# Try to force $M_{bb} = 125.7 GeV$

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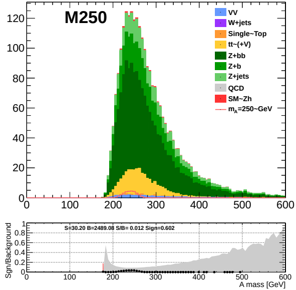
# Force $M_{bb} = M_h$

**What it is about:**

- We have a supposedly $h$ reconstructed in signal;
- we know $M_h = 125.7$;
- Try to force $M_{bb} = M_h$ and look at $M_A$;
- Do we have a better significance or not?
- Plot side by side $M_A$ with $M_{bb}$ not forced (left) and forced (right)
- Bottom is S/B ratio. Numbers S,B,... refers to all spectrum $M_A \in [0, 600]$ $GeV$
- Gray error bar on S/B to be checked!

# $M_A = 250\ GeV$

## $M_{bb}$ not forced

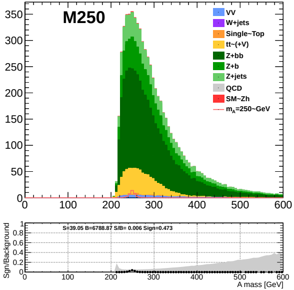



$M_A = 239.2 \pm 0.1\ GeV$

$\sigma_{M_A} = 14.5 \pm 0.1\ \ GeV$

$S = 30.20 \quad B = 2500$

## $M_{bb} = M_h$

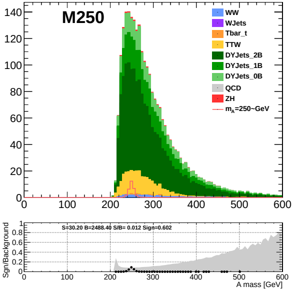



$M_A = 249.01 \pm 0.05\ GeV$

$\sigma_{M_A} = 7.23 \pm 0.05\ GeV$

$S = 39.20 \quad B = 6800$

## $M_{bb} = M_h$ if $90 < M_{bb} < 140\ GeV$



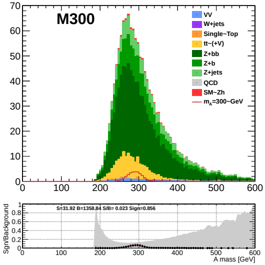

$M_A = 249.11 \pm 0.05\ GeV$

$\sigma_{M_A} = 6.18 \pm 0.04\ GeV$

$S = 30.20 \quad B = 2500$

# $M_A = 300\ GeV$

$M_{bb}$ not forced

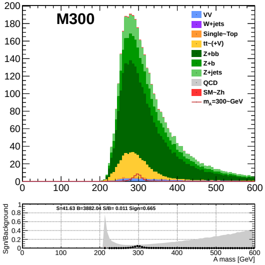



$M_A = 288.6 \pm 0.1\ GeV$

$\sigma_{M_A} = 18.9 \pm 0.1\ \ GeV$

$S = 32 \quad B = 1350$

$M_{bb} = M_h$

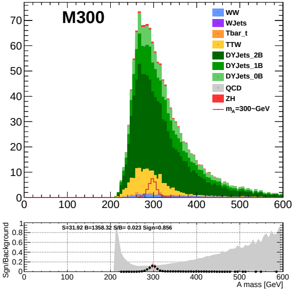



$M_A = 296.60 \pm 0.09\ GeV$

$\sigma_{M_A} = 12.59 \pm 0.09\ GeV$

$S = 42 \quad B = 3880$

$M_{bb} = M_h$ if $90 < M_{bb} < 140\ GeV$



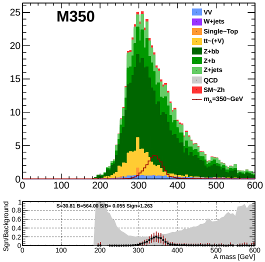

$M_A = 297.00 \pm 0.08\ GeV$

$\sigma_{M_A} = 10.50 \pm 0.08\ GeV$

$S = 32 \quad B = 1350$

# $M_A = 350\ GeV$

## $M_{bb}$ not forced

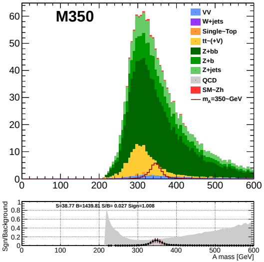



$M_A = 339.1 \pm 0.2\ GeV$

$\sigma_{M_A} = 21.5 \pm 0.1\ \ GeV$

$S = 31 \quad B = 560$

## $M_{bb} = M_h$

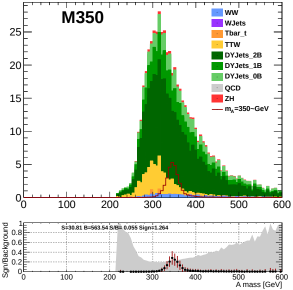



$M_A = 345.21 \pm 0.12\ GeV$

