MEG II実験陽電子タイミングカウンターのコミッショニング2017 -較正-

Commissioning of positron timing counter for MEG II Experiment in 2017: Calibration

Mitsutaka Nakao

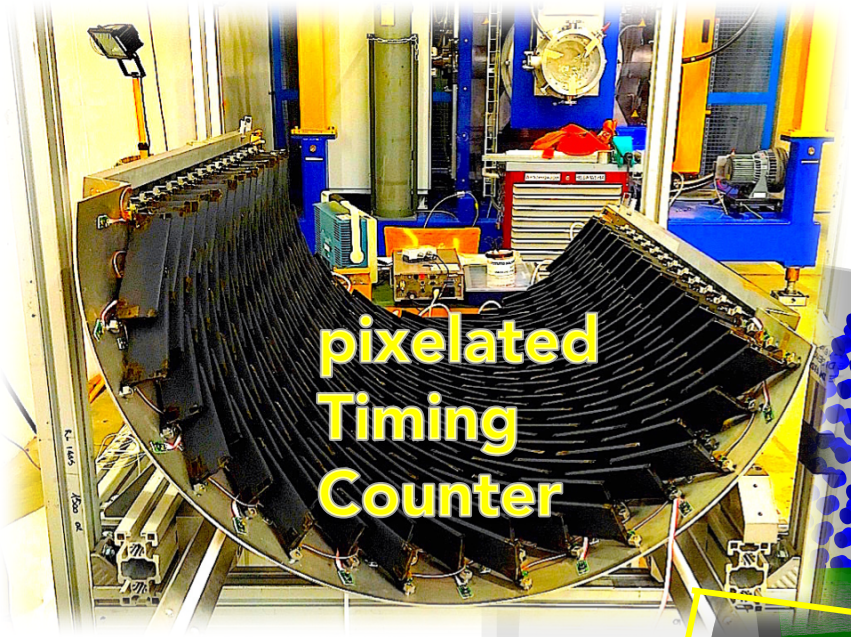
(The University of Tokyo)

On behalf of MEG II Collaboration

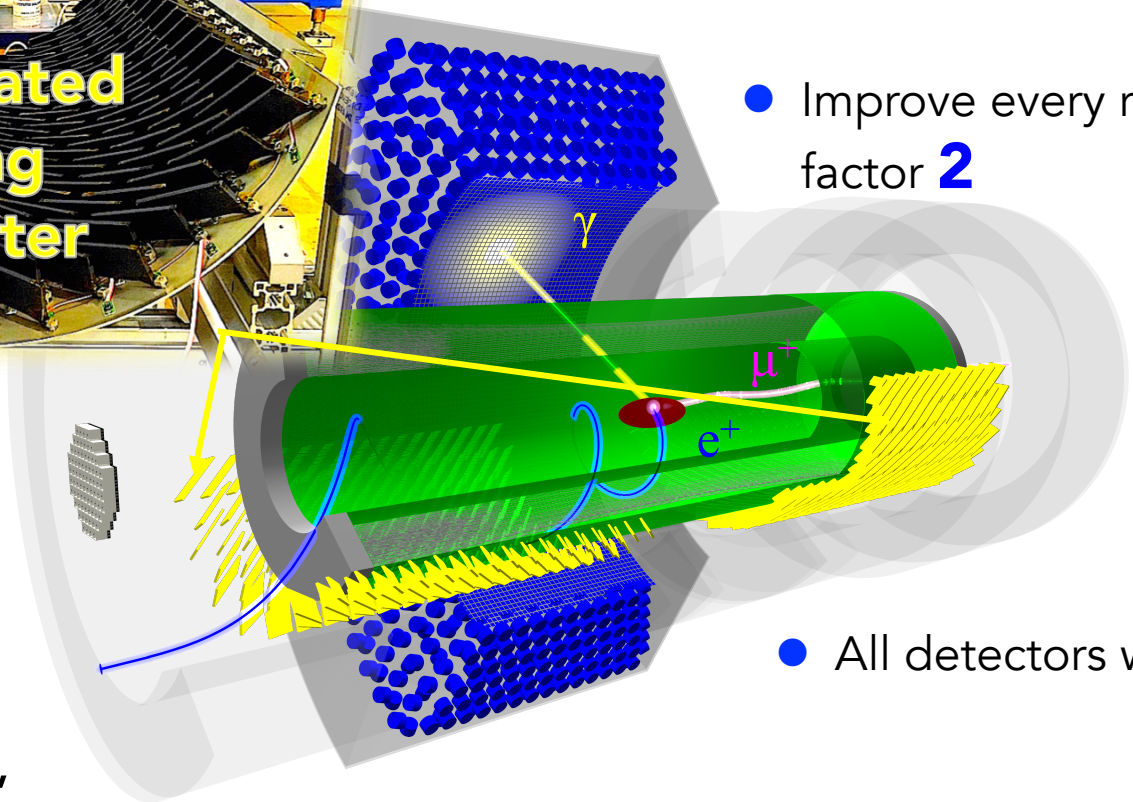
ICEPP The University of Tokyo

MEG II Detector

At **P**aul **S**cherrer **I**nstitut in Switzerland



- Search for cLFV ($\mu^+ \to e^+\gamma$) with unprecedented sensitivity: **6×10^{-14}**
  - ➢ x**10** improvement from MEG (4.2×10^{-13}, 2016)



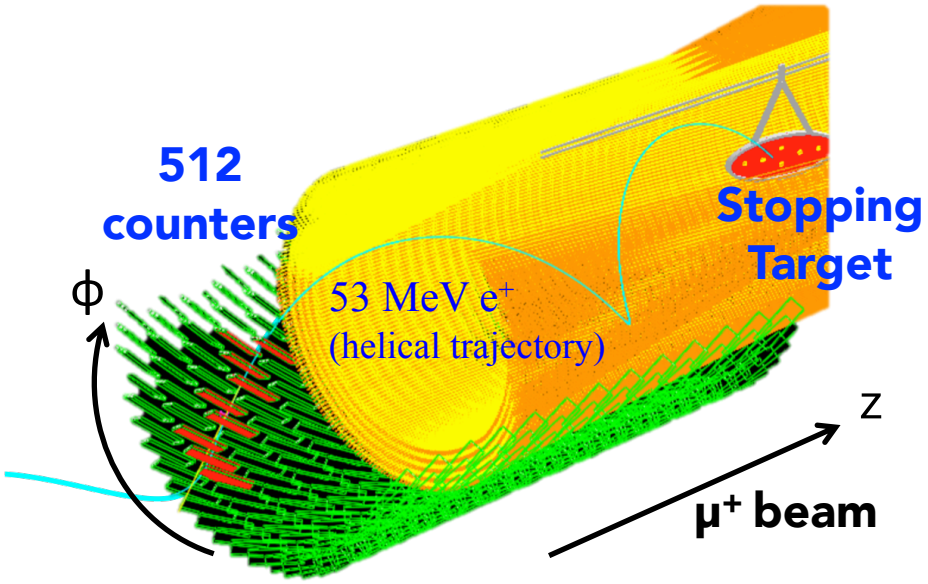
- Improve every resolution by factor **2**
- All detectors will be ready in **2018**

