「宇宙核物理実験の現状と将来」研究会@RCNP 2014年8月7日

ダークマターの直接探索実験の現状

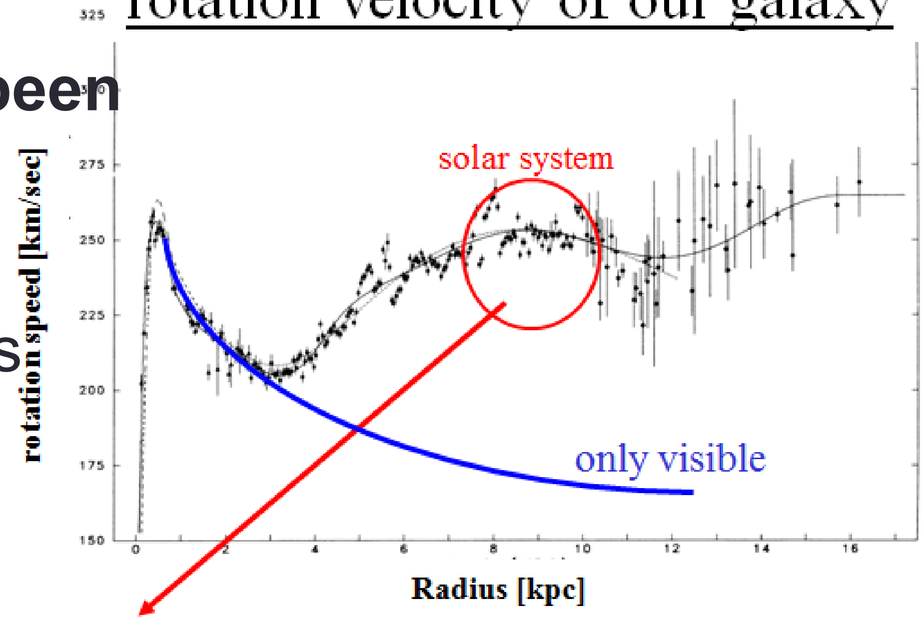
大阪産業大学　　　　　　　硲　隆太

Based on 極低バックグラウンド素粒子原子核研究懇談会@富山2013/4/23
SNOWMASS 2013@Mississippi 2013/7/29~8/6
http://www.lowbg.org
http://www.snowmass213.org
arXiv: 1310.8327[hep-ex]CF1 Summary: WIMP Dark Matter Direct Detection
Symposium on Search for Dark Matter @UCLA, USA Feb/2014
http://www.pa.ucla.edu/sites/default/files/webform/

DARK MATTER

- Dark matter has **already been discovered** through
  - Galaxy clusters
  - Galactic rotation curves
  - Lensing
  - Hot gas in clusters
  - CMB
  - etc

rotation velocity of our galaxy



$v_{solor} \approx 220\ km/\sec$

$$v = \sqrt{\frac{GM(r)}{r}}$$

local halo density

$$\rho_{halo} = \rho_{total} - \rho_{visible}$$

$$\approx 0.3GeV/cm^3$$

背景ニュートリノ（現在の制限<0.23eV/c^2 (CMB)）

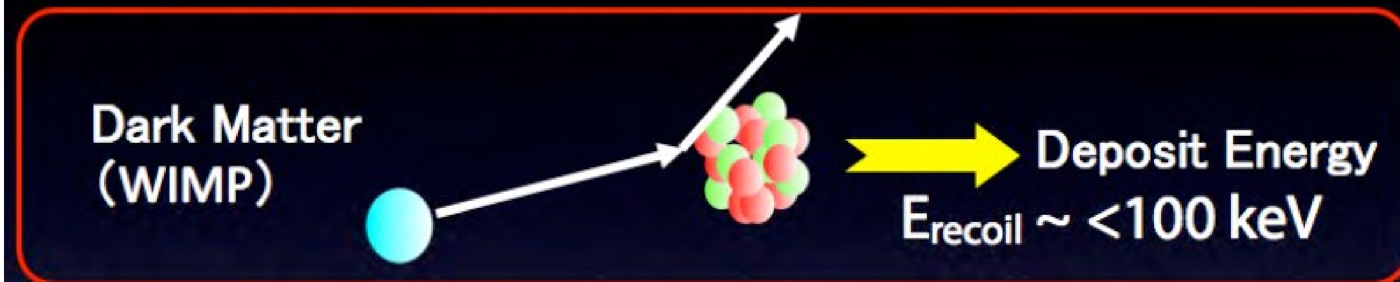
⇒銀河の脱出速度630km/secを越えてしまう

- We are entering the **decade of dark matter identification**

速度が遅いdark matterが必要　⇒Cold Dark Matter

Direct Detection Principle

WIMPs elastically scatter off nuclei in targets, producing nuclear recoils.



