Radiation Detector Development for Direct Dark Matter Search

ISRD 2016 KEK
2016 January 18th

Kobe University

Kentaro Miuchi

SUMMARY

- Dark Matter: one of the frontiers of astro and particle physics.
- Still a lot of room to use your beautiful detectors for direct detection of DM.
  - What is required for that? ← My Talk

The History of the Dark started

A long time ago

in galaxies far far away

not quantitative at all

VOLUME 86 — OCTOBER 1937 — NUMBER 3

ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

F. ZWICKY

Year: 1930s

2. We must know how much dark matter is incorporated in nebulae in the form of cool and cold stars, macroscopic and microscopic solid bodies, and gases.

A long time ago in galaxies far far away

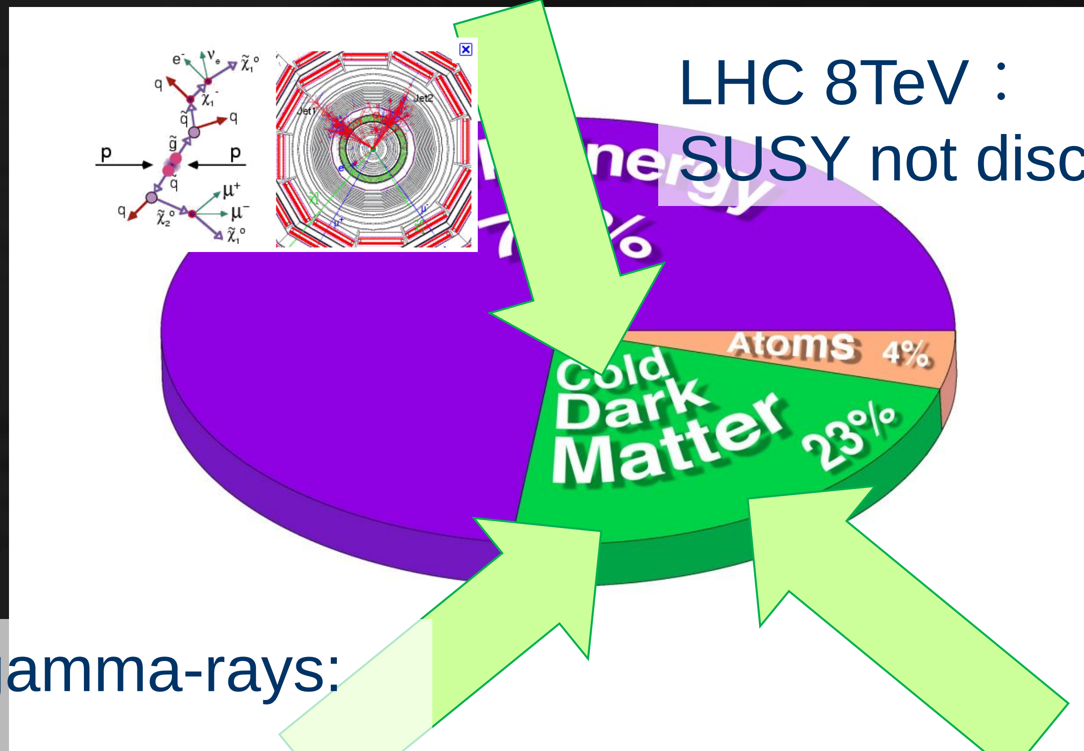
Distance: 300 million light-years

Method iii is based on the *virial theorem* of classical mechanics. The application of this theorem to the Coma cluster leads to a minimum value $\overline{M} = 4.5 \times 10^{10} M_\odot$ for the average mass of its member nebulae.

Dark Matter

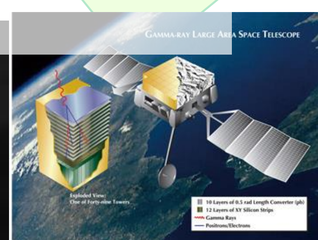
Accelerator

LHC 8TeV：
SUSY not discovered



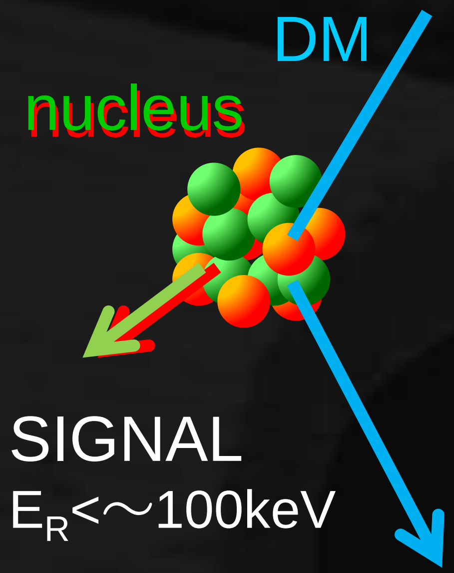
anti matter, gamma-rays:
no signal

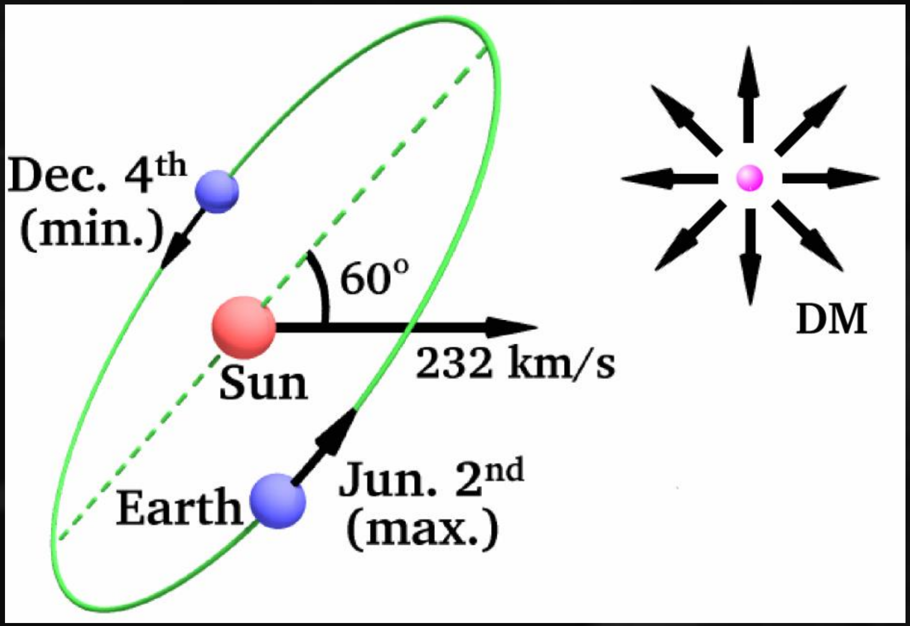
Indirect Detection

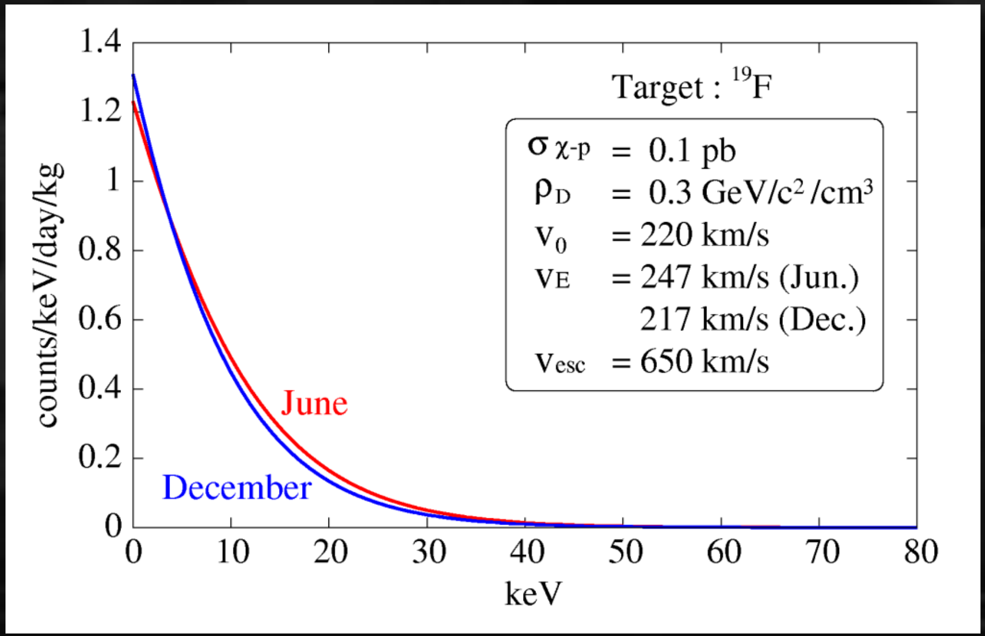


Direct Detection

DM direct detection



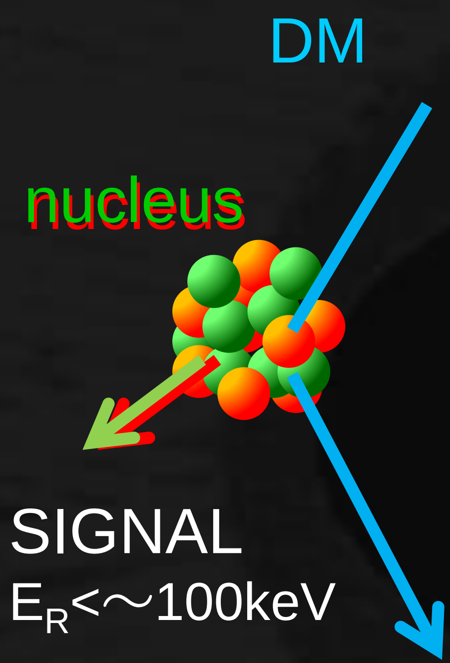


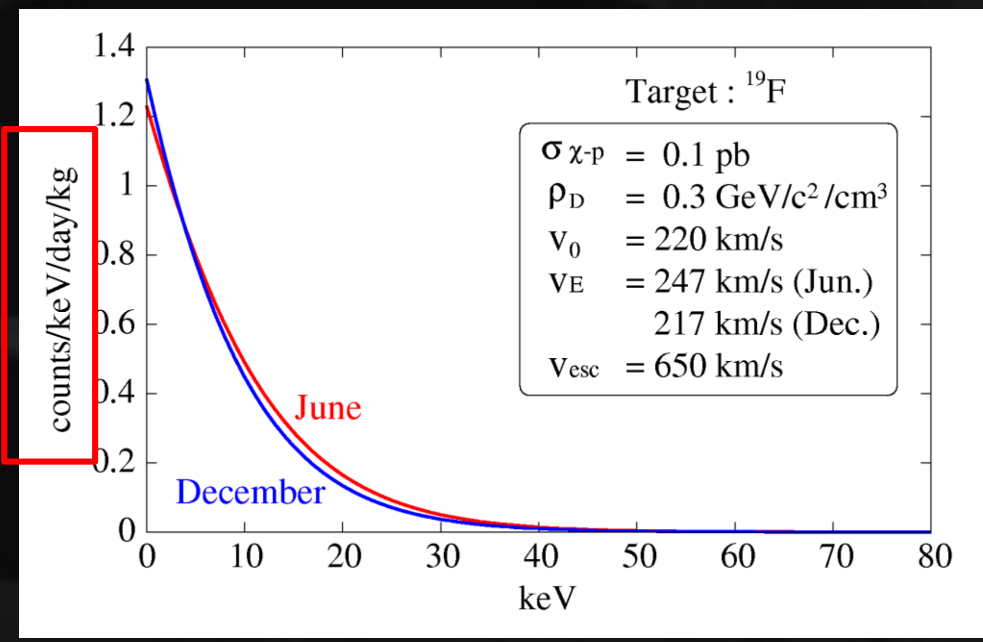


expectedd DM signals

- ① observed * events
- ② energy spectrum
- ③ seasonal modulation
- ④ direction-sensitive