$\sigma_{M_A} = 17.25 \pm 0.13\ GeV$

$S = 39 \quad B = 1440$

## $M_{bb} = M_h$ if $90 < M_{bb} < 140\ GeV$

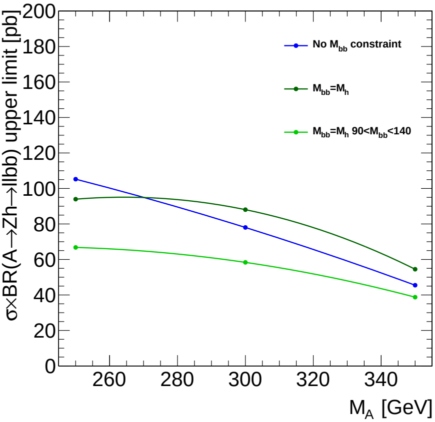



$M_A = 345.72 \pm 0.11\ GeV$

$\sigma_{M_A} = 14.50 \pm 0.10\ GeV$

$S = 31 \quad B = 560$

# Conclusion I




- Forcing $M_{bb}$ to $M_h$ reduces significantly the width of the 4-body invariant mass $M_A = M_{\ell\ell bb}$;
- If it is applied to all events, the S/B worsen a lot since we cannot select events with $M_{bb}$;
- If it is applied only to events passing a selection on $M_{bb}$: $90 < M_{bb} < 140\ GeV$, the S/N is the same (by construction) but the reduced width improves the expected limit.

# Kinematical fit of $M_{bb}$ to $M_h$

## Idea

- Try a better constraint for $M_{bb}$ than just force it to $M_h$;
- Change Jets $p_T$ within jet resolution to get $M_{bb}$ closer to $M_h$;
  1. Get jet resolution on $p_T$ from MC (we neglect resolution on $\phi$ and $\eta$, supposedly less important);
  2. Build a 4-momentum for Jets starting from the measured one and varying the $p_T$;
  3. Apply a gaussian constraint on $p_T$ using jet resolution as width;
  4. Get as close as possible to $M_h$.

## Formulas

- Jets 4-momentum:

$$p_{b_i}(\alpha_i) = \{p_T + \alpha_i \sigma_{p_T},\ \eta,\ \phi,\ E + \alpha_i \cdot \sigma_E\}$$

- Minimize $\chi^2$

$$\chi^2(\alpha_1, \alpha_2) = \left(\frac{M_{bb}(\alpha_1, \alpha_2) - M_h}{\sigma_{M_h}}\right)^2 + {\alpha_1}^2 + {\alpha_2}^2$$

  - $\sigma_{p_T}$ is jet resolution on $p_T$: depend on $p_T, \eta$[a]
  - Assume $\sigma_{p_T}/p_T = \sigma_E/E$
  - $M_h = 125.7\ GeV$;
  - $\sigma_{M_h}$ set to $18, 10, 1\ GeV$: 18 is $M_{bb}$ resolution for $h \to bb$ from MC.
- Use $\alpha_1, \alpha_2$ to redefine b-jets ($b'$), and look at $M_{b'b'}$ and $M_{b'b'll}$

[a] from AN 2010 371

# Jet resolution

*AN 2010 371*: Jet resolution vs $p_T$ for various $|\eta|$ bins.

