Charged hadron identification and TOP in Belle II

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Belle II summer school
July 26, 2023

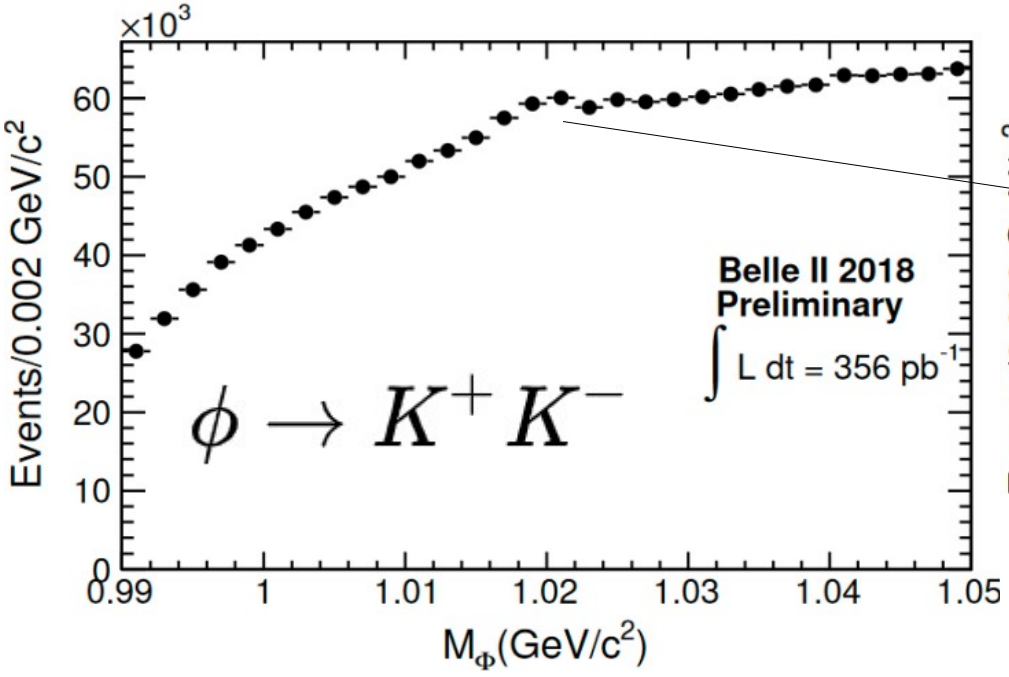
Why do particle identification?

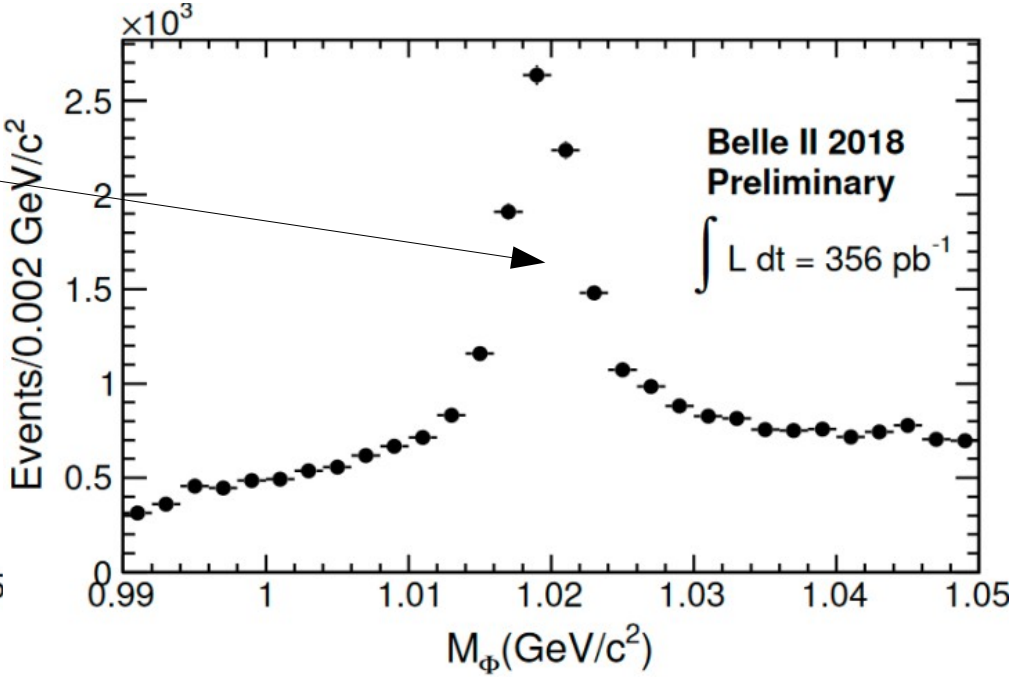
π π π π K π π
π π π
K p π π
π π π K

π π π K π π
π π π
K p π π
π π π K

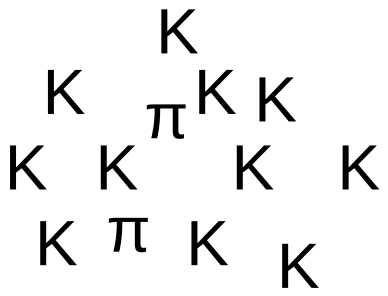
No PID

with PID



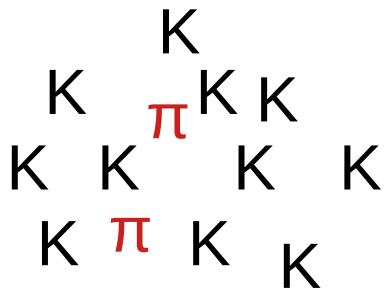


Why do particle identification?

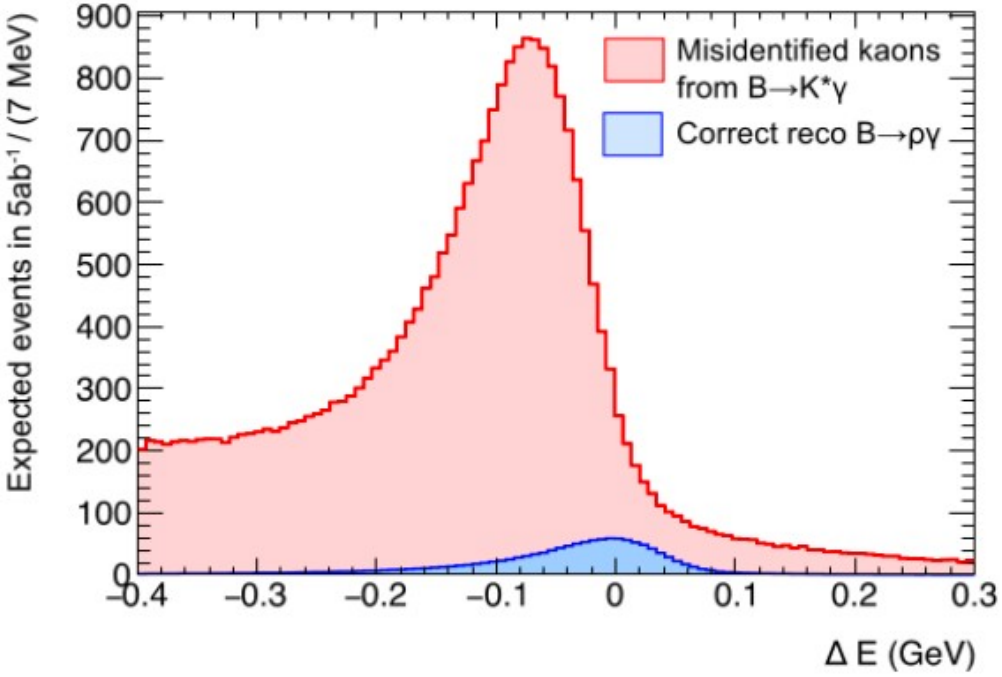


$$B \to \rho^0 (K^+ \pi^-)\, \gamma : \ 10^{-5}$$

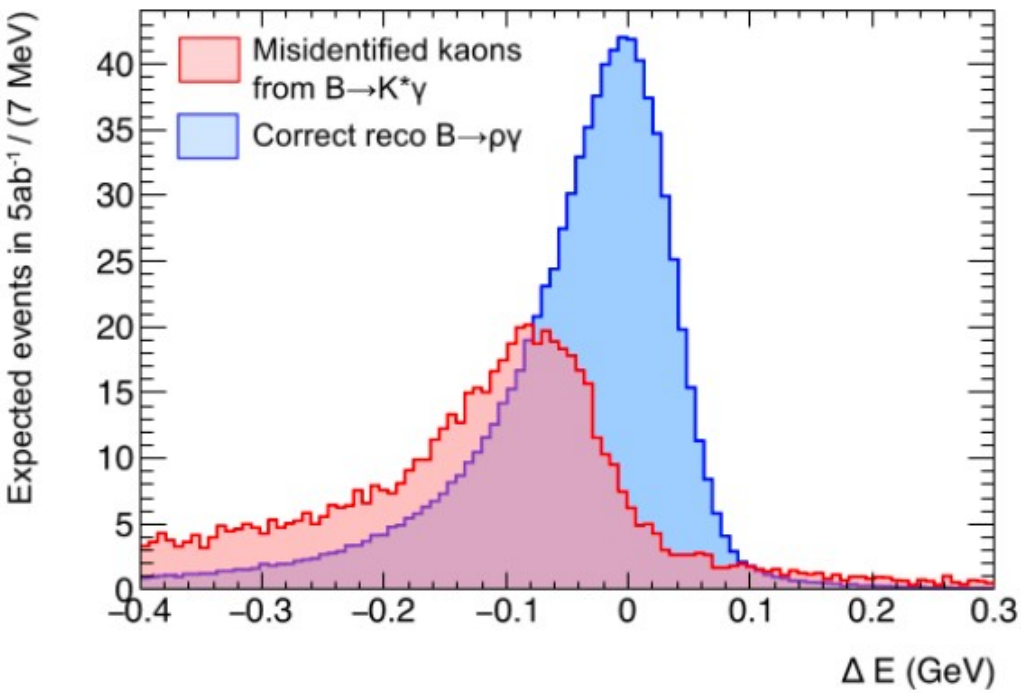
$$B \to \rho^0 (\pi^+ \pi^-)\, \gamma : \ 10^{-7}$$



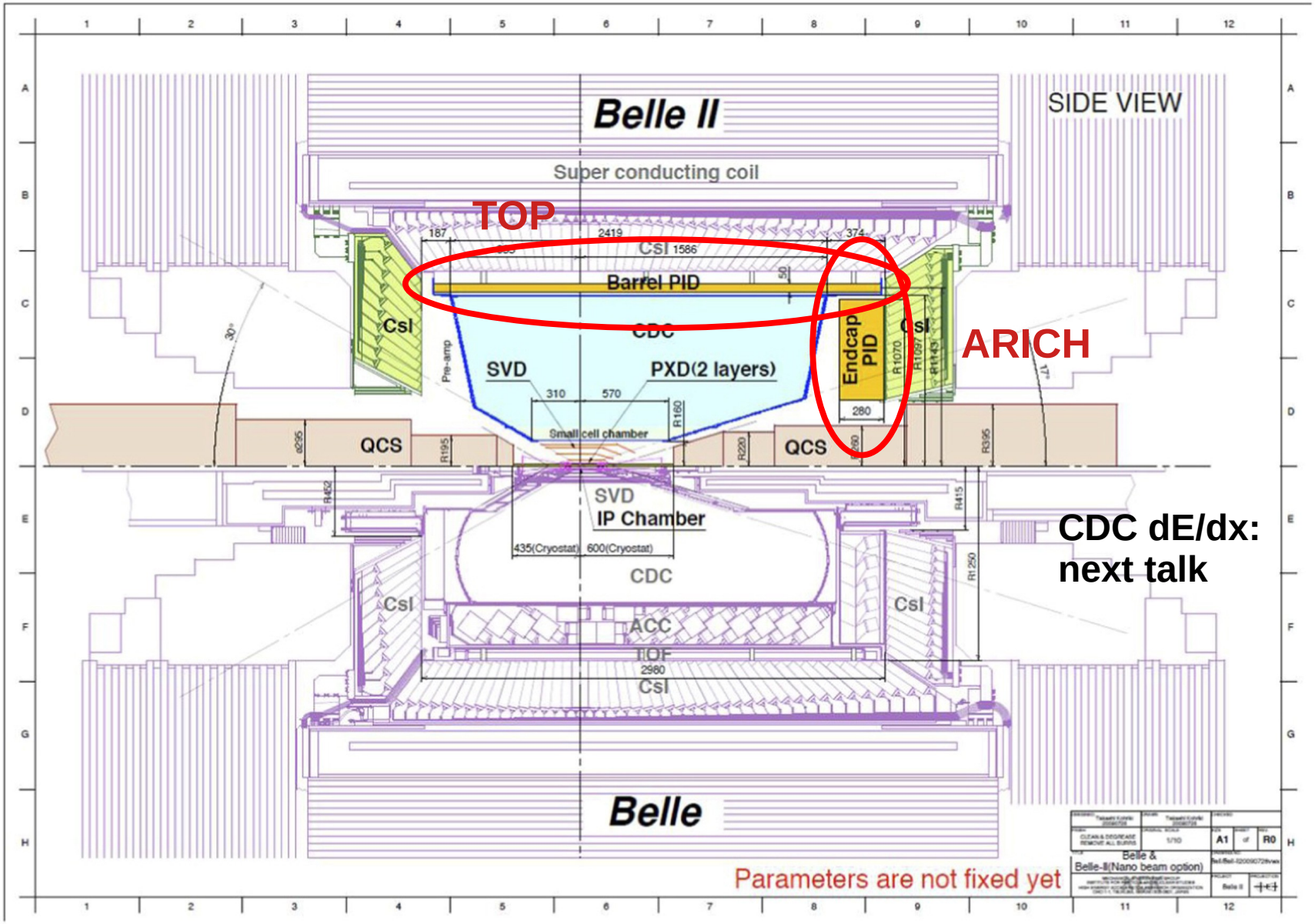
No PID



with PID



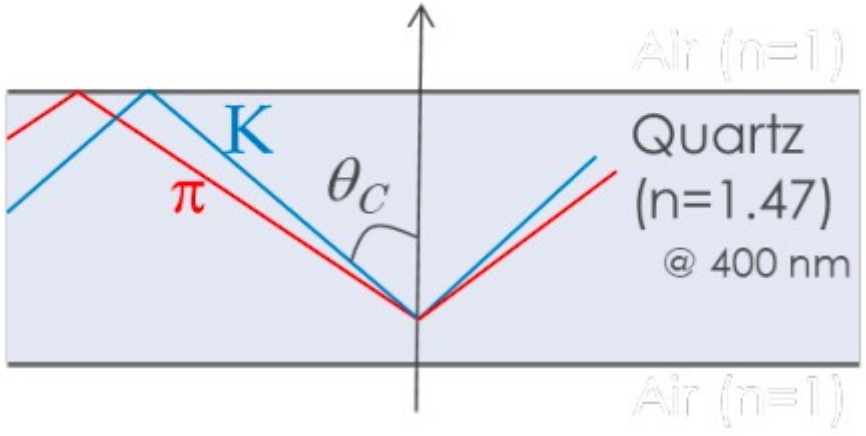
PID subdetectors



Cherenkov radiation

- Light emission from particles faster than local speed of light
- Angle depends on velocity of particle
- Use velocity and momentum -> calculate mass
- Same concept in ARICH and TOP

