Development of Upstream MEG II Radiative Decay Counter

MEG II 輻射崩壊同定用カウンター上流側検出器のプロトタイプビーム試験と設計最適化

Ryoto Iwai (東大理)

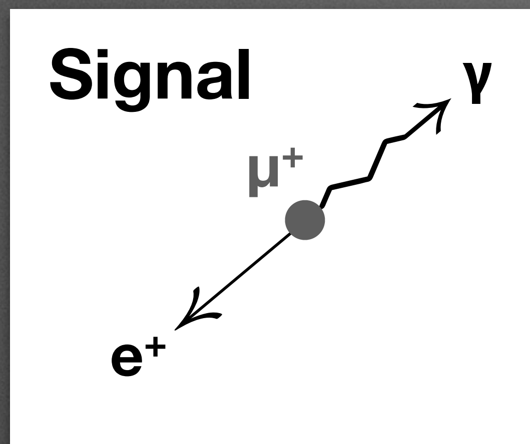
on behalf of MEG II collaboration

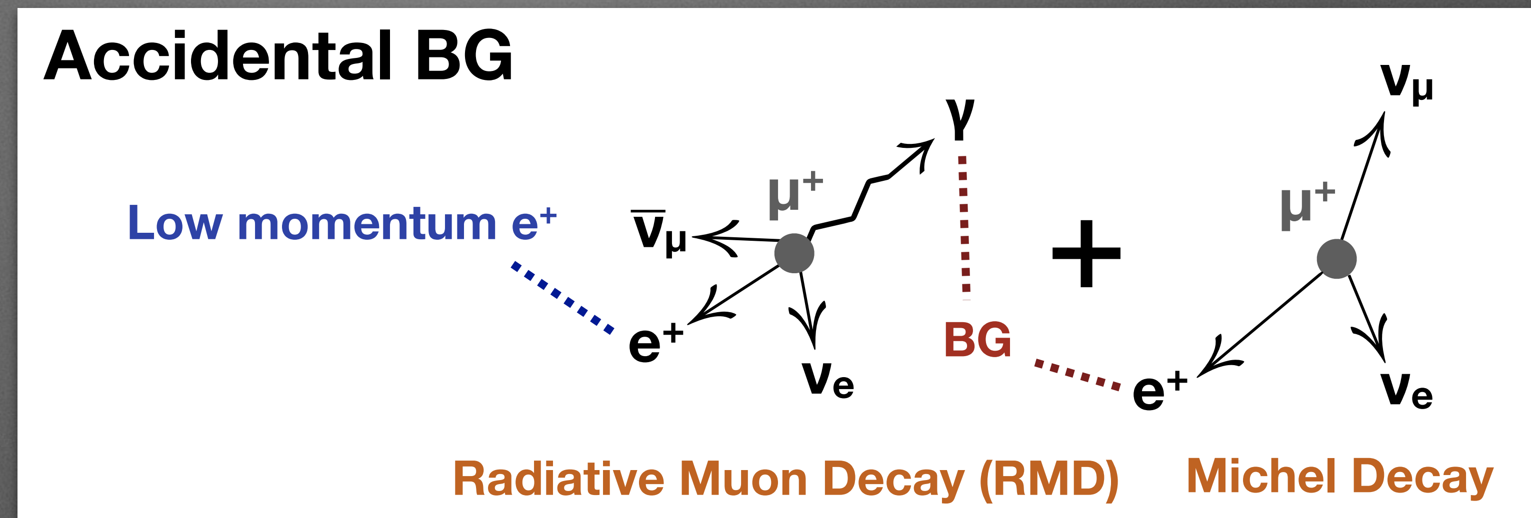
Contents

1. Introduction

Radiative Decay Counter (RDC)

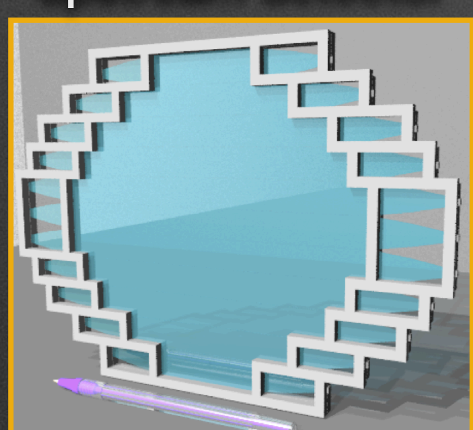
- Accidental BG is the dominant BG in $\mu^+ \to e^+\gamma$ search



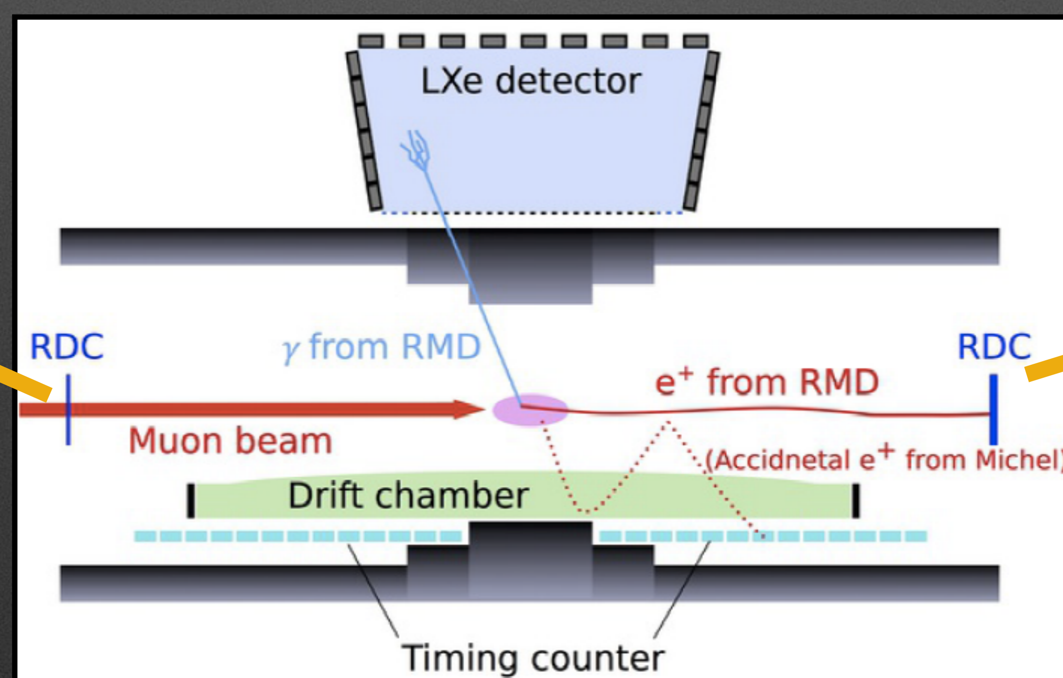


- RDC measures time coincidence of low momentum e^+ and BG γ on μ beam axis by fast timing counters based on plastic scintillators

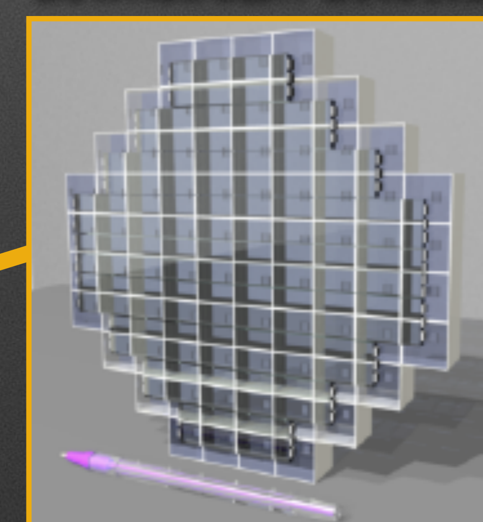
upstream detector



Scintillation fiber



downstream detector



Plastic scintillator

+

LYSO calorimeter

to distinguish high energy Michel e^+ →

Upstream detector

- The detector is designed to minimize the influence on μ beam
- Upstream detector measures only timing of e^+ with scintillation fiber

Scintillation fiber

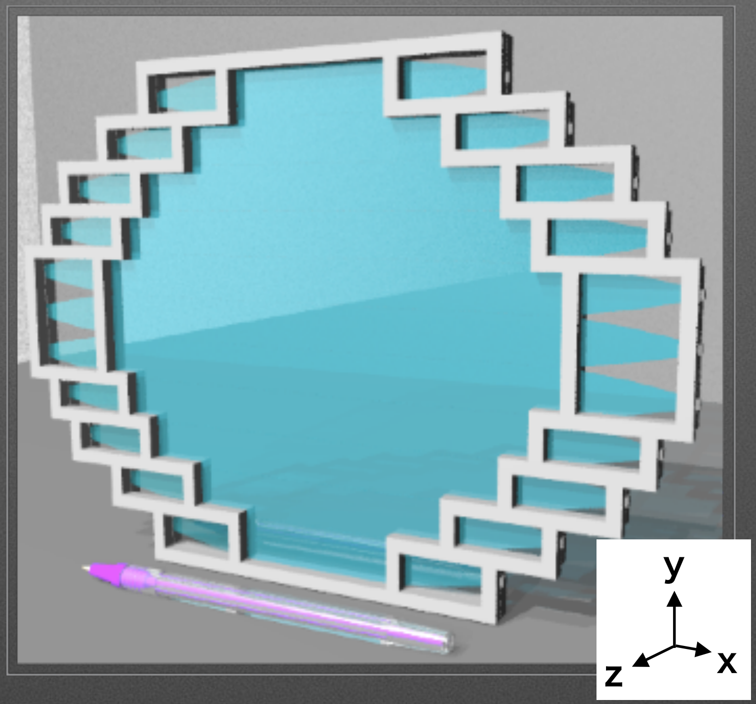
~20cm length

250 × 250μm^2 square shape

Photosensors

Hamamatsu, MPPC

readout at both ends



	MEG II sensitivity
w/o RDC	5.0×10^{-14}
w/ downstream	4.3×10^{-14}
w/ downstream + upstream*	3.9×10^{-14}

*assuming detection efficiency ~90%

*inefficiency due to μ pile-up is NOT considered

- Following studies are needed
    1. Influence on the μ beam properties
    2. Detection inefficiency due to μ pile-up
    3. Radiation damage of scintillation fiber & MPPC

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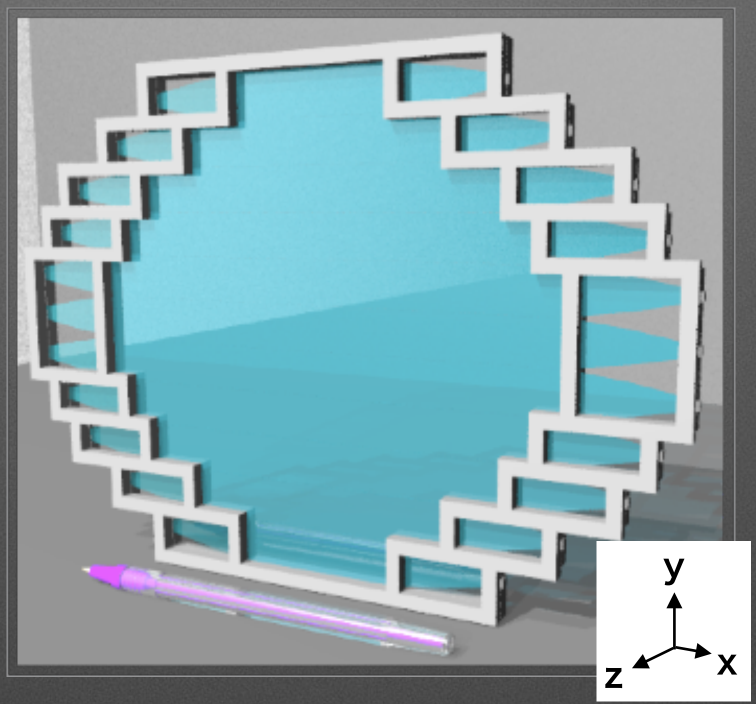

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- Following studies are needed
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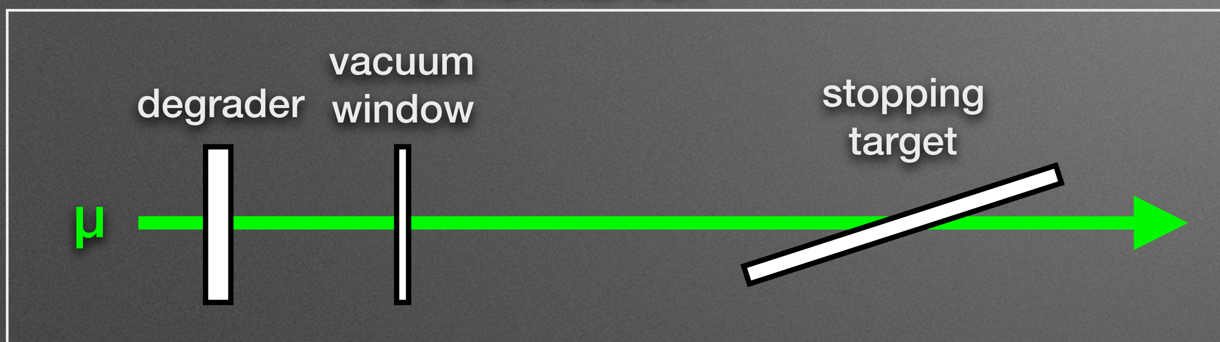
Today's topic

2. Impact on μ beam

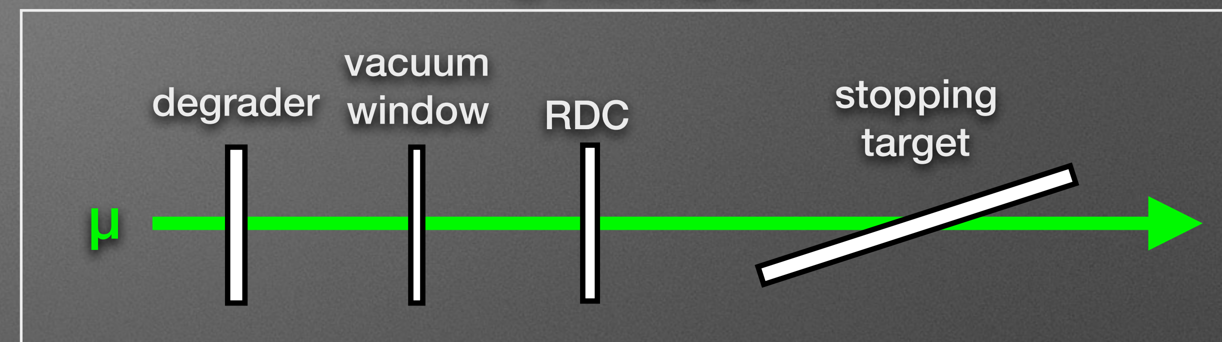
Study on beam spot

- 28MeV/c μ beam is slowed-down by degrader
- RDC will be installed with equalizing amount of material

① normal run



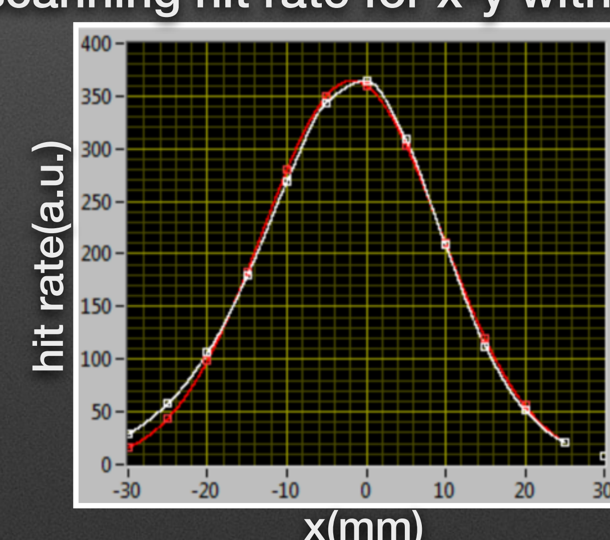
②with RDC



- <u>μ beam might be affected by putting material in different position</u>
- Studied influence with “dummy” RDC

dummy RDC
(230μm MYLAR foil)

scanning hit rate for x-y with APD



data
+
gauss fit

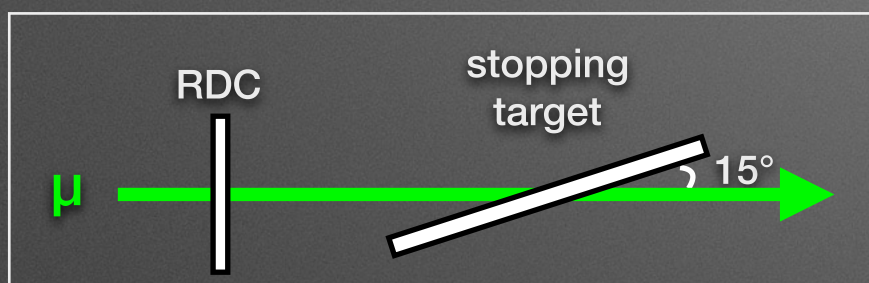
	σ_x(mm)	σ_y(mm)
normal run	10.7 ± 0.2	10.4 ± 0.2
dummy test	11.5 ± 0.2	11.2 ± 0.2

