# MEG II実験陽電子スペクトロメータにおける検出効率改善のための再構成アルゴリズムの研究

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日本物理学会2018年秋季大会@信州大学

MEG II Mu - E - Gamma collaboration

ICEPP The University of Tokyo

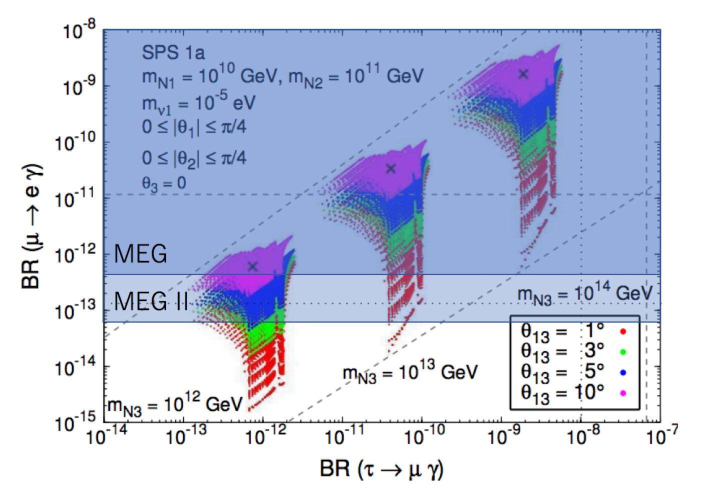
Core-to-Core Program

# Introduction

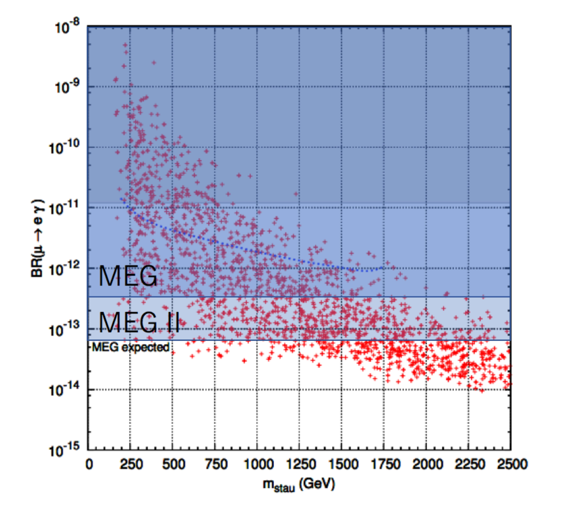
- ☐ Introduction
  - ✓MEG II experiment
  - ✓Positron spectrometer
- ☐ Performance study on positron spectrometer
- ☐ Summary and prospect

# $\mu \to e\,\gamma$ search

- Charged Lepton Flavor Violation (cLFV);
  - ✓Prohibited in standard model
    - Even with neutrino oscillation, Br($\mu \to e\gamma$) ~ O($10^{-54}$)
  - ✓Predicted in beyond standard model
    - Many models (SUSY-GUT, Extra-dimension etc…), Br($\mu \to e\gamma$) ~ O($10^{-14}$)
- To discover $\mu \to e\gamma$ means to discover the new physics!




SUSY-Seesaw

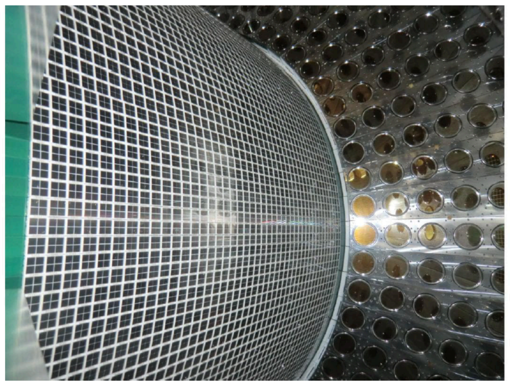


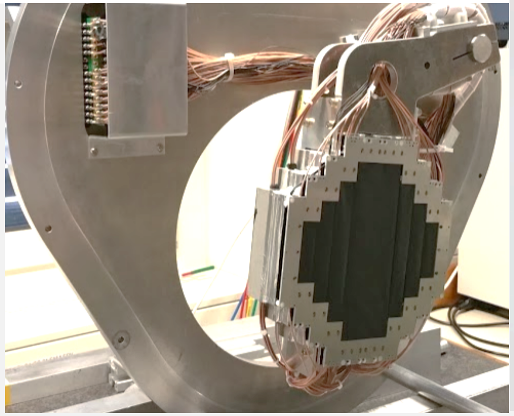

SO(10) SUSY GUT

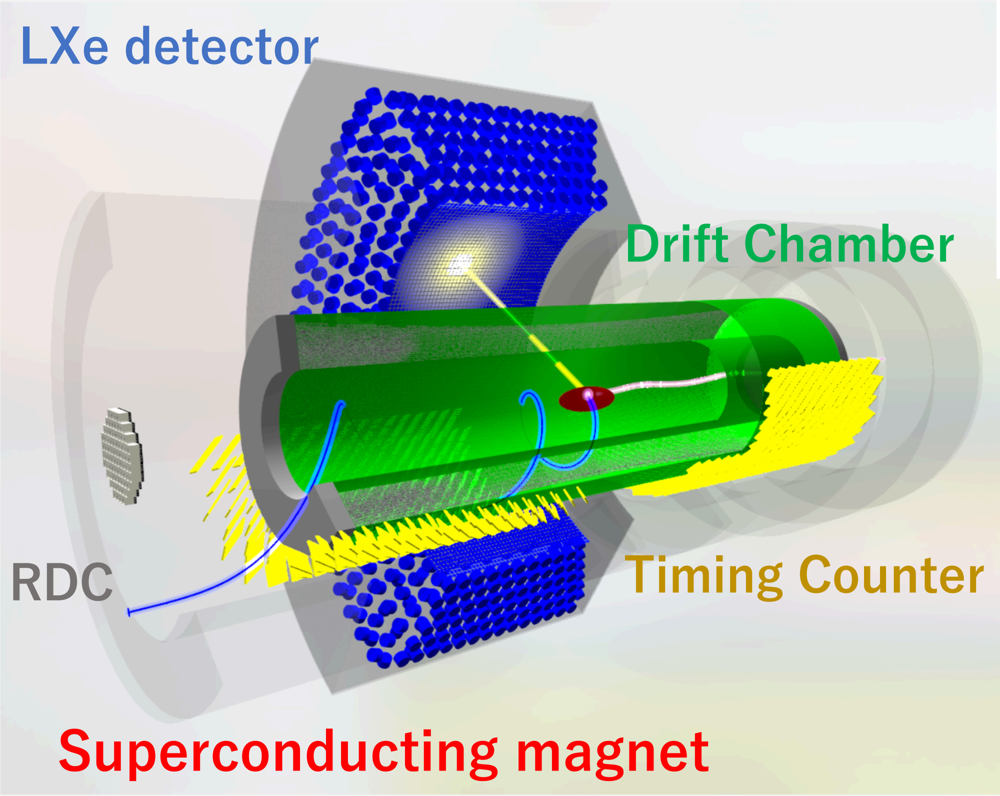
Expected branching ratio is within the reach of experiment.
Current upper limit (MEG, 2016):
$Br(\mu \to e\gamma) < 4.2 \times 10^{-13}$ (90% C.L.)
Target sensitivity of MEG II:
$Br(\mu \to e\gamma) \sim 6 \times 10^{-14}$

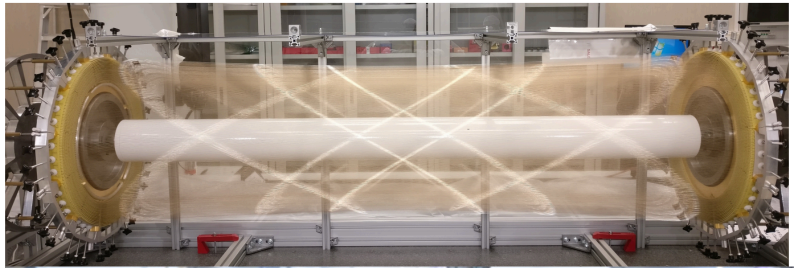

SUSY-Seesaw : S. Antusch et al. "Impact of $\theta_{13}$ on Lepton Flavour Violating processes within SUSY Seesaw" Journal of High Energy Physics 2006 (11), 090
SO(10) SUSY-GUT : Lorenzo Calibbi et al. "Flavour violation in supersymmetric SO(10) unification with a type II seesaw mechanism." JHEP, 0912:057, 2009.
にMEG、MEG IIの範囲を書き足して作成
MEGの最終結果：A.M.Baldini et al. "Search for the lepton flavour violating decay $\mu^+ \to e^+\gamma$ with the full dataset of the MEG experiment", Eur. Phys. J. C (2016) 76:434