$$\chi + N \rightarrow \chi + N$$

For example, assuming

$M_W = 100$ GeV/c2 , $M_T = 100$ GeV/c2 , r = 1

WIMP velocity: $v \sim 0.75 \times 10^{-3}$ = 220 km/sec

$$E_R = \frac{1}{2} M_W \beta^2 c^2$$
$$= 1/2 \times 100 \times \mathrm{GeV}/c^2 \, (0.75 \times 10^{-3})\, c^2$$
$$= 30 \text{ keV}$$

Masaki Yamashita

Direct Dark Matter Search in the World

激しい国際競争（実験規模 数億円以下）

Masaki Yamashita

MOORE'S LAW FOR DARK MATTER

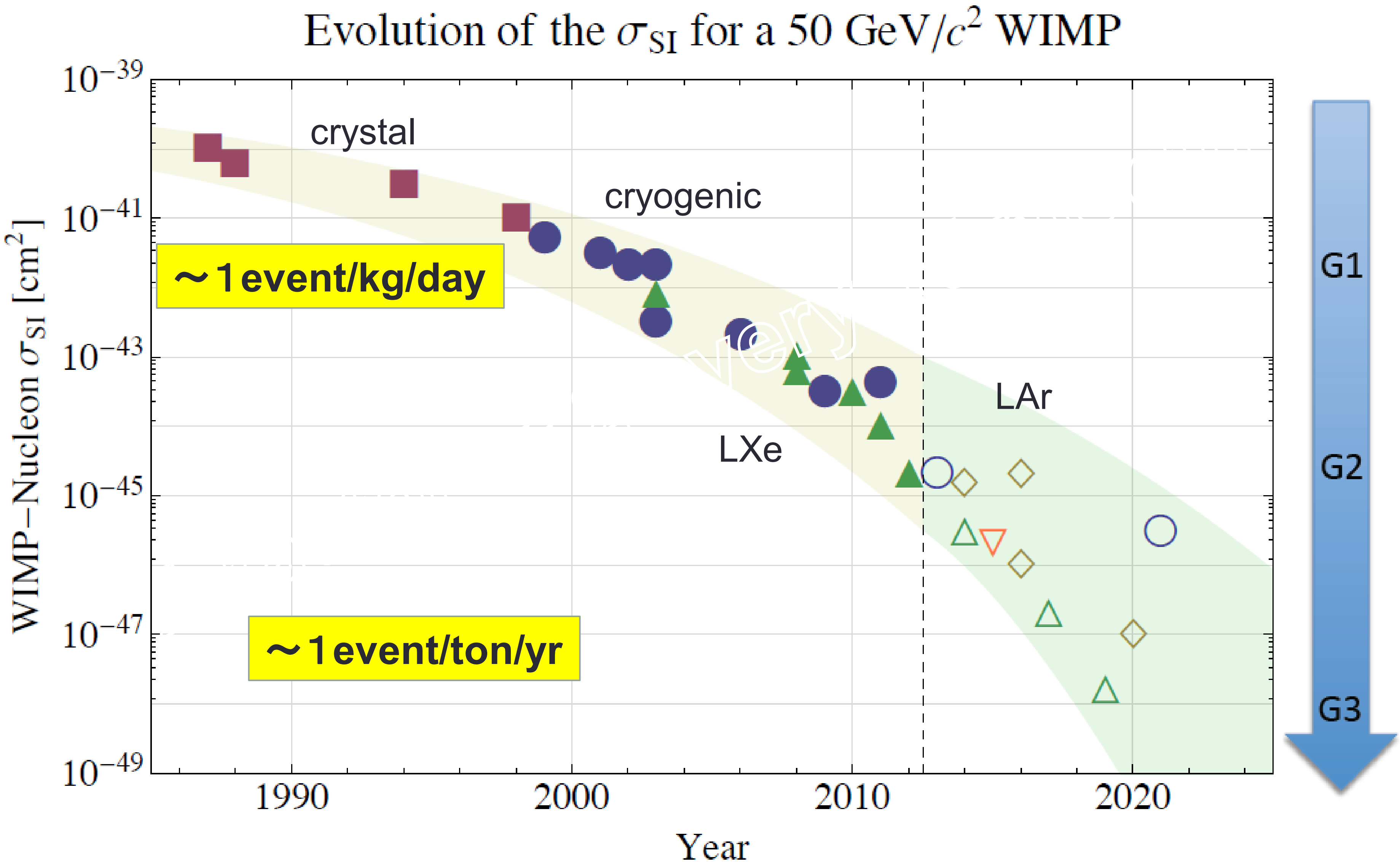
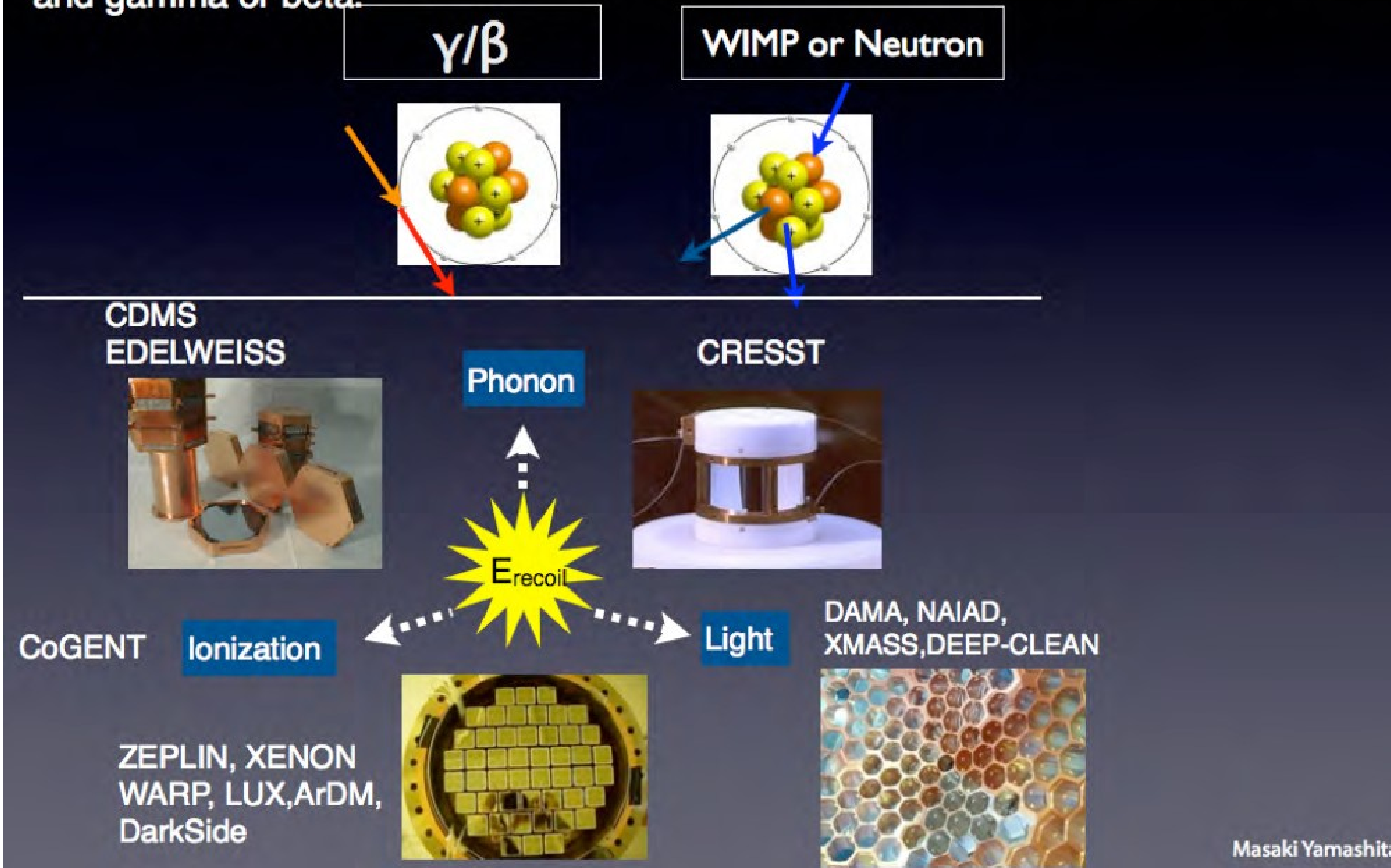


