Signatures of the Milky Way's Dark Disk in Current and Future Experiments

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Outline

- **Properties of the Dark Disk**

- **Direct detection (arXiv:0804.2896 [astro-ph])**
- **Expected rates in current and future detectors**
- **Annual modulation signal**

- **Indirect detection**
- **Expected μ fluxes in ν telescopes**

- **Summary**

Properties of the dark disk

The solar system is embedded in the macroscopic structure of the dark disk.

Density of the dark disk is constrained by

- $\delta = \frac{\rho_{DD}}{\rho_{SHM}} \leq 2$

Kinematics of the dark disk match the Milky Way's stellar thick disk at the solar neighbourhood:

- $v_{DD} = [0, 50, 0]\ km/s$ **rotation lag with respect to the local circular velocity**
- $\sigma_{DD} = [69, 39, 39]\ km/s$

Dispersions quiet uncertain so for simplicity take:

- $\sigma_{DD} = 50\, km/s$

Standard values for the Standard Halo Model (SHM)

- $v_{SHM} = [0, 220, 0]\ km/s$
- $\rho_{SHM} = 0.3\ GeV/cm^3$
- $v_{esc} = 544\ km/s$

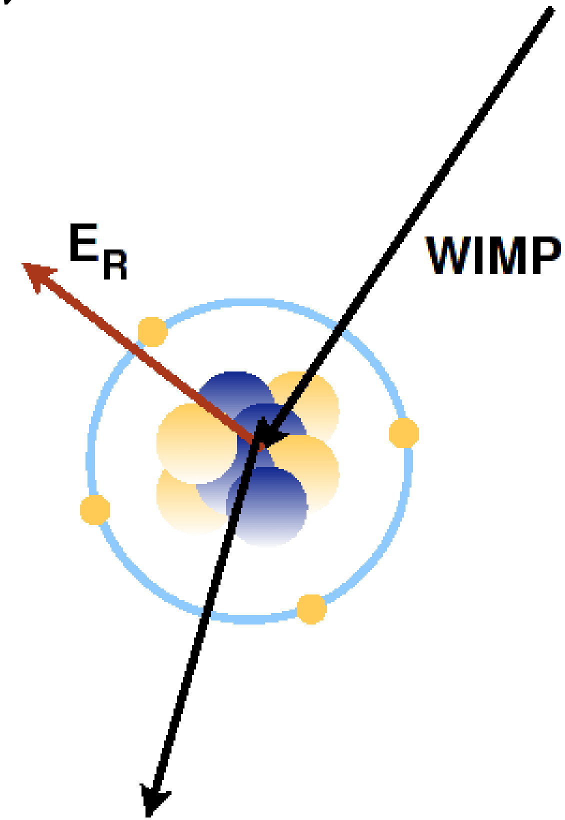
Direct Detection principle

Detect the dark matter particles (WIMPs) by their elastic scattering on atomic nuclei

$$\frac{dR}{dE_R} = \frac{\rho\,\sigma_{WN}\left|F(E_R)\right|^2}{2\,M_W\,\mu} \cdot \int_{v>\sqrt{m\,E_R/2\mu^2}}^{v_{max}} \frac{f(\vec{v},t)}{v}\,d^3v$$

WIMP velocity distribution is modelled by a simple 1D Maxwellian :

$$f(\vec{v},t) \propto \exp\left(\frac{-(\vec{v}+\vec{v}_E(t))^2}{2\sigma^2}\right)$$



Two components of dark matter.

Rate in a direct detection detector:

$$\left(\frac{dR}{dE_R}\right)_{Total} = \left(\frac{dR}{dE_R}\right)_{SHM} + \left(\frac{dR}{dE_R}\right)_{DD}$$

