



# Uncertainties in Heavy-Ion Colliders

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# Uncertainties in heavy-ion collider results



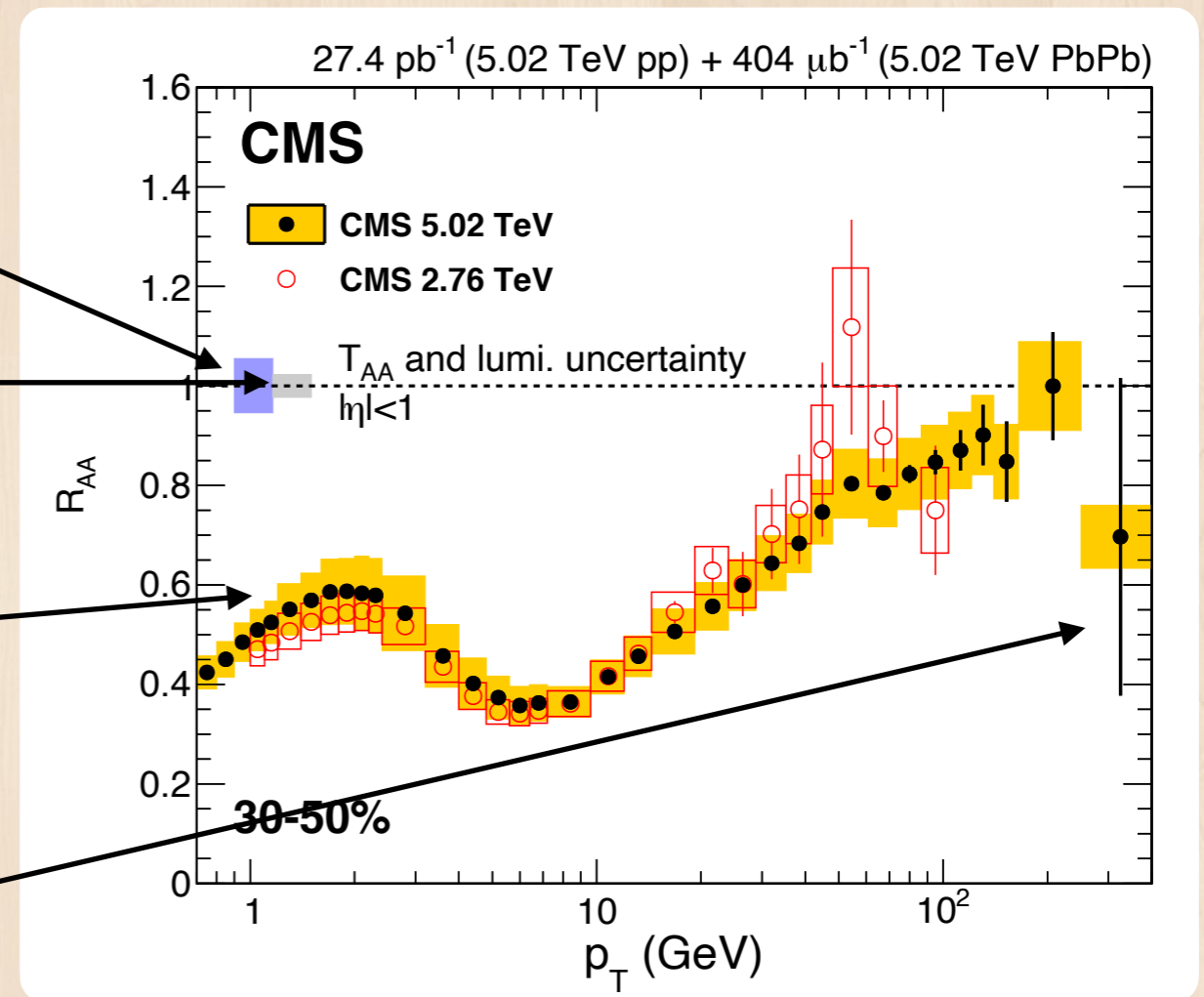
# Typical example in HI

$T_{AA}$

Luminosity

Other Systematic Uncertainties

Statistical Uncertainty



Usually there is a “**catch-all**” with little information  
We don't have too much beyond these error bands



# Precision is the key

- The measurements are only as useful as the uncertainties
- Depending on the target precision (direction of change? 10% effect? 1% effect? 0.1% effect?), the way we report things can make a big difference
  - Importance growing as we collect more data

