Combination for dihiggs searching with two different final states of bbbb and bbyy
[Statistcal interpretation]

Introduction

- Two analyses are ongoing in parallel for searching dihiggs production with different final states of
  - bbbb
  - bbyy
- The search results could be interpreted as non-resonance or resonance
- Our goal is to combine the search results of these two analyses
  - A first try will be on the interpretation for the resonance
- Combination strategy:
  - Construct a binned Likelihood function
  - Include ~32 bins on the invariant mass spectrum from bbbb analysis
  - Include ~2 bins for event counting separately in signal and background regions from bbyy analysis

Construction of the binned likelihood

- As usual, we consider that the event yields in each bin follow Poisson distributions
  - with the expected value from MC/data-driven (S+B)
  - and the random value from the measured data

$$\prod_{b \in \text{bins}} \text{Pois}(n_b | \mu \nu_b^{\text{sig}} + \nu_b^{\text{bkg}})$$

measured data

expected signal and bkgs

signal strength POI

- POI is our signal strength *mu*
- All the systematic uncertainties are considered as nuisance parameters encapsulated in $\boldsymbol{\nu}^{\text{sig/bkg}}$

Systematic uncertainties (nuisance)

- Nuisance parameters are introduced into the expectation $\boldsymbol{\nu}^{\text{sig/bkg}}$ to take into account systematic uncertainties
- For example, concerning systematic sources (indexed by p), they modify the nominal $\boldsymbol{\nu}^{\text{sig/bkg}}$ expectation by a factor of

$$\eta_s(\boldsymbol{\alpha}) = \prod_{p \in \text{Syst}} I_{\text{exp.}}(\alpha_p; 1, \eta_{sp}^+, \eta_{sp}^-)$$

Nuisance parameter

$$I_{\text{exp.}}(\alpha; I^0, I^+, I^-) = \begin{cases} (I^+/I_0)^{\alpha} & \alpha \geq 0 \\ (I^-/I_0)^{-\alpha} & \alpha < 0 \end{cases}$$

- Many options are available for **interpolation**
- We choose **piecewise exponential interpolation**
  - Simple and keeps η above zero
- All nuisance parameters are constrained by gaussian or poisson distributions

Statistical Model (SM)

- Consider everything discussed by now, our SM is

$$\mathcal{P}(n_{cb}, a_p \mid \phi_p, \alpha_p, \gamma_b) =$$

$$\prod_{c \in \text{channels}} \prod_{b \in \text{bins}} \text{Pois}(n_{cb}|\nu_{cb}) \cdot G(L_0|\lambda, \Delta_L) \cdot \prod_{p \in \mathbb{S}+\mathbf{\Gamma}} f_p(a_p|\alpha_p)$$

- *c*: channels (like bbbb_ch1, bbbb_ch2, bbyy_sr, bbyy_cr)
- *b*: bins
- *Pois*: the Poissonian term (expectation ***v***, random value ***n***)
- *G*: the Gaussian constraint on the nuisance *lambda* for lumi
  - L_0 the measured value
  - *DeltaL* is the uncertainty
- *F*: the constraints on nuisance parameters for other systematics

