Development of beam position detector for CEX calibration of MEG II

MEG II実験液体キセノンガンマ線検出器の較正実験に用いるパイオンビーム位置測定器の開発

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Outline

- Introduction
  - LXe Calorimeter of MEG II
  - CEX calibration
- Simulation Study
  - optimization of configuration
  - light yield & radiation hardness
- Active target
  - advantage of active target
  - reaction on scintillator
  - rate consideration

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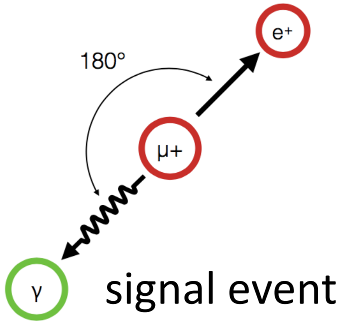
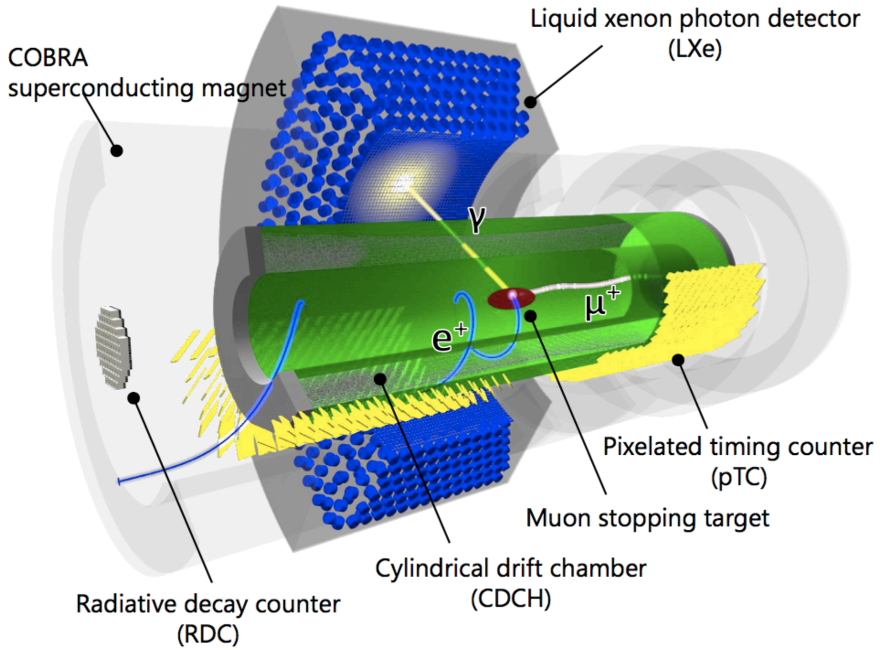
LXe Calorimeter of MEG II

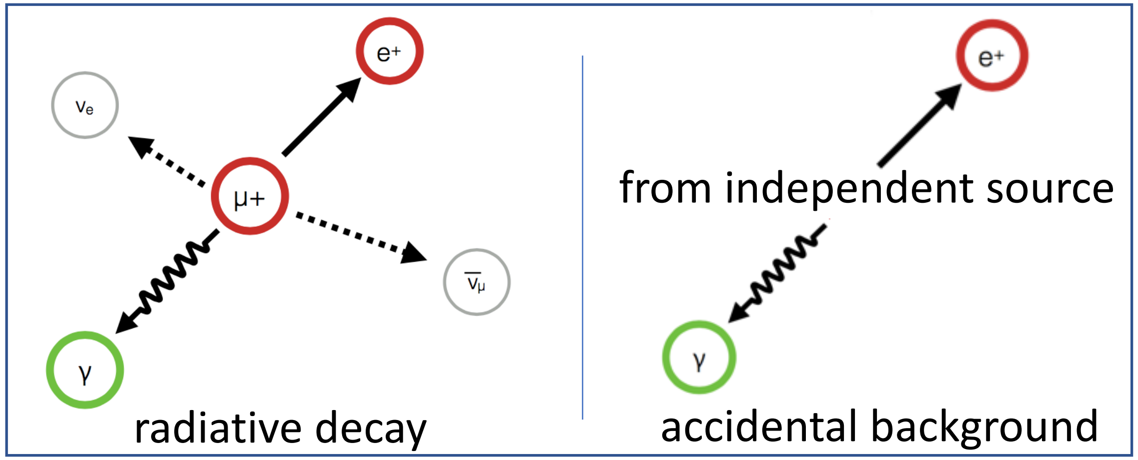
- MEG II searches for $\mu \rightarrow e\gamma$
  - 52.8 MeV/c
  - back-to-back
  - same timing