Figure 16 History and projected evolution with time of spin-independent WIMP-nucleon cross section limits for a 50 GeV WIMP. The colors correspond to technologies: cryogenic solid state (blue), crystal detectors (purple), liquid argon (brown), liquid xenon (green) and threshold detectors (orange). The band gives a rough idea of the difference in projected versus actual results, due mainly to unexpected backgrounds and delays in achieving sensitivities.

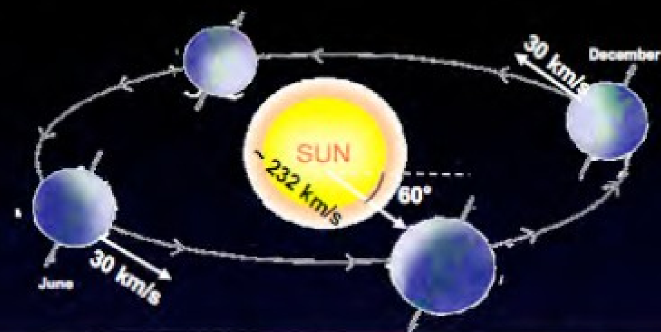
Techniques for Detector

Various Targets: Ge, Xe, Ar, Ne and so on.
Two Signals are used to particle identification to distinguish btw Nuclear Recoil and gamma or beta.