"The design of the MEG II experiment"
arXiv:1801.04688
(submitted to EPJC)

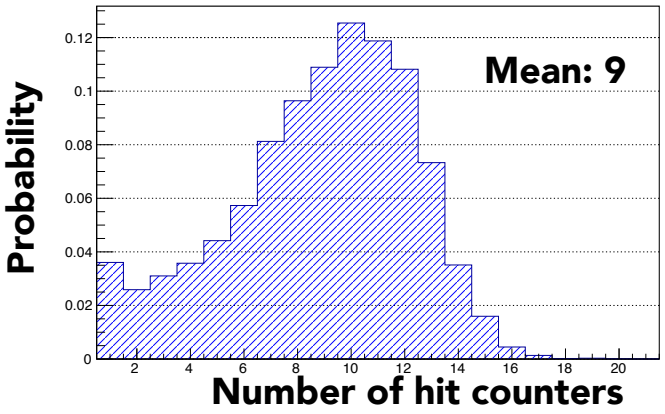
pTC: concept

Key Concept

- Improve time resolution by averaging the signal time of multiple hits.



- Averaged hit multiplicity for signal e^+s: 9 (MC)



- The total time resolution is expected to improve with $\frac{1}{\sqrt{N_{\rm hit}}}$ and ~ 35 ps can be achieved at 9 hits.

Stochastic term　　Constant term

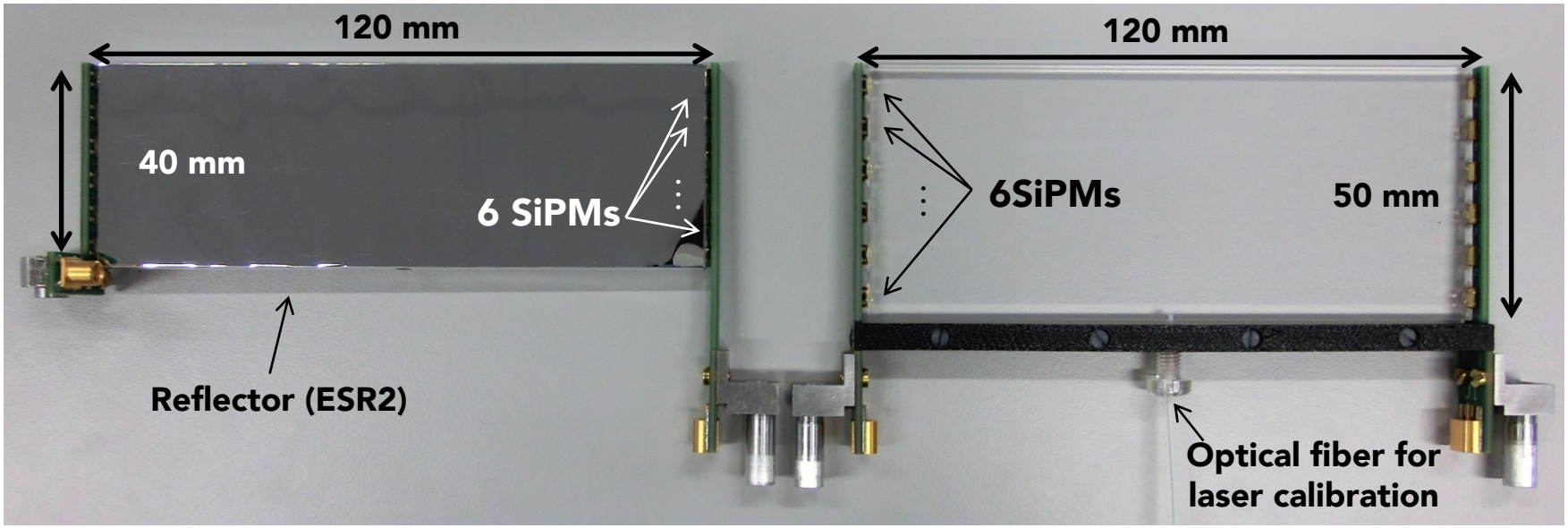
$$\sigma_{\rm all}(N_{\rm hit}) = \sqrt{\frac{\sigma^2_{\rm intrinsic}}{N_{\rm hit}} + \frac{\sigma^2_{\rm inter-pixel}}{N_{\rm hit}} + \sigma^2_{\rm MS}(N_{\rm hit}) + \sigma^2_{\rm const}}$$

Intrinsic resolution: 70~80 ps

Multiple scattering: ~4 ps at 9 hits

pTC: a counter

- Upstream (256 counters) + Downstream (256 counters)= 512 counters
- Fast plastic scintillator (BC422, 40 (50) x 120 x 5 mm^3)
- Readout by 6 SiPMs* with series connection (in total 6144 SiPMs) at each of both sides.
- Time calibration accuracy among counters: < 30 ps



*AdvanSiD, ASD-NUV3S-P High-Gain, 3x3 mm^2, 50x50 μm^2, $V_{breakdown}$ ~ 24 V

pTC: reconstruction

Calibrations →

Waveform Analysis

Hit Reconstruction

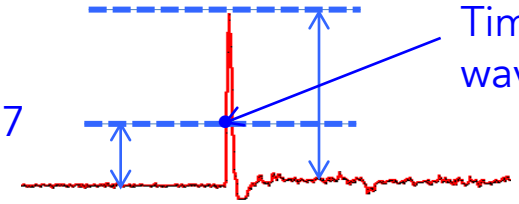
Clustering

Positron Reconstruction

Positron Timing
by pTC

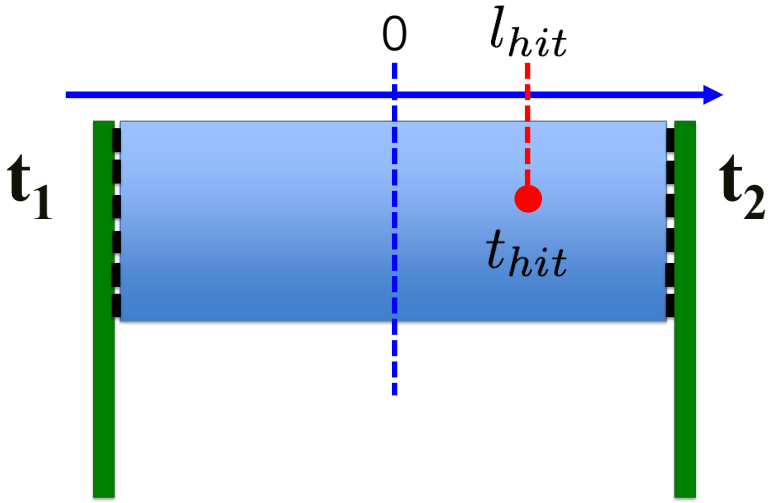
- Waveform time (t_1, t_2) is calculated by using constant fraction method.

