Kinematic Fit for heavy Higgs decays

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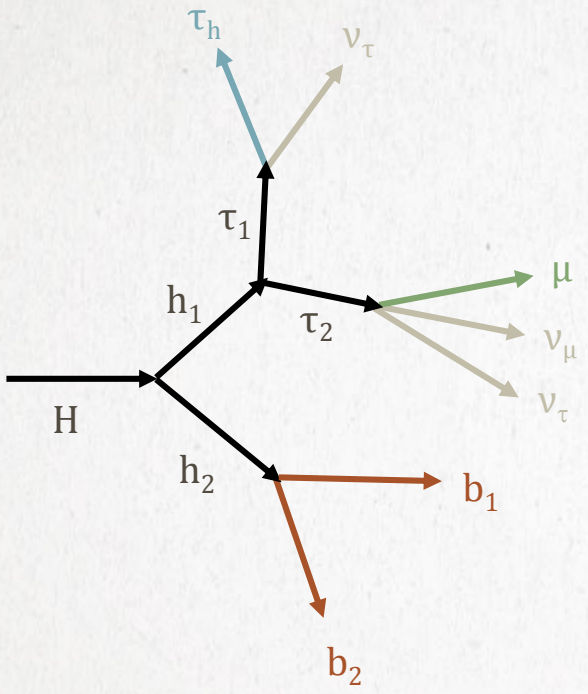
Overview

- Introduction
- Kinematic fits in general
- HHKinFit
- Performance of HHKinFit
- First Look 13 TeV Data

Heavy Higgs searches



MSSM:

– $m_{h1} = m_{h2} = 125$ GeV

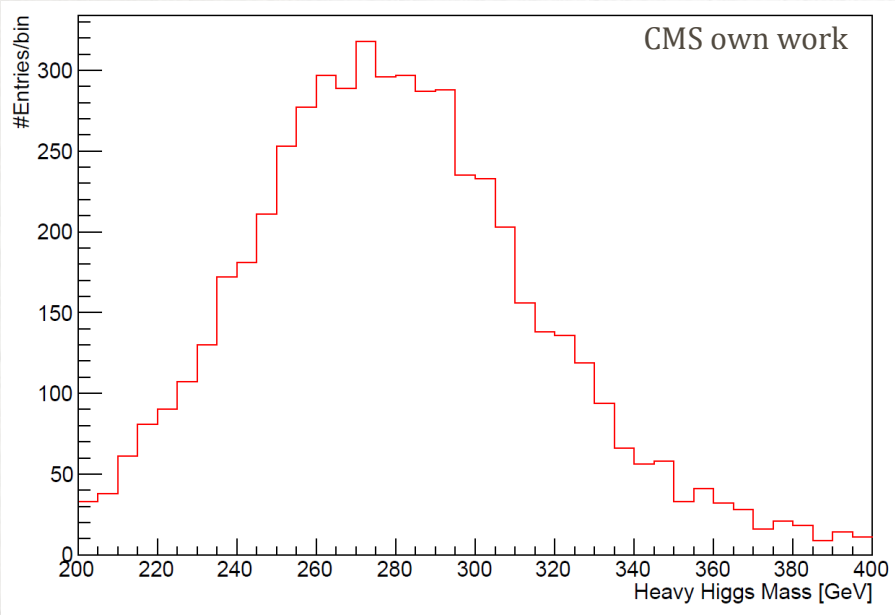
NMSSM:

– Additional scalar singlet ⇒

$m_{h1} \neq m_{h2}$

In the following: MSSM

Motivation for kinematic fit



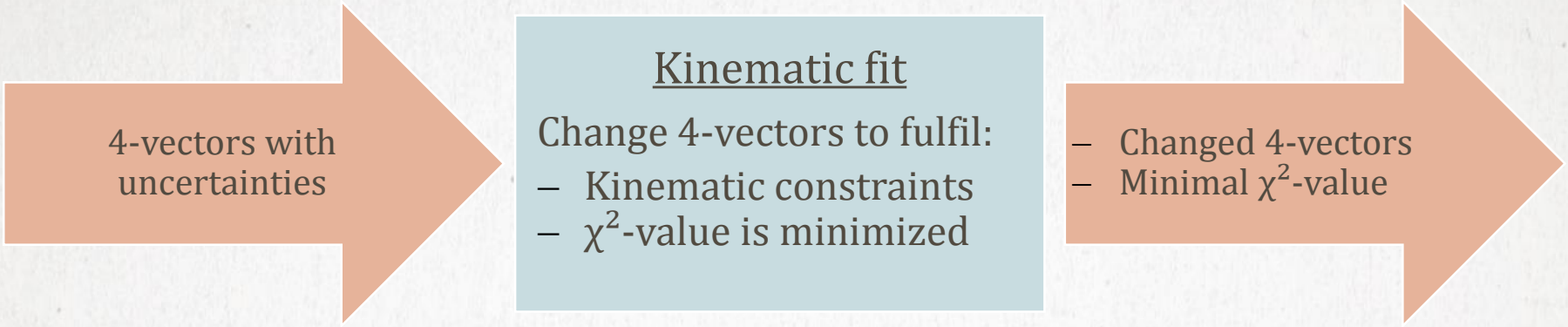
Analysis Challenges:

- Big, irreducible ttbar background
- Heavy Higgs mass reconstruction very difficult

Kinematic constraints on event topology:

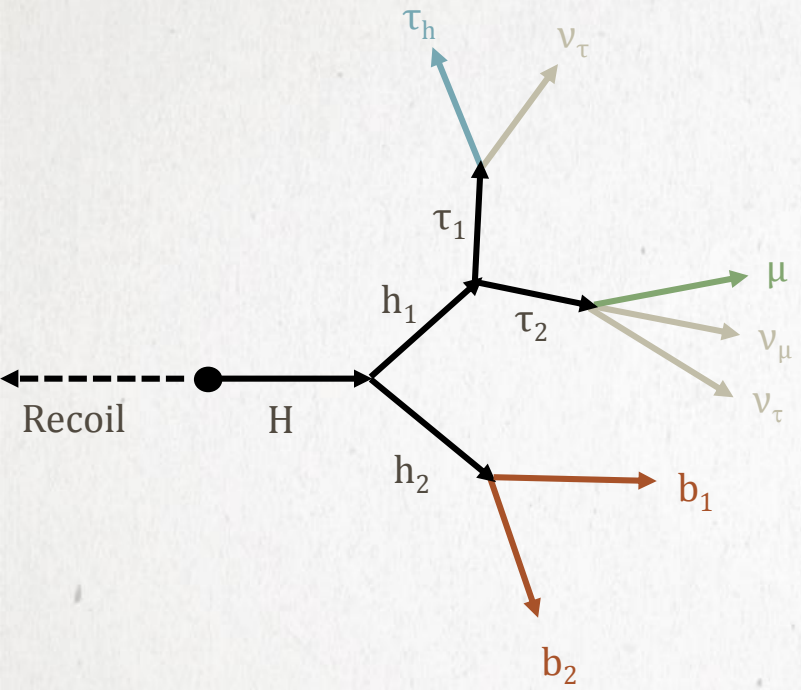
- Invariant mass of tau and b-jet pair known
- Taus have high lorentz boost ⇒ tau decay products in tau direction
- Heavy Higgs p_T equal to p_T of recoil

Kinematic fits in general

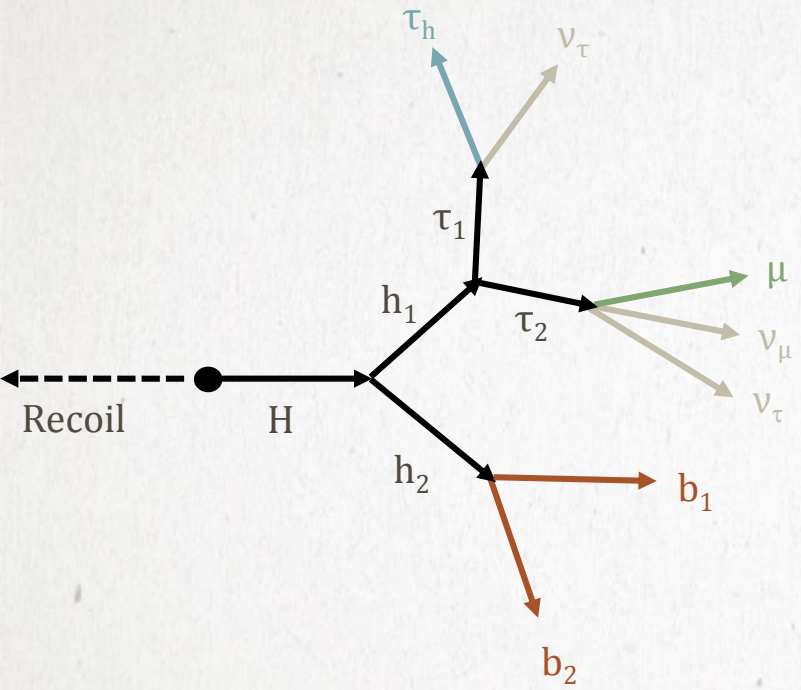


- Changed 4-vectors can be used to determine dependent quantities with increased precision
- χ^2-value can be used to separate background and signal events

