Determination of Higgs Width Uncertainty in $ee \rightarrow HZ, H(ZZ^{*}) \rightarrow 4l + xx$ Final State at FCC-ee

(FCC-ee Simulations)

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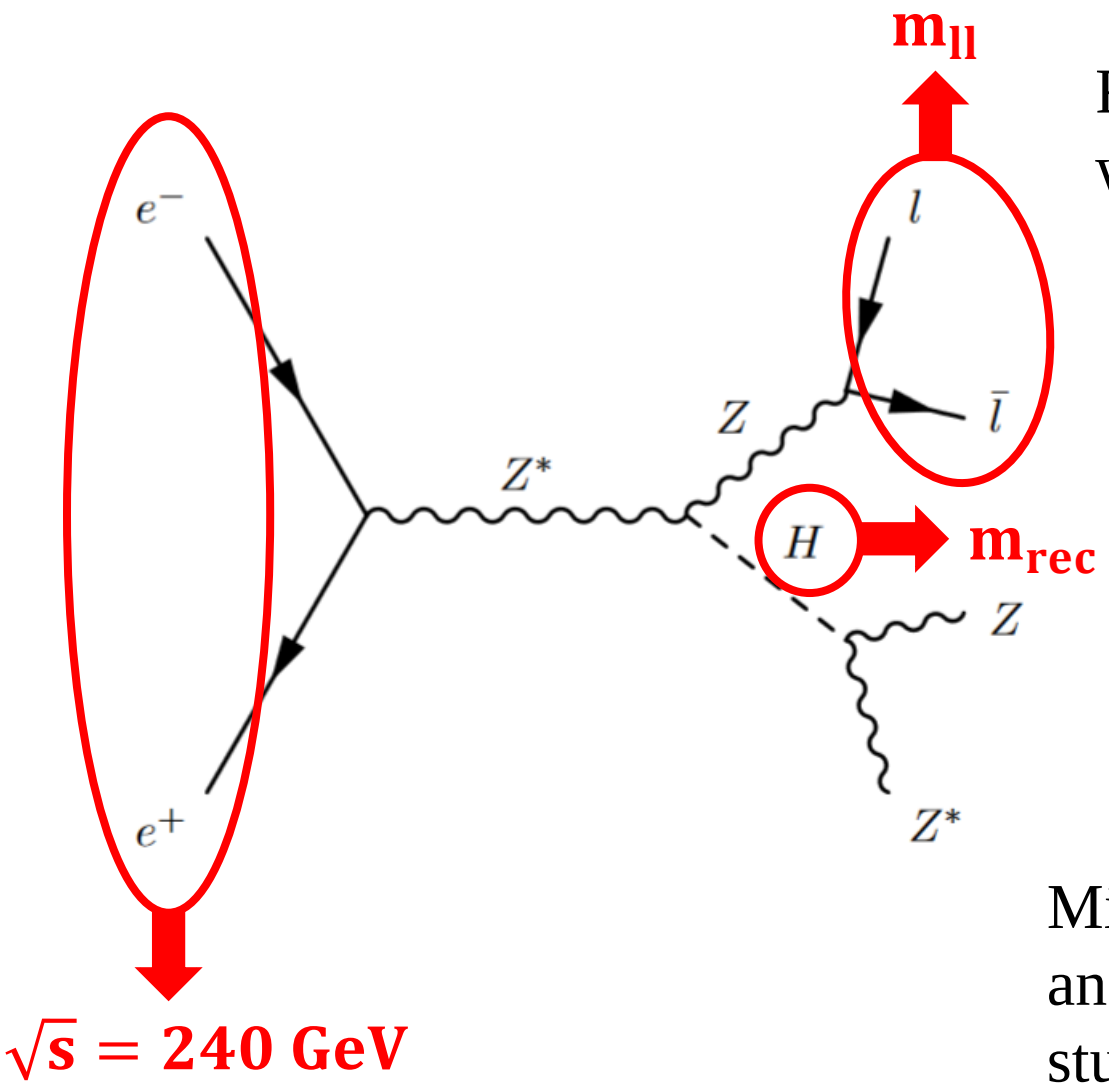
2023-2024

Signal: ZH, H(ZZ*)



Recoil mass method to measure ZH cross section without any assumption about Higgs branching ratios

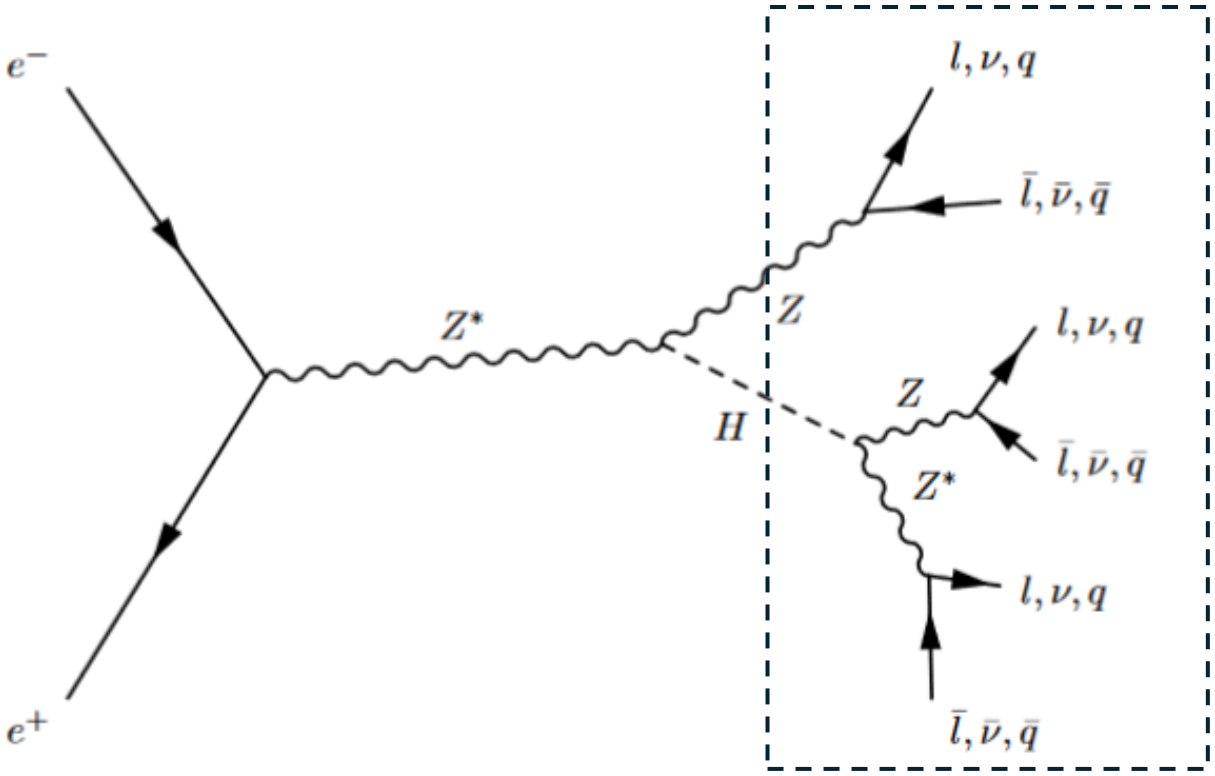
$$m^2_{rec} = (\sqrt{s} - E_{ll})^2 - p^2_{ll} \longrightarrow \sigma_{tot}(ee \to VH)$$

Combine with measurements of exclusive Higgs decay cross sections to extract total width Γ_H

$$\frac{\sigma_{tot}}{\sigma(ee \to VH, H(ZZ^*))}\Gamma_{ZZ} \longrightarrow \Gamma_H$$

Mixed final states (different combinations of ll jj νν) and 4 jets final states (ll jj jj) have already been studied studied by Ines Combes.

Signal: ZH, H(ZZ^*)



$ZH, H(ZZ^*)$ Feynman diagram with possible decays of the Z bosons.

Decay	Fraction
$l\bar{l}$ $(e^+e^-, \mu^+\mu^-, \tau^+\tau^-)$	~10 %
$\nu\bar{\nu}$ $(\nu_e\bar{\nu}_e, \nu_\mu\bar{\nu}_\mu, \nu_\tau\bar{\nu}_\tau)$	~20 %
$q\bar{q}$ $(u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}, b\bar{b})$	~70 %

Main decays of the Z boson.

