PROCEEDINGS OF SCIENCE

Thirty years of the Beauty Conference

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This paper remembers thirty years of the Beauty conference series and celebrates its 20th meeting. The conference highlights are reviewed.

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1. Introduction

This paper highlights 30 years of the Beauty Conference series from a personal perspective. It is broken down into four distinct periods. In the early years, 1993–1999, the predominant focus of the conference was to prepare the first dedicated B-physics experiments for future hadron machines. The second period, 1999–2009, saw the first measurements of CP-violation and rare B decays, dominated by the B-factory e^+e^- and Tevatron experiments. Between 2009–2022 came the LHC era, where the ATLAS, CMS and LHCb experiments took the lead in B-physics measurements. Finally, beyond 2019 saw the start-up of the Belle-II experiment and the transition to the LHC upgrades, taking B-physics into a new high-luminosity era. An overview of the timeline is presented in Fig. 1. A full list of the twenty Beauty conferences is given below.

Year	**Conference location**
1993	Liblice Castle, Melnik, Czech Republic
1994	Le Mont Saint Michel, Normandy, France
1995	Oxford, United Kingdom
1996	Rome, Italy
1997	Santa Monica, CA, United States
1999	Bled, Slovenia
2000	Sea of Galilee, Kibbutz Maagan, Israel
2002	Santiago de Compostela, Spain
2003	Pittsburgh, PA, United States
2005	Assisi, Perugia, Italy
2006	Oxford, United Kingdom
2009	Heidelberg, Germany
2011	Amsterdam, Netherlands
2013	Bologna, Italy
2014	Edinburgh, United Kingdom
2016	Marseille, France
2018	La Biodola, Elba Island, Italy
2019	Ljubljana, Slovenia
2020	Kavli Institute, IPMU, Japan (online conference)
2023	Clermont-Ferrand, France

2. The early years of the conference : 1993–1999

The first Beauty conference, Beauty 1993, was held at Liblice Castle, Melnik, Czech Republic [1], see Fig. 2. It was initiated by the "father" of the Beauty conference series, Peter Schlein (1932-2008) and close colleagues. The conference began as a forum for discussion of the merits of the different methods of B-physics experimentation, at that time at the e^+e^- B-factories, the LHC and the SSC accelerators, and with the HERA-B experiment.

The second conference, Beauty 1994, was held in Mont-Saint-Michel, France [2], and was arguably one of the most vibrant of the whole series. Three proposals for B physics at the LHC were presented and are shown in Fig. 3: COBEX, running in LHC collider mode, the Large Hadron

