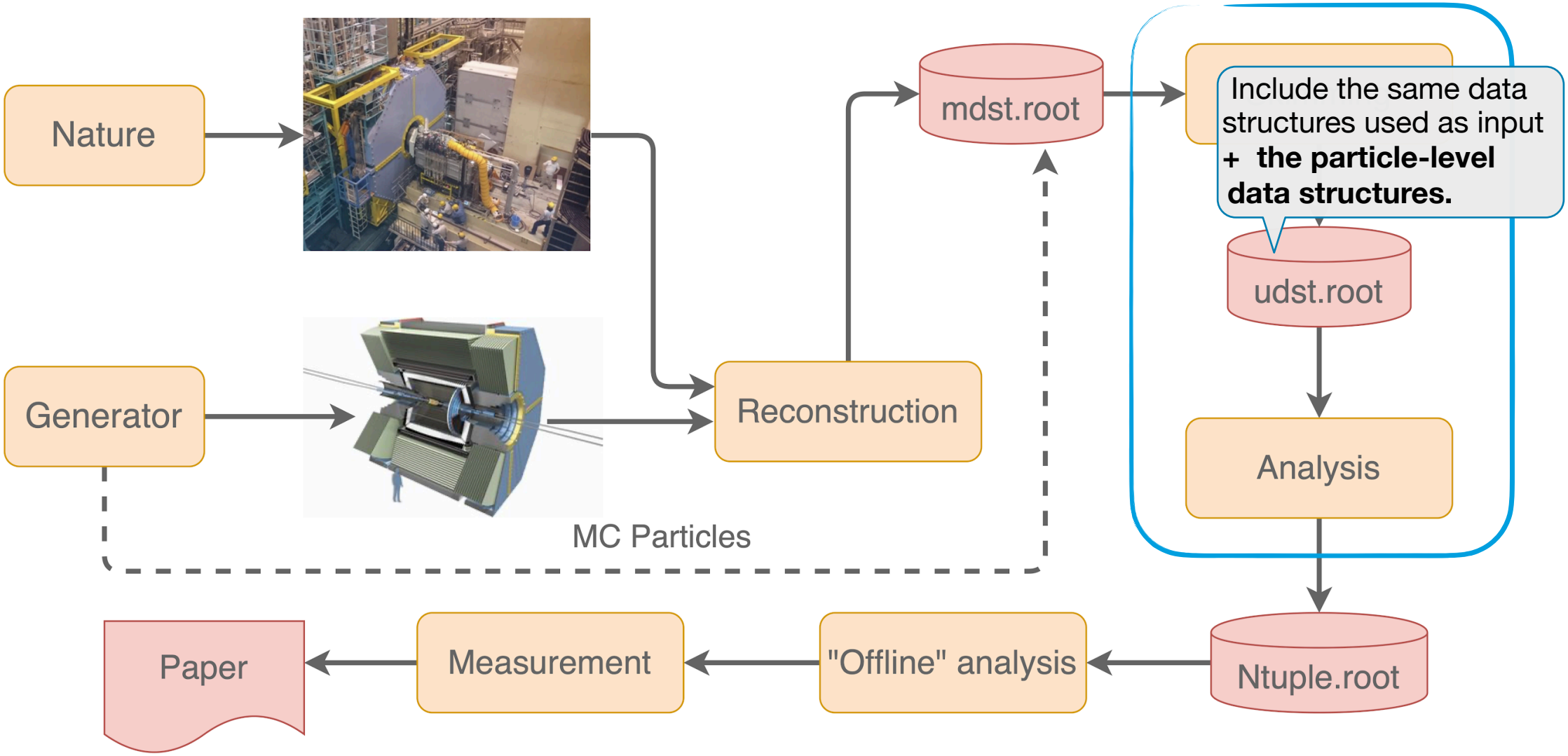


mDST & uDST

Objects stored for characterisation of events/particles

- The mDST content is strictly limited to information required by general physics analyses.

- **Tracking**
  - *Track*: Objects representing reconstructed trajectories. Contain references to track fit results for multiple mass hypotheses and a quality indicator.
  - *TrackFitResult*: five helix parameters, their covariance matrix, a fit *p*-value, and the pattern of layers with hits in the vertex detector and drift chamber, degrees of freedom of the fit.

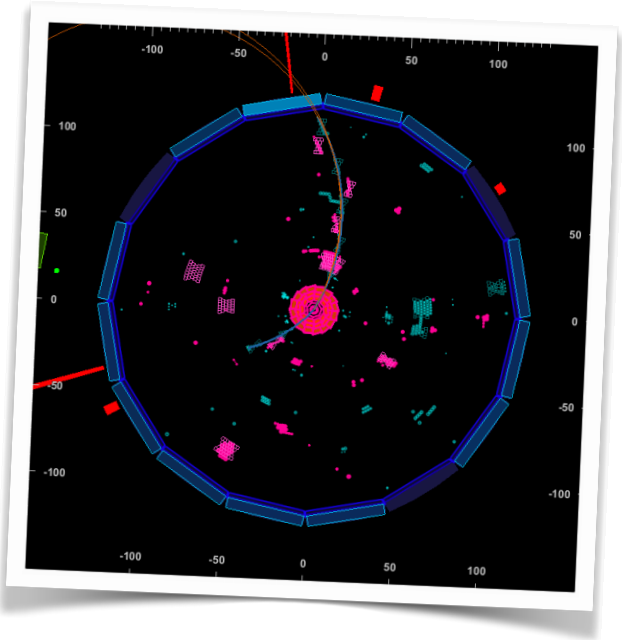
- **Vertex**:
  - *V0*: Candidate of a K_S^0 or Λ decay, or a converted photon, with references to the pair of positively and negatively charged daughter tracks.

- **Energy Clusters**
  - *ECLCluster:* energy and position measurements and their correlations, along with shower-shape variables.
  - *KLMCluster:* position measurement and momentum estimate for a cluster in the K_L^0 and muon detector.

mDST & uDST (cont)

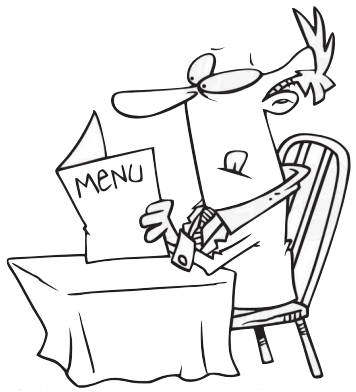
Objects stored for characterisation of events/particles