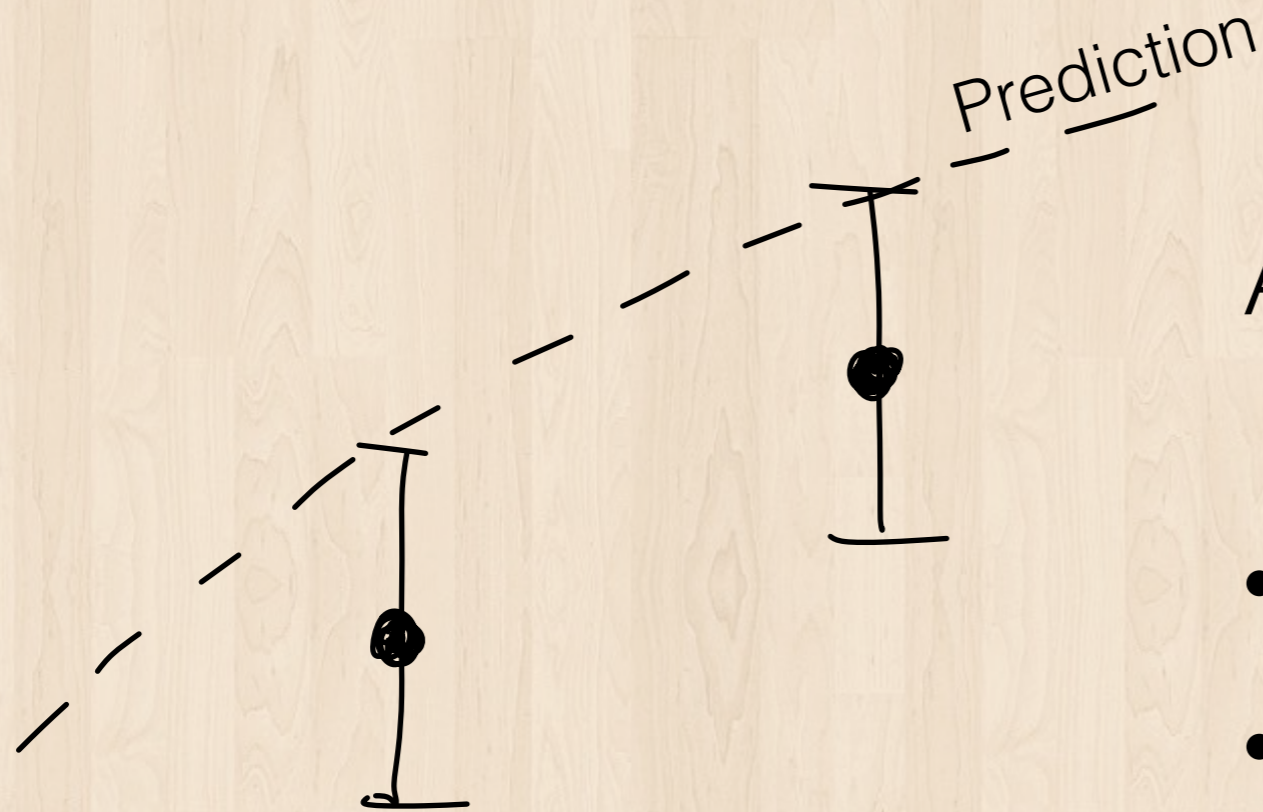


# How to do better?

\* Not an exhaustive list



# Correlations



Correlation is important!

Agreement depends on uncertainty correlation

- Fully Correlated:  $1\sigma$
- Non-correlated:  $2\sigma$
- Anti-correlated:  $>2\sigma$

**Correlation** and **direction** of the correlation are very important information



# Shape of the uncertainties

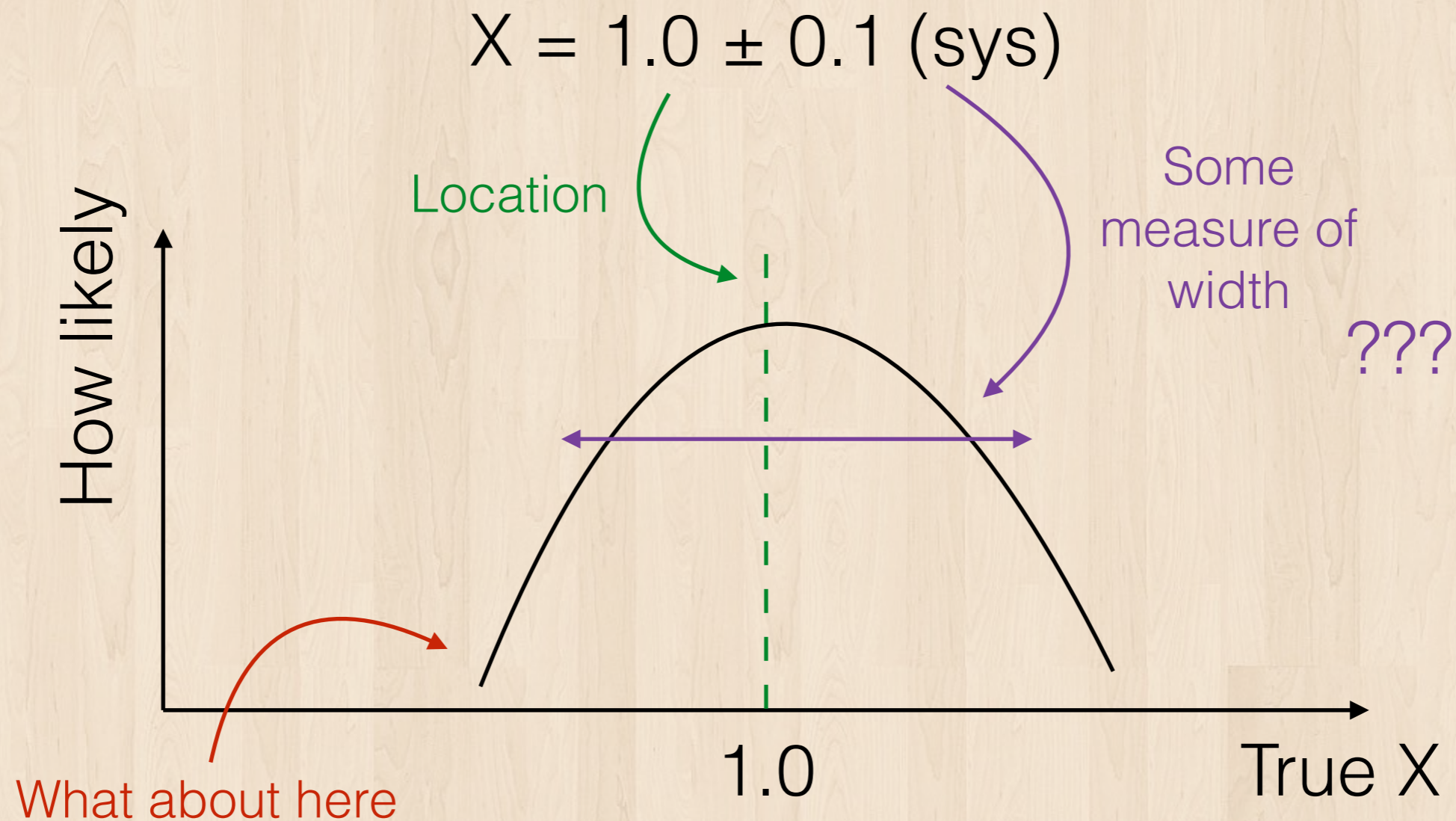
What does this really mean in HI measurements?

$$X = 1.0 \pm 0.1 \text{ (sys)}$$



# Shape of the uncertainties

What does this really mean in HI measurements?





# Shape of the uncertainties

- There is a lot of ambiguities in what we mean by “width” from measurement to measurement
- Usually it is a combined quantity from ~a dozen different systematic sources
  - Each systematic source may not be Gaussian themselves → cross talk opportunity
- Contracting all these information into just one number forces people to make assumptions (Gaussian? Log-normal? Poisson? ...)
- It's very important in comparisons (Exp:  $1.0 \pm 0.1$ , Th: 1.5)



# Factoring uncertainties

- It would be beneficial to factor out uncertainties that are not unique to certain measurements and report them separately
- For example the  $T_{AA}$  and luminosity that are already ~standard to factor out
- One can go one step further and think about things like uncertainty on jet energy correction from a given experiment
- Allows correlation across measurements