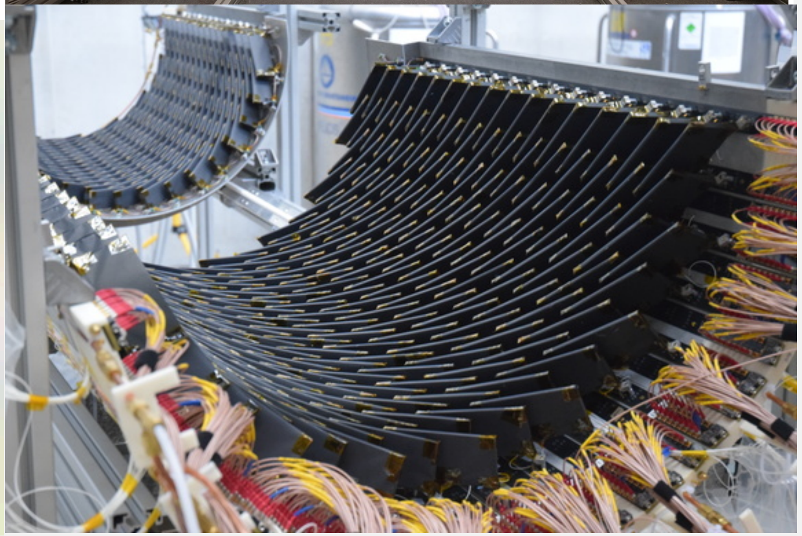
# MEG II Experiment Detectors







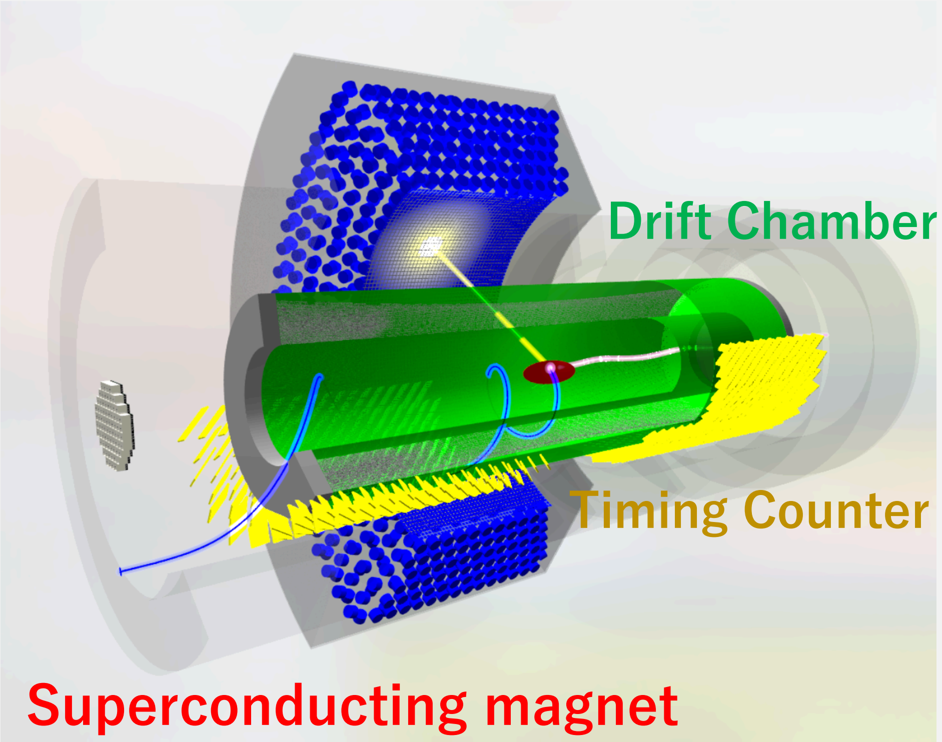


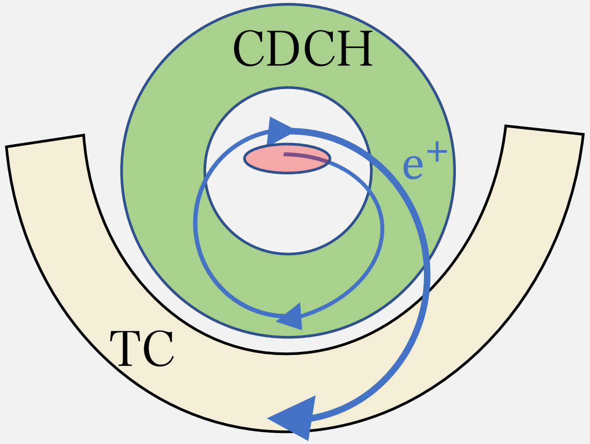
- □ **Overall talk:** 14aS20 (Finished)
- □ **Positron spectrometer:** 15pS28 4--5
- □ **LXe gamma-ray detector:** 16aS41 7--8
- □ **Radiative decay counter:** 16aS41 5

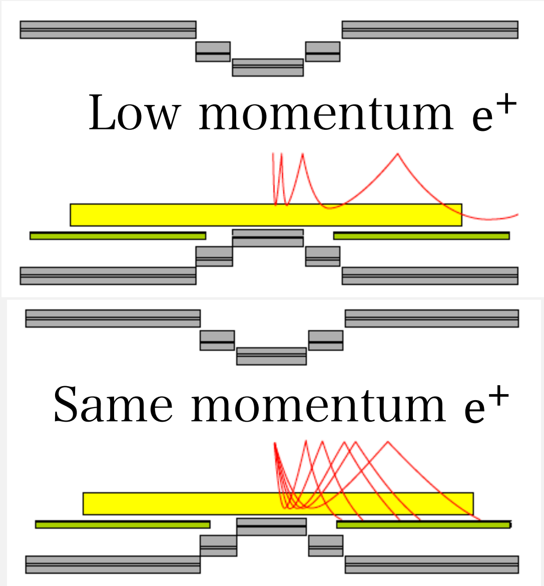
LXe: Baldini, A.M., Baracchini, E., Bemporad, C. et al. Eur. Phys. J. C (2018) 78: 380. ”The design of the MEG II experiment”
arXiv: arXiv:1801.04688v1 [physics.ins-det]
DCH : Taken by DCH group in Dec.
RDC : 2017年秋季大会大強度 $\mu^+$ 粒子ビーム中で動作する MEG II 実験輻射崩壊同定用カウンターの開発, K Ieki

# MEG II Experiment Detectors

Positron Timing Measurement to Search for Lepton Flavor Violating Decay in MEG II, Miki Nishimura, May 2018, Doctor thesis (The Univ. of Tokyo)



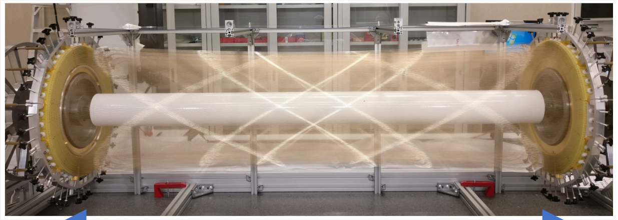

- ✓ $e^+$ turns in the detector region
- ✓ Constant bending radius
- ✓ Low momentum $e^+$ does not enter TC region

## ◘Positron Spectrometer:

- ✓ Superconducting magnet + Drift Chamber + Timing Counter
- ✓ Superconducting magnet & magnetic field measurement: Next talk

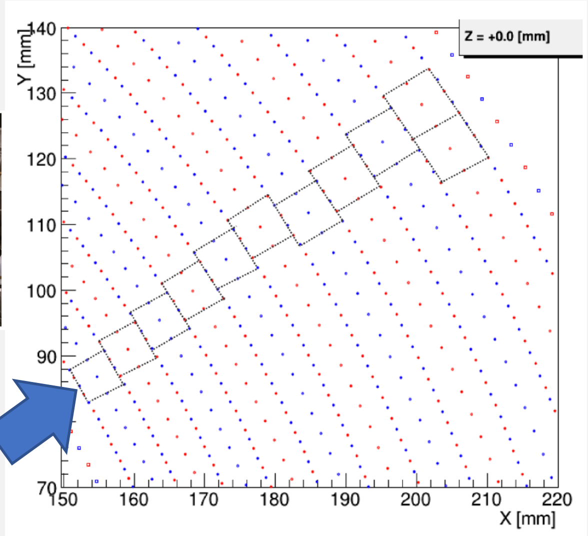
# Positron Spectrometer Detectors

Cylindrical one-volume

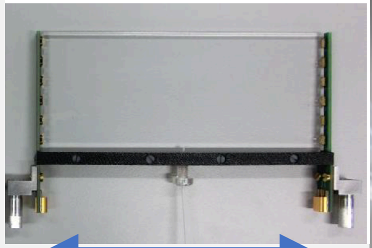


~2 m

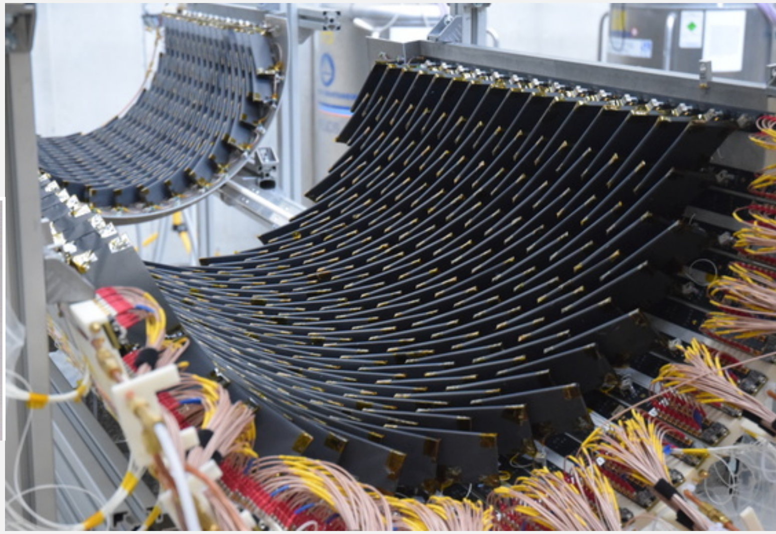
~7 mm square drift cell




Pixelated Scintillation Counter



12 cm



## ◻Drift Chamber (CDCH)

- ✓ Ultra-low mass (90% helium based gas mixture + 10% isobutene) cylindrical drift chamber with stereo wires
- ✓ 192 drift cell (~7mm × 7mm) in each layer
- ✓ The most outer layer was reduced (10 -> 9 layers design) to be on schedule for commissioning
- ✓ Detector construction completed. Detector will be installed in this year.

