CoEPP – CAASTRO 2nd Joint Workshop
Dark Matter Direct Detection
Sept. 29-30, 2014 at Great Western, Victoria, Australia

WIMPs and their DIRECT SEARCHES

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INFN and Univ. of Padua

I. Why to search for DM

- **The man in the street** → we've to know what more than 80% of the matter in the Universe is made of
- **The physicist**: man in the street + since DM is non-baryonic → **DM portal to new physics beyond the SM** of particle physics
- **The particle physicist**: man in the street + physicist + DM may be related to O(1 TeV) new physics needed to **naturally stabilize the energy where the electroweak symmetry breaking** occurs

2012: the conquest of a new energy scale in physics

- ~1900 **ATOMIC SCALE** **10^{-8} cm.** $1/(\alpha m_e)$
- ~1970 **STRONG SCALE** **10^{-13} cm.** $M e^{-2\Pi/\alpha_s b}$
- ~2010 **WEAK SCALE** **10^{-17} cm.** TeV^{-1}

FUNDAMENTAL OR **DERIVED SCALE**?

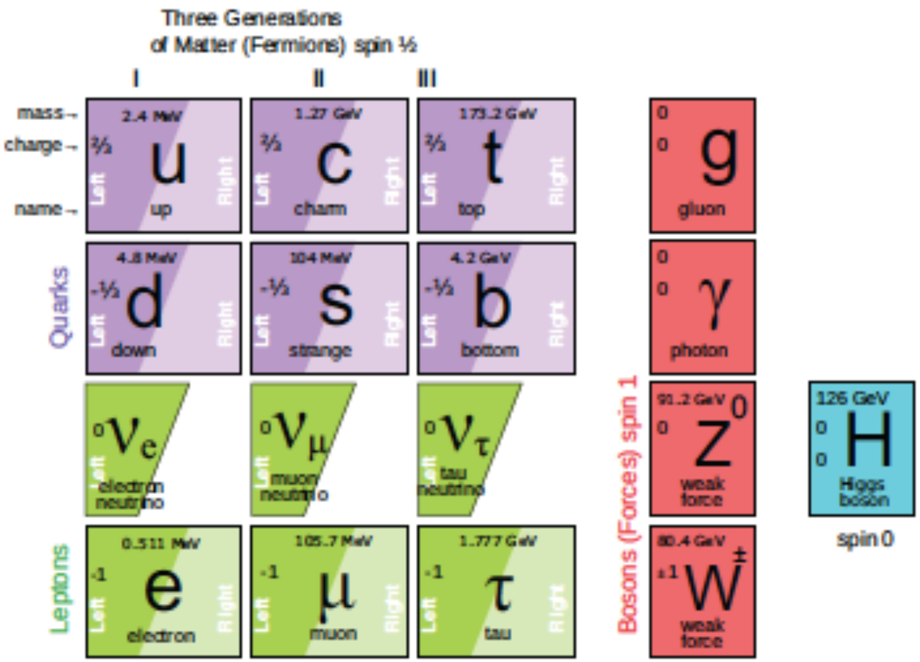
EX. **EXTRA-DIMENSIONS**
or
TeV STRING THEORY

EX.: **TECHNICOLOR** or
SUSY with ELW RAD. BREAKING

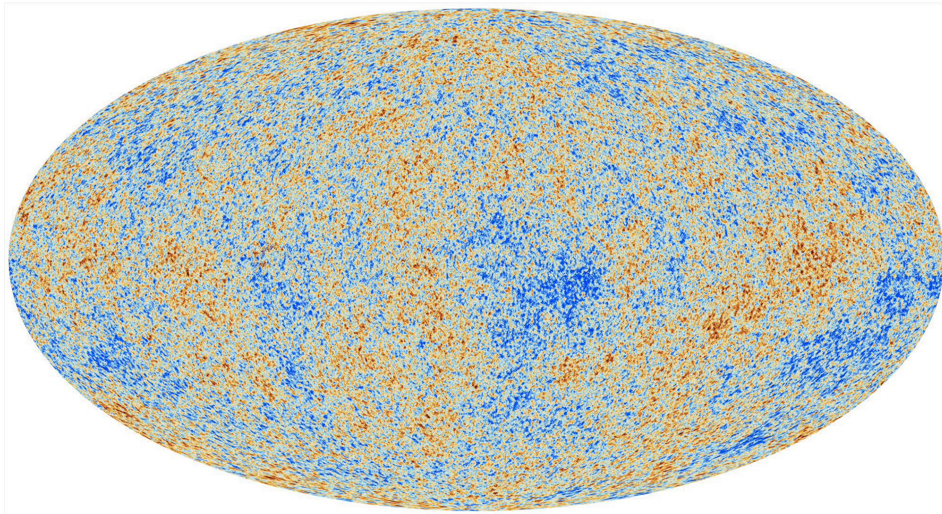
NEW PARTICLES AT THE TEV SCALE?

2013: the thiumph of the STANDARD

- **PARTICLE STANDARD MODEL**



- **COSMOLOGY STANDARD MODEL**



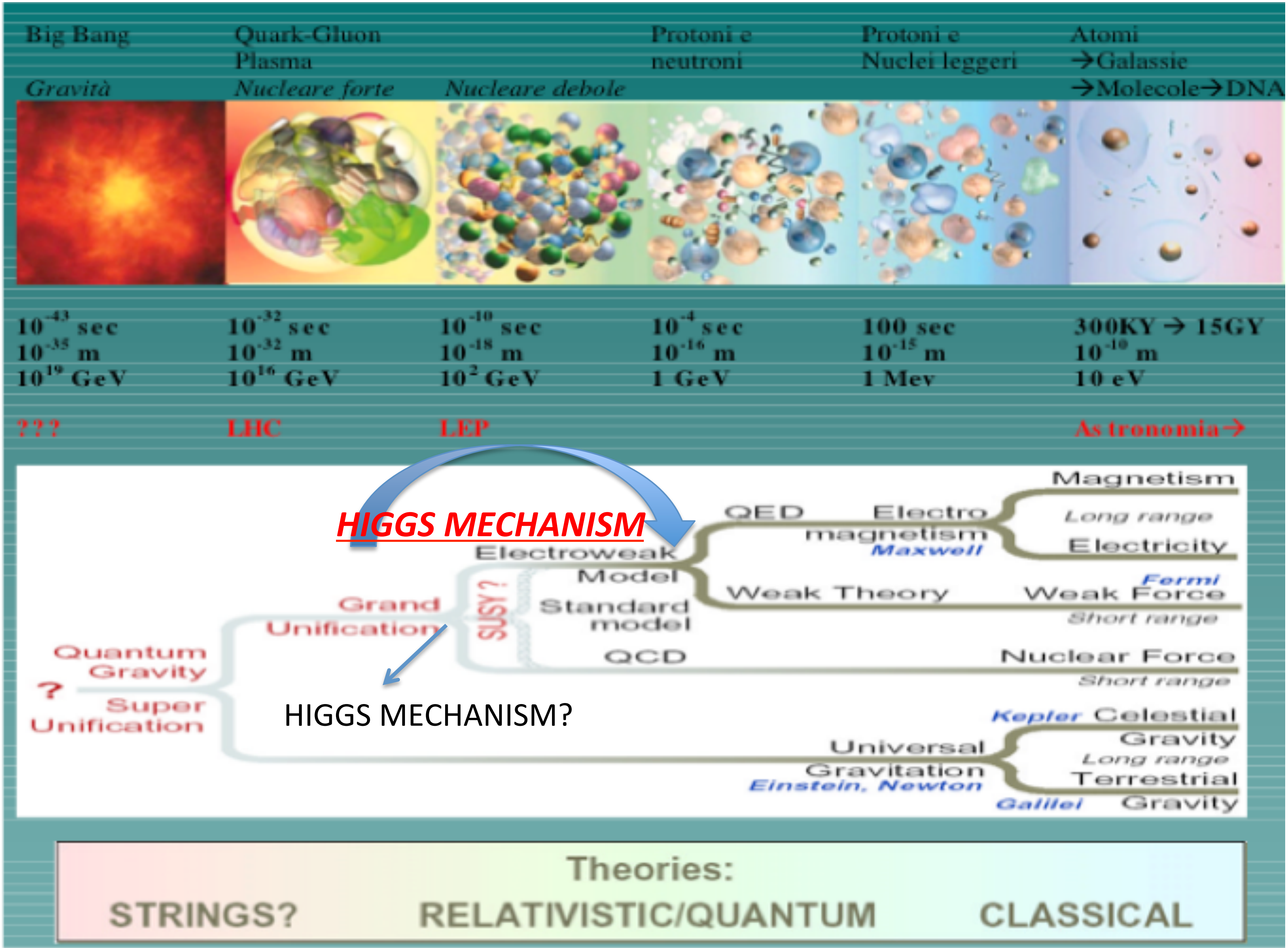
ΛCDM + "SIMPLE" INFLATION

$\Omega_\Lambda = 0.686 \pm 0.020$

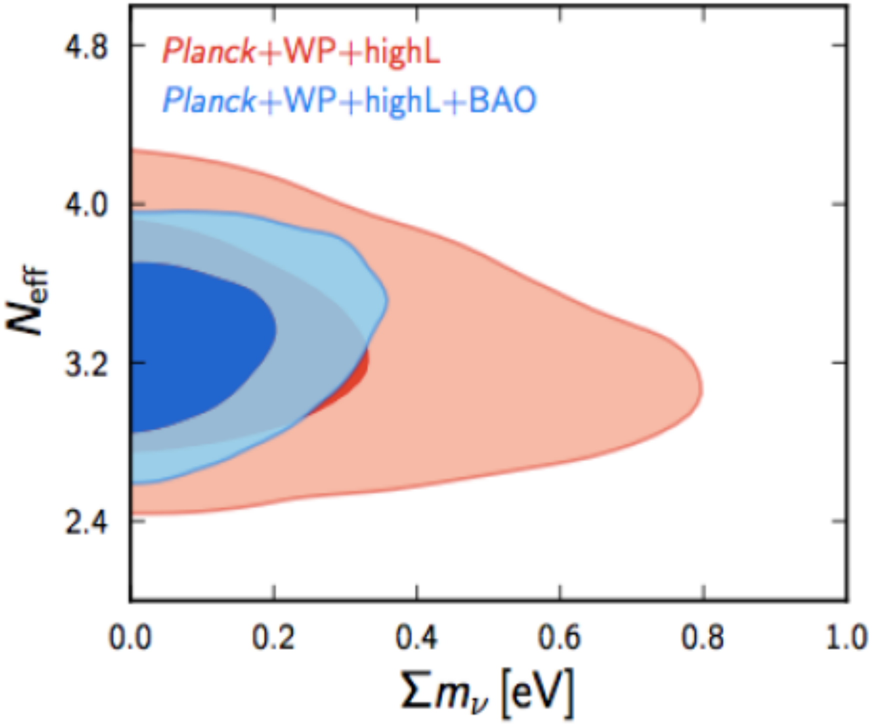
$\Omega_m = 0.314 \pm 0.020$

$\Omega_b h^2 = 0.02207 \pm 0.00033$

$h = 0.674 \pm 0.014$



Big Bang
Gravità
Quark-Gluon Plasma
Nucleare forte
Nucleare debole
Protoni e neutroni
Protoni e Nuclei leggeri
Atomi →Galassie →Molecole→DNA
10^{-43} sec
10^{-35} m
10^{19} GeV
10^{-32} sec
10^{-32} m
10^{16} GeV
10^{-10} sec
10^{-18} m
10^{2} GeV
10^{-4} sec
10^{-16} m
1 GeV
100 sec
10^{-15} m
1 Mev
300KY → 15GY
10^{-10} m
10 eV
? ? ?
LHC
LEP
Astronomia→
HIGGS MECHANISM
Magnetism
QED
Electro magnetism
Maxwell
Long range
Electricity
Electroweak Model
Standard model
SUSY ?
Weak Theory
Fermi
Weak Force
Short range
Grand Unification
QCD
Nuclear Force
Short range
Quantum Gravity
?
Super Unification
HIGGS MECHANISM?
Kepler
Celestial Gravity
Universal Gravitation
Einstein, Newton
Long range
Terrestrial Gravity
Galilei
Theories:
STRINGS?
RELATIVISTIC/QUANTUM
CLASSICAL



N_{eff}=3.36±0.34

The extracted value of N_{eff} depends whether one makes use of the value of the Hubble parameter from the Planck data or from independent observations

Σm_ν< 0.23- 0.8 eV

Recent (and controversial!) **BICEP2** results:

from the measurement of the B-mode polarization of the CMB photons

→ initial **inflationary epoch** at energies ~ **$V^{1/4}$ = 1.94 x 10^{16} GeV $(r/0.12)^{1/4}$;** r= ratio of the CMB tensorial/scalar components – from BICEP2 r ~0.2 , r≠0 at ~6 σ

INFLATON at ~ 10^{16} GeV, not standard Higgs inflation (see, however, Bezrukov and Shaposhnikov)

MICRO

MACRO

GWS STANDARD MODEL

HOT BIG BANG
STANDARD MODEL

UNIVERSE EXPANSION +
WEAK INTERACTIONS **NUCLEOYINTHESIS**
1 sec. after BB

NUMBER OF BARYONS and **OF NEUTRINO SPECIES** → CONFIRMED FROM CMB **350000 YEARS** AFTER BB

BUT ALSO

FRICTION POINTS

-COSMIC MATTER-ANTIMATTER ASYMMETRY

-INFLATION ???

- DARK MATTER + DARK ENERGY

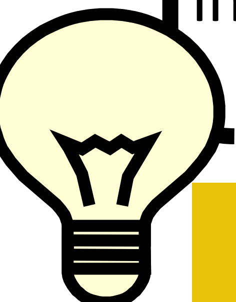
OBSERVATIONAL EVIDENCE OF NEW PHYSICS

BEYOND THE STANDARD

The Energy Scale from the "Observational" New Physics

- neutrino masses
- dark matter
- baryogenesis
- inflation C

NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE



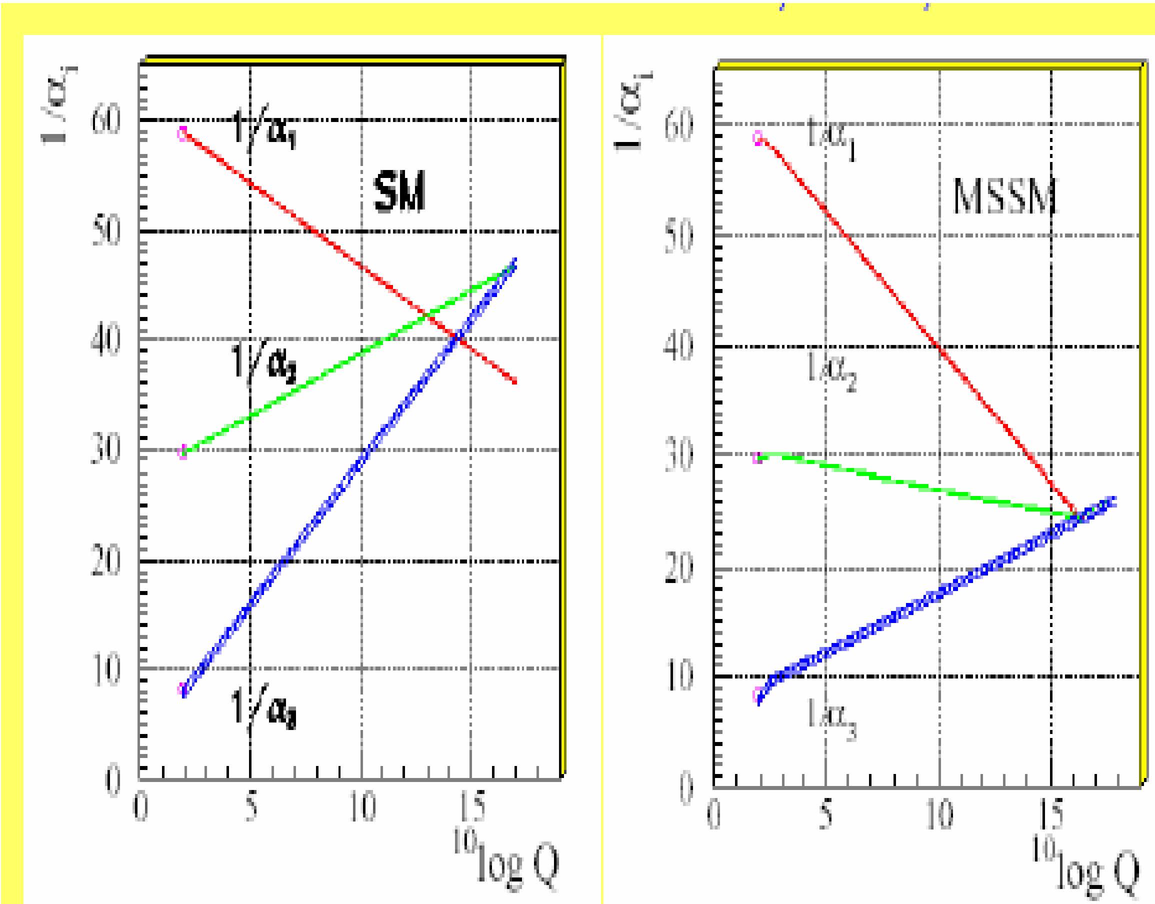
The Energy Scale from the "Theoretical" New Physics

★ ★ ★ **Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale**

+

★ **CORRECT GRAND UNIFICATION "CALLS" FOR NEW PARTICLES AT THE ELW. SCALE**

LOW-ENERGY SUSY AND UNIFICATION



Input

$\alpha^{-1}(M_Z) = 128.978 \pm 0.027$

$\sin^2\theta_{\overline{MS}} = 0.23146 \pm 0.00017$

$\alpha_s(M_Z) = 0.1184 \pm 0.0031$

Output

$M_{SUSY} = 10^{3.4 \pm 0.9 \pm 0.4}$ GeV

$M_{GUT} = 10^{15.8 \pm 0.3 \pm 0.1}$ GeV

$\alpha_{GUT}^{-1} = 26.3 \pm 1.9 \pm 1.0$

THE COMPREHENSION OF THE ELECTROWEAK SCALE

$$V = \mu^2 |H|^2 + \lambda |H|^4$$ **μ ~ 10^2 GeV**

- M = O(10^{16} GeV)

	SU(3)	SU(2)	U(1)		SO(10)
L	1	2	-1/2		
e	1	1	1		
Q	3	2	1/6	→	16
u	3*	1	-2/3		
d	3*	1	1/3		

$$m_H^2 \sim -2\mu^2 + \frac{g^2}{(4\pi)^2} M^2$$

ONLY FOR SCALARS; SM FERMIONS AND GAUGE BOSON MASSES ARE PROTECTED BY THE SU(2) × U(1) SYMMETRY !

To comprehend (i.e. stabilize) the elw. scale need NEW PHYSICS (NP) to be operative at a scale $m_{NP} \ll M$

$$m_H^2 \sim -2\mu^2 + \frac{g^2}{(4\pi)^2} M^2$$

- **UNNATURAL or FINE-TUNING SOLUTION** tuning of parameters at the scale M with precision O(m_H/M)^2

- **NATURAL SOLUTION**
Dynamics or symmetries or space-time modifications giving rise to a UV cut-off ~ (m_H)^2

- **SYMMETRY vs. MULTIVERSE**

DM: the most impressive evidence at the "quantitative" and "qualitative" levels of **New Physics beyond SM**

- QUANTITATIVE: Taking into account the latest WMAP data which in combination with LSS data provide stringent bounds on Ω_{DM} and Ω_B → **EVIDENCE FOR NON-BARYONIC DM AT MORE THAN 10 STANDARD DEVIATIONS!! THE SM DOES NOT PROVIDE ANY CANDIDATE FOR SUCH NON-BARYONIC DM**

- QUALITATIVE: it is NOT enough to provide a mass to neutrinos to obtain a valid DM candidate; LSS formation requires DM to be COLD → **NEW PARTICLES NOT INCLUDED IN THE SPECTRUM OF THE FUNDAMENTAL BUILDING BLOCKS OF THE SM !**

II. DM and ELW. SYMMETRY BREAKING

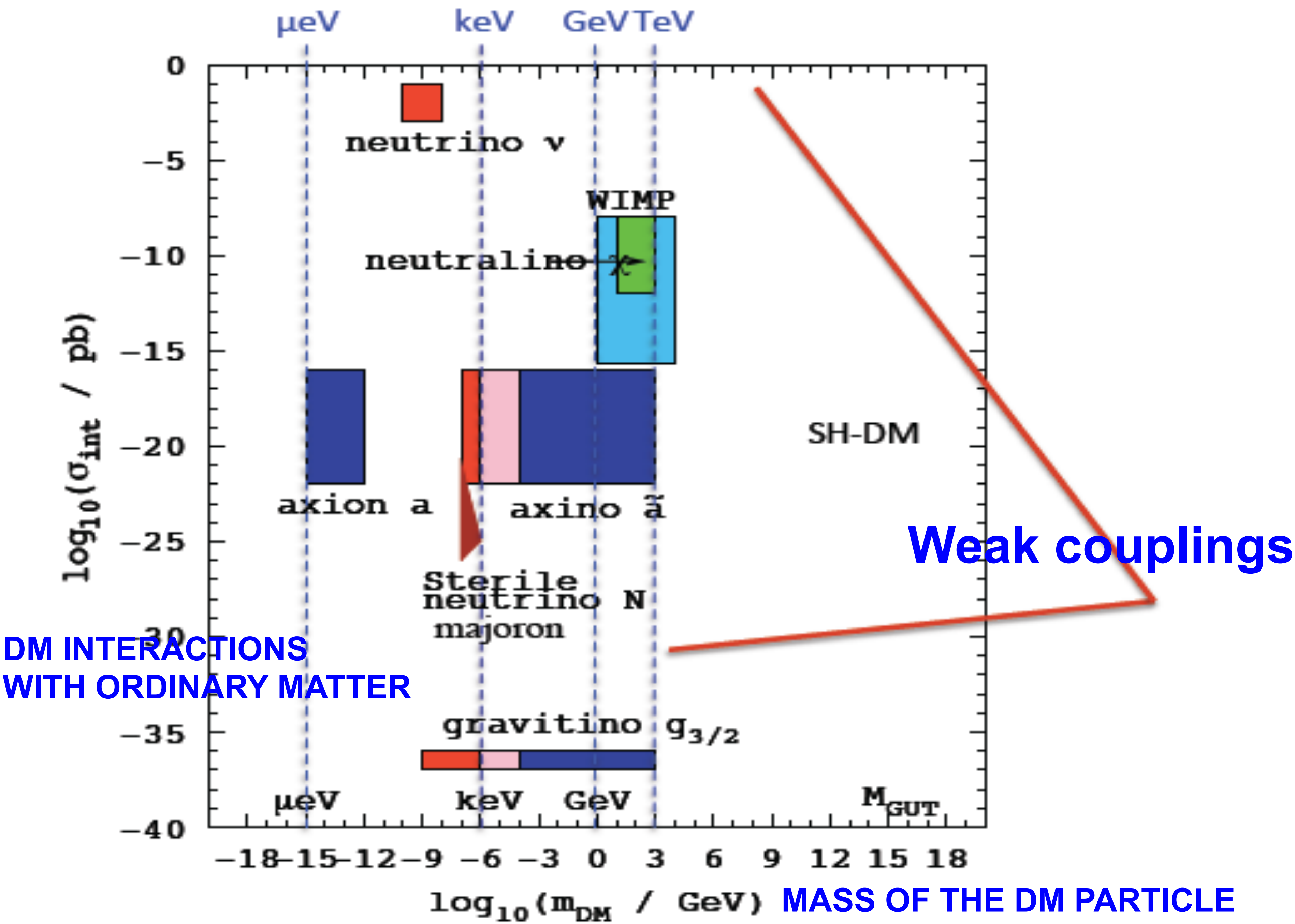
THE DM ROAD TO NEW PHYSICS BEYOND THE SM:

IS **DM** A PARTICLE OF THE ***NEW PHYSICS AT THE ELECTROWEAK ENERGY SCALE*** **?**

TEN COMMANDMENTS TO BE A "GOOD" DM CANDIDATE

BERTONE, A.M., TAOSO

- **TO MATCH THE APPROPRIATE RELIC DENSITY**
- **TO BE COLD**
- **TO BE NEUTRAL**
- **TO BE CONSISTENT WITH BBN**
- **TO LEAVE STELLAR EVOLUTION UNCHANGED**
- **TO BE COMPATIBLE WITH CONSTRAINTS ON SELF – INTERACTIONS**
- **TO BE CONSISTENT WITH DIRECT DM SEARCHES**
- **TO BE COMPATIBLE WITH GAMMA – RAY CONSTRAINTS**
- **TO BE COMPATIBLE WITH OTHER ASTROPHYSICAL BOUNDS**
- **"TO BE PROBED EXPERIMENTALLY"**


μeV
keV
GeV
TeV
neutrino ν
WIMP
neutralino χ
SH-DM
axion a
axino ã
Weak couplings
Sterile
neutrino N
majoron
DM INTERACTIONS
WITH ORDINARY MATTER
gravitino $g_{3/2}$
μeV
keV
GeV
M_{GUT}
$\log_{10}(\sigma_{int}$ / pb)
0
−5
−10
−15
−20
−25
−30
−35
−40
−18
−15
−12
−9
−6
−3
0
3
6
9
12
15
18
$\log_{10}(m_{DM}$ / GeV)
MASS OF THE DM PARTICLE

CDM Controversies?

