MEG II実験陽電子タイミングカウンターの較正方法の開発

Development of calibration methods for MEG II positron timing counter

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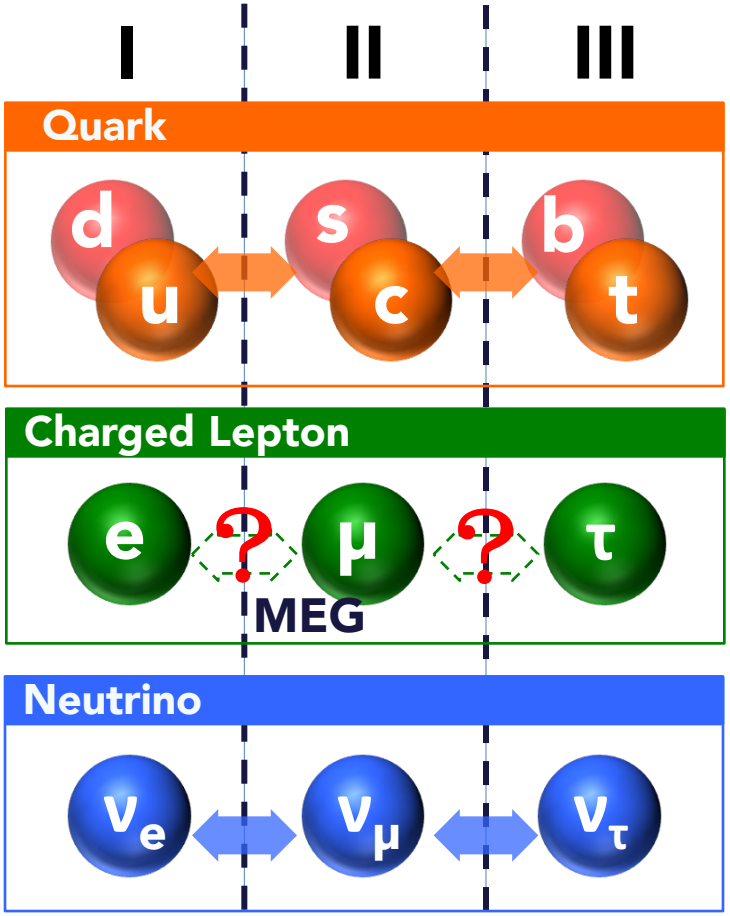
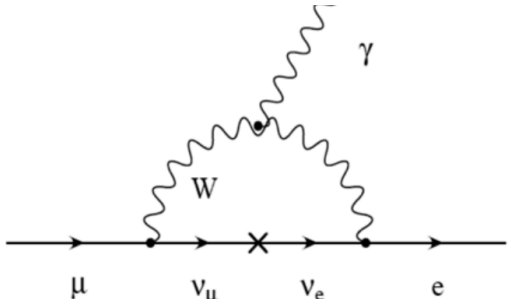
On behalf of MEG II Collaboration

ICEPP The University of Tokyo

Charged Lepton Flavour Violation



- Inter-generational mixing have not been observed only for charged lepton sector.
- Too small branching ratio is predicted in the framework of the standard model + neutrino mass.



$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M_W^2}\right|^2 \simeq 10^{-54}$$

- Beyond the standard model (SUSY GUT etc) predicts that charged lepton should also mix at experimentally observable rate: $O(10^{-11}) \sim O(10^{-15})$

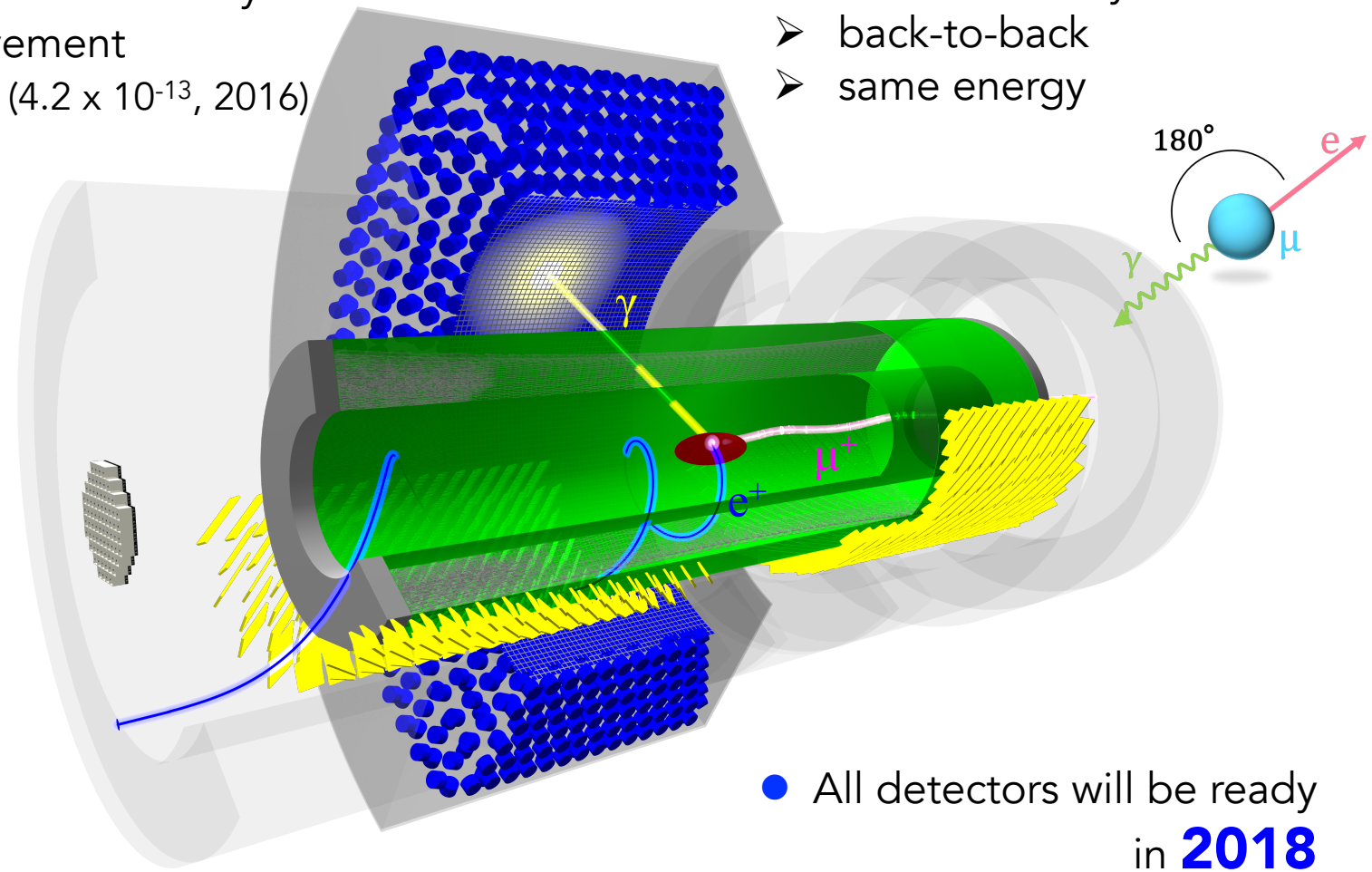
The discovery of cLFV is clear evidence for new physics