HHKinFit



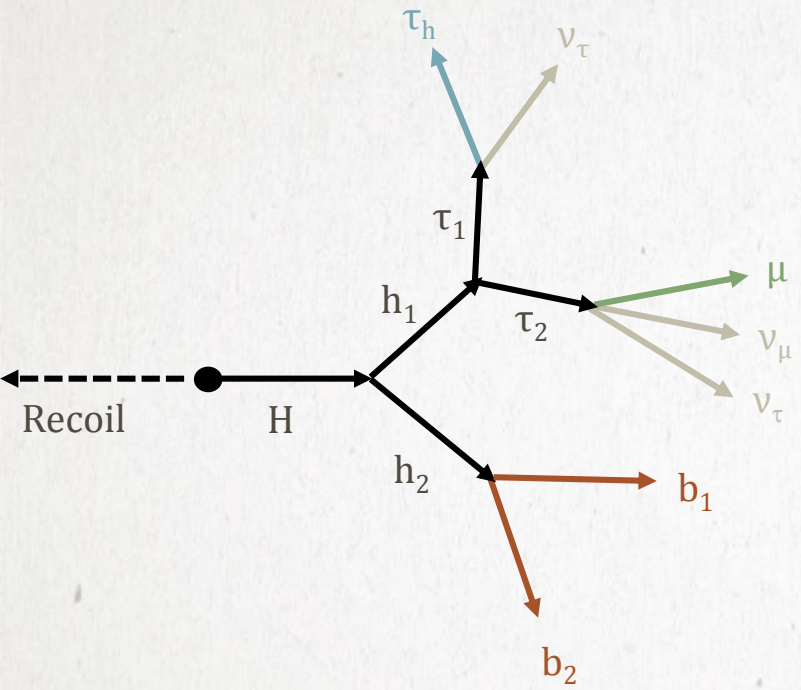
HHKinFit



Constraints on event topology:

- Invariant mass(τ_1, τ_2) = m_h
- Invariant mass(b_1, b_2) = m_h
- $\vec{P}_{T,H} = -\vec{P}_{T,Recoil}$

HHKinFit



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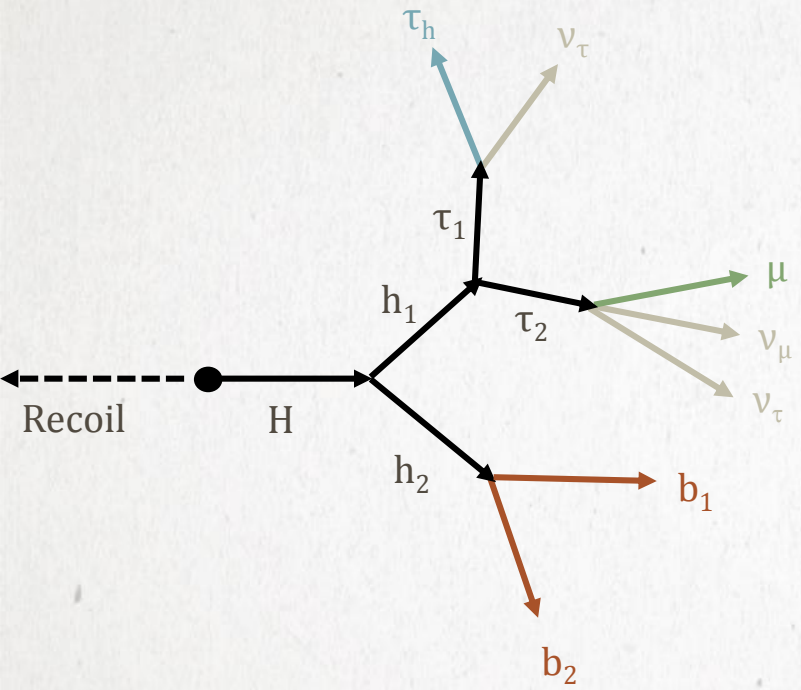
Assume collinearity:

- τ direction equal to τ decay products direction (Lorentz boost)
- Uncertainty on b-jet direction negligible

HHKinFit



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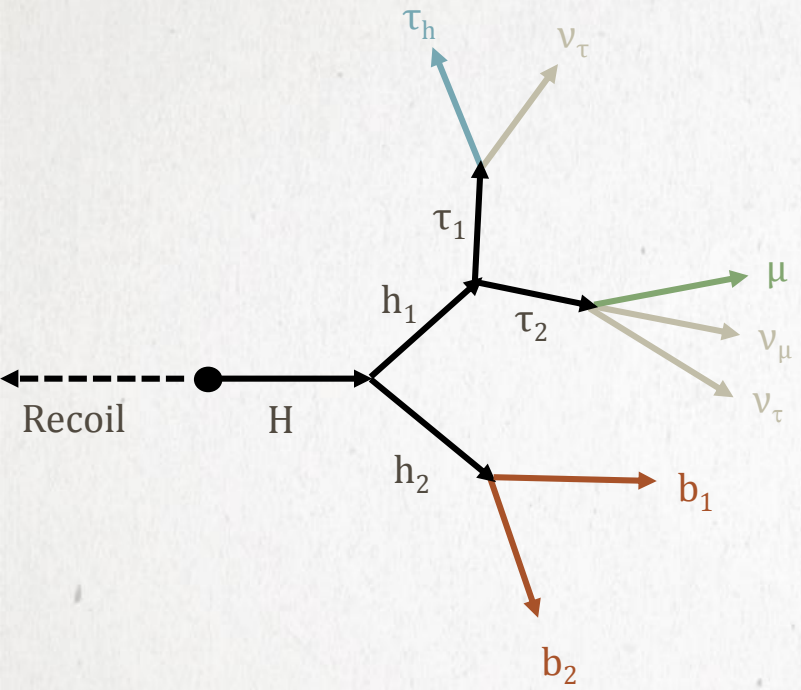
Fitting procedure:

- Vary E_{b1} - E_{b2} follows (Inv. mass = m_h)
- Vary $E_{\tau 1}$ - $E_{\tau 2}$ follows (Inv. mass = m_h)

⇒ Two degrees of freedom

HHKinFit



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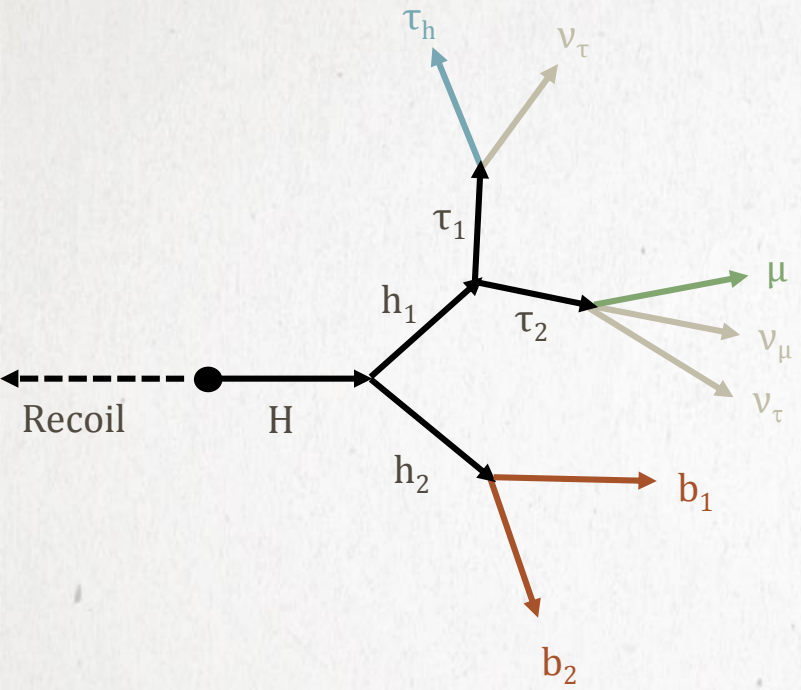
  $\Rightarrow$ Two degrees of freedom
- Minimize χ^2-function

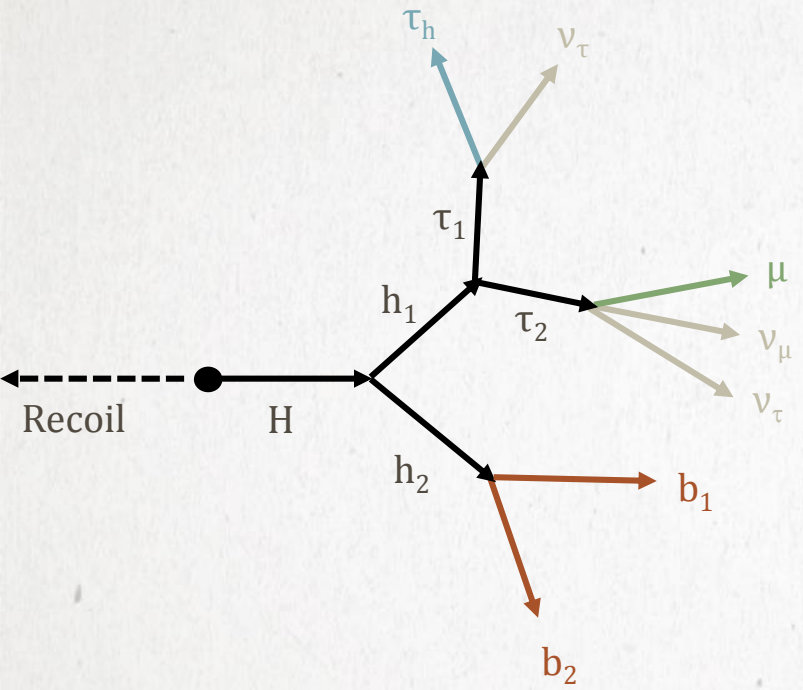
χ^2-function

- b-Jet contribution:

$$\chi^2_b = \left(\frac{E_b^{fit} - E_b^{reco}}{\sigma_{E(b)}} \right)^2$$



χ^2-function



– b-Jet contribution:

$$\chi^2_b = \left(\frac{E_b^{fit} - E_b^{reco}}{\sigma_{E(b)}} \right)^2$$

– Balance contribution:

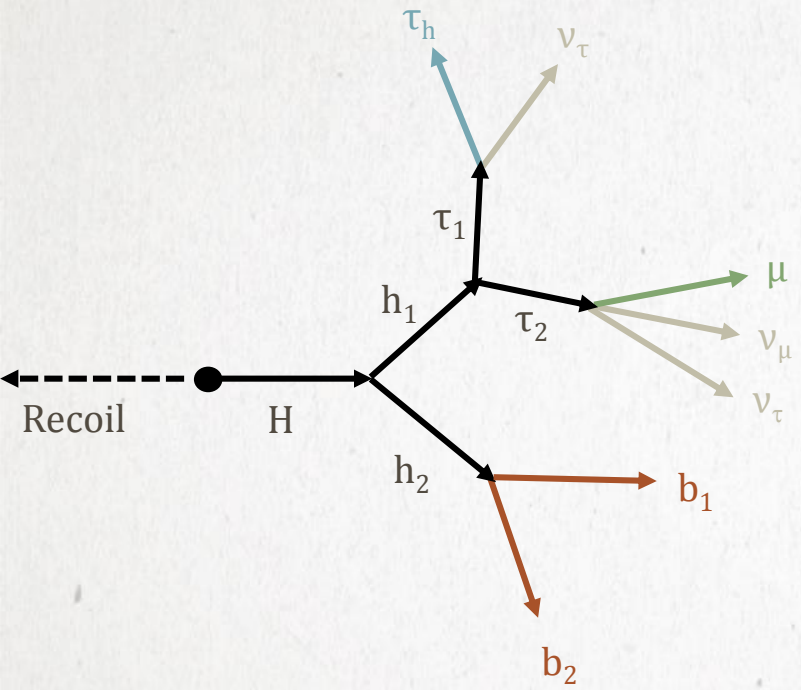
$$\vec{P}_{T,H} = -\vec{P}_{T,Recoil}$$

$$-\vec{P}_{T,Recoil} = \vec{P}_{MET} + \vec{P}_{T,b1} + \vec{P}_{T,b2} + \vec{P}_{T,\tau_h} + \vec{P}_{T,e}$$

$$COV_{T,Recoil} = COV_{MET} + COV_{T,b1} + COV_{T,b2} + COV_{T,\tau_h} + COV_{T,e}$$

$$\chi^2_{Balance} = \left(\vec{P}^{fit}_{H,T} + \vec{P}_{T,Recoil} \right)^T COV^{-1}_{T,Recoil} \left(\vec{P}^{fit}_{H,T} + \vec{P}_{T,Recoil} \right)$$

χ^2-function



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$$\chi^2 = \sum_{i=1}^{2} \chi^2_{b_i} + \chi^2_{Balance}$$

Minimization

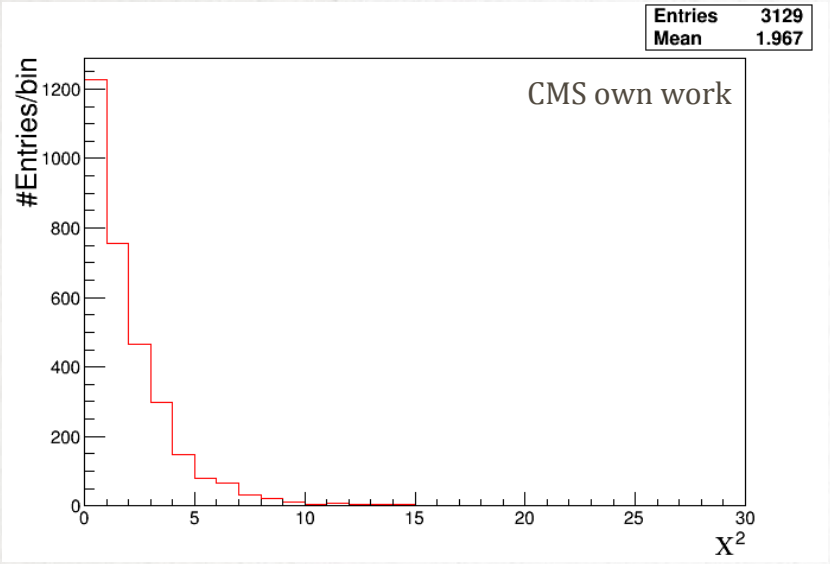
- No analytical function $\Rightarrow$ No Minuit

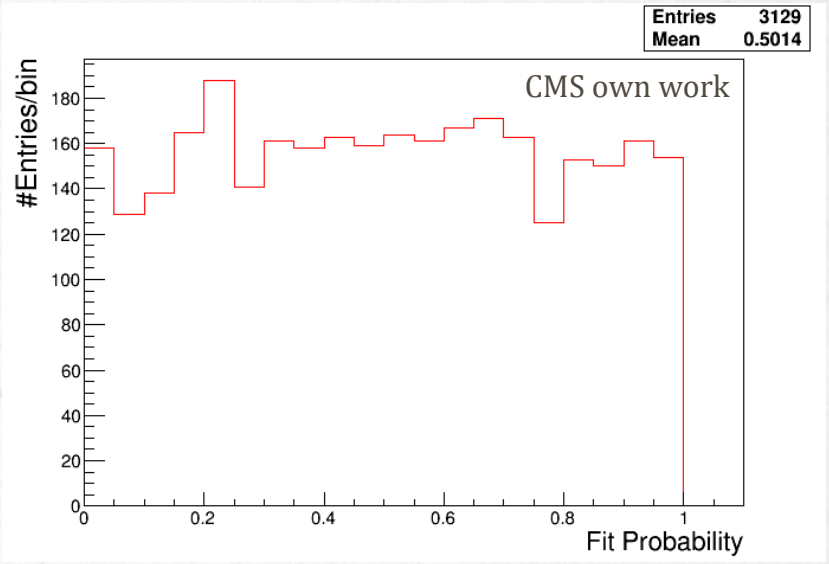
- Minimization by combination of line search and Newton‘s method
  - Start with linesearch in arbitrary direction
  - Try to find a solution with Newton‘s Method
  - No solution: Start new linesearch in direction of steepest decline
  - repeat until solution was found or until χ^2 and fit parameter-variation becomes smaller than chosen precision

- Very fast (≈10 ms per event)

Performance

- Test on toy Monte Carlo:
  H → hh → bbττ → bbeμ
  - b-Jet energy smeared by a Gaussian
  - Recoil momentum smeared by a Gaussian

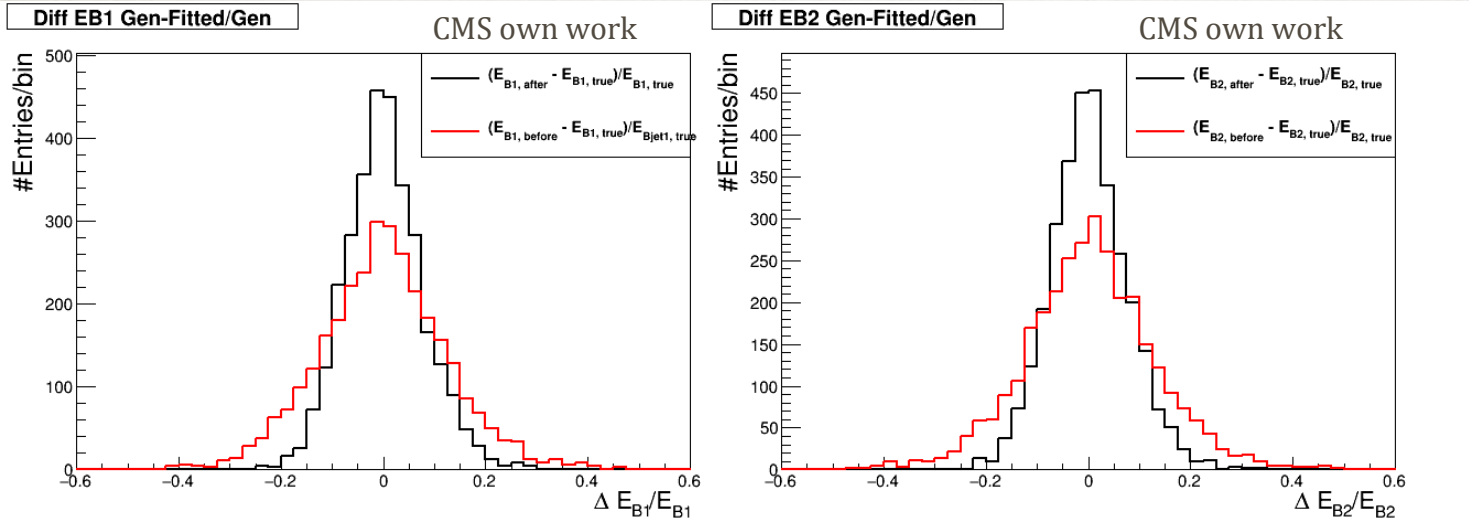




- χ^2-function can be translated as fit probability
- Fit probability flat ⇒ χ^2-function defined correctly for Gaussian uncertainties

