MCP-PMT's and HAPD's for Belle-II PID detectors

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on behalf of the Belle-II TOP and ARICH groups

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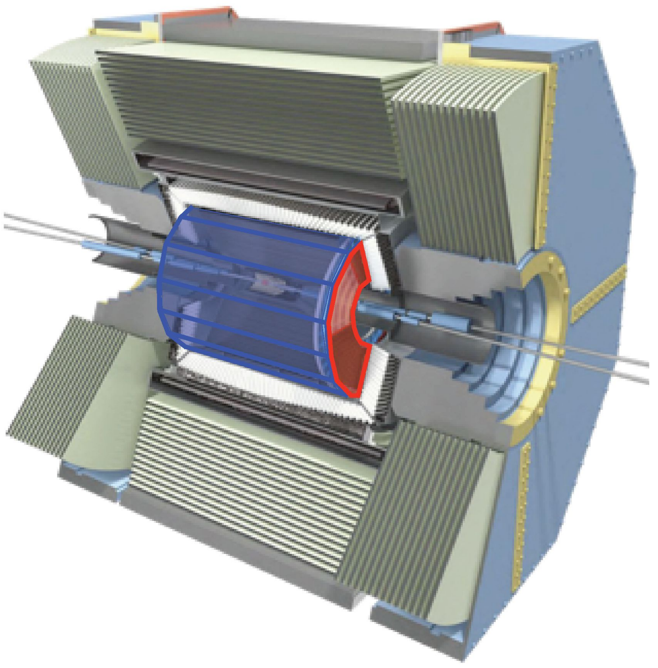
TOP and ARICH

- The TOP and ARICH are (mostly) devoted to the separation of charged π and K;
- Common concept: measure the angle of the Cherenkov light emitted when the particles traverse a medium and derive the particle velocity:

$$\cos\theta_C = \frac{1}{n\beta}$$

- Combine this with the momentum measured by the tracking system, and discriminate between π and K.



Barrel PID: TOP
Endcap PID: ARICH

Performance:	Belle-II	Belle
π/K selection eff.	≥ 95%	~90%
with π/K mis-ID prob.	≤ 5%	10-15%
(using also dE/dx from trackers)		

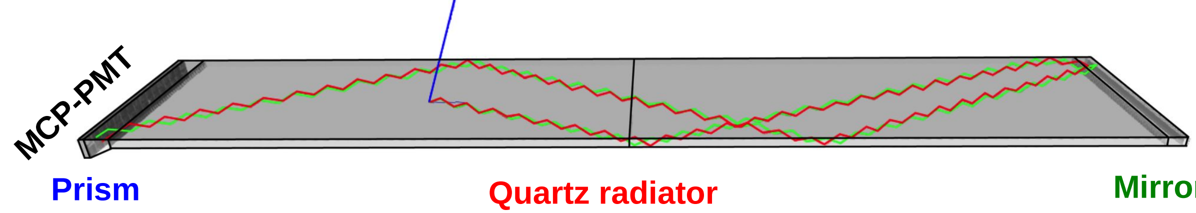
TOP: overview

The TOP detector is constituted by 3 key elements:

1) Quartz radiators:

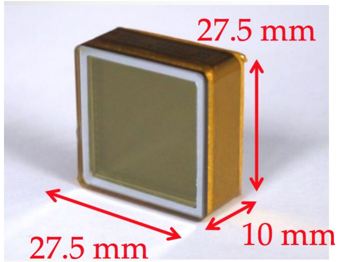
16 TOP modules

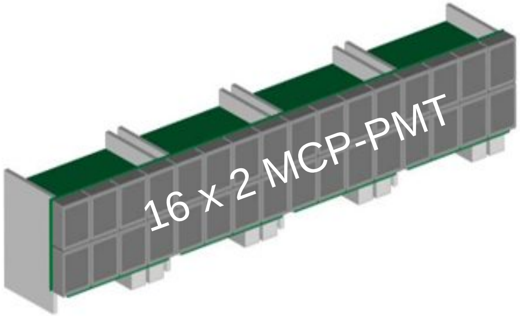
L = 100+2500+100 mm W = 450 mm H = 20 – 50 mm



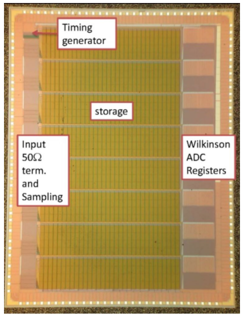
2) Photo-detectors:

(I will concentrate mostly on these, in the rest of my talk)

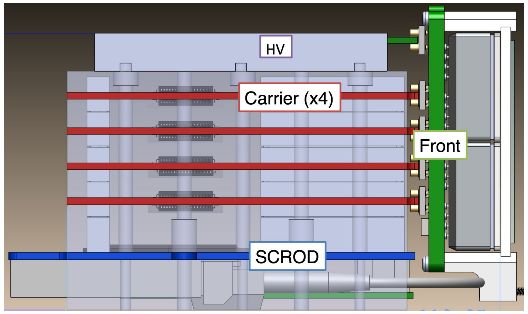




3) Front-end electronics:



ASIC



4 carrier boards x 4 ASICs

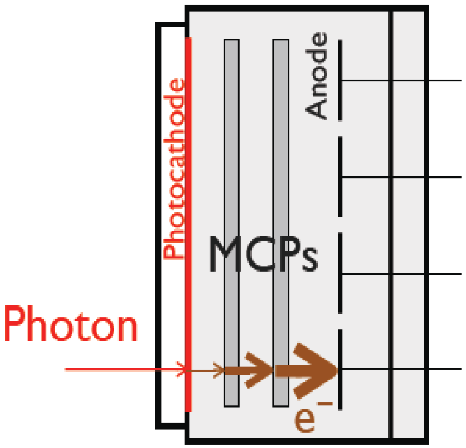
Photo-sensors

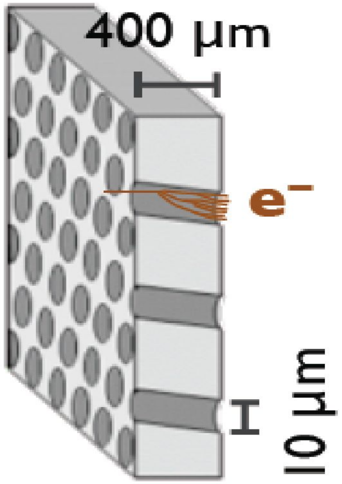
Strict requirements are set for the photo-detectors:

- Fast time response and small Transit Time Spread (TTS);
  - ➔ TTS < 50 ps;
- High gain for single photon detection;
- High quantum efficiency;
  - ➔ The typical track produces O(100) Cherenkov photons;
- Has to operate within a 1.5T magnetic field;
- Has to be "square" in order to minimize dead space.