MEG II Experiment

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

- Search for cLFV ($\mu^+ \rightarrow e^+\gamma$) with unprecedented sensitivity: **4 x 10^{-14}**
  - x**10** improvement from MEG (4.2 x 10^{-13}, 2016)

- **Signal (e^+, γ)**
  - Simultaneously emitted
  - back-to-back
  - same energy

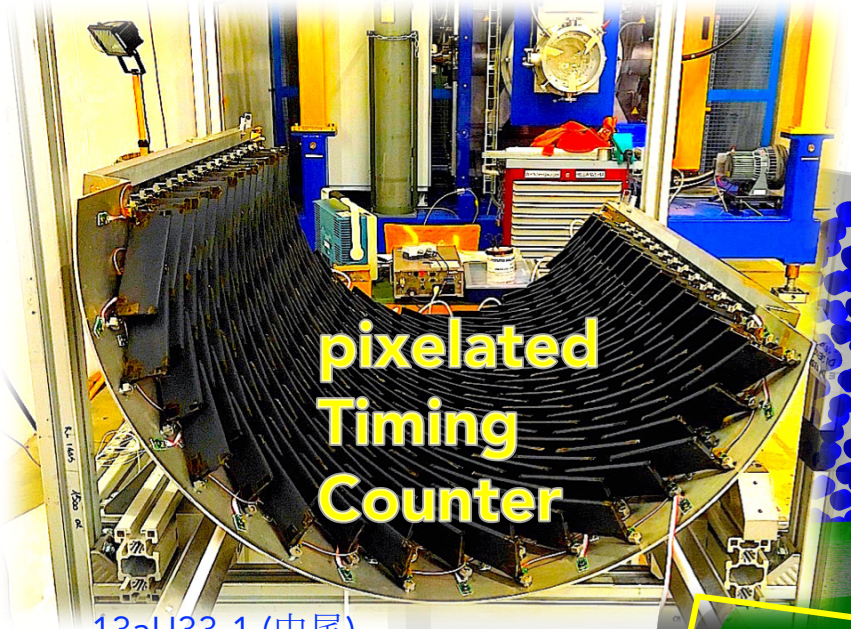


- All detectors will be ready in **2018**

- Improve every resolution by factor **2**

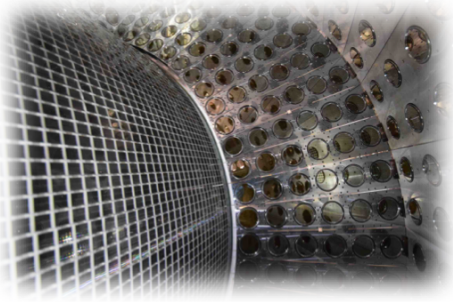
MEG II Detector

At Paul Scherrer Institut in Switzerland



-13aU33-1 (中尾)
-13aU33-2 (宇佐見)
-14aS36-7 (中尾)

Liquid Xenon Gamma-ray Detector



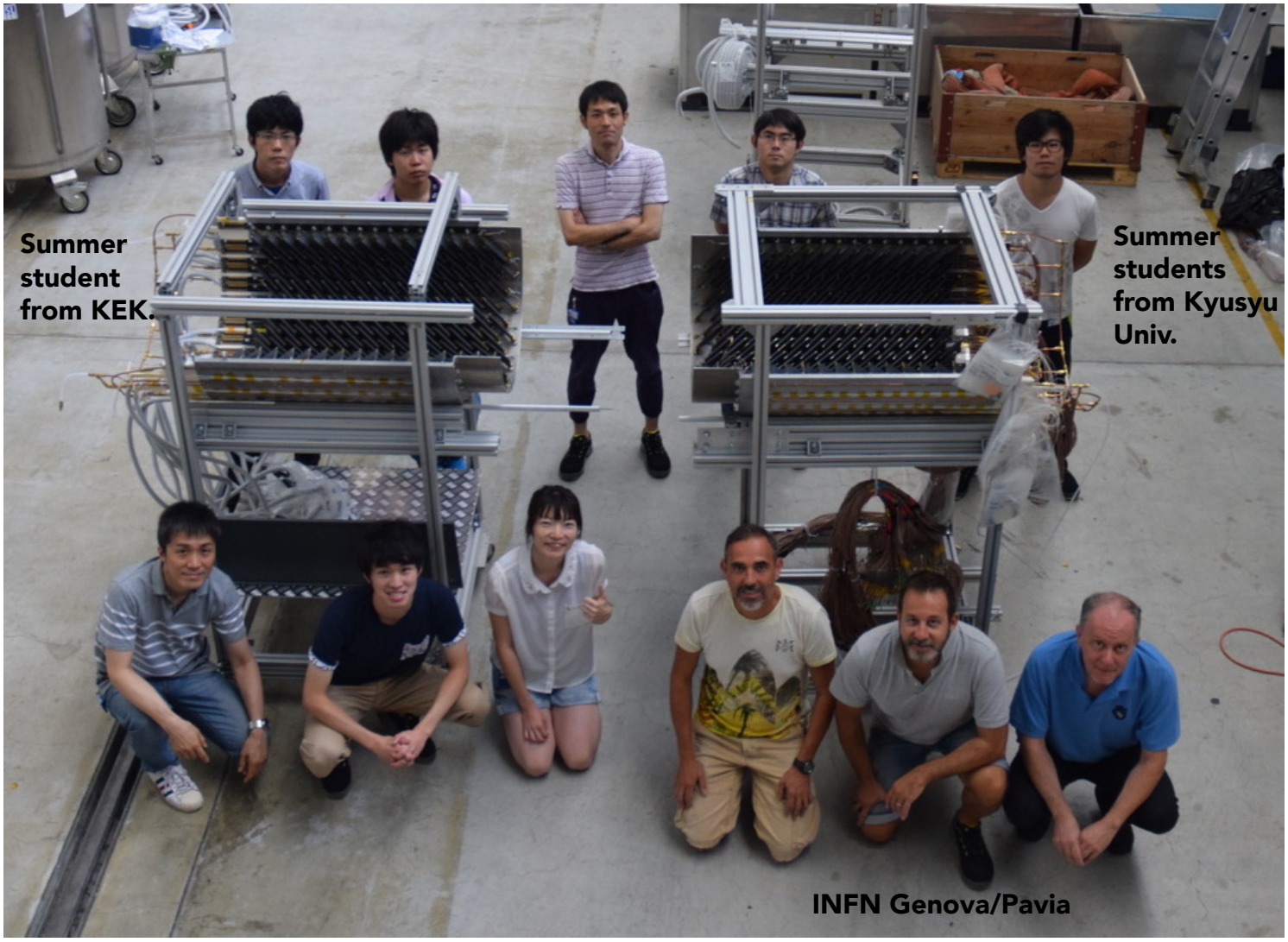
-13aU33-3 (恩田)
-13aU33-7 (家城)
-13aU33-9 (小川)
-13aU33-10 (松澤)

