MIRACLUE
Migdal effect search using position sensitive gaseous detectors

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on behalf of MIRACLUE collaboration

IDM, 2024/07/09, L'Aquila (Italy)

Introduction

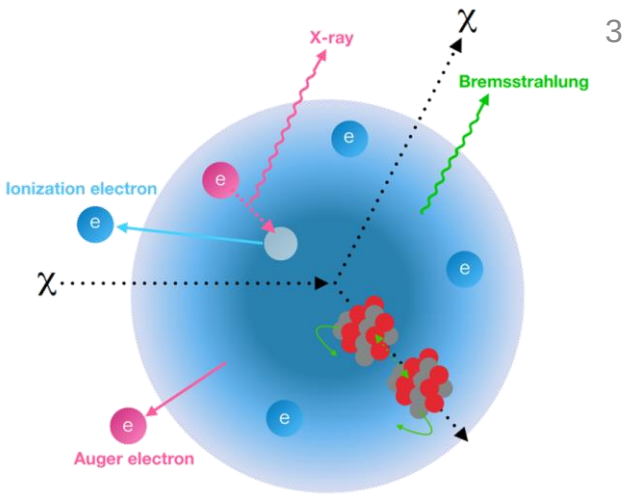
MIRACLUE project

Introduction

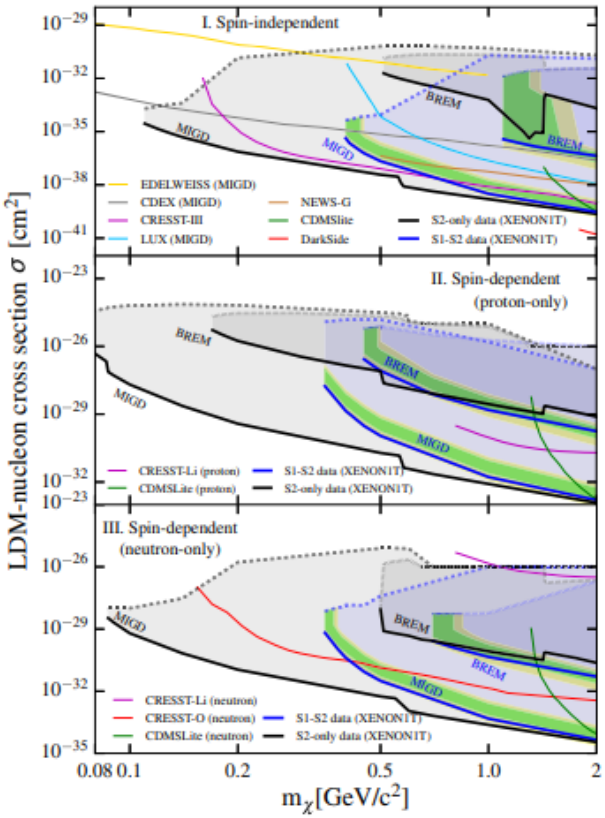
- Migdal effect
  - Sudden nuclei movement --> additional ionization/excitation (low probability)
  - First raised by A.B.Migdal 1939

- Dark matter search
  - Nuclear recoil + Migdal effect
  - increase observable energy
  - increase low-mass DM sensitivity

- --> We would like to measure Migdal effect !



