Belle II TOP detector
before and after the long shutdown

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for the TOP group
Belle II

Pisa meeting,
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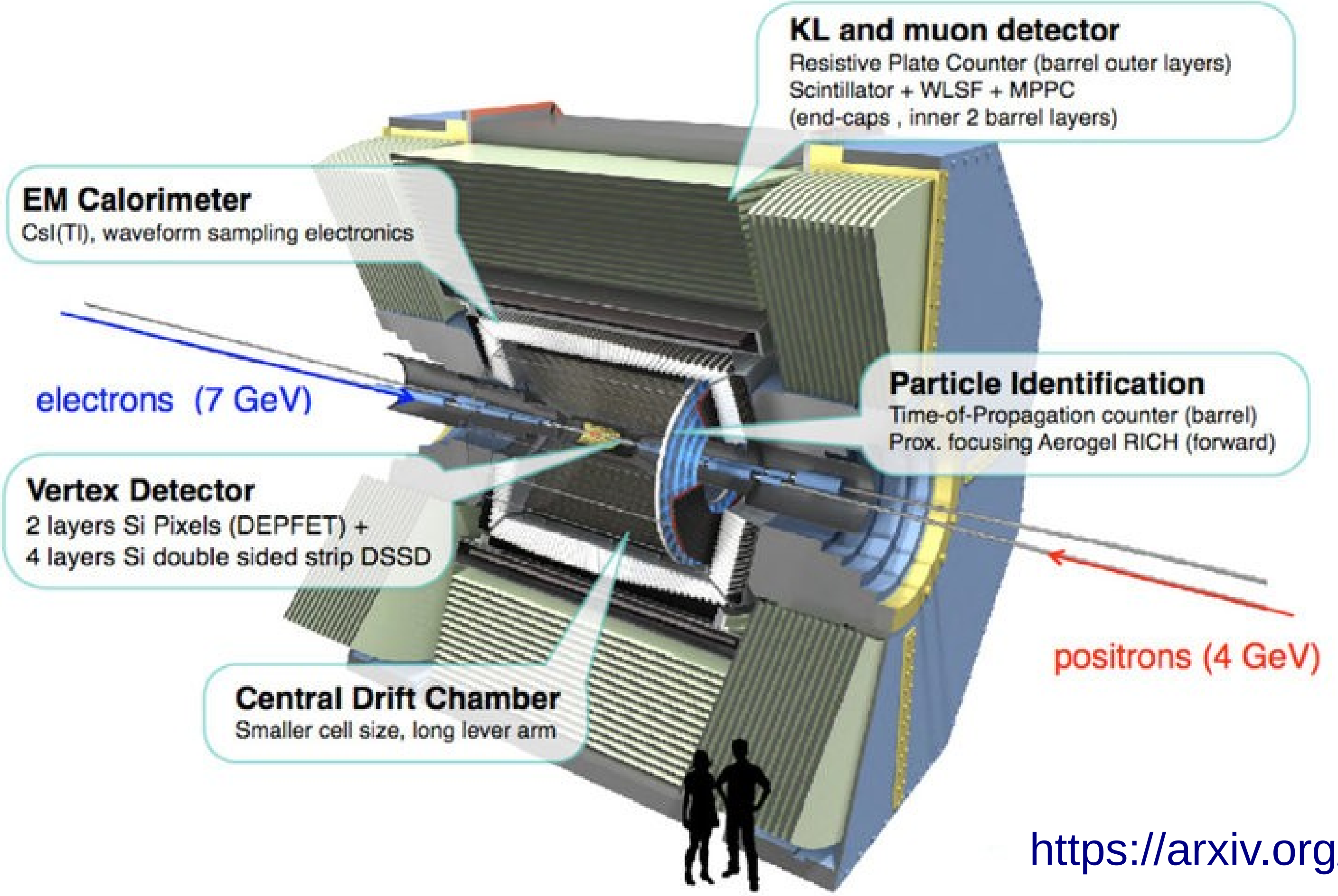
Belle II

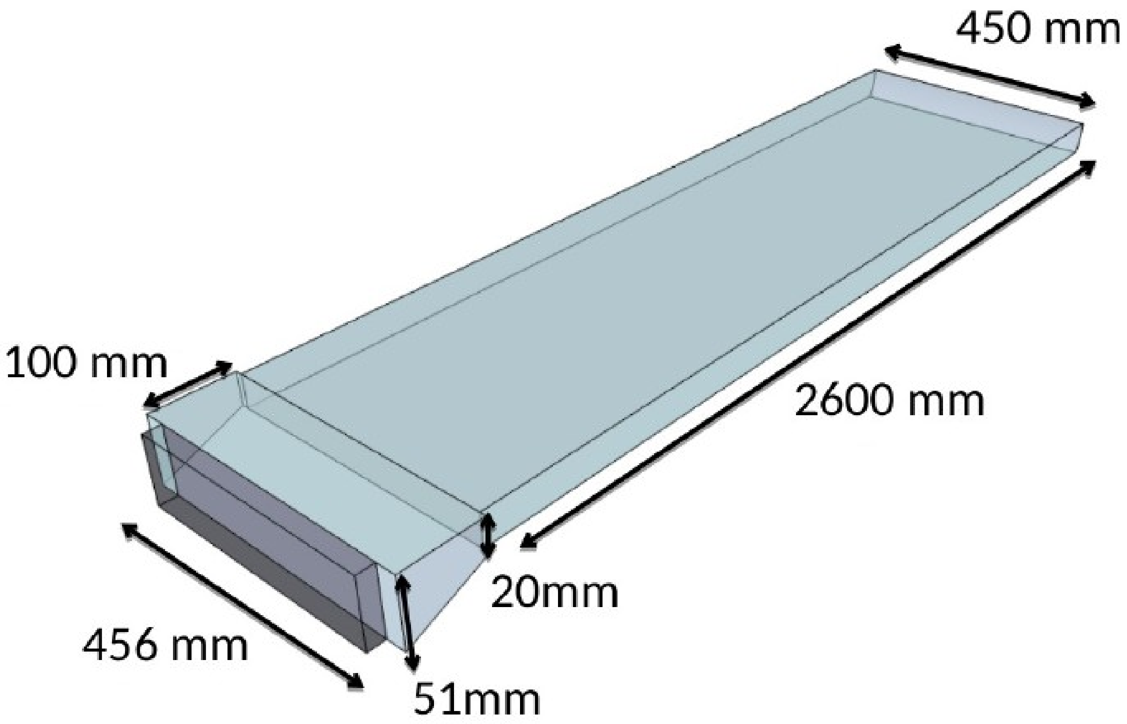
- Detector for SuperKEKB B-factory
- Higher luminosity than KEKB: 6E35/(cm^2 s) and 50/ab
- More precision, 30 kHz trigger rate, larger tracking detector

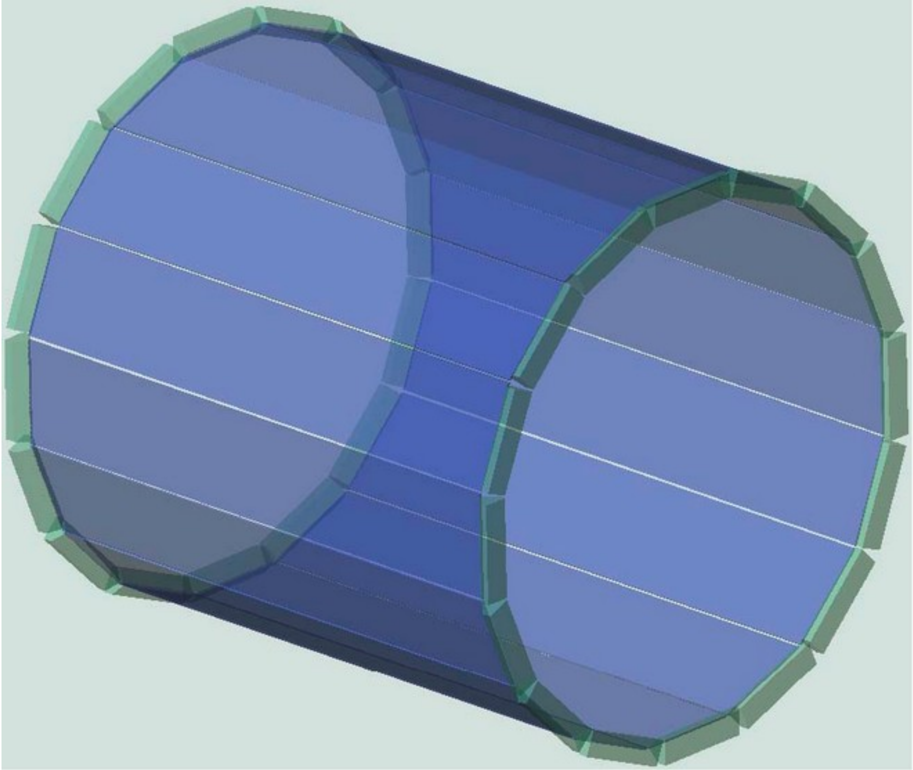


https://arxiv.org/abs/1011.0352

TOP

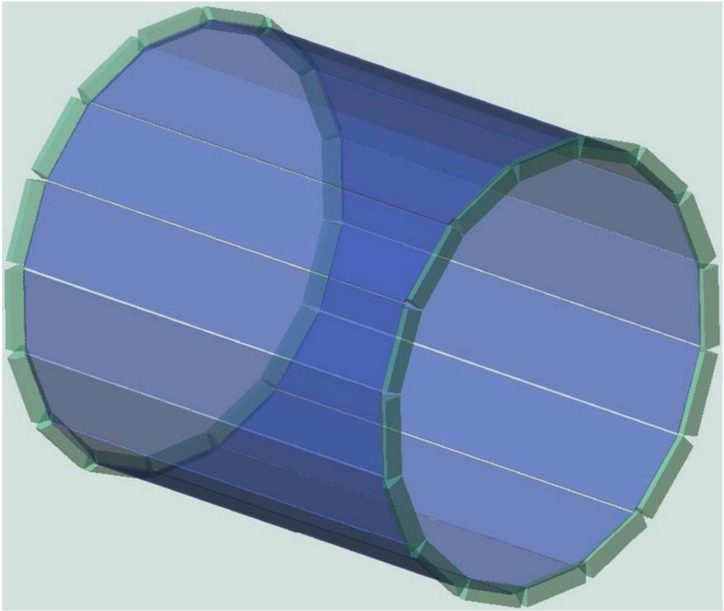
- imaging **T**ime-**O**f-**P**ropagation detector
- Particle identification in 2 cm
- Cherenkov detector
- Angle reconstructed from position and time of arrival
- 16 modules around interaction point

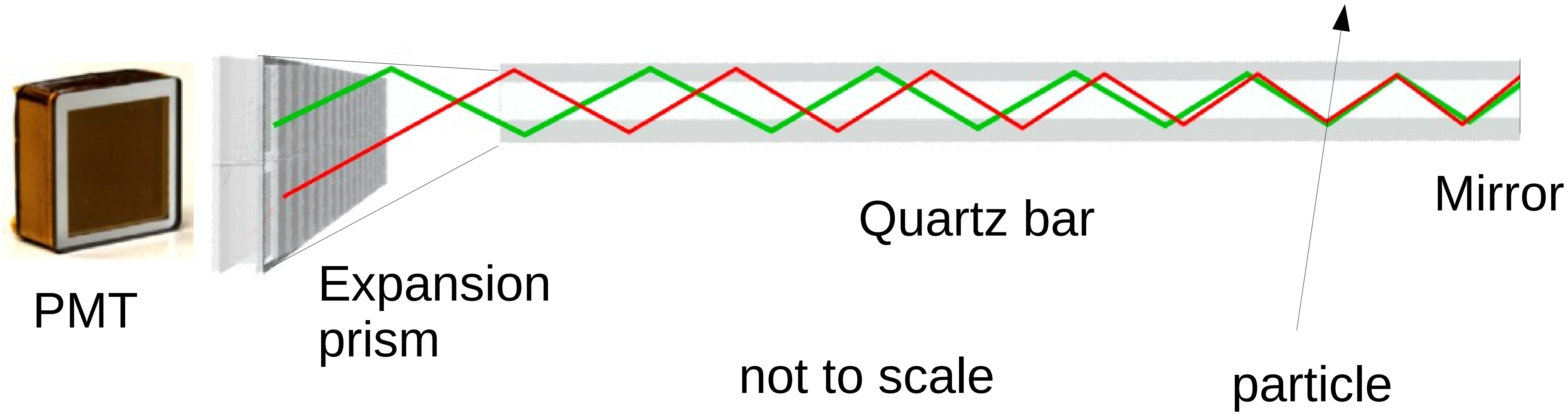




Light path

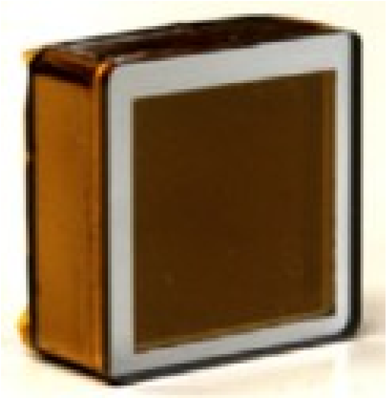
- Total internal reflection
  (>100 times)
- Expansion prism at backward side
  spatial resolution
- Mirror at forward side
- PMTs for detection
- 64x8 pixels per module

