荷電レプトンフレーバを破る $\pi^0 \to \mu e$崩壊探索実験の提案

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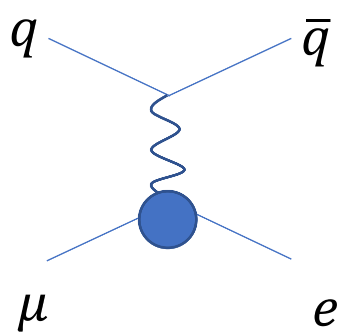
Outline

- $\pi^0 \to \mu e$ decay
  - Overview
  - P0EM experiment
  - Signal and BG
- Expected experimental setup
  - MEG II experiment
  - Detector: CDCH
  - Target: LH2 target
- Current status of P0EM experiment
- Detection efficiency
  - Optimize LH2 target size
  - Signal selection
  - Trigger DAQ
- Summary & prospects

$\pi^0 \to \mu e$ decay

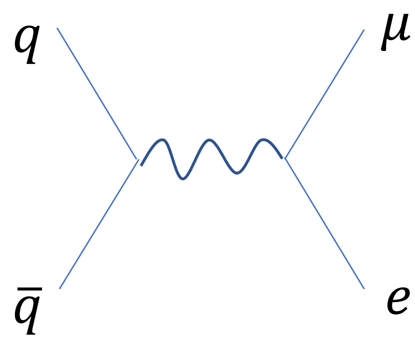
- $\pi^0 \to \mu^+ e^-$ decay violates charged lepton flavour
- The decay is similar to $\mu - e$ conversion, which is one mode of charged lepton flavour violation (cLFV)

$\mu - \mathrm{e}$ conversion



- Present upper limit on the decay: 3.63 x 10^{-10} (90% C.L.) [1]
- This limit is given by KTeV experiment at Fermilab in 2008 as a by-product of kaon rare decay search [2]

$\pi^0 \to \mu e$



References:

[1] 2018 PDG

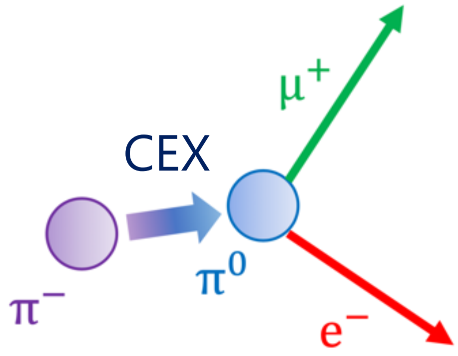
[2] "Search for Lepton-Flavor-Violating Decays of the Neutral Kaon", Phys. Rev. Lett. (2008) 100:13

P0EM experiment

- P0EM experiment: Experiment to search for $\pi^0 \rightarrow \mu^+ e^-$ decay at Paul Scherrer Institut (PSI) in Switzerland

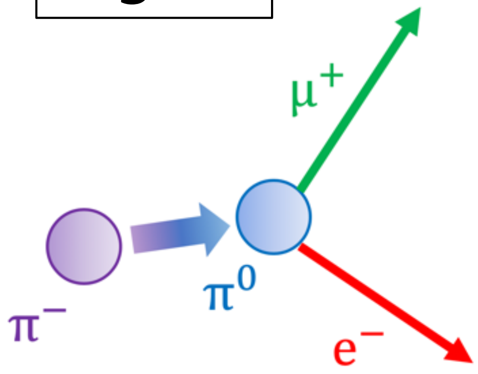
- The advantages over previous searches are:
  - High statistics
    - 1.4 x 10^6 π^-/s are incident on liquid hydrogen (LH2) target
    - ~60% π^- generates π^0 by charge exchange (CEX) process ($\pi^- + p \rightarrow \pi^0 + n$) in LH2

    → ~10^{11} π^0 are generated in one day
  - Low background
    - Source of μ^+ would not exist

