Performance of both-end readout system of CsI crystal for KOTO experiment

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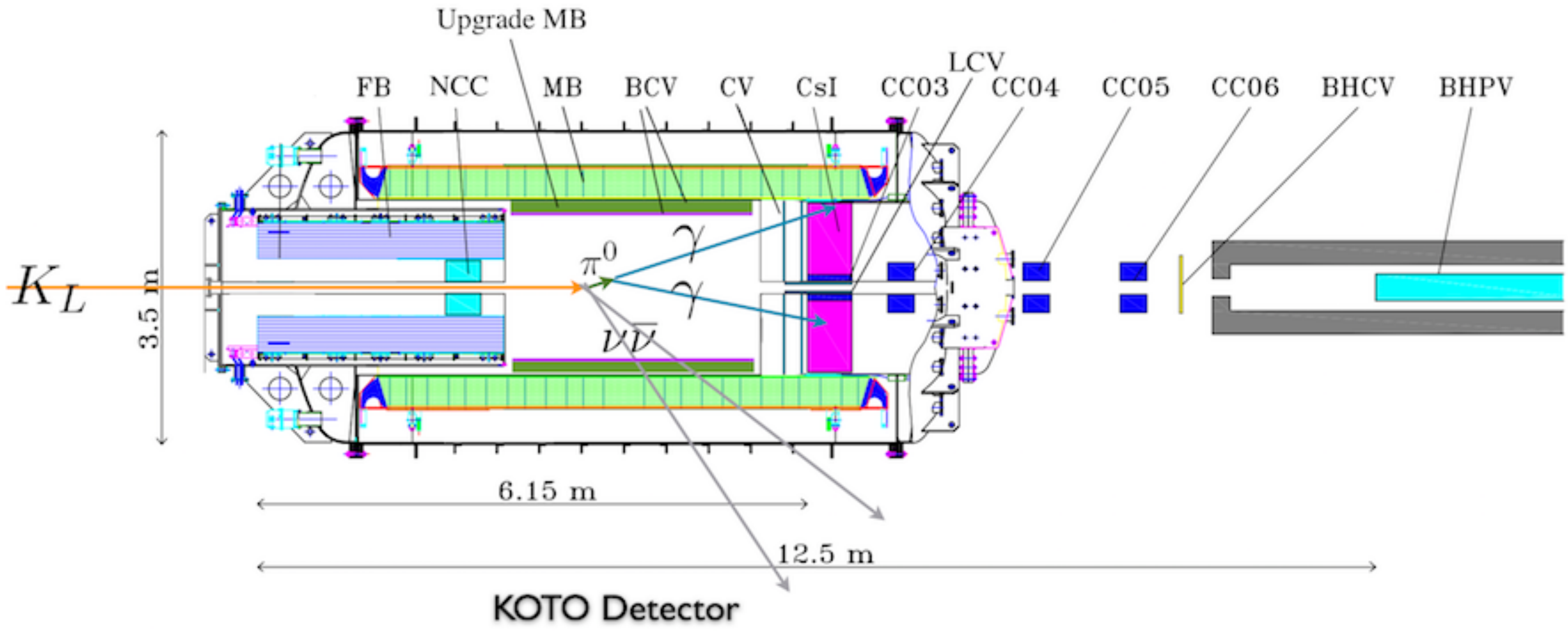
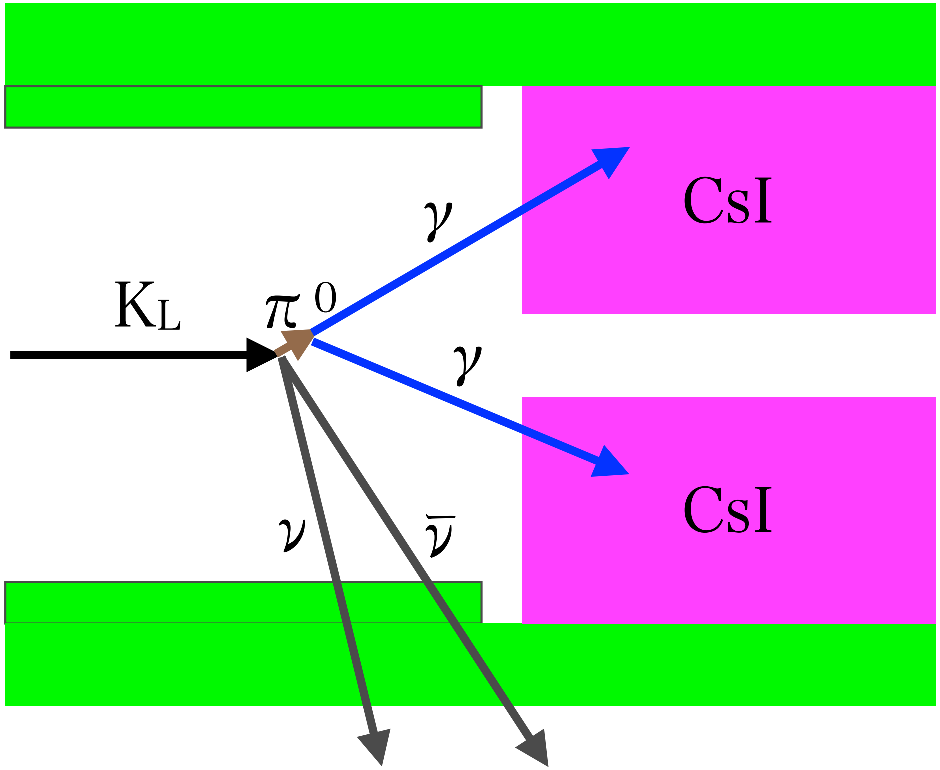
Introduction of the KOTO experiment



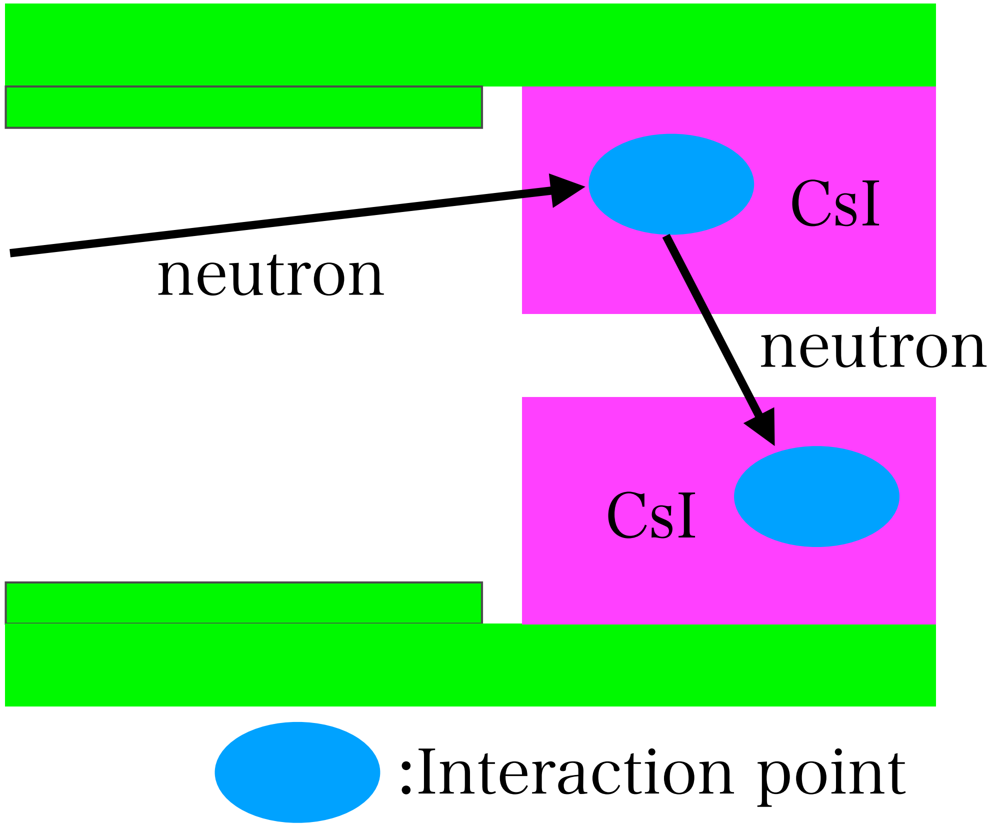
- Study for the $K_L \rightarrow \pi_0 \nu \overline{\nu}$
  - Two photons detected by CsI electro-magnetic calorimeters.
  - Veto

Halo neutron background

Signal ($K_L \to \pi^0 \nu \overline{\nu}$)