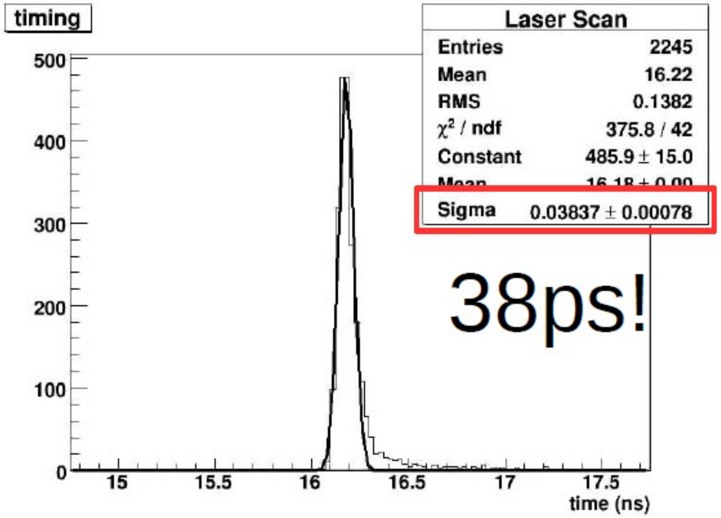


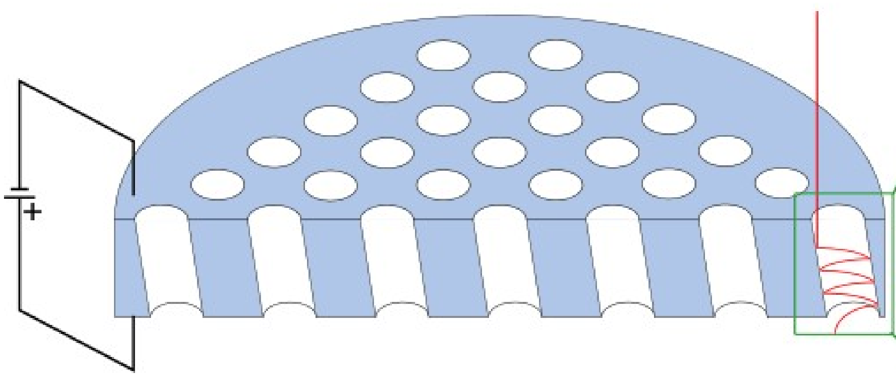


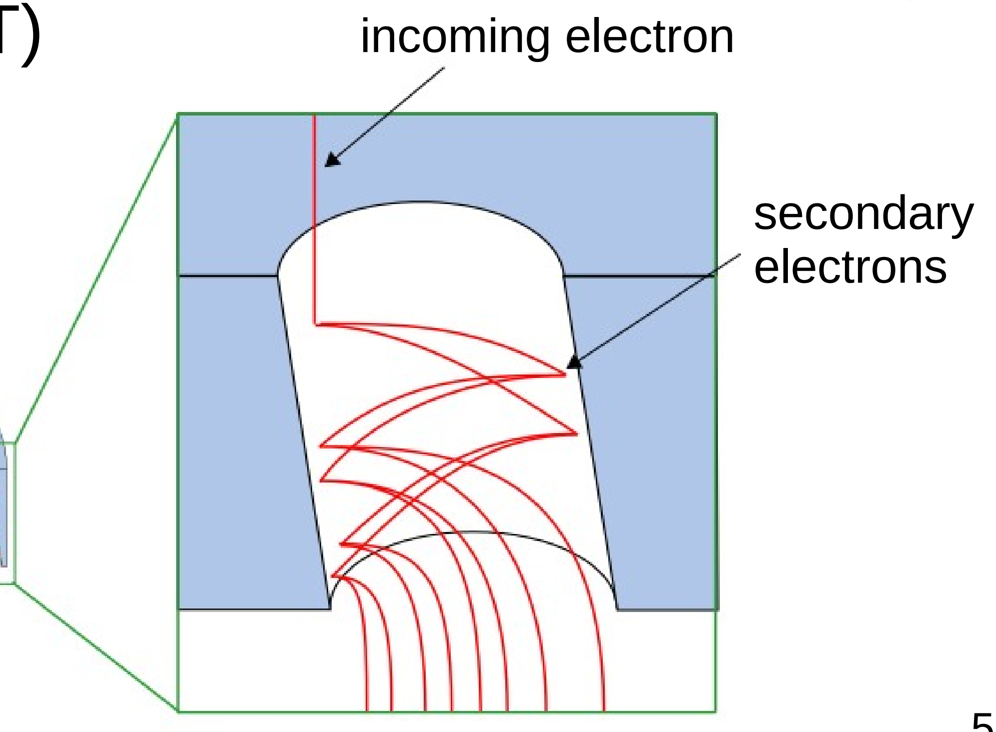
MCP-PMTs

- Microchannel plate PMTs
  25 mm x 25 mm
- Single photon sensitivity
- Excellent time resolution
- 16 channels each
- Large sensitive area
- Works in magnetic field (1.5T)
- Can handle MHz hit rates
  per PMT





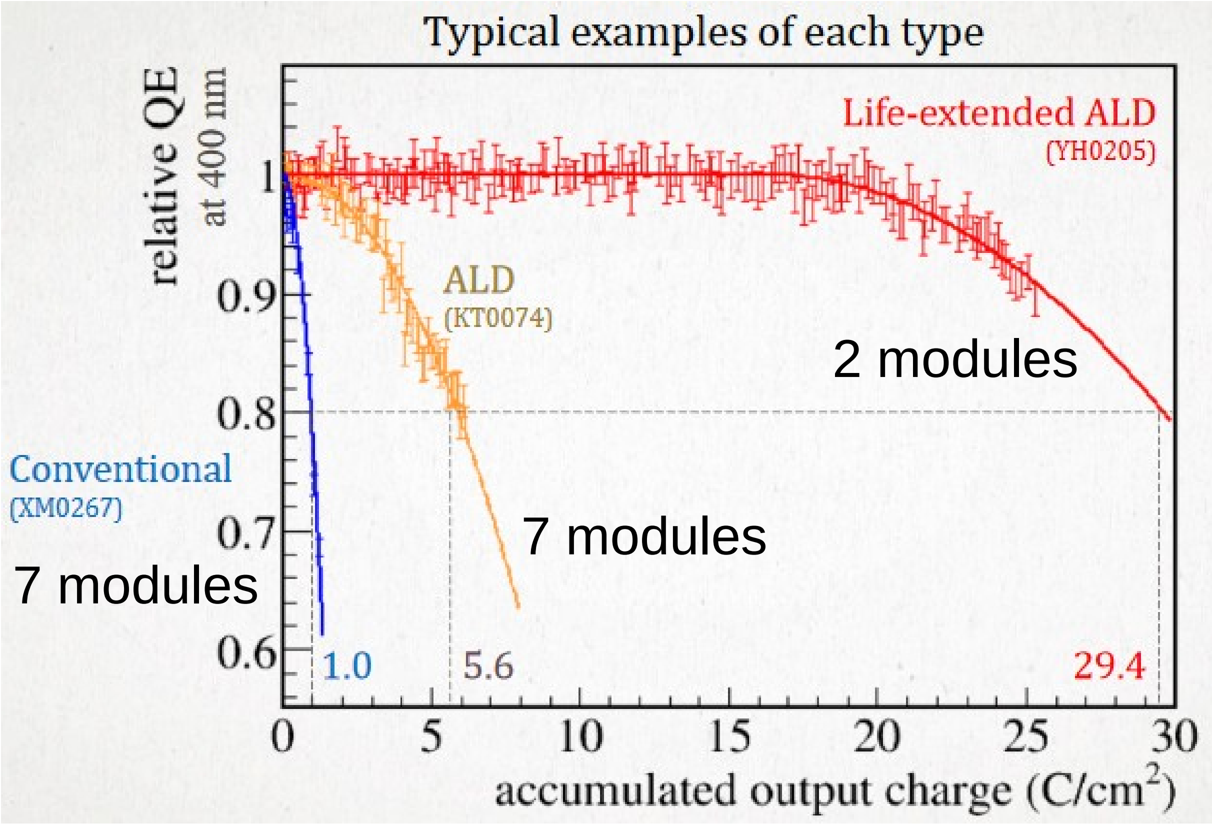




PMT lifetime

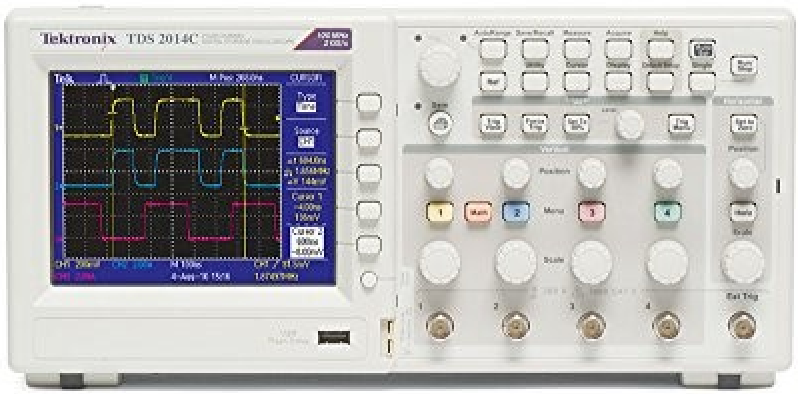
- PMTs at $3*10^5$ gain accumulate several C/cm^2
- Major challenge for MCP-PMTs:
  Outgassing reduces efficiency
- Hamamatsu: Improvements during mass production

- Three types installed in initial detector
- Plot shows lifetime test in lab



Digitization

- Need ~100 ps resolution → 2.7 GSamples/s, 12 bit
- Oscilloscopes?
  4 channels

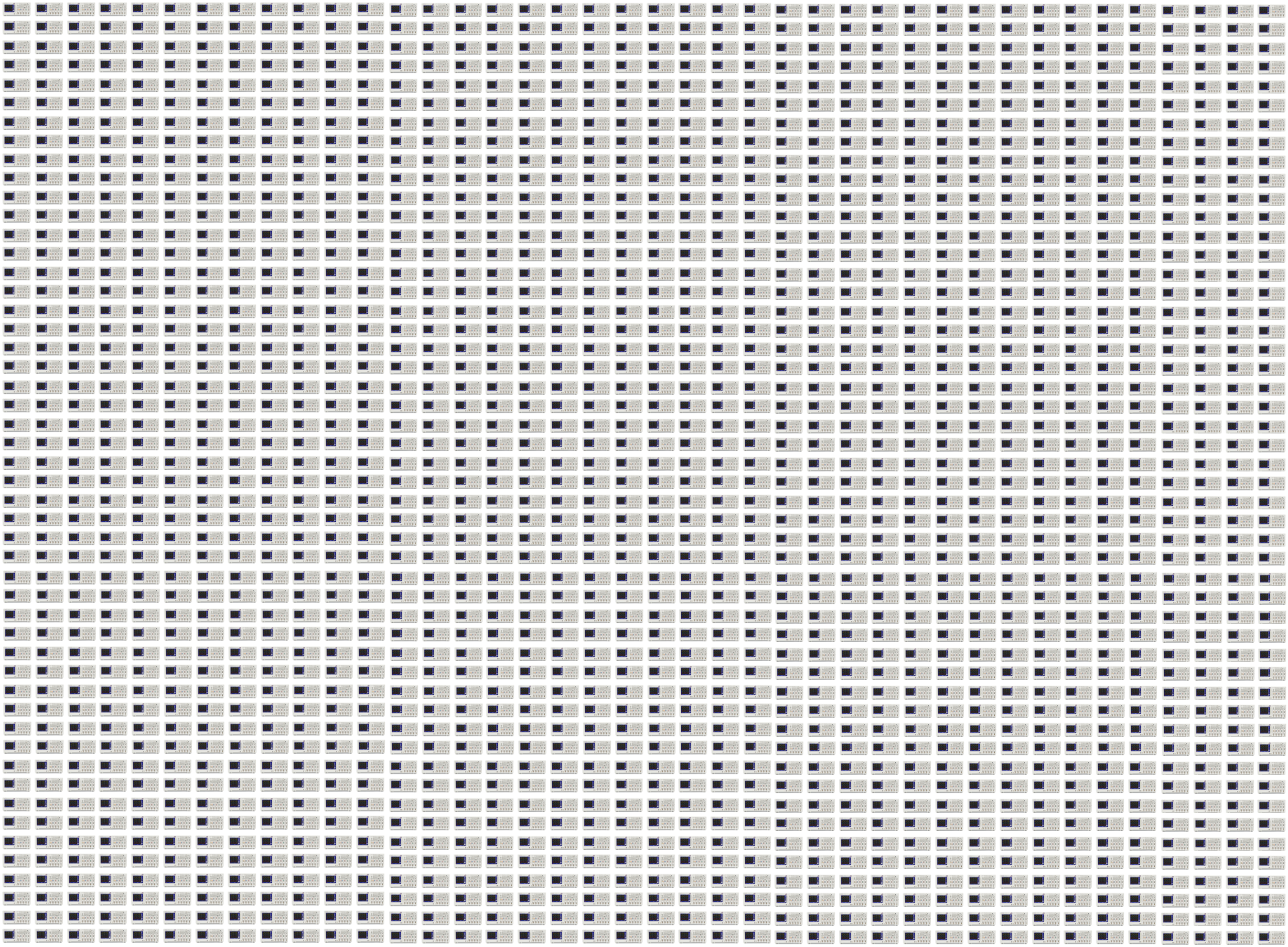


- Detector: 8192 channels
  multiply: 33 TB/s

- 2000 oscilloscopes?

