Try to incorporate material from parallel session

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UC Dark Matter Initiative

Happy to be here to see the fulfillment of a long time dream of Tran Tan Vanh

Direct Detection of Galactic Dark Matter

Perspective

3 paradigms (Axions, "SUSY" WIMPs, Dark Sector:e.g., asymmetric dark matter)

Axions

WIMP Direct Detection

As one of 4 complementary approaches: Cosmological observations, scattering, annihilation and production at accelerators

"Weak Scale" WIMPs

Low Mass WIMPs

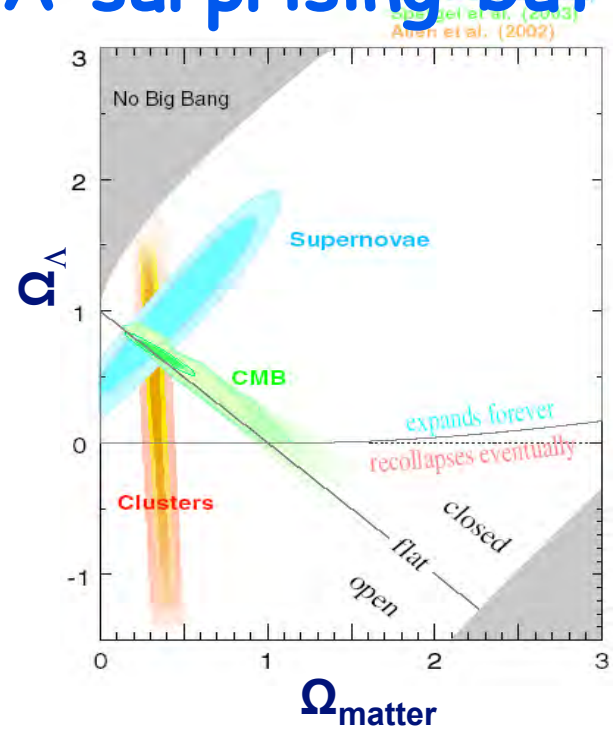
The future of direct detection

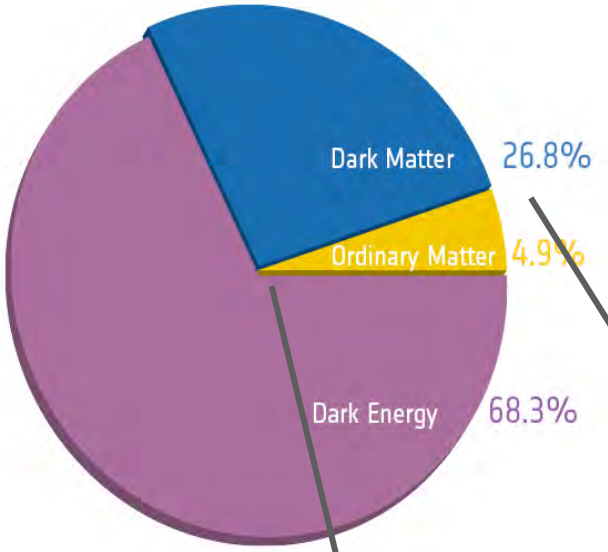
Focus both on high mass and low mass

Need for at least 2 technologies -> can approach fundamental neutrino limit

Standard Model of Cosmology

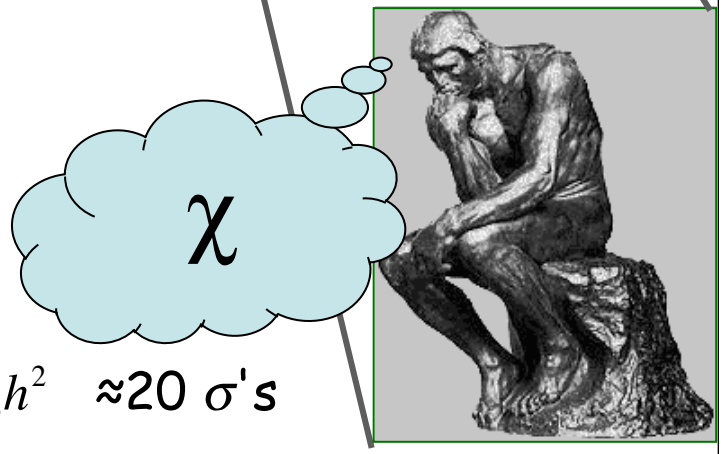
A surprising but consistent picture





Not ordinary matter (Baryons)

$\Omega_m >> \Omega_b = 0.049 \pm 0.001$ from | Nucleosynthesis | WMAP/Planck



+ internally to WMAP/Planck $\Omega_m h^2 \neq \Omega_b h^2$ ≈20 σ's

Mostly cold: Not light neutrinos ≠ small scale structure

Three Paradigms

Axions <= Strong CP problem

Peccei Quinn solution: dynamic restoration of CP

Weak scale WIMPs <= hierarchy problem

Freeze out when annihilation rate ≈ expansion rate

$$\Rightarrow \Omega_x h^2 = \frac{3 \cdot 10^{-27} cm^3 / s}{\langle \sigma_A v \rangle} \Rightarrow \sigma_A \approx \frac{\alpha^2}{M^2_{EW}}$$

coincidence between Cosmology and Particle Physics

Dark Matter Hidden Sector: not necessarily weak scale

e.g., Asymmetric Dark Matter (Zurek) <-> Baryon-Antibarium asymmetry

WIMP-less Dark Matter (Feng)

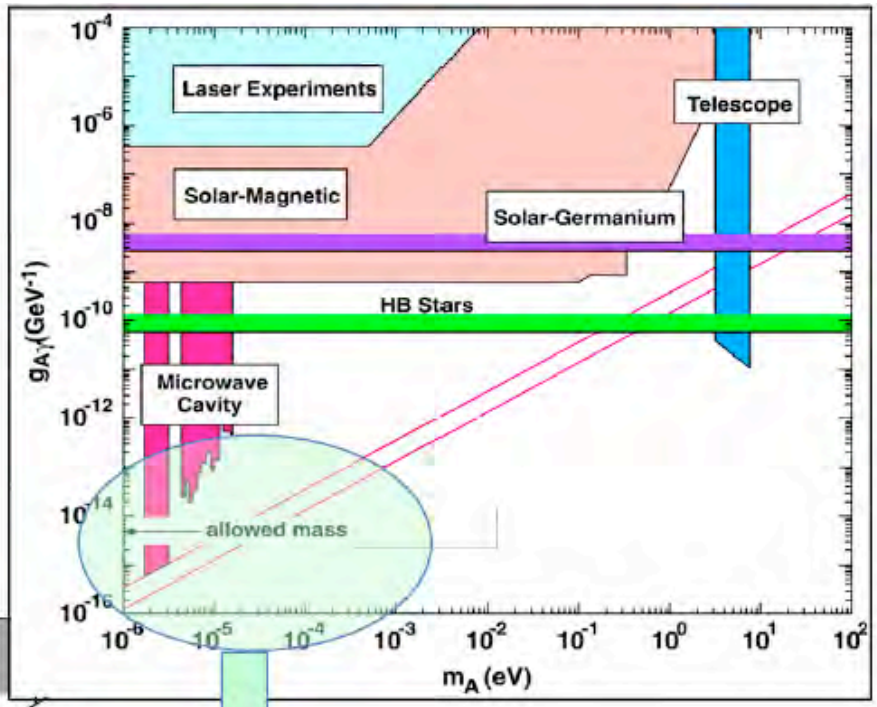
Dark Photon (Arkani Hamed-Finkbeiner-Weiner), atomic DM, Self Interacting etc..

