暗黒物質探索の国際情勢

2013/04/23

極低バックグラウンド素粒子原子核研究懇談会

東京大学宇宙線研神岡宇宙素粒子施設

山下雅樹

Masaki Yamashita

暗黒物質探索の国際情勢

超 @Y. Suzuki はじめに

2013/04/23

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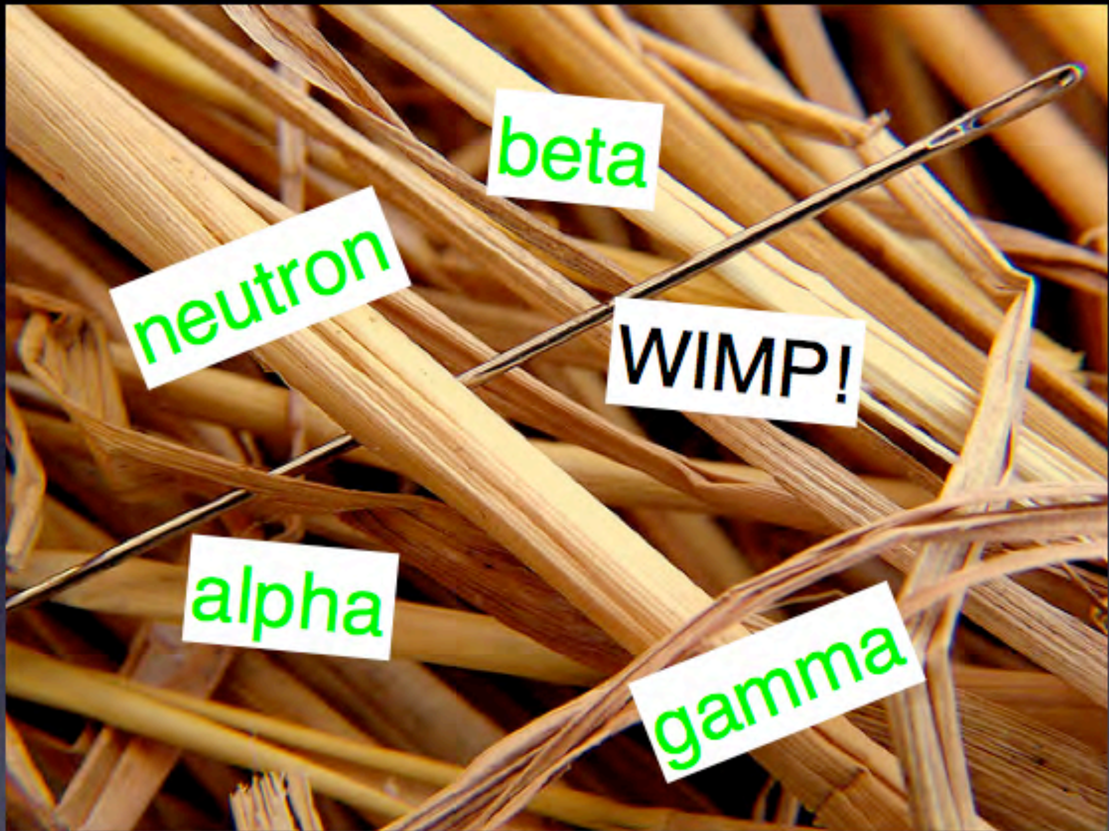
山下雅樹

暗黒物質探索ものがたり (まさに干し草の中の針)



シールド無し　10^6 counts/day

↓

WIMP event　$<10^{-4}$ counts/day

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暗黒物質探索ものがたり
(まさに干し草の中の針)

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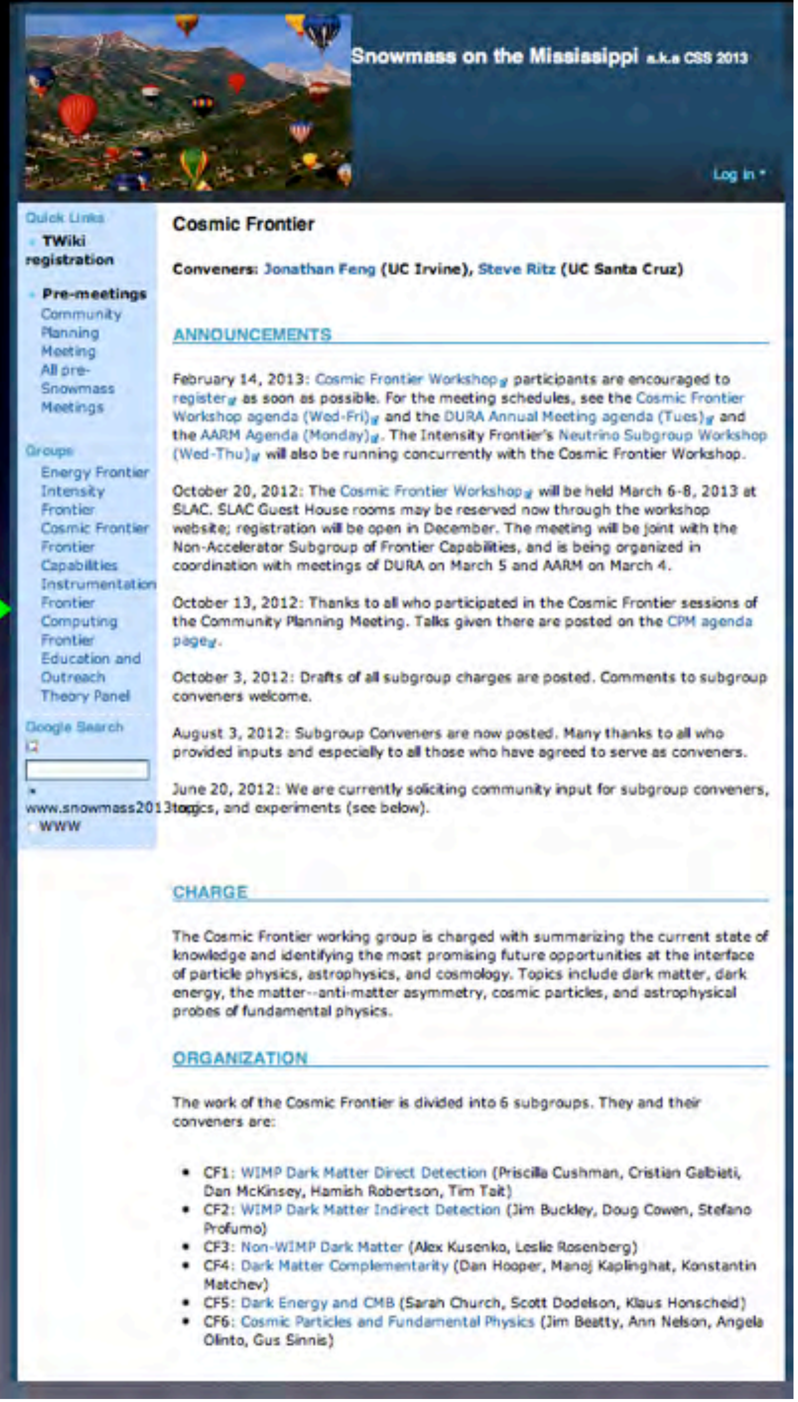
暗黒物質探索ものがたり (まさに干し草の中の針)

暗黒物質探索ものがたり
(まさに干し草の中の針)

Outline

- 暗黒物質直接探索
- 直接探索のこれまで(日本以外)
- 世界の動き

最新の情報がsnowmass2013のページから得られる
http://www.snowmass2013.org/tiki-index.php?page=SLAC


Snowmass on the Mississippi a.k.a CSS 2013
Log in

Quick Links
TWiki registration
Pre-meetings
Community Planning Meeting
All pre-Snowmass Meetings
Groups
Energy Frontier
Intensity Frontier
Cosmic Frontier
Frontier Capabilities
Instrumentation Frontier
Computing Frontier
Education and Outreach
Theory Panel
Google Search
www.snowmass2013.org
WWW

Cosmic Frontier

Conveners: Jonathan Feng (UC Irvine), Steve Ritz (UC Santa Cruz)

ANNOUNCEMENTS

February 14, 2013: Cosmic Frontier Workshop participants are encouraged to register as soon as possible. For the meeting schedules, see the Cosmic Frontier Workshop agenda (Wed-Fri) and the DURA Annual Meeting agenda (Tues) and the AARM Agenda (Monday). The Intensity Frontier's Neutrino Subgroup Workshop (Wed-Thu) will also be running concurrently with the Cosmic Frontier Workshop.

October 20, 2012: The Cosmic Frontier Workshop will be held March 6-8, 2013 at SLAC. SLAC Guest House rooms may be reserved now through the workshop website; registration will be open in December. The meeting will be joint with the Non-Accelerator Subgroup of Frontier Capabilities, and is being organized in coordination with meetings of DURA on March 5 and AARM on March 4.

October 13, 2012: Thanks to all who participated in the Cosmic Frontier sessions of the Community Planning Meeting. Talks given there are posted on the CPM agenda page.

October 3, 2012: Drafts of all subgroup charges are posted. Comments to subgroup conveners welcome.

August 3, 2012: Subgroup Conveners are now posted. Many thanks to all who provided inputs and especially to all those who have agreed to serve as conveners.

June 20, 2012: We are currently soliciting community input for subgroup conveners, topics, and experiments (see below).

CHARGE

The Cosmic Frontier working group is charged with summarizing the current state of knowledge and identifying the most promising future opportunities at the interface of particle physics, astrophysics, and cosmology. Topics include dark matter, dark energy, the matter--anti-matter asymmetry, cosmic particles, and astrophysical probes of fundamental physics.

ORGANIZATION

The work of the Cosmic Frontier is divided into 6 subgroups. They and their conveners are:

- CF1: WIMP Dark Matter Direct Detection (Priscilla Cushman, Cristian Galbiati, Dan McKinsey, Hamish Robertson, Tim Tait)
- CF2: WIMP Dark Matter Indirect Detection (Jim Buckley, Doug Cowen, Stefano Profumo)
- CF3: Non-WIMP Dark Matter (Alex Kusenko, Leslie Rosenberg)
- CF4: Dark Matter Complementarity (Dan Hooper, Manoj Kaplinghat, Konstantin Matchev)
- CF5: Dark Energy and CMB (Sarah Church, Scott Dodelson, Klaus Honscheid)
- CF6: Cosmic Particles and Fundamental Physics (Jim Beatty, Ann Nelson, Angela Olinto, Gus Sinnis)

質問事項

1. Experiment Status and Target Mass
2. Fiducial target mass
3. Backgrounds after passive and active Shielding
4. Detector Discrimination
5. Energy Threshold
6. Sensitivity versus WIMP mass
7. Experimental Challenges
8. Annual Modulation
9. Unique Capabilities
10. Determining WIMP properties and astrophysical parameters

暗黒物質直接探索について

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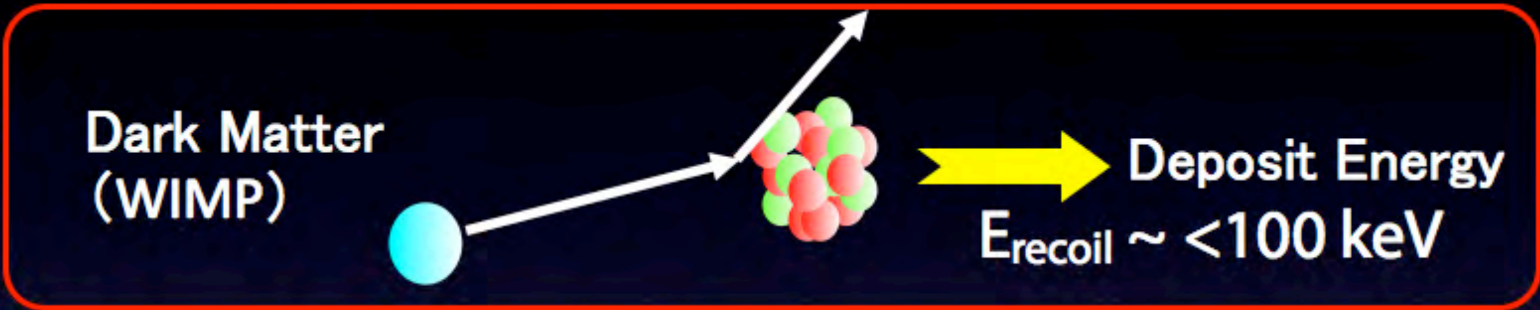
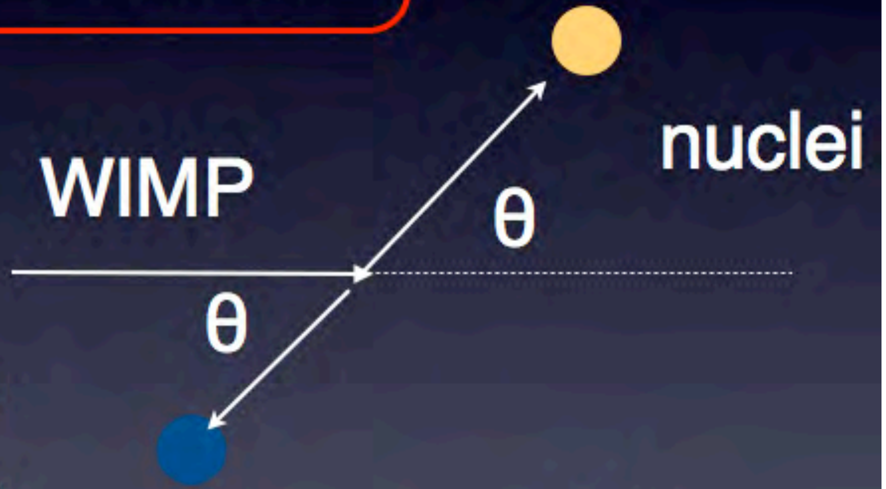
Direct Detection Principle

