Trigger and Data Acquisition (DAQ) Systems at the Belle II Experiment

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EPS-HEP

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Trigger and DAQ Challenges at Belle II (I)

- High instantaneous luminosity
  - Designed peaking luminosity at SuperKEKB : ***8×10^{35} cm^{-2}s^{-1} (40 x KEKB)***
  - Total physics event rate ~15kHz @8×10^{35} cm^{-2}s^{-1}
- High beam-induced backgrounds
  - Touschek scattering is dominate
    - Proportional to the inverse of the beam size
    - "Nano-Beam" scheme at Belle II → smaller beam size
  - One order higher than Belle
- Huge data flow from pixel detector (PXD) ~1MB/event

Process	σ (nb)	Rate (Hz) @ L=8×10^{35}
Upsilon(4S)	1.2	960.0
Continuum	2.8	2200.0
μμ	0.8	640.0
ττ	0.8	640.0
Bhabha *	44.0	350.0
γ-γ *	2.4	19.0
Two photon **	13.0	10000.0
Total	67	~15000

* Rate of Bhabha and γ-γ are pre-scaled by factor 100

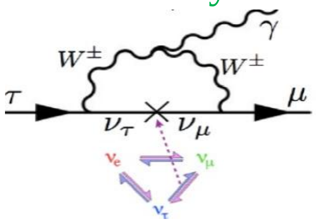
** Rates are estimated by the luminosity component in Belle L1 trigger rate

Trigger and DAQ Challenges at Belle II (II)

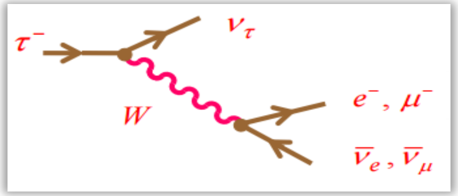
- >99.9% efficient for B and D physics
- Low multiplicity processes challenge the trigger due to substantial QED background
  - LFV τ decay: $\tau \rightarrow e/\mu\ \gamma$
  - Leptonic τ decay: $\tau \rightarrow e/\mu\ \nu\nu$
  - Precision electroweak tests: ee and $\mu\mu$
  - Precision ISR for g-2: $\pi\pi$/KK/pp/... and one photon
  - Searches for Dark Photons and Light Higgs:

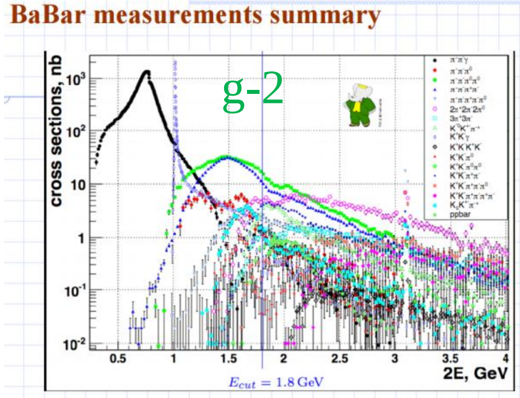
    0/2/4 charged particles and one photon
  - ......

LFV tau decay

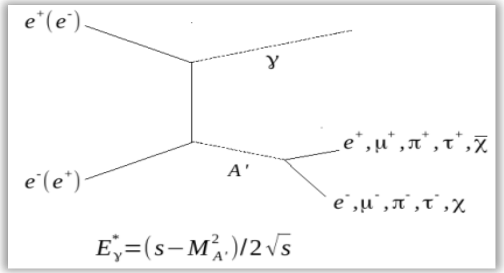


Leptonic tau decay

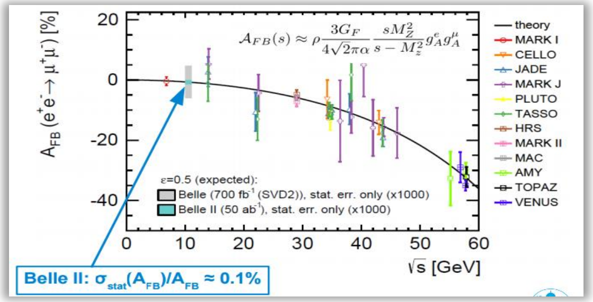




Dark photon search



Precision electroweak tests



Trigger

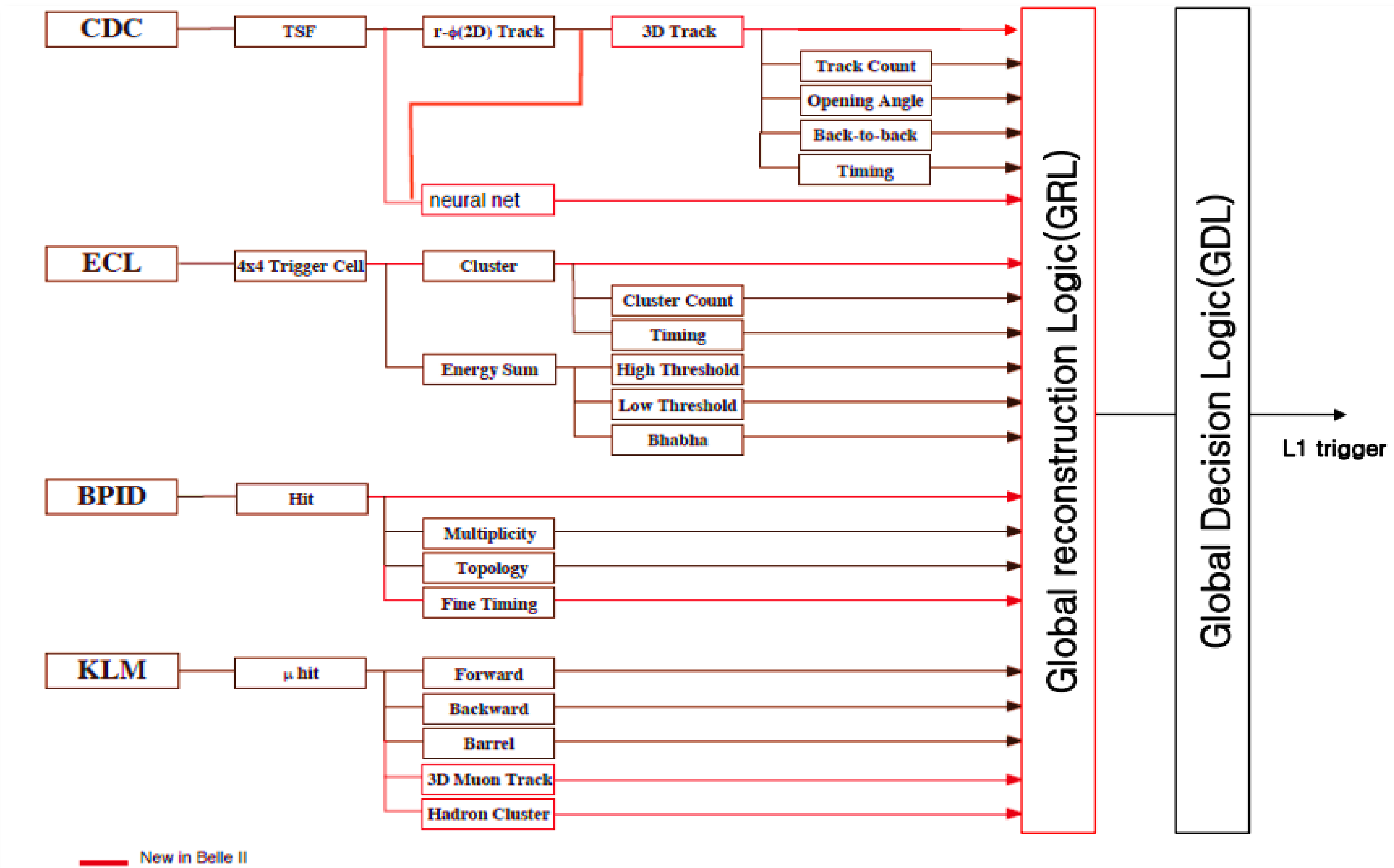
Scheme: Hardware trigger + Software trigger

