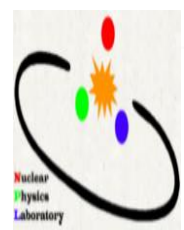




Simulation of Neutron Detector with Realistic Pulse Response for the High-energy LAMPS at RAON

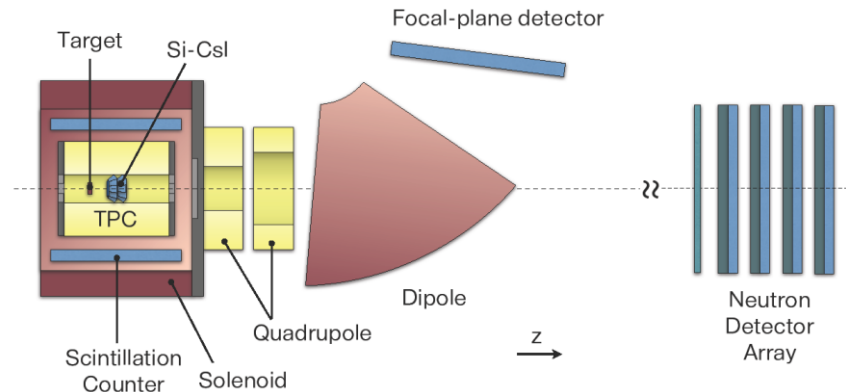
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ByungSik Hong,
(Korea Univ.)



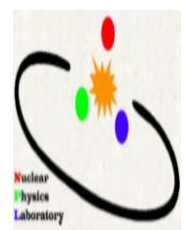
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- “RAON” – Korea Rare Isotope Accelerator at RISP
 - A Future multipurpose accelerator for the basic & applied sciences.
- LAMPS(Large Acceptance Multi-Purpose Spectrometer)
 - Primary purpose : Nuclear symmetry energy
 - Also useful for nuclear structure & nuclear astrophysics.
- Neutron detector
 - Neutron measurement is important to understand the isospin dependence of nuclear symmetry energy.
 - Should cover from a few tens to a few hundreds MeV.

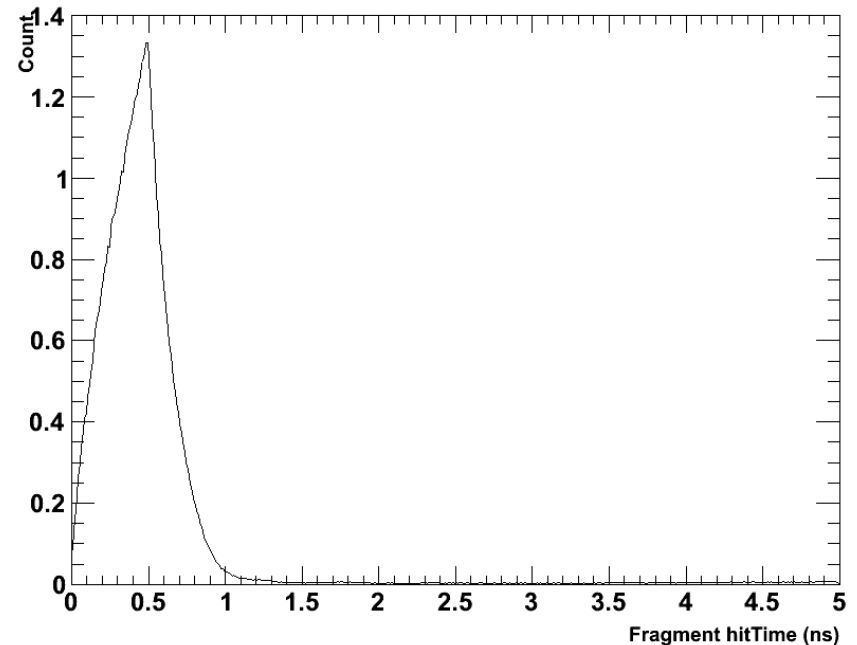
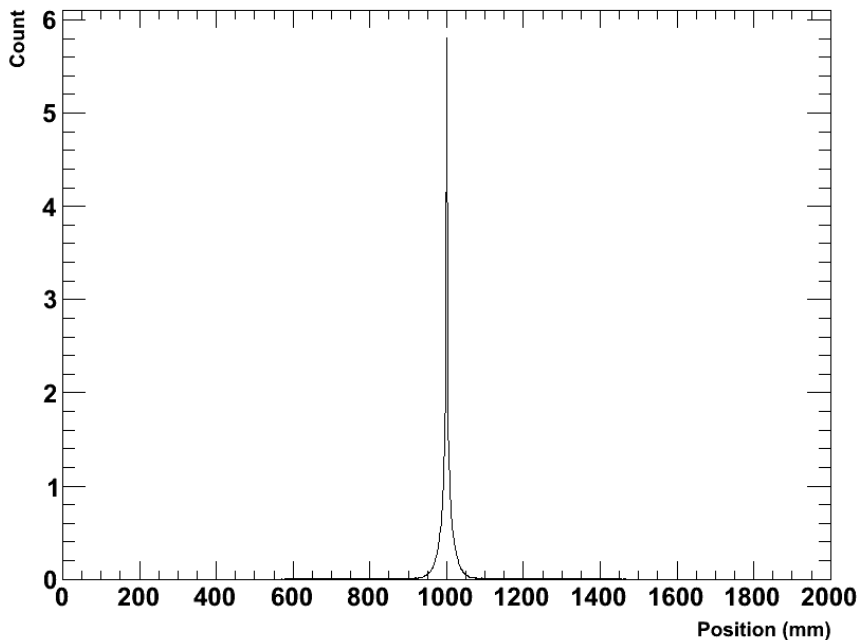


Motivation

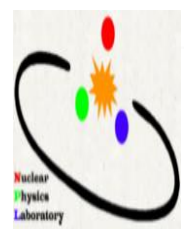


Grouping of Hit Fragments

- ❖ GEANT4 simulation 을 이용, $0.1 \times 0.1 \times 2 \text{ m}^3$ **bar-type scintillator module** 의 가운데에 300 MeV 의 중성자가 지나가면서 만들어지는 hit fragments 의 위치 및 시간 분포
 - Hit fragments 를 group 별로 분류하기 위한 시간 및 위치 조건을 보기 위함.

