Adding ZZ fusion processes for extra scalar searches at 550 GeV

Teresa Núñez - DESY

- Motivation
- Previous decay model independent searches
- Event selection
- Flow cut tables
- Sensitivity
- Conclusions

ILD Software and Analysis Meeting
May 26th, 2026

HELMHOLTZ GEMEINSCHAFT

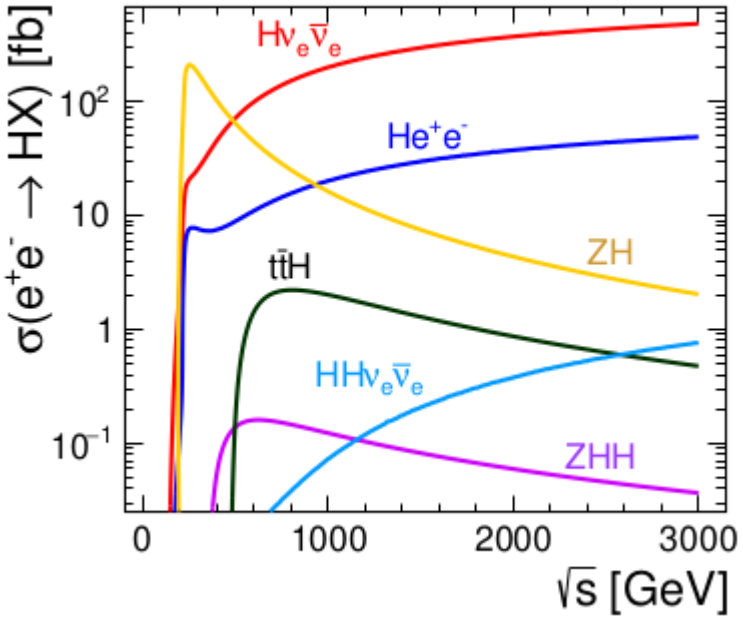
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

Motivation

Scalar-strahlung, similar to the Higgs-strahlung, could be the dominant light extra scalar production channel for $\sqrt{s}$ below 450 GeV

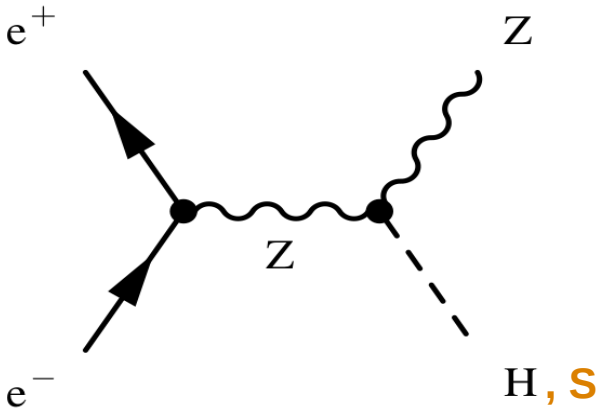
Model independent searches based on the recoil of the scalar against the Z mostly exclude extra scalar production by other processes that could be relevant at higher $\sqrt{s}$ values



Higgs-Strahlung

WW fusion

ZZ fusion



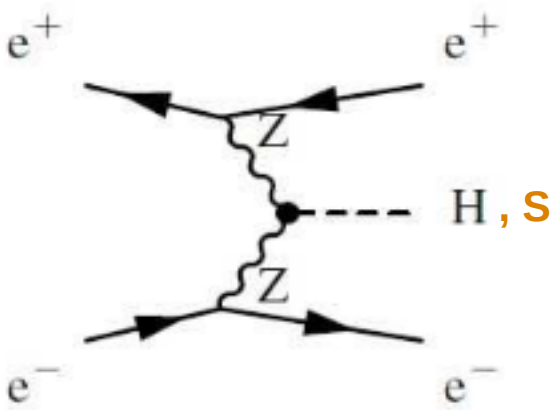
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

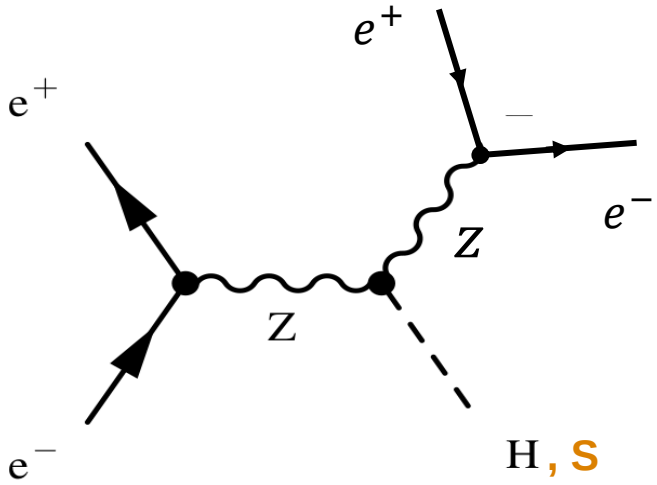
Motivation

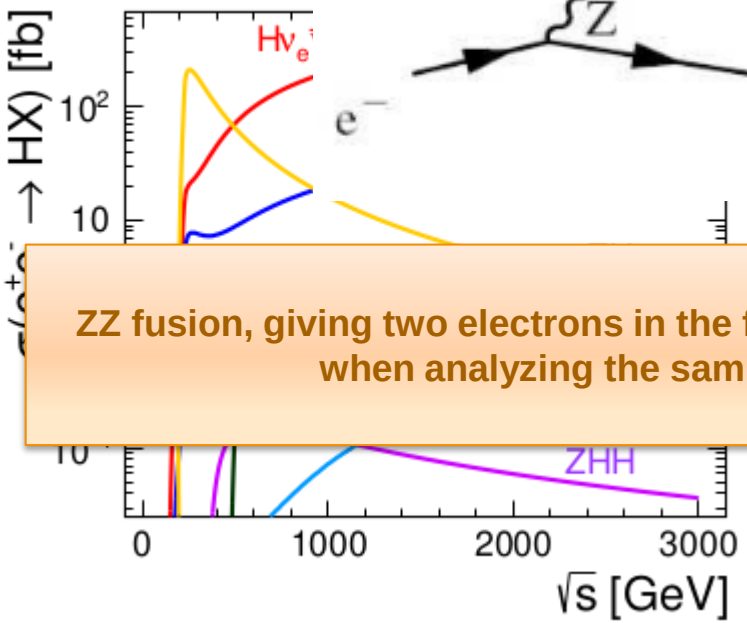
Scalar-strahlung, similar to the Higgs-strahlung, could be the dominant light extra scalar production channel for $\sqrt{s}$ below 450 GeV

Model independ
the scalar again
production b
rele



coil of scalar be





ZZ fusion, giving two electrons in the final state, should be taken into account at $\sqrt{s}$ = 550 GeV when analyzing the samples with an extra scalar and two electrons

ZZ fusion

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

Previous decay model independent searches

Previous studies based on the ILD@ILC:

- $\sqrt{s}$ = 500 GeV:
  - full simulation and reconstruction procedures for signal and background … but …
  - not current ILD@ILC experimental conditions
  - decays of the Z to two muons
  - not standard Marlin processors for the analysis

- $\sqrt{s}$ = 250 GeV:
  - full simulation and reconstruction procedures for background, SGV fast simulation for signal
  - current ILD@ILC experimental conditions
  - decays of the Z to two muons and two electrons
  - standard Marlin processors for the analysis (when possible)

- $\sqrt{s}$ = 550 GeV:
  - SGV fast simulation for detector simulation and reconstruction for background and signal samples
  - ILD@ILC 500 GeV experimental conditions (extension to different luminosity and polarisation scenarios)
  - Decays of the Z to two muons and two electrons
  - Same analysis flow as for the previous analysis at $\sqrt{s}$ = 250 GeV

Previous decay model independent searches

Previous studies based on the ILD@ILC:

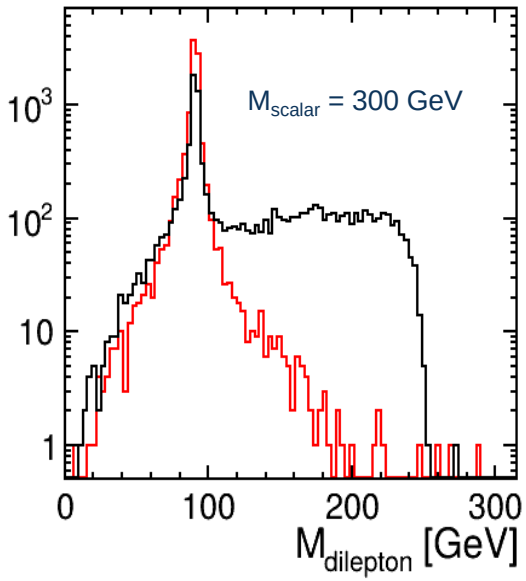
- $\sqrt{s}$ = 500 GeV:
  - full simulation and reconstruction procedures for signal and background … but …
  - not current ILD@ILC experimental conditions
  - decays of the Z to two muons
  - not standard Marlin processors for the analysis

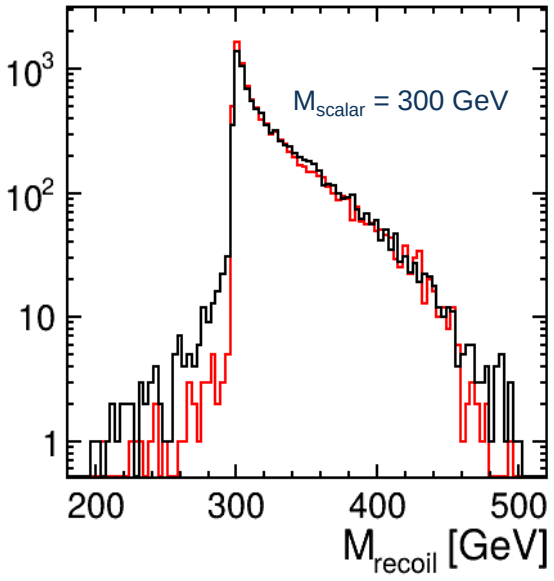
- $\sqrt{s}$ = 250 GeV:
  - full simulation and reconstruction procedures for background, SGV fast simulation for signal
  - current ILD@ILC experimental conditions
  - decays of the Z to two muons and two electrons
  - standard Marlin processors for the analysis (when possible)

- $\sqrt{s}$ = 5
  - SGV f
  - ILD@
  - Decays of the Z to two muons and two electrons
  - Same analysis flow as for the previous analysis at $\sqrt{s}$ = 250 GeV

Remove Z constraints in searches at 550 GeV with two electrons in the final state

How profit from the ZZ fusion production?





