Measurement of the CKM angle ϕ_3 at Belle II

Resmi P K

(On behalf of Belle II Collaboration)

Indian Institute of Technology Madras

Chennai, India

J-SYMPOSIUM 2019

Krakow, Poland

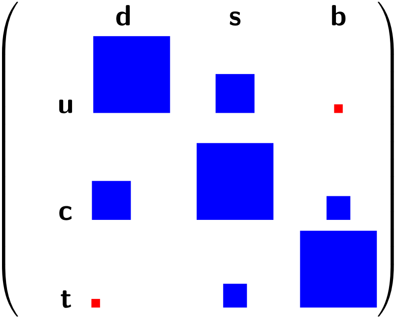
June 26, 2019

Outline of the talk

- Introduction
  - CKM matrix
  - Current experimental status of parameters
- CKM angle ϕ_3/γ
  - Estimation
  - Different methods
  - World average values
- Status of Belle II experiment
- ϕ_3 sensitivity at Belle II
- Summary

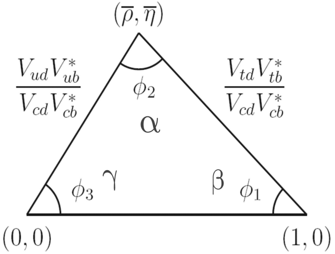
Introduction

- The CKM matrix is of the form



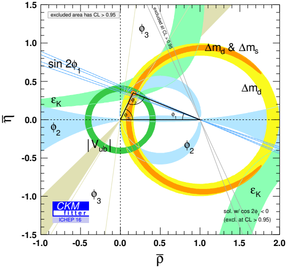
- Unitarity conditions between 1^{st} and 3^{rd} columns

$$\Downarrow$$



- *CP* violation is measured as the complex phase coming in CKM elements V_{ub} and V_{td}.
- A precise measurement required to establish SM description of *CP* violation.

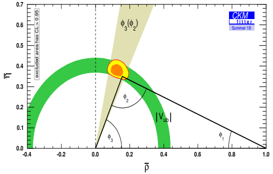
CKM parameters - current status



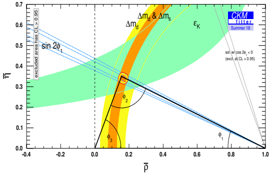
Constraints on CKM parameters [1].

Current best results for CKM angles [1,2]

- $\phi_1^{\text{measured}} = (21.9^{+0.7}_{-0.7})^\circ$
- $\phi_3^{\text{measured}} = (73.5^{+4.2}_{-5.1})^\circ$
- $\phi_3^{\text{predicted}} = (65.3^{+1.0}_{-1.7})^\circ$



Constraints from tree quantities.



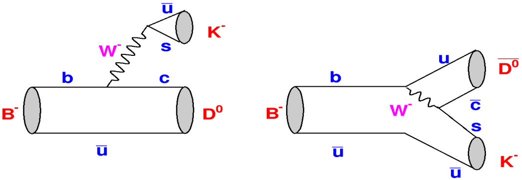
Constraints from loop quantities.

[1] http://ckmfitter.in2p3.fr

[2] http://www.slac.stanford.edu/xorg/hflav/triangle/moriond2018/index.shtml

ϕ_3 measurements from $B \to DK$ decays

- Determine ϕ_3 via interference between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$, tree-level diagrams $\Rightarrow 10^{-7}$ theoretical uncertainty [3].



colour allowed | **colour suppressed**

$B^- \to D^0 K^- \approx V_{cb} V_{us}^*$ | $B^- \to \bar{D}^0 K^- \approx V_{ub} V_{cs}^*$

$\mathbf{A_1}$ | $\mathbf{A_1 r_B e^{i(\delta_B - \phi_3)}}$

- Statistically limited due to small branching fractions of decays involved.
- The statistical uncertainty on $\phi_3 \propto r_B$.
- $r_B^{DK} \approx 0.1$ and $r_B^{D\pi} \approx 0.005$; So $B \to D\pi$ decays are not sensitive!
- But they serve as excellent calibration modes due to similar topology as of $B \to DK$. Larger sample ($\frac{\mathcal{B}(B \to D\pi)}{\mathcal{B}(B \to DK)} \approx 10$) due to Cabibbo-favoured nature.

[3] J. Brod, J. Zupan, JHEP **01**, 051 (2014)

Primary methods

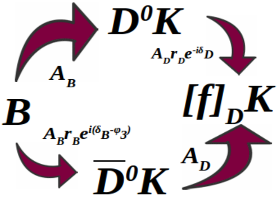
- The methods differ according to the D final state considered.

