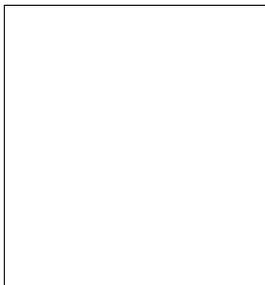# WIMP MASS FROM DIRECT, INDIRECT DARK MATTER DETECTION EXPERIMENTS AND COLLIDERS: A COMPLEMENTARY AND MODEL-INDEPENDENT APPROACH.

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We study the possibility of identifying dark matter properties from direct (XENON100) and indirect (GLAST) detection experiments. In the same way, we examine the perspectives given by the next generation of colliders (ILC). All this analysis is done following a model-independent approach. We have shown that the three detection techniques can act in a highly complementary way. whereas direct detection experiments will probe efficiently light WIMPs, given a positive detection (at the 10% level for $m_\chi \sim 50$ GeV), GLAST will be able to confirm and even increase the precision in the case of a NFW profile, for a WIMP-nucleon cross-section $\sigma_{\chi-p} < 10^{-8}$ pb. However, for heavier WIMP (~ 175 GeV), the ILC will lead the reconstruction of the mass.

1 Direct detection

Dark Matter (DM) direct detection experiments measure the elastic collisions between WIMPs and target nuclei in a detector, as a function of the recoil energy E_r. The detection rate depends on the density $\rho_0 \simeq 0.3$ GeV cm^{-3} and velocity distribution $f(v_\chi)$ of WIMPs near the Earth (a Maxwellian halo will be considered). The differential rate per unit detector mass and per unit of time can be written as:

$$\frac{dN}{dE_r} = \frac{\sigma_{\chi-N}\,\rho_0}{2\,m_r^2\,m_\chi}\,F(E_r)^2 \int_{v_{min}(E_r)}^{\infty} \frac{f(v_\chi)}{v_\chi}\,dv_\chi\,, \tag{1}$$

where $\sigma_{\chi-N}$ is the WIMP-nucleus scattering cross section, m_χ the WIMP mass and m_r is the WIMP-nucleon reduced mass. $F(E_r)$ is the nucleus form factor; we assume it has the Woods-Saxon form.

The XENON [1] experiment aims at the direct detection of DM via its elastic scattering off xenon nuclei. In this study we will consider the case of a 100 kg Xenon-like experiment and 3

years taking data. We consider 7 energy bins between 4 and 30 keV. For this experiment we took a zero background scenario; of course a more detailed analysis could take into account non-zero background simulating the detector and in particular the neutron spectrum. So, in that sense our results will be optimistic.

One option to discriminate between a DM signal and the background is to use the χ^2 method. Let us call N^{sign} the signal, N^{bkg} the background and $N^{tot} \equiv N^{sign} + N^{bkg}$ the total signal measured by the detector. For an energy range divided into n bins the χ^2 is defined as:

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

We assume a Gaussian error $\sigma_i \equiv \sqrt{\frac{N_i^{tot}}{M \cdot T}}$ on the measurement, where M is the detector mass and T the exposure time.

2   Indirect detection

The spectrum of gamma–rays generated in dark matter annihilations and coming from the galactic center can be written as

$$\Phi_\gamma(E_\gamma) = \sum_i \frac{dN_\gamma^i}{dE_\gamma} \, Br_i \, \langle \sigma v \rangle \, \frac{1}{8\pi \, m_\chi^2} \int_{line \ of \ sight} \rho^2 \ dl \ , \tag{3}$$

where the discrete sum is over all dark matter annihilation channels, dN_γ^i/dE_γ is the differential gamma–ray yield, $\langle \sigma v \rangle$ is the annihilation cross-section averaged over the WIMPs' relative velocity distribution and Br_i is the branching ratio of annihilation into the i-th final state. It is possible to concentrate ourselves on a process which gives 100% annihilation into WW pairs, as this choice will not influence significantly the result of the study [2]. The dark matter density ρ is usually parametrized as

$$\rho(r) = \frac{\rho_0}{(r/R)^\gamma \, [1 + (r/R)^\alpha]^{(\beta-\gamma)/\alpha}}. \tag{4}$$

We assume a NFW profile with $\alpha = \gamma = 1$, $\beta = 3$ and $R = 20$ kpc, producing a profile with a behavior $\rho(r) \propto r^{-\gamma}$ in the inner region of the galaxy.