The decays we are interested in: **HZ, H(ZZ^*) → 4l + xx**

- **Z(ll) Z(ll) Z(jj)**
- **Z(ll) Z(ll) Z($\nu\nu$)**

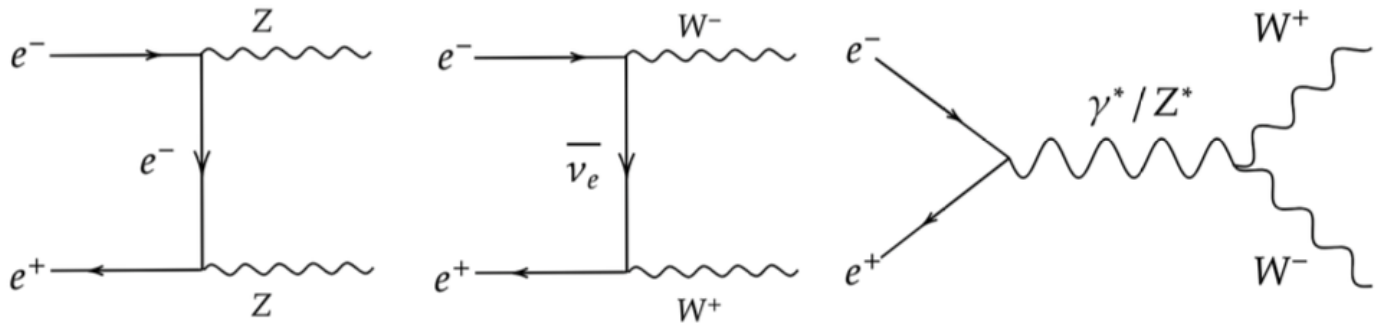
→ **2 on shell leptonic Z**

- **Z(ll) Z(jj) Z(ll)**
- **Z(ll) Z($\nu\nu$) Z(ll)**
- **Z(jj) Z(ll) Z(ll)**
- **Z($\nu\nu$) Z(ll) Z(ll)**

→ **1 on shell leptonic Z and 1 off shell leptonic Z**

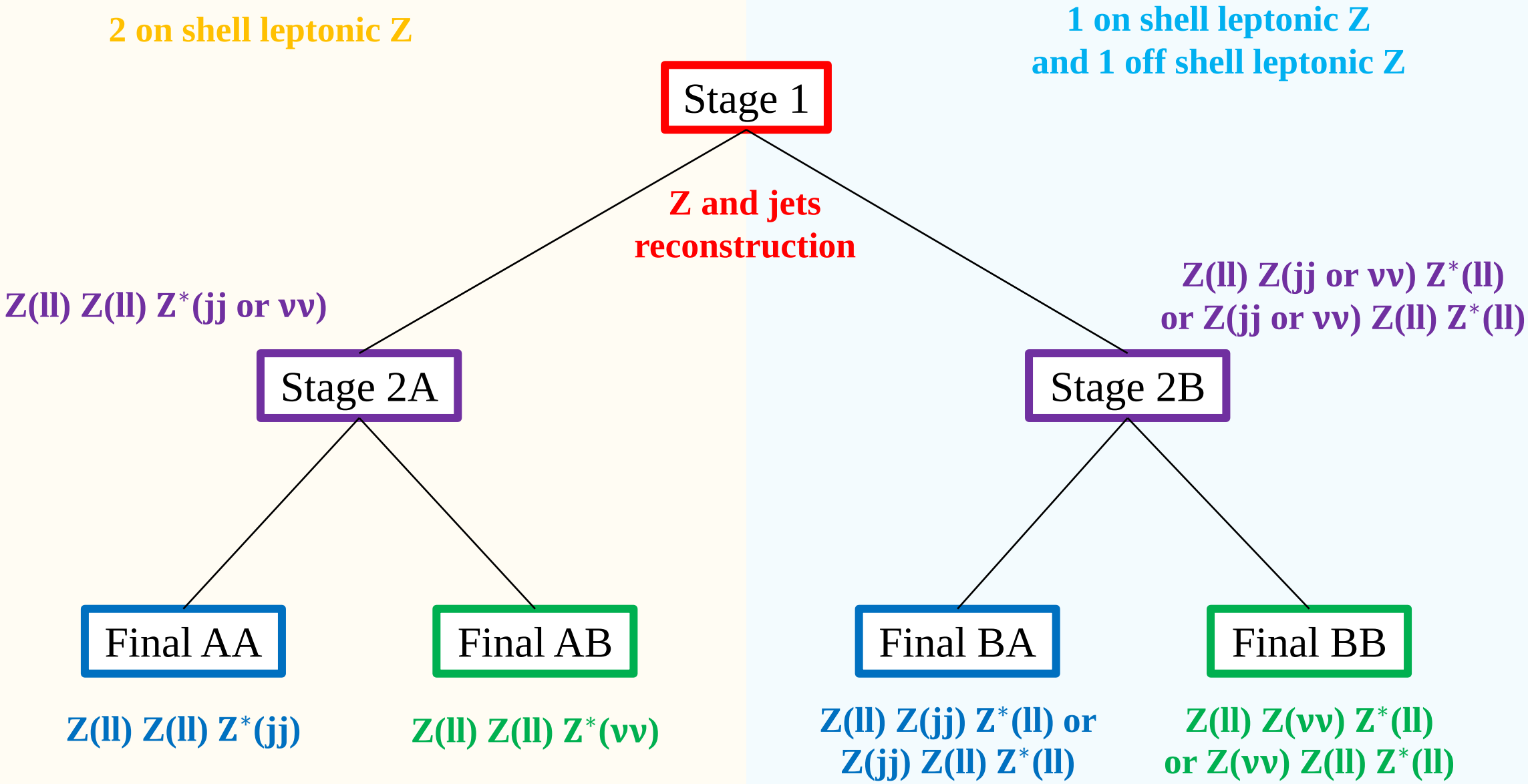
Background

- ee → ZZ (1% of the data)
- ee → WW (0.1% of the data)



- ee → ZH, Z(ee, μμ, νν) with **other Higgs decays** { **H → WW**, **H → ττ**, **H → μμ**, **H → qq (cc, ss, bb)**, **H → gg**, **H → Zγ**, **H → γγ**

Analysis Stages



Analysis Stages

Stage 1

Z reconstruction with a loose preselection on the leptons and jets reconstruction

In Stage 1, we reconstruct up to three leptonic Z bosons: two "on shell" Z from electrons and muons with $p \in [20, 80]$ GeV (**on_Z_leptonic**) and one "off shell" Z from electrons and muons with $p > 5$ GeV (**off_Z_leptonic**).

All the particles, except the leptons that reconstructed the Z bosons, are used to reconstruct **jets** through the Durham algorithm.

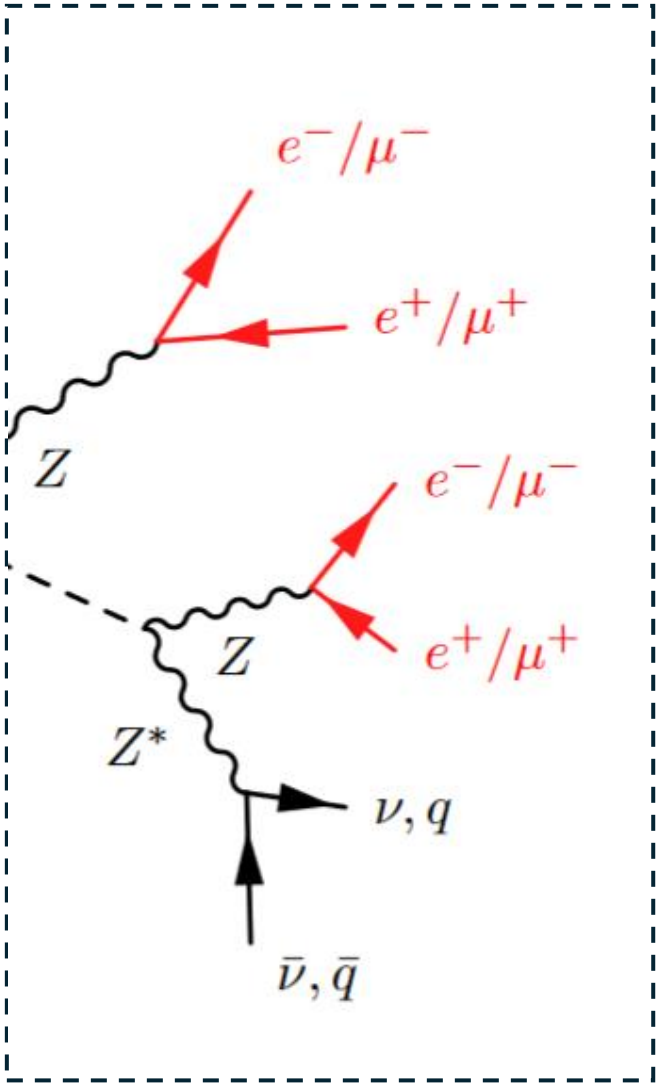
Analysis Stages

Stage 1

Stage 2A

Considering 2 on shell leptonic Z bosons
Z(ll) Z(ll) Z^*(jj or νν)

$$\begin{cases} \text{Number(on\_Z\_leptonic)} = 2 \text{ which gives } \boldsymbol{Z_a} \text{ and } \boldsymbol{Z_b} \\ \text{Number(off\_Z\_leptonic)} = 0 \end{cases}$$