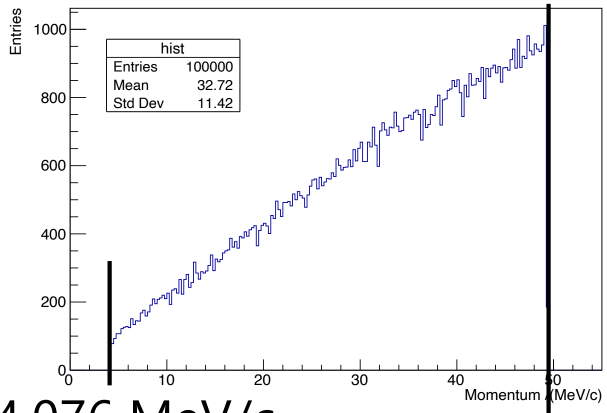


Signal & Background

Signal



μ^+ momentum



4.076 MeV/c

49.30 MeV/c

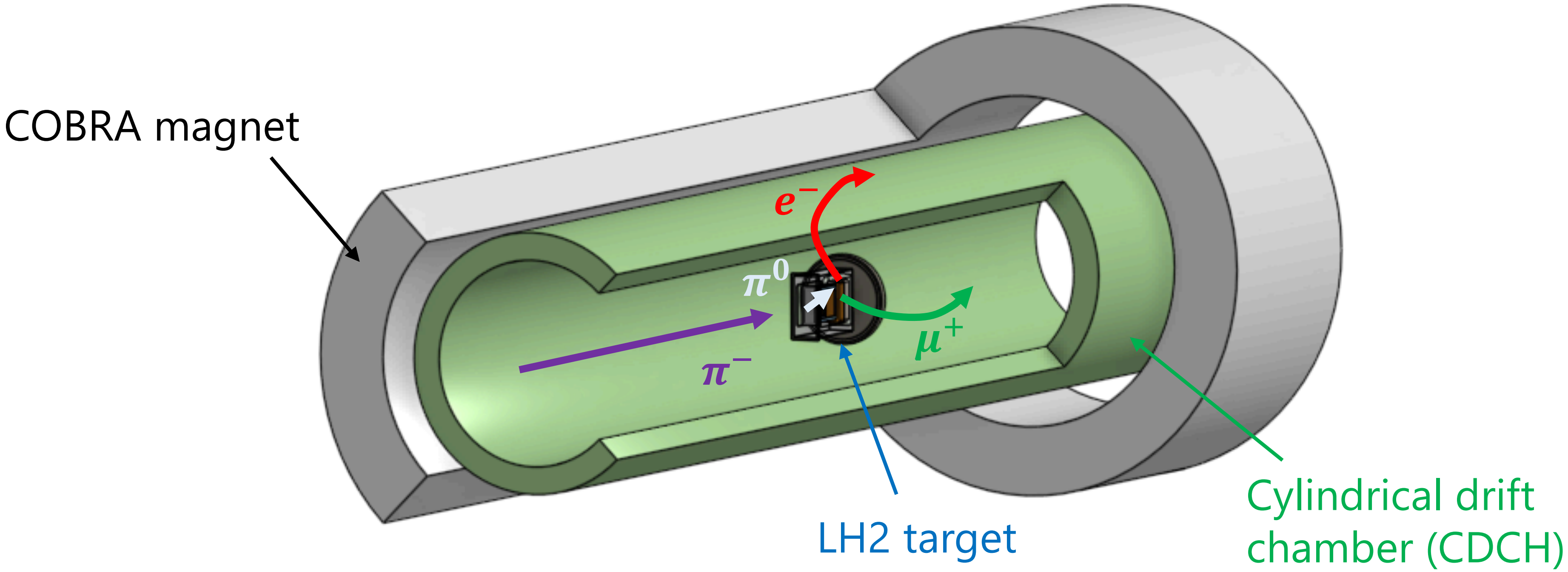
Background

- e from scattering, $\pi^0 \to e^+e^-\gamma$ decay, or pair production
- μ^- from π^- decay in flight
- p from π^- interaction w/ nuclei
  - Elastic or inelastic scattering:
    $\pi^- + N \to \pi^- + N$ (or N')
  - Absorption:
    $\pi^- + N \to N' +$ several nuclei

Distinguish signal μ^+ from BG by energy deposit and trajectory

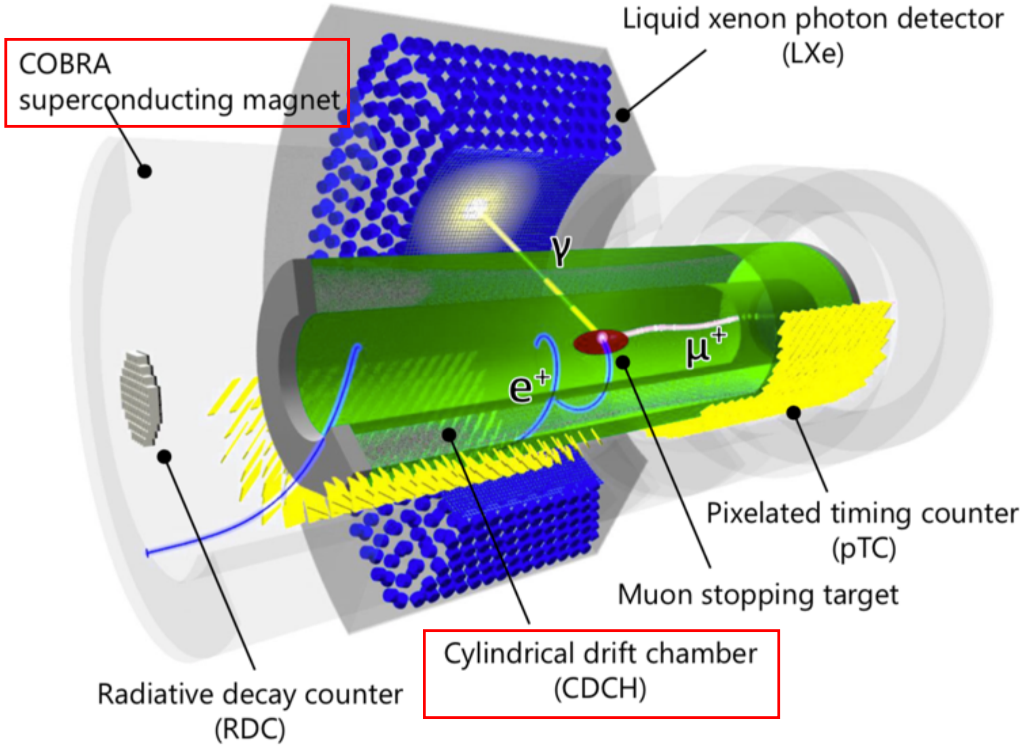
Expected experimental setup

- High-intensity π^- beam at PSI
- Target is liquid hydrogen
- Detector for signal μ^+ from $\pi^0 \to \mu^+ e^-$ decay is cylindrical drift chamber (CDCH) used in MEG II
- COBRA magnet used in MEG II is used for bending charged particles



MEG II experiment

- MEG II searches for $\mu \to e\gamma$ decay which is one of cLFV
- Use the most intense μ beam
- P0EM experiment will be a parasite on MEG II
- P0EM will use CDCH and COBRA magnet w/ 0.8 magnetic field scale factor
- COBRA magnet is developed for bending MEG II signal e^+ w/ constant radius
- Charge can be identified by particles' trajectory bent by magnetic field

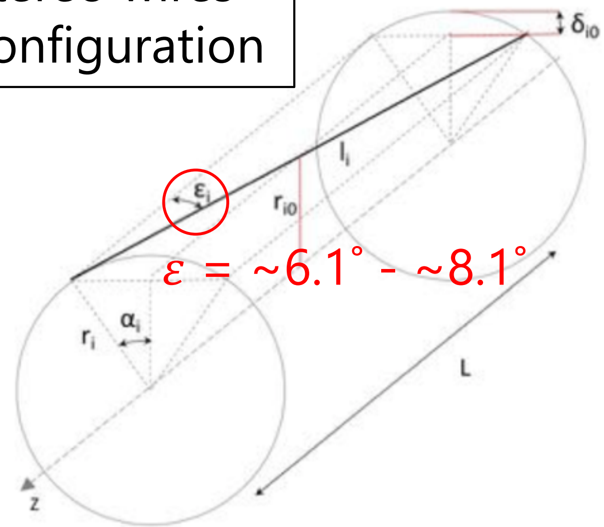


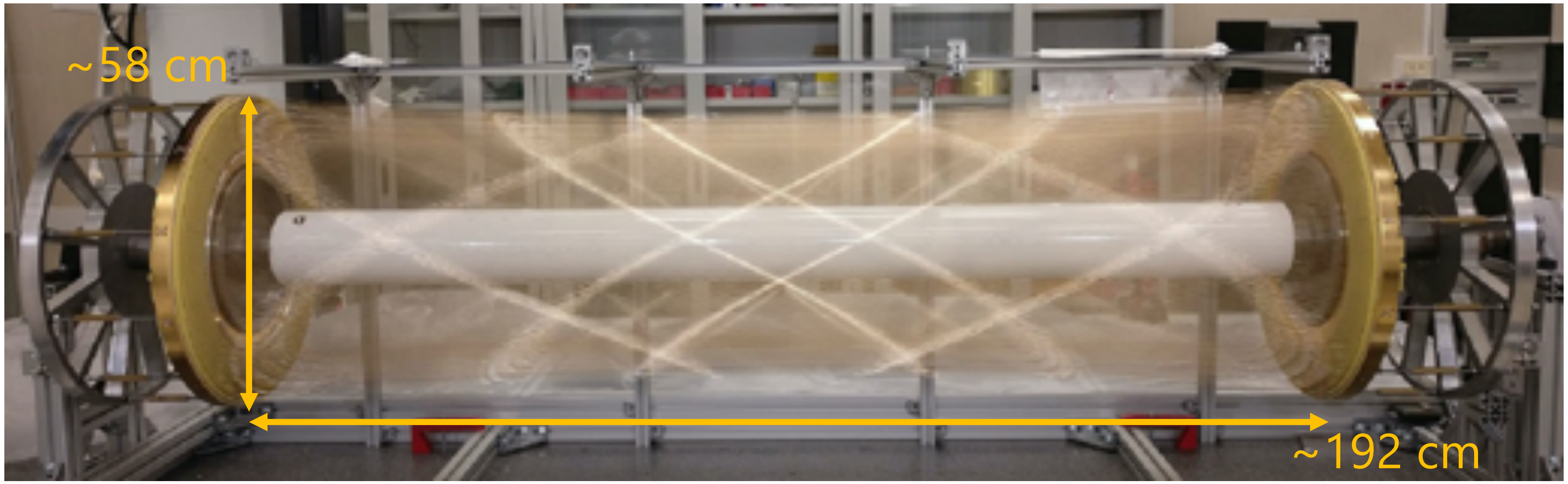
Reference:
"The design of the MEG II experiment",
Eur. Phys. J. C (2018) 78:38

