Bilinear R-Parity Violation Neutrino Physics at the ILC.

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Bilinear R parity violation

In the case of bilinear R parity violation (bRPV) additional Lepton number violating terms are added to the R parity conserving (RPC) superpotential:

$$W^{\mathrm{MSSM}} = W^{\mathrm{MSSM}}_{\mathrm{RPC}} + \epsilon_i L_i H_u$$

These additional terms introduce a mixing in the neutral fermion sector, so that bRPV can account for neutrino mixing. The atmospheric neutrino mixing angle e.g. can be expressed in terms of alignment parameters Λ_i:

$$\tan(\theta_{23}) = \frac{\Lambda_\mu}{\Lambda_\tau} \qquad \Lambda_i = \mu v_i + v_d \epsilon_i$$

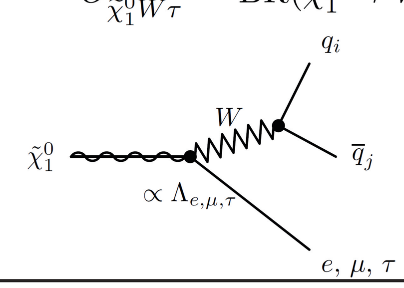
Herein μ is the MSSM Higgs parameter, v_d the MSSM down-type Higgs VEV. ϵ_i and v_i are bRPV parameters.

The analysis of the neutralino-W-lepton coupling shows that this is also proportional to the bRPV alignment parameters:

$$O_{\tilde{\chi}^0_1 W l_i} \simeq \Lambda_i \cdot f(M_1, M_2, \mu, v_d, v_u) \propto \Lambda_i$$

This can be used to study neutrino mixing angle, by analysing neutralino decay modes involving a W boson.

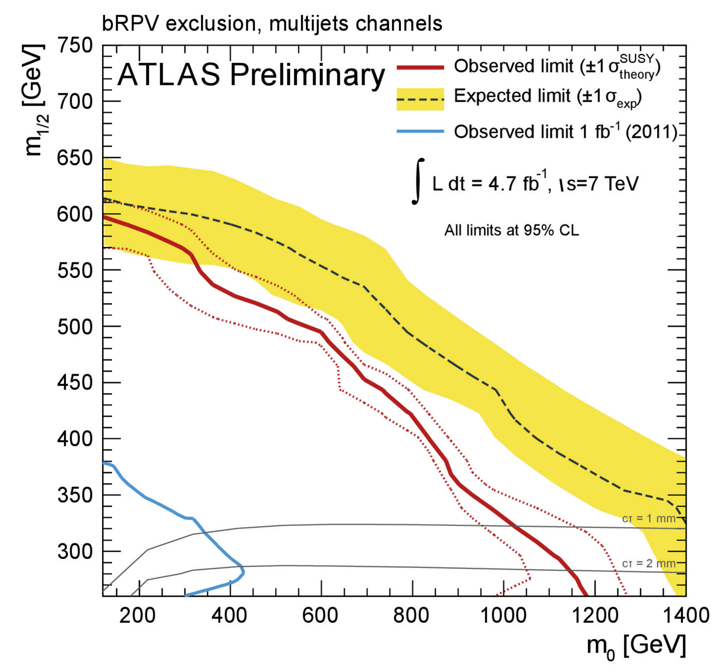
$$\tan^2(\theta_{23}) \simeq \frac{O^2_{\tilde{\chi}^0_1 W\mu}}{O^2_{\tilde{\chi}^0_1 W\tau}} = \frac{\mathrm{BR}(\tilde{\chi}^0_1 \to W\mu)}{\mathrm{BR}(\tilde{\chi}^0_1 \to W\tau)}$$



Status at the LHC

The ATLAS collaboration performed a dedicated bRPV SUSY search in the framework of the CMSSM, where the RPV parameters were fitted to neutrino data. This study excludes a wide range of the CMSSM parameter plane.
However, most of the exclusions of the parameter space result from limits on coloured particles for the specific parameter points. A light electroweak sector is not ruled out.

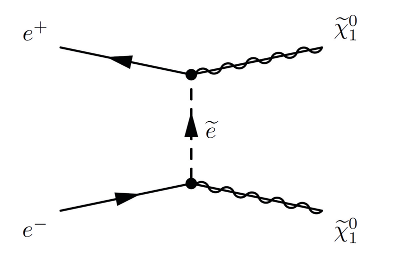
LHC starts to become also sensitive to RPV SUSY in direct electroweakino production channels, but the derived limits are quite dependent on assumptions for the type and the strength of the RPV coupling. It is not directly possible to re-interpret those limits for an bRPV scenario, which accounts for neutrino data.



