

# ZeroMQ Online ROOT-Output Storage and Express-Reconstruction System for the Belle II Experiment

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KEK

*on behalf of the Belle II DAQ group*

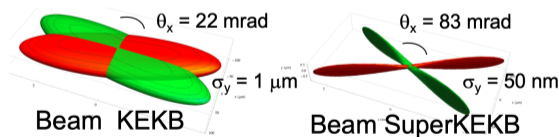
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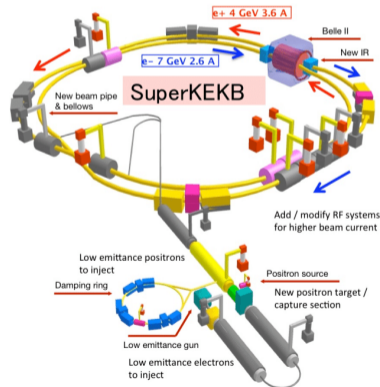


# SuperKEKB

- Electron-positron collider with 7 GeV  $e^-$  and 4 GeV  $e^+$ 
  - ▶ Focused on  $\Upsilon(nS)$ , mainly  $\Upsilon(4S)$
- Aiming at  $50 \text{ ab}^{-1}$  of data (=  $50 \times$  Belle) → Achieved  $424 \text{ fb}^{-1}$
- Aiming at  $6.5 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$  of peak lumi (=  $30 \times$  KEKB) → Achieved  $4.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ 
  - ▶ corresponding to 30 kHz L1 trigger rate
  - ▶ 1/20 of beam size (nanobeam scheme)
  - ▶ 150% of beam current

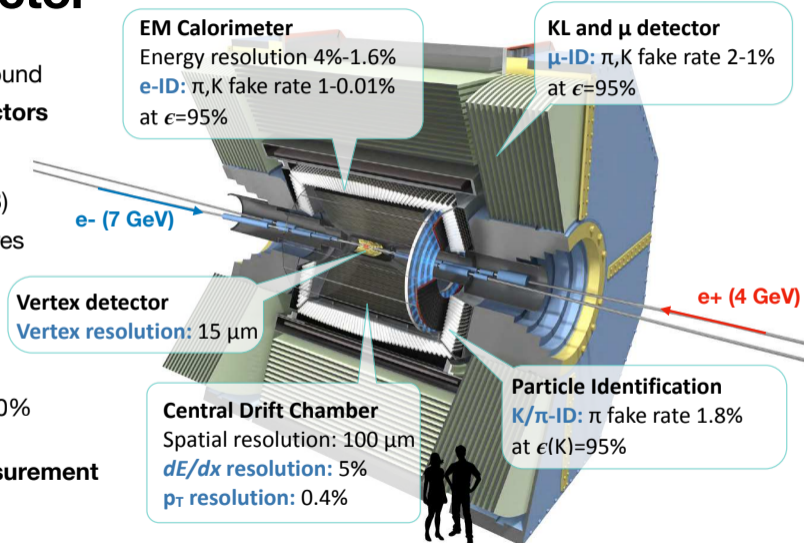


$$L = \frac{N_+ N_- n_b f_0}{4\pi \sigma_{x,\text{eff}}^* \sqrt{\epsilon_y \beta_y^*}}$$

