MEG II 実験における
陽電子の時間再構成法の改善

Study on improving positron timing reconstruction
in the MEG II experiment

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日本物理学会 第74回年次大会

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Core-to-Core Program

Outline

- Introduction
  - MEG II experiment
  - pTC design
  - pTC performance
- Energy deposit correction
- Intra-pixel position correction
- Inter-pixel position correction
  - General idea
  - Dependence
  - Correction procedure
  - Simulation result
  - Application on data
- Summary & prospect

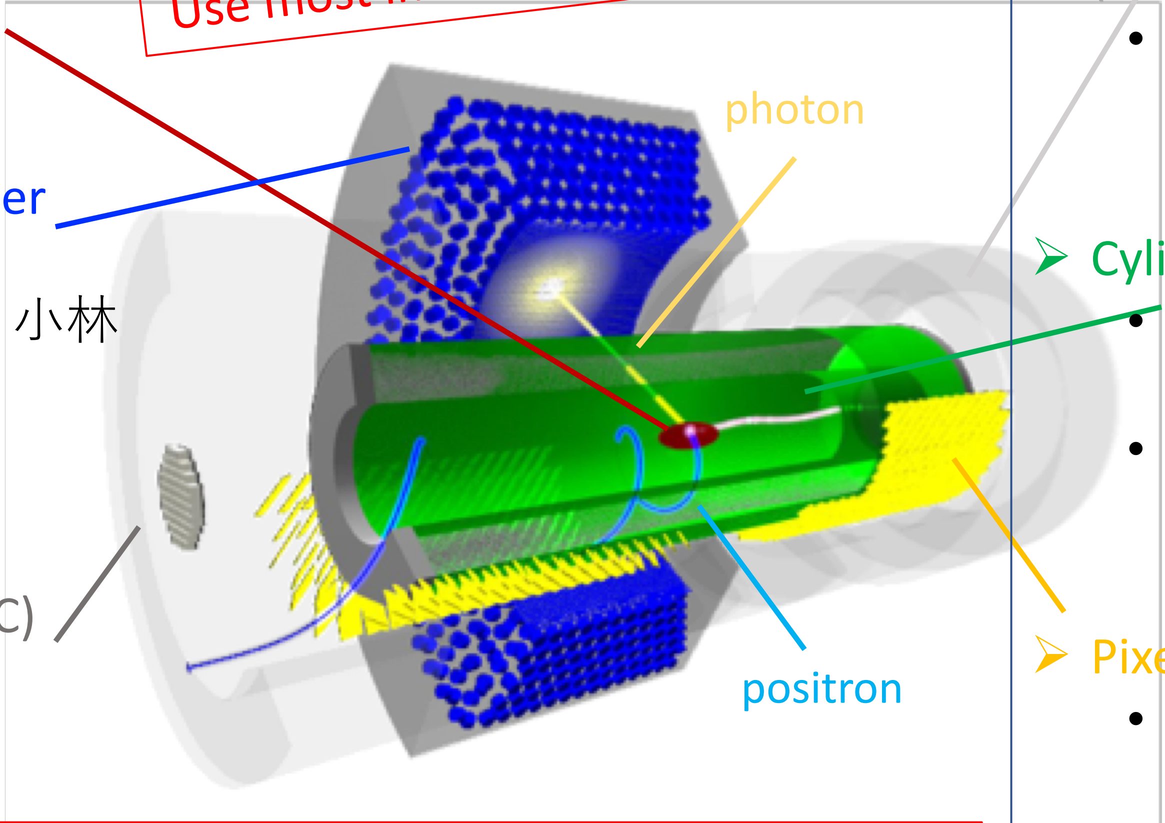
MEG II experiment

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

  c.f. 15aK210 家城、小川、小林
  17aK104 豊田
- Radiative decay counter (RDC)
  - Detects background positrons

  c.f. 14aK209 大矢
  17aK104 恩田

Use most intense muon beam at PSI



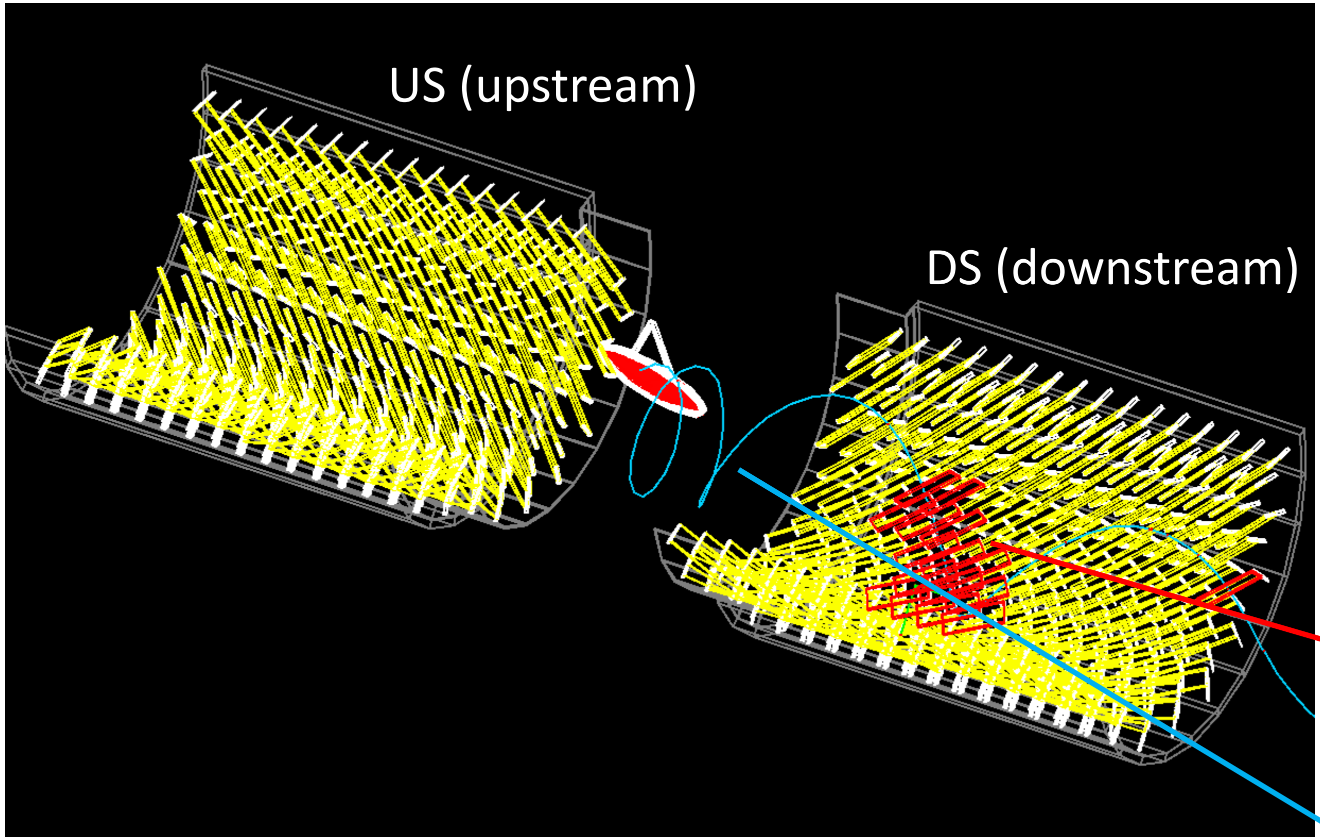
Search for $\mu^+ \rightarrow e^+\gamma$ reaction

Positron spectrometer

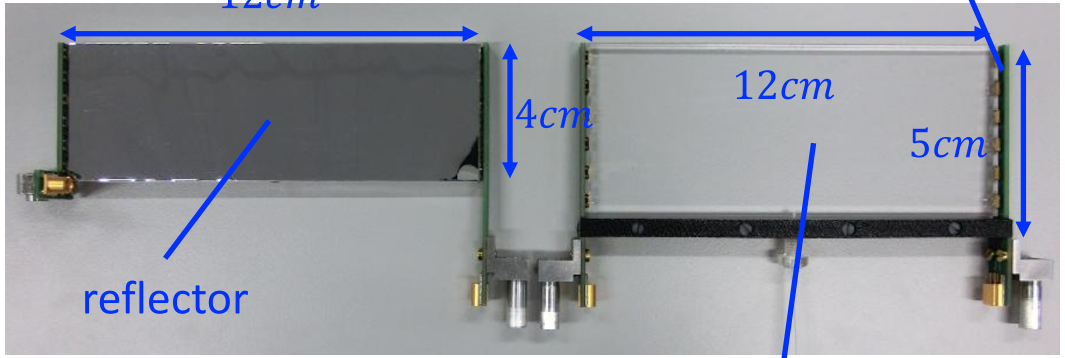
- Superconducting solenoid magnet (COBRA)
  - Bends signal positrons with constant radius
- Cylindrical drift chamber (CDCH)
  - Single volume wire chamber with He based gas
  - Reconstructs positron track
- Pixelated timing counter (pTC)
  - Plastic scintillator + SiPM readout
  - Reconstructs positron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

