Dark Matter Search with Direction sensitive Scintillator II

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1. Future Prospects of
   Organic Crystalline Scintillator

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Neutralino-nucleus cross section

$$\sigma_{\chi-N} = 4G_F^2 \mu_{\chi-N}^2 (C_N^{SI} + C_N^{SD})$$

$\mu_{\chi-N} = \frac{M_\chi M_N}{M_\chi + M_N}$ Reduced mass

G_F Fermi coupling constant

C_N^{SI} Enhancement factor for Spin-Independent interaction

C_N^{SD} Enhancement factor for Spin-Dependent interaction

The enhancement factors carry all particle physics model information.
Nuclei which have higher enhancement factor are useful for the dark matter detection.

Enhancement factor

- Spin-Independent Interaction

$$C_N^{SI} \propto A^2$$

A Mass number of a target nucleus

Heavier nuclei provide higher interaction probability.
NaI(Tl) and Liquid Xe scintillators are favorable.

- Spin-Dependent Interaction

$$C_N^{SD} \propto \lambda^2 J(J+1)$$

λ Landé factor

J Total spin of a target nucleus

^{19}F provides the highest interaction probability except ^{1}H and ^{3}He.

Isotope	unpaired	Abundance	$\lambda^2 J(J+1)$
^{1}H	p	100%	0.750
^{19}F	p	100%	0.647
^{23}Na	p	100%	0.041
^{3}He	n	100%	0.928
^{129}Xe	n	26.4%	0.124

Using odd group model

Organic crystalline scintillator

Direction sensitivity of organic crystalline scintillators is useful for dark matter searches.

Organic scintillators consist of hydrogen and carbon.

- Hydrogen is too light.
- Carbon is also light and has no unpaired nucleon.

Neither are useful for SI or SD interactions.

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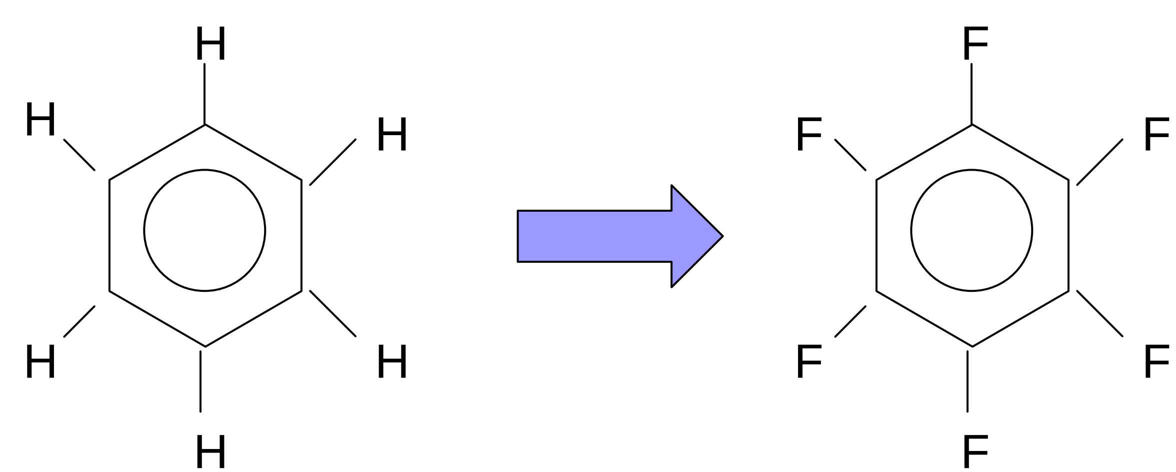
Replacing all hydrogen nuclei by fluorine makes SD interaction possible.

Fluoroaromatic compound

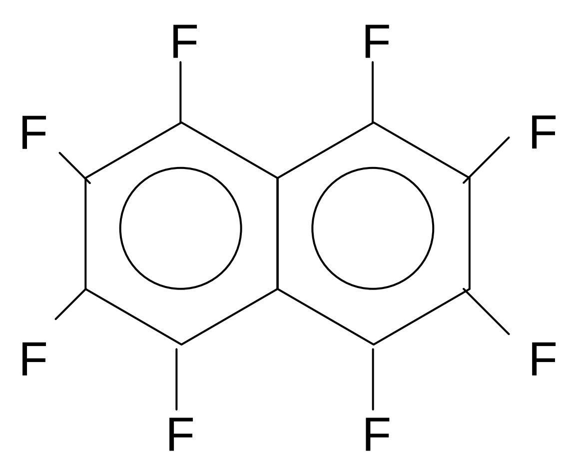
- The scintillation of organic crystals originate from benzene nuclei. Therefore fluoric aromatic compounds may have potential of scintillation.
- Possible candidates are hexafluorobenzene, octafluoronaphthalene, and decafluoroanthracene.
- Octafluoronaphthalene is a common compound.