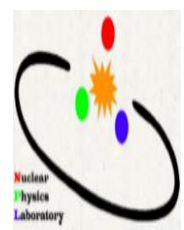


- Hit fragments 의 위치는 중성자가 지나간 위치 l_n 을 기준으로 약 100 mm 이내에 분포.
- Hit fragments 의 생성 시간은 중성자가 scintillator 내에 입사한 시간을 기준으로 약 2 ns 내에 분포.



Grouping of Hit Fragments

- 각각의 event에서, gate time(= 150 ns) 동안 bar scintillator 에 남겨지는 모든 hit fragments 를 모은다.
- 실제 실험에서 하나의 bar scintillator 안에 2개 이상의 signal 이 존재할 때,
 - 생성된 위치의 거리가 **100 cm** 이상 떨어져 있거나,
 - 생성 시간이 **2 ns** 이상 차이가 날 때,각각 구분 가능.
이 결과를 적용하여, hit fragments 를 각각의 group 으로 분류.
- 각각의 group 내의 hit fragments 에 대해서, Birks formula 를 적용.



Birks Formula

❖ Birks Formula

$$\frac{dL}{dz} = \frac{SdE/dz}{1 + kBdE/dz + C(dE/dz)^2}$$

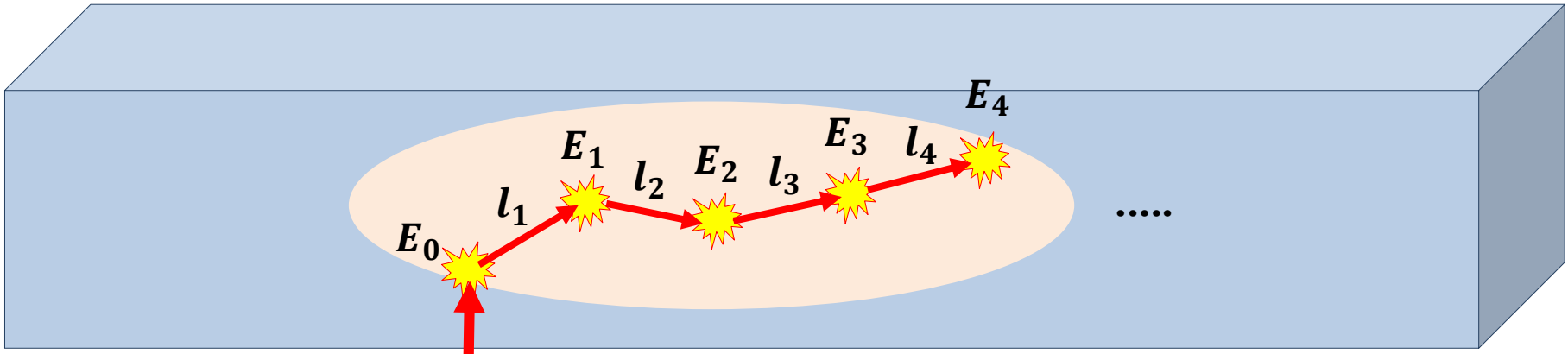
- Empirical formula for the **light yield per path length** as a function of the **energy loss per path length**.
- L : Scintillation response. In simulation, $L = E_{corr}$
- E : Specific energy loss at a depth z
- z : Path length
- S : Electronics response per specific energy loss at the non-quenching limit. Mostly, $S = 1$
- kB : 1st order parameter. From experiment, $kB = 0.977 \times 10^{-2} \text{ g cm}^{-2} \text{ MeV}^{-1}$
- C : 2nd order parameter

It is expected strength is about two-order smaller than the one for kB .

It becomes significant as the specific energy loss exceeds

Therefore, it does not have to be considered for neutron event.

Birks Formula



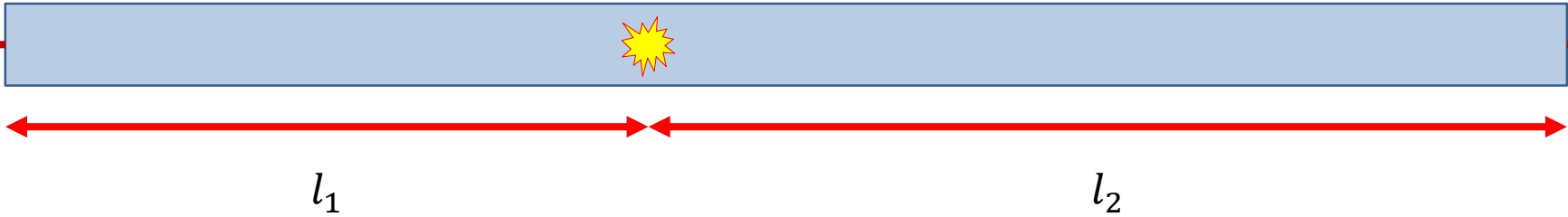
$$E \equiv \sum E_i$$

- Scintillator(BC-408) density $\rho = 1.032 \text{ g cm}^{-3}$
- Path length $z_i \equiv (\text{density}) \cdot (\text{distance between } (i - 1)\text{-th \& } i\text{-th hit}) = \rho l_i \text{ (g cm}^{-2}\text{)}$
- (i-th GEANT4 deposited energy) / $z_i \equiv E_i/z_i = E_i/\rho l_i \text{ (MeV g}^{-1} \text{ cm}^2\text{)}$
- (i-th corrected deposited energy) / z_i / ((i-th GEANT4 deposited energy) / z_i)

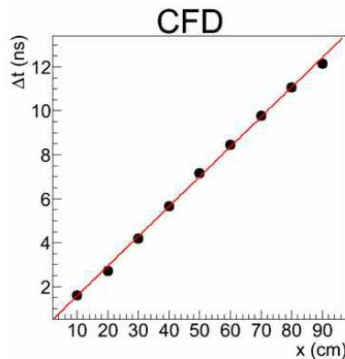
$$= \frac{E_{\text{corr}-i}/z_i}{E_i/z_i} = \frac{1}{1 + kB(E_i/z_i)} \quad (\text{Birks parameter } kB \approx 0.977 \times 10^{-2} \text{ g cm}^{-2} \text{ MeV}^{-1})$$