20% in Pilot Run 2017



- Hit time (t_{hit}) is calculated by averaging both ends.

$$t_{hit} = \frac{t_1 + t_2}{2} \qquad l_{hit} = v_{eff}\frac{t_1 - t_2}{2}$$



pTC: calibrations

Today1

Time Calibration

- We have to know time offset of all 512 counters with the accuracy of 30 ps.
- We have 2 complementary methods to calibrate time offset b/w counters: laser-based method and track-based method.
- Radiative Muon Decay($\mu \rightarrow e\gamma\nu\nu$) is used for absolute calibration for relative timing b/w e^+ and gamma.

Today2

Position Calibration

- Hit distribution within a counter is aligned to design value.
- For detail in later slides.

Energy Calibration

- Reconstructed energy (landau distribution) is aligned to MIP peak.

Time

Purpose of this study

Today1

Time Calibration

- We have to know time offset of all 512 counters with the accuracy of 30 ps.
- We have 2 complementary methods to calibrate time offset b/w counters: laser-based method and track-based method.
- Radiative Muon Decay($\mu \to e\gamma\nu\nu$) is used for absolute calibration for relative timing b/w e^+ and gamma.

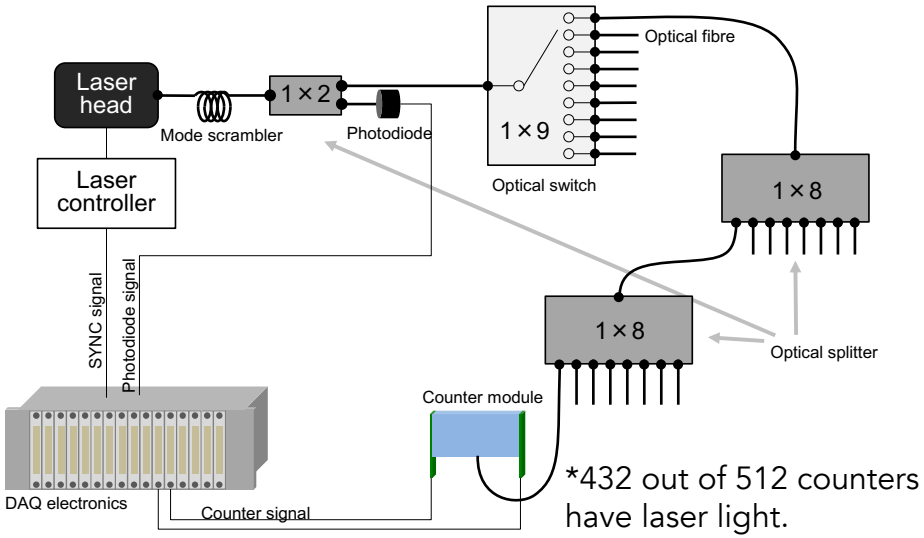
What we did so far(~2016)

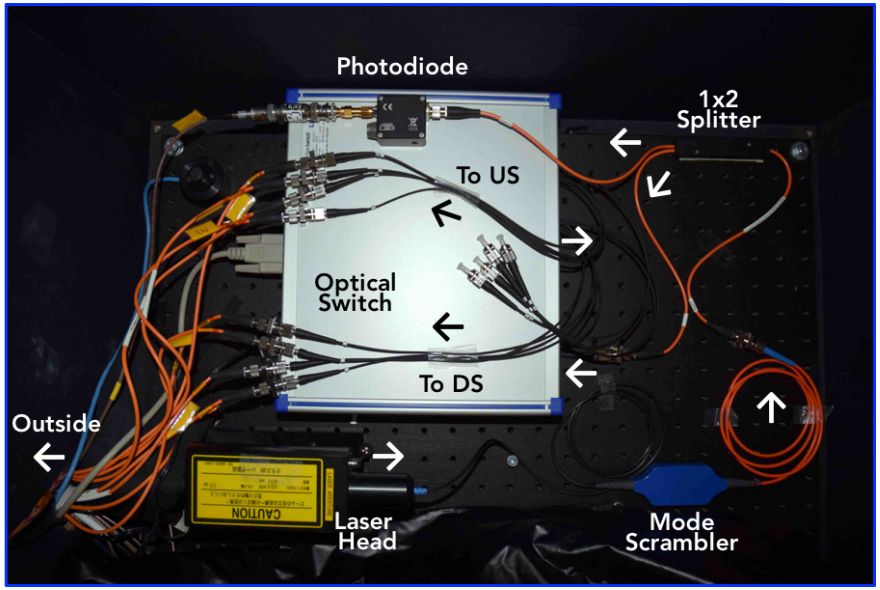
- We performed beam test using ¼ of pTC under the MEG II beam.

Purpose of This Study(2017)

- Operate full laser calibration system.
- Check stability of time offset.
- Consistency check b/w laser calibration and Michel calibration.

Laser-based method: concept





- PLP-10 (Hamamatsu) is used as a light source.

