H->ZZ* and Higgs production in ZZ fusion at 1.4 TeV CLIC

G. Milutinovic-Dumbelovic[1], A.Robson[2]
P.Roloff[3], I. Bozovic-Jelisavcic[1]

[1]Vinca Institute of Nuclear Sciences, University of Belgrade
[2]University of Glasgow
[3]CERN

on behalf of the CLICdp collaboration

LCWS14, 6–10 October 2014, Belgrade

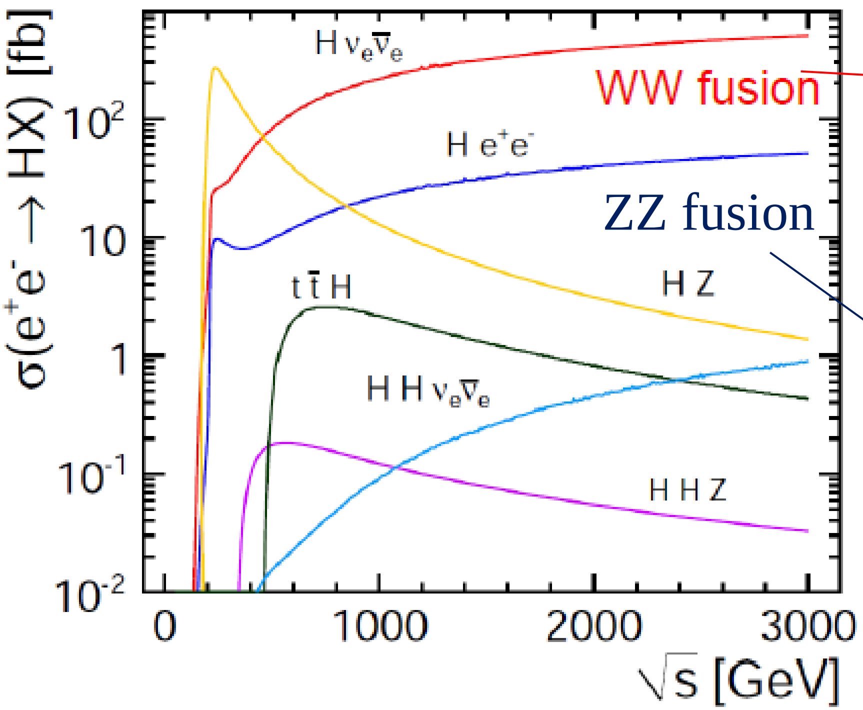
Overview

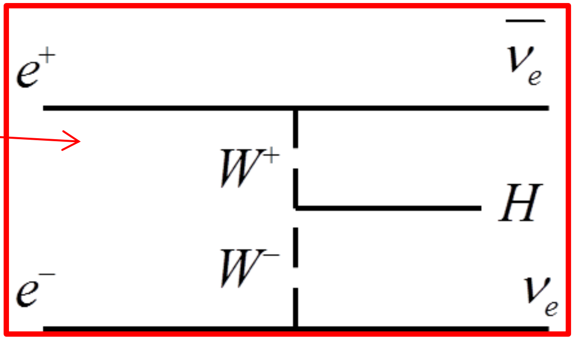
- What is in common
- Introduction
- $H \rightarrow ZZ^*$
- Higgs production in ZZ fusion
- Conclusion

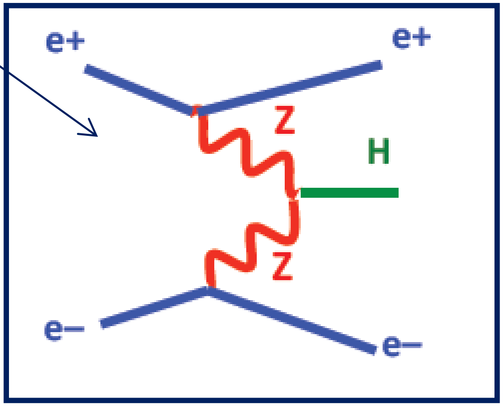
What is in common

- Both analysis are converging to final figures up to the minor tuning.
- CLIC_ILD detector model is fully simulated in both analysis.
- Similar approach to the method: preselection, b-tagging, MVA to handle numerous backgrounds.

Higgs production at 1.4 TeV

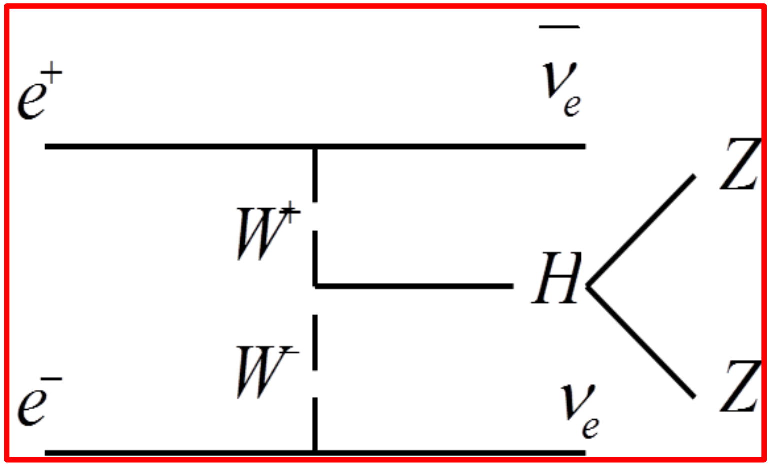


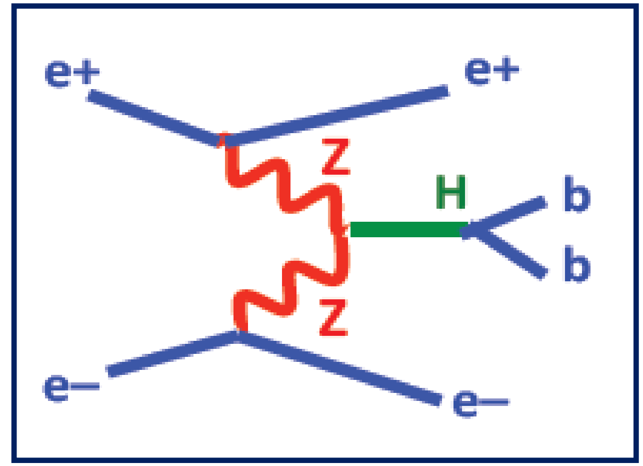




- Using WHIZARD V.1.95, including ISR and realistic CLIC beam spectrum
- WW fusion: σ(e+e → Hνν) ≈ 244 fb
- ZZ fusion: σ(e+e → Hee) ≈ 24.5 fb

Signal processes





- BR(H→ZZ*) ≈ 2.89% ⇒ σ_{HWW} × BR ≈ 7.05 fb
- BR(Z→qq) ≈ 70 %
- N_s(ZZ* → qqqq) ≈ 5175/1.5 ab^{-1}
- BR(Z→e+e–, Z→μ+μ–) ≈ 6.8 %
- N_s(ZZ*→qqe+e–, ZZ*→qqμ+μ–) ≈ 900/1.5 ab^{-1}

$$\frac{g^2_{HWW} \cdot g^2_{HZZ}}{\Gamma_H}$$

- BR(H→bb) ≈ 56.1% ⇒

σ_{HZZ} × BR ≈13.74 fb

- N_s ≈ 3878/1.5 ab^{-1}

$$\frac{g^2_{HZZ} \cdot g^2_{Hbb}}{\Gamma_H}$$

Main background processes

- Both analyses have numerous background processes
- Background are mostly suppressed with preselection cuts and MVA

Hνν, H→ *ZZ*

- WW fusion gives irreducible background:

$e^+e^- \to H\nu_e\overline{\nu}_e, H \to WW \to qqqq$

- Large x-sec background samples:

$e\gamma \to qqq\nu$ → sensitive to P_T^{jet} observable

$\gamma\gamma \to qqqq$
$e\gamma \to qqqe$
→ sensitive to P_T^{jet}, E_{vis} and $-\log_{10}y_{23}$

$e\gamma \to qq\nu$
$e\gamma \to qqe$
$\gamma\gamma \to qq$
→ Removed with MVA

- Multi-jet background:

$e^+e^- \to qq\nu_e\overline{\nu}_e$ → Large x-sec background, can not be fully suppressed with y_{23} transition

Hee, H→b$\overline{\text{b}}$

- Main background:

$e^+e^- \to e^+e^-qq$ →

Several processes with the same final state, sensitive to b-tagging

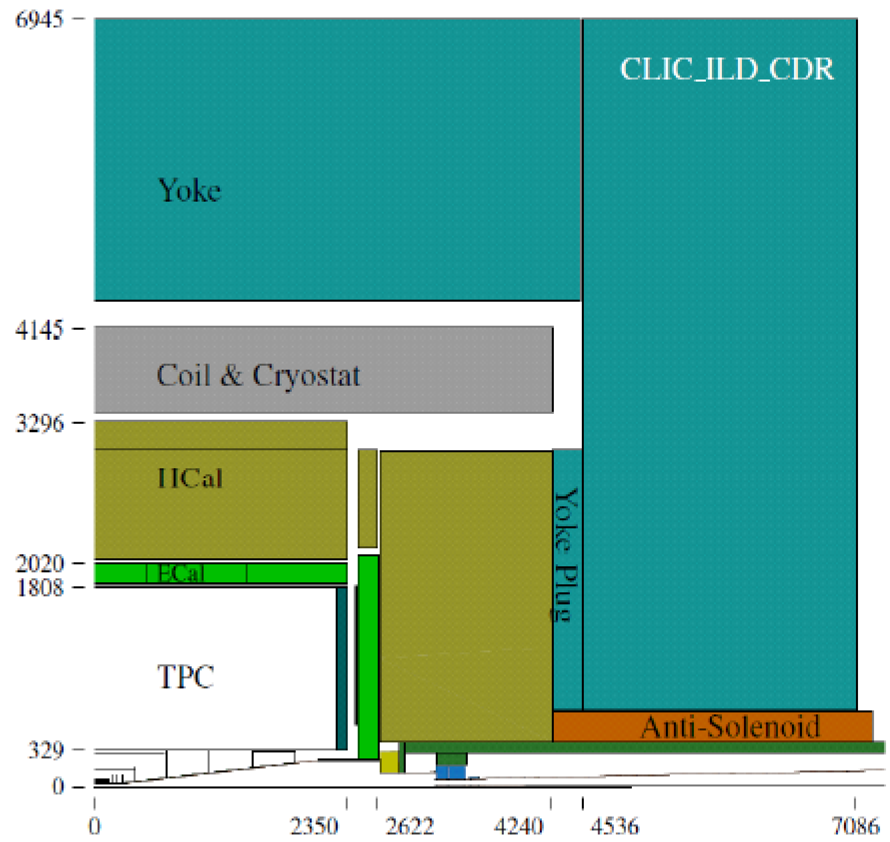
- Other background processes:

$e^+e^- \to e^+e^-ll$ → Rare leptons E>100 GeV

$e^+e^- \to e^+e^-qqqq$
$e^+e^- \to e^-\nu qqe^+\nu$
$e^+e^- \to e^+e^-qqe\nu$
Gives no contribution after preselection

Detector simulation and reconstruction

- Full CLIC_ILD detector simulation
- Overlay of beam-induced background $\gamma\gamma \rightarrow$ hadrons
- Full event reconstruction



H->ZZ* at 1.4 TeV

Gordana Milutinovic-Dumbelovic

Signal and background x-sections

Signal 1 [fb]: $H \to ZZ \to qqqq$	**Signal 2[fb]:** $H \to ZZ \to qqll$
3.45	0.6

Common background [fb]	
$e^+e^- \to qq\nu_e\bar{\nu}_e$	788
$e^+e^- \to qqqq\nu_e\bar{\nu}_e$	24.7
$e^+e^- \to H\nu_e\bar{\nu}_e, H \to WW \to qqqq$	27.6
$e^+e^- \to qq$	4009.5
$e^+e^- \to qqqq$	1245.1
$e^+e^- \to qqqqll$	71.7
$e^+e^- \to qqqql\nu$	115.3
$e^+e^- \to H\nu_e\bar{\nu}_e, H \to b\bar{b}$	136.94
$e^+e^- \to H\nu_e\bar{\nu}_e, H \to ZZ \to qqll / llll$	0.177

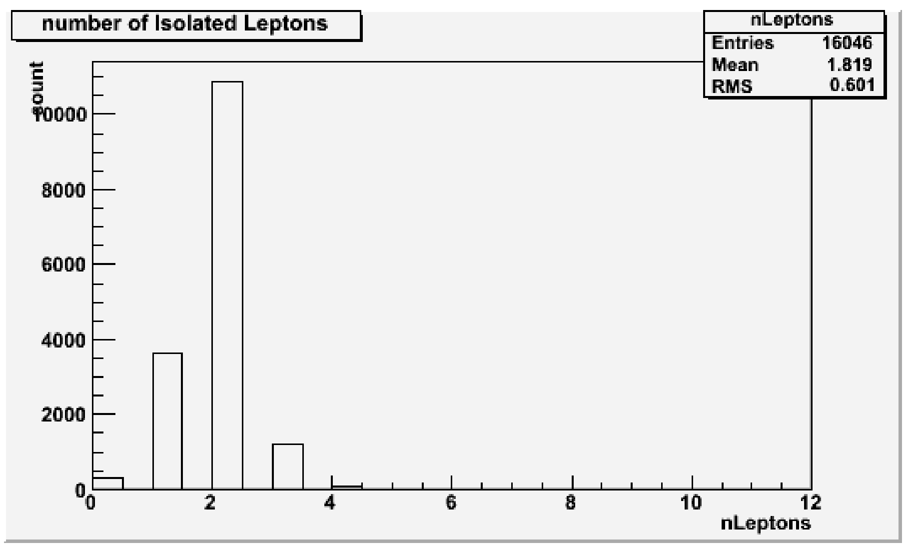
Signal 1 specific background[fb]		**Signal 2 specific background[fb]**	
$e\gamma \to qqq\nu$	338.5	$e^+e^- \to qqll$	2725.8
$\gamma\gamma \to qqqq$	30212	$e\gamma \to qq\nu$	37125.3
$e\gamma \to qqqe$	2891	$e\gamma \to qqe$	63838.8
		$\gamma\gamma \to qq$	112038.6

Analysis strategy

ISOLATED LEPTON FINDER	only for qqll final state
FASTJET	Force events into 4 jets for the qqqq final state and 2 jets for the qqll final state (k_T exclusive, SELECTEDPFOs, R=1.0)
LCFI VERTEX	helps to reduce $e^+e^- \to H\nu_e\bar{\nu}_e, H \to b\bar{b}$
PRESELECTION	helps to reduce large x-sec background
MV SELECTION	Multivariate analysis (BDT) is used to suppress $e\gamma$ and $\gamma\gamma$ background
FINAL RESULTS	Higgs mass distributions are used to estimate statistical uncertainty $\frac{\sqrt{S+B}}{S} * 100\%$

Step by step: Isolated Lepton Finder

- We have to identify e^- and μ form the $H \rightarrow ZZ \rightarrow qqll$ final state
  - Track energy > 7 GeV
  - Energy contained in a cone around the track: $\cos\theta<0.995$
  - Impact parameters: $d_0<0.2$ *mm*, $z_0<0.2$ *mm*, $R_0<0.2$ *mm*
  - ECAL/HCAL depositions: 0.025< μ ECAL to HCAL fraction<0.3, e^- ECAL to HCAL fraction>0.9



74% efficiency in reconstruction of the lepton pair

Step by step: Preselection

- Main aim of the preselection is to reduce large x-sec background

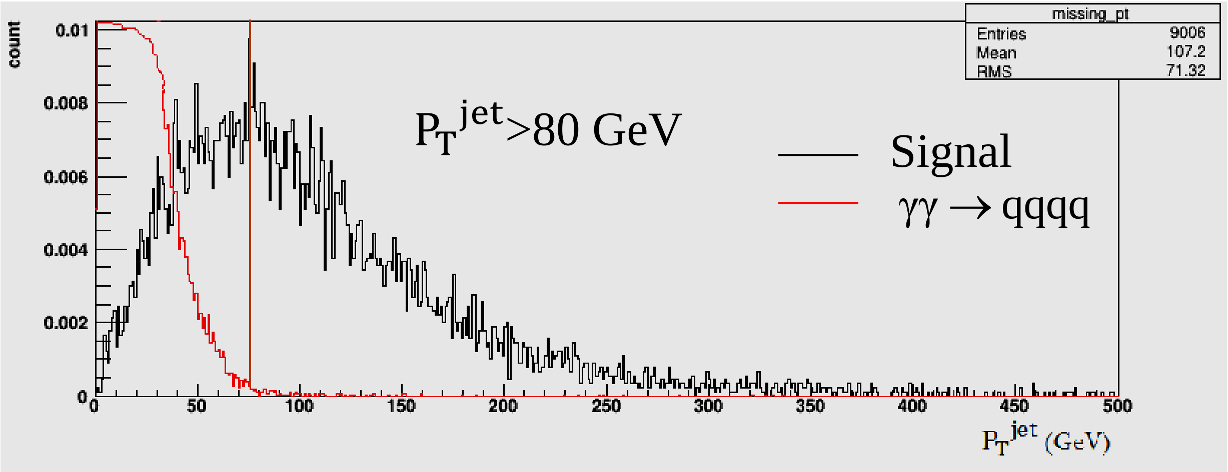
Preselecton for qqqq final state: 45GeV<m_Z<110GeV, m_{Z^*}<65GeV, 90 GeV <m_H<165 GeV, -$\log_{10}y_{34}$<3.5, -$\log_{10}y_{23}$<3.0, 100GeV<E_{vis}<600GeV, P_T^{jet}>80 GeV, $P(b)^{jet1}$ <0.95, $P(b)^{jet2}$ <0.95