## ◻Timing Counter (TC)

- ✓ Composed of 512 scintillation counters
- ✓ Each counter has 6-series connected SiPMs on both sides of scintillator (BC 422)
- ✓ Using multiple hit information
- ✓ Cooling system is updated to suppress radiation damage effect (dark current increase)
- ✓ Ready for physics run.

Drift cell & single counter: Baldini, A.M., Baracchini, E., Bemporad, C. et al. Eur. Phys. J. C (2018) 78: 380.
arXiv: arXiv:1801.04688v1 [physics.ins-det]

# Requirement for $e^+$ Spectrometer

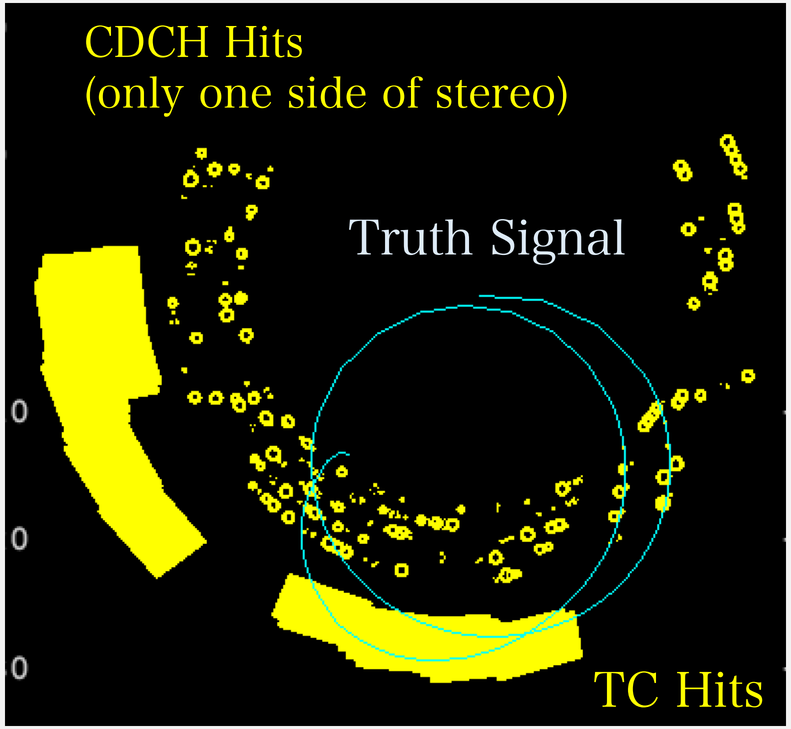
## Upgrade from MEG:

- ✓× 2 **higher beam intensity** : $3 \times 10^7 \rightarrow 7 \times 10^7\ \mu/s$
- ✓× 2 **better detector resolution** : See result page
- ✓× 2 **positron reconstruction efficiency** : 30 % → 70 %

## Challenging

- ✓Background events drastically increased ($BG_{accidental} \propto (Beam\ rate)^2$ )
- ✓3-4 times hit occupancy in CDCH cell compared with MEG case
  - 1.7—0.8 MHz/cell
  - <Nhit> ~ 650 in event in 250 ns
- ✓Higher radiation environment

## Understanding and upgrading more effective analysis are essential to achieve target sensitivity !



# Positron Reconstruction

- ☐Introduction on MEG II experiment
- ☐Performance study on positron spectrometer
  - ✓Overview
  - ✓Analysis review
  - ✓Final result
- ☐Summary and prospect

