Operational Status of the Belle II Time-of-Propagation (TOP) Detector

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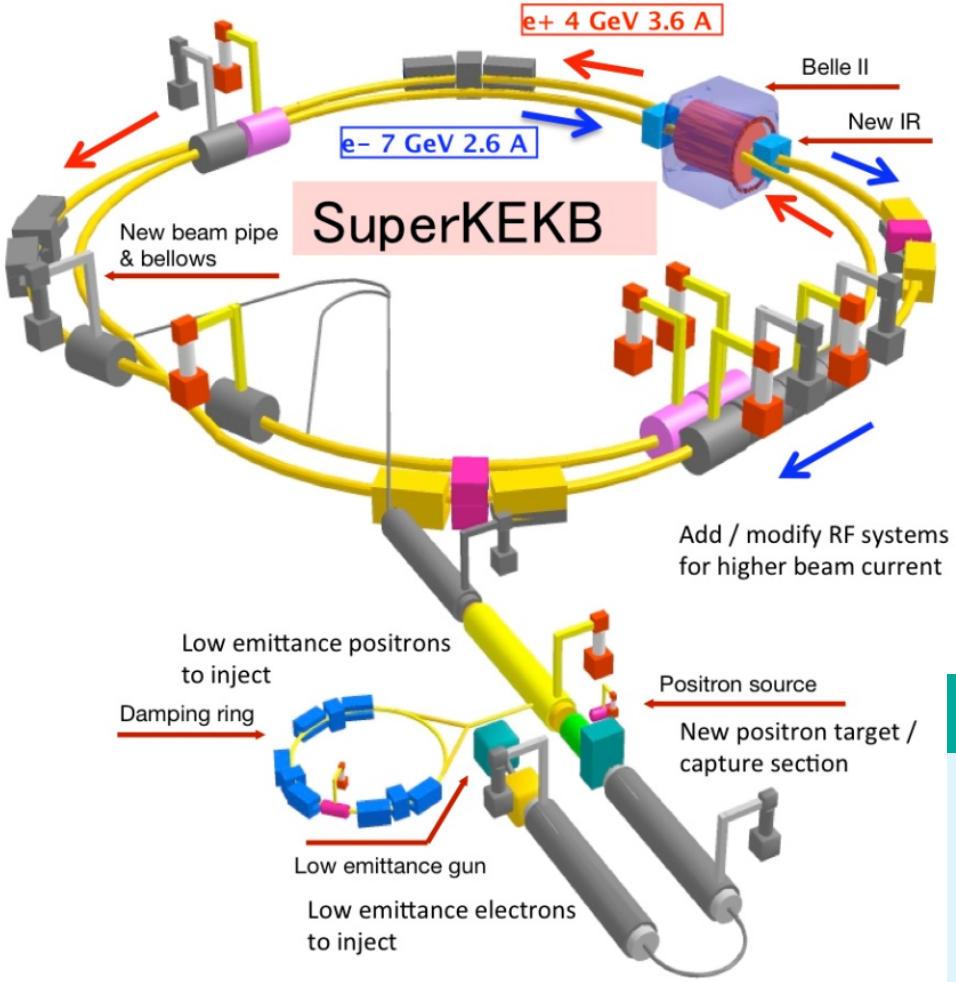
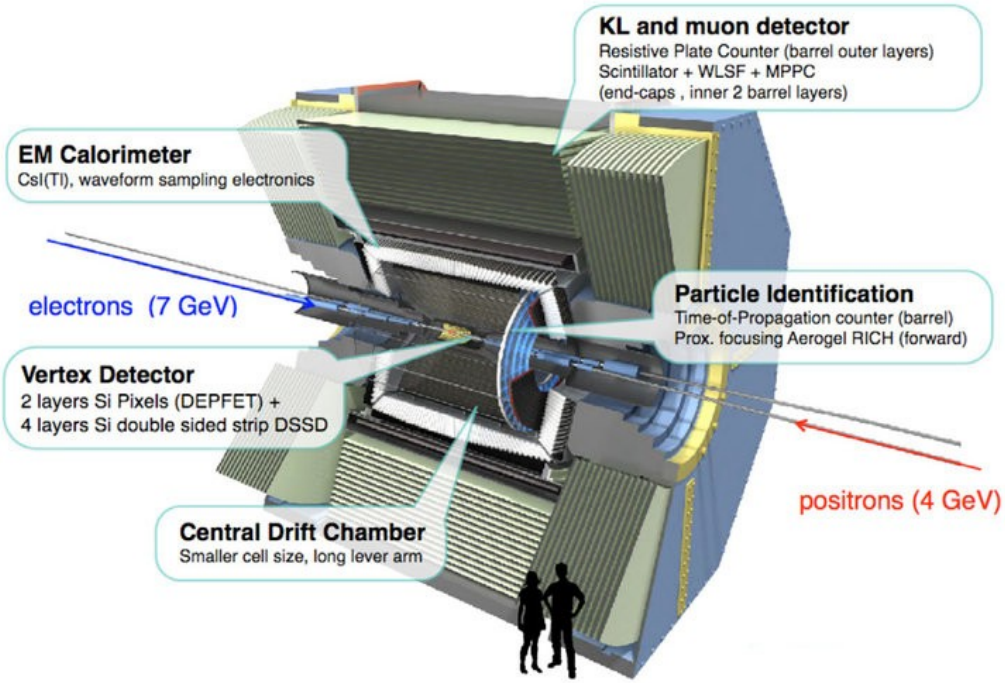
SuperKEKB and Belle-II