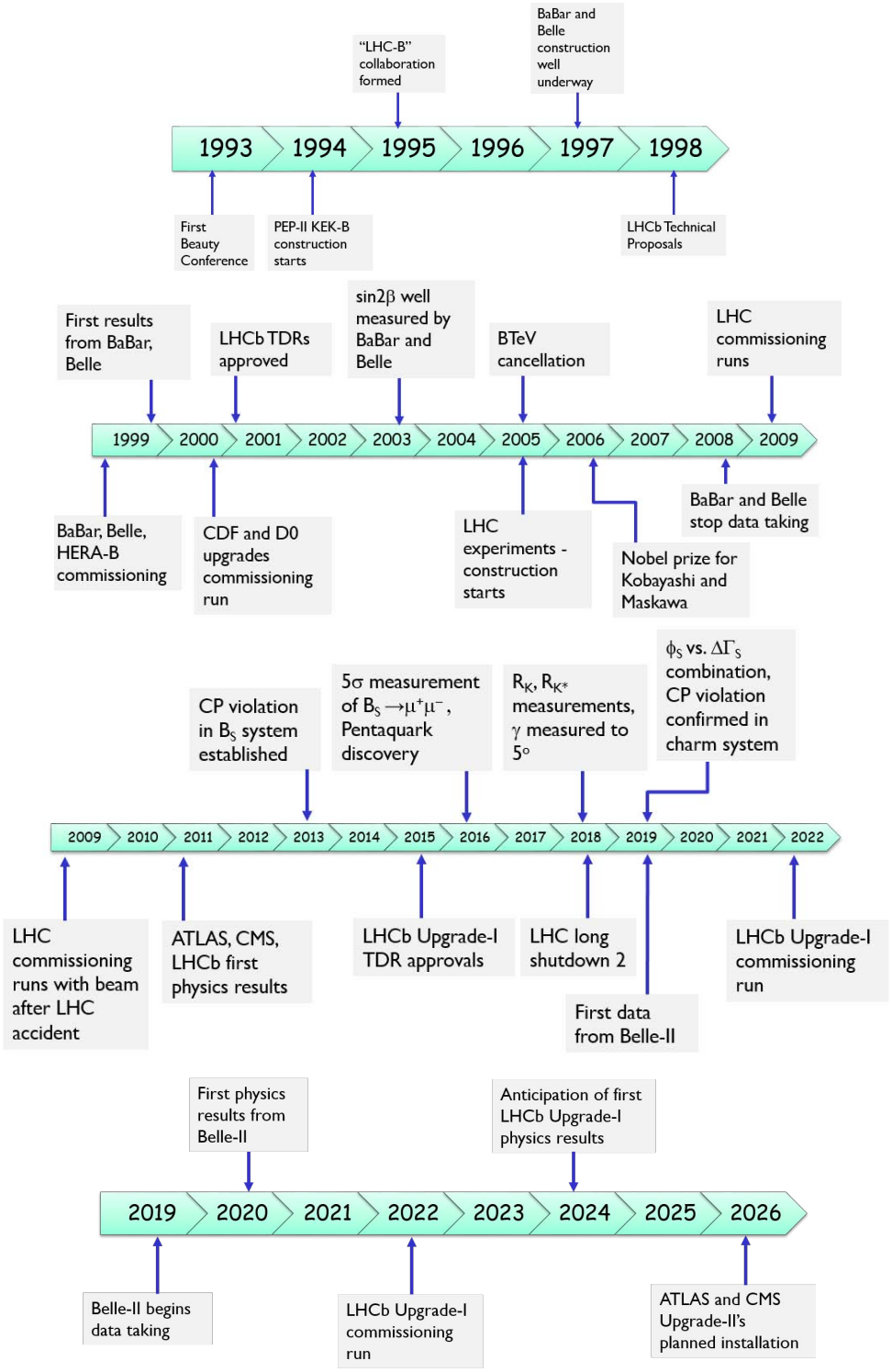

Figure 1: From the top : the early years of the conference, 1993–1999; the e^+e^- and Tevatron era, 1999–2009; the LHC era, 2009–2022; the era of Belle-II and the LHC upgrades, beyond 2019.

Figure 2: A group photo of the participants of first Beauty Conference held in Liblice Castle, Melnik, Czech Republic. Peter Schlein can be seen kneeling front row, sixth from the right.

Beauty (LHB) experiment, running with beam extraction, and GAJET, running with an internal gas jet target. Emotions ran high in discussing the proposals' relative benefits, and in addition there was a strong lobby for HERA-B. After the conference, the CERN Large Hadron Collider Committee (LHCC) reviewed the strengths and weaknesses of the three proposals. The conclusions drawn were that none of the collaborations had the necessary resources, the collider mode had the greater potential, however an optimized design of spectrometer did not yet exist. The Committee therefore encouraged all participants to join together to prepare a Letter of Intent for a new collider-mode B-physics experiment. The new collaboration was subsequently born and the "LHC-B" Letter of Intent was submitted [3]. The collaboration was cemented at Beauty 1995 in Oxford [4].

By the time of the Beauty 1996 conference in Rome [5], the BaBar and Belle experiments were well in preparation. The LHC-B experiment was pushing towards a Technical Proposal and BTeV, at the Tevatron, had received its initial approval. CDF reported the first $B^0 \to J/\psi K^0_s$ signal to be observed at a hadron collider.

3. The e^+e^- B-Factory and Tevatron era : 1999–2009

At Beauty 1999 in Bled, Slovenia [6], the Belle, BaBar and HERA-B experiments were commissioning and producing first results. The OPAL and CDF experiments provided the first hints of CP violation in the B sector by measuring non-zero $\sin 2\beta$ ($\sin 2\phi_1$), albeit with very limited precision: $\sin 2\beta = 3.2 \pm 1.9 \pm 0.5$ (OPAL) and $\sin 2\beta = 0.79 \pm 0.44$ (CDF). The Beauty conference then had a four-year gap.

By the time of Beauty 2003 [7], hosted at Pittsburgh, $\sin 2\beta$ ($\sin 2\phi_1$) had been well established by BaBar and Belle with better than a 10% uncertainty from each experiment. Figure 4 (left)