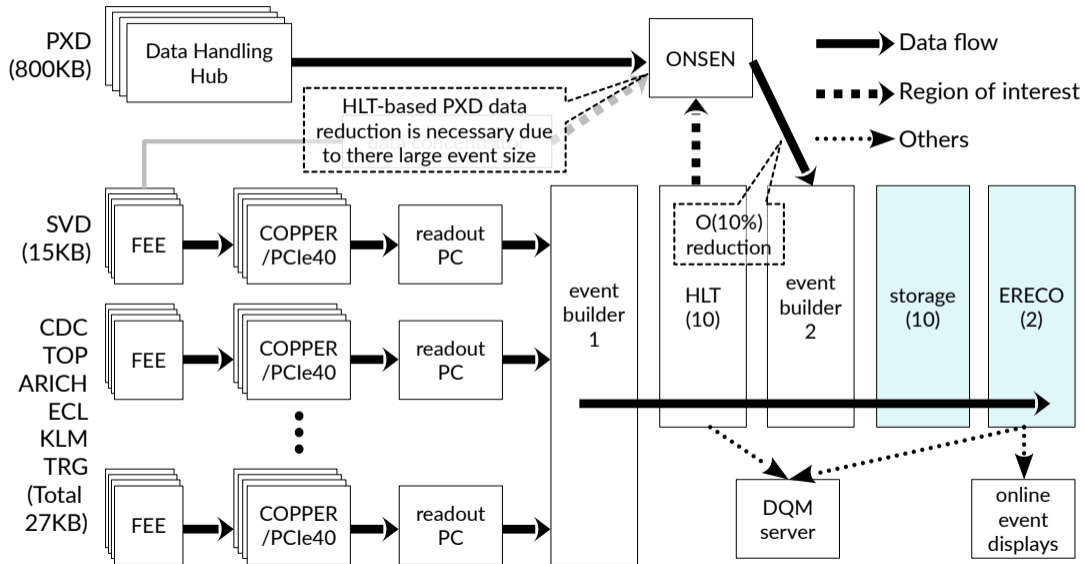


# Belle II detector

- Increased beam background  
→ **Upgraded sub-detectors and trigger**
- $\beta\gamma=0.28$  (vs 0.42 @KEKB)  
→ Reduced boost requires **improved vertex reconstruction:**
- Solid angle coverage  $>90\%$   
→ **High hermeticity for missing energy measurement**



# DAQ data flow



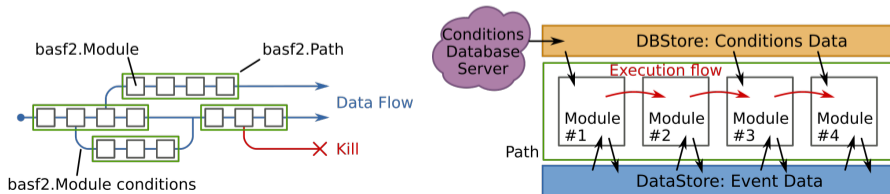
# Introduction

## ■ Items to be shown

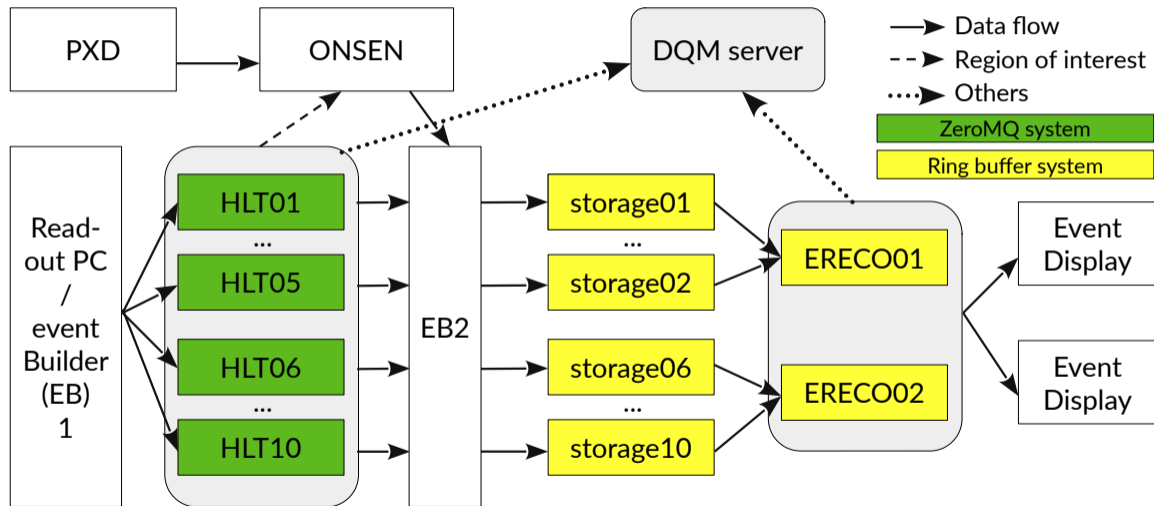
- ▶ Storage: online raw data storage, 32-48 threads CPU with three ~40 TB RAID units × 10
- ▶ ERECO: Express-reconstruction system for online data quality monitoring (DQM), especially for vertex detectors and physics features
  - Till 2022: 2 ERECO consist of input, output (= control), and 8 worker nodes
  - ERECO has ~640 threads CPU → 10 times smaller than HLT (~6400 threads)