Cylindrical drift chamber (CDCH)

- CDCH has been developed for measuring trajectory and momentum of MEG II signal e^+
- The features are the following:
  - 1,728 sense wires (= 192 wires/layer x 9 layers)
  - Stereo wires configuration
  - Gas choice: He:isobutane = 90:10
- Readout from 2/3 wires
- The performance study is in progress

Stereo wires configuration





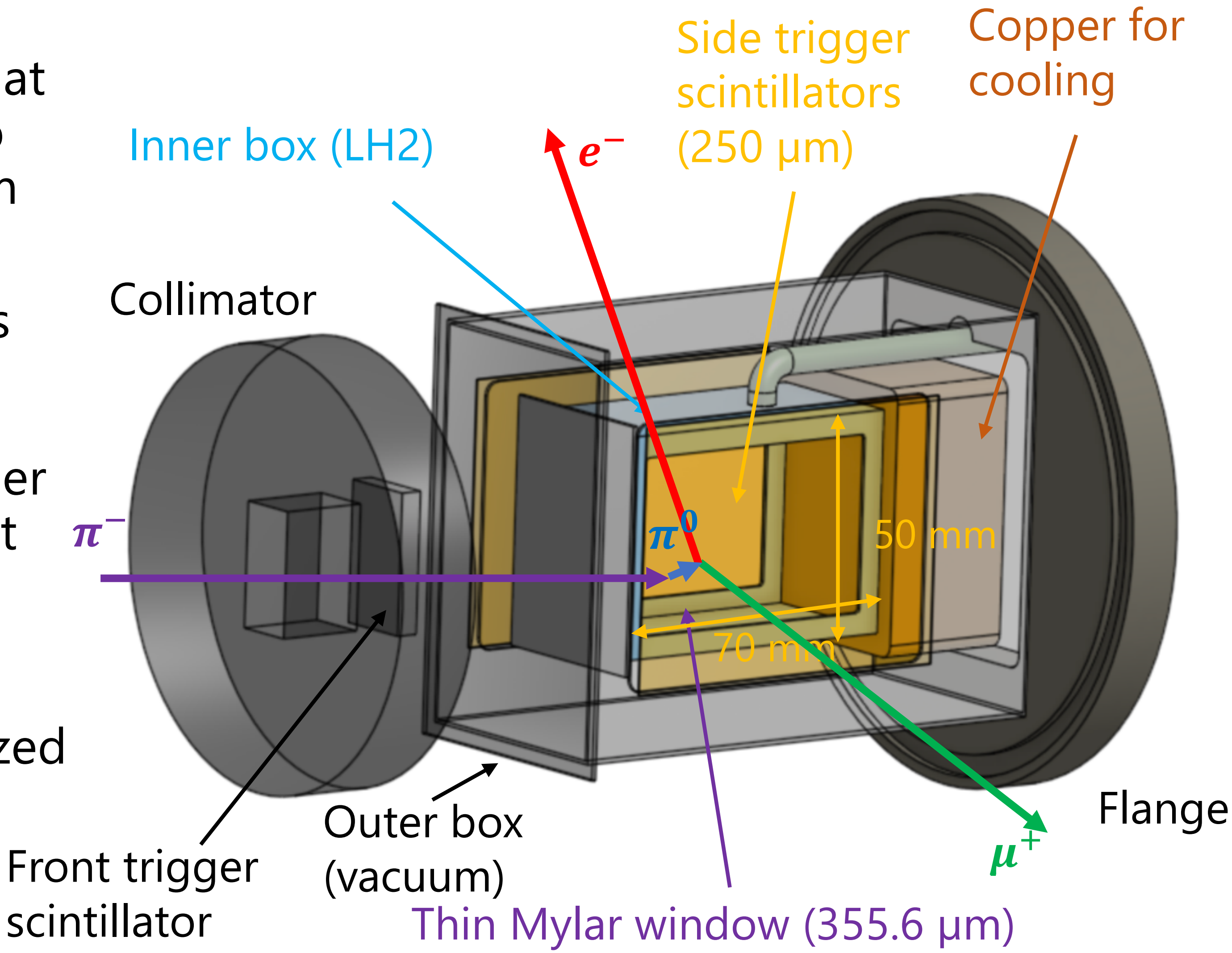
Liquid hydrogen (LH2) target

- Most signal μ^+ stop at target frames due to their low momentum (<50 MeV/c)

→ Thin Mylar windows

- Scintillators for trigger in front of LH2 target and at both sides

- Target size is optimized by μ^+ detection efficiency in CDCH



Current status

- Plan to start P0EM experiment
  - Examine $\pi^0 \to \mu e$ decay
  - Experimental setups

Done

- Estimate sensitivity ← Need to know efficiency
  - Optimize LH2 target
  - Signal selection
  - Trigger DAQ
  - Sensitivity