Analysis Stages

Stage 1

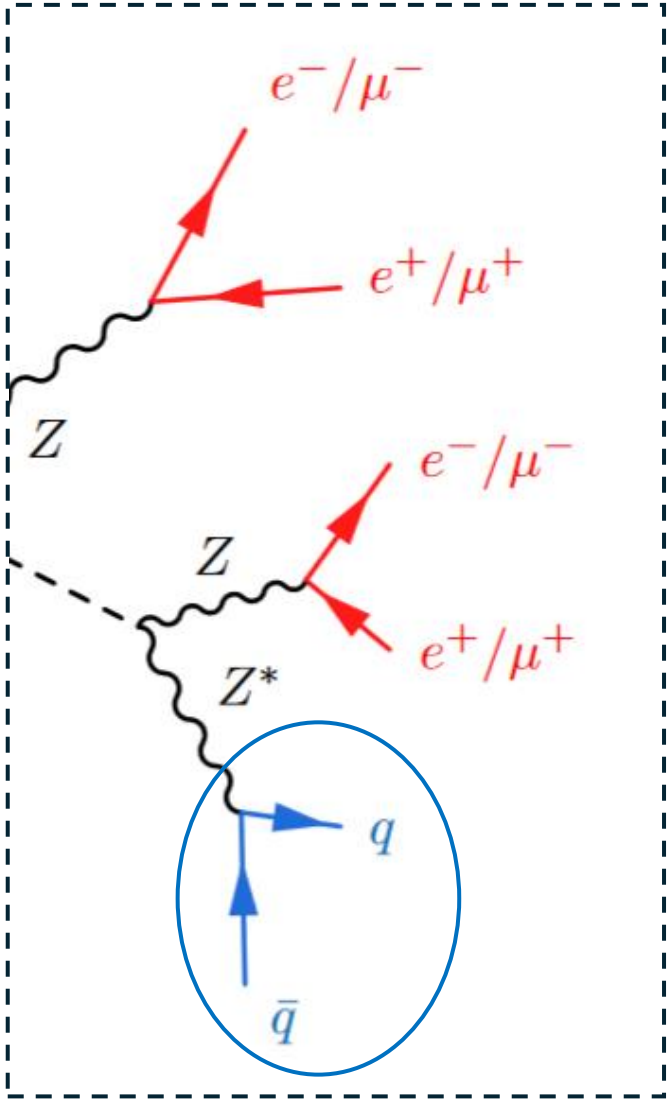
Stage 2A

Final AA

Z(ll) Z(ll) Z*(jj)

We consider that the off shell Z decays into two quarks: jj (dijet)

$E_{miss} < 8$ GeV + additional conditions on the Z and jj masses



Analysis Stages

Stage 1

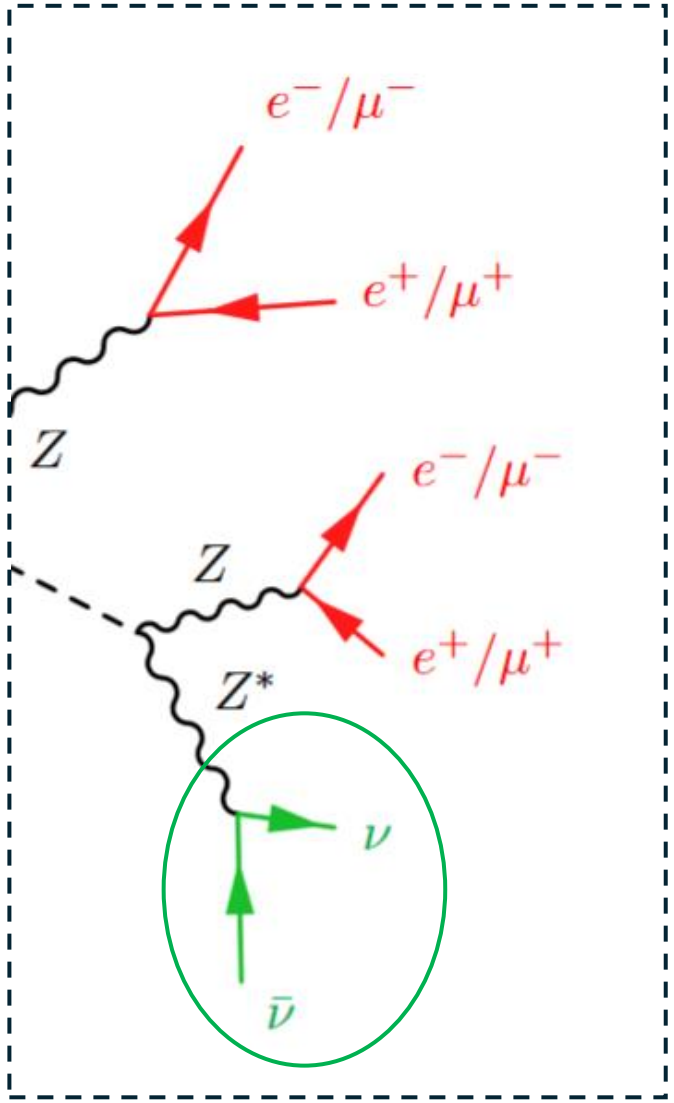
Stage 2A

Final AB

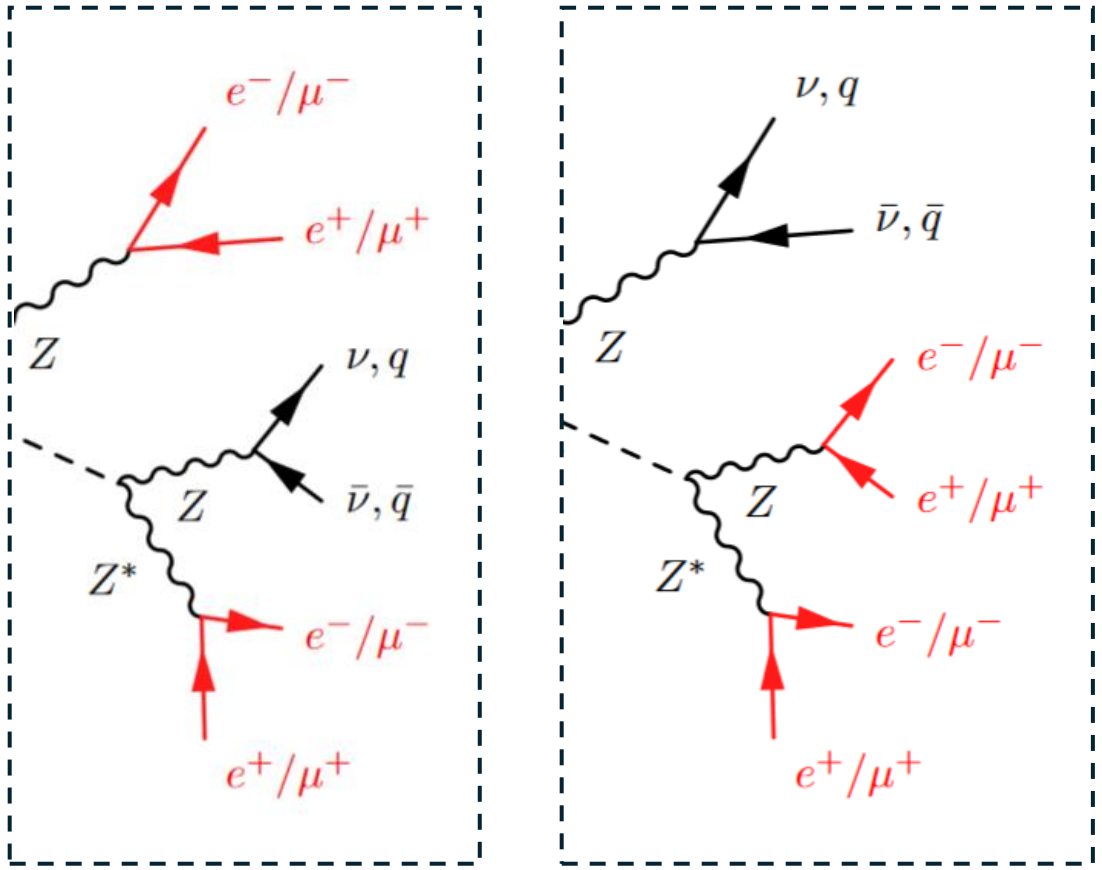
We consider that the off shell Z decays into two neutrinos