Z to electron pair

Z to muon pair

Remove Z constraints in searches at 550 GeV with two electrons in the final state

Keep the search based on recoil of the new scalar against the two electrons in the final state

Event selection: Z to $e^+ e^-$ channel

~~Use "Z-tagging" for unbiased selection of scalar production events~~

$e^+e^- \longrightarrow ZS^0 \rightarrow e^+ e^- S^0$

- Identification of ISR photons
- Select events without high-energetic ISR photon:
  - none or $E\gamma$ less than a limit depending on the scalar mass ([200, 60] GeV)
- Identification of isolated leptons
- Perform isolated lepton pairing
- ~~Cuts on kinematic variables (FSR corrections applied), accepted if~~
  - ~~$M_{e+e-} \in [70, 110]$ GeV~~
  - ~~$P^T_{e+e-} \in [0, 270]$ GeV~~
- Cuts on output of two BDTGs, 2f-MTVA and 4f-MTVA, trained against 2 fermion and 4 fermion backgrounds, respectively.
  - Input variables: ~~M_{e+e-}^{FSR}~~, $\cos\theta_{e+}^{FSR}$, $\cos\theta_{e-}^{FSR}$, $\cos\theta_{e+e-}^{FSR}$, $\cos\theta e-e^{FSR}$, $\pi - (\phi_{e+} - \phi_{e-})$
  - training done for each scalar mass separately
  - same limits used for all scalar masses
- Select events with less than 50 GeV ISR energy
- Limits computed based on fractional event counting using the M_{recoil} distribution (with ISR correction)

Avoid any possible dependence on the scalar decay channels (could even be exotic or invisible)

HELMHOLTZ GEMEINSCHAFT

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

Event selection: Z to $e^+ e^-$ channel

~~Use "Z-tagging" for unbiased selection of scalar production events~~

$e^+e^- \longrightarrow ZS^0 \rightarrow e^+ e^- S^0$

- Identification of ISR photons
- Select events without high-energetic ISR photon:
  - none or $E\gamma$ less than a limit depending on the scalar mass ([200, 60] GeV)
- Identification of isolated leptons
- Perform isolated lepton pairing
- Cuts on ~~kinematic variables (FSR corrections applied)~~, accepted if
  - $M_{e+e-} \in [70, 110]$ GeV
  - ~~P~~
- Cu ly.
  - In
  - tr
  - same limits used for all scalar masses
- Select events with less than 50 GeV ISR energy
- Limits computed based on fractional event counting using the M_{recoil} distribution (with ISR correction)

ZZ fusion events are killed by the cut in MVA training output

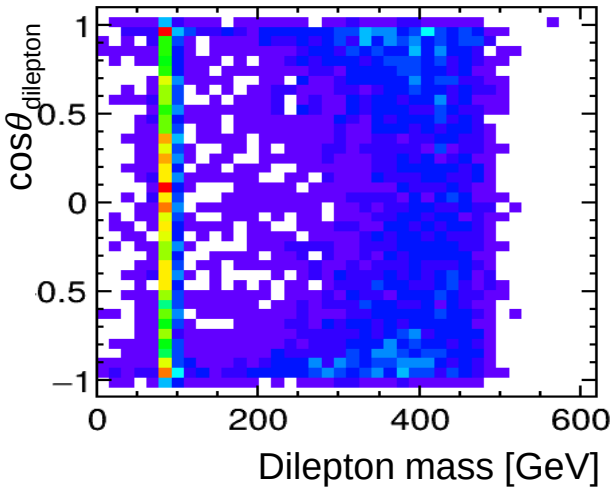
Avoid any possible dependence on the scalar decay channels (could even be exotic or invisible)

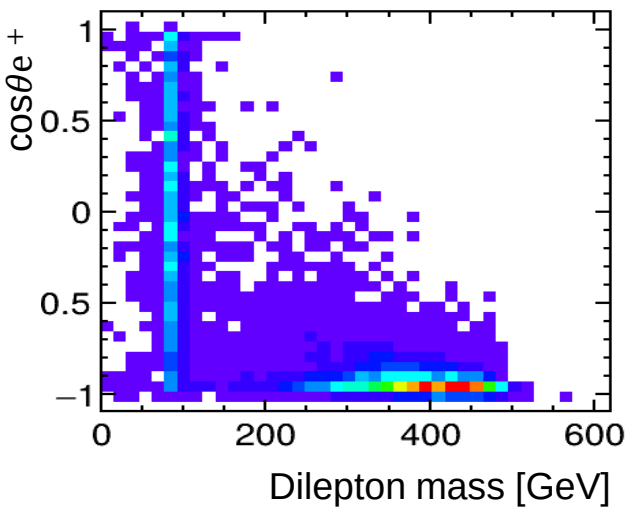
HELMHOLTZ GEMEINSCHAFT

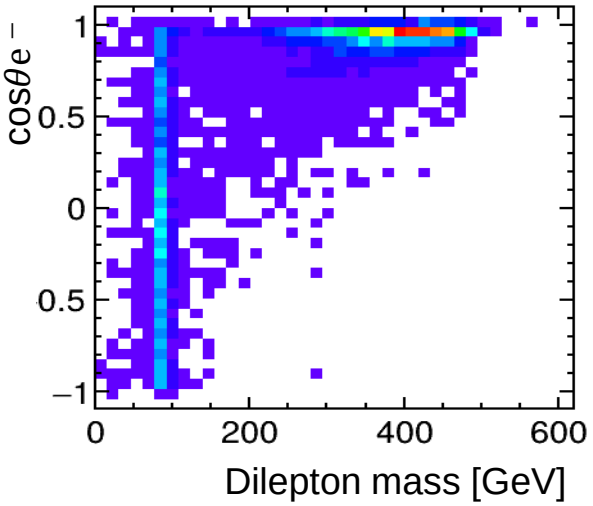
CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

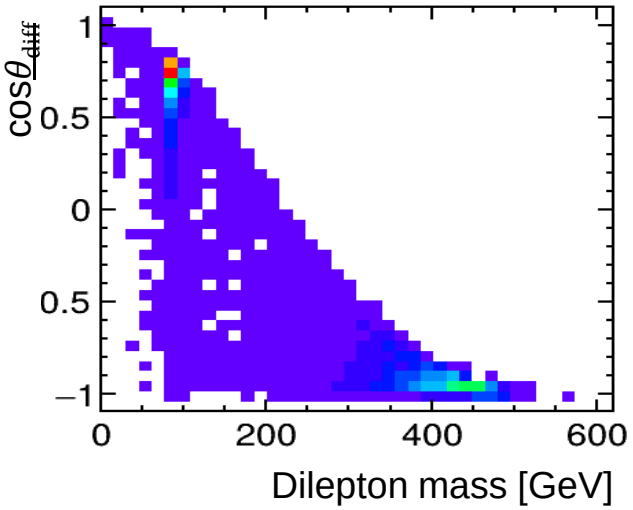
DESY.