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



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



For example, assuming

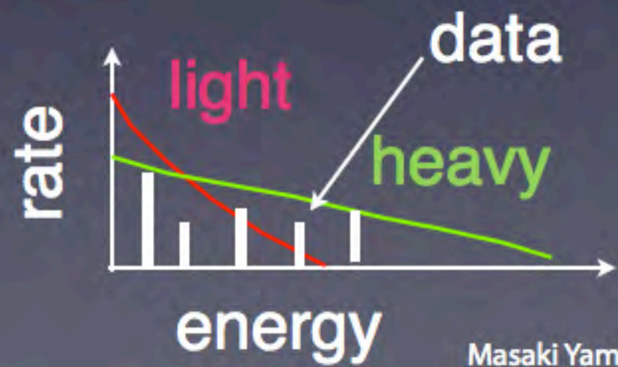
M_W = 100 GeV/c2 , M_T = 100 GeV/c2 , r = 1

WIMP velocity: v~ 0.75 X 10^{-3} = 220 km/sec

$$E_R = \frac{1}{2} M_W \beta^2 c^2$$

$$= 1/2 \times 100 \times GeV/c^2 \, (0.75 \times 10^{-3}) \, c^2$$

$$= 30 \text{ keV}$$



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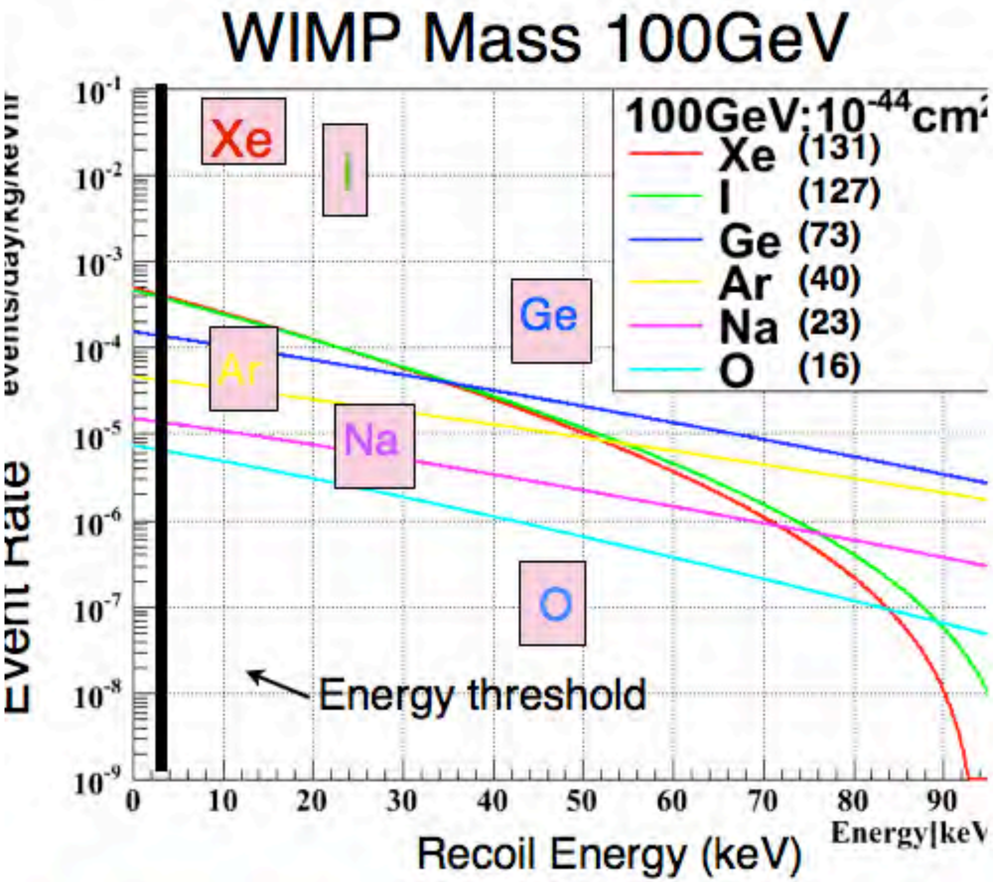
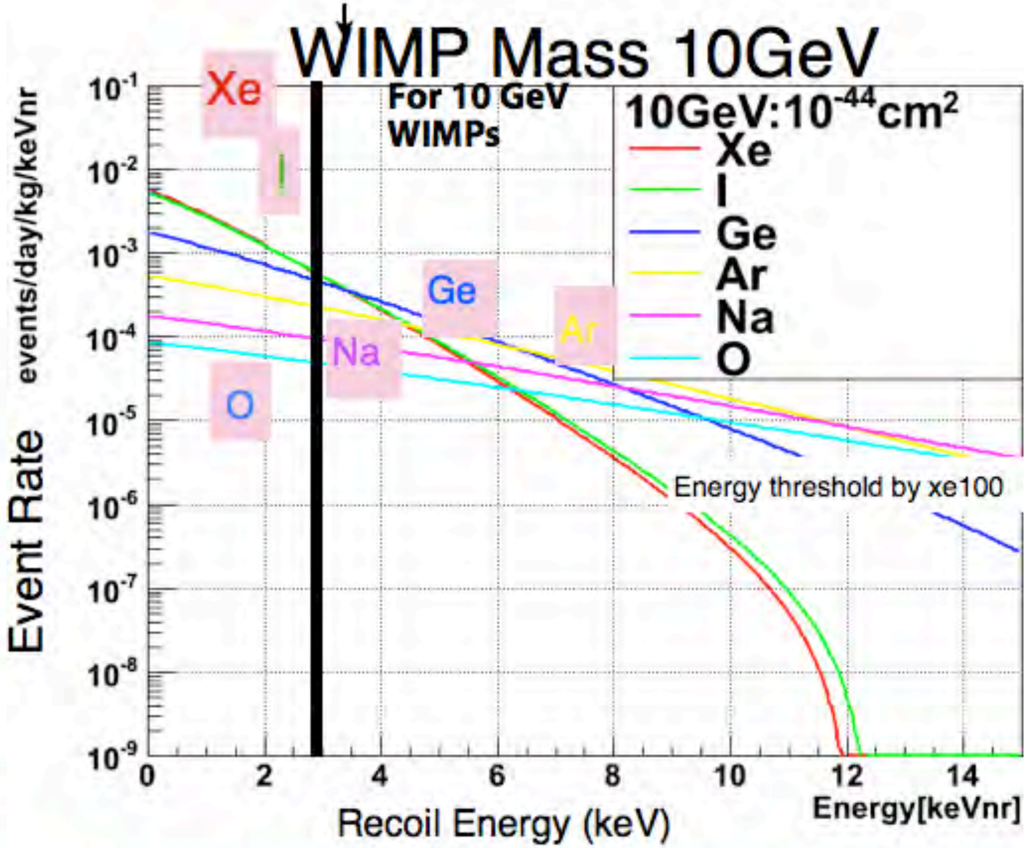
Energy spectrum (spin independent)

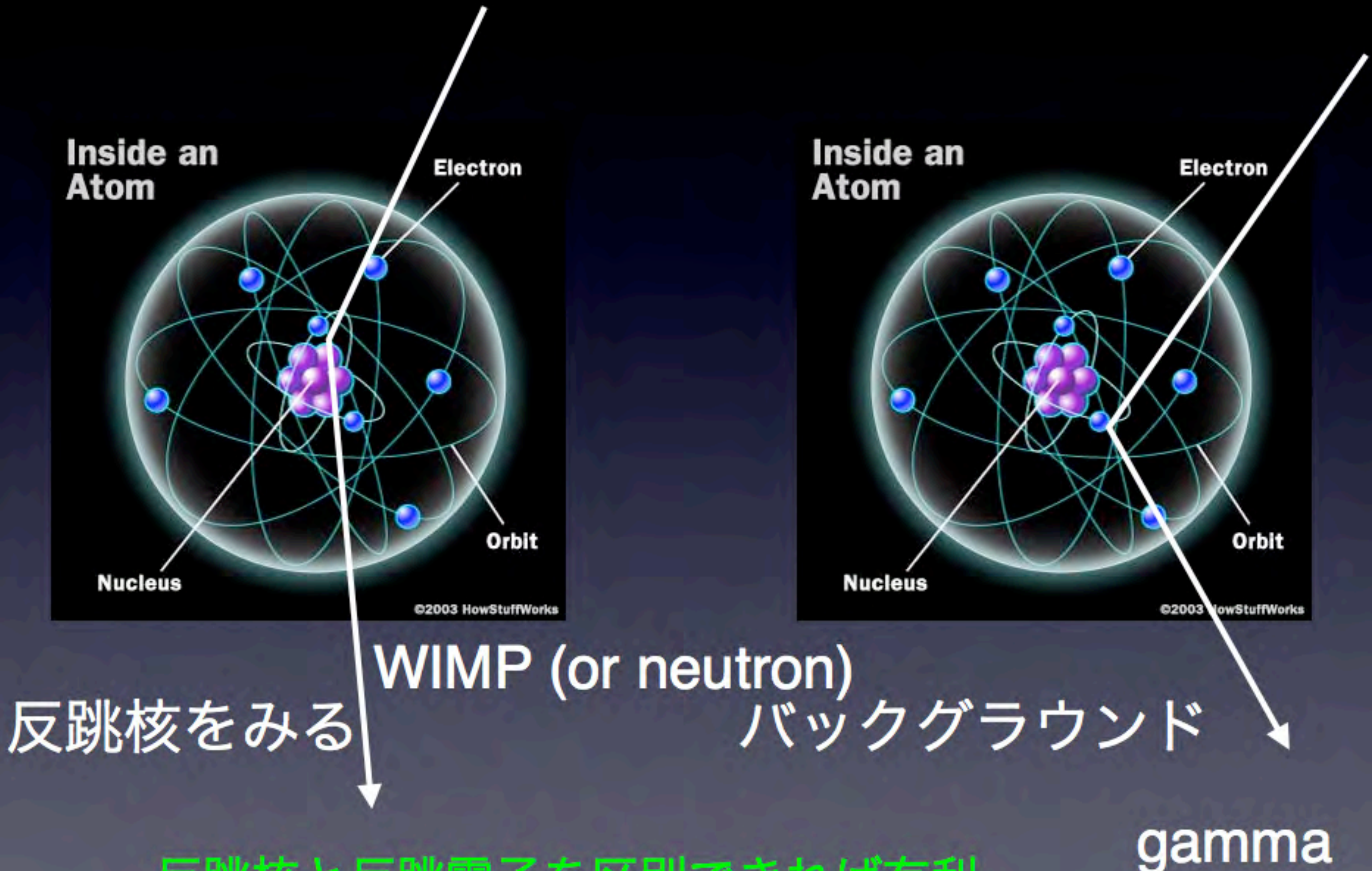


Detector mass is important. (> 100 kg)



Energy threshold is very important.

