# Updates about Higgs Combination Measurement on CEPC

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# Higgs Combination

- Individual Higgs channel analysis
  - correlations between different signal modes were not taken into account
  - the ZH backgrounds in one channel is another channel's signal
    - should consider in the fit of the cross section and the constrain of the couplings.
  - systematics and their correlations are difficult to address
- We introduce combination measurement
  - uniformed, simultaneous statistical procedure and framework
  - can easily include necessary correlations
  - gives more potential for future interpretation of the results

# Fit techniques

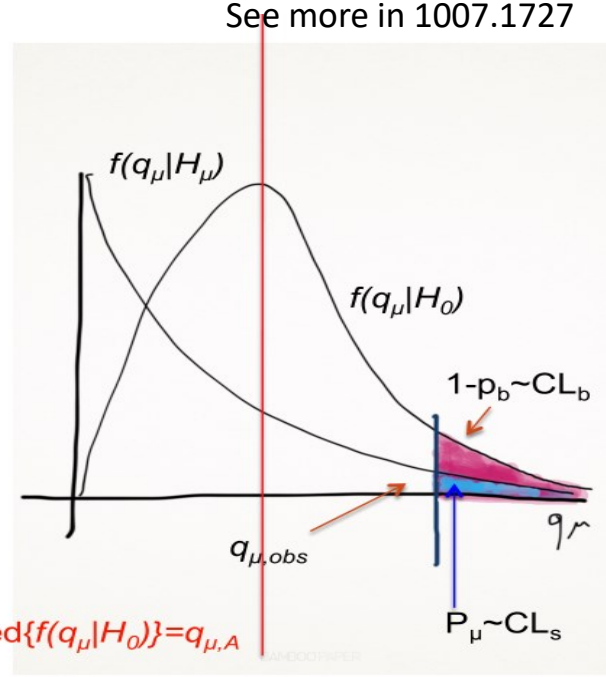
PDF for fit: signal: CB ball + Gaussian
bkg: 2rd poly exp

Actually now we fit out the uncertainties on signal strength $\mu$, which equals to relative uncertainties on $\sigma * Br$

- Workspace: the likelihood model container
- Input: invariant/recoil mass spectrum
- POI(parameter of interest): $\sigma * Br$, $Br$, Higgs coupling $\kappa$
- Asimov s+b dataset
  - the median of $f(q_\mu|H_0)$
  - suppresses statistic uncertainties.
  - parameters all replaced to their expected value
- NP(nuisance parameter): function & constrains in model besides POI
  - hold systematic uncertainties
  - correlated NP share the same name
  - currently we set $\Delta\sigma = 0.5\%, \Delta\mathrm{Lumi} = 0.1\%$

More NP awaiting settlement.

See more in 1007.1727



# Channels Table (now 29)

*H->ee/eμ not listed since low stats.

| Signal Z | Signal H | Who takes charge | Last update |
|---|---|---|---|
| **H->qq** | | | |
| ee | bb | ZhenXing | 2016.9 |
| | cc | | |
| | gg | | |
| μμ | bb | | |
| | cc | | |
| | gg | | |
| qq | bb | Baiyu | 2016.8 |
| | cc | | |
| | gg | | |
| **H→γγ** | | | |
| ll | γγ | Feng | 2015 |
| vv | | | |
| qq | | Yitian | 2017.4 |
| **Others** | | | |
| μμ | ττ | Dan | 2016.8 |
| Inc. | μμ | Cui | 2016.8 |

qq group use template fit with b-tagging to determine the ratio, and the higgs mass spectrum of bb/cc/gg is indistinguishable.
Here the result is only statistics effect.
To be developed.

with problem, waiting to fix

| Signal Z | Signal H | Who takes charge | Last update |
|---|---|---|---|
| **H->ZZ** | | | |
| νν | μμjj | Yuqian | 2016.9 |
| μμ | νvjj | | |
| ee | νvjj | | |
| qq | νννν | MoXin | 2016.8 |
| **H->WW** | | | |
| μμ | μνμν | Libo | 2017.4 |
| | evev | | |
| | evμν | | |
| | evqq | | |
| | μνqq | | |
| ee | μνμν | | |
| | evev | | |
| | evμν | | |
| | evqq | | |
| | μνqq | | |
| νν | qqqq | | |
| μμ | qqqq | Yuqian | Preparing |

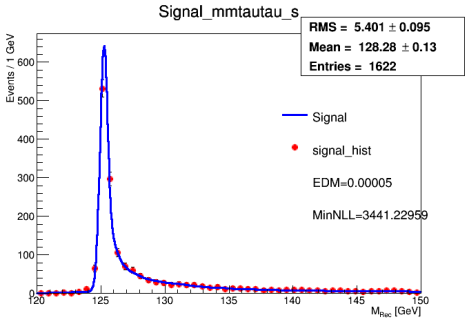
# Signal yields

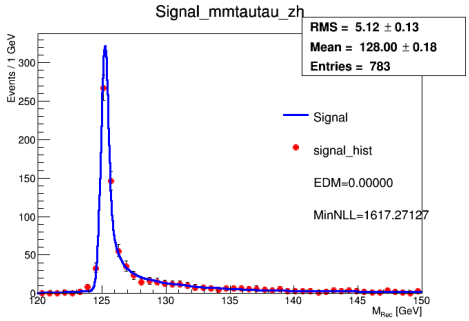
*Obsdata provided by each individual analysist.

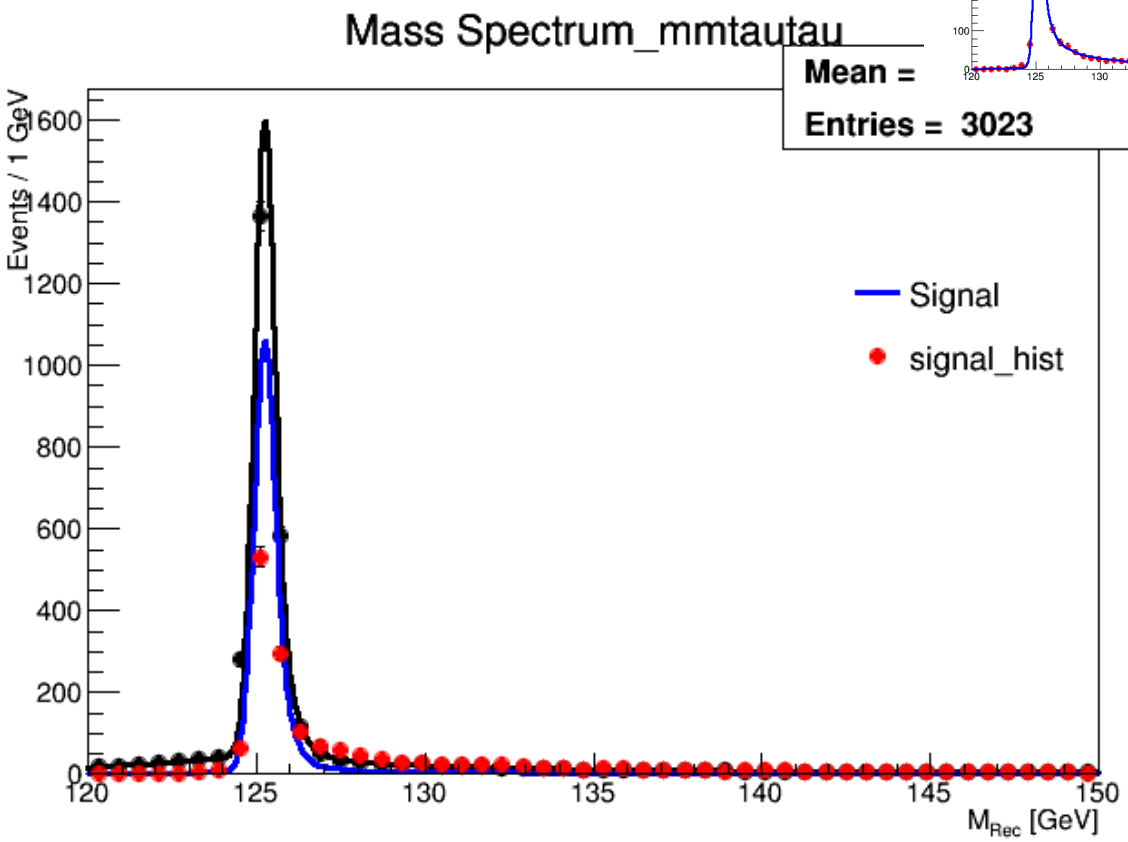
| Signal | | Observed | Expect Before cut flow |
|---|---|---|---|
| Z | H | | |
| H->qq | | | |
| ee | bb | 7805 | 20586 |
| | cc | 361 | 961 |
| | gg | 1242 | 3062 |
| μμ | bb | 12326 | 20586 |
| | cc | 615 | 961 |
| | gg | 1755 | 3062 |
| qq | bb | 148749 | 428876 |
| | cc | 3887 | 20034 |
| | gg | 25564 | 63812 |
| H→γγ | | | |
| ll | γγ | 90 | 164 |
| vv | | 328 | 488 |
| qq | | 828 | 1707 |
| Others | | | |
| μμ | ττ | 1658 | 2257 |
| Inc. | μμ | 47 | 233 |