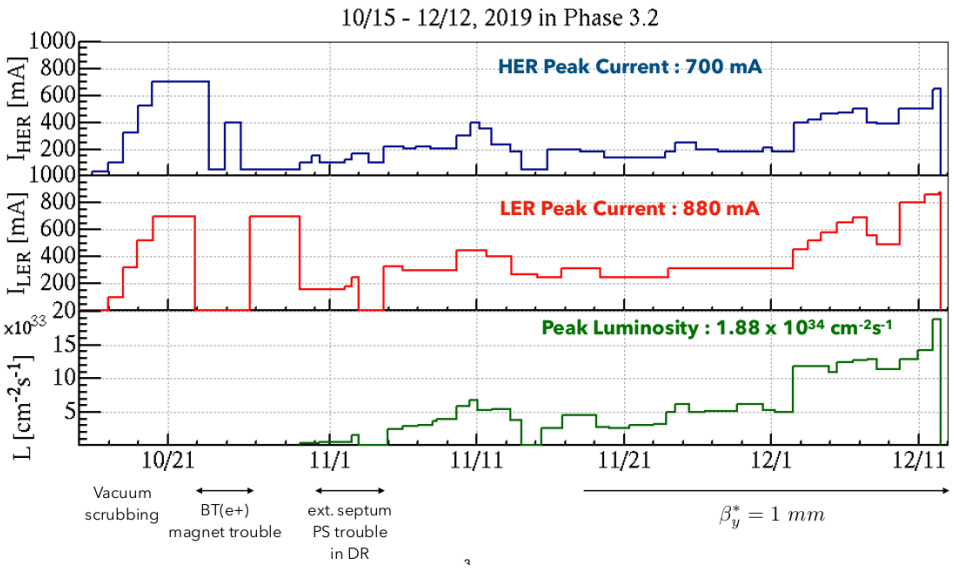


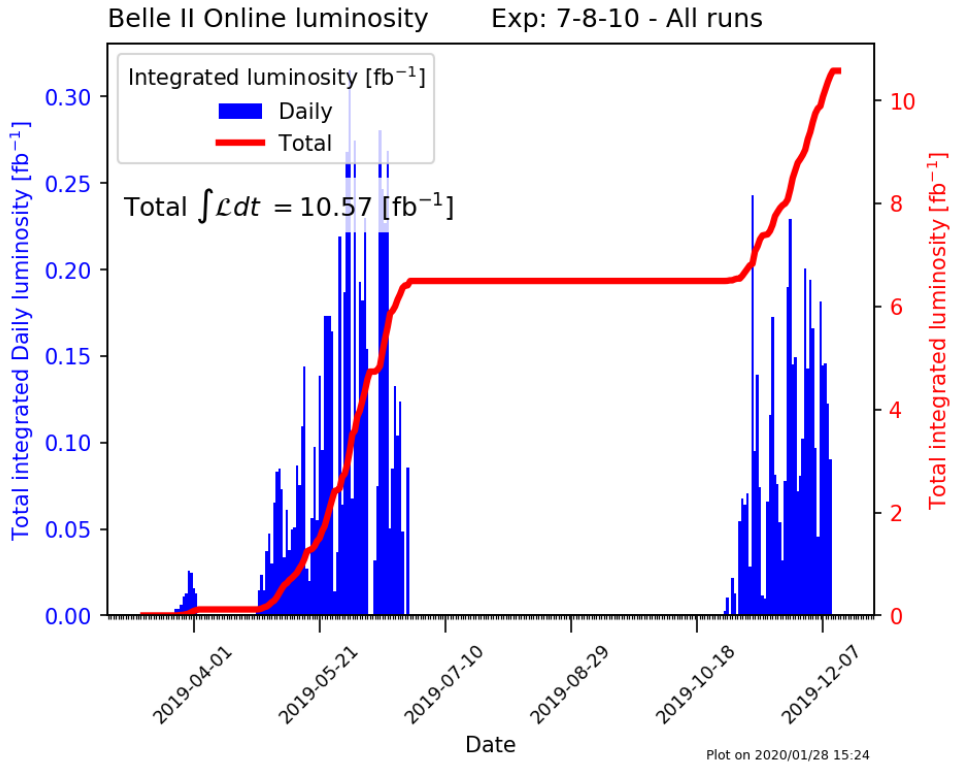


Belle → Belle-II

- ×50 data
- higher rates, mostly new detector

Data taking with Belle-II



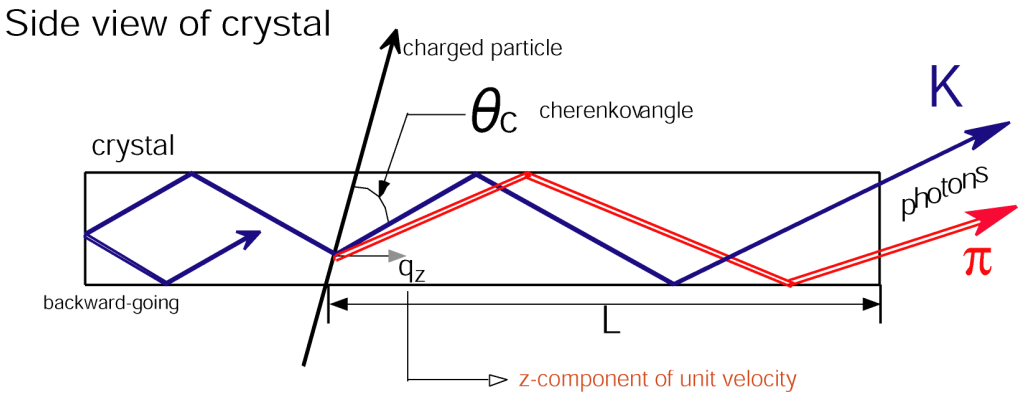


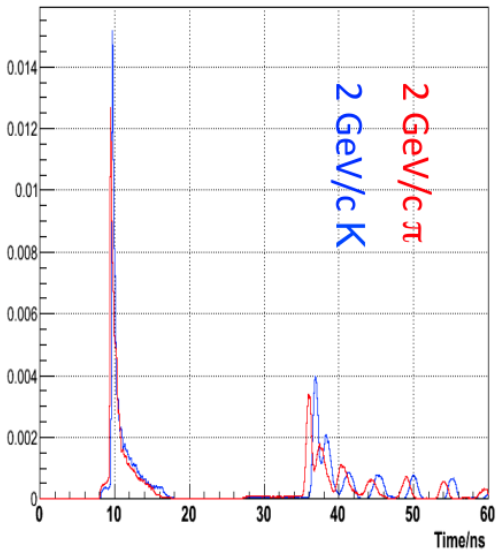
New peak luminosity record!

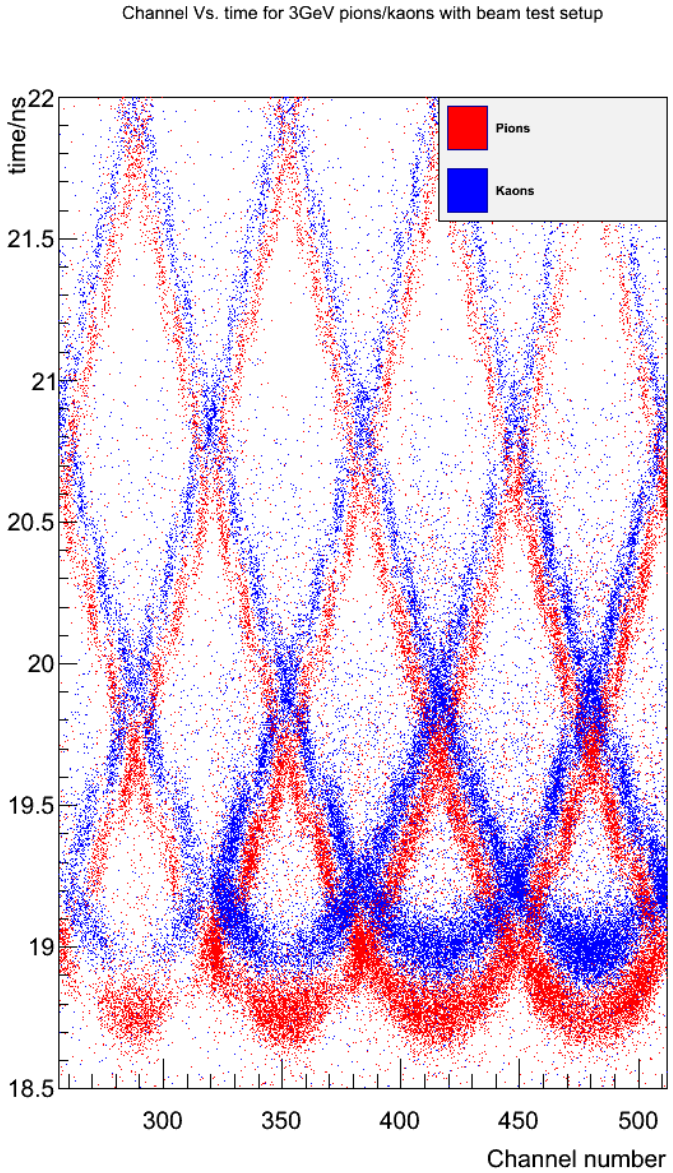
$1.138 \times 10^{34} cm^{-2} s^{-1}$ (w/ detector ON)