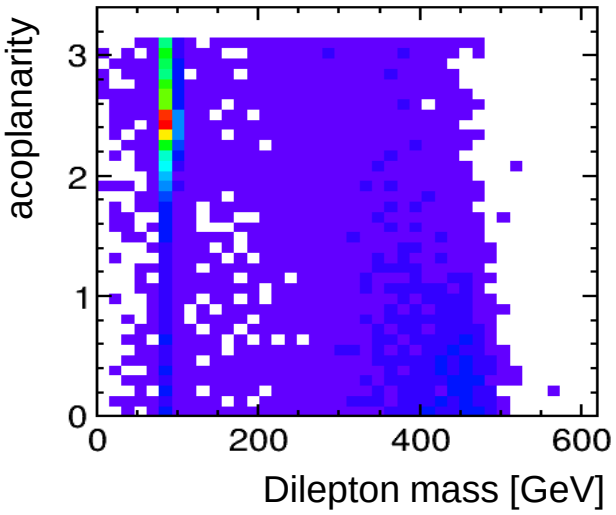
MVA training variables and response

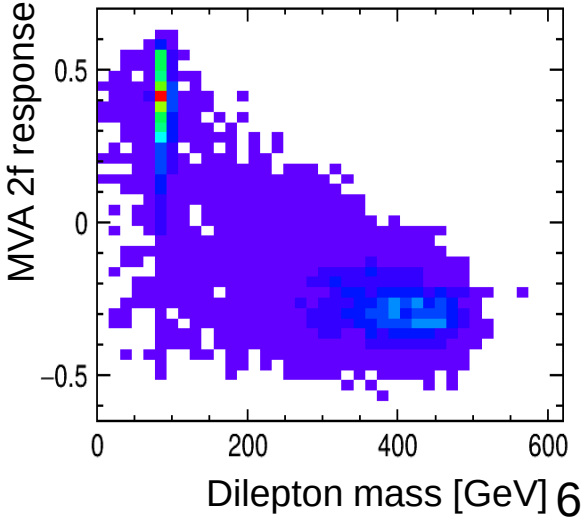




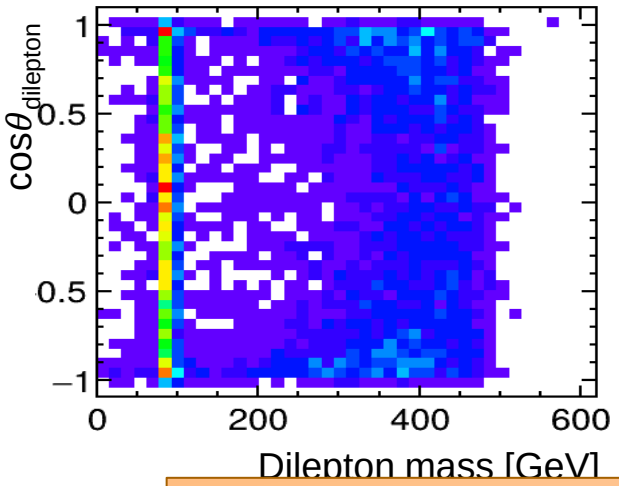


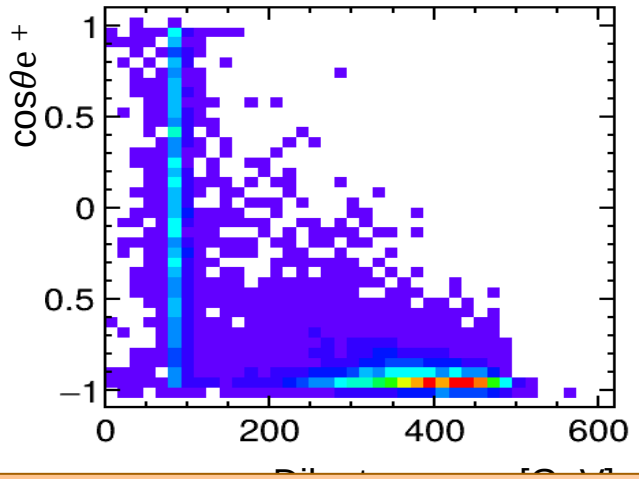


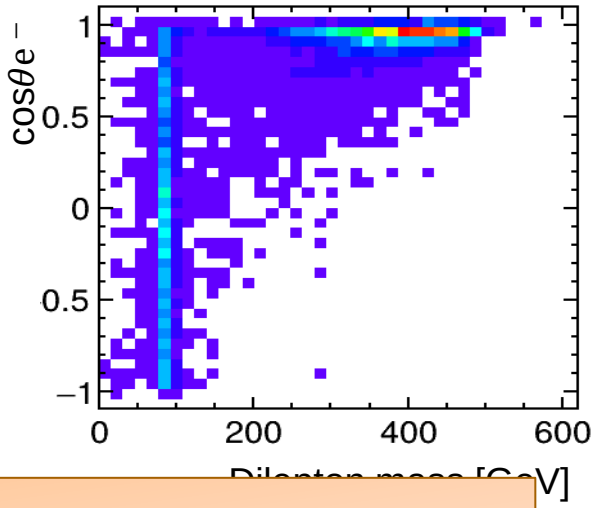




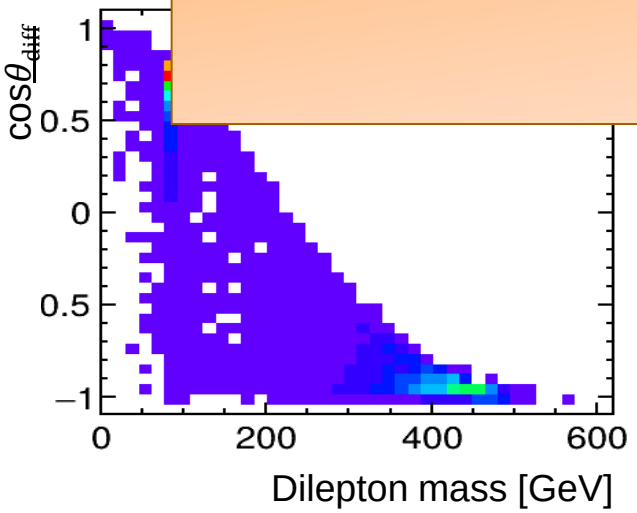
MVA training variables and response

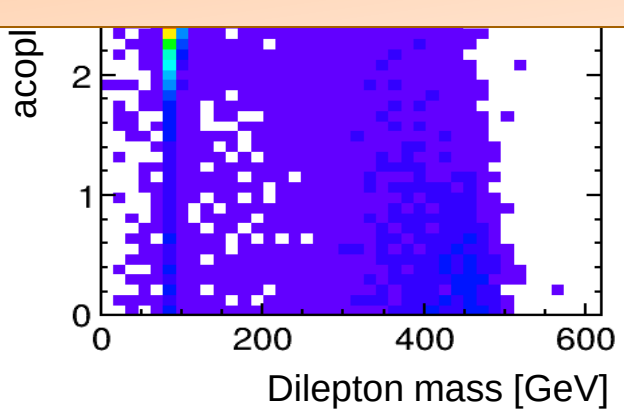


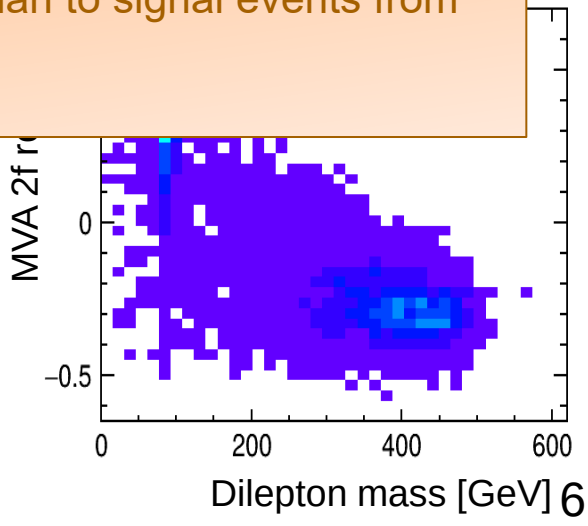




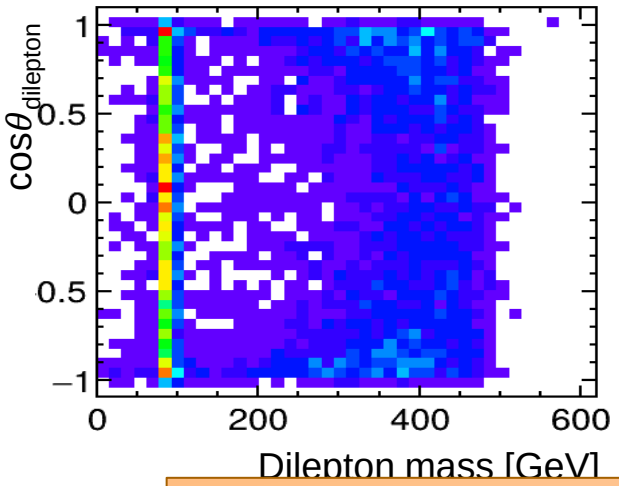
… since ZZ fusion kinematics is closer to background than to signal events from scalar-strahlung