| Signal | | Observed | Expect Before cut flow |
|---|---|---|---|
| Z | H | | |
| H->ZZ | | | |
| vv | μμjj | 190 | 264 |
| μμ | vvjj | 72 | 264 |
| ee | vvjj | 209 | 264 |
| qq | vvvv | 225 | 784 |
| H->WW | | | |
| μμ | μνμν | 52 | 87 |
| | evev | 36 | 88 |
| | evμν | 105 | 175 |
| | evqq | 663 | 1111 |
| | μνqq | 717 | 1103 |
| ee | μνμν | 44 | 87 |
| | evev | 22 | 88 |
| | evμν | 81 | 175 |
| | evqq | 612 | 1112 |
| | μνqq | 684 | 1104 |
| vv | qqqq | 9022 | 20808 |

# $ZH \to \mu\mu\tau\tau$: shape separation




Black: S+B Asimov model

Blue: signal

$\tau\tau$ channel, ZH bkg (main WW) has same peak shape with signal, the significance is affected.

Fit result reduced when mass shape separation power is not good, (Like bb/cc/gg, here $\tau\tau$)

Considering using another observe variables in this situation.

# Fit Result

| | PreCDR | Manqi's on Aug 2016 | My result of $\Delta(Br*\sigma)$ | My result of $\Delta Br$ |
|---|---|---|---|---|
| $\sigma(ZH)$ | 0.51% | 0.50% | set to 0.50% | |
| $\Delta(Br*\sigma)$ | 0.28% | Not shown | 0.23% | 0.56% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{bb})$ | 0.28% | **0.21%** | **0.25%** | 0.57% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{cc})$ | 2.1% | **2.5%** | **2.73%** | 2.82% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{gg})$ | 1.6% | **1.3%** | **1.16%** | 1.26% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{WW})$ | 1.5% | **1.0%** | **1.24%** | 1.35% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{ZZ})$ | 4.3% | **4.3%** | **5.72%** | 5.75% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \tau\tau)$ | 1.2% | **1.0%** | **3.12%** | 3.21% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \gamma\gamma)$ | 9.0% | **9.0%** | **8.21%** | 8.23% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mu\mu)$ | 17% | **17%** | **19.4%** | 19.4% |
| $\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{inv.})$ | 95% CL, 1.4e-3 | 1.4e-3 | 237% | 237% |

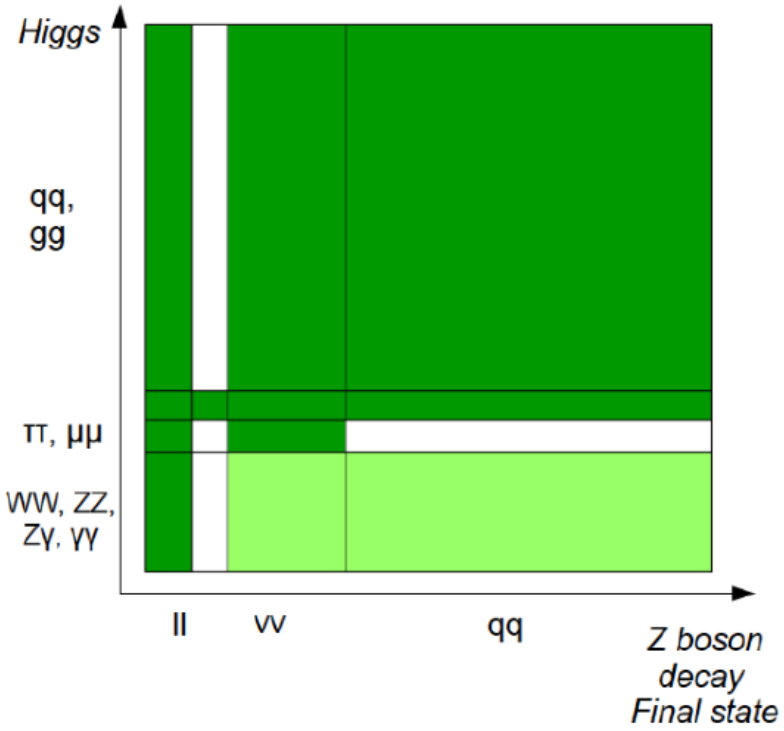
Results are compatible.

# Next step to do

- Updates whenever new histogram is ready.
- Improve fit strategy
- Introduce NPs into framework
- Turn to $\kappa$-parameterization framework for future research