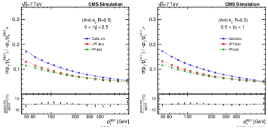


Figure 9: MC truth resolution for $0.0 \le |\eta| < 0.5$ (*left*) and $0.5 \le |\eta| < 1.0$ (*right*)

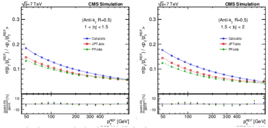


Figure 10: MC truth resolution for $1.0 \le |\eta| < 1.5$ (*left*) and $1.5 \le |\eta| < 2.0$ (*right*)

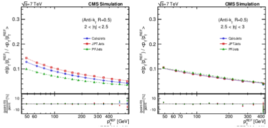
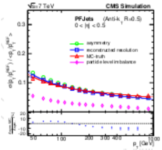
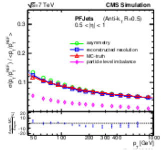


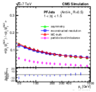
Figure 11: MC truth resolution for $2.0 \le |\eta| < 2.5$ (*left*) and $2.5 \le |\eta| < 3.0$ (*right*)



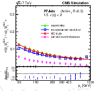
d CaloJets (*left*), JPTJets (*middle*)
rticle-level (magenta) results are
parison to the MC truth derived
**netry resolution measurements**
**Collaboration).**



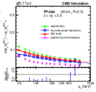
PFJets (*right*) at $0.5 \le |\eta| < 1.0$.



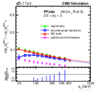
PFJets (*right*) at $1.0 \le |\eta| < 1.5$.



PFJets (*right*) at $1.5 \le |\eta| < 2.0$.



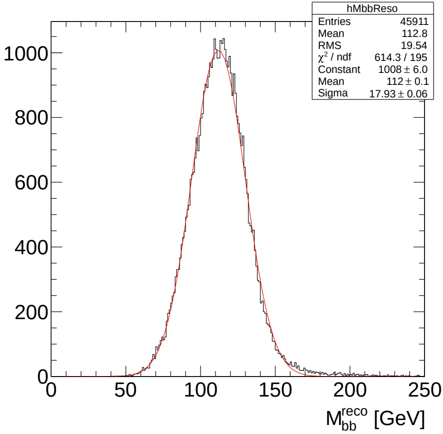
PFJets (*right*) at $2.0 \le |\eta| < 2.5$.



PFJets (*right*) at $2.5 \le |\eta| < 3.0$.

# Di-jet Mass resolution

$M_{bb}$ reco, with both jet matched to the $b$-jets from $h_{125} \to bb$ decay.

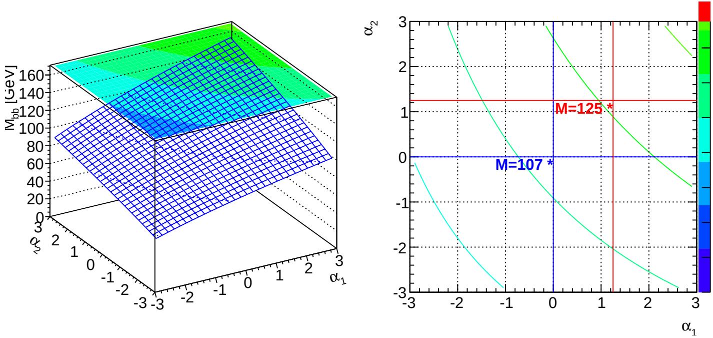



- $\sigma_{M_h} = 18 GeV$
- but the uncertainty on the peak value $M_h$ is much smaller! $\sim 400\ MeV$
- Try and see the effect to use $\sigma_{M_h} = 18/10/1\ GeV$

# An example

Consider two jets, $J_{1,2}$ with $p_{T,1} = 39.9\ GeV$, $p_{T,2} = 35.1\ GeV$, and $M_{jj} = 107\ GeV$

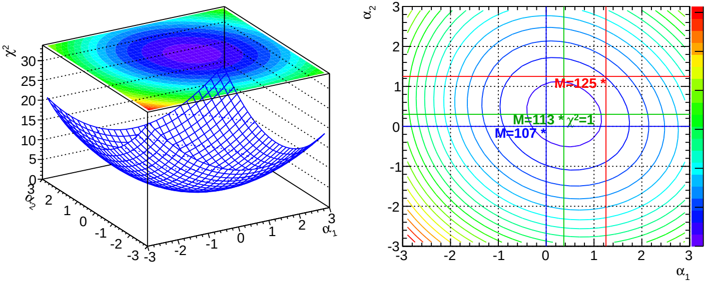
Let vary $P_{T,i} = p_T \cdot (1. + \alpha_i \cdot \sigma_{p_T})$, and $E_i$ likewise. Look at $M_{jj}(\alpha_1, \alpha_2)$




To force $M_{jj} = M_h$ we would need to stretch the jet $p_T$ by $\sim 1.25 \cdot \sigma_{p_T}$

## Minimimization

Build and minimize the $\chi^2$ as defined above with $\sigma_{M_{bb}} = 18\ GeV$