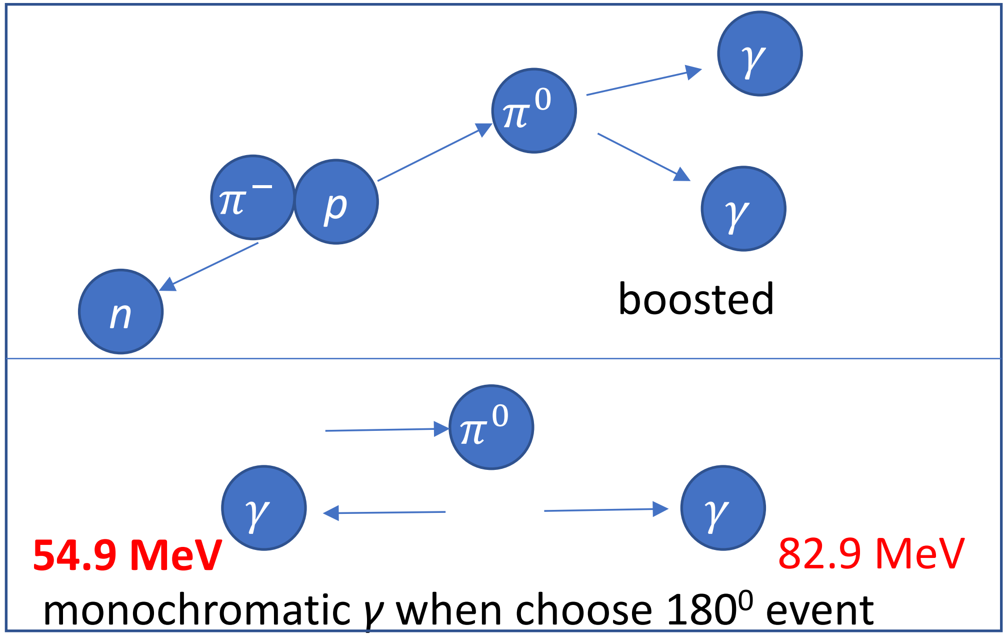
- reconstruct γ using
  - LXe (Liquid Xenon) scintillator
  - 4092 SiPM, 668 PMT

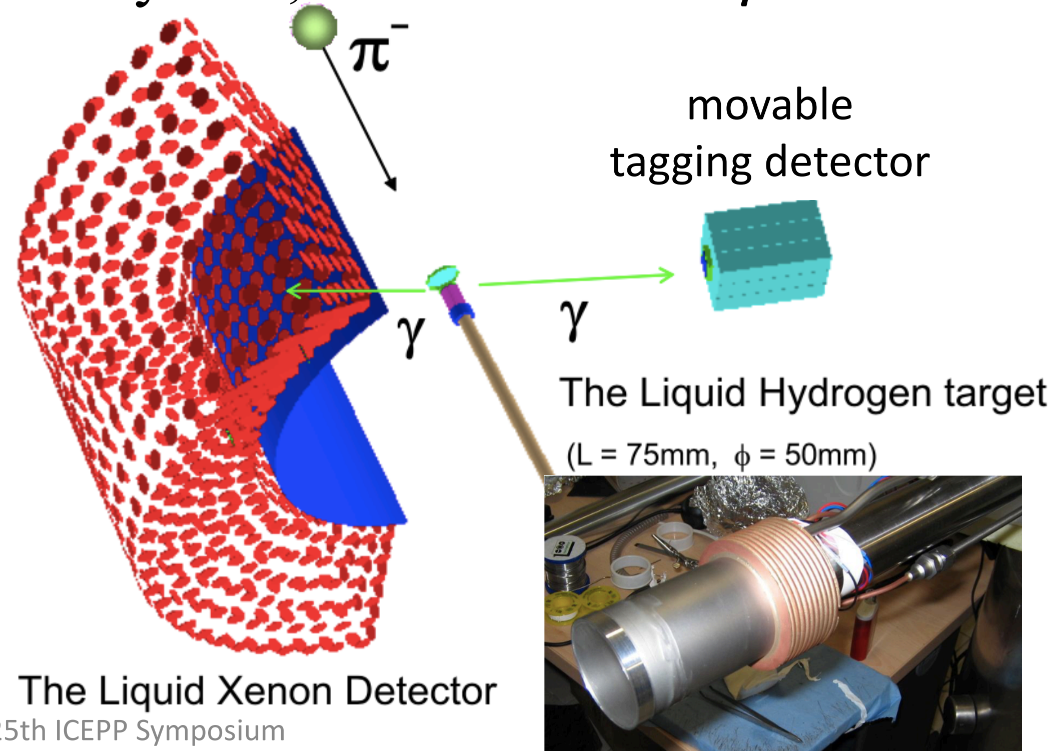
- background events
  - radiative muon decay
  - accidental background
  - → resolution is important

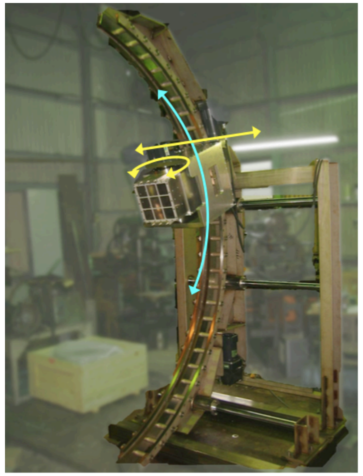


CEX Calibration

- CEX (Charge EXchange): $\pi^- + p \rightarrow \pi^0 + n,\ \pi^0 \rightarrow \gamma + \gamma$
  - stop π^- beam on hydrogen target at rest
  - π^0: momentum is 28 MeV/c
  - E_γ depends on angle b/w two γ in Lab. system (54.9 MeV – 82.9 MeV)
  - when choose back-to-back event in Lab. system, monochromatic γ can be obtained.





