Operational status of the Belle II Time-Of-Propagation counter readout and data acquisition system

Maeda Yosuke (KMI, Nagoya Univ.) *et al*., for the Belle II TOP group
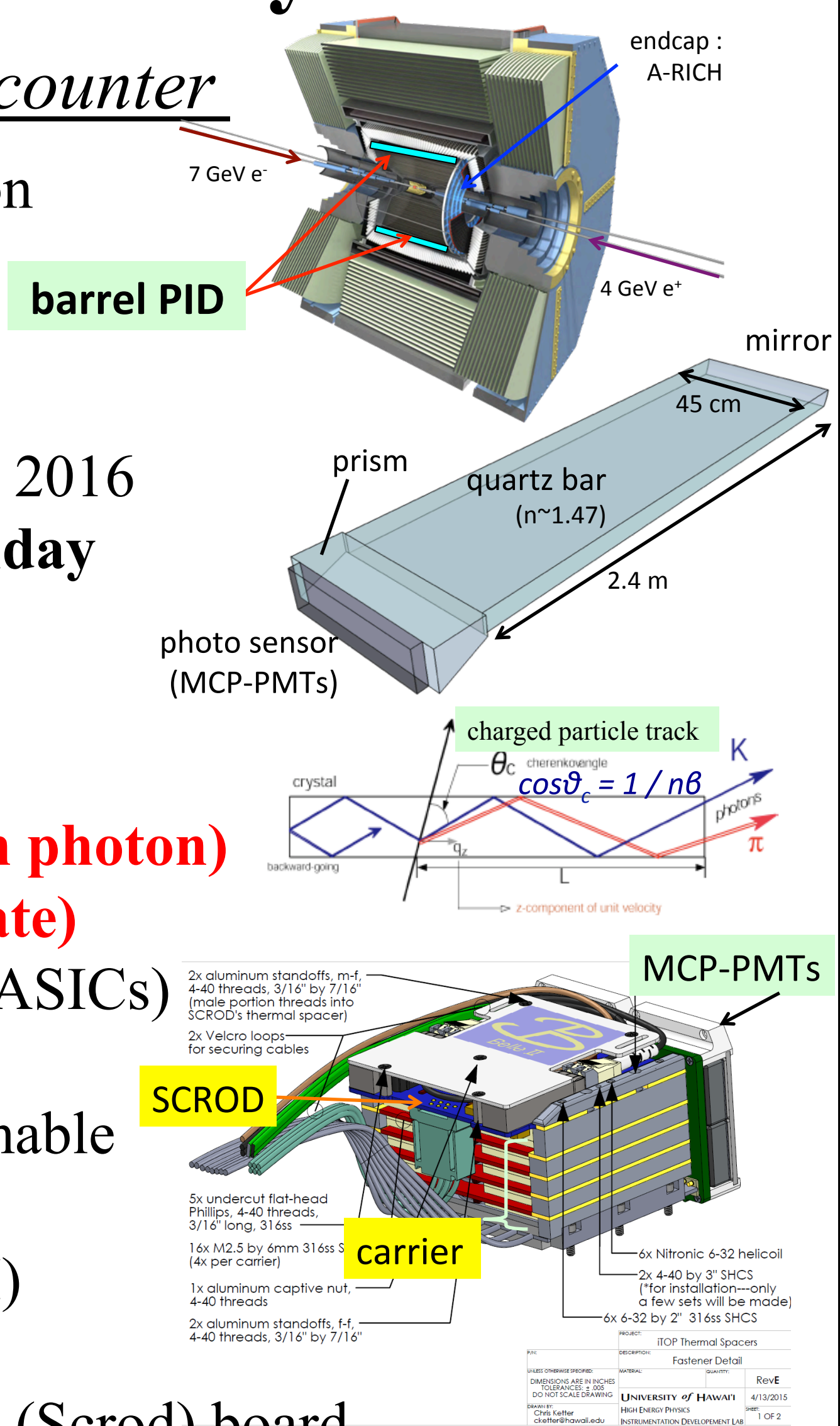
I. TOP counter and its readout system