→ $\sigma_x \times \sigma_y$ increased by ~16%

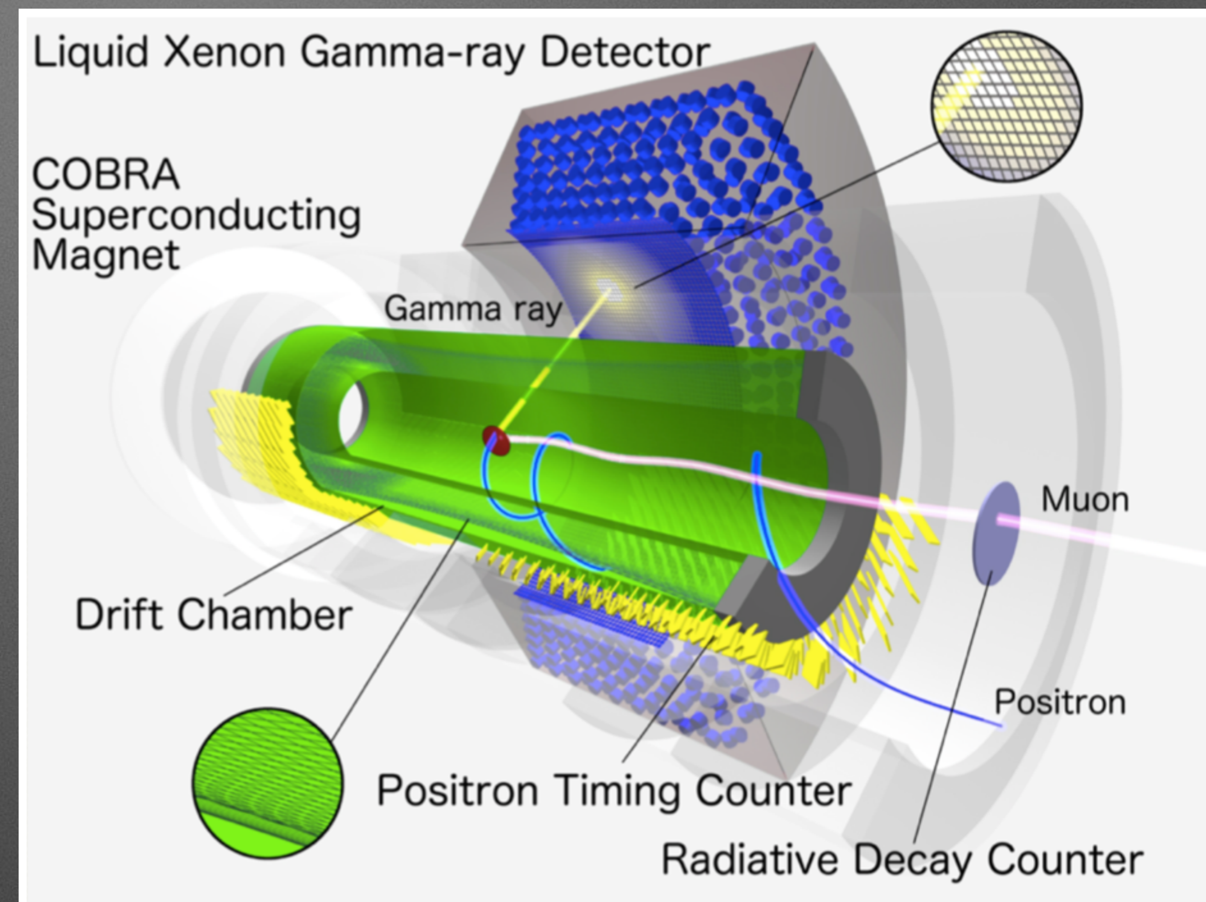
Influence with bigger beam spot

- e^+ trajectory bend by COBRA magnet

0.49T (endcap) ⟷ 1.27T (center)



μ vertex distributed in z
becomes wider



- Performance of e^+ tracking might be affected

① Long good track in the Drift Chamber might decrease
(more e^+ cross outer frame at the 1st turn)

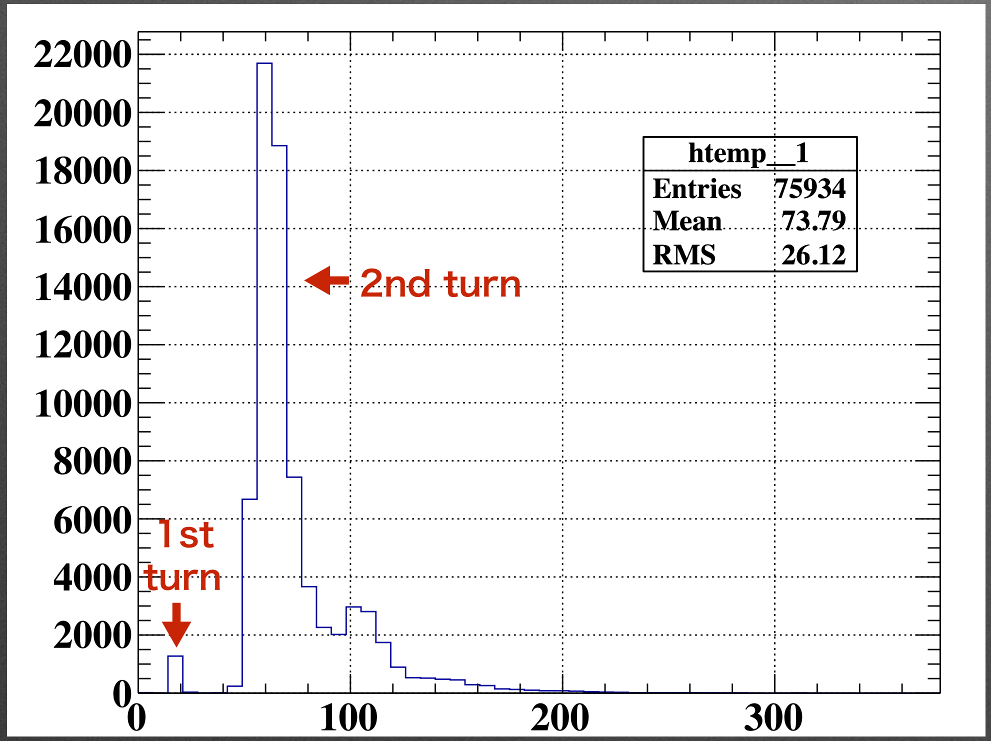
② Number of hitting Timing Counters might decrease

③ Hit rate might increase in the inner part of the Drift Chamber

Simulation study(Geant4 based)

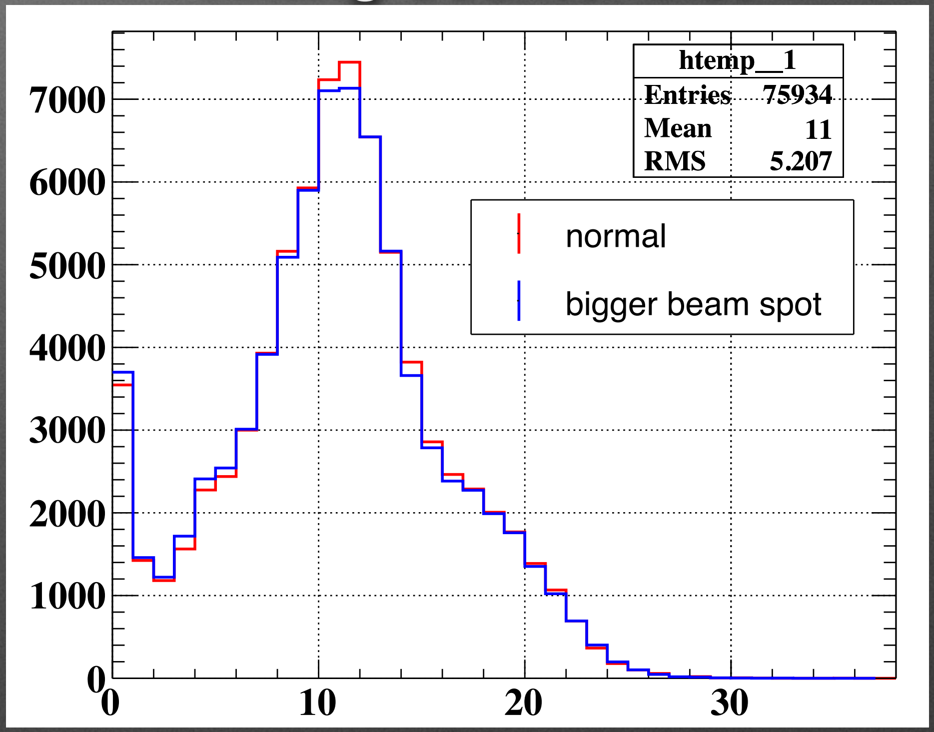
- Studied efficiency loss with signal event (event cut with LXe acceptance)

① N_{event} which crosses outer frame of Drift Chamber after 2nd turn



number of wire hits before crossing outer frame

② N_{event} which crosses at least 1 Timing Counter tiles



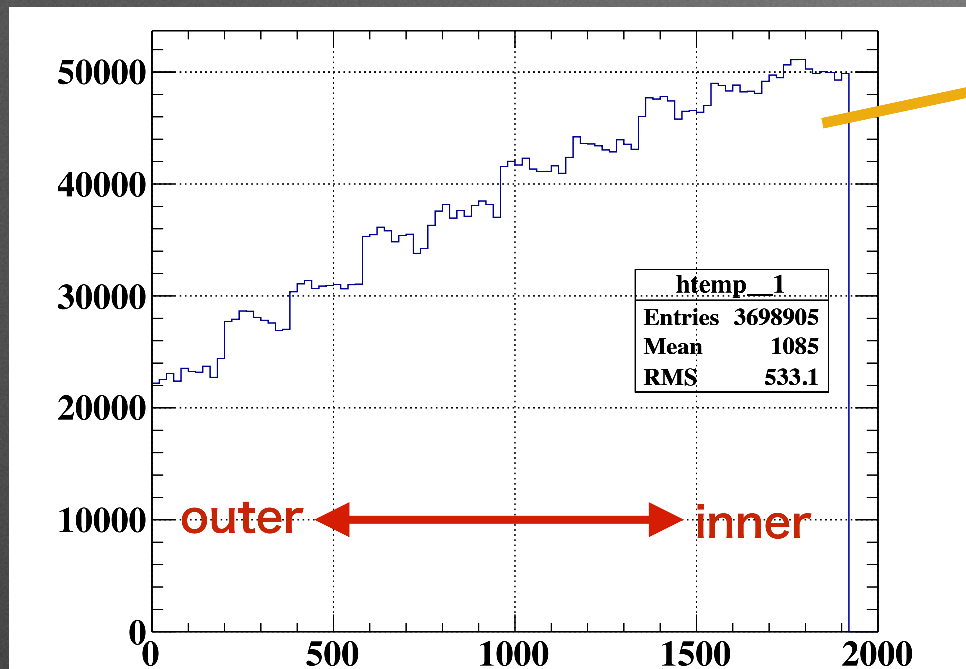
number of counters hit

efficiency of long tracking e^+

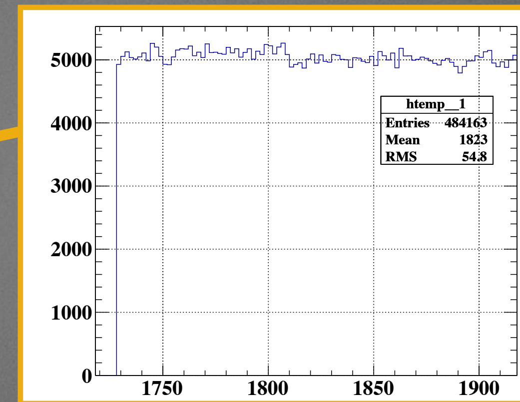
	①Drift Chamber	②Timing Counter	①×②
normal	98.25 ± 0.05%	95.33 ± 0.08%	93.73 ± 0.09%
bigger beam spot	97.65 ± 0.06%	95.11 ± 0.08%	92.99 ± 0.09%

→ efficiency decreased by ~0.8%

- Studied hit rate with Michel event (4π angle range, $7\times10^7 \mu/s$)
  - ③ Drift Chamber hit rate at the innermost layer



hit wire id



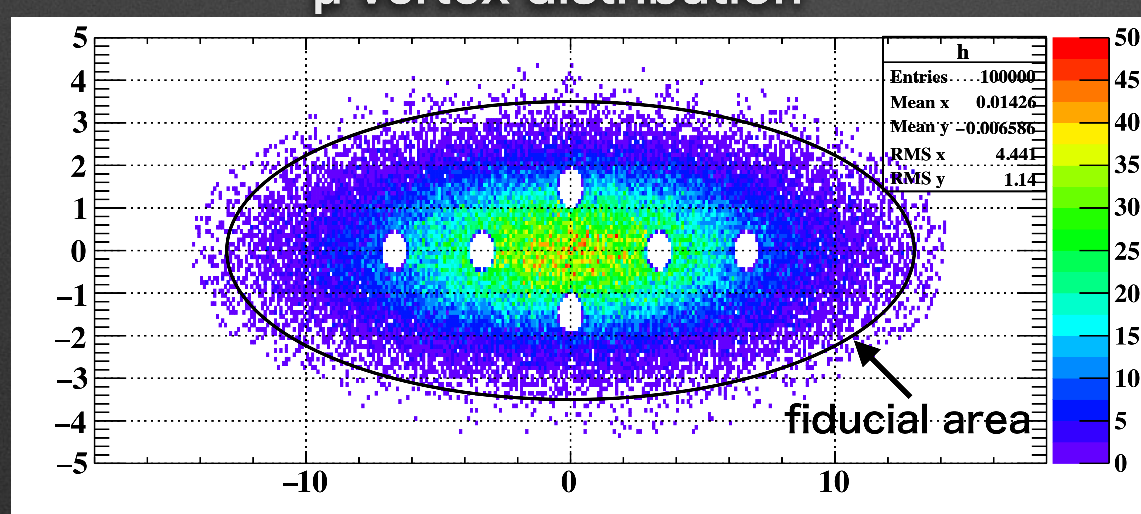
innermost layer (192wires)

	hit rate of single wire
normal	1.765 ± 0.003MHz
bigger beam spot	1.779 ± 0.003MHz

→ increased by ~0.8%

- Event loss on the target was also studied

μ vertex distribution



→ acceptance decreased by ~0.1%

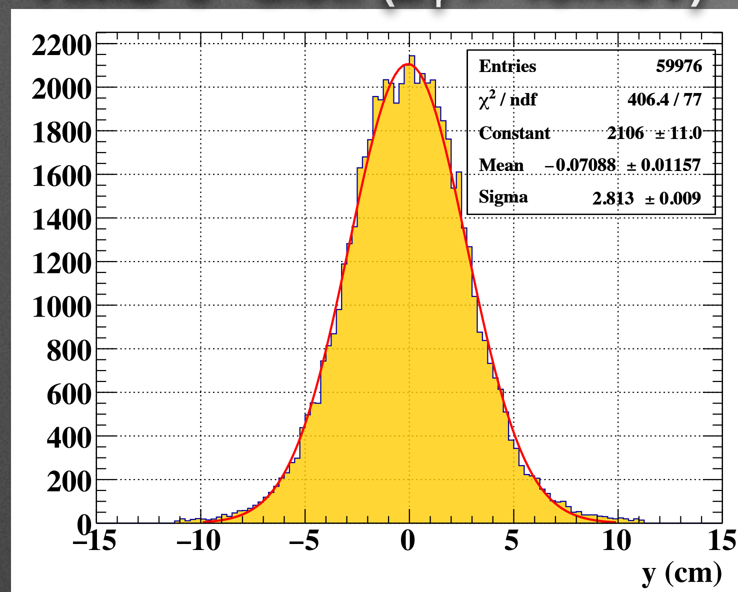
- The influence on beam seems small

3. Detection inefficiency due to μ pile-up

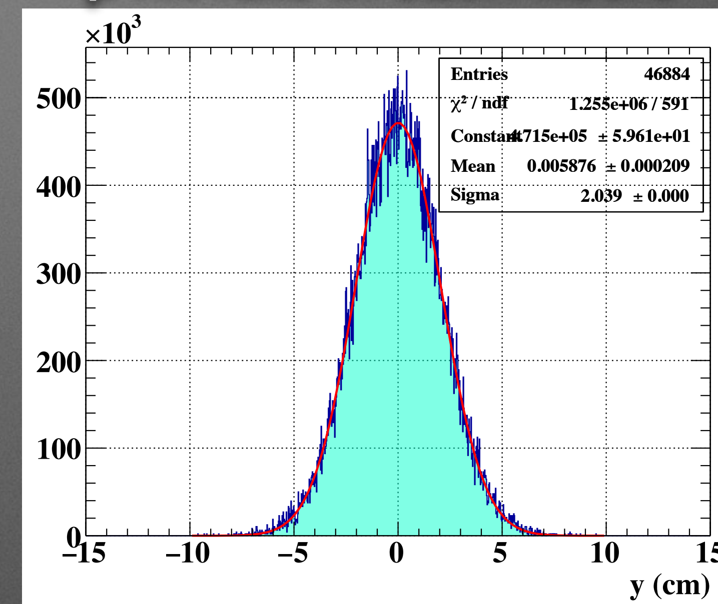
Detection Inefficiency due to μ pile-up

- Large μ hit rate at the central fiber (~500kHz with 10^8 μ/s intensity)

RMD e⁺ dist. (E_γ > 48MeV)