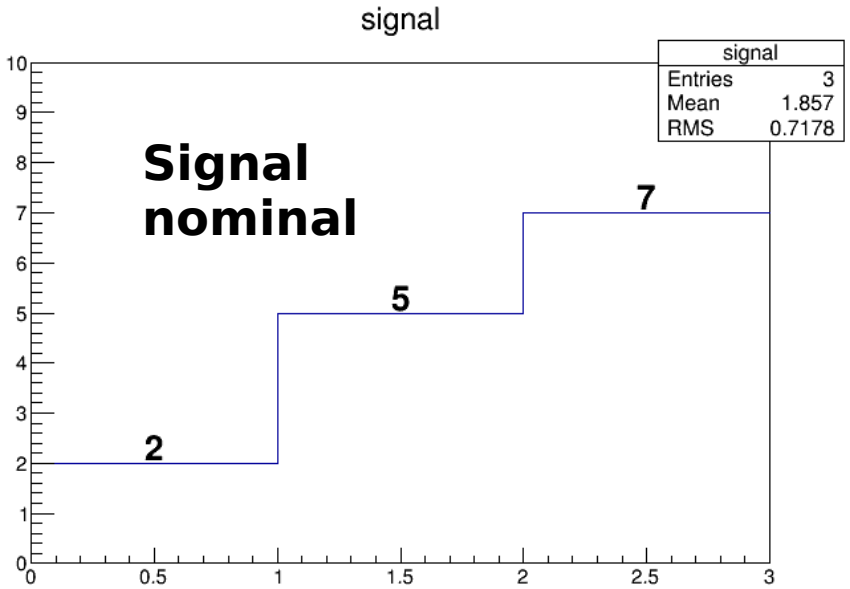
Realization

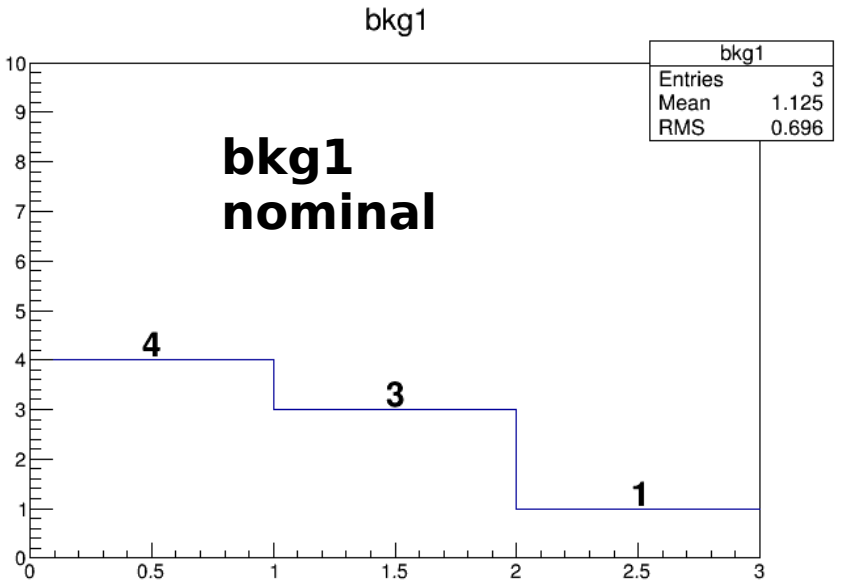
- To realize our statistical model, we use roofit and roostats packages
- We need the inputs from the two analysis groups
  - both provide workspaces produced by an official tool HistFactory
  - both use the unified naming scheme for the names of the parameters (nuisance, POI, global observable)
- The combination machinery is in place
- Before the real inputs ready from the two groups, I made a toy model to validate the newly-made combination tool

