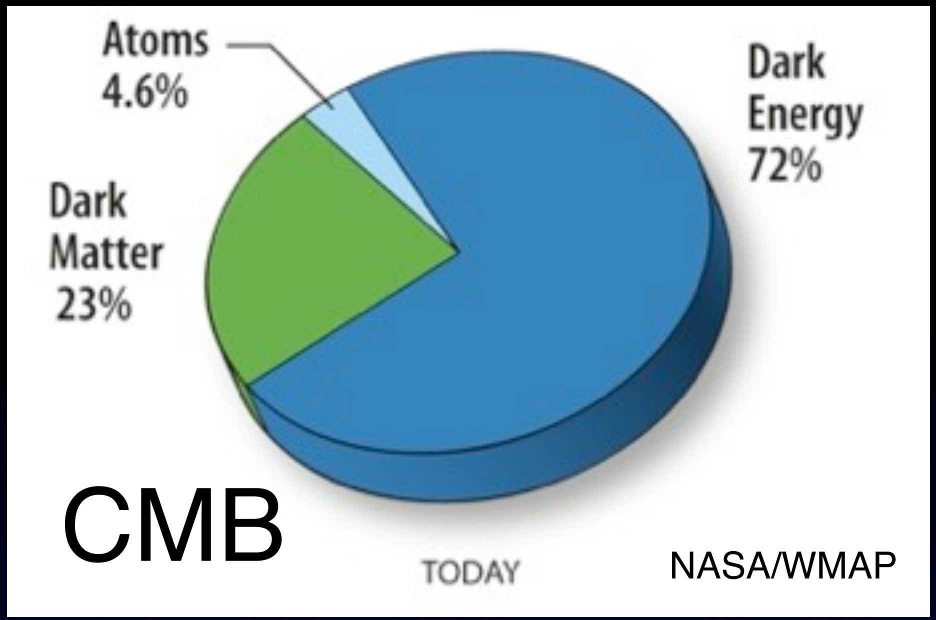
Direct Dark Matter searches

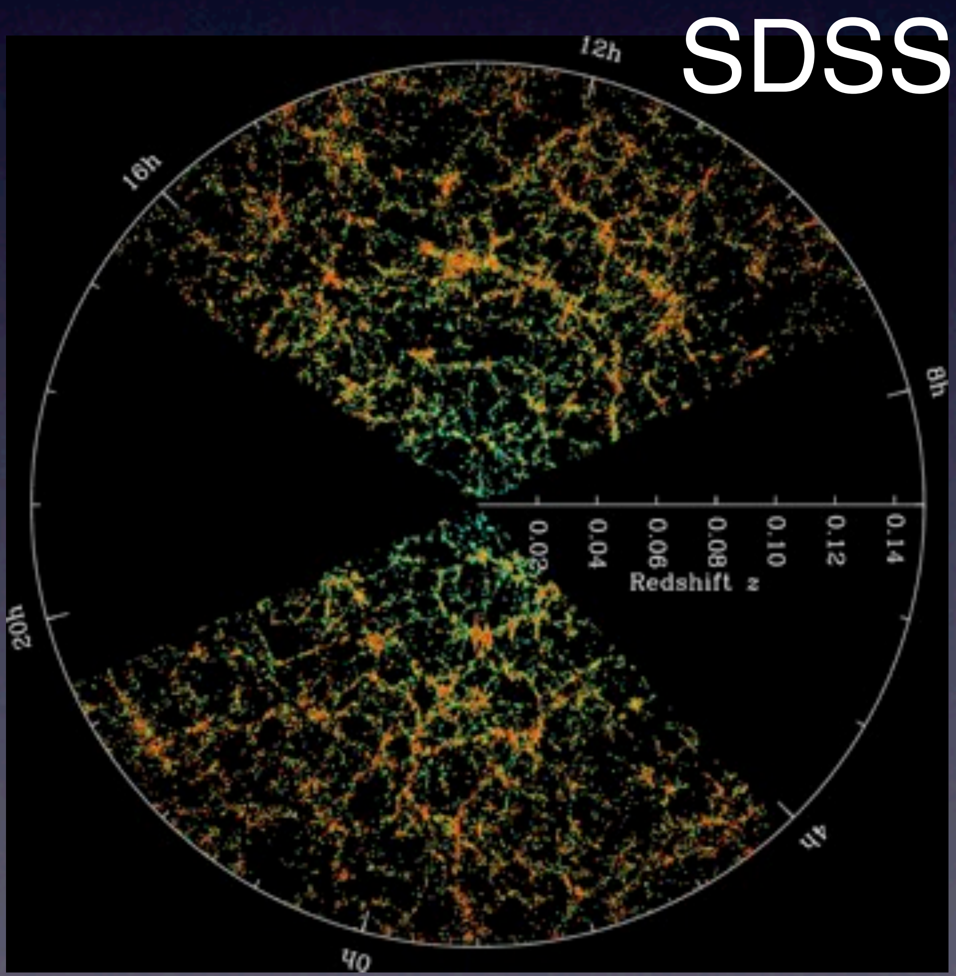
Kamioka Observatory , ICRR,
University of Tokyo
Masaki Yamashita

Outline

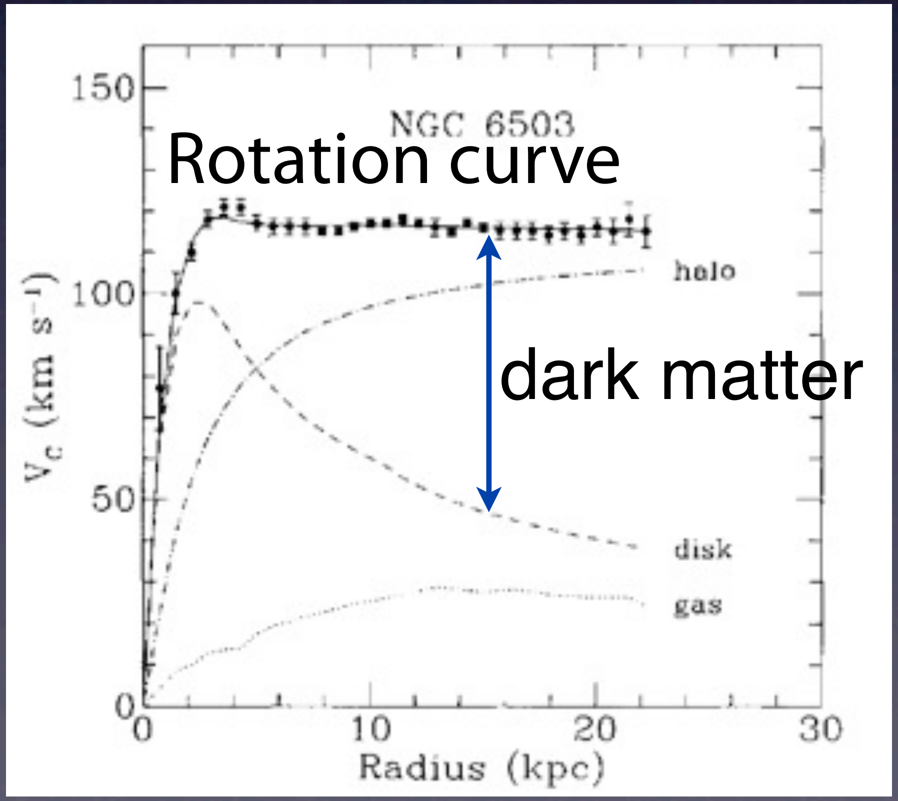
- Introduction
- Detection of WIMP
- Review of Direct Dark Matter Search Experiments
- Summary and Future prospects

Variety Observation





M. Blanton and the SDSS



Weakly Interacting Massive Particle

astrophysics

Dark Matter is required to be

- Neutral
  ➡ can not see ...
- Non-baryonic
  ➡ weakly interacting
- Cold (non-relativistic)
  ➡ large scale structure
- New Particle ?
  ➡ neutralino, Kaluza-Klein particle, axion gravitino ...

particle physics

SUSY

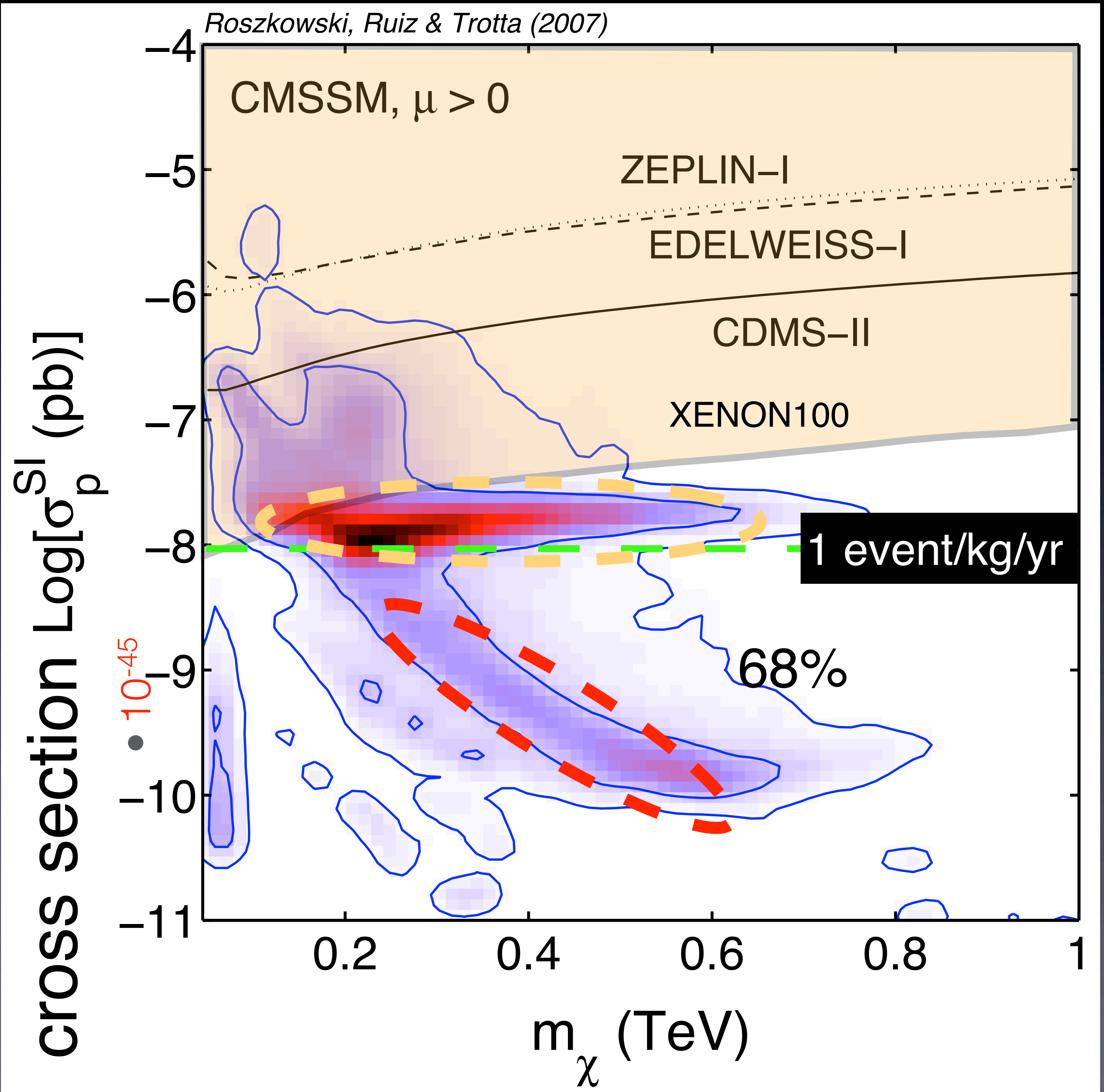
⇒ One of the favored scenario:

The lightest SUSY particle is stable and likely becomes a dark matter candidate

Linear combination of SUSY particles

$$\chi_1^0 = \alpha_1 \tilde{B} + \alpha_2 \tilde{W} + \alpha_3 \tilde{H}_u^0 + \alpha_4 \tilde{H}_d^0$$

Sensitivity and SUSY Parameter

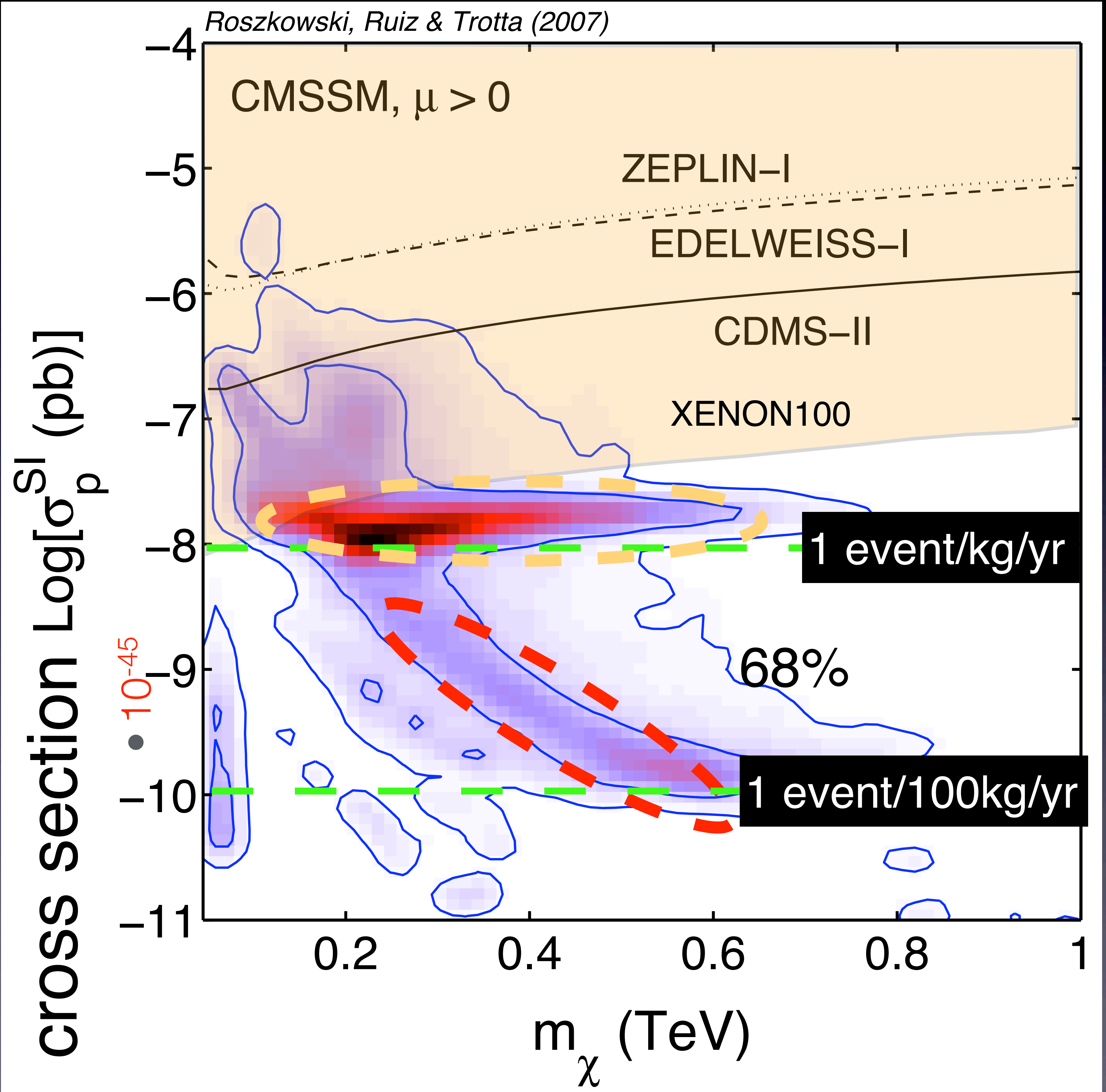


CMSSM in 2007
hep-ph 0705.2012v1
Roszkowski et al.

near future

Super CDMS, XENON100, LUX, XMASS, COUPP, CRESST-II, EDELWEISS-II, ZEPLIN-III,...

Sensitivity and SUSY Parameter



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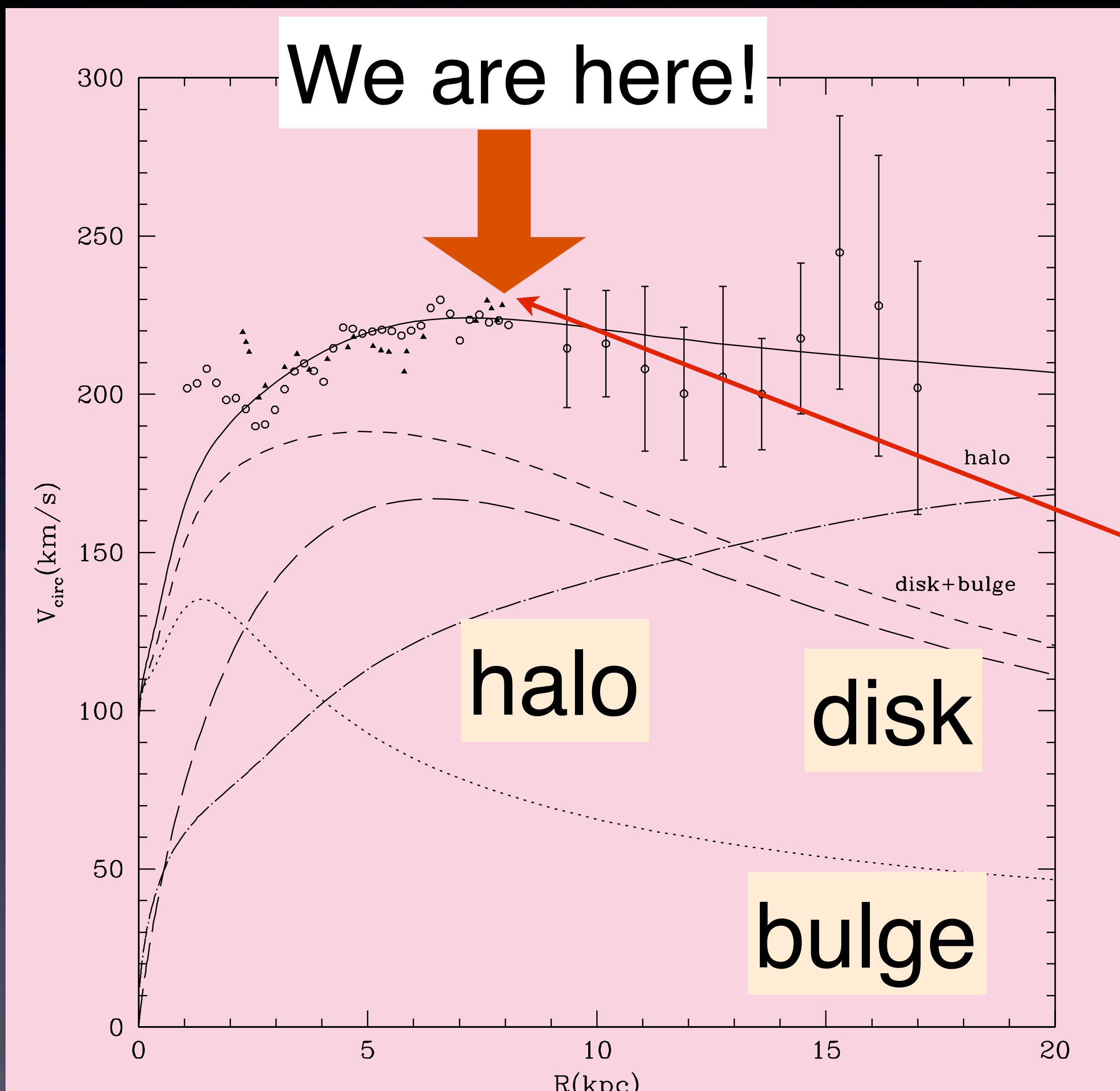
near future

Super CDMS, XENON100, LUX, XMASS, COUPP, CRESST-II, EDELWEISS-II, ZEPLIN-III,...