TOP detector : principle of operation

- Particle identification in barrel region
- Time-of-flight + Cherenkov angle

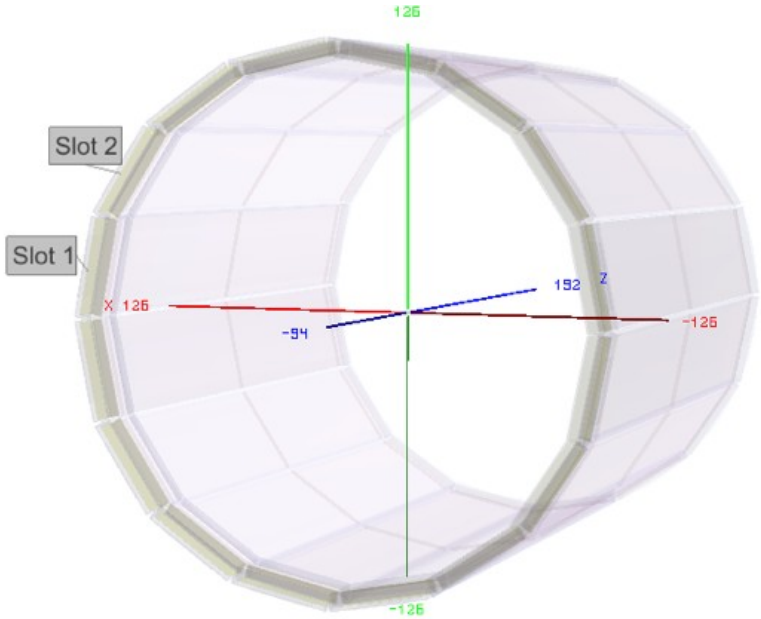


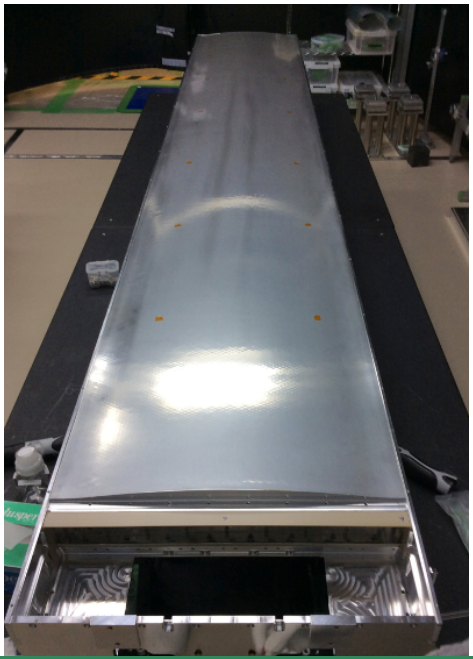


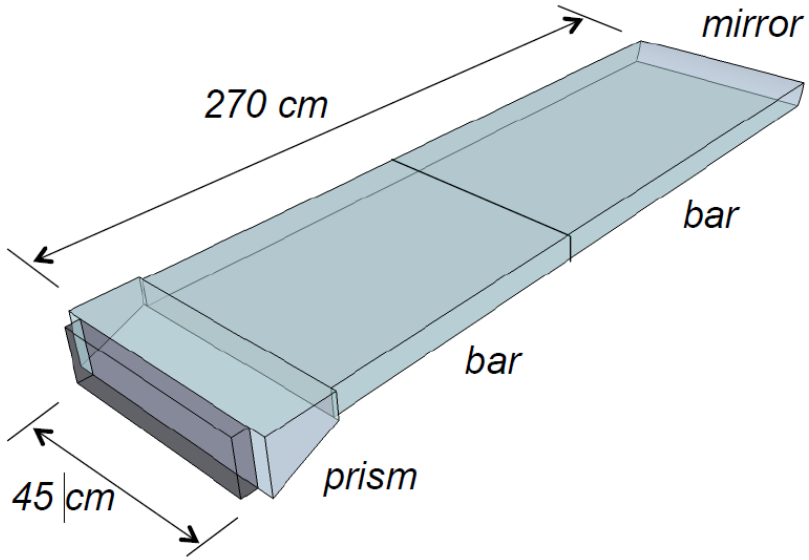


TOP detector : geometrical structure

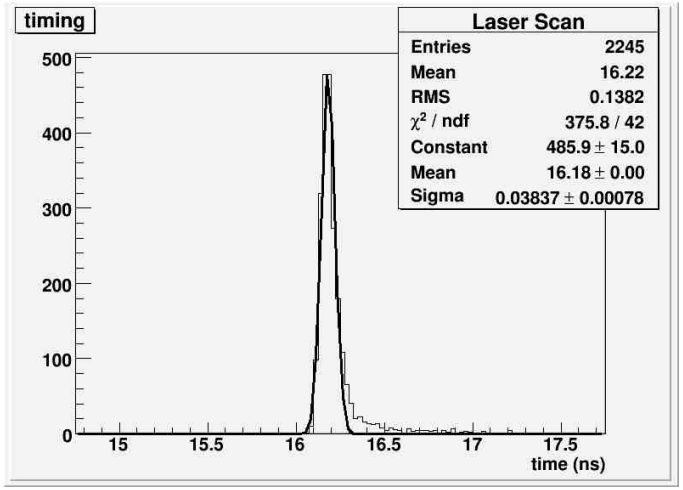
- 16 quartz Cherenkov radiator bars
- $270 \times 45 \times 2\mathrm{cm}^3$
- Flatness is better than $6\mu m$
- 32 MCP-PMTs with 16 pixels each are attached to the prism surface for Cherenkov light read out







Microchannel Plate (MCP) PMTs



Properties

- Hamamatsu R10754-07-M16(N) developed for TOP
- Photocathode area of $23 \times 23\ \mathrm{mm}^2$
- 16 channels
- Measured peak Quantum Efficiency $= 29.3\%$ on average
- Timing resolution of about 34 ps
- Works in magnetic field of 1.5 T
- Can operate on MHz range hit rates

MCP-PMT lifetime

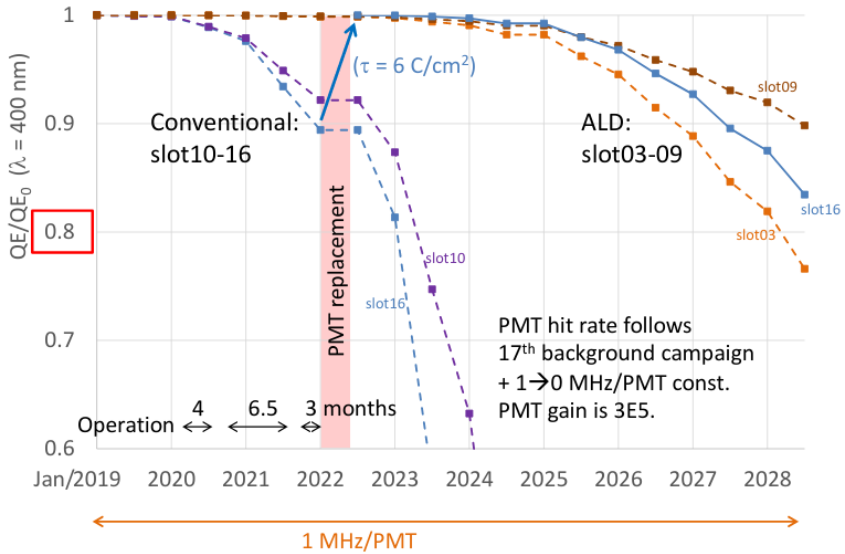
Types of MCP-PMTs installed in the detector. 512 MCP-PMTs in total

type	Quantity	Lifetime, $\mathrm{C/cm^2}$
"Conventional" PMTs	224	1.1
Atomic Layer Deposition (ALD) PMTs	220	10.4
Life-extended(LE) ALD PMTs	68	> 13.6

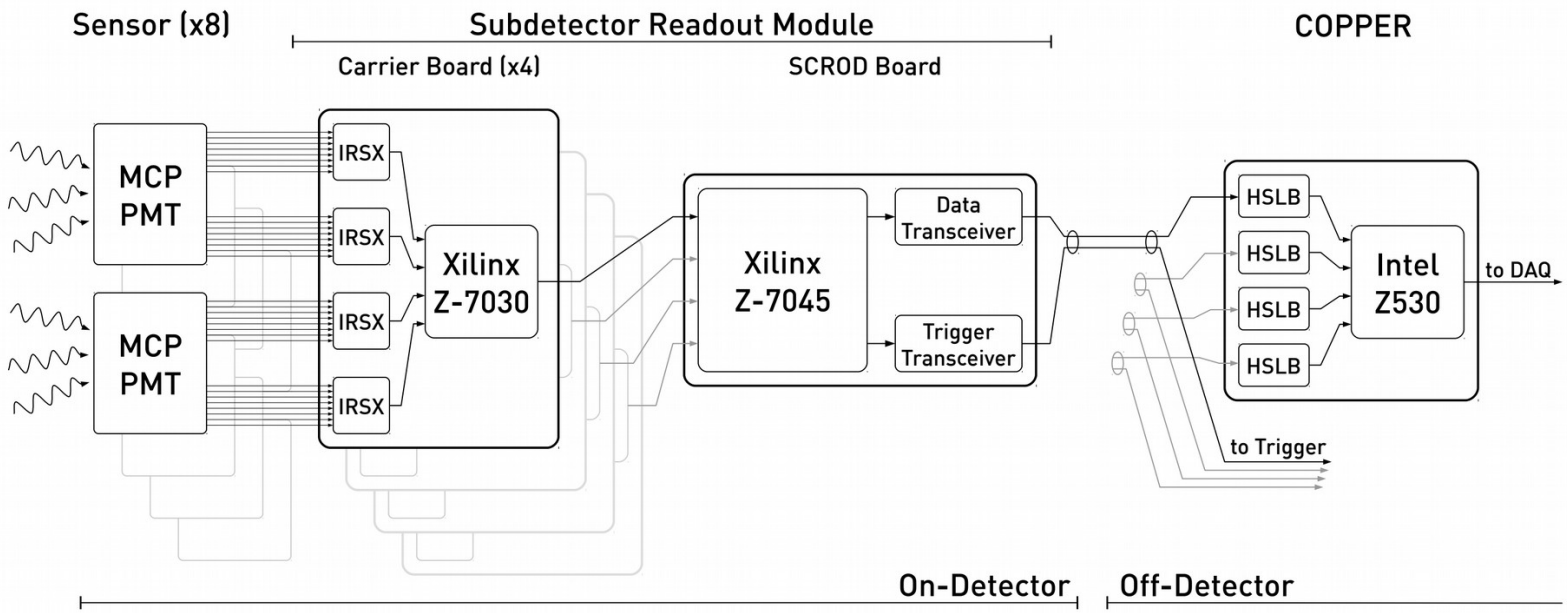
Year	2020				2021				2022
Month	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3
Option 1		Physics run			TOP & PXD				
Option 2							TOP		PXD
Option 3 (new)									TOP & PXD