Introduction

➢pTC design



Positron event display



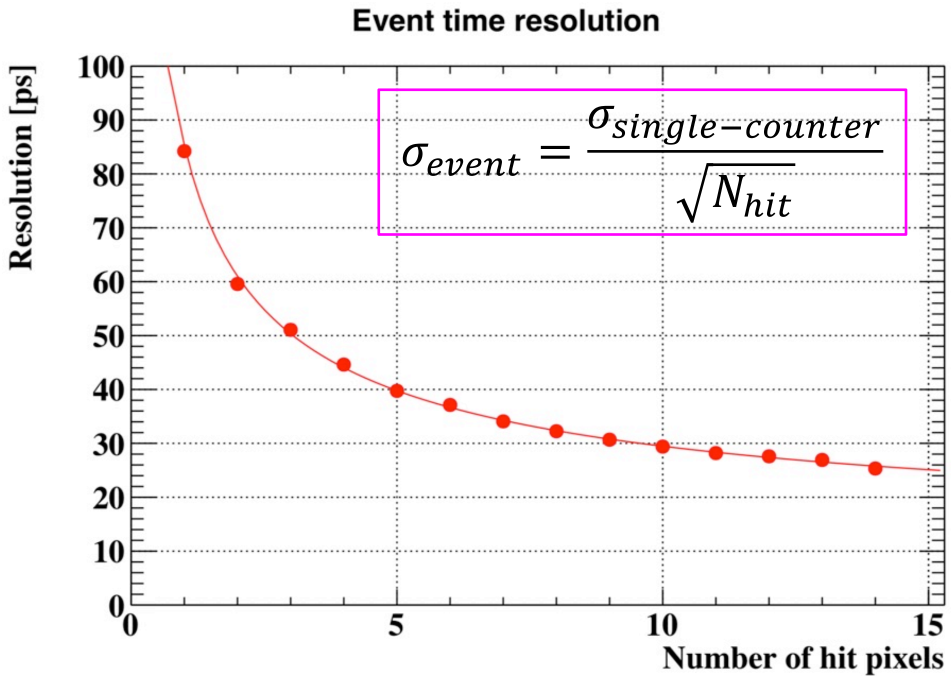
Single counter design

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

Introduction

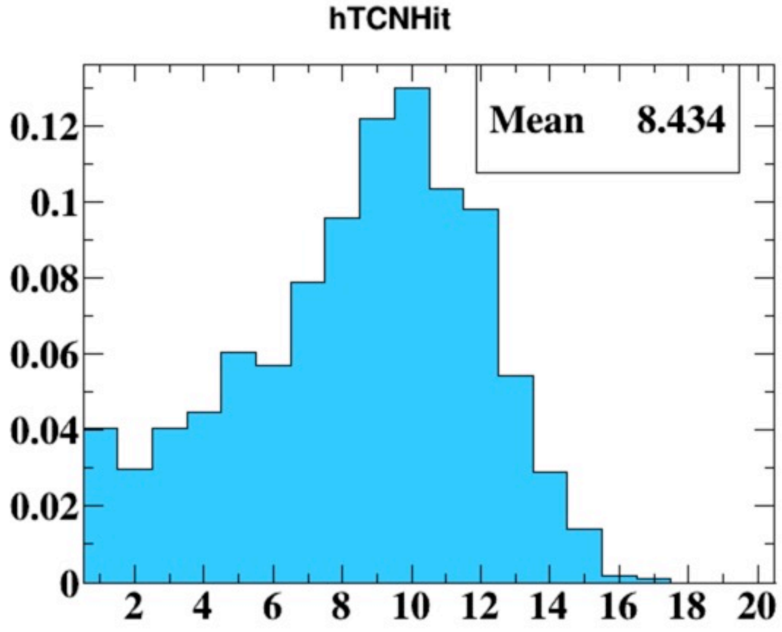
➢pTC performance

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



pTC time resolution obtained from MC

$\times$



Number of hits distribution

$= {\sim}38.5ps$

Outline

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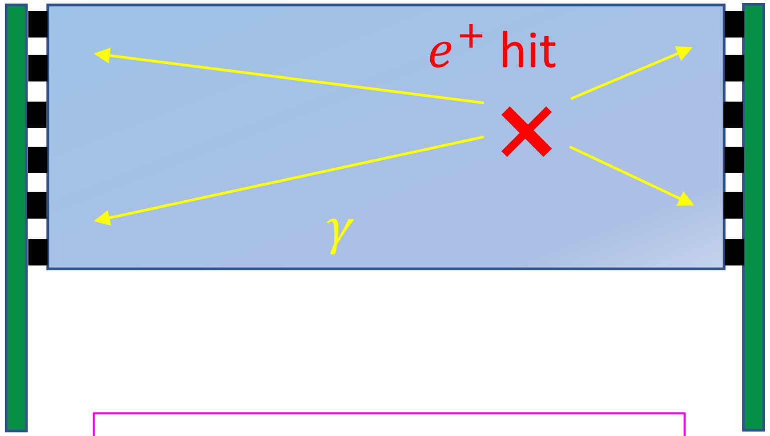
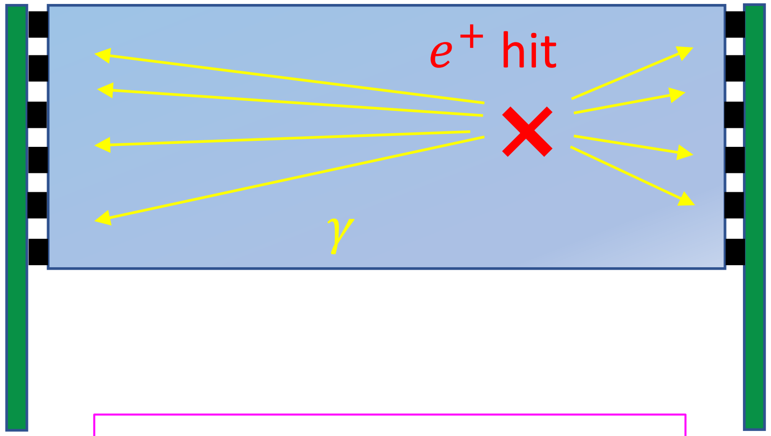
- Inter-pixel position correction
  - General idea
  - Dependence
  - Correction procedure
  - Simulation result
  - Application on data
- Summary & prospect

Energy deposit correction

➢General idea

- Each hit time resolution depends on amount of collected light





Small energy deposit		Large energy deposit
||		||
Small photon statistics	⟺	Large photon statistics
||		||
Bad hit time resolution		Good hit time resolution

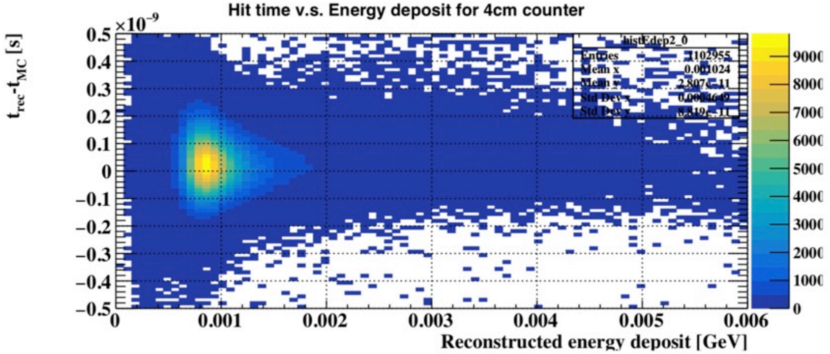
This dependence can be made use of when combining each hit time to obtain total positron time

(Current algorithm treats all hits equally)

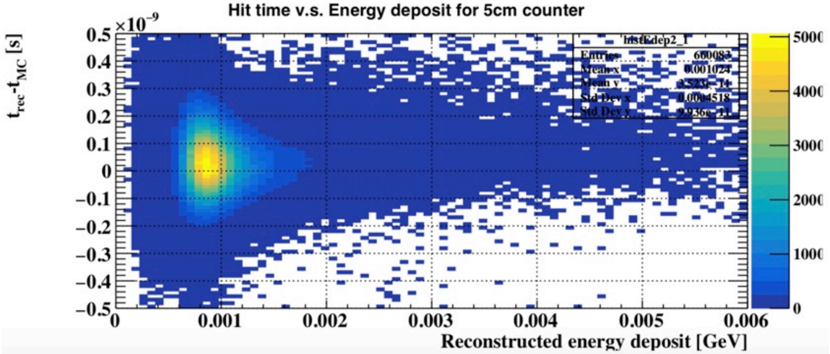
Energy deposit correction

➢Energy deposit dependence (MC)