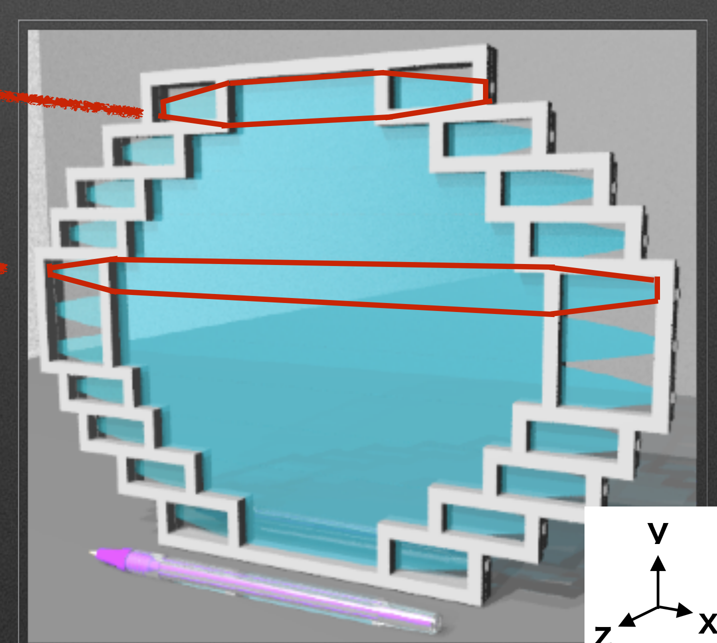
μ hit rate in each fibers



- Fibers are bundled and readout with single MPPC

larger bundles to minimize the number of channels

smaller bundle to minimize pile-up



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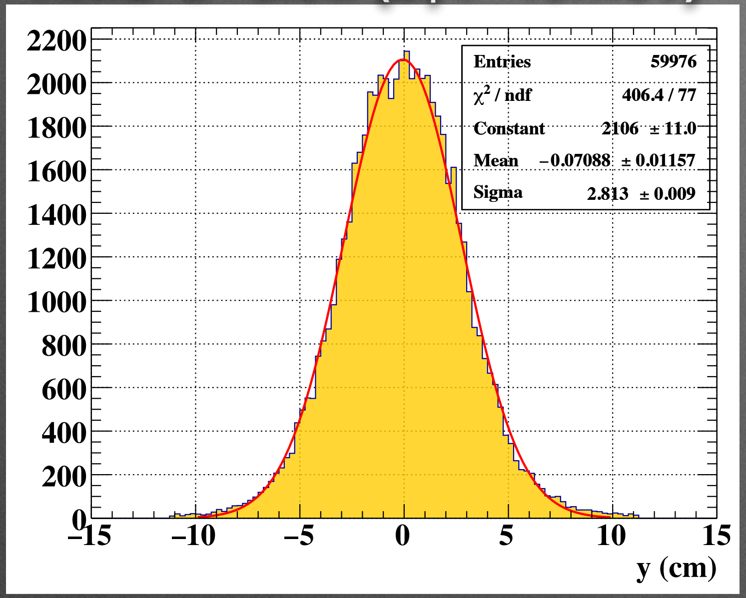
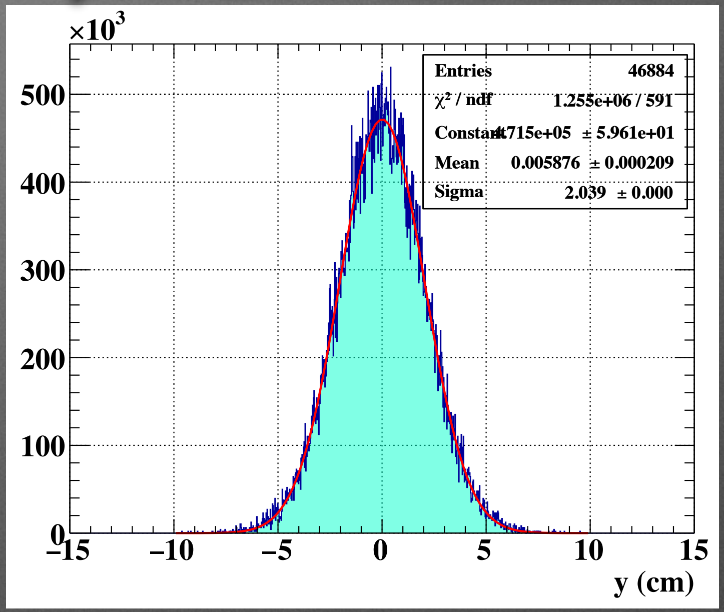


μ hit rate in each fibers



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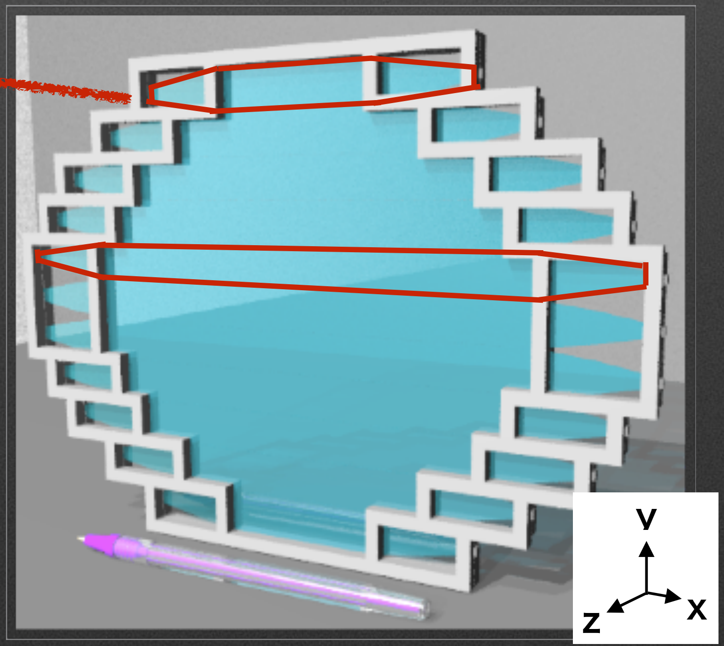
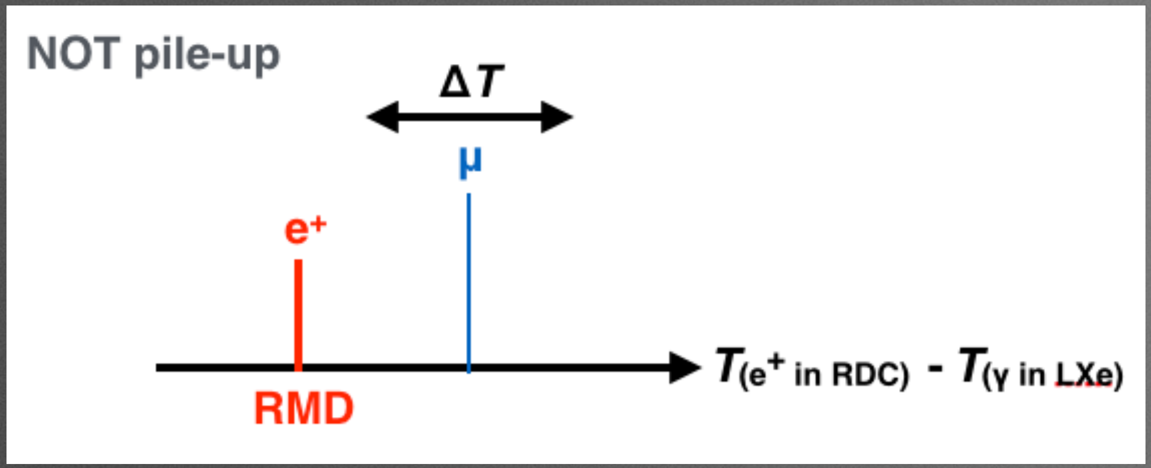
larger bundles to minimize the number of channels

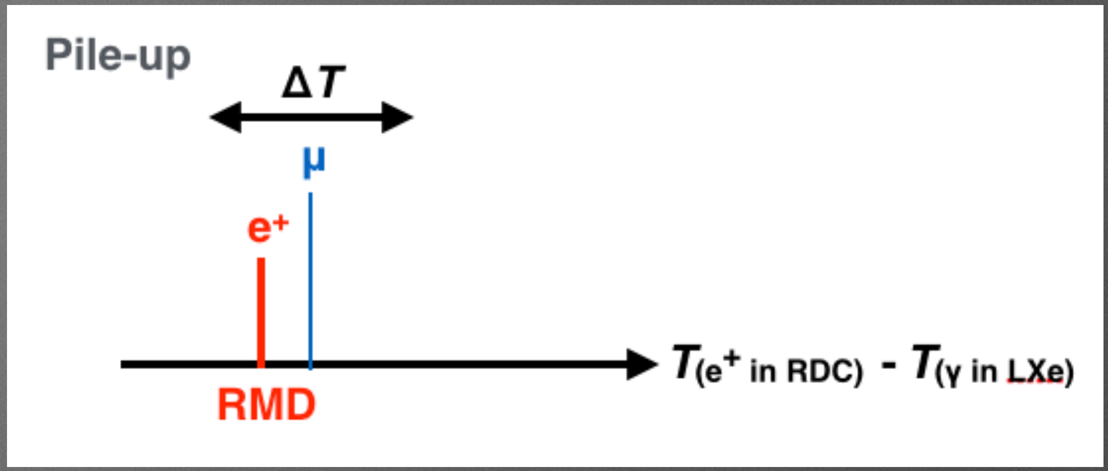
smaller bundle to minimize pile-up

Bundling way should be optimized



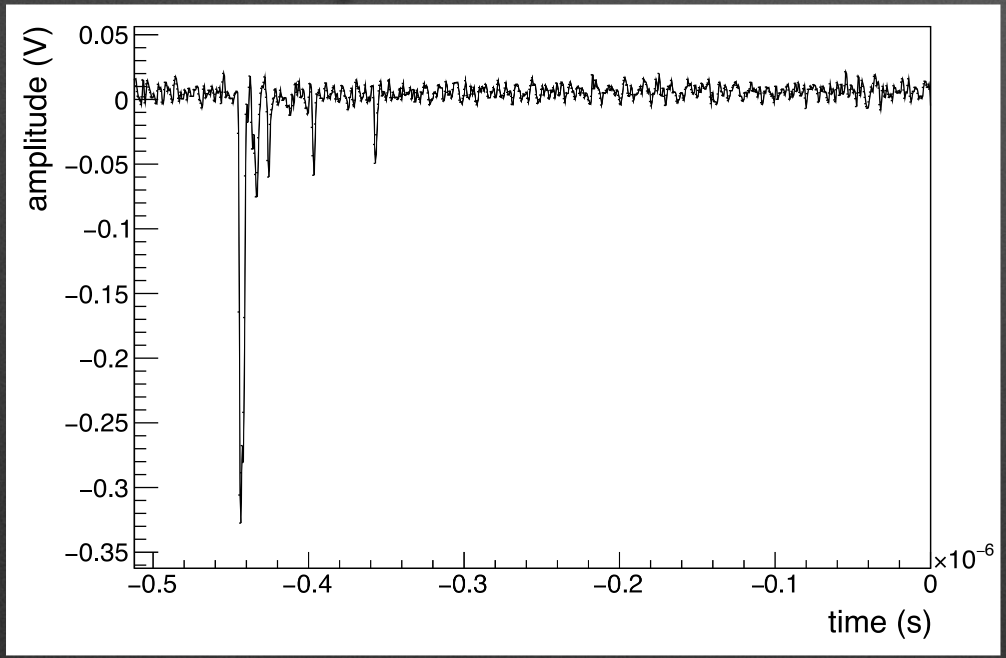
- Minimum timing difference(ΔT) to distinguish 2 waveforms



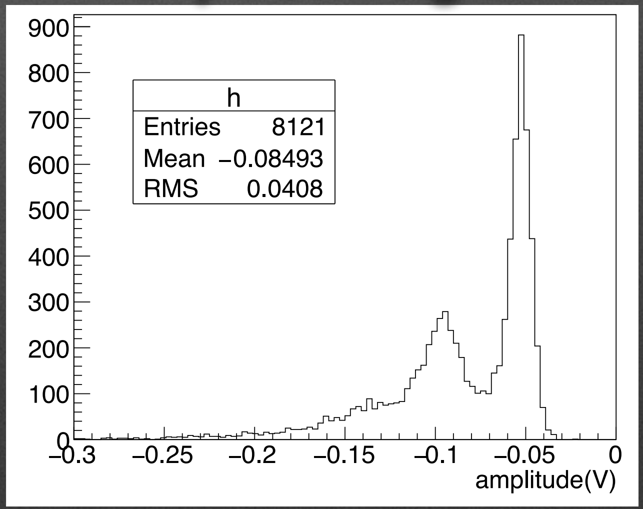


- μ waveforms have large width & after pulse

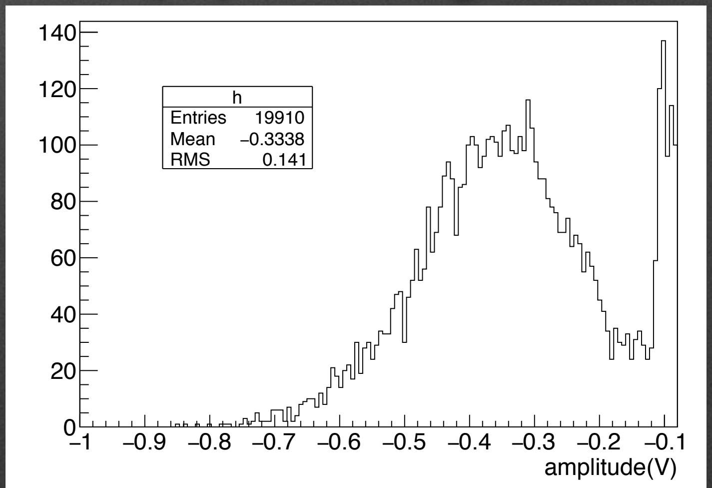
μ waveform



e+ pulse height



μ pulse height



- Actual ΔT needs be studied by acquiring real waveforms

- We used 28MeV/c μ & e^+ beam (at PiE5)

- Prototype detector (developed for RDC & 2D beam monitoring device)

Multi-clad scintillation fibre

2 layers (21fibers each)

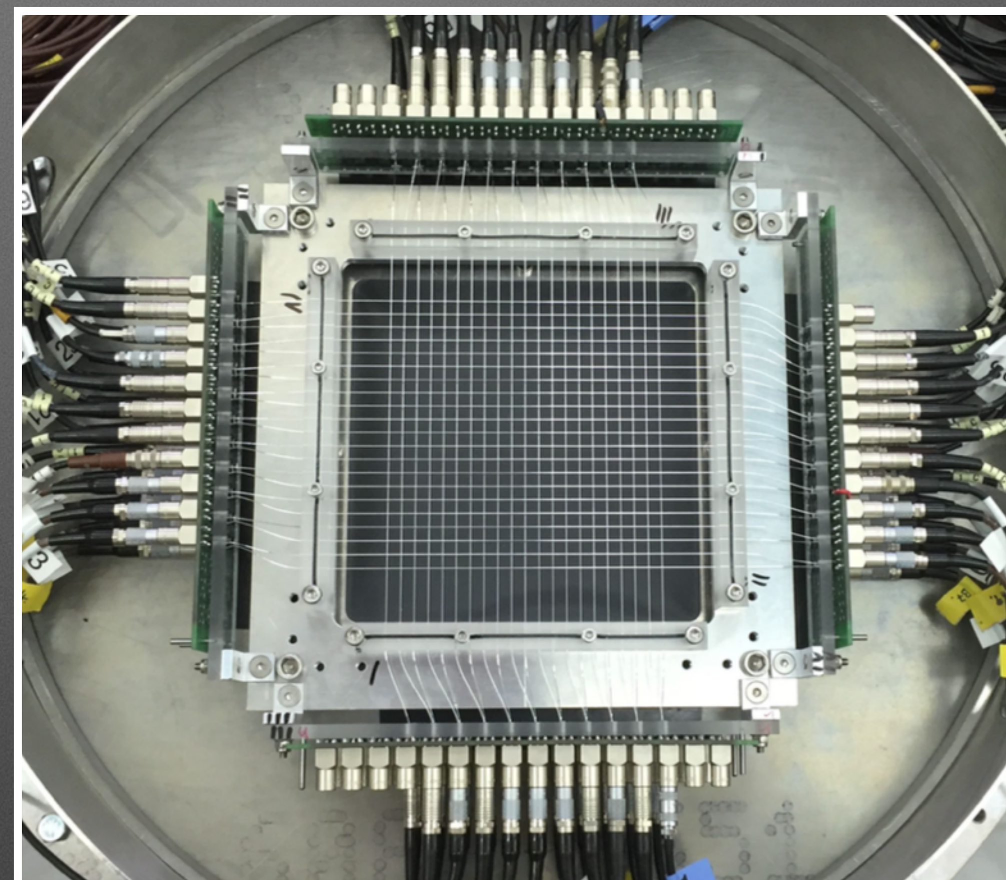
Saint Gobain (BCF12)

length ~20cm

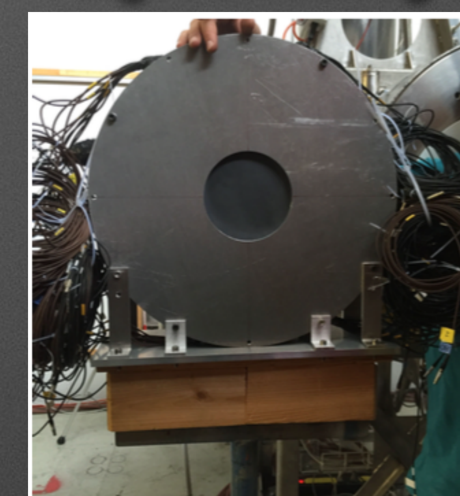
250μm × 250μm square shape

Photosensors

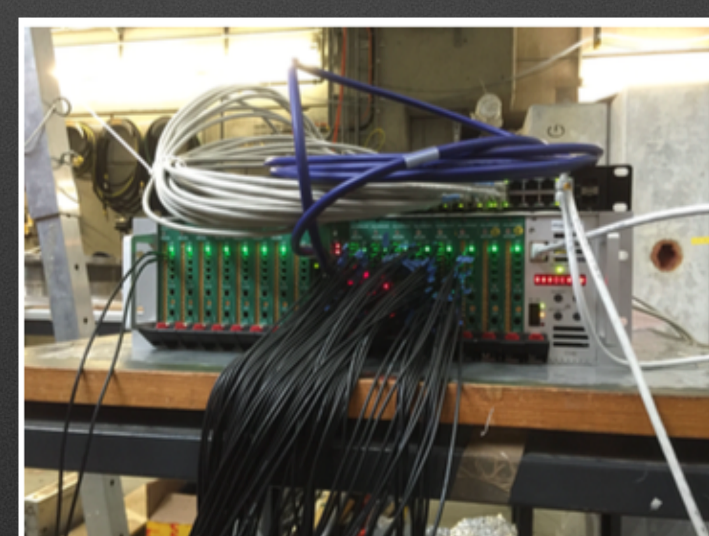
Hamamatsu
(MPPC, S13360-1350CS)