Belle II Time-Of-Propagation (TOP) counter

✓ novel PID device to cover the barrel region
of the Belle II detector
✓ measure timing of Cherenkov photons
to reconstruct ring image
✓ fully operational since installation in May 2016
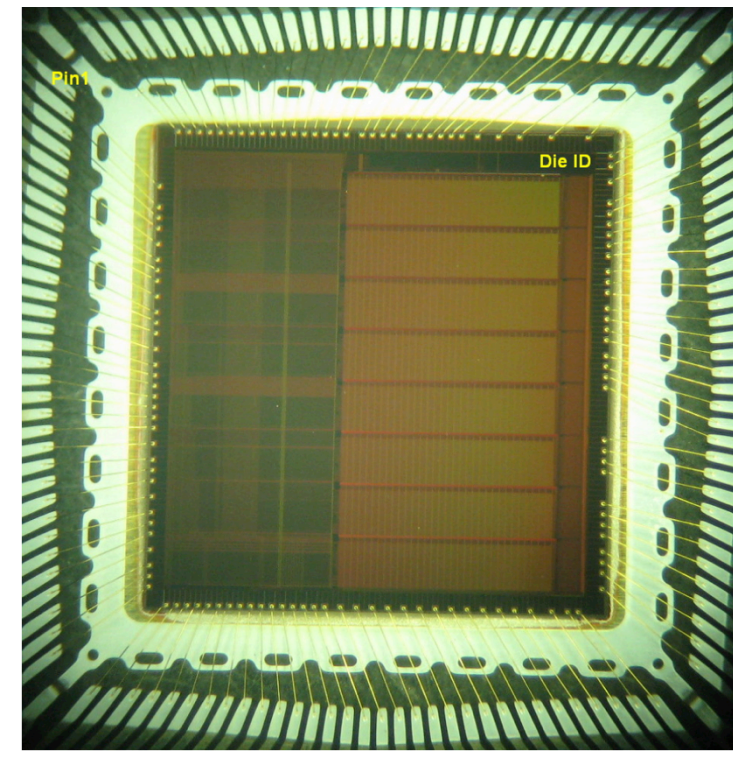→ **talk by U. Tamponi at 10:05-10:30 Monday**

TOP readout overview

✓ challenging requirements :
**excellent time resolution (<100 ps for each photon)
+ high speed readout (30 kHz trigger rate)**
✓ Application Specific Integrated Circuits (ASICs)
for fast waveform sampling and digitization
✓ online data processing by Field Programmable
Gate Array (FPGA) and on-chip processors
✓ each Subdetector Readout Module (SRM)
4 ASIC carrier boards
+ 1 Standard Control for ReadOut and Data (Scrod) board

III. operation history

✓ readout performance is determined by firmware/software of SoCs, which has been developed step-by-step.

Full waveform readout (2016)

✓ digitize all the samples for all the channels
and readout full waveform
☺ robust, no bias
☹ very slow (<10 Hz)
☹ large data size
☹ short buffer

~700 ns

✓ used for stand-alone calibration runs
and cosmic ray data taking
✓ timing performance :
30 ps electronics resolution

distribution of # of photon hits

time difference of two test pulses
→ 42 ps/sqrt(2) ~ 30 ps resolution

cosmic ray data taking with additional trigger counter

Interim-Feature-Extraction (2017)

✓ **feature extraction** : readout only timing and pulse height
+ short waveform only for channels with hits
☺ reasonably fast (< 500 Hz)
☺ deep enough buffer
☹ single hit per channel
☹ not fully pipe-lined
✓ combined data taking
with other Belle II subsystems

timing
height
~100 ns

hits in associated TOP modules

cosmic ray data taking
with drift chamber and
calorimeter trigger

Production version (2018)

✓ close to design performance
☺ fast readout (~20 kHz)
☺ multi-hit capability
☺ no dead time
✓ large calibration samples
✓ used in collision data taking
in **phase 2 operation**
✓ **stable operation with ≲1 kHz
trigger rate**

the first collision data

~10 ns

Cherenkov ring image of
kinematically tagged kaon from D*
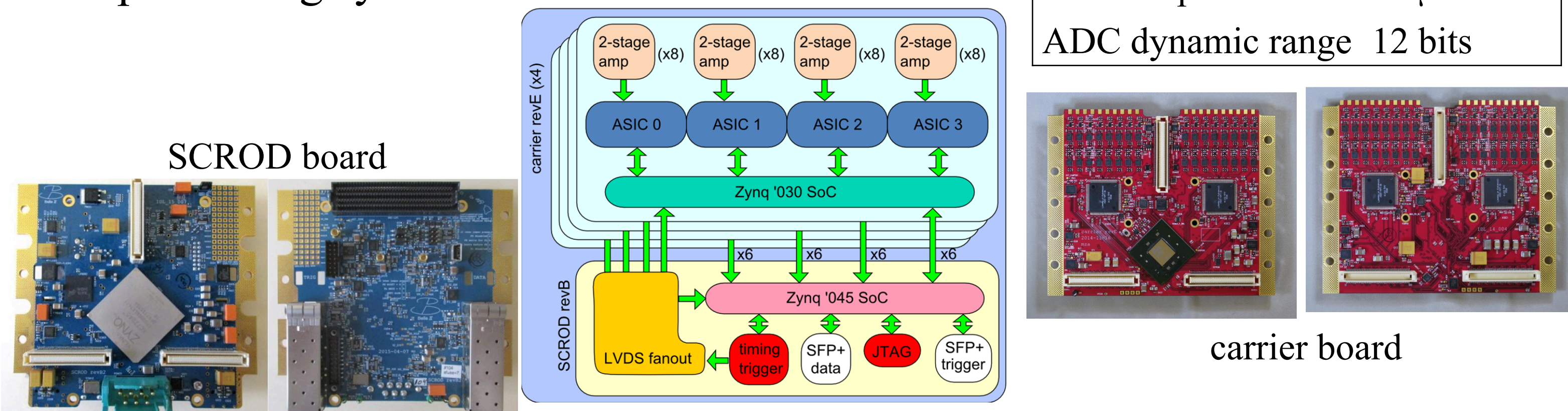(U. Tamponi)

