Migdal effect detection capability

Kiseki Nakamura (ICRR)

Physics > Instrumentation and Detectors

[Submitted on 13 Sep 2020]

Detection capability of Migdal effect for argon and xenon nuclei with position sensitive gaseous detectors

Kiseki D. Nakamura, Kentaro Miuchi, Shingo Kazama, Yutaro Shoji, Masahiro Ibe, Wakutaka Nakano

Migdal effect is attracting interests because of the potential to enhance the sensitivities of direct dark matter searches to the low mass region. In spite of its great importance, the Migdal effect has not been experimentally observed yet. A realistic experimental approach towards the first observation of the Migdal effect in the neutron scattering was studied with Monte Carlo simulations. In this study, potential background rate was studied together with the event rate of the Migdal effect by a neutron source. It was found that a table-top sized $\sim (30\mathrm{cm})^3$ position-sensitive gaseous detector filled with argon or xenon target gas can detect characteristic signatures of the Migdal effect with sufficient rates (O($10^2 \sim 10^3$) events/day). A simulation result of a simple experimental set-up showed two significant background sources, namely the intrinsic neutrons and the neutron induced gamma-rays. These background rates were found to be much higher than those of the Migdal effect in the neutron scattering. As a consequence of this study, it is concluded that the experimental observation of the Migdal effect in the neutron scattering can be realized with a good understanding and reduction of the background.

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Submission history

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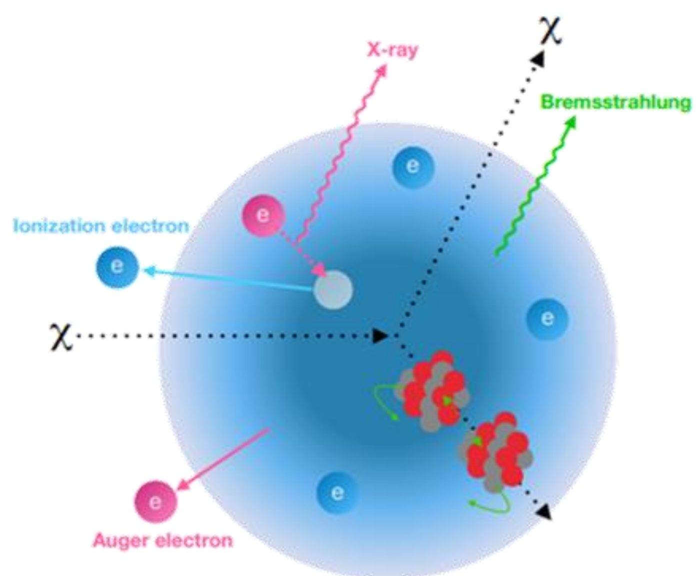
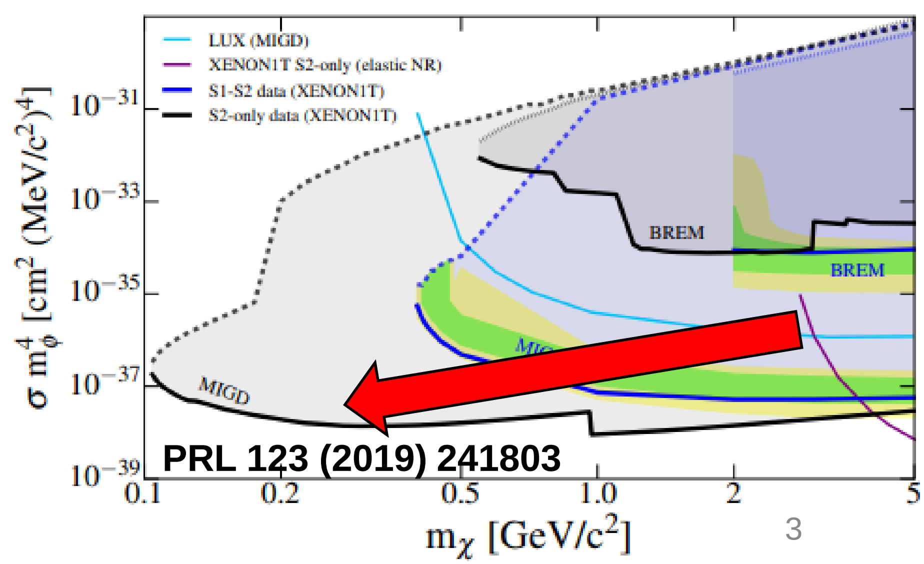
Content

- Our setup
  - neutron beam --> Ar/Xe gas detector
- Signal simulation
  - How to generate Migdal signal simulation
- Background simulation
  - neutron BG (intrinsic)
  - gamma-ray BG (n,gamma)

Migdal for dark matter search

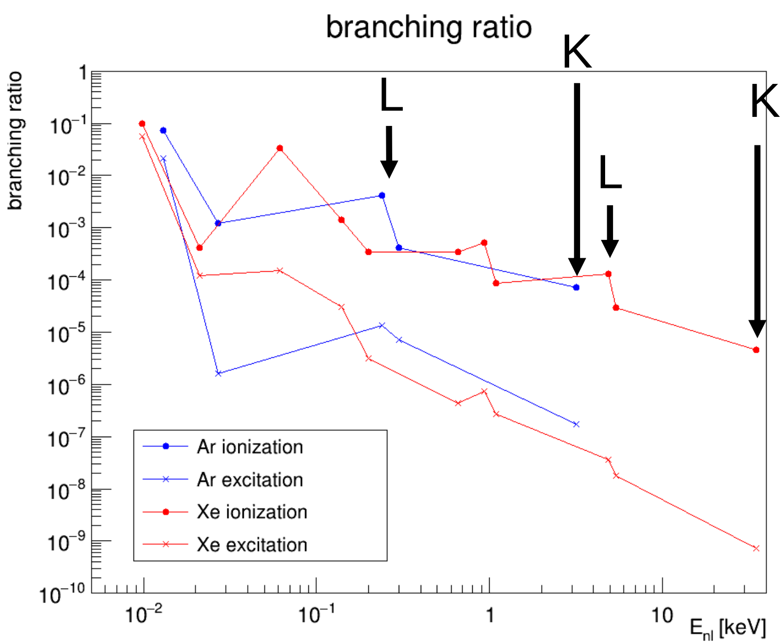
- Migdal effect
  - sudden nuclear movement --> ionization / excitation
- Migdal for dark matter search
  - additional electronic energy --> improve sensitivity
- Let's confirm Migdal effect by neutron beam !

