A New Method For Measuring Higgs Mass At linear Colliders

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ILC: International Linear Collider

ILC for collisions at 250GeV with upgrades to 500GeV and up to 1TeV possible. (linearcollider.org)

- 20km e^+e^- colliders project in Japan to create and study the Higgs boson and high energies

- Initial operation at 250 GeV but improvements up to 500 GeV and 1TeV possible.

Physics Motivation

m_H is a crucial parameter in the calculation of couplings: H→ZZ* or H→WW*

The theory is very sensitive to precision on mass:

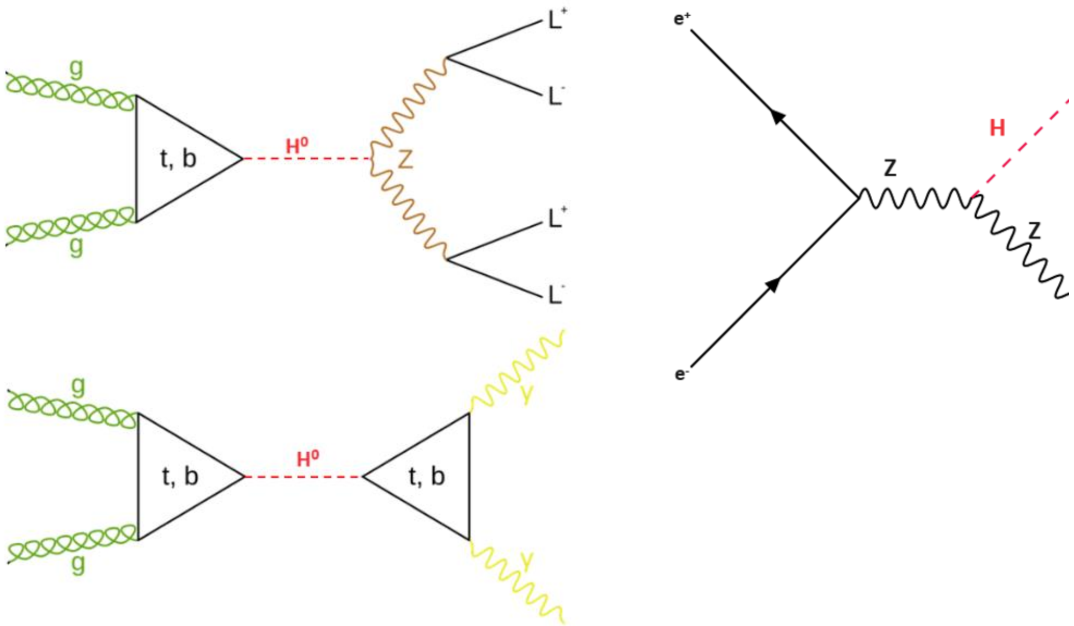
$$\frac{\Delta\Gamma(H\rightarrow ZZ^*)}{\Gamma(H\rightarrow ZZ^*)} = 16 * \frac{\Delta m_H}{m_H}, \quad \frac{\Delta\Gamma(H\rightarrow WW^*)}{\Gamma(H\rightarrow WW^*)} = 14 * \frac{\Delta m_H}{m_H}$$

For an accuracy of 0.1% to 0.5%, an uncertainty of 16 to 80MeV is required for mH. This will be our criterion for this study.

Classical Methods For m_H:

At LHC, Higgs is reconstructed directly from measurements of momentum of each decay product using invariant mass.

At ILC, another method studied is the Recoil mass with M_{Recoil} given by full 4-momentum conservation. Main drawback is a long tail for $m > m_H$.



Processes used to measure m_H at LHC (left) and Higgstrahlung (right) used in this study

1, 2 are H decay products, pt the transverse momentum and θ, ϕ the different angles of jets.
Using only transverse momentum conservation instead of full 4-momentum conversion:

$$\binom{p_1}{p_2} = \frac{p_t}{\sin \phi_{12}} \begin{pmatrix} \frac{\sin(\phi - \phi_2)}{\sin(\theta_1)} \\ \frac{\sin(\phi_1 - \phi)}{\sin(\theta_2)} \end{pmatrix}, \quad \begin{matrix} p_1 \sin\theta_1 \cos\phi_1 + p_2 \sin\theta_2 \cos\phi_2 = p_x \\ p_1 \sin\theta_1 \sin\phi_1 + p_2 \sin\theta_2 \sin\phi_2 = p_y \end{matrix}$$