Radiative Decay Counter

-14pS35-8 (家城)

Cylindrical Drift Chamber

pTC Status: Ready for Installation

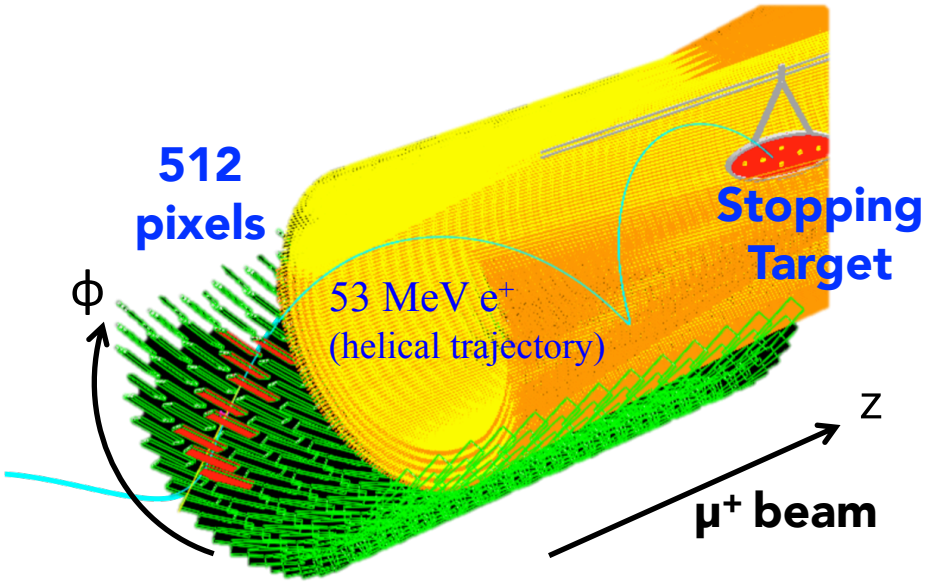


- We have completed our detector and ready for installation into experimental site.

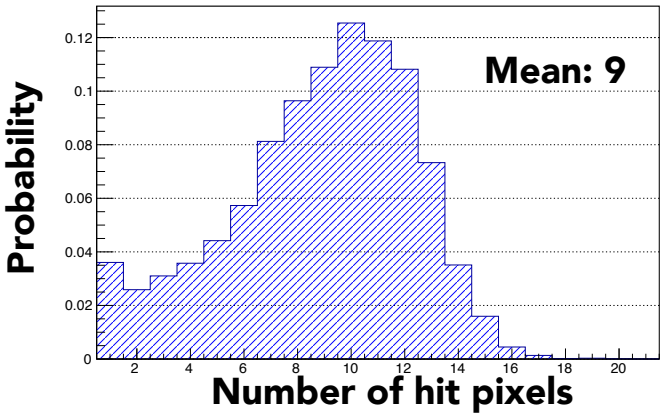
pTC (1): Concept

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

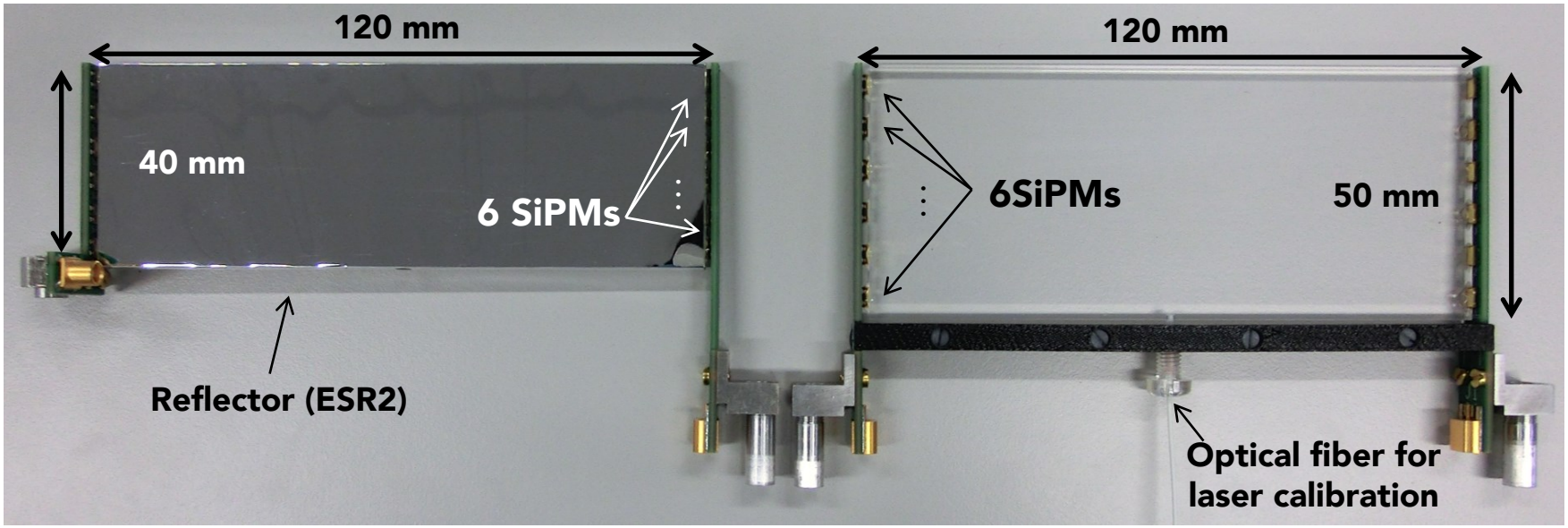
$$\sigma_{\rm all}(N_{\rm hit}) = \sqrt{\frac{\sigma^2_{\rm intrinsic}}{N_{\rm hit}} + \frac{\sigma^2_{\rm inter-pixel}}{N_{\rm hit}} + \sigma^2_{\rm MS}(N_{\rm hit}) + \sigma^2_{\rm const}}$$