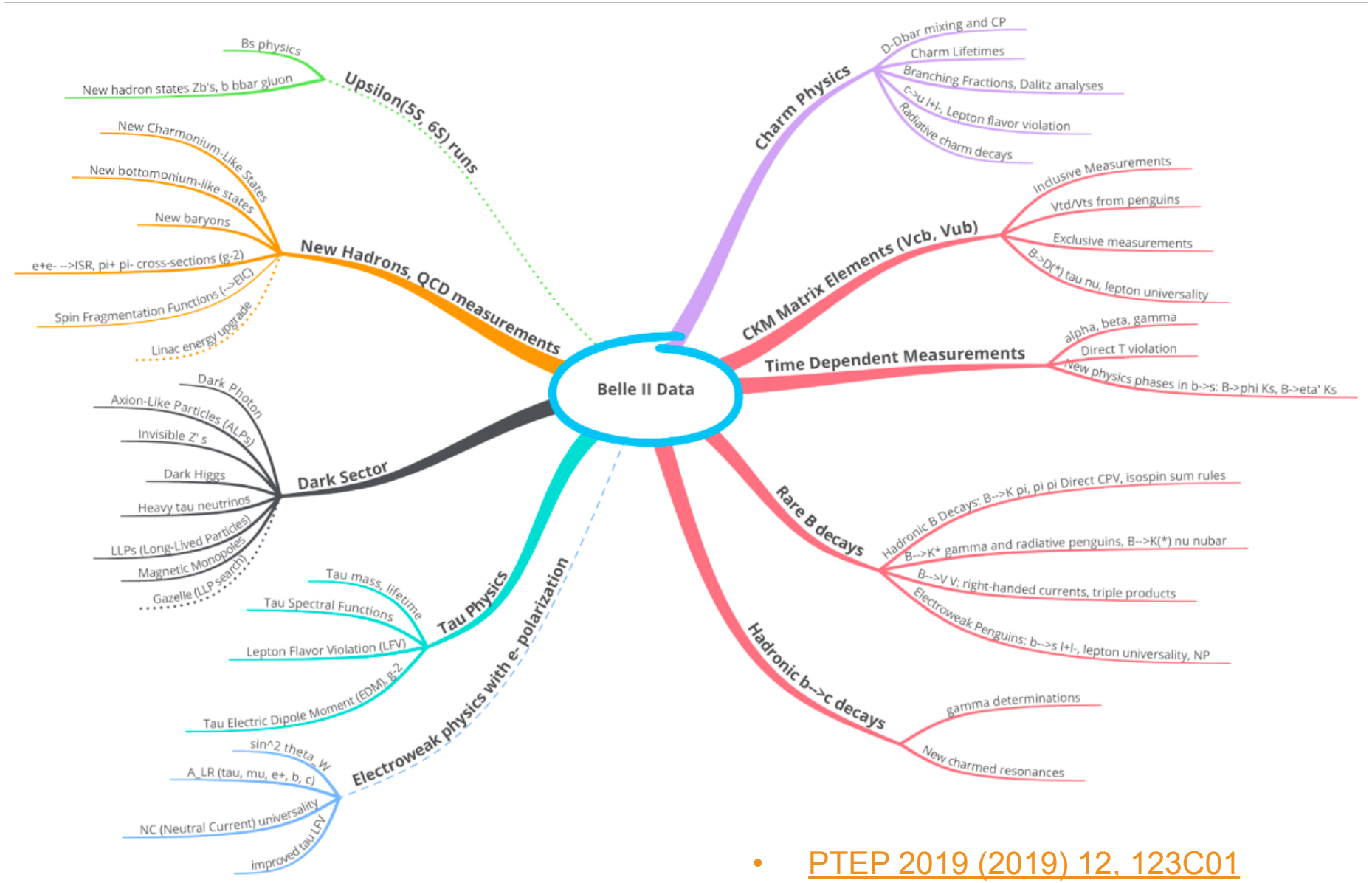
- **Particle Identification**
  - *PIDLikelihood:* likelihoods for being an electron, muon, pion, kaon, proton or deuteron from each detector.
  - *KlId:* candidate for a K_L^0 meson, providing particle identification information in weights of relations to KLM and/or ECL clusters.
- **Trigger**
  - *TRGSummary*: information about level 1 trigger decisions before and after prescaling.
  - *SoftwareTriggerResult*: the decision of the high-level trigger.
- **MC information**
  - *MCParticle:* Information about a simulated particle containing the momentum, production and decay vertex, relations to mother and daughter particles.
- **Particle candidates** (only uDST)**:**
  - *ParticleList*: stores a collection of *Particle* objects (*link* to GitHub).



Belle II Physics Program

- The physics program of Belle II covers measurements in B decays, charm, dark sectors, exotic particles, etc.
- Each physics working group has its own (often unique) analysis requirements.





- PTEP 2019 (2019) 12, 123C01

Skim Definition

Python-based classes developed by liaisons of each WG.

```
@fancy_skim_header
class LeptonicUntagged(BaseSkim):
    """
    Reconstructed decays
        * :math:`B^- \\to e^-`
        * :math:`B^- \\to \\mu^-`

    Cuts applied
        * :math:`p_{\\ell}^{*} > 2\\,\\text{GeV}` in CMS Frame
        * :math:`\\text{electronID} > 0.5`
        * :math:`\\text{muonID} > 0.5`
        * :math:`n_{\\text{tracks}} \\geq 3`
    """

    __authors__ = ["Phillip Urquijo"]
    __contact__ = __liaison__
    __description__ = (
        "Skim for leptonic analyses, "
        ":math:`B_{\\text{sig}}^-\\to\\ell\\nu`, where :math:`\\ell=e,\\mu`"
    )
    __category__ = "physics, leptonic"

    RequiredStandardLists = {
        "stdCharged": {
            "stdE": ["all"],
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https://github.com/belle2/basf2/tree/main/skim/scripts/skim/WGs

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1. Load the required particle lists.

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```python
    def build_lists(self, path):
        ma.cutAndCopyList(
            "e-:LeptonicUntagged",
            "e-:all",
            "useCMSFrame(p) > 2.0 and electronID > 0.5",
            True,
            path=path,
        )
        ma.cutAndCopyList(
            "mu-:LeptonicUntagged",
            "mu-:all",
            "useCMSFrame(p) > 2.0 and muonID > 0.5",
            True,
            path=path,
        )
        ma.reconstructDecay("B-:LeptonicUntagged_0 -> e-:LeptonicUntagged", "", 1, path=path)
        ma.reconstructDecay("B-:LeptonicUntagged_1 -> mu-:LeptonicUntagged", "", 2, path=path)
        ma.applyCuts("B-:LeptonicUntagged_0", "nTracks>=3", path=path)
        ma.applyCuts("B-:LeptonicUntagged_1", "nTracks>=3", path=path)
        lepList = ["B-:LeptonicUntagged_0", "B-:LeptonicUntagged_1"]
        self.SkimLists = lepList
```