$4cm$ counter

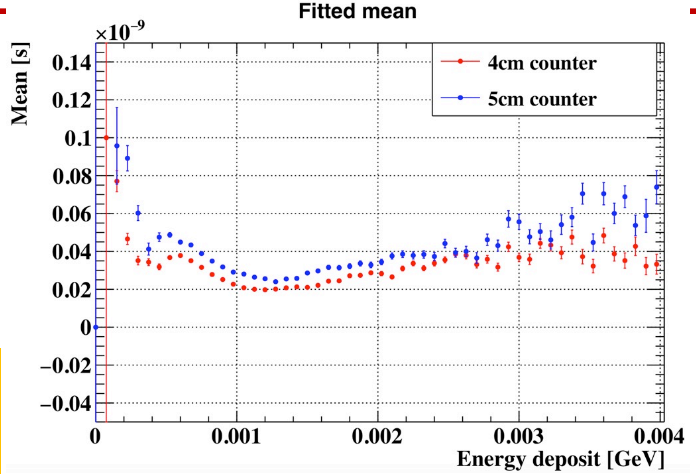


$5cm$ counter



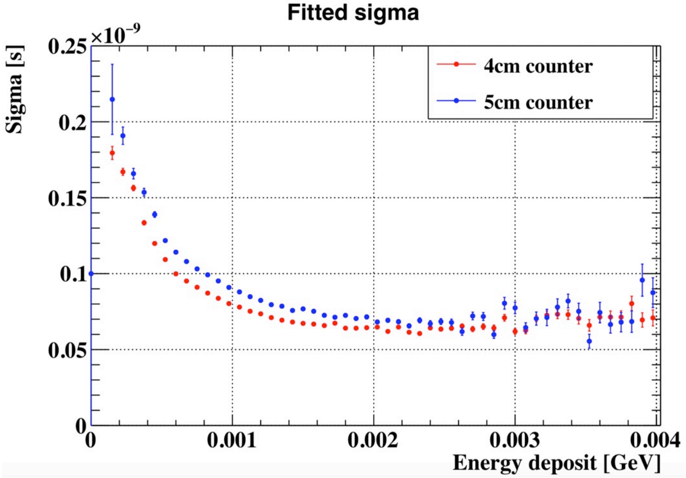
$t_{rec} - t_{MC}$ v.s. energy deposit

Profile histogram & Gaussian fit



Mean v.s. energy deposit

Time walk effect

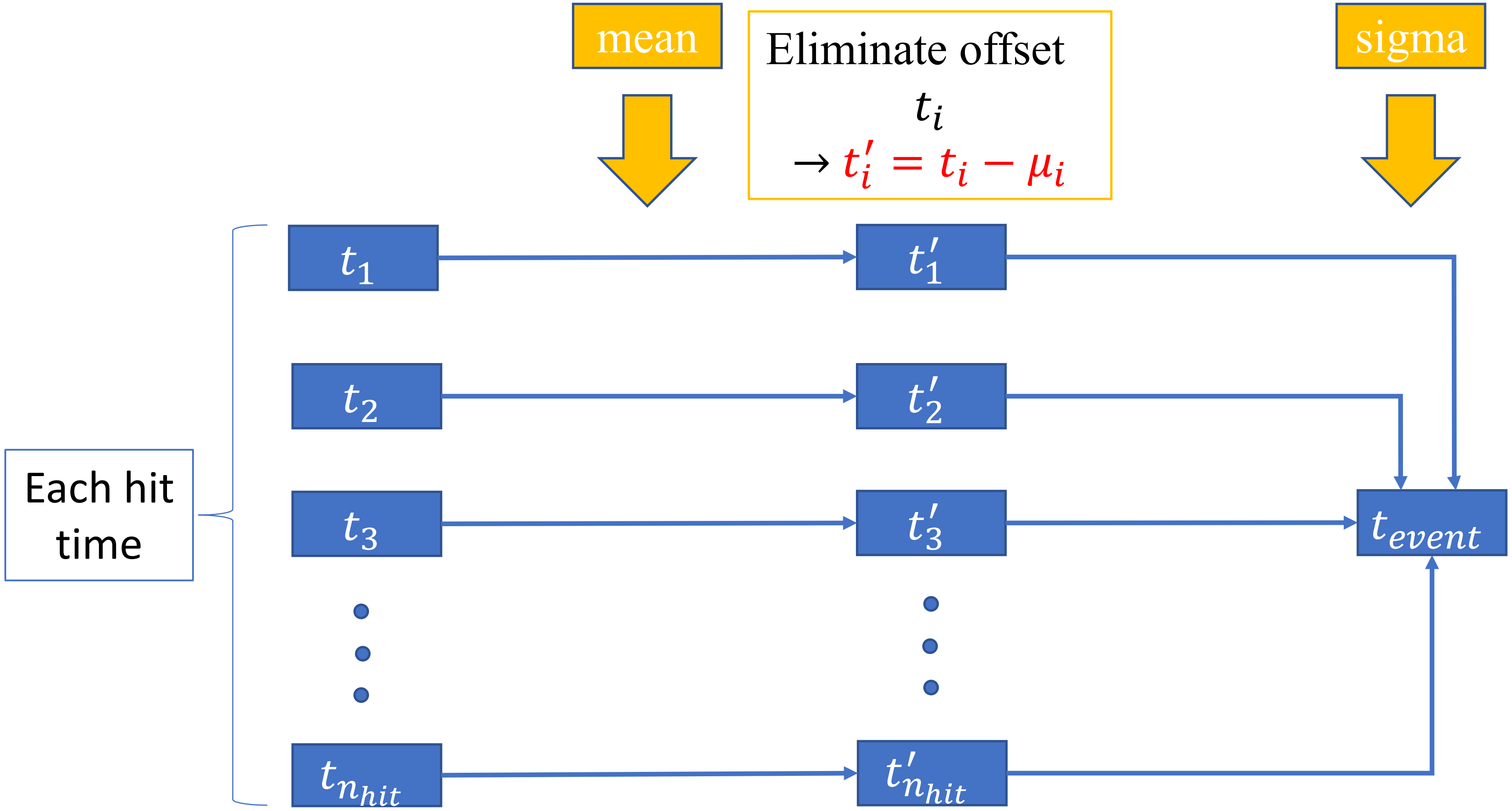


Sigma v.s. energy deposit

Expected dependence

Energy deposit correction

➢Correction procedure



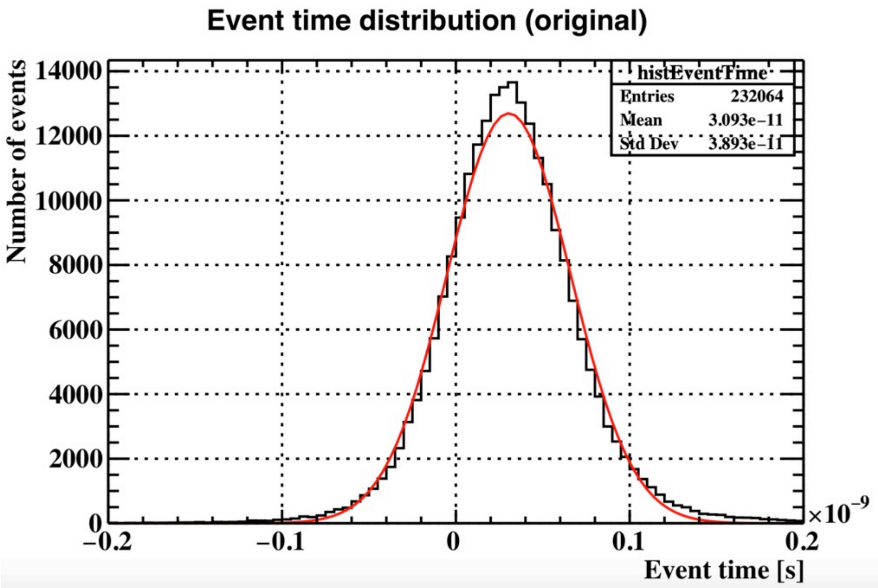
Weighted mean
(rather than simple mean)

$$t_{event} = \frac{1}{n_{hit}} \sum_{i=1}^{n_{hit}} t_i$$

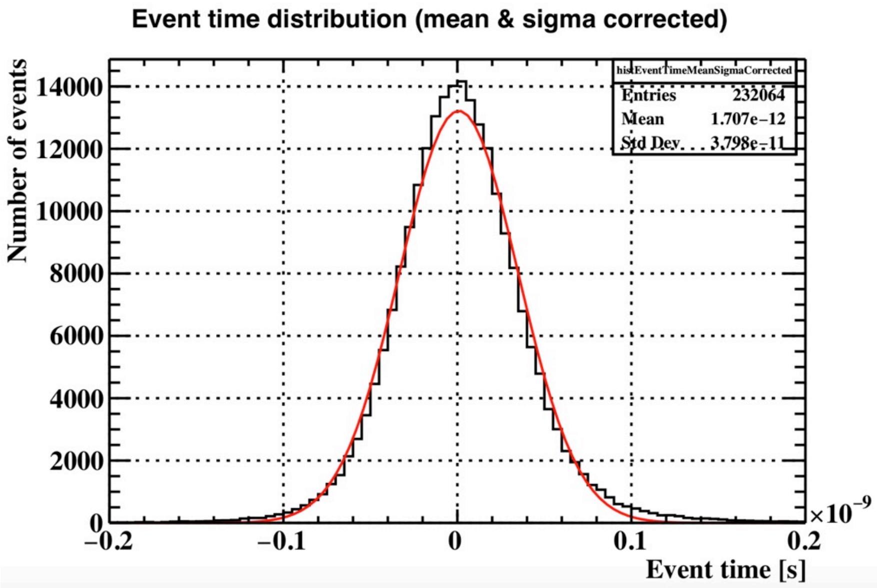
$$\rightarrow t_{event} = \frac{\sum_{i=1}^{n_{hit}} \frac{t'_i}{\sigma_i^2}}{\sum_{i=1}^{n_{hit}} \frac{1}{\sigma_i^2}}$$

Energy deposit correction

➢Energy deposit correction (MC)



Before correction



After correction

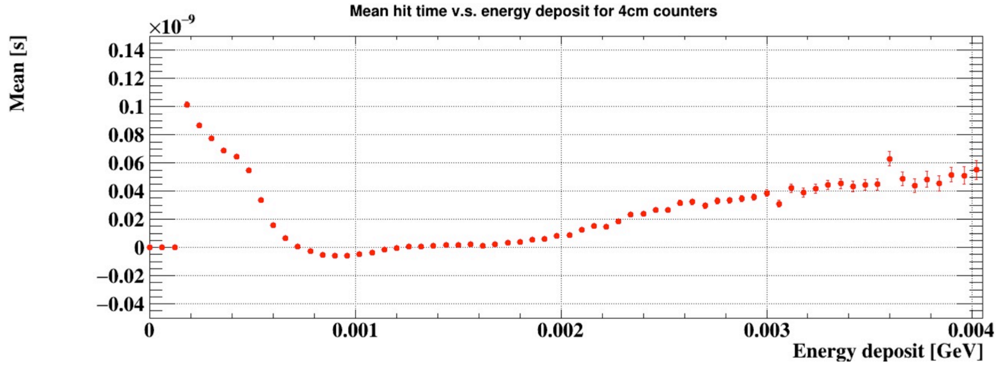
$\sigma_{event} \sim 35.6[ps]$ → $\sigma_{event} \sim 34.2[ps]$

-4.0%

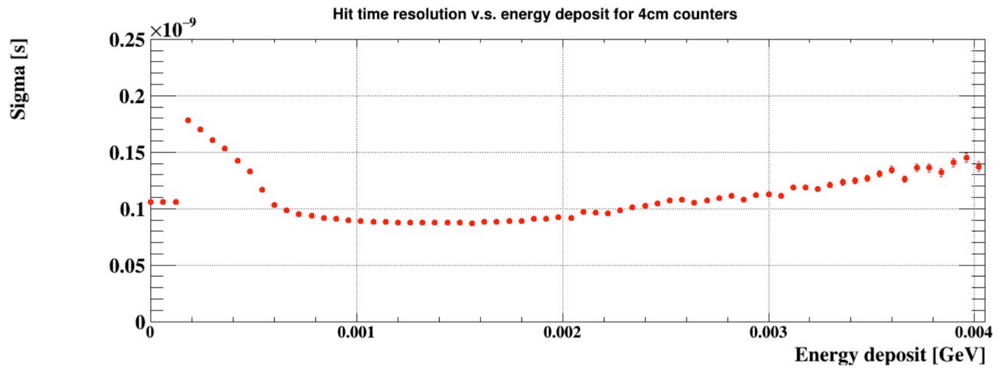
Energy deposit correction

➢Energy deposit dependence (data)