- Level 1 (L1): hardware based
- High Level Trigger (HLT): software based

L1 Trigger

- Requirements
  - High efficiency for physics processes
  - Maximum trigger rate 30kHz
  - Trigger latency ~5μs
  - Timing precision ≤10ns
  - Two-event separation ≥200ns
- Scheme
  - Belle trigger concept: Sub-Triggers + Global Decision Logic
  - Basic idea is the same at Belle II, but each components will be improved
    - Data flow : parallel → high-speed serial links
    - Data rate : 16 Mbps → 190 Mbps (CDC wire case)
    - Logic : hard-coded →FPGA

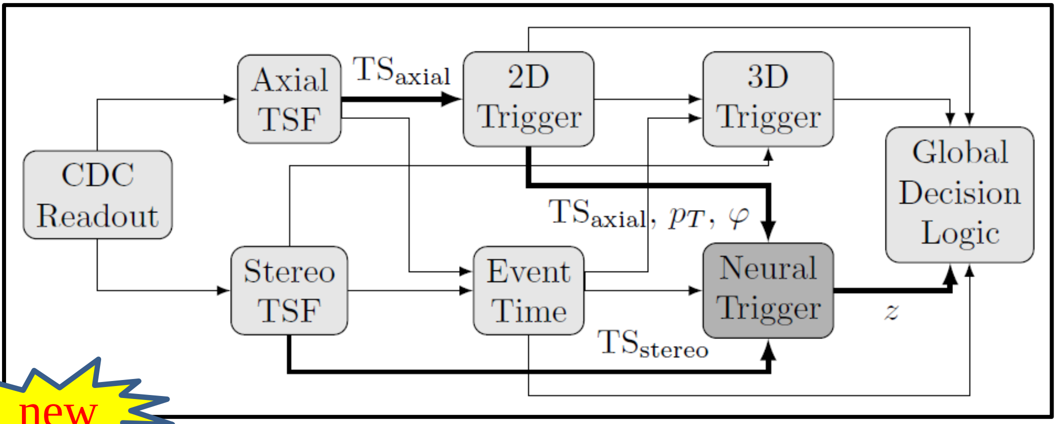
L1 Trigger Scheme

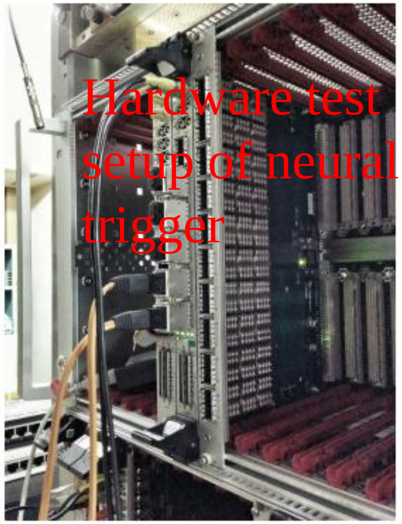


CDC Trigger

- CDC: axial and stereo Track Segments (TS)
- 2D track: axial TS
- 3D trigger
  - 2D tracks in r-ϕ space
  - Combine with stereo TS to determine the z-vertex
- Neural z-vertex trigger
  - Networks of Multi Layer Perceptron (MLP)
  - 2D tracks & stereo TS as input

