MEG II 実験における陽電子タイミングカウンターのコミッショニング 2018

Commissioning of Positron Timing Counter in the MEG II Experiment 2018

2019/02/17

ICEPP シンポジウム

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Outline

➢Introduction
- cLFV (charged Lepton Flavor Violation)
- $\mu \to e\gamma$ reaction
- Signal & background events
- MEG II experiment
- Detectors
- pTC (pixelated Timing Counter)

➢Operation
- Installation & motivation
- Cooling system
- HV setting

➢Calibration
- Positron reconstruction
- Laser system
- Time calibration

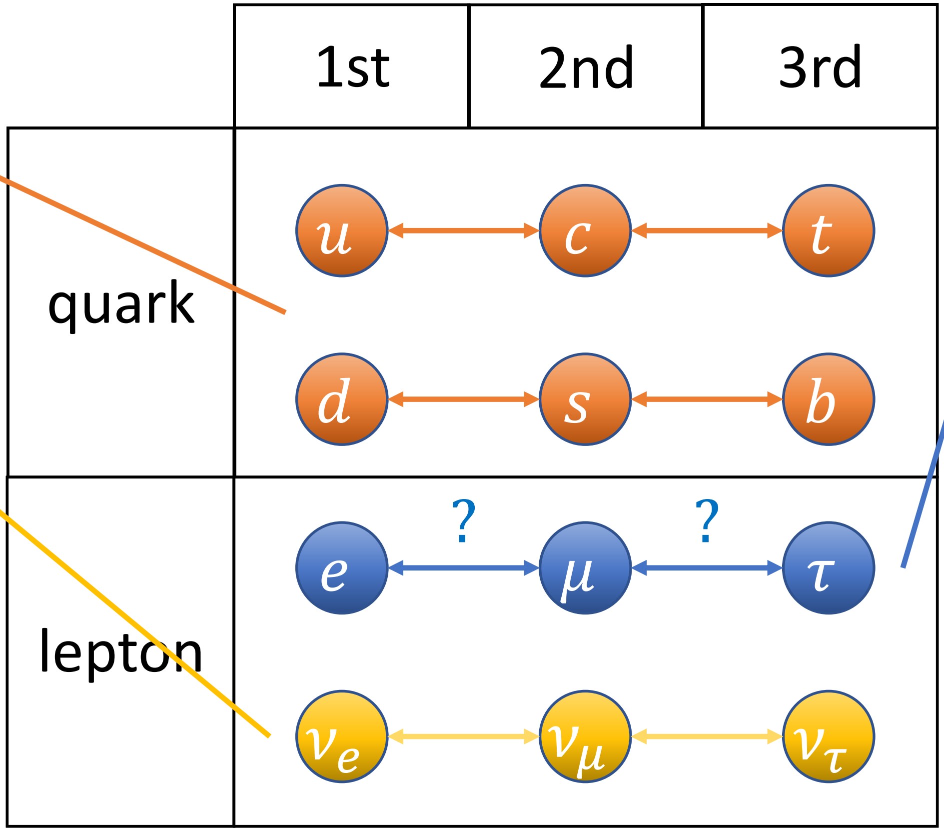
➢Data analysis
- Clustering & tracking
- N-hit analysis
- pTC self tracking

➢Summary & prospect

cLFV (charged Lepton Flavor Violation)

- **Quark mixing**
  - Included in SM
  - Explained by CKM theory
- **Neutrino oscillation**
  - Discovered in Super-Kamiokande
  - Forbidden in SM
  - Firm proof of bSM physics

→ Suggests possibility of flavor violation in charged lepton sector



- **Charged lepton flavor violation (cLFV)**
  - Forbidden in SM
  - Included in many new physics models
  - If discovered, certain proof of new physics
  - Has been searched in many experiments

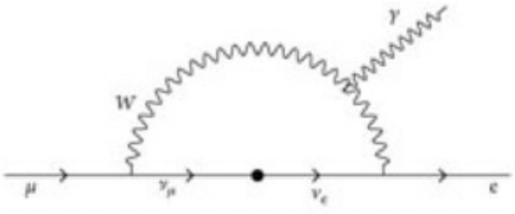
$\mu \to e\gamma$ reaction

➢Motivation

- Considering neutrino oscillation, possible but very rare
- Included in many new physics models at observable rate
- Can search for new physics w/o directly creating new heavy particles

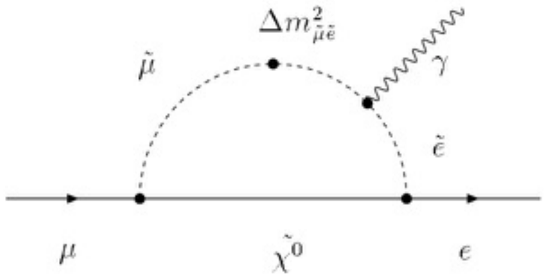
➢Status of cLFV search

- Current upper limit is obtained by MEG
  - $Br(\mu \to e\gamma) \sim 4.2 \times 10^{-13}$ (90% C.L.)
- MEG II aims for one order higher sensitivity
  - $Br(\mu \to e\gamma) \sim 6.0 \times 10^{-14}$ (90% C.L.)



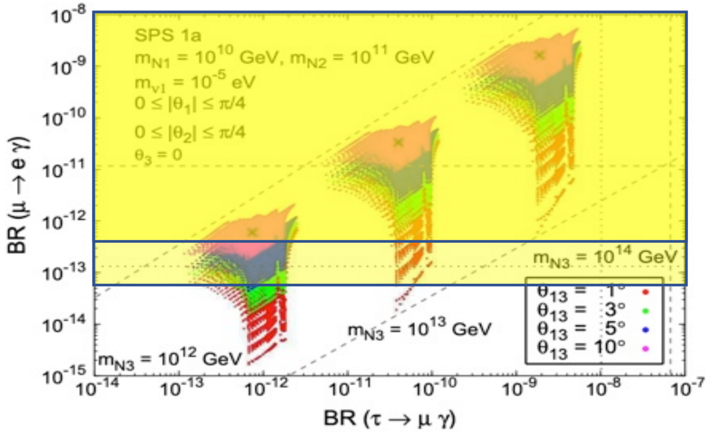
SM + neutrino oscillation

$Br(\mu \to e\gamma) \sim 10^{-54}$
(little background)

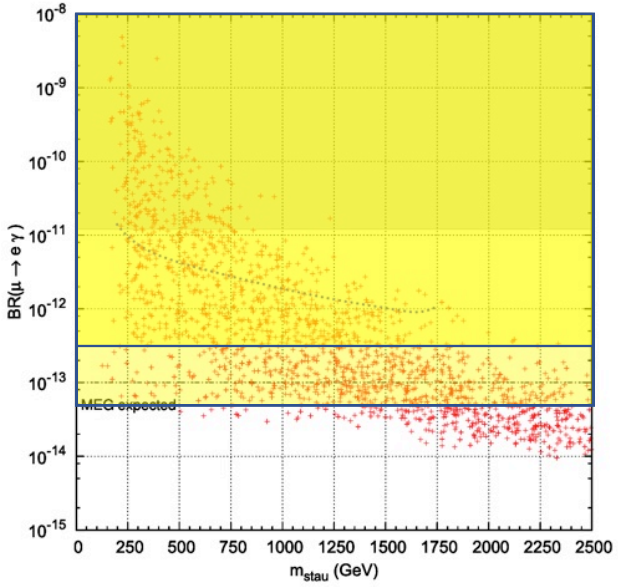


SUSY model

$Br(\mu \to e\gamma) \sim 10^{-15} - 10^{-11}$



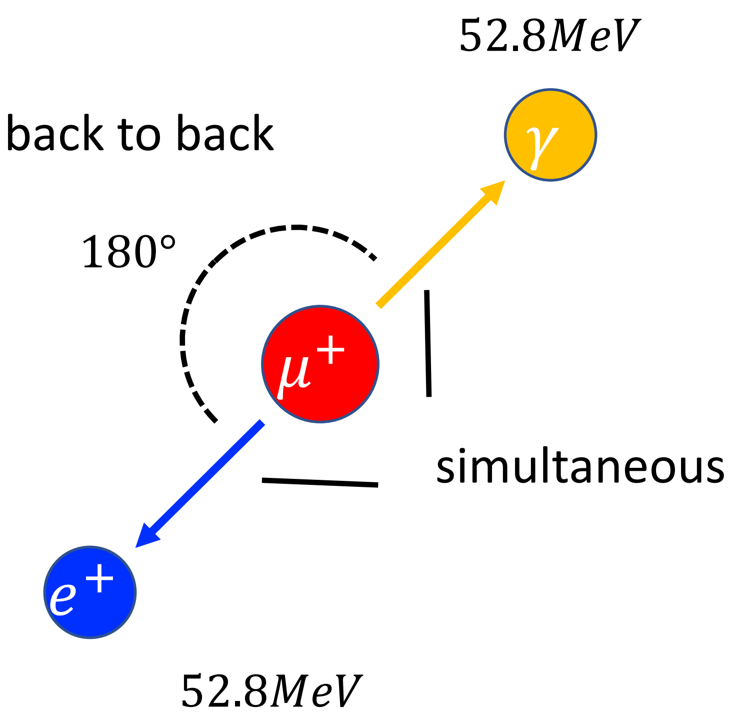
SUSY see-saw



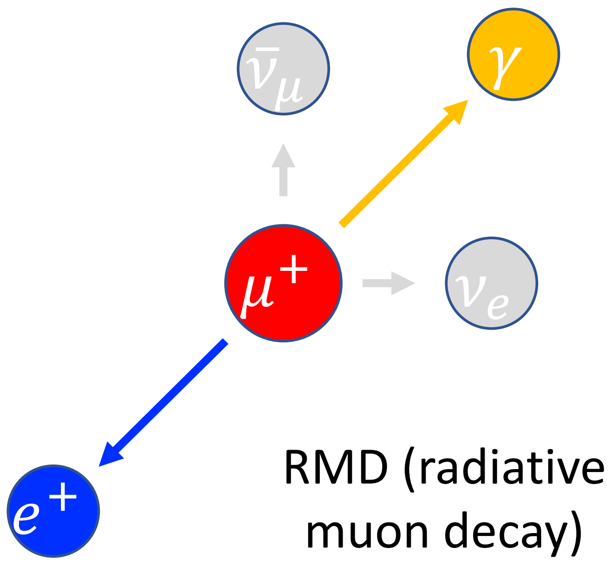
SUSY GUT

SUSY-Seesaw Lorenzo Calibbi et al. "Flavour violation in supersymmetric SO(10) unication with a type II seesaw mechanism." JHEP, 0912:057, 2009.
SO(10) SUSY-GUT: S. Antusch et al. "Impact of θ23 on Lepton Flavour Violating processes within SUSY Seesaw" Journal of High Energy Physics 2006 (11), 090