- $E_{\text{corr}} \equiv \sum E_{\text{corr}-i}$: Scintillator-response-corrected total deposited energy

Propagation & Attenuation



- ❖ It takes some time until the light reach to the PMT at each side of scintillator.



$$x = |l_1 - l_2|$$

$$\Delta t = \frac{x}{0.5 v} = \frac{|l_1 - l_2|}{0.5 v}$$

$$1/(\text{slope}) = v \approx 160 \text{ mm/ns}$$

$$\text{Propagation time } t_p = \frac{l}{v}$$

- ❖ As the light moves through scintillator, it loses its energy.
 - BC-408 bulk attenuation length : 380 cm = 3800 mm

$$E_{PMT1} = E_{corr} \exp\left[-\frac{l_1}{3800}\right]$$

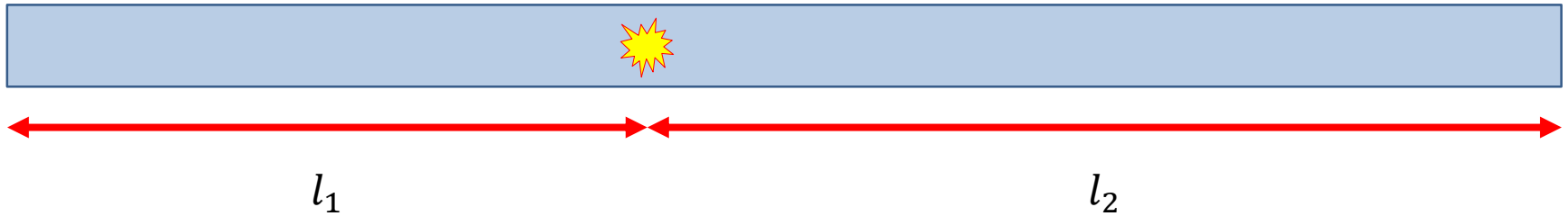
$$E_{PMT2} = E_{corr} \exp\left[-\frac{l_2}{3800}\right]$$

Signal Generation

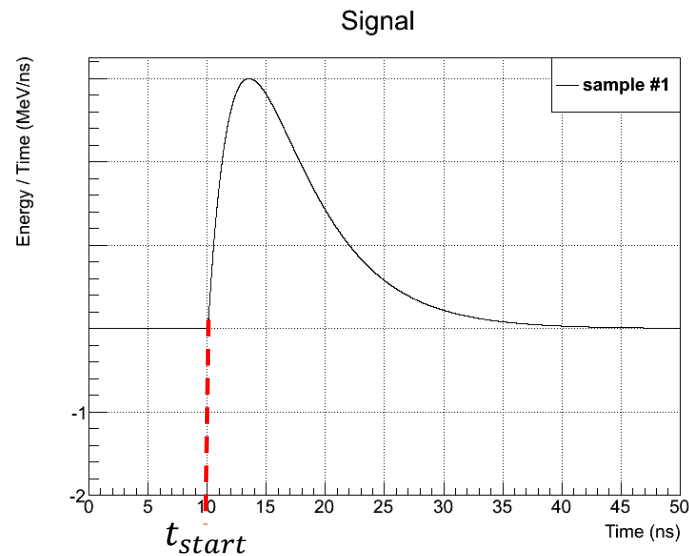
$$t_{start1} = t_0 + t_{p1} = t_0 + \frac{l_1}{v}$$

t_0

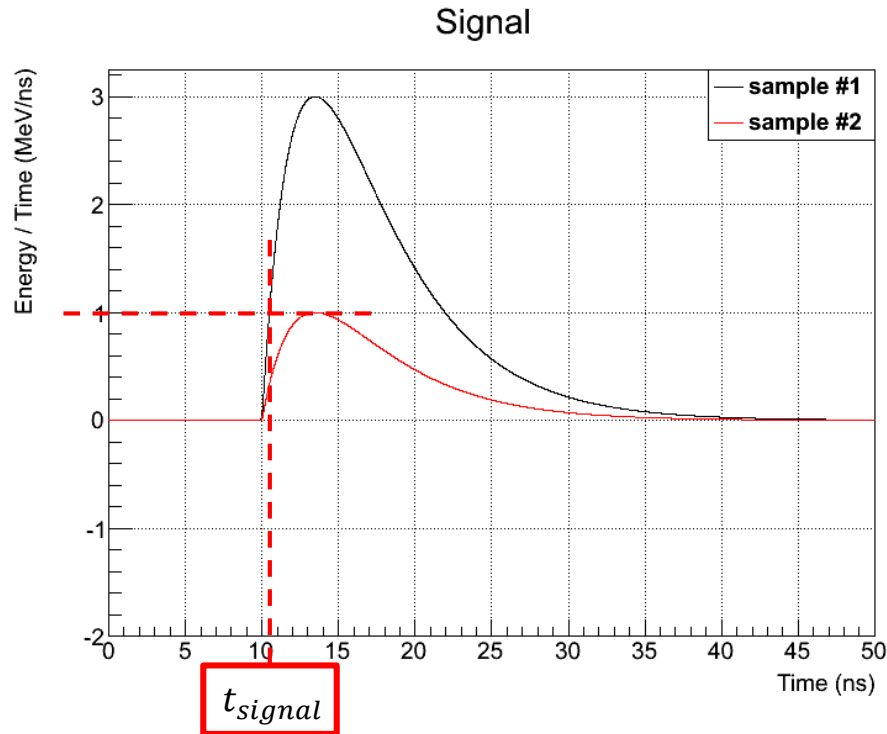
$$t_{start2} = t_0 + t_{p2} = t_0 + \frac{l_2}{v}$$