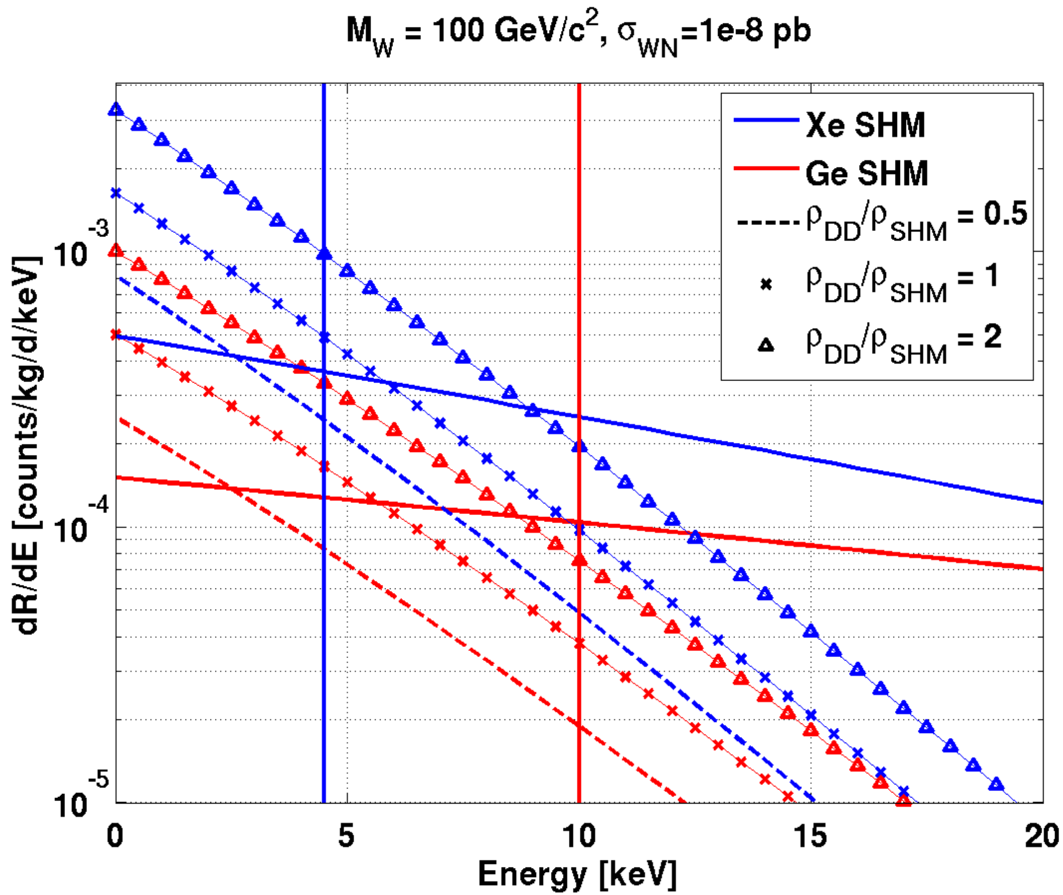
Expected recoil spectra

Consider two exemplary target nuclei: Xe, Ge

Only SI scattering, which is dominant for A > 30

Two featureless spectra

Both differential rates will depend on the particle's mass

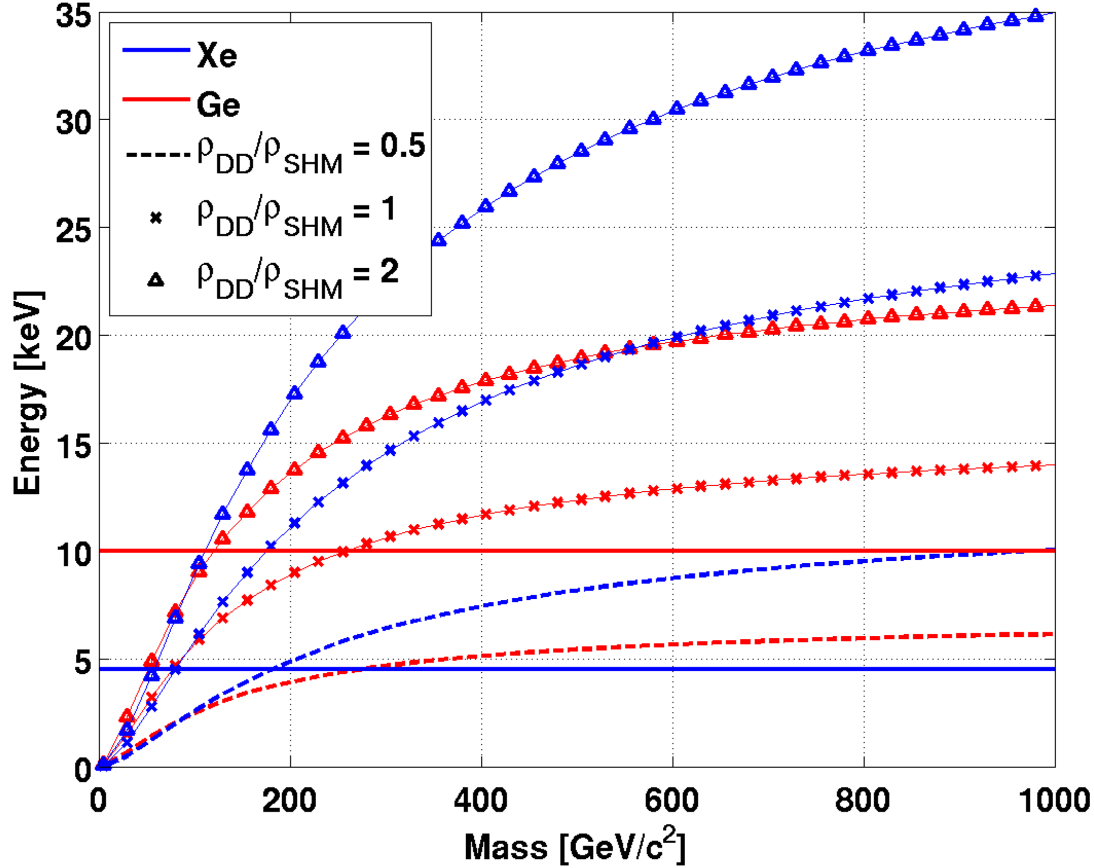


Detection of the dark disk component crucially depends on the detector's energy threshold (vertical lines indicate the thresholds of the XENON10 and CDMS-II experiment)

The rise of the dark disk

Higher particle masses allow higher recoil energies

The energy below which the dark disk dominates is shifted to higher values



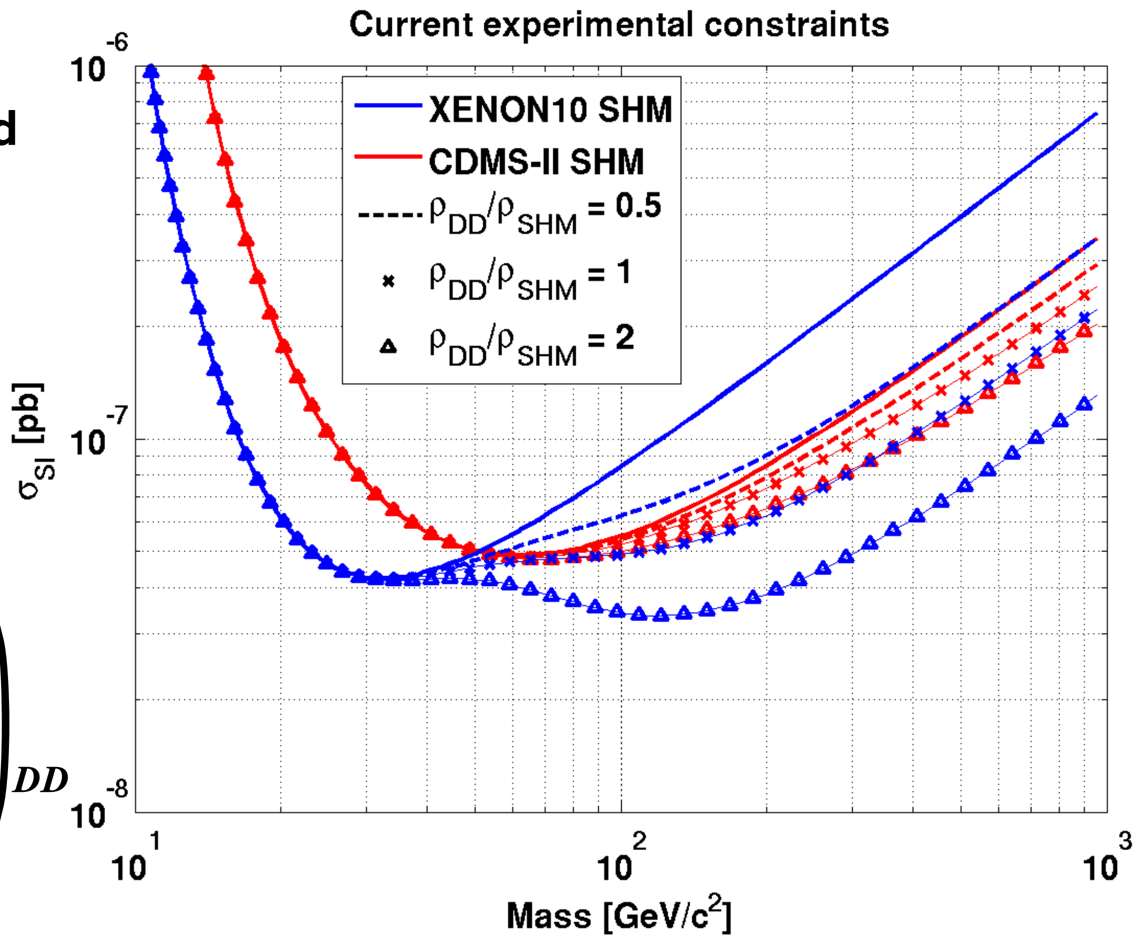
XENON10 and CDMS-II thresholds are shown