2. Apply cuts.

https://github.com/belle2/basf2/tree/main/skim/scripts/skim/WGs

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        lepList = ["B-:LeptonicUntagged_0", "B-:LeptonicUntagged_1"]
        self.SkimLists = lepList
```

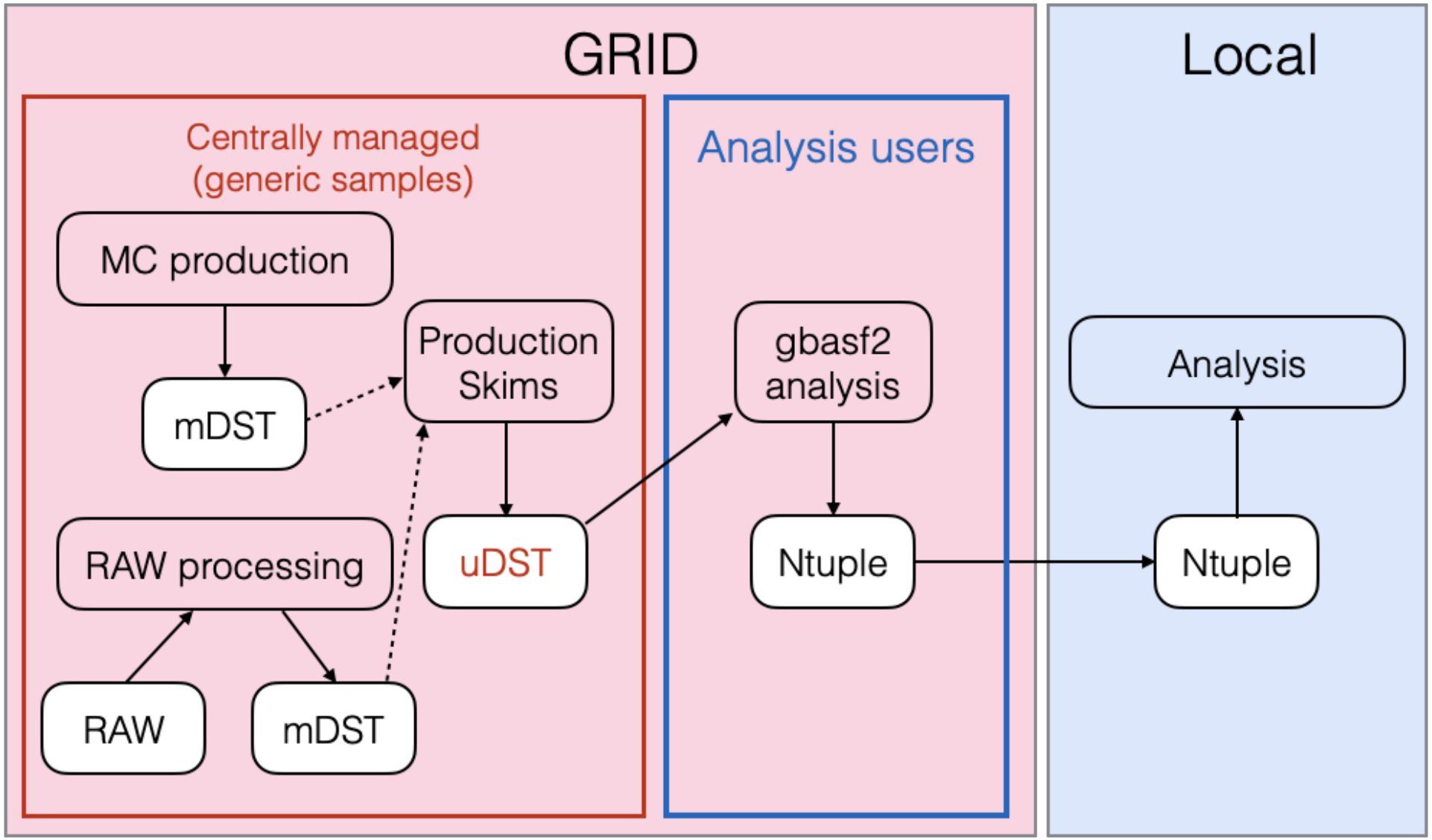
3. Reconstruct output particle lists
(will be available in the udst).

https://github.com/belle2/basf2/tree/main/skim/scripts/skim/WGs

- Requirements on retention rate / memory usage defined by the skimming managers must be fulfilled.

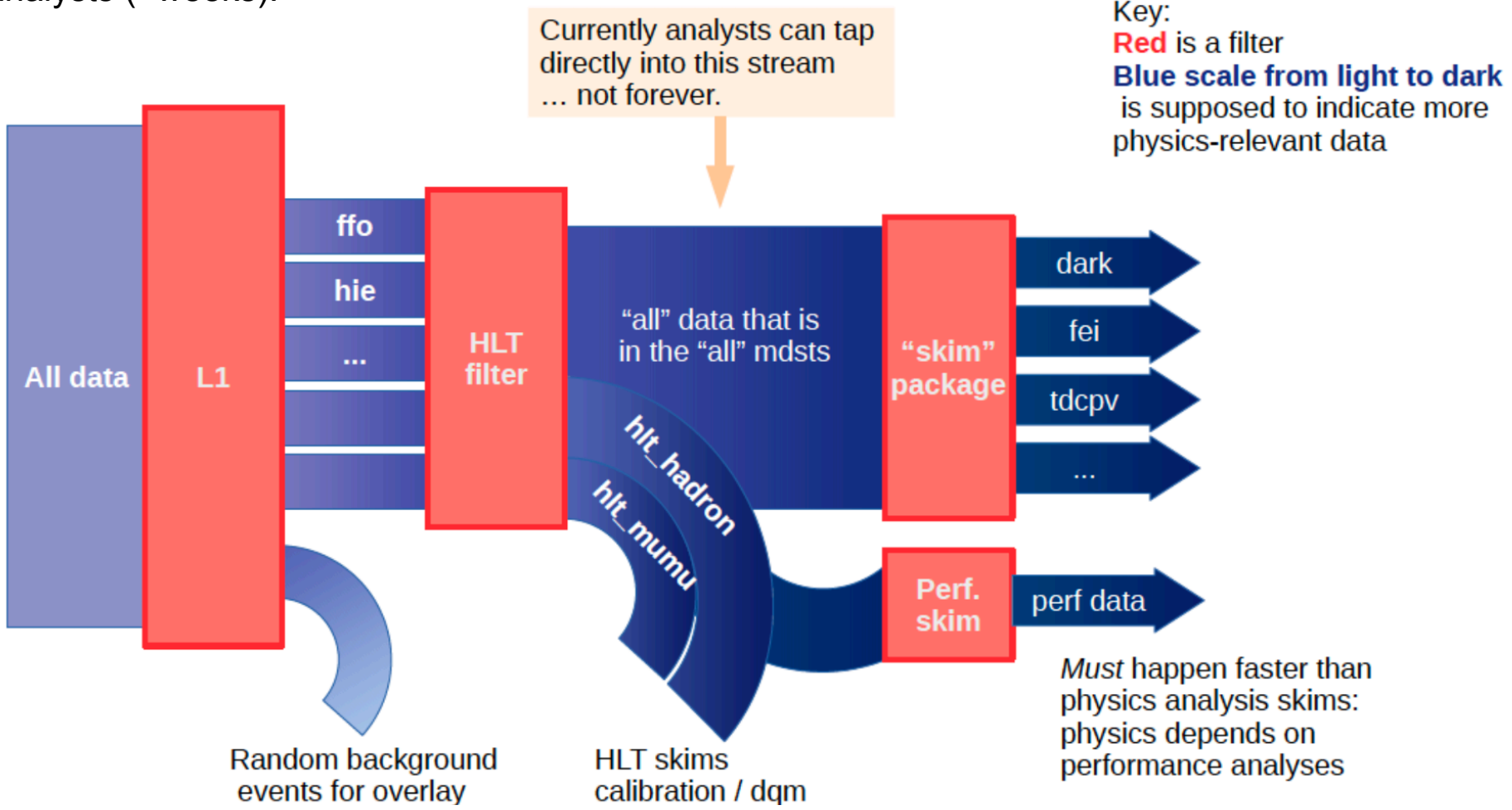
Data Processing

Scheme



Analysis on Reduced Data

- Analysis skims run on all data events every reprocessing campaign.
  - A considerable delay for analysts (~weeks).
- Running on HLT skimmed data (<10%) can improve the processing time.
  - But not suitable for all physics groups.
- Not all analyses are suitable for a skim definition.
  - They present very high retention rates.



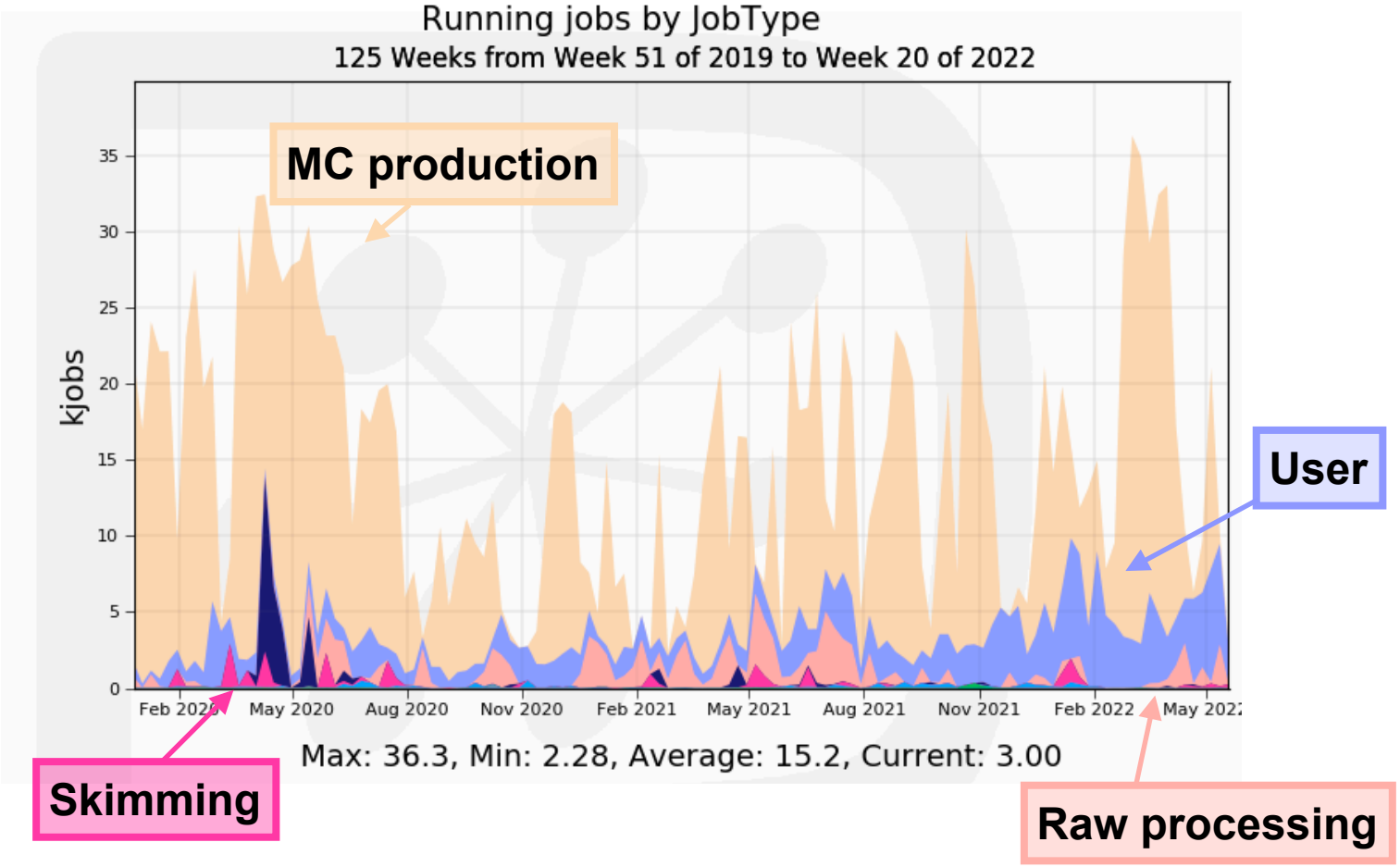
Activity on the grid

Performing grid-based analysis on data since Jan 2020

- Production activities dominate the grid CPU usage
  - MC production: 81%
  - Data processing: 7%
  - Skimming: 2%

- Skimming represent heavy I/O operations without significant impact in CPU.

- **Issues identified:**
  - Current bottleneck in analysis is the production of skims from data due to the heavy IO operations.
  - 70-80 individual skims are defined.
