Study of scintillator based muon detector

Xiaolong Wang

Fudan University, Shanghai

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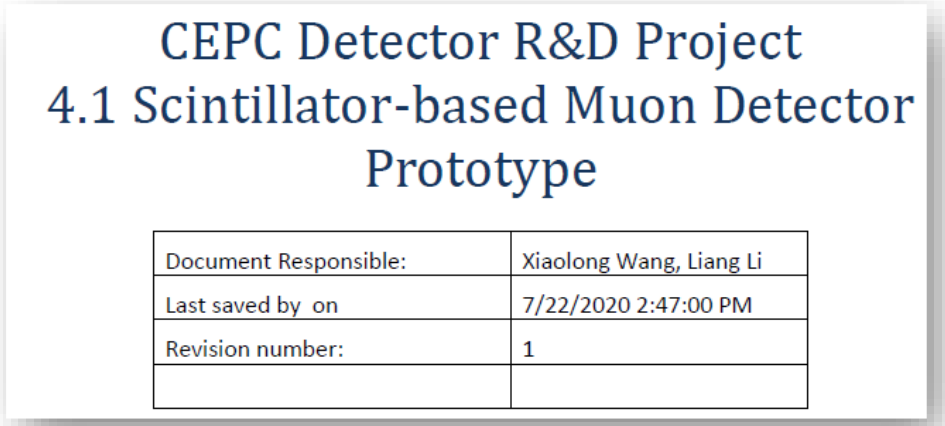
Subprojects of R&D

1. SiPMs and Scintillator strips procurement
2. WLS fiber and optical couplings
3. Time/spatial resolution measurements
4. Radiation Hardness of SiPM and scintillator
5. Prototype construction: Multi-layer detectors



CEPC Detector R&D Project
4.1 Scintillator-based Muon Detector Prototype

Document Responsible:	Xiaolong Wang, Liang Li
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Revision number:	1

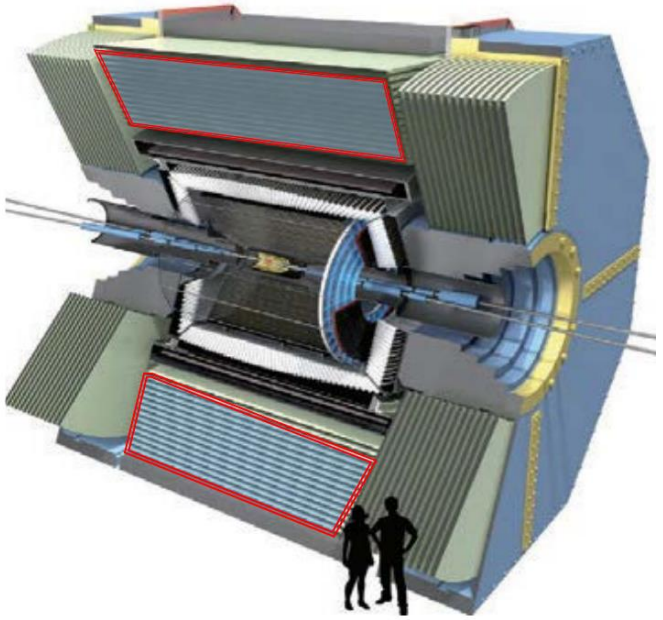
It's ongoing…

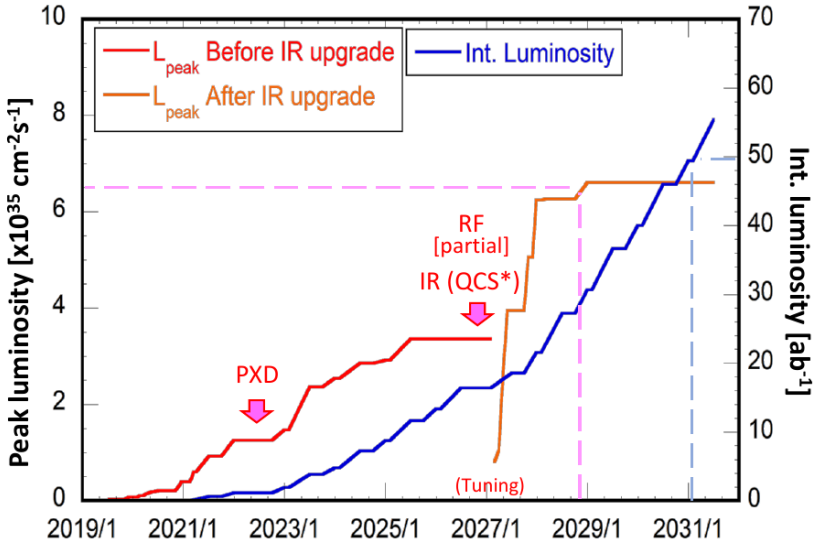
Outline

- Introduction on Belle II KLM detector
- Materials for R&D: SiPM, WLS fibre, scintillator
- Parameters of SiPM
- Study on scintillator detector
- Time calibration from Belle II KLM

KLM@Belle II

- KLM: KL and muon detector
- Barrel KLM:
  - Scintillator modules: NEW, inner most 2 layers
  - RPC modules: Legacy, the other 13 layers, rate limited
- Endcap KLM: all scintillator modules
- The next upgrade for KLM is on the Belle II table.

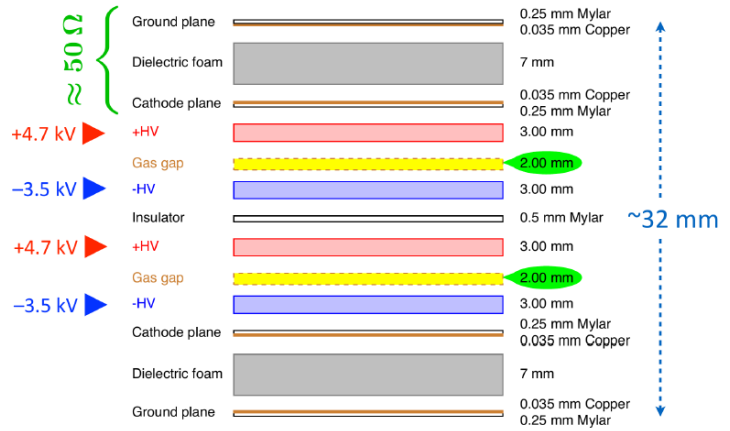




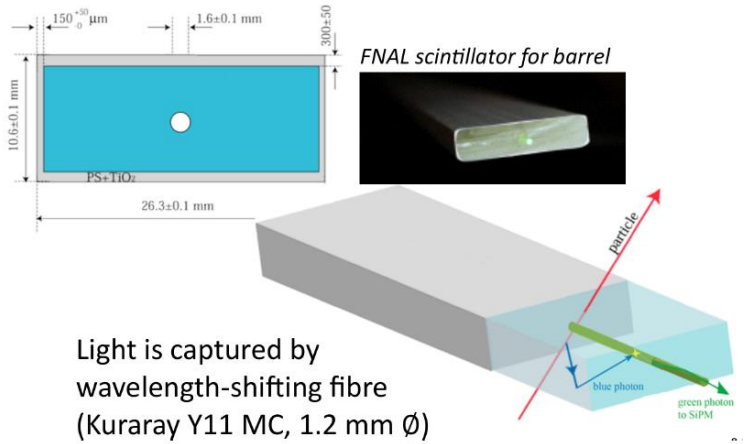
From RPC to scintillator

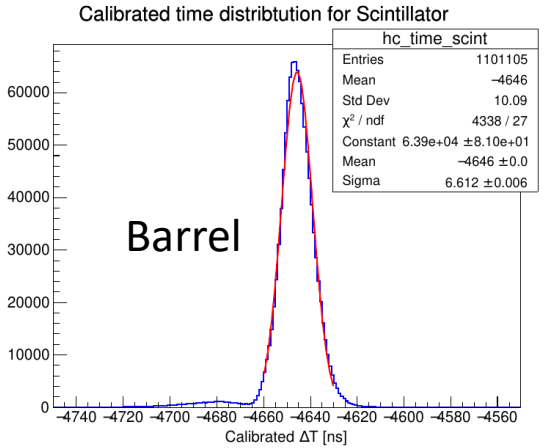
- The new scintillator modules have been showing very good performance during data taking.
- $\tau_D \sim 2ns$, no need to worry about the rate-limit problem.
- Each channel is isolated, and the structure is quite simple. It's easy for repair.
- Excellent time resolution is possible.

