暗黒物質の探し方

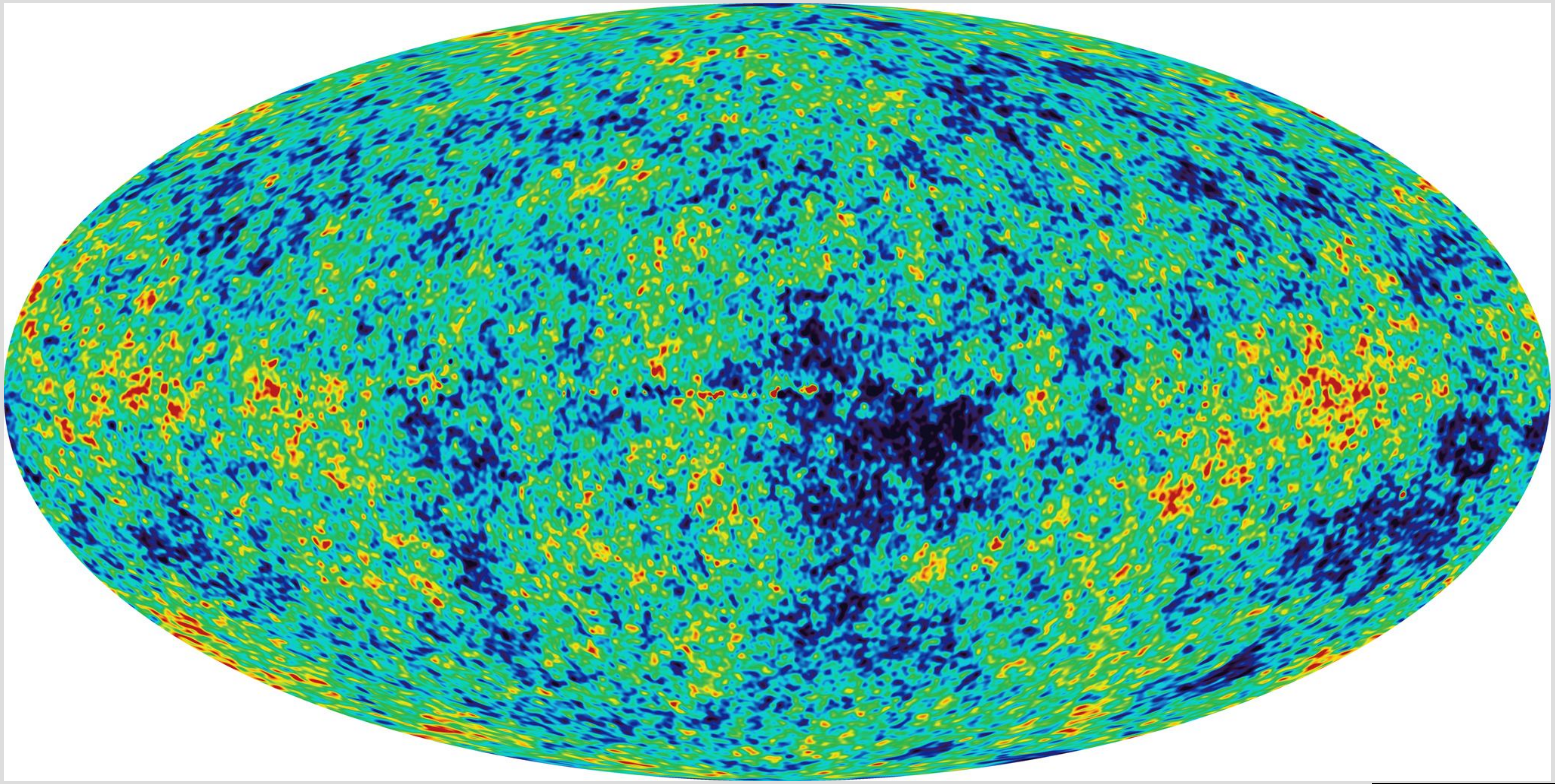
東京大学大学院理学系研究科
物理学教室

蓑輪　眞

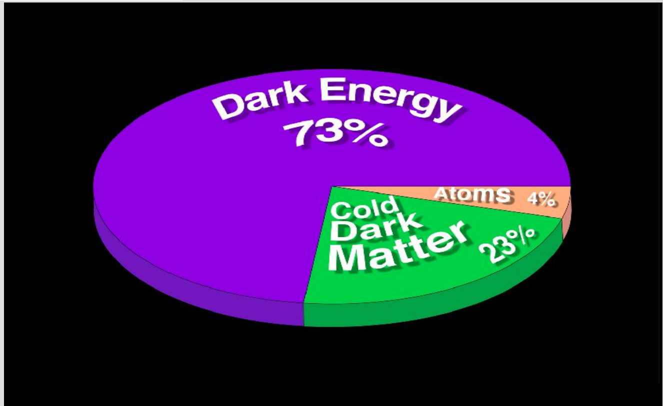
暗黒物質の“歴史”

- 1933　F. Zwicky　かみのけ座銀河団の速度分散　Helv. Phys. Acta. 6 (1933) 110
  Virial 定理　≪　赤方偏移の光学観測 → Dark Matter の存在
- 1965　A. Penzias & R. Wilson 宇宙マイクロ波背景輻射 (CMB) の発見
  電波観測の発達
- 1973　J. Ostriker & P. Peebles　ApJ. 186 (1973) 467
  多体系のシミュレーションによる回転銀河の安定条件
  ≪　我々の銀河の回転速度 220km/s → Dark Matter の存在
- 1970 年代後半　電波（HI ガス 21cm 輝線）による銀河回転曲線の観測
  → Dark Matter の存在の立証
- 1992 COBE　宇宙マイクロ波背景輻射のゆらぎの発見
  → インフレーションモデル、 $\Omega_{tot} = 1$ を示唆
- 1998 Super Kamiokande　ニュートリノ質量の発見
  → ~~HDM~~　CDM

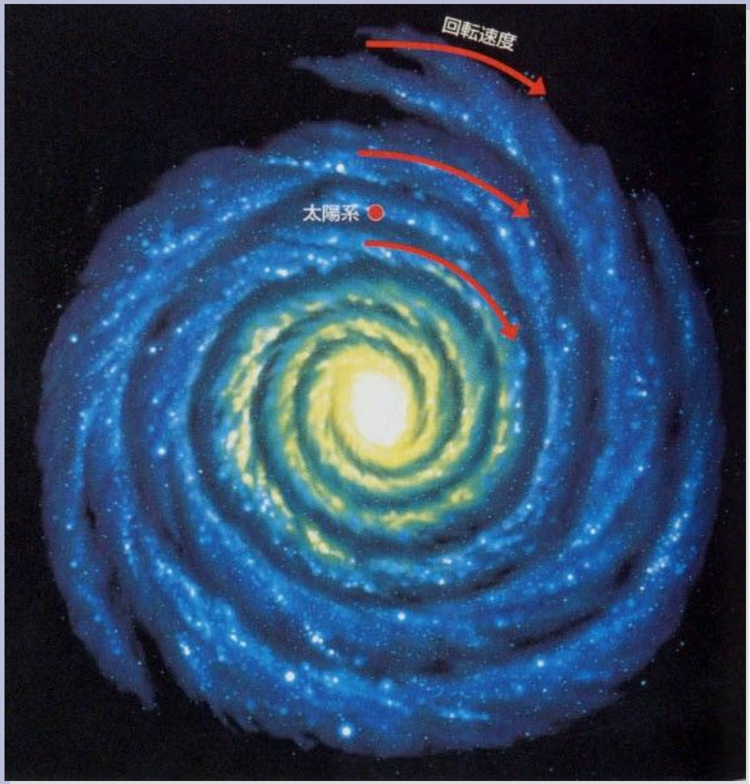
WMAP の援護射撃

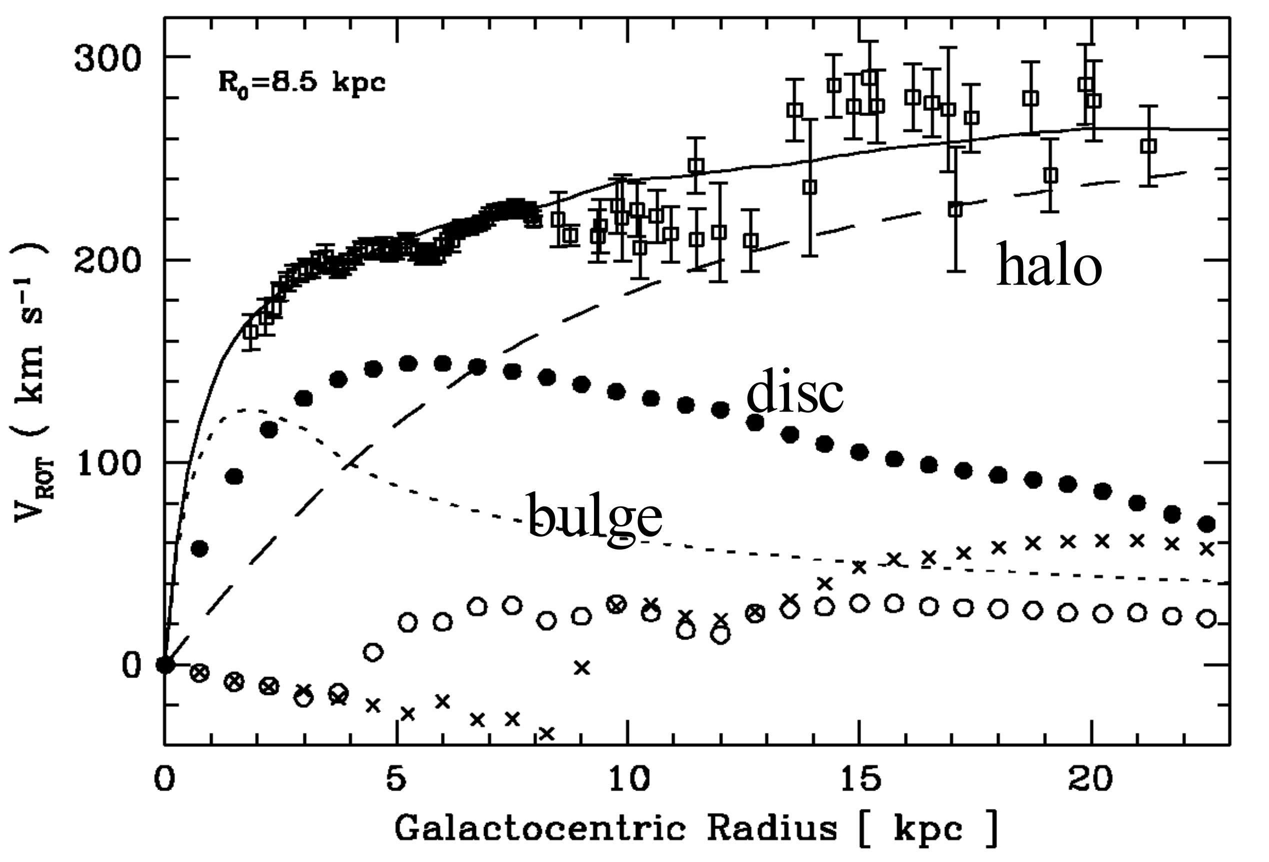


Pictures: NASA/WMAP Science Team;
http://map.gsfc.nasa.gov/



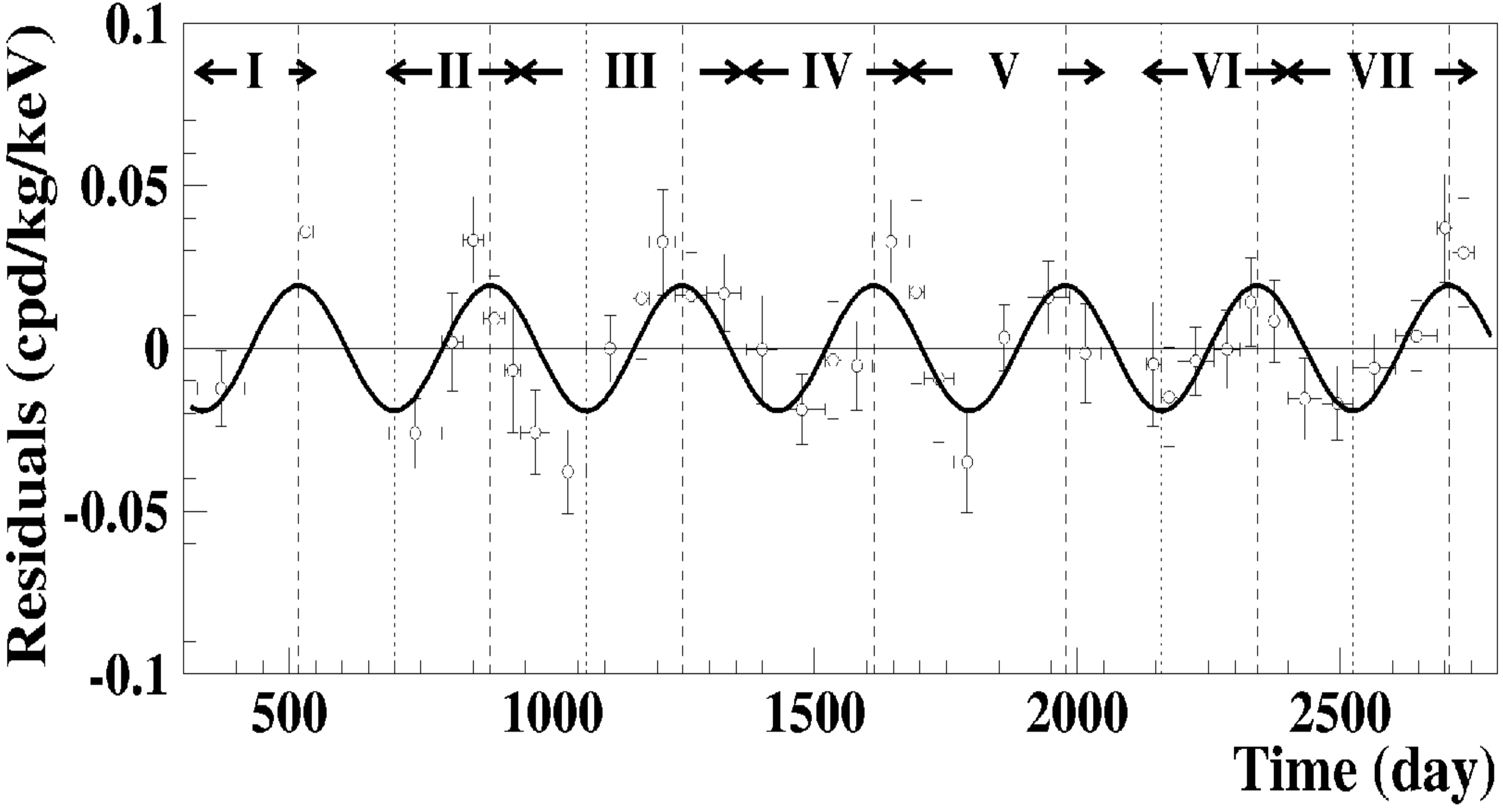
近傍にある証拠


回転速度
太陽系


R_0=8.5 kpc
halo
disc
bulge
V_{ROT} (km s^{-1})
Galactocentric Radius [kpc]
300
200
100
0
0
5
10
15
20

DAMA's <discovery> by annual modulation

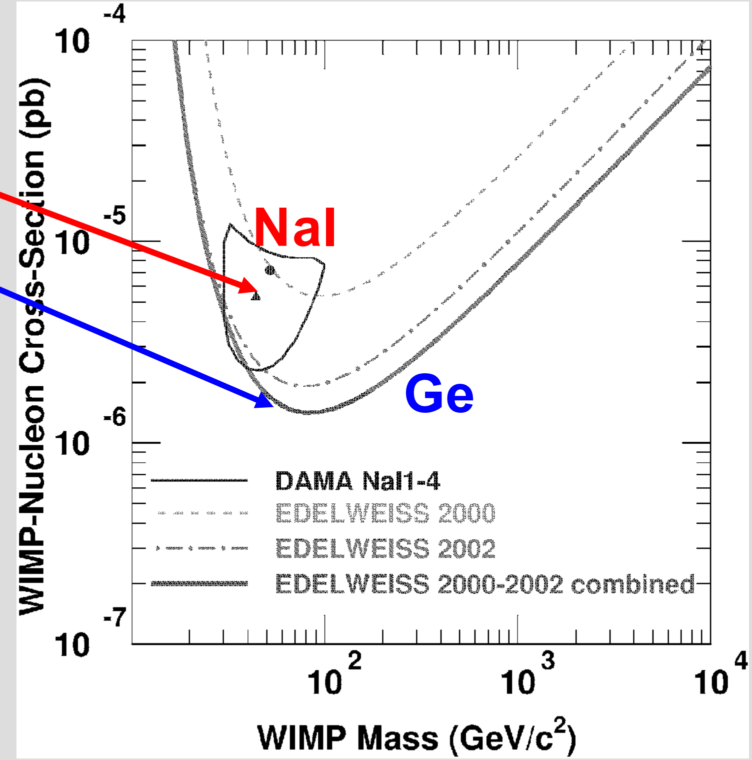
R. Bernabei et al., Riv. Nuovo Cim. 26(2003)1.)



The story

- 1998　イタリア　DAMA
  “Annual Modulation を確認”
- 2000　アメリカ　CDMS
- 2002　フランス　EDELWEISS
  “すべてのイベントを暗黒物質”
  とするconventional な方法で
  DAMA region をExclude

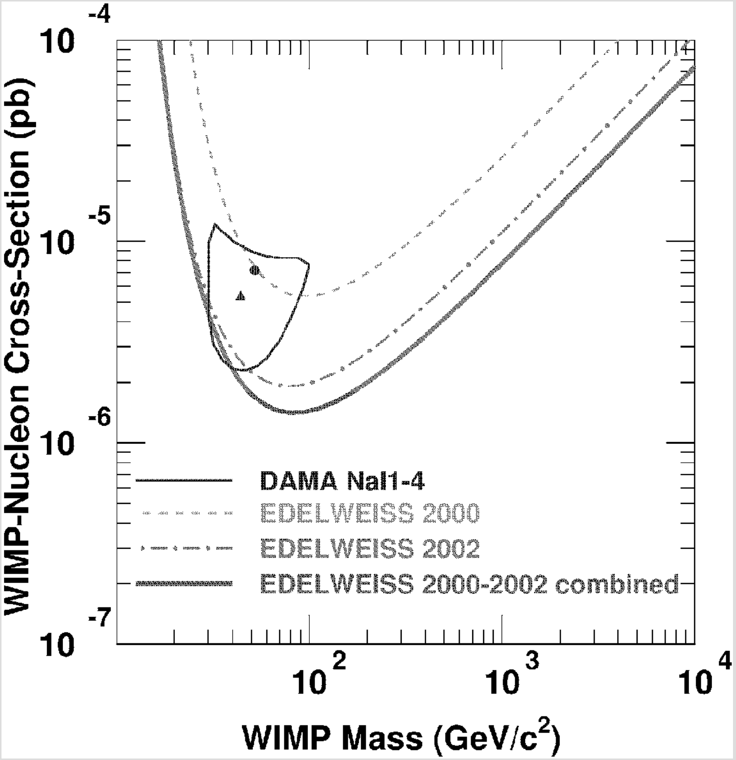
Spin Independent Interaction



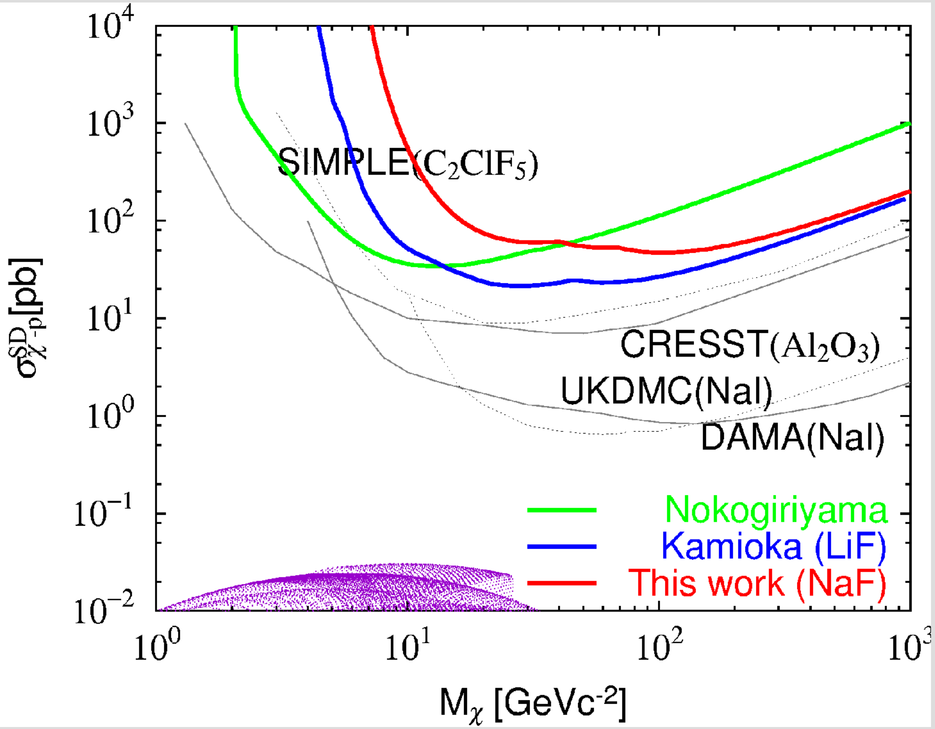
(Phys. Lett. B **545** (2002) 43)

Current exclusion limits in $\sigma^{SI}_{\chi-n}$ and $\sigma^{SD}_{\chi-p}$

SI



SD



Dark Matter Candidates

- Axion （KSVZ, DFSZ）

$$m_a \propto \frac{1}{f_{PQ}} \qquad 10^{-6}\mathrm{eV} \leq m_a \leq 10^{-2}\mathrm{eV}$$

- Neutralino

  - Lightest Supersymmetric Particle
  - R-parity の保存から安定

→ 宇宙初期に生成され現在まで存在し続ける

$$\chi = a_1\tilde{B} + a_2\tilde{W}_3 + a_3\tilde{H}_1 + a_4\tilde{H}_2$$

- gauginos と higgsinos の線形結合の基底状態
- coupling　SUSY モデル依存
- $39\mathrm{GeV} < m_\chi$

Searches, direct and indirect

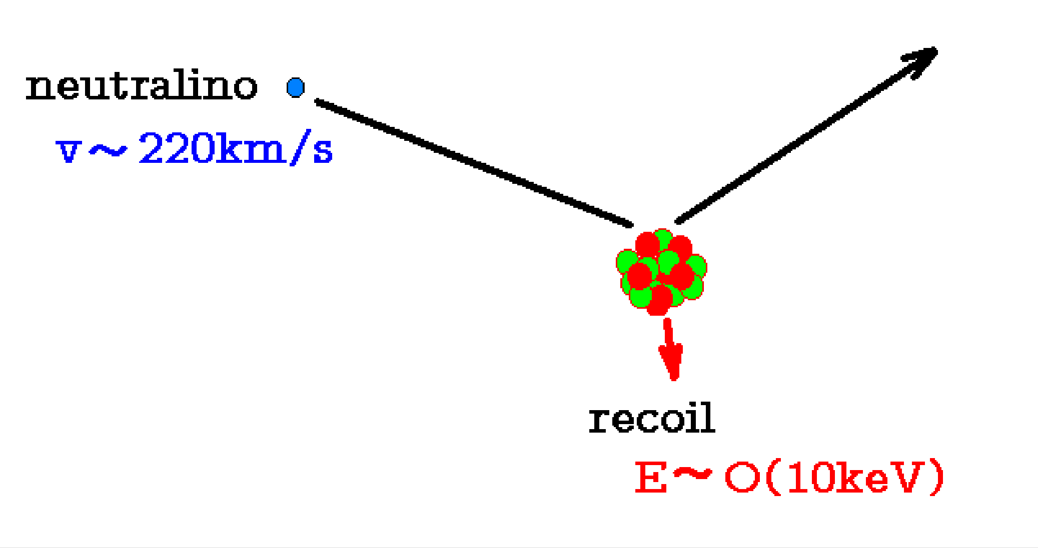
INDIRECT searches

$$\chi\chi \rightarrow WW, ZZ, \gamma\gamma \rightarrow e^{-}, p^{-}, d^{-}, \gamma, \upsilon, \ldots$$

BESS, GLAST, AMS, SK, AMANDA, MACRO, . . .

DIRECT searches

Nuclear recoil detection



Direct detection, relevant parameters

- Event rate

SUSY

$$R \sim \sigma_{\chi-\mathrm{N}} \times n \langle v \rangle \propto \sigma_{\chi-\mathrm{N}} \times \left(\frac{\rho}{M_\chi} \right) \times \int v\, f(v)\, dv$$

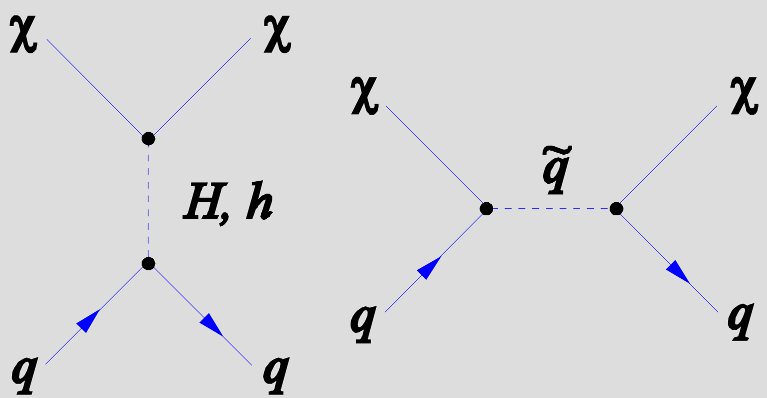
$$\rho(r) = \frac{\rho_0}{1 + r^2/r_0^2}$$

Isothermal Halo Model

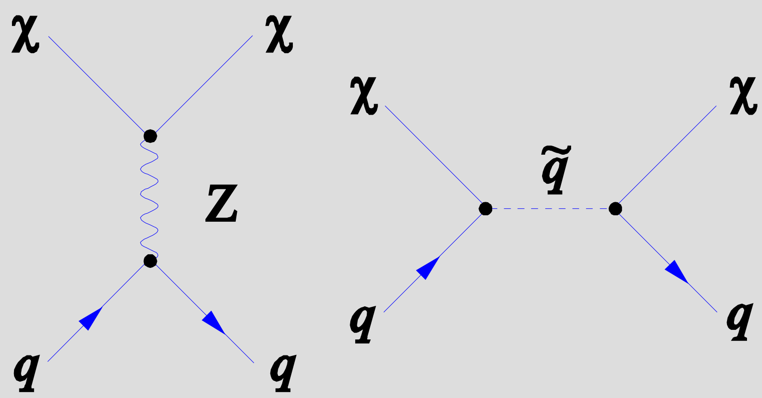
$$f(\vec{v}) = \frac{1}{\pi^{3/2} v_0^3} e^{-|\vec{v}|^2/v_0^2}$$

Cross section

- $\sigma_{\chi-N}$ depends fundamentally on the χ-quark interaction strength.
  - Spin-independent (SI): H, h, squark exchange
  - Spin-dependent (SD): Z, squark exchange



SI interaction



SD interaction

Spin Independent and Spin Dependent cross sections

- Cross Section

$$\sigma_{\chi-\mathrm{N}}=\sigma^{\mathrm{SI}}_{\chi-\mathrm{N}}+\sigma^{\mathrm{SD}}_{\chi-\mathrm{N}}$$

  - SI interaction

$$\sigma^{\mathrm{SI}}_{\chi-\mathrm{N}}\simeq A^{2}\frac{\mu^{2}_{\chi-\mathrm{N}}}{\mu^{2}_{\chi-\mathrm{p}}}\sigma^{\mathrm{SI}}_{\chi-\mathrm{n}}$$

A : atomic number

μ : reduced mass

  - SD interaction

$$\sigma^{\mathrm{SD}}_{\chi-\mathrm{N}}=\frac{\lambda^{2}J(J+1)}{0.75}\frac{\mu^{2}_{\chi-\mathrm{N}}}{\mu^{2}_{\chi-\mathrm{p}}}\sigma^{\mathrm{SD}}_{\chi-\mathrm{p}}$$

λ : Landé factor

J : total spin of the nucleus

SD Cross Section

- conventional approximation
  using the odd-group model in which
  the contribution of either proton or neutron is considered.

