Migdal効果の現状
～DAY1のおさらい～

2020年12月9日

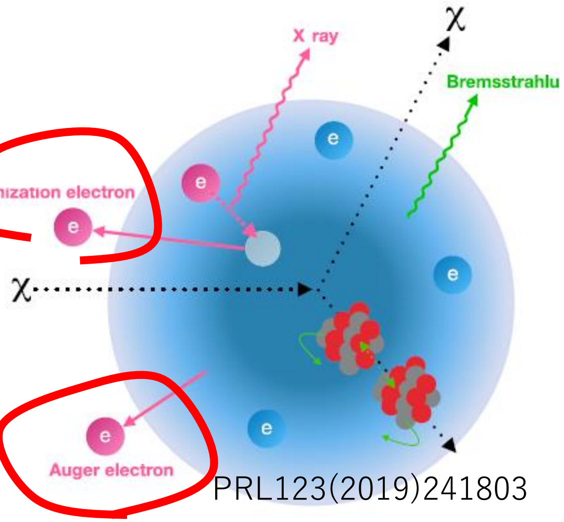
身内賢太朗（神戸大学）

Migdal Effect in Dark Matter Direct Detection Experiments

Masahiro Ibe (ICRR)
2020/11/24

Based on a collaboration
arXiv:1707.07258 [with W. Nakano, Y. Shoji, K. Suzuki @ ICRR]

伊部



PRL123(2019)241803

Pawel

Migdal In Galactic Dark mAtter expLoration

Pawel Majewski
(STFC/Rutherford Appleton Laboratory)
for the MIGDAL Collaboration

Migdal observation investigative workshop 2020, 24 November 2020

Migdal効果による暗黒物質探索

風間慎吾
名古屋大学 KMI / IAR

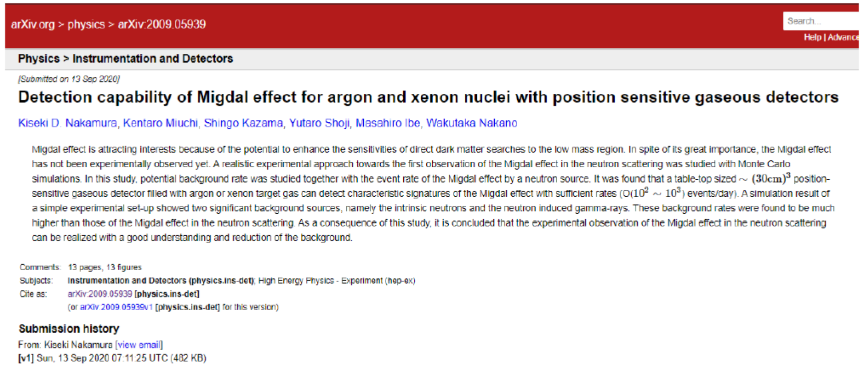
風間

@ミグダル観測検討会2020

中村

Migdal effect detection capability

Kiseki Nakamura (ICRR)



arXiv.org > physics > arXiv:2009.05939

Search...
Help | Advance

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.

Comments: 13 pages, 13 figures
Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2009.05939 **[physics.ins-det]**
(or arXiv:2009.05939v1 **[physics.ins-det]** for this version)

Submission history
From: Kiseki Nakamura [view email]
[v1] Sun, 13 Sep 2020 07:11:25 UTC (482 KB)

Migdal Effect in Dark Matter Direct Detection Experiments

Masahiro Ibe (ICRR)
2020/11/24

伊部

Based on a collaboration
arXiv:1707.07258 [with W. Nakano, Y. Shoji, K. Suzuki @ ICRR]

✔ *Reformulation of the Migdal Effect*

✔ Migdal's approach

Initial state of the DM scattering : ***(DM plane wave) x (Nucleus plane wave)***
Final state of the DM scattering : ***(DM plane wave) x (Nucleus plane wave)***
Migdal Effect = ***Final state effects***

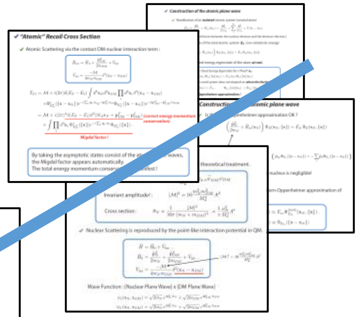
The Migdal Effect is treated separately from the nuclear scattering

✔ New approach　散乱を原子として考えました。

Initial state of the DM scattering : ***(DM plane wave) x (Atomic plane wave)***
Final state of the DM scattering : ***(DM plane wave) x (Atomic plane wave)***

The Migdal Effect is automatically taken into account !