Preselecton for qqll final state: It is important to find two isolated leptons

- Dominant remaining background:

For qqqq final state: $H \to WW \to qqqq$ $e^+e^- \to qq\nu_e\overline{\nu_e}$, $e\gamma \to qqq\nu$, $H \to b\bar{b}$

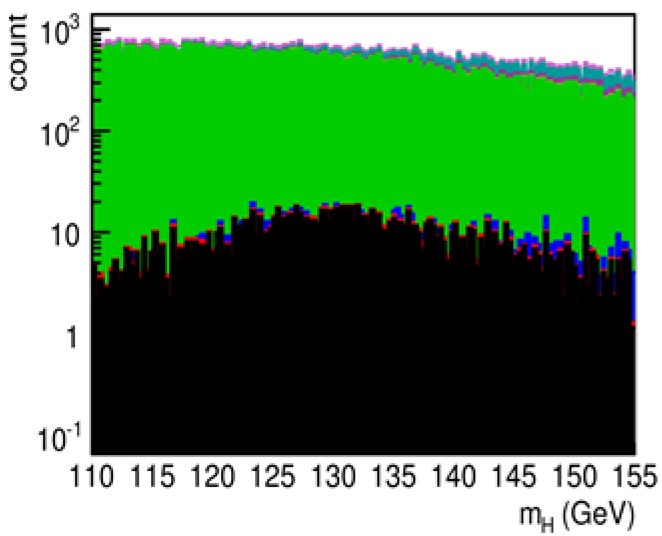
For qqll final state: $e^+e^- \to qqll$, $e\gamma \to qq\nu$, $e\gamma \to qqe$, $\gamma\gamma \to qq$, $H \to b\bar{b}$



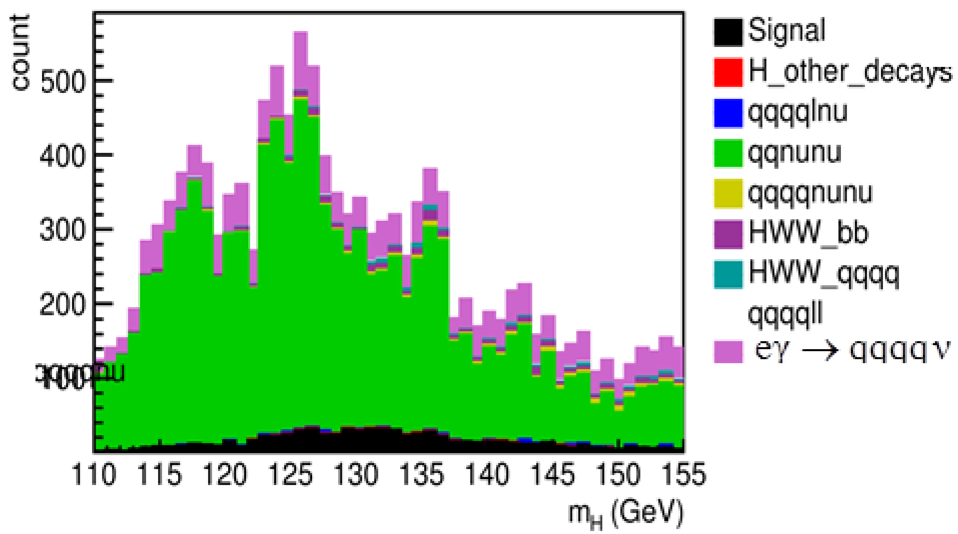
Step by step: MVA analysis

qqqq final state

- BDT is trained on $e^+e^- \to H\nu_e\overline{\nu_e}, H \to b\bar{b}$, $e^+e^- \to qq\nu_e\overline{\nu_e}$, $e\gamma \to qqq\nu$
- TMVA input variables ($m_H, m_Z, m_{Z^*}, E_{vis}$, $-\log_{10}y_{34}$, $-\log_{10}y_{23}$, P_T^{jet}, $P(b)^{jet1}$, $P(b)^{jet2}$, $P(c)^{jet1}$, $P(c)^{jet2}$).
- For combined background all input variables have similar discriminating power



Preselection efficiency 30.2%



Overall signal efficiency 18%

Step by step: MVA analysis

qqqq final state cont.

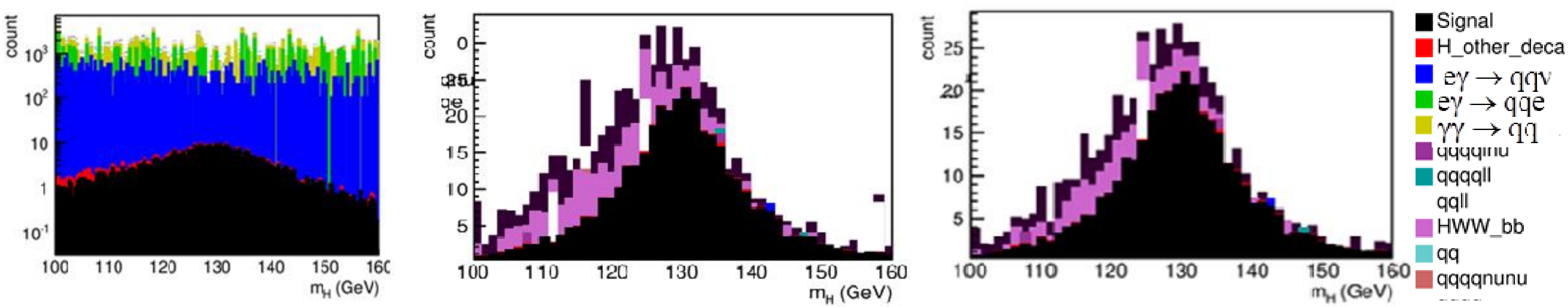
- Preselection efficiency is relatively low due to P_T^{jet} > 80 GeV cut in order to suppress $e\gamma \to qqqq\nu$ and $e\gamma \to qqqqe$
- After MVA $e\gamma \to qqqq\nu$ $(e^+e^- \to qq\nu_e\overline{\nu_e})$ are reduced by factor 2(3).
- Statistical uncertainty of the measurement $(\sigma_{HWW} \times BR)$ is estimated from the Higgs mass distribution after MVA

$$\frac{\sqrt{S+B}}{S} * 100\% = 18.3\%$$

Step by step: MVA analysis

qqll final state cont.

- BDT is trained on total background
- TMVA input variables (m_H, m_Z, m_{Z^*}, E_{vis}, $-\log_{10}y_{34}$, $-\log_{10}y_{23}$, $-\log_{10}y_{12}$, $P(b)^{jet1}$, $P(b)^{jet2}$, $P(c)^{jet1}$, $P(c)^{jet2}$, P_T^{jet}, θ_{Higgs}, E_{vis}- E_{Higgs}, N_{PFOs}).
- Differently from qqqq final state preselection is looser and the final selection (P_T^{jet}<500 GeV, E_{vis}- E_{Higgs}< 220 GeV, 40< N_{PFOs} <160) is applied in order to suppress remaining background.



Preselection efficiency 74%   MVA efficiency 33%   Overall signal efficiency 33%

$$\frac{\sqrt{S+B}}{S}*100\% = 6.1\ \%$$

Results

$H \to ZZ \to qqqq$	
ε_S	**18%**
$\sigma_{WWH} \times BR(H \to ZZ \to qqqq)$	**3.45 fb**
$\delta(\sigma_{WWH} \times BR(H \to ZZ \to qqqq))$	**18.3%**

$H \to ZZ \to qqll$	
ε_S	**33%**
$\sigma_{WWH} \times BR(H \to ZZ \to qqll)$	**0.6 fb**
$\delta(\sigma_{WWH} \times BR(H \to ZZ \to qqll))$	**6.1%**

- For the qqqq final state, uncertainty of the measurement is dominated by background with large x-sections and by irreducible background with the same topology as the signal
- For the qqll final state, uncertainty of the measurement is dominated by background from WW fusion processes, $e^+e^- \to H\nu_e\bar{\nu}_e, H \to WW$ and $e^+e^- \to H\nu_e\bar{\nu}_e, H \to b\bar{b}$
- Unpolarized beams are assumed. Statistics can be improved with polarization due to the boost of the production x-section.
- *Further optimisation of the Isolated Lepton finder will be done to (slightly) increase efficiency in reconstruction of the lepton pair. τ leptons will be included in the analysis.*

Higgs production in ZZ fusion

Aidan Robson

Analysis strategy

FASTJET — Events forced into 4-jet (k_T exclusive clustering of PFOs, R=1.0)

↓

SIMPLE KINEMATIC SELECTION — 2 opposite-charge electrons, E>100GeV and separated $\Delta\eta$>1