MCP-PMT replacement

- 224 MCP-PMTs in total
- Most part is produced
- Production will be finished in Sep. 2020 at latest



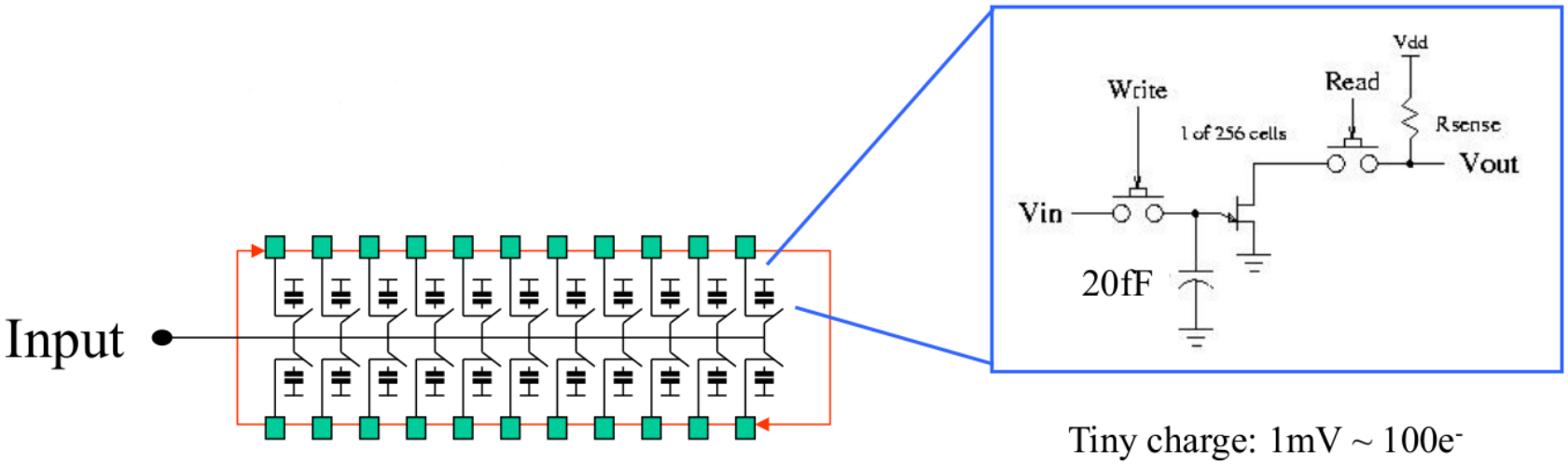
Readout Electronics

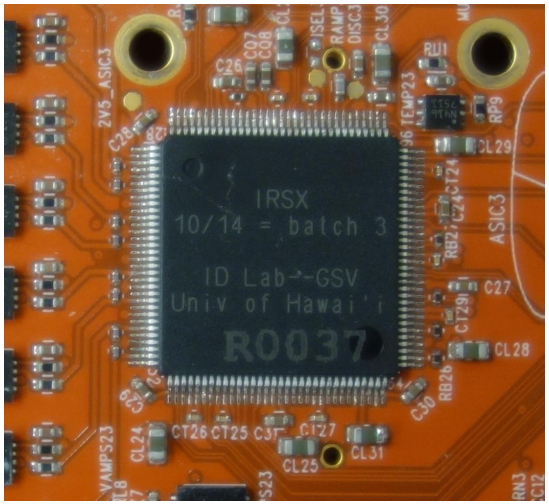


Requirements

- 8192 readout channels in total
- Up to 30 kHz trigger rate
- Time resolution better than 100 ps
- Can operate under radiation conditions

Readout Electronics : IRSX Asics

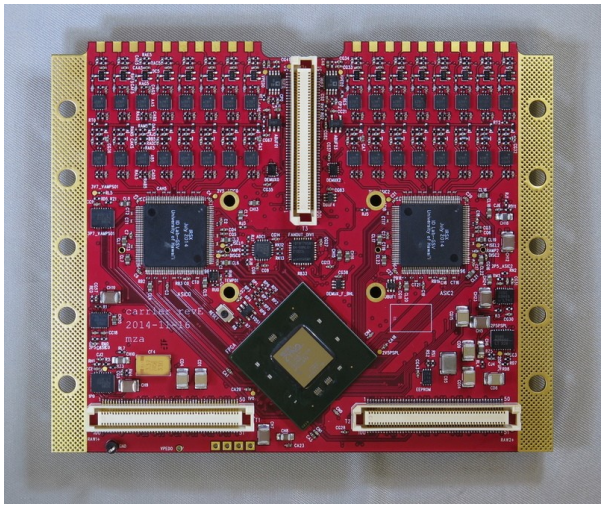


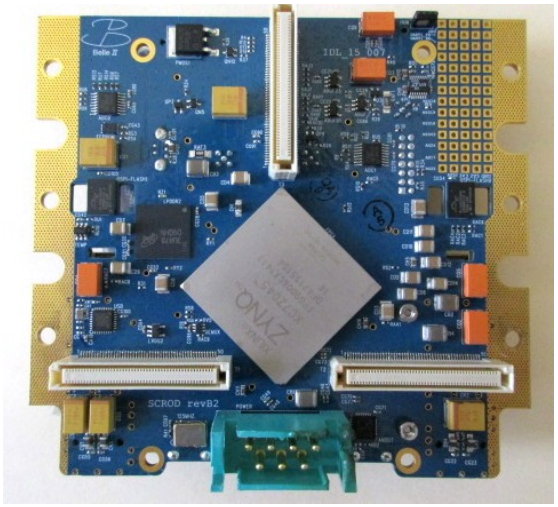


IRSX

- Waveform sampling ASIC
- 8 input channels
- Sampling rate of 2-4 GSa/s (2.7 GSa/s in TOP)
- 12 bit resolution of Wilkinson ADC
- ~600 MHz analog bandwidth
- 32k analog storage cells (about 10μs)
- power consumption of ~100 mW per channel