    - Data popularity in Rucio will provide answers if all of them are used.
  - Analysis with non-skimmed data put a heavy load on the grid services.



Challenges for data preservation

Considering the long-term implications

- By the end of the Belle II experiment, ~14 PB of skimmed data + 15 PB of MC will be preserved.
  - At least one order of magnitude larger than the data preserved by previous experiments (CDF, D0, BaBar).
  - Multiple copies of the Belle II data should be preserved to avoid data loss from hardware failures.

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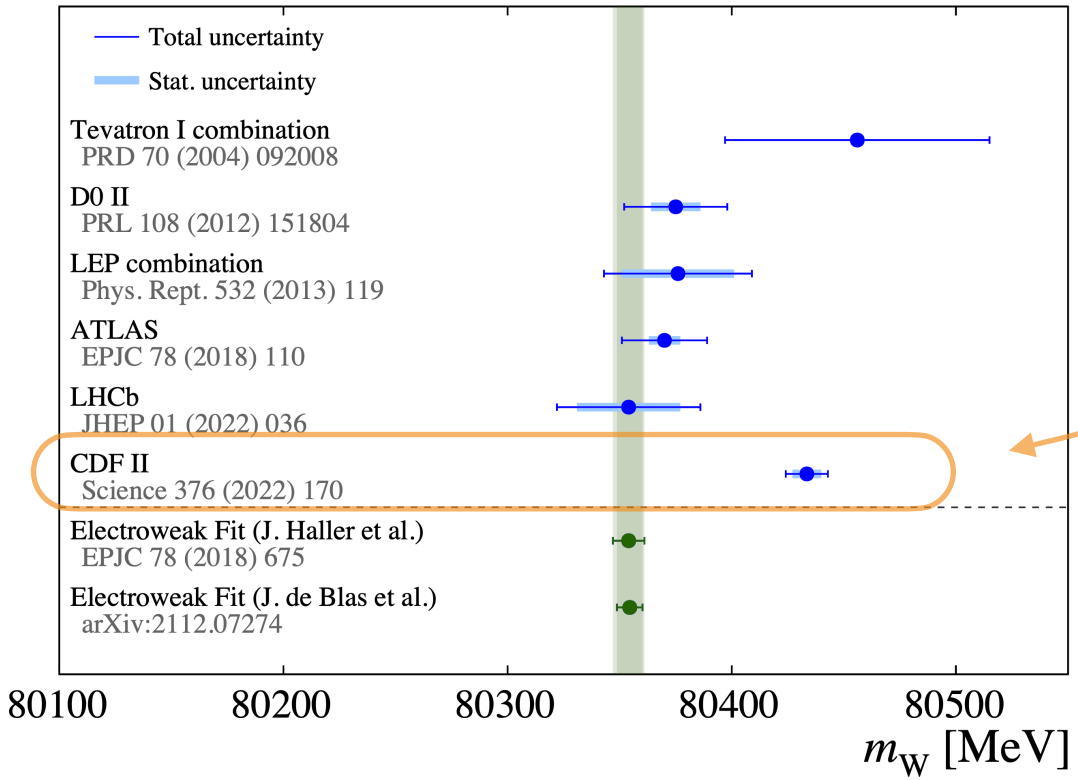

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  - Data reprocessing require of operative central services (like conditions DB).

- The Belle II analysis software framework (and therefore the capacity of **interpreting correctly the data formats**) depends on external libraries and several software packages.
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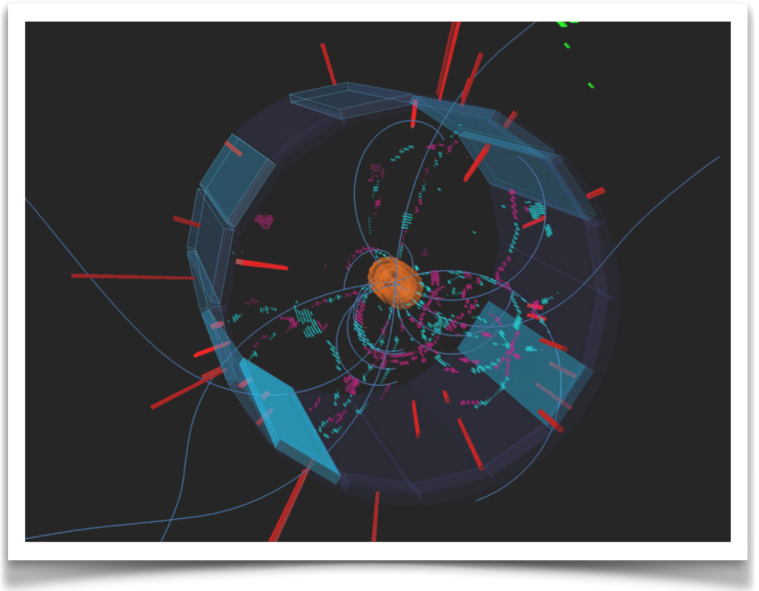
  - Considerations must be made to **ensure usability of the software** after the shutdown of the experiment.

- Broader discussions of the feasibility of long-term data analysis that relies on central services would be valuable to the HEP community.
  - In particular, **identifying services that would benefit from common use by many experiments** would aid long-term data preservation and analysis plans.

Summary