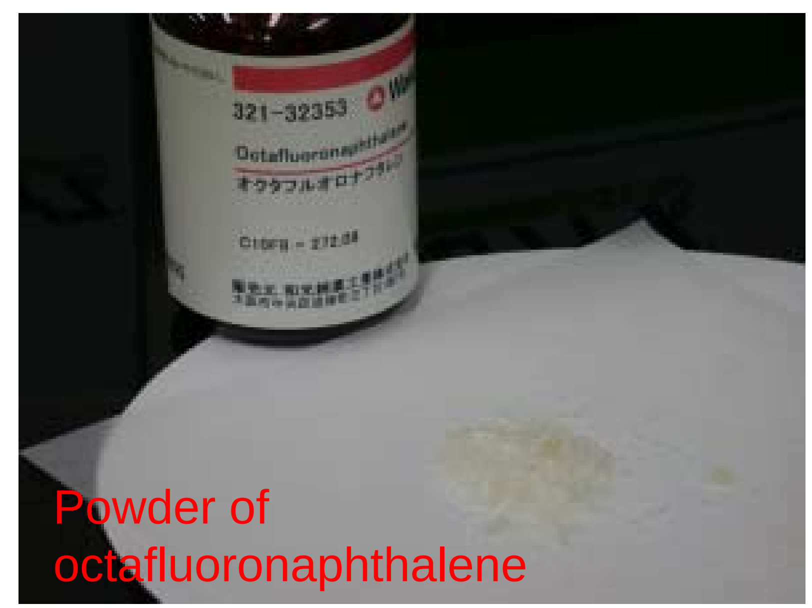
Octafluoronaphthalene

- It is usually used for gas chromatography.
- replacing hydrogen by fluorine in naphthalene
- white or yellow crystalline powder
- melting point ~87-88℃

It may be possible to crystallize it by the Bridgman method.



Molecular structure

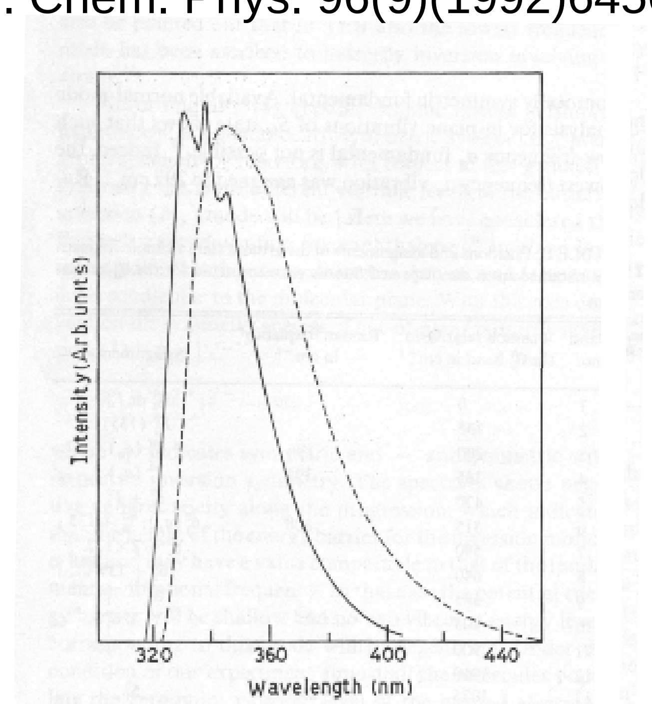


Powder of octafluoronaphthalene

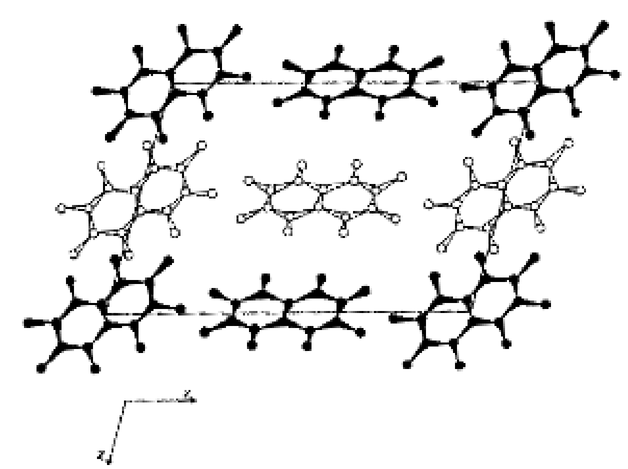
Characteristics

- UV fluorescence is known.
- Anisotropic crystalline structure

Fluorescence emission spectrum
In n-heptane matix.
T. Chakraborty et al.
J. Chem. Phys. 96(9)(1992)6456