DM direct detection



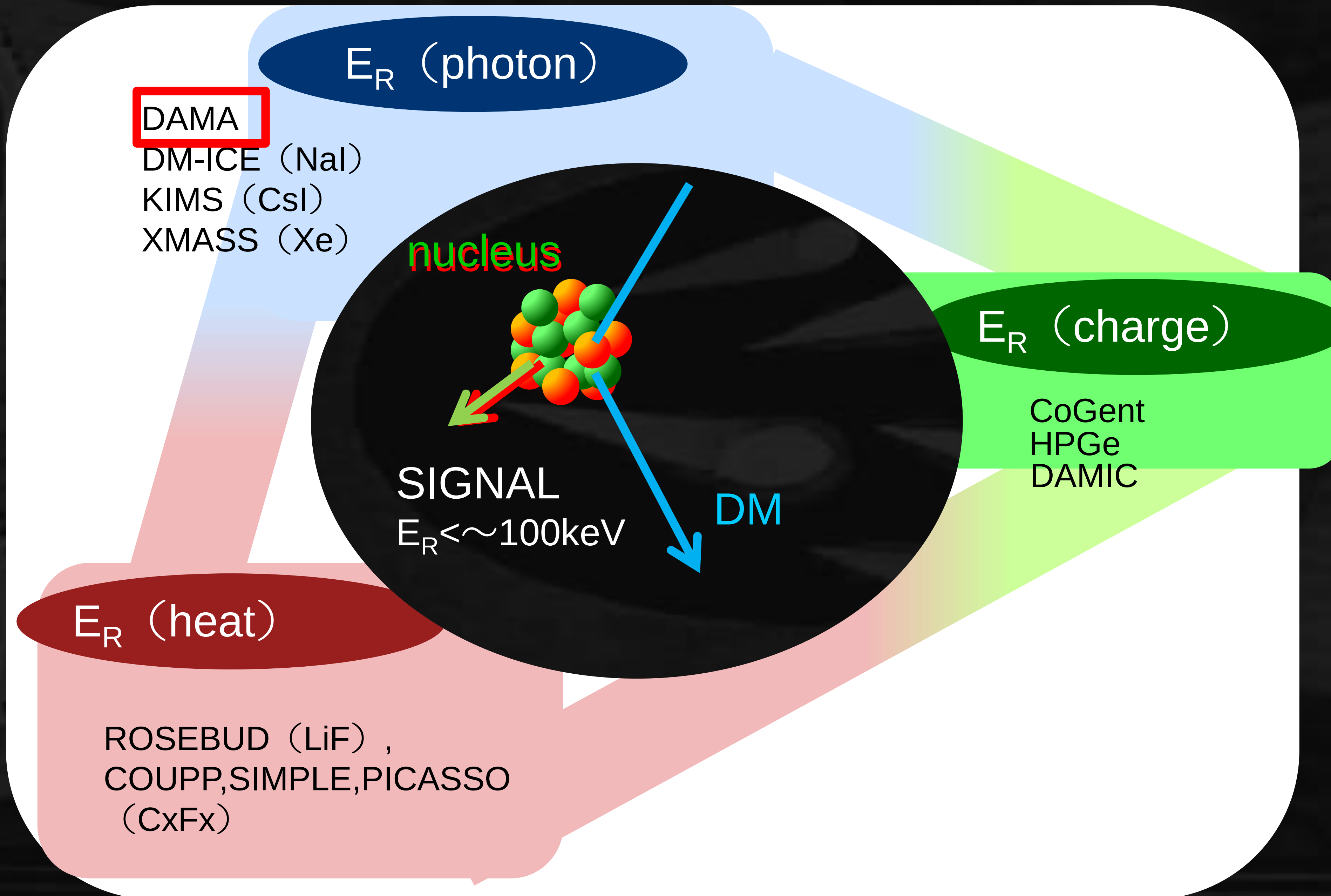


Key feature 1 : Large mass

world-wide underground laboratories

- To reduce cosmic-ray background

Direct Detection Methods



What's special with DAMA?

- Large: 250kg
- Pure (clean): low contamination of radioctive background source (Uranium, Thorium, 40K)

IAIAD/DM-Ice17 crystals: (arXiv:1401.4804v1, PLB 616 (2005) 17–24)

- ~30x DAMA's K-40 contamination
- 5 - 10x DAMA's single-hit event rate (no multi-hit cut appli in NAIAD/DM-Ice17)

Neil Spooner, Reina Maruyama
on behalf of the DM-Ice Collaboratio

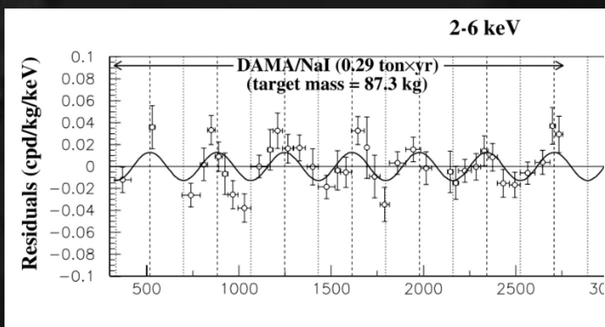
TeVPA/IDM - Astroparticle Physics 2014
June 26, 2014
Amsterdam

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	7.6	7.7	410
Bicron/Saint Gobain	Crystal	NaIAD/DM-Ice17	55	33	550
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
	PICO-LON(Tokushima)		~8ppt	<1ppt	not yet

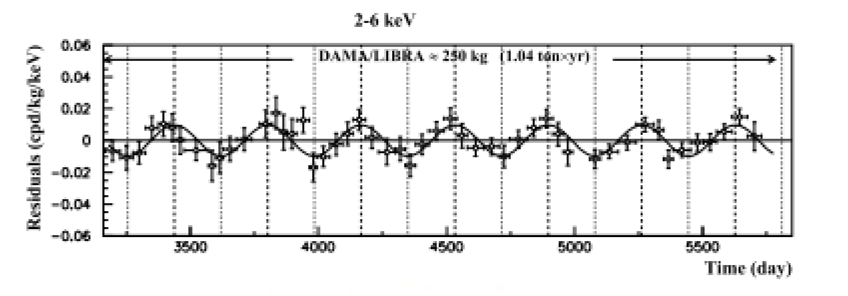
*DAMA ppt numb
for other crystals

DAMA/LIBRA

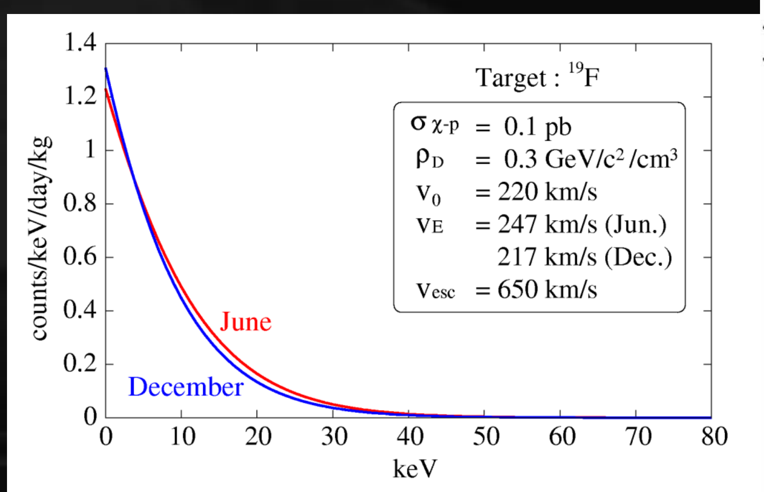
- 250kg NaI scintillators
- Exposure: 1.33ton • years
- 14cycles seasonal modulation （9.3σ）

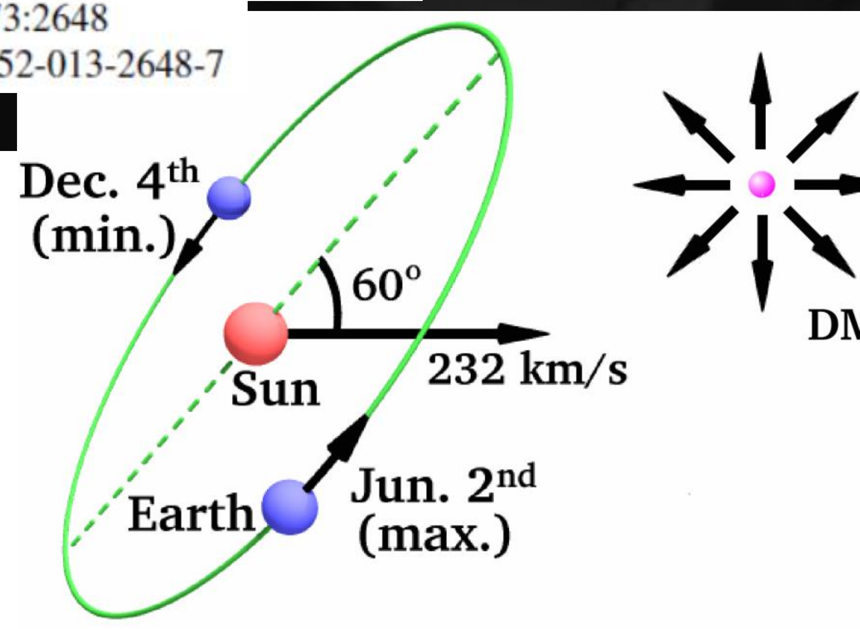


Eur. Phys. J. C (2008) 56: 333–355
DOI 10.1140/epjc/s10052-008-0662-y



Eur. Phys. J. C (2013) 73:2648
DOI 10.1140/epjc/s10052-013-2648-7

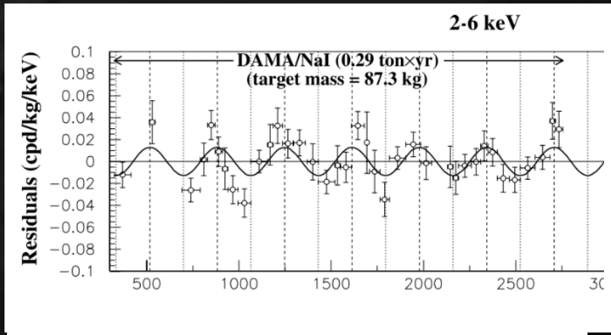




DAMA/LIBRA

- 250kg NaI scintillators
- Exposure: 1.33ton • years
- 14cycles seasonal modulation （9.3σ）