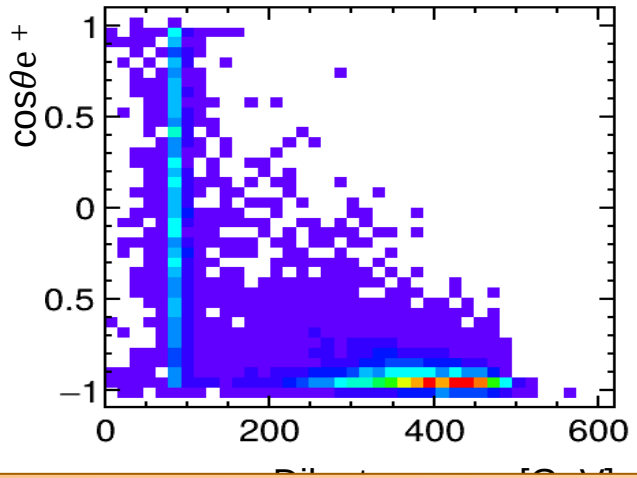


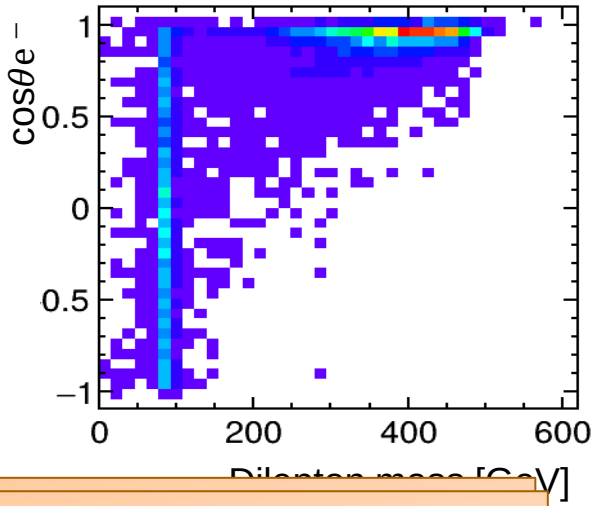




MVA training variables and response

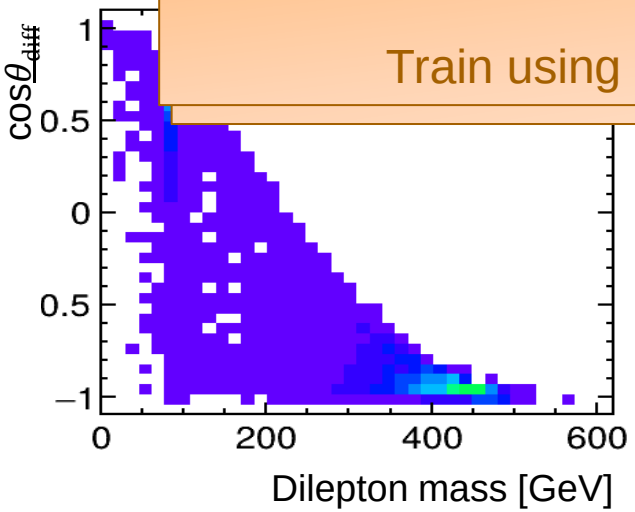


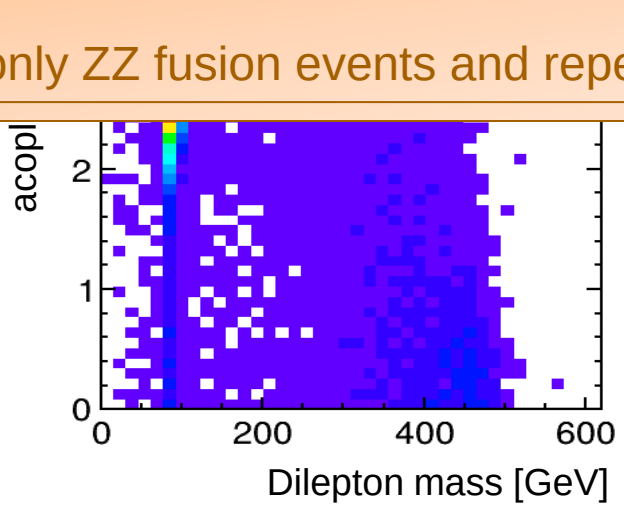


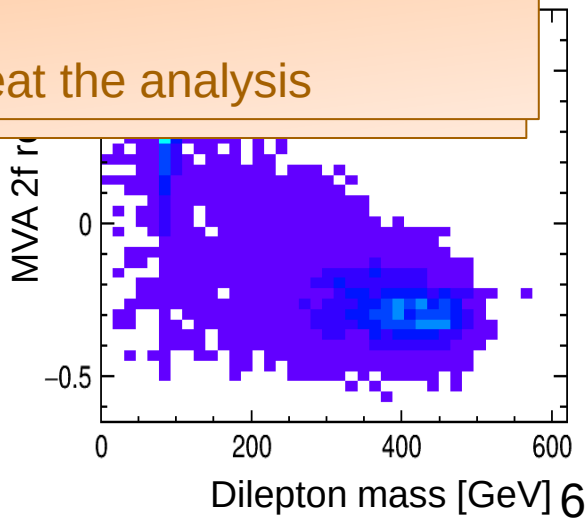


Select only ZZ fusion events (based on the reconstructed dielectron mass)

Train using only ZZ fusion events and repeat the analysis







Event selection: only ZZfusion events

Not constraints in Z

Same cut flow as the one used for the previous studies, but …

$e^+e^- \rightarrow e^+ e^- S^0$

- Identification of ISR photons
- Select events without high-energetic ISR photon:
  - none or $E\gamma$ less than a limit depending on the scalar mass ([200, 60] GeV)
- Identification of isolated leptons
- Perform isolated lepton pairing
- Cuts on kinematic variables, accepted if
  - $M_{e+e-} > 130$ GeV

… selecting ZZ fusion events

- Cuts on output of two BDTGs, 2f-MTVA and 4f-MTVA, trained against 2 fermion and 4 fermion backgrounds, respectively.
  - Input variables: $\cos\theta_{e+}^{FSR}$, $\cos\theta_{e-}^{FSR}$, $\cos\theta_{e+e-}^{FSR}$, $\cos\theta e-e^{FSR}$, $\pi - (\phi_{e+} - \phi_{e-})$
  - training done for each scalar mass separately
  - same limits used for all scalar masses

… removing dilepton mass from training

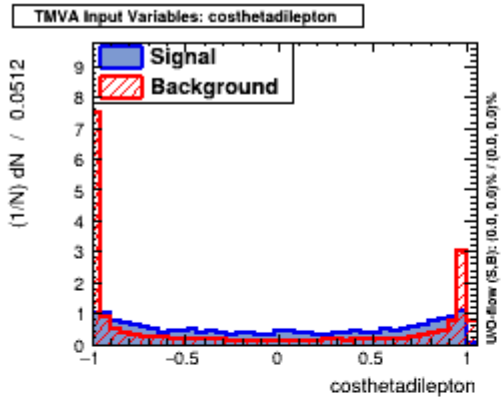
- Select events with less than 50 GeV ISR energy
- Limits computed based on fractional event counting using the M_{recoil} distribution (with ISR correction)

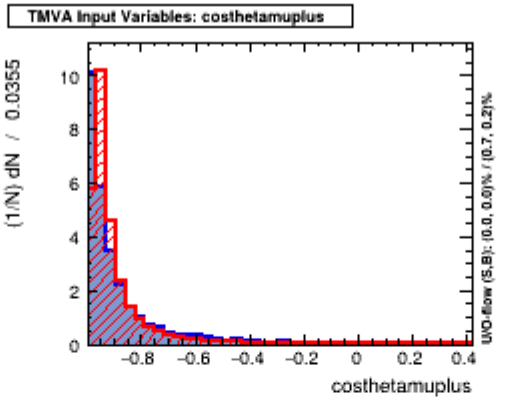
HELMHOLTZ GEMEINSCHAFT

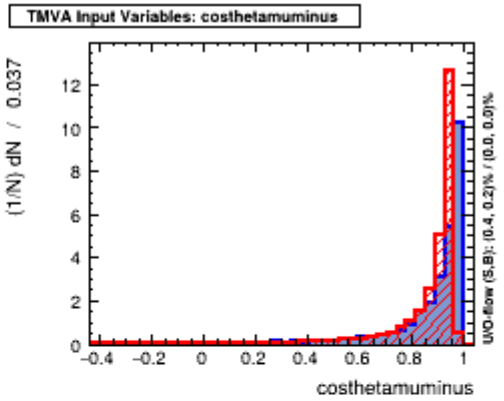
CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

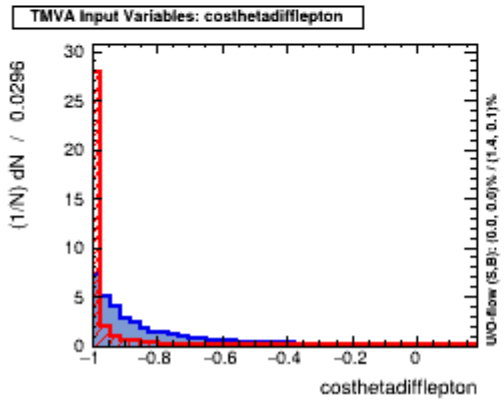
DESY.