[ATLAS-CONF-2012-140]

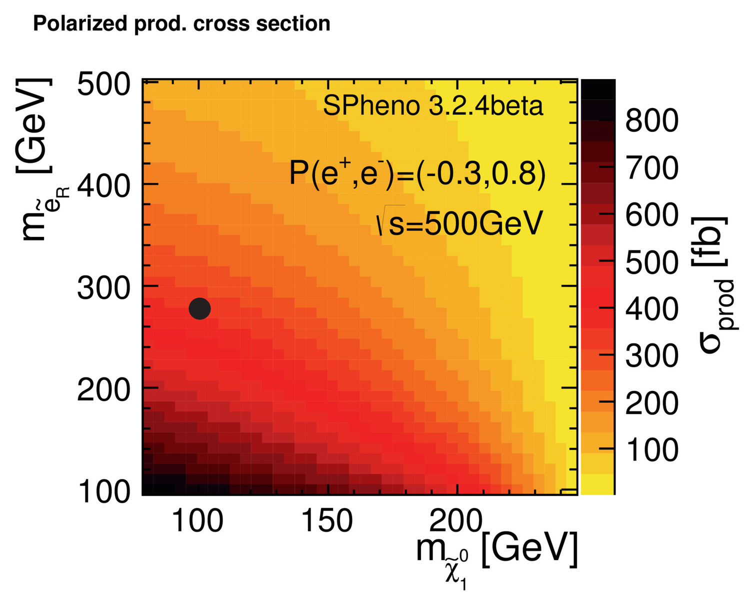
Simplified model

At the ILC, electroweakino production is dominant and the electroweak sector can directly be probed.
In a simplified model it is assumed, that the lightest neutralino is a Bino. This leaves only the t-channel production for direct LSP pair production.



The production cross section is mainly driven by the LSP mass and the selectron mass. All other masses are set to a multi-TeV scale.
For the detector simulation the following parameter point was used:

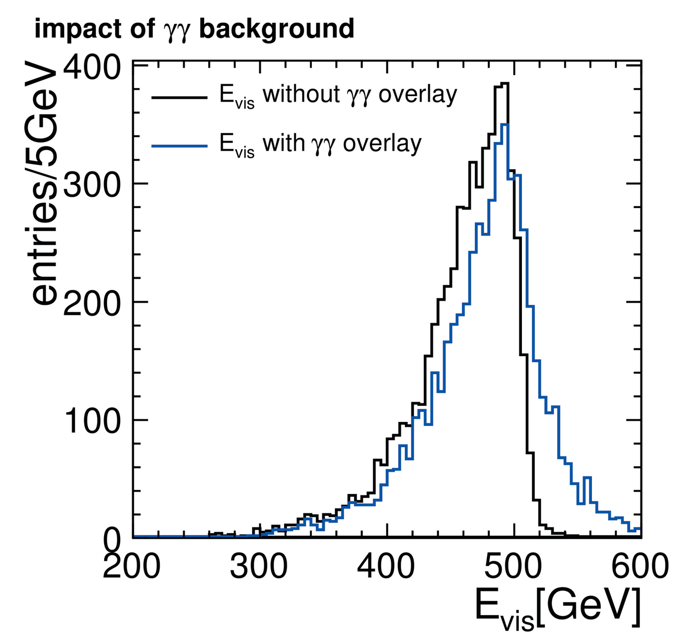
$$m_{\tilde{\chi}^0_1} = 98.48 \text{ GeV}$$
$$m_{\tilde{e}_R} = 280.72 \text{ GeV}$$