$$\cos\theta_c = 1/n\beta$$

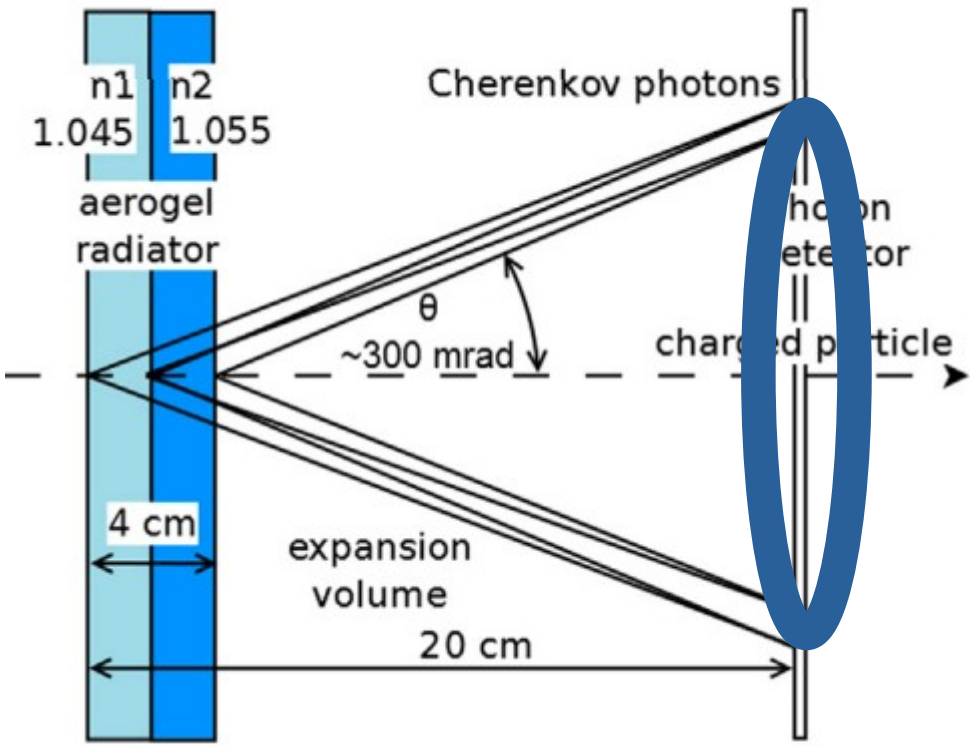


Quartz in TOP
Aerogel in ARICH

ARICH

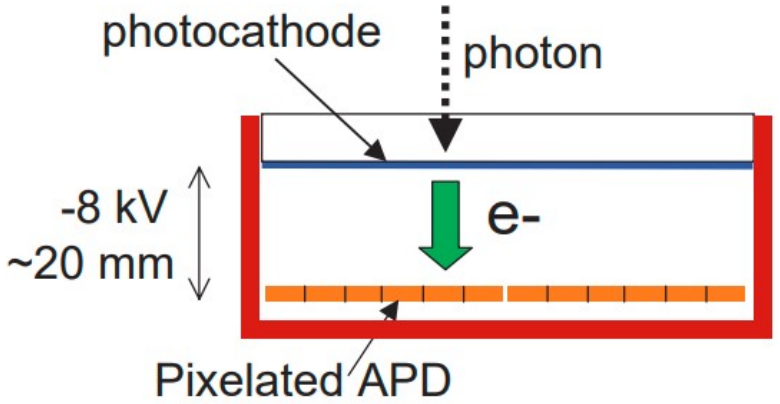
Aerogel Ring Imaging Cherenkov Detector

- Forward endcap of Belle II
- Direct ring imaging
- Two aerogel tiles to increase light collection

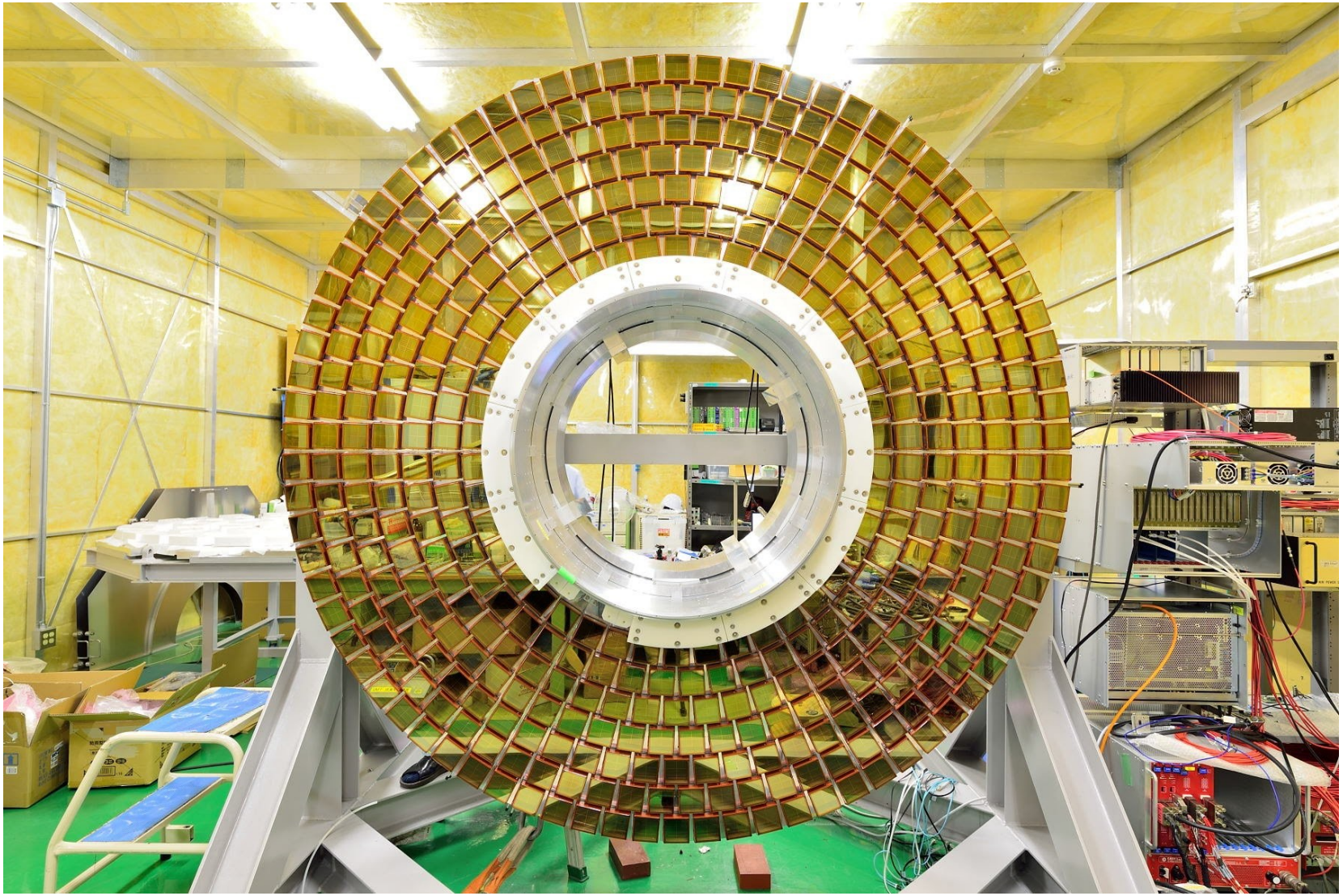


- Single-photon detection over large area
- Hybrid Avalanche Photo Detector (HAPD)
  2 amplification stages

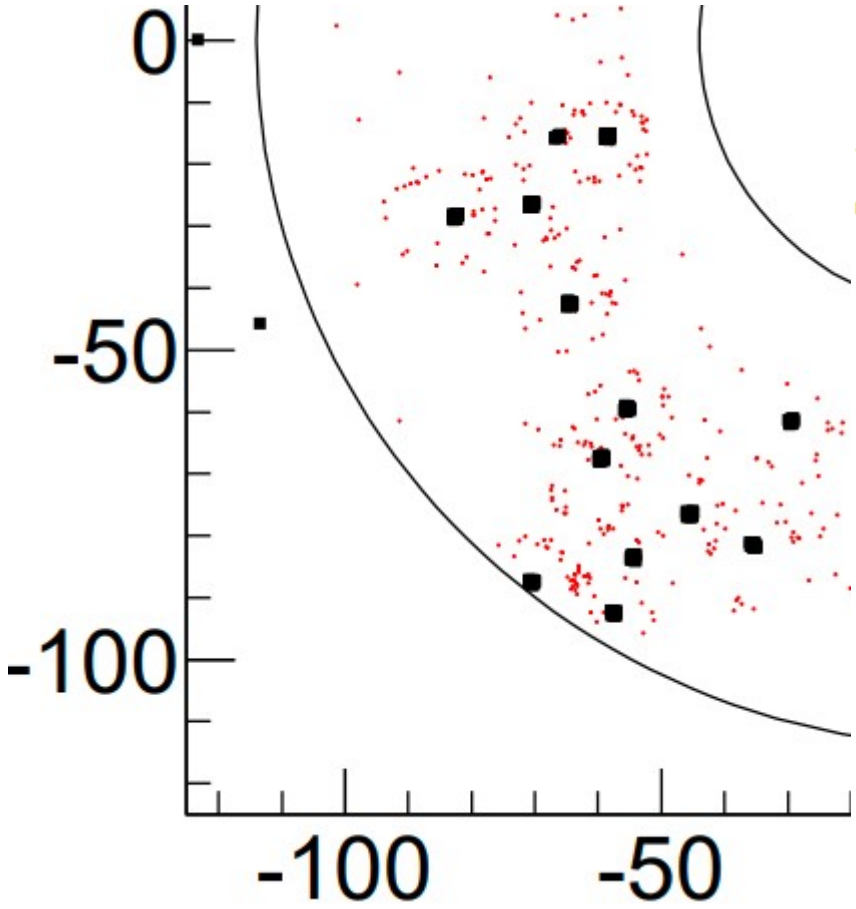
- 5mm x 5mm pixels,
  60000 channels overall

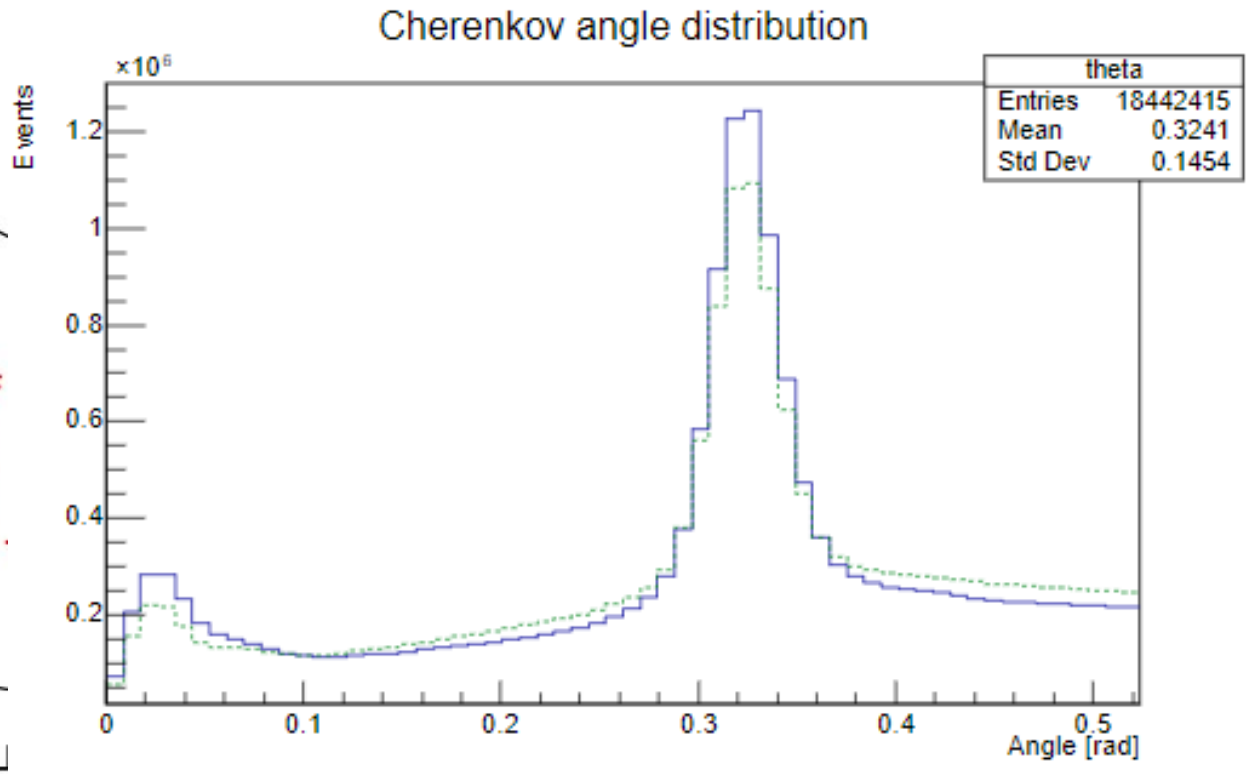


ARICH



ARICH

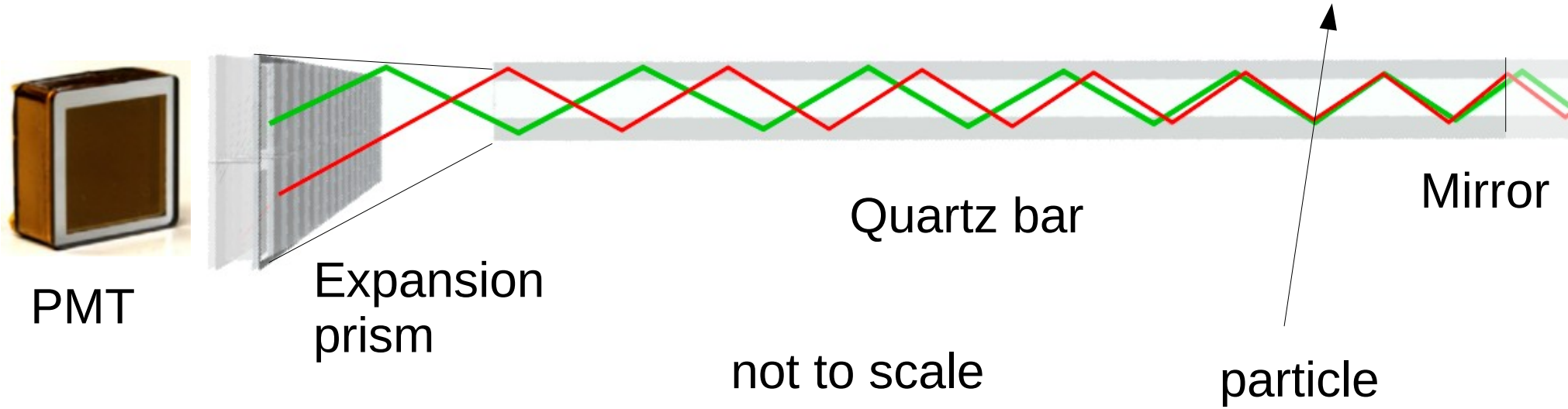

0
-50
-100
-100
-50


Cherenkov angle distribution
×10⁶
Events
1.2
1
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
Angle [rad]
theta
Entries 18442415
Mean 0.3241
Std Dev 0.1454

