MEG II実験陽電子タイミングカウンターの較正手法の研究開発

Development of calibration methods for MEG II positron timing counter

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MEG II Experiment
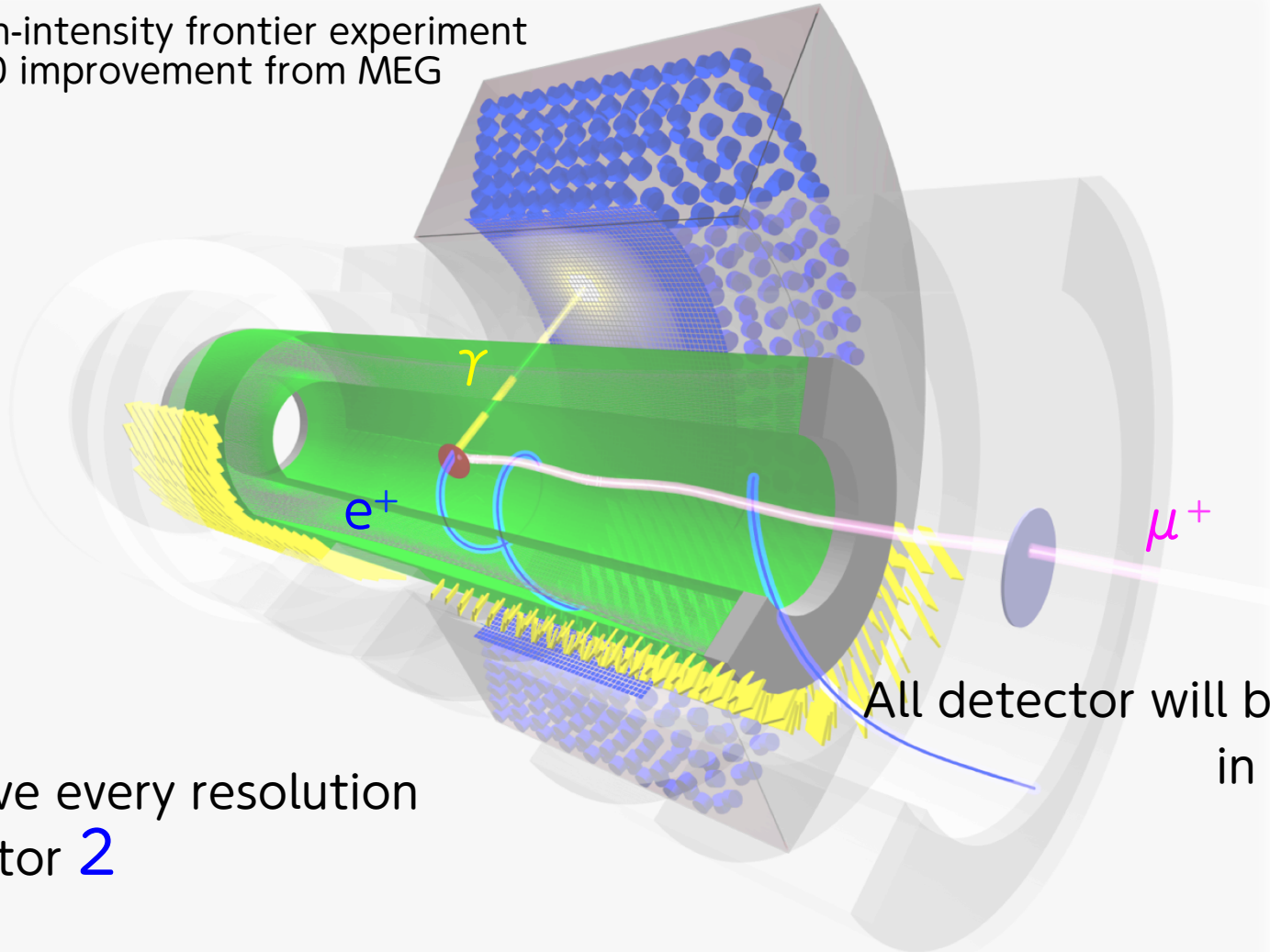
1 Search for cLFV($\mu^+ \rightarrow e^+ \gamma$)