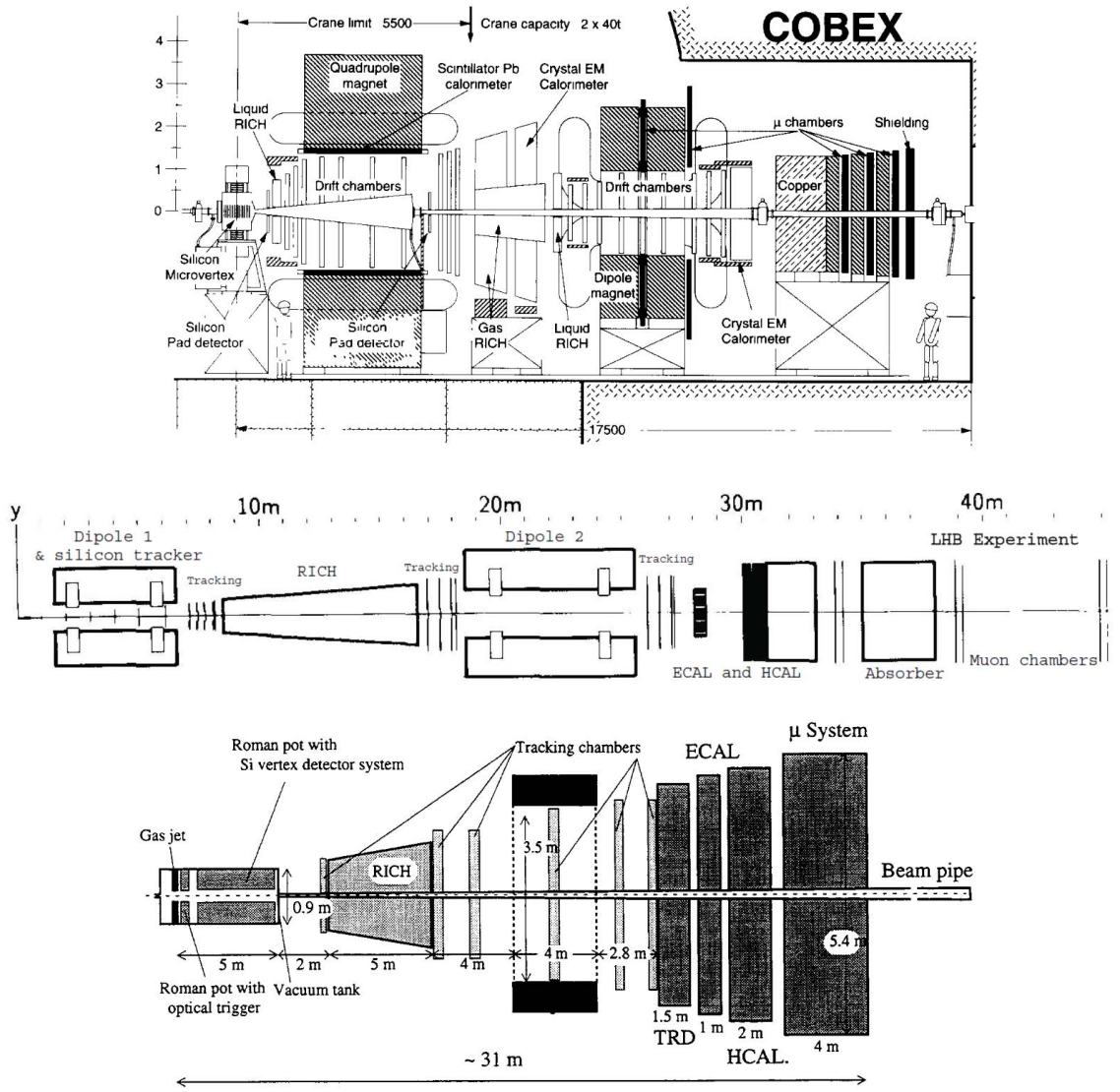

Figure 3: The three propoals for B physics at the LHC: from the top, COBEX (LHC Collider mode), LHB (beam extraction), GAJET (internal gas jet target).

shows the Belle time-dependent asymmetry measurement in $B^0 \to J/\psi K^0_s$ decays after 140 fb^{-1} of integrated luminosity, giving $\sin 2\phi_1 = 0.733 \pm 0.057 \pm 0.028$ [8]. The first measurements of the CKM angles α (ϕ_2) and γ (ϕ_3) were also emerging [9], see Fig. 4 (right). CDF and D0 were setting the standards for B physics at hadron machines, measuring 5% precision on B lifetimes. Unfortunately HERA-B's physics output was very limited, restricted to the measurement of the $b\overline{b}$ cross-section at 920 GeV proton energy [10].

At Beauty 2005 in Assisi, Italy [11], BaBar presented a new measurement of angle $\alpha(\phi_2) = (103^{+9}_{-11})^\circ$. The LHC experiment R&D was now at an end, and construction had started. Sadly this year had seen the cancellation of BTeV by the US Department of Energy.

