WP5 common tools

Statistical tools for combinations

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KEK Jun 2, 2024

EU grant n.822070

[Task 5.3] Make the most of (all) data - and more

Identify and document sound statistical methods to combine results from different experiments

Pros

- Faster science: maximize informing/constraining power of data — accelerate progress
- Better science: Discussion, sharing, and comparison of experiment-specific practices fosters cross-fertlization. Converge toward standard scientific practices (the good ones, hopefully)
- Open, persistent science: combining lots of highly multidimensional data forces experiments to think in advance about standard formats, and document them sufficiently
- Seeding future science: inter-experiment interaction and collaboration generates scientific and personal bounds that will yield future ideas, collaborations etc

Caveats

- Risk for bias/group-think: compartimentation and competition among experiments has a solid scientific motivation: diversity of approaches and forced self-reliance reduces the risk of experimenters' biases in the final results ==> important that combinations happen *after* individual results are approved and reported publicly.
- Risk of temporary inefficiencies/slow-downs: more careful analysis design from the get go (e.g., think in advance / agree on coherent classification of systematic sources, statistical inference etc)
- Risk of proliferation/incoherence: structured groups devoted to combinations of published results exist. Need to interact/collaborate with them to avoid proliferation of conflicting results

Belle II and T2K approach: learning-by-doing

The early attempts…

First publication of **Belle+BelleII combination**

Combined analysis of Belle and Belle II data to determine the CKM angle ϕ_3 using $B^+ \to D(K^0_S h^+ h^-)h^+$ decays

The Belle and Belle II collaborations

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Abstract: We present a measurement of the Cabibbo-Kobayashi-Maskawa unitarity triangle angle ϕ_3 (also known as γ) using a model-independent Dalitz plot analysis of $B^+ \to D\,(K^0_S h^+ h^-)\,h^+$, where D is either a D^0 or $\bar{D}^0$ meson and h is either a π or K. This is the first measurement that simultaneously uses Belle and Belle II data, combining samples corresponding to integrated luminosities of 711 fb^{-1} and 128 fb^{-1}, respectively. All data were accumulated from energy-asymmetric e^+e^- collisions at a centre-of-mass energy corresponding to the mass of the $\Upsilon(4S)$ resonance. We measure $\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$, where the first uncertainty is statistical, the second is the experimental systematic uncertainty and the third is from the uncertainties on external measurements of the D-decay strong-phase parameters.

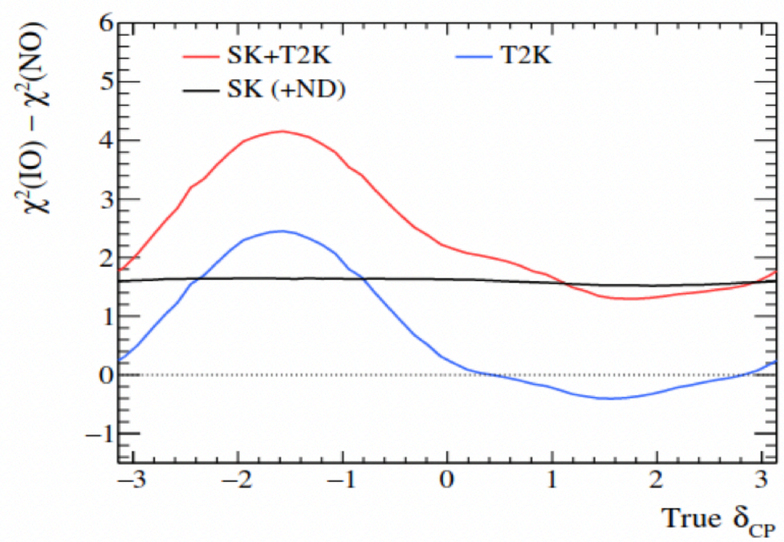
Keywords: B Physics, CKM Angle Gamma, e^+-e^- Experiments