Intrinsic resolution: 70~80 ps

Multiple scattering: ~4 ps at 9 hits

pTC (2): Pixel

- Upstream (256 pixels) + Downstream (256 pixels)= 512 pixels
- 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 pixels: < 30 ps



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

pTC (3): Time Calibration

Time Calibration

- We have to know time offset of all 512 counters with the accuracy of 30 ps.
- Radiative Muon Decay($\mu \rightarrow e\gamma\nu\nu$) 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: laser-based method and track-based method.

Purpose of This Study

Time Calibration

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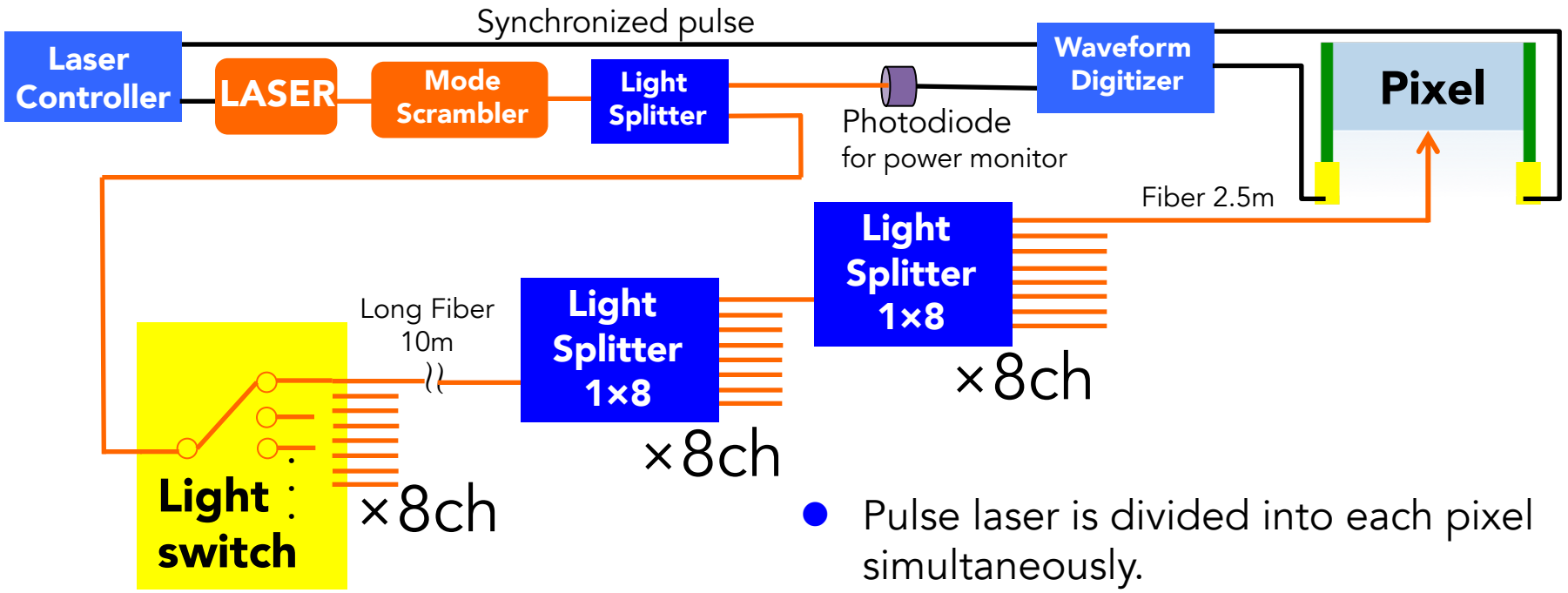
What we did so far

- We performed beam test using ¼ of pTC under the MEG II beam.
- We checked the consistency b/w 2 calibration methods under a limited situation:
  - Laser-based method: laser system was installed into 40 counters.
  - Track-based method: w/o Drift Chamber.

Purpose of This Study

- Laser-based method: extend to full laser system.
- Track-based method: develop w/ Drift Chamber.