- Cusp-vs-Core problem
- Missing satellites problem
- To-big-to-fail problem

Possible solutions

- Baryonic physics:
  gas cooling, star formation,
  supernova feedback,…
- Dark Matter:
  warm dark matter
  Decaying DM
  Self-Interacting DM

Spergel et al, Sigurdson et al,
Boehm et al, Kaplinghat et al,
Loeb et al, Tulin et al,
van de Aarseen et al,
….

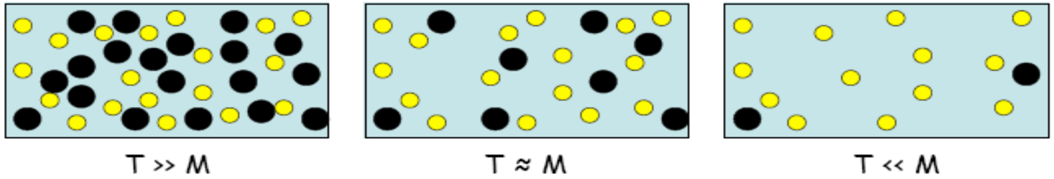
THE "*WIMP MIRACLE*"

Bergstrom

Table 1. Properties of various Dark Matter Candidates

Type	Particle Spin	Approximate Mass Scale
Axion	0	μeV-meV
Inert Higgs Doublet	0	50 GeV
Sterile Neutrino	1/2	keV
Neutralino	1/2	10 GeV - 10 TeV
Kaluza-Klein UED	1	TeV

Many possibilities for DM candidates, but WIMPs are really special: peculiar coincidence between particle physics and cosmology parameters to provide a VIABLE DM CANDIDATE AT THE ELW. SCALE



WIMPS (Weakly Interacting Massive Particles)

#χ exp(-mχ/T)χ

#χ does not change any more

#χ~#γ m_χ

$T_{decoupl.}$ typically ~ m_χ /20

Ω_χ depends on particle physics ($\sigma_{annih.}$)χ and "cosmological" quantities (H, T_0, …

$$\Omega_\chi h^2 \simeq \frac{10^{-3}}{<(\sigma_{annih.})\, V \chi > \;\; \mathrm{TeV}^2}$$

$<(\sigma_{annih.}) V\chi>$ ~ α^2 / M^2_χ

TeV² → From $T^0\, M_{Planck}$

COSMO – PARTICLE CONSPIRACY

$\Omega_\chi h^2$ in the range 10^{-2} -10^{-1} to be cosmologically interesting (for DM)

$m_\chi \sim 10^2 - 10^3$ GeV (weak interaction) $\Omega_\chi h^2 \sim 10^{-2}$ -10^{-1} !!!

THERMAL RELICS (WIMP in thermodyn.equilibrium with the plasma until $T_{decoupl}$)

CONNECTION DM – ELW. SCALE

THE WIMP MIRACLE :STABLE ELW. SCALE WIMPs

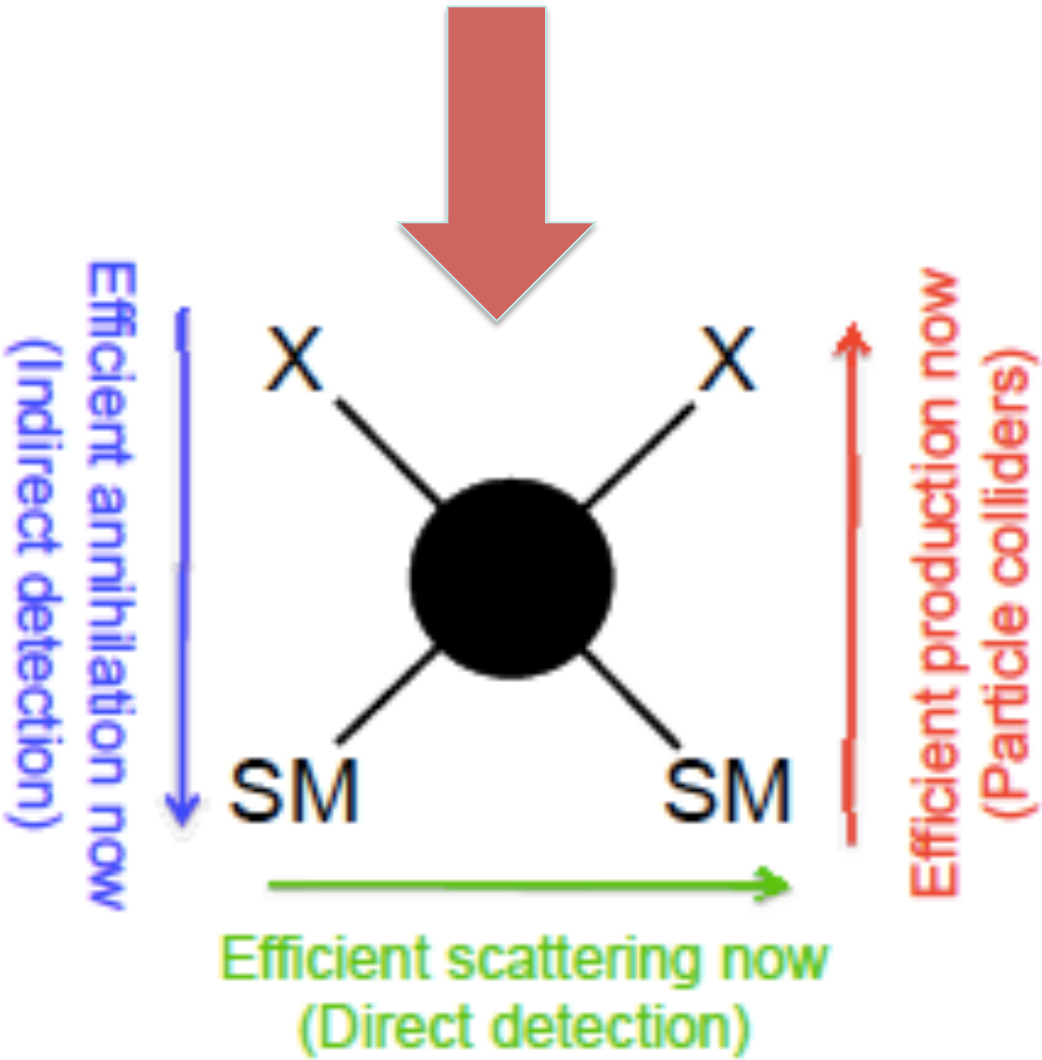
	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) **ENLARGEMENT OF THE SM**	(x^{μ}, θ)	(x^{μ}, j^{i})	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) **SELECTION RULE**	***R-PARITY LSP***	***KK-PARITY LKP***	***T-PARITY LTP***
→ **DISCRETE SYMM.**	Neutralino spin 1/2	spin1	spin0
→ **STABLE NEW PART.**	↓	↓	↓
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

SUSY & DM : a successful marriage

- Supersymmetrizing the SM does not lead necessarily to a stable SUSY particle to be a DM candidate.
- However, the mere SUSY version of the SM is known to lead to a too fast p-decay. Hence, necessarily, the SUSY version of the SM has to be **supplemented with some additional (ad hoc?) symmetry to prevent the p-decay catastrophe.**
- Certainly the simplest and maybe also the most attractive solution is **to impose the discrete R-parity** symmetry
- MSSM + R PARITY → LIGHTEST SUSY PARTICLE (LSP) IS STABLE .
- The LSP can constitute an interesting DM candidate in several interesting realizations of the MSSM (i.e., with different SUSY breaking mechanisms including gravity, gaugino, gauge, anomaly mediations, and in various regions of the parameter space).

III. DESPERATELY SEEKING (SUSY) WIMPS

DM COMPLEMENTARITY: efficient annihilation in the early Universe implies today



Info to extract from the direct searches

Y. Kahn, IPA2014
Kahn, McCullough, Fox 2014

$= g(v_{min})$

$$\frac{dR}{dE_R} = \frac{\rho_\chi \sigma_n}{2 m_\chi \mu_{n\chi}^2} N_A m_n C_T^2(A,Z) \int dE'_R G(E_R, E'_R) \epsilon(E'_R) F^2(E'_R) \int_{v_{min}(E'_R)}^{\infty} \frac{f(\mathbf{v}+\mathbf{v}_E)}{v} d^3v$$

DM model — detector properties — nuclear physics — DM halo model

$v_{min}(E'_R)$: min. DM velocity required for nuclear recoil E'_R

Usual method: DM model + halo model → limits/preferred values in $m_\chi - \sigma_n$ space

Halo-independent: DM model → limits/preferred values in $v_{min} - g(v_{min})$ space

No assumptions about DM halo, easy to compare multiple experiments (esp. signal vs. exclusion)

Direct WIMP detection: principle

Goodman and Witten, PRD31, 1985

- Elastic collision with atomic nuclei in ultra-low background detectors
- Energy of recoiling nucleus: few keV to tens of keV

N.B.: crucial for a comparison of the m_W – σ exclusion regions among different exps.

Astrophysics

$$\frac{dR}{dE_R} = N_N \frac{\rho_0}{m_W} \int_{v_{min}} d\mathbf{v} f(\mathbf{v}) v \frac{d\sigma}{dE_R}$$

Particle+nuclear physics

N_N = number of target nuclei in a detector

ρ_0 = local density of the dark matter in the Milky Way

f(v) = WIMP velocity distribution in lab frame

m_W = WIMP-mass

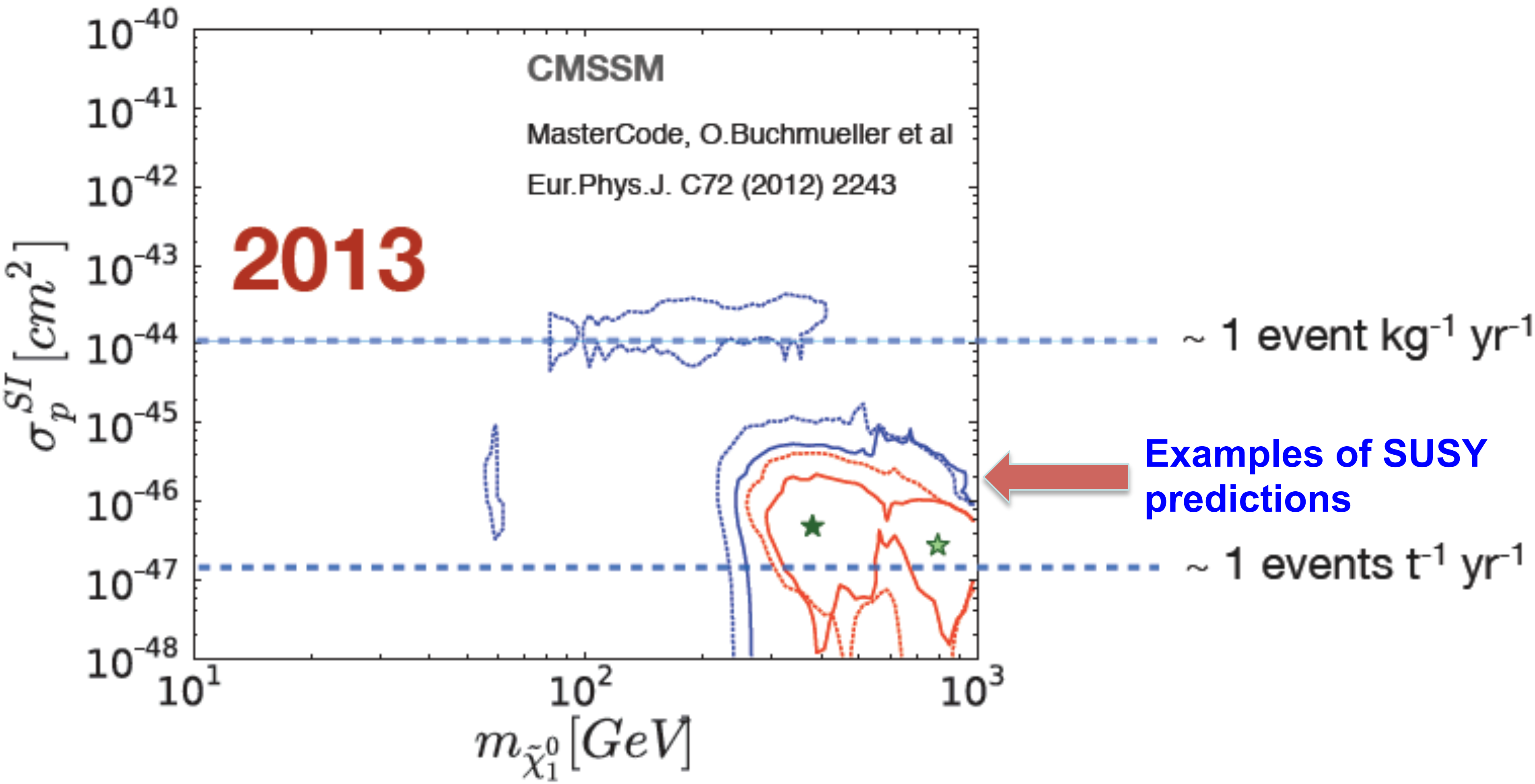
σ =cross section for WIMP-nucleus elastic scattering

$$v_{min} = \sqrt{\frac{m_N E_{th}}{2\mu^2}}$$

INTERACTION RATE FOR ELASTIC SCATTERING

after integrating over WIMP velocity distribution

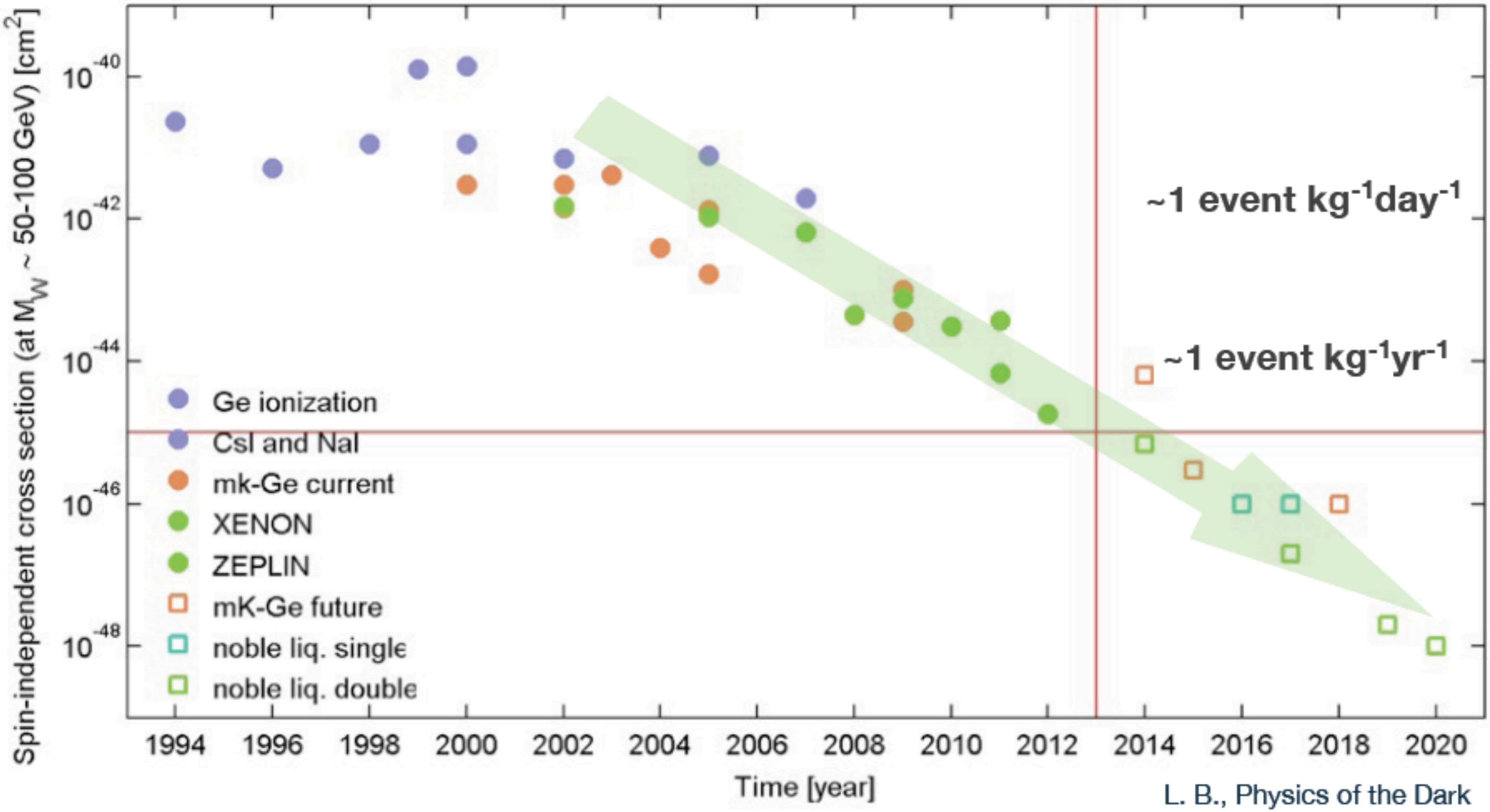
$$R \sim 0.13 \, \frac{\text{events}}{\text{kg year}} \left[\frac{A}{100} \times \frac{\sigma_{WN}}{10^{-38}\,\text{cm}^2} \times \frac{\langle v \rangle}{220\,\text{km s}^{-1}} \times \frac{\rho_0}{0.3\,\text{GeV cm}^{-3}} \right]$$



Direct detection: sensitivity versus time

Factor ~ 10 every two years!

L. BAUDIS



L. B., Physics of the Dark Universe 1, 94 (2012)

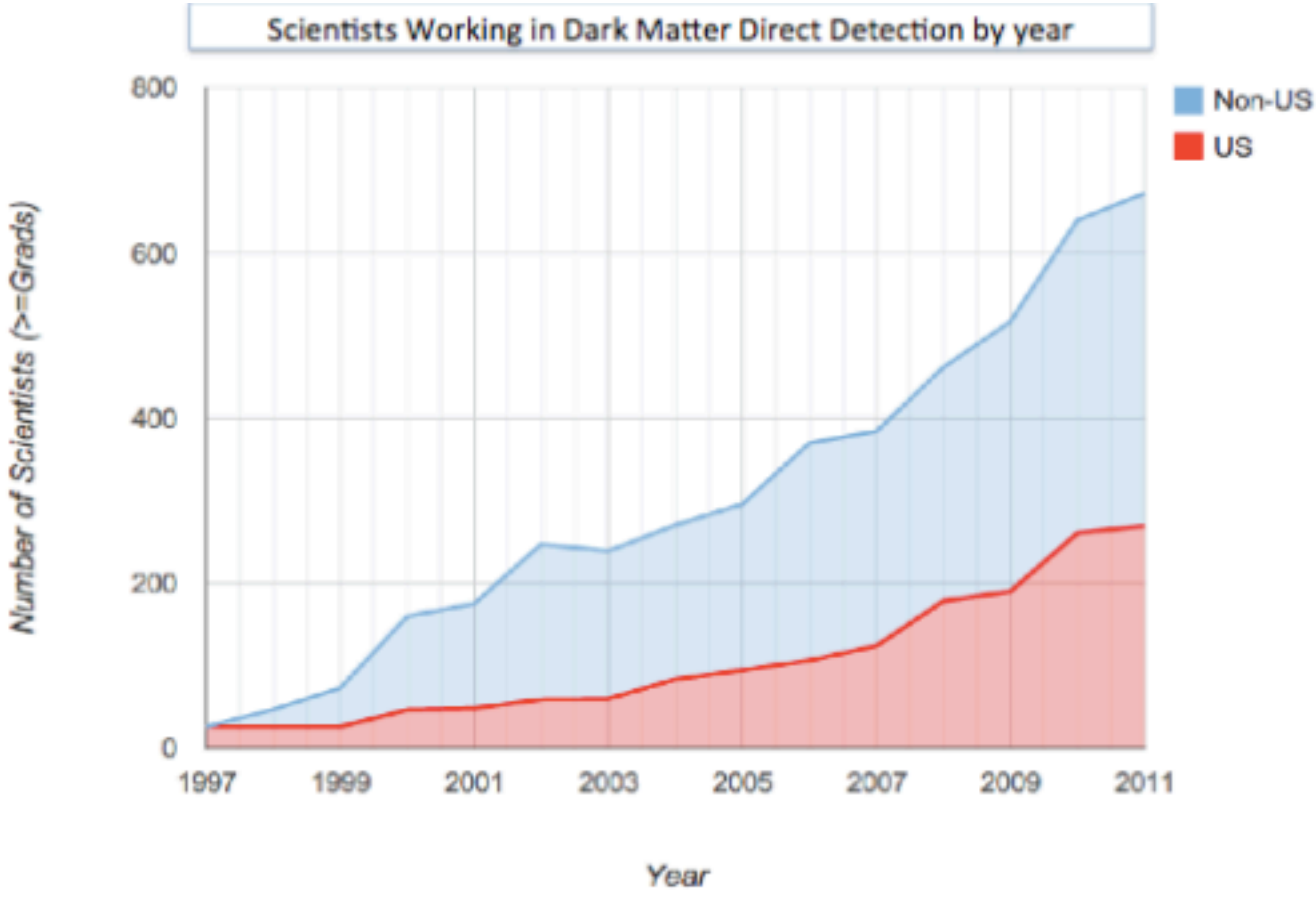
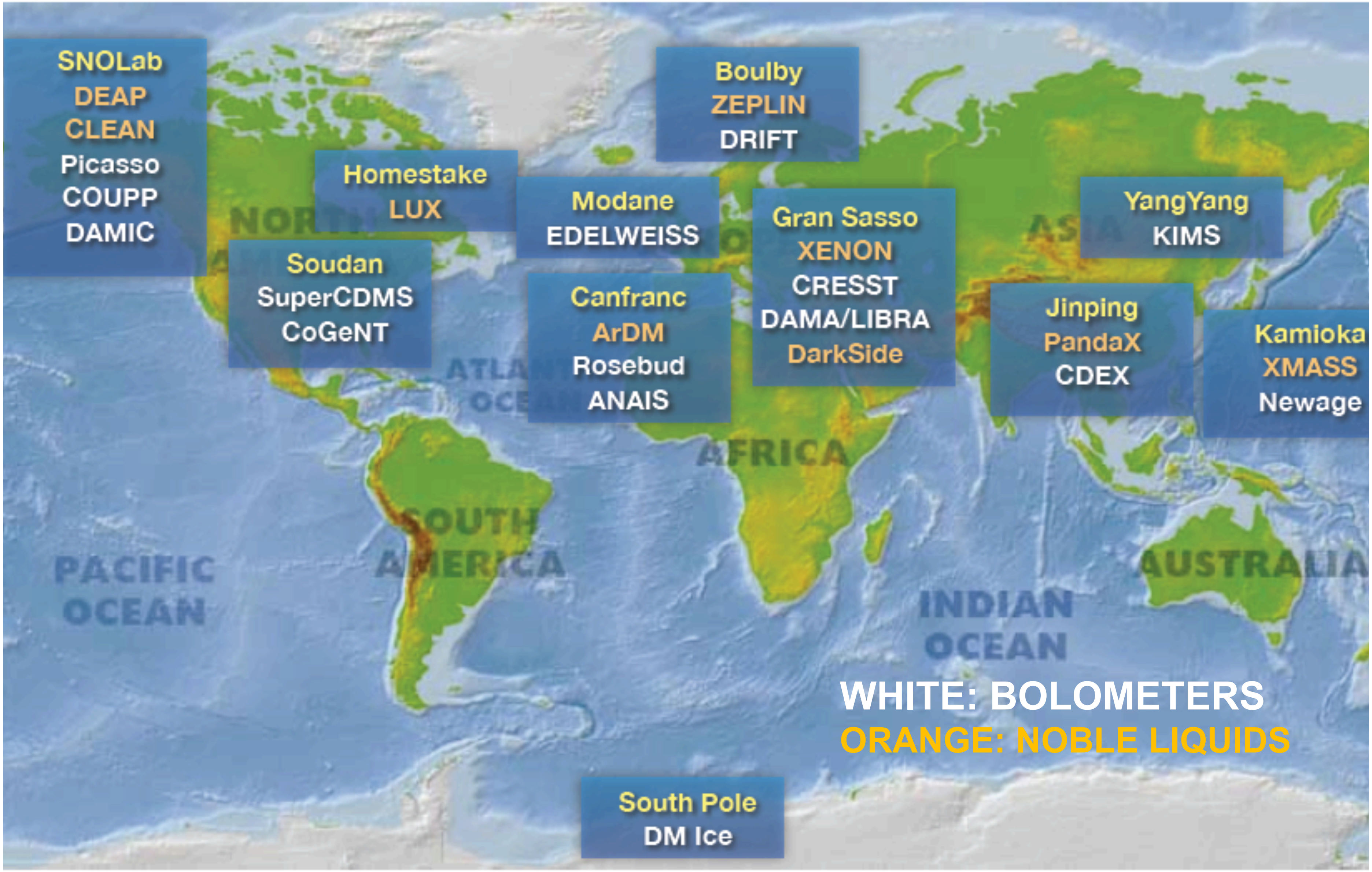


