Development of Two-Dimensional Neutron Imager with a Sandwich Configuration

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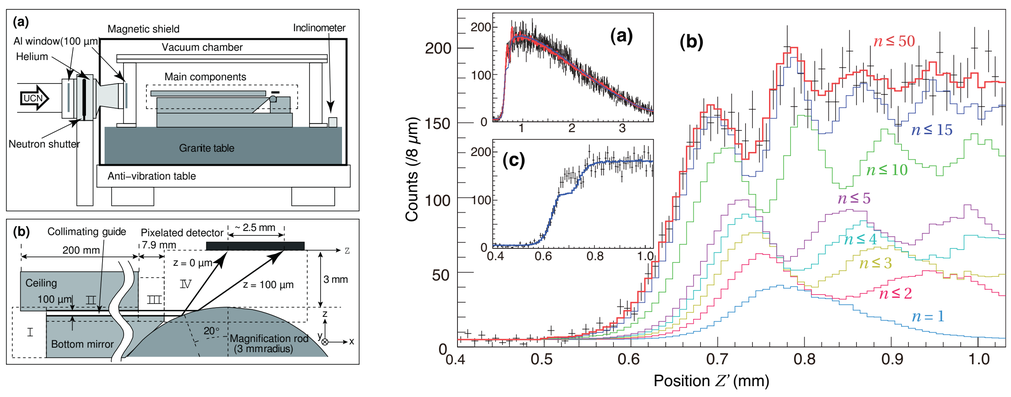
(A) Abstract

+ We are conducting experiments to examine the equivalence principle in Quantum regime.
+ Time-resolved neutron imager is an essential device for the experiment.
+ We have developed boron-coated SOI-CMOS based imager, called ^{10}B-INTPIX4.
+++ It showed fine spacial resolution less than 4 microns as a sigma of line spread function[1].
+ To mitigate/correct the one of error sources on the neutron positioning, new neutron imager with sandwich configuration, ^{10}B-INTPIX4-sw, has been developed.
+++ This presentation shows the first measurements of neutron with this new imager configuration.

(B) Testing Equivalence Principle

+ Discussions regarding the expression of the equivalence principle within the framework of quantum theory are not mature.
+ We expect to develop and test models for that, by analysing a spacial and a temporal behaviour of quantum bound states of ultra-cold neutrons (UCNs) under the gravity.

= (1) demonstration of the binding system of UCNs[2] =



$$\{-\frac{\hbar^2}{2m}\frac{\mathrm{d}^2}{\mathrm{d}z^2}+V(z)\}\psi_n(z)=E_n\psi_n(z)$$

where $V(z)=\begin{cases} mgz, & z\geq 0 \\ \infty, & z\leq 0 \end{cases}$

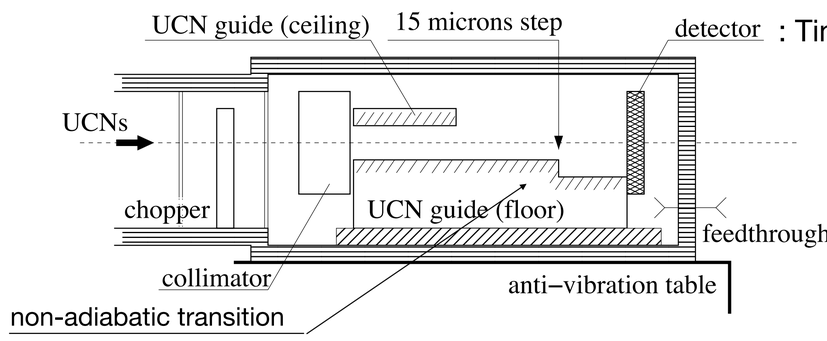
scales

$$z_0 = (\frac{\hbar^2}{2m_i m_g g})^{1/3} \sim 6\ \mu\mathrm{m}$$

$$E_0 = (\frac{m_g^2 g^2 \hbar^2}{2m_i})^{1/3} \sim 0.6\ \mathrm{peV}$$

m_g : gravitational mass
m_i : inertial mass

= (2) testing equiv. principle in quantum regime[3] =



: Time-resolved neutron imager developed based on
+ ^{10}B neutron converter
+ SOI-CMOS pixelated sensor