DAMA/LIBRA in Gran Sasso

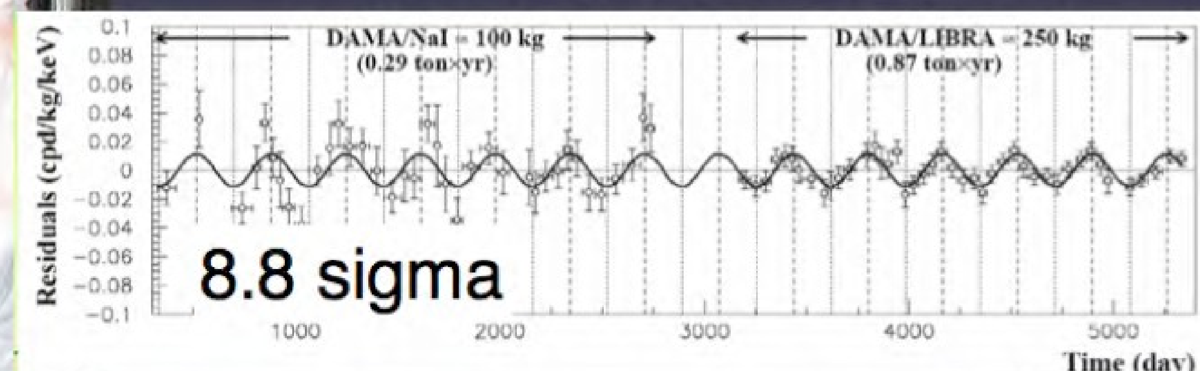
- DAMA(~100 kg) + LIBRA (~250 kg) of NaI
- Annual Modulation 8.8σ (DAMA 7 yrs + LIBRA 4yrs -> 1.17ton x yr)
- Muon rate in Gran Sasso ?(arXiv:1202.4179v2)
  phase is different.
- Other experiment can do same thing ?
  Especially by NaI ? (->DM-ICE program)



- v_{sun} ~ 232 km/s (Sun velocity in the halo)
- v_{orb} = 30 km/s (Earth velocity around the Sun)
- $\gamma = \pi/3$
- $\omega = 2\pi/T$ T = 1 year
- t_0 = 2^{nd} June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb}\cos\gamma\cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k}\cos[\omega(t-t_0)]$$



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他のグループによる検証は？

- NaI(Tl)を作る会社が少なくなった
  - BICRON
  - HARSHOW

  → Saint Gobain → DAMA/LIBRA

  - Horiba　　I.S.C.Lab. → PICO-LON

- Fragmented set-up
- etc.

ULB NaI(Tl) also allows the study of several rare processes

High benefits/cost

To develop ULB NaI(Tl): many years of work, specific experience in the specific detector, suitable raw materials selections, developments of purification strategies and of growing/handling protocols, long dedicated time and efforts, etc. etc. The developments themselves are difficult and uncertain experiments.

ULB NaI(Tl) – as whatever ULB detector - cannot be simply bought or made by another researcher for you …

Northern Hemisphere	Gran Sasso **DAMA/Libra** 250kg running	Gran Sasso **Princeton-NaI** R&D	Canfranc **ANAIS** 250 kg starting in 2014?	**PICO-LON** **KIMS** etc...
Southern Hemisphere	South Pole **DM-Ice** 17 kg running R&D for 250 kg	**ANDES** Lab (proposed) expected start ~~2018~~ 2017		

Concept of PICO-LON detector

ice rock

under development

Several Groups conducting ultra-pure crystal with several vendors to go to the full scale

Manufacturer	Form	Measurement	^{238}U (ppt)	^{232}Th (ppt)	^{nat}K (ppb)
Saint Gobain	Powder	DAMA (HPGe)	< 20	< 20	< 100
Saint Gobain	Crystal	DAMA/LIBRA	0.7 - 10	0.5 - 7.5	< 20
Saint Gobain	Crystal	ANAIS-0	6.1	3.2	410
Bicron/Saint Gobain	Crystal	NaIAD/DM-Ice	20*	20*	650*
Sigma-Aldrich	Powder (standard grade)	DM-Ice (HPGe)	40	89	440
Sigma-Aldrich	Powder (astro grade)	DM-Ice (HPGe)	63	< 95	< 126
Sigma-Aldrich	Powder (astro grade)	A-S (ICPMS)	-	-	~ 4
Alpha-Spectra	Powder	DM-Ice (HPGe)	< 100	< 200	< 120
Alpha-Spectra	Powder	ANAIS-25 (HPGe)	< 55	< 130	< 90