with unprecedented sensitivity: 4×10^{-14}

✓ High-intensity frontier experiment
✓ x 10 improvement from MEG

γ

e^+

μ^+

3 All detector will be ready in **2017**

2 Improve every resolution by factor **2**

Experiment: **3** numbers

Positron Timing Counter

Liquid Xenon Gamma-ray Detector

$(\mu^+ \rightarrow e^+ \gamma)$

with unprecedented sensit

ntier experiment
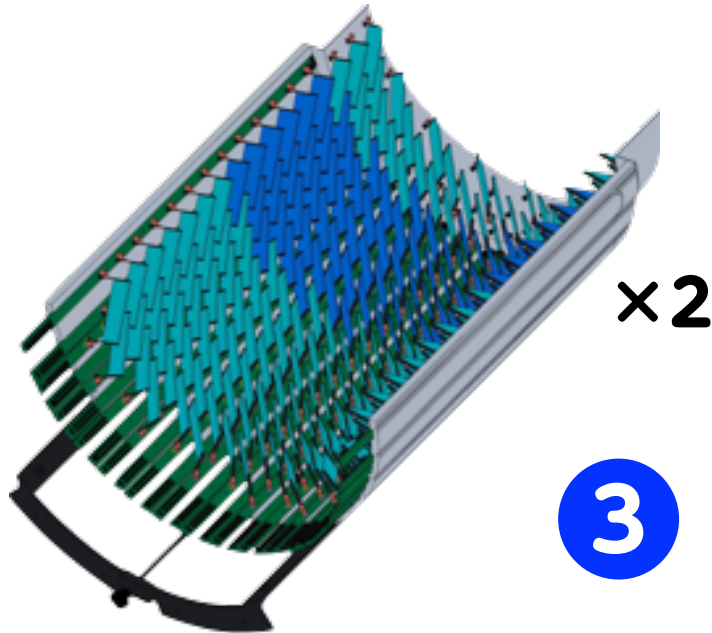t from MEG

γ

e^+
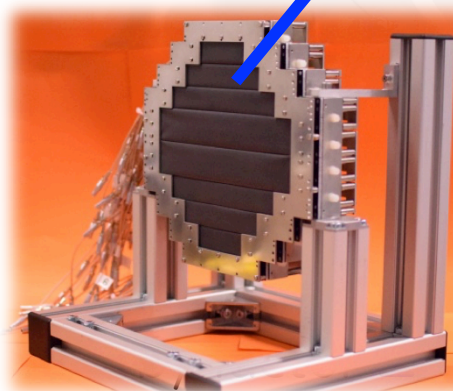
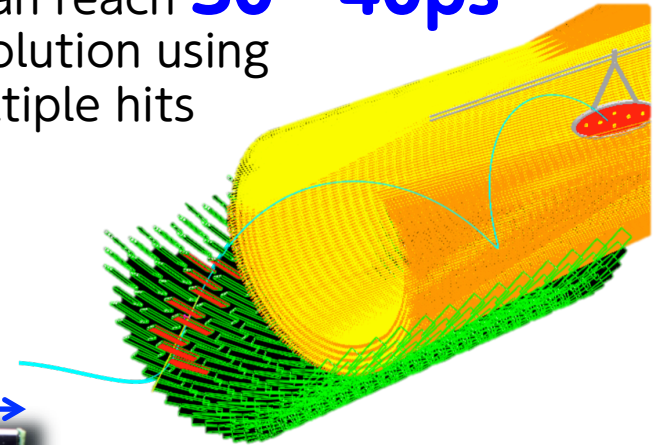resolution

Radiative Decay Counter

Numbers in Positron Pixelated Timing Counter

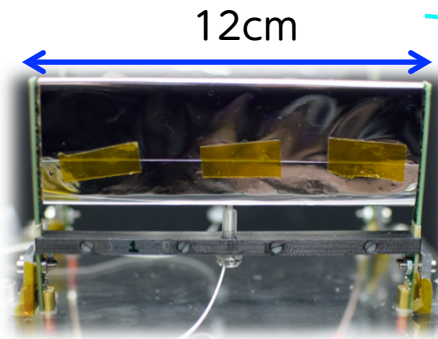**①** **512** pixelated scintillator counters

② **9** counter hits

→can reach **30~40ps** resolution using multiple hits

×2

③

12cm

✓ Fast Plastic Scintillator(BC422)

✓ **6144** SiPMs(AdvanSiD)

✓ **6** series at the both ends

✓ Accuracy for inter-calibration b/w counters: **30ps** by using pulse laser and Michel decay positron

Status

MEGII

2015

2016

2017
~

μ → eγ
Discovery

Detector
Installation

Engineering
Run

Physics
Run

Pilot Run
2015

Pilot Run
2016

Detector
Construction

Timing
Counter

Positron Timing Analysis

Waveform Analysis

Hit Reconstruction

Energy Calibration

Position Calibration

Time Calibration

❖ **Laser Calibration**
❖ **Michel Calibration**

Next Talk (23pSG-4)

Clustering

This Talk (23pSG-3)

Drift Chamber
(First hit position and momentum of e$^+$)

Positron Reconstruction

Positron Timing
by Timing Counter
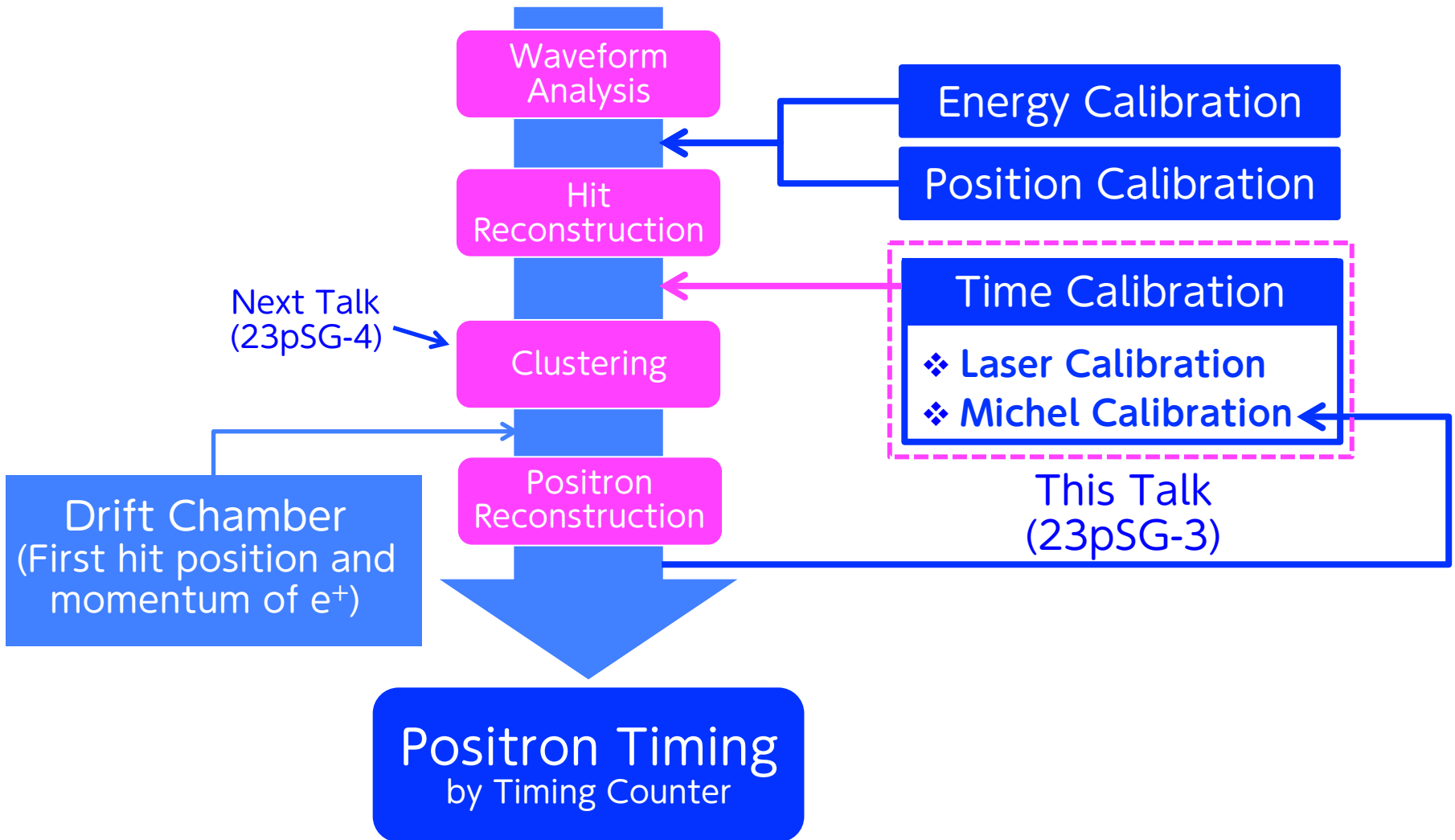
Time Calibration Methods

- We have to know time-offset of all 512 counters with the accuracy of 30 ps.
- Radiative Muon Decay($\mu \to e\gamma\nu\nu$) is used for absolute calibration for relative timing b/w e$^+$ and gamma.
- We have two complementary methods to calibrate time offset b/w counters: Michel Calibration and Laser Calibration

Michel Calibration

- Positrons from Michel Decay($\mu \to e\nu\nu$) are used.
- Hit reconstruction → Clustering → Tracking.
- Calculate TOF b/w counters of each tracking.
- Calculate time offset of each counter to minimize χ^2 function below.