- Similar dependence as MC is found

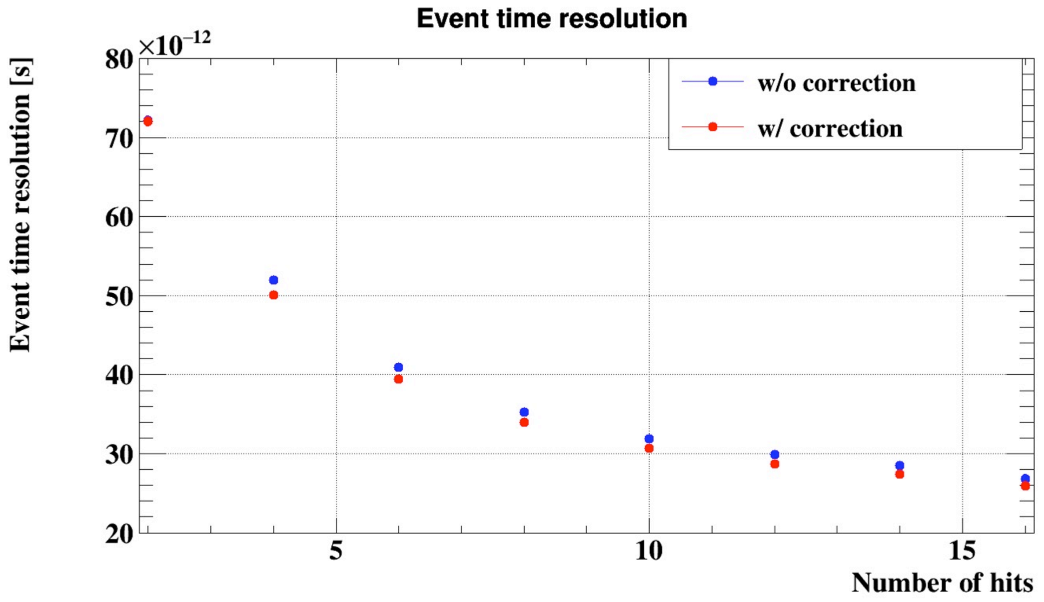


Mean v.s. energy deposit



Sigma v.s. energy deposit

➢Energy deposit correction (data)



Event time resolution v.s. number of hits

$\sigma_{event} \sim 39.5[ps]$ → $\sigma_{event} \sim 38.1[ps]$

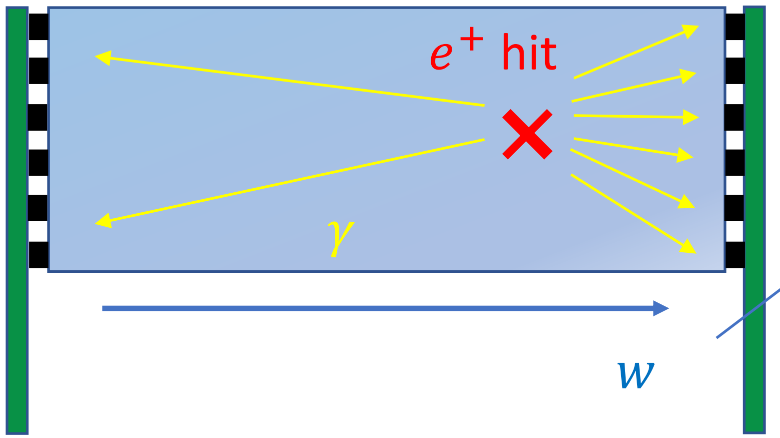
-3.7%

Outline

Intra-pixel position correction

➢General idea

- Time resolution of each channel depends on amount of collected light



w information can be obtained from CDCH tracking with $\sim$5mm precision

Ch1		Ch2
Far from hit position		Close from hit position
ǁ		ǁ
Small photon statistics	⟺	Large photon statistics
ǁ		ǁ
Bad hit time resolution		Good hit time resolution

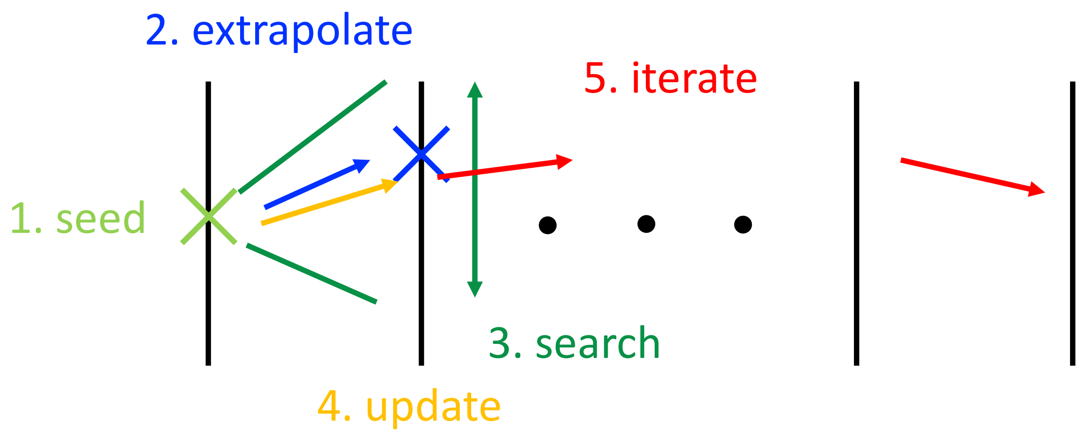
This dependence can be made use of when combining each channel time to obtain hit time

(Current algorithm treats both channels equally)

Intra-pixel position correction

➢Positron tracking

- Combine discontinuous hit information into single positron track
- Kalman Filter technique is used to extrapolate track and include following hits
- Segments are fitted with GENFIT
- Two types of tracking (pTC tracking & CDCH tracking) exists
  - CDCH tracking is used for MC study
  - pTC tracking is used for data analysis (due to limited CDCH readout electronics)



Kalman Filter
Efficient recursive algorithm to estimate the state vector & its covariance matrix based on previous steps

GENFIT
Generic toolkit for track reconstruction for experiments in particle & nuclear physics

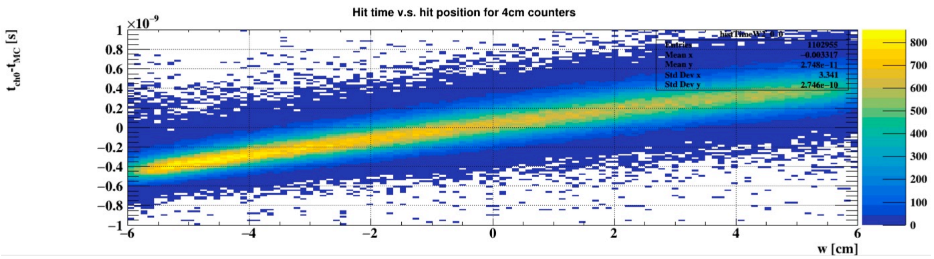
Intra-pixel position dependence

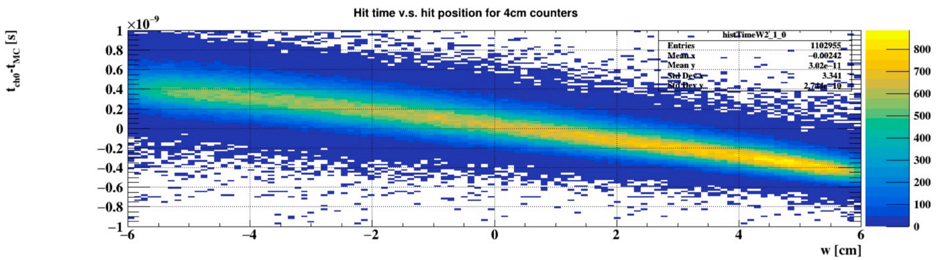
➢Position dependence (MC)