$$P(\chi^2_{obs}) = \int_{\chi^2_{obs}}^{\infty} PDF(\chi^2, ndf)d\chi^2$$

Performance

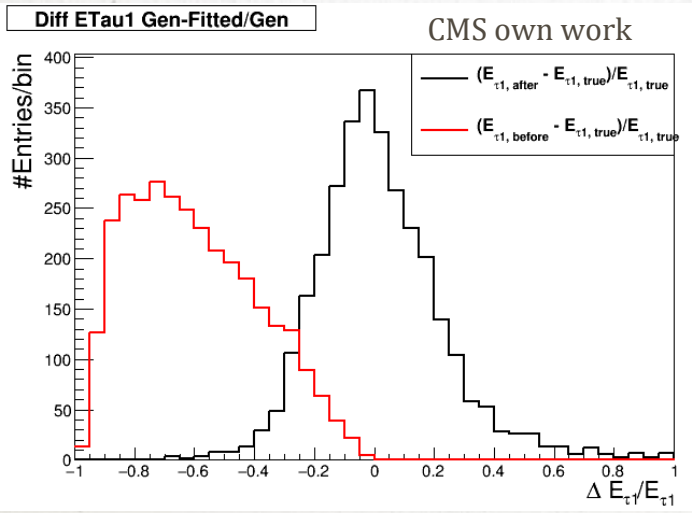


Energy difference b-Jet 1

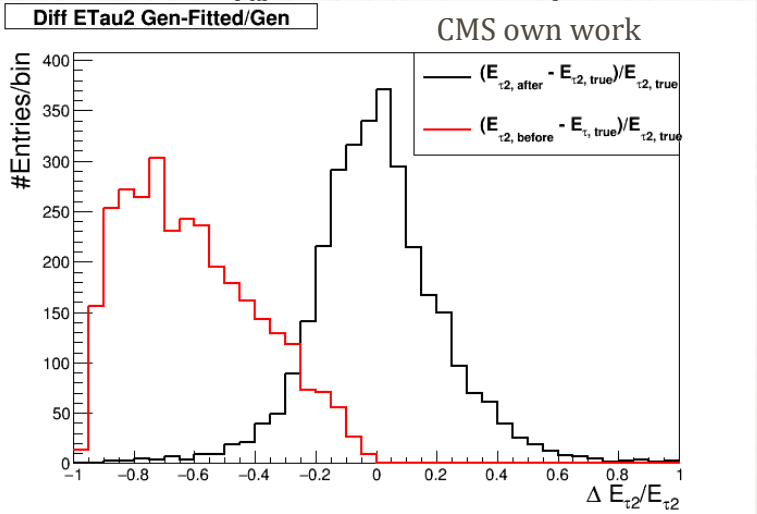
Energy difference b-Jet 2

$$\frac{E_{B\,before} - EB_{\,true}}{E_{B\,true}}$$

$$\frac{E_{B\,after} \_ EB_{\,true}}{E_{B\,true}}$$



Energy difference τ 1

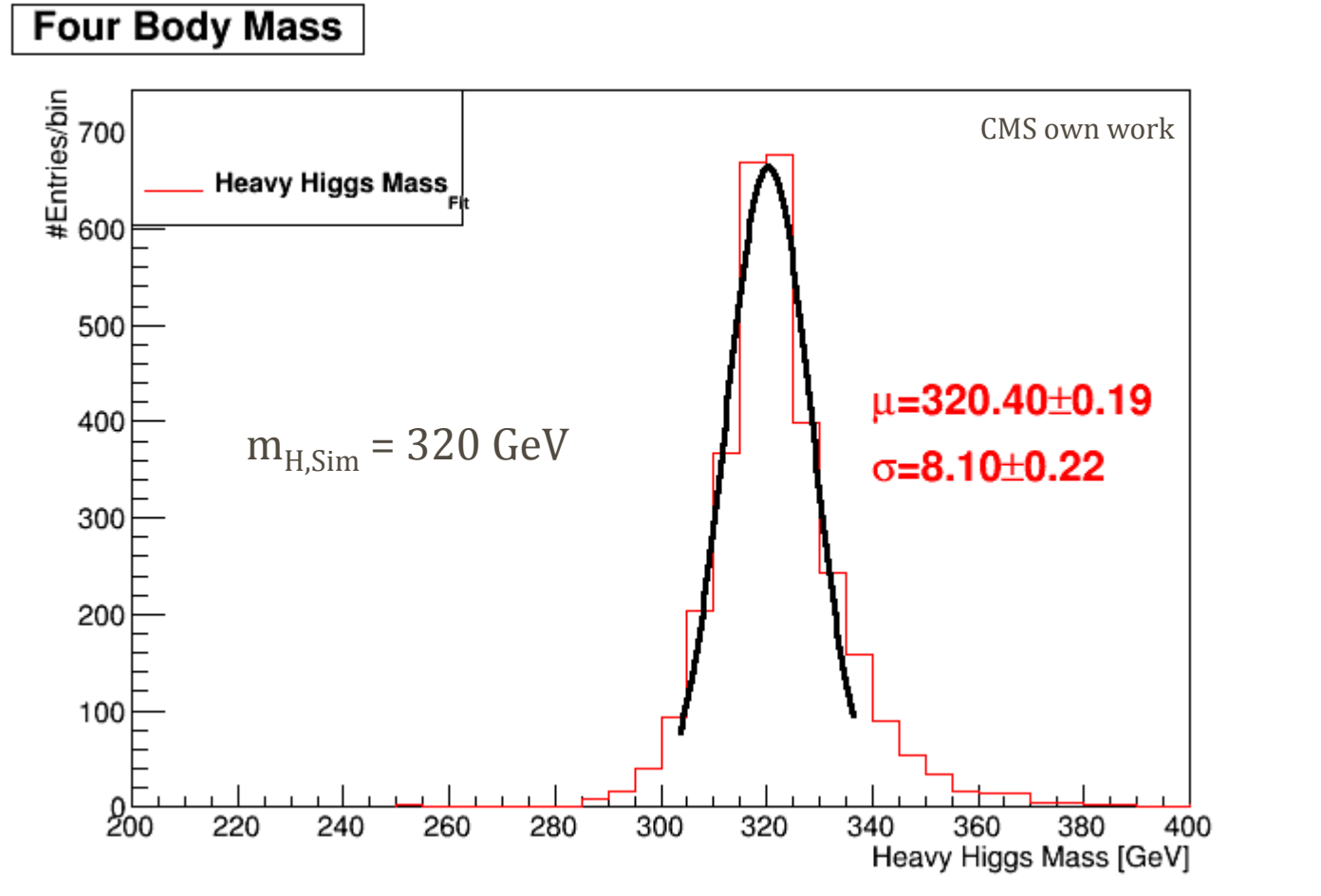


Energy difference τ 2

$$\frac{E_{\tau\,before} - E_{\tau\,true}}{E_{\tau\,true}}$$

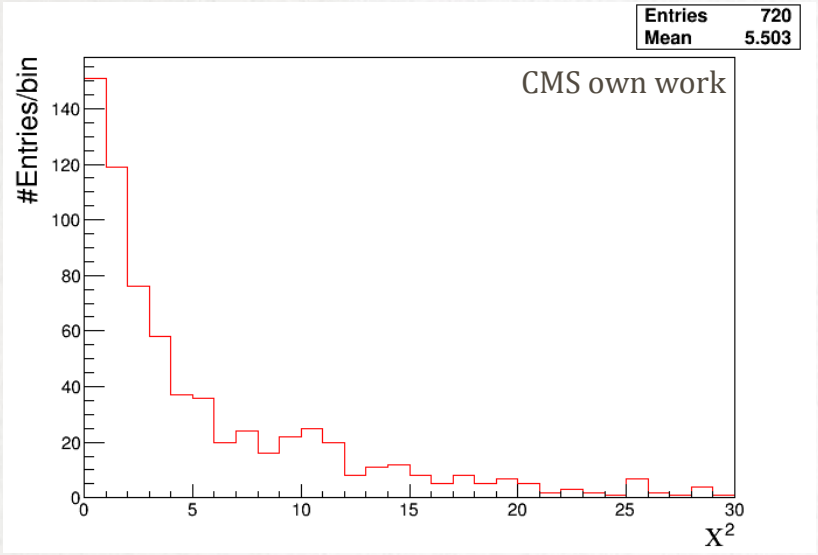
$$\frac{E_{\tau\,after} \_ E_{\tau\,true}}{E_{\tau\,true}}$$