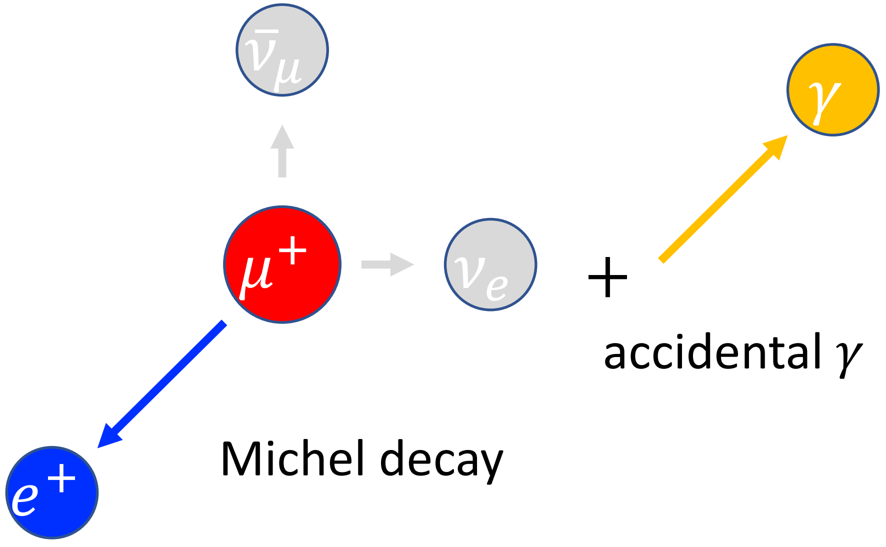
Signal & background events



Signal



Physics background



Accidental background

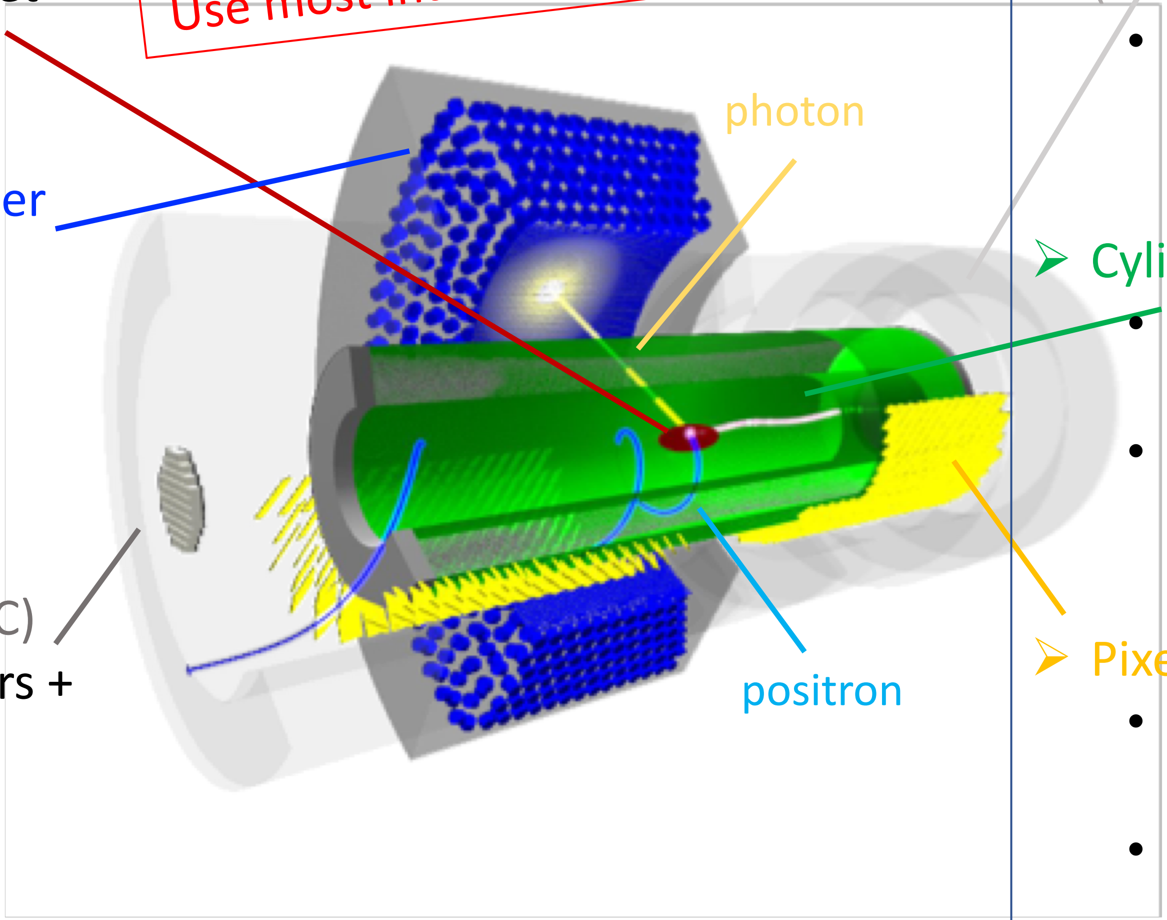
MEG II experiment

- Target
  - Stops muons inside target
- Liquid Xenon (LXe) calorimeter
  - Detects signal photons

c.f. 小林暁、豊田和樹

- Radiative decay counter (RDC)
  - 12 plastic scintillator bars + 76 LYSO crystals
  - Detects background positrons

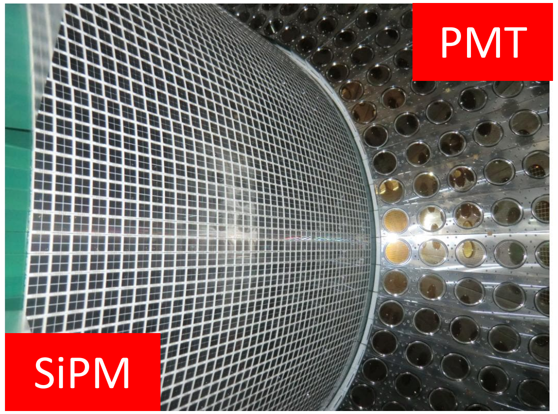
Use most intense muon beam at PSI



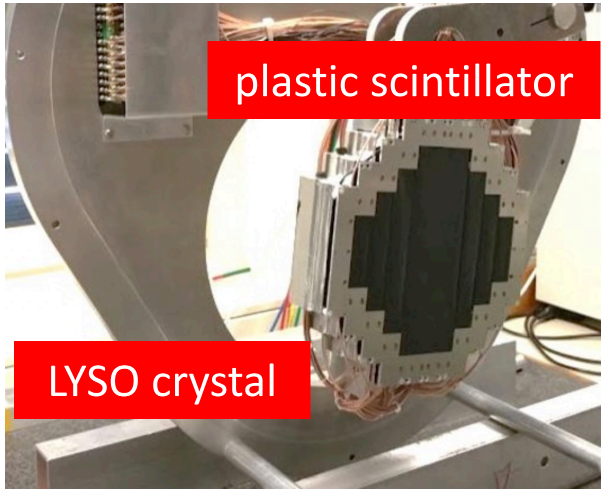
Positron spectrometer

- Superconducting solenoid magnet (COBRA)
  - Bends signal positrons with constant radius
- Cylindrical drift chamber (CDCH)
  - Single volume wire chamber with He based gas
  - Reconstructs positron track
- Pixelated timing counter (pTC)
  - Plastic scintillator + SiPM readout
  - Reconstructs positron time