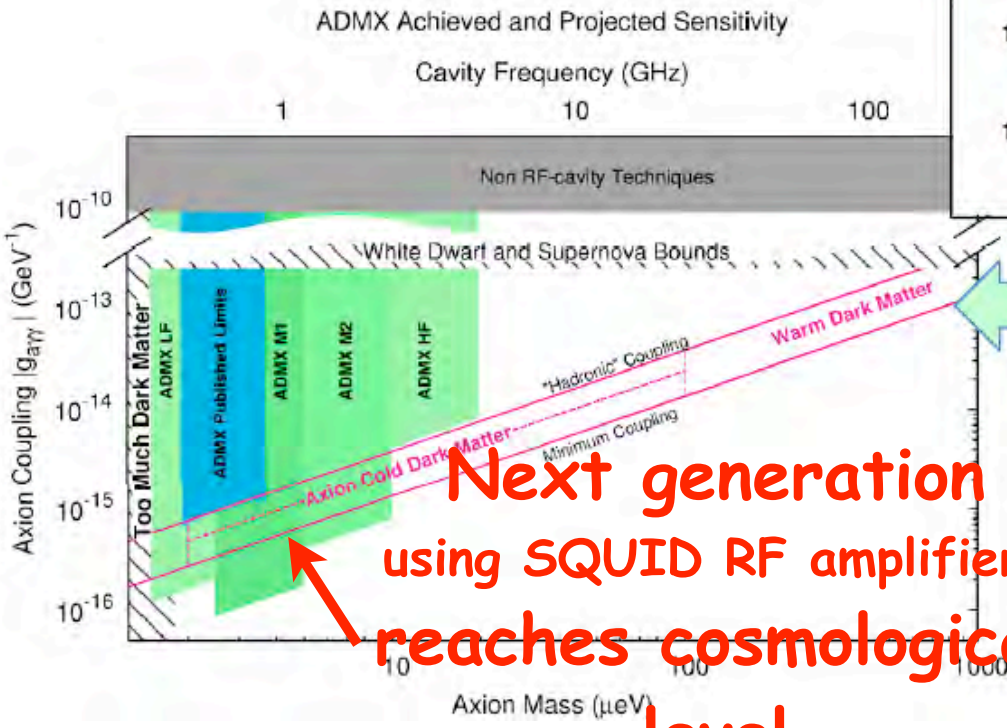
Intriguing but less predictive

Axions

Parameter space constrained by

- Supernova cooling
- White dwarf cooling
- Red giant energy transport
- Relic density
- Direct detection constraints





- Favored mass: μeV to meV
- ADMX is projected to cover the first of these three decades in its first year of operations, and the second decade over the following two years

Next generation using SQUID RF amplifiers reaches cosmological level

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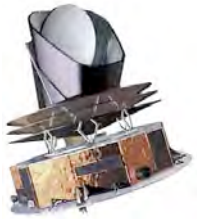
4 Complementary Approaches

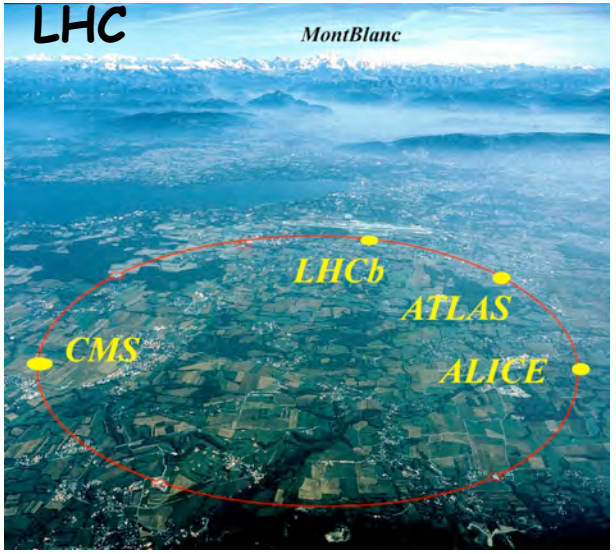
Cosmological Observations



Planck

Keck telescopes

Dark Matter
Galactic Halo (simulation)



WIMP production on Earth

VERITAS, also HESS, Magic + IceCube (ν)

WIMP annihilation in the cosmos

Fermi/GLAST

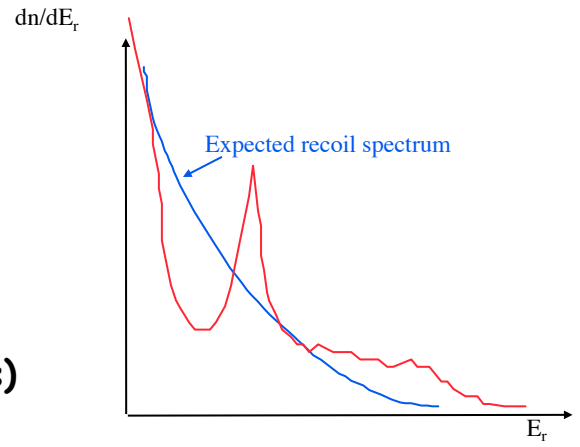
CDMS

WIMP scattering on Earth:e.g. CDMS, Xenon 100,etc.

Halo WIMP Scattering "Direct Detection"

Elastic scattering

Expected event rates are low
(<< radioactive background)
Small energy deposition (≈ few keV)
<< typical in particle physics
Signal = nuclear recoil (electrons too low in energy)
≠ Background = electron recoil **(if no neutrons)**