TOP concept

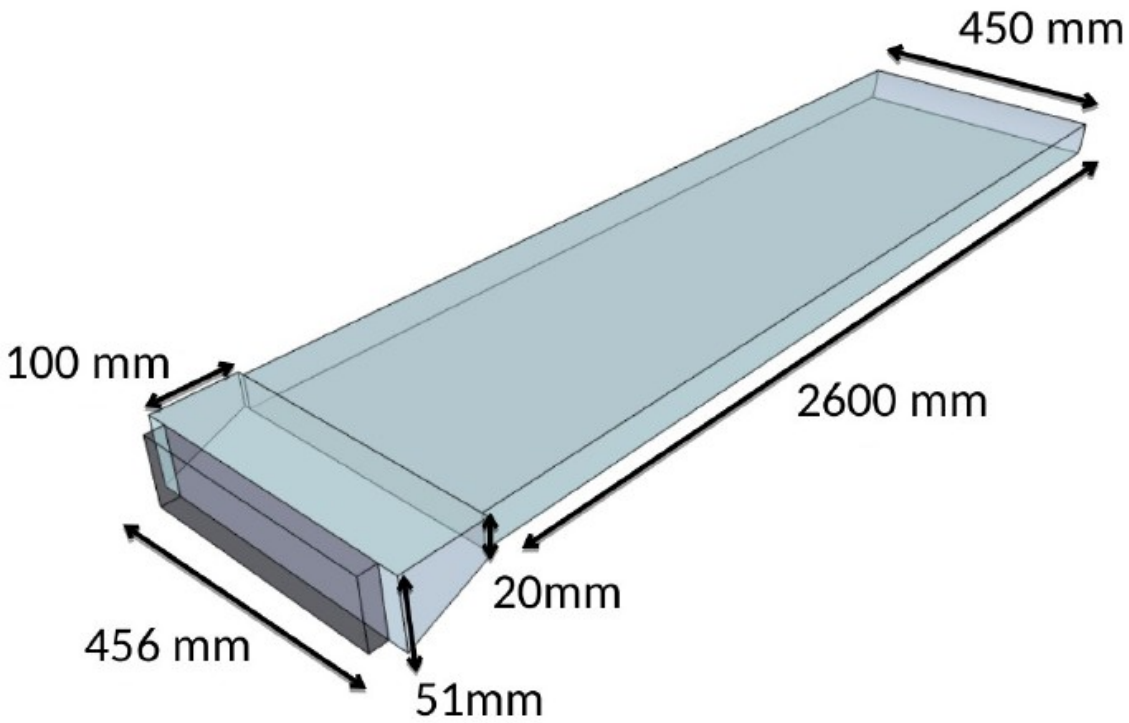
(imaging) Time Of Propagation

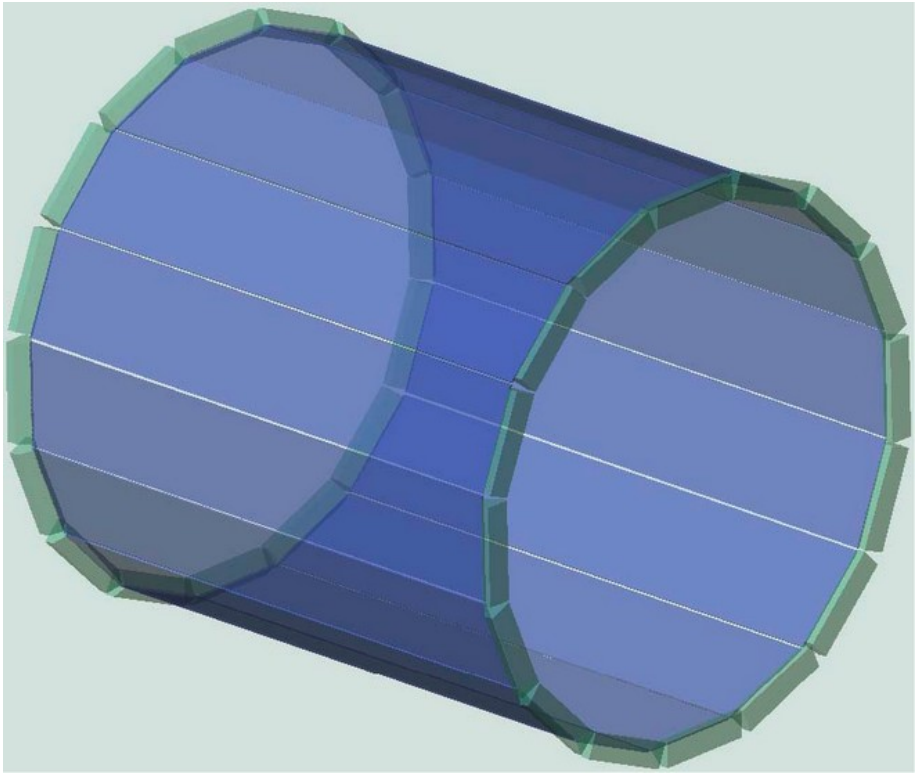
- Cherenkov light in quartz bar
- Total internal reflection
  (>100 times)
- Expansion prism at backward side
  -> spatial resolution
- Mirror at forward side
- PMTs for detection
- 64x8 pixels per module



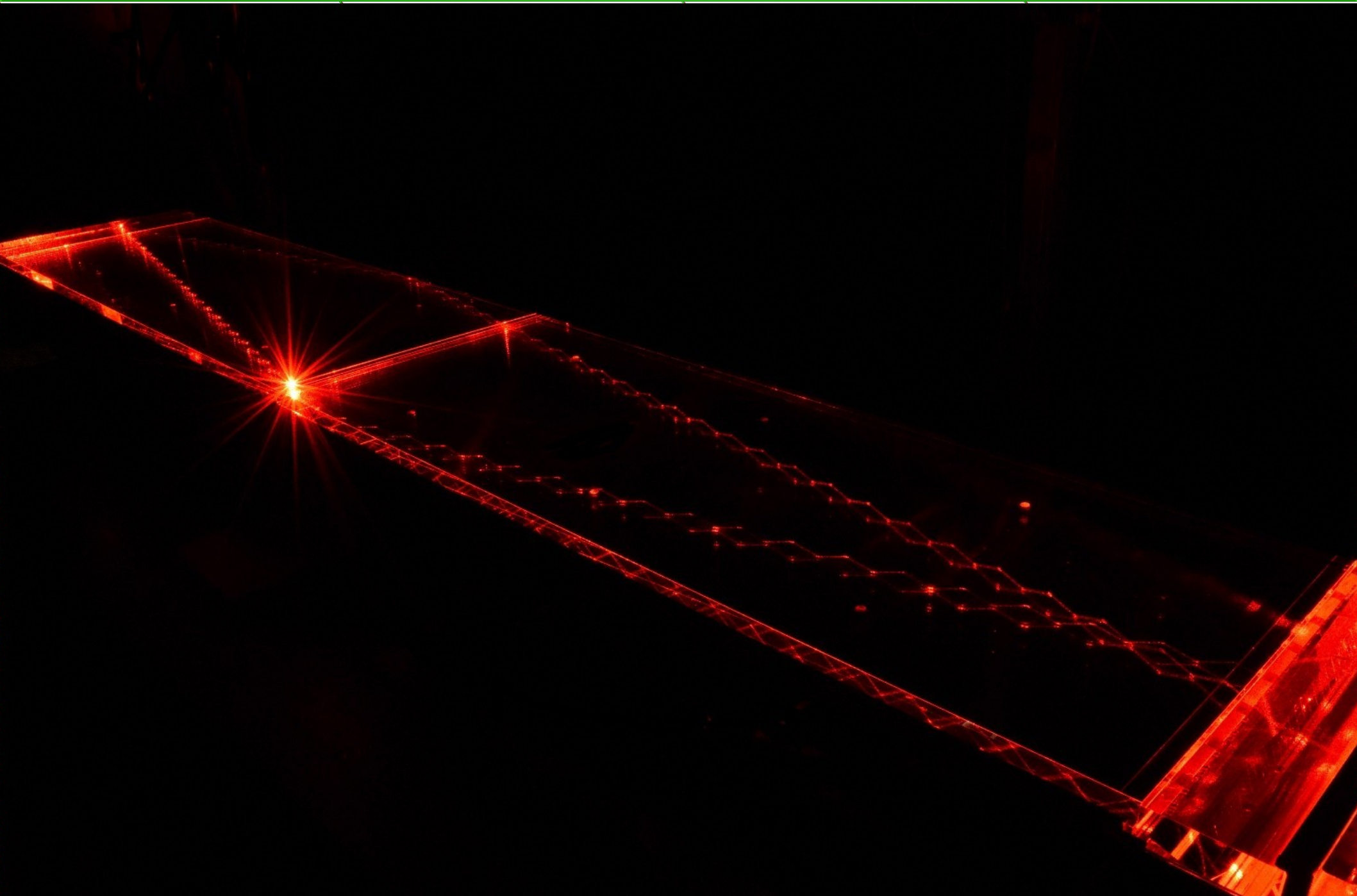
TOP

- 16 modules around interaction point
- Cherenkov angle reconstructed from position and time of arrival
- 2 cm detector in active region