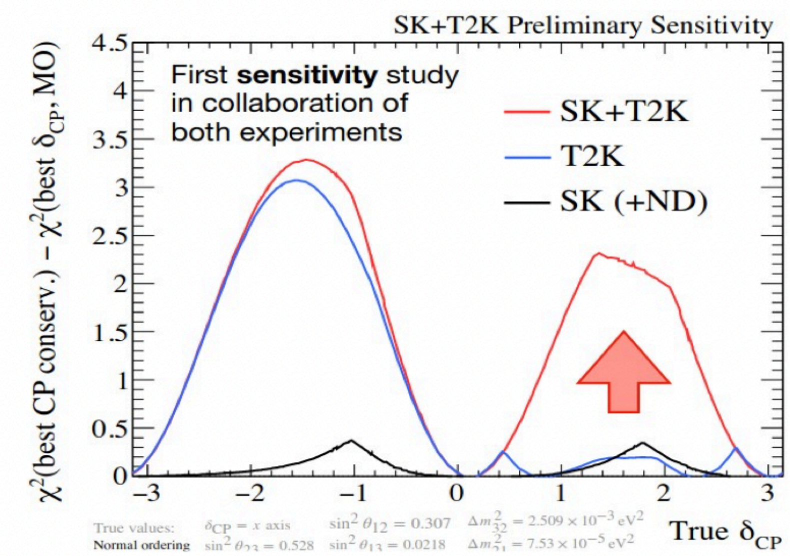
ArXiv ePrint: 2110.12125

JHEP02(2022)063

Combination of **neutrinos from cosmic rays (SuperKamiokande) and from accelerator (T2K):** big boost in sensitivity!

Sensitivity presented at Neutrino 2022 conference: DOI 10.5281/zenodo.6683820





…have become the new standard

JHEP
Published for SISSA by Springer
Received: *June 6, 2023*
Accepted: *September 8, 2023*
Published: *September 21, 2023*

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

JHEP09(2023)146

BELLE Belle II

The Belle and Belle II collaborations
https://belle.kek.jp/
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JHEP
Published for SISSA by Springer
Received: *August 14, 2023*
Revised: *January 30, 2024*
Accepted: *March 29, 2024*
Published: *May 17, 2024*

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

JHEP05(2024)212

Belle II

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Abstract: We report results from a study of $B^\pm \to DK^\pm$ decays followed by D decaying to the CP-even final state K^+K^- and CP-odd final state $K^0_S\pi^0$, where D is an admixture of D^0 and $\bar{D}^0$ states. These decays are sensitive to the Cabibbo-Kobayashi-Maskawa unitarity-triangle angle ϕ_3. 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-positron collisions at the $\Upsilon(4S)$ resonance. We measure the CP asymmetries to be $\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%$ and $\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%$, and the ratios of branching fractions to be $\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036$ and $\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019$. The first contribution to the uncertainties is statistical, and the second is systematic. The asymmetries $\mathcal{A}_{CP+}$ and $\mathcal{A}_{CP-}$ 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 $(163.3^\circ < \phi_3 < 171.5^\circ)$ and $0.321 < r_B < 0.465$.

Keywords: B Physics, CKM Angle Gamma, CP Violation, e^+-e^- Experiments

ArXiv ePrint: 2308.05048

…the new standard…

Belle II Preprint 2023-015
KEK Preprint 2023-31

Prepared for submission to JHEP

Determination of the CKM angle ϕ_3 from a combination of Belle and Belle II results

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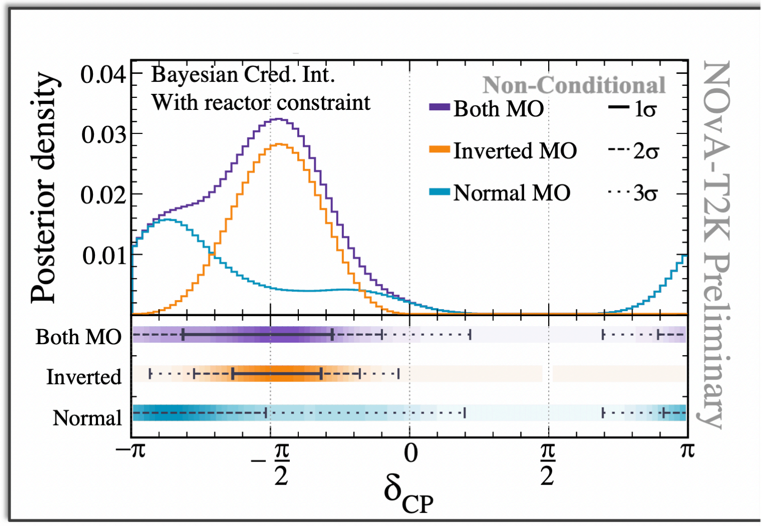
Search for the decay $B^0 \to \gamma\gamma$ using Belle and Belle II data