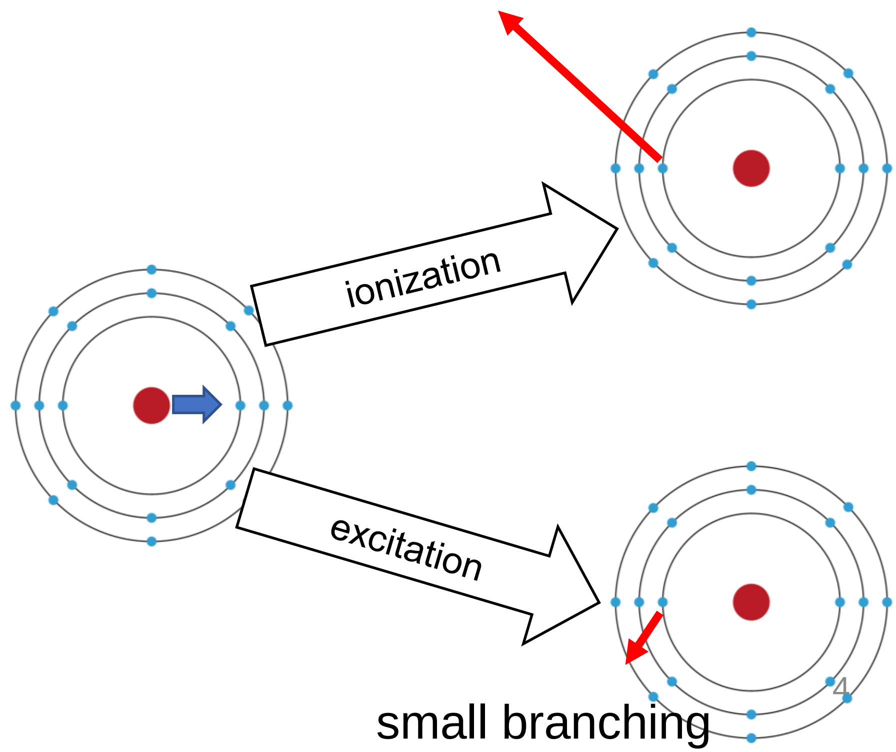




Branching ratio of Migdal

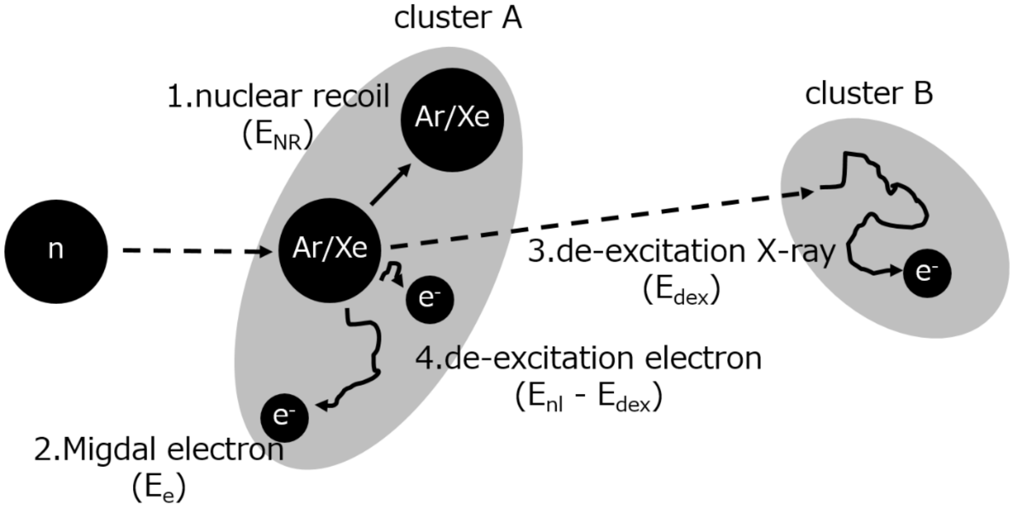
- Migdal branching
  - Ionization > excitation
  - low energy > high energy
- Our choice
  - K-shell ionization





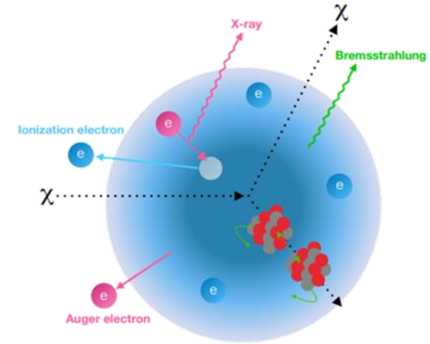
Event topology of Migdal

- Situation
  - Migdal ionization (K-shell) --> Migdal electron and hole
  - X-ray by de-excitation
- Feature
  - two cluster (in the gaseous medium)
  - cluster-B is fixed energy
  - --> position sensitive gaseous detector



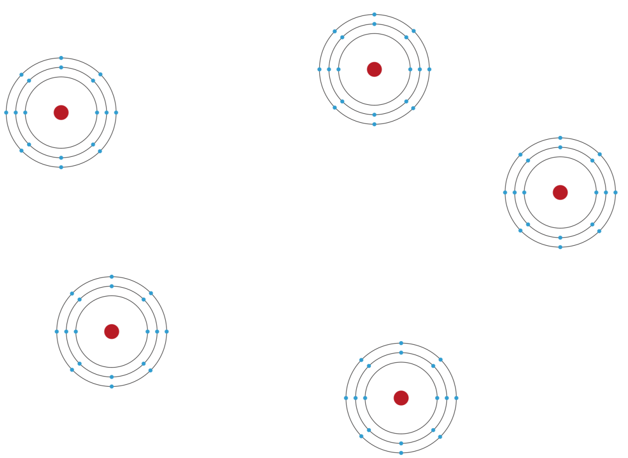
target	Ar 1atm	Xe 8atm
energy	4keV	30keV
X-ray absorption length	2.95cm	2.19cm
fluorescence yield	0.13	0.9