Figure 4. *Dark matter direct detection experiment demographics.*

arXiv:1310.8327

IMPRESSIVE EFFORT TO LOOK FOR WIMPS WORLDWIDE



7) Funding

Comments:

-most projects in some state of upgrade proposal

-nearly all are coordinated proposals to agencies across EU/ North America

-collaboration sizes range from 2-20 groups

Project Name	Funding status	EU Stakeholders (main non-EU)
EDELWEISS	funded	ANR, HAP, BMBF, RFBF
CRESST	funded	MPP, TUM
EURECA	complete 2013	ASPERA
XENON 100 / 1T	funded	many + (US NSF, DOE)
XENON N-T	proposed	many + (US NSF)
LUX	funded	STFC (US DOE)
LZ	proposed	STFC (US DOE G2)
DEAP	funded	ERC, STFC (Canada CFI)
DarkSide	upgrade proposal	INFN (US DOE G2, NSF)
ArDM	funded	SSNF, Ciemat
DARWIN	complete 2013	ASPERA
DAMA/LIBRA	funded	INFN (IHEP)
ANAIS	upgrade proposal	MICINN, MEC
DM-ICE	upgrade proposal	(US NSF)
SABRE	proposed	(US NSF)
PICO	upgrade proposal	(US DOE G2)
SIMPLE	upgrade proposal	ERC, Portugese Science Foundation
CAST/IAXO	upgrade proposal	CERN, EU, Int'l Partners
MiMAC	upgrade proposal	ANR
DMTPC	funded	STFC (US DOE, NSF)
DRIFT	upgrade proposal	(US NSF)

8) Convergence

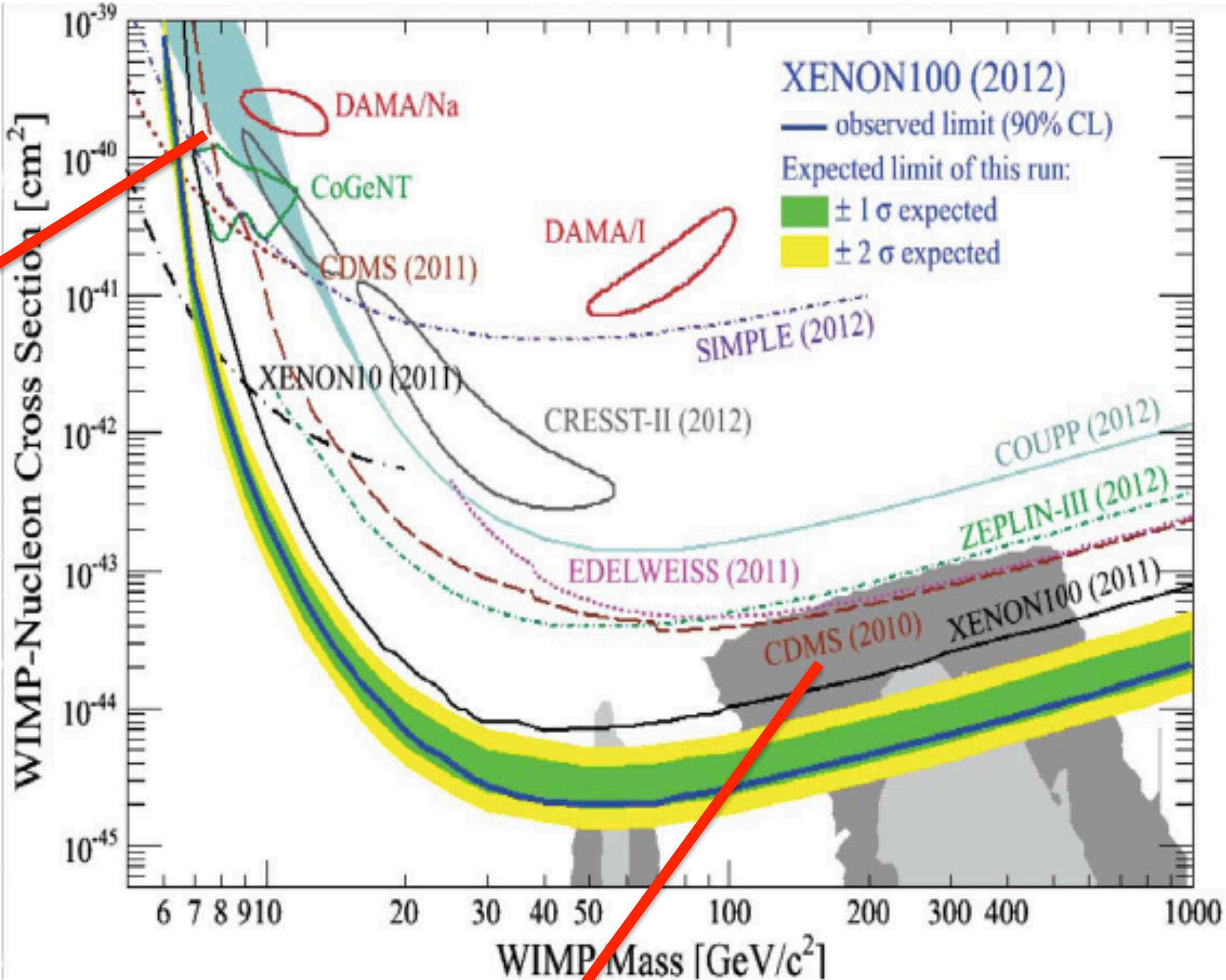
<u>Duplication:</u>
-21 projects,
8 unique combinations of target species & technology

<u>Convergence:</u>
(so far)
-EURECA = CRESST + EDELWEISS
-PICO = COUPP + PICASSO
-DARWIN = XENON + DarkSide + ArDM
-CYGNUS = MiMAC + DMTPC DRIFT + NEWAGE

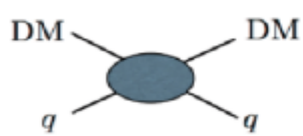
Project Name	Target	Detector Technology
EDELWEISS	Ge	iZIP bolometers
CRESST	CaWO4	SQUIDs
EURECA	Ge	iZIP bolometers
XENON 100 / 1T	Xe	2-phase TPC
XENON N-T	Xe	2-phase TPC
LUX	Xe	2-phase TPC
LZ	Xe	2-phase TPC
DEAP	Ar	single phase
DarkSide	Ar	2-phase TPC
ArDM	Ar	2-phase TPC
DARWIN	Ar & Xe	2-phase TPC
DAMA/LIBRA	NaI	scintillator + PMTs
ANAIS	NaI	scintillator + PMTs
DM-ICE	NaI	scintillator + PMTs
SABRE	NaI	scintillator + PMTs
PICO	CF3I	bubble chamber + acoustic
SIMPLE	CF3I	bubble chamber + acoustic
CAST	axion	solar axion telescope
MiMAC	CF4 + He	gas TPC, micromegas readout
DMTPC	CF4	gas TPC, CCD readout
DRIFT	CF4 + CS2	gas TPC, MWPC readout

Low-mass region:
either unexplained backgrounds in DAMA, CoGeNT, and CRESST-II, …
or
… other experiments do not understand low recoil energy calibration, …
or
… can't compare different experiments

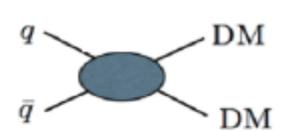
Kolb SUSY2012



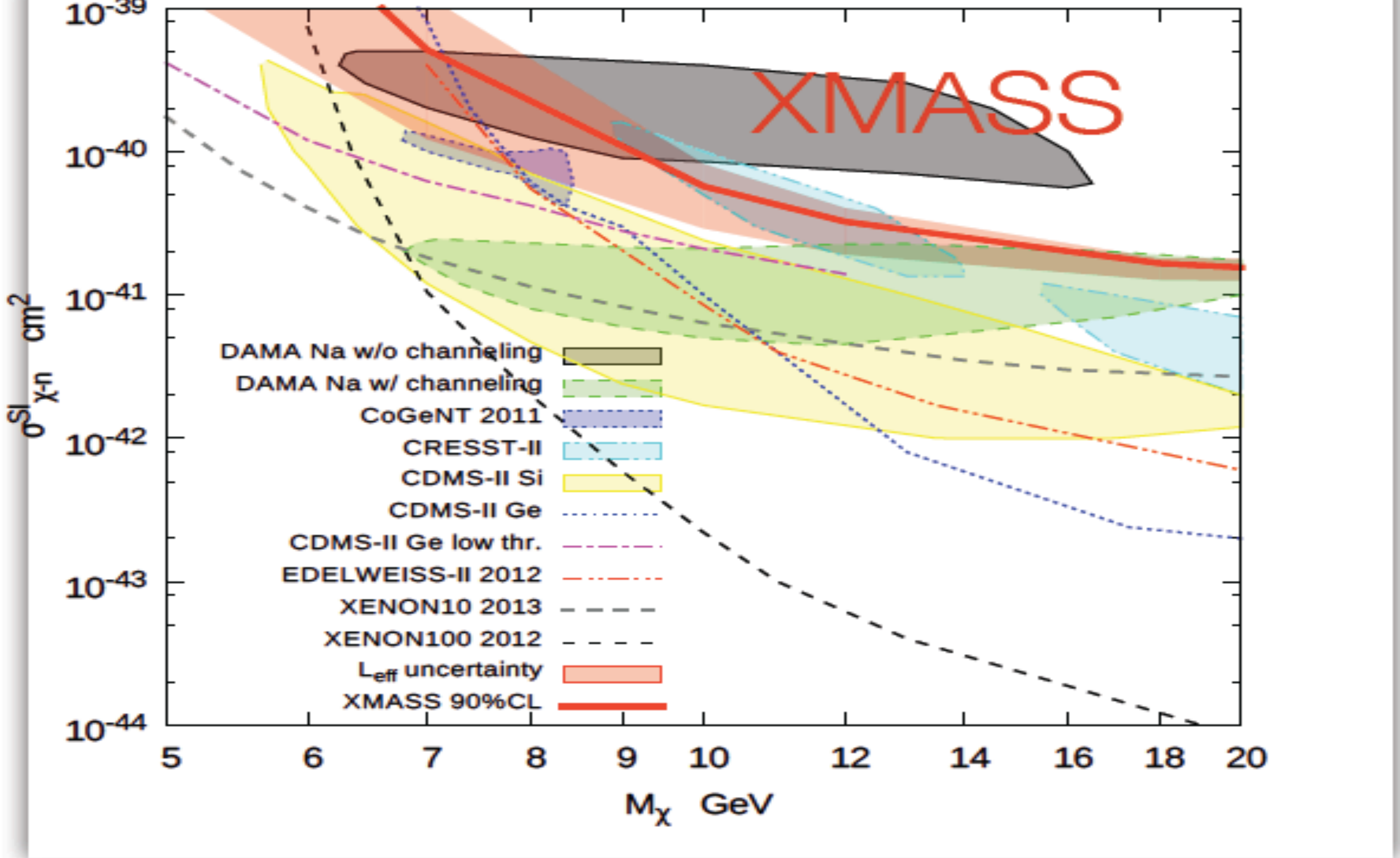
Relevant to intensify the efforts here: ex. **asymmetric DM** with **DM particles of mass~ baryon mass given that ρ_{DM} not much different from ρ_B**



Direct Detection (t-channel)



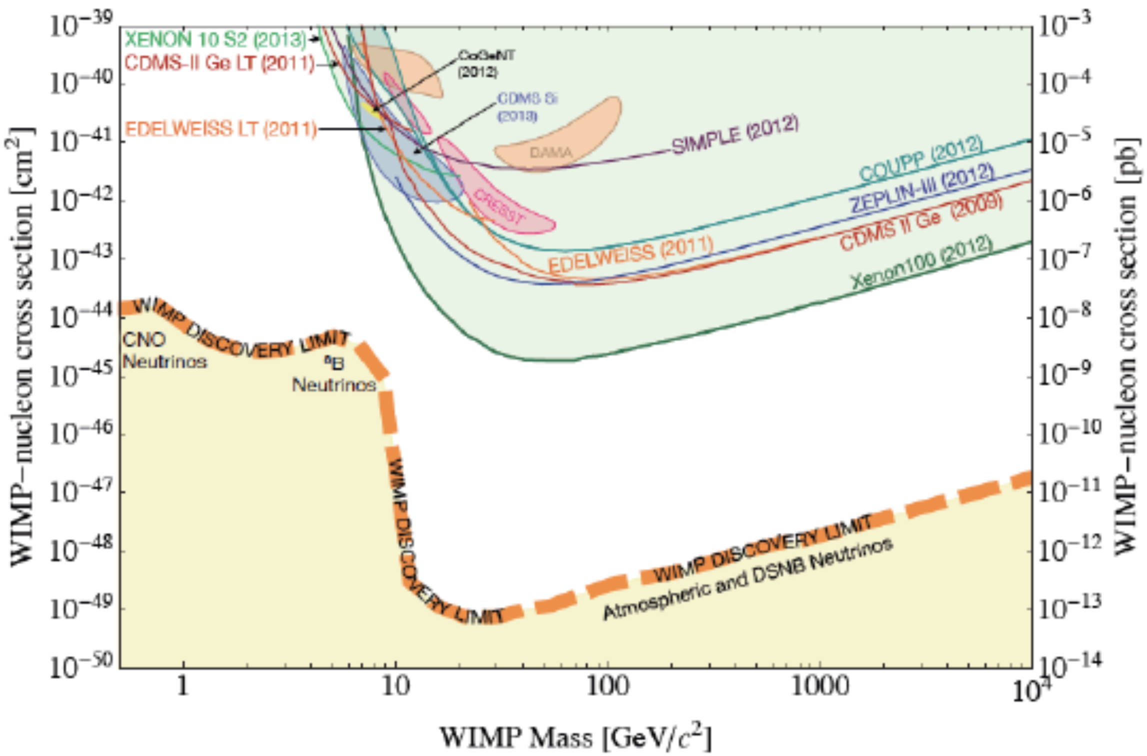
Collider Searches (s-channel)



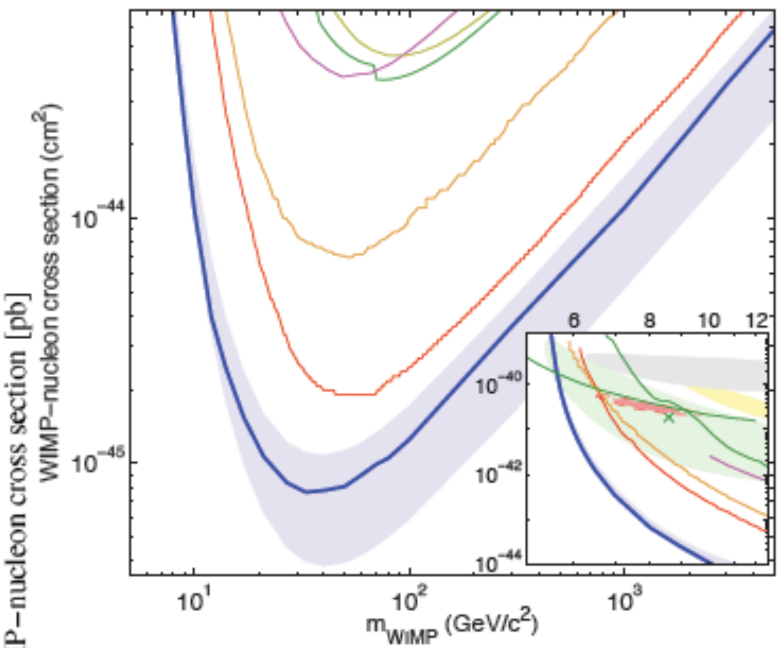
RELEVANCE OF THE DAMA-LIBRA RESULT– IMPORTANCE OF AN INDEPENDENT VERIFICATION (hard to reach the same level of sensitivity)

WIMP parameter space

Overview of results before Oct 30, 2013 and neutrino backgrounds

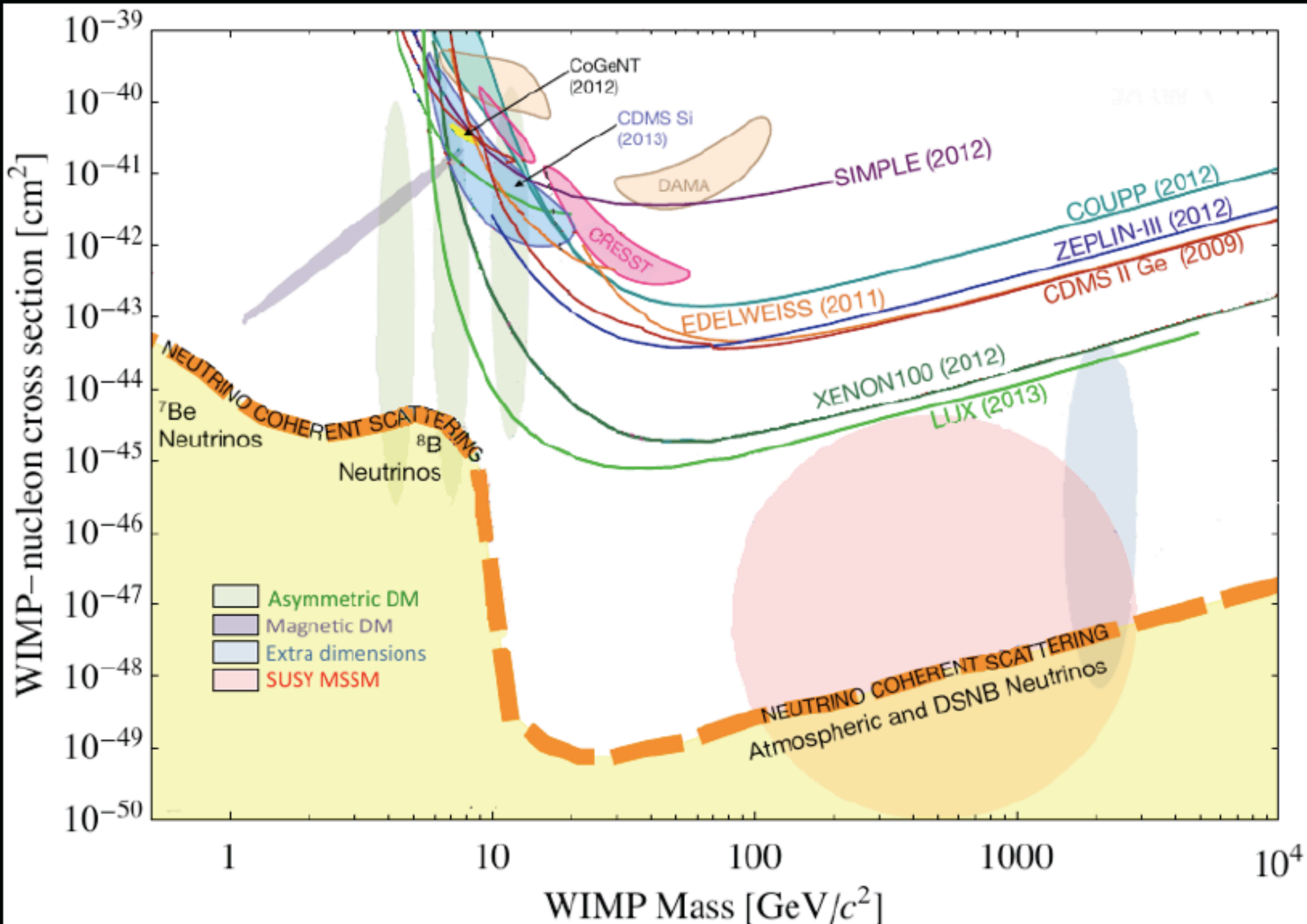


LUX result, Oct 30, 2013



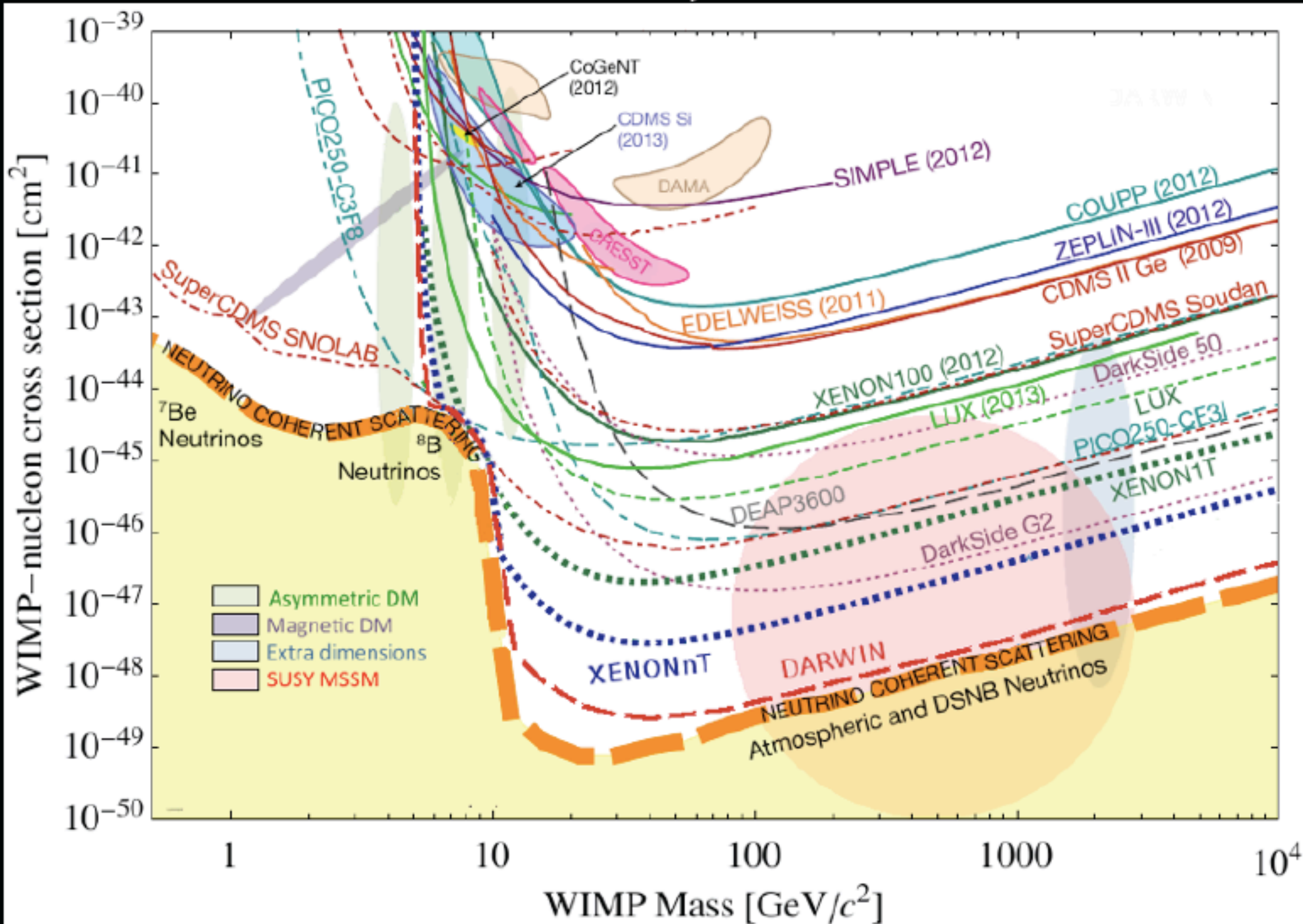
L. BAUDIS, SAC of APPEC April 2014

1) Science Goals: Dark Matter Discovery



so far: ~3 years / order of magnitude

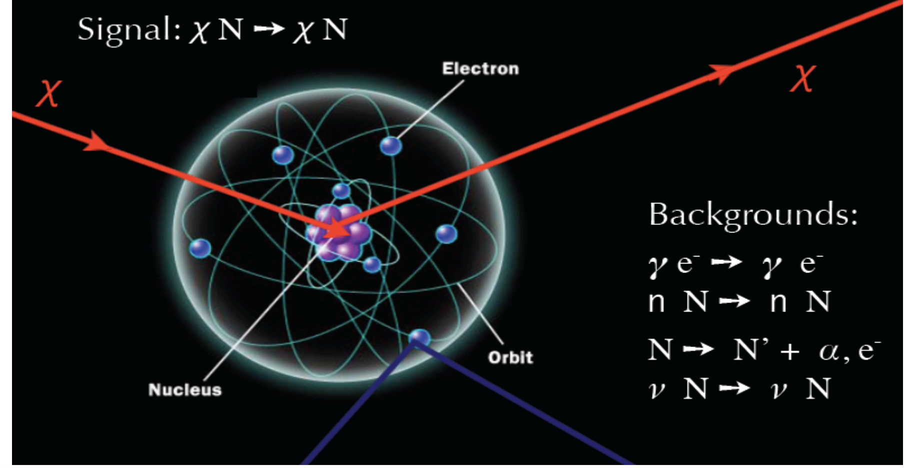
1) Science Goals: Dark Matter Projected Sensitivities



What if 2+ of these experiments observe strong candidate dark matter signals?