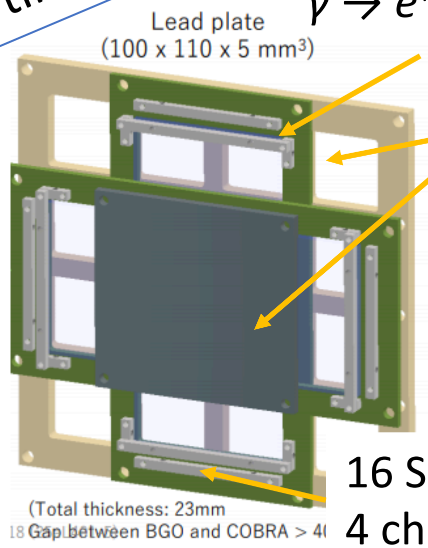


Estimation of Energy

- timing is calculated from Time of Flight
- energy is determined from $\theta_{\gamma\gamma}$

timing

Pb for conversion
$\gamma \to e^+e^-$



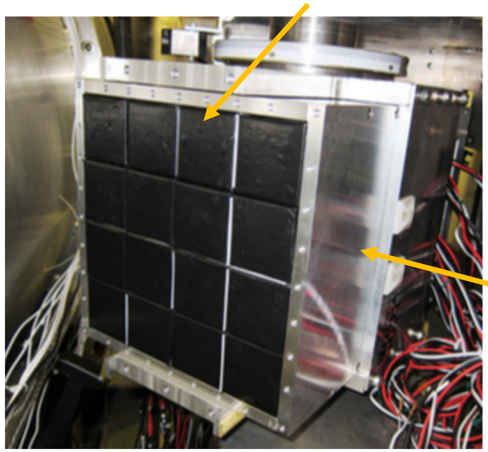
Plastic Scintillator

16 SiPM
4 channel readout

pre-shower counter
position resolution: ～ 7 mm
timing resolution : ～ 40 ps

energy

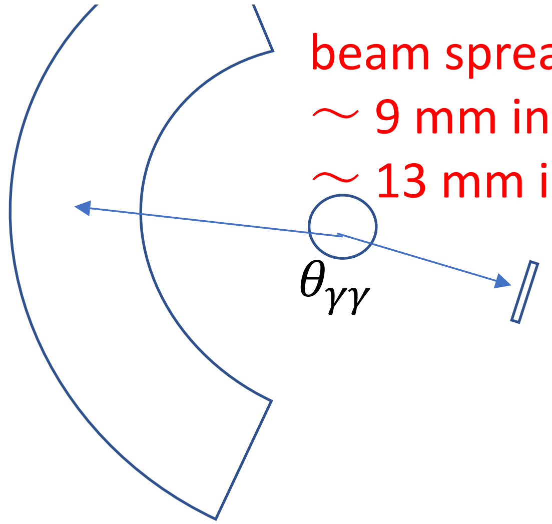
4 × 4 BGO crystal
46 × 46 × 200 mm each



PMT behind each crystal

BGO calorimeter
position resolution: ～ 10 mm
energy resolution : ～ 2.4 %

XEC
position resolution: O(mm)
(expected energy resolution: ～ 50 ps)
(expected energy resolution: ～ 500 keV)



uncertainty of vertex position leads to uncertainty in esitimation
→ need vertex position information