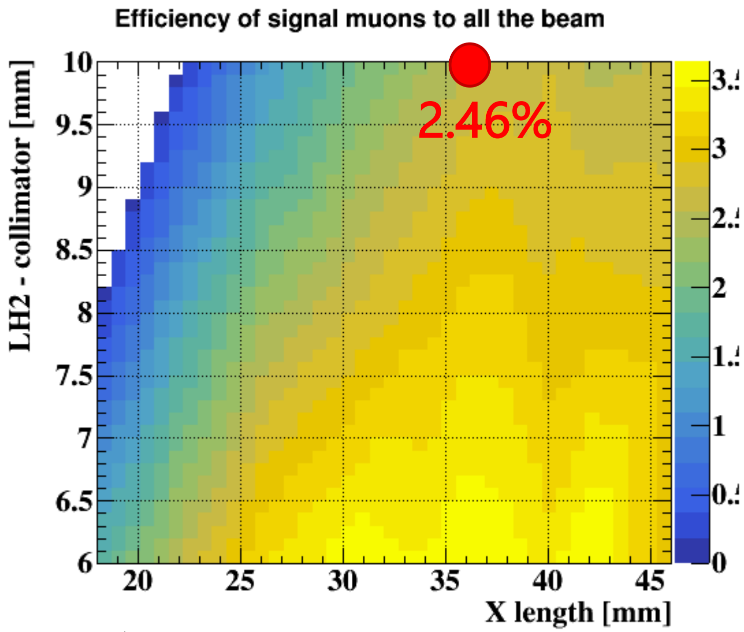
Today's topics

- Prepare LH2 target
- Construct analysis method
- Do beam test at PSI

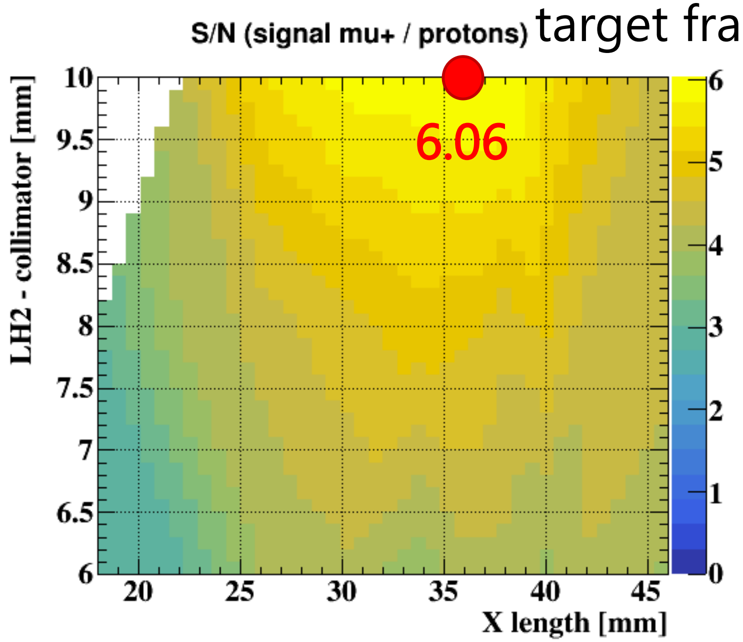
Optimize target size

Detection =
3 or more hits in CDCH

Collimator window is smaller



Less π^- interact in target frames



More π^- stop at collimator

More μ^+ stop in LH2

- 36.0% π^- generate π^0 by CEX
- 14.9% signal μ^+ exit from LH2 target out of π^0
- 45.9% signal μ^+ are detected in CDCH out of exiting μ^+

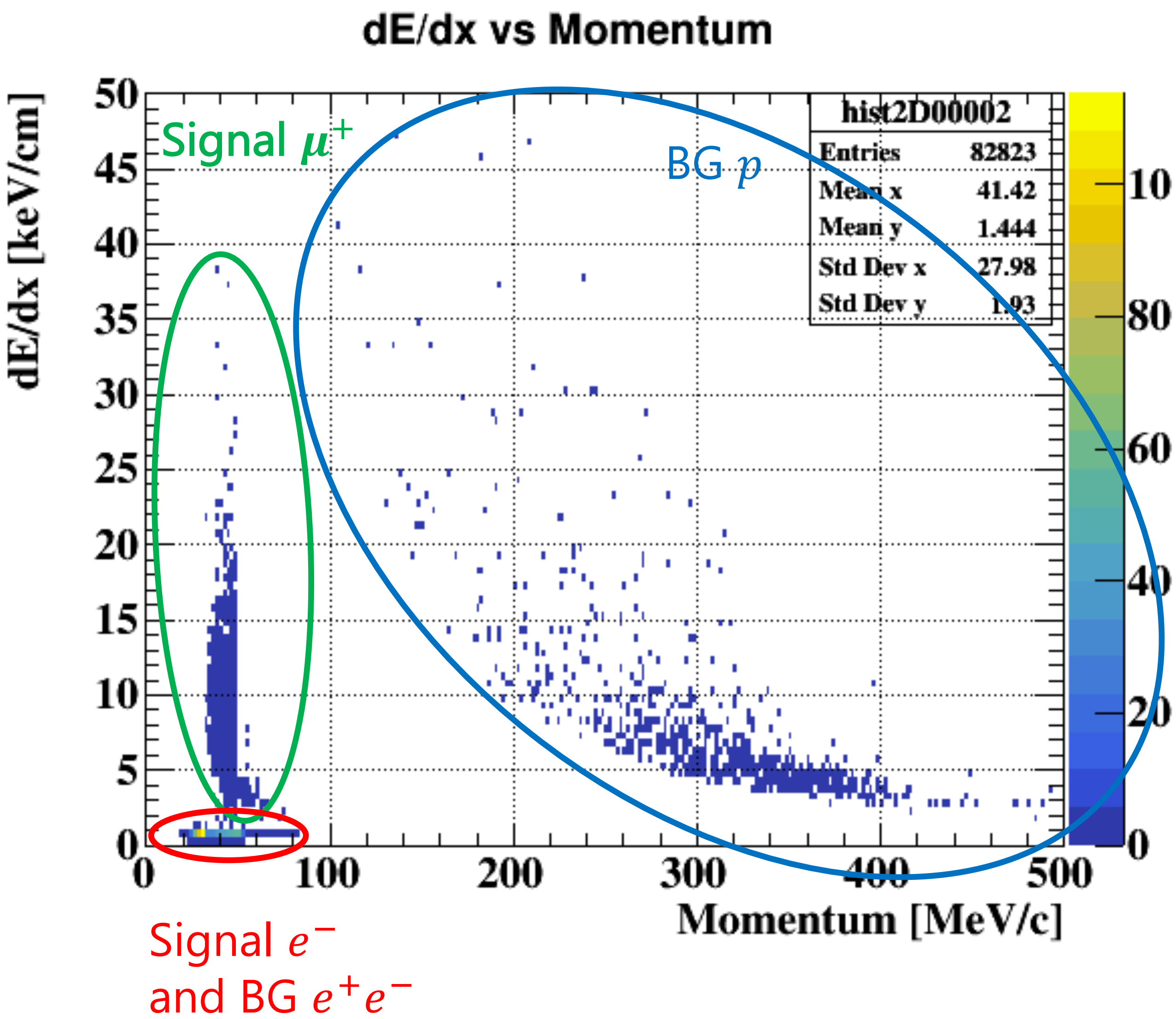
X length of LH2 target = 36 mm
→ **μ^+ detection efficiency = 2.46%**
out of all the π^- beam

Signal selection in analysis (1/2)