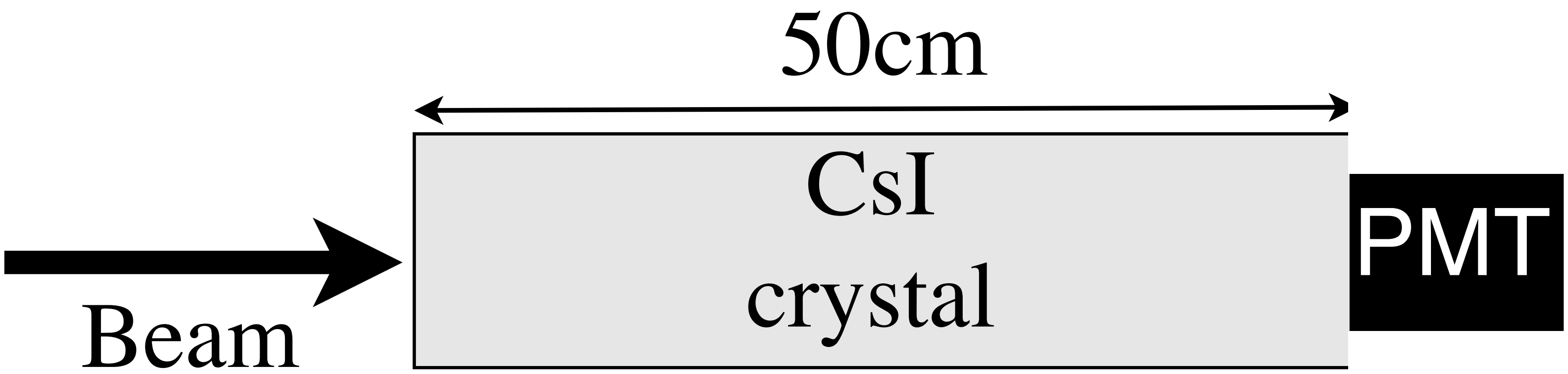


Halo neutron



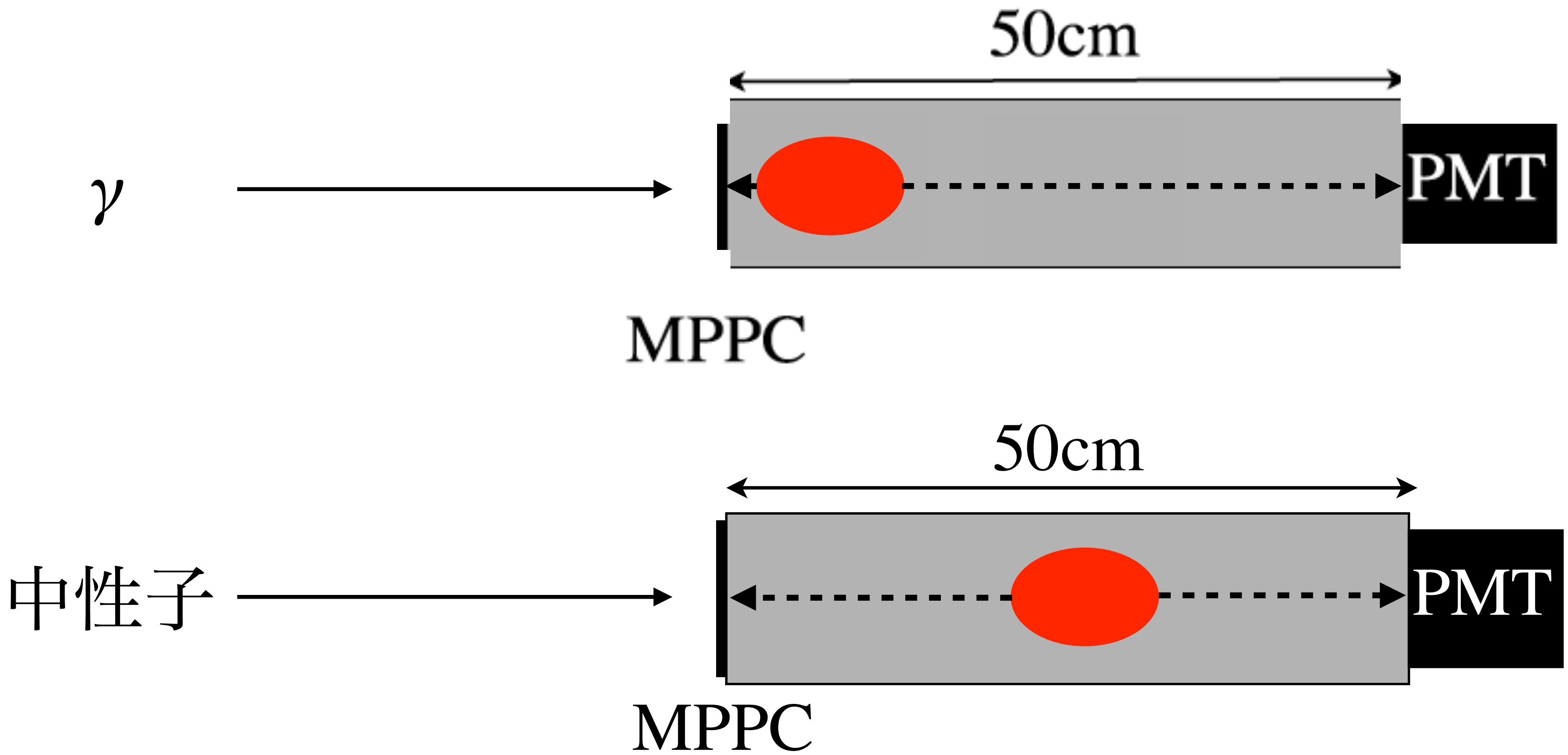
- Single event sensitivity : $\sim 10^{8}$
- Reduction power of established cut : $O(1/10^{2})$
- Reduction power of O(1/10) must be necessary to reach SM.
  - Introducing Both-end readout system of CsI crystal

Current readout system



- Currently, we readout the signal only by downstream PMT.

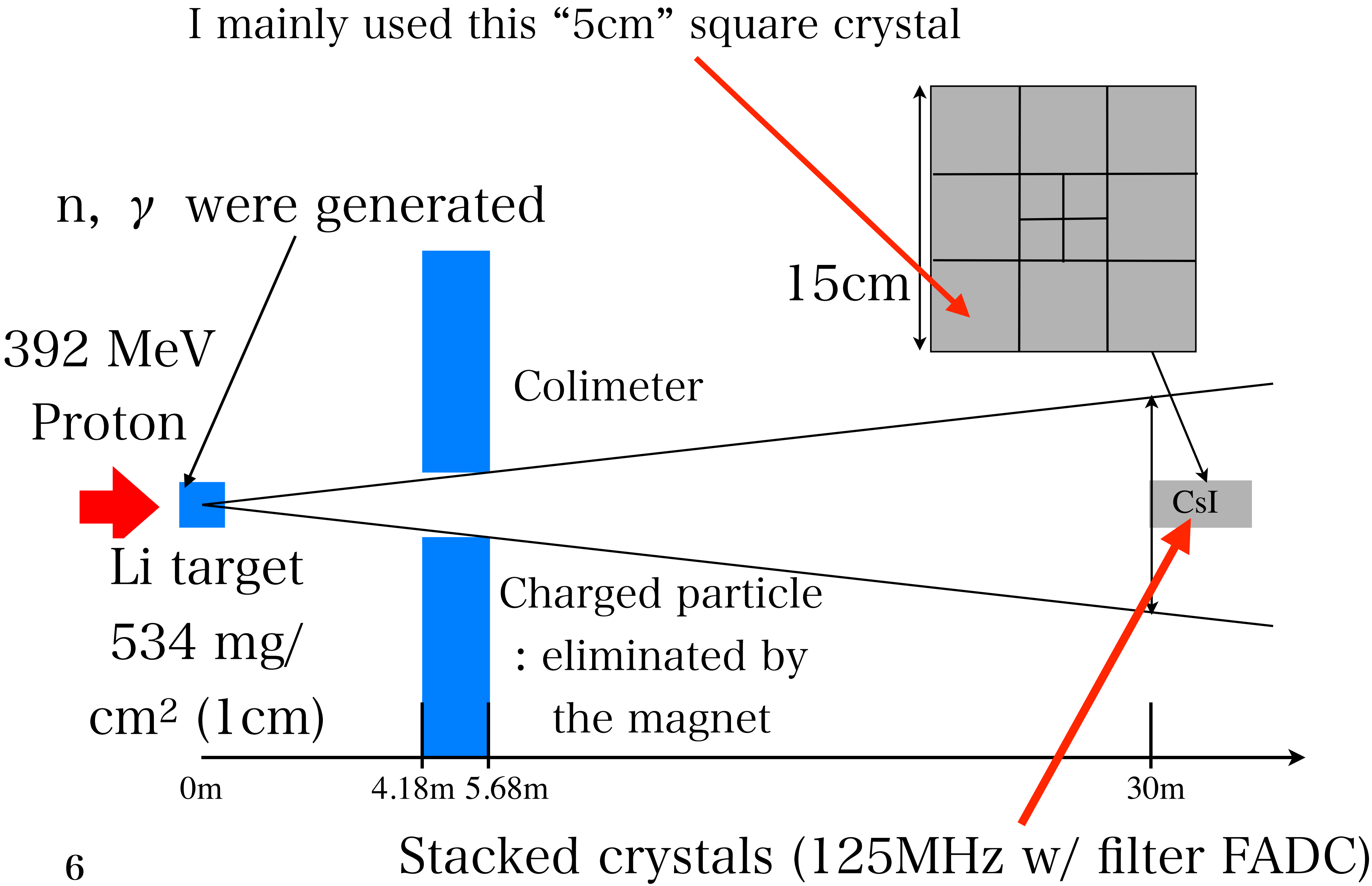
CsI両読み機構



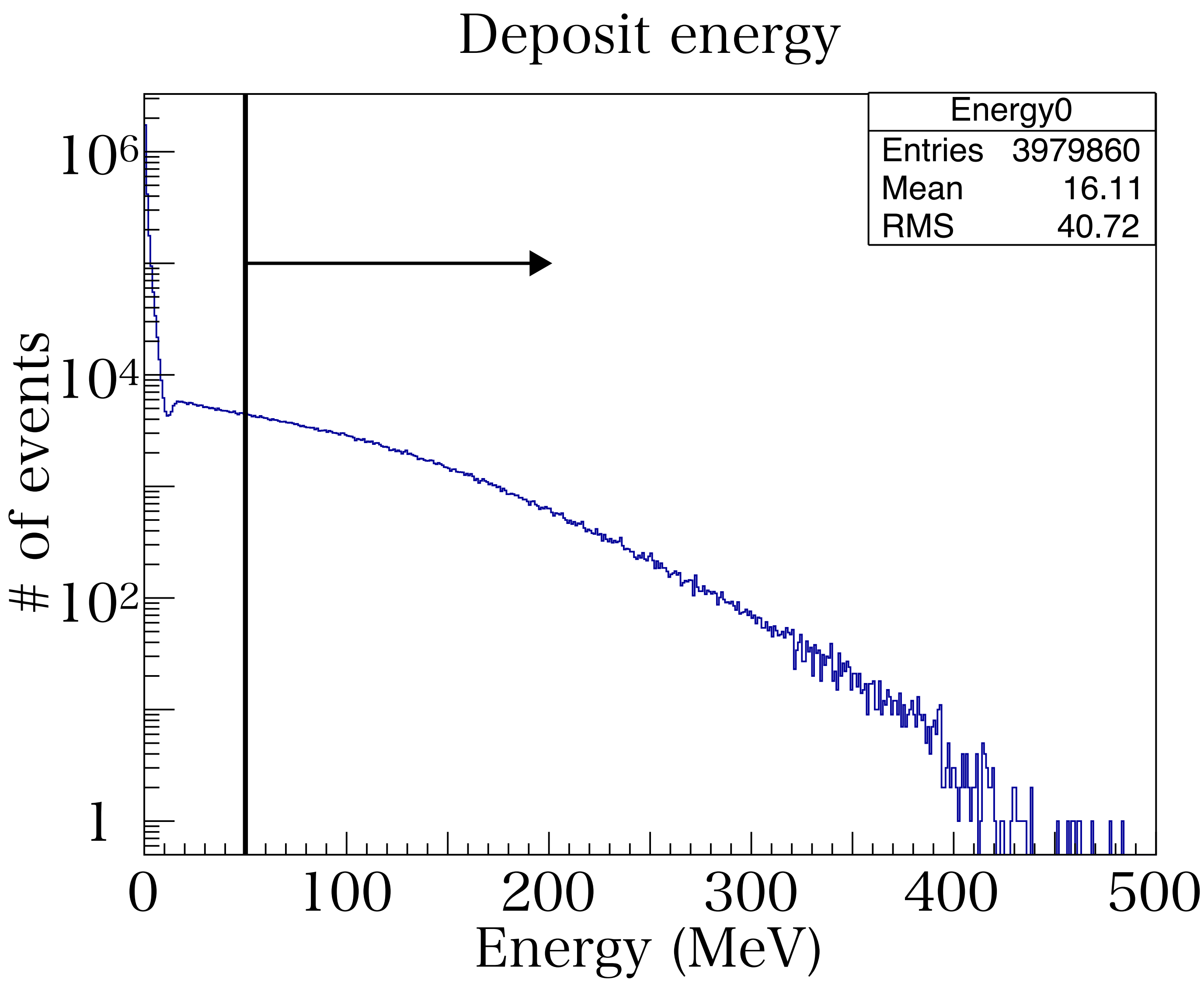
- Timing difference→Position
  - γ →Radiation length (~2cm)
  - Neutron→Interaction length (~40cm)