$$\psi_{(z,t=0)} = a_1\phi_{1(z)} + a_2\phi_{2(z)}$$

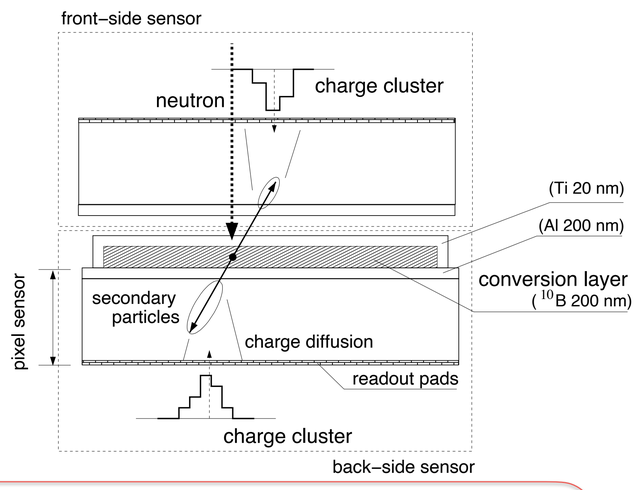
$$|\psi_{(z,t)}|^2 = |\psi_{(z,t=0)}|^2 - 4a_1a_2\phi_{1(z)}\phi_{2(z)}\sin^2\frac{(\varepsilon_2-\varepsilon_1)}{2}t$$

energy scale

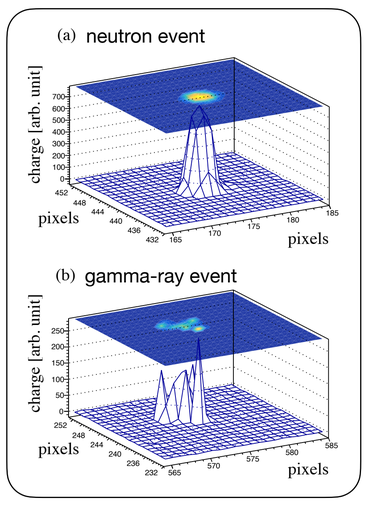
oscillating term

(C) Neutron Imager with Sandwich Configuration

sandwich configuration



signal cluster [1]

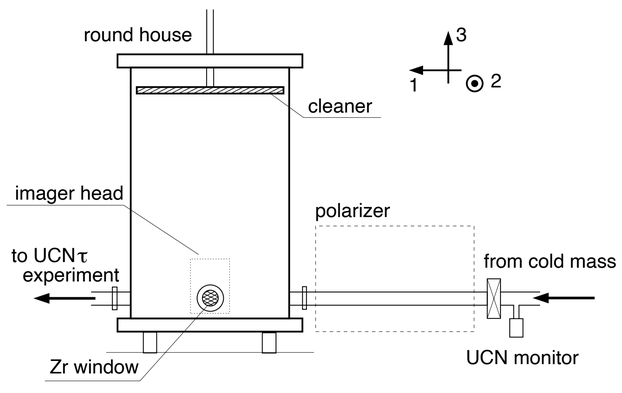


specification of the base sensor (INTPIX4):

pixel size:	17 x 17 microns^2
number of pixel:	832 x 512 pixel^2
readout time:	280 ns/pixel
wafer thickness:	300 microns