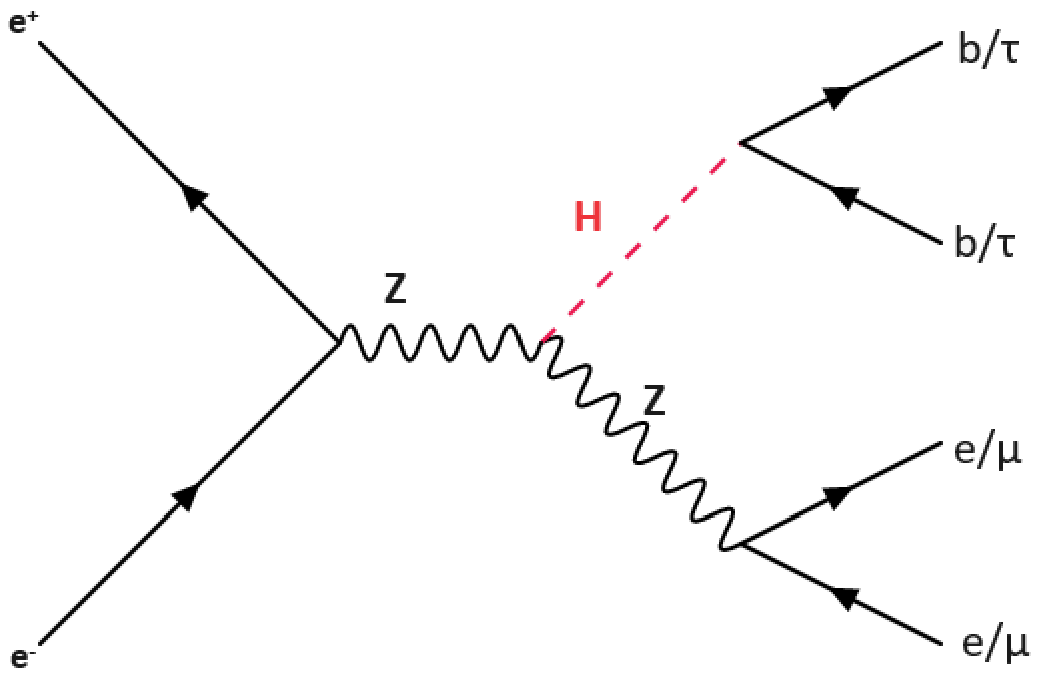
Advantages:

-no energy dependence of the jets in the mass, only their directions.

-Less uncertainty about the energy calibration of beams (Beamstrahlung, ISR), especially at high energies.

-Complementary method to the "Recoil Mass" method which will be used at ILC.

Proposed New Method:



Higgstrahlung Process studied for our signal with Z→2 leptons for maximum accuracy

The process studied here is: $e^+e^- \rightarrow ZH,\ Z \rightarrow \mu^+ \mu^-$ where we will compare $H \rightarrow \tau^+\tau^-$ and $H \rightarrow b\bar{b}$.

Only transverse momentum used here.

A study at 500 GeV of H→bb̄ has already been done by J. Tian and this one will be done at 250 GeV for 2 modes of H.

Simulation Setup

- Whizard: event generator with the ISR and the Beamstrahlung. The hadronization and parton jets are done by Pythia.
- ILCSoft package including:

  GEANT4: Simulates detectors and output signals.

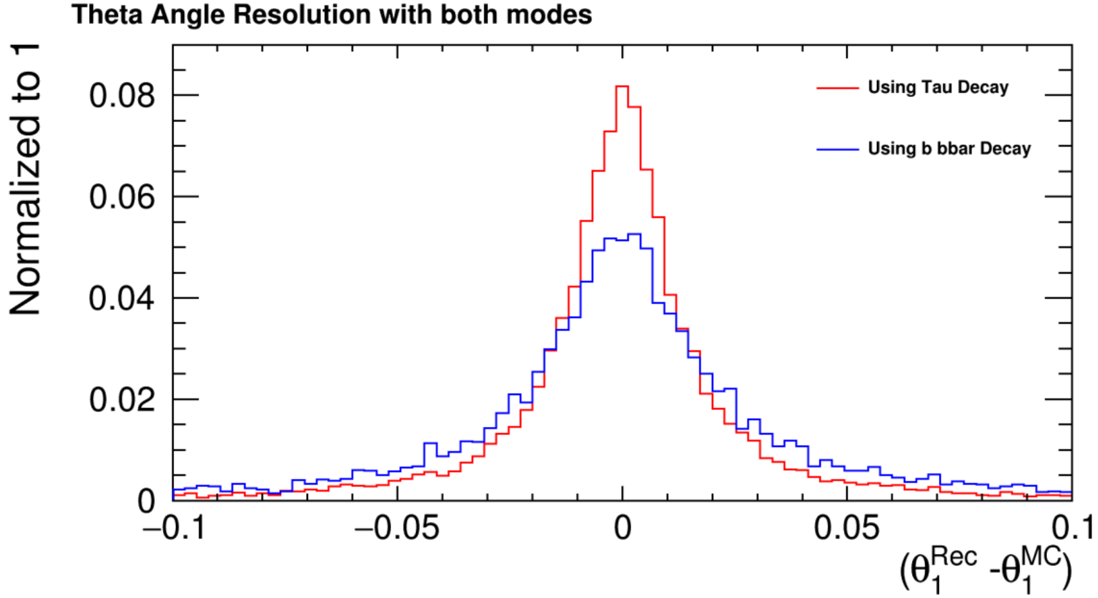
  PandoraPFA and LCFIPlus: Event reconstruction with particle flow analysis and jets reconstruction…