DAMA page



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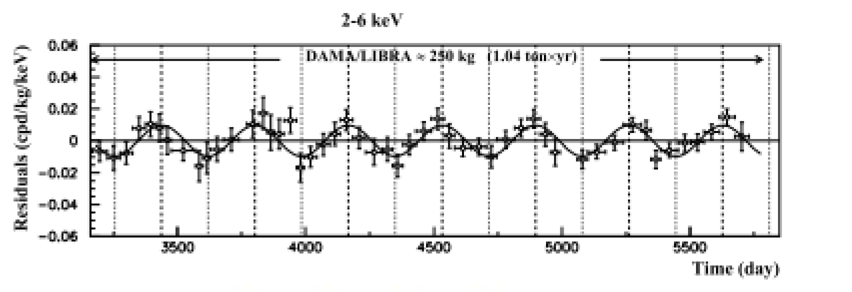
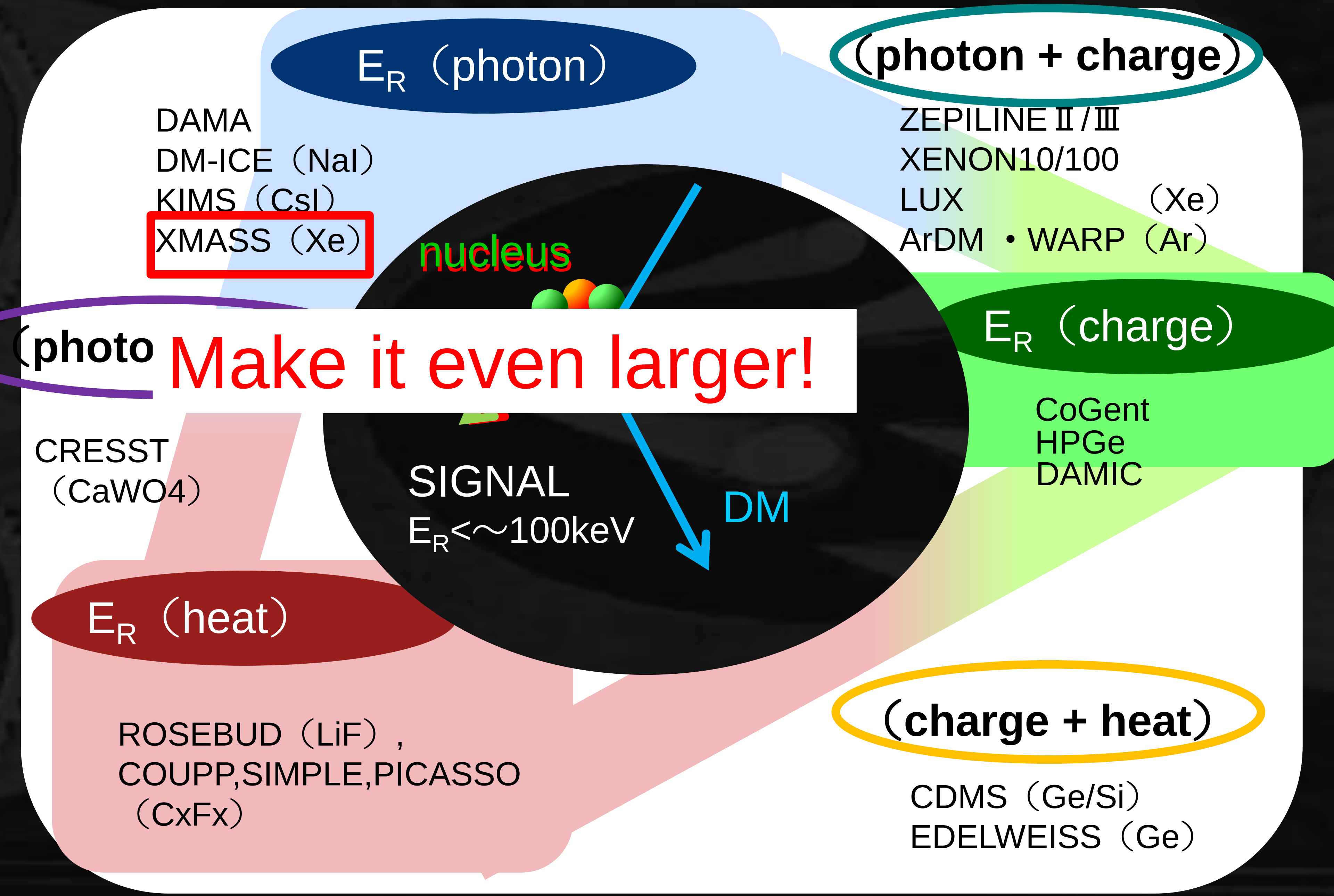


Eur. Phys. J. C (2013) 73:2648
DOI 10.1140/epjc/s10052-013-2648-7

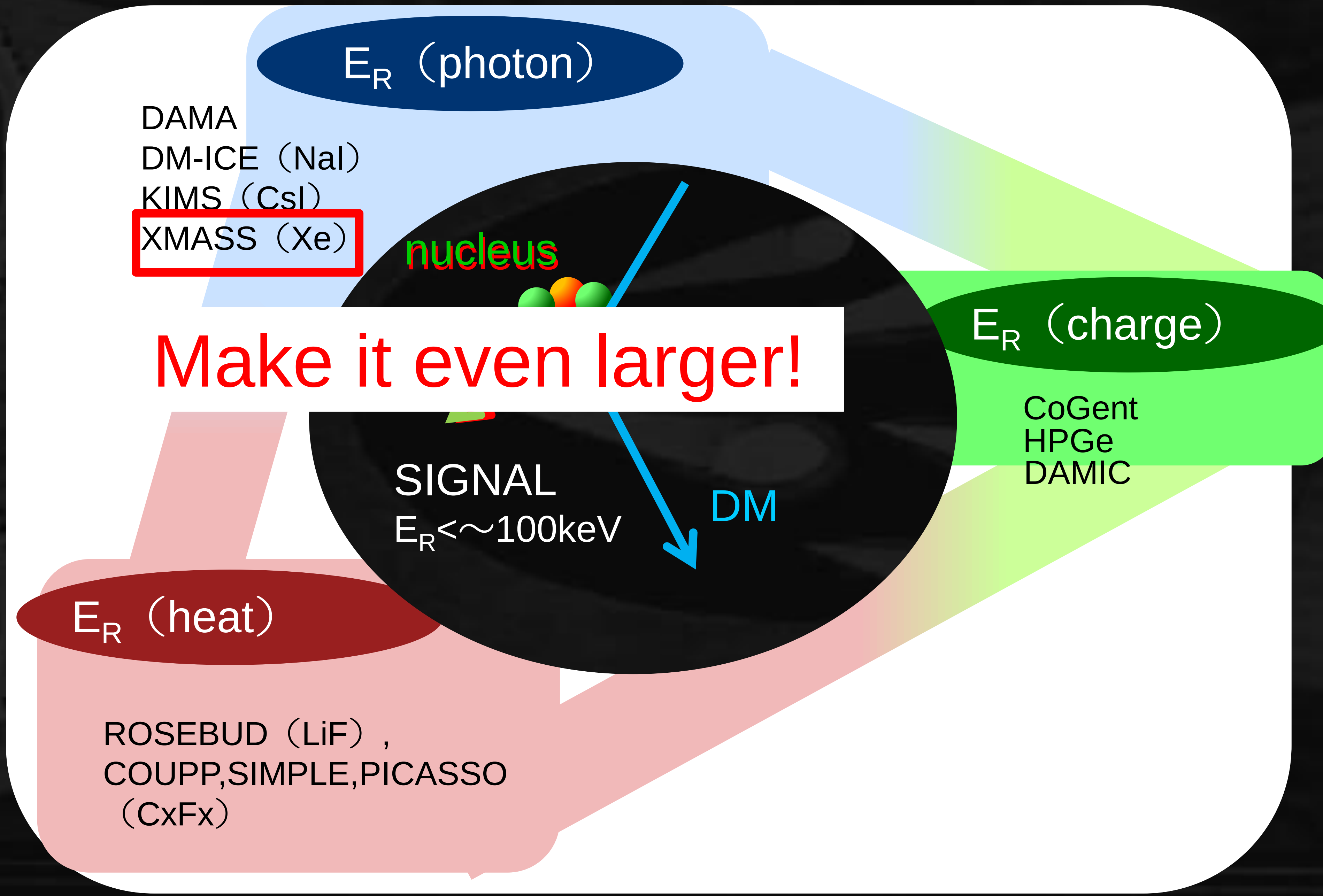
We have SIGANALS, it's done?

No…

Direct Detection Methods

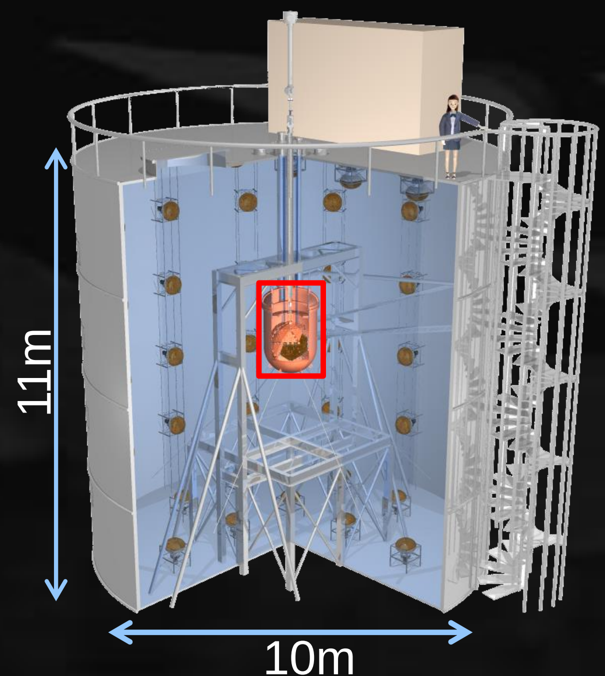


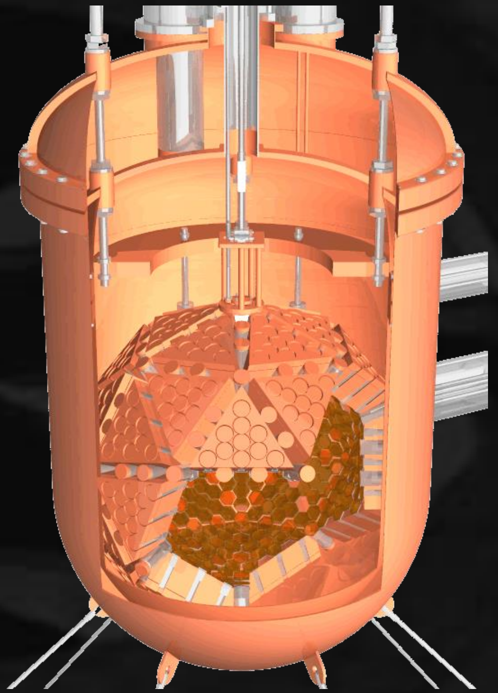
Direct Detection Methods



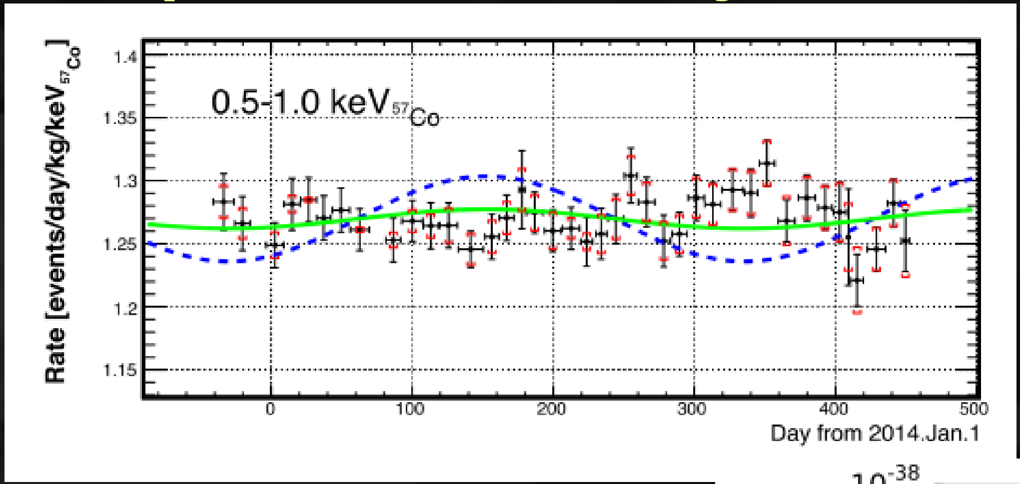
XMASS (Japan)