$E_{miss} > 8$ GeV + additional conditions on the Z masses

Z(ll) Z(ll) Z^*(νν)



Analysis Stages



Stage 1

Stage 2B

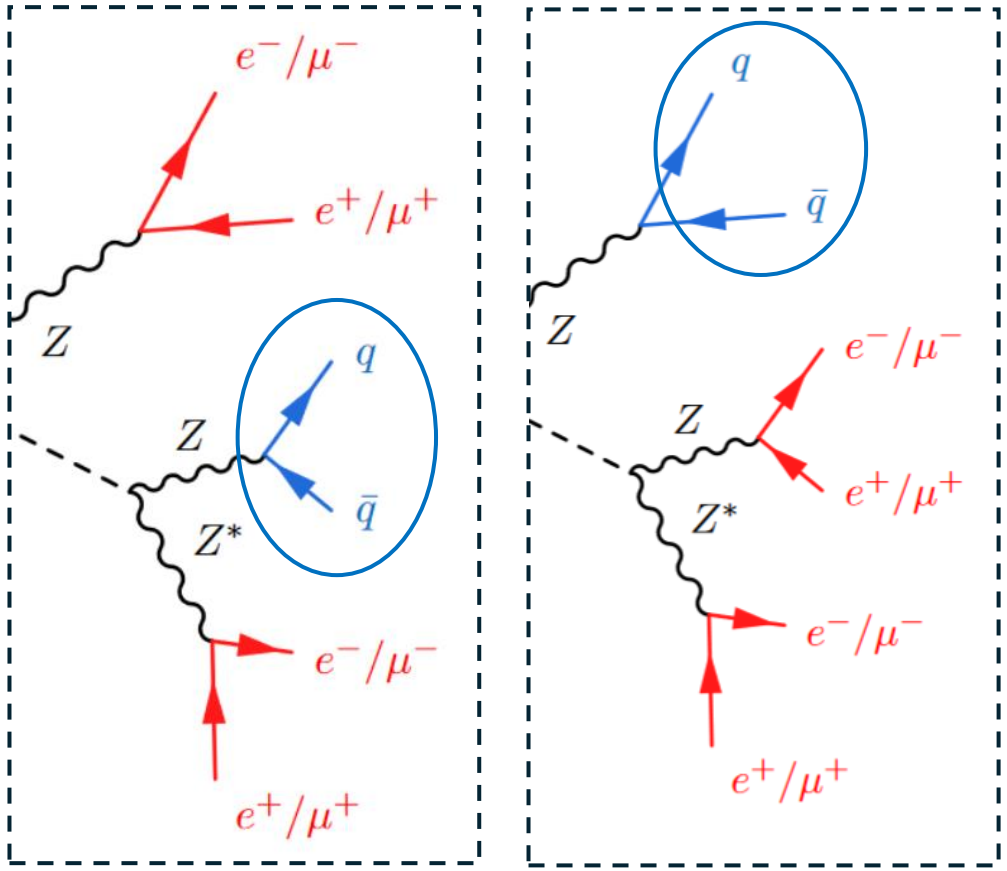
Considering 1 on shell leptonic Z and 1 off shell leptonic Z

Z(ll) Z(jj or νν) Z*(ll)

or Z(jj or νν) Z(ll) Z*(ll)

$$\begin{cases} \text{Number(on\_Z\_leptonic)} = 1 \text{ which gives } \boldsymbol{Z_a} \\ \text{Number(off\_Z\_leptonic)} = 1 \text{ which gives } \boldsymbol{Z_b} \end{cases}$$

Analysis Stages



Stage 1

Stage 2B

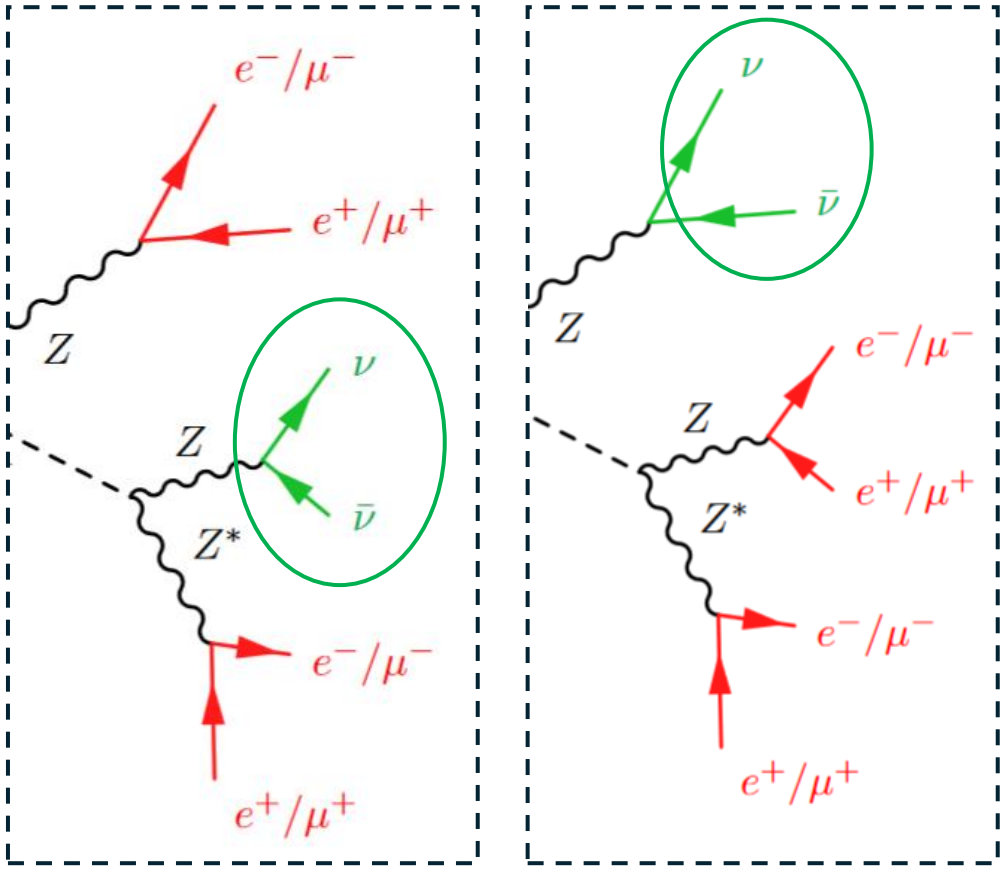
Final BA

Z(ll) Z(jj) Z*(ll) or Z(jj) Z(ll) Z*(ll)