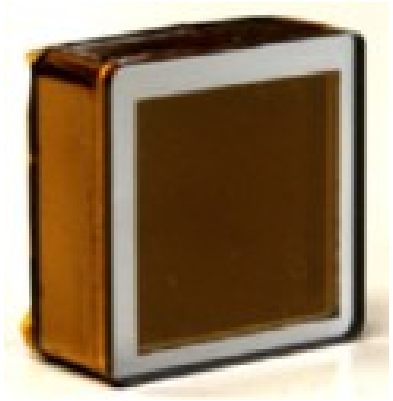


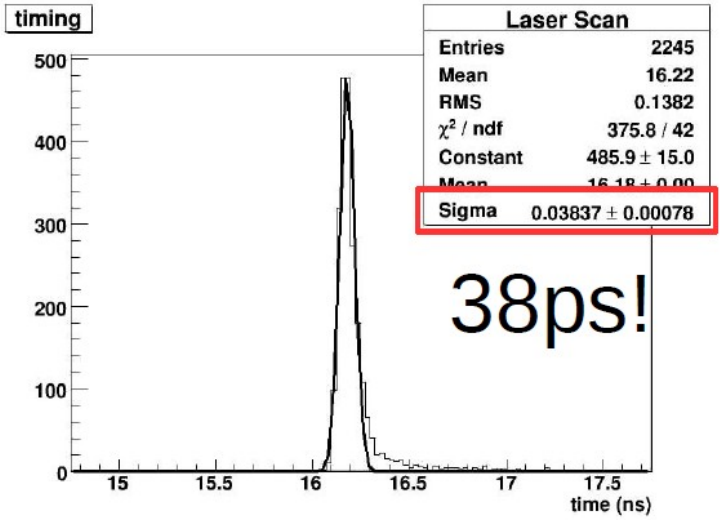
Light path

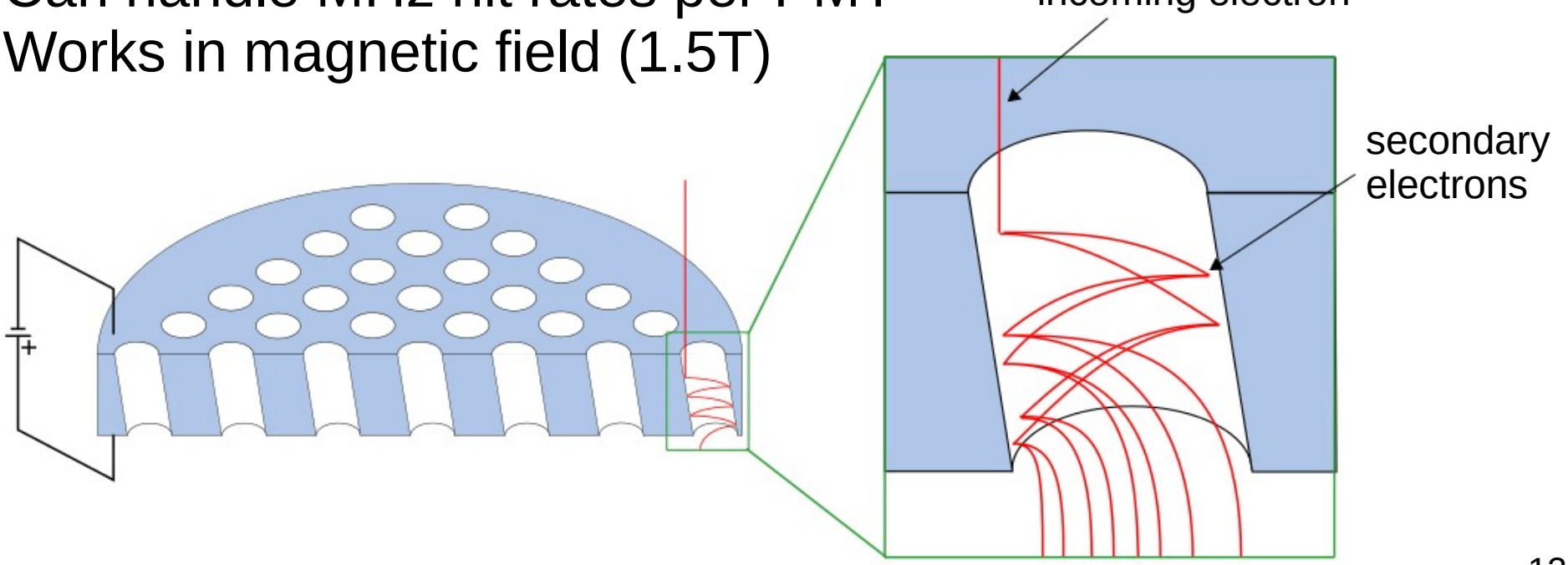


TOP MCP-PMTs

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



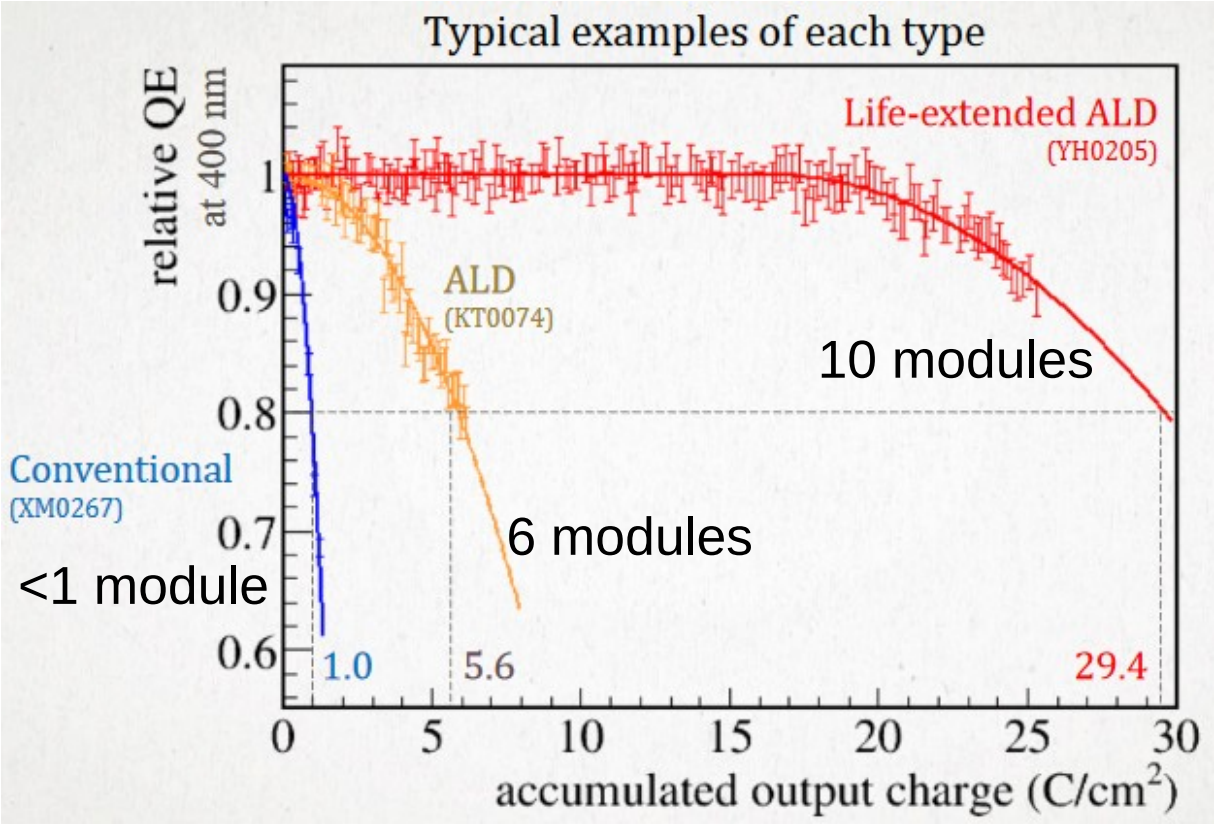




PMT lifetime

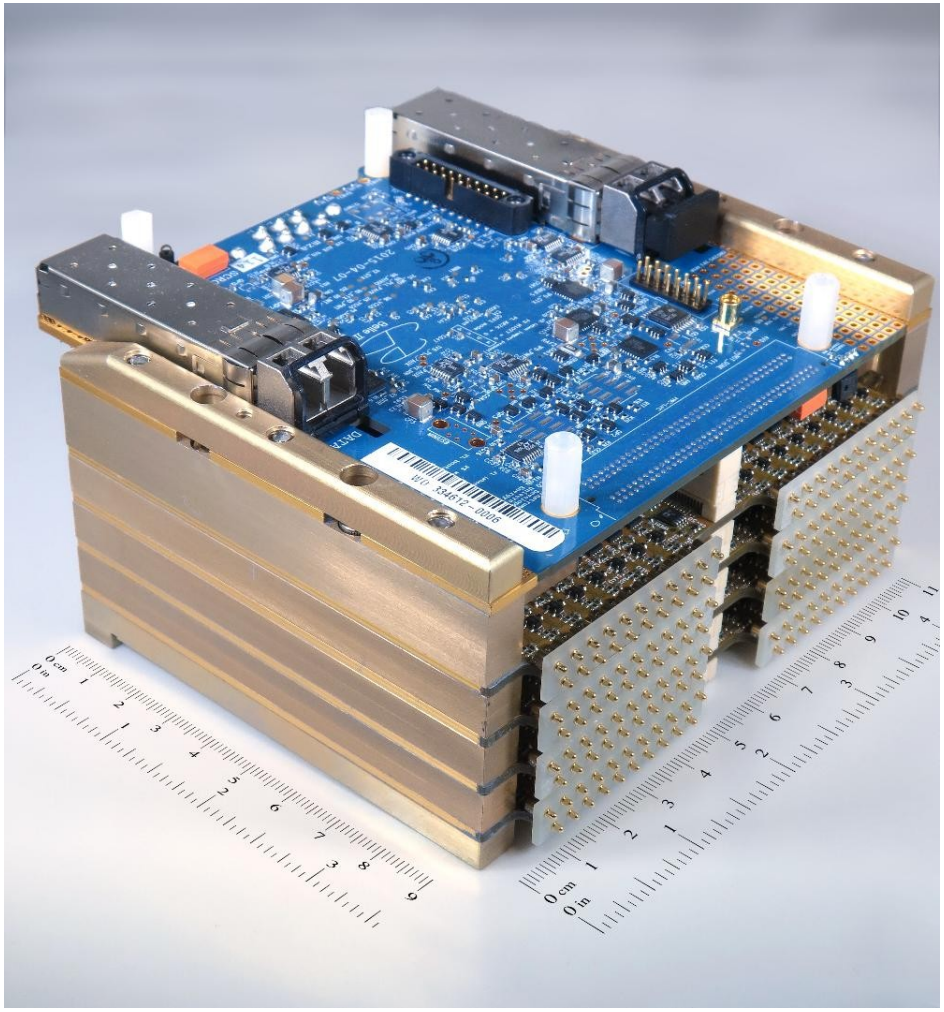
- PMTs accumulate several C/cm^2
- Major challenge for MCP-PMTs:
  Outgassing reduces efficiency
- Hamamatsu: Improvements during mass production

- Three types installed
- Seem to degrade faster than expected
- Conventional PMTs replaced in March/April
- Studying ALD PMT lifetime



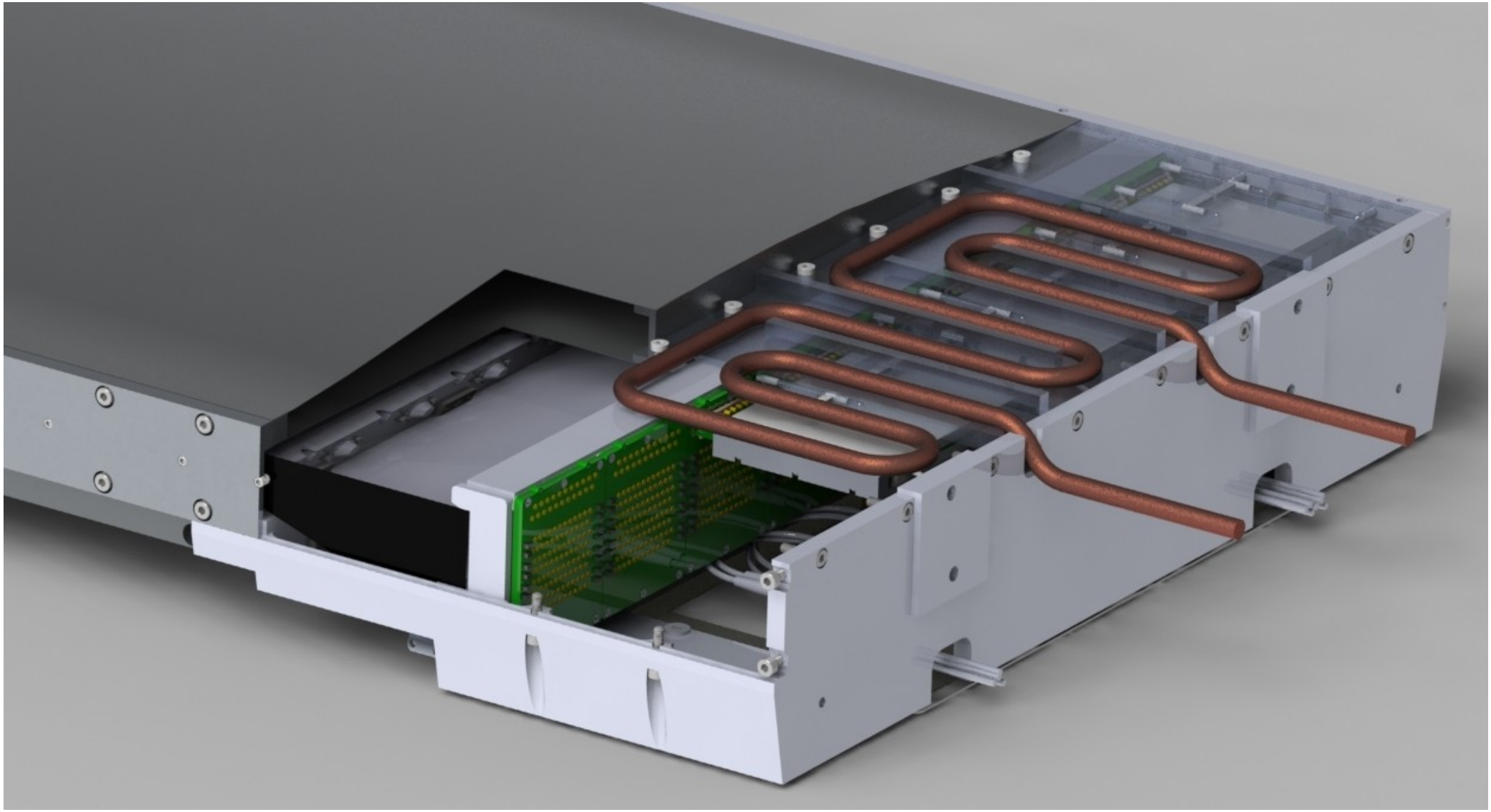
Readout electronics

- “boardstacks”
- Primary data-taking unit
- Custom development for TOP
- Digitize hits from PMTs and send event data to DAQ
- <100 ps time resolution



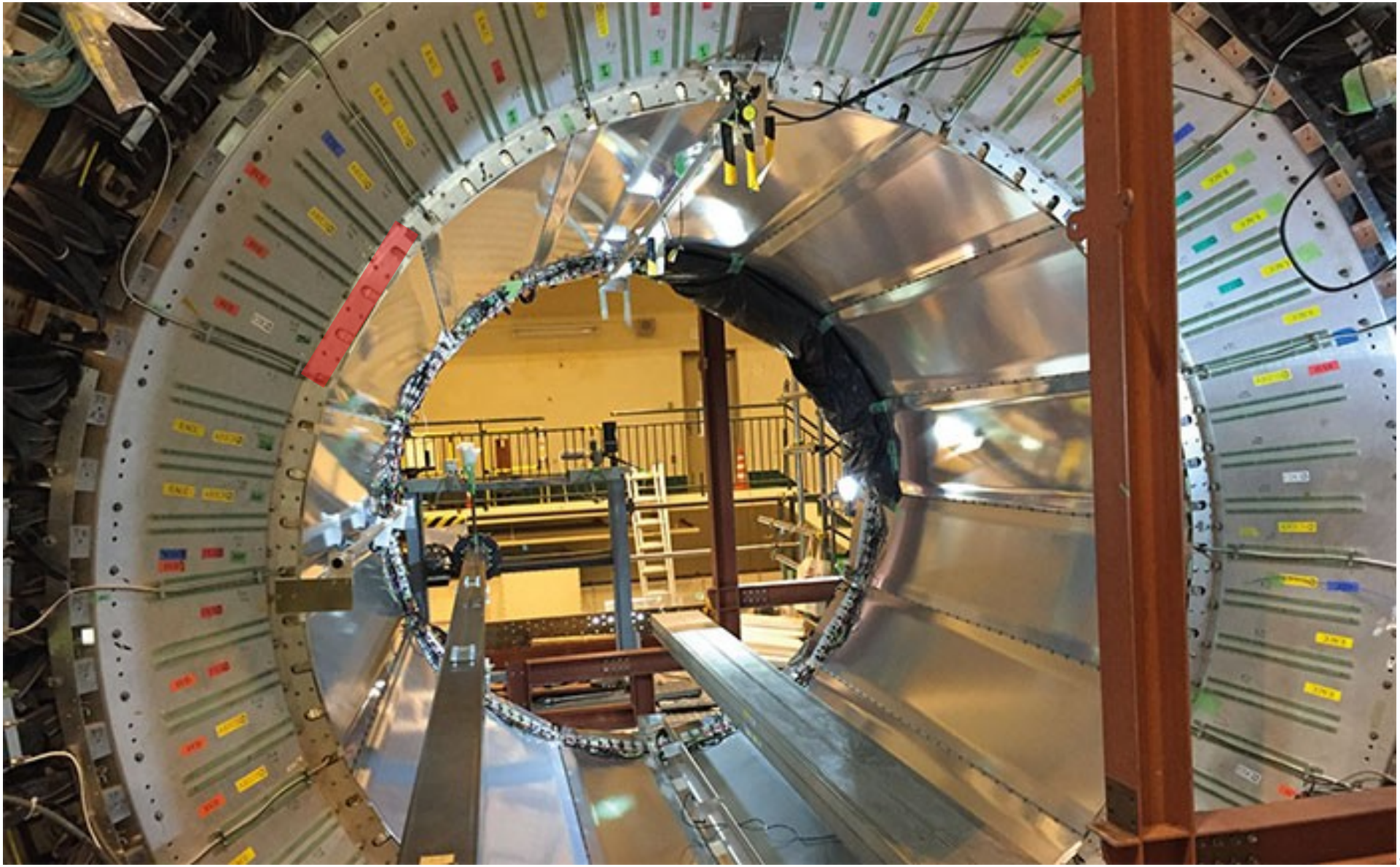
TOP module

4 boardstacks per module



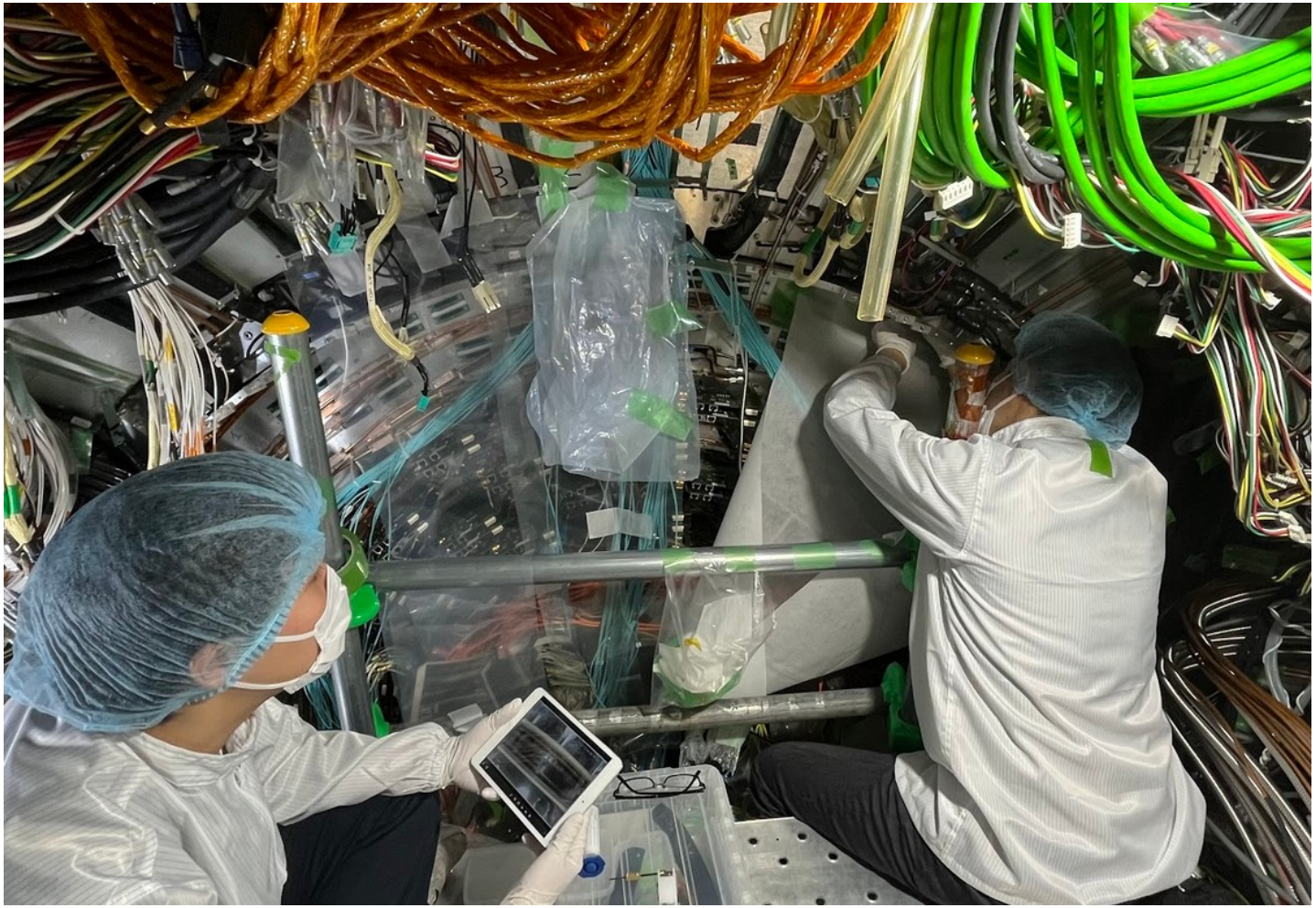
Assembled detector

16 modules



Assembled detector

After CDC + VXD installation...