Light shielding



- DAQ machine (WaveDREAM)



amplifier (gain 100)
waveform shaper
waveform digitizer

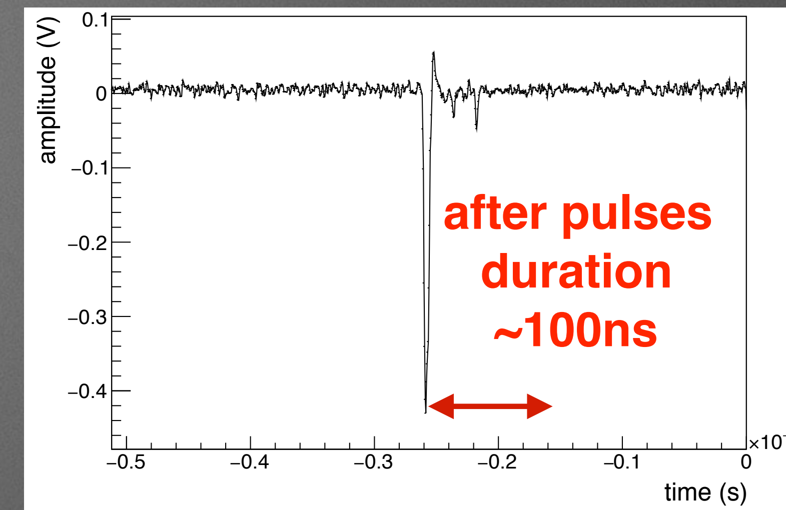
Waveform Analysis

- Step 1: μ & e^+ waveform selection

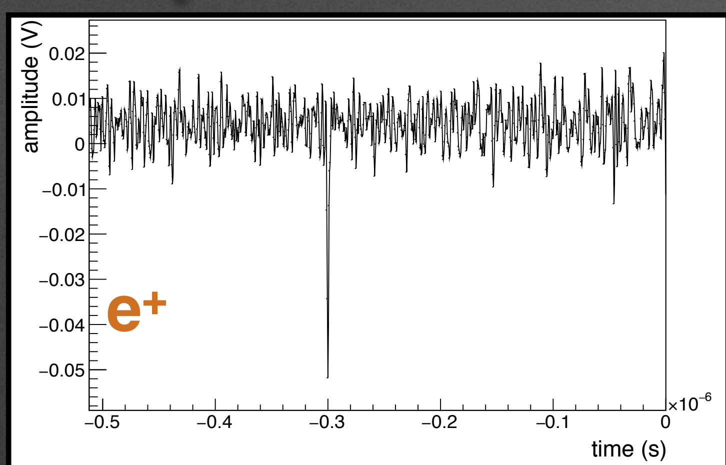
① coincidence at the both fiber ends

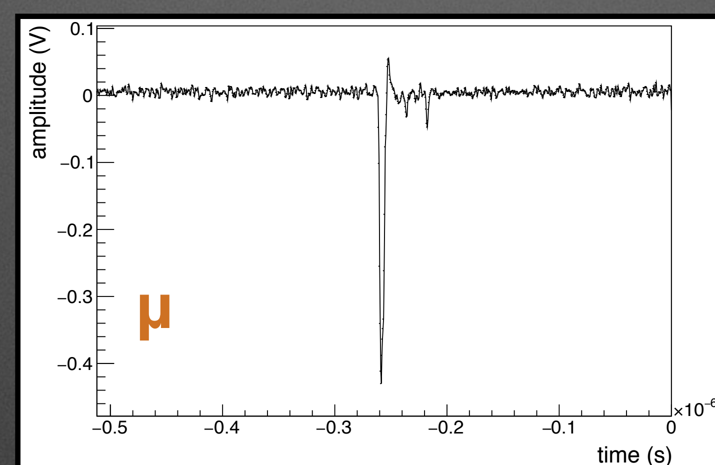
&&

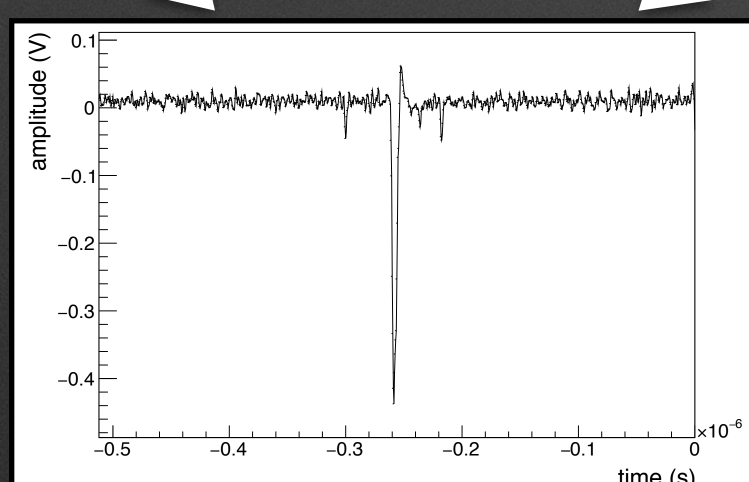
② single pulse cluster in each event



- Step 2 : Mix 2 waveforms

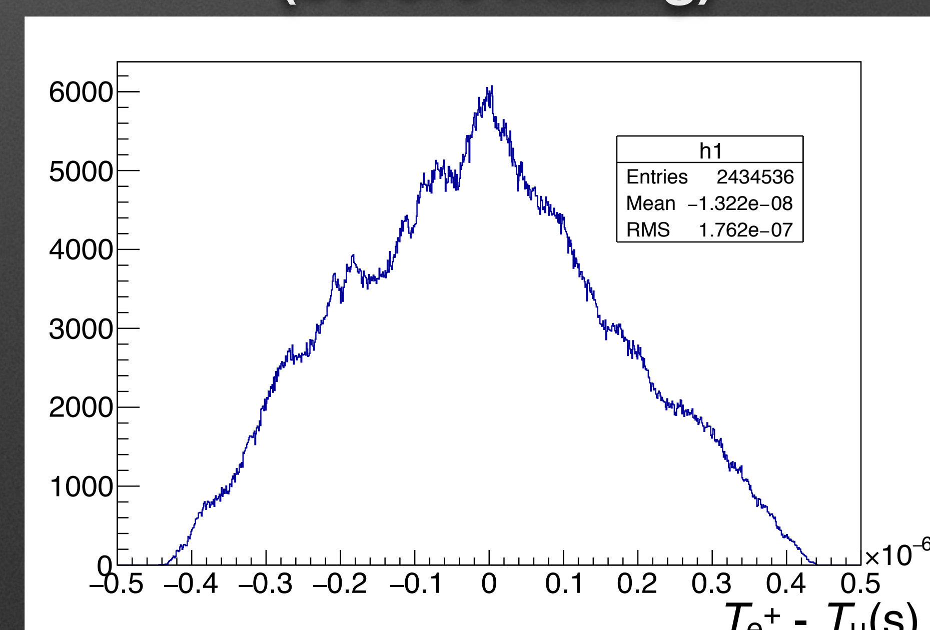






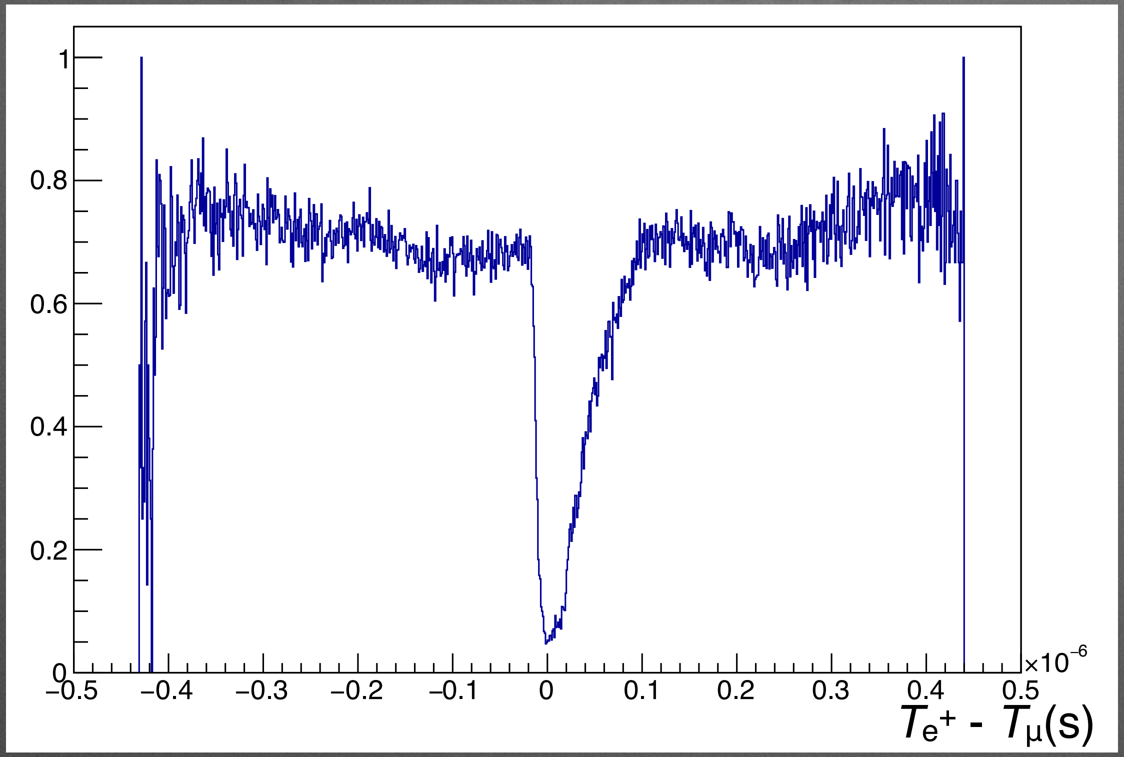
*noise level increased by 54%

time difference of 2 waveforms (before mixing)



- Step 3 : Reanalyze and search e^+ pulse in mixed waveforms

the ratio of e^+ found event



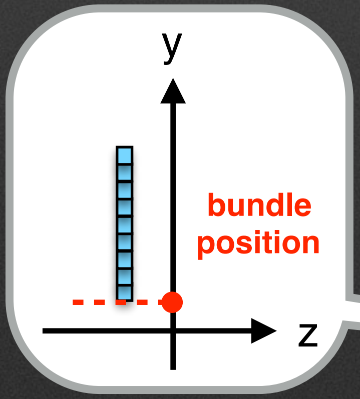
→ event decreased for ~120ns

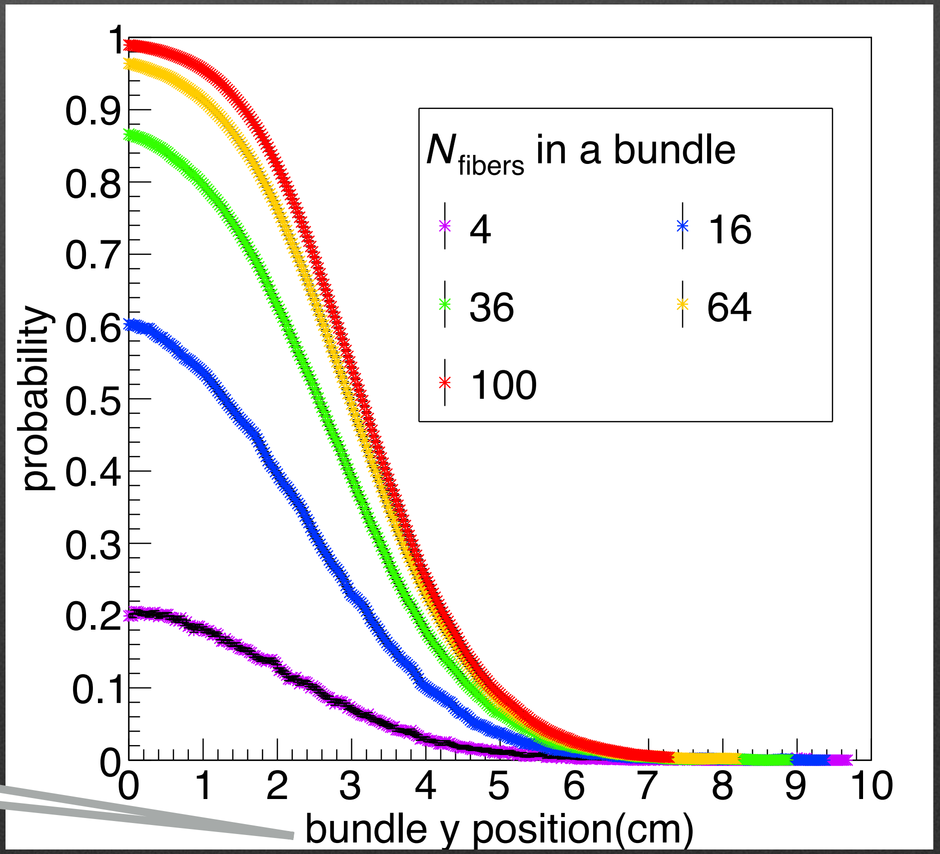
- Probability of pile-up was calculated for each bundle size (ΔT = 120ns)

$$P = N_{\text{pile-up}}/N_{\text{RMD}}$$

$N_{\text{pile-up}}$: number of pile-ups with μ in a bundle

N_{RMD} : number of detected RMD e^+ in a bundle



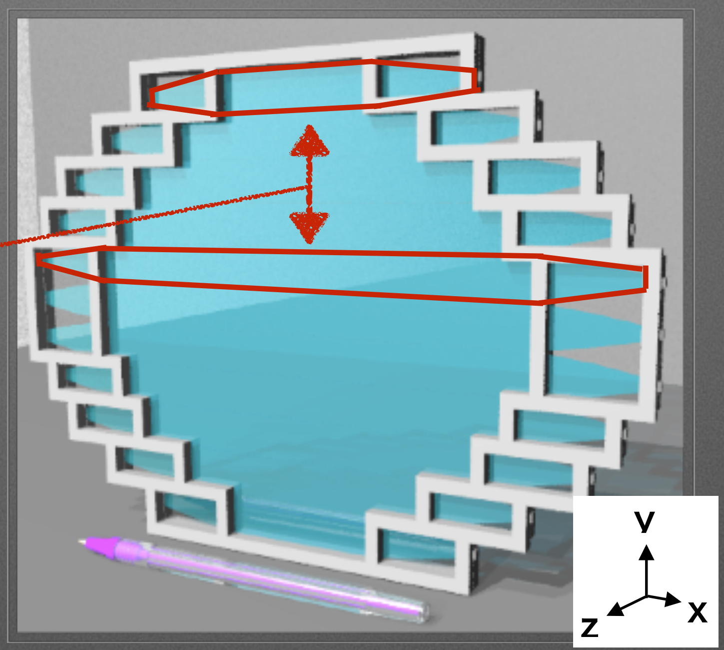


Inefficiency & Sensitivity

- In provisional design, $N_{\text{bundle}} = 18$

optimized combination to minimize Ineff.

bundle size	N_{bundle}
100	2
49	1
36	1
25	1
16	4

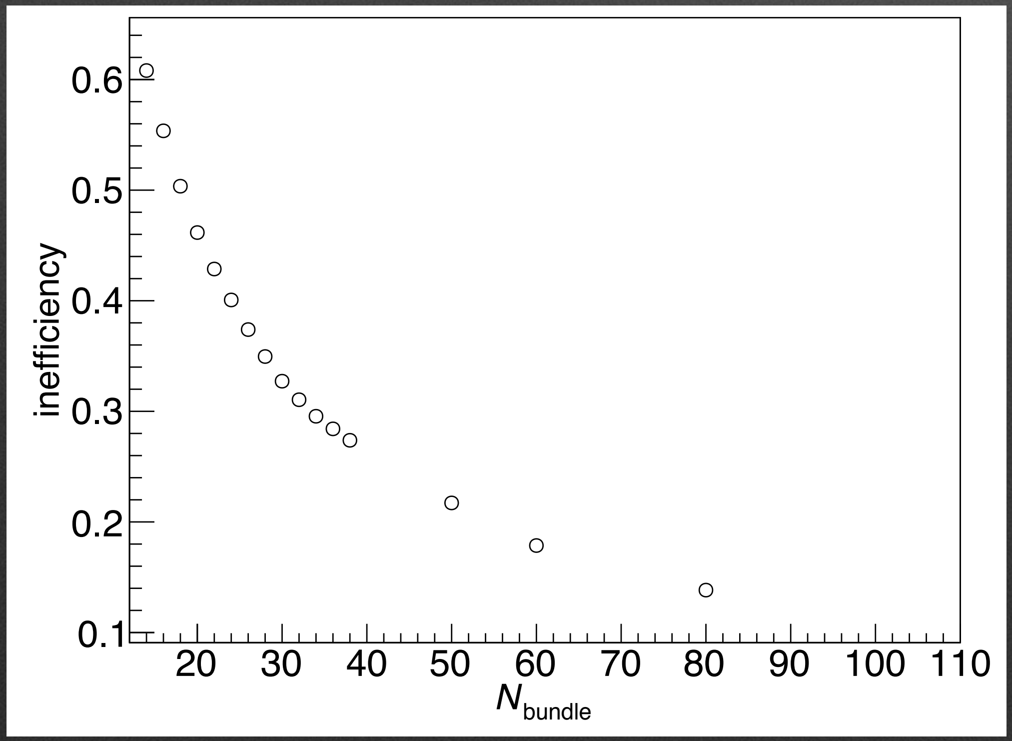


minimum Ineff. (ΔT = 120ns) = 50.4 ± 0.1%

BG reduction capability -> ~ -28%

estimated sensitivity -> BR($\mu \to e\gamma$) ~4.11×10^{-14}

- N_{bundle} vs Ineff. (ΔT = 120ns)