# Analysis Overview

Track Reconstruction from CDCH hits

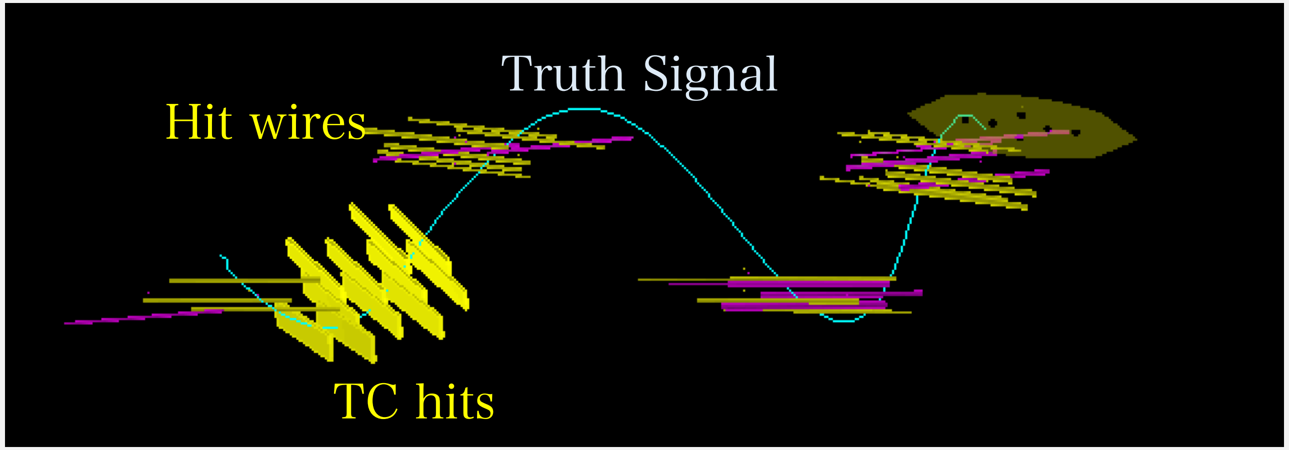
Timing Reconstruction from TC cluster

CDCH-TC Matching & Refinement

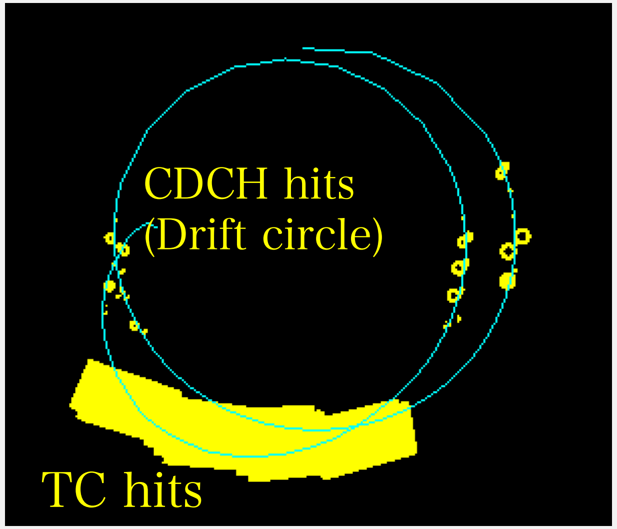
Positron Reconstruction

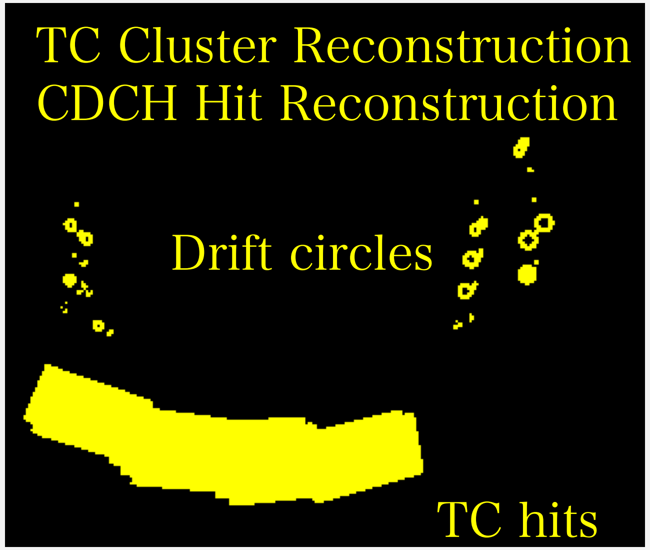
# Positron Reconstruction

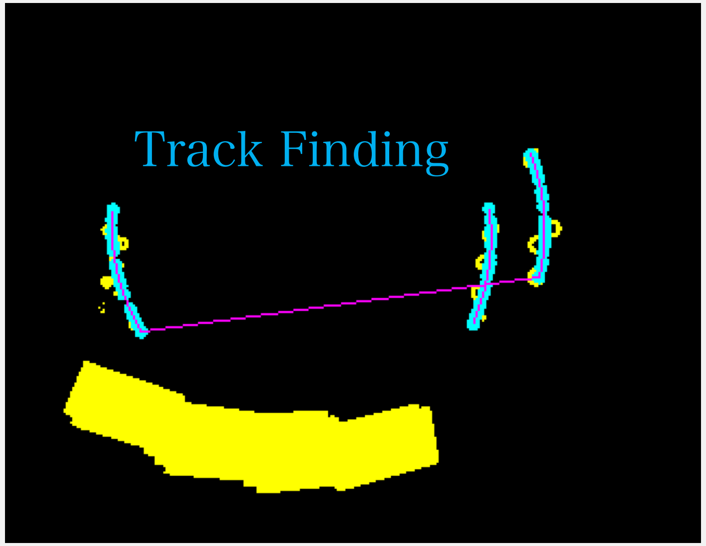
purple wires are not shown in 2D

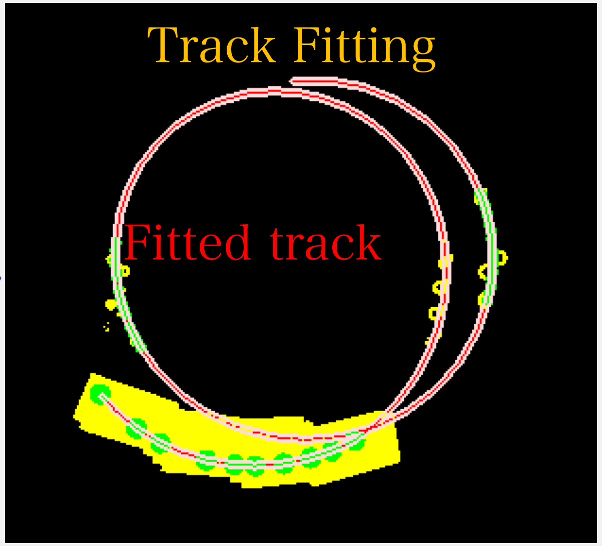



2D Projection



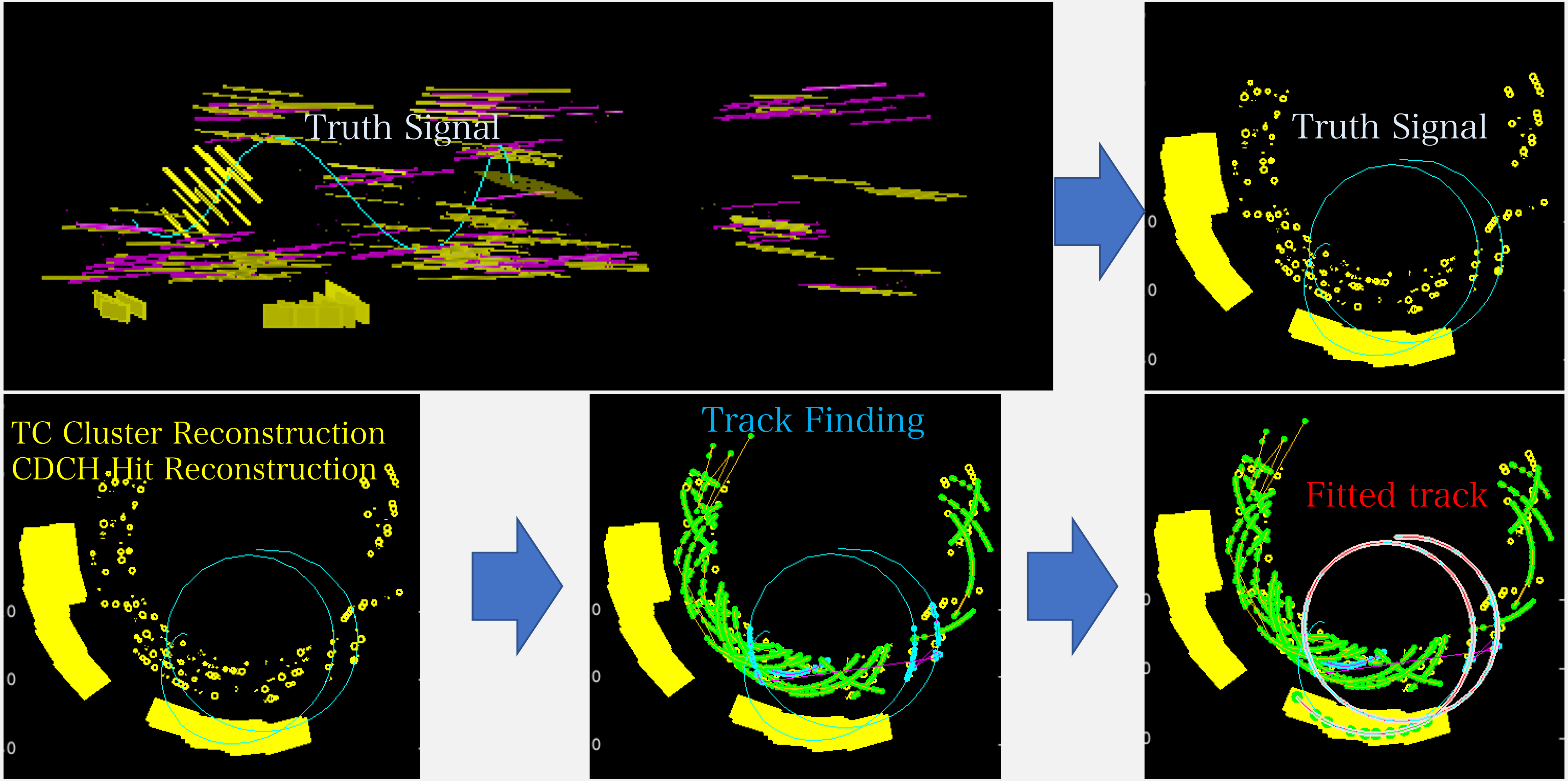



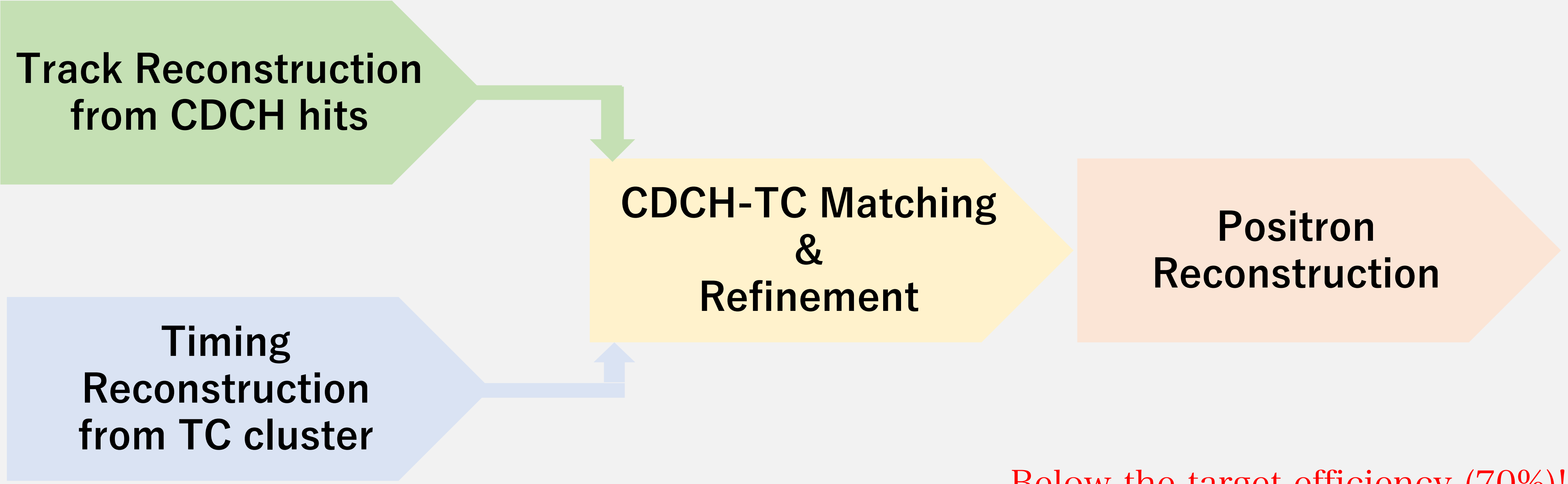



# Positron Reconstruction

Difficulty comes from
- ✓ ~1MHz Hits/cell in CDCH
- ✓ Short track information



# Efficiency @ 2018 Spring




Below the target efficiency (70%)!

<u>Signal only case</u>
Efficiency: 76.4 % @ 10 layer

<u>Signal + Background (BG)</u>
Efficiency: 56.1% @ 10 layer
-> ~50% @ 9 layer
~10% Efficiency loss by reducing layer!

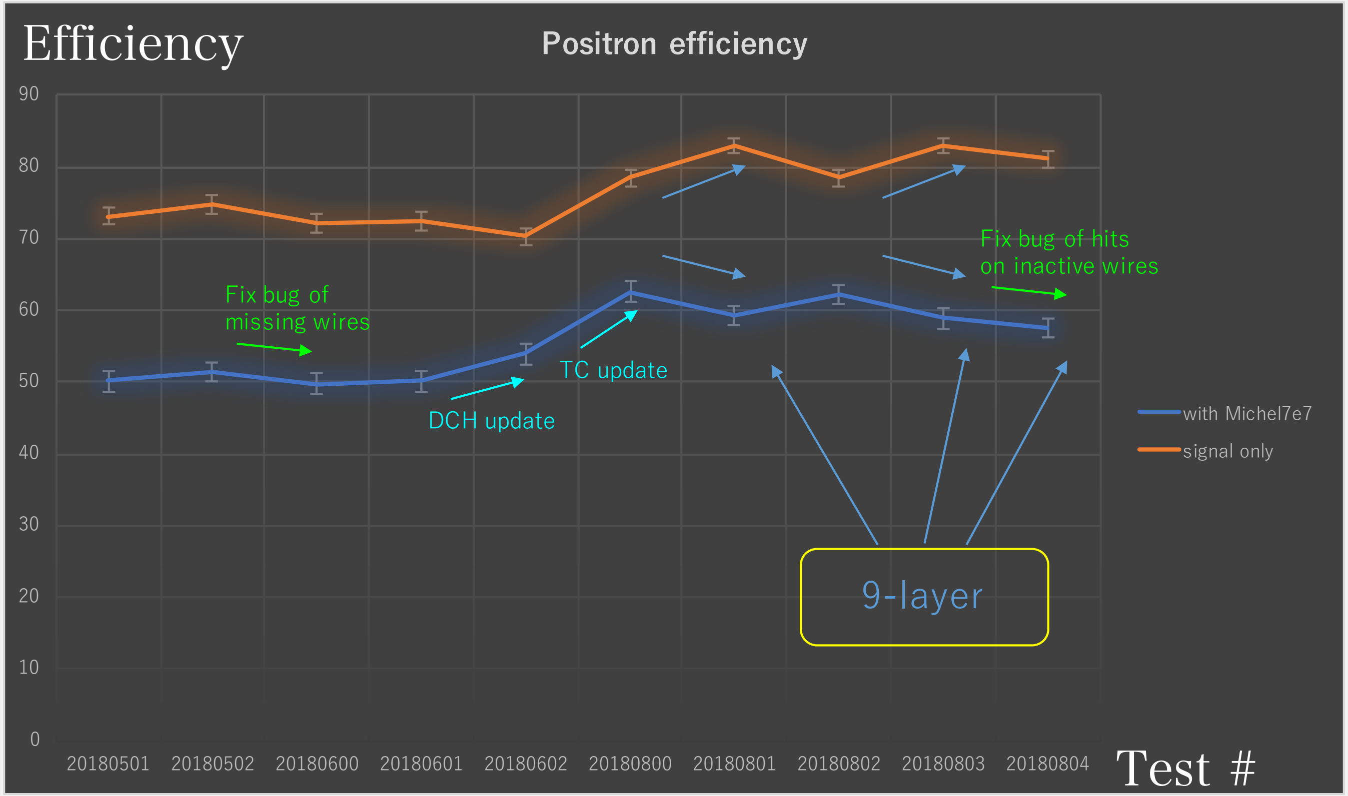
Reference: Positron Timing Measurement to Search for Lepton Flavor Violating Decay in MEG II, Miki Nishimura, May 2018, Doctor thesis (The Univ. of Tokyo)