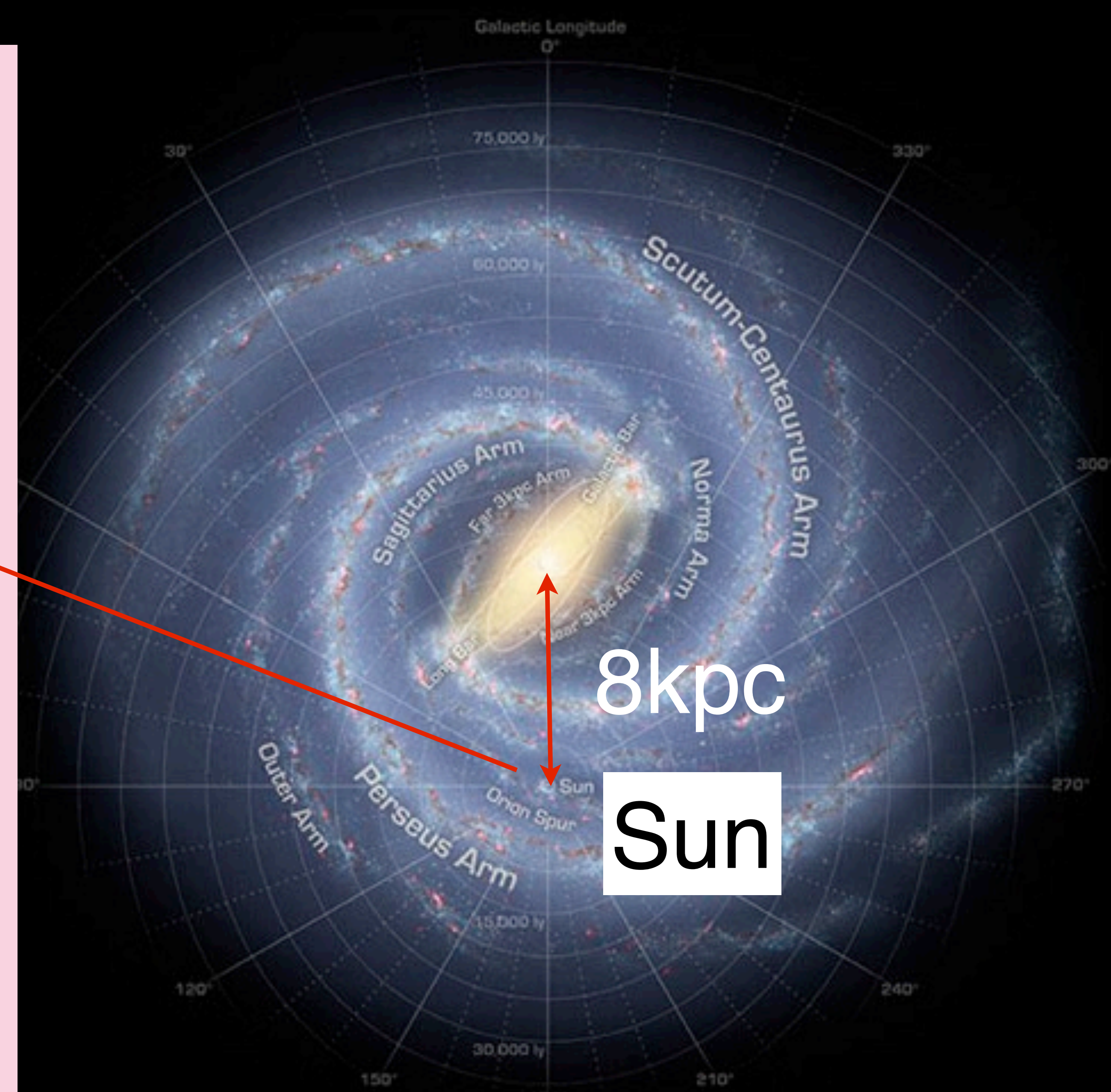
Future experiments

SuperCDMS1t, XENON1t, LZ, Darwin ArDM ,XMASS 20T, ...

How much DM around us ?



KLYPIN et al. APJ 2002



NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

Normally, we take ρ_{dm} ~0.3 GeV/cm^3 , v_{earth} ~ 230km/sec

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How much DM around us ?

Kinematical and chemical vertical structure of the Galactic thick disk[1,2]
II. A lack of dark matter in the solar neighborhood

arXiv:1204.3924v1

C. Moni Bidin

Departamento de Astronomía, Universidad de Concepción, Casilla 160-C, Concepción, Chile

cmbidin@astro-udec.cl

G. Carraro[1]

European Southern Observatory, Alonso de Cordova 3107, Vitacura, Santiago, Chile

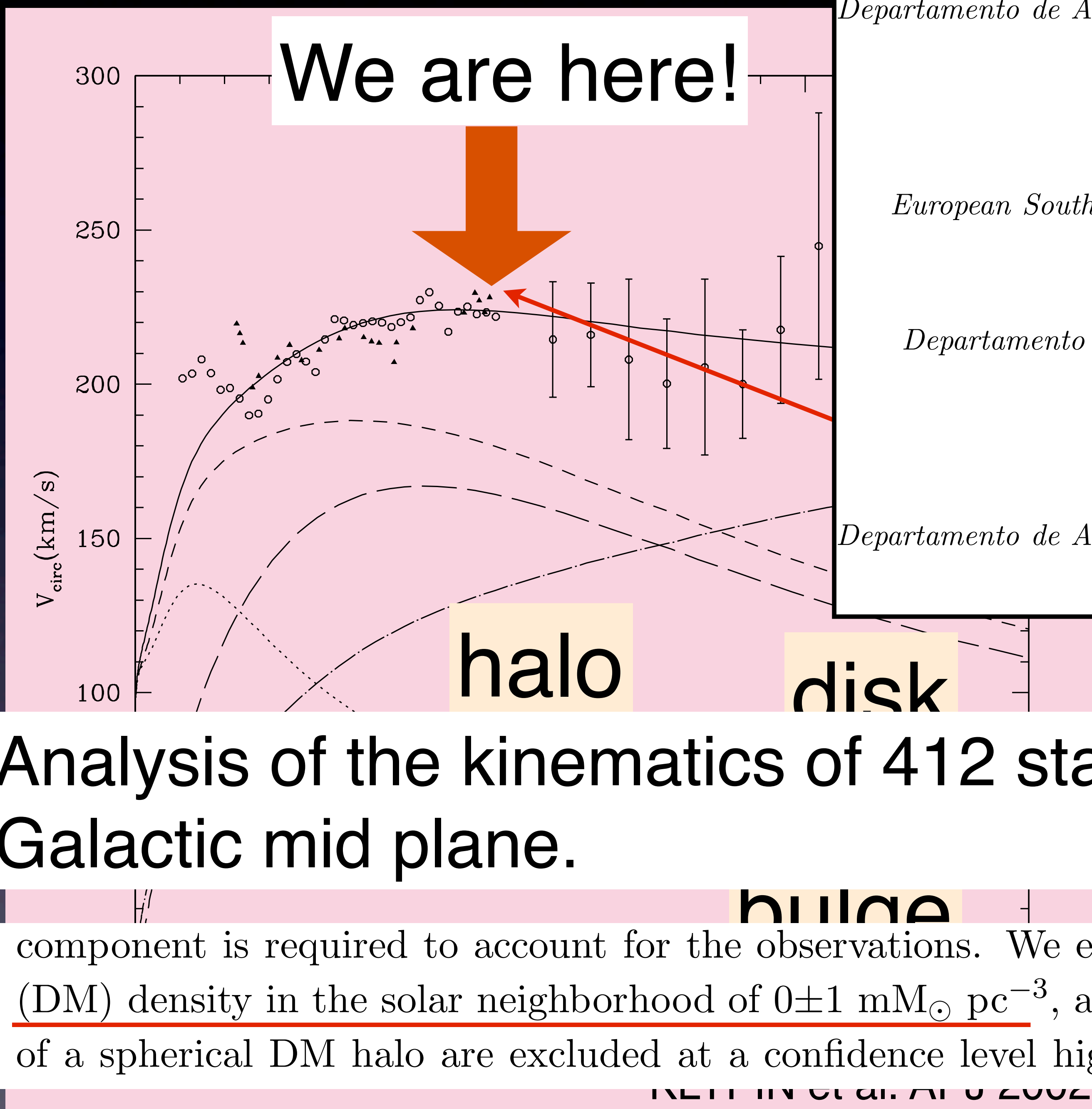
R. A. Méndez

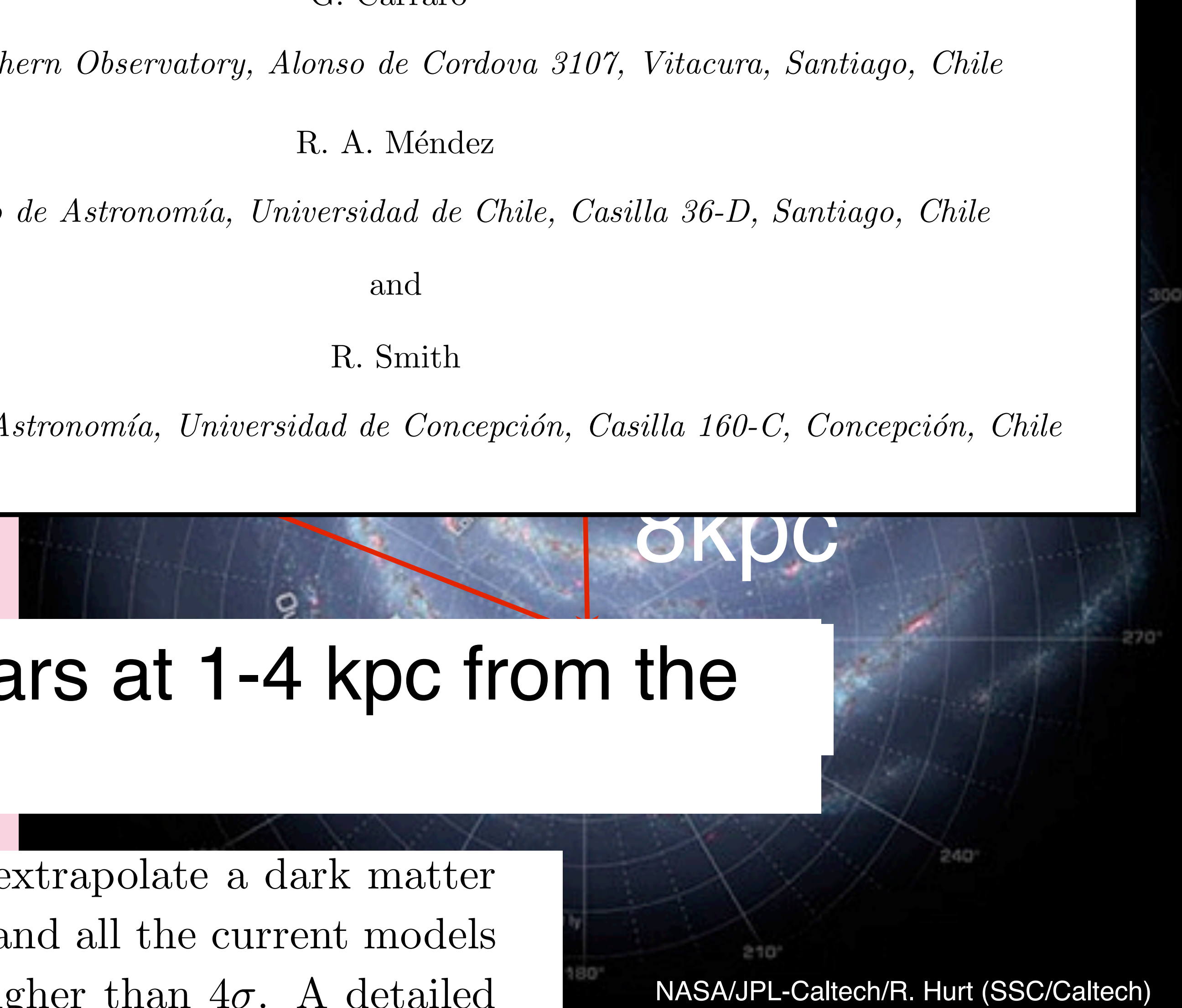
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

and

R. Smith

Departamento de Astronomía, Universidad de Concepción, Casilla 160-C, Concepción, Chile





Analysis of the kinematics of 412 stars at 1-4 kpc from the Galactic mid plane.

component is required to account for the observations. We extrapolate a dark matter (DM) density in the solar neighborhood of 0 ± 1 mM$_\odot$ pc^{-3}, and all the current models of a spherical DM halo are excluded at a confidence level higher than 4σ. A detailed

Normally, we take ρ_{dm} ~0.3 GeV/cm^3 , v_{earth} ~ 230km/sec

Masaki Yamashita

How much DM around us ?

Kinematical and chemical vertical structure of the Galactic thick disk[1,2]
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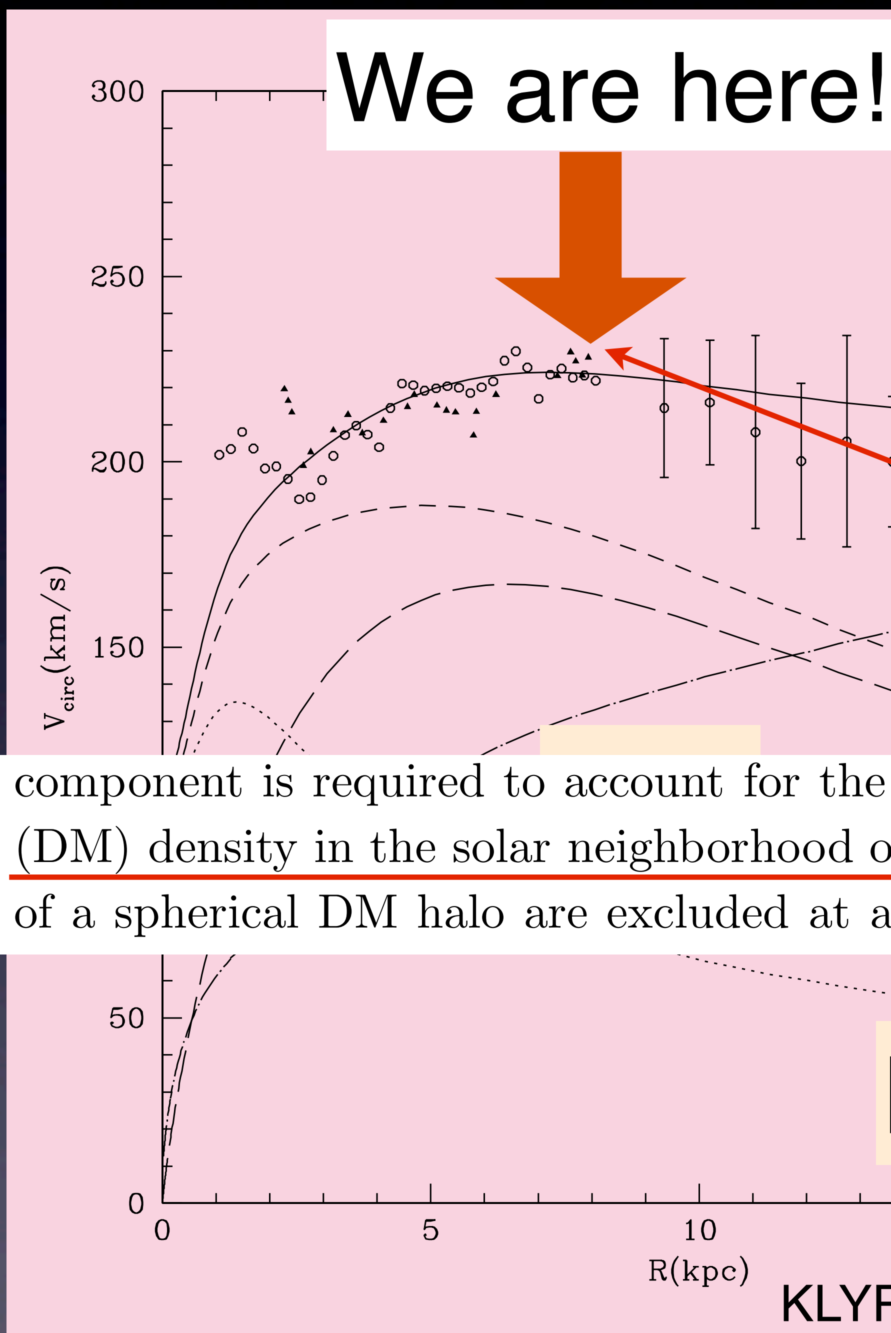

component is required to account for the
(DM) density in the solar neighborhood o
of a spherical DM halo are excluded at a

On the local dark matter density

Jo Bovy[1] and Scott Tremaine

Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540, USA

ABSTRACT

An analysis of the kinematics of 412 stars at 1–4 kpc from the Galactic mid-plane by Moni Bidin et al. (2012) has claimed to derive a local density of dark matter that is an order of magnitude below standard expectations. We show that this result is incorrect and that it arises from the invalid assumption that the mean azimuthal velocity of the stellar tracers is independent of Galactocentric radius at all heights; the correct assumption—that is, the one supported by data—is that the circular speed is independent of radius in the mid-plane. We demonstrate that the assumption of constant mean azimuthal velocity is physically implausible by showing that it requires the circular velocity to drop more steeply than allowed by any plausible mass model, with or without dark matter, at large heights above the mid-plane. Using the correct approximation that the circular velocity curve is flat in the mid-plane, we find that the data imply a local dark-matter density of $0.008 \pm 0.002\, M_\odot\, \mathrm{pc}^{-3} = 0.3 \pm 0.1\, \mathrm{Gev\ cm}^{-3}$, fully consistent with standard estimates of this quantity. This is the most robust direct measurement of the local dark-matter density to date.