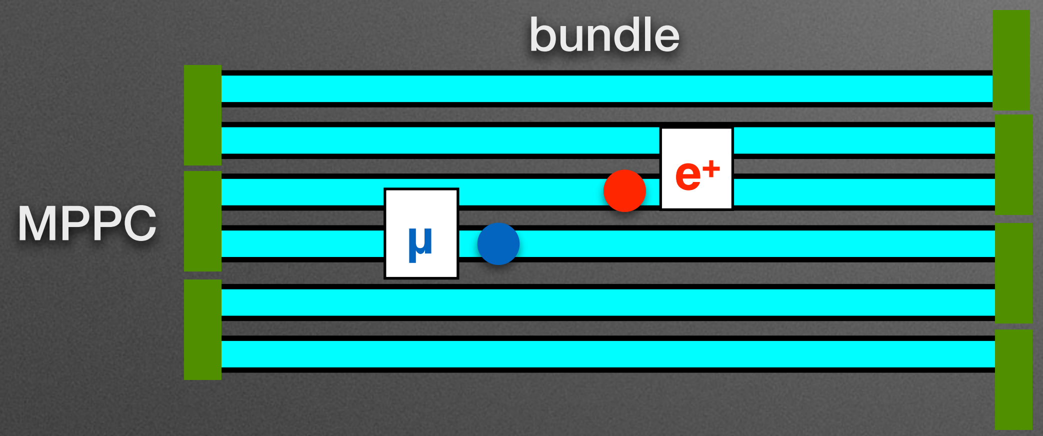
- ΔT vs Ineff. ($N_{\text{bundle}} = 18$)

ΔT (ns)	Ineff.	sensitivity($\times10^{-14}$)
0	0.0%	3.90
30	16.6%	3.97
60	30.1%	4.03
100	44.5%	4.09
120	50.4%	4.11

Prospect to make Ineff. smaller

- 1. Increase N_{bundle} (currently limited by available space for readout)

- 2. Staggered reading out method



*e⁺ can be detected in one side with pile-up

*Ineff. can be reduced by ~1/2

*possibility of this design is under discussion

- 3. Make PDF of the after pulse and use it in likelihood analysis (characterization of the after pulse should be studied)

- 4. Optimize MPPC (50μm pixel pitch was used in this test)

Summary

- R&D of the upstream RDC is ongoing
- The impact on μ beam was studied
- The influence with the bigger beam spot is small

relative changes with the upstream RDC

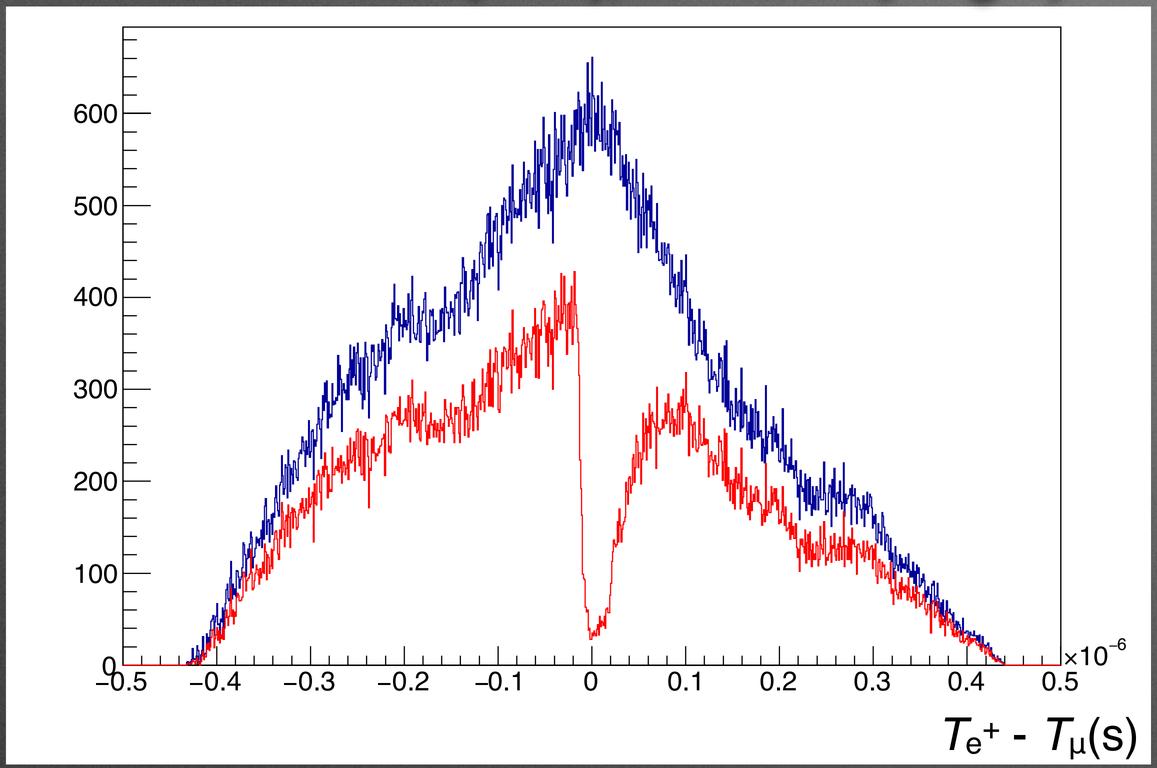
beam spot($\sigma_x \times \sigma_y$)	acceptance	e^+ long tracking efficiency	Drift Chamber hit rate
+16%	-0.1%	-0.7%	+0.7%

- However, the detection inefficiency due to μ pile-up is large(~50%)
- The way to minimize it is under investigation

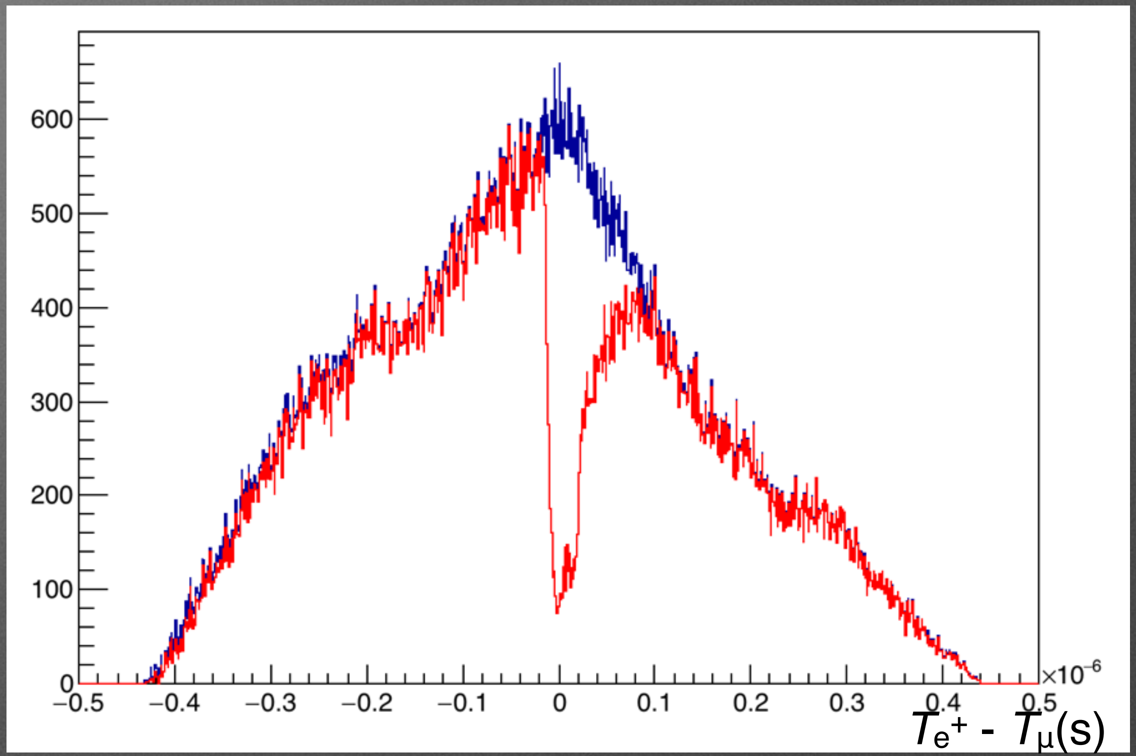
Back up

Distribution of T_{e^+} - T_μ(s)

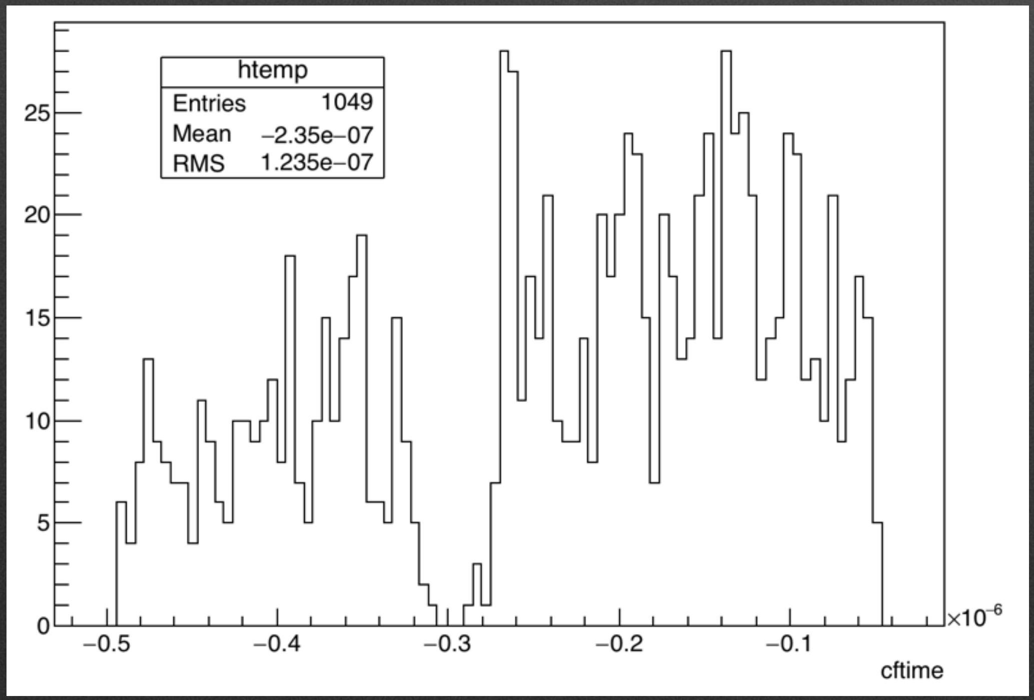
e⁺ true +/- 10ns(time), +/- 10mV(height)



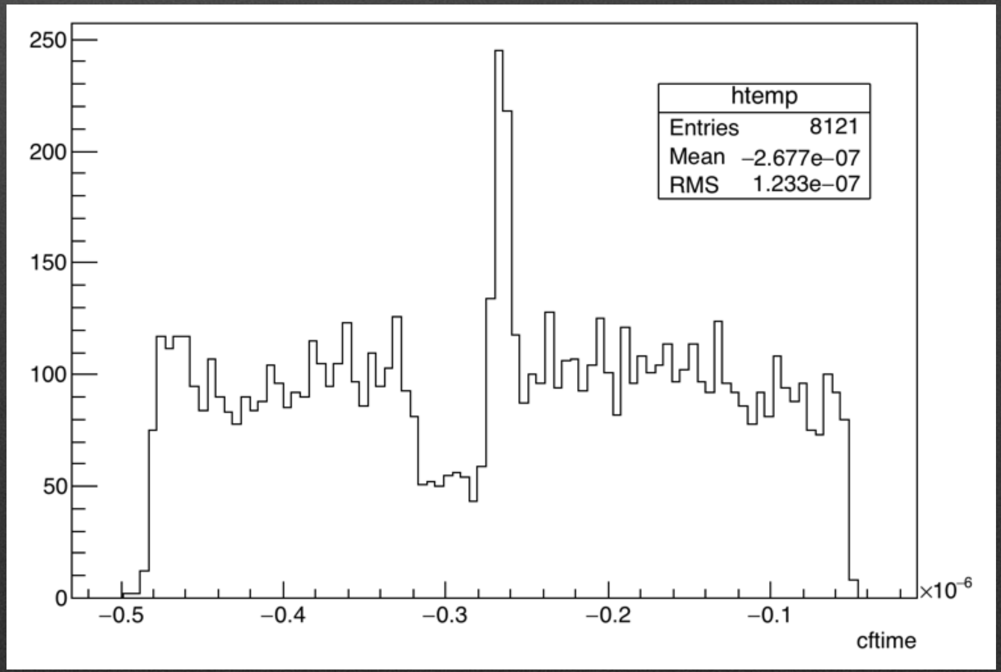
e⁺ true +/- 20ns(time), +/- 20mV(height)