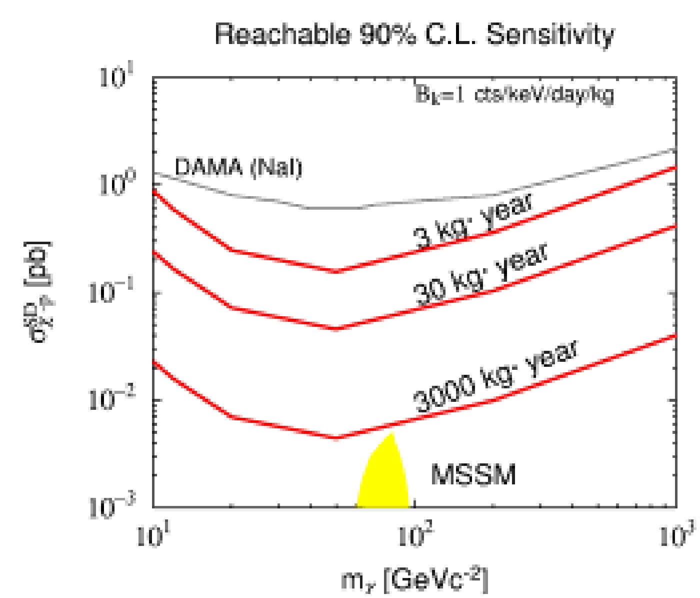


Projection of crystalline structure
of octafluoronaphthalene
G. A. Mackenzie et al.
J. Phys. C 10(1977)1133



Present status

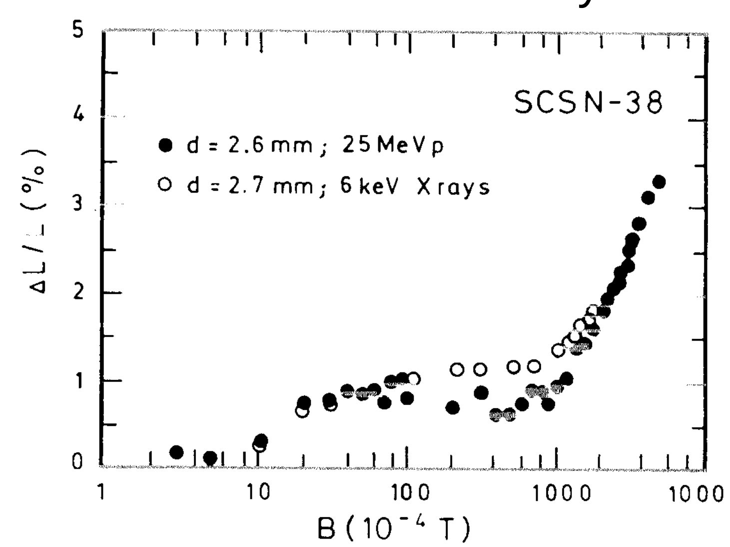
- We obtained octafluoronahtalene powder.
- Purification and crystallization are needed.
- If the crystal has anisotropic scintillation efficiency such as stilbene, we can obtain strict limits for SD interaction.



Plastic scintillator in magnetic fields

- Increase of the scintillation efficiency with magnetic fields is known.
- increase of ~3% with 0.45T
- No variation in decay time

The variation of
Scintillation efficiency



D.Blomker and U.Holm,
NIMA311 (1992) 505

Possible reasons

- Separation of electrons reduces saturation effect.
- Magnetic fields influence the delayed fluorescence.

Not fully understood.

Our purpose

- Confirmation of the increase in plastic scintillator
- Influence on the directional response of stilbene scintillators
- Possibility of application to dark matter search