Normally, we take ρ_{dm} ~0.3 GeV/cm^3 , v_{earth} ~ 230km/sec

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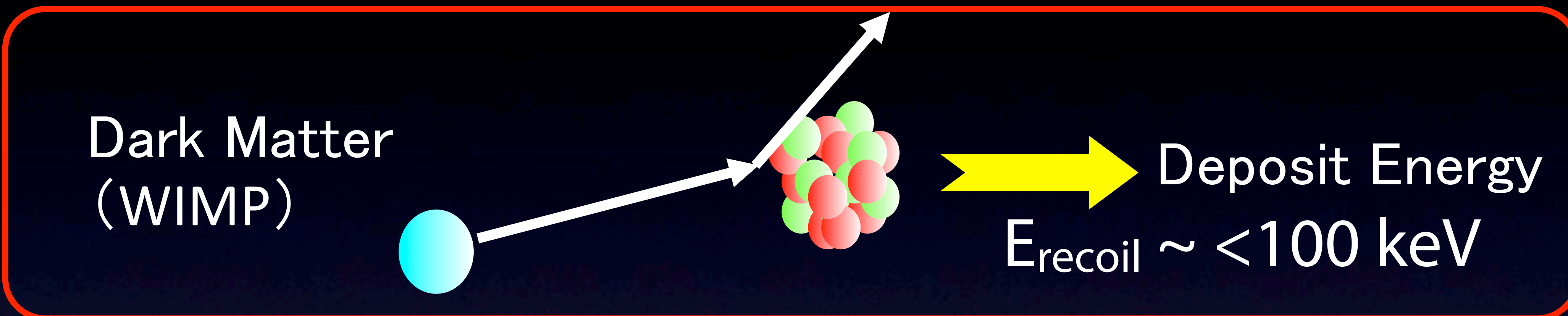
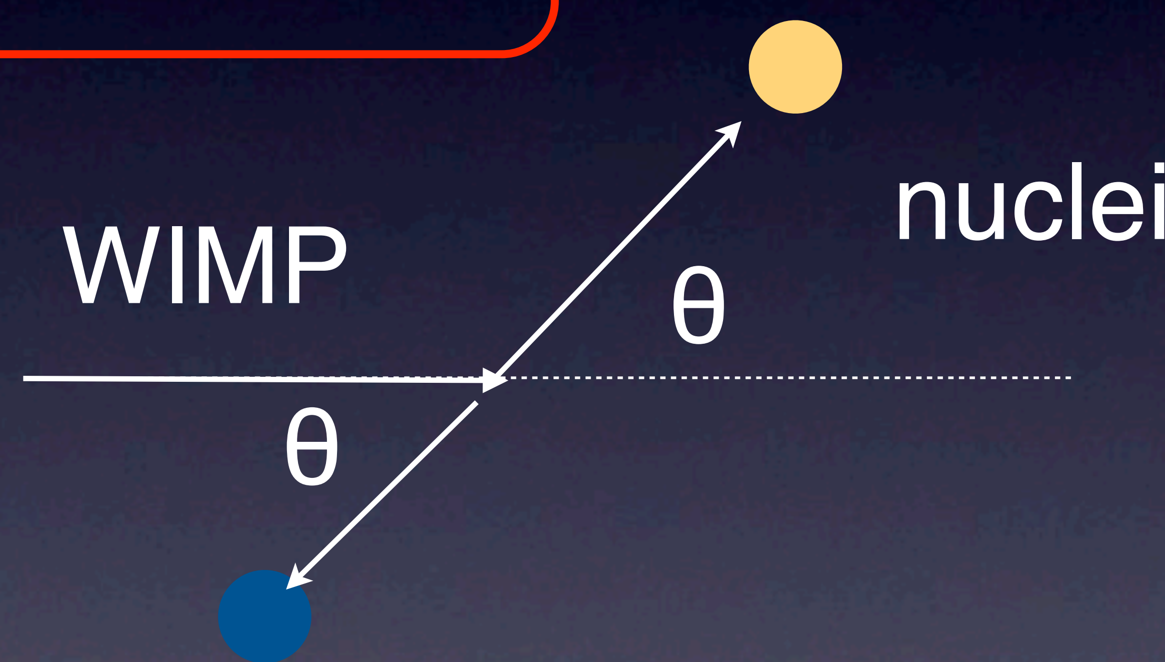
Direct Detection Principle

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

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

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

$$= 30 \text{ keV}$$

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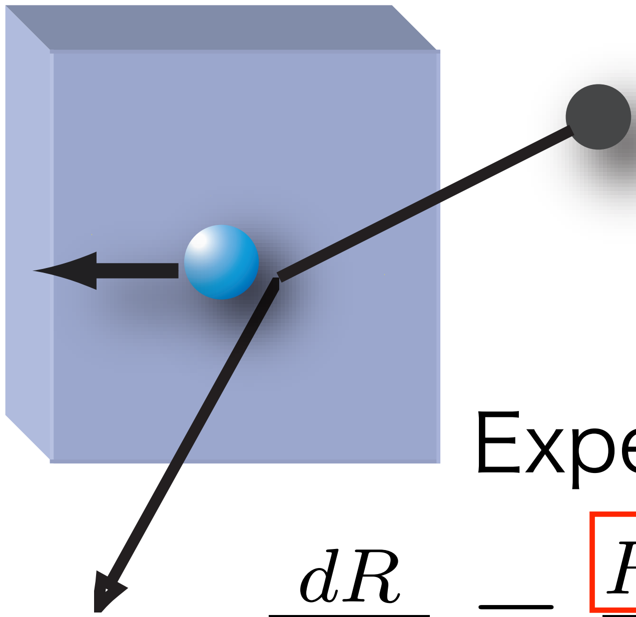
Differential Rate



Measuring the deposited energy due to elastic scattered nuclei by WIMP.

Expected spectrum:

$$\frac{dR}{dE_R} = \frac{R_0 F^2(E_R)}{E_0 r} \frac{k_0}{k} \frac{1}{2\pi v_0} \int_{v_{min}}^{v_{max}} \frac{1}{v} f(\mathbf{v}, \mathbf{v_E}) d^3\mathbf{v}$$

R0: Event rate

F: Form Factor

(depends on atomic nuclei)

motion dynamics

Maxwellian distribution for DM velocity is assumed.

V :velocity onto target,

VE: Earth's motion around the Sun

$$R_0 = \frac{377}{M_\chi M_N} \left(\frac{\sigma_0}{1\text{pb}}\right) \left(\frac{\rho_D}{0.3\text{GeVc}^{-2}\text{cm}^{-3}}\right) \left(\frac{v_0}{230\text{km s}^{-1}}\right) \text{kg d}^{-1}$$

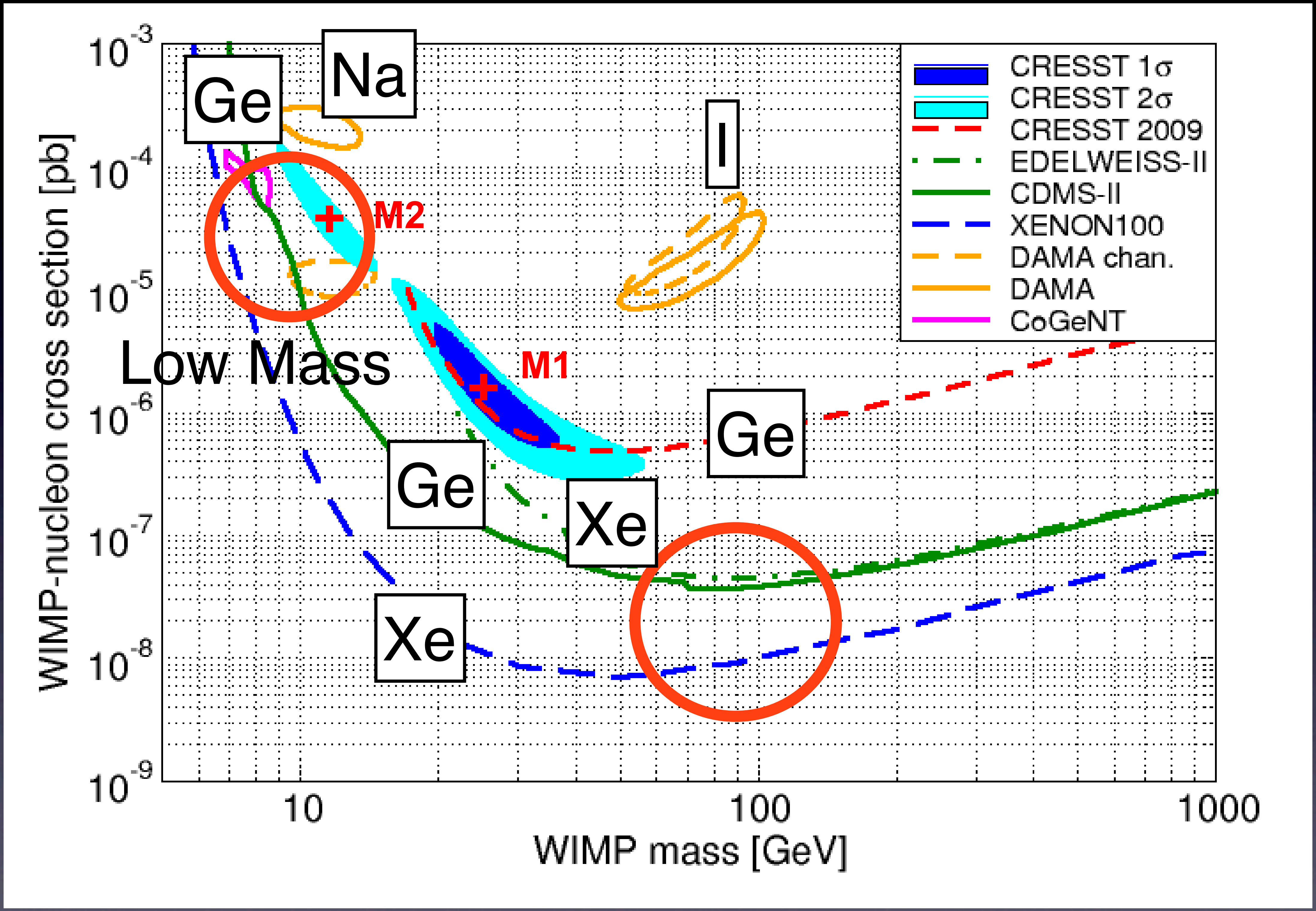
Spin independent

$$\sigma_0 = A^2 \frac{\mu_T^2}{\mu_p^2} \sigma_{\chi-p}$$

Spin dependent

$$\sigma_0 = \frac{(\lambda_{N,Z}^2 J(J+1))^{\text{Nuclear}}}{(\lambda_{p,Z}^2 J(J+1))^{\text{proton}}} \frac{\mu_T^2}{\mu_p^2} \sigma_{\chi-p}$$

Current Status

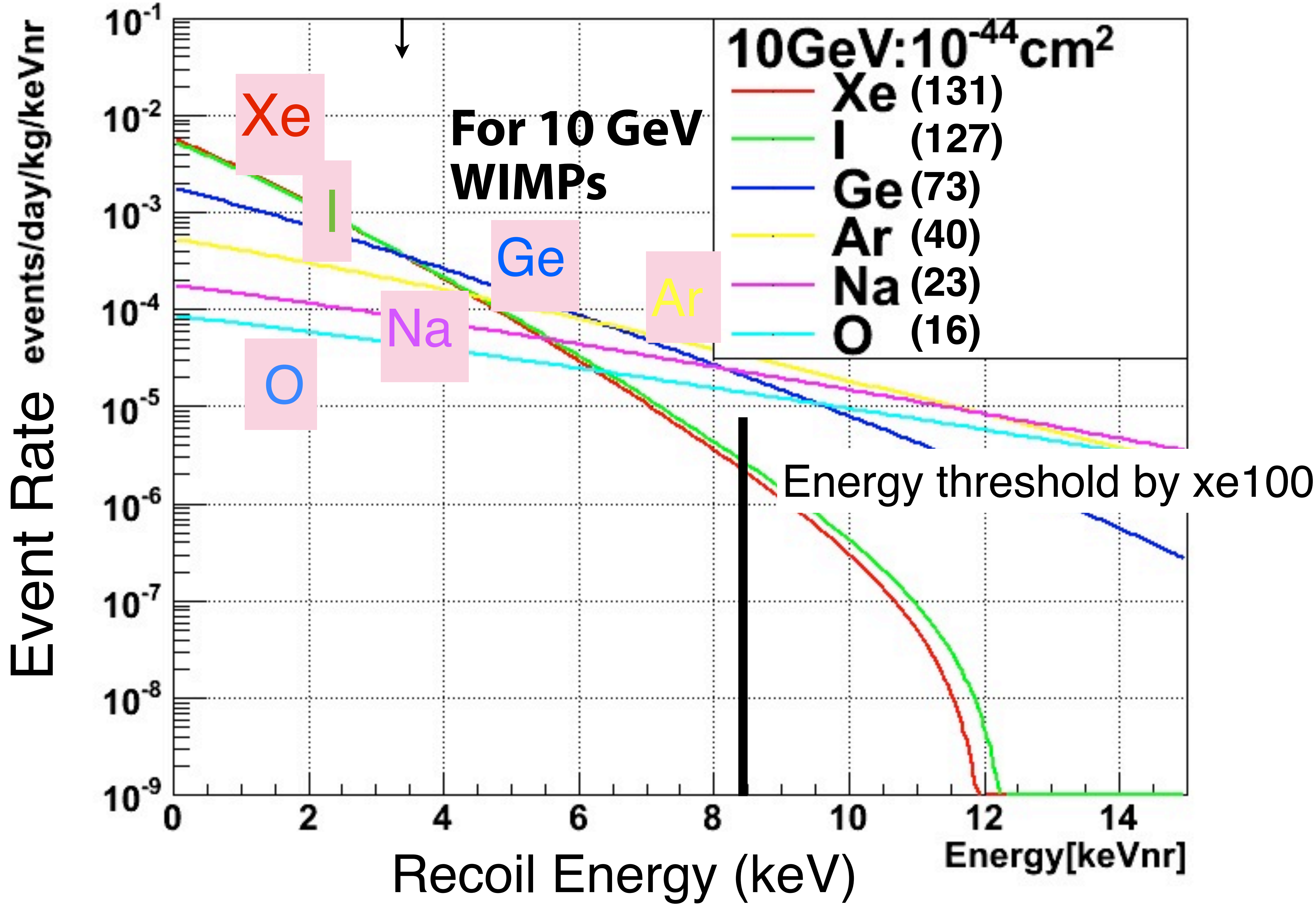


It should be consistent among same target material.

Energy spectrum(spin independent)

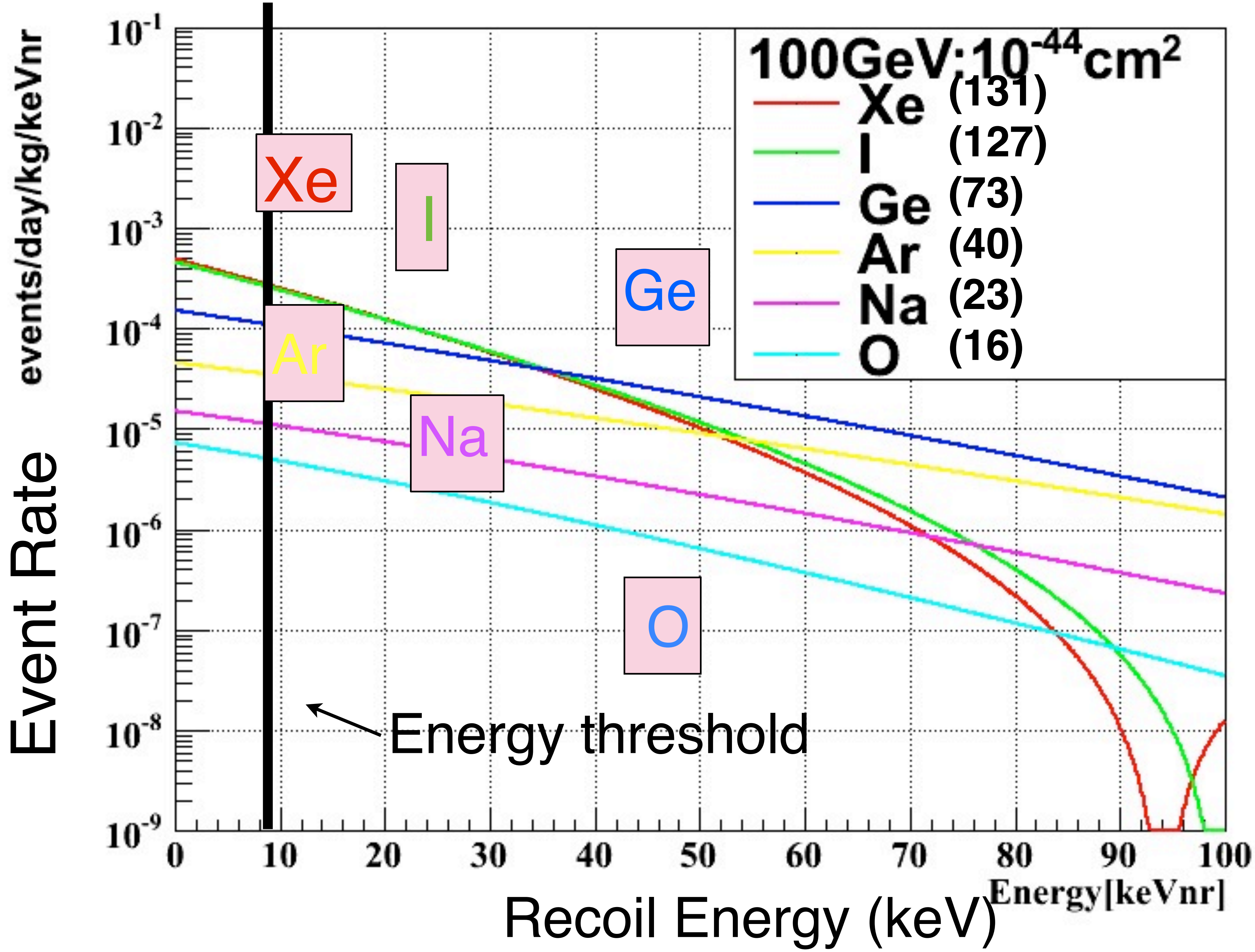
Low mass WIMP -> advantage for small Atomic Mass (Eth>6keVnr)

Energy threshold is very important.



Energy spectrum (spin independent)

heavier WIMP -> advantage for Large Atomic Mass
Detector mass is important. (> 100 kg)



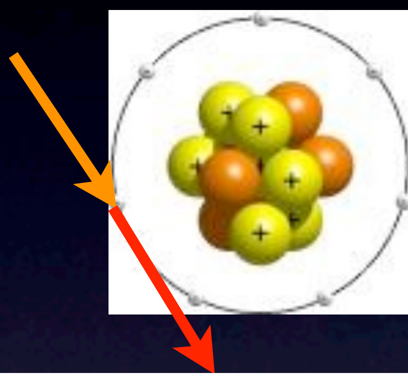
Direct Dark Matter Search in the World

Techniques for Detector

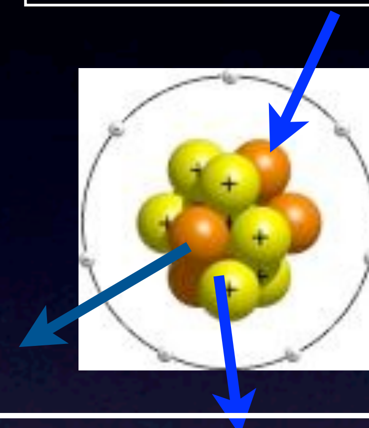
Various Targets: Ge, Xe, Ar, Ne and so on.