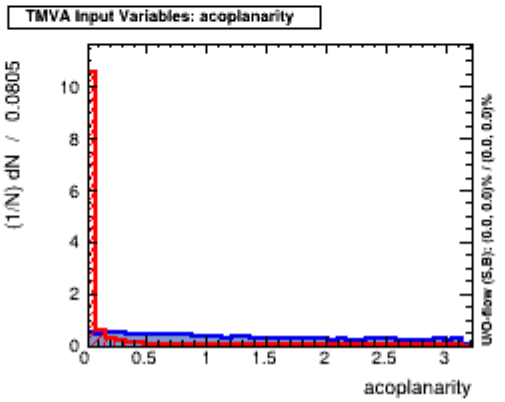
2f-MVA training only ZZ fusion events

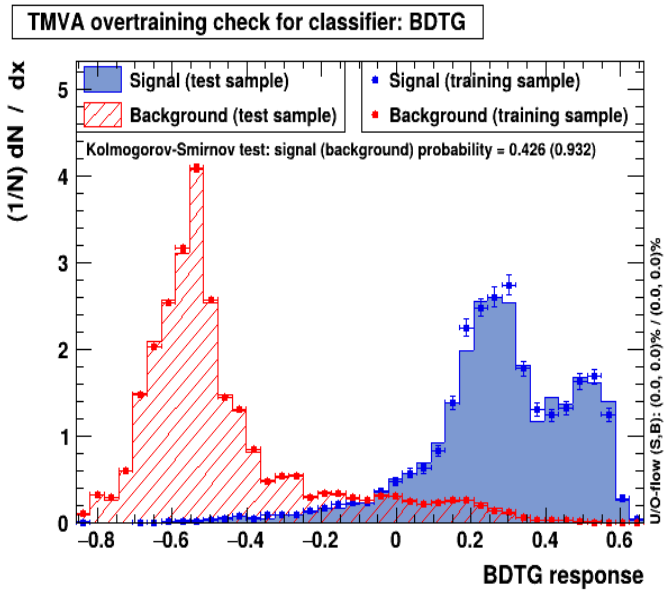






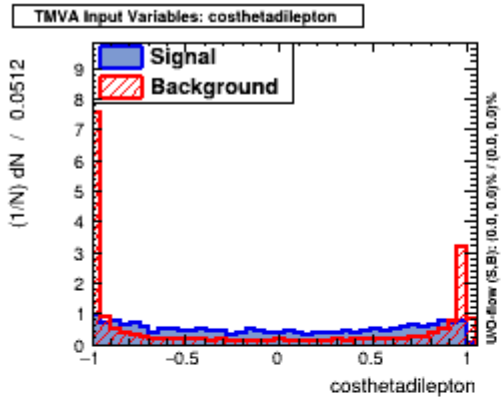


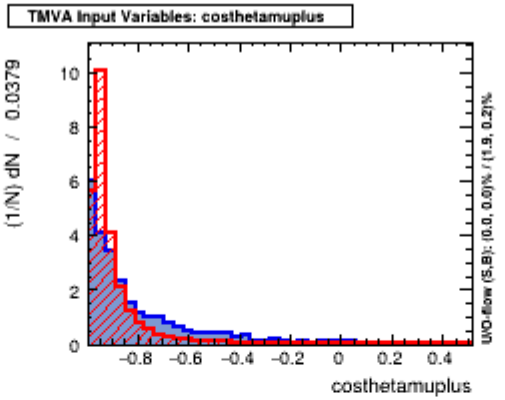


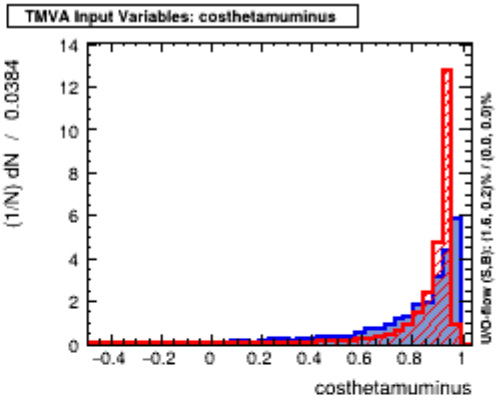


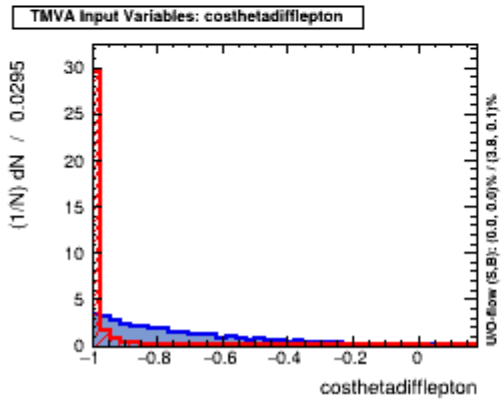
M_{scalar} = 70 GeV

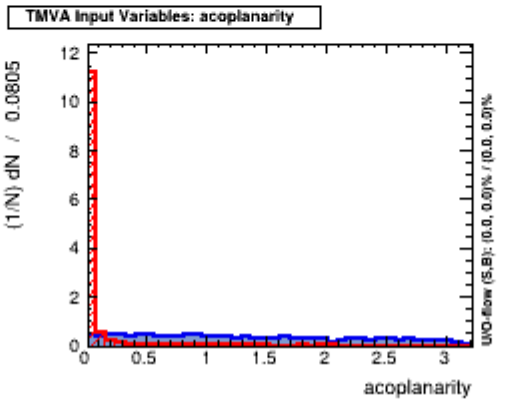
2f-MVA training only ZZ fusion events

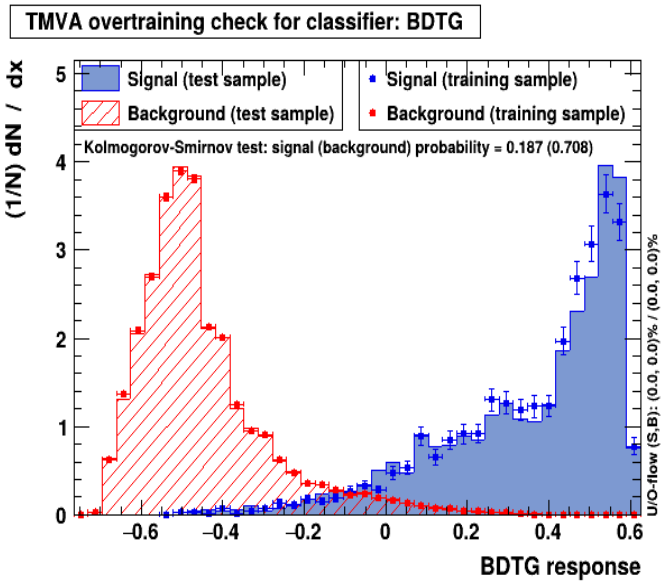












M_{scalar} = 350 GeV

HELMHOLTZ GEMEINSCHAFT

QUANTUM UNIVERSE

Event flow selecting ZZ fusion events

Training only ZZ fusion events

Training without dilepton invariant mass

Scalar mass 70 GeV

Polarisation LR

	Signal	4f leptonic	4f semileptonic	2f leptonic	BhaBha	Others	Total background	Significance
Total	29852.2	1.3e+07	4.4e+06	4.5e+06	1.7e+08	6936.7	1.9e+08	0
ISR veto	28170.4	8.1e+06	2.7e+06	3.6e+06	1.2e+08	6932.1	1.4e+08	2.41
Dielectron request	19448.1	482707	276582	9890.4	5.5e+07	3.1	5.6e+07	2.60
MVA 2f	13912.7	189601	146642	91.5	1.3e+06	1.5	1.6e+06	10.76
MVA 4f	11451.7	52829.9	62970.9	2.0	1.1e+06	1.5	1.2e+06	10.30
ISR cut	10902.6	31740.8	53421.2	0	54467.6	1.5	139631	28.10

Scalar mass 350 GeV

Polarisation LR

	Signal	4f leptonic	4f semileptonic	2f leptonic	BhaBha	Others	Total background	Significance
Total	1926.4	1.3e+07	4.4e+06	4.5e+06	1.7e+08	6936.7	1.9e+08	0
ISR veto	1902.1	6.8e+06	2.3e+06	3.5e+06	1.2e+08	6854.1	1.3e+08	0.17
Dielectron request	543.0	364141	266137	9748.1	5.2e+07	3.1	5.2e+07	0.08
MVA 2f	425.6	78907.3	134217	2.0	199454	1.5	412581	0.66
MVA 4f	368.0	29245.9	61046.7	0	153706	1.5	244000	0.74
ISR cut	365.4	24677.1	57365.1	0	2649.7	1.5	84693.5	1.25

“Dielectron request” selects ZZ fusion events asking for dielectron invariant mass above 130 GeV

HELMHOLTZ GEMEINSCHAFT

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

Event flow selecting ZZ fusion events

Training only ZZ fusion events

Training without dilepton invariant mass

Scalar mass 70 GeV

Polarisation LR

	Signal	4f leptonic	4f semileptonic	2f leptonic	BhaBha	Others	Total background	Significance
Total	29852.2	1.3e+07	4.4e+06	4.5e+06	1.7e+08	6936.7	1.9e+08	0
ISR veto	28170.4	8.1e+06	2.7e+06	3.6e+06	1.2e+08	6932.1	1.4e+08	2.41
Dielectron request	19448.1	482707	276582	9890.4	5.5e+07	3.1	5.6e+07	2.60
MVA 2f	13912.7	189601	146642	91.5	1.3e+06	1.5	1.6e+06	10.76
MVA 4f	11451.7	52829.9	62970.9	2.0	1.1e+06	1.5	1.2e+06	10.30
ISR cut	10902.6	31740.8	53421.2	0	54467.6	1.5	139631	28.10

For higher scalar masses not only the cross section is smaller but the ZZ fusion contributes less to production, hence very small significance

Scalar mass 350 GeV

Polarisation LR

	Signal	4f leptonic	4f semileptonic	2f leptonic	BhaBha	Others	Total background	Significance
Total	1926.4	1.3e+07	4.4e+06	4.5e+06	1.7e+08	6936.7	1.9e+08	0
ISR veto	1902.1	6.8e+06	2.3e+06	3.5e+06	1.2e+08	6854.1	1.3e+08	0.17
Dielectron request	543.0	364141	266137	9748.1	5.2e+07	3.1	5.2e+07	0.08
MVA 2f	425.6	78907.3	134217	2.0	199454	1.5	412581	0.66
MVA 4f	368.0	29245.9	61046.7	0	153706	1.5	244000	0.74
ISR cut	365.4	24677.1	57365.1	0	2649.7	1.5	84693.5	1.25

“Dielectron request” selects ZZ fusion events asking for dielectron invariant mass above 130 GeV