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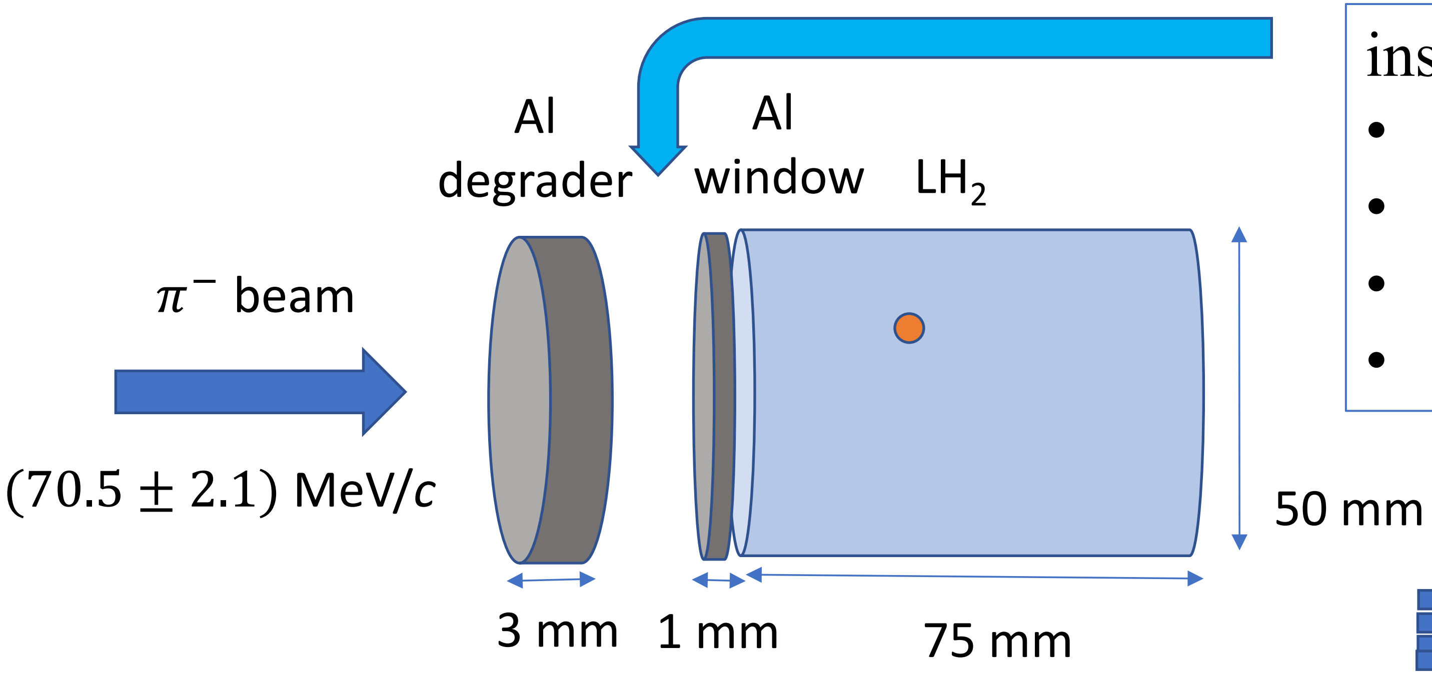
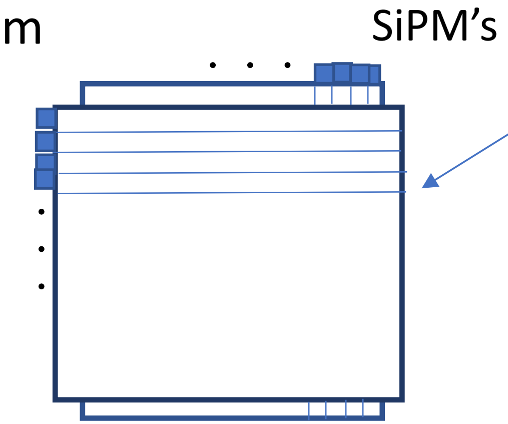
Idea of π^- Beam Position Detector

➢ put Sci-Fi (Scintillating Fiber) in front of target



insert new detector
- 100 mm length, 500 or 250 μm thickness
- some fibers make a bundle
- 1 SiPM for 1 bundle
- 2 layers for x & y

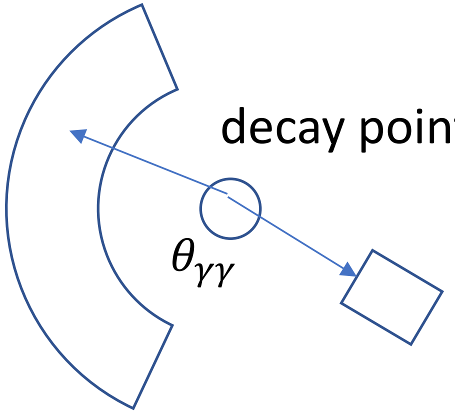


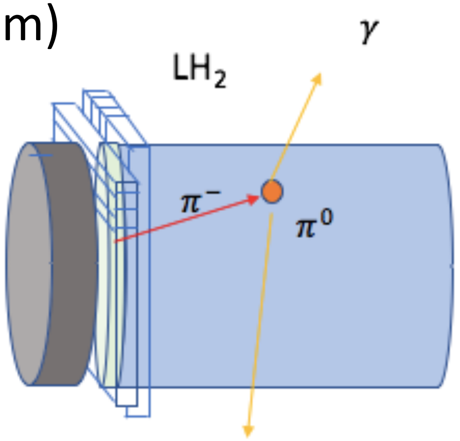
each bundle is made of some fibers

- how finely should it be segmented?
- large enough signal?
- radiation hardness? → simulation study