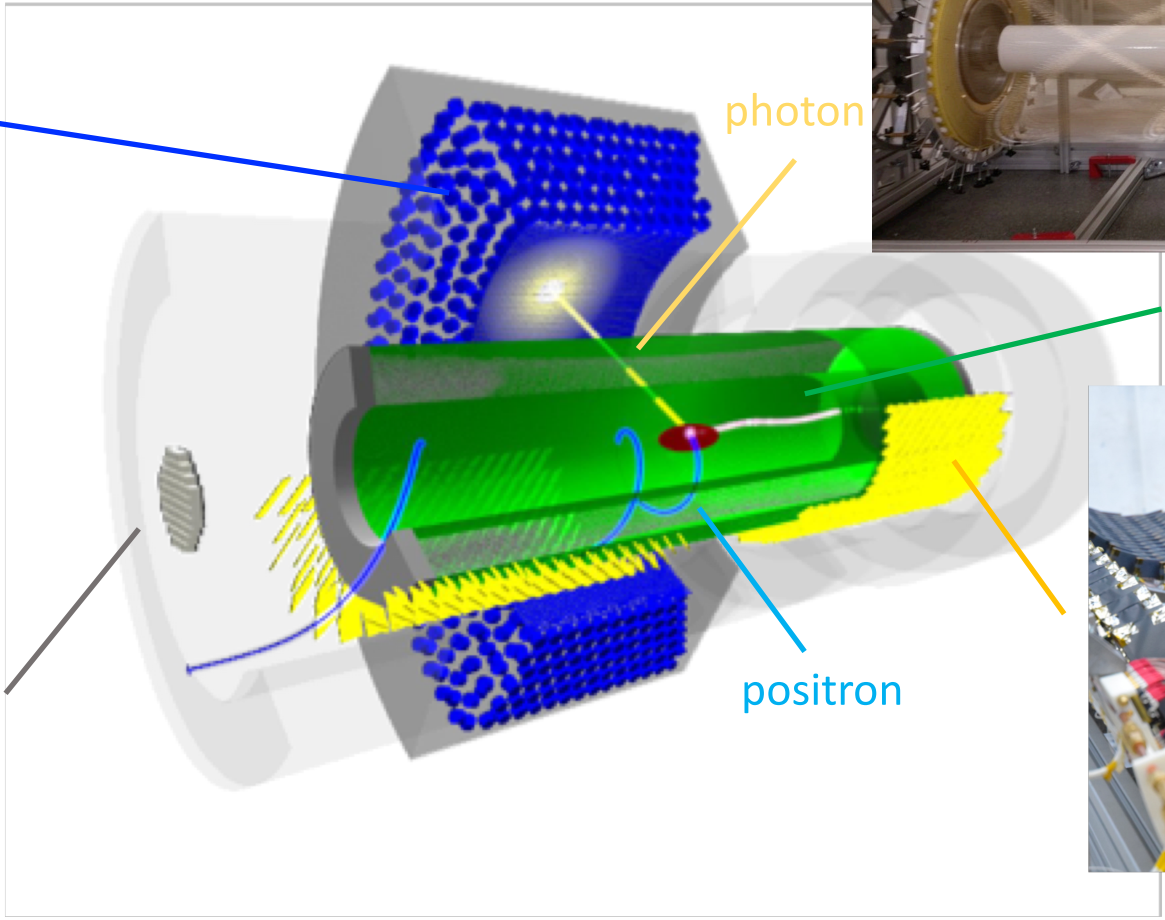
Detectors

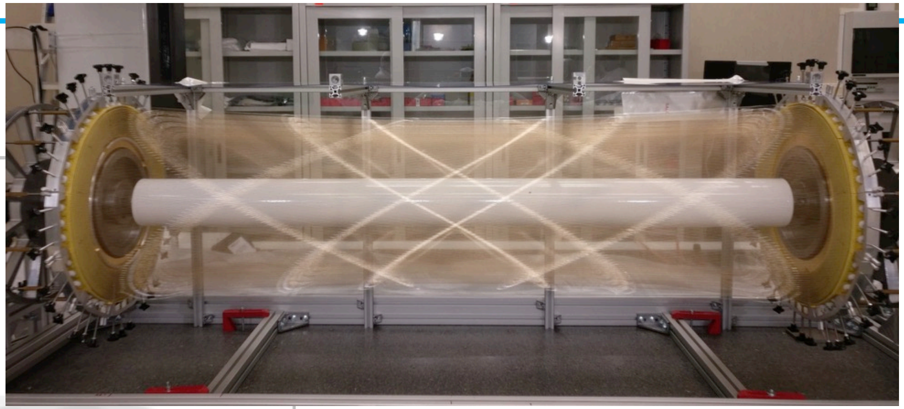


LXe calorimeter

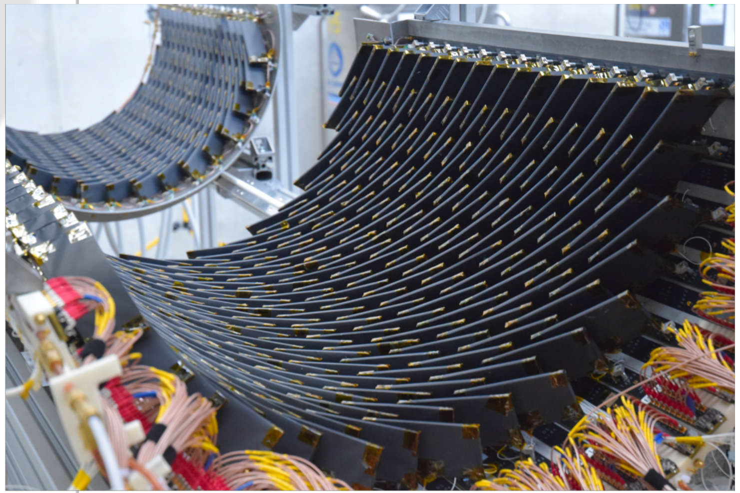


RDC





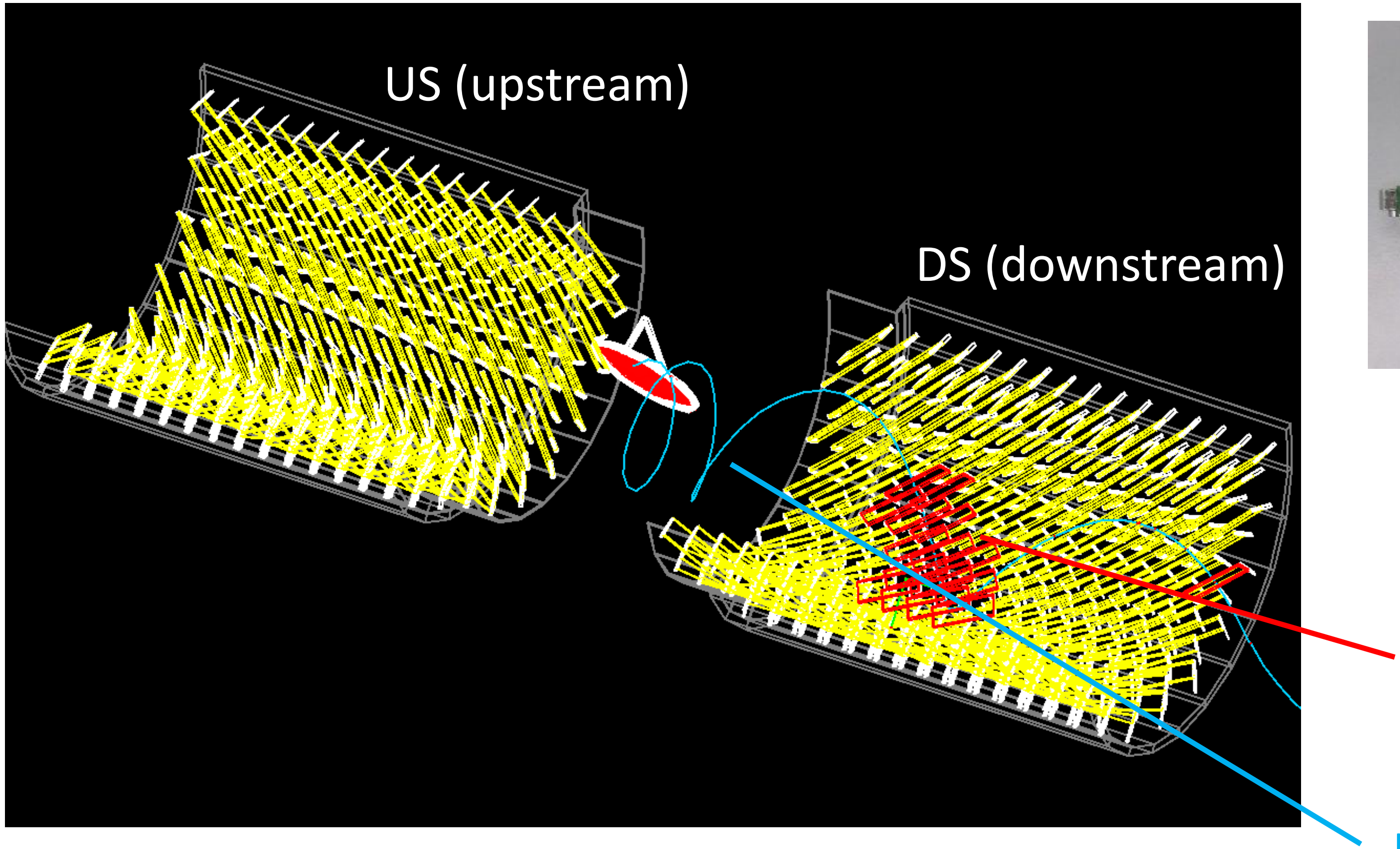
CDCH



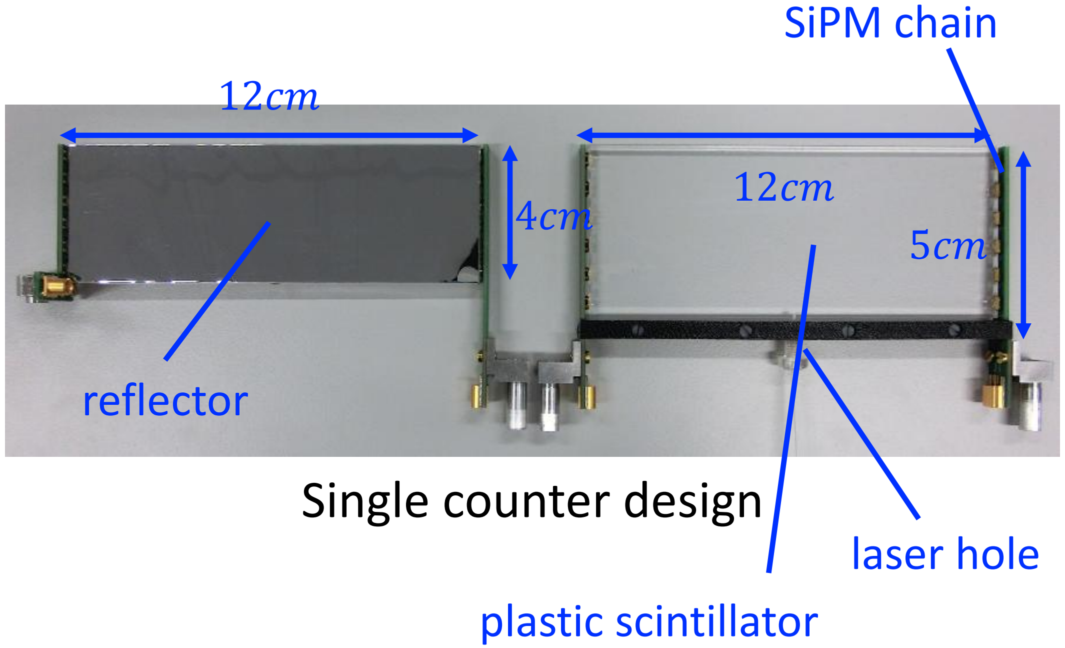
pTC

Pixelated timing counter (pTC)

➢Design



Positron event display



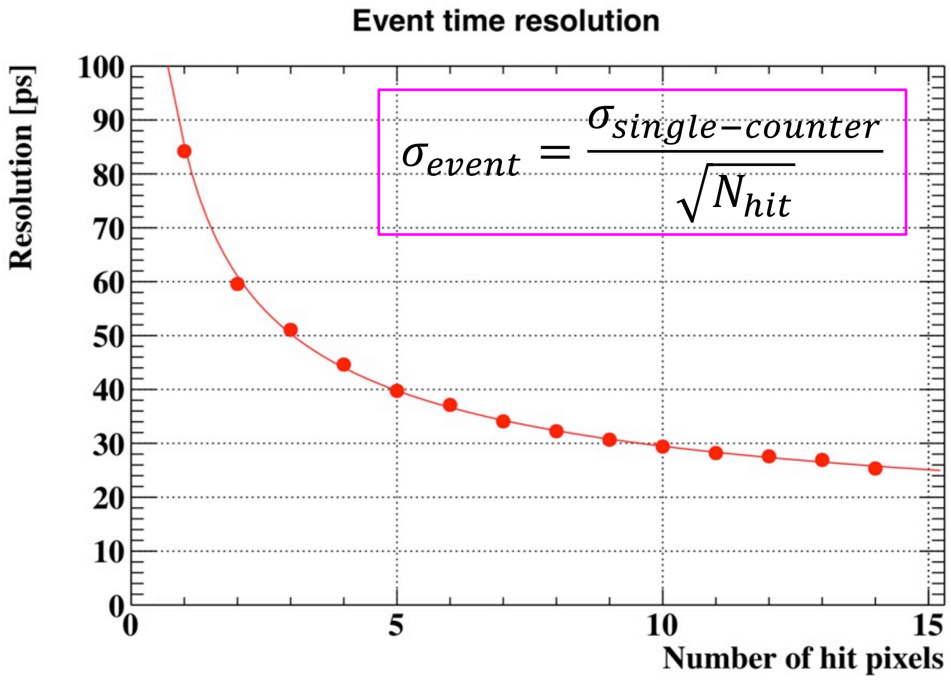
Single counter design

Pixelated design of pTC allows multiple-hits for signal positron event

Pixelated timing counter (pTC)

➢Performance

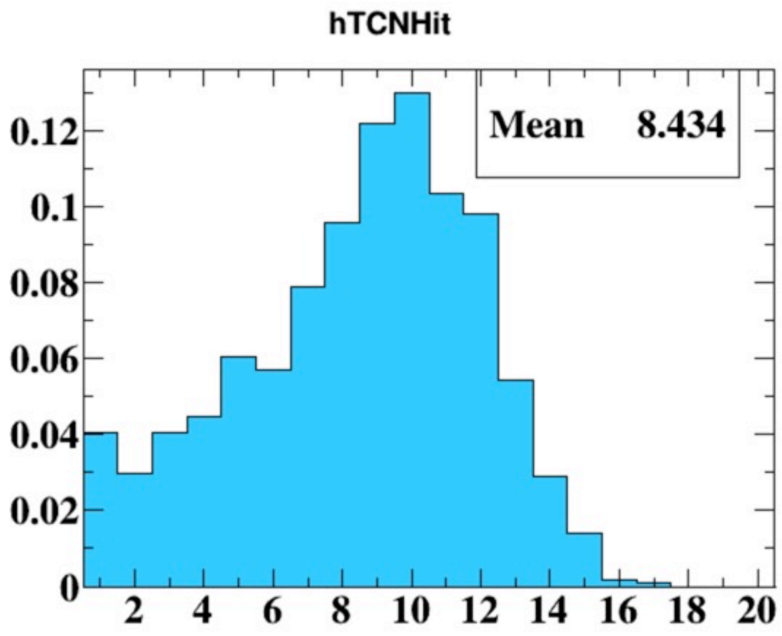
- Pixelated design allows $N_{hit} \sim 8$ for signal event
- High time resolution can be achieved for multiple-hit events



$$\sigma_{event} = \frac{\sigma_{single-counter}}{\sqrt{N_{hit}}}$$

pTC time resolution obtained from MC

×



Number of hits distribution

$= \sim 38.5ps$

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- HV setting

➢Calibration
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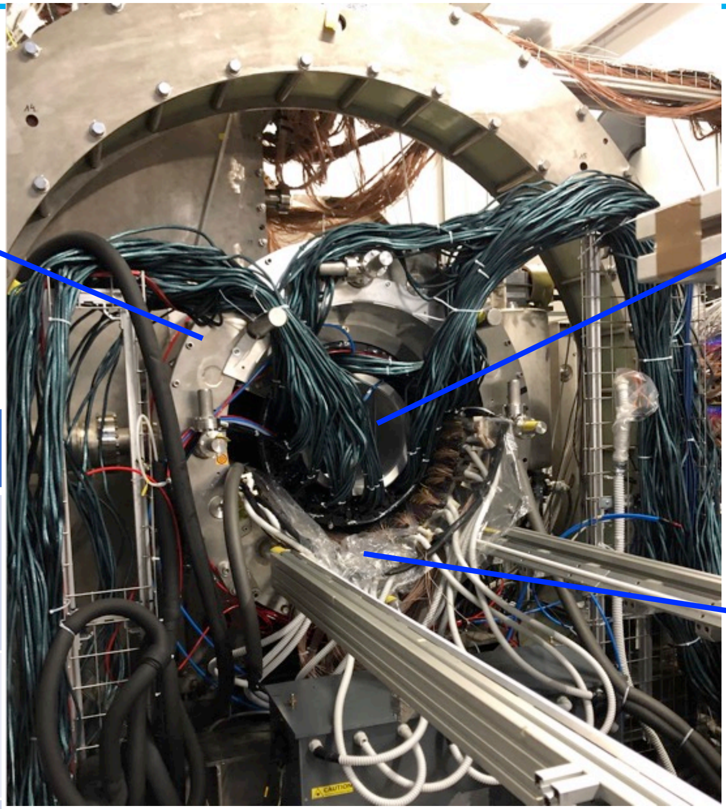
➢Summary & prospect

Installation & motivation

➢Installation

- DS pTC was installed for pre-engineering run 2018
- Only 2nd-half of DS pTC was readout



pTC installation

➢New this year

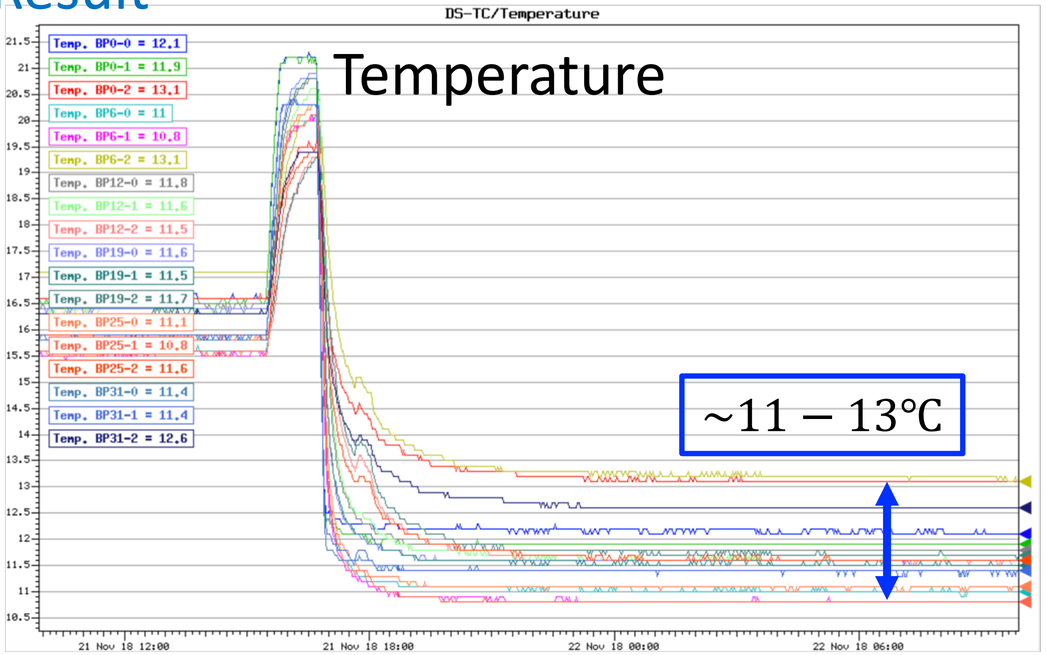
	Pilot run 2017	Pre-engineering run 2018
Beam	$\sim 6.0\times 10^{7}\,\mu^{+}/s$	Full MEG II intensity $\sim 7.0\times 10^{7}\,\mu^{+}/s$
Detectors	LXe, pTC, RDC	LXe, pTC, RDC + (partly-operational) CDCH
Electronics	Limited	Limited
pTC detector	DS → US (in turn)	1/2 of DS
pTC cooling system	20℃ operation	10℃ operation
Positron analysis	pTC clustering	pTC self tracking