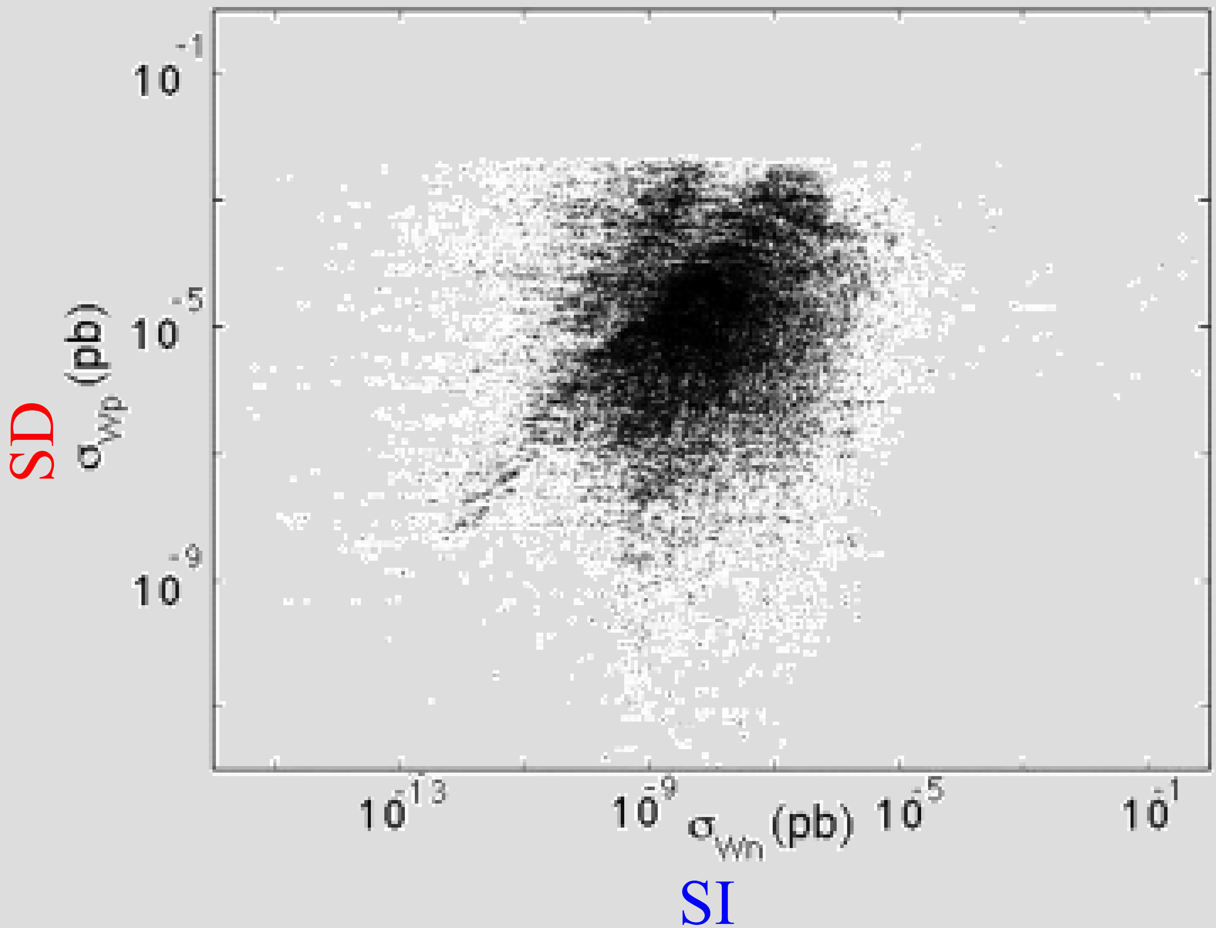
$$\sigma^{\mathrm{SD}}_{\chi-\mathrm{N}} = \frac{\lambda^2 J(J+1)}{0.75} \frac{\mu^2_{\chi-\mathrm{N}}}{\mu^2_{\chi-\mathrm{p}}} \sigma^{\mathrm{SD}}_{\chi-\mathrm{p}}$$

Isotope	unpaired	abundance	$\lambda^2 J(J+1)$
^{7}Li	p	92.5%	0.411
^{19}F	p	100%	0.647
^{23}Na	p	100%	0.041
^{73}Ge	n	7.8%	0.065
^{127}I	p	100%	0.023

→ LiF for SD

(odd-group model)

Spin Dependent (SD) and Spin Independent (SI)



$$\frac{\sigma^{SD}_{\chi-p}}{\sigma^{SI}_{\chi-n}}$$

can be as large as

$$10^3 \sim 10^4$$

Fig. 10 of J. I. Collar et al, New J. of Phys. 2 (2000) 14.1

- Expected energy spectra

$$\frac{dR}{dE_R} = c_1 \frac{R_0}{E_0 r} e^{-c_2 E_R / E_0 r} \quad \text{[count/keV/kg/day]}$$

$$R_0 = \frac{361}{M_\chi M_N}\left(\frac{\sigma_{\chi-N}}{1\text{pb}}\right)\left(\frac{\rho_D}{0.3\text{GeVcm}^{-3}}\right)\left(\frac{v_0}{230\text{km/s}}\right) \quad \text{[count/kg/day]}$$

R : countrate

E_R : recoil energy

c_1, c_2 : const

E_0 : kinetic energy of DM

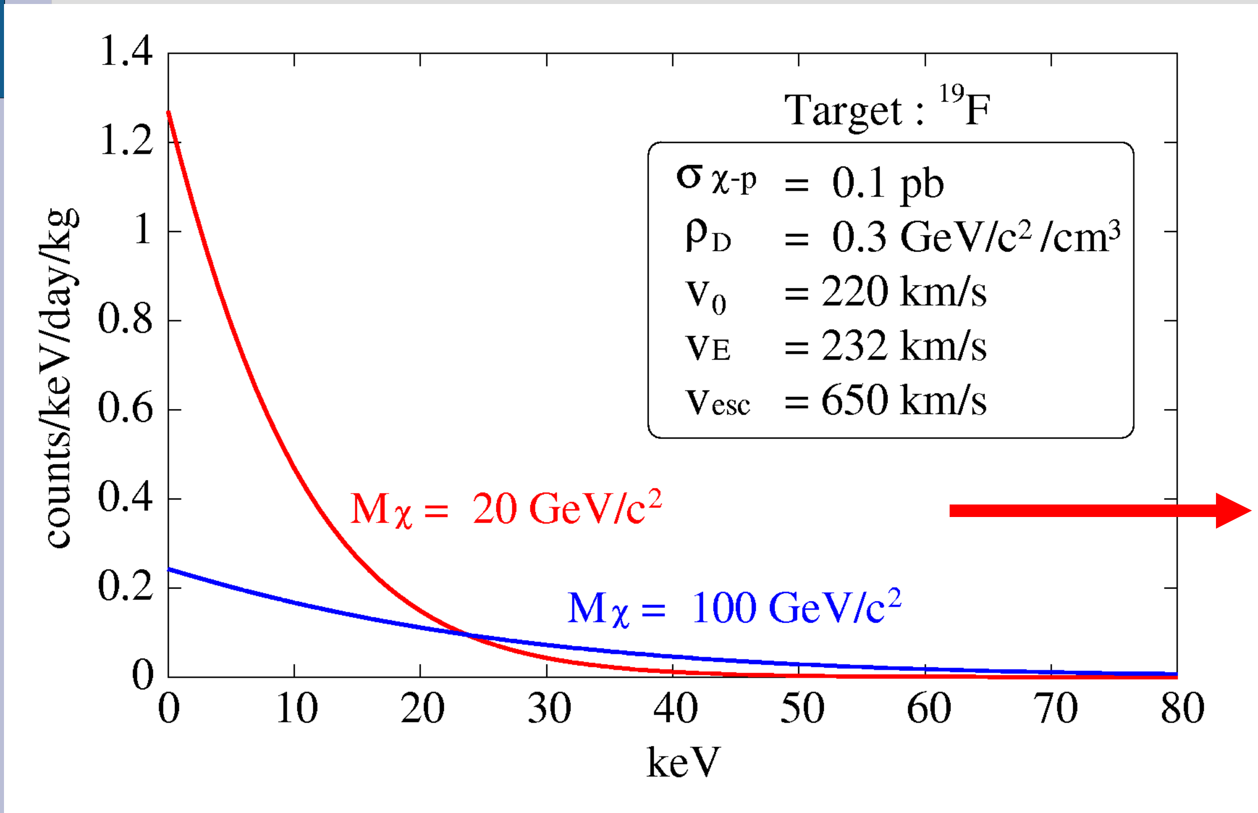
v_0 : DM velocity

M_χ : DM mass

M_N : target mass

$$r = \frac{4M_\chi M_N}{(M_\chi + M_N)^2}$$

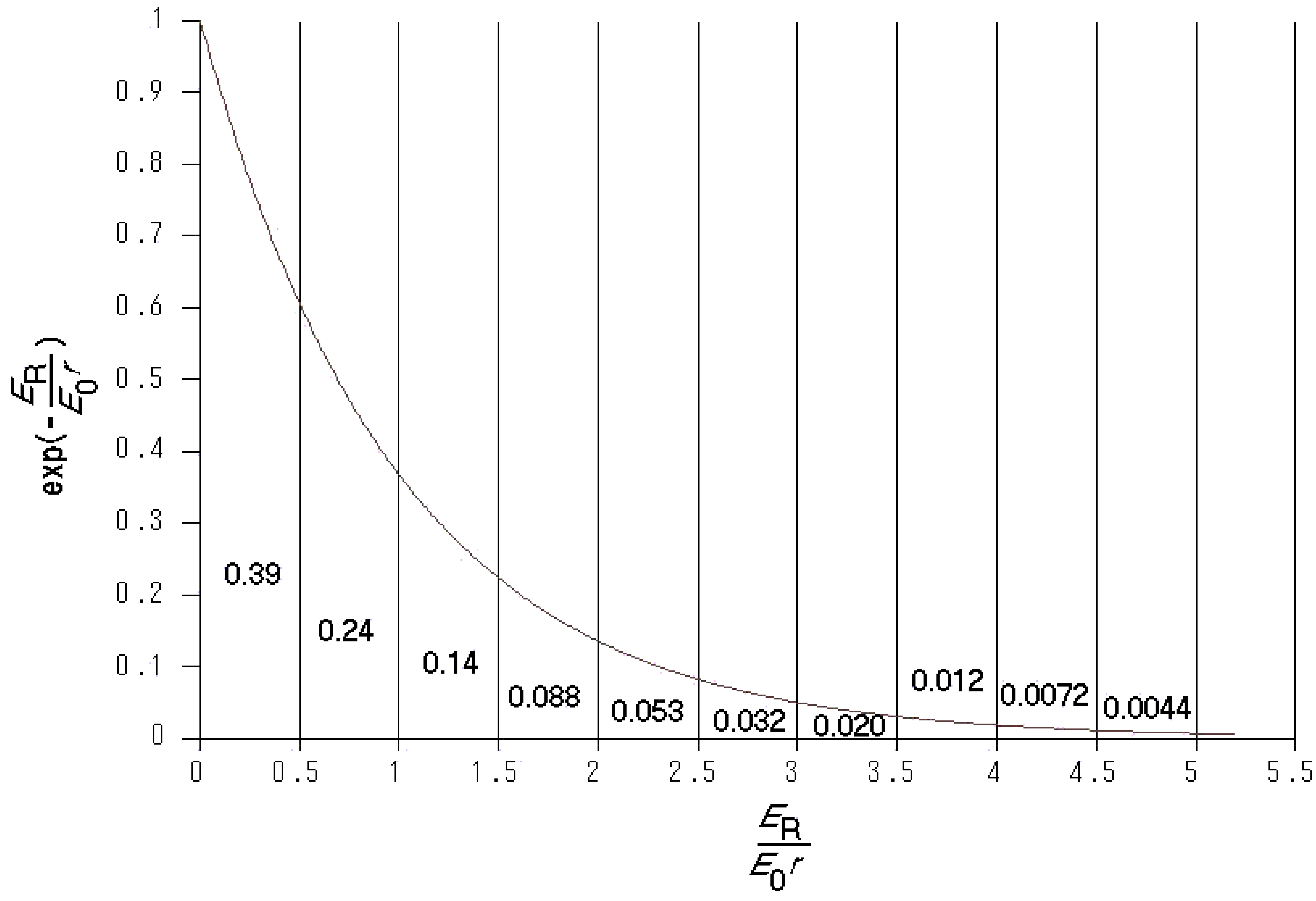
ρ_D : DM density



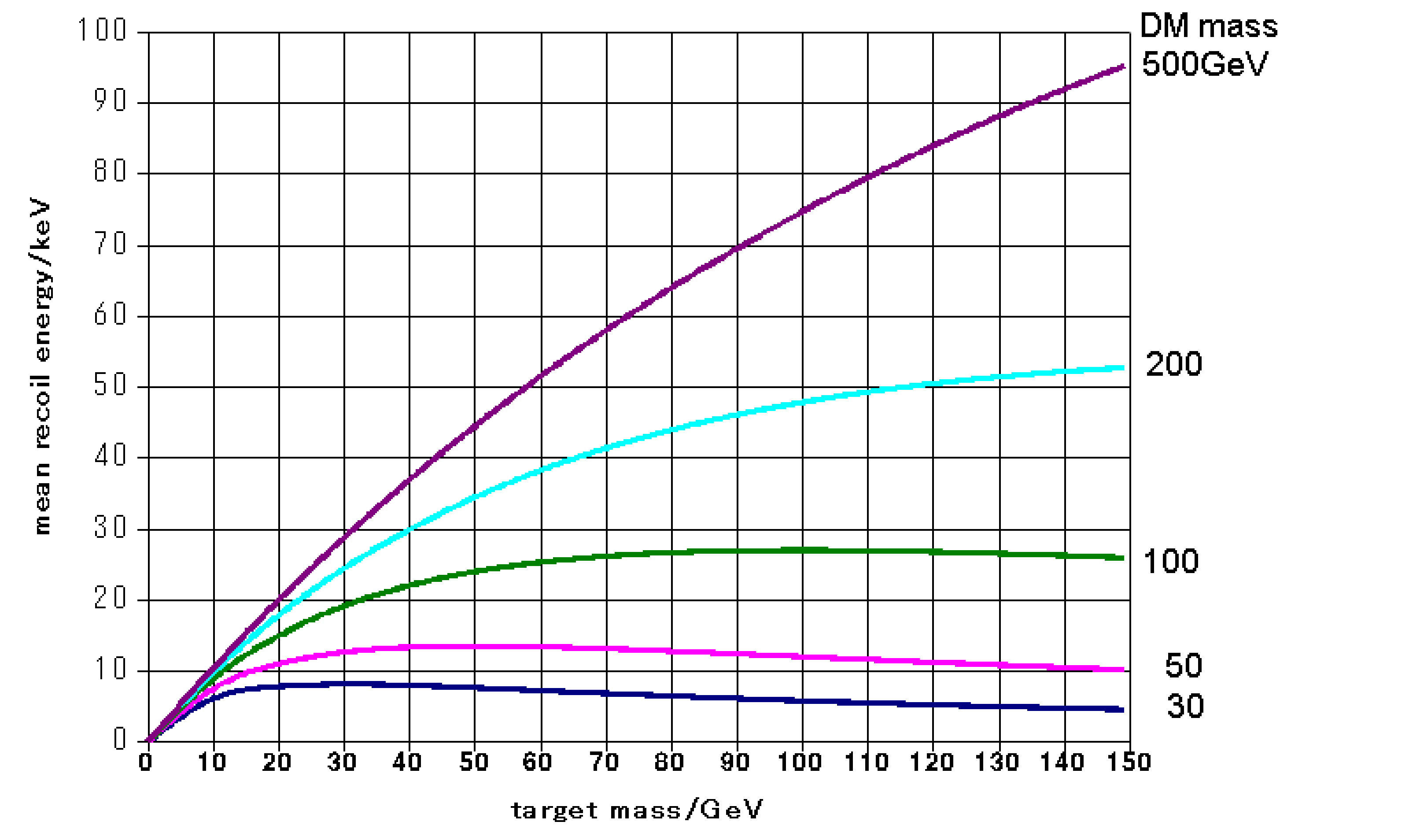
low threshold and
low BG are required

$$E_0 = \frac{1}{2} M_x v_0^2 \qquad r = \frac{(4 M M_N)}{(M + M_N)^2} \qquad E_0 r = 10 \text{ keV}$$

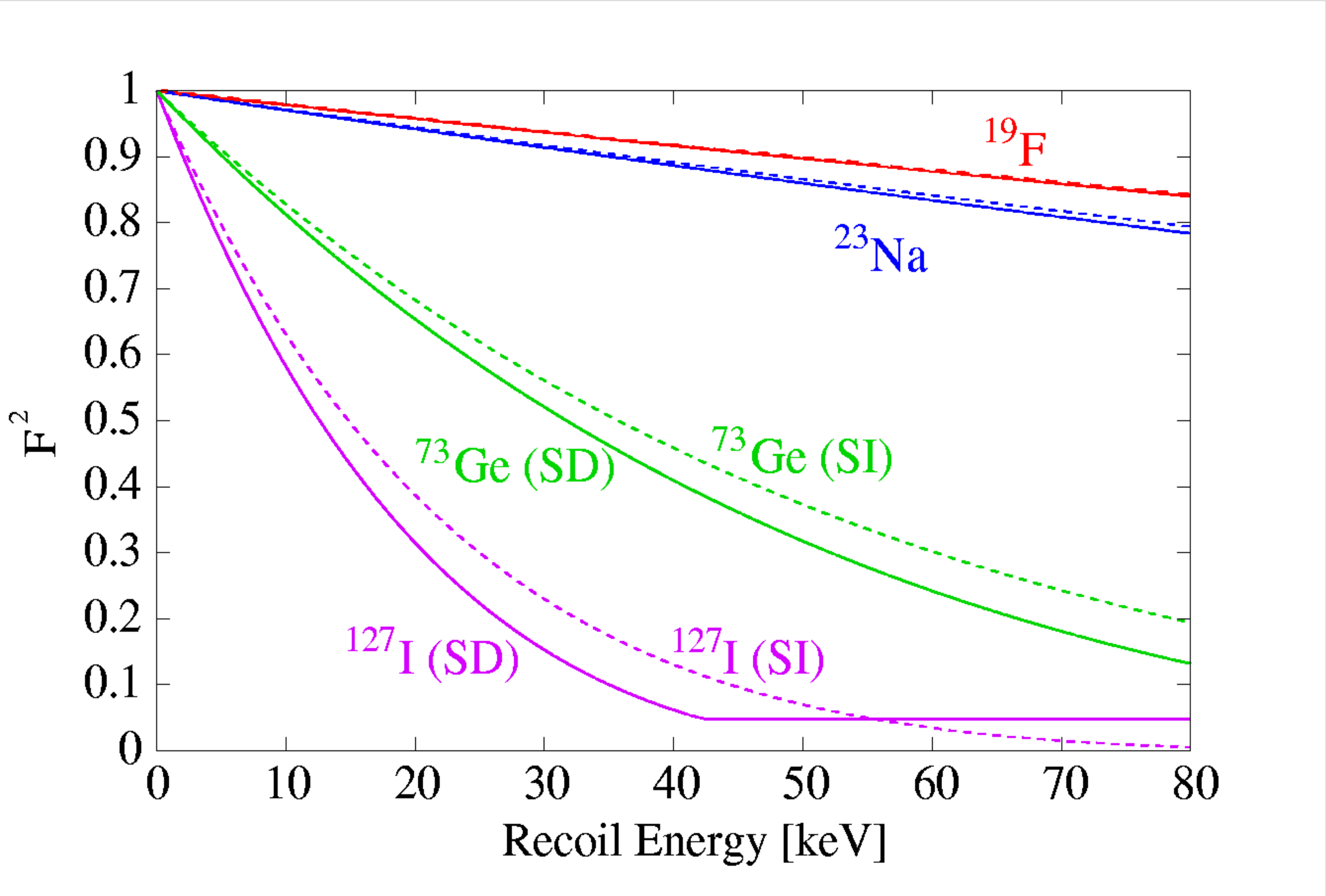
for M=50GeV and A=19



Mean recoil energy $E_o r$ vs target mass



Nuclear form factor



Running experiments and projects (not complete)

<u>Bolometers</u>

- CDMS(Ge/Si)
- Tokyo(LiF/NaF)
- CRESST(Al_2O_3)

<u>Scintillators/semiconductors</u>

- DAMA(NaI, CaF_2, LXe)
- UK(NaI)
- HDMS(Ge), GENIUS(Ge)
- Osaka(CaF_2)
- XMASS(LXe)

Quenching factor

$$q = \frac{E_{\text{visible}}}{E_{\text{R}}}$$

- $q < 1$ for scintillators and semiconductors

  0.3 (Na),   0.09 (I)
  0.25 (Ge)
  0.46 (LXe)

  $\rightarrow$ low effective threshold

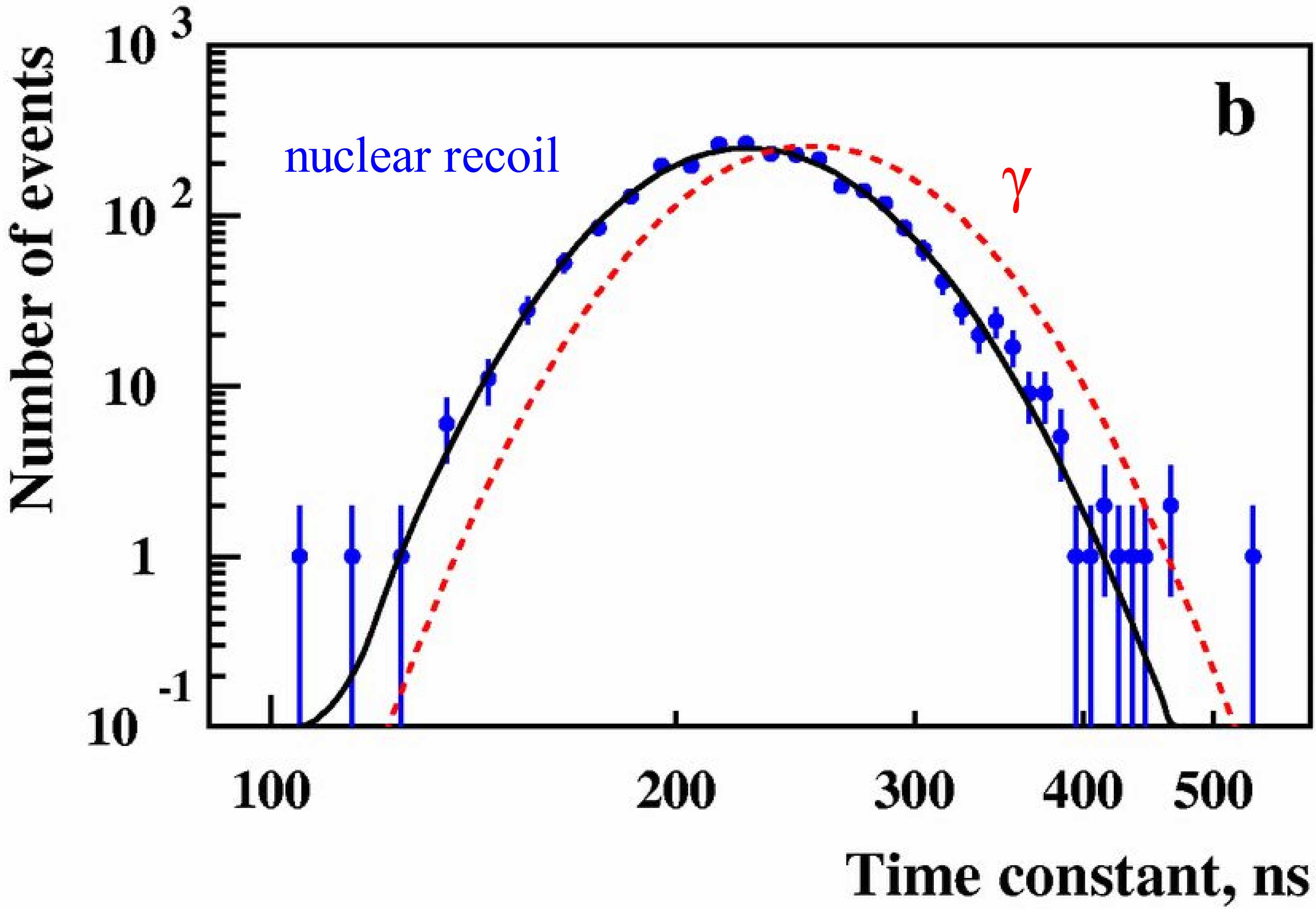
- $q = 1$ for bolometers

Techniques for DM detection

- Pulse shape discrimination/analysis PSD/PSA (e/ γ - nuclear recoil separation)
- Bolometry (q = 1)
- Phonon-ionization simultaneous measurement (e/ γ - nuclear recoil separation)
- Annual modulation
- Direction sensitive detection
- Background shields