- In Kamioka
- A single-phase detector with ~830kg LXe
- Equipped with 642 PMTs
- Active water shield

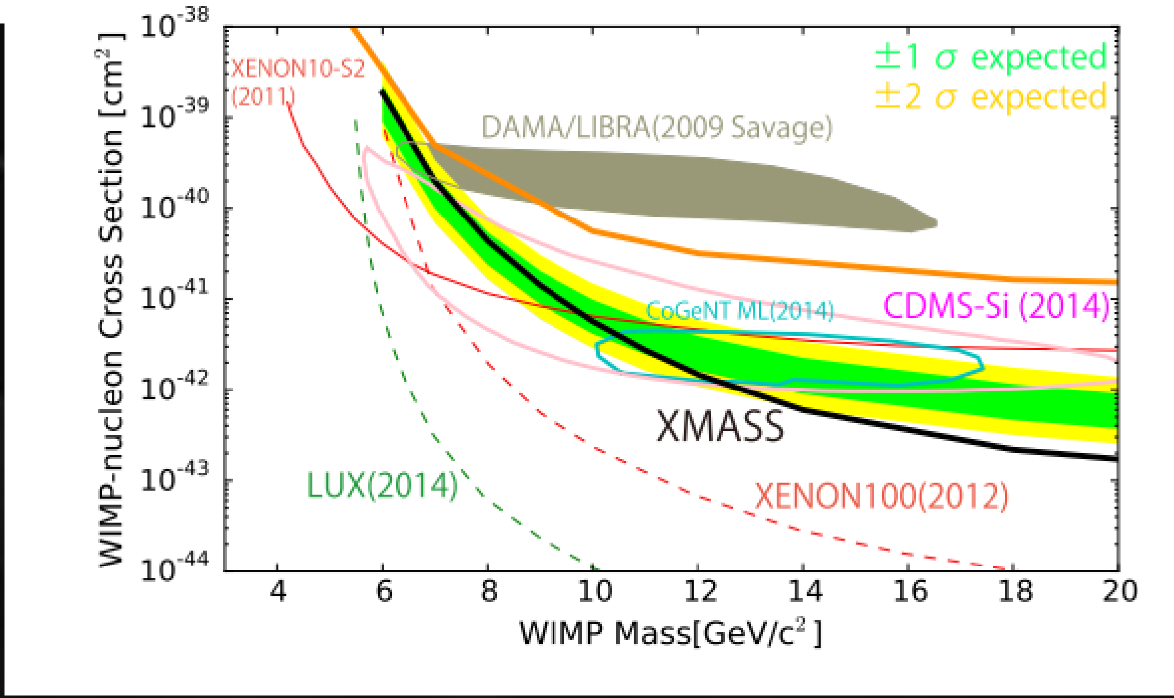




- **exposure 0.86ton years in only 1.3years**

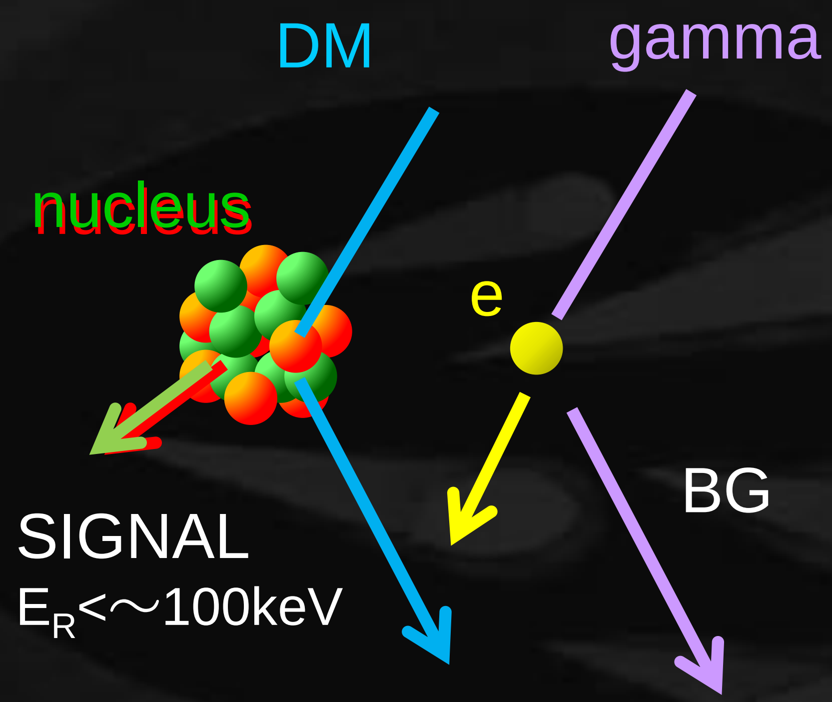


XMASS arXiv1151.04807



- **excluded some part of DAMA region with seasonal modulation analysis**

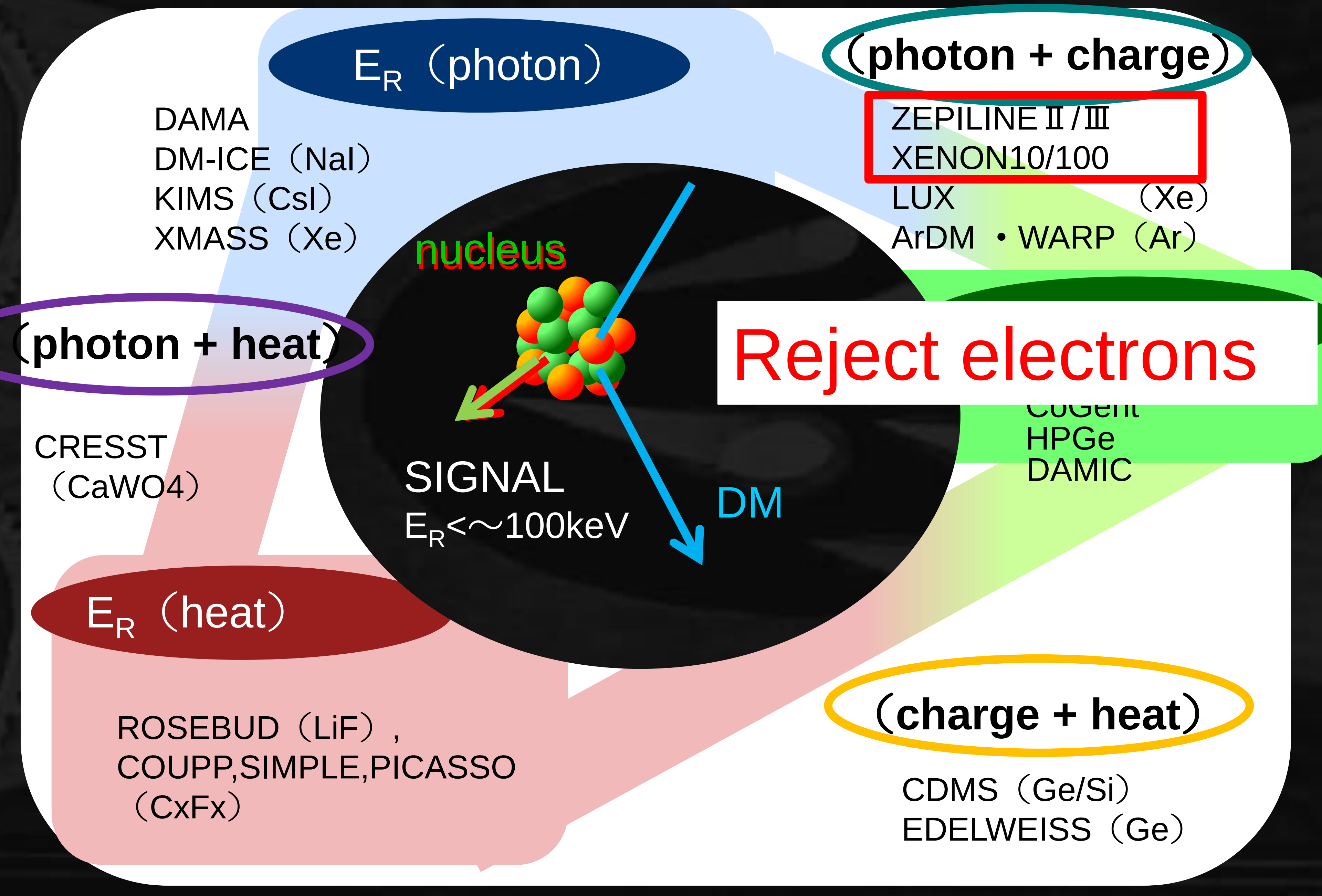
DM direct detection



Key feature 2 :