Digitization

- Need
- Oscil
  4

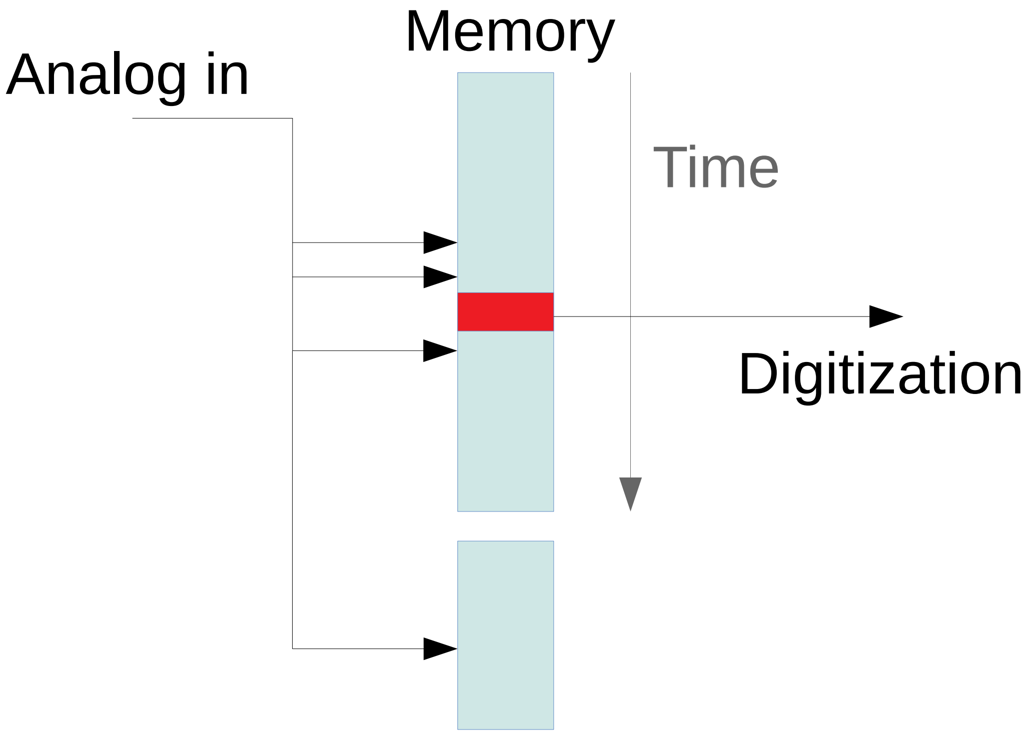


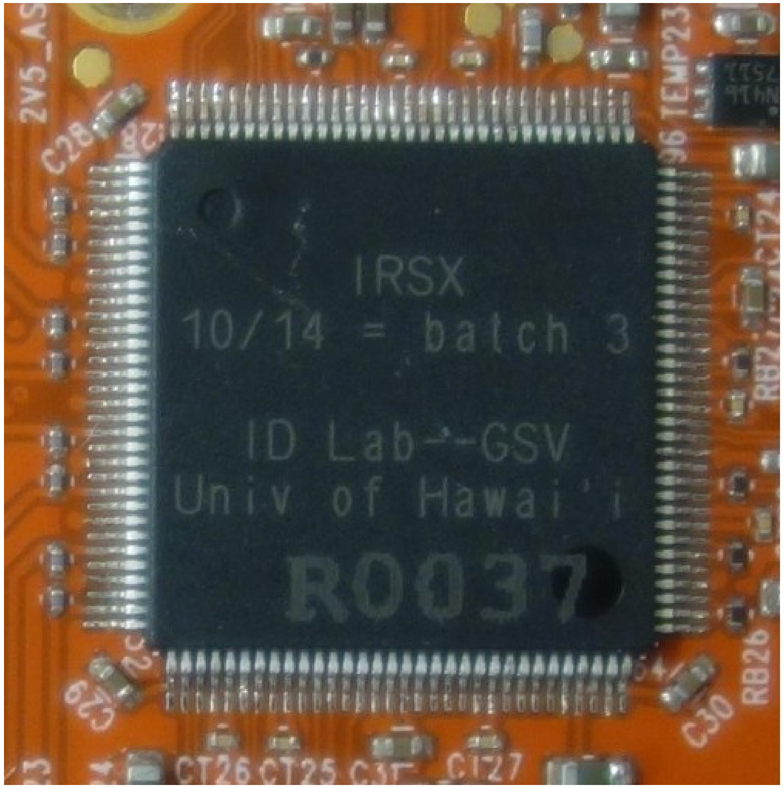
- Detec
  m
- 2000

Readout system: IRSX

- Custom chips, 8 channels/chip
- Write continuously to analog ring buffer (10 us)
- Internal trigger
  - Flags regions of interest
  - Digitize if there is a global trigger
- Extra memory region to avoid overwriting hits

https://arxiv.org/abs/1804.10782



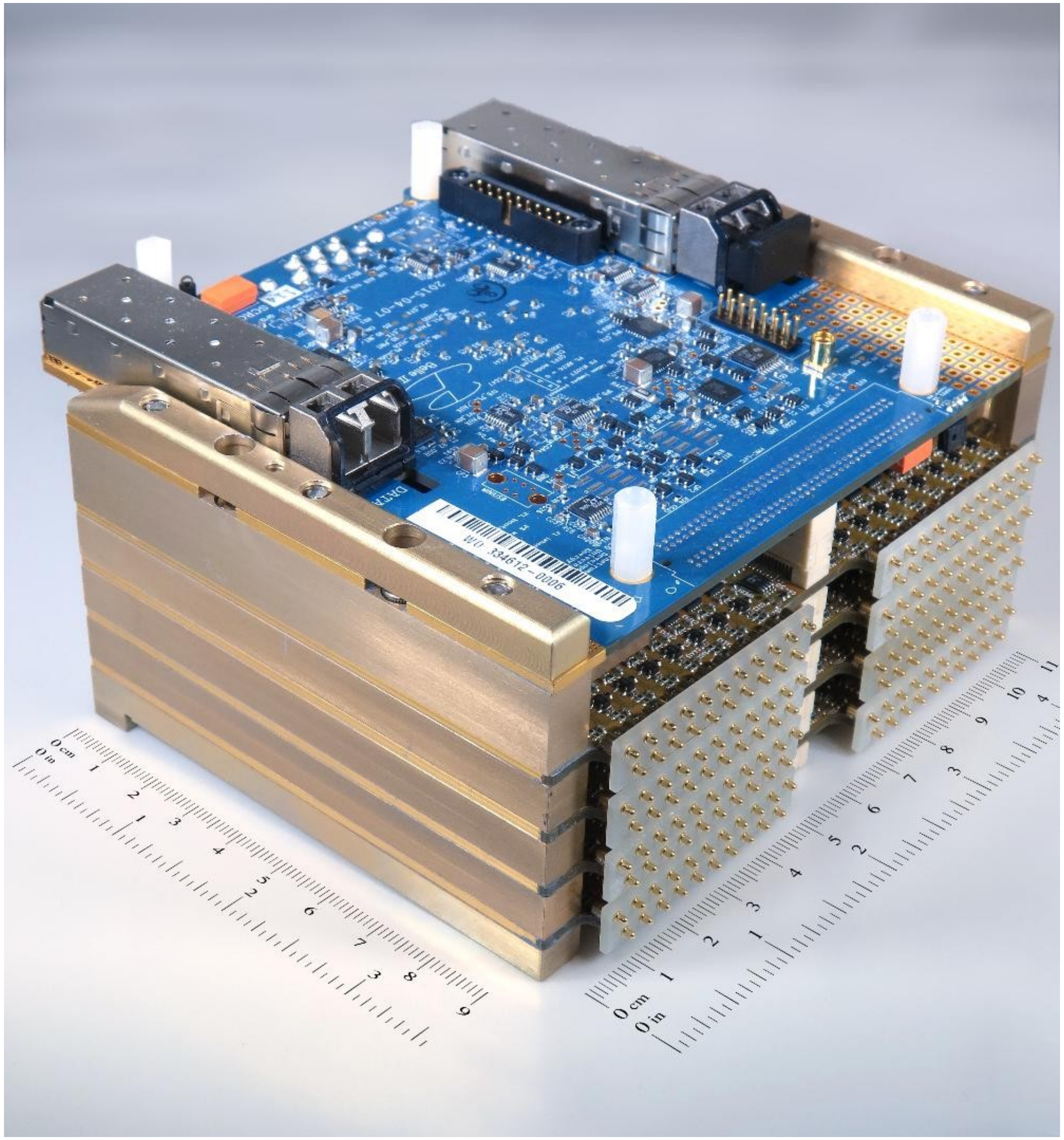


Data processing

- 8 channels per IRSX
- 4 IRSX per carrier PCB
- 4 carriers per boardstack

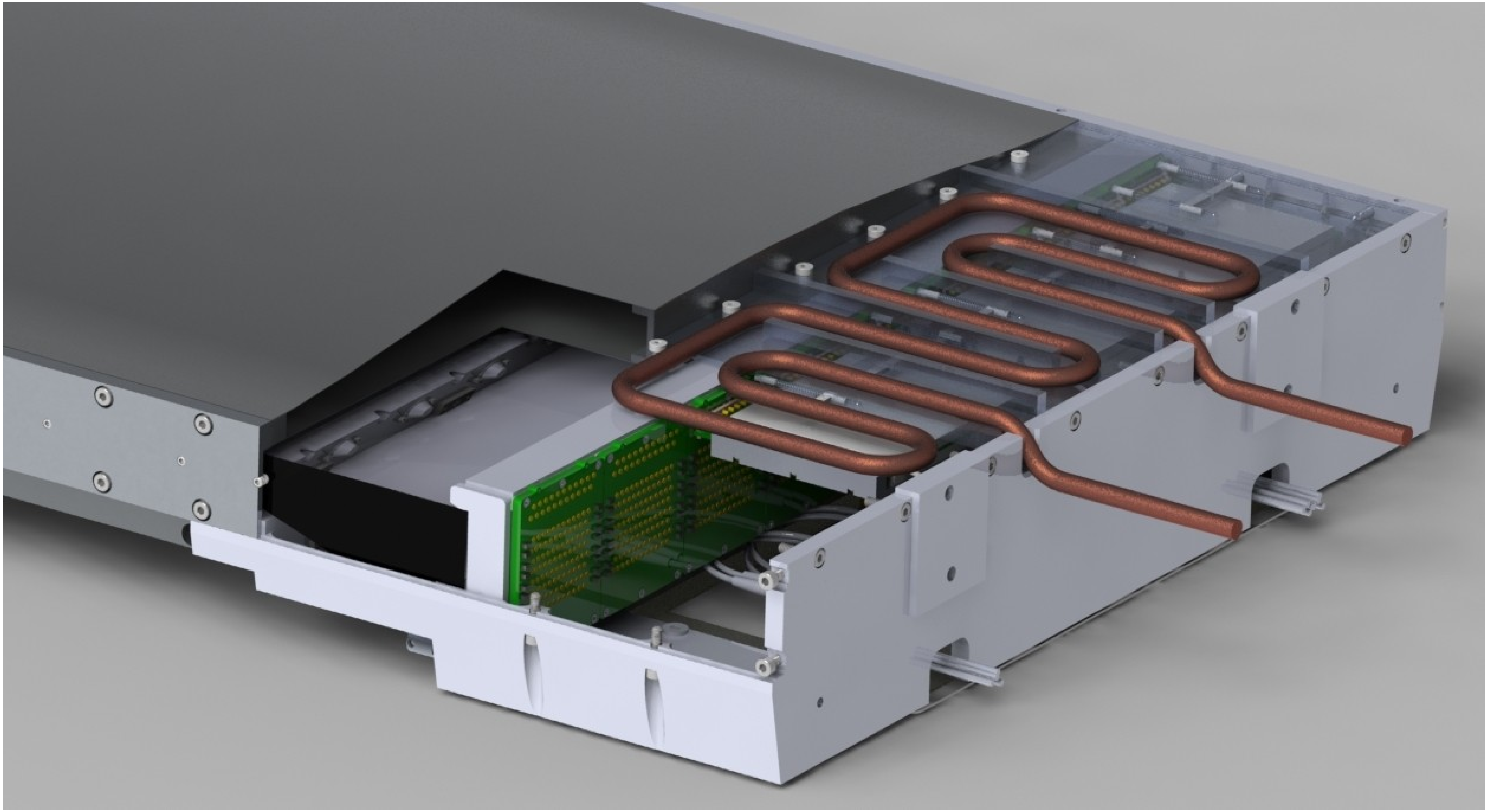
- Each step collects data from subsystems
- Feature extraction of digitized wave forms (50% constant fraction)
- Hits sorted to form events