PSD/PSA (NaI(Tl))

B. Ahmed, et al., Astropart. Phys. 19 (2003) 691.



6-8 keV

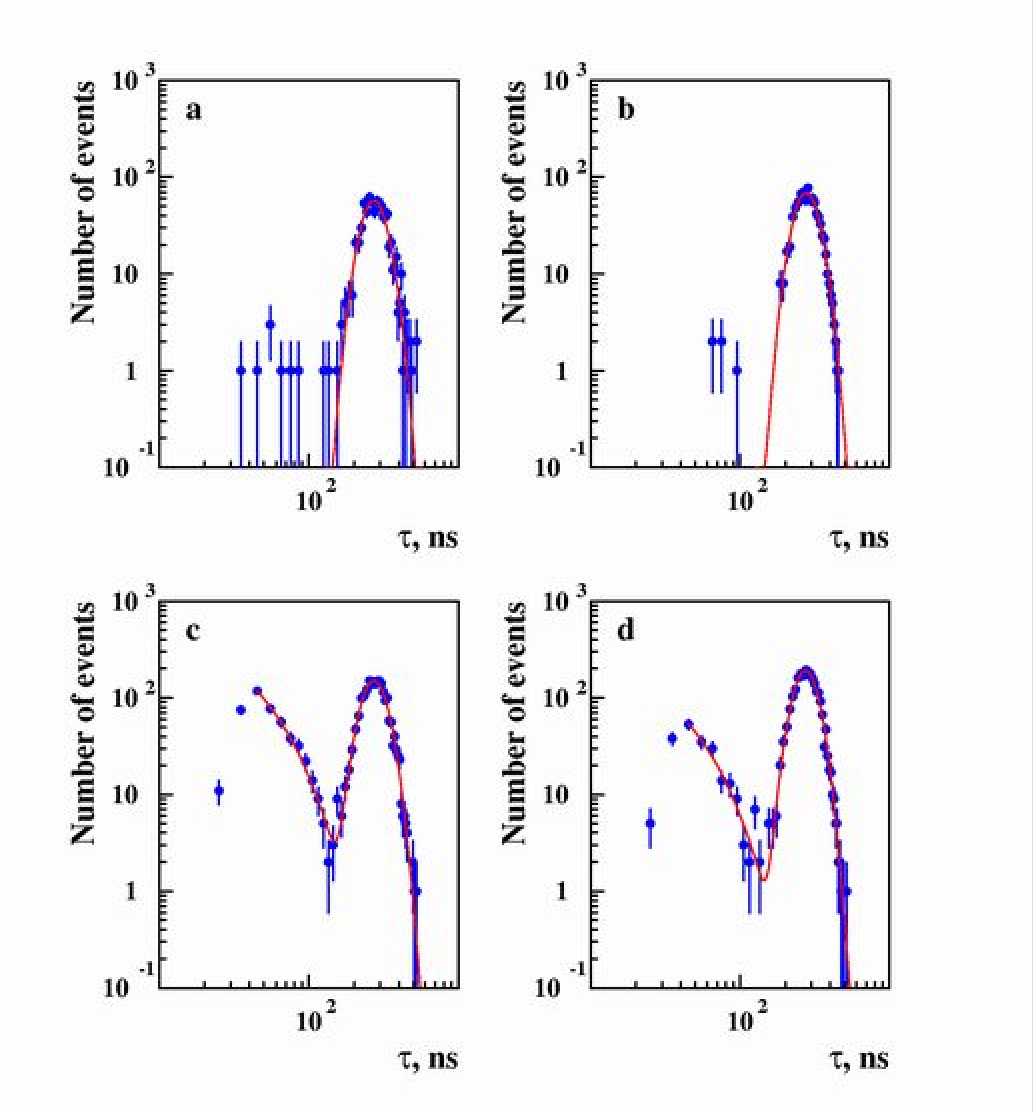
Statistical subtraction

B. Ahmed, et al., Astropart. Phys. 19 (2003) 691.

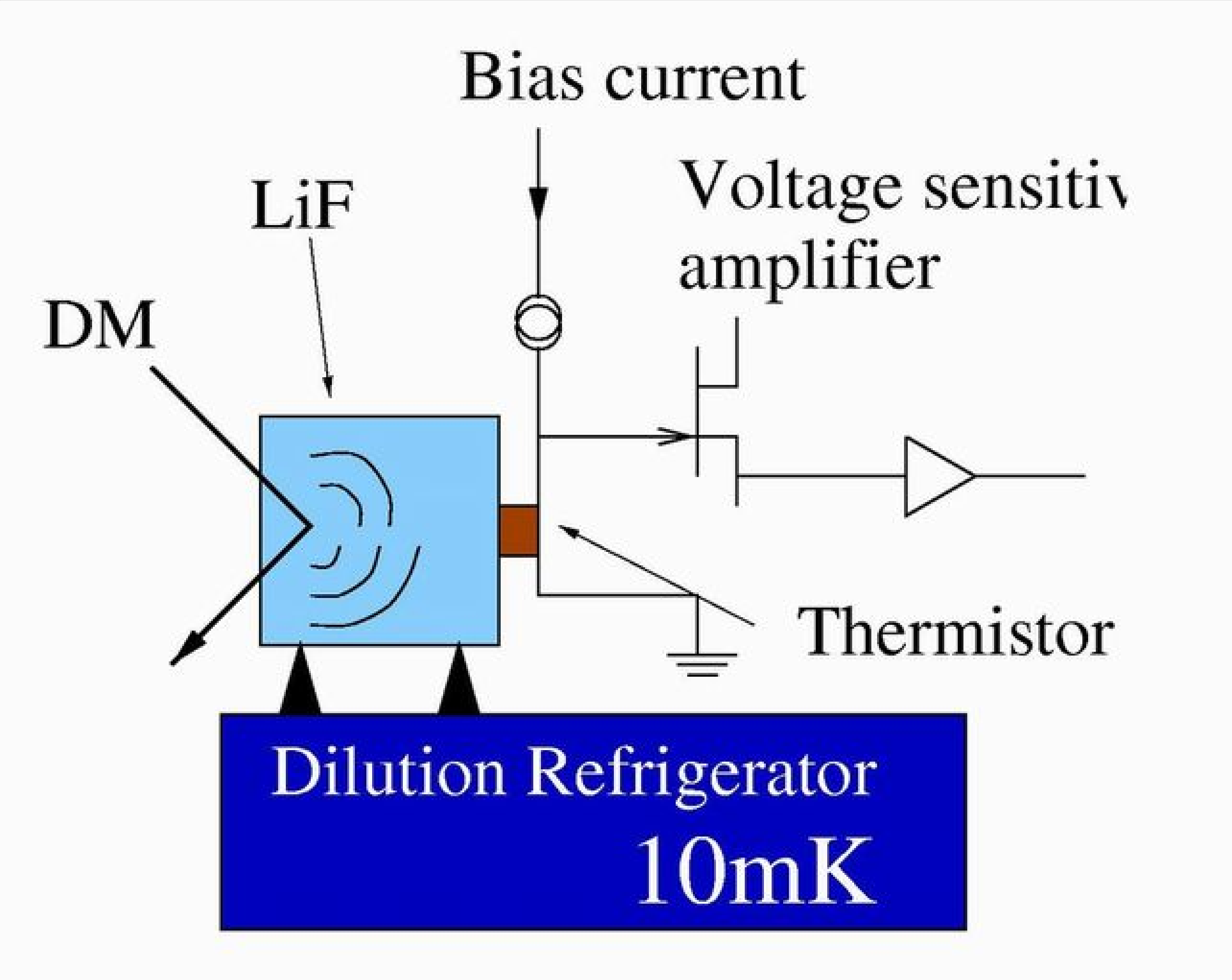
6 – 7 keV 7 – 8 kev

γ-calibration

real data



Bolometer

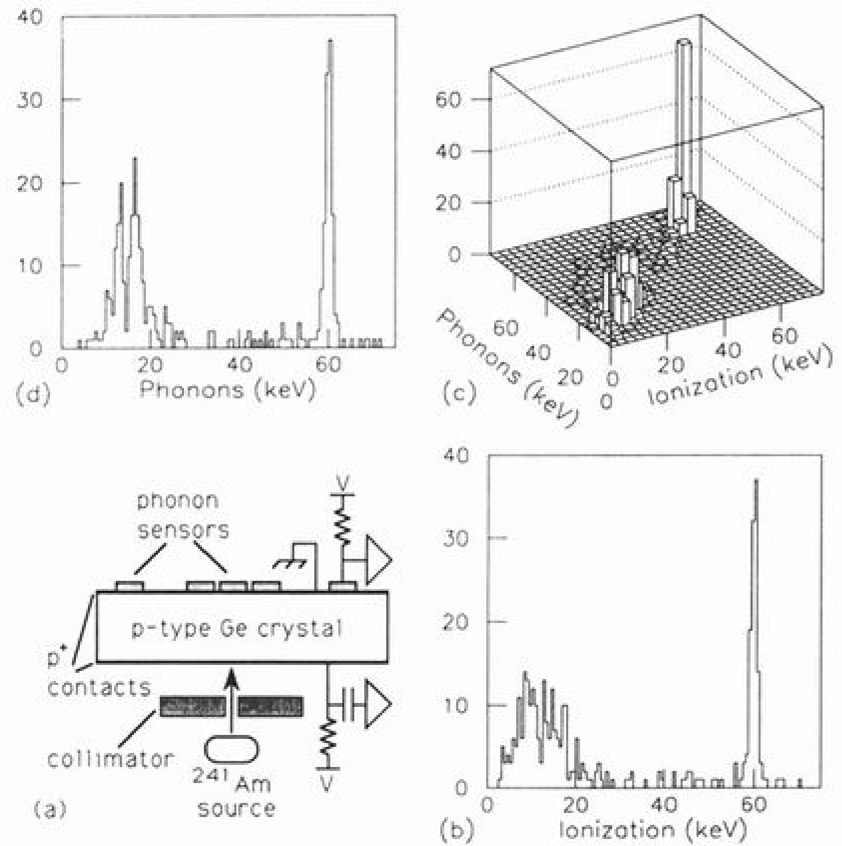


Specific heat:

$$C \propto \left(\frac{T}{\Theta_D} \right)^3$$

Θ_D : Debye temperature

Phonon – ionization simultaneous measurement



T. Shutt et. al., Phys. Rev. Lett. 69 (1992) 3531

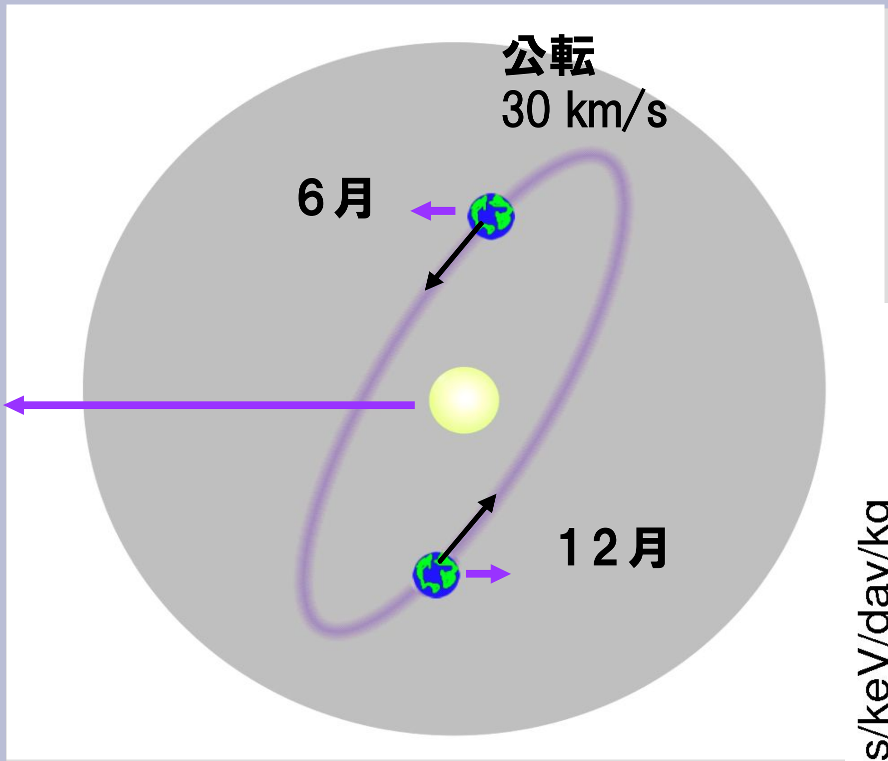
Same response to e/γ

but

to nuclear recoil,
$q = 1$ for phonon
$q = 0.25$ for ioninzation

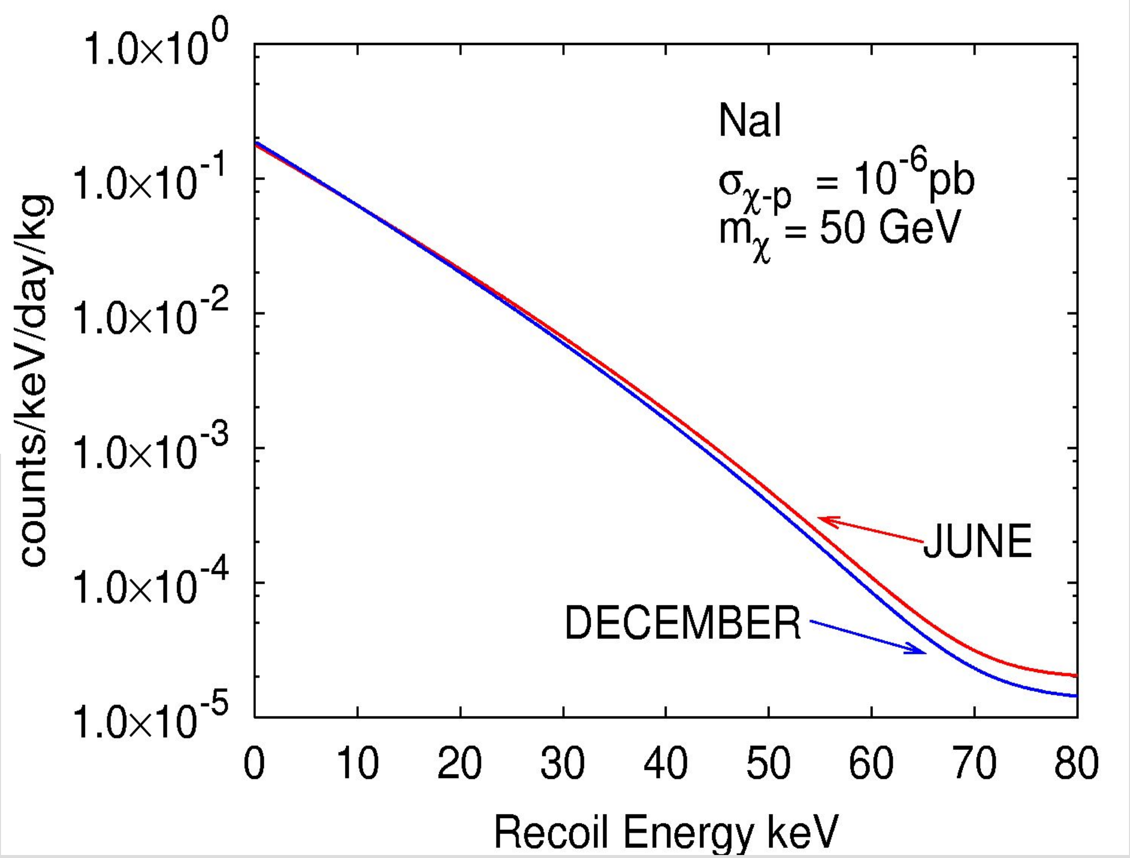
e/ γ - nuclear recoil separation

Annual modulation

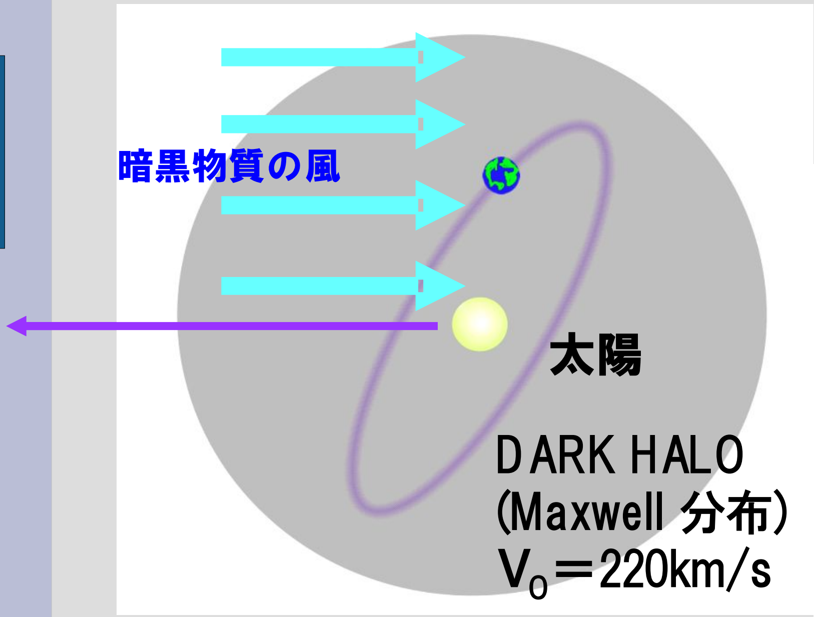


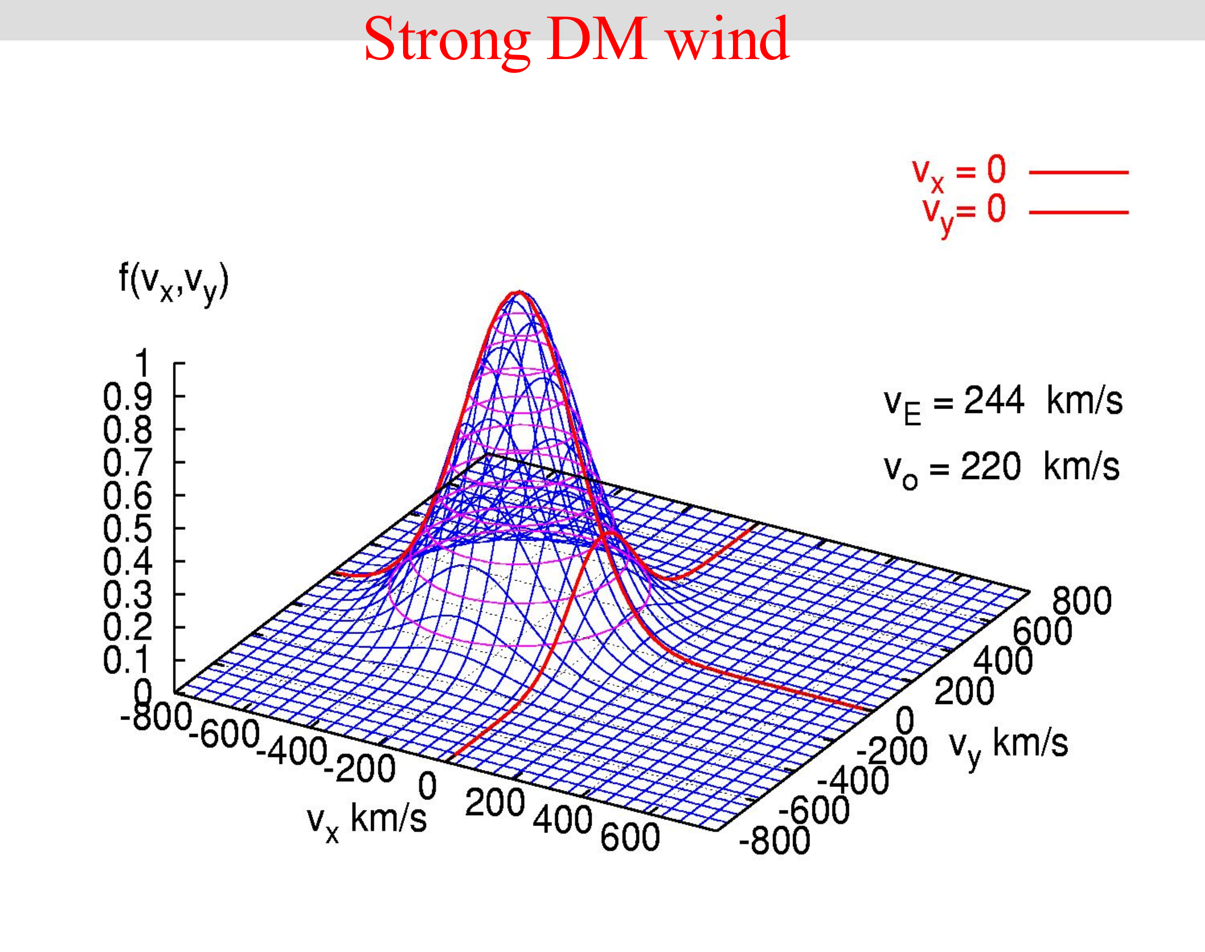
$$\vec{v}_{\mathrm{E}} = \vec{v}_{\mathrm{SUN}} + \vec{v}_{\mathrm{ES}}$$

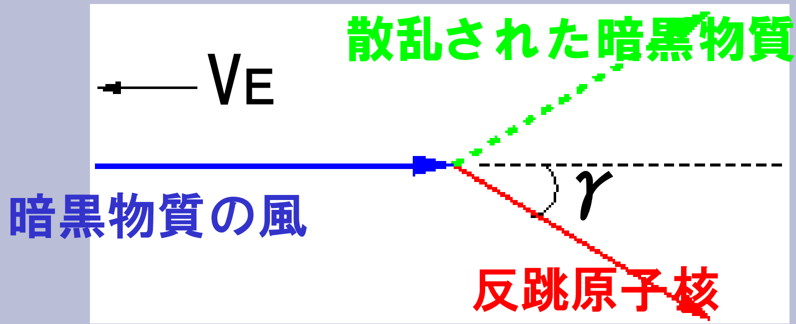
Only a few % effect



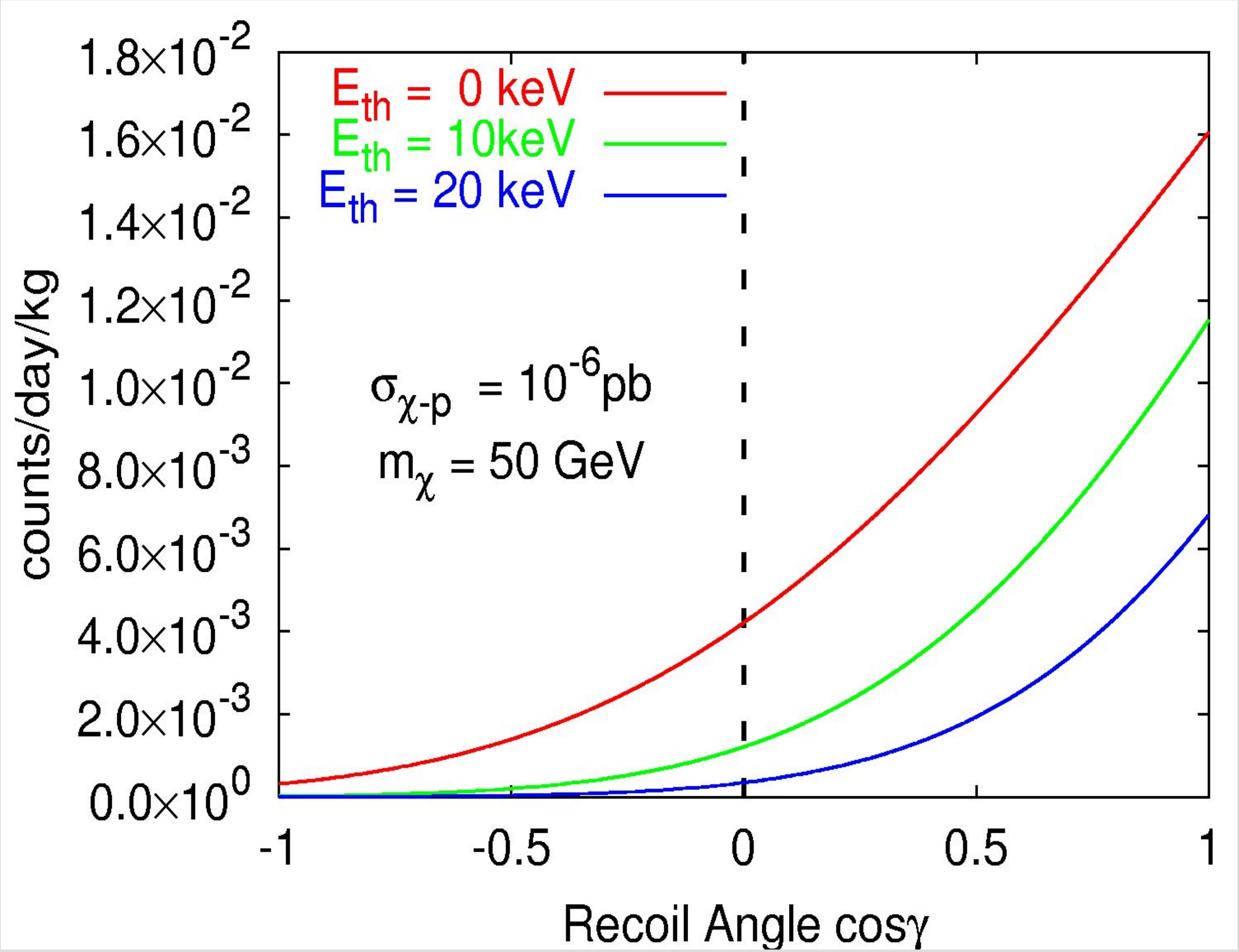
Direction sensitive detection







散乱された暗黒物質
VE
γ
暗黒物質の風
反跳原子核



Eth = 0 keV
Eth = 10keV
Eth = 20 keV
σχ-p = 10-6pb
mχ = 50 GeV
counts/day/kg
Recoil Angle cosγ

Background shields

- Oxygen Free High Conductivity Copper (OFHC)
- Old-age(archaeological) lead

$$\boxed{T_{1/2}(^{210}\mathrm{Pb}) \sim 20\ \mathrm{years}}$$

- Pure water
- Active self shielding

$\rightarrow$ $\boxed{\text{fiducial volume}}$

- Radon purge

Tokyo Group (Minowa)

- Bolometer experiments (SD-sensitive)
  - Pilot run LiF Nokogiriyama(~15m.w.e.) ~1999
  - Results LiF/NaF Kamioka(~2700m.w.e.) ~2003
- R&D, direction sensitive scintillators 2003~
  - Pilot run stilbene Kamioka

Bolombeter SD limits in a_p and a_n

$$\sigma^{\mathrm{SD}}_{\chi-\mathrm{N}} = \frac{\lambda^2 J(J+1)}{0.75} \frac{\mu^2_{\chi-\mathrm{N}}}{\mu^2_{\chi-\mathrm{p}}} \sigma^{\mathrm{SD}}_{\chi-\mathrm{p}} = 4 G_{\mathrm{F}}^2 \mu^2_{\chi-\mathrm{N}} C^{\mathrm{SD}}_{\mathrm{N}}$$

$$C^{\mathrm{SD}}_{\mathrm{N}} \propto \left(a_{\mathrm{p}} \langle S_{\mathrm{p(N)}} \rangle + a_{\mathrm{n}} \langle S_{\mathrm{n(N)}} \rangle\right)^2 \frac{J+1}{J}$$

$a_{\mathrm{p}},\ a_{\mathrm{n}}$: χ - nucleon couplings

$\langle S_{\mathrm{p(N)}} \rangle,\ \langle S_{\mathrm{n(N)}} \rangle$: expectation values of p, n spin in N

$\langle S_{p(N)} \rangle$ and $\langle S_{n(N)} \rangle$

Isotope	odd	$\langle S_{p(N)} \rangle$	$\langle S_{n(N)} \rangle$
^{7}Li	p	0.497	0.004
^{19}F	p	0.441	-0.109
^{23}Na	p	0.248	0.020
^{73}Ge	n	0.009	0.372
^{127}I	p	0.309	0.075

For a_p , a_n determination,

- ^{19}F is complementary to ^{23}Na, ^{73}Ge, ^{127}I due to opposite sign of $\langle S_{p(N)} \rangle / \langle S_{n(N)} \rangle$
- NaF is more sensitive to a_n than LiF.