→ Able to Discriminate

Setup of the beamiest

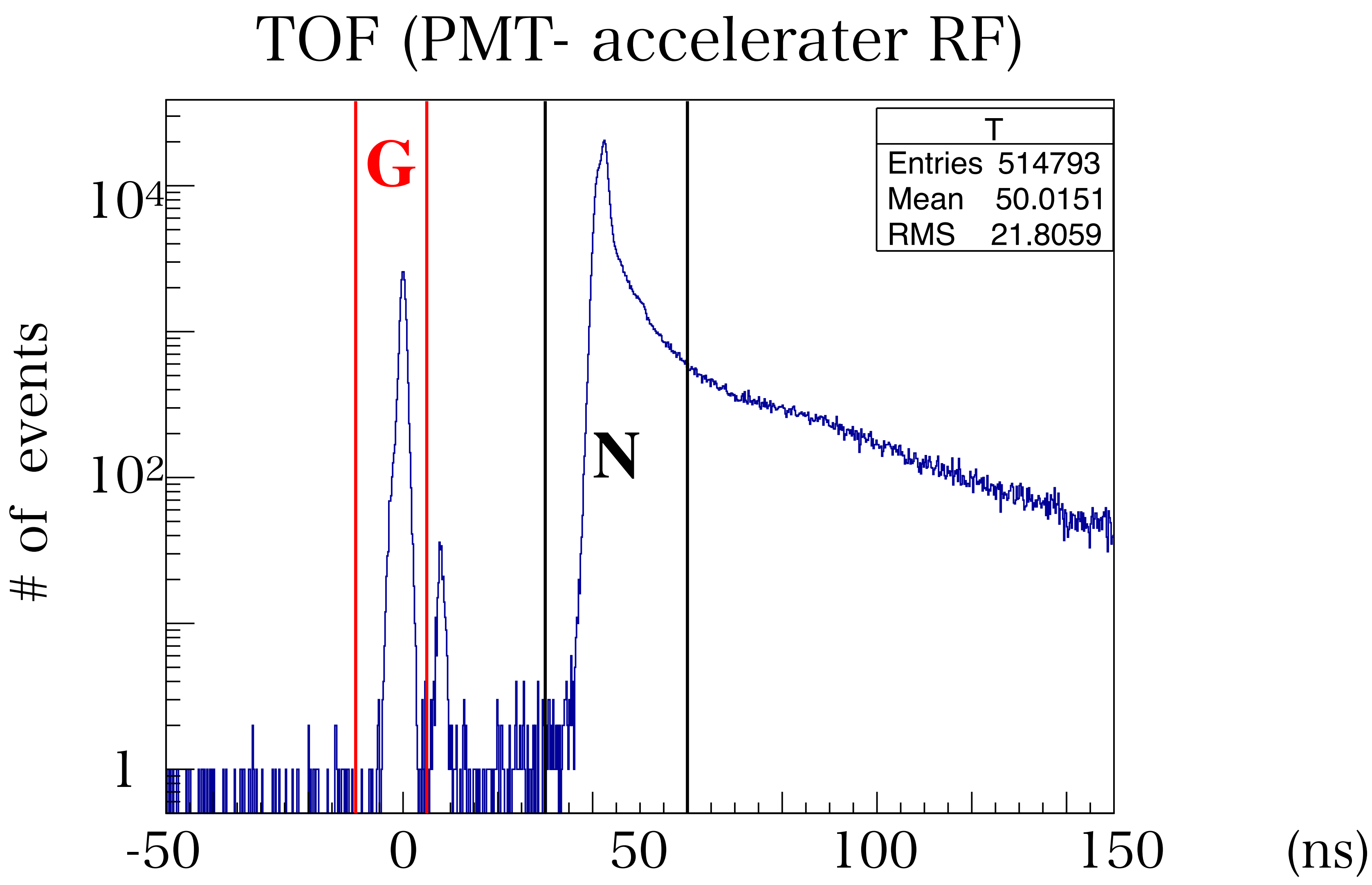


Deposit energy



I used Edep > 50 MeV events

TOF

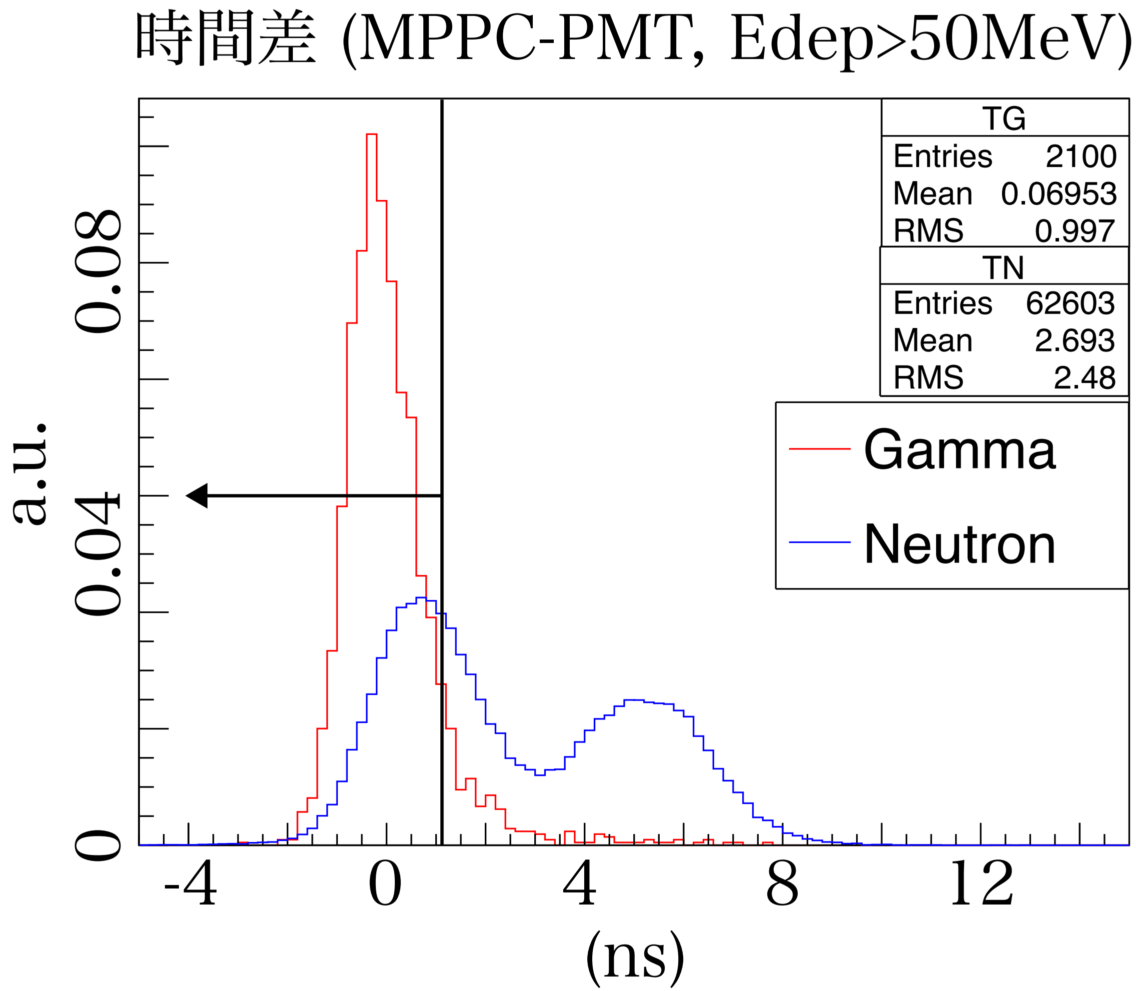


Beam : Pulse beam (Interbal : 500ns, width of a pulse: 200 ps)

→We can be able to discriminate neutrons & γ s by using TOF

Speed of neutron & gamma is different in air.

時間差 (MPPC-PMT)



- Neutrons and γs have different timing difference
  - We can eliminate neutron event by timing difference.

γ event efficiency : 90 %
→Cut efficiency of neutron : 35.5 %

Second cluster of halo neutron events : reacted @ downstream region
→Cut efficiency of neutron is estimated less than 10 %

Method of timing difference

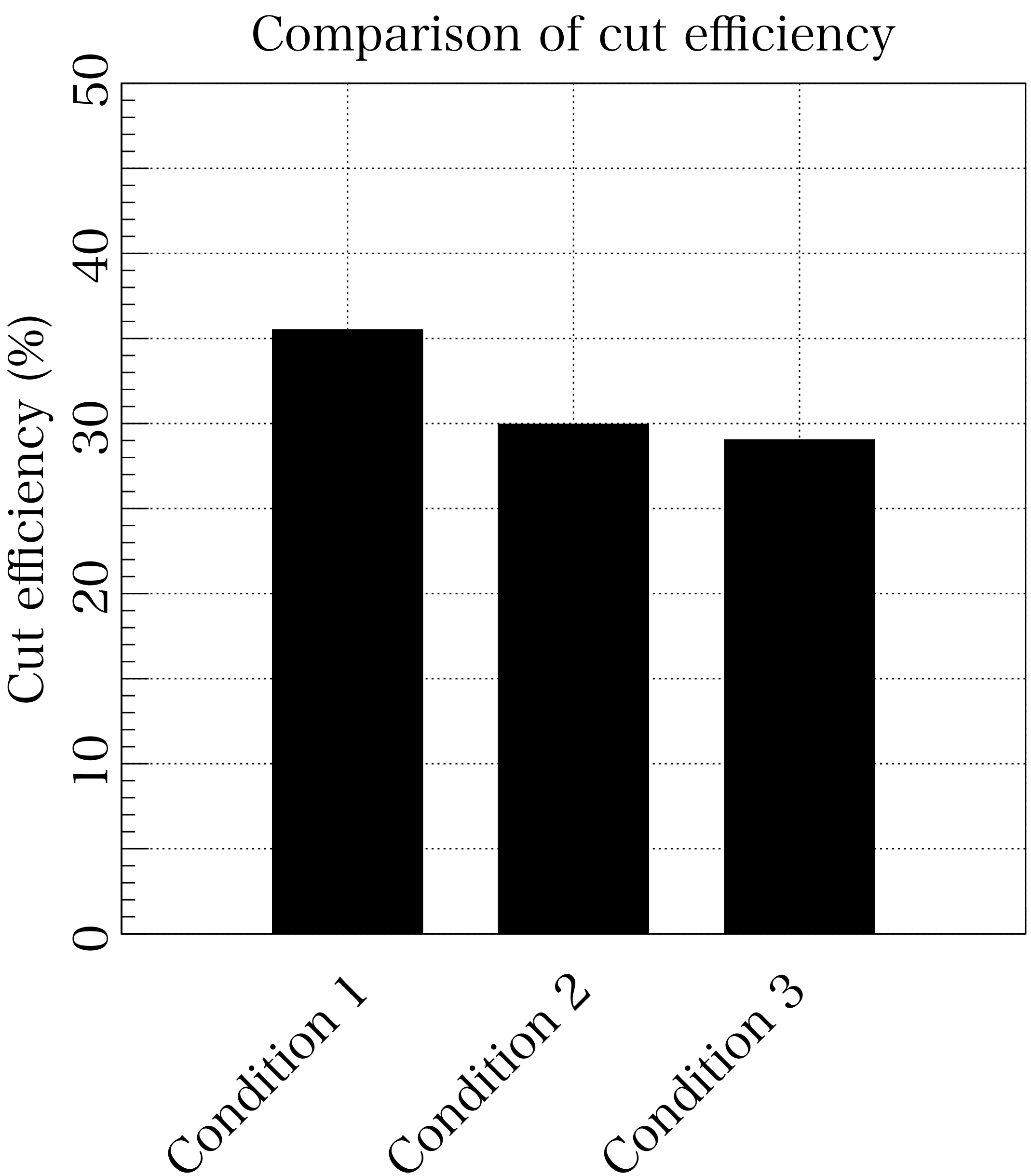
- In order to improve the cut efficiency, I will check next three method

