# Data Acquisition System for Belle II

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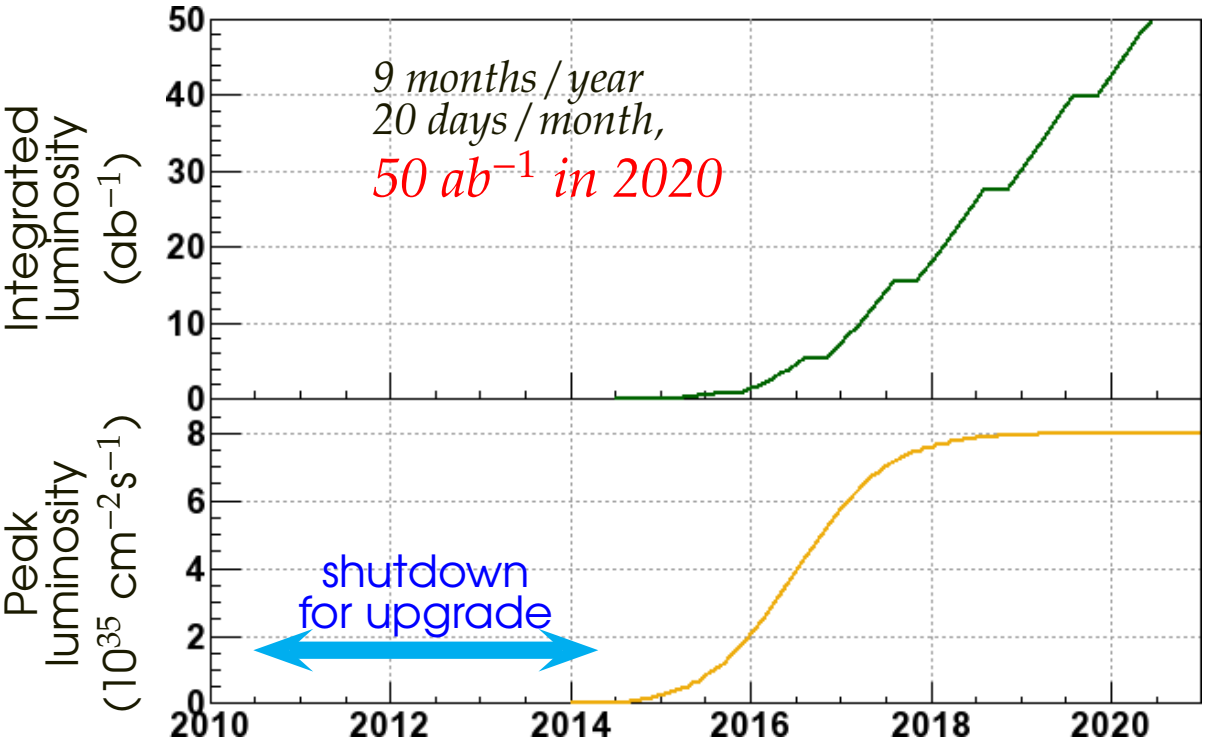
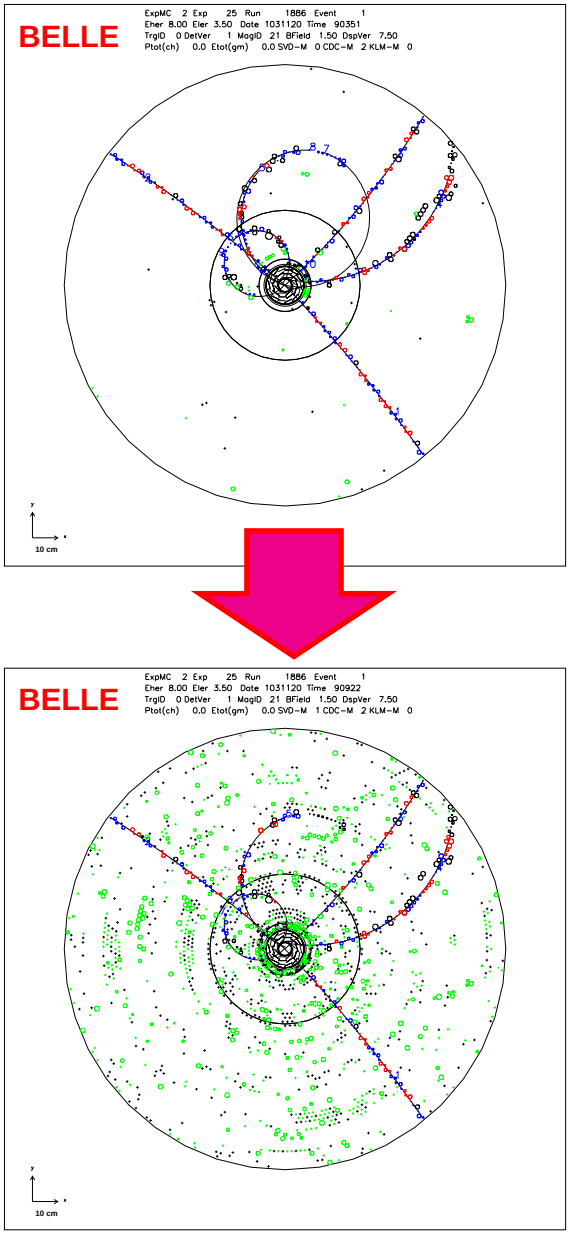
# Belle II at SuperKEKB

- KEKB/Belle has been extremely successful, yet ...
- Flavor physics ($B$, $D$ & $\tau$) with 50 ab$^{-1}$ *(~50 billion of each)* to identify new physics *(synergy with direct searches at LHC)*
  - *400 collaborators from Asia, Europe and US*
  - *Project approved this year, funding has started* 
- Challenges to detectors and DAQ, lots of fun in coming years



# Wishes & Challenges

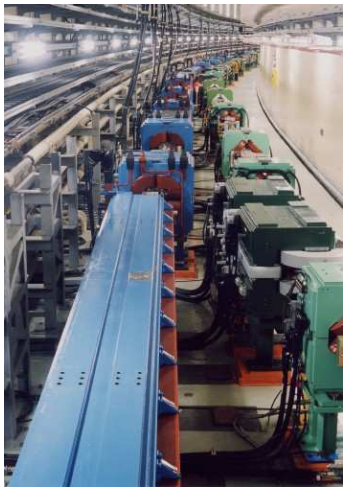
- For a higher luminosity
  - *More beam background (~20 times)*
  - *Higher trigger rate (~40 times)*
  - *More radiation*
- To improve the detector
  - *Pixel detector (DEPFET)*
  - *New particle ID system*
  - *Finer granularity (more channels)*
  - *Faster electronics (shorter time window)*
- Other constrains
  - *Limited human/funding resources*
  - *Limited space (no hermeticity gain/loss)*
  - *~100% efficiency is required*