Measured time   Calculated time

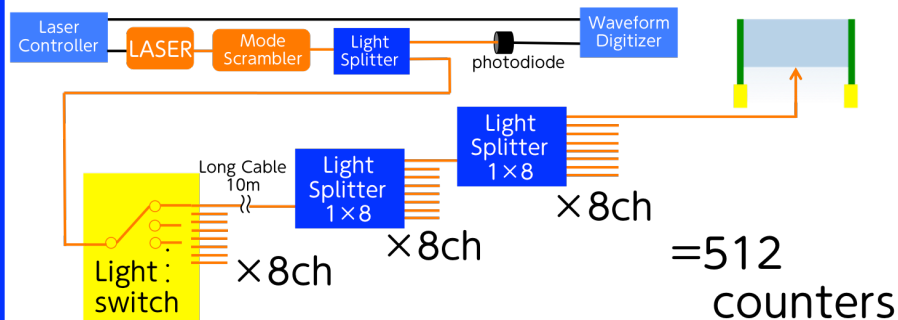$$\chi^2 = \sum_{i}^{N_{ev}} \sum_{j}^{N_{hit}} ((T_{ij} - (T_{0i} + TOF_{ij} + \Delta T_j)/\sigma))^2$$

Time offset of each counter
:What we want to know

- Needs tracking information of DCH.

Laser Calibration

- Pulse laser is divided into each counter simultaneously.
- Complementary to Michel Calibration.
  - No position dependence.
  - No needs to take run data.
  - Be able to monitor time offset.

Laser Controller — LASER — Mode Scrambler — Light Splitter — photodiode — Waveform Digitizer

Long Cable 10m — Light Splitter 1×8 — Light Splitter 1×8 — ×8ch

Light : switch — ×8ch — ×8ch

×8ch

=512 counters

Purpose of This Study

To know time-offset of each counter

Laser Calibration in Pilot Run 2016
- To operate laser system.
- To monitor the time-offset of laser counters.
- To find unexpected change of time-offset using laser data.
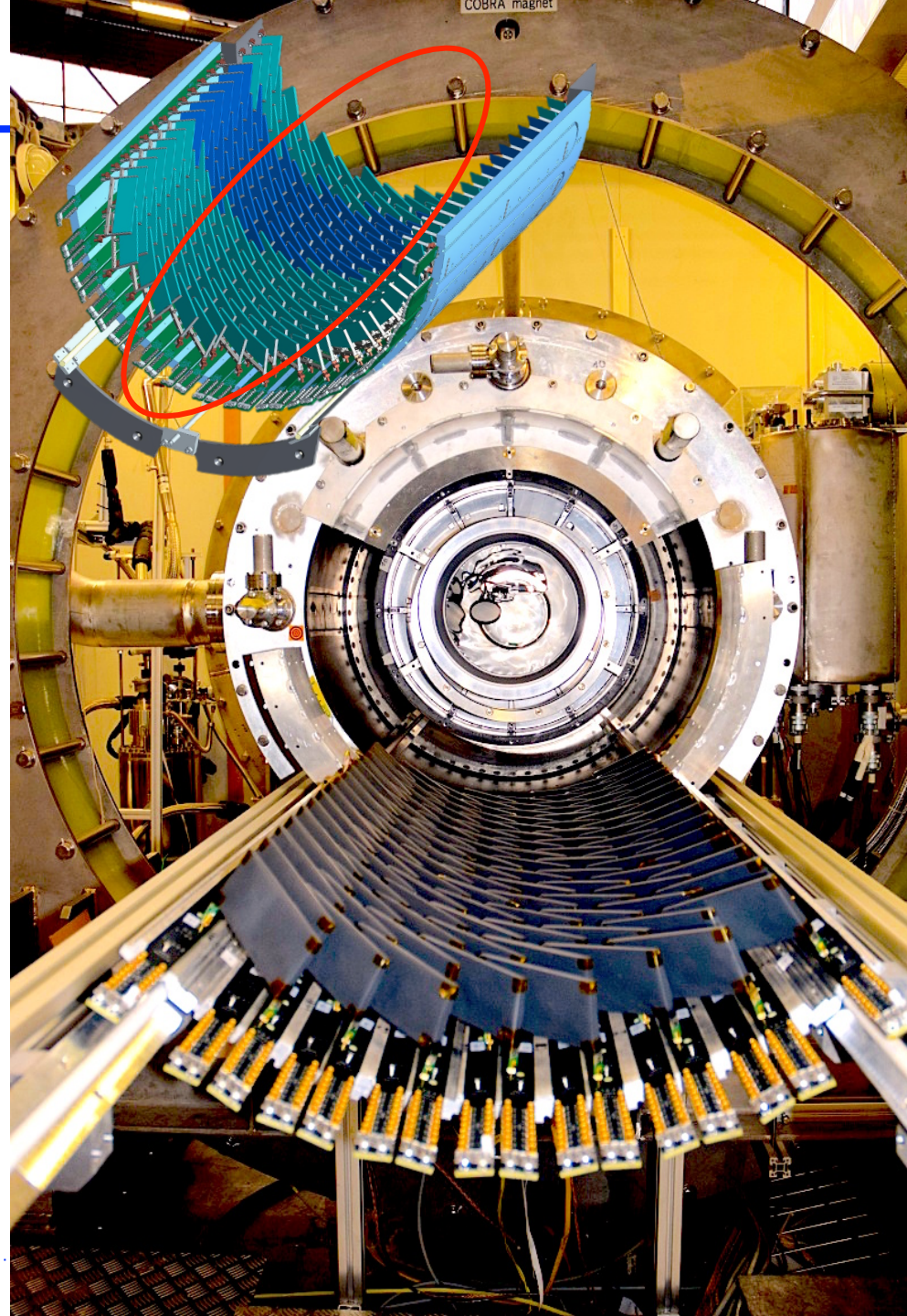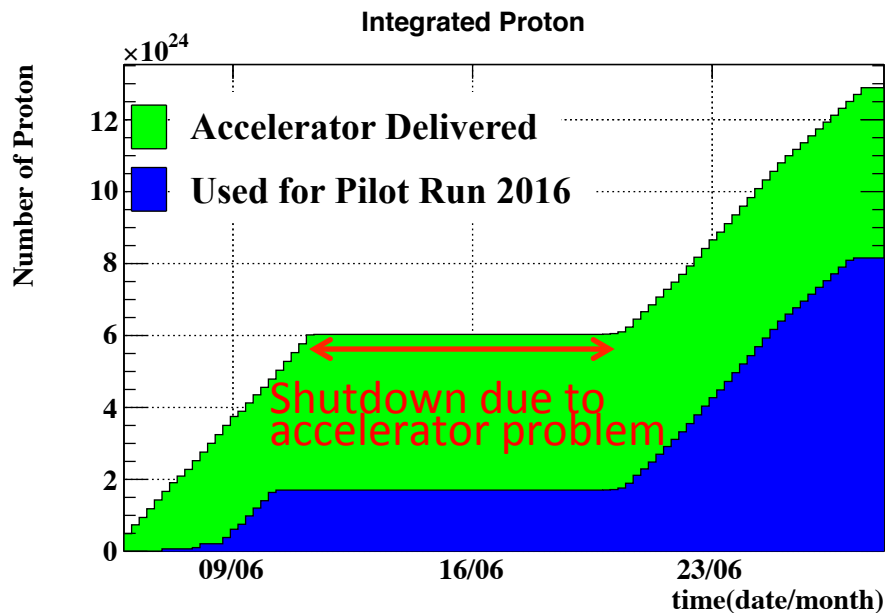
Michel Calibration in Pilot Run 2016
- Monte-Carlo Study
- Apply to Data