## ■ ZeroMQ library: embeddable networking library to give sockets that carry atomic messages across various transports like in-process, inter-process, TCP, and multicast

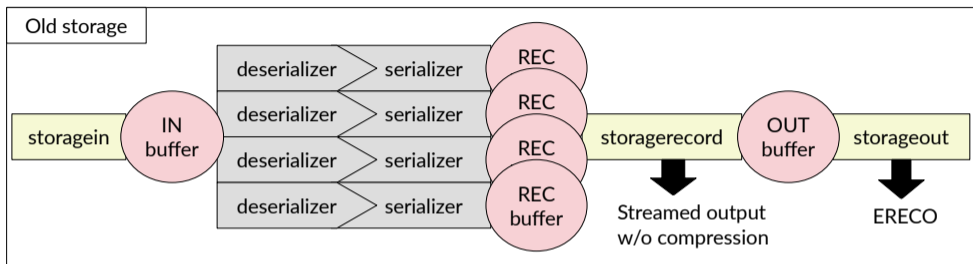
## ■ BASF2: Belle II Analysis Software Framework



# DAQ data flow: HLT to ERECO



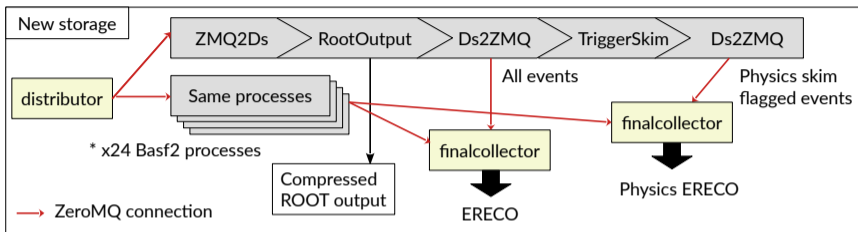
# storage: Old



## ■ Old storage

- ▶ Ring buffer + socket event distributor w/o HLT skim results
- ▶ Streamed output without compression, single output
- ▶ Pros: Small CPU usage for recording, no merging for reducing the number of output files, easy file salvage in case of troubles
- ▶ Cons: Large file size, additional ROOTization from the offline side

# storage: New



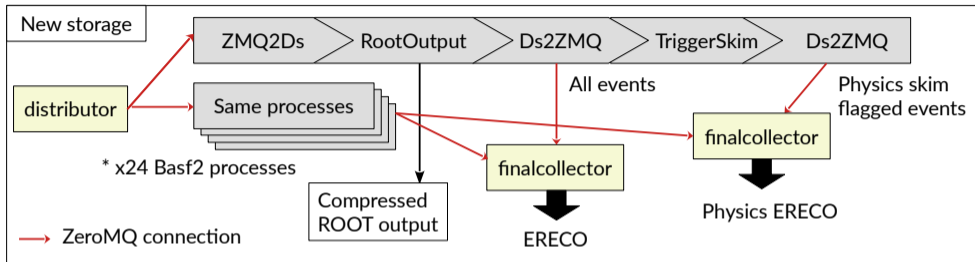
## ■ New storage

- ▶ ZeroMQ connections with HLT skim flags
- ▶ Normal ROOT format with compression, multiple outputs
- ▶ Events categorization by the HLT results for ERECO
- ▶ Pros: Small file size, no additional offline processing
- ▶ Cons: Large CPU usage for compression, requiring online side small-sized file merging, additional broken file salvage

