Report from the Nature of Dark Matter Group:

October 10, 2016

Carmen Carmona, Enectali Figueroa-Feliciano

Brief Introduction

- **Science Drivers**

Identify the new physics of dark matter

Astrophysical observations imply that the known particles of the Standard Model make up only about one-sixth of the total matter in the Universe. The rest is dark matter. Dark matter is presumed to consist of one or more kinds of new particles. The properties of these particles, which are all around us, are unknown. Dark matter represents a bizarre shadow world of fundamental particles that are both omnipresent and largely imperceptible. Experiments are poised to reveal the identity of dark matter, a discovery that would transform the field of particle physics, advancing the understanding of the basic building blocks of the Universe.

Relevant presentations

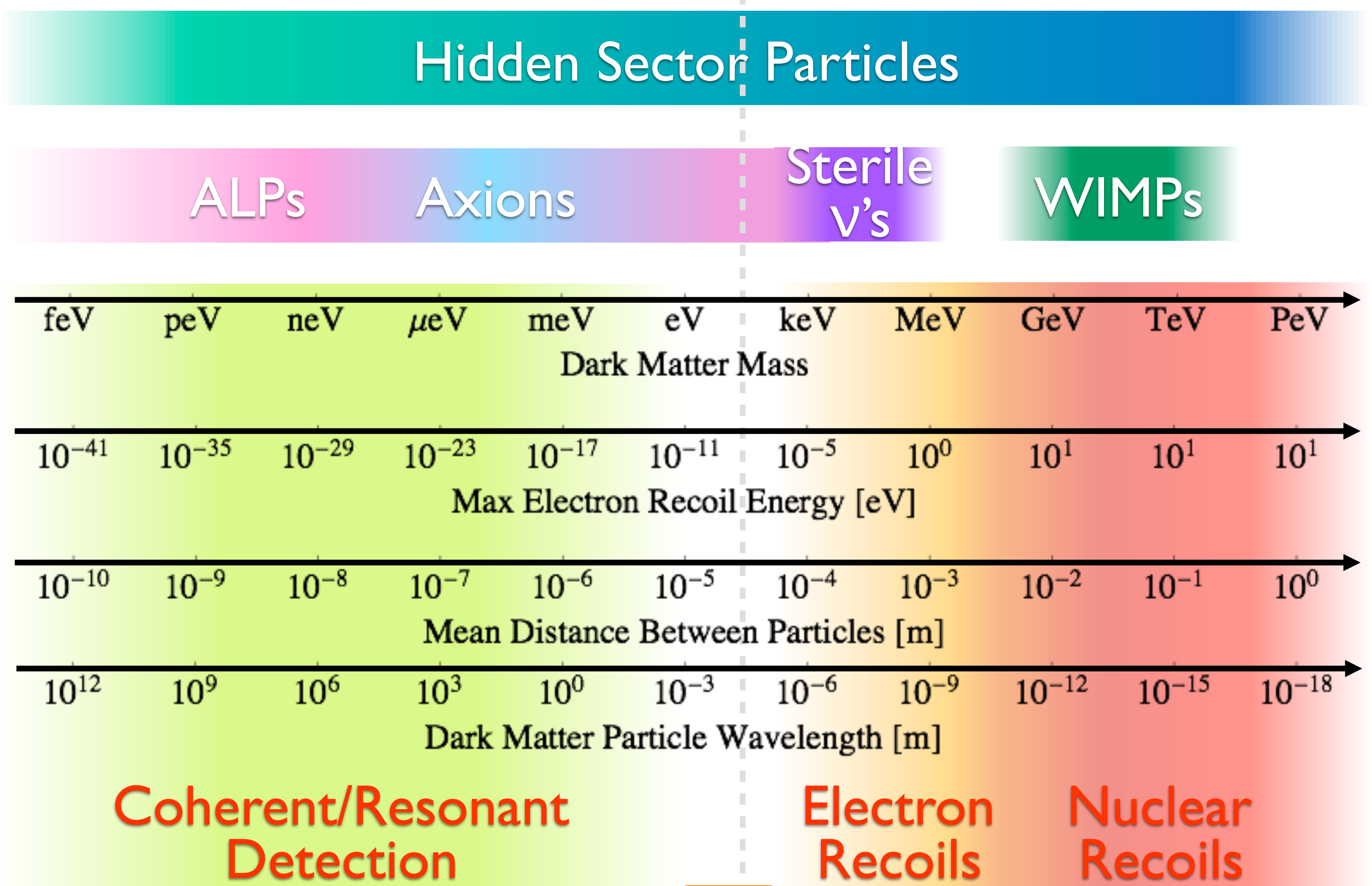
Plenary session

- Nature of Dark Matter (Enectali Feliciano-Figueroa)