# Analysis Review

- ☐ Introduction on MEG II experiment
- ☐ Performance study on positron spectrometer
  - ✓ Overview
  - ✓ Analysis review
  - ✓ Final result
- ☐ Summary and prospect

# Updates Summary

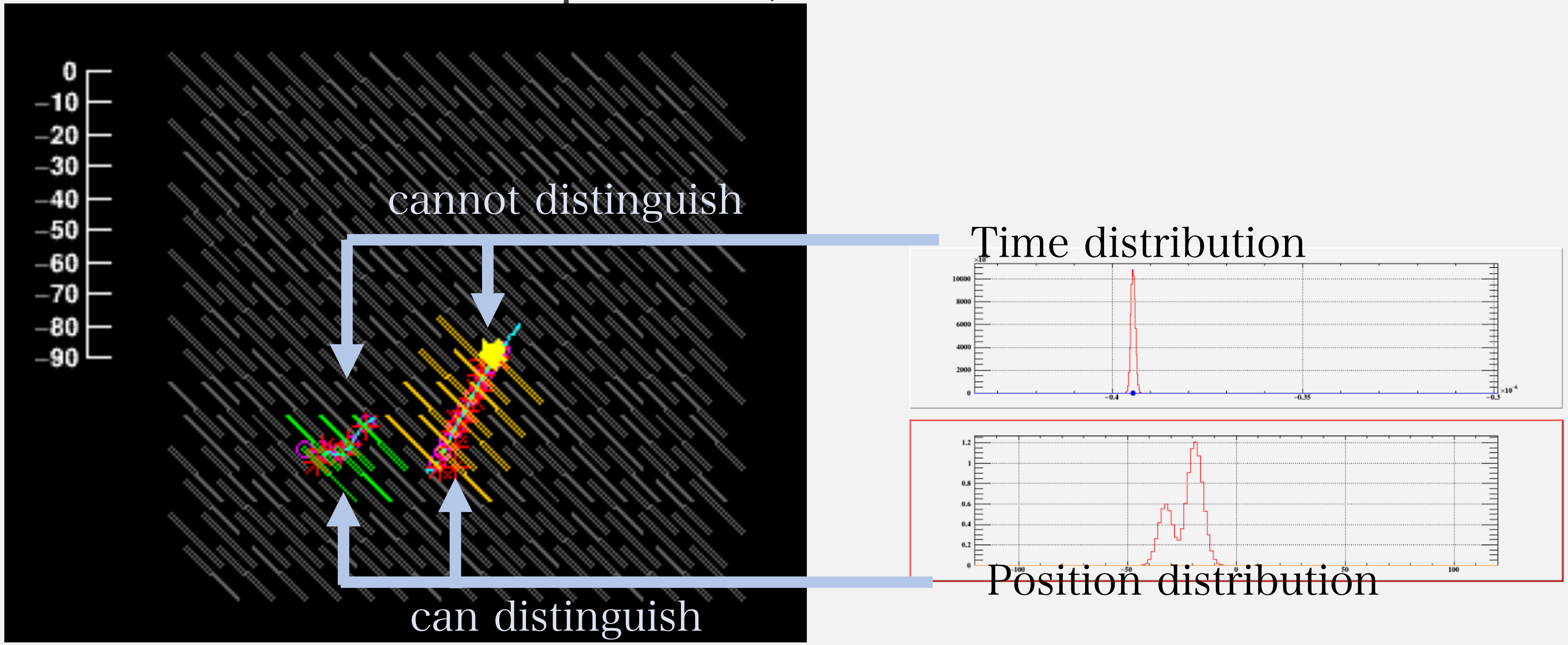
- CDCH tracking reconstruction
  - ✓ 9 layer scheme
  - ✓ Broken wire effect investigation
  - ✓ z reconstruction by time difference
  - ✓ Additional seeding combination
  - ✓ Shared hits comparison in tracks
  - ✓ TOF correction and recalculation
- Information matching
  - ✓ Added Timing information
  - ✓ Backward matching
  - ✓ Refinement
- TC Cluster Reconstruction
  - ✓ Added position information
  - ✓ CDCH independent tracking for seed




- And many more updates during this summer!

# TC Cluster Reconstruction

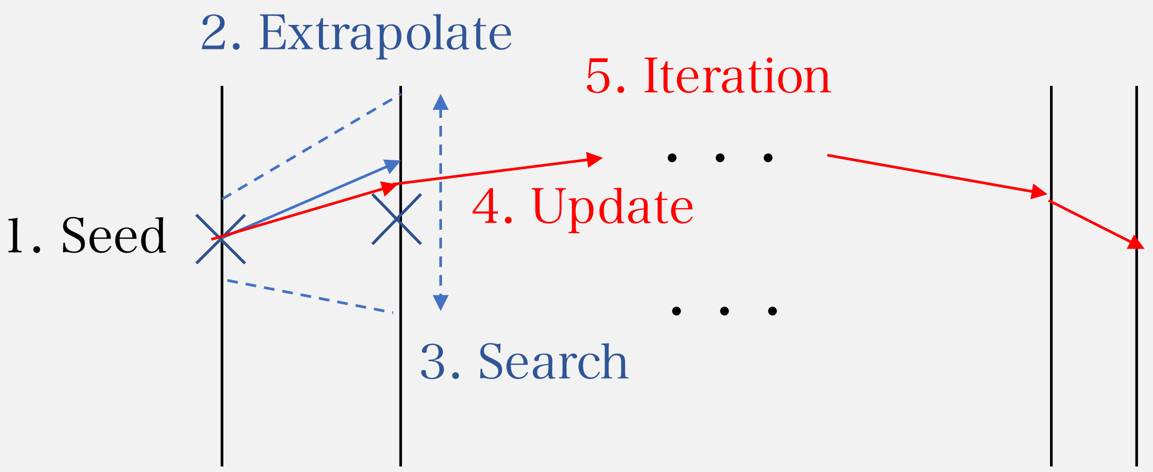
- TC cluster reconstruction was done based on “time”
- This time we added “position information” for criteria
  - ✓Sometimes small radius turn positrons after scattering makes tail events. Based on hit position, we remove those hits.



# Track Reconstruction

- Tracking Strategy: **Local method** (**Track following**) based on Kalman Filter technique
  - ✓ Track is started from track seed
  - ✓ Track is prolongated by Kalman Filter to add hits through layers from seeds
  - ✓ Fit the segments with GENFIT

**Kalman Filter**
Efficient recursive algorithm to estimate the state vector and its covariance matrix based on previous states.
**GENFIT**
A generic toolkit for track reconstruction for experiments in particle and nuclear physics.