I. Adachi, L. Aggarwal, H. Aihara, N. Akopov, A. Aloisio, S. Al Said, N. Althubiti, N. Anh Ky, D. M. Asner, H. Atmacan, T. Aushev, V. Aushev, M. Aversano, R. Ayad, V. Babu, H. Bae, S. Bahinipati, P. Bambade, Sw. Banerjee, S. Bansal, M. Barrett, J. Baudot, A. Baur, A. Beaubien, F. Becherer, J. Becker, K. Belous, J. V. Bennett, F. U. Bernlochner, V. Bertacchi, E. Bertholet, M. Bessner, S. Bettarini, B. Bhuyan, F. Bianchi, L. Bierwirth, T. Bilka, D. Biswas, A. Bobrov, D. Bodrov, A. Bolz, J. Borah, A. Boschetti, A. Bozek, M. Bračko, P. Branchini, R. A. Briere, T. E. Browder, A. Budano, S. Bussino, Q. Campagna, M. Campajola, L. Cao, G. Casarosa, C. Cecchi, J. Cerasoli, M.-C. Chang, P. Chang, P. Cheema, C. Chen, B. G. Cheon, K. Chilikin, K. Chirapatpimol, H.-E. Cho, K. Cho, S.-J. Cho, S.-K. Choi, S. Choudhury, L. Corona, J. X. Cui, F. Dattola, E. De La Cruz-Burelo, S. A. De La Motte, G. De Nardo, M. De Nuccio, G. De Pietro, R. de Sangro, M. Destefanis, S. Dey, R. Dhamija, A. Di Canto, F. Di Capua, J. Dingfelder, Z. Doležal, I. Domínguez Jiménez, T. V. Dong, M. Dorigo, D. Dorner, K. Dort, D. Dossett, S. Dreyer, S. Dubey, K. Dugic, G. Dujany, P. Ecker, M. Eliachevitch, D. Epifanov, P. Feichtinger, T. Ferber, T. Fillinger, C. Finck, G. Finocchiaro, A. Fodor, F. Forti, A. Frey, B. G. Fulsom, E. Ganiev, M. Garcia-Hernandez, G. Gaudino, V. Gaur, A. Gaz, A. Gellrich, G. Ghevondyan, D. Ghosh, H. Ghumaryan, G. Giakoustidis, R. Giordano, A. Giri, A. Glazov, B. Gobbo, R. Godang, O. Gogota, P. Goldenzweig, W. Gradl, E. Graziani, D. Greenwald, Z. Gruberová, T. Gu, K. Gudkova, I. Haide, Y. Han, T. Hara, C. Harris, K. Hayasaka, H. Hayashii, S. Hazra, C. Hearty, M. T. Hedges, A. Heidelbach, I. Heredia de la Cruz, M. Hernández Villanueva, T. Higuchi, M. Hoek, M. Hohmann, P. Horak, C.-L. Hsu, T. Humair, K. Inami, N. Ipsita, A. Ishikawa, R. Itoh, M. Iwasaki, P. Jackson, W. W. Jacobs, D. E. Jaffe, E.-J. Jang, S. Jia, Y. Jin, A. Johnson, K. K. Joo, H. Junkerkalefeld, D. Kalita, A. B. Kaliyar, J. Kandra, K. H. Kang, S. Kang, G. Karyan, T. Kawasaki, F. Keil, C. Kiesling, C.-H. Kim, D. Y. Kim, K.-H. Kim, Y.-K. Kim, H. Kindo, K. Kinoshita, P. Kodyš, T. Koga, S. Kohani, K. Kojima, A. Korobov, S. Korpar, E. Kovalenko, R. Kowalewski, P. Križan, P. Krokovny, T. Kuhr, Y. Kulii, J. Kumar, R. Kumar, K. Kumara, T. Kunigo, A. Kuzmin, Y.