検出原理



反跳核と反跳電子を区別できれば有利。

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考えられる暗黒物質探索へのアプローチ

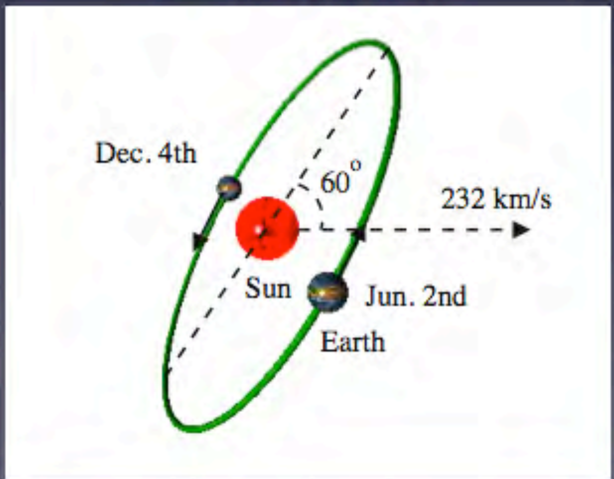
暗黒物質の

- エネルギースペクトルを見る。 ->バックグランドの理解が重要
- 季節変動を見る 夏と冬で数~数十%の違い(大統計)
- ターゲット（核種）による違いを見る。 核種で数倍の違い(質量数 Aの違い)
(複数の実験またはターゲットの入れ替え)
- 到来方向を見る (NEWAGE,NITなど) 非対称１０倍

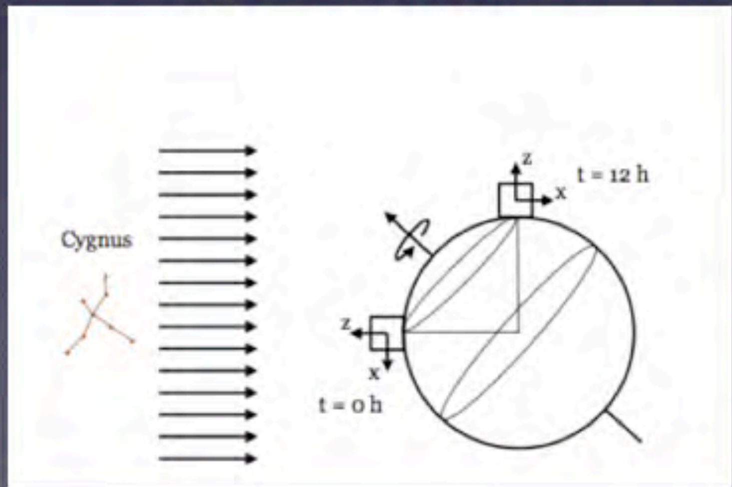
将来（チャレンジ）

#時間の都合上、方向に感度のある探索がカバーされていない。すいません。

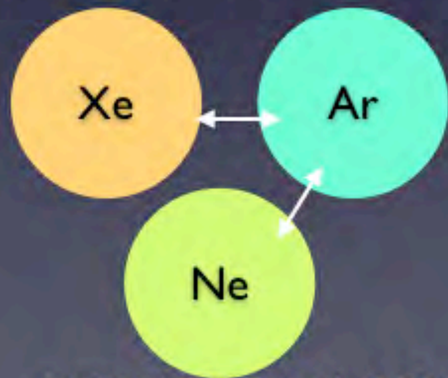
季節変動



方向を見る



ターゲットを替える



DEAP-CLEAN, MAX..

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これまでの実験

Direct Dark Matter Search in the World

激しい国際競争（実験規模 数億円以下）

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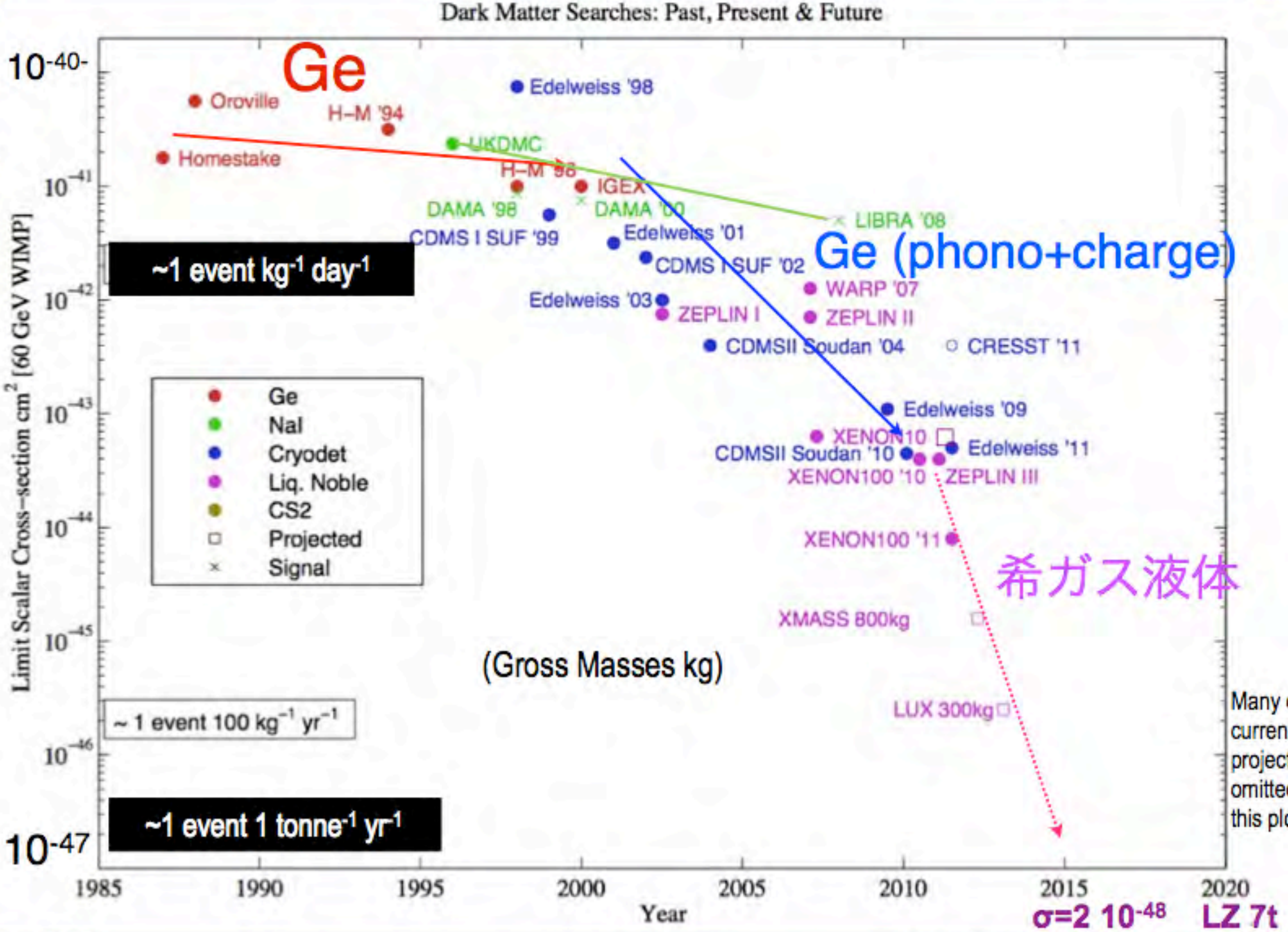
歴史 DM Direct Search Progress Over Time (2012)

Plot does not track low mass WIMPs 10 GeV



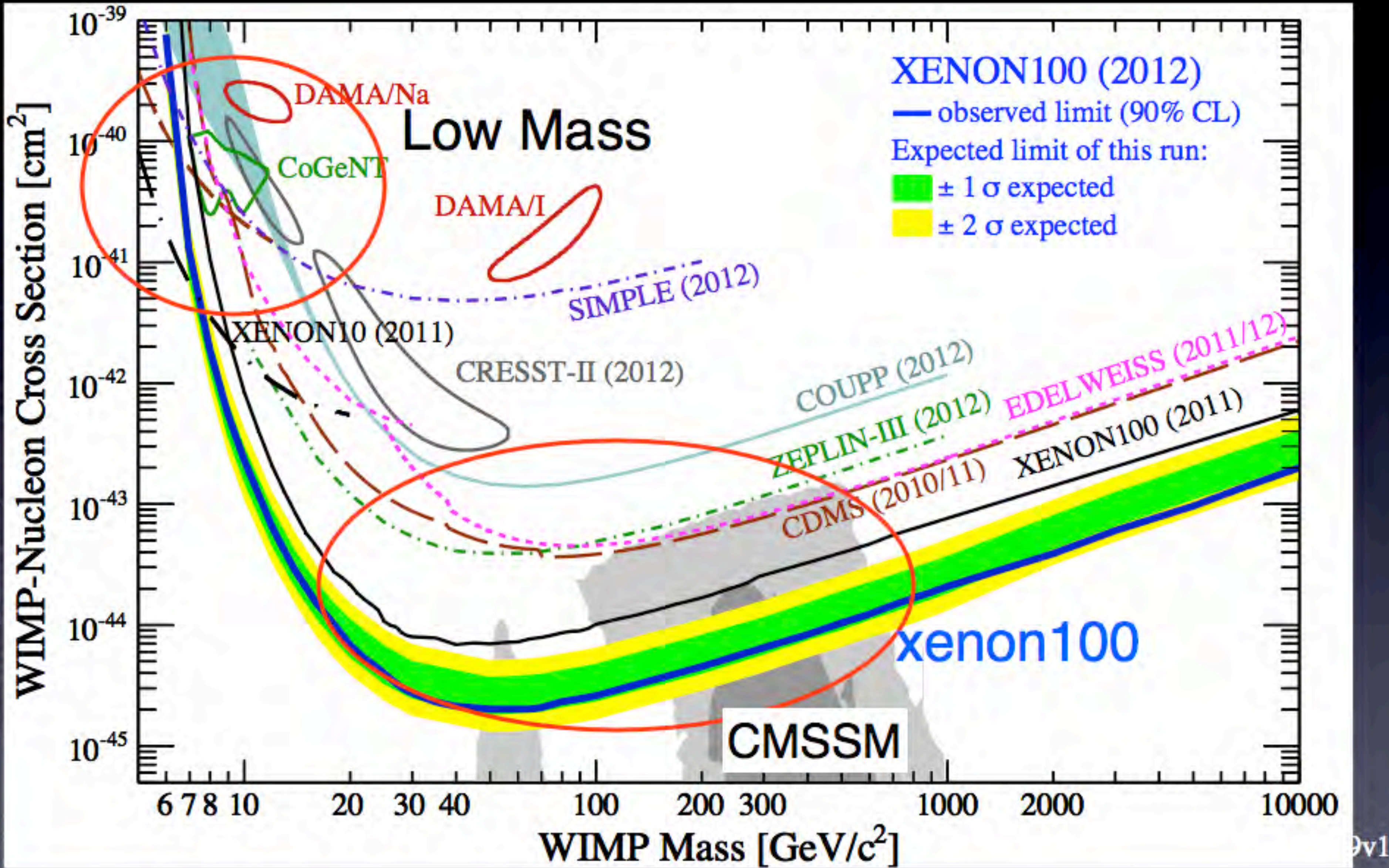
Many of current projections omitted from this plot