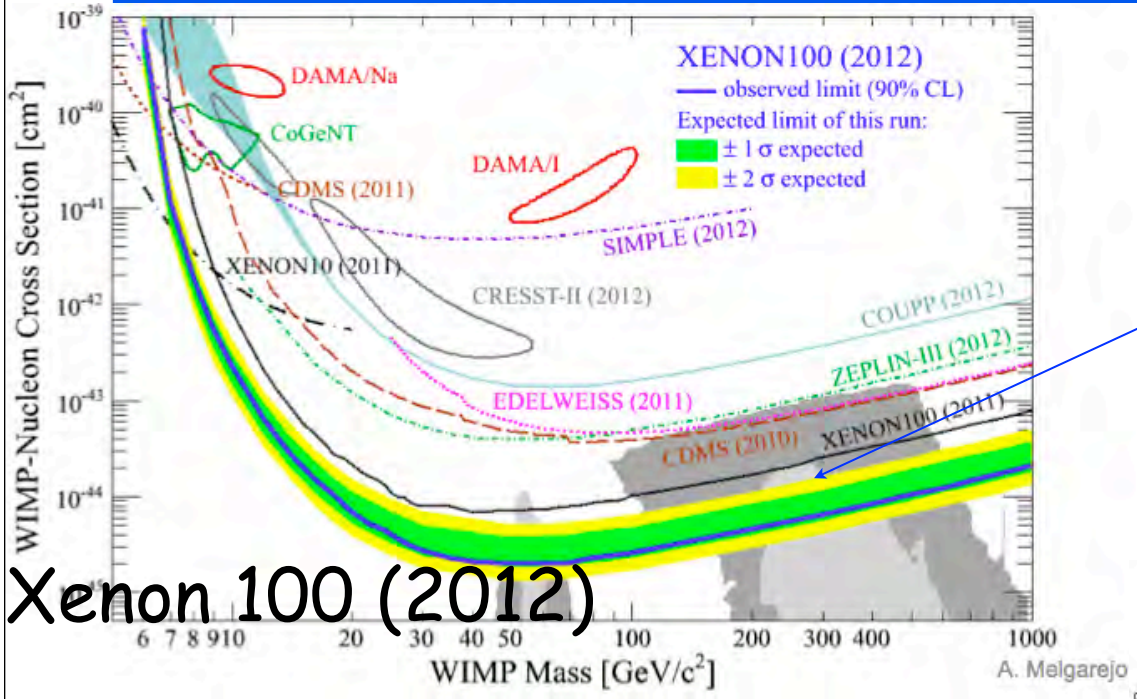
Signatures

- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector ≠background from outside

Linked to galaxy

- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Direct Detection Status August 2013



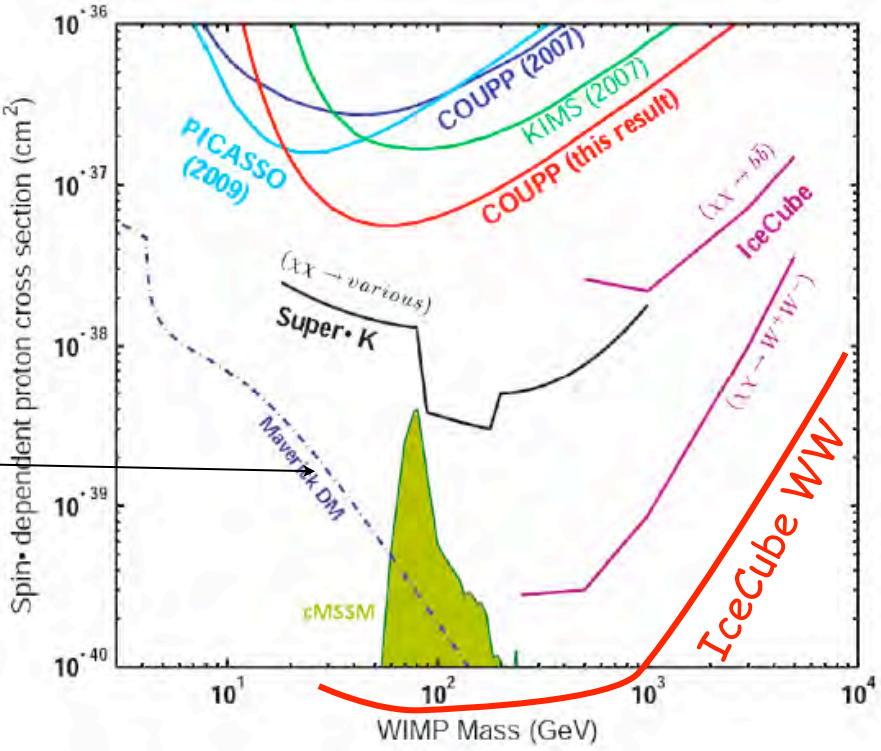
Xenon 100 (2012)

CMSSM≈mSUGRA Focal point region
(old Buchmueller 2011)