PRL121(2018)101801

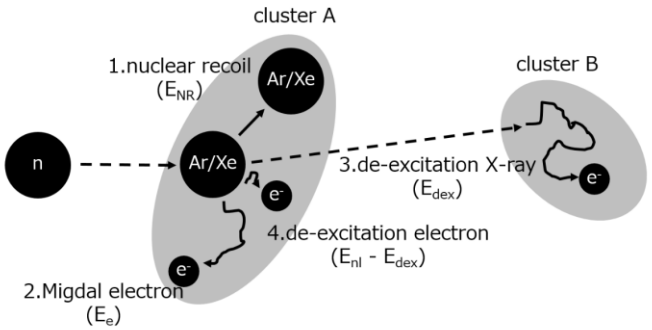


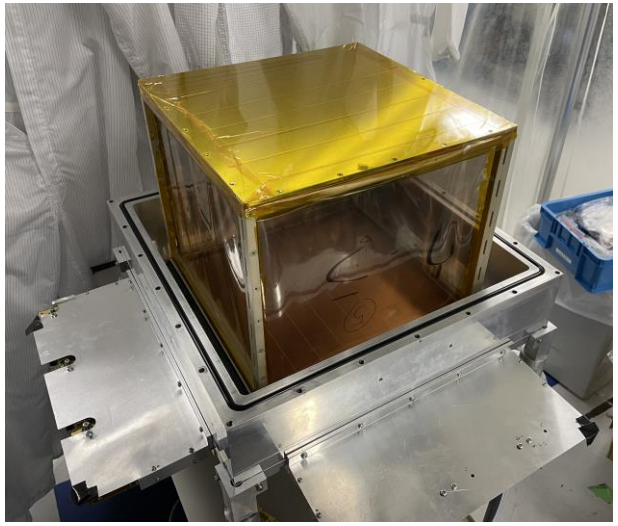
MIRACLUE experiment

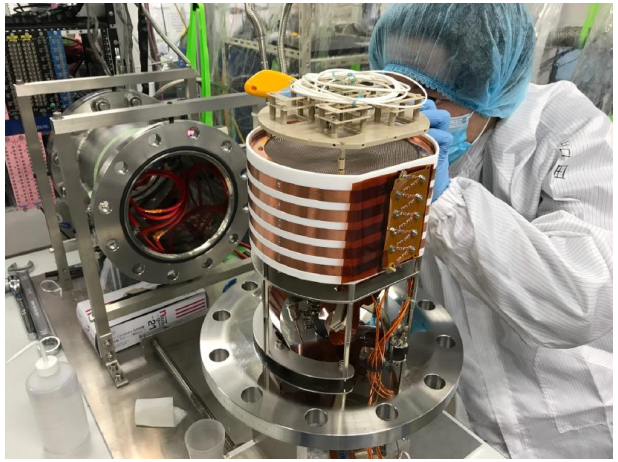
- About MIRACLUE experiment
  - neutron beam experiment using position sensitive gaseous detectors
  - 2-cluster topology as a signal
  - Developing Xe (Tohoku univ.) and Ar (Kobe univ.) detectors
  - PTEP (2020）ptaa162
  - Noble gas in gas state is similar situation to Ibe's paper [JHEP 03 (2018) 194]

- Ar detector
  - NEWAGE (DM search) technique
  - μ-PIC 400μm readout
  - Thin film TPC cage

- Xe detector
  - AXEL (0nbb search) technique
  - 1cm pitch pixel readout with EL photons
  - High energy resolution

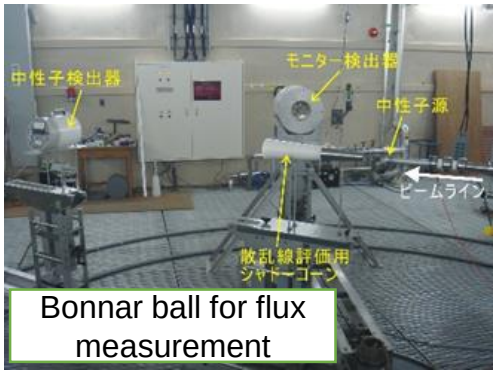




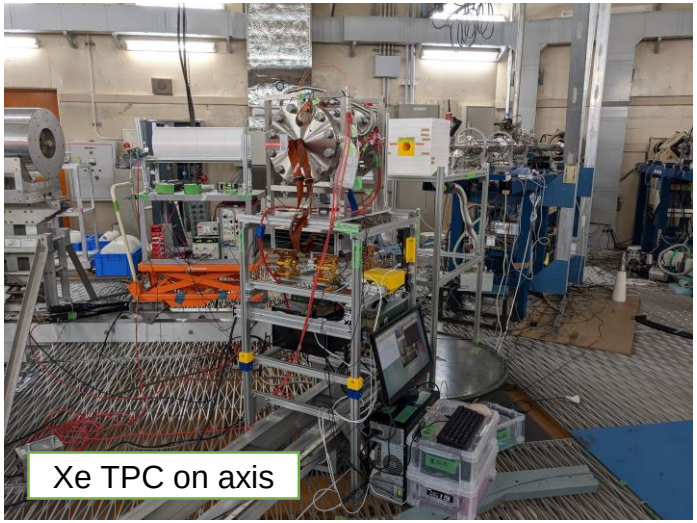


Beam test history

- AIST (Tsukuba city)
  - Provide standard neutron field
  - Several energy choice: 565keV, 14.8MeV, etc.
  - Grating floor to reduce gamma-ray by (n,γ)



Bonnar ball for flux measurement


Xe TPC on axis

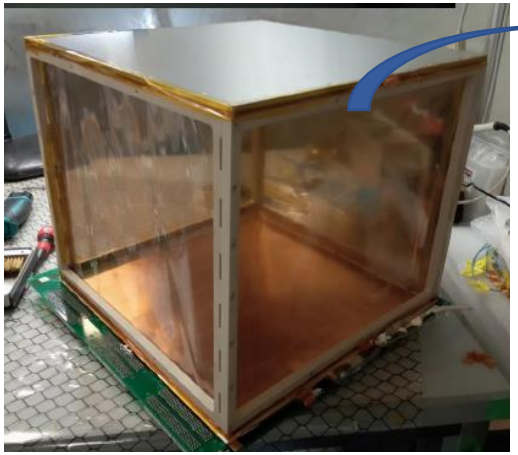
date	place	energy	detector	purpose
2022/3	AIST	565keV	He3、BGO	environmental measurement
2022/4	AIST	565keV	Xe、Ar	trial of gas (Xe, Ar) detectors
2022/12	AIST	565keV	Ar、BGO	large Ar detector
2023/7	CYRIC	~10MeV	Xe、He3、BGO	CYRIC test (w/ old Xe)
2024/1	AIST	~~565keV~~ -->14MeV	Ar、He3、BGO	Ar detector

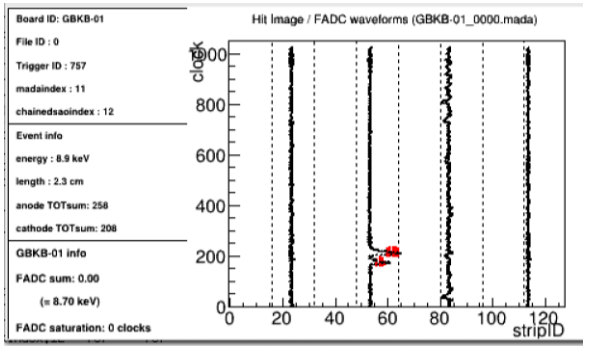
Today's main talk

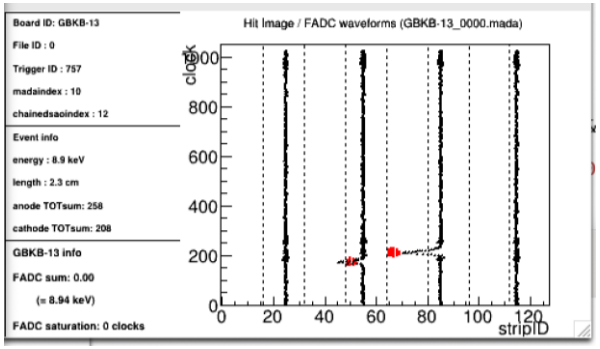
brief highlight

14MeV beam test for Ar detector

- Beam: 14.8MeV (DT neutron) , 1.25 x 10^2 /cm^2/sec
- Thin chamber: EVOH bag
- 2 cluster demonstration
- Analysis ongoing