- Data sent out with optical link



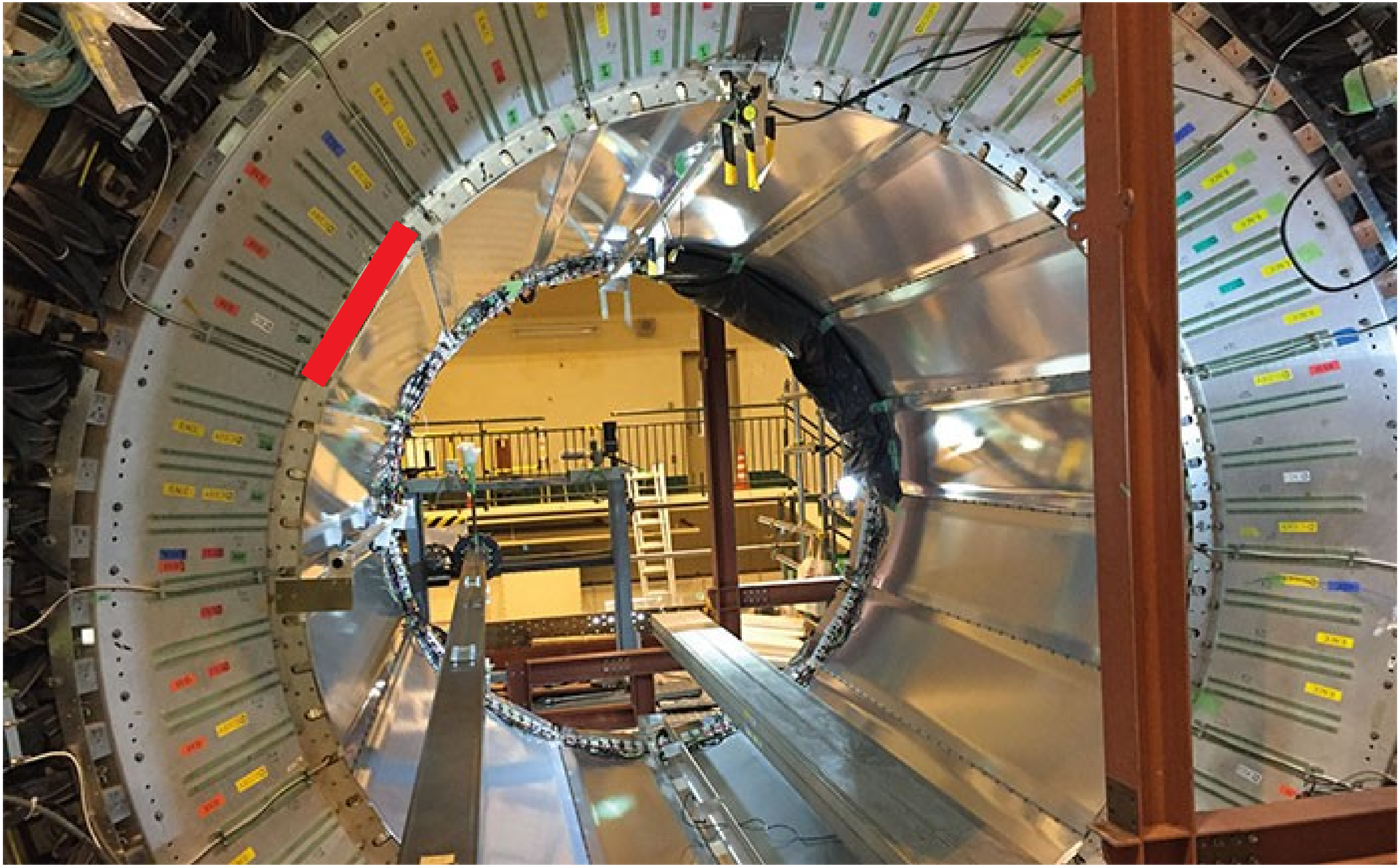
TOP module

4 boardstacks per module



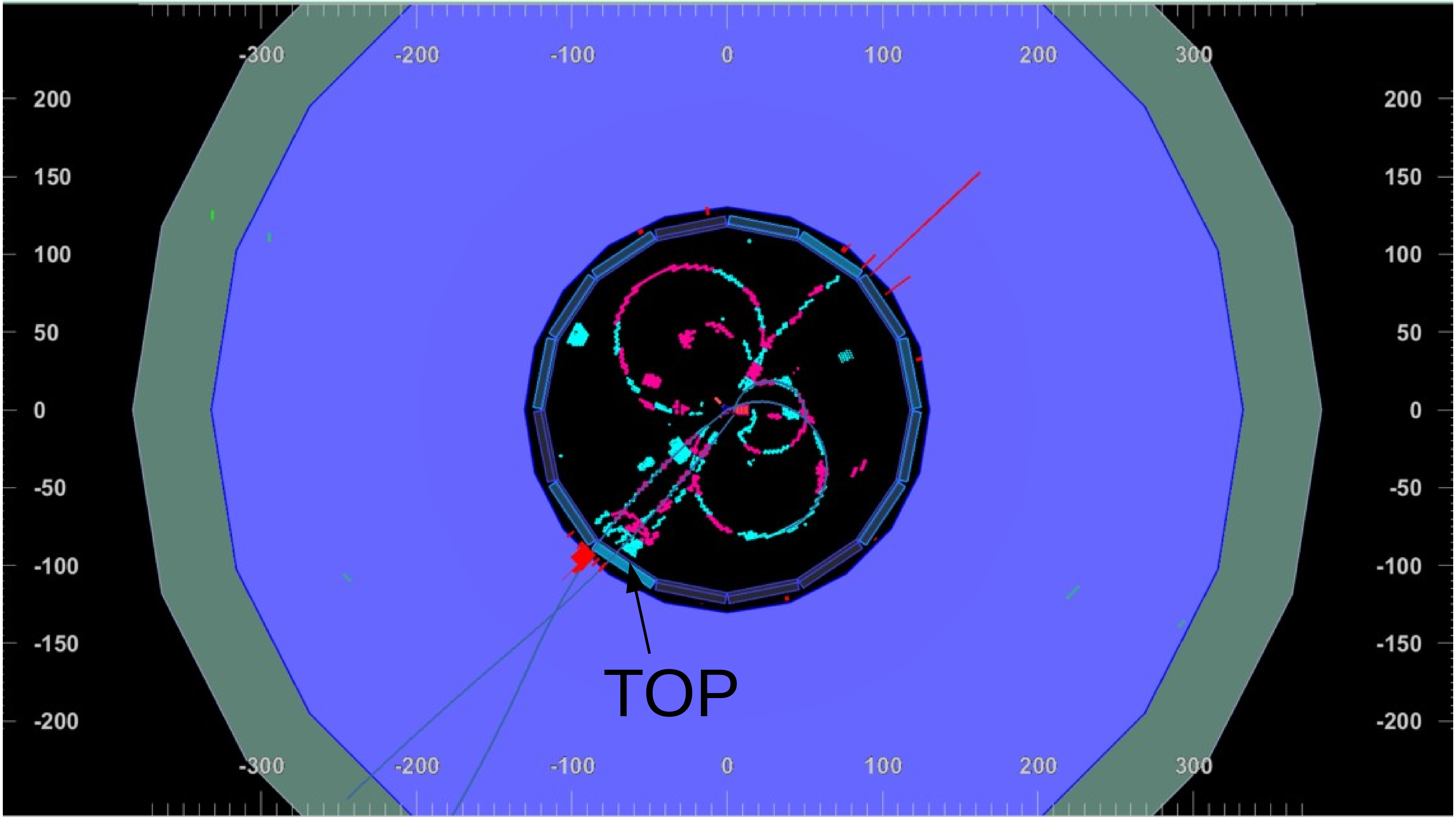
Putting it together...

16 modules



Event display

Data-taking started in 2018



Time calibration

Goal: ~100 ps time resolution
Done in 4 steps:

- Within channels
  - Inject electronic pulses with known delay
- Between channels
  - Inject laser pulses in module
- Between modules
  - Cosmic muons, collision data
- Relative to collision time
  - Collision data

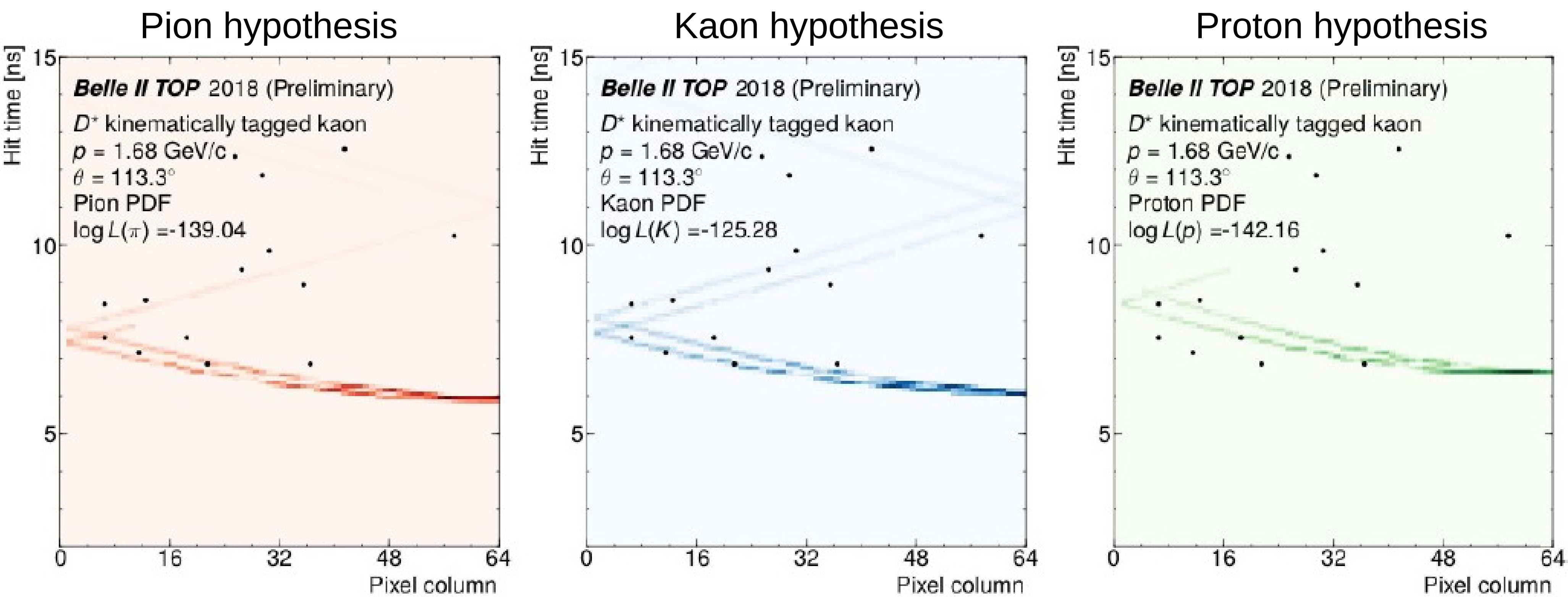
- Geometrical alignment
  - Cosmic muons, collision data

