MINISTÈRE
DE L'ENSEIGNEMENT SUPÉRIEUR,
DE LA RECHERCHE
ET DE L'INNOVATION

Reconstruction of di-τ mass using ML based techniques

IN2P3/IRFU Machine Learning Workshop

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IP2I (Lyon) & MSSM $H \to \tau\tau$ analysis group

March 16th 2021

1. Few words on di-τ events

2. Building the ML model
   - Lucas Torterotot, Ece Aşılar, Colin Bernet (IP2I Lyon), Sebastian Wozniewski (KIT)

3. Comparison against SVfit
   - Lucas Torterotot & the $H \to \tau\tau$ MSSM analysis group

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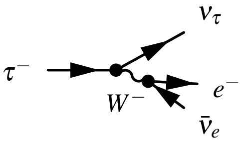
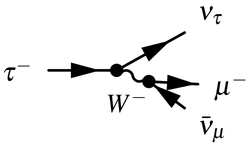
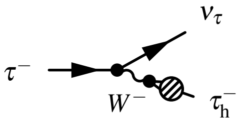
$X \to \tau\tau$ events: 2 to 4 neutrinos in final state!



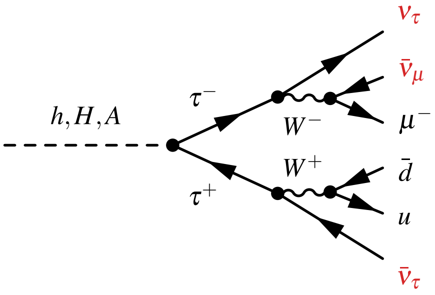
$\tau \to e + \nu_e + \nu_\tau \Rightarrow e$
17.8 %



$\tau \to \mu + \nu_\mu + \nu_\tau \Rightarrow \mu$
17.4 %



$\tau \to \text{hadrons} + \nu_\tau \Rightarrow \tau_h$
64.8 %



- 6 different channels:
  - $\tau_h\tau_h$: 2 neutrinos,
  - $\mu\tau_h$, $e\tau_h$: 3 neutrinos,
  - $\mu\mu$, $e\mu$, ee: 4 neutrinos.
- Neutrinos = invisible in CMS!
- Impossible to get the full invariant mass.

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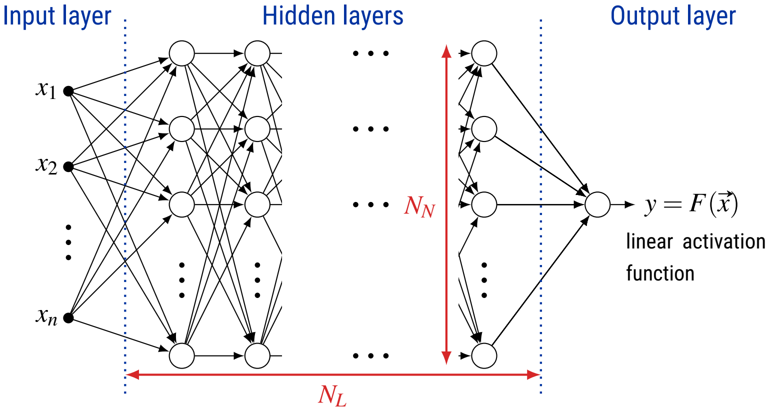
Build a neural network: deep but simple structure!



- Here $N_L = 3$ and $N_N = 1000$

Build a neural network: choosen hyperparameters

- NN hyperparameters (and tested values):
  - **Adam** optimizer (Adam, Adadelta, SGD),
  - Weight initialized with **Glorot uniform** (Glorot normal, Glorot uniform, normal, uniform),
  - **MAPE** loss (MAPE, MSE),

$$\mathit{MAPE}(y_{\text{true}}, y_{\text{pred}}) = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{y_{\text{pred},i} - y_{\text{true},i}}{y_{\text{true},i}} \right|$$

  - **Softplus** activation function (ReLU, ELU, SELU, Exponential, Softplus),

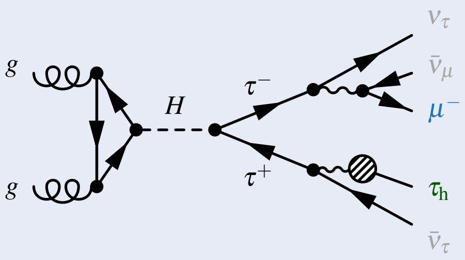
$$\mathit{softplus}(x) = \ln(1 + e^{x})$$

  - 3 hidden layers (2 to 5),
  - 1000 neurons per hidden layer (200, 600, 1000, 1400 for all other hyperparameters + 200 to 2000 per steps of 100 after focus),

Build a neural network: target and inputs?

- Model target: generated Higgs mass.
- Model inputs:
  - τ_1 (here = μ^-) and τ_2 (here = τ_h) p_T, η, ϕ;
  - PuppiMET p_T, ϕ;
  - METcov xx, xy and yy;
  - $m_\mathrm{T}^{(1,MET)}$, $m_\mathrm{T}^{(2,MET)}$, $m_\mathrm{T}^{(1,2)}$, $m_\mathrm{T}^{\mathrm{tot}}$ (Puppi);
  - jet 1, jet 2 p_T, η, ϕ;
  - remaining hadronic activity p_T, η, ϕ;
  - `npvsGood` $\to$ how much PU;
  - Number of neutrinos from tau decays.

$gg \to H \to \tau\tau \to \mu\tau_\mathrm{h}$

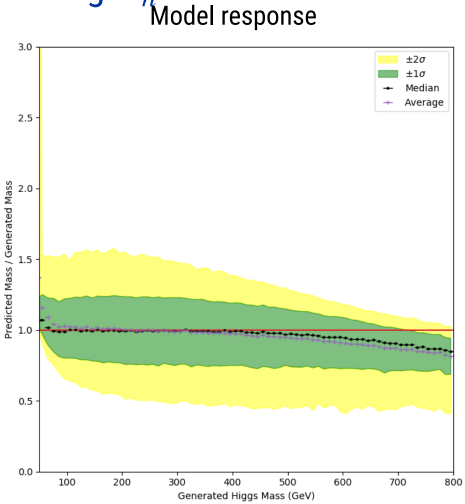


$$\boxed{m_\mathrm{T}^{\mathrm{tot}} = \sqrt{m_\mathrm{T}^2(\tau_1, E_\mathrm{T}{}^{\mathrm{miss}}) + m_\mathrm{T}^2(\tau_2, E_\mathrm{T}{}^{\mathrm{miss}}) + m_\mathrm{T}^2(\tau_1, \tau_2)}}, \quad m_\mathrm{T}(1,2) = \sqrt{2p_T^{(1)}p_T^{(2)}(1-\cos\Delta\phi)}$$

Model trained on $ggH \to \tau\tau$ samples with floating m_h

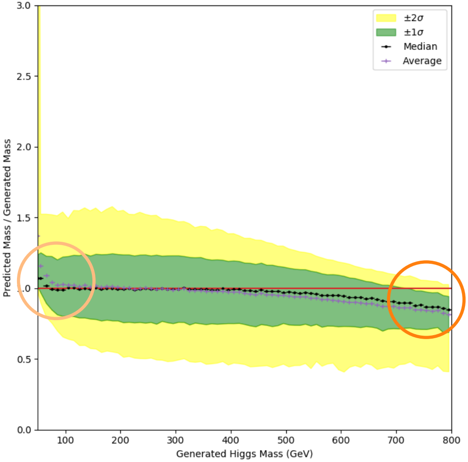
Model response as function of target $\longrightarrow$

- Reconstruction achieved from 70 to $\sim 500\,\mathrm{GeV}$!
  - Below $70\,\mathrm{GeV}$: small overestimation.
  - Above $500\,\mathrm{GeV}$: small underestimation.
  - Due to the dataset boundaries!

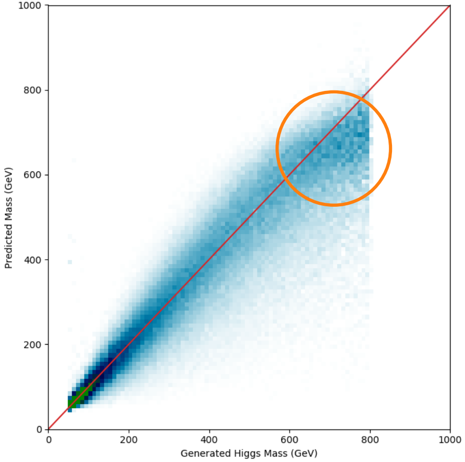


Upgrade of the model: training sample boudaries effects

Model response

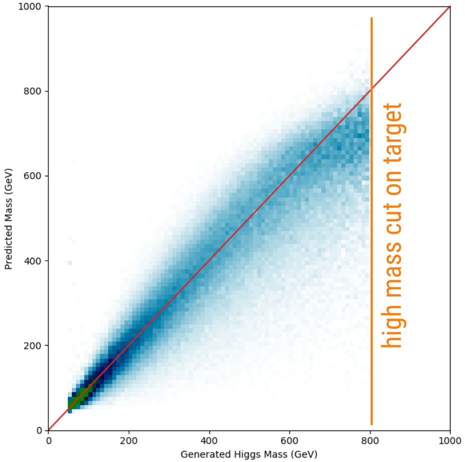


Predictions vs truth



Upgrade of the model – origin of the over/under-estimations

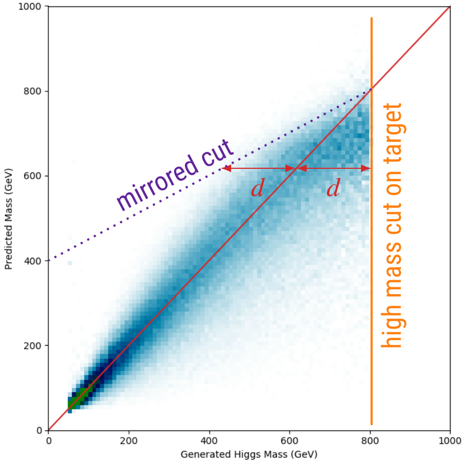
- Due the to $800\,\mathrm{GeV}$ cut on the target:
  - The NN never sees events above $800\,\mathrm{GeV}$;
  - The NN is not likely to predict above $800\,\mathrm{GeV}$.
- Same (reversed) effect at low mass!
- How to cope with the boundaries?
  - Bias to be balanced,
  - Extend the mass range?
    - Would be nice!
    - Not always feasible...



Upgrade of the model – mirror the boundaries!

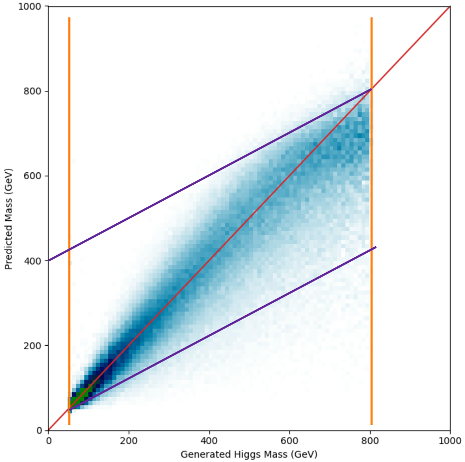
- The hard cut at $800\,\mathrm{GeV}$ is equivalent to having events but not counting them in the loss.

- We test the following:
Take events into account for the loss only if they are within the mirrored boundary *i.e.* if they are not further away from the red line than the red line to the boundary.



Upgrade of the model – mirror the boundaries at low mass too

Take events into account for the loss only if they are within the mirrored boundary *i.e.* if they are not further away from the red line than the red line to the boundary.



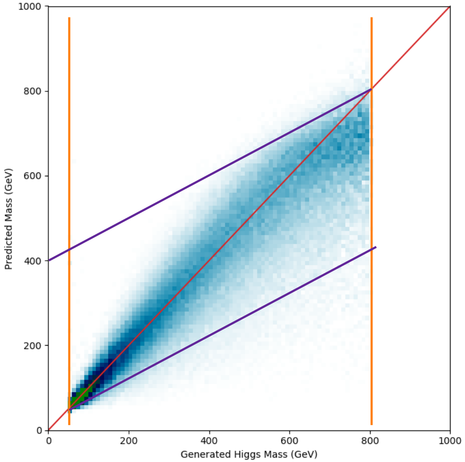
Upgrade of the model – tuning the loss in the central region

- MAPE loss is

$$MAPE(y_{\text{true}}, y_{\text{pred}}) = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{y_{\text{pred},i} - y_{\text{true},i}}{y_{\text{true},i}}\right|$$

- We found out that better constrains at high masses is obtained with $MAPE \times \sqrt{y_{\text{true}}}$

$$MAPEsqrt(y_{\text{true}}, y_{\text{pred}}) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_{\text{pred},i} - y_{\text{true},i}}{\sqrt{y_{\text{true},i}}}\right|$$

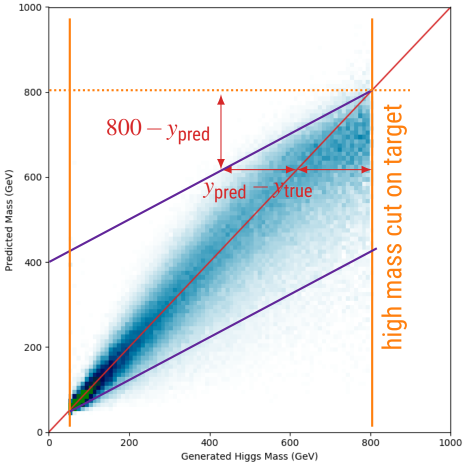


Upgrade of the model – custom loss

- custom loss = *MAPEsqrt* $\times$ boundary cuts:

```
1  def custom_loss(y_true, y_pred):
2    loss = tf.abs(
3      (y_true - y_pred)/(y_true**.5) * where(
4        kb.greater_equal(
5          y_pred - y_true, 800 - y_pred
6        ),
7        0.0,
8        where(
9          kb.greater_equal(
10           y_true - y_pred, y_pred - 50
11         ),
12         0.1,
13         1.0,
14   )))
15   return tf.reduce_mean(loss, axis=-1)
```

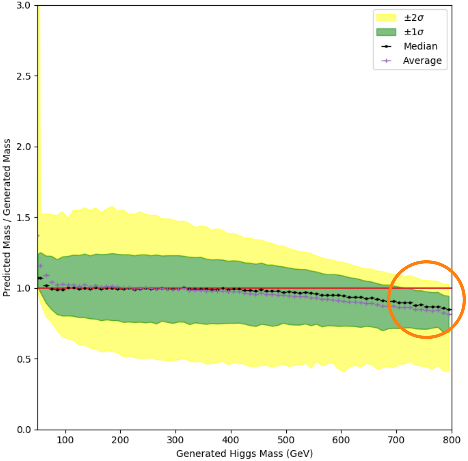
  - line 5: upper boundary condition.
  - line 10: lower boundary condition.



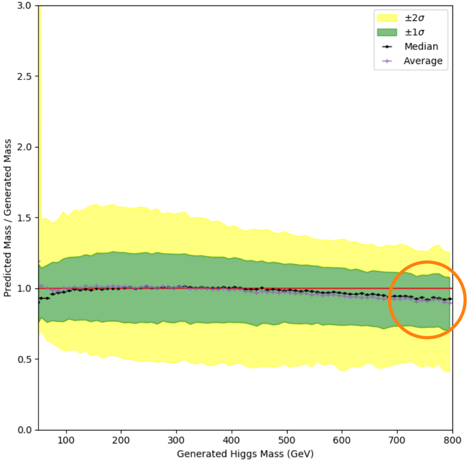
- Convergence problems can appear $\Rightarrow$ the 0.1 factor for low mass is applied because of that (instead of 0.0).

Custom loss reduces the boundaries effect by a factor of 2!

Native MAPE loss



Custom loss



Notes on the loss

- The loss function obtained does **not** respect the condition:

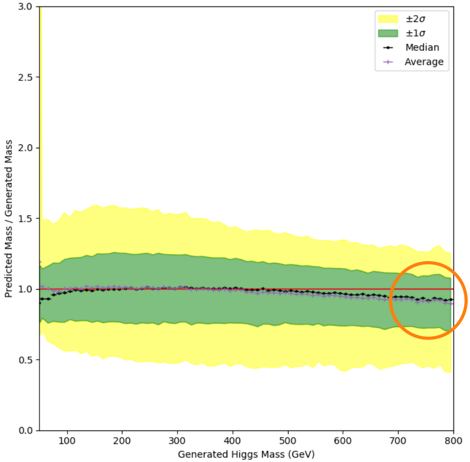
$$Loss = 0 \Leftrightarrow y_{\text{pred}} = y_{\text{true}}$$

i.e. loss can be 0 even with predictions different from truth ...

- Yet the boundary effect is reduced with this loss!
  - This confirms our interpretation.
- This loss also provides a good model.
- Other possibility:
  - For each y_{pred} value, instead of setting a mirrored boundary hard cut:
    - tune weights to have equal weighted-quantity of events above and below y_{true}
- Did anyone encounter the same boundary issue?
  - Regardless of our case: what if generating other mass points (lower and higher) can't be done?

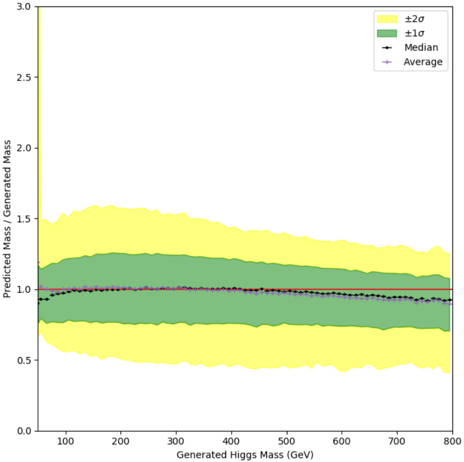
Native MAPE vs custom loss: custom reduces the boundaries effect!

- We still have a small underestimation at high mass;
- Take advantage of the generated Higgs width:
  - Setting $m_H = 800\,\mathrm{GeV}$ we end up with events at $850\,\mathrm{GeV}$, $1\,\mathrm{TeV}$, ...