↓

LCFI VERTEX — b-tag for final state

↓

MV SELECTION — Multivariate likelihood analysis

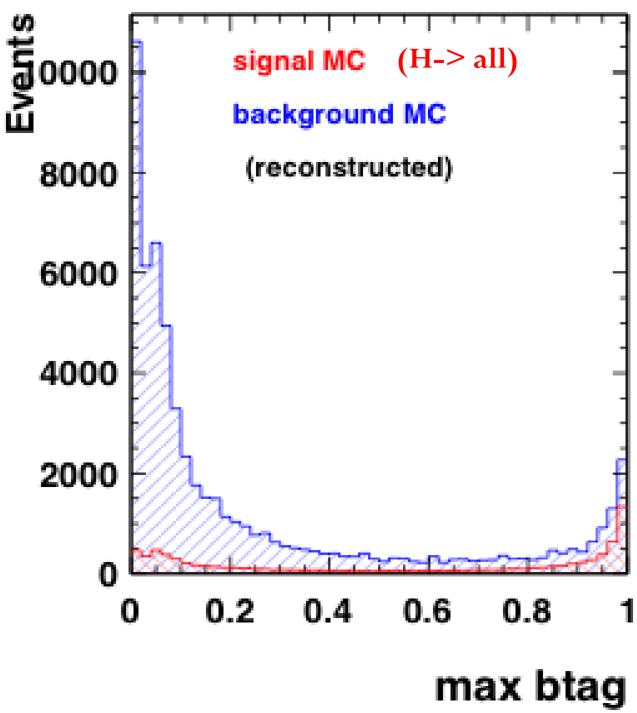
↓

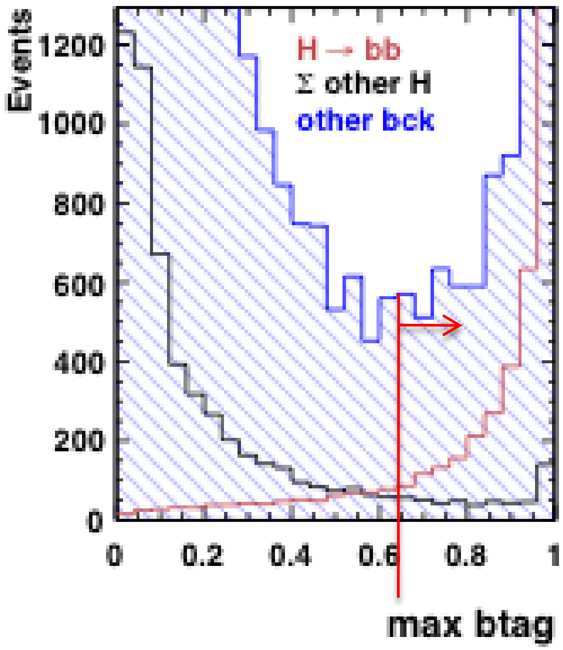
FIT — Extract statistical uncertainty $\delta(\sigma_{ZZH} \times BR(H \rightarrow b\bar{b}))$

b-tagging final state

- After kinematic pre-selection:
- In 4-jet exclusive clustering, identify two jets that match $e^{\pm}$ candidates, and look at larger b-tag of other two jets ('max btag')
- Using LCFIVertex and generic Zvv, Z->bb/cc/light datasets to train

- all Higgs decays included here





- Choose max btag > 0.65

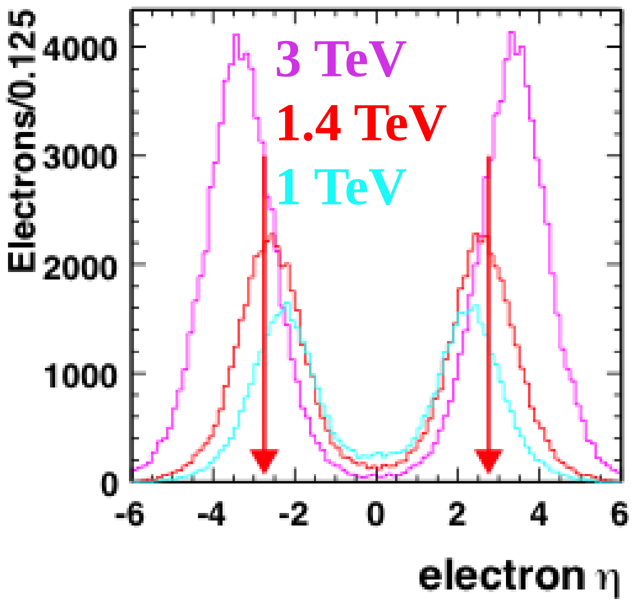
Preselection + btag

Major acceptance loss is geometrical effect of electrons falling outside detector

	Signal $e^+e^- \rightarrow He^+e^-, H \rightarrow b\bar{b}$		qqll background	
	surviving	σ(fb)	surviving	σ(fb)
All events		13.47		2726.7
==2 electron cands, *E*>100GeV	28.0%	3.77	2.1%	56.86
opposite charge	27.6%	3.72	2.0%	54.41
Δη>1	26.5%	**3.56**	1.8%	**48.12**
Max btag > 0.65	19.3%	**2.6**	0.2%	**6.44**

Preselection + btag

Major acceptance loss is geometrical effect of electrons falling outside detector

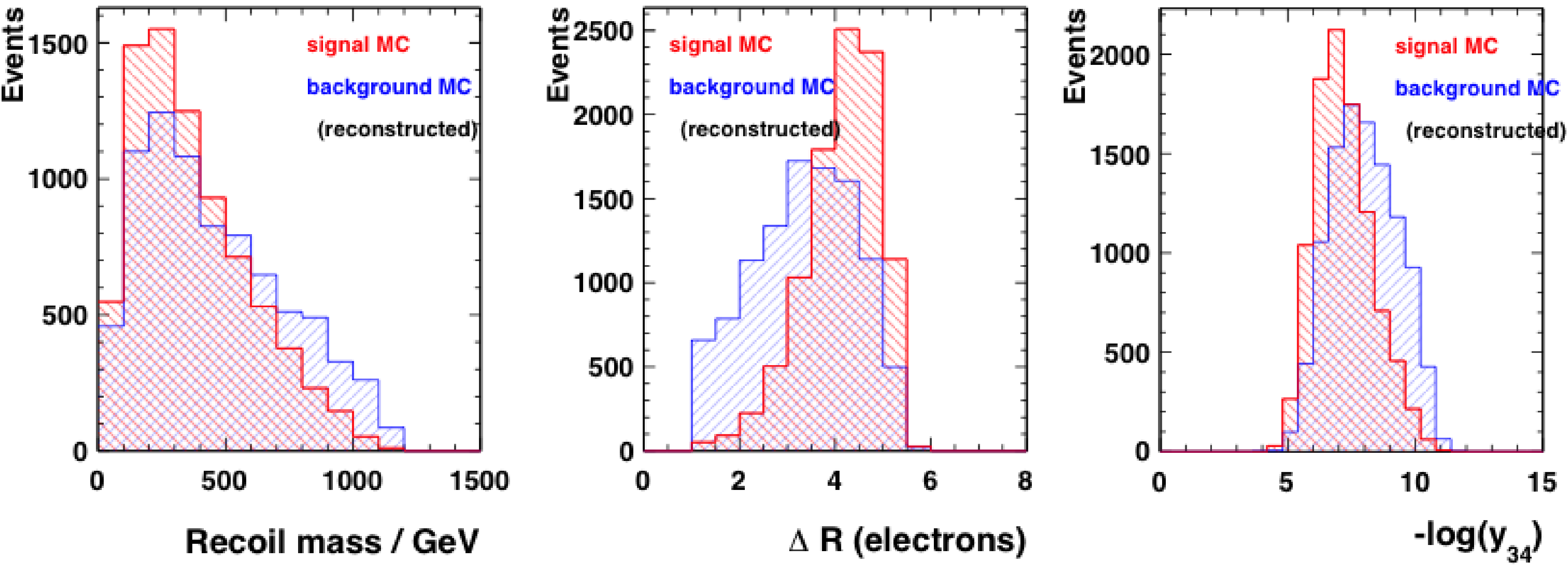


$e^+e^- \to He^+e^-, H \to b\bar{b}$ Signal		qqll background	
surviving	σ(fb)	surviving	σ(fb)
	13.47		2726.7
28.0%	3.77	2.1%	56.86
27.6%	3.72	2.0%	54.41
26.5%	**3.56**	1.8%	**48.12**
19.3%	**2.6**	0.2%	**6.44**