Ch1

Ch2

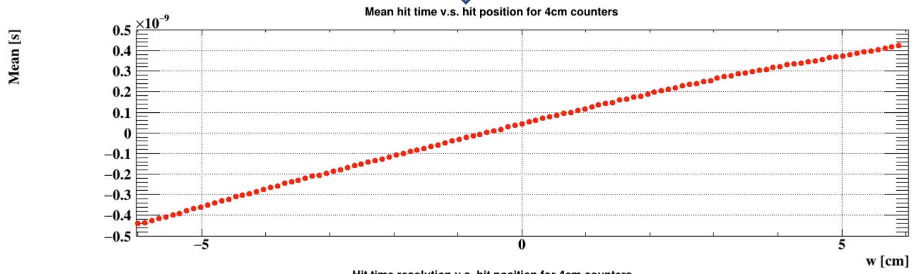
$t_{rec} - t_{MC}$ v.s. w

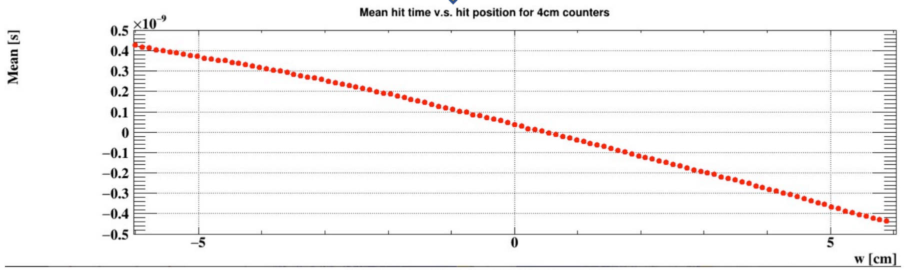




Profile histogram & Gaussian fit

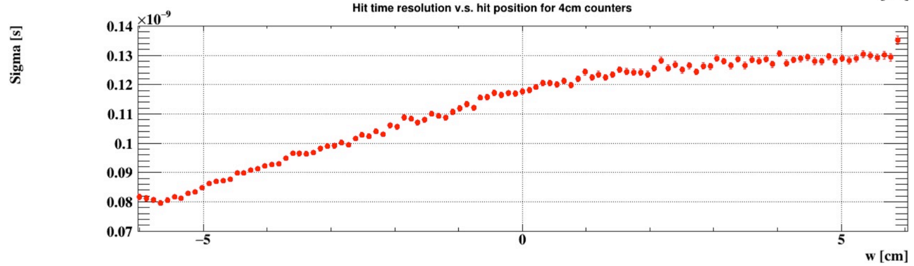
Mean v.s. w

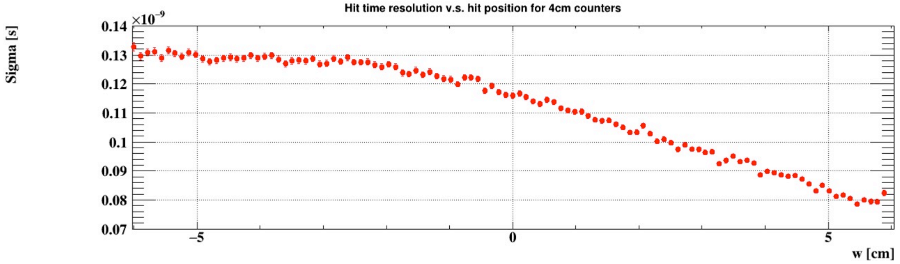




Propagation speed of scintillation light

Sigma v.s. w





Expected dependence

Intra-pixel position correction

➢Correction procedure

mean → propagation speed

sigma

Signal time of each channel: t_{ch1}, t_{ch2}

$t_{ch1} \rightarrow t'_{ch1}$

$t_{ch2} \rightarrow t'_{ch2}$

t'_{ch1}, t'_{ch2} → t_{hit}

Constant fraction method is used

Obtain hit time from each channel

$$t'_{ch1} = t_{ch1} - v_{scinti} \times |w_{hit} - w_{ch1}|$$
$$t'_{ch2} = t_{ch2} - v_{scinti} \times |w_{hit} - w_{ch2}|$$

Weighted mean (rather than simple mean)

$$t_{hit} = \frac{t_{ch1} + t_{ch2}}{2}$$

$$\rightarrow t_{hit} = \frac{\frac{t'_{ch1}}{\sigma_1^2} + \frac{t'_{ch2}}{\sigma_2^2}}{\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2}}$$

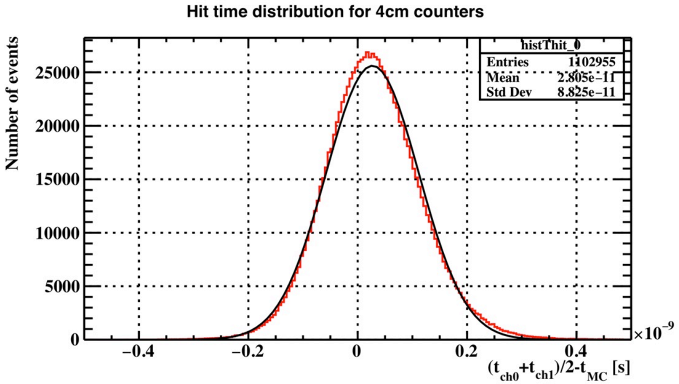
Intra-pixel position correction

➢Intra-pixel position correction (MC)

Before correction

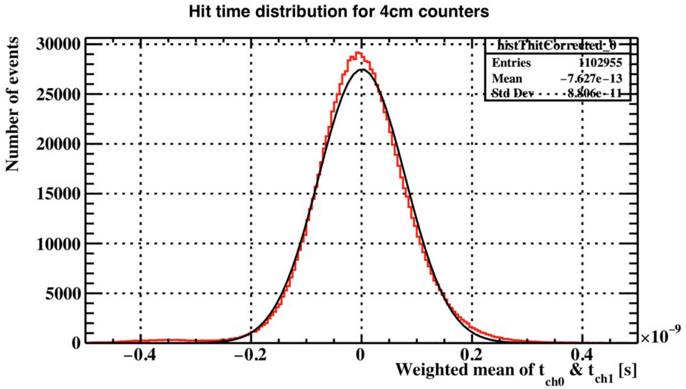
After correction

$4cm$ counter



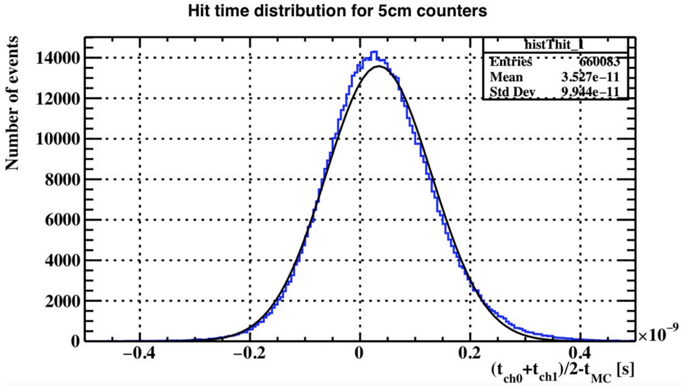
σ_{hit}~$85.0[ps]$

-4.1%



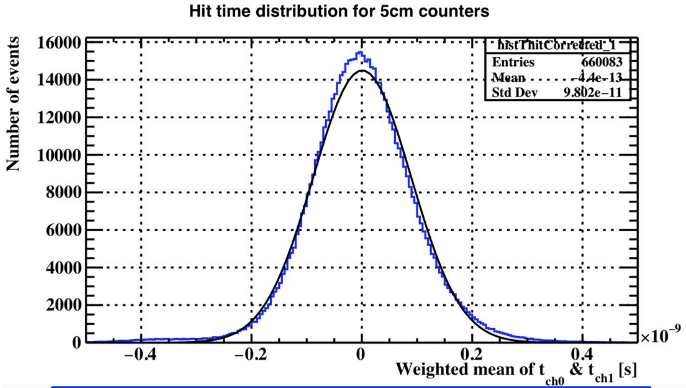
σ_{hit}~$81.5[ps]$

$5cm$ counter



σ_{hit}~$95.8[ps]$

-4.7%



σ_{hit}~$91.3[ps]$

Intra-pixel position correction

➢Position dependence (data)

- Mean dependence is similar as MC
- Sigma dependence is different from MC
  - Resolution is not better for closer hit

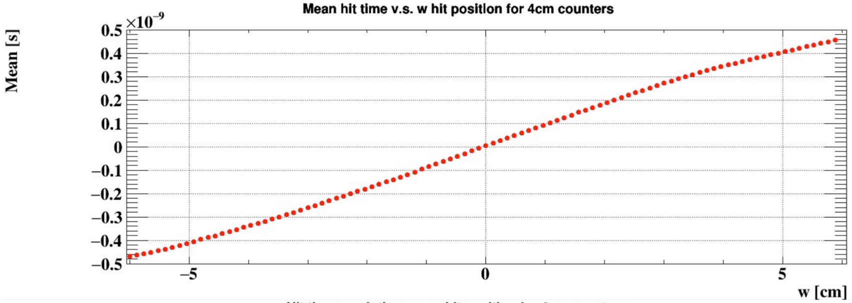
➢Intra-pixel position correction (data)

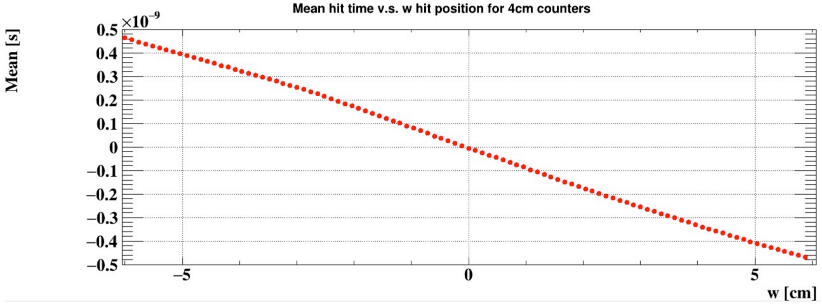
- $4cm$ counter
  - $94.2[ps] \rightarrow 93.9[ps]$ (-0.3%)
- $5cm$ counter
  - $105.8[ps] \rightarrow 105.4[ps]$ (-0.4%)

Ch1

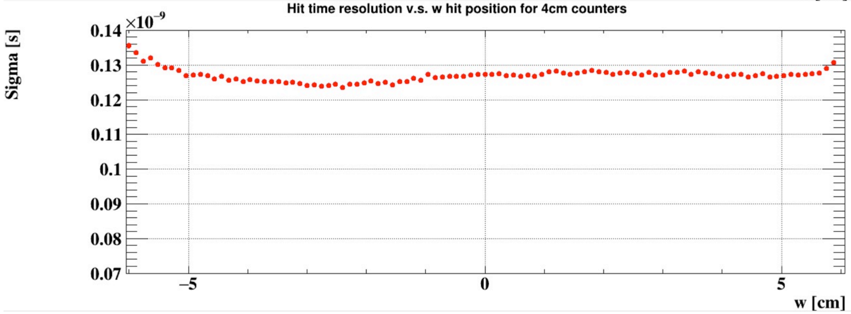
Ch2

Mean v.s. w





Sigma v.s. w



Outline

Inter-pixel position correction

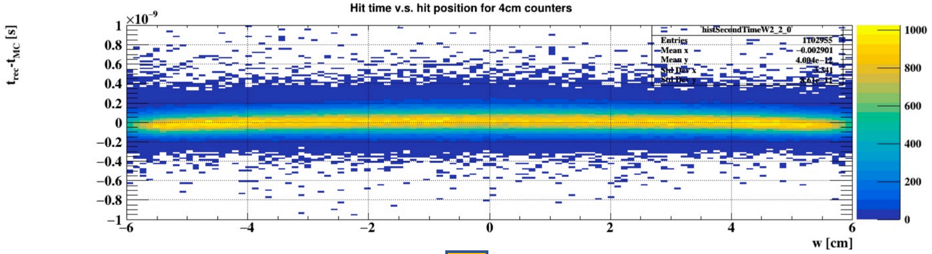
➢Position dependence (MC)