The remaining on shell Z decays into two quarks: jj

$E_{miss} < 8$ GeV + additional conditions on the Z and jj masses

Analysis Stages



Stage 1

Stage 2B

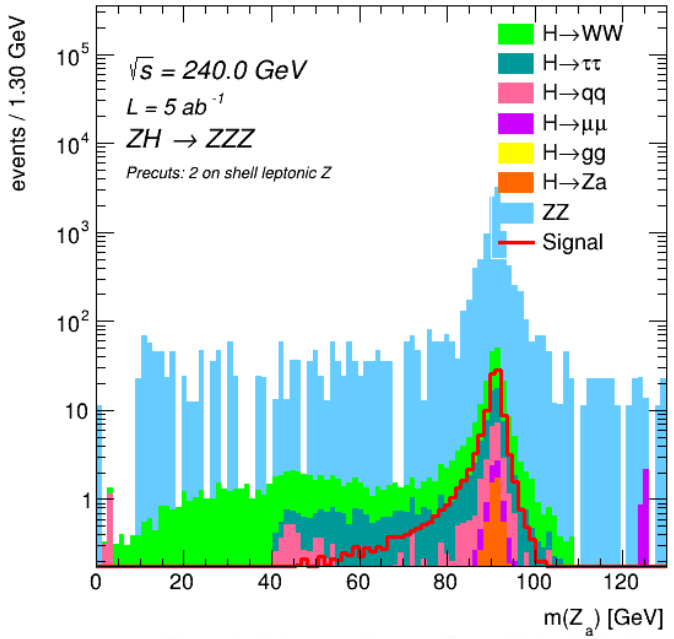
Final BB

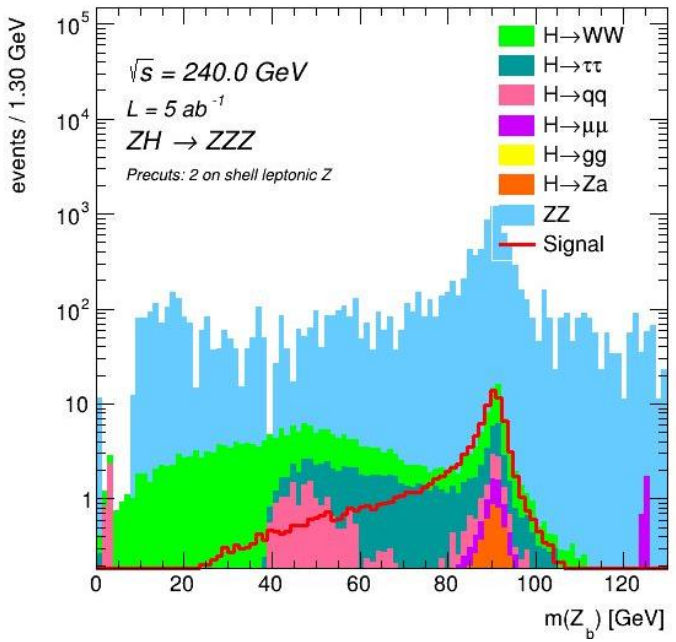
Z(ll) Z(νν) Z*(ll)
or Z(νν) Z(ll) Z*(ll)

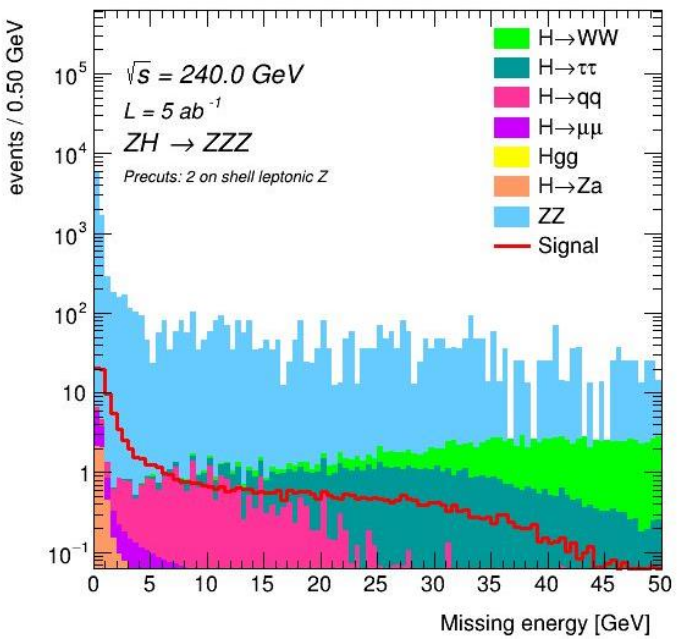
The remaining on shell Z decays into two neutrinos

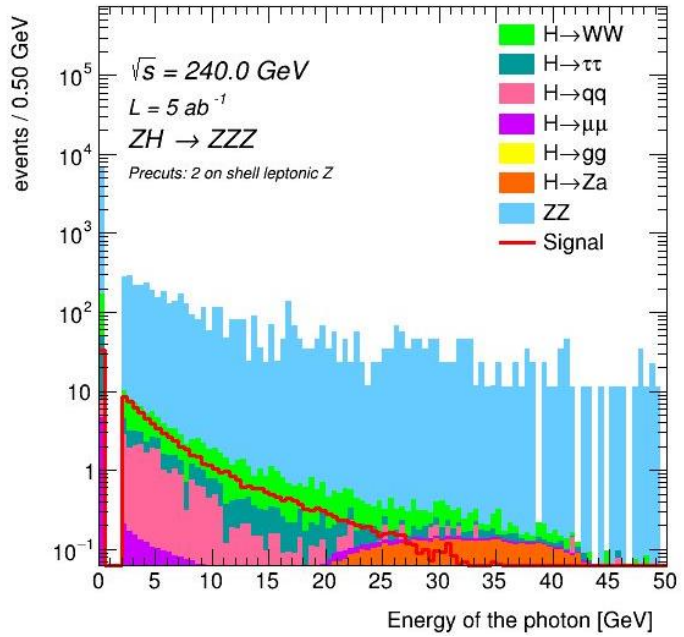
$E_{miss} > 8$ GeV + additional conditions on the Z masses

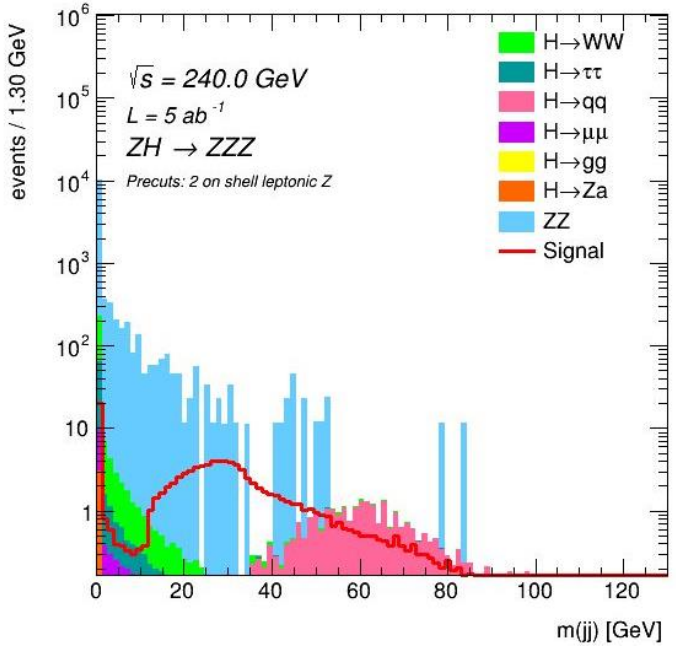
After Stage 2A: 2 On Shell Leptonic Z Requiered