Laser-based Method: Concept



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

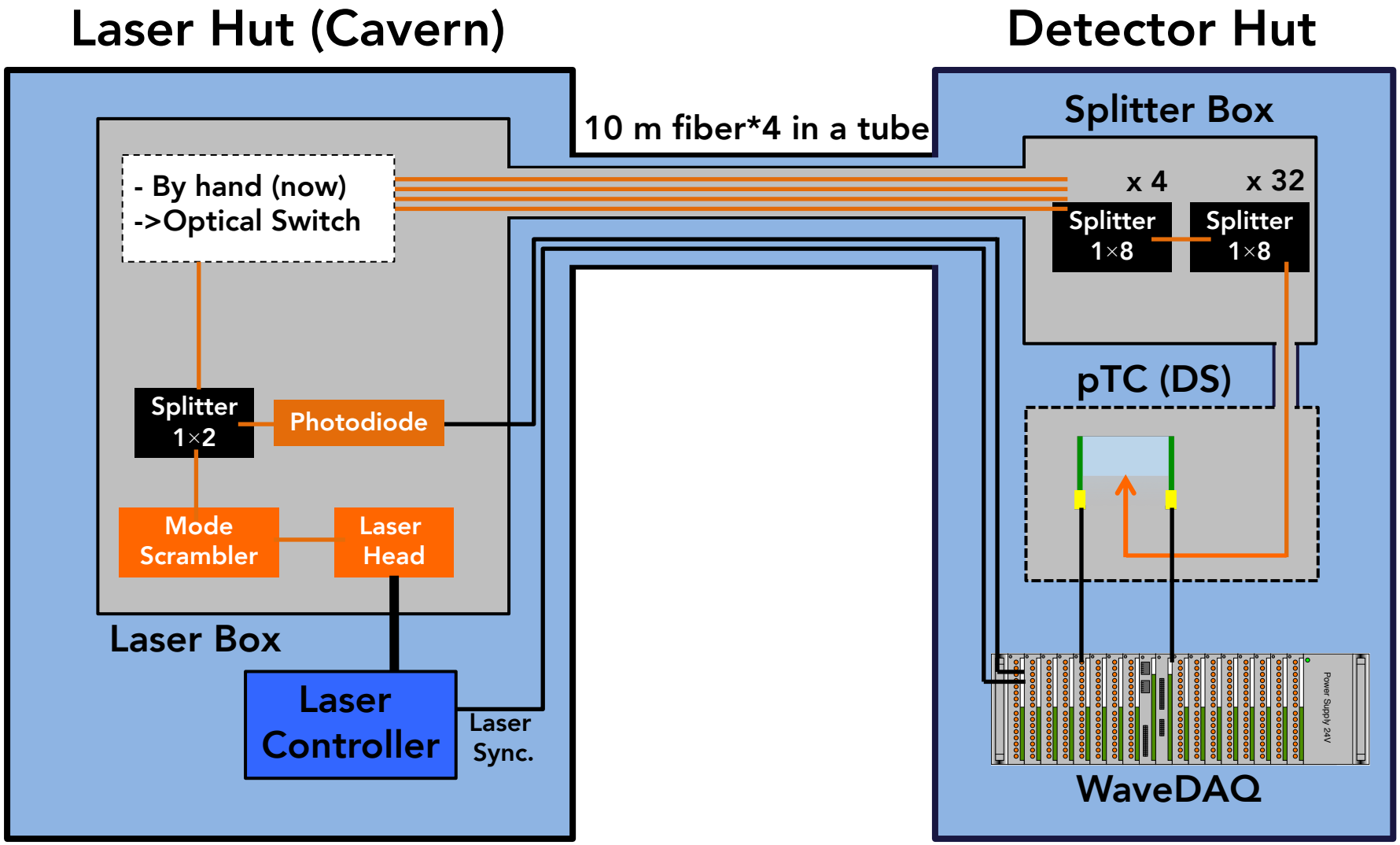
(cited from Hamamatsu HP)

-Wavelength 405 nm
-Wavelength FWHM < 10 nm

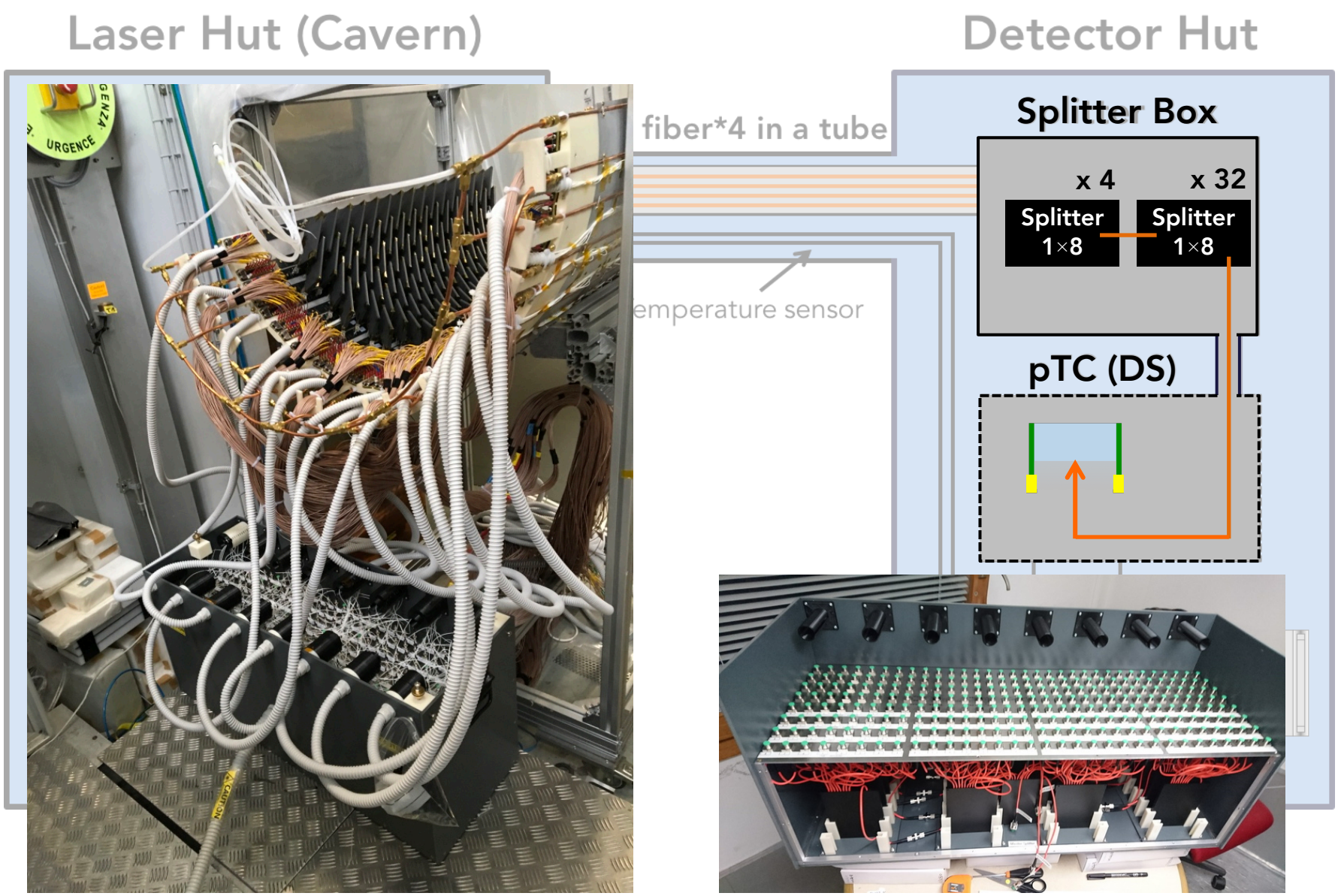
-Pulse duration typ. (max) 60 (100) ps

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

Test Installation (1)



