Direct dark matter detection and the spin-dependent sensitivity of XENON100

Stefan Vogl

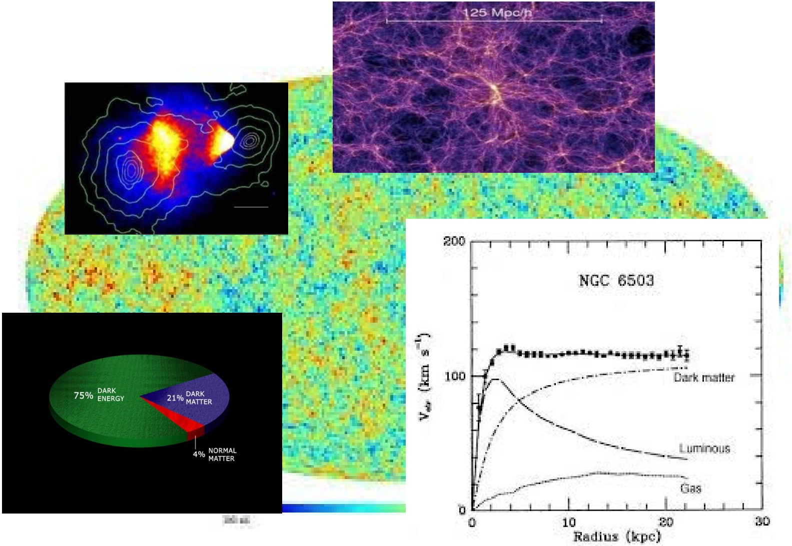
based on arXiv:1211.4573
with Mathias Garny (DESY), Alejandro Ibarra (TUM) and Miguel Pato (TUM)

Technische Universität München

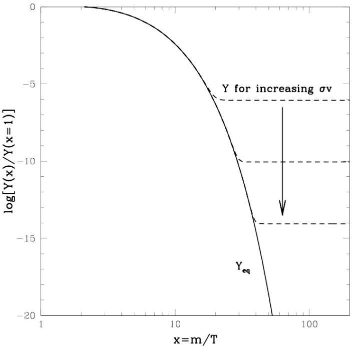
Outline

- Introduction
- Direct detection at a glance
- Limits from Xenon100
- Theoretical Models
- Prospects
- Conclusion

Evidence for dark matter



Thermal WIMP

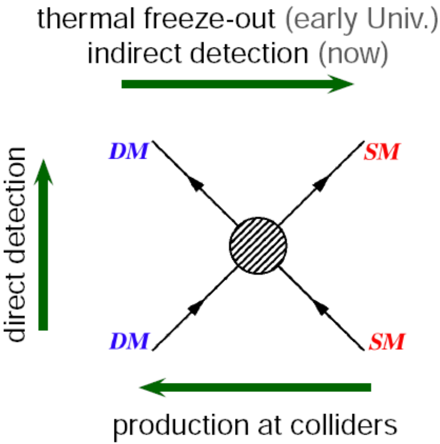


- dark matter relic density $\Omega_\chi h^2 \approx 0.1$
- WIMP miracle:

$$\Omega_\chi h^2 = \frac{3 \times 10^{-27} cm^3 s^{-1}}{\langle \sigma v \rangle}$$

- $\mathcal{O}$(100 GeV) particles and weak interaction → right relic abundance

How do we search for dark matter?

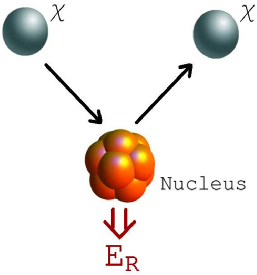


Direct detection

- dark matter passes detector
- scatters of off the nucleus

  $\rightarrow$ observe recoil

- number of events, recoil rate ...



From recoils to fundamental physics

$$\begin{pmatrix}\text{number of}\\\text{recoils}\end{pmatrix} = \begin{pmatrix}\text{detector}\\\text{physics}\end{pmatrix} \times \begin{pmatrix}\text{astro}\\\text{physics}\end{pmatrix} \times \begin{pmatrix}\text{particle}\\\text{physics}\end{pmatrix}$$

$$\begin{pmatrix}\text{astro}\\\text{physics}\end{pmatrix} \sim \text{Flux}$$

$$\begin{pmatrix}\text{particle}\\\text{physics}\end{pmatrix} \sim \text{cross section}$$

Astrophysics factor

$$(\text{astrophysics}) = \rho \int_{v>v_{min}} \frac{f(\vec{v})}{v} \mathrm{d}^3 v$$

- ρ : local density
- $\frac{f(\vec{v})}{v}$: velocity distribution $\rightsquigarrow$ often Maxwell-Boltzmann