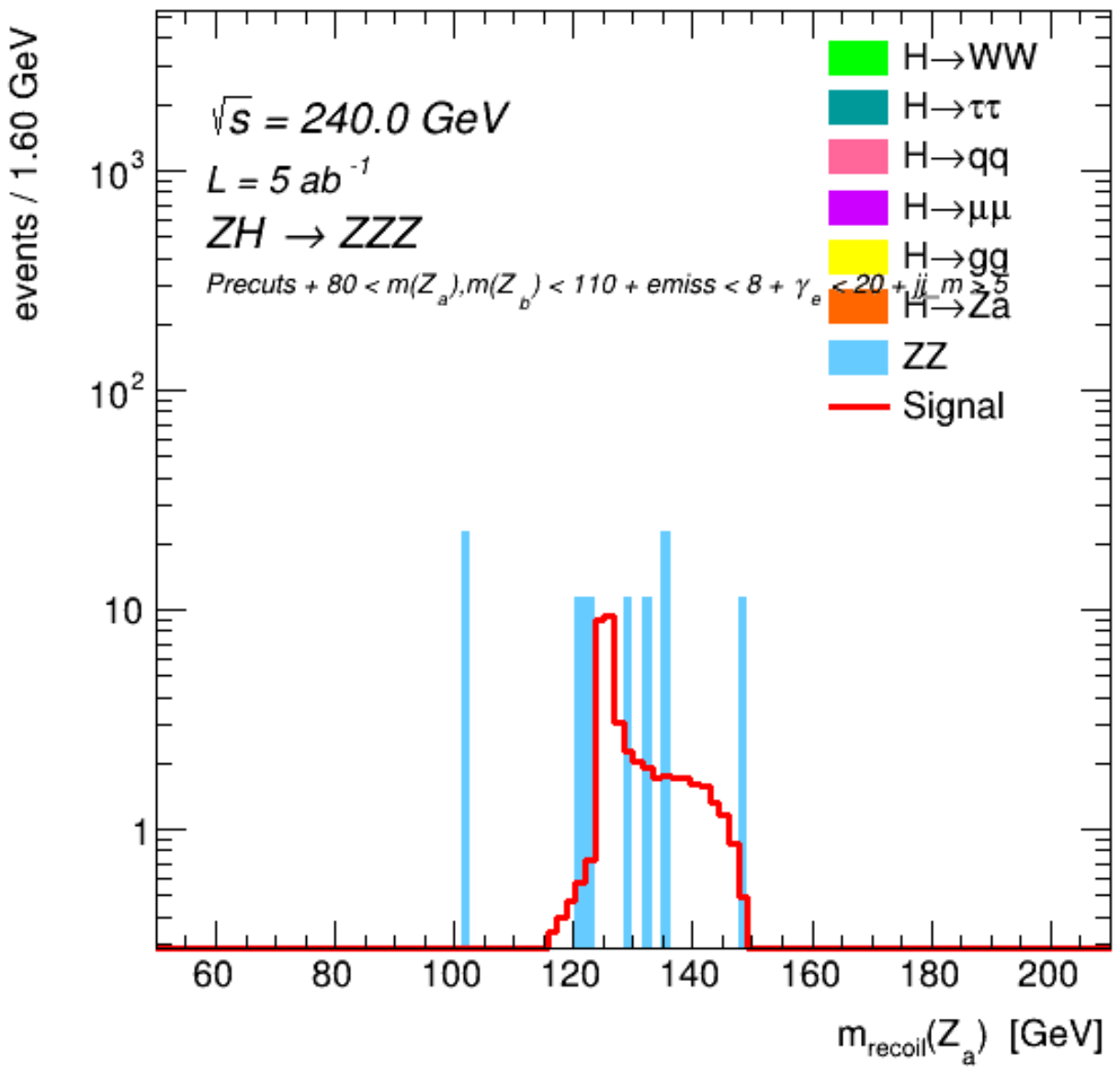




From left to right, up to down:

- Mass of the 1st dilepton (Z_a)
- Mass of the 2nd dilepton (Z_b)
- Missing energy
- Energy of the highest energy photon
- Mass of the dijet

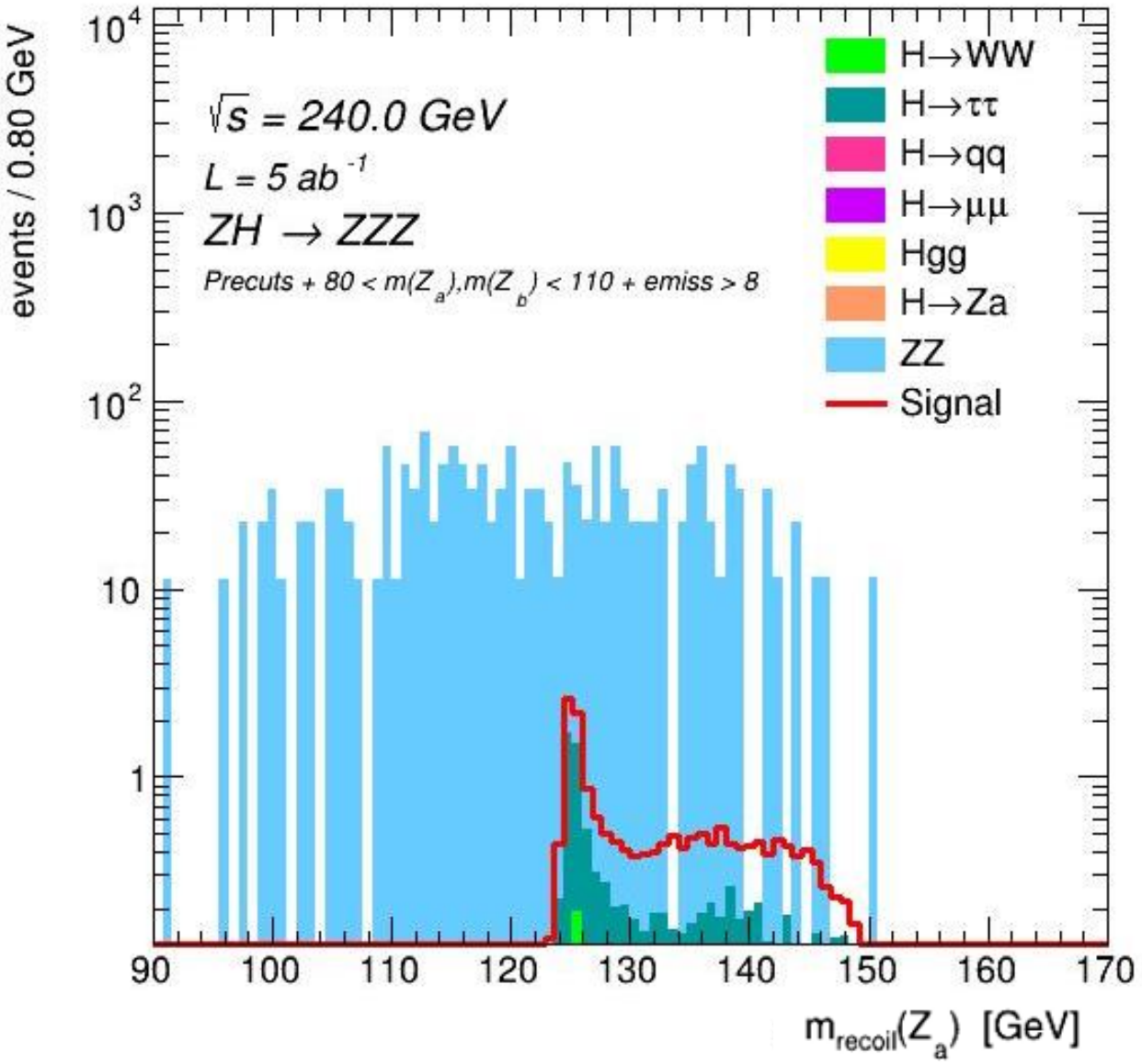
After Final AA: Z(ll) Z(ll) Z^*(jj)



Recoil mass of the 1st dilepton (Z_a) after the following cuts:

- 2 on shell leptonic Z requiered
- $80\ \text{GeV} < m(Z_a) < 110\ \text{GeV}$
- $80\ \text{GeV} < m(Z_b) < 110\ \text{GeV}$
- $E_{miss} < 8\ \text{GeV}$
- $E(\gamma) < 20\ \text{GeV}$
- $m(jj) > 10\ \text{GeV}$

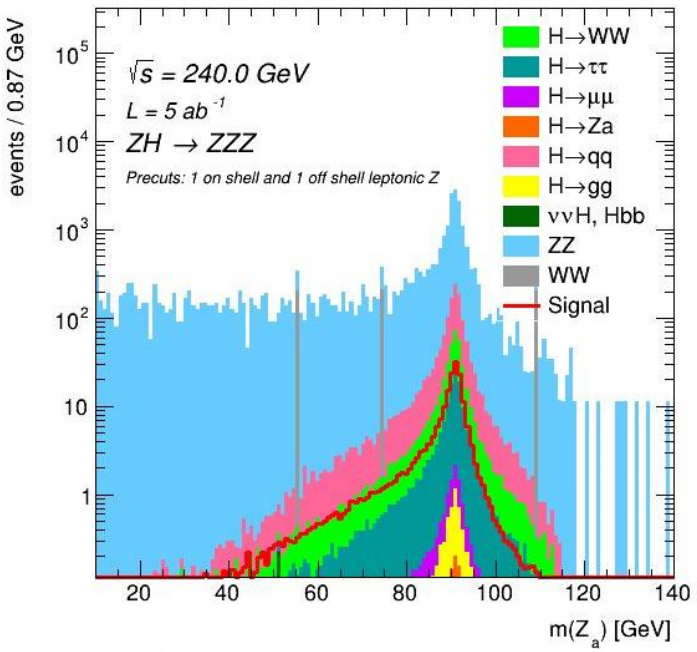
After Final AB: Z(ll) Z(ll) $Z^*(\nu\nu)$