No threshold for Direct Detection

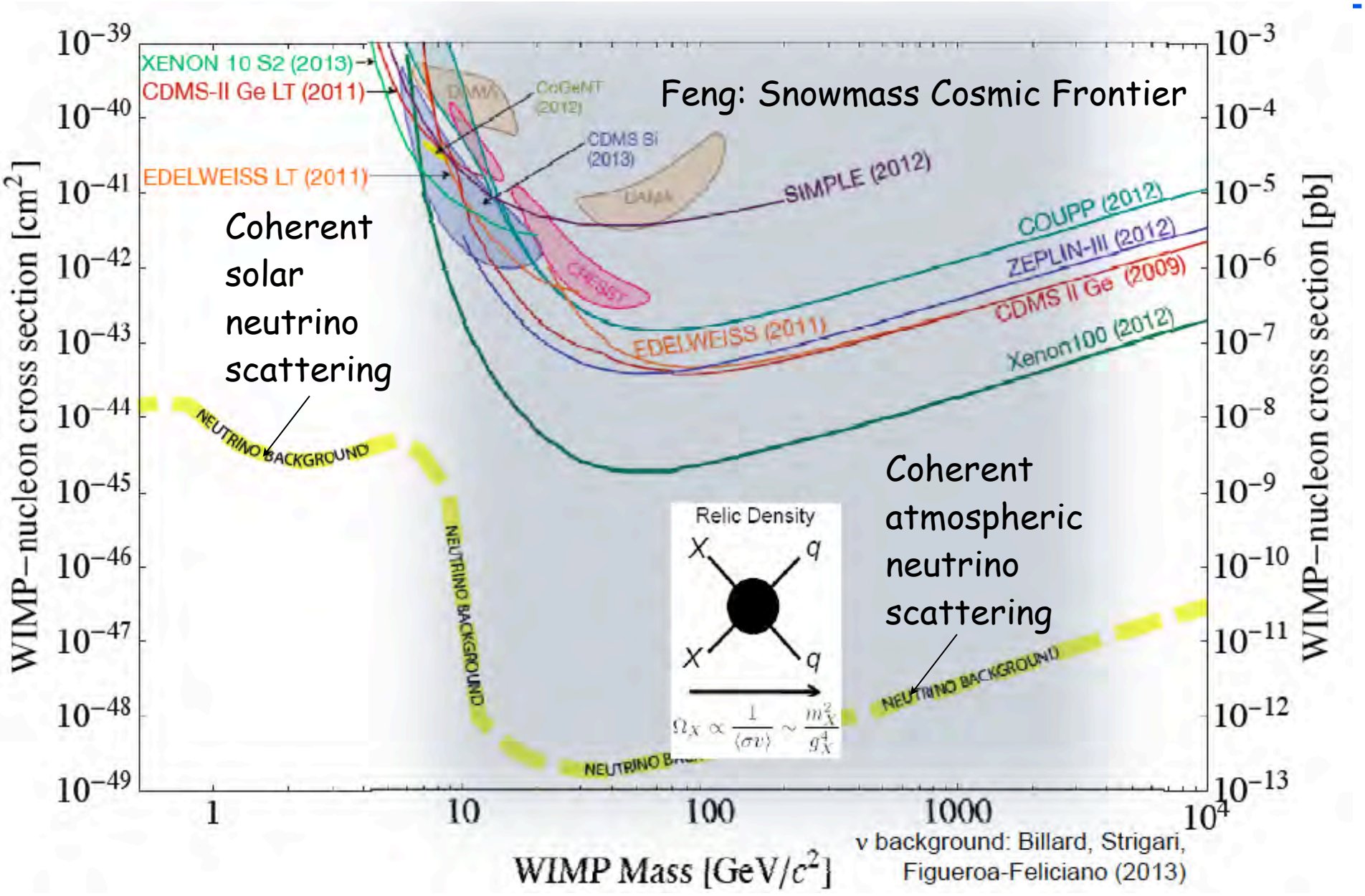
LHC Monojets

$$\left(\bar{\chi}\gamma_\mu\gamma_5\chi\right)\left(\bar{q}\gamma_\mu\gamma_5 q\right)$$



Weak Scale WIMPs

High Mass WIMP Parameter Space



No evidence yet for Weak Scale WIMPs

No direct indication of weak scale by cosmology

Nothing in Direct Detection

Best limit: Xenon 100

No smoking gun in Indirect Detection

Positron excess can be pulsars

Fermi: not yet sensitive enough for high mass (unless unphysical boosting factors)

135 GeV line? Not WIMP-like (no continuum=> dark sector or sterile ν)

No sign yet for SUSY at LHC

mSUGRA≈CMSSM too simple: excluded except focus point (high m_0,$m_{1/2}$)

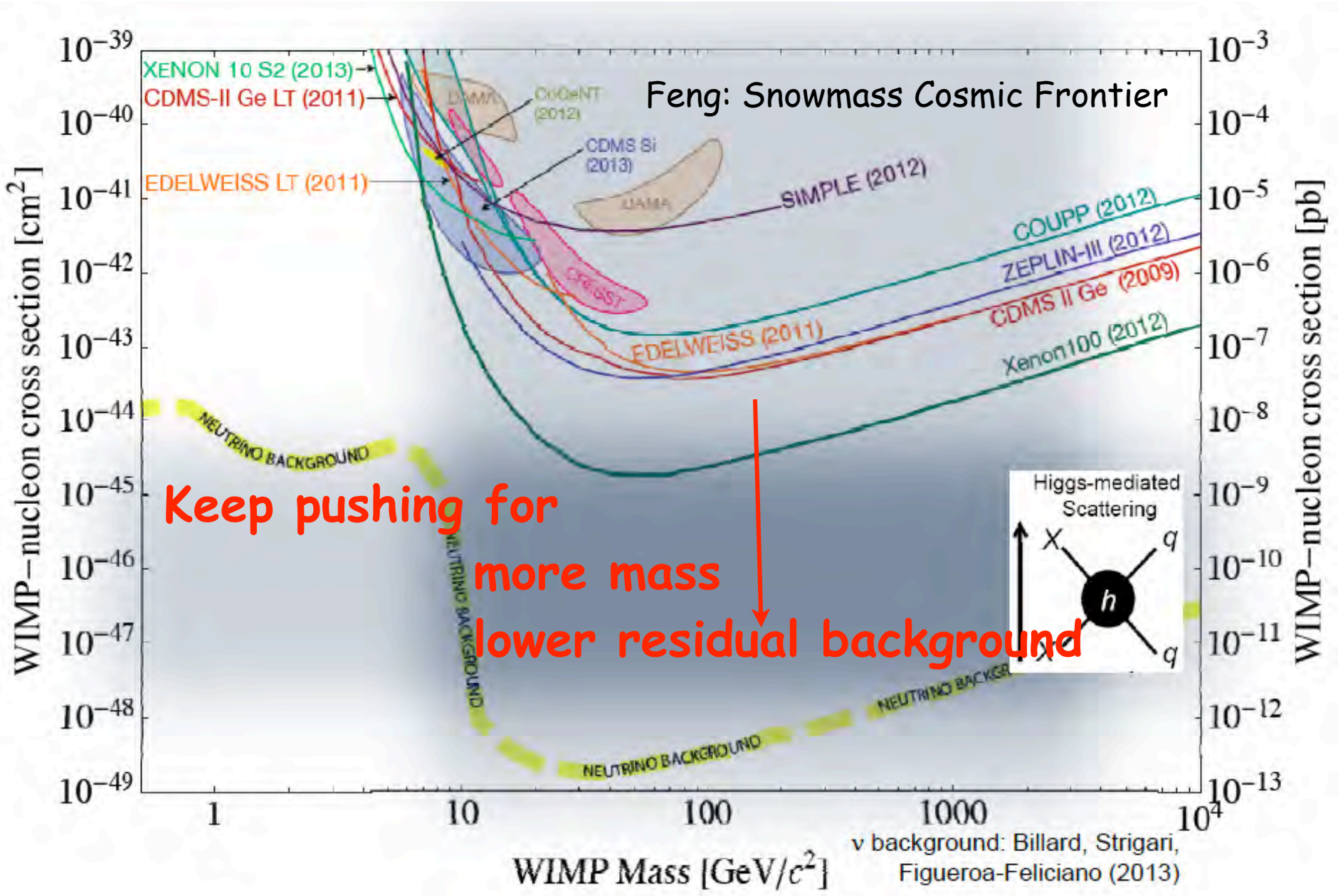
Natural, Simplified models M >600 GeV/c^2

Models with more parameters (pMSSM) have no problem but fine tuning...