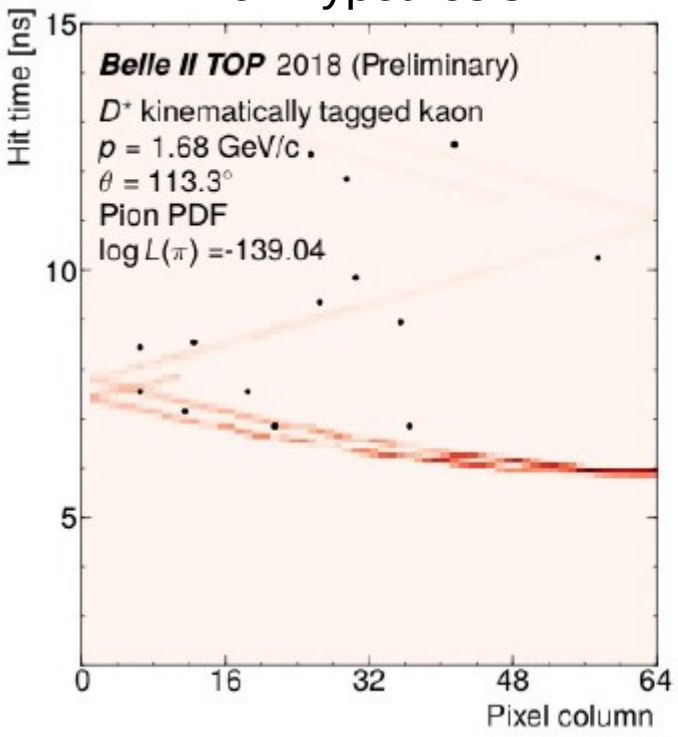


Reconstruction

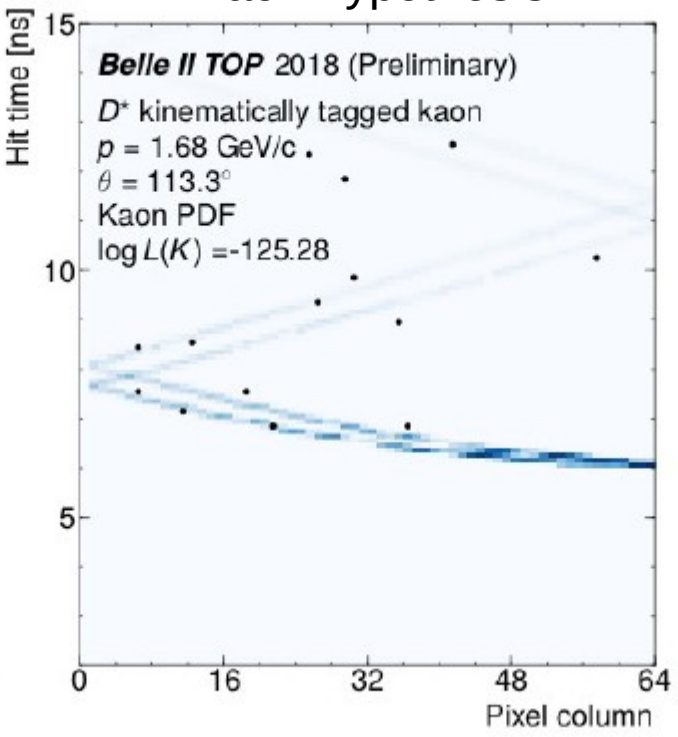
- Channel: $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$

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

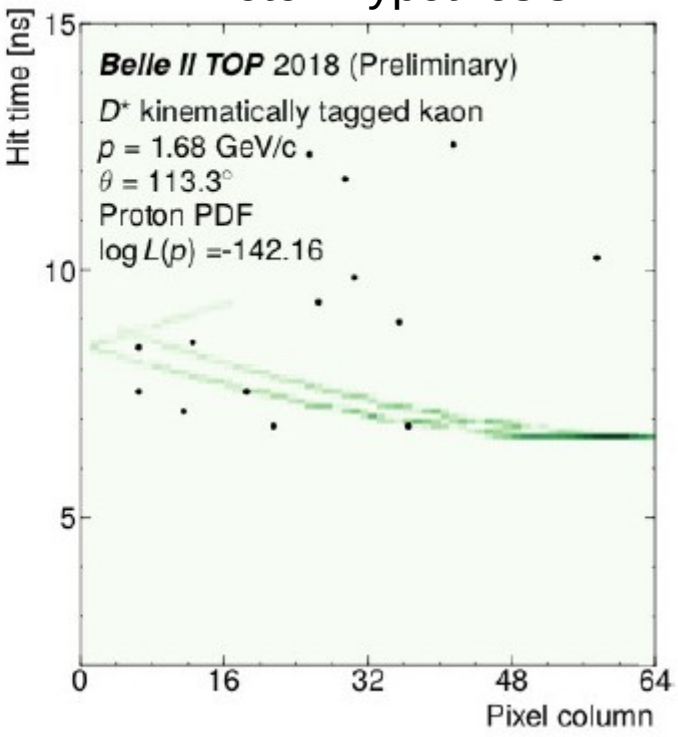
Pion hypothesis



Kaon hypothesis



Proton hypothesis

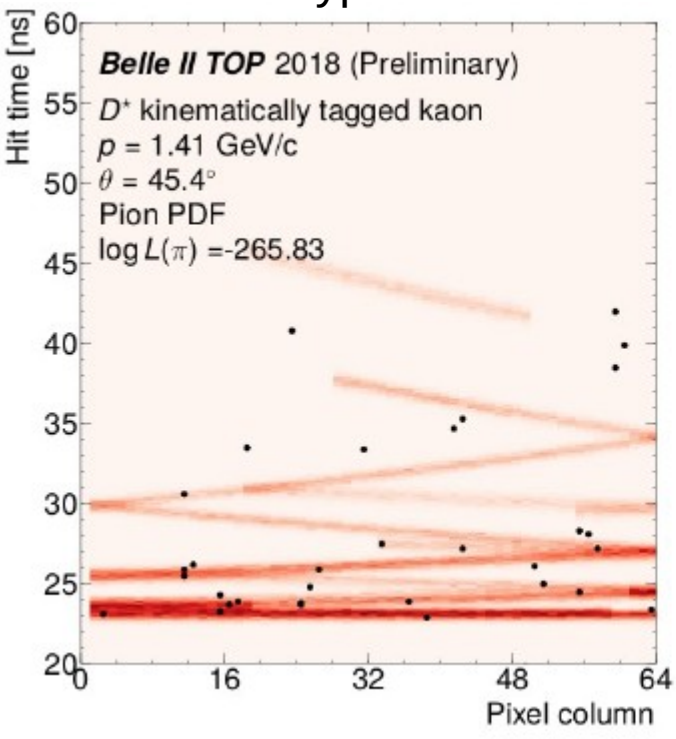


Reconstruction

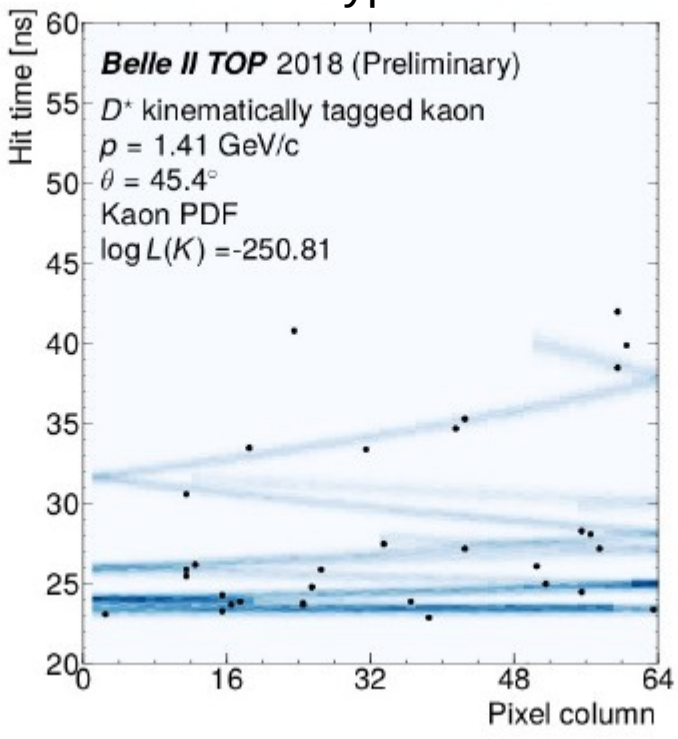
- Channel: $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$

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

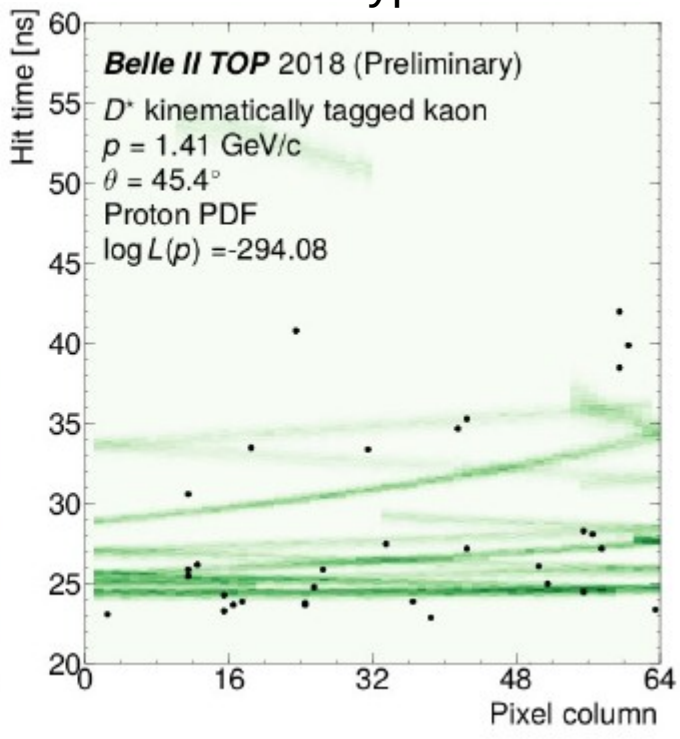
Pion hypothesis



Kaon hypothesis



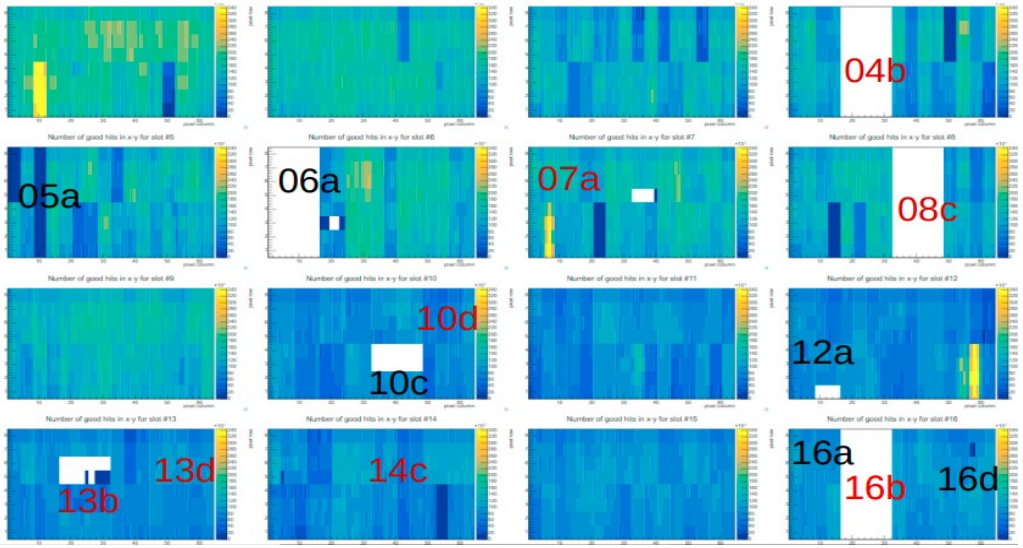
Proton hypothesis



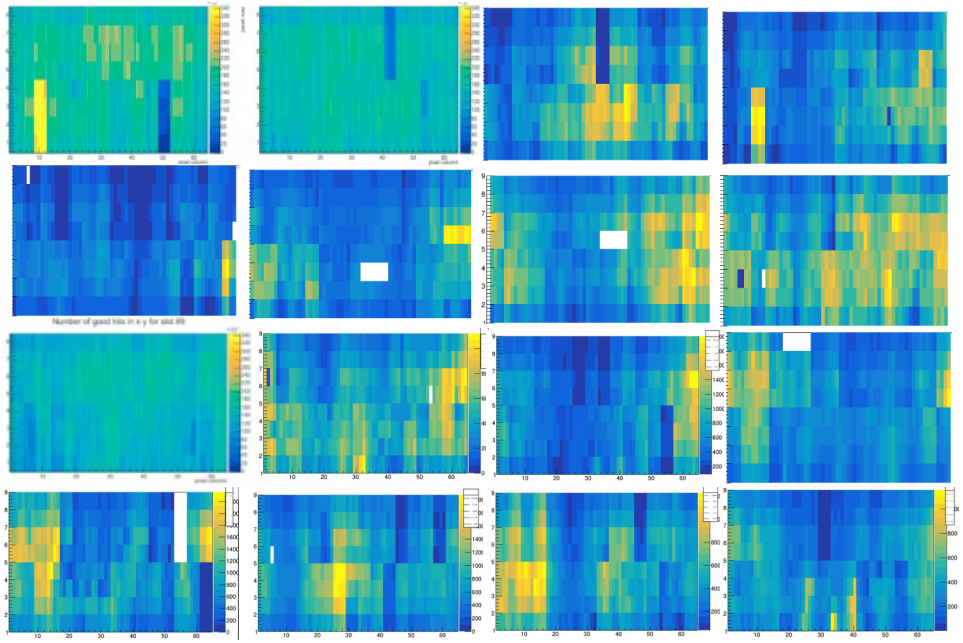
TOP in LS1

- First access since initial installation
- Replaced aging PMTs
- Exchanged/repaired bad boardstacks
- Exchanged/upgraded some cables