-Wavelength 405 nm
-Wavelength FWHM < 10 nm

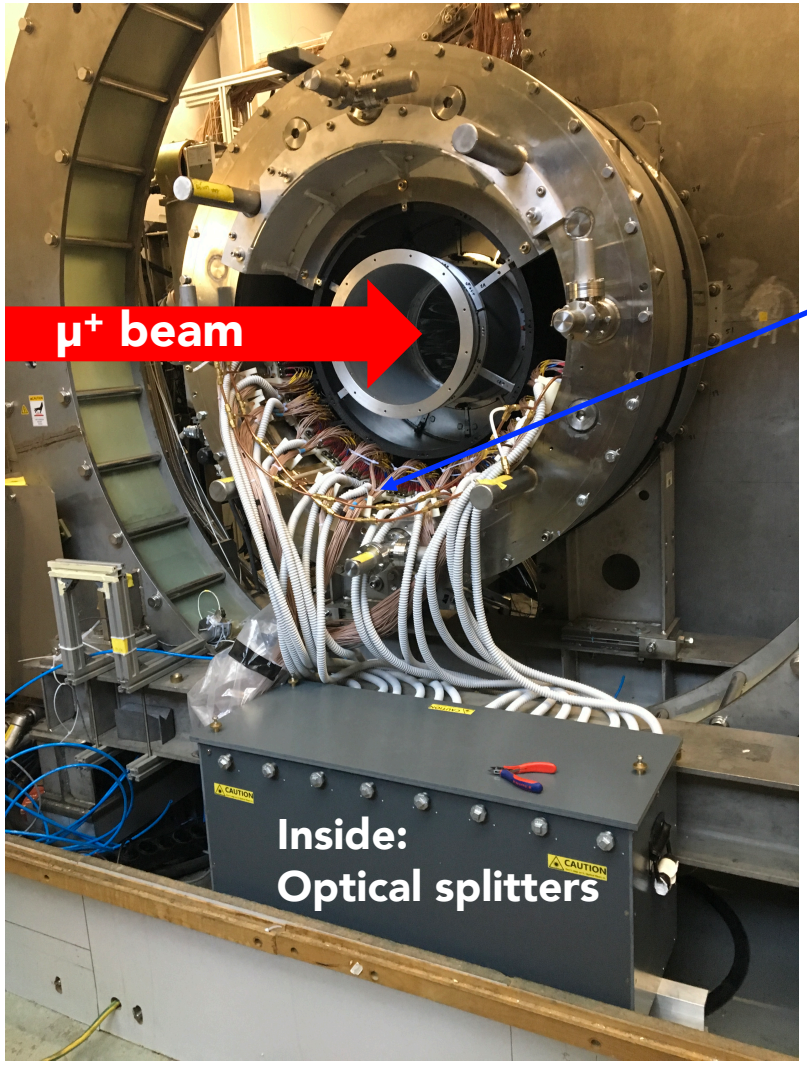
-Pulse duration typ. (max) 60 (100) ps

- Pulse laser is divided into each counter simultaneously.
- Time offset of each counter is measured relative to laser-synchronized pulse.
- Calibration uncertainty is estimated as 24 ps by testing all parts of laser calibration system.

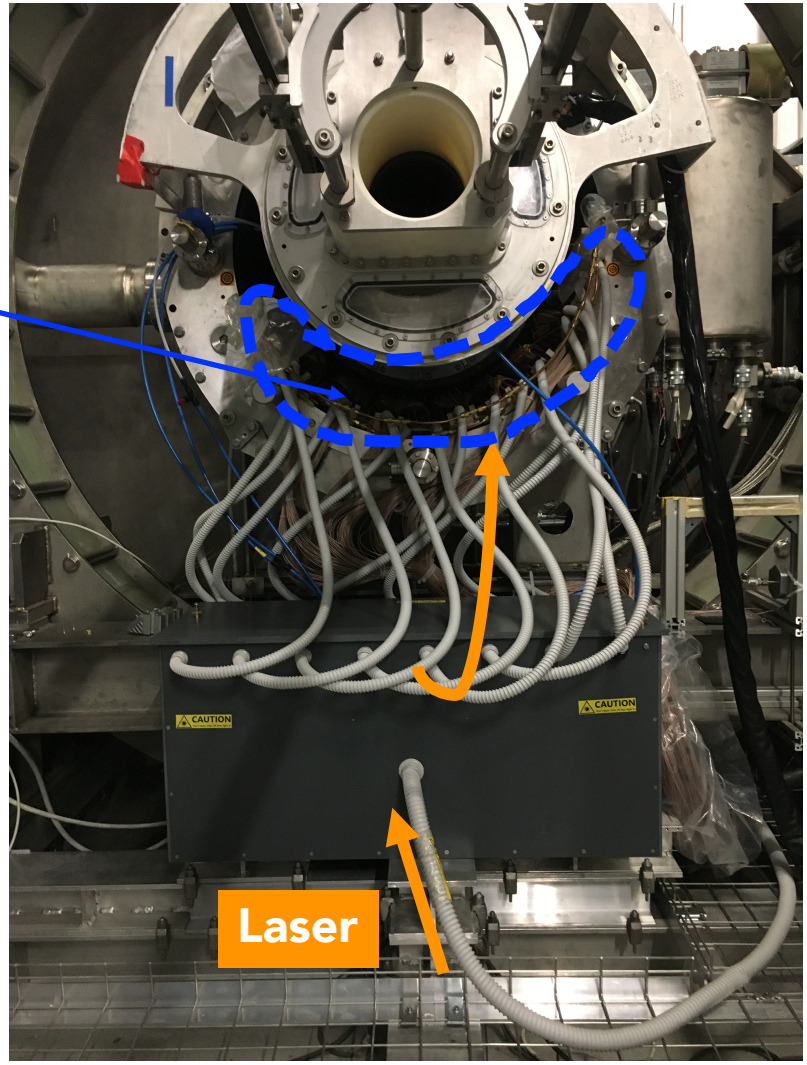
Time(Laser)

US/DS installation

Upstream (5th Sep., 2017)



Downstream (25th Oct., 2017)

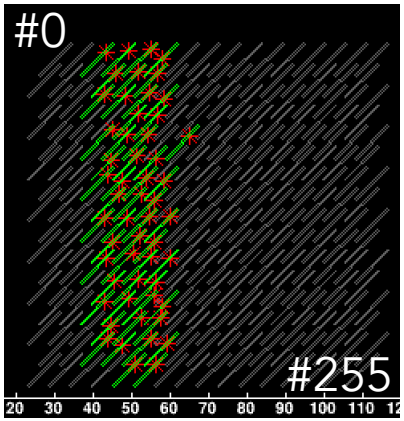


Time(Laser) First full operation (Oct. 2017)

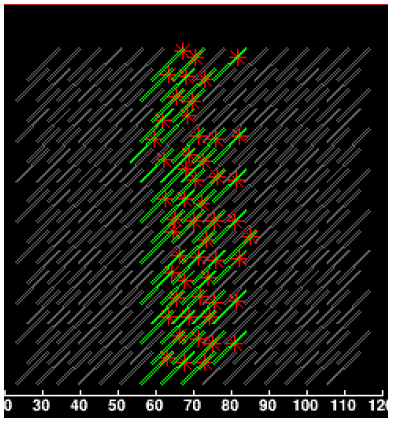
*different configuration of US/DS because of easier assembly work.