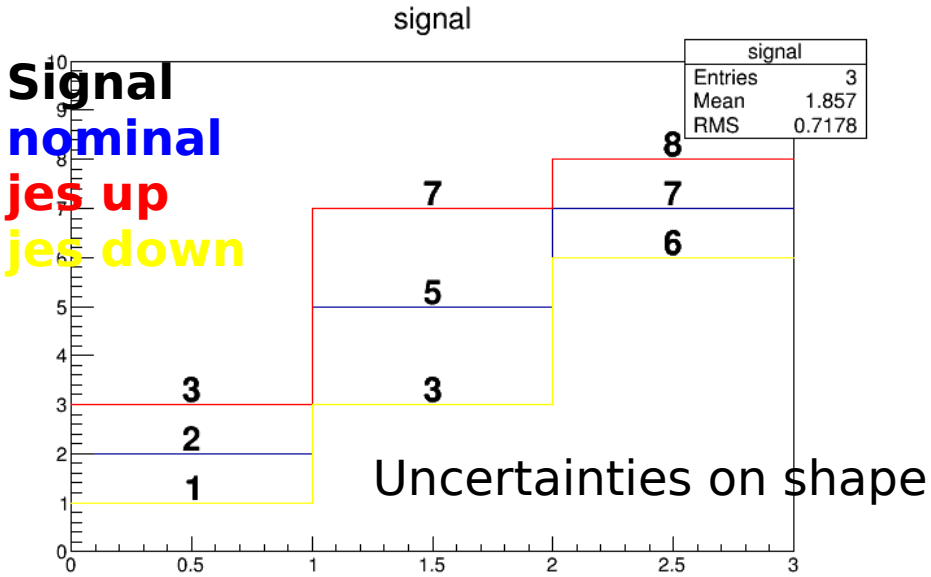
The toy model

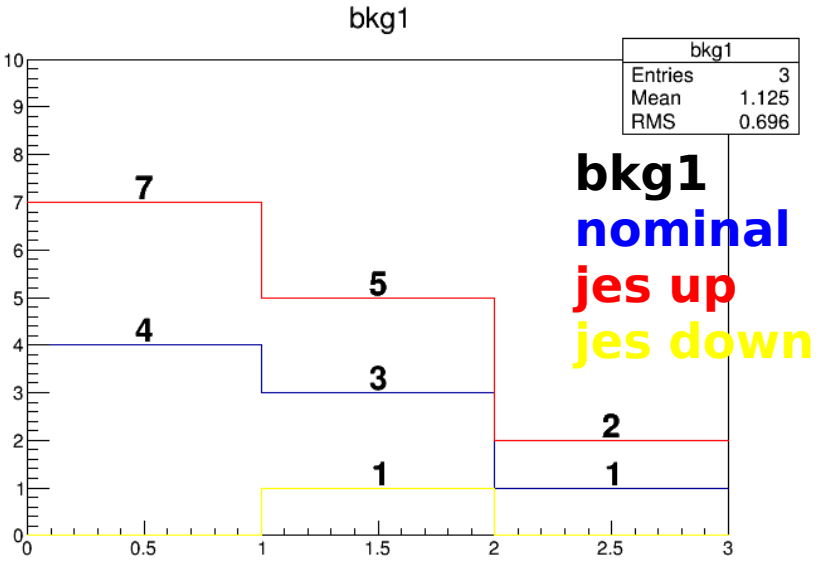
- Toy model is made from
  - bbbb-toy
  - bbyy-toy
- In both toys, there are signal and bkg1 affected by two systematic uncertainties from
  - lumi 0.018
  - jes (component-dependent)
- I will introduce bbbb/bbyy-toy one after the other
  - Show the fitting results for each standalone
  - Show the fitting results for combination

bbbb-toy (histogram templates)