-J. Kwon, S. Lacaprara, K. Lalwani, T. Lam, J. S. Lange, M. Laurenza, R. Leboucher, M. J. Lee, C. Lemettais, P. Leo, D. Levit, L. K. Li, S. X. Li, Y. Li, Y. B. Li, J. Libby, Z. Liptak, M. H. Liu, Q. Y. Liu, Z. Q. Liu, D. Liventsev, S. Longo, T. Lueck, C. Lyu, Y. Ma, M. Maggiora, S. P. Maharana, R. Maiti, S. Maity, G. Mancinelli, R. Manfredi, E. Manoni, M. Mantovano, D. Marcantonio, S. Marcello, C. Marinas, C. Martellini, A. Martens, A. Martini, T. Martinov, L. Massaccesi, M. Masuda, K. Matsuoka, D. Matvienko, S. K. Maurya, J. A. McKenna, F. Meier, M. Merola, F. Metzner, C. Miller, M. Mirra, S. Mitra, K. Miyabayashi, G. B. Mohanty, S. Mondal, S. Moneta, H.-G. Moser, M. Mrvar, I. Nakamura, M. Nakao, Y. Nakazawa, M. Naruki, D. Narwal, Z. Natkaniec, A. Natochii, M. Nayak, G. Nazaryan, M. Neu, M. Niiyama, S. Nishida, S. Ogawa, Y. Onishchuk, H. Ono, G. Pakhlova, S. Pardi, K. Parham, H. Park, J. Park, S.-H. Park, B. Paschen, A. Passeri, S. Patra, S. Paul, T. K. Pedlar, R. Peschke, R. Pestotnik, M. Piccolo, L. E. Piilonen, G. Pinna Angioni, P. L. M. Podesta-Lerma, T. Podobnik, S. Pokharel, C. Praz, S. Prell, E. Prencipe, M. T. Prim, I. Prudiiev, H. Purwar, P. Rados, G. Raeuber, S. Raiz, N. Rauls, M. Reif, S. Reiter, M. Remnev, L. Reuter, I. Ripp-Baudot, G. Rizzo, S. H. Robertson, M. Roehrken, J. M. Roney, A. Rostomyan, N. Rout, S. Sandilya, L. Santelj, Y. Sato, V. Savinov, B. Scavino, S. Schneider, G. Schnell, M. Schnepf, K. Schoenning, C. Schwanda, Y. Seino, A. Selce, K. Senyo, J. Serrano, M. E. Sevior, C. Sfienti, W. Shan, C. Sharma, C. P. Shen, X. D. Shi, T. Shillington, T. Shimasaki, J.-G. Shiu, D. Shtol, A. Sibidanov, F. Simon, J. B. Singh, J. Skorupa, R. J. Sobie, M. Sobotzik, A. Soffer, A. Sokolov, E. Solovieva, S. Spataro, B. Spruck, M. Starič, P. Stavroulakis, S. Stefkova, R. Stroili, Y. Sue, M. Sumihama, N. Suwonjandee, H. Svidras, M. Takizawa, U. Tamponi, K. Tanida, F. Tenchini, A. Thaller, O. Tittel, R. Tiwary, D. Tonelli, E. Torassa, K. Trabelsi, I. Ueda, T. Uglov, K. Unger, Y. Unno, K. Uno, S. Uno, Y. Ushiroda, S. E. Vahsen, R. van Tonder, K. E. Varvell, M. Veronesi, A. Vinokurova, V. S. Vismaya, L. Vitale, V. Vobbilisetti, R. Volpe, A. Vossen, B. Wach, M. Wakai, S. Wallner, E. Wang, M.-Z. Wang, X. L. Wang, Z. Wang, A. Warburton, S. Watanuki, C. Wessel, E. Won, Y. Xie, X. P. Xu, B. D. Yabsley, S. Yamada,