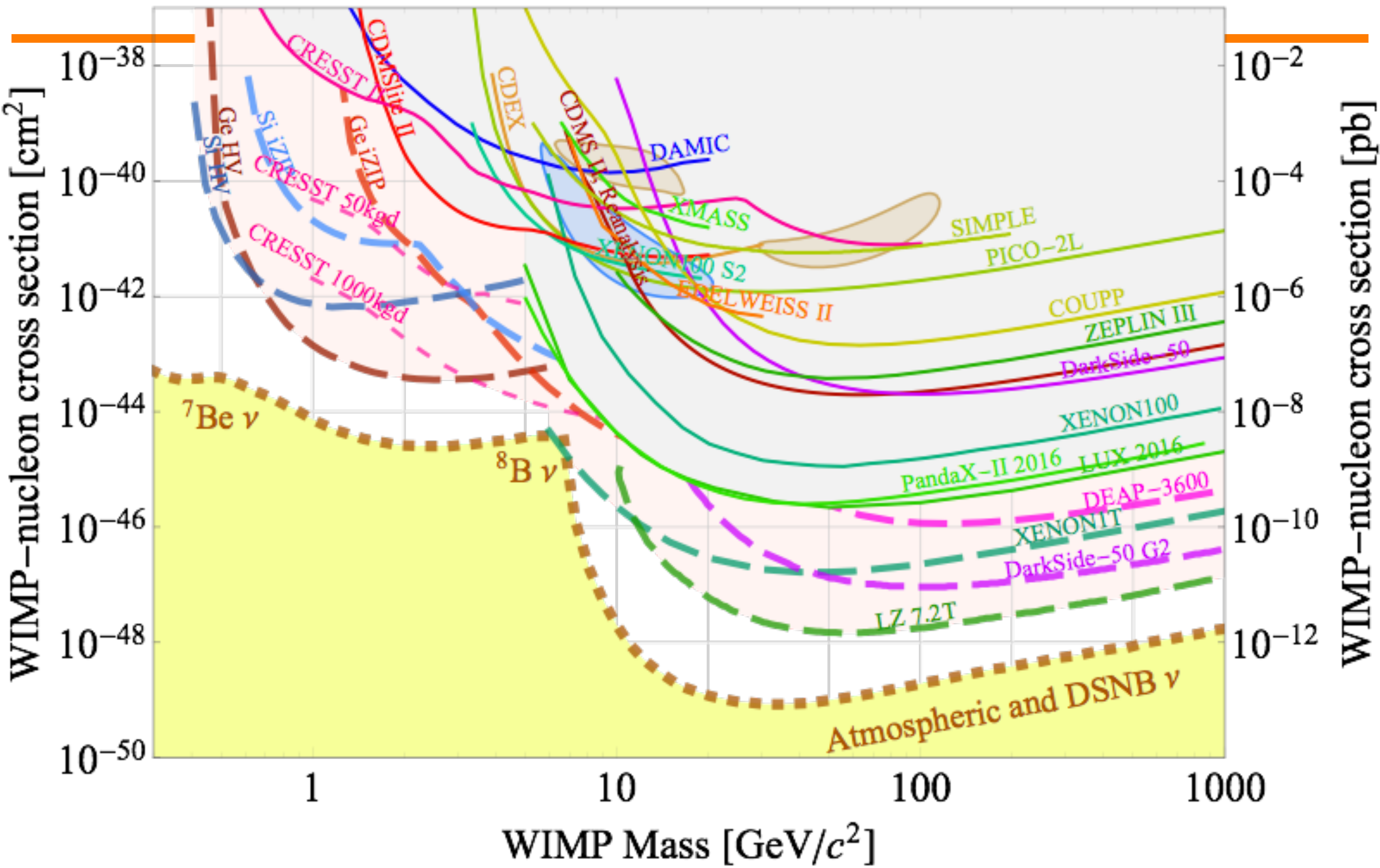
Parallel session:

- Theory: below 1 eV (Asmina Arvanitaki)
- Theory: above 1 eV (Tim Tailt)
- Direct Detection: below 1 eV (David Tanner)
  - Speaker couldn’t be here, because of the hurricane in Florida
- Direct Detection: above 1 eV (Scott Hertel)
- Indirect Detection Searches (Simona Murgia)
- Dark Matter Searches at the LHC (Antonio Boveia)

Dark Matter Detection Channels



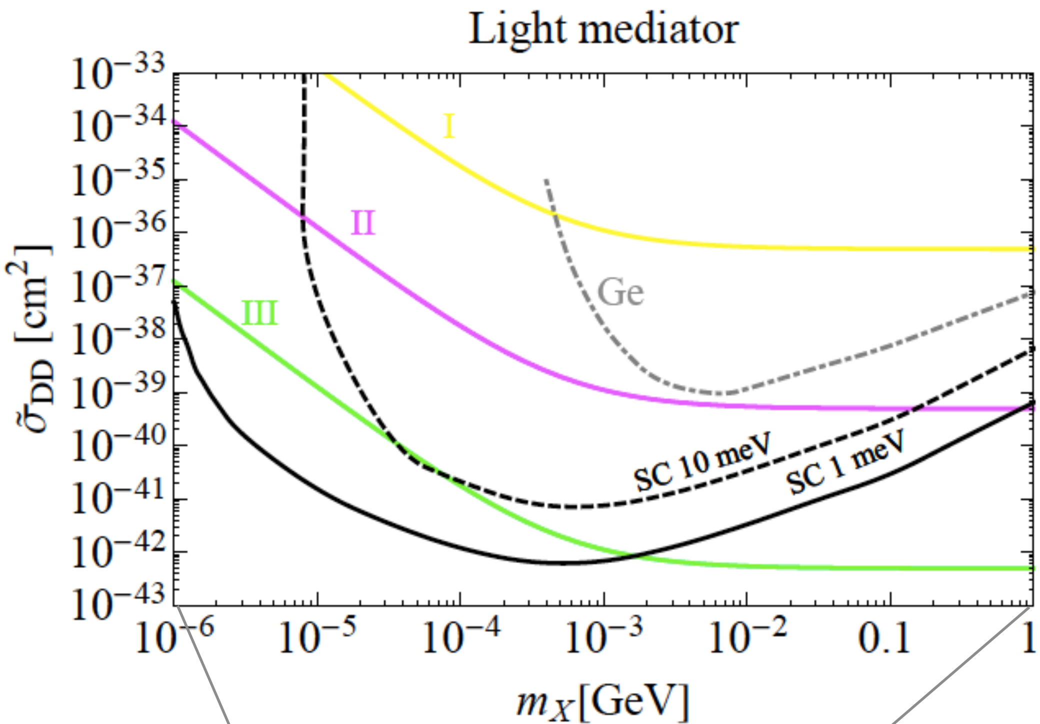
Projections for Second Generation DM Searches (G2)

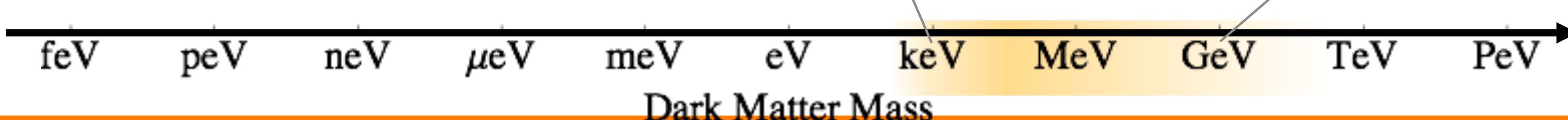


How do we look for DM with electron recoils?

- Pretty much all experiments that look for nuclear recoils also see electron recoils!
- Single electron sensitivity expected in both liquid noble and crystal experiments.
- The main issues are threshold, fiducialization, and lowering backgrounds.
- Using materials with a band gap or even quasiparticles in superconductors can drastically reduce the threshold!

Hochberg et al. 1504.07237
see also Essig et al. 1108.5383





Bosonic Dark Matter

What kind of Bosons?