The following year the conference re-visited Oxford with Beauty 2006 [12]. BaBar and Belle

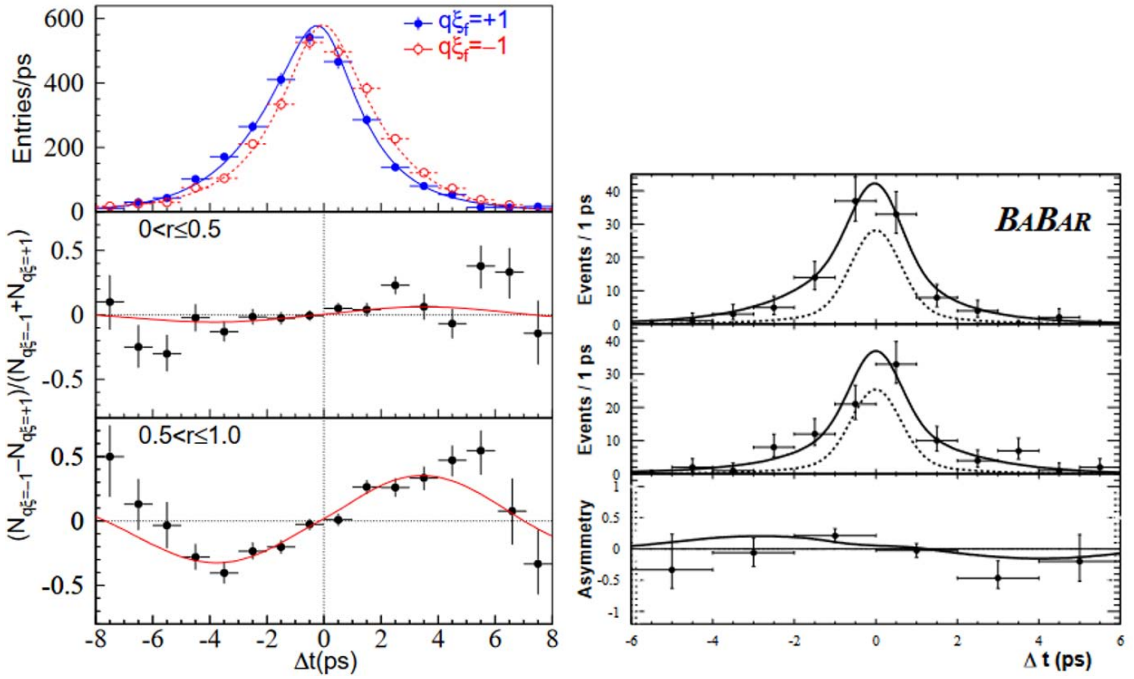

Figure 4: Decay-time distributions and charge asymmetries and a function of decay time for (left) $B^0 \to J/\psi K^0_s$ from Belle [8], and (right) $B^0 \to \pi^+\pi^-$ from BaBar [9].

made the first measurements of angle $\gamma(\phi_3)$ in $B^+ \to D^{(*)}K^{+(*)}$ decays, albeit with 30% errors. Arguably the highlight of the conference was the measurement of the $B_s - \overline{B}_s$ oscillation frequency with significance greater than 5σ by CDF [13]. The Δm_s amplitude scan, shown in Fig. 5 yielded a value of $\Delta m_s = (17.77 \pm 0.10 \pm 0.07)\,\text{ps}^{-1}$. A quote from the conference editorial stated "As this (in 2006) is the last conference in the series before the start-up of the LHC, Beauty 2006 has been a timely opportunity to review the status of the field." This statement was made prior to the LHC accident in 2008, which resulted in an additional year's gap in the conference programme.

4. The LHC era : 2009–2022

Beauty 2009 in Heidelberg [14] saw the first preliminary data from the LHC experiments after the LHC accident. Whilst statistics were limited, first B lifetime measurements were presented. The conference also saw the end of data taking for BaBar and Belle with a $\sim$1.5 ab^{-1} combined total integrated luminosity. An amazing legacy of B-factory results was presented, including the observation of $B \to \tau\nu$, the forward-backward asymmetry in $B \to K^*\ell^+\ell^-$, angle $\beta(\phi_1)$ now known to 1°, $\alpha(\phi_2)$ known to 5° and $\gamma(\phi_3)$ known to better than 15°. In 2009 the unitarity triangle had been impressively constrained by the B-factory experiments, demonstrated in Fig. 6.

The first significant physics results from the LHC experiments were reported at Beauty 2011 in Amsterdam [16] . This included LHCb's observation of direct CP violation in $B \to K^+\pi^-$ decays and the first observation of $B_s \to J/\psi\phi$ decays from three LHC experiments, following first results from the Tevatron in 2009-2011.