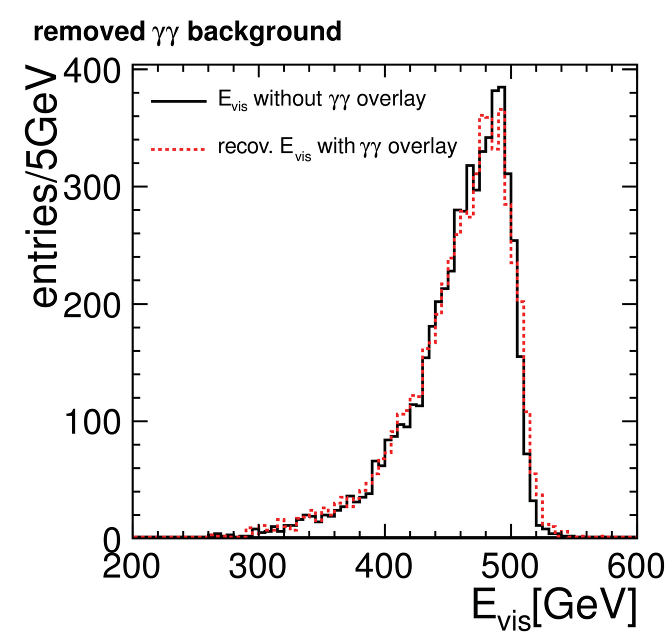


The chosen parameter point is a worst case scenario, since the LSP mass is close to the W/Z boson mass and W and Z pairs are expected to be the dominant SM background.
Polarization of the incomming beams can help to enhance the signal cross section.

γγ background

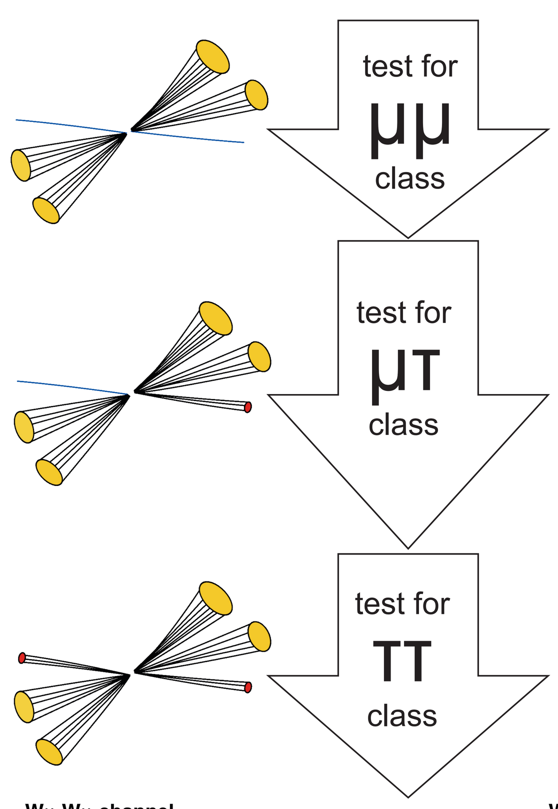
With the instantaneous luminosity forseen at the ILC, on average 1.7 interactions of photons leading to the production of low p_t hadrons are expected per bunch-crossing, which is incorporated in the event simulation and reconstruction.
The background can be successfully removed in the analysis step by applying an exclusiv jet clustering algorithm and removing the beam jets from the event.





Event class selection

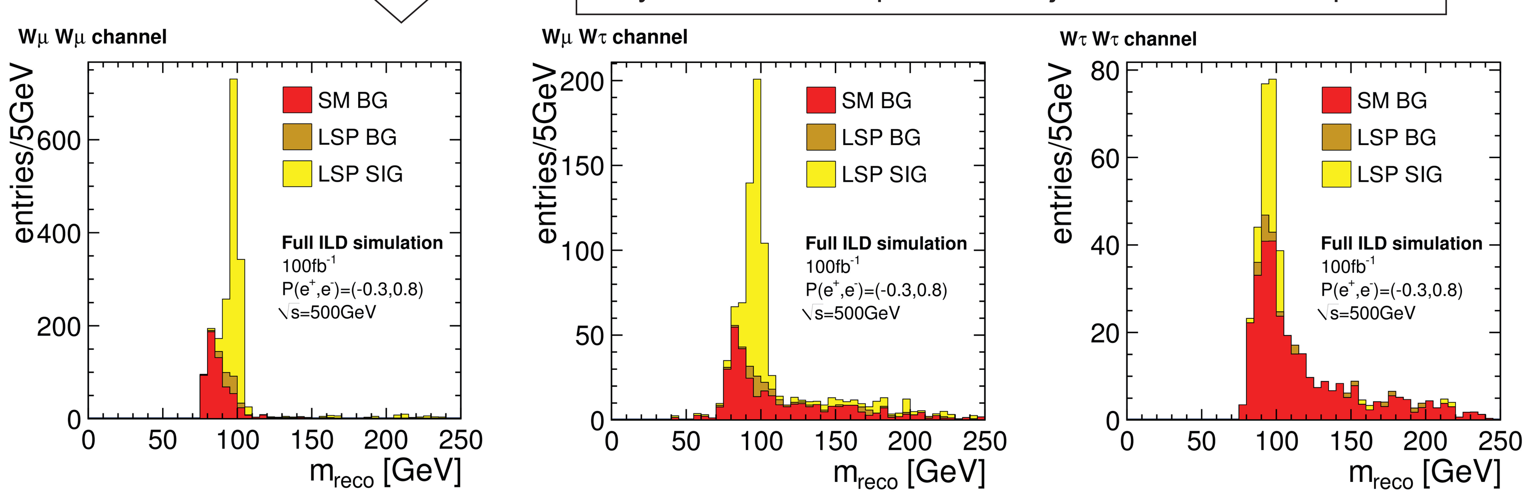
In the signal events the produced LSPs decay into either a μ or τ plus a W boson. Considering only hadronic W decays, the event is fully reconstructable with 6 visible fermions in the final state.