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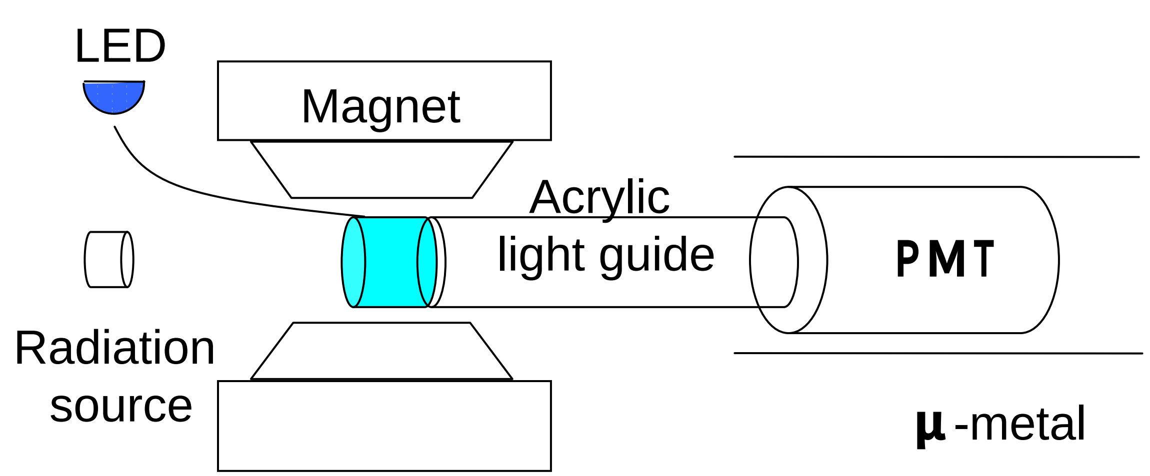
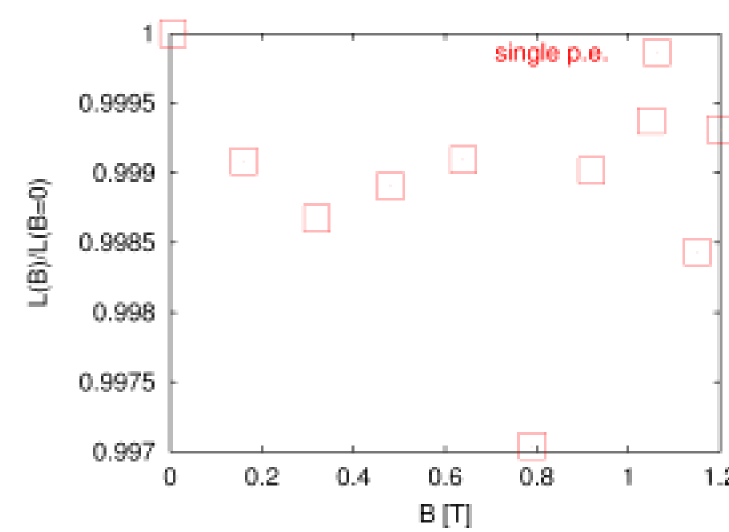
First, we measured the variation of scintillation efficiency of plastic and stilbene scintillators in magnetic fields using γ-ray sources.
In addition, we measured the nuclear recoils.

Experimental methods

- Plastic scintillator BC-412 , Stilbene scintillator
- Magnet 0.16~1.1T
- Radiation source ^{137}Cs,^{60}Co

μ-metal shields a PMT from magnetic fields.
Influence for PMT < 0.3% (LED measurements)