new





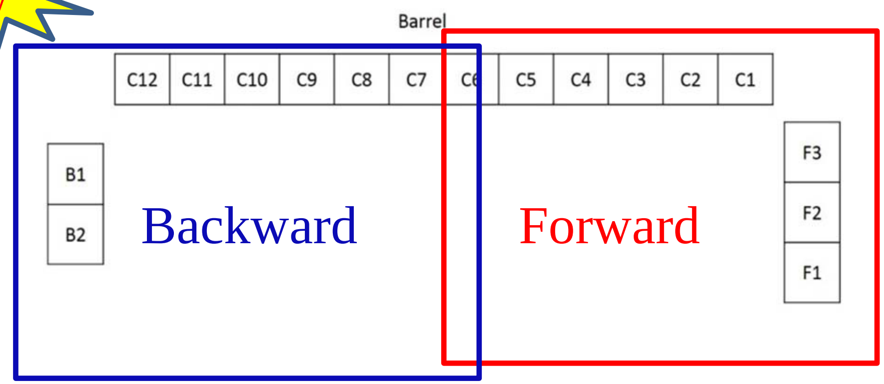
Hardware test setup of neural trigger

ECL Trigger

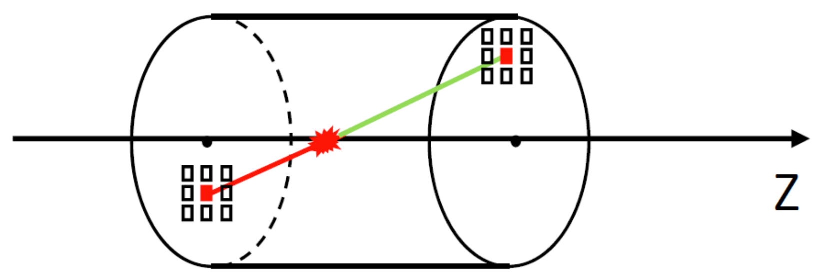
- Efficient trigger for both neutral and charged particles
- Total trigger timing latency~3μs
- Upgraded 3D Bhabha-veto logic: higher efficiency for interesting low multiplicity physics

new

- Divide ECL to forward and backward parts
- Find the most energetic clusters in each parts



- 3D Bhabha-veto logic
  - Satisfy the back-to-back topology (look-up table)
  - Cluster energy requirements

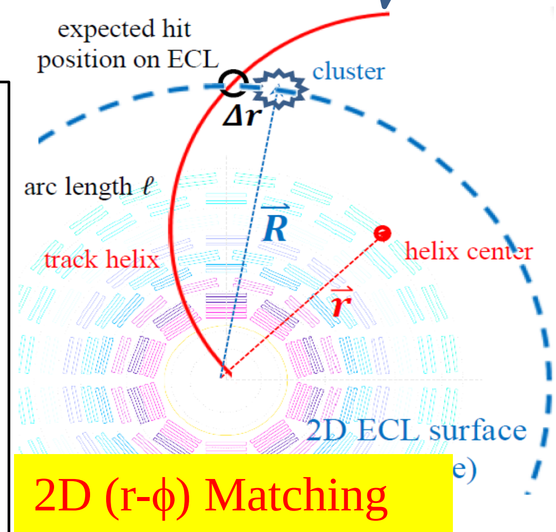


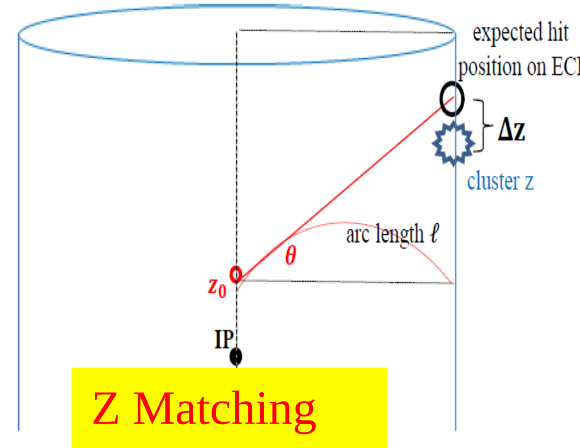
Bhabha in CM frame

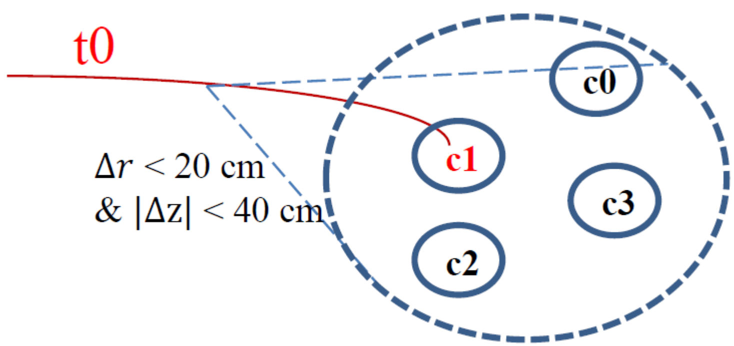
GRL

- CDC track and ECL cluster matching new

- Match in r-ϕ and Z directions
- Δr, Δz: the deviations between cluster position and expected hit position in r-ϕ and Z directions on ECL, respectively.
- Expected hit position: extrapolate tracks from CDC with 3D tracking information

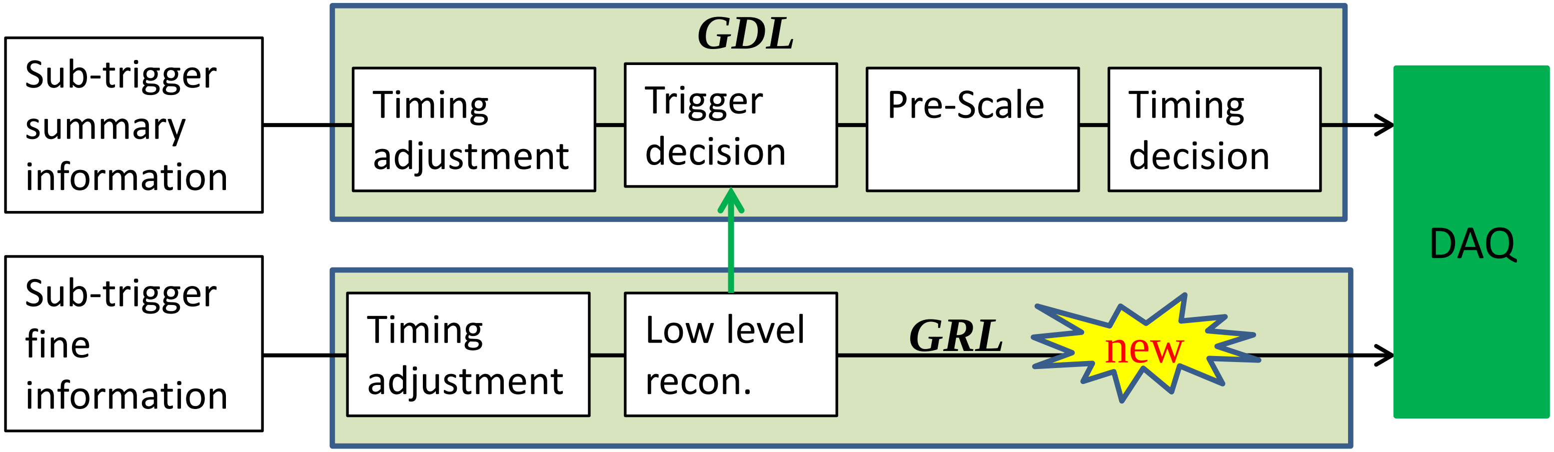






- Define (Δr, Δz) region
- Match track t0 to the cluster c1 with the smallest Δr in its (Δr, Δz) region
- The rest are neutral clusters
- Electron ID with E/P

