Charged Higgs production and decay for signature of Inert Dark model (old title)

$\Longrightarrow$

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 25% of the Universe is made from Dark Matter (DM).
Different candidates for particles of DM have common property: They conserve specific discrete quantum number, we name it D-parity..
Usually particles with new value of D-parity form some family — D-family, the lightest from them is DM particle.

$\boxed{MSSM}$: DM is lightest superparticle, often – fermion, $D \to R$-parity

$\boxed{Inert\ Dark\ Model,\ \ IDM}$: DM – Higgs-like scalar, $D \equiv D$-parity .....

We consider first models in which lightest D-particles are – neutral D^0 – properly DM particle and charged $D^{\pm}$ with identical spin so that main their interaction with ordinary matter is $D^{\pm}D^0W^{\mp}$.

In the estimates we have in mind $M_{D^{\pm}} \gtrsim 100$ GeV (LEP data)
and $M_{D^0} < M_{D^{\pm}} < E \equiv \sqrt{s}/2$ – electron beam energy of ILC

Production. Decay. Signature

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

Cross section is $\sim \sigma(e^+e^- \to \mu\mu)$ – huge for ILC.

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

Observable final state (**signature**)

Two dijets, representing W^+ and W^-

$(2/3)^2 \approx 0.44$ total cross section;

One dijet + e or μ, representing W^+ and W^-

– $2 \times (2/3) \times 2[1/9(1+0.17)] \approx 0.35$ total cross section

(0.17 is fraction of μ or e from decay of τ)

AND *large missing* $p_\perp$ *and energy*

Cross sections of SM processes with the same observable final state is typically 2 orders of value ($\sim \alpha$) less, since they include radiation of ν's or somewhat else.

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

Additional signature: effective mass of dijet close to M_W.

We denote $\Delta(s; s_1, s_2) = \sqrt{s^2 + s_1^2 + s_2^2 - 2ss_1 - 2ss_2 - 2s_1 s_2}$.

In the rest frame of D^+ the energy and momentum of $W^\pm$ from decay $D^+ \to DW^+$ are

$$E_W^r = \frac{M_{D+}^2 + M_W^2 - M_{d^0}^2}{2M_{D+}}, \quad p^r = \frac{\Delta(M_{D+}^2, M_W^2, M_{D^0}^2)}{2M_{D+}}.$$

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 $E_W^L = \gamma(E_W^r + cvp^r)$. W's are distributed within interval $\boxed{E(-) = \gamma(E_W^r - vp^r),\ E(+) = \gamma(E_W^r + vp^r)}$.

The end point values $E(\pm)$ give two equations for determination of masses $D^\pm$ and D^0.

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 $D^\pm$.

For scalars it is evident, for fermions there is dependence on the $D^\pm$ spin direction. It results in correlations like those in Z-peak

After determining of $M_{D^\pm}$, cross section of $e^+e^- \to D^+D^-$ process is calculated precisely with QED for each D-particle spin value. It allows to determine spin of D particles via measuring of cross sections

(typically $\sigma(e^+e^- \to D^+D^-)/\sigma(e^+e^- \to \mu^+\mu^-)$

is about 1/4 if $D^\pm$ – scalar, it is about 1 if $D^\pm$ – fermion)

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.

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

single decay channel is $D^+ \to D^0 W^*$, where W^* means dijet ($q\bar{q}$) or $\ell\nu$ system having effective mass $M^* < M_W$. ($M^* < M_{D^+} - M_{D^0}$). All above results are valid for each separate value M^* with the change in all equations $M_W \to M^*$.

The energy and M^* distributions for each pair of dijets are independent from each other.

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

proper width of $D^\pm$ is large enough (for scalars

$$\frac{\Gamma(D^+ \to D^0 W^+)}{M_{D^+}} = \frac{\alpha}{2\sin^2\theta_W} \frac{(p^r)^3}{M_W^2 M_{D^\pm}}.$$

(This ratio > 0.1 at $M_{D^\pm} \gtrsim 500$ GeV). In this case the energy and M^* distribution of dijets 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 $p_\perp$ gives good signature of DM.

If $M_{D^\pm} > M_{D^A} + M_W$

cascade processes like

$$e^+e^- \to D^+D^- \to D^A W^+ D^0 W^- \to D^0 Z W^+ D^0 W^-$$

become possible. In this case the energy distribution for W-produced di-jets will be sum of distributions of the first case types and additional signature in the form of dilepton pair also exist.

SUMMARY

In many models of DM the process $e^+e^- \to D^+D^-$ must be studied.

The signature:

2 di-jets, representing W or 1 di-jet +lepton plus large missing $p_\perp$ and energy with cross section close to main cross section of e^+e^- annihilation

Masses of $D^\pm$ and DM candidate D^0

will be determined via end points of energy distribution of W representing di-jets either at $M^* \approx M_W$ or at $M^* < M_W$.

Spin

will be determined via (even rough) measuring of total cross section

SUMMARY (continuation)

If particle D^A having parity opposite to that of D^0 exists,

the process $e^+e^- \to D^0 D^A \to D^0 D^0 Z$ must be studied.

The signature:

di-jet or dilepton, representing Z plus large missing $p_\perp$ and energy with cross section close to main cross section of e^+e^- annihilation

Masses of D^A and DM candidate D^0

will be determined via end points of energy distribution of Z representing di-jet or dilepton.

Spin

will be determined via (even rough) measuring of total cross section