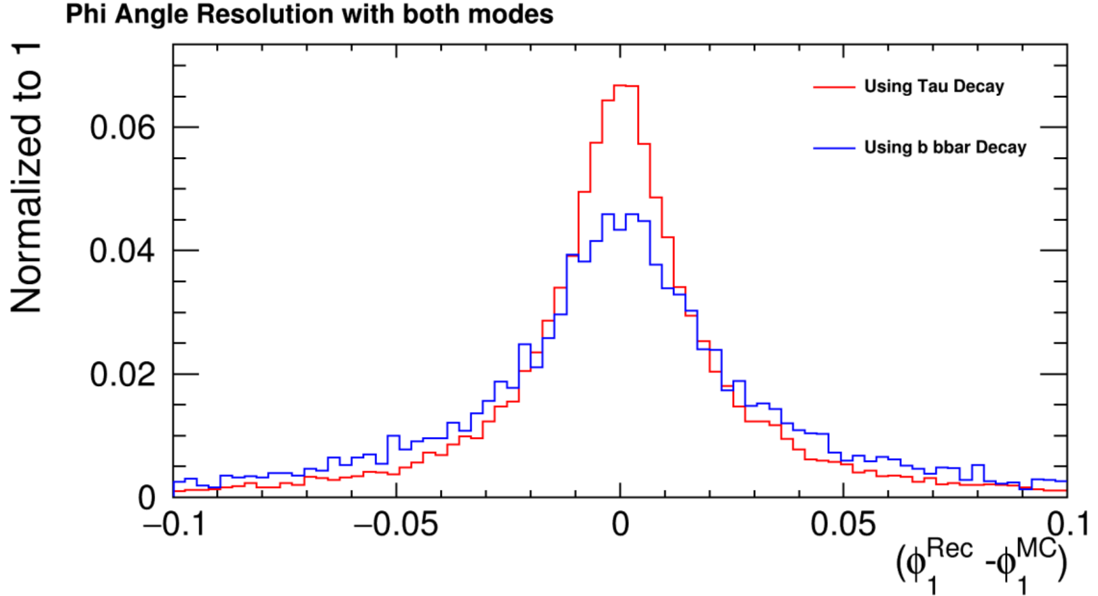
- The analysis is done at 250 GeV and for 2 possible polarizations:

$P = \frac{N_R - N_L}{N_R + N_L}$ = (-0,8 , 0,3) or (0,8, -0,3) for (e^-, e^+), full simulations only done at (-0,8 , 0,3)

Integrated luminosity: $\int L dt = 2000\ fb^{-1}$

Resolution For Jet Angles:



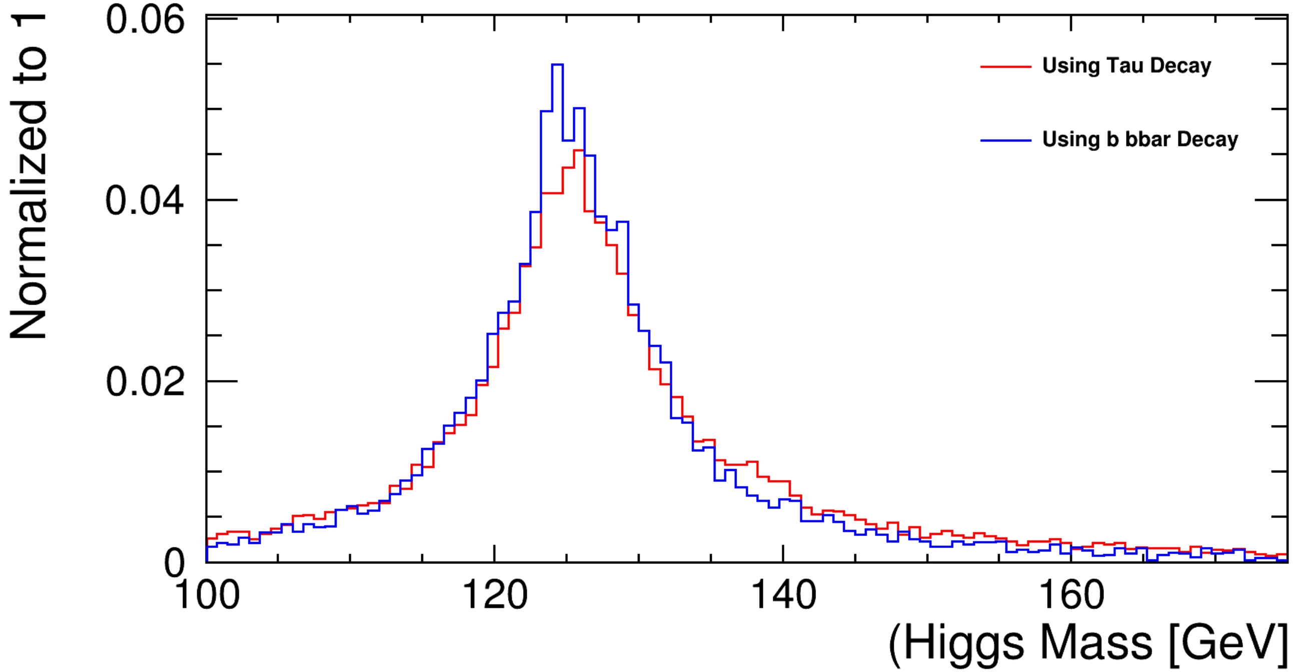


The data are computed for the 2 decay modes and compared on graphs

The absolute resolutions on the angles and relative on mH are adjusted by Gaussians on ROOT to obtain the errors.

Similar distributions in each case but ττ seems to have better peaks

m_H measurement:



Resolution	θ_1 [°]	ϕ_1 [°]	Δm_H [GeV]
Mode $b\bar{b}$	0,80±0,03	0,92±0,02	4,17±0,16
Mode $\tau^+\tau^-$	0,67±0,01	0,73±0,01	4,51±0,14

With a 2000fb^{-1} luminosity, a 100% efficiency and μμ channel for Z decay assuming no background,

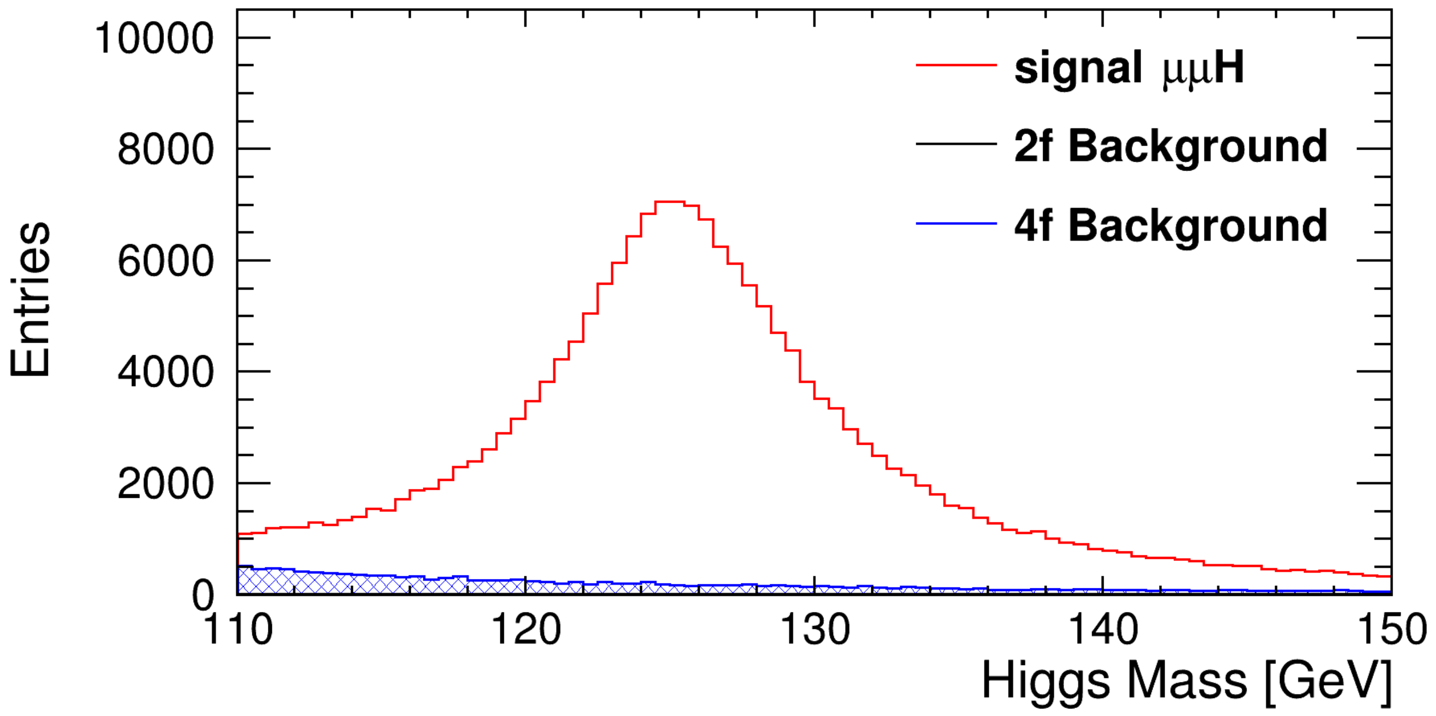
The error is $\partial m_H = \frac{\Delta m_H}{\sqrt{N}}$ ~20 MeV for $b\bar{b}$ and ~100 MeV for $\tau^+\tau^-$.