DS

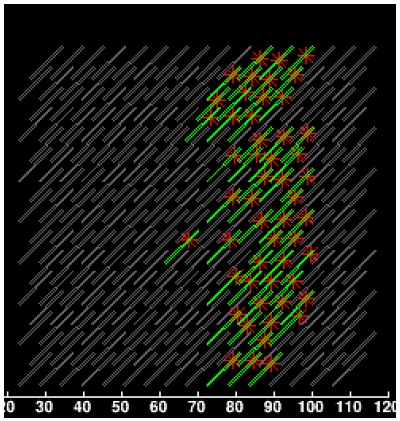
Fiber 1



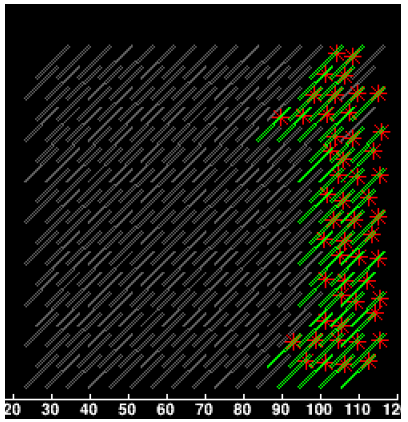
Fiber 2



Fiber 3

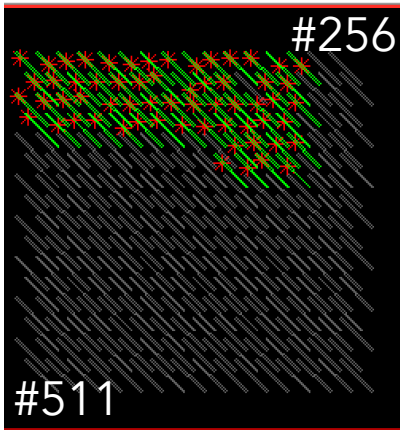


Fiber 5

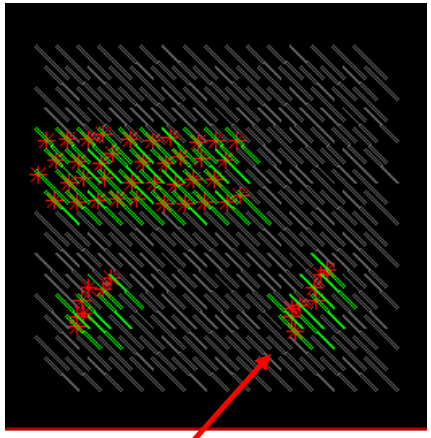


US

Fiber 9

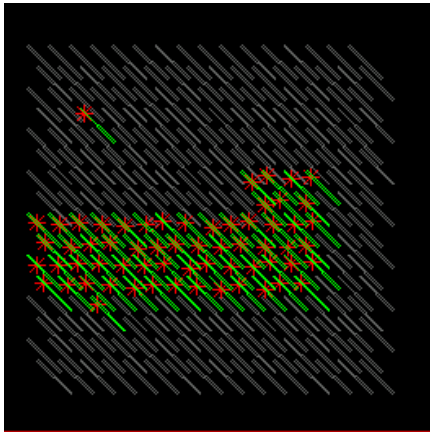


Fiber 6

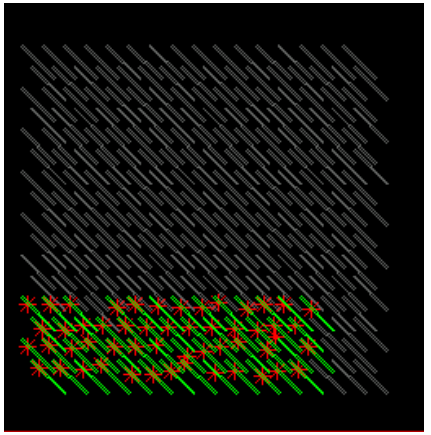


positron track

Fiber 8



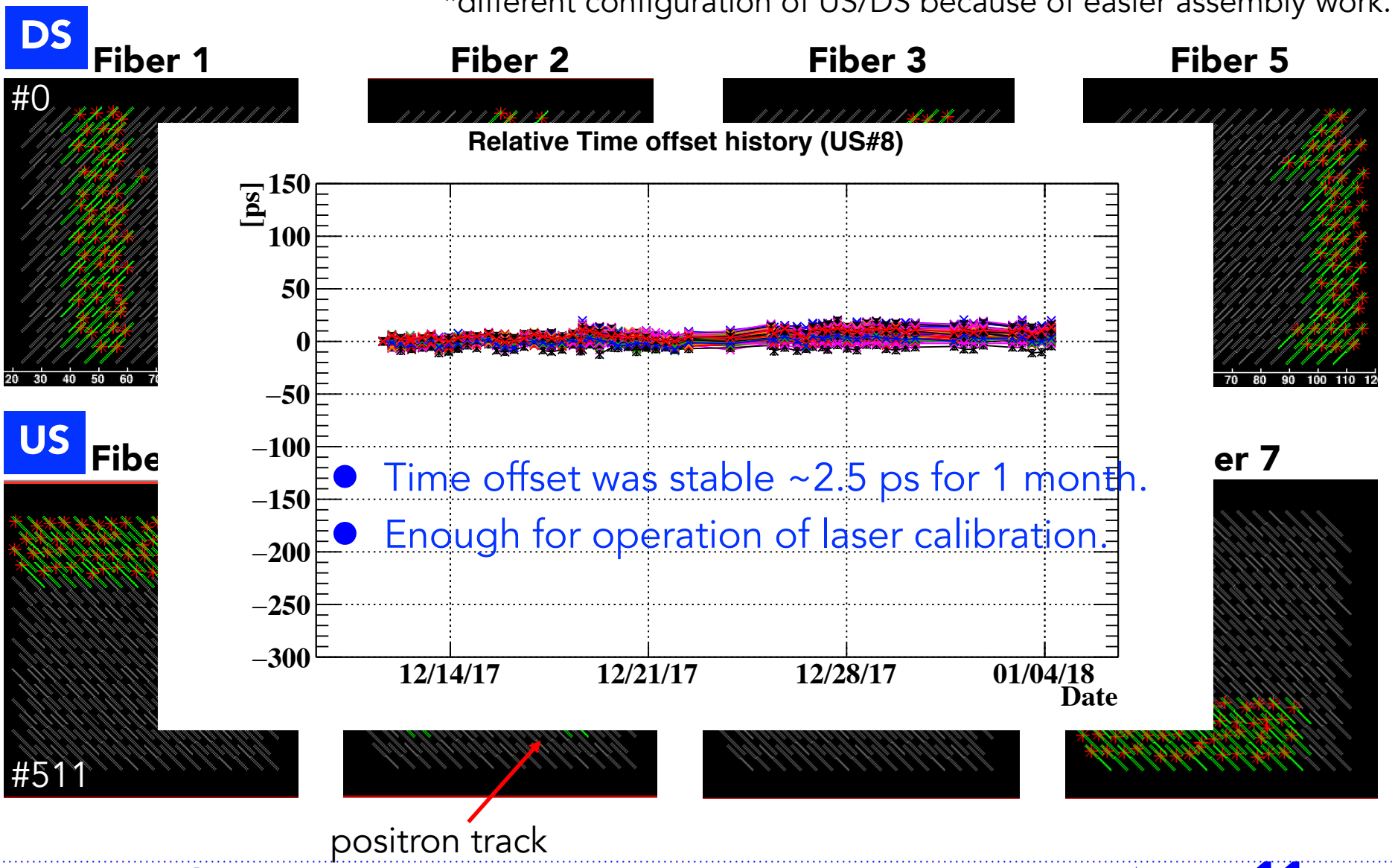
Fiber 7



Time(Laser)