The Hamamatsu MCP-PMT's

- The chosen photo-detectors are Micro Channel Plate Photo Multiplier Tubes, developed by Hamamatsu Photonics K.K. and the Nagoya University;
- Size: 23 x 23 mm^2 sensitive area, 4 x 4 channels;
- NaKSbCs photocathode;
- Two Micro Channel Plates (MCP), 400 μm thick, with 10 μm diameter holes perform the electron multiplication;



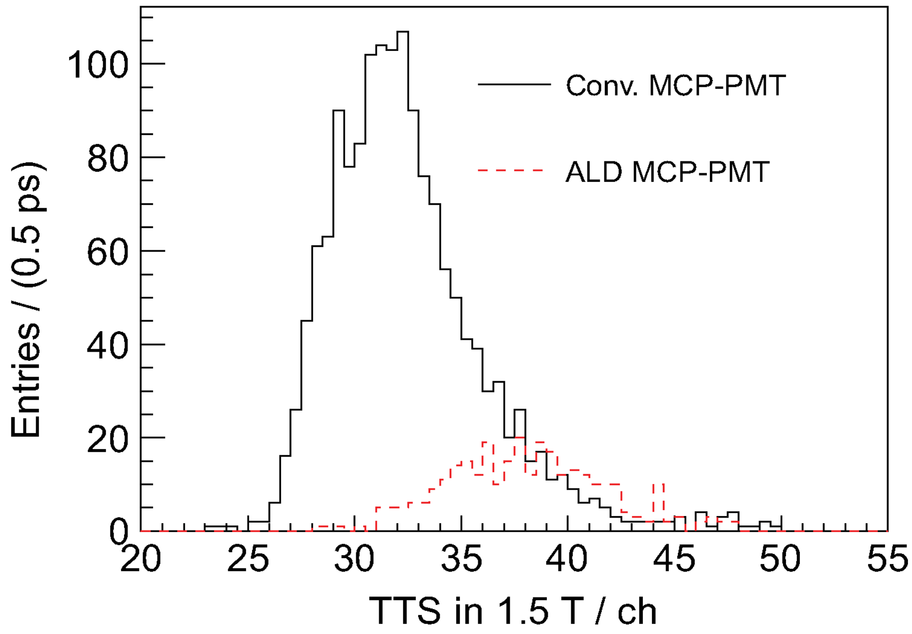


- Nominal voltage: ~3 kV.

MCP-PMT's: performance

- Gain: 2 x 10^6 at ~3 kV;

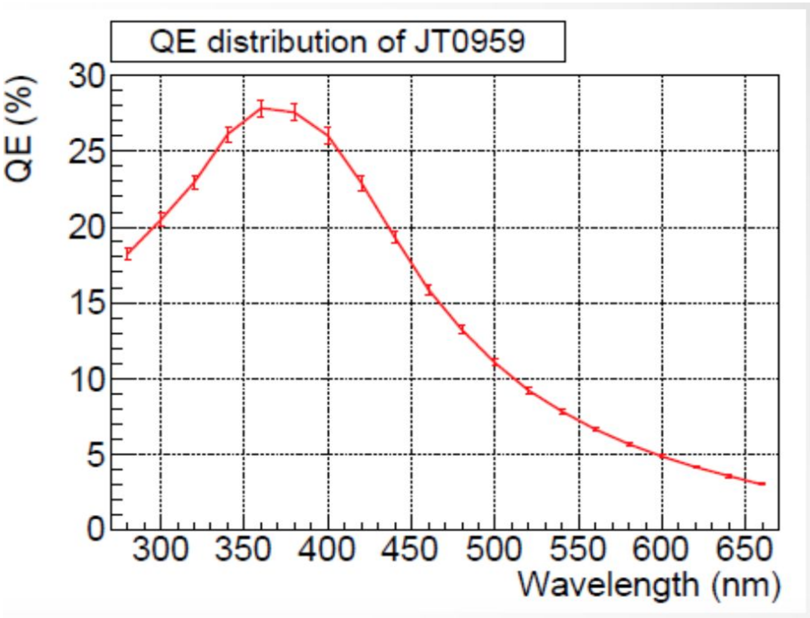
  (but we plan to operate them at 5 x 10^5, to extend their lifetime)
- Collection Efficiency (MCP aperture ratio): 50-55%;
- Quantum Efficiency: minimum 24% (average 28%) at λ = 380 nm;
- Transient Time Spread: 30-40 ps;

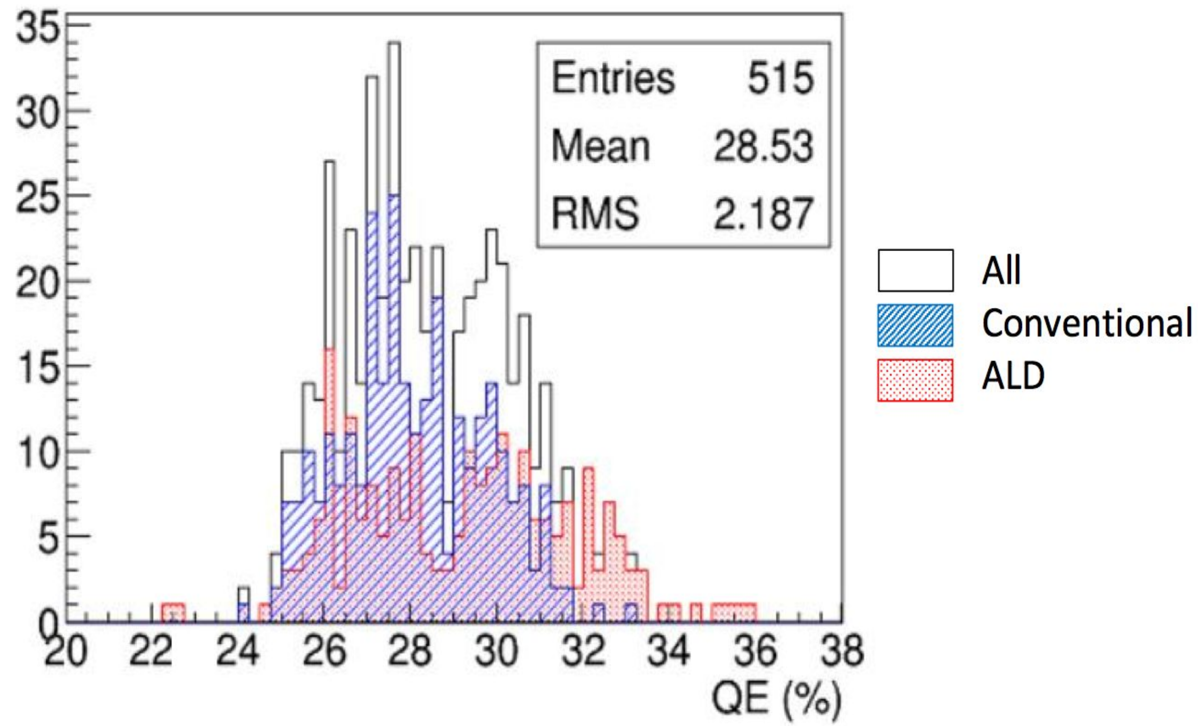


- MCP-PMT's have demonstrated to operate in 1.5T magnetic field without significant loss of performance.

MCP-PMT's: Quantum Efficiency

- Example and average of Quantum Efficiency for the PMT's tested so far:

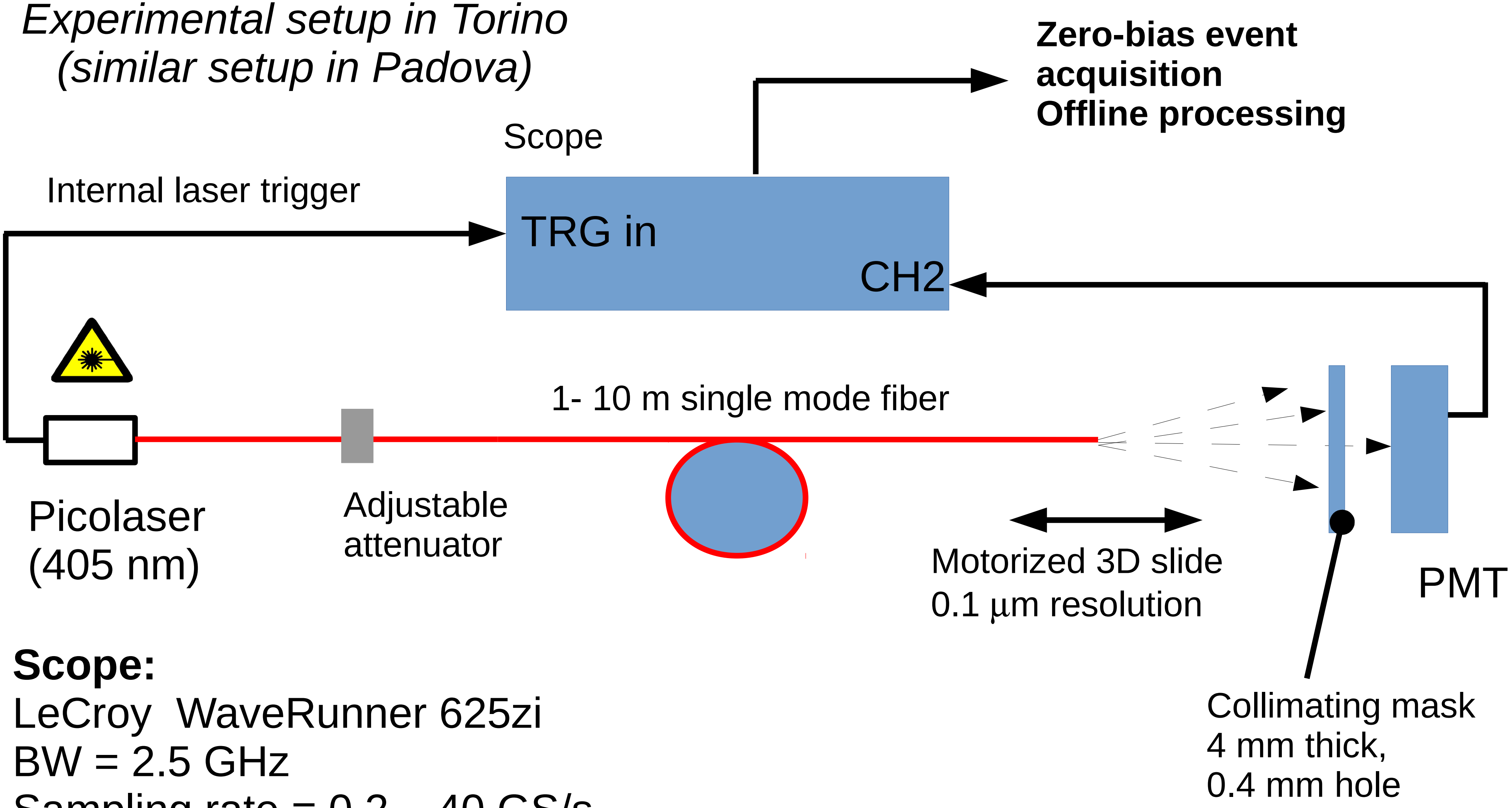




- Monitoring the stability of the QE over time and across the channels is an important step of the quality control process;
- Some PMT's have shown a degradation of QE: most likely due to a slow vacuum leak.

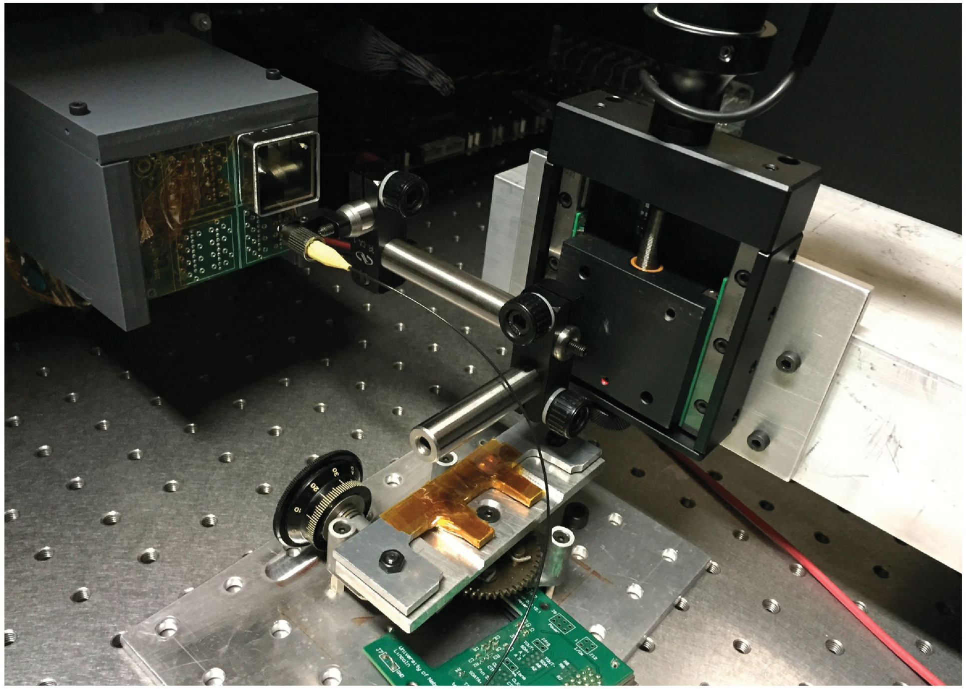
MCP-PMT's: characterization

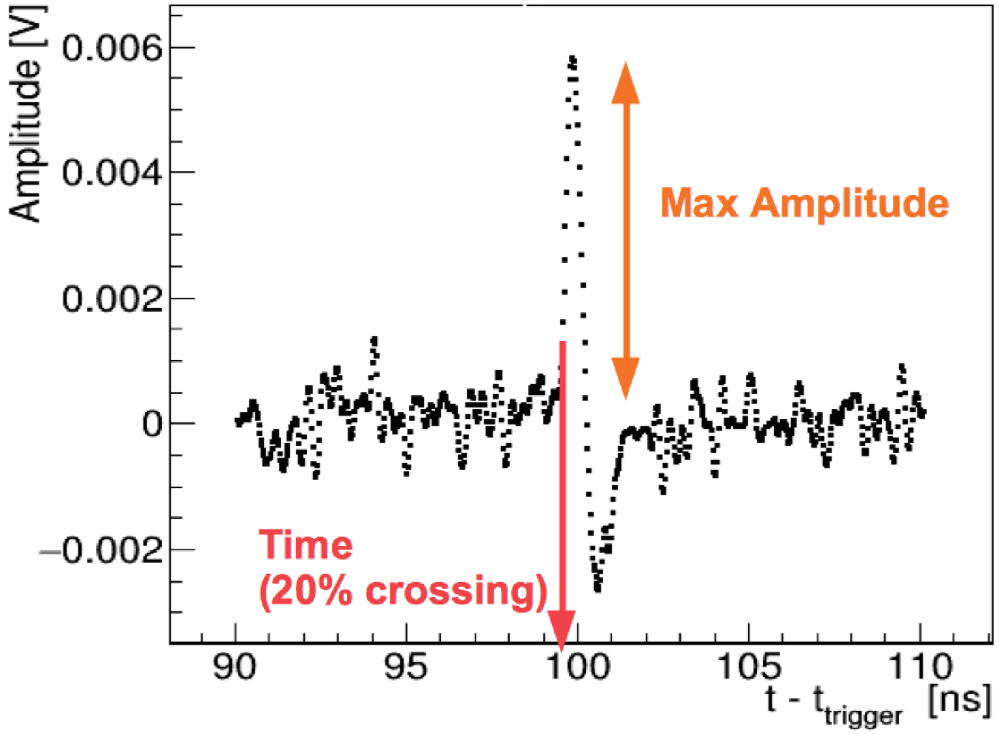
Experimental setup in Torino
(similar setup in Padova)