# backups

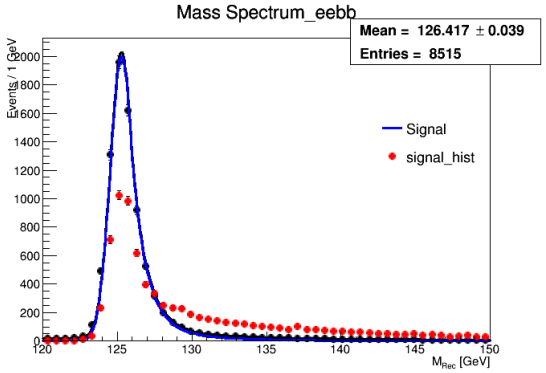
# CEPC: Simulation Studies

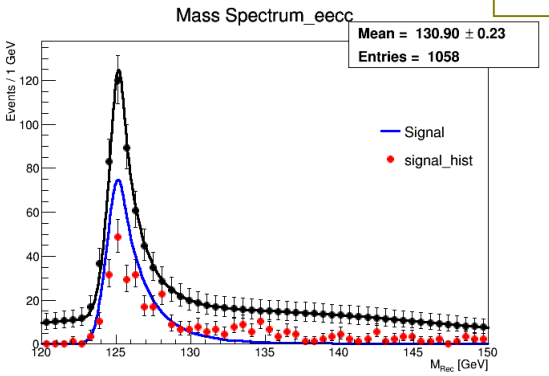


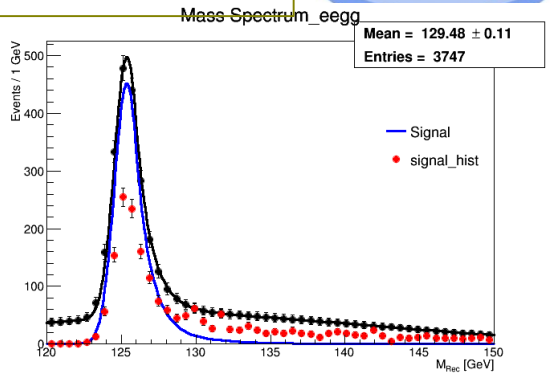

| | PreCDR (Jan 2015) | Now (Aug 2016) |
|---|---|---|
| σ(ZH) | 0.51% | 0.50% |
| σ(ZH)*Br(H→bb) | 0.28% | 0.21% |
| σ(ZH)*Br(H→cc) | 2.1% | 2.5% |
| σ(ZH)*Br(H→gg) | 1.6% | 1.3% |
| σ(ZH)*Br(H→WW) | 1.5% | 1.0% |
| σ(ZH)*Br(H→ZZ) | 4.3% | 4.3% |
| σ(ZH)*Br(H→ττ) | 1.2% | 1.0% |
| σ(ZH)*Br(H→γγ) | 9.0% | 9.0% |
| σ(ZH)*Br(H→Zγ) | - | ~4 σ |
| σ(ZH)*Br(H→μμ) | 17% | 17% |
| σ(vvH)*Br(H→bb) | 2.8% | 2.8% |
| Higgs Mass/MeV | 5.9 | 5.0 |
| σ(ZH)*Br(H→inv) | 95%. CL = 1.4e-3 | 1.4e-3 |
| Br(H→ee/emu) | - | 1.7e-4/1.2e-4 |
| Br(H→bbχχ) | $<10^{-3}$ | 3.0e-4 |

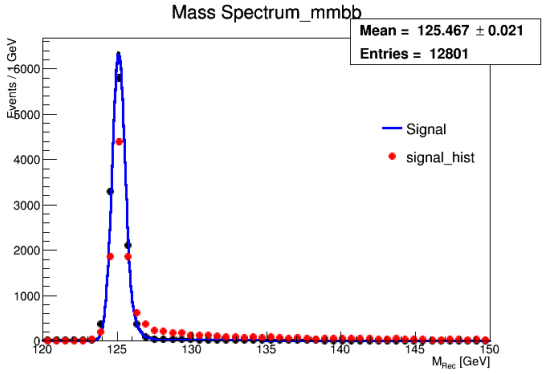
# $ee/\mu\mu/qq + bb/cc/gg$ plot

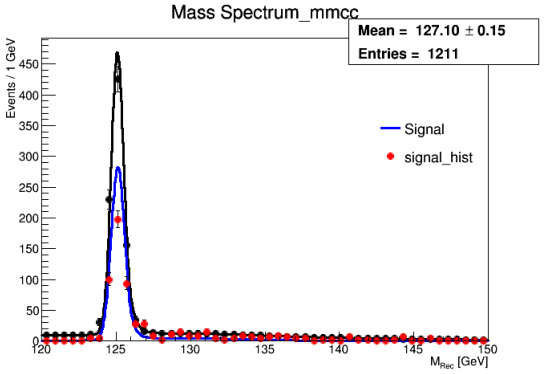
Here ee signal data/pdf actually is the same, see signal plots.
To be solved.