II. specification of readout system

ASIC : Ice Ray Sampler Version. X (IRSX)

✓ developed by U. Hawaii group
✓ fast waveform sampling with switched capacitor array
✓ deep analog buffer
to cope with Belle II L1 trigger latency (5 μs)
✓ selective readout to minimize digitized samples
✓ Wilkinson ADC for digitization

total # of channels	8192
# of SRM	64
	→128ch/SRM
expected occupancy	2.5%
input trigger rate	30 kHz
ASIC properties	
# of channels	8/ASIC
sampling rate	2.7 GSa/s
buffer depth	11 μs
ADC dynamic range	12 bits

online data processing with Zynq SoCs

✓ Z-7030 for each carrier board
and Z-7045 for SCROD board
✓ asic control and communication with backend
data acquisition system by programmable logic
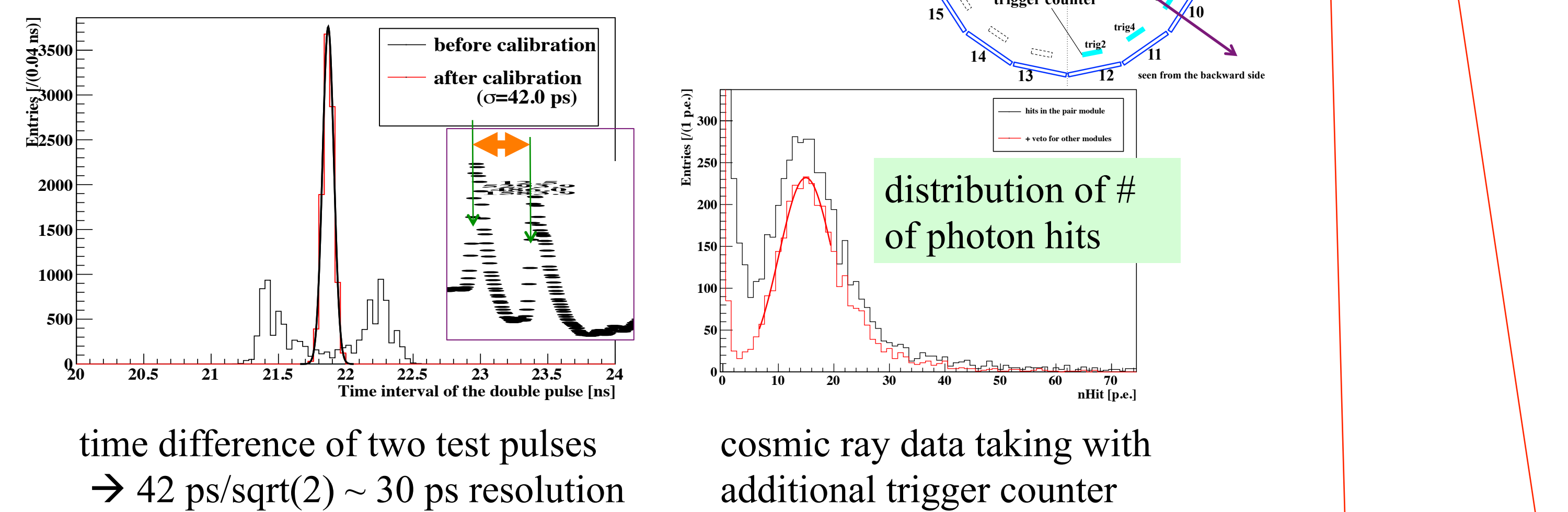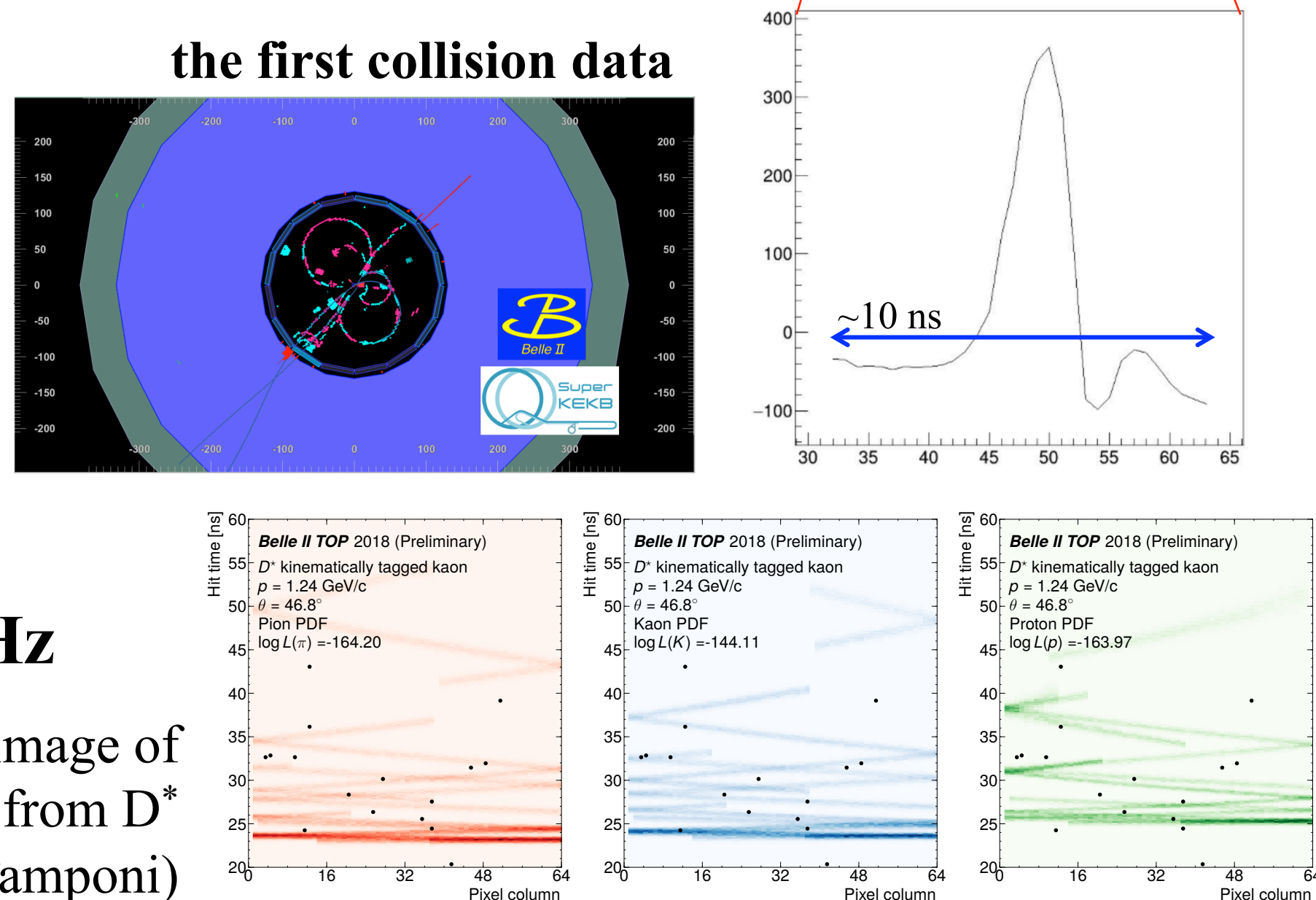✓ online-waveform analysis (**feature extraction**)
in processing system

SCROD board

carrier board

trigger signal from Belle II
global decision logic
TOP trigger system
Belle II backend data
acquisition system

IV. rooms for improvements

template fitting in feature extraction

✓ planning to implement waveform fitting in feature extraction
✓ expect improvement of timing resolution for low-amplitude photon hits

