Update on new light scalar searches in $b\bar{b}$ decay channel
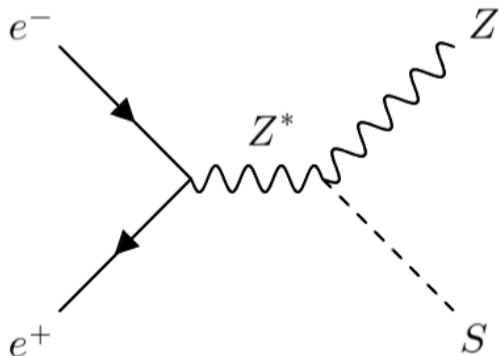
Bartłomiej Brudnowski

University of Warsaw

January 15, 2025

Introduction

There are many models containing a second scalar particle that is not currently excluded by the measurements. ILC at 250 GeV can search for new scalar production up to masses of about 160 GeV.

The general goal is to estimate 95% C.L. limits on the cross section ratio of the new extra scalar particle production to the SM Higgs production cross section at given mass:

$$\alpha = \sigma \left(e^+ e^- \to ZS \right) / \sigma_{SM}$$
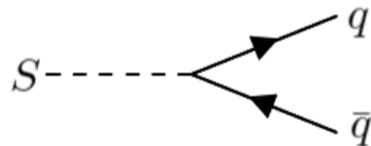
Decay channels

Considered in the presented study is decay

$$S \rightarrow b\bar{b}$$

which is expected to be a dominant decay channel in many models.

Results presented at the ECFA workshop were based on the SGV simulation of

$$Z \rightarrow e^+e^- \quad \text{and} \quad Z \rightarrow \mu^+\mu^-$$

Today:

- updated SGV results (with higher MC statistics)
- new results for $Z \rightarrow q\bar{q}$

Full simulation/SGV study

Background samples:

- 250 GeV center-of-mass energy,
- generated with Whizard v.2.8.5,
- SetA beam-spectrum,
- simulated and reconstructed with ILD_l5_o2_v02 model and ILCSoft v02-02-01.

New results:
more background samples processed (allowing for finer binning of BDT response histograms)

Signal samples:

- 250 GeV center-of-mass energy,
- generated with Whizard v.2.8.5,
- SetA beam-spectrum,
- detector simulation done by SGV.

Full simulation/SGV study

$Z \to ll$ **analysis**

- Only events with two isolated leptons (e^+e^- or $\mu^+\mu^-$) taken into account
- N=2 exclusive jet clustering and b-tagging with LCFI+
- event classification with root TMVA
  classification considered separately for each beam polarization

Limit calculations

Combined BDT response histogram

Combined BDT response for all weighted events
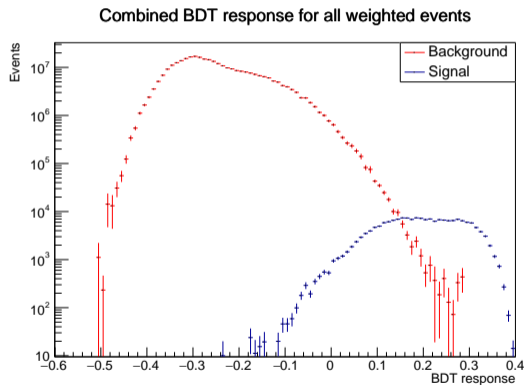
signal normalized to cross section ratio $\alpha = 1\%$

Limit calculations

Limits on the cross section ratio parameter $\alpha = \sigma\left(e^+e^- \to ZS\right) \cdot \mathcal{B}(S \to b\bar{b})/\sigma_{SM}$
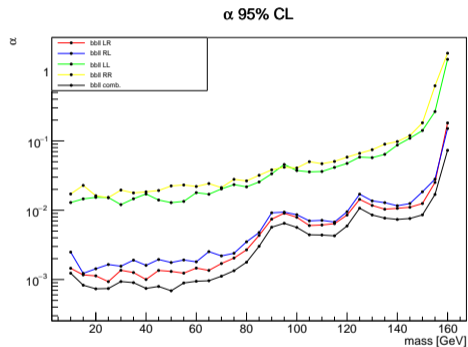are obtained assuming template fit to the BDT response histogram.
Expected uncertainty from the template fit (background only hypothesis)

$$\sigma_\alpha = \left(\sqrt{\sum_i \left(\frac{s_i^2}{b_i} \right)} \right)^{-1},$$
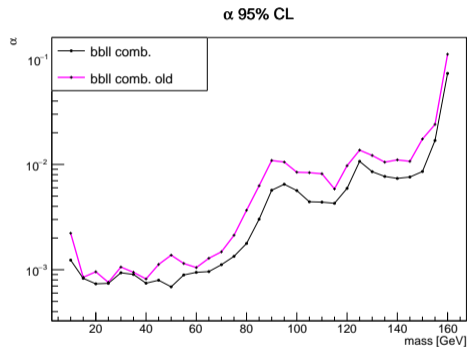
where s_i is the signal level in each bin (number of events expected for $\alpha = 1$) and b_i is the background level. Expected limit is then calculated as:

$$\alpha_{95\%CL} = 1.64 \cdot \sigma_\alpha$$

Limits for different beam polarizations   Combined limits (new vs old)