http://inspirehep.net/record/1642909/

Reconstruction

- Channel: $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$

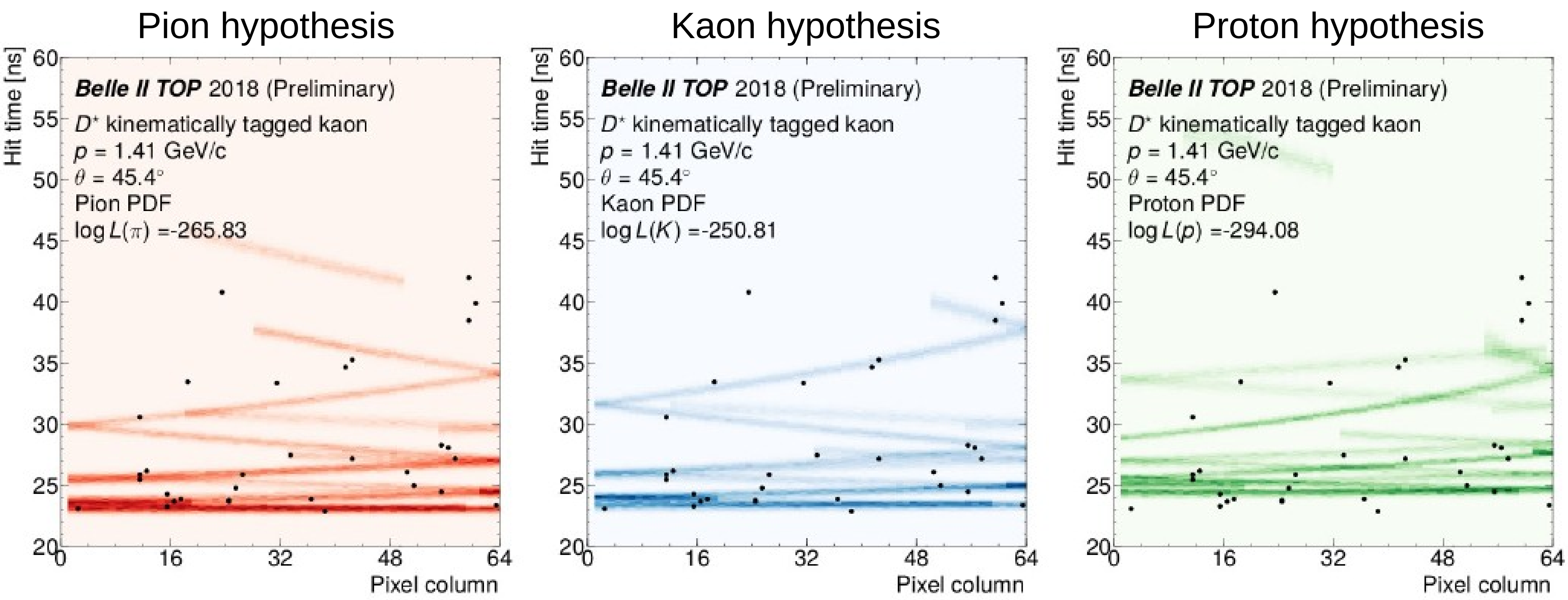
  Tagging from π_s^+
- Position vs. time diagram
- Kaon flying towards prism
- PID from time of flight



Reconstruction

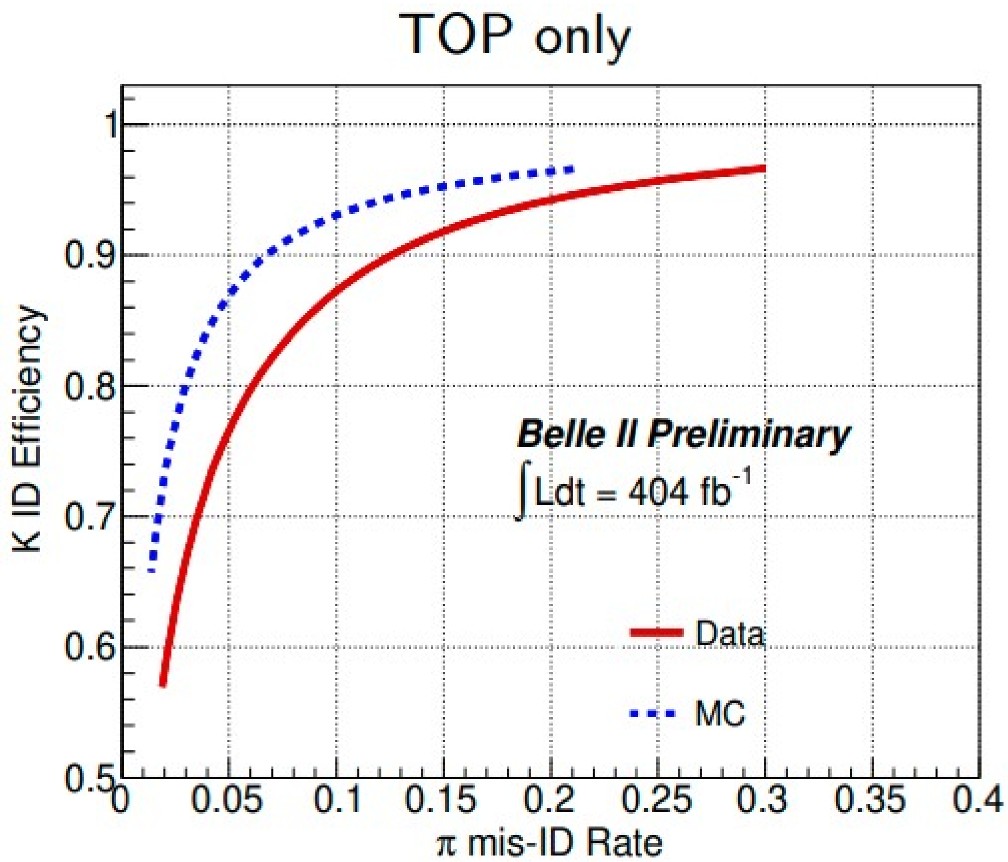
- Channel: $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$

  Tagging from π_s^+
- Position vs. time diagram
- Kaon flying away from prism
- PID from pattern of photons



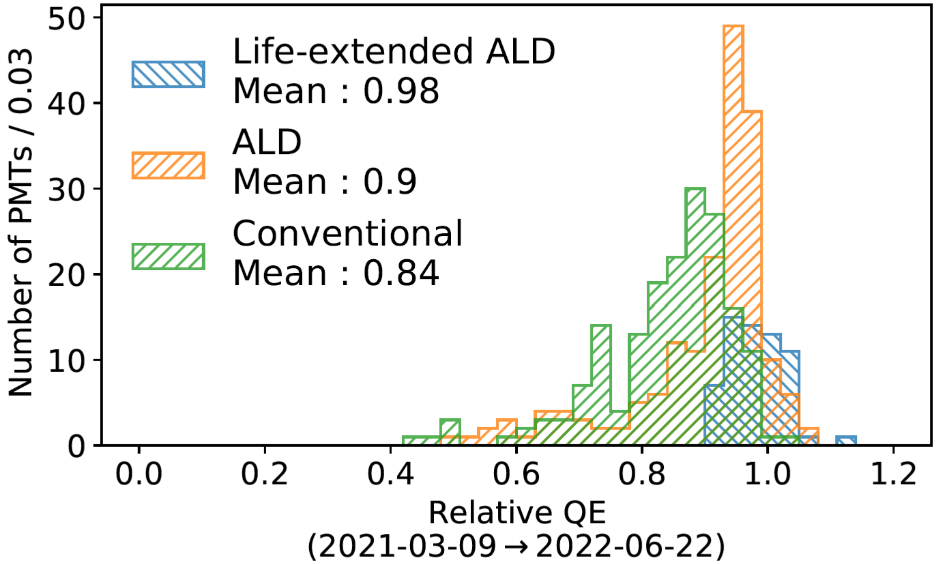
Particle identification

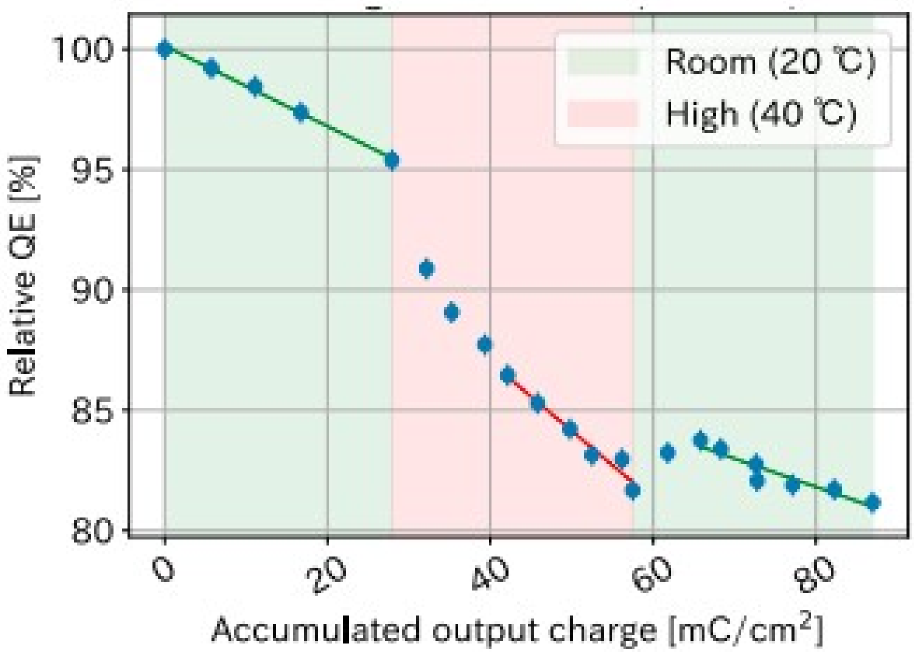
- TOP delivers likelihood ratios
- Combined with other subdetectors
- Selected by each analysis for their needs
- Trade-off between efficiency and mis-identification



MCP-PMT lifetime

- Detector operation 2018-2022, long shutdown (LS1) 2022-2024
- 0.3-0.4 C/cm^2 before LS1
- Laboratory tests predicted no/minimal PMT degradation
- Efficiency drop observed in two types
  - no change in life-extended PMTs
- Cause of the difference not yet understood
  - Temperature is one contribution
  - Magnetic field?
  - Years of operation?