Separating signal from background

- Look for event variables to characterise signal
  - separation between electrons ΔR
  - recoil mass
  - y_{34} to characterise final state shape

fairly independent of decay mode, for visible decays



Background normalised to **signal** here

Likelihood incorporating final state jets

- ΔR between tagging electrons
- recoil mass
- y_{34}
- m_{jj}

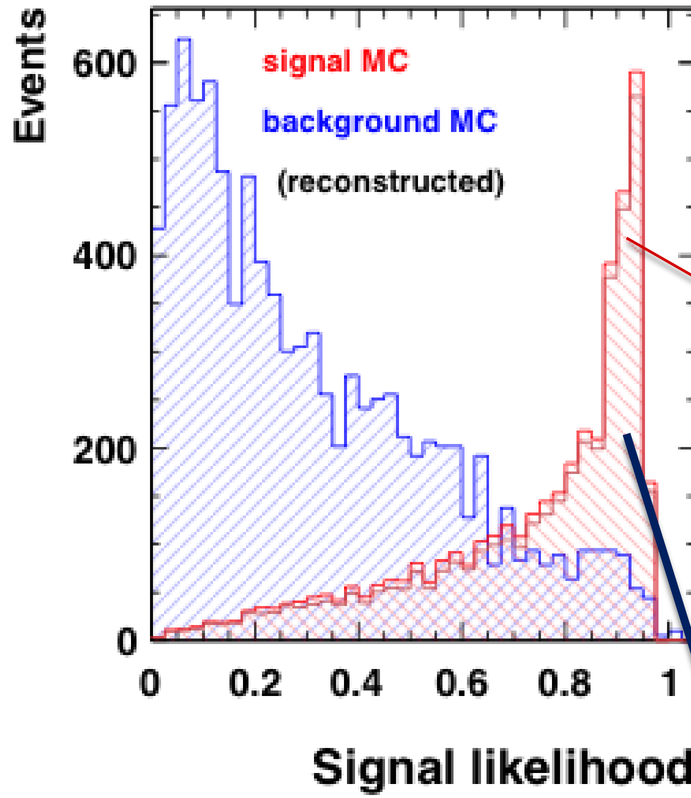
Construct probabilities:

$$L_{sig} = P_{sig}(\Delta R) \times P_{sig}(m_{recoil}) \times P_{sig}(y_{34}) \times P_{sig}(m_{jj})$$

Signal likelihood:

$$\mathcal{L}_{sig} = \frac{L_{sig}}{L_{sig} + L_{bck}}$$

after max b-tag requirement



normalised to 1.5 ab^{-1}

$H \to all$ and showing component that is $H \to b\bar{b}$

4190 $ZZ \to H$ events in 1.5 ab^{-1} of which 3880 are $ZZ \to H \to b\bar{b}$

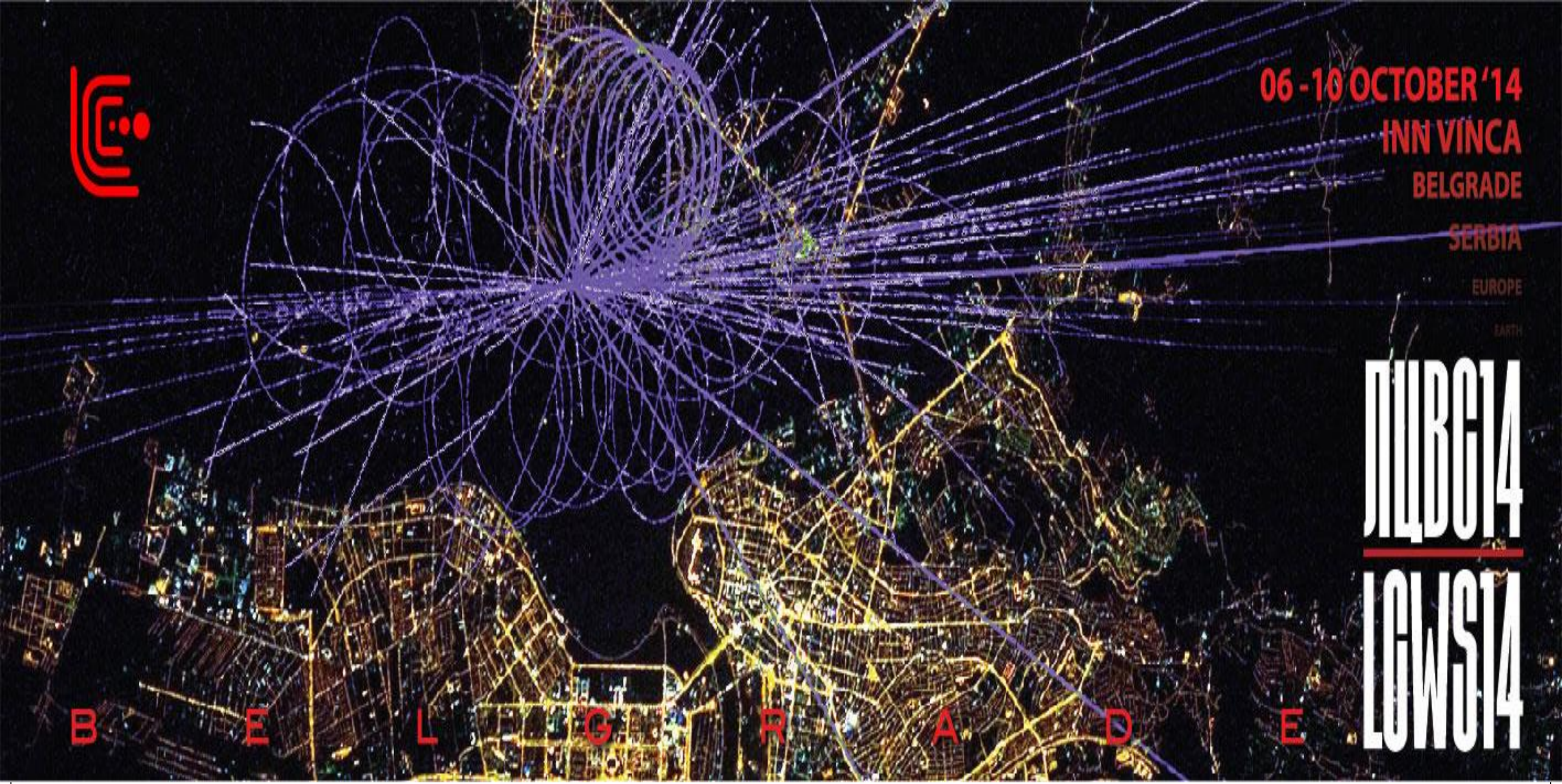
Results

$e^+e^- \to He^+e^-, H \to b\bar{b}$	
$\boldsymbol{\varepsilon_S}$	**19.3%**
$\boldsymbol{\sigma_{ZZH} \times BR(H \to b\bar{b})}$	**13.74 fb**
$\boldsymbol{\delta(\sigma_{ZZH} \times BR(H \to b\bar{b}))}$	**1.7%**

- Systematic effects of 0.3% from limited knowledge of beam spectrum and 0.5% from b-tagging give total uncertainty 1.7%.
- Measurement proportional to $\frac{g^2_{HZZ} \cdot g^2_{Hbb}}{\Gamma_H}$ and result is included in global Higgs fit to contribute to g_{HZZ} determination.

Conclusion

- Two analysis at 1.4 TeV CLIC are presented: $\sigma_{WWH} \times BR(H \to ZZ^*)$ and $\sigma_{ZZH} \times BR(H \to b\bar{b})$.
- Full simulation of physics and background processes is performed with the CLIC_ILD detector model at 1.4 TeV cms energy.
- These measurements allow us to access $\frac{g^2_{HWW} \cdot g^2_{HZZ}}{\Gamma_H}$ and $\frac{g^2_{HZZ} \cdot g^2_{Hbb}}{\Gamma_H}$ and contribute to the global fit.
- Corresponding statistical accuracies are:
  a. 18.3% $(\sigma_{WWH} \times BR(H \to ZZ^* \to qqqq))$
  b. 6.1% $(\sigma_{WWH} \times BR(H \to ZZ^* \to qqll))$
  c. 1.7% $(\sigma_{ZZH} \times BR(H \to b\bar{b}))$
- Statistical accuracies are dominantly coming from: irreducible background and limited statistic of the signal in a and b,c respectively.
- Overall uncertainty of all measurements is dominated by statistics.