## ■ With higher input rate, the pros of new storage is more important.



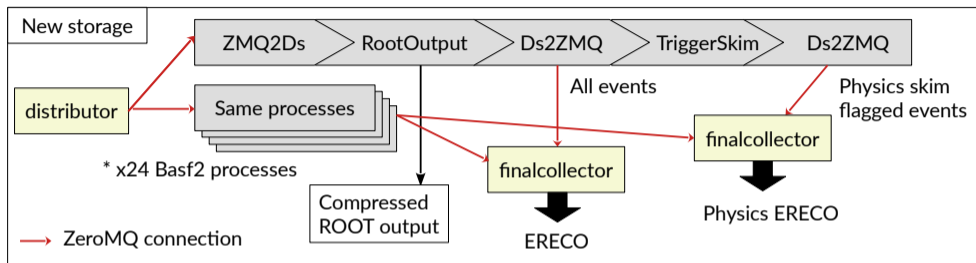
# ZeroMQ connections



## ■ Three types of input/output connections

- ▶ Load-balanced: 1 (input) / N (output) clients
- ▶ Confirmed: N (input) / 1 (output) clients
- ▶ Raw: 1 (input) / N (output) clients, for non-ZMQ applications

# ZeroMQ connections

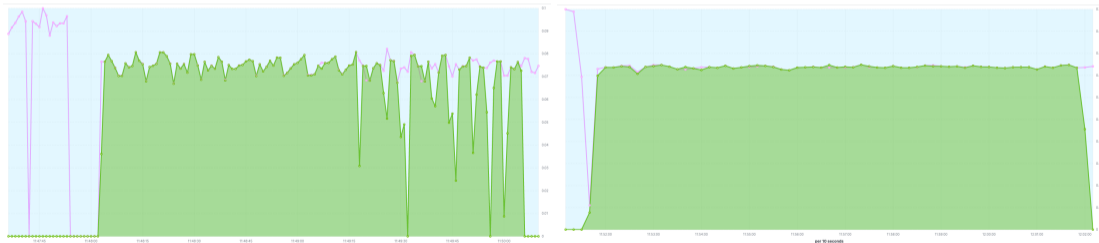


## ■ Combinations of the input/output connections create ZMQ applications

- ▶ distributor: Raw input + load-balanced output
- ▶ finalcollector: Confirmed input + Raw output
- ▶ ZMQ2Ds module: Load-balanced input to BASF2 DataStore
- ▶ Ds2ZMQ module: Confirmed output from BASF2 DataStore

# ROOT output: Performance test

- We measured CPU consumption and disk usage using the real storage server.
  - ▶ Compression algorithm: Zstandard
  - ▶ 1-proc can store 150 Hz events without event drop.
  - ▶ 24-proc can easily store the maximum rate of events from the Belle II detector.
  - ▶ Total disk I/O per second for Poisson trigger 3kHz is 93 MB/s = 327 GB/h.
    - Far away from the limit of the disk I/O