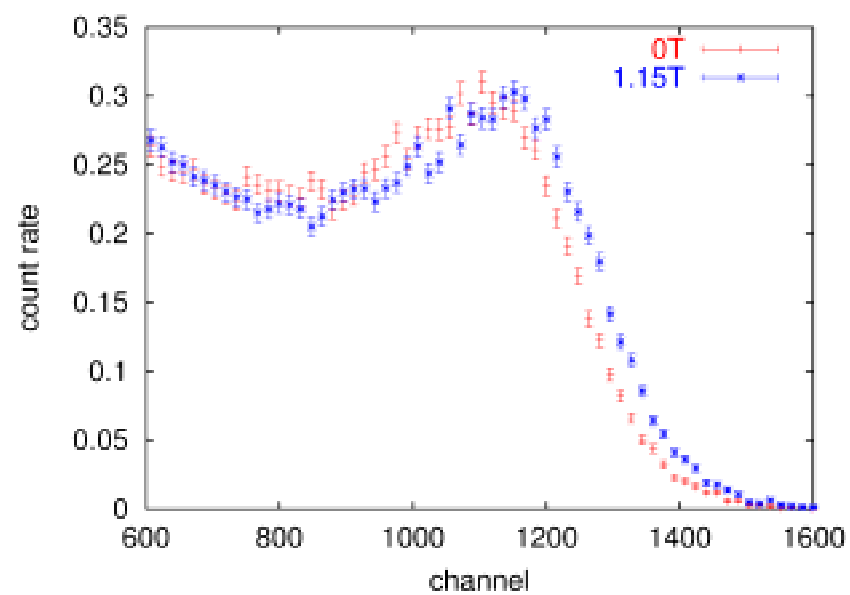


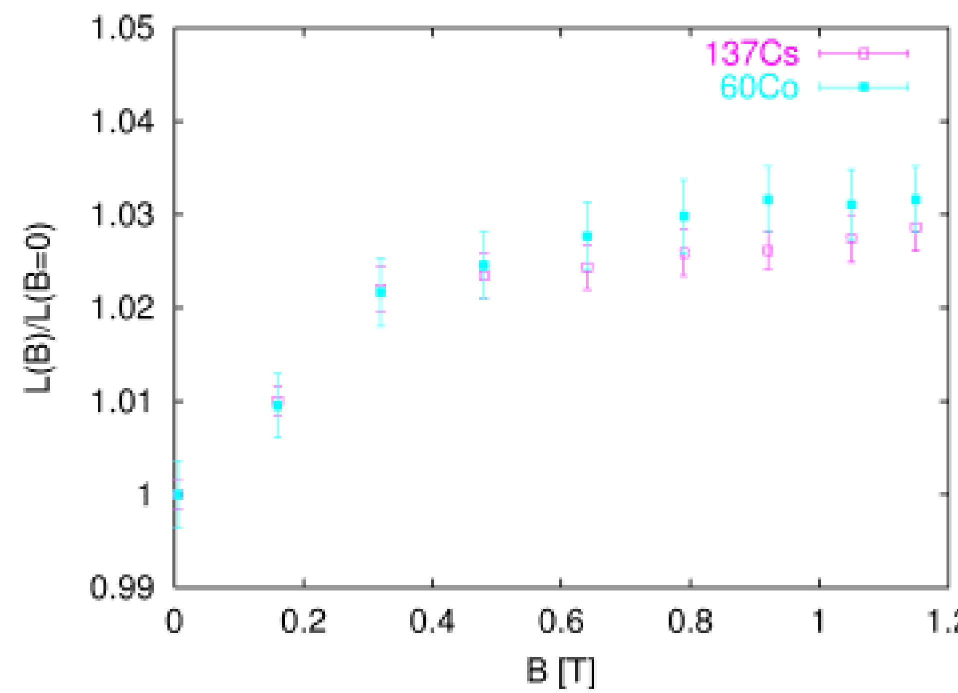
Plastic scintillator

^{137}Cs 662keV Compton edge

^{60}Co 1113,1333keV Compton edge

^{137}Cs



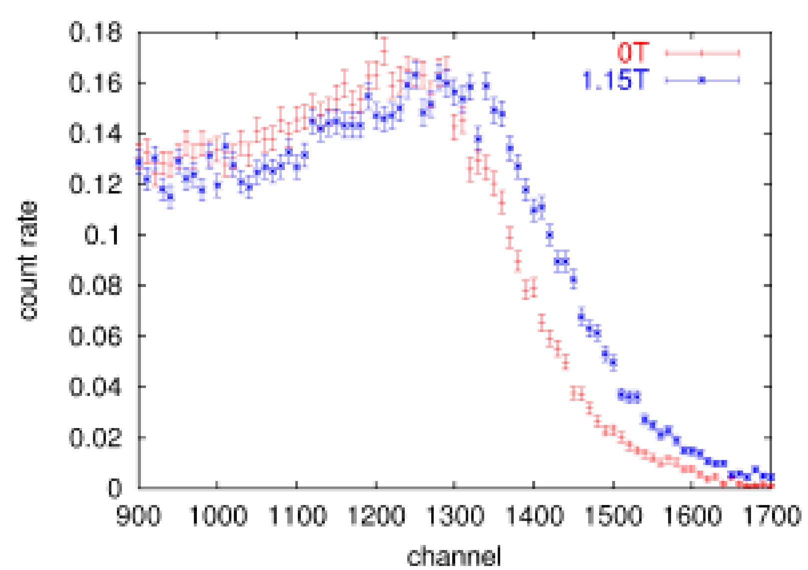


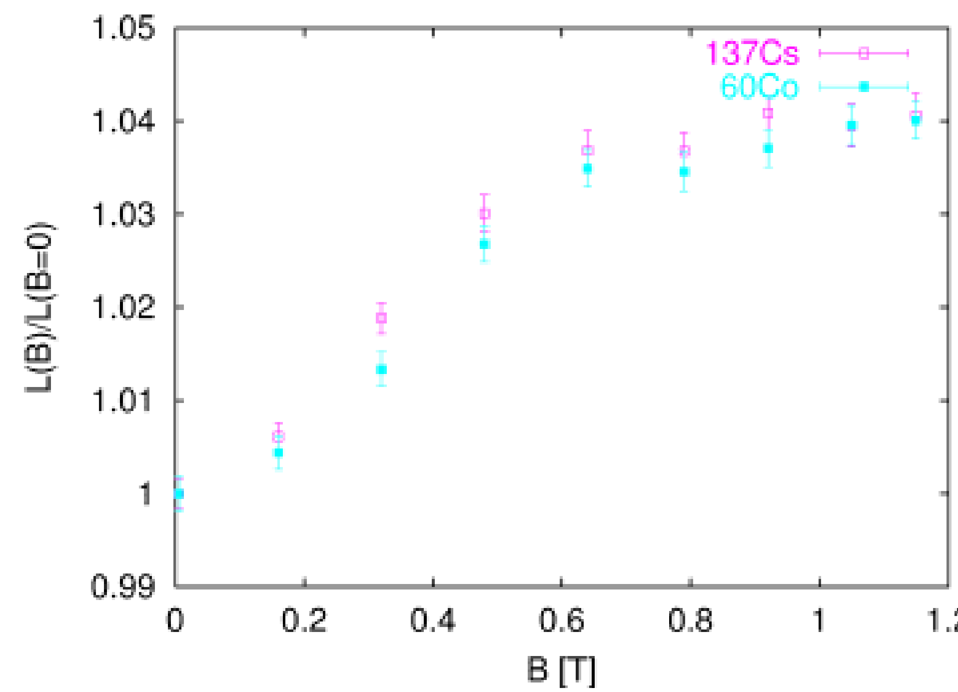
The scintillation efficiency was increased by magnetic fields.