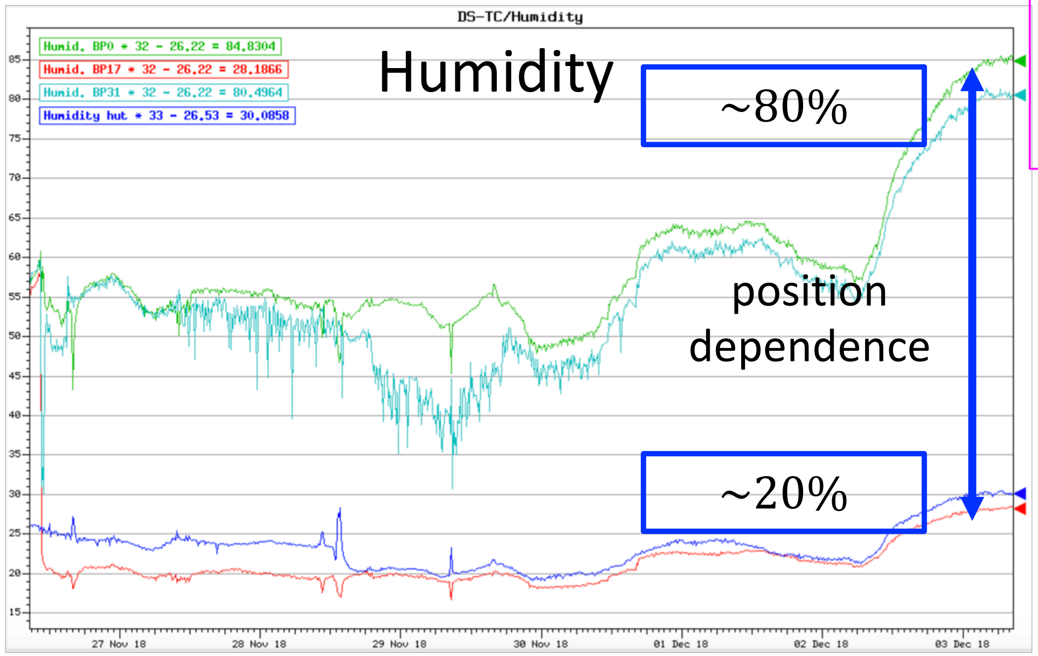
Cooling system

➢Motivation

- In three years of data taking, radiation damage to SiPMs could increase dark current & deteriorate time resolution of pTC
- We plan ~10℃ operation (new in 2018) using water chillers to minimize dark current
    - Deterioration would be suppressed to ~5% rather than ~30% at 30℃

➢Result





Confirmed no water condensation

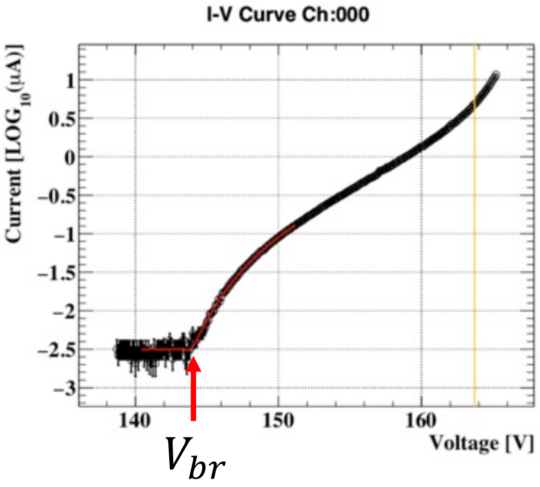
HV setting

➢Motivation

- Breakdown voltage of SiPMs has temperature dependence
- Optimal HV must be re-determined to give best counter time resolution

➢IV data

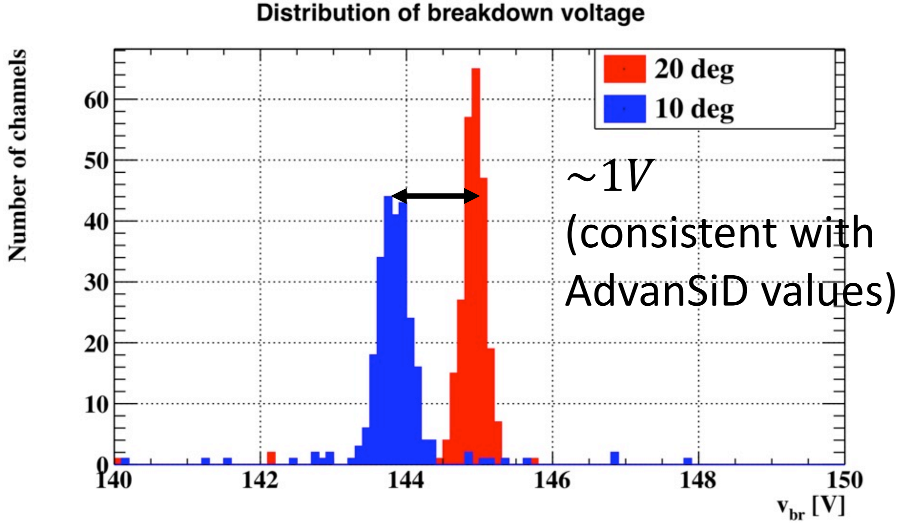
- IV data can be taken using readout electronics with $\sim 4nA$ precision
- Breakdown voltage is obtained by template fit of I-V curve



➢Breakdown voltage

- Breakdown voltage of AdvanSiD SiPM depend on temperature $\sim 25mV/°C$

→ $\sim 1.5V$ per $10°C$ per SiPM chain

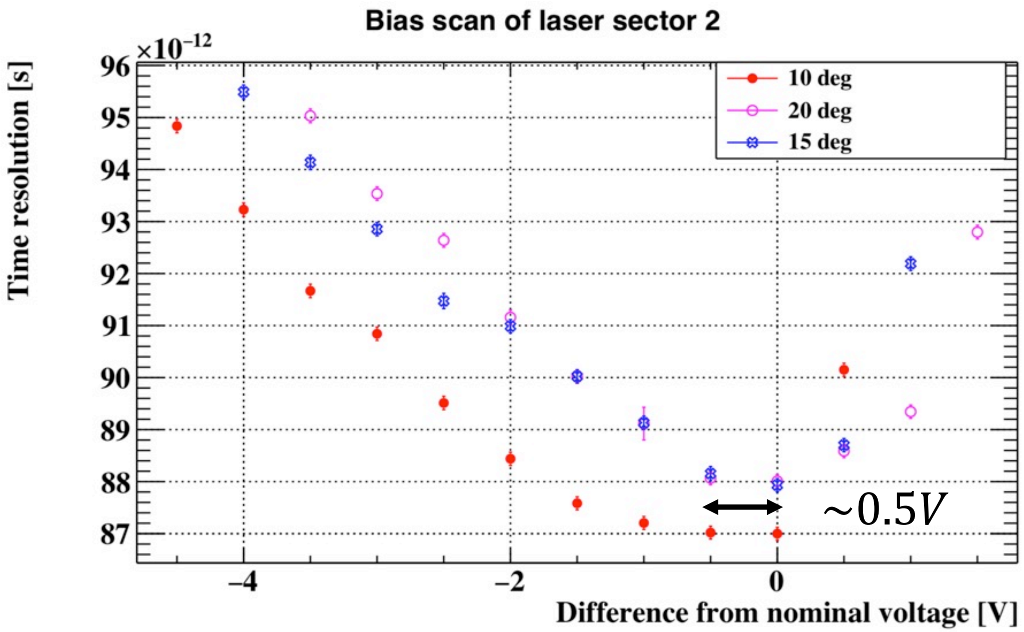


Distribution of breakdown voltage

HV setting

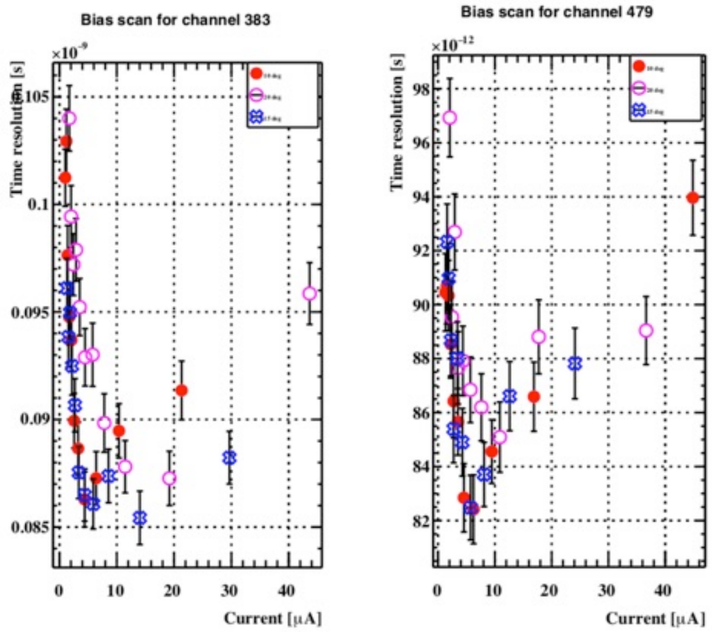
➢Bias voltage scan

- Optimal voltage = best time resolution
- Optimal voltage is obtained with best S/N



Mean time resolution v.s. V_{br}

- Optimal voltage differs channel by channel
- Clearer relation can be obtained from ”time resolution v.s. current”



→ Optimal voltage @ $\sim 6\mu A$ for each channel

※ Laser system is used for bias scan (→ will be explained later)

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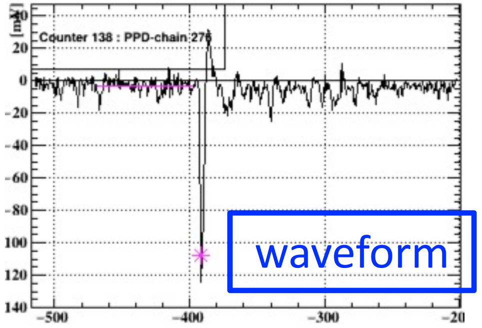
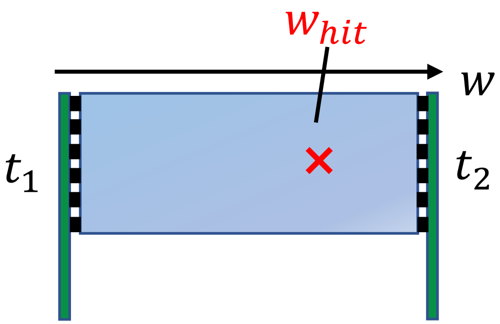
Summary & prospect