- Belle II is a multipurpose, high-intensity experiment that will collect x50 times more int luminosity than previous B-Factories.
- Reduced data formats at Belle II are ROOT files with subsets of events, designed for reducing impact in storage and I/O operations while maximising the physics potential.
- Skims are defined by the needs of each WG, keeping only events that pass the minimum criteria.
- Analysts only have to run over skims without need to recreate the particle-level information, greatly reducing the necessary computing power, though at the cost of storage needs.
- Major challenge is how to deal with current and future analyses not compatible with the skimming scheme.
  - Retention rate too high, or signal not covered by any skim definition.

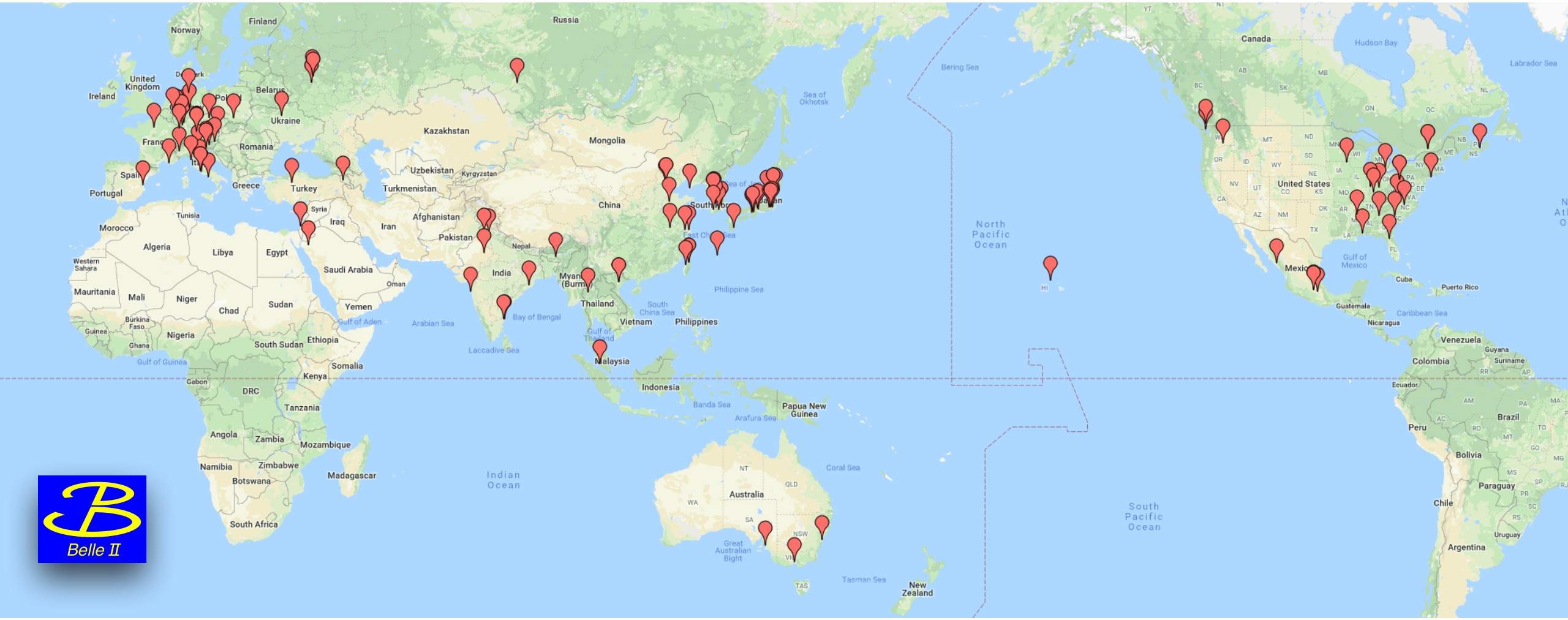


Thank you

Backup

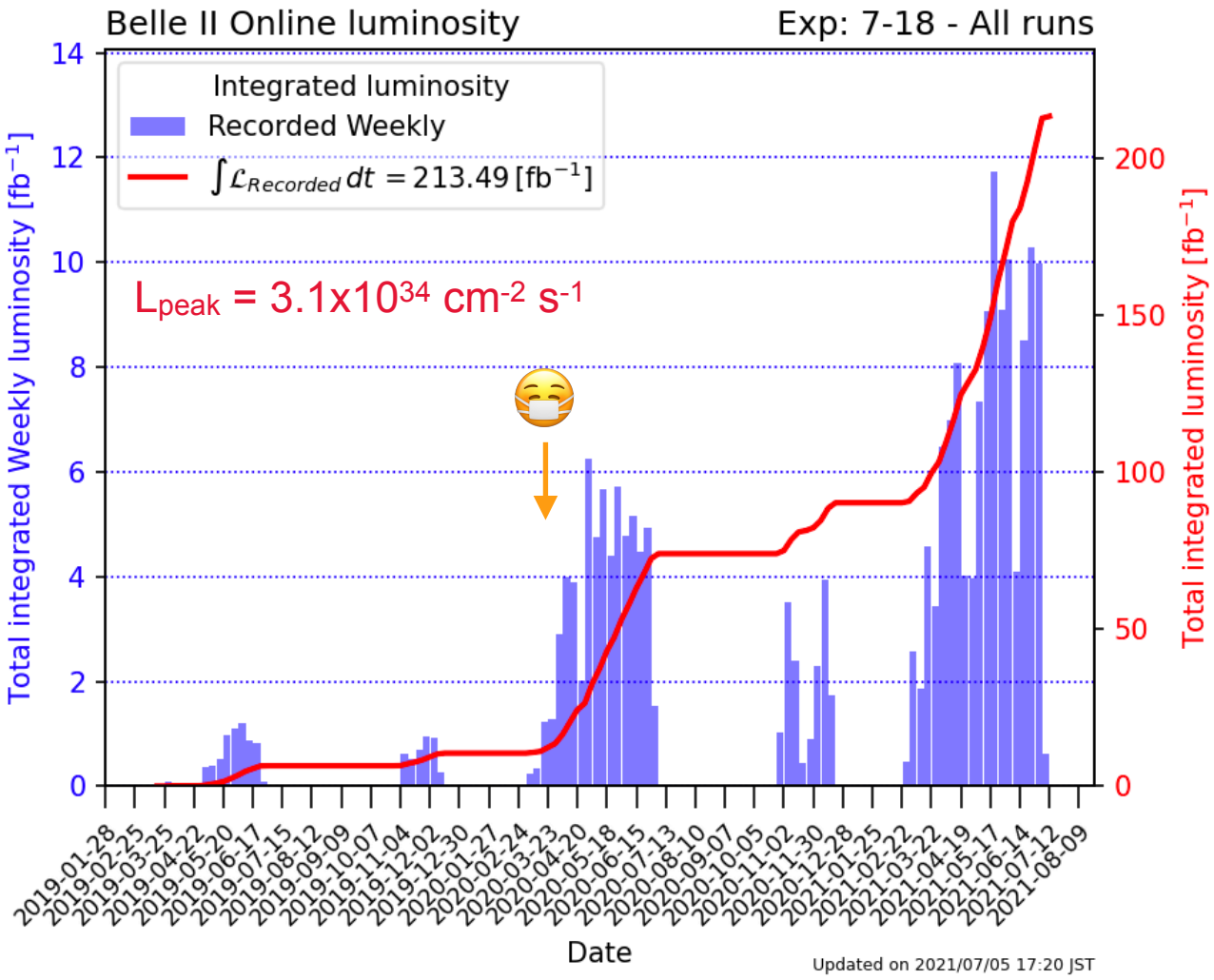
The Belle II Collaboration

1100 members, 123 institutions, 26 countries



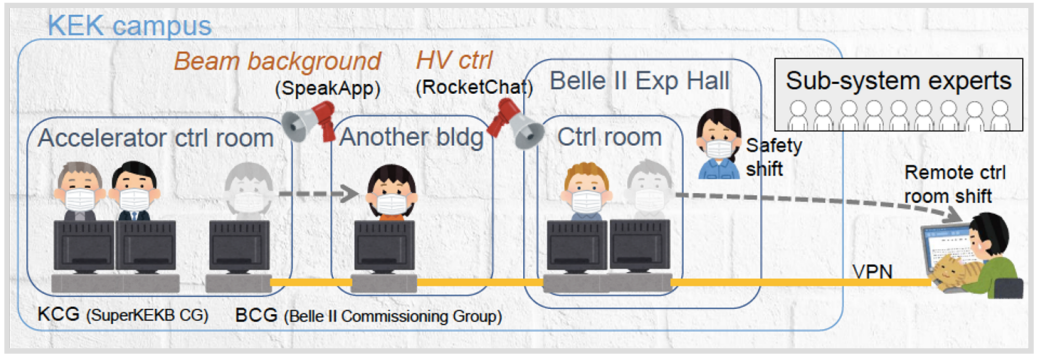
Integrated Luminosity: Today

(Well… yesterday when I did the slides)



- **Super B-factory performance levels**, despite a global pandemic.
  - World records:
    - 2.96 fb^{-1}/day,
    - 12 fb^{-1}/week,
    - 40 fb^{-1}/month
  - Luminosity above the B factories and LHC, with a product of beam currents 3.5 times lower than KEKB.

- "Social distancing" scheme for on-site shifts, and mobilized remote shifters around the world



UI

A steering file for analysis