1. All the events (E>50 MeV)

2. Max deposit energy events (E>50 MeV)

3. Energy weighted timing difference (Using all the crystals (E>50 MeV)

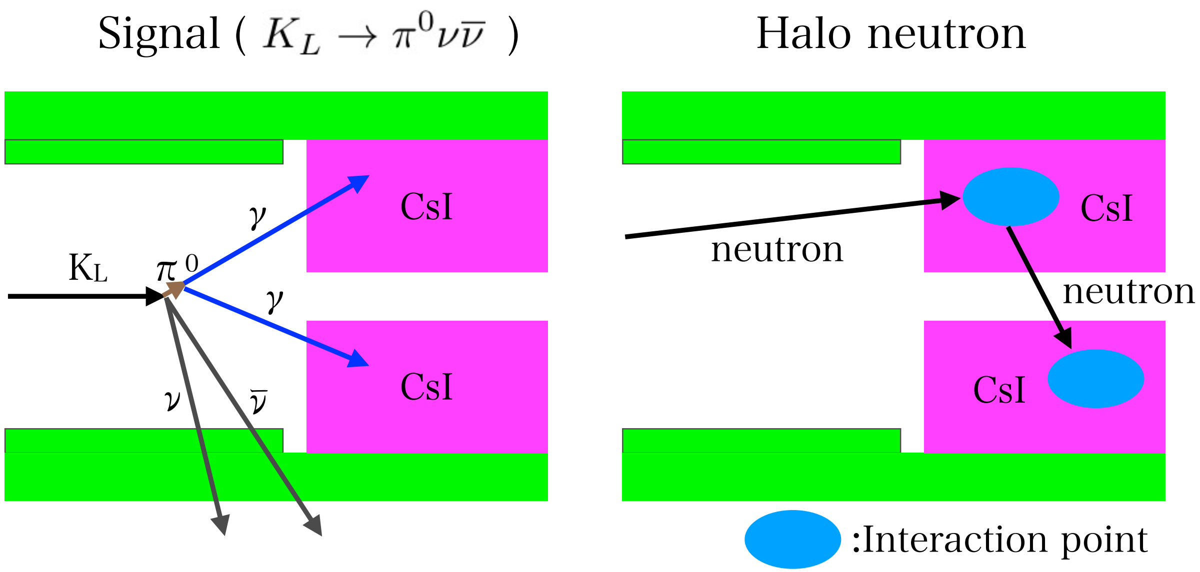
result



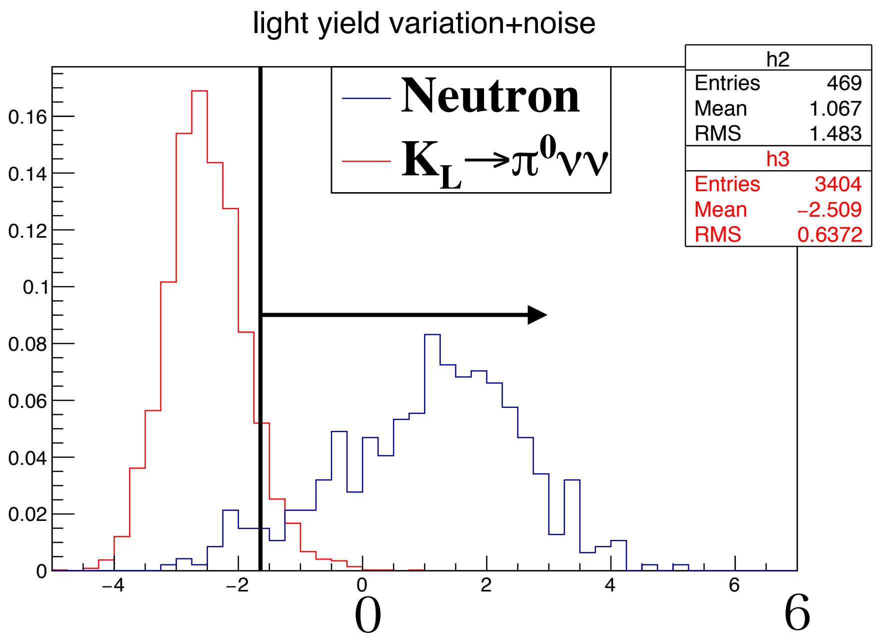
- Condition1 : All the events
- Condition2 : Max deposit energy events
- Condition3 : Energy weighted timing difference

- Cut efficiency of Energy weighted timing difference : best

Simulation w/ real KOTO detector



Using larger timing difference



X axis : Timing difference (ns)

Y axis : a.u.

Cut efficiency : 5.8 % (KL->pi0nunu : 90%)

Summary

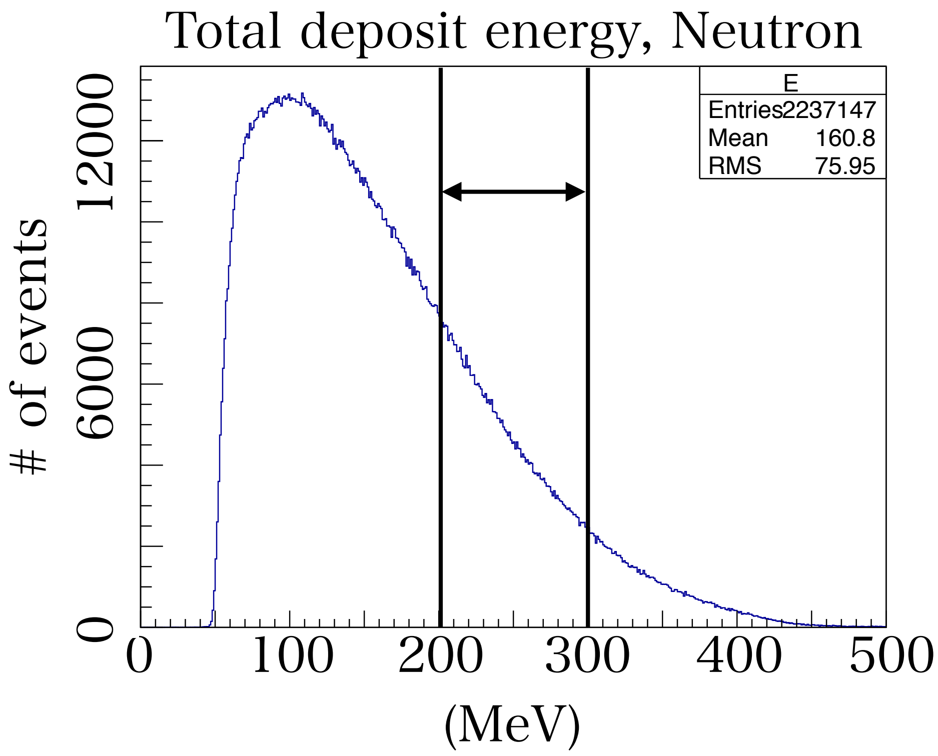
- We did the performance test of CsI readout system w/ 392 MeV neutron beam @ RCNP.
  - We can eliminate neutron events by timing difference.
- Best cut efficiency : Energy weighted timing difference
- Estimated the cut efficiency w/ real KOTO detector
  - Cut efficiency : less than 10 %

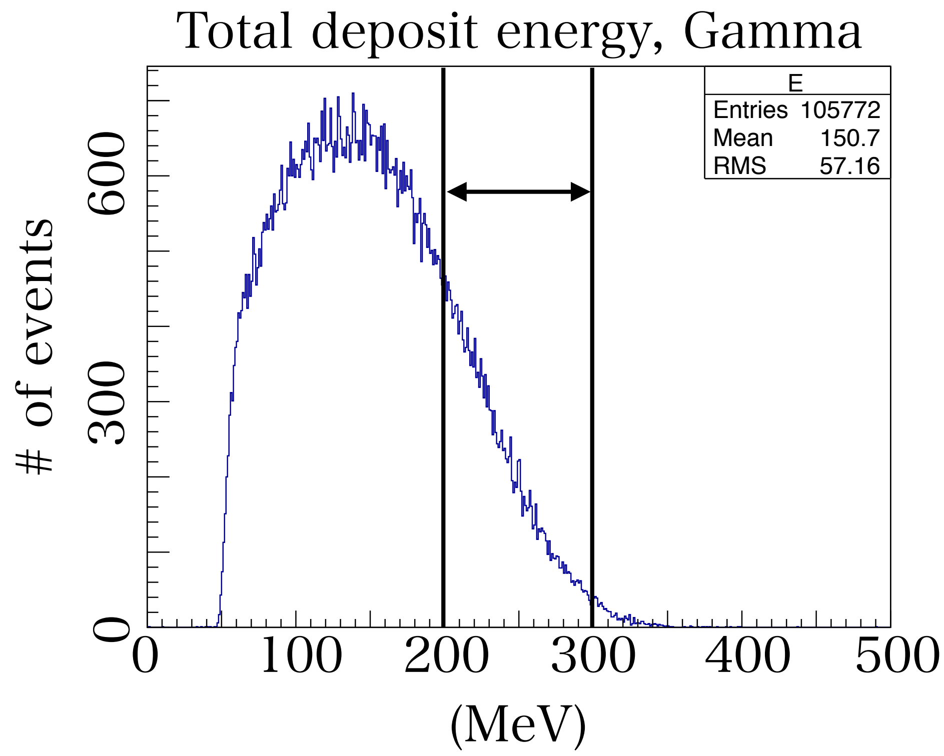
Prospects

- Detail simulation of halo neutron background estimation w/ KOTO detector
  - correlation w/ established cut.
- Study of the valley in timing difference distribution of neutron
  - Optical photon simulation

Backup

Total deposit energy



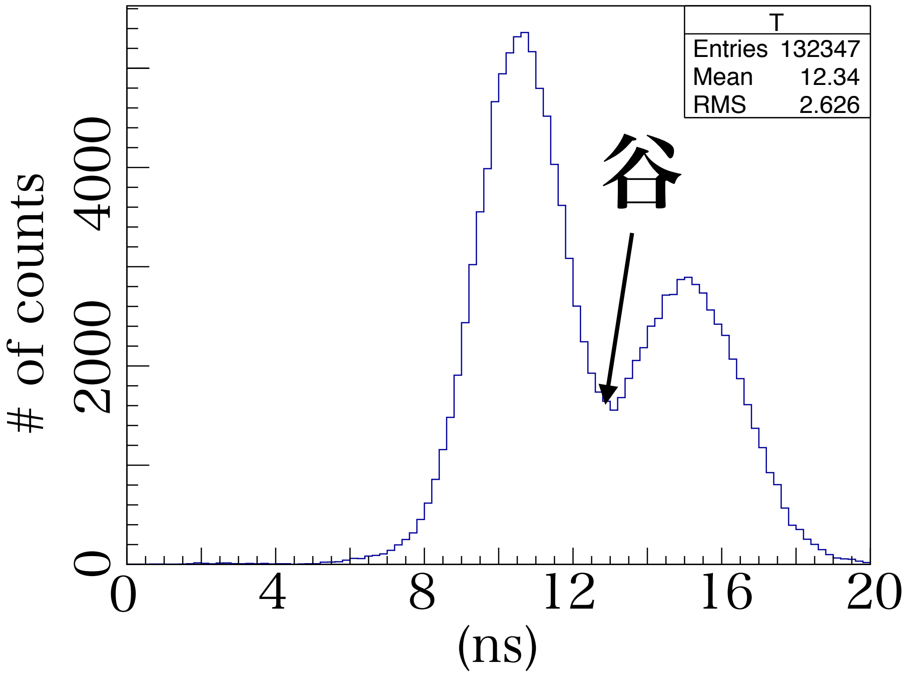


Using 200 (MeV)<totalEnergy < 300 (MeV)

中性子による時間差分布の理解

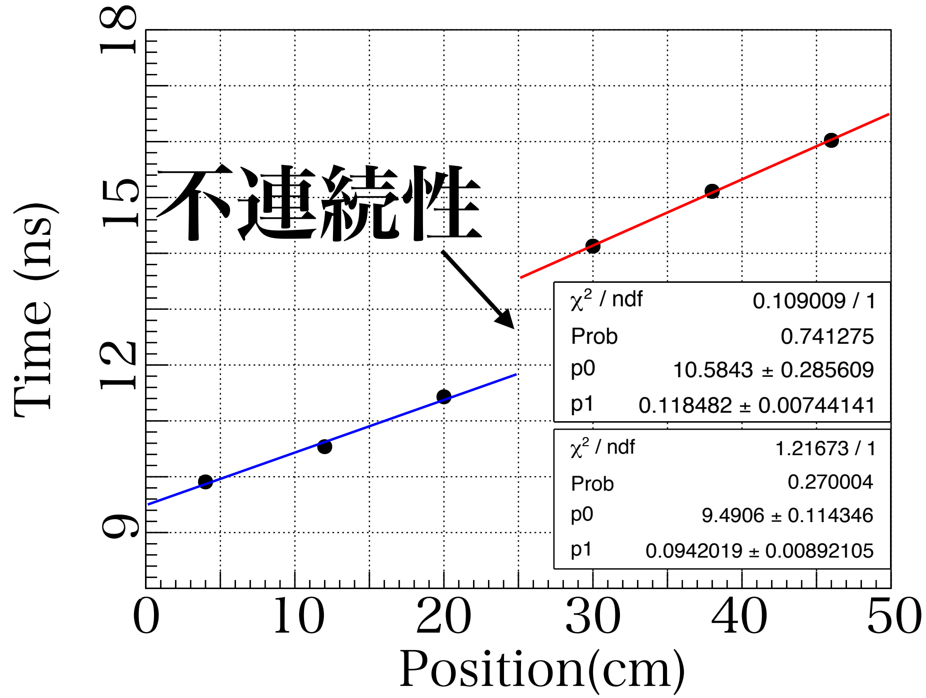
中性子の時間差分布 (50<Edep<100)

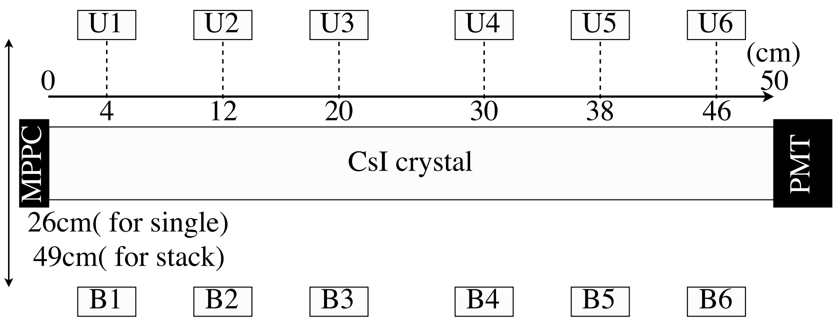
Timing difference (MPPC-PMT)