μ time

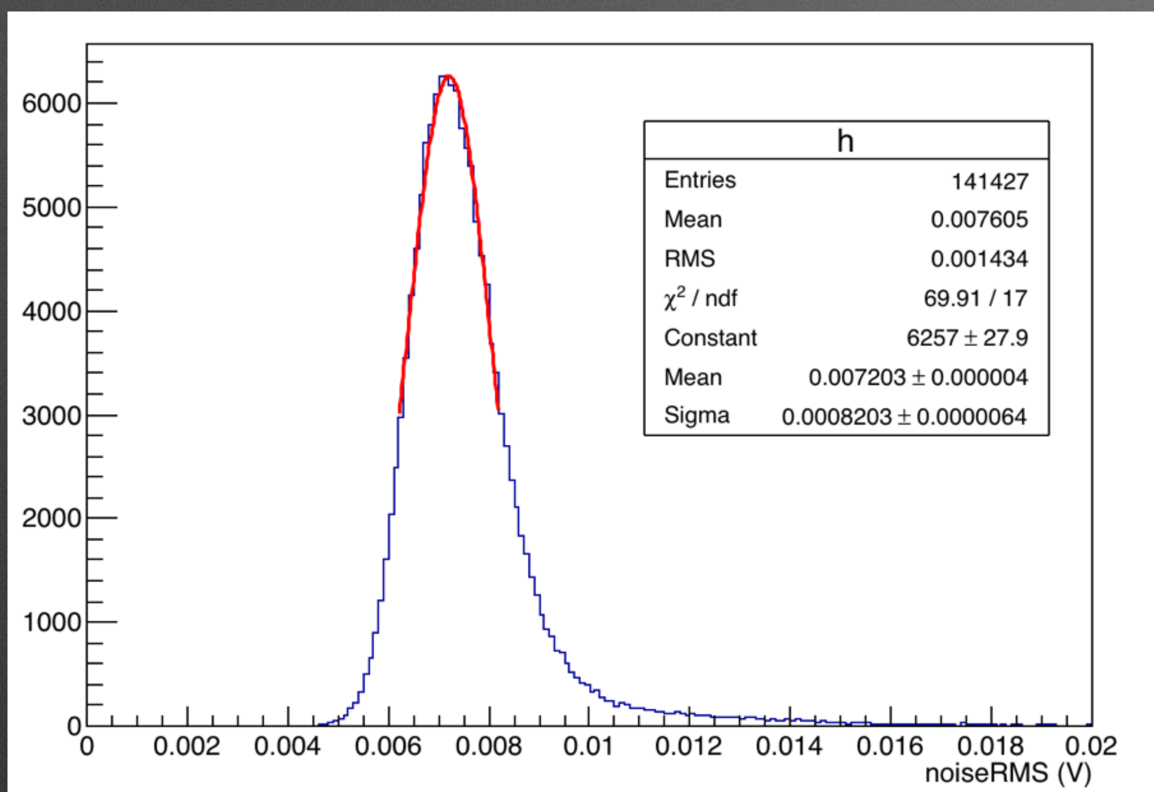


e⁺ time

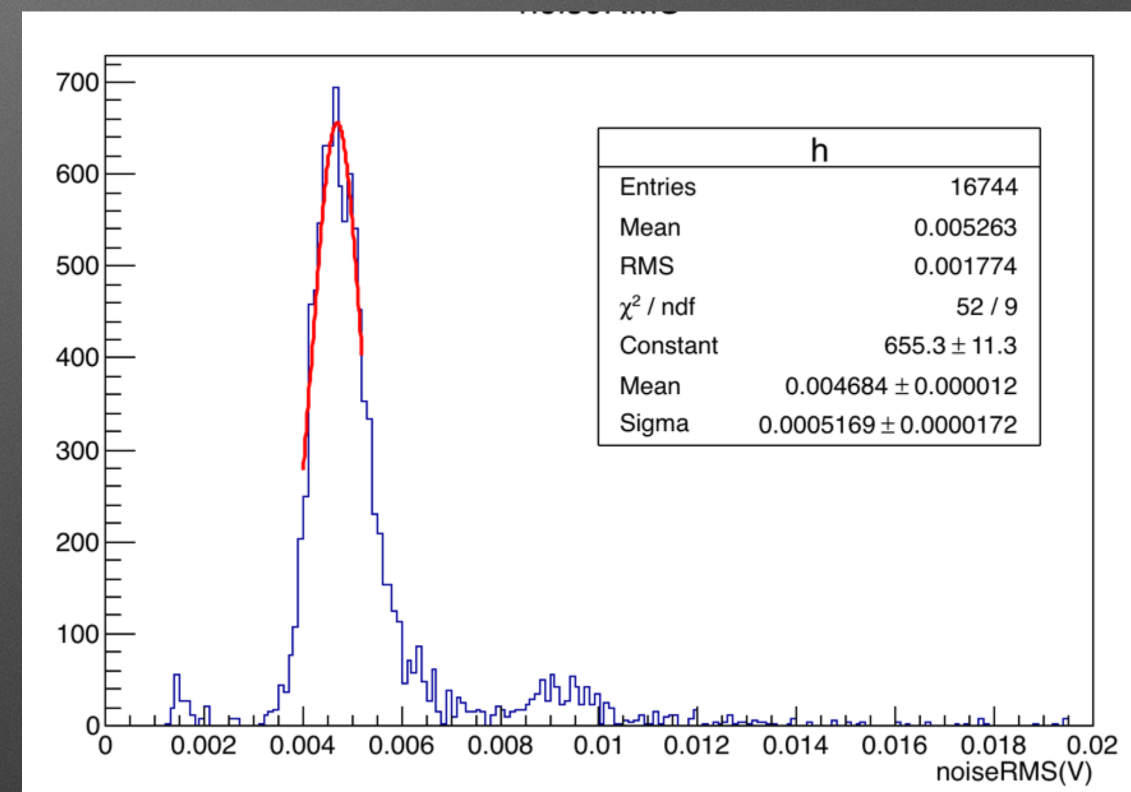


Noise RMS

Mixed waveforms



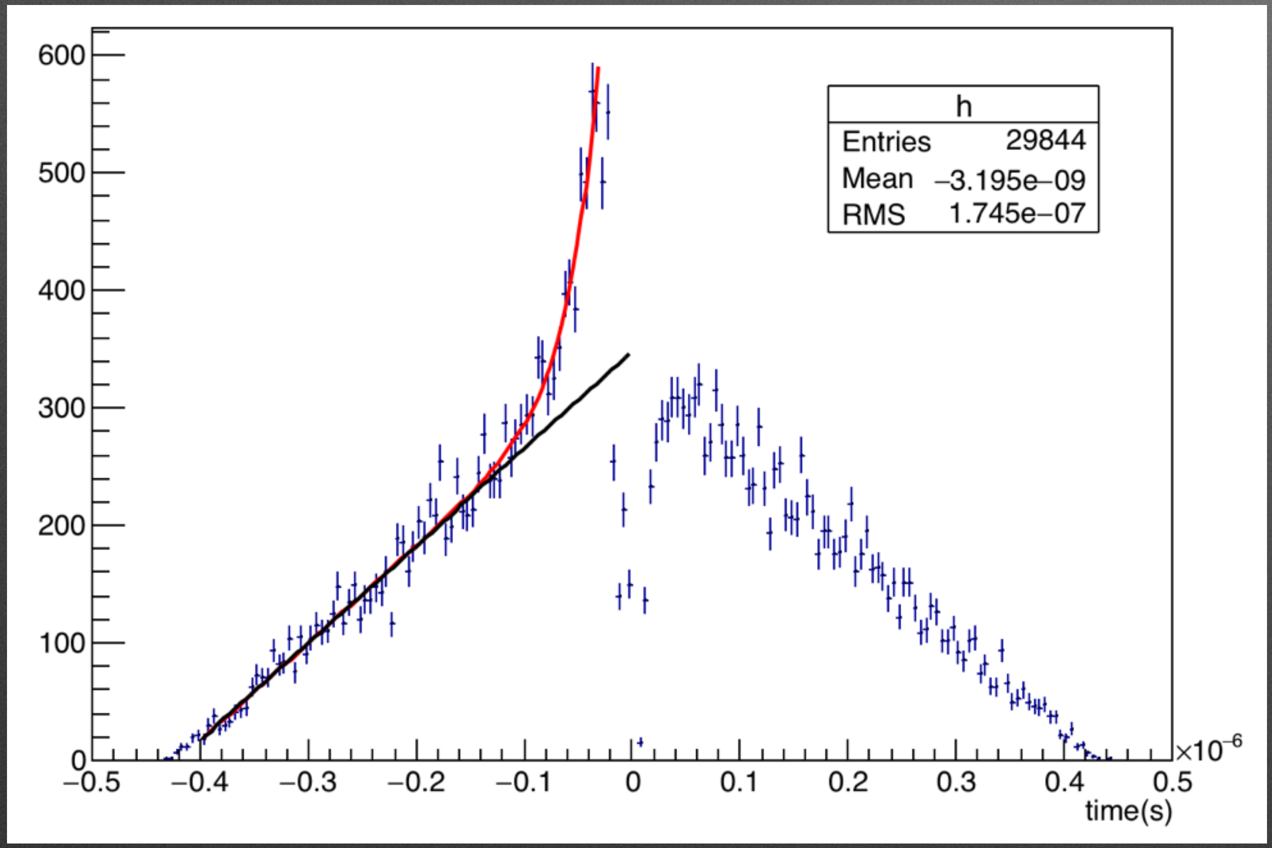
Before mixing



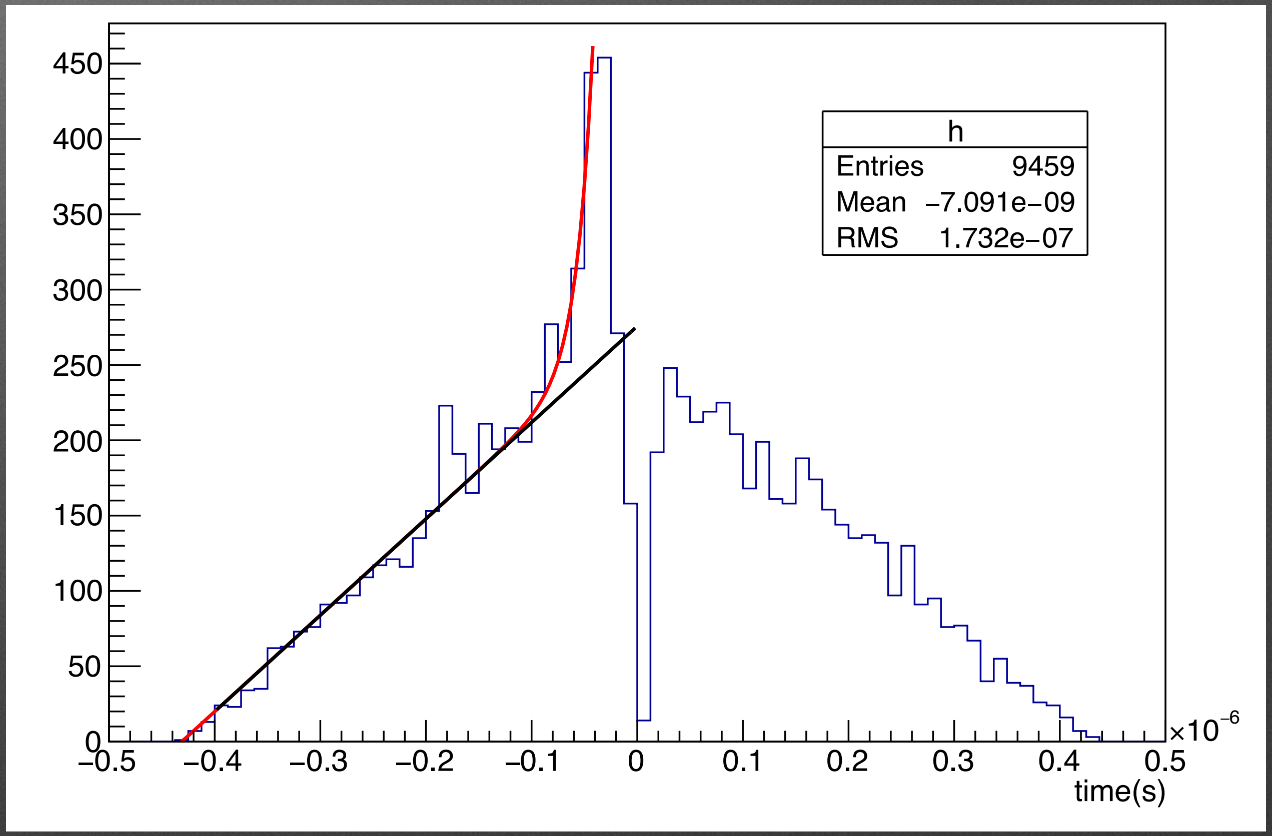
After pulse time

- Time difference from main pulse (largest pulse height)

e+



μ

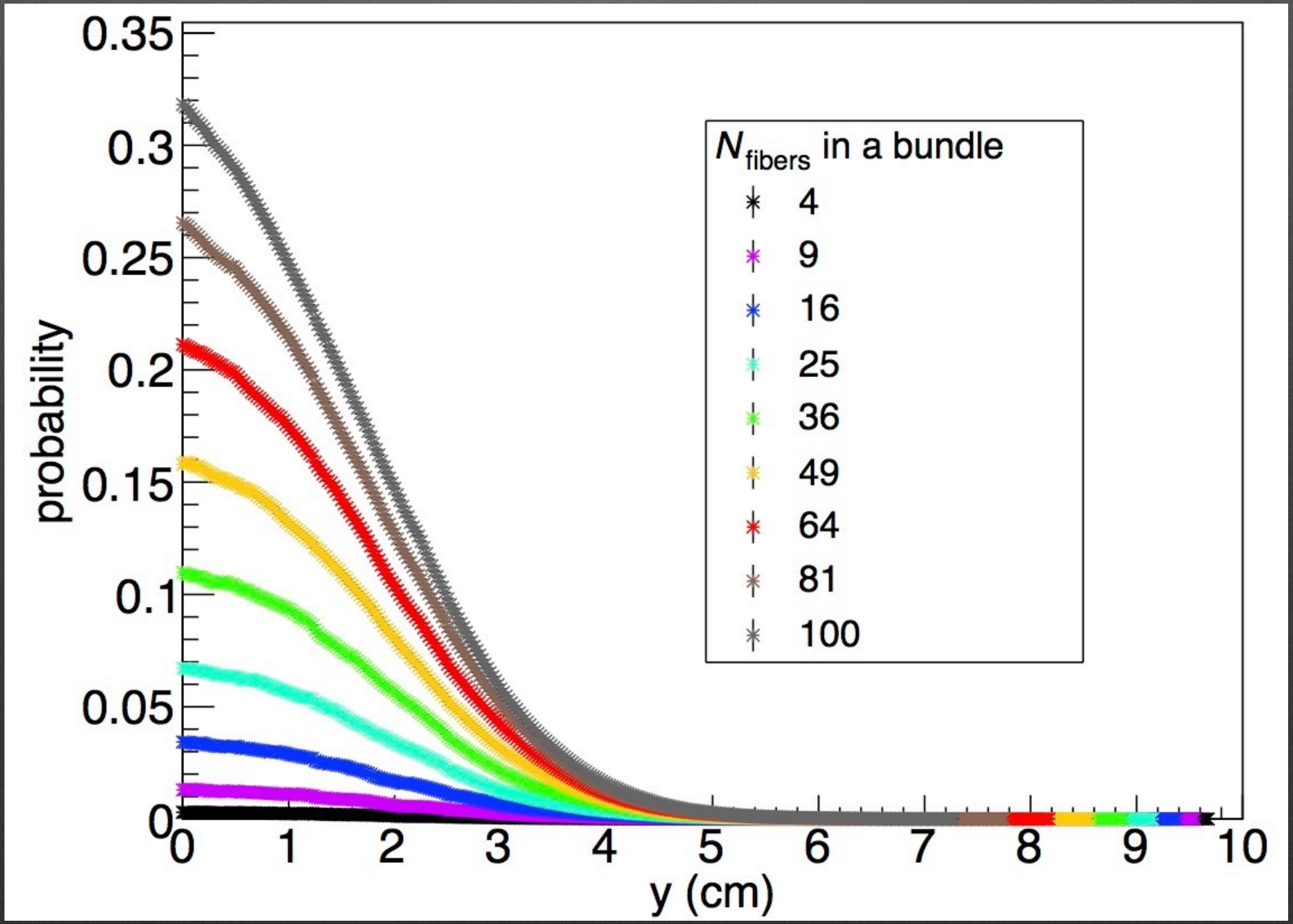


Probability of pile-up 2

P2 = $N_{\text{pile-up}}/N_{\text{RMD2}}$

$N_{\text{pile-up}}$: number of pile-ups with μ in a bundle

N_{RMD2} : number of detected RMD e^{+} in a whole detector



Beam & Target parameters

- Beam parameters (from result of dummy test)

	σ_x(mm)	σ_y(mm)
normal	10.7 ± 0.2	10.4 ± 0.2
w/ dummy	11.5 ± 0.2	11.2 ± 0.2

- Target angle : $\theta = 15°$

- 2 target shape

  → standard : same size as the beam test

  → bigger : able to cover both $6\sigma_x$ and $6\sigma_y$ with dummy

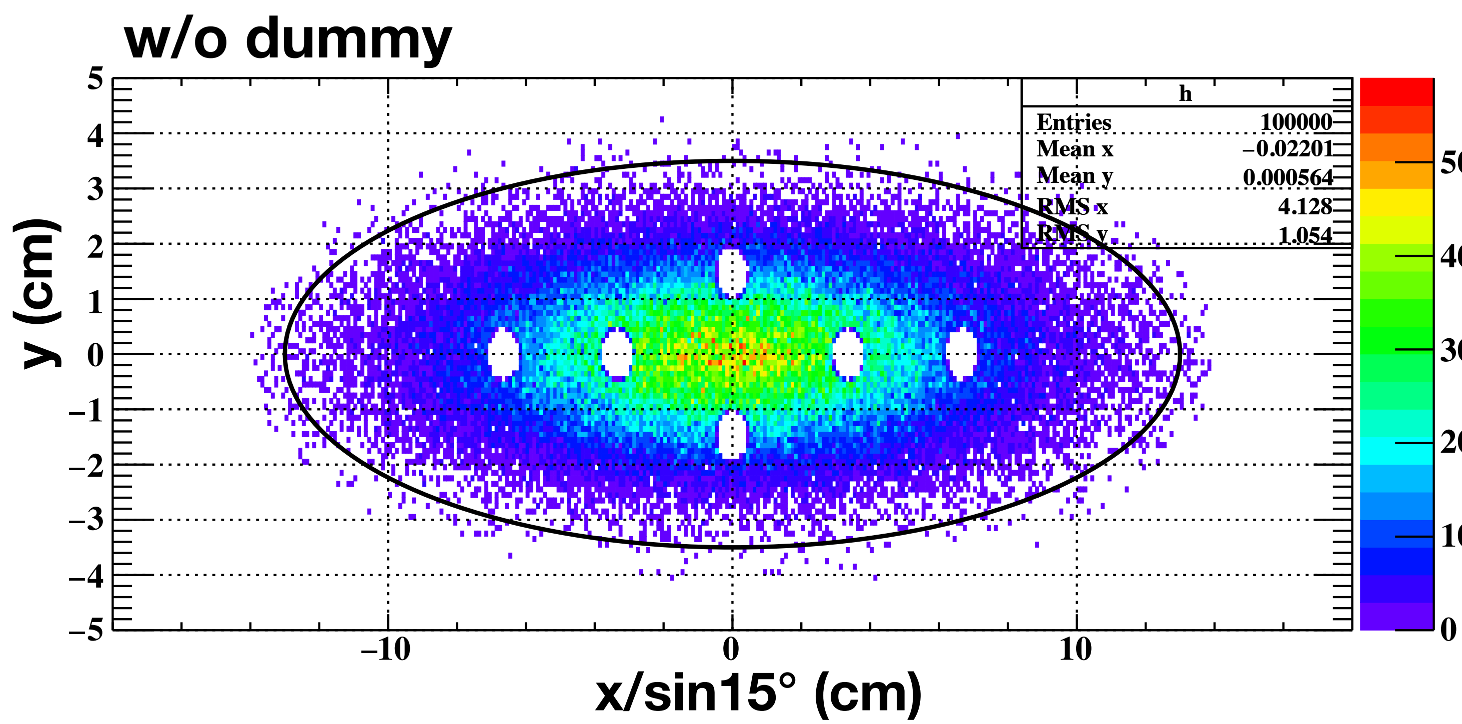
	major axis(mm)	minor axis(mm)	thickness (μm)
standard	260	70	120
bigger	267	70	120

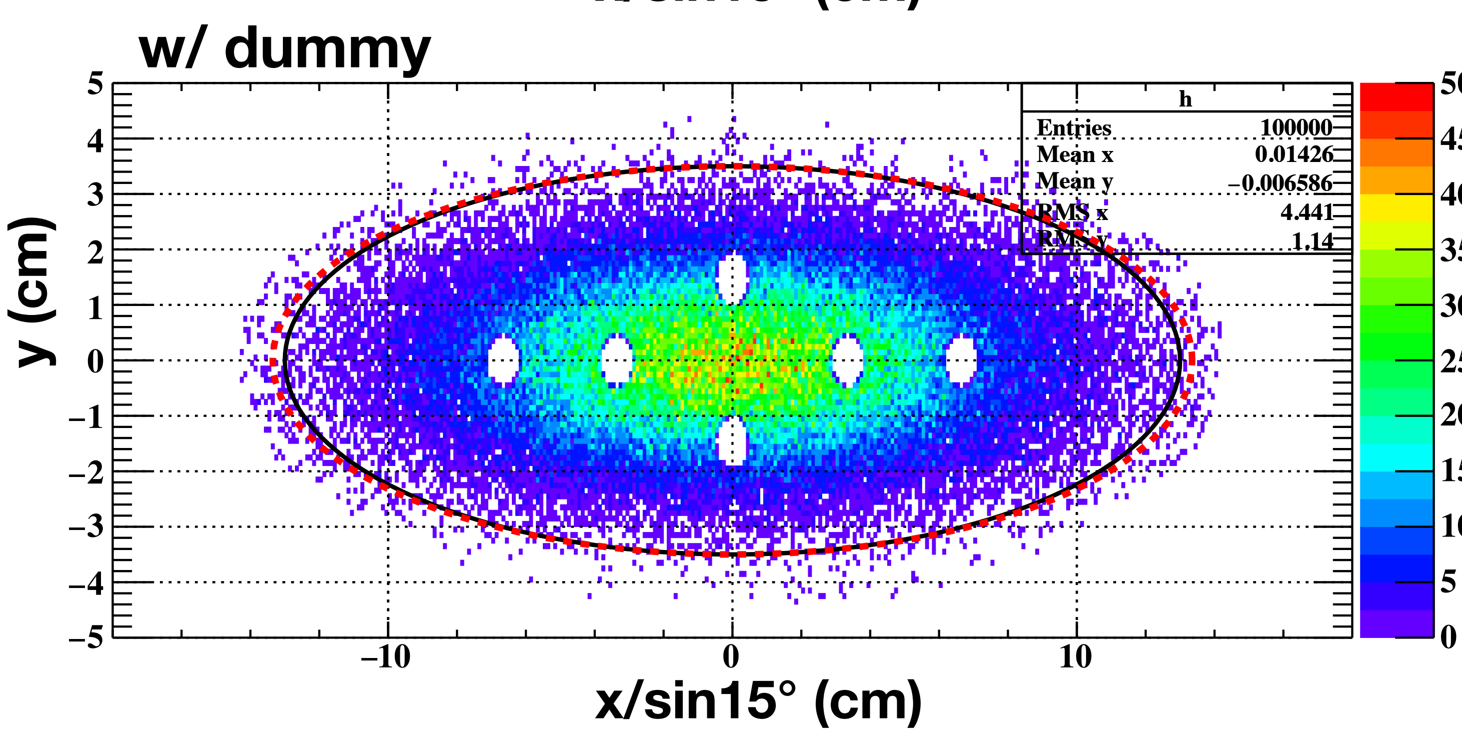
***fiducial size**

- Target has a 10mm frame

Beam & Target parameters

- If we use standard target (solid line) with dummy instead of bigger target (red dash line), event loss will be 0.13 ± 0.01%