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2024/1	AIST	~~565keV~~ -->14MeV	Ar、He3、BGO	Ar detector

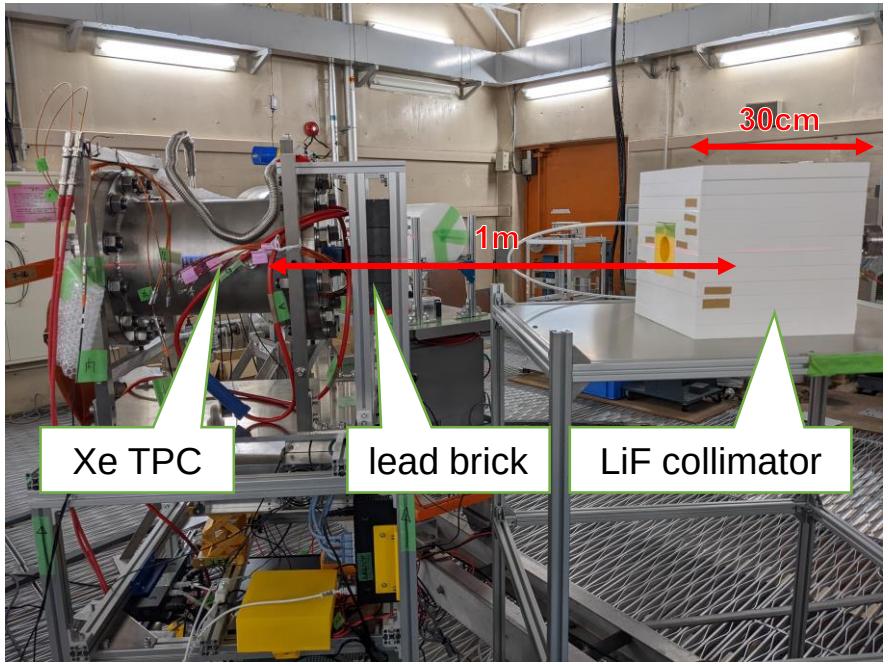
brief highlight

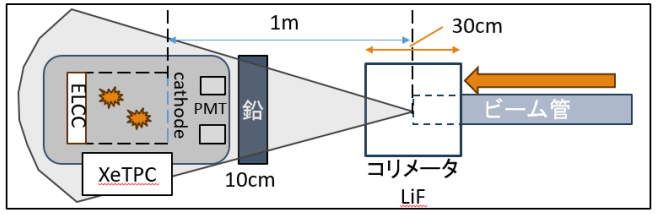
Xe TPC

neutron beam test and analysis

565keV beam test for Xe detector

- Neutron beam
  - 565keV neutron
  - ~2000 neutron/cm^2/sec@1m
- Collimator
  - neutron shield
  - LiF50% doped polyethylene
- Lead brick
  - gamma-ray shield
    - 2.2MeV from collimator
    - 478keV from target





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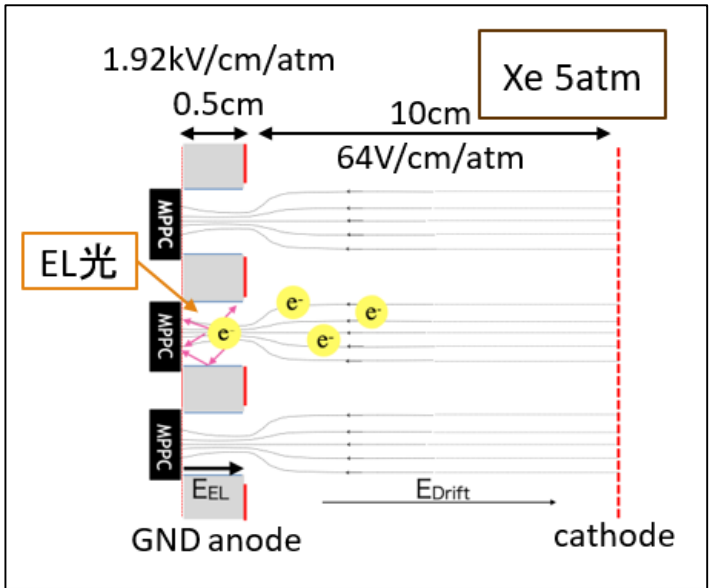
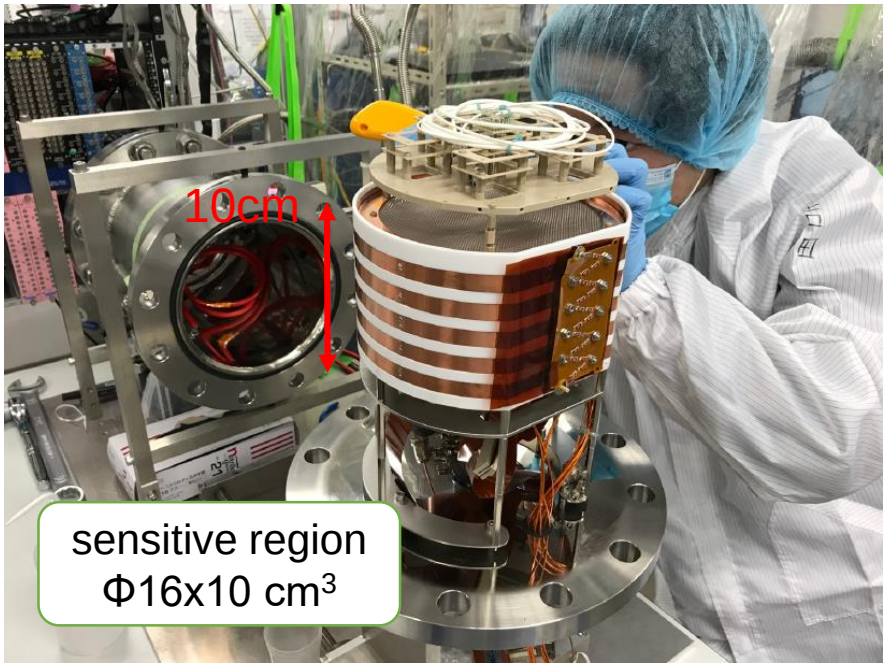
Today's main talk