μμ class:
- select 2 leading muons in the event
- force rest of the event into 4 jets
- find 2 good W candidates from jets
- try to combine 2 equal mass objects from Ws and leptons

μτ class:
- select leading muon in the event
- force rest of the event into 5 jets
- test goodness of 5 jets configuration
- select jet with lowes multiplicity as tau
- find 2 good W candidates from remaining 4 jets
- try to combine 2 equal mass objects from Ws and leptons

ττ class:
- force event into 6 jets
- test goodness of 6 jets configuration
- select 2 jets with lowes multiplicity as taus
- find 2 good W candidates from remaining 4 jets
- try to combine 2 equal mass objects from Ws and leptons



Mass measurement

The μμ class has a very clear signal peak, which can be used for measuring the LSP mass.
After SM background subtraction and a fit of a Gaussian to the distribution one gets:

$$m^{\mathrm{fit}}_{\tilde{\chi}^0_1} = 98.39 \pm 0.13(\mathrm{stat.})$$

The measured value is within the error in very good agreement with the input mass of the example point.

This precision measurement of the LSP mass in the μμ channel can now be used to define a signal region $m^{fit} \pm 10$GeV. This further reduces the background fraction in the selected event classes.

	$S/\sqrt{B}$
μμ class	53.9
μτ class	23.1
ττ class	4.9

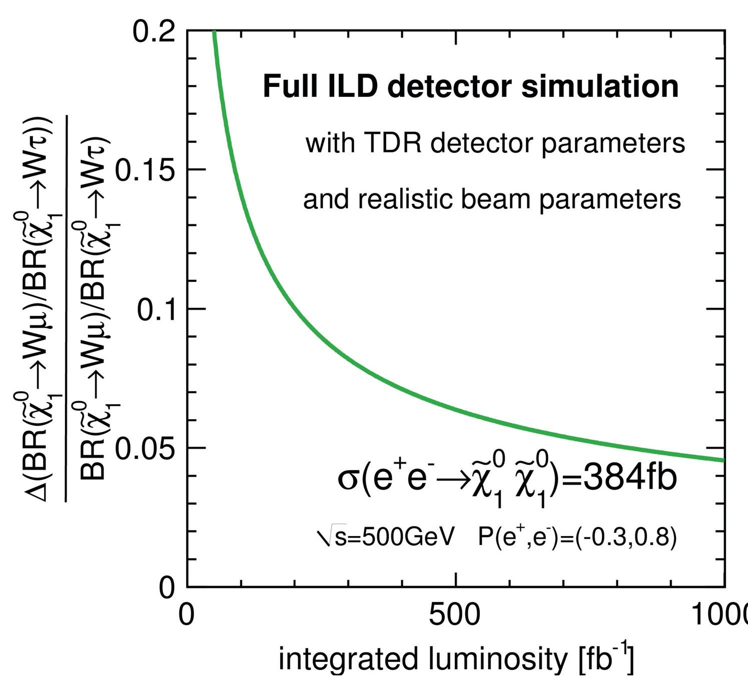
Precision of branching ratio measurement

From Monte-Carlo simulation determined selection efficiencies and impurities can be used to calculate the number of real events per event class.
Because of the low selection purity in the ττ channel, the μτ and μμ channel are used to determine the ratio of branching ratios.

$$\frac{\mathrm{BR}(\tilde{\chi}^0_1 \to W\mu)}{\mathrm{BR}(\tilde{\chi}^0_1 \to W\tau)} = \frac{2N^{\mathrm{true}}_{\mu\mu}}{N^{\mathrm{true}}_{\mu\tau}}$$