The more the merrier

So far direct detection experiments (CDMS-II / XENON10) only reported null observation / backgrounds

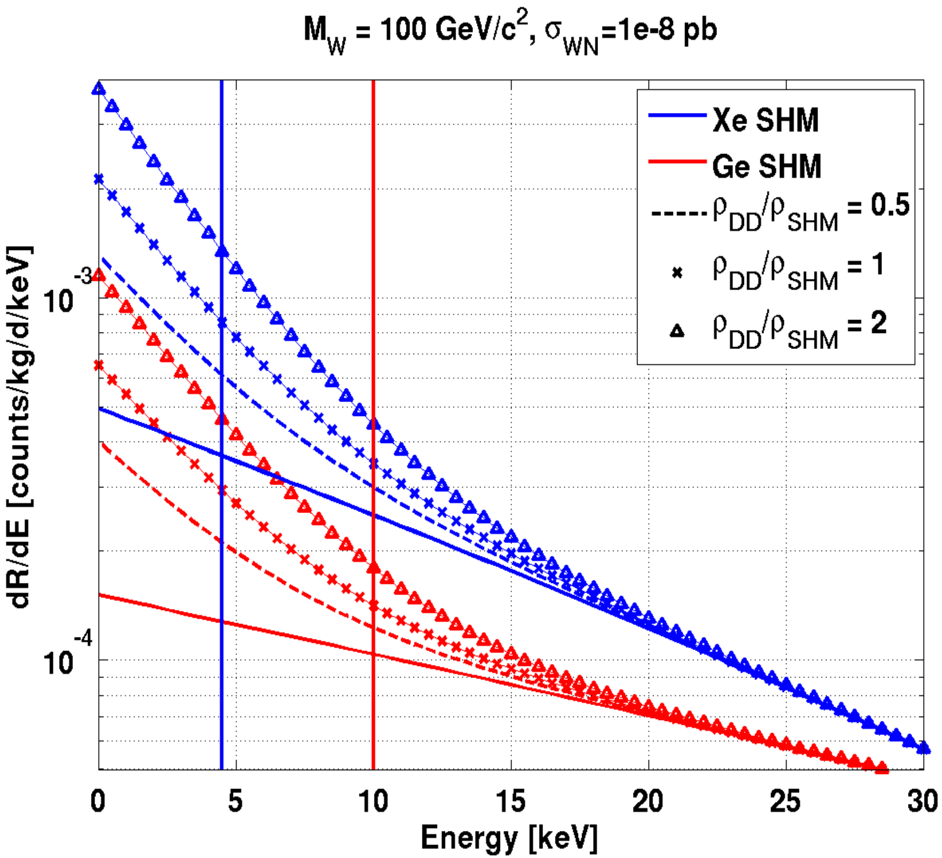
For given exposure the upper limit on the interaction cross section is determined by the flux of dark matter particles

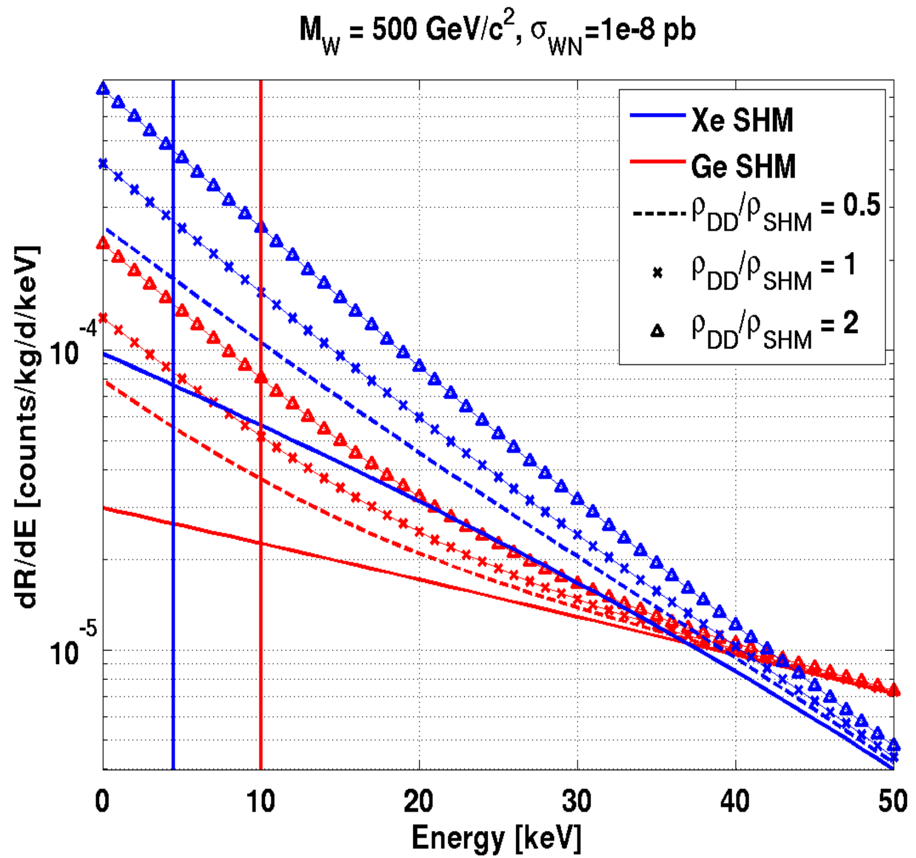
$$\left(\frac{dR}{dE_R}\right)_{Total} = \left(\frac{dR}{dE_R}\right)_{SHM} + \left(\frac{dR}{dE_R}\right)_{DD}$$



Improved constraints on the interaction cross section due to the additional dark matter particle flux from the dark disk component