"Only new fact": Higgs at 126 GeV/c^2

-> scale of interaction

Higgs Exchange



Low Mass WIMPs

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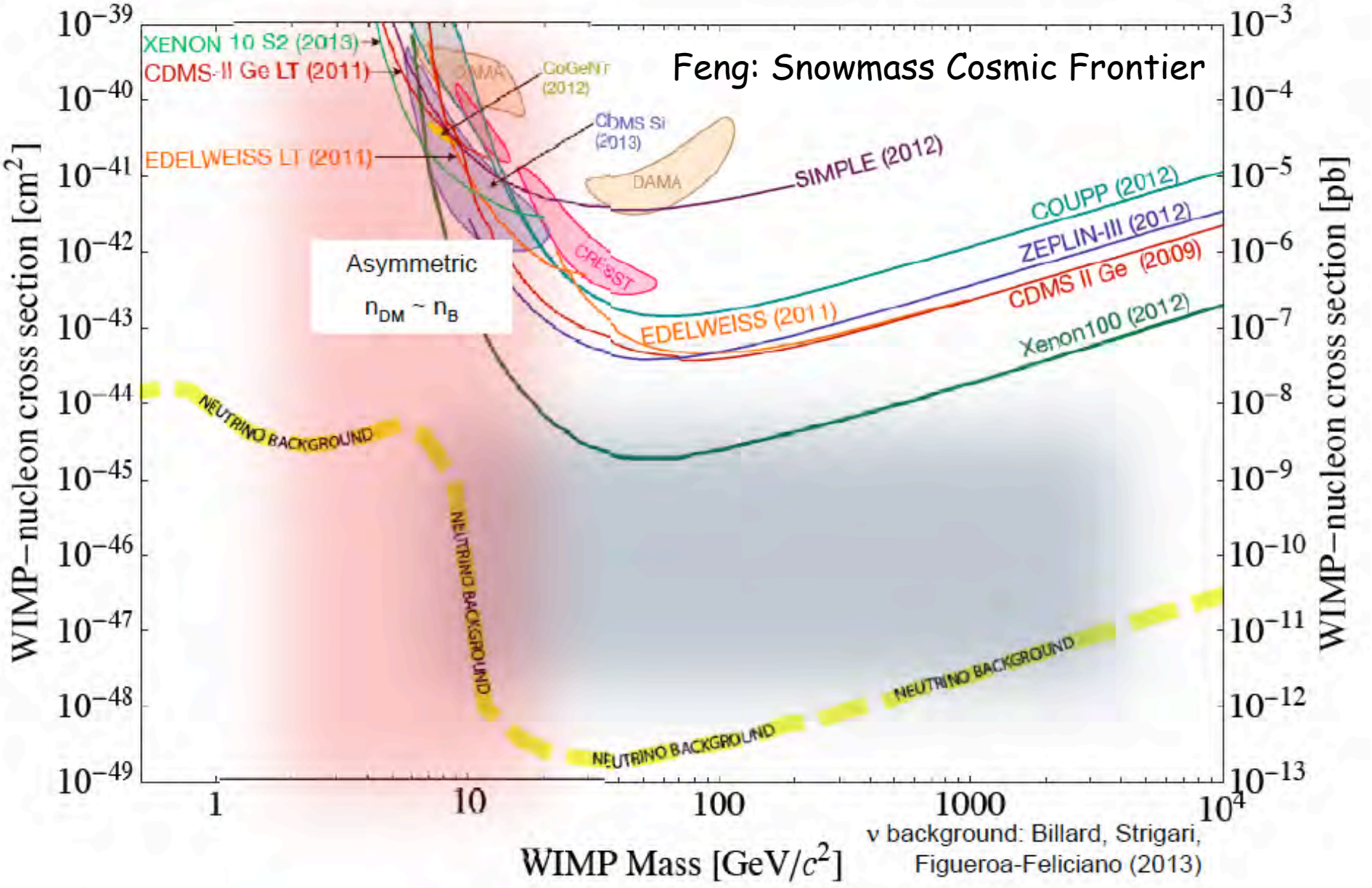
=> atomic DM, Self Interacting etc..

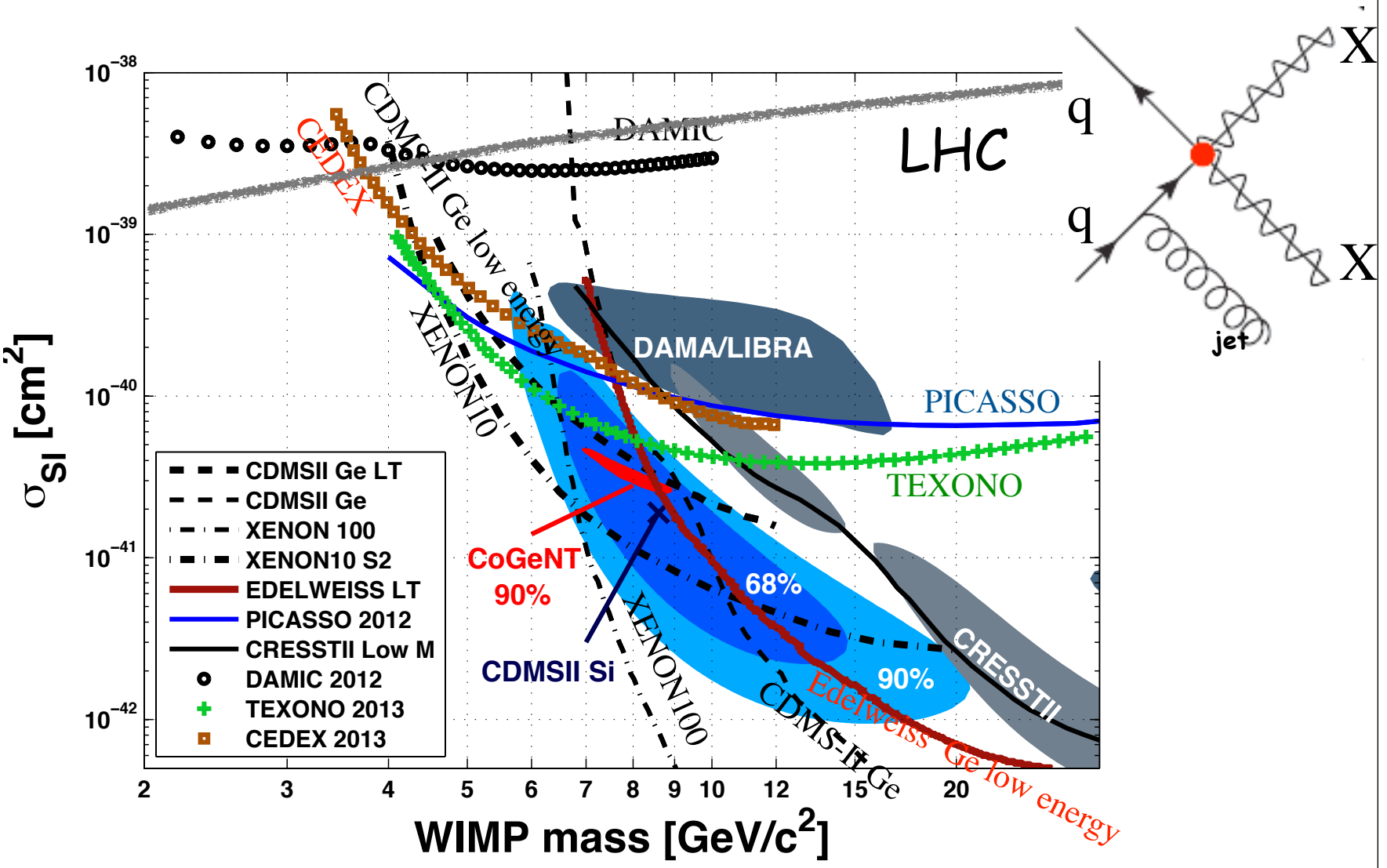
Intriguing but less predictive

Note that if cores in dwarf galaxies + deficit of large satellites are confirmed, and if astrophysics processes (baryon ejection) are not powerful enough, we may need strongly self interacting dark matter => Dark sector