Positron reconstruction

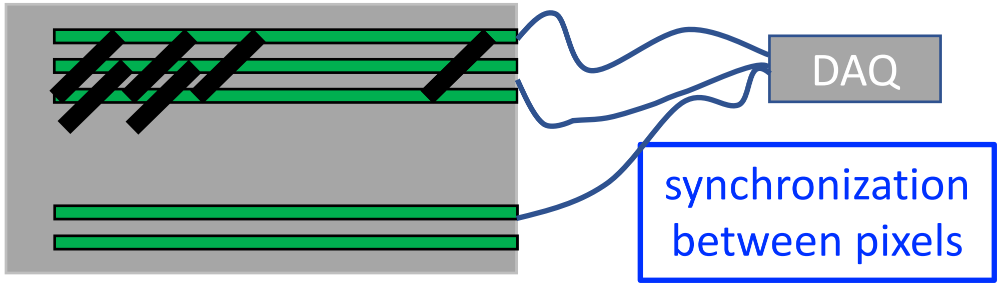


charge → energy



$$t_{hit} = \frac{t_1 + t_2}{2}$$

$$w_{hit} = v_{eff} \times \frac{t_2 - t_1}{2}$$



Waveform analysis optimization

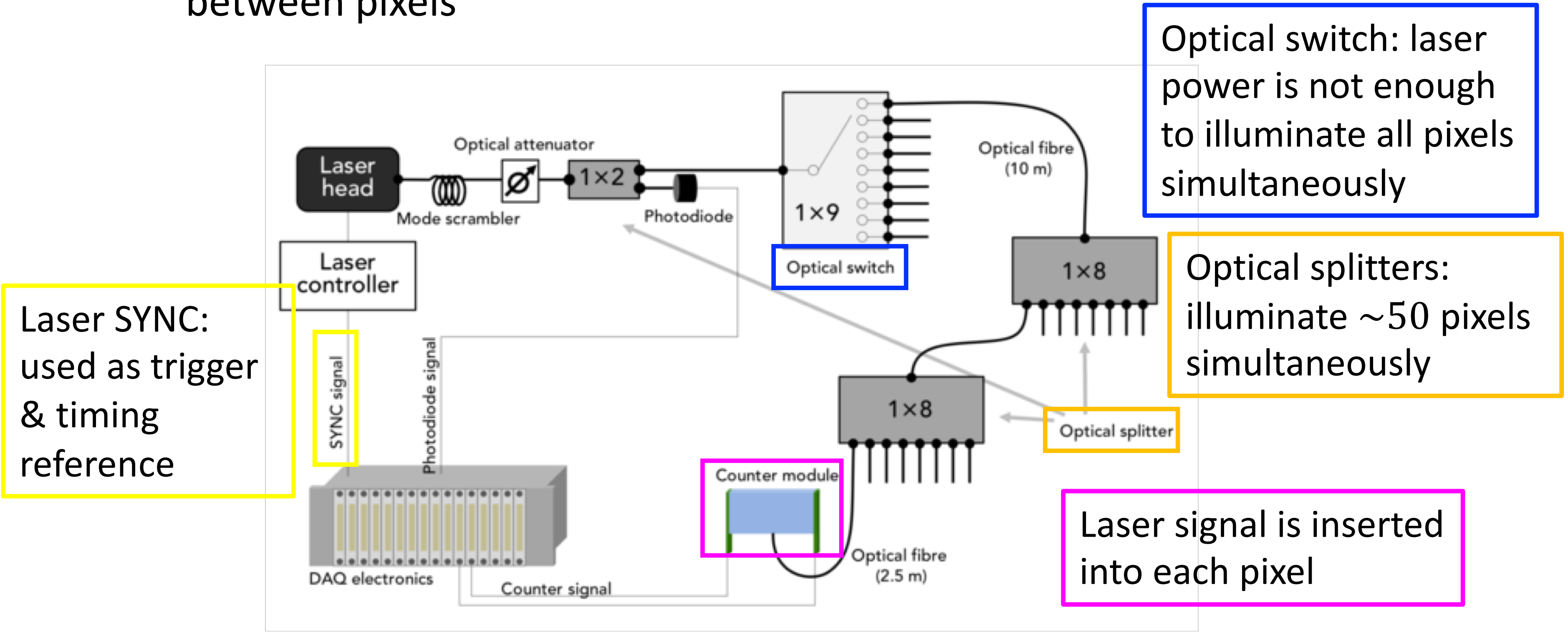
Calibrations
- Energy
- Position
- Time

Waveform analysis → Hit reconstruction → Clustering → Tracking → Positron time & track

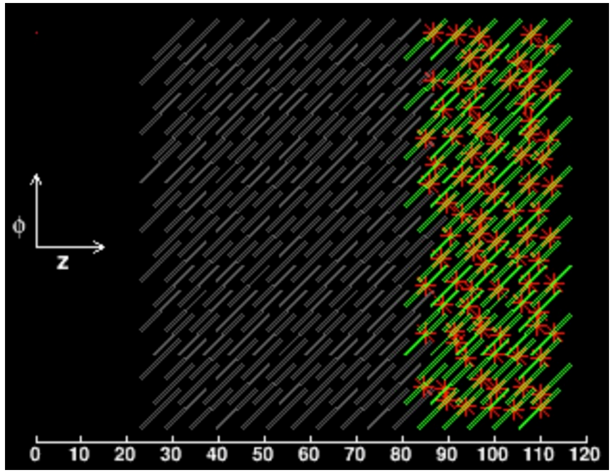
Laser system

➢Motivation

1. Laser signals can be used for signal check, bias voltage scan, various monitoring, etc. w/o beam
2. Laser signals can be inserted into each pixel simultaneously, and can be used for time calibration between pixels



Laser system

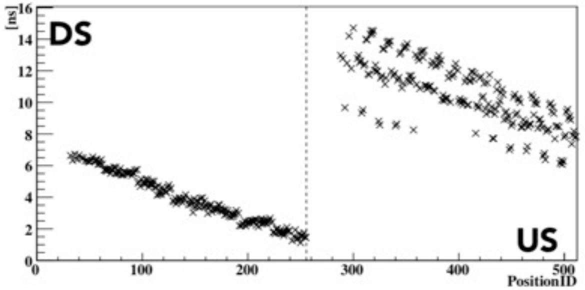


Laser signal monitor

Time calibration

➢Laser-based method

- $\sim 24ps$ precision can be achieved



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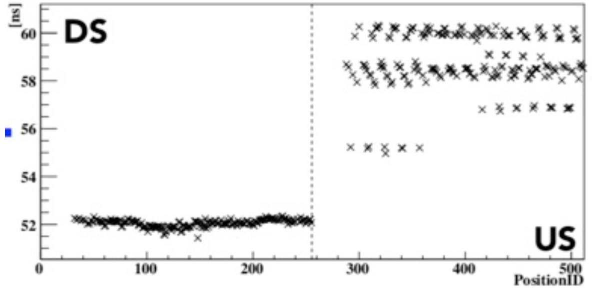

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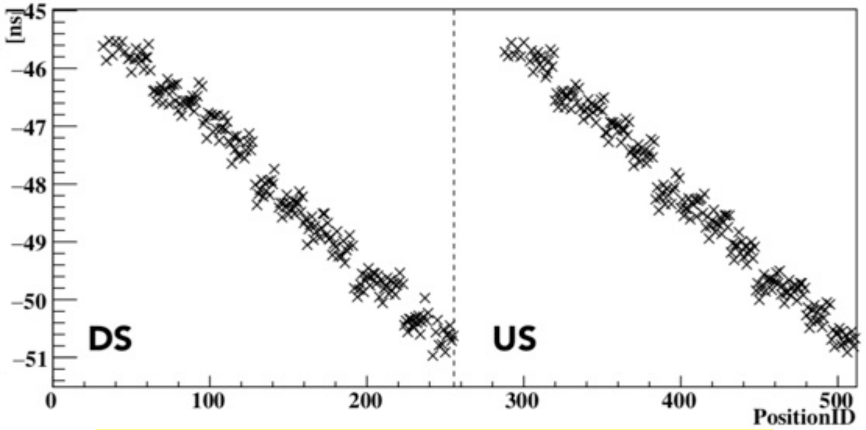

Laser run
- Backplane
- Cable
- DAQ
- Laser components

Mass test
- Laser components (fiber, splitter, etc.)

Inter-pixel time offset
- Backplane
- Cable
- DAQ

➢Track-based calibration

- Multiple-hit Michel events ($\mu^+ \rightarrow e^+ \bar{\nu}_e \nu_\mu$) can be used to calibrate time between adjacent counters
- $\sim 10 - 15ps$ precision should be achieved
- Calibration study for pre-engineering run 2018 still ongoing

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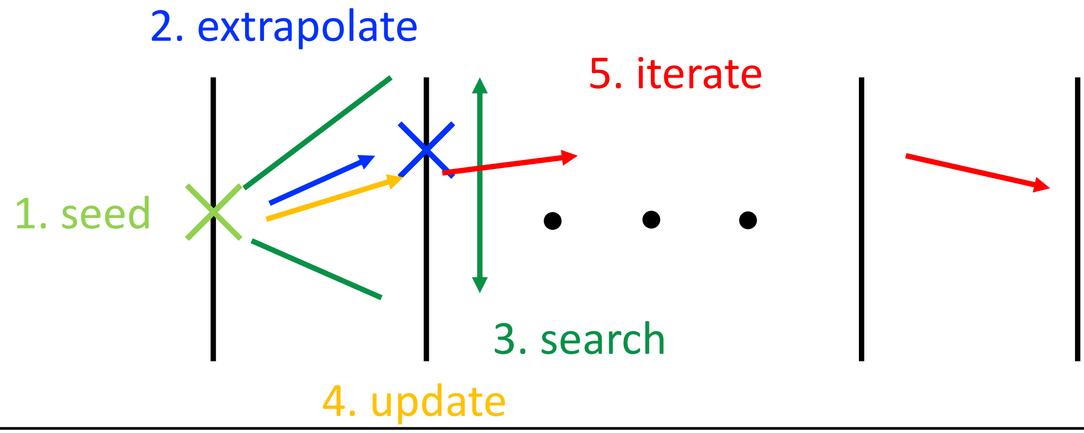
Clustering & tracking

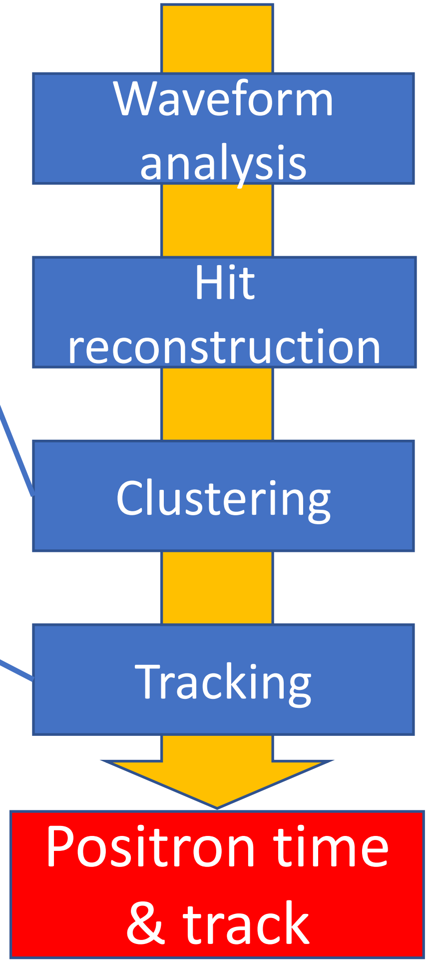
➢ Clustering

- Make cluster of hits at roughly same time

➢ Tracking

- Combine discontinuous hit information into single track
- Track starts from track seed
- Kalman Filter is used to extrapolate track
- Segments are fitted with GENFIT

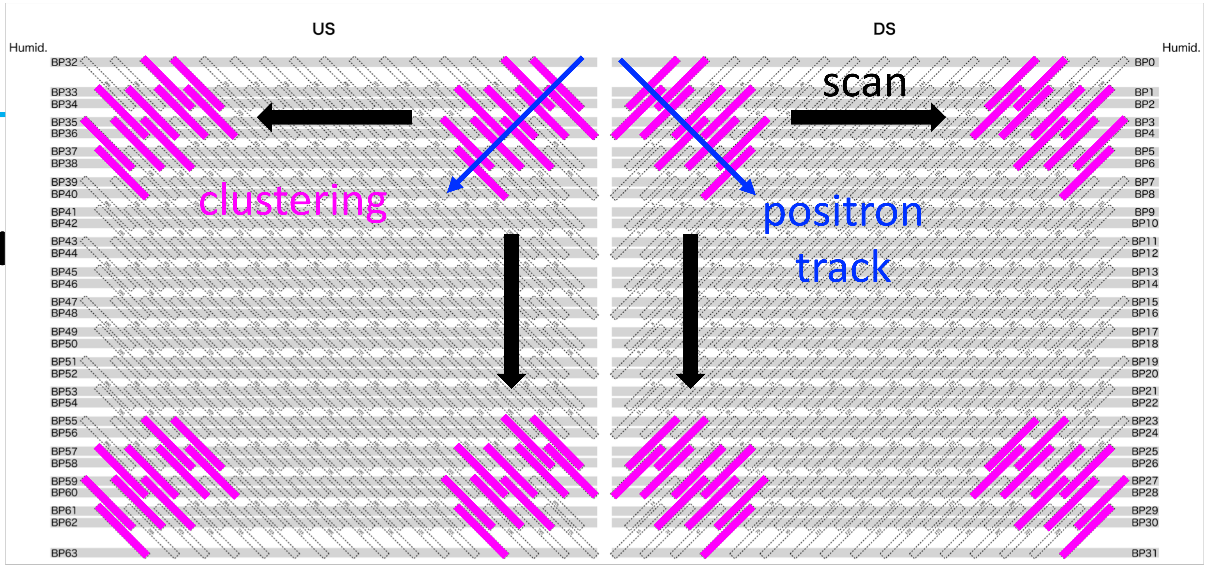




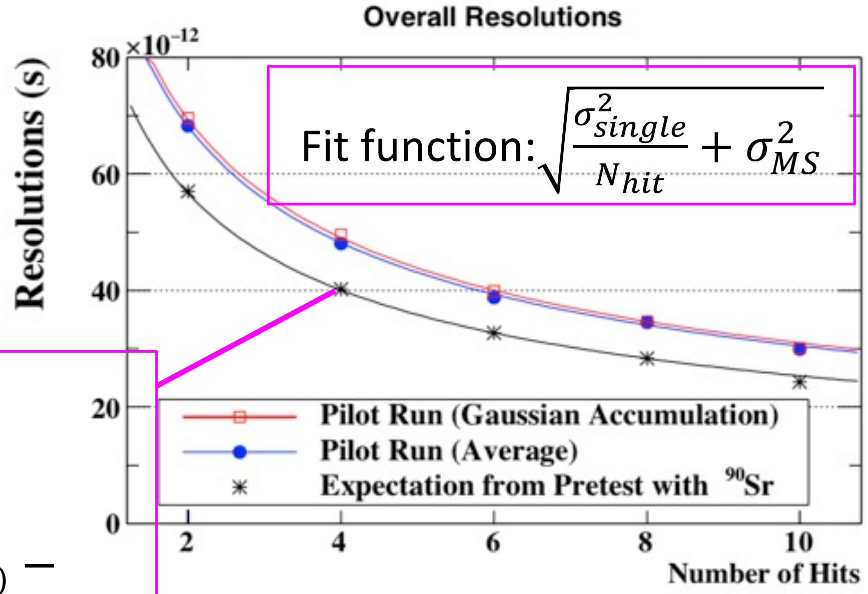
N-hit analysis

➢Motivation

- No track information from (no/partly-readout) CDCH
- pTC analysis must be performed with cluster information
- Fixed geometrical combination of pixels can be used