宇宙線測定による位置と時間差の関係

Timing difference : Position





不連続性が大きく谷ができる。

→ optical photonのシミュレーションでこの谷間と不連続性を調査する。

シミュレーションのセットアップ

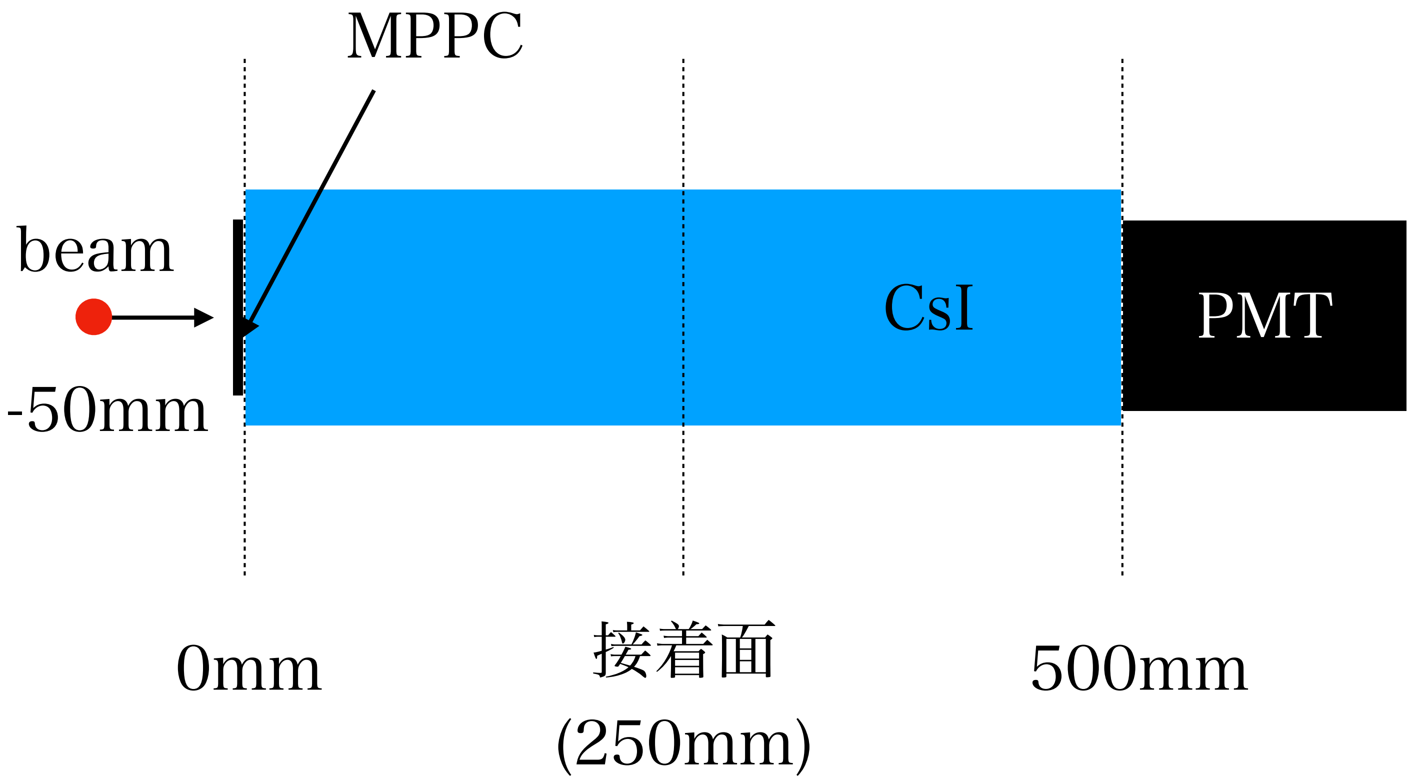
KOTOで使用しているCsI結晶は大半が真中で接着剤で接着されている。

屈折率

CsI結晶：2

接着剤：1.47

空気：1



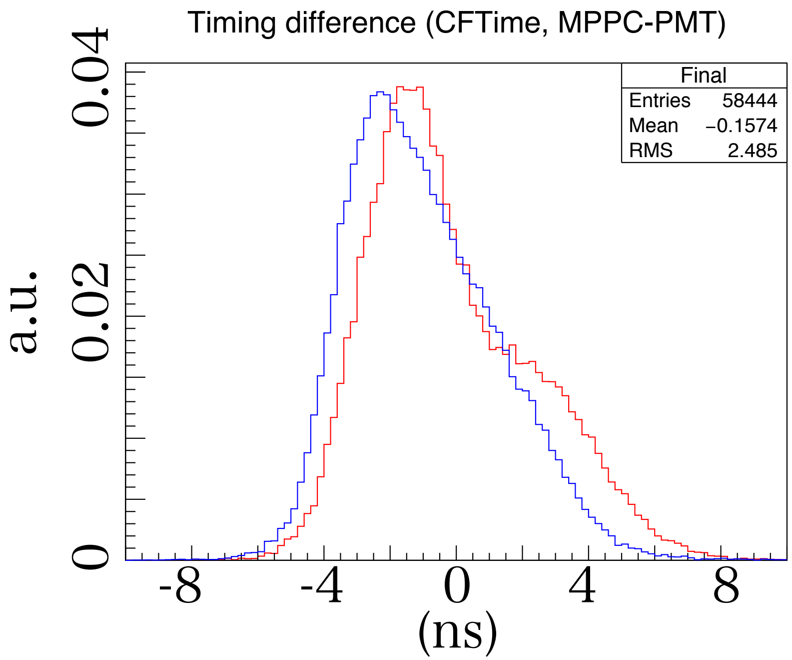
接着面における反射

1. 反射あり
2. 反射なし

反射に関して、側面は全反射、
他の面はフレネル反射を考える。

結果

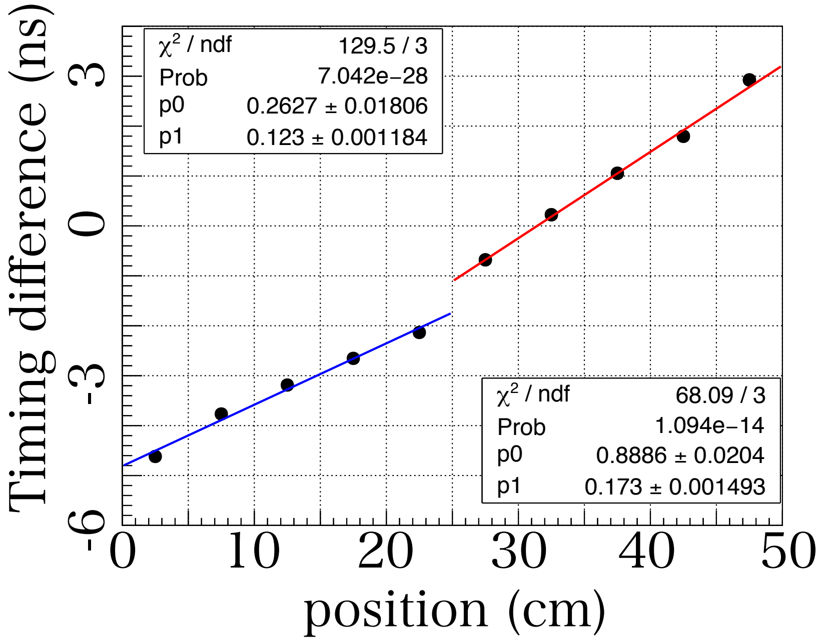
時間差 (400-MeV の中性子)