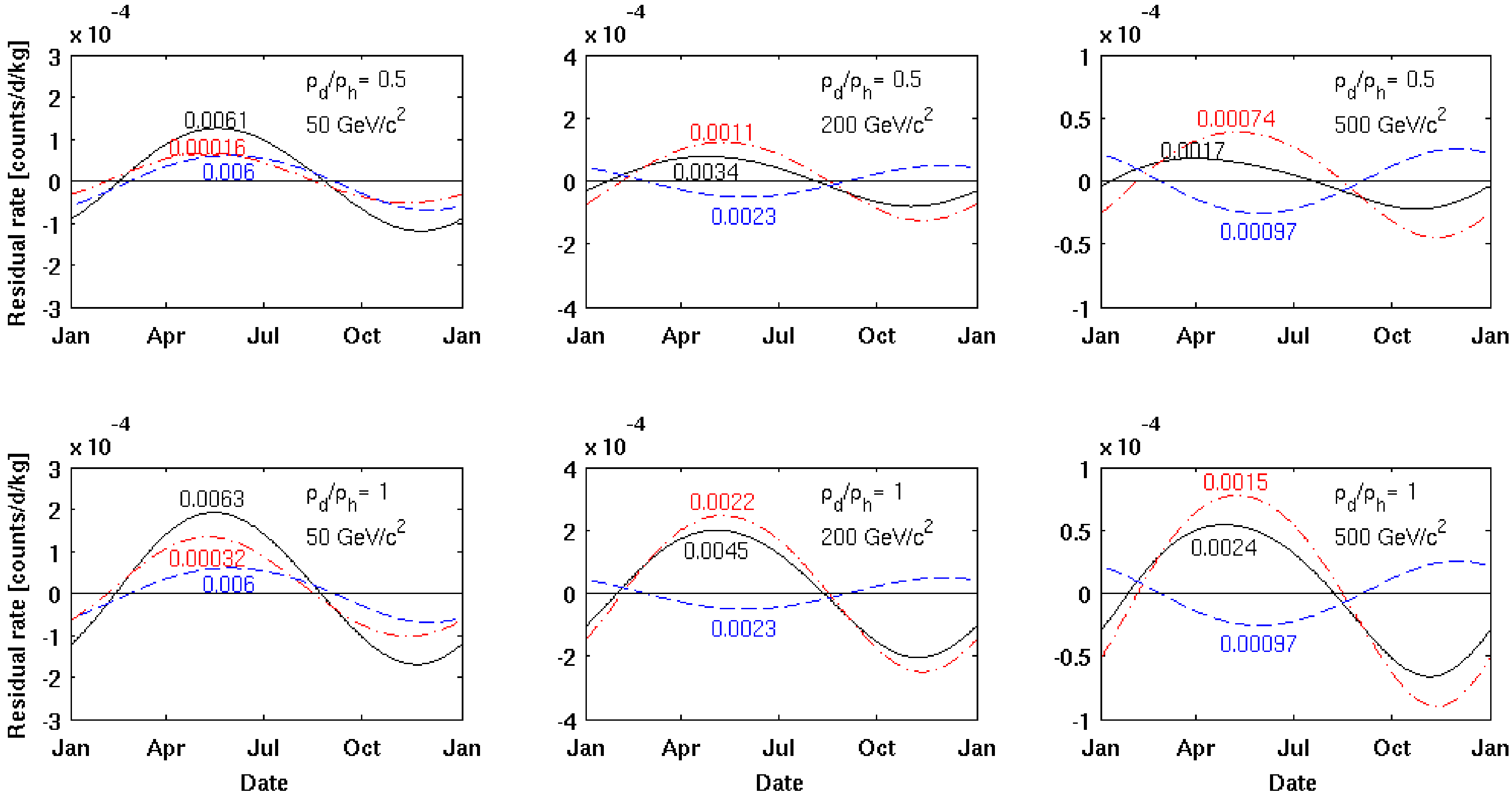
Characteristic shape





Upon detection, the shape of the recoil spectra will improve the constraints on the particle's mass

What about the annual modulation signal



The phase (defined at maximum rate) of the annual modulation signal from the dark disk component is shifted by ~ 3 weeks with respect to the SHM signal

While the phase of each component does not depend on the mass, their sum does because their amplitudes depend on the WIMP mass.

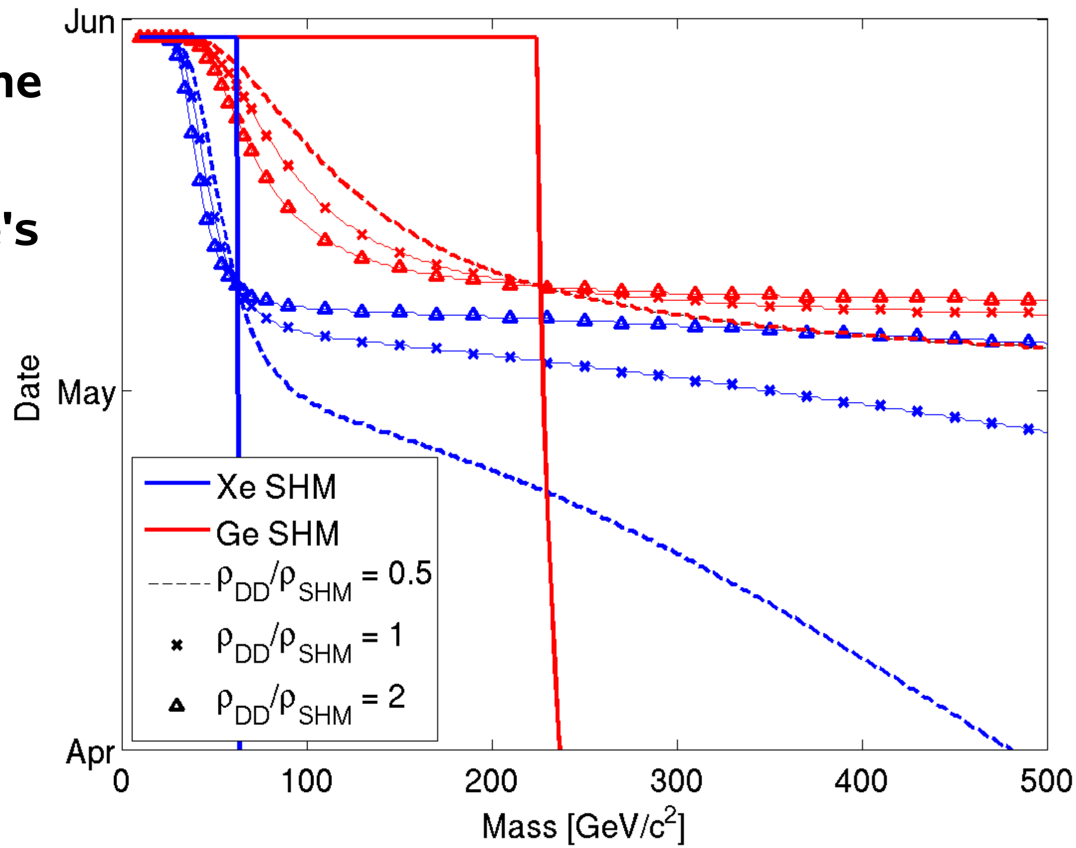
More information on the particle's mass

The phase of the annual modulation signal becomes a unique function of the particle's mass