GLW PLB **253**, 483 (1991), PLB **265**, 172 (1991)

- CP eigenstates like K^+K^-, $\pi^+\pi^-$, $K^0_S\pi^0$ *etc*.
- CP-content as external input for multibody decays like $\pi^+\pi^-\pi^0$.

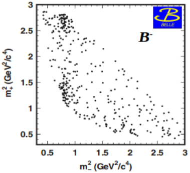
ADS PRL **78**, 3357 (1997)

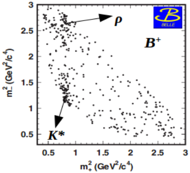
- DCS modes $K^+\pi^-$,$K^+\pi^-\pi^0$,$K^+\pi^-\pi^+\pi^-$
- δ_D, r_D - charm inputs.



GGSZ PRD **68**, 054018 (2003)

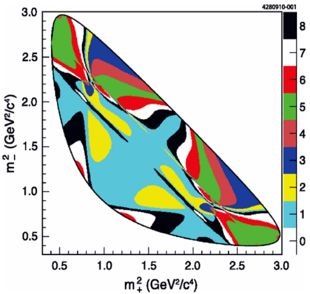
- Multibody self-conjugate states
- Model-dependent and independent approaches





Model-independent method

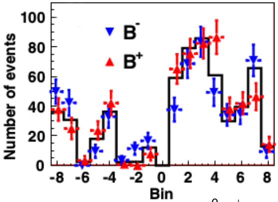
- Model-independent method by binning the Dalitz plot of multibody D final states like $K^0_{\mathrm{S}}\pi^+\pi^-$, $K^0_{\mathrm{S}}K^+K^-$, $K^0_{\mathrm{S}}\pi^+\pi^-\pi^0$.



Dalitz plot binning for $K^0_{\mathrm{S}}\pi^+\pi^-$.

PRD**82**, 112006(2010)

- For the decay $B^- \to D(K^0_{\mathrm{S}}h^+h^-)K^-$, $\Gamma^-_i = K_i + r_B^2\bar{K}_i + 2\sqrt{K_i\bar{K}_i}(c_ix_- + s_iy_-)$, and similarly for the B^+ decay.



B^+ and B^- yields for D final state $K^0_{\mathrm{S}}\pi^+\pi^-$ at Belle.

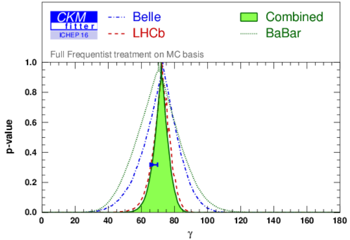
PRD**85**, 112014(2012)

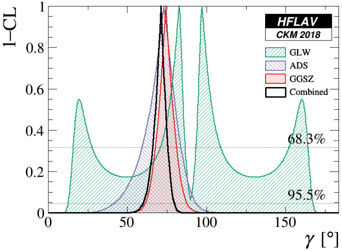
- $\mathbf{x}_\pm = r_B\cos(\delta_B \pm \phi_3)$; $\mathbf{y}_\pm = r_B\sin(\delta_B \pm \phi_3)$.
- $\mathbf{c_i}$, $\mathbf{s_i}$ - cos and sin of the strong phase difference between D^0 and $\bar{D}^0$ averaged over the region of phase space $\Rightarrow$ input from CLEO-c or BESIII.
- $\mathbf{K_i}$, $\mathbf{\bar{K}_i}$ - fraction of flavour-tagged D^0 and $\bar{D}^0$ events from $D^{*\pm} \to D\pi^\pm$ decays.

ϕ_3: Average values

- From all measurements of $B \to D(^*)K(^*)$ from GLW, ADS, and GGSZ.