Simulation Setup

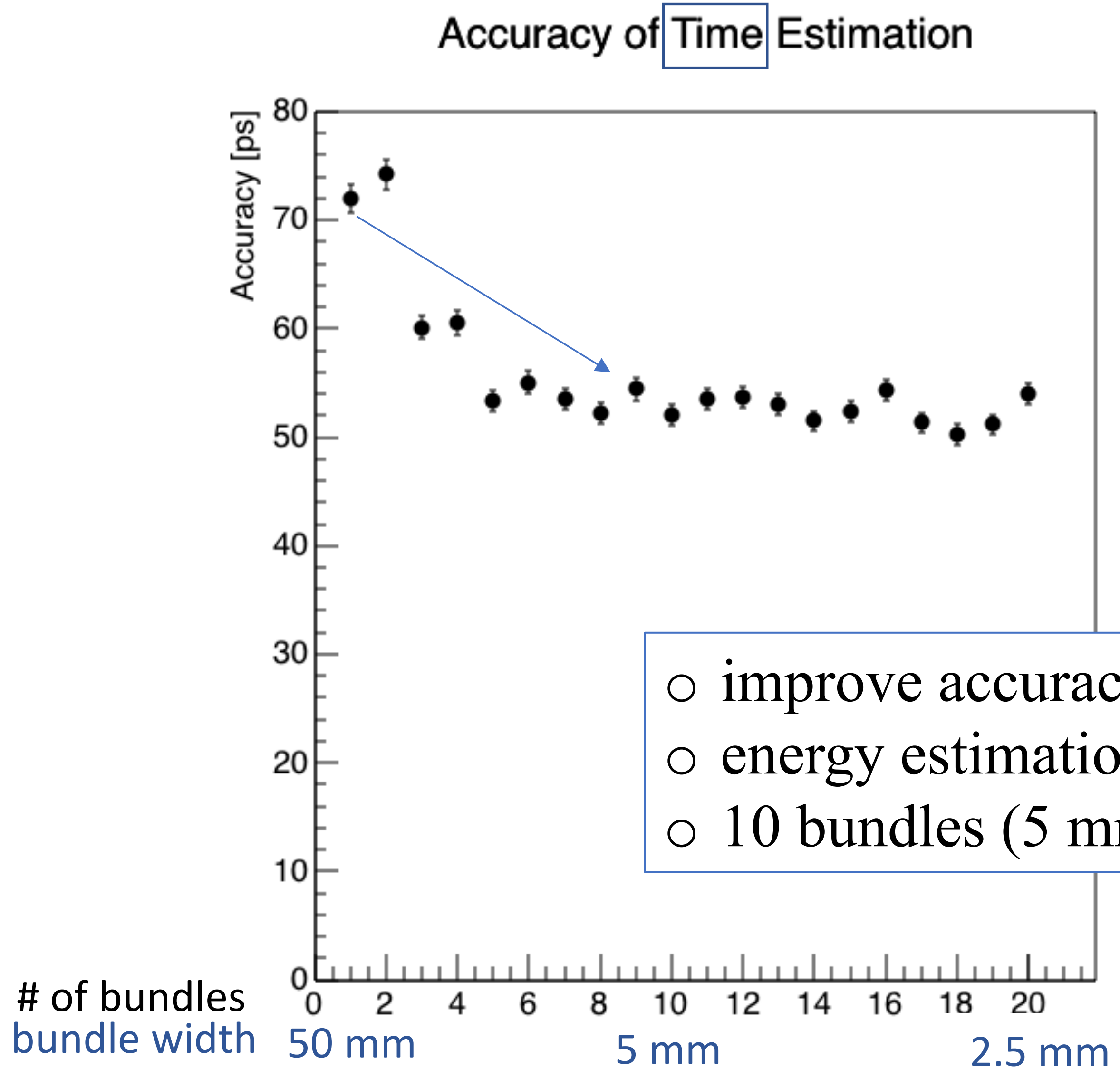
- use geant4 (ver. 10.3.1)
- inject (70.5 ± 2.1) MeV/c π^- (100,000 events)
- uncertainty of each detector is considered
  - π^- position detector
  - tagging detectors
    - pre-shower counter
    - BGO calorimeter
  - XEC