Dark Matter, Sept 2007

Rick Gaitskell, Brown University, DOE

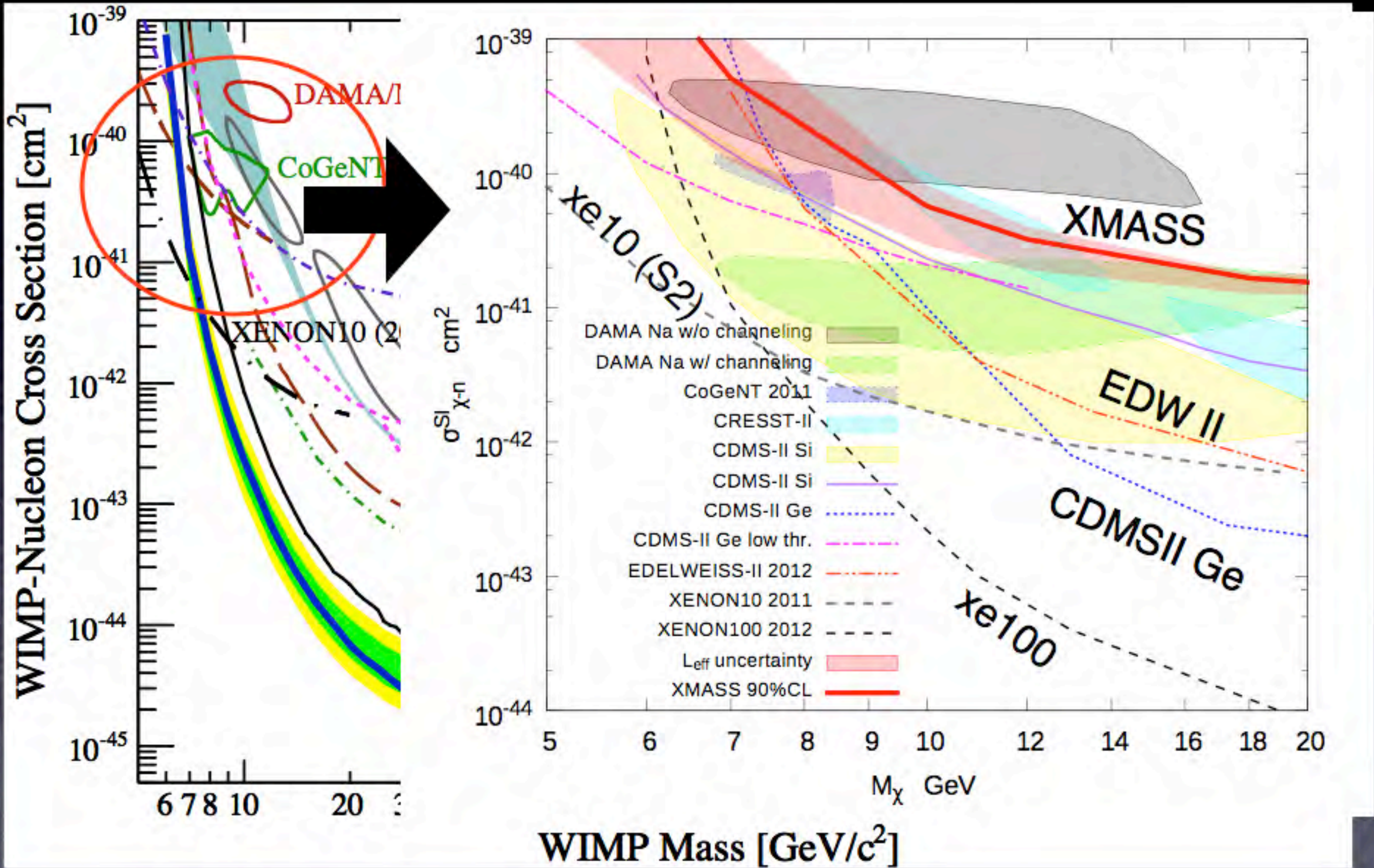
Masaki Yamashita

現状



Masaki Yamashita, ICRR, Univ of Tokyo

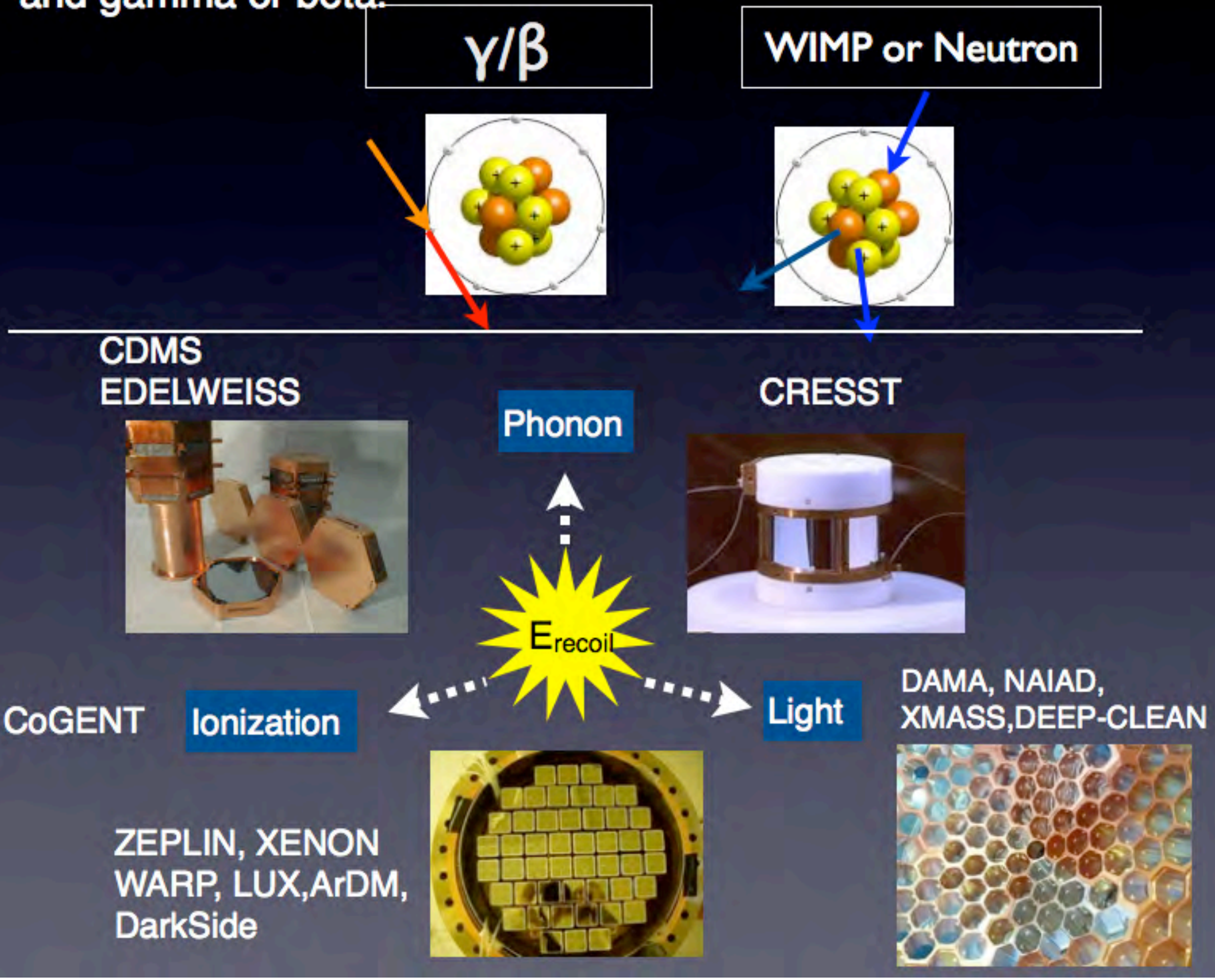
現状



DAMA/I
CoGeNT
XENON10 (2
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
XMASS
EDW II
CDMSII Ge
xe10 (S2)
xe100
DAMA Na w/o channeling
DAMA Na w/ channeling
CoGeNT 2011
CRESST-II
CDMS-II Si
CDMS-II Si
CDMS-II Ge
CDMS-II Ge low thr.
EDELWEISS-II 2012
XENON10 2011
XENON100 2012
L_{eff} uncertainty
XMASS 90%CL
$\sigma^{SI}_{\chi-n}$ cm^2
M_χ GeV

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.



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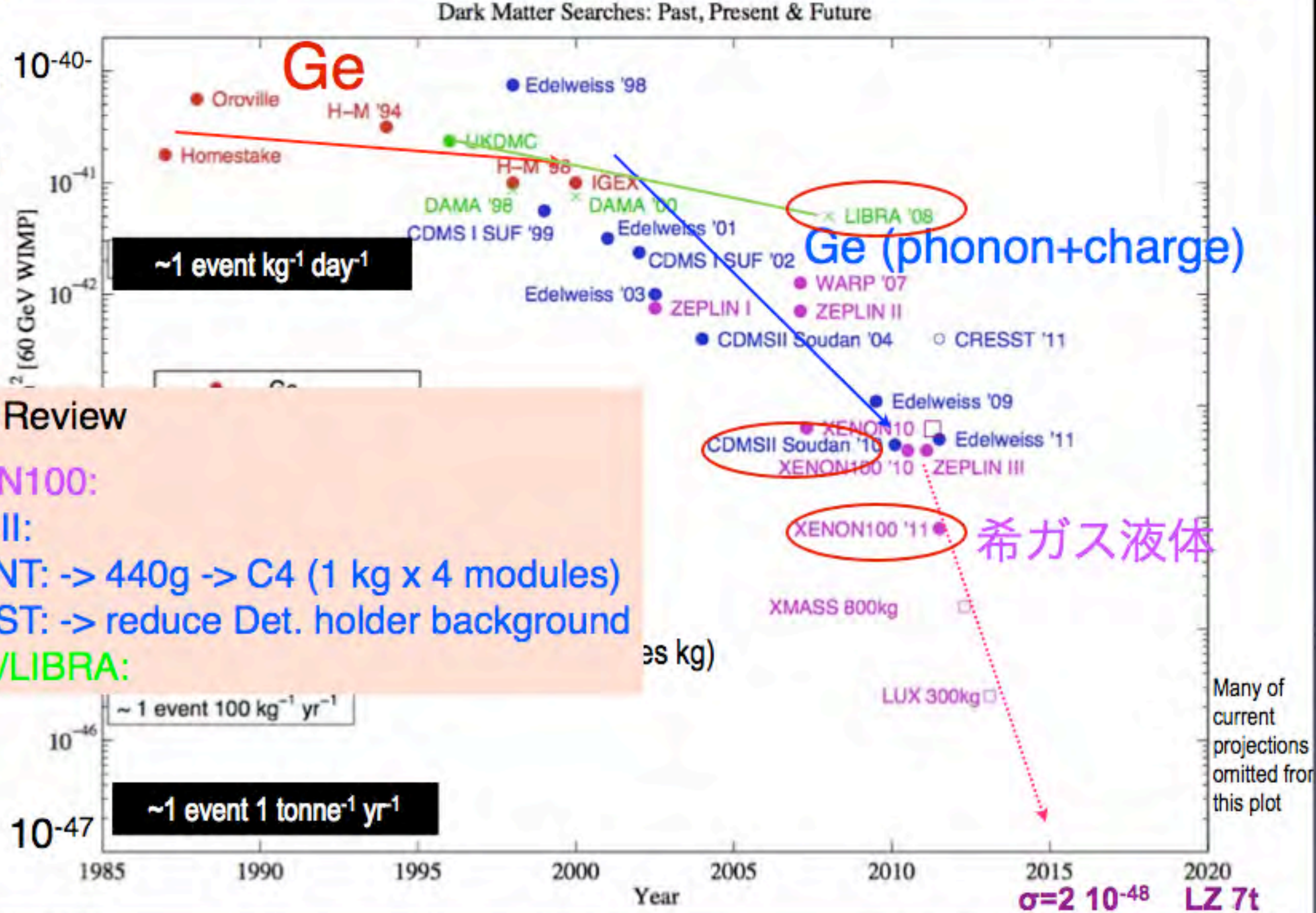
DM Direct Search Progress Over Time (2012)

Plot does not track low mass WIMPs 10 GeV



現状のReview

XENON100:
CDMSII:
CoGENT: -> 440g -> C4 (1 kg x 4 modules)
CRESST: -> reduce Det. holder background
DAMA/LIBRA:

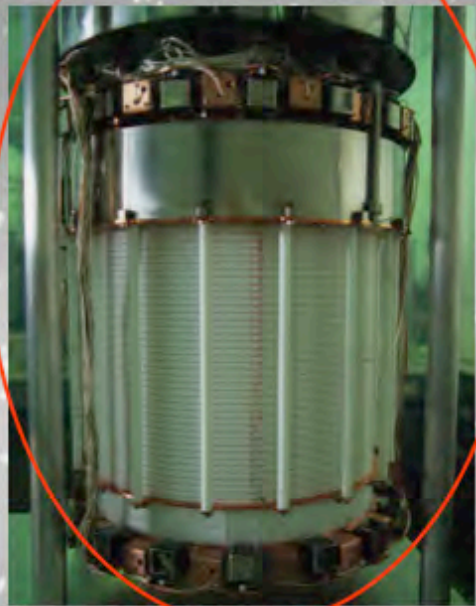
XENON at Gran Sasso, Italy

The XENON Roadmap

XENON10

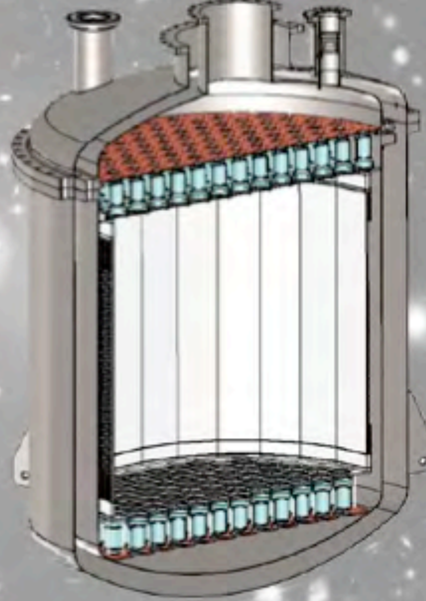
2005-2007
PRL100
PRL101
PRL 107
PRD 80
NIM A 601

XENON100



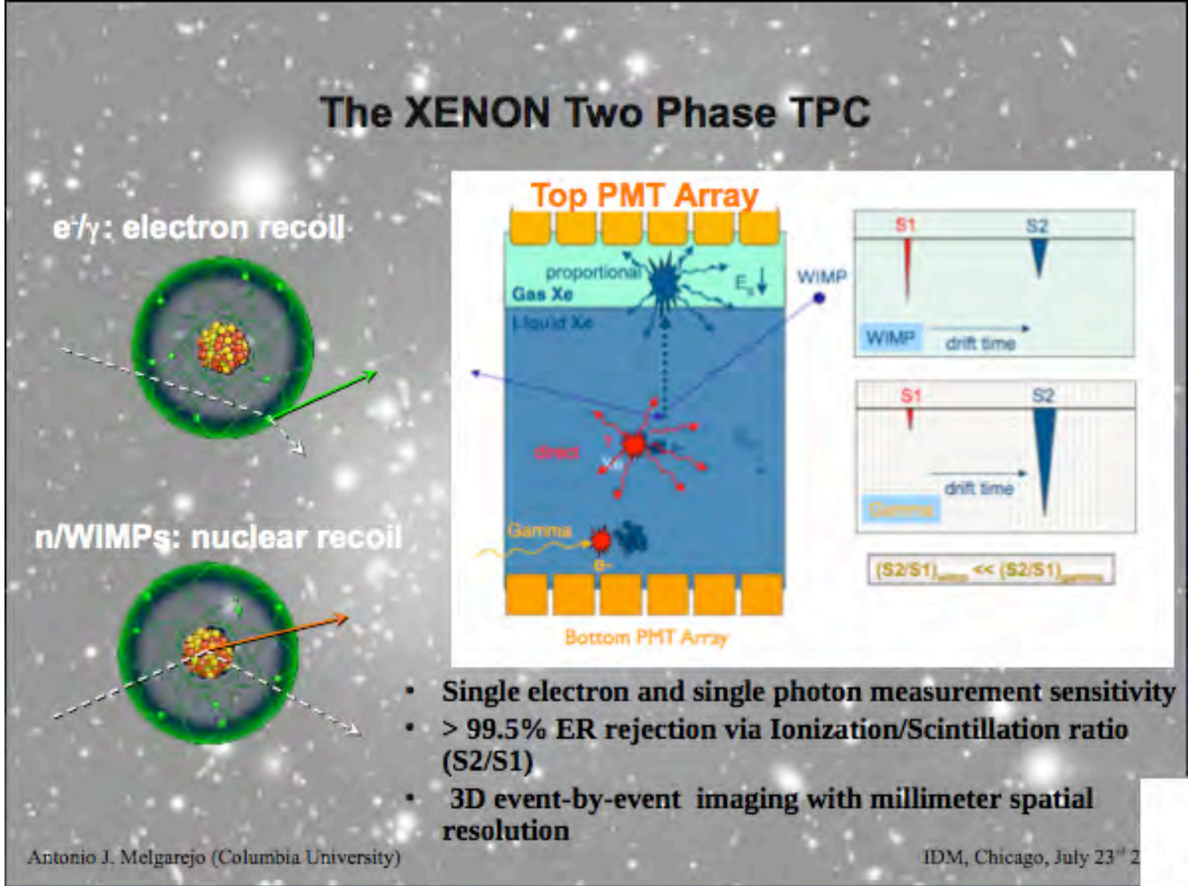
2008-2013
first results:
PRL105, PRL107, PRD84
More to come soon