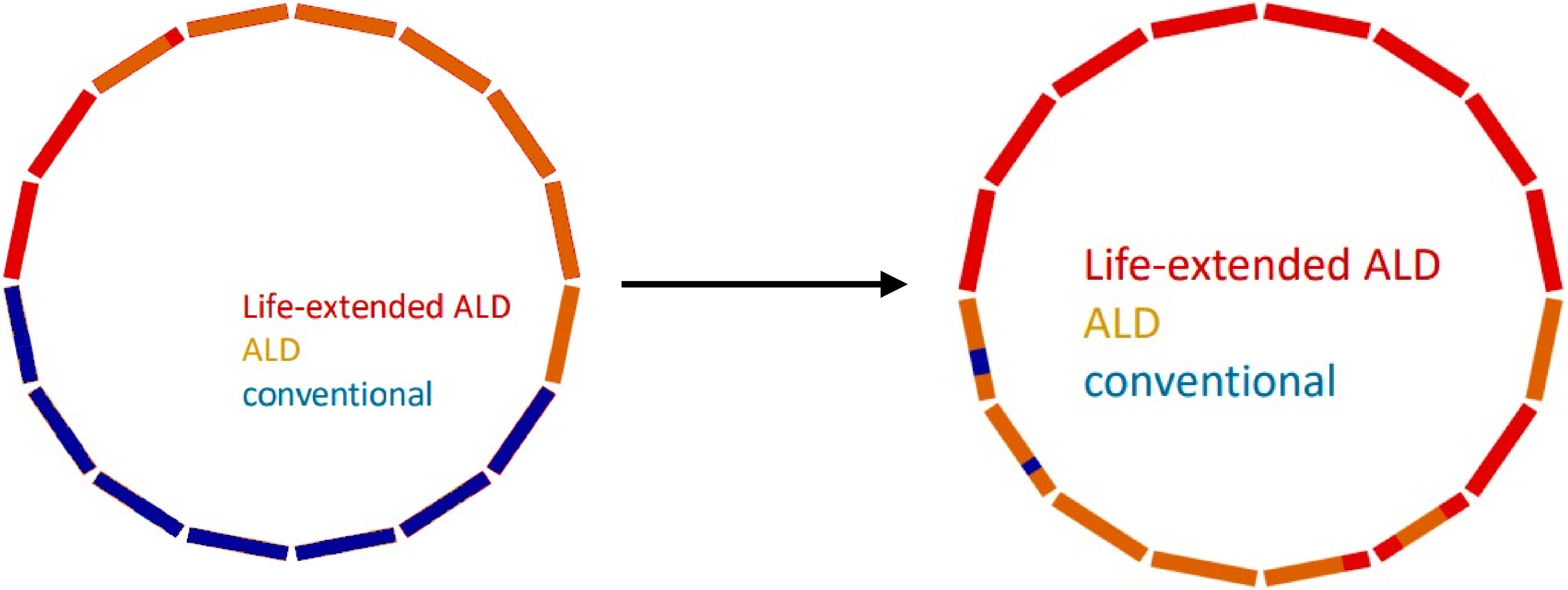




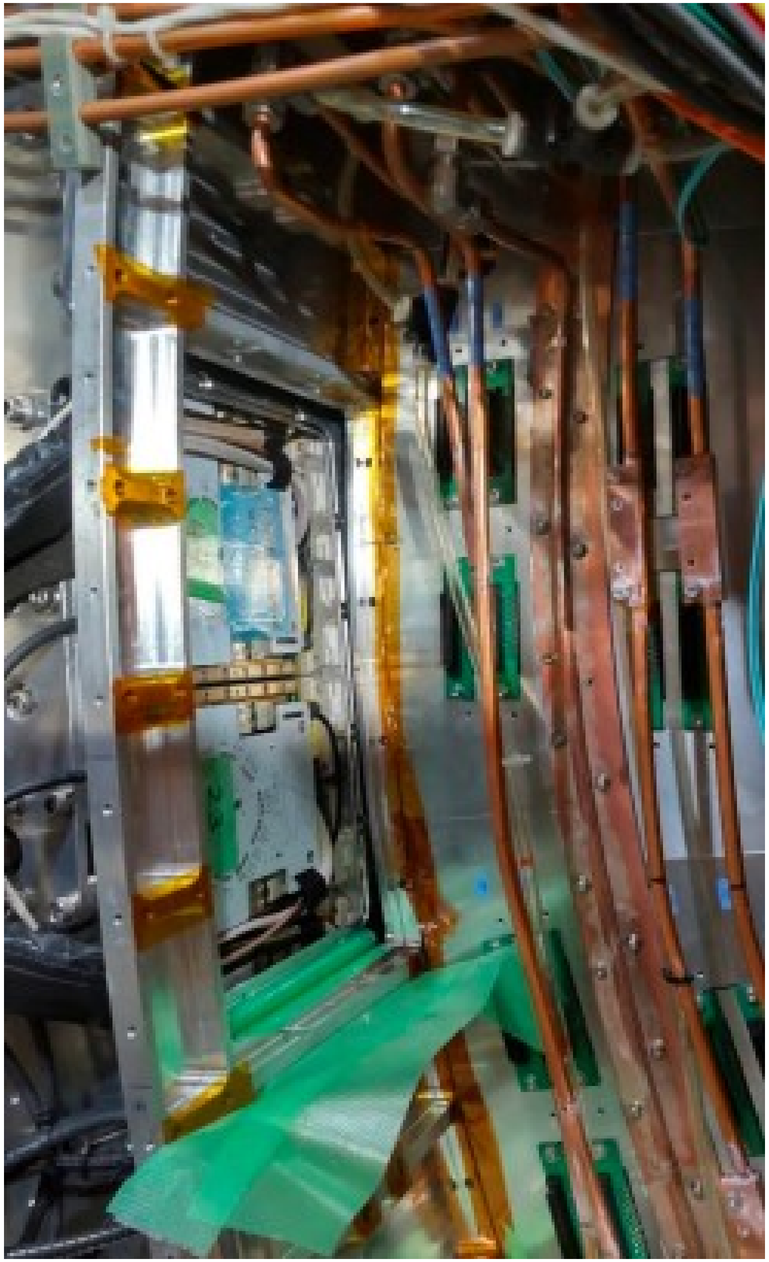
LS1

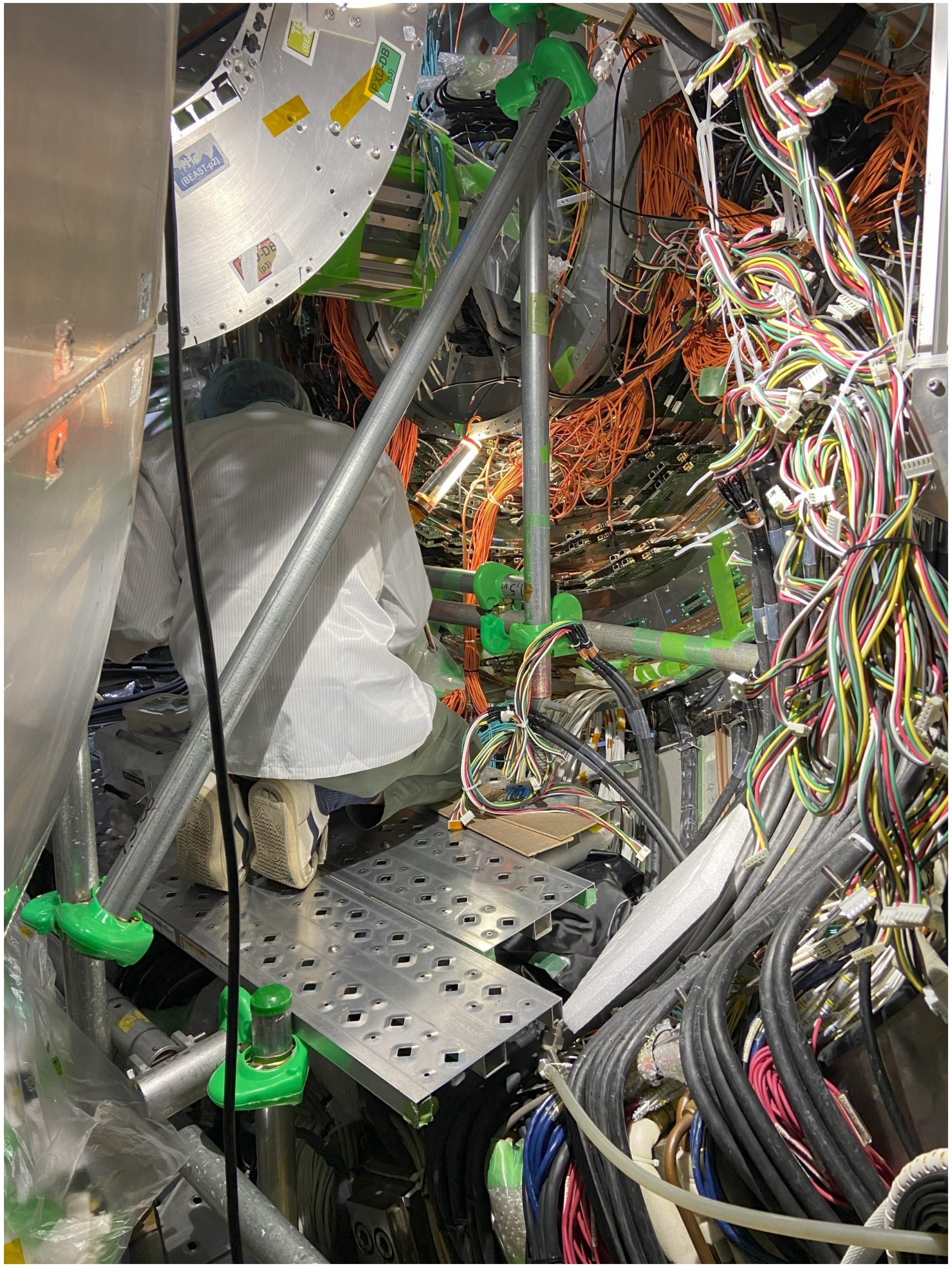
- Replaced oldest type with new life-extended PMTs
- Replaced damaged/faulty electronics
- Installed additional temperature sensors

- Remaining ALD PMTs to be exchanged in the future



LS1



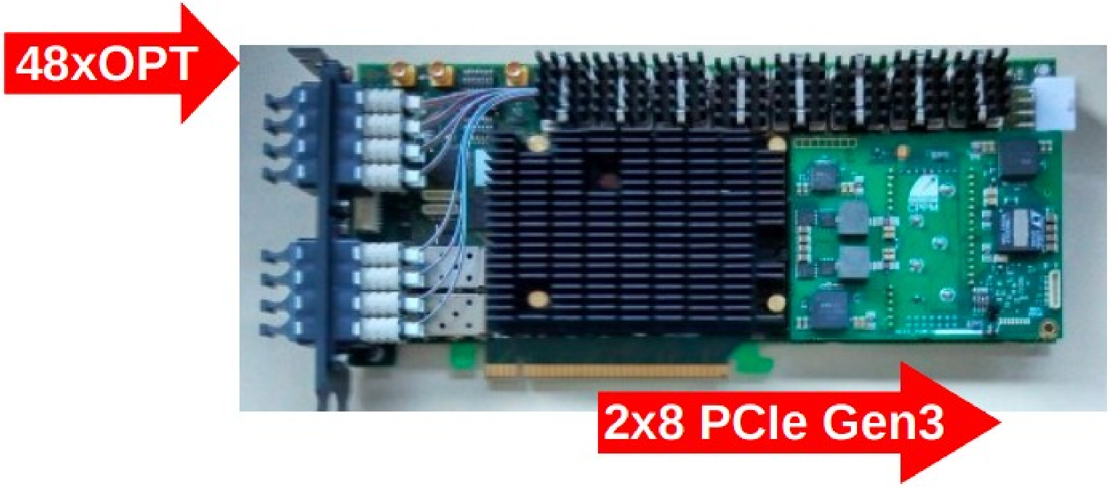


Single event upsets

- Significant neutron background in electronics
- Single event upsets can change data (negligible) or configuration
- Can cause processing system to lock up (~twice/day)
- Exclude boardstack, resume running, power cycle and include back
- Temporary loss of a few hits per track

- Small impact on runtime, tiny impact on data quality

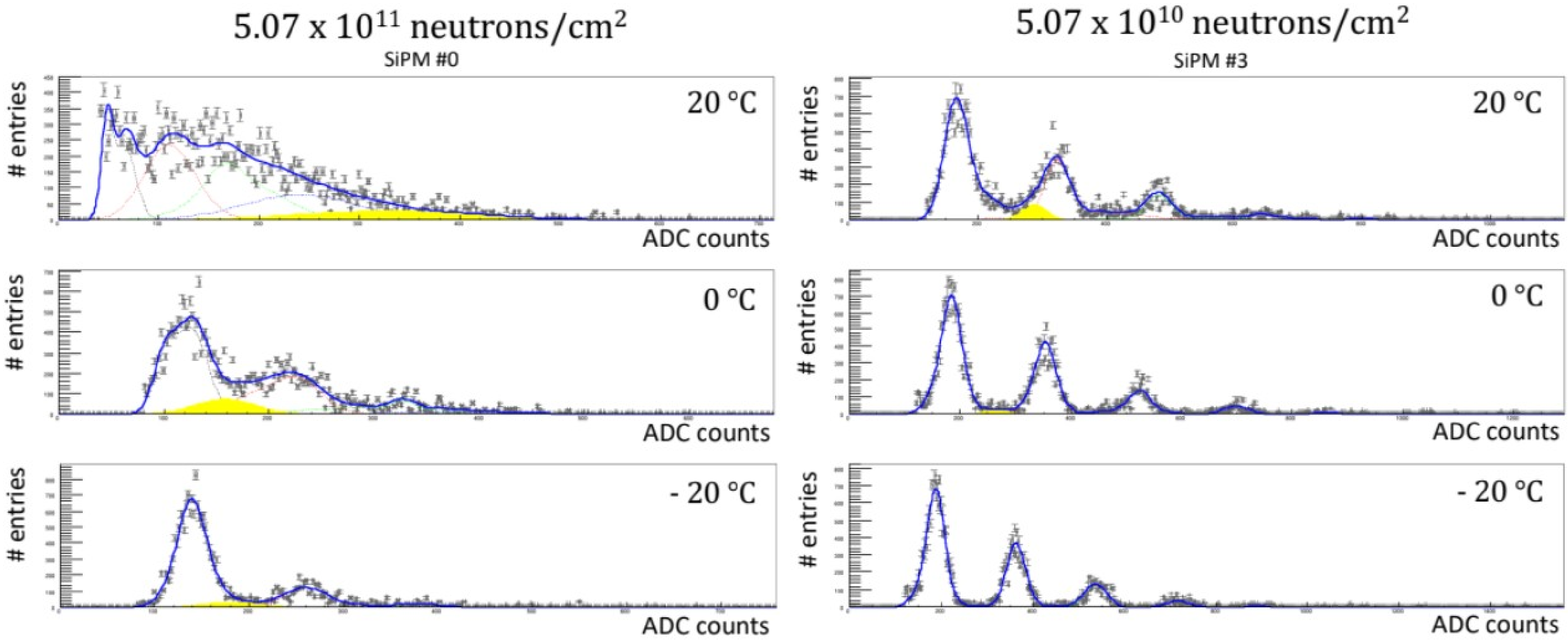
- Plan: Move most processing to DAQ (PCIe40)



Outlook

- PMT lifetime guides future plans

- Baseline: Use life-extended ALD PMTs everywhere
- If necessary: Replace with another set in the future
- Studying lower-power electronics, cooling upgrade
- Upgrade proposal: SiPM and new electronics