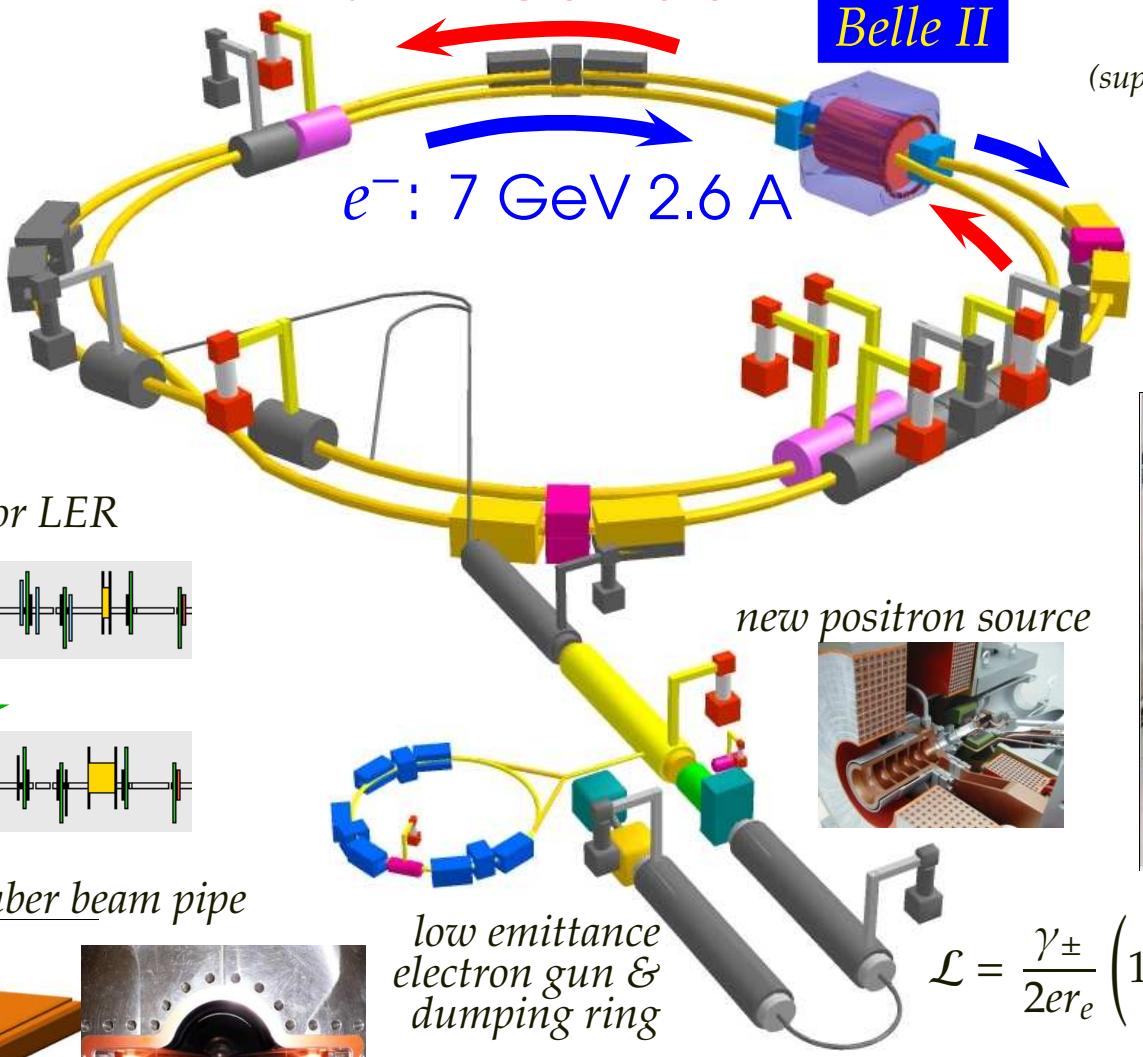



*an example with 20× noise hits*

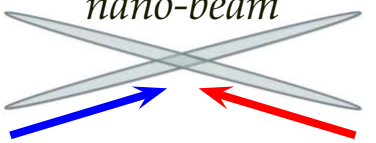
# SuperKEKB collider

*Reusing KEKB components (gray)* + *many new systems (color)*





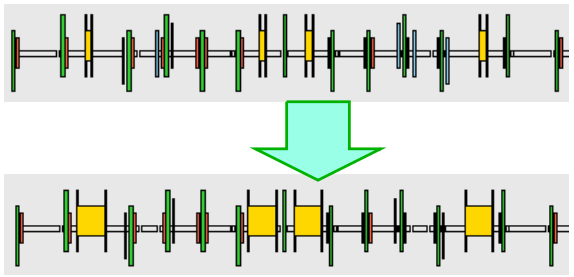

*colliding bunches*
*"nano-beam"*



*final focusing quad*
*(superconducting+permanent)*

*more RF systems*

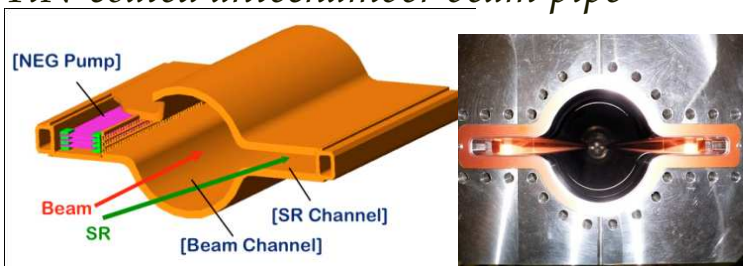
*low emittance optics*
*with longer dipoles for LER*