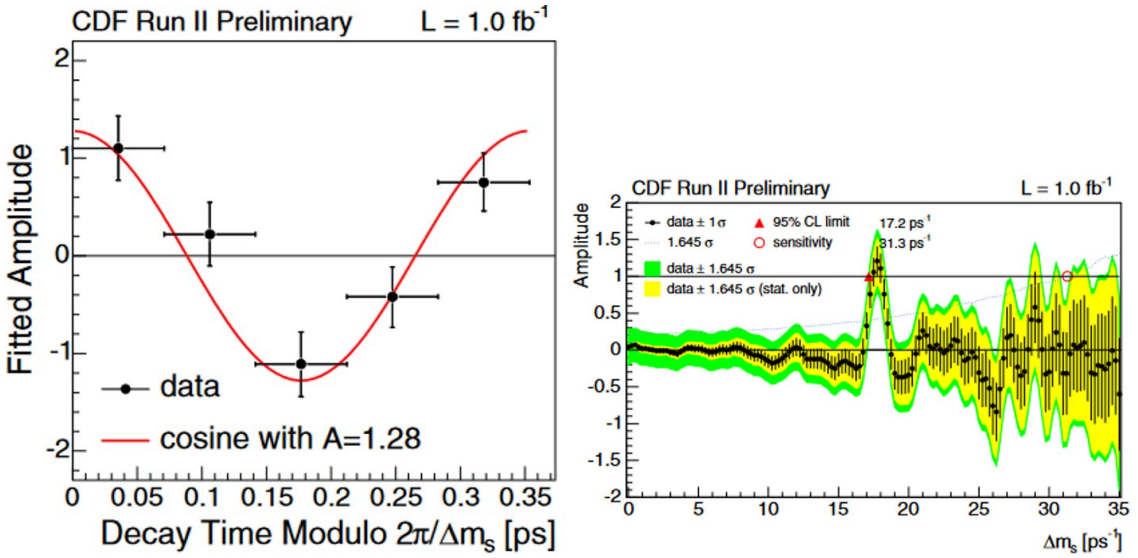

Figure 5: The observation of $B_s - \overline{B}_s$ oscillations at the CDF experiment [13]. (Left) the oscillation signal in bins of proper decay time modulo the measured oscillation period, (right) the Δm_s amplitude scan.

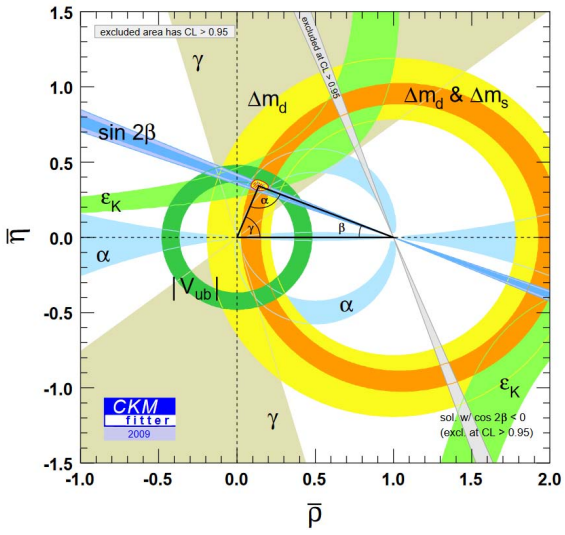

Figure 6: The Unitarity Triangle in 2009 [15]. Many of the measured parameters are dominated by BaBar and Belle measurements.

Beauty 2013 in Bologna [17] saw the LHC experiments start to push the boundaries. This included the first evidence for $B_s \to \mu^+\mu^-$ from LHCb with a measured branching ratio of $(3.2 \pm {}^{+1.4}_{-1.2} \pm {}^{+0.5}_{-0.3}) \times 10^{-9}$. There were much-improved constraints on the B_s mixing phase in $B_s \to J/\psi\phi$ decays from ATLAS, CMS and LHCb, and the first observation in a single experiment of $D^0 - \overline{D}^0$ mixing from LHCb, an impressive 9.1 σ. LHCb also presented new world-best B^0 and B_s mixing measurements, shown in Fig. 7, giving $\Delta m_d = (0.5156 \pm 0.0051 \pm 0.0033)$ ps^{-1} [18] and $\Delta m_s = (17.768 \pm 0.023 \pm 0.006)$ ps^{-1} [19], respectively.