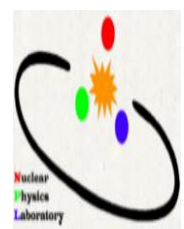
- Light arrival time at the end of the scintillator = signal start time (t_{start1}, t_{start2})



Threshold & Signal hitTime



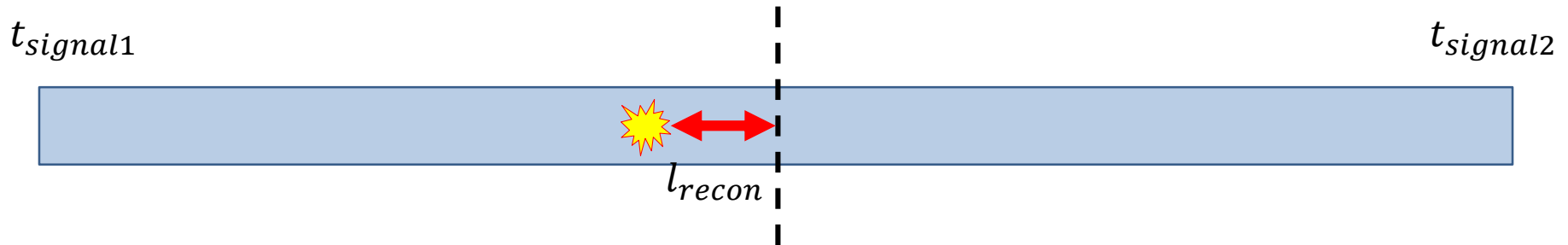
- Signal 과 시작점이 같고, 파형이 같은 threshold signal 을 만든다.
- (Signal 의 높이가 threshold signal 의 최대값과 같아지는 지점에서의 시간)
= (simulation 에서 사용하는 signal hitTime)
≈ (실제 실험에서 얻어지는 signal hitTime)



Threshold & Signal hitTime

- **Signal hitTime t_{signal}**
 - = (중성자에 의해 scintillator 에 light 이 발생하는 시간 t_0)
 - + (light propagation time $t_p = \frac{l}{v}$)
 - + (PMT 에서 발생한 signal 의 높이가 threshold signal 의 최대값과 같아질 때까지 걸리는 시간)
- Deposited energy 값에 따라, 중성자가 같은 위치를 지나가는 경우만을 비교하더라도 signal hitTime 이 달라질 수 있다.
 - **Time resolution**
- 양 쪽 PMT 에서 만들어지는 두 signal 모두 threshold signal height 를 넘길 때에만 true 로 간주 하고, true signal hitTime 을 계산하여 저장한다.
 - **True signal hitTime = $0.5 \times (t_{signal1} + t_{signal2})$**

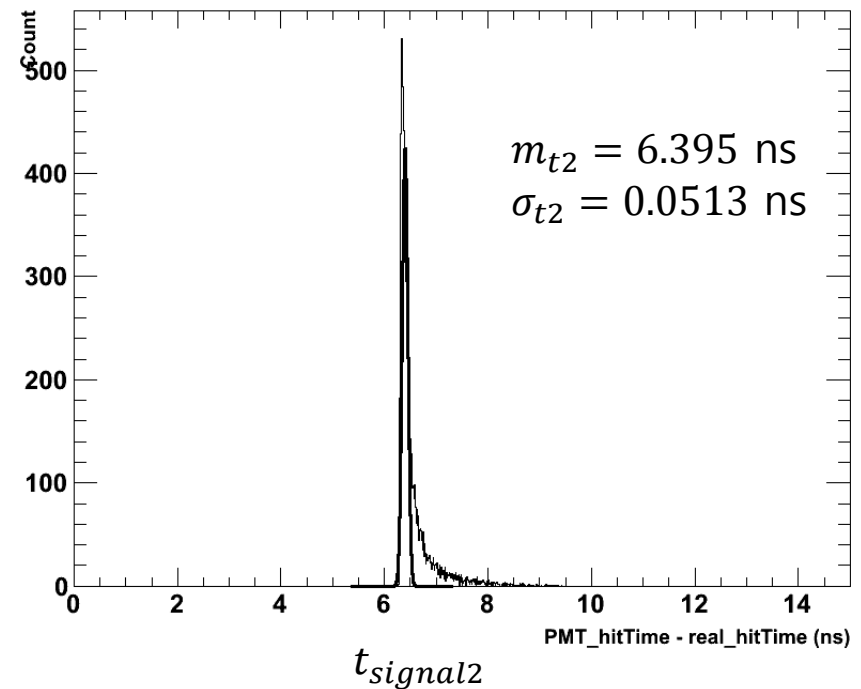
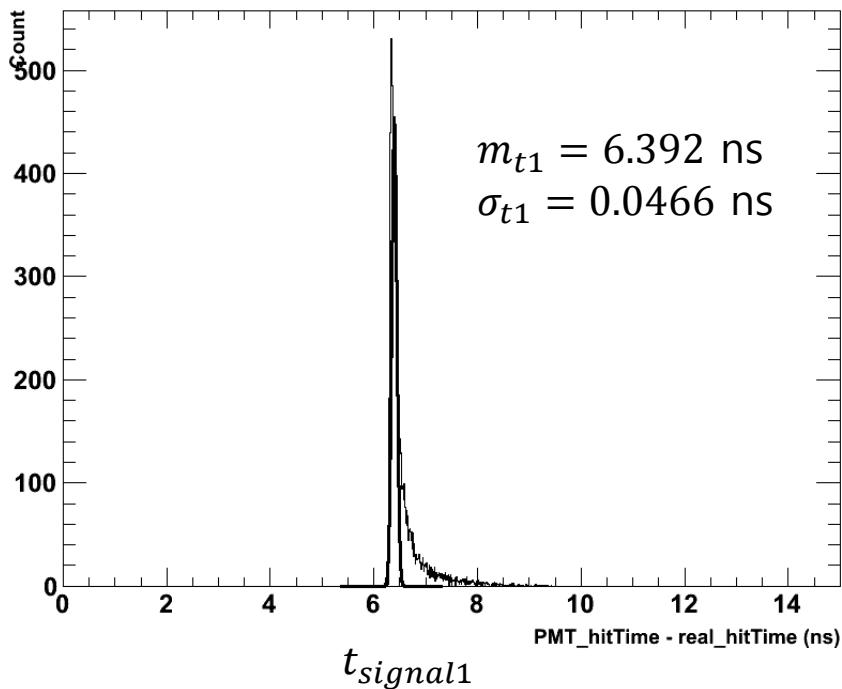
Position Reconstruction