SD limits in a_p and a_n

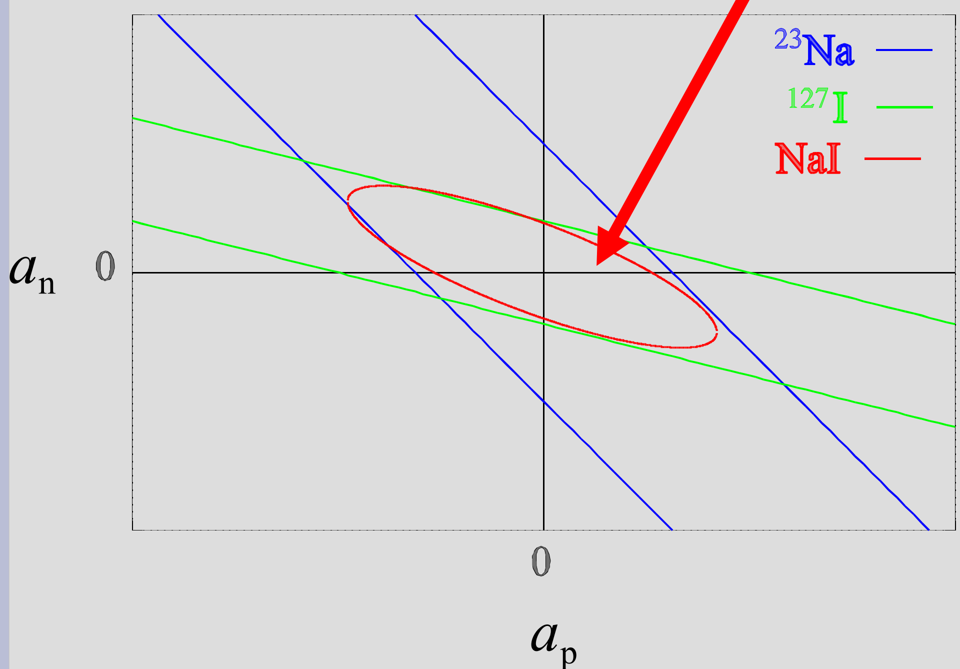
- $\langle S_{p(N)} \rangle / \langle S_{n(N)} \rangle > 0$

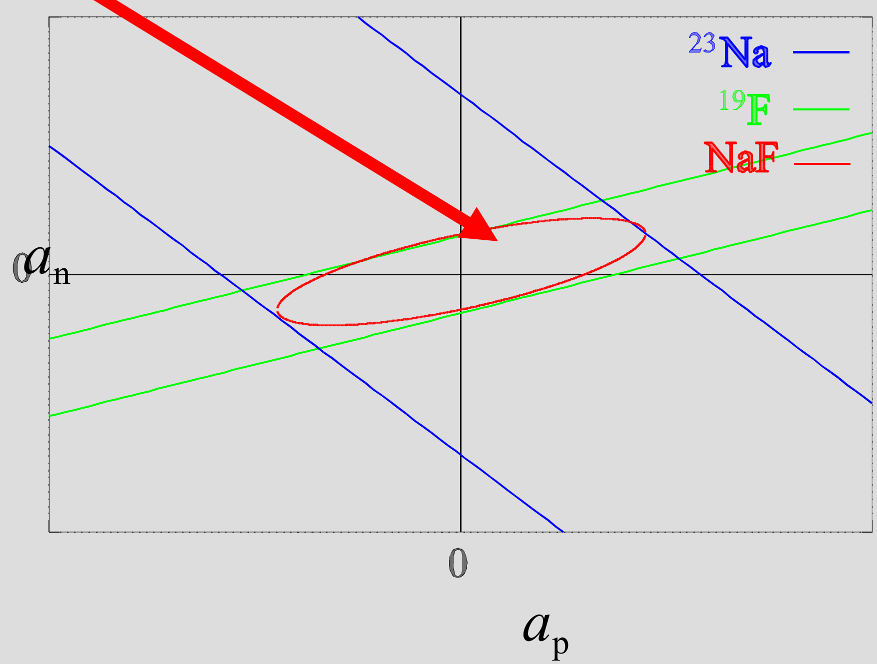
  e.g. $N_i = {}^{23}\mathrm{Na}, {}^{127}\mathrm{I}$

- $\langle S_{p(N)} \rangle / \langle S_{n(N)} \rangle < 0$

  e.g. $N_i = {}^{19}\mathrm{F}$

COMPLEMENTARY

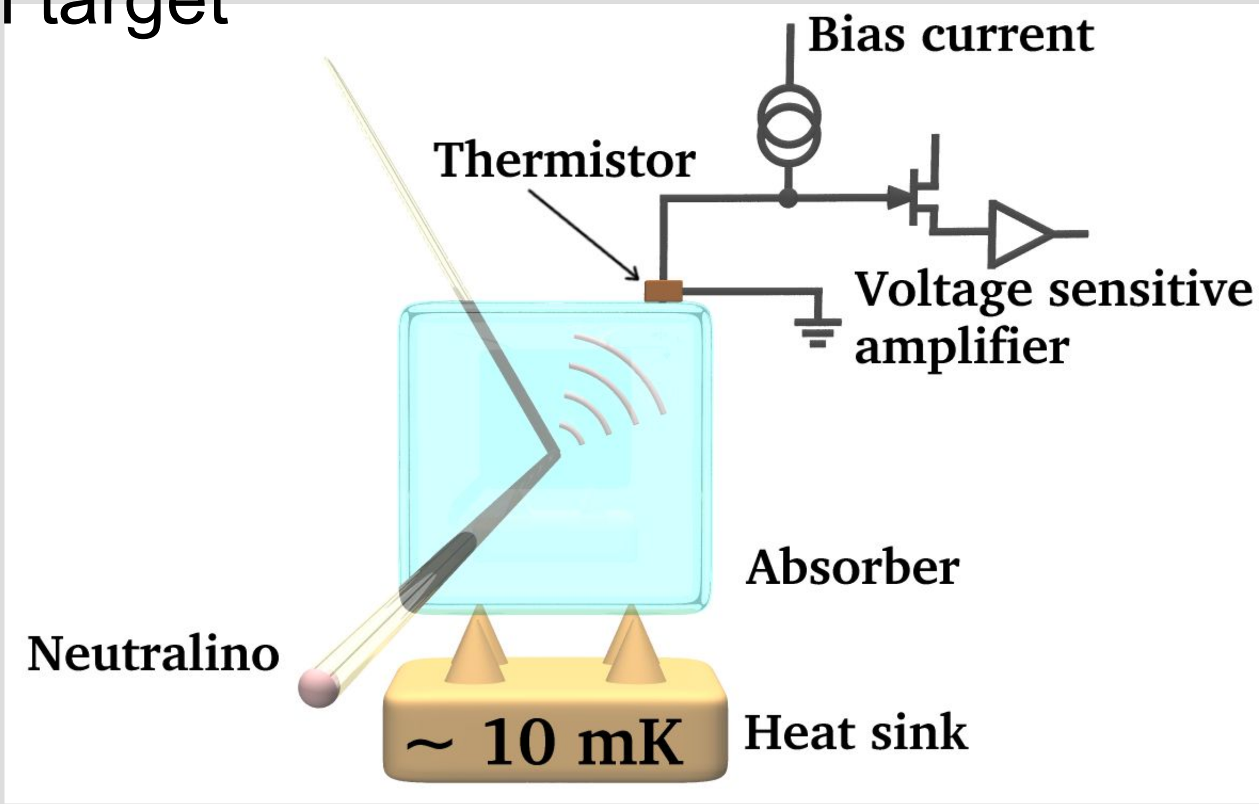




Detector

- Bolometer
  - Wide choice of target
  - High resolution
  - Low threshold
  - No quenching

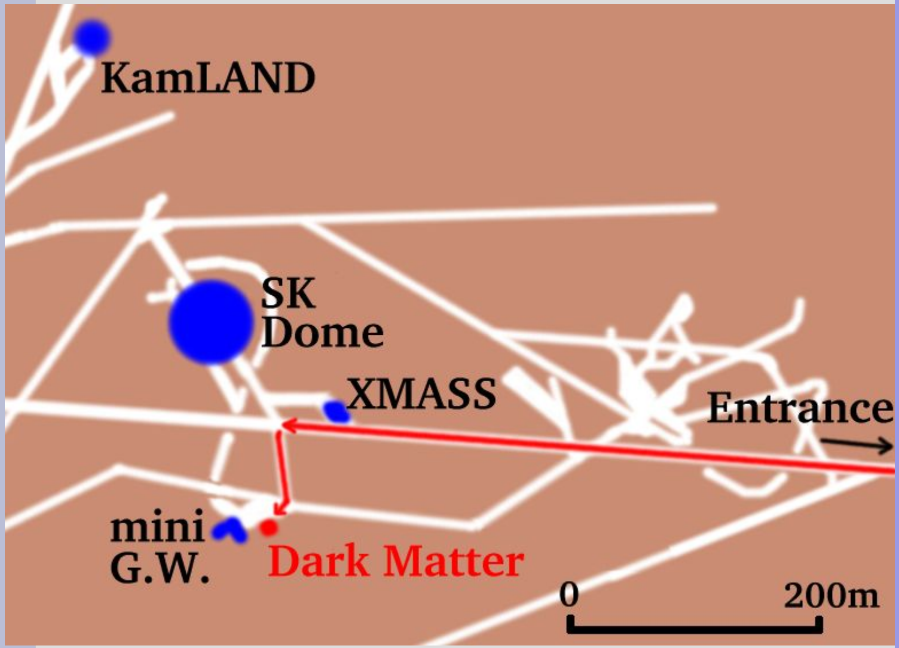
$(E_{\text{visible}} = E_{\text{recoil}})$



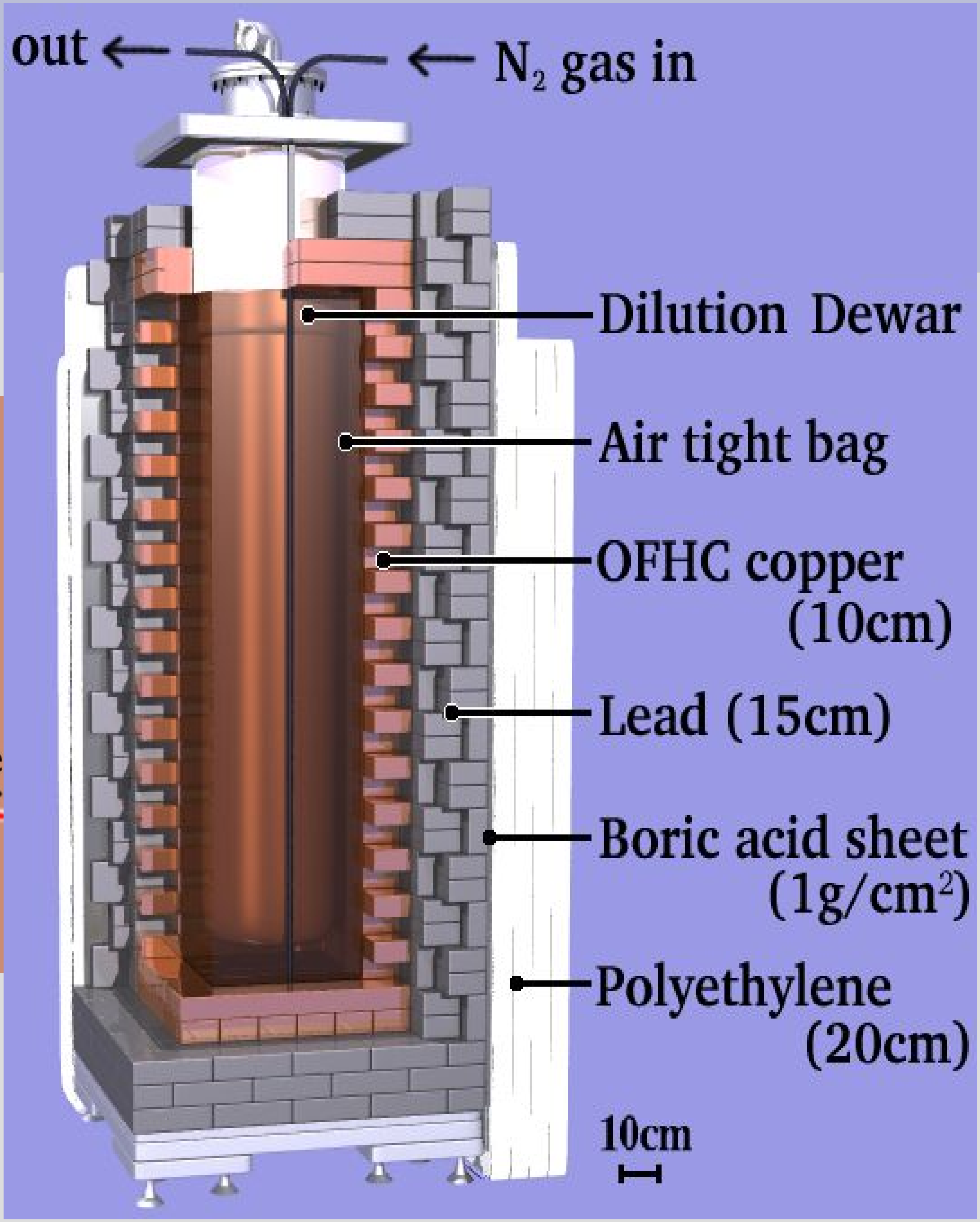
Schematic drawing of a bolometer

- NTD Ge thermistor
  - Neutron Transmutation Doped Germanium

- Set Up
  - Outer Shields



- set at **Kamioka Observatory** (~2700m.w.e.)



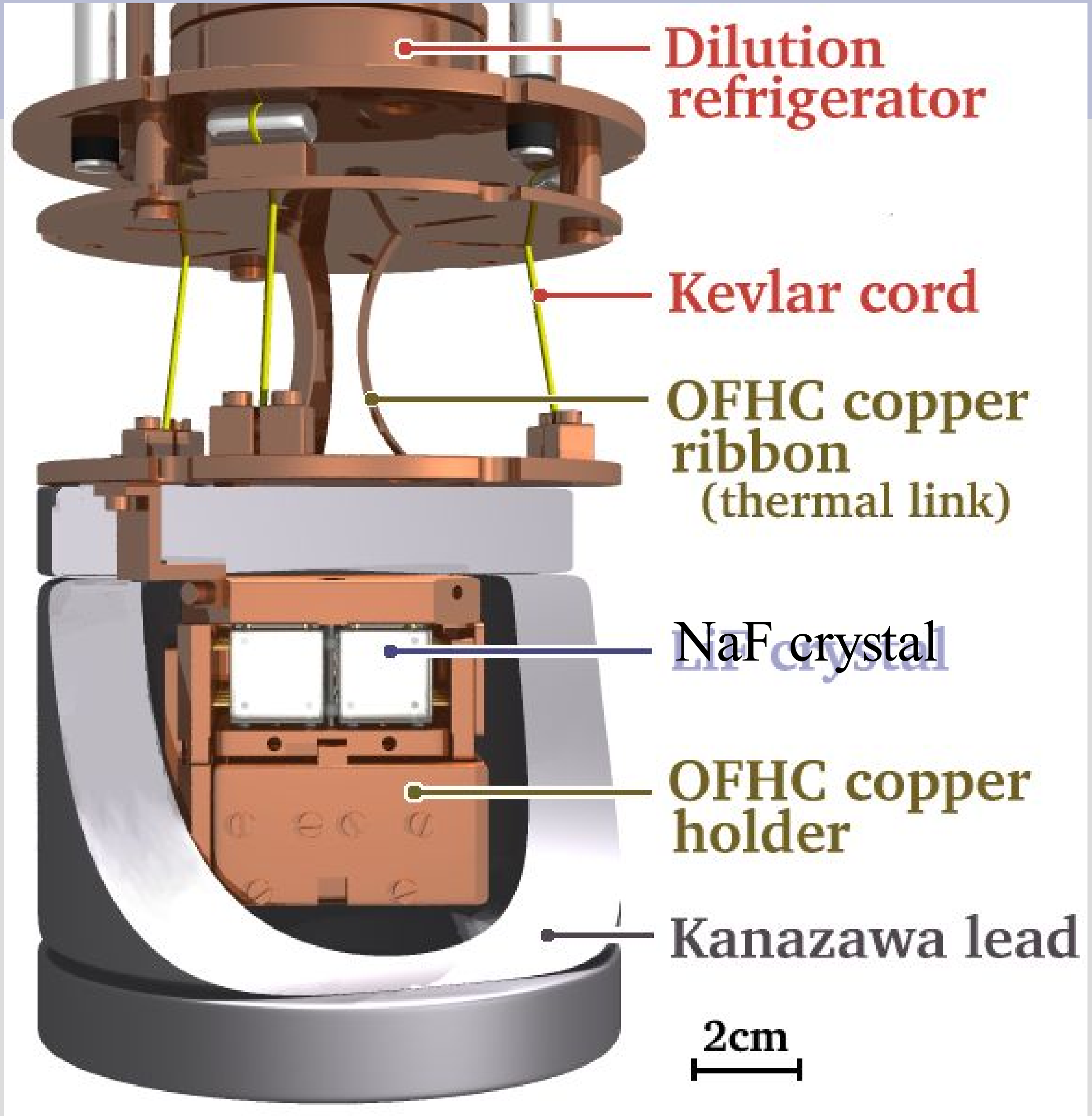
- Inner Shield
-

old lead (>400yrs.)
from a wrecked ship.

21 Pb < 2.0 Bq/kg
0

suspending it
with kevlar cords.

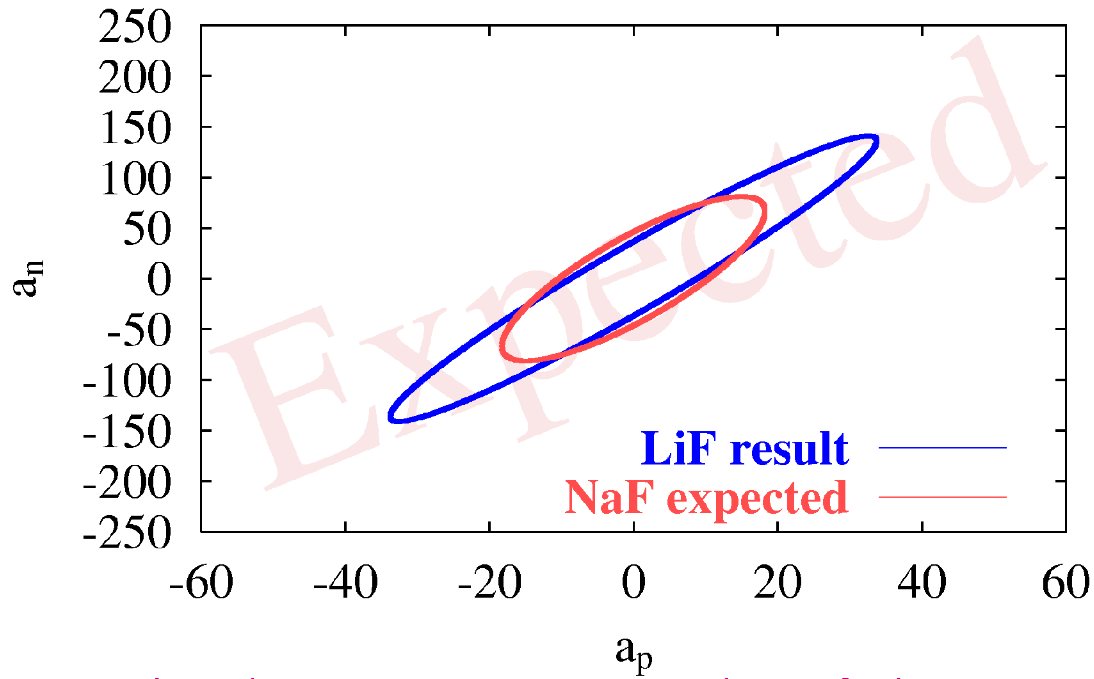
→ vibration noise
reduction



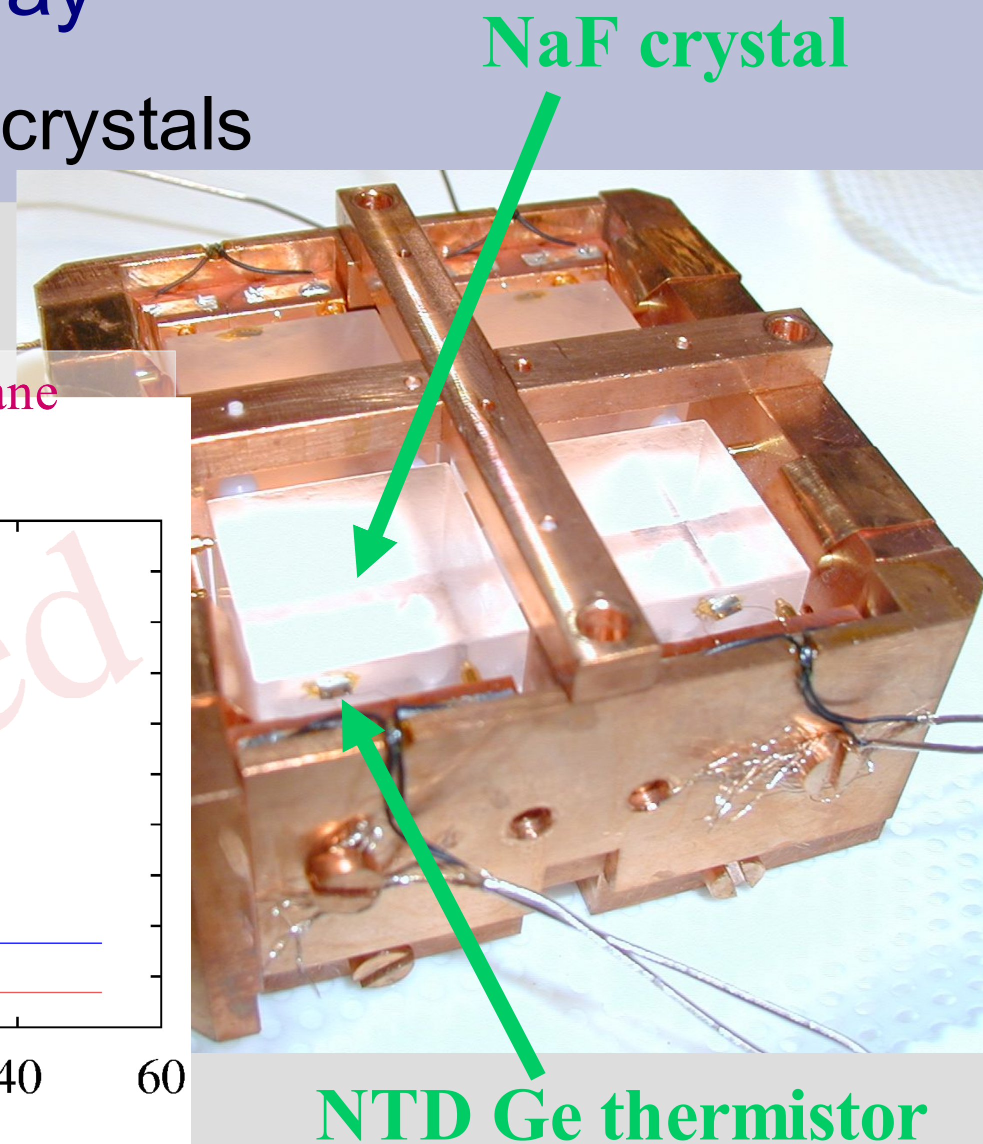
- NaF Bolometer Array
  - 8pcs×22g NaF crystals ($2\times2\times2$ cm^3)

