Celebrating 30 years of the Beauty conference series (and the 20th meeting)

Neville Harnew

University of Oxford

Beauty 2023 Clermont-Ferrand

4th July 2023

Outline

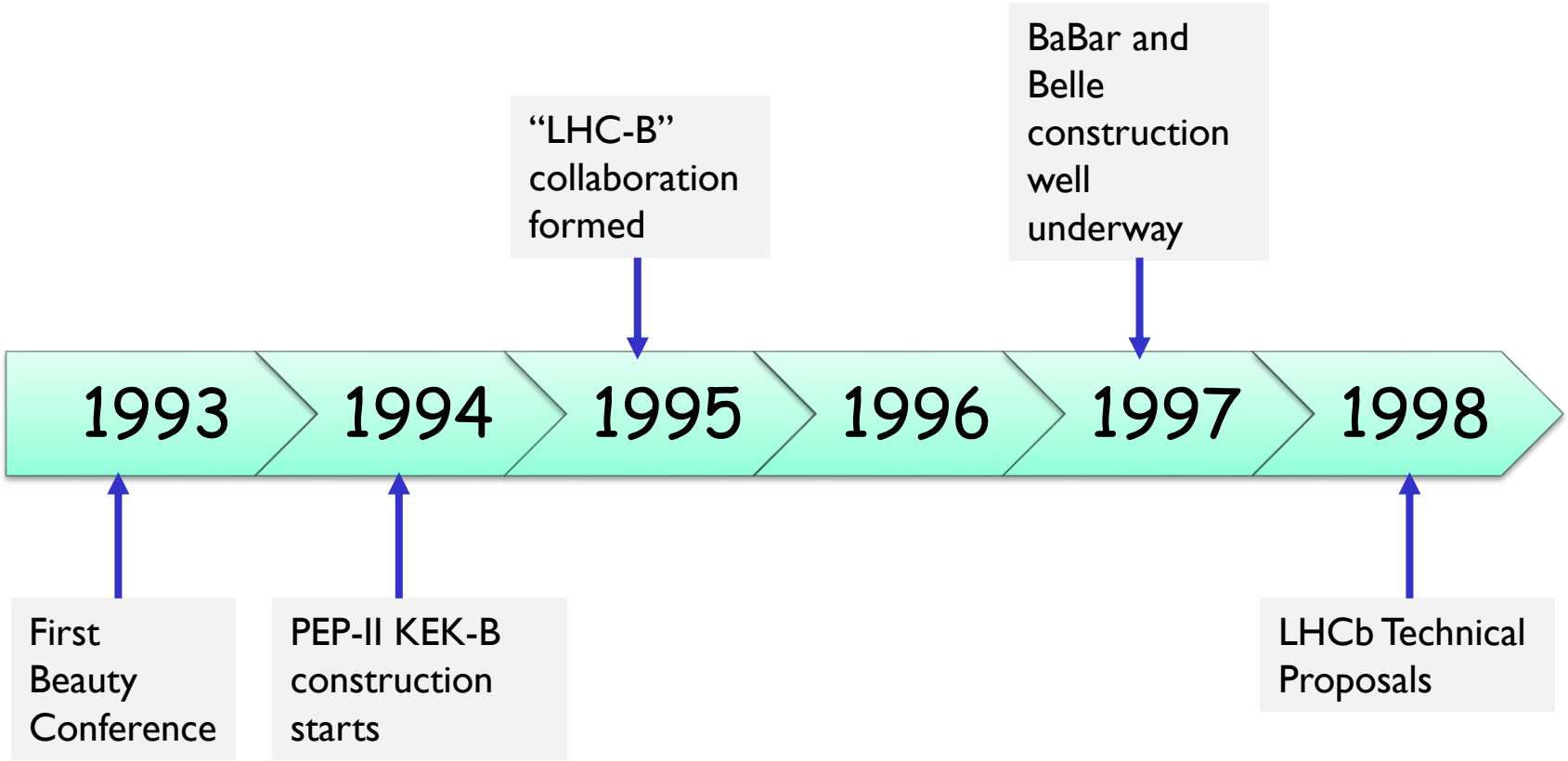
- *The early years* of the conference 1993-1999
  - Focus predominantly on preparing B-physics experiments for *hadron* machines
- The e+e- *and Tevatron era* : 1999-2009
- The *LHC era* : 2009-2022
- The onset of the *era of Belle-II and the LHC upgrades* : 2022 and beyond
- Summary