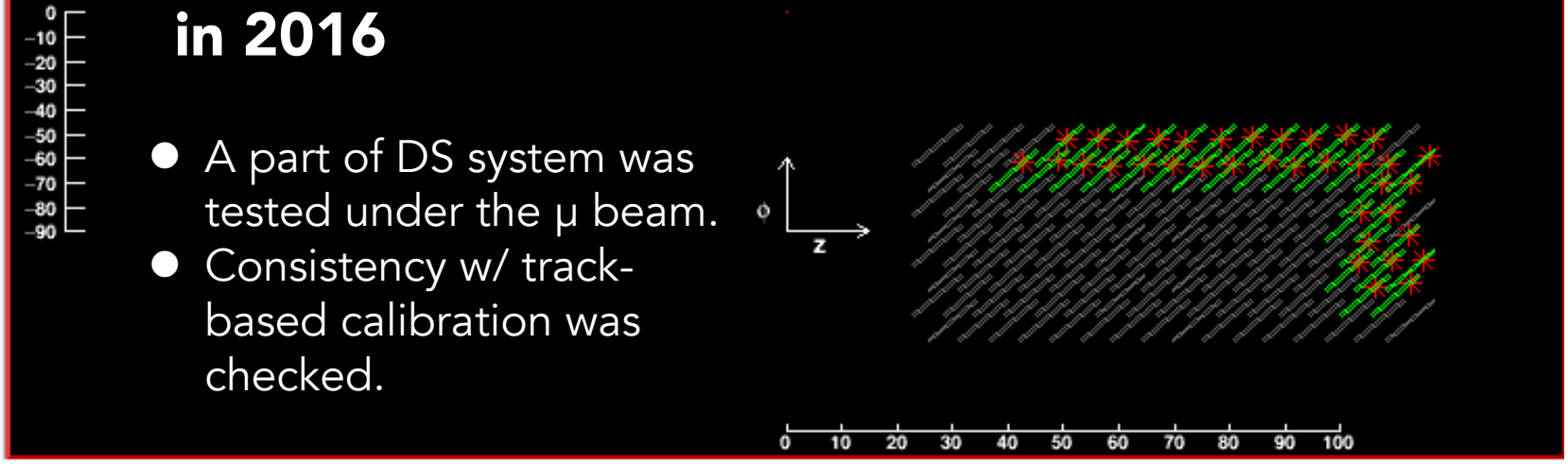
Test Installation (2)



Status & Event Display

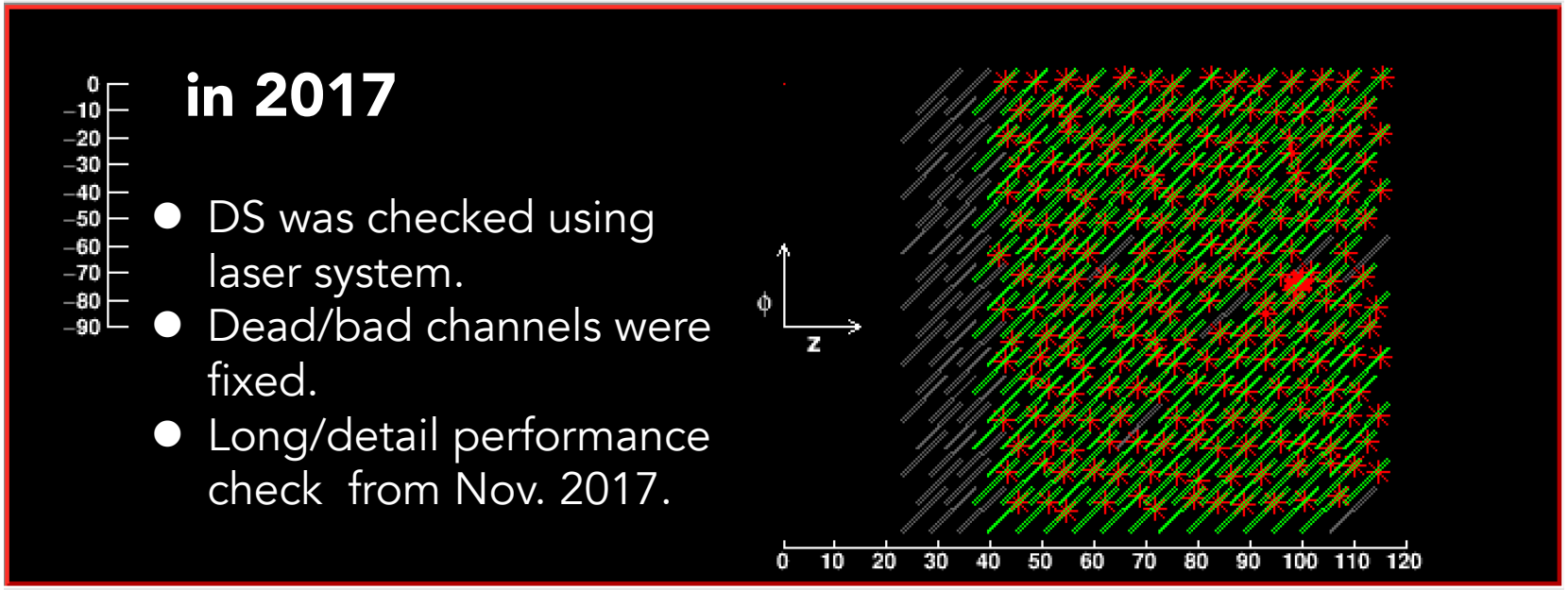
in 2016

- A part of DS system was tested under the μ beam.
- Consistency w/ track-based calibration was checked.



in 2017

- DS was checked using laser system.
- Dead/bad channels were fixed.
- Long/detail performance check from Nov. 2017.