New: $Z \to q\bar{q}$

Delphes analysis framework

- Signal and background samples generated with Whizard 3.1.2 using built-in SM_CKM model.
- Signal generated by varying H mass in the model and forcing its decay to $b\bar{b}$.
- All relevant four-fermion final states considered as background.
- SM-like Higgs boson contribution included in the background estimate.
- Contribution from two-fermion and six-fermion processes found to be small.
- ISR and luminosity spectra for ILC running at 250 GeV taken into account
- Total luminosity of $2\,\text{ab}^{-1}$, with $\pm 80\%/\pm 30\%$ polarisation for e^-/e^+. (H-20 scenario)
- Fast detector simulation with Delphes ILCgen model.

BDT classification for $Z \to q\bar{q}$

For classifying the events Boosted Decision Trees were used, implemented in ROOT under TMVA. Following variables were used:

- number of b-jets,
- invariant mass of a quark pair,
- invariant mass of a bb pair,
- recoil mass calculated from the quark pair,
- recoil mass calculated from the bb pair,
- number of photons, electrons and muons,
- total energy,
- $cos(\theta)$ of one of the jets in the CM frame of the jet pair,
- transverse momentum of one of the jets,
- energy and transverse momentum of the jet pair.

BDT classification for $Z \to q\bar{q}$
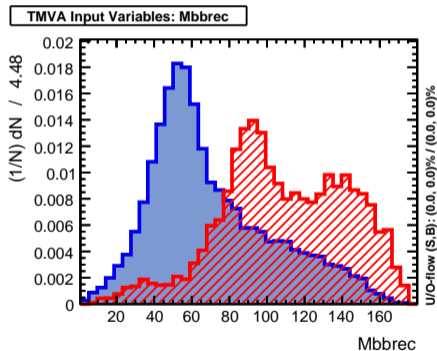
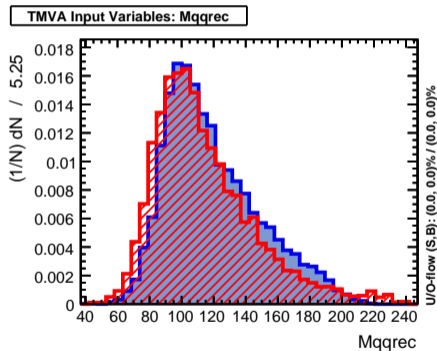Signal for $M_S = 50$ GeV (blue) vs SM background (red):
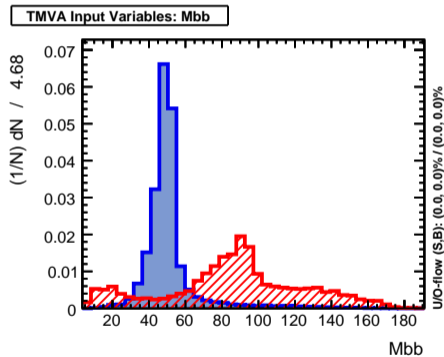
Scalar mass from b-jet pair
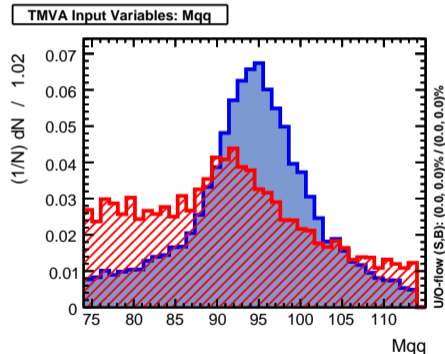
Z mass from untagged jet pair