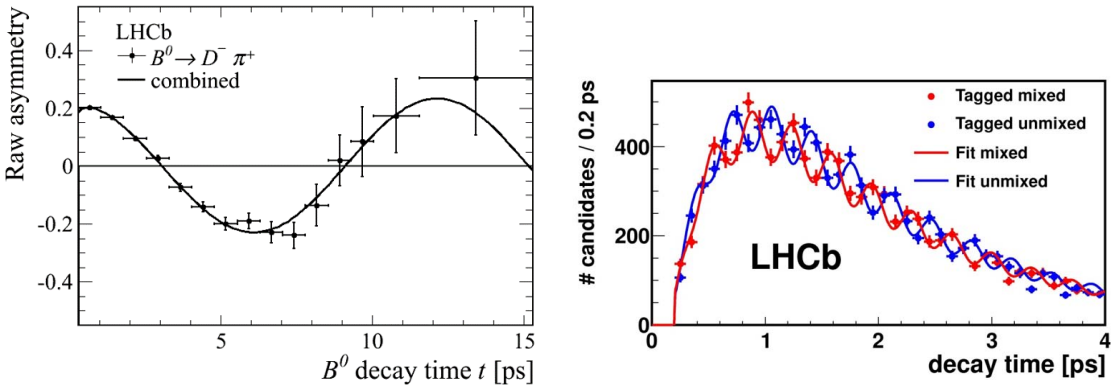

Figure 7: LHCb B mixing measurements showing the $B - \overline{B}$ asymmetry versus B decay time; (left) B^0 [18] and (right) B_s^0 [19].

Beauty 2014 in Edinburgh [20] saw the name of the conference change. "International Conference on B-Physics at Hadron Machines" became "International Conference on B-Physics at Frontier Machines", to better reflect democracy in results from pp and $p(\overline{p})$ and e^+e^- machines. Improved $\gamma(\phi_3)$ combination measurements to 9° were reported at the conference, and LHCb first reported an interesting anomaly in the so-called P_5' variable in $B \to K^*\mu\mu$ decays. In addition, preparation had started on the new Belle-II experiment in Japan.

The highlight of Beauty 2016 held in Marseille [21] was arguably the first observation of $B_s \to \mu^+\mu^-$ and evidence for $B^0 \to \mu^+\mu^-$ from a combination of LHCb and CMS measurements [22], shown in Fig. 8. This represented a culmination of 35 years of intense searching. The combined fit led to the branching-fraction measurements $\mathcal{B}(B_s \to \mu^+\mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$ and $\mathcal{B}(B_s \to \mu^+\mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$. The second highlight was the discovery of the pentaquark, reported by LHCb [23], and shown in Fig. 9. Two states, the so-called $P_c^+(4380)$ and $P_c^+(4450)$, were observed in the $(J/\psi p)$ mass spectrum in $\Lambda_b^0 \to K^- J/\psi p$ decays, with significances of 9 and 12 σ, respectively. A subsequent analysis with more data has shown this system to be even richer than first thought [24].

Beauty 2018 in La Biodola, Isle of Elba [25], was the "year of the anomaly". This was the first presentation of the LHCb measurements of the quantities R_K and R_{K^*}, the ratios of B mesons decaying into $K^{(*)}\mu^+\mu^-$ and $K^{(*)}e^+e^-$. The measurements differed from unity by 2.5 σ, potentially hinting at lepton non-universality. This resulted in much discussion and interesting speculation at the conference. In other news, LHCb measured $\gamma(\phi_3)$ via a combination of decay channels to almost 5°, namely $\gamma = (74.0^{+5.0}_{-5.8})°$.

A highlight of the Beauty 2019 in Ljubljana, Slovenia [26], was LHCb's discovery of CP violation in the charm system at 5.3 σ significance [27]. The measure of the difference of the CP asymetries in the D^0 meson decaying into K^+K^- and $\pi^+\pi^-$, ΔA_{CP} was measured to be $(-15.4 \pm 2.9) \times 10^{-4}$. The Belle-II collaboration was congratulated on the first data-taking run of the experiment.

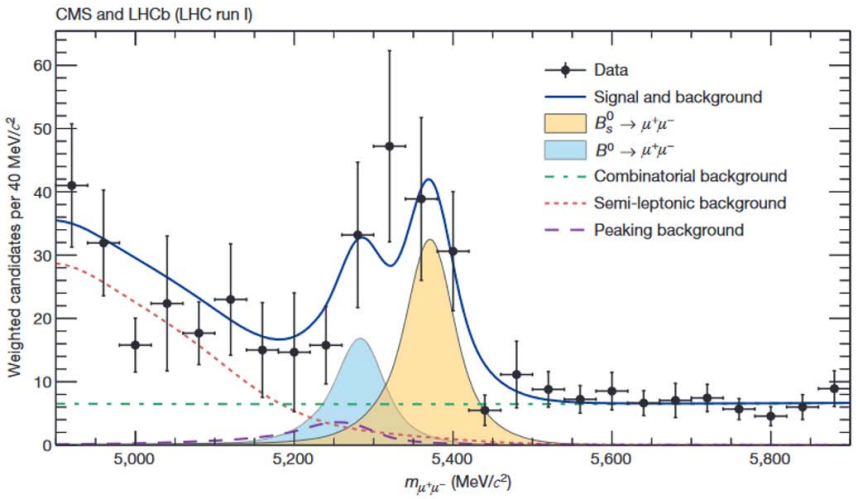

Figure 8: The $\mu^+\mu^-$ mass spectrum from a combination of LHCb and CMS data [22].