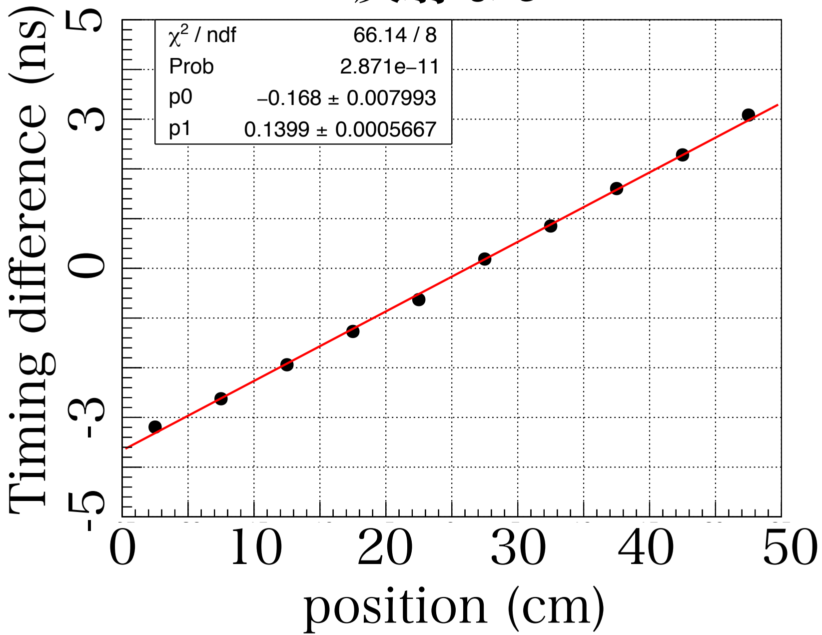
- 赤: w/ reflection
- 青: w/o reflection

- 接合部での反射を入れることで不連続性を再現できた。
- 谷については、見えてはいるが、不十分

反射あり

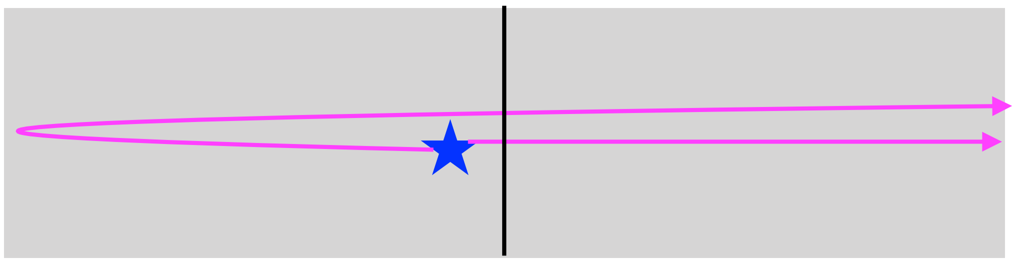


反射なし



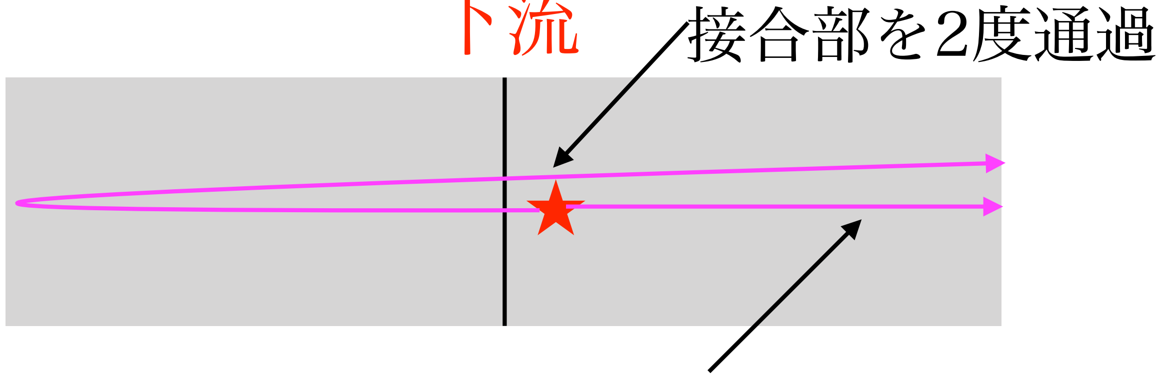
不連続な部分ができる原因

上流

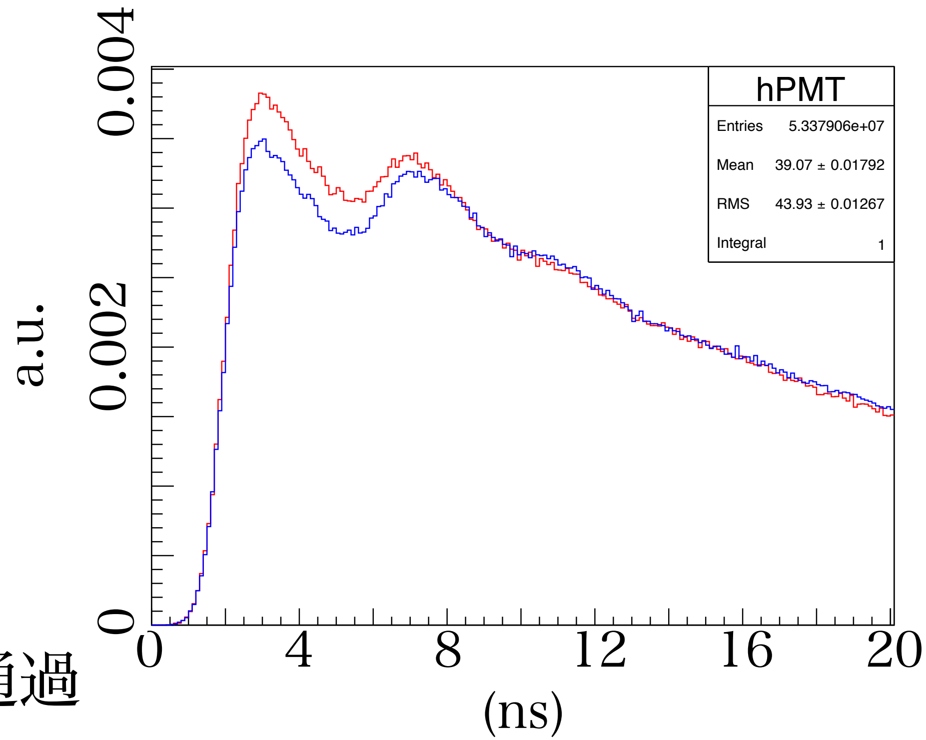


直接光、反射光共に接合部を通過する。

下流



Photon arrival timing distribution (detect at PMT)



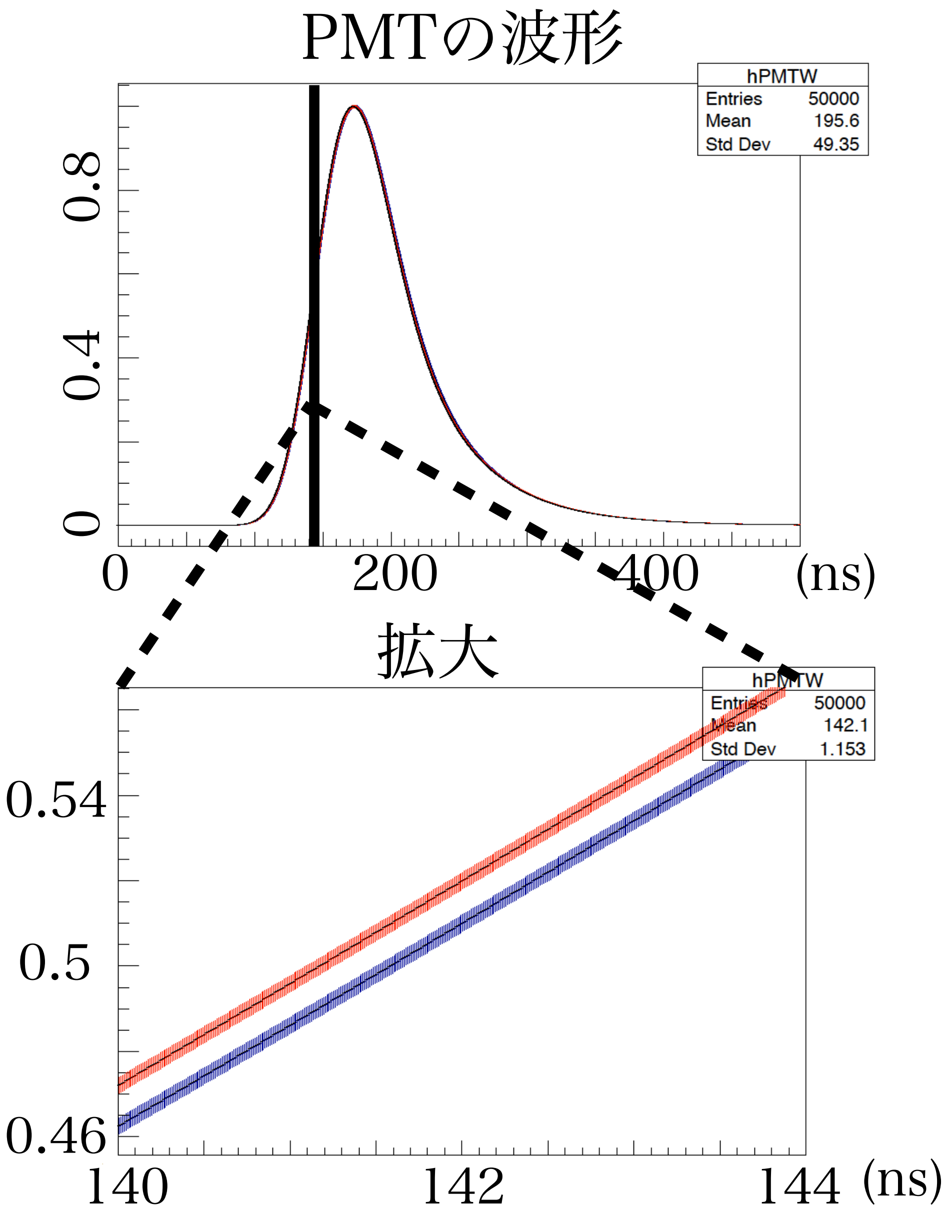
- 青：上流
- 赤：下流

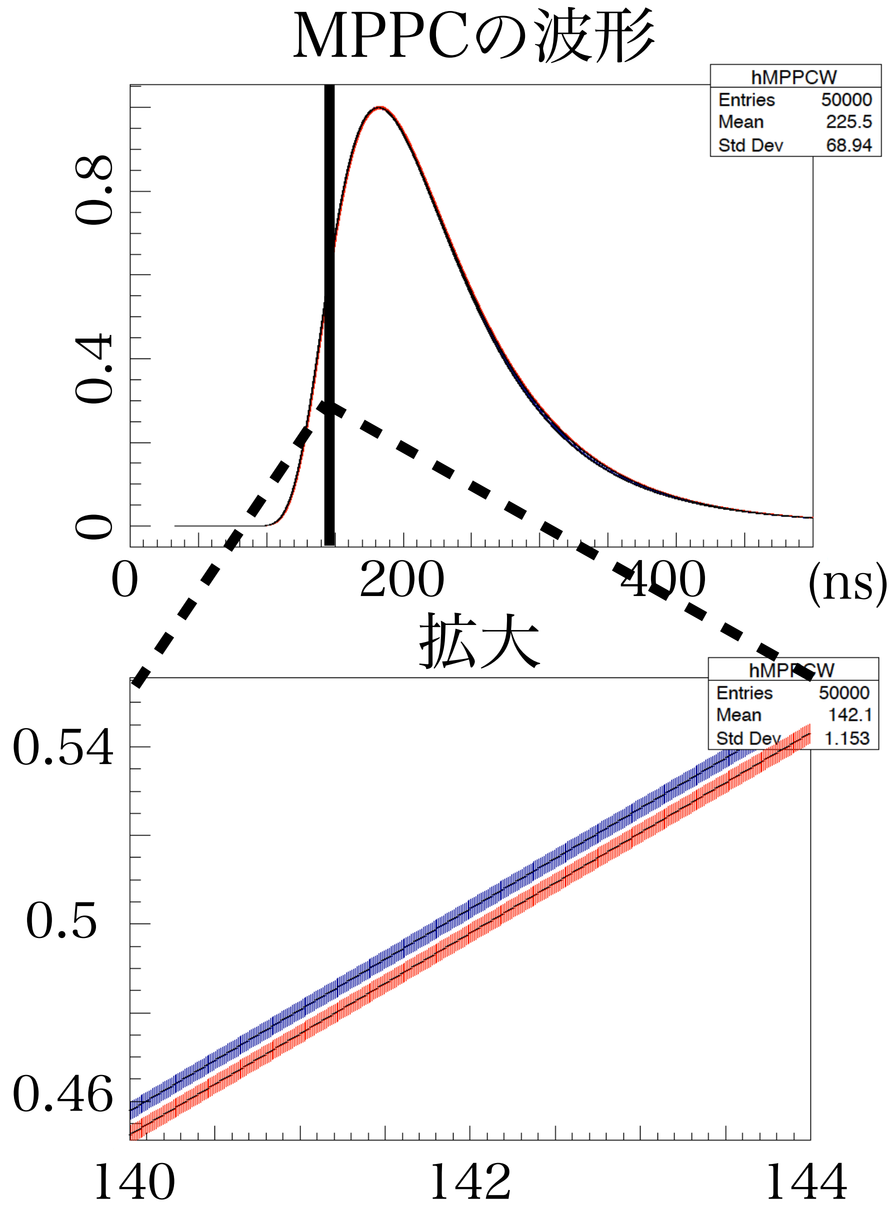
(±0.1mm)