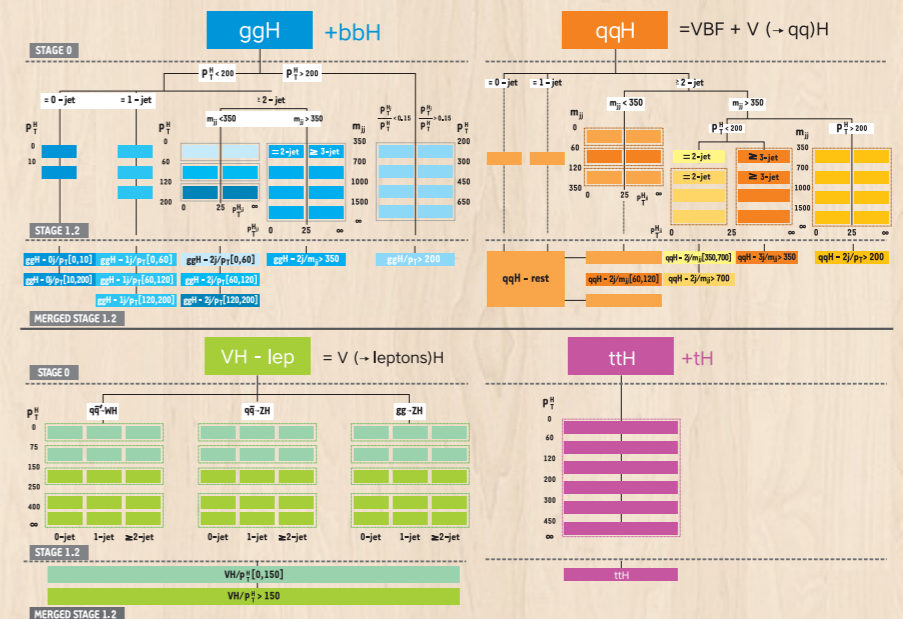


Examples from pp



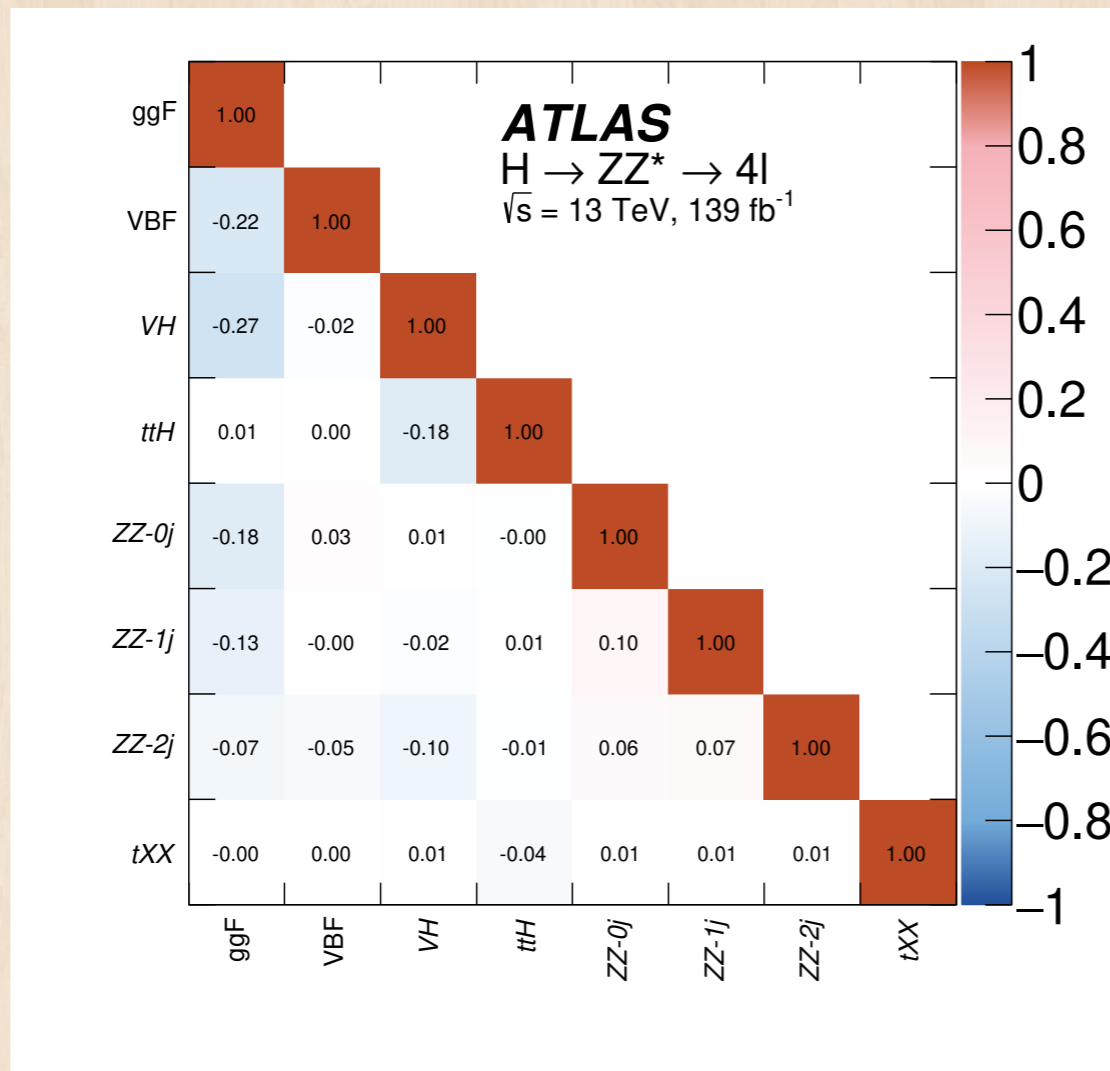
# Example: Higgs

- Recent ATLAS & CMS measurement as an example
- Classify different Higgs events based on event content
  - Measure the contributions from production modes
- Then we can go on to fit for different BSM couplings
  - For example Wilson coefficients for d=6 operators