BDT classification for $Z \to q\bar{q}$
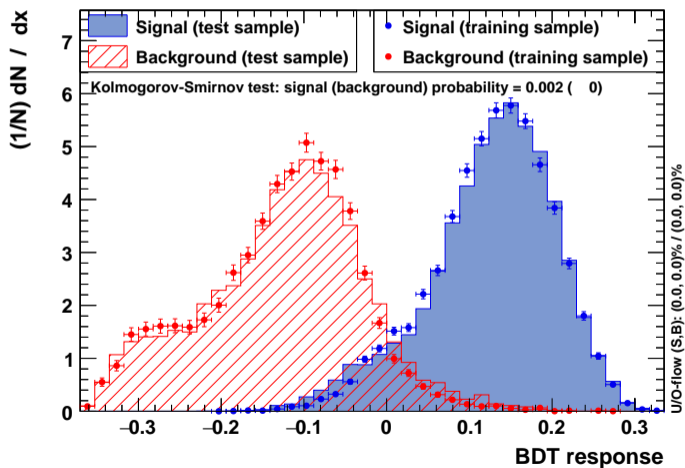
Signal for $M_S = 50$ GeV (blue) vs SM background (red):

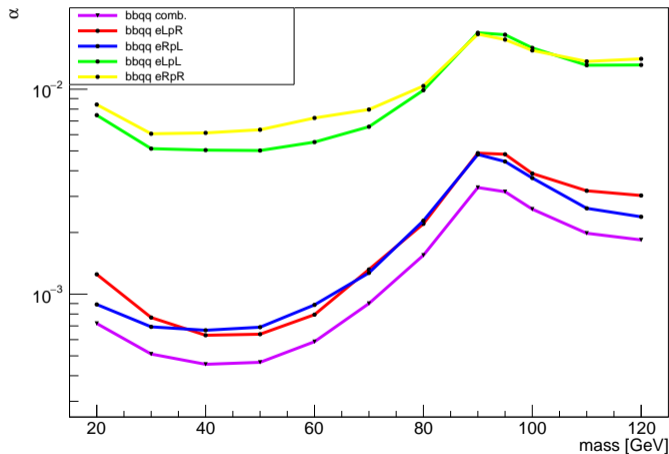Scalar mass from Z recoil   Z mass from scalar recoil
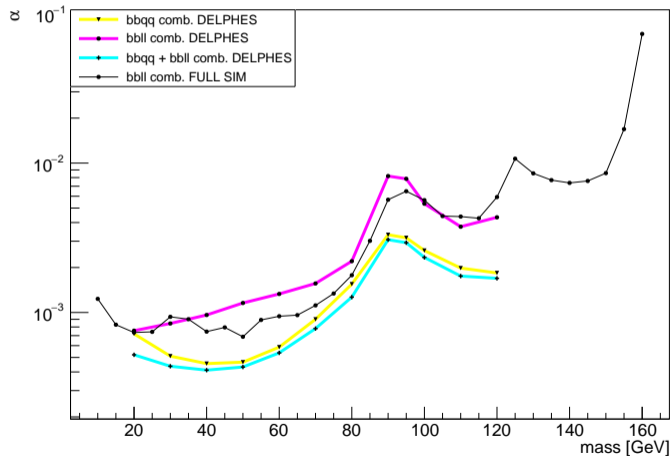
BDT response for $Z \to q\bar{q}$

Limit plot for $Z \to q\bar{q}$

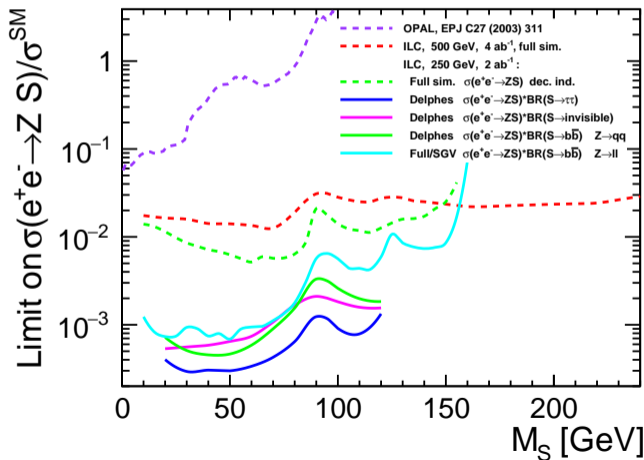Comparison of 95% C.L. limits on cross section ratio for different beam polarizations

Limit comparison

Comparison of limits from $Z \to ll$ and $Z \to q\bar{q}$ studies

Limit comparison

Updated plot for ECFA report (only ILD results included)

Conclusions

Results on light exotic scalar searches in the $S \to b\bar{b}$ decay channel proposed to be included in the ECFA report revision:

- updated results from full simulation/SGV analysis for $Z \to ll$
  based on higher statistics of the background MC samples
- new results from Delphes level analysis for $Z \to q\bar{q}$
  improved sensitivity thanks to higher Z branching ratio

Analysis of $Z \to q\bar{q}$ channel on SGV level will follow, but timescale for ECFA report too tight...

Questions?