Carrier/Scrod





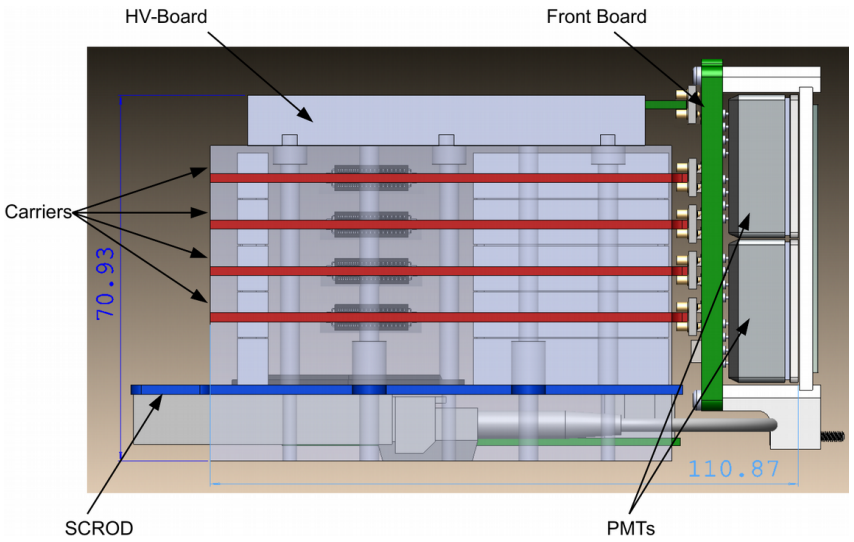
Carrier board

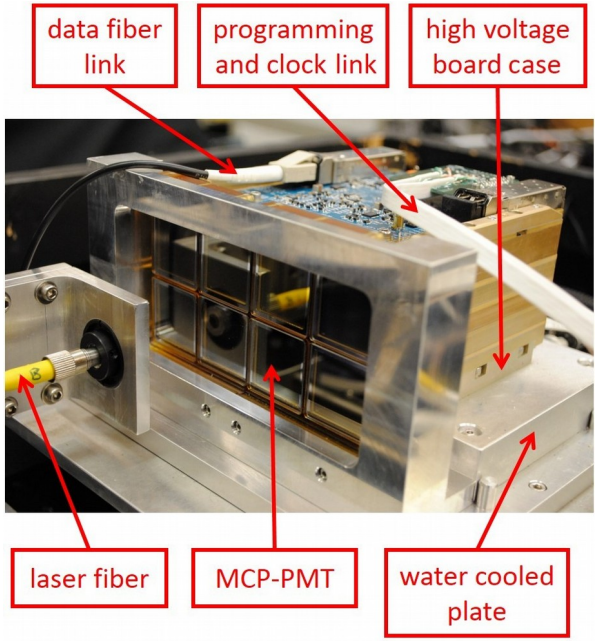
- Carries PMT preamps, 4 IRSX ASICs
- Xilinx Zynq 7030 SoC : FPGA + ARM CPU
- FPGA collects data from ASICs and streams data to a SCROD board
- ARM – only housekeeping, but may be used for data processing

SCROD board

- Xilinx Zynq 7045 SoC
- Receives ASIC data streams from Carrier boards
- Makes a DAQ package and sends it via optical transceivers
- ARM processor serves for online data processing

Readout Electronics : Boardstack



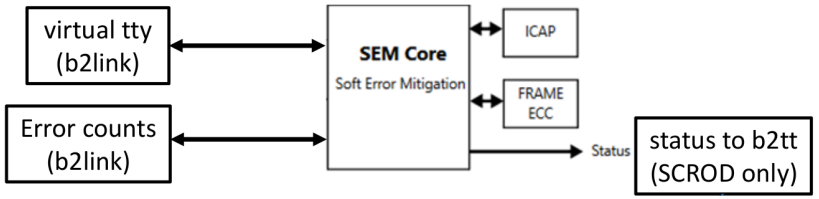


TOP boardstack

- 1 SCROD + 4×Carrier + HV control board
- Serves 8 MCP-PMTs
- 4 boardstacks per TOP module (bar)
- Sealed inside the module cover →
- Electronics operate under the radiation environment

FPGA configuration corruption due to radiation

- Single-Event-Upset (SEU) – change of the state of FPGA configuration caused by ionizing particles
- SEUs are being monitored, but even uncorrected SEUs being detected are mostly harmless (do not affect essential bits)
- Only configuration bits are being checked (no BRAM or PS)
- No significant impact has been seen so far



SEM monitor

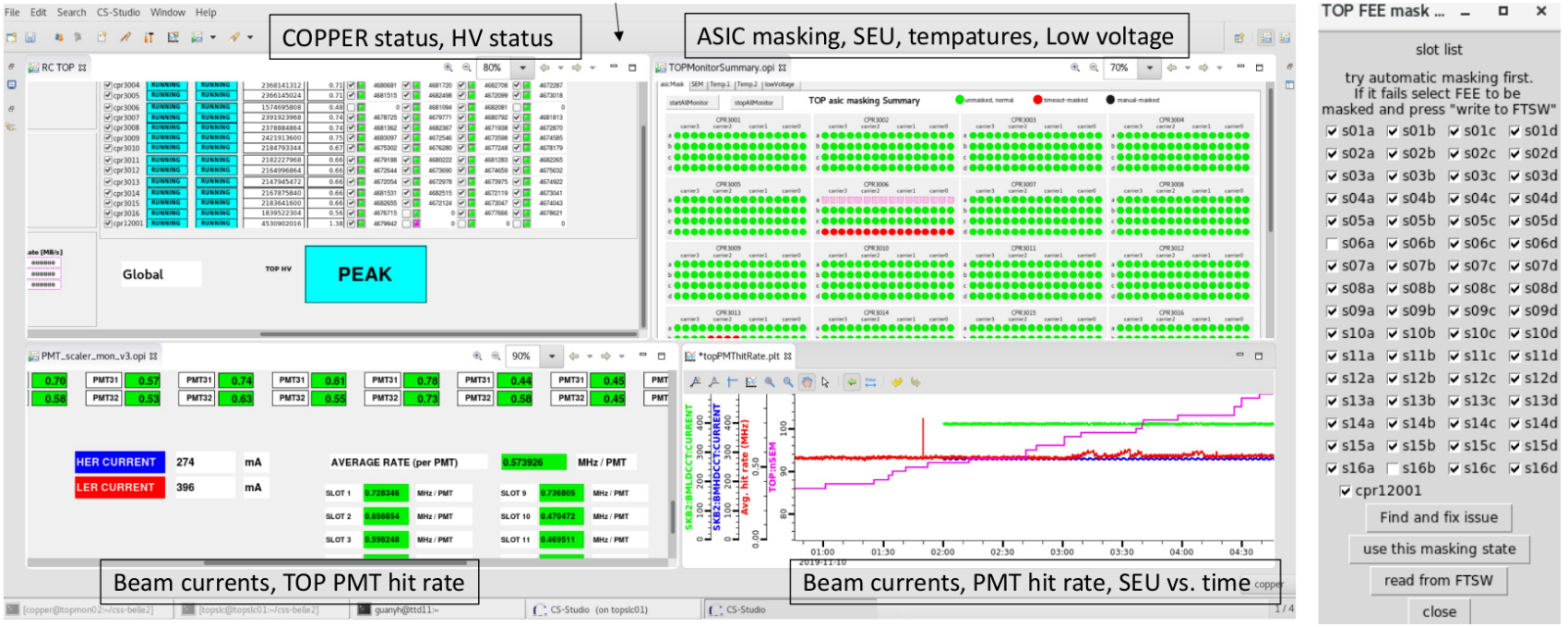
	s01		s02		s03		s04		s05		s06		s07		s08	
SCORD	5.0	0.0	0.0	0.0	1.0	0.0	3.0	0.0	3.0	0.0	2.0	0.0	7.0	0.0	1.0	0.0
Carrier	9.0	0.0	8.0	0.0	1.0	0.0	2.0	1.0	5.0	0.0	3.0	0.0	4.0	0.0	7.0	0.0
	s09		s10		s11		s12		s13		s14		s15		s16	
SCORD	2.0	0.0	1.0	0.0	2.0	0.0	5.0	0.0	0.0	0.0	4.0	0.0	1.0	0.0	3.0	0.0
Carrier	5.0	0.0	1.0	0.0	2.0	0.0	3.0	0.0	3.0	0.0	1.0	0.0	4.0	0.0	6.0	0.0