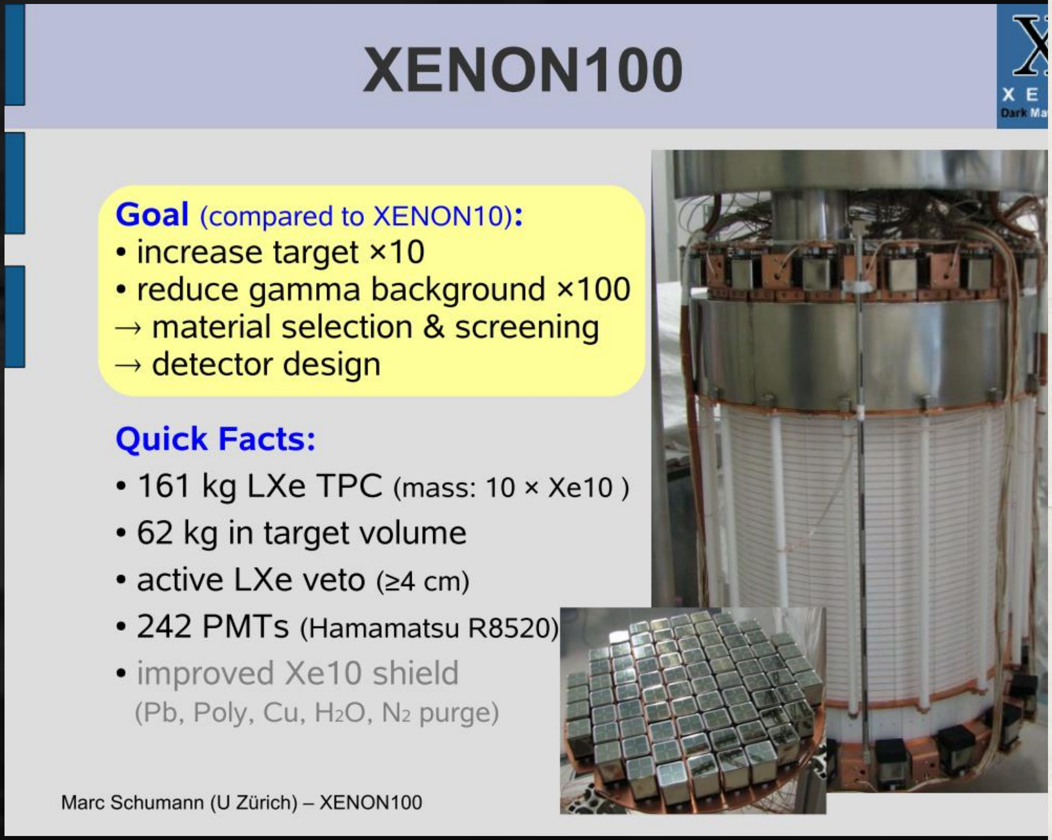
Particle ID for low background

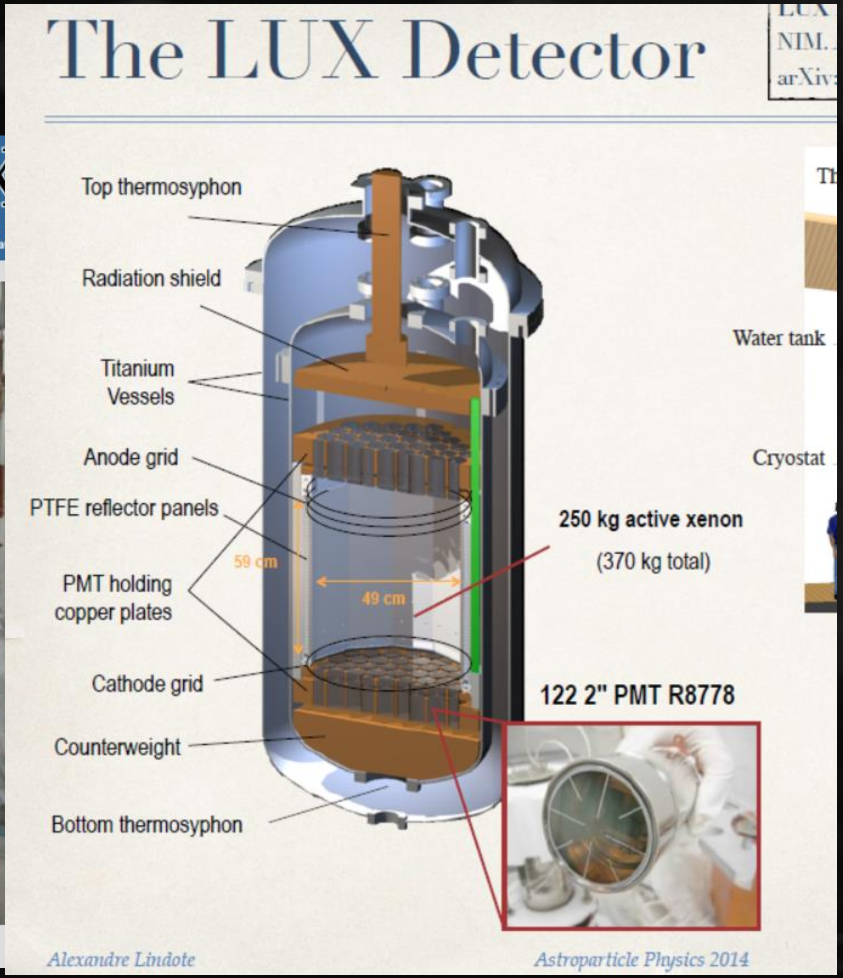
Direct Detection Methods



2-phase Liquid Xenon

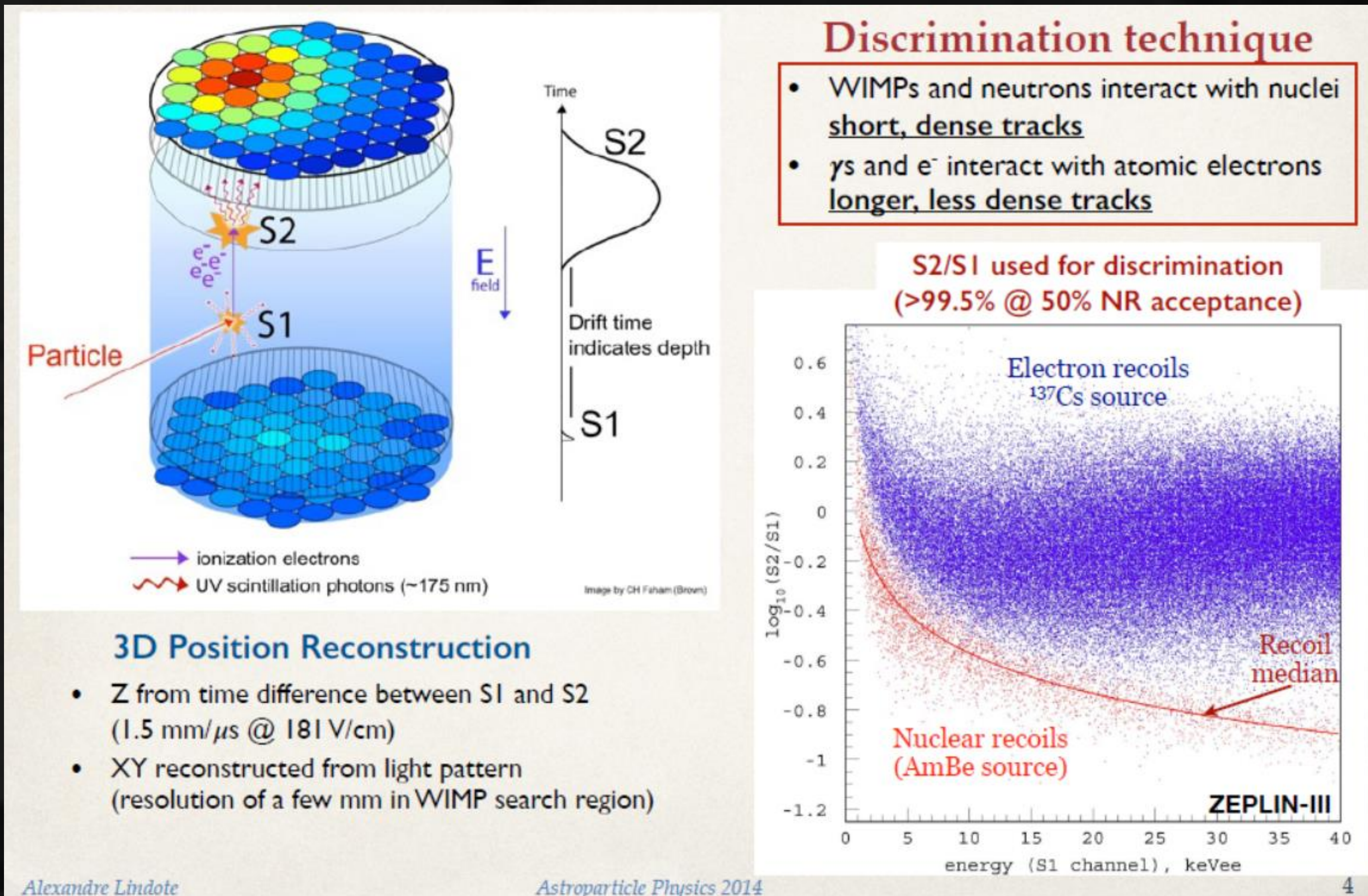
- XENON100：161kg
- LUX：370kg



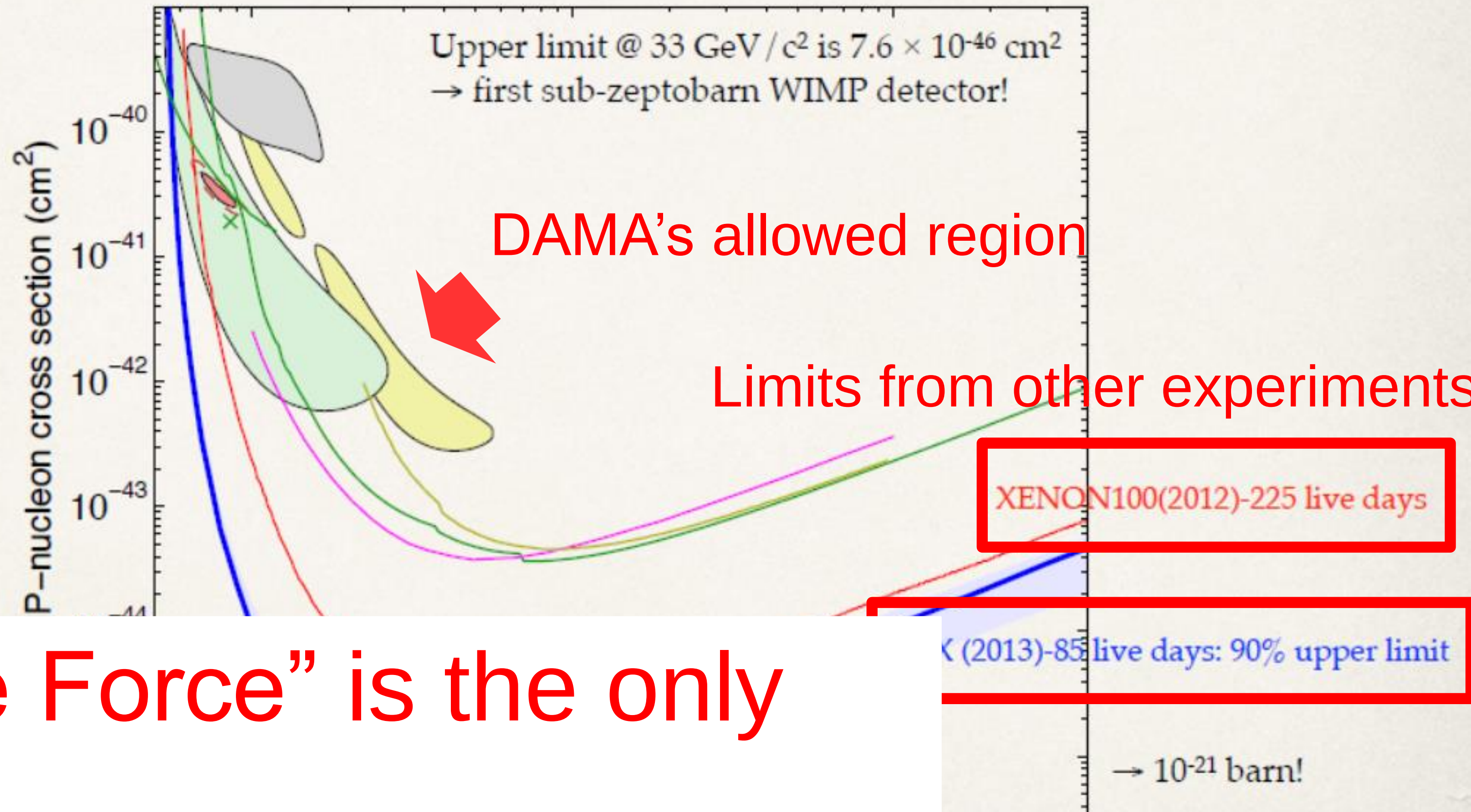


2-phase Liq. Xenon

- **electron rejection**



Spin-independent limit



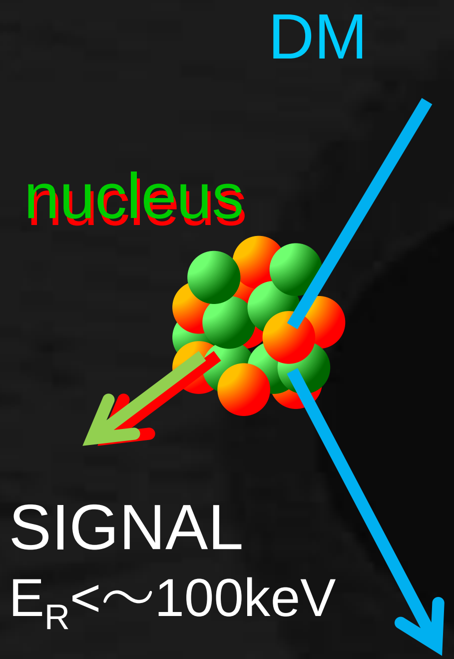
DAMA's allowed region

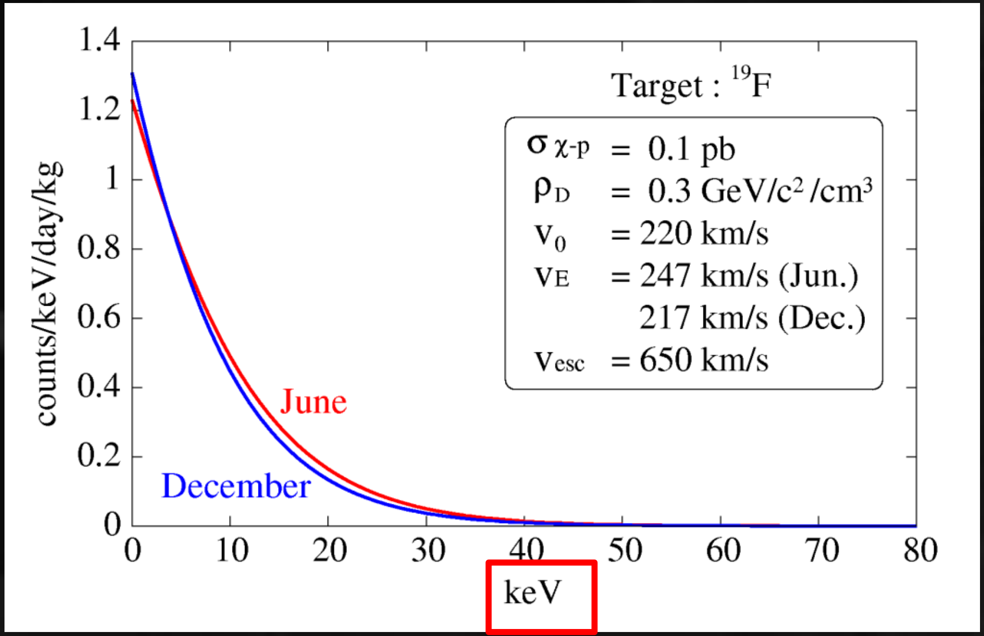
Limits from other experiments

"Brute Force" is the only way?

again NO!

DM direct detection





Key feature 3: Low threshold

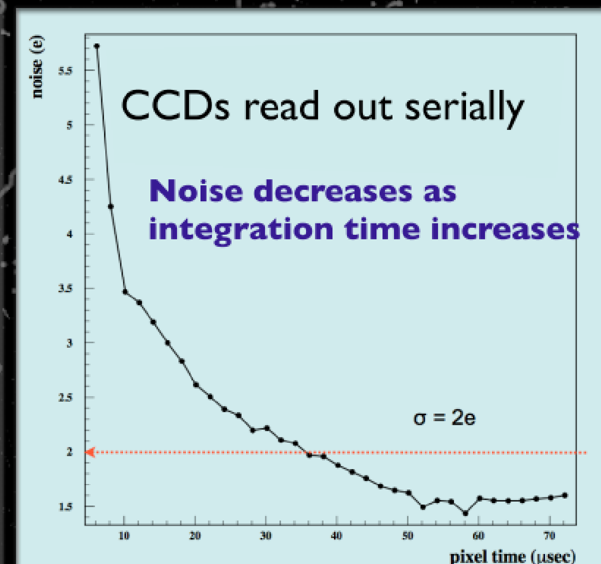
Low threshold

J. Barreto et al. / Physics Letters B 711 (2012) 264–269

- DAMIC （CCD　0.5 g）
- Extremely low threshold

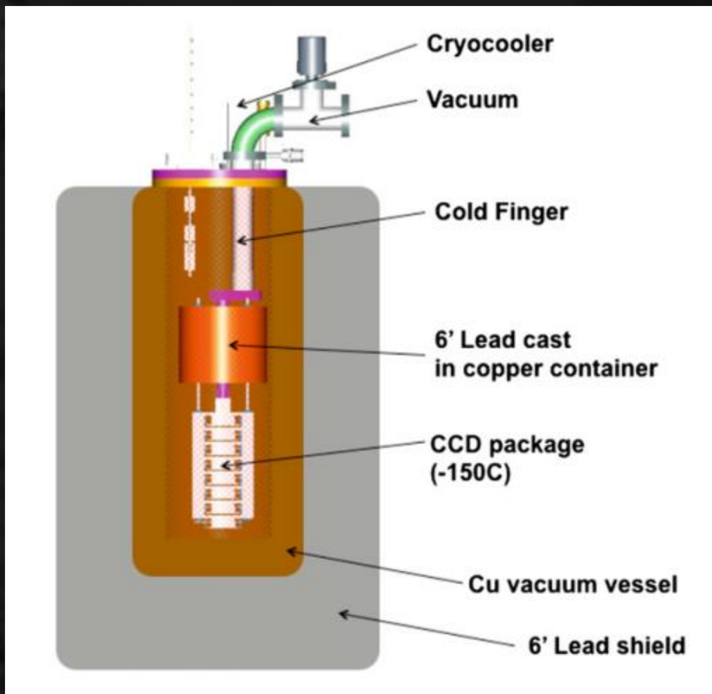
Energy threshold for DM search

- CCDs cooled to -150 C to reduce noise
- 50 μs / pixel
  - RMS of 2 e-
    - 7.2 eV equivalent ionizing in Silicon
  - Threshold of 40 eVee
    - Lowest of current DM experiments