*preliminary

PICO-LON for WIMPs search

- Planar
- Inorganic
- Crystal
- Observatory for
- LOw-background
- Neutr(al)ino

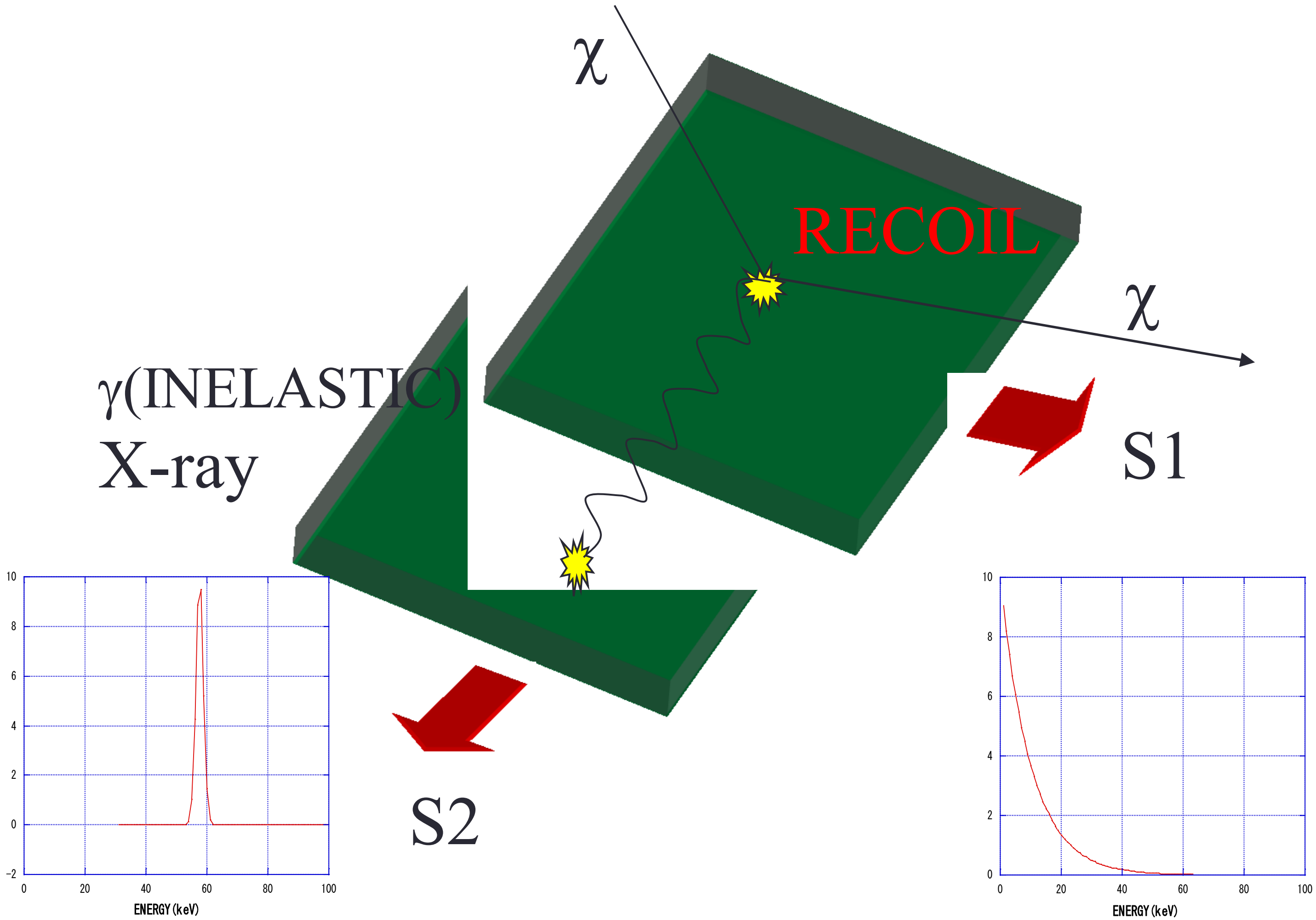
- High selectivity
- Background reduction

- Sensitive to
- Elastic scattering (SI+SD)
- Inelastic scattering (SD)