About GENFIT: http://genfit.sourceforge.net/Main.html

# Track Reconstruction

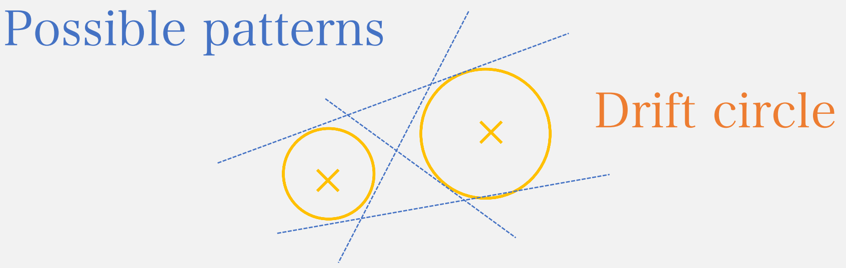


**Basic seed process:**

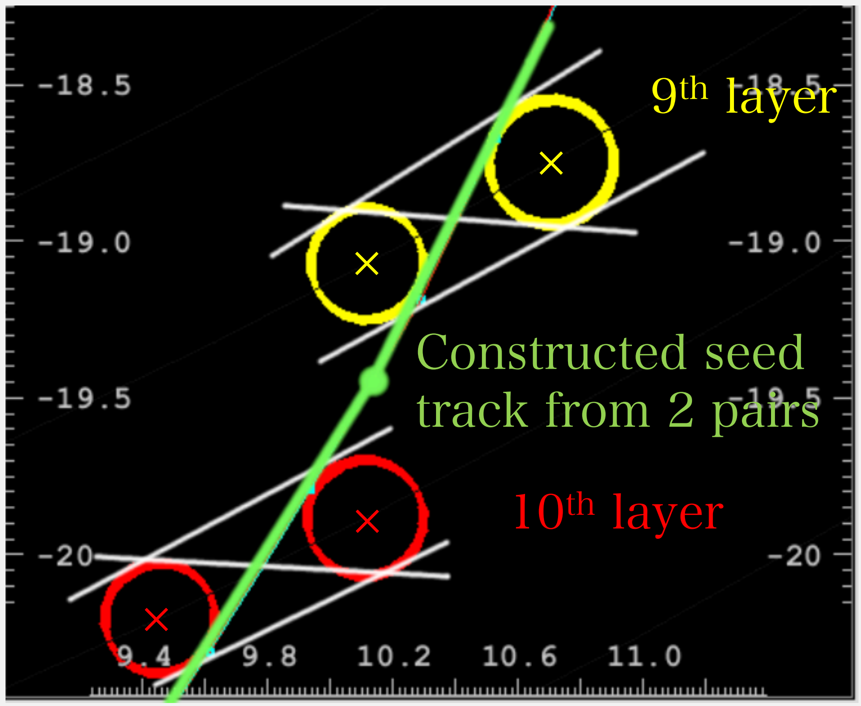
1. Timing from possible TC cluster or nearest 3 wires
2. 2 consecutive hits (pair) in the same layer is picked up
3. 2 pairs from nearest layer is combined
4. Start track following

**Additional seeding patterns**

1. More T0 pattern
2. Seed w/ 2 gap
3. 3 unused wires (Default unused option)
4. Seed from TC cluster track (under development)




4 possible patterns in 1 pair
-> 4 x 4 candidate in 1 seed



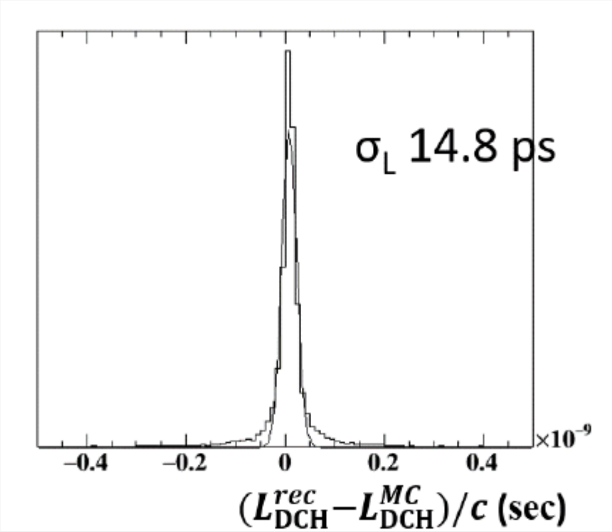

Original: http://cmd.inp.nsk.su/~ignatov/meg2Tracking_Lecce_2016.pdf, 2016 June, Fedor Ignatov

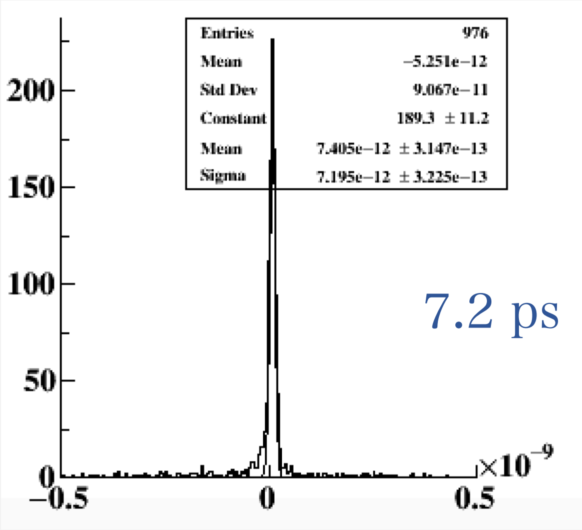
# TOF (Path Length)



- ◻TOF calculation is one of main improvement from MEG
  - ✓75 ps in MEG
  - ✓14.8 ps were reported by MC study in Spring
- ◻We iterated the calculation with smoothed track (used smoothed track trajectory for calculation) and it became ~ 7 ps resolution. × 10 improvement from MEG

2018 Spring



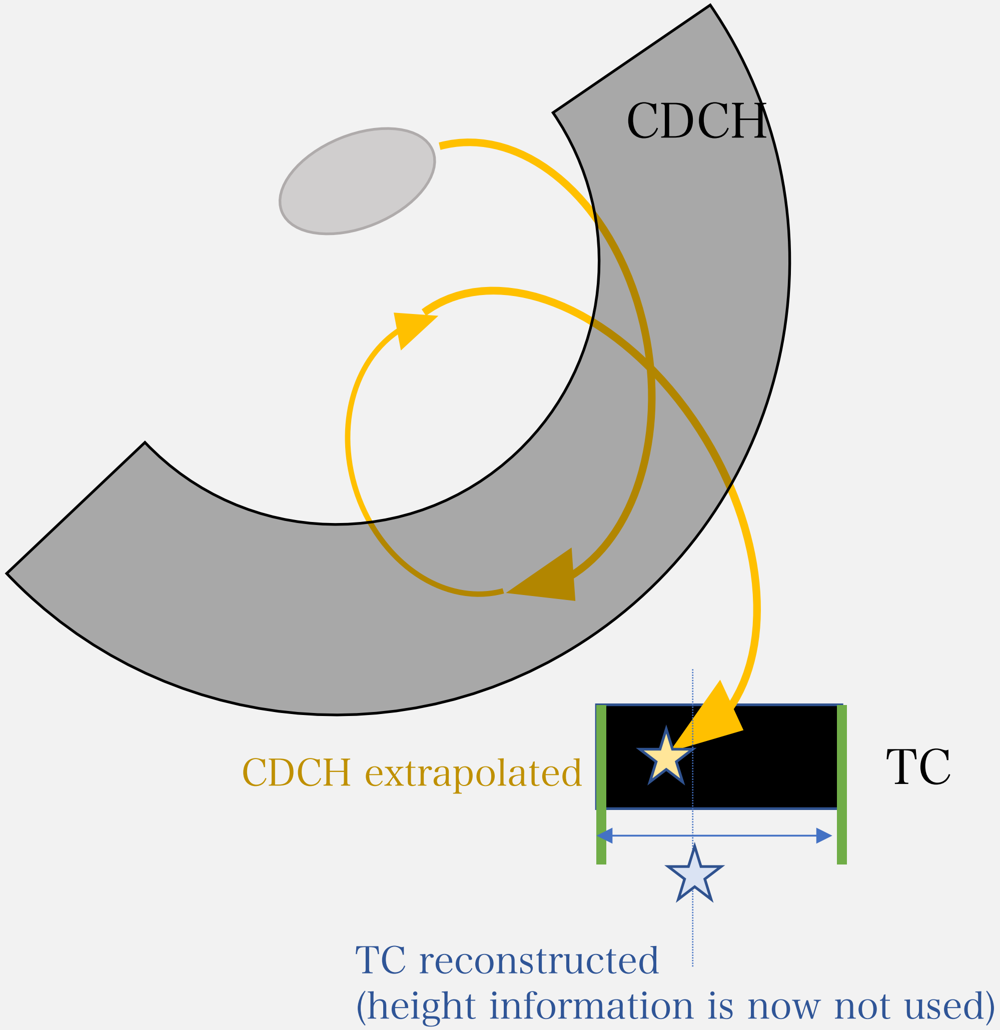




2018 Autumn

Reference: Positron Timing Measurement to Search for Lepton Flavor Violating Decay in MEG II, Miki Nishimura, May 2018, Doctor thesis (The Univ. of Tokyo)

# CDCH-TC Matching

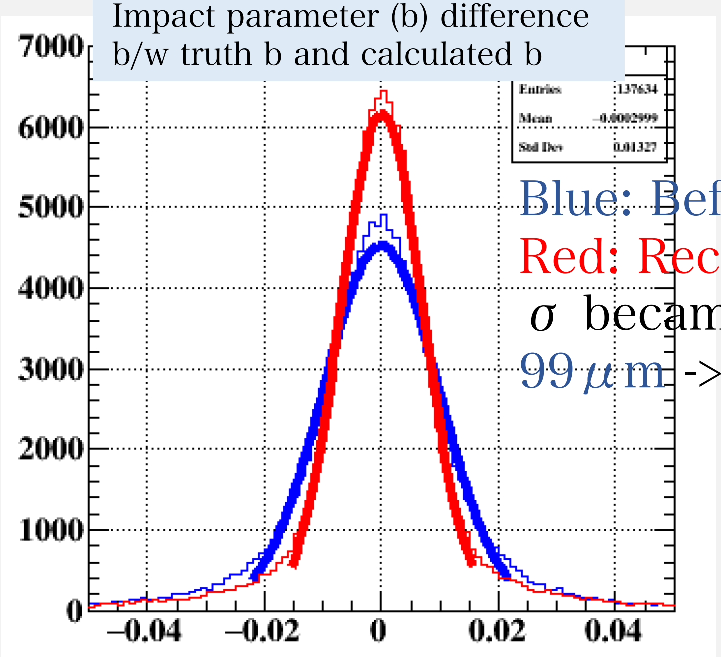
- CDCH track and TC cluster is matched based on extrapolated "position"
  - ✓ $< 5\,\sigma$ difference b/w CDCH and TC
- We also added timing difference b/w tracks and TC for criteria
  - ✓ 15 ns timing window
  - ✓ Roughly ~ **30%** background matching cut, avoid fake matching event