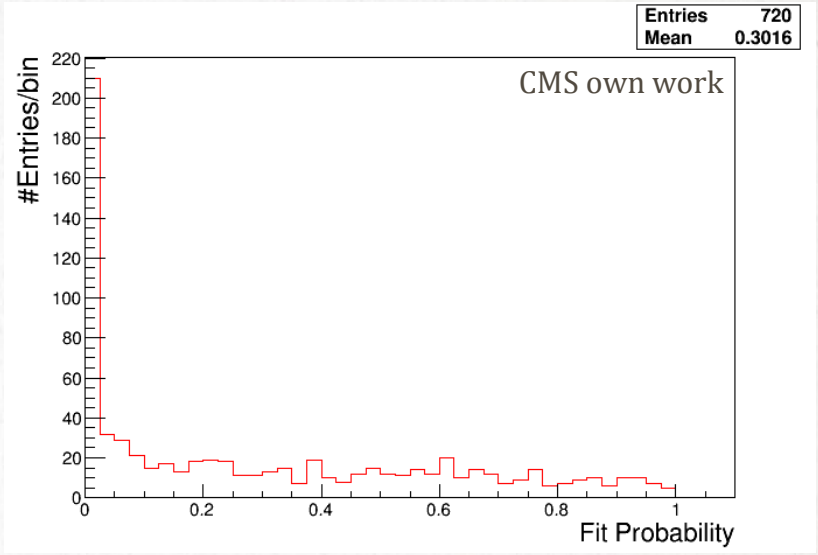
Heavy Higgs mass



Performance

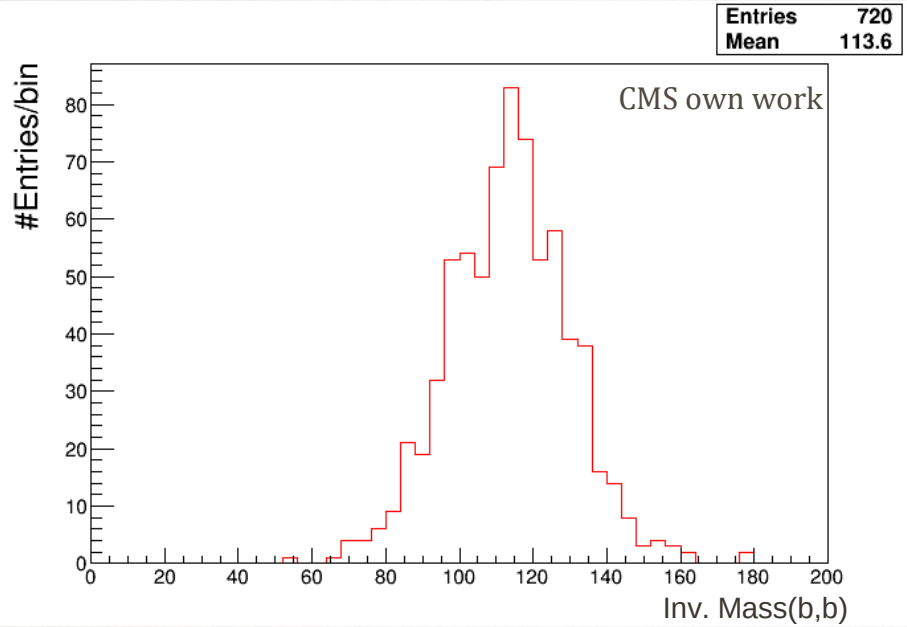
- Test on Monte Carlo including CMS detector-simulation:
  $H \rightarrow hh \rightarrow bb\tau\tau \rightarrow bbl\tau_h$
  - Both jets within $\Delta R < 0{,}1$ of a generator jet

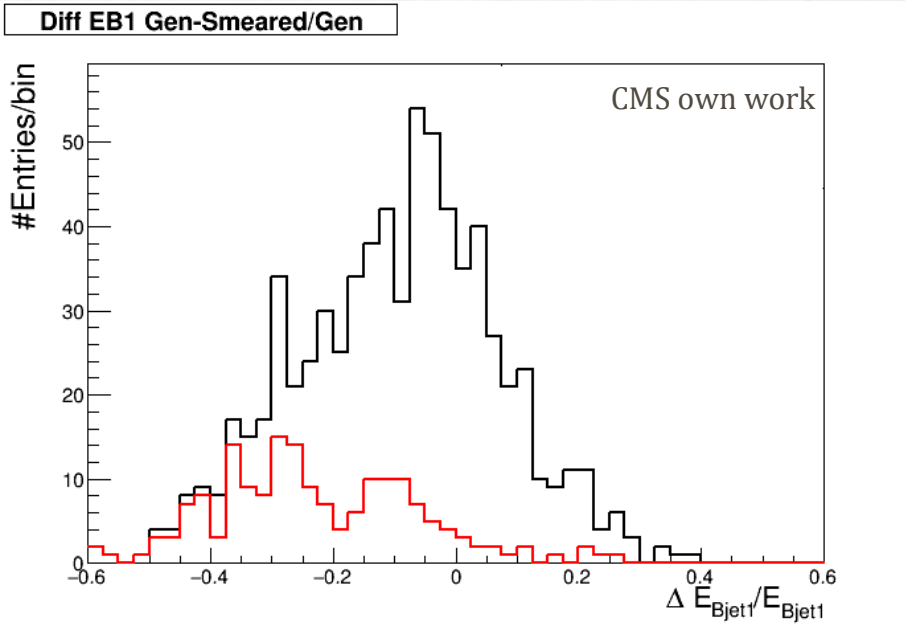




- Fit probability flat for $p > 0.1$
- Peak at $p < 0.05$ due to systematic mismeasurement of b-jet energies (neutrinos)

Peak at low p-values

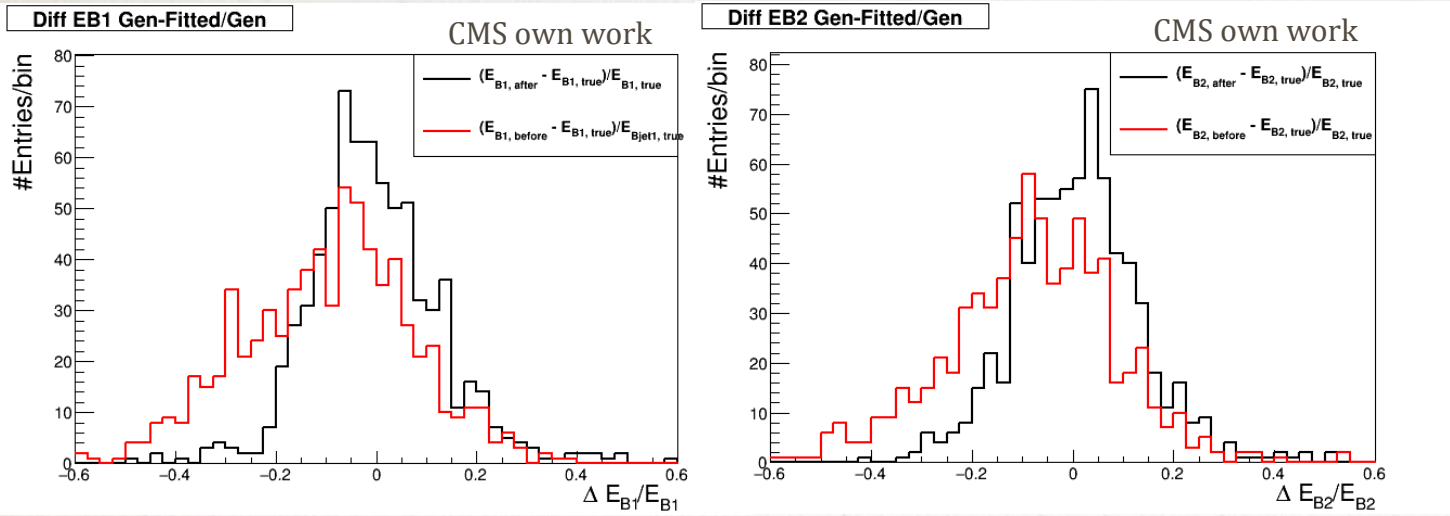




p < 0.05

all events

Performance



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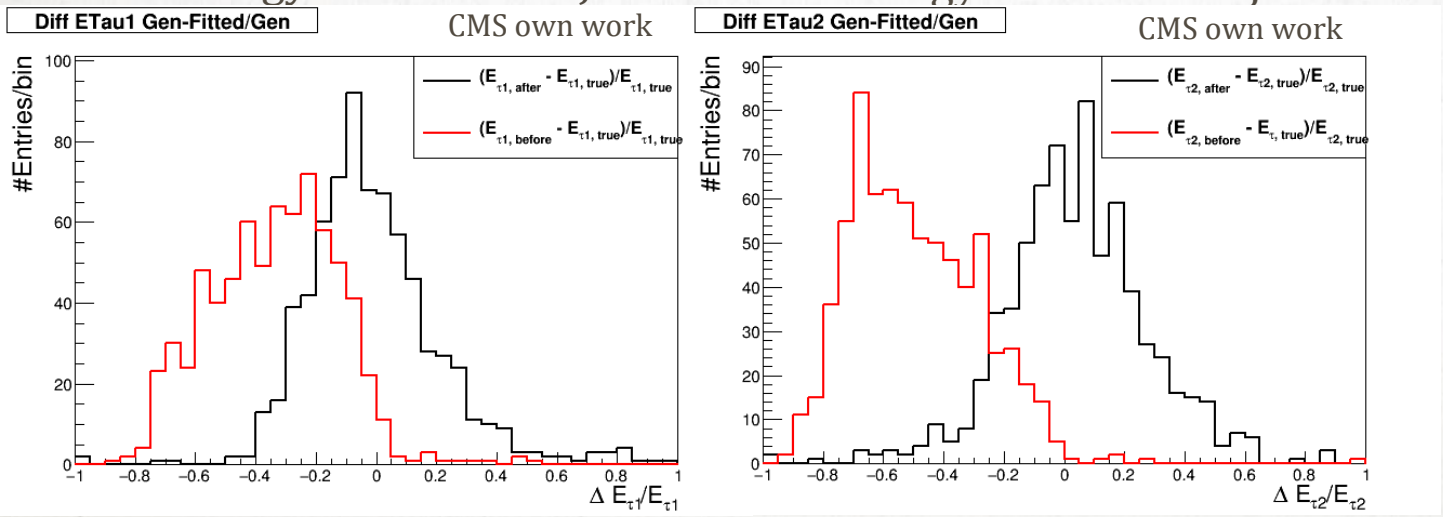