GRL and GDL



- O(200) L1 bits available → abundant triggers
- Trigger menus for running conditions (i.e. E_{cm}, background)

DAQ

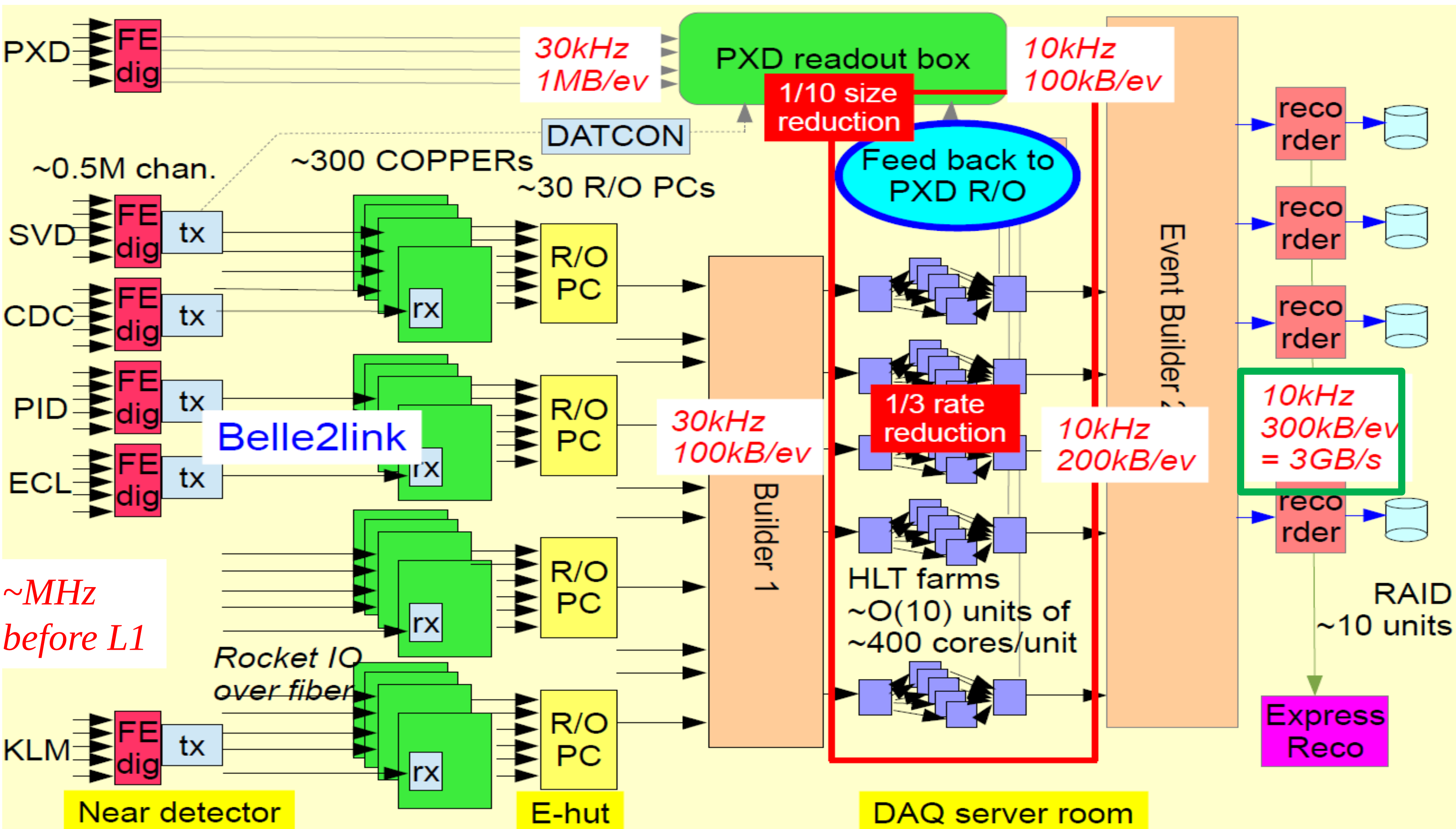
Components:

- Unified data link (Belle2Link)
- Common pipeline platform for electronics readout (COPPER)
- Merge data pieces from all detectors (Event builder)
- High level trigger (HLT): software based