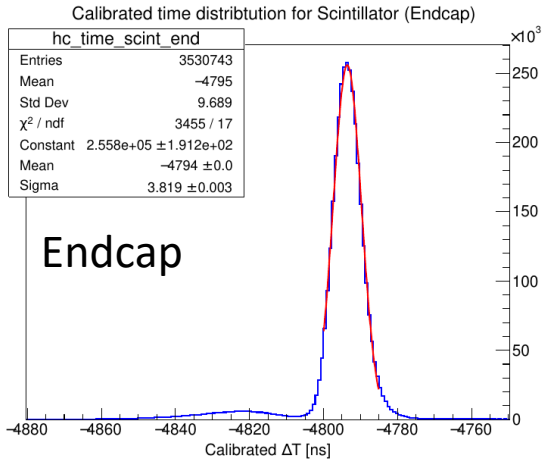
RPC structure:



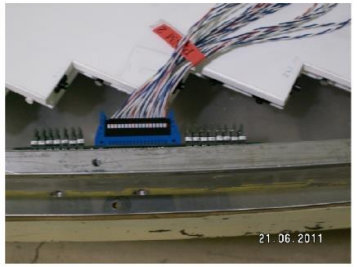
Scintillator structure:

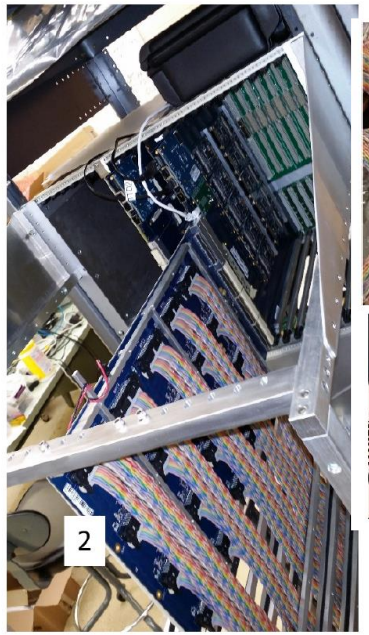


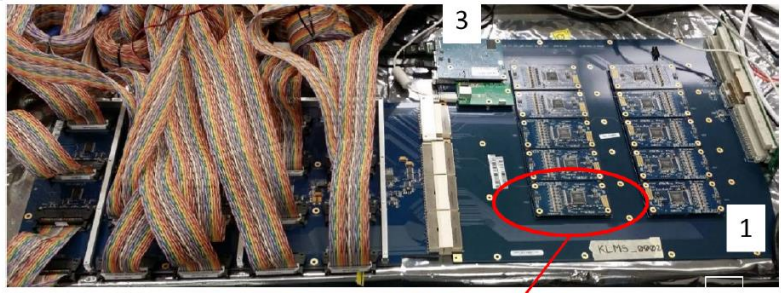


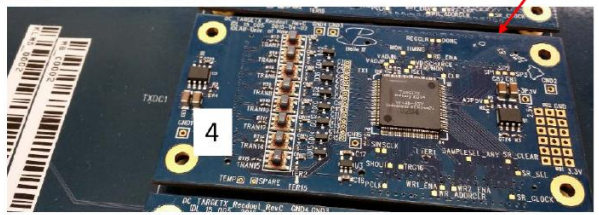


Current readout





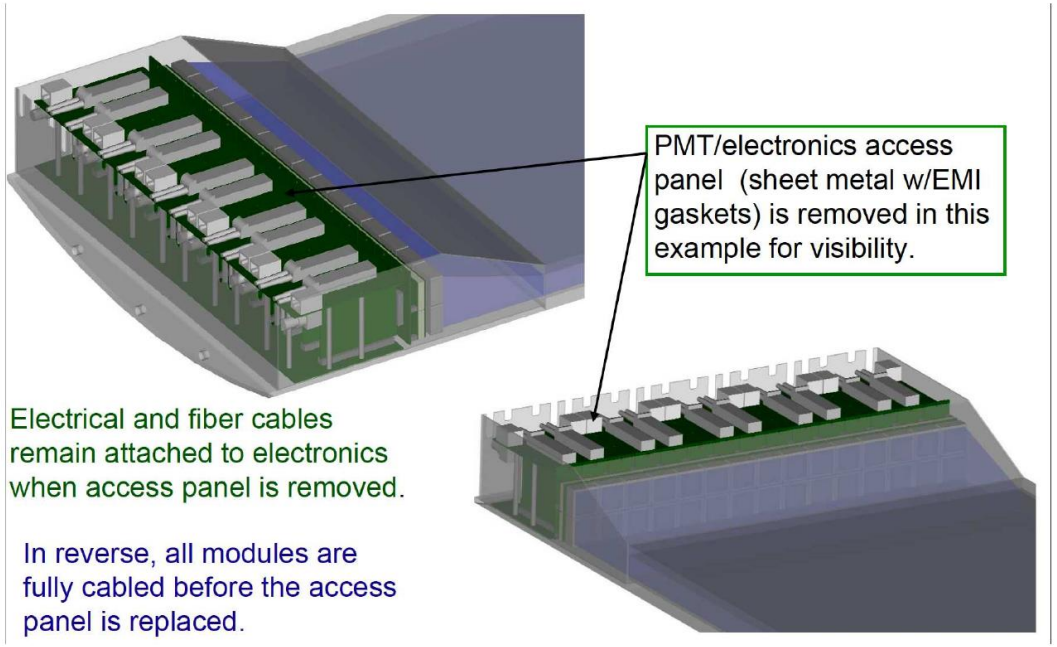




- Typical FE and BE
- A lot of ribbon cables between FE and BE with the length 3-15 m
- A lot of troubles due to the long cables

Upgrade on readout system

- Improve power/readout scheme with all electronics and push into the detector panel.
  - System-on-Chip Readout Electronics;
  - 50-70 V integrated power supply for SiPM;
  - Clock/timing distribution and data concentration;
  - Fibre for digitized data transmission;
  - Considering the triggerless DAQ.
- Same CMOS technology as iTOP's IRXS (Belle II PID detector)



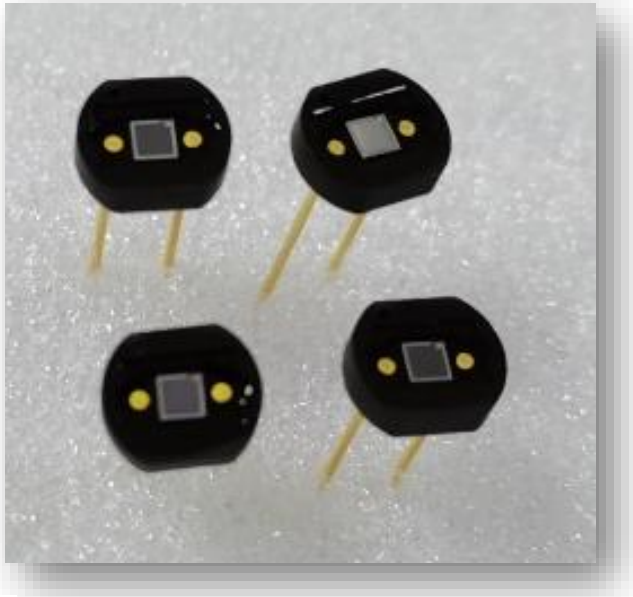
More technologies will be available for a CEPC muon detector.

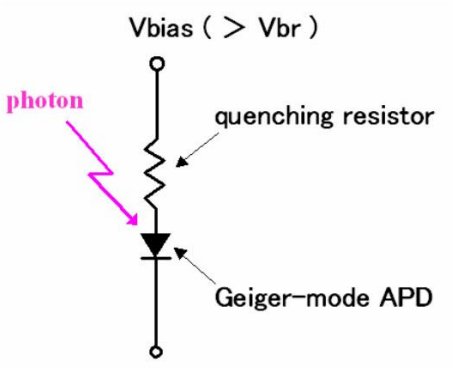
Materials for R&D

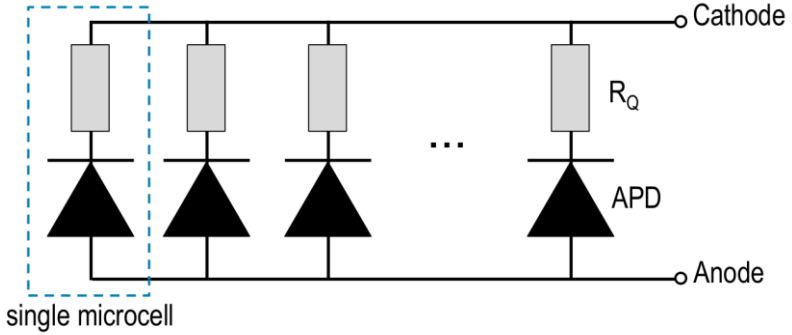
- SiPM: Hamamatsu S13360-13**CS
  - Or MPPC, aka Multi-pixel photon counter
  - Belle II uses S10362-13-050C
- Scintillator: provided by 高能科迪 (Gao Neng Ke Di Company)
  - Geometry: $1cm \times 4cm \times 1.5m$
  - Plastic scintillator extruded.
- Fibre: wave-length-shift fibre,
  - Wave-length-shift (WLS) fibre by Saint-Gobain
  - $D = 1\ mm$
  - Belle II uses Kuraray Y11(200)MSJ, $D = 1.2\ mm$

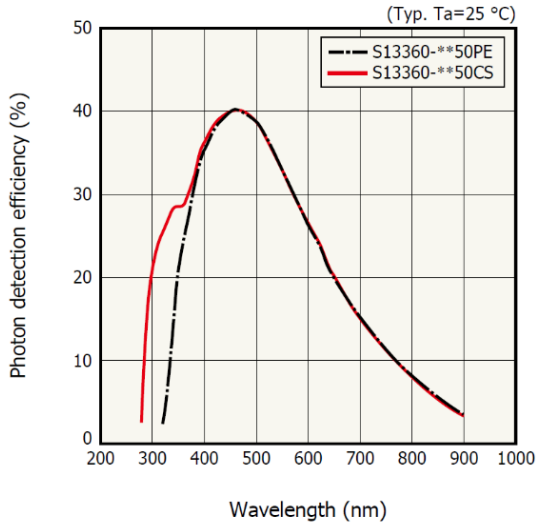
MPPCs

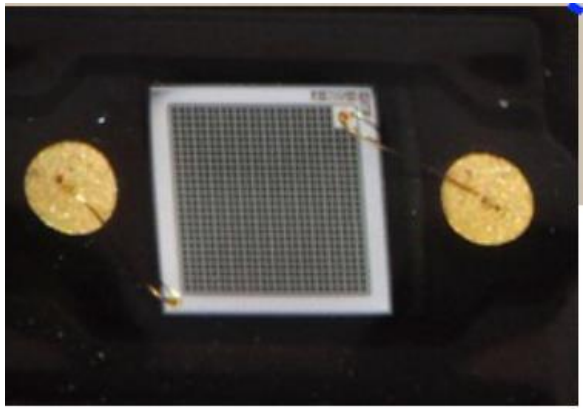
- Hamamatsu MPPCs with 25, 50 and 75μm pixel pitch
  - 50μm type has 667 pixels.
- Effective Photo-sensitive area: $1.3\ cm \times 1.3 cm$.
- Terminal capacitance 60 pF.
- Spectral response range 270 to 900 nm.