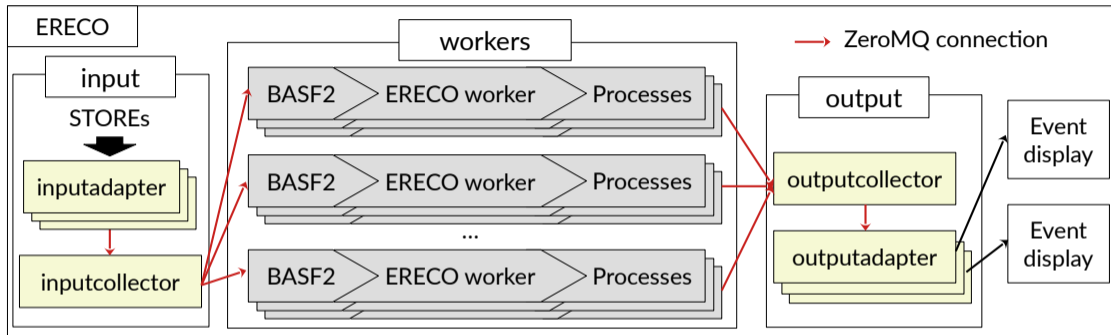


Test results of 200 (left) and 150 (right) Hz input rate. The pink line is the input rate, and the green colored region is the output rate.

# ROOT output: After Processing Tool

- After creating raw ROOT output files, the After Processing Tool performs additional treatment:
  - ▶ Recovering incomplete output files caused by unknown errors
  - ▶ Merging small-size files
  - ▶ Checksum calculation
  - ▶ Making the final file list to be transferred
  - ▶ Updating the number of events / output files and "ready to be sent" flag into the run information DB
  - ▶ Getting the file transfer status and removing the completed files

# ERECO overview

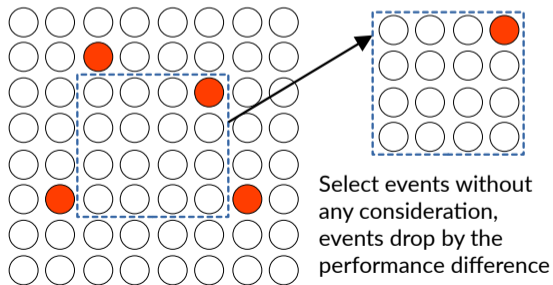


- **Functionality is the same with the current ring buffer + socket ERECO.**
  - ▶ However, the new ERECO gives better maintainability and stability.
    - No more shared memory-related issues
  - ▶ ERECO allows events to drop, unlike the HLT or storage.
  - ▶ From the HLT result based selection, dedicated ERECO for physics is possible.

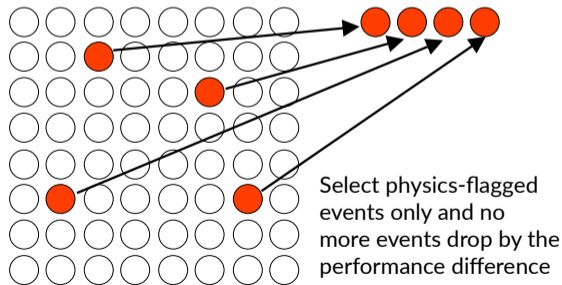
# HLT result based selection for ERECO

- # of ERECO is smaller than HLT, therefore only a part of events can be processed.
- The less performance ERECO occurs random event selection caused by event drops.
- We want more statistics of physics features while keeping the random sampling.
  - ▶ The random sampling is also important, especially for the pixel detector, since the pixel detector information is not in HLT.

< Random sampling >

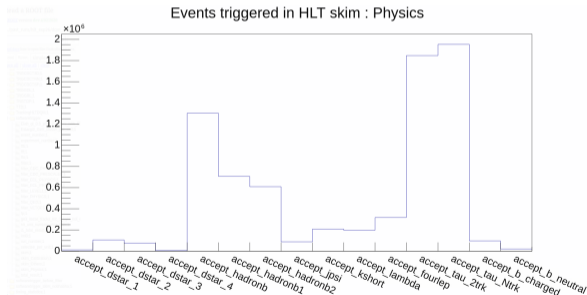


< Physics sampling >



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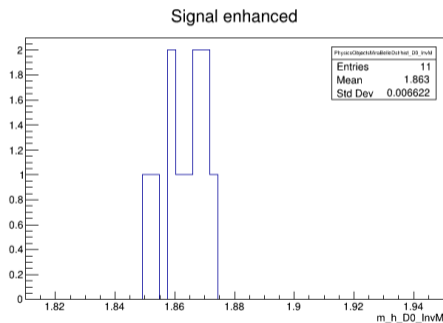
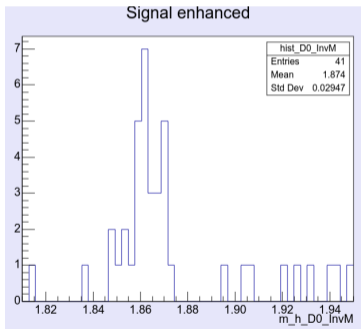