…the new standard…

CP Violation

- For both mass orderings, $\delta_{CP} = \pi/2$ lies outside 3-sigma credible interval.
- Normal Ordering allows for a broad range of permissible δ_{CP}
- For the Inverted Ordering, CP conserving values of δ_{CP} (0, π) lie outside the 3-sigma credible interval.



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

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Lessons learned

The task is just as challenging as previous anticipated (but not more challenging).
The benefits surpass our anticipations.

In addition to increasing knowedge by sharing, impact on physics results oftentimes exceeds naive expectations.

When data are scarce and likelihoods far from the asymptotic regime, combinations of data sets enable precision gains that exceed, sometimes significantly the expected ~1/sqrt(N) as solution degeneracies are lifted and non-Gaussian likelihoods become more Gaussian.

The second aspect that requires further checks is our better-than-expected sensitivity to ϕ_3 [40]. We investigate this by studying separately the contribution of the individual inputs to the ϕ_3 precision, as shown in Table 5. The precision on ϕ_3 improves significantly, from 11° to 8.2°, when the ADS inputs from $B^+ \to D(\to K^+\pi^-)h^+$ are combined with the BPGGSZ inputs. This enhancement is driven by the $R_{\rm ADS}$ observable of the $B^+ \to D\pi^+$ channel. The relation of this observable with hadronic parameters is

$$R_{\rm ADS}^{D\pi,K\pi} = (r_B^{D\pi})^2 + (r_D^{K\pi})^2 + 2r_B^{D\pi}r_D^{K\pi}\cos(\delta_B^{D\pi} + \delta_D^{K\pi})\cos\phi_3. \qquad (6.1)$$

Substitution in the above equation of our $r_B^{D\pi}$ value, the auxiliary input $r_D^{K\pi}$, and their uncertainties, greatly enhances the precision on the interference (last) term as compared to the $B^+ \to DK^+$ case. Furthermore, our value $\delta_B^{D\pi} \approx 347°$ leads to a precise determination of $\cos(\delta_B^{D\pi} + \delta_D^{K\pi})$ close to one. The combined effect of both factors improves the precision of our ϕ_3 result. The ADS contribution to the sensitivity of ϕ_3 is primarily attributed to three elements: the small relative uncertainty of the large $r_B^{D\pi}$ value favoured by Belle and Belle II measurements, the availability of a precise value of $r_D^{K\pi}$ from global averages, and the large $\delta_B^{D\pi}$ value favoured by Belle and Belle II measurements.