# CDCH-TC Refinement

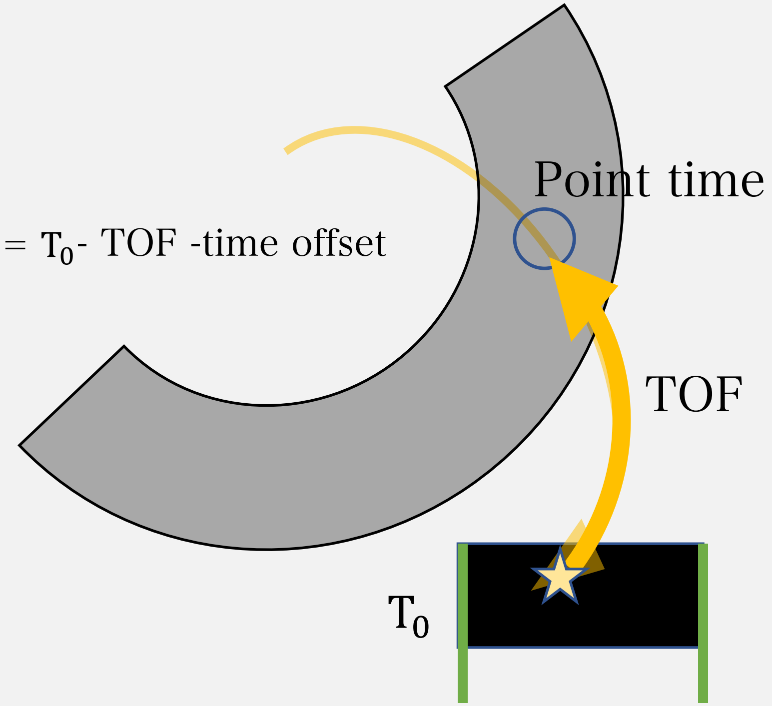
- After matching we recalculate the drift distance based on TOF calculated from CDCH track length and timing from TC cluster
  - ✓More precise drift time can be calculated
- By using more precise drift distance, we can get more precise track
  - ✓Currently we succeed in improving re-calculation of drift distance, but not yet completed the fitting & extrapolation process

Impact parameter (b) difference b/w truth b and calculated b




Blue: Before
Red: Recalculation
$\sigma$ became
99 $\mu$m -> 71 $\mu$m

Point time = $T_0$ - TOF -time offset



# Result

- ☐ Introduction on MEG II experiment
- ☐ Performance study on positron spectrometer
  - ✓ Overview
  - ✓ Analysis review
  - ✓ Result
- ☐ Summary and prospect

# Efficiency and resolutions @2018 Autumn



**Signal only case**
Efficiency: 76.4%
10 layer configuration

↓

**Signal only case**
Efficiency: 80±1%
9 layer configuration

**Signal + BG**
Efficiency: 56.1% (~50%)
10 (9) layer configuration

↓

**Signal + BG**
Efficiency: 60±1%
9 layer configuration

- Though CDCH layer was reduced, **60±1%** efficiency was obtained from analysis development.
  - ✓Better efficiency is expected by…
    - More seeding pattern (from TC cluster track)
    - Hit reconstruction optimization, additional global track finding etc…

# Resolutions



| Positron Resolution | MEG | Design (10 layer) | Updated (9 layer) |
|---|---|---|---|
| Theta (mrad) | 9.4 | 5.3 | 5.9 |
| Phi (mrad) | 8.7 | 3.7 | 5.3 ※A |
| Momentum (keV) | 380 | 130 | 83 |
| Vertex Z (mm) | 2.4 | 1.6 | 1.3 |
| Vertex Y (mm) | 1.2 | 0.7 | 0.72 |
| Positron time (ps) | 108 | 46 | 49 ※B |

※A. Correction based on theta and phi correlation is not applied, though expected value include it.
※B. 1 year radiation damage effect is roughly simulated, w/o cooling condition. $\sigma(T_{calib})$ ~10 ps, $\sigma(T_{WDB\_sync})$ ~25 ps is added.
(Baldini, A.M., Baracchini, E., Bemporad, C. et al. Eur. Phys. J. C (2018) 78: 380. )

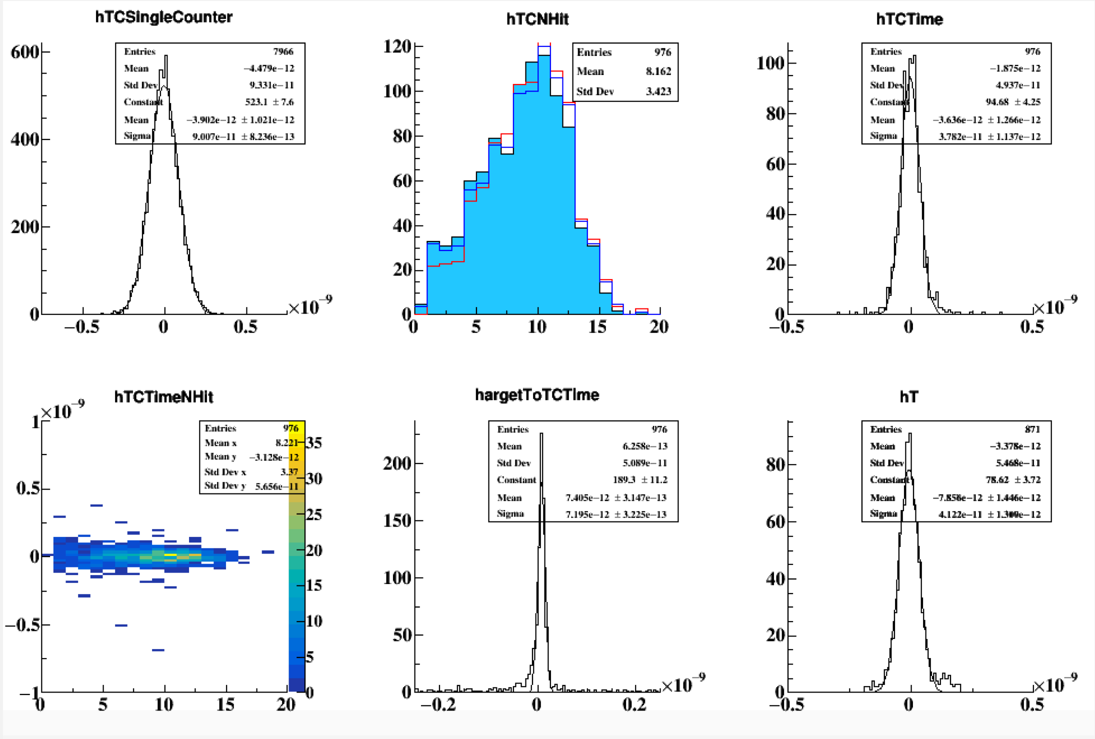
- ◻Good resolutions were obtained compared with expected values
- ◻Better resolution is expected from…
  - ✓Tracking: Iteration fitting with re-calculated drift distance etc…

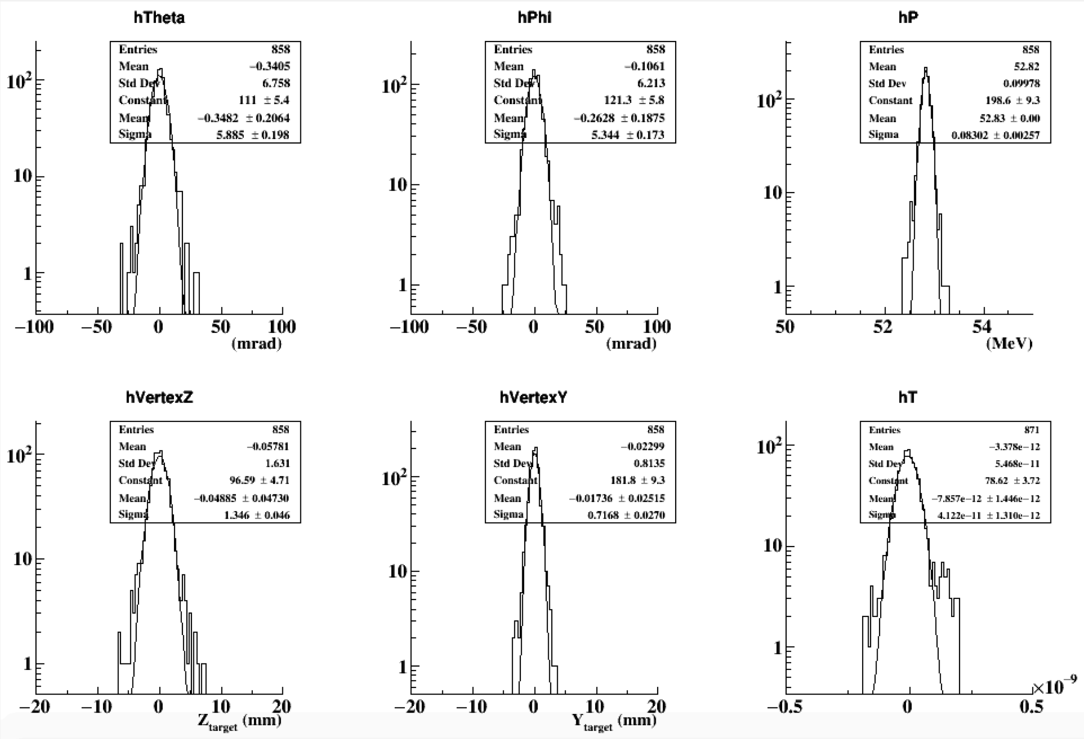
# Summary & Prospect

- Positron spectrometer
  - ✓Detectors are ready for commissioning in this winter
  - ✓CDCH+TC positron reconstruction algorithms are being developed, aiming at 70% reconstruction efficiency (designed value)
  - ✓Currently we simulated 60±1% efficiency with 9 layer CDCH
    - Great progress & encouraging result in each reconstruction step during this summer by positron analysis group!
- To improve the reconstruction efficiency, what can we do?
  - ✓Additional seeding pattern (TC tracking w/o CDCH information)
  - ✓Try global pattern recognition methods in addition to local method
  - ✓Re-calculation of drift distance, iterate the fitting process
  - ✓Hit reconstruction optimization etc….