How do we construct the plane wave function of the atoms?



✔ *Numerical Transition Rate (by using Flexible Atomic Code)*

Xe ($q_e = m_e \times 10^{-3}$)

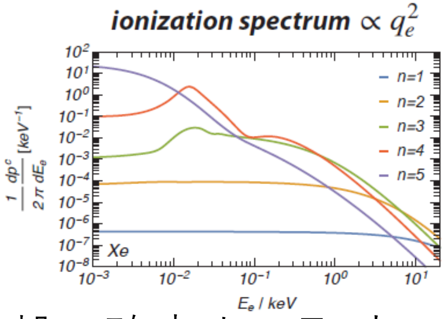
(n,ℓ)	$\mathcal{P}_{\to 4f}$	$\mathcal{P}_{\to 5d}$	$\mathcal{P}_{\to 6s}$	$\mathcal{P}_{\to 6p}$	$E_{n\ell}$ [eV]	$\frac{1}{2\pi}\int dE_e \frac{dp^c}{dE_e}$
	Excitation					Ionization
1s	–	–	–	7.3×10^{-10}	3.5×10^4	4.6×10^{-6}
2s	–	–	–	1.8×10^{-8}	5.4×10^3	2.9×10^{-5}
2p	–	3.0×10^{-8}	6.5×10^{-9}	–	4.9×10^3	1.3×10^{-4}
3s	–	–	–	2.7×10^{-7}	1.1×10^3	8.7×10^{-5}
3p	–	3.4×10^{-7}	4.0×10^{-7}	–	9.3×10^2	5.2×10^{-4}
3d	2.3×10^{-9}	–	–	4.3×10^{-7}	6.6×10^2	3.5×10^{-3}
4s	–	–	–	3.1×10^{-6}	2.0×10^2	3.4×10^{-4}
4p	–	4.1×10^{-8}	3.0×10^{-5}	–	1.4×10^2	1.4×10^{-3}
4d	7.0×10^{-7}	–	–	1.5×10^{-4}	6.1×10	3.4×10^{-2}
5s	–	–	–	1.2×10^{-4}	2.1×10	4.1×10^{-4}
5p	–	3.6×10^{-2}	2.1×10^{-2}	–	9.8	1.0×10^{-1}

(n,ℓ)	$4f$	$5d$	$6s$	$6p$
$E_{n\ell}$[eV]	0.85	1.6	3.3	2.2

initial state

(transition is possible only for $|\Delta\ell| = 1$)

ionization spectrum $\propto q_e^2$



内殻　確率小　Ee大
外殻　確率大　Ee小

E_e spectrum is purely determined the structure of the electron cloud !
E_e spectrum is independent of the dark matter velocity v_{DM} and m_{DM}.
Rate is proportional to q_e^2

✔ *Implication on Dark Matter Direct Detection Experiments*

Electron Orbits

The number of electrons in a shell for the ground state configurations.

	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p
Na	2	2	6	~~1~~	0	0	0	0	0	0	0	0
Ar	2	2	6	~~2~~	~~6~~	0	0	0	0	0	0	0
Ge	2	2	6	2	6	10	~~2~~	~~2~~	0	0	0	0
I	2	2	6	2	6	10	2	6	10	0	~~2~~	~~5~~
Xe	2	2	6	2	6	10	2	6	10	0	~~2~~	~~6~~

We cannot use our results based on the isolated atoms for the valence electrons.

For the inner electrons, the effects from the environments are not significant.