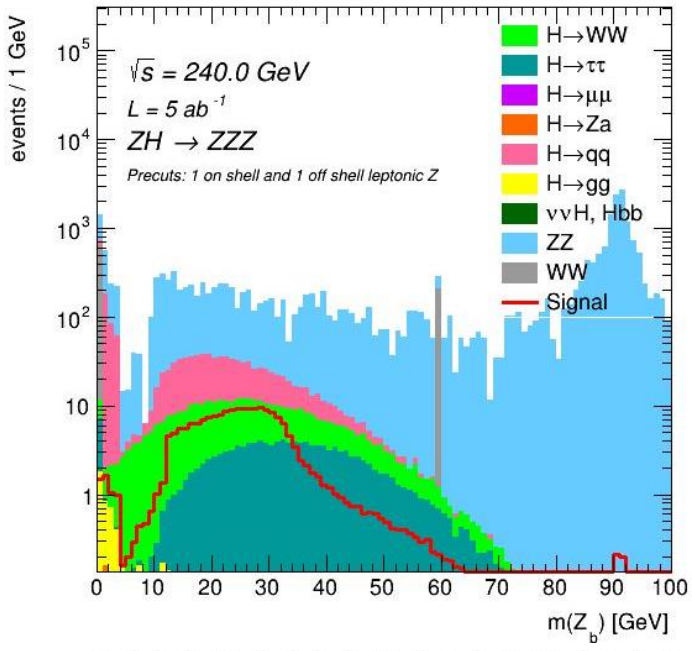


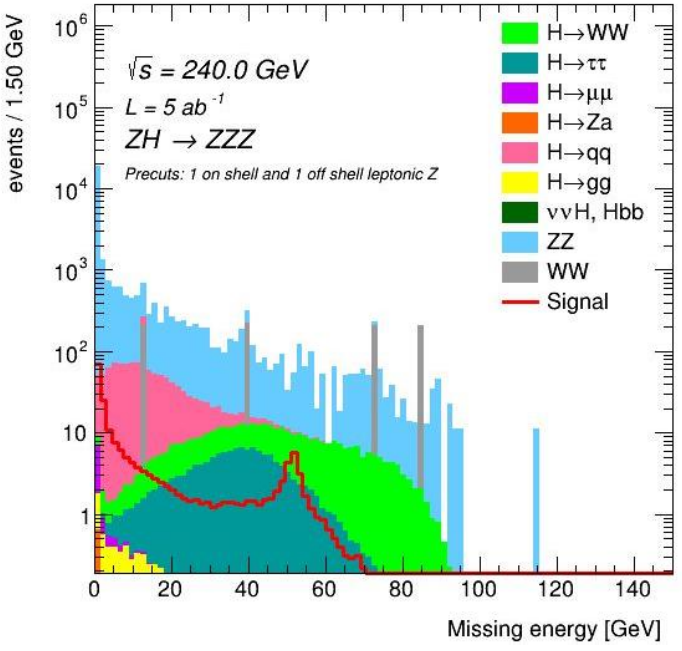
Recoil mass of the 1st dilepton (Z_a) after the following cuts:

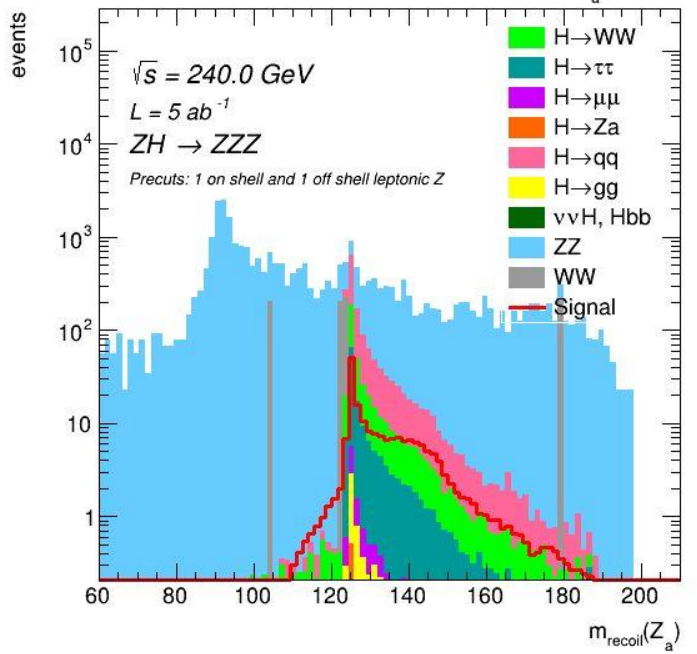
- 2 on shell leptonic Z requiered
- $80\ \text{GeV} < m(Z_a) < 110\ \text{GeV}$
- $80\ \text{GeV} < m(Z_b) < 110\ \text{GeV}$
- $E_{miss} > 8\ \text{GeV}$

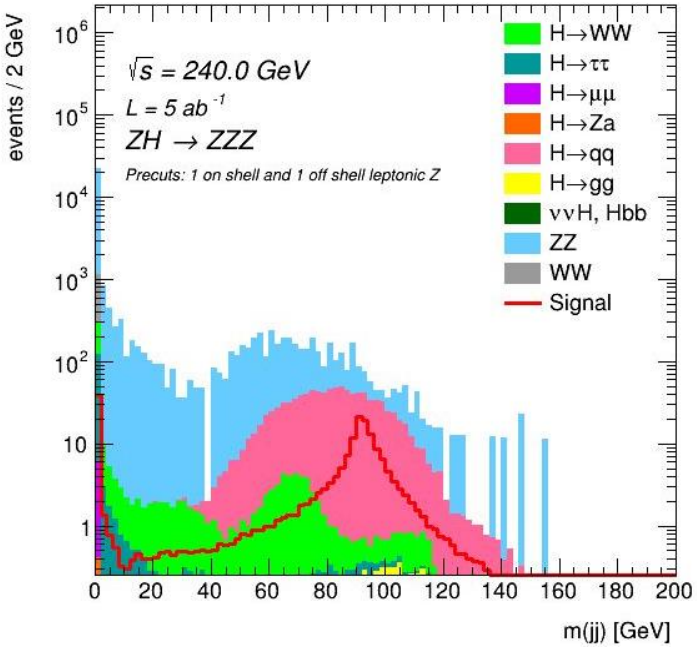
After Stage 2B: 1 On Shell and 1 Off Shell Leptonic Z Requiered