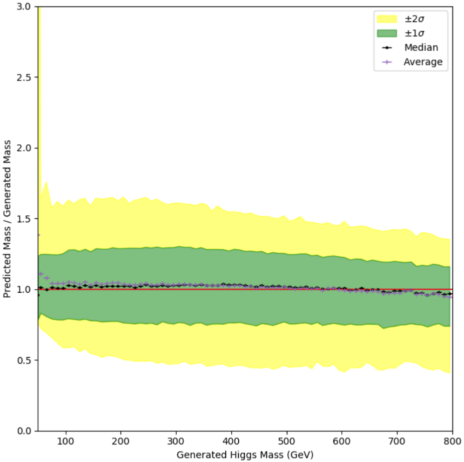


Upgrade of the model – go even up to $1\,\mathrm{TeV}$ using the target distribution tails

Custom loss (up to $800\,\mathrm{GeV}$)



Custom loss + up to $1\,\mathrm{TeV}$



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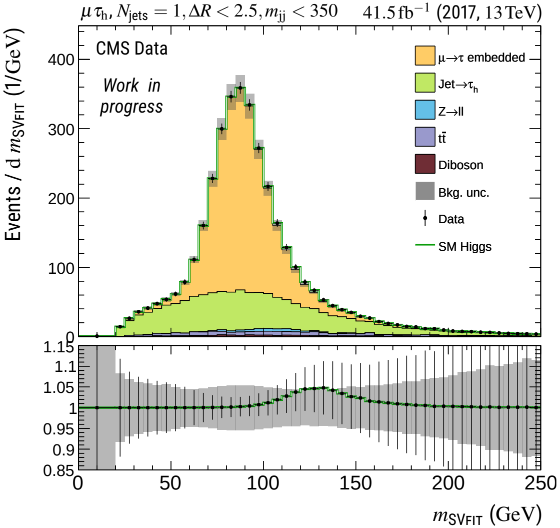
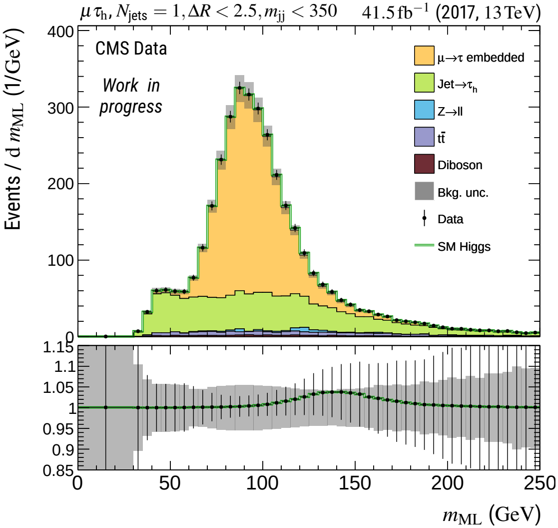
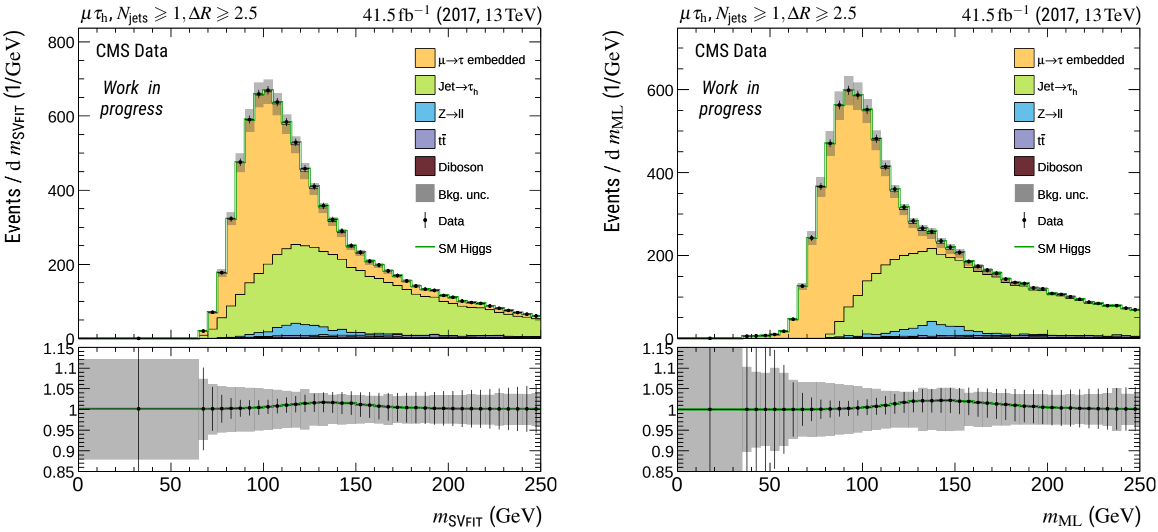
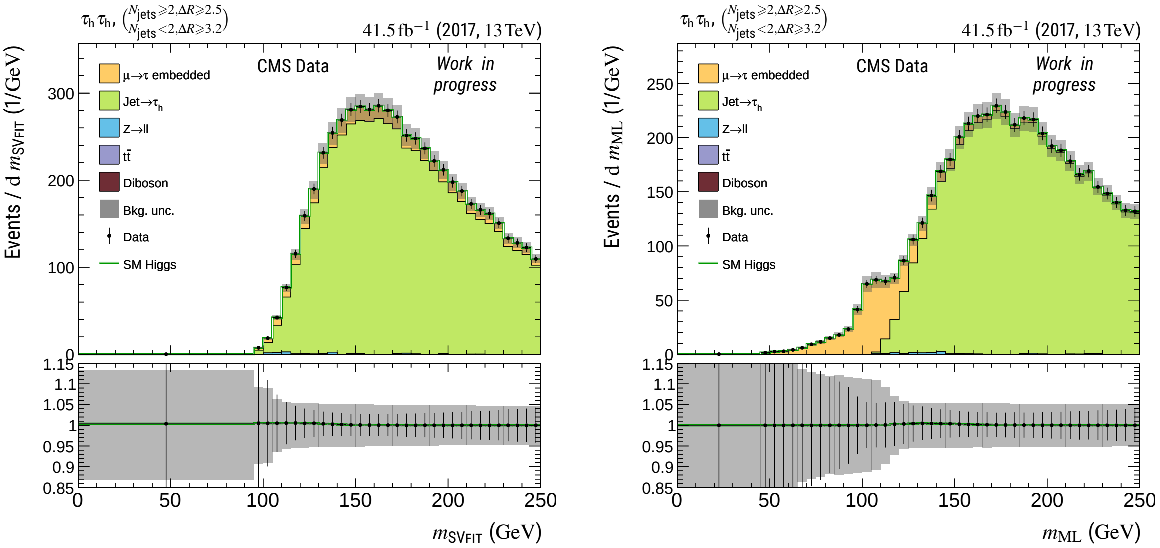




- **Similar SM Higgs signal sensitivity**, small (expected) overestimation from our model.



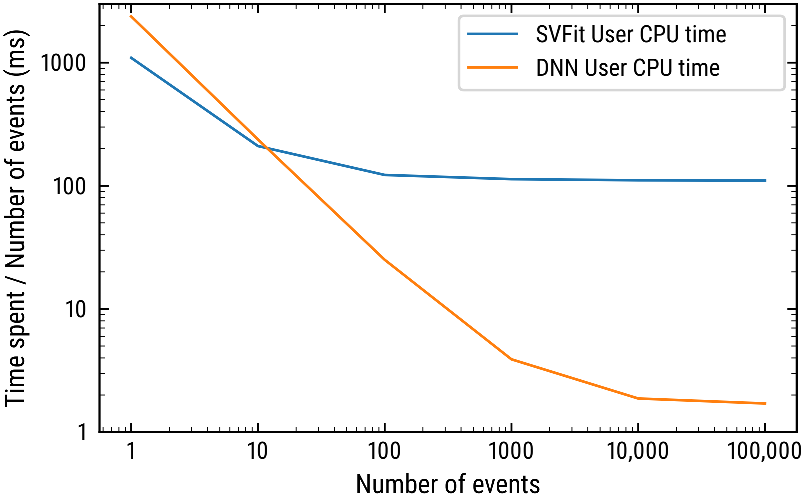
▶ **Better DY estimations** (peak at $100\,\mathrm{GeV}$ for m_{SVFIT}, $92\,\mathrm{GeV}$ for m_{ML}) and fakes at higher masses!



▶ Our model finds $Z \to \tau\tau$ events when SVFIT does not!

Computing time: DNN (Python) is $\sim 60\times$ faster than SVFIT (C++)!

- SVFIT:
  - fit to find the best mass
  - for each event
- DNN:
  - fit done once (training)
  - apply the DNN formula



Conclusion

- Successful m_H reconstruction in di-τ events!
  - Not only $H \to \tau\tau$ but any $X \to \tau\tau$ analysis could benefit!
- SVFIT comparison:
  - Similar Higgs sensitivity!
  - Better Z estimation observed (the model has been trained on $h \to \tau\tau$ with various masses only);
  - Faster (about 60 times)!

If you want to go deeper in:

- The DNN GitHub repository:

  https://github.com/lucastorterotot/DL_for_HTT_mass

- The training events generation:

  https://github.com/easilar/cmssw/blob/from-CMSSW_10_2_22/README

- The DNN/SVFIT derivation scripts used for the benchmark:

  DNN: shorturl.at/gmsN8 SVFIT: shorturl.at/agyN0

Thanks for your attention!

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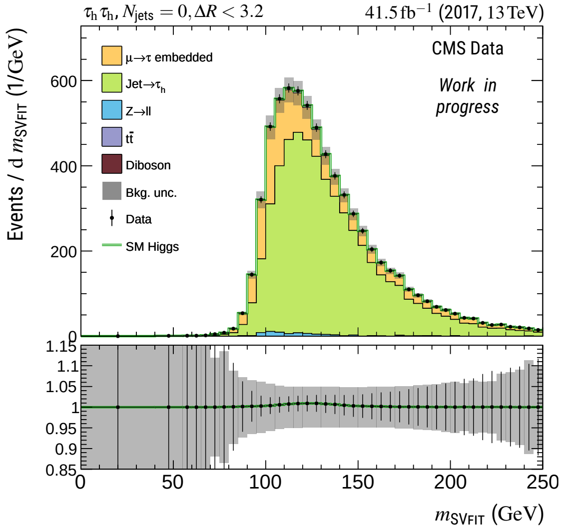
Obtaining datasets

- Trained on SM $h \to \tau\tau$ with $m_h \in [\![50, 800]\!]\,\mathrm{GeV}$.
  - We generated events with FastSim, see Github repository here.
    - Pile-Up added with the 2017 PU profile with MinBias events.
  - Event selection similar to the current MSSM $H \to \tau\tau$ analysis (p_T and η cuts, DeepTau, lepton vetoes, ...).
    - See CMS AN 2020/218.
  - More events at low mass to account for the selection efficiency and have statistics:

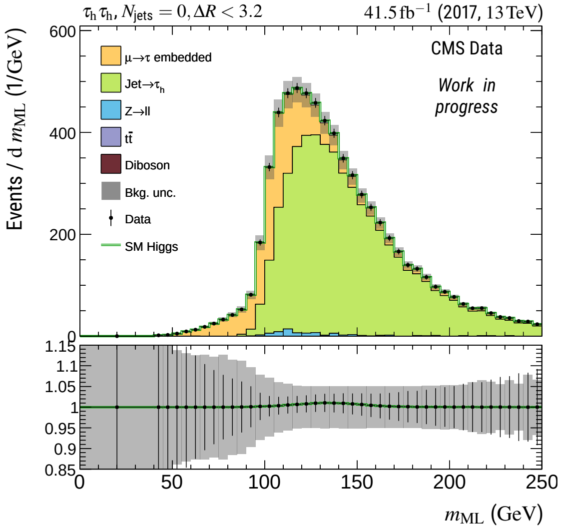
$50\,\mathrm{GeV}$ – $300\,\mathrm{GeV}$	$300\,\mathrm{GeV}$ – $500\,\mathrm{GeV}$	$500\,\mathrm{GeV}$ – $800\,\mathrm{GeV}$	m_h
60 k	20 k	10 k	

- 22 M events, 3 M ($14\,\%$) selected in the mass range (due to the mass width).
- Split into 3 subsamples, use weights to flatten the target distribution:

Purpose	training	validation	tests
Quantity	$70\,\%$	$20\,\%$	$10\,\%$



$\tau_h\tau_h, N_{jets} = 0, \Delta R < 3.2$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)



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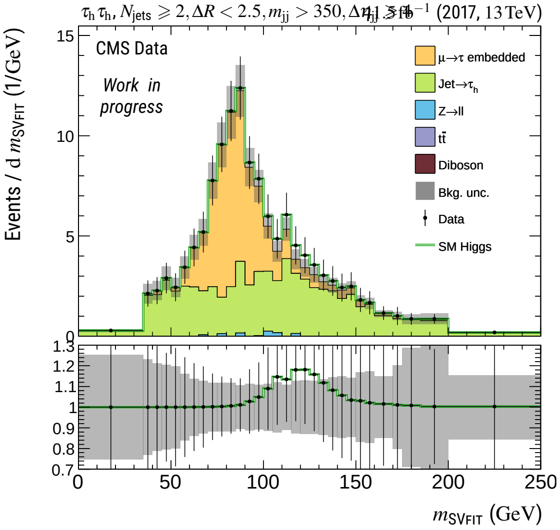
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$\tau_h\tau_h, N_{jets} \geqslant 2, \Delta R < 2.5, m_{jj} > 350$, 41.5 fb^{-1} (2017, 13 TeV)
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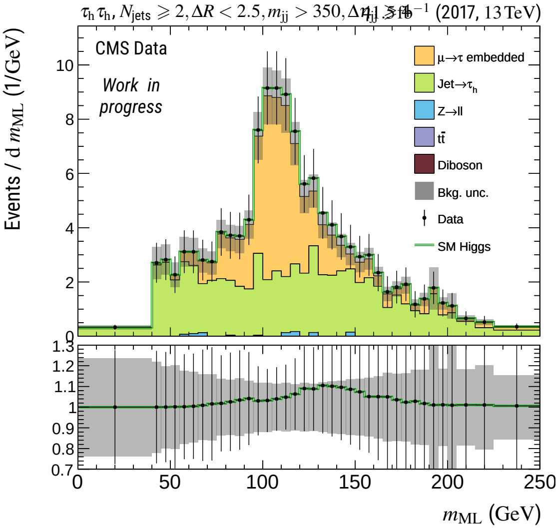
m_{SVFIT} (GeV)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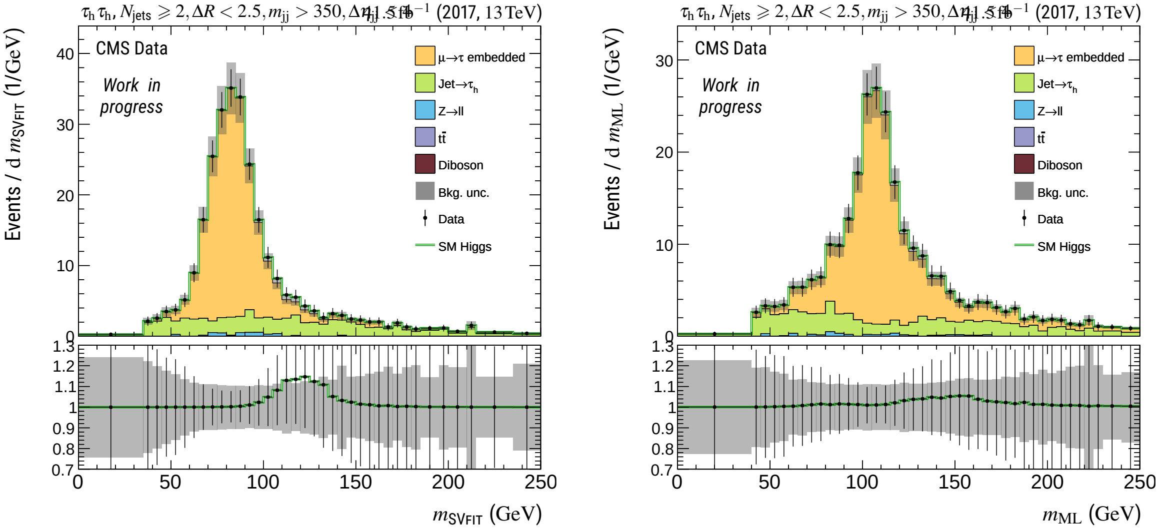

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Events / d m_{ML} (1/GeV)
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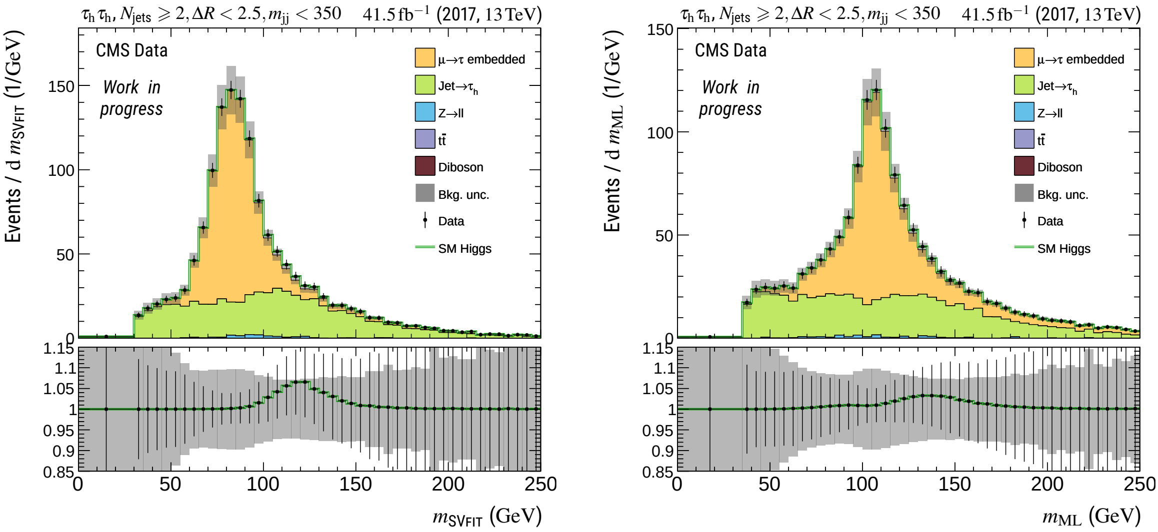
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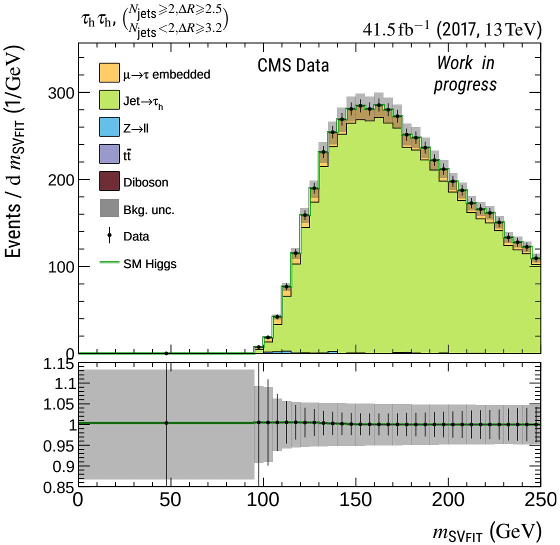

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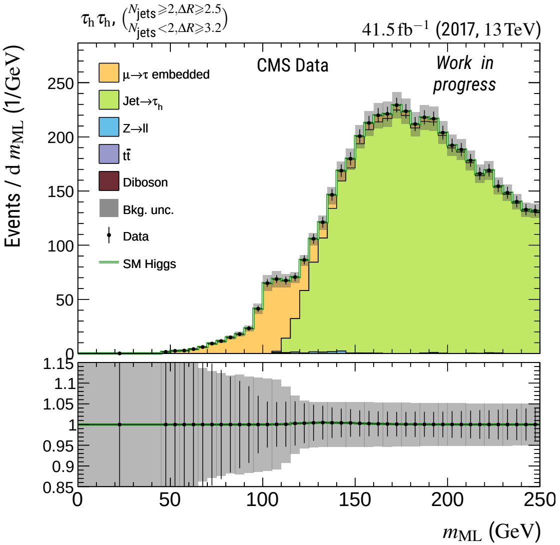

