Determining the WIMP mass using the complementarity between direct and indirect detection experiments

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43rd Rencontres de Moriond - Electroweak session

Work in progress, in collaboration with Y. MAMBRINI & C. MUÑOZ

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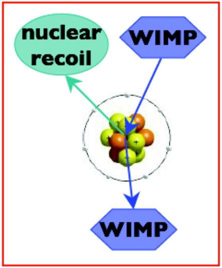
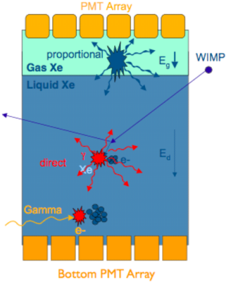
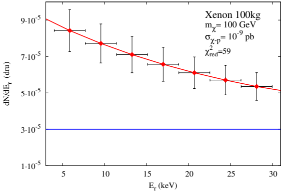
Direct detection

Direct detection experiments are designed to detect **dark matter particles** by their **elastic collision with target nuclei**, placed in a detector on the Earth.





Xenon100 typical signal after 3years



Recoil rates

$$\frac{dN}{dE_r} = \frac{\sigma_{\chi-p} \cdot \rho_0}{2\, M_r^2\, m_\chi} F(E_r)^2 \int_{v_{\min}(E_r)}^{v_{esc}} \frac{f(v)}{v}\, dv$$

Reduced mass $M_r = \dfrac{m_\chi\, m_N}{m_\chi + m_N}$

N: number of scatterings $(s^{-1}kg^{-1})$
E_r: nuclear recoil energy $\sim$few keV
m_χ: WIMP mass
$\sigma_{\chi-p}$: WIMP-proton cross-section
(Assuming spin-independent coupling)
ρ_0: local WIMP density 0.3 GeV cm^{-3}
$f(v)$: WIMP local vel. distribution M.B.
F: nuclear form factor Woods-Saxon

7 energy bins $[4.5, 26.9]$ keV

cf. talk by R. Santorelli

Direct detection

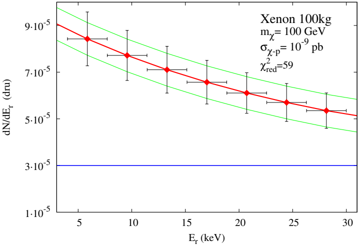
Direct detection experiments can determine the mass of the WIMP by measuring the distribution of the recoil energy.

✓ $m_\chi \ll m_N$: $\frac{dN}{dE_r} \propto e^{\frac{-E_r}{m_\chi^2}}$

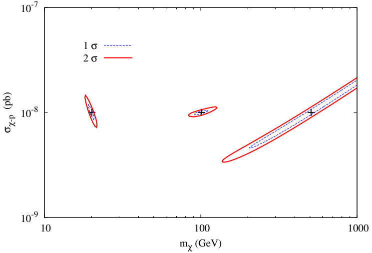
✗ $m_\chi \gg m_N$: $\frac{dN}{dE_r} \propto e^{-E_r}$

$$\chi^2 = \sum_{i=1}^{n} \left(\frac{N_i^{\rm tot} - N_i^{\rm bkg}}{\sigma_i} \right)^2$$

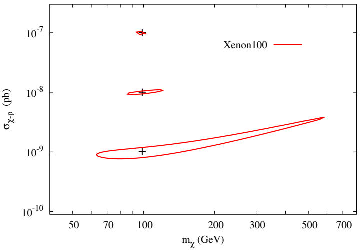
σ: Gaussian error



→ **Xenon** M=100kg T=3 years



Distribution of the maximum likelihood wimp mass and cross section.



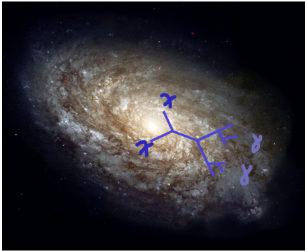
✗ $m_\chi \lesssim$ 10 GeV → detector energy threshold

✗ $m_\chi \gtrsim$ 500 GeV → only a lower limit

★ Independent of the microscopic theory.

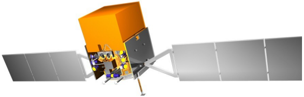
Indirect detection

We study the ability of **gamma-ray** experiments to identify **DM annihilation** radiation from the Galactic Center region by using spectral information.



The spectrum depends on the nature of χ

$\chi\bar{\chi} \to b\bar{b}, \underline{WW}, ZZ, \tau\bar{\tau}, HZ \cdots \to \gamma + \dots$



Glast Gamma-ray telescope (May '08)

Gamma-rays flux

$$\Phi_\gamma(E_\gamma, \psi) = \sum_i \frac{dN_\gamma^i}{dE_\gamma} \langle \sigma_i v \rangle \frac{1}{8\pi {m_\chi}^2} \int_{los} \rho(r)^2 dl$$

$\frac{dN}{dE}$: spectrum of secondary particles
E_γ: gamma energy
$\langle \sigma v \rangle$: averaged annihilation cross-section by velocity
$\langle \sigma v \rangle \sim 3 \cdot 10^{-26}\ \mathrm{cm}^3\mathrm{s}^{-1}$
$\rho(r)$: dark matter halo profile

$$\rho(r) = \frac{\rho_0}{(r/R)^\gamma [1 + (r/R)^\alpha]^{(\beta-\gamma)/\alpha}}$$

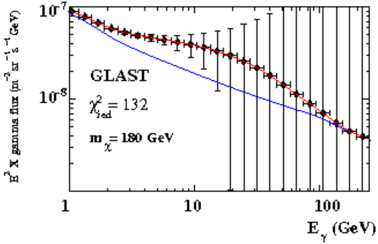
$$\rho(r) \propto r^{-\gamma} \quad \text{at the galactic center} \quad r \ll R$$

	R (kpc)	α	β	γ
NFW	20.0	1.0	3.0	1.0
Moore	28.0	1.5	3.0	1.5
Iso	3.5	2.0	2.0	0

Indirect detection

Once gamma rays are identified as having been produced in DM annihilations, such observations could then be used to measure the characteristics of the DM particle, including its m_χ and $\langle\sigma v\rangle$. Such determinations are an important step toward identifying the particle nature of DM.