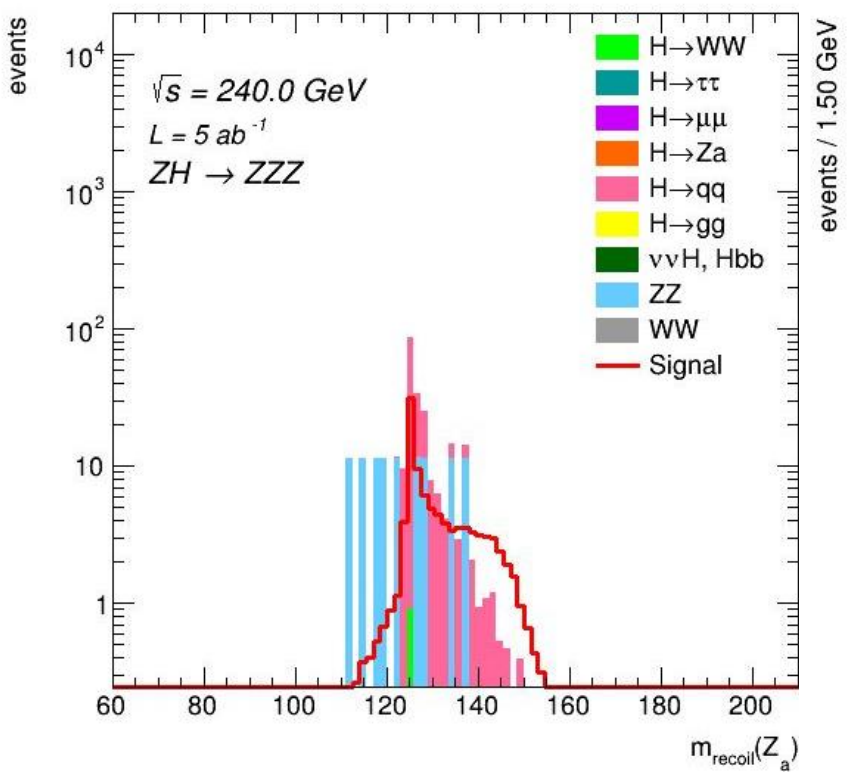


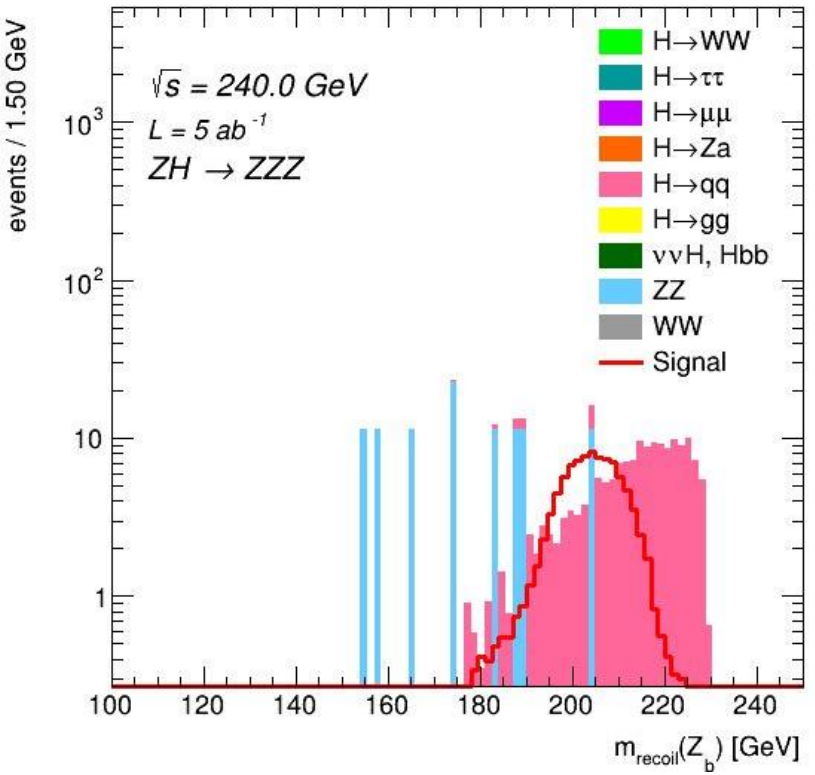


From left to right, up to down:

- Mass of the 1st dilepton (Z_a)
- Mass of the 2nd dilepton (Z_b)
- Missing energy
- Recoil mass of the 1st dilepton (Z_a)
- Mass of the dijet

After Final BA: Z(ll) Z(jj) Z*(ll) or Z(jj) Z(ll) Z*(ll)

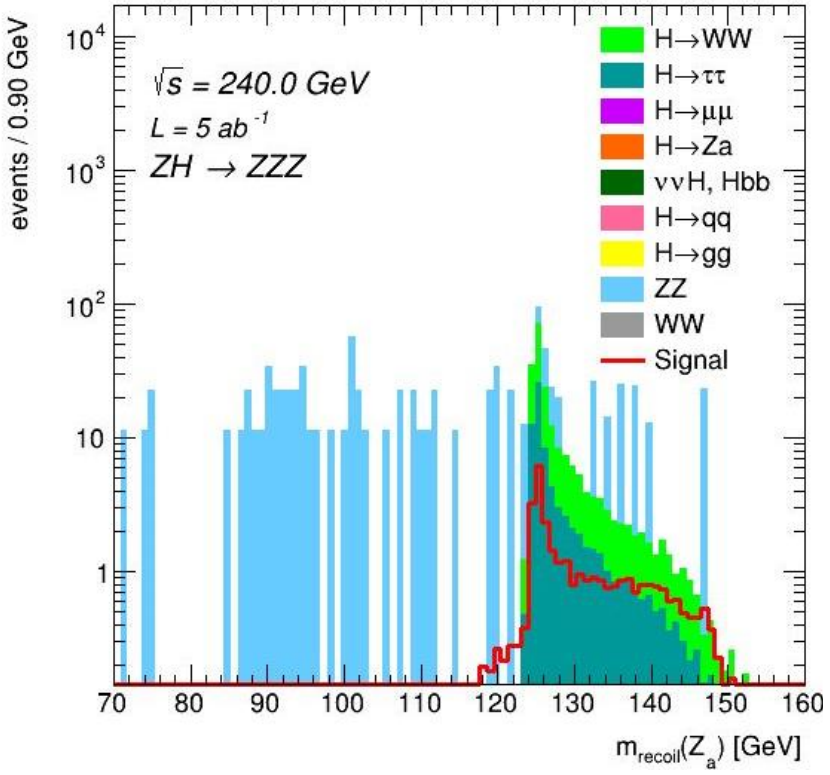


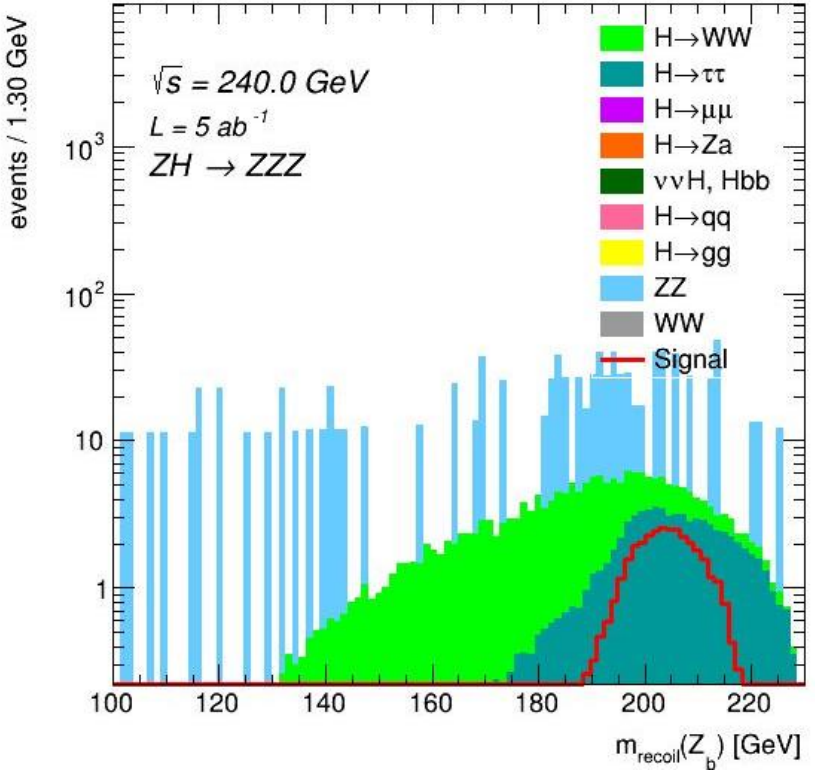


From left to right, recoil mass of the 1st dilepton (Z_a) and recoil mass of the 2nd dilepton (Z_b) after the following cuts:

- 1 on shell and 1 off shell leptonic Z requiered
- $80\ \text{GeV} < m(Z_a) < 110\ \text{GeV}$
- $10\ \text{GeV} < m(Z_b) < 65\ \text{GeV}$
- $E_{miss} < 8\ \text{GeV}$
- $m(jj) > 10\ \text{GeV}$
- $m_{recoil}(Z_a) > 110\ \text{GeV}$

After Final BB: Z(ll) Z(νν) Z*(ll) or Z(νν) Z(ll) Z*(ll)





From left to right, recoil mass of the 1st dilepton (Z_a) and recoil mass of the 2nd dilepton (Z_b) after the following cuts:

- 1 on shell and 1 off shell leptonic Z requiered
- $80\ \text{GeV} < m(Z_a) < 110\ \text{GeV}$
- $10\ \text{GeV} < m(Z_b) < 40\ \text{GeV}$
- $E_{miss} > 8\ \text{GeV}$

Conclusion and Next Steps

- Z(ll) Z(ll) Z(jj) final state: pretty clean after simple cuts on the dilepton and dijet masses

  ➡ We can already apply a fit on this channel

- Other final states: simple cuts aren't enough. Background coming mainly from $H \rightarrow \tau\tau$, $H \rightarrow qq$ and $ee \rightarrow ZZ$

  ➡ Try more complexe methods than simple cuts: machine learning based on kinematic properties of signal and background

- Compute S/B ratio for each channel

- Use combine to fit the data