Only lower / upper limit on the particle's mass in the SHM

Phase shifts expected for the XENON10 (4.5 – 27 keV recoil energy range) and CDMS-II (10 – 100 keV recoil energy range) experiment

The particle mass can be directly determined from the measured phase for known properties of the dark disk



Combining this with spectral information may break the degeneracy between the particle's mass and δ.

Indirect detection by annihilation products

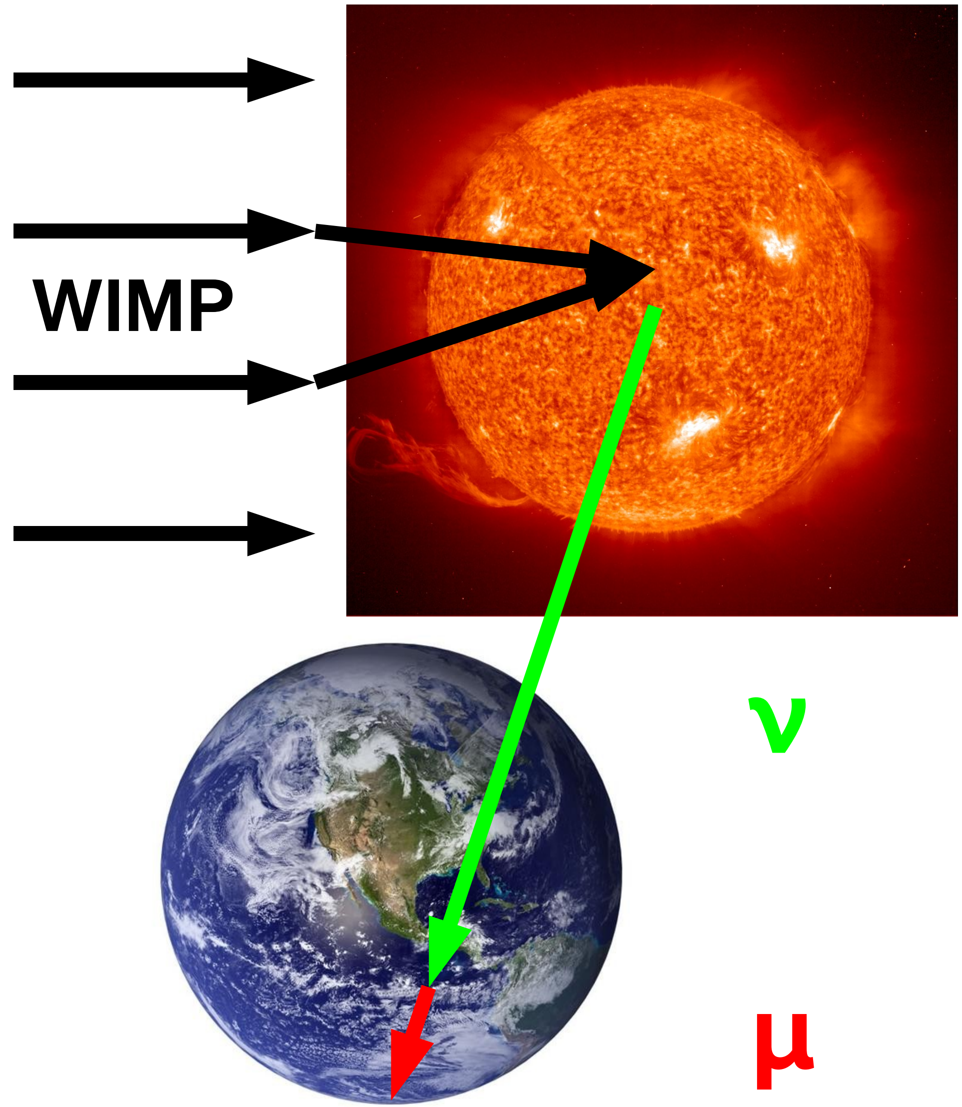
WIMPs will be captured by the sun and earth if their velocity drops below the escape velocity

Lower initial velocity → less scattering needed → higher probability for capture

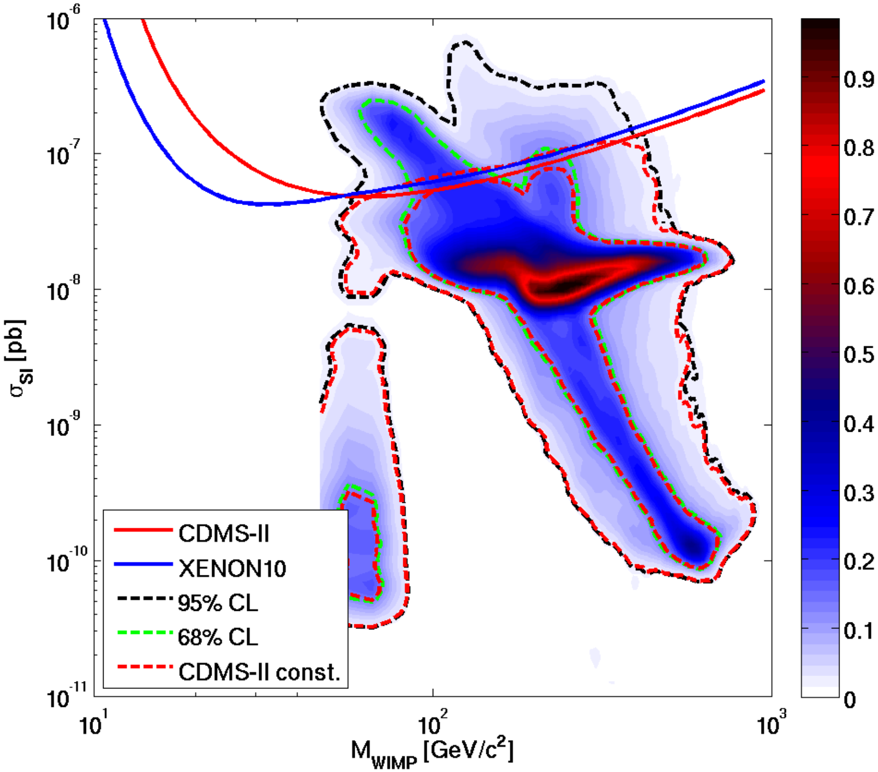
Accumulation of WIMPs in the core → enhanced probability for annihilation