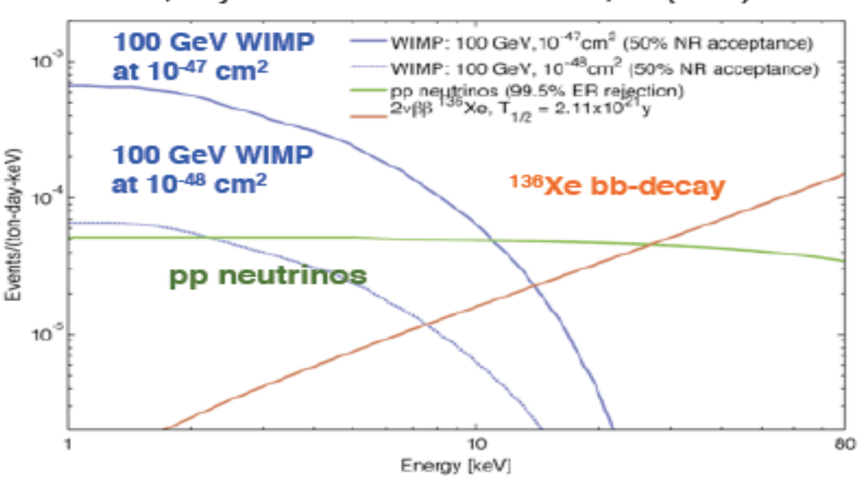
Build a directional detector to establish astrophysical origin.

NEUTRINOS, the ultimate, uneliminable background



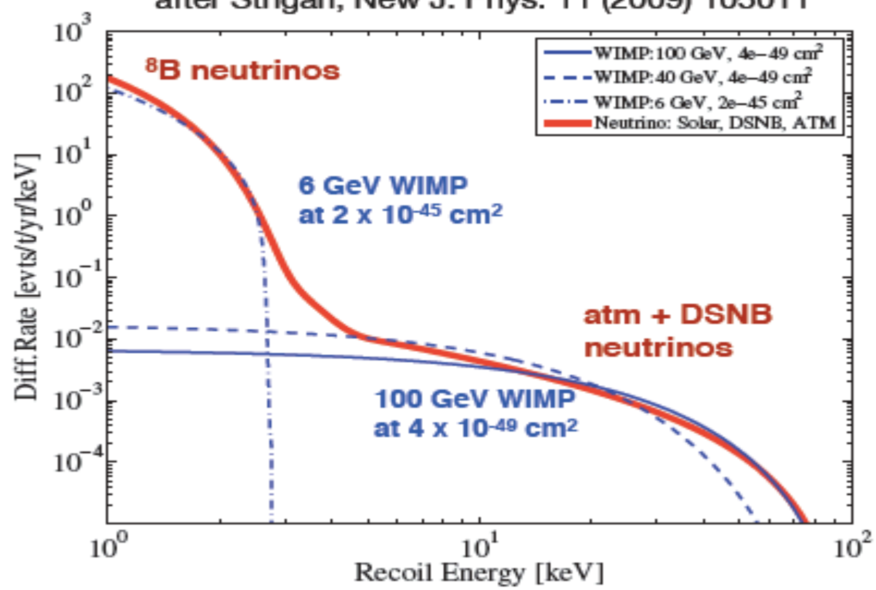
- Electronic recoils from pp solar neutrinos: ~ 10^{-48} cm²
- Nuclear recoils from ^{8}B solar neutrinos: below ~10^{-45} cm² for low-mass WIMPs
- Nuclear recoils from atmospheric + DSNB: below ~10^{-48} cm²

Baudis, Physics of the Dark Universe 1, 94 (2012)



$$\nu + e^- \rightarrow \nu + e^-$$

after Strigari, New J. Phys. 11 (2009) 105011



$$\nu + N \rightarrow \nu + N$$

Underground Space for a Directional Detector

Eventually: large detector, 10^{-46} cm^2 sensitivity,
how big is it?

MiniBooNE:
$6 \times 6 \times 6$ m^3

Directional Detection Observatory (10^{-46} cm^2)
$16 \times 16 \times 16$ m^3

1 ton of CF_4 @50Torr

MINOS:
$15 \times 13 \times 30$ m^3

SNO:
$21 \times 21 \times 34$ m^3

SuperK:
$40 \times 40 \times 40$ m^3

detector size for 10^{-46} cm^2 SI sensitivity

IV. TOUGH LIFE FOR A
SUSY WIMP:
controversial medical bulletins on neutralino health:
(still) alive, sick, dead?

M. Cahill-Rowley, R. Cotta, A. Drlica-Wagner,
S. Funk, J. Hewett, A. Ismail, M. Wood &
T. Rizzo

1305.6291, 1307.8444 & to appear 11/14/13

The p(henomenological)MSSM

→ The MSSM has > 100 parameters -- we make experimentally motivated assumptions to reduce these to some 'reasonable' level :

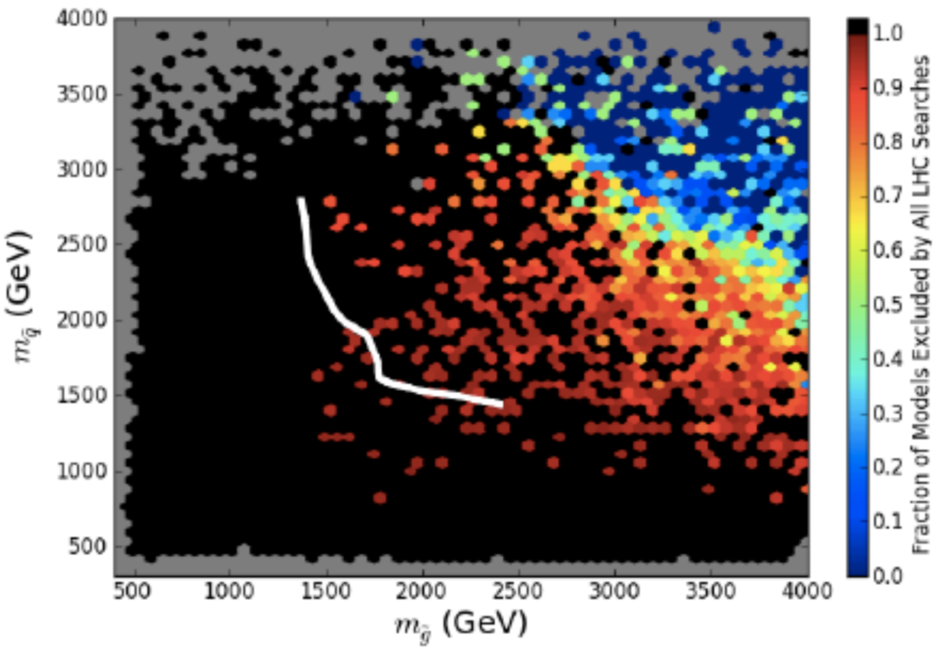
- The general, CP-conserving MSSM with R-parity
- Minimal Flavor Violation at the TeV scale (the CKM controls flavor)
- The lightest neutralino is the LSP
- The first two sfermion generations are degenerate (type by type).
- The first two generations have negligible Yukawa's & A-terms.
- The WMAP/Planck relic density is not necessarily saturated by the LSP

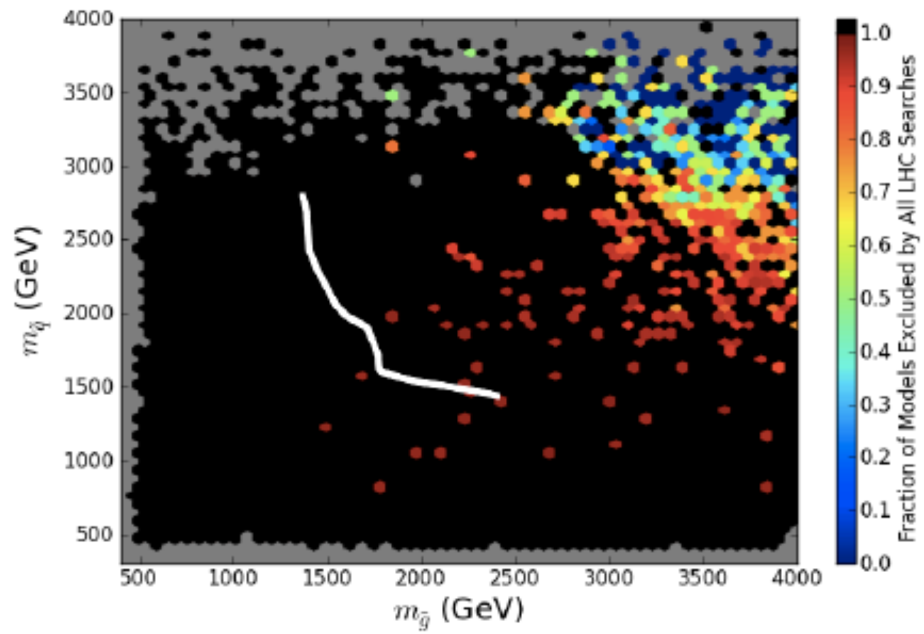
→ the pMSSM with 19 TeV-scale parameters…

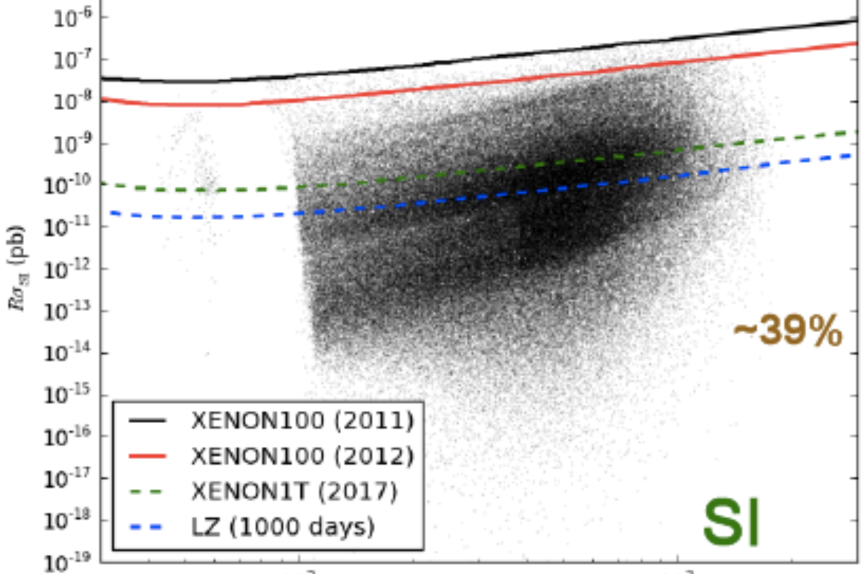
Goal: obtain ~225k points ('models') satisfying existing data & study them…going for 'breadth not depth'. NO FITS!

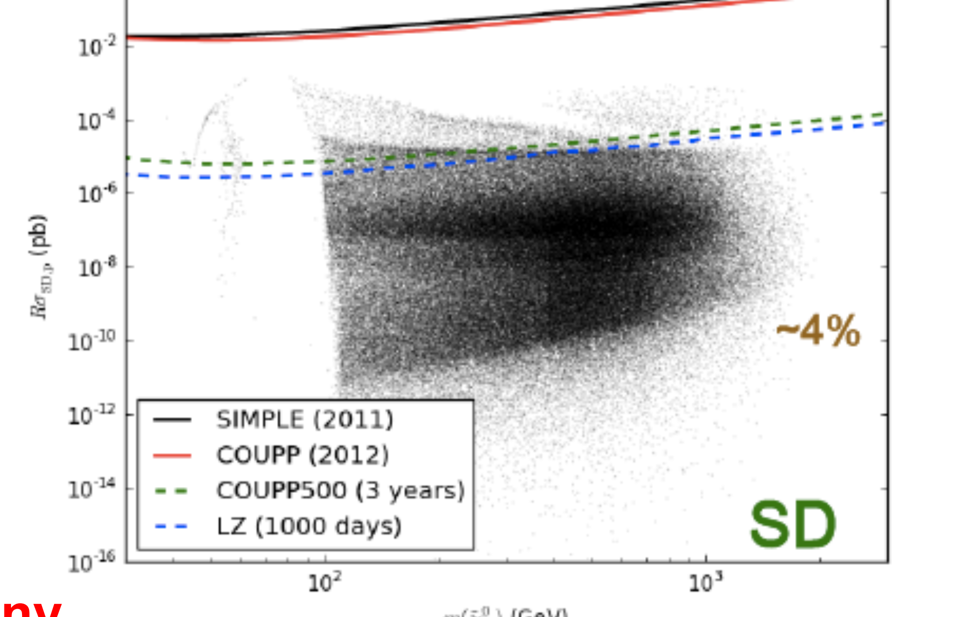
Extrapolation of the LHC pMSSM Coverage for Both 0.3 & 3 ab^{-1}

This is JUST the 0-l, jets+MET analysis plus the 0&1-l stop analyses results for the subset of models surviving the 7&8 TeV searches with a Higgs mass of $m_h = 126 \pm 3$ GeV . The coverage is already VERY good !



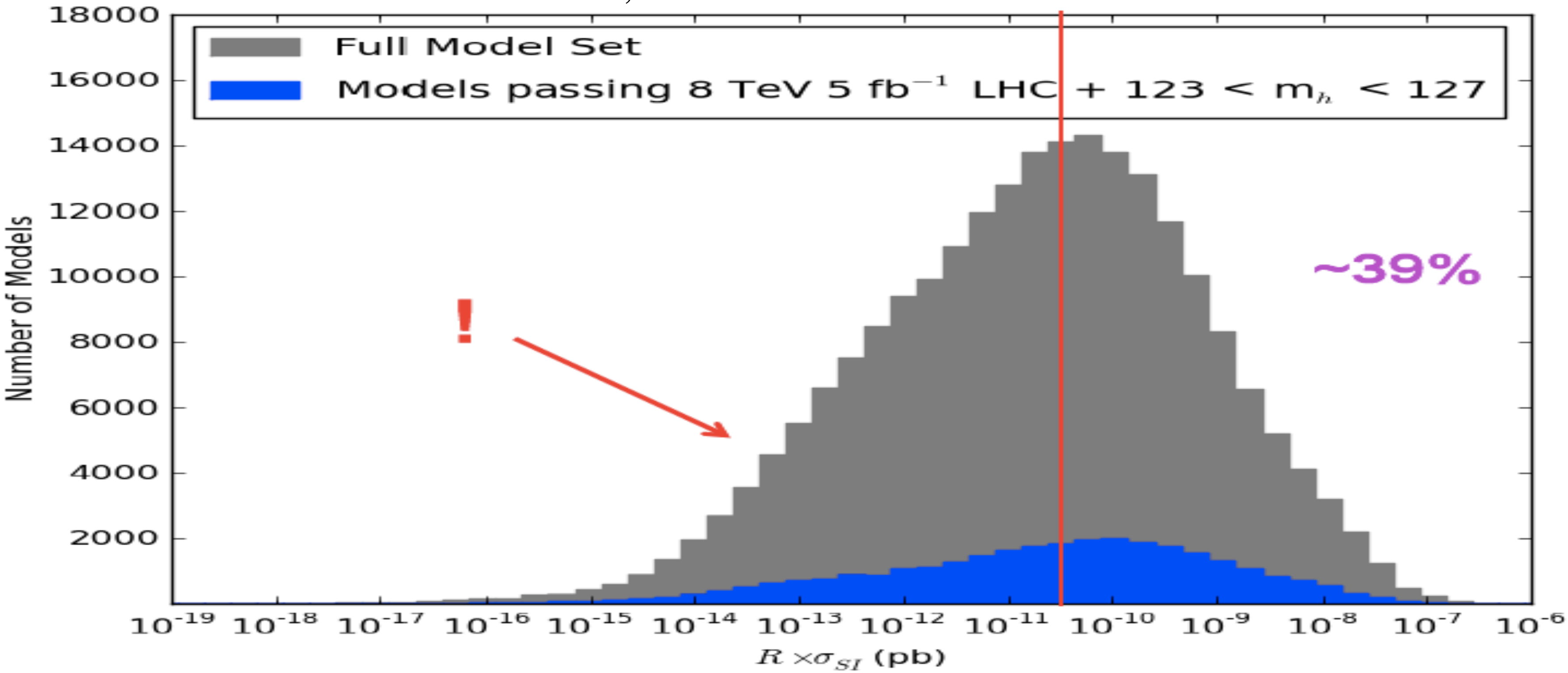


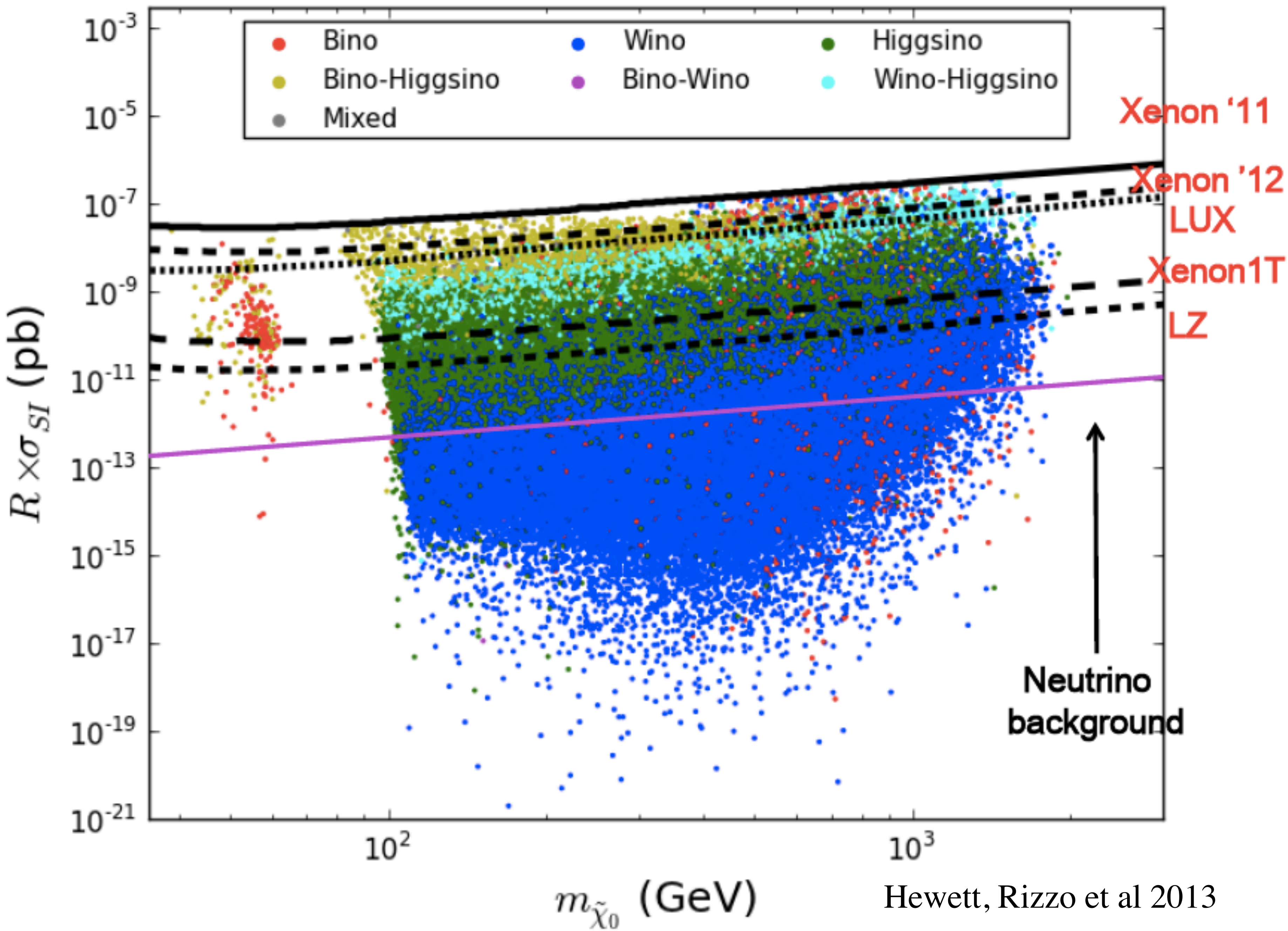




125k models pMSSM under scrutiny

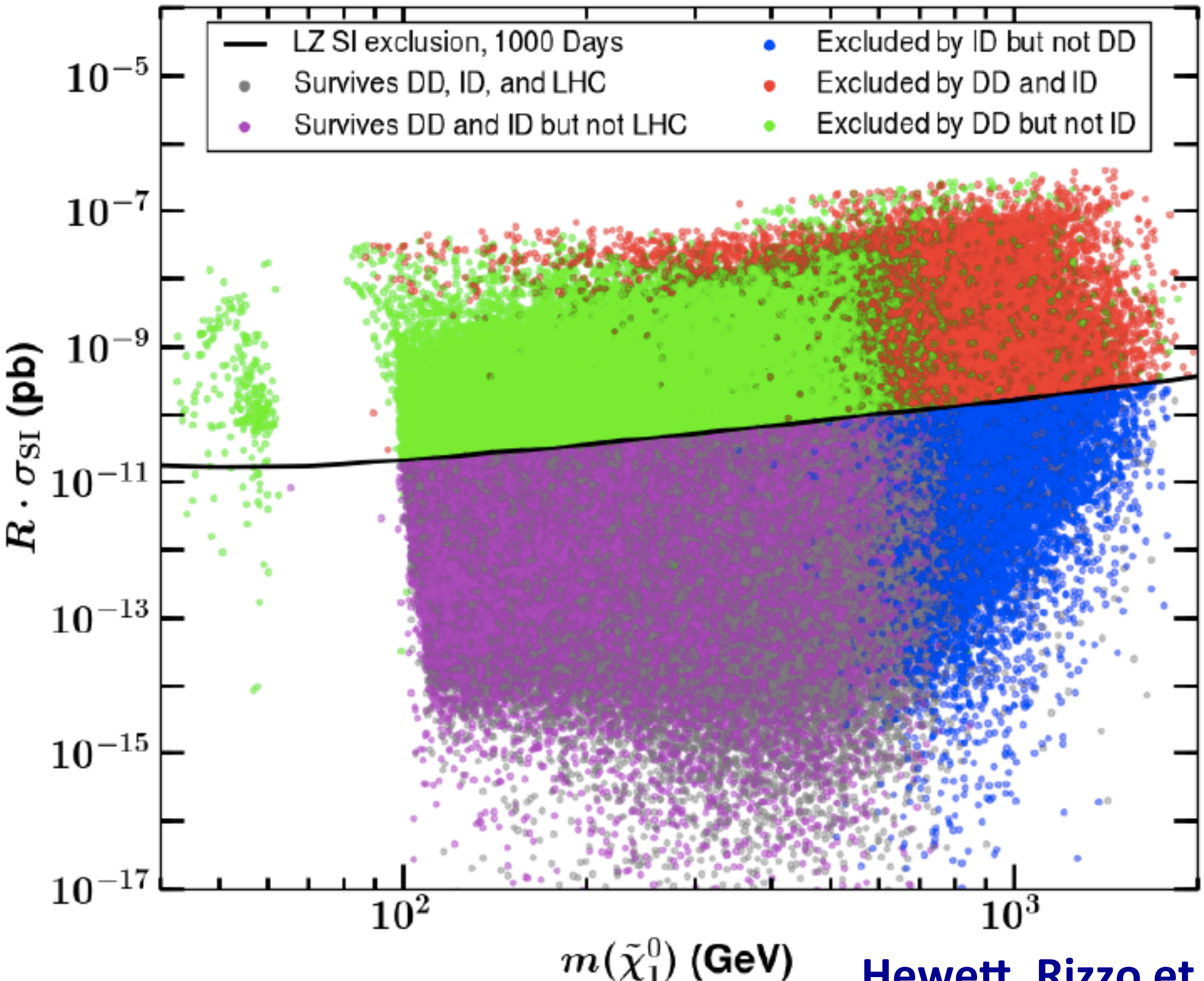
Hewett, Rizzo et al





Hewett, Rizzo et al 2013

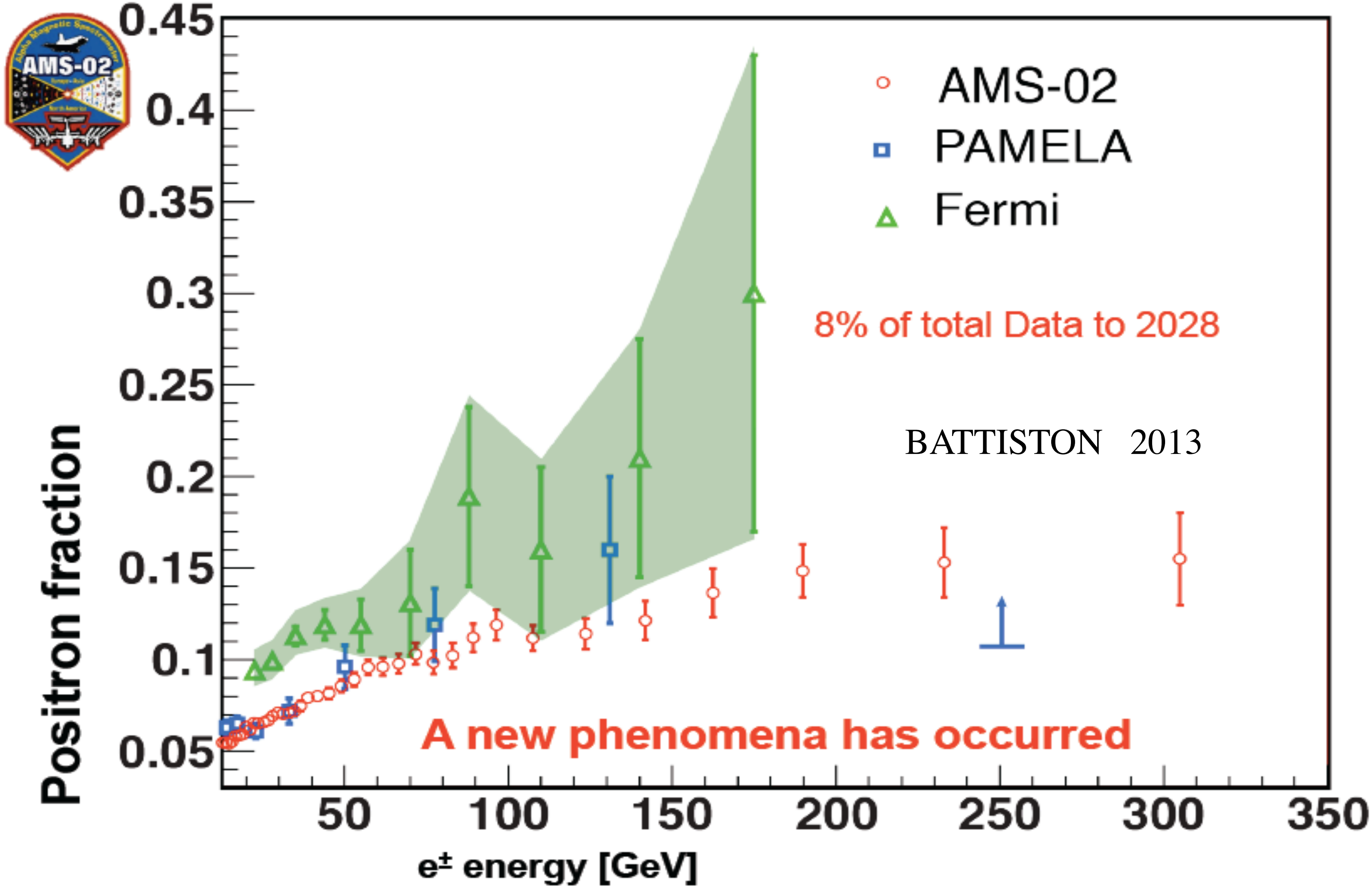
pMSSM models DD = LZ both SI + SD ID = FERMI + CTA