State of medium

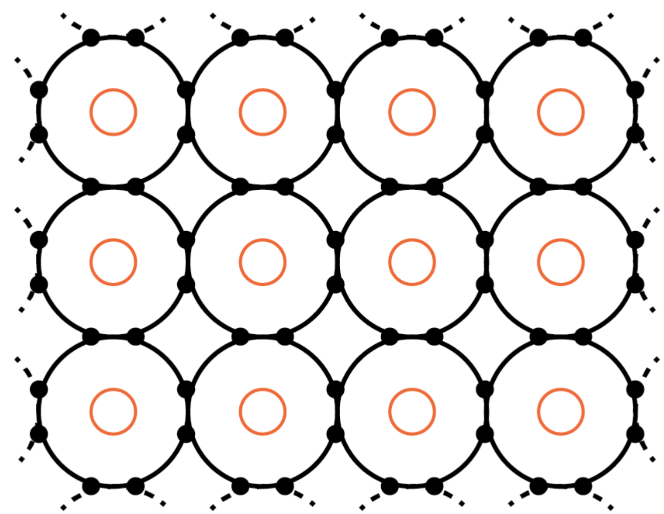


- Gaseous detector
  - two cluster identification
  - simple system (match to Ibe-san's calculation)
- Solid detector
  - very recently, Migdal in semiconductors is calculated (arXiv:2011.09496)

gas



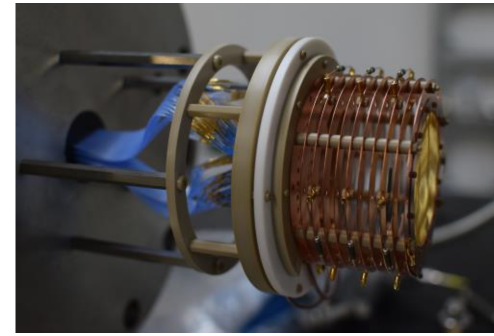
solid

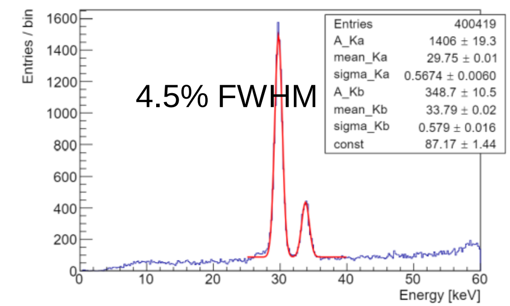


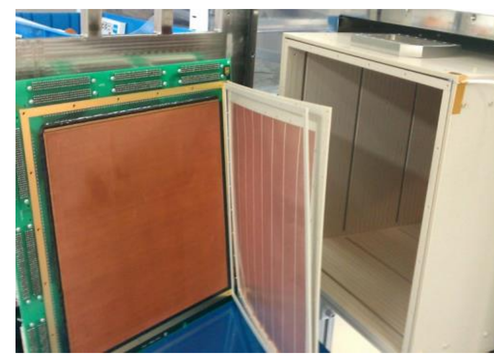
Gas as a target

- Xenon target (8atm)
  - K-shell X-ray is 30 keV and easily to see
  - good energy resolution (~5%)
  - experiment: XENON, LUX etc.
- Argon target (1atm)
  - no inelastic scattering with neutron
  - experiment: Darkside etc.
- --> ~1000 ev/day is expected

target	Ar 1atm	Xe 8atm
K-shell energy	4keV	30keV
absorption length	2.95cm	2.19cm
fluorescence yield	0.14	0.9
event rate	603 ev/day	975 ev/day

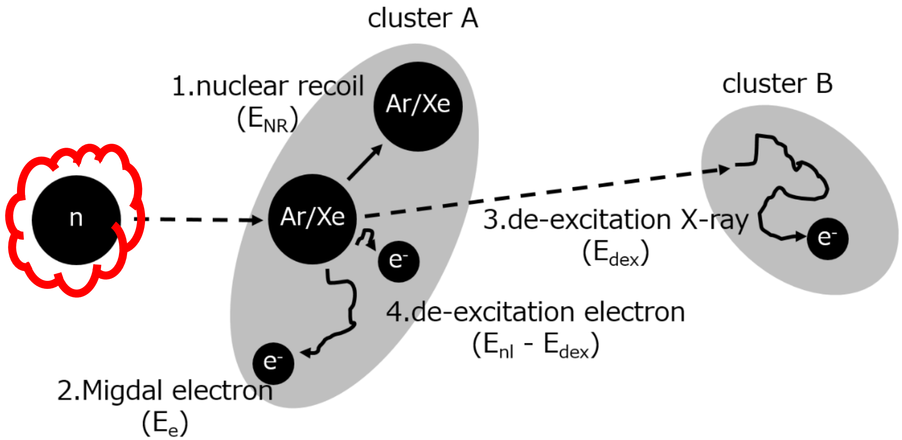


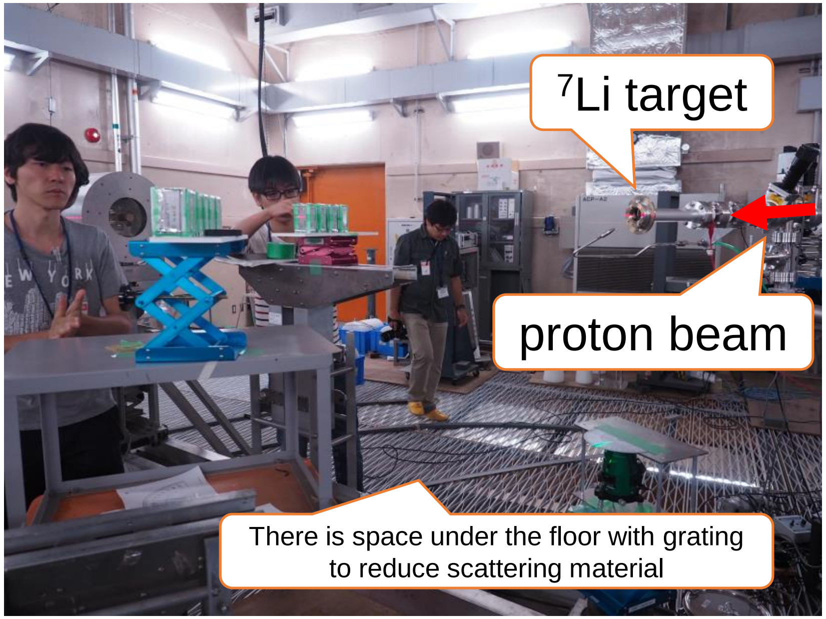




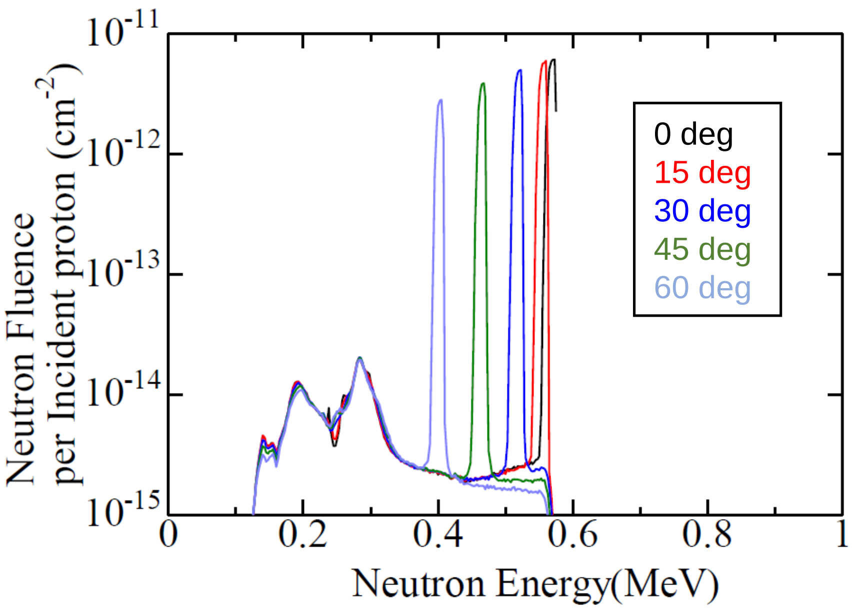
Neutron beam

- Neutron beam at AIST
  - interaction: $^{7}Li(p,n)^{7}Be$
  - energy: 565keV (on face)
  - flux: 1000 /s/cm^2 (at 1m)