Beauty conferences in the series

1) Beauty 1993 Liblice Castle, Melnik, Czech Republic
2) Beauty 1994 Le Mont Saint Michel, Normandy, France
3) Beauty 1995 Oxford, United Kingdom
4) Beauty 1996 Rome, Italy
5) Beauty 1997 Santa Monica, CA, United States
6) Beauty 1999 Bled, Slovenia
7) Beauty 2000 Sea of Galilee, Kibbutz Maagan, Israel
8) Beauty 2002 Santiago de Compostela, Spain
9) Beauty 2003 Pittsburgh, PA, United States
10) Beauty 2005 Assisi, Perugia, Italy
11) Beauty 2006 Oxford, United Kingdom
12) Beauty 2009 Heidelberg, Germany
13) Beauty 2011 Amsterdam, Netherlands
14) Beauty 2013 Bologna, Italy
15) Beauty 2014 Edinburgh, United Kingdom
16) Beauty 2016 Marseille, France
17) Beauty 2018 La Biodola, Elba Island, Italy
18) Beauty 2019 Ljubljana, Slovenia
19) Beauty 2020 Online Conference, hosted by Kavli, IPMU, Japan
20) Beauty 2023 Clermont-Ferrand, France

https://inspirehep.net/conferences?sort=datedesc&size=25&page=1&start_date=all&q=series.name%3A%22Beauty%22

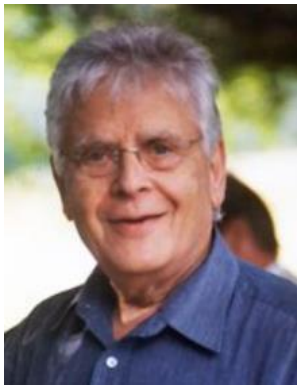
The early years of the conference 1993-1999



The first conference 2003 : Liblice Castle, Czech Republic – participant list

Valery Balbekov, IHEP, Protvino, Russian Federation
Ivan Belyaev, ITEP, Moscow, Russian Federation
Piotr Bialas, Jagellonian University, Krakow, Poland
Vladimir Bolotov, Institute for Nuclear Research, Moscow, Russian Federation
Sergio Conetti, University of Virginia, Charlottesville, USA
Flavio Costantini, Universita di Pisa and INN, Italy
Daniel Denegri, CEN-Saclay, Gif-sur-Yvette, France
Rustem Dzhelyadin, IHEP, Protvino, Russian Federation
Paula Eerola, CERN, Geneva, Switzerland
Samim Erhan, University of California, Los Angeles, USA
Fernando Ferroni, Universita di Roma and INFN, Italy
Pavel Galoumian, University of Lausanne, Switzerland
Boris Govorkov, Lebedev Institute, Moscow, Russian Federation
Gennady Gurov, IHEP, Protvino, Russian Federation
Paul Harrison, Queen Mary & Westfield College, London, UK
Jan Hladky, Institute of Physics, Prague, Czech Republic
Werner Hofmann, Max Planck Institut fur Kermphysik, Heidelberg, Germany
Julius Hrivnac, Institute of Physics, Prague, Czech Republic
Vaclav Kohl, Institute of Physics, Prague, Czech Republic
Michael Kreisler, University of Massachusetts, Amherst, USA
Yves Lemoigne, CEN-Saclay, Gif-sur-Yvette, France
Anatoly Likhoded, IHEP, Protvino, Russian Federation
Elizabeth Locci, CEN-Saclay, Gif-sur-Yvette, France
Thomas Lose, Max Planck Institut fur Kernphysik, Heidelberg, Germany
Michelangelo Mangano, Scuola Normale Superiore, Pisa, Italy
Evgeny Mazepa, JINR, Dubna, Russian Federation
Michael Medinnis, University of California, Los Angeles, USA
Silvio Morganti, Universita di Roma and INFN, Italy
Giuseppe Nardulli, Universita di Bari and INFN, Italy
S. Nemecek. Institute of Physics, Prague, Czech Republic
Norbert Neumeister, Institut fur Hochenergiephysik, Vienna, Austria
Yuri Potrebenikov, JINR, Dubna, Russian Federation
Jerome Rosen, Northwestern University, Evanston, USA
Mariusz Sadzikowski, Jagellonian University, Krakow, Poland
Yoshihide Sakai, KEK, Tsukuba-City, Ibaraki, Japan
Peter Sanders, University of Liverpool, UK
Roberta Santacesaria, Universita di Roma and INFN, Italy
Claudio Santoni, University of Basel, Switzerland
Peter Schlein, University of California, Los Angeles, USA
Jaroslav Sedlak, Institute of Physics, Prague, Czech Republic
Michael Shafranov, JINR, Dubna, Russian Federation
Vladislav Simak, Institute of Physics, Prague, Czech Republic
Sergei Slabospitsky, IHEP, Protvino, Russian Federation
Maria Smizanska, Institute of Physics, Prague, Czech Republic
Sheldon Stone, Syracuse University, Syracuse, USA
Leonid Tkatchev, JINR, Dubna, Russian Federation
Enzo Valente, Universita di Roma and INFN, Italy
Thomas Ypsilantis, College de France, Paris, France
Alexander Zaitsev, IHEP, Protvino, Russian Federation
Alexander Zlobin, IHEP, Protvino, Russian Federation
John Zweizig, University of California, Los Angeles, USA

Beauty 1993, Czech Republic