Two Signals are used to particle identification to distinguish btw Nuclear Recoil and gamma or beta.

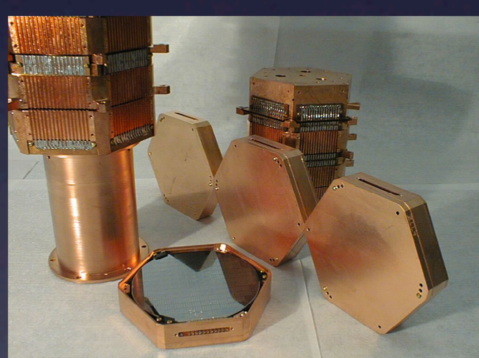
γ/β



WIMP or Neutron

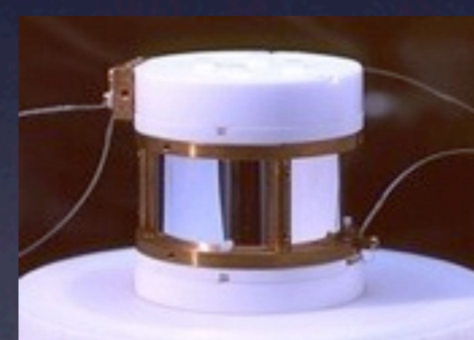


CDMS
EDELWEISS



Phonon

CRESST



CoGENT

Ionization

Light

DAMA, NAIAD,
XMASS,DEEP-CLEAN

ZEPLIN, XENON
WARP, LUX,ArDM,
DarkSide

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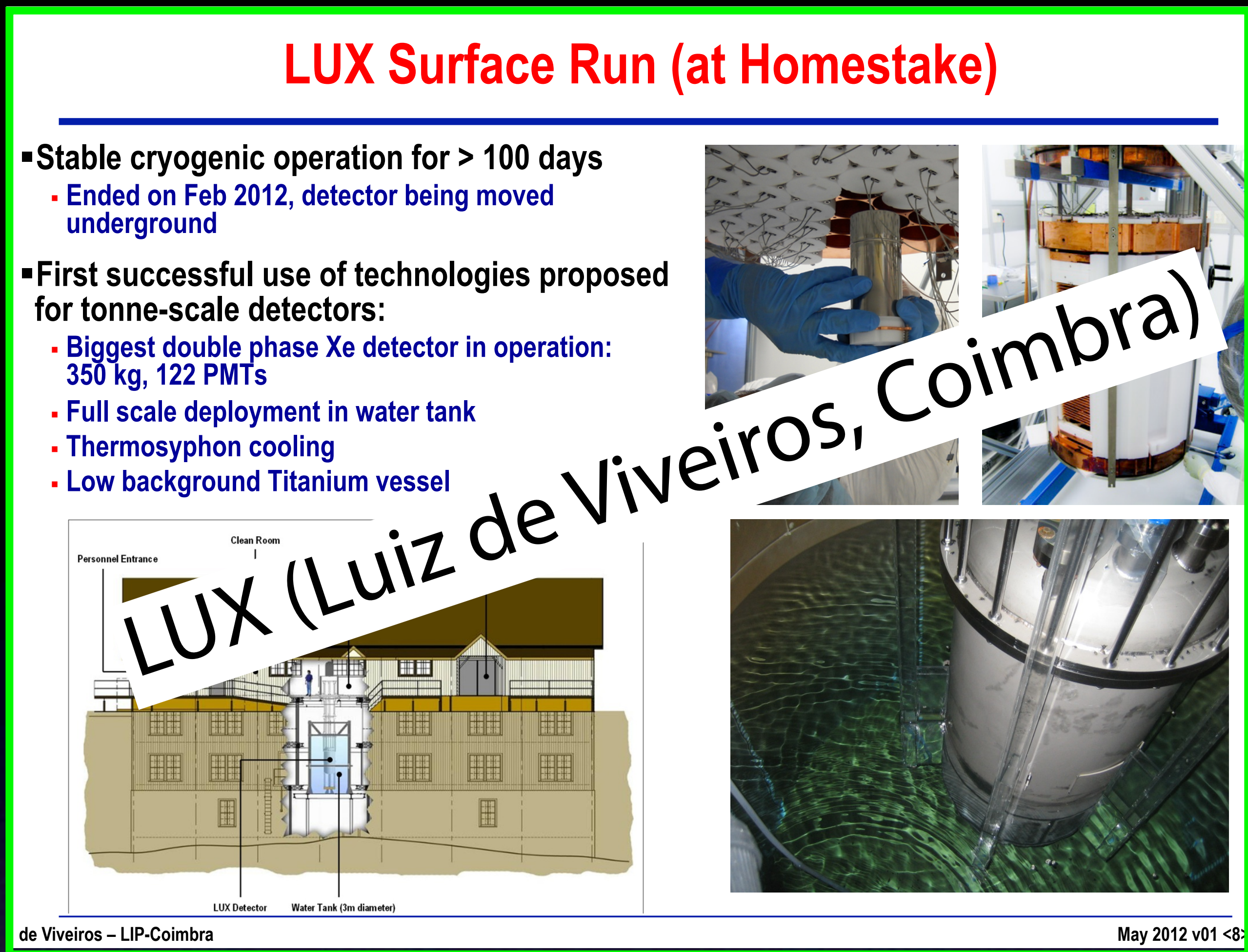
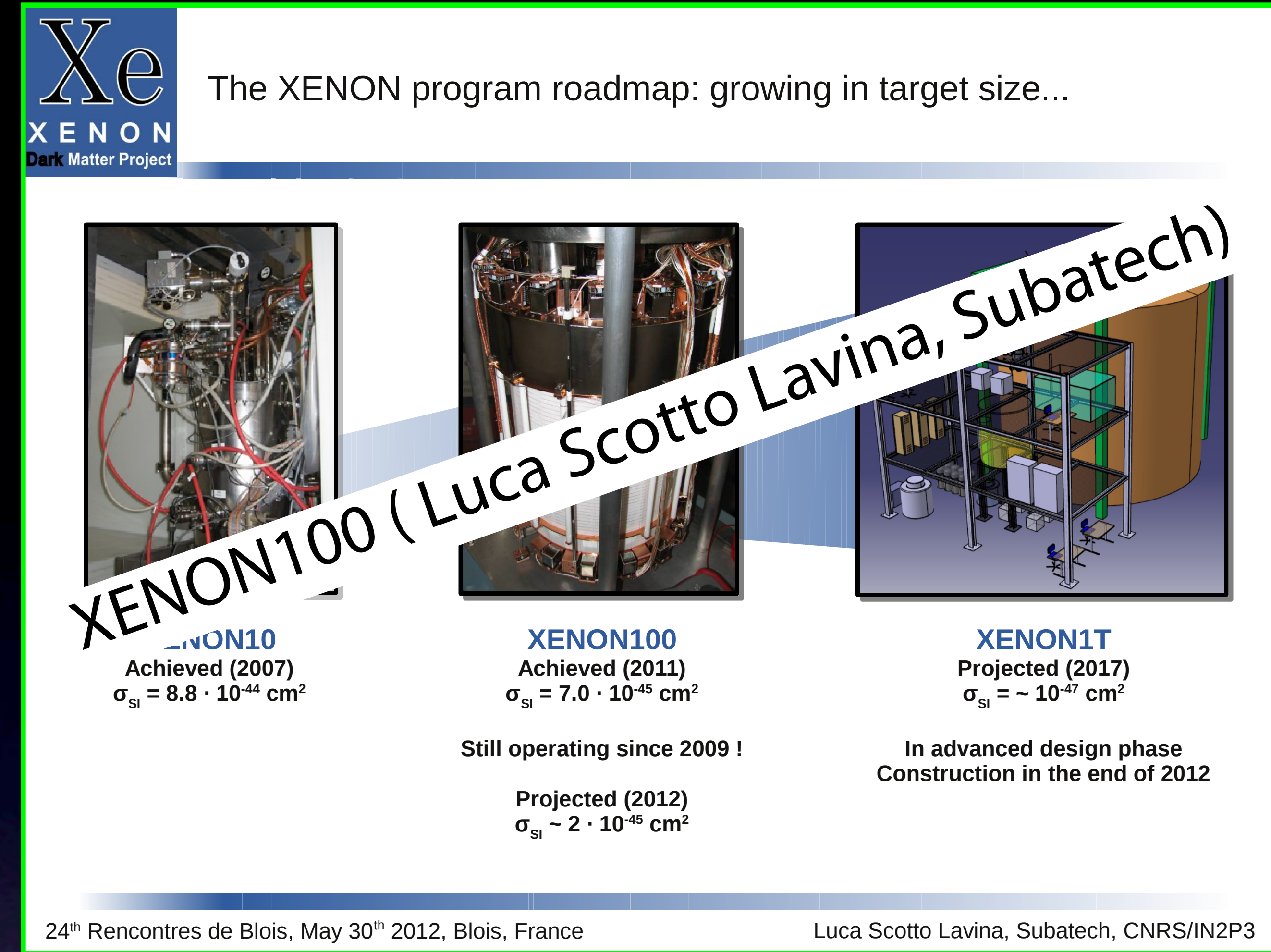
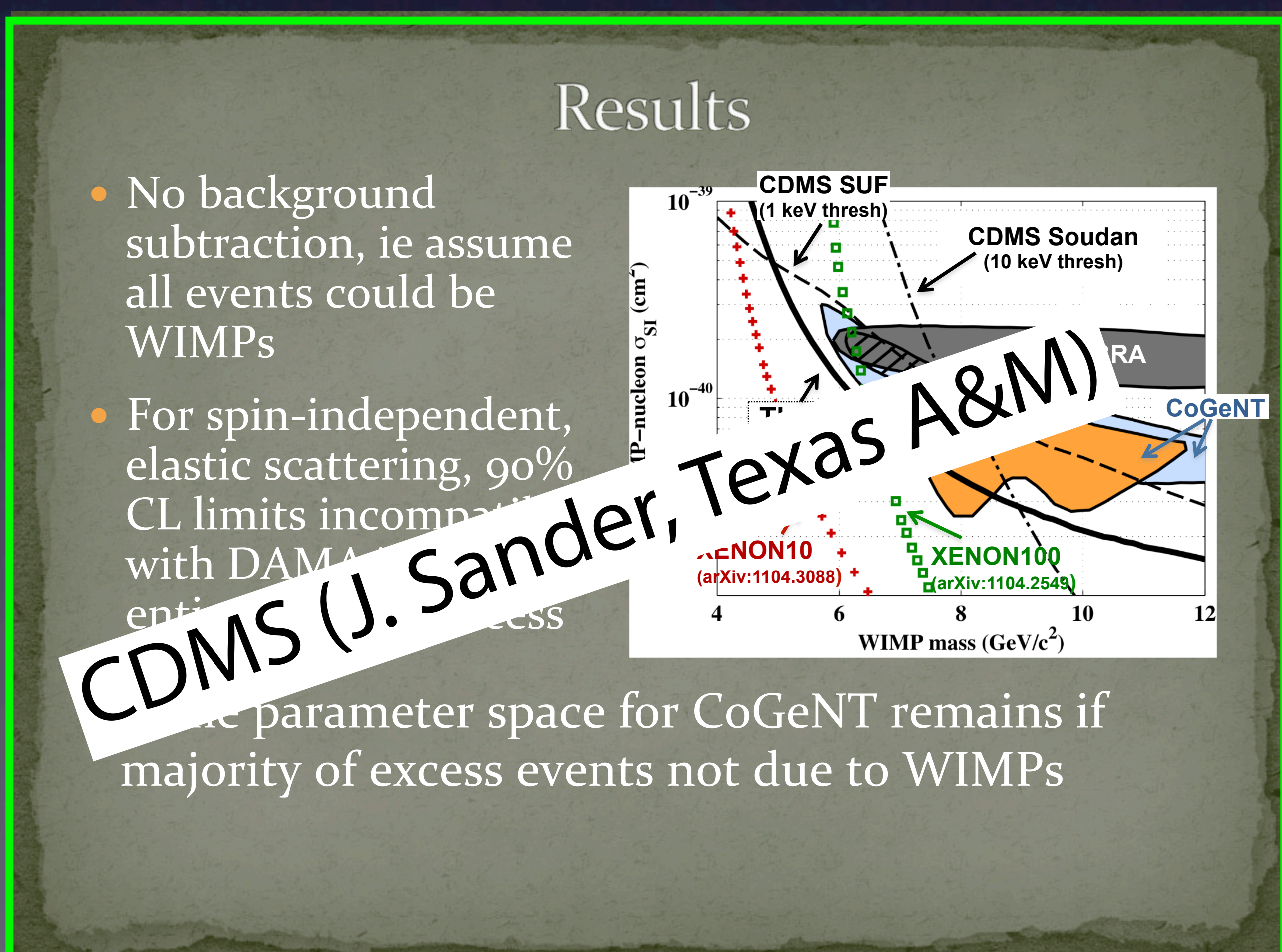
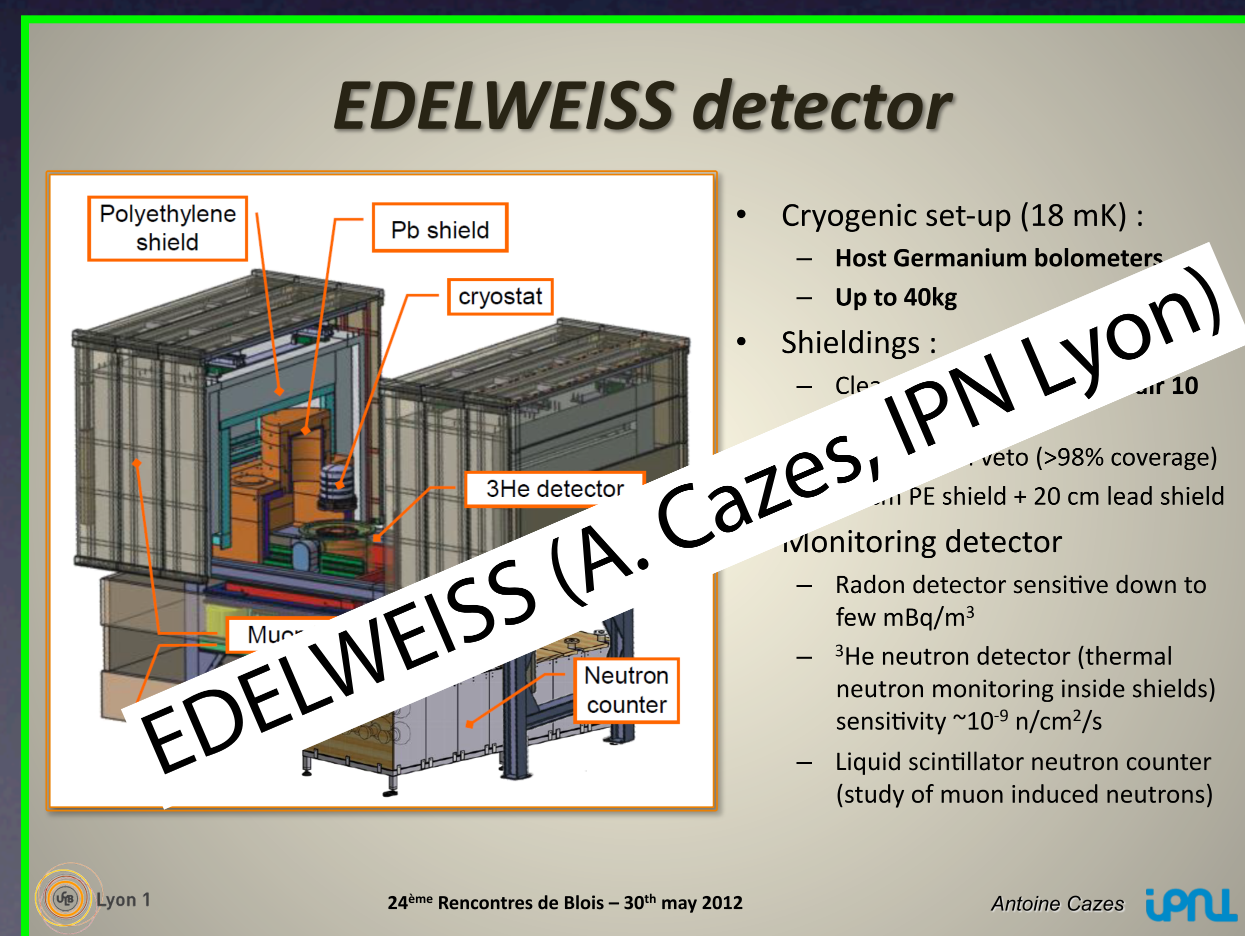

LUX Surface Run (at Homestake)
Stable cryogenic operation for > 100 days
Ended on Feb 2012, detector being moved underground
First successful use of technologies proposed for tonne-scale detectors:
Biggest double phase Xe detector in operation: 350 kg, 122 PMTs
Full scale deployment in water tank
Thermosyphon cooling
Low background Titanium vessel
Clean Room
Personnel Entrance
LUX Detector
Water Tank (3m diameter)
de Viveiros – LIP-Coimbra
May 2012 v01
LUX (Luiz de Viveiros, Coimbra)


Xe
XENON
Dark Matter Project
The XENON program roadmap: growing in target size...
XENON10
Achieved (2007)
σSI = 8.8 · 10-44 cm2
XENON100
Achieved (2011)
σSI = 7.0 · 10-45 cm2
Still operating since 2009 !
Projected (2012)
σSI ~ 2 · 10-45 cm2
XENON1T
Projected (2017)
σSI = ~ 10-47 cm2
In advanced design phase
Construction in the end of 2012
24th Rencontres de Blois, May 30th 2012, Blois, France
Luca Scotto Lavina, Subatech, CNRS/IN2P3
XENON100 (Luca Scotto Lavina, Subatech)


Results
No background subtraction, ie assume all events could be WIMPs
For spin-independent, elastic scattering, 90% CL limits incompatible with DAMA ... entire ... excess
... parameter space for CoGeNT remains if majority of excess events not due to WIMPs
CDMS SUF
(1 keV thresh)
CDMS Soudan
(10 keV thresh)
CoGeNT
XENON10
(arXiv:1104.3088)
XENON100
(arXiv:1104.2549)
WIMP mass (GeV/c2)
CDMS (J. Sander, Texas A&M)


EDELWEISS detector
Polyethylene shield
Pb shield
cryostat
3He detector
Neutron counter
Cryogenic set-up (18 mK) :
Host Germanium bolometers
Up to 40kg
Shieldings :
veto (>98% coverage)
PE shield + 20 cm lead shield
Monitoring detector
Radon detector sensitive down to few mBq/m3
3He neutron detector (thermal neutron monitoring inside shields) sensitivity ~10-9 n/cm2/s
Liquid scintillator neutron counter (study of muon induced neutrons)
Lyon 1
24ème Rencontres de Blois – 30th may 2012
Antoine Cazes
EDELWEISS (A. Cazes, IPN Lyon)