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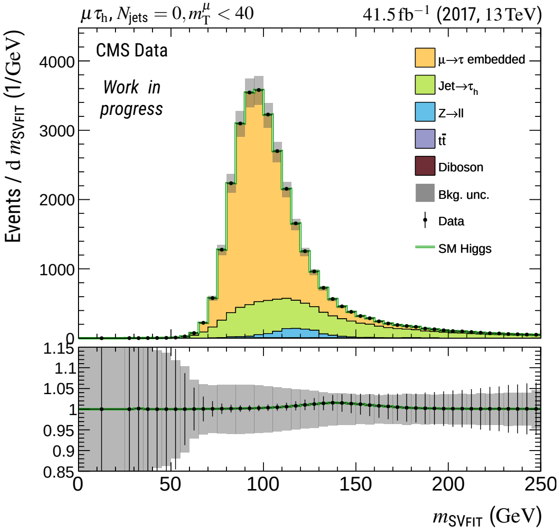

$\mu\tau_h, N_{jets} = 0, m_T^{\mu} < 40$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
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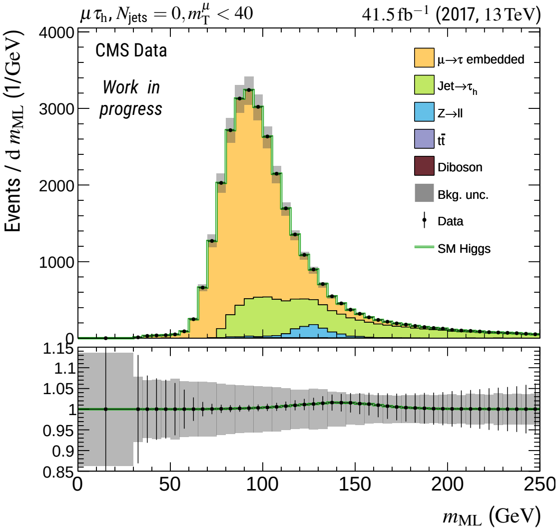

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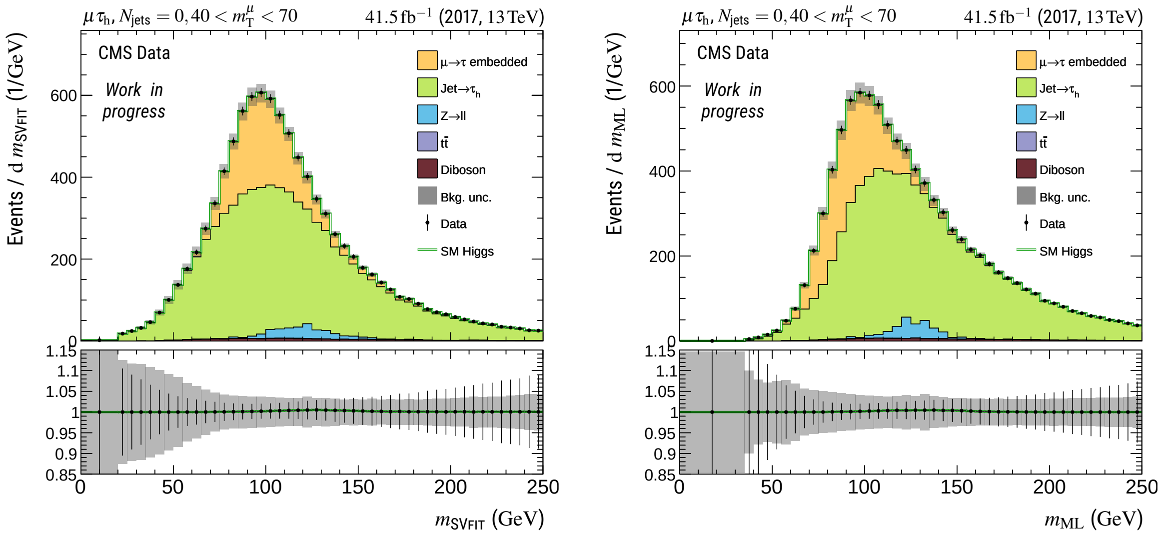
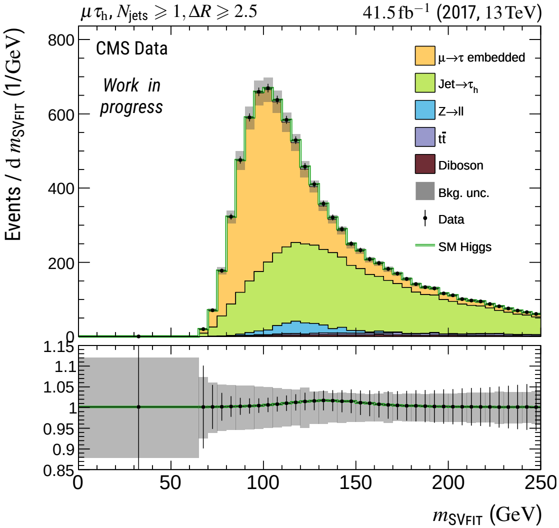
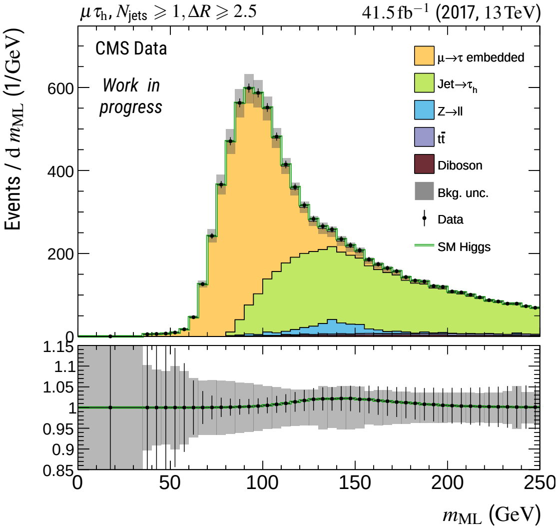
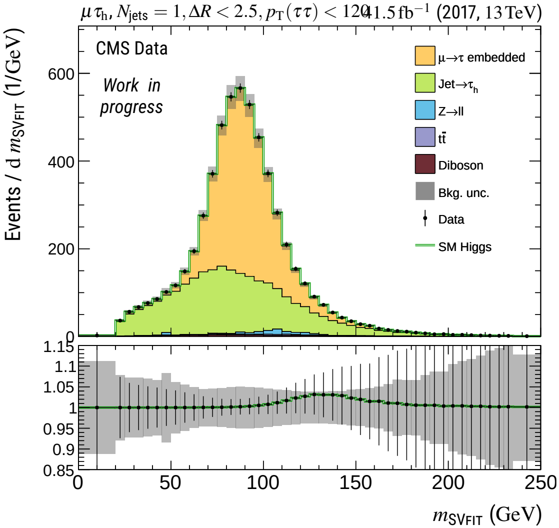
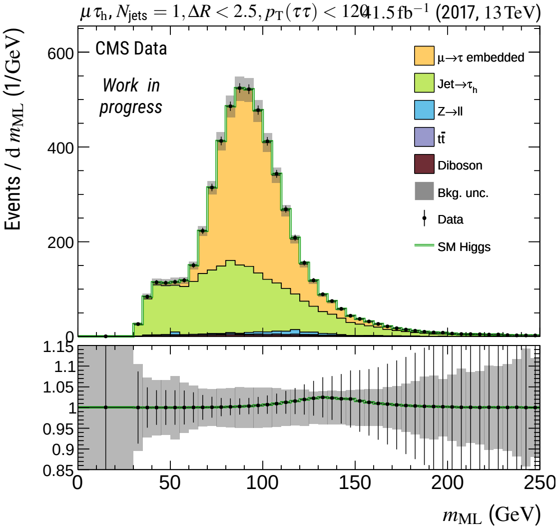
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

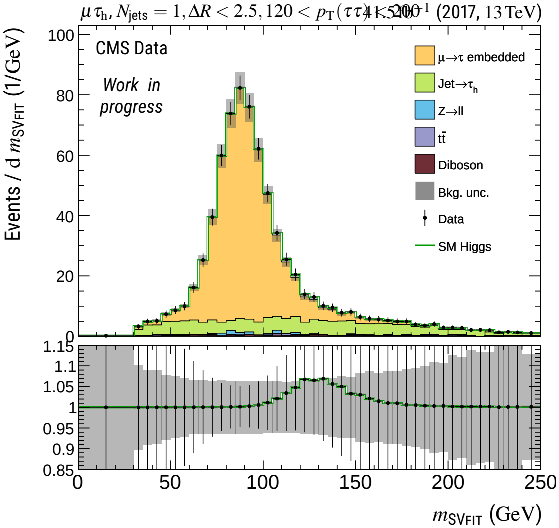

$\mu\tau_h, N_{jets} = 0, 40 < m_T^{\mu} < 70$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

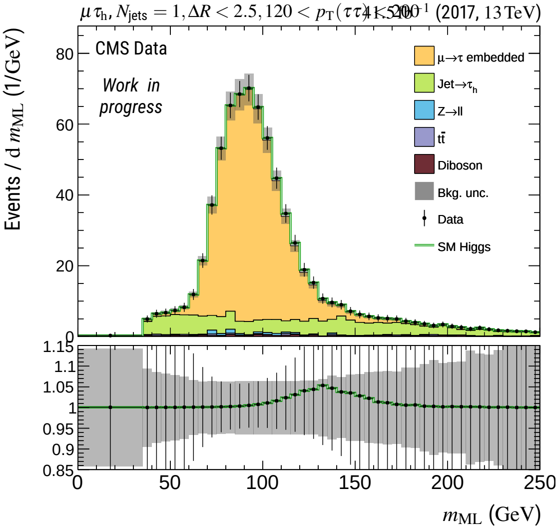

$\mu\tau_h, N_{jets} \geqslant 1, \Delta R \geqslant 2.5$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

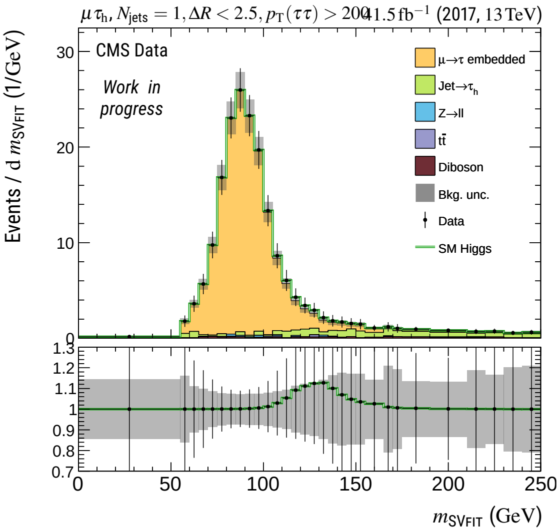

$\mu\tau_h, N_{jets} \geqslant 1, \Delta R \geqslant 2.5$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) < 120$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

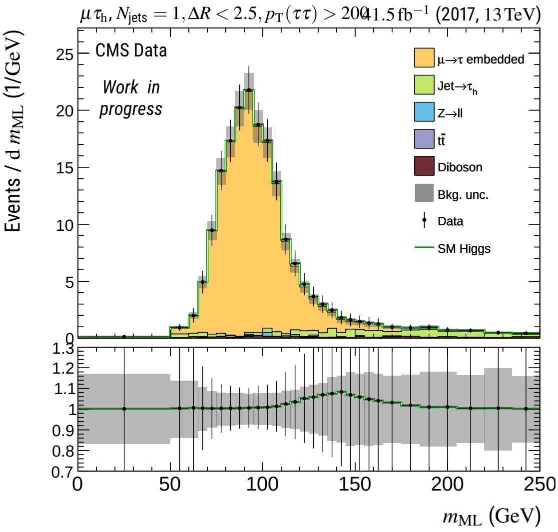

$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) < 120$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, 120 < p_T(\tau\tau) < 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

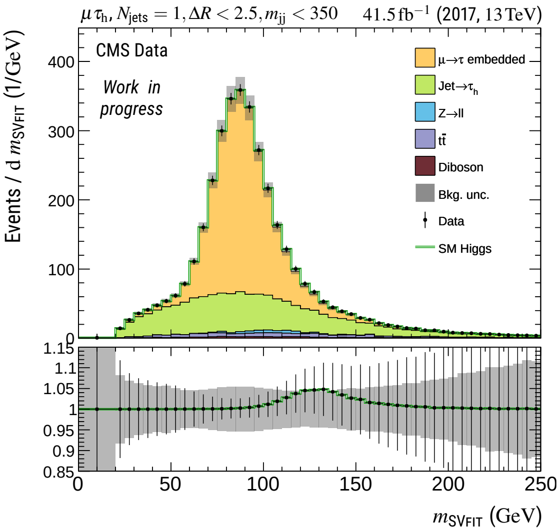

$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, 120 < p_T(\tau\tau) < 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



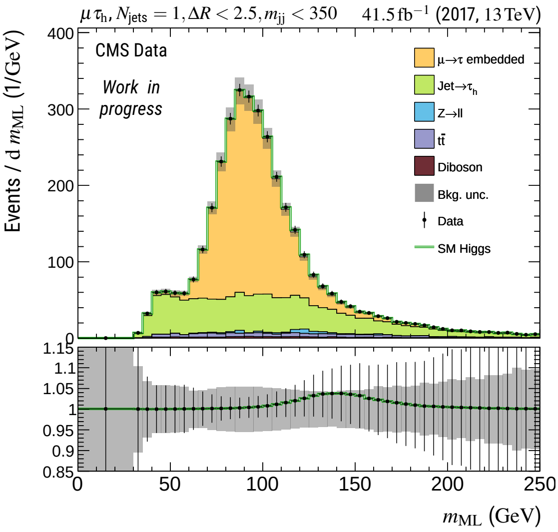
$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) > 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)



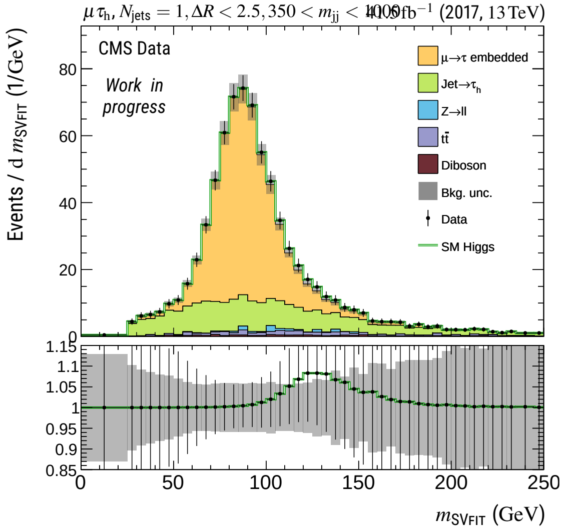
$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) > 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

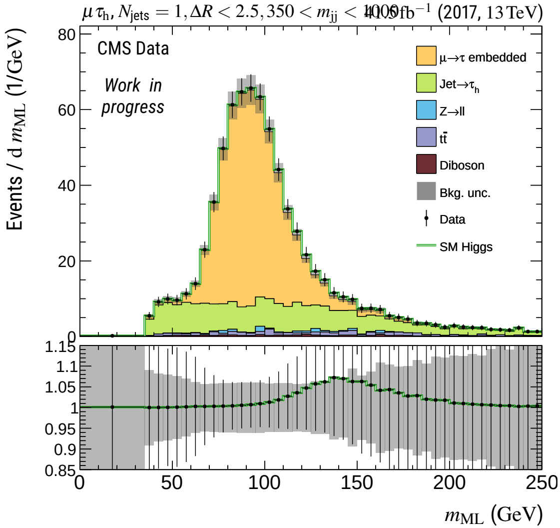


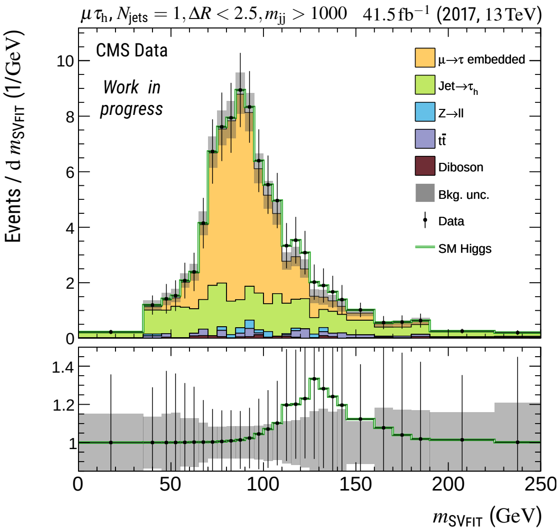
$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, m_{jj} < 350$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ$_h$
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

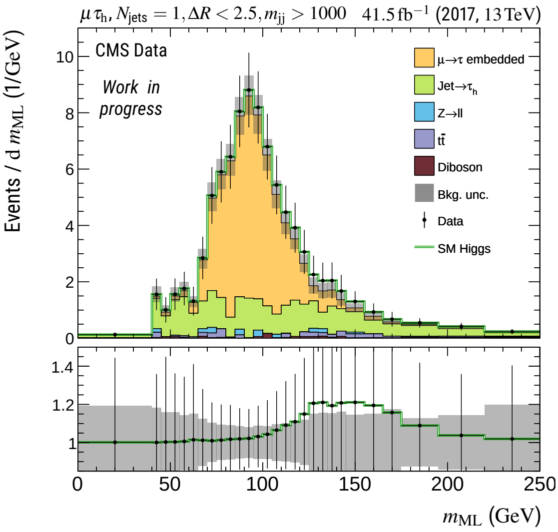


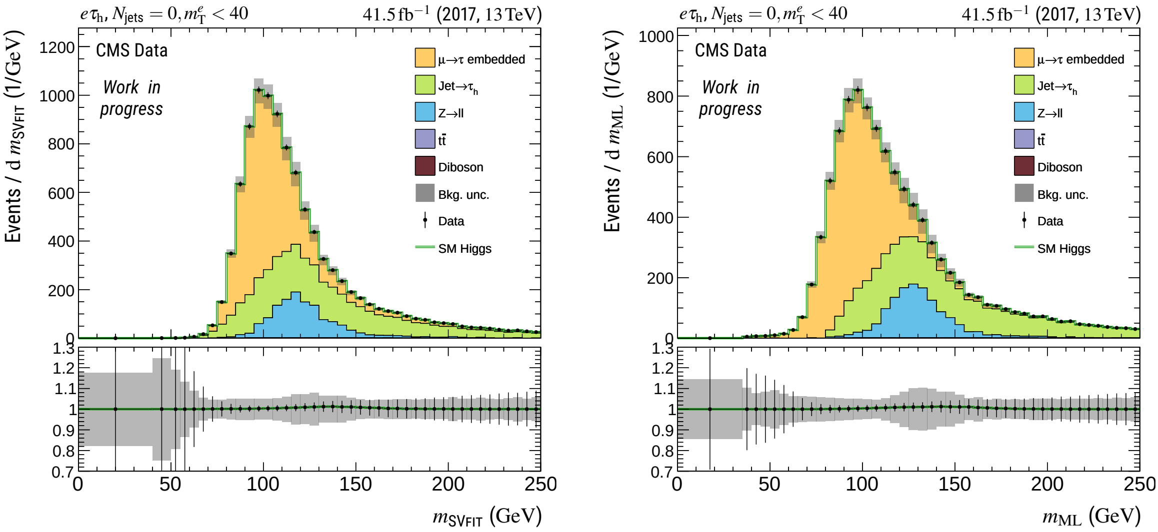
$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, m_{jj} < 350$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ$_h$
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, 350 < m_{jj} < 1000$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