Stilbene scintillator

Same measurements as plastic scintillator

^{137}Cs

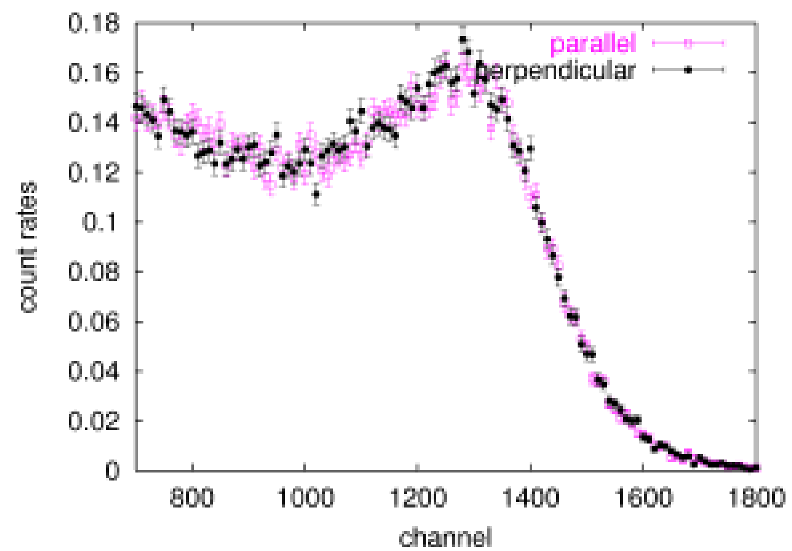


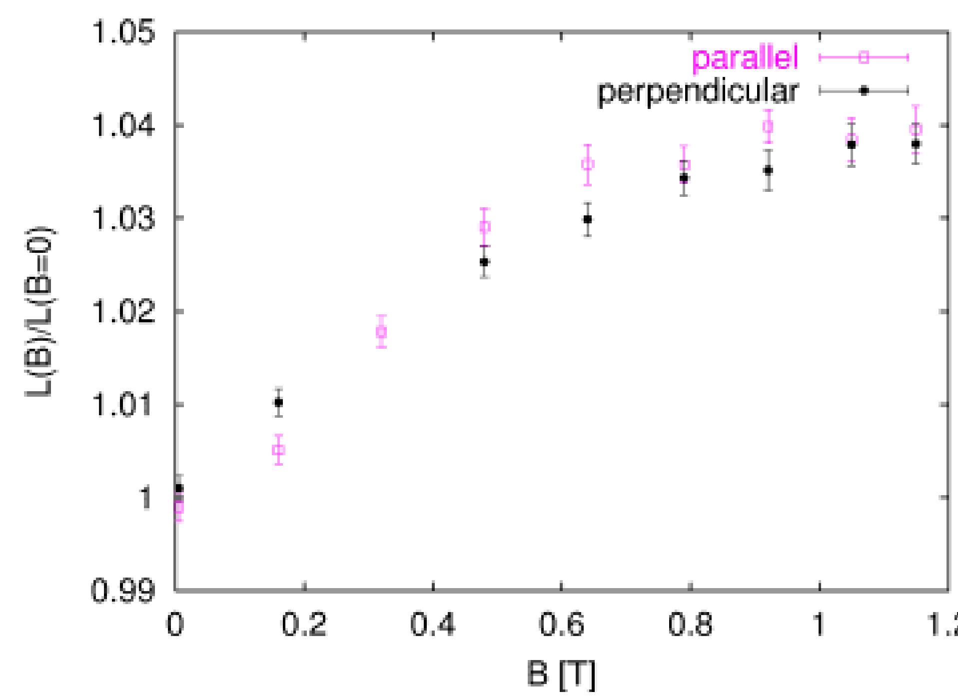


Increase of the efficiency of the stilbene is higher than the plastic scintillator.