Combination
- To compare two complementary time calibration method
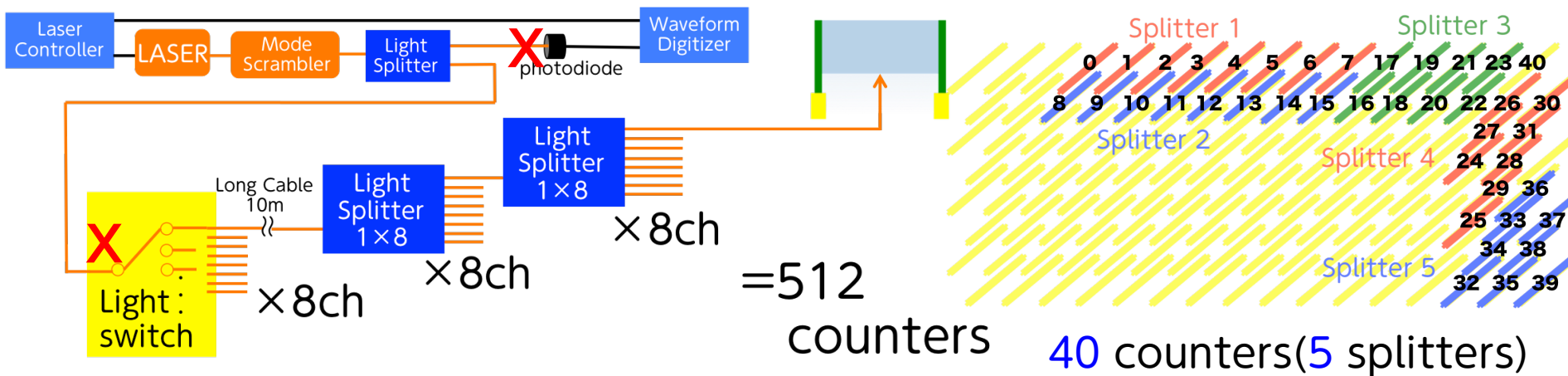 : Laser Calibration and Michel Calibration.

Pilot Run 2016
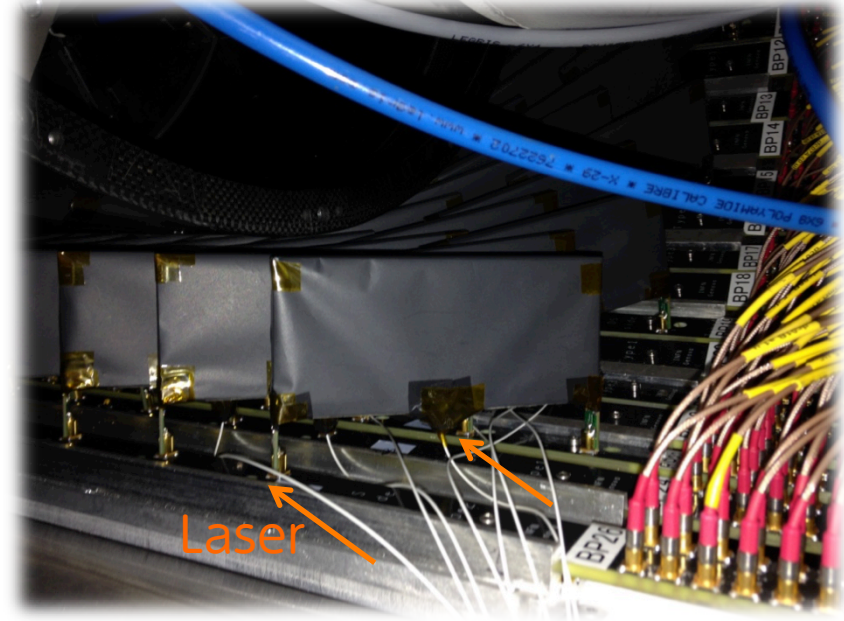
- ¼ TC = 128 Counters are installed.

- Beam time for 3 weeks.

- μ^+ with MEG II intensity (Stopping Rate: 7.0×10^7 Hz).

Integrated Proton

$\times 10^{24}$

Number of Proton

■ Accelerator Delivered

■ Used for Pilot Run 2016

Shutdown due to accelerator problem

09/06   16/06   23/06
time(date/month)

Laser Calibration

Laser Calibration: Setup

- Laser system was successfully installed into 40 counters out of 128 counters.

- Signal is divided by means of optical splitters.