Xe Target Experiments

XENON at Gran Sasso, Italy

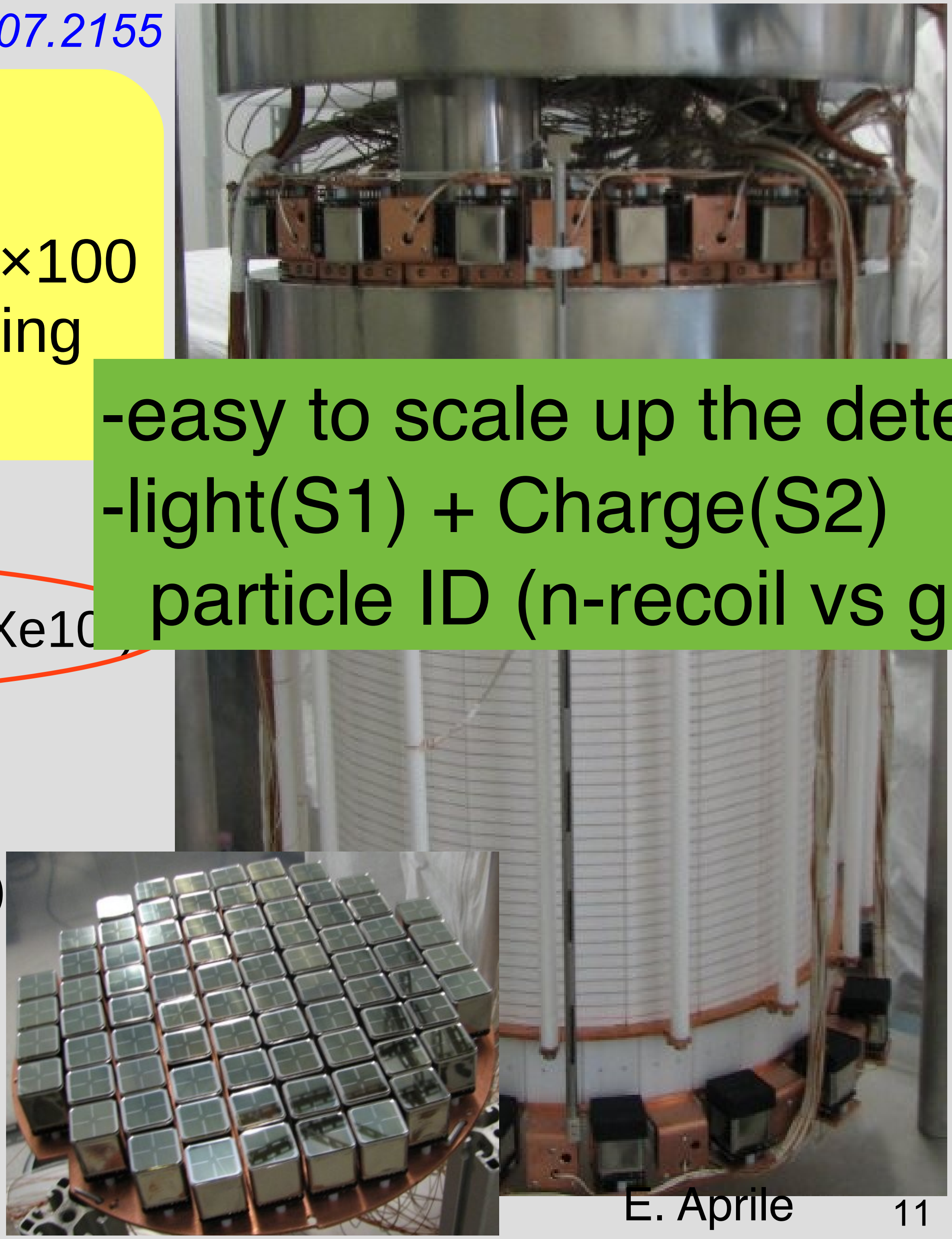
XENON100

XENON
Dark Matter Project

arXiv:1107.2155

Goal (compared to XENON10)**:**
- increase target ×10
- reduce gamma background ×100
  - ➞ material selection & screening
  - ➞ detector design

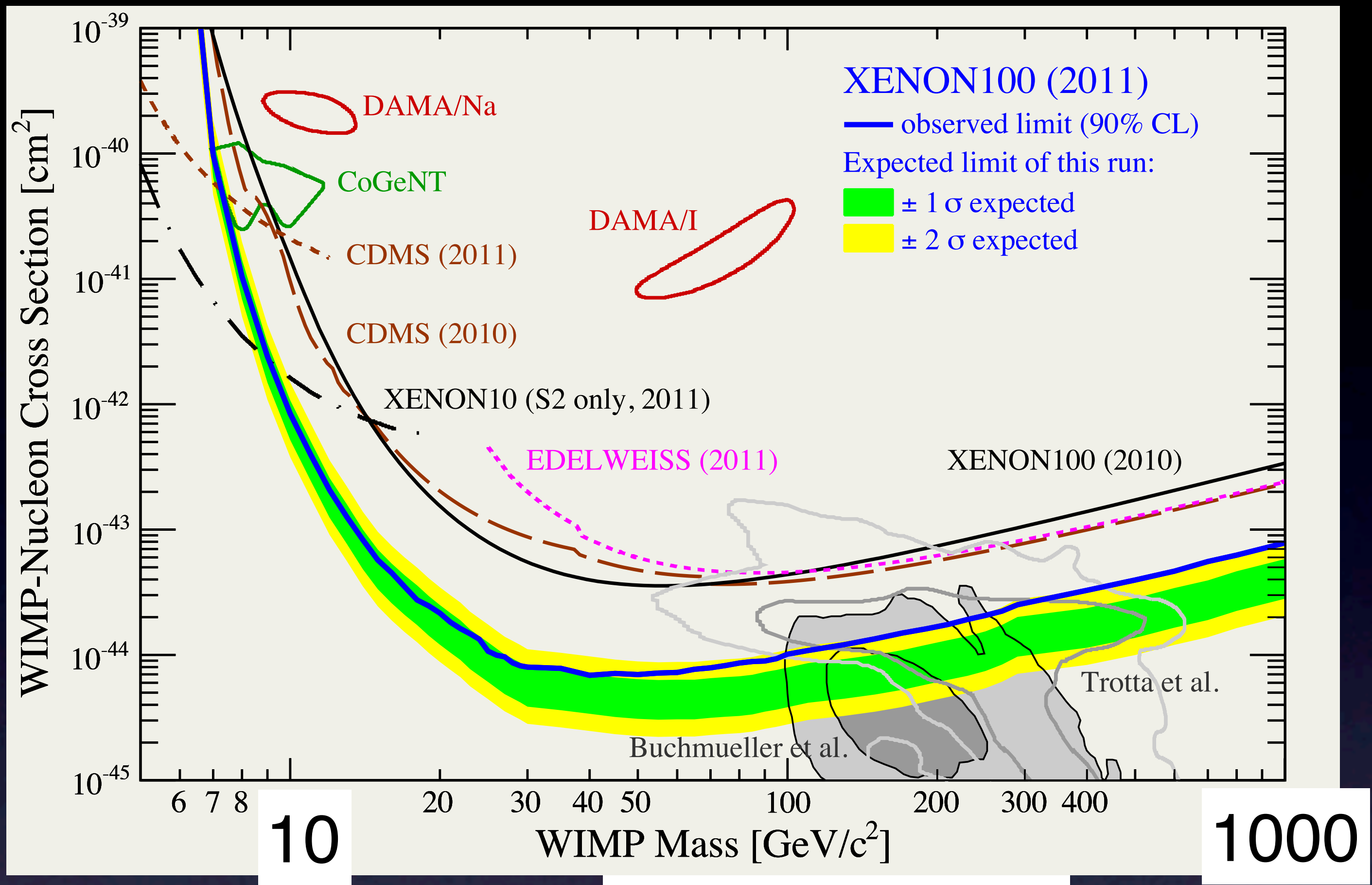
Quick Facts:
- 161 kg LXe TPC (mass: 10 × Xe10)
- 62 kg in target volume
- active LXe veto (≥4 cm)
- 242 PMTs (Hamamatsu R8520)
- passive shield
  (Pb, Poly, Cu, H_2O, N_2 purge)



-easy to scale up the detector
-light(S1) + Charge(S2)
particle ID (n-recoil vs gamma)

E. Aprile

Result of XENON100



arXiv:1104.2549

- data taken in first half of 2010
- 100.9 life days
- 48 kg fiducial volume out of 62 kg
- data blinded in ROI

Expected Background
Gaussian Leakage: 1.14 ± 0.48
Anomalous Leakage: 0 .56± 0.25
Neutron Background: 0.11 ± 0.08
Total: 1.8 ± 0.6 events

Observe 3 events
- likelihood for 3 or more events is 28%
- Profile Likelihood analysis also does not yield significant signal -> calculate limit

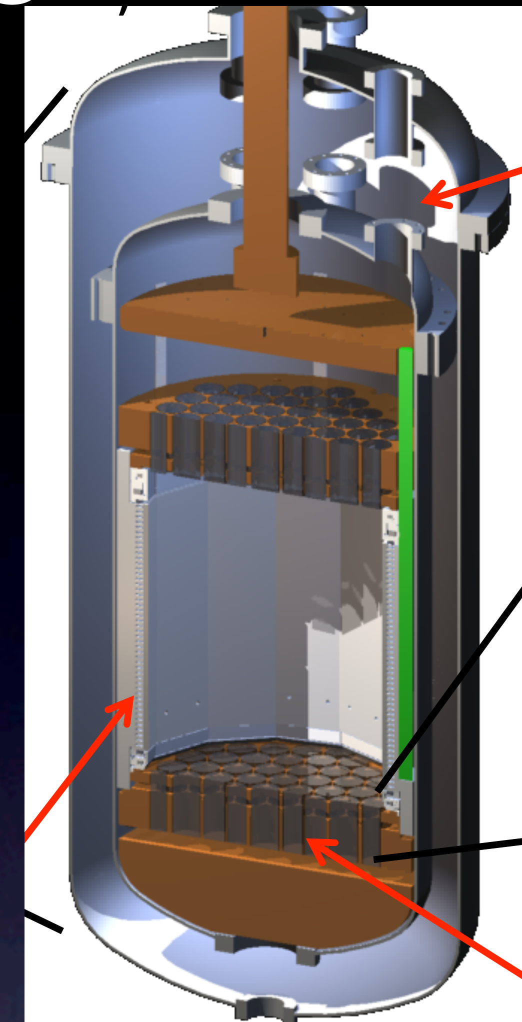
- **Data taking** for Dark Matter search is terminated!
- From March 1st 2011 up to now. **More than one year** of continuous operation
- More than **220 live days** of data collected Excellent Detector Performance and Stability
- Blind analysis in advanced state
- XENON1T phase: construction in Fall 2012.

→ in a few weeks.

Masaki Yamashita, ICRR, Univ of Tokyo

LUX at Homestake in US

- Two phase Xe TPC
-Homestake: 1.5 km deep
(4300 m.w.e., μ flux reduced x10^{-7} compared to sea level)
-350kg Liquid Xe Detector (59 cm height, 49 cm diameter)
-122 Hamamatsu R8778 PMTs (d = 5 cm)
-61 on top, 61 on bottom ▪▪ Low-background Ti Cryostat



expected to have lower background than XENON100

Underground Science Timeline

Start dismantling surface March 2012
Start installation underground May 21, 2012
Finish installation September 2012
Finish commissioning November 2012
First data before the end of 2012
First result in first quarter of 2013
300 days result by end 2013

XMASS at Kamioka in Japan

–Sensitive volume 835 kg LXe out of 1100 kg

(DAMA 7 yrs + LIBRA 4yrs -> 1.17ton x yr)

- Scintillation only, self-shielding (Fiducial ~ 100 kg)

–Total: 642 Hex PMTs

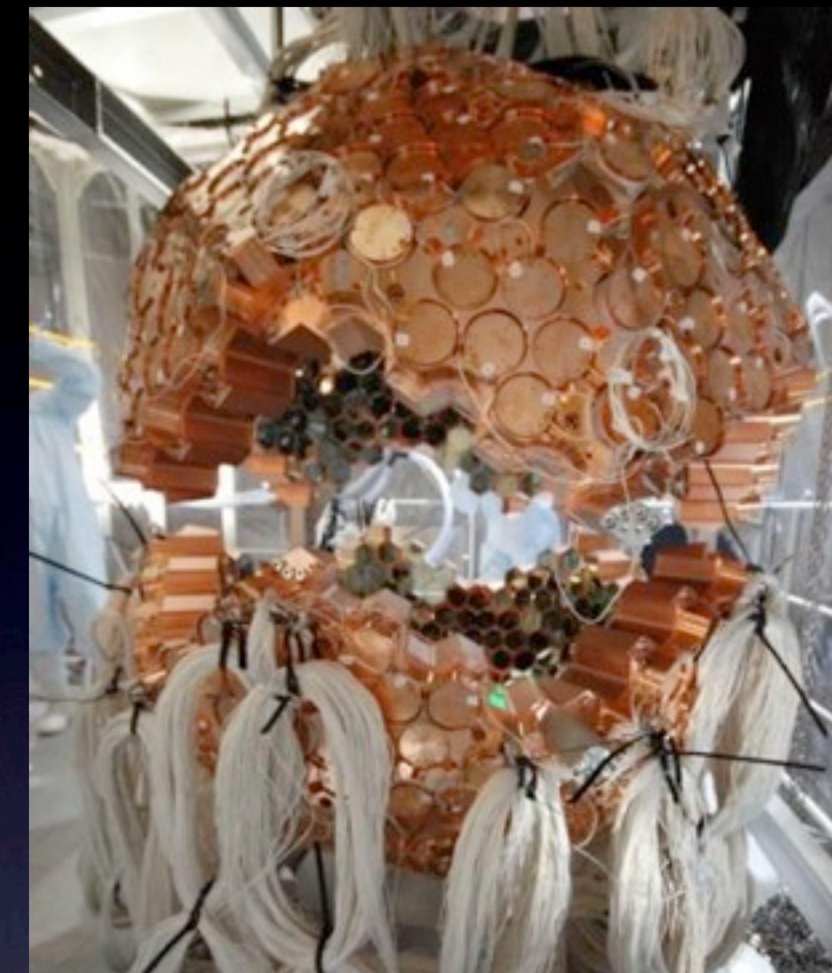
(low radioactive PMT R10789)

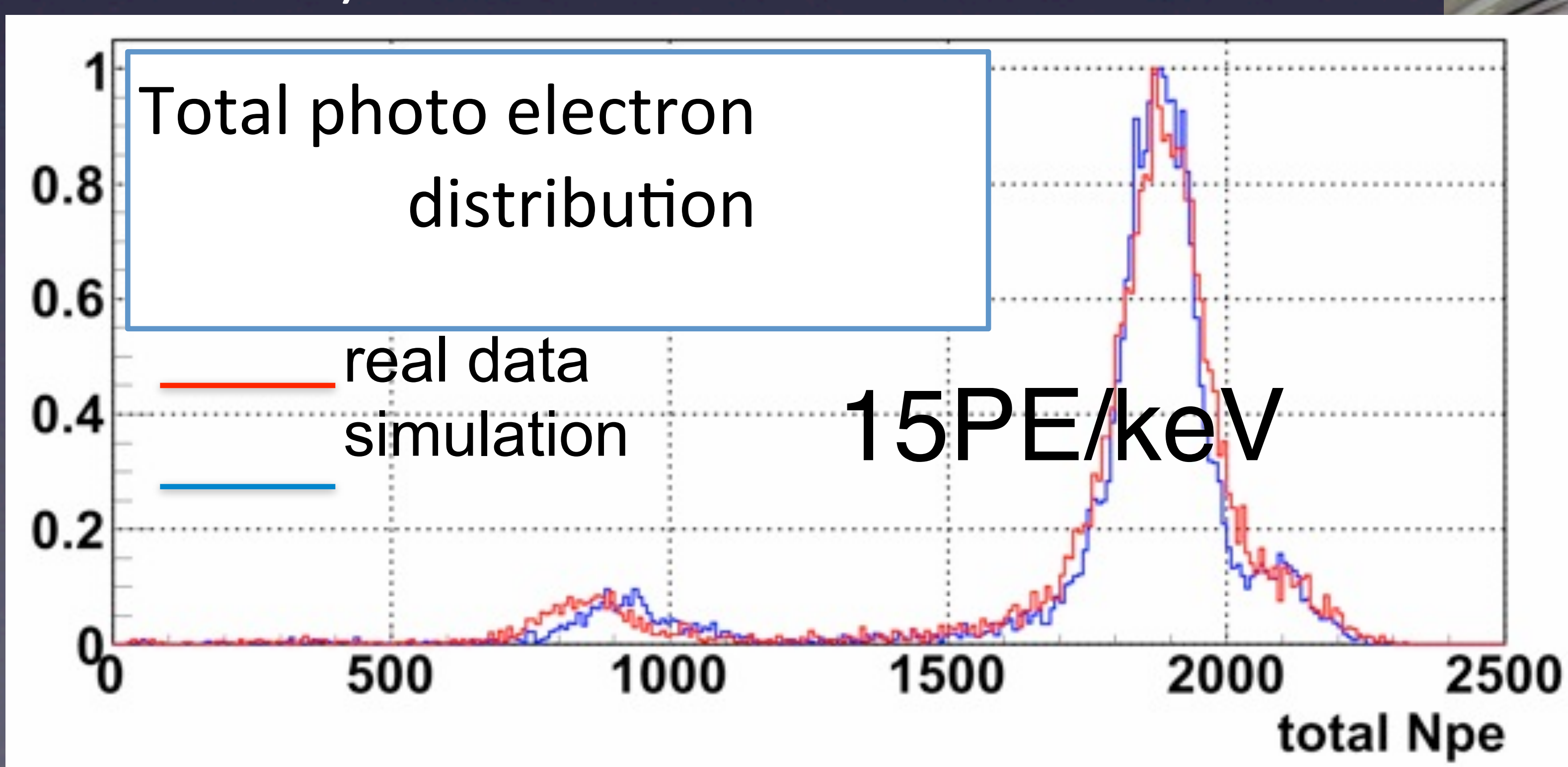
-High Photo coverage: 62%

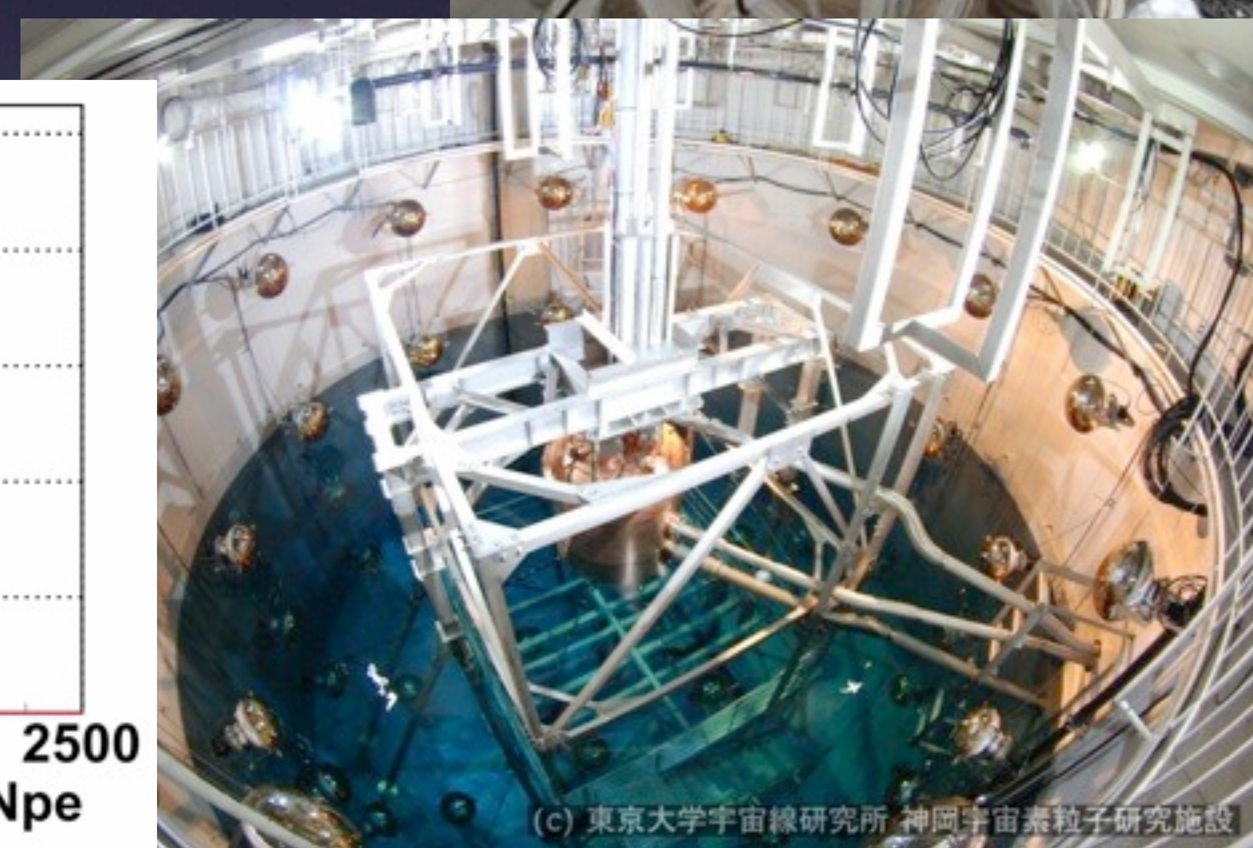
- 15 Photoelectron/keV

(best among DM scintillator)