Low Mass WIMP Parameter Space



An expanded view



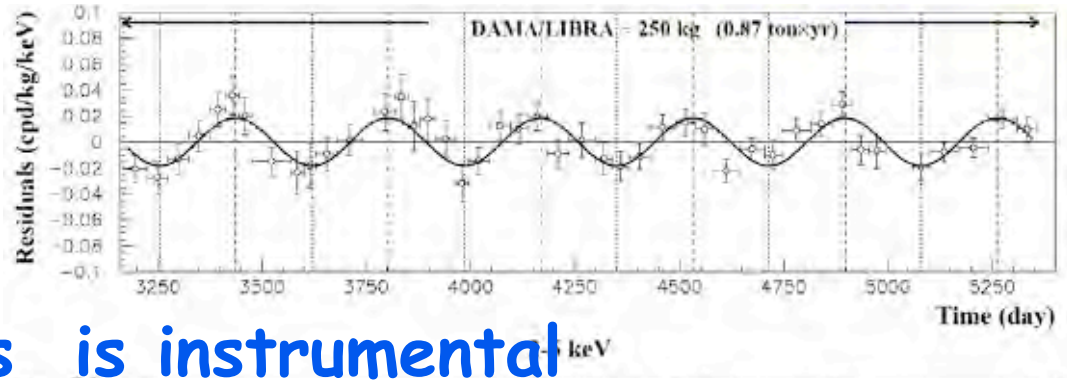
Compatible with LHC monojet limits

unless DM couples to gluons (D11 matrix ≈10^{-45} cm^2/nucleon)

Making sense of a confusing situation

DAMA

clear summer-winter modulation



Wide suspicion that this is instrumental

but no convincing explanation so far! Subtle problem!

Repeat the experiment

South Pole: DMIce

Princeton

KIMS (100kg CsI, 3 keVee, next NaI, cf Hongjoo Kim's talk)

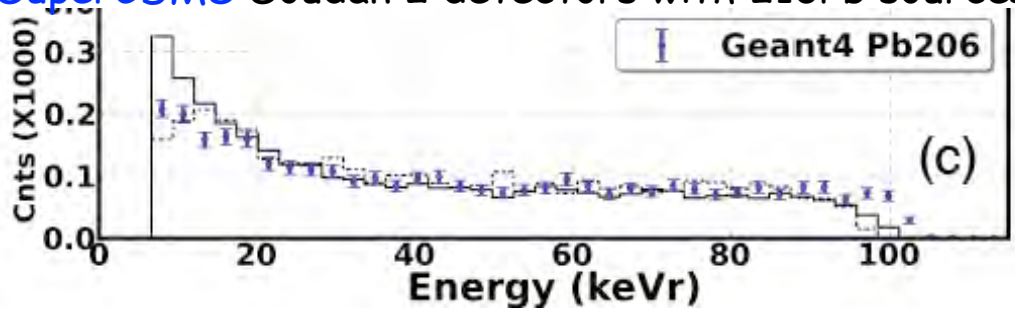
CRESST

High background

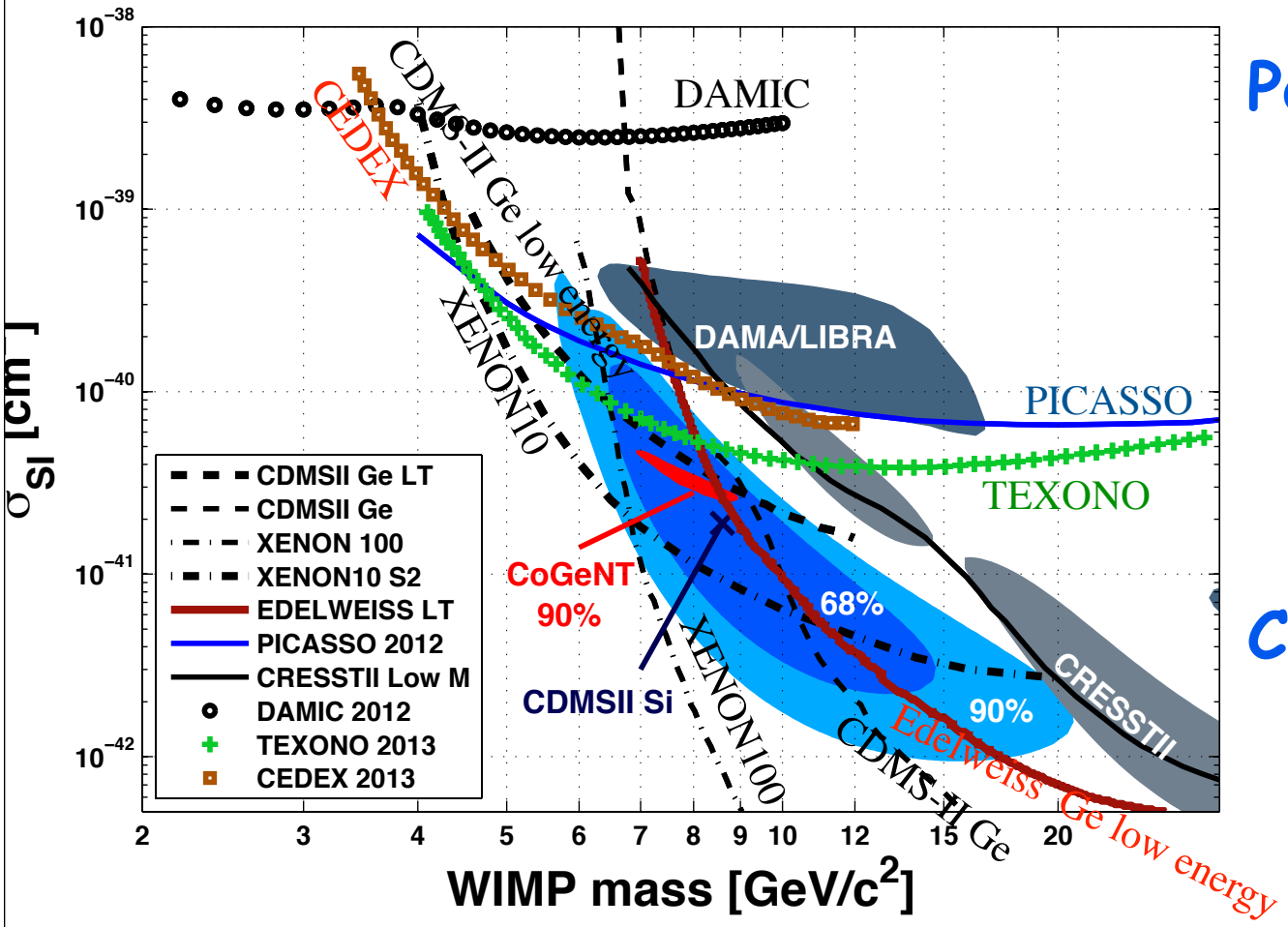
Likely ^{206}Pb

New run with reduced background

SuperCDMS Soudan 2 detectors with 210Pb sources



Ge/Si Detectors



Point contact detectors

CoGeNT evolving: 75% are surface events

<= contact simulations

But Malbeck "We cannot establish a clear separation" => upper limit, cf. CEDEX and TEXONO

CDMS II

Ge: Collar and Fields claim

But needs detailed understanding of zero charge events.