nSEU sum: **104**

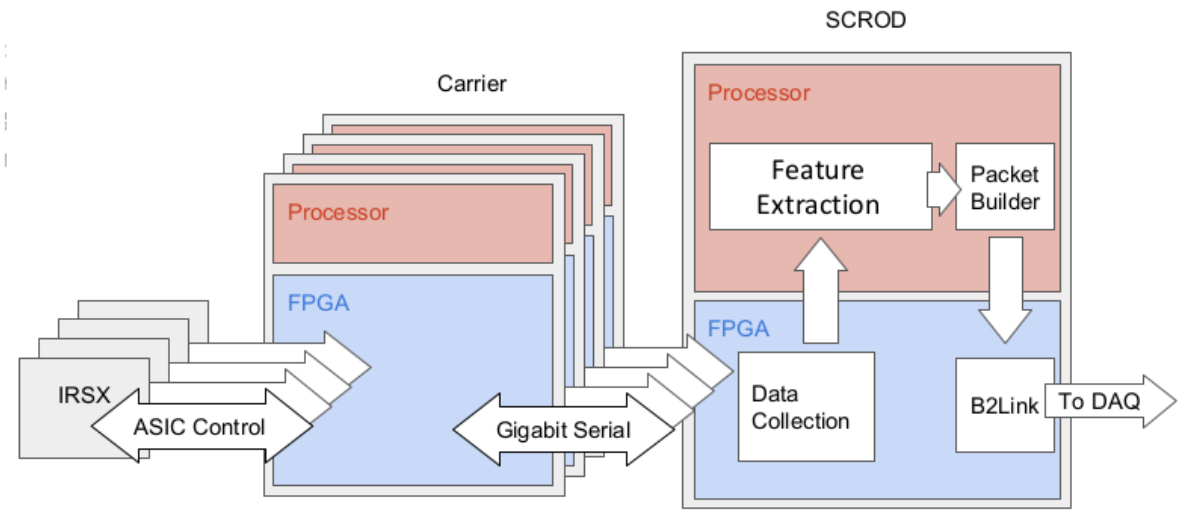
slot details

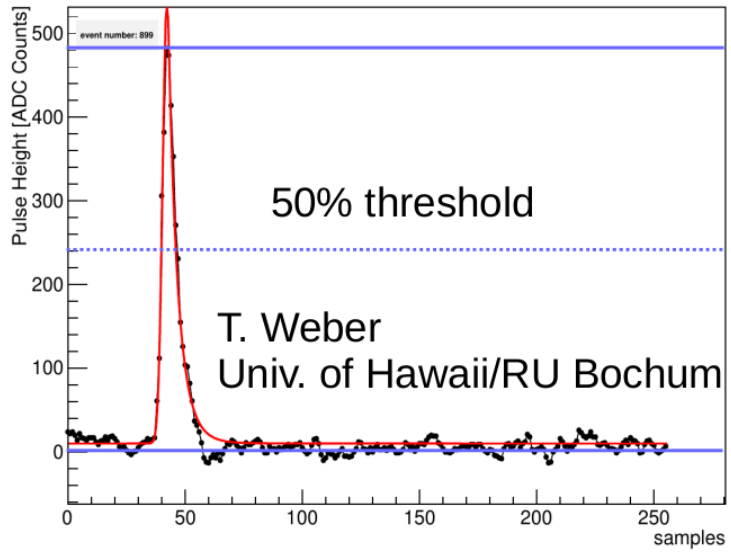
Configuration and slow control

- Radiation conditions → no non-volatile memory on-board
- Initialization :
  - FPGAs configuration
  - Embedded software downloading
  - Setting operational parameters of frontend electronics



Feature extraction



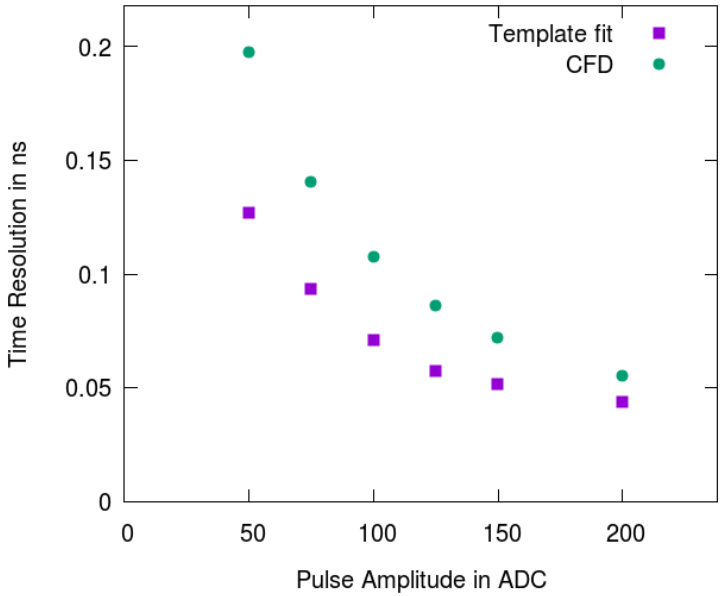


Current algorithm

- Constant fraction threshold (50%) $\rightarrow$ linear approximation $\rightarrow$ (t,A)

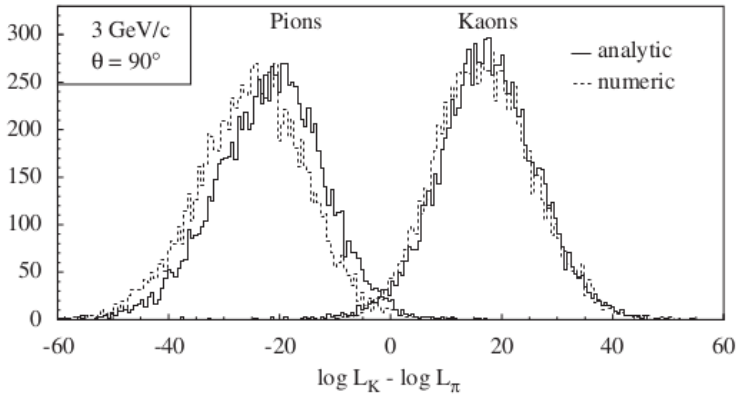
Further development : online fitting

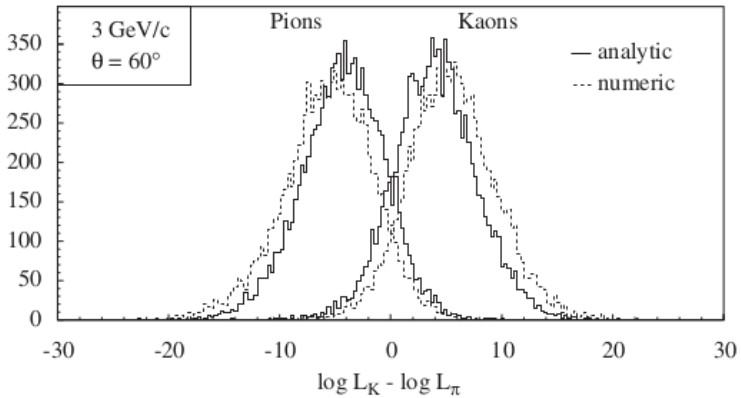
- Template fitting in the Processing System
- Difficulty : signal shape depends on the amplitude
- Needs large configuration datasets

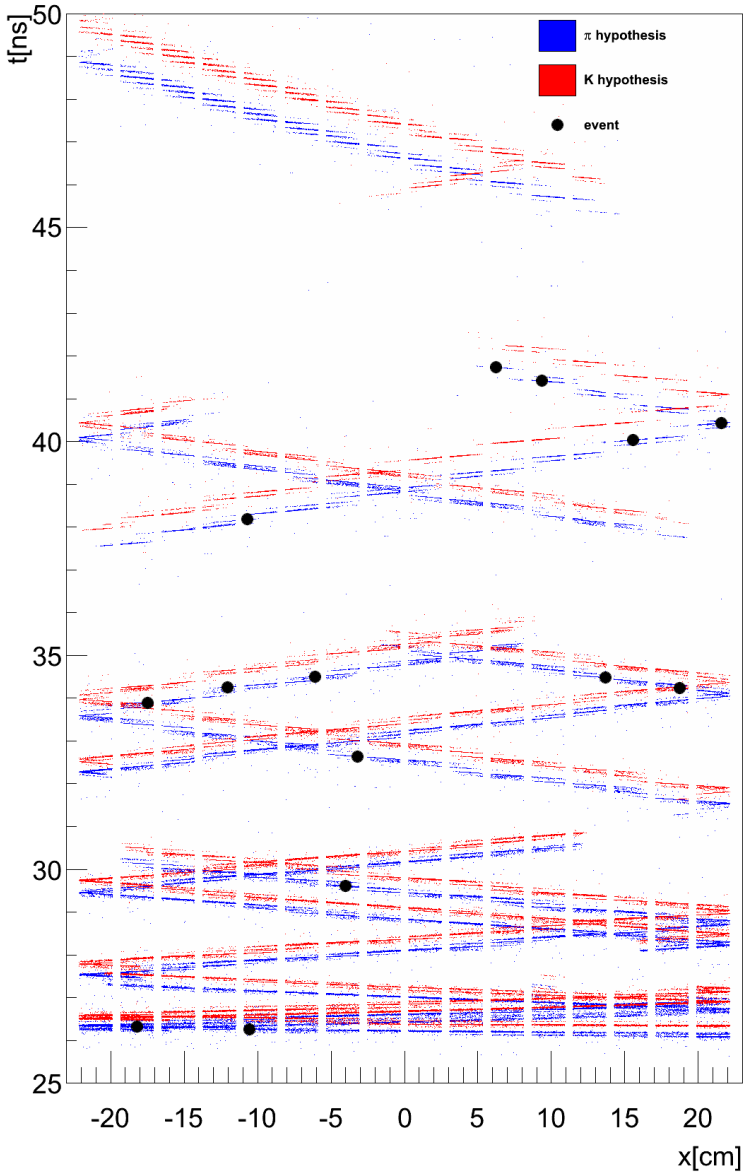


Data reconstruction

- about 20-30 photons per particle
- PDF depends on particle impact position and angles and calculated per every particle and event
- Likelihood parameter is build using PDF function and detected photons coordinates and times