DAQ

Designed maximum readout rate: 30kHz

Data Flow: L1 →Belle2Link →COPPER →EventBuilder →HLT

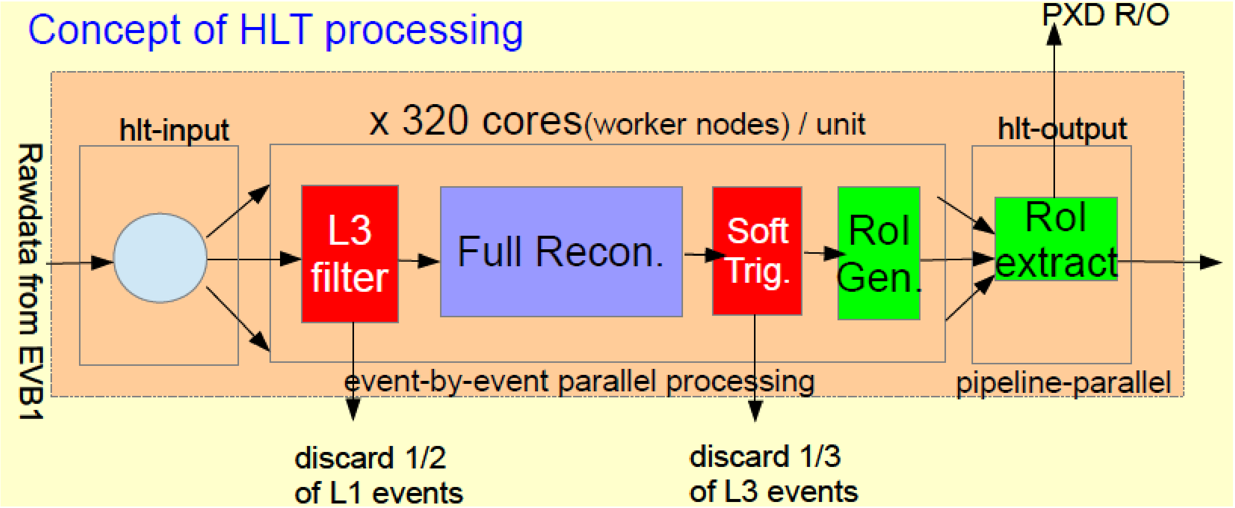


HLT

L3
- dedicated recon. algorithms
  - CDC tracking
  - ECL clustering
- 30kHz → 15 kHz

Full reconstruction
- offline software framework (basf2)
- offline recon. algorithm with all detectors except PXD.

Physics-level event categories
- hadronic physics: B, D...
- low-multi.: ττ, DM...
- QED: ee, μμ, γγ...
- trigger menu
- 15 kHz →10 kHz

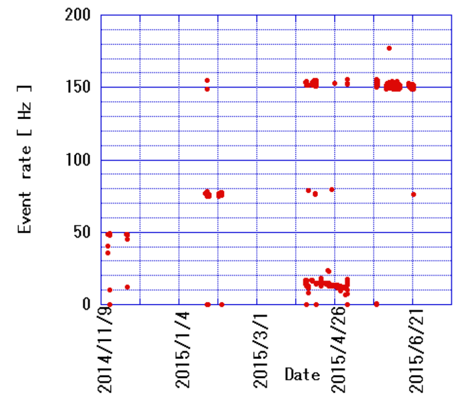


Parallel processing
- allowed in basf2 → extended to network cluster in HLT
- (20 nodes x 16 cores) /unit
- ≥5 units @$2\text{x}10^{35}$ $cm^{-2}s^{-1}$, added as luminosity increase

DAQ Integration

- Cosmic ray tests (CRT) of sub-detectors and DAQ has been performed since last November.
  - CDC CRT with 6 FEEs was started , more FEEs are added
  - Stability of ECL DAQ is improved
  - KLM DAQ for CRT is ready
- Demonstration on June this year
  - ECL and CDC data-taking were run successfully.

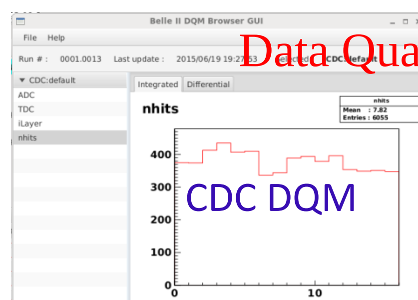
Event rate of ECL CRT

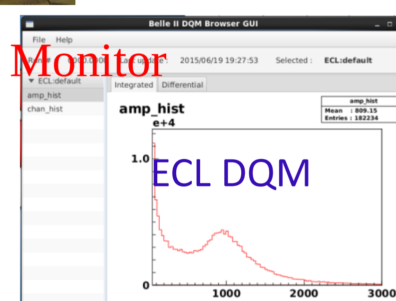


COPPER rack for KLM

Run control
Simplified operations are available (Run start / stop / abort)

Data Quality Monitor





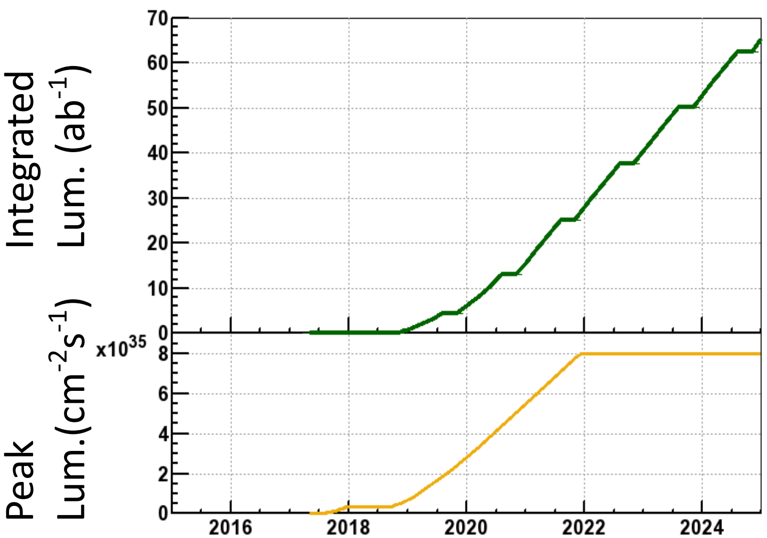
Summary

- Belle II's trigger/DAQ systems have been much improved, and will capture more low multiplicity physics than Belle ever did, such as dark sectors, precision tests, τ decays.
  - Upgraded electronics
  - 3D CDC tracking, 3D Bhabha-veto
  - Match ing between CDC tracking and ECL cluster
  - Low level reconstruction in GRL
  - Trigger Menu
- Trigger/DAQ will be ready before Belle II commissioning (w/o VXD) on May 2017.