Fixed geometrical combination



Final result of 2017

Even-odd analysis

$$t_{even-odd}(N_{hit}) = \frac{1}{N_{hit}} \sum_{i=1}^{N_{pair}} (t_{hit(2i)} - t_{hit(2i-1)} - ToF_{2i-1\rightarrow 2i})$$

➢Result

- Single counter resolution is worse than expectation due to noise, electronics jitter
- Overall time resolution degradation is suppressed by multiple-hit scheme

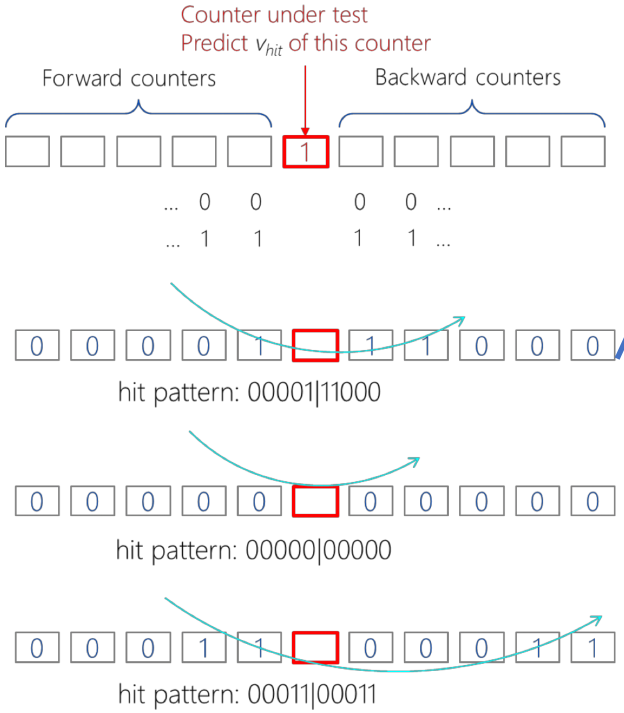
pTC self tracking

➢Motivation

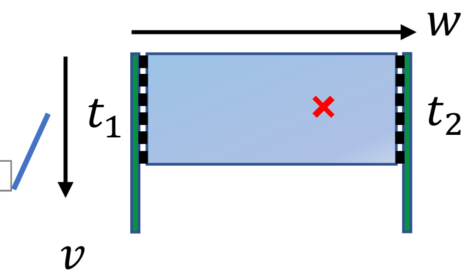
- pTC can now be used as tracker as well as simple timing detector
- Events with arbitrary combination of hit pixels can be analyzed
- More realistic pTC performance can be evaluated

➢Idea of self tracking

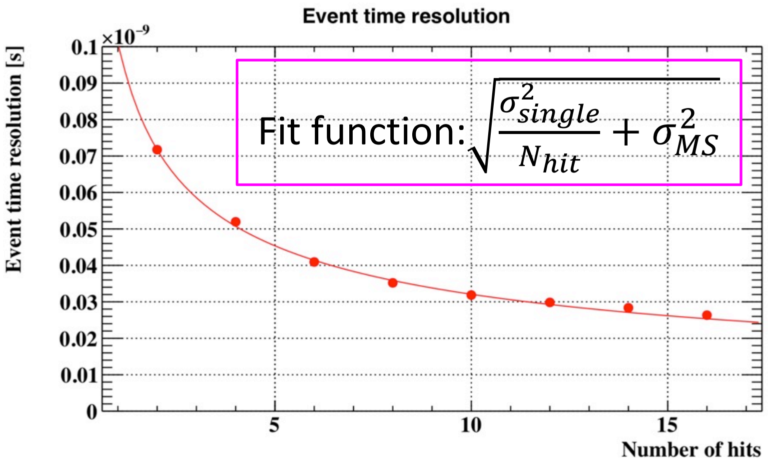
- Horizontal position from channel time difference
- Radial coordinate of hits from hit pattern



$$w_{hit} = v_{eff} \times \frac{t_2 - t_1}{2}$$



➢Result



Positron time resolution

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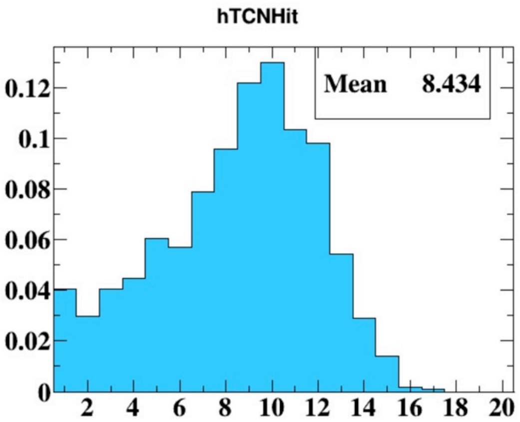

Number of hits distribution

$= \sim 39.5ps$

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Summary & prospect

Summary

- MEG II experiment searches for new physics through cLFV with unprecedented sensitivity
- All detectors were installed in pre-engineering run 2018 for the first time
- Commissioning of pTC was successfully completed

Prospect

	Pilot run 2017	Pre-engineering run 2018	Engineering run 2019
Beam	$\sim 6\times10^{7}\ {\mu^+}/{s}$	Full MEG II intensity $\sim 7.0\times10^{7}\ {\mu^+}/{s}$	Full MEG II intensity $\sim 7.0\times10^{7}\ {\mu^+}/{s}$
Detectors	LXe, pTC, RDC	LXe, pTC, RDC, (partly-operational) CDCH	LXe, pTC, RDC, (fully-operational) CDCH
Electronics	Limited	Limited	Full
pTC detector	DS → US (in turn)	DS 2nd-half	Both DS & US
Positron analysis	pTC clustering	pTC self tracking	pTC + CDCH tracking

- First data analysis using both pTC & CDCH information is ongoing
- pTC time reconstruction method is being revised for further improvement (→74th JPS 14aK210-11)

Backup slides

Positron spectrometer

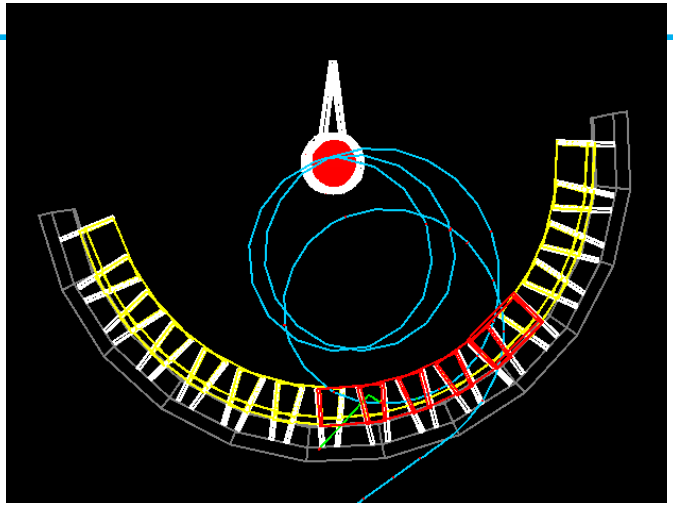
➢COBRA (COnstant Bendint RAdius)

- Bends positrons at a constant radius independent of emission angles

→ Signal positrons enter pTC region

- Gradient field to sweep positrons away from detector region

→ Reduce pile-up



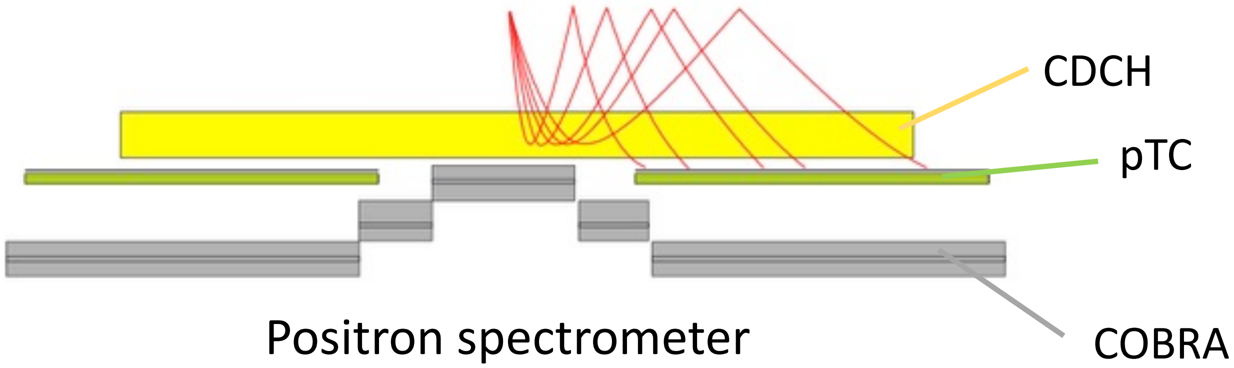
Positron event display

➢CDCH (Cylindrical Drift CHamber)

- Reconstructs positron track

➢pTC (pixelated Timing Counter)

- Reconstructs positron time

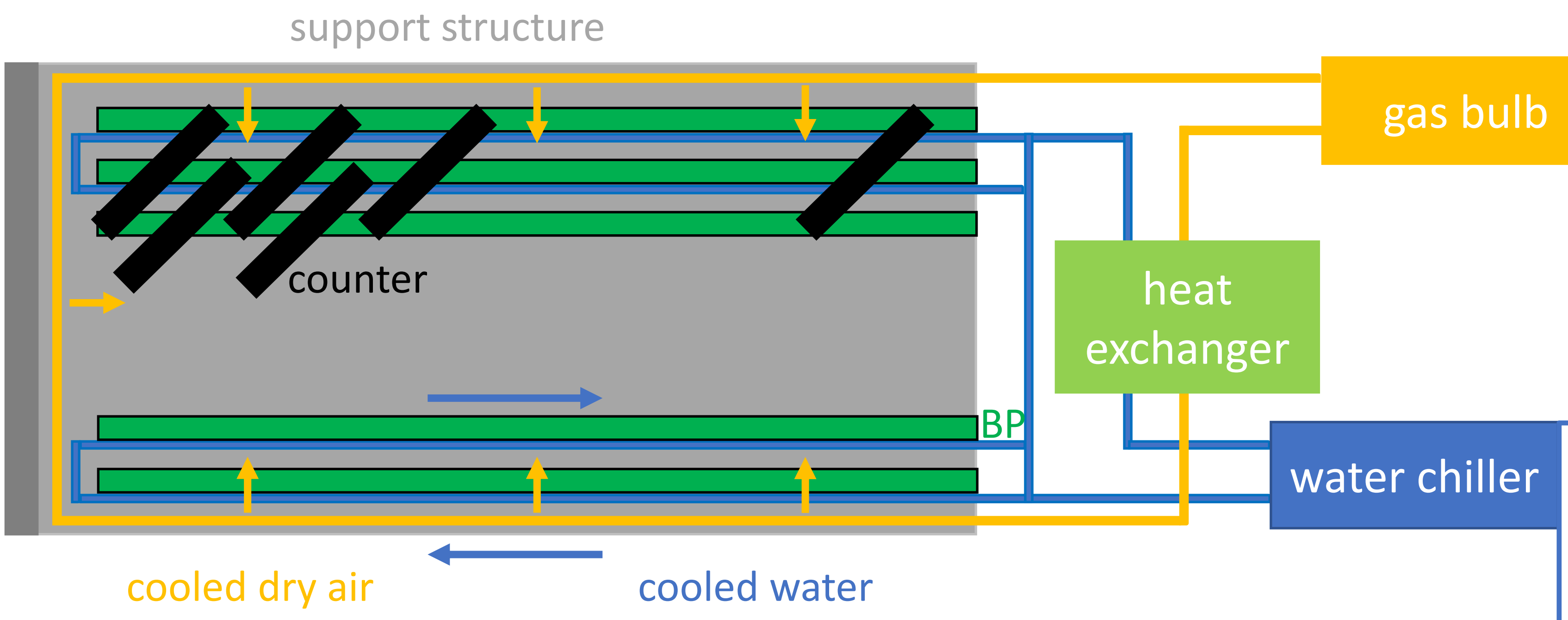


Positron spectrometer

Cooling system

➢How it works

- Water from water chiller circulate around BP & cool each SiPM chain
- Dry air flows out of gas tubes to prevent water condensation