Clearly incorrect (signal in multiples!)

Si: 3σ effect

But blind analysis

Need to extend to lower energy (cf.parallel session)

new results soon!

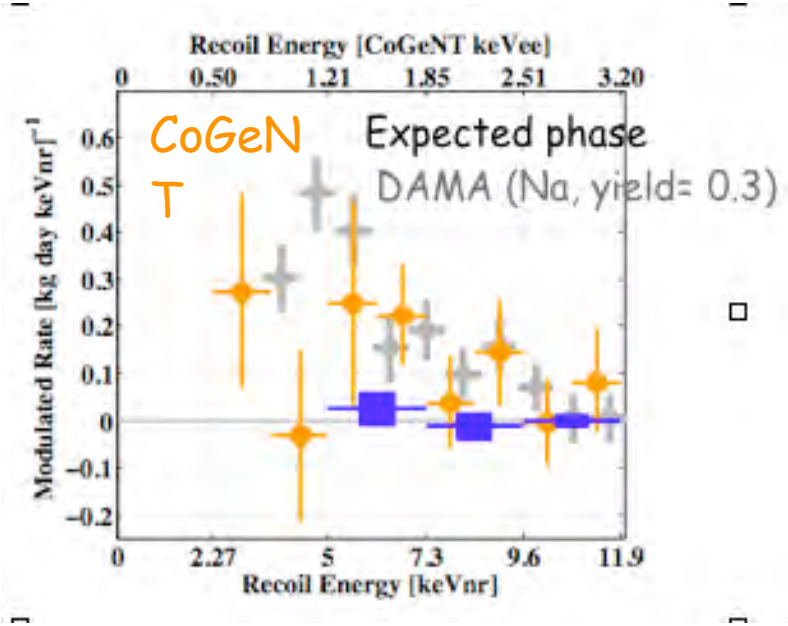
Tension with Xenon

Xenon 10 erratum: no big problem

Xenon 100: Are the two events seen compatible (Hooper)? ≠ M. Lindner's talk + uncertainty in calibration

Sensitivity to halo velocity

Low mass WIMPs?



Claims for very large modulations

Statistical significance of CoGeNT marginal (2.8 sigma) => more statistics.

Malbeck (≈same) does not see any modulation

CDMS does not see modulation (but needs to go below 5 keV: about to publish)

KIMS (CsI) no modulation 2 σ discrepancy with DAMA (cf. Hongjoo Kim's talk)

Indirect Detection

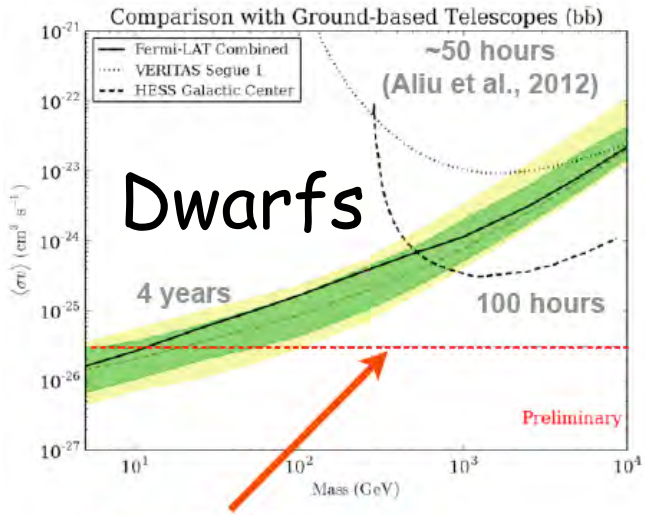
Fermi Dwarf limit:

apparent exclusion comes from 100% BR assumption e.g. in bbar

Disappears in realistic BR models

Galactic Center low energy excess: Hooper

Fermi team: not statistically significant when taking the "look elsewhere" effect