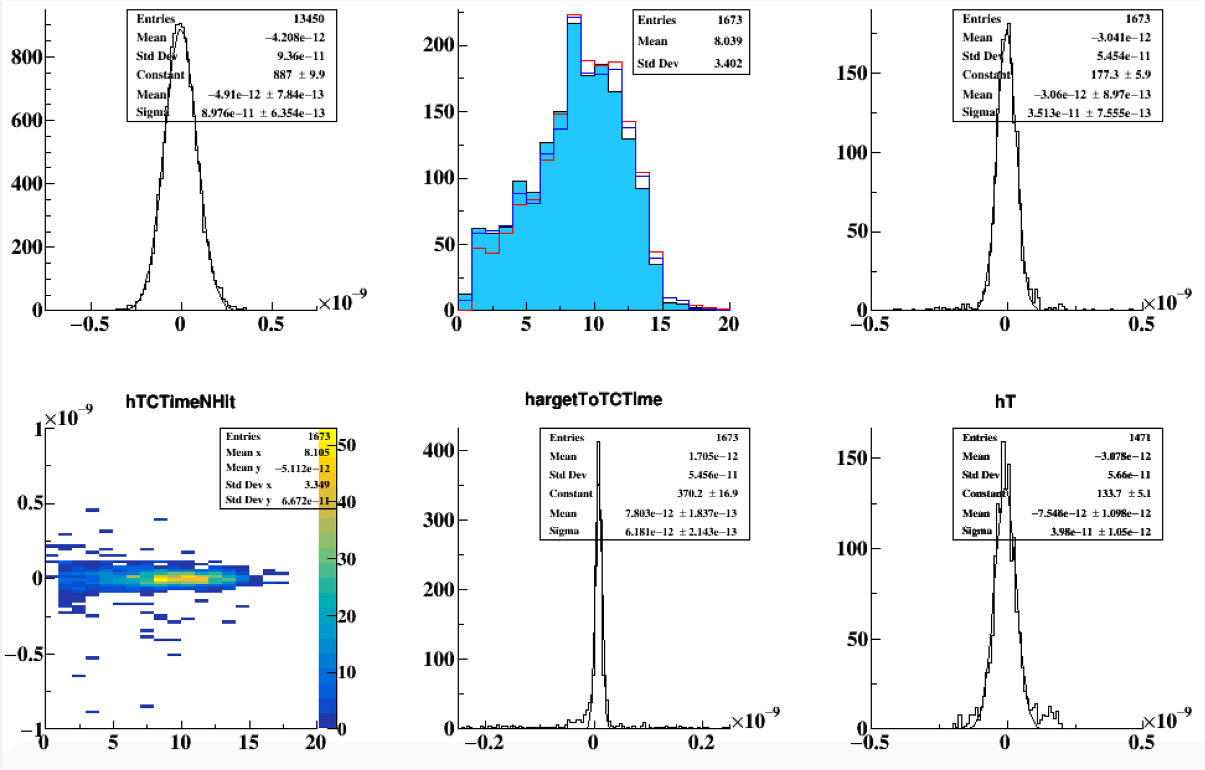
# Backup

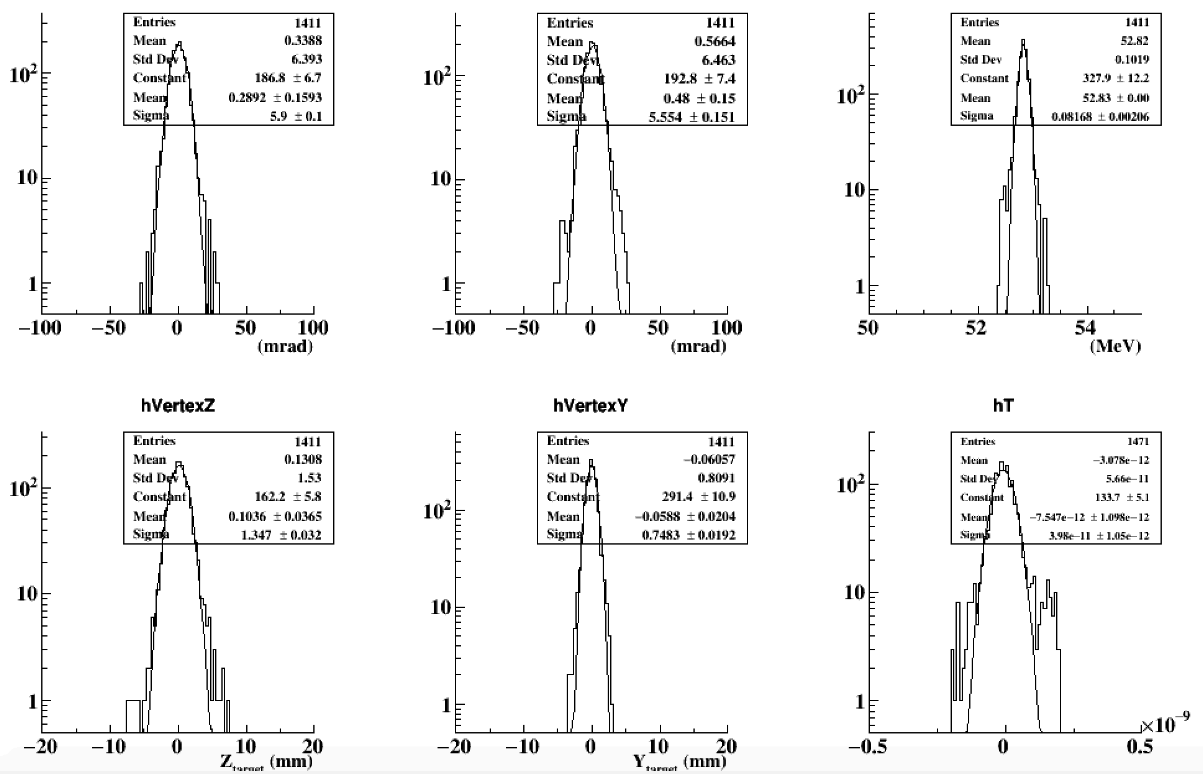
# Resolution Histograms



# 10 Layer


Entries 13450
Mean −4.208e−12
Std Dev 9.36e−11
Constant 887 ± 9.9
Mean −4.91e−12 ± 7.84e−13
Sigma 8.976e−11 ± 6.354e−13
Entries 1673
Mean 8.039
Std Dev 3.402
Entries 1673
Mean −3.041e−12
Std Dev 5.454e−11
Constant 177.3 ± 5.9
Mean −3.06e−12 ± 8.97e−13
Sigma 3.513e−11 ± 7.555e−13
hTCTimeNHit
Entries 1673
Mean x 8.105
Mean y −5.112e−12
Std Dev x 3.349
Std Dev y 6.672e−11
hargetToTCTime
Entries 1673
Mean 1.705e−12
Std Dev 5.456e−11
Constant 370.2 ± 16.9
Mean 7.803e−12 ± 1.837e−13
Sigma 6.181e−12 ± 2.143e−13
hT
Entries 1471
Mean −3.078e−12
Std Dev 5.66e−11
Constant 133.7 ± 5.1
Mean −7.548e−12 ± 1.098e−12
Sigma 3.98e−11 ± 1.05e−12


Entries 1411
Mean 0.3388
Std Dev 6.393
Constant 186.8 ± 6.7
Mean 0.2892 ± 0.1593
Sigma 5.9 ± 0.1
(mrad)
Entries 1411
Mean 0.5664
Std Dev 6.463
Constant 192.8 ± 7.4
Mean 0.48 ± 0.15
Sigma 5.554 ± 0.151
(mrad)
Entries 1411
Mean 52.82
Std Dev 0.1019
Constant 327.9 ± 12.2
Mean 52.83 ± 0.00
Sigma 0.08168 ± 0.00206
(MeV)
hVertexZ
Entries 1411
Mean 0.1308
Std Dev 1.53
Constant 162.2 ± 5.8
Mean 0.1036 ± 0.0365
Sigma 1.347 ± 0.032
$Z_{target}$ (mm)
hVertexY
Entries 1411
Mean −0.06057
Std Dev 0.8091
Constant 291.4 ± 10.9
Mean −0.0588 ± 0.0204
Sigma 0.7483 ± 0.0192
$Y_{target}$ (mm)
hT
Entries 1471
Mean −3.078e−12
Std Dev 5.66e−11
Constant 133.7 ± 5.1
Mean −7.547e−12 ± 1.098e−12
Sigma 3.98e−11 ± 1.05e−12

# 10 Layer vs. 9 Layer @ Autumn

| Positron Resolution | Design (10 layer) | Updated, 3000eve (10 layer) | Updated,2000eve (9 layer) |
|---|---|---|---|
| Theta (mrad) | 5.3 | 5.9 | 5.9 |
| Phi (mrad) | 3.7 | 5.6 | 5.3 ※A |
| Momentum (keV) | 130 | 82 | 83 |
| Vertex Z (mm) | 1.6 | 1.3 | 1.3 |
| Vertex Y (mm) | 0.7 | 0.75 | 0.72 |
| Positron time (ps) | 46 | 48 | 49 ※B |

65±1%
10 layers -> 9 layers: -8% effect