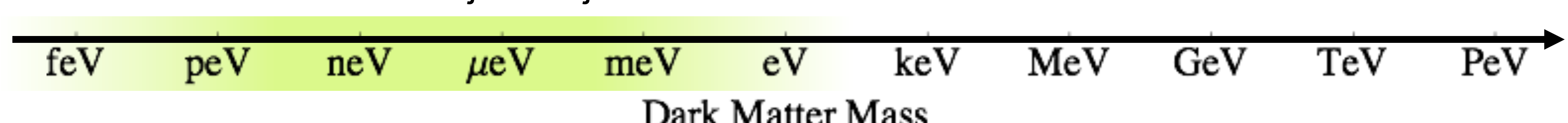
pseudoscalar → **Spin 0**
Axions and other Goldstone Bosons

- Electromagnetism $\left(\frac{a}{f_a} F\tilde{F}\right)$
- Nuclear Force $\left(\frac{a}{f_a} G\tilde{G}\right)$ QCD Axion
- Nuclear Spin $\left(\frac{\partial_\mu a}{f_a} \bar{N}\gamma^\mu \gamma_5 N\right)$ General Axions

vector → **Spin 1**
Hidden Photon or other Vector Field

- Nuclear Spin $\left(\frac{F'_{\mu\nu}}{f_a} \bar{N}\sigma^{\mu\nu} N\right)$ Dipole moment
- Electro-magnetism $\left(\epsilon F' F\right)$ Kinetic Mixing
- Nucleon Current $\left(g A'_\mu J^\mu_{B-L}\right)$ B-L

Slide From Surjeet Rajendran



Findings

- There is a rich landscape of theoretical ideas; what is needed are experimental results to select among them and refine the parameter space.
- Complementarity between dark matter production (accelerators), direct detection and indirect detection.
- Any potential signal needs to be confirmed with different technologies.
- There is a vibrant program that covers a huge space of possibility from ultra-weakly interacting particles such as axions and sterile neutrinos to WIMPs and beyond.
- Astronomical probes can access properties such as the rate of self-interaction which are otherwise difficult to extract, and difficult cases where the interactions between dark matter and the SM are very tiny.

Findings

- G2 program well established, and should be able to reach neutrino floor.
- Neutrinos is a background for direct Dark Matter experiments, but they are also an interesting signal themselves (e.g. coherent neutrino-nucleus scattering).
- LHC data has great potential for constraining dark matter parameters. New approaches with simplified models probe different regions of parameter space.
- NR can explore down to ~10 MeV DM masses, and for lightest DM we can use ER or multi-excitation signal mechanisms.
- Single electron sensitivity expected in both liquid noble and crystal experiments. The main issues are threshold, fiducialization, and lowering backgrounds.

Findings

- There is excellent theoretical motivation for boson DM candidates below 1 eV in mass. Many new ideas are being pursued, applying precision measurement techniques to the search for dark matter.

Comments

- Direct detection still has a lot of potential, and lots of R&D work to do, using both ER and NR signals.
- R&D relevant for extending the reach of direct detection to low mass DM needed.
- R&D relevant to lower backgrounds in direct detection experiment needed.
- Putting together a detailed description of the particle properties of dark matter is vital to better understand fundamental physics.

Identification of Risks and Opportunities

- Work is needed to better integrate LHC, direct detection, and indirect detection searches.
- Robust NR calibration needed to push down the threshold of direct detection experiments.
- Challenges in indirect detection include large and often poorly understood backgrounds and uncertainties in the dark matter distribution.

Recommendations

- More details in Detector Sessions
- The direct detection technology to approach the neutrino floor is close, but more R&D to reach the neutrino floor is required.
- New ideas need development to achieve sensitivity to WIMP dark matter below the neutrino background.
- Backgrounds for low mass dark matter poorly understood. Further studies are needed.
- Confirm signal through various targets and techniques
- Continuing work is needed in background reduction and energy scale calibration.
- High synergy between 2 β decay and DM detectors… opportunity for HEP+NP collaboration.

Recommendations

- R&D to extend sensitivity in all mass ranges should be encouraged.
- We need to combine the data from direct detection with LHC searches and indirect detection to elucidate the properties of any candidate signal.
- Precision measurements and any other ideas for boson DM should be pursued.
- New technologies to probe 1 keV to 1 GeV DM mass range are required

Grand Challenge Idea

- **The Low-mass Dark Matter Frontier**
  - Develop new technologies to search for nuclear and electron scattering from dark matter between 1keV and 1GeV, and coherent effects from 10^{-24} eV to 1 eV.