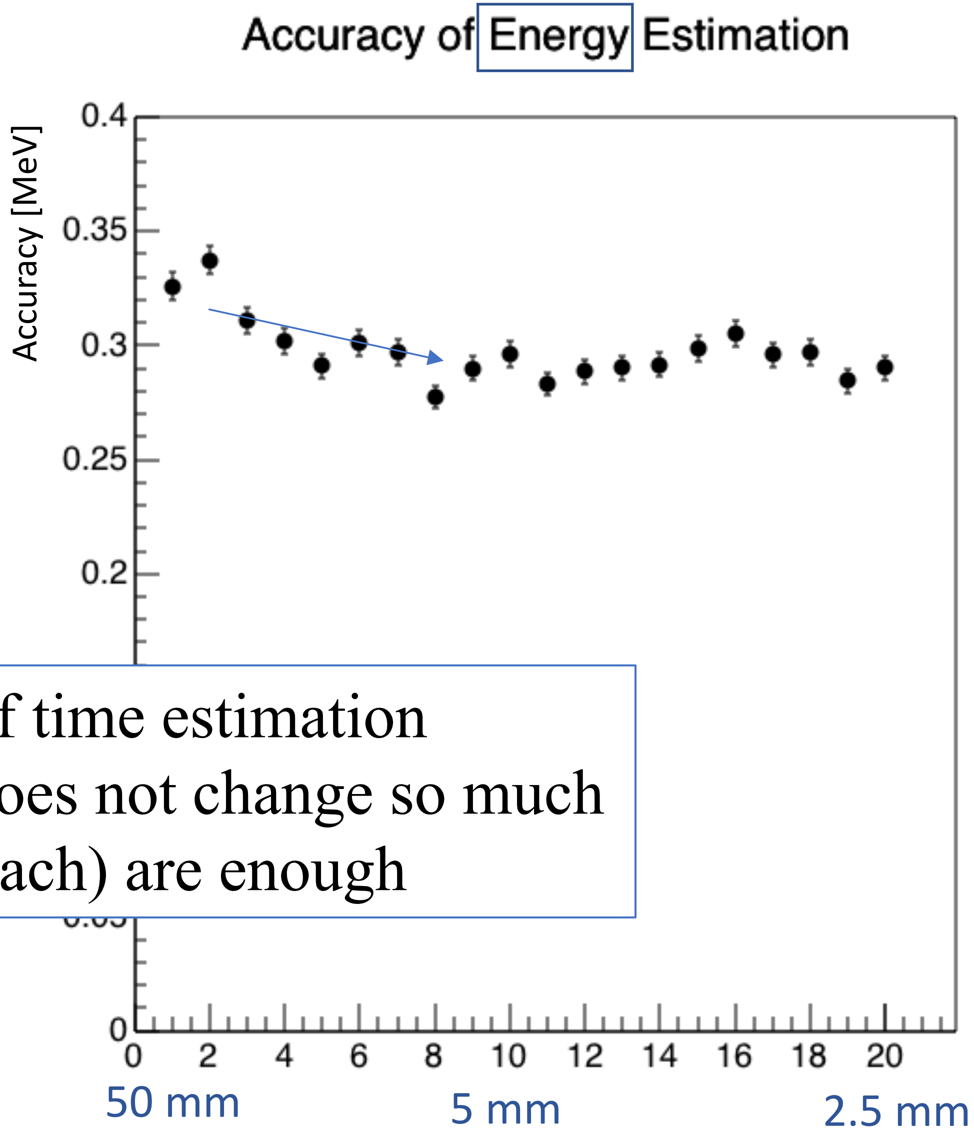




- scintillation photon is not simulated
- calculate "accuracy" :
  standard deviation of "estimated time or energy" – "truth"

Segmentation Optimization





- improve accuracy of time estimation
- energy estimation does not change so much
- 10 bundles (5 mm each) are enough

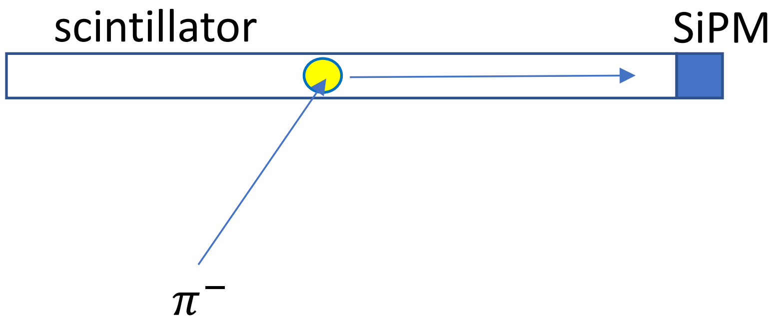
Light Yield

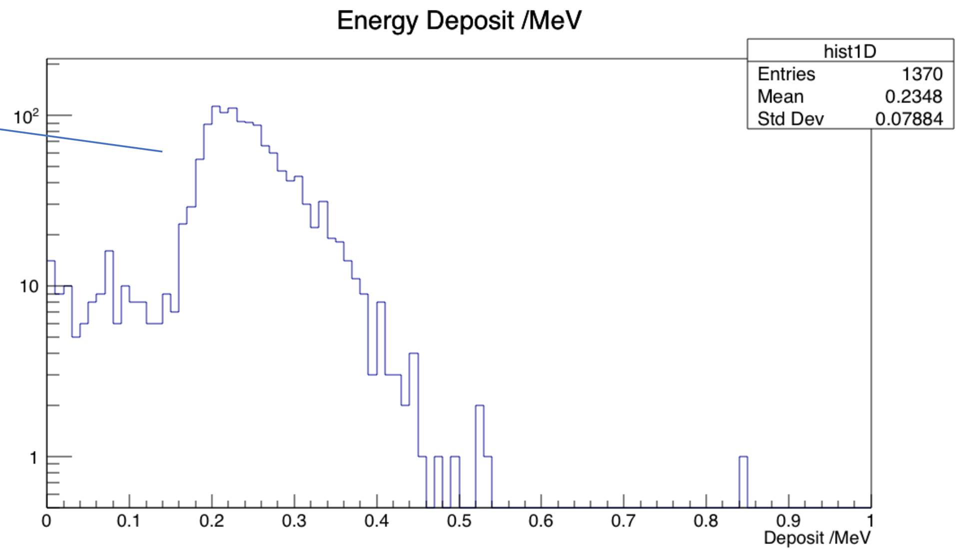
- $N_{pe} = N_{gen} \cdot T \cdot PDE$
  - N_{pe} : # of photons counted by SiPM
  - N_{gen}: # of generated scintillation photons

$$N_{gen} = \frac{\Delta N_\gamma}{\Delta E} \Delta E$$

> 0.2 MeV

8,000 photon/MeV (BCF-12)





  - T: probability of reaching SiPM

$$T = \frac{\delta\Omega}{4\pi} e^{-\frac{L}{L_{att}}}$$

～ 7 %

15 cm

  - PDE: photon detection efficiency ～ 40 %

$\rightarrow$ $N_{pe} \sim 27$ pe (large enough!)