上流：直接光 ~ 反射光

下流：直接光 >> 反射光

上流、下流の波形の違い

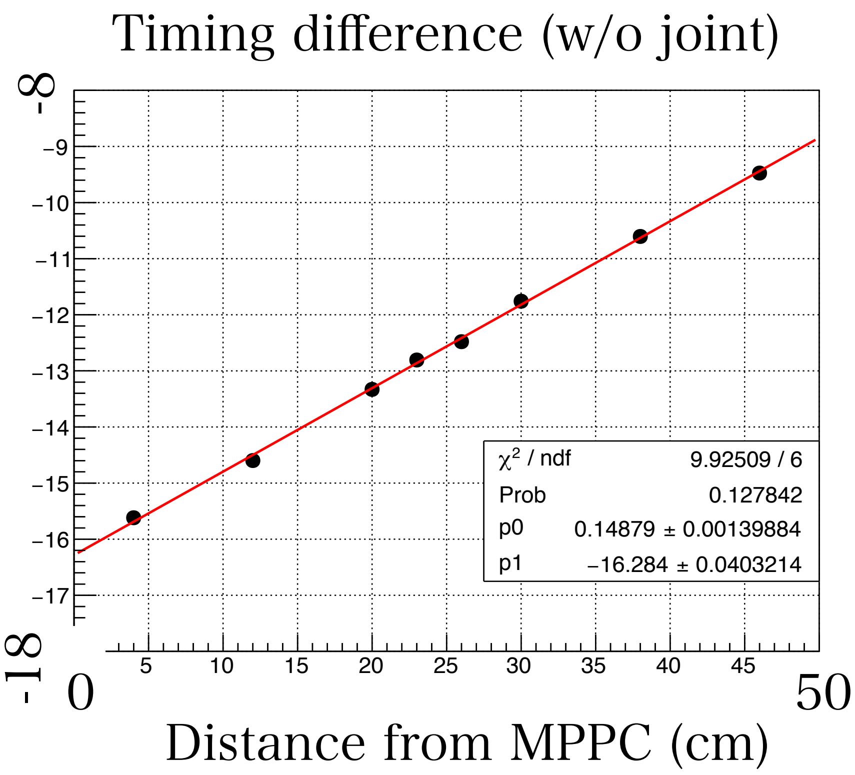


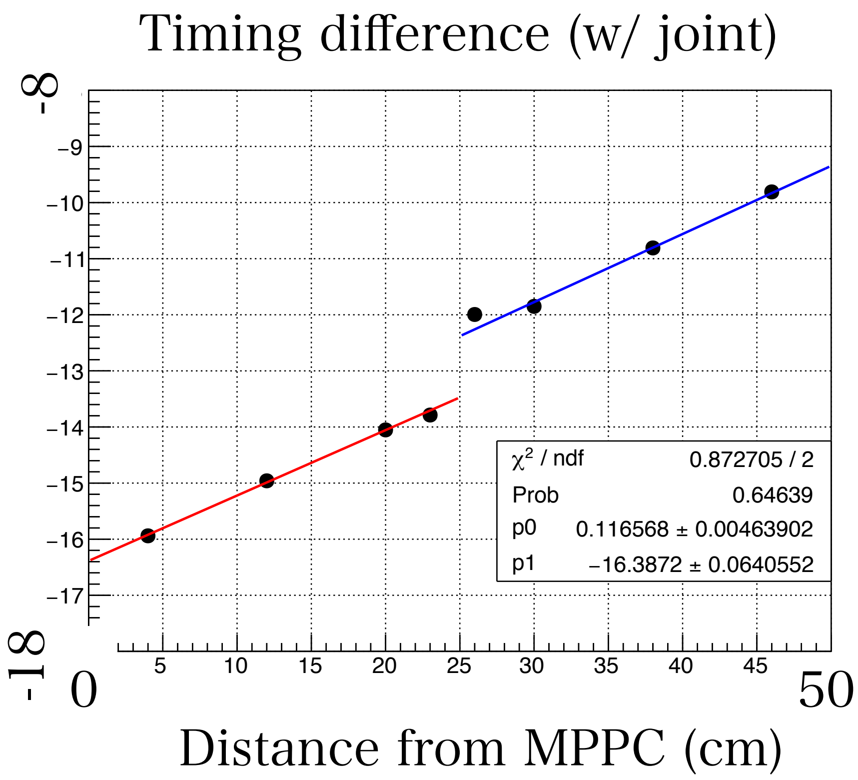


- 赤：下流
- 青：上流

反射光、直接光の違いにより時間差に違いが生じる
→時間差分布に不連続性が生じる。

Effect of crystal joint





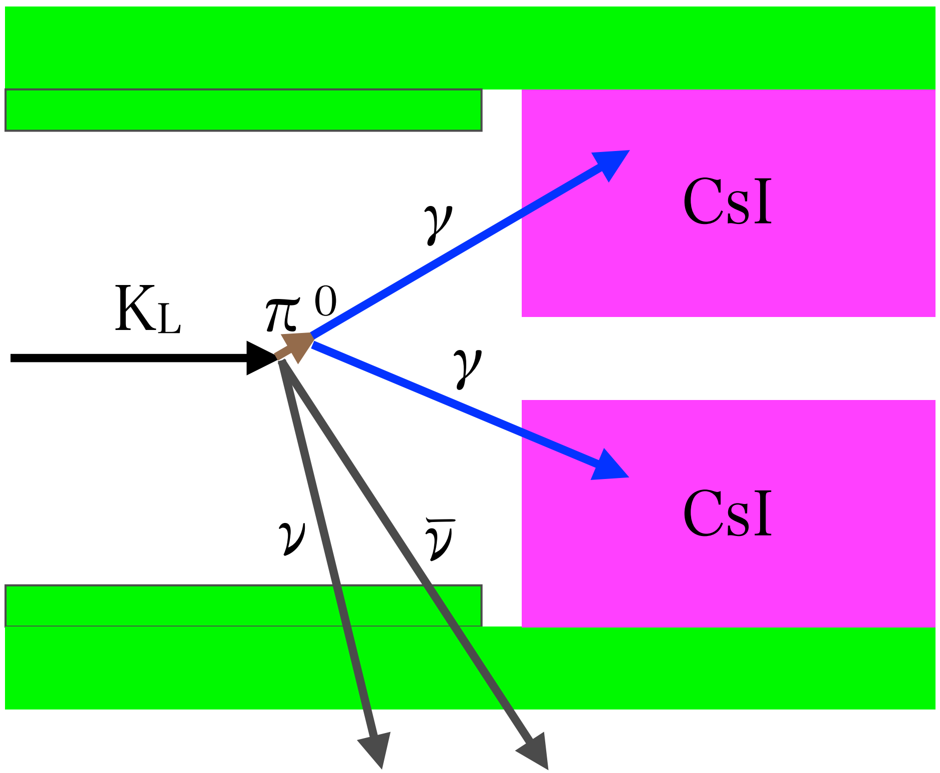
Joint makes the discontinuity for the timing difference distribution

Halo neutron background estimation

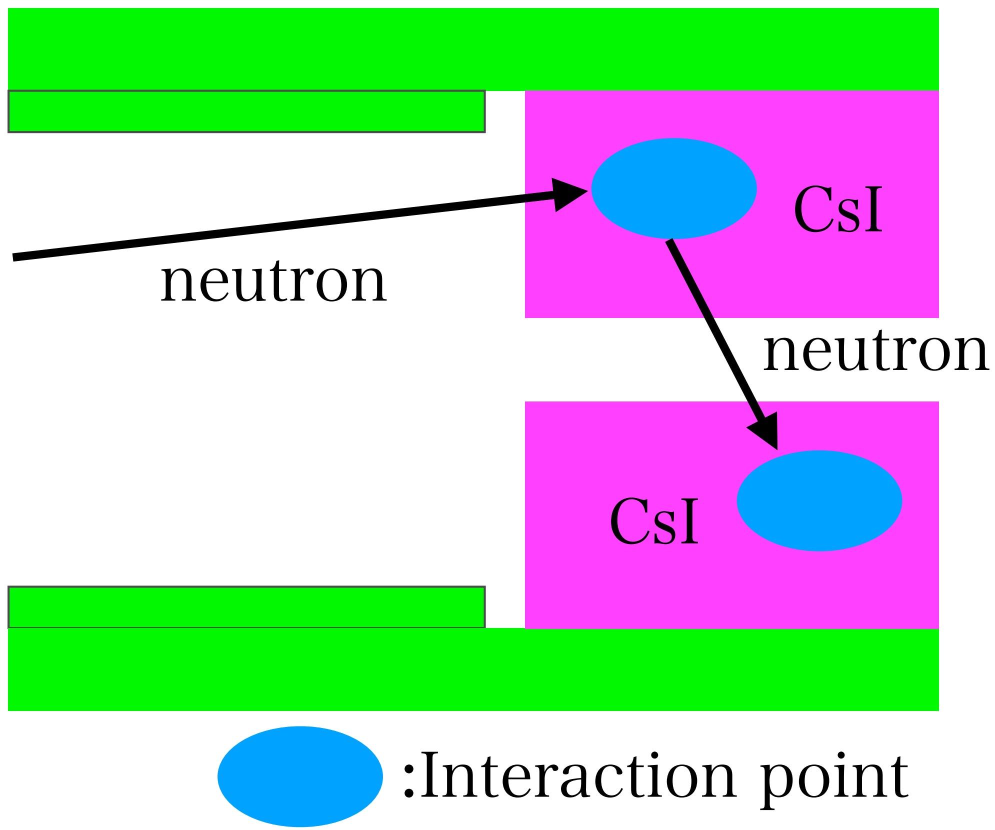
- To know the cut efficiency for the halo neutron background, I did the gsim simulation w/ KOTO detectors.
- Checked the cut efficiency w/ different light yields of MPPC readout
  - Light yield of MPPC affect timing resolution (Light yield worse → timing resolution worse → cut efficiency worse)

Halo neutron background

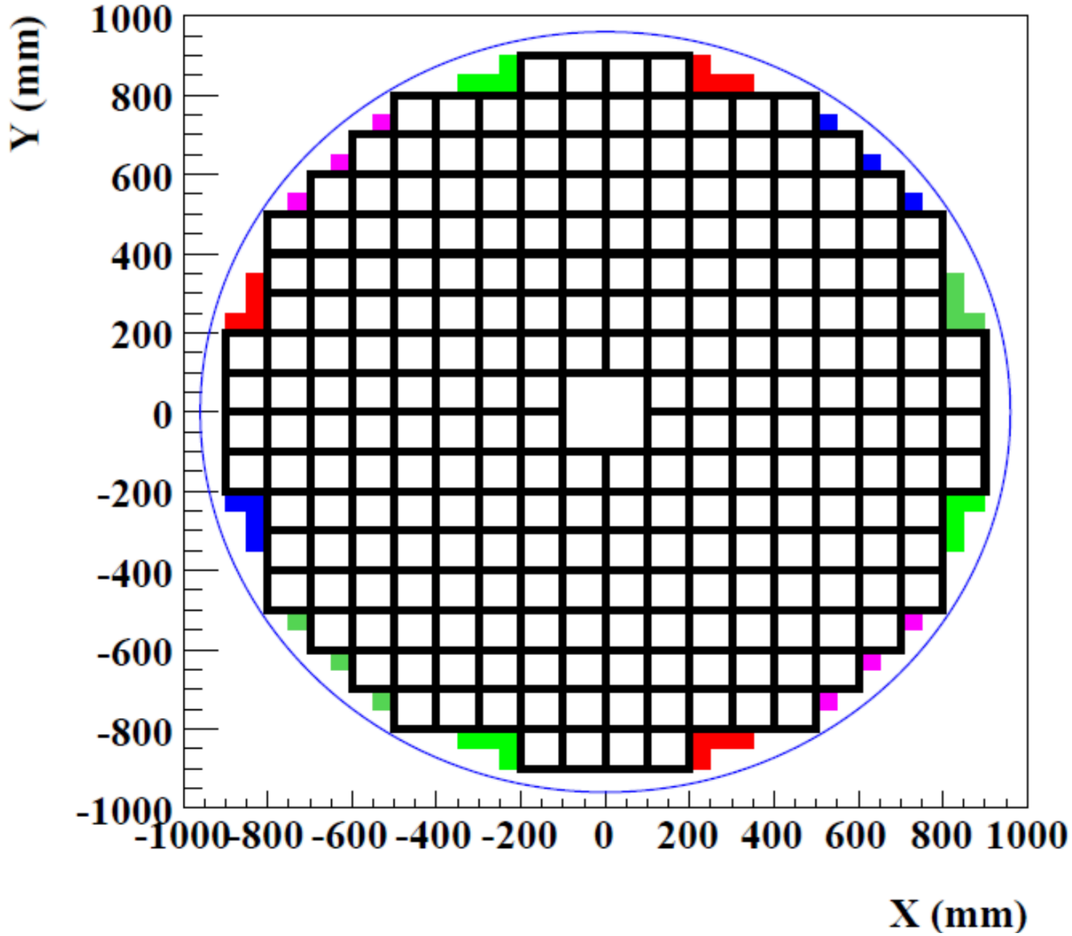
Signal ($K_L \to \pi^0 \nu \overline{\nu}$)