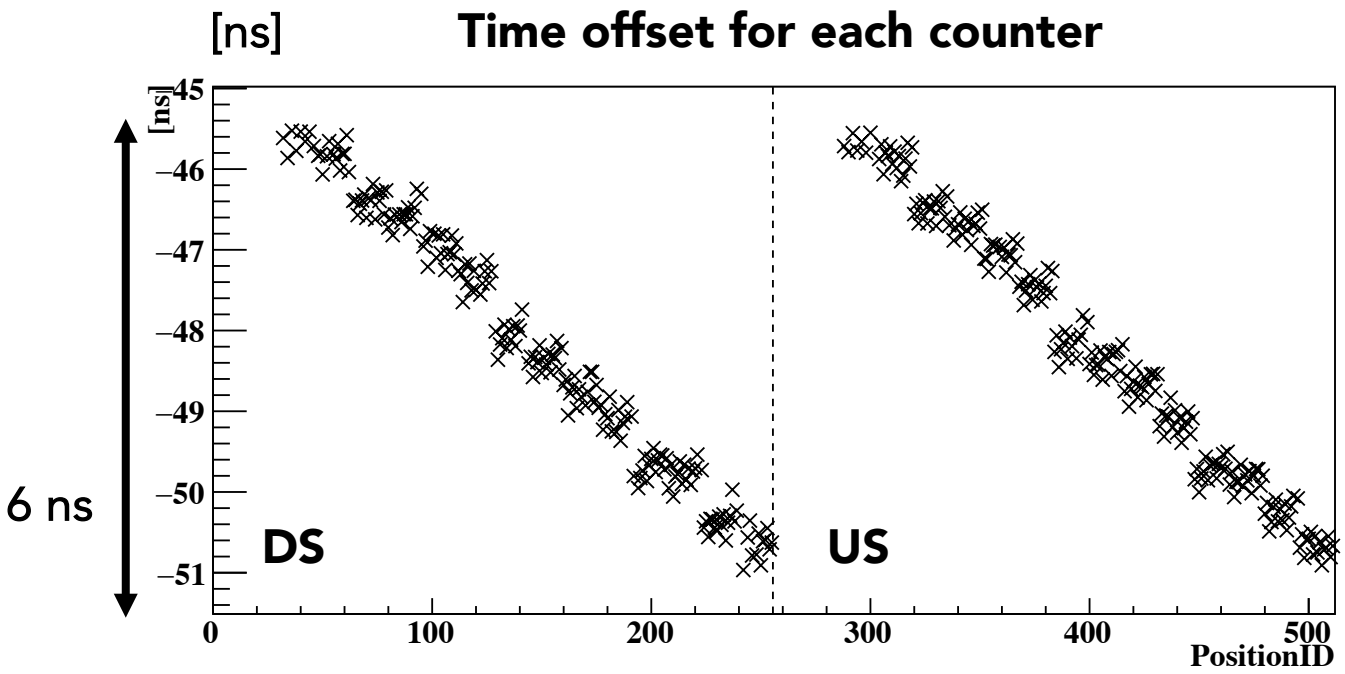
First full operation (Oct. 2017)

*different configuration of US/DS because of easier assembly work.



Time offset

- In order to know time offset to calibrate, we need to subtract "laser components" from time offset measured in laser run.



- This includes
  - cables
  - electronics
- This does not include "laser components"

Track-based method: concept

- Positron tracks from Michel decay ($\mu^+ \rightarrow e^+ \nu\nu$) are used for calibration.

Measured time　　Expected time

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

Time offset of each counter :What we want to know

1. Calculate TOF values for every counter by Monte Carlo*.
2. Define χ^2 as the difference b/w measured time and expected time.
3. Minimize χ^2 using Millepede II.
4. Find ΔT_j.

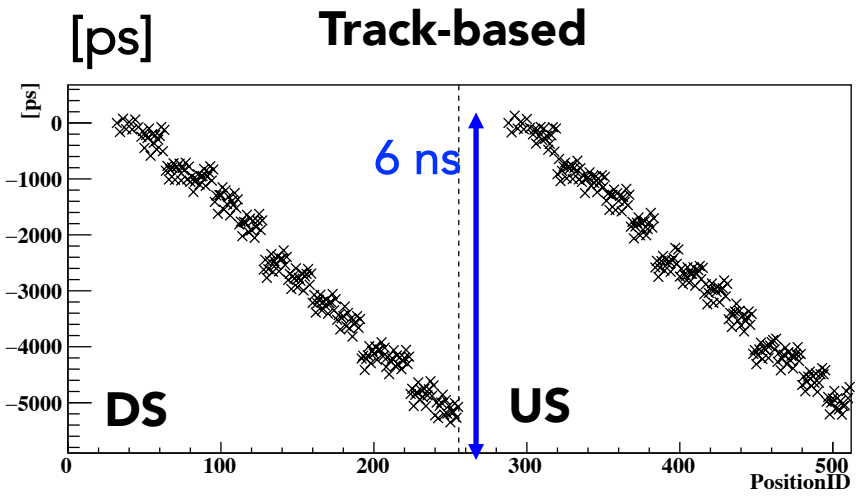
- Calibration uncertainty is estimated as 6 ps by MC study.

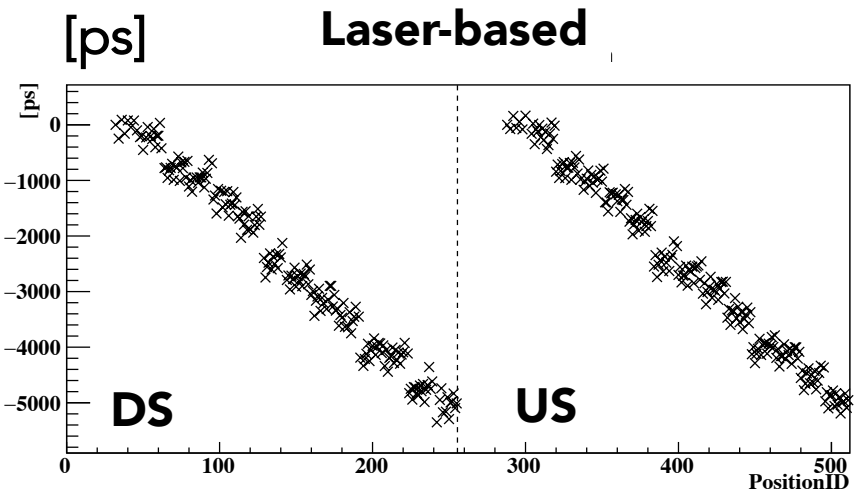
* This setup is for Pilot Run w/o DCH. TOF will be calculated by DCH in physics run.

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.

Comparison b/w 2 methods

- Relative time offset: time offset difference from first counter of each side.
  - position#32 (DS) and position#288 (US) is set to 0 ps.