- We are pushing energy threshold even further
  - RMS of 0.2 e- may be possible



Experiment	Threshold
DAMIC	0.04 keV_{ee}
COGENT	0.5 keV_{ee}
CDMS II	3 keV_{ee}
Xenon 100	8.4 keV_{nr}

- exposure 0.5g × 11month
- comparable to kg-scale detectors



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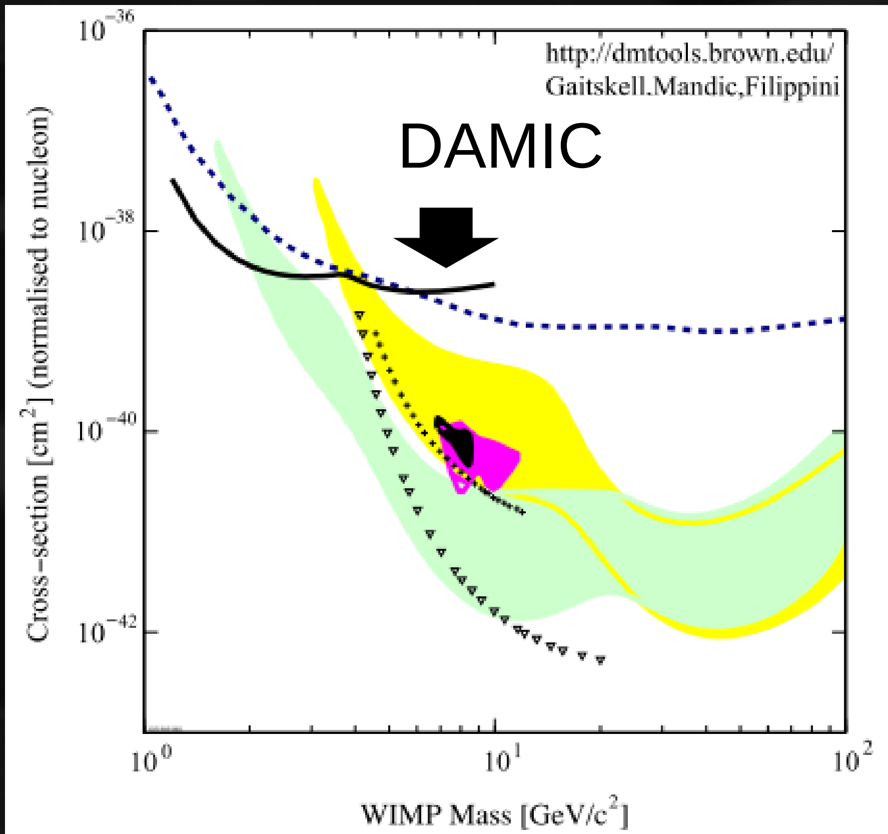
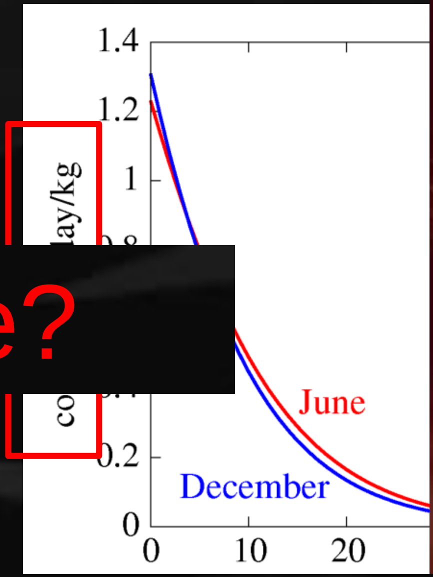
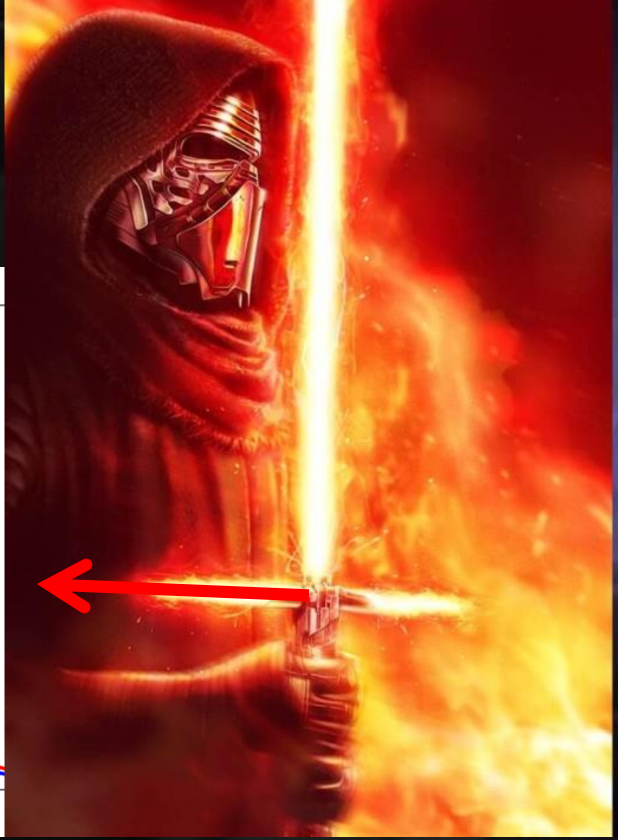


Fig. 13. Cross section upper limit at 90% C.L. for the DAMIC results (solid black) compared to CRESST 2001 (dashed blue), XENON10 [40] (triangles) and CDMS [41] (crosses). The shaded areas correspond to the 5-sigma contour consistent with the DAMA/LIBRA annual modulation signal (yellow: no ion channeling, green: ion channeling) [39]. The magenta contour corresponds to the DM interpretation of the CoGent observed excess and the black contour is the region of interest for the CoGent annual modulation signal [4]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

DM direct detection

ANYTHING else?