Halo neutron



CsI group

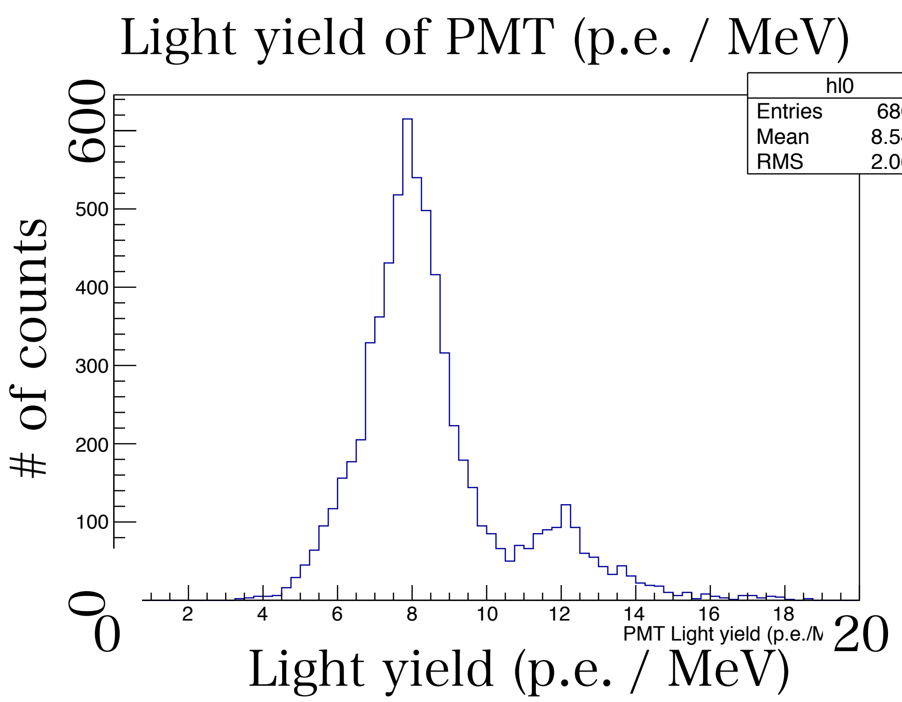


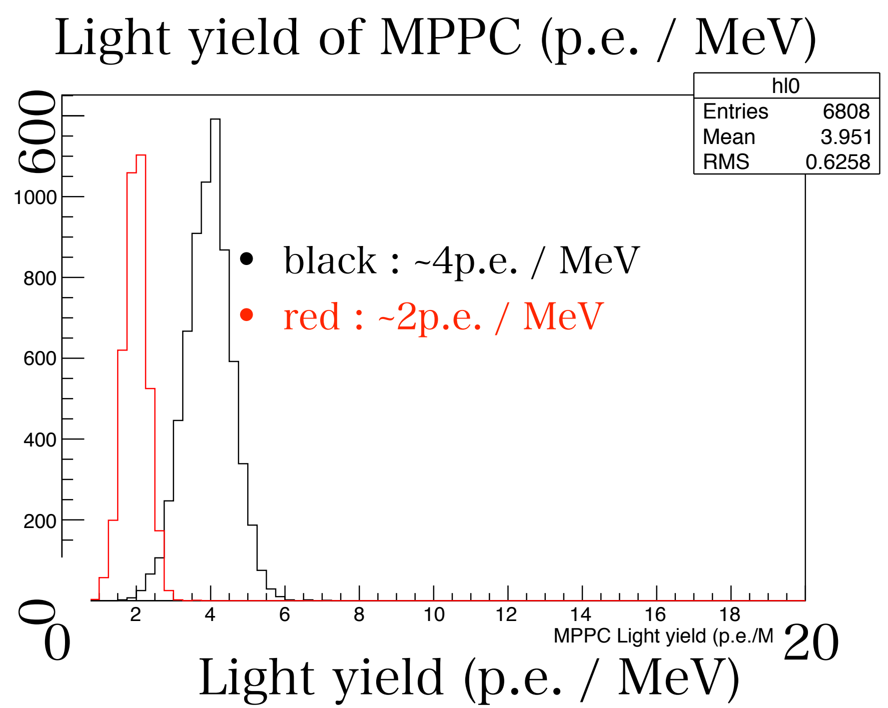
- I grouped CsI crystals in 10cm × 10cm regions
  - For both PMT and MPPC, I summed up the waveforms
- The crystal shown in color were not used

Event selection

- For both halo neutron events & KL->pi0nunu, I only use the event that can be reconstructed pi0
  - Also cut by COE, CsI total energy, Cluster RMS
  - Only using the veto cut for CBAR & CV
  - Did not use max shape chi2 & pulse shape likelihood cut.

Light yield of PMT & MPPC

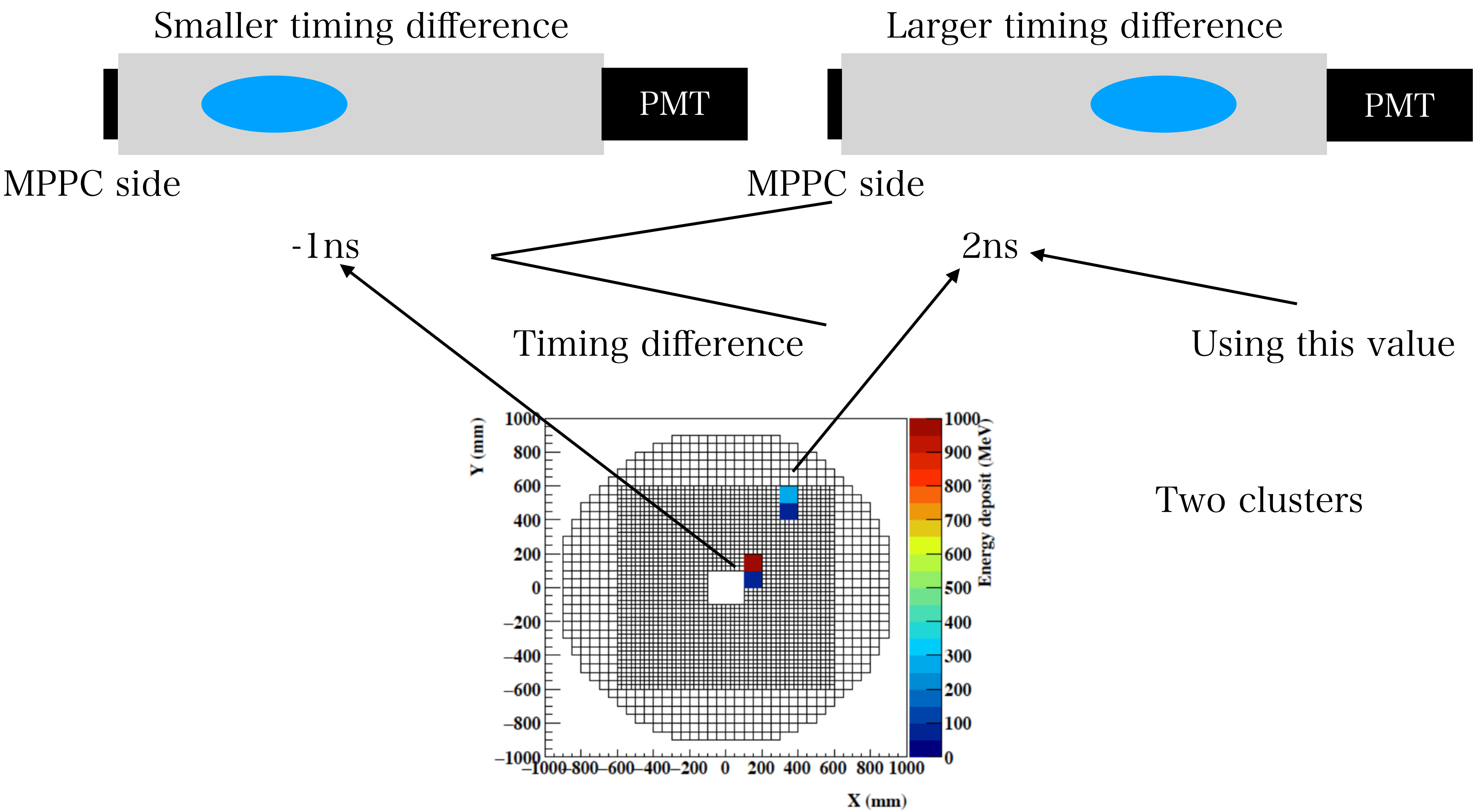




- Took the light yield variation btw/ crystals into account.
- Mean light yield = 8~9p.e. / MeV

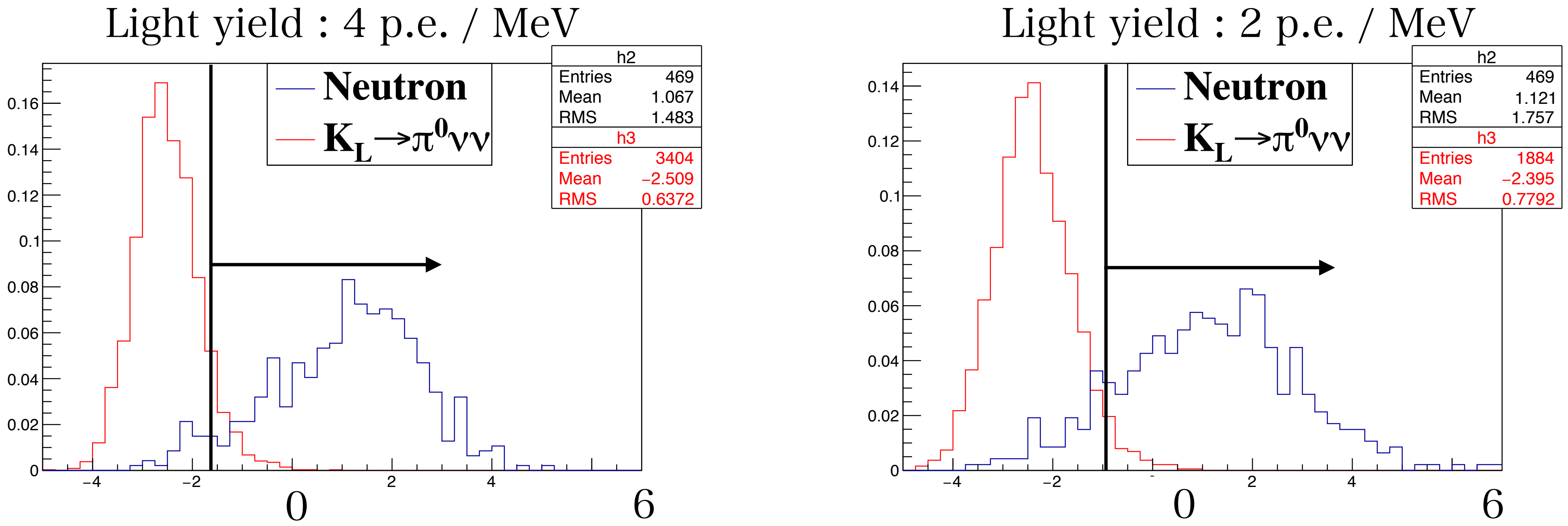
- Standard light yield for MPPCs = 4 p.e./MeV
- Also tried 2 p.e./MeV

Event example (Timing difference of the cluster)



On this time, I used the larger timing difference for the analysis.

Timing difference btw/ MPPC & PMT



X axis : Timing difference (ns)

Y axis : a.u.

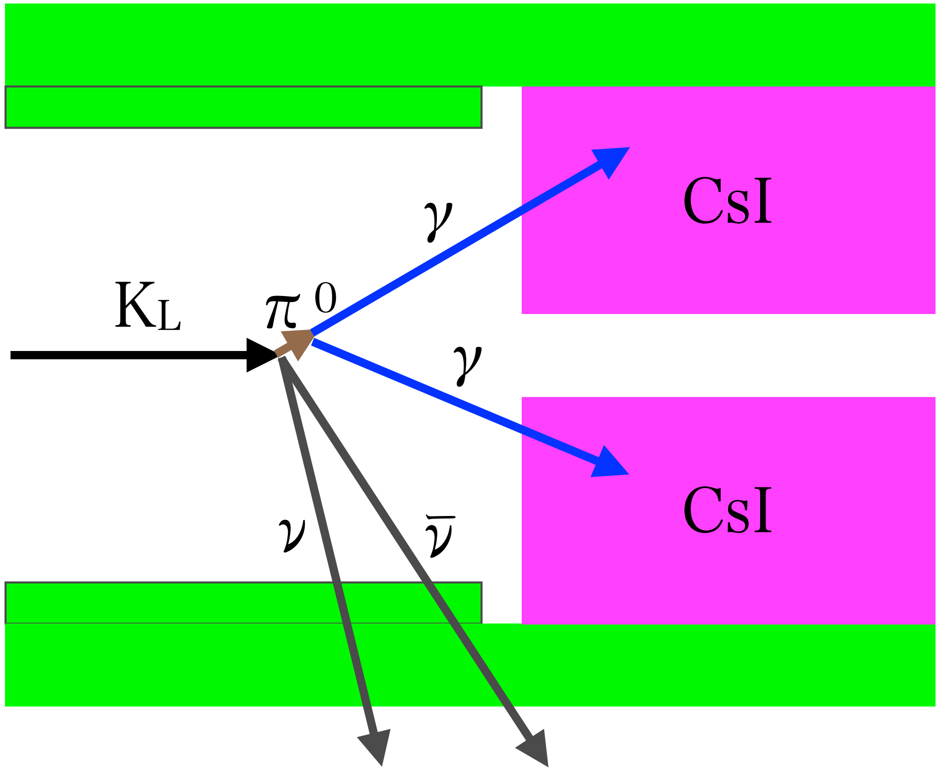
Cut efficiency : 5.8 % (KL->pi0nunu : 90%)

Cut efficiency : 7.7 % (KL->pi0nunu : 90%)

Cut efficiency w/ standard light yield is 1.5 times better than that w/ half light yield (MPPC)

→It must be affect @ standard model region

Signal ($K_L \to \pi^0 \nu \overline{\nu}$)



Halo neutron