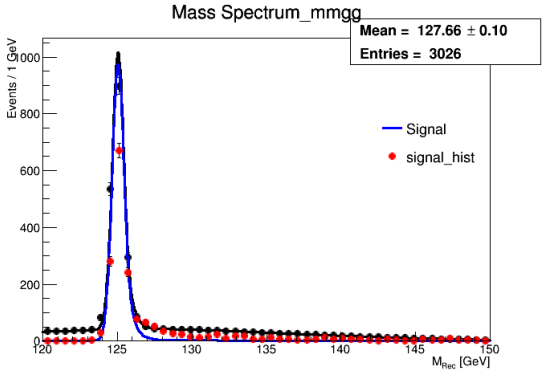


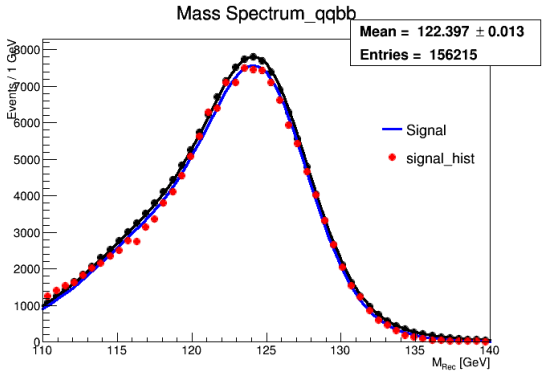



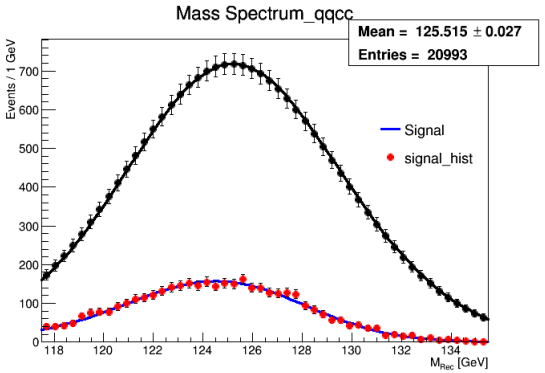



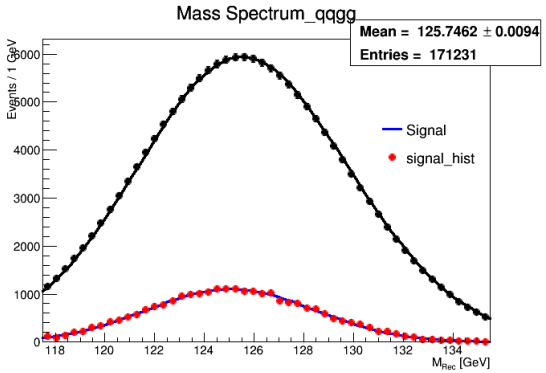



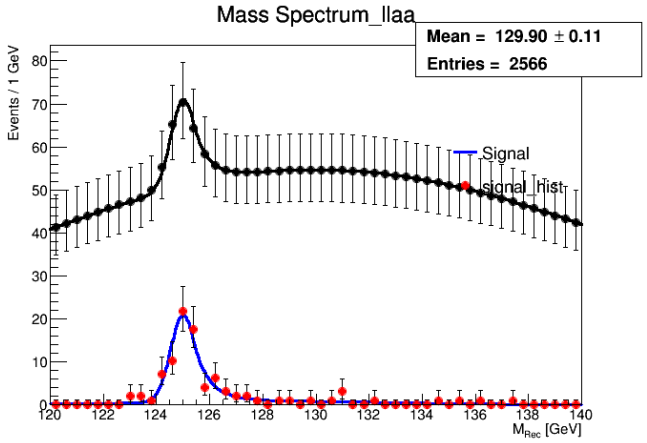



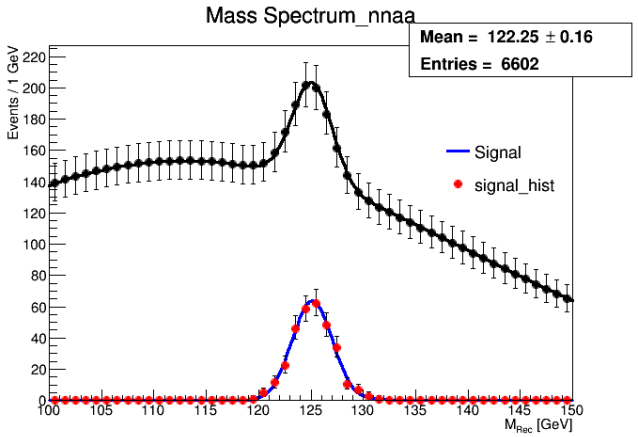
# $\gamma\gamma$ plot

## Old ll+$\gamma\gamma$ plot

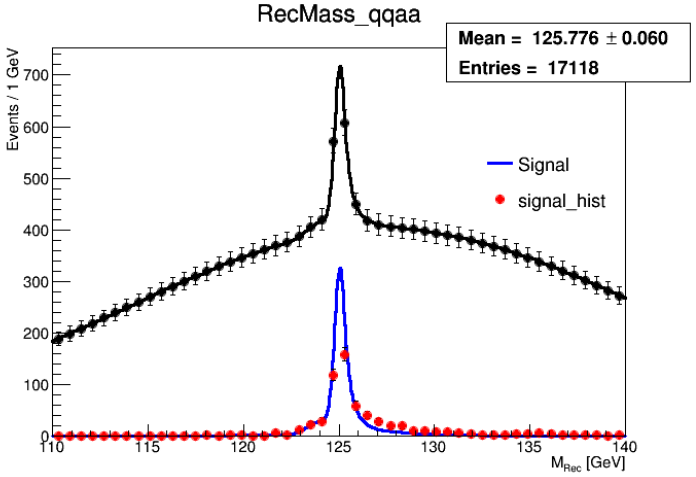



with problem

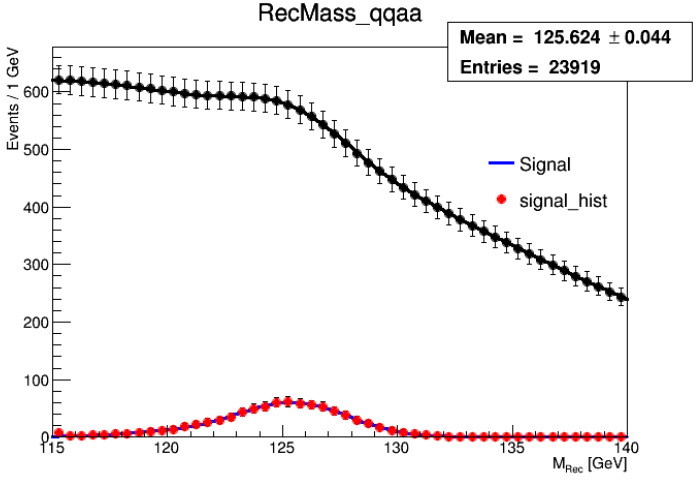
## Old nn+$\gamma\gamma$ plot



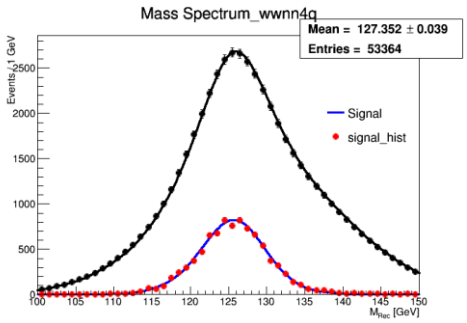

## Old qq+$\gamma\gamma$ plot

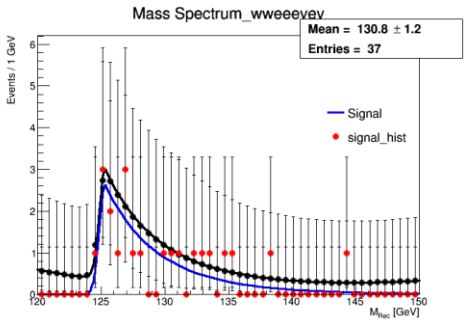


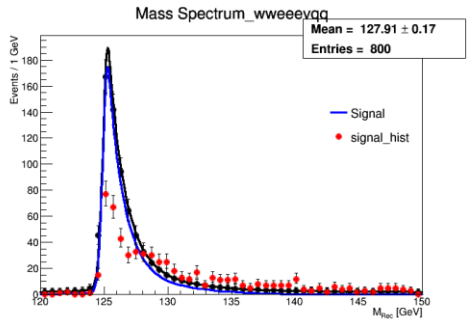

## Current qq+$\gamma\gamma$ plot

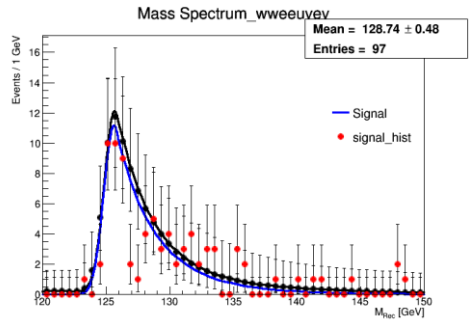


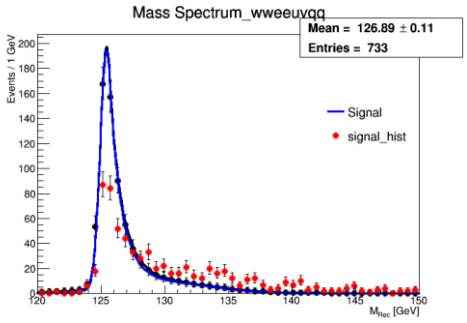
# WW plot

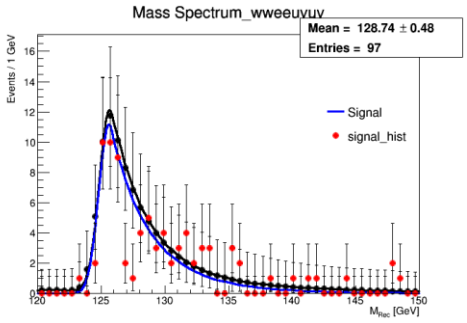

Mass Spectrum_wwnn4q
Mean = 127.352 ± 0.039
Entries = 53364
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

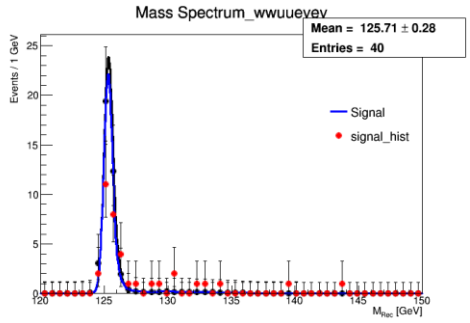

Mass Spectrum_wweeevev
Mean = 130.8 ± 1.2
Entries = 37
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

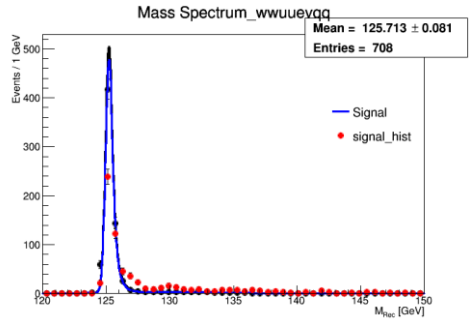

Mass Spectrum_wweeevqq
Mean = 127.91 ± 0.17
Entries = 800
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

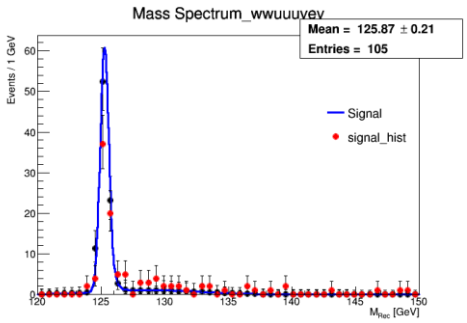

Mass Spectrum_wweeuvev
Mean = 128.74 ± 0.48
Entries = 97
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