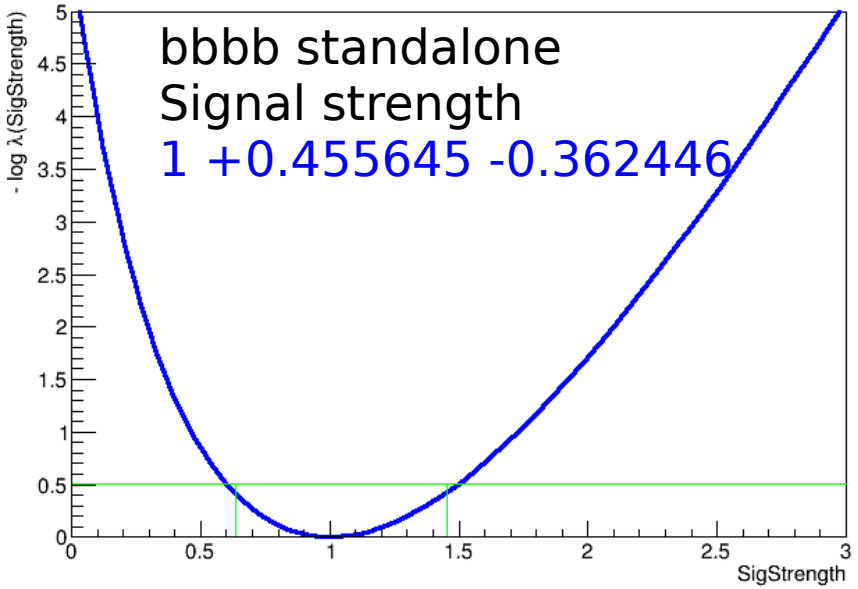


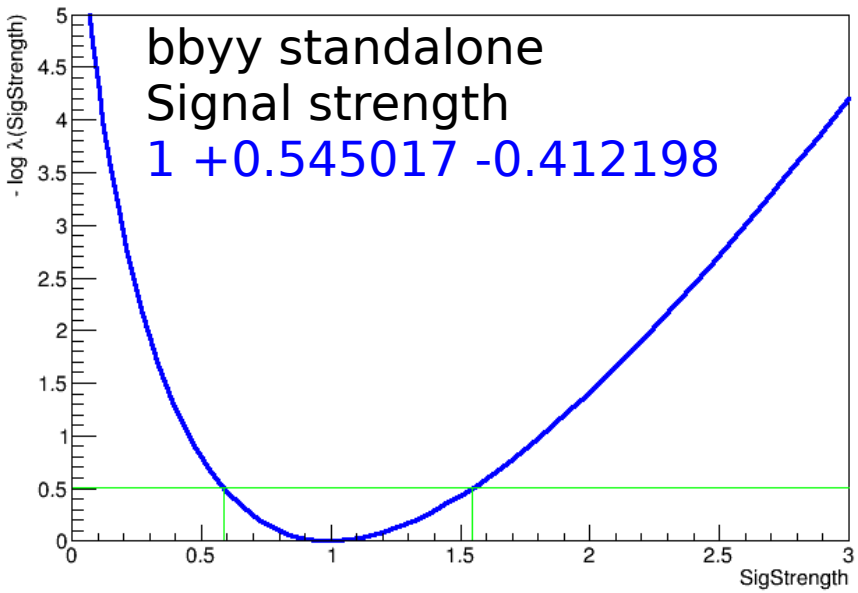
bbyy-toy (simple counting)

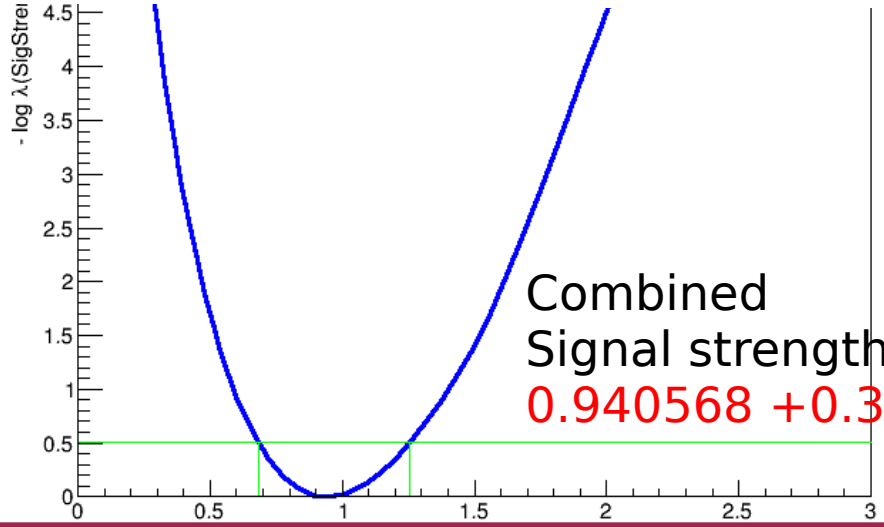
- signal (nominal) = 5.2 (jes) +-5%
- bkg1 (nominal) = 0.8 (jes) +- 8%
- Only rate uncertainties are considered in this model

Fit to the expectations

- By implementing a profile likelihood fit, we can extract the signal
- Standalone fit with bbbb-toy, bbyy-toy and their combination