XENON1T



2012-2017
Projected sensitivity
$2 \times 10^{-47} cm^2$

XENON at Gran Sasso, Italy

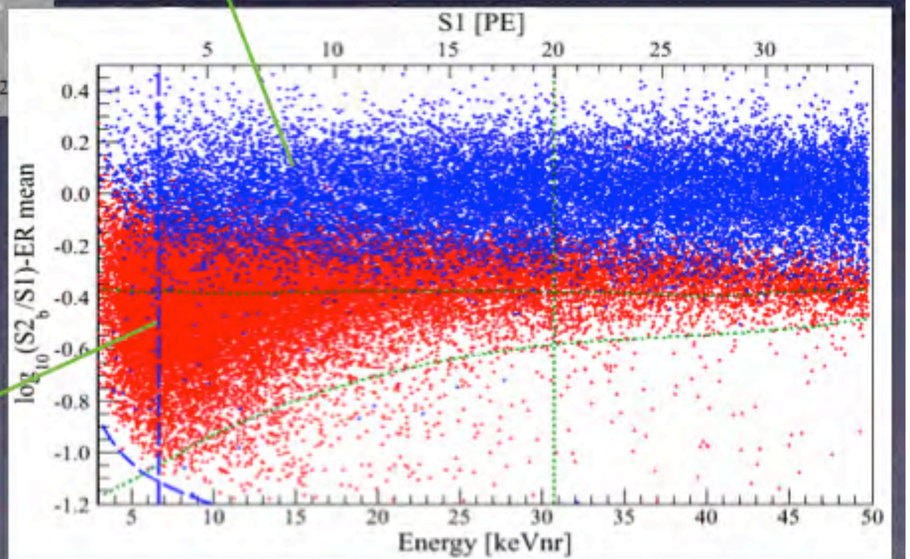


- Geなどにくらべ簡単に大きくできる
- 比例蛍光でPMTだけで電離信号を見る(S2)
- 優れたParticle ID
- 優れた位置精度（数mm)

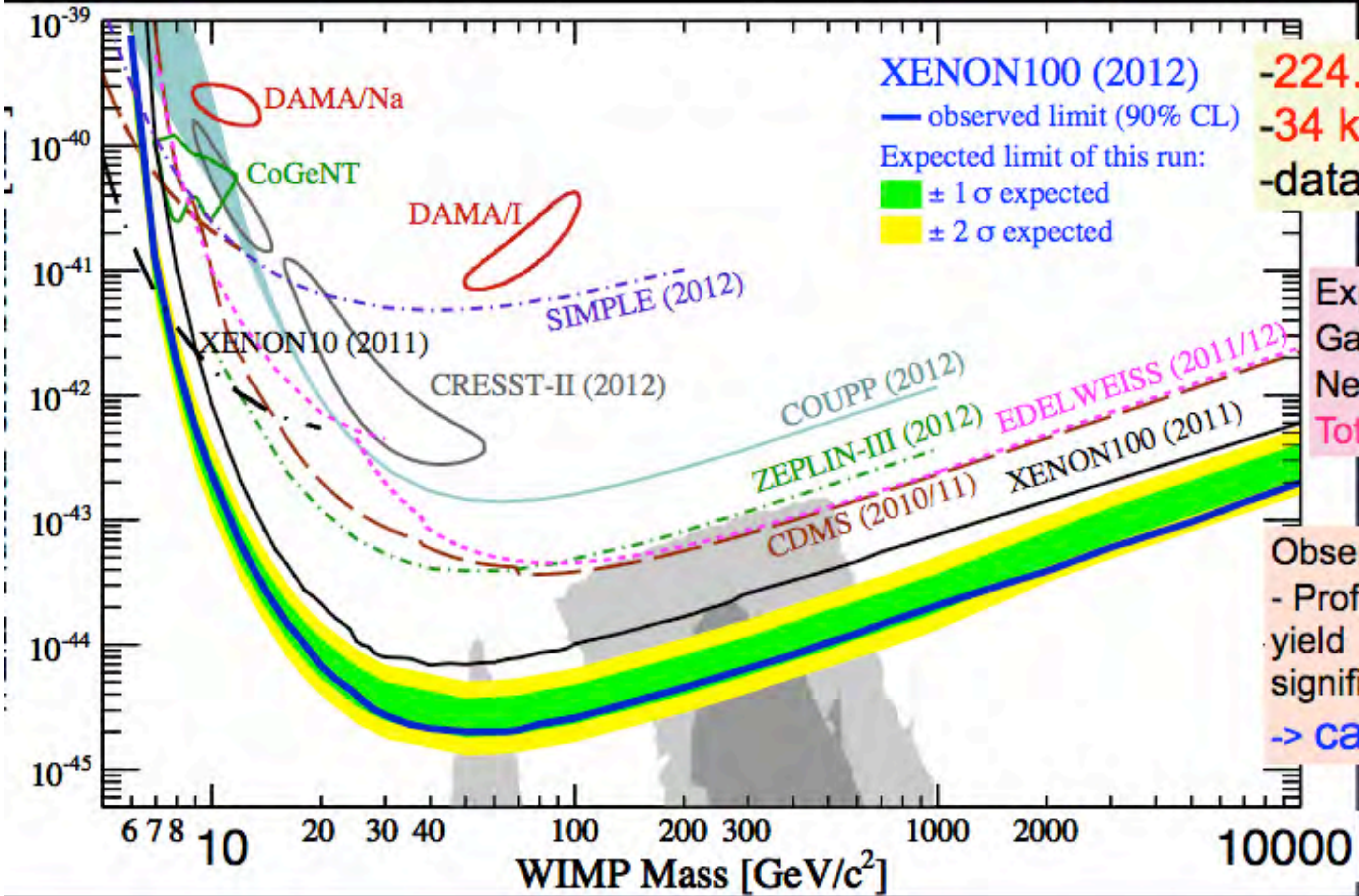
-> fiducial volume, 多重散乱カット

gamma

recoil
AmBe
n-source



Result of XENON100



- 224.6 life days
- 34 kg fiducial volume out of 62 kg
- data blinded in ROI

Expected Background
Gamma Leakage: 0.79 ± 0.16
Neutron Background: 0.17 +0.12-0.07
Total: 1.0± 0.2 events

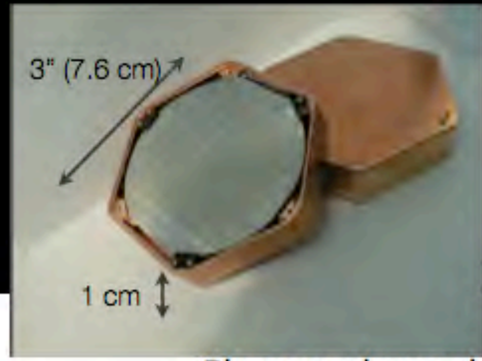
Observe 2 events
- Profile Likelihood analysis also does not yield
significant signal
-> calculate limit

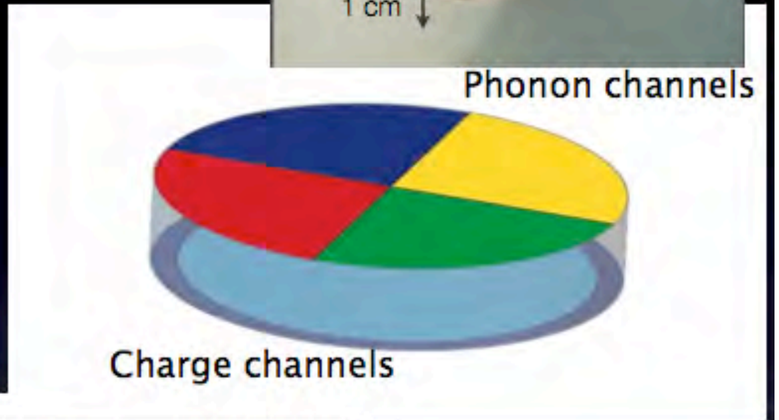
CDMS II

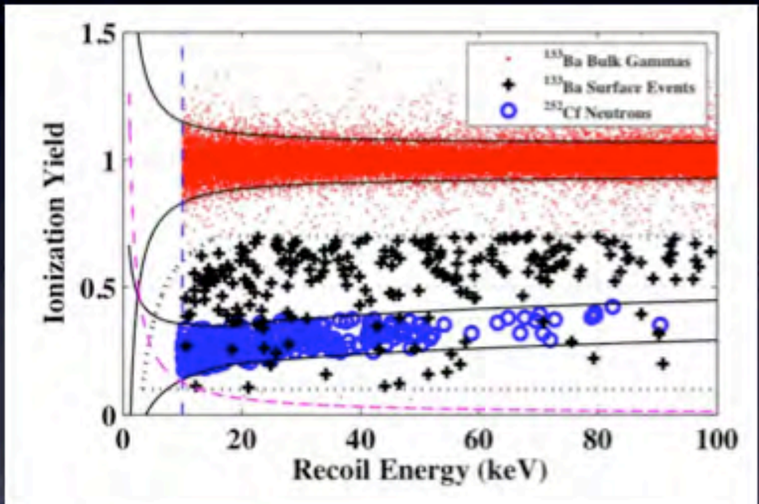
- Soudan in US.
- powerful particle ID by Phonon + Charge signal

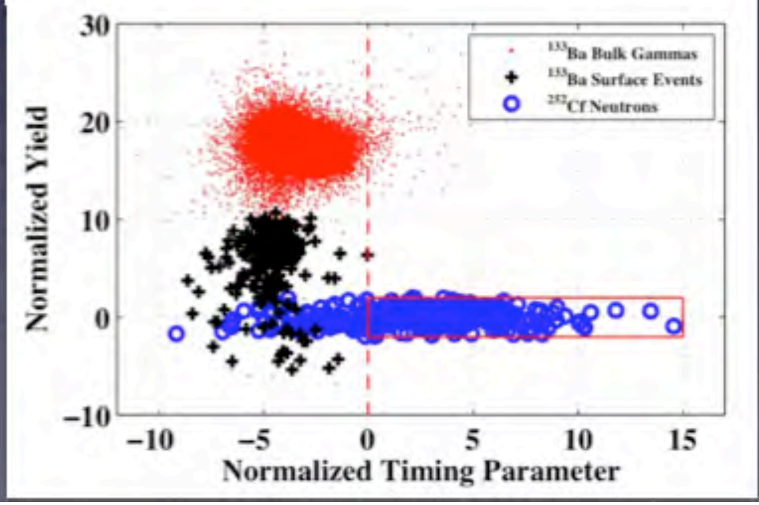
-612 kg-days with lowest noise 8 Ge detectors (~230 g each)