Summary

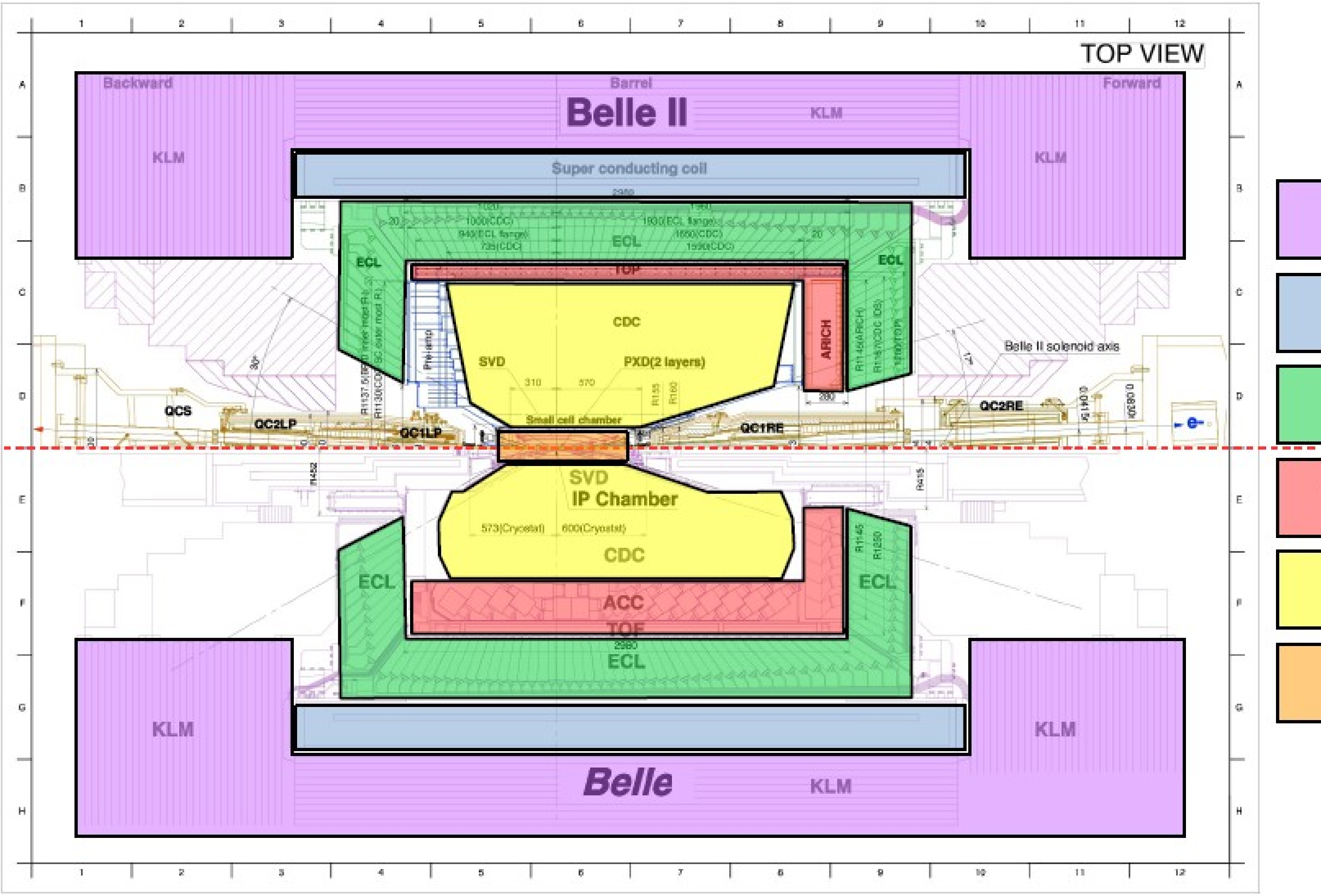
- Belle II: More data, higher precision than Belle
- TOP: New detector type for particle identification
  Imaging + Time Of Propagation
- Excellent time resolution for single photons at high rate
- Particle identification in barrel region

- MCP-PMT lifetime shorter than expected
- Replaced some PMTs and electronics in LS1