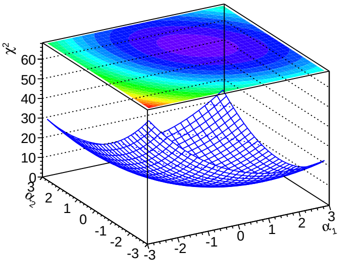


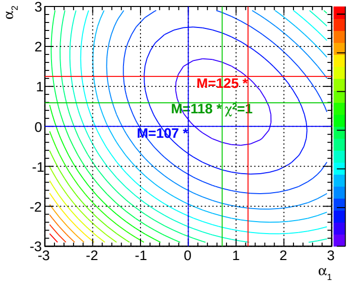

## Results

$\chi^2$ minimized correspond to $M_{jj} = 112.6\ GeV$ with $\chi^2 = 0.75$

## Minimimization

Build and minimize the $\chi^2$ as defined above with $\sigma_{M_{bb}} = 10\ GeV$



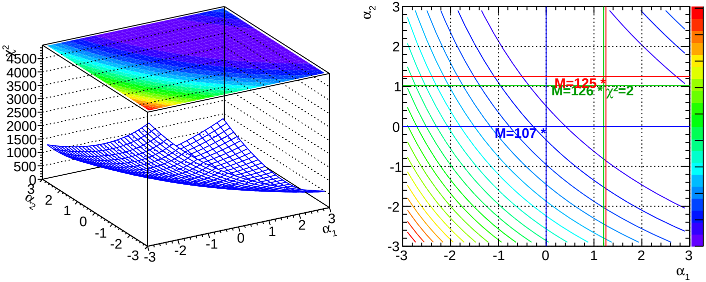




## Results

$\chi^2$ minimized correspond to $M_{jj} = 117.9\ GeV$ with $\chi^2 = 1.46$

## Minimimization

Build and minimize the $\chi^2$ as defined above with $\sigma_{M_{bb}} = 1\ GeV$

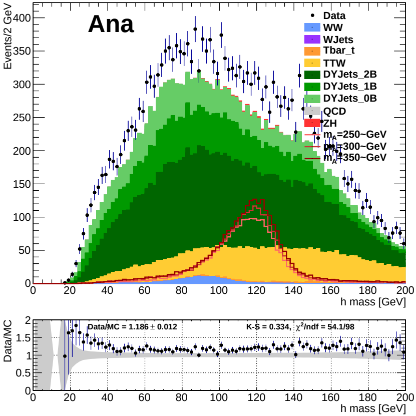



## Results

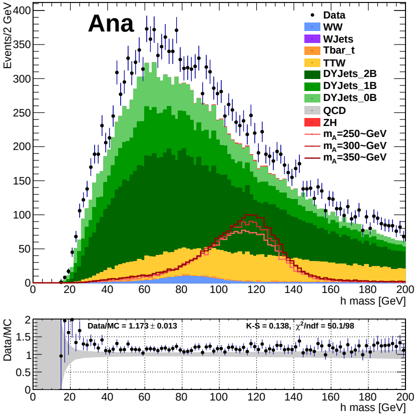
$\chi^2$ minimized correspond to $M_{jj} = 125.6\ GeV$ with $\chi^2 = 2.50$

# $M_{bb}$ distribution

## Z mass cut + 1 CVST + 1 CVSL ($\sigma_{signal} = 1pb$)




$M_{bb}$ after kinematical fit with $\sigma_{M_{bb}} = 18\ GeV$ no cut on $M_{bb}$

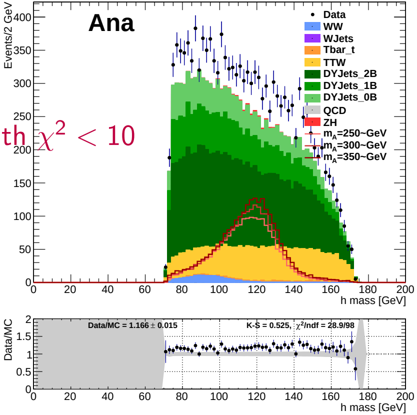


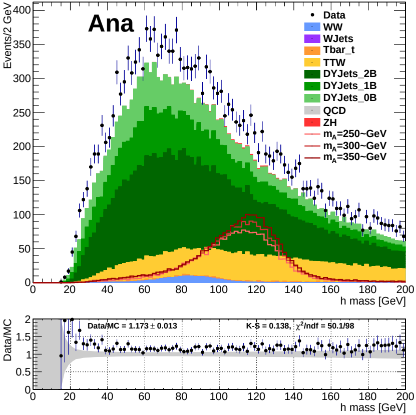

Likewise w/o kin fit

# $M_{bb}$ distribution

Z mass cut + 1 CVST + 1 CVSL ($\sigma_{signal} = 1pb$)