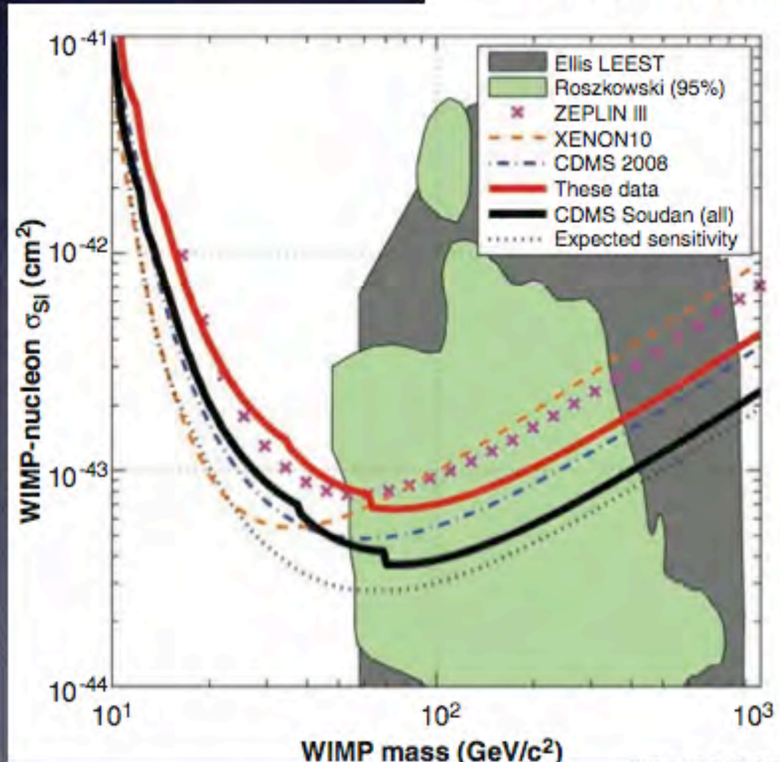
- data: July/2007 - Sep 2008











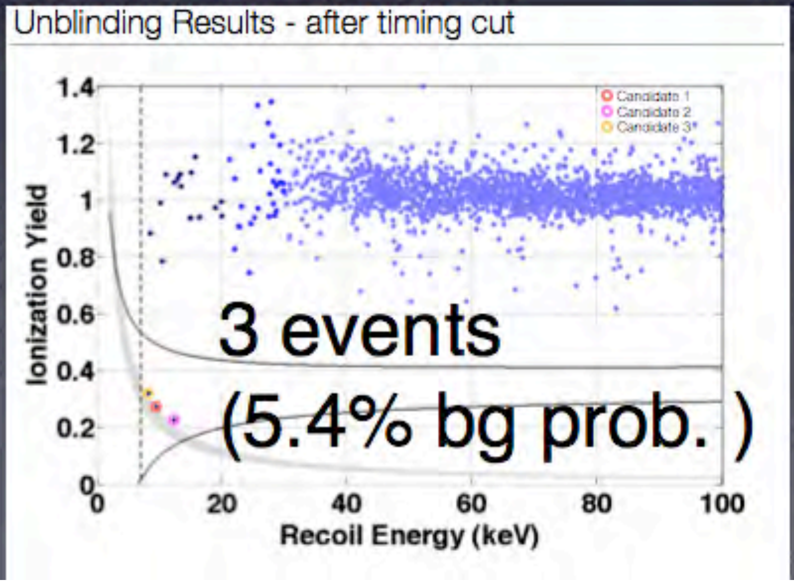
CDMSII (Si) APS2013

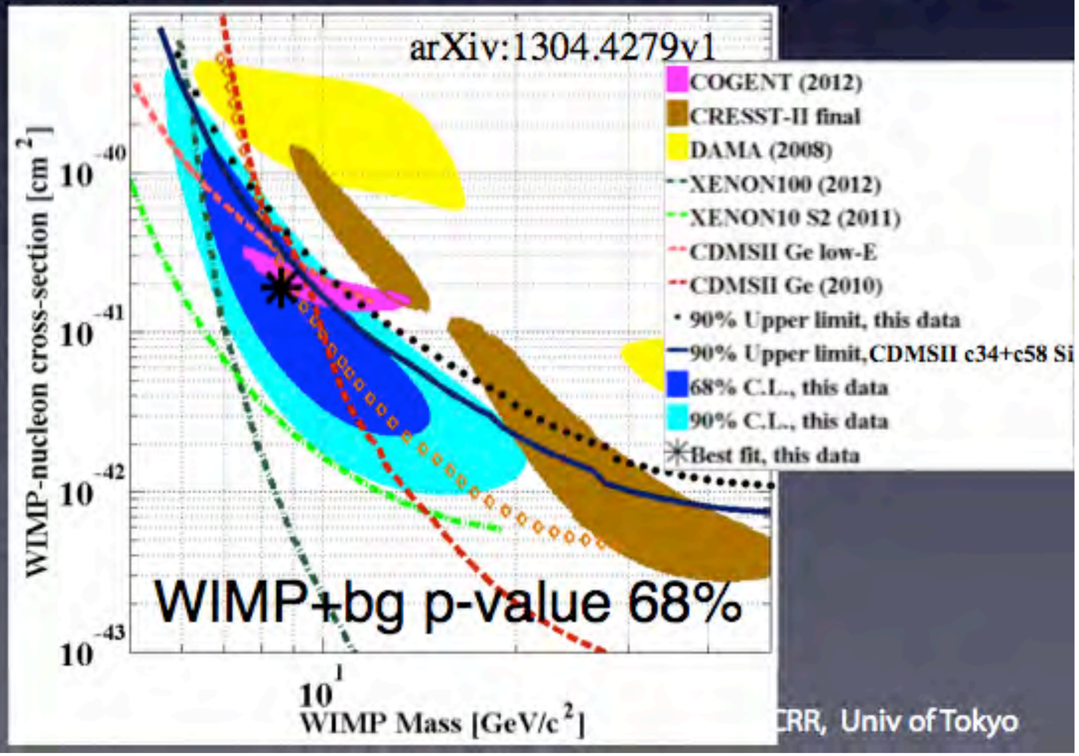
-140.2 kg-days with lowest noise 8 out of 11 Si detectors (~106 g each)
- data: July/2007 - Sep/2008

CDMS-II Exposure

- Oct. 2003 - Aug. 2004
- 42.7 kg-days in 4 Si detectors
- Oct. 2006 - July 2007
- 55.9 kg-days in 6 Si detectors
- July 2007 - Sep. 2008
- 140.23 kg-days in 8 Si detectors

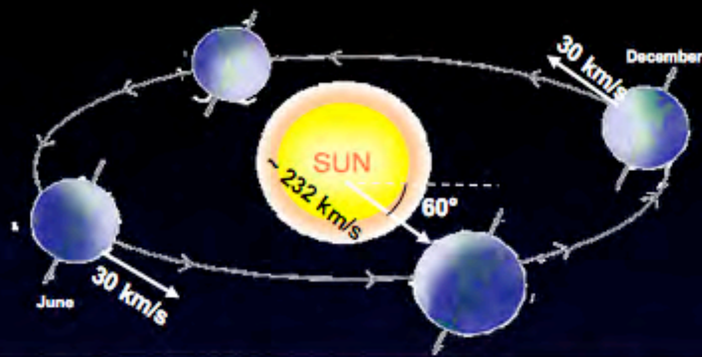
array of crystal (Ge/Si)





DAMA/LIBRA in Gran Sasso

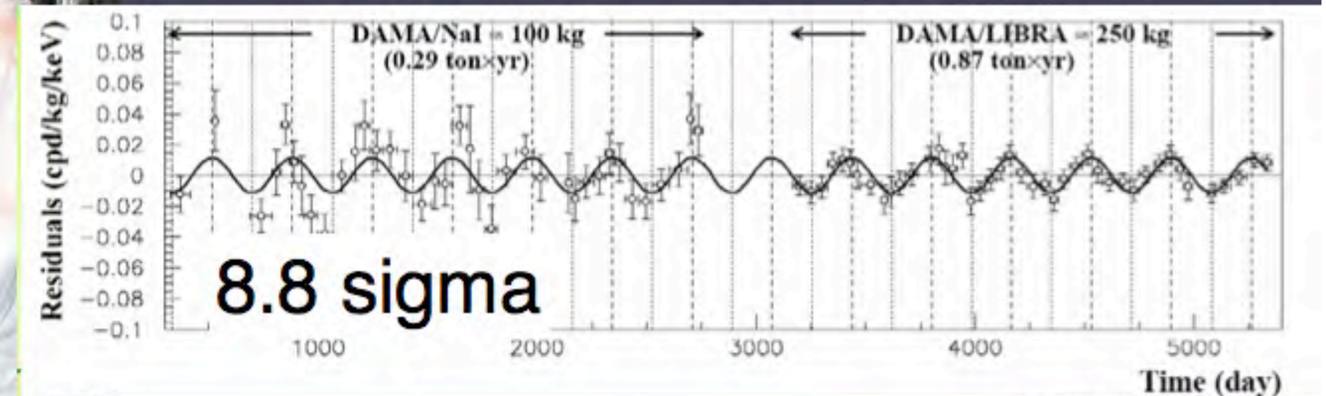
- DAMA(~100 kg) + LIBRA (~250 kg) of NaI
- Annual Modulation 8.8σ (DAMA 7 yrs + LIBRA 4yrs -> 1.17ton x yr)
- Muon rate in Gran Sasso ?(arXiv:1202.4179v2)
  phase is different.
- Other experiment can do same thing ?
  Especially by NaI ? (->DM-ICE program)



- 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 = 2nd 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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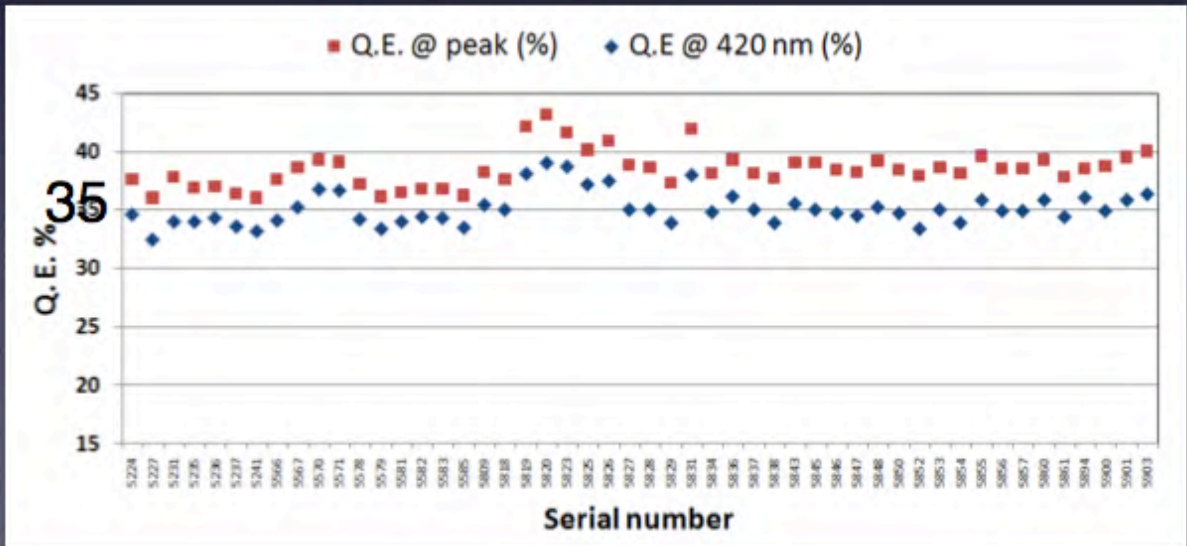
DAMA/LIBRA upgrade in Nov/Dec 2010

hamamatsu PMT

- high QE 35% at 420nm
- Energy threshold
  2keV -> 1keV
- a better energy resolution
- a better noise/scintillation discrimination
- less radioactivity



JINST 2012 7 P03009

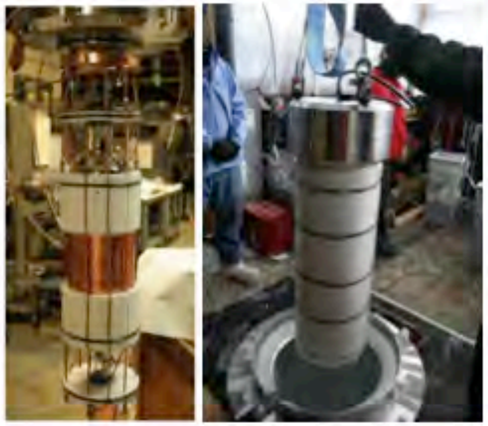
なぜ他のグループによる検証がないのか？

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 …

PPFPC 2012, R. Bernabei

Currently in Operation: DM-Ice17



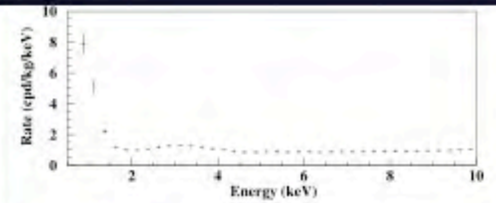


Fig. 1 Cumulative low-energy distribution of the *single-hit* scintillation events (that is each detector has all the others as veto), as measured by the DAMA/LIBRA detectors in an exposure of 0.53 ton × yr. The energy threshold of the experiment is 2 keV and corrections for efficiencies are already applied

Crystal contamination in DM-Ice17 & DAMA

	DM-Ice17	DAMA
^{nat}K	500 ppb	< 20 ppb
^{232}Th	50 ppt	0.5 - 7.5 ppt
^{238}U (upper part of chain)	7.5 ppt	0.7 - 10 ppt
^{238}U (below Pb-210)	2 mBq/kg	5 - 30 μBq/kg