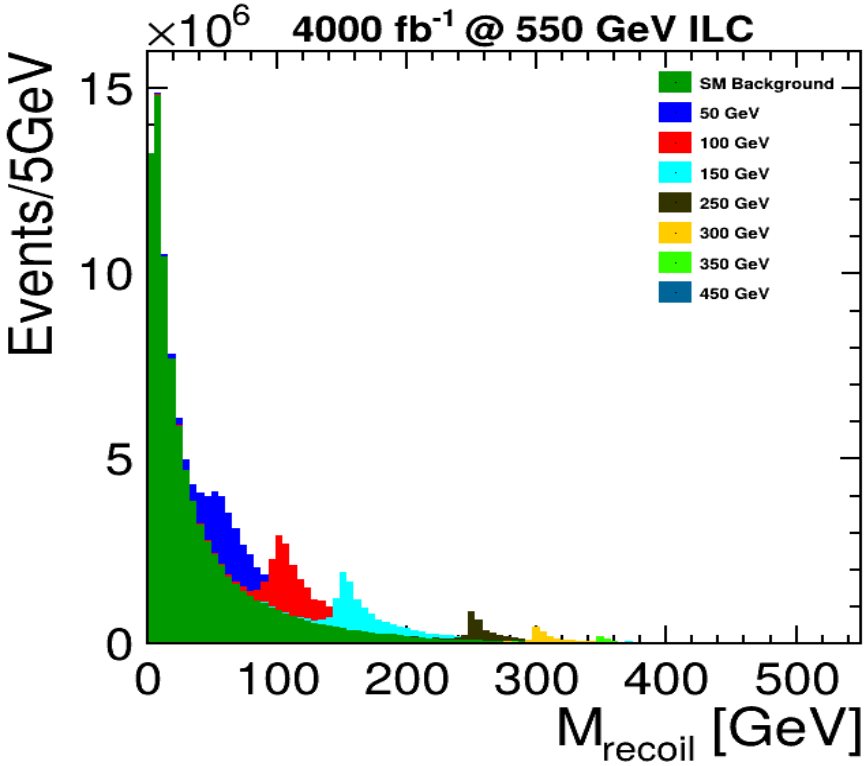
HELMHOLTZ GEMEINSCHAFT

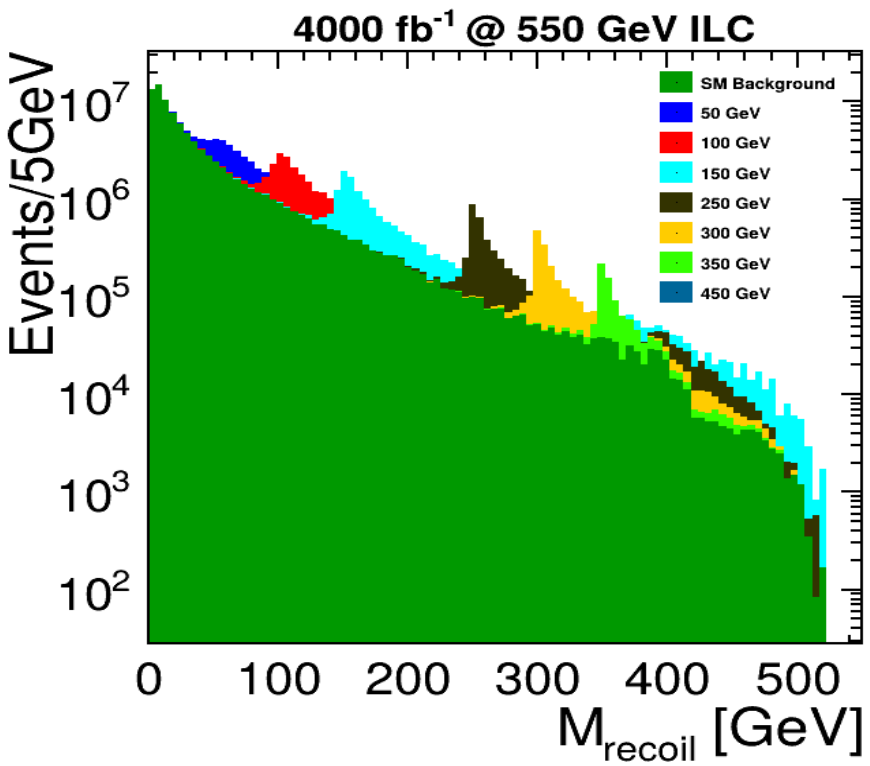
CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

Recoil mass distributions selecting ZZ fusion events

Before MVA cuts





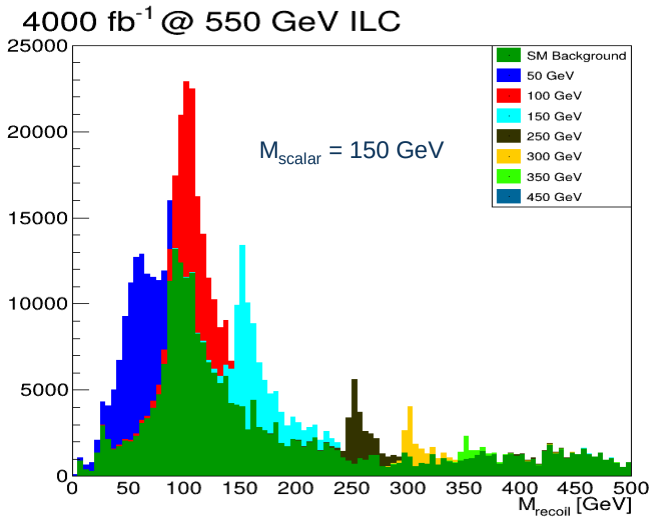
HELMHOLTZ GEMEINSCHAFT

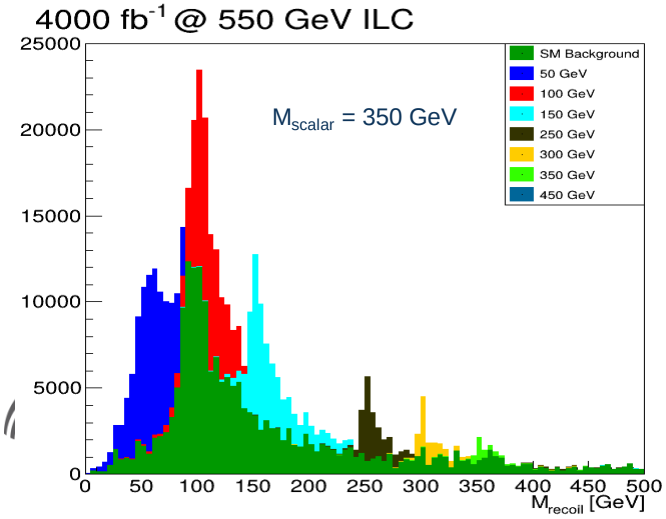
CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

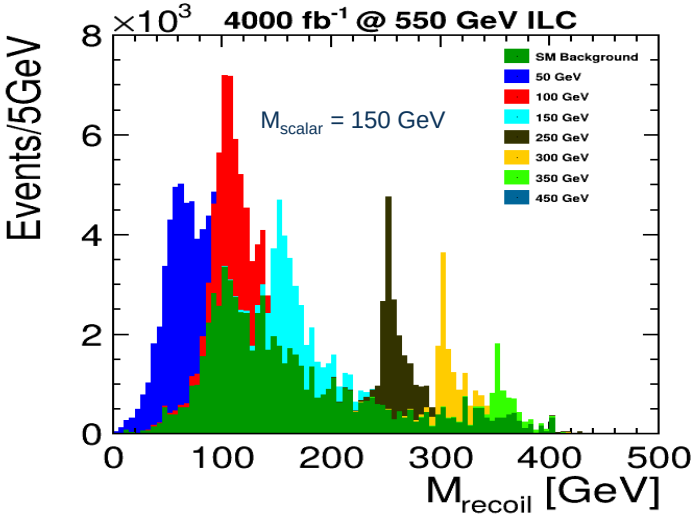
Recoil mass distributions selecting ZZ fusion events

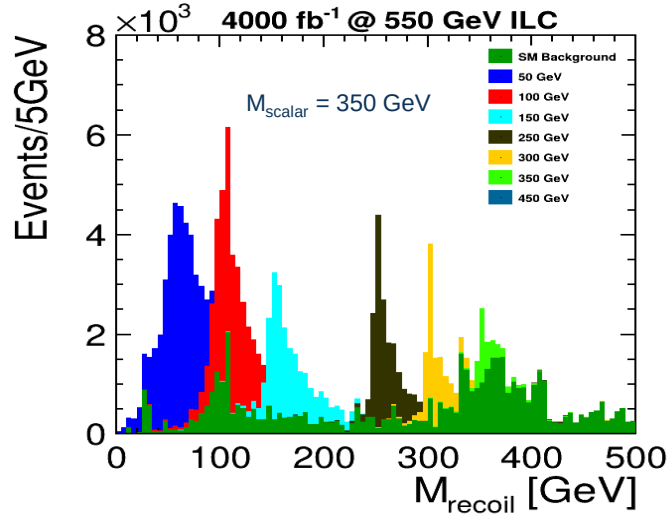
Training without dilepton invariant mass