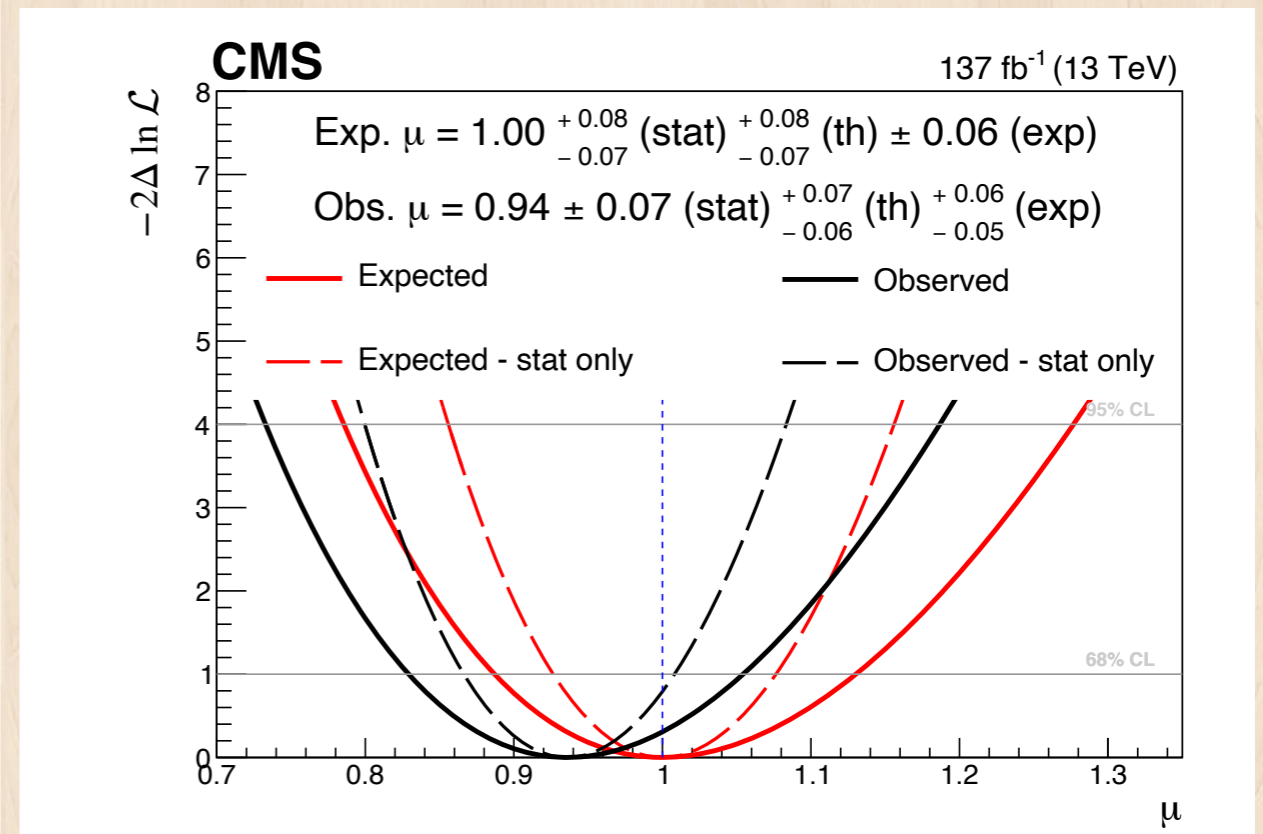




# Example: Higgs



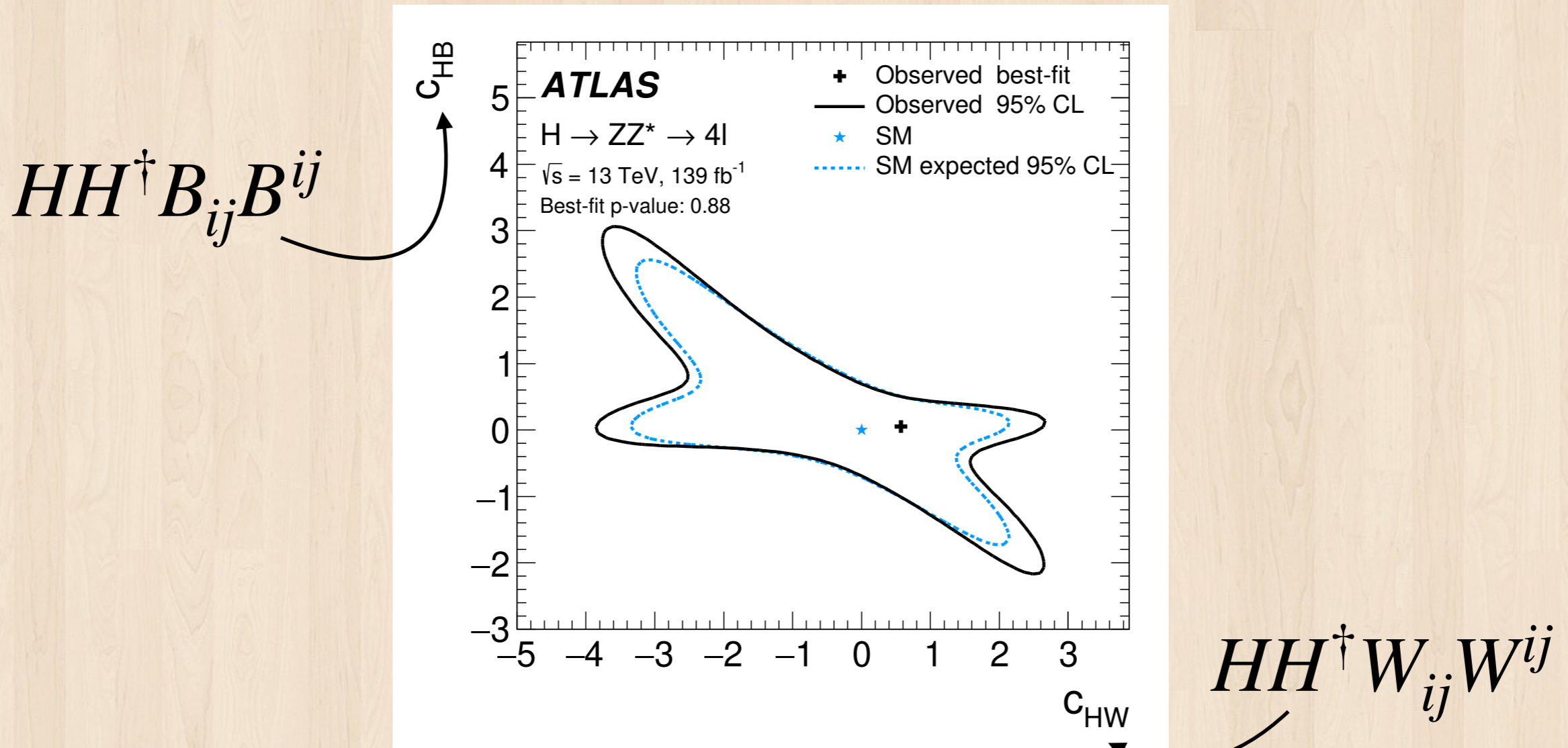
Correlations between measured cross section and ZZ/tXX normalizations