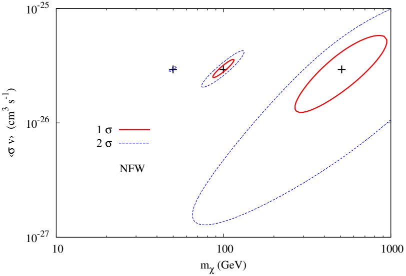
→ **GLAST** typical signal after 3 years



Conservative background:
interpolation between HESS and EGRET

$$\chi^2 = \sum_{i=1}^{n} \left(\frac{\Phi_i^{tot} - \Phi_i^{bkg}}{\sigma_i} \right)^2 ; \quad \sigma_i = \sqrt{\frac{\Phi^{tot}}{A\,T}}$$

Distribution of the maximum likelihood wimp mass and annihilation cross section.



25 energy bins distributed log [1, 300] GeV
$2^\circ \times 2^\circ$ field view → $\Delta\Omega = 4 \cdot 10^{-3}$ sr
Acceptance $A = 10^4$ cm^{2}sr

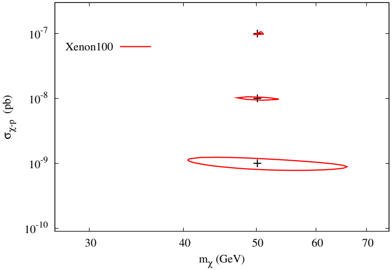
★ Independent of the microscopic theory
✗ Strong dependence in the halo profile
✗ coannihilation not taken into account

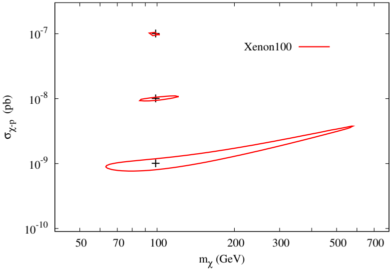
Complementarity

Direct detection

Ability to reconstruct the WIMP mass $\Delta m_\chi / m_\chi$:

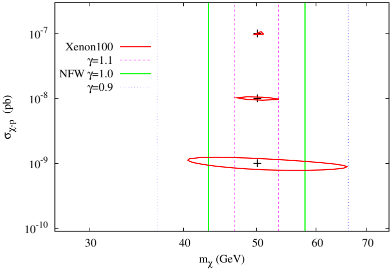
m_χ	$\sigma_{\chi-p}$ (pb)	
50	10^{-7}	2%
	10^{-8}	15%
	10^{-9}	50%
100	10^{-7}	5%
	10^{-8}	40%

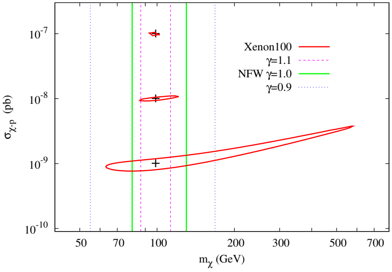




Complementarity

Indirect & **Direct** detection





Ability to reconstruct the WIMP mass $\Delta m_\chi / m_\chi$:

m_χ	$\sigma_{\chi-p}$ (pb)		γ 1.1	γ 1	γ 0.9
50	10^{-7}	2%	15%	30%	60%
	10^{-8}	15%			
	10^{-9}	50%			
100	10^{-7}	5%	30%	60%	120%
	10^{-8}	40%			

→ We have examined the accuracy which it will be possible to determine the WIMP mass from direct and indirect detection experiments.

→ Complementarity allows to improve the WIMP mass resolution, especially for big m_χ or small $\sigma_{\chi-p}$

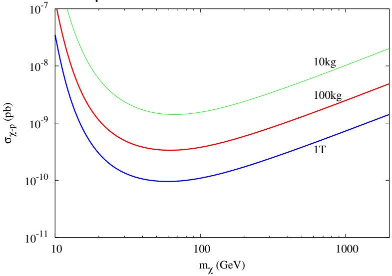
→ Model independent analysis

→ Dark matter should be detected by both direct & indirect experiments

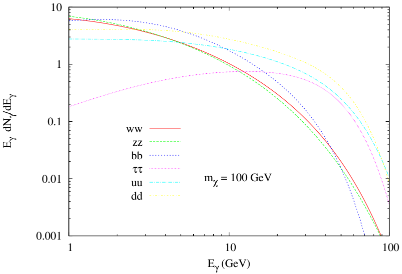
→ Complementarity with model independent DM searches in colliders (ILC).

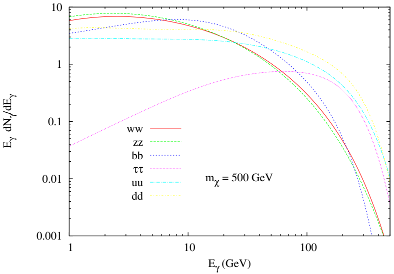
Bonus track

Xenon M=100kg T=3 years
spin ind. exclusion limits:



Bonus track


ww
zz
bb
ττ
uu
dd
mχ = 100 GeV
Eγ dNγ/dEγ
Eγ (GeV)


ww
zz
bb
ττ
uu
dd
mχ = 500 GeV
Eγ dNγ/dEγ
Eγ (GeV)