- Cut tracks whose initial position is out of LH2 target

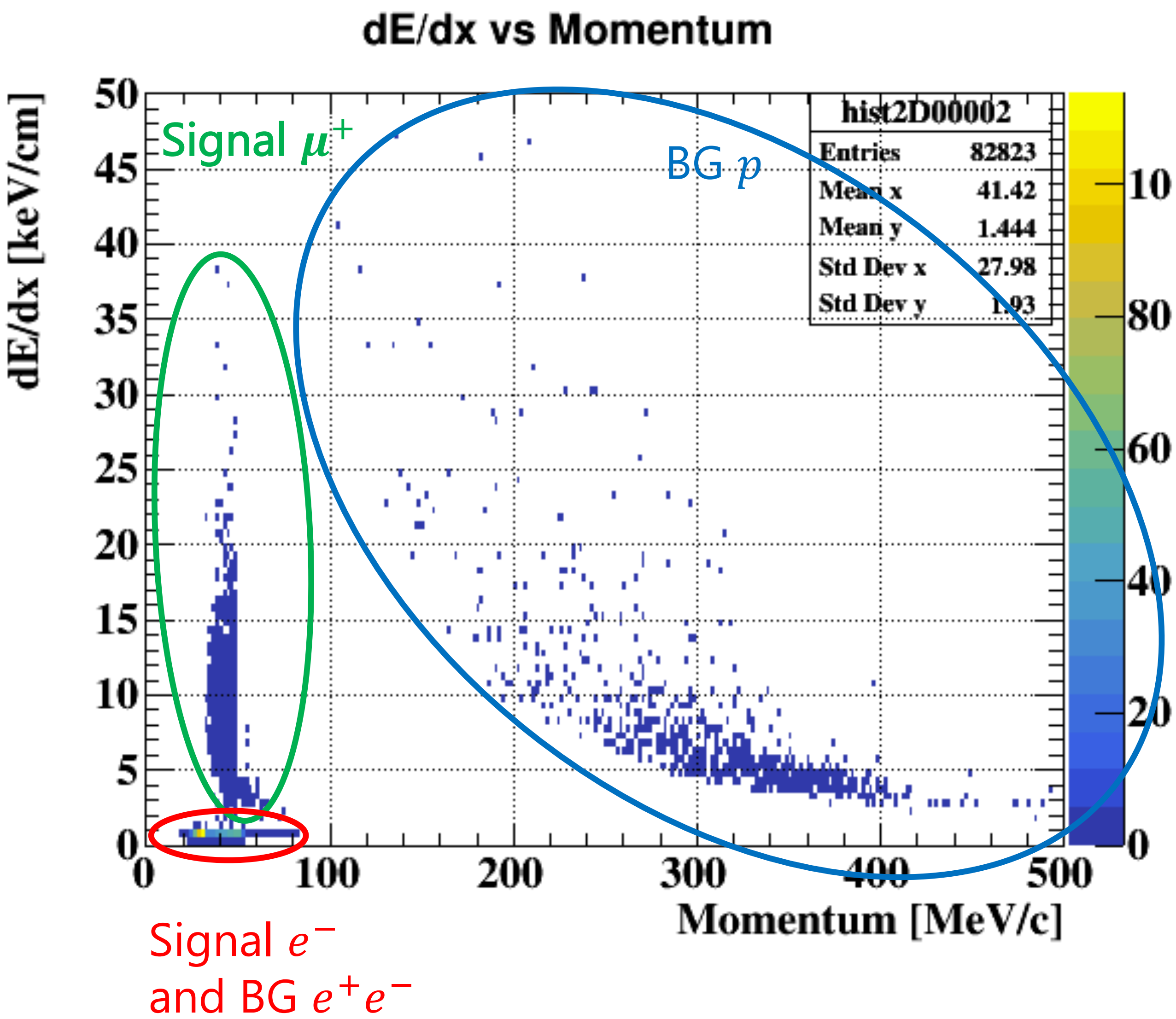
← It has no influence on μ^+ detection efficiency due to no cut of signal μ^+ tracks

- dE/dx is calculated by energy deposit in CDCH divided by track length
- Uncertainty of track length and of energy deposit?



Signal selection in analysis (2/2)

- Momentum will be calculated by rotation radius of the track
- Charge of particles can be identified by reconstructed tracks orientation
- Signal μ^+ can be identified in CDCH



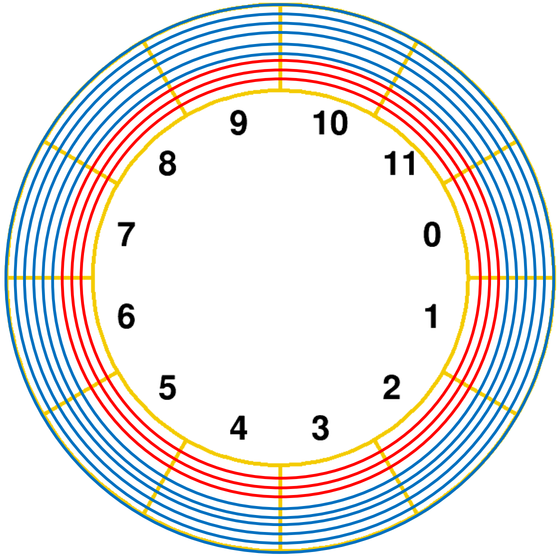
Trigger DAQ

- P0EM plans to use MEG II DAQ system
- MEG II DAQ rate ~ 10 Hz → Rough idea in P0EM

- Trigger conditions requirements:
  - Easy construction of online logic
  ← Reconstructed information cannot be used

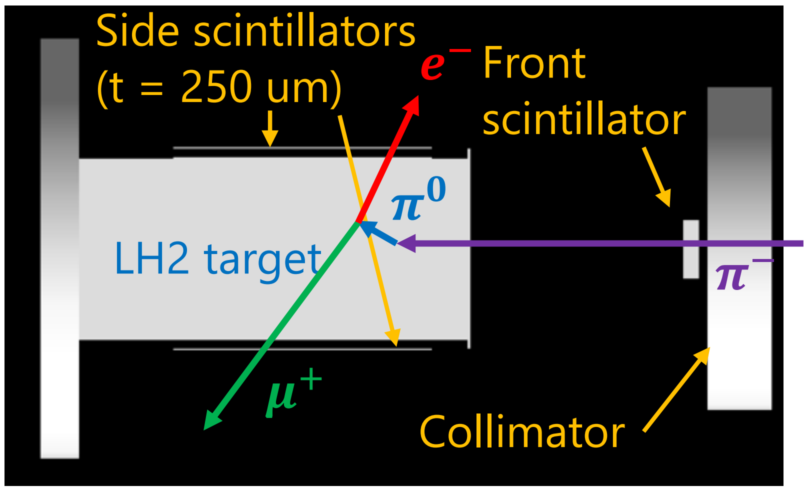
  - Selection of more signal-like events
  ← Exit from LH2 target & Large energy deposit

Trigger conditions



Scinti TRG

- Install plastic scintillators for trigger
- Require hits at trigger scintillators
- Require energy deposit over 200 keV threshold at side scintillators