Belle + BaBar + LHCb run I





$$(\phi_3)_{\text{Belle}} = (73^{+13}_{-15})^{\circ}$$ [4]

$$(\phi_3)_{\text{BaBar}} = (69^{+17}_{-16})^{\circ}$$ [5]

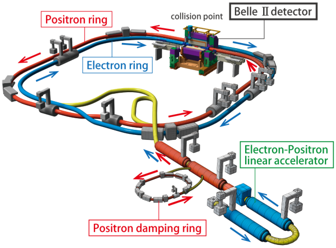
$$(\phi_3)_{\text{LHCb}} = (74.0^{+5.0}_{-5.8})^{\circ}$$ [6]

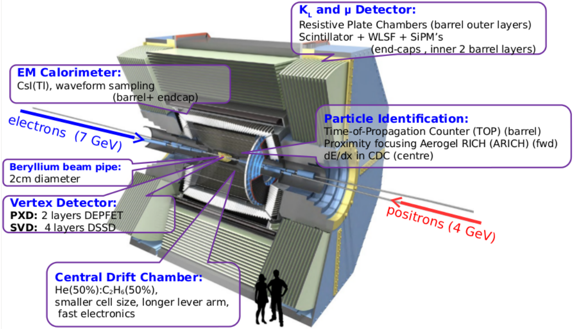
- Dominated by LHCb result and GGSZ method.

$$(\phi_3)_{\text{Combined}} = (73.5^{+4.2}_{-5.1})^{\circ}$$

4 PRD **85**, 112014 (2012)
5 PRD **87**, 052015 (2013)
6 LHCb-CONF-2018-002

SuperKEKB and Belle II experiment





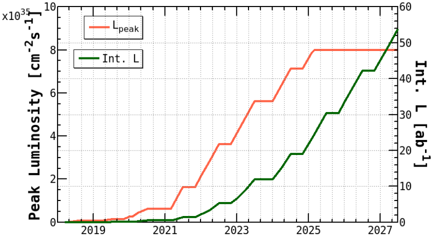
- Center-of-mass energy at $\Upsilon(4S)$ resonance which decays to $B\overline{B}$ pair.

Important improvements for ϕ_3

- Improved K_S^0 reconstruction efficiency
- Better K/π separation

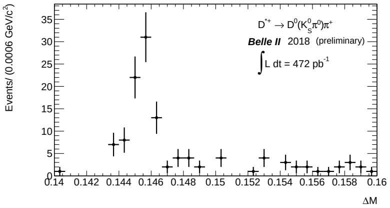
Status of Belle II

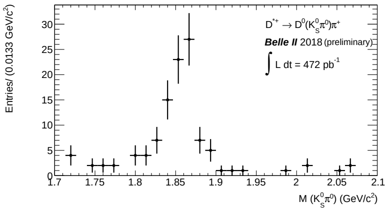
- **Phase II** $\Rightarrow$ **25 April to 17 July 2018.**
  - **Without full vertex detectors.**
  - **Accumulated $\approx$ 0.5 fb^{-1} data.**
- **Phase III** $\Rightarrow$ **First collisions on 25 March 2019.**
- **The ultimate goal is**
  - $\mathcal{L}_{\text{int}} = 50\ \text{ab}^{-1}$ **(50 $\times$ Belle)**
  - $\mathcal{L}_{\text{peak}} = 8 \times 10^{35}\ \text{cm}^{-1}\text{s}^{-1}$ **(40 $\times$ KEKB)**



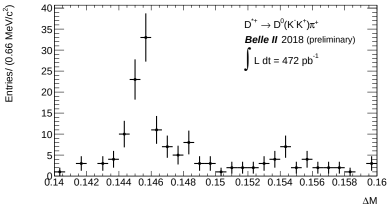
Results from phase II

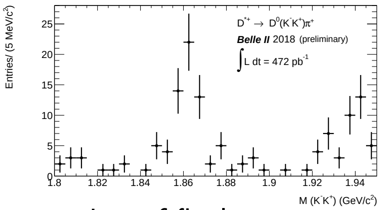
- $D^{*\pm} \to D(K^0_S\pi^0)\pi^\pm_{\text{slow}}$ decays : *CP*-odd eigenstate





- $D^{*\pm} \to D(K^+K^-)\pi^\pm_{\text{slow}}$ decays : *CP*-even eigenstate

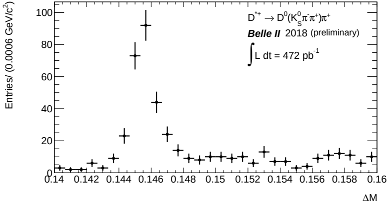


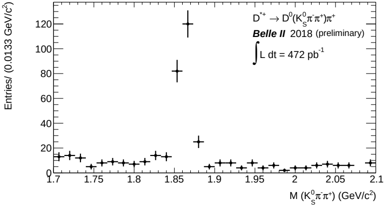


- Belle II is capable of reconstructing a variety of final states including neutrals.