*new positron source*



*TiN-coated antechamber beam pipe*

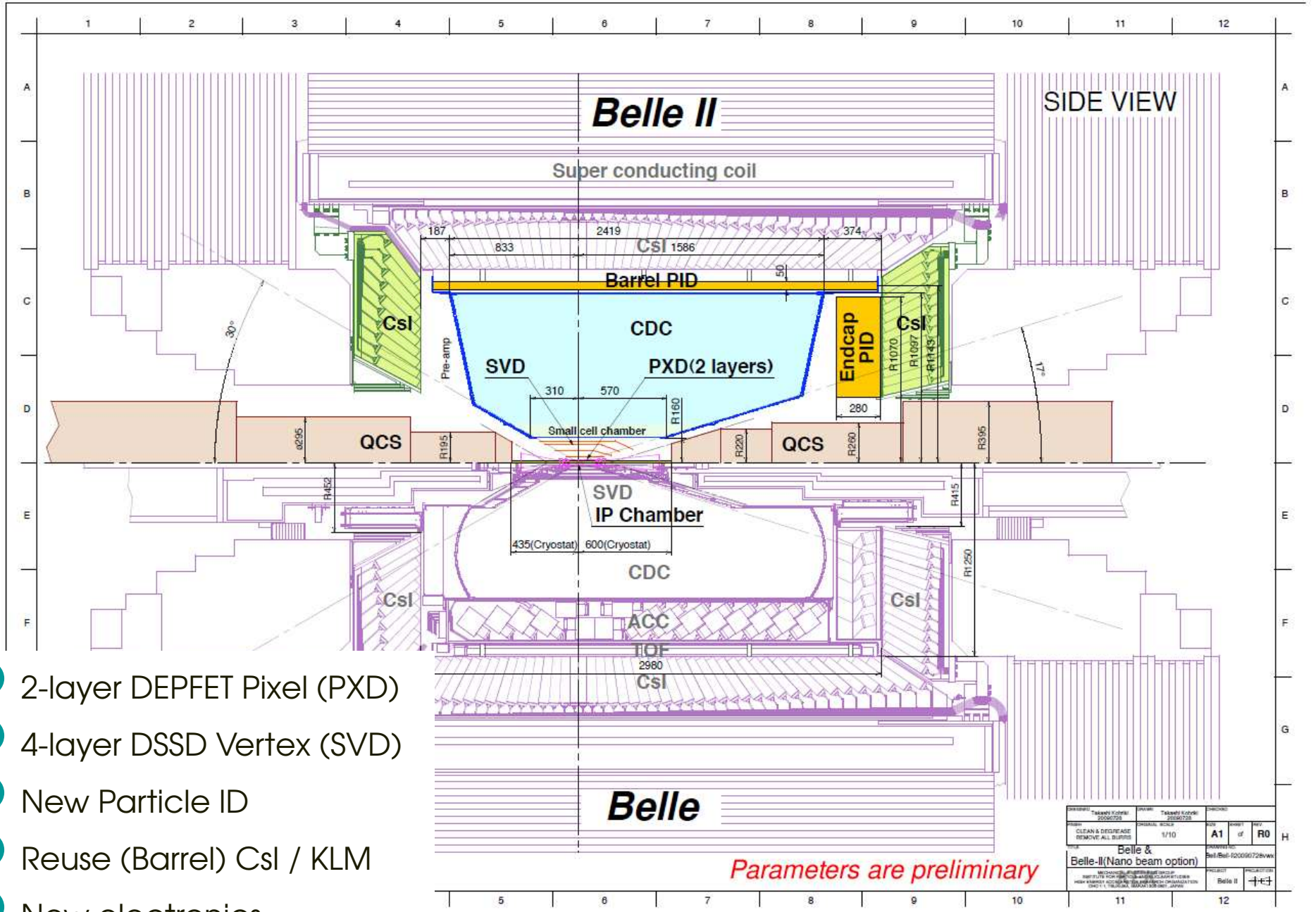



*low emittance*
*electron gun &*
*dumping ring*

$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

target $\mathcal{L} = 8\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

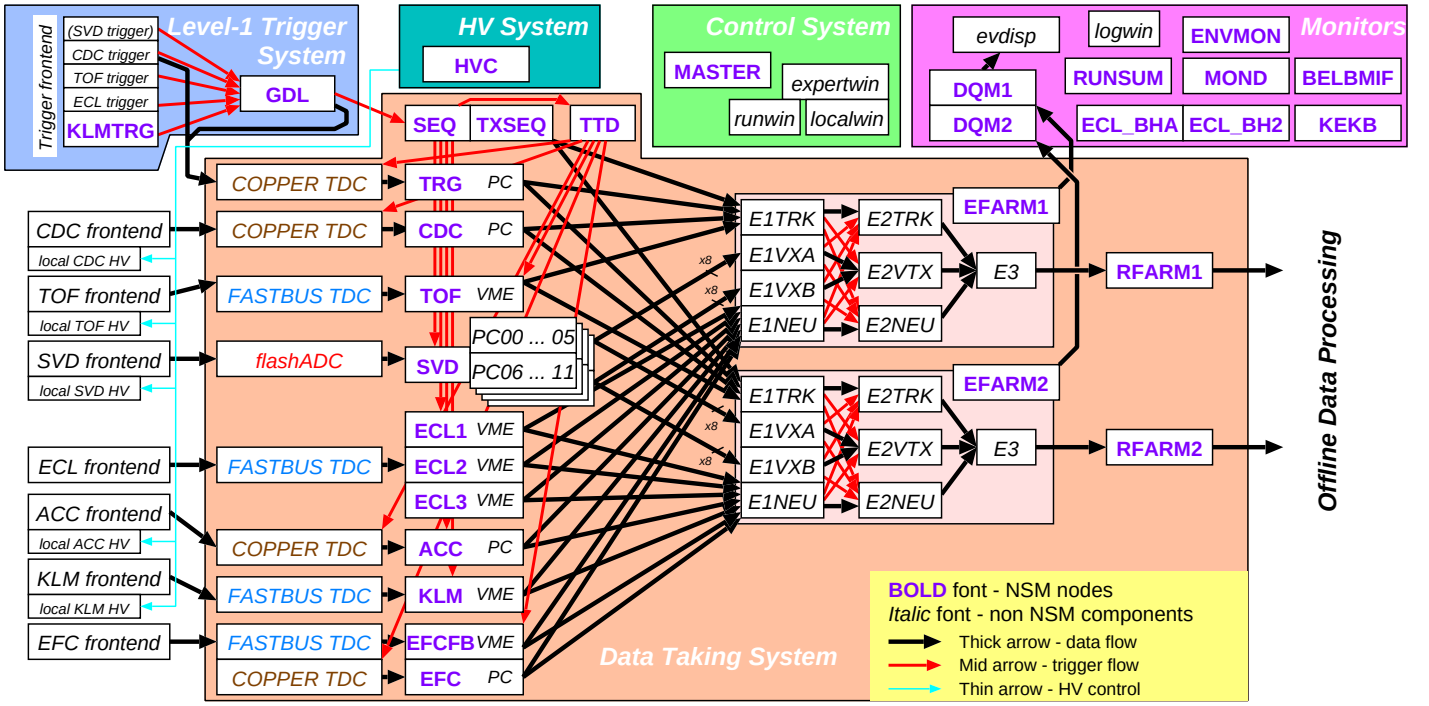
# Belle II detector




- 2-layer DEPFET Pixel (PXD)
- 4-layer DSSD Vertex (SVD)
- New Particle ID
- Reuse (Barrel) CsI / KLM
- New electronics

# Experiences at Belle I

- "Unified" readout system — Q-to-T and multihit TDC
- Low trigger rate, up to 500 Hz, readout not pipelined
- 40 kB / event, 20 MB/s total rate,
  Point-to-point TCP connection for L3 trigger / event building
- Limited human resources, smoothly operated over 10 years

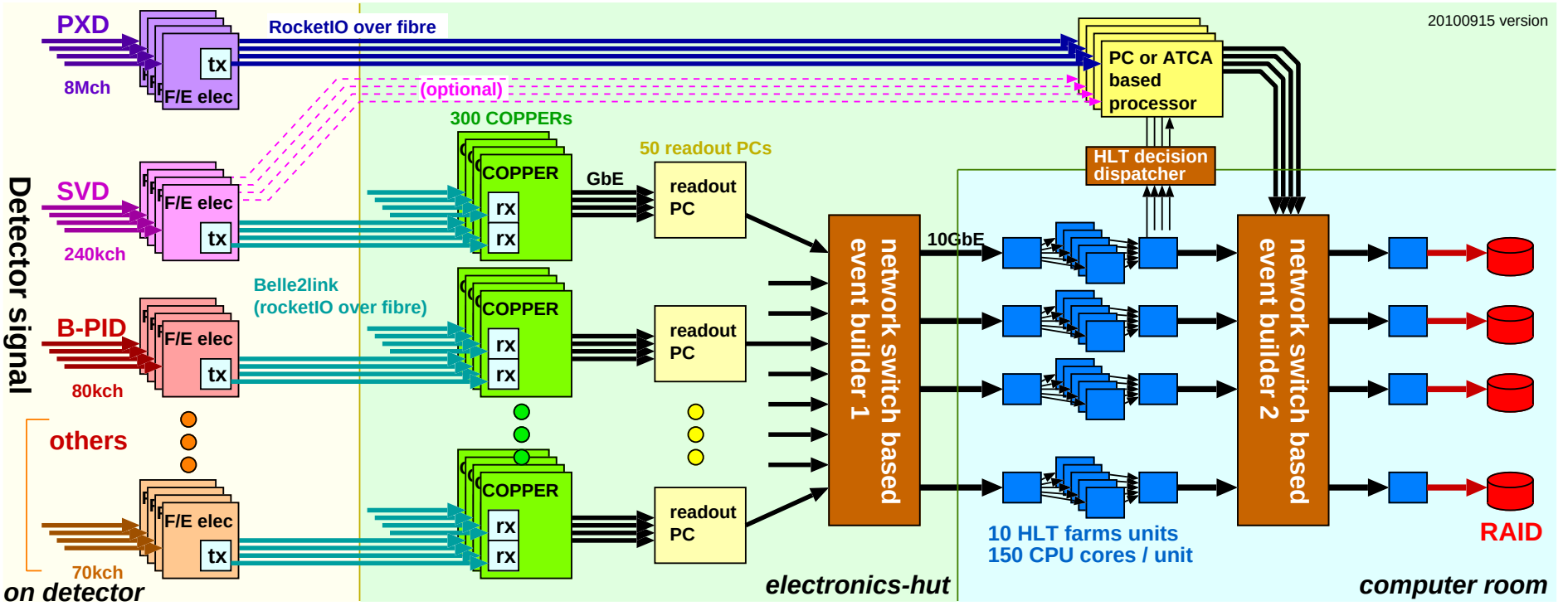


# Belle II DAQ constraints

- 20 kHz nominal L1 trigger rate (40 times higher)
  *~1 kHz each of $b\bar{b}$, $c\bar{c}$, $\tau^+\tau^-$, >99% efficiency for $b\bar{b}$*
- 5 $\mu$s L1 trigger latency (only twice longer)
  *Limited by the APV25 readout of SVD*
- 2ns beam bunch spacing (unchanged)
  *Colliding bunch is not identified online, resolved in offline*
- Huge data from Pixel detector
  *Special handling, dominating the bandwidth*
- Still huge data even without Pixel detector
  *Fast optical transmission & network system, challenges to offline*
- Limited human resources (unchanged :-< )
  *Unification based on universal components (reusing Belle concepts)*