Scope:
LeCroy WaveRunner 625zi
BW = 2.5 GHz
Sampling rate = 0.2 – 40 GS/s

MCP-PMT's: characterization



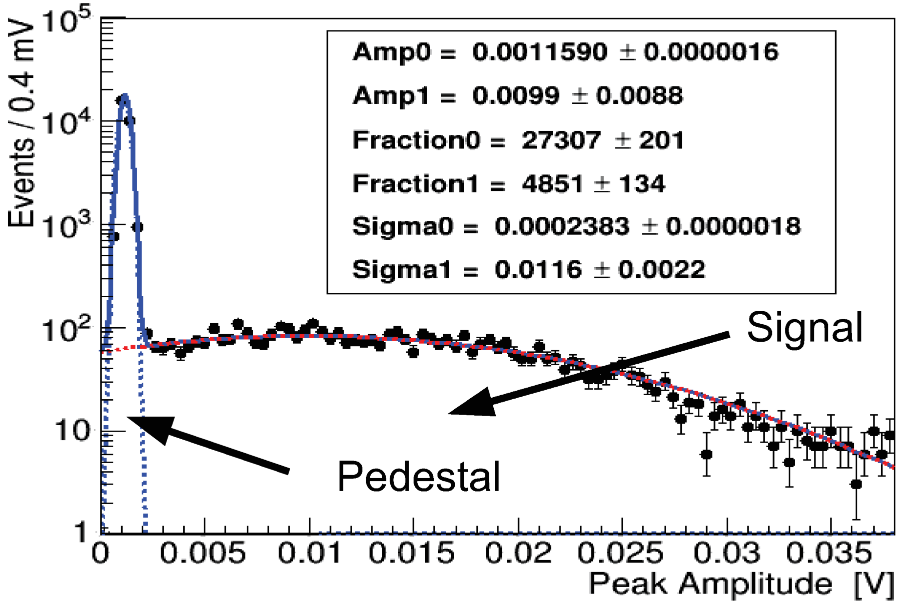


Typical signal pulse (inverted)

Similar experimental setup in Padova is going to be used to measure the timing resolution of the calibration system built by the Italian groups

After baseline subtraction, the maximum amplitude of the signal is determined from a quadratic fit.
The response time is determined from a linear fit (±3 points around chosen threshold).
The results are stable against the choice of the threshold (20-80%).

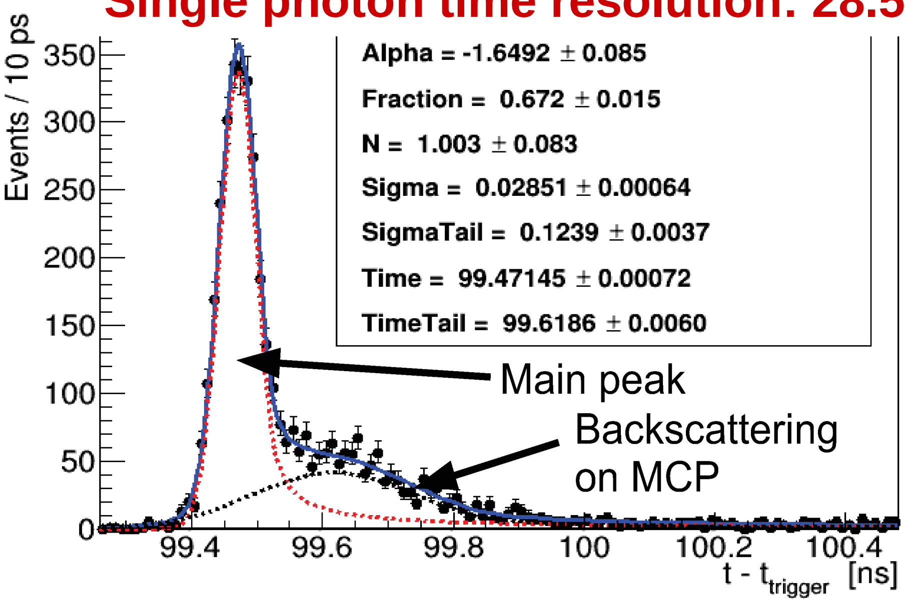
MCP-PMT's: amplitude and timing



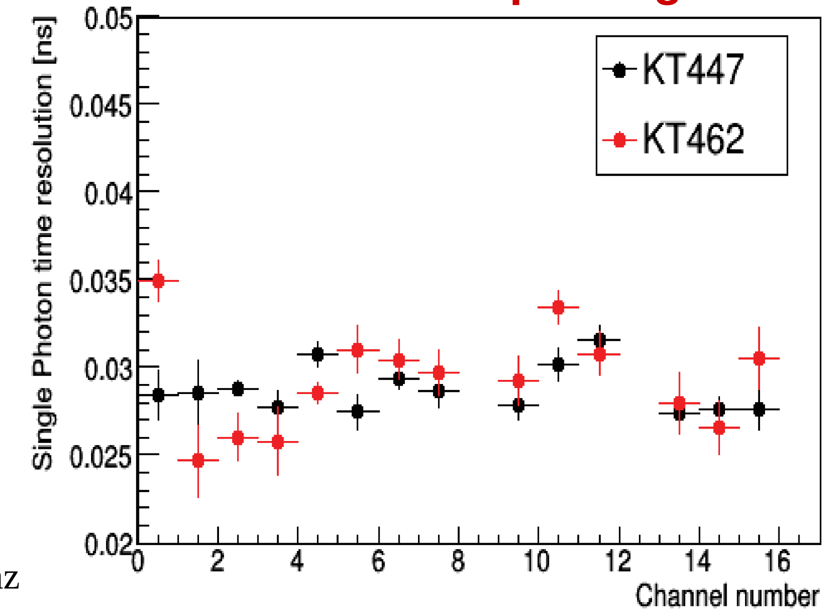
Single photon regime
KT447, Channel 3

Avg. pedestal amplitude:	1.1 mV
Pedestal gaussian fluctuation:	0.2 mV
Signal events:	4851 ± 134
Pedestal events:	27307 ± 201
Avg. signal amplitude:	(10 ± 9) mV

Single photon time resolution: 28.5 ps

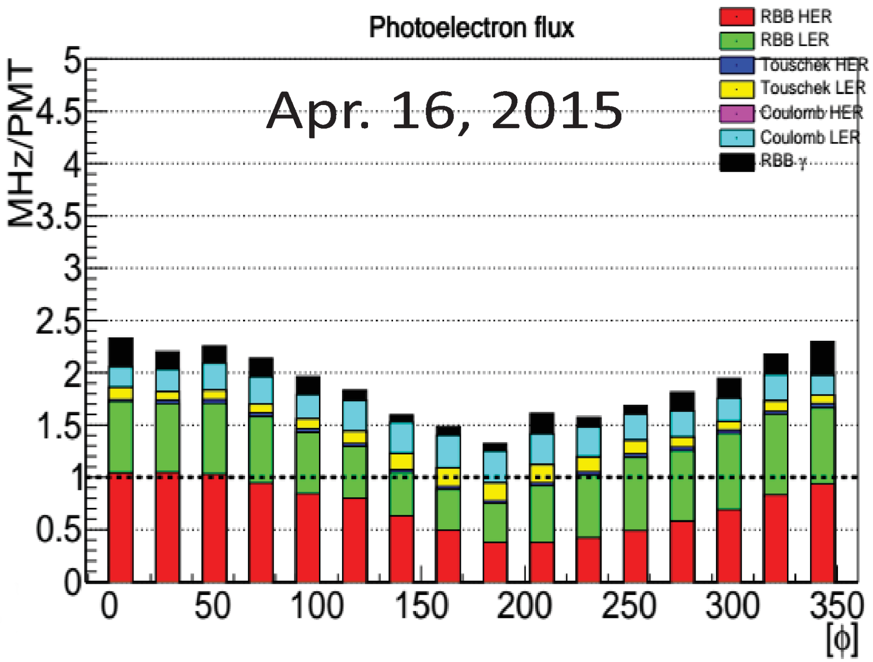


Single photon resolution in the 25-35 ps range:



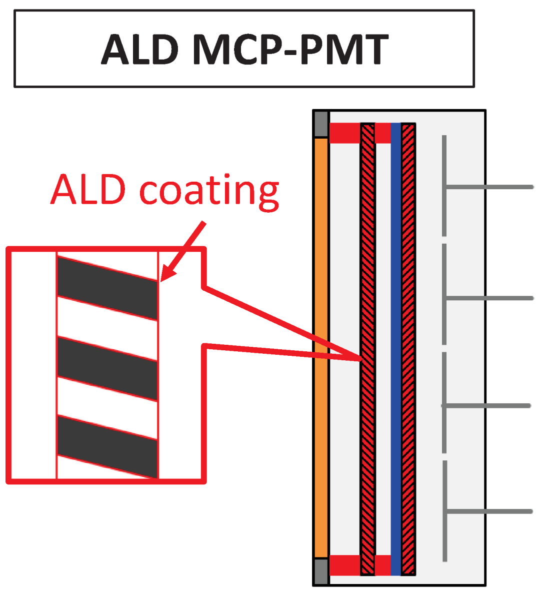
MCP-MPT's: lifetime

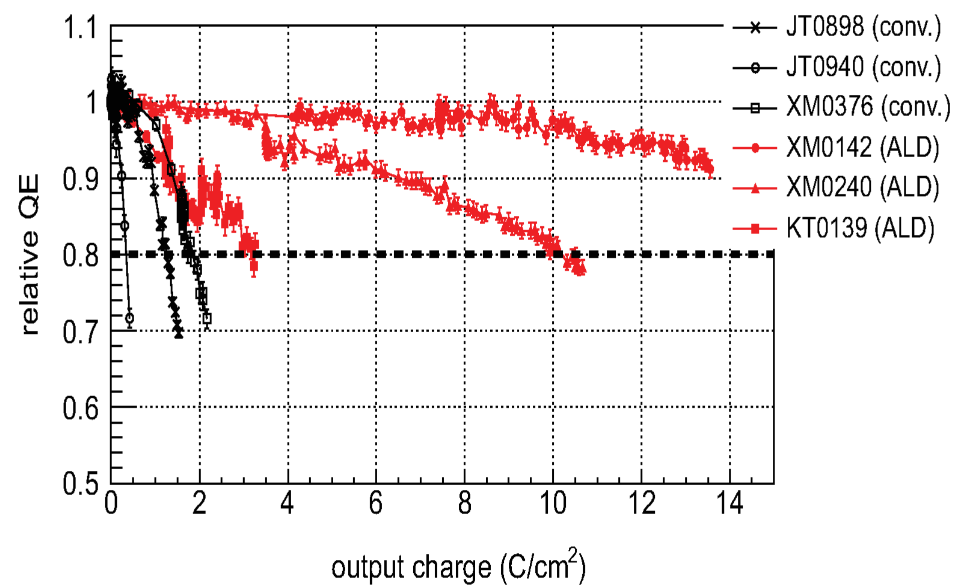
- The major concern about the use of MCP-PMT's regards their lifetime;
- The collisions of secondary electrons in the MCP's produce gases that degenerate the photocathode, reducing its QE;
- The QE of the PMT's is expected to drop to 80% of the initial value after receiving 1 C/cm^2;
- This corresponds to the charge deposited by a background rate of 1 MHz for the equivalent of 50 ab^{-1} of integrated luminosity;
- Our most recent background predictions indicate that we are going to exceed this value by a factor ~2.



ALD MCP-PMT's

- To overcome this issue, Hamamatsu has developed a new kind of PMT's;
- The Atomic Layer Deposition (ALD) MCP-PMT's have a protective layer that significantly reduces the aging of the photocathode;





- Hamamatsu is still working on the construction procedures, to further improve the PMT's lifetime. More results are expected in a few months.

PMT layout

We need 512 (+ spares) PMT's to instrument the 16 modules that will operate in Belle-II. Three different kinds of PMT's are going to be used:

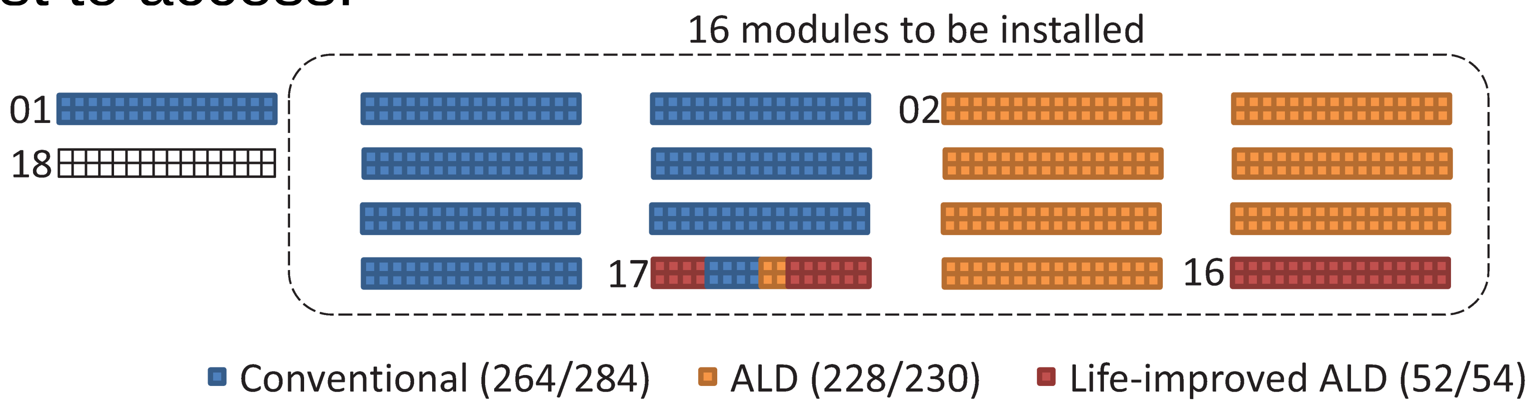
1) "Conventional": **284 PMT's**;

2) ALD: **230 PMT's**;

3) "Lifetime improved": **54 PMT's**.

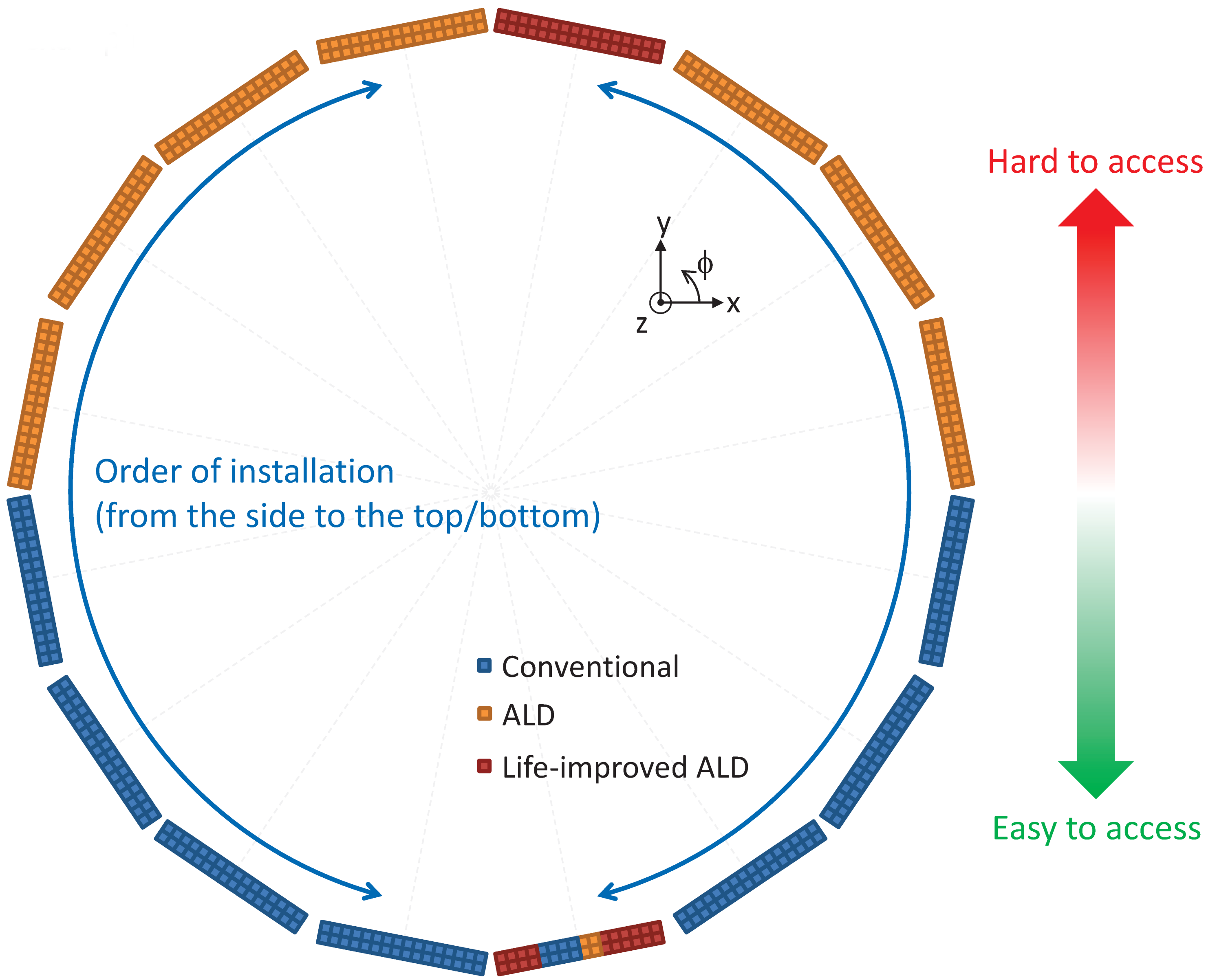
Guiding principles for the layout:

- Instrument a module using only a specific type of PMT's;
- Put modules instrumented with conventional PMT's in regions easiest to access:

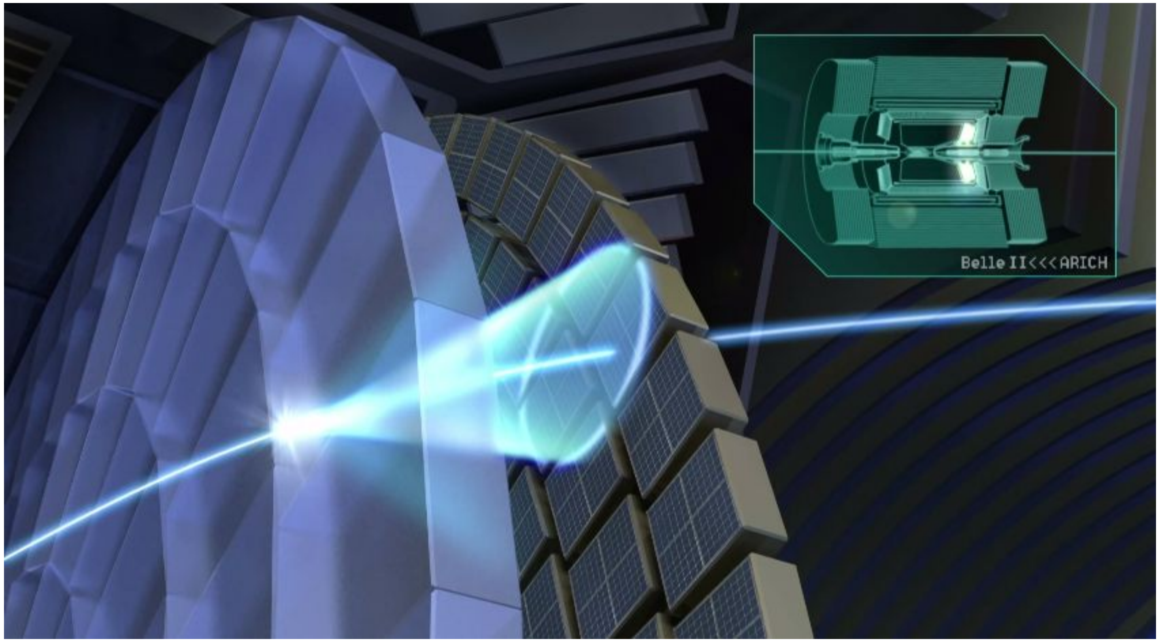


PMT layout

Preliminary

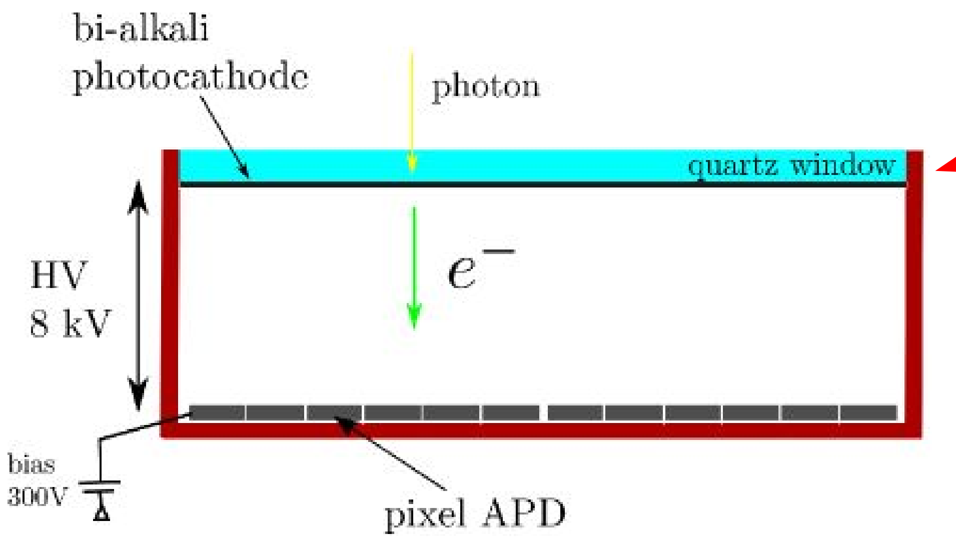


ARICH: HAPD's

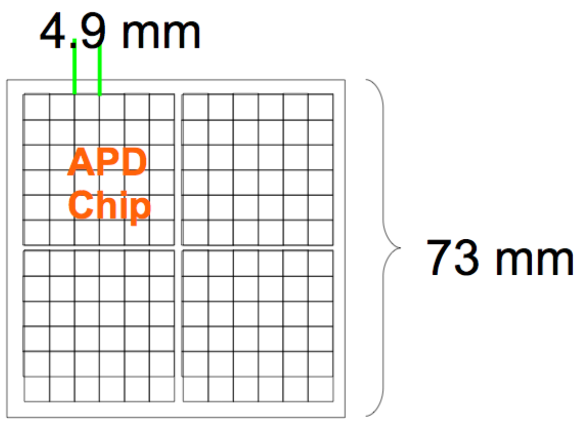


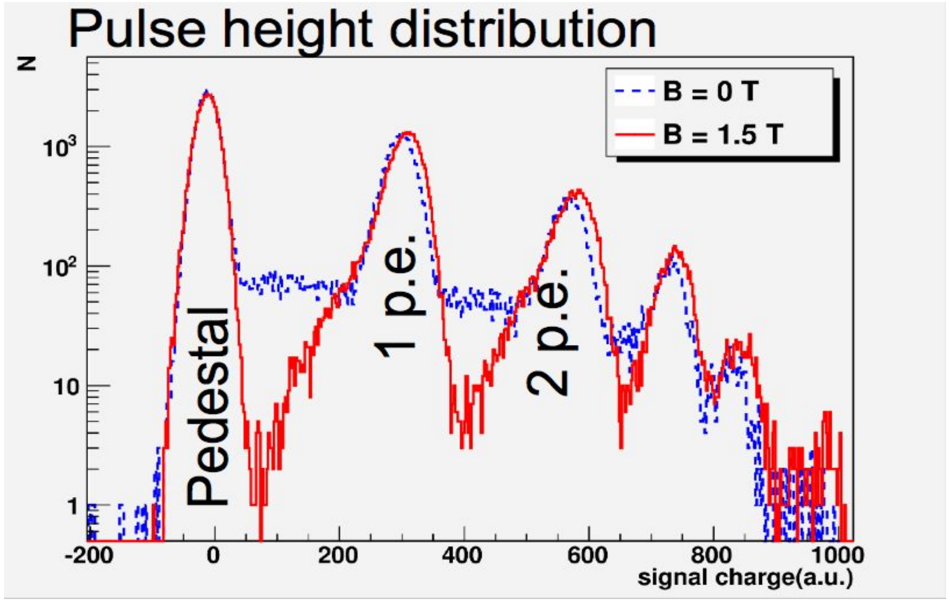
- When traversing the aerogel layers, the typical track produces O(30) Cherenkov photons;
- Need to detect them with high efficiency and position resolution;
- Hamamatsu Photonics K. K. developed the Hybrid Avalanche Photon Detector (HAPD);