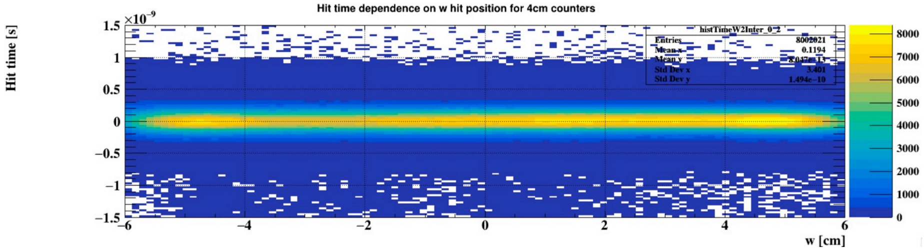
- Even after intra-pixel position correction, position dependence can be found

➢Position dependence (data)

- Small position dependence is found

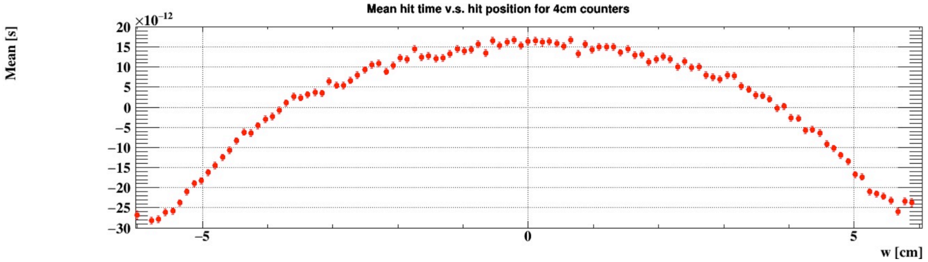
$t_{rec} - t_{MC}$ v.s. w

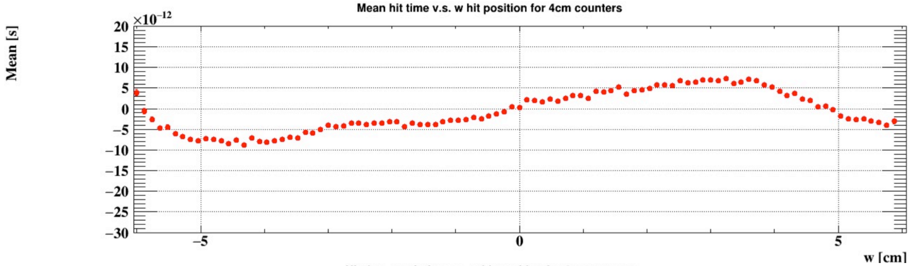




Profile histogram & Gaussian fit

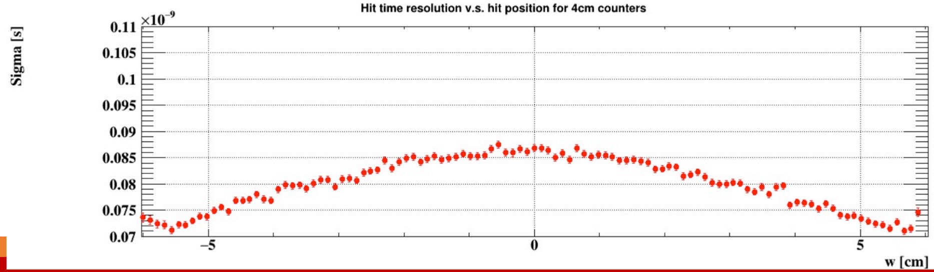
Mean v.s. w

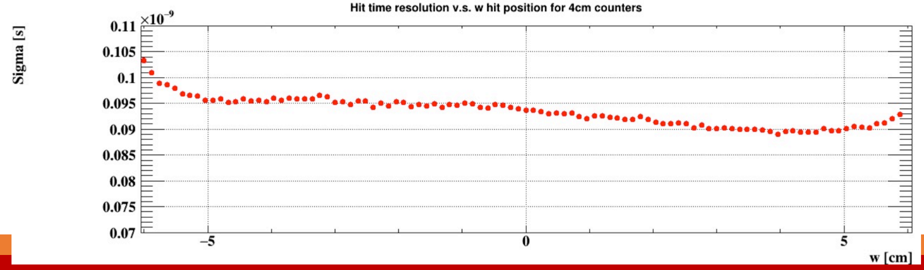




Position dependence of time offset

Sigma v.s. w

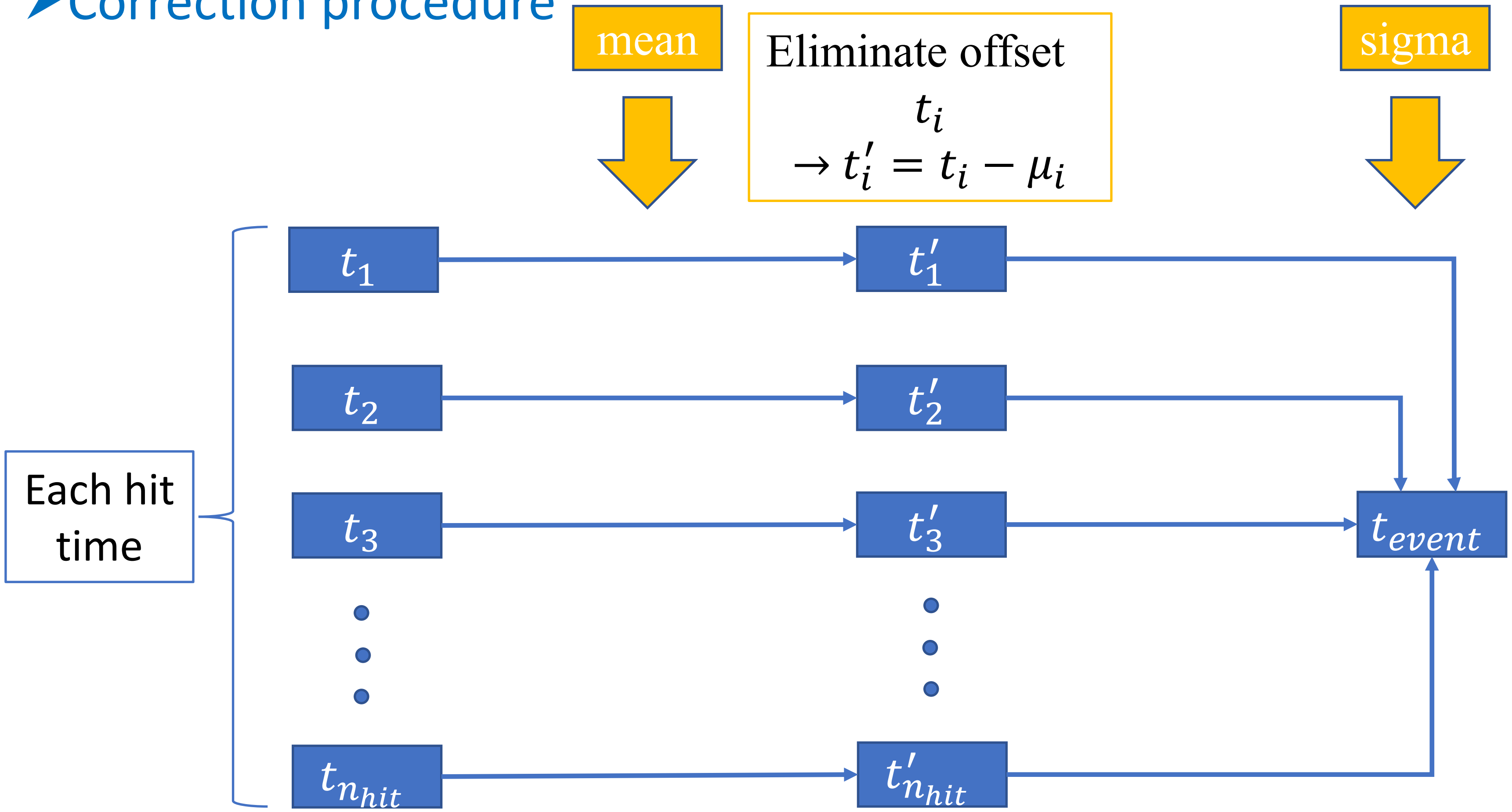




Position dependence of time resolution

Inter-pixel position correction

➢Correction procedure



Weighted mean
(rather than simple mean)

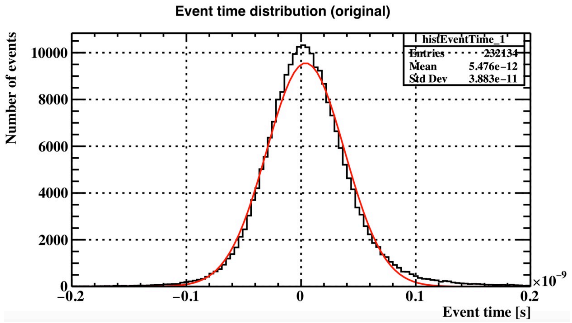
$$t_{event} = \frac{1}{n_{hit}} \sum_{i=1}^{n_{hit}} t_i$$

$$\to t_{event} = \frac{\sum_{i=1}^{n_{hit}} \frac{t_i'}{\sigma_i^2}}{\sum_{i=1}^{n_{hit}} \frac{1}{\sigma_i^2}}$$