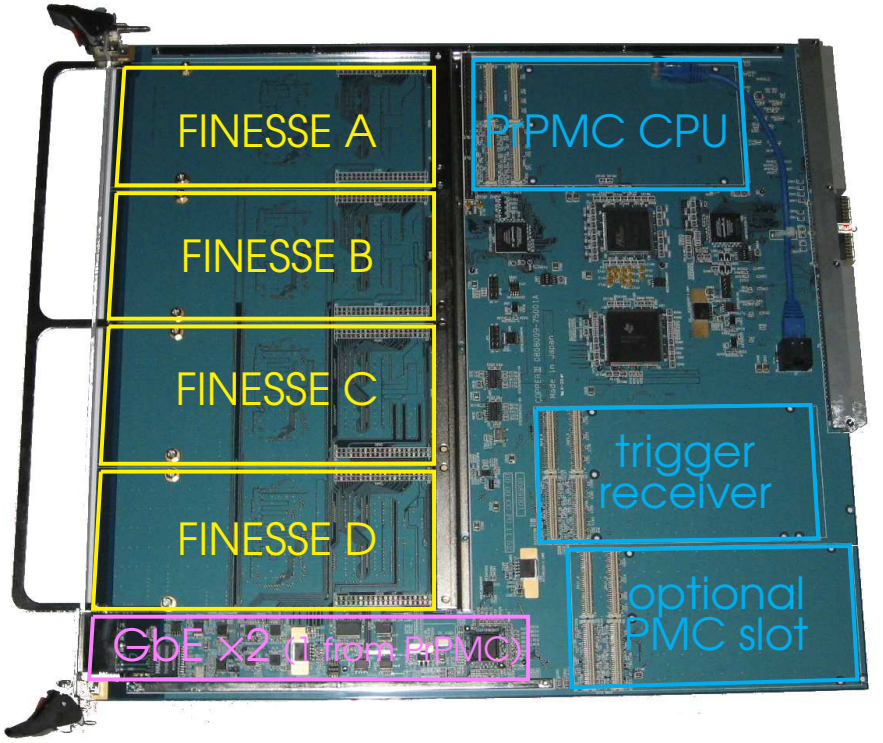
# Belle II DAQ concept

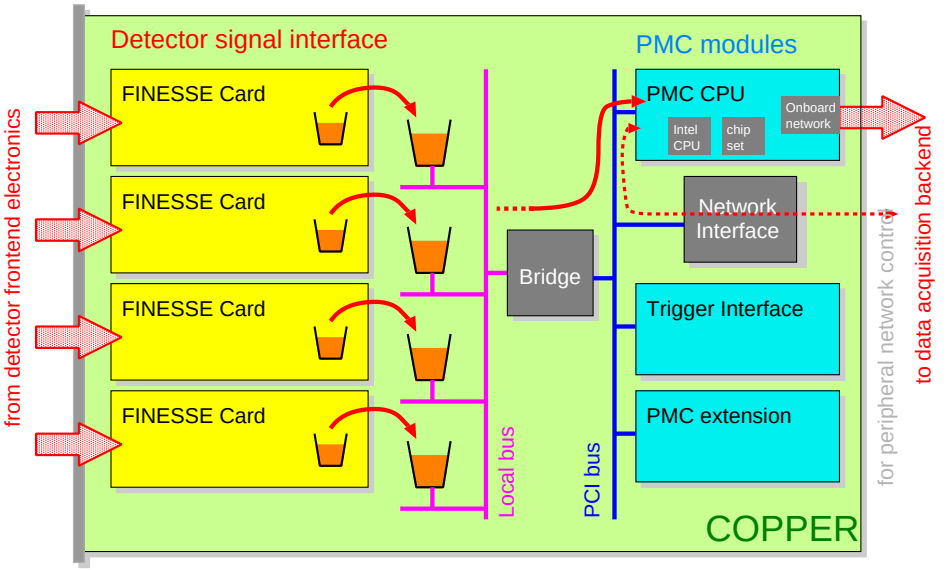
- Detector specific digitization + unified datalink
- Common receiving platform (COPPER) and GbE
- Network switch based 2-stage event building
- "Offline" reconstruction at high level trigger (HLT) farm
- PXD data as an additional dataflow



# COPPER platform

- **Modular structure**
  *4x FINESSE daughter cards, PrPMC CPU, trigger receiver*
- **Dedicated for readout**
  *1MB FIFO per FINESSE, fast control signals*




- **Compact VME 9U board**
- *COPPER2 designed in 2002, ~ 200 boards used in Belle, widely used at KEK & J-PARC*
- *COPPER3 board: revised in 2008 for next 10-year lifetime*
- **Limitations** — *32-bit 33 MHz PCIbus, PrPMC performance*

# PrPMC

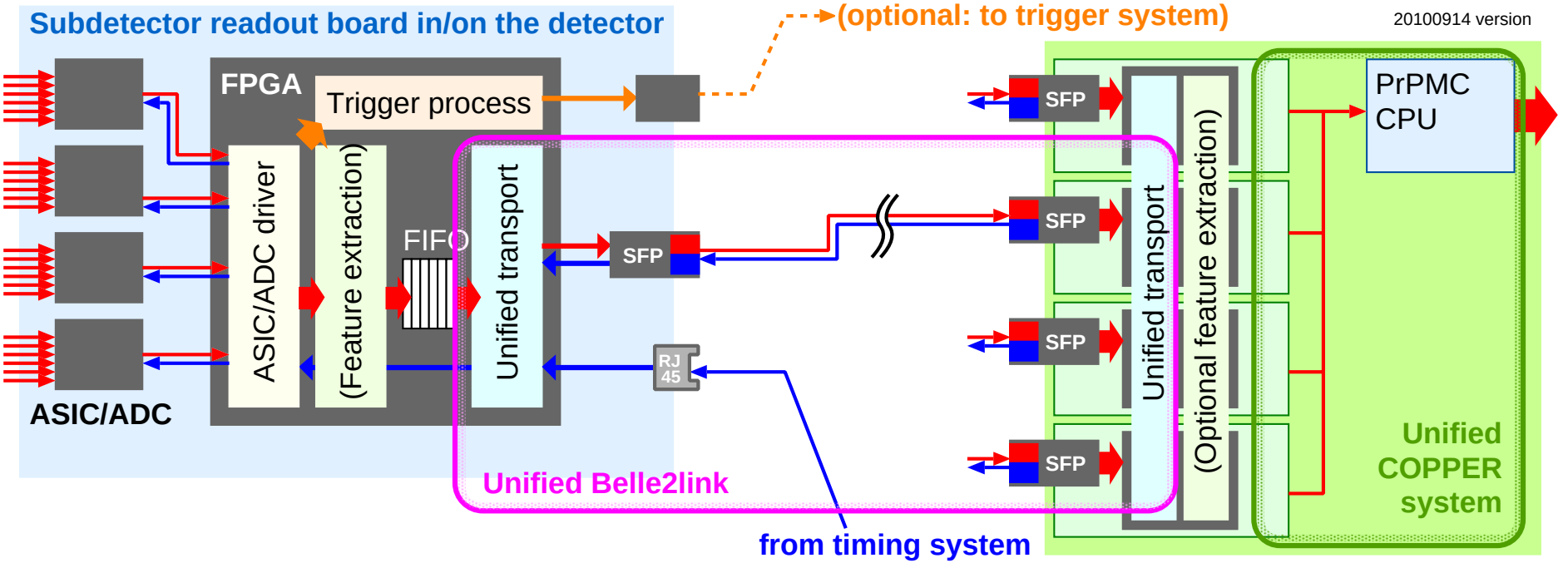
- Intel x86 CPU in a small PMC form factor
  - *Running Linux OS (RedHat, CentOS)*
- Pentium III 800MHz based PrPMC in Belle

