GammaCombo

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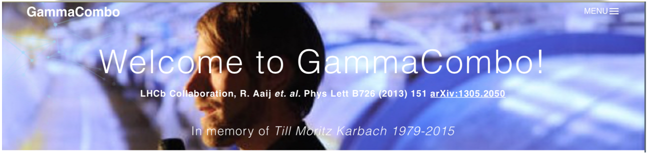
Introduction

- Not designed to be a technical talk
- Just some ideas for you guys to think about as analysts
- Instructions for getting the package are available at:
  http://gammacombo.hepforge.org
- There is an example tutorial
- There are instructions for reproducing standard plots
- There is a quite extensive ($\sim$ 40 pages) users manual here:
  http://gammacombo.hepforge.org/web/HTML/GammaComboManual.pdf

GammaCombo on the web

http://gammacombo.hepforge.org

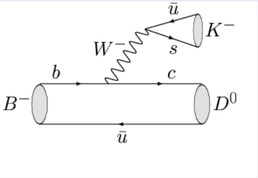


1. Measuring gamma

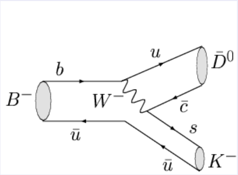
Measuring gamma

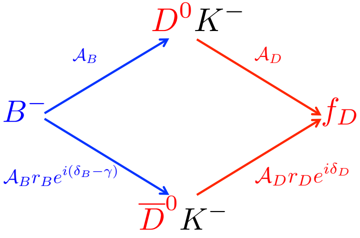
- Look for decays of type $B \to Dh$
- Use the interference between the *favoured* and *suppressed* decays

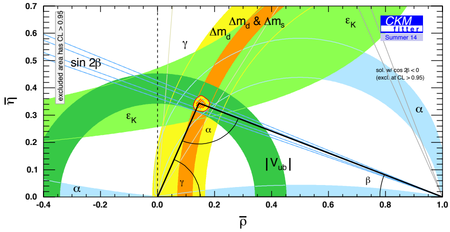
Favoured



Suppressed

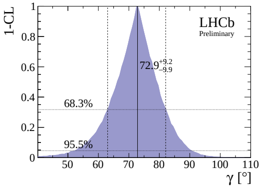


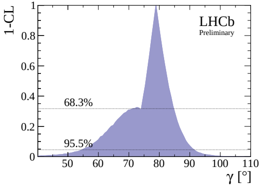




LHCb gamma measurement

- The goal is to provide the physics community with a single measurement of CKM angle from measurements made using LHCb
- Subsequently it is better for us if we have one (Gaussian-ish) number





Current result

$B \to DK$ *(robust)*	$B \to Dh$ *(full)*
$\gamma = 72.9^{+9.2}_{-9.9}$	$78.9^{+5.8}_{-7.4}$ $72.8^{+11.9}_{-1.3}$

Uncertainty on gamma?

Current precision	$\sim 10^{\circ}$
After Run 2	$\sim 3-4^{\circ}$
After Upgrade	$< 1^{\circ}$
Future upgrade	?????
Current indirect (CKM)	$\sim 1-2^{\circ}$
Belle2	$\sim 1-2^{\circ}$

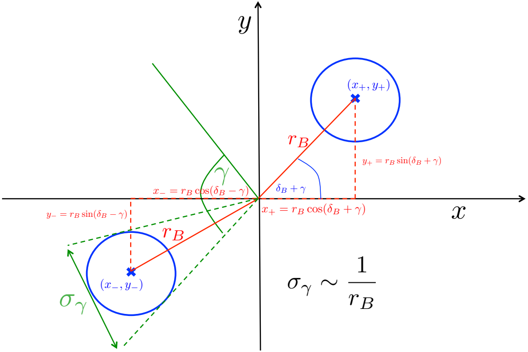
Hard to know without central values of other parameters

Uncertainty on gamma

Something to watch out for

- Adding measurements to a combination *can increase* the uncertainty
- It can be difficult to estimate the error if you don't know the central values