Expected sensitivity in the a_p–a_n plane

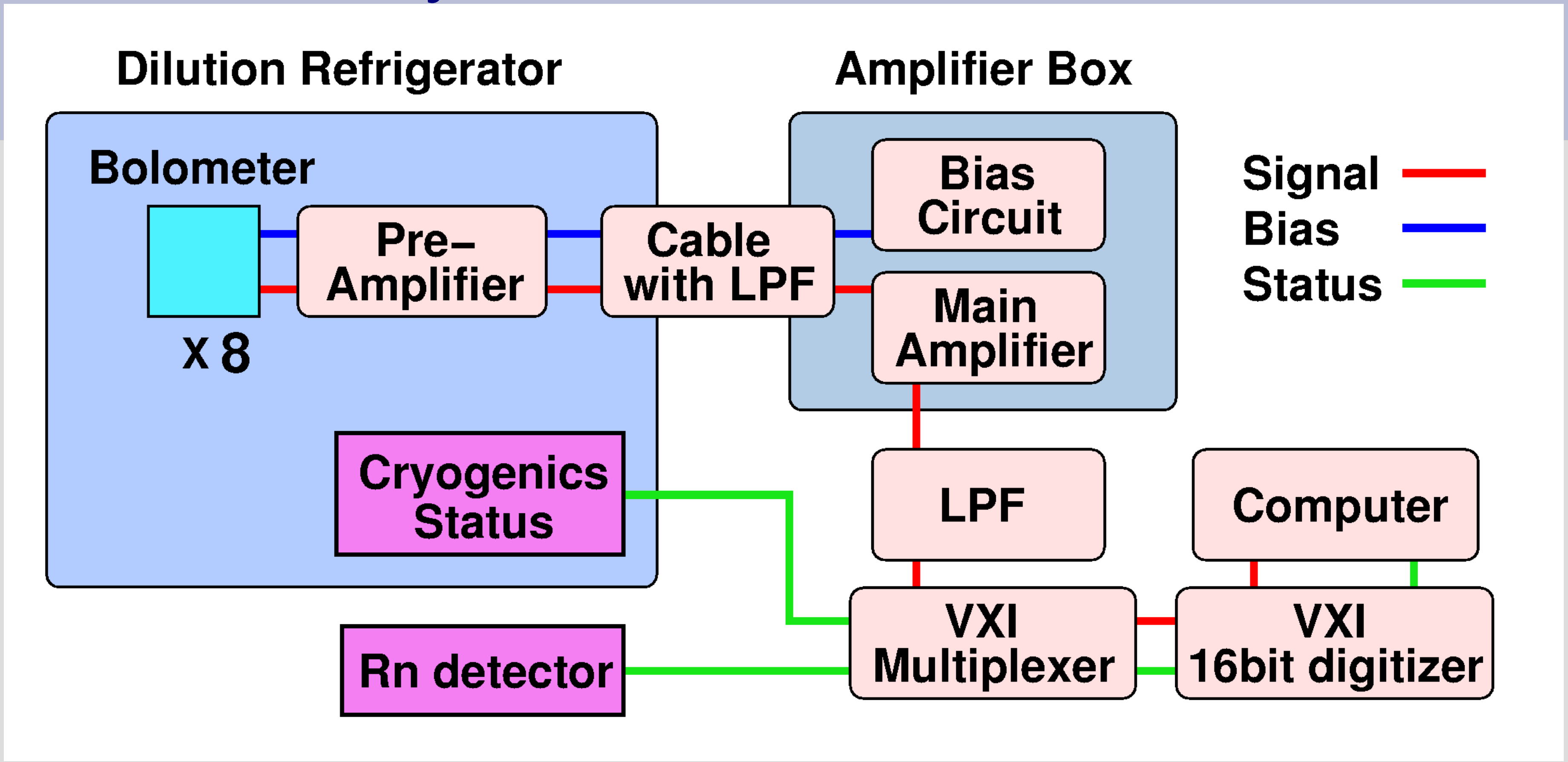
M_{WIMP} = 50 GeV



Assuming the same spectrum as that of LiF target

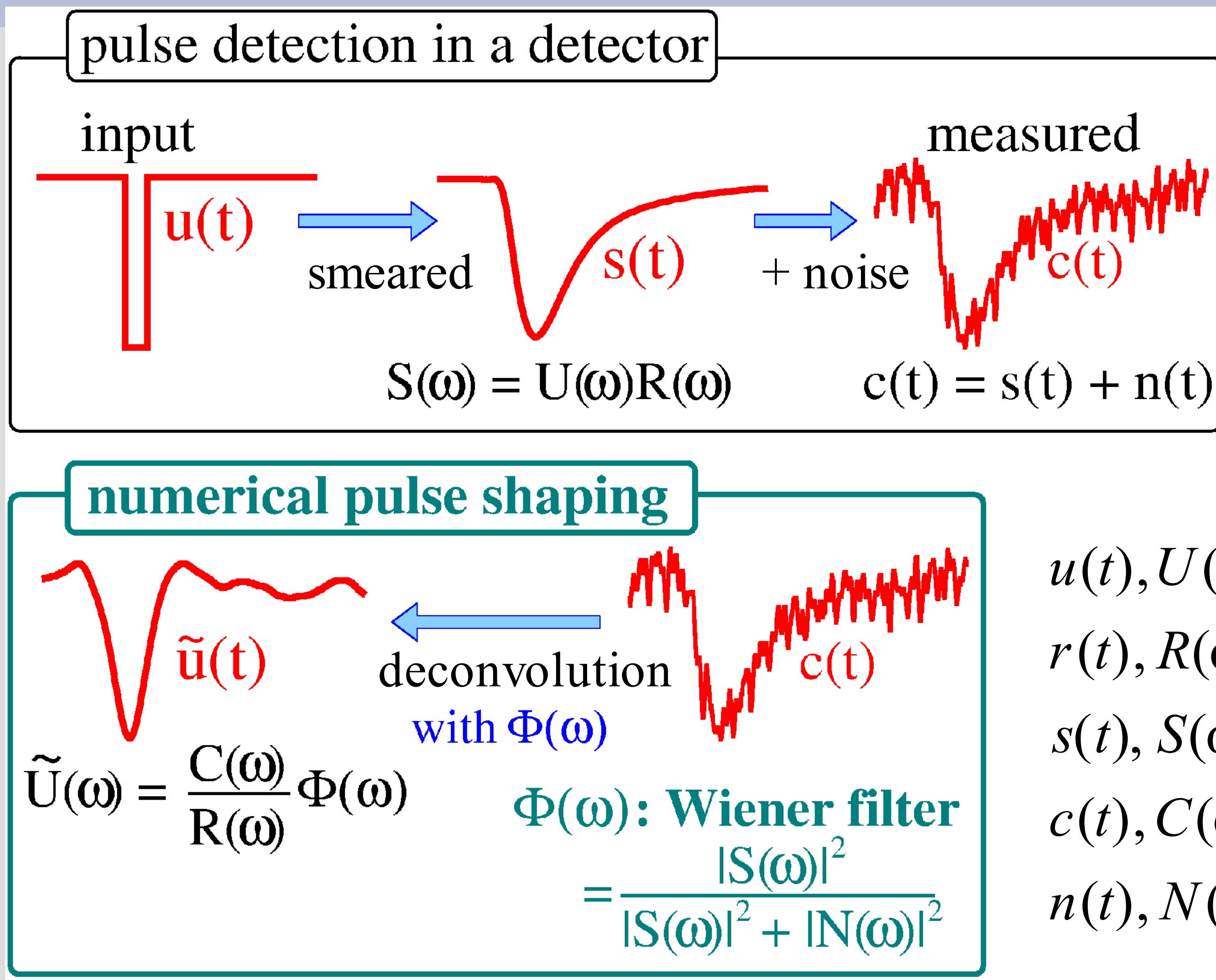


- DAQ System



- All data are taken without any online trigger with 1 kHz.
  → complete off line analysis
- Data size is 74 Mbyte / hour.

Numerical Pulse Shaping with Wiener Filter



convolution

$$f * g \equiv \int_{-\infty}^{\infty} f(\tau)g(t-\tau)d\tau$$

$$\Leftrightarrow F(\omega)G(\omega)$$

$u(t), U(\omega)$: uncorrupted signal

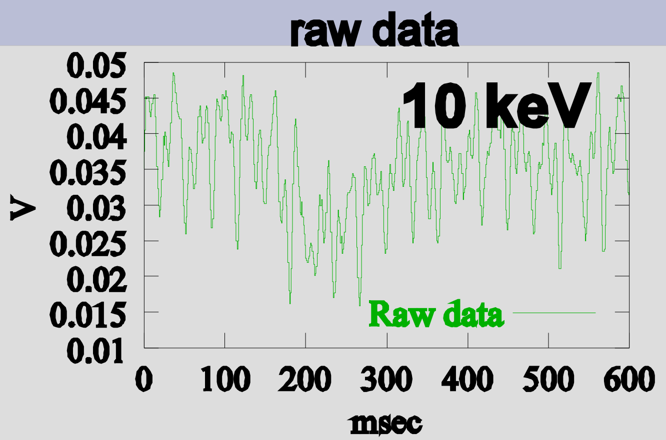
$r(t), R(\omega)$: response function

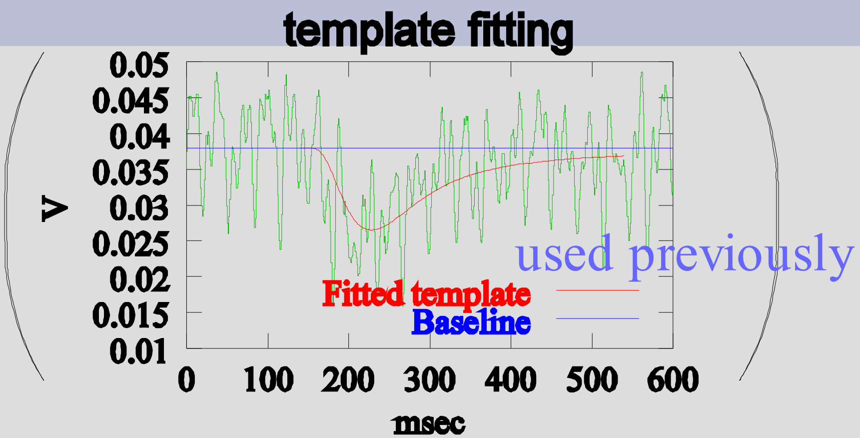
$s(t), S(\omega)$: smeared signal

$c(t), C(\omega)$: measured signal

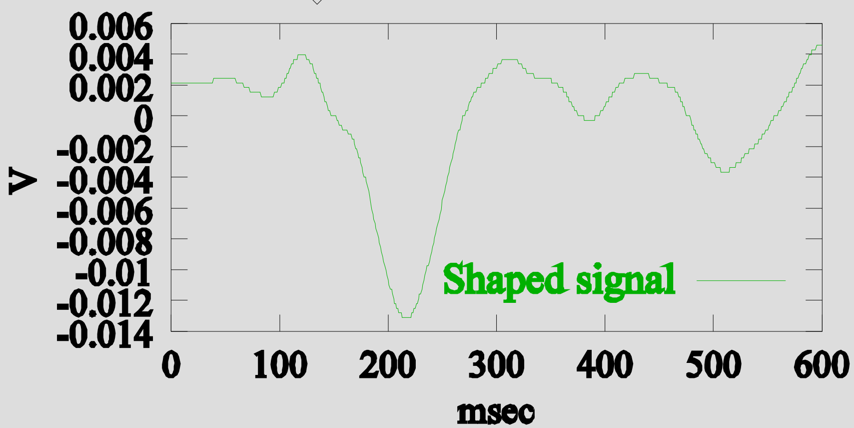
$n(t), N(\omega)$: noise

- Numerical Pulse Shaping with Wiener Filter





numerical
pulse shaping



used for this analysis.

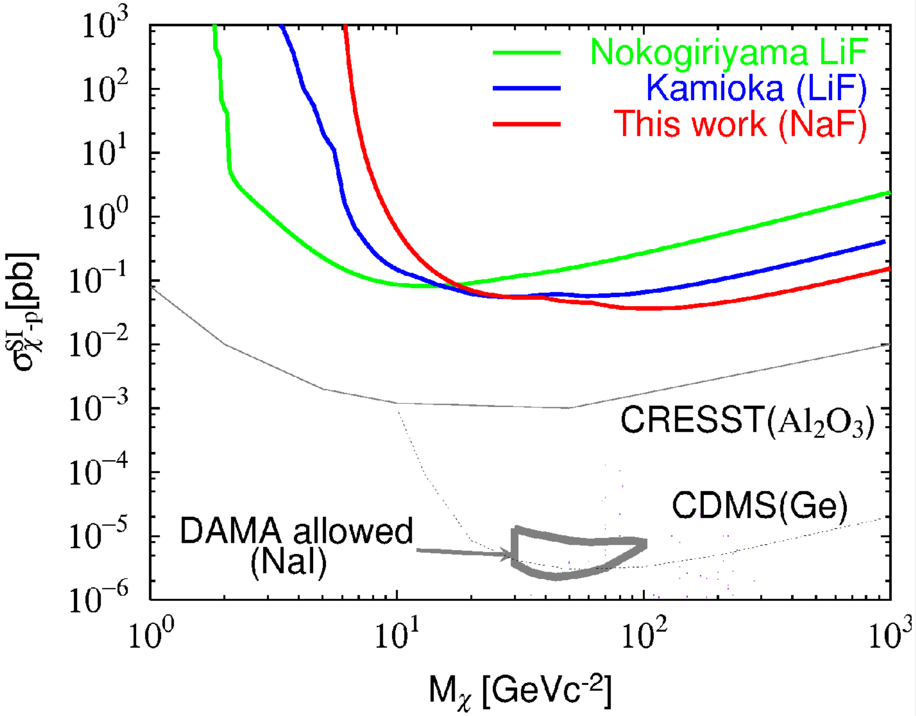
$$U(\omega) = \frac{S^*(\omega)C(\omega)}{|N(\omega)|^2}$$

in Fourier space

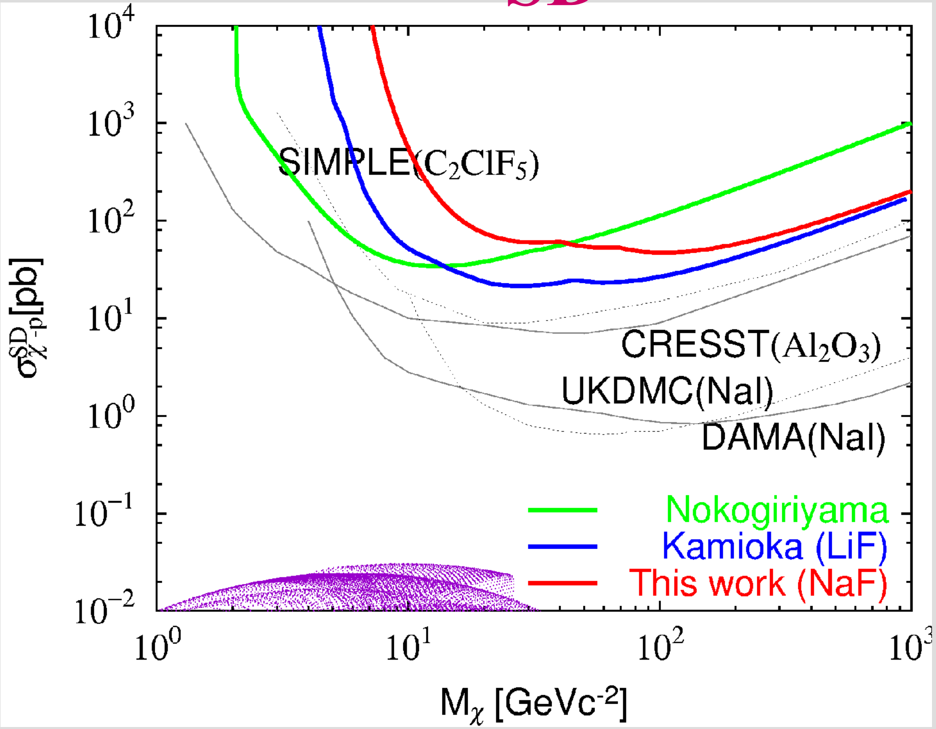
$U(\omega)$: shaped waveform
$S(\omega)$: ideal signal waveform
$C(\omega)$: measured waveform
$N(\omega)$: noise

- Result (SI and SD $\sigma_{\chi\text{-}p}$ limit)
  - Assumption : All events are dark matter events

SI



SD

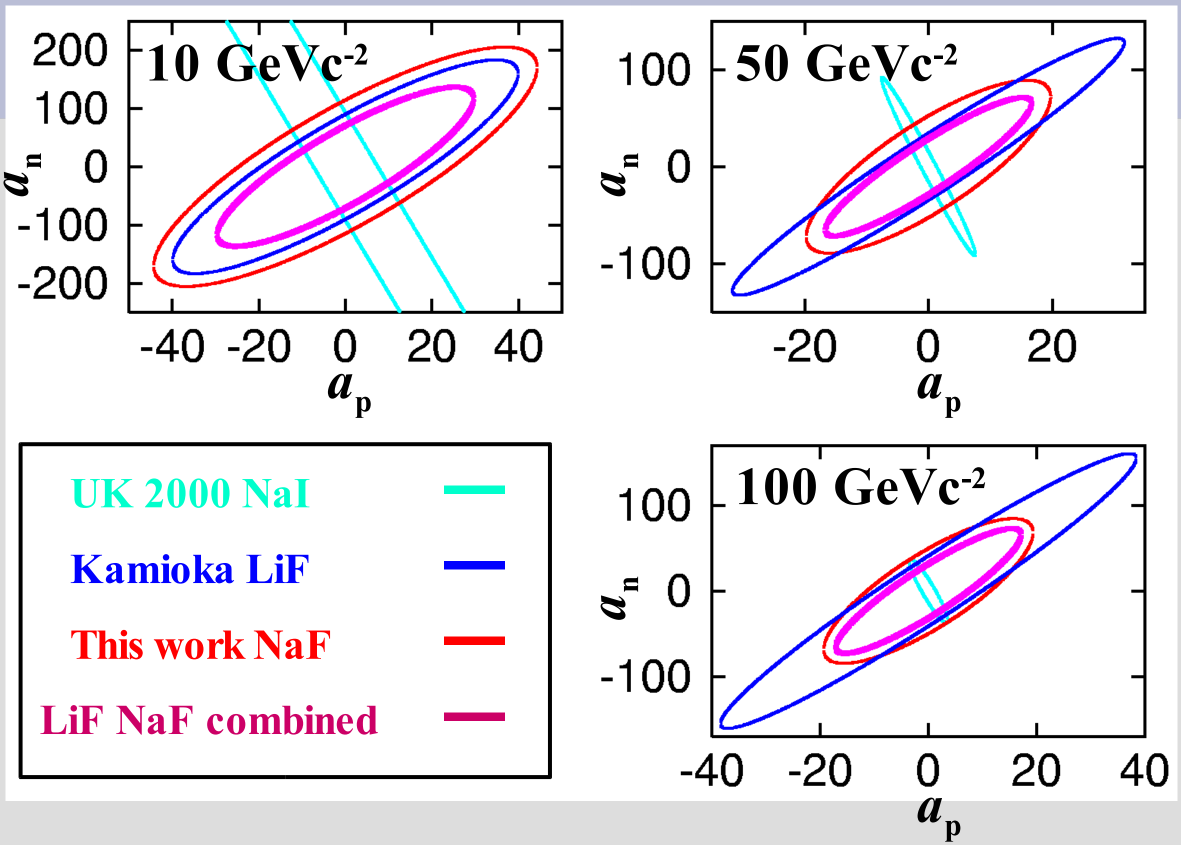


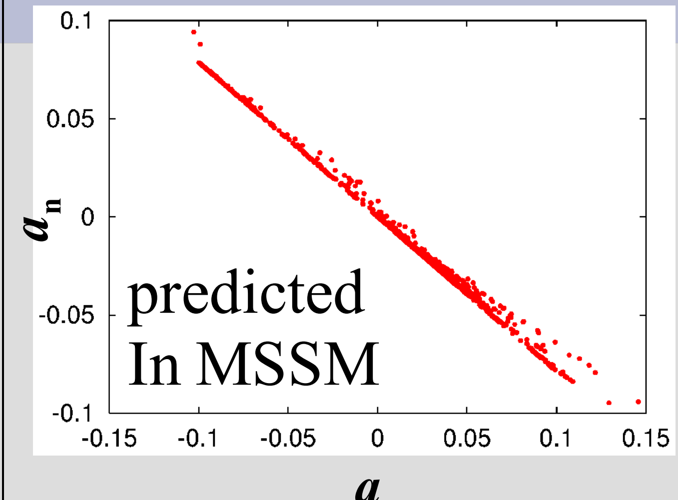
- Best limits (for 103 GeV)

SI : 0.036 pb

SD : 47 pb

• Result (SD limits in the a_p–a_n plane)





$\tan\beta = 2, 8$

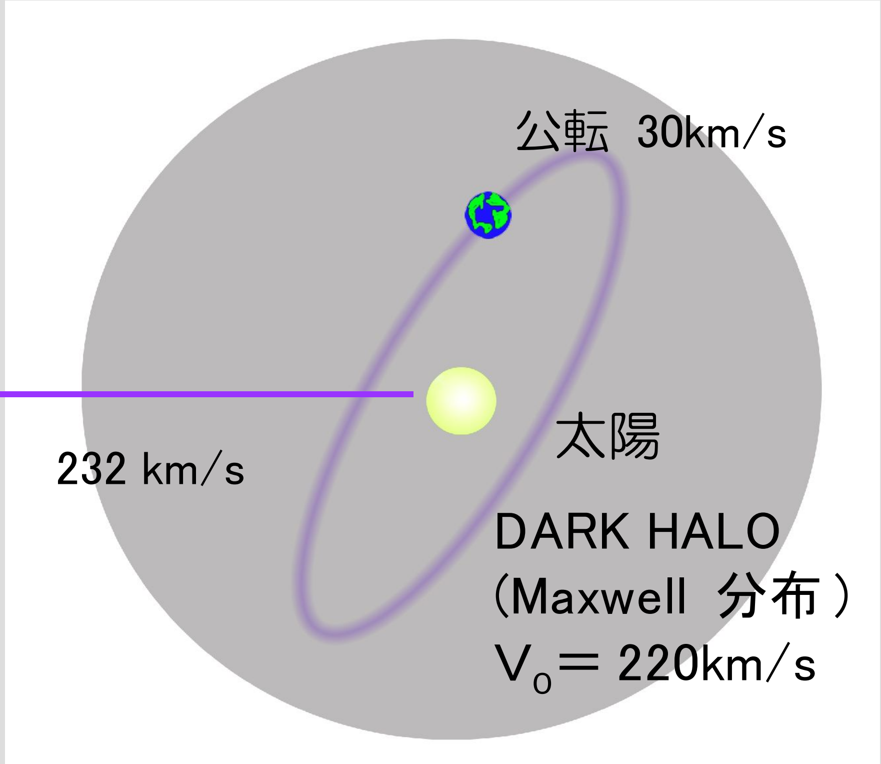
$10\,\mathrm{GeV} \le M_2 \le 1\,\mathrm{TeV}$

$10\,\mathrm{GeV} \le |\mu| \le 1\,\mathrm{TeV}$

- We **improved LiF limits** in a part of the parameter space.
- Combined limits with the results of LiF are **more stringent than UK2000 limits** for 10, 50 and 100 GeV^{-2}.

Direction sensitive scintillators R&D

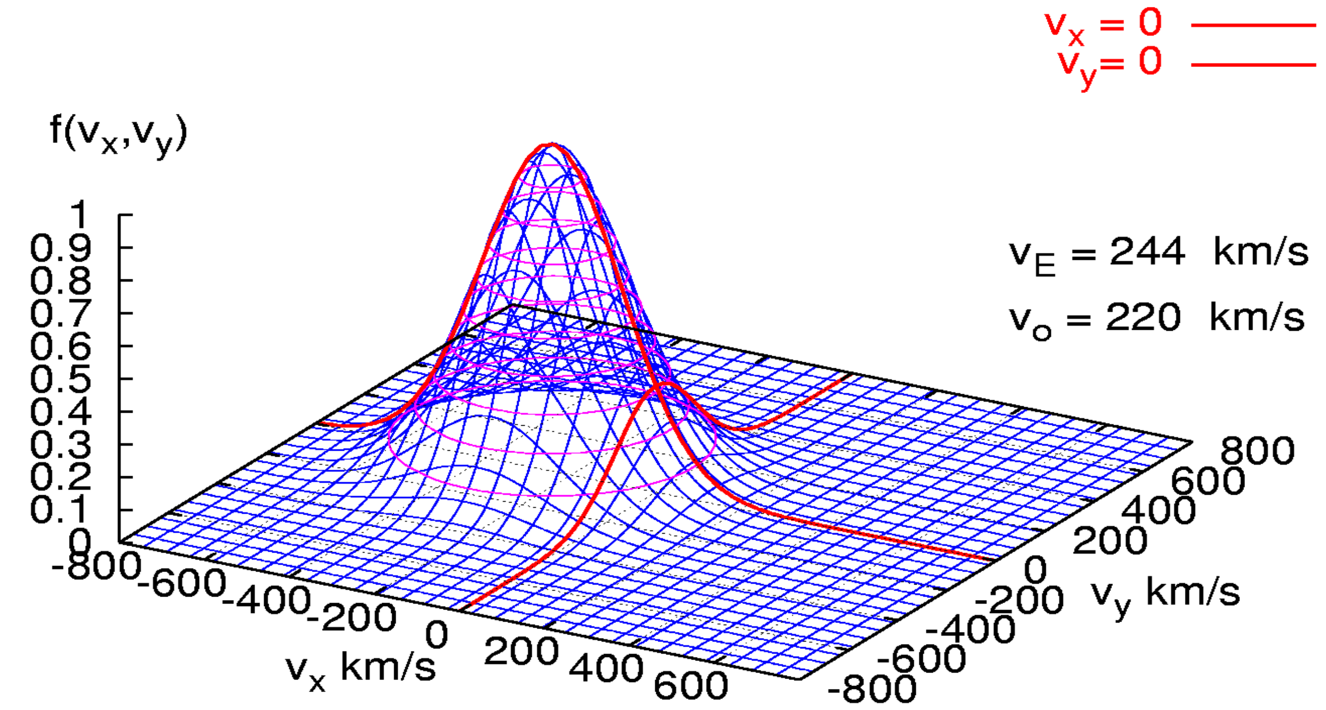
銀河中での地球の動き



地球の自転 → DM の入射方向の日変化

地球の自転動きが暗黒物質のシグナルを生む

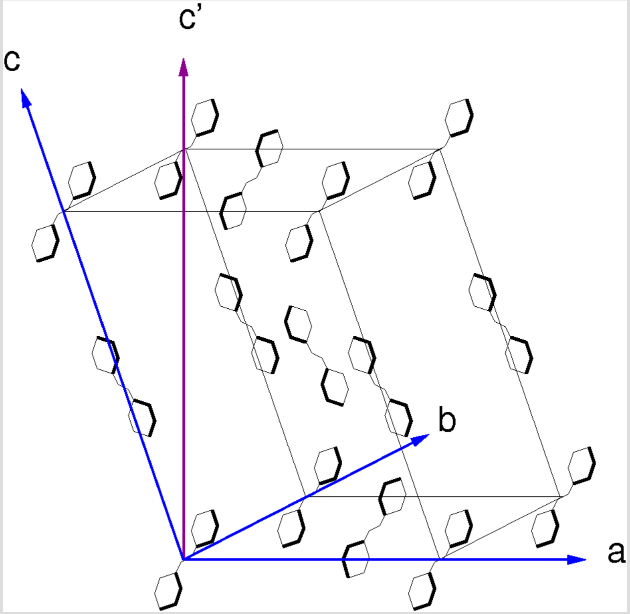
DM wind is fairy strong



スチルベンシンチレーター

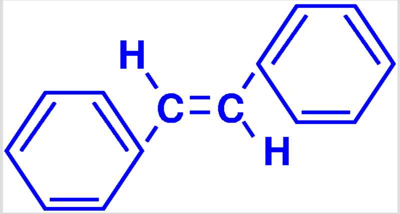
重荷電粒子の入射方向によって発光量が異なる　Z. Phys. 162 (1961) 122