Atom Z530 1.6 GHz based PrPMC for Belle II

  - *To be used for next 10 years*
  - *Newly developed by the manufacturer who made COPPER*
- Software and running environment resources developed for Belle
- New PrPMC under evaluation
  - *Functionally OK*
  - *Tested at 40 kHz L1 trigger*

# Belle2link

- Frontend for CDC & PID are inside the detector, Serialized datalink to reduce the number of cable
- Unified datalink protocol on Xilinx RocketIO (GTP) from detector area to COPPER (~20m)
- Integrated timing system interface (LVDS)
- Two paths for their remote control (optical/LVDS)



# FINESSE

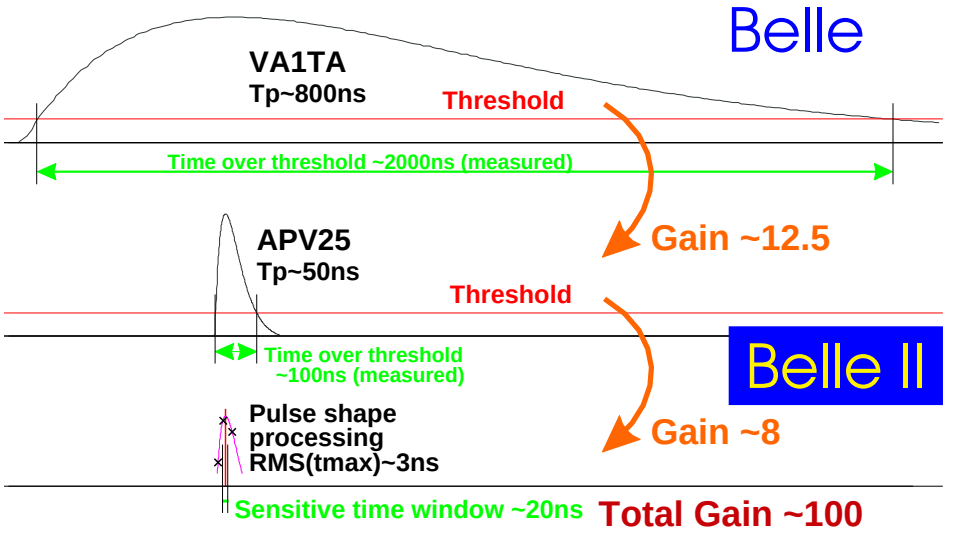
- TDC FINESSE has been used in Belle
  (compatible to LeCroy FASTBUS TDC)
- Belle2link receiver FINESSE in Belle II
  - *Xilinx Virtex5-LXT FPGA (RocketIO GTP up to 3 Gbps)*
  - *For most of the detector, FINESSE is just a receiver, bandwidth will never saturate*
  - *Feature extraction (DSP) for barrel-PID & endcap-KLM, raw sampling data transmitted over Belle2link*

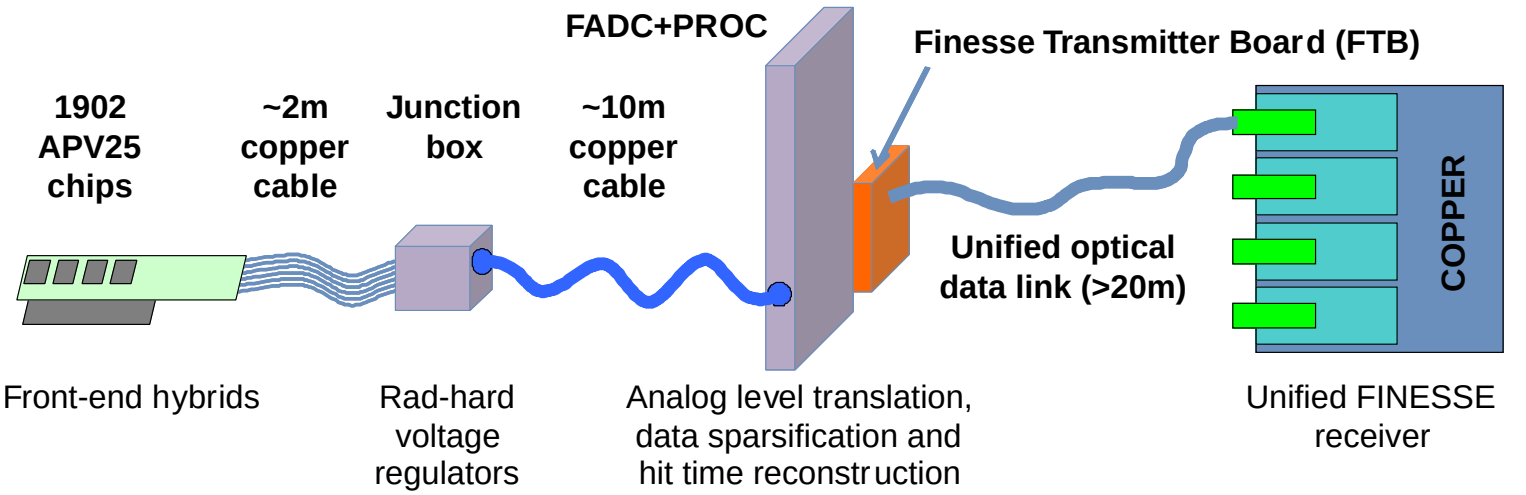
Standard Belle2link Receiver Prototype


DSP Belle2link Receiver Prototype

# SVD readout

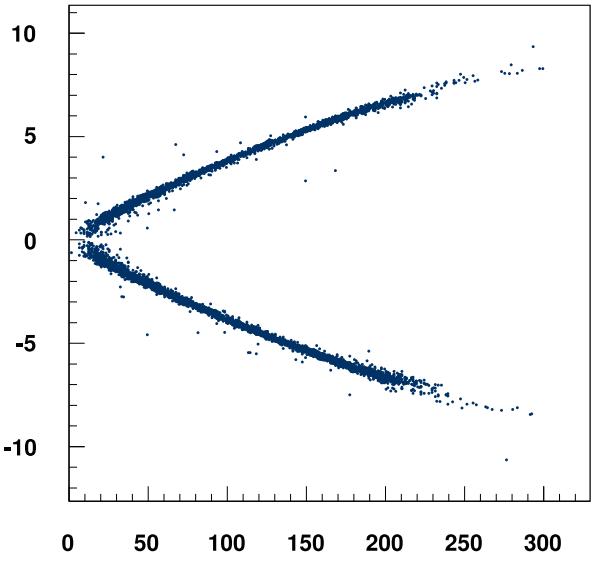
- APV25: 6 sample readout & external pulse finding,
  *timewise occupancy reduction makes it even more quiet than Belle*
- Driven by 32MHz clock
  - *5μs buffer*
  - *200 ns trigger interval*
  - *up to 5 triggers in pipeline*
  - *27 μs to readout*
  - *3.5% deadtime at 30 kHz*