The gamma-ray telescope GLAST [3] will perform an all-sky survey covering an energy range $1 - 300$ GeV. We will consider a GLAST-like experience with an effective area and angular resolution on the order of 10^4 cm^2 and $0.1° \times 0.1°$ ($\Delta\Omega \simeq 10^{-5}$ sr) respectively, who will be able to point and analyze the inner centre of our galaxy. We consider also 3 years of effective data acquisition experiment.
For this experiment, the background can be modeled by interpolating [2] the gamma-ray spectrum measured by HESS [4] (for $E_\gamma > 160$ GeV) and EGRET [5] (for $E_\gamma < 10$ GeV) missions.

3   Colliders

Recently an approach was proposed by A. Birkedal et al.[6] which allows to perform a model-independent study of WIMP properties at lepton colliders. Since the known abundance of DM gives specific values for the DM annihilation cross section, one might hope this cross section can be translated into a rate for a measurable process at a collider.
The starting point is to relate total annihilation cross section to the cross section into e^+e^- pairs

$$\kappa_e \equiv \sigma(\chi\chi \to e^+e^-)/\sigma(\chi\chi \to all). \tag{5}$$
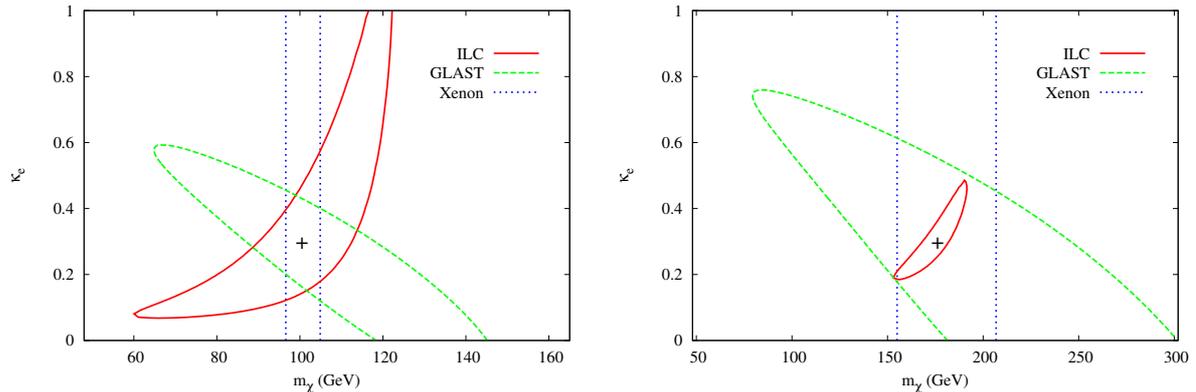
Figure 1: Comparison between a 100 kg XENON-like experiments (dotted line) with $\sigma_{\chi-p} = 10^{-7}$ pb, GLAST (dashed line) in the case of an NFW halo profile with $\langle\sigma v\rangle = 3 \cdot 10^{-26}$ cm^{3}s^{-1}, and unpolarized ILC sensitivity (solid line) at 2σ of confidence level, for different WIMP masses $m_\chi = 100$ and 175 GeV, and $\kappa_e = 0.3$.

Then we can use the *detailed balancing* equation to relate $\sigma(\chi\chi \to e^+e^-)$ to $\sigma(e^+e^- \to \chi\chi)$, for non-relativistic WIMPs. But this kind of process containing only WIMPs in the final state is not visible in a collider since they manifest themselves just as missing energy. However this process can be correlated to the radiative WIMP pair-production $\sigma(e^+e^- \to \gamma\,\chi\chi)$ using the *collinear factorization*. This approach is valid for photons which are either soft or collinear with respect to the colliding beams. The accuracy of the approximation outside the previous region has been discussed [6] with the conclusion that the approach works quite well.