with $\chi^2 < 10$



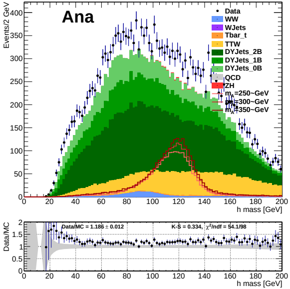

$M_{bb}$ after kinematical fit with $\sigma_{M_{bb}} = 18\ GeV$ no cut on $M_{bb}$

Likewise w/o kin fit

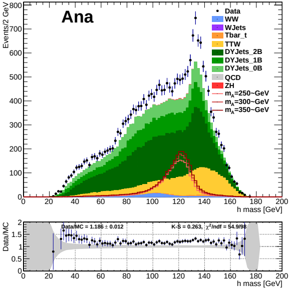
# $M_{bb}$ distribution

## Z mass cut + 1 CVST + 1 CVSL ($\sigma_{signal} = 1pb$)

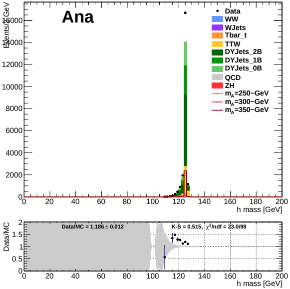
$M_{bb}$ kinematical fit with :




$\sigma_{M_{bb}} = 18\ GeV$




$\sigma_{M_{bb}} = 10\ GeV$

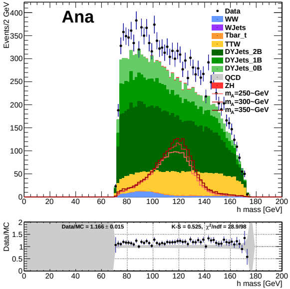



$\sigma_{M_{bb}} = 1\ GeV$

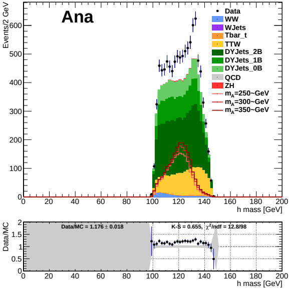
# $M_{bb}$ distribution

## Z mass cut + 1 CVST + 1 CVSL ($\sigma_{signal} = 1pb$)

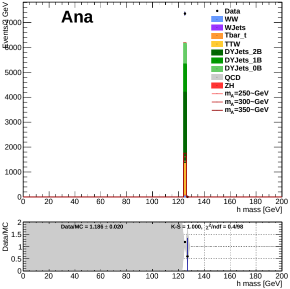
$M_{bb}$ kinematical fit with $\chi^2 < 10$ and:




$\sigma_{M_{bb}} = 18\ GeV$



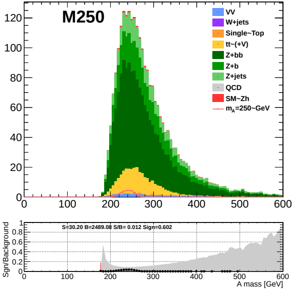

$\sigma_{M_{bb}} = 10\ GeV$




$\sigma_{M_{bb}} = 1\ GeV$

# $M_A = 250\ GeV$

$M_{bb}$ not forced

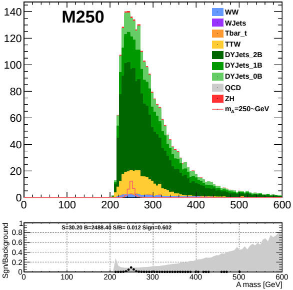



$M_A = 239.2 \pm 0.1\ GeV$

$\sigma_{M_A} = 14.5 \pm 0.1\ \ GeV$

$S = 30 \quad B = 2490$

$M_{bb} = M_h$ if
$90 < M_{bb} < 140\ GeV$

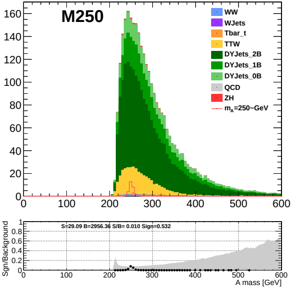



$M_A = 249.11 \pm 0.05\ GeV$

$\sigma_{M_A} = 6.18 \pm 0.04\ GeV$

$S = 30.20 \quad B = 2500$

Kin fit $M_{bb}$ to $M_h$
$\sigma_M = 1\ GeV$



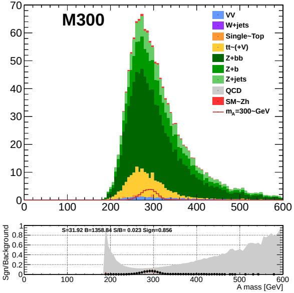

$M_A = 250.89 \pm 0.04\ GeV$

$\sigma_{M_A} = 5.69 \pm 0.04\ GeV$

$S = 29 \quad B = 2960$

# $M_A = 300\ GeV$

$M_{bb}$ not forced




$M_A = 288.6 \pm 0.1\ GeV$

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$M_{bb} = M_h$ if

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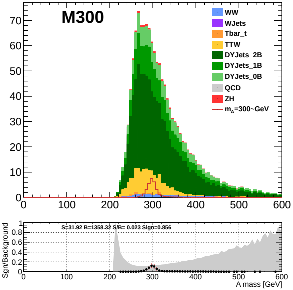


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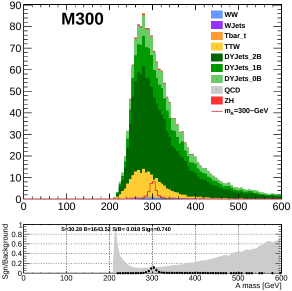
Kin fit $M_{bb}$ to $M_h$

$\sigma_M = 1\ GeV$



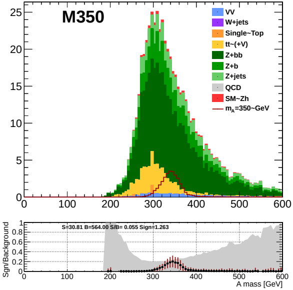

$M_A = 301.44 \pm 0.07\ GeV$

$\sigma_{M_A} = 9.42 \pm 0.08\ GeV$

$S = 30.3 \quad B = 1640$

# $M_A = 350\ GeV$

$M_{bb}$ not forced



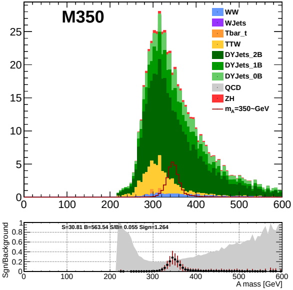

$M_A = 339.1 \pm 0.2\ GeV$

$\sigma_{M_A} = 21.5 \pm 0.1\ \ GeV$

$S = 31 \quad B = 564$

$M_{bb} = M_h$ if

$90 < M_{bb} < 140\ GeV$




$M_A = 345.72 \pm 0.11\ GeV$

$\sigma_{M_A} = 14.50 \pm 0.10\ GeV$

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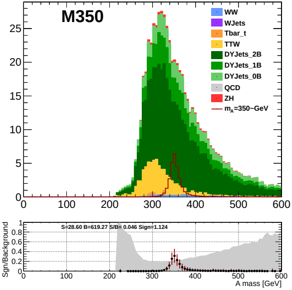
Kin fit $M_{bb}$ to $M_h$

$\sigma_M = 1\ GeV$

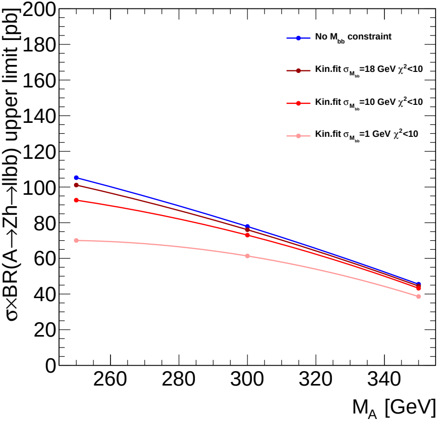



$M_A = 352.37 \pm 0.10\ GeV$

$\sigma_{M_A} = 12.46 \pm 0.10\ GeV$

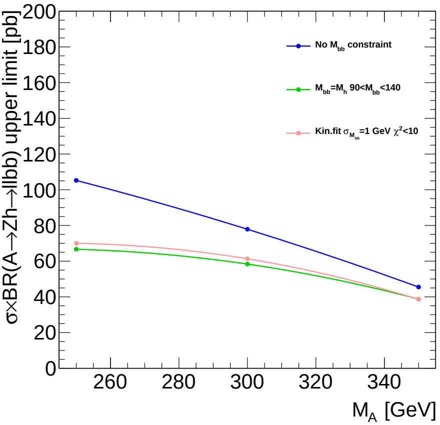
$S = 28.6 \quad B = 620$

# Conclusion II




- Kinematical Fit improves the expected limits;
- The smaller $\sigma_{M_{bb}}$ the better the limit