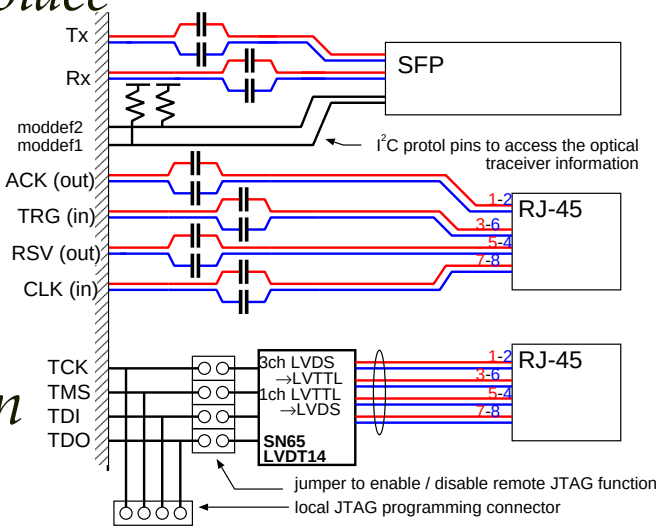
# CDC readout

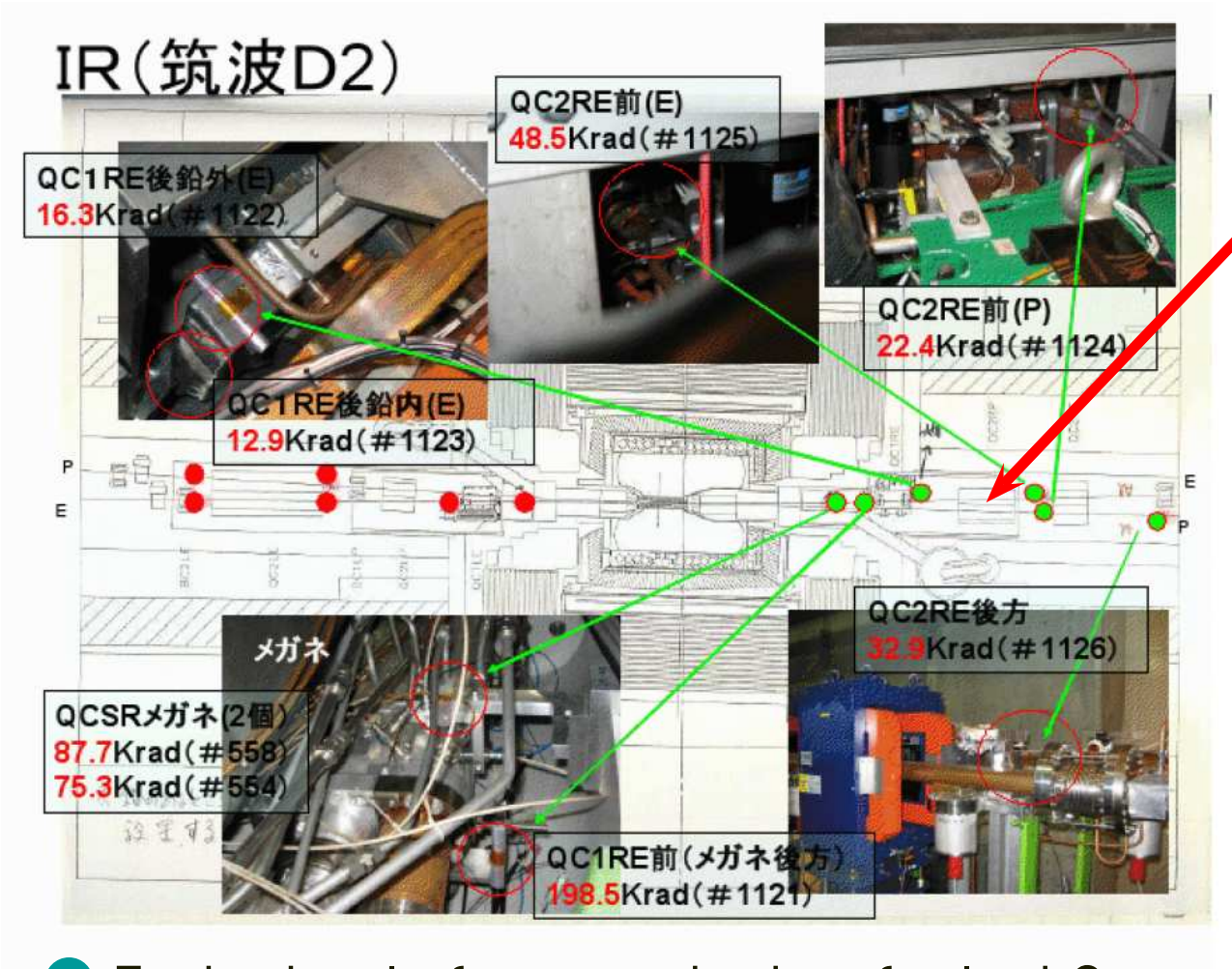
- FlashADC + FPGA-TDC(1GHz)
- *Prototype readout board is ready with a test chamber (x-t curve)*
- *48 ch per board, just behind the CDC endplate (inside detector) including preamp, ADC, FPGA, and optical transceiver*
- *Extracting the analog signal out of the detector is no more realistic due to the increase in the number of channel*
- *Trigger information also generated*
- Radiation and maintenance could be an issue
  *(similar worries on B- and E-PID)*



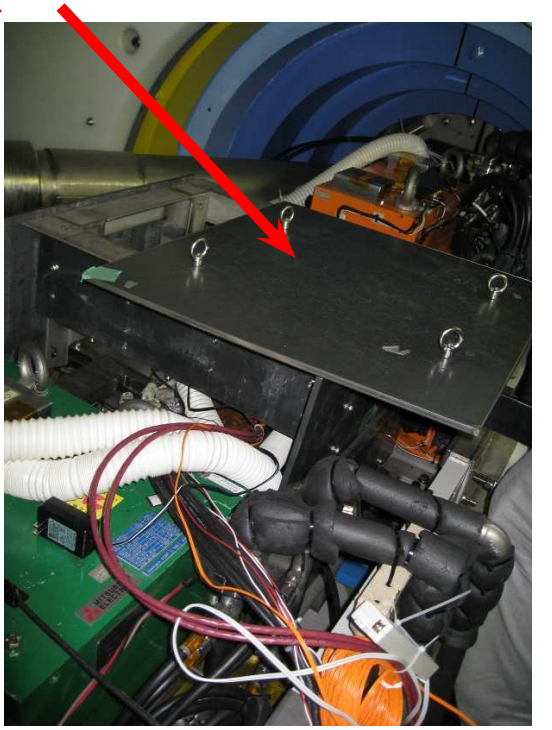
# Radiation issues

- From DAQ point-of-view, we worry the frontend electronics inside the detector (CDC / BPID / EPID)
  - *Measured by Belle and scaled to Belle II: only 0.6 krad / year*
  - *Neutron flux: O(Hz)/cm$^2$*
  - *Configuration flash (Xilinx XCF) & optical transceivers (Avago AFBR-57R6APZ) damaged by a irradiation test in the KEKB tunnel (may be too harsh environment, further radiation tests scheduled)*
  - *Difficult to access, takes a few weeks to replace*
- JTAG-on-LVDS over a LAN cable
  - *Readback CRC of Virtex5 for monitoring*
  - *Recovery from SEU by reprogramming, tested during the KEKB tunnel irradiation*