Xe TPC

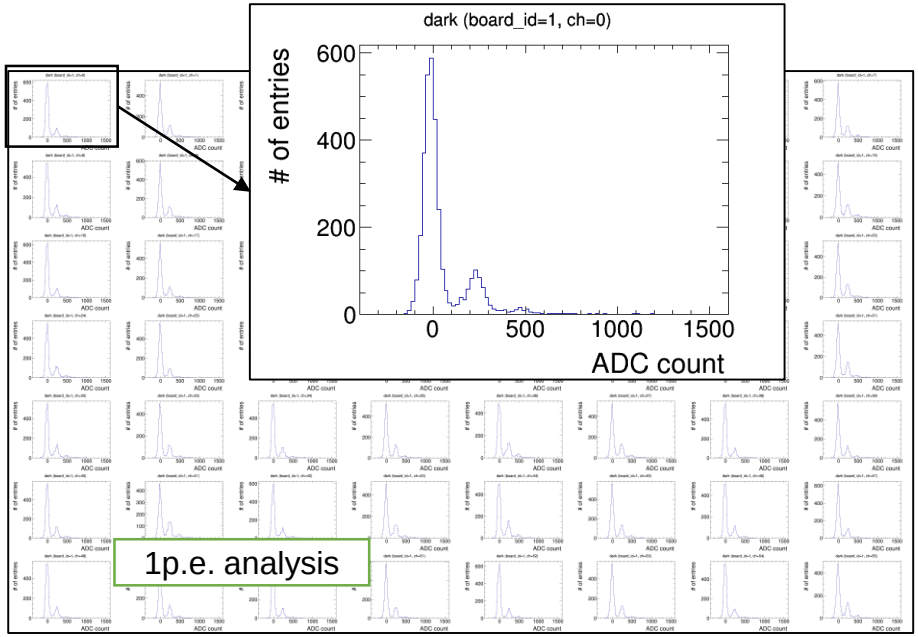
- TPC
  - EL readout
  - 168ch 1cm pitch
- Gas
  - Xe 5atm, sealed gas, passive filter
- Electric field
  - drift region: 64 V/cm/atm
  - EL region: 1.92 kV/cm/atm



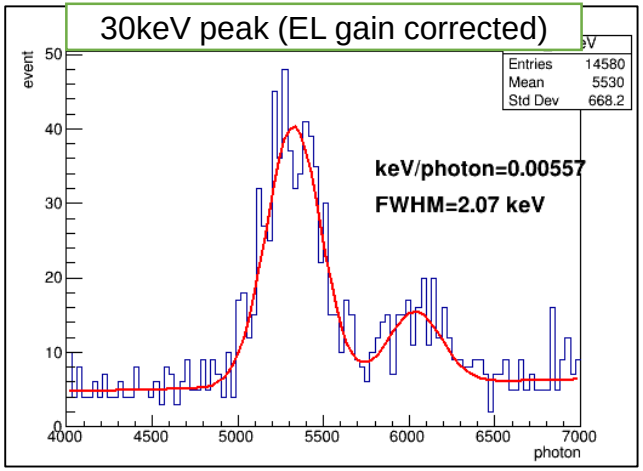


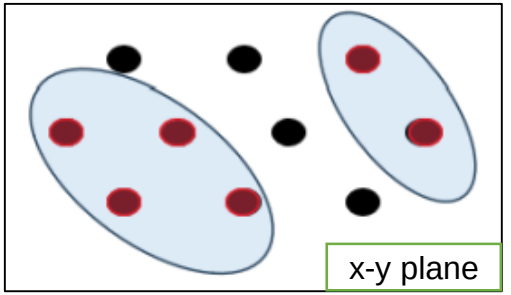
Analysis of Xe data

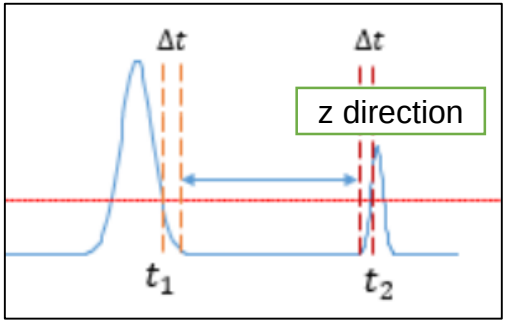
- Energy
  - waveform
    - ↓ 1p.e. gain
  - photon number
    - ↓ MPPC saturation correction
  - photon number correction
    - ↓ EL gain
  - energy