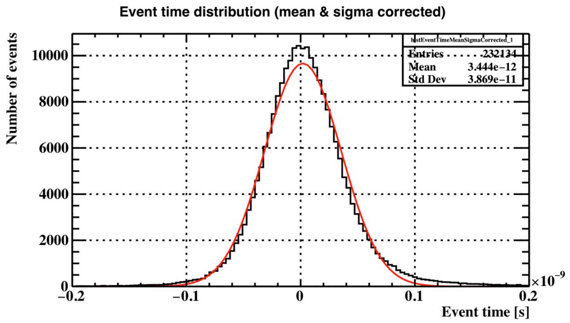
Remaining position dependence can be made use of when combining each hit time to obtain total positron time

Inter-pixel position correction

➢Inter-pixel position correction (MC)



Before correction

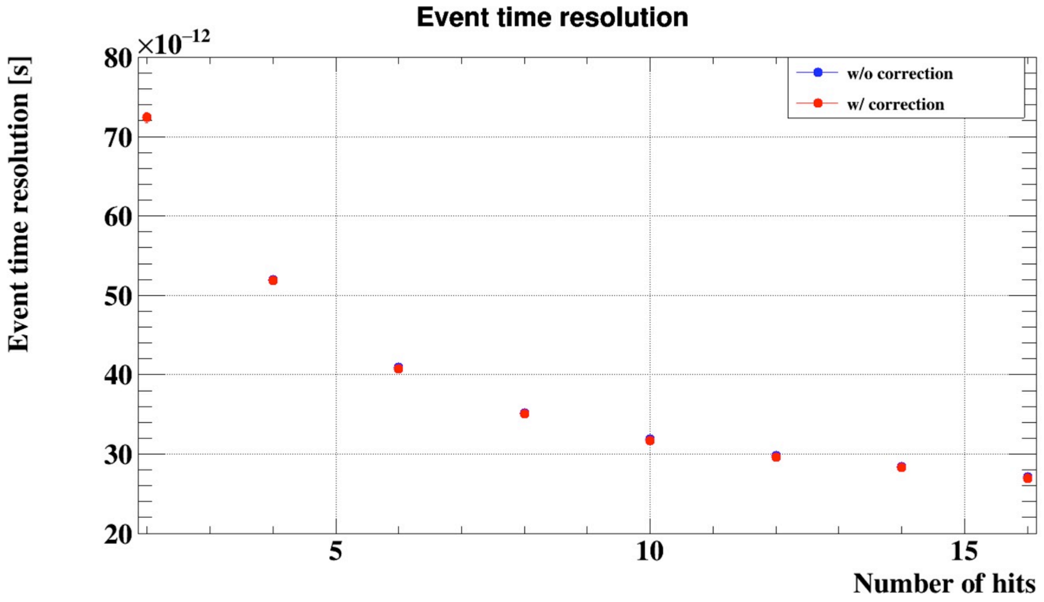


After correction

$\sigma_{event} \sim 34.1[ps]$ → $\sigma_{event} \sim 33.6[ps]$

-1.3%

➢Inter-pixel position correction (data)



Event time resolution v.s. number of hits

$\sigma_{event} \sim 39.5[ps]$ → $\sigma_{event} \sim 39.4[ps]$

-0.4%

Outline

➢Introduction

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

➢Energy deposit correction

➢Intra-pixel position correction

➢Inter-pixel position correction

- General idea
- Dependence
- Correction procedure
- Simulation result
- Application on data

➢Summary & prospect

Summary & prospect

➢Summary

- Hit time & hit time resolution of MEG II pTC was found to depend on energy deposit & hit position
- Improved time reconstruction method was developed using these dependences
- MC simulation result shows promising result
  - $35.6[ps] \rightarrow 32.5[ps]$ (-8.6%) in total
- Applying algorithm on data is less effective due to different position dependence
  - $39.5[ps] \rightarrow 37.9[ps]$ (-4.0%) in total

➢Prospect

- Difference of position dependence behavior between MC & data is to be investigated

Backup slides

cLFV (charged Lepton Flavor Violation)

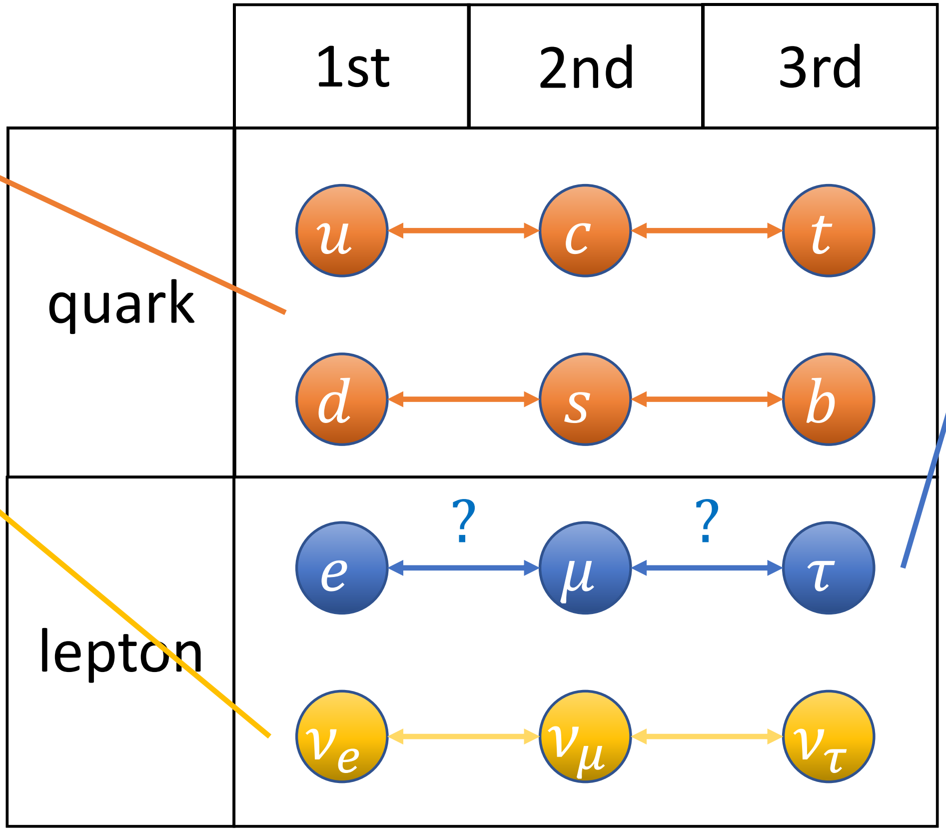
➢ Quark mixing

- 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



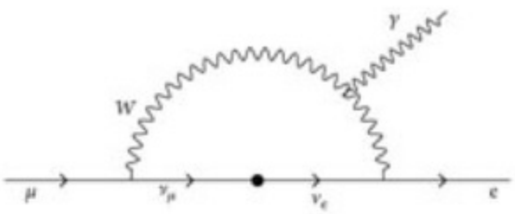
➢ Charged lepton flavor violation (cLFV)

- Forbidden in SM
- Included in many new physics models
- If discovered, certain proof of new physics
- Has been searched in many experiments

$\mu \rightarrow e\gamma$ reaction

➢Motivation

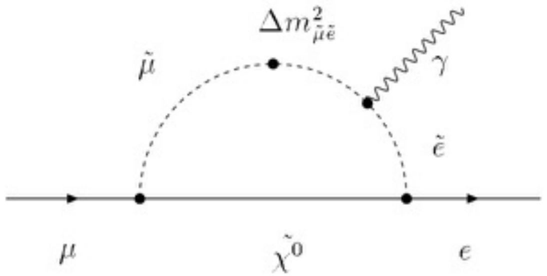
- Considering neutrino oscillation, possible but very rare
- Included in many new physics models at observable rate
- Can search for new physics w/o directly creating new heavy particles



SM + neutrino oscillation

$Br(\mu \rightarrow e\gamma) \sim 10^{-54}$

(little background)

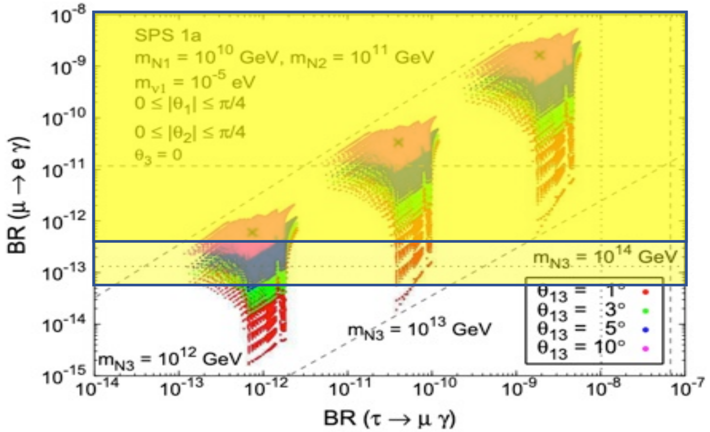


SUSY model

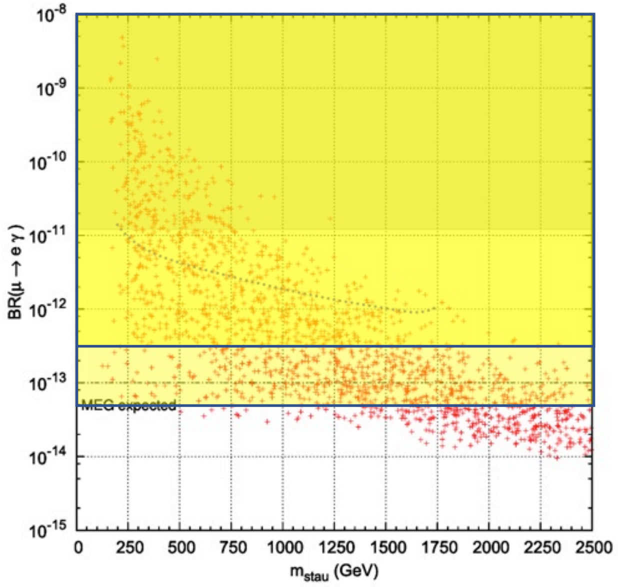
$Br(\mu \rightarrow e\gamma) \sim 10^{-15} - 10^{-11}$