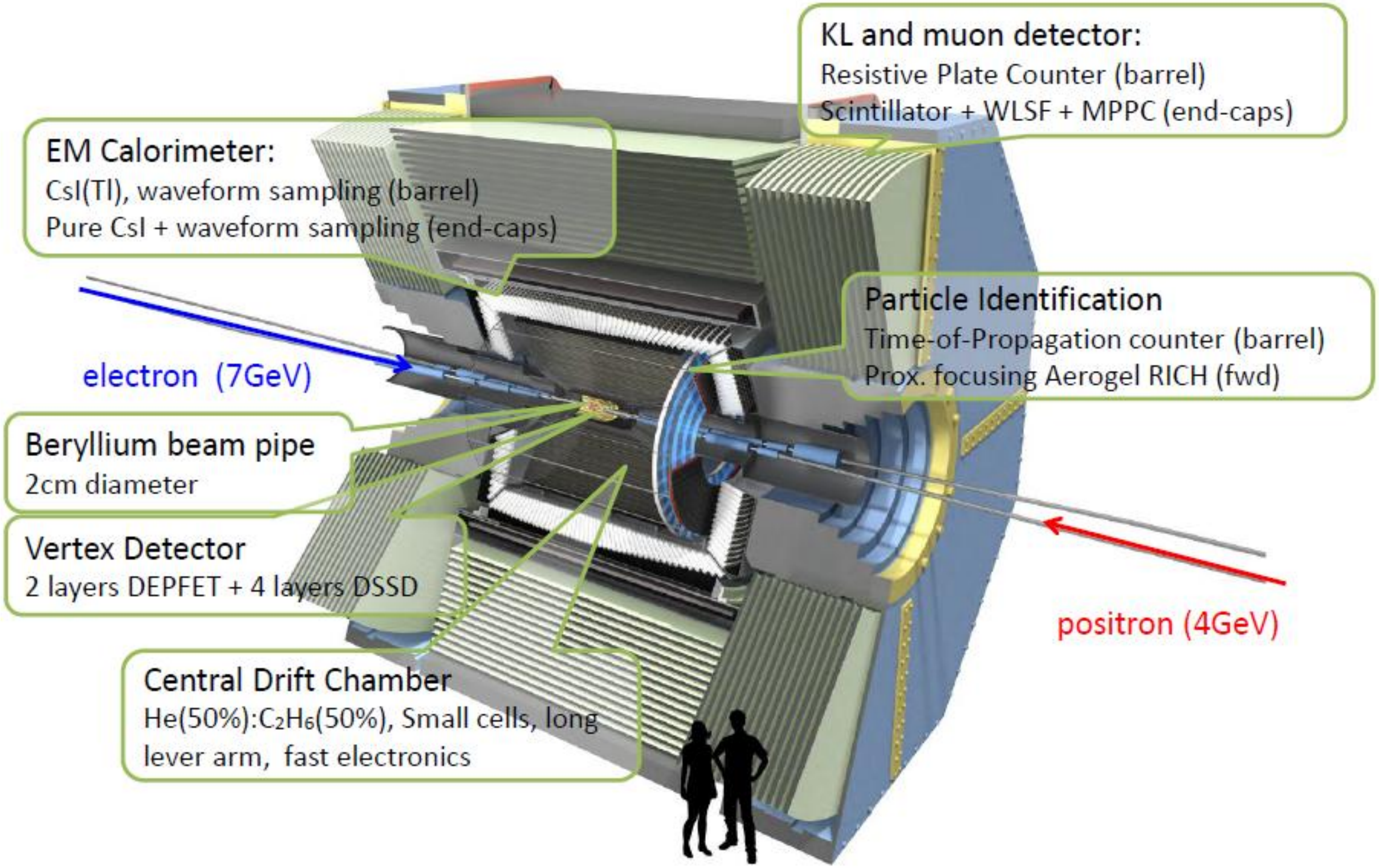
Backup

SuperKEKB

- An asymmetric electron-positron collider in Tsukuba, Japan
- Asymmetric beam energies
  e^{+}~ 4GeV e^{-}~ 7GeV
- Target Luminosity
  L_{int} > 50 ab^{-1} by 2020s (50 x Belle)
  L_{peak} = 8 x 10^{35} $cm^{-2}s^{-1}$ (40 x KEKB)