- Study the interaction type of WIMPs

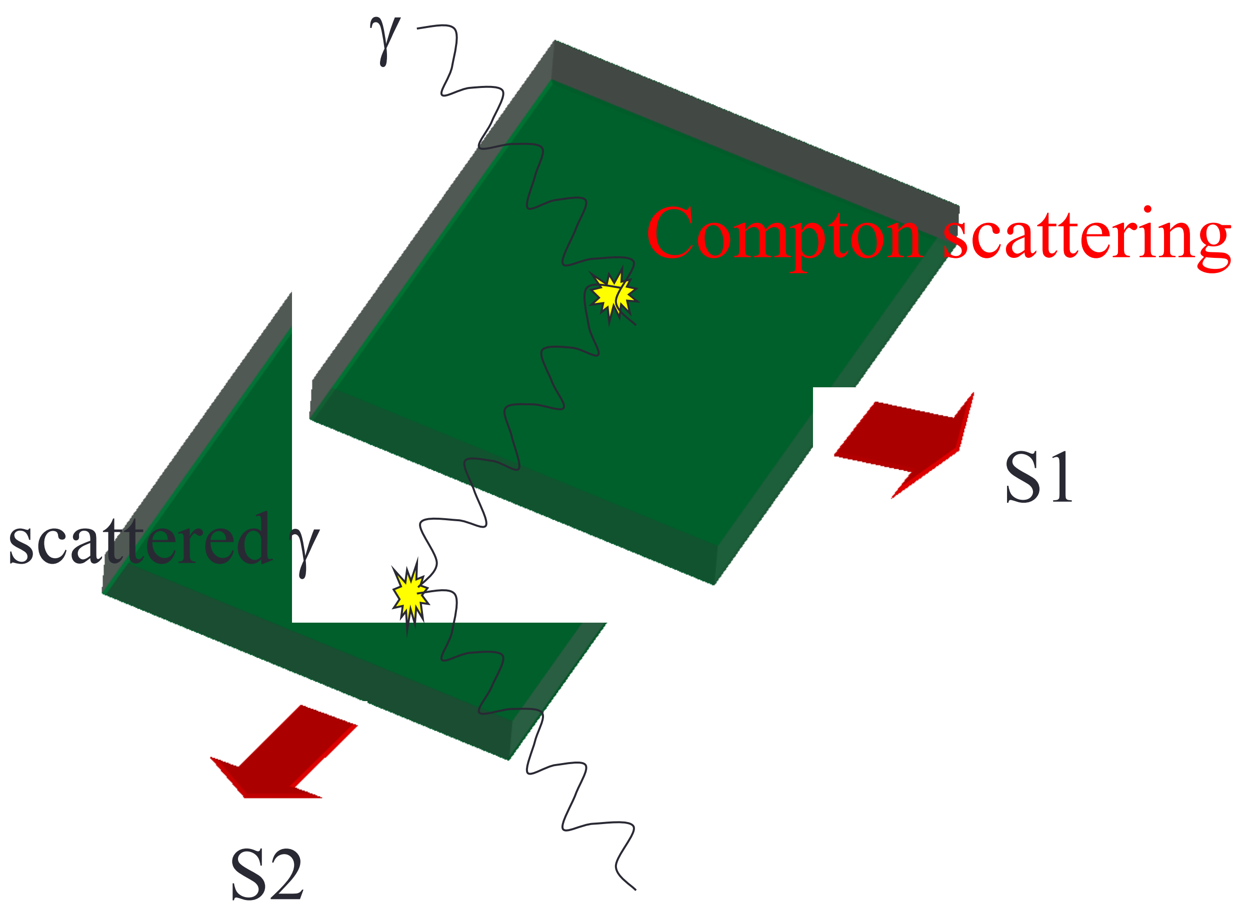
徳島大学
伏見賢一

Concept of PICO-LON detector



伏見賢一

Background reduction



Segmented detector → Remove Compton scattering

PICO-LONの基本思想

- ^{127}I γ線を隣り合う結晶で検出
  - NaI(Tl)結晶の厚さ ＜ 0.1 cm
- 低エネルギー閾値
  - 検出感度を上げるのに重要
- 高エネルギー分解能
  - 同時測定のためにバックグラウンドを識別
  - ^{210}Pbの46.5 keVを避ける
- 大容量
  - 検出感度を上げるのに重要
  - 大面積の結晶 10 cm 角 ~ 18 cm 角
  - たくさん積み上げられる