-under investigating surface events (Al seal of PMT, Cu surface)





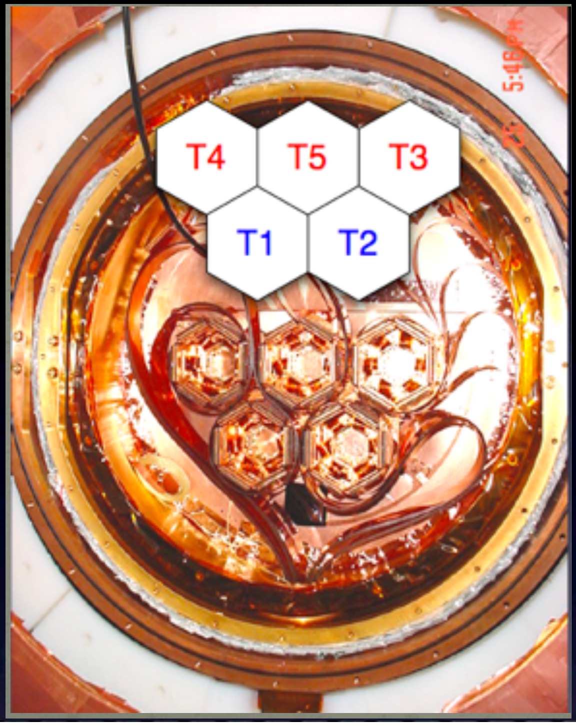


Ge Target Experiments

Masaki Yamashita, ICRR, Univ of Tokyo

CDMS(Low threshold analysis)

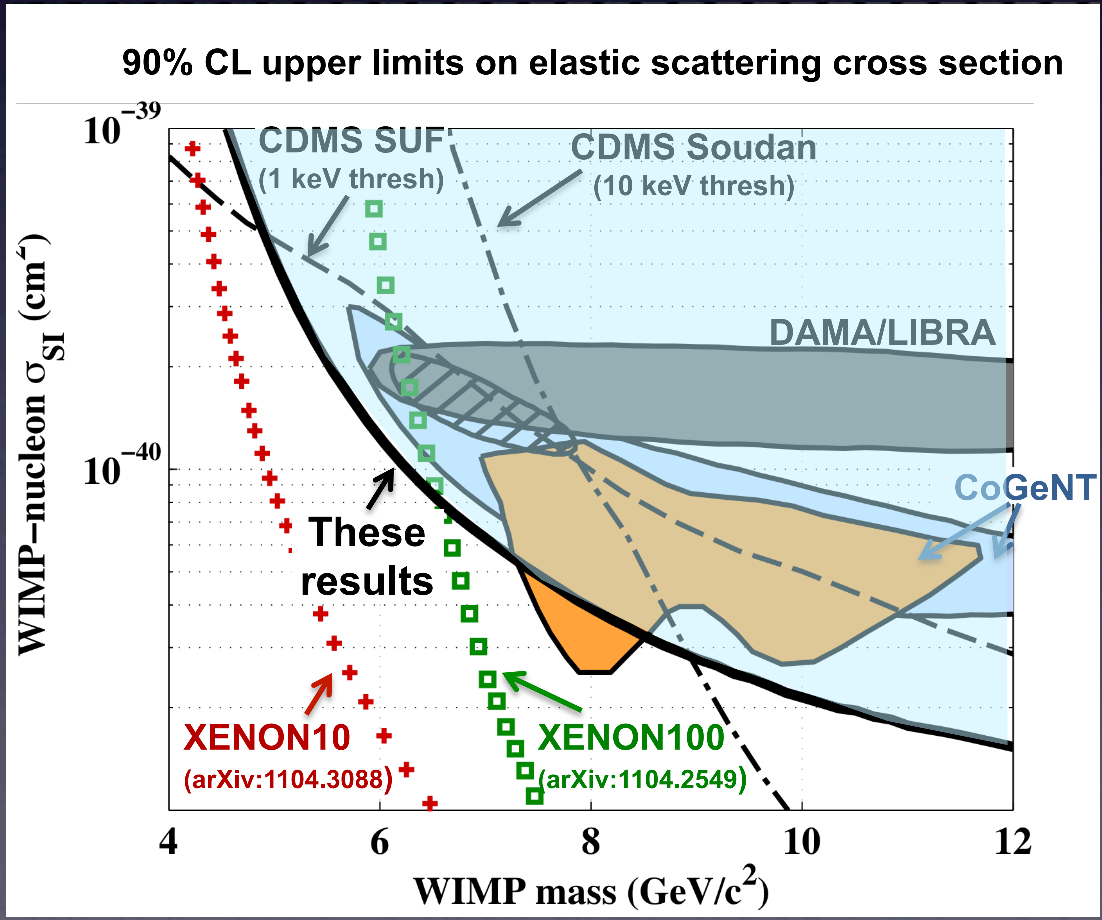
- Soudan in US.
- powerful particle ID by Phone + Charge signal
-241 kg-days with lowest noise 8 Ge detectors (~230 g each)
- data: Oct/2006 - Sep 2008
- Energy threshold (1.5-2.5 keV)



-No background subtraction, ie assume all events could be WIMPs

-For spin-independent, elastic scattering, 90% CL limits incompatible with DAMA/LIBRA and entire CoGeNT excess

-Some parameter space for CoGeNT remains if majority of excess events not due to WIMPs

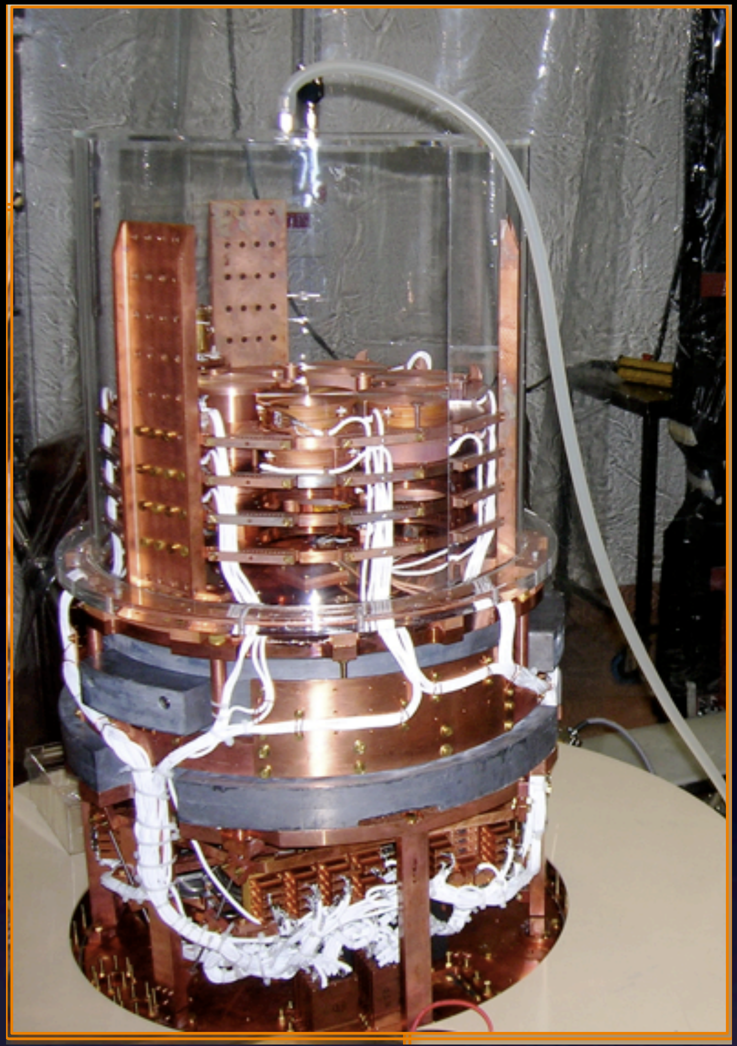


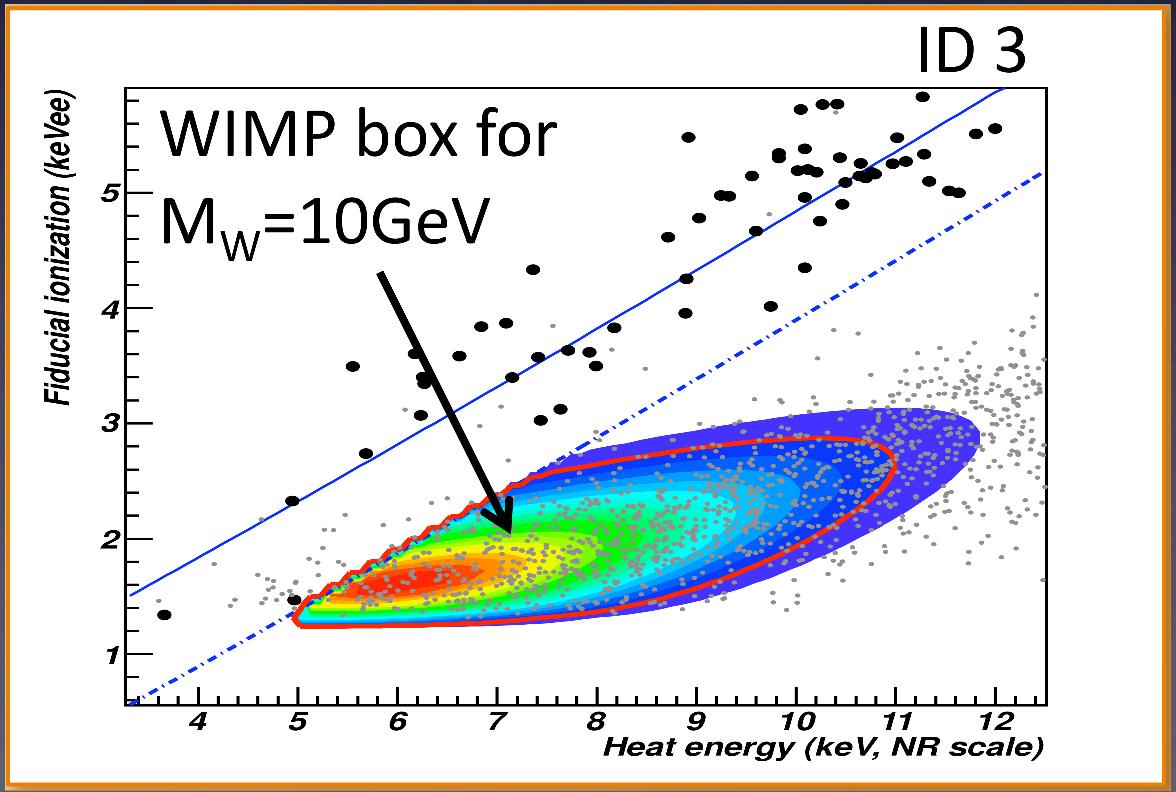
CDMS Collaboration, PRL 106, 131302 (2011)

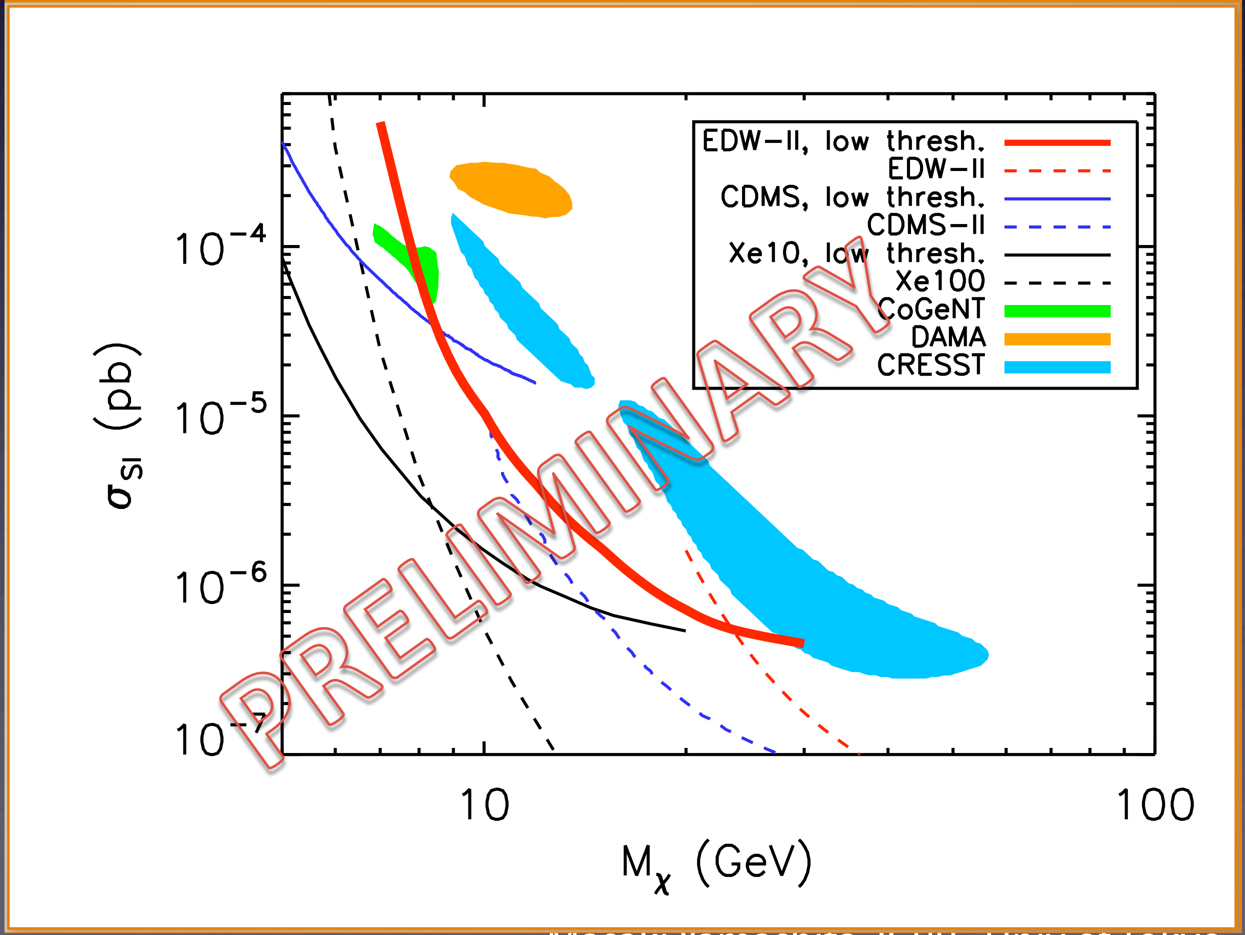
EDELWEISS

Cryogenic set-up (18 mK) :

- Host Germanium bolometers (Heat + Charge)
- Up to 40kg
- Low Threshold Analysis (< 5keV)
  1. exposure: 113 kg.d
  2. Es+mated background :
     1. Neutron < 1.7
     2. Gamma : 1.2
     3. Heat-only << 1
     4. Surface events are negligeable background.
  3. Limit derived from simple Poisson sta+s+cs in the «WIMP box»





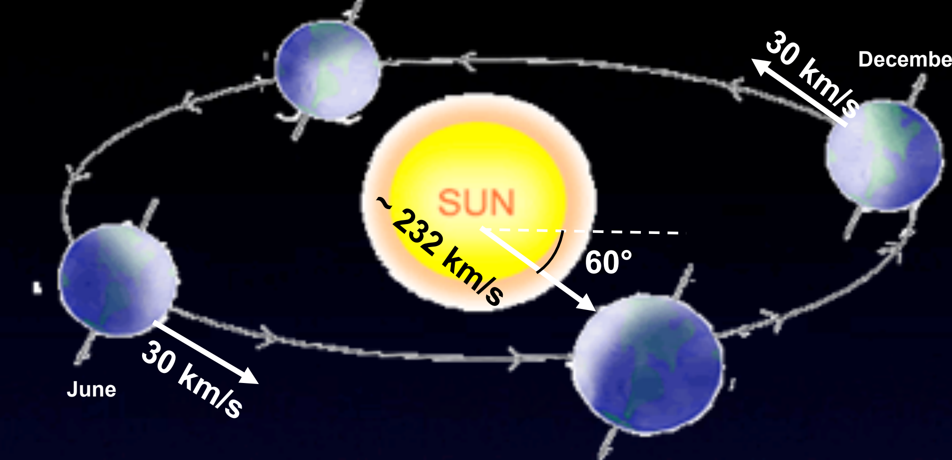


2012 Blois, Antoine Cazes

Others (NaI, $CaWO_4$)