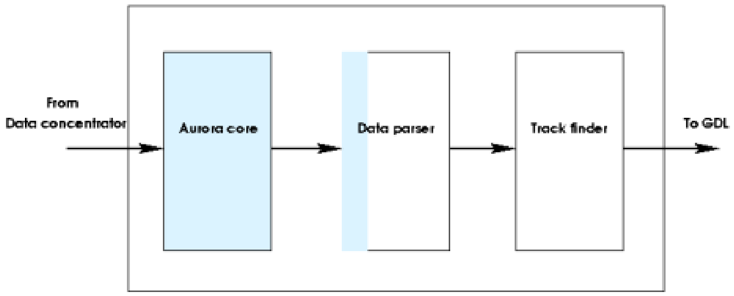


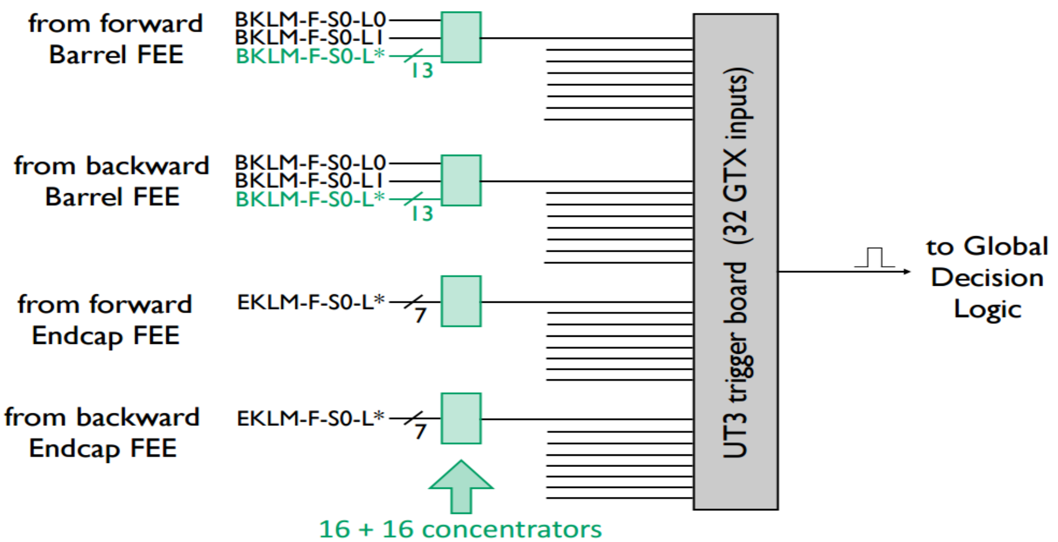
Belle II Detector



KLM Trigger

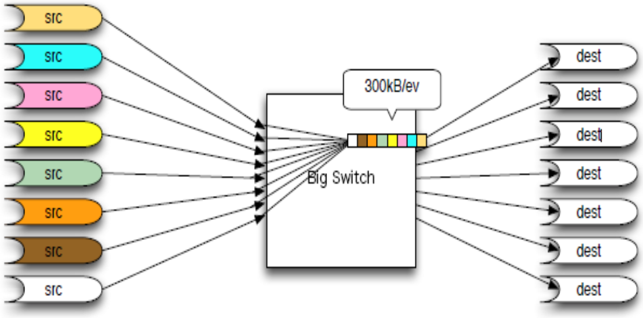
- Important to the detector calibrations and increase the trigger efficiency of low-multiplicity events.
- Data exchange with Aurora core is done and works well.
- Data parser development is started
- KLM trigger finds muon tracks and K_L clusters

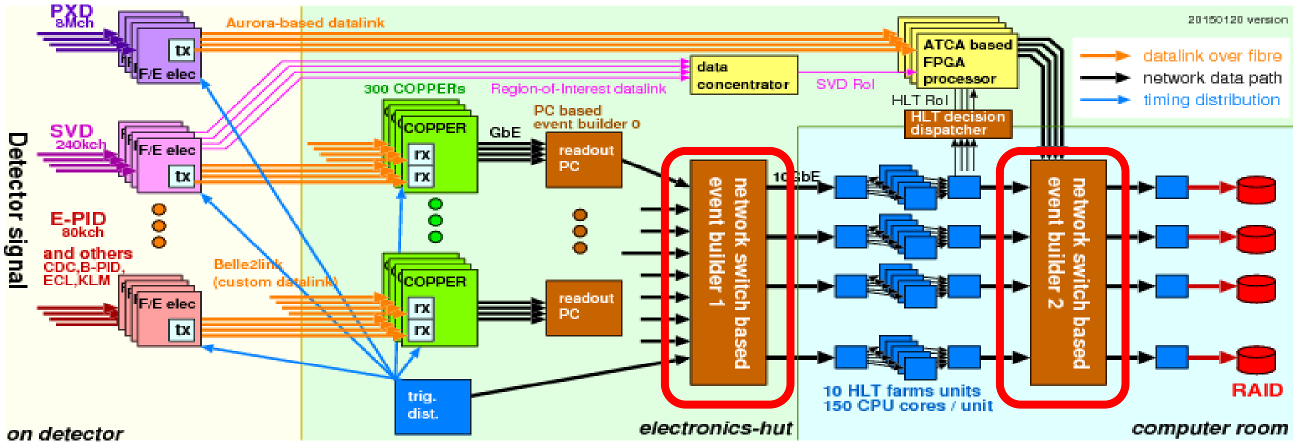




Event Builder

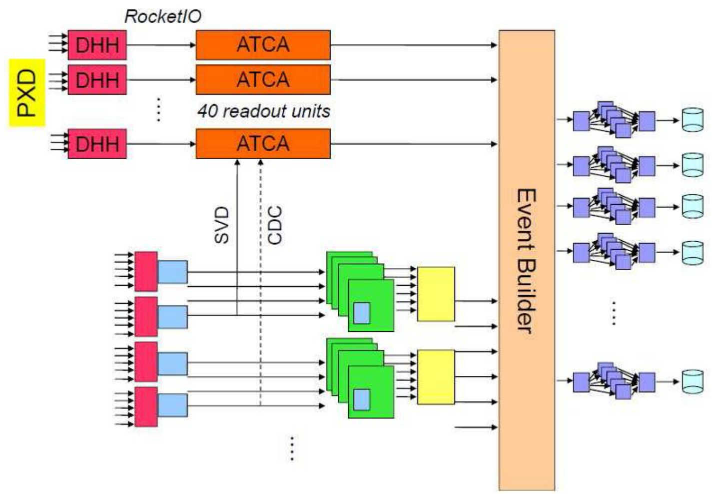
- Merge data pieces from all detectors to one event
- Large network switch
- Enough large buffers to avoid data loss or retransmission
- Two event builders before and after HLT
  - Builder 1 merge data w/o PXD for HLT
  - Builder 2 merge data from all detectors