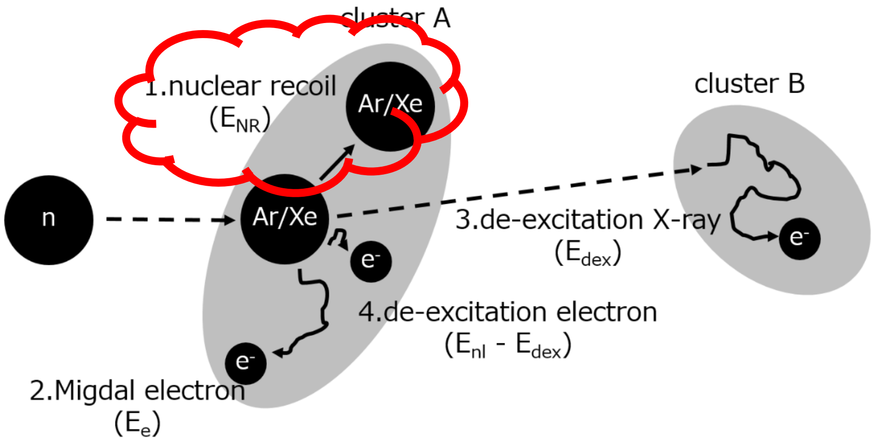




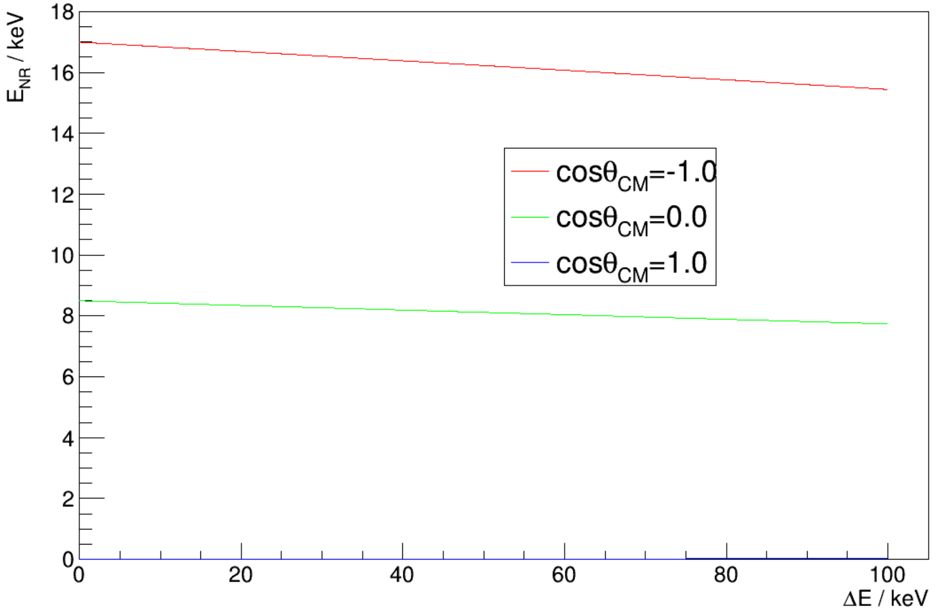
angular dependence of neutron energy
--> used for (n,γ) BG estimation