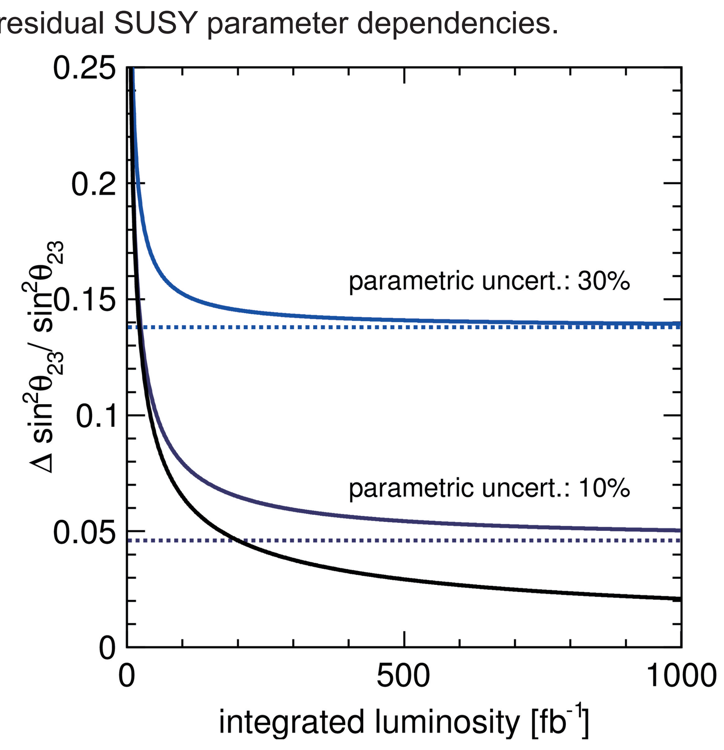
$$N^{\mathrm{true}}_{\mu\mu} = N_{\tilde{\chi}^0_1\tilde{\chi}^0_1} \cdot \mathrm{BR}^2(\tilde{\chi}^0_1 \to W\mu)$$
$$N^{\mathrm{true}}_{\mu\tau} = N_{\tilde{\chi}^0_1\tilde{\chi}^0_1} \cdot 2 \cdot \mathrm{BR}(\tilde{\chi}^0_1 \to W\mu) \cdot \mathrm{BR}(\tilde{\chi}^0_1 \to W\tau)$$

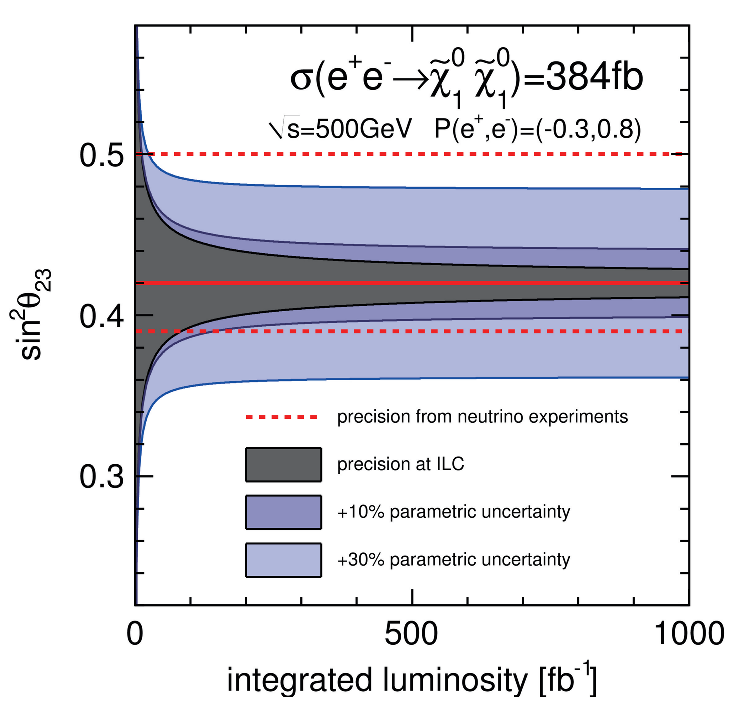
The uncertainty on the ratio of $N_{\mu\mu}^{true}$ and $N_{\mu\tau}^{true}$ accounts for BG fluctuations as well as fluctuations in the number of measured events in the event classes.
The resulting statistical uncertainty for the studied parameter point for an integrated luminosity of 100fb⁻¹ is about 14%. This scales down to roughly 6% for 500fb⁻¹, which is the desired integrated luminosity at ILC500 in a first stage.