- Relative time-offset = difference from first counter

Laser

Laser Controller
LASER
Mode Scrambler
Light Splitter
✗ photodiode
Waveform Digitizer

Light switch
Long Cable 10m
Light Splitter 1×8
Light Splitter 1×8

×8ch
×8ch
×8ch

=512 counters

Splitter 1 Splitter 3
0 1 2 3 4 5 6 7 17 19 21 23 40
8 9 10 11 12 13 14 15 16 18 20 22 26 30
Splitter 2
Splitter 4 24 28
27 31
29 36
25 33 37
34 38
Splitter 5 32 35 39

40 counters(5 splitters)

History of Relative Time-offset in Pilot Run 2016

- Time-offset of each counter was able to be monitored during the run.
- This history should be compared with Michel Calibration.
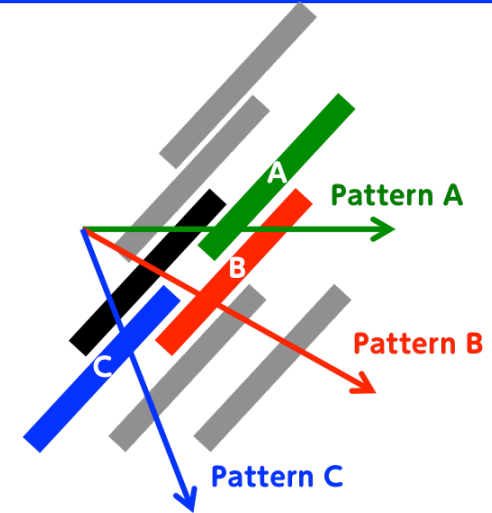- The variation was at most 50 ps.

Time-offset [ps]

100 [ps]
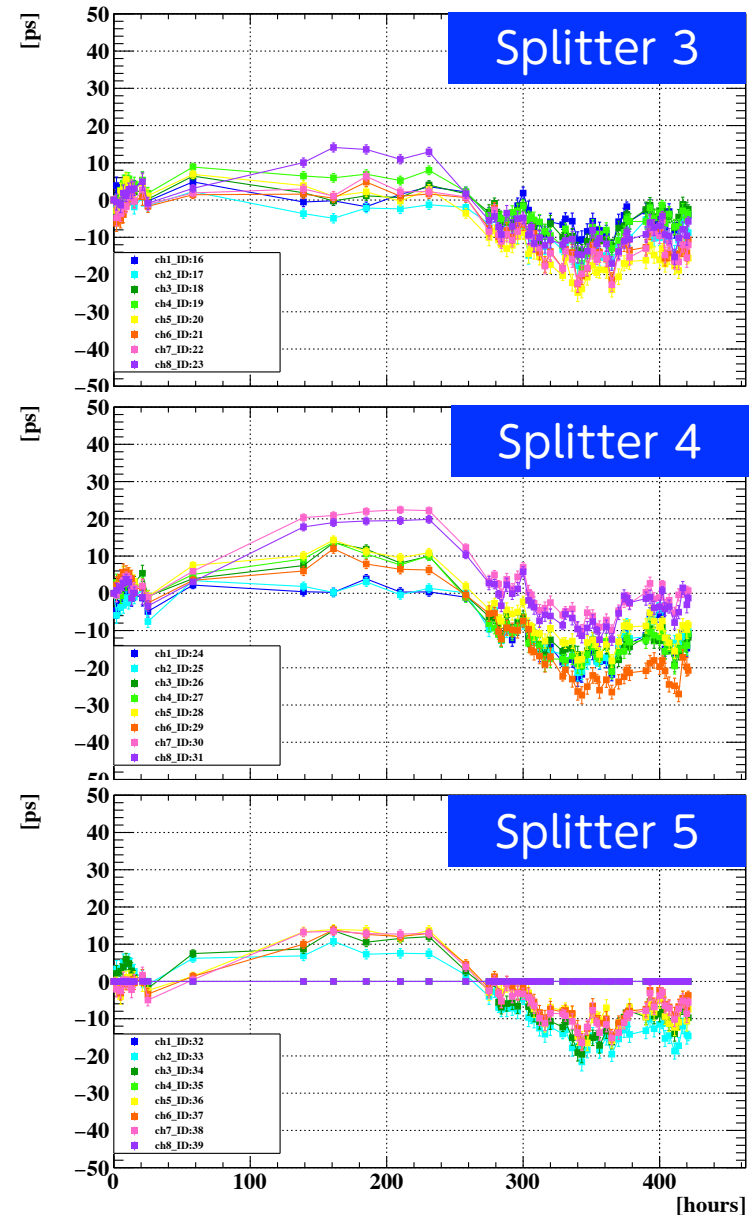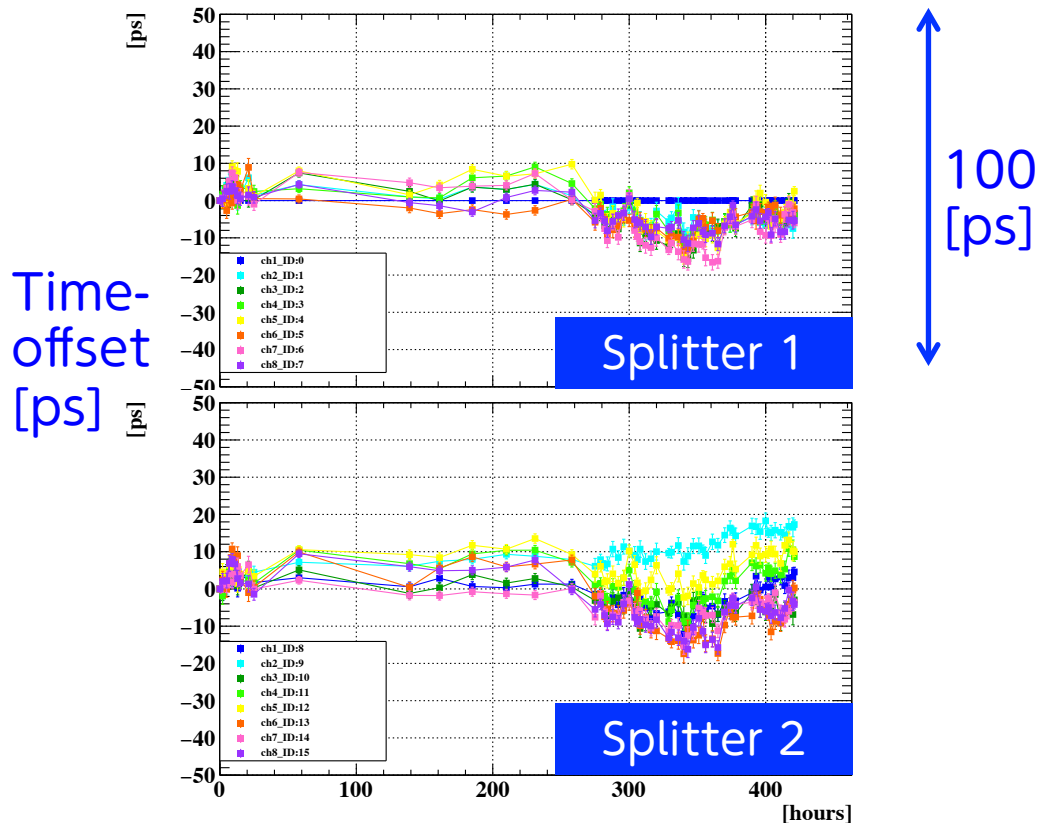
Michel Calibration