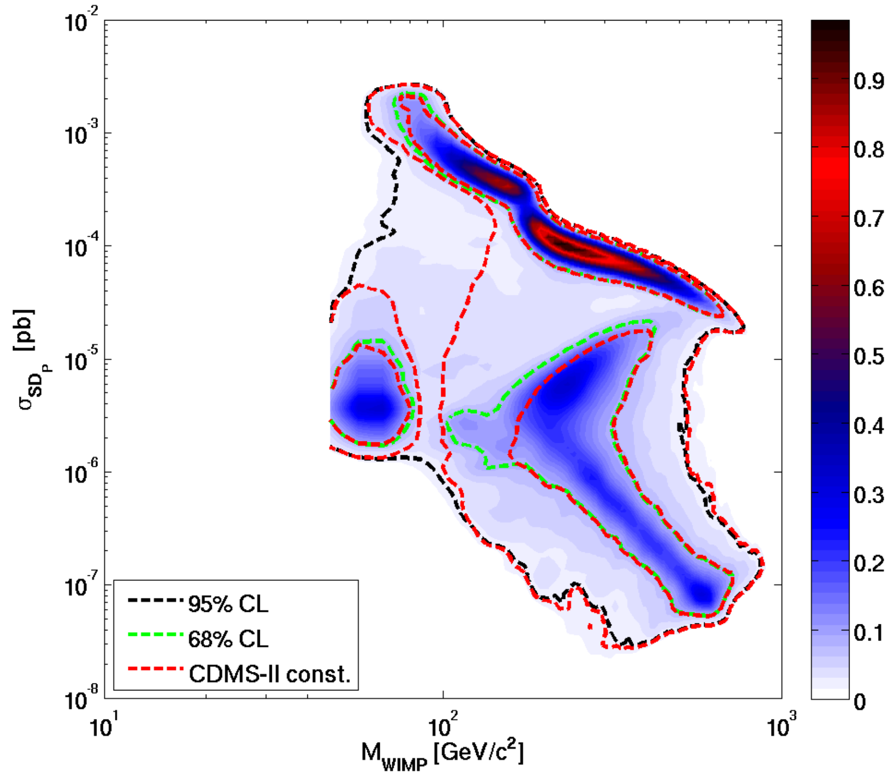
Neutrinos from these annihilations can escape and reach the earth

Muons from neutrino back conversion can be detected in large area detectors like IceCube



Capture of WIMPs in the sun



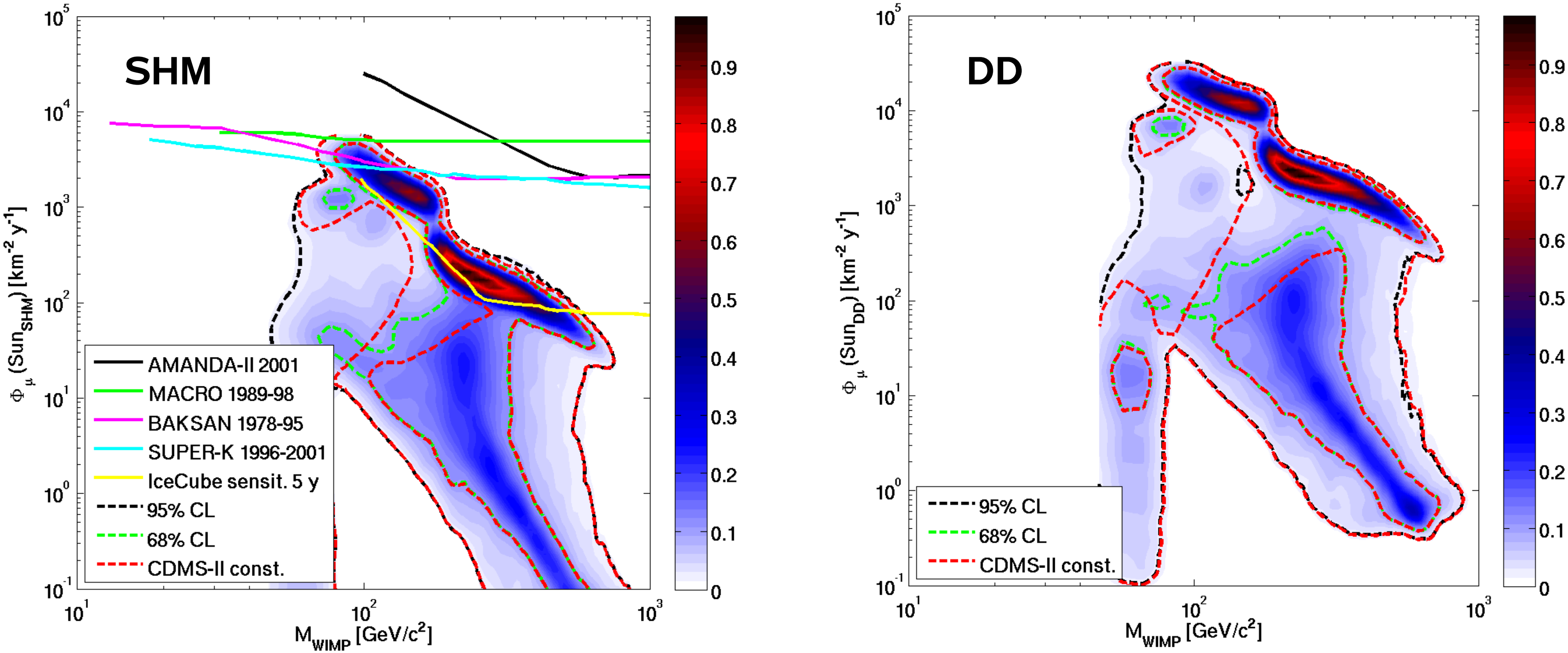


Generate theory sample compatible with current constraints using the SuperBayes (v1.13) package (JHEP05 (2006) 002, JHEP07 (2007) 075). Change in constraints: use 5 year WMAP data to constrain the relict density

The capture rate in the sun is dominated by SD - scattering (scattering on protons)

Constraints on the SI coupling constrain SD coupling in theory sample

Expected μ-flux in ν-telescopes



Calculate the expected muon flux at the earth with the DarkSUSY (v4.1) code

In the SHM only, current experiments do not set strong constraints on the allowed theory parameter space.