➢Status of cLFV search

- Current upper limit is obtained by MEG
  - $Br(\mu \rightarrow e\gamma) < 4.2\times10^{-13}$ (90% C.L.)
- MEG II aims for one order higher sensitivity
  - $\sim 6.0\times10^{-14}$



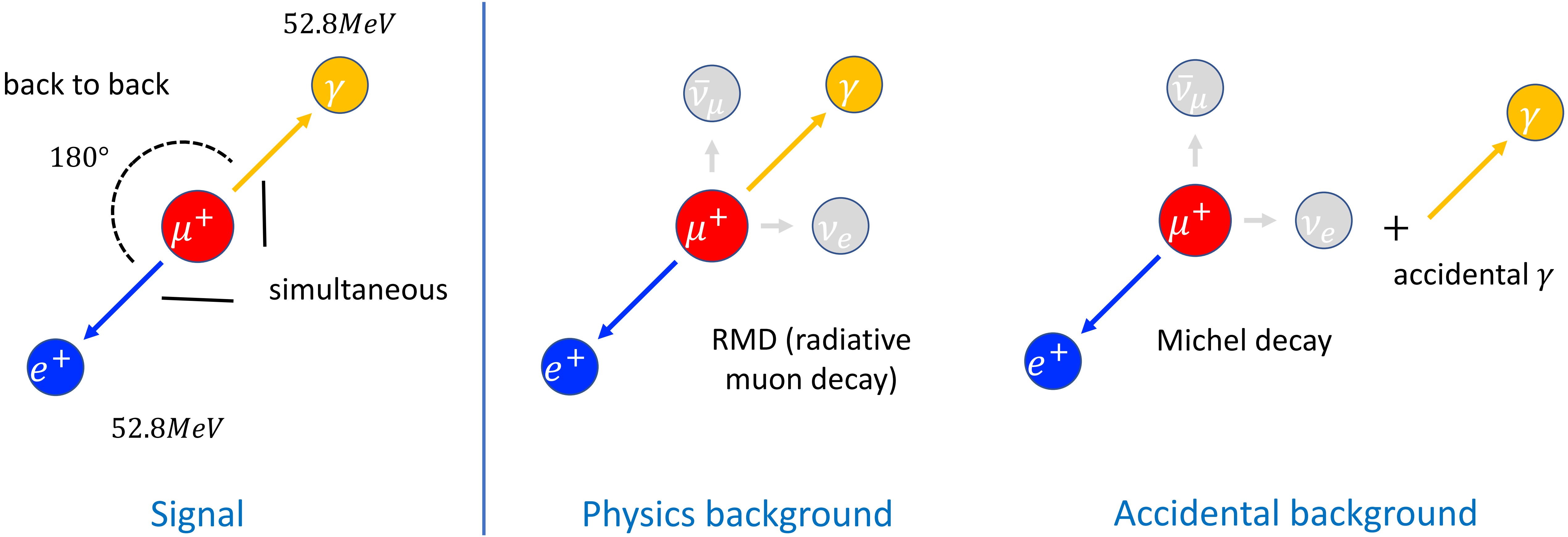
SUSY see-saw



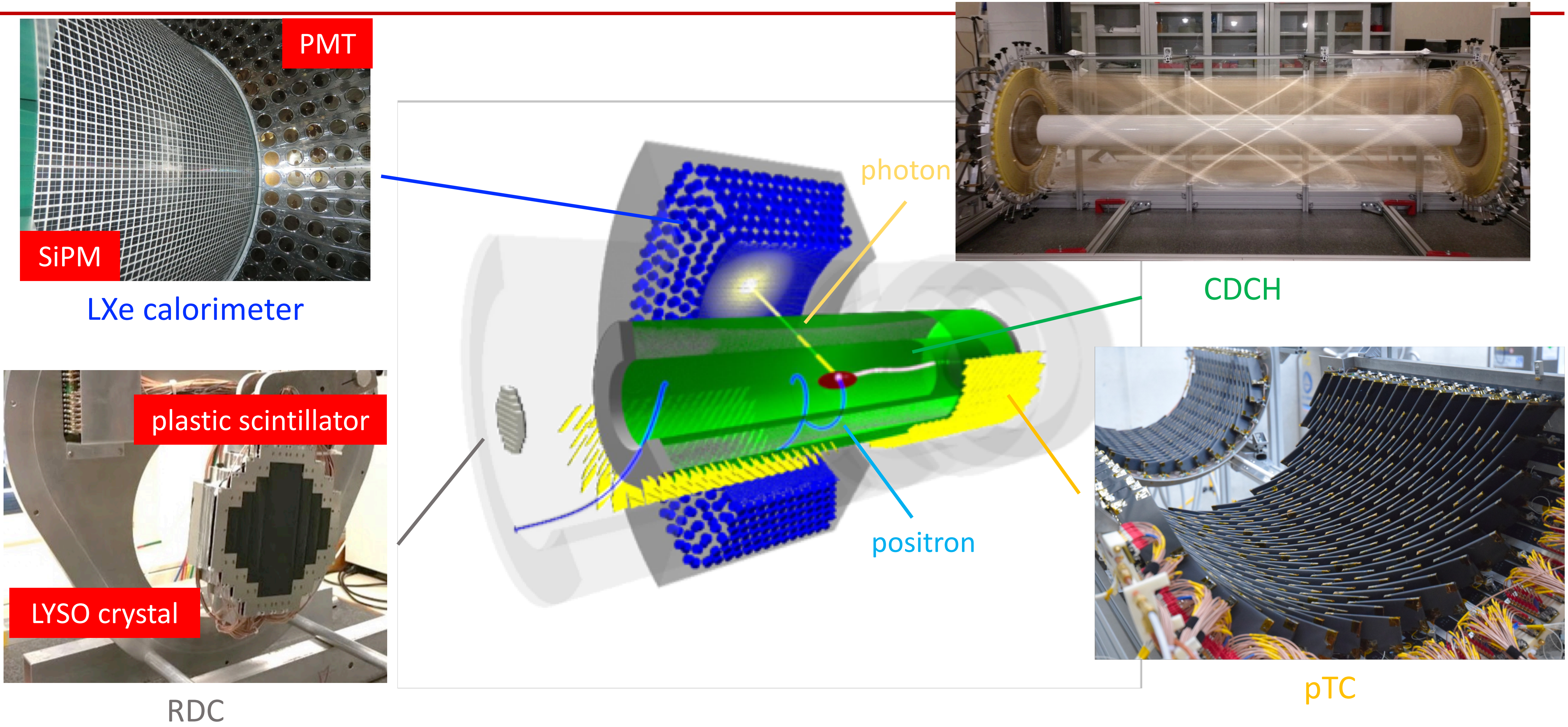
SUSY GUT

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



Detectors


PMT
SiPM
LXe calorimeter
plastic scintillator
LYSO crystal
RDC
photon
CDCH
positron
pTC

Positron spectrometer

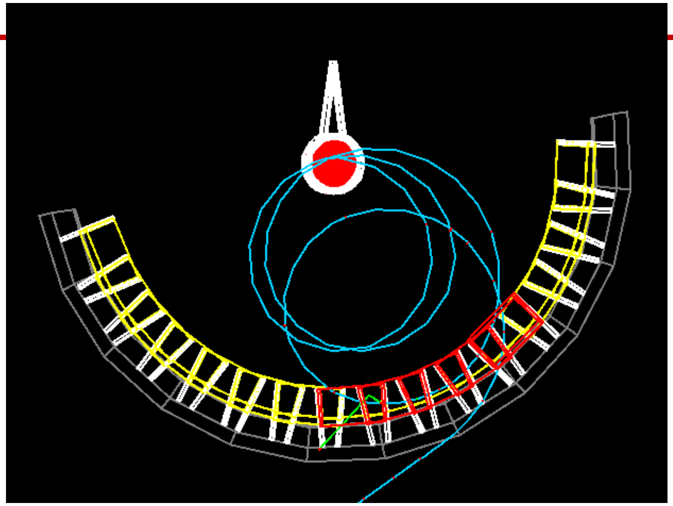
➢COBRA (COnstant Bendint RAdius)

- 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



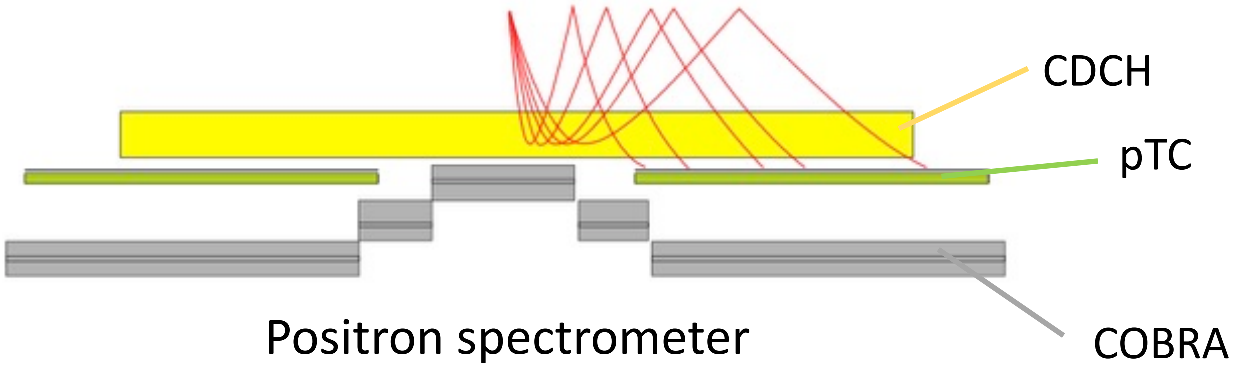
Positron event display

➢CDCH (Cylindrical Drift CHamber)

- Reconstructs positron track

➢pTC (pixelated Timing Counter)

- Reconstructs positron time



Positron spectrometer

pTC tracking

➢Idea

- Horizontal position can be reconstructed from the time difference of two channels
- Radial coordinate can be reconstructed from hit pattern information

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