Magnetic fields was applied to parallel and perpendicular directions to c’ axis.

^{137}Cs B =1.15T



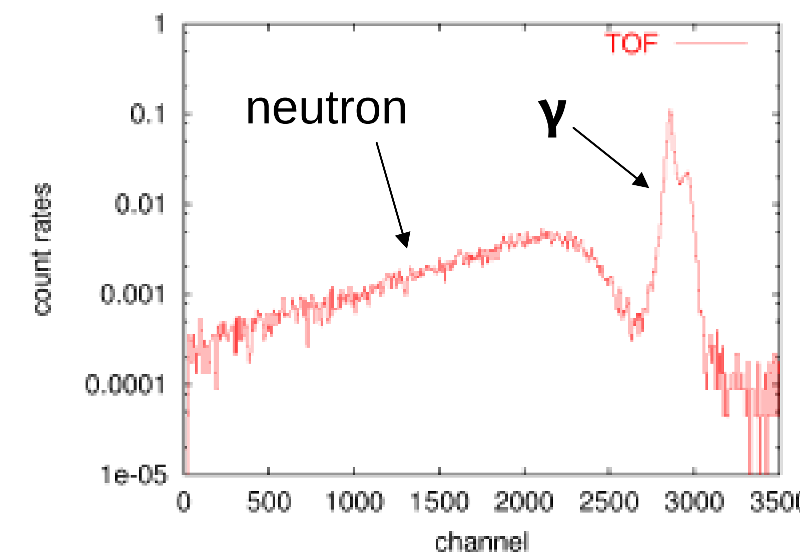


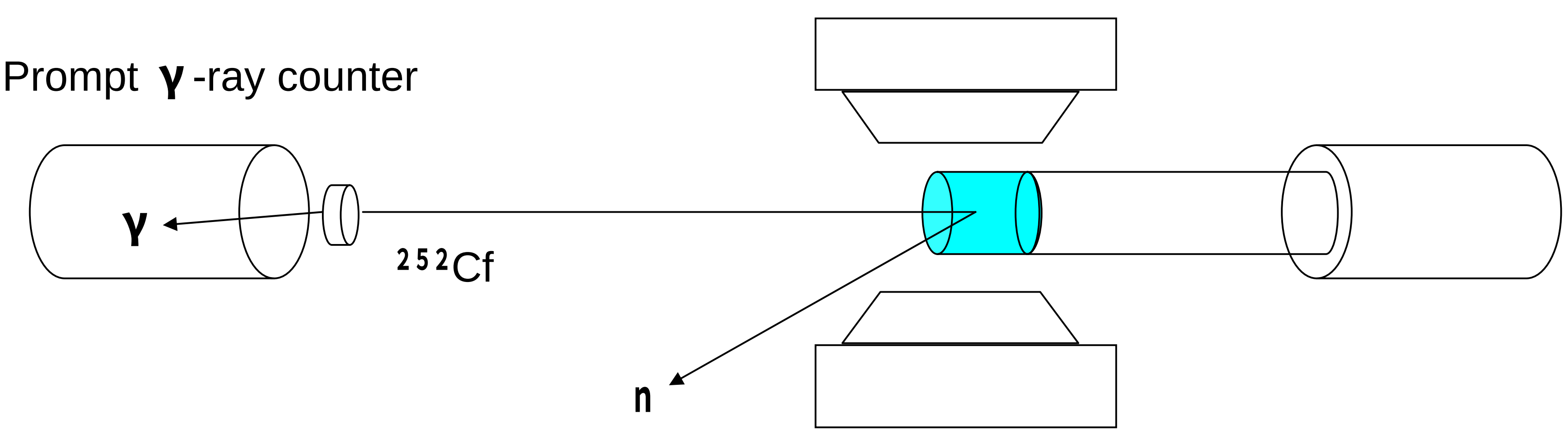
The difference is small.

Measurements of proton recoils

- Neutron source ^{252}Cf
- Stilbene scintillator
- Obtained by elastic scattering of neutrons
- Observing prompt γ-ray to measure time of flight (TOF)