ХВАЛА

THANK YOU

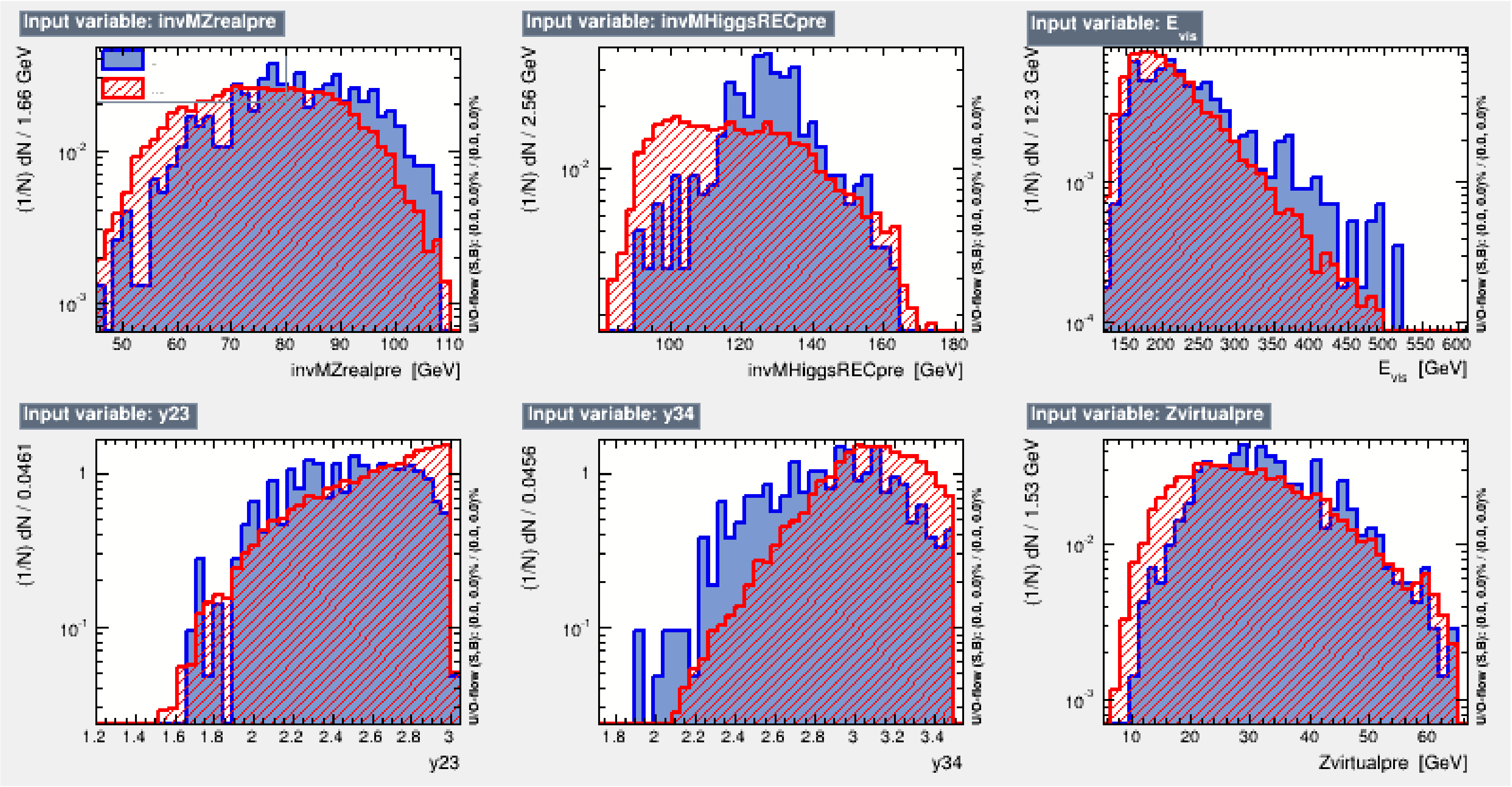
BACK UP

MVA analysis

Signal

Background

$$e^+e^- \to H\nu_e\overline{\nu_e}, H \to bb$$
$$e^+e^- \to qq\nu_e\overline{\nu_e}$$
$$e\gamma \to qqqq\nu$$