- Keep humidity low in pTC region
- Prevent water condensation

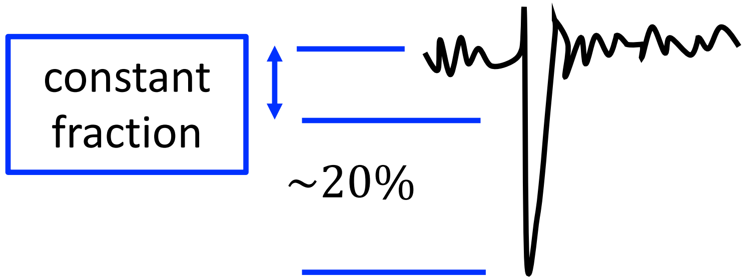
- Cool SiPMs through backplane
- Suppress dark current after radiation damage

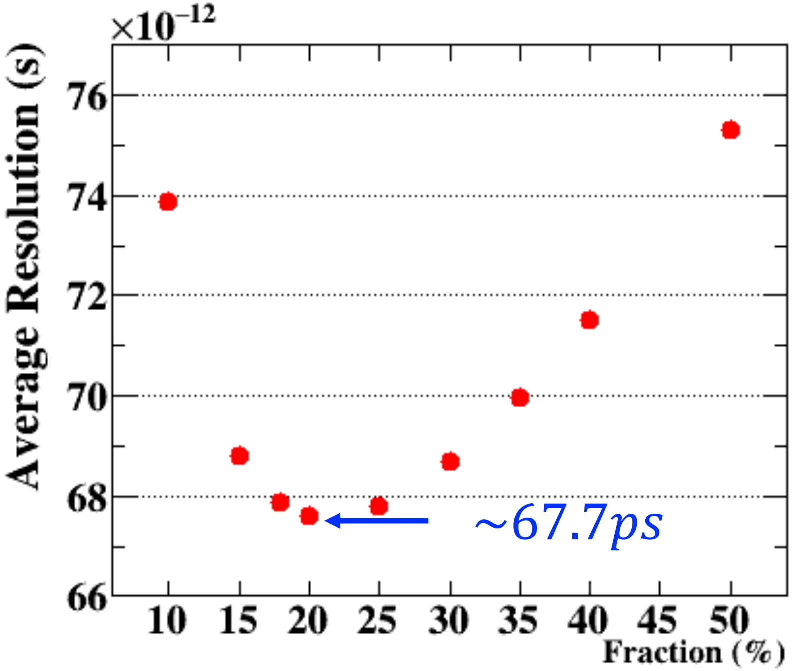
pTC cooling system

Waveform analysis optimization

➢Motivation

- Constant fraction method is used to obtain signal time
- Optimal fraction to give best time resolution can be obtained from constant fraction scan
- Two hit analysis is used





constant fraction scan

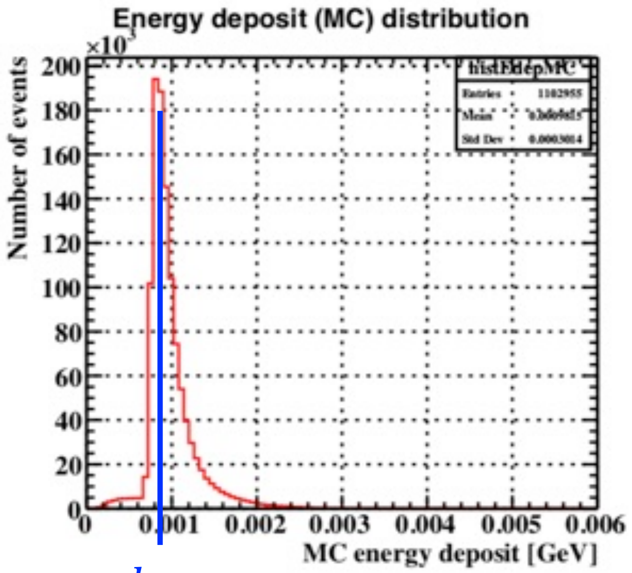
Energy calibration

➢Goal

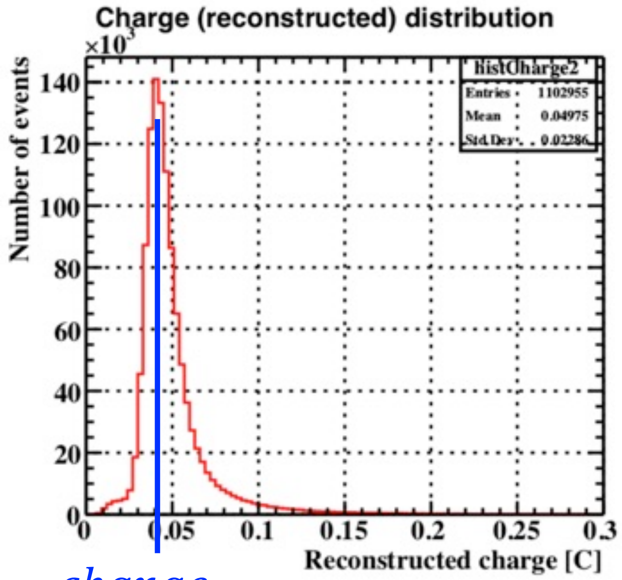
- Obtain relation between charge & energy deposit for each pixel independently

➢Method

- Compare reconstructed charge distribution with MC energy deposit distribution
- Obtain energy scale factor so that peak position in the two distributions match



$edep_{peak}$

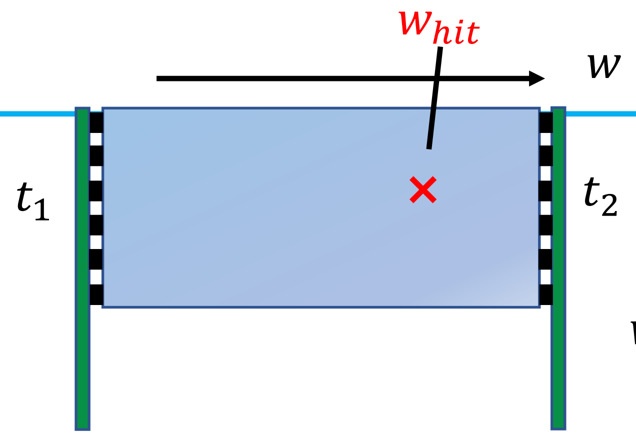


$charge_{peak}$

$$Energy\ scale\ factor = edep_{peak} \div charge_{peak}$$

(for each pixel)

Position calibration



$$t_{hit} = \frac{t_1 + t_2}{2}$$

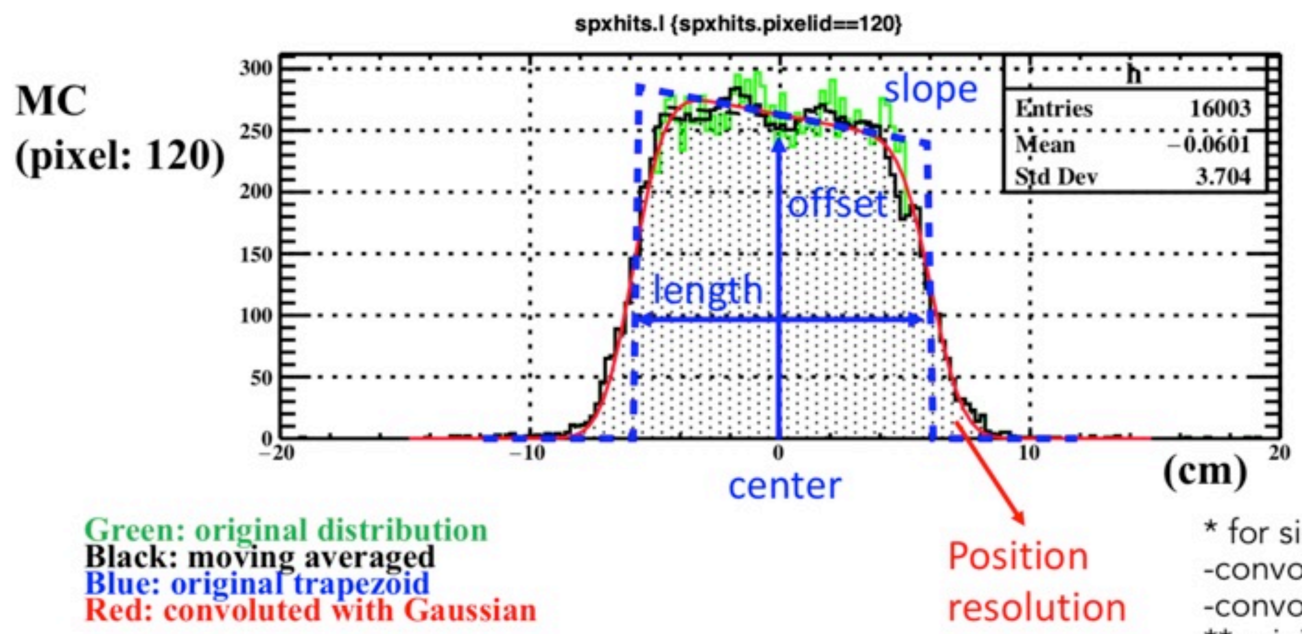
$$w_{hit} = v_{eff} \times \frac{t_2 - t_1}{2}$$

➢Goal

- Obtain v_{eff} & t_{offset}
  - v_{eff}: effective velocity of scintillation light in pixel
  - t_{offset}: time offset between two channels included in $t_2 - t_1$

➢Method

- Fit hit distribution with trapezoid convoluted with Gaussian
  - center: calibrate v_{eff}, t_{offset}
  - length: calibrate v_{eff}
  - sigma: position resolution