(D) Response Tests

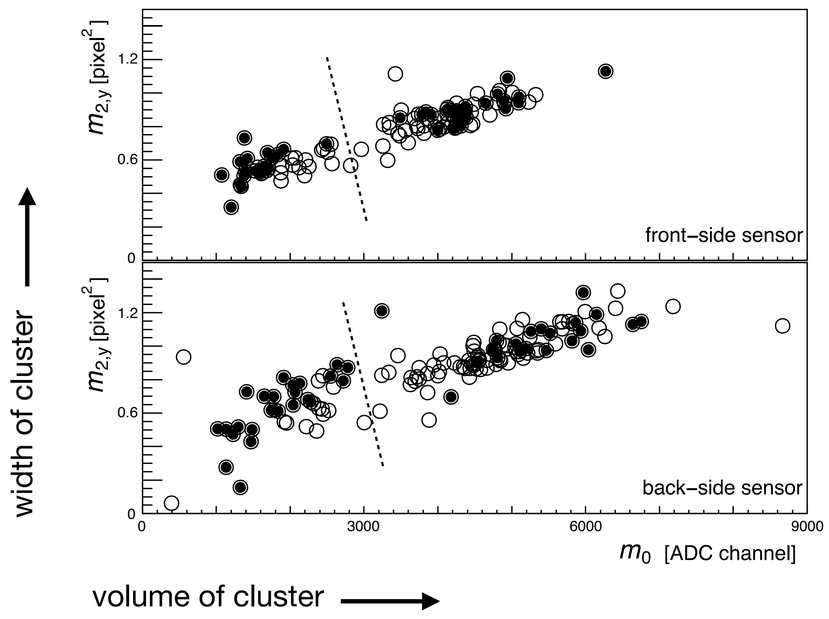
- at Los Alamos Neutron Science Center (LANSCE)



+ The cleaner remove higher energy UCNs.
+ It was set to extract 100 neV UCNs.
+ UCN flux was measured to be 1.8 1/cm^2/s by ZrS/^{10}B reference detector

(E) UCN Signals

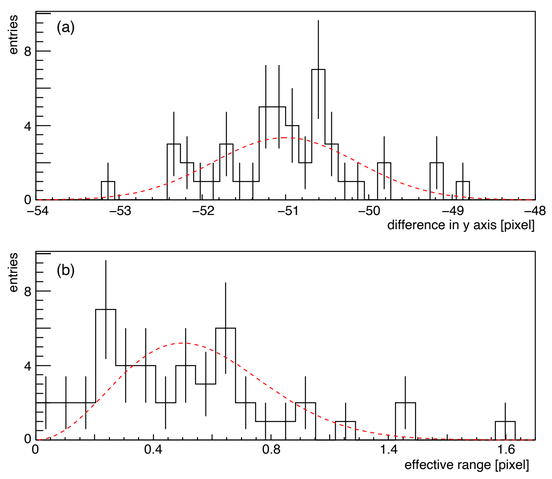
^{6}Li-particle origin alpha-particle origin



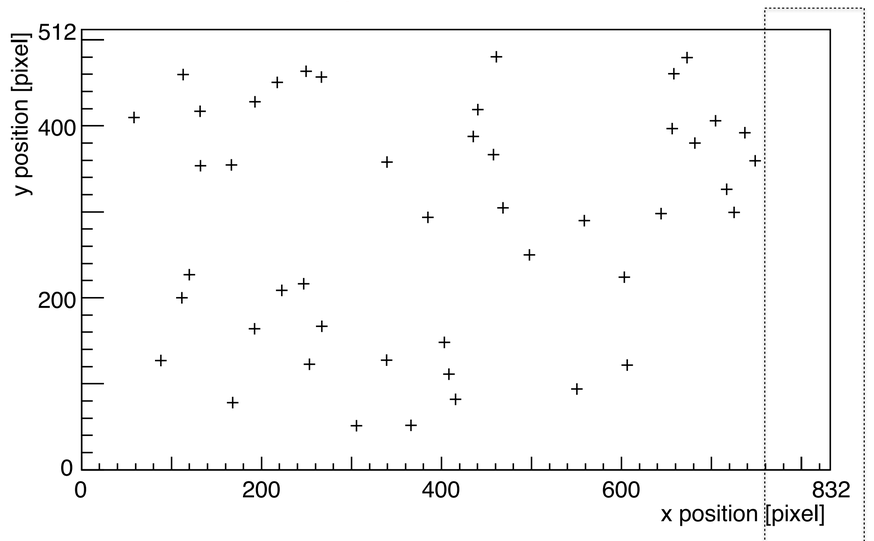
coloured circle:
paired event
front-side sensor
111 => 46 events
back-side sensor
133 => 46 events

+ acceptance of the confidence condition is about 1/3

position difference of the paired cluster



estimated neutron position no converter here



+ averaged range of the secondary particle is about a half of pixel
+ relative efficiency for UCNs was 16% with respect to the reference detector

References

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[3] Y. Kamiya, The Physics of Fundamental Symmetries and Interactions - PSI2016 (2016) and PSI2019(2019).

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