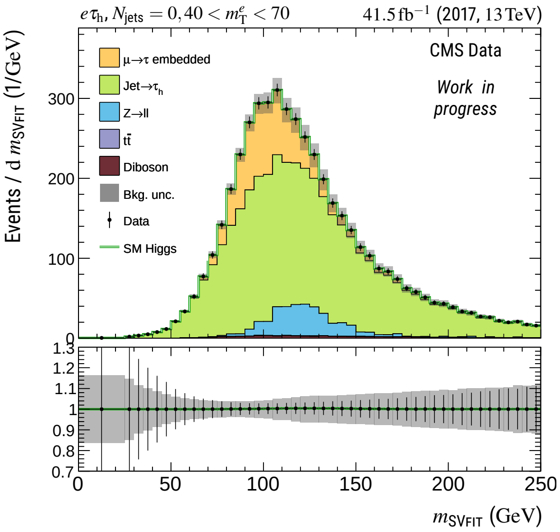

$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, 350 < m_{jj} < 1000$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

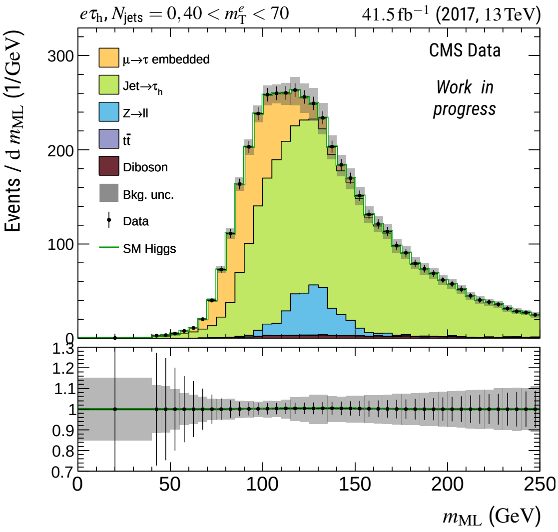

$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, m_{jj} > 1000$ $41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
$Z\to ll$
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

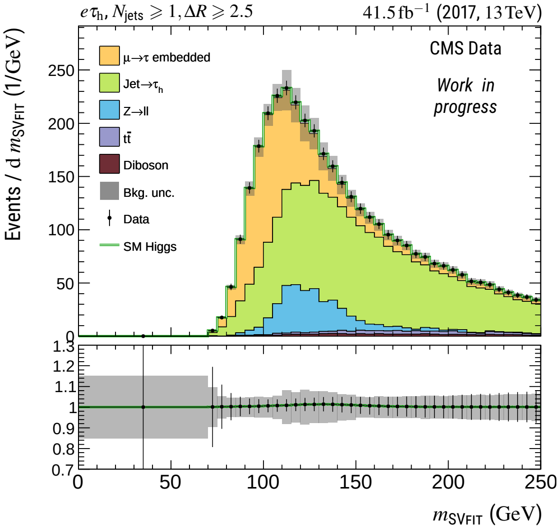

$\mu\tau_h, N_{jets} = 1, \Delta R < 2.5, m_{jj} > 1000$ $41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
$Z\to ll$
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

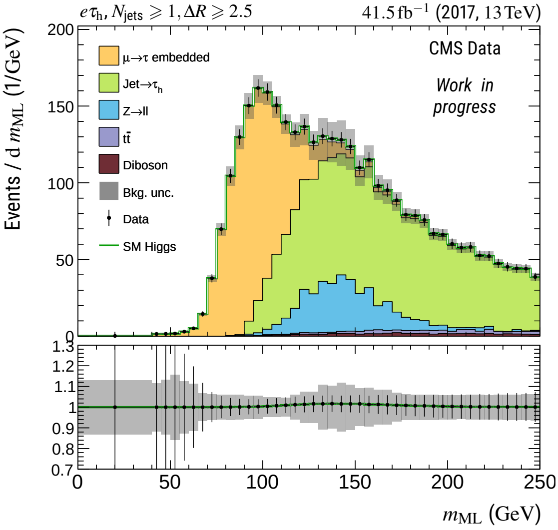


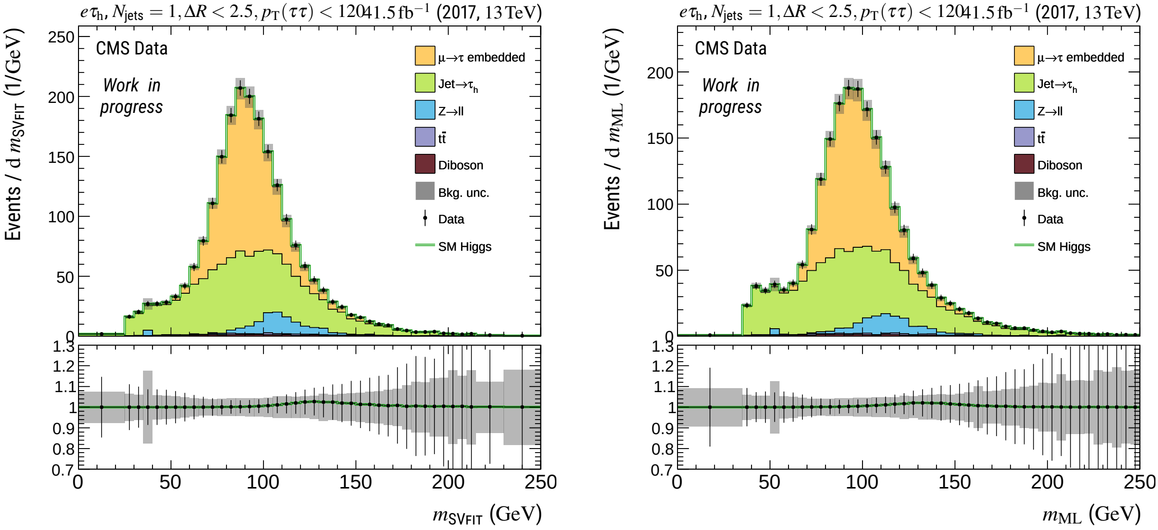
$e\tau_h, N_{jets} = 0, m_T^e < 40$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ$_h$
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$e\tau_h, N_{jets} = 0, 40 < m_T^e < 70$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τh
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

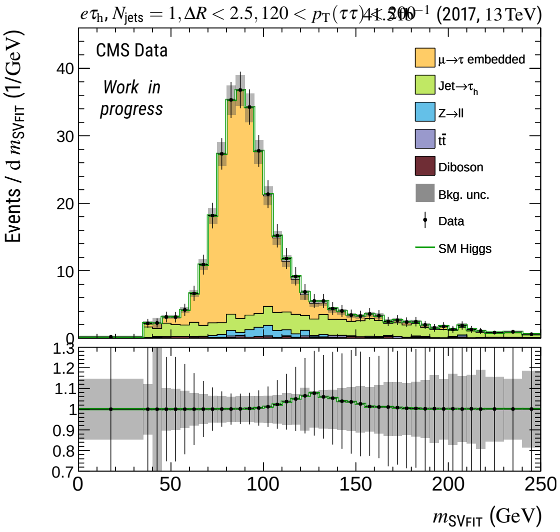

$e\tau_h, N_{jets} = 0, 40 < m_T^e < 70$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τh
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$e\tau_h, N_{jets} \geqslant 1, \Delta R \geqslant 2.5$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

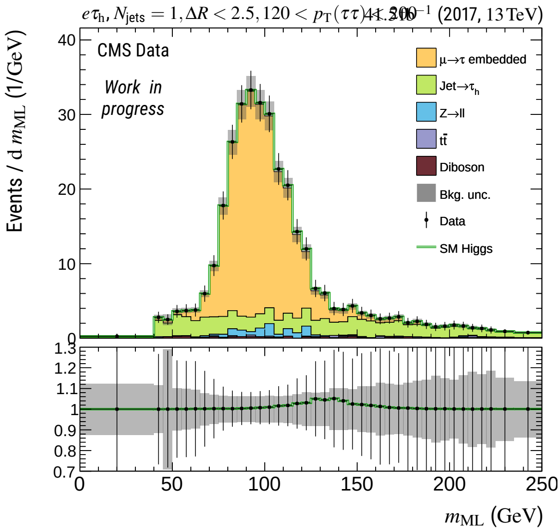

$e\tau_h, N_{jets} \geqslant 1, \Delta R \geqslant 2.5$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



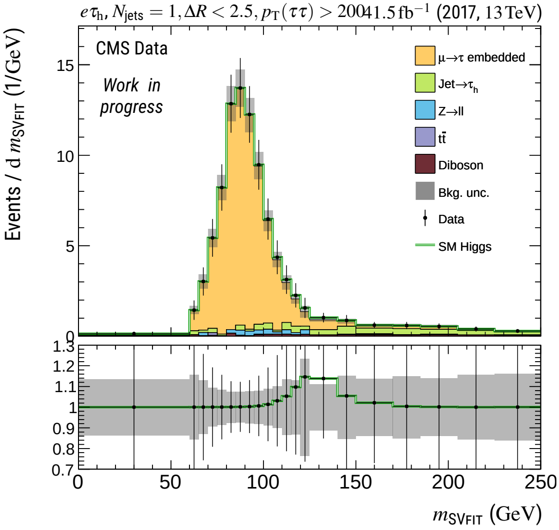
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) < 120$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



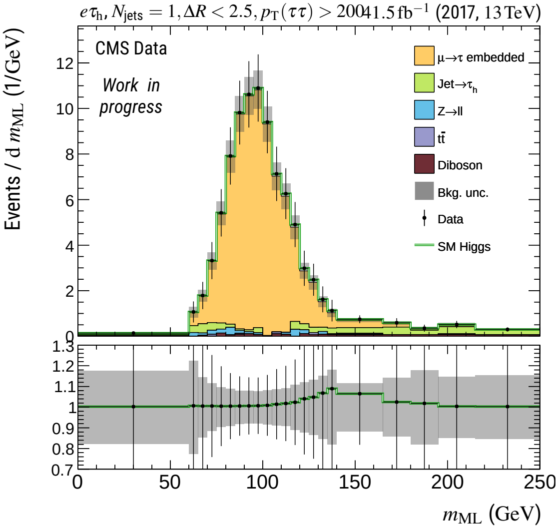
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, 120 < p_T(\tau\tau)$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)



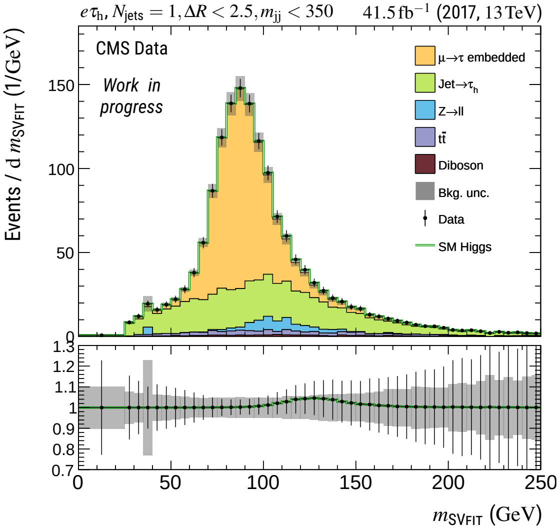
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, 120 < p_T(\tau\tau)$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

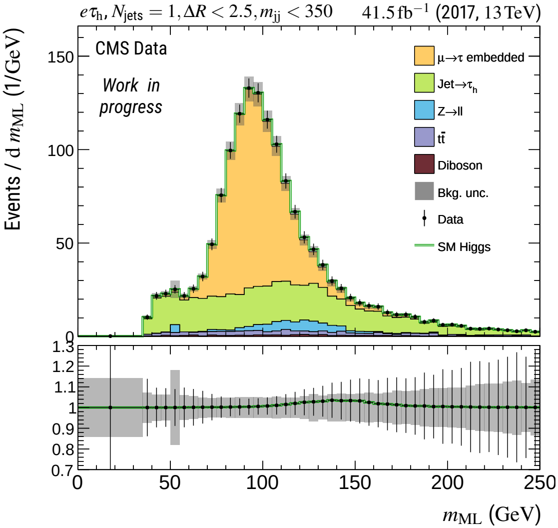


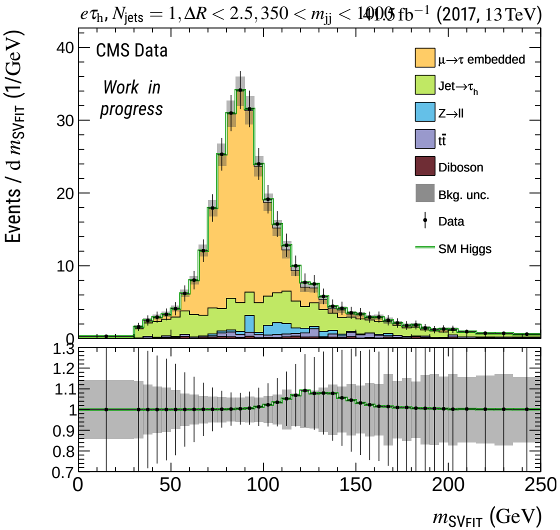
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) > 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)



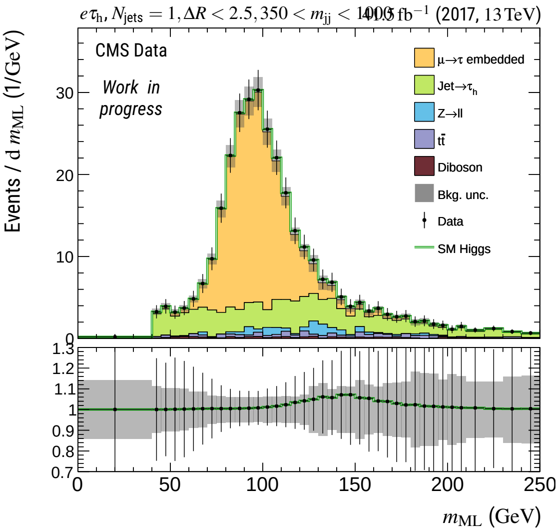
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, p_T(\tau\tau) > 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


eτh, Njets = 1, ΔR < 2.5, mjj < 350
41.5 fb−1 (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τh
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d mSVFIT (1/GeV)
mSVFIT (GeV)

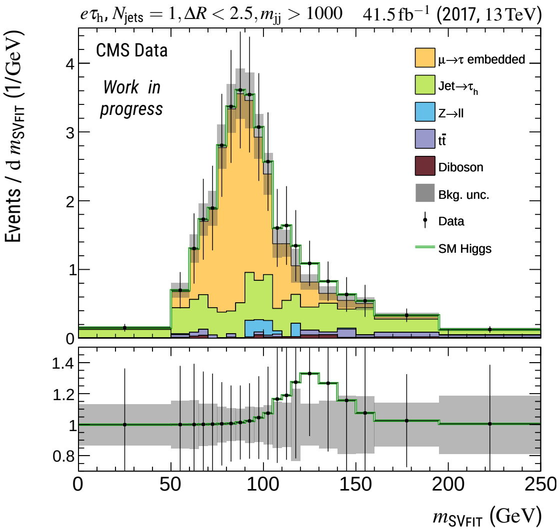

eτh, Njets = 1, ΔR < 2.5, mjj < 350
41.5 fb−1 (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τh
Z→ll
tt̄
Diboson
Bkg. unc.
Data
SM Higgs
Events / d mML (1/GeV)
mML (GeV)

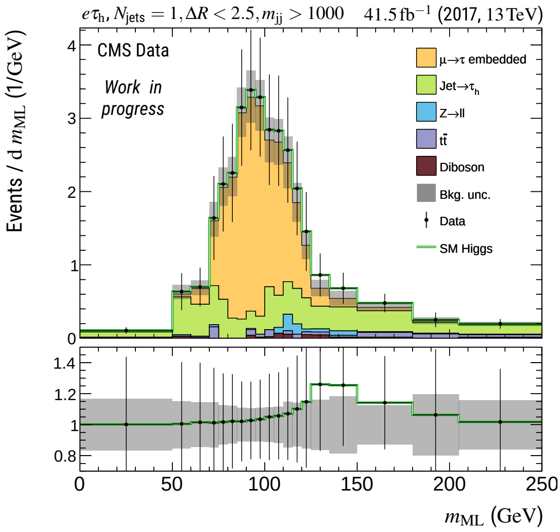


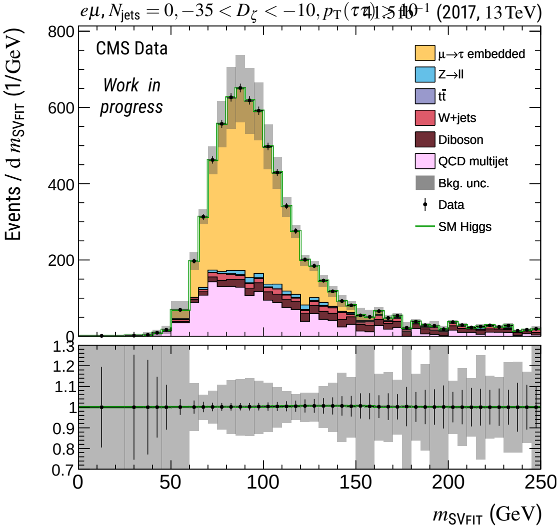
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, 350 < m_{jj} < 1000$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

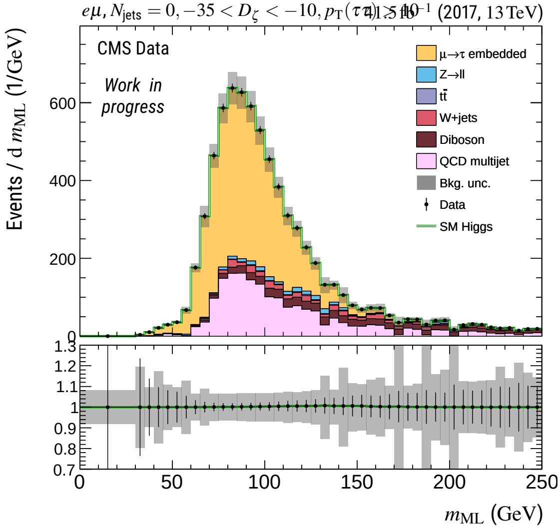


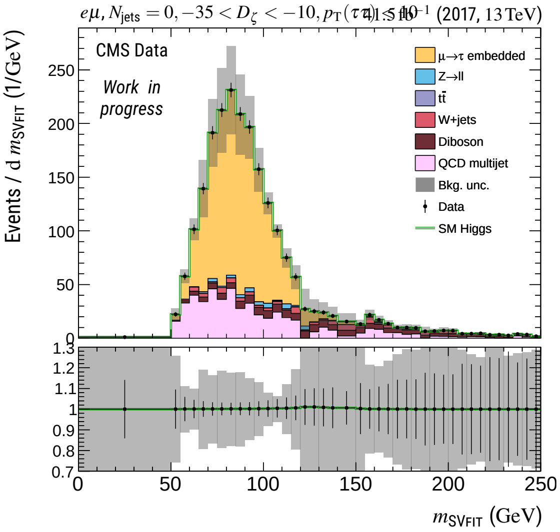
$e\tau_h, N_{jets} = 1, \Delta R < 2.5, 350 < m_{jj} < 1000$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