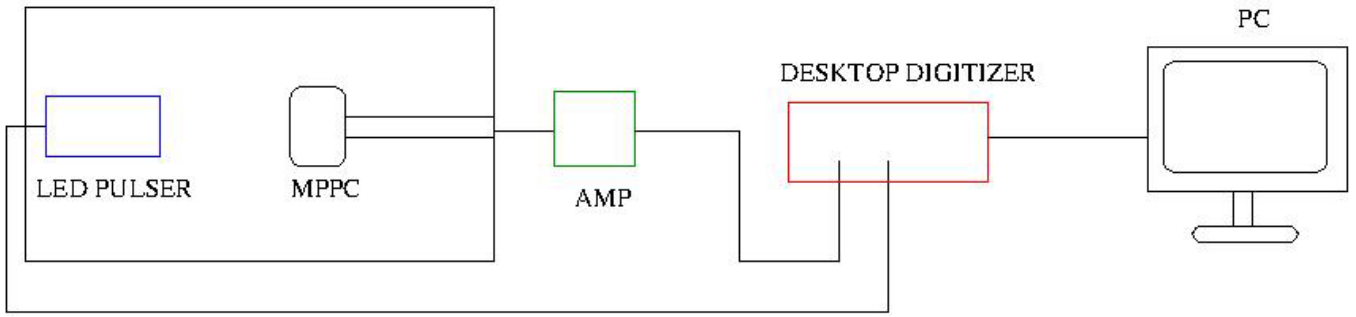


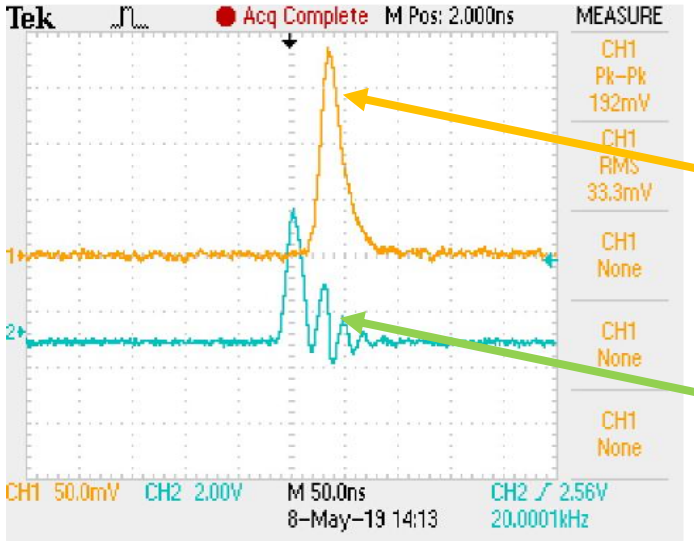




Setup for MPPC study

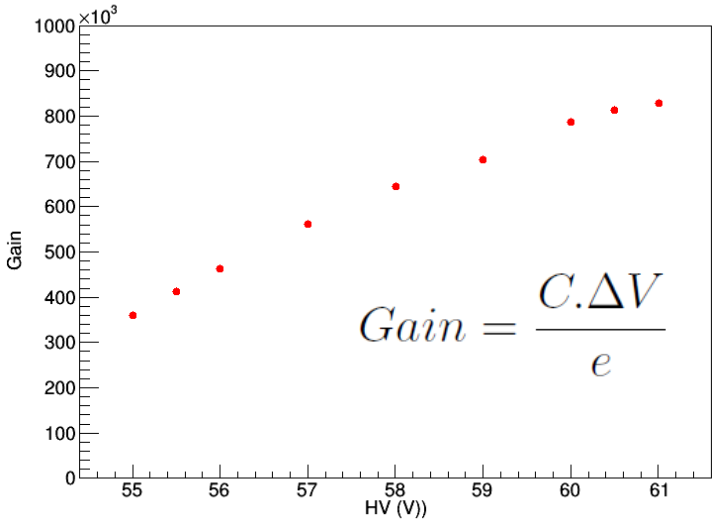
- A blue LED diode is as a photon source.
- A pulse generator is used to make a pulse light source, and as a trigger too.
- A pre-amplifier circuit is used to for MPPC signal.
- A high voltage power supply is used to drive the MPPC.

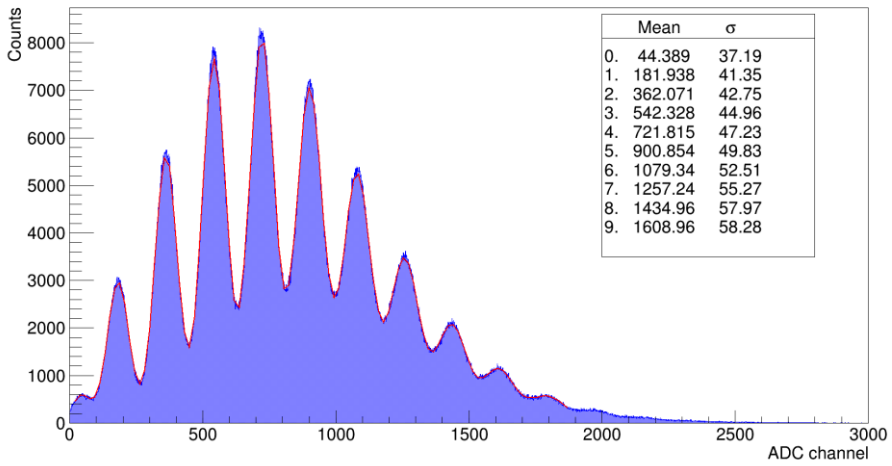


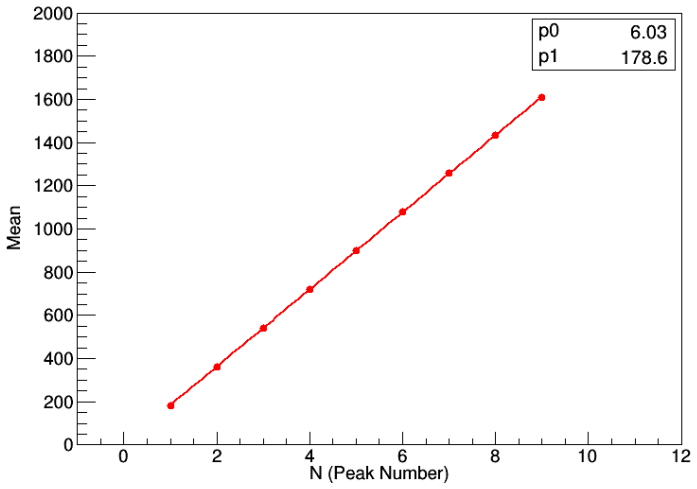


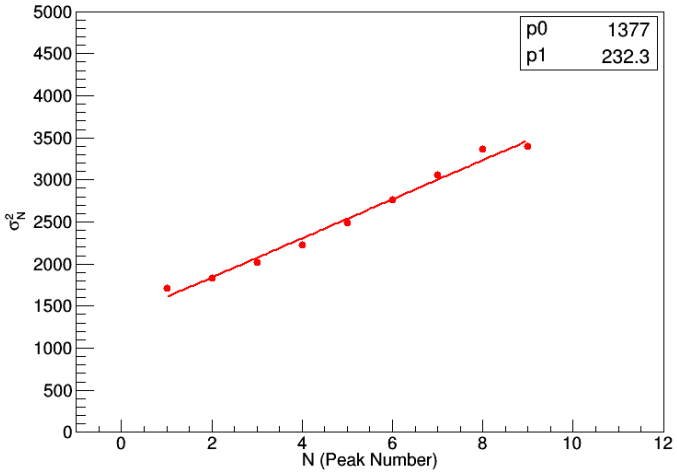
MPPC parameters (I)

- ADC measurement with $HV = 57.0\ V$.
- Up to 11 p.e. could be seen.
- Fit to the photon spectrum.
- The gain: 5.5×10^5at $57.0\ V$.