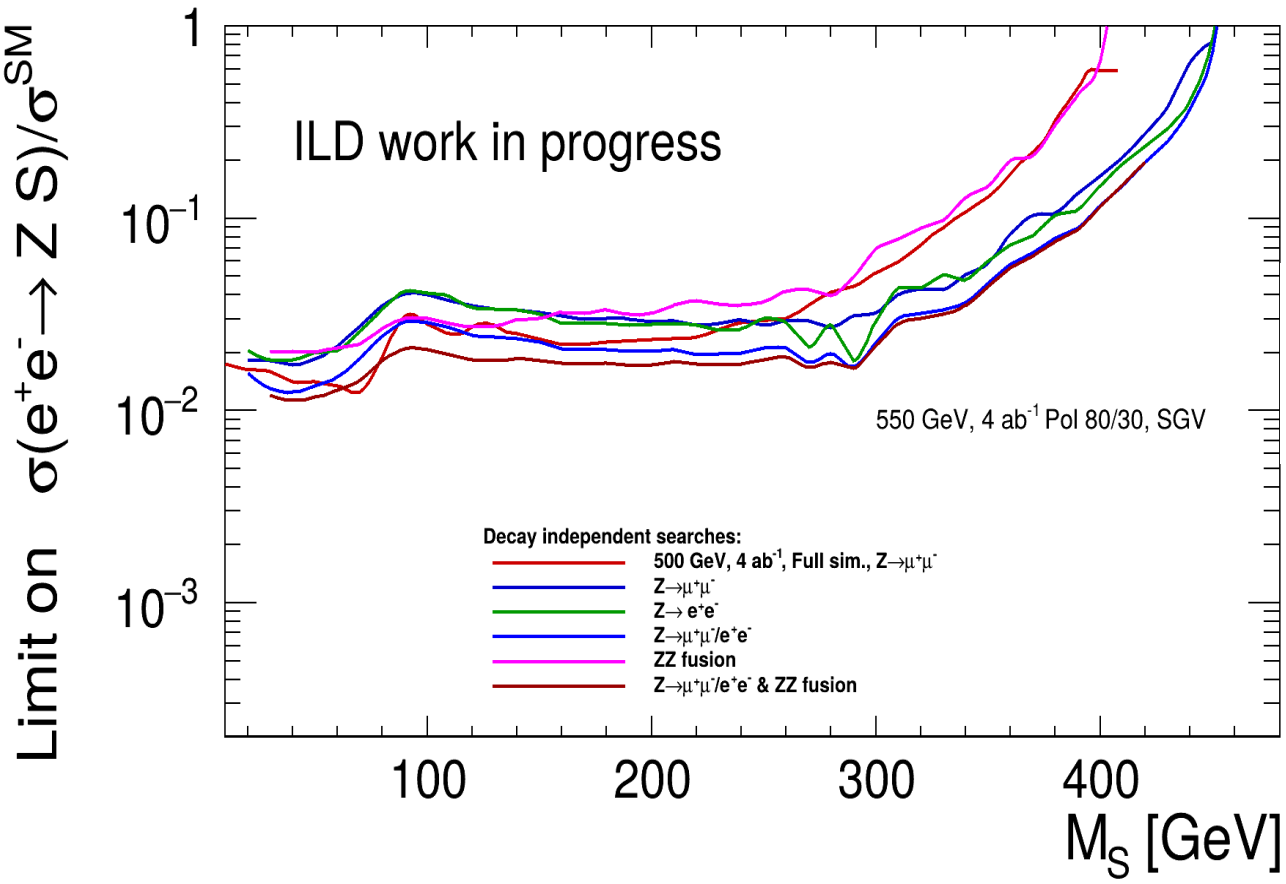
Training with dilepton invariant mass





After MVA cuts

Limits @ 550 GeV

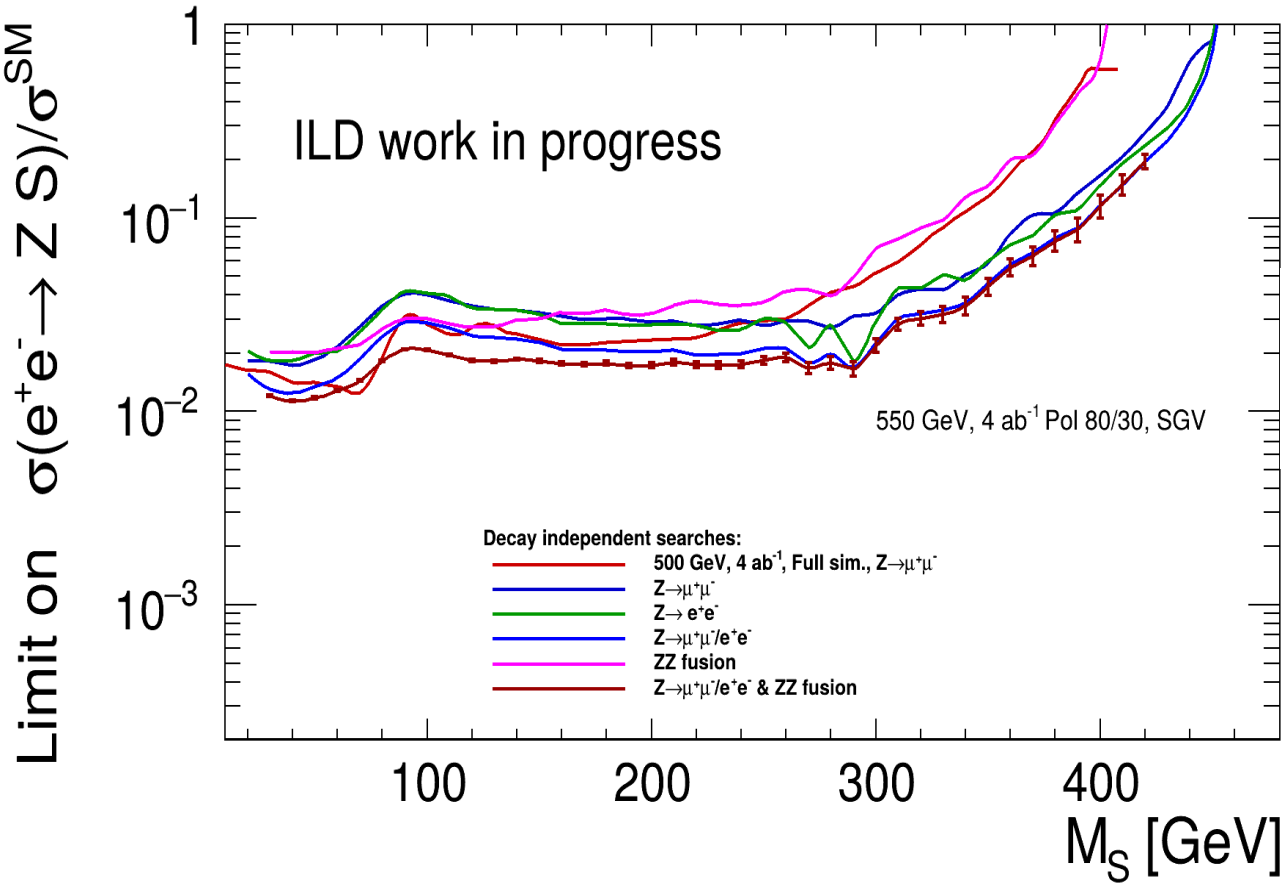


Scalar production cross section relative to SM Higgs boson production cross section at given mass

Limits computed based on the recoil mass distributions using fractional event counting

Channels combined using likelihood ratio statistics applied to each bin used by the fractional event counting

Limits @ 550 GeV



Scalar production cross section relative to SM Higgs boson production cross section at given mass

Limits computed based on the recoil mass distributions using fractional event counting

Channels combined using likelihood ratio statistics applied to each bin used by the fractional event counting

Conclusions

- Model independent searches for new scalars @550 GeV, based on newest MC production and ILD software, have been extended to cover the decay of the ZZ fusion processes
- Combination of searches in the Z to two muons, Z to two electrons and ZZ fusion processes has been performed
- Higher sensitivity for extra scalar masses below ~300 GeV is observed

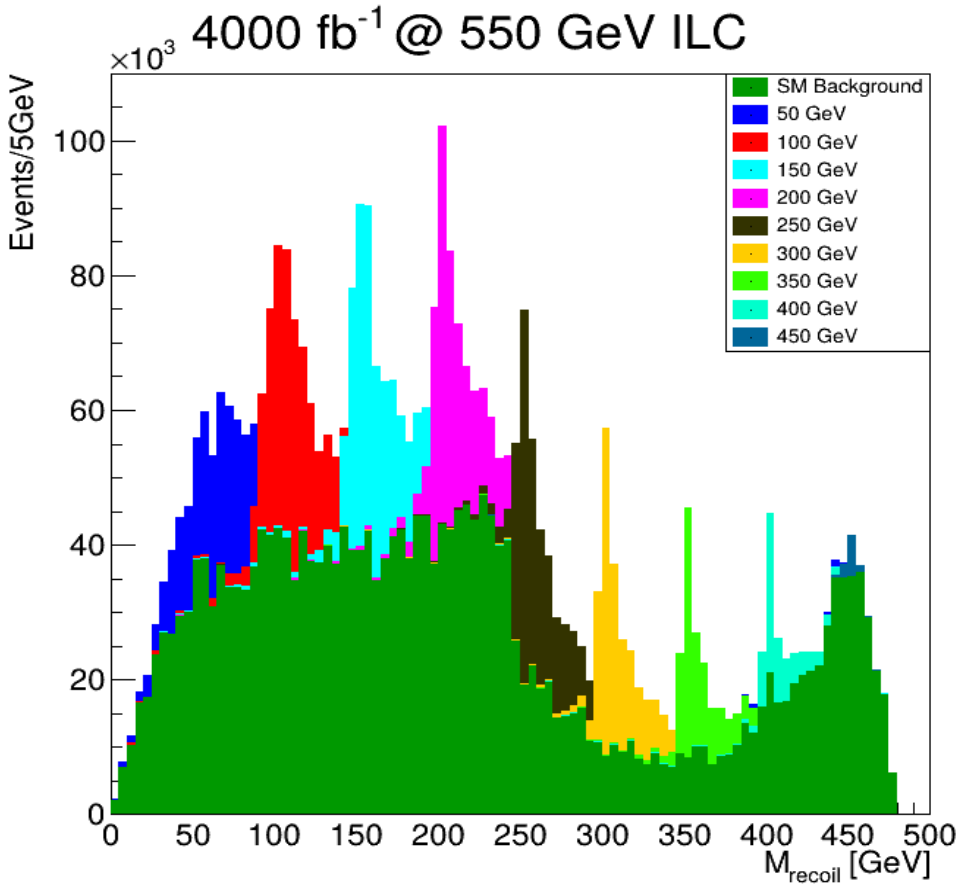
HELMHOLTZ GEMEINSCHAFT

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

Backup slides

Recoil mass spectrum: signal vs background



$e^+e^- \rightarrow ZS^0 \rightarrow e^+ e^- S^0$

Before final cuts

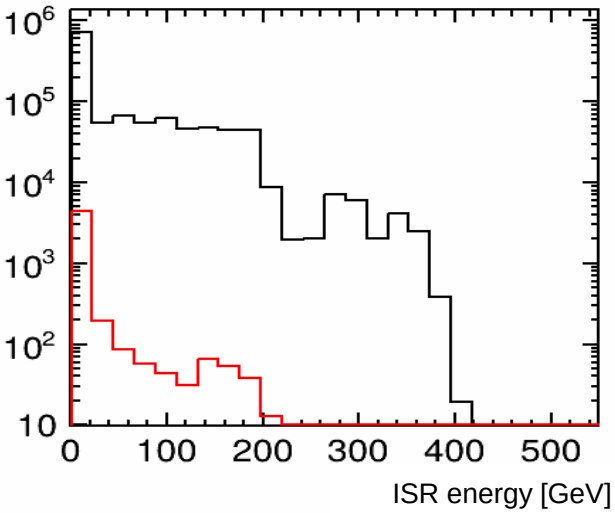
$$M^2_{rec} = (\sqrt{s} - E_{ll})^2 - \left|\vec{P}_{ll}\right|^2$$