The lower velocity of the particles in the dark disk enhances the capture rate and thus increases the expected muon flux by a factor of ~ 5 - 10 for δ = 0.5.

Prospects for ν-telescopes

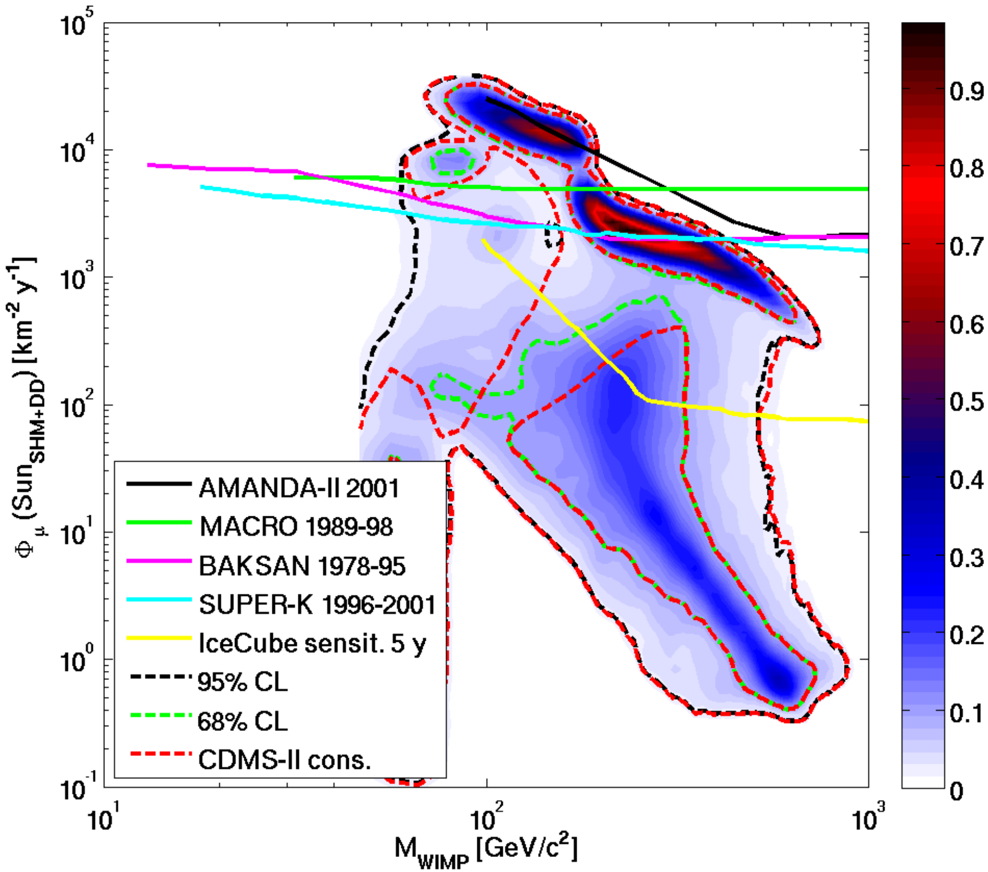
Total flux is the sum of both fluxes

Dominated by the dark disk flux

Results from current experiments significantly restrict the allowed parameter space and thus the SD coupling

Future ν telescopes like IceCube can explore a big chunk of the parameter space.

Check new DarkSUSY release including ν oscillations.



Also the capture rate in the earth will be enhanced by the dark disk component. Ratio sun / earth flux may depend on δ.

Need to evaluate the gravitational impact on the velocity distribution.

Summary

Direct Detection

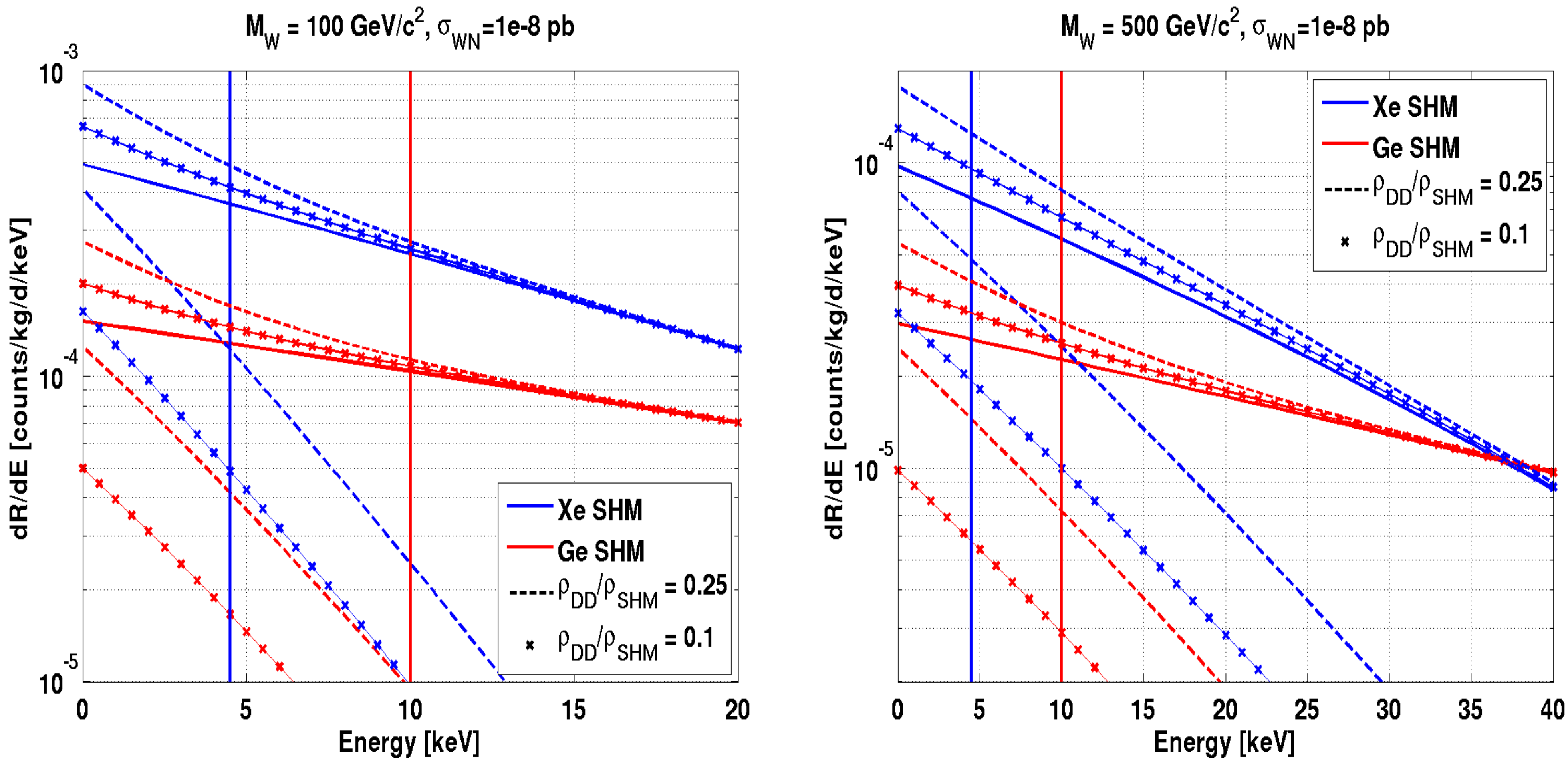
- Additional scattering rate at lower energy
- Contribution visible in current experiments
- Increased sensitivity of current experiments
- Sum of the two recoil spectra introduces mass dependent characteristic → Improvement in the constraints on the particle's mass upon detection
- Annual modulation signal shifted with respect to the SHM signal → The phase of the sum shows a unique mass dependence → Determine mass directly from the phase