```
import basf2
from modularAnalysis import inputMdst, reconstructDecay, fitVertex, variablesToNtuple
from stdCharged import stdPi
from stdPhotons import stdPhotons

mypath = basf2.Path()

# configure modules
inputMdst("default", basf2.find_file('analysis/tests/mdst.root'), path=mypath)
stdPi("good", path=mypath)
stdPhotons("good", path=mypath)
reconstructDecay('rho0:myrhos -> pi+:good pi-:good', '0.5 < M < 1.0', path=mypath)
fitVertex('rho0:myrhos', path=mypath)
reconstructDecay('B0:myBs -> rho0:myrhos gamma:good', '5.0 < M < 6.0', path=mypath)

# output modules
momenta = ['px', 'py', 'pz']
variablesToNtuple('B0:myBs', momenta, path=mypath)

basf2.process(mypath)
```

Particles are created from reconstructed objects (tracks, clusters in ECL, etc.)

UI

A steering file for analysis

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import basf2
from modularAnalysis import inputMdst, reconstructDecay, fitVertex, variablesToNtuple
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# output modules
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variablesToNtuple('B0:myBs', momenta, path=mypath)

basf2.process(mypath)
```

A DecayString is used to declare the structure and the particles of a decay tree.

Cross sections and Trigger rates

The total cross section from physics processes at the $\Upsilon(4S)$ energy region and expected trigger rates at the peak luminosity of 80×10^{34} $cm^{-2}s^{-1}$ [5,6].

Physics process	Cross section (nb)	Rate (Hz)
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$	1.1	880
$e^+e^- \to q\bar{q}$	3.4	2700
$e^+e^- \to \mu^+\mu^-$	1.1	880
$e^+e^- \to \tau^+\tau^-$	0.9	720
Bhabha[a]	44.0	350[c]
$\gamma\gamma$[a]	2.4	19[c]
$e^+e^- \to e^+e^- + 2\gamma$[a b]	13.0	10,000[d]
Total		~15,000

[a] $\theta_{lab} \geq 17°$.

[b] $p_t \geq 0.1$ GeV.

[c] Pre-scaled by factor of 1/100.