→ 反跳原子核の方向に対する感度が期待される



単斜晶系　単結晶

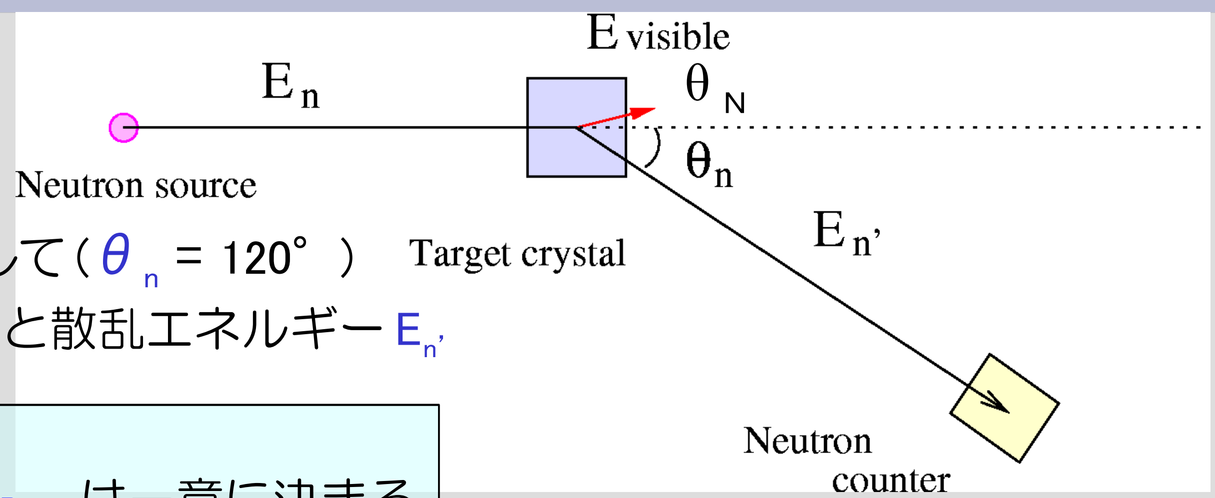
trans-stilbene



- 発光量　：30% of NaI
- 発光波長　：410 nm
- 減衰時間　：即発成分 5 ns
- 結晶軸 c' に対する角度により光量異なる

m_χ o(10GeV) の暗黒物質に感度のある低エネルギー（100keV 以下）の炭素反跳について測定を行った

中性子による発光効率測定



炭素反跳測定の原理

中性子散乱角　θ_n を固定して（θ_n = 120°）

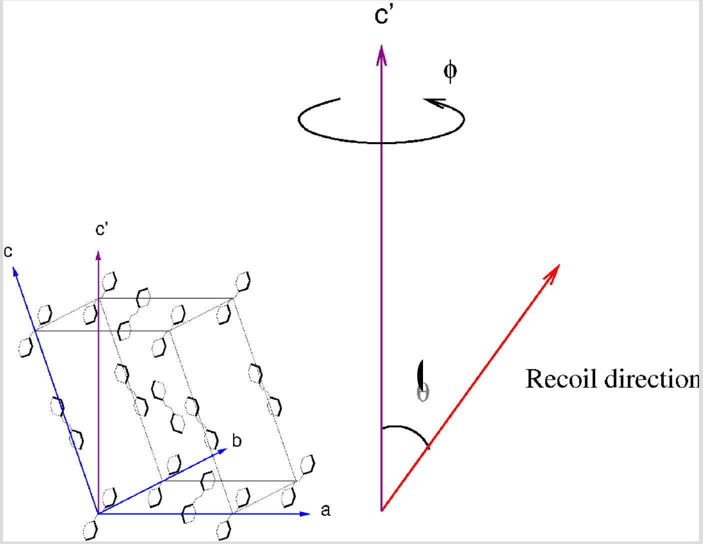
TOF で入射エネルギー E_n と散乱エネルギー $E_{n'}$

を測定

→ 反跳原子核
反跳エネルギー E_R　は一意に決まる
反跳角 θ_N

kinematics

中性子↔ＷＩＭＰ



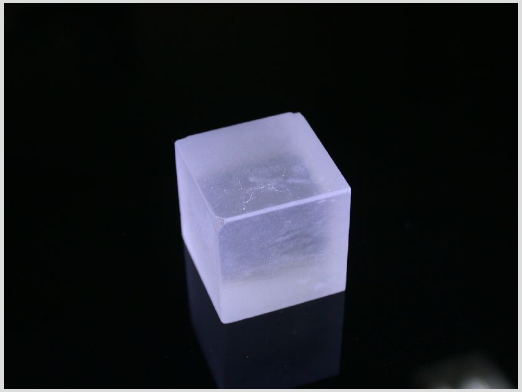
求めるべきもの

発光効率の c’ 軸に対する反跳角 θ 依存性

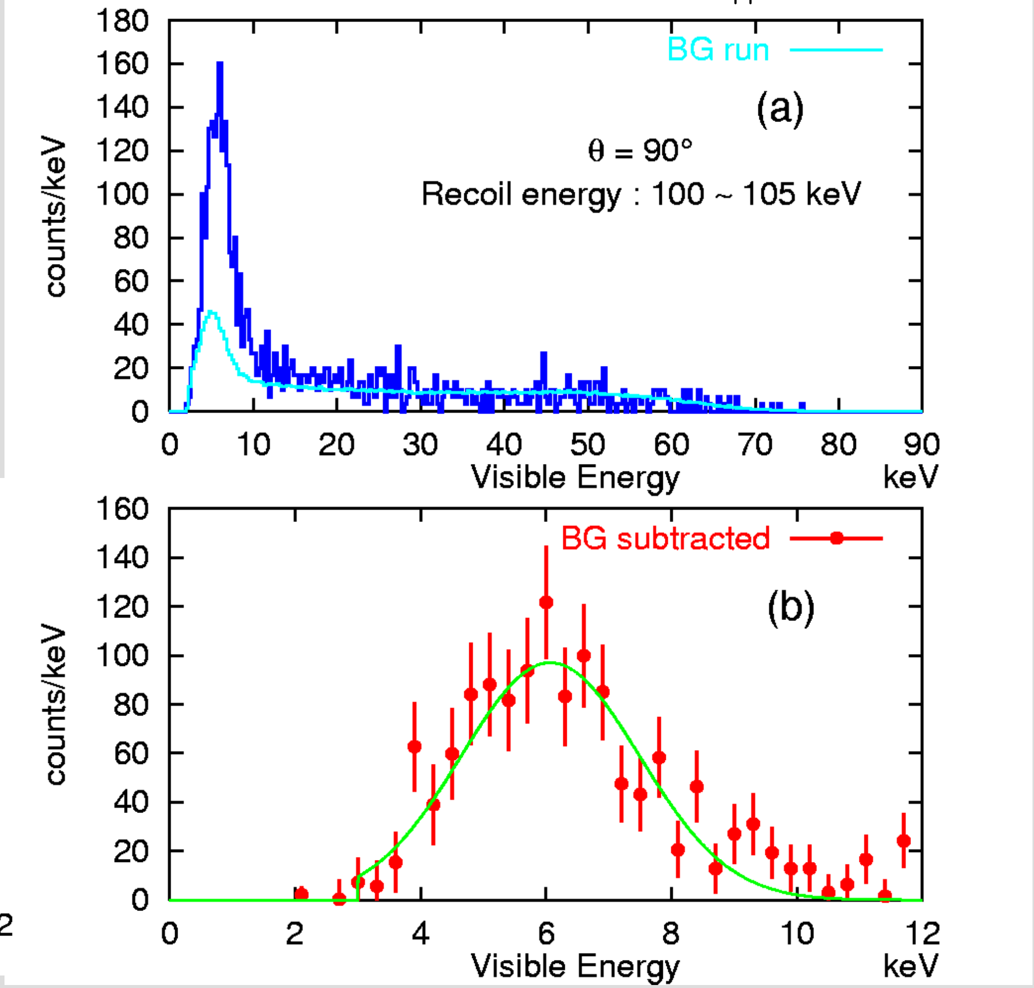
$$\text{Relative efficiency} \quad q(E_R, \theta) = \frac{E_{\text{visible}}}{E_R}$$

測定

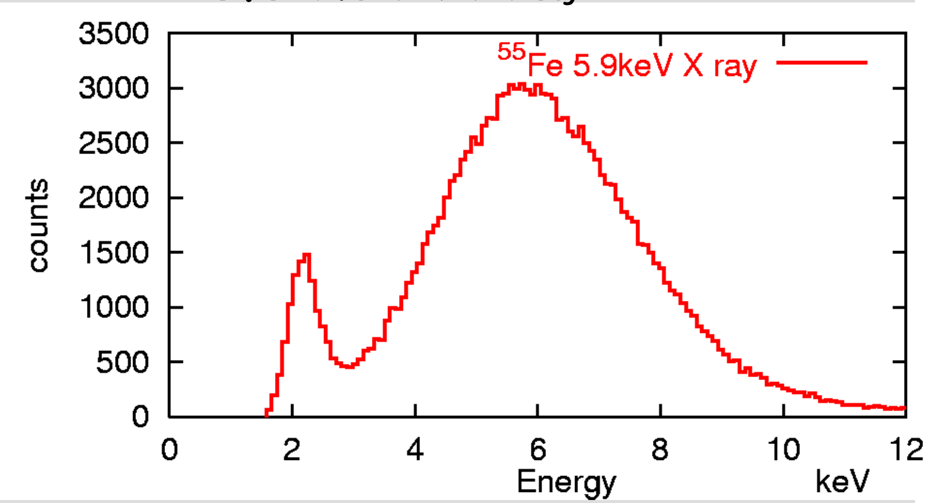
2cm x 2cm x 2cm　スチルベン結晶



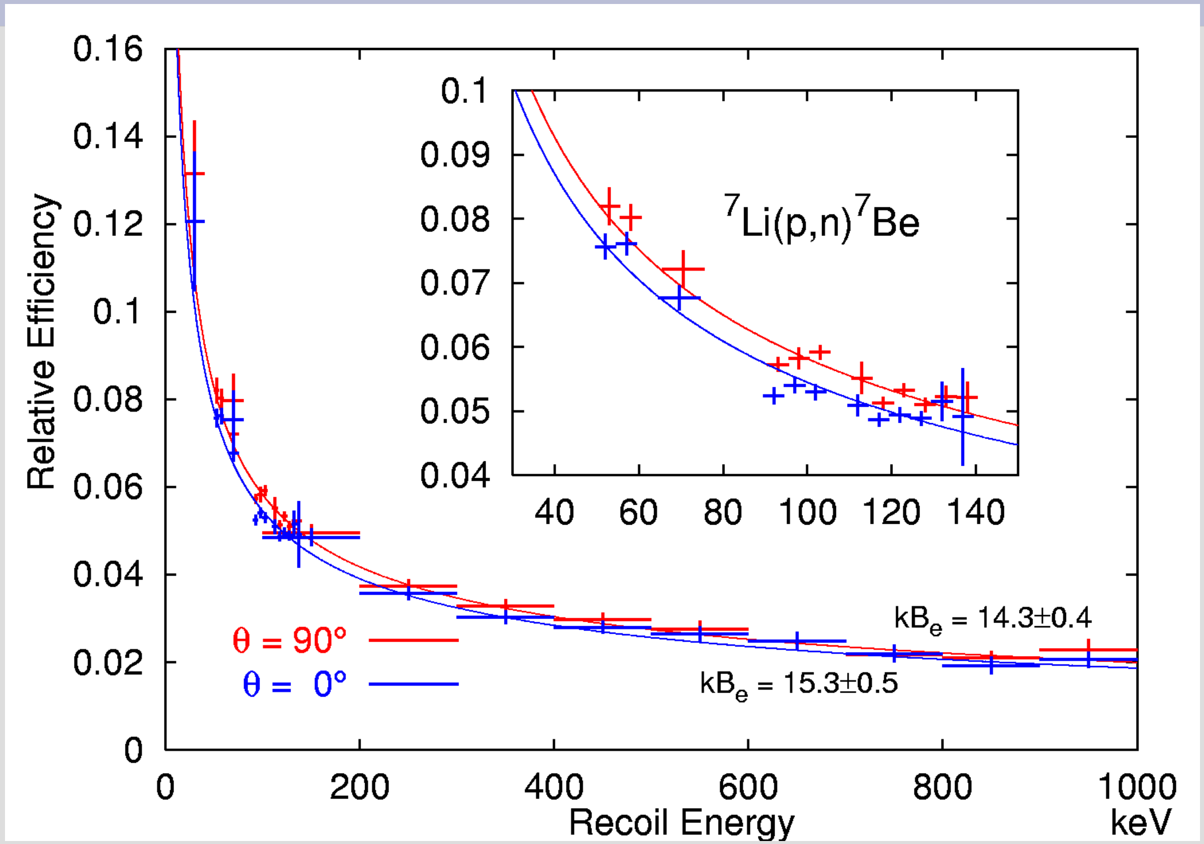
●450 keV 中性子 θ_n=120°

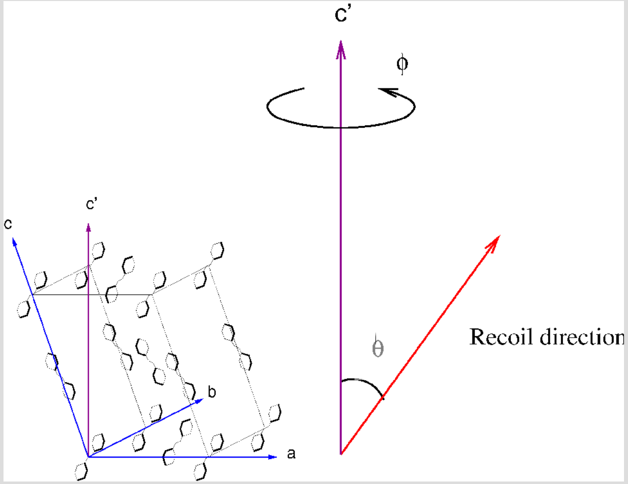


●5.9 keV X-ray



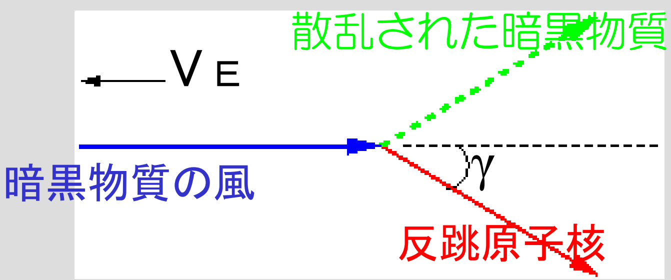
結果

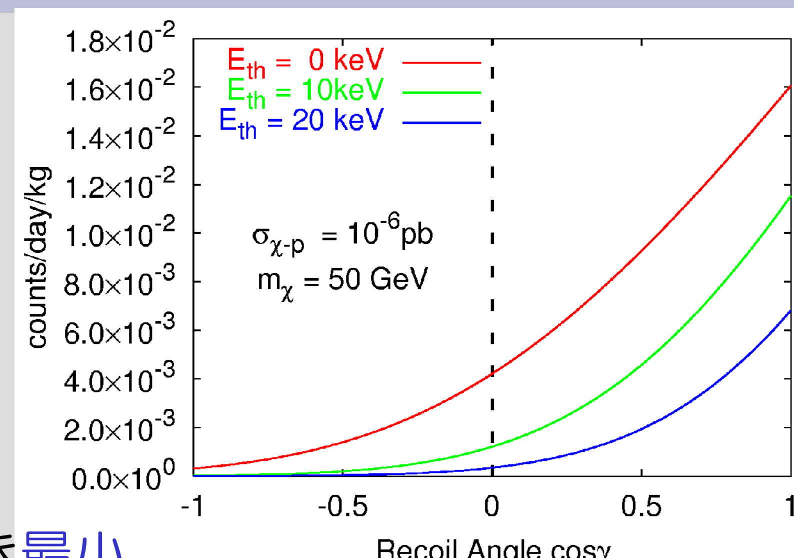




- 炭素反跳の発光効率は c' axis に関して 7 % 変化
- ほかの軸に対する（ φ ）依存性は見られなかった

暗黒物質探索への利用



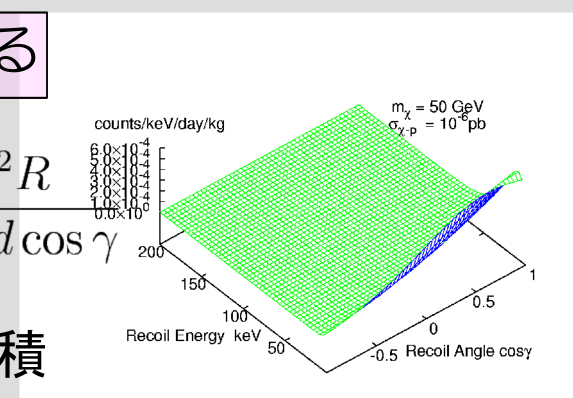


スチルベンの発光量は

- c’ // VE のとき最小
- c’ ⊥ VE のとき最大

暗黒物質にシグナルは光出力スペクトルに現れる

$$\frac{dR'}{dE_{\rm vis}} = \int dE_R d\cos\gamma\,\delta\left(E_{\rm vis} - q(E_R,\cos\gamma)E_R\right)\frac{d^2R}{dE_R d\cos\gamma}$$

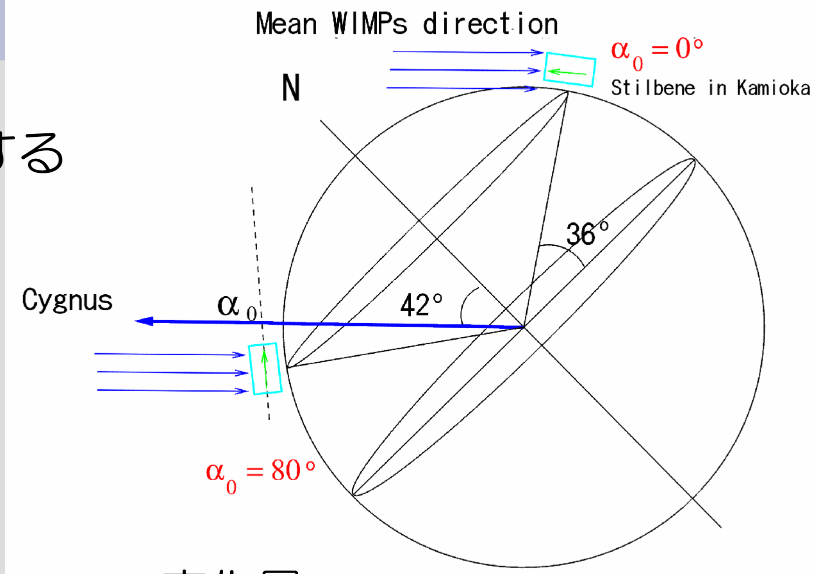


cos θ = c’ の方向と反跳方向の内積

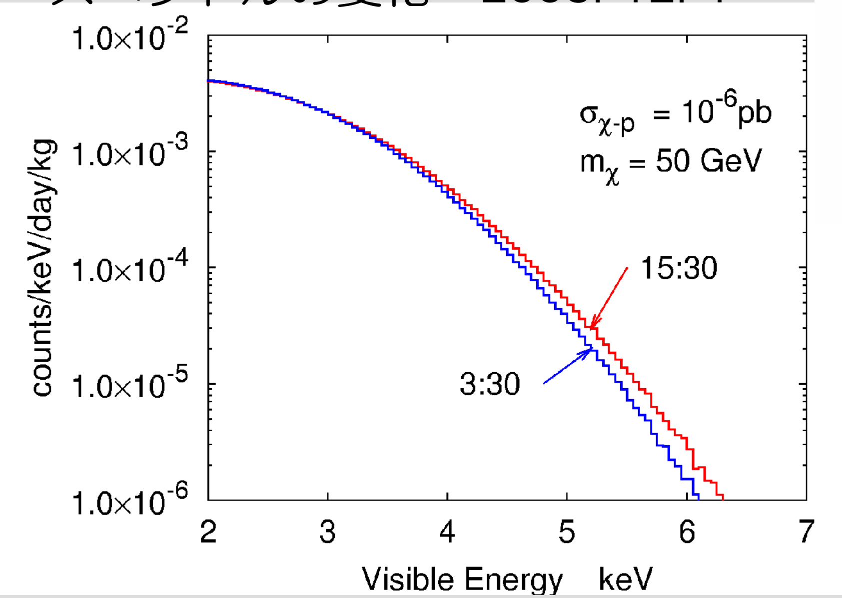
暗黒物質探索への利用

- Cygnus. の方向
  RA21 h 12 m, dec.+48.19°
- 神岡（北緯 36 度 25 分）で実験する

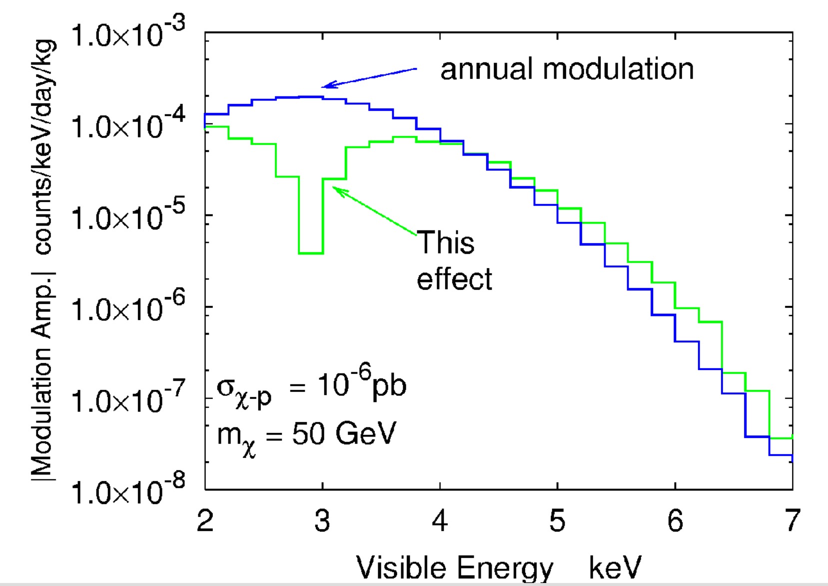
c’ 軸を北極に向けておけば地球の自転により風向きとc’ 軸の角度が約 80° 変化する。



スペクトルの変化 2003. 12. 1

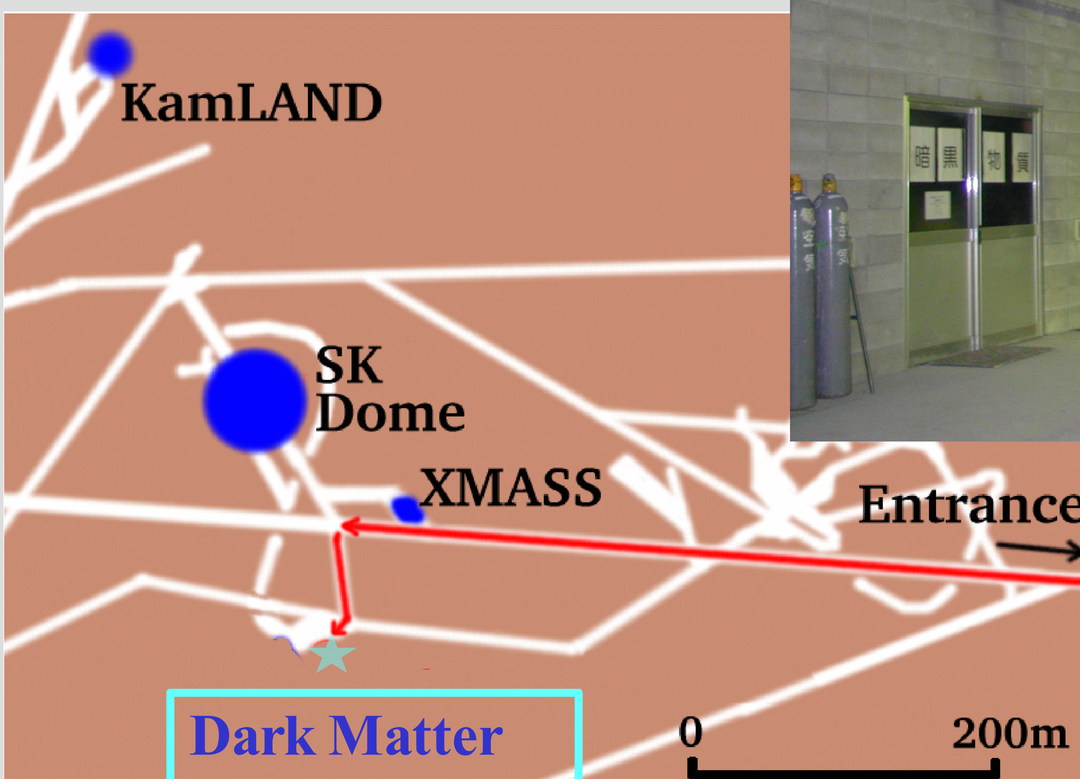


変化量



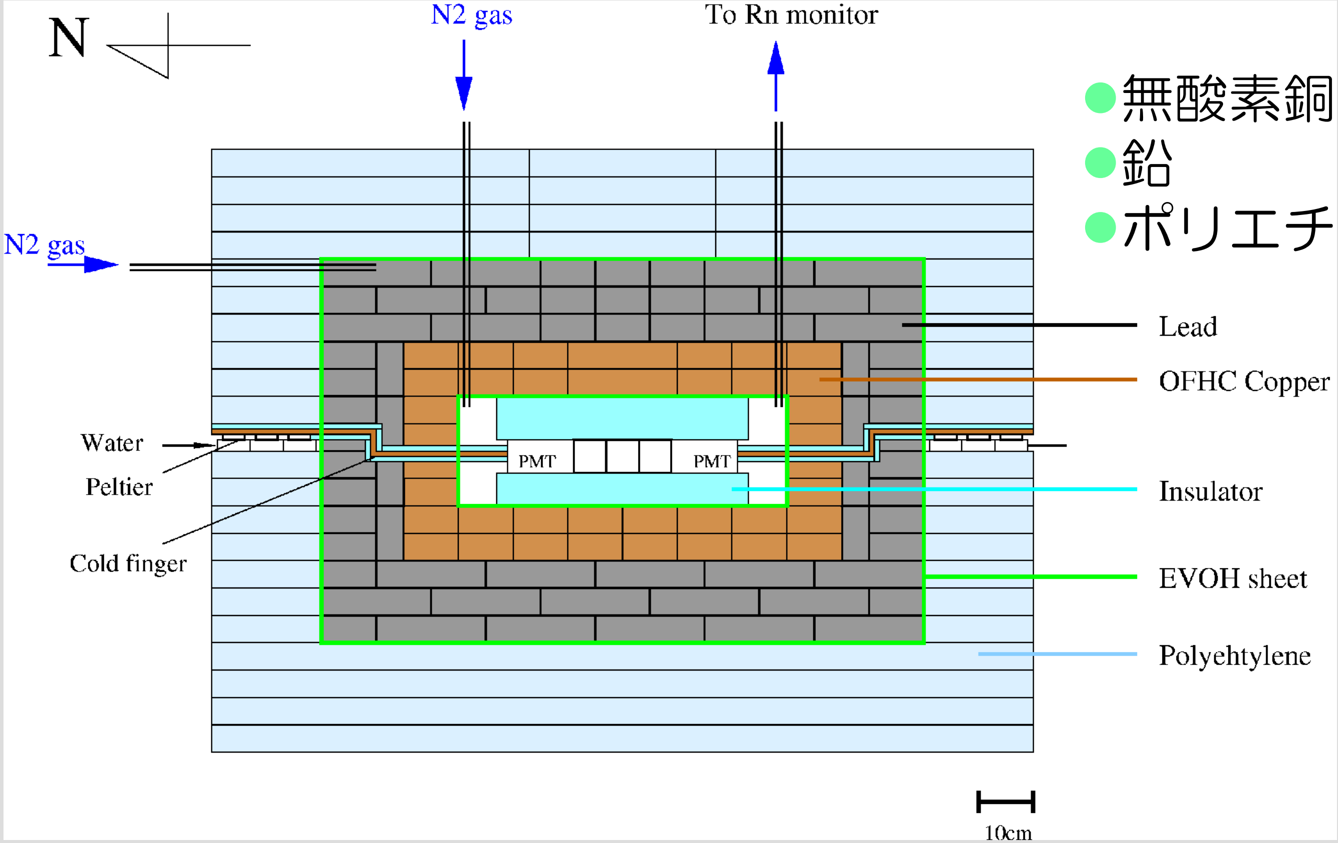
神岡地下実験室での測定

- 地下　2700 m.w.e
  (1000 m)
- Muon flux
  $\sim 10^{-7}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$