Indirect Detection

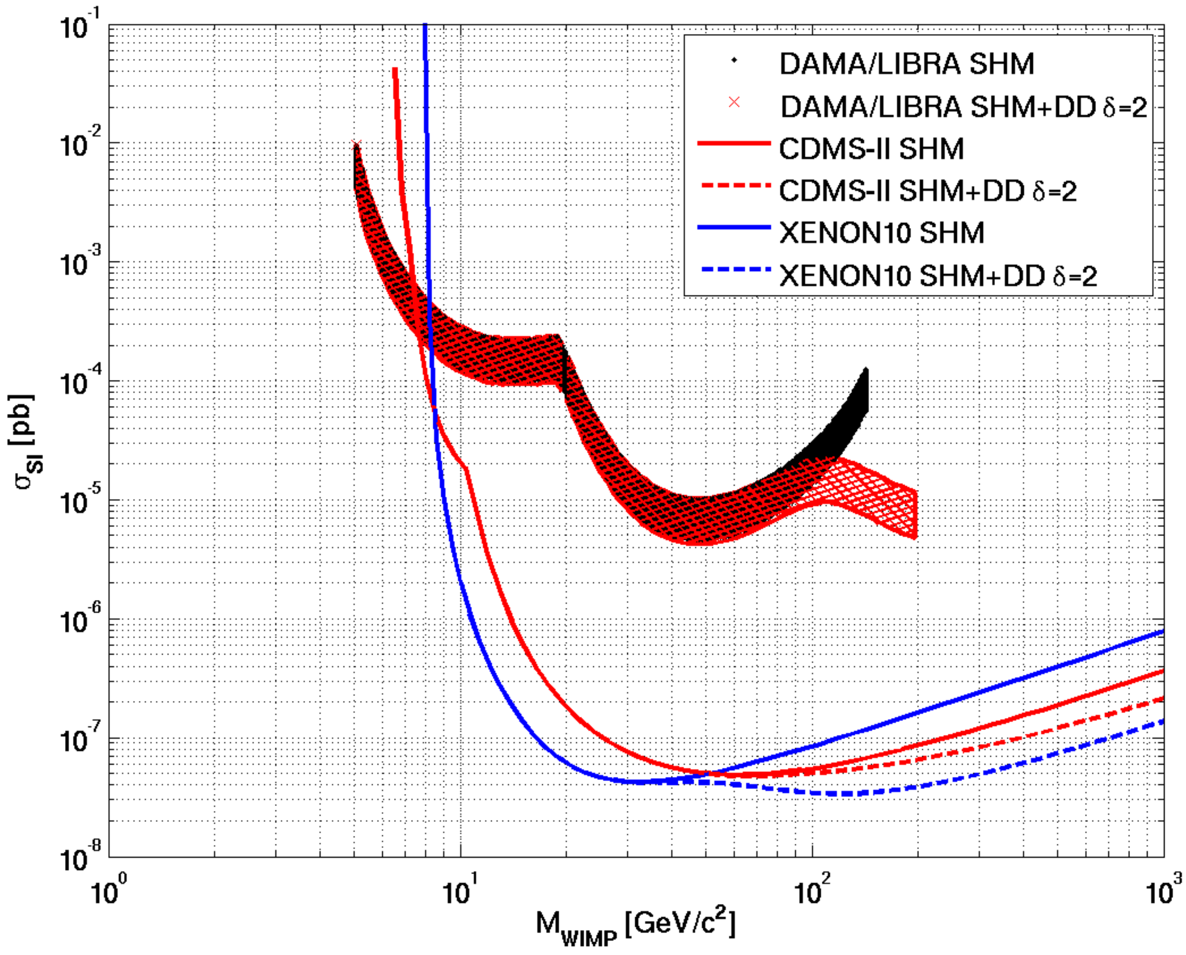
- Lower velocity enhances the capture rate in the earth and sun
- Higher flux of annihilation products
- Even for low $\delta = 0.5$ the flux from the sun is increased by a factor ~5
- Limits from current experiments restrict interesting parameter space not accessible yet by direct detection experiments
- Future experiments will cover a big chunk of the parameter space
- Increased flux from the earth needs some additional studies

BACKUP SLIDES

Lower density ratios



DAMA/LIBRA including the dark disk



2-6 keVee:

0.0107 $\pm$ 0.0019 cpd/kg/keVee

6-14 keVee:

0.0009 $\pm$ 0.0011 cpd/kg/keVee

Phase (t0):

144 $\pm$ 11 d

DAMA/LIBRA exposure:

192824 kg/d

Threshold (Recoil Energy)

Na ~ 6 keV I ~ 22 keV

DAMA/LIBRA including the dark disk II