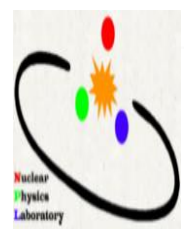


- Scintillator 양쪽 끝 PMT 의 hitTime 의 차이를 이용하여, light 이 발생한 위치(\approx 중성자가 지나간 위치)를 계산.
- **Reconstructed position** $l_{recon} = 0.5 \times (t_{signal1} - t_{signal2}) \times v$

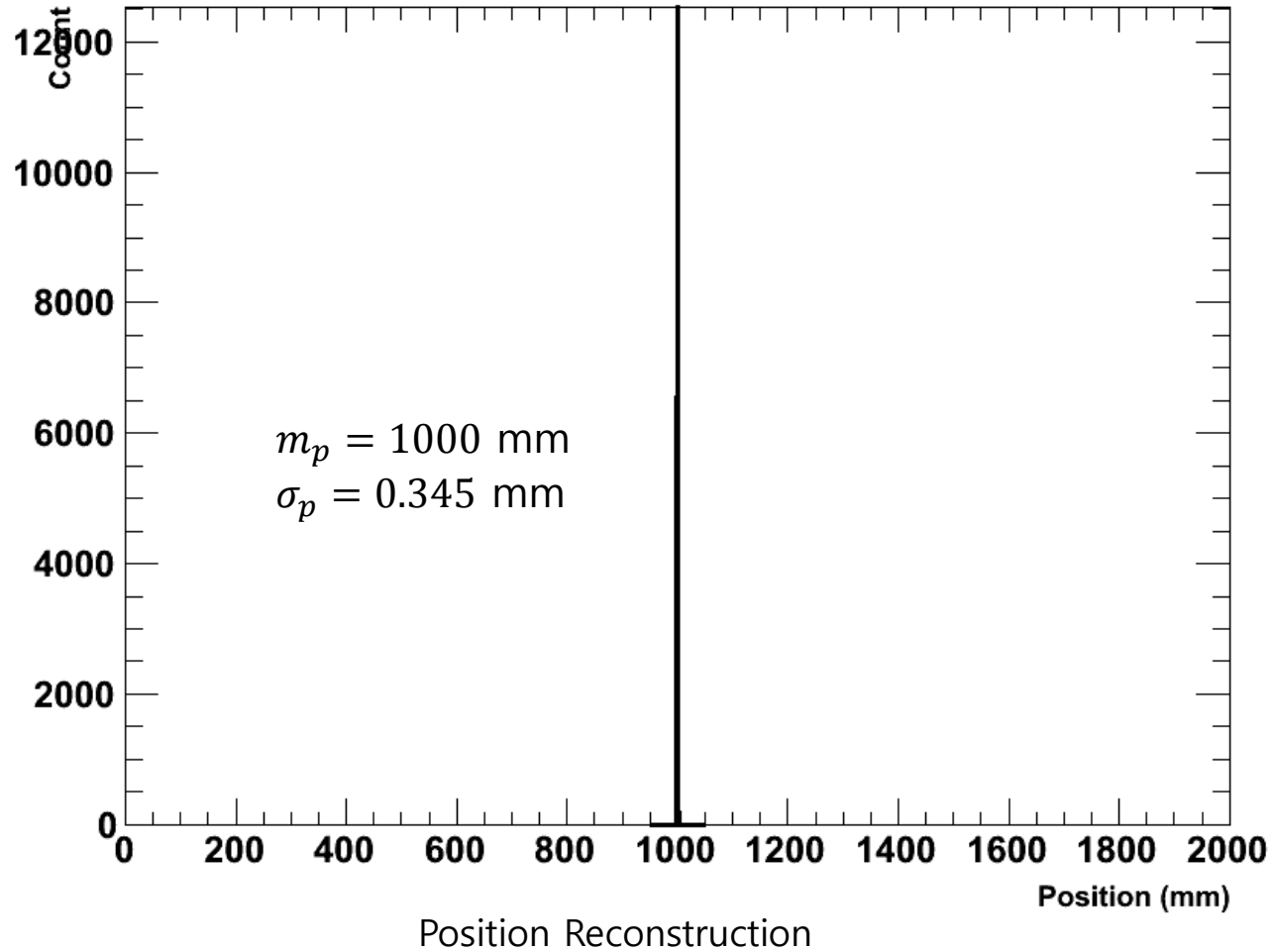
Result

- ❖ 300 MeV 의 중성자가 $0.1 \times 0.1 \times 2 \text{ m}^3$ bar-type scintillator module 을 지나간 경우 의 signal hitTime & position reconstruction distribution
 - Electron equivalent threshold = 5 MeV
- $l_1 = 100 \text{ cm}$, $l_2 = 100 \text{ cm}$ (center)