hit map before LS1

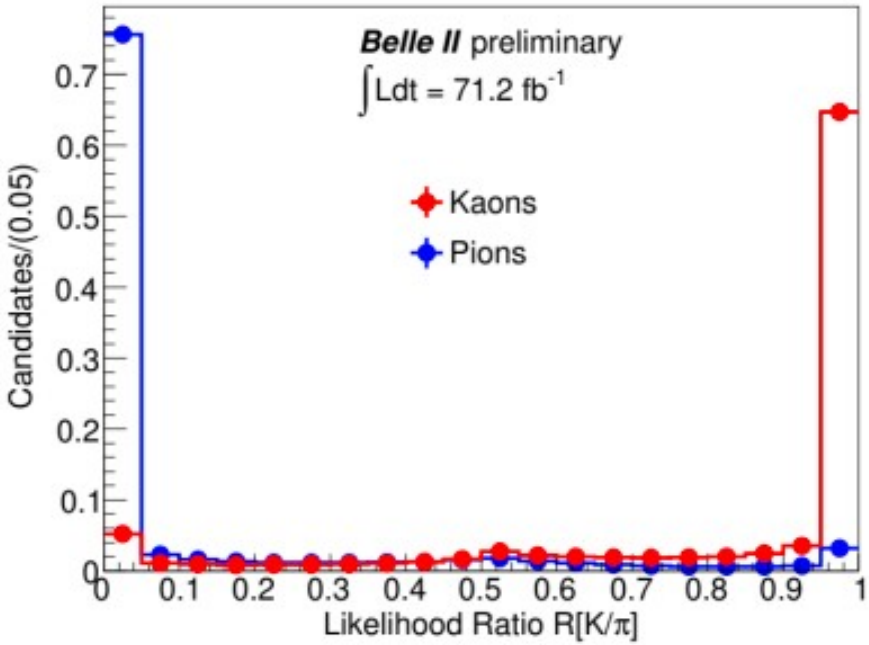


hit map now

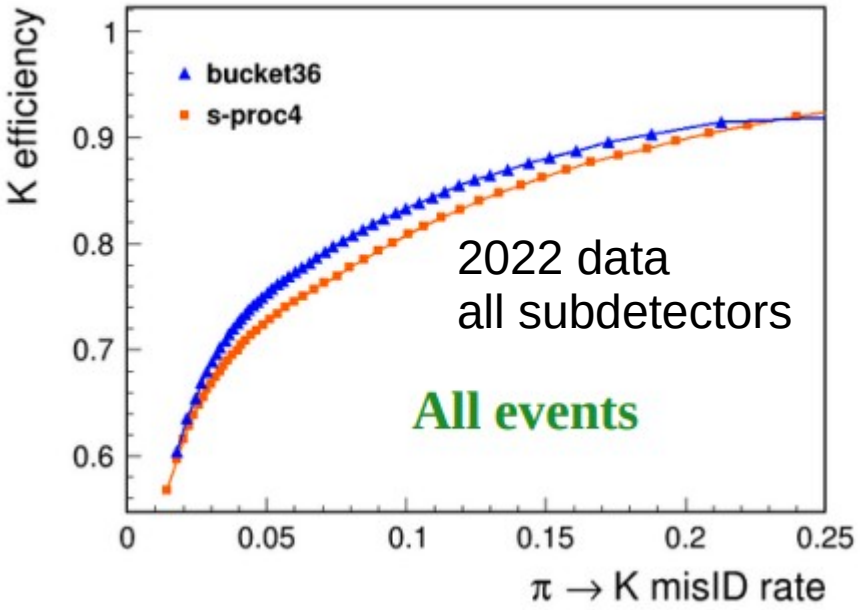


PID decision

- Calculate likelihood based on all photons
- Take ratios, e.g. L(K)/(L(π)+L(K))
- Compare to a cutoff
  doesn't have to be 0.5!
- Ideal cutoff depends on analysis



- ROC curve (receiver operating characteristic)

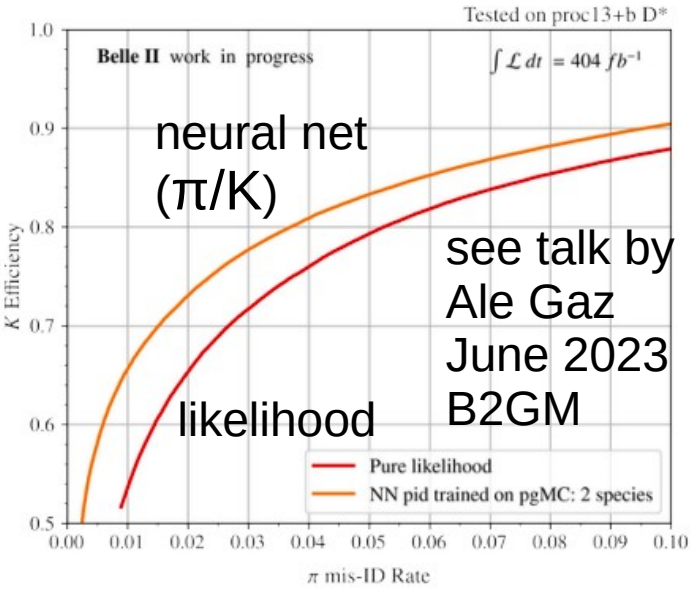


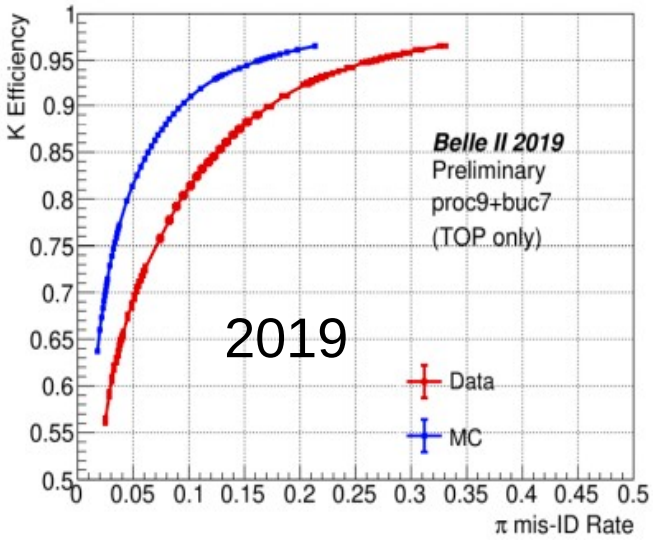
PID performance

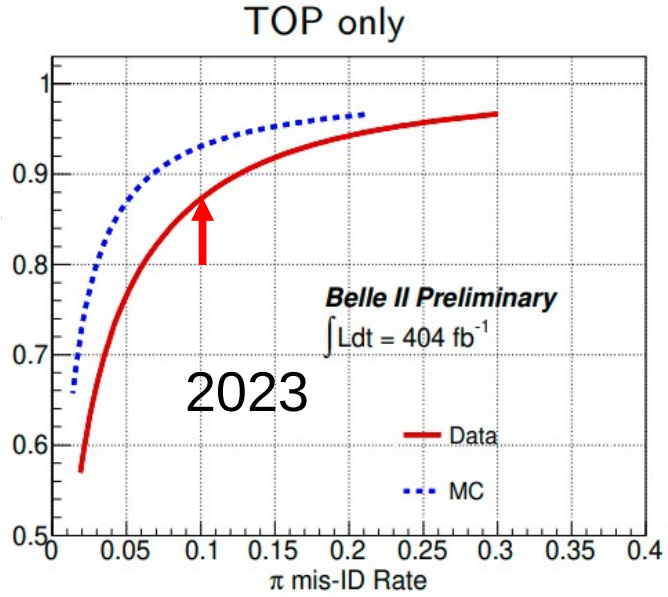
- Main metric: π->K mis-id vs. K->K efficiency
- Other separations behave the same way

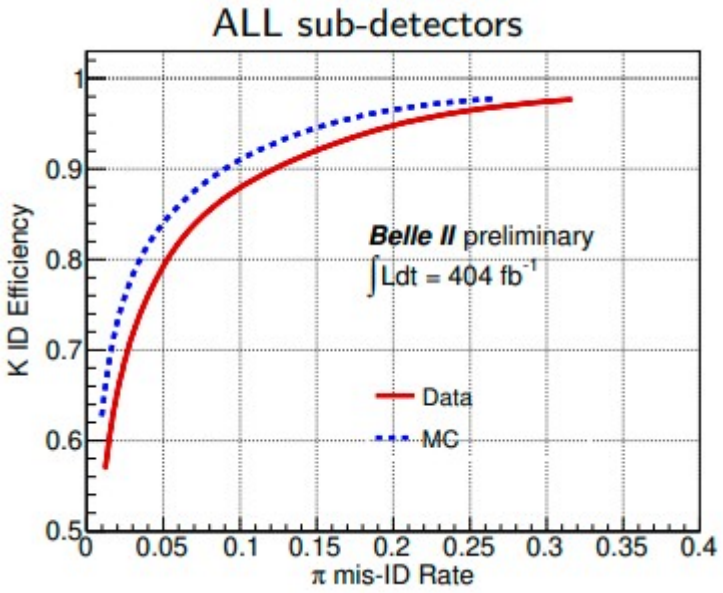
- Gradual improvement, but more work needed
- Some known issues, some unknown sources
  e.g. in TOP: bunch finder, multi-track events

- Product of likelihoods *should* be ideal...
  ... but neural nets can beat it (in development)



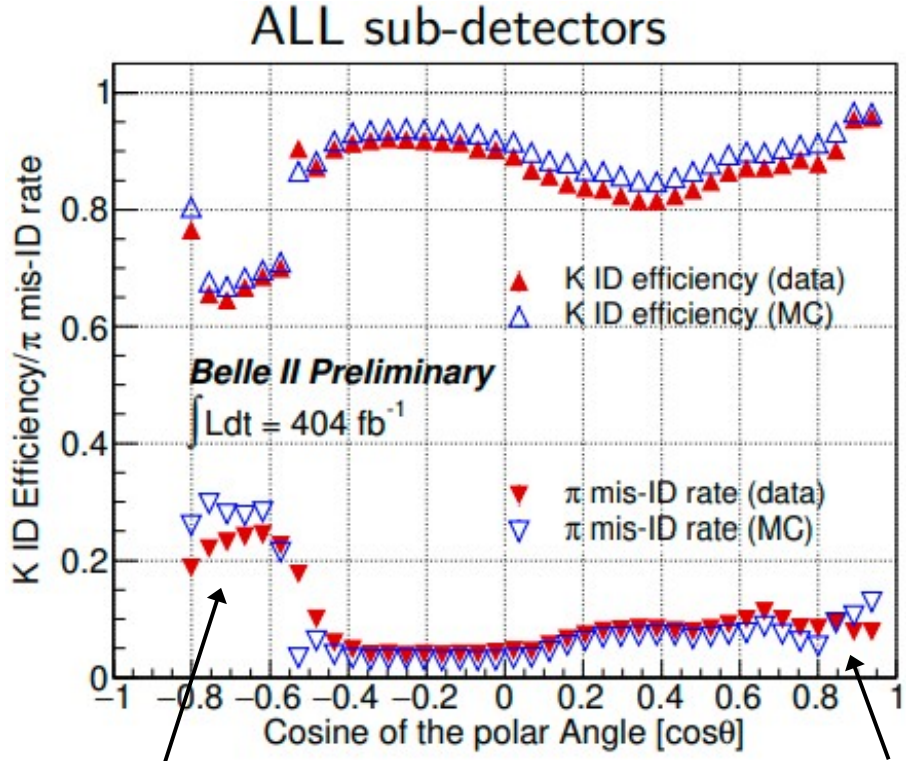


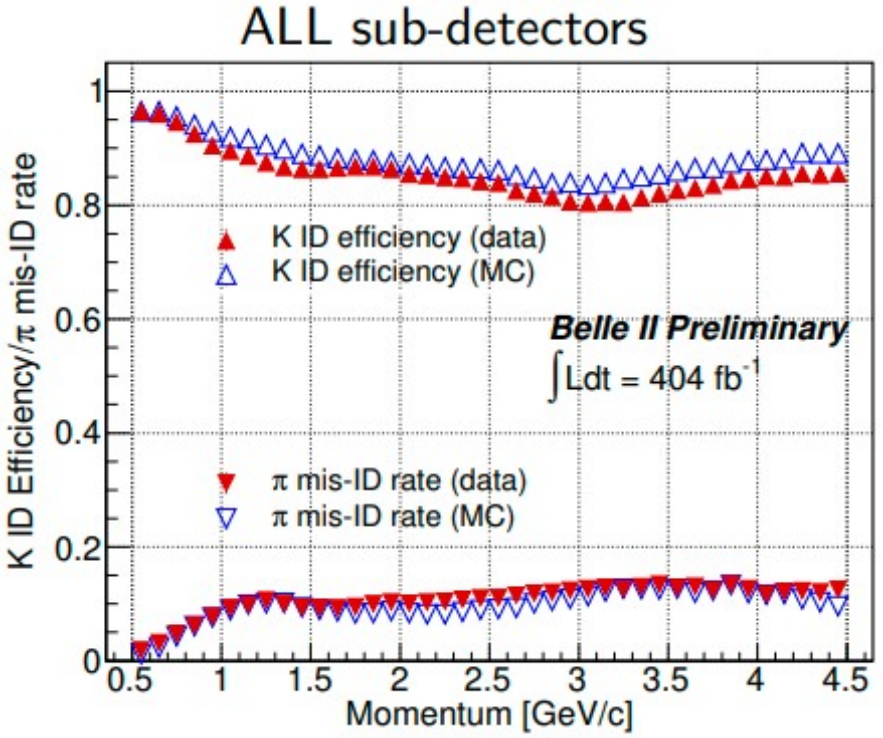


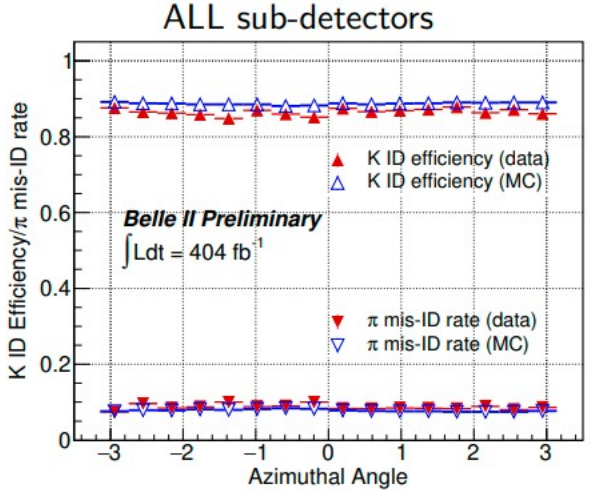


Kinematic dependence

PID quality depends on momentum and flight direction







Summary

- Particle identification critical for physics analyses
- Two dedicated PID detectors in Belle II
  - ARICH in forward endcap
  - TOP in barrel

