

# WP5 Common tools: combination of experiments

JENNIFER2 final meeting (April 2025, Pisa)

S.Bolognesi (CEA Saclay)

### Combination of experiments

The Jennifer2 era has been the years if 'combination' both for Belle2 (+Belle) and for T2K (+SK, +NOVA) communities!

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Measurement of CP asymmetries and branching-fraction ratios for  $B^{\pm} \rightarrow DK^{\pm}$  and  $D\pi^{\pm}$ with  $D \rightarrow K^0_c K^{\pm} \pi^{\mp}$  using Belle and Belle II data



The Belle and Belle II collaborations

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Measurement of branching-fraction ratios and CP asymmetries in  $B^{\pm} \rightarrow D_{CP+}K^{\pm}$  decays at Belle and Belle II



The Belle and Belle II collaboration

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ABSTRACT: We report results from a study of  $B^{\pm} \rightarrow DK^{\pm}$  decays followed by D decaying to the CP-even final state  $K^+K^-$  and CP-odd final state  $K_S^0\pi^0$ , where D is an admixture of  $D^0$  and  $\bar{D}^0$  states. These decays are sensitive to the Cabibbo-Kobayashi-Maskawa unitaritytriangle angle  $\phi_1$ . The results are based on a combined analysis of the final data set of  $772 \times 10^{6} B\bar{B}$  pairs collected by the Belle experiment and a data set of  $198 \times 10^{6} B\bar{B}$  pairs collected by the Belle II experiment, both in electron-nositron collisions at the Y(4S) resonance We measure the CP asymmetries to be  $A_{CP\pm} = (\pm 12.5 \pm 5.8 \pm 1.4)\%$  and  $A_{CP\pm} = (-16.7 \pm$ 5.7  $\pm$  0.6)%, and the ratios of branching fractions to be  $\mathcal{R}_{CP+}=1.164\pm0.081\pm0.036$  and  $\mathcal{R}_{con} = 1.151 \pm 0.074 \pm 0.019$ . The first contribution to the uncertainties is statistical, and the second is systematic. The asymmetries  $A_{CP+}$  and  $A_{CP-}$  have similar magnitudes and opposite signs; their difference corresponds to 3.5 standard deviations. From these values we calculate 68.3% confidence intervals of  $(8.5^{\circ} < \phi_3 < 16.5^{\circ})$  or  $(84.5^{\circ} < \phi_3 < 95.5^{\circ})$  or  $(163.3^{\circ} < \phi_1 < 171.5^{\circ})$  and  $0.321 < \tau_B < 0.465$ 

KEYWORDS: B Physics, CKM Angle Gamma, CP Violation, e<sup>+</sup>-e<sup>-</sup> Experiments

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#### **CP** Violation



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Determination of the CKM angle  $\phi_3$  from a combination of Belle and Belle II results

#### The Belle and Belle II collaborations

E-mail: coll-publications@belle2.org

ABSTRACT: We report a determination of the CKM angle  $\phi_3$ , also known as  $\gamma$ , from a combination of measurements using samples of up to 711 fb<sup>-1</sup> from the Belle experiment and up to 362 fb<sup>-1</sup> from the Belle II experiment. We combine results from analyses of  $B^+ \rightarrow DK^+$   $B^+ \rightarrow D^{-+}$  and  $B^+ \rightarrow D^*K^+$  decays where D is an admixture of  $D^0$  and  $\overline{D}^0$  mesons in a likelihood fit to obtain  $\phi_1 = (75.2 \pm 7.6)^{\circ}$  We also briefly discuss the interpretation of this result.

KEYWORDS: B Physics, CKM Angle Gamma, CP Violation, e<sup>+</sup>-e<sup>-</sup> Experiments

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First joint oscillation analysis of Super-Kamiokande atmospheric and T2K accelerator

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Both MO - 10

- Inverted MO --- 20

= Normal MO ···· 3e

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A lot of results from combination of experiments with pivotal participation from Jennifer2 members!

Oney Access O The Anthony

# Workshop (2/3 April, Pisa)

-3 Apr 2025					
FN and University of Pisa				Q	
rope/Rome timezone					
Workshop format	Physics Workshop organized by the JENNIFER2 project (funded by EU under grant agreement 822070)				
Overview	jointly for neutrinos, quarks and charged-lepton flavour-physics communities.				
Timetable	No fee is required but registration is mandatory. Organization includes coffee breaks and two light				
Zoom connections	lunches on April 2nd and 3rd (for those who will select either of them in the registration form).				
Contribution List	A social dinner will be organized on april 2nd and will be offered by the JENNIFER2 project.				
Registration	Remote participation will be also guarant	teed.			
Participant List					
Scientific and Local	Starts 2 Apr 2025, 09:00	0	INFN and University of Pisa		
Committee	Ends 3 Apr 2025, 14:00	Y	131		
√enue	Europe/Rome		Largo Bruno Pontecorvo, 3		
Travel Info		O,	🕒 accomodation Pisa center.pdf	0	
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	coffee			
16:00	131, INFN and University of Pisa	15:40 - 16:10		
	Combination techniques for neutrino experimental results	Dr Mark Scott		
	131, INFN and University of Pisa	16:10 - 16:35		
	Combination techniques for flavour experimental results	Abner Soffer		
	131, INFN and University of Pisa	16:35 - 17:00		
17:00	Model testing with flavour results: CKM Fitter	Luiz Vale Silva		
	131, INFN and University of Pisa	17:00 - 17:25		