Track-based Method: Concept

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

  1. Calculate TOF values b/w adjacent counters.
  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.

Measured time

Expected time

Time offset of each pixel
:What we want to know

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

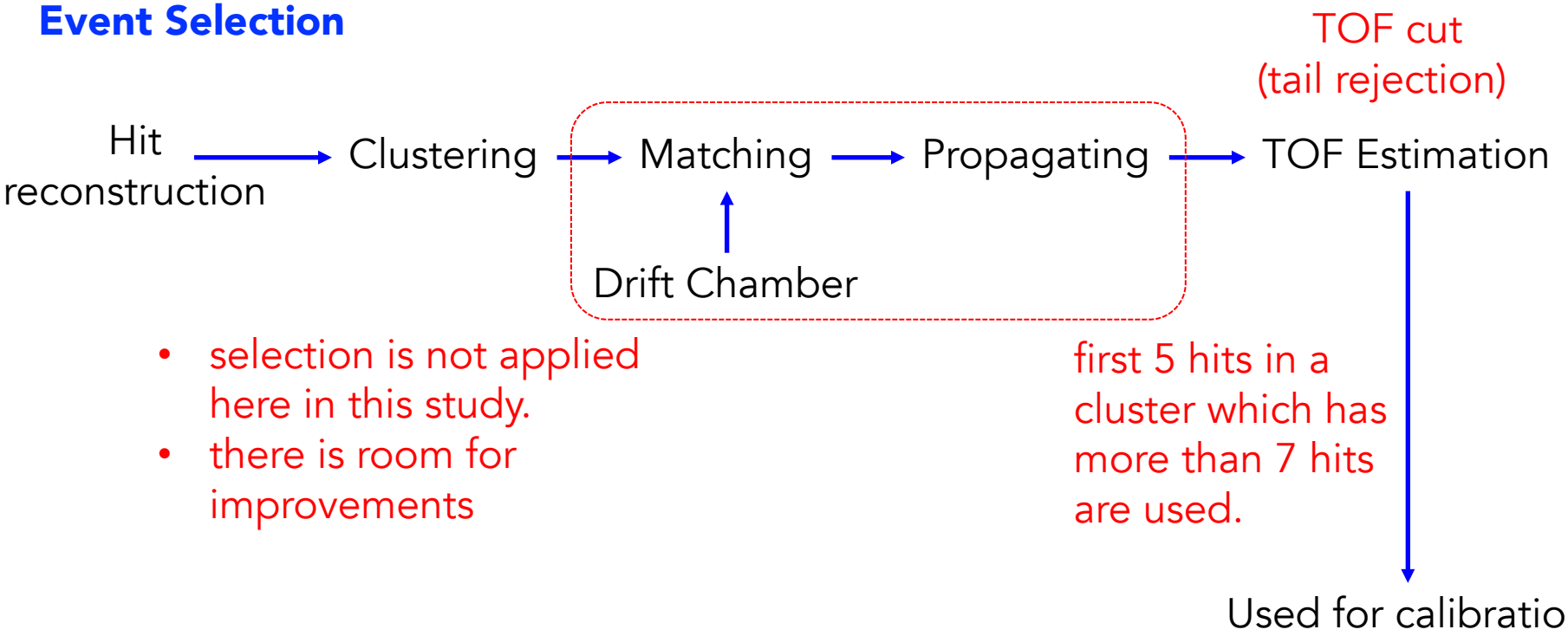
Millepede II www.desy.de/~kleinwrt/MP2
A software provided by DESY to solve the linear squares problems, such as detector alignment and calibration based on track fits.

Setup and Event Selection

MC Setup

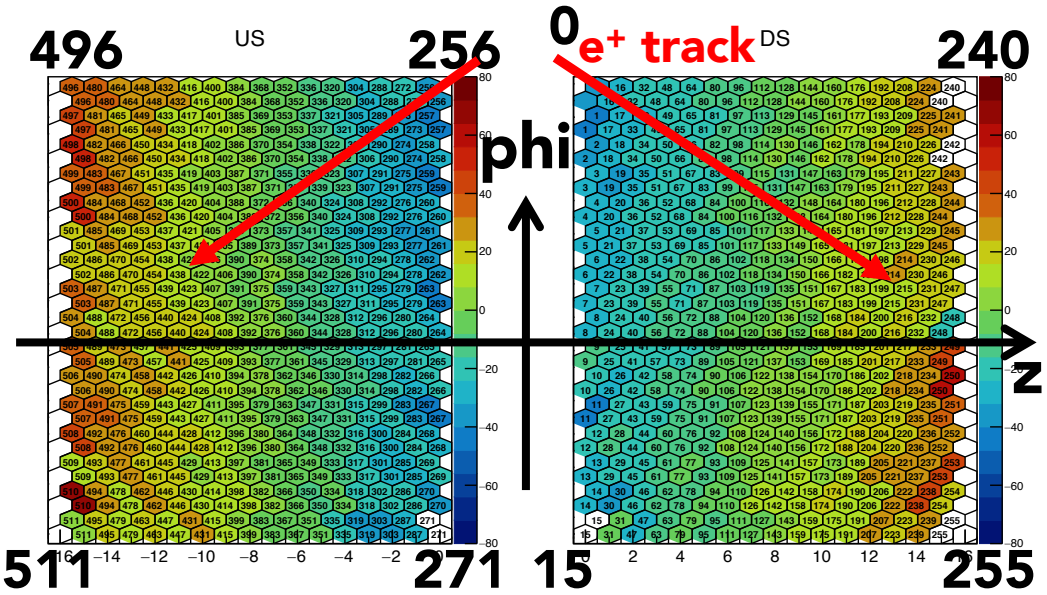
- Generated from μ^+ beam mixed at 7×10^7.
- Time offset was set by randomly (:=Gaus(0, 100 ps)).
- Evaluate the performance with the difference b/w calculated time offset and original time offset.
- Number of events: 260k.