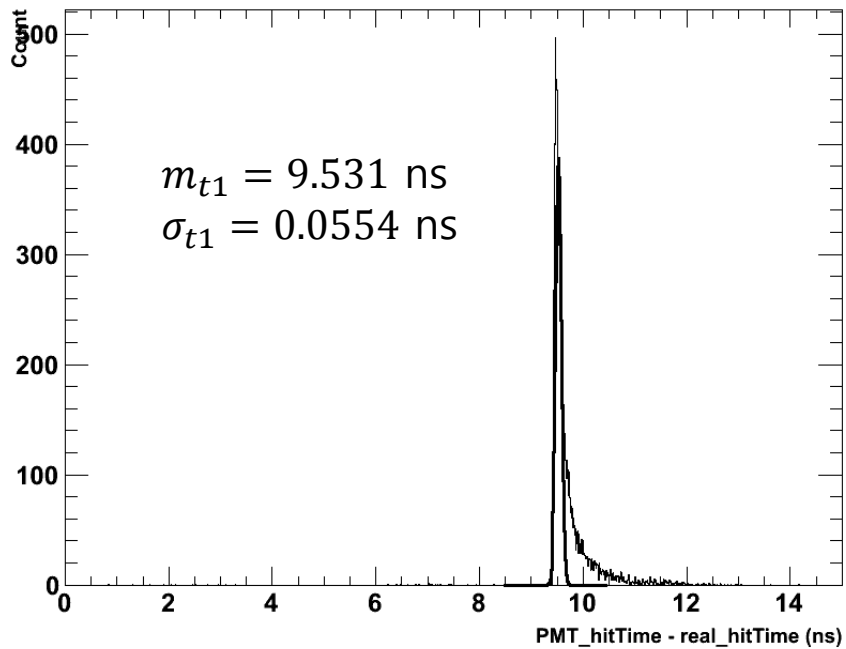


Result

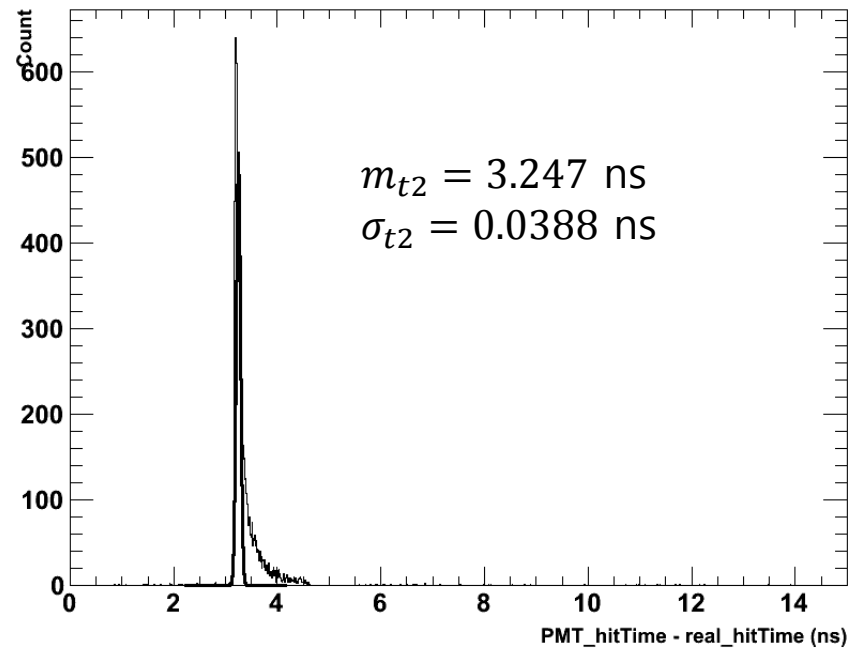


Result

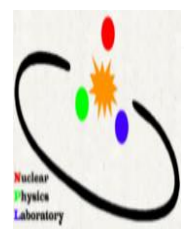
- $l_1 = 150$ cm, $l_2 = 50$ cm



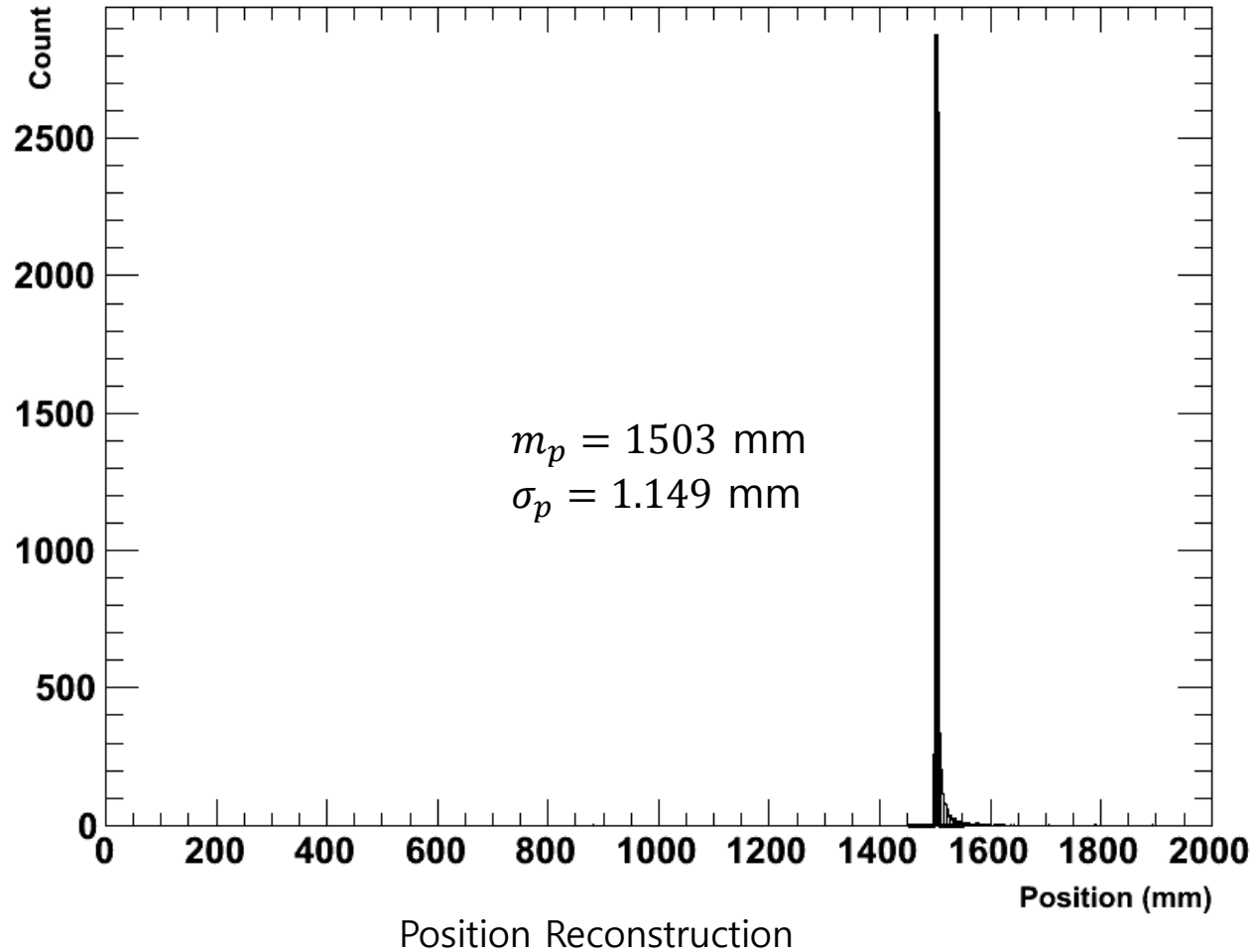
$t_{signal1}$

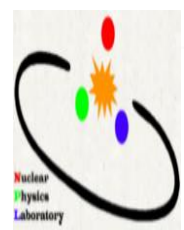


$t_{signal2}$



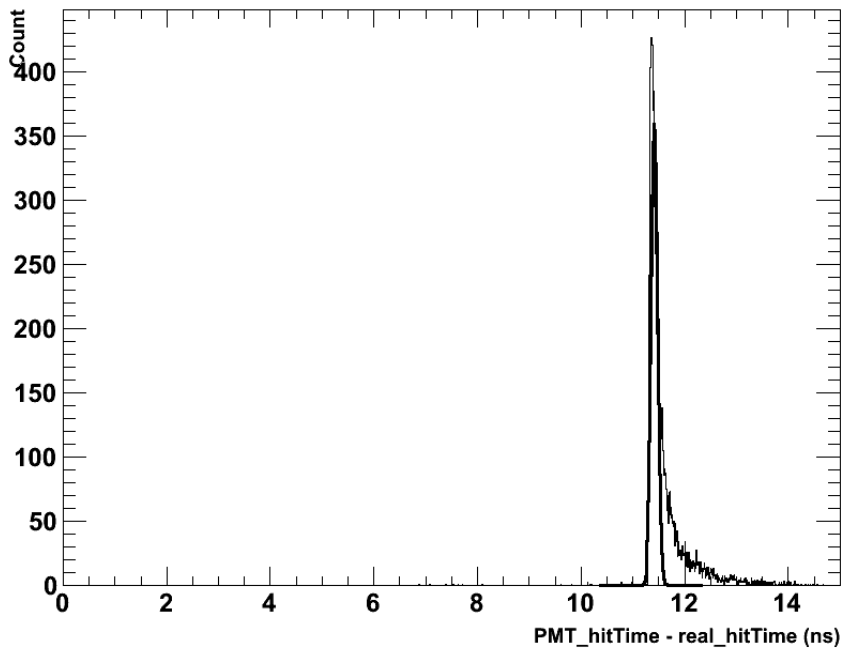