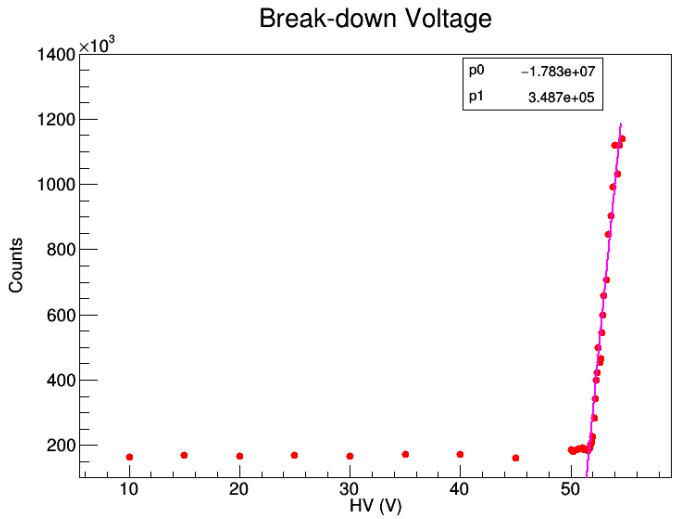


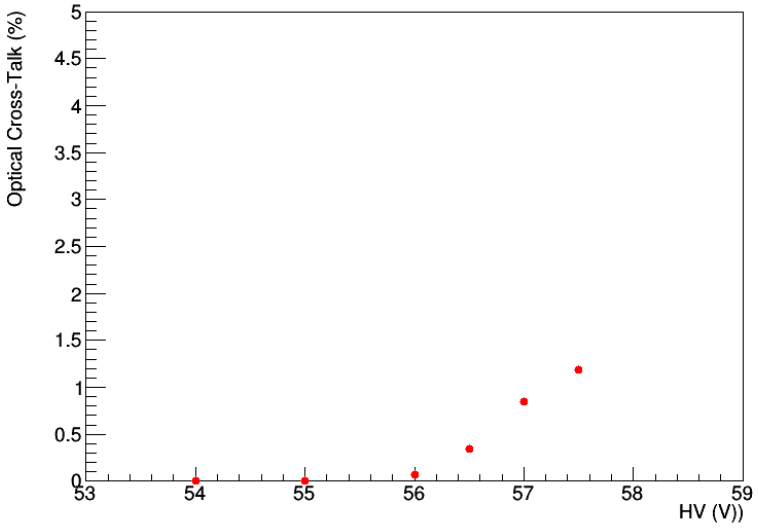


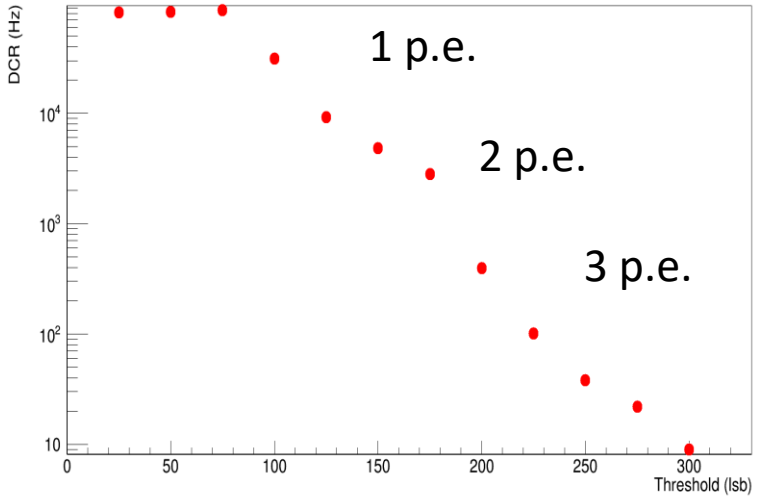
MPPC parameters (II)

- Break-down Voltage: the voltage MPPC starts to work
- Dark Current Rate (DCR):
  - Major nosie due to the thermally generated electrons in absence of light.
  - Typical DCR is maximum 81 KHz at $V_{OP} = 56\ V$, threshold = 0.5 p.e.
  - The threshold could be 3 p.e.
- Optical Cross Talk (OCT)

$$OCT = \frac{(DCR)_{1.5p.e.}}{(DCR0)_{0.5p.e.}}$$

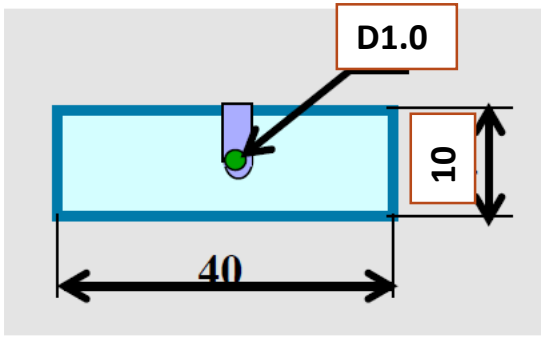


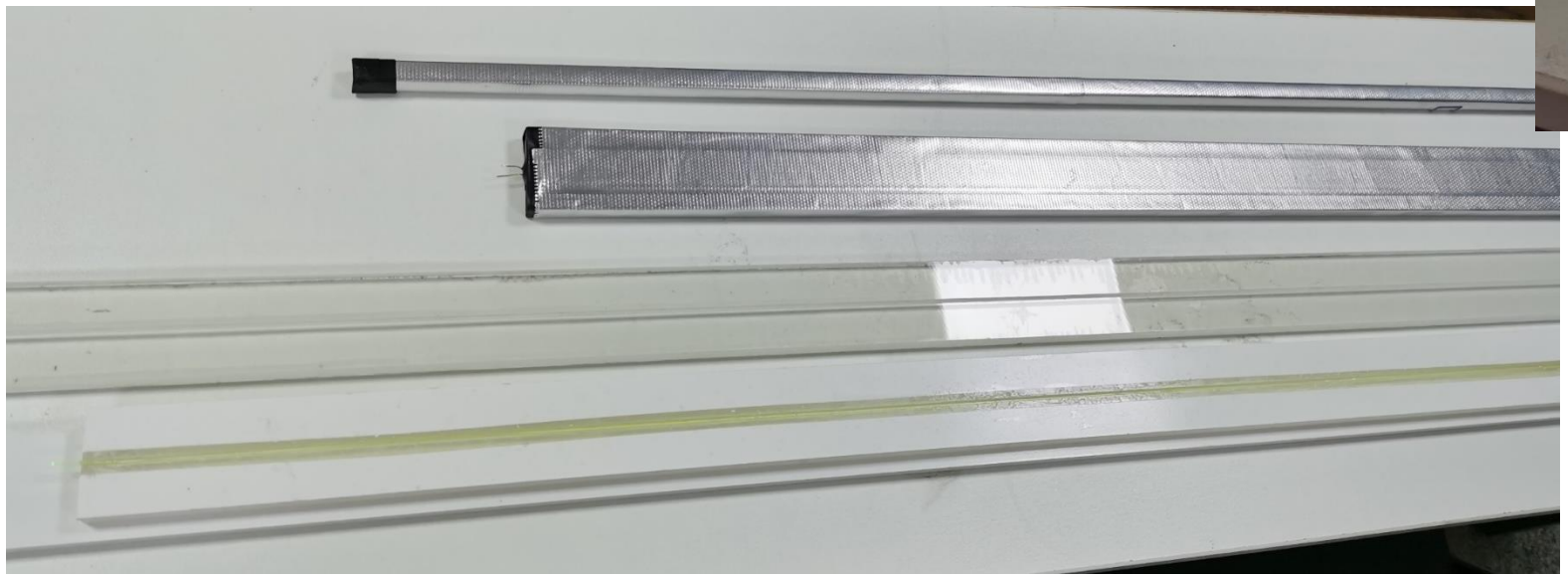




Plastic scintillator

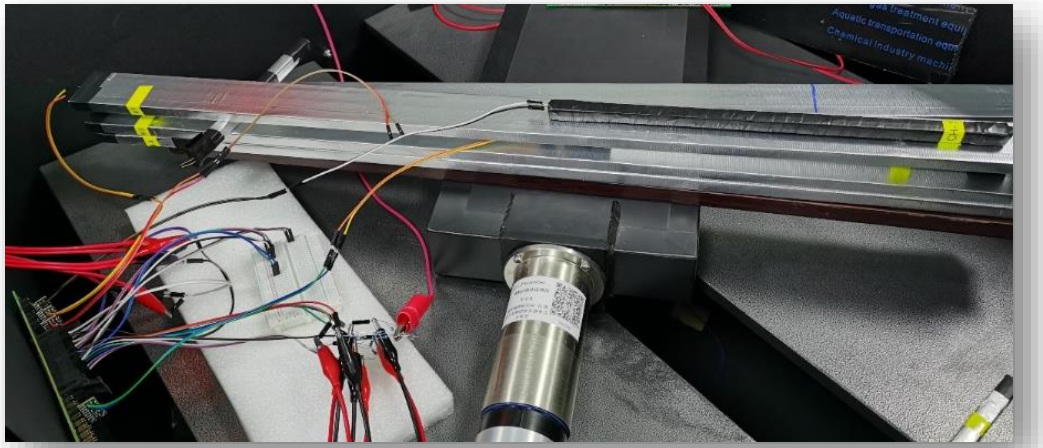
- Purchased in China
- Geometry: $1cm \times 4cm \times 1.5m$
- Reflective cover: Teflon
- Groove for WLS fibre is sawed into the top surface
- Structure is like Belle II endcap KLM.