11.4%
29.2%
7.2%
27.5%
24.7%

Hewett, Rizzo et al. 2013

INDIRECT SEARCHES FOR DM
IN SPACE



AMS Positron Fraction 2014 @ Low Energies

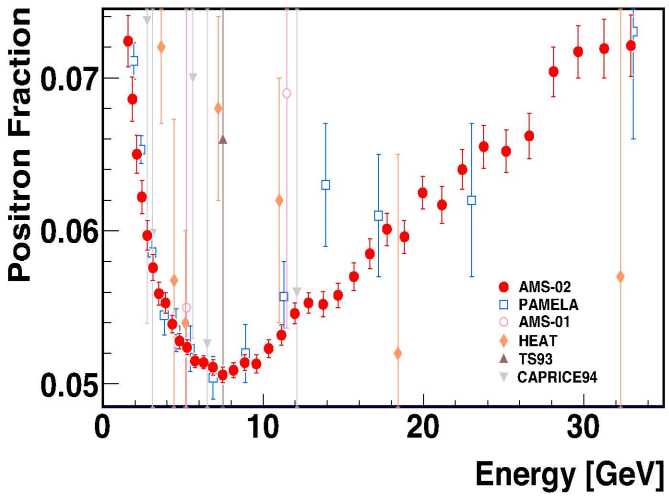
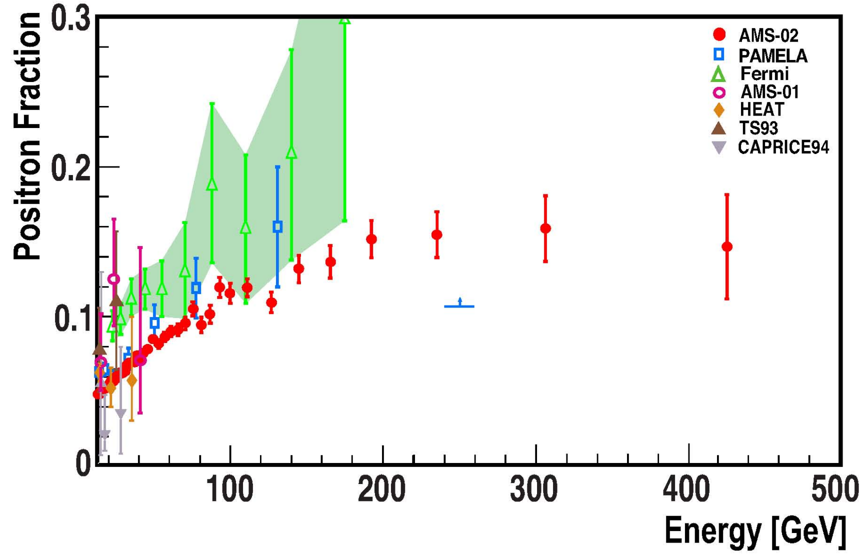


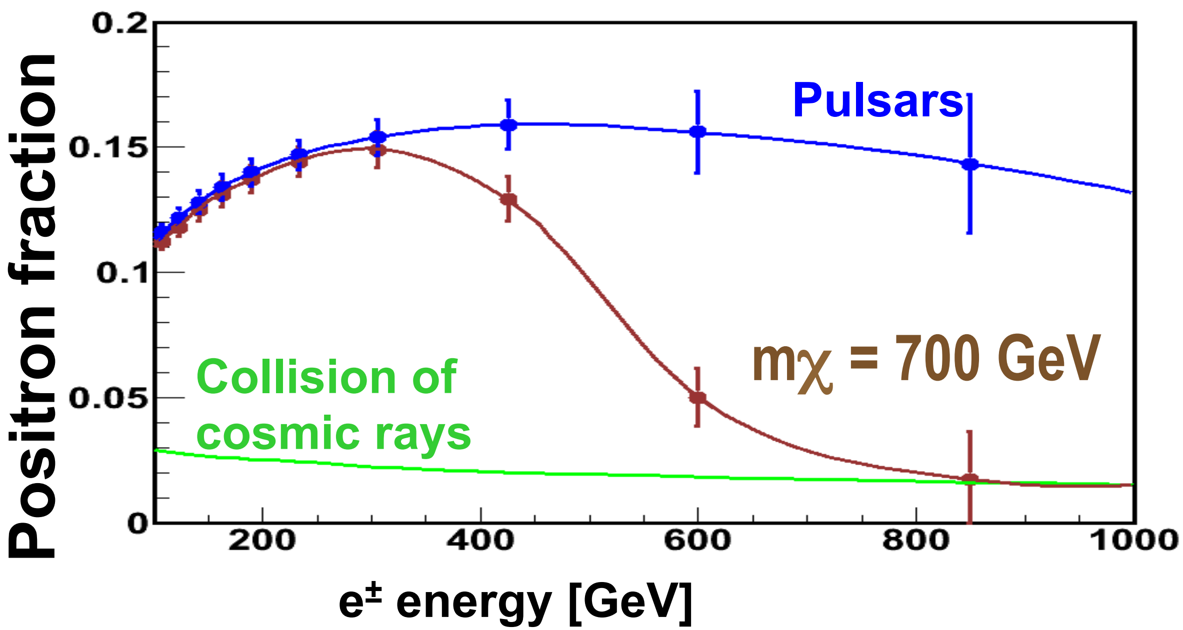
FIG. 2. The positron fraction from 1 to 35 GeV. It shows
provide accurate information on the minimum of the posi

AMS Positron Fraction 2014 @ High Energies



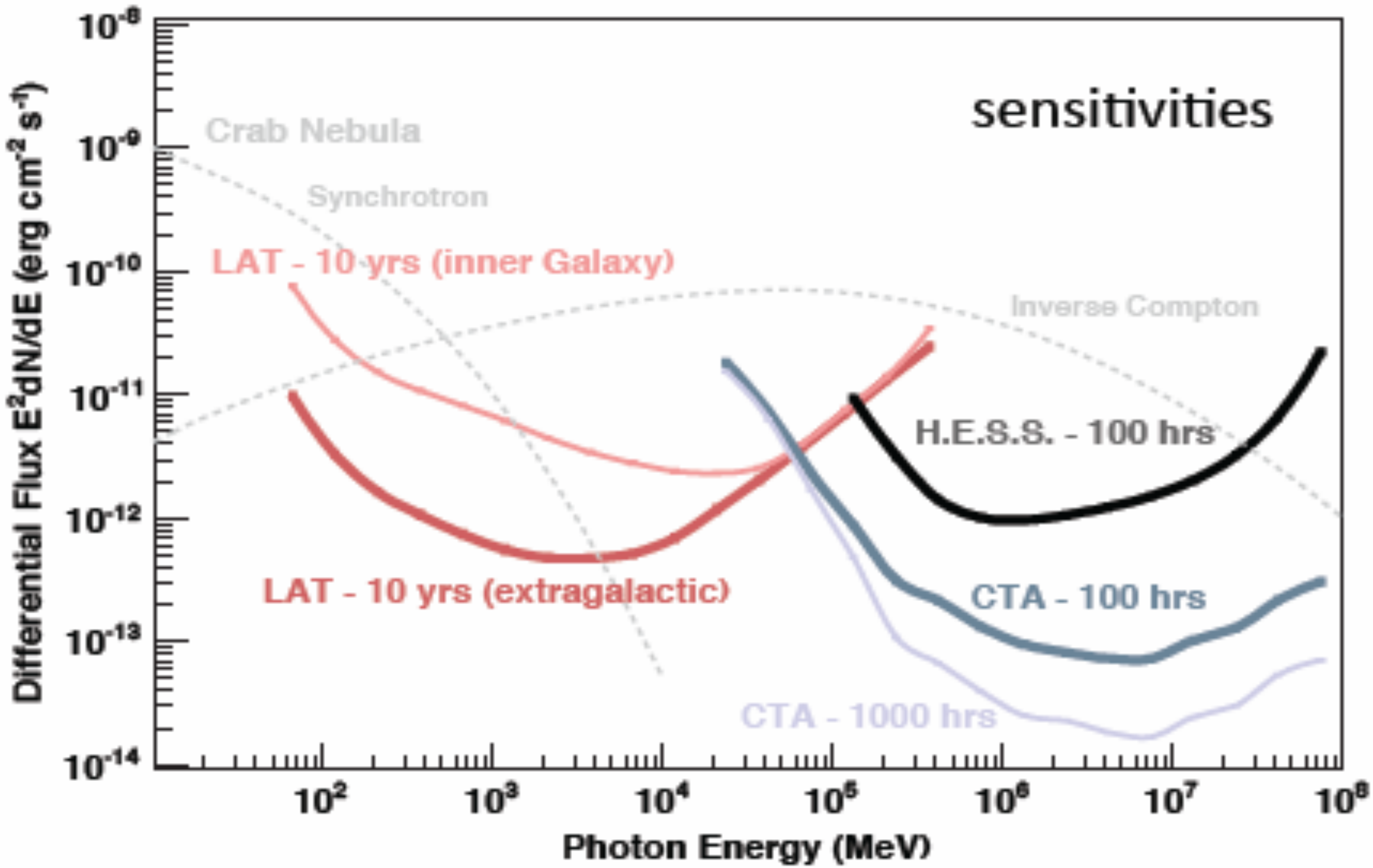
nds the energy range to 500 GeV
m PAMELA [21] (the horizontal

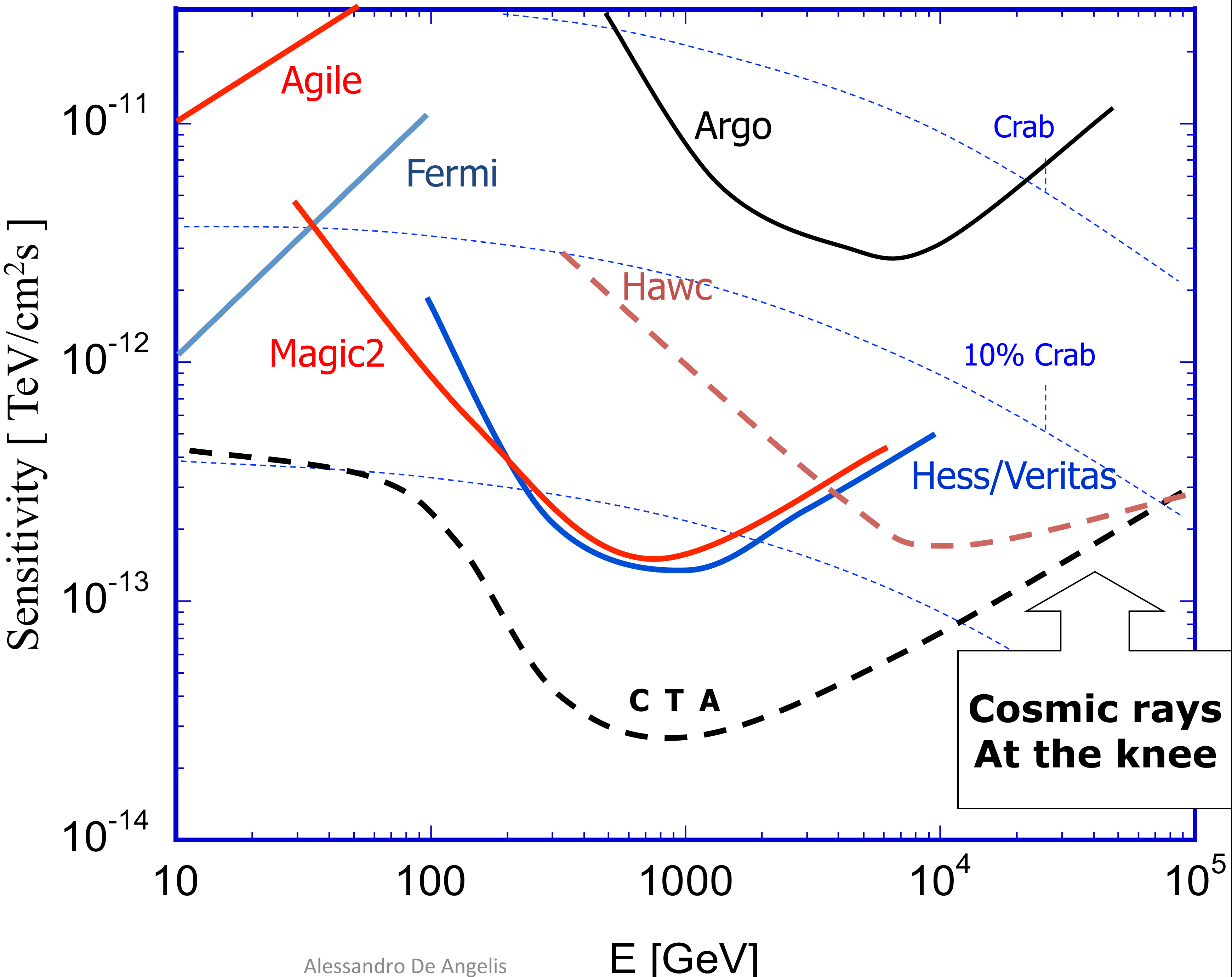
Origin of Positron Fraction: Particle Physics or Astrophysics ?



M. Pohl, IPA2014

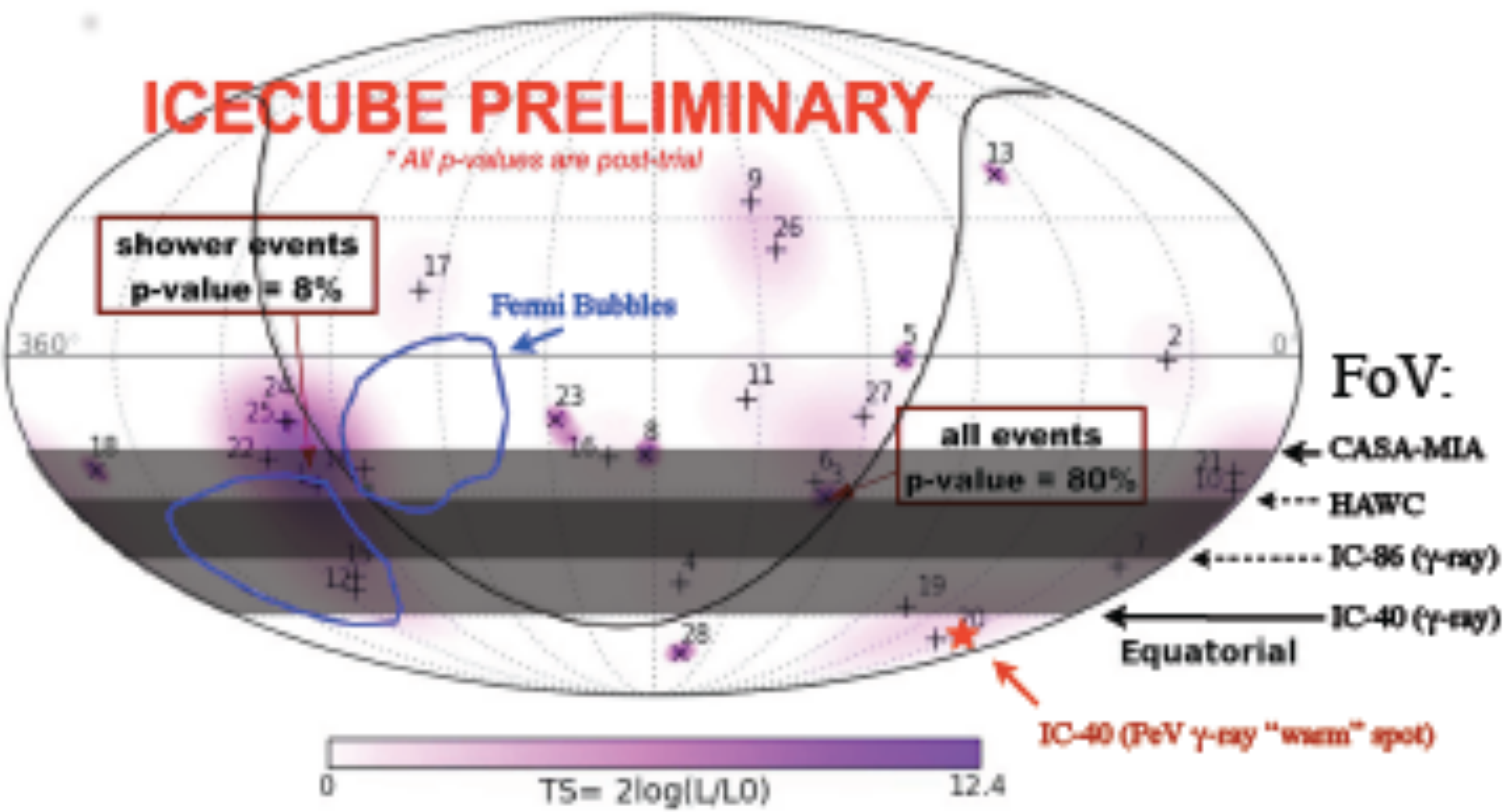
GAMMA – ASTRONOMY FROM EARTH AND SPACE





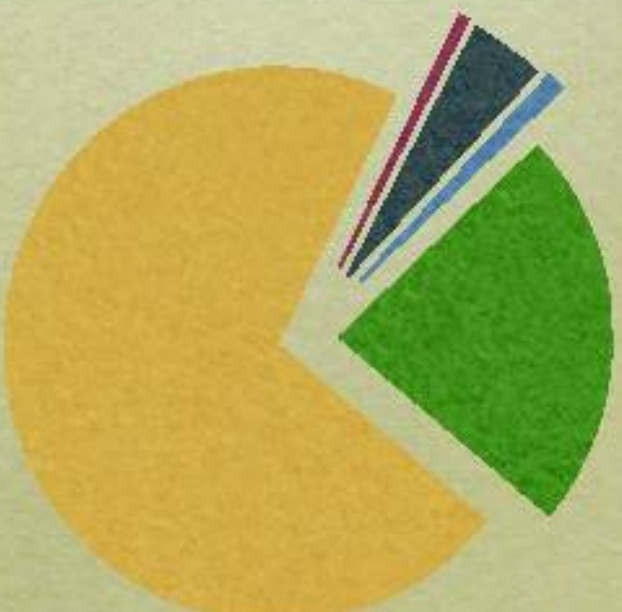
Alessandro De Angelis

HE NEUTRINOS: good news from the ice (28 events to attribute to HE eneutrinos), encouraging news for KM3



DM, DE, ANTIMATTER AND VACUUM ENERGY

- *Stars and galaxies are only ~0.5%*
- *Neutrinos are ~0.1–1.5%*
- *Rest of ordinary matter (electrons, protons & neutrons) are 4.4%*
- *Dark Matter 23%*
- *Dark Energy 73%*
- *Anti-Matter 0%*
- *Higgs Bose-Einstein condensate ~10^{62}%??*



Courtesy of H. Murayama

PHD Syndrome

(Post Higgs Depression)?

(Savas Dimopoulos, GGI, July 2013)

Post-Higgs Depression? No, thanks just the opposite....