The number of events for each physics skims from 4.7M events.

# HLT result based selection for ERECO

## Simple ratio calculation for accept\_dstar\_1 events

- ▶ Random sampling: 41  $D^0$  from  $D^*$  events with 4.7M inputs  $\rightarrow 8.7 \times 10^{-6}$
- ▶ HLT result based selection: 11  $D^0$  from  $D^*$  events with 46K inputs  $\rightarrow 2.4 \times 10^{-4}$
- ▶ Roughly, over 25 times statistics for the physics flagged events

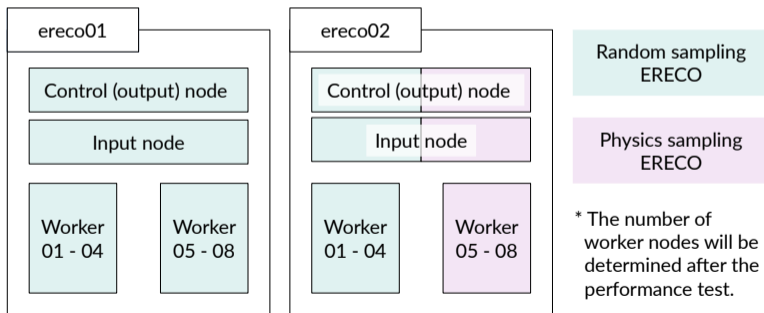


$D^0$  from  $D^*$  invariant mass histogram of 4.7M random sampling data (left) and 46K HLT result based sampling data (right).

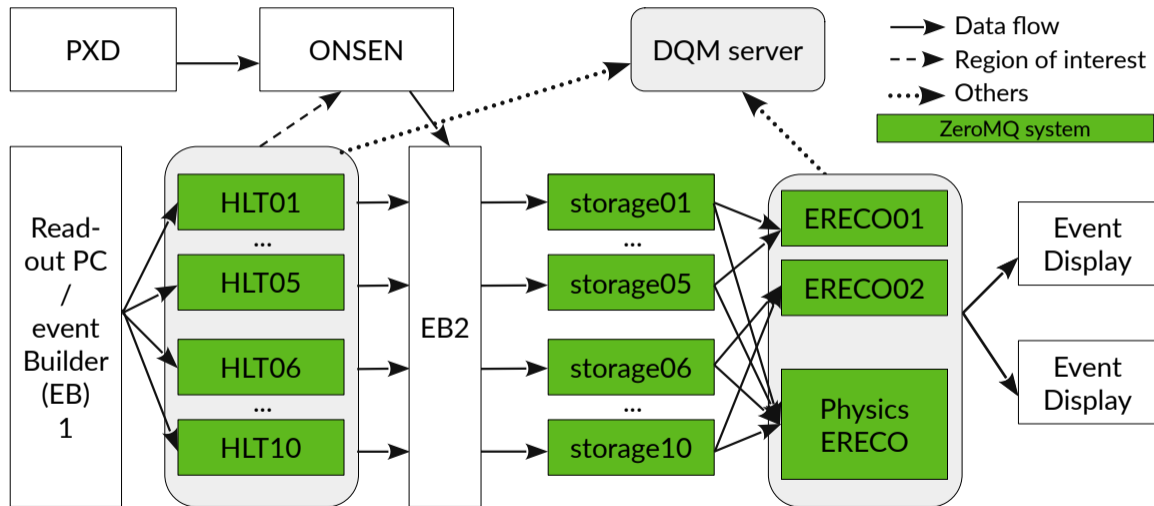


## ■ The physics ERECO and one of normal ERECO share the same farm.

- ▶ Both ERECO share input and output (control) nodes.
- ▶ A few worker nodes are dedicated to physics ERECO.
- ▶ The number of physics ERECO worker nodes will be decided by the performance test and physics trigger menu.