YES, we have another AXIS

Key feature 1 : Large mass

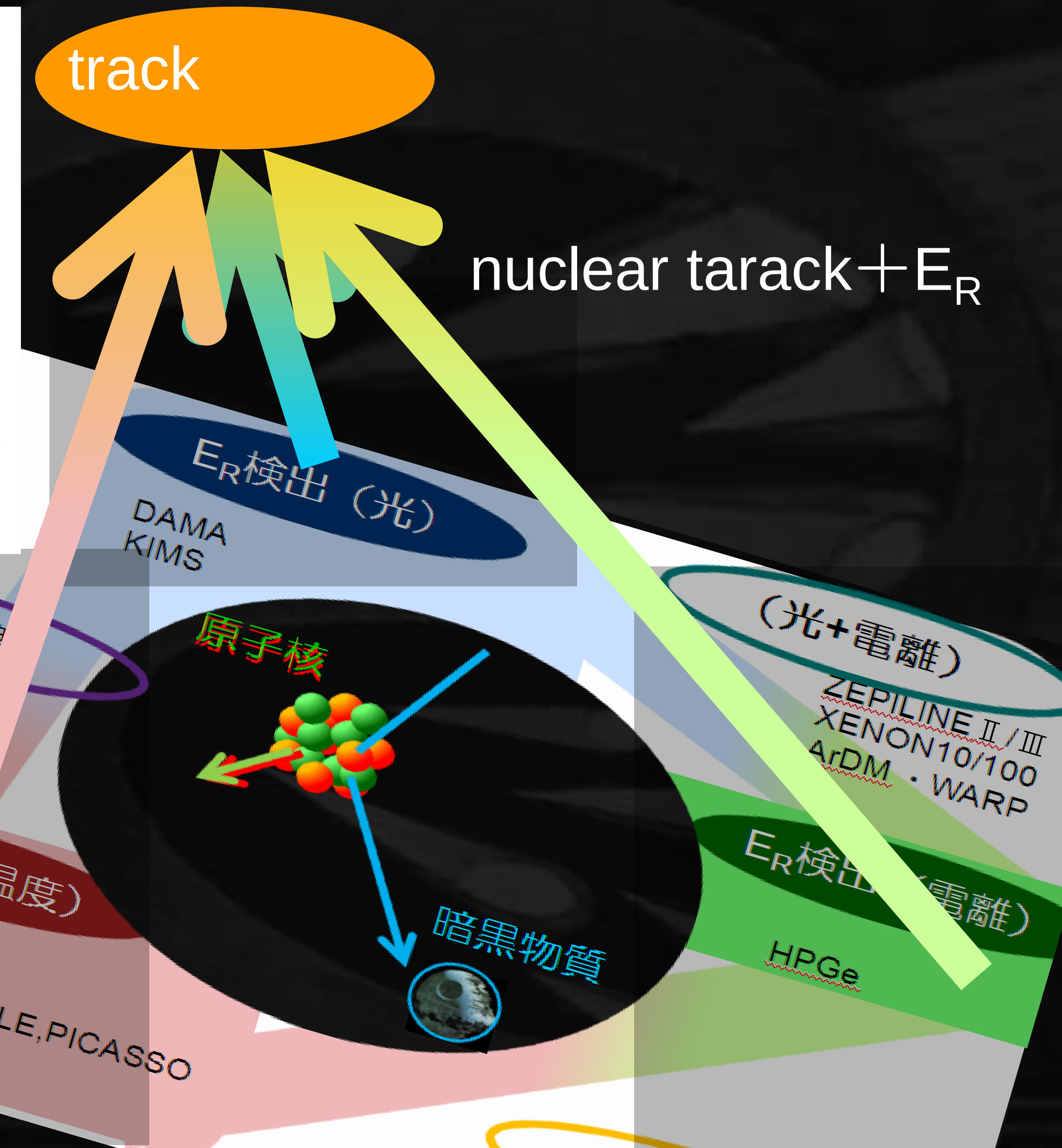
Key feature 2 : Particle ID

Key feature 3: Low threshold

another axis：nuclear track

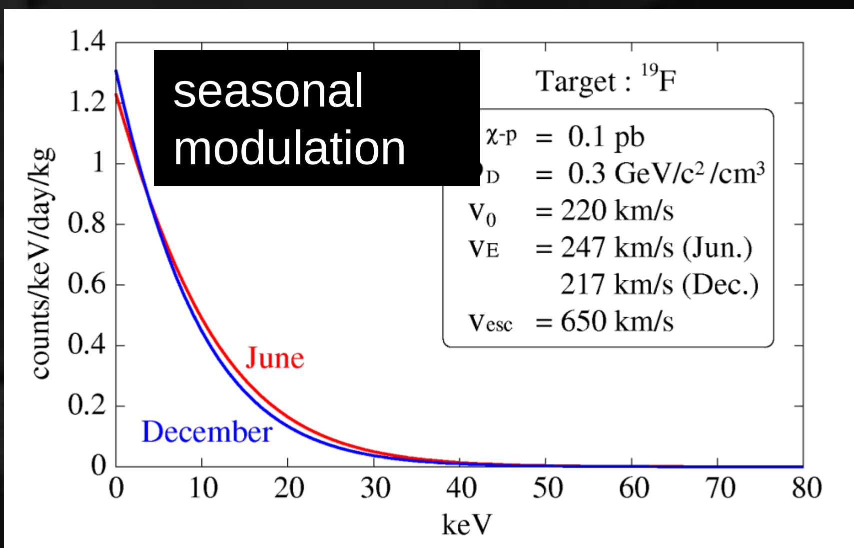
PRL73(1994)1067

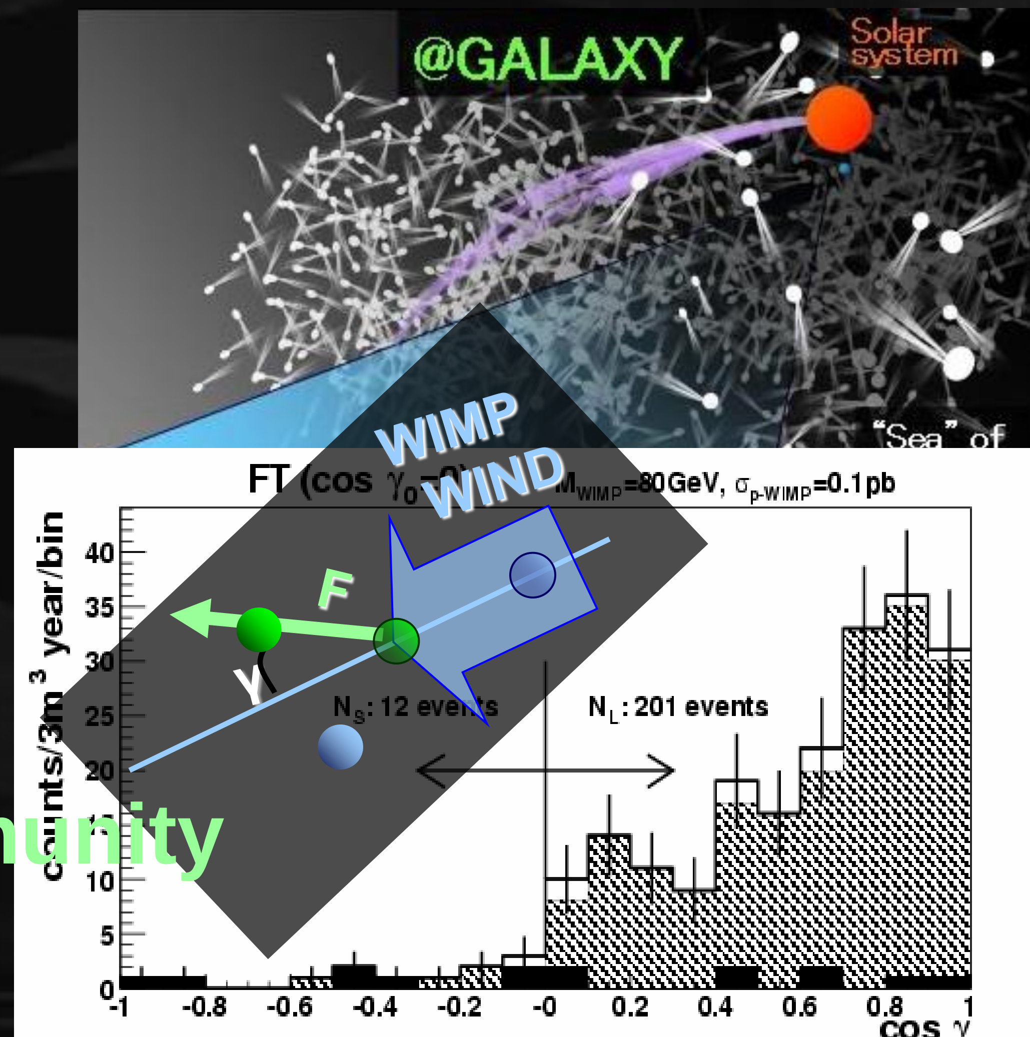
FIG. 2. A false color CCD image resulting from a ^{252}Cf neutron source. The colors black, blue, red, and white represent the order of increasing light intensity levels. The area displayed represents a 25 cm by 25 cm section of the detector plane. See the text for a description of image features.



Recoil nucleus tracks?