# Conclusion II




- Kinematical Fit improves the expected limits;
- The smaller $\sigma_{M_{bb}}$ the better the limit
- Forcing $M_{bb} = M_h$ gives results as good as kinematical fit with $\sigma_{M_{bb}} = 1\ GeV$, provided it is applied only to those events with $90 < M_{bb} < 140\ GeV$.

# Conclusion

## Force $M_{bb} = M_h$

- Background is not peaked as much as Signal;
- If we cut on $M_{bb}$ before forcing $M_{bb} = M_h$: S/B is significantly better!
- If not, Background is significantly higher!!

## Kinematical fit

- $M_A$ peak can be narrowed by $M_h$ kinematical fit
- With small $\sigma_{M_{bb}} = 1\ GeV$, the results are similar to that of forcing the mass with a prior cut on $M_{bb}$

# Backup

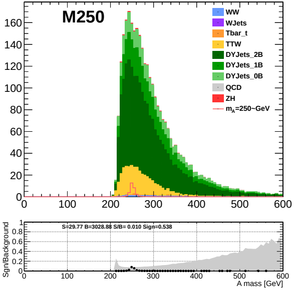
## Backup

Guess what?

Yep, backup slides ahead!

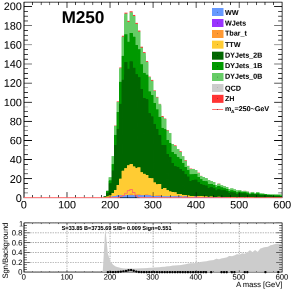
# $M_A = 250\ GeV$

Kin fit $M_{bb}$ to $M_h$
$\sigma_M = 1\ GeV$



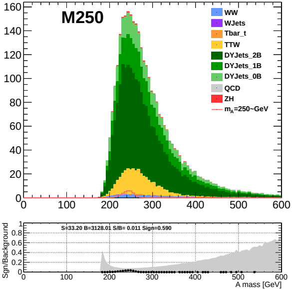

$M_A = 250.89 \pm 0.04\ GeV$
$\sigma_{M_A} = 5.69 \pm 0.04\ GeV$
$S = 30 \quad B = 3030$

Kin fit $M_{bb}$ to $M_h$
$\sigma_M = 10\ GeV$




$M_A = 245.44 \pm 0.07\ GeV$
$\sigma_{M_A} = 9.90 \pm 0.06\ GeV$
$S = 34 \quad B = 3730$

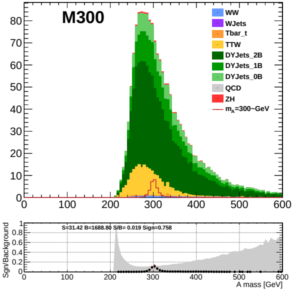
Kin fit $M_{bb}$ to $M_h$
$\sigma_M = 1\ GeV$




$M_A = 241.54 \pm 0.10\ GeV$
$\sigma_{M_A} = 13.38 \pm 0.08\ GeV$
$S = 33 \quad B = 3130$

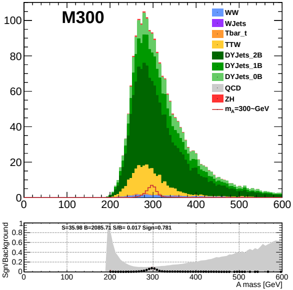
# $M_A = 300\ GeV$

**Kin fit $M_{bb}$ to $M_h$**
**$\sigma_M = 1\ GeV$**



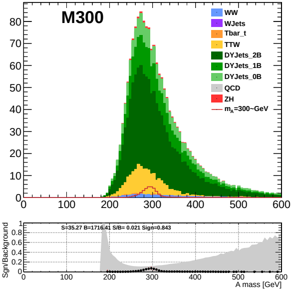

$M_A = 301.44 \pm 0.07\ GeV$
$\sigma_{M_A} = 9.42 \pm 0.08\ GeV$
$S = 31 \quad B = 1690$