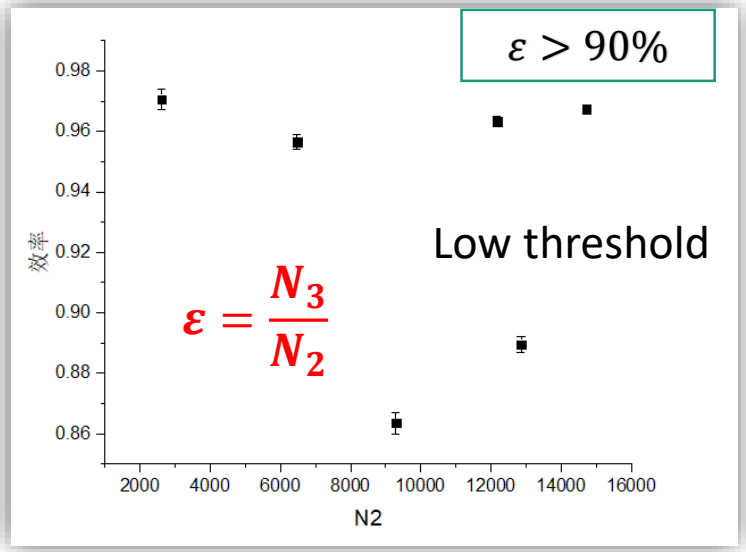


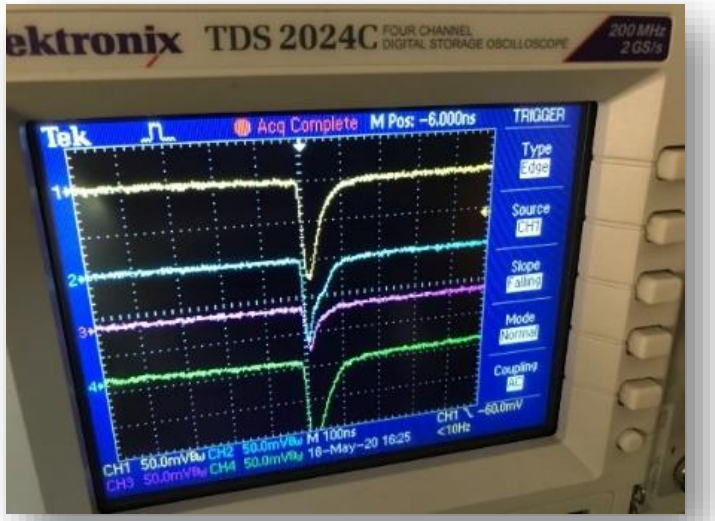


Testing setup

- FE readout designed from Belle II
- Pre-amplifier: ~10
- Cut to be 75 cm to fit in a dark box.
- Test with cosmic rays.
- Small strip for trigger, close to the position of fibre.

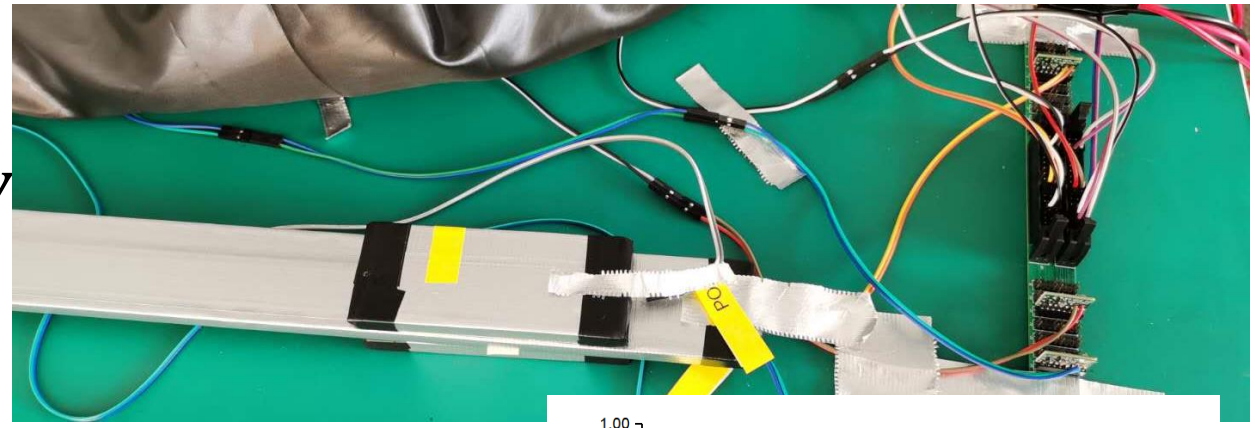


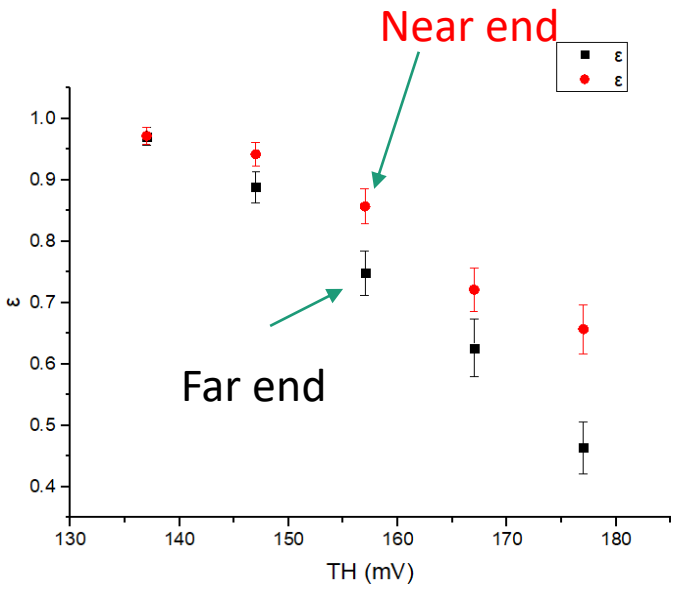




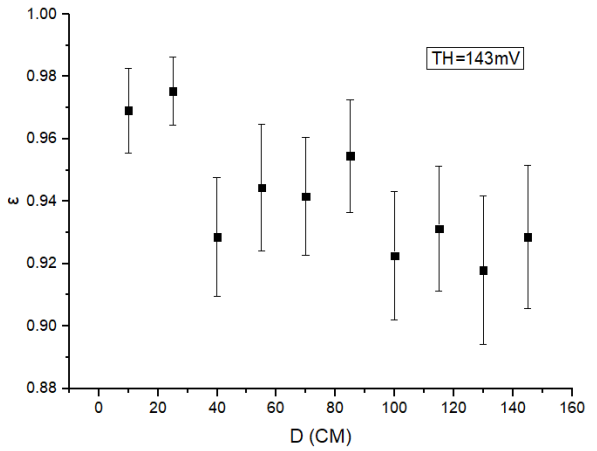
Efficiency of scintillator strip

- 1.5 m long.
- $\Delta V \cong 8\ mV$ for 1 p.e., $V_{ped} \approx 123\ mV$





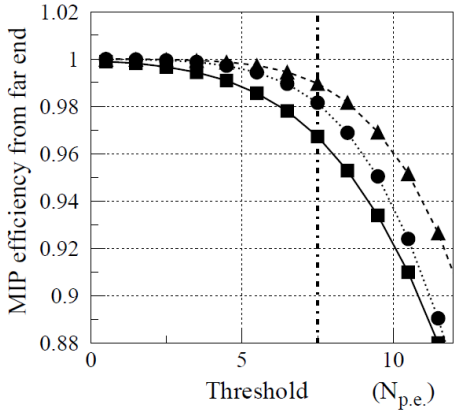
TH(mV)	Count rate（Hz）
137	98009 ± 28
147	557.2 ± 2.2
157	25.8 ± 0.5
167	11.0 ± 0.3
177	5.2 ± 0.2
150	183.3 ± 1.2

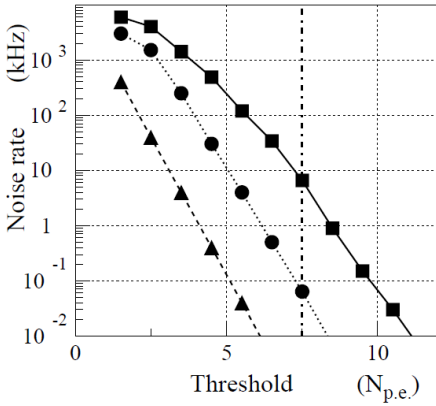


Thresohld for 4 p.e.

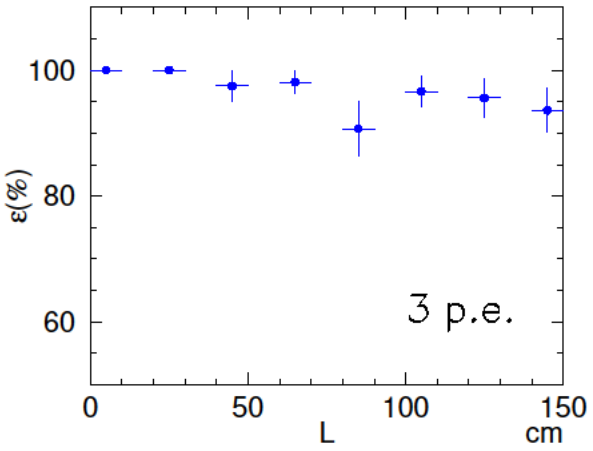
Efficiency of scintillator strip

- Efficiency measured with different threshold.
- Noise level of pedestal is quite low.
- With a threshold of 4 p.e., the efficiency could be high.
- Still need to improve the light collection with better couplings and better reflection cover.