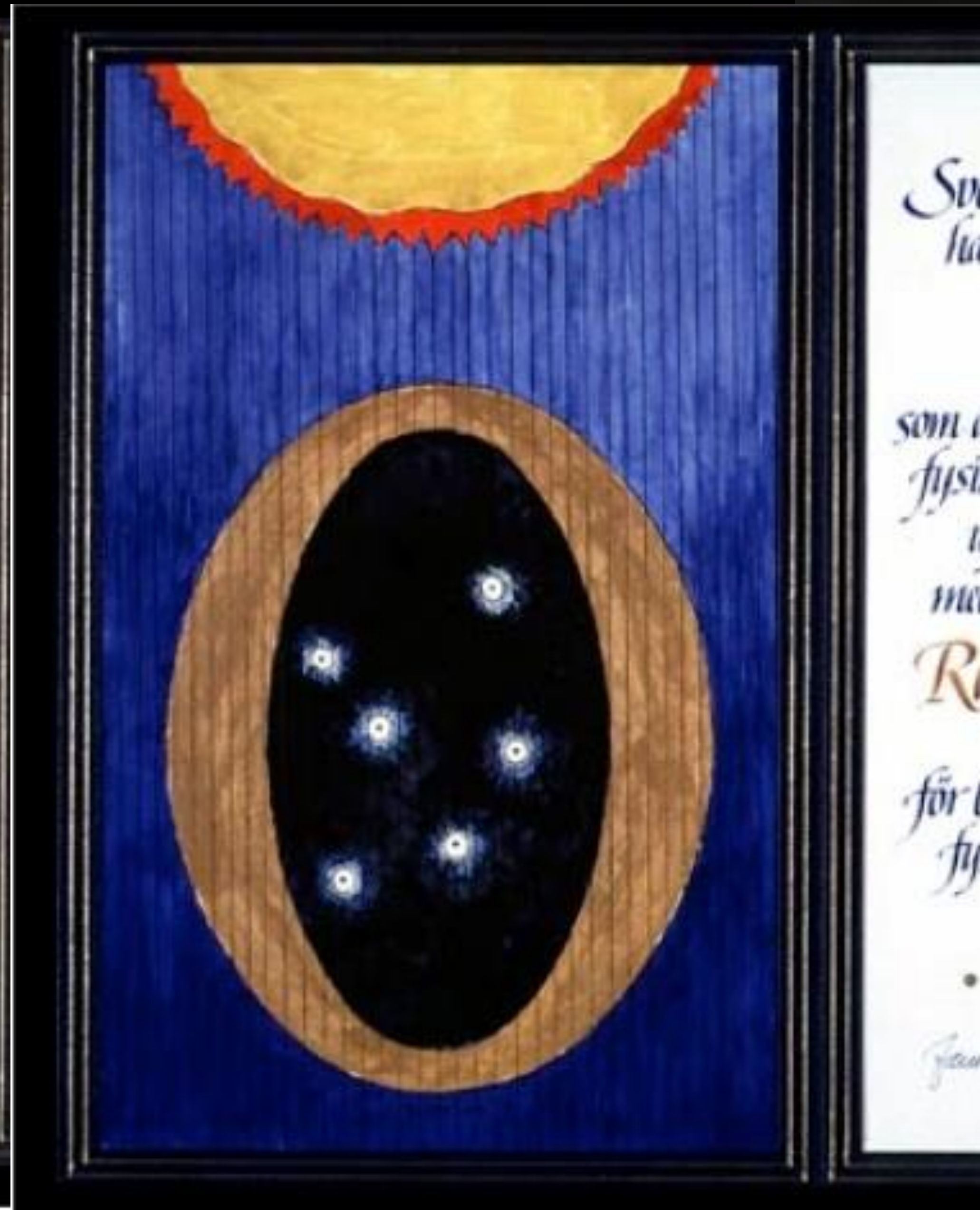
- Direction-sensitive to DM
- Large asymmetry due to the solar motion
- DM-WIND



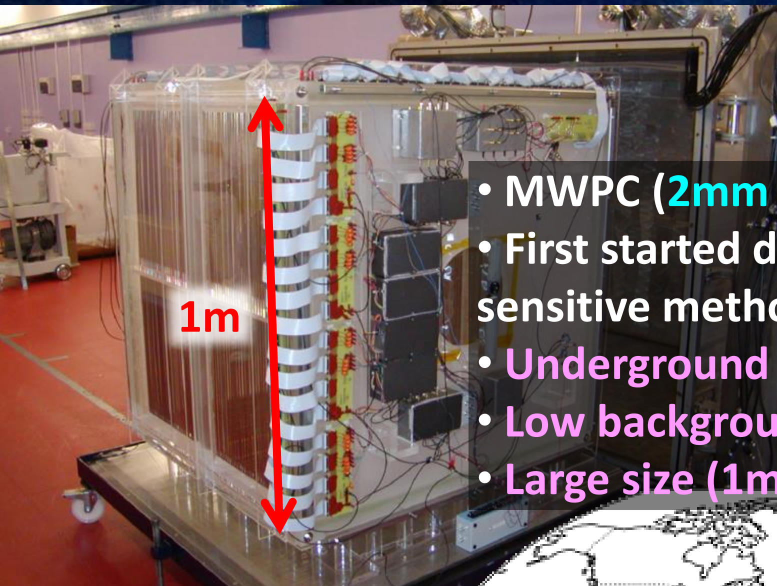


International community "CYNGUS"

- Is direction sensitivity important? YES.

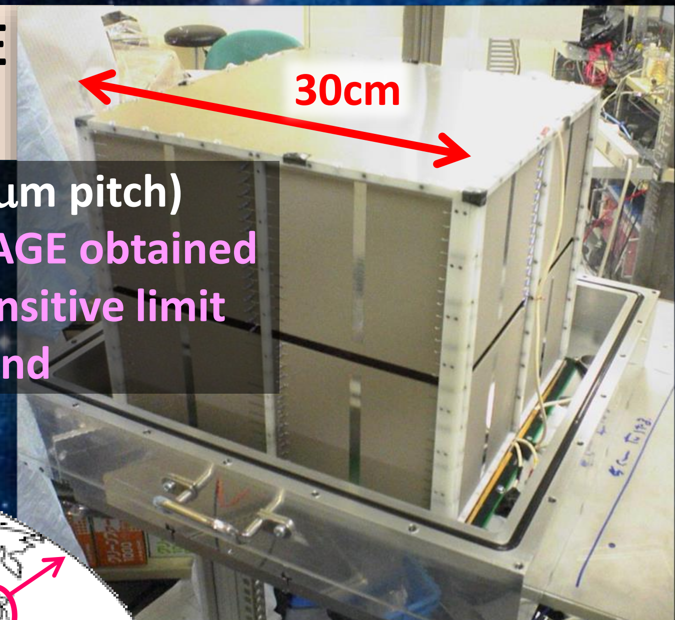


Cygnus, awaken.



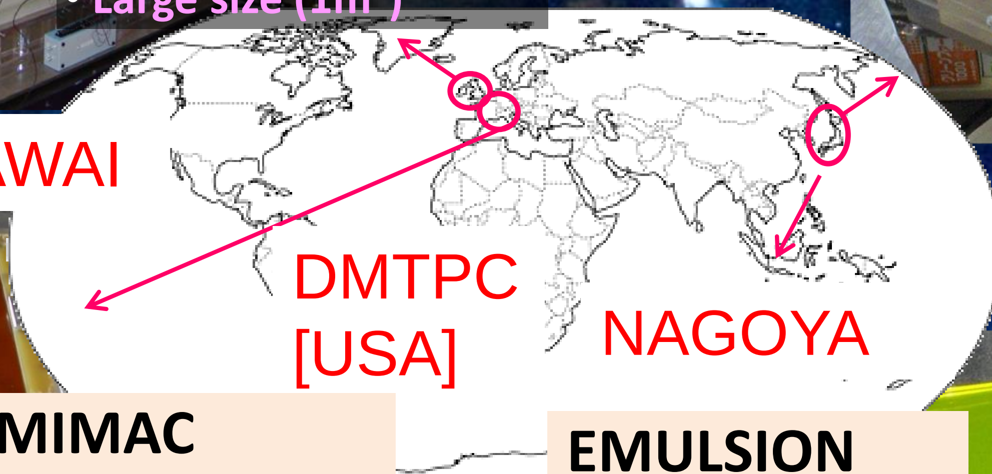
DRIFT
[UK]

- MWPC (2mm pitch)
- First started direction-sensitive method
- Underground
- Low background
- Large size (1m³)



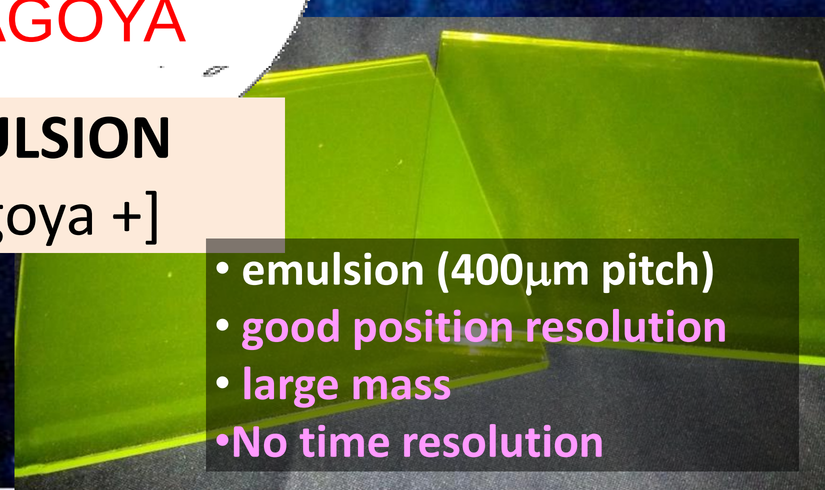
NEWAGE
[Kobe＋]

- μ-PIC (400μm pitch)
- Only NEWAGE obtained direction-sensitive limit
- Underground



MIMAC
[France]

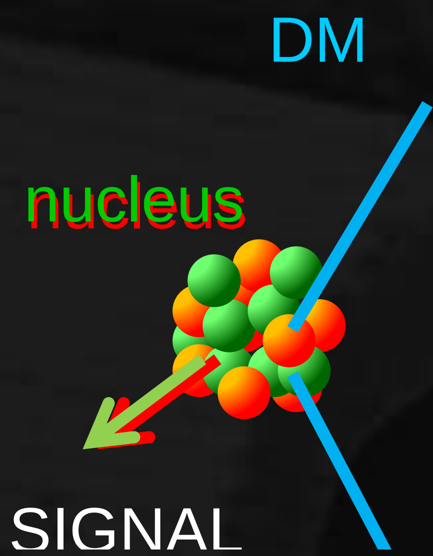
- Micromegas (~400μm pitch)
- Measured quenching factor in detail
- R&D at surface

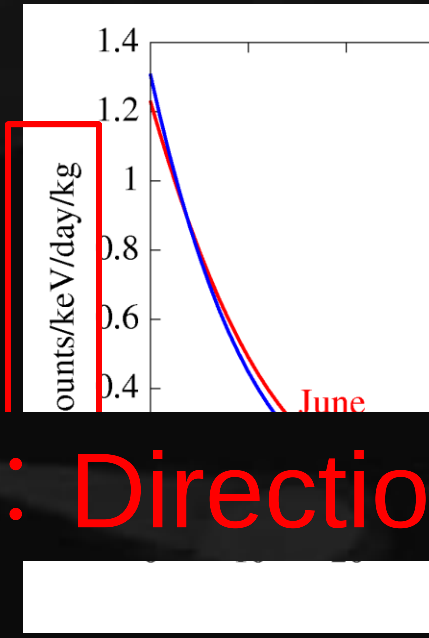


EMULSION
[Nagoya +]

- emulsion (400μm pitch)
- good position resolution
- large mass
- No time resolution

DM direct detection





Special feature：Direction-sensitivity

Key feature 1 : Large mass

Key feature 2 : Particle ID

Key feature 3: Low threshold

Thank you

May the Dark Matter be with you.