SecLay TRG

- Require hits at inner 3 layers at a sector

← Signal μ^+ must pass through CDCH from inside

dE/layer TRG

- Require energy deposit over 95 keV threshold at a layer in CDCH

← Signal μ^+ has larger energy deposit than e

~90% signal events were cut at trigger DAQ rate = 9.1 Hz

μ^+ detection efficiency

- 36.0% π^- generate π^0 by CEX
- 14.9% signal μ^+ generated by $\pi^0 \rightarrow \mu^+ e^-$ exit from LH2 target
- 45.9% μ^+ out of exiting from LH2 target is detected in CDCH

→ **Signal μ^+ detection efficiency is 2.46% out of all the π^- beam**

- 10.5% μ^+ out of detected in CDCH is triggered at 9.1 Hz

→ **Signal μ^+ detection efficiency is 0.26% out of all the π^- beam**

- Much lower detection efficiency than we expected

→ Need to review trigger conditions

Summary

- We propose the P0EM experiment to search for $\pi^0 \to \mu^+ e^-$ decay which is one of cLFV modes at PSI
- P0EM experiment will be a parasite on MEG II
- The setups use CDCH to detect signal μ^+, COBRA magnet to bend tracks of charged particles , and LH2 target
- LH2 target size is optimized
- Signal μ^+ can be identified in CDCH
- Detection efficiency of μ^+ is 2.46% w/o trigger
- Thinking of trigger DAQ in progress

Prospects

- Review trigger conditions to find detection efficiency

→ Estimate sensitivity

- Make LH2 target
    - Target strength test is on going
- Construct analysis method
    - Online logic in trigger
    - Reconstruction of particles' tracks

→ Prepare to do beam test

Backups

π^- interactions and BG

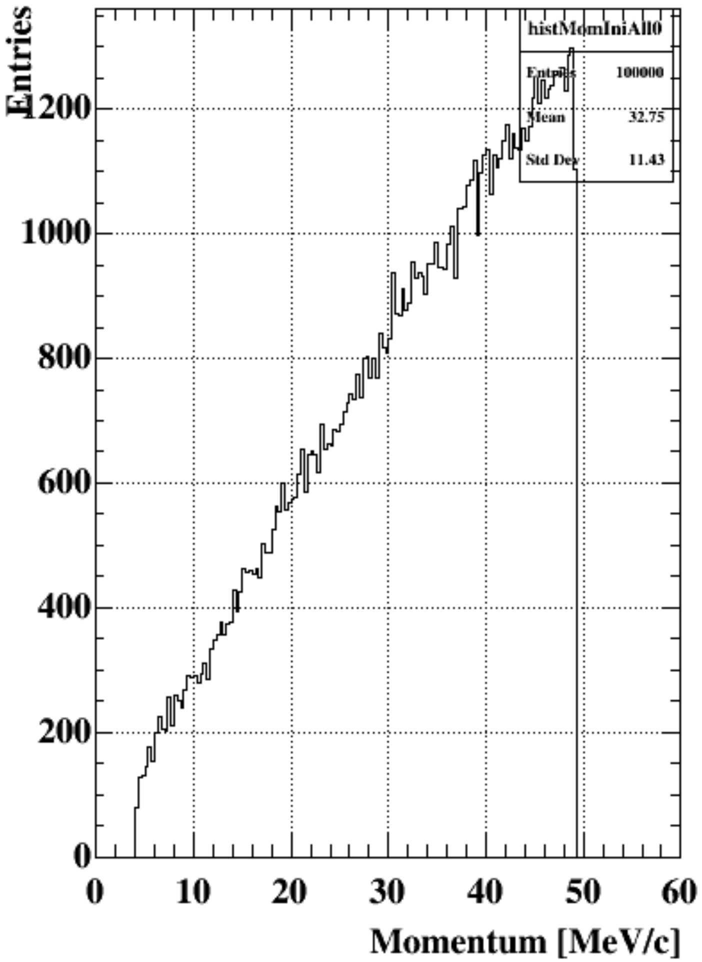
- π^- interacts with nucleus in the following reactions:
  - Elastic or inelastic scattering: $\pi^- + N \rightarrow \pi^- + N$ (or N')
  - Absorption: $\pi^- + N \rightarrow N' + \text{several nucleus}$
  - Charge exchange (CEX): $\pi^- + N \rightarrow \pi^0 + N'$
  - Radiative capture: $\pi^- + N \rightarrow \gamma + N'$
- The nuclei generated through scattering will deposit too much energy in CDCH due to its little momentum

→ The nuclei will not be BG candidates

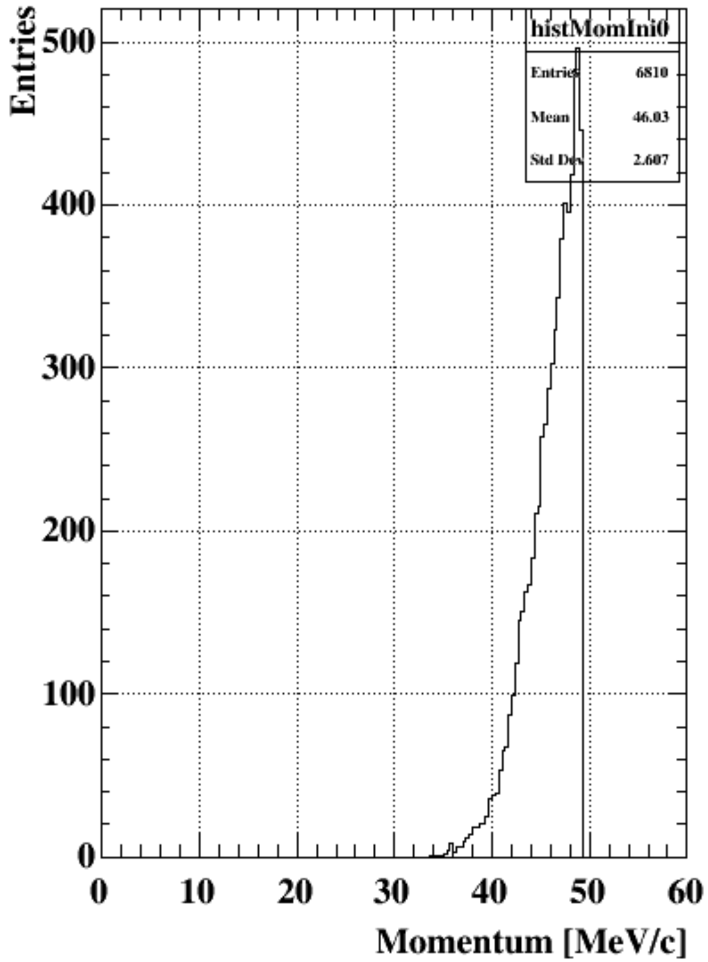
- Absorption does not occur in LH2 because violating energy conservation
- But absorption occurs in materials w/ larger Z than that of hydrogen