放射線シールド

- シールドごと北を向けている

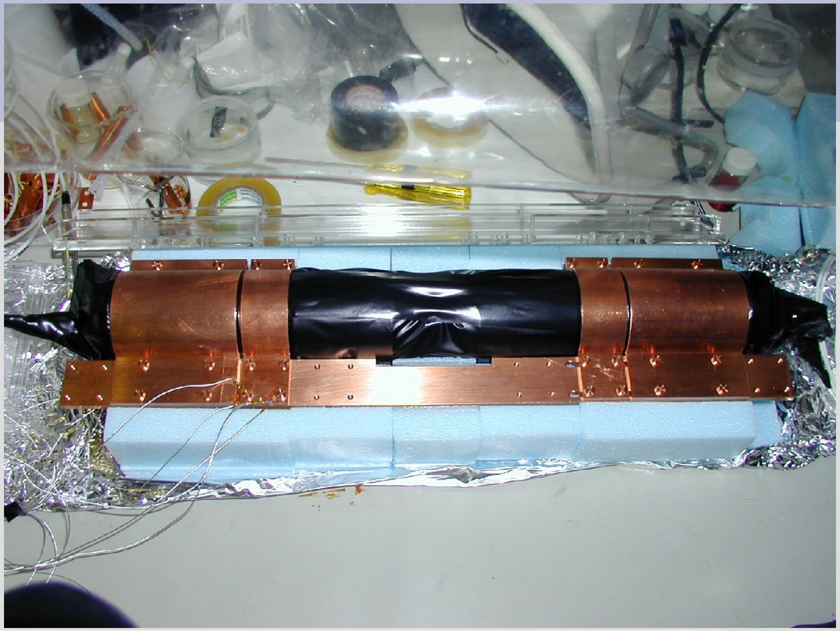


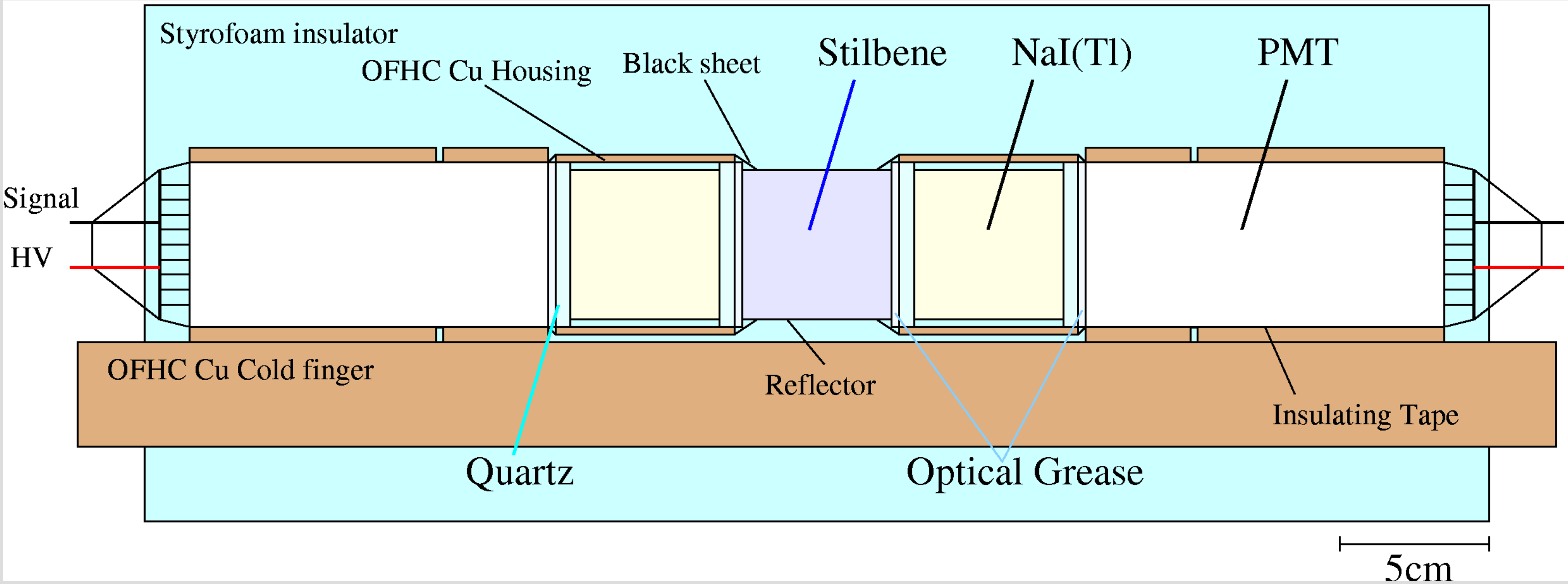
- 無酸素銅 10cm
- 鉛 15cm
- ポリエチレン 20cm

- 蒸発窒素ガスによるラドンパージ → ～1 Bq/m^3

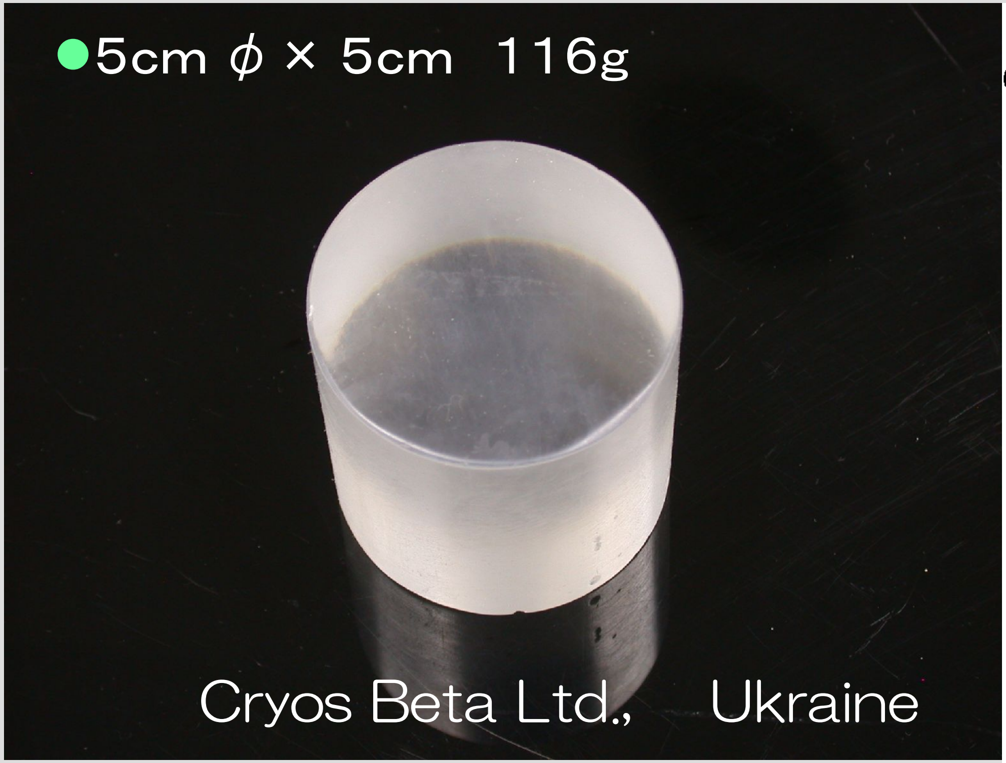
検出器

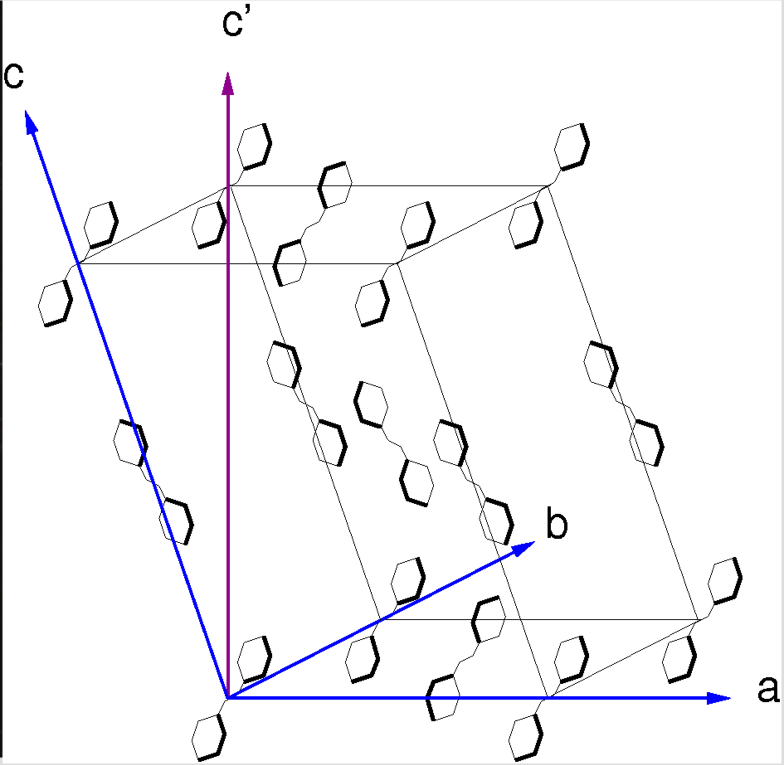
- 116ｇ　スチルベン結晶
- Low BG PMT 浜松 R8778MOD
  ２本による両読み出し
- NaI(Tl) によるアクティブシールド
- ペルチェ素子による PMT 冷却





スチルベン結晶





PMT　R8778MOD

- XMASS実験用のR8778の光電面を可視光用に変更
- 金属バルブの低バックグラウンド仕様

浜松ホトニクス　R8778MOD-ASSY

NaI(Tl) シールド

- PMT からの放射線を防ぐため

R8778　1本あたり
Ge による測定
by Xmass

U 系列	Th 系列	^{40}K	^{60}Co
1.8×10^{-2}Bq	6.9×10^{-3}Bq	1.4×10^{-1}Bq	5.5×10^{-3}Bq