※最外殻電子は使わないでね。
「内側でも数10%くらいは計算不定性あります。」
測ってね。

Migdal効果を用いた暗黒物質探索

EDELWEISS (Germanium): "Searching for low-mass dark matter particles with a massive Ge bolometer operated above-ground", arXiv:1901.03588

CDEX-1B (Germanium): "Constraints on Spin-Independent Nucleus Scattering with sub-GeV Weakly Interacting Massive Particle Dark Matter from the CDEX-1B Experiment at the China Jin-Ping Laboratory" arXiv:1905.00354

LUX (Xenon): "Results of a Search for Sub-GeV Dark Matter Using 2013 LUX Data", arXiv:1811.1124

XENON1T (Xenon): "A Search for Light Dark Matter Interactions Enhanced by the Migdal effect or Bremsstrahlung in XENON1T", arXiv:1907.12771

SENSEI (Si): "SENSEI: Direct-Detection Results on sub-GeV Dark Matter from a New Skipper-CCD", arXiv:2004.11378

2017年の伊部論文を受けて、流行ってます。

	CDEX-1B	EDELWEISS-SURF	LUX	XENON1T	SENSEI
Detector	Ge (charge-only) No ER/NR discri.	Ge (heat-only) (above ground)	LXe TPC (S1-S2)	LXe TPC (S1-S2, S2-only)	CCD (Si) (charge-only, 135 K)
Size	939 g	33.4 g	118 kg	~1.3 ton	~2g
Exposure	737.1 kg day	0.03 kg day (1-day blind, 5-days unblind)	13,775 kg day	S1-S2: 1 ton year S2-only: 22 ton day	~20 g day
Threshold	160 eVee	60 eVee	~1 keVee	S1-S2: ~1 keVee S2-only: 186 eVee	O(1) eVee (詳細不明) (1,2,3,4 e-)

XENON Dark Matter Project

KMI

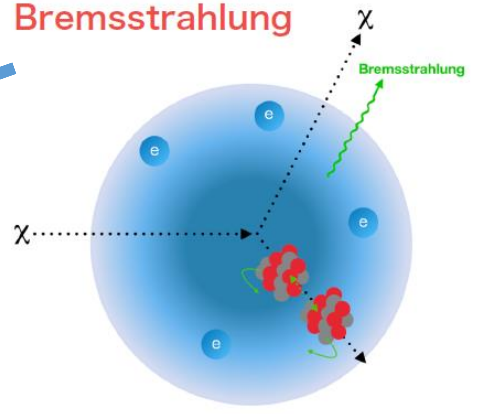
Migdal効果による暗黒物質探索

風間

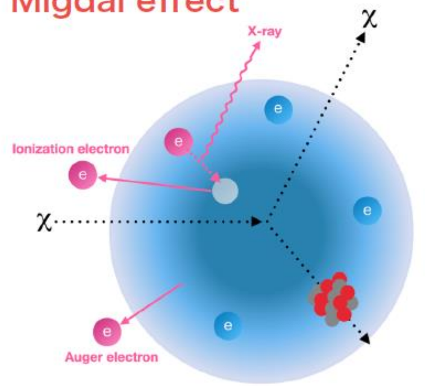
風間慎吾
名古屋大学 KMI / IAR

不明な(怪しい)点？

Bremsstrahlung



Migdal effect



ヤバさは認識して使いましょう。

- Migdal効果に関わるIonization electron, x-ray/Auger electron + NRの全てのエネルギー損失がほぼ一点で起こる。LXe TPCの場合、同時にER+NRが起こる場合の再結合モデル等はよく分かってない(ER, NRを独立だと思った時のレスポンスと同じではない？)
    - LUX/XENON1Tでは、NRの寄与が無視できる範囲のみ探索を行っているのでOK
- Migdal効果が起きた場合、例えばXe+の様に原子核はプラスの電荷を帯びている。この場合、検出器レスポンスは中性の時と異なる？