Nuclear recoil

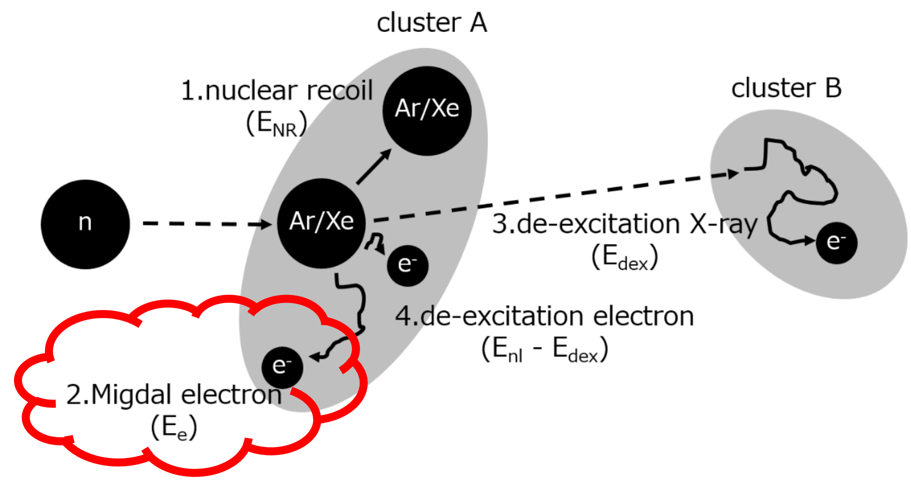


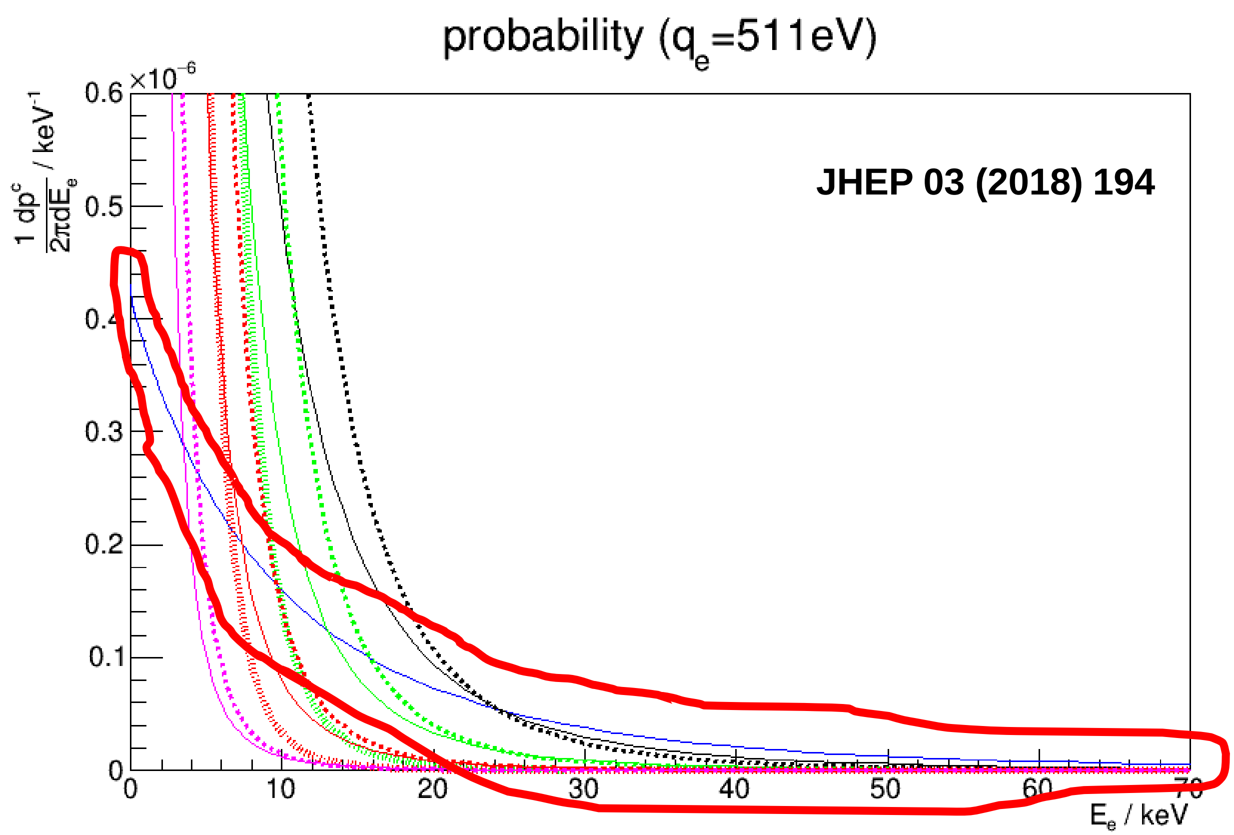
- "inelastic" effect is seen a little
  - due to transferred energy (ΔE=Ee+Enl)
  - Take into account it to the Geant4 simulation