DAMA/LIBRA in Gran Sasso

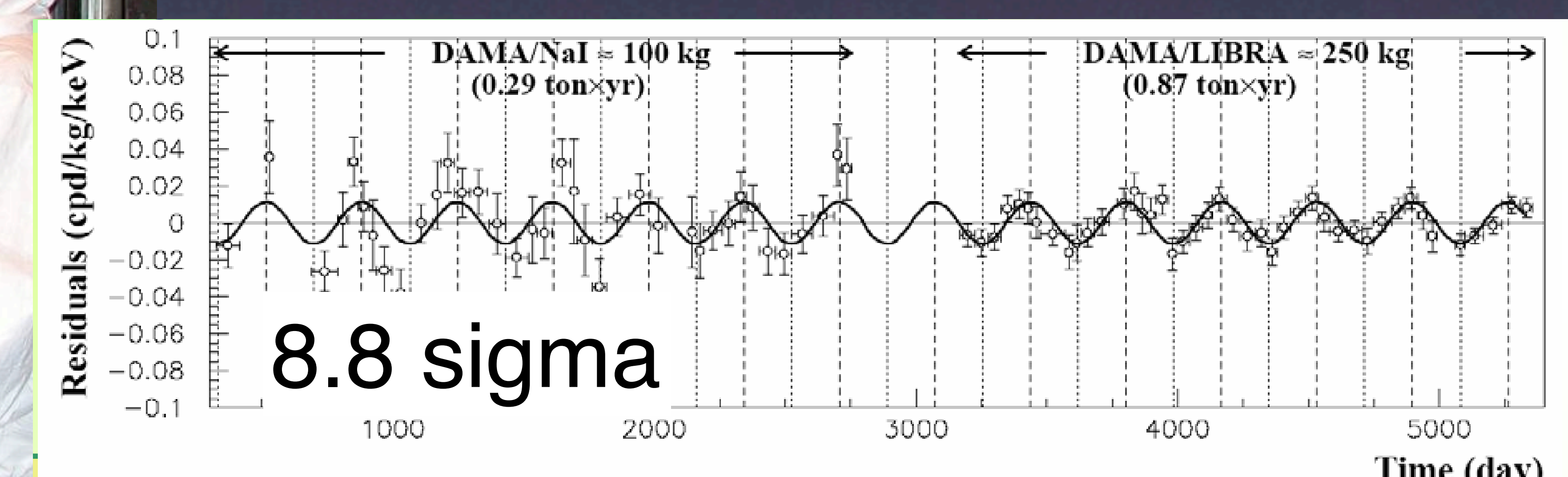
- DAMA(~100 kg) + LIBRA (~250 kg) of NaI
- Annual Modulation 8.8σ (DAMA 7 yrs + LIBRA 4yrs -> 1.17ton x yr)
- Muon rate in Gran Sasso ?(arXiv:1202.4179v2) phase is different.
- Other experiment can do same thing ? Especially by NaI ? (->DM-ICE program)



- 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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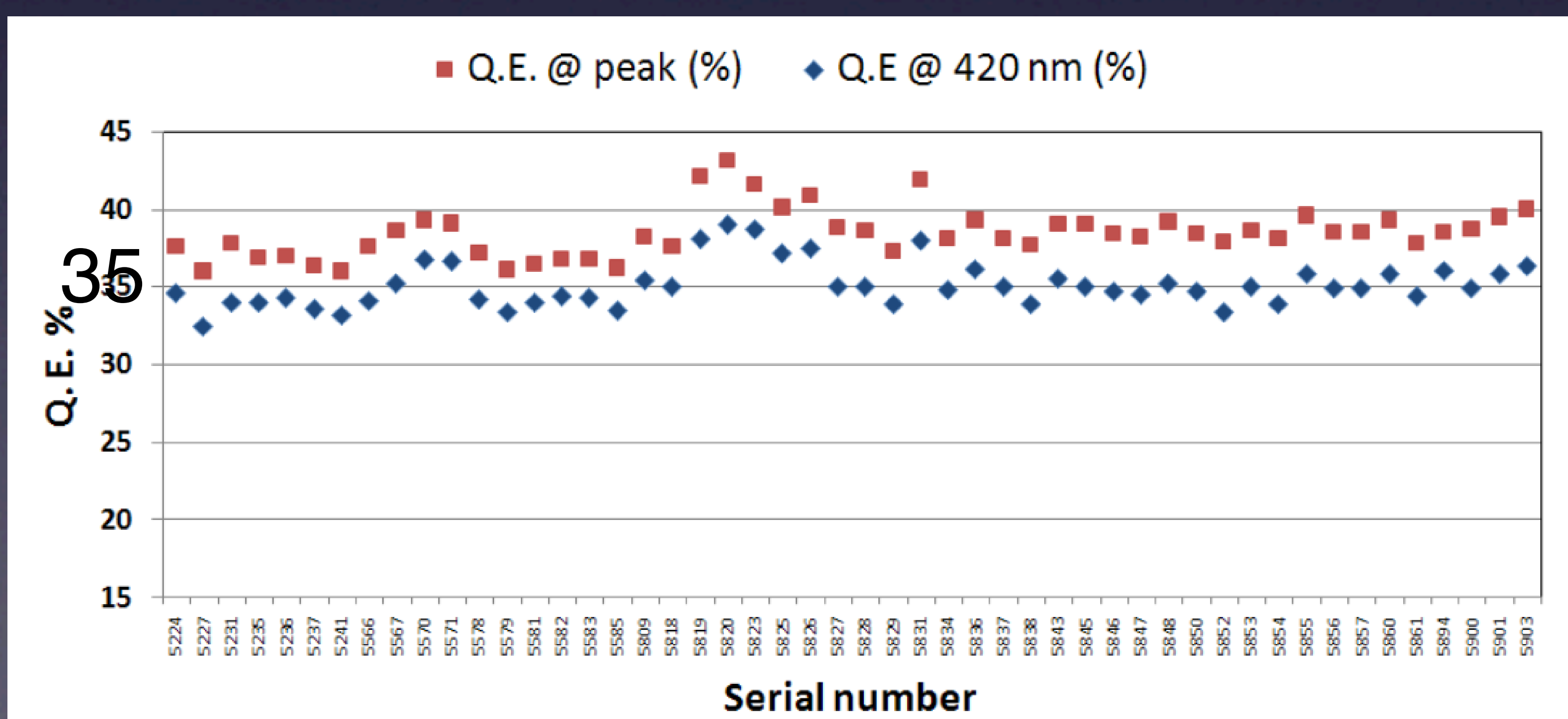
DAMA/LIBRA upgrade in Nov/Dec 2010

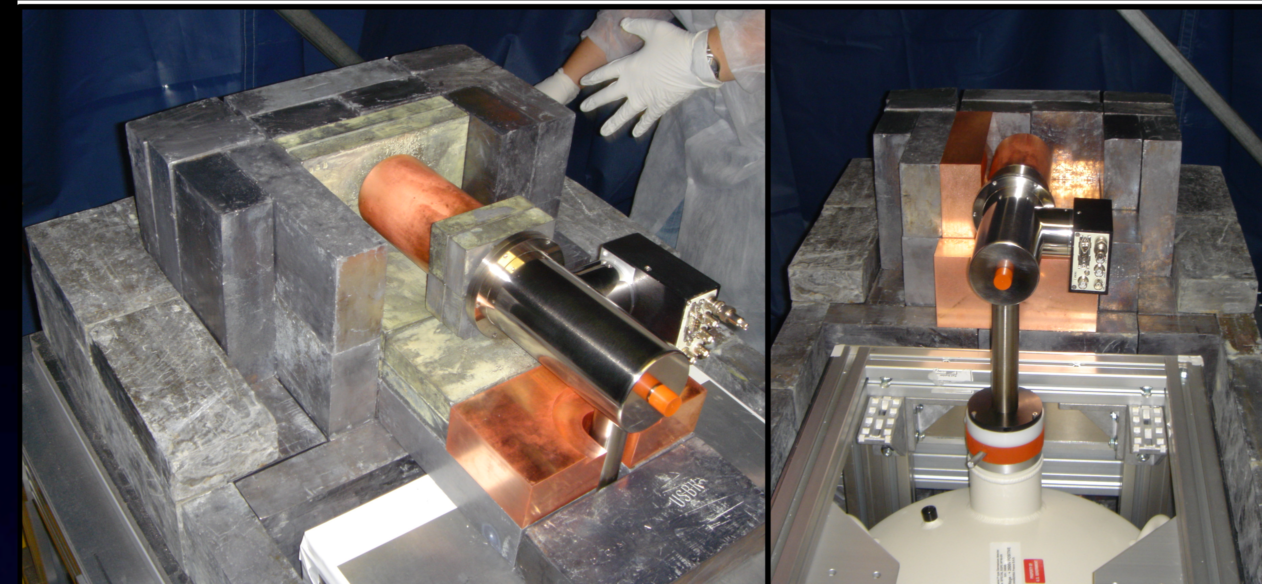
- high QE 35% at 420nm
- Energy threshold
  2keV -> 1keV
- a better energy resolution
- a better noise/scintillation discrimination
- less radioactivity



JINST 2012 7 P03009

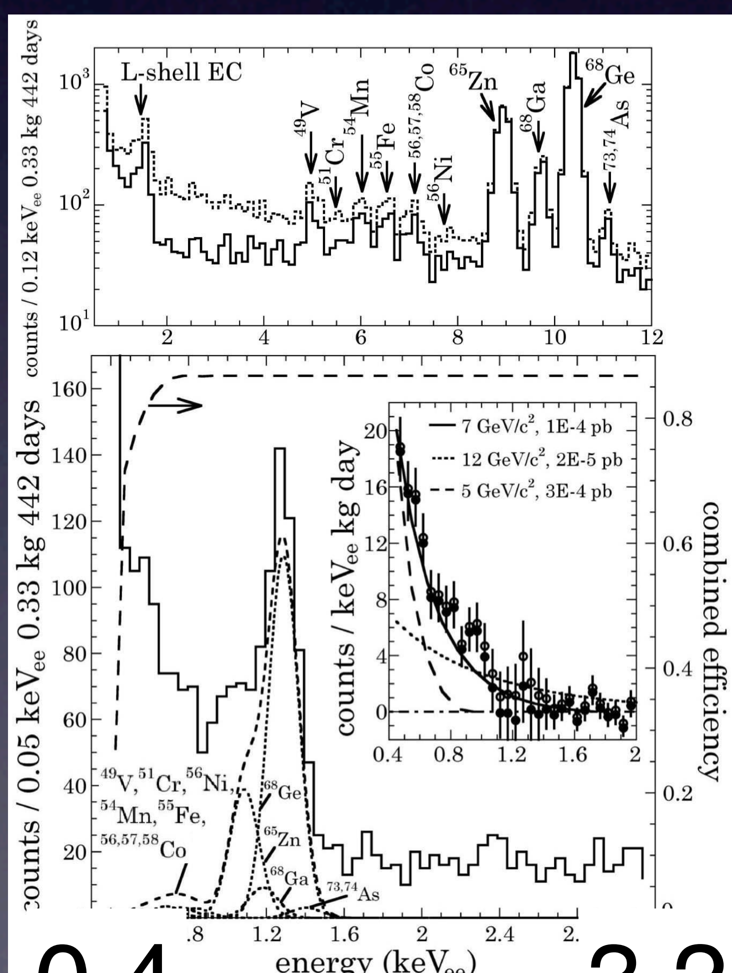
CoGENT at Soudan

- 440-gram
high purity germanium ionization spectrometer
- p-type Point Contact
- ~0.5 keV energy threshold
- In low-background shield at Soudan Underground Lab



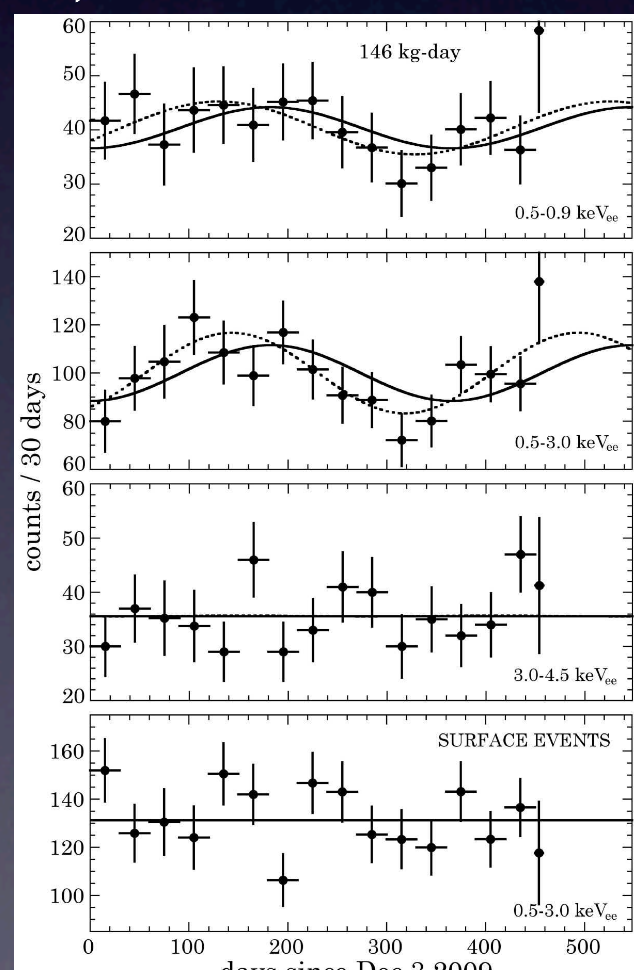
John L. Orrell, TAUP2011

C.E. Aalseth et al. PRL 106,



0.4 keV

3.2 keV



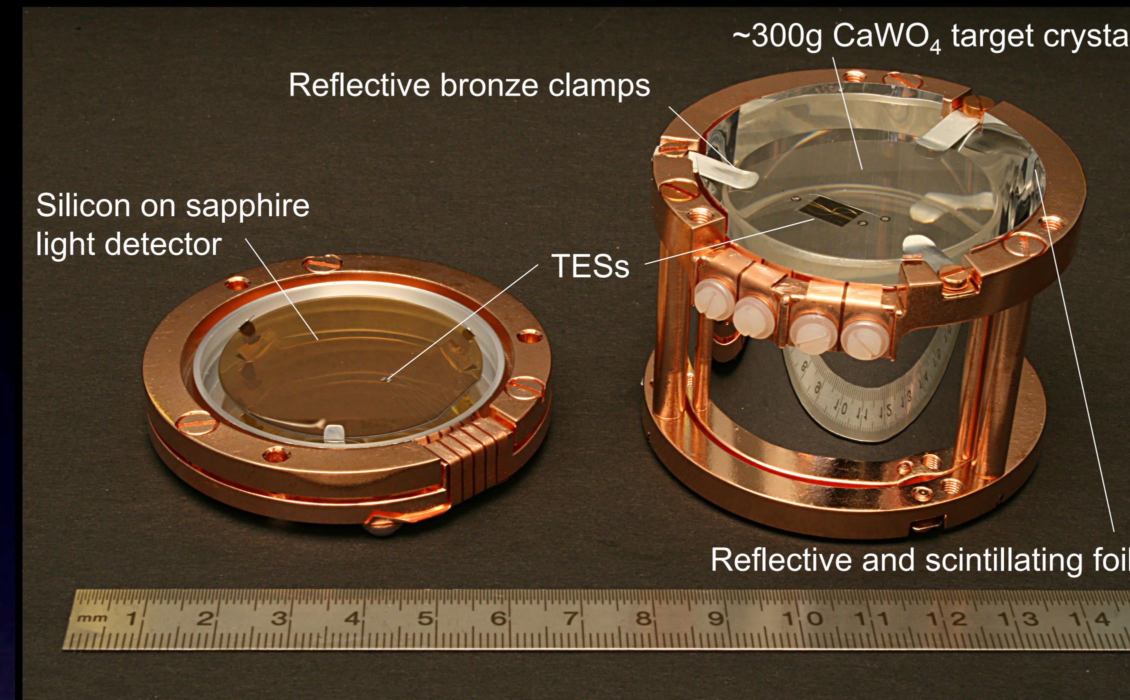
solid: best-fit

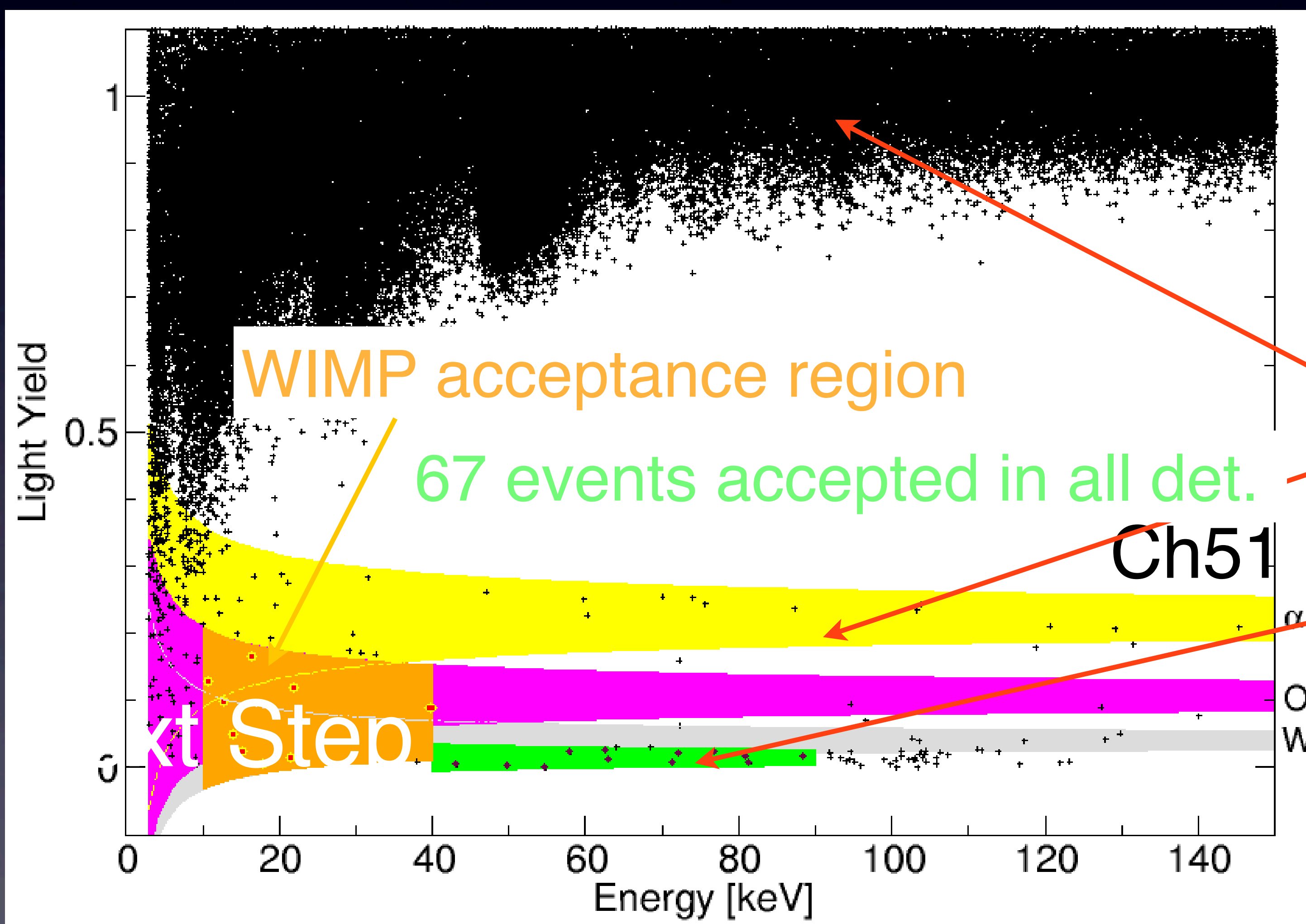
- Energy threshold 0.5 keV
- 0.33 kg x 442 days
- modulation hypothesis
  2.8 sigma
- 16.6±3.8% amplitude
- 347±29 days period
- minimum in Oct 16±12 d

to increase statistic: 440g
-> C4 (1 kg x 4 modules)