Complete likelihood shape:  
 Statistical vs Stat+Sys



# Example: Higgs

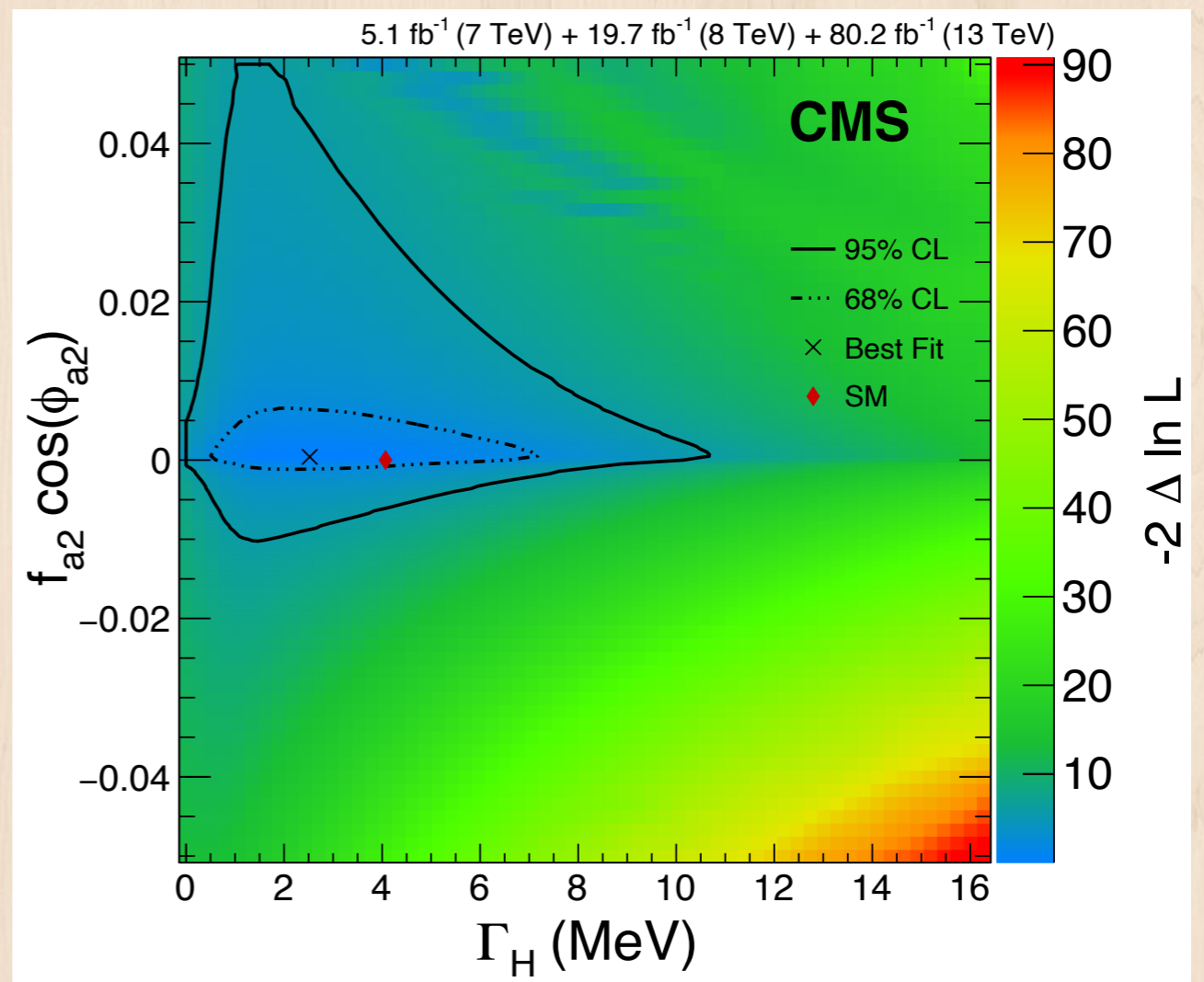
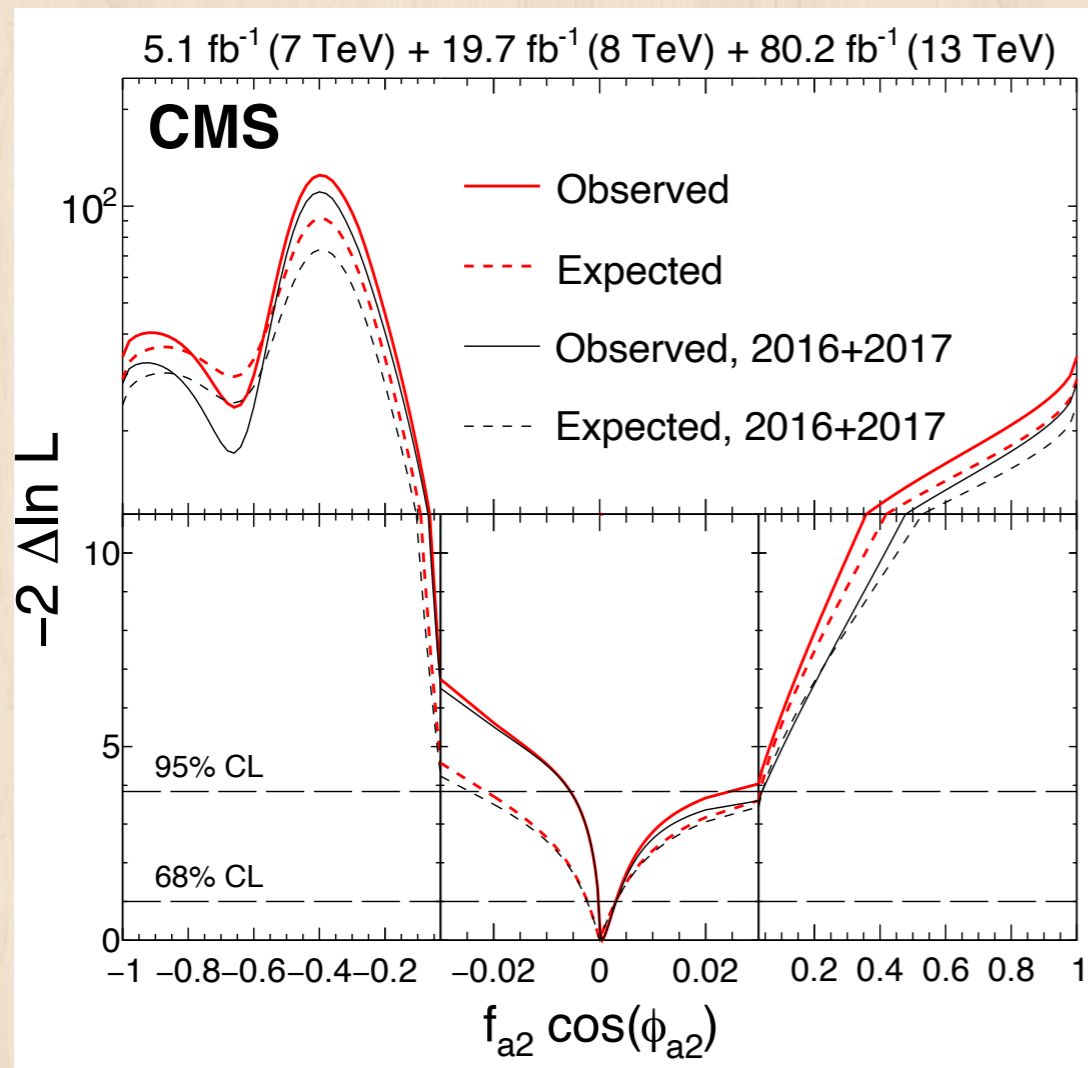