- Clustering
  - hit position and time
    - ↓ connect
  - cluster number



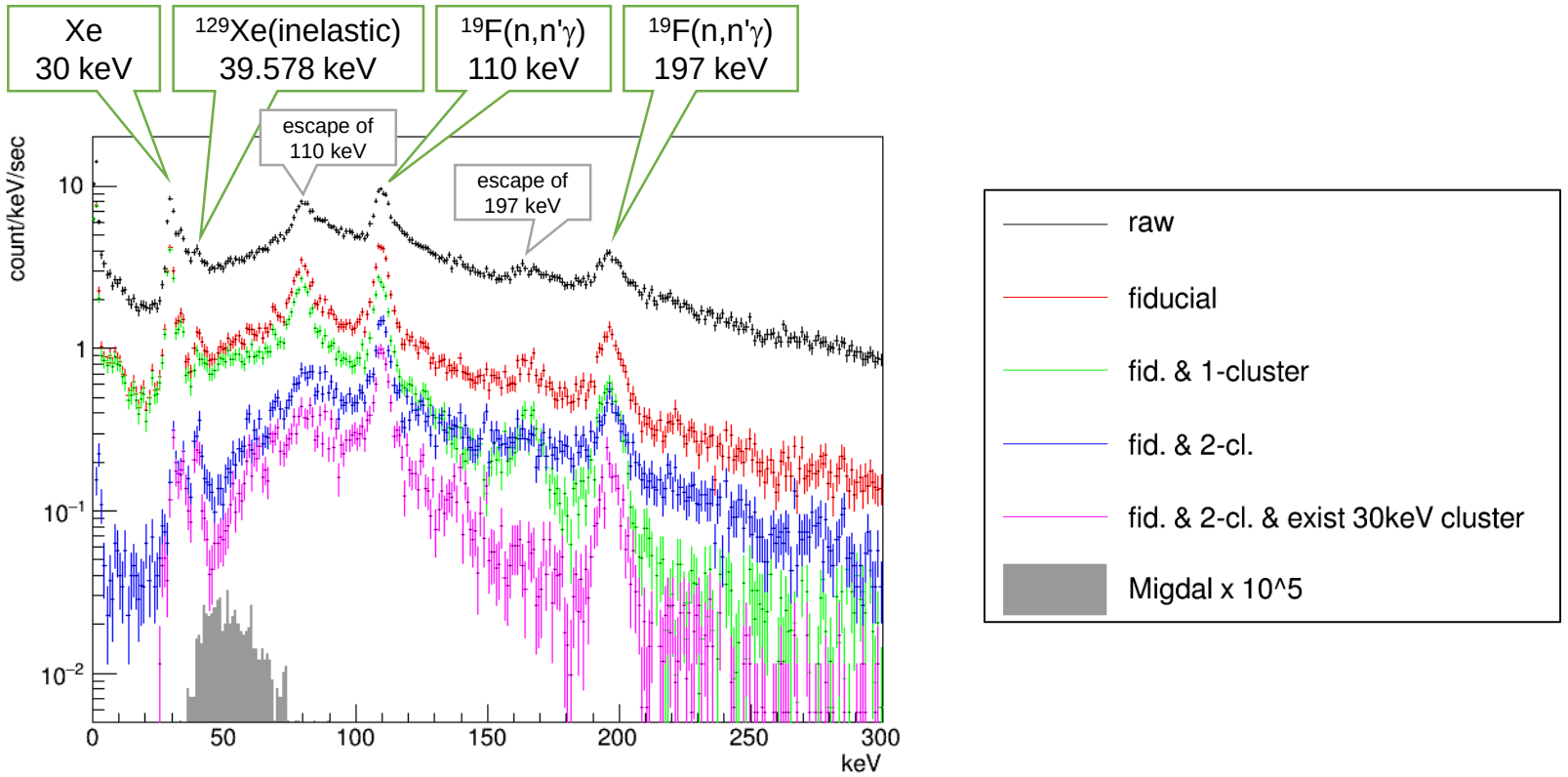




Energy spectrum

565keV neutron beam test

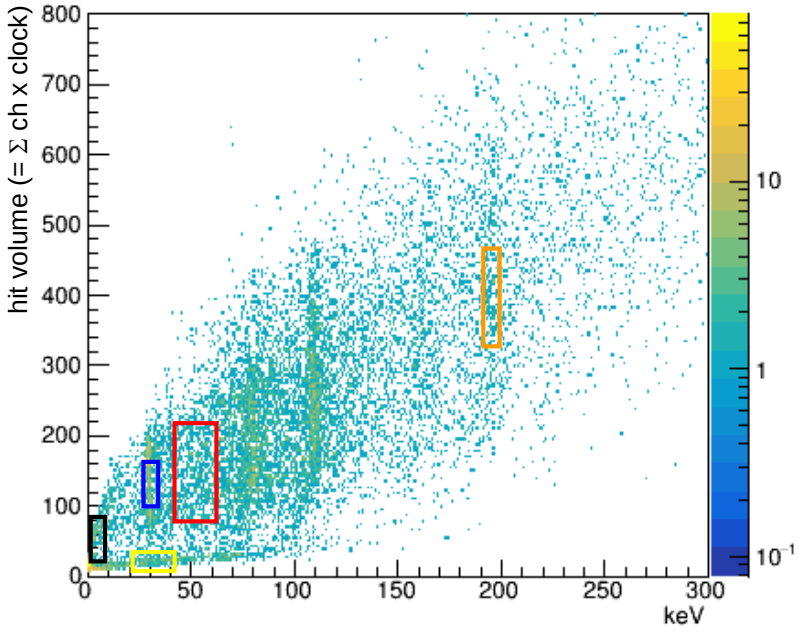
- Several peaks are clearly observed (w/ good energy resolution)
  - gamma-rays from F and Xe
- Measured time
  - realtime: 6545.5 sec
  - livetime: 174.106 sec (livetime ratio: only 2.7%)
  - In reality, the systematic error of pile-up due to accidental hits can be exist
- current sensitivity (about ~10^5) is limited by BG