So, starting from the total annihilation cross section σ_{an} we can compute $\sigma(e^+e^- \to \gamma\,\chi\chi)$

$$\frac{d\sigma(e^+e^- \to \chi\chi\gamma)}{dx\,dcos\theta} \approx \frac{\alpha\,\kappa_e\,\sigma_{an}}{16\,\pi}\,\frac{1+(1-x)^2}{x}\,\frac{1}{\sin^2\theta}\,2^{2\,J_0}\,(2S_\chi+1)^2\left(1-\frac{4\,m_\chi^2}{(1-x)\,s}\right)^{1/2+J_0}. \quad (6)$$

Here $x \equiv 2\,E_\gamma/\sqrt{s}$, θ is the angle between the photon and the incoming beam, S_χ and J_0 are the spin of the WIMP and the dominant value of the angular momentum in the velocity expansion for $\langle\sigma v\rangle$.

We place ourselves in the framework of the ILC project with a center-of-mass energy of $\sqrt{s} = 500$ GeV and an integrated luminosity of 500 fb^{-1}. For this process with only a single photon detected, the main background in the standard model is radiative neutrino production [2].

4 Complementarity

Recently, several works have studied the determination of the WIMP mass for the case of direct [7] and indirect [8] detection experiments. Furthermore, Drees and Shan [9] showed that one can increase such a precision with a combined analysis of two experiments of direct detection.

In figure 1 we compare the precision levels for direct and indirect detection experiments, along with the corresponding results of the method we followed for the ILC for $\kappa_e = 0.3$ and two cases of WIMP masses $m_\chi = 100$ (left panel) and 175 GeV (right panel). All the results are plotted for a 2σ confidence level. The green-dashed lines correspond to the results for a GLAST-like experiment assuming a NFW halo profile. The total annihilation cross-section has been taken to be $\langle\sigma v\rangle = 3 \cdot 10^{-26}$ cm^{3}s^{-1}. The red-plain line represents the result for an ILC-like collider with non-polarized beams. The blue-dotted line corresponds to a 100 kg XENON-like experiment, assuming a WIMP-nucleus scattering cross-section of 10^{-7} pb. All the parameter space points that lie within the marked regions can not be discriminated by the corresponding experiments. It is pertinent to study the complementarity between the three experiences listed above firstly

Table 1: Precision on a WIMP mass expected from the different experiments at 2σ after 3 years of exposure, for $\sigma_{\chi-p} = 10^{-7}$ pb, a NFW profile and a 500 GeV unpolarized linear collider with a luminosity of 500 fb^{-1}. All values are given in GeV.

m_χ	XENON	GLAST	ILC
50	± 1	± 8	$**$
100	± 6	$-25/+32$	$-40/+20$
175	$-25/+35$	$-70/+100$	$-20/+15$
500	$-250/**$	$-350/**$	$**$

because the mass reconstruction yields comparable results, hence a combination of these data can substantially improve the final result. Secondly, because we can probe different regions in the parameter space.

For the case of a 100 GeV WIMP, a GLAST- or an ILC-like experiment alone can provide a limited precision for the WIMP mass ($\sim 60\%$). Combined measurements can dramatically increase the precision , reaching an accuracy of $\sim 25\%$. If we additionally include direct detection measurement, we can reach a precision of the order of $\sim 9\%$.

In table 1 we show the precision expected for several dark DM masses. A light WIMP mass (~ 50 GeV) can be reconstructed by both direct and indirect DM experiments with a high level of precision; however for the ILC the model independent procedure fails because of the relativistic nature of the WIMP. On the contrary, the ILC will be particularly efficient to measure a WIMP with a mass of about 175 GeV. Concerning a 500 GeV WIMP, only a loose lower bound could be extracted form direct and indirect experiments. In this case the ILC will not be kinematically able to produce so heavy WIMPs.

Acknowledgments

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