Particle physics factor

$$(\text{particle physics}) = \frac{\sigma_{SI}(E) + \sigma_{SD}(E)}{2m\mu^2}$$

- $\sigma_{SI}(E)$ and $\sigma_{SD}(E)$: spin-independent and spin-dependent cross section
- μ : reduced mass

Spin independent scattering

$$\sigma_{SI}(E) = \frac{4\mu^2}{\pi} |Zf_p + (A - Z)f_n|^2 |F(E)|^2$$

- $E_{recoil} \approx E_{kin} \approx mv^2 \approx 10$ keV
- use effective theory
- $f_{p,n}$: effective coupling to proton/neutron
- $F(E)$: nuclear density, measure for decoherence
- coupling gets enhanced by A^2

Spin dependent scattering

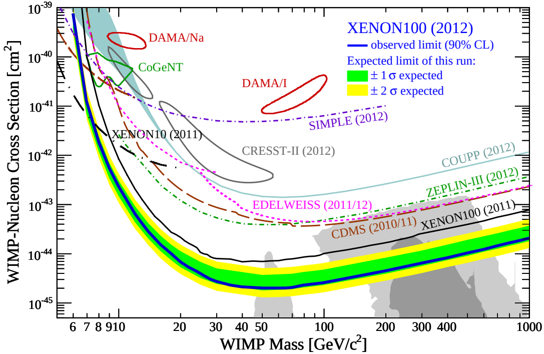
$$\sigma_{SD} = \frac{32\mu^2 G_F^2}{2J+1}[a_p^2 S_{pp} + a_p a_n S_{pn} + a_n^2 S_{nn}]$$

- $a_{p,n}$: coupling to proton/neutron
- S_{pn} : nuclear spin structure functions
- no enhancement with nucleus mass $\rightarrow$ weaker limits

Spin independent dark matter nucleus cross section

$$\frac{d\sigma_{\chi N}}{dE_R} = \frac{m_N}{2\mu_N^2 v^2}\left(\sigma_0^{SI} F_{SI}^2(E_R) + \sigma_0^{SD} F_{SD}^2(E_R)\right)$$

$$\Downarrow$$



Best limits from XENON100 (arxiv:1207.5988)

Spin dependent dark matter nucleus cross section

$$\frac{d\sigma_{\chi N}}{dE_R} = \frac{m_N}{2\mu_N^2 v^2}(\sigma_0^{SI} F_{SI}^2(E_R) + \sigma_0^{SD} F_{SD}^2(E_R))$$

$$\Downarrow$$

?

Spin dependent dark matter nucleus cross section

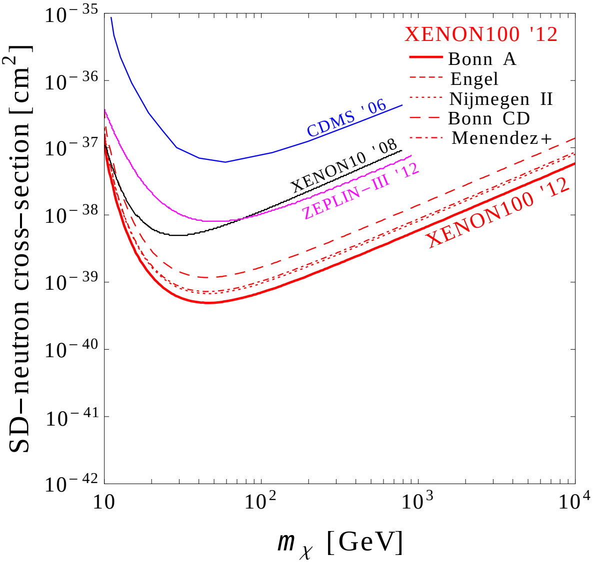
$$\frac{d\sigma_{\chi N}}{dE_R} = \frac{m_N}{2\mu_N^2 v^2}(\sigma_0^{SI} F_{SI}^2(E_R) + \sigma_0^{SD} F_{SD}^2(E_R))$$

$$\Downarrow$$

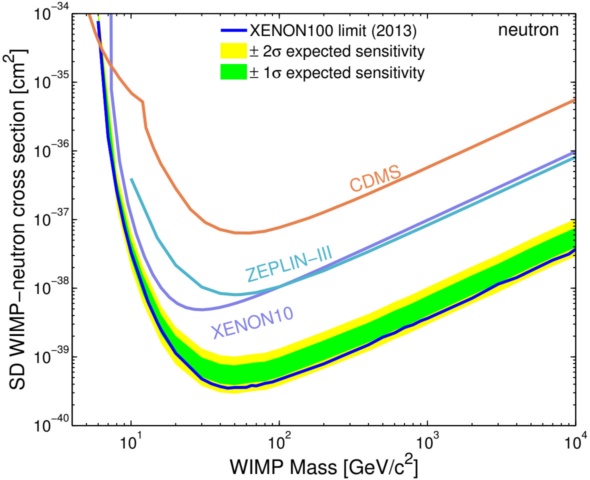
^{129}Xe ^{131}Xe ✓

well known, see J. Angle et al. (XENON10 Collaboration), Phys. Rev. Lett. 101, 091301 (2008). and others