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

Position calibration

➢Goal

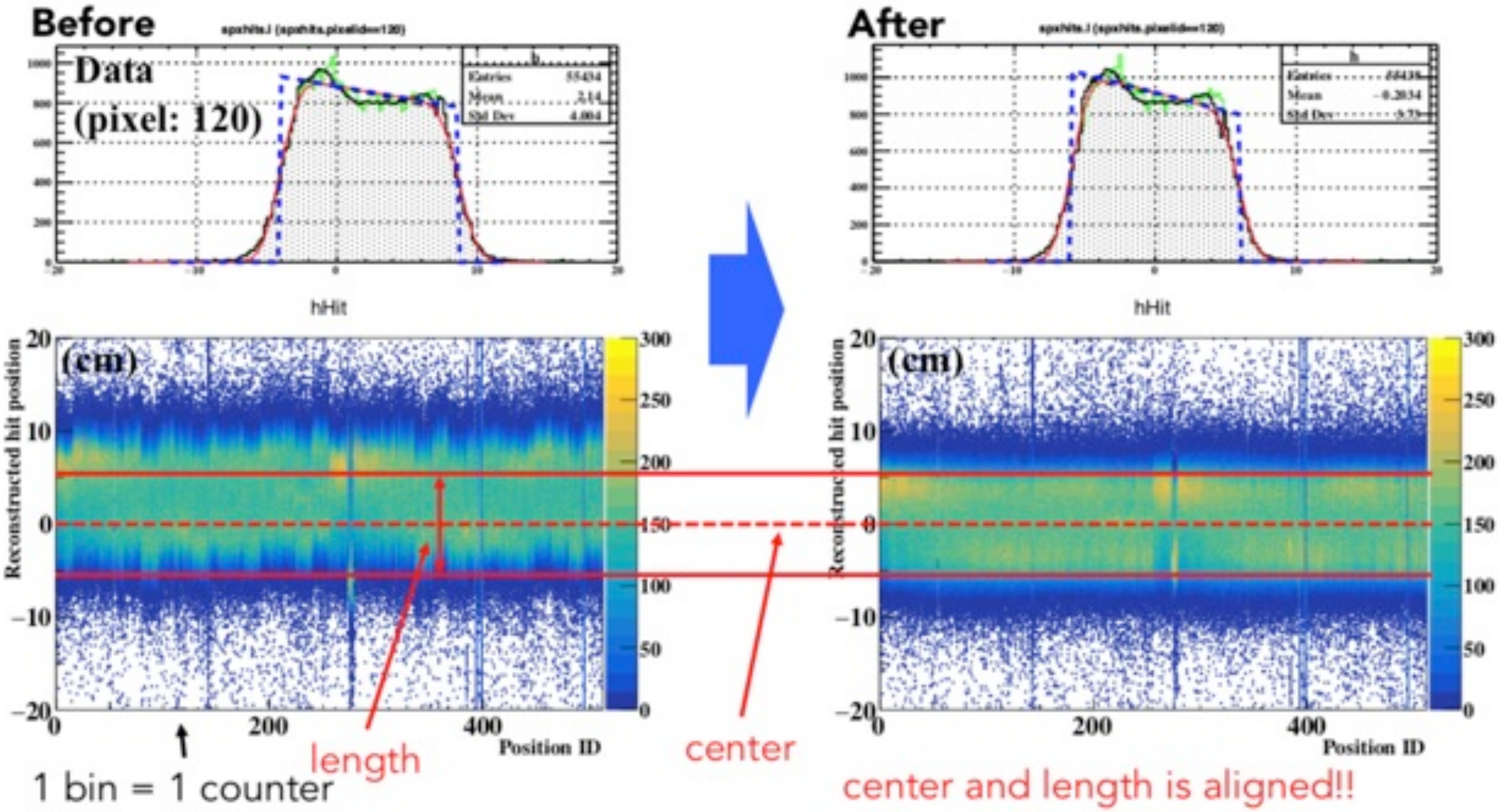
- Obta
  -
  -

$t = \frac{t_1 + t_2}{2}$

$= v_{eff} \times \frac{t_2 - t_1}{2}$

➢Methoc

- Fit h trape Gaus
  -
  -
  -



plicity, I set
tion step: 100
tion range: +-5σ
ization using chi2

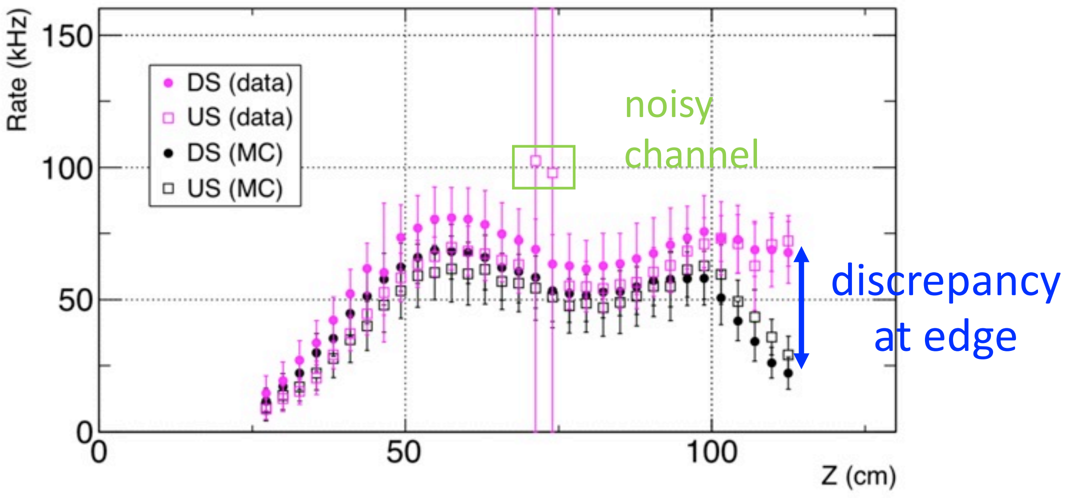
Hit rate distribution

➤Motivation

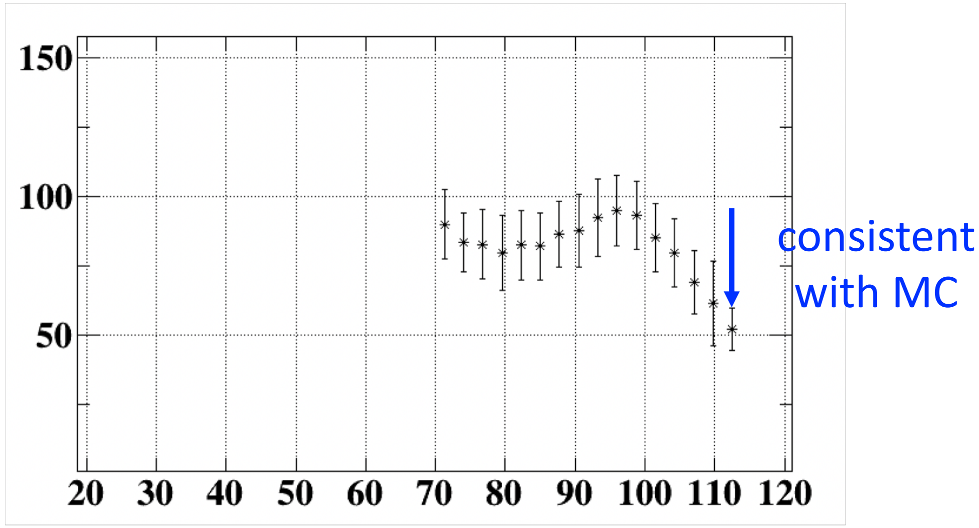
- Mockup CDCH was installed in 2017
- Hit rate distribution was inconsistent with MC ← due to mockup CDCH material?

➤Result

- Achieved hit rate distribution was consistent with MC



2017 hit rate distribution

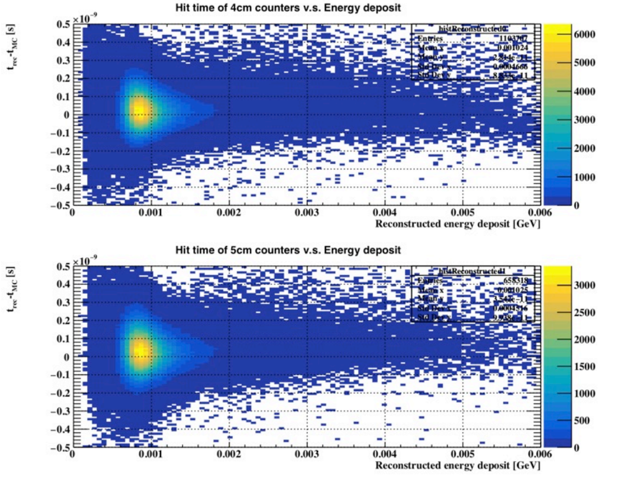


2018 hit rate distribution

Time reconstruction improvement

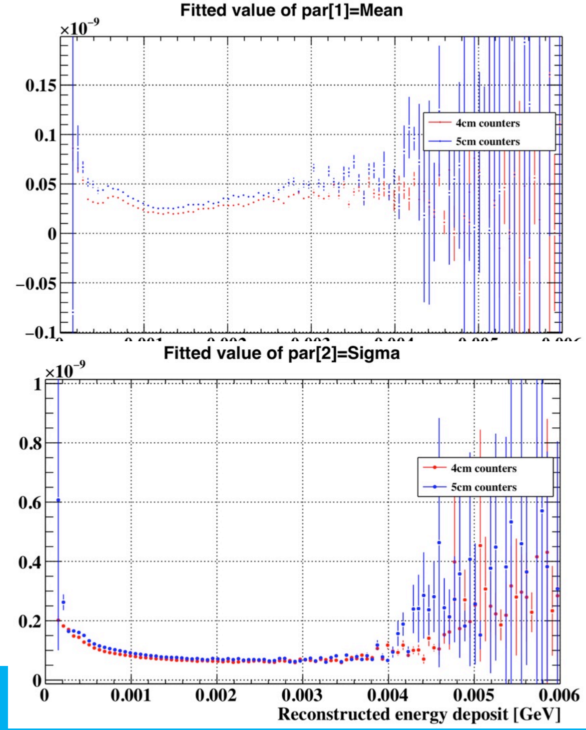
➢Energy deposit dependence

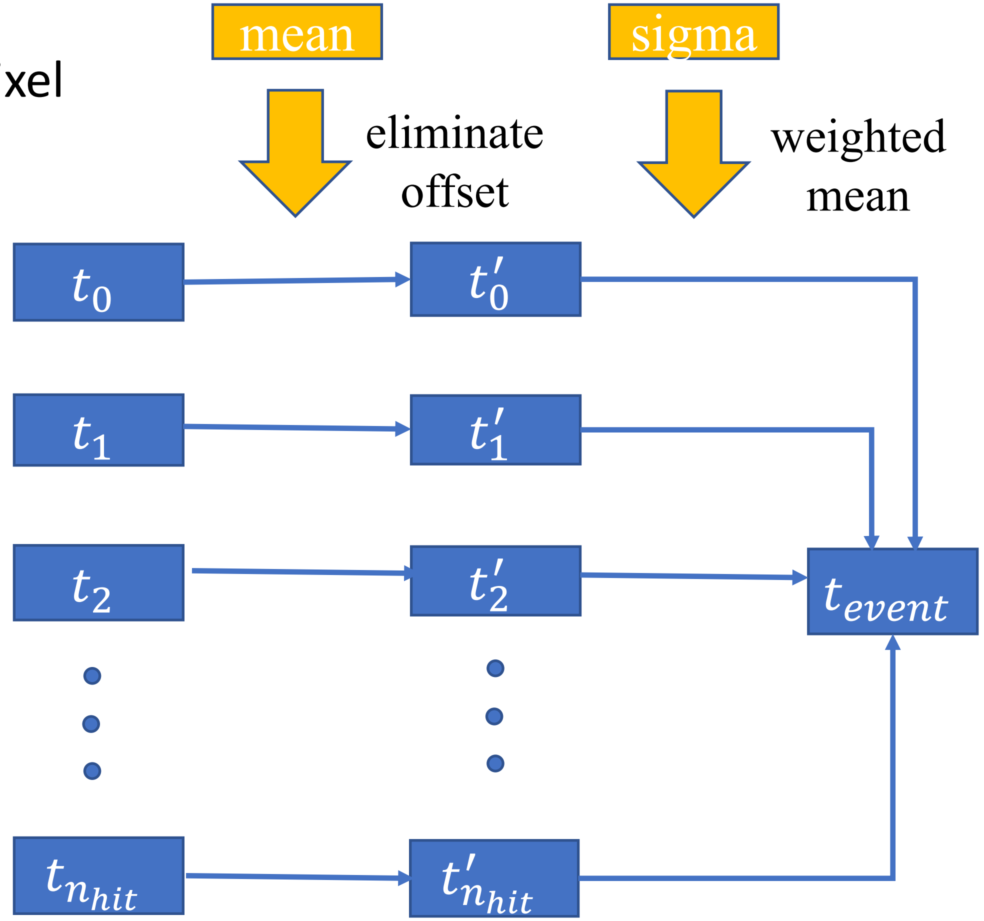
- Hit time & hit time resolution depend on energy deposit in pixel due to time walk effect & photon statistics
- Better positron time resolution can be obtained by
  - Correcting time walk effect
  - Putting weight on hits with larger energy deposit



$t_{rec} - t_{MC}$ v.s. energy deposit

profile

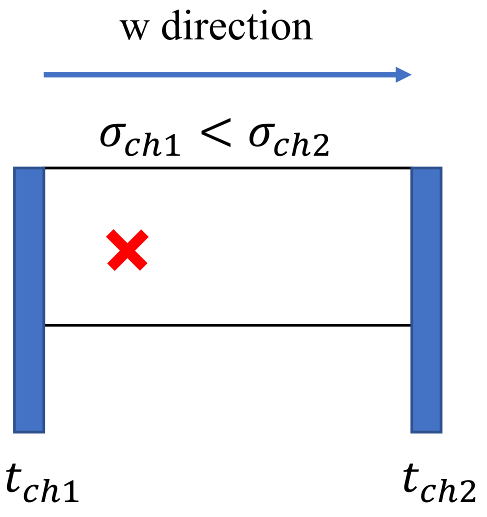




Time reconstruction improvement

➢w position dependence

- Closer channel to hit point is expected to have better time resolution than the other
- Hit time reconstruction should be optimized according to the hit position



$$t_{hit} = \frac{t_{ch1} + t_{ch2}}{2} \rightarrow t_{hit} = \frac{\frac{t_{ch1}}{\sigma_{ch1}^2} + \frac{t_{ch2}}{\sigma_{ch2}^2}}{\frac{1}{\sigma_{ch1}^2} + \frac{1}{\sigma_{ch2}^2}}$$