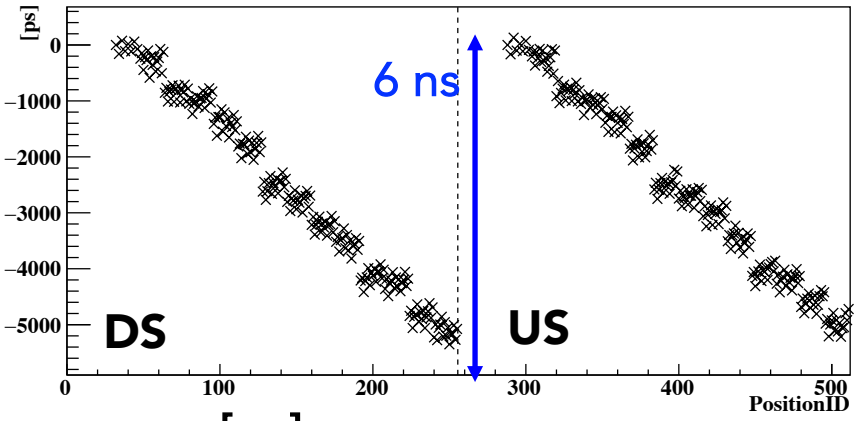


- Cables
- Electronics

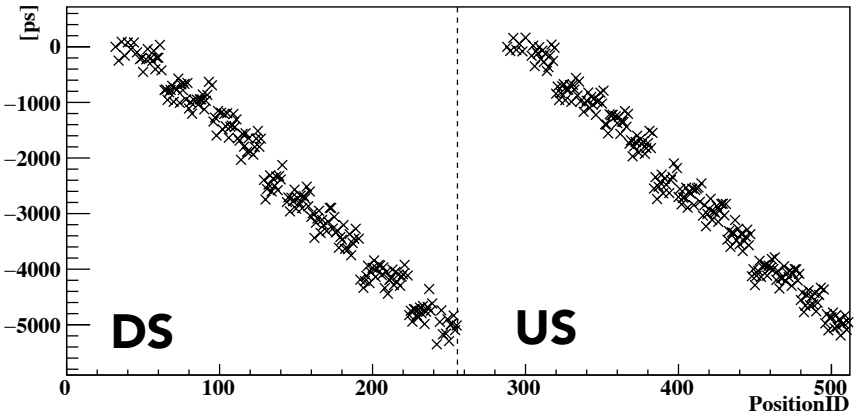
Comparison b/w 2 methods

- Relative time offset: time offset difference from first counter of each side.
  - position#32 (DS) and position#288 (US) is set to 0 ps.

[ps] **Track-based**

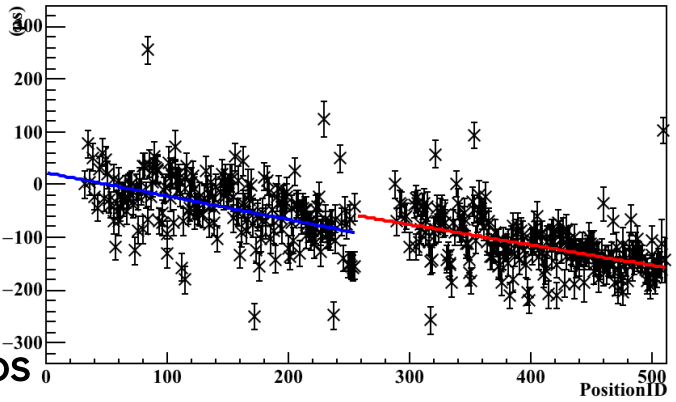


[ps] **Laser-based**



[ps]

300 ps



-300 ps

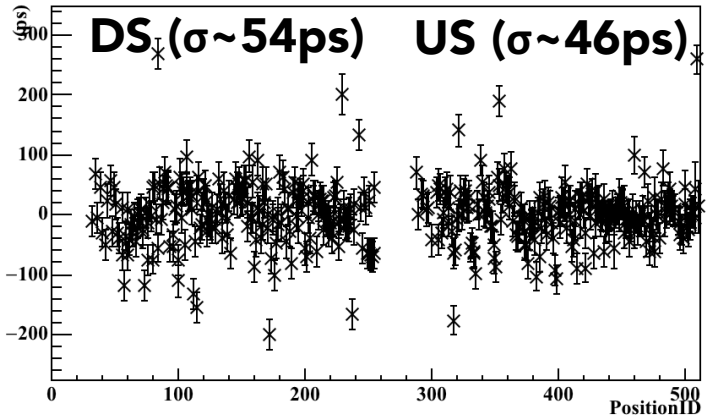
- TOF difference b/w data and MC accumulates according to counter order and causes this kind of bias (MC studies).
- "Laser" can not cause these bias (no position dependence)

→ can be corrected by using data.

Discussion

- Systematic difference of TOF used as a reference b/w data and MC causes position dependent bias, but can be corrected (see bottom left).
- 2 methods are consistent within ~ 50ps (="Laser"⊕"Track")
- 2 methods are complimentary and they should be integrated.

After correction



	Laser	Track
Position dependence	**no**	yes
DAQ time	**short;~30min**	long;~2 days
Beam	**not necessary**	necessary
Coverage	84%	**100%**
Uncertainty	24 ps	**6 ps (MC)**

- **Our strategy:** time offset calculated from "Track" is mainly used, and its time-dependence is monitored by "Laser" (**established**).
  →effectively, accuracy of $\frac{50}{\sqrt{2}} \sim 35$ ps* is expected.
  →good, but still have room for improvements.

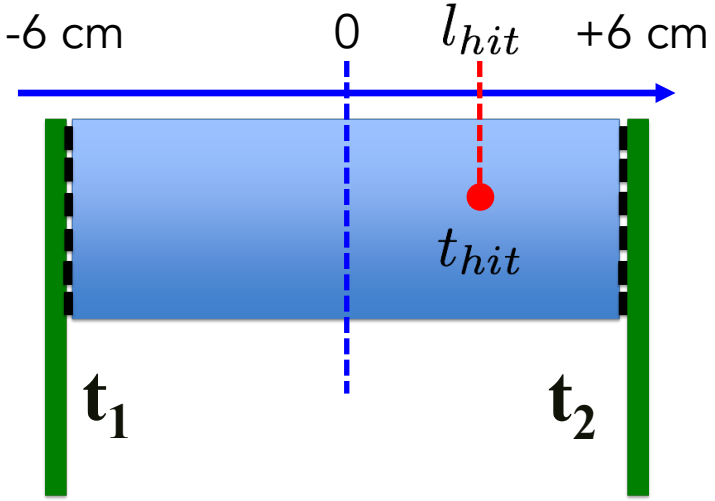
*this value is not directly used in physics analysis.

Position calibration

- Hit position: $l_{hit} = v_{eff}\dfrac{t_1 - t_2}{2}$
  - v_{eff} : effective velocity
  - T_{offset} : t_1-t_2 includes time offset difference b/w 2 channels.

Goal

- Calibrate v_{eff} and T_{offset}.
- Hit distribution should be aligned less than position resolution ~ 1cm.