$E_{ee} < 5\mathrm{keV}$

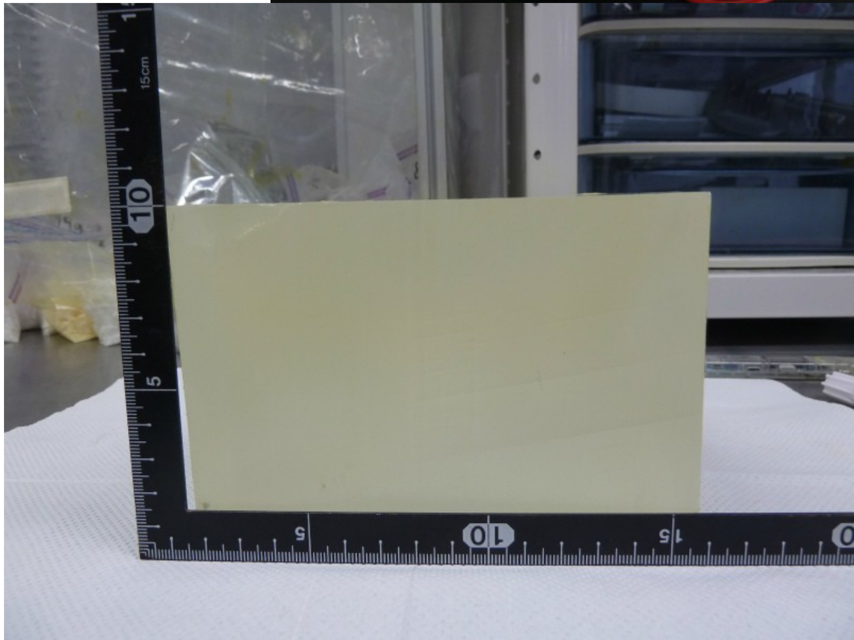
$\Delta E_{ee} = 12\mathrm{keV}$

ΔE/E=15% at 80keV

R&D for pure NaI(Tl) production

- I.S.C. Lab.により開発
- 坩堝の選別
- NaI(Tl)原料の選別と純化
- 周辺環境の整備

- 3.0”ϕX3.0” NaI(Tl)
- Improvement step by step



Present result

	DAMA	DM-Ice	Ingot 23	Goal of PICO-LON
^{nat}K (ppb)	<20	660	Not yet	<20
^{232}Th(ppt)	0.5-0.7	2.5	3.3±2.0	<1
^{238}U(ppt)	0.7-10	1.4	5.4±0.9	<1
^{210}Pb (μBq/kg)	5-30	1470	58±26	<100

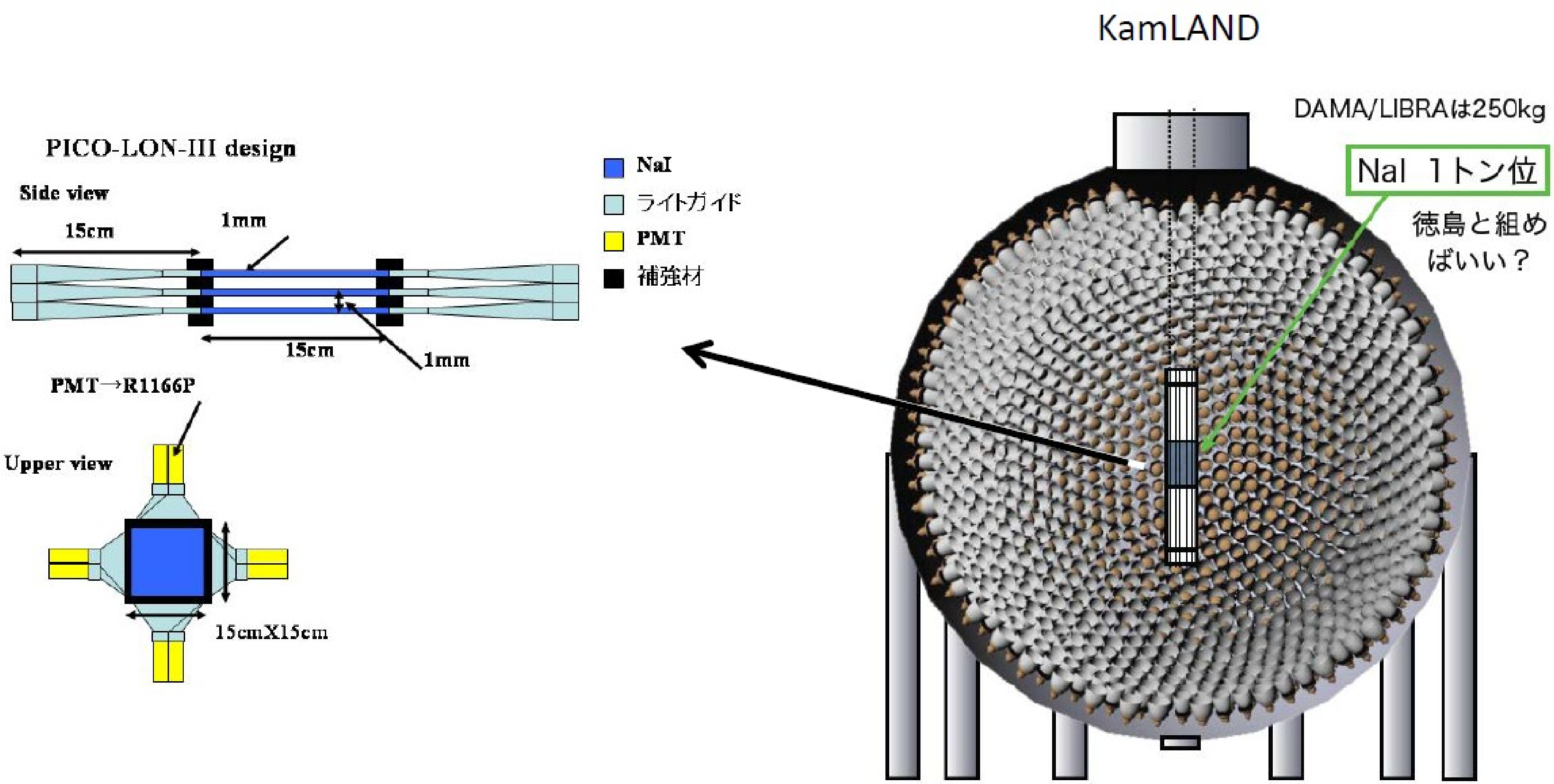
- U-chain: 1ppt= 12.3μBq/kg
- Th-chain: 1ppt= 4.0μBq/kg
- ^{210}Pb: 1ppt=2.5kBq/kg