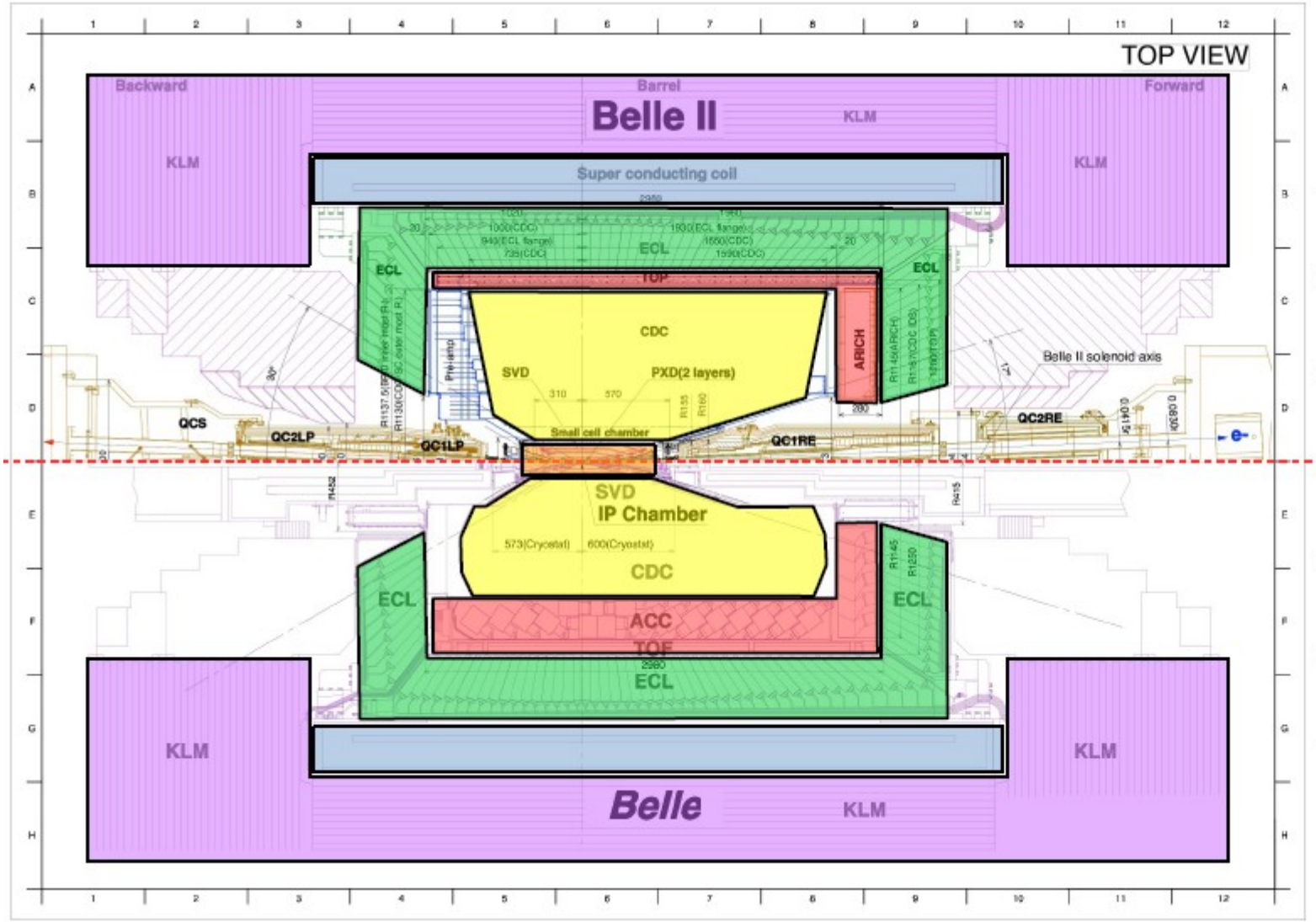
  Both use Cherenkov radiation

- Major repair/exchange campaign for TOP during LS1
- Ongoing work to improve PID algorithms