Signal μ^+ momentum distribution

Momentum of all the signal μ^+

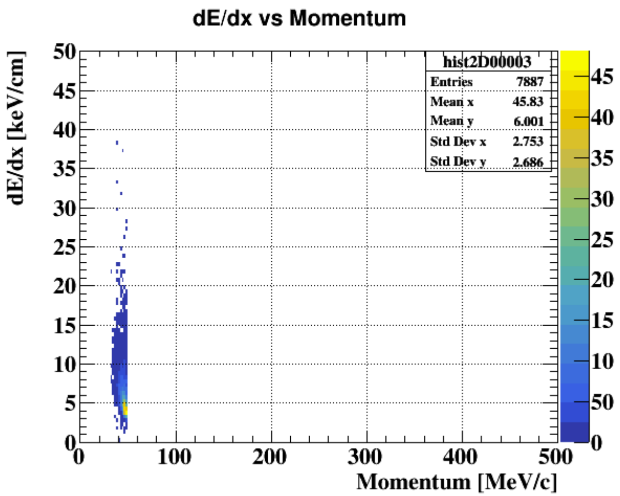


Momentum of detected signal μ^+

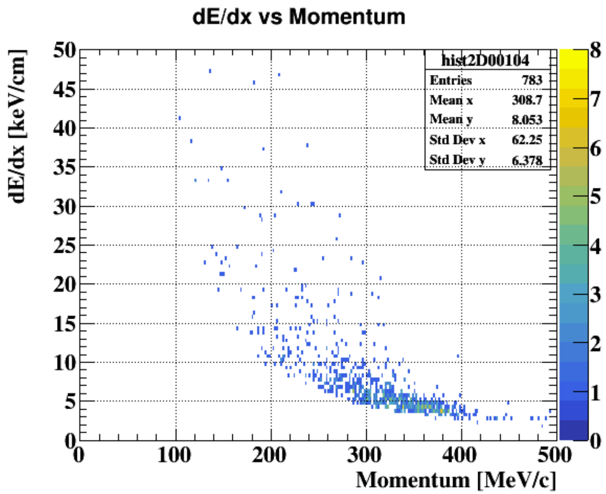


dE/dx vs momentum

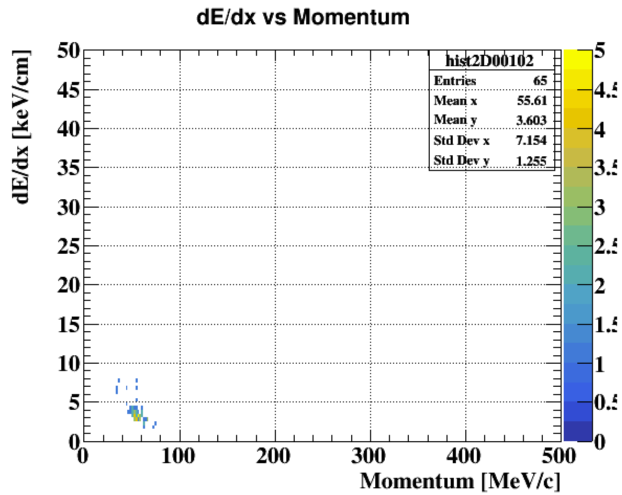
Signal μ^+



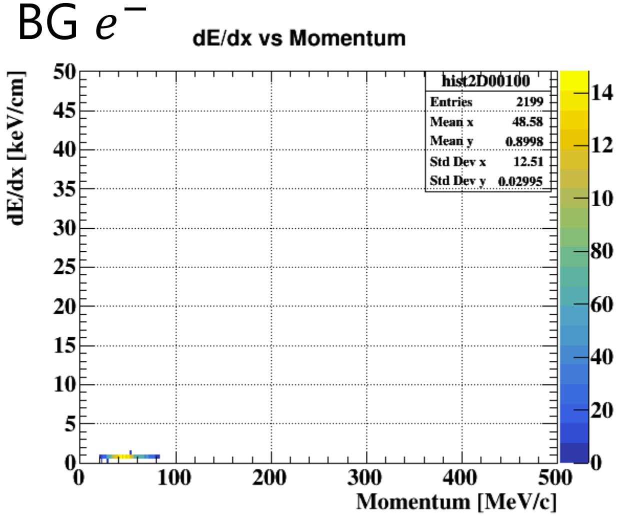
BG p



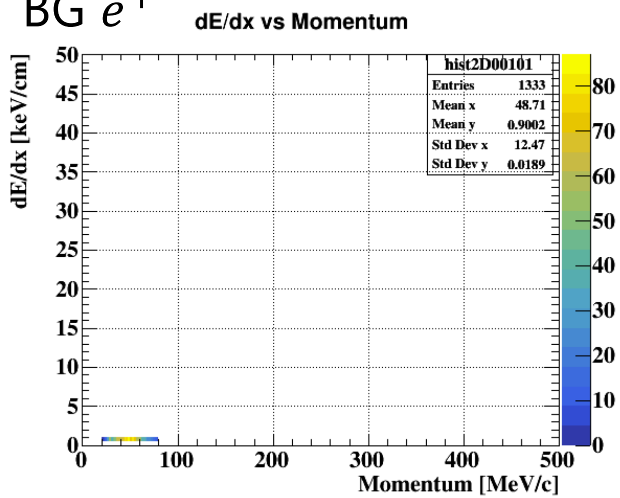
BG μ^-



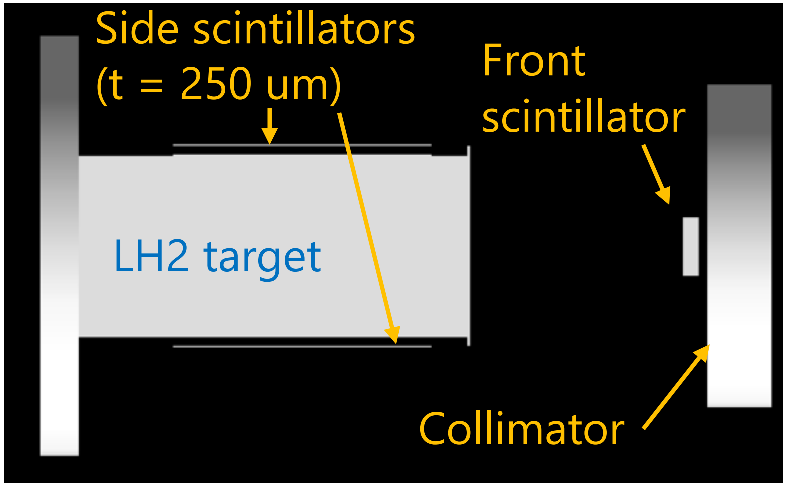
BG e^-



BG e^+

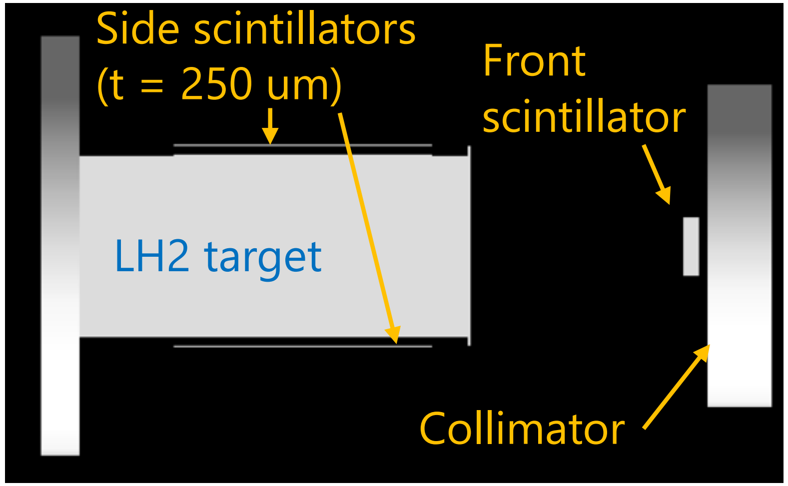


Scinti TRG (1/2)