Energy difference τ 1

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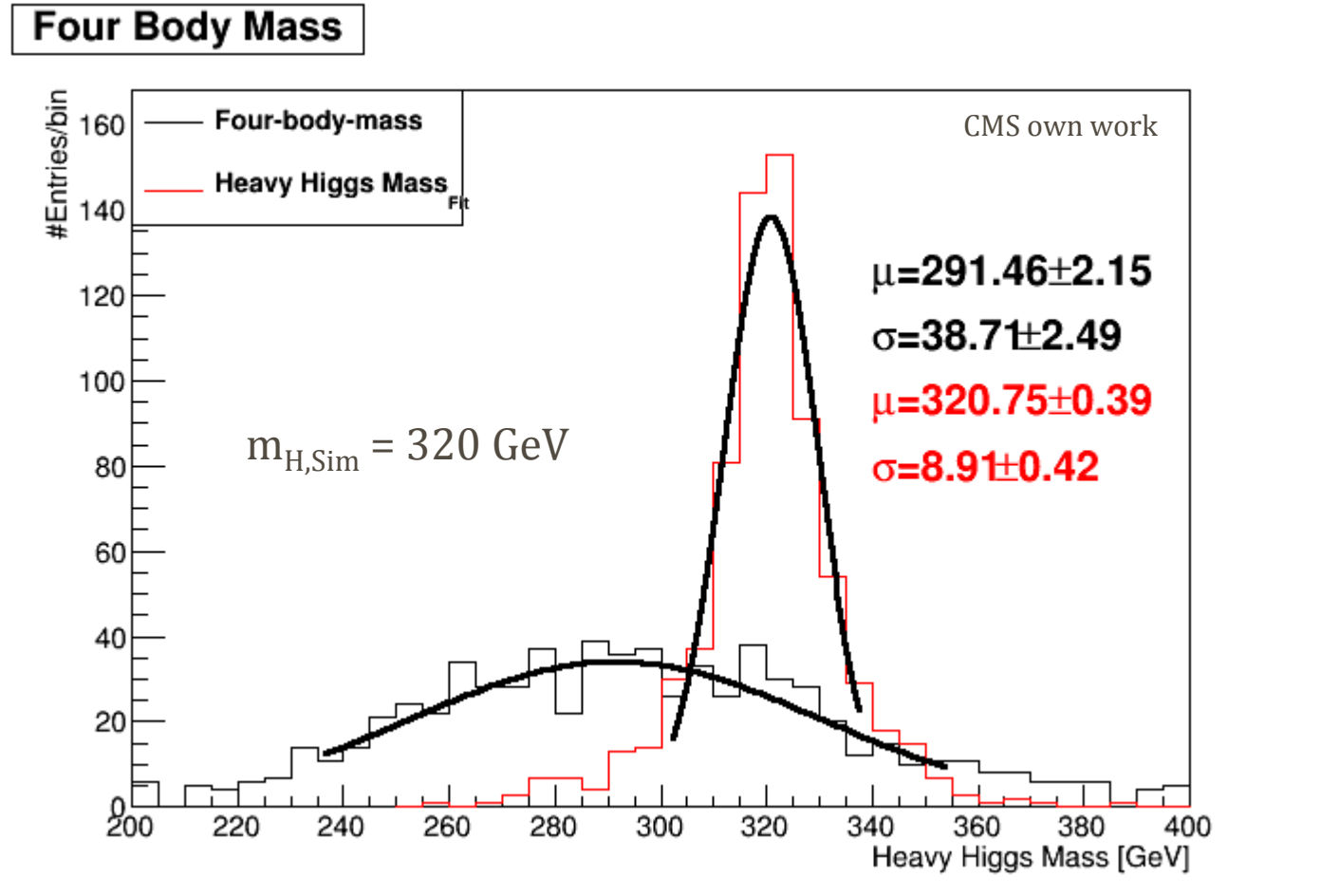
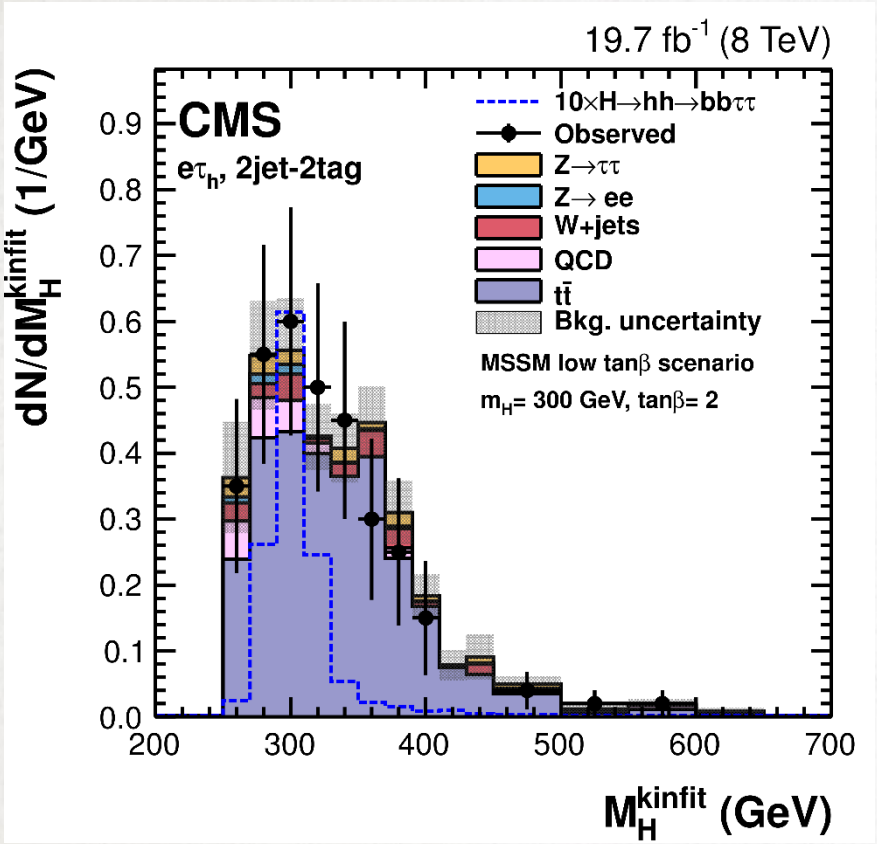
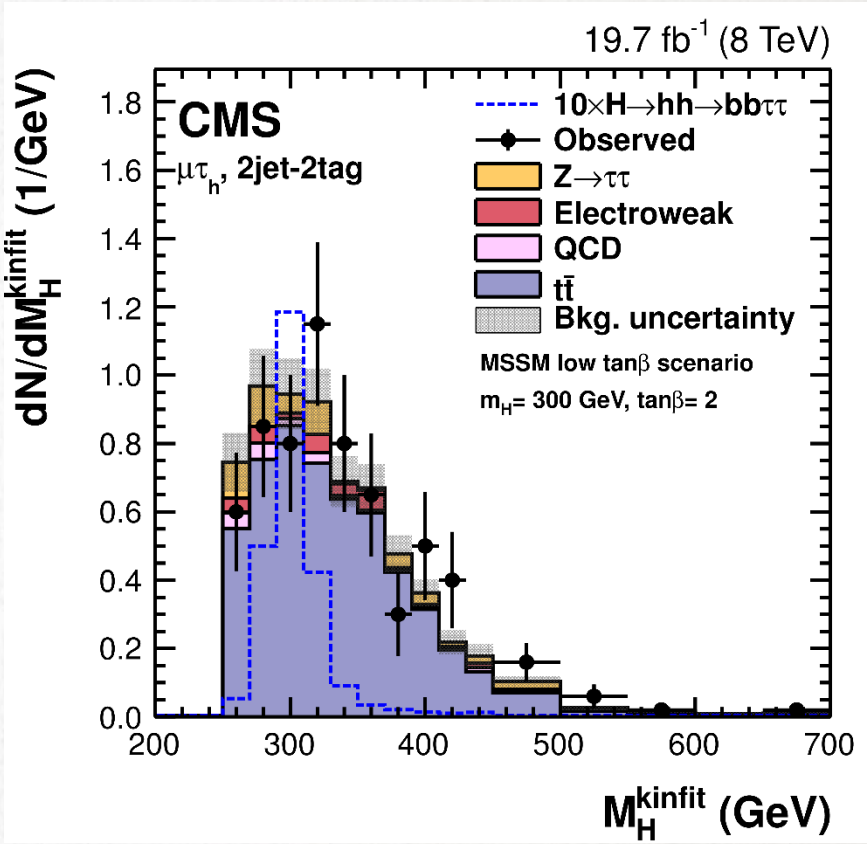
Heavy Higgs mass



8 TeV Analysis

HIG-14-034





First Look 13 TeV

- 1.56 fb^{-1} of 13 TeV data
- 25 ns bunch-crossings
- Data Trigger:
  HLT_IsoMu18
- MC Trigger:
  HLT_IsoMu17_eta2p1 && Pt matched Trig.Obj. > 18 GeV

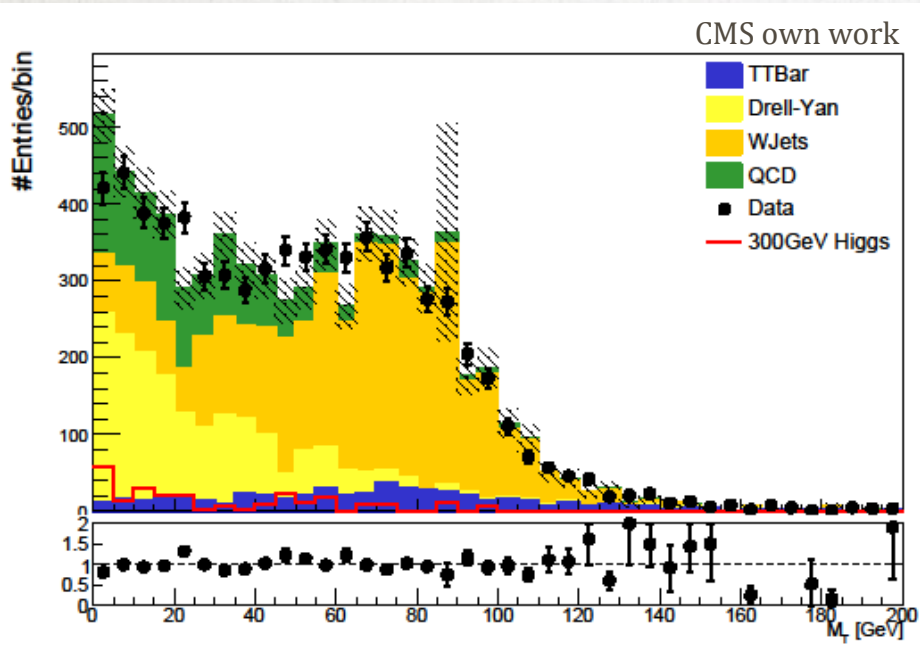
- Background estimation methods taken from 8 TeV analysis
  - TTbar and DY: taken from MC
  - W-Jets: scale from data, shape from MC
  - QCD: ABCD Method from same sign/anti-isolated regions

- PU reweighting implemented
- No Embedding for DY background
- No id/iso and trigger efficiency mc vs data correction applied
- Signal MC scaled to arbitrary signal strength

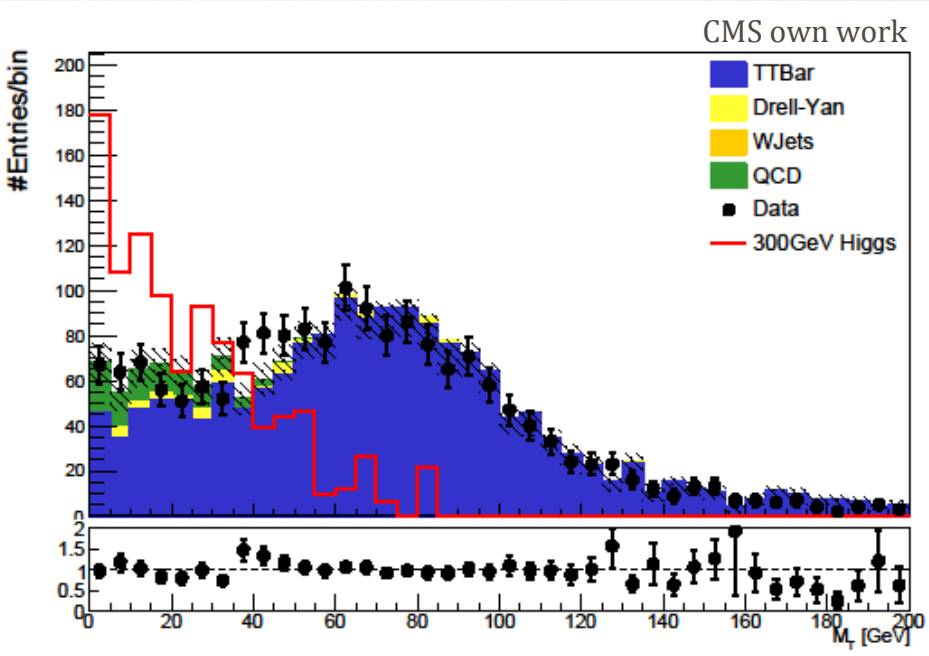
Preselection:
- Isolated μτ-pair with opposite sign
- At least two jets

First Look 13 TeV

No B-Jets



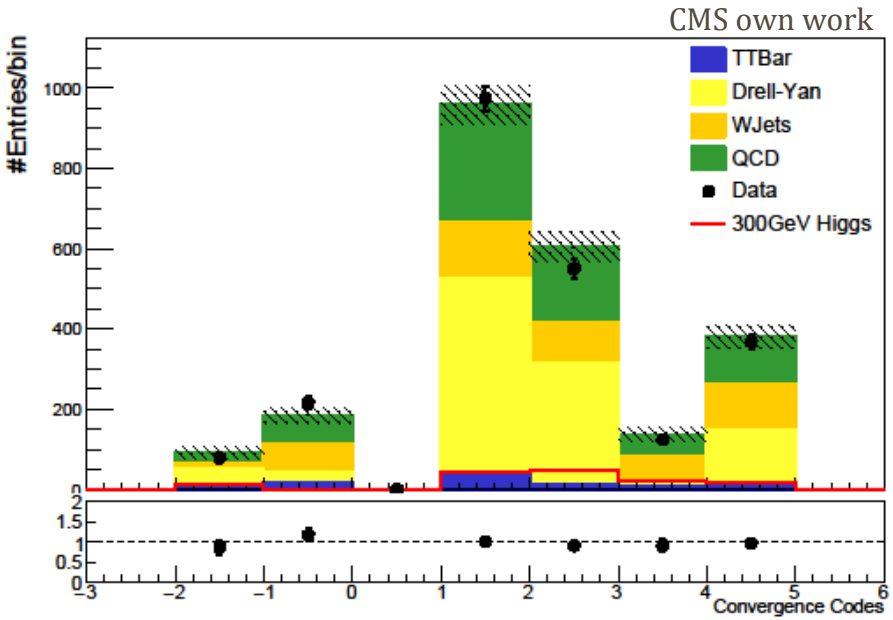
≥ 2 B-Jets



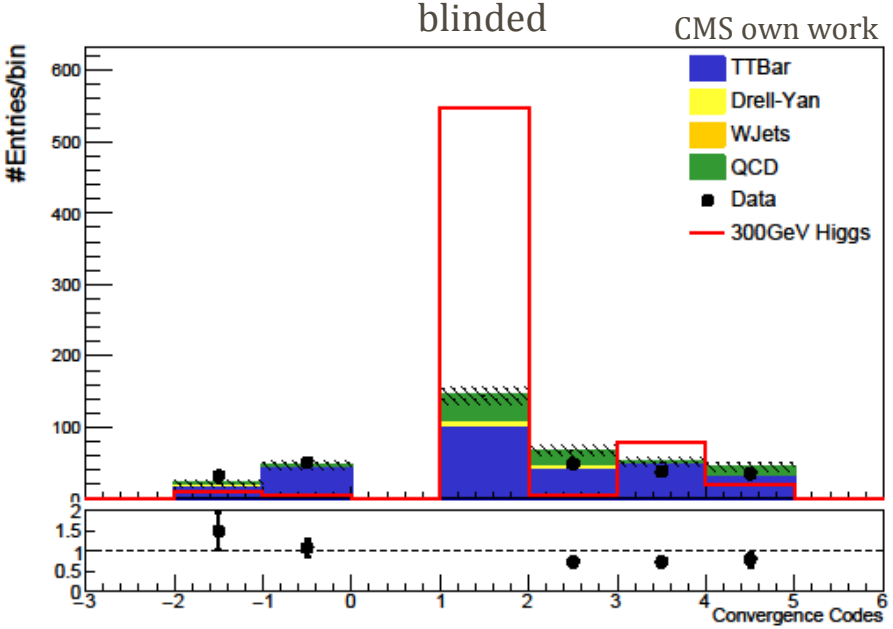
- Background estimation describes data
- Apply cut at $M_T < 30$ GeV

First Look 13 TeV

No B-Jets



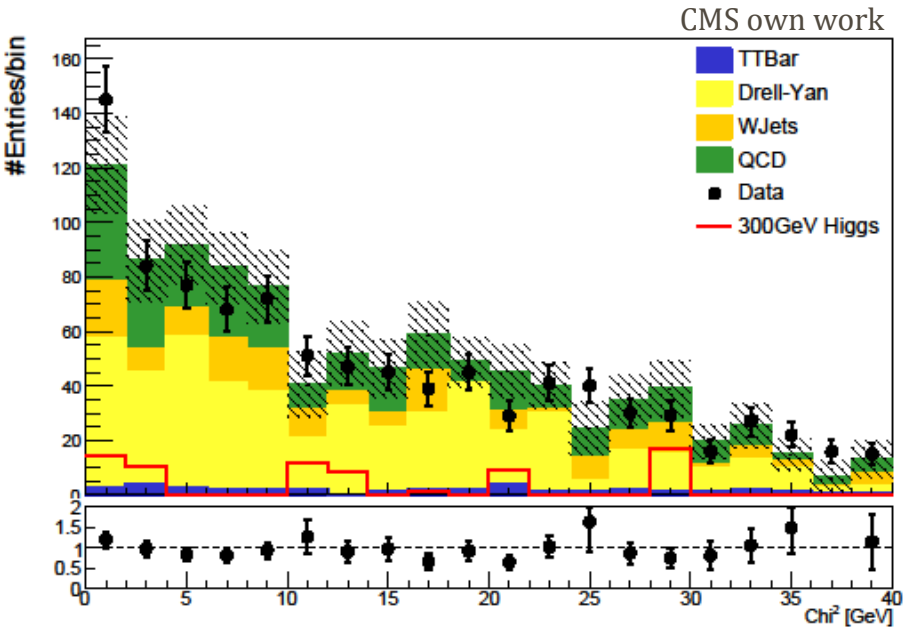
≥ 2 B-Jets
blinded



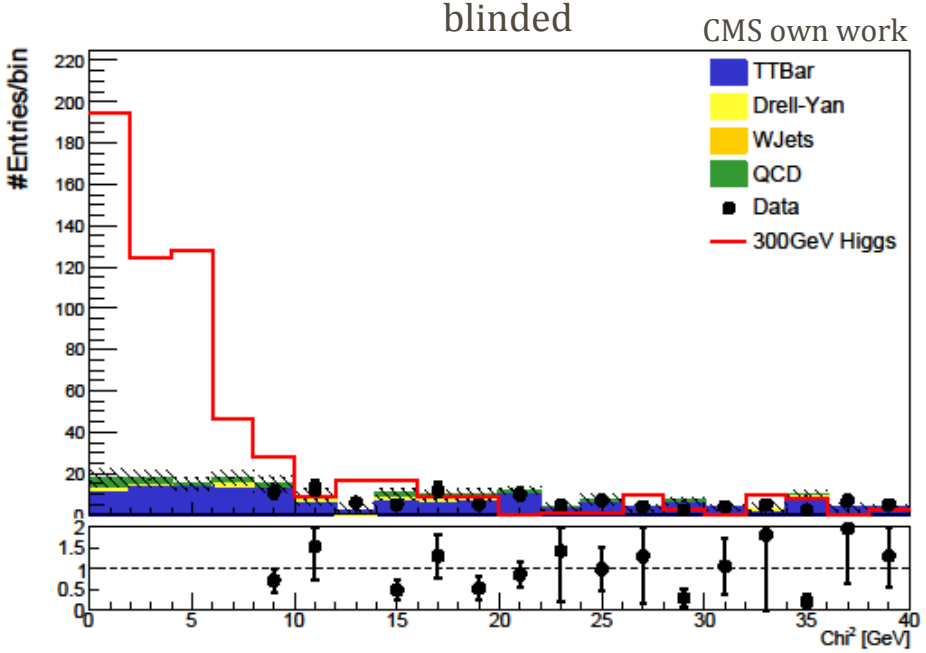
- Convergence Codes:
  - <0: No possible solutions within 5σ of σ_{Jet} or with $E_\tau < E_{\tau,vis}$
  - =0: Fit did not converge
  - =1: Fit converged
  - >1: Fit converged at 5σ-limit of Jet or at $E_\tau = E_{\tau,vis}$
- Apply cut at convergence > 0

First Look 13 TeV

No B-Jets



≥ 2 B-Jets blinded

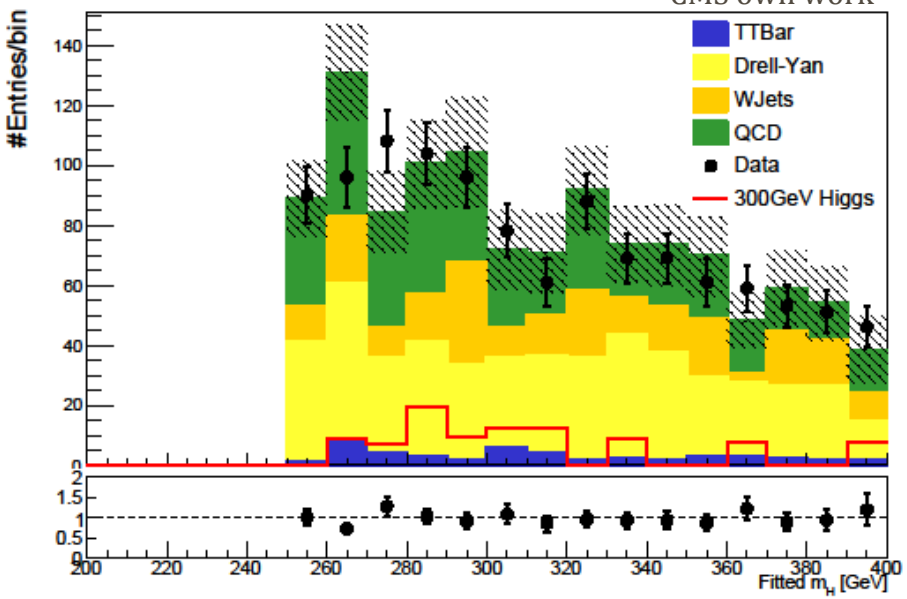


- Background estimation describes data
- Chi2 distribution might be interesting for background seperation

First Look 13 TeV

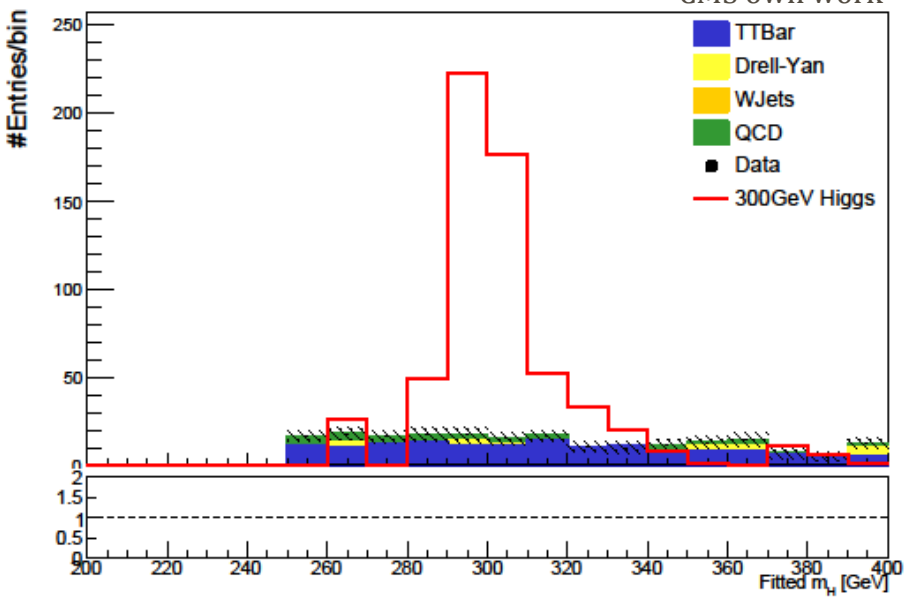
No B-Jets

CMS own work



≥ 2 B-Jets blinded

CMS own work



- Fitted heavy Higgs mass distribution flat for background events
- Signal peaks at correct mass

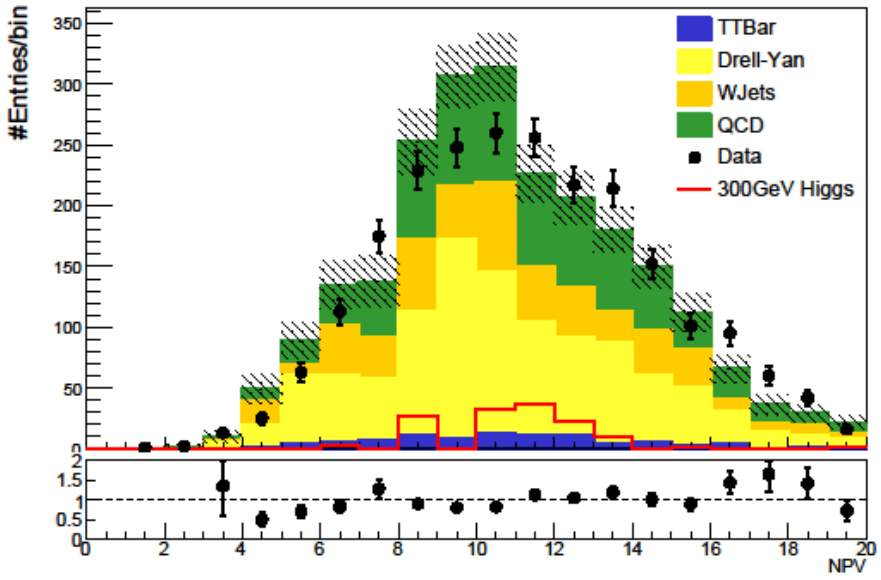
Conclusion

- The kinematic fit reconstructs the heavy Higgs Mass very precisly
- Fit was used for 8TeV heavy Higgs analysis within CMS (Hig-14-034)
- χ^2-distribution could be used for seperation of signal from background
  - Compare/Combine with inv.Mass cuts
  - Test kinematic fit outputs as MVA inputs
- Fitting code partly rewritten for 13 TeV analysis
  - Modular approach allows for easy modification
- Work on 13 TeV analysis in progress

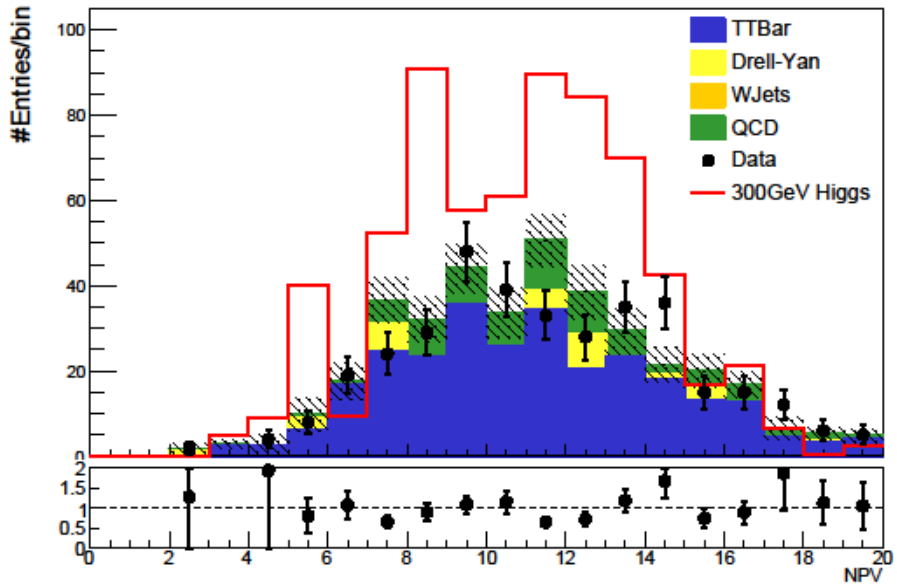
Backup

First Look 13 TeV

No B-Jets



≥ 2 B-Jets



– PU reweighting seems to have worked