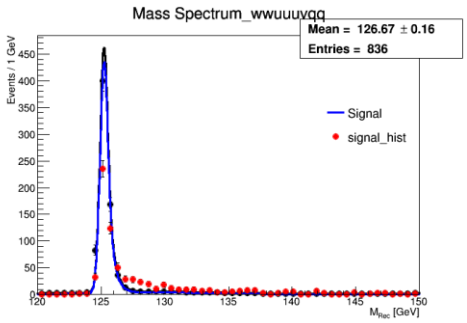

Mass Spectrum_wweeuvqq
Mean = 126.89 ± 0.11
Entries = 733
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

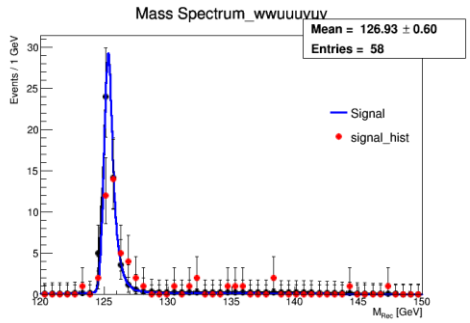

Mass Spectrum_wweeuvuv
Mean = 128.74 ± 0.48
Entries = 97
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

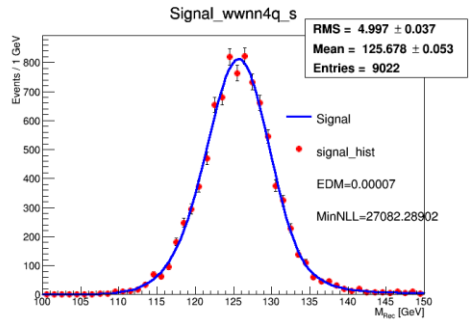

Mass Spectrum_wwuuevev
Mean = 125.71 ± 0.28
Entries = 40
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]


Mass Spectrum_wwuuevqq
Mean = 125.713 ± 0.081
Entries = 708
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]


Mass Spectrum_wwuuuvev
Mean = 125.87 ± 0.21
Entries = 105
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

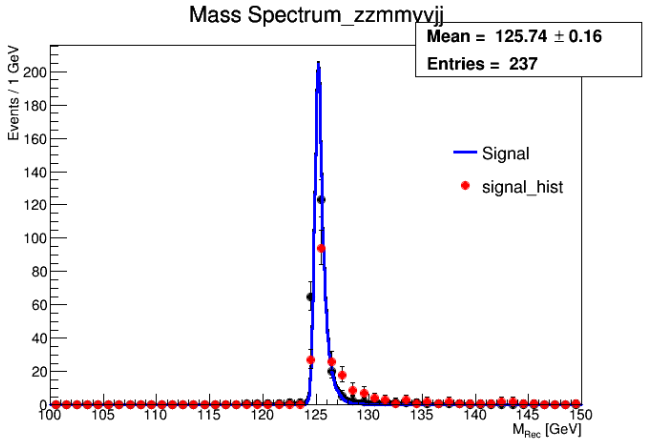

Mass Spectrum_wwuuuvqq
Mean = 126.67 ± 0.16
Entries = 836
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

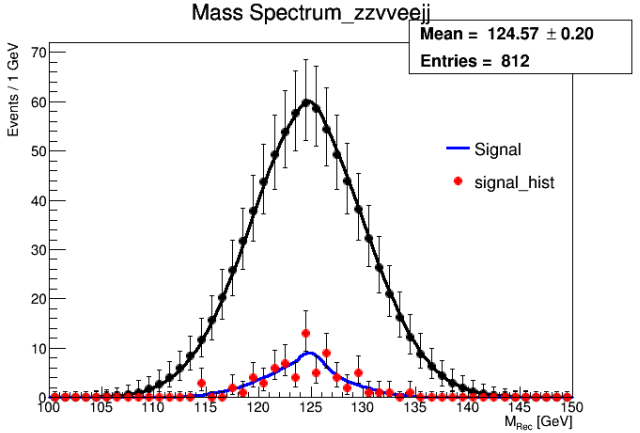

Mass Spectrum_wwuuuvuv
Mean = 126.93 ± 0.60
Entries = 58
Signal
signal_hist
Events / 1 GeV
M_Rec [GeV]

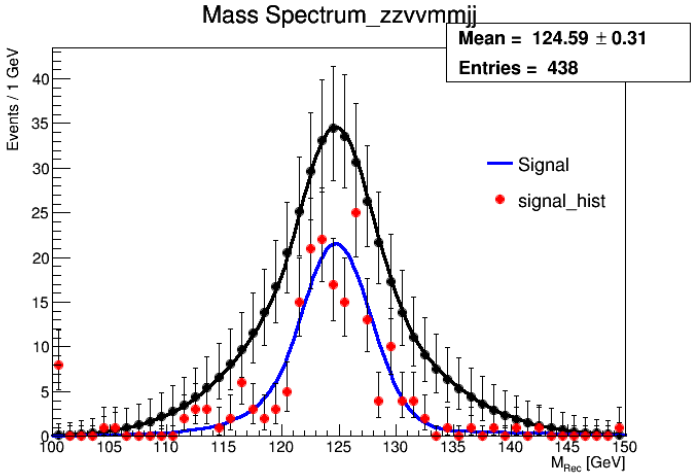

Signal_wwnn4q_s
RMS = 4.997 ± 0.037
Mean = 125.678 ± 0.053
Entries = 9022
Signal
signal_hist
EDM=0.00007
MinNLL=27082.28902
Events / 1 GeV
M_Rec [GeV]

# ZZ plot

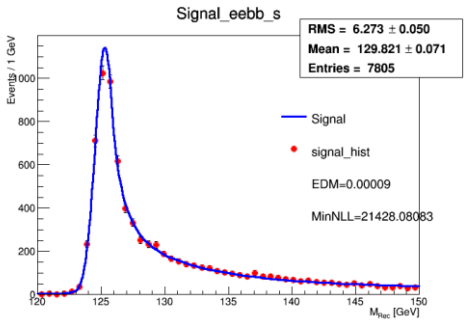
Other ZZ channel are less sensitive, to be continued