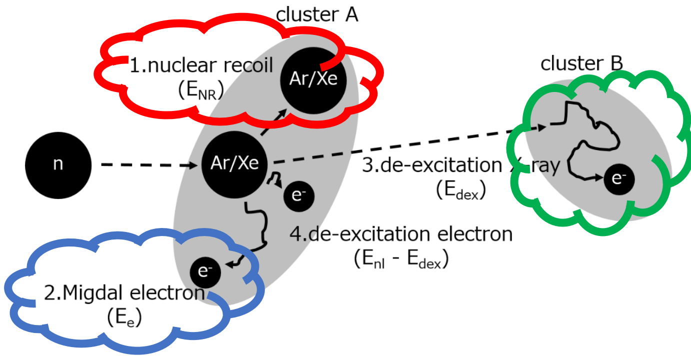
Migdal electron

- For K-shell of Xe
  - typically 10keV
  - shape is like exponential

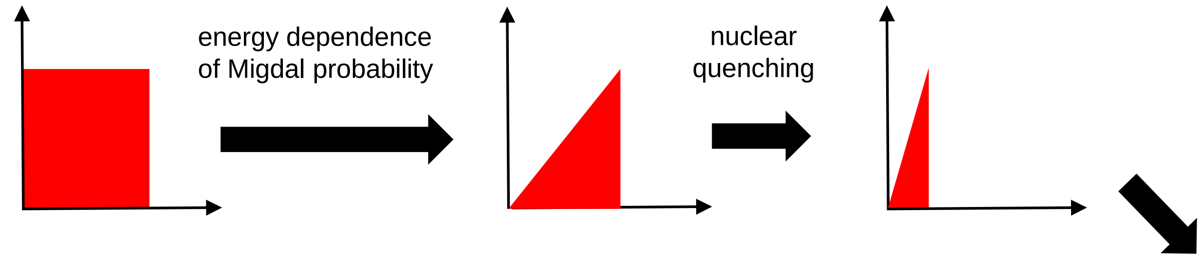


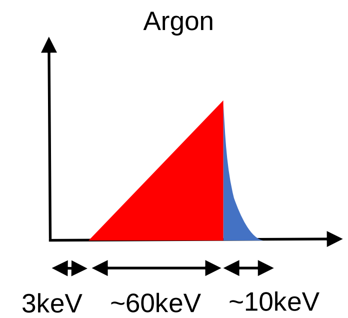


Migdal signal

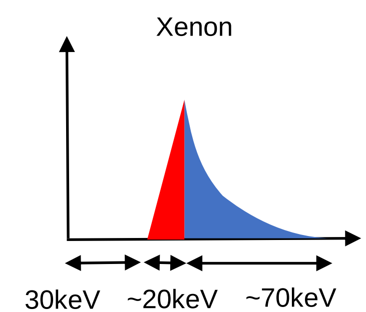


- nuclear recoil

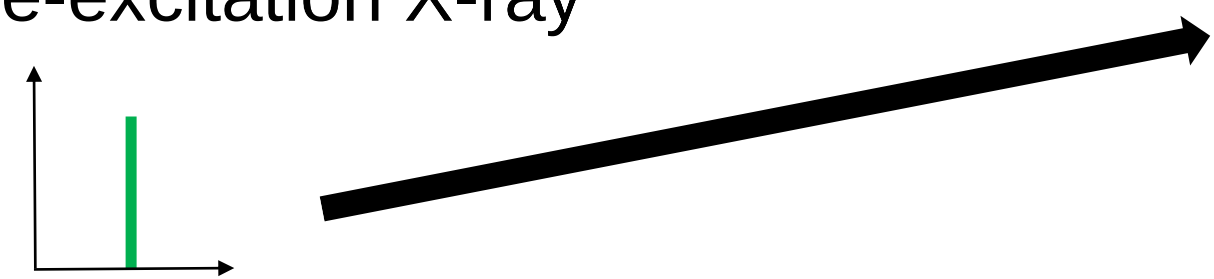




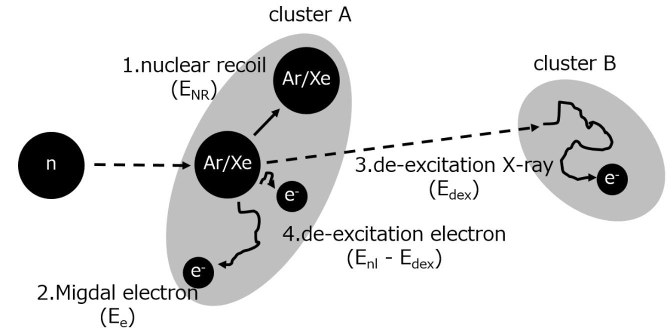
- Migdal electron



- de-excitation X-ray

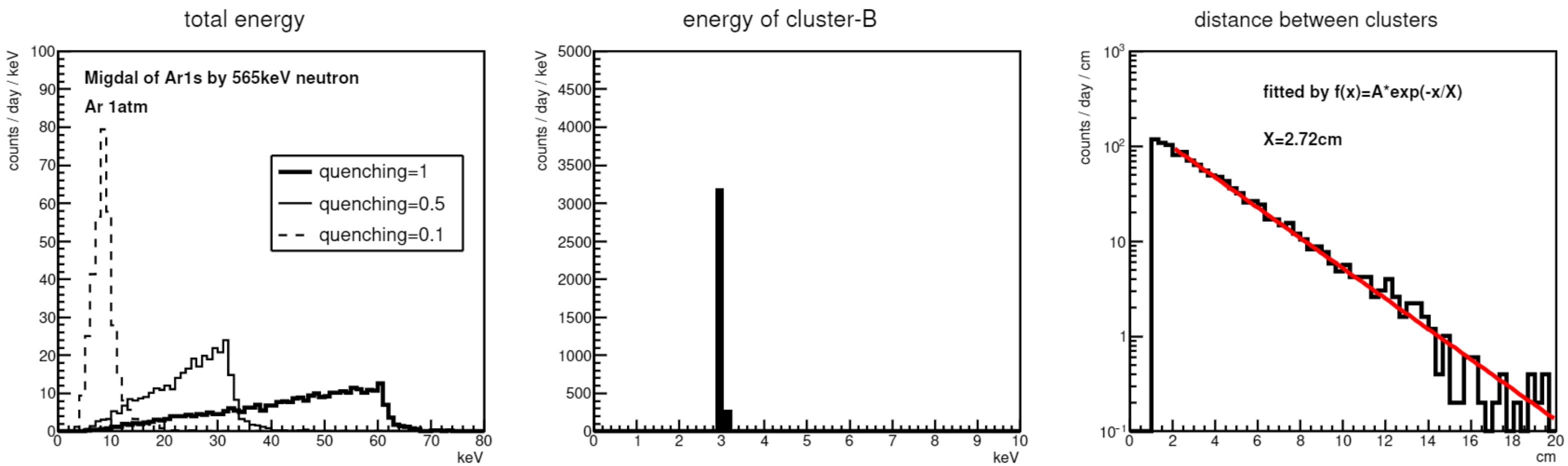


Migdal signal (Geant4)

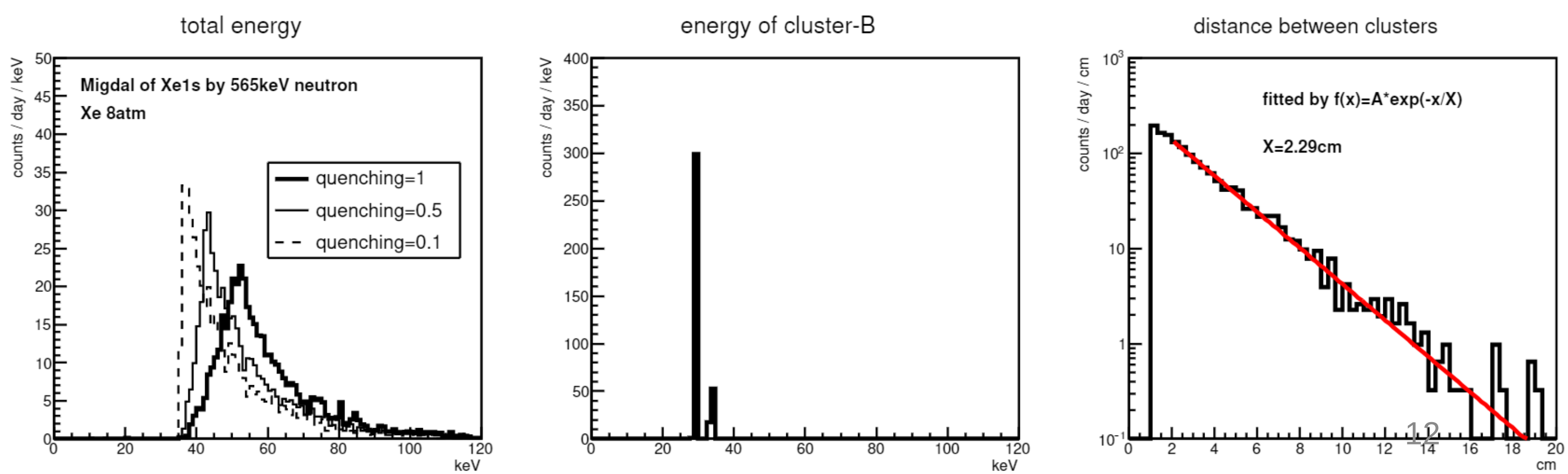


- after "cluster num == 2" selection
- mono-energetic cluster-B is obtained
- cluster distance is consistent to X-ray absorption length