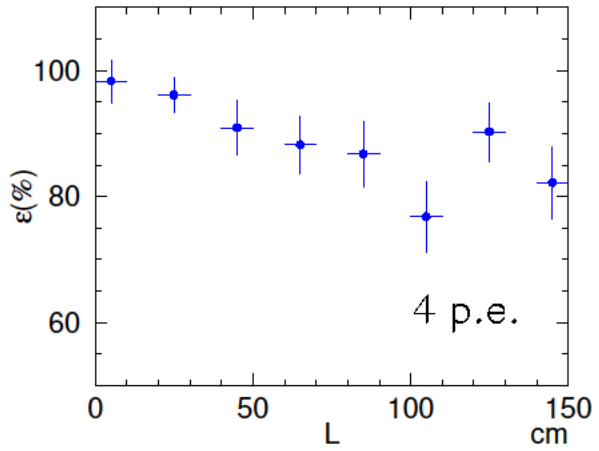




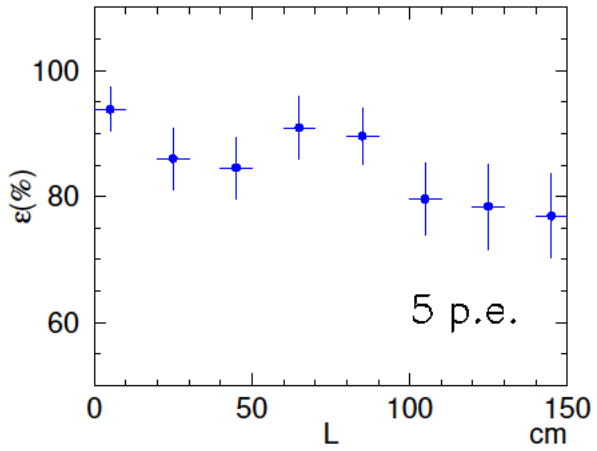
Belle II TDR



$V_{th} = 146\ mV$



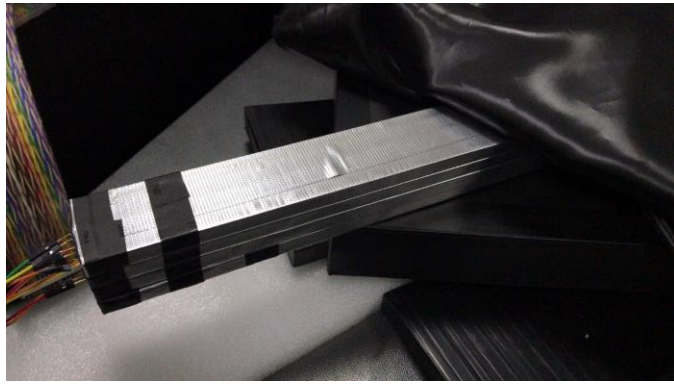
$V_{th} = 152\ mV$

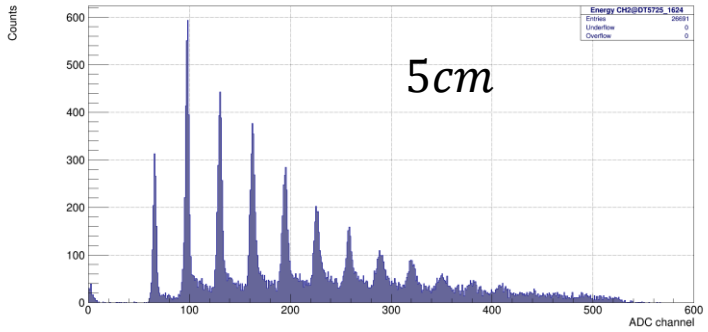


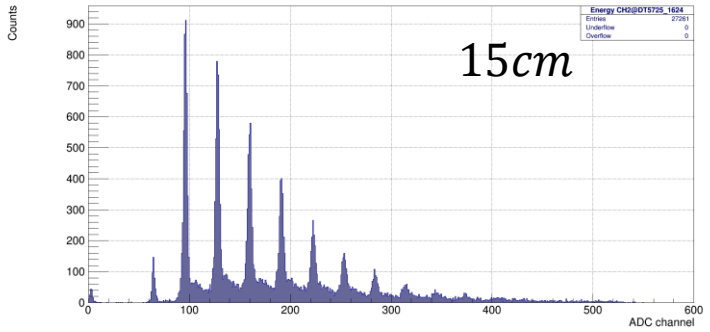
$V_{th} = 162\ mV$

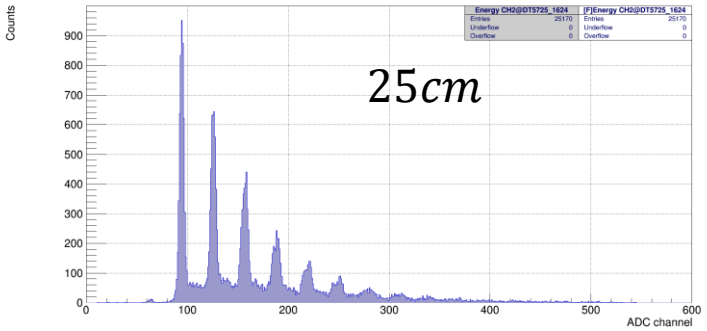
ADC distributions from different position

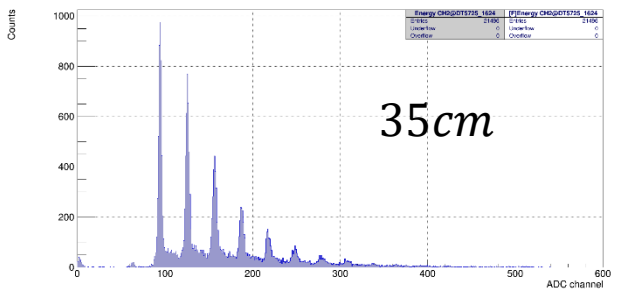
- Test on 75 cm strip.
- Trigger CR signals at different postion: $L = 5, 15, 25 \ldots cm$ from the near end.

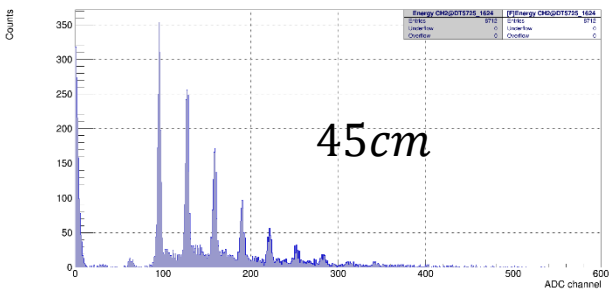


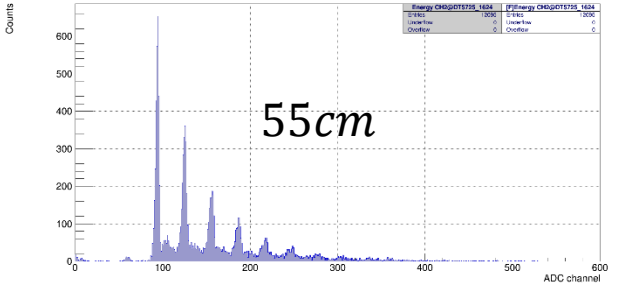


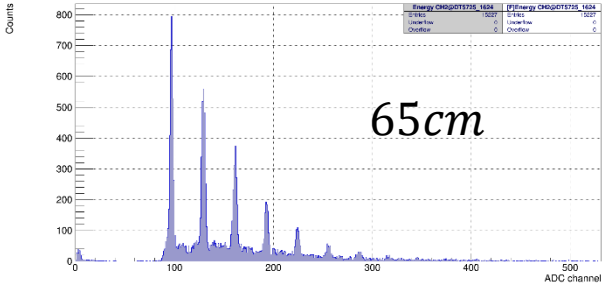






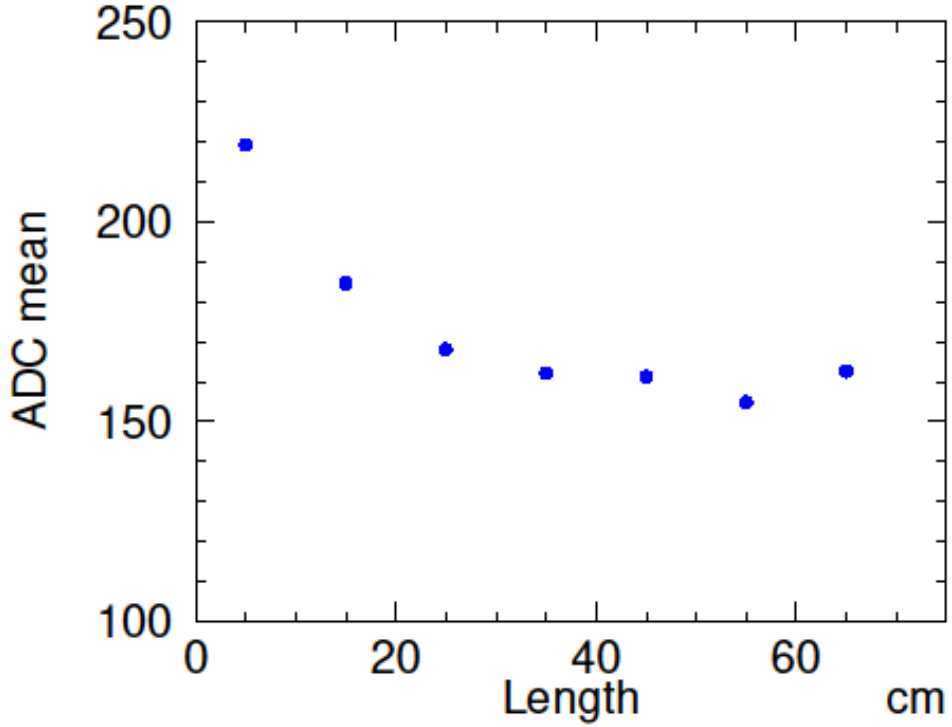


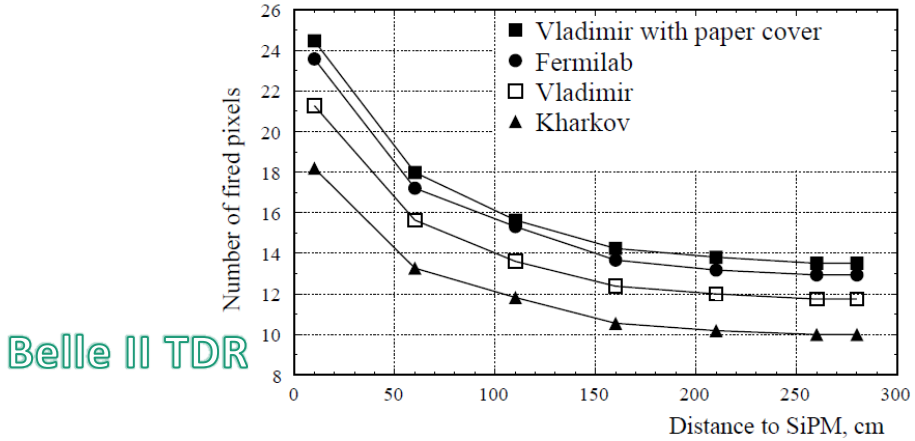




ADC vs. length

- Get the means from the distributions.
- The errors are not so accurate, too small.
- Near end is much better, no obvious difference since $L = 25\ cm$
- Going to improve the measurement with better coupling and reflection cover.