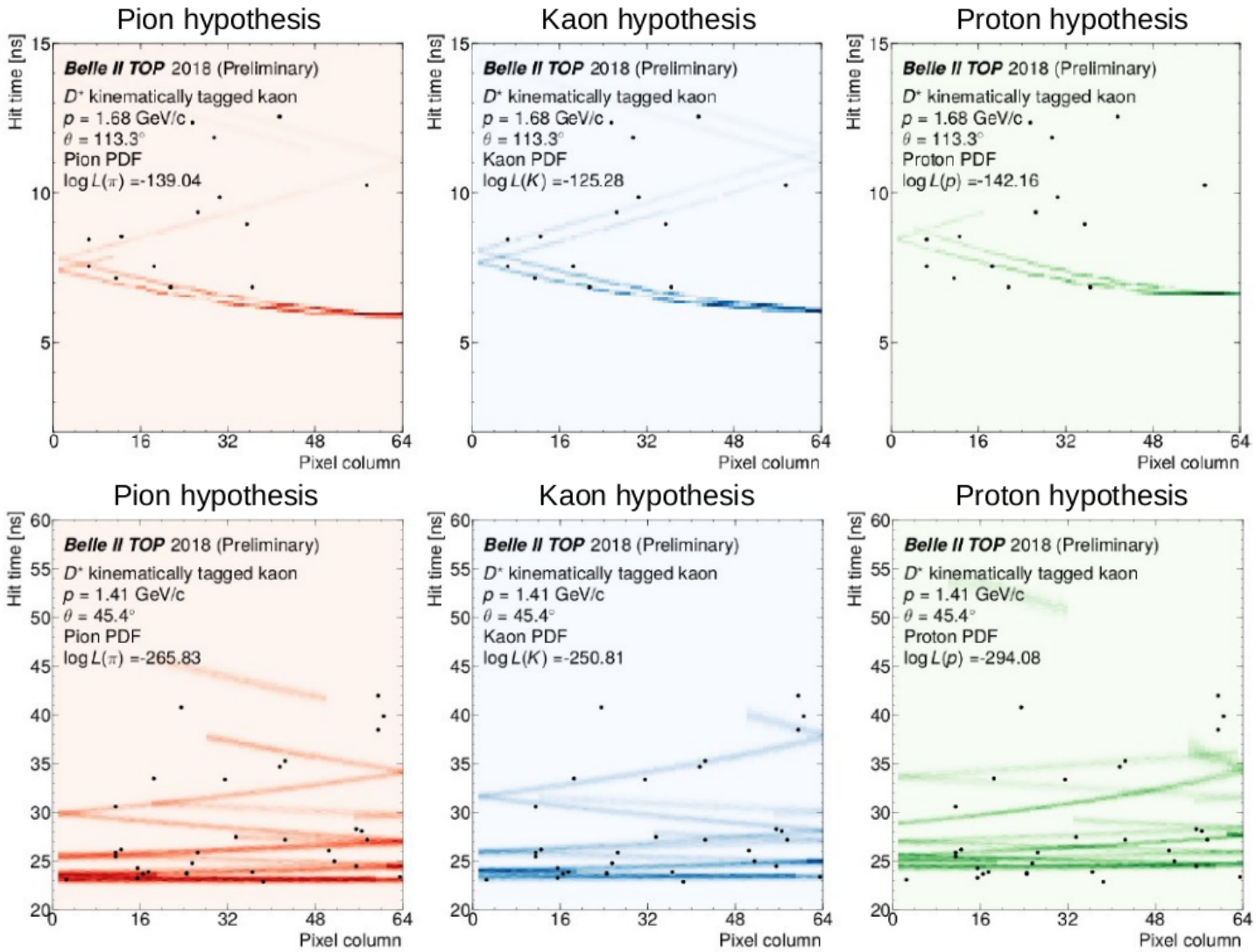






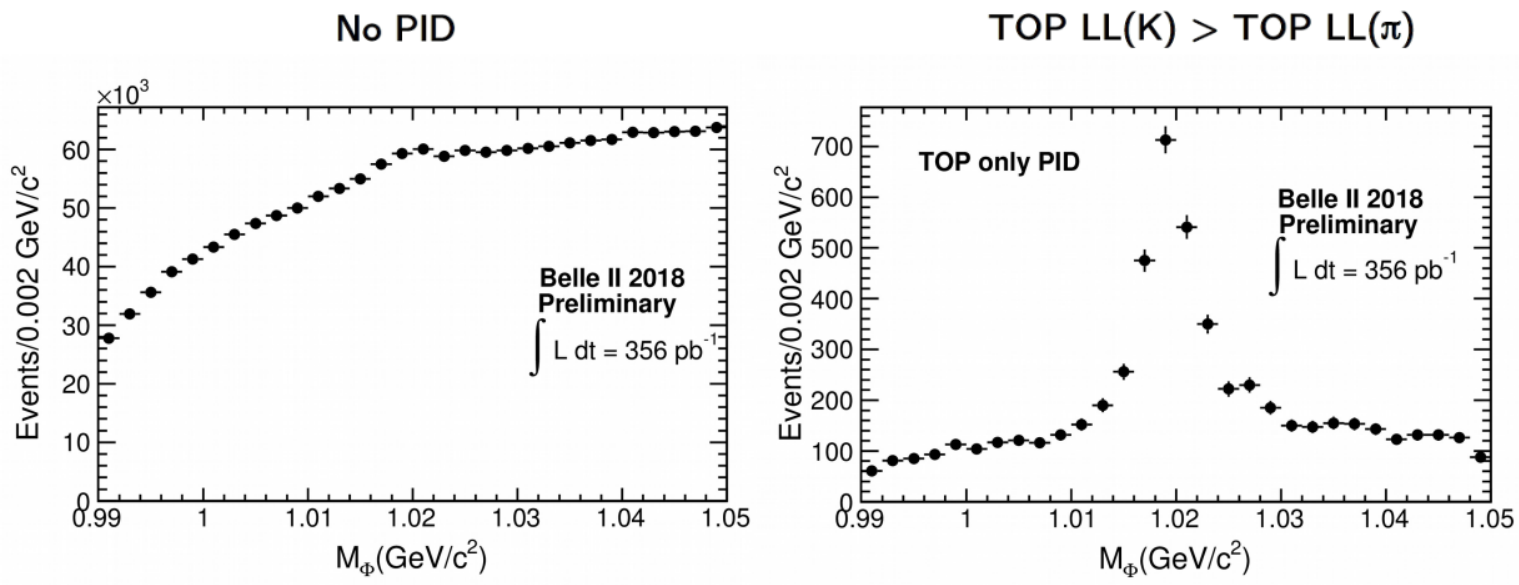
Data reconstruction : $D^* \to D^0\pi, D^0 \to K^-\pi^+$