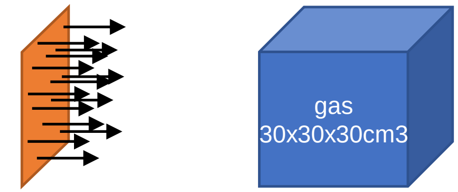
Ar 1atm



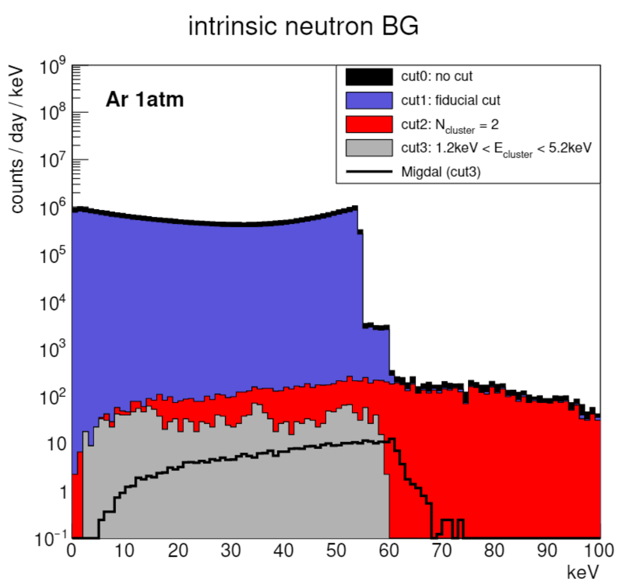
Xe 8atm

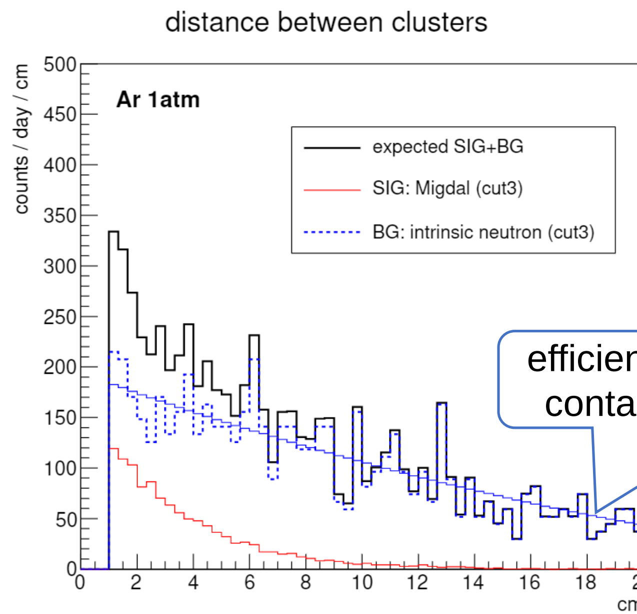


Neutron BG（Ar 1atm）



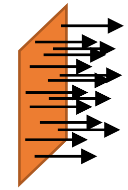
- neutron --> gas target only
- dominant BG : neutron multiple scattering
- cluster distance distribution is different to signal

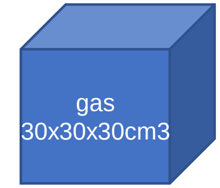




efficiency curve where event is contained in volume $(30cm)^3$

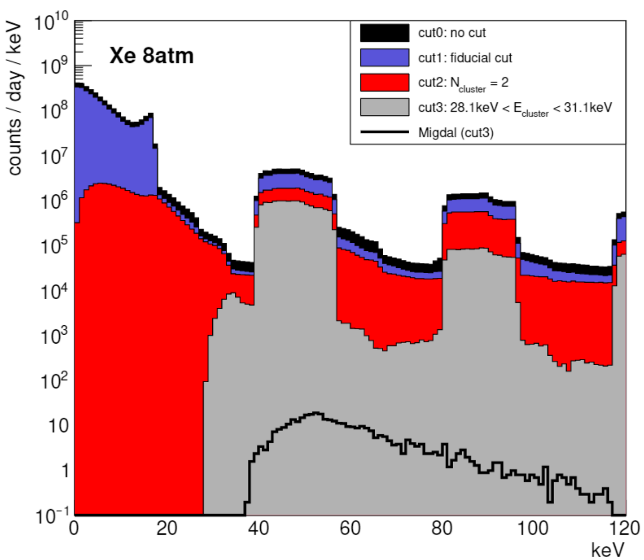
Neutron BG（Xe 8atm）



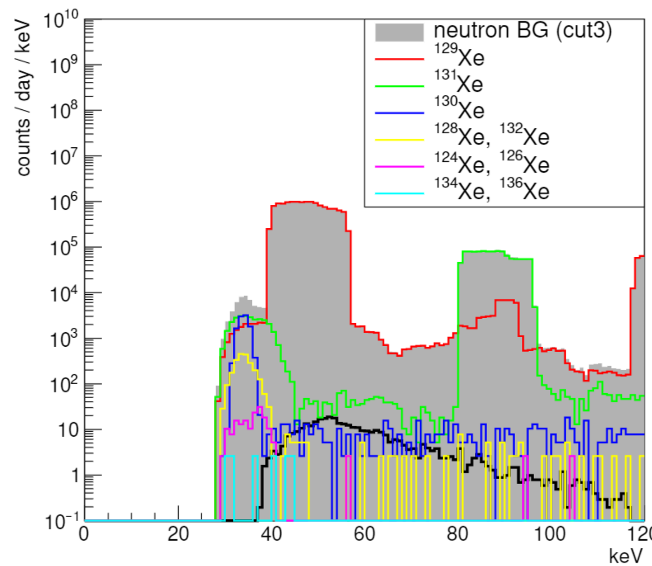


- neutron --> gas target only
- dominant BG:
  - gamma-rays from ^{129}Xe (inelastic)
  - gamma-rays from ^{131}Xe (capture)
- ^{134}Xe, ^{136}Xe selection is needed by enrichment