- Studying upgrade concepts

Backup slides

Belle II vs. Belle



K$_L$/Muon System

Magnet Coil

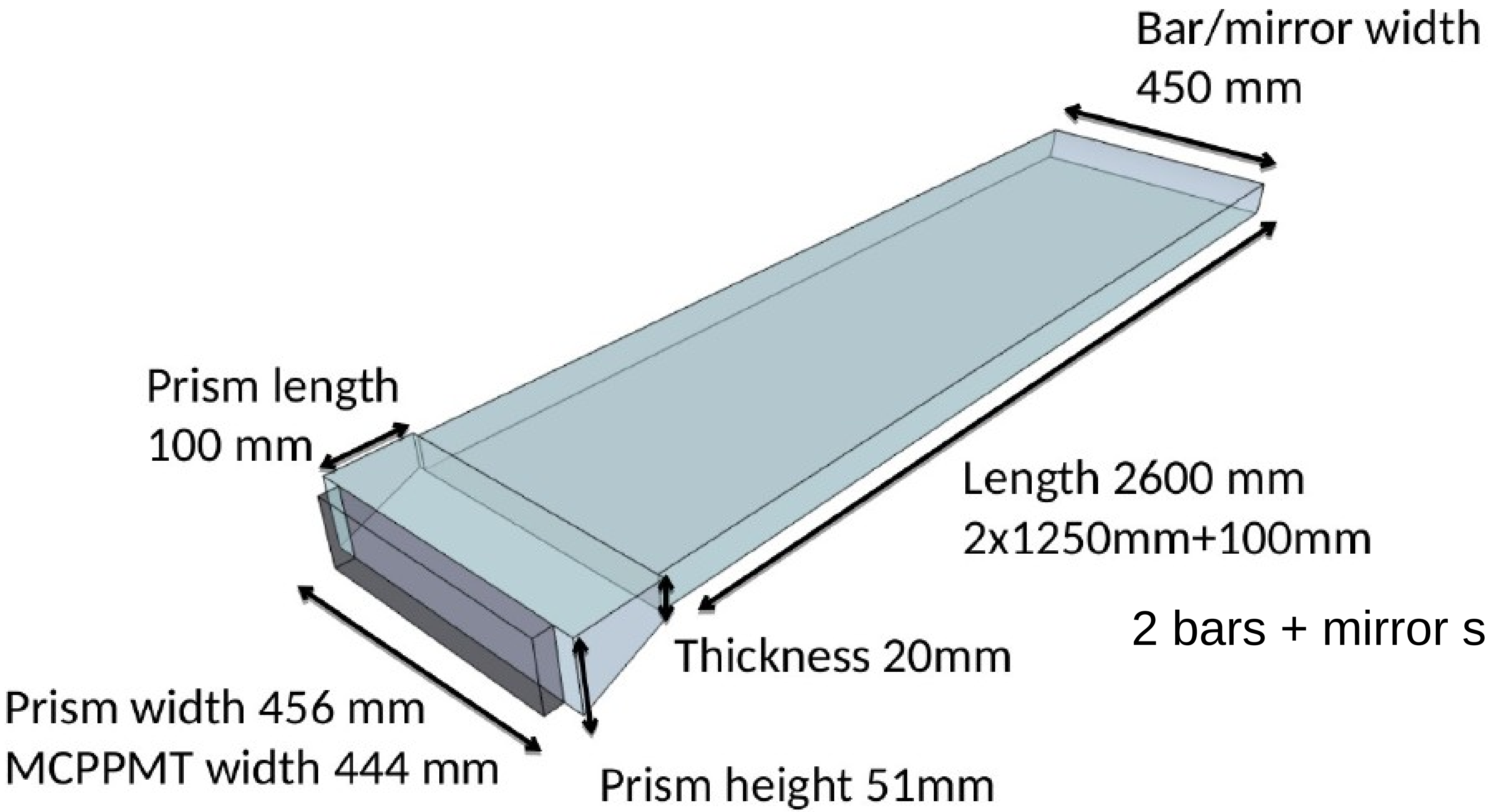
EM Calorimeter

π/K Identification

Drift Chamber

Silicon Tracking

Quartz bar

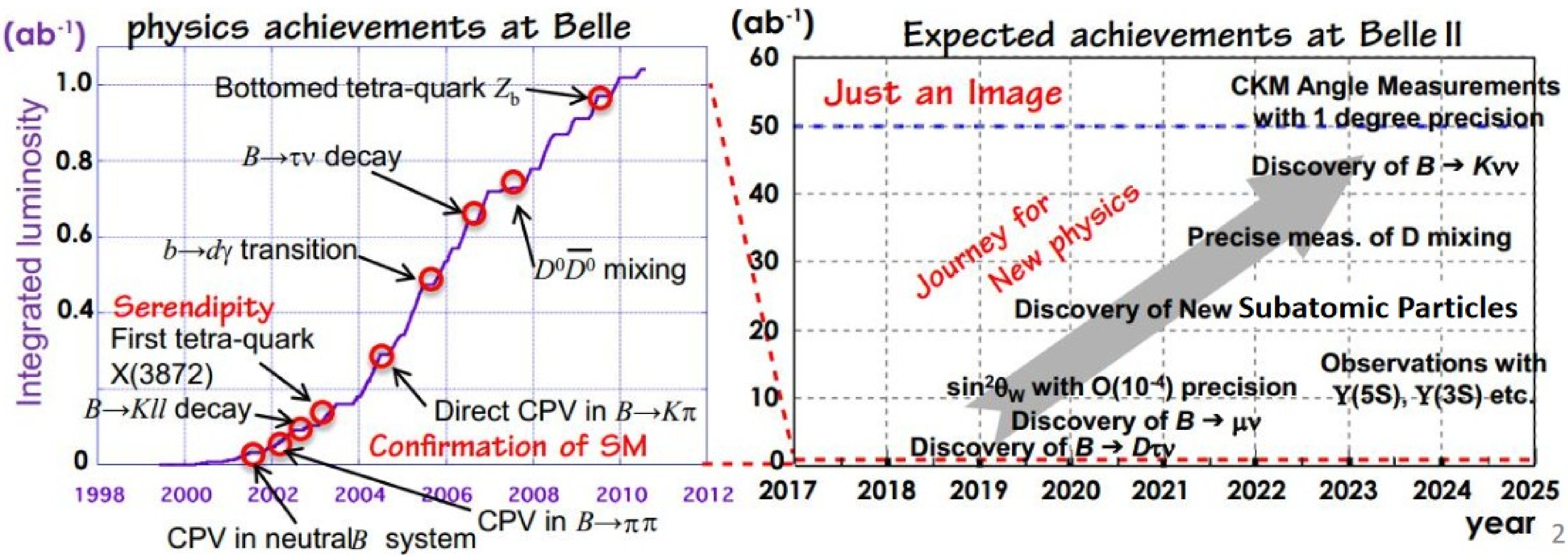


2 bars + mirror segment

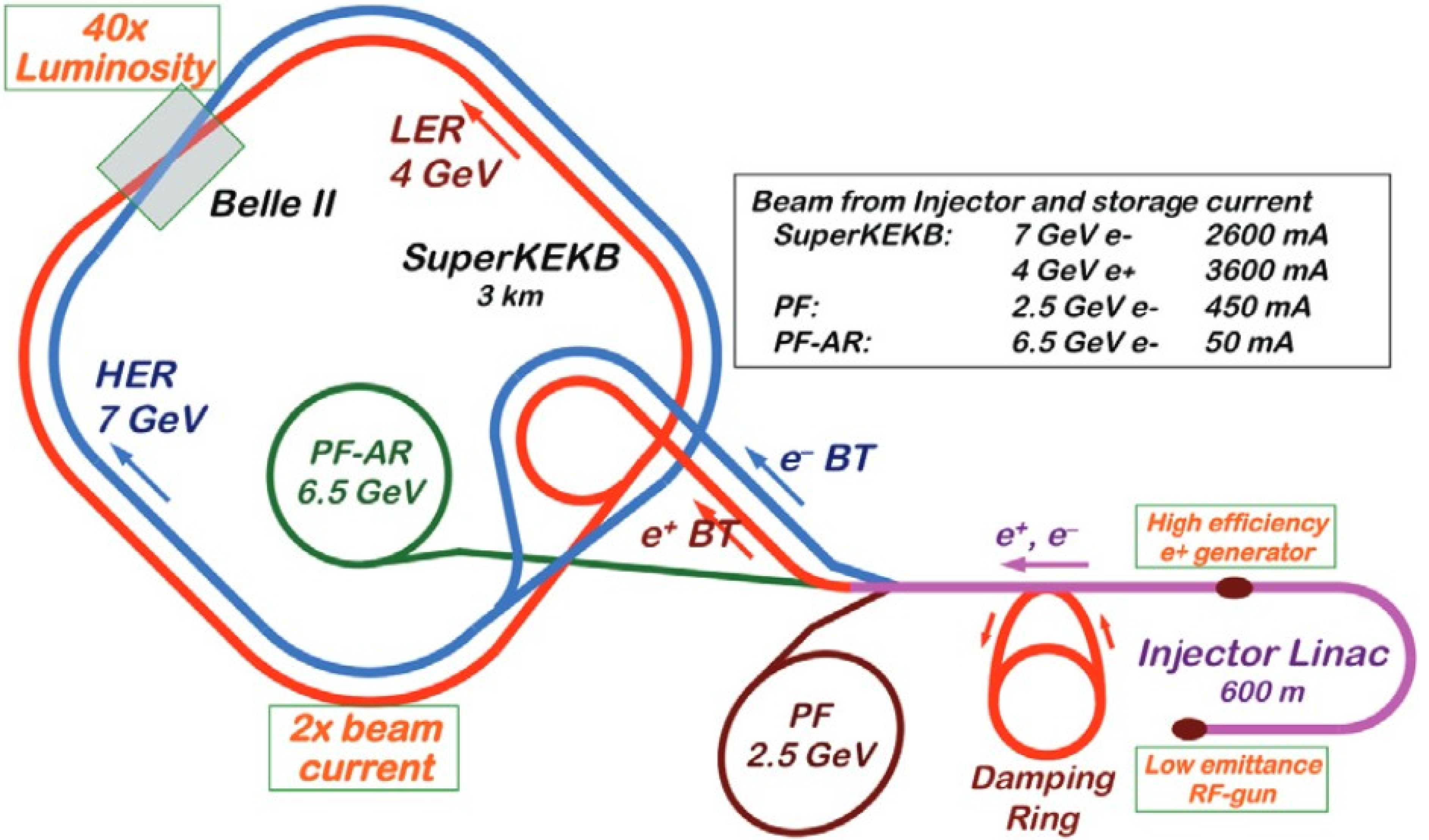
n=1.47

Comparison: Belle timeline

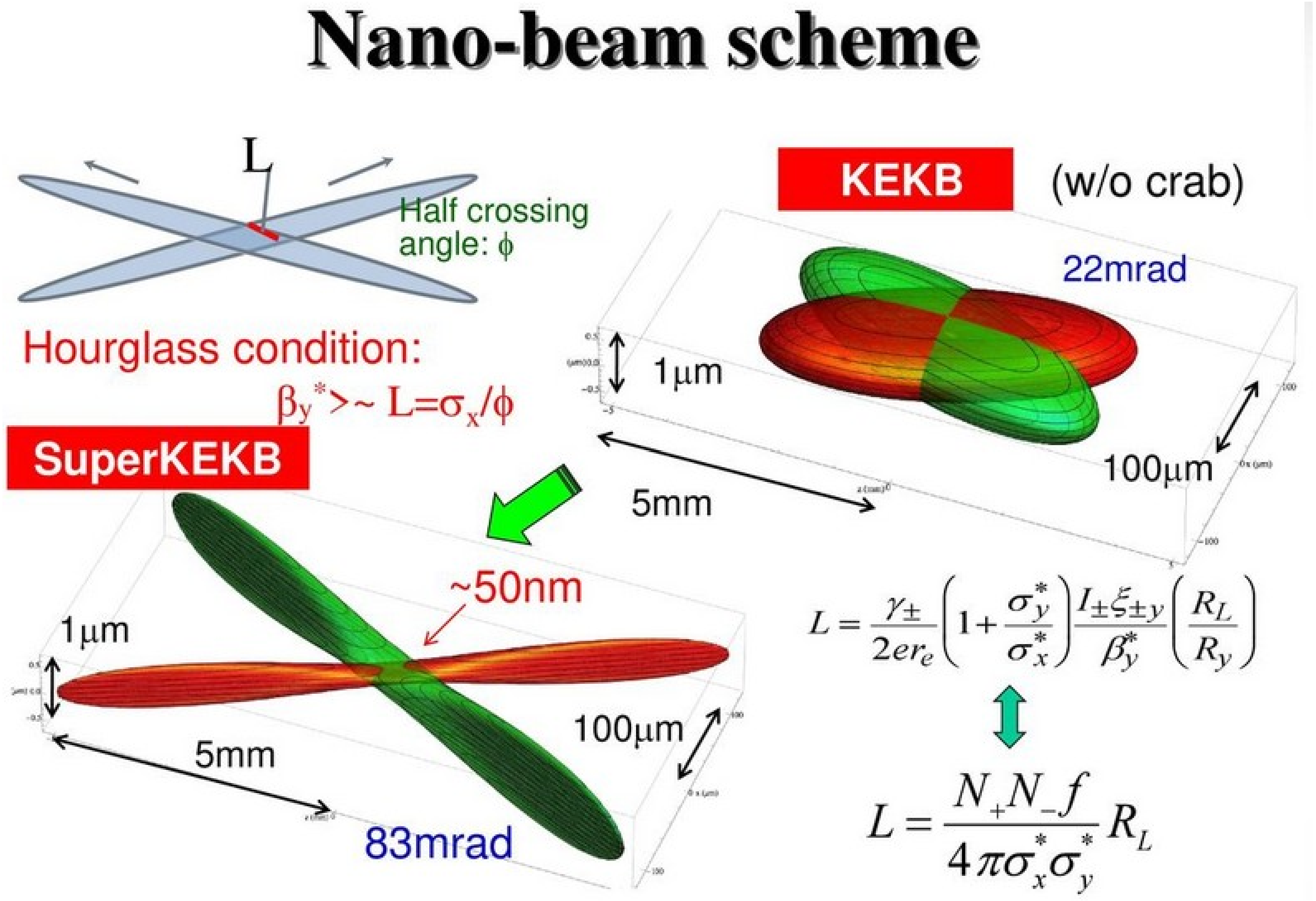
Hua YE, “Belle & Belle II Activities”, 2016



SuperKEKB

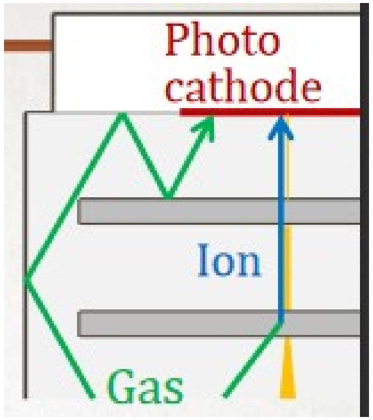

40x Luminosity
Belle II
LER
4 GeV
SuperKEKB
3 km
HER
7 GeV
PF-AR
6.5 GeV
Beam from Injector and storage current
SuperKEKB: 7 GeV e- 2600 mA
4 GeV e+ 3600 mA
PF: 2.5 GeV e- 450 mA
PF-AR: 6.5 GeV e- 50 mA
e⁻ BT
e⁺ BT
e⁺, e⁻
High efficiency e+ generator
Injector Linac
600 m
2x beam current
PF
2.5 GeV
Damping Ring
Low emittance RF-gun

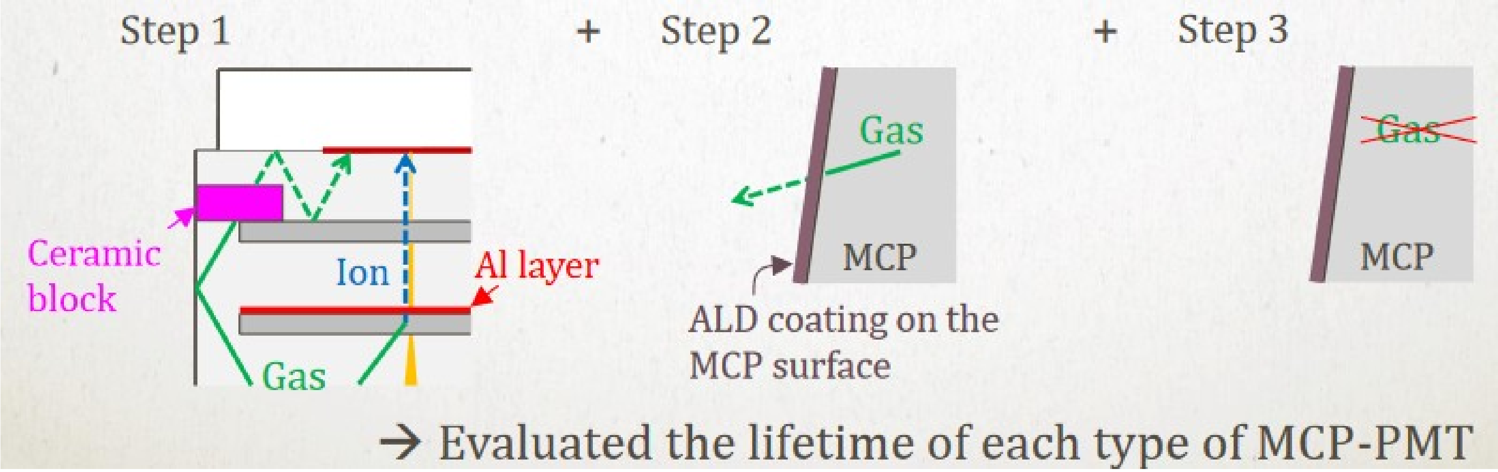
SuperKEKB collisions

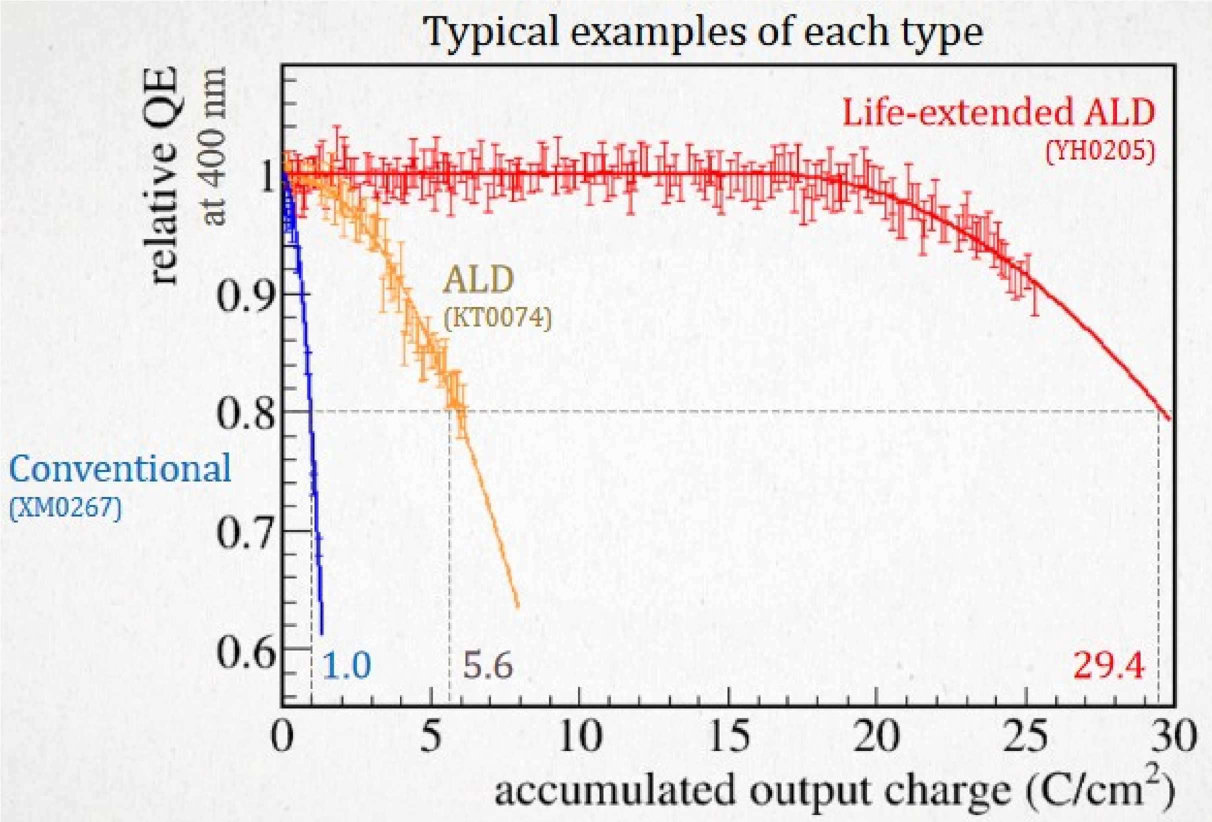


See poster by Luka Šantelj:
“Measurements of Beam Backgrounds at SuperKEKB”

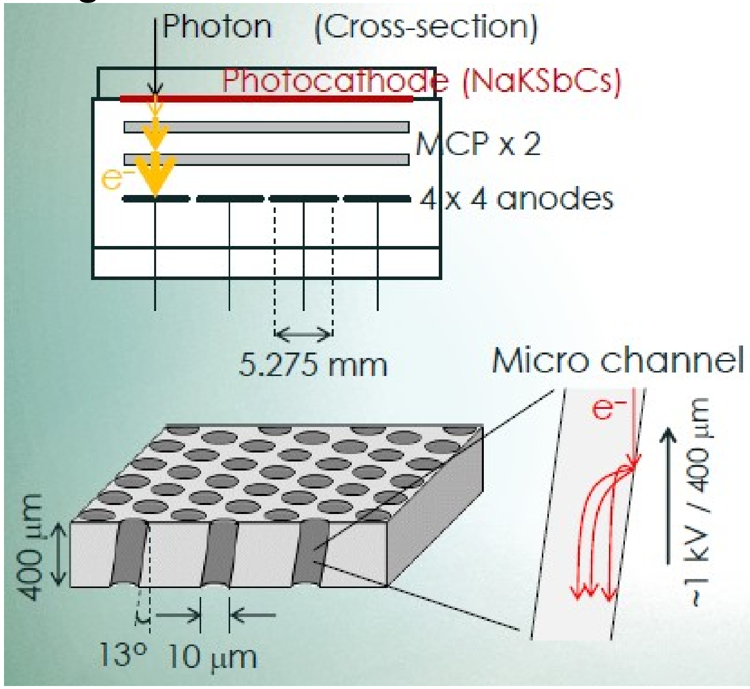
MCP PMT lifetime







Kodai Matsuoka, “Improvement of the MCP-PMT performance under a high count rate”, TIPP 2017



Endcap PID: ARICH