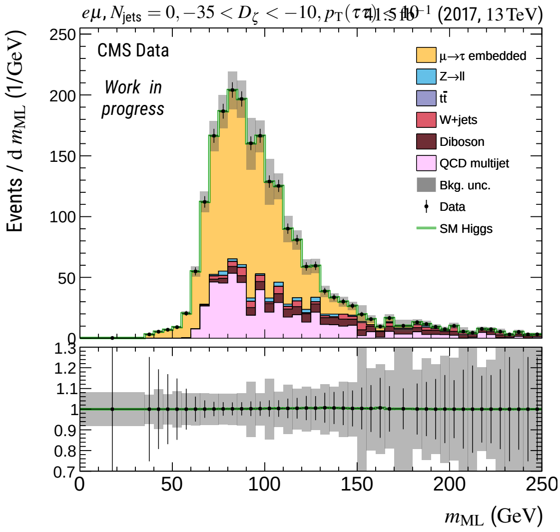

$e\tau_h, N_{jets} = 1, \Delta R < 2.5, m_{jj} > 1000$ $41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

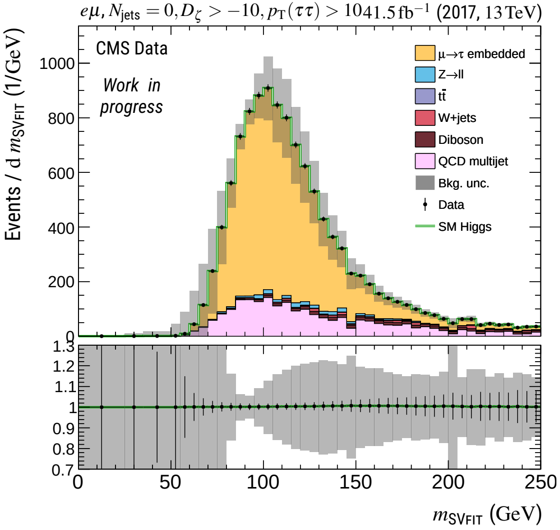

$e\tau_h, N_{jets} = 1, \Delta R < 2.5, m_{jj} > 1000$ $41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

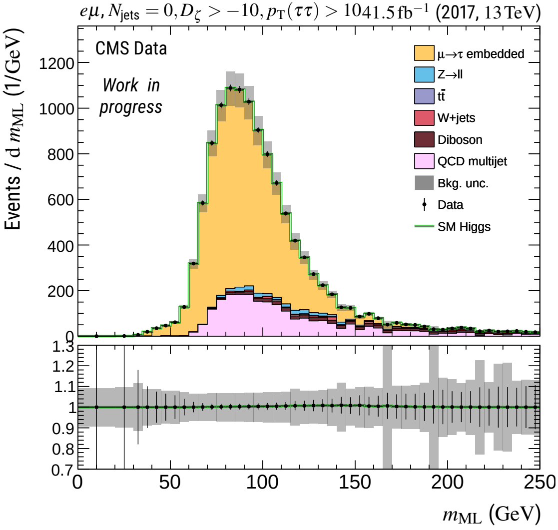

41.5 fb⁻¹ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

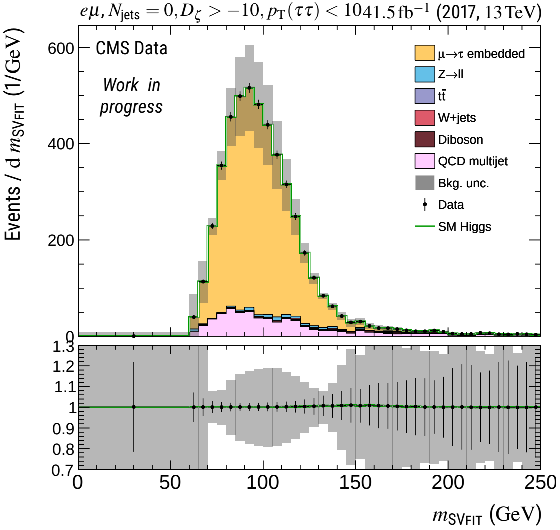

41.5 fb⁻¹ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

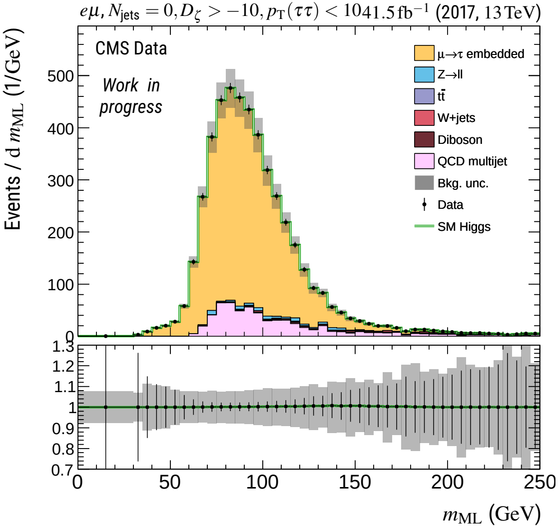

$e\mu, N_{\text{jets}} = 0, -35 < D_\zeta < -10, p_T(\tau\tau)$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

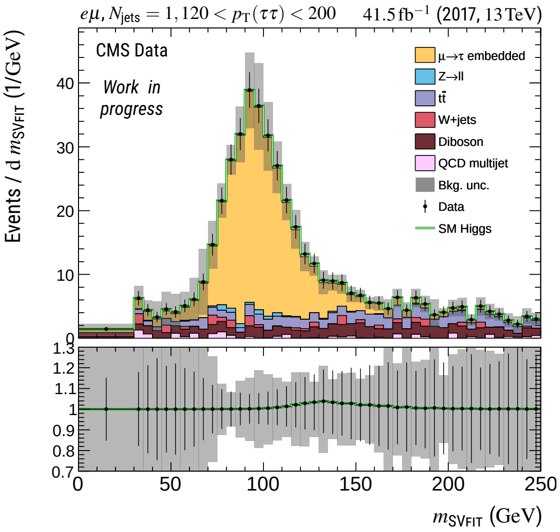

$e\mu, N_{\text{jets}} = 0, -35 < D_\zeta < -10, p_T(\tau\tau)$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

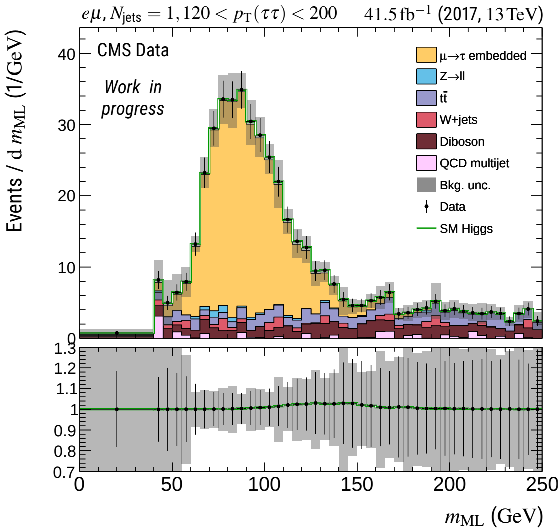

$e\mu, N_{\text{jets}} = 0, D_\zeta > -10, p_T(\tau\tau) > 10$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

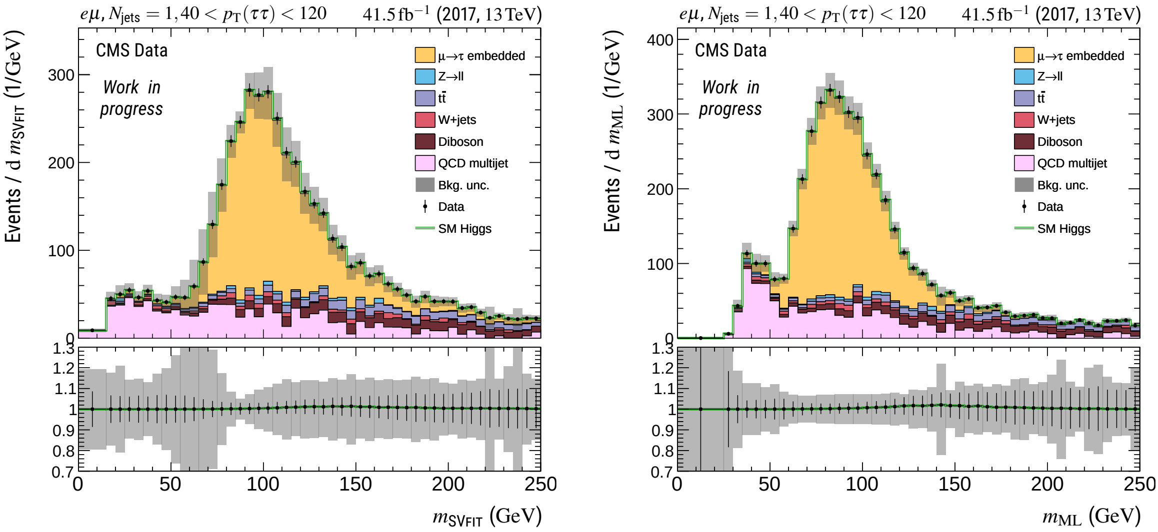

$e\mu, N_{\text{jets}} = 0, D_\zeta > -10, p_T(\tau\tau) > 10$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$e\mu, N_{\text{jets}} = 0, D_\zeta > -10, p_T(\tau\tau) < 10$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

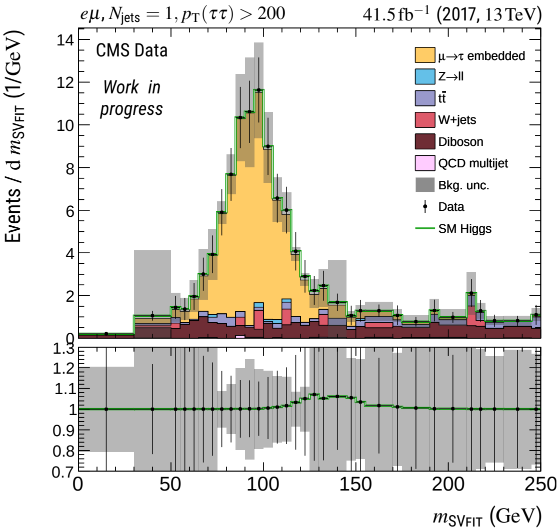

$e\mu, N_{\text{jets}} = 0, D_\zeta > -10, p_T(\tau\tau) < 10$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$e\mu, N_{\text{jets}} = 1, 120 < p_T(\tau\tau) < 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

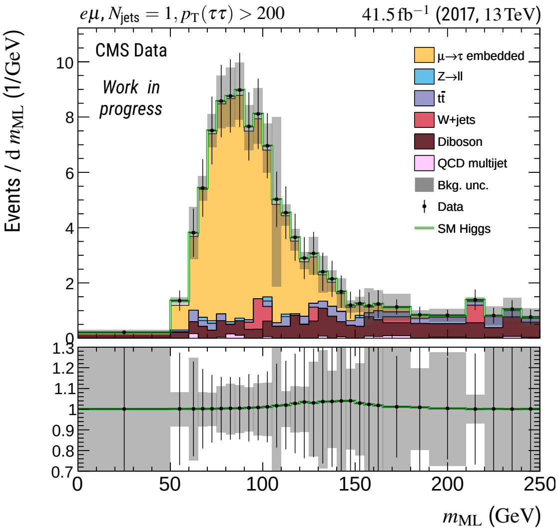

$e\mu, N_{\text{jets}} = 1, 120 < p_T(\tau\tau) < 200$ 41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



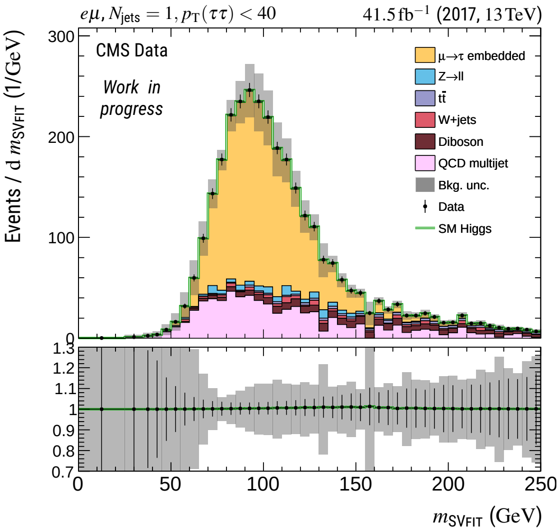
$e\mu, N_{\text{jets}} = 1, 40 < p_T(\tau\tau) < 120$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

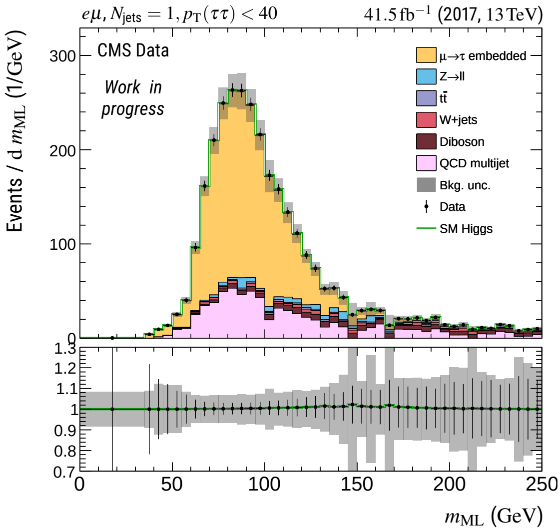


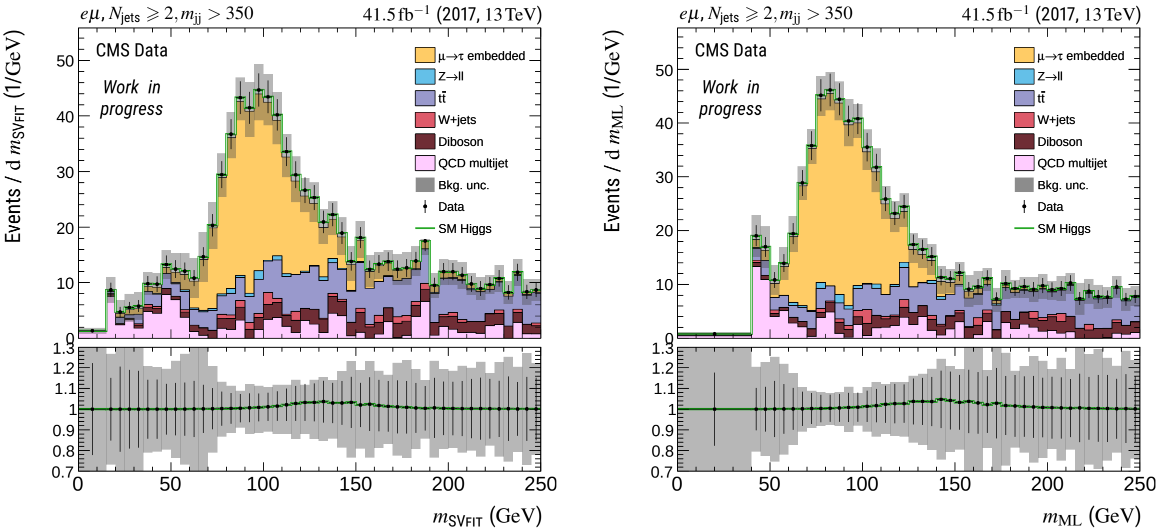
$e\mu, N_{\text{jets}} = 1, p_T(\tau\tau) > 200$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)

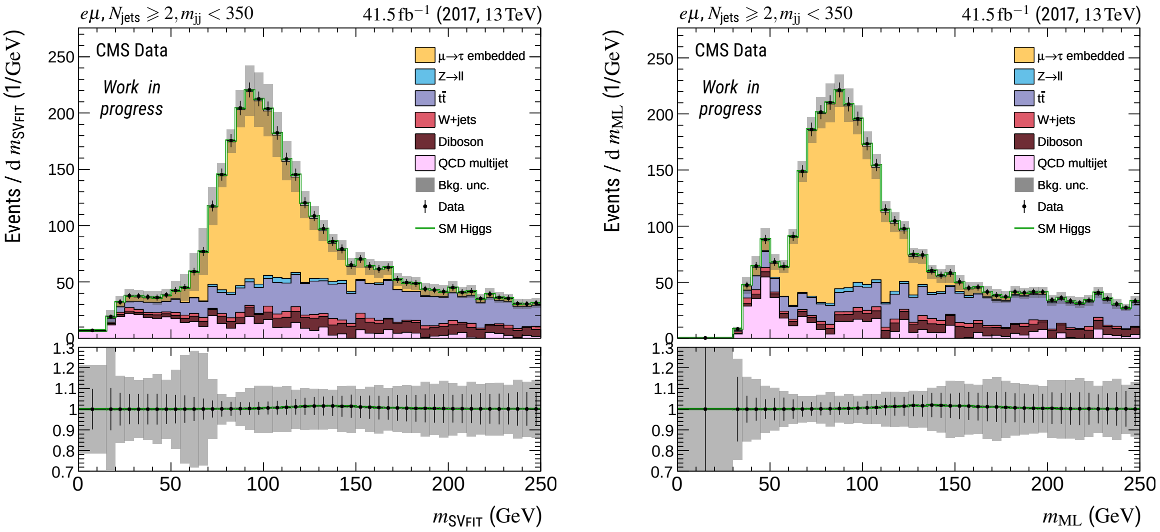


$e\mu, N_{\text{jets}} = 1, p_T(\tau\tau) > 200$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

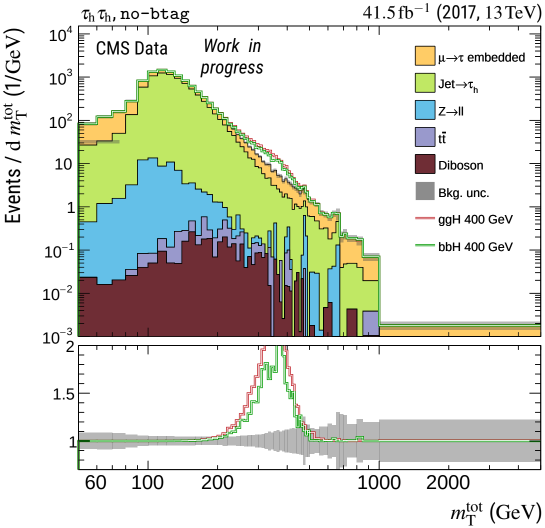

$e\mu, N_{\text{jets}} = 1, p_T(\tau\tau) < 40$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)


$e\mu, N_{\text{jets}} = 1, p_T(\tau\tau) < 40$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

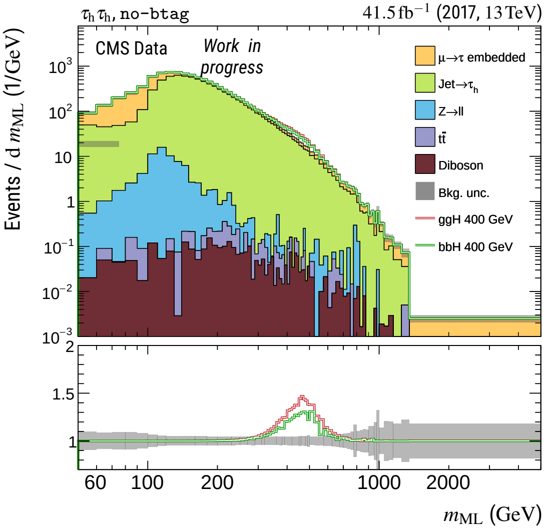

$e\mu, N_{\text{jets}} \geqslant 2, m_{\text{jj}} > 350$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



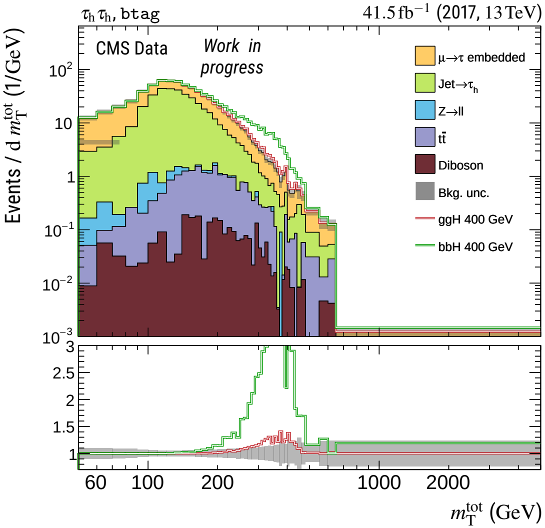
$e\mu, N_{\text{jets}} \geqslant 2, m_{\text{jj}} < 350$
$41.5\,\text{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
Data
SM Higgs
Events / d m_{SVFIT} (1/GeV)
m_{SVFIT} (GeV)
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



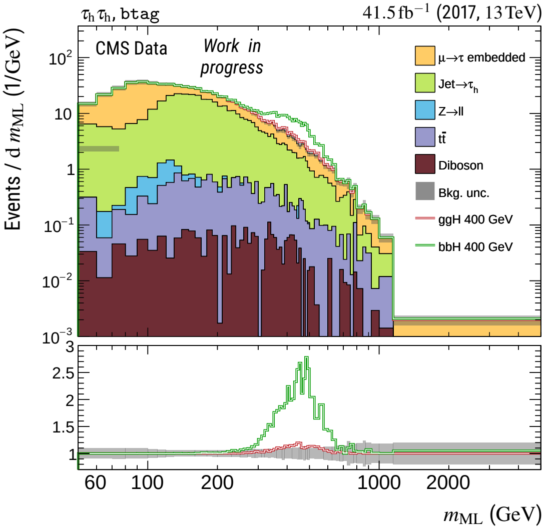
$\tau_h\tau_h$, no-btag
$41.5\,\mathrm{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



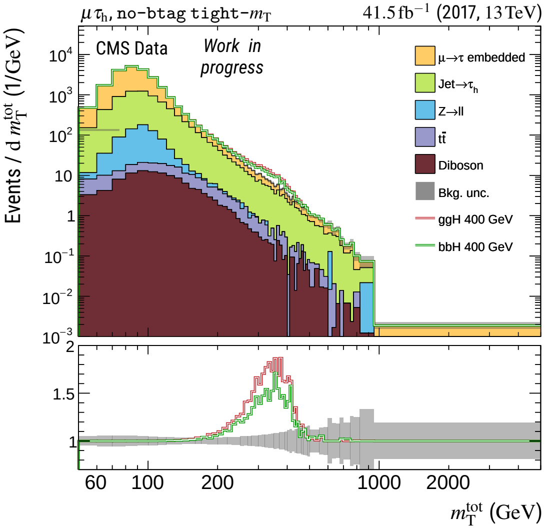
$\tau_h\tau_h$, no-btag
$41.5\,\mathrm{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

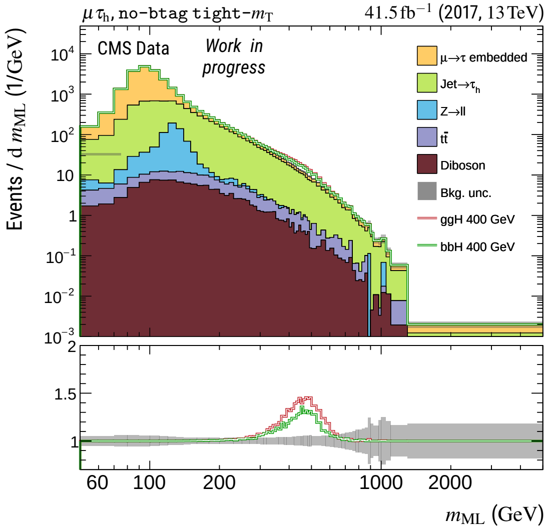


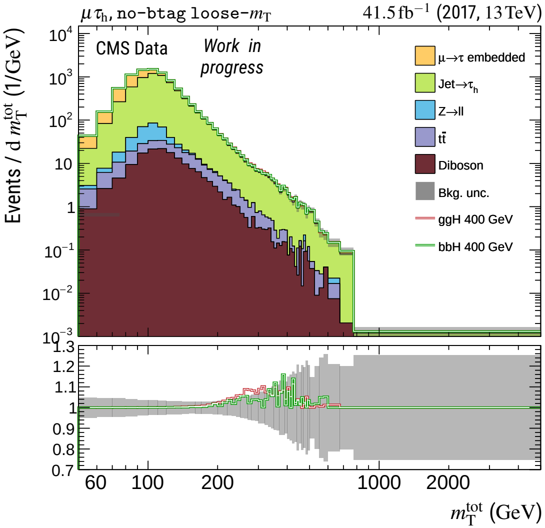
$\tau_h\tau_h$, btag
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

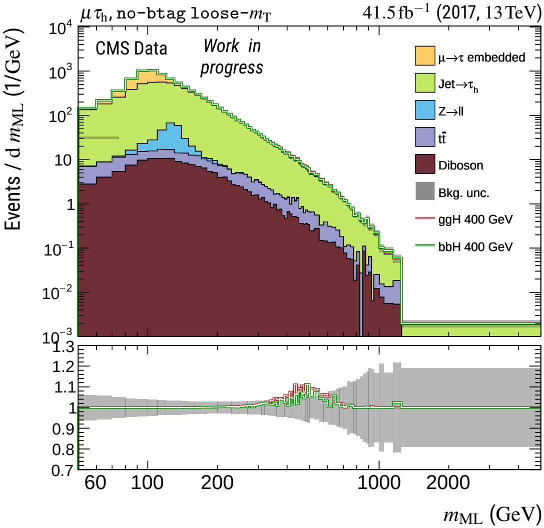


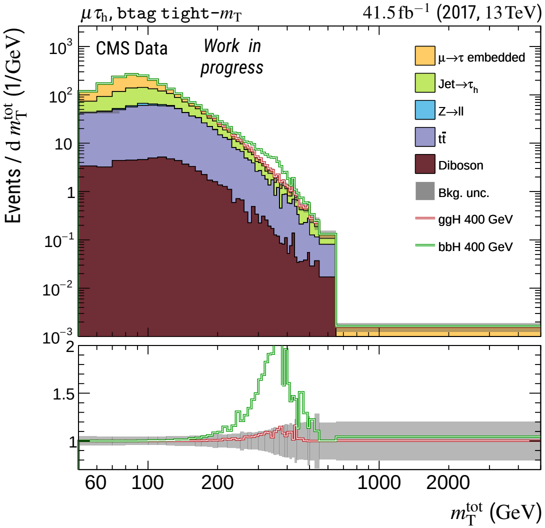
$\tau_h\tau_h$, btag
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$\mu\tau_h$, no-btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

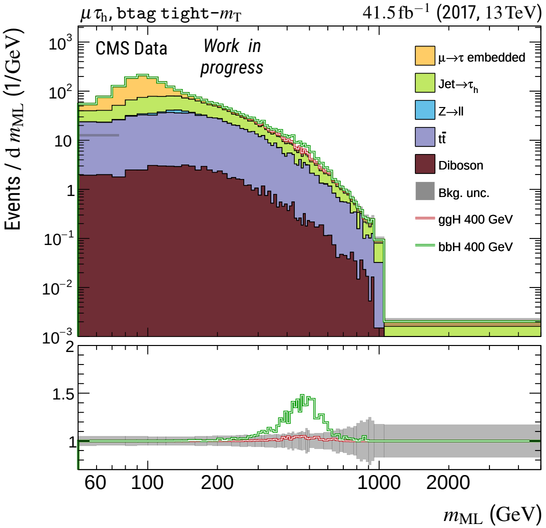

$\mu\tau_h$, no-btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$\mu\tau_h$, no-btag loose-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

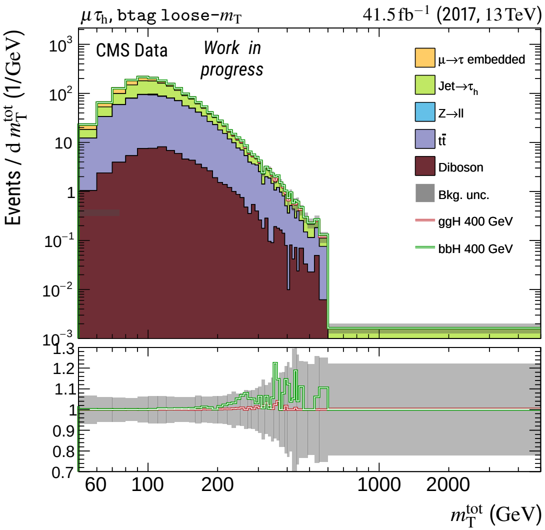

$\mu\tau_h$, no-btag loose-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



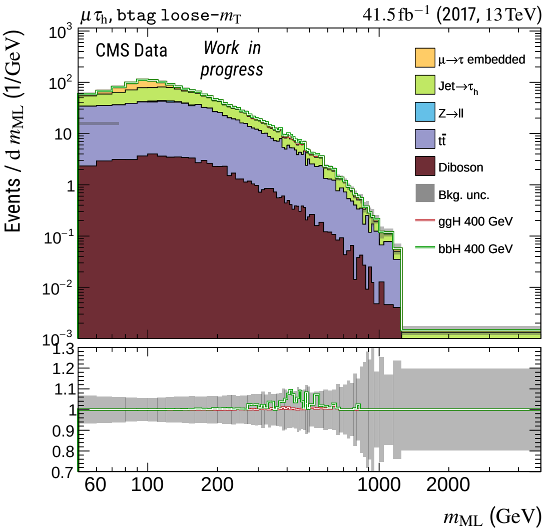
$\mu\tau_h$, btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



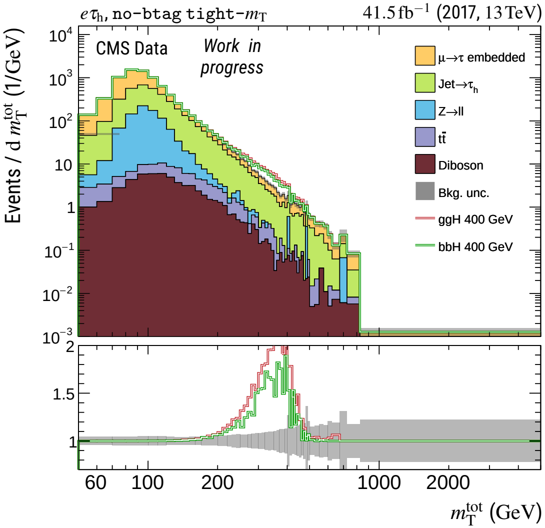
$\mu\tau_h$, btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
$\mu\to\tau$ embedded
Jet$\to\tau_h$
Z$\to$ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



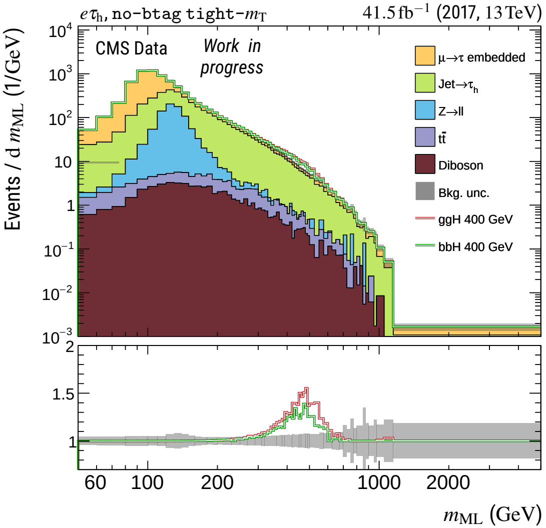
$\mu\tau_h$, btag loose-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



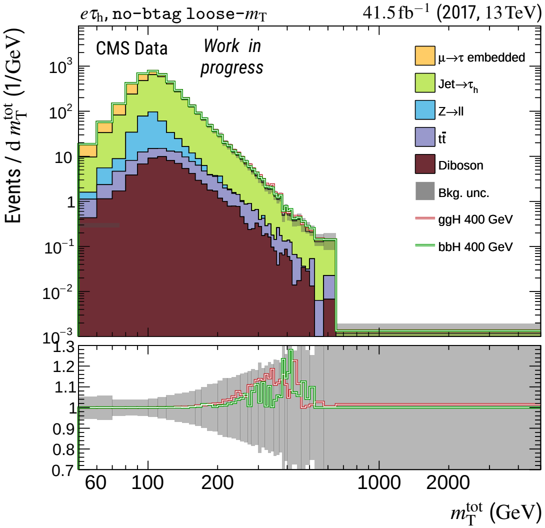
$\mu\tau_h$, btag loose-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

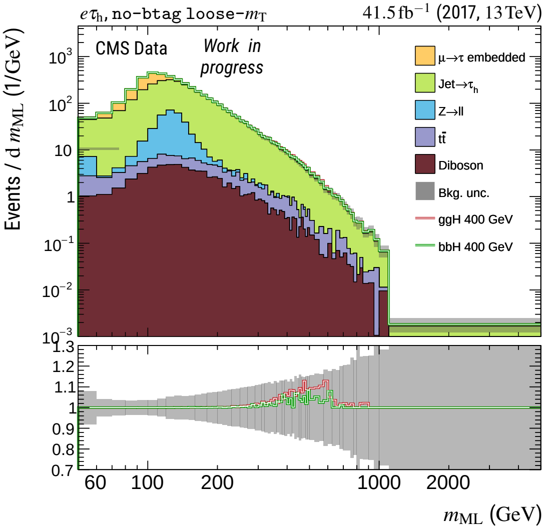


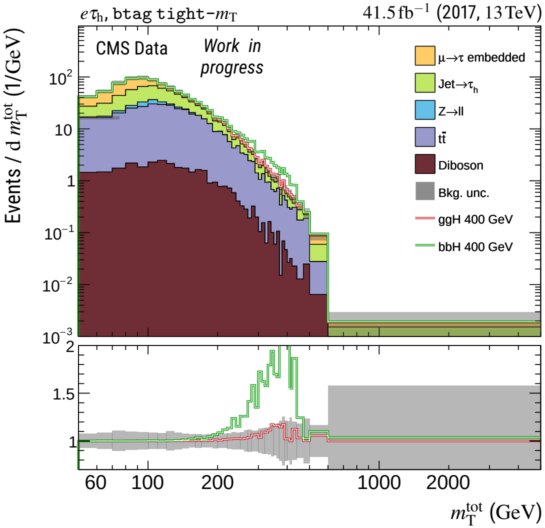
$e\tau_h$, no-btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

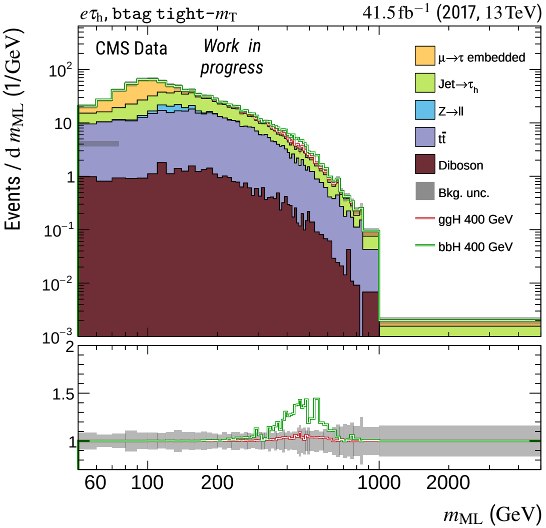


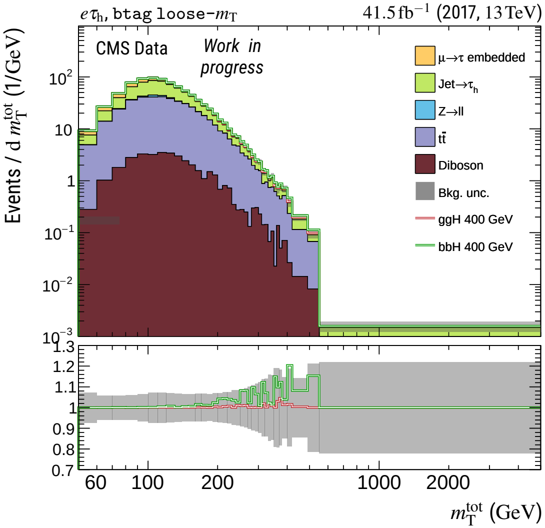
$e\tau_h$, no-btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

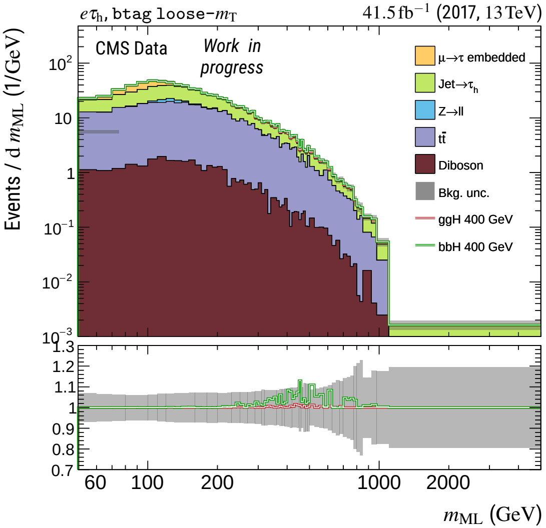

$e\tau_h$, no-btag loose-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

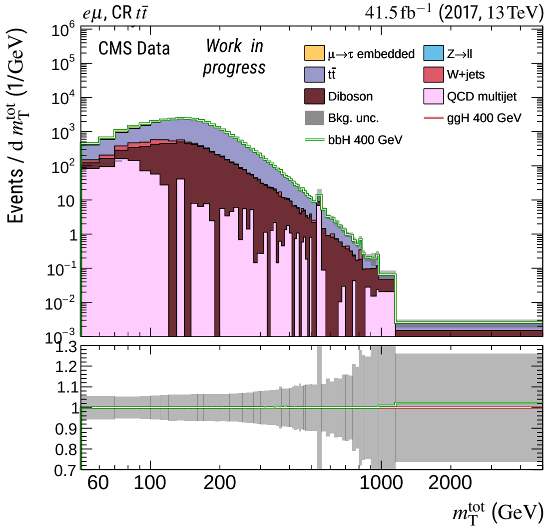

$e\tau_h$, no-btag loose-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


$e\tau_h$, btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

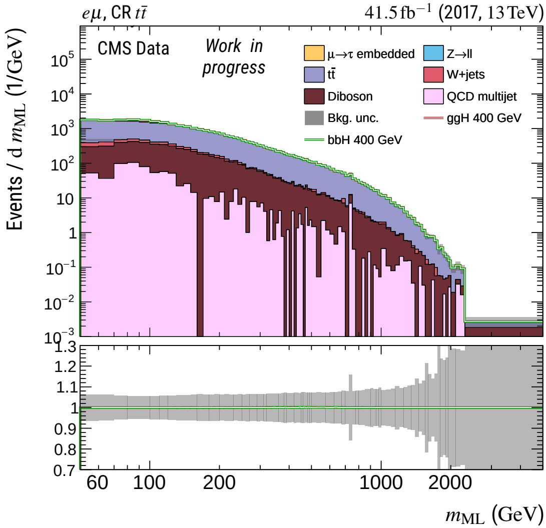

$e\tau_h$, btag tight-m_T
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)


eτh, btag loose-mT
41.5 fb−1 (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τh
Z→ll
tt̄
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d mTtot (1/GeV)
mTtot (GeV)

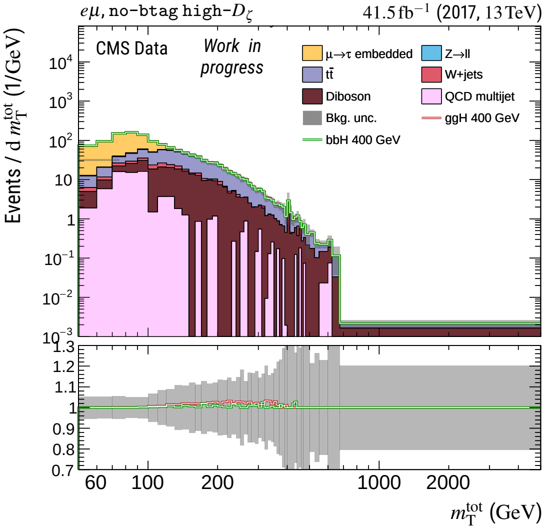

eτh, btag loose-mT
41.5 fb−1 (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τh
Z→ll
tt̄
Diboson
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d mML (1/GeV)
mML (GeV)



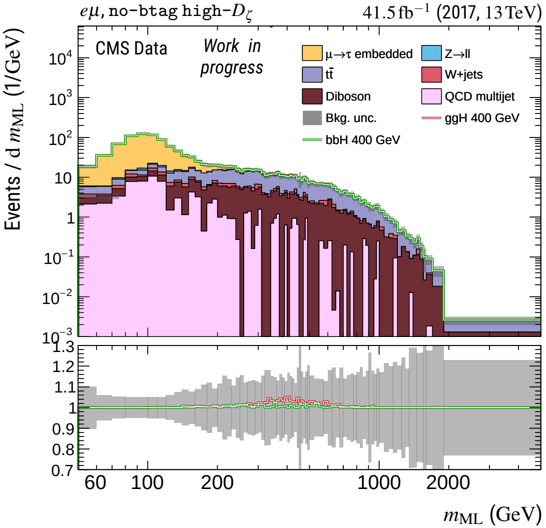
$e\mu$, CR $t\bar{t}$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



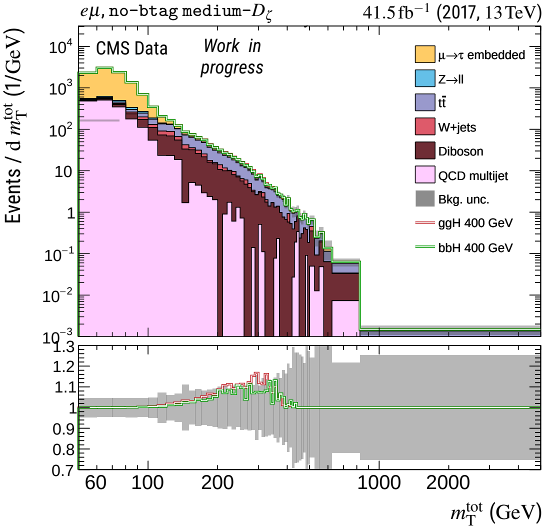
$e\mu$, CR $t\bar{t}$
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



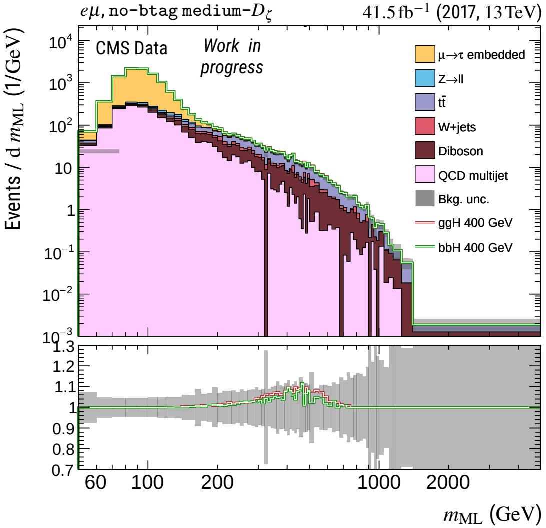
$e\mu$, no-btag high-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
$t\bar{t}$
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



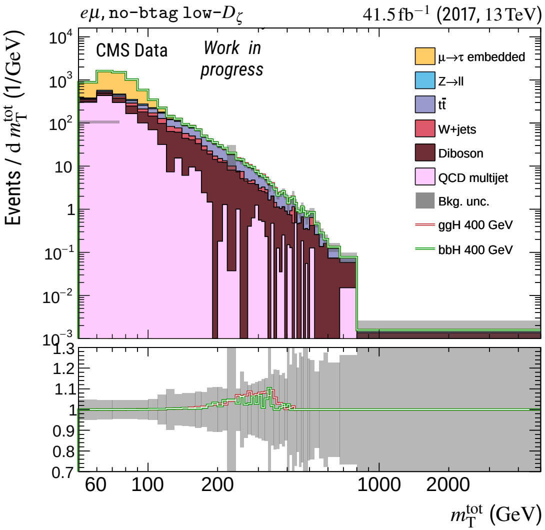
$e\mu$, no-btag high-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
$t\bar{t}$
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



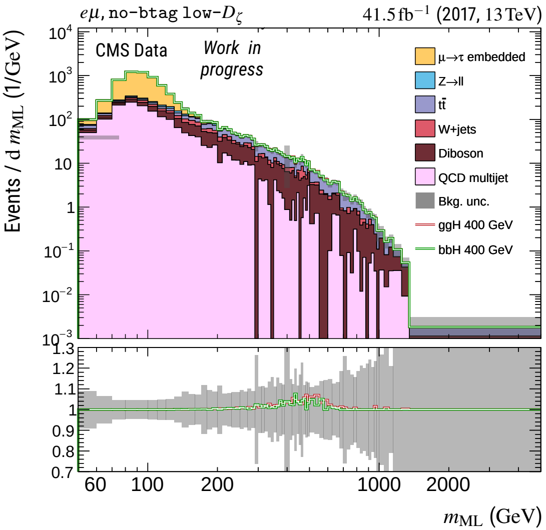
$e\mu$, no-btag medium-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



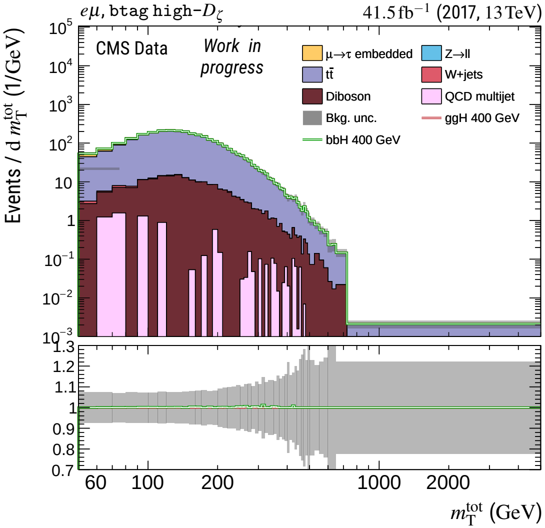
$e\mu$, no-btag medium-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



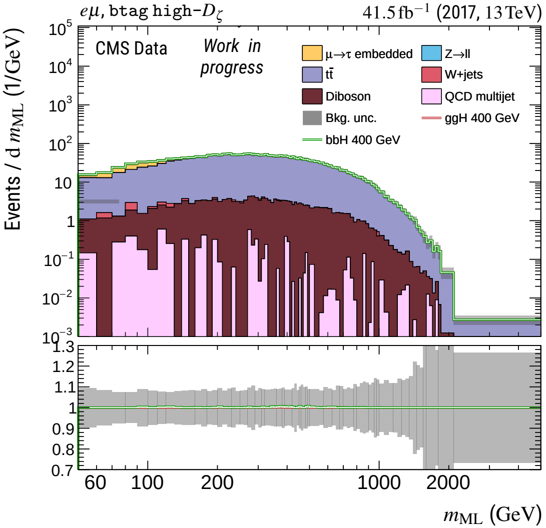
$e\mu$, no-btag low-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)



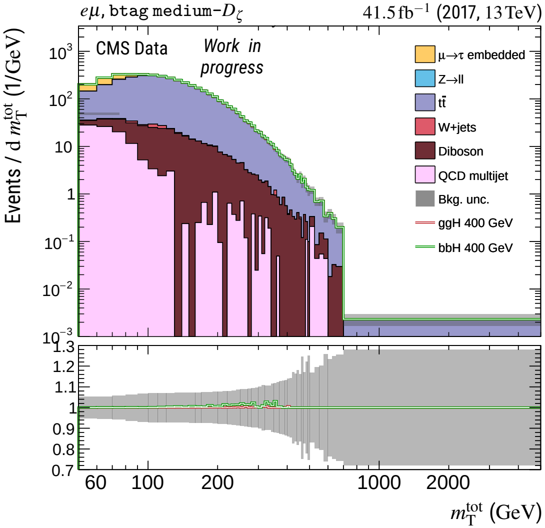
$e\mu$, no-btag low-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

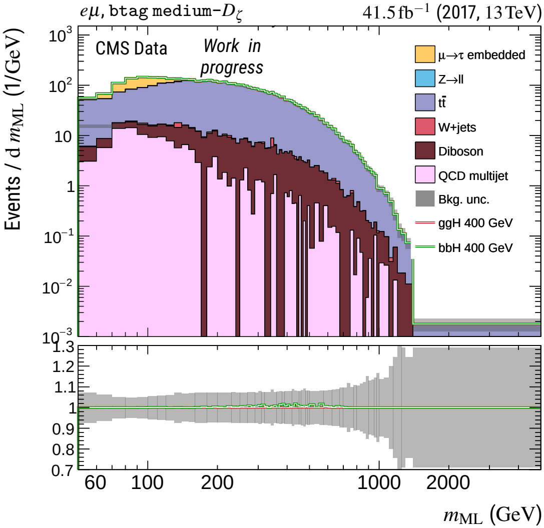


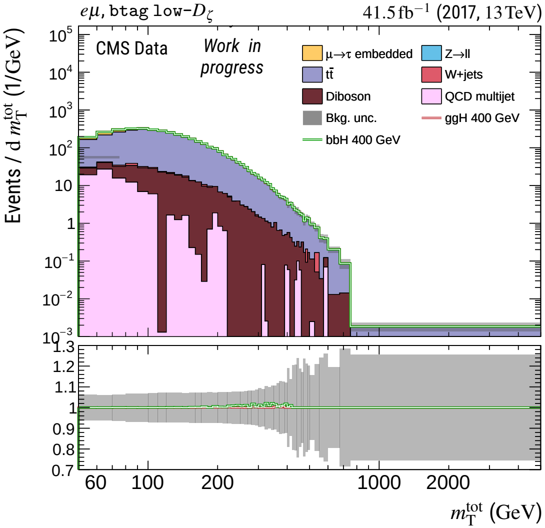
eμ, btag high-Dζ
41.5 fb⁻¹ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^tot (1/GeV)
m_T^tot (GeV)



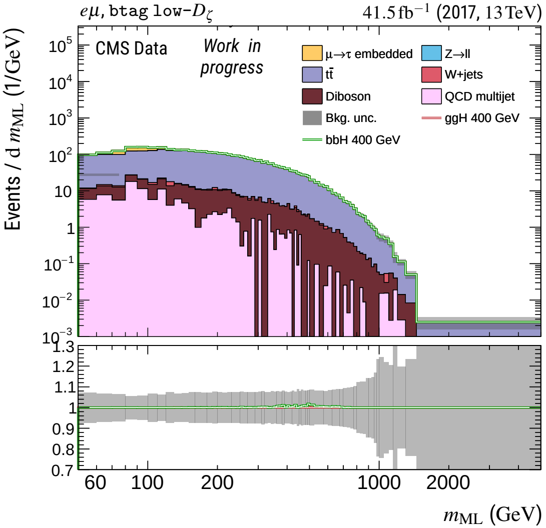
eμ, btag high-Dζ
41.5 fb⁻¹ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_ML (1/GeV)
m_ML (GeV)


eμ, btag medium-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
$t\bar{t}$
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

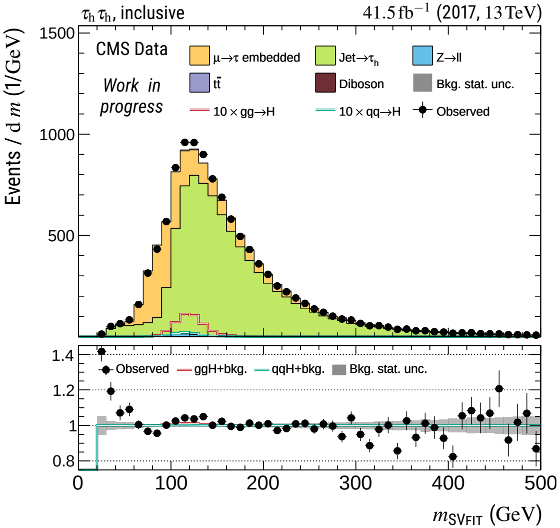

eμ, btag medium-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
$t\bar{t}$
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)

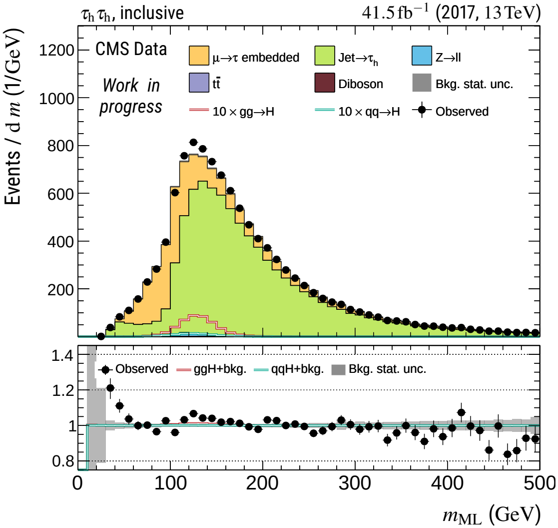


$e\mu$, btag low-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
$t\bar{t}$
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_T^{tot} (1/GeV)
m_T^{tot} (GeV)

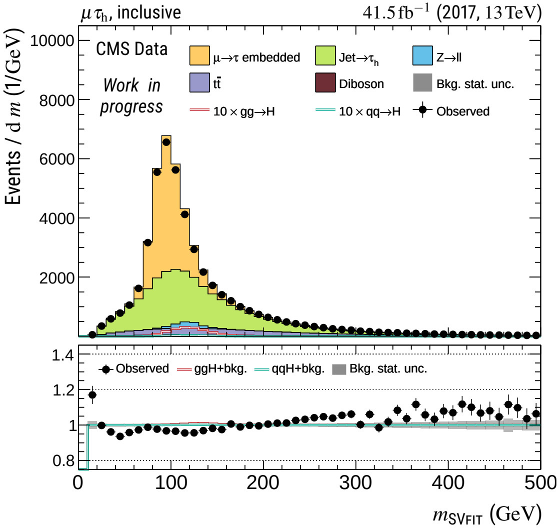


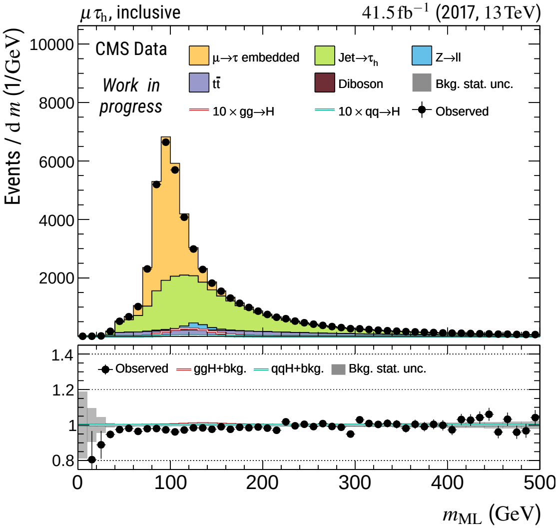
$e\mu$, btag low-D_ζ
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
$t\bar{t}$
W+jets
Diboson
QCD multijet
Bkg. unc.
ggH 400 GeV
bbH 400 GeV
Events / d m_{ML} (1/GeV)
m_{ML} (GeV)



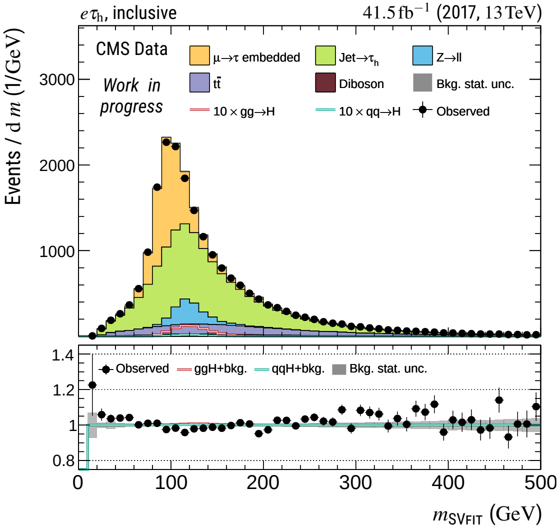


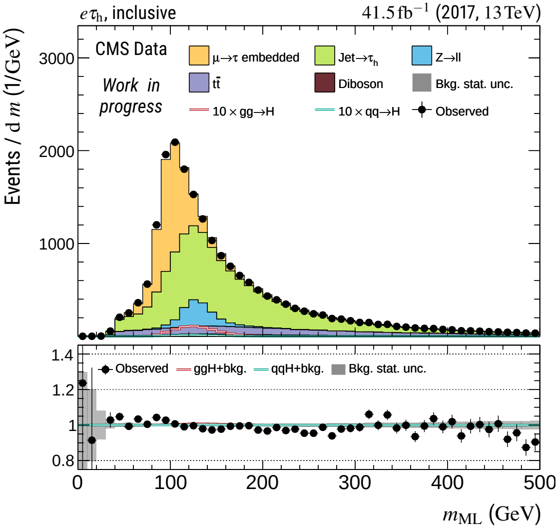
- ***vs* $m_{\mathbf{SVFIT}}$**: Same looking shapes, expected.



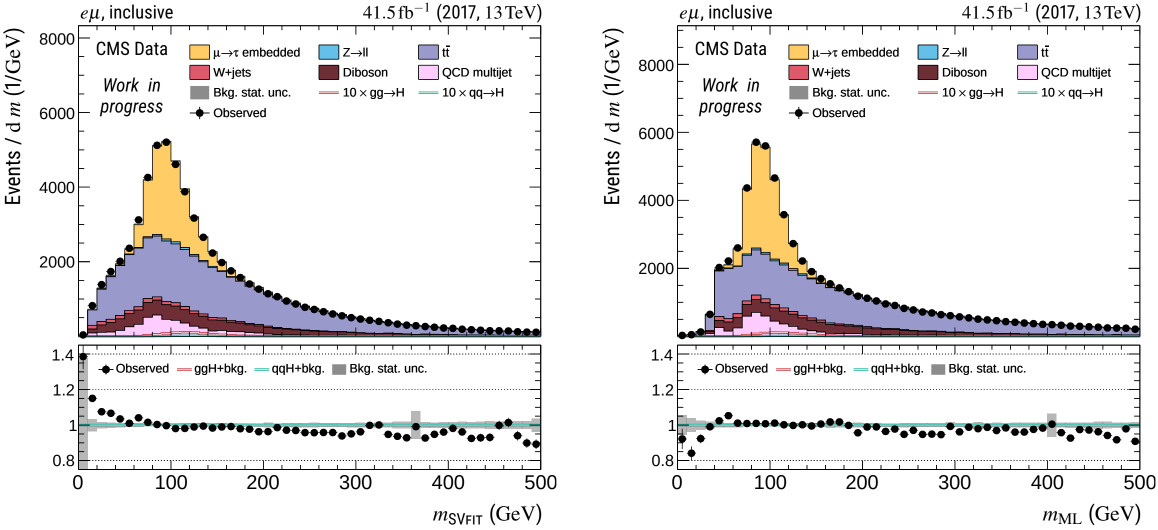


- ***vs*** $m_{\mathbf{SVFIT}}$: Better Data-Bkg agreement with m_{ML}!

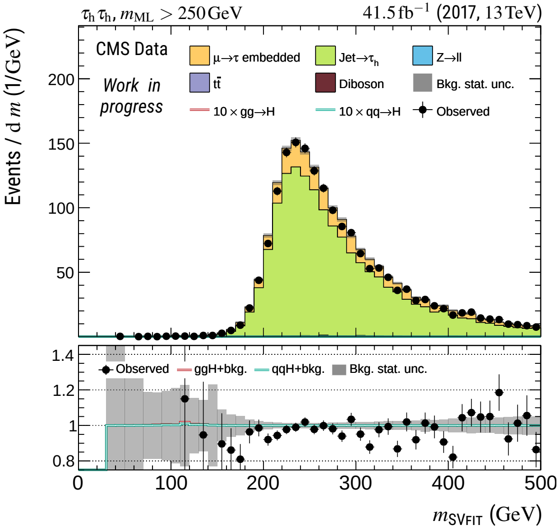


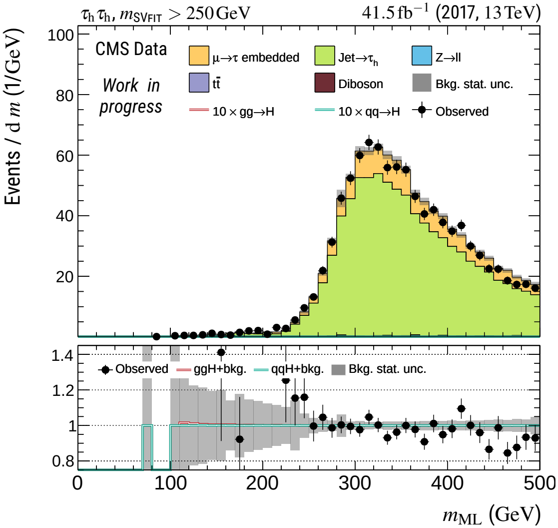


- ***vs*** m_{SVFIT}: Slightly better Data-Bkg agreement with m_{ML}.

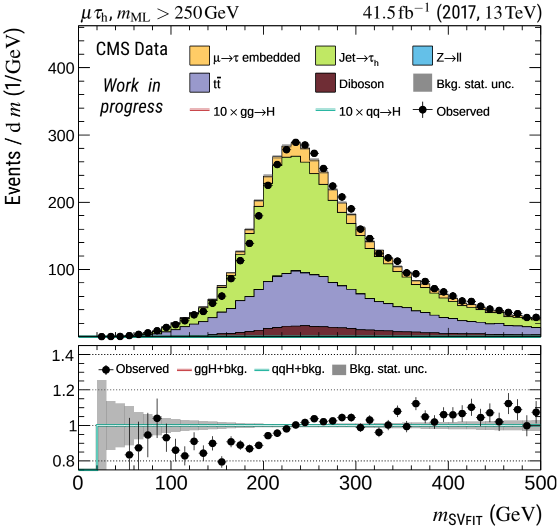


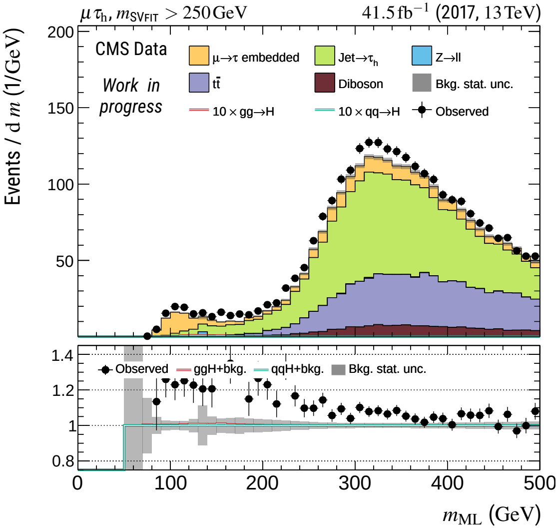
- ***vs*** $m_{\mathbf{SVFIT}}$: Slightly better Data-Bkg agreement with m_{ML}.



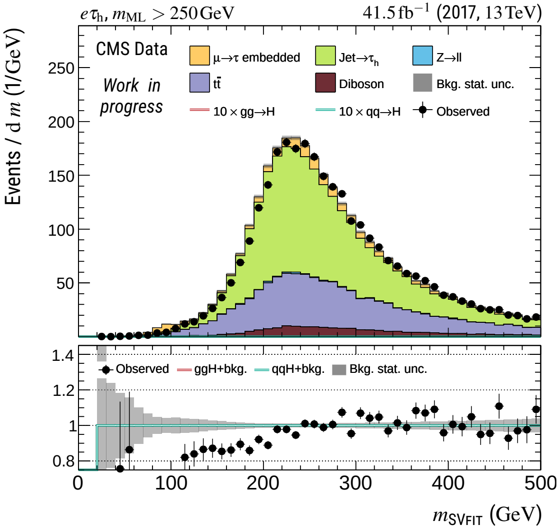


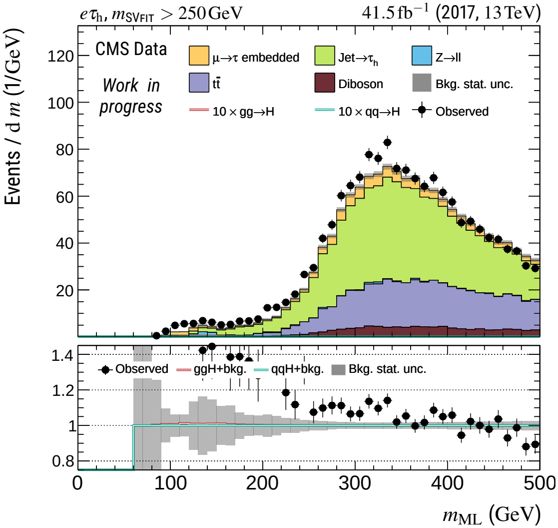
- Distributions start to populate at 200 or 300 GeV. **Yield is different**



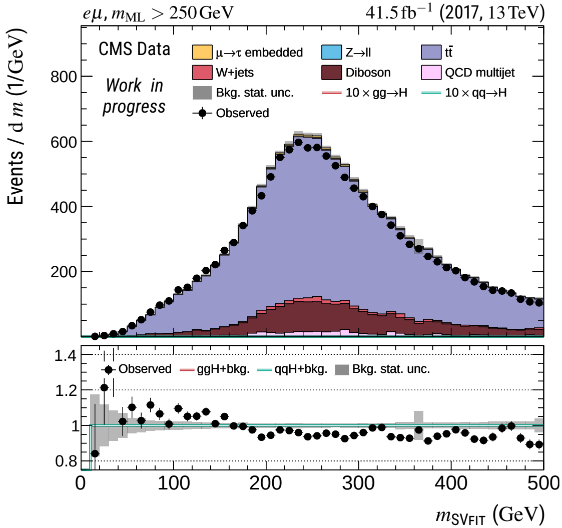


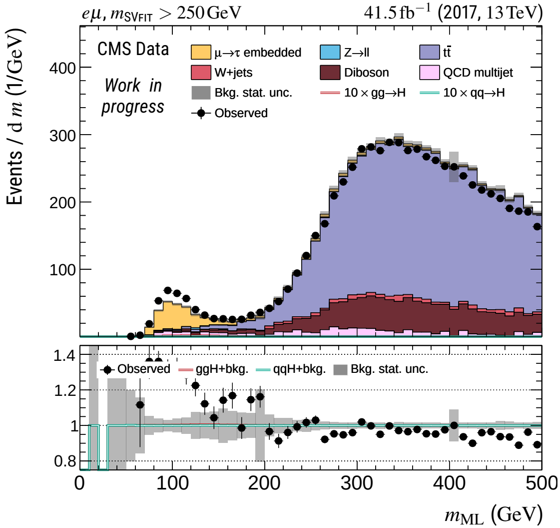
- Our model finds $Z \to \tau\tau$ events at $\sim 100\,\mathrm{GeV}$ in the $m_{\mathrm{SVFIT}} > 250\,\mathrm{GeV}$ region!



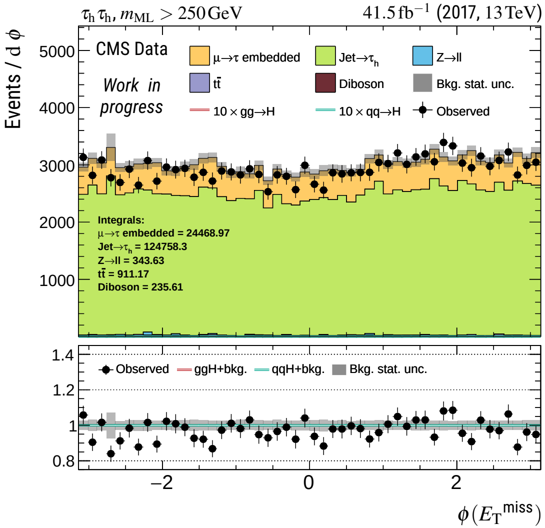


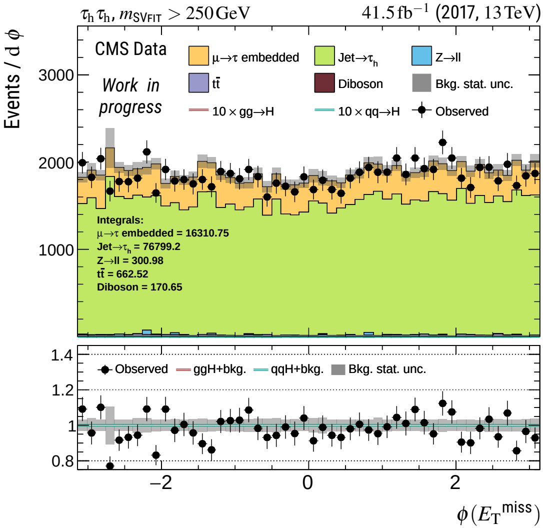
- Same kind of effect as seem in $\mu\tau_h$.

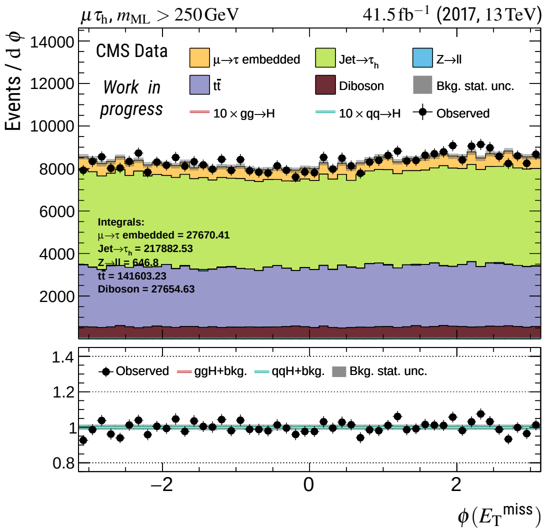


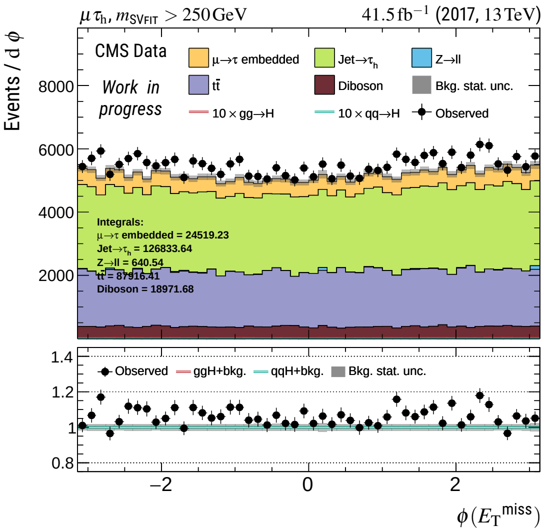


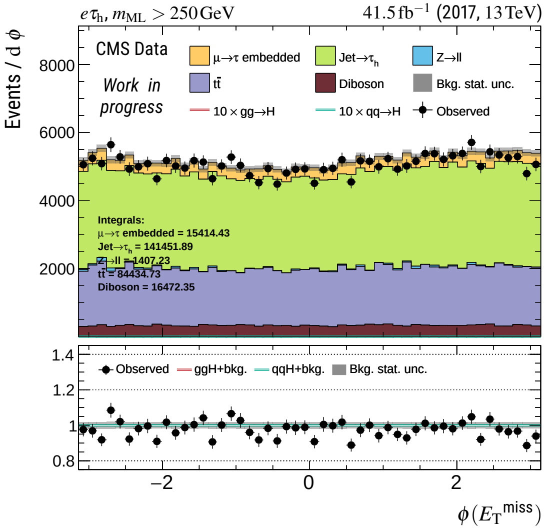
- Same kind of effect as seem in $\mu\tau_{\mathrm{h}}$.

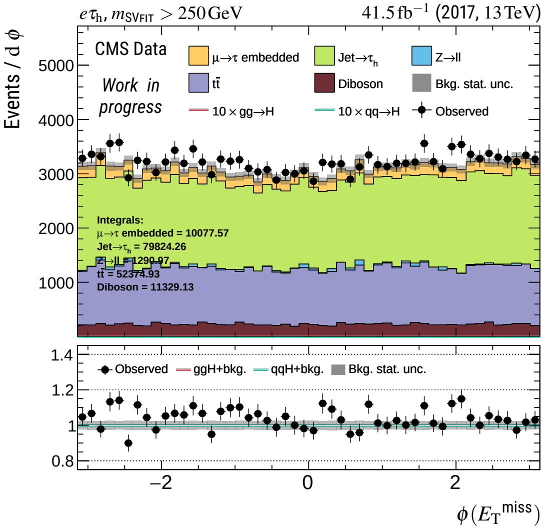

$\tau_h \tau_h$, $m_{ML} > 250$ GeV
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 24468.97
Jet→τ_h = 124758.3
Z→ll = 343.63
tt̄ = 911.17
Diboson = 235.61
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi(E_T^{miss})$

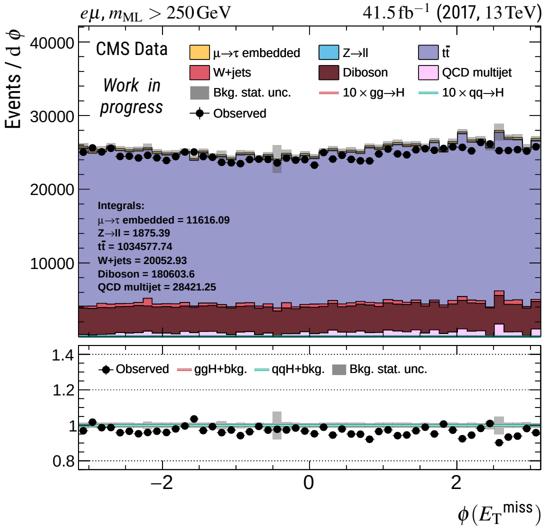

$\tau_h \tau_h$, $m_{SVFIT} > 250$ GeV
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 16310.75
Jet→τ_h = 76799.2
Z→ll = 300.98
tt̄ = 662.52
Diboson = 170.65
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi(E_T^{miss})$

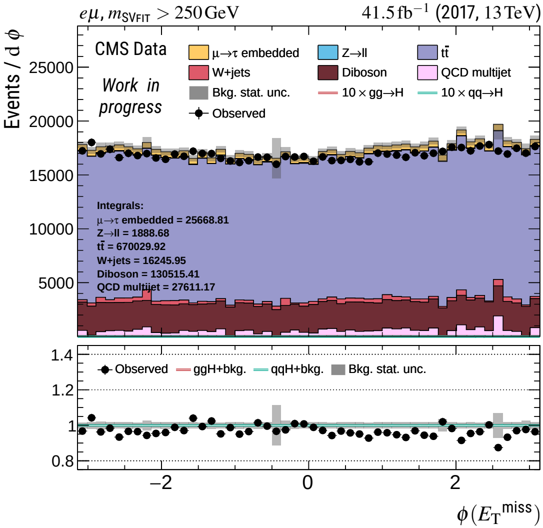

$\mu\tau_h, m_{ML} > 250\,GeV$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 27670.41
Jet→τ_h = 217882.53
Z→ll = 646.8
$t\bar{t}$ = 141603.23
Diboson = 27654.63
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi\,(E_T^{miss})$


$\mu\tau_h, m_{SVFIT} > 250\,GeV$
$41.5\,fb^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
$t\bar{t}$
Diboson
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 24519.23
Jet→τ_h = 126833.64
Z→ll = 640.54
$t\bar{t}$ = 87916.41
Diboson = 18971.68
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi\,(E_T^{miss})$


$e\tau_h$, $m_{ML} > 250$ GeV
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 15414.43
Jet→τ_h = 141451.89
Z→ll = 1407.23
tt̄ = 84434.73
Diboson = 16472.35
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi(E_T^{miss})$


$e\tau_h$, $m_{SVFIT} > 250$ GeV
41.5 fb^{-1} (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Jet→τ_h
Z→ll
tt̄
Diboson
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 10077.57
Jet→τ_h = 79824.26
Z→ll = 1290.97
tt̄ = 52374.93
Diboson = 11329.13
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi(E_T^{miss})$


$e\mu$, $m_{\mathrm{ML}} > 250\,\mathrm{GeV}$
$41.5\,\mathrm{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 11616.09
Z→ll = 1875.39
tt̄ = 1034577.74
W+jets = 20052.93
Diboson = 180603.6
QCD multijet = 28421.25
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi(E_T^{\mathrm{miss}})$


$e\mu$, $m_{\mathrm{SVFIT}} > 250\,\mathrm{GeV}$
$41.5\,\mathrm{fb}^{-1}$ (2017, 13 TeV)
CMS Data
Work in progress
μ→τ embedded
Z→ll
tt̄
W+jets
Diboson
QCD multijet
Bkg. stat. unc.
10 × gg→H
10 × qq→H
Observed
Integrals:
μ→τ embedded = 25668.81
Z→ll = 1888.68
tt̄ = 670029.92
W+jets = 16245.95
Diboson = 130515.41
QCD multijet = 27611.17
Events / d ϕ
Observed
ggH+bkg.
qqH+bkg.
Bkg. stat. unc.
$\phi(E_T^{\mathrm{miss}})$