Simple method for measuring of properties of Dark Matter particles at ILC for different models of DM

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Dark matter. Candidates

About 20% of the Universe is made from Dark Matter (DM).
Different candidates for particles of DM:
Fermion. Lightest superparticle — LSP.
Scalar. Higgs-like field — Inert Dark Model, IDM .....
They are usually members of families of particles (called here as D-particles), having some additional quantum number, which conservation guarantees stability of lightest member of this family. For SUSY this quantum number is R-parity, for IDM that is specific D-parity

Most probable:

Dark matter particle is neutral D^0,

Mass $< 60-70$ GeV,(to prevent annihilation $D^0D^0 \to W^+W^-$ even slightly below threshold)

The charged particles having the same quantum number $D^\pm$ are heavier than 100 GeV (LEP),

In the scalar case the counterpart with opposite P-parity D^A also exists, they are lighter than about 120 GeV(LEP).

Perhaps, more strong limitations can be obtained for separate models.

Main (or single) decay channels:

$$D^\pm \to D^0W^\pm, \qquad D^A \to D^0Z$$

where W and Z are represented their decay products either on mass shell or with lower effective mass.

Production. Decay. Signature

In the estimates we assume $M_{D^\pm} \ll \sqrt{s}/2 = E_e$.

Main production channel $e^+e^{\to}D^+D^-$

Cross section is about $\sigma(e^+e^- \to \mu\mu)/4 \quad for\ \ scalars$
$\sigma(e^+e^- \to \mu\mu) \quad for\ \ fermions.$

Than — decay $D^+ \to W^+D$ with branching close to 1.

$$M_{D^\pm} > M_{D^0} + M_W$$

Signature: Two dijets with effective mass close to M_W (observed cross section $(2/3)^2\sigma(e^+e^- \to D^+D^-) = 0.44\sigma(e^+e^- \to D^+D^-)$ —or 1 dijet $+e$ or μ (observed cross section $2 \times (2/3) \times 2[(1/9)(1 + 0.17]\sigma(e^+e^- \to D^+D^-) \approx 0.35\sigma(e^+e^- \to D^+D^-)$.

Large missing energy and $p_\perp$

Processes of SM with the same kinematics demand production additional ν or something else. Their cross sections contains additional factor α – two orders lower. $\Rightarrow$ Even rough measurement of cross section gives value of spin of DM

We denote $\Delta(s;s_1,s_2)=\sqrt{s^2+s_1^2+s_2^2-2ss_1-2ss_2-2s_1s_2}$.
In the rest frame of D^+ the energy and momentum of $W^\pm$ from decay $D^+\to DW^+$ are $E_W^r=\dfrac{M_{D^+}^2+M_W^2-M_{d^0}^2}{2M_{D^+}}$, $p_{W^+}^r=\dfrac{\Delta(M_{D^+}^2,M_W^2,M_{D^0}^2)}{2M_{D^+}}$.
In the lab system energy of $D^\pm$ is equal to beam energy E and velocity of $D^\pm$ is $v=\sqrt{1-M_{D^\pm}^2/E^2}$, $\quad\gamma=E/M_{D^\pm}$.
Denoting W escape angle in D^+ rest frame relative to direction of D^+ motion in the lab system by θ and $c=\cos\theta$ we have energy of W^+ in the lab system $E_W^L=\gamma(E_W^r+cvp_W^r)$. W's are distributed within interval $(E(-)=\gamma(E_W^r-vp_W^r),\ E(+)=\gamma(E_W^r+vp_W^r))$.
Boundary values $E(\pm)$ give two equations for determination of masses $D^\pm$ and D^0 with accuracy better 10 GeV (preliminary estimate).
The distribution of these dijets in energy is uniform. $dN(E)\propto dE$ since there is no correlation between escape angle of W in the rest frame of $D^\pm$ and production angle of $D^\pm$.

After determining of $M_{D^{\pm}}$, cross section of $e^+e^- \to D^+D^-$ process is calculated precisely for each D-particle spin value. It allows to determine spin of D particles more definite via measuring of cross sections (factor about 4 difference).

Observation of process $e^+e^- \to D^+D^- \to D^0D^0jj\ell + \nu$'s allow to determine sign of charge of 2-jets $W = q\bar{q}$ in each separate case. It allows to study charge and polarization asymmetries (like at Z-peak) for checking on more detail properties of D-particles.

$$M_{D^\pm} < M_{D^0} + M_W$$

In this case single decay channel is $D^+ \to D^0 W^{+*}$, where W^{+*} means dijet ($q\bar{q}$) or $\ell\nu$ system having effective mass $w < M_w$. ($w < M_{D^+} - M_{D^0}$). All above results are valid for each separate value w with the change in all equations $M_W \to w$.
The energy distributions for each pair of dijets are independent from each other.

$$M_{D^\pm} \gg M_{D^0} + M_W$$

In this case proper width of $D^\pm$ is large so that we can observe non-uniform energy distribution of dijets which will be convolution of uniform distribution for narrow $D^\pm$ with Breit-Wigner mass distribution. One can hope that the measuring of violation of the observed energy distribution from uniform will allow to determine both mass of $D^\pm$ and its width.

Axial D-particle D^A

For scalar D-particles, the pseudoscalar D^A also exists, it has interaction ZD^AD^0.
Therefore the process $e^+e^- \to Z \to D^0D^A \to D^0D^0Z$ has only cross section of the same order as $e^+e^- \to \mu^+\mu^-$ and observable either dilepton (e^+e^- or $\mu^+\mu^-$) or dijet with effective mass equal to M_Z (with accuracy to Z width).
Almost entire above discussion is valid in this case. The observation of these dilepton or dijet with large missed energy and $p_\perp$.

The case of very light D^0 (few GeV) demands additional simulation to determine its sensitivity.