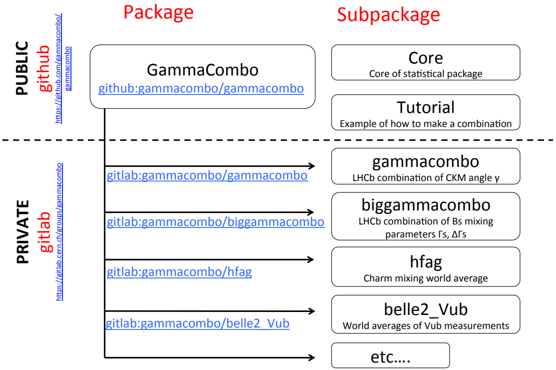
For example GGSZ analyses (inputs are $x_\pm, y_\pm$ which subsequently constrain r_B, δ_B, γ:



2. The GammaCombo framework

The framework in a nutshell

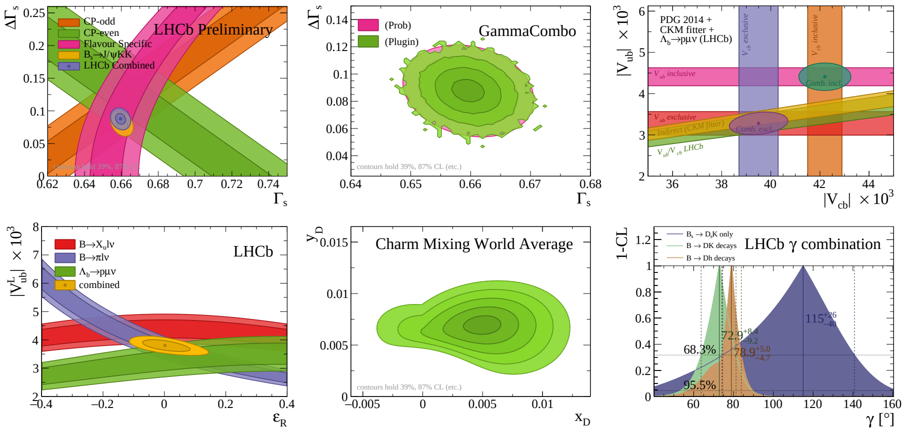
- GammaCombo is a statitical combination package
  - hosted on github here
- Each use combination as its own subpackage
  - hosted on CERN gitlab here
  - Confusingly the one for the lhcb gamma combination is also called gammacombo



Note: the terminology is confusing. There is a github organization, a gitlab group, the package core and one of the subpackages which ALL have the name "gammacombo"

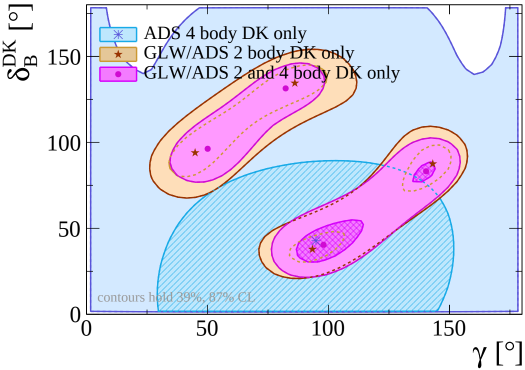
Some publicity

- GammaCombo is used for many combinations
- You can find many more details at the webpage: http://gammacombo.hepforge.org



Some encouragement

- Your measurement will (nearly) always be useful!



Some more publicity

- Getting more and more users of GammaCombo
- Lots of effort has been put in to make it more user friendly, more flexible and provide "prettier" output
- Webpage with (quite) extensive documentation: gammacombo.hepforge.org
- *I plan on adding a bunch of standard statistical tools in there as well (for doing simple things that you can't be bothered to work out on pen/paper)*
  - Propagating errors
  - Combining / comparing sets of measurements
  - CLs tools
  - Covariance matrix calculations etc.