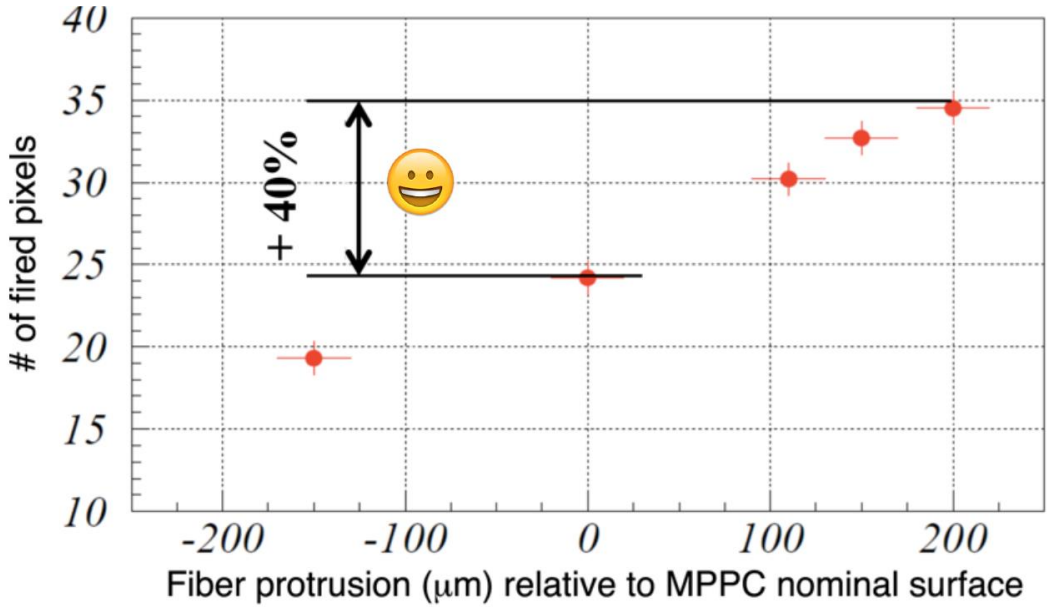


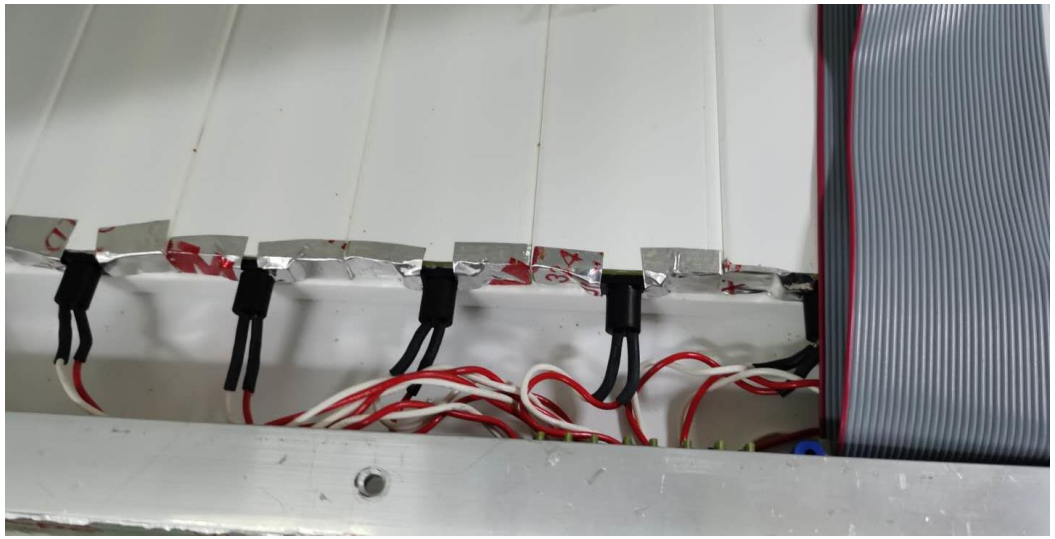


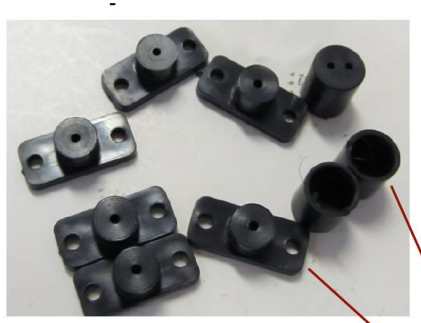
Belle II TDR

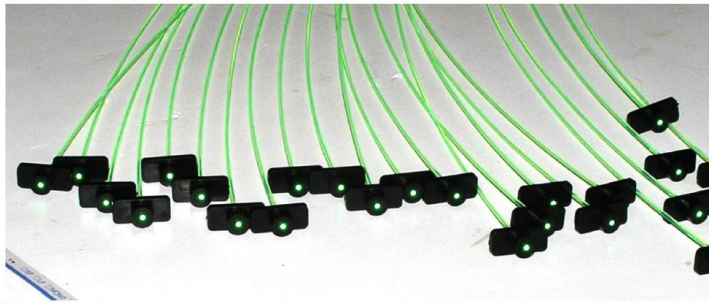
Some problems

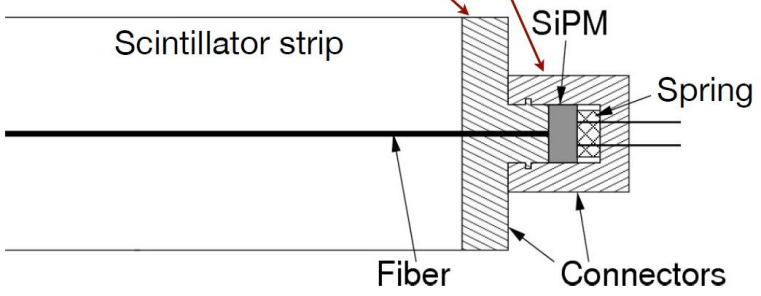
- Electronic noise.
- Coupling between fibre and MPPC:
  - Belle II uses small item to hold fibre and MPPC to get good coupling.
  - We don't have it now. The coupling was poor, but we did some improvement.
  - The coupling needs to be improved further

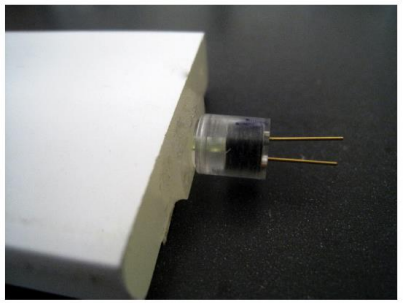












Time calibration at Belle II

- Fudan Group in charge of KLM time calibration.
- Good time resolution would be important for next generation experiment with high luminosity.
- The first item of a large size subdetector is due to pass length, mainly from cable length.

$$T_{\text{record}} = T_0 + T_{\text{fly}} + T_{\text{prop}} + T_{\text{collect}} + T_{\text{cable}}$$

From VXD and CDC

Based on MC and extrapolate hits

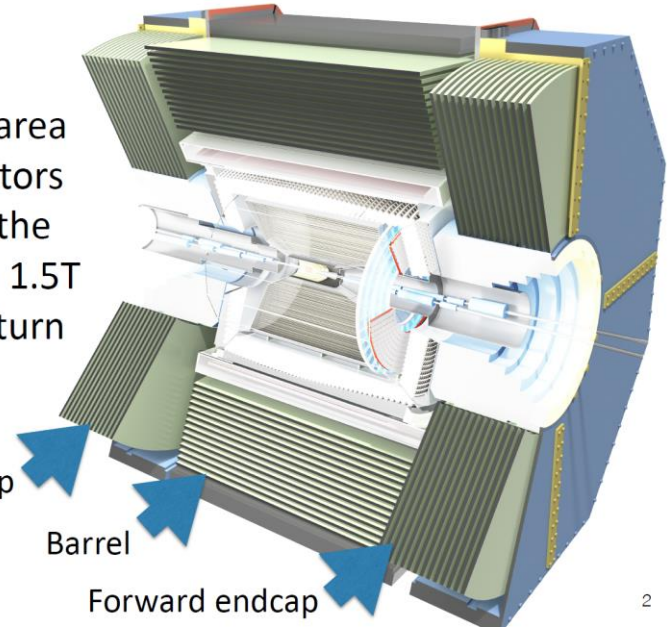
Local position over effected light speed

Time of SiPM collect photon
is related to signal energy and number of photon.
Ignored for now.

Time on cable, determined by cable length. Need to be corrected.