- The gain comes from electron bombardment (x 1700) and avalanche (x 40) in a photo-diode, for a total of 6-7.0 x 10^4: single photon detection is feasible;
- The detectors must withstand high dose of γ (1000 Gy) and n (10^{12} cm^{-2}) radiation and perform in a 1.5T magnetic field.

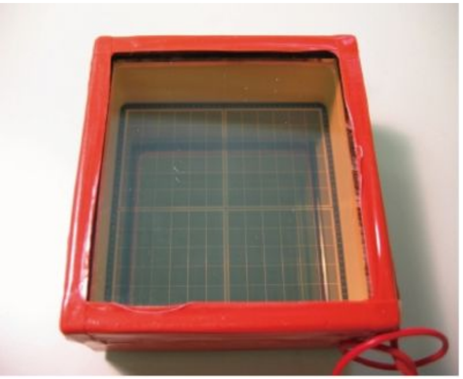
HAPD's



Quantum efficiency ~30%

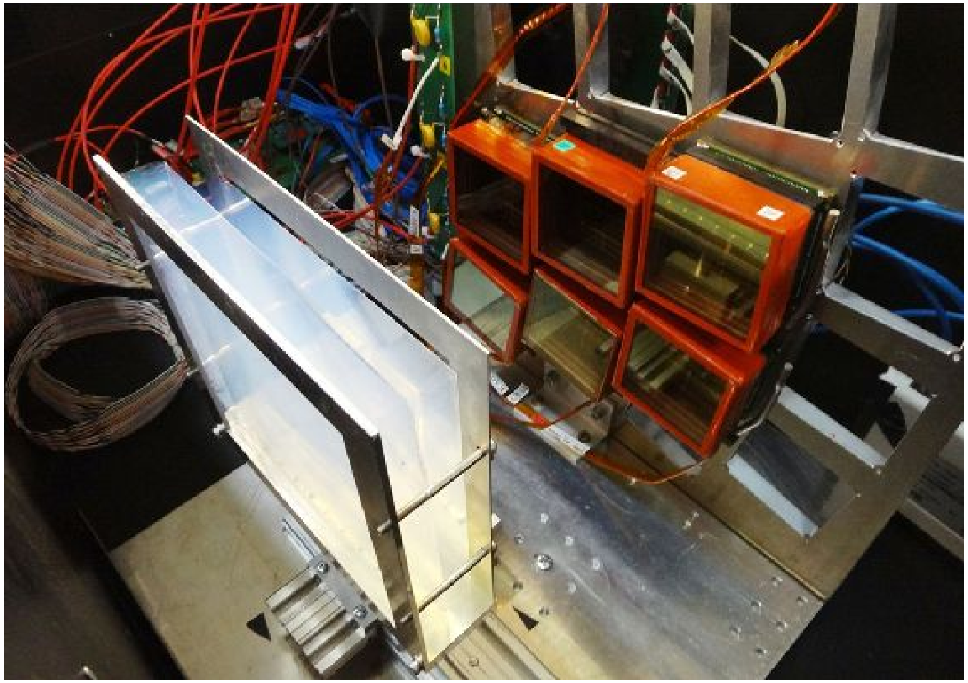


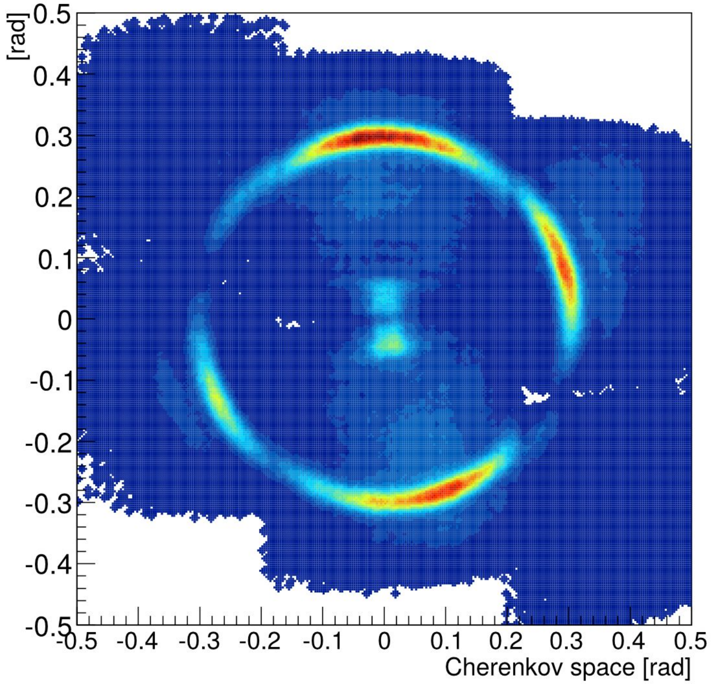


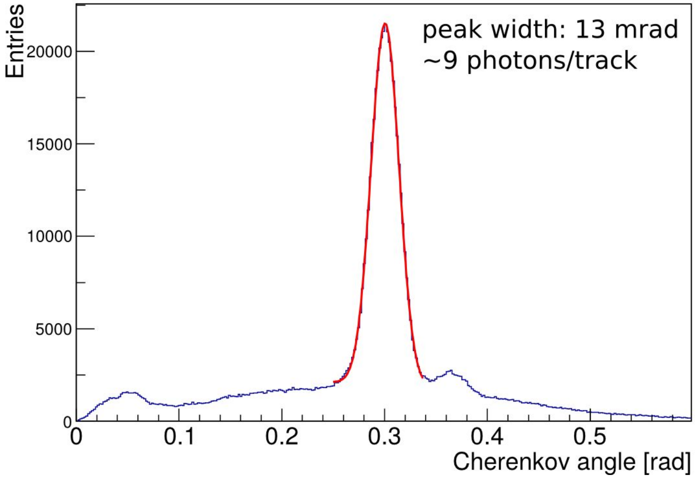


HAPD's: performance

Test at DESY with 4-5 GeV electron beam:







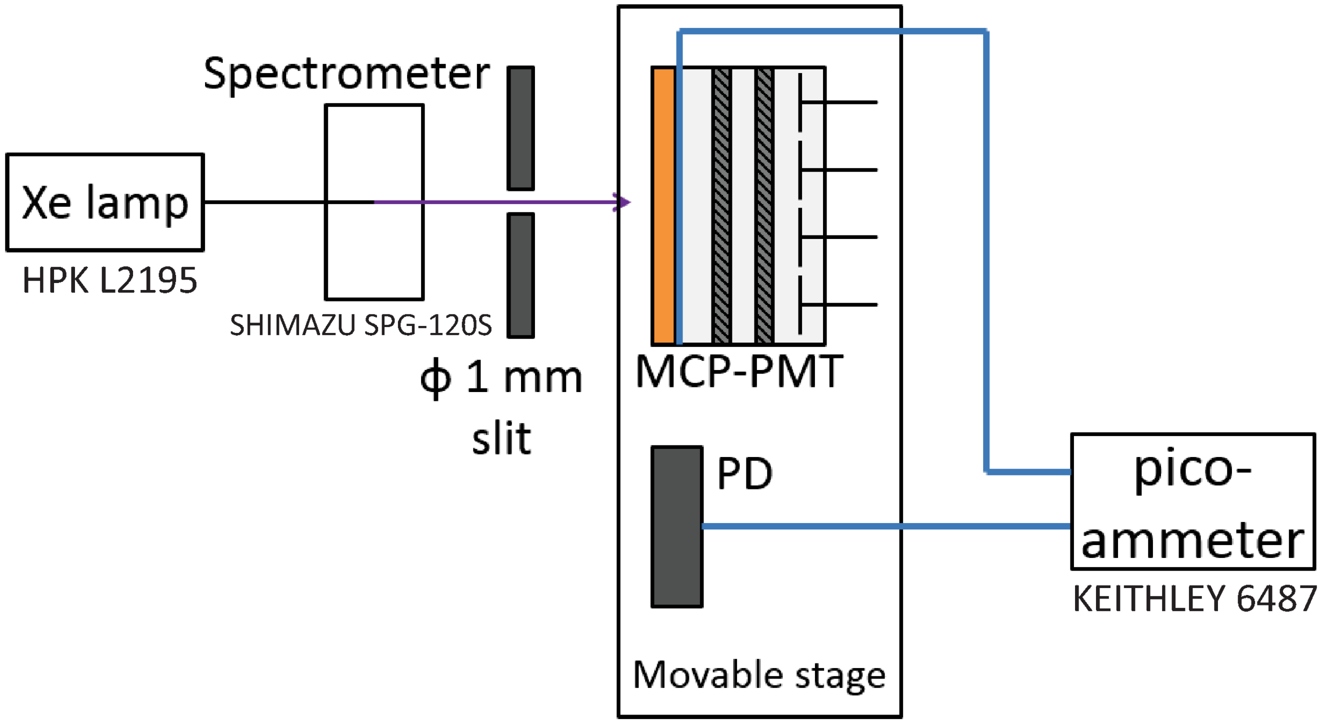
Detection efficiency and resolution matching the expectations

Conclusions / outlook

- The TOP and ARICH at Belle-II are very ambitious and challenging detectors. Their performance depends critically on the quantum efficiency (and timing resolution) of their photo-detectors;
- The detectors have to perform reliably in the magnetic field and harsh background conditions;
- After years of R&D and testing, the MCP-PMT's for TOP and HAPD's for ARICH produced by Hamamatsu have proven to be adequate for the task;
- We are eager to start Physics data taking in 2018!

Backup Slides

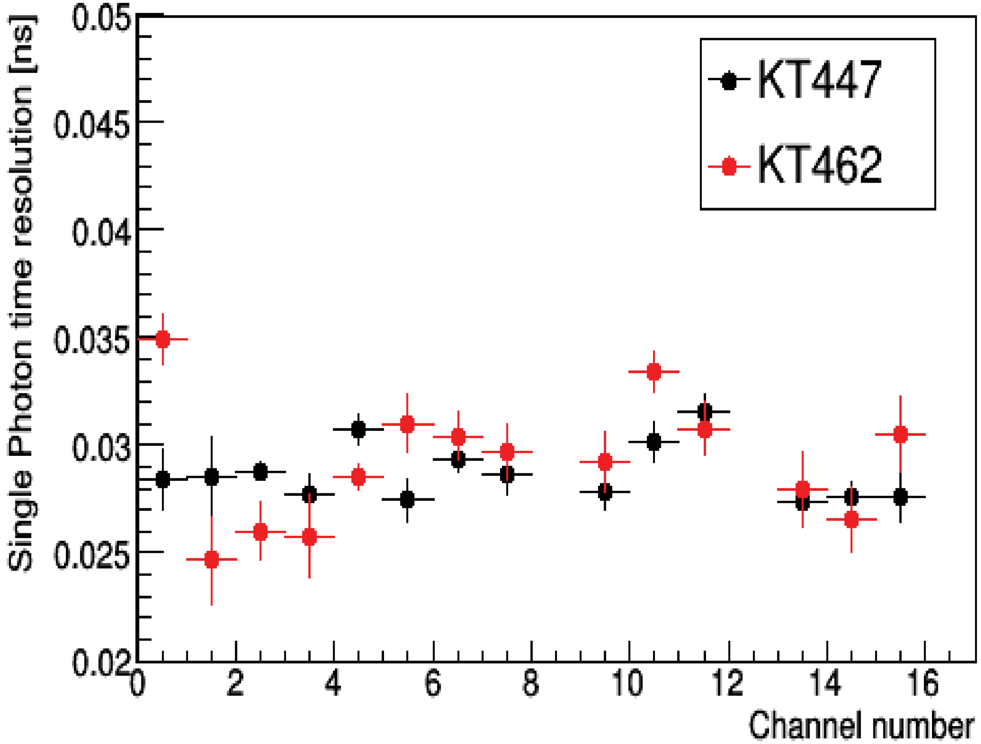
QE measurement

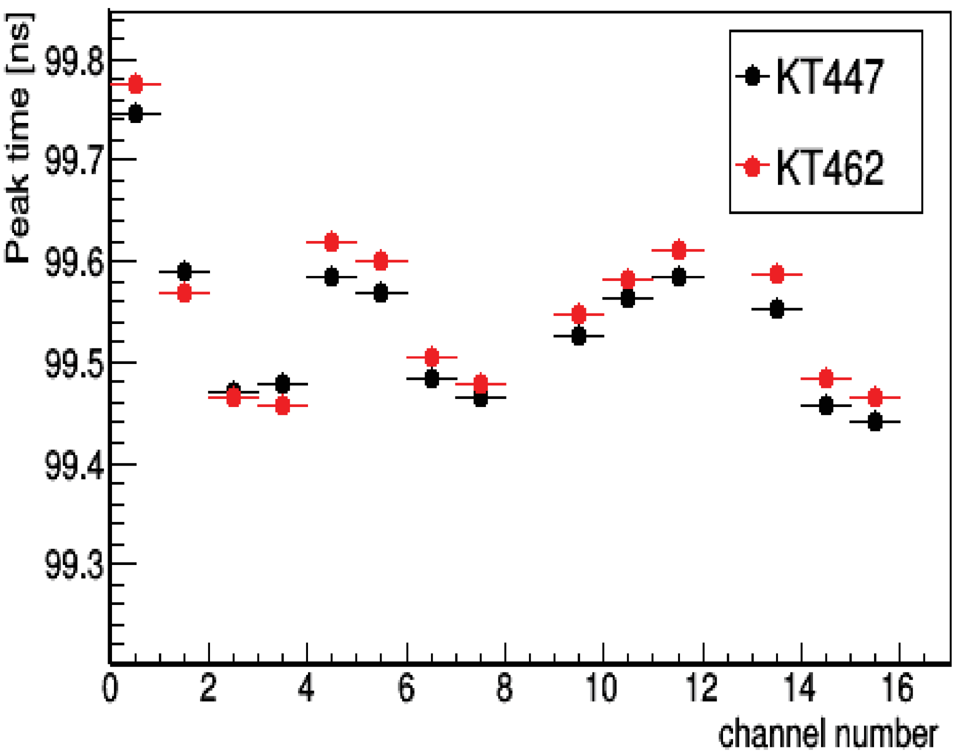


- In the setup, the PMT under study and a reference photo-diode (PD) are illuminated in turn with the monochromatic light;
- The QE of the photo-diode is accurately known and the QE of the PMT is measured by taking the ratio of the currents of the two detectors.

MCP-PMT's: uniformity

Comparison between two different PMT's





Single photon time resolution in the 25-35 ps range

Differences due to cabling length differences (and different fiber positions for the two PMT's).
Not an issue, since channels will be calibrated separately.