An example of template
fitting and expected timing
resolution
(T. Weber)
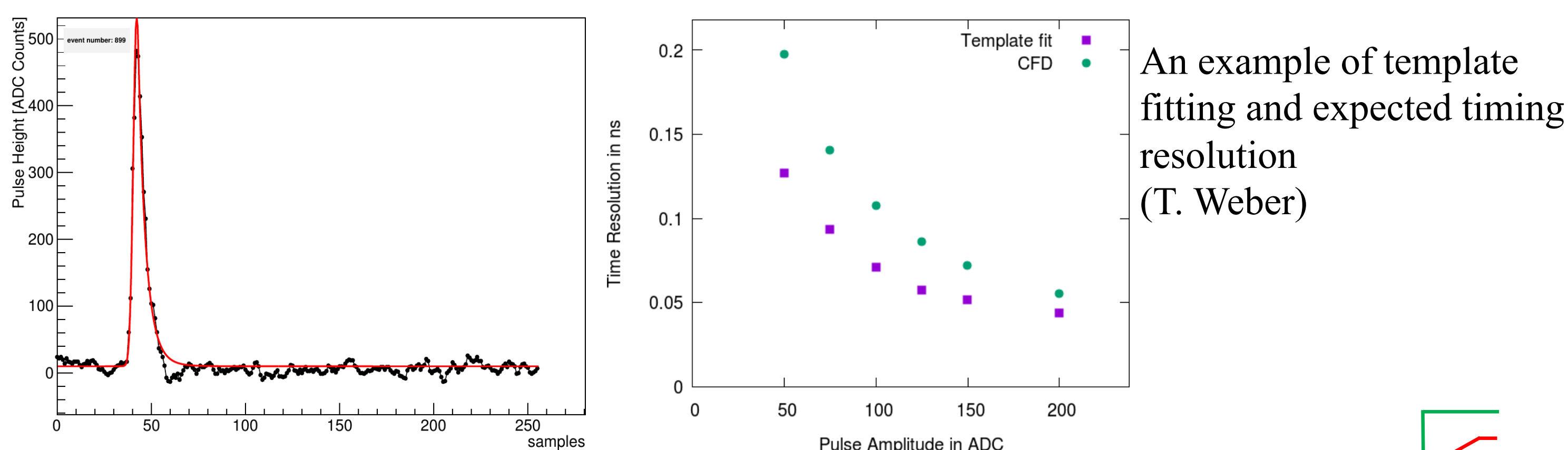
optimization of ADC parameters

✓ slope of V_{ramp} can be optimized to reduce a range
of output values
✓ can help operation with high trigger rate
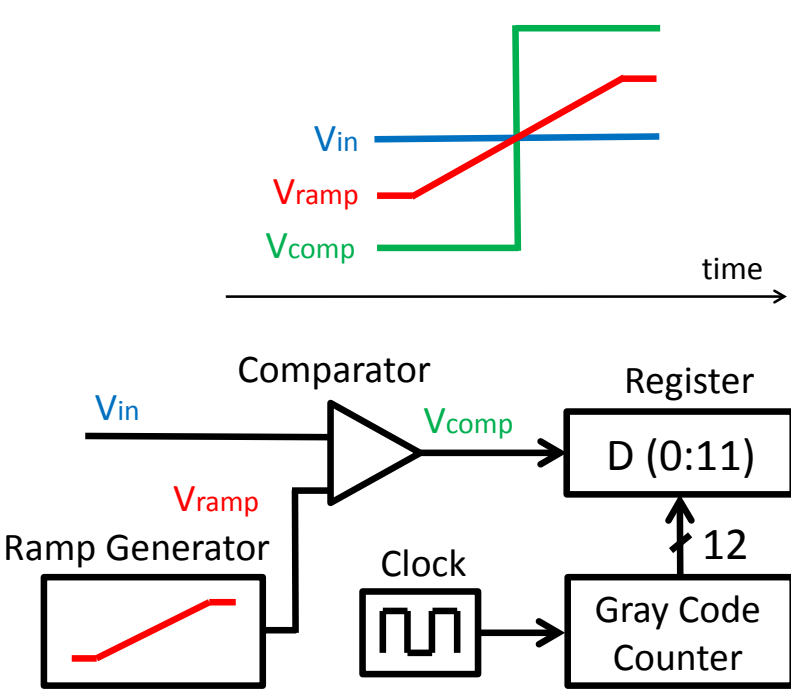
V. summary and prospects

✓ Frontend electronics for Belle II TOP counter, where a lot of challenging requirements must be satisfied, was developed and now is fully operational.
✓ To achieve designed readout performance, much effort of firmware (FW) development has been made since detector installation.
✓ With the current version of FW, TOP readout system has been working successfully in phase2 collision data taking ; 1 kHz stable operation and we also confirmed that it can work at 20 kHz trigger rate
✓ Thanks to readout improvement, large calibration samples became available, which helped to understand detector and demonstrate initial PID performance with phase2 collision data.
✓ Further works to improve the performance are on-going.