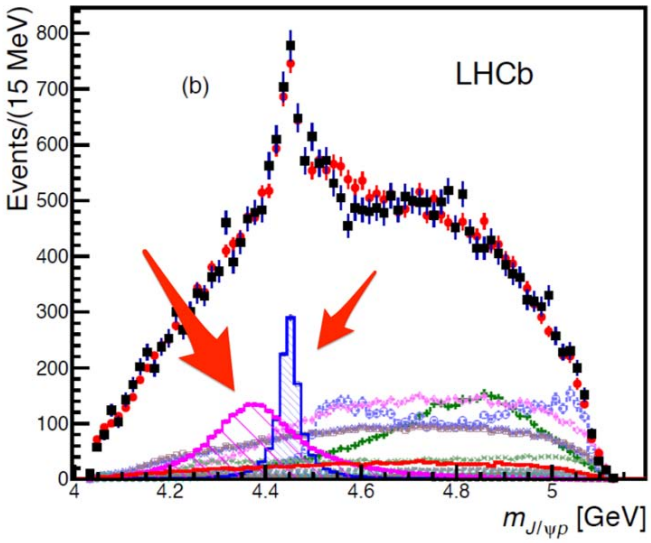

Figure 9: The LHCb measurement of the $(J/\psi p)$ mass spectrum in $\Lambda_b^0 \to K^- J/\psi p$ decays [23]. The arrows show the $P_c^+(4380)$ and $P_c^+(4450)$ pentaquark states.

5. The era of Belle-II and the LHC upgrades

The year 2020 saw the Covid pandemic and Beauty 2020, hosted by Tokyo, was the first completely online Beauty conference [28]. Although participants were unable to meet in person, many exciting results were presented. The conference highlighted first results from Belle-II, an example being the mass distribution and angular distribution of $B^+ \to \phi K^+$.

The current meeting, Beauty 2023 in Clermont-Ferrand, saw the LHC resuming operation after three years of long shut-down and the LHCb Upgrade-I start taking data. Together with Belle-II, a new fresh exciting chapter for flavour physics had started. The community can look forward to

the ATLAS and CMS upgrades in Long Shutdown 3 of the LHC and the LHCb Upgrade-II in the early 2030's, and the high-quality and no-doubt surprising results that will surely come from these projects.

6. Summary

The 30-year history of the Beauty conference series has seen many exciting experimental developments, and the conferences have been enlightened by a healthy mixture of theoretical presentations. Figure 10 shows the evolution of the Unitarity Triangle over this period [15].

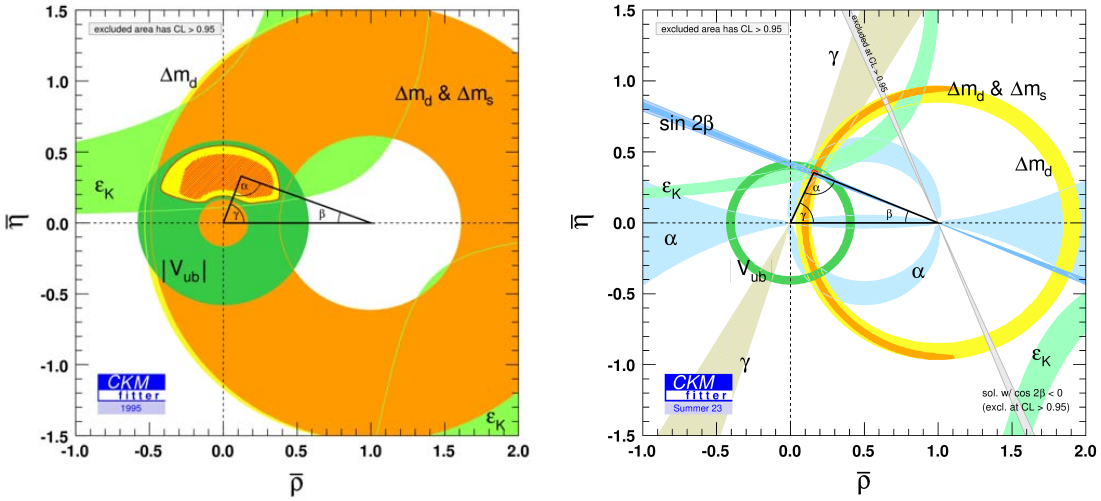

Figure 10: Evolution of the Unitarity Triangle over the 30 years of the Beauty conference [15].