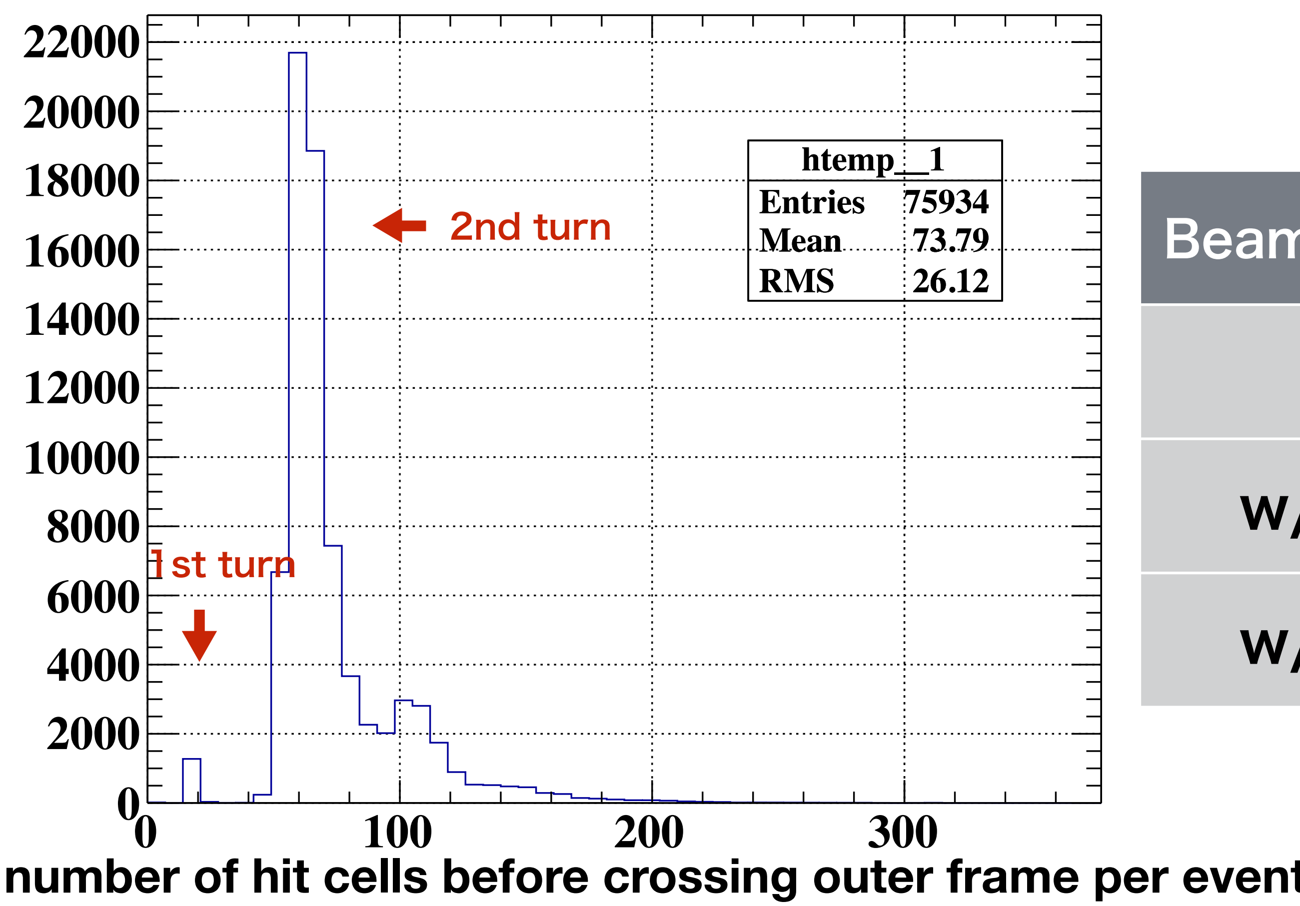




①. Efficiency loss by hitting the outer shell of CDCH in the 1st turn

- 100k signal events with extended angle range (|cosθ|<0.45, |ϕ|<7π/18) were generated on the target

- The percentage of N_{event} which will cross outer frame since 2nd turn was calculated
  → Event selection with LXe acceptance (r=64.97, |z|<23.9, |v|<67.9)



Beam parameters	Target	Result
normal	standard	98.25 ± 0.05%
w/ dummy	standard	97.65 ± 0.06%
w/ dummy	bigger	97.53 ± 0.06%

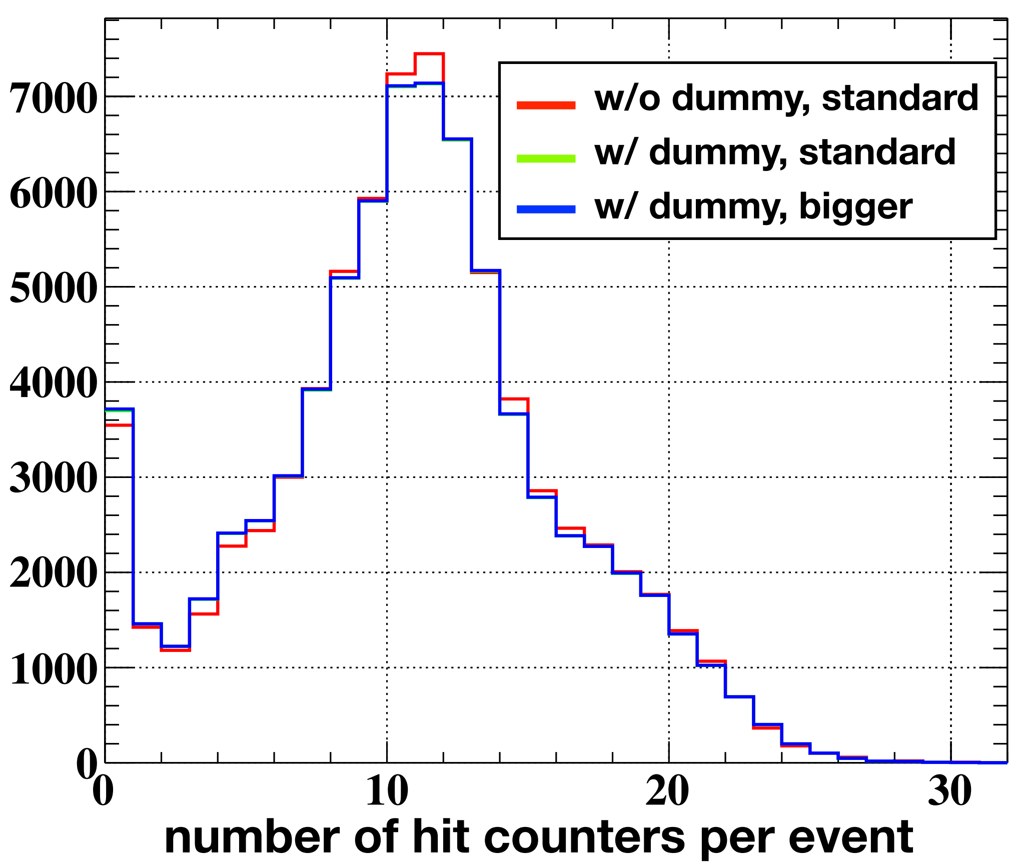
- Efficiency for long track changed by **- 0.74 ± 0.08%** with dummy and bigger target

②. TC hitting efficiency

- 100k signal events with extended angle range (|cosθ|<0.45, |ϕ|<7π/18) were generated on the target

- The percentage of selected N_{event} which will cross at least 1 counter was calculated

  → Event selection with LXe acceptance (r=64.97, |z|<23.9, |v|<67.9)



Beam parameters	Target	Result
normal	standard	95.33 ± 0.08%
w/ dummy	standard	95.11 ± 0.08%
w/ dummy	bigger	95.09 ± 0.08%

- Efficiency changed by **- 0.25 ± 0.12%** with dummy and bigger target

Efficiency of ① AND ②

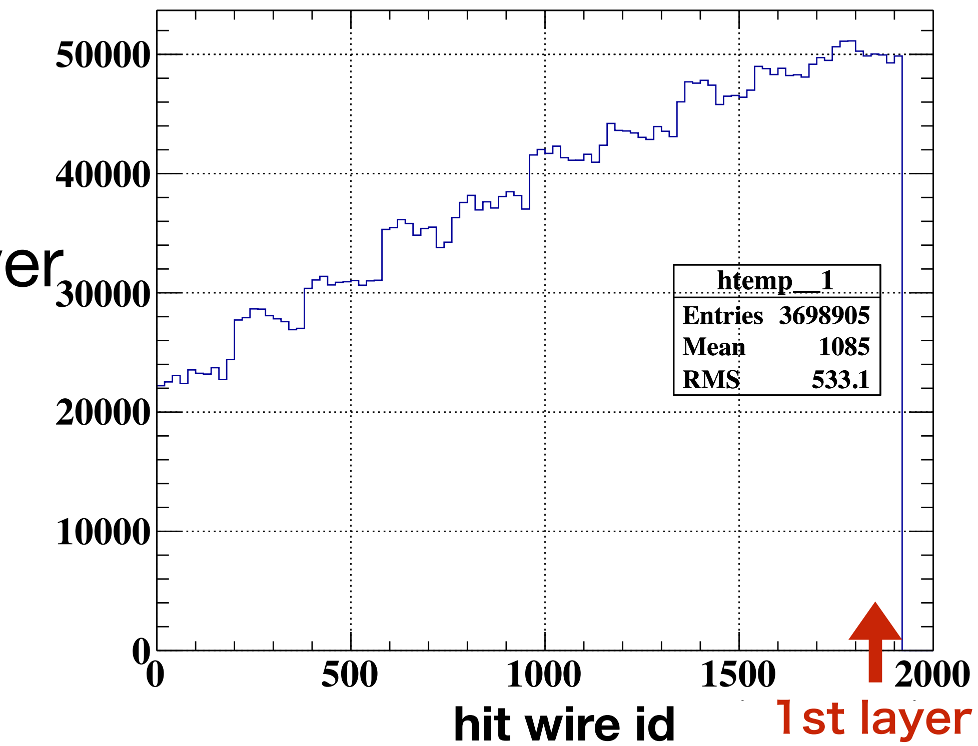
- From selected events with LXe acceptance, we estimated how much the efficiency of ① AND ② will be decreased

Beam parameters	Target	Result
normal	standard	93.73 ± 0.09%
w/ dummy	standard	92.99 ± 0.09%
w/ dummy	bigger	92.95 ± 0.09%

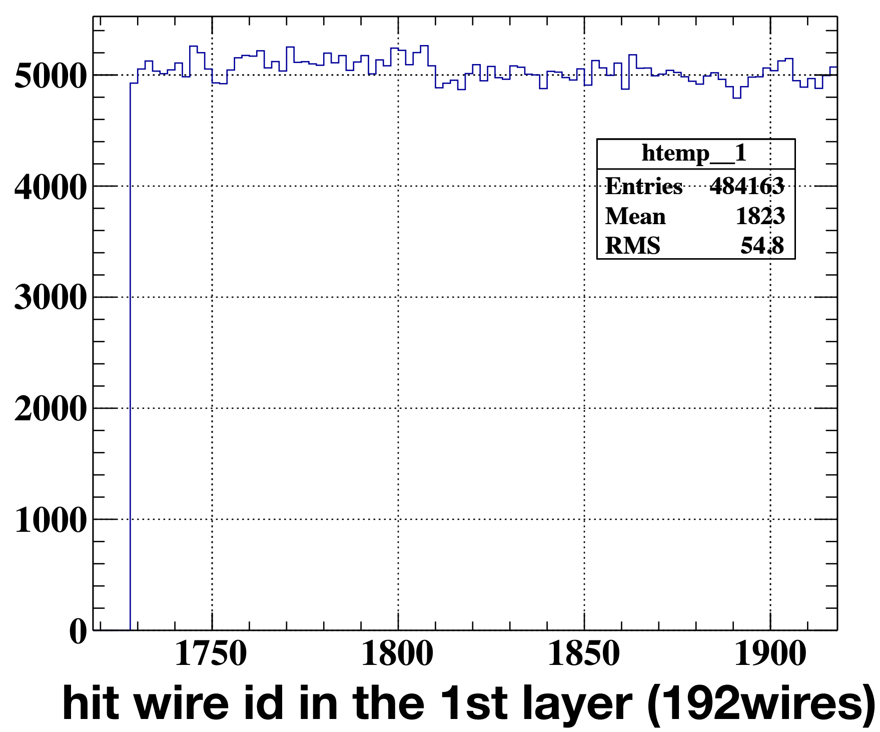
- Efficiency changed by **- 0.83 ± 0.16%** with dummy and bigger target

③. Hit rate of single cell in the 1st layer of CDCH

- 100k Michel events with 4π angle range
- CDCH has large number of hits in the innermost layer



- Hit rate of single cell in the 1st layer with 7×10^7 intensity



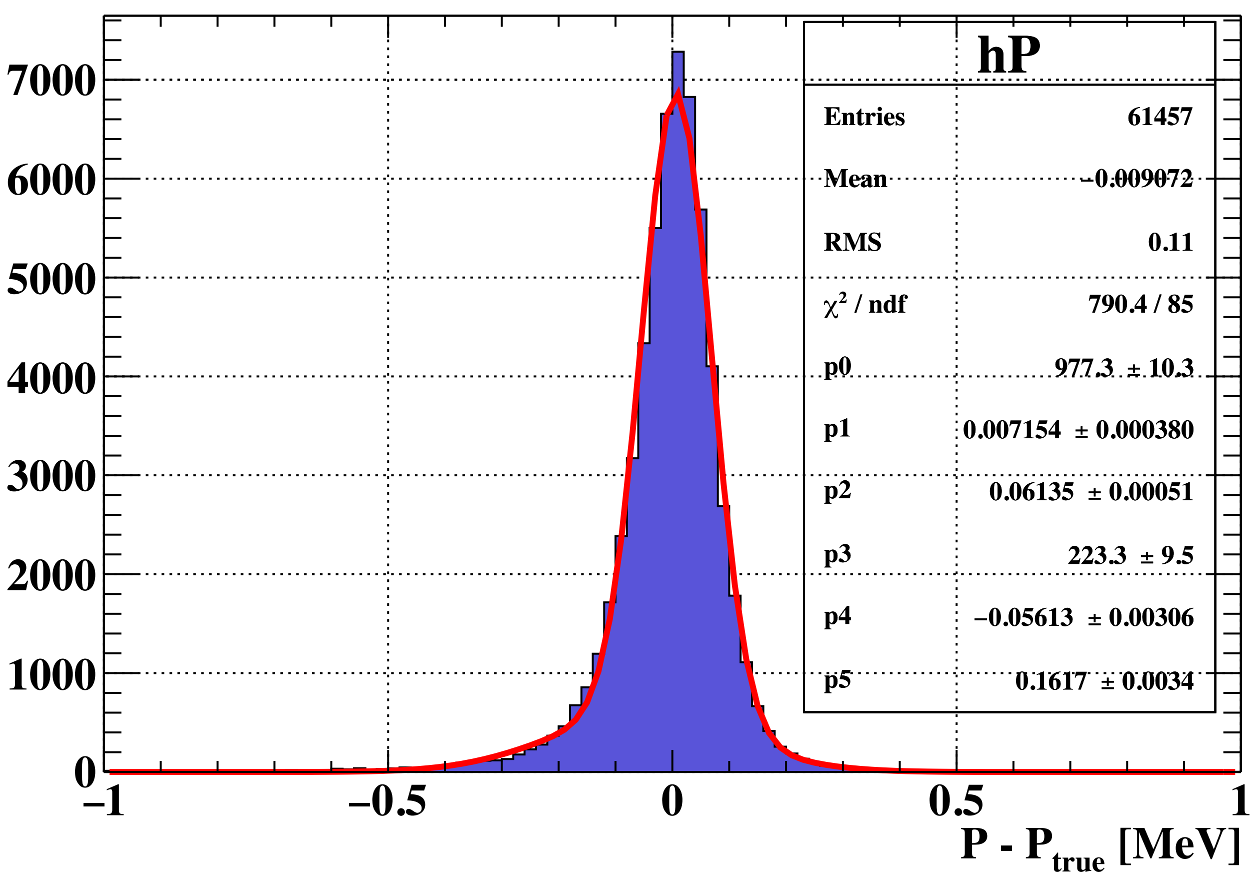
Beam parameters	Target	Result
normal	standard	1.765 ± 0.003MHz
w/ dummy	standard	1.779 ± 0.003MHz
w/ dummy	bigger	1.779 ± 0.003MHz