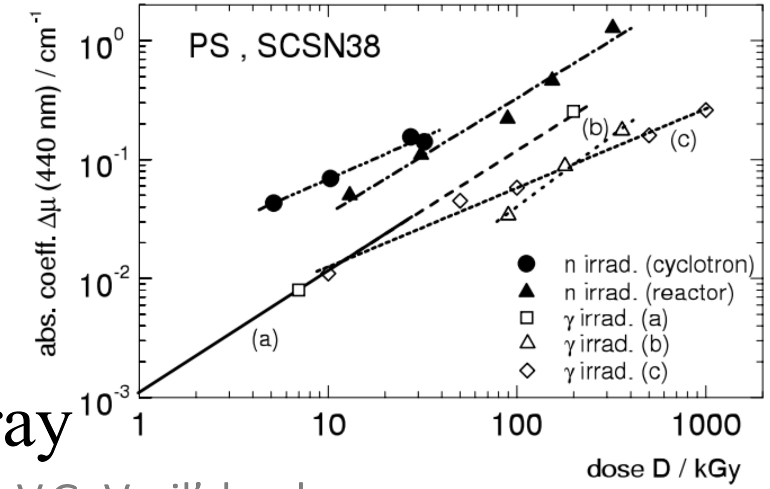
Radiation Damage on Fiber

- Calculation of Dose (Gy = J/kg)
  - o beam rate: 1.4 MHz
  - o e^- contamination: 26 times of π^- (can distinguish by ToF and signal size)
  - o DAQ days = 10 days/year × 3-5 years

  → 15,000 Gy at center of beam spot

- effect to property
  - o light yield: 50-65 % at 34,000 Gy of γ ray
  - o transmittance: ~ 40 % at 10 cm at 15,000 Gy of γ ray

  → still detect ~ 10 pe after 5 years DAQ



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Nucl. Instr. and Meth. in Phys. Res. B 95 (1995) 496-500

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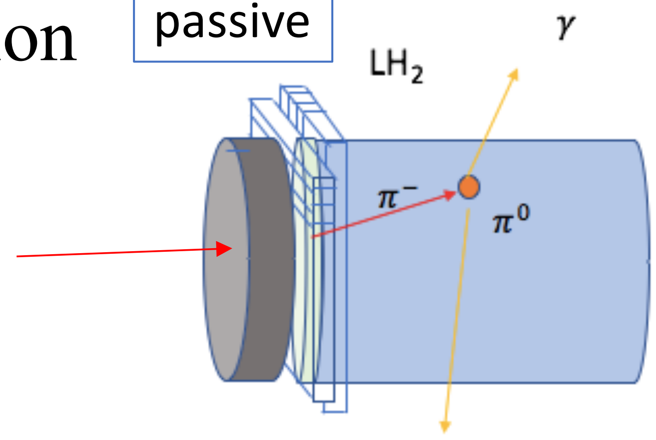
Idea of Active Target

- scintillator itself is target
  - obtain not only injection point but also vertex position
  - z information is also available
    → accuracy of estimation improves

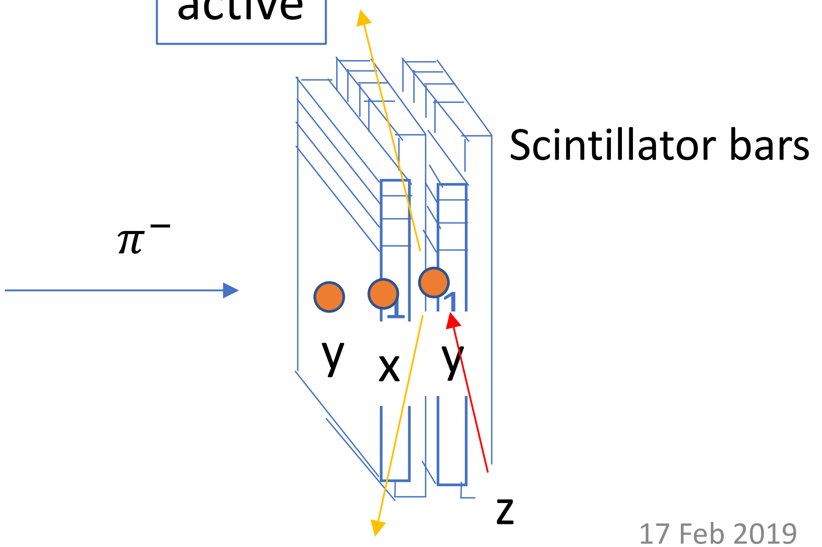
	timing [ps]	energy [keV]
No Detector	73	320
Scintillating Fibers in front of LH2 (bundle width: 5 mm)	51	300
Scintillating Target (width, thickness: 5 mm)	**39**	**230**

  - easier to operate than LH_2
  - but reaction on scintillator is not understood well
    - low rate?
    - undesirable reactions?