Over the last thirty years, rare decays have been measured down to the one in a billion level, and whole families of new particle states have been discovered. Unitarity Triangle measurements are consistent with the Standard Model and new physics is becoming increasingly constrained. Nevertheless there is still need for increased precision, which Belle-II and the LHC upgrades will provide in future years. Although the field of Flavour Physics has taken a huge leap over the last 30 years, there still remains a whole lot to learn. We all look forward to the next 30 years of the Beauty conference series!

Acknowledgments

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References

[1] Proceedings of Beauty 1993, Nucl. Instrum. and Meth. A333 (1993) 1.

[2] Proceedings of Beauty 1994, Nucl. Instrum. and Meth. A 351 (1994) 1.

[3] The LHC-B Letter of Intent, A Dedicated LHC Collider Beauty Experiment for Precision Measurements of CP Violation. CERN/LHCC/95-5.

[4] Proceedings of Beauty 1995, Nucl. Instrum. and Meth. A368 (1996) 1.

[5] Proceedings of Beauty 1996, Nucl. Instrum. and Meth. A384 (1996) 1.

[6] Proceedings of Beauty 1999, Nucl. Instrum. Meth. A384 (2000) 1.

[7] Proceedings of Beauty 2003, AIP Conference Proceedings 722 (2004) 1.

[8] Belle Collab. , Measurement of CP-Violation parameter $\sin(2\phi_1)$ with 152 million $B\overline{B}$ pairs, https://doi.org/10.48550/arXiv.hep-ex/0308036

[9] A. Watson (BaBar Collab.), Towards α (ϕ_2) and α (ϕ_3) at the B factories. AIP Conference Proceedings 722 (2004) 42.

[10] HERA-B Collab. Improved measurement of the $b\overline{b}$ production cross section in 920 GeV fixed-target proton-nucleus collisions, Phys. Rev. D73 (2006) 052005.

[11] Proceedings of Beauty 2005, Nucl. Phys.B Proc. Suppl. 156 (2006) 1.

[12] Proceedings of Beauty 2006, Nucl. Phys.B Proc. Suppl. 170 (2007) 1.

[13] CDF Collab., Observation of $B_s - \overline{B}_s$ Oscillations. Phys. Rev. Lett. 97:242003, 2006

[14] Proceedings of Beauty 2009, Proceedings of Science BEAUTY2009 (2009).

[15] CKMfitter Group (J. Charles et al.), http://ckmfitter.in2p3.fr

[16] Proceedings of Beauty 2011, Proceedings of Science BEAUTY2011 (2011).

[17] Proceedings of Beauty 2013, Proceedings of Science BEAUTY2013 (2013).

[18] LHCb Collab. Measurement of the time-dependent CP asymmetry in $B^0 \to J/\psi K^0_S$ decays Phys. Lett B721 (2013) 24.

[19] LHCb Collab. Precision measurement of the $B^0_s - \overline{B}^0_s$ oscillation frequency with the decay $B^0_s \to D^-_s \pi^+$. New J. Phys. 15 (2013) 053021.

[20] Proceedings of Beauty 2014, Proceedings of Science BEAUTY2014 (2014).

[21] Proceedings of Beauty 2016, Proceedings of Science BEAUTY2016 (2016).

[22] CMS and LHCb Collabs. Observation of the rare $B^0_s \to \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data. Nature 522 (2015) 68–72.

[23] LHCb Collab. Observation of $J/\psi p$ resonances consistent with pentaquark states in $\Lambda_b^0 \to J/\psi K p$ decays. Phys. Rev. Lett. 115 (2015) 072001.

[24] LHCb Collab. Observation of a narrow pentaquark state, $P_c(4312)^+$, and of two-peak structure of the $P_c(4450)^+$. Phys. Rev. Lett. 122 (2019) 222001.

[25] Proceedings of Beauty 2018, Proceedings of Science BEAUTY2018 (2018).

[26] Proceedings of Beauty 2019, Proceedings of Science BEAUTY2019 (2019).

[27] LHCb Collab. Observation of CP violation in charm decays. Phys. Rev. Lett. 122 (2019) 211803.

[28] Proceedings of Beauty 2020, Proceedings of Science BEAUTY2020 (2020).