**Kin fit $M_{bb}$ to $M_h$**
**$\sigma_M = 10\ GeV$**




$M_A = 295.39 \pm 0.09\ GeV$
$\sigma_{M_A} = 13.00 \pm 0.10\ GeV$
$S = 36 \quad B = 2085$

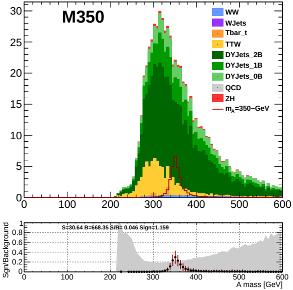
**Kin fit $M_{bb}$ to $M_h$**
**$\sigma_M = 1\ GeV$**




$M_A = 291.24 \pm 0.13\ GeV$
$\sigma_{M_A} = 17.30 \pm 0.12\ GeV$
$S = 35 \quad B = 1716$

# $M_A = 350\ GeV$

## Kin fit $M_{bb}$ to $M_h$ $\sigma_M = 1\ GeV$

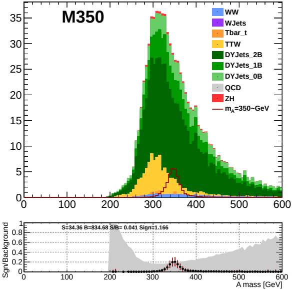



$M_A = 352.37 \pm 0.10\ GeV$

$\sigma_{M_A} = 12.46 \pm 0.10\ GeV$

$S = 31 \quad B = 670$

## Kin fit $M_{bb}$ to $M_h$ $\sigma_M = 10\ GeV$

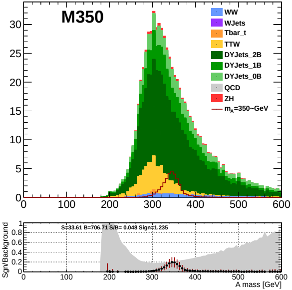



$M_A = 346.43 \pm 0.11\ GeV$

$\sigma_{M_A} = 15.38 \pm 0.12\ GeV$

$S = 35 \quad B = 834$

## Kin fit $M_{bb}$ to $M_h$ $\sigma_M = 1\ GeV$

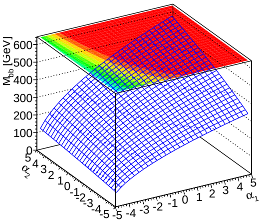


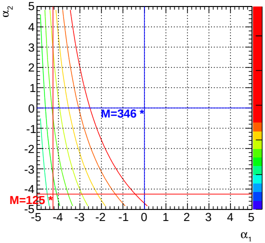

$M_A = 342.13 \pm 0.14\ GeV$

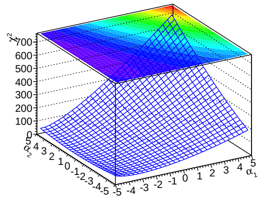
$\sigma_{M_A} = 19.32 \pm 0.14\ GeV$

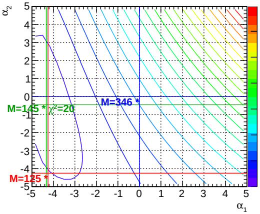
$S = 34 B = 706$

# A bad example: $M_{bb} = 345\ GeV$ with $\sigma_{M_{bb}} = 18\ GeV$

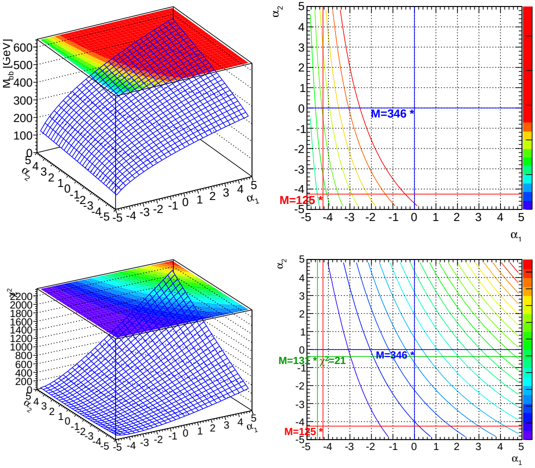


# A bad example: $M_{bb} = 345\ GeV$ with $\sigma_{M_{bb}} = 10\ GeV$



# A bad example: $M_{bb} = 345\ GeV$ with $\sigma_{M_{bb}} = 1\ GeV$