- **If the naturalness issue is indeed a relevant issue, the fact that we discovered a light higgs means that there MUST EXIST some mechanism stabilizing its mass and this mechanism NECESSARILY ENTAILS THE PRESENCE OF SOME FORM OF NEW PHYSICS AT THE ELECTROWEAK SCALE**
- Time to get ready (joint exp.-theor. effort) for the new results **in high energy, high intensity, neutrino physics, gravitational waves, cosmic radiation, dark matter and dark energy searches**

WHAT NEXT

In view of the complex landscape we have to confront, INFN has recently started a process to identify the most important research themes that we should focus on amongst those that in this moment do not receive enough attention (people, funding). FERRONI

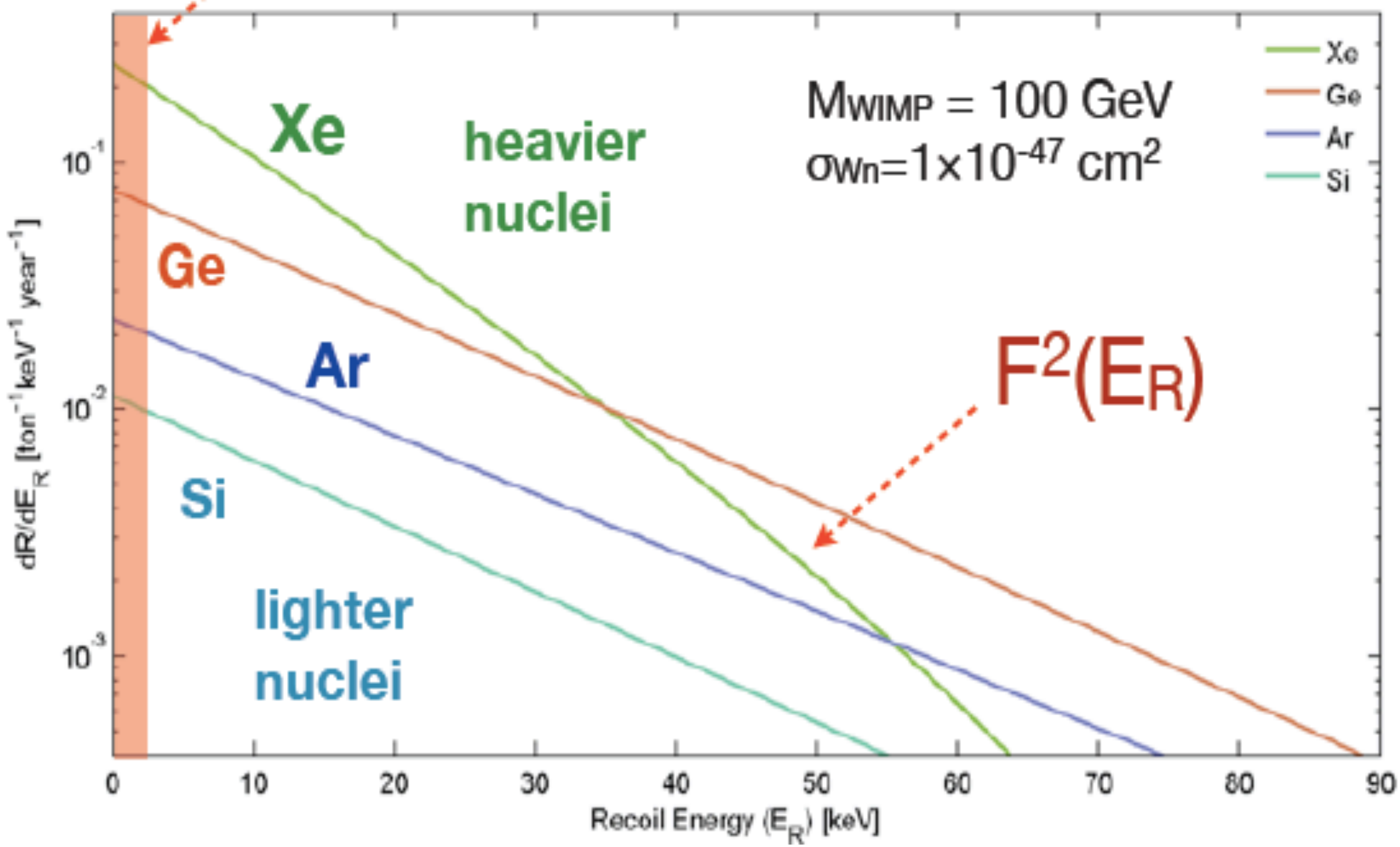
HIGH ENERGY, HIGH-INTENSITY, ASTROPARTICLE PHYSICS COMPLEMENTARY ATTACK TO THE NEW PHYSICS FORTRESS

BACKUP SLIDES

Some final considerations

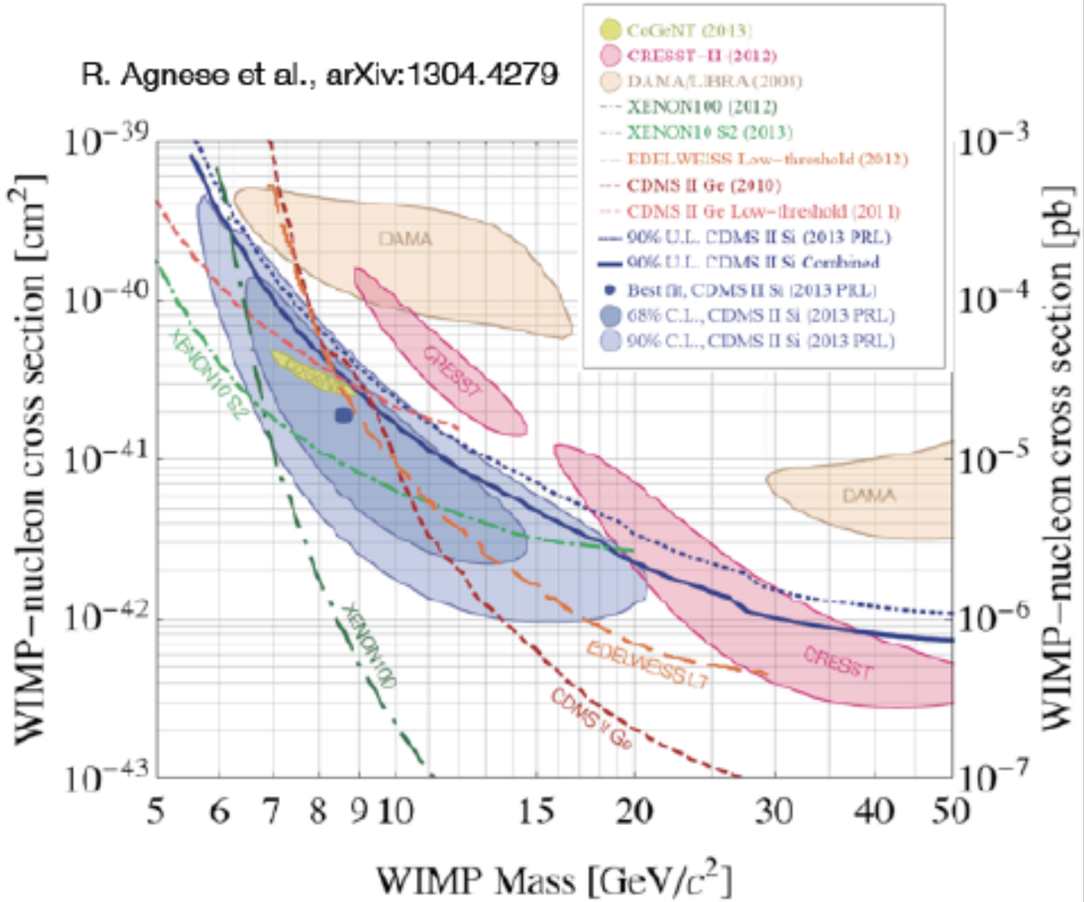
- The search for DM is crucial in our quest for new physics beyond the SM
- Most efforts are now focused on WIMPS: best (theoretically motivated) candidate for DM at the TeV scale – interplay with the LHC for searching new physics at the elw. Scale
- Important to coordinate the efforts at least in the two main areas of searches with bolometers and with noble liquids (exchange of codes, data, etc.)
- Joint effort with the theoretical community (also for theor. Groups beneficial to coordinate)
- At the same time, given our ignorance of what DM may be, it's healthy to keep alternative approaches open; actually, they should be encouraged
- Direct, Indirect, LHC DM searches: vast communities which have to efficiently interact for this difficult, but fascinating, enterprise.

$$v_{min} = \sqrt{\frac{m_N E_{th}}{2\mu^2}}$$



Profile Likelihood analysis

- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9×10^{-41} cm^2
- Probability of observing 3 or more events from background fluctuations is equal to 5.4%
- Goodness of fit of the WIMP +Background model is 68.6%
- A profile likelihood ratio test statistic favors the WIMP +Background hypothesis over the background only at 99.81% C.L.



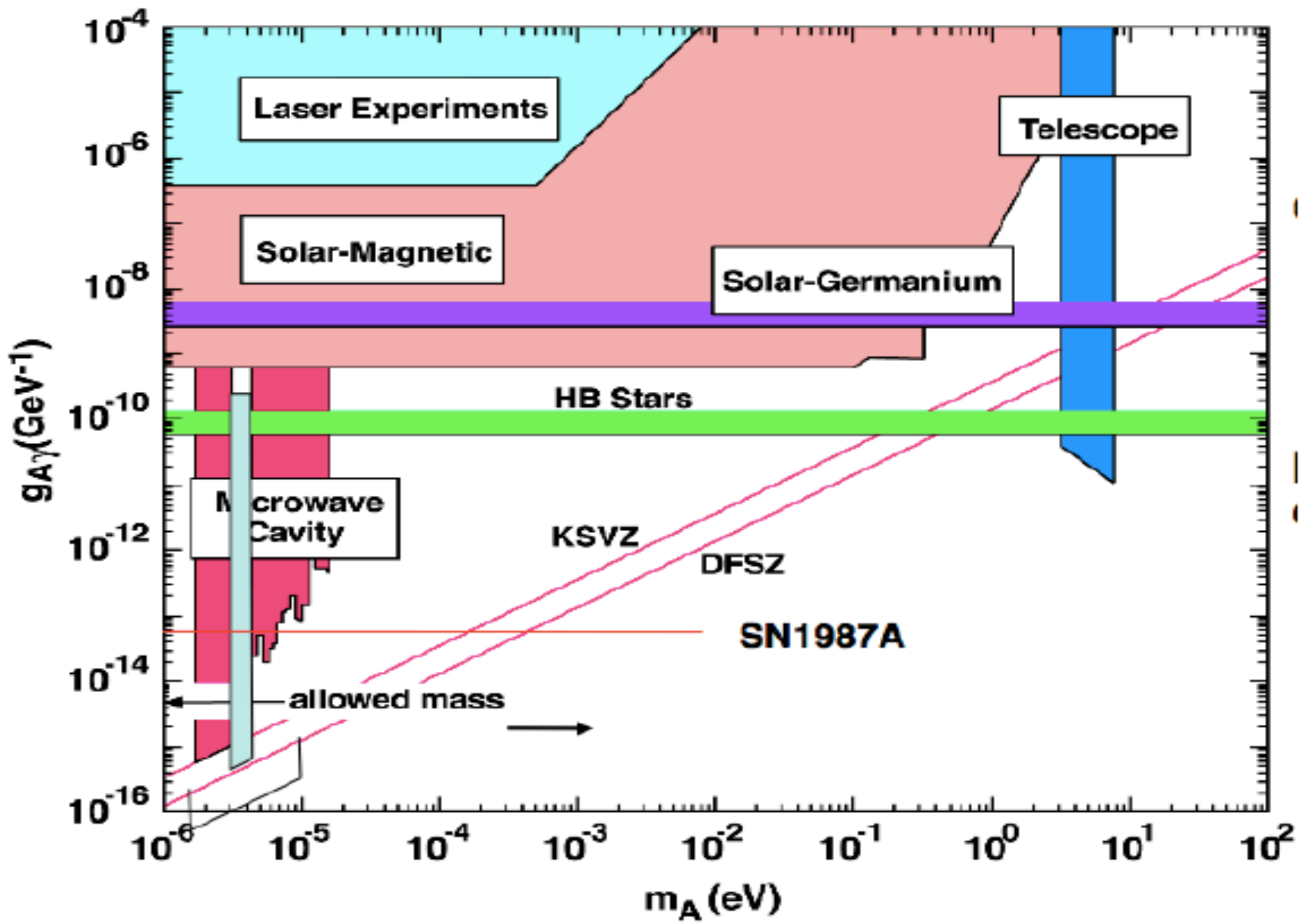
We do not believe this result rises to the level of a discovery, but does call for further investigation.

Julien Billard (MIT) - TAUP2013

11

Now: considering some SuperCDMS detectors from Si, and testing phonon-only analysis.

Keep in mind: we don't know at all what DM is made of ! Alternatives to WIMPs – for instance, AXIONS



CDMS II (Ge+Si)

- 4.6 kg Ge (19 x 240 g)
- 1.2 kg Si (11 x 106g)
- 35% NR acceptance

SuperCDMS Soudan

- Increased mass: 9.0 kg Ge (15 x 600 g)
- Increased acceptance
- Improved surface event discrimination

SuperCDMS SNOLAB

- Proposed 200kg Ge array
- Extensive R&D underway
- Scale to 1 kg crystals

Projected sensitivity of 8 x 10^{-47} cm^2

Timeline/Projection EDELWEISS-III

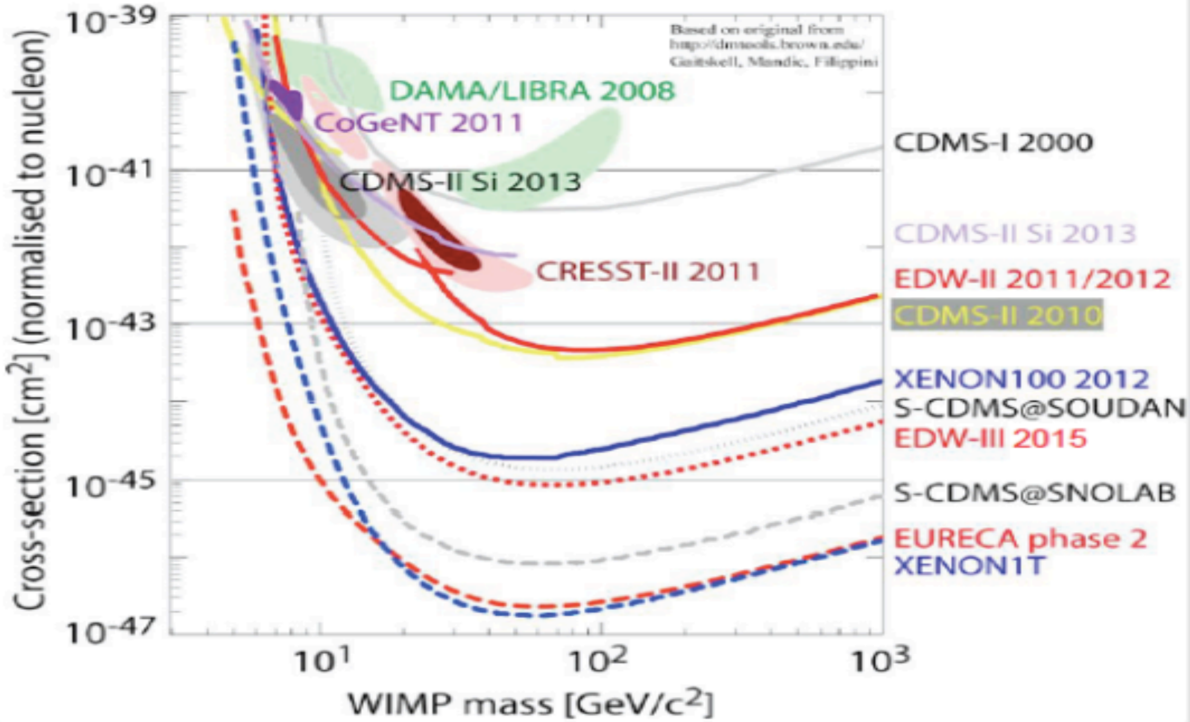
Karlsruhe Institute of Technology

Sept. 2013 (now)

- **EDELWEISS-III commissioning runs**
- upgraded cryogenics
- 15 FID 800g detectors
- upgraded readout electr + Kapton cables
- inner PE shield + new Cu screens

end of 2013

- fully equipped cryostat with 40 FID 800g detectors



EURECA

Concept design: staged programme of 150 to 1000 kg of EDELWEISS+ CRESST detectors, in LSM extension

Global Convergence for Cryogenic Detectors

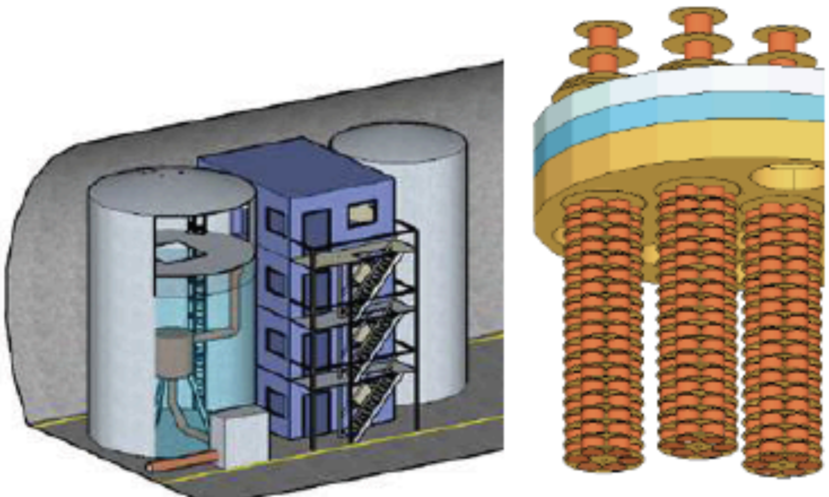
CDMS
Soudan
Germanium
phonon - ionization

Edelweiss
Germanium

CRESST
Gran Sasso
$CaWO_4$
phonon – scintillation

SuperCDMS ↔ EURECA-I (150kg)

GEODM ↔ EURECA

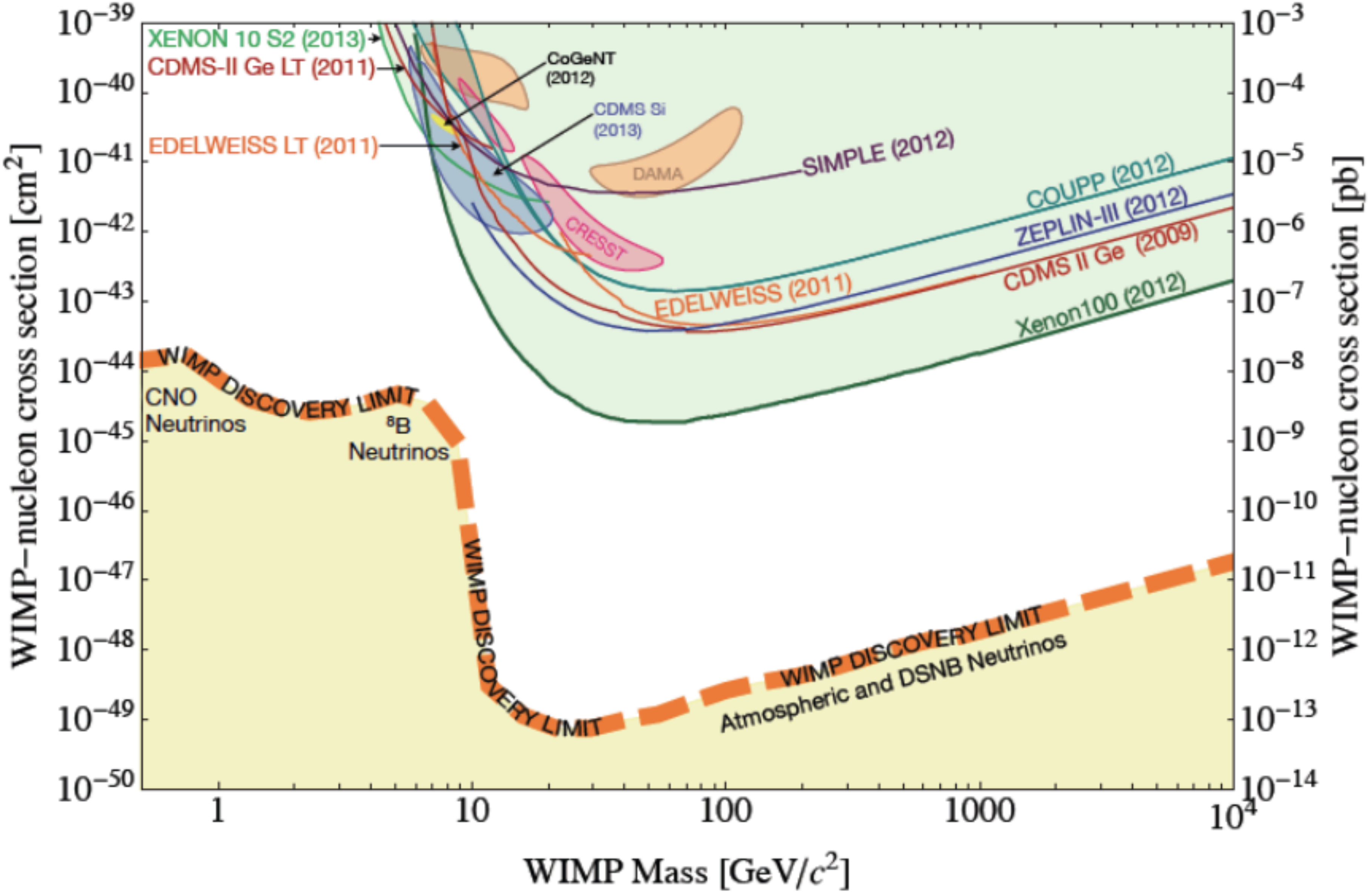


EURECA	Goals
Phase 1	
Cross section (SI)	$3 \cdot 10^{-10}$ pb
Mass to be operated	150 kg
Residual background (all sources)	10^{-2} evts/kg/y in RoI
Duty cycle	70 %
Time of operation	1 year
Phase 2	
Cross section (SI)	$2 \cdot 10^{-11}$ pb
Mass to be operated	1000 kg
Residual background (all sources)	$< 10^{-3}$ evts/kg/y in RoI
Duty cycle	70 %
Time of operation	3 years

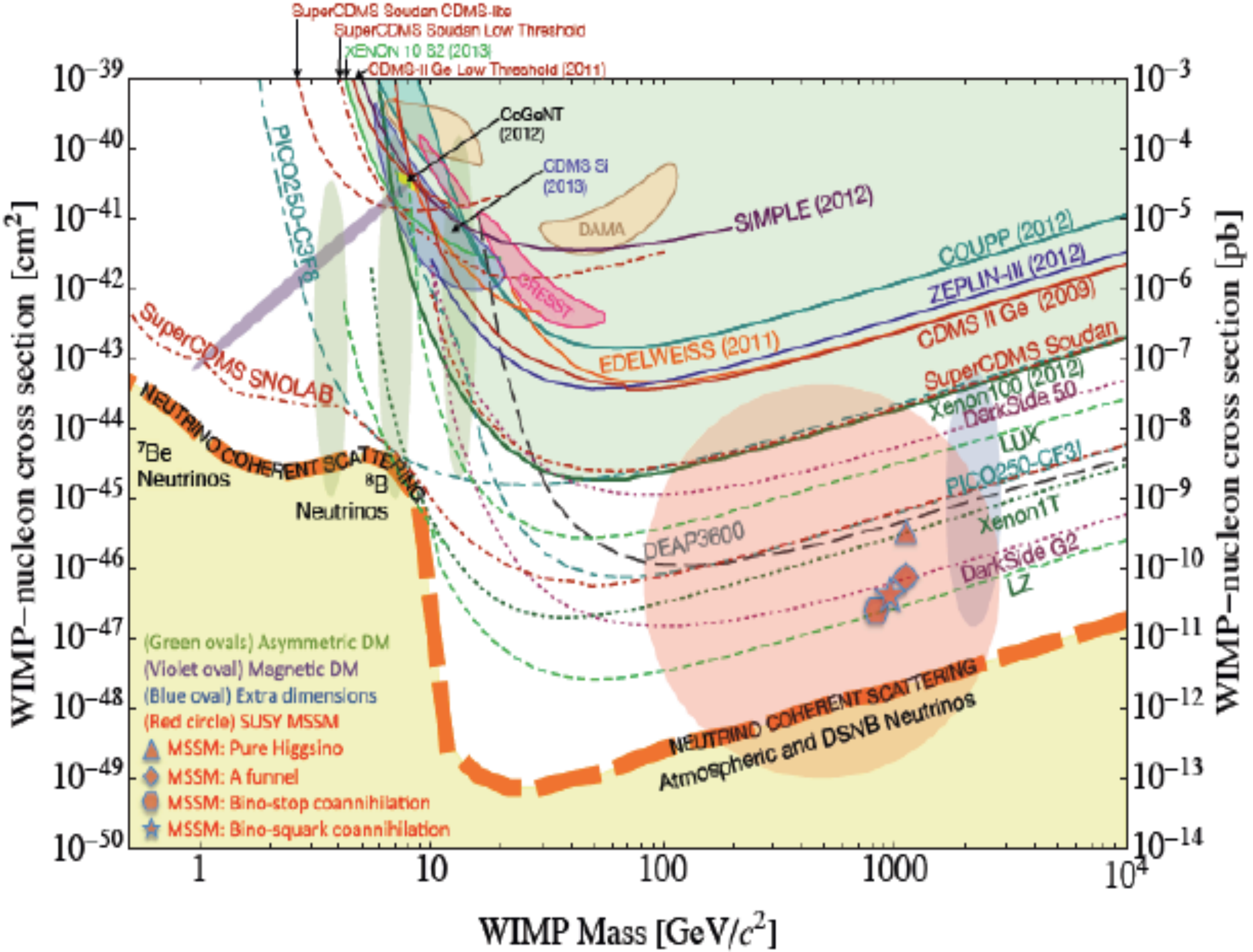
- EURECA CDR 2012 (14m x 14m x 14m)
- LSM extension approved 2012, excavation from 2014-5, occupy 2016-7
- since 2009 coordination with GeoDM (US) participating in G2 competition (aim: construction 2014-17)

(material thanks to H. Kraus)