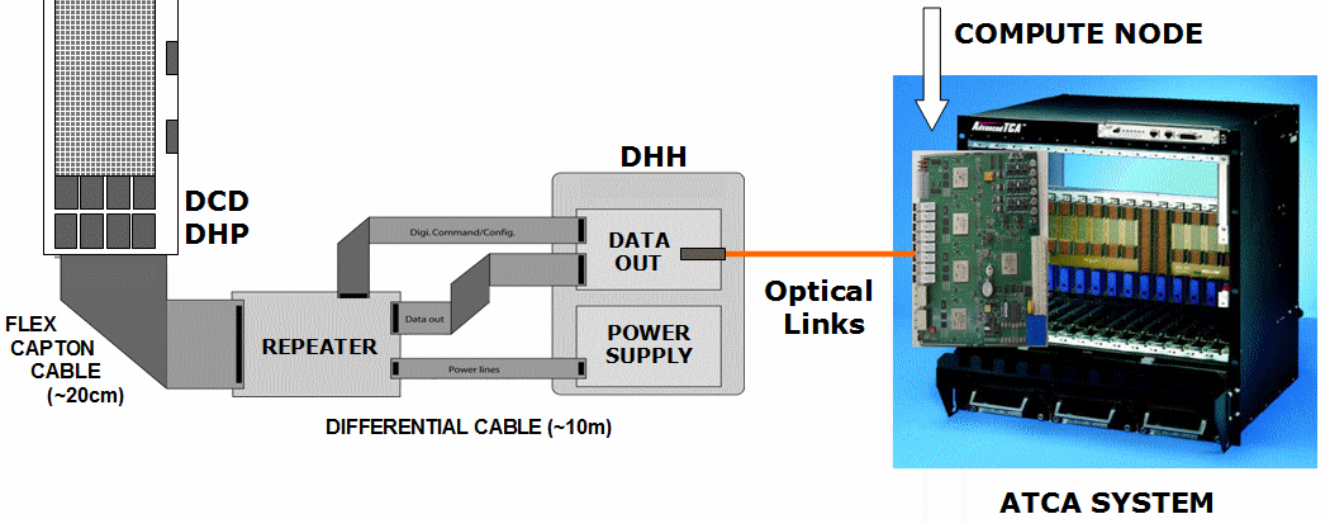

Placed inside a lead box



- Tested only for one device for last 2 months of KEKB
- 4.4 kRad per week (by TLD)
- 0.4 rad of thermal neutron
- 7.3 kHz/cm$^2$ high energy (>100 MeV) neutron measured by Au $\rightarrow$ $^{185}$Os production rate (not existing inside Belle II)

# PXD readout

- 8 M channel × 1–2% occupancy (80-160k hits / trigger)
  - *~10 charged tracks in an event, only regions-of-interest are needed*
  - *Tracks reconstructed by a hardware SVD tracker and/or HLT system, RoI selected by ATCA system or PC with PCIe optical receiver*
  - *RoI selection happens only after 5s of HLT processing time*
    - 20$\mu$s to readout the entire ladder
      - *Multiple triggers may overlap in a single frame*
      - *May conflict with SuperKEKB continuous injection scheme*




40 ladders, DCD-DHP-DHH chains to ATCA/PC

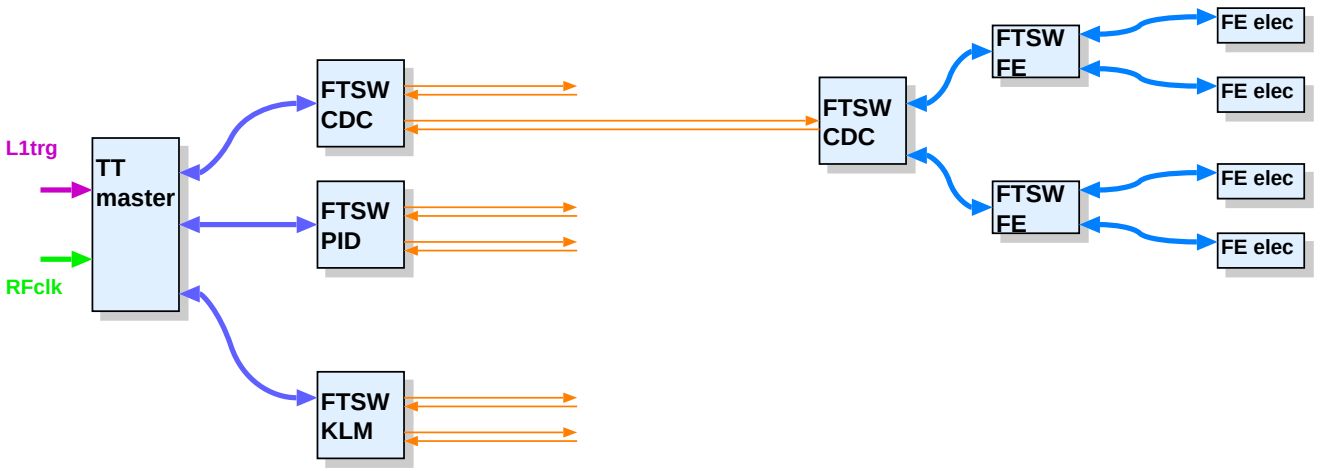
# Readout summary

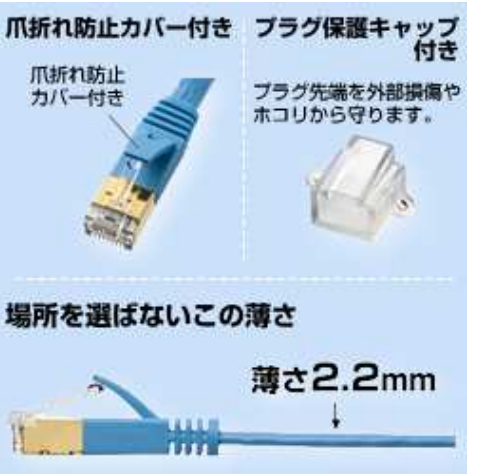
| | #ch | occ (%) | #link | /link (B/s) | #CPR | ch sz (B) | ev sz (B) | total (B/s) | /CPR (B/s) |
|---|---|---|---|---|---|---|---|---|---|
| PXD (pixel detector) | 8M | 1 | 40 | 182M | — | 4 | 320k | 7.2G (before RoI) | — |
| SVD (silicon vertex detector) | 243456 | 1.9 | 80 | 6.9M | 80 | 4 | 18.5k | 555M | 6.9M |
| CDC (central drift chamber) | 15104 | 10 | 300 | 0.6M | 75 | 4 | 6k | 175M | 2.3M |
| BPID (barrel particle ID / time-of-propagation) | 8192 | 2.5 | 128 | 7.5M | 8 | 16 | 4k | 120M | 15M |
| EPID (endcap particle ID / aerogel RICH) | 77760 | 1.3 | 138 | 0.87M | 35 | 0.5 | 4k | 120M | 15M |
| ECL (CsI electromagnetic calorimeter) | 8736 | 33 | 52 | 7.7M | 26 | 4 | 12k | 360M | 15M |
| BKLM (glass-RPC barrel $K_L/\mu$ detector) | 21696 | 1 | 86 | 9.7M | 6 | 8 | 2K | 60M | 10M |
| EKLM (scintillator tile endcap $K_L/\mu$ detector) | 16800 | 2 | 66 | 19.5M | 5 | 4 | 1.4k | 42M | 8.4M |

- 1.4GB/s total bandwidth without PXD
- ~1000 optical links to readout the entire system
- Up to 300–400 COPPERs, rearrangeable according to the rate