Highly non-trivial correlation between Wilson coefficients



# Example: Higgs again

Measure  $HZ^\mu Z_\mu, HZ^{\mu\nu} Z_{\mu\nu}$  contributions from angular correlations in 4l events (on shell + off shell)

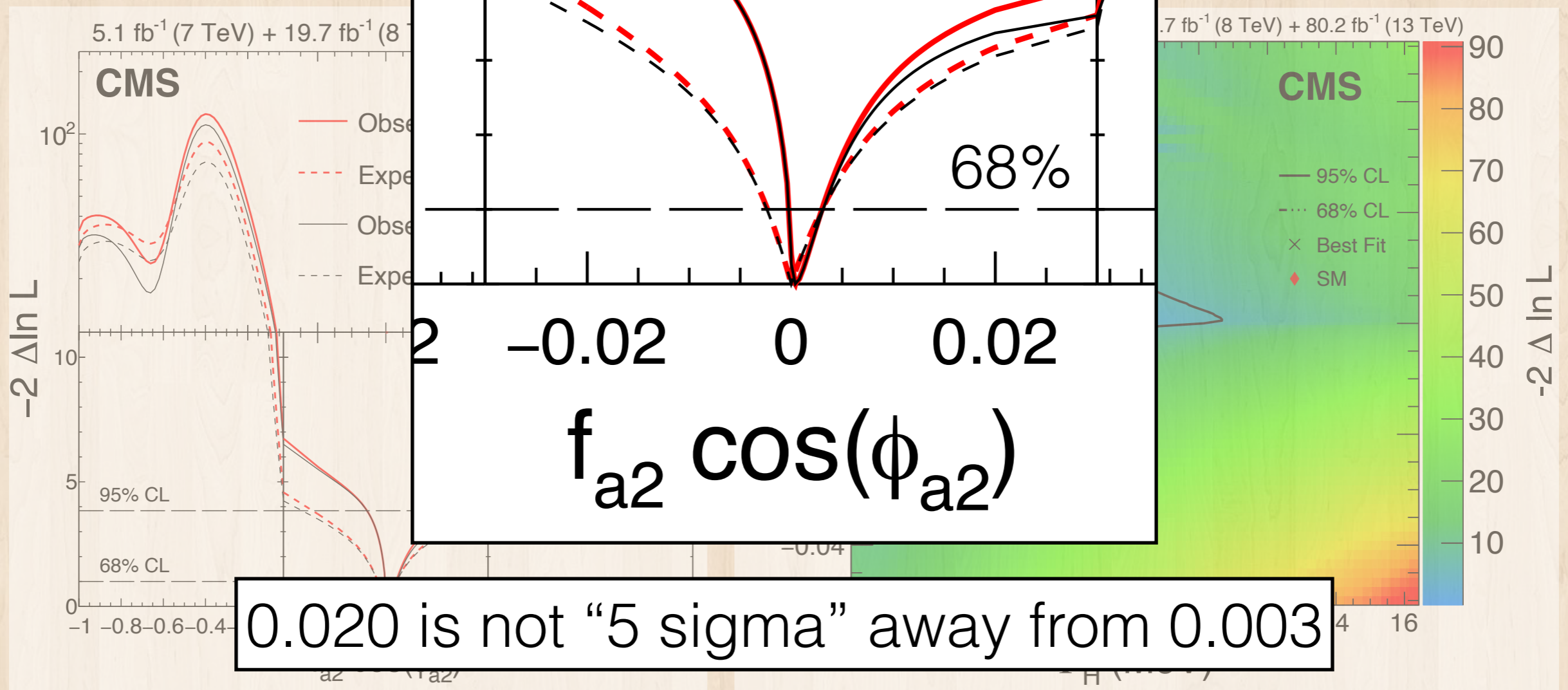


Full likelihood shape reported



# Example: Higgs again

Measure  $HZ^{\mu}Z_{\nu}, HZ^{\mu\nu}Z_{\mu\nu}$  contributions from angular correlations (off shell)