Spin-Independent Cross Section: Current Experiment Results



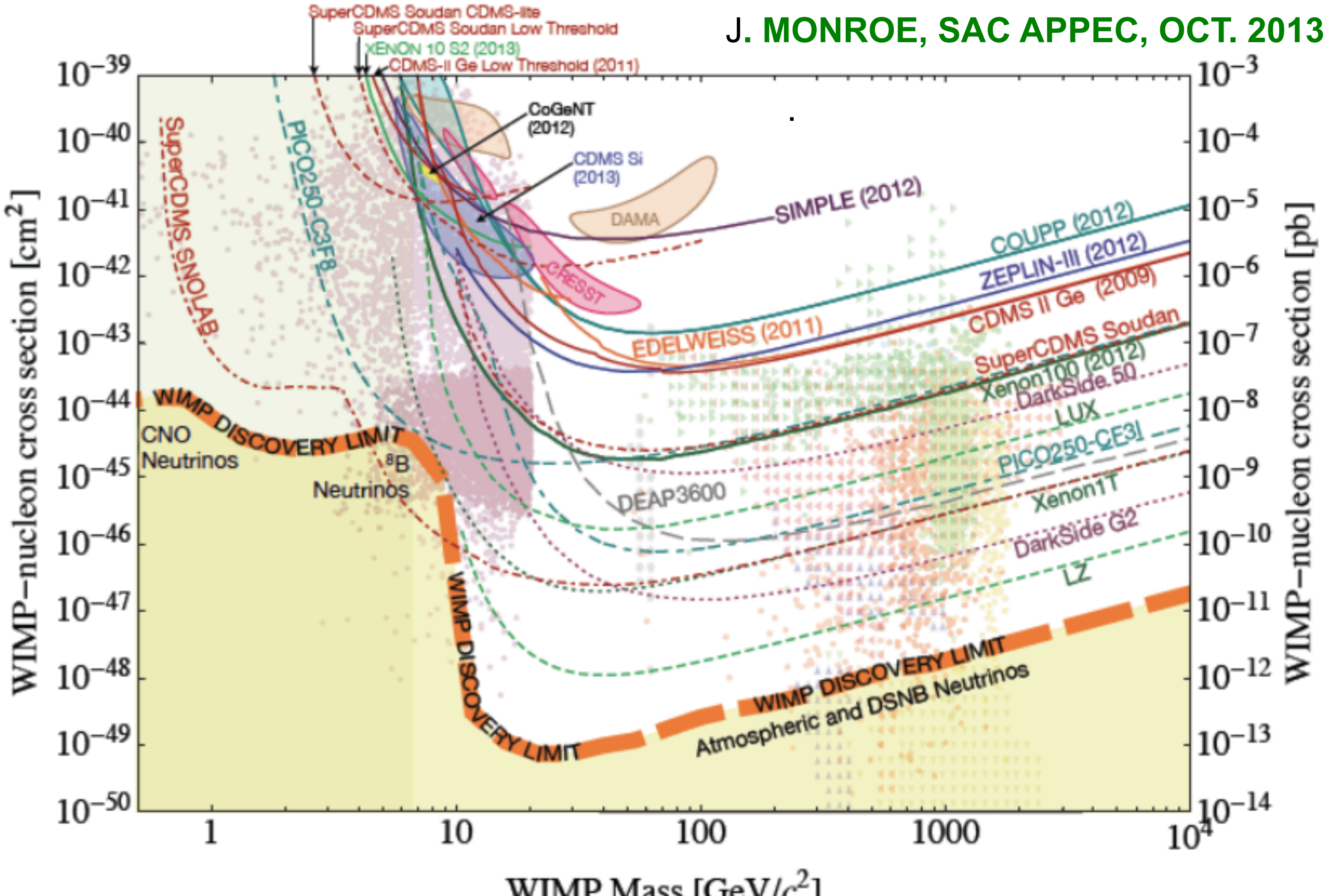
so far: ~3 years / order of magnitude

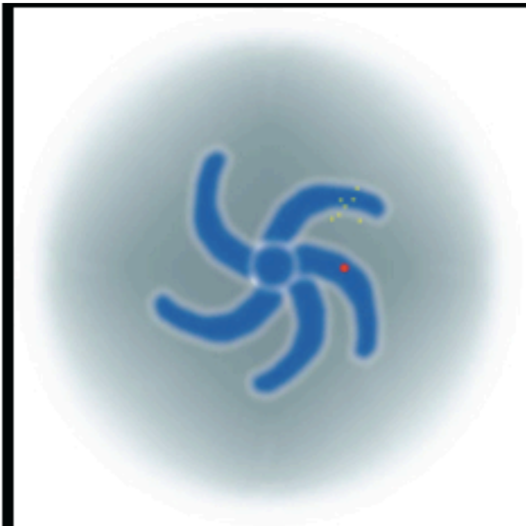


SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
PICO250-C3F8
CRESST
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
DEAP3600
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c2]

PROJECTED SENSITIVIES FOR THE SPIN-INDEPENDENT CROSS SECTIONS

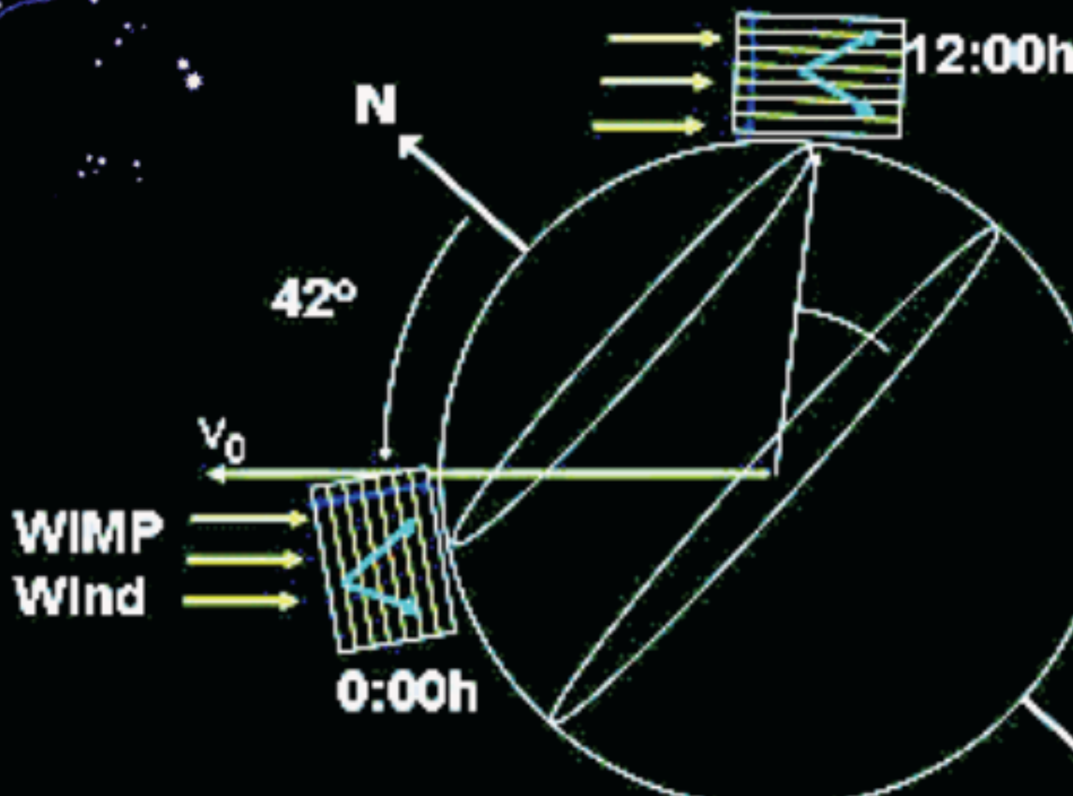
J. MONROE, SAC APPEC, OCT. 2013





The Dark Matter Wind apparently "blows" from Cygnus

directional detection:
search for a dark matter source



Daily direction modulation:
asymmetry ~ 20-100%
in forward-backward
event rate.

Spergel, Phys. Rev. D36:1353 (1988)

DM NOBLE LIQUIDS DETECTORS

SINGLE-PHASE DETECTORS (position resolution ~cm)

XMASS-RFB at Kamioka:

835 kg LXe (100 kg fiducial),
single-phase, 642 PMTs
unexpected background found
detector refurbished (RFB)
new run this fall -> 2013

CLEAN at SNOLab:

500 kg LAr (150 kg fiducial)
single-phase open volume
under construction
to run in 2014

DEAP at SNOLab:

3600 kg LAr (1t fiducial)
single-phase detector
under construction
to run in 2014

DOUBLE-PHASE DETECTORS (position resolution ~mm

XENON100 at LNGS:

161 kg LXe
(~50 kg fiducial)

242 1-inch PMTs
taking new science data

LUX at SURF:

350 kg LXe
(100 kg fiducial)

122 2-inch PMTs
physics run since spring 2013
first result by the end of this year

PandaX at CJPL:

125 kg LXe
(25 kg fiducial)

143 1-inch PMTs
37 3-inch PMTs
started in 2013

ArDM at Canfranc:

850 kg LAr
(100 kg fiducial)

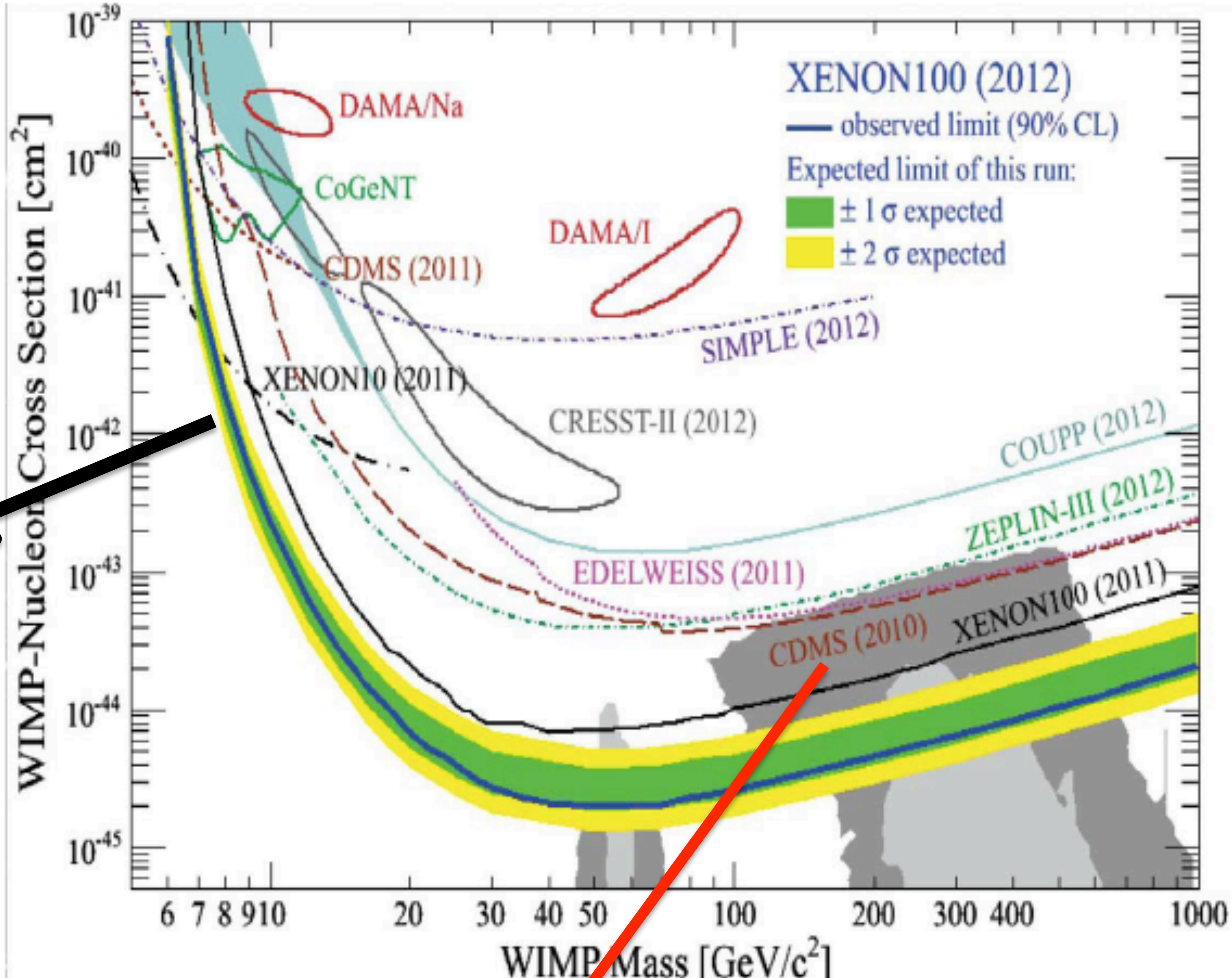
28 3-inch PMTs
in commissioning
to run 2014

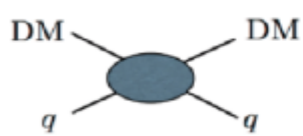
DarkSide at LNGS

50 kg LAr (dep in ^{39}Ar)
(33 kg fiducial)

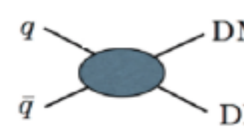
38 3-inch PMTs
in commissioning
since May 2013
to run in fall 2013

Relevant to intensify the efforts here: ex. **asymmetric DM** with **DM particles of mass~ baryon mass given that ρ_{DM} not much different from ρ_B**

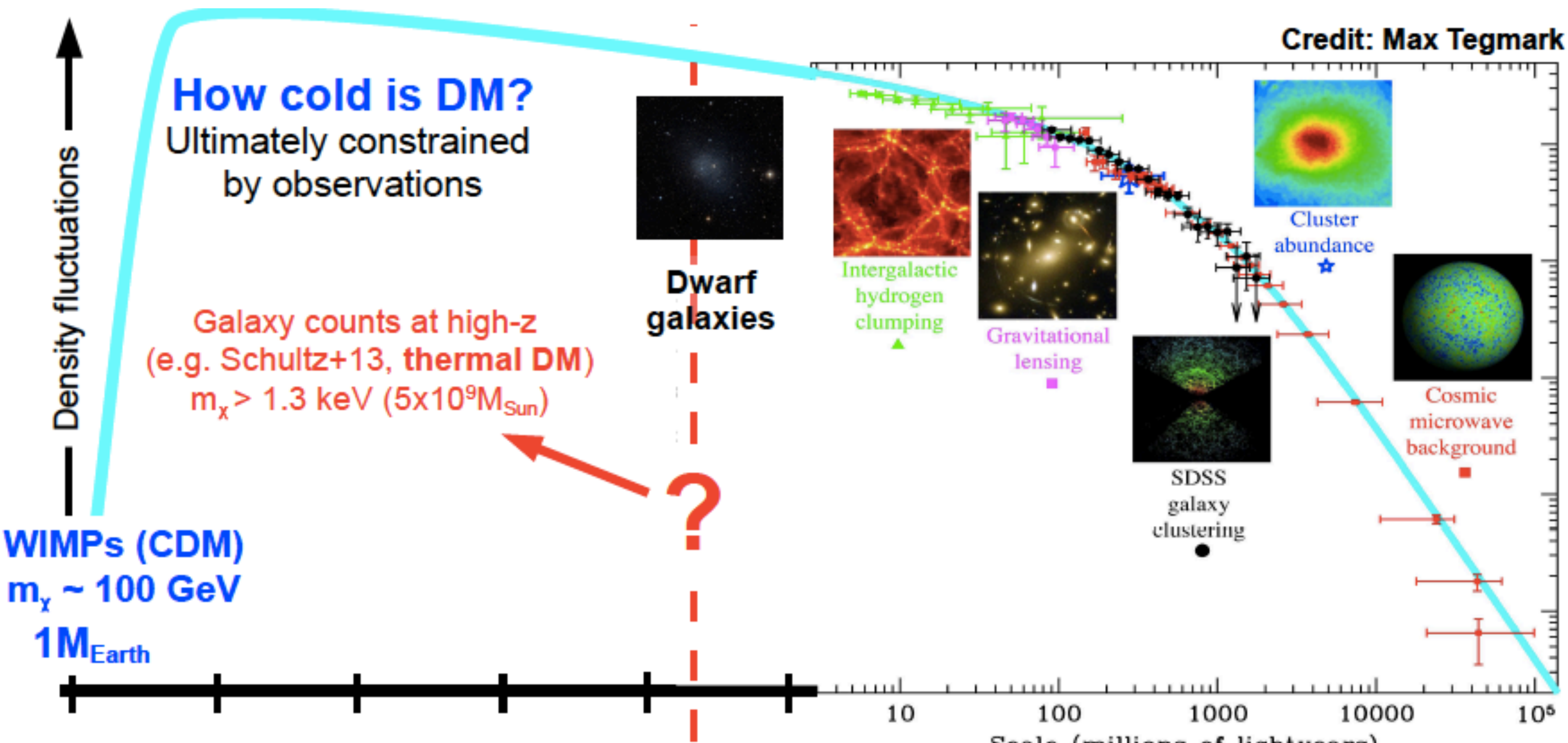




Direct Detection (t-channel)



Collider Searches (s-channel)


Credit: Max Tegmark
How cold is DM?
Ultimately constrained by observations
Density fluctuations
Dwarf galaxies
Galaxy counts at high-z
(e.g. Schultz+13, thermal DM)
m_χ > 1.3 keV (5x10^9 M_Sun)
?
WIMPs (CDM)
m_χ ~ 100 GeV
1M_Earth
Intergalactic hydrogen clumping
Gravitational lensing
Cluster abundance
SDSS galaxy clustering
Cosmic microwave background
10
100
1000
10000
10^5
Scale (millions of lightyears)

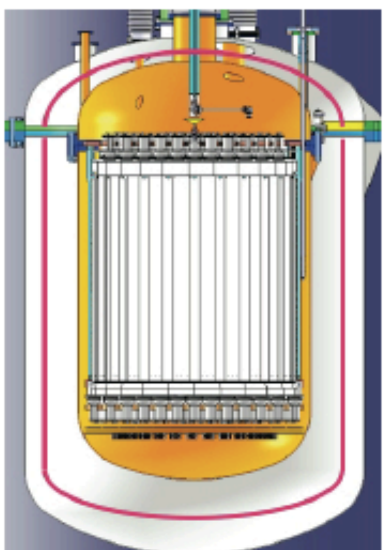
- XENON1T at LNGS, 3.5 t LXe in total
  - ➡ commissioning in 2014, first run in 2015
  - ➡ goal for SI WIMP-nucleon XS: 2×10^{-47} cm²

PROJECT UNDER CONSTRUCTION

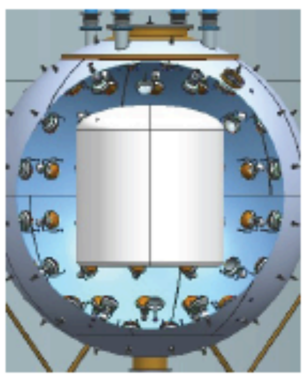
- Near future + design and R&D projects:
  - ➡ XENONnT (~6 t LXe), XMASS-1.5 (5 t LXe)
  - ➡ DarkSide-5000 (5 t LAr), LZ (7 t LXe)
  - ➡ DARWIN (20 t LXe, possibly also 30 t LAr)

FUTURE ARGON AND XENON DM DETECTORS

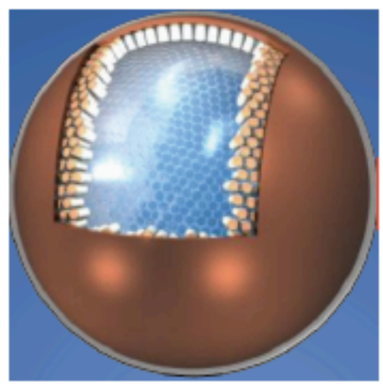
L. BAUDIS, SAC of APPEC OCT. 2013



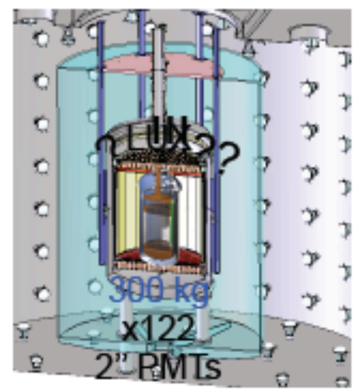
XENONnT: ~6 t LXe



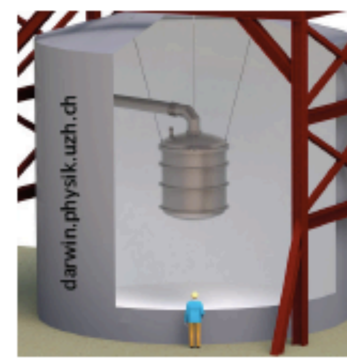
DarkSide: 5 t LAr



XMASS: 5t LXe



LZ: 7t LXe



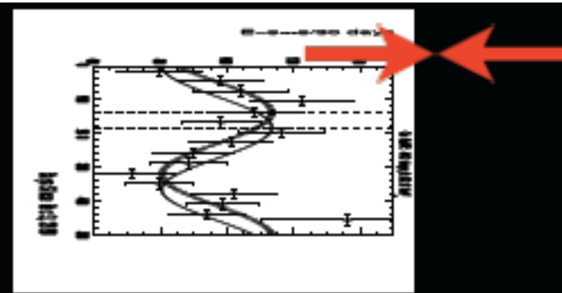
DARWIN: 20 t LXe/LAr

Experiments Testing Annual Modulation

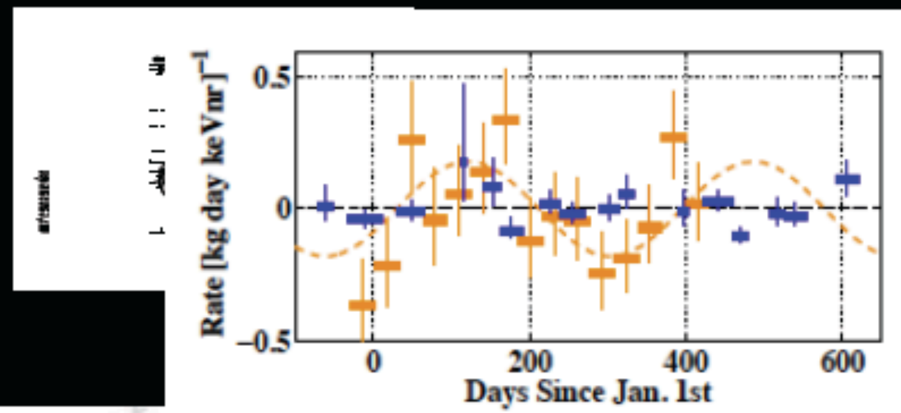
Ge: *COGENT(~consistent with DAMA/LIBRA)*
CDMS (not consistent)

CsI: *KIMS (not consistent)*

NaI: many efforts underway, all <25 kg active mass, scale up depends on crystal radiopurity