IV-Full Simulations

A pre-selection is made to find pairs of isolated leptons that can come from a $Z \rightarrow \mu\mu$. Loose cuts are applied to the lepton pair on the angles and mass. Remaining particles are clustered in jets using a Durham algorithm.

Signal processing of $H \rightarrow b\bar{b}$;

- Cut 1: the pair of leptons must be 2 muons with a mass close to m_H to the nearest 10GeV
- Cut 2: $n_{ChargedPFOs}$ >3 in each jets
- Cut 3: $E_{vis}+E_{lep}$ >150 GeV
- Cut 4: b-likeness > 0,66
- Cut 5: The angle of the lepton pair must be abs(cos) < 0,9
- Cut 6: Tight cut on the ground found: $110<m_H^{new}<150$ GeV



Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llh	Signal	σ
Events	2.596e+07	4.637e+08	3.16159e+07	3.832e+07	3.360e+07	5.935e+08	20616.5	11916	
Cut0	1.46e+06	11852	3.27e+06	824121	270143	5.57e+06	19429	11311	8.23
Cut1	1.03e+06	21	82040	158666	0	1.28e+06	17449	10169	15.39
Cut2	2.40	15468	3187	122529	0	123000	14174	9537	38.99
Cut3	2.40	15303	3187	122529	0	123000	14161	9537	38.97
Cut4	0	733	219	290778	0	291000	9237	8959	47.37
Cut5	0	733	0	22627	0	22600	8416	8162	47.96
Cut6	0	0	0	2514	0	2514	7281	7085	74.32

TABLE II: Cuts Table for $b\bar{b}$ Mode with each process and all $ll \to H$ processes

Criteria for cuts :

$$\eta = \frac{N_{signal}}{\sqrt{N_{signal} + N_{Background}}}$$

$$\varepsilon = \frac{N_{after\ cut}}{N_{before\ cut}}$$

Must be optimized for:

$$\frac{\Delta\sigma_{\mu\mu H} * BR(H \to b\bar{b})}{\sigma_{\mu\mu H} * BR(H \to b\bar{b})} = \frac{1}{\eta}$$

60% efficiency and 72 η of significance for the $b\bar{b}$ mode.

An adjustment by a Gaussian fit gives:

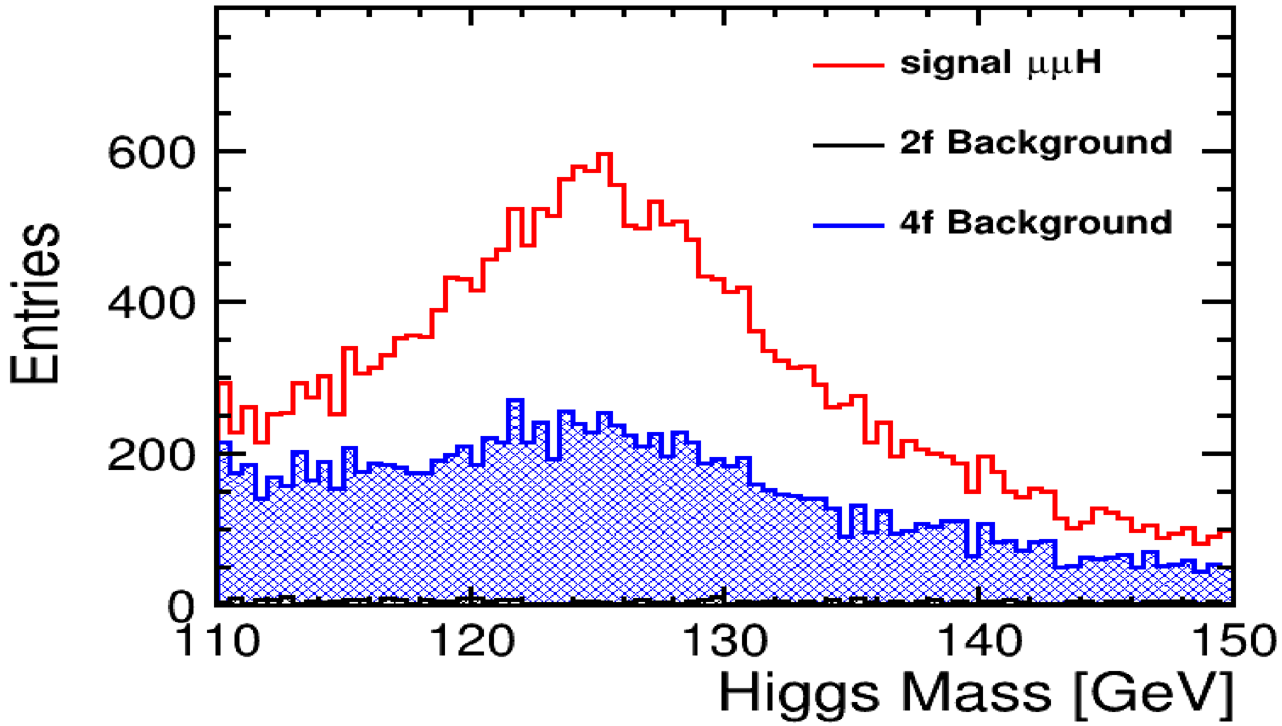
m_H=125,28±0,019 GeV

$\frac{1}{\eta}$=1,35%

$H \rightarrow \tau\tau$, τ leptons are reconstructed as jets so the previous work can be adapted to this decay channel for the Higgs boson.

New criteria are to be applied

- Cut 1: Same as the bb mode
- Cut 2: $n_{PFOsChargées}$ <4 in each jet because τ decays into 1 or 3 charged particles
- Cut 3: $E_{vis}+E_{lep}$ >100 GeV
- Cut 4: $E_{vis}+E_{lep}$<220 GeV (Hadronic noise suppression)
- Cut 5: abs(cos) < 0,9
- Cut 6: At least 1 charged particle $n_{ChargedPFOs}$ >0 (Hadronic noise suppression)
- Cut 7: Cut on the value of the system's Recoil Mass: $110<m_{recoil}<150$ GeV
- Cut 8: Cut on the found mass: $110<m_H^{new}<150$ GeV



Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llh	Signal	σ
Events	2.596e+07	4.637e+08	3.16159e+07	3.832e+07	3.360e+07	5.935e+08	20616.5	1313	
Cut0	1.45e+06	16048	3.27e+06	824124	271	5.56e+06	19429	1221	0.518
Cut1	1.03e+06	31	82041	158666	0	1.28e+06	17449	1095	0.97
Cut2	1.03e+06	1	81438	2133	0	1.12e+06	1604	1063	1.00
Cut3	1.02e+06	1	80886	2133	0	1.10e+06	1600	1063	1.00
Cut4	1.02e+06	0	44015	1137	0	1.07e+06	1460	966	1.83
Cut5	235463	0	26977	1060	0	2.64e+05	1350	929	4.52
Cut6	13176	0	4117	136	0	1.74e+04	1080	741	10.03
Cut7	460	0	2294	30	0	2780	648	606	11.10

TABLE III: Cuts Table for $\tau\tau$ Mode with each process and all $ll \to H$ processes

Worse performance with 48% efficiency and η=15.