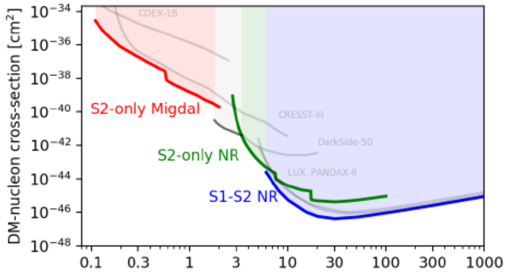
SUMMARY

- Direct dark matter detection experiments based on LXe are leading the search for GeV-TeV scale DM, but have limited sensitivity to sub-GeV WIMPs because of the small momentum transfer of WIMP-nucleus elastic scattering.
- However, there is an irreducible contribution of inelastic signals that accompanies the elastic scattering, which leads to emission of photon and the excitations / ionizations of atomic electrons.
  → Bremsstrahlung and Migdal Effect

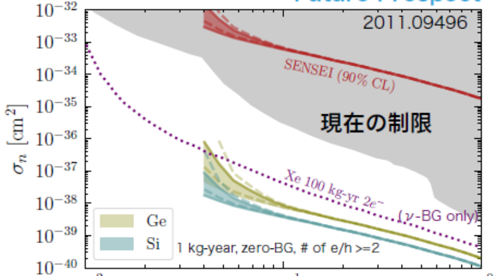
「発見能力はないけど」ぶっちぎれます

- XENON1T is currently leading the searches both in low & high mass regions!

Current Results



Future Prospect



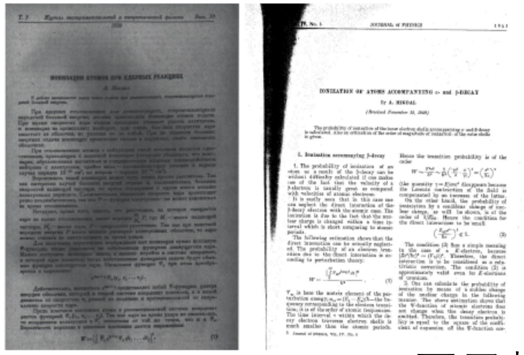
Migdal In Galactic Dark mAtter expLoration

Pawel Majewski
(STFC/Rutherford Appleton Laboratory)
for the MIGDAL Collaboration

Pawel　　nativeはこんな“MIGDAL“も可。

Migdal observation investigative workshop 2020, 24 November 2020

What do we already know about the Migdal effect ?



A. Migdal publications:

- Ionisation in nuclear reactions [1]
- Ionisation in radioactive decays [2]

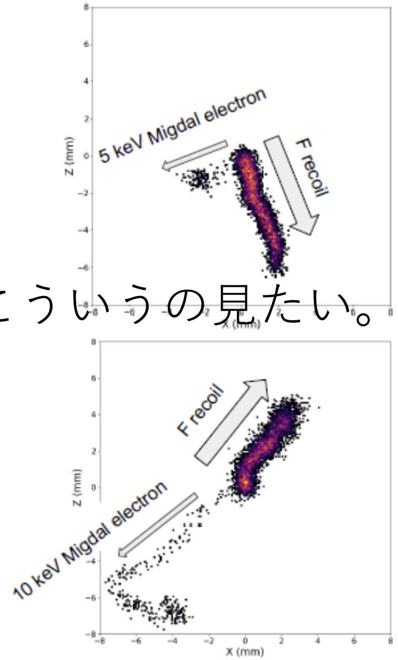
First observations of the Migdal effect in :

- Alpha decay [3,4,5]
- Beta decay [6,7]
- Positron decay [8]
- Nuclear scattering [ ]

原子核反跳のMIGDALがmissing!!!