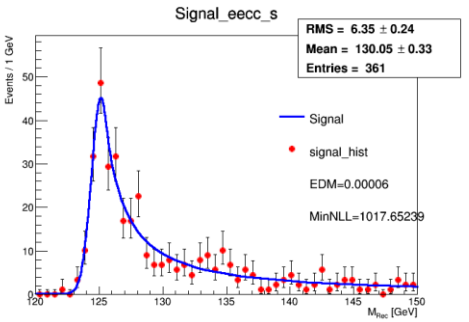


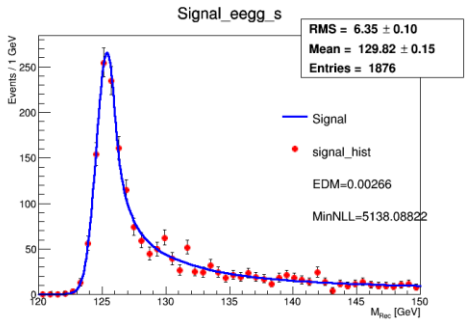



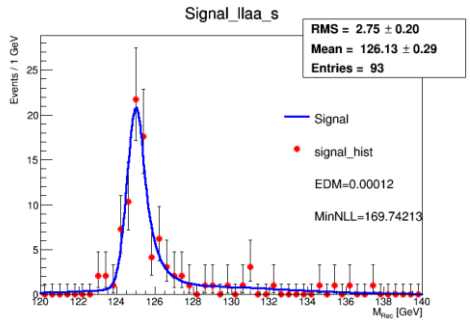



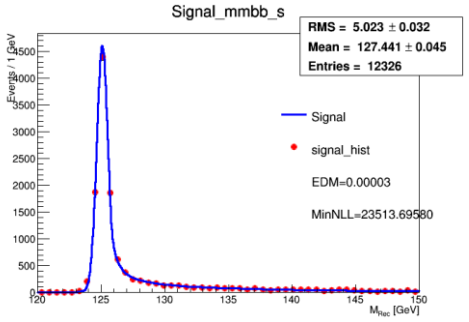
# Signal plot

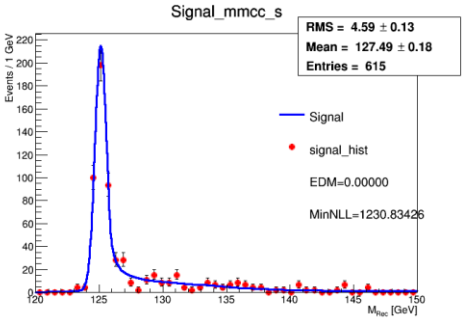

Signal_eebb_s
RMS = 6.273 ± 0.050
Mean = 129.821 ± 0.071
Entries = 7805
Signal
signal_hist
EDM=0.00009
MinNLL=21428.08083
Events / 1 GeV
$M_{Rec}$ [GeV]

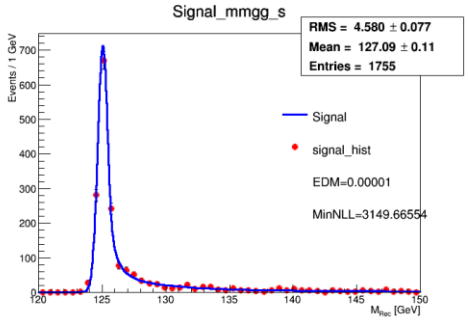

Signal_eecc_s
RMS = 6.35 ± 0.24
Mean = 130.05 ± 0.33
Entries = 361
Signal
signal_hist
EDM=0.00006
MinNLL=1017.65239
Events / 1 GeV
$M_{Rec}$ [GeV]

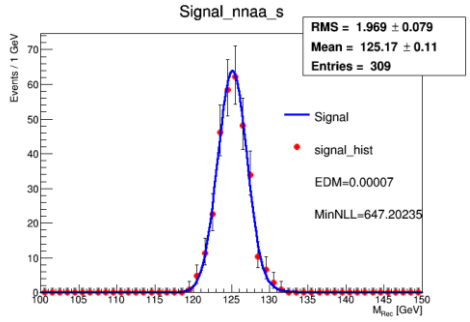

Signal_eegg_s
RMS = 6.35 ± 0.10
Mean = 129.82 ± 0.15
Entries = 1876
Signal
signal_hist
EDM=0.00266
MinNLL=5138.08822
Events / 1 GeV
$M_{Rec}$ [GeV]

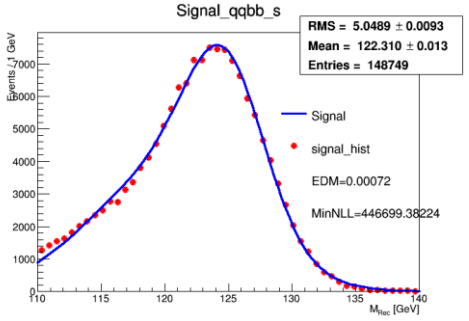

Signal_llaa_s
RMS = 2.75 ± 0.20
Mean = 126.13 ± 0.29
Entries = 93
Signal
signal_hist
EDM=0.00012
MinNLL=169.74213
Events / 1 GeV
$M_{Rec}$ [GeV]

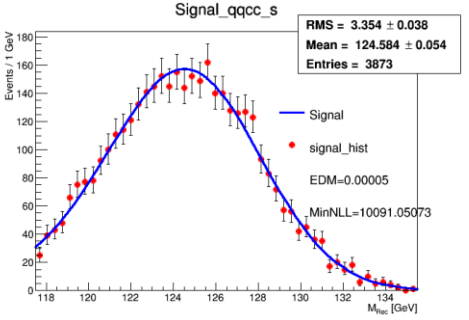

Signal_mmbb_s
RMS = 5.023 ± 0.032
Mean = 127.441 ± 0.045
Entries = 12326
Signal
signal_hist
EDM=0.00003
MinNLL=23513.69580
Events / 1 GeV
$M_{Rec}$ [GeV]

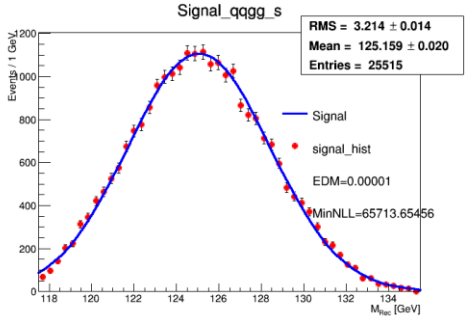

Signal_mmcc_s
RMS = 4.59 ± 0.13
Mean = 127.49 ± 0.18
Entries = 615
Signal
signal_hist
EDM=0.00000
MinNLL=1230.83426
Events / 1 GeV
$M_{Rec}$ [GeV]

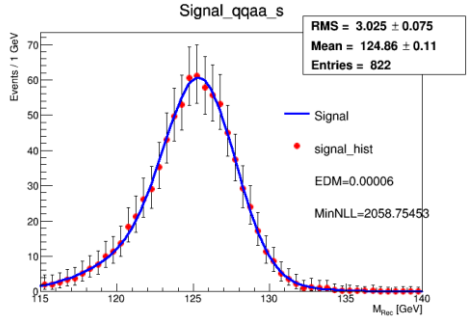

Signal_mmgg_s
RMS = 4.580 ± 0.077
Mean = 127.09 ± 0.11
Entries = 1755
Signal
signal_hist
EDM=0.00001
MinNLL=3149.66554
Events / 1 GeV
$M_{Rec}$ [GeV]


Signal_nnaa_s
RMS = 1.969 ± 0.079
Mean = 125.17 ± 0.11
Entries = 309
Signal
signal_hist
EDM=0.00007
MinNLL=647.20235
Events / 1 GeV
$M_{Rec}$ [GeV]

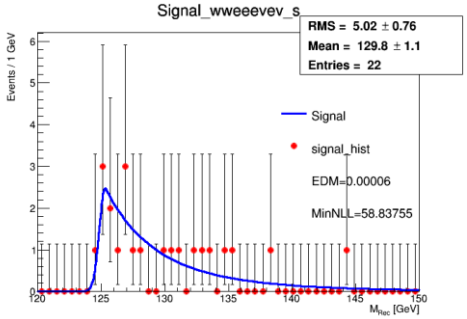

Signal_qqbb_s
RMS = 5.0489 ± 0.0093
Mean = 122.310 ± 0.013
Entries = 148749
Signal
signal_hist
EDM=0.00072
MinNLL=446699.38224
Events / 1 GeV
$M_{Rec}$ [GeV]