# Conclusion

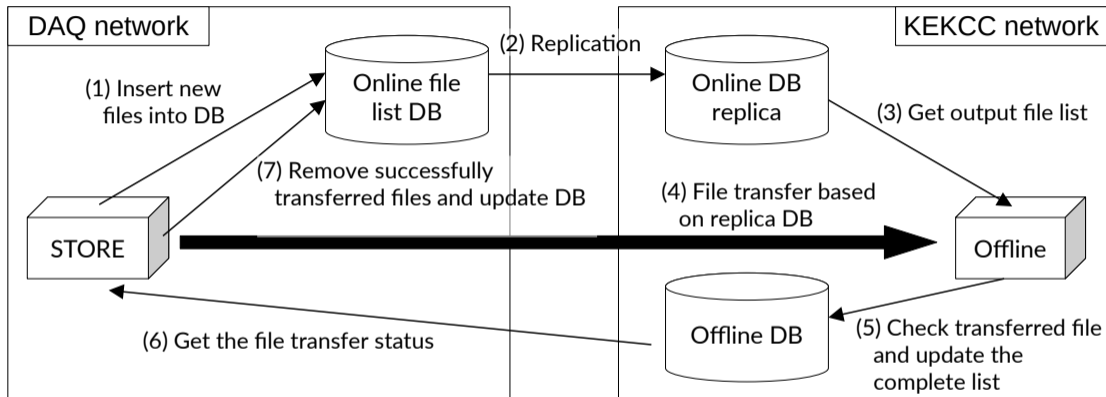


# Conclusion

- Belle II is a long shutdown period, and this is the chance to upgrade our storage and ERECO.
- Storage and ERECO will use the ZeroMQ framework, the same as HLT.
  - ▶ Better maintainability and stability
- storage will have new features:
  - ▶ Direct ROOT output with compression
  - ▶ HLT result based sampling for ERECO
- Dedicated physics ERECO will be used for more statistics of physics events from online data quality monitoring.

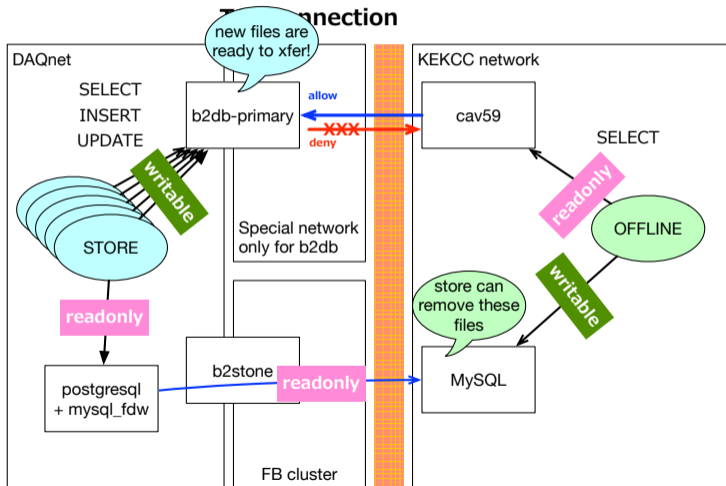
**Backup**

# ROOT output: File list sharing b/w online and offline



- **DAQ network and KEKCC network are basically disconnected.**
  - ▶ Only the special connection is allowed for security reasons.
- **The overall design is still under discussion, including the online file list DB contents.**

# File list sharing: Detail



# accept\_dstar\_1 trigger rate