Michel Calibration: Idea

Measured time   Calculated time

$$\chi^2 = \sum_i^{N_{ev}} \sum_j^{N_{hit}} ((T_{ij} - (T_{0i} + TOF_{ij} + \Delta T_j)/\sigma))^2$$

Time offset of each counter
:What we want to know

Pattern A

Pattern B

Pattern C

- Calculate TOF by Monte Carlo.
- Assume every counter has 3 different TOF value(pattern A, B and C).
- Define χ^2 as the difference b/w measured time and calculated time.
- Minimize χ^2 using Millepede II.
- Find ΔT_j.

Millepede II www.desy.de/~kleinwrt/MP2
A software provided by DESY to solve the linear squares problems, such as detector alignment and calibration based on track fits.
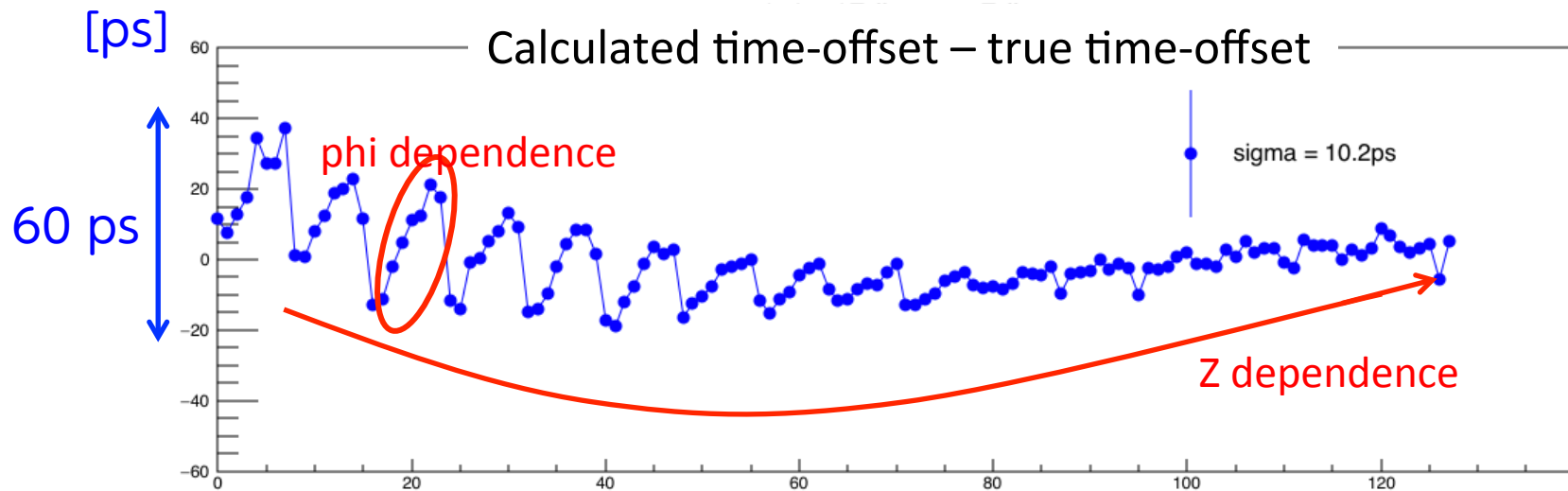
Michel Calibration: Monte Carlo

Setup
- Time-offset was set randomly.
- Calculate time-offset
  by Michel Calibration.
- Subtract from true value.

Results
- z and phi bias were observed.
  →need detail investigation
- Overall variation was 10.2 ps.
  →enough to be compared with Laser Calibration

Monte Carlo
- Based on Geant4.
- Generate muons, which stop a target.
- e+ from normal muon decay hits the TC.
- Detector: 1/4TC and No DCH.
  → the same as Pilot run 2016

[ps]

Calculated time-offset − true time-offset

60 ps

phi dependence

sigma = 10.2ps

Z dependence

Michel Calibration: Monte Carlo

Setup
- Time-offset was set randomly.
- Calculate time-offset
  by Michel Calibration.
- Subtract from true value.