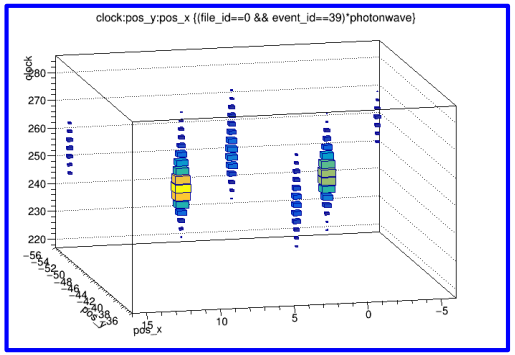


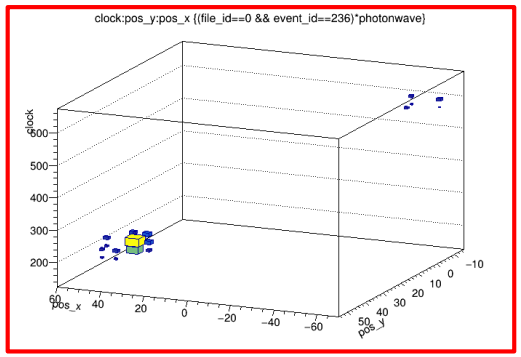
Event topology

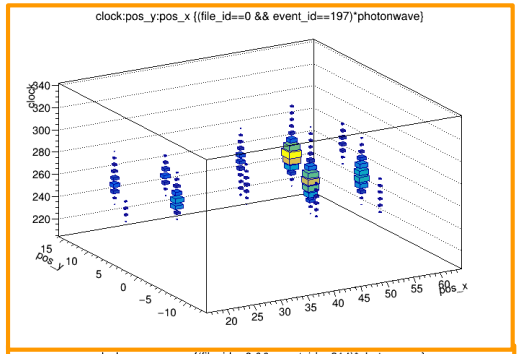
565keV neutron beam test

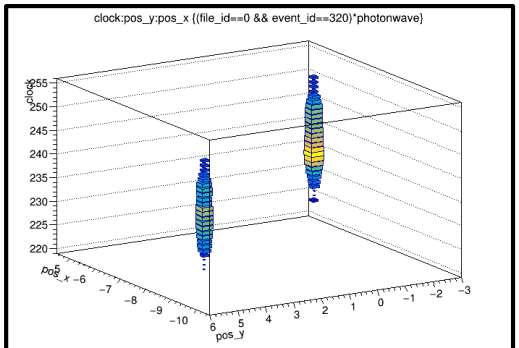
- Category
  - Black: nuclear recoil ?
  - Blue: 30keV gamma-ray event
  - Red: 2-cluster event (signal region)
  - Orange: 200keV gamma-ray event
  - yellow: spark like ?
- --> 2-cluster event is clearly obtained!