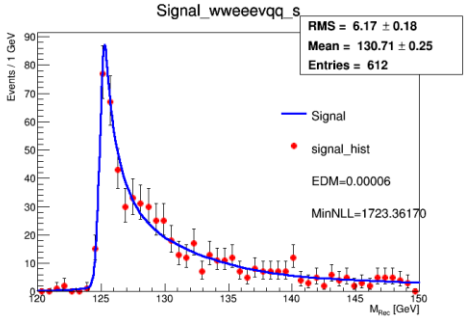

Signal_qqcc_s
RMS = 3.354 ± 0.038
Mean = 124.584 ± 0.054
Entries = 3873
Signal
signal_hist
EDM=0.00005
MinNLL=10091.05073
Events / 1 GeV
$M_{Rec}$ [GeV]

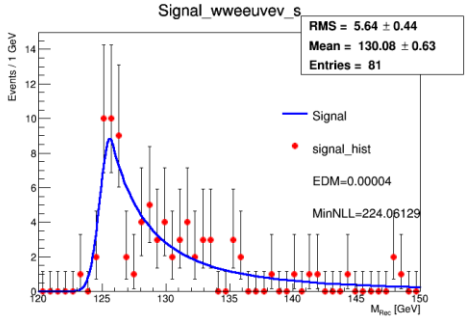

Signal_qqgg_s
RMS = 3.214 ± 0.014
Mean = 125.159 ± 0.020
Entries = 25515
Signal
signal_hist
EDM=0.00001
MinNLL=65713.65456
Events / 1 GeV
$M_{Rec}$ [GeV]

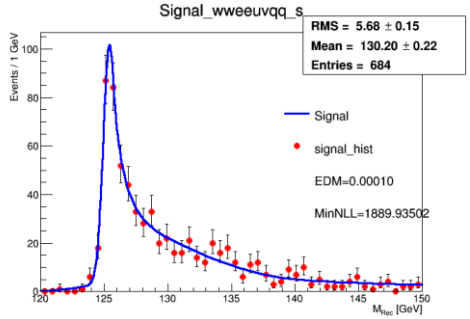

Signal_qqaa_s
RMS = 3.025 ± 0.075
Mean = 124.86 ± 0.11
Entries = 822
Signal
signal_hist
EDM=0.00006
MinNLL=2058.75453
Events / 1 GeV
$M_{Rec}$ [GeV]

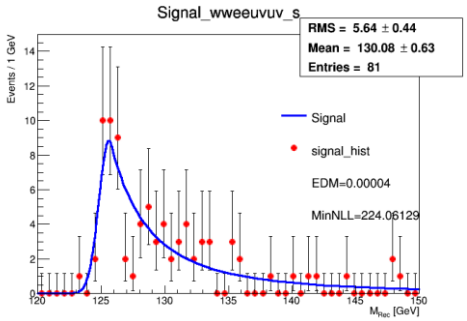
# Signal plot

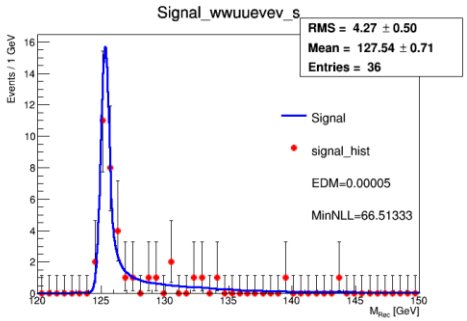

Signal_wweeevev_s
RMS = 5.02 ± 0.76
Mean = 129.8 ± 1.1
Entries = 22
Signal
signal_hist
EDM=0.00006
MinNLL=58.83755
Events / 1 GeV
$M_{Rec}$ [GeV]

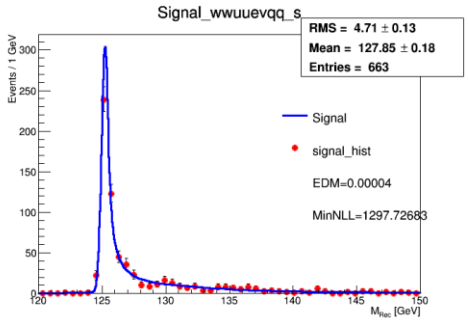

Signal_wweeevqq_s
RMS = 6.17 ± 0.18
Mean = 130.71 ± 0.25
Entries = 612
Signal
signal_hist
EDM=0.00006
MinNLL=1723.36170
Events / 1 GeV
$M_{Rec}$ [GeV]

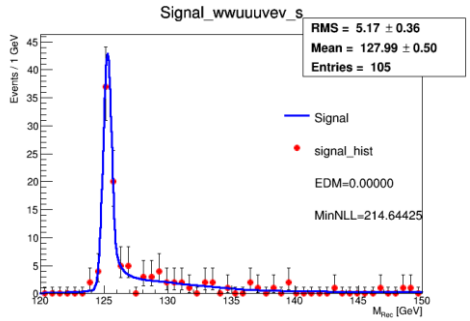

Signal_wweeuvev_s
RMS = 5.64 ± 0.44
Mean = 130.08 ± 0.63
Entries = 81
Signal
signal_hist
EDM=0.00004
MinNLL=224.06129
Events / 1 GeV
$M_{Rec}$ [GeV]

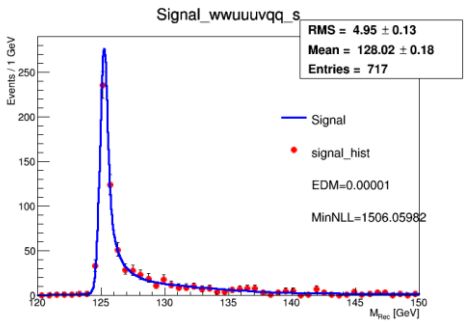

Signal_wweeuvqq_s
RMS = 5.68 ± 0.15
Mean = 130.20 ± 0.22
Entries = 684
Signal
signal_hist
EDM=0.00010
MinNLL=1889.93502
Events / 1 GeV
$M_{Rec}$ [GeV]

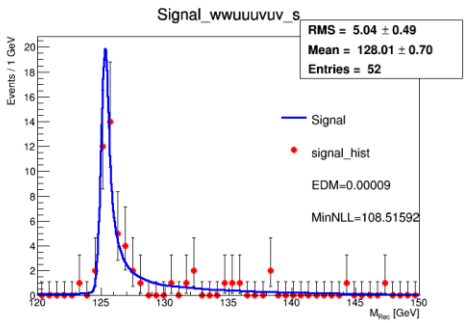

Signal_wweeuvuv_s
RMS = 5.64 ± 0.44
Mean = 130.08 ± 0.63
Entries = 81
Signal
signal_hist
EDM=0.00004
MinNLL=224.06129
Events / 1 GeV
$M_{Rec}$ [GeV]

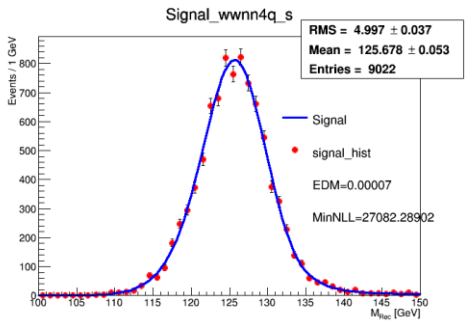

Signal_wwuuevev_s
RMS = 4.27 ± 0.50
Mean = 127.54 ± 0.71
Entries = 36
Signal
signal_hist
EDM=0.00005
MinNLL=66.51333
Events / 1 GeV
$M_{Rec}$ [GeV]


Signal_wwuuevqq_s
RMS = 4.71 ± 0.13
Mean = 127.85 ± 0.18
Entries = 663
Signal
signal_hist
EDM=0.00004
MinNLL=1297.72683
Events / 1 GeV
$M_{Rec}$ [GeV]