Result



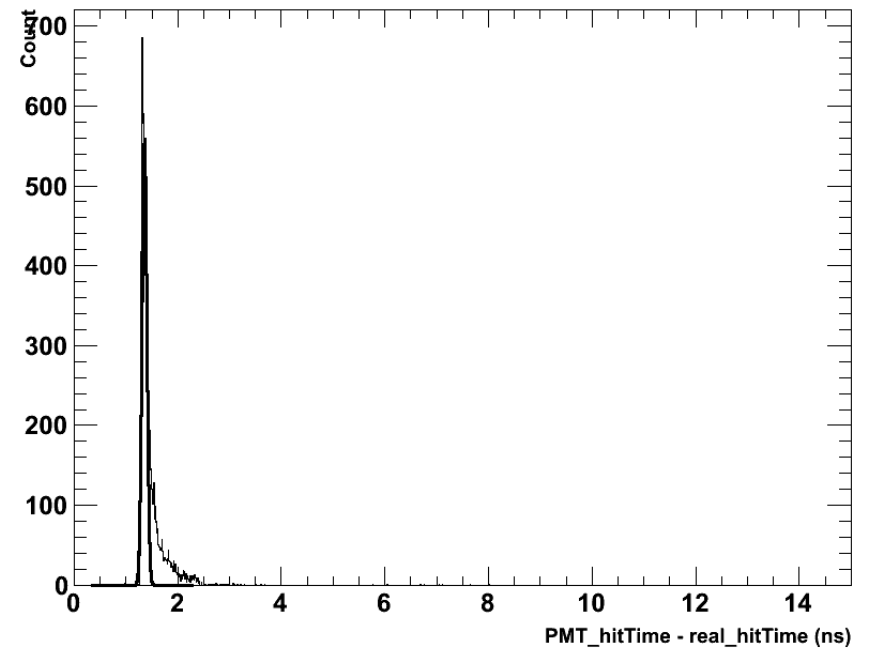


Result

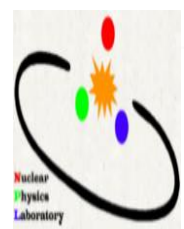
- $l_1 = 180$ cm, $l_2 = 20$ cm



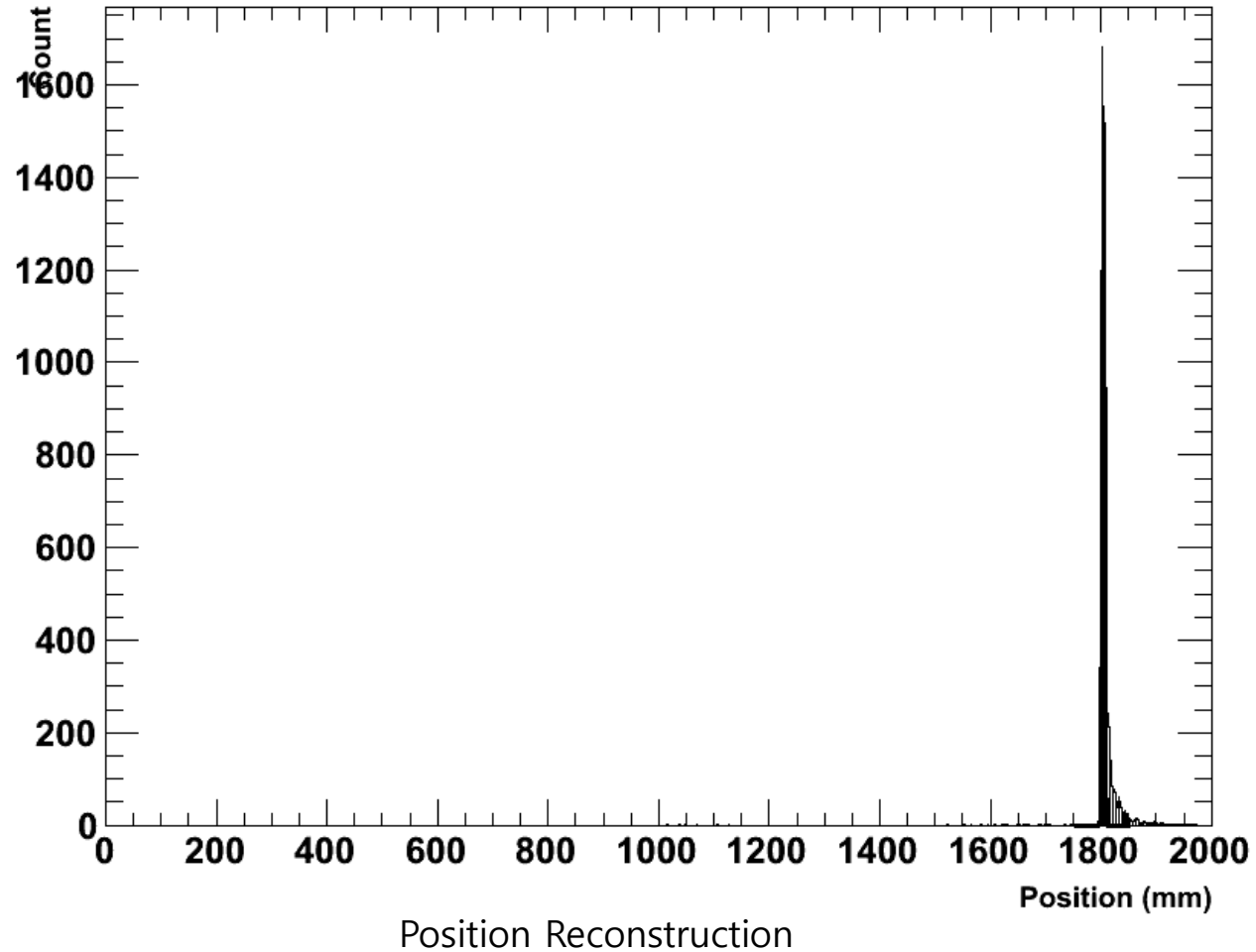
$t_{signal1}$

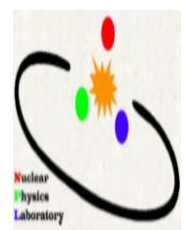


$t_{signal2}$



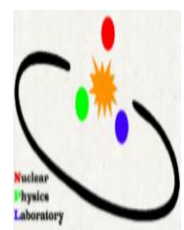
Result