Neutrino interpretation

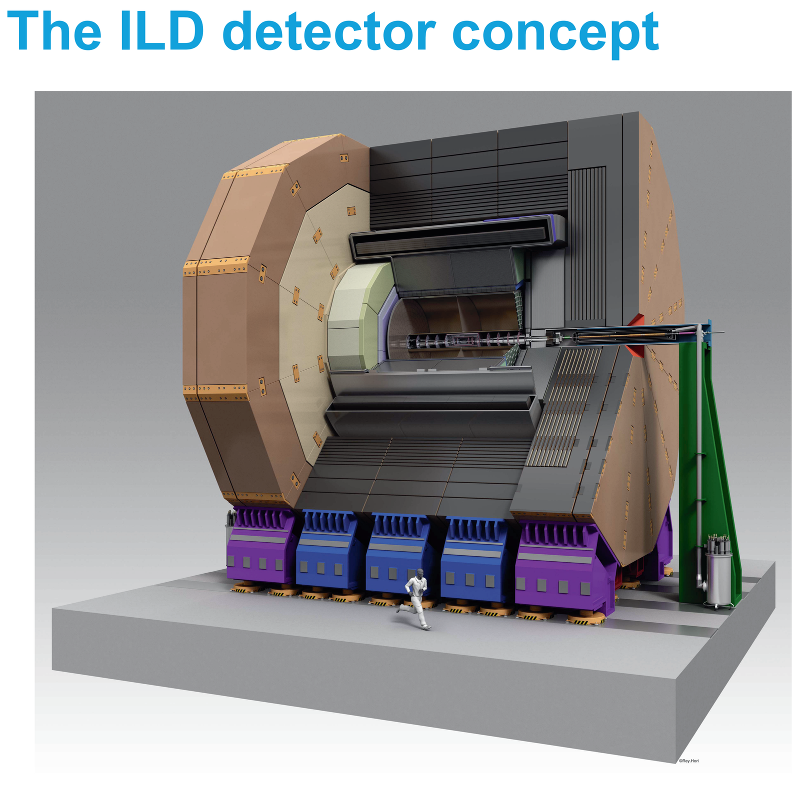
The uncertainty of the measured ratio of branching ratios can be translated into an uncertainty of the measurement of the atmospheric mixing angle.
The given relation is only an approximation and there are additional parametric uncertainties coming from residual SUSY parameter dependencies.





Two scenarios for the parametric uncertainty (10%, 30%) are shown. Hereby, 30% is a rather conservative assumption.
The comparison of the estimated precision at the ILC with the precision of current neutrino experiments shows that ILC can test if neutrino mixing and mass generation is introduced by RPV.

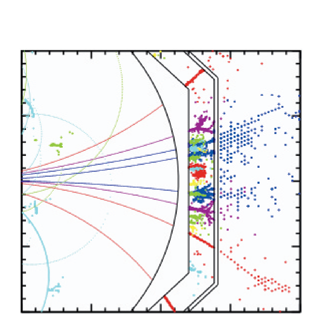
The ILD detector concept



The International Large Detector concept (ILD) is one of two studied detector concepts at the ILC.
It is optimised with a clear view on precision.
Excellent calorimetry and tracking performanc are combined to obtain the best possible overall event reconstruction, including the capability to reconstruct individual particles within jets for particle flow calorimetry.

Subdetector performance:

- vertex detector
  $\sigma_{ip} = 5\mu m \oplus \frac{10}{p(GeV)\sin^{3/2}\theta}\mu m$
- tracking
  $\sigma_{1/p_T} \approx 2 \times 10^{-5} GeV^{-1}$
- jet energy resolution
  $\frac{\sigma_E}{E} = \frac{0.3}{\sqrt{E(GeV)}}$



Curious?

W. Porod, M. Hirsch, J. Romao, J.W.F. Valle: "Testing neutrino mixing at future collider experiments" [arXiv: hep-ph/0011248].
J. List, B. Vormwald: "Bilinear R Parity Violation at the ILC - Neutrino Physics at Colliders" [arXiv:1307.4074 [hep-ex]].
ILC Technical Design Report: `http://www.linearcollider.org/ILC/Publications/Technical-Design-Report`

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