Full likelihood shape reported



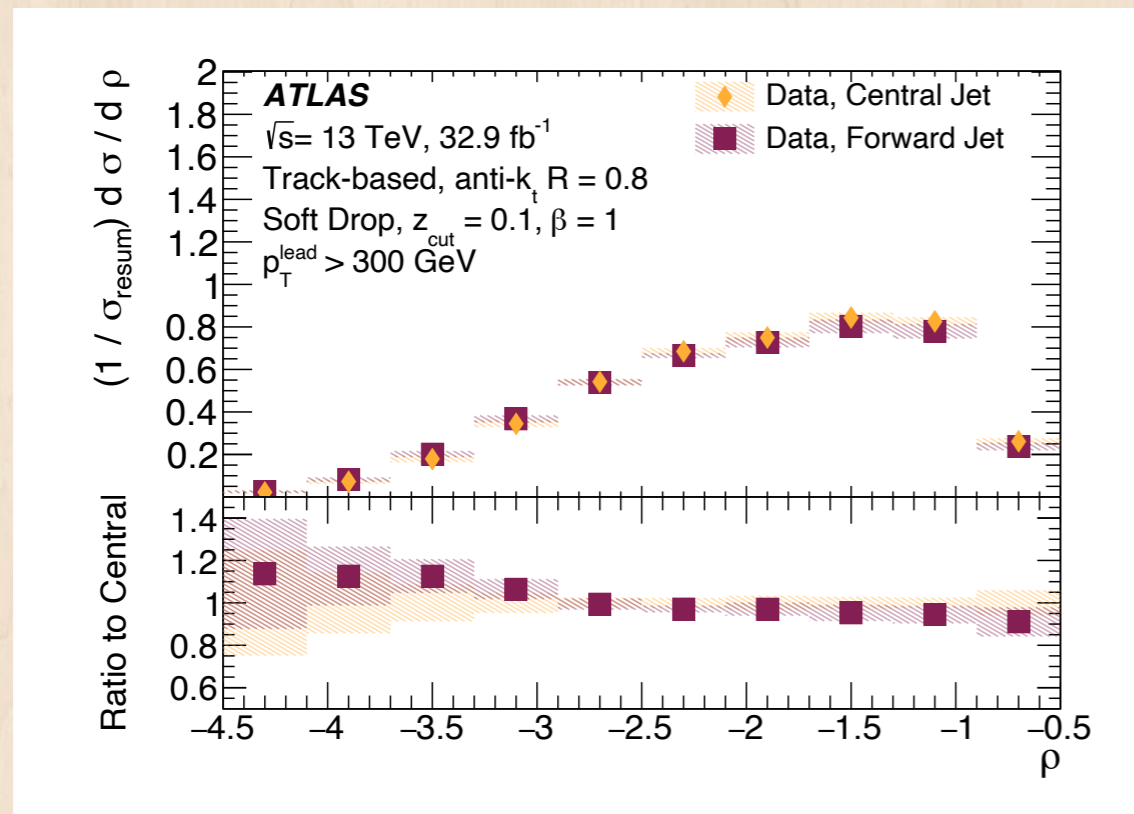
# Another example: jet grooming

- Measure spectra for different (soft drop) grooming settings for anti- $k_T$  jets with  $R = 0.8$  in pp
- $z_g, R_g, \rho (=2 \ln(m_g/p_T))$
- Soft drop settings:  $z_{\text{cut}} = 0.1, \beta = 0, 1, 2$
- Track-based vs calorimeter-based measurements

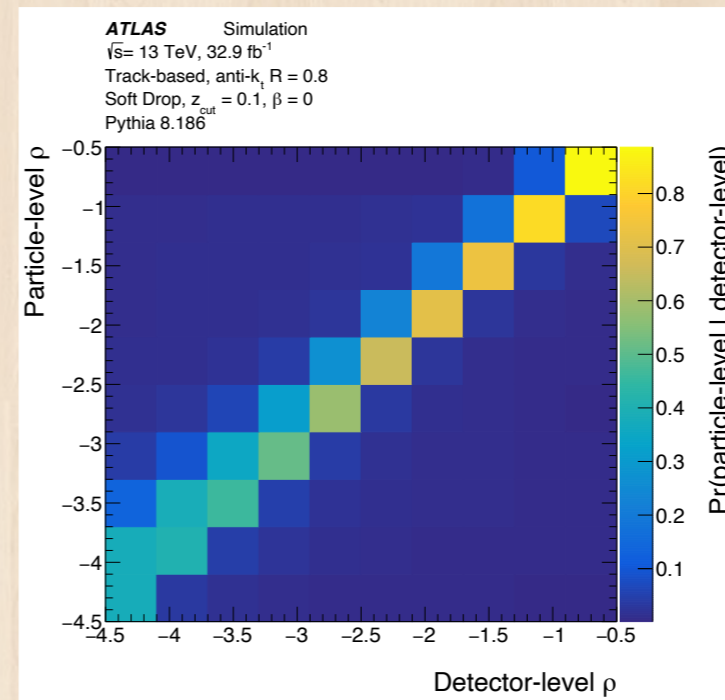


# Jet grooming

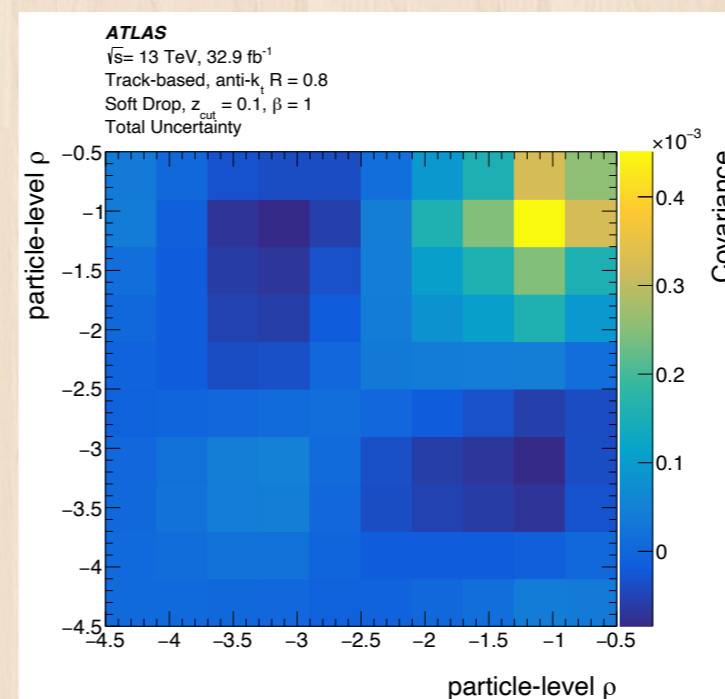
What is provided?



Unfolded result



Response matrix



Total covariance





# Summary



# Summary

- Uncertainty == usefulness of the data
- The better we report our uncertainties, the better our results can be used
  - Correlation of uncertainties
  - Shape of the uncertainties
  - Different sources
  - ...
- Covariance matrix is a good start, but still forces people to make assumptions further away
  - Tail is always important