- Hit rate changed by **+ 0.79 ± 0.24%** with dummy and bigger target

Reconstructed energy resolution

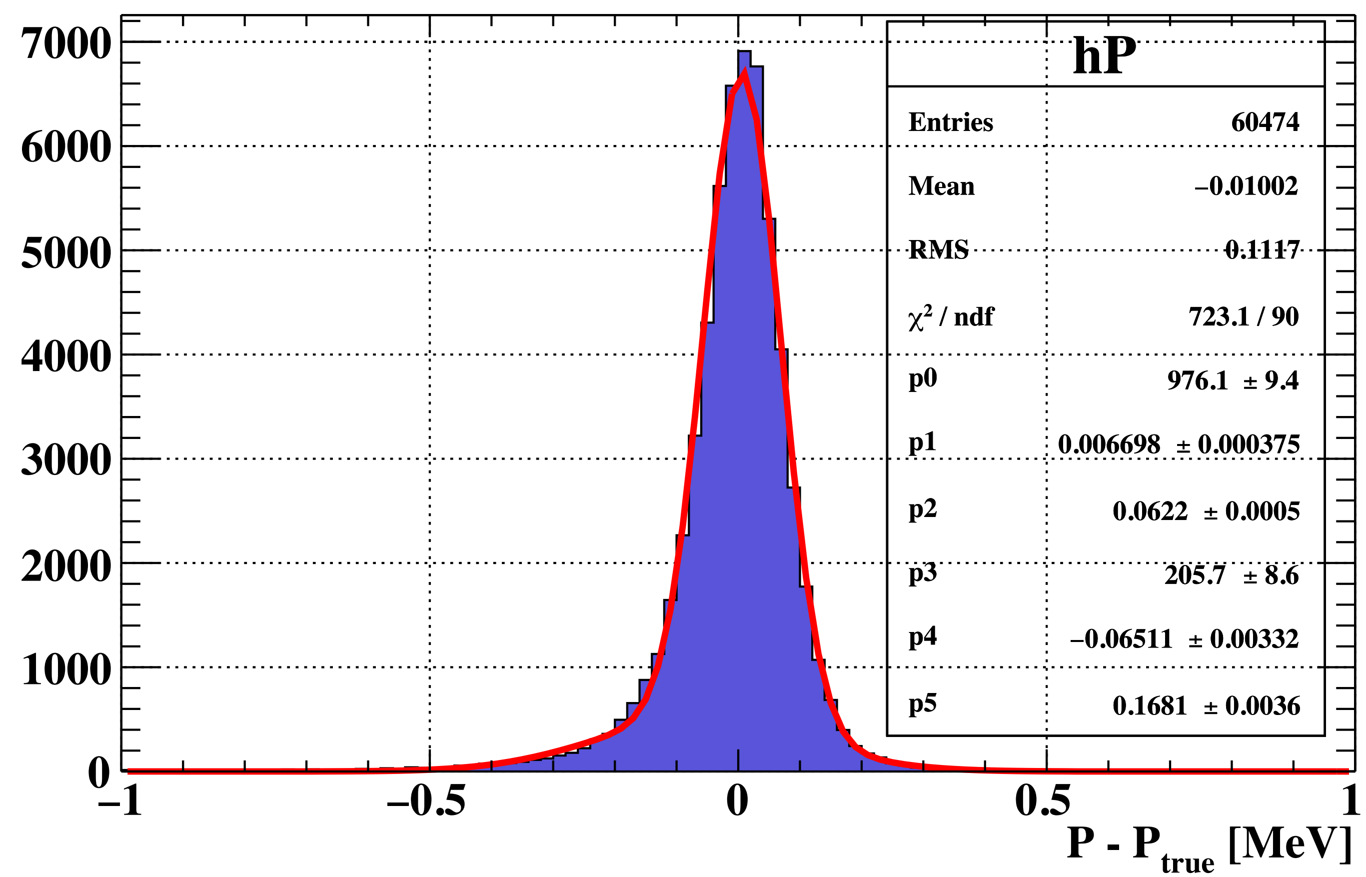
- 100k signal events with extended angle range (|cosθ|<0.45, |ϕ|<7π/18) were reconstructed with gem4_fit_genfit.xml
- Tracking selection with LXe acceptance (r=64.97, |z|<23.9, |v|<67.9)
- True hit was used and smeared with resolution

w/o dummy, standard target



σ_P = 0.0614 ± 0.0005 MeV

w/ dummy, bigger target



σ_P = 0.0622 ± 0.0005 MeV

Summary

- The influence of bigger beam spot on the efficiency was studied with MC

Efficiency changes with bigger beam spot compared to normal beam size

target size	μ stopping efficiency	long track efficiency	TC hitting efficiency	total efficiency
standard	**-3.13%**	**-0.61%**	**-0.21%**	**-3.90%**
bigger	**-3.00%**	**-0.74%**	**-0.25%**	**-3.81%**

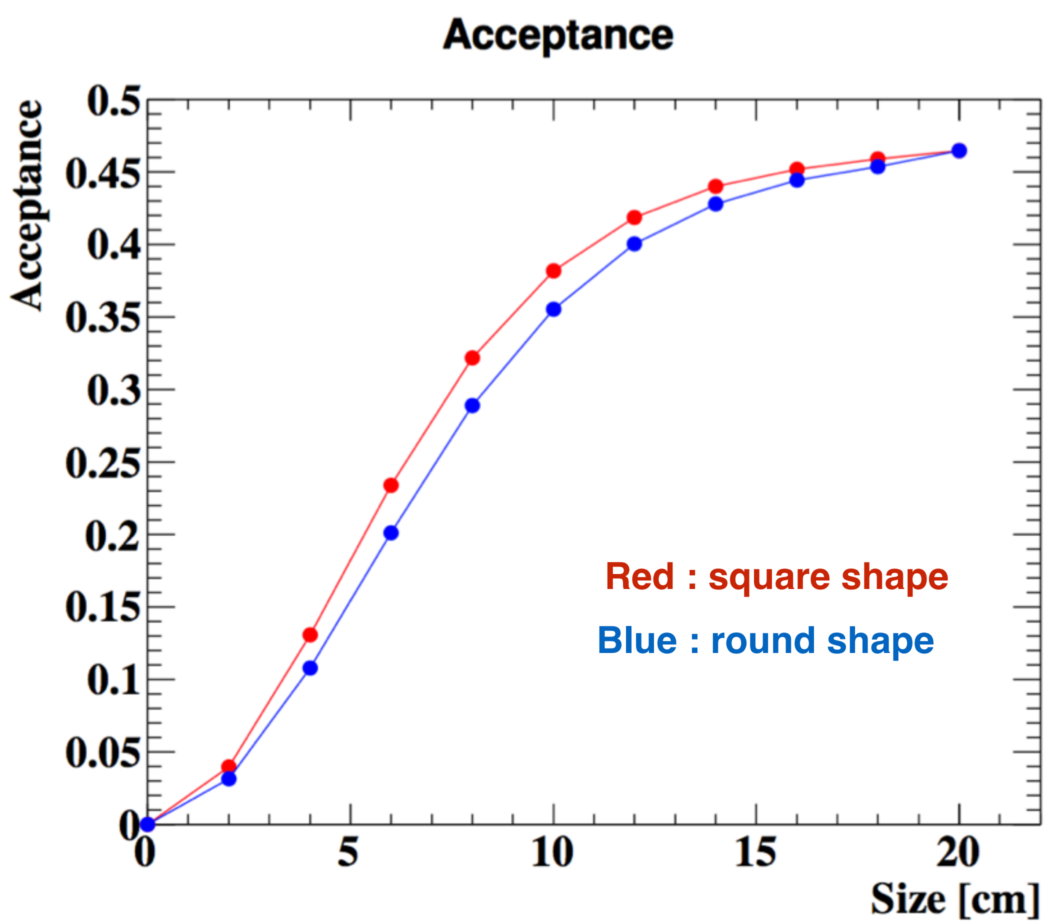
- The influence on hit rate of single cell in the 1st layer of CDCH was studied

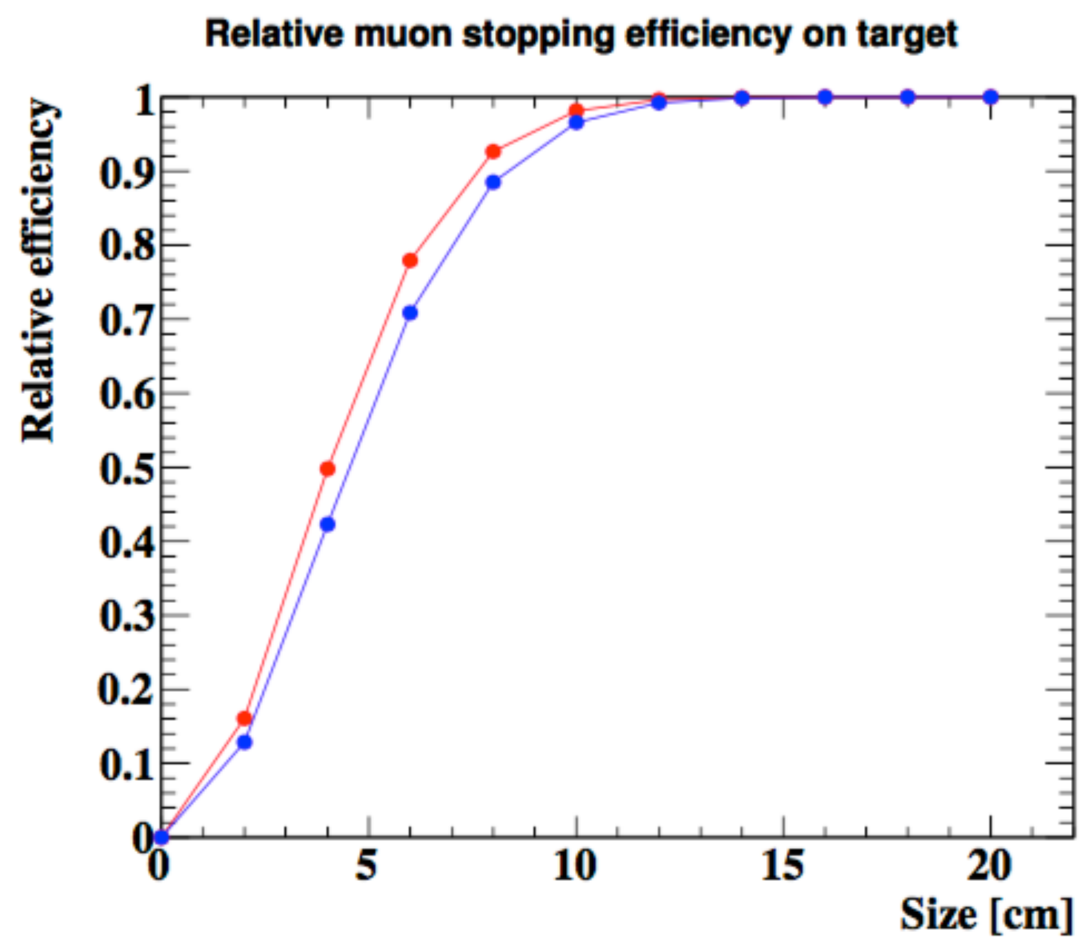
- The influence on the reconstructed energy resolution was studied

- These influence seems small

Concerning the detector size

- Simulation results with gem4 from RDC report 2014
- Acceptance of RMD e^+ with $E_\gamma > 48$MeV & μ stopping efficiency with several detector size (width or diameter)

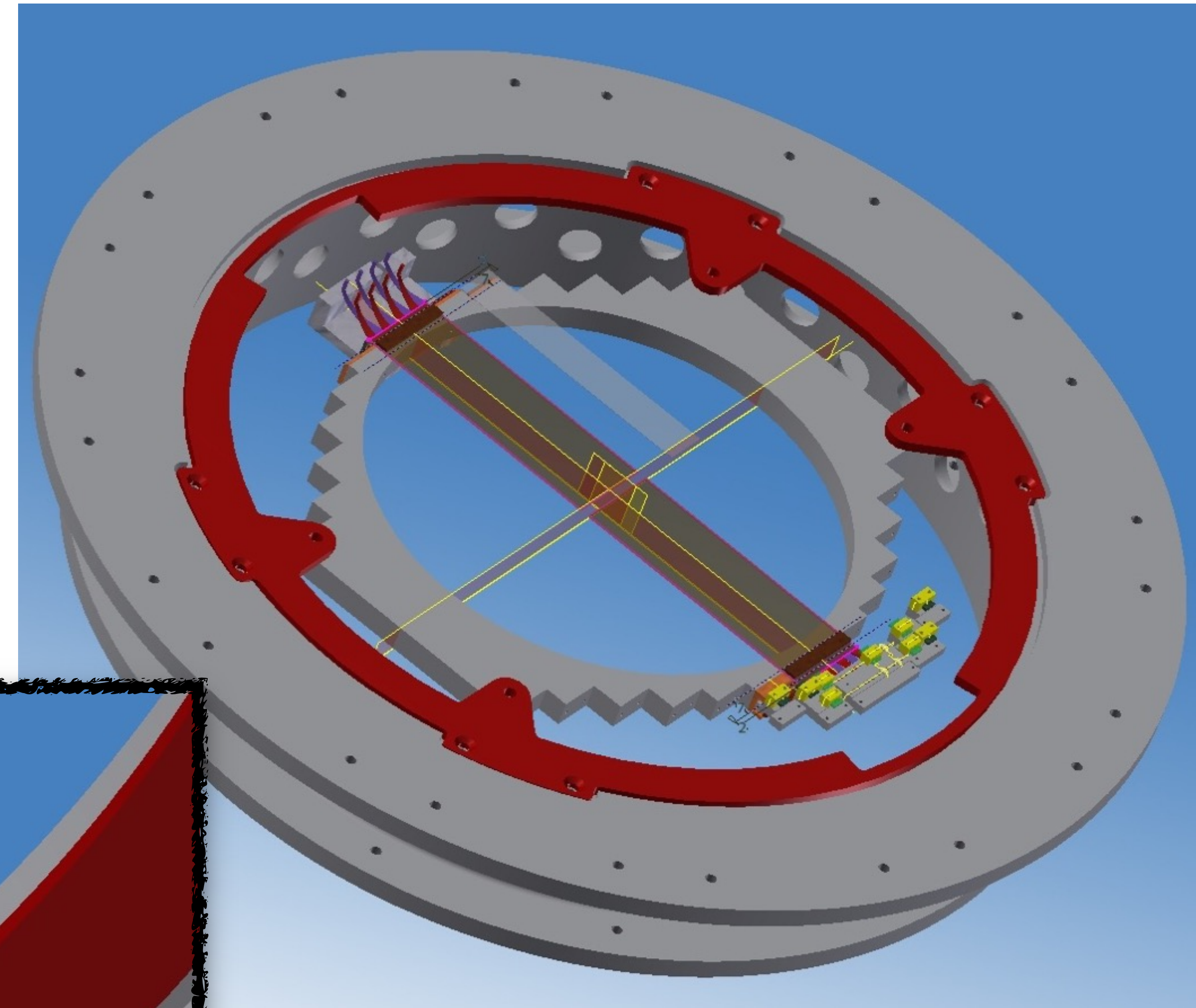


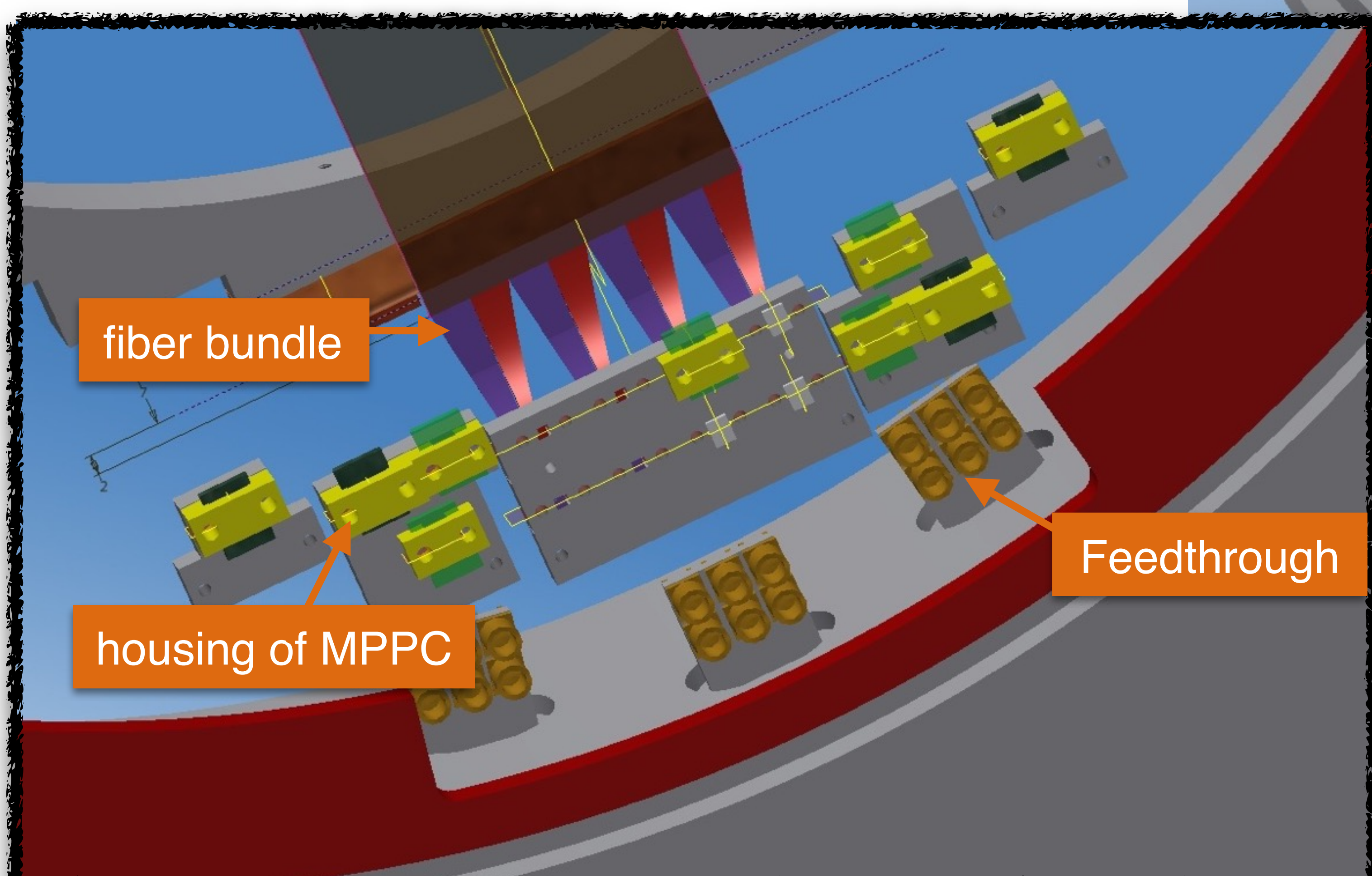


- <u>US RDC should not reduce μ stopping efficiency</u> (the size should be 14cm~)

N_{bundle} in provisional mechanical design

- N_{bundle} will be limited by available space around the detector
- Provisional mechanical design by Florian





- N_{bundle} : 18
- The smallest bundle is 16 fiber bundle