Results
- z and phi bias were observed.
  → need detail investigation
- Overall variation was 10.2 ps.
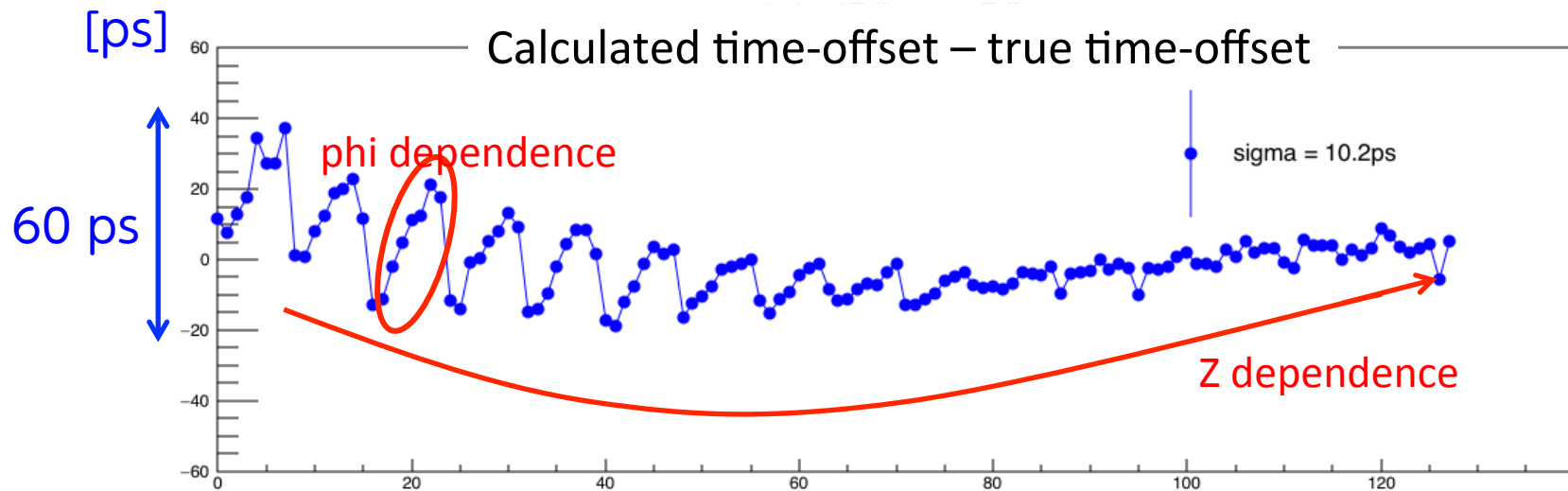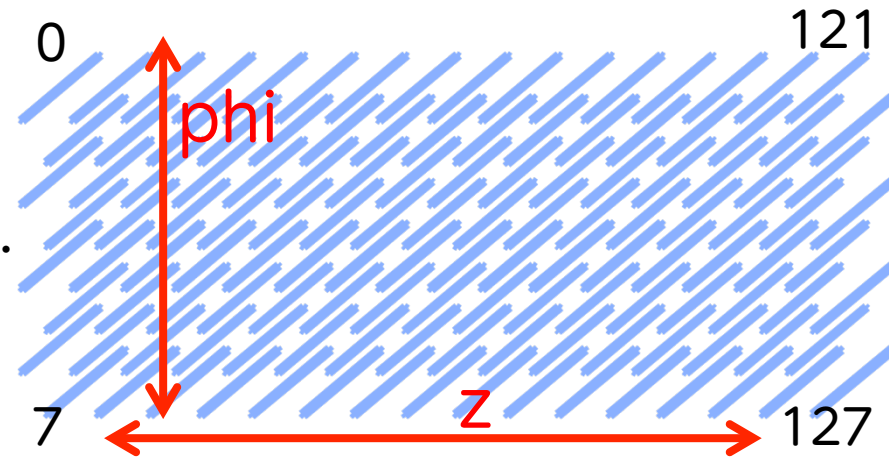 → enough to be compared with Laser Calibration

0   121
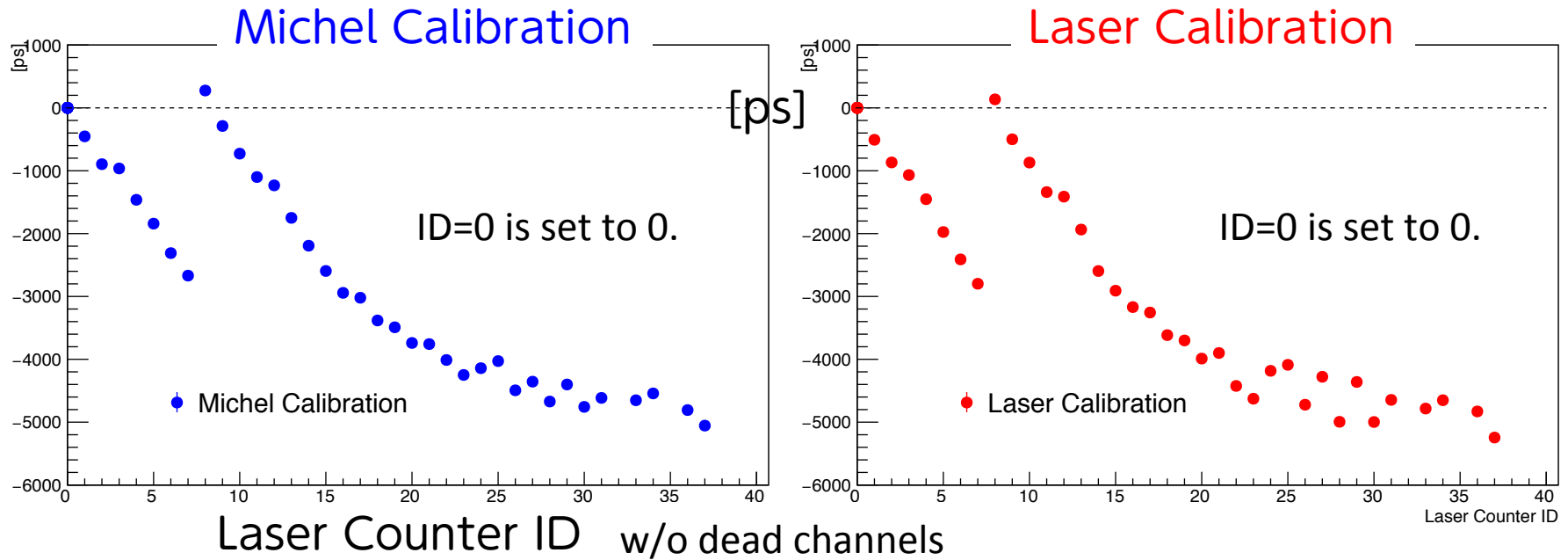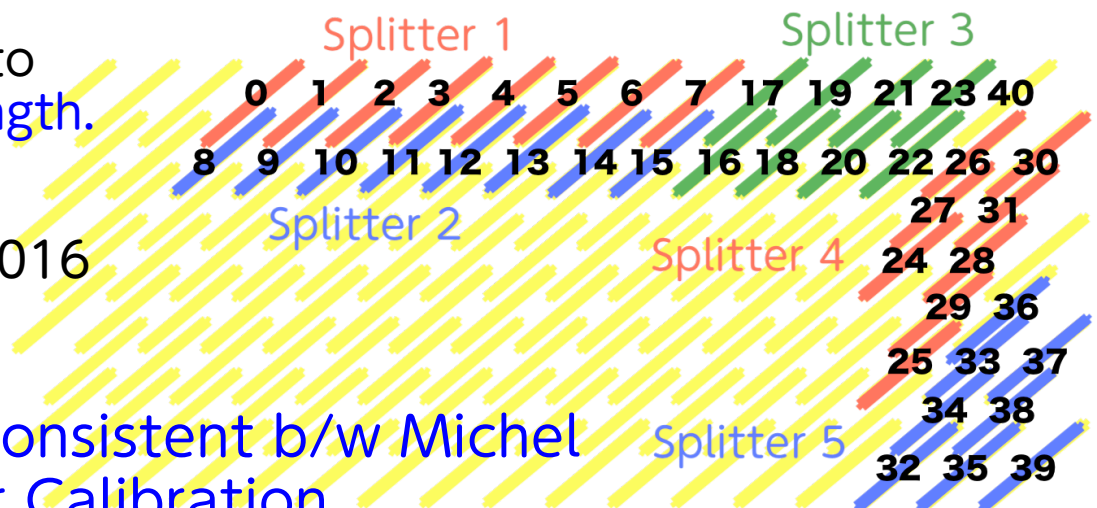
phi

7   z   127

[ps]

60 ps

Calculated time-offset − true time-offset

phi dependence

sigma = 10.2ps

Z dependence

Michel Calibration: Pilot Run 2016

Michel Calibration

[ps]

ID=0 is set to 0.