- [1] A. Migdal *Ionizatsiya atomov pri yadernykh reaktsiyakh, ZhETF, 9, 1163-1165 (1939)*
- [2] A. Migdal *Ionizatsiya atomov pri α- i β- raspade, ZhETF, 11, 207-212 (1941)*
- [3] E. E. Berlovich et al., *Investigation of the "jolting" of electron shells of oriented molecules containing ^{32}P, Sov. Phys. JETP, Vol. 21 , 675 (1965)*
- ...S. Rapaport, F. Asaro and I. Pearlman *K-shell electron shake-off accompanying alpha decay, PRC 11, 1740-1745 (1975)*
- ...S. Rapaport, F. Asaro and I. Pearlman *L- and M-shell electron shake-off accompanying alpha decay, PRC 11, 1746-1754 (1975)*
- ...oehm and C. S. Wu *Internal Bremsstrahlung and Ionization Accompanying Beta Decay, Phys. Rev. 93, Number 3, 518 (1954)*
- ...ouratin et al. , *First Measurement of Pure Electron Shakeoff in the β Decay of Trapped ^{6}He^{+}Ions, PRL 108, 243201 (2012)*
- ...abian et al., *Electron Shakeoff following the β^{+} decay of Trapped ^{19}Ne^{+} and ^{35}Ar^{+} trapped ions, PRA, 97, 023402 (2018)*

Detector operation and the signal signature

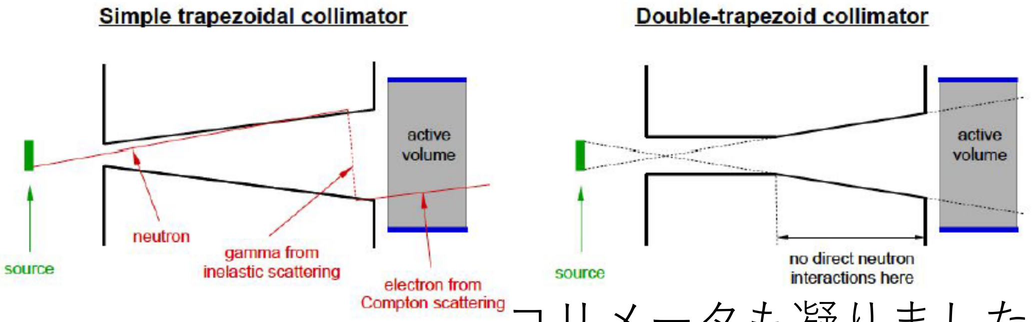


こういうの見たい。

- Example of the Migdal effect with 250 keV Fluorine recoil & 5 (10) keV electron (after 10 mm of drift in CF_4 at 50 Torr)
- Simulated with SRIM and garf++ (recoil) and DEGRAD (electron)
- Clear "fork-like" topology
- Clear different dE/dx distribution for both track
  - Opposite head-and-tail ionisation distribution
- Clear different ionisation density for both track

→ At this moment we do not assume any specifi angular distribution of the Migdal electron emi We will have capability to measure it.

DT and DD neutron generators , beam collimation and shielding



コリメータも凝りました

- Extended neutron source - 1.36 x 1.36 cm T target in the DT generator - simple trapezoidal collimator leads to electrons produced near active volume : NR/all events ~ 35 %
- Double-trapezoidal shape has been design with an extensive Geant4 simulations achieving NR/all events ~ 84 %

議論：BG BG BG！！！

Migdal effect detection capability

Kiseki Nakamura (ICRR) 中村

arXiv.org > physics > arXiv:2009.05939

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

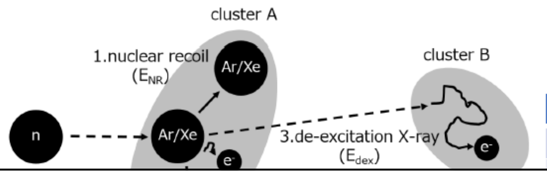
Migdal effect is attracting interests because of the potential to enhance the sensitivities of direct dark matter searches to the low mass region. In spite of its great importance, the Migdal effect has not been experimentally observed yet. A realistic experimental approach towards the first observation 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.