TOF spectrum



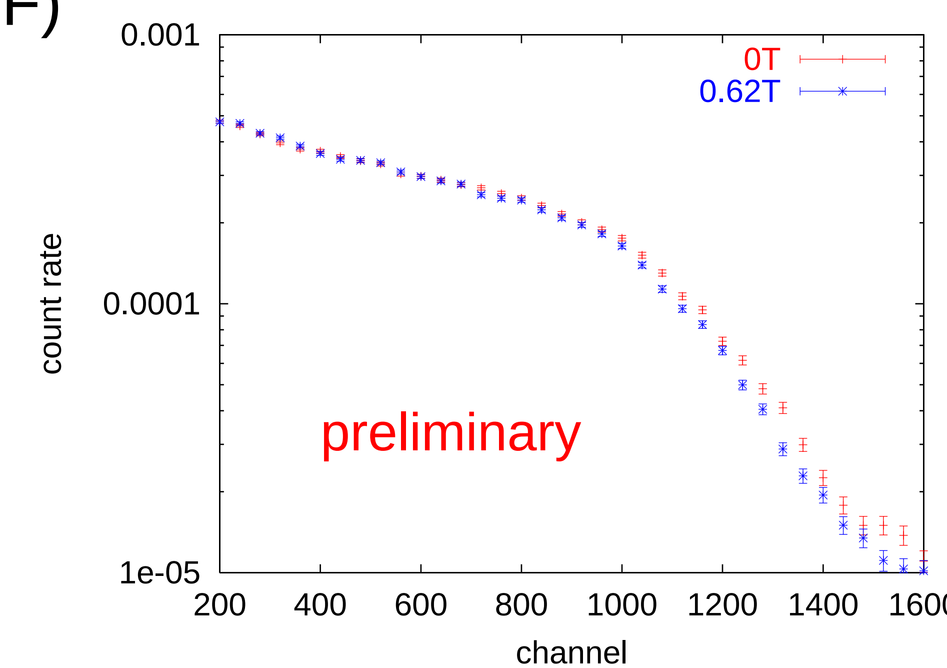


We measured proton recoil events in the stilbene with 0.62T.
Neutrons energy ~ 2MeV (TOF)

Preliminary result

- Variation ~ 3%.
- The efficiency decreases with magnetic fields.

Proton recoil spcetrum in stilbene



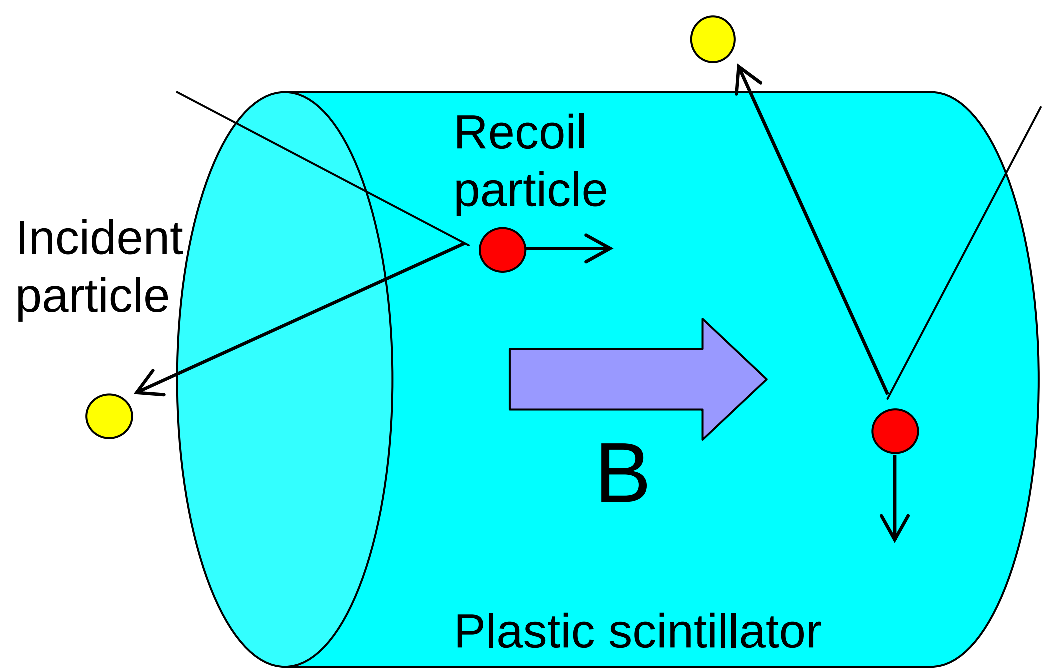
This is a contrary result to other experiments using high energy protons.

→ Further investigations are needed.

Conclusion from the experiment using magnetic fields

- We measured the dependency of scintillation efficiency of plastic and stilbene scintillator on magnetic fields.
- The variation was a few percents.
- The variation was different between BC412 and stilbene.
- Nuclear recoils obtained by elastic scattering of dark matter is smaller (< 100keV). Investigation in smaller energy region are needed.

If the scintillation characteristics depend on a direction of a recoil particle with respect to magnetic fields, they can be used for direction sensitive detectors.



This time we cannot confirm directional effects because of the shape of our magnet.

Mechanism of the variation

- This effect cannot be explained by electrons which leave the surface of scintillators, which is confirmed by 60keV γ-ray measurements.