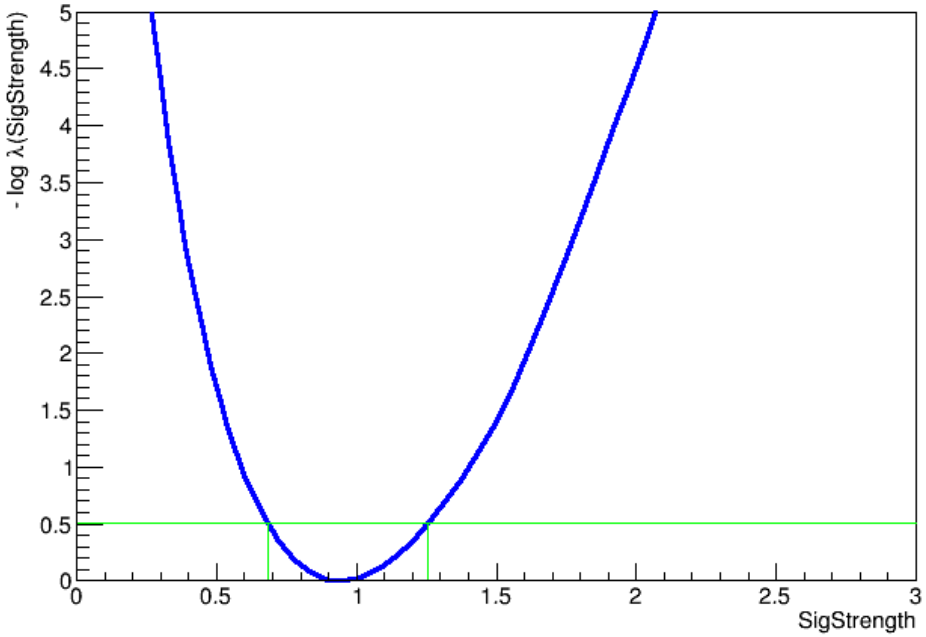




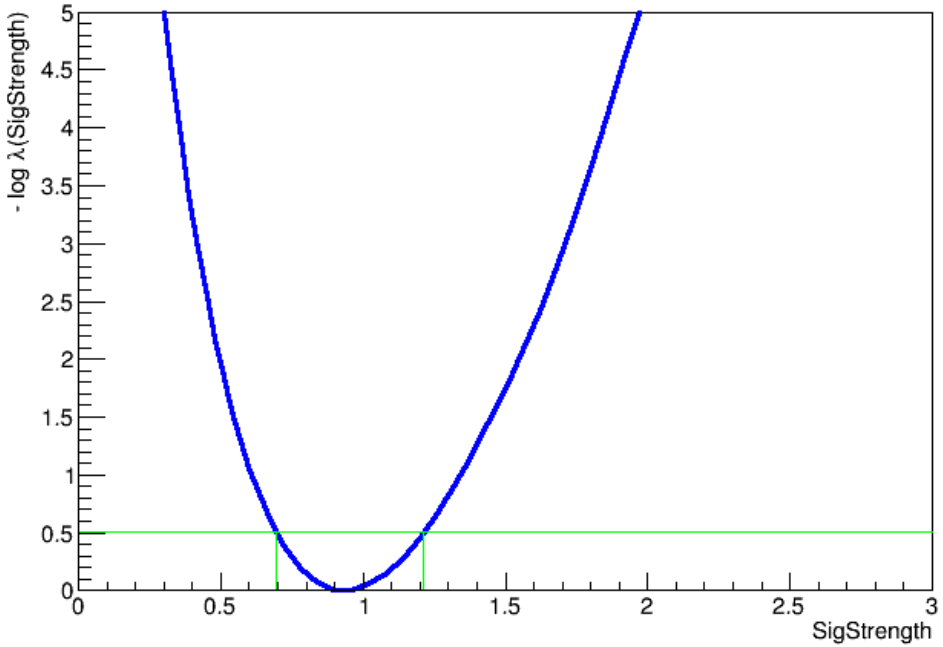


Correlations?

- In bbbb and bbyy, the jes/lumi uncertainties are 100% correlated
- We should correlate them in the combination!!!



Combined (no jes correlation)
Signal strength
0.940568 +0.314423 -0.258715



Combined (with jes correlated)
Signal strength
0.932028 +0.280914 -0.236857

Checks on nuisance parameters

- bbbb standalone
- Floating Parameter FinalValue +/- Error
- ---------- ----------
- Lumi 1.0000e+00 +/- 1.79e-02
- SigStrength 1.0000e+00 +/- 4.01e-01
- alpha_jes 2.7311e-12 +/- 1.88e-01

- bbyy standalone
- Floating Parameter FinalValue +/- Error
- ---------- ----------
- Lumi 1.0000e+00 +/- 1.80e-02
- SigStrength 1.0000e+00 +/- 4.67e-01
- alpha_jes 0.0000e+00 +/- 9.93e-01

- Combination without correlations
- Floating Parameter FinalValue +/- Error
- ---------- ----------
- Lumi 1.0000e+00 +/- 1.27e-02
- SigStrength 9.4057e-01 +/- 2.82e-01
- alpha_jes_a0 -7.7821e-02 +/- 8.76e-01
- alpha_jes_a1 1.6363e-02 +/- 9.88e-01
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- Combination with correlations
- Floating Parameter FinalValue +/- Error
- ---------- ----------
- Lumi 1.0000e+00 +/- 1.27e-02
- SigStrength 9.3203e-01 +/- 2.56e-01
- alpha_jes -3.6658e-02 +/- 6.75e-01
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Conclusions

- The combination machinery is in place
- Basically, the machinery can run within expectations (uncertainties are smaller after combination)
- Correlations are considered and realized

- Need to find out why the combination has a bias
- Need to connect to limit setting (already started)
- After Xmas vacation, contact two analysis groups to converge the mass points and models as soon as possible
- Possibly make another toy model that is more like a mass spectrum to test the machinery