Our Analysis of XENON100

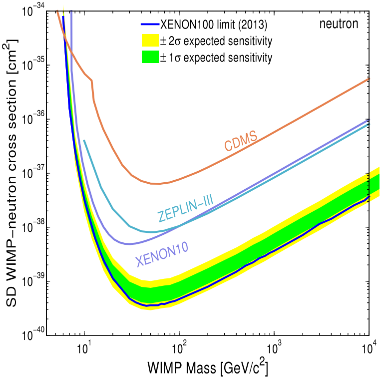


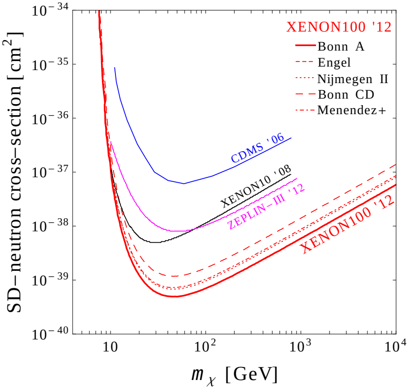
XENON100 Collaboration



arxiv:1301.6620

Comparison





better by factor $\lesssim 2$

When are SD interactions relevant?

A tale of two models

Mass Degenerate Model

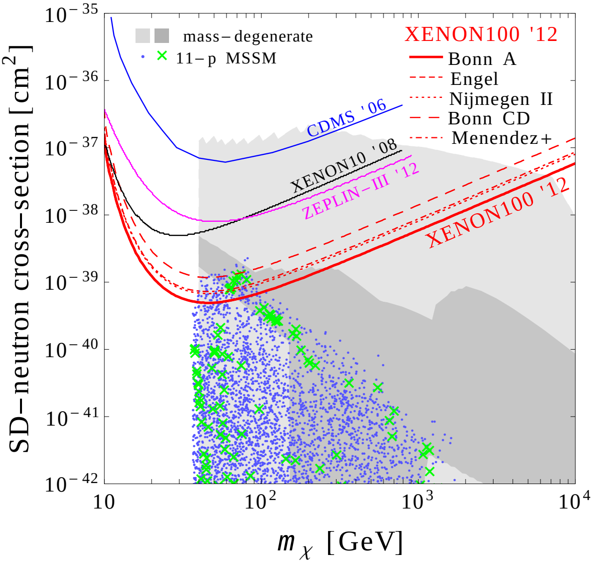
- Majorana dark matter χ
- scalar η
- $\mathcal{L} = -f\bar{\chi}u_R\eta$
- small mass difference

MSSM

- scan 11 parameter pMSSM
- correct Higgs mass
- heavy squarks to avoid LHC

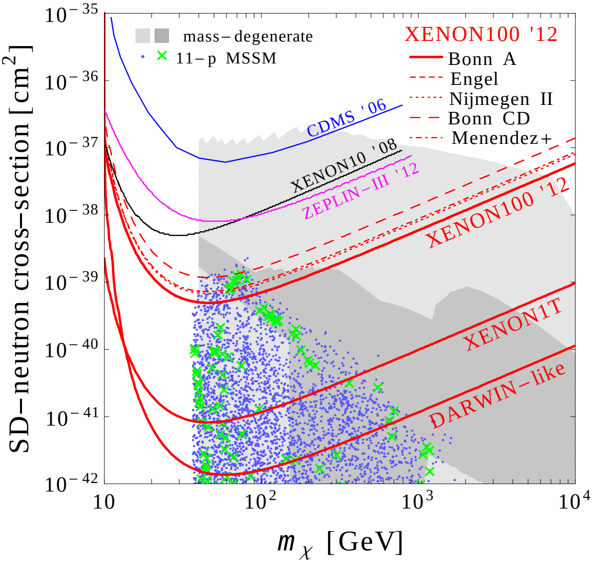
- SI cross section not excluded by Xenon100

Theoretical Models



What is coming next?