- Detectors are preparing for data-taking after LS1

Backup slides

Belle II vs. Belle



K_L/Muon System

Magnet Coil

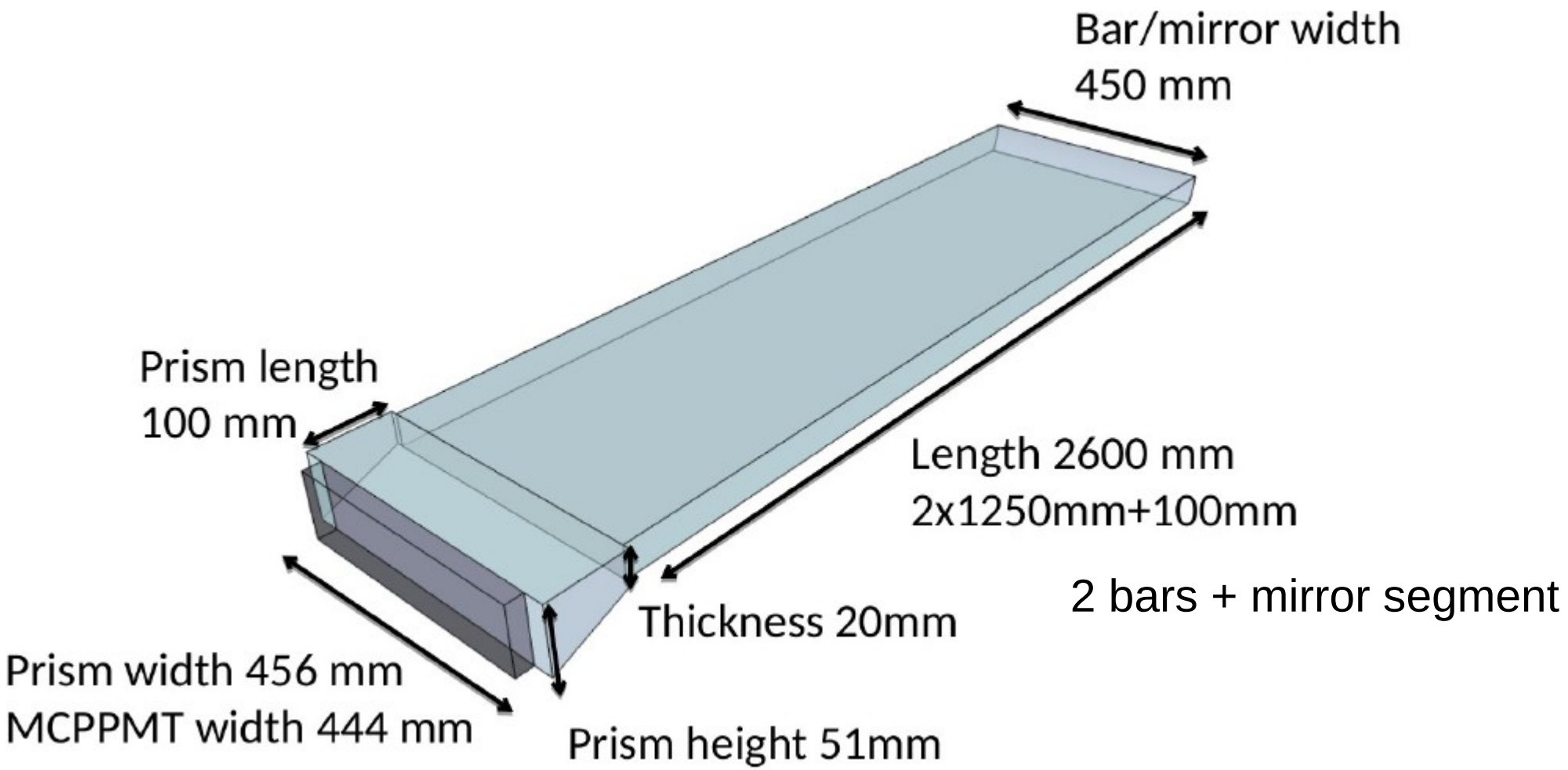
EM Calorimeter

π/K Identification

Drift Chamber

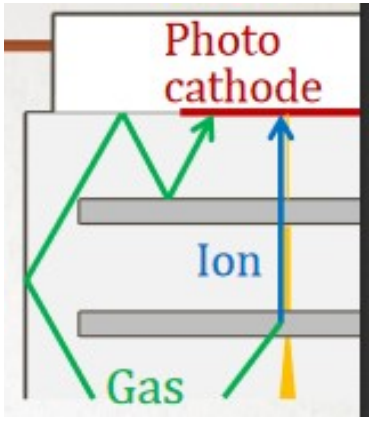
Silicon Tracking

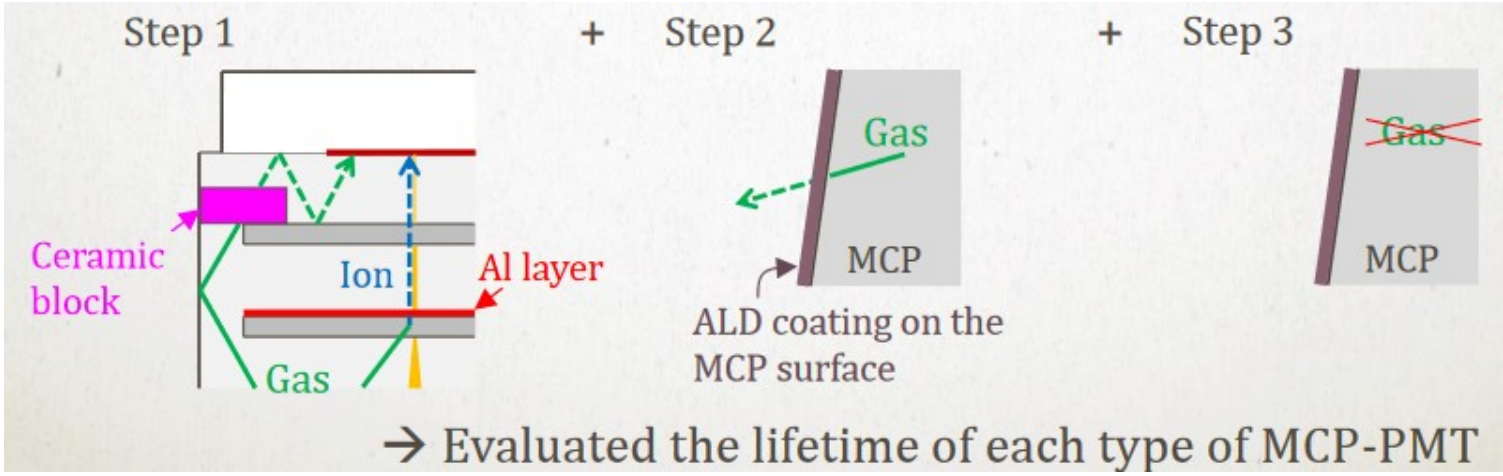
Quartz bar

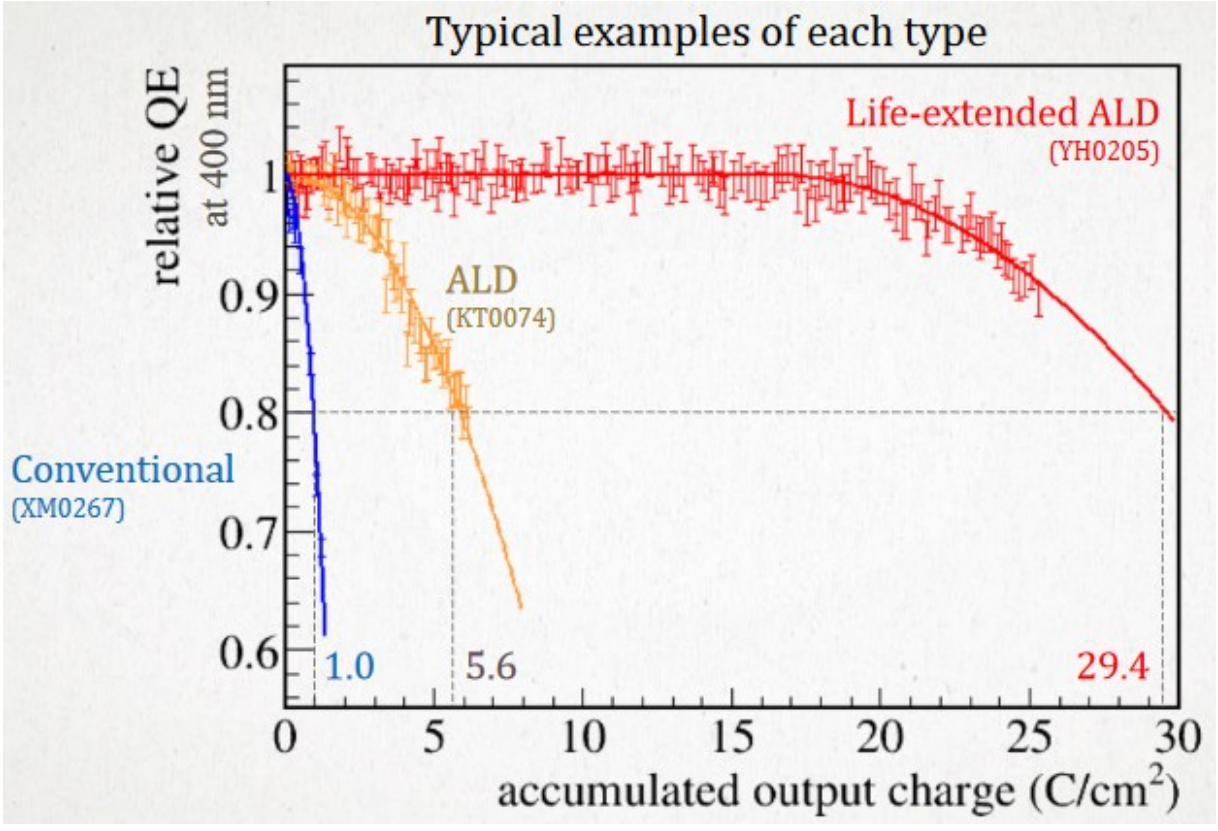


n=1.47

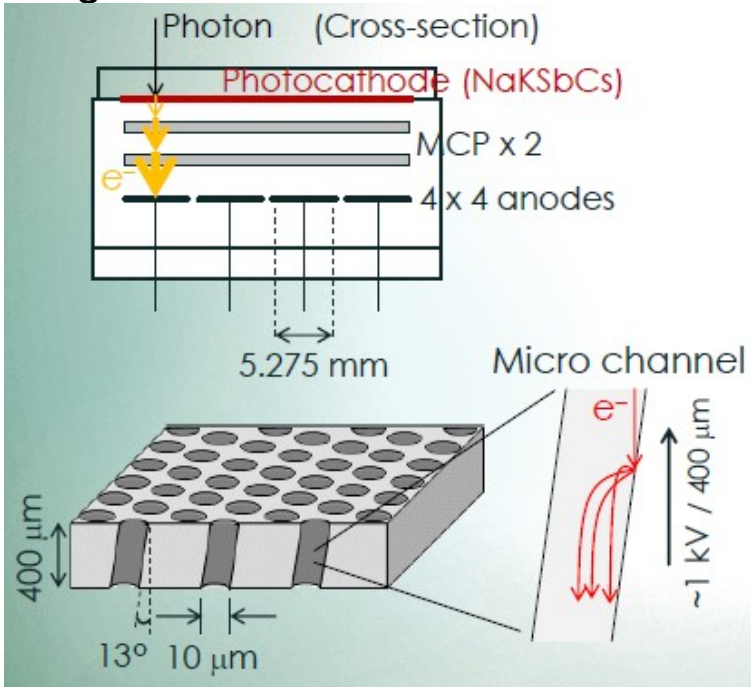
MCP PMT lifetime





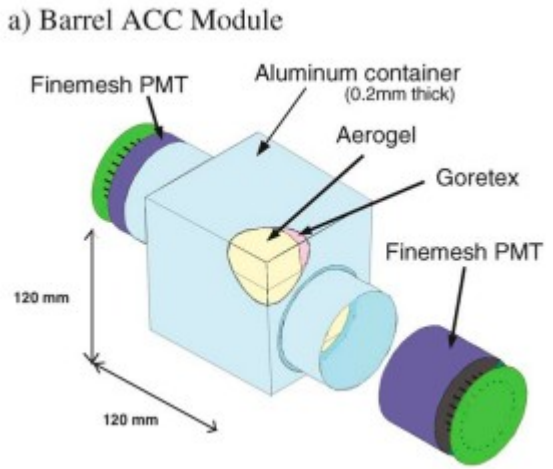


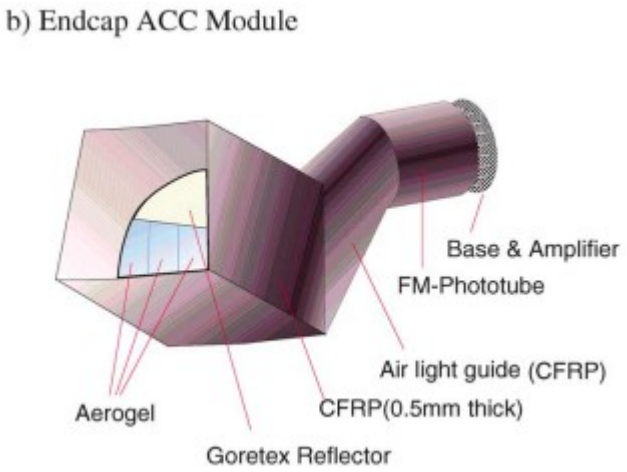
Kodai Matsuoka, “Improvement of the MCP-PMT performance under a high count rate”, TIPP 2017

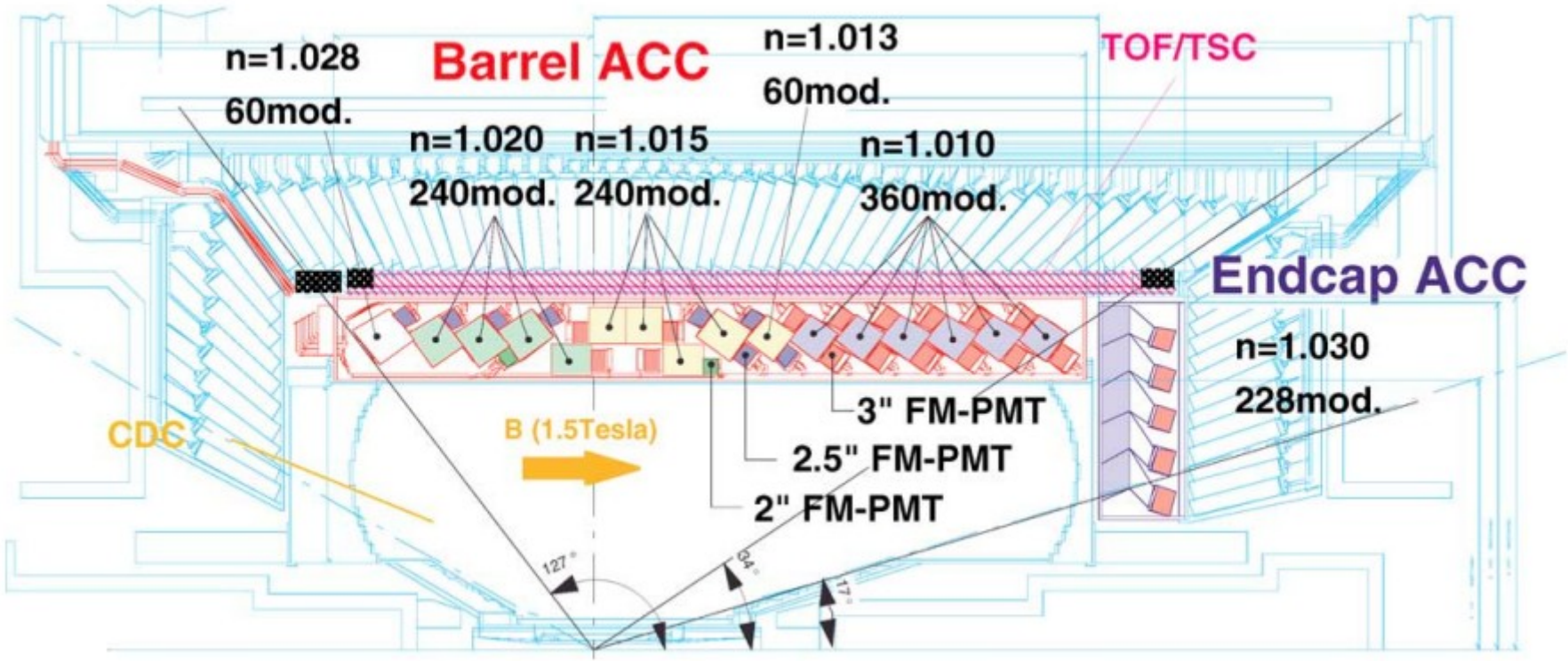


Belle's ACC

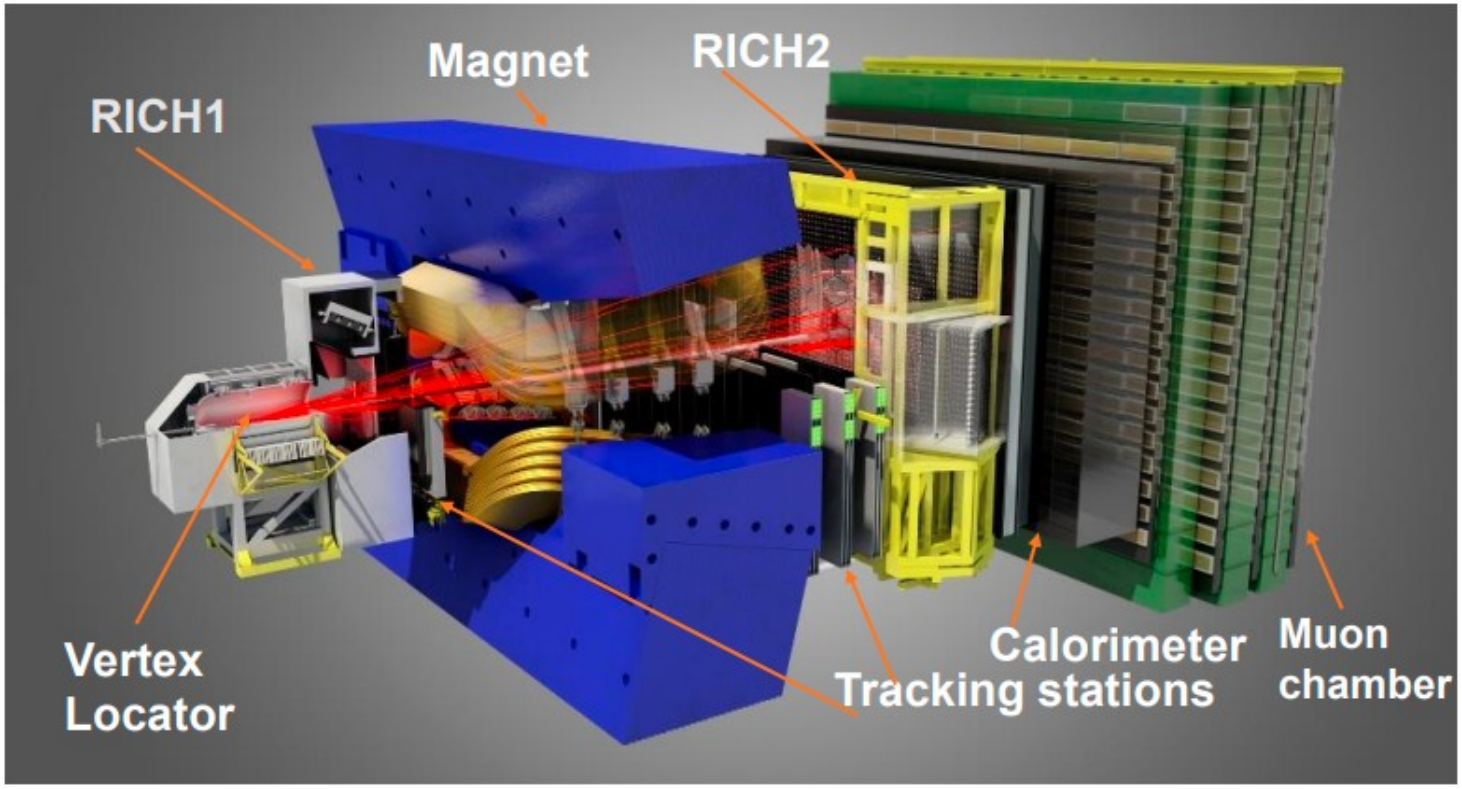
Aerogel Cherenkov Counter

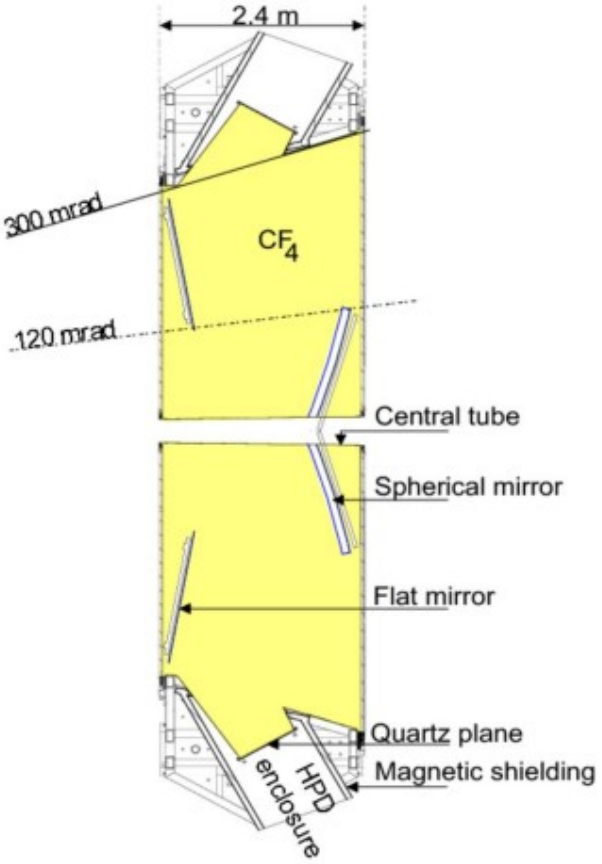






LHCb's RICH



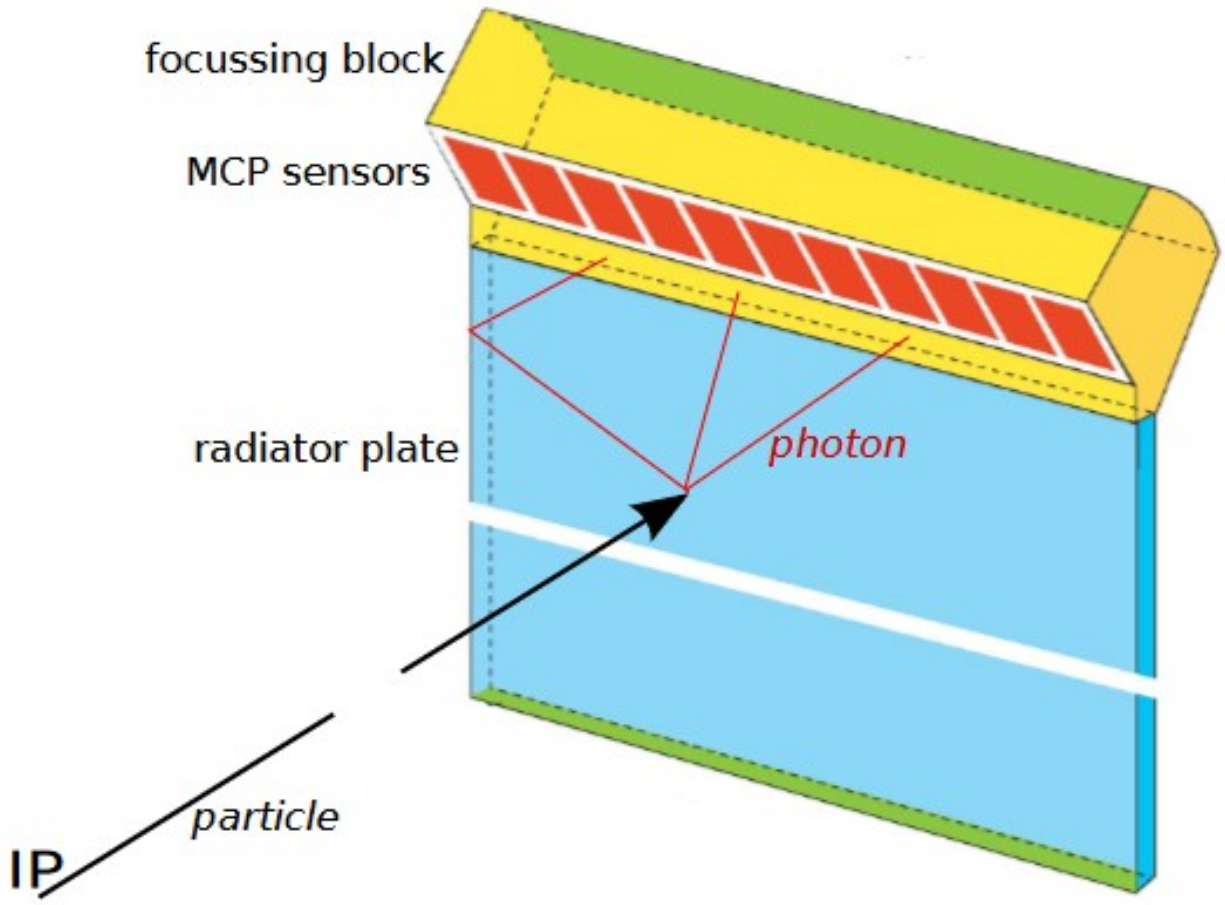


C_4F_{10}
n = 1.0014

CF_4
n = 1.0005

Sajan Easo
https://indico.cern.ch/event/1022051/contributions/4333562/

LHCb's TORCH (planned)



https://cds.cern.ch/record/1981563