Much lower number of events because

H→ ττ 6%

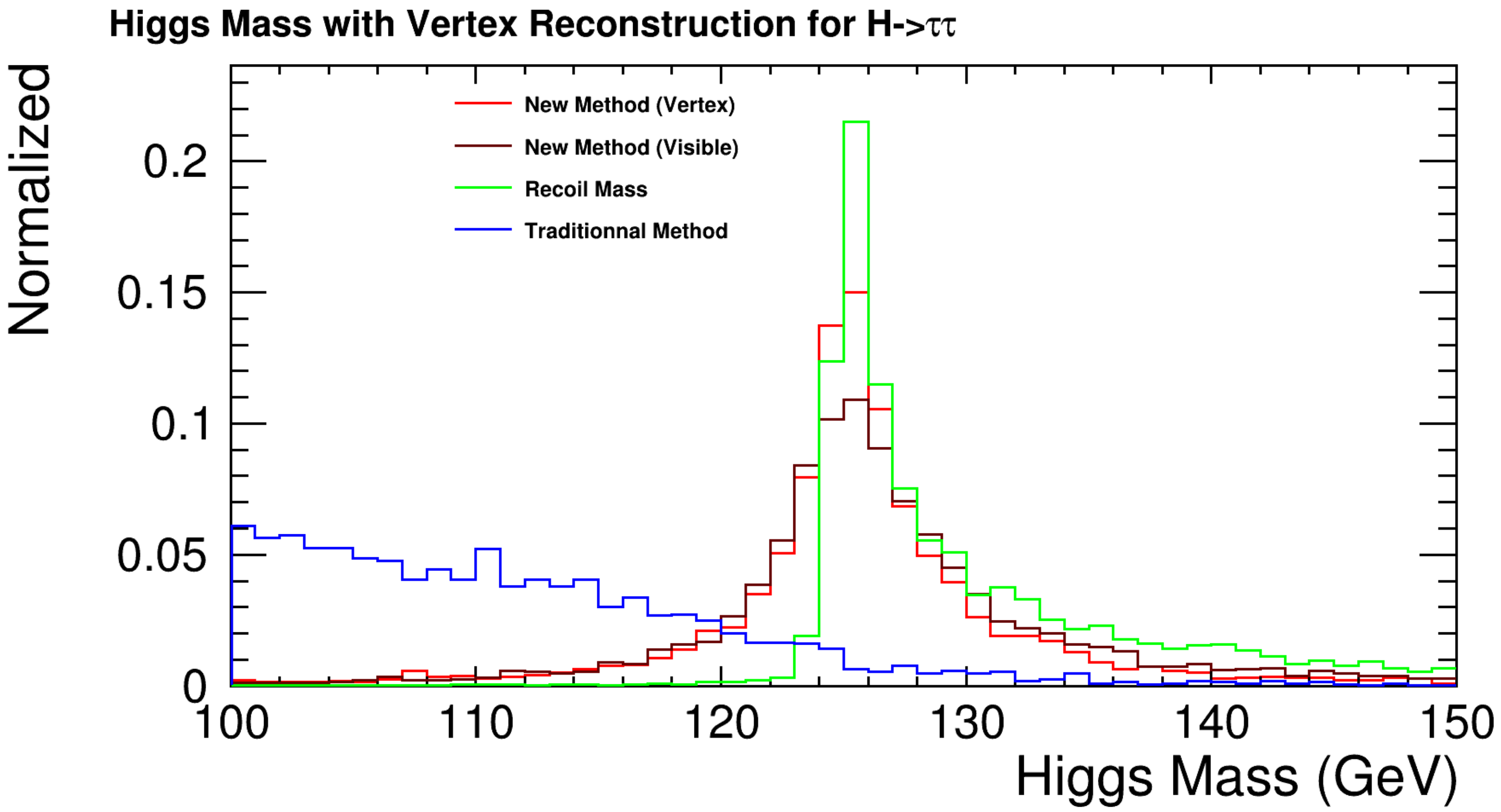
H→bb 58%

The fit gives:

m_H=125,31± 0,072 GeV

$\frac{1}{\eta}$=6,67%

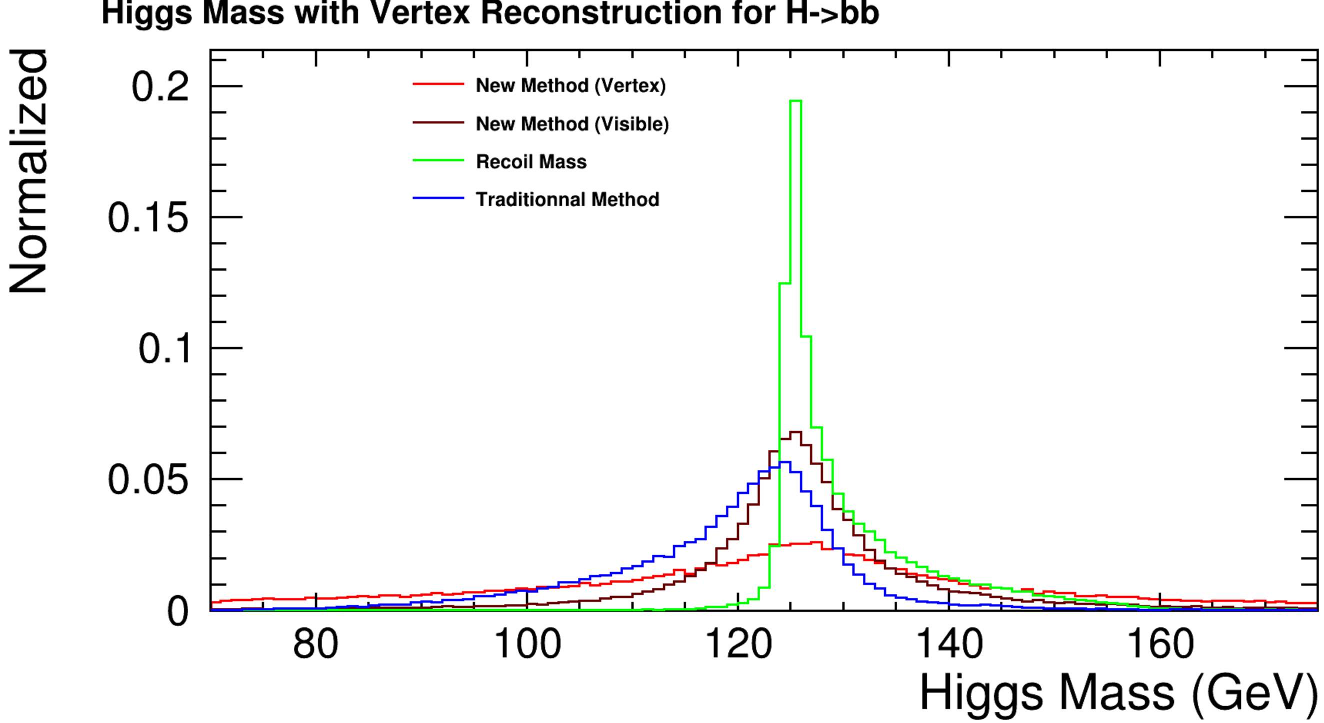
Possible improvements:

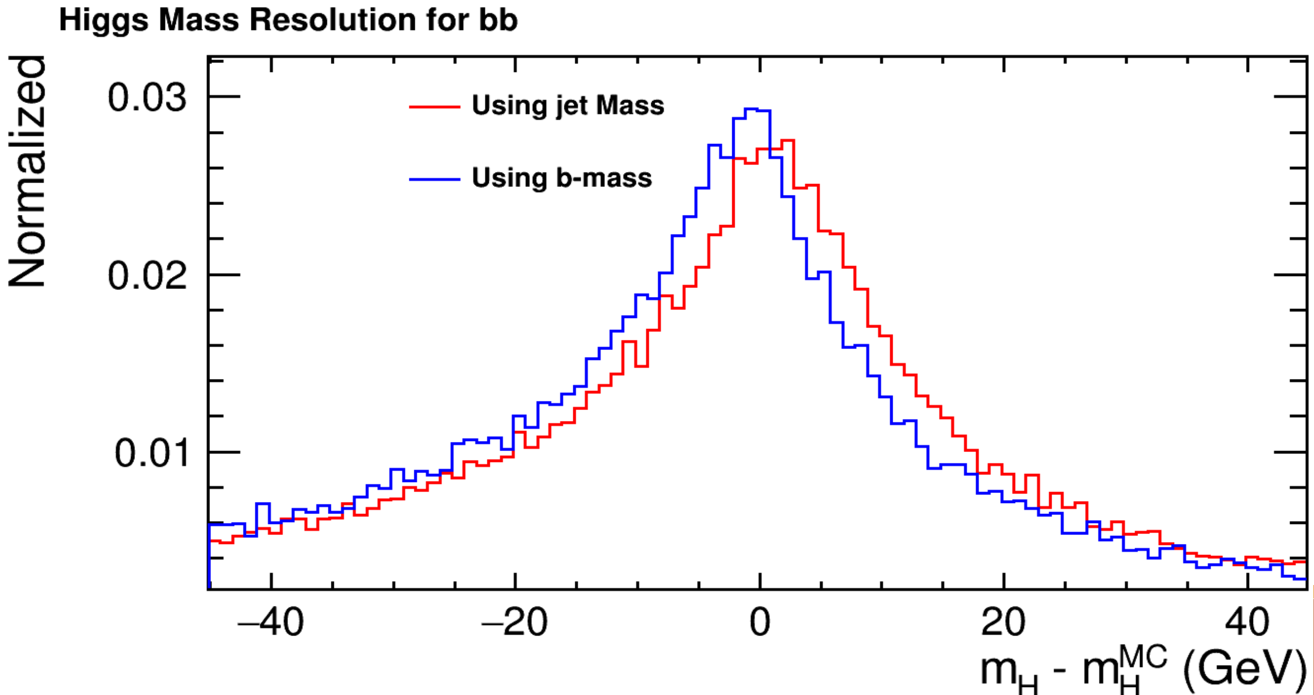


Use the position of the decay vertices and the interacion point to measure the direction of the b momentum or τ momentum

Sharper peak for τ τ : σ=2GeV

Few statistics➔Could be used to the LHC or add channels such as Z→e^+e^+.





For bb, more events but worse performance than before without using decay vertex reconstruction:

σ=7,4 GeV

By studying the resolution on mH, the difference between the mass of the reconstructed jets and the expected mass of a b quark. The peaks are not centered at 0.

Conclusion

Thus, the proposed new method obtains accuracies comparable to those needed to study the Higgs boson for the bb mode and for the ττ mode by finding the decay vertex for the leptons.

Noise filtering is effective for these processes with a good significance obtained and a good accuracy without the long tail from beamstrahlung that we would have obtained with the Recoil Mass method.

To increase accuracy, Z to hadrons can be studied with $H \rightarrow \tau\tau$ to have more statistics if the resolution is enough.

Thank you for your attention