HELMHOLTZ GEMEINSCHAFT

DESY.

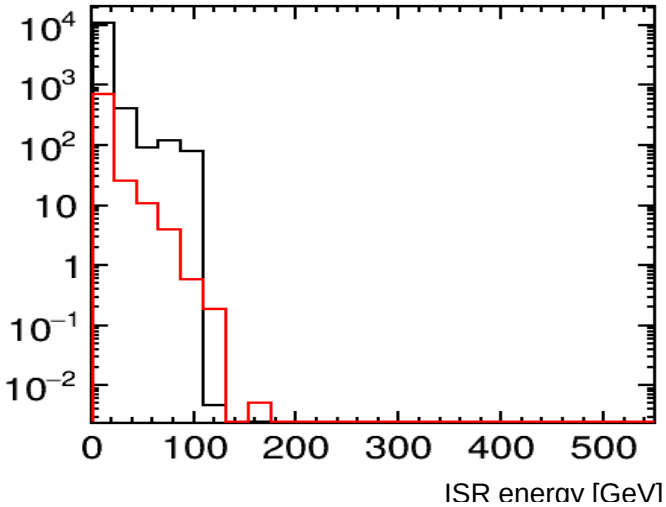
Try to improve taking profit of the ZZ fusion production?

Before MVA cuts

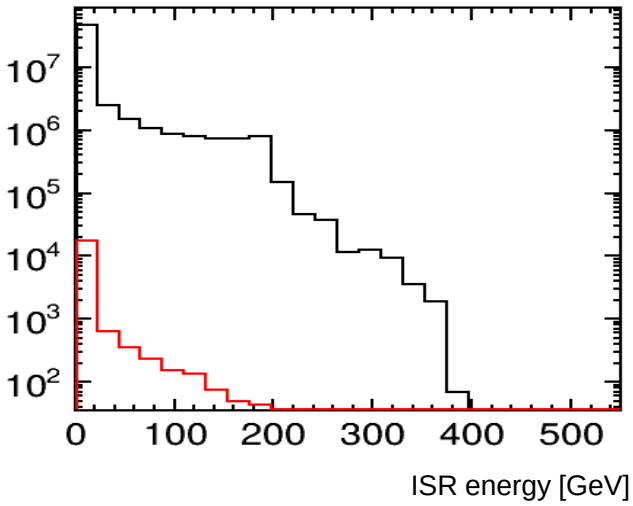


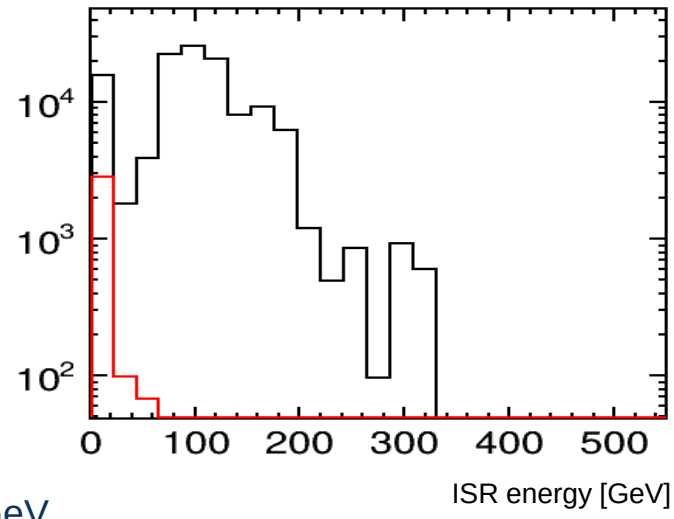
All ee S events

After MVA cuts



ZZ fusion events





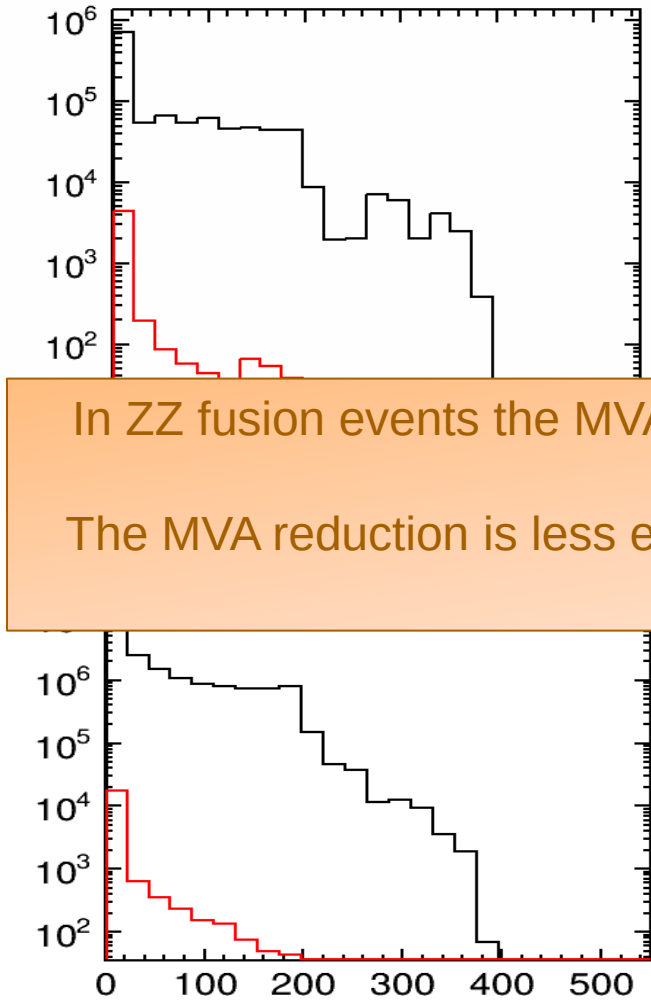
M_{scalar} = 70 GeV

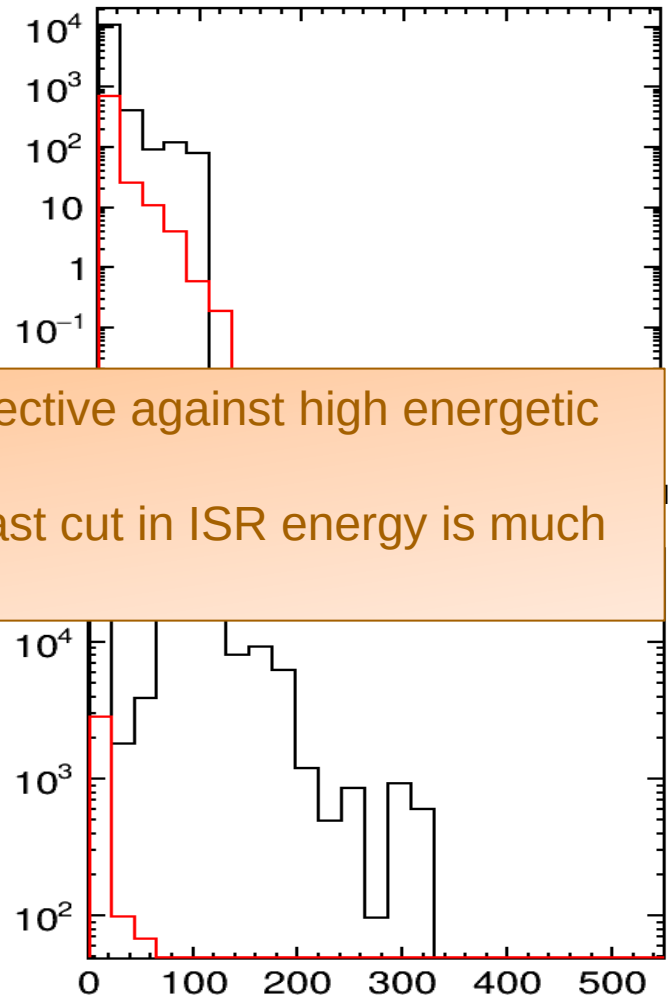
Try to improve taking profit of the ZZ fusion production?

Before MVA cuts

All ee S events

After MVA cuts





In ZZ fusion events the MVA cuts are not effective against high energetic ISR photons

The MVA reduction is less effective but the last cut in ISR energy is much more effective

M_{scalar} = 70 GeV