passive



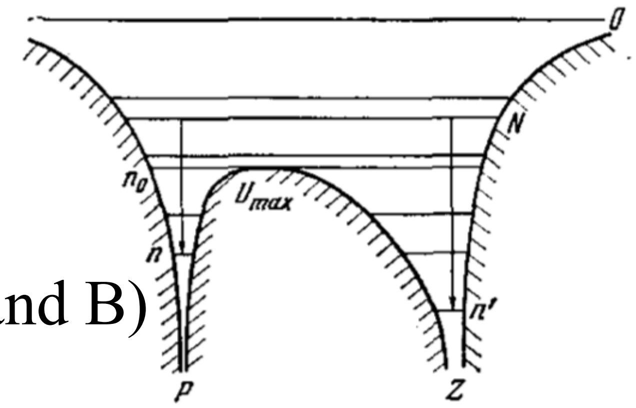
active



Reaction on Scintillator

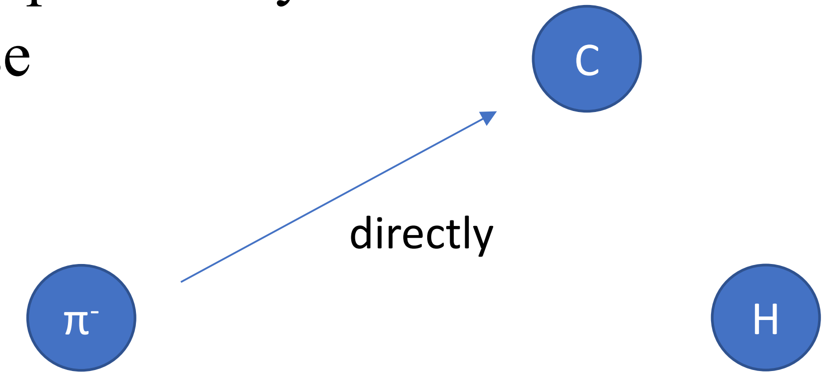
- coherent
  - stopped π^- is captured by a molecule ($\propto Z^{-1}$)
  - π^- moves from molecular orbital to atomic orbital ($\propto Z^2$)
    (ref: Gerstein et al. Usp. Fiz. Nauk (USSR) **97**, 3 (1969))
  - CEX cannot happen in Cπ^- (because of energy difference b/w C and B)

  → can use only CEX on H



- incoherent
  - moving π^- directly collides with nucleus with small probability
  - momentum of generated π^0 is not 28 MeV/c because
    - π^- is moving
    - in C, proton has Fermi momentum

  → can be source of background



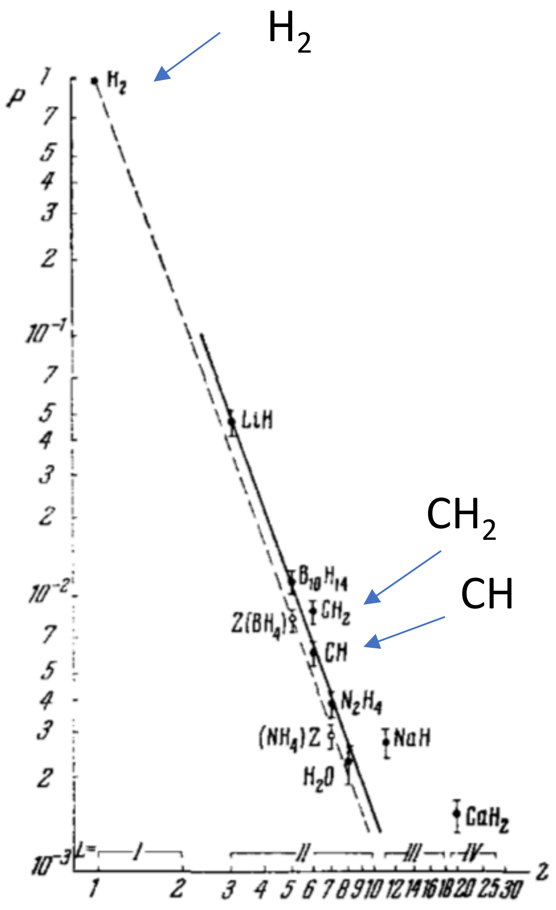
Effect of Undesirable Property

- Rate
  - Experimental results of probability (relative to H_2) of coherent CEX on CH_2
    - min 0.77 % (ref: A. F. Dunaitsev et al. Nuovo Cimento **34**, 521 (1964))
    - max 1.45 % (ref: Petrukhin et al. Sov. Phys. JETP **42**, 955 (1976))
    - # of H per C is smaller than CH_2 in scintillators
      → smaller probability
  - Comparison; MEG 2011 LH_2 → MEG II scintillator
    - probability : 100 % → 0.5-1 %
    - beam intensity: 4.4 % → 100 %

      * slit was used to reduce too large hit rate and pi- momentum fluctuation
    - rate : 12.5 Hz (2.5 h/patch) → 1.5-3 Hz (10-20 h/patch)

      * 26 patches to cover whole face

  → not unreasonable. test experiment is under planning.



Summary

- Passive Target
  - by placing Sci-Fi in front of target, estimation of timing & energy improves
    σ_t: 70 ps → 50 ps, σ_E: 320 keV → 300 keV
  - signal will be large enough even after 5 years radiation

- Active Target
  - estimation accuracy improves more if target itself is scintillator
    σ_t: 70 ps → 40 ps, σ_E: 320 keV → 230 keV
  - need to understand more about reaction on scintillator
    → test experiment is under planning
    - rate decrease
    - effect on energy distribution
    - other background …?