Comments: 13 pages, 13 figures
Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2009.05939 **[physics.ins-det]**
(or arXiv:2009.05939v1 **[physics.ins-det]** for this version)

Submission history
From: Kiseki Nakamura [view email]
[v1] Sun, 13 Sep 2020 07:11:25 UTC (482 KB)

Event topology of Migdal

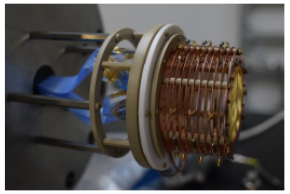
- Situation
  - Migdal ionization (K-shell) --> Migdal electron and hole
  - X-ray by de-excitation
- Feature　　特徴的な信号：2クラスター!
  - two cluster (in the gaseous medium)
  - cluster-B is fixed energy
  - --> position sensitive gaseous detector

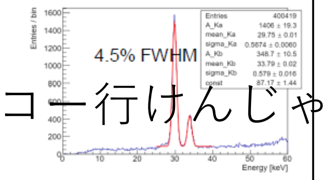


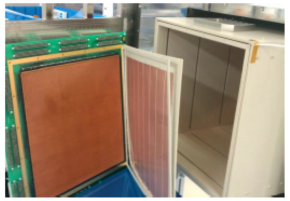
target	Ar 1atm	Xe 8atm
energy	4keV	30keV
		2.19cm
		0.9

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)　手持ちでソッコー行けんじゃね?
  - no inelastic scattering with neutron
  - experiment: Darkside etc.
- --> ~1000 ev/day is expected





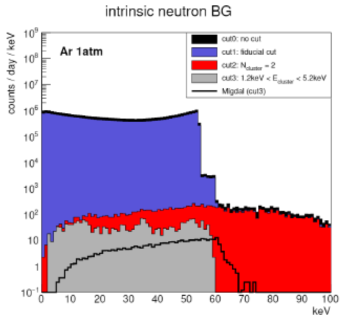


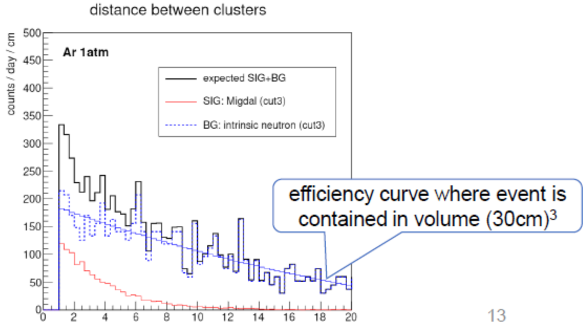
target	Ar 1atm	Xe 8atm
K-shell energy	4keV	30keV
absorption length	2.95cm	2.19cm
fluorescence yield	0.14	0.9
event rate	603 ev/day	975 ev/day

Neutron BG（Ar 1atm）

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

hopefully キラープロット





- 物理（理論）
  - 計算　原子核・密度依存　実験（α崩壊　β崩壊　β+崩壊）との比較
    - 計算精密化　簡単な電子配置を使っている dipole transitionとの比較で確認可能か。
    - 反跳エネルギーが大きくなるともう少し精度を上げる。
  - Migdal anomaly?
    - あまりないだろう。
  - 特徴的な信号
    - １S stateだと原子核反跳と電子の方向がそろう。
    - 特性X線でドップラーが見えないか?　(v/c=1e-4程度)難しい。

庄司　The Migdal effect in semi-conductors
中野　dark photon mediator模型

（飛び込み講演）永田

- 物理（DM探索）
  - XENONnT　「発見能力がない」
    →なんで、どうしたらいい?　：　水越
- 観測
  - 戦略
  - ビームライン　サーベイ：東野
  - 他実験（α崩壊　β崩壊　β+崩壊など）
  - シミュレーション
    - BG（中性子と実験室、Xe、、、）
    - 遮蔽設計
  - 検出器
    - Ar、Xe、Si　F、、、

BG測定結果：島田

XeのBG：亀井

「手持の技術でサクッと」：　吉田・池田

ミグダル観測に向けて：議論
～イチバンを目指すために～

2020年11月24日
神戸大　身内賢太朗

DAY 2 ： Let's Migdal（神戸大学梅田インテリジェントラボ）

2020/12/9(水) 10:00-17:00

DAY2は公募トーク中心にしたいと思っております。
本日の研究会・この議論を通じて、何かできそうだと思った方、
世話人までご一報ください。
ひとまず11/27までに頭出しいただけるとありがたいです。

中村

「DM検出するより難しいんじゃね?」
→　終わりの言葉：関谷