K^- reconstruction with TOP

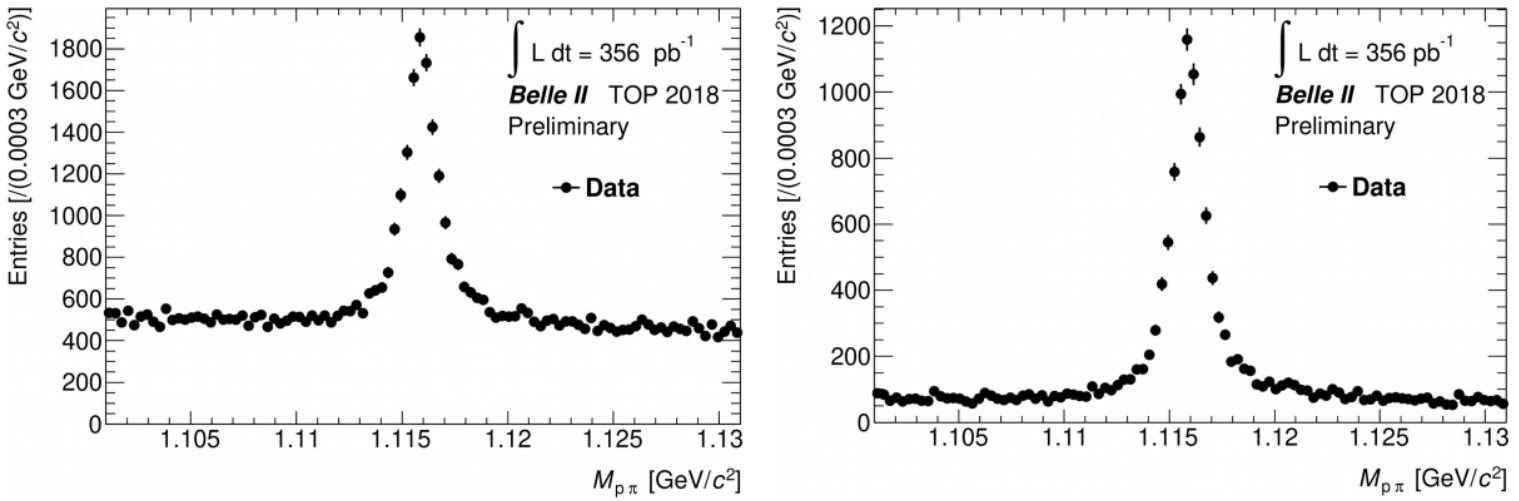


TOP PID performance : $\phi \to K^+K^-$, $\Lambda \to p\pi$

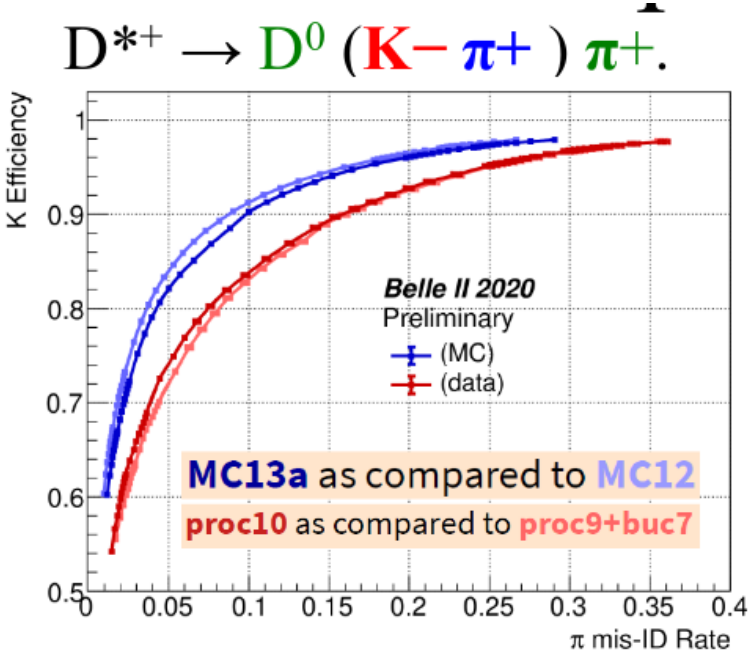
$\phi \to K^+K^-$

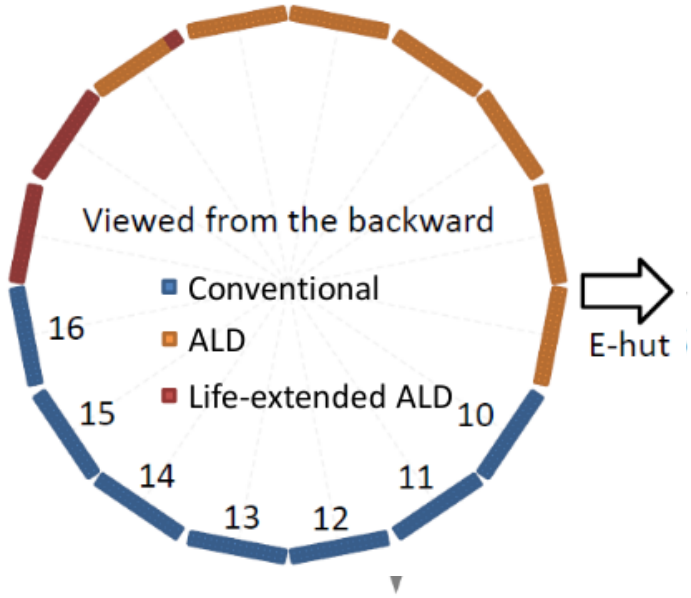


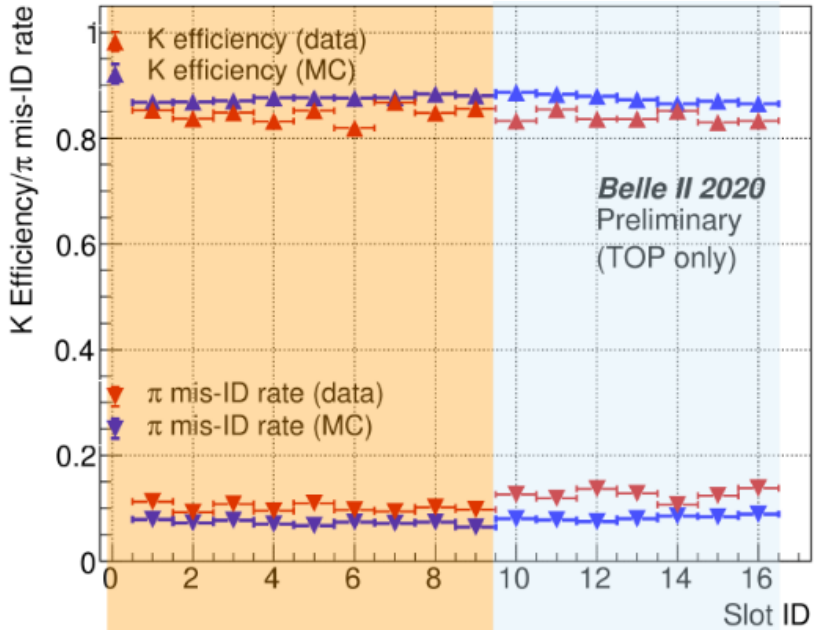
$\Lambda \to p\pi$

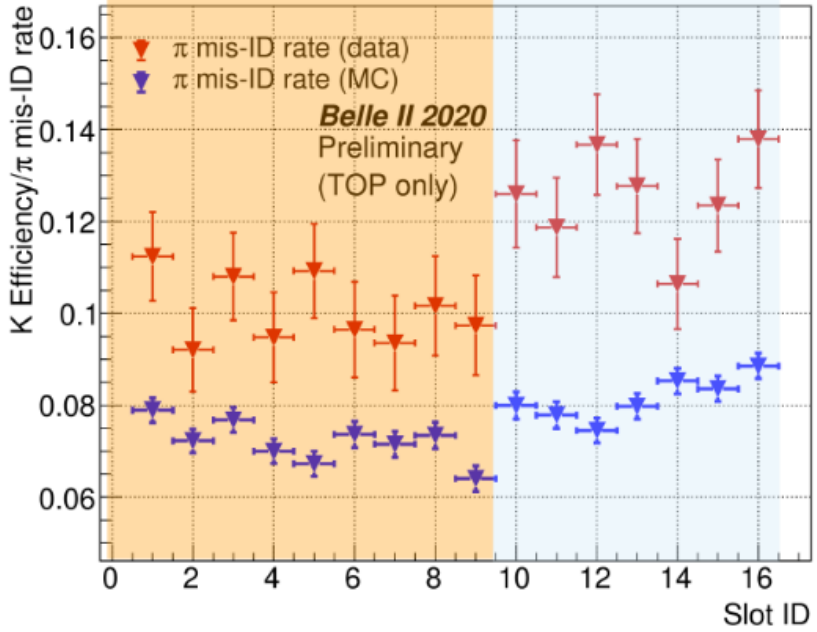


TOP PID performance : $D^{*+} \to D^0 pi^+$









Conclusion

- TOP detector has been operating stably since physics runs started in 2018
- Excellent time resolution achieved in high rate runs without dead time
- TOP PID is being successfully used in the ongoing Belle-II analyses
- MCP-PMT replacement is scheduled with two time options
- Further development of the online data reconstruction is in progress