2013 snowmass DM-ICE

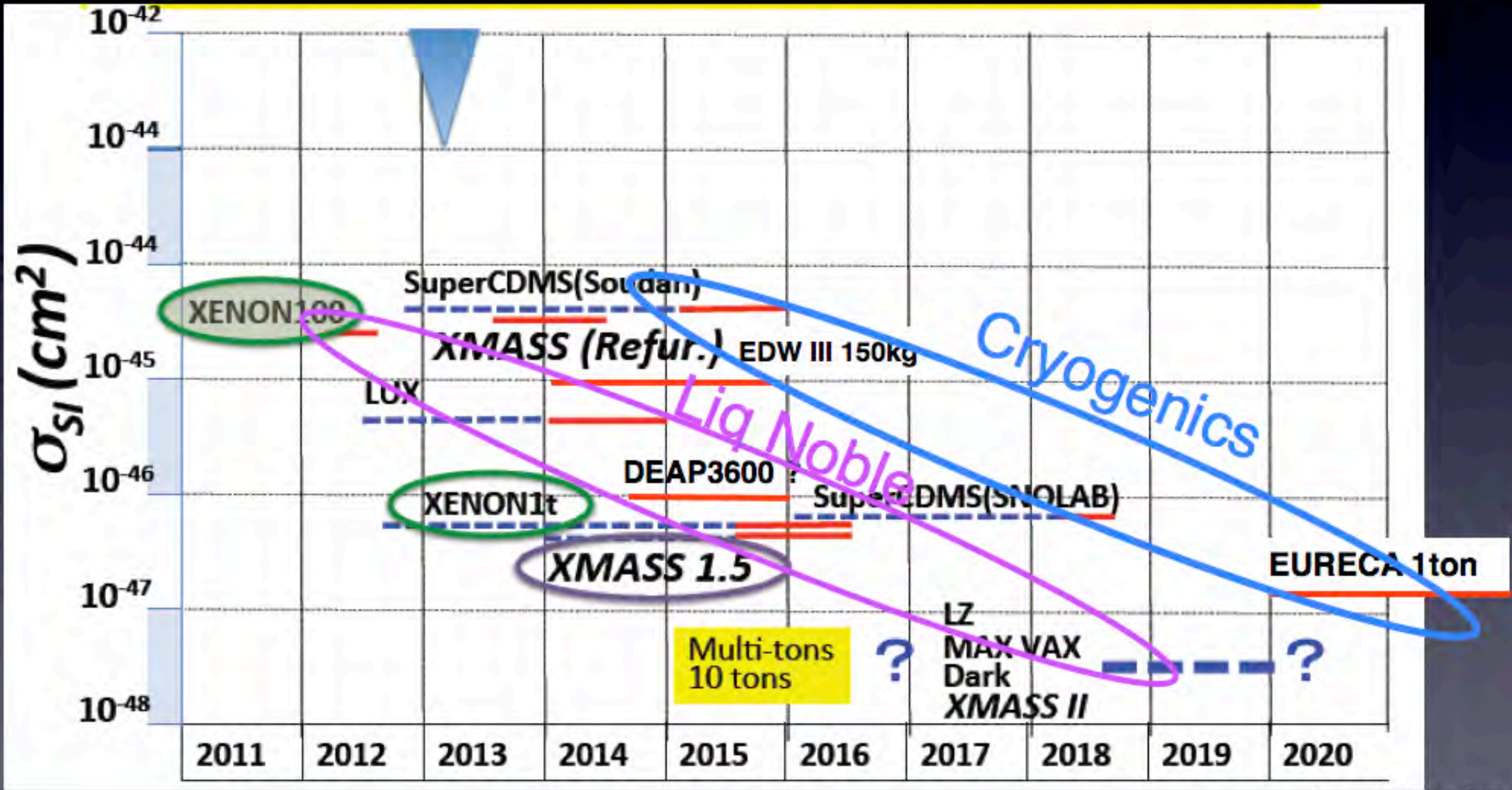
海外の将来計画

大きく分けて

Cryogenics -> Super CDMS, EURECA
Liq Noble -> XENON, LUX, DEAPなど

海外における今後の展開

Cryogenics関係はスケジュール的に遅め
Liq Noble が先行
XENON1Tが本命、DEAP3600(LAr single phase)が大穴？



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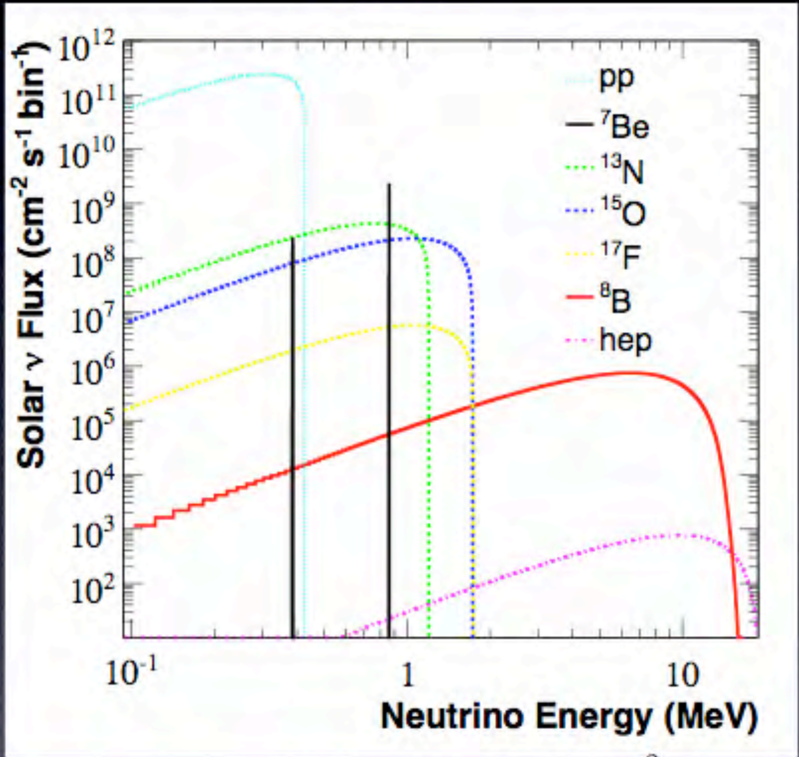
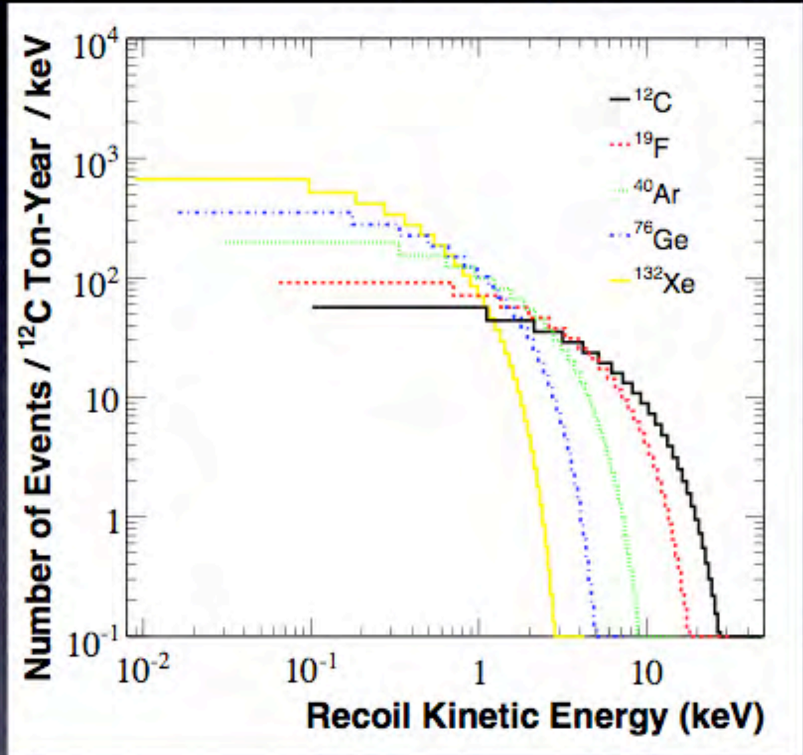
将来どこまで目指せるか？
(究極のバックグランド ?)

arXiv:0706.3019 [astro-ph]



coherent scattering (solar neutrino)



2.7×10^{-3}

2.7×10^{-5}

2.7×10^{-7}

event/day/kg/keV

10^{-7} event/day/kg/keV -> 10^{-47}~ 10^{-48}cm^2

~10tonの検出器サイズ

キセノンー＞世界の生産量 ~1/10

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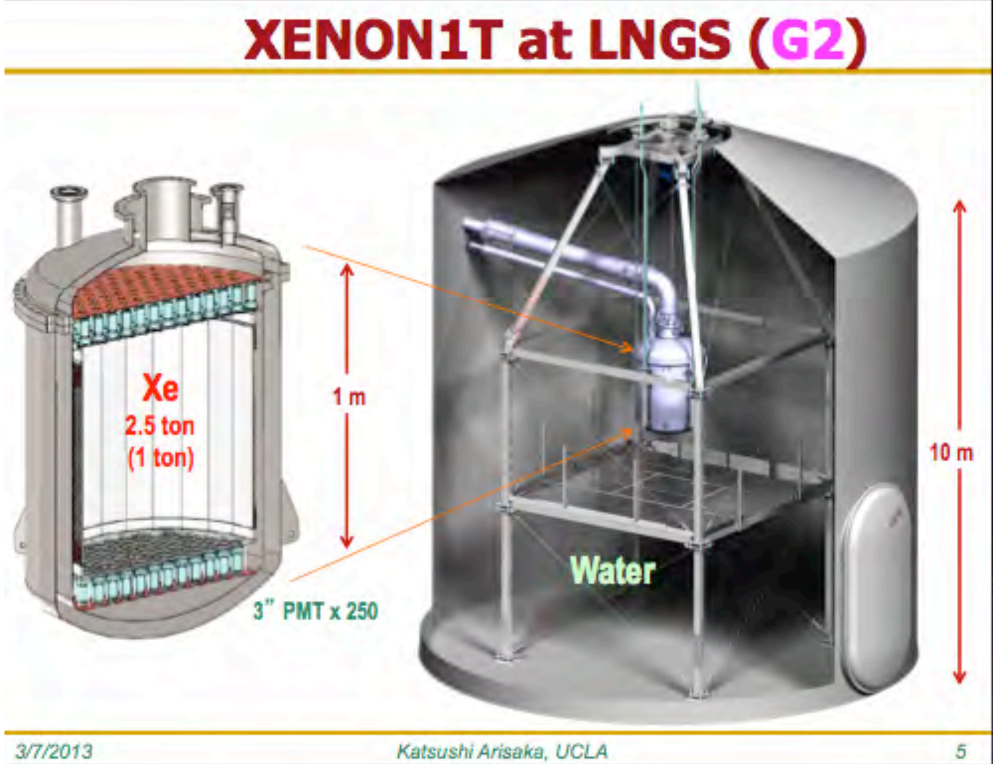
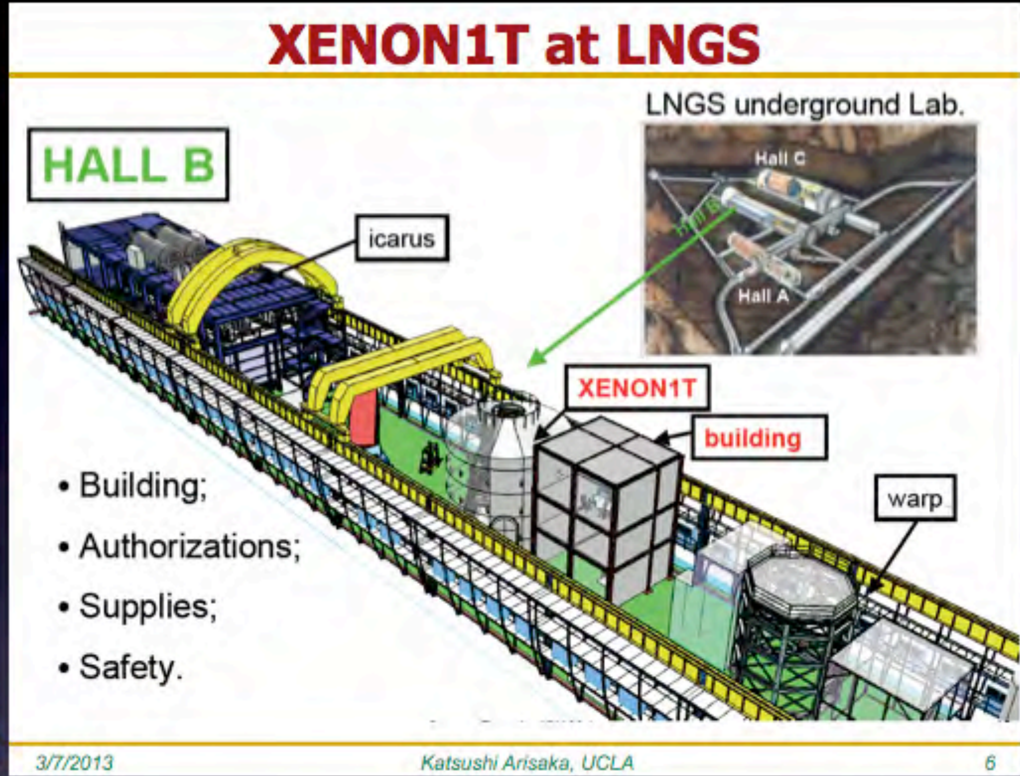
XENON1T





Gran Sasso HALL B
2.5 ton LXe, 1ton fiducial
1m drift (~-100kV on cathode)
Water shield in Gran Sasso
3inch Hamamatsu PMTs
13M$ (50% US, 50% non-US)
operation will be started in 2015.