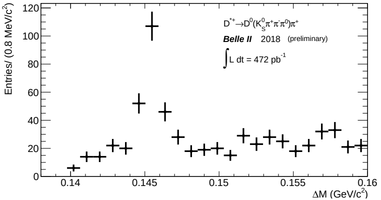
Results from phase II

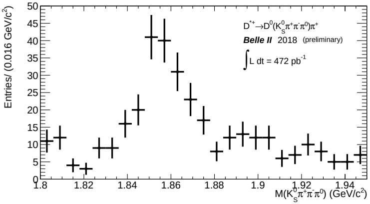
- $D^{*\pm} \to D(K^0_S\pi^+\pi^-)\pi^\pm_{\rm slow}$ decays





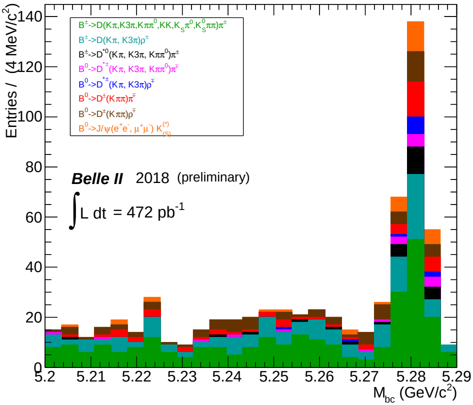
- $D^{*\pm} \to D(K^0_S\pi^+\pi^-\pi^0)\pi^\pm_{\rm slow}$ decays



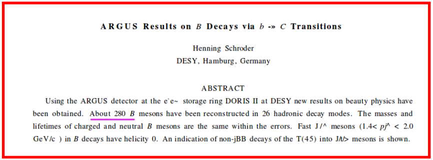


- Multibody self-conjugate final states, important for ϕ_3 estimation.

B mesons in phase II data



- About 245 B candidates reconstructed from hadronic final states.



ARGUS Results on B Decays via b -» C Transitions

Henning Schroder
DESY, Hamburg, Germany

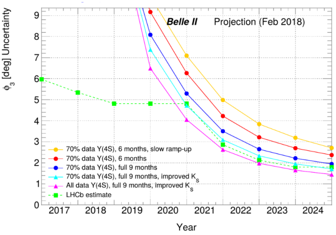
ABSTRACT

Using the ARGUS detector at the e'e~ storage ring DORIS II at DESY new results on beauty physics have been obtained. About 280 B mesons have been reconstructed in 26 hadronic decay modes. The masses and lifetimes of charged and neutral B mesons are the same within the errors. Fast J/^ mesons (1.4< pj^ < 2.0 GeV/c) in B decays have helicity 0. An indication of non-jBB decays of the T(45) into J/t/> mesons is shown.

- $B \to D\pi$ decays are good calibration modes for ϕ_3 estimation from $B \to DK$ decays.

ϕ_3 sensitivity at Belle II

- $B^{\pm} \to D(K^0_S\pi^+\pi^-)K^{\pm}$: golden mode at Belle II.
- $\delta(\phi_3)^{50\ \mathrm{ab}^{-1}} = \mathbf{3.0}^\circ$ (with 10 fb^{-1} BESIII data)
- $B^{\pm} \to D(K^0_S\pi^+\pi^-\pi^0)K^{\pm}$: another promising mode.
- $\delta(\phi_3)^{50\ \mathrm{ab}^{-1}} = \mathbf{4.4}^\circ$[7] (Assuming $\epsilon \times BF$ similar to $K^0_S\pi^+\pi^-$).



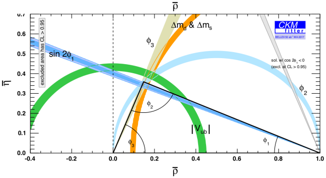
- The GLW modes from $B \to D^{(*)}K$ also has significant impact on the projected uncertainty.

- Better PID, K^0_S selection, continuum suppression would bring further improvements.

[7] JHEP **01**, 82 (2018)

Summary

- Current precision on average value of ϕ_3 is $\approx 5^\circ$.
- Precise measurement is crucial for establishing SM picture of *CP* violation.
- A combined sensitivity of **1.6°** is expected with
  - full 50 ab^{-1} data,
  - additional $D^{(*)}$ modes.



Expected precision on CKM parameters with 50 ab^{-1} Belle II data[8].

- Measurements of D hadronic parameters from 10 fb^{-1} BESIII data is crucial.

8 B2TIP report arXiv:1808.10567 [hep-ex]