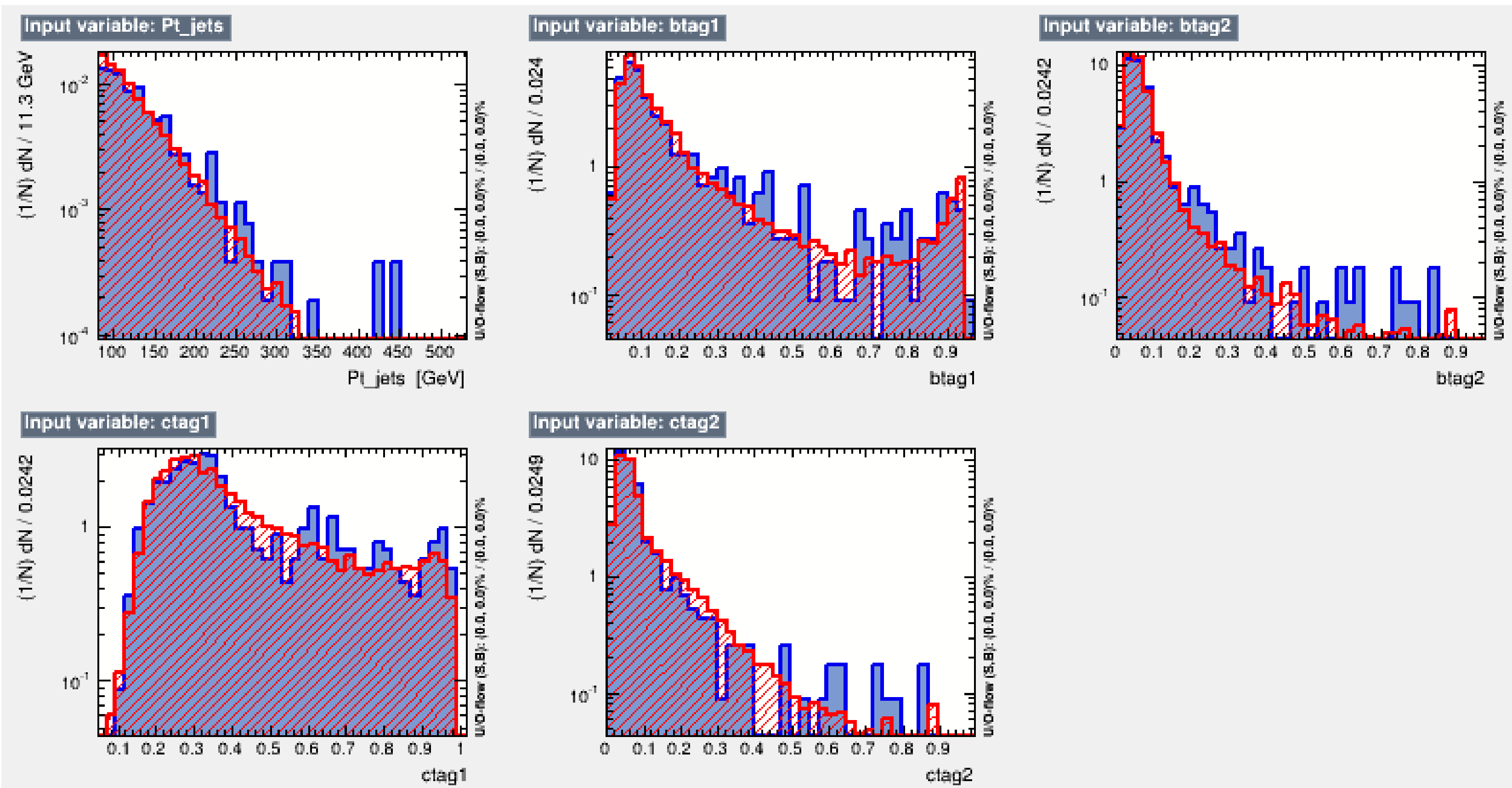


MVA analysis

Signal

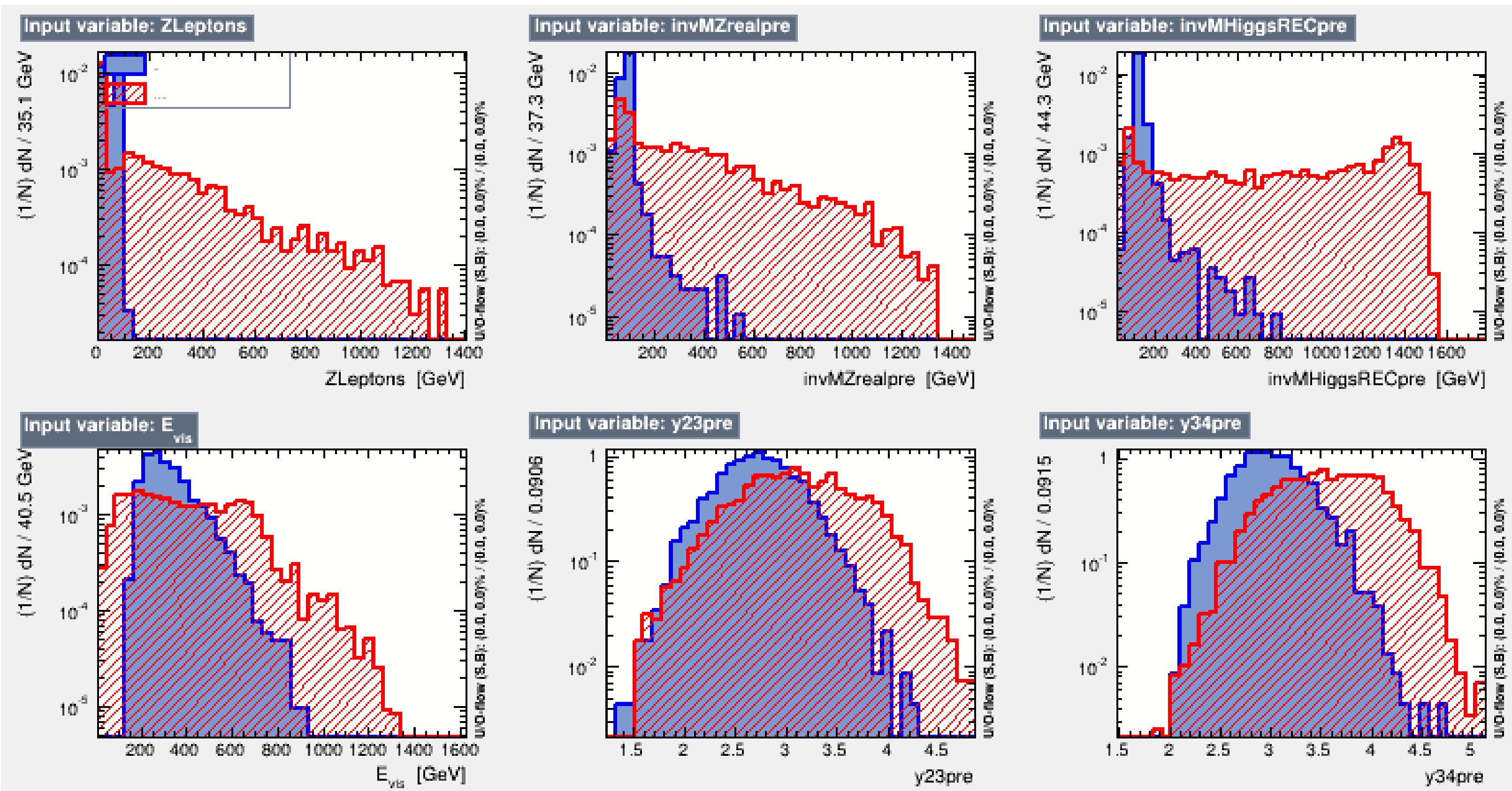
Background

$$e^+e^- \rightarrow H\nu_e\overline{\nu_e}, H \rightarrow bb$$
$$e^+e^- \rightarrow qq\nu_e\overline{\nu_e}$$
$$e\gamma \rightarrow qqqq\nu$$

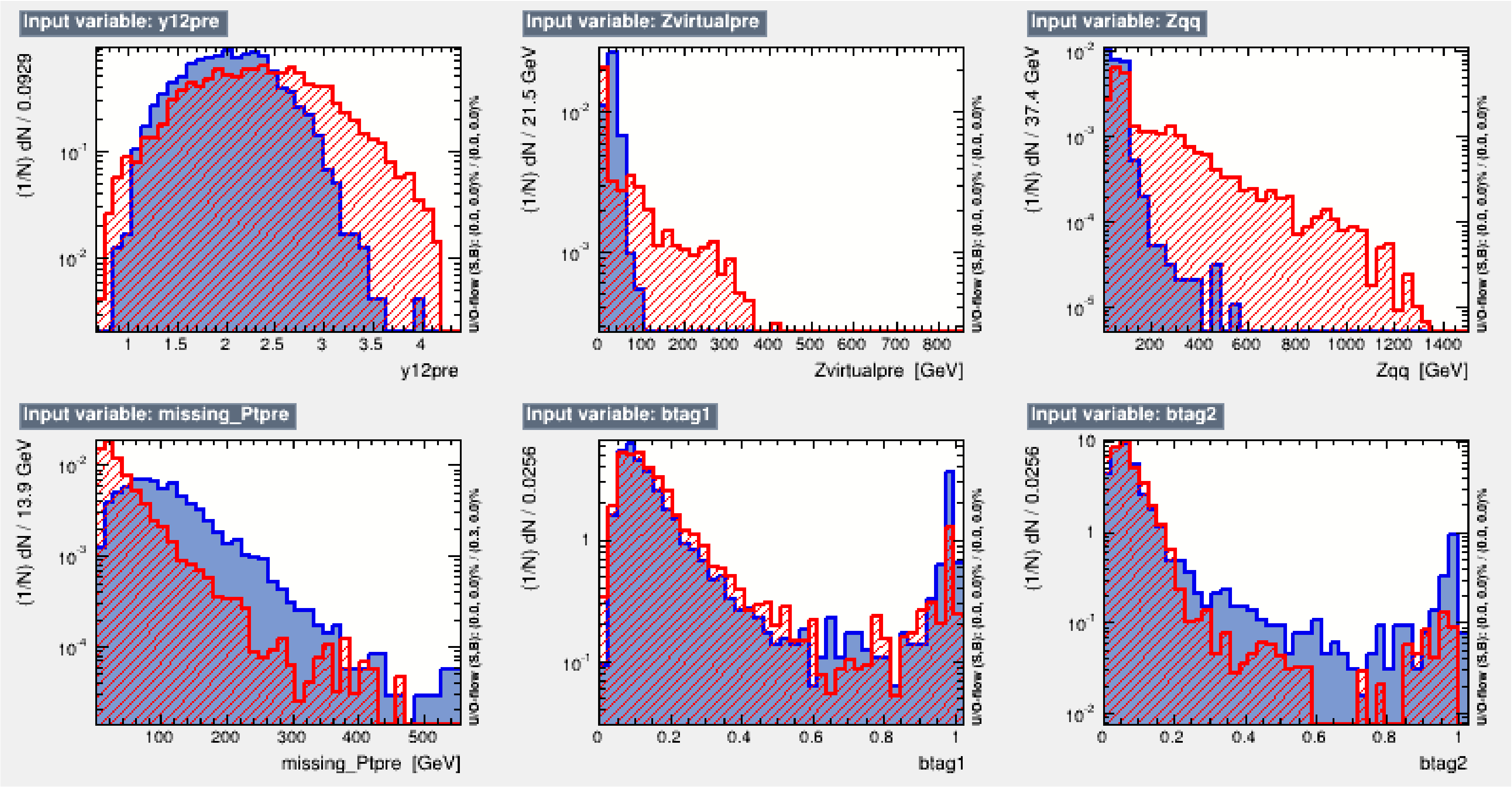


MVA analysis

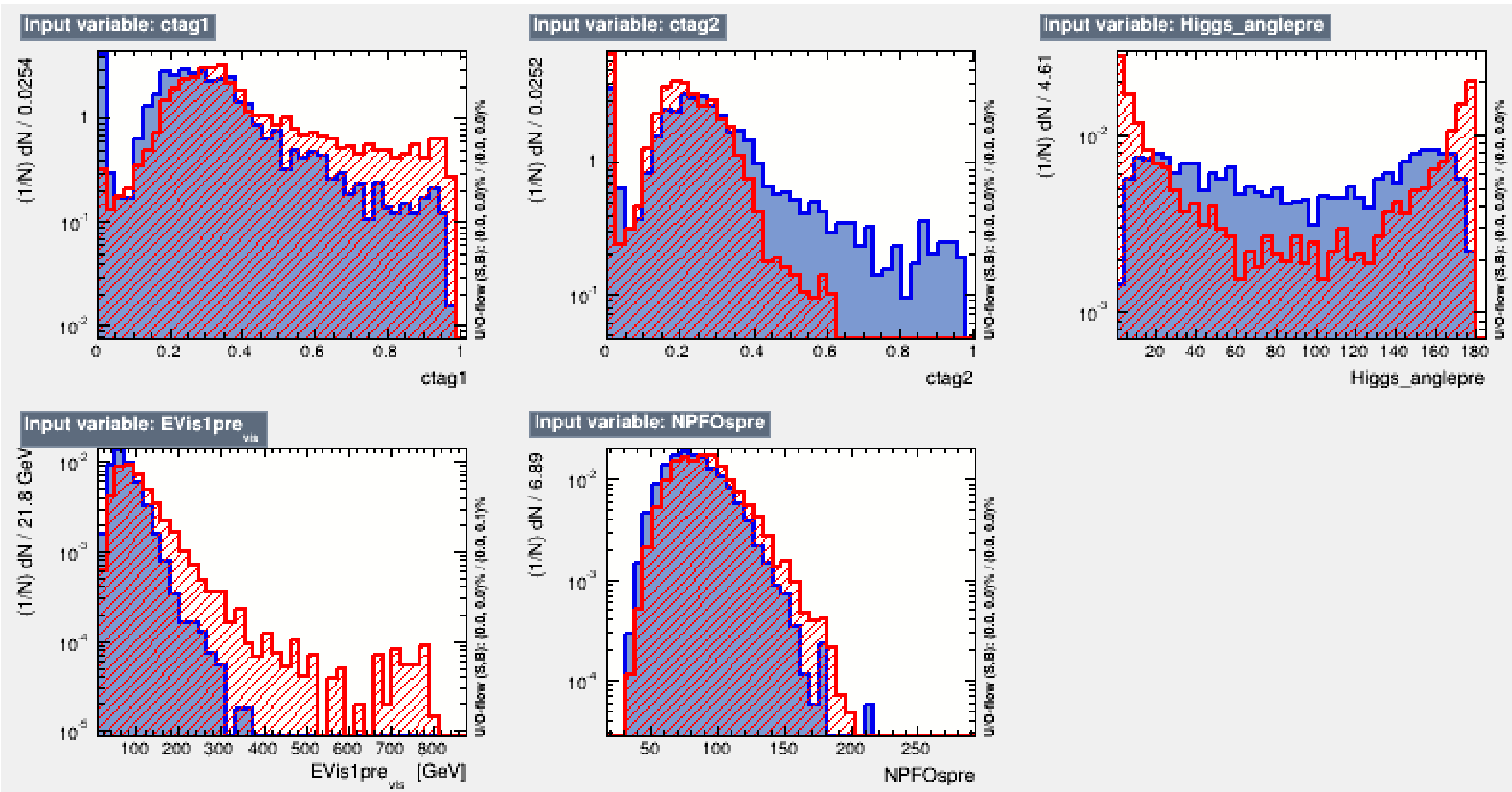
- TMVA trained with sensitive observables (m_{Z1}, -log (y_{34}), -log(y_{23}), -log(y_{12}), $P(b)^{jet1}$, $P(b)^{jet2}$, $P(c)^{jet1}$, $P(c)^{jet2}$, Evis, missing_Pt, Higgs_angle, m_H, Zleptons, Zqq, Evis1, NPFOs) on total background