2015-2016 data taking

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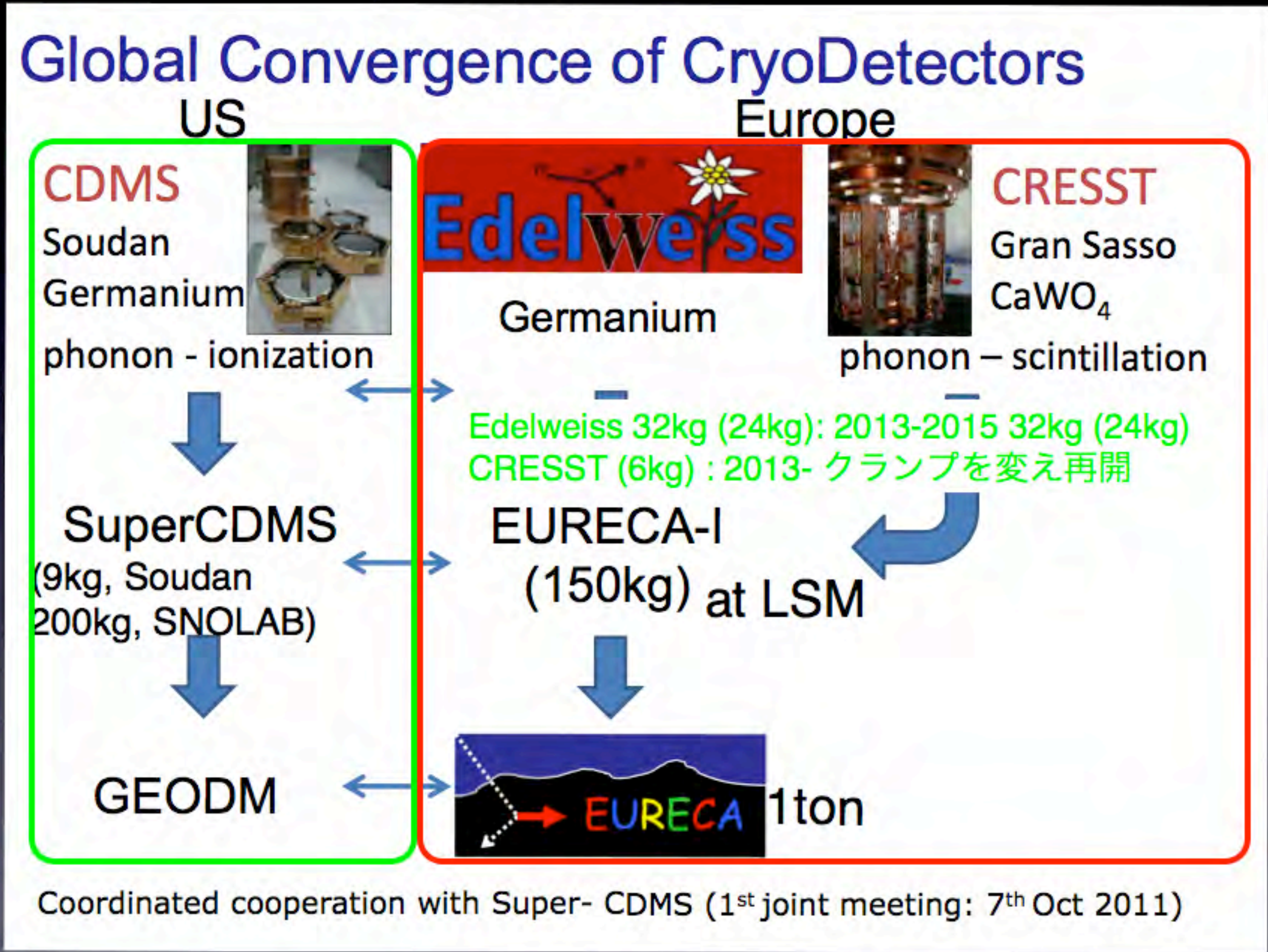
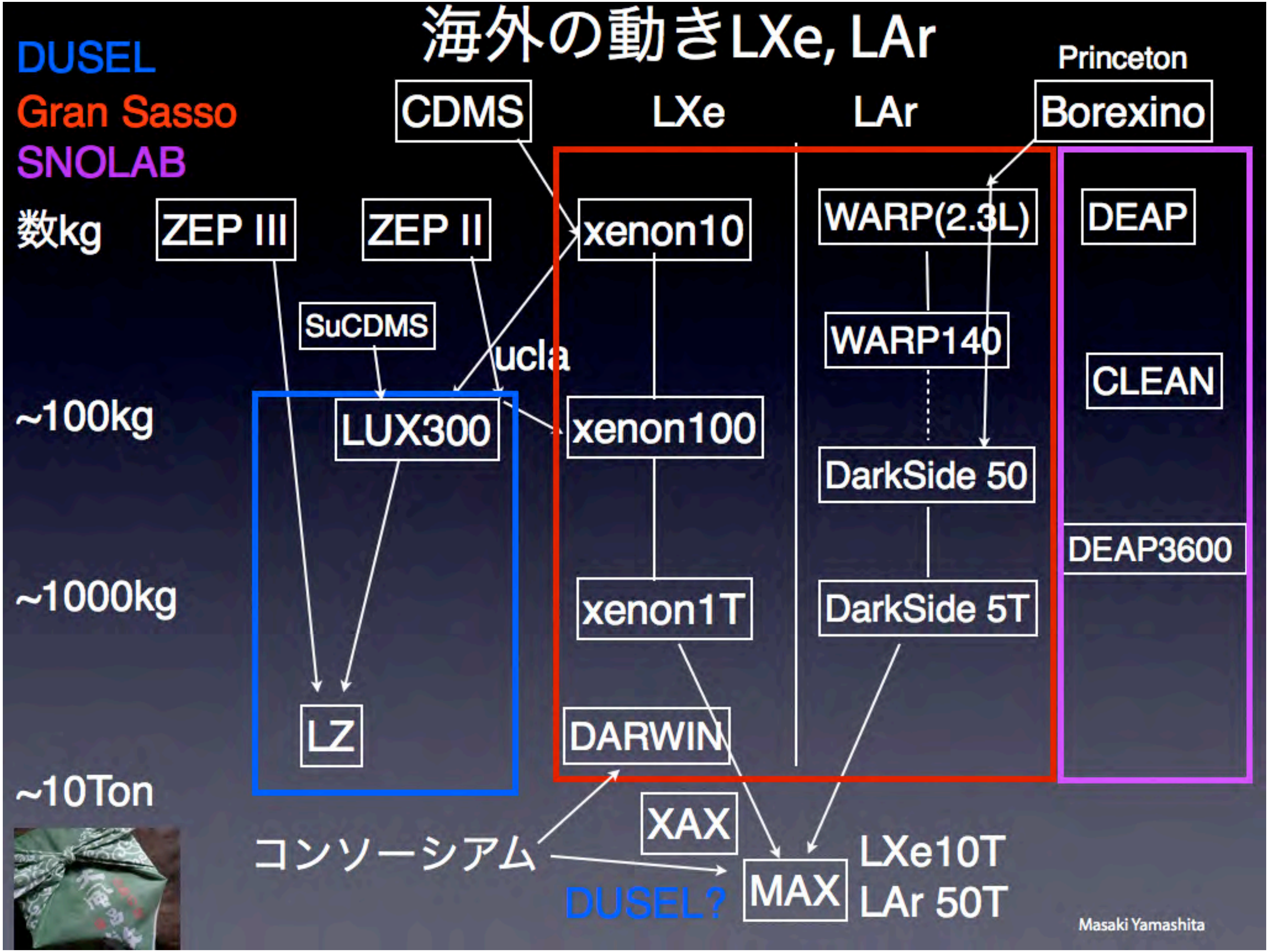
Cryogenics Detector

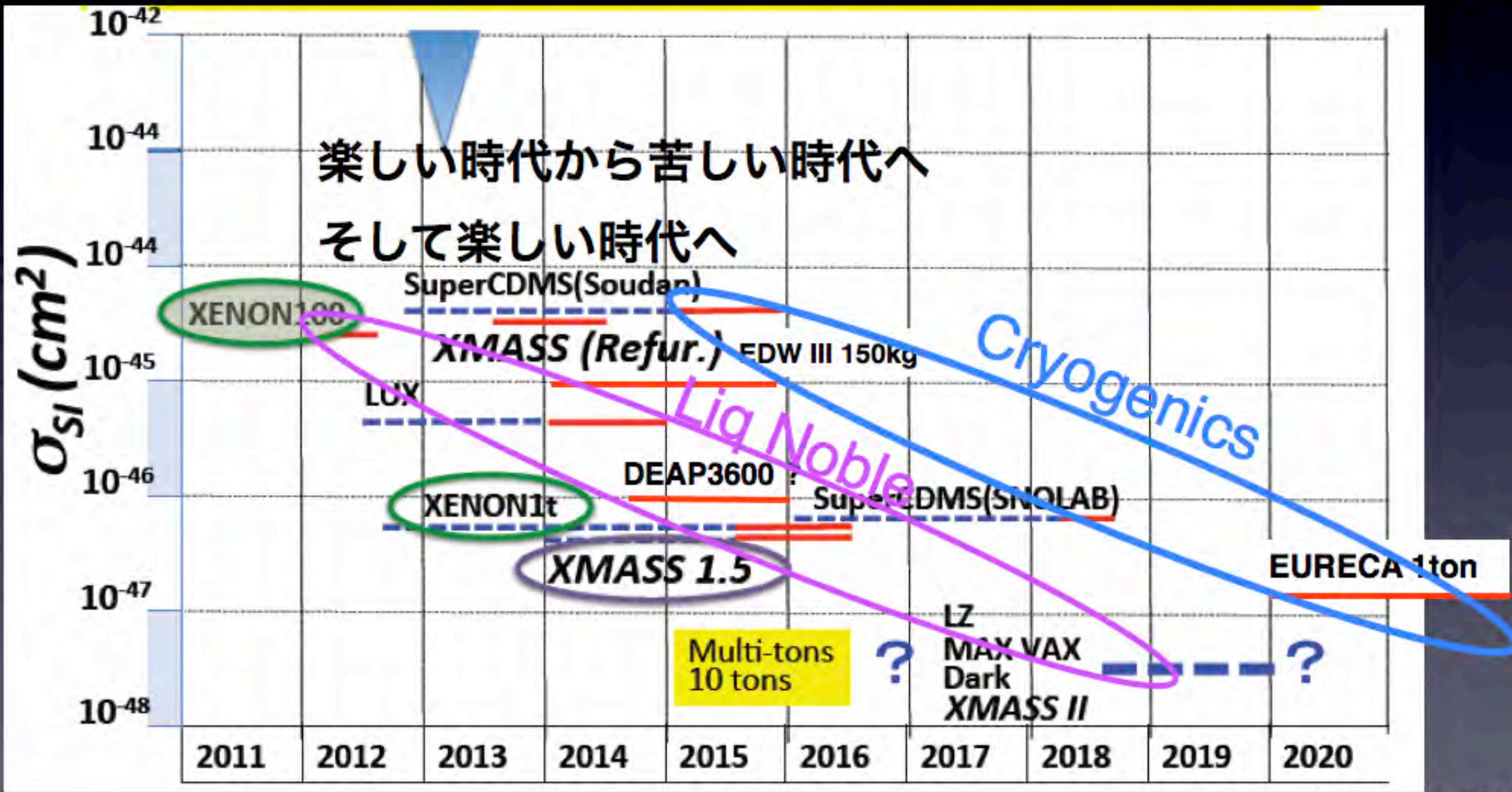


IDM2012 H. Krauss


海外の動きLXe, LAr
DUSEL
Gran Sasso
SNOLAB
数kg
~100kg
~1000kg
~10Ton
CDMS
LXe
LAr
Princeton
Borexino
ZEP III
ZEP II
xenon10
WARP(2.3L)
DEAP
SuCDMS
ucla
WARP140
CLEAN
LUX300
xenon100
DarkSide 50
DEAP3600
xenon1T
DarkSide 5T
LZ
DARWIN
XAX
コンソーシアム
MAX
LXe10T
LAr 50T
DUSEL?
Masaki Yamashita

海外における今後の展開

Cryogenics関係はスケジュール的に遅め
Liq Noble が先行
XENON1Tが本命、DEAP3600(LAr single phase)が大穴？



Masaki Yamashita

DARWIN コンソーシアム

(dark matter WIMP search with noble liquids)

http://darwin.physik.uzh.ch

-ヨーロッパにおける将来計画のデザインのスタディを行う。Roadmap (ASPERA)

-トンクラスの液体キセノン、液体アルゴン検出器の建設を目指す。

- ヨーロッパ、アメリカにおけるXENON, WARP, ArDM + 低バックグランド、Cryogenicsなどのワーキンググループからなる。