Backup Slides Ahead

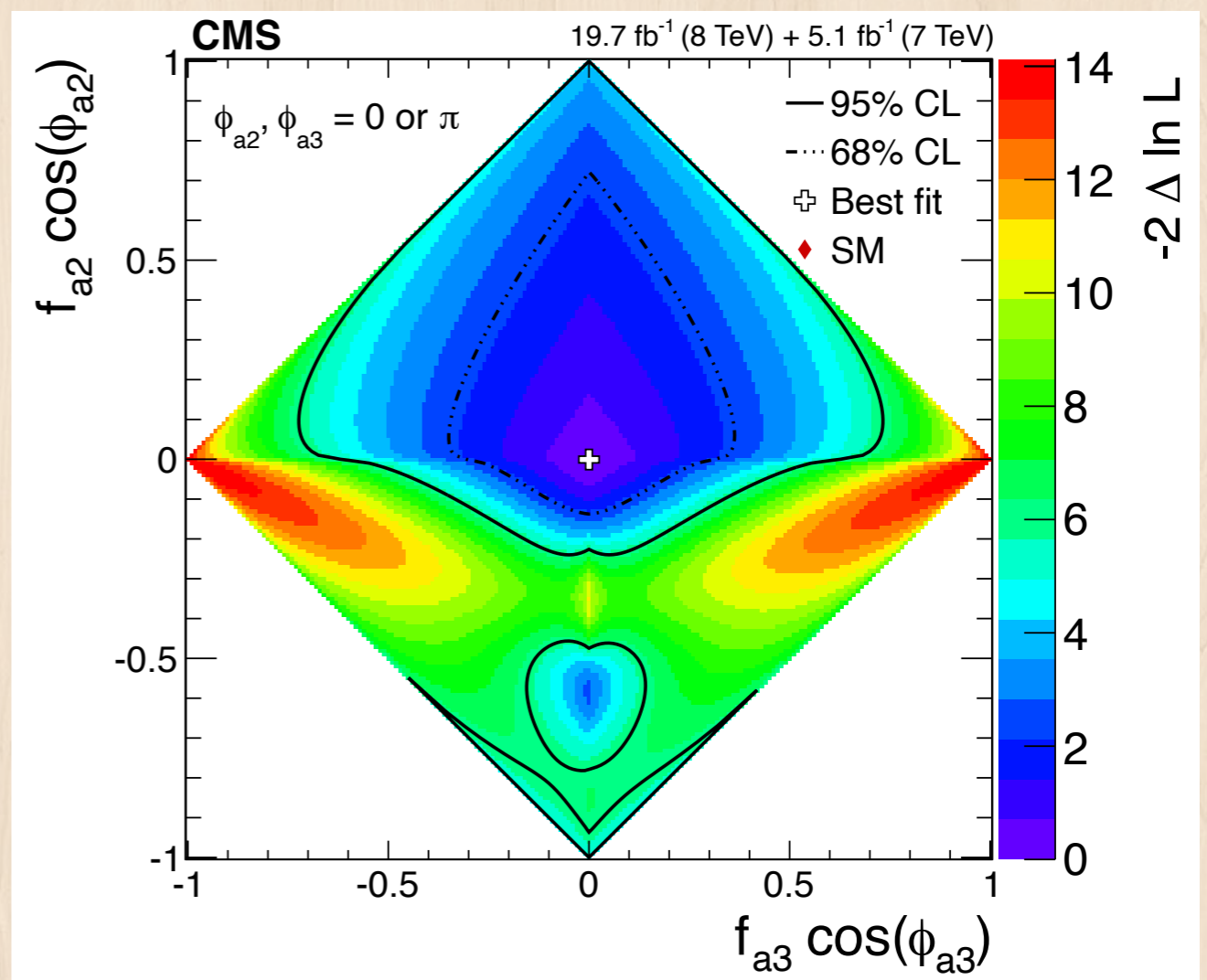
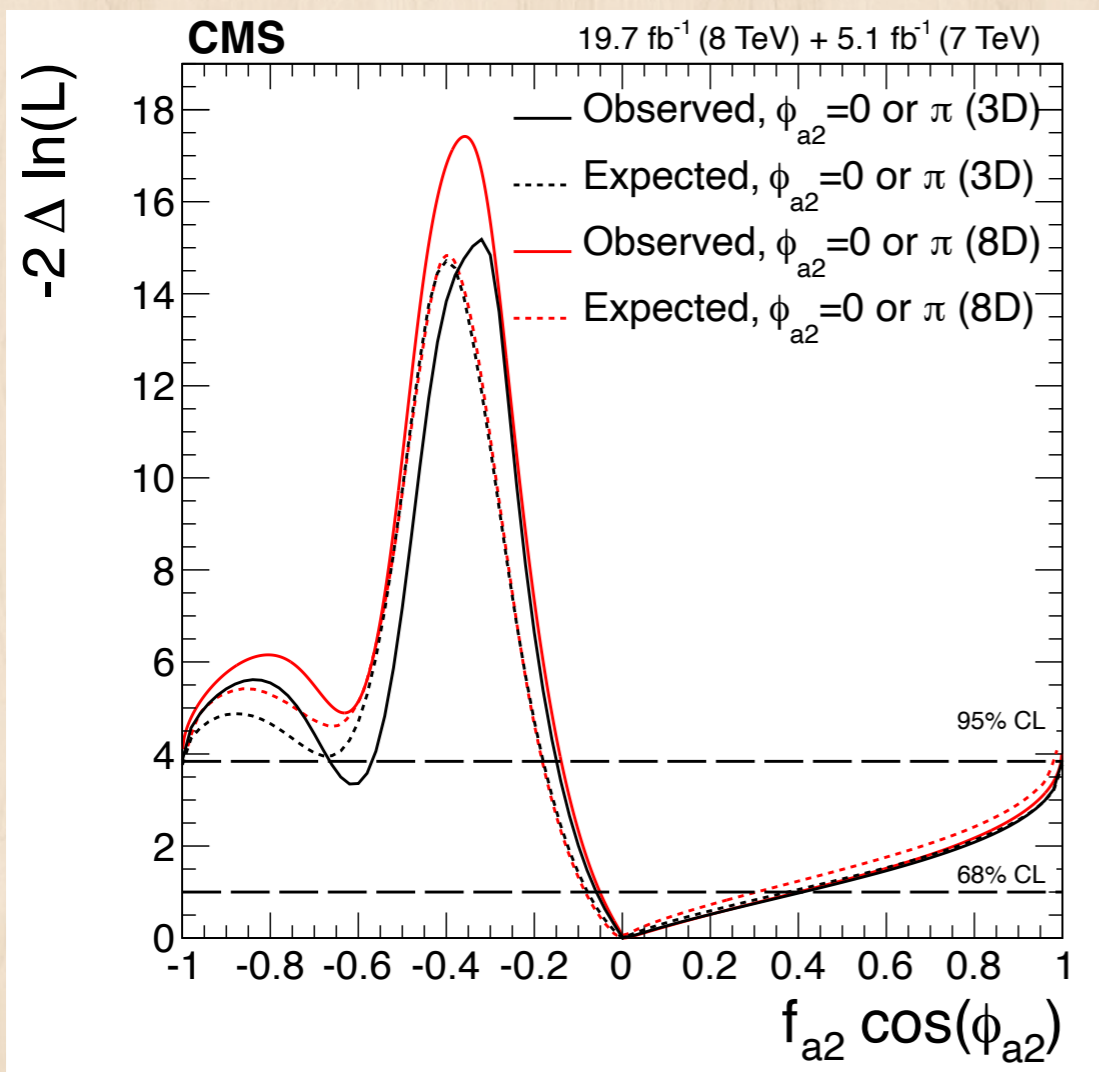






# Example: Higgs back in Run 1

Measure  $HZ^\mu Z_\mu$ ,  $HZ^{\mu\nu} Z_{\mu\nu}$ ,  $H\tilde{Z}^{\mu\nu} Z_{\mu\nu}$  contributions from angular correlations in 4l events



Full likelihood shape reported



# How compatible?