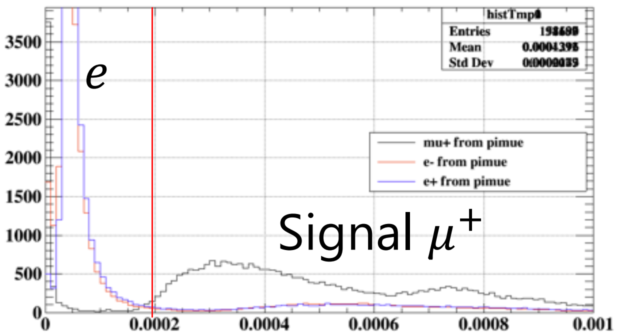
- Install plastic scintillators for trigger
- Front scintillator is installed in front of LH2 target
- The size is 18 mm x 32 mm x 5 mm
- (Collimator hole size is 14.4 mm x 28.4 mm)
- Require hit at front scintillator
- This is for removing CDCH detection of μ^- generated by π^- decay

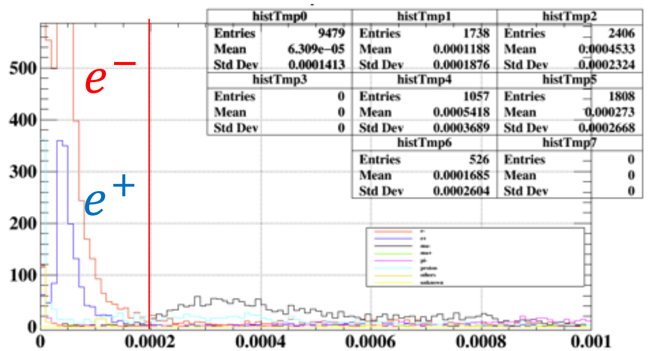
Scinti TRG (2/2)



- Side scintillators are installed by Mylar windows of outer box
- The size is 60 mm x 80 mm x 250 μm
- (Outer Mylar window size is 60 mm x 80 mm)
- Require hit at side scintillator and energy deposit over 200 keV
- The thickness is 250 μm due to direct detection of signal μ^+
- # of triggered events is 1,764 out of 100,000 π^- events

Energy deposit at side scintillator

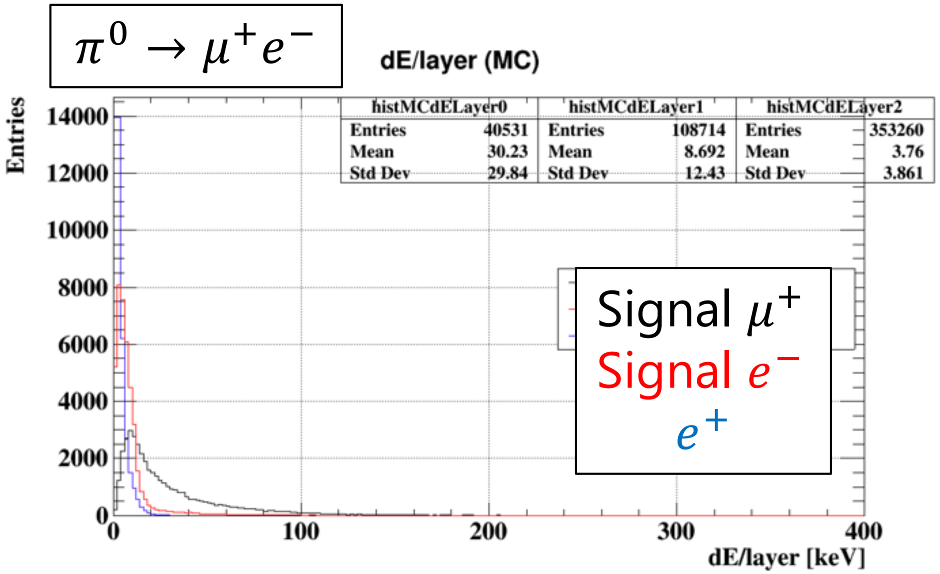


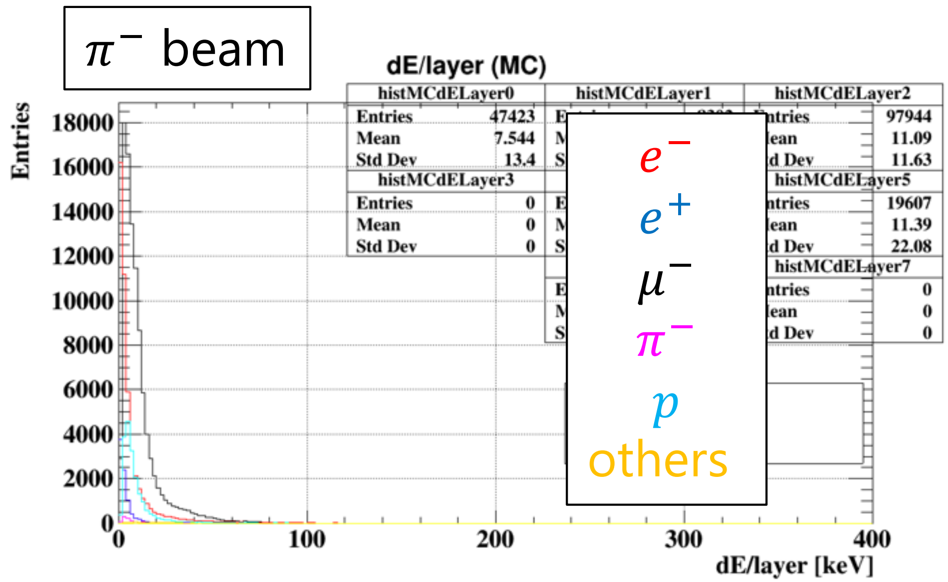


dE/layer TRG

- Signal μ^+ has larger energy deposit per layer than e

→ Cut e tracks w/ small dE/layer





- Threshold is 95 keV/layer to make trigger rate <10 Hz w/ 3 triggers

← This results in too large signal loss (Triggered signal μ^+ is ~10% out of detected in CDCH)