# Timing system

- L1 trigger & clock delivered to every front-end board
- Pipeline status is monitored to avoid buffer overflow
  *signals collected from the frontend and COPPERs*
- Deadtime only due to frontend buffer structure
- Entire system is synchronized to reduced RF clock (127 MHz) and beam revolution (100 kHz)
- Inter-connected by a thin CAT7 cable, or optical fibres between detector and electronics-hut



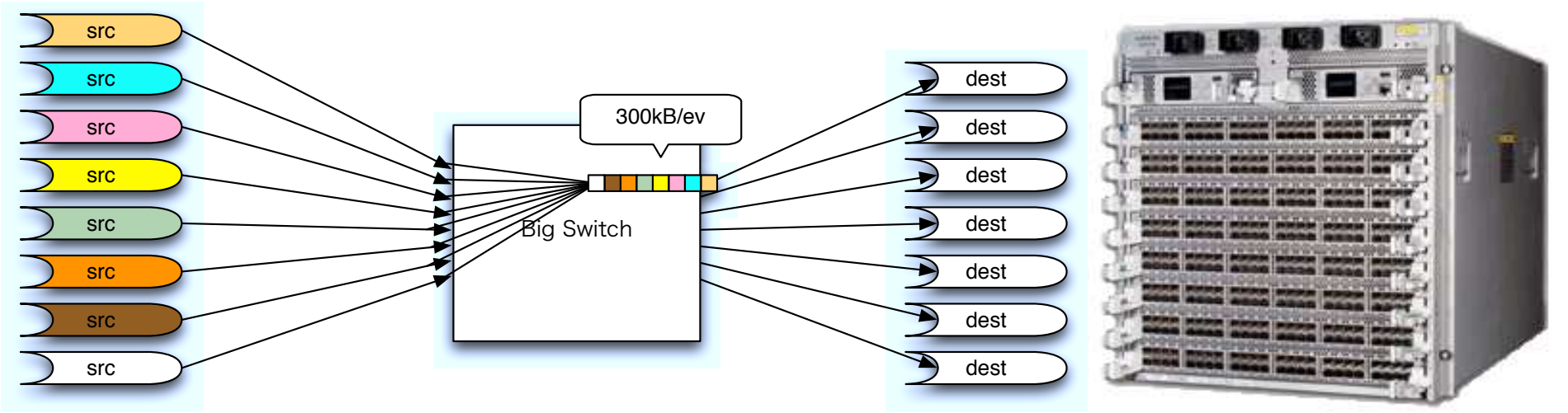



# Timing system

- Entire system is synchronized to a reduced RF clock (127 MHz) and beam revolution (100 kHz)
- Trigger timing and status information embedded in a serialized signal (Xilinx OSERDES)
- 8b10b-encoded 32bit word at 254Mbps (every 157 ns)
- One type of PC board to cover all
  - 1-to-20 distribution using LVDS embedded in CAT7
  - 1-to-4 distribution using optical ports on FMC
  - ~1000 destinations in total

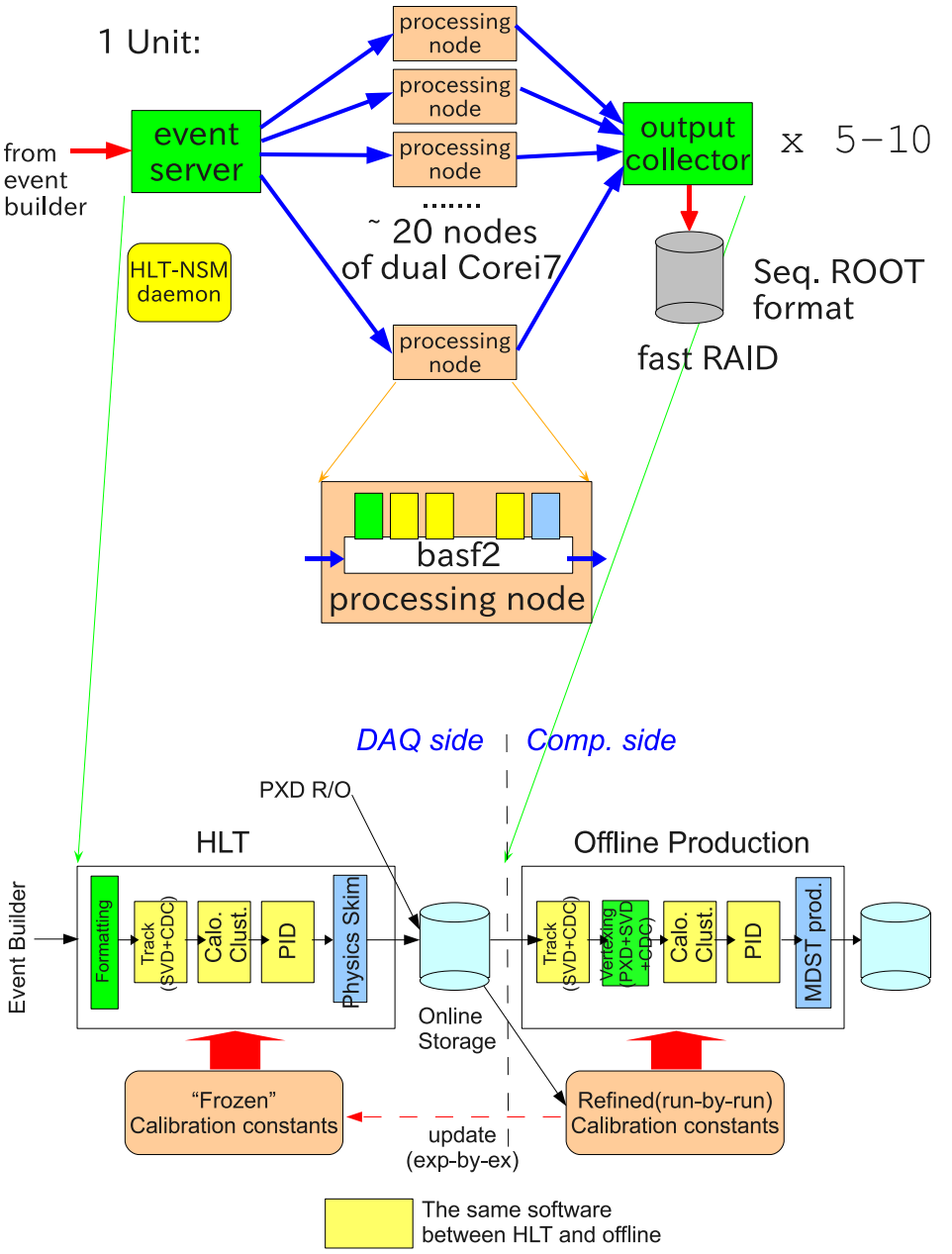
# Event building

- ~50× GbE input, ~10× 10 GbE output, multi GB/s
- Large network switch (e.g. ARISTA 7500 series)
  *(or cascading smaller switches as a backup option)*
- Large enough buffer (>300kB buffer / port)
  *to avoid data loss / retransmission*
- 10GbE port tends to be expensive
  *bundle multiple GbE into 10GbE by a smaller switch before feeding into the large switch*



# HLT

- The same offline software running online
  (basf2 framework)
- Frozen calibration constants are used
  *faster updating is under consideration*
- 5 sec latency to provide track information to PXD
  *or save all hits if it takes more*
- Physics skim to reject junk events
  (#track, #clulster, $E_{\mathrm{ECL}}$, event topology, . . . )



# Summary

- Belle II construction has officially started,
  data acquisition system are on the track as well 

  8 subdetectors, 30 kHz L1 rate, multi-GB/s bandwidth

  and will be ready in next 3 years
- Decision making and prototyping work on going,
  potential issues to be hopefully resolved soon
- Participation to Belle II is always highly welcome  
  shortage of electronics people in many places