intrinsic neutron BG



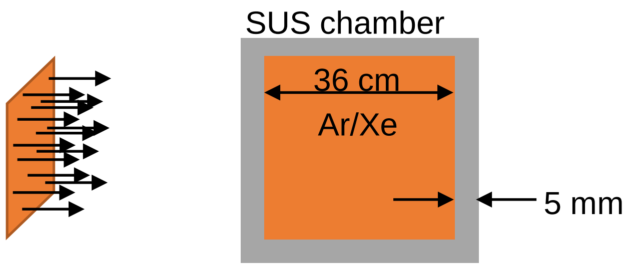
isotope ratio of neutron BG

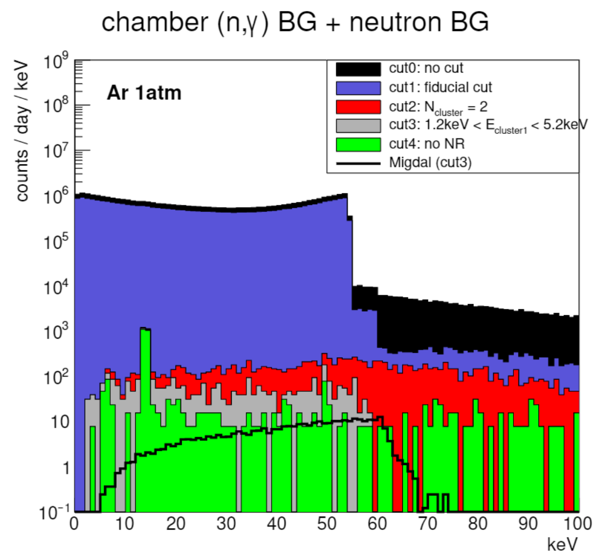


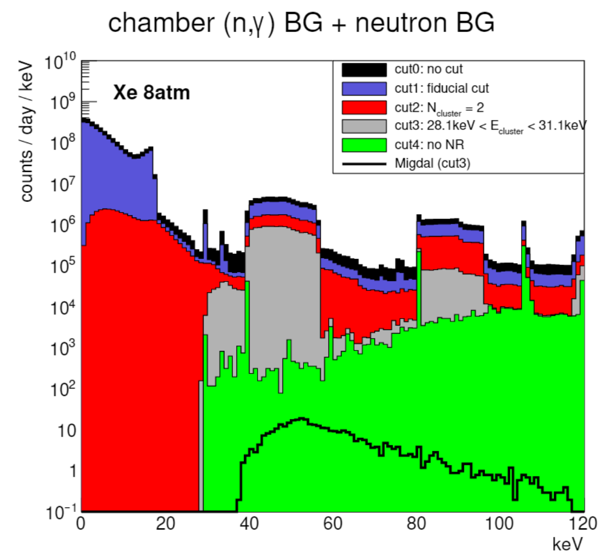
Gamma ray BG

- Too much BG exist for the simple constitution

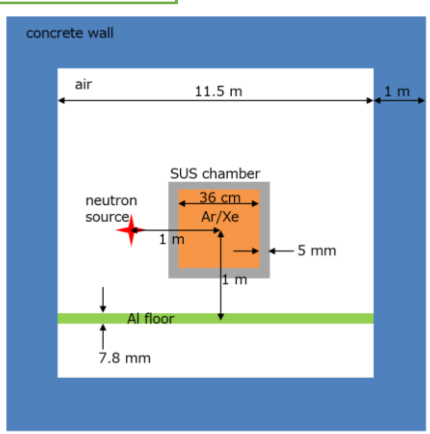
chamber BG

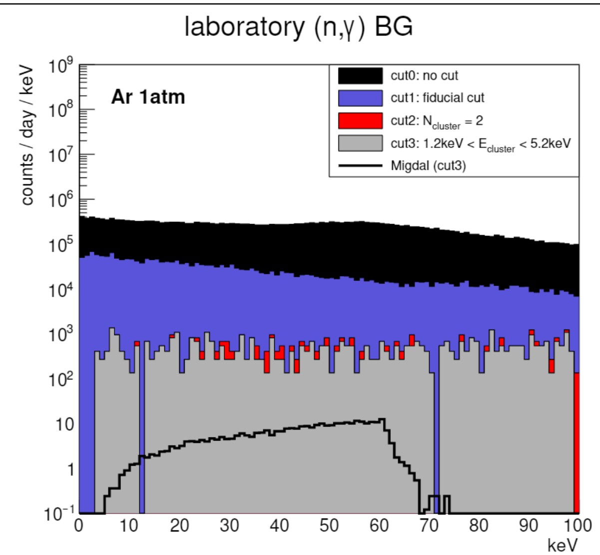


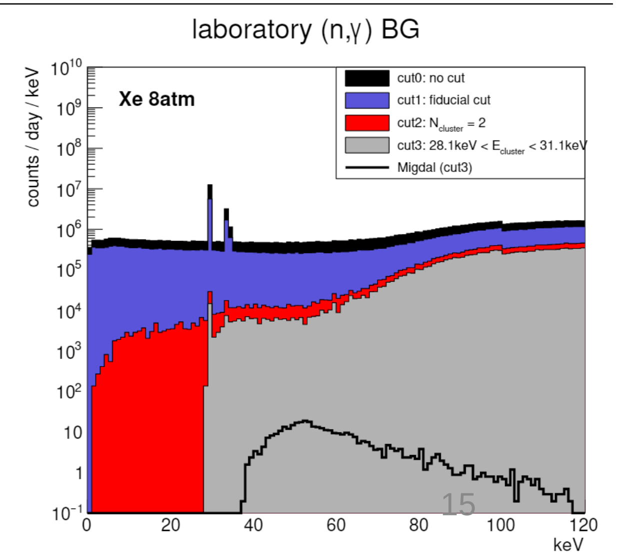




laboratory BG

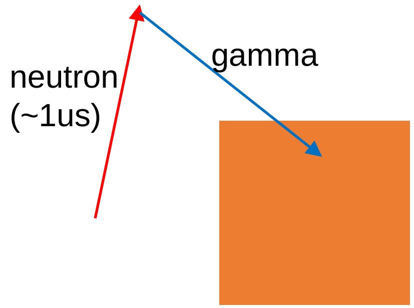




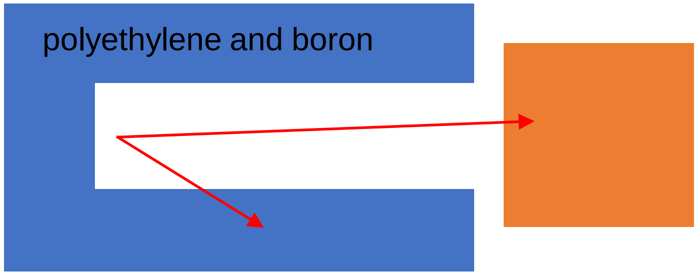


Ideas of BG reduction

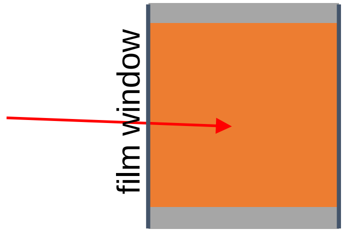
Pulse neutron beam



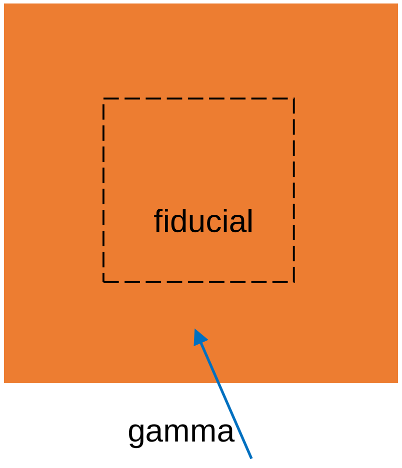
Neutron shield



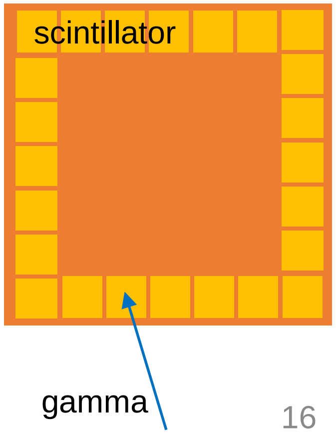
Thin chamber



Self shield



Active shield



Summary

arXiv: 2009.05939

- Migdal effect is very attractive for DM search
  - Observation of Migdal effect by neutron beam will be a great step for DM direct detection field
- Our simulation study
  - Detector: position sensitive gaseous detector (Ar/Xe)
  - Signal: a certain event rate ~1000 ev/day
  - BG: a lot (intrinsic neutron BG / (n,γ) gamma-ray BG)
  - -->More specialized design is needed for actual experiment
  - code is to be uploaded to somewhere (maybe slack)
- Other possibilities
  - L-shell electron, neutron energy, gas pressure, detector size, solid state, ...