Session dedicated to combination of experiments for neutrino and quark flavour

The final word on the achievements during the Jennifer2 era → important learned lesson for the future

The future precision era / New Physics Searches will be dominated by combinations!

> (Big and personal thanks to the speakers for the great talks! Here just a summary of their inputs)

# Neutrino oscillations

Different channels ( $\nu_{\alpha} \rightarrow \nu_{\beta}$ : 3x3) at different energies

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$0 \qquad \sqrt{\frac{1}{6}} \sqrt{\frac{1}{3}} \sqrt{\frac{1}{2}} \sqrt{\frac{2}{3}}$$

1

Many experiments to enjoy (oscillation focus)





# Why combining?

- **Breaking degeneracies** in the PMNS parameter space



- **Overconstraining** the PMNS parameter space: eg, unitarity



- **Distinguish New Physics** scenarios: eg, NSI



## How combining?



DIFFICULT





#### **Sum of final Gaussian errors** on single parameter:

- non-gaussian effects?
- correlations?



## How combining?



DIFFICULT



### Sum of final Gaussian errors on single parameter:

- non-gaussian effects?
- correlations?



#### Sum of multidimensional likelihood

- handle large dimensionality, especially for systematic uncertainties
- if partial likelihood: marginalization/profile could hide correlations and/or New Physics effects



## How combining?



DIFFICULT



### Sum of final Gaussian errors on single parameter:

- non-gaussian effects?
- correlations?



#### Sum of multidimensional likelihood

- handle large dimensionality, especially for systematic uncertainties
- if partial likelihood: marginalization/profile could hide correlations and/or New Physics effects

 $\rightarrow$  Full joint data fits between experiments! (and even in that case, what about different models?)

#### PRECISE

## Main message for the future

#### Imperial College London

#### **Overcoming difficulties**

- Start talking about them!
  - Help experiments develop analyses with ease of combination in mind
  - Help with sociological side of combined analyses
  - Support development of common formats (NuHEPMC etc.)
- Start doing it now!
  - T2K + NOvA and T2K + SK demonstrate how to do this
  - Discover (and address) potential issues for future experiments
- Potential to have joint facilities in future!
  - NA61/SHINE for next gen experiments
  - Neutrino beamline at CERN (NuSTORM, EnuBET etc.) with argon, scintillator, water Cherenkov detectors

### Flavour joint fits: CKMFit



# How to treat theoretical systematics?

#### Standard approach:



# How to treat theoretical systematics?

#### Standard approach:





-3

-2 -1 0

1 2

# How to treat theoretical systematics?

#### Standard approach:





#### And it does matter!!

**Example**: combination of different extractions of  $B_K^{\overline{\text{MS}}}$  (2 GeV)



13

-2 -1 0

# HFLAV: averaging physics variables

Heavy Flavor Averaging Group https://hflav.web.cern.ch

"The Heavy Flavor Averaging Group (HFLAV) was established at the May 2002 Flavor Physics and CP Violation Conference (Philadelphia) and continues the LEP Heavy Flavor Steering Group's tradition of providing regular updates to the world averages of heavy flavor quantities."

#### Requests and recommendations

- When publishing limits, also publish the central value and uncertainty
  - Well-known rule, but you'd be surprised how often it's not followed...
- When possible, provide the likelihood function of your measurement with respect to all the parameters considered.
  - This will enable the most accurate calculation of averages while updating nuisance parameters
- In any case, provide the values and systematics associated with nuisance parameters to enable executing the  $y_i$ -update procedure
  - E.g.,  $Br(\Upsilon(4S) \rightarrow B^0 \overline{B}^0)$
- Publish measurements of BR ratios (more precise than measurements of BRs)!
  - LHCb does this regularly since they can't measure the number of b hadrons produced.
  - $e^+e^-$  experiments utilize their ability to measure  $N_B$  and  $Br(Υ(4S) → B^0 \overline{B}{}^0)$ , so usually quote absolute BRs, which are less precise. Therefore, averaging requires accounting for correlations, which can be difficult (different samples taken at slightly different energies by same/different experiments) 14

# Conclusions (?)

- **Combination of experiments** is more important than ever in neutrino and quark flavour sector.
- Basic procedures and main
  challenges have been identified
  → major results published!
- The best way to address them **remains a challenge** for the years to come!