Michel Calibration

Laser Counter ID   w/o dead channels

Laser Calibration

[ps]

ID=0 is set to 0.

Laser Calibration
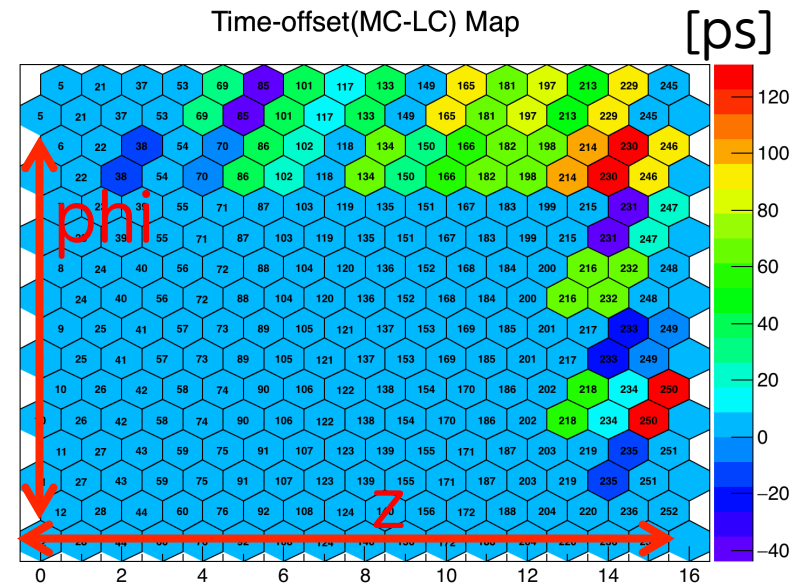
Laser Counter ID

- Tendency is mainly due to Back plane and cable length.
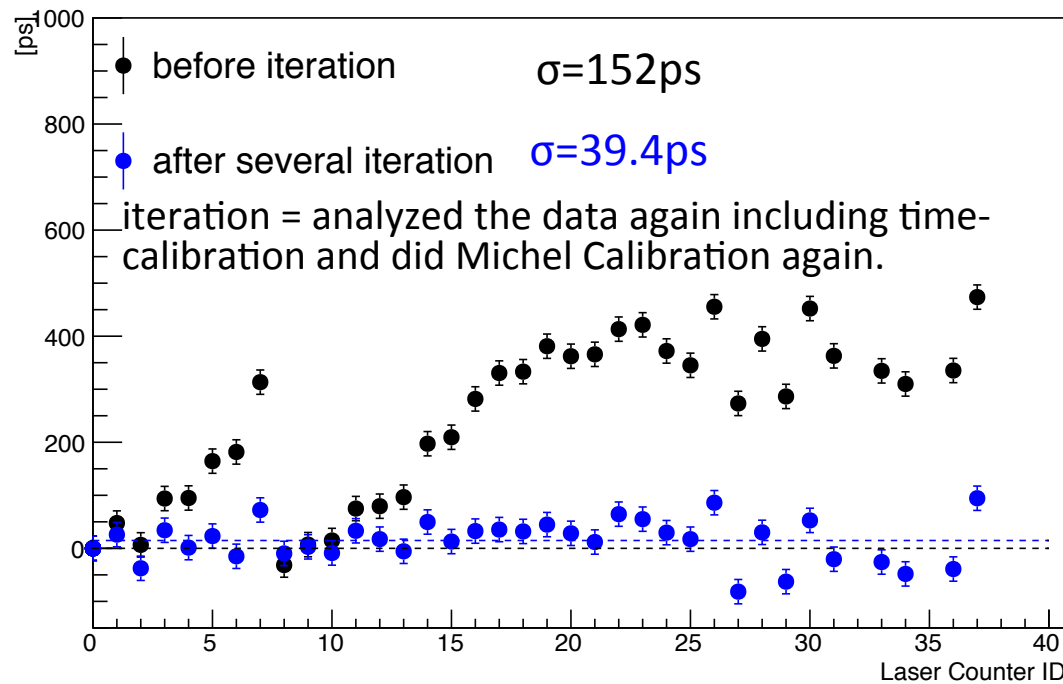
Datasets:
the first day of Pilot Run 2016

- Overall tendency is consistent b/w Michel Calibration and Laser Calibration

Splitter 1   Splitter 3

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 17 | 19 | 21 | 23 | 40 |

| 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 18 | 20 | 22 | 26 | 30 |

Splitter 2

27 31

Splitter 4

24 28

29 36

25 33 37

34 38

Splitter 5

32 35 39

Comparison b/w Michel and Laser

Toffset(MC-LC)

- before iteration   σ=152ps
- after several iteration   σ=39.4ps

iteration = analyzed the data again including time-calibration and did Michel Calibration again.

Time-offset(MC-LC) Map

[ps]

- Difference got much smaller.
- Accuracy was not enough to observe z/phi bias.
- Good agreement with two calibration method.
- To be improved by detail study using full data of Pilot Run 2016.

Future Work

Laser Calibration

- Installation of Laser Calibration system into final detector(work in progress).

Michel Calibration

- History of time-offset of Pilot Run 2016.
- Study of systematics.
- Michel Calibration using Drift Chamber.

Schedule

- TC assembly until 2017 spring.
- Engineering run in 2017 autumn, immediately followed by physics run.

Summary

Introduction

❖ MEGII searches for cLFV with unprecedented sensitivity from 2017.

Time Calibration

❖ There are two time calibration methods which can **achieve σ~30 ps accuracy**:
    Laser **C**alibration
    Michel **C**alibration

❖ We **successfully installed** LC into 40 counters in Pilot Run 2016.

❖ We **successfully monitored** the time-offset during Pilot Run 2016.

❖ We **successfully applied** MC to the data of Pilot Run 2016.

❖ MC and LC were **well consistent** with σ~**40 ps.**

❖ To be improved by further study and data.