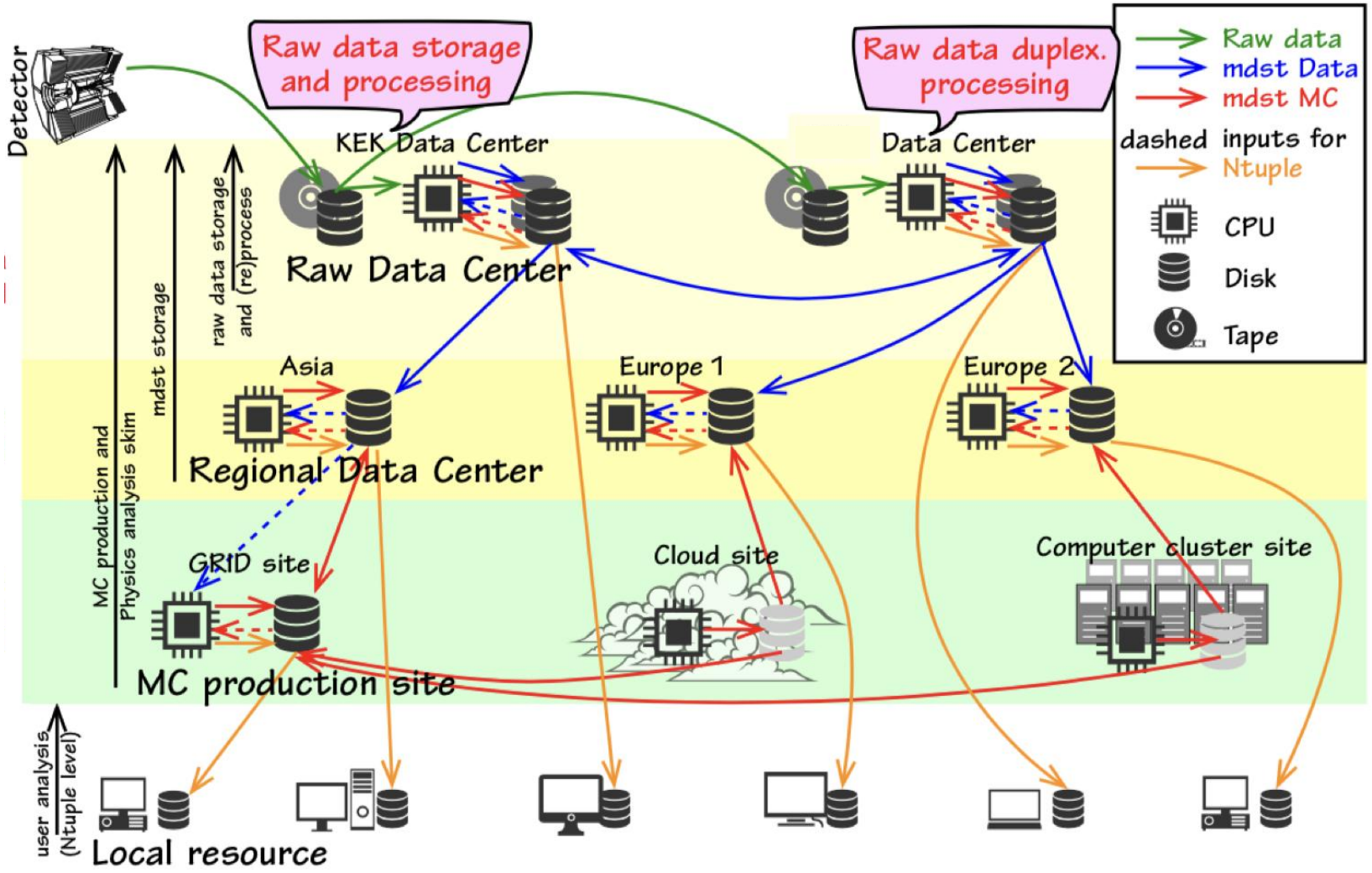
[d] Estimated from the Belle level 1 trigger rate.

https://doi.org/10.1016/j.nima.2021.165748

Distributed Computing

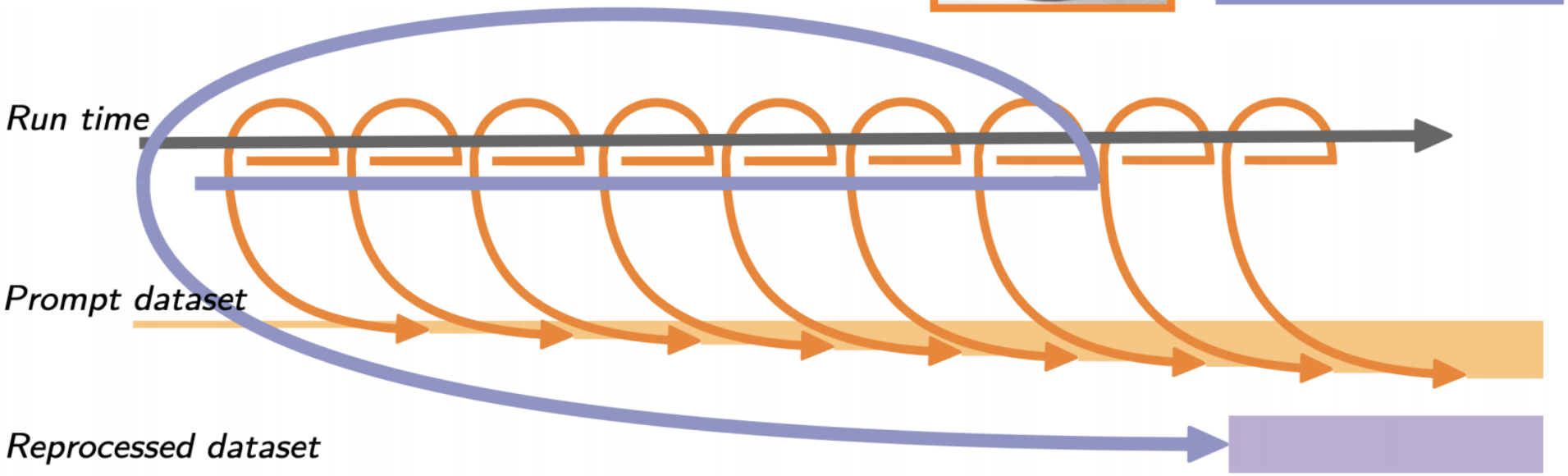
The computing model

- The grid system comprises 60 computing sites around the world.
- The Belle II analysis framework is distributed through **CMVFS**.
- Dedicated data centers keep two copies of the full raw data set.
- Raw data is staged, reprocessed, skimmed and distributed over storage sites.
- Analyzers access data and MC sending jobs to the grid and downloading the output to local resources.



Processing Scheme

- Ensure smooth, timely production of data for performance studies and physics analysis.
- Data is calibrated weekly in “prompt buckets”, containing ~ 2 TB in mDST format.
- A full reprocessing is performed ~yearly, aiming for physics publications.