CRESST

-CaWO4 target (~300g)
-Measuring both scintillation light and phonon.
-8 CaWO4 was used for analysis out of fully operated 18 modules.
- Total exposure 730 kg days

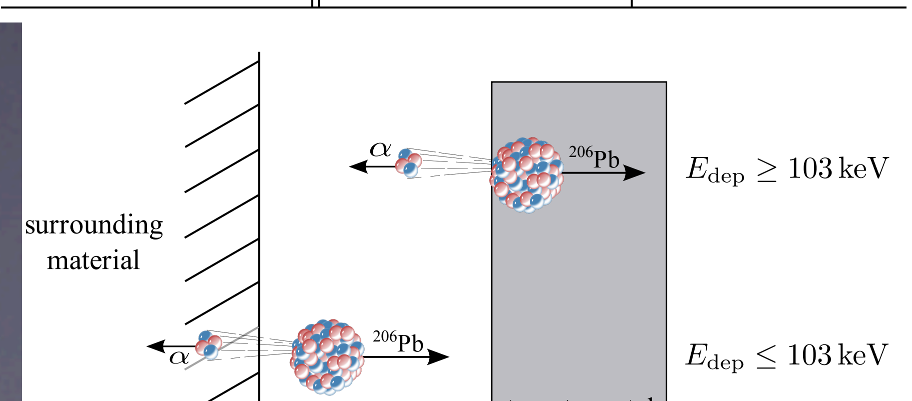




two maximum in Likelihood

	M1	M2
e/γ events	8.00 ± 0.05	8.00 ± 0.05
α events	$11.5^{+2.6}_{-2.3}$	$11.2^{+2.5}_{-2.3}$
neutron events	$7.5^{+6.3}_{-5.5}$	$9.7^{+6.1}_{-5.1}$
Pb recoils	$15.0^{+5.2}_{-5.1}$	$18.7^{+4.9}_{-4.7}$
signal events	$29.4^{+8.6}_{-7.7}$	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	25.3	11.6
σ_{WN} [pb]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

Background Reduction:
-Modification of the clamps holding the crystals to reduce α and Pb-recoils backgrounds
-Installation of an additional internal neutron shielding



Summary

XENON100:
XE100 operation was terminated. 200 days data will be open soon.
preparing XENON1T -> DARWIN program (multi ton Xe+Ar target)
LUX:
Moving the detector from surface to underground lab.
XMASS:
High light yield (15 PE/keV). Analysis and identifying of the background is on going.

Xe

EDELWEISS:
<5keV threshold analysis. Move to Phase EDELLWEISS III
CDMS:
Low threshold analysis. Super CDMS (iZIP) 10kg is on going.
CoGENT:
statistical improve 0.4 kg -> 1kg Upgrade. (C4)

Ge

DAMA/LIBRA:
Upgrade to higher QE in Nov/Dec 2010.

DM-ICE

NaI

CRESST:
Upgrade to reduce background from crystal holder and will add more shield for neutron.

CaWO4

I apologize for the experiments which could not be covered in this talk.

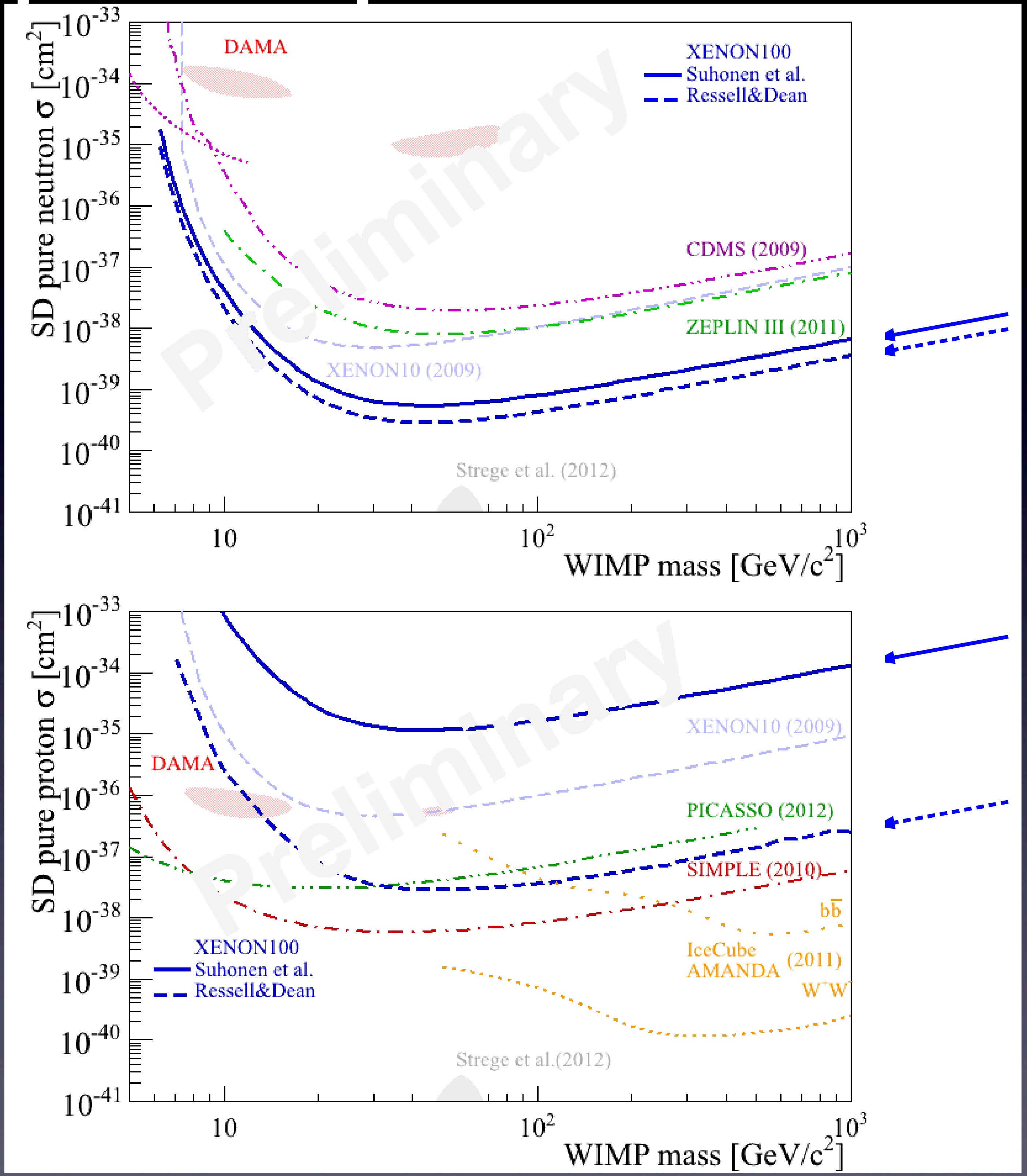
Thank you.

Masaki Yamashita

backup

Masaki Yamashita

spin dependent case



XENON100, Luca Scotto Lavina, May 30th, 2012, Blois

What is the background ?

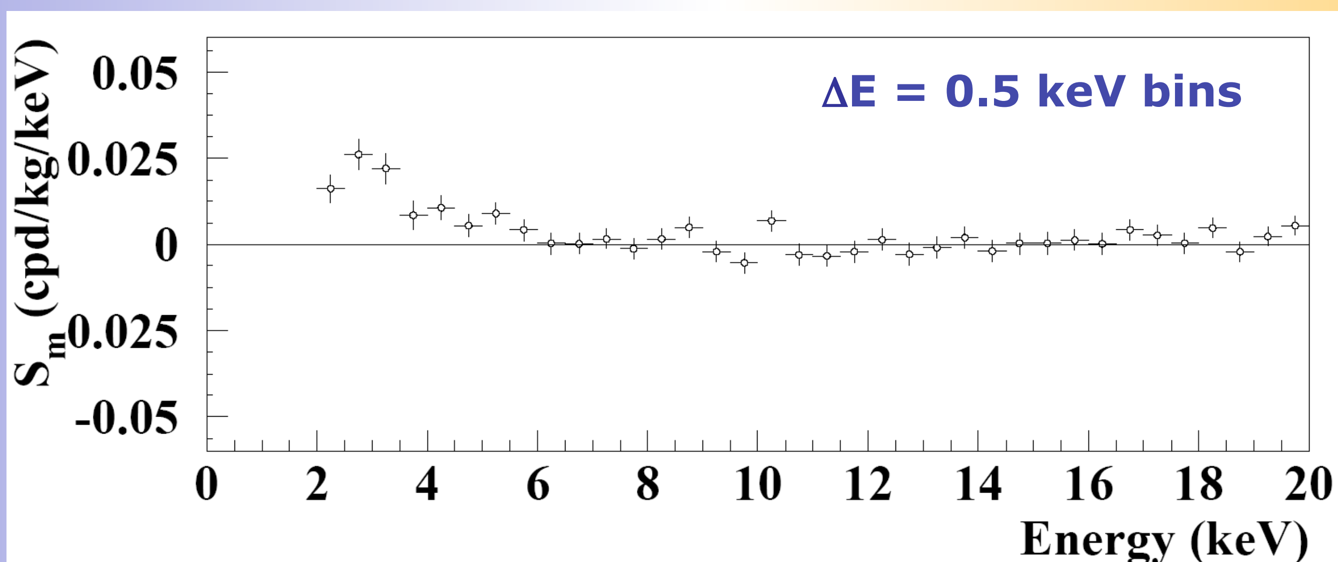
Energy distribution of the modulation amplitudes

$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$

hereT=2π/ω=1 yr and t_0= 152.5 day

DAMA/NaI (7 years) + DAMA/LIBRA (6 years)

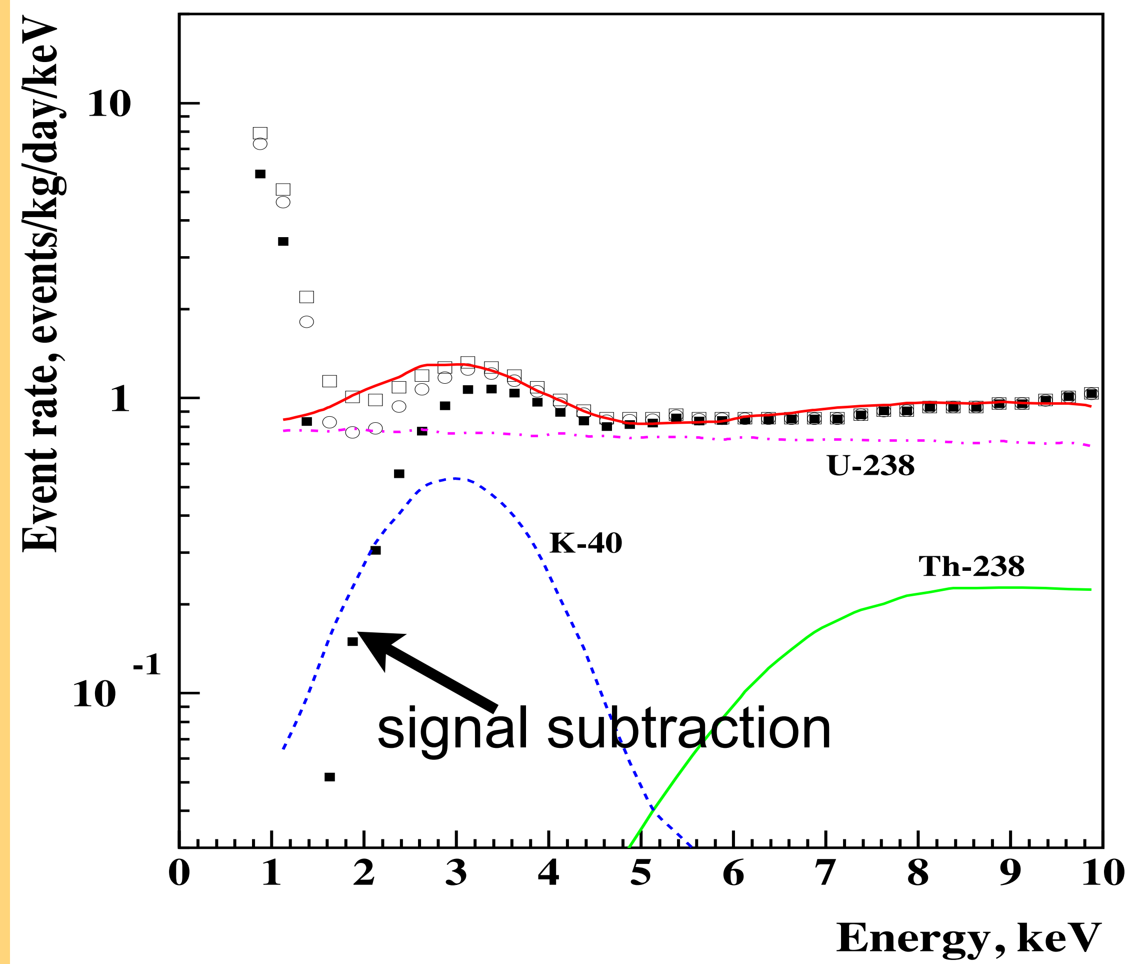
total exposure: 425428 kg×day ≈1.17 ton×yr



A clear modulation is present in the (2-6) keV energy interval, while S_m values compatible with zero are present just above

The S_m values in the (6–20) keV energy interval have random fluctuations around zero with χ^2 equal to 27.5 for 28 degrees of freedom

A.Incicchi



Kudryavtsev, et al J. Of Phys. Conf. Ser. 203(2009)012039

DAMA recently upgrade to Higher QE PMTs.

background induced by muon

Case of fast neutrons produced by μ P. Belli, DM2012

Measured neutron Yield @ LNGS:
$Y = 1 \div 7 \; 10^{-4} \; n/\mu/(g/cm^2)$
R_n = (fast n by μ)/(time unit) = $\Phi_\mu Y M_{eff}$

Annual modulation amplitude at low energy due to μ modulation:

$$S_m^{(\mu)} = R_n \, g \, \varepsilon \, f_{\Delta E} \, f_{single} \, 2\% / (M_{setup} \, \Delta E)$$

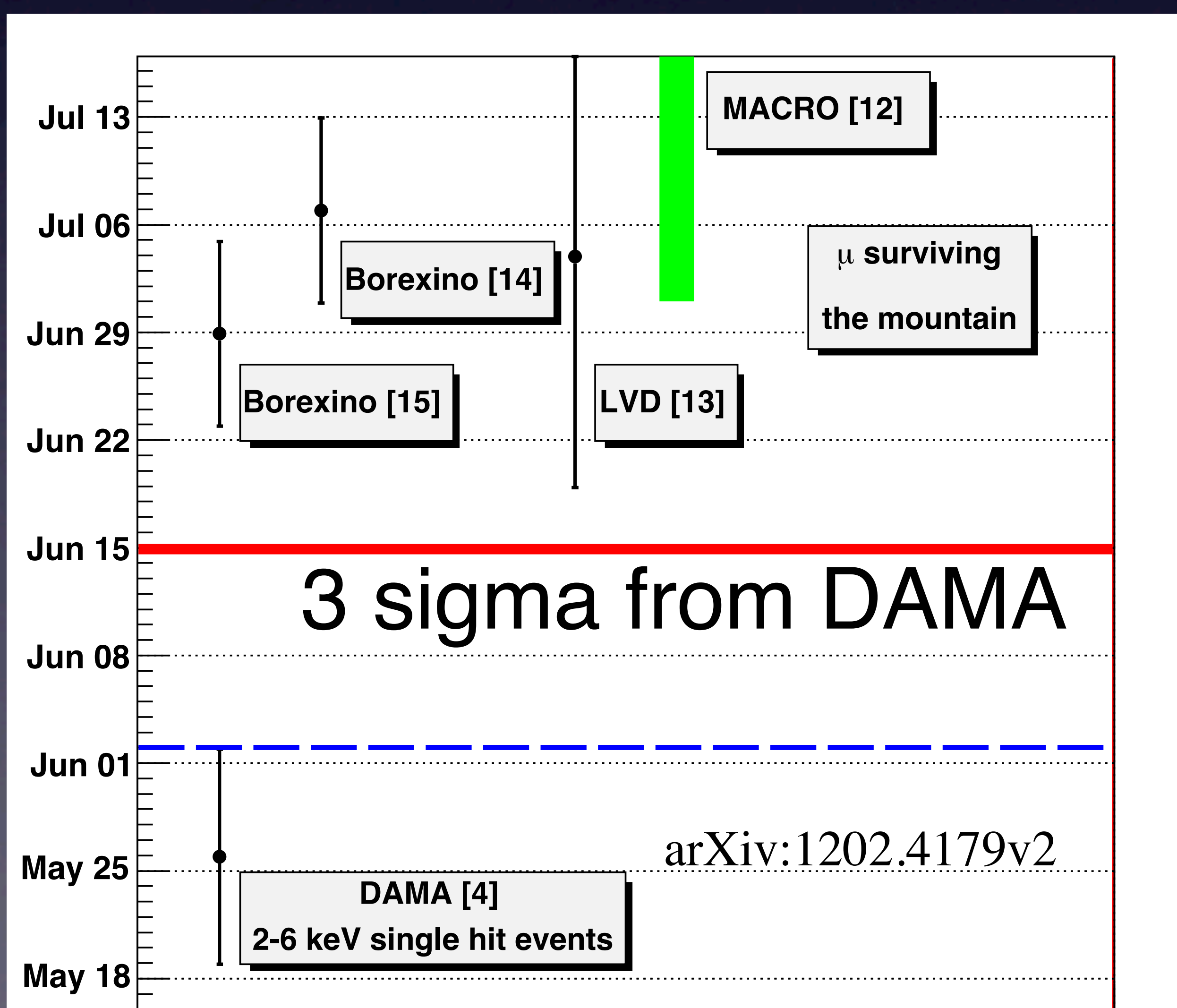
g = geometrical factor; ε = detection effic. by elastic scattering
$f_{\Delta E}$ = energy window (E>2keV) effic.; f_{single} = single hit effic.

Hyp.: M_{eff} = 15 tons; $g \approx \varepsilon \approx f_{\Delta E} \approx f_{single} \approx 0.5$ (cautiously)
Knowing that: $M_{setup} \approx 250$ kg and ΔE=4keV

→ **$S_m^{(\mu)} < (0.3\text{-}2.4) \times 10^{-5}$ cpd/kg/keV**

Moreover, this modulation also induces a variation in other parts of the energy spectrum and in the *multi-hits* events

It cannot mimic the signature: already excluded by R_{90}, by *multi-hits* analysis + different phase, etc.



Phase of muons

R. Bernabei [arXiv:1202.4179v2]
D. Nygren, [arXiv:1102.0815].
K. Blum, [arXiv:1110.0857].