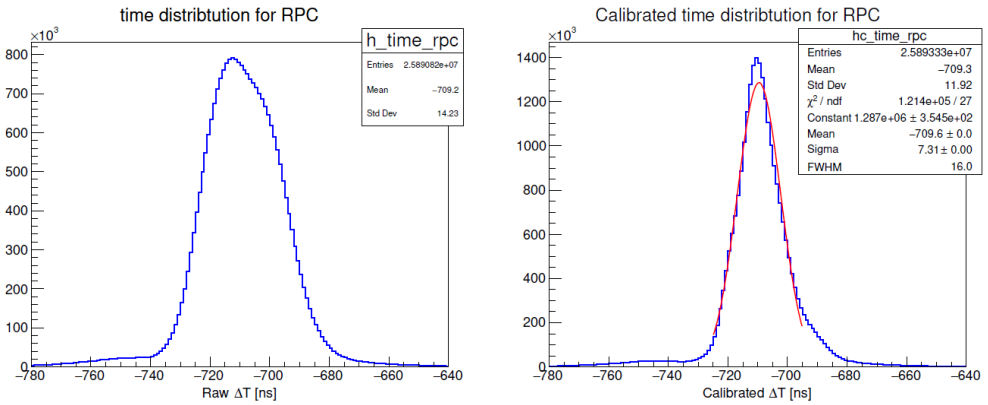
The KLM ("K_L–Muon detector")

consists of large-area thin planar detectors interleaved with the iron plates of the 1.5T solenoid's flux return yoke.



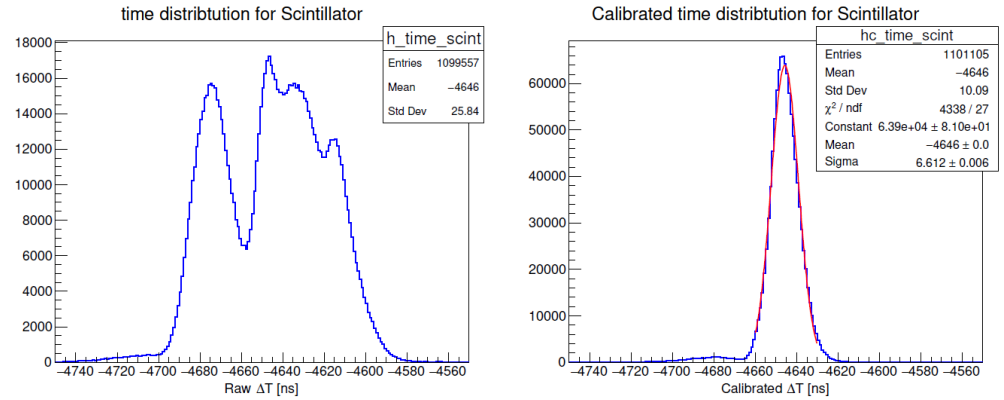
Time resolution after calibration

- Three subsystems of KLM: RPC in BKLM, scintillator in BKLM and scintillator in EKLM
- The time resolutions achieved: $6.6ns, 7.3ns, 3.8ns$
- Resolution of readout is $\sim 1ns$
- Still possible to improve it in the future.



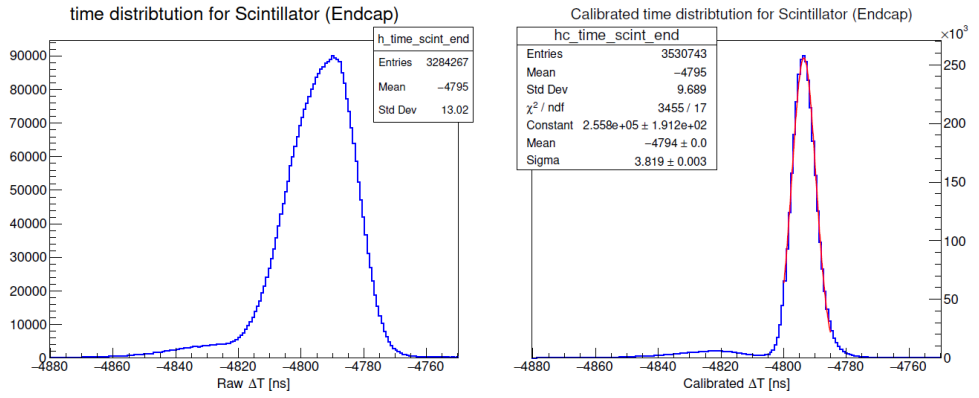
(a) (b)

FIG. 11: Global ΔT distribution before (a) and after (b) calibration for RPC.



(a) (b)

FIG. 12: Global ΔT distribution before (a) and after (b) calibration for BKLM scintillator.

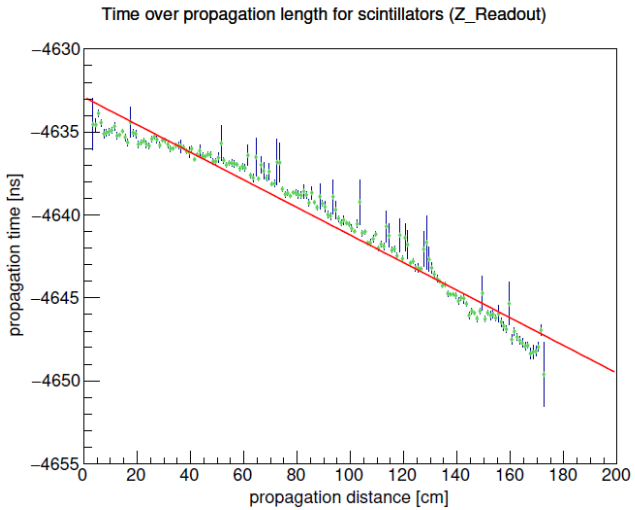


(a) (b)

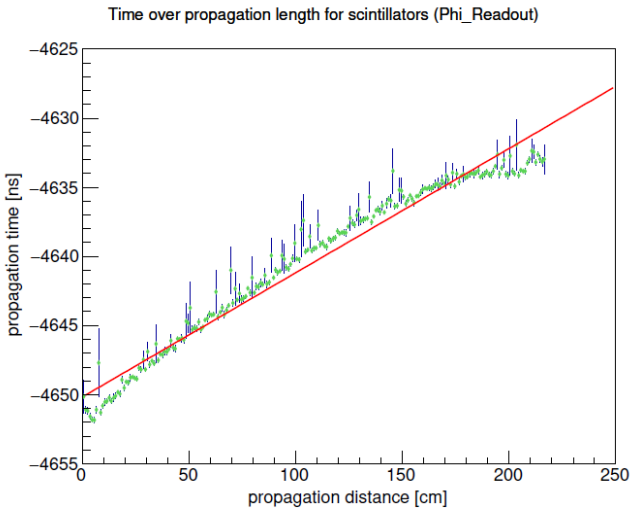
FIG. 13: Global ΔT distribution before (a) and after (b) calibration for EKLM scintillator.

β of light in materials

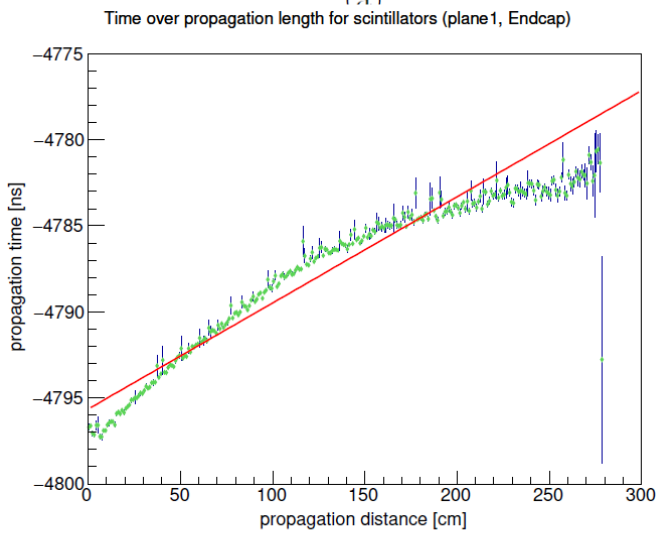
- Propogation time in a strip: scintillator and fibre
- Get $\beta \sim 0.5$
- This can be measured in the lab later.



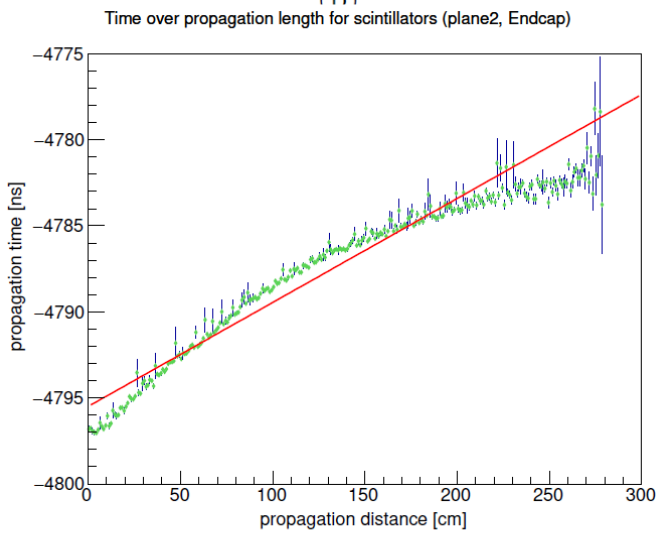
(a)



(b)



(a)



(b)

Summary

- Items got for muon detector R&D:
  - Scintillator, WLS fibre, MPPC, FE readout
- Systems setup for testings:
  - efficiency, ADC (light collection), …
- Study of MPPC parameters has been performed.
- Time calibration for Belle II KLM, which yields experience for CEPC muon detector.
- Two problems: noise from readout, coupling between MPPC and fibre.
  - Noise is mainly due to the power supply and no good ground.
- Plans:
  - More studies on scintillator, test with Belle II scintillator from Fermilab
  - Test with Kuraray WLS fibre, $D = 1.2mm$
  - Improve the quality of scintillator with company
  - Prototype construction: Multi-layer detectors
  - Precise time measurement
  - Unite more institutions for R&D?