MVA analysis



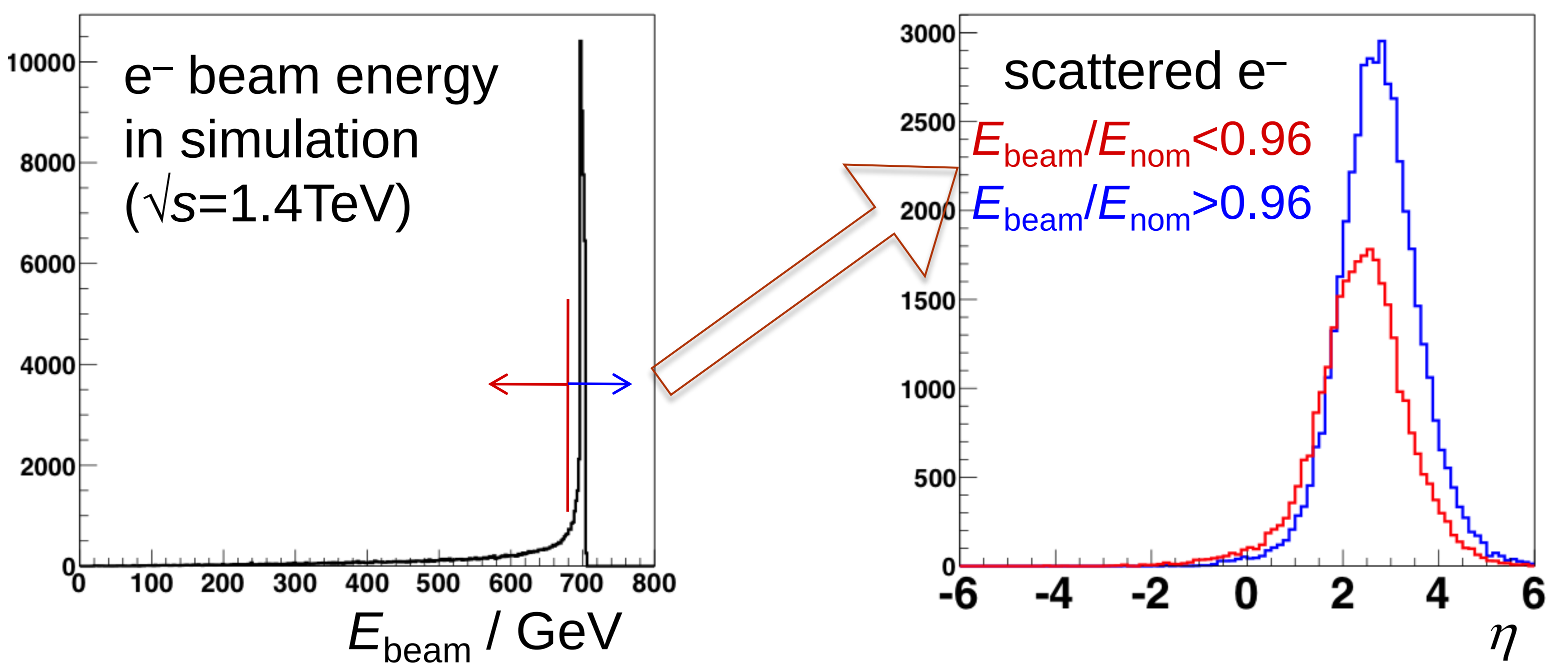
MVA analysis



Beam spectrum systematic

Detector acceptance cuts into electron η distribution.
To measure cross-section need to know acceptance.
Beam spectrum?

Just before hard scatter: After hard scatter:



Low tail is important in this measurement. How well do we know it?

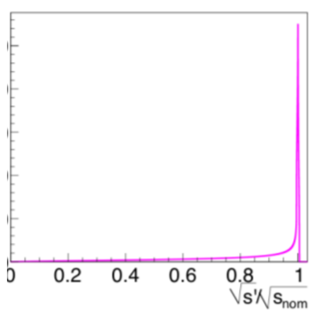
Beam spectrum systematic

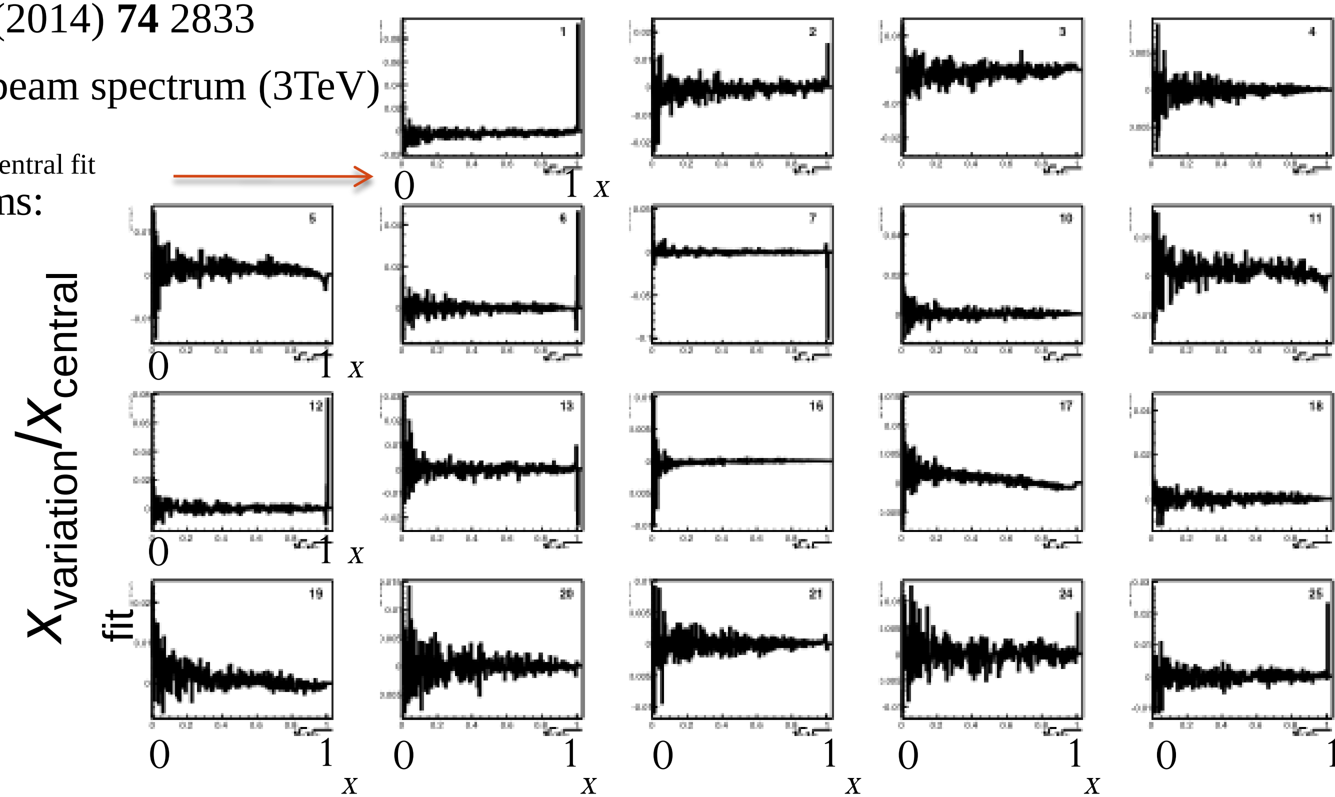
Beam spectrum is determined from data: *Luminosity spectrum reconstruction at linear colliders*
Sailer & Poss Eur. Phys. J. C (2014) **74** 2833

Parameterised model fitted to beam spectrum (3TeV)

Ratios of histograms $x_{variation}/x_{central\ fit}$
for +1s variations in fit params:

$x = \sqrt{s_{effective}}/\sqrt{s_{nominal}}$





These are used to reweight $x = \sqrt{s_{effective}}/\sqrt{s_{nominal}}$ distribution in ZZ fusion signal MC by±1s variations for 19 parameters (ie propagating the uncertainties only)
Looked at effect on *h* distribution of scattered electrons, and total acceptance.
Acceptance variations combined using parameter correlation matrix.
Resulting systematic on cross-section is ± 0.3 %