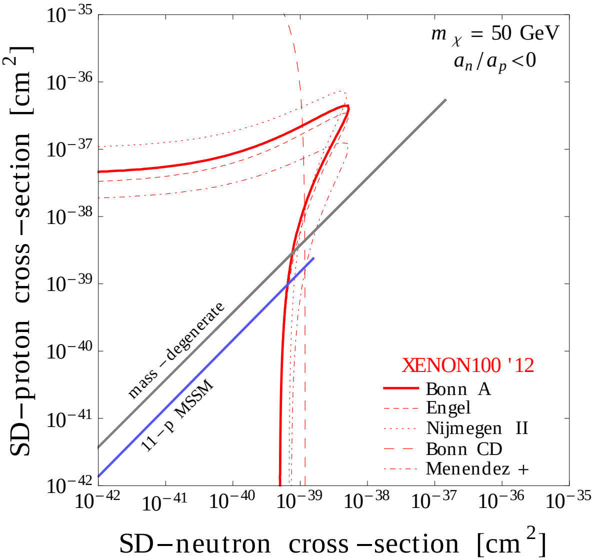
Prospects


SD−neutron cross−section [cm²]
10⁻³⁵
10⁻³⁶
10⁻³⁷
10⁻³⁸
10⁻³⁹
10⁻⁴⁰
10⁻⁴¹
10⁻⁴²
10
10²
10³
10⁴
mχ [GeV]
mass−degenerate
11−p MSSM
XENON100 '12
Bonn A
Engel
Nijmegen II
Bonn CD
Menendez+
CDMS '06
XENON10 '08
ZEPLIN−III '12
XENON100 '12
XENON1T
DARWIN−like

Nuclear uncertainties and SD proton

- results depend on nuclear structure
- need to know nuclear matrix elements for quarks currents
  $\Rightarrow$ structure functions S_{ij}
- determined from nuclear models
- small uncertainties for neutrons large uncertainties for protons

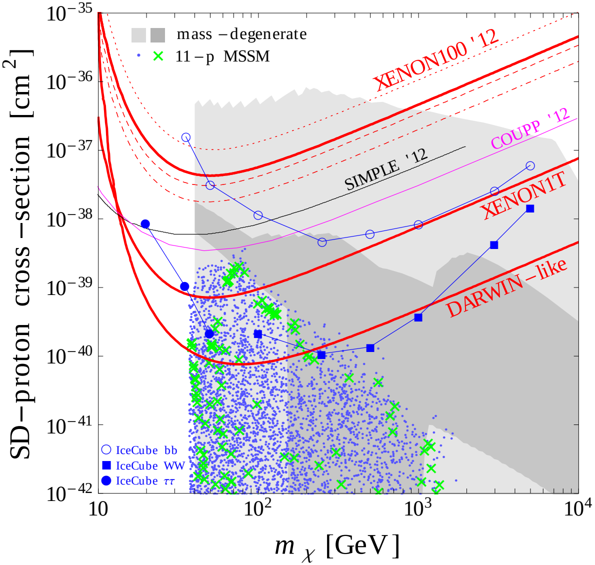
Limit on combination of SD neutron and proton



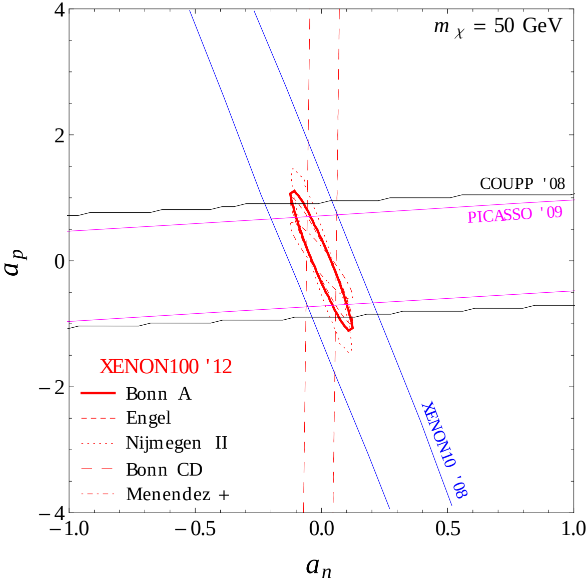
Conclusions

- basic idea of dark matter direct detection
- sometimes you can learn more from experiments than you thought
- SD can be more relevant than SI
- examples in the MSSM
- upcoming experiments probe large regions of parameter space

Backup Limit on SD proton



Backup



m_χ = 50 GeV
COUPP '08
PICASSO '09
XENON100 '12
Bonn A
Engel
Nijmegen II
Bonn CD
Menendez +
XENON10 '08
a_p
a_n
4
2
0
−2
−4
−1.0
−0.5
0.0
0.5
1.0