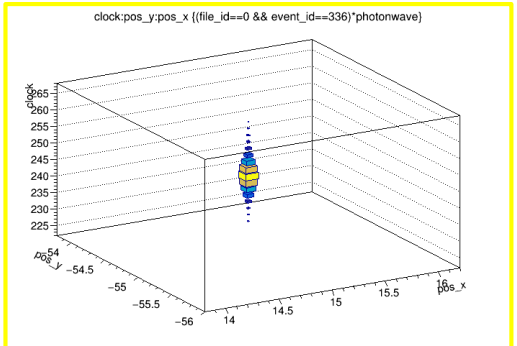


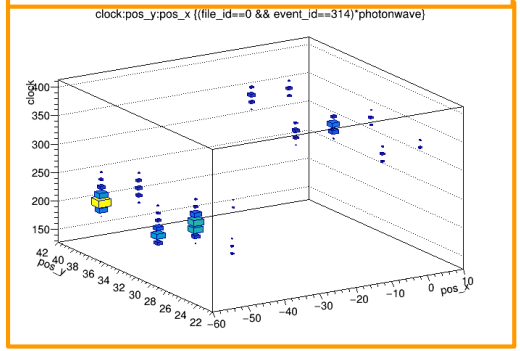








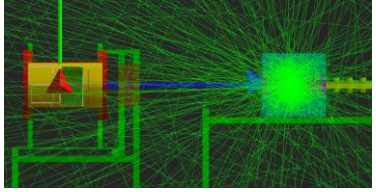




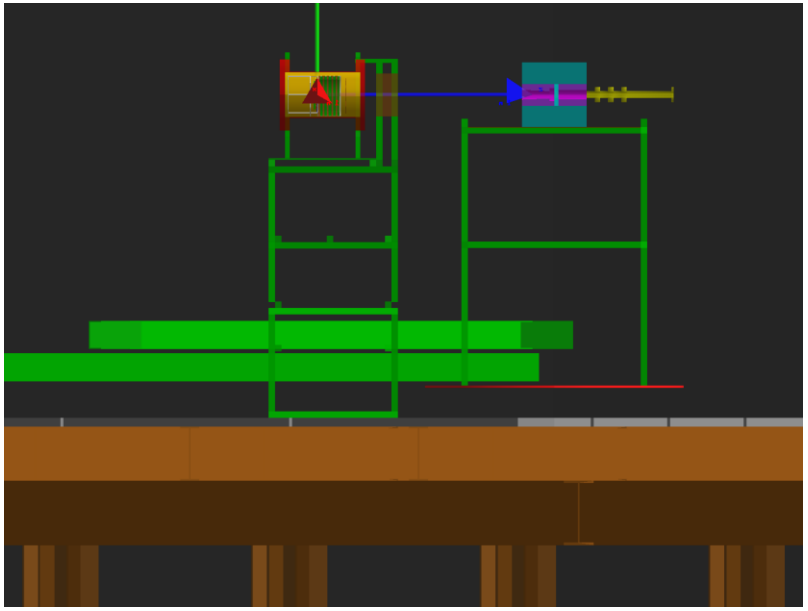
BG study

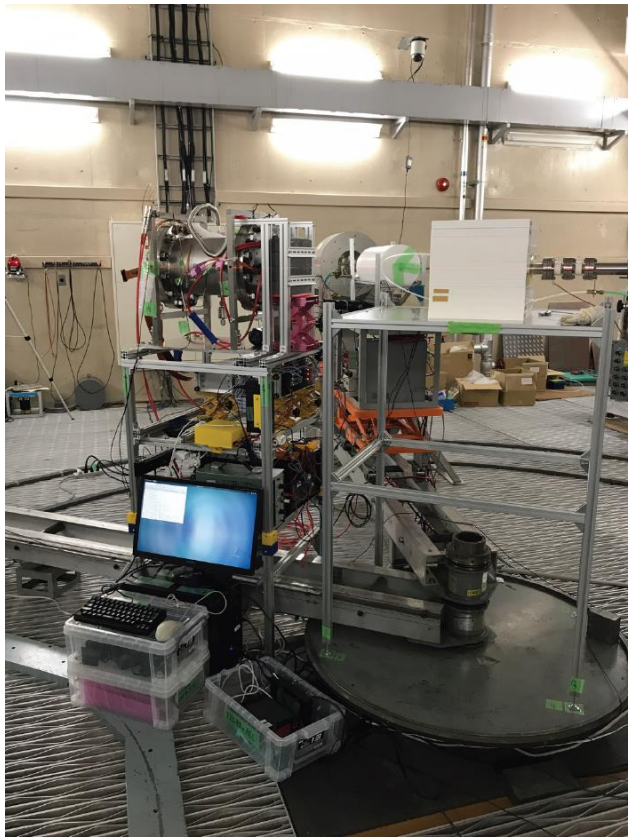
with Geant4

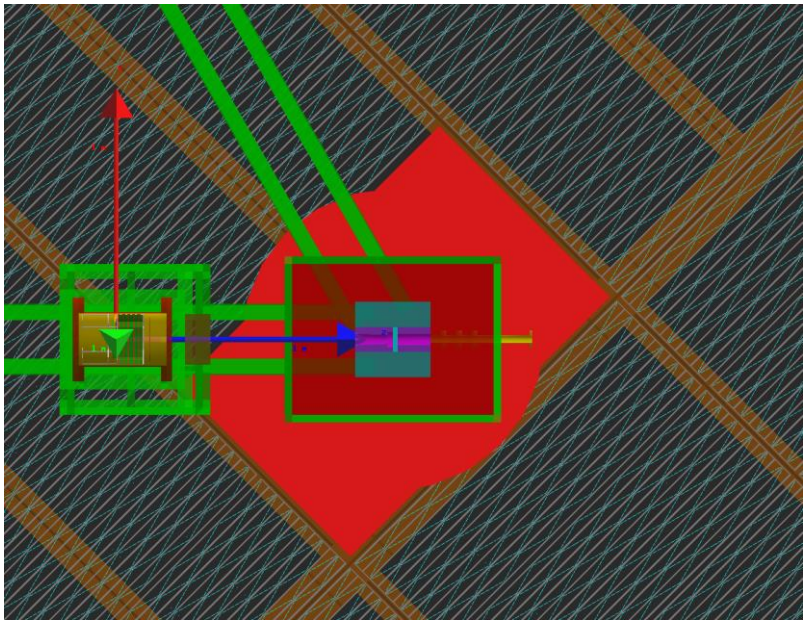
Background study by Geant4



- Construct Geant4 geometry to study the origin of the background



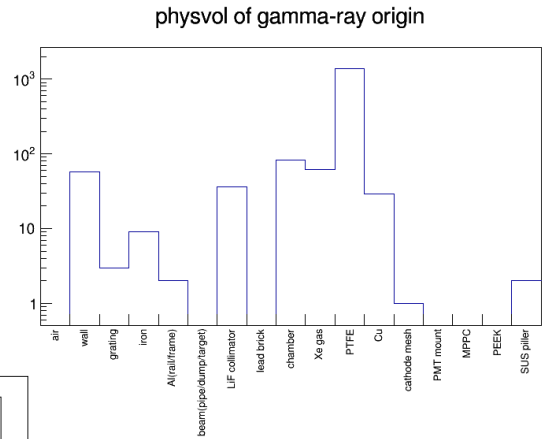


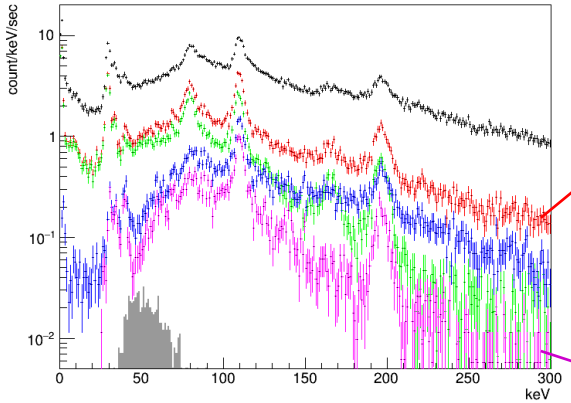


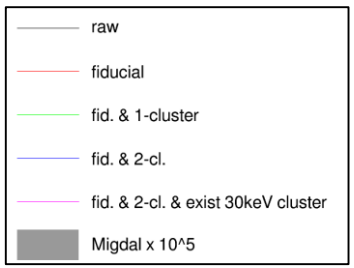
Background study by Geant4

- Reproduced the spectrum shape roughly
  - for both selected samples

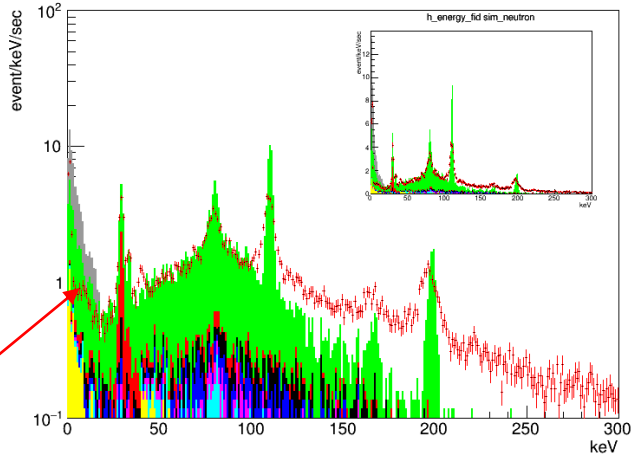
- Identified gamma ray origin
  - PTFE: the largest factor
  - ^{129}Xe: second largest
  - No unknown component in singal samples



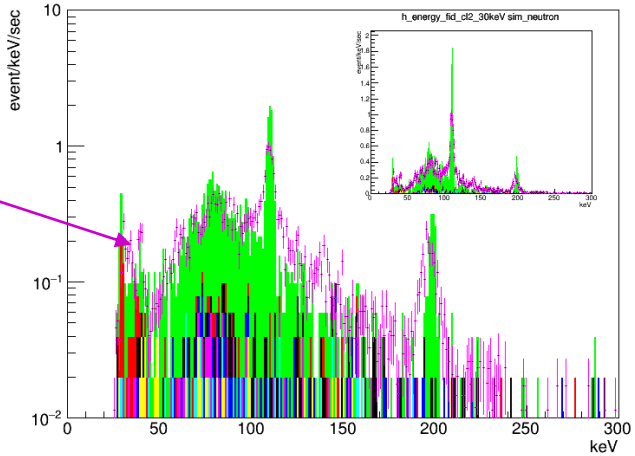




[fiducial]



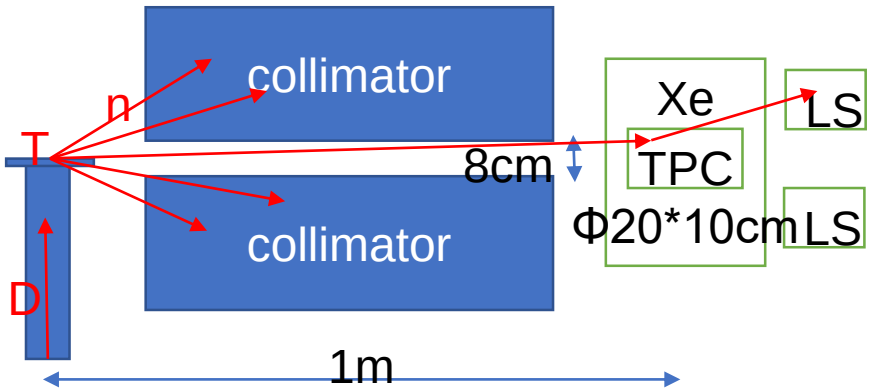
[fiducial & 2 cluster & exist 30keV cluster]



Future plan

- 5 order S/N improvement ideas

update	signal	BG
Energy: 565keV --> 14MeV	20 (Migdal probability)	O(1)
Low material TPC (w/o PTFE)	1	1/20 (Geant4 suggestion)
Liquid scintillator	0.1 (due to solid angle)	O(1e-3)
neutron shield	1	
livetime: 3min --> 3day	1440	1440
total	3e3 times	7e-2 times



1. neutron tagging to improve S/N of Migdal

2. Form factor measurement

3. Quenching factor measurement

Summary

- MIRACLUE experiment
  - Migdal effect search with position sensitive gaseous detectors (Xe, Ar)
  - Select 2-cluster event topology by K-alpha X-ray

- 565keV neutron beam test for Xe detector as a trial
  - clear gamma-ray BG peaks are observed
  - energy resolution and tracking ability is good
  - current sensitivity for Migdal search is not so good due to gamma-ray BG, but the origin of the source is well identified by Geant4 simulation

- Future plan
  - Xe TPC
    - 14MeV neutron beam test
    - Low material TPC cage (w/o PTFE)
  - Ar TPC
    - 565keV neutron beam test
    - considering dynamic range of signal size
  - LS tagging
    - to obtain high purity nuclear scattering data
    - quenching facto measurement in the gaseous Xenon
    - form factor measurement to check the consistency of ENDF database