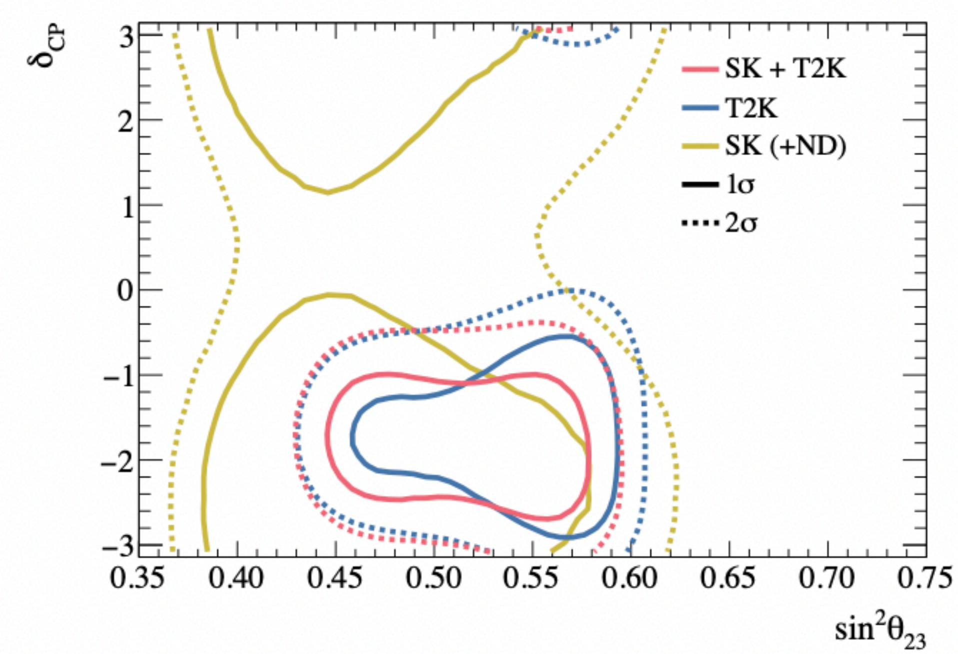
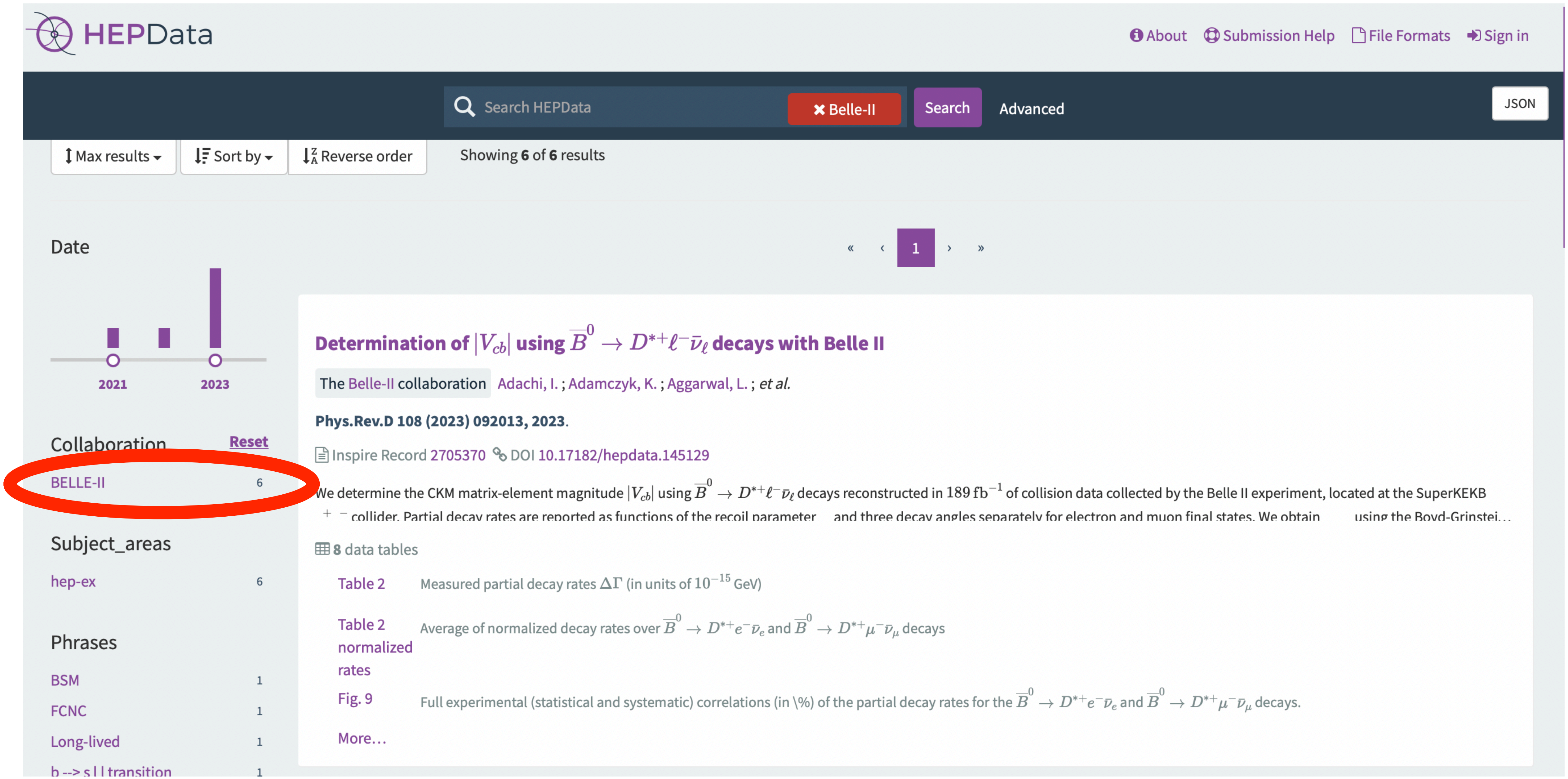


FIG. 1. The $(\sin^2\theta_{23}, \delta_{\rm CP})$ credible regions obtained with the SK, T2K, and combined datasets. The MO is marginalized over and a prior uniform in $\delta_{\rm CP}$ is used.

In parallel: data preservation becoming a standard too



Now and next

Distilling the lessons into a coherent set of guidelines, good practices, and caveats and reverse them in a short document