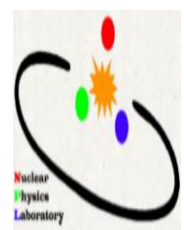




Result







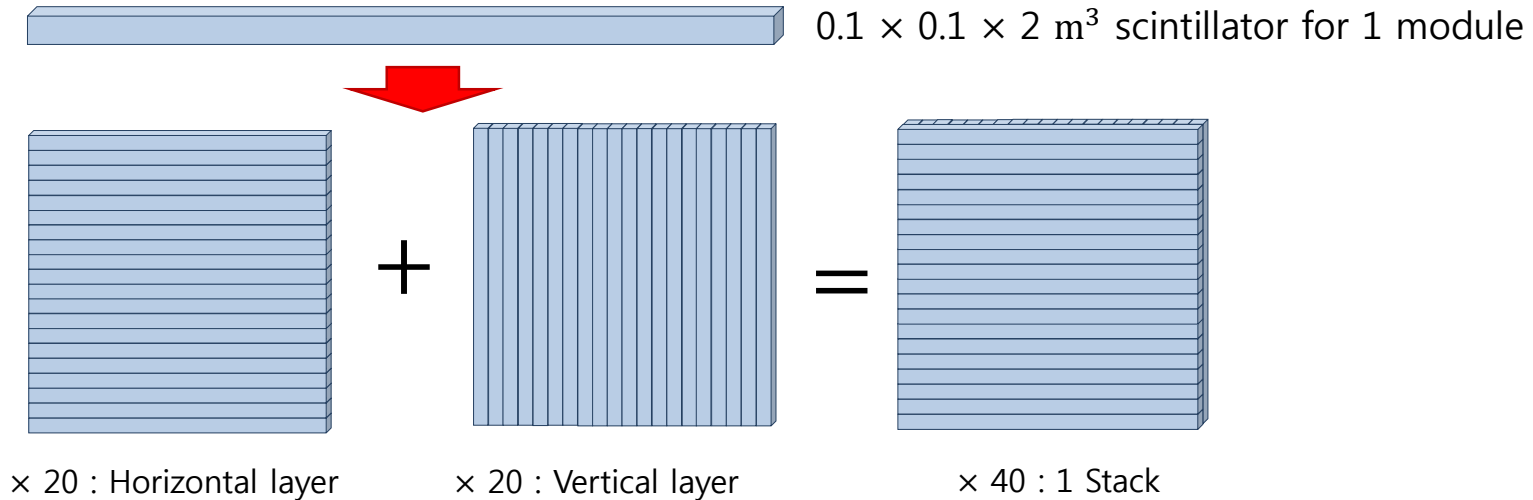
Back Up



Back Up

High-energy Neutron Detector Simulation for LAMPS

❖ Structure



- 4 Stacks (8 layers)
- 40 cm gap between stacks
- 20 module for 1 layer
- Veto counter & Helium bag in front of neutron detector