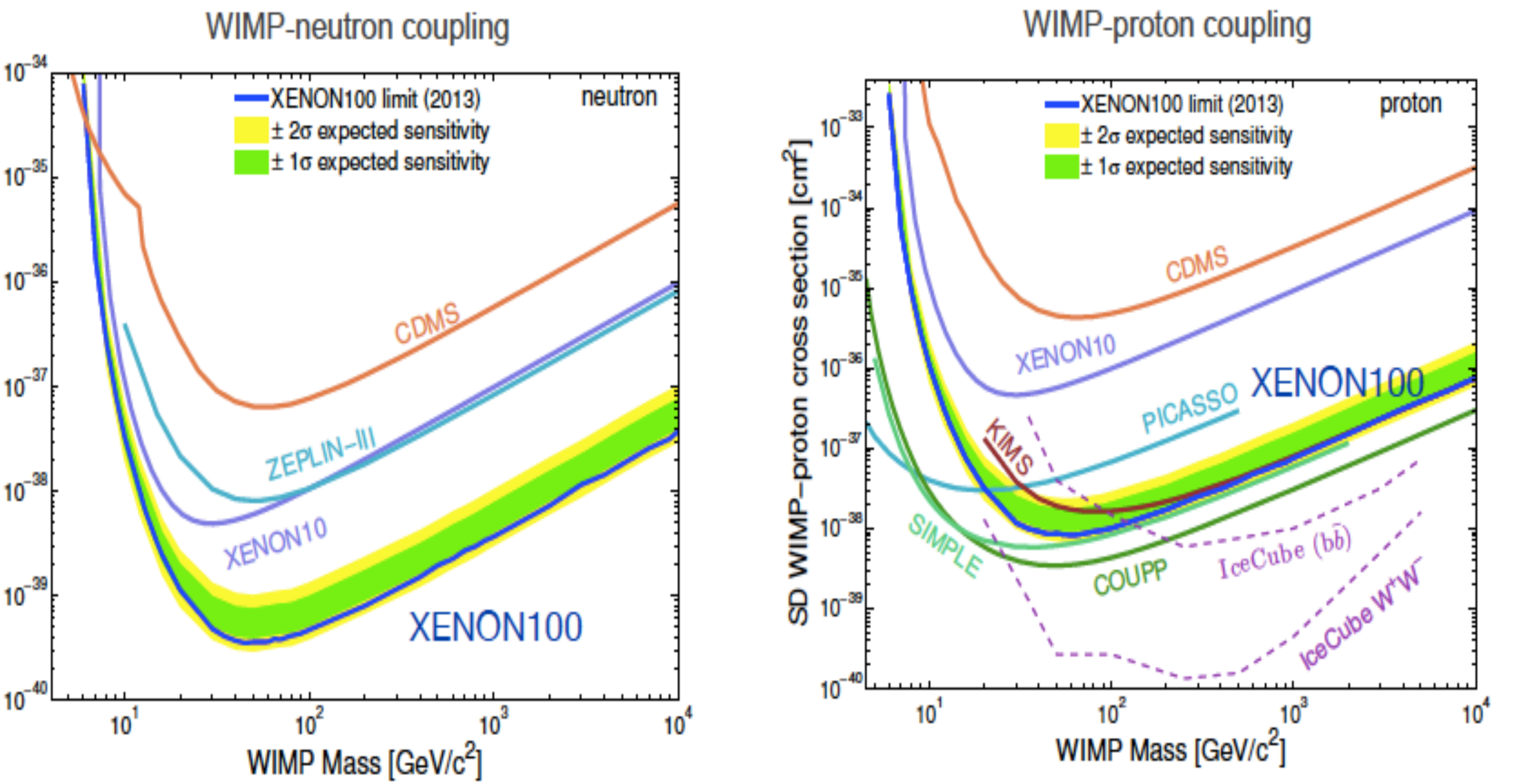
J. Monroe, SAC
APPEC 2013



Northern Hemisphere	Gran Sasso **DAMA/Libra** 250kg running	Gran Sasso **Princeton-NaI** R&D	Canfranc **ANAIS** ~100kg 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		

ice rock

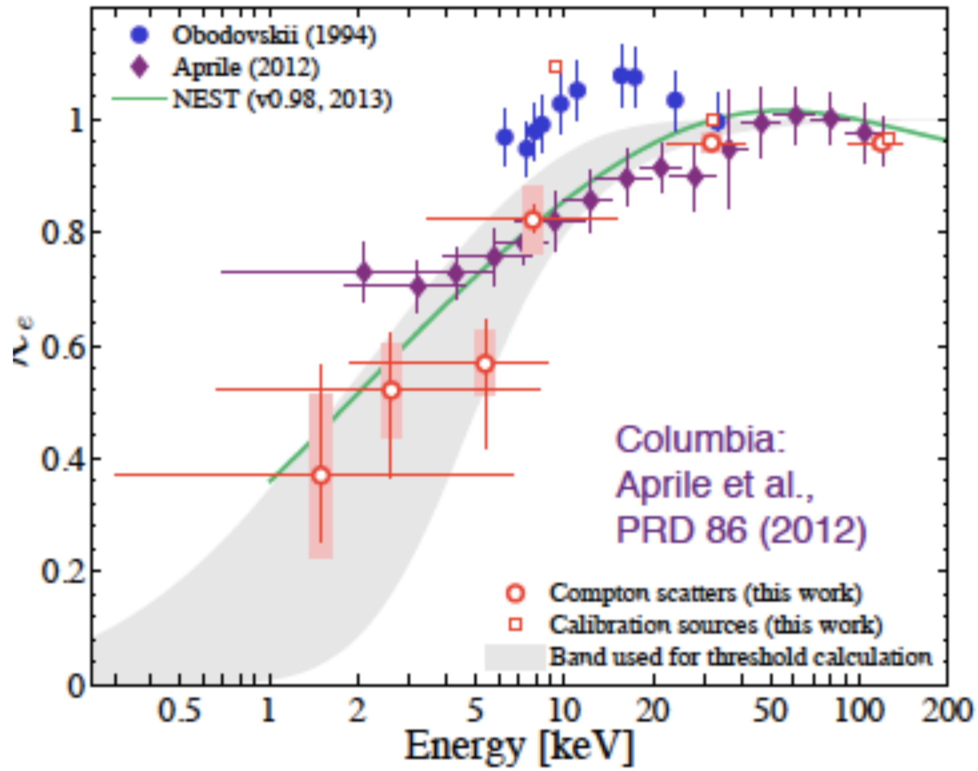
SPIN-DEPENDENT LIMITS



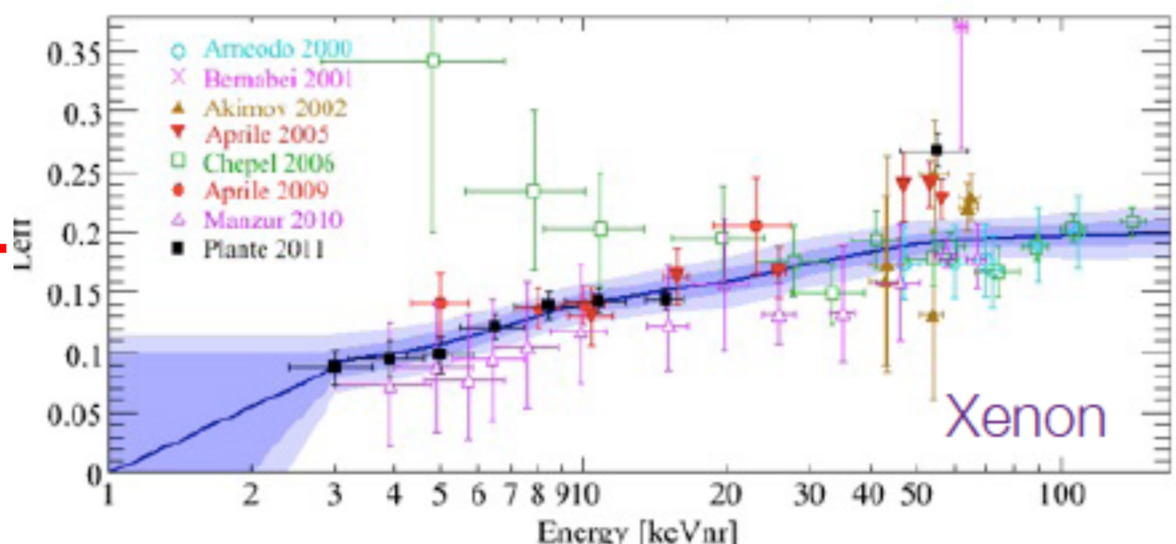
XENON collaboration, Phys. Rev. Lett. 111 (2013)

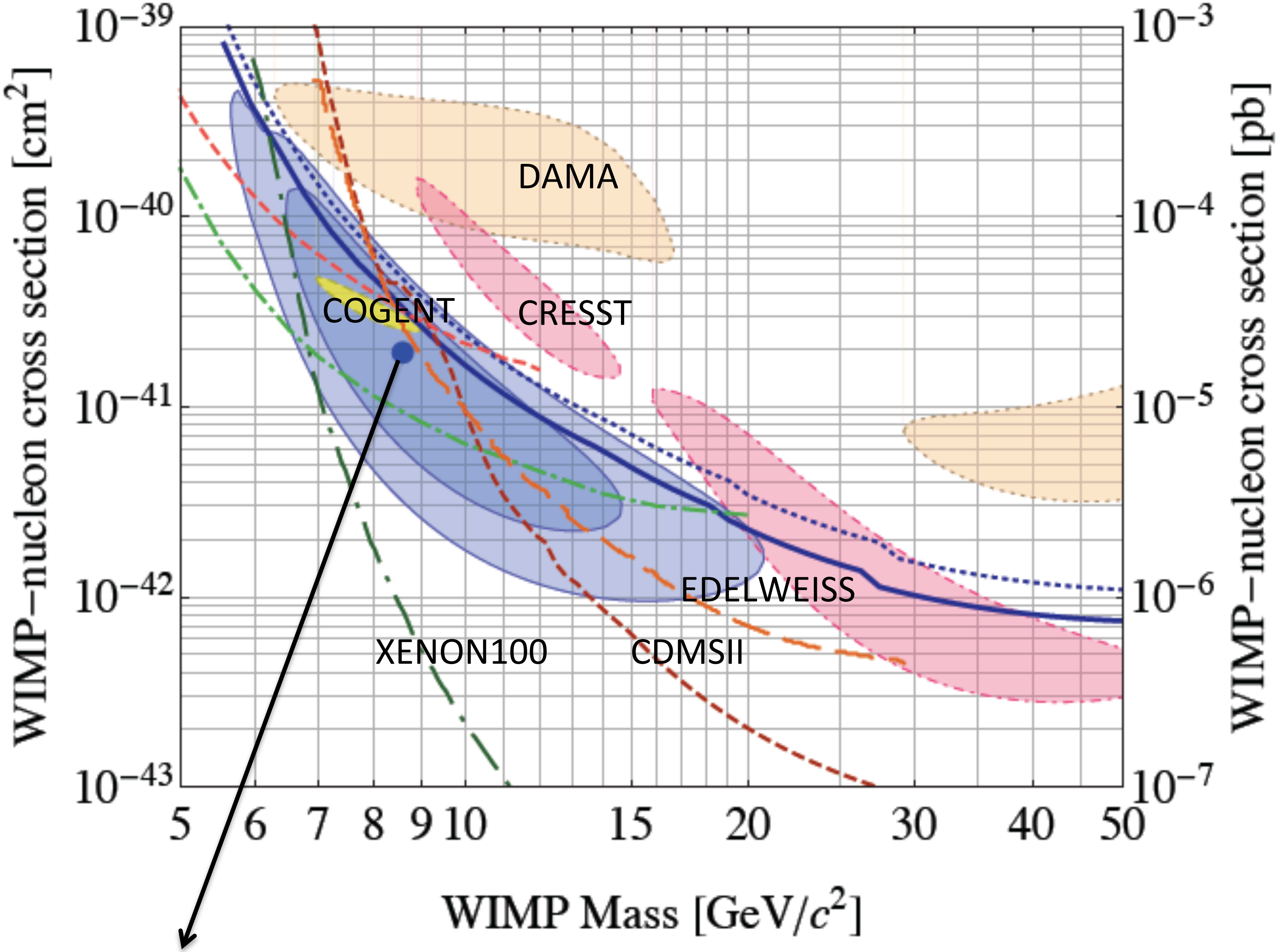
ENERGY SCALE FOR ELECTRONIC RECOILS → LIGHT YIELD

Relative light yield to 32.1 keV of ^{83m}Kr



ENERGY SCALE FOR NUCLEI RECOILS → LIGHT YIELD

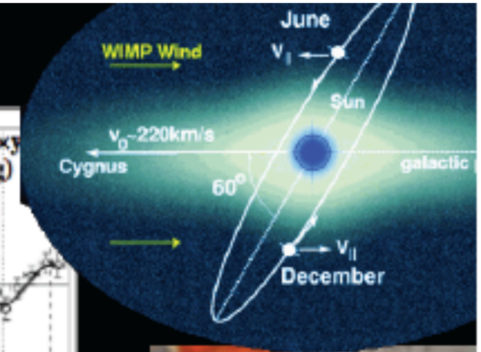




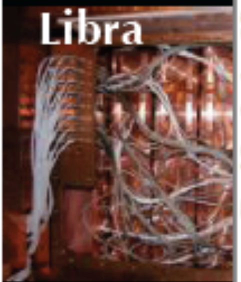
M_{WIMP} = 8.6 GeV ; $\sigma = 1.9 \times 10^{-41}$ cm^2

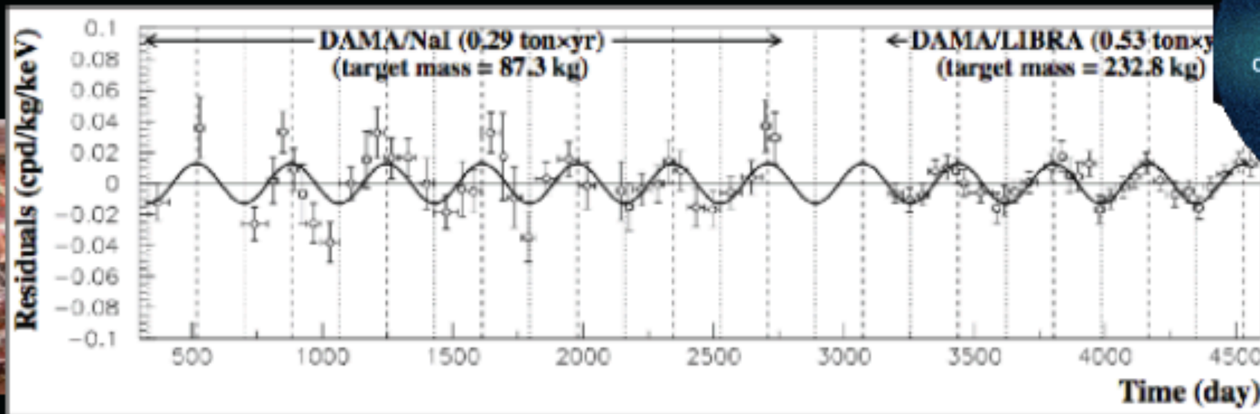
CDMSII 2013

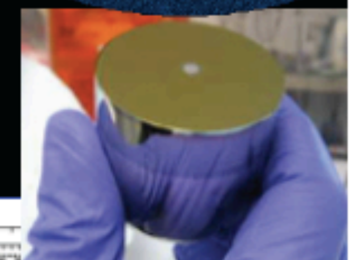
Experiments with Candidate Signals



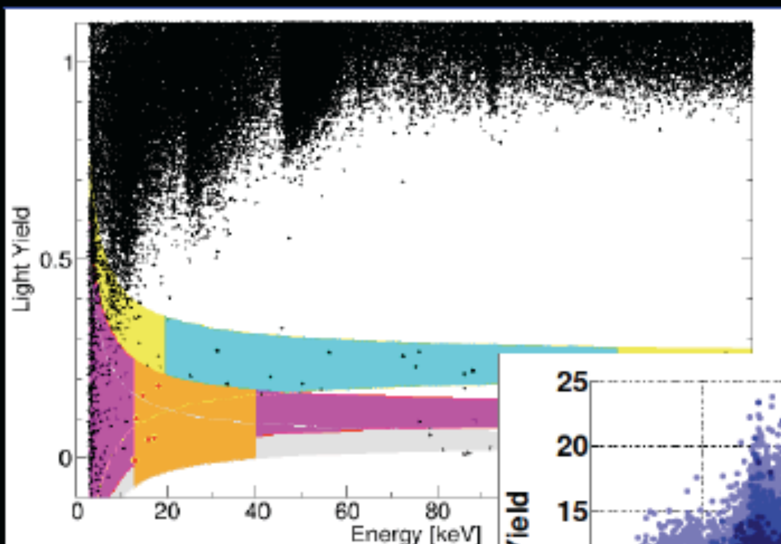
DAMA/ Libra

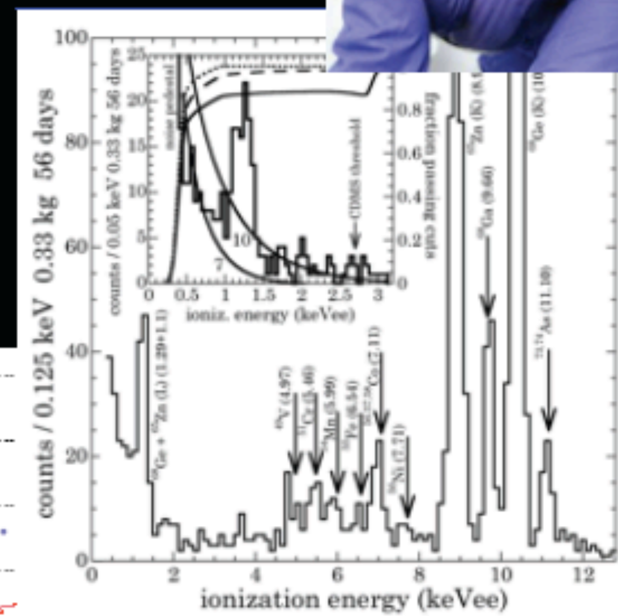




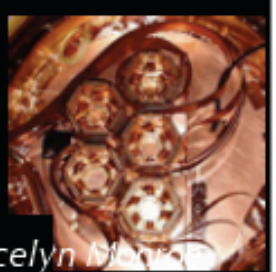


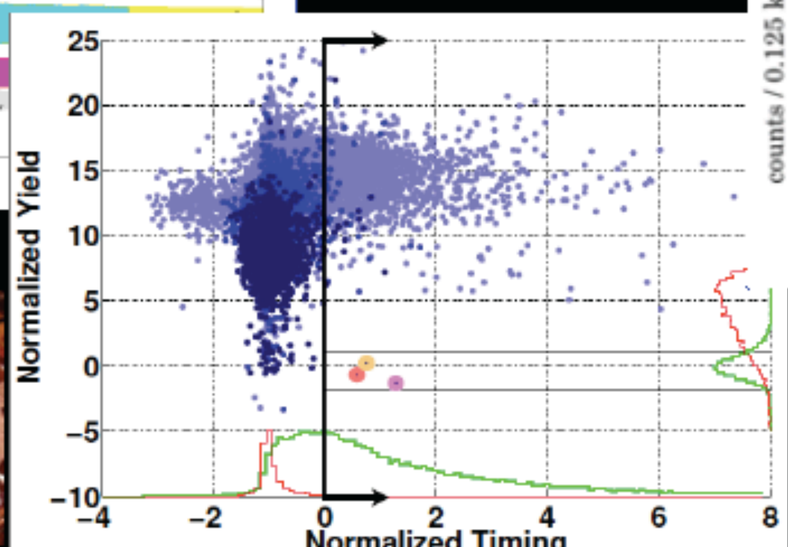
CRESST-II



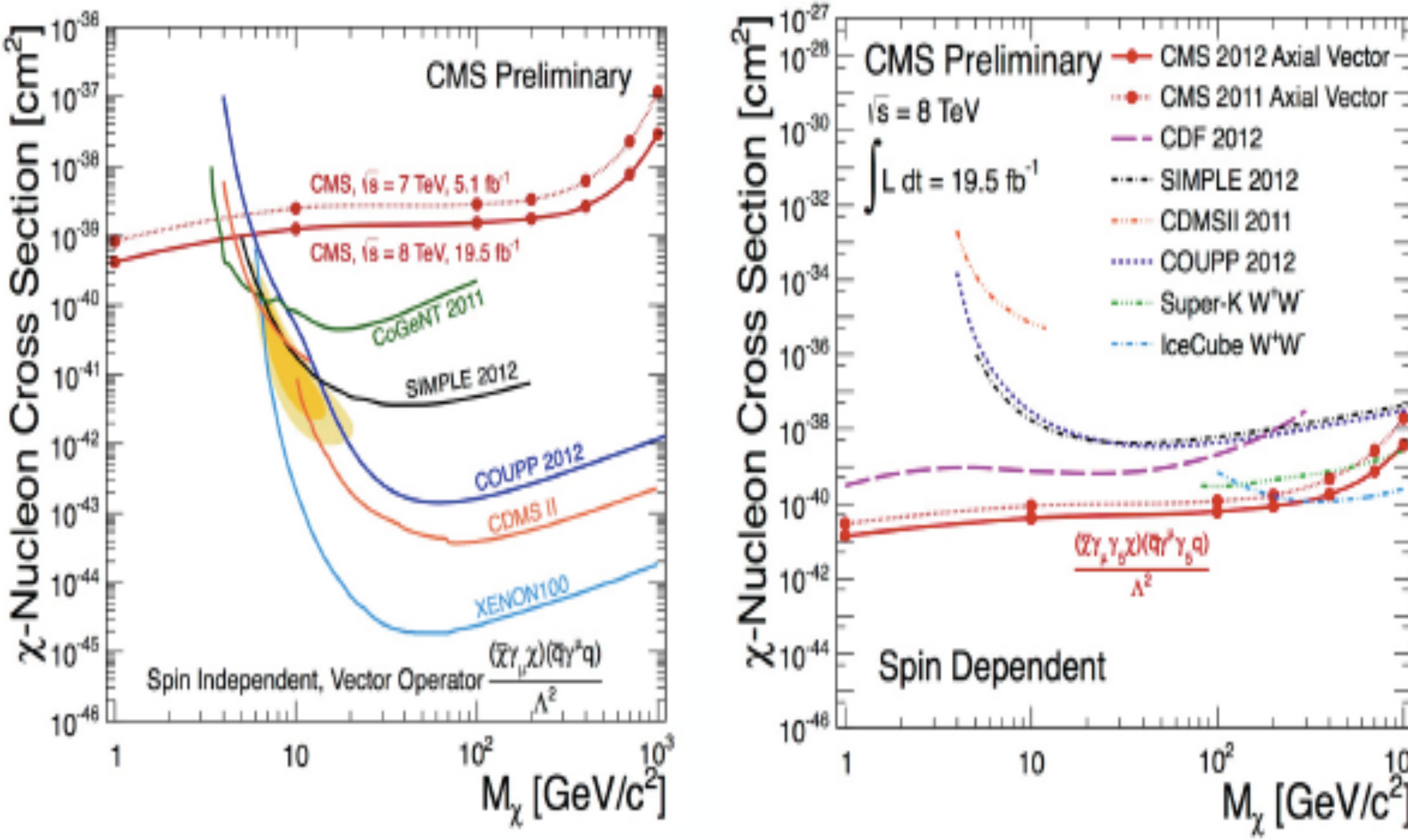


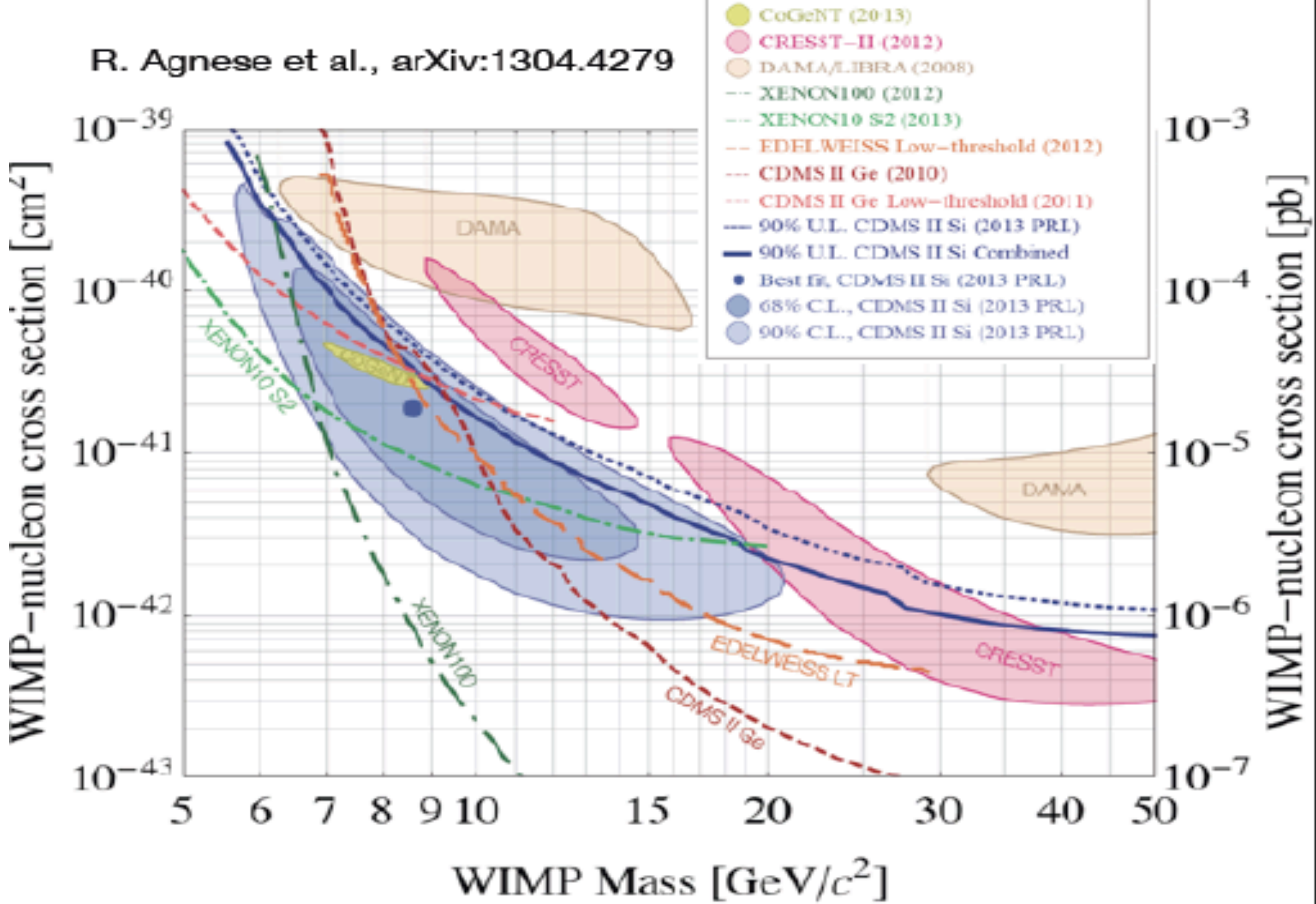
CDMS





dark matter?
backgrounds?


CMS Preliminary
CMS, √s = 7 TeV, 5.1 fb⁻¹
CMS, √s = 8 TeV, 19.5 fb⁻¹
CoGeNT 2011
SIMPLE 2012
COUPP 2012
CDMS II
XENON100
Spin Independent, Vector Operator
χ-Nucleon Cross Section [cm²]
M_χ [GeV/c²]
CMS Preliminary
√s = 8 TeV
∫L dt = 19.5 fb⁻¹
CMS 2012 Axial Vector
CMS 2011 Axial Vector
CDF 2012
SIMPLE 2012
CDMSII 2011
COUPP 2012
Super-K W⁺W⁻
IceCube W⁺W⁻
Spin Dependent
χ-Nucleon Cross Section [cm²]
M_χ [GeV/c²]



RELEVANCE OF THE DAMA-LIBRA RESULT– IMPORTANCE OF AN INDEPENDENT VERIFICATION (hard to reach the same level of sensitivity)