Event Selection

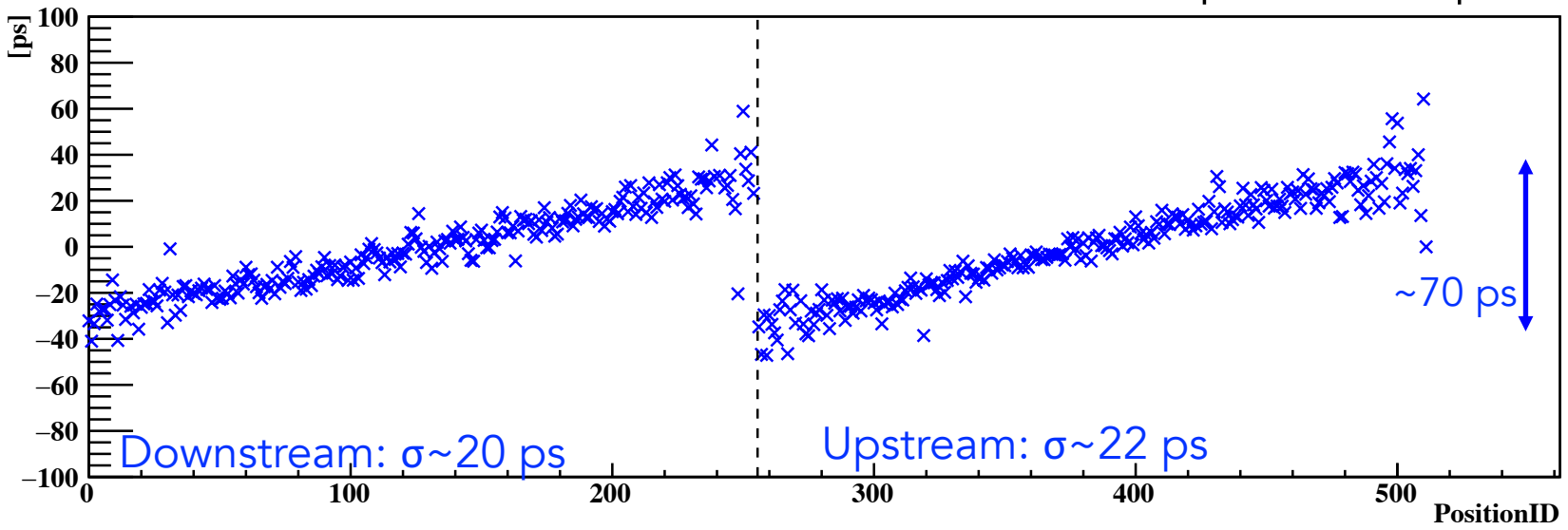


Results

- First results w/ Drift Chamber.
- Bias depending on counter position was observed.
  - TOF calculation in propagation.
  - Position dependence of statistics.
- Accuracy of < ~22 ps was achieved.
  - Needs further improvements.



↓Calculated time offset – true time offset / ↑its position dependence



Prospects

Key months

Nov.

2017

Jul.

2018

- **Pilot Run 2017**
  - pixelated Timing Counter, Liquid Xenon Gamma-ray Detector, Radiative Decay Counter will be installed.
  - ~7 weeks of combined detector DAQ is planned under the MEG II environment.
  - Laser-based and track-based calibration will be applied for full pTC.
  - Performance check of full pTC using μ beam is planned.
- **Installation of all detectors**
  - Maintenance after Pilot Run 2017.
  - Including Drift Chamber.
- **Engineering Run**
  - 6 months of performance data-taking.
  - This run may evolve into physics run if things get ready.
  - Inter-detector calibrations.
- **Physics Run**
  - Start searching for $\mu^+ \to e^+\gamma$ with unprecedented sensitivity.

Consistency Check b/w 2 Methods

Key months

Nov.

2017

Jul.

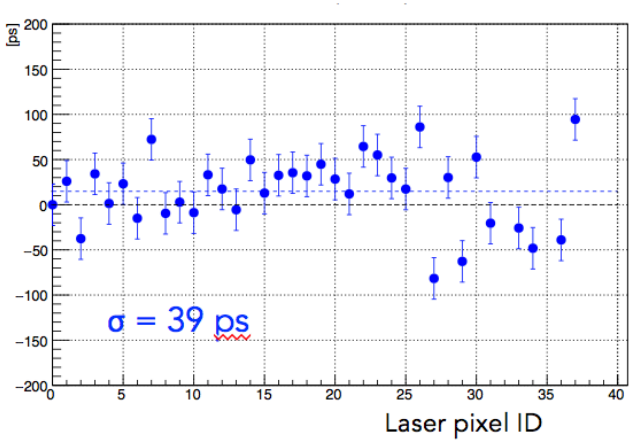
2018

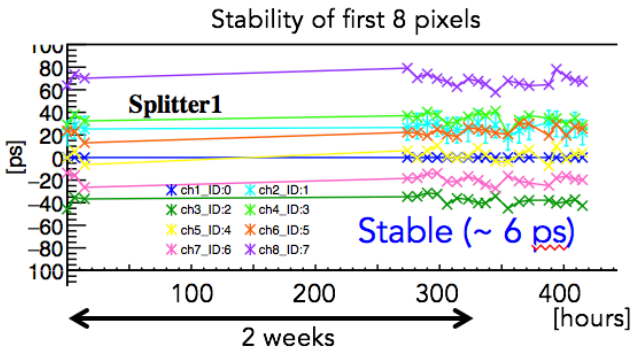
Pilot Run 2016

- **Pilot Run 2017**
  - ➢ pixelated Timing Counter, Liquid Xenon Gamma-ray Detector, Radiative Decay Counter will be installed.

Results **Consistency b/w Time Calibration Methods**

- Time-offset difference b/w laser-based method and track-based method (left) and its stability (right).





- The variation of time-offset difference is σ = 39 ps.
  - ➢ Including systematic uncertainty of laser-based and track-based methods.
- Time-offset difference is stable in time (~ 6 ps).

Prospects

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2018

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- **Physics Run**
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Summary

- We have developed and constructed 2 complementary methods for time calibration.

- Laser-based method:
  - extended to full laser system.
  - ready for long-term and detail performance check from Nov. 2017.

- Track-based method:
  - first results w/ Drift Chamber was presented.
  - accuracy of 22 ps was achieved, but have some bias.
  - it needs improvements at each step of analysis chain.

- Beam test w/pTC, LXe and RDC is planned from Nov. 2017 (Pilot Run 2017).