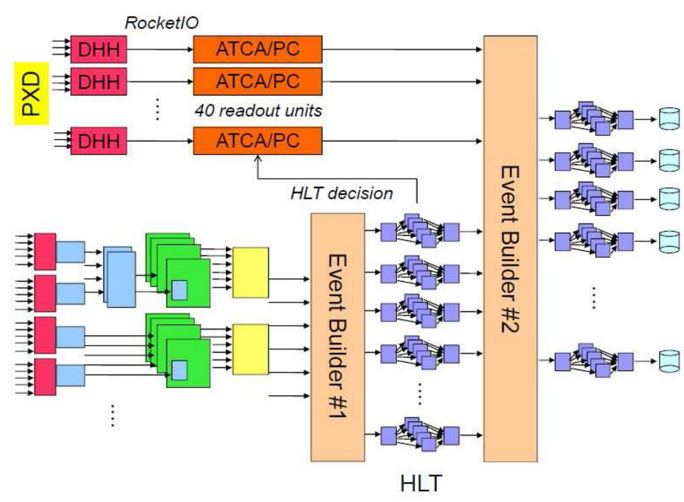




PXD Integration

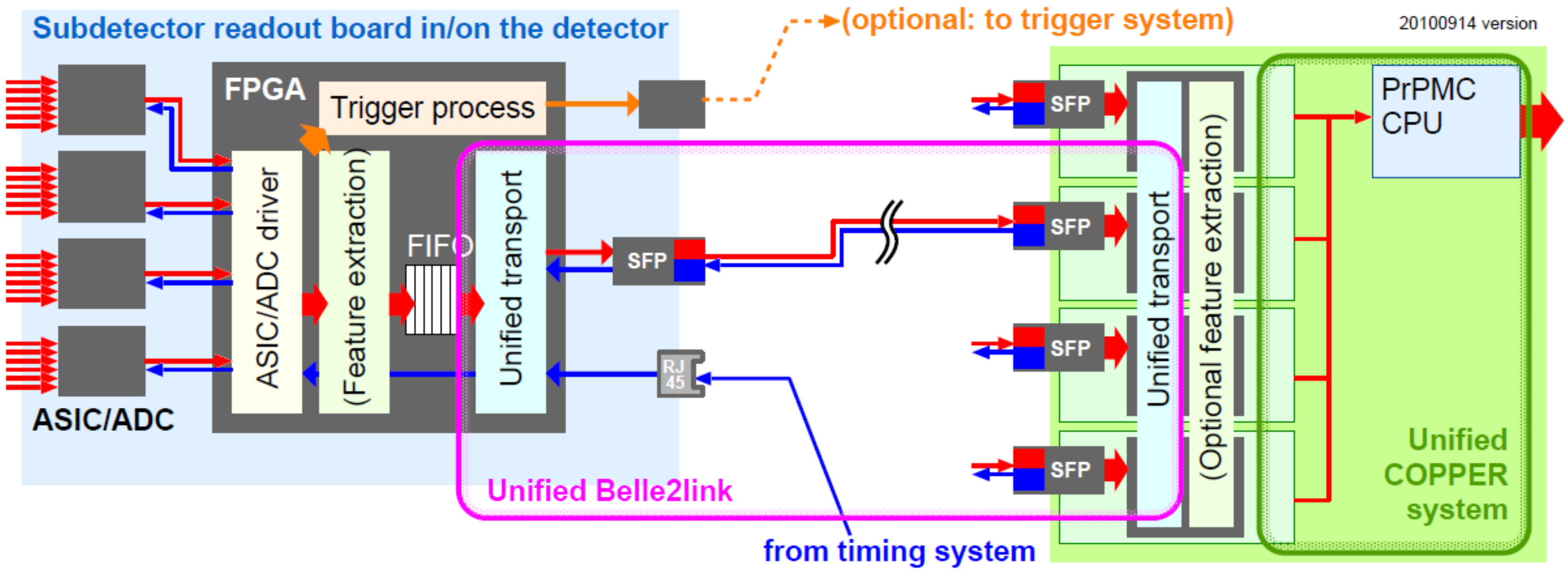
- Large event size from the PXD ~1MB/event, COPPER can not manage such huge data flow
- ATCA crate receive data from PXD.
- Two ways to reduce PXD data size and rate
  - RoI selected by ATCA system.
  - The track finding is done with SVD and CDC hit signals, the PXD hits associated with tracks are sent to the event builder.
  - The hit-track association is perform with the track parameters from HLT system.
- RoI selection happens after 5s of HLT processing time





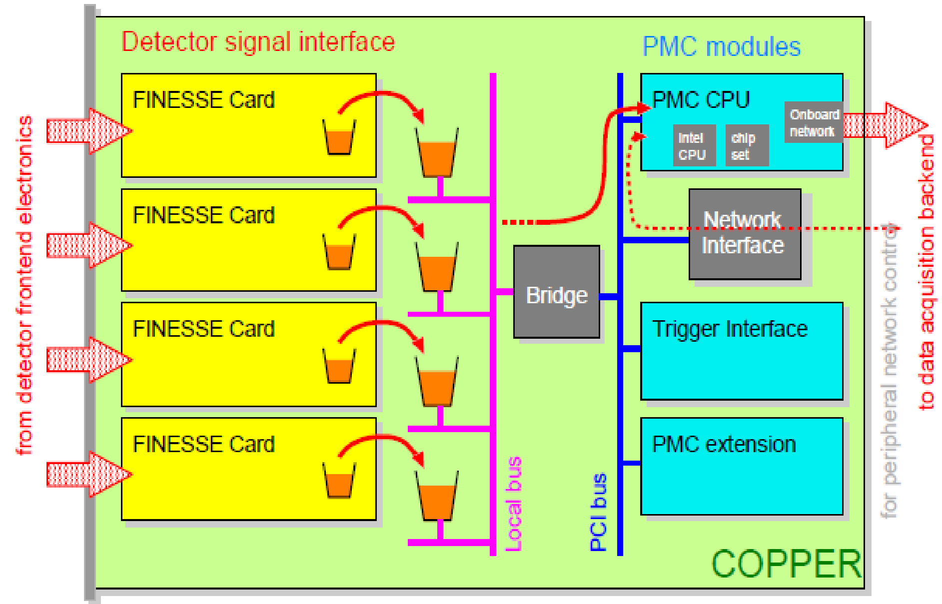
Belle2link

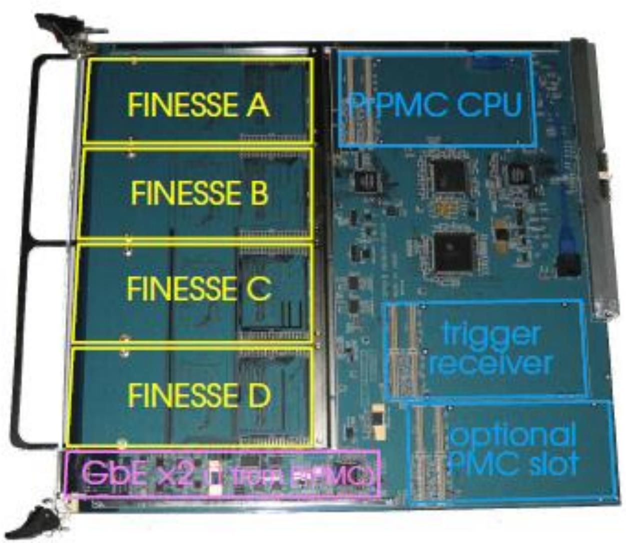
- Unified datalink protocol on RocketIO (GTP) technology over optical fibers.
- Data transmission between front-end electronics of detectors to back-end COPPER based on DAQ system.
- Integrated trigger timing system interface.



COPPER Readout System

- A general purpose pipelined readout platform
- FINESSE: Belle2link receiver, receive the data from front-end
- PrPMC: a commencial CPU card, format and reduce data
- Send to event builder through ethernet connection





COPPER board:
4x FINESSE daughter cards,
PrPMC
Trigger receiver