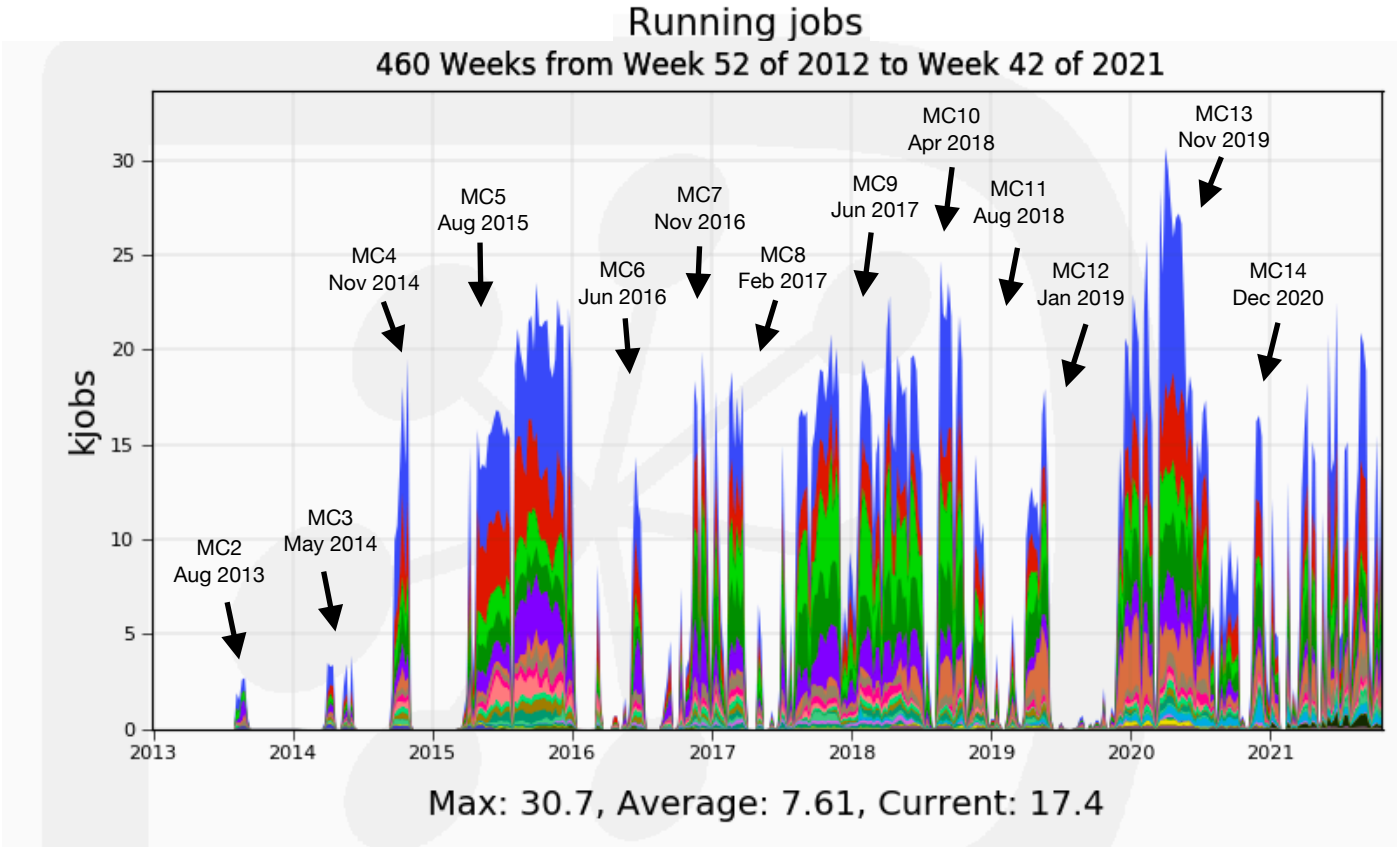


MC production campaigns

Simulation intended for analysis

- Centralized MC production with unique campaign names.
  - Generic MC.
  - Signal requests by each physics WG.

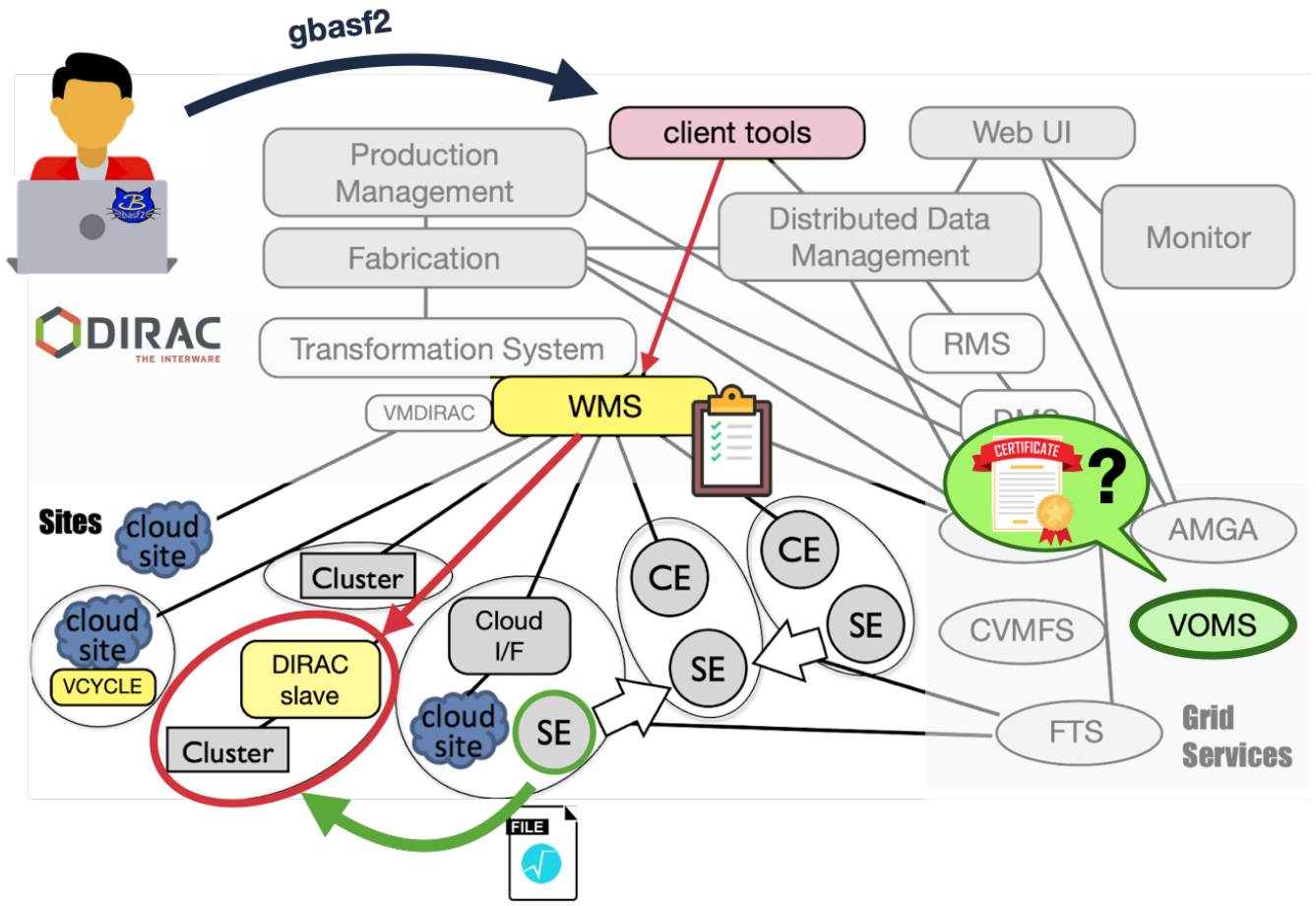
- Usually, launched every time a major basf2 version is released.



gbasf2

The distributed analysis client for Belle II

- gbasf2 (grid + basf2) is a command-line tool for users intended to submit grid-based jobs.
- The same Python steering files used with Basf2, work with gbasf2 on the grid.
  - Users test their code on local resources, then submit the job with same steering file.
- Authentication is performed presenting x509 certificates to a VOMS server.
- Users perform operations such as **monitor jobs, manage replicas** and **download the output** through a set of command-line tools provided within the gbasf2 environment.




```
~ $ gb2_project_summary --date 1w
       Project            Owner    Status    Done    Fail    Run    Wait    Submission Time(UTC)    Duration
=============================================================================================================
gb2Tutorial_Bd2JpsiKs     michmx   Good      5       0       0      0       2020-07-07 08:41:40     00:18:04
BdJpsiKs_proc11_exp10     michmx   Good      874     0       0      0       2020-07-07 09:29:07     02:24:27
gb2Tutorial_B02JpsiKs     michmx   Good      5       0       0      0       2020-07-07 21:53:12     02:49:34
gb2TutorialProc11Exp10    michmx   Bad       95      779     0      0       2020-07-07 22:32:23     00:34:38
```

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