Motivation

- Calibrate length of signal line
- Better performance in the later analysis
  - Better clustering/tracking in pTC
  - Matching b/w pTC and Cylindrical Drift Chamber (e^+ tracker).
- Pileup rejection

How to calibrate

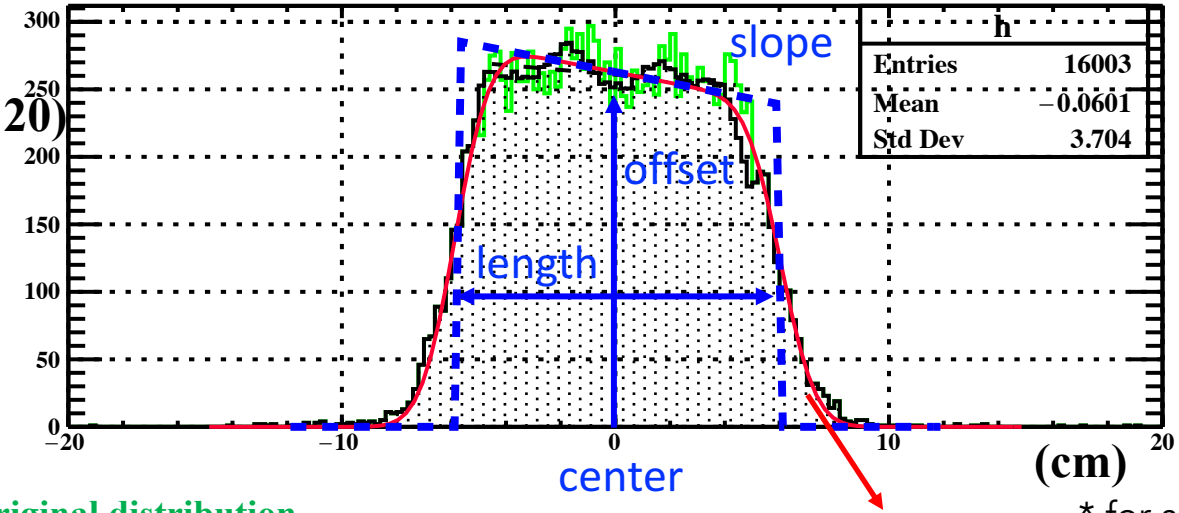
- Hit distribution within a counter is aligned to design value.

Fitting

- Fitting function(red): trapezoid(blue) convoluted with Gaussian*,**.
  - **"center"**: calibration of **Toffset b/w 2 channels/effective velocity**.
  - **"length"**: calibration of **effective velocity**.
  - **"sigma"**: interpreted as **position resolution**.
- Uncertainties of the fitting are estimated using MC to be the followings;
  - **center: 0.11 cm**, length: 0.27 cm, sigma: 0.14 cm

Reconstructed hit distribution in a 12cm-long counter

MC
(counter: 120)



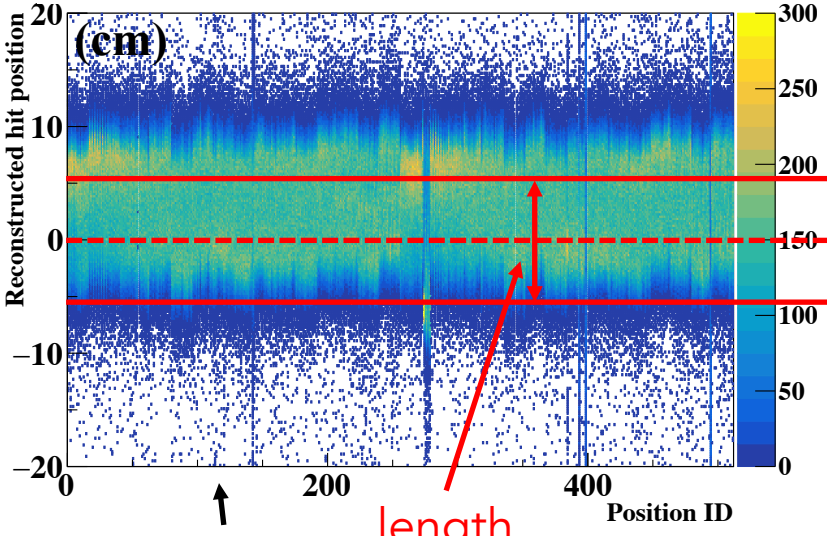
Green: original distribution
Black: moving averaged
Blue: original trapezoid
Red: convoluted with Gaussian

* for simplicity, I set
-convolution step: 100
-convolution range: +-5σ
** minimization using chi2

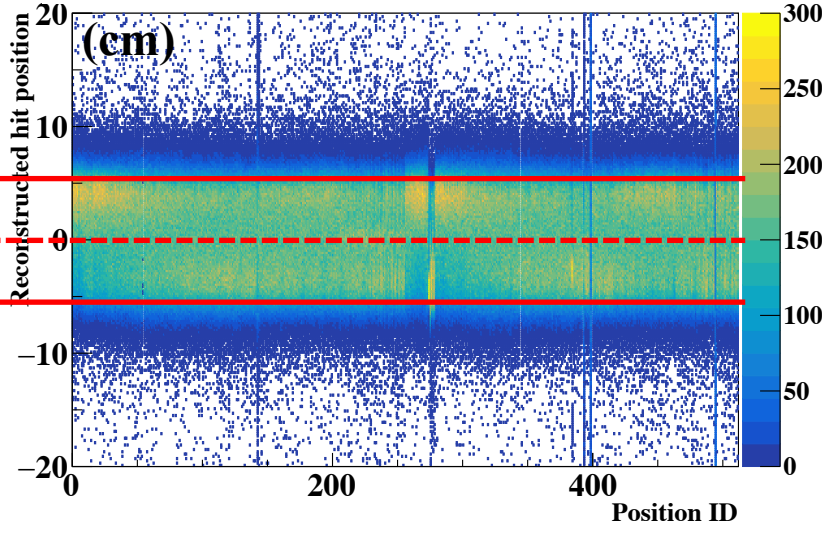
Results

- Effective velocity (12.44±0.40) under the beam is consistent with lab test using ^{90}Sr source (measured at 3 fixed points).
- Toffset b/w 2 channels are reasonable taking into account signal line and electronics contributions.
- Hit distribution is aligned (see below).
- Fitting uncertainties: **center(0.11 cm)**, length(0.27 cm) is better than requirement (~1 cm).

Reconstructed hit distribution (Before)



Reconstructed hit distribution (After)



Summary

Today1

Time Calibration

- Full laser system was successfully installed.
- Time offset is enough stable ~ 2.5 ps over 1 month.
- We have established 2 complementary methods to calibrate time offset b/w counters: laser-based method and track-based method.

Today2

Position Calibration

- Effective velocity and time offset b/w 2 channels are calibrated.
- Hit distribution is aligned better than position resolution.

Conclusion

- pTC calibration is established and ready for physics run.
- Performance evaluation of pTC and its prospects → **see next talk!**