高感度NaI(Tl)検出器開発の現状

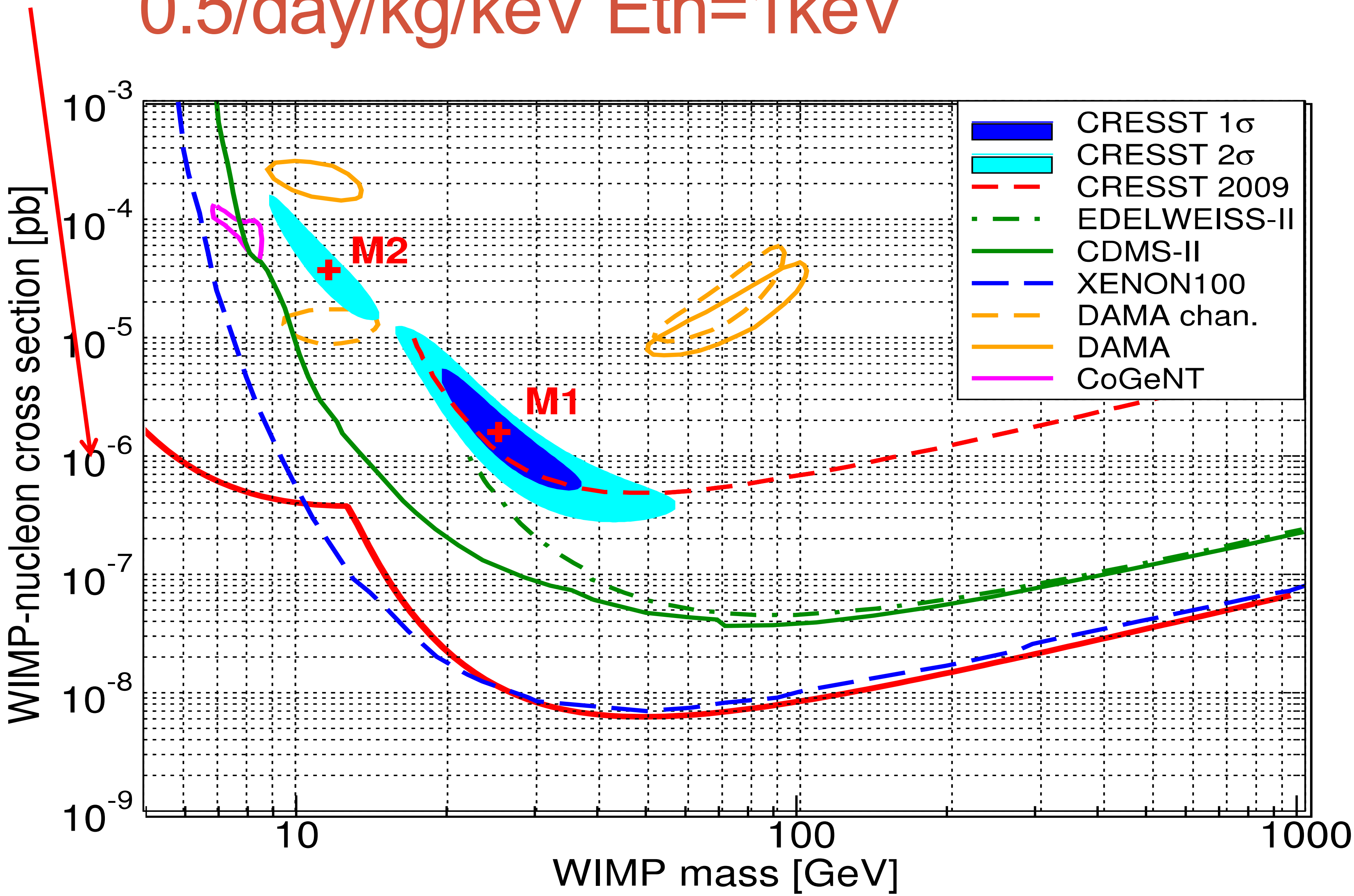
- 低エネルギー閾値
  - 2 keV electron equivalent.
- 結晶の高純度化
  - R&D 進行中
  - ^{210}Pb → DAMA/LIBRAと同等になった
  - ^{40}K 現在神岡で測定中

KamLAND-PICOの将来計画

- Install PICO-LON detector into KamLAND
- KamLAND is an ideal active shield.



Expected sensitivity (Elastic, 1ton*yr) 0.5/day/kg/keV Eth=1keV



宇宙の歴史をひもとく地下素粒子原子核研究

- 新学術領域研究　H26年度採択
- 二重ベータ崩壊
  - 2～4 MeVの領域で低バックグラウンド環境を達成する
- 宇宙暗黒物質探索
  - 10 keV　以下の領域で低バックグラウンド環境を達成する
- 探すもの、エネルギー領域が異なるが技術は同じ
  - 情報を共有するコミュニティの形成