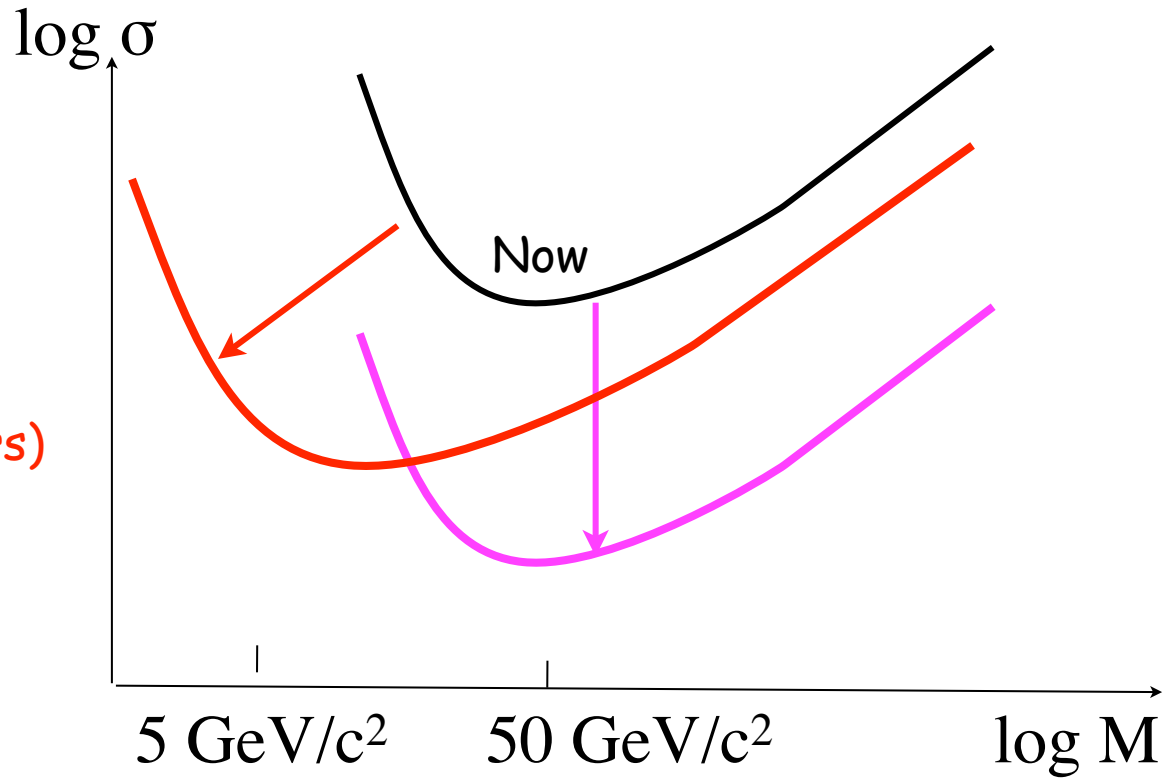
Experimental Strategy

Experimental Strategy

2 directions

1. Improve sensitivity at large mass (e.g., liquid noble)

2. Improve sensitivity at small mass
(low temperature detectors)



Lessons learnt in the last few years

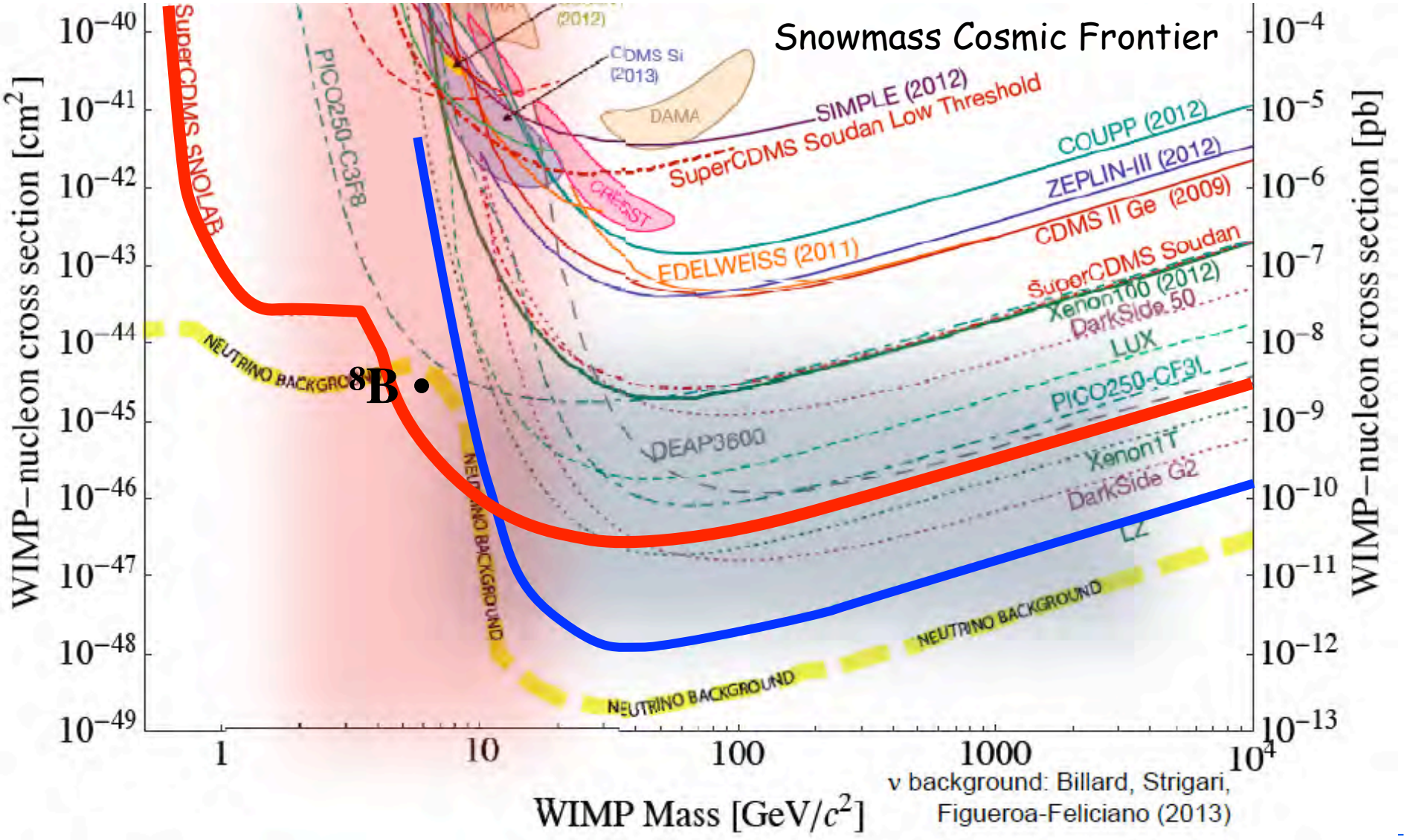
Phenomenology may be more complex than for the "vanilla" WIMP scenarios.
Difficulty to get unambiguous results

Significantly more than 2 detectors worldwide

Several technologies with complementary capabilities
Different susceptibility to background.
Enough sensitivity overlap to have at least a second experiment able to cross-check any claim.

Generation 2

Combination of liquid Xe/Ar + low temperature detectors can approach fundamental neutrino limit +^{8}Be detection



Need for R&D

Lower thresholds

Low temperature detectors (with full rejection -> ^{8}Be)
UV photosensors (Ar)
Gaseous detectors (cf Gerbier's talk about spherical ionization detectors)

Better energy calibration + relevant yields

+ systematics for modulation

Low background

PM (cf Yoichiro Susuki's talk)
High throughput liquid purification of noble gases
Material (e.g. Rn emanation) , underground fabrication

Cheaper technologies

e.g., MKIDS for low temperature detectors

Directionality

Depends on what we find (cf. Vergados' talk)
DNA labelled Au balls(Drukier)???

Conclusions

Axions: we can reach the cosmological limit (at low mass)

WIMPs: ≥Two paradigms

- Weak scale
- Dark Sector

Phenomenology (e.g., dependence on the target nucleus) may be more complex than for the "vanilla" WIMP scenarios.

Fascinating time

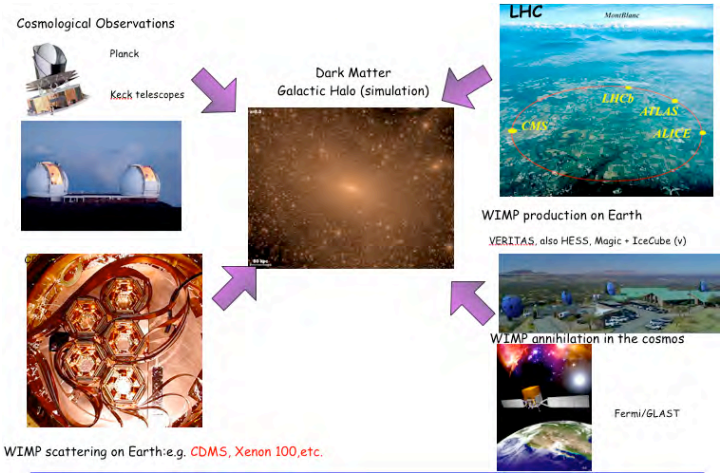
4 prong approach=>

complementary coverage

constrain theory speculations

No convincing result so far

But both paradigms still in good shape



Strategy for WIMP Direct Detection

Several technologies with complementary capabilities

2 frontiers:

- high WIMP mass natural region of noble liquids (background control)
- low WIMP mass: S/N of low temperature (target mass cost)

Good chance that we can reach the neutrino background

An Exciting Time

Credit: Joerg Jaeckel