- スチルベンの発光量少ない

→ NaI　可視光を透過する High Z な物質

R8778MOD の暗電流

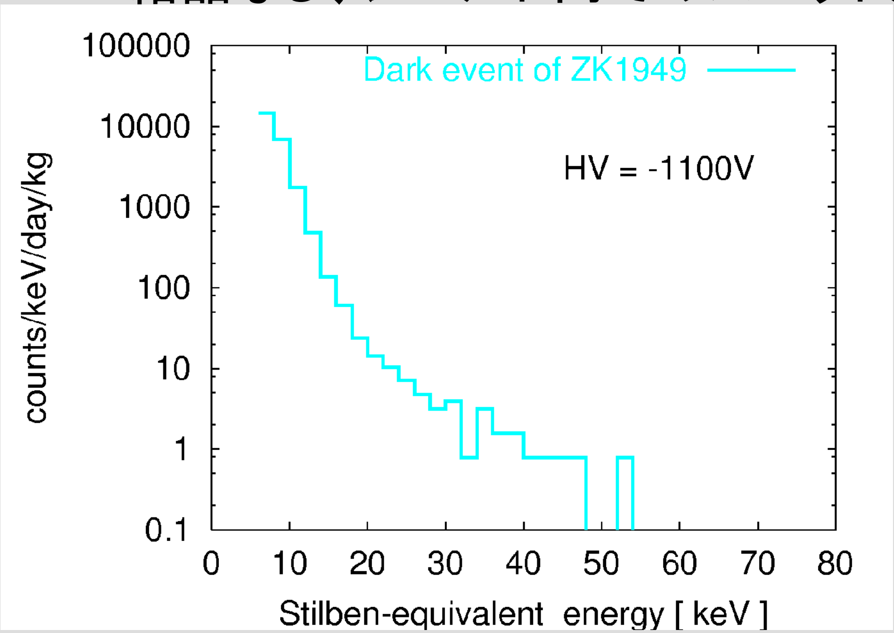
- 可視光用光電面、少量生産

→ 暗電流（パルス）が多い

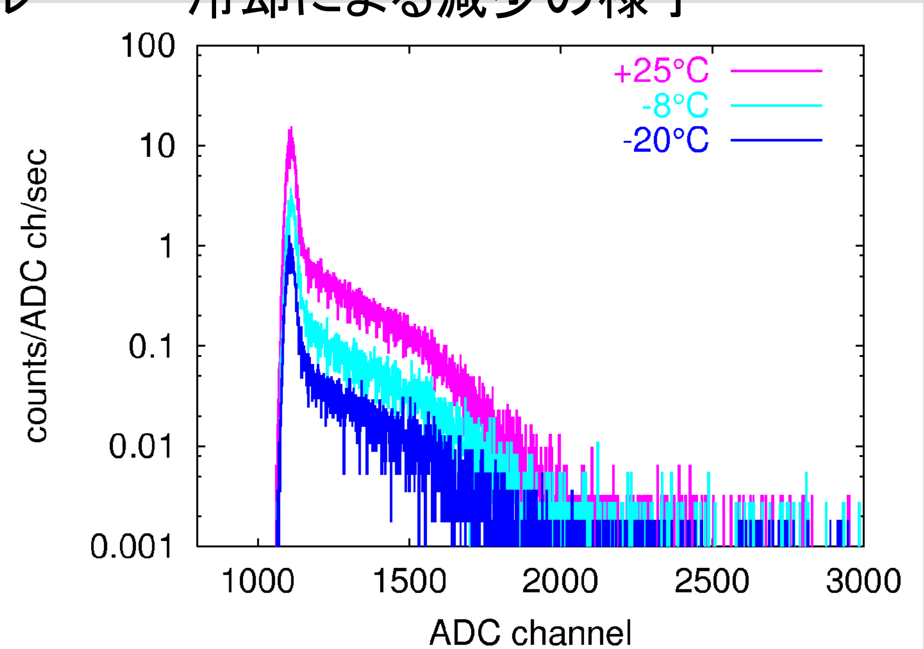
- ペルチェ素子を用いて冷却
- ２本のコインシデンスとる

→ 影響なくなる。

結晶なし、シールド内でのスペクトル

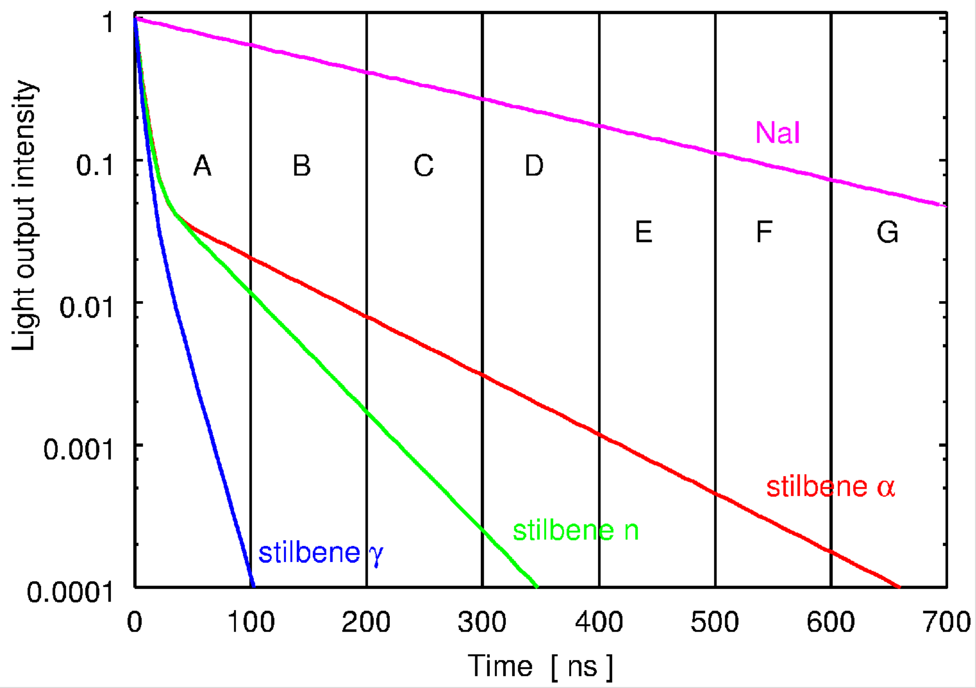


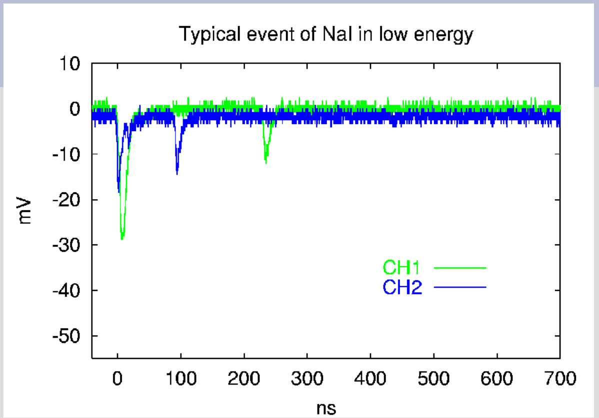
冷却による減少の様子



イベント選択

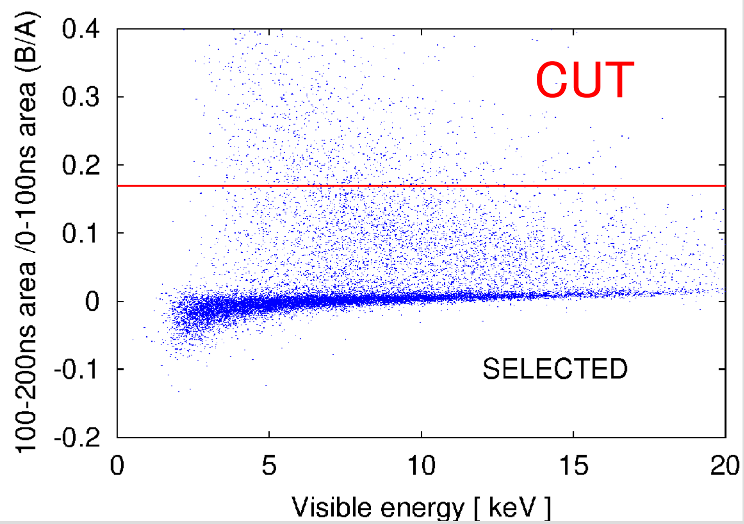
低エネルギーではNaIは“波形”を成さない



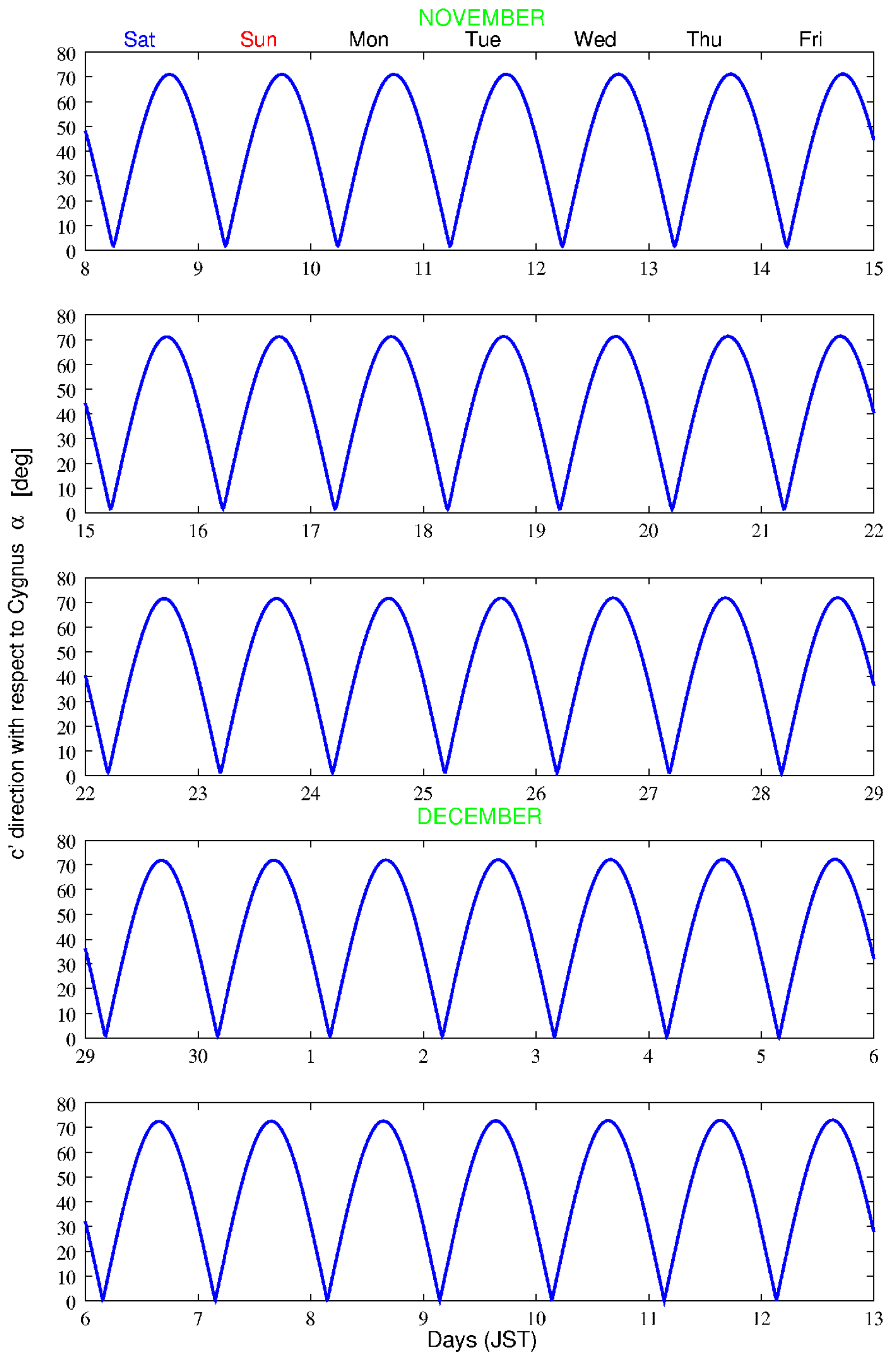


オシロスコープで取得した
波形を領域に分けて
低エネルギーでの
NaI（Tl）イベントを除去

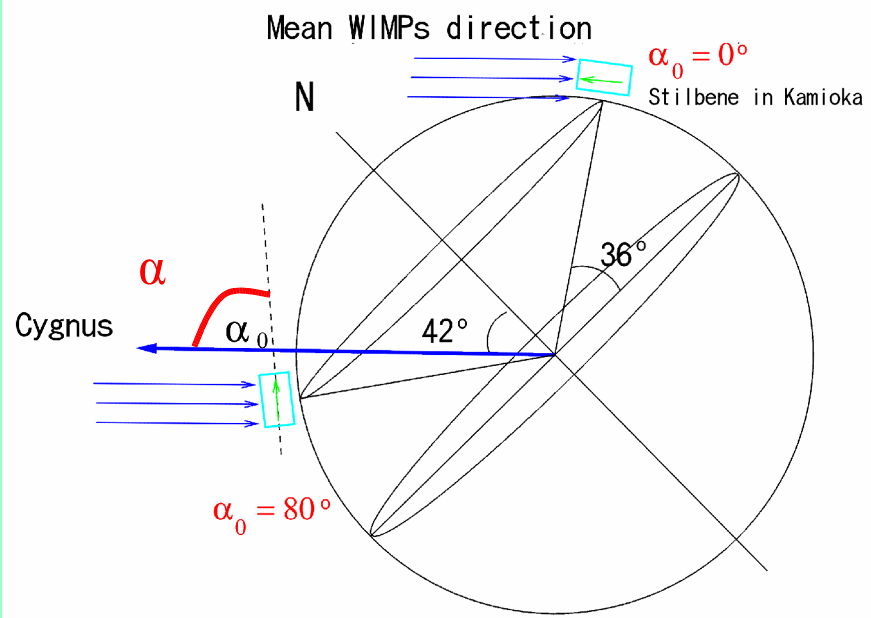
それぞれの領域の波形を積分して
領域Aでの値との比に対してCUT
をかける



風向きの変化

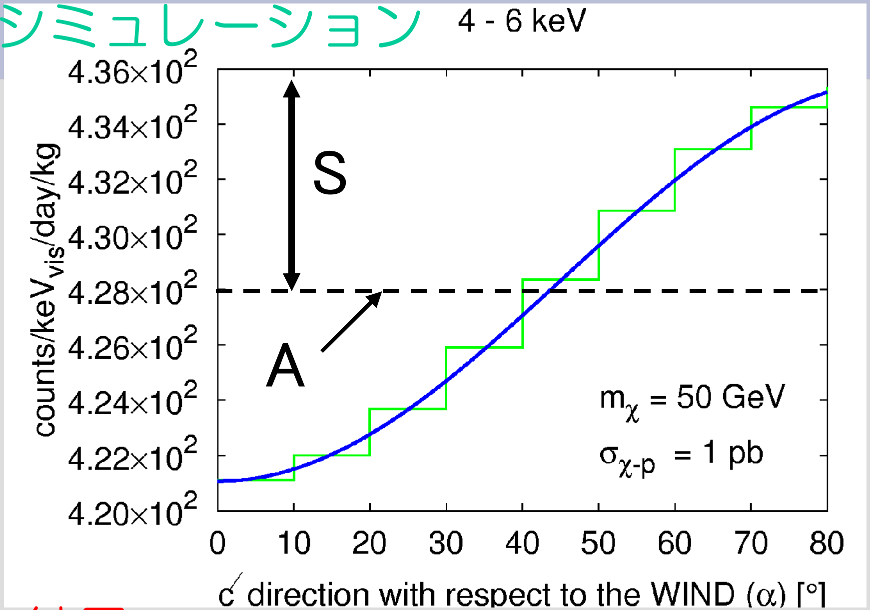


測定期間中の
地球の進行方向と結晶軸 c'
のなす角 α の変化



断面積に対する制限の導出

シミュレーション

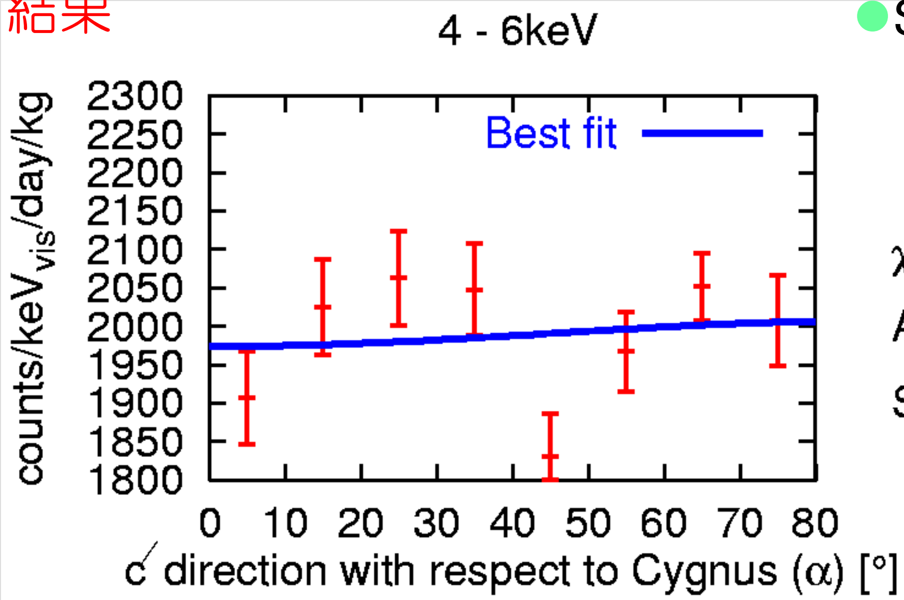


αによる
予想されるレート（シミュレーション）
と測定結果を比較する

$$A - S\cos 2\alpha$$ と変化する

- A の比較
  すべてのイベントを暗黒物質
  とした conventional な制限
- S の比較
  暗黒物質の風からの制限

結果



χ^2/ndf = 2.43228

A^{exp}_k = 1990.71 ± 19.70

S^{exp}_k = 16.9364 ± 30.51

→ α に対してフラット

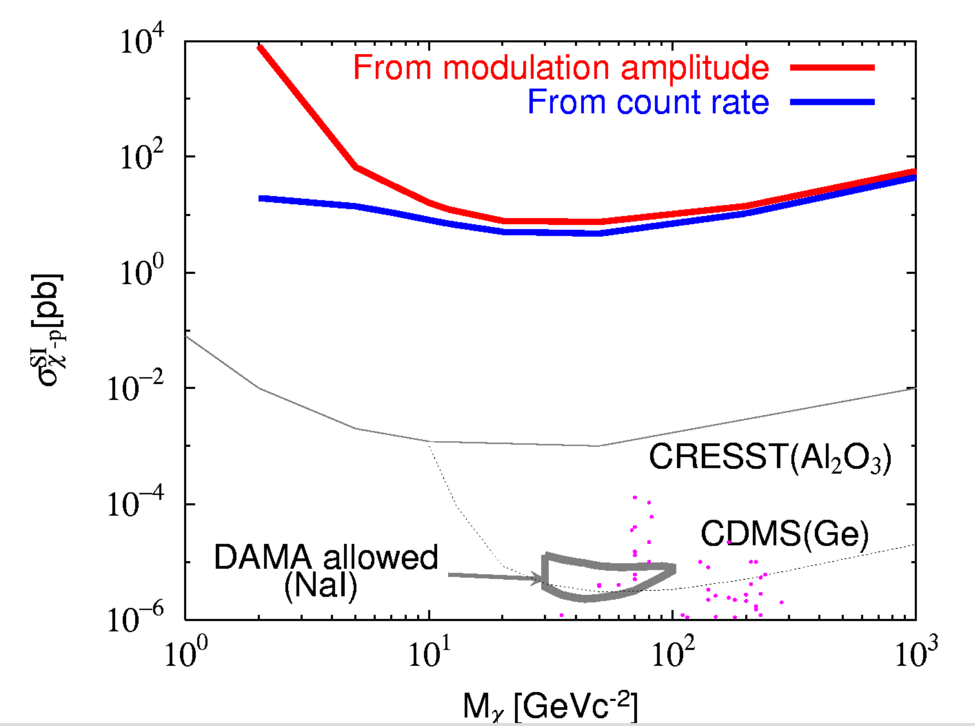
暗黒物質に対する制限曲線

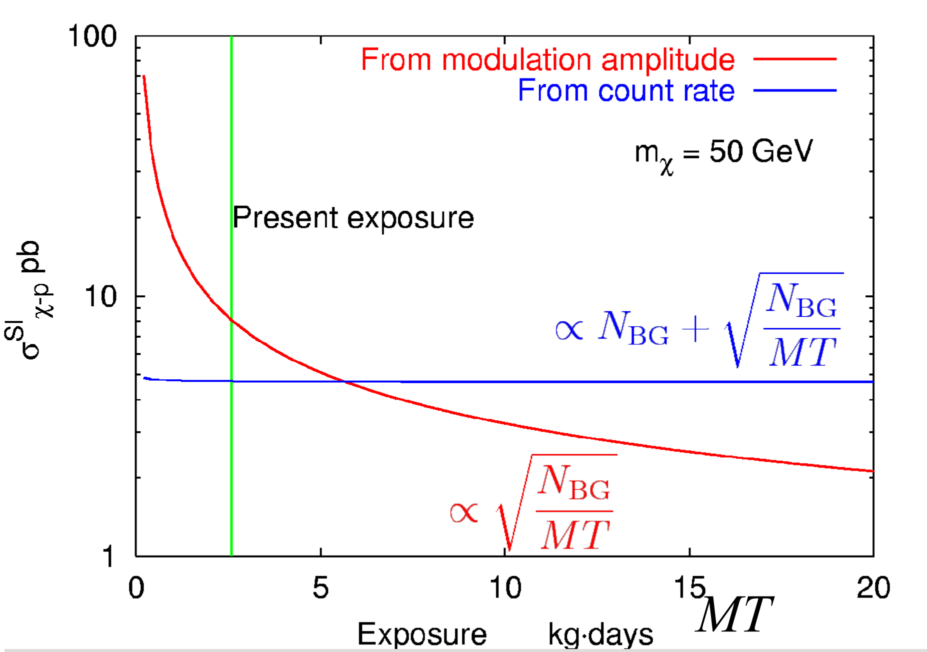
暗黒物質の風からの制限

conventional な制限

予想される制限

N_{BG} 得られたBGレート





長時間・大質量の測定で逆転、
バックグラウンドを下げずとも、さらに制限できる

今後

実験を制限しているもの

1. バックグラウンドレート

PMT 中の放射性不純物
（ダイノード構造のセラミック、ステム部分のガラス）

→
- 結晶の周りを古い鉛で囲う
- 光検出器の改善（量子効率の意味でも）
  Avalanche Photodiode, Prism PMT など

2. スチルベン結晶

Anisotropy not sufficient

A=12 is not large enough for SI detection $\left(\sigma^{\mathrm{SI}}_{\chi-\mathrm{N}} \propto A^2\right)$

→
- より異方性のある、アントラセン・ナフタレンの使用
- Spin に依存した相互作用に有利な ^{19}F を含む結晶の製造
  Octafluoronaphtalene, dodecafluoroanthracene

END
Tokyo Group Results

Publications

H. Sekiya, M. Minowa, Y. Shimizu, Y. Inoue, W. Suganuma:
Measurements of anisotropic scintillation efficiency for carbon recoils in a stilbene crystal for dark matter detection,
astro-ph/0307384, Physics Letters B571 (2003) 132-138.

A.Takeda, M.Minowa, K.Miuchi, H.Sekiya, Y.Shimizu, Y.Inoue, W.Ootani, Y.Ootuka:
Limits on the WIMP-Nucleon Coupling Coefficients from Dark Matter Search Experiment with NaF Bolometer,
astro-ph/0306365, Physics Letters B572 (2003) 145-151.

Y. Shimizu, M. Minowa, H. Sekiya, Y. Inoue:
Directional scintillation detector for the detection of the wind of WIMPs,
astro-ph/0207529, Nuclear Instruments and Methods in Physics Research Section A 496 (2003) 347-352.

K. Miuchi, M. Minowa, A. Takeda, H. Sekiya, Y. Shimizu, Y. Inoue, W. Ootani, and Y. Ootuka:
First results from dark matter search experiment with LiF bolometer at Kamioka Underground Laboratory,
astro-ph/0204411, Astroparticle Physics 19 (2003) 135-144.

Another challenging DM search XMASS experiment

- Goals

☆ Direct detection of Dark Matter

→ <u>Discovery of Dark Matter</u>

☆ Real time observation of low energy solar ν (pp, ^{7}Be)

→ <u>Precise determination of ν oscillation parameters</u>

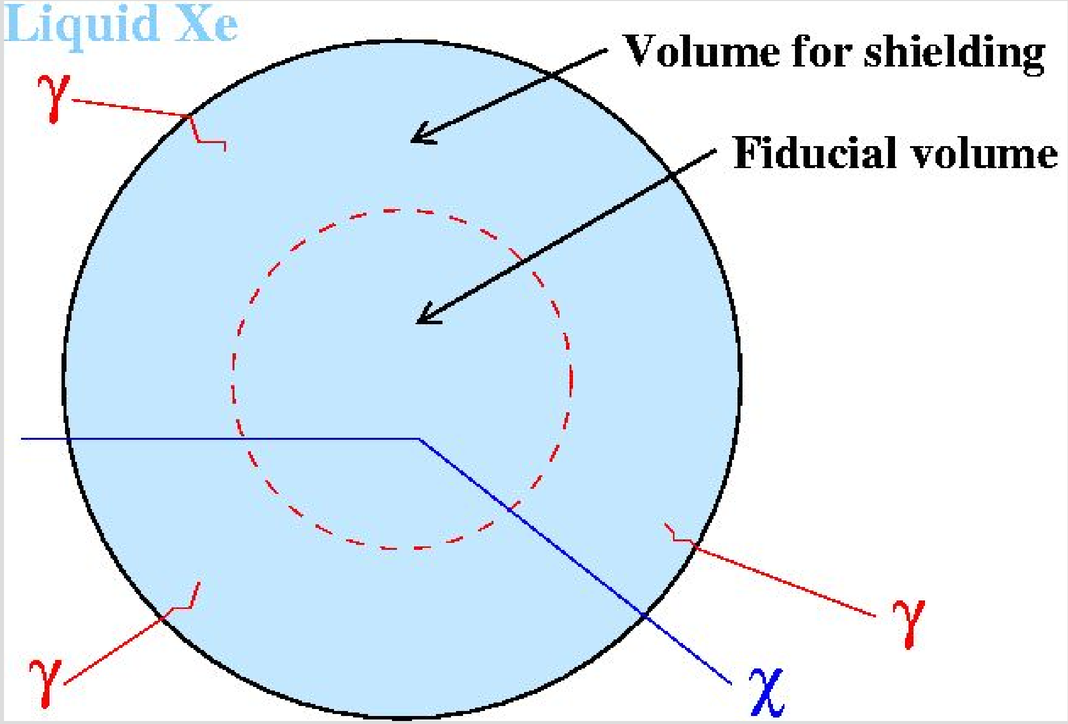
☆ Observation of $0\nu\beta\beta$ decay

→ <u>Majorana property and absolute mass of ν</u>

XMASS = Multipurpose Ultra low-background detector
with liquid Xe

- Key idea

Self shielding for γ ray background by liquid Xe (Z=54)



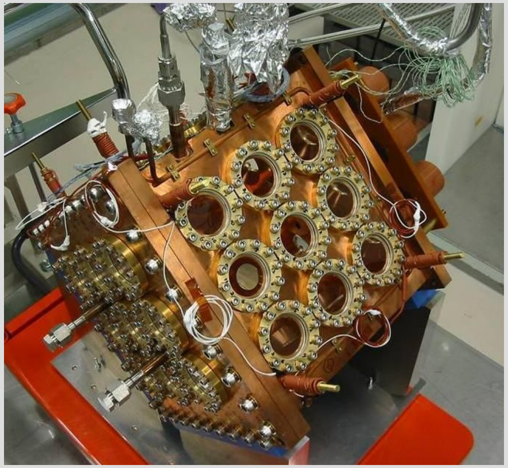
Reconstruct the vertex of events from PMTs information

→ γ ray backgrounds are absorbed in outer volume

→ Dark matter can go into fiducial volume

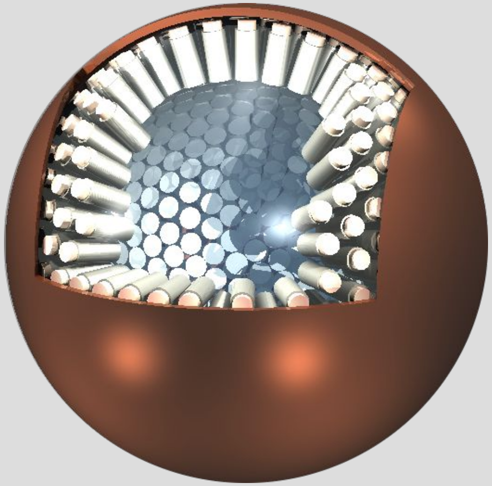
- Strategy of the scale-up

100kg prototype



~ 30cm

800kg detector



~ 80cm

~ 10ton detector

~ 2.5m

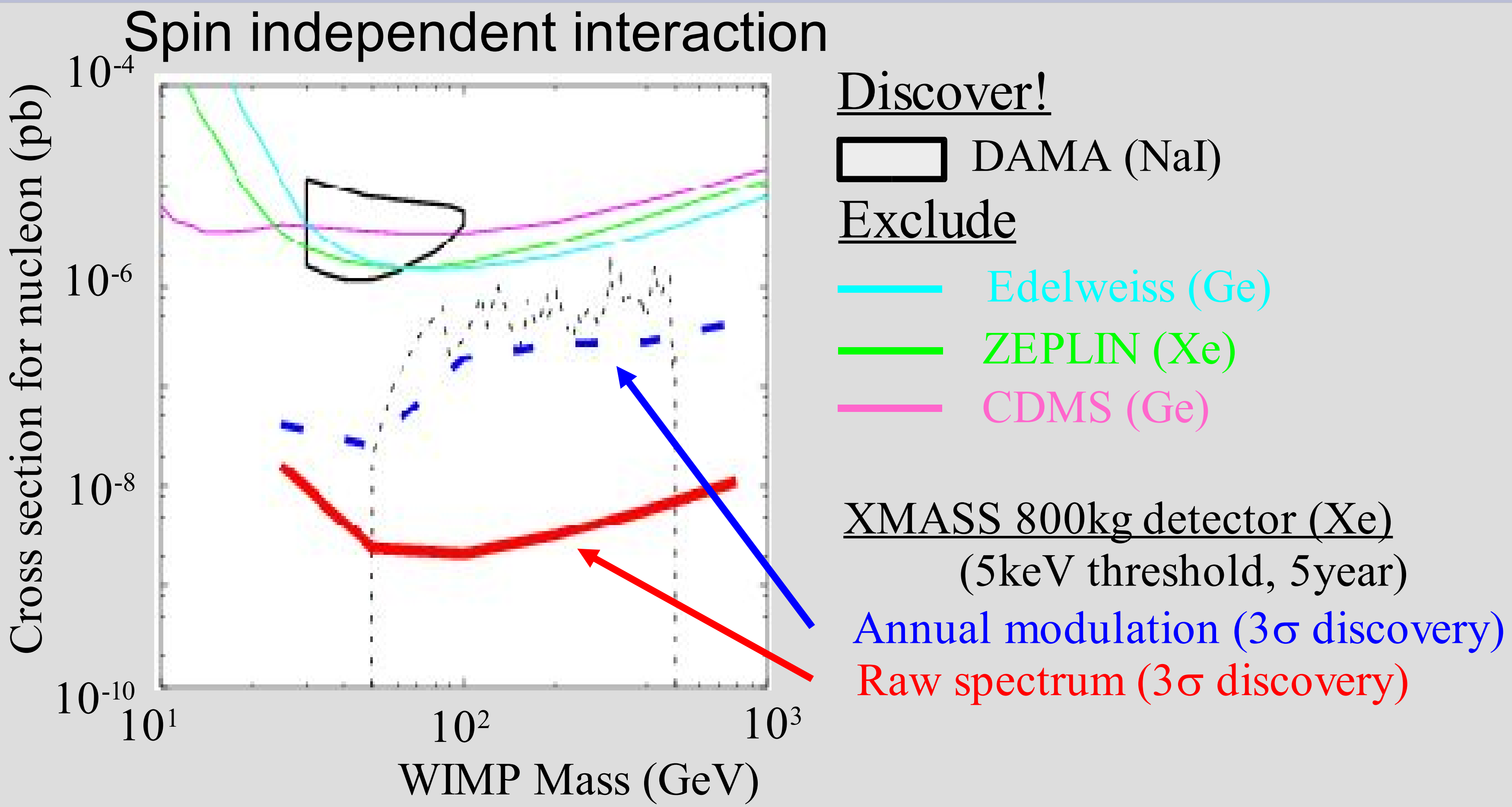
R&D

Now

Dark matter search

Multipurpose detector

- Sensitivity of 800kg detector for DM (SI)



>10^2 improvement of sensitivity for existing experiments

>10^2 improvement of sensitivity for existing experiments

R&D status with 100kg detector

- 100kg liquid Xe detector
  - Liquid Xe in ~30cm cube (30lite

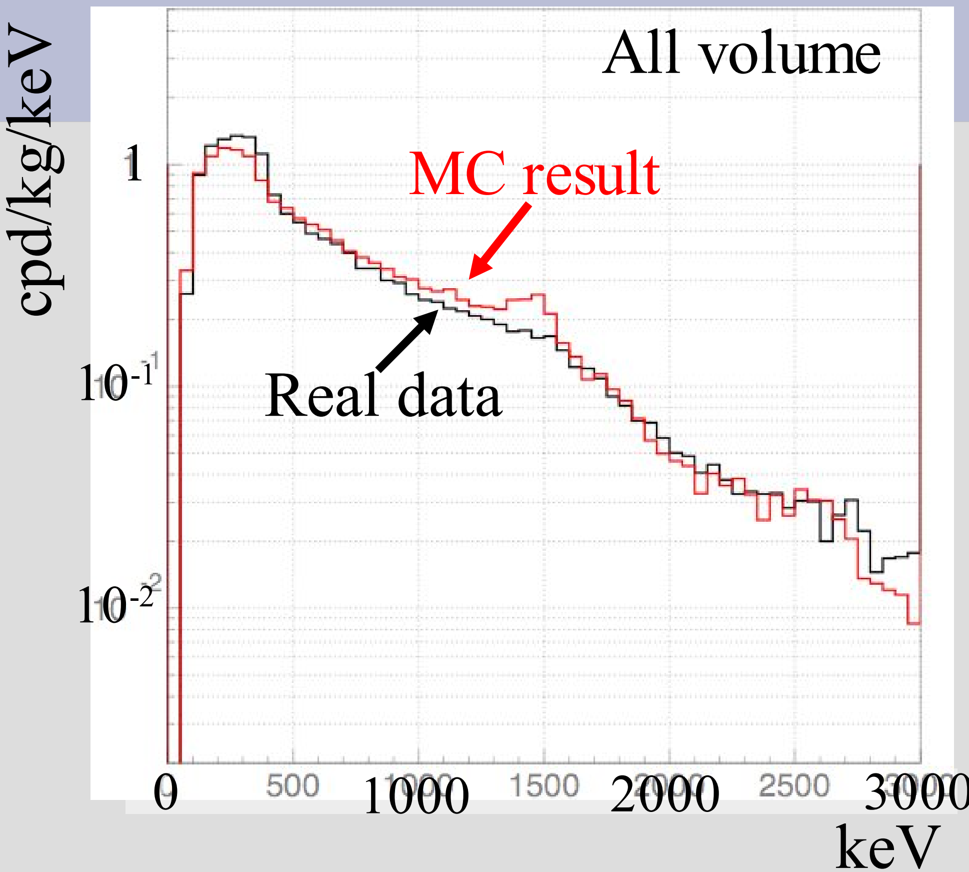
  - High purity copper chamber

- Targets of 100kg detector

☆ Confirmation of 800kg detector performance estimation

  - Reconstruct vertex and energy of events by fitter
  - Demonstrate the self shielding power for γ ray BG
  - Measure photon yield and its attenuation length
  - Understand the environmental BG inside the shield
  - Measure a content of radioactive impurities in Xe

- Compare real data and MC estimation



☆ Real data

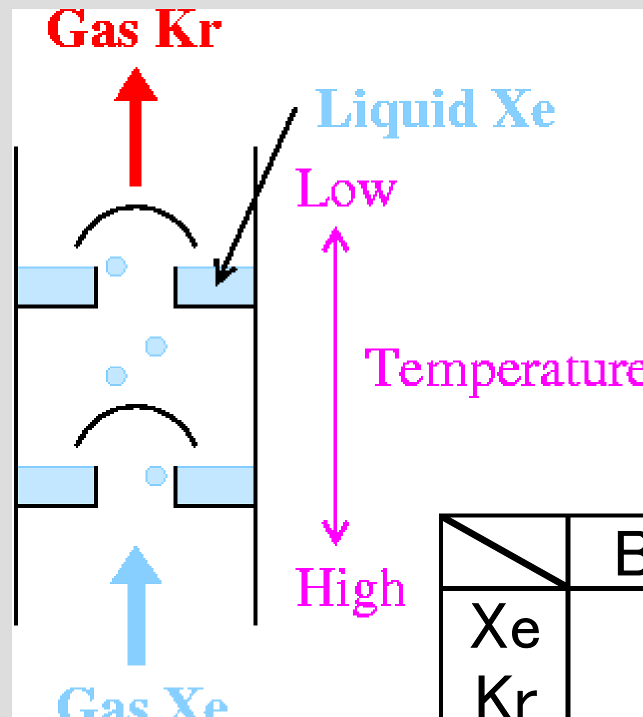
→ Live time ~ 0.9days

☆ MC (γ ray background)

- Outside of the shield
- RI sources in PMTs
- ^{210}Pb in the lead shield

Good agreement!

- Purification of Xe by distillation
  - ☆ Test using 1.6kg Xe in September 2003
  - ☆ XMASS succeeds to reduce Kr concentration in Xe from 310[ppb] to < 5[ppb] with one cycle (~1/100)



	Boiling point
Xe	165K
Kr	120K

→ Full process of 100kg Xe next week!

- Radioactive impurity in Xe

Content of radioactive impurity in Xe

	1 st 100kg run	Target
Kr (ppt)	< 2000 →	0.35
Th−chain (g/g)	$< 8.4 \times 10^{-13}$ →	2.0×10^{-14}
U−chain (g/g)	6.4×10^{-13} →	1.0×10^{-14}

☆ Kr reduction

→ ~2 cycle purification by purification tower

☆ Th-chain, U-chain

→ Target value of 800kg detector is close at hand

→ Identify the source and

remove it by cleaning up and filtering

END

XMASS Project

Sensitivity necessary for the discovery of DM (SI)

- How can one reach as shown in Nihei's talk?

$$\boxed{\sigma^{\mathrm{SI}}_{\chi-\mathrm{n}} \geq 2\times 10^{-12}\,\mathrm{pb}}$$

- Current typical limit with NaI(Tl) – PSA by UK group

$$\frac{\mathrm{d}R}{\mathrm{d}E_{\mathrm{visible}}} \leq 4\times 10^{-1}\,\mathrm{events/kg/day/keV}\,(@\,4-5\,\mathrm{keV})$$

$$\longrightarrow \quad \sigma^{\mathrm{SI}}_{\chi-\mathrm{n}} \leq 2\times 10^{-5}\,\mathrm{pb}\,(@\,M_{\chi}\sim 100\,\mathrm{GeV})$$

Well experienced experimentalist would not say that

- One has to go down to

$$\frac{\mathrm{d}R}{\mathrm{d}E_{\text{visible}}} \le \boxed{4\times 10^{-8}}\,\text{events/kg/day/keV}\,(@\,4-5\,\text{keV})$$

- with 6 p.e. /keV (NaI(Tl))
  5 p.e. /keV (LXe)
- even lower p.e.'s for larger volume detectors

To go further,

- Huge mass conventional detectors never help even with PSA.
- Bolometr background rate is too high.
- Annual modulation effect is too small.
- Innovation needed
- Direction sensitive (and, hopefully, SD-sensitive) detector
- Self-shielding ultra pure material(e.g. LXe)