Contributors are always welcome

It *should* be fairly easy to pick up the code and use it out of the box

3. How to make a combination

Adding a measurement to the combination

- How γ gets constrained depends on the final state and the "type" of analysis (e.g. GGSZ, GLW/ADS, $D_s^+ K$)
- HFAG has a really good page on all of them and the equations that can be used to constrain γ:

  http://www.slac.stanford.edu/xorg/hfag/triangle/latest/#gamma_DCPK
- For example (GLW):

$$R_{CP}^{\pm} = 1 + r_B^2 \pm 2 r_B \cos(\delta_B) \cos(\gamma) \tag{1}$$

$$A_{CP}^{\pm} = \frac{\pm 2 r_B \sin(\delta_B) \sin(\gamma)}{R_{CP}^{\pm}} \tag{2}$$

Setting up a constraint

- Build a PDF for each input to the combination
  - *This gets converted to a likelihood which can be minimised / scanned*
- 99% of the inputs to gamma combo are multi-variable Gaussians

$$PDF = Gaus_{nD}(obs, theory, covMatrix) \tag{3}$$

where,

$$\begin{aligned}
obs &= \begin{pmatrix} R_{CP} \\ A_{CP} \end{pmatrix}, \\
theory &= \begin{pmatrix} 1 + r_B^2 \pm 2r_B\cos(\delta_B)\cos(\gamma) \\ (\pm 2r_B\sin(\delta_B)\sin(\gamma))/R_{CP}^{\pm} \end{pmatrix}, \\
covMatrix &= \begin{pmatrix} \sigma_{R_{CP}}^2 & \sigma_{R_{CP}}\rho(R_{CP}, A_{CP})\sigma_{A_CP} \\ \sigma_{A_{CP}}\rho(R_{CP}, A_{CP})\sigma_{R_{CP}} & \sigma_{A_{CP}}^2 \end{pmatrix}
\end{aligned} \tag{4}$$

Combining measurements

- Each input (measurement / analysis) is summarised with a PDF [i]
- Take the product of all the PDFs to make a combined PDF
- Then construct a negative log likelihood function and minimise it
  - Profile over all parameters
  - This is the so called `PROB` method (the standard profile likelihood)
  - *This is cheap and fast*
- Also have other statistical methods e.g:
  1. Feldman-Cousins
  2. Feldman-Counsins (plugin)
  3. Feldman-Counsins (BergerBoos)
  4. Feldman-Cousins (Cousins-Hyland)
- *These are exspensive and slow*

For studies and checks we always use the `PROB` method. `PLUGIN` used for producing results and final numbers

[i] implemented in RooFit so must inherit from RooAbsPdf

External inputs

- Several measurements need external input
- For example many of the $B \to Dh$ modes can have D mixing (depending on the final state of the D being studied)
  - Use latest charm mixing input from CLEO and HFAG
- $B_s^0 \to D_s^+ K$ needs input of ϕ_s
  - Use latest combination of ϕ_s from HFAG
- These are constructed in a similar way to the measurement PDFs above

Something to be careful about

We need to make sure our single analysis measurements are independent of external input which `GammaCombo` will reuse
For example: when you do your analysis fit for x make sure you're not constraining some other parameter y if it will then get floated (profiled) in `GammaCombo`

Note: if you need external input a class for it probably already exists somewhere in the code

Why use Gaussian inputs?

This is a request to all analysts:

Gaussian is best

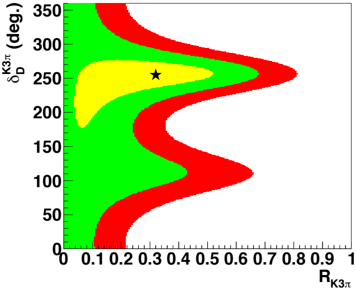
Try your best to make sure that your output observables are Gaussian

Some reasons why:

- These numbers are nearly always available from the paper alone
  - Helps with reproducibility - information is public
- The likelihood is easy to parametrise (n-dimensional Gaussian)
- Minimisation code (scanning parameter space) is effective for Gaussian distributions
  - You much less likely to miss minima hidden in parameter space
- The `PROB` method is much more likely to give good agreement with the `PLUGIN` method
  - It is particulary annoying if you have done all your preliminary studies with the `PROB` but then you get to the end and realise things are very different with the `PLUGIN`
- You are more likely to get a Gaussian (or close to Gaussian) outputvalue
  - This is of huge importance for people who use our results of γ

What about non-Gaussian inputs

- This of course can be done
- A `GammaCombo` input PDF can be of any type
  - So you could write your own (as long as it inherits from `RooAbsPdf`)
  - Or you could make it from a histogram (`RooHistPdf` and similar classes)
- Sometimes this is unavoidable - for example CLEO *D*-mixing input



Non-Gaussian inputs need justification

If it is absolutely essential it can be done

4. Just a little bit of stats

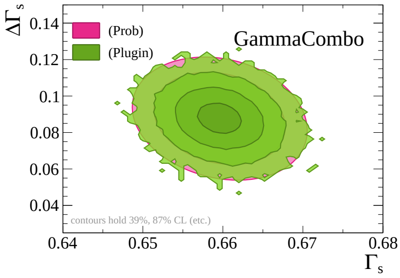
PLUGIN or PROB?

- PROB - This is the standard profile likelihood
  - Its fast (even in 2D)
- PLUGIN - This is an implementation of the Feldman-Cousins plugin method
  - Fix nuisance parameter values
  - Throw toys from a particular observable value (e.g. γ)
  - Compute 1-CL from the toys
- Other methods are available

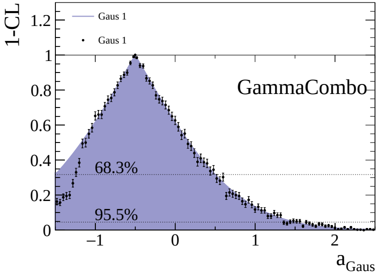
Method	**Notes**
Feldman Cousins (full)	Generate in all possible dimensions (don't fix nuisance parameters) - guaranteed coverage
Berger-Booz	Generate random nuisance values within the toys in a uniform confidence interval (90%, 95%, 99%)
Cousins-Hyland	Generate random nuisance values within the toys given a Gaussian distribution from the PROB method (*used in Higgs a lot*)

Plugin or Prob?

- With simple combinaions of Gaussian numbers which are not near boundaries - Prob is sufficient

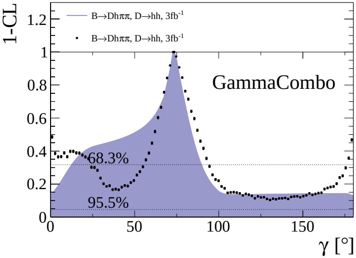


- This is not necessarily the case even with nice Gaussian inputs if you hit a physical parameter limit



Plugin or Prob?

- In LHCb γ combination we have multiple effects going on



Plugin or Prob

For LHCb γ combo we always present results with Plugin
We have then before made a further correction for undercoverage if necessary

5. The next γ combo

A rough plan

- The current plan is for a CONF note sometime soon (i.e. this summer)
- The future plan is a Run 1 "legacy" paper which summarises all $3\,\mathrm{fb}^{-1}$ results from LHCb
- This will be sometime next year (hopefully early next year)
- This depends on who is ready
- If you want to make it in for this combination - get working :) !

6. Summary

Summary

- GammaCombo on the web: http://gammacombo.hepforge.org
- Contributors are always welcome
  - It *should* be fairly easy to pick up the code and use it out of the box
- Somethings to watch out for:
  - Adding measurements to a combination *can increase* the uncertainty
  - It can be difficult to estimate the error if you don't know the central values
  - Make sure you are not using a constraint in your fit that GammaCombo will do something different with
  - Try to make output observables Gaussian
  - Bear in mind the PROB and PLUGIN methods can give different results

Thanks for listening!