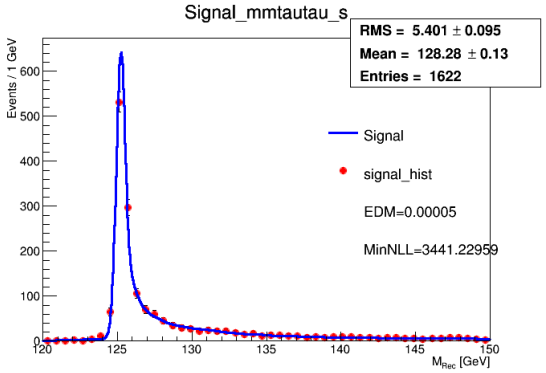

Signal_wwuuuvev_s
RMS = 5.17 ± 0.36
Mean = 127.99 ± 0.50
Entries = 105
Signal
signal_hist
EDM=0.00000
MinNLL=214.64425
Events / 1 GeV
$M_{Rec}$ [GeV]

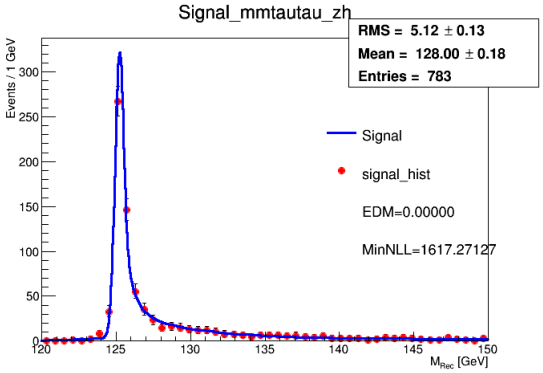

Signal_wwuuuvqq_s
RMS = 4.95 ± 0.13
Mean = 128.02 ± 0.18
Entries = 717
Signal
signal_hist
EDM=0.00001
MinNLL=1506.05982
Events / 1 GeV
$M_{Rec}$ [GeV]

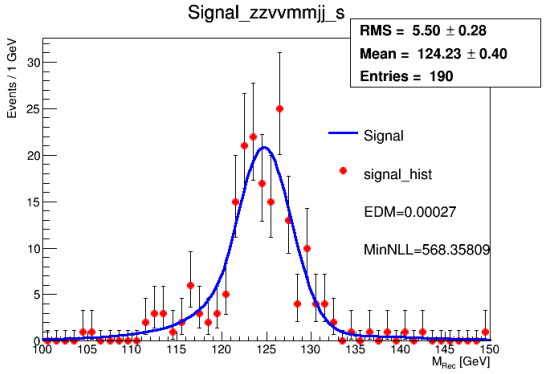

Signal_wwuuuvuv_s
RMS = 5.04 ± 0.49
Mean = 128.01 ± 0.70
Entries = 52
Signal
signal_hist
EDM=0.00009
MinNLL=108.51592
Events / 1 GeV
$M_{Rec}$ [GeV]

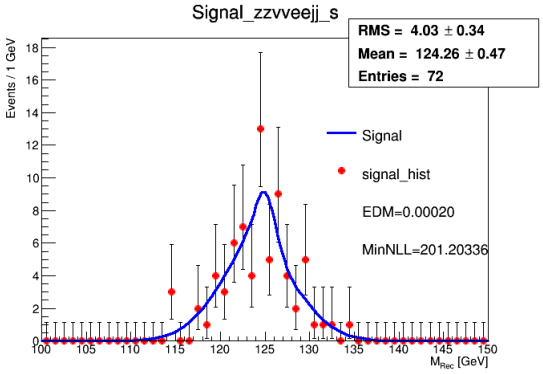

Signal_wwnn4q_s
RMS = 4.997 ± 0.037
Mean = 125.678 ± 0.053
Entries = 9022
Signal
signal_hist
EDM=0.00007
MinNLL=27082.28902
Events / 1 GeV
$M_{Rec}$ [GeV]

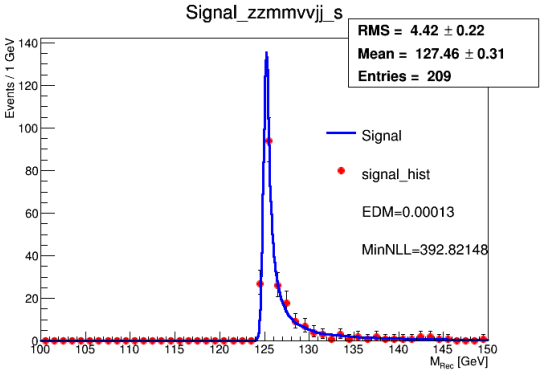
# Signal plot

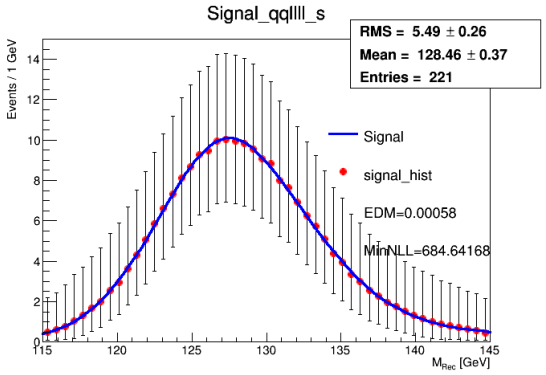

Signal_mmtautau_s
RMS = 5.401 ± 0.095
Mean = 128.28 ± 0.13
Entries = 1622
Signal
signal_hist
EDM=0.00005
MinNLL=3441.22959
Events / 1 GeV
M_Rec [GeV]

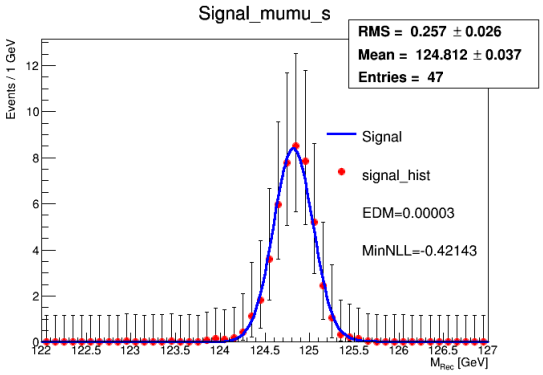

Signal_mmtautau_zh
RMS = 5.12 ± 0.13
Mean = 128.00 ± 0.18
Entries = 783
Signal
signal_hist
EDM=0.00000
MinNLL=1617.27127
Events / 1 GeV
M_Rec [GeV]


Signal_zzvvmmjj_s
RMS = 5.50 ± 0.28
Mean = 124.23 ± 0.40
Entries = 190
Signal
signal_hist
EDM=0.00027
MinNLL=568.35809
Events / 1 GeV
M_Rec [GeV]


Signal_zzvveejj_s
RMS = 4.03 ± 0.34
Mean = 124.26 ± 0.47
Entries = 72
Signal
signal_hist
EDM=0.00020
MinNLL=201.20336
Events / 1 GeV
M_Rec [GeV]


Signal_zzmmvvjj_s
RMS = 4.42 ± 0.22
Mean = 127.46 ± 0.31
Entries = 209
Signal
signal_hist
EDM=0.00013
MinNLL=392.82148
Events / 1 GeV
M_Rec [GeV]


Signal_qqllll_s
RMS = 5.49 ± 0.26
Mean = 128.46 ± 0.37
Entries = 221
Signal
signal_hist
EDM=0.00058
MinNLL=684.64168
Events / 1 GeV
M_Rec [GeV]


Signal_mumu_s
RMS = 0.257 ± 0.026
Mean = 124.812 ± 0.037
Entries = 47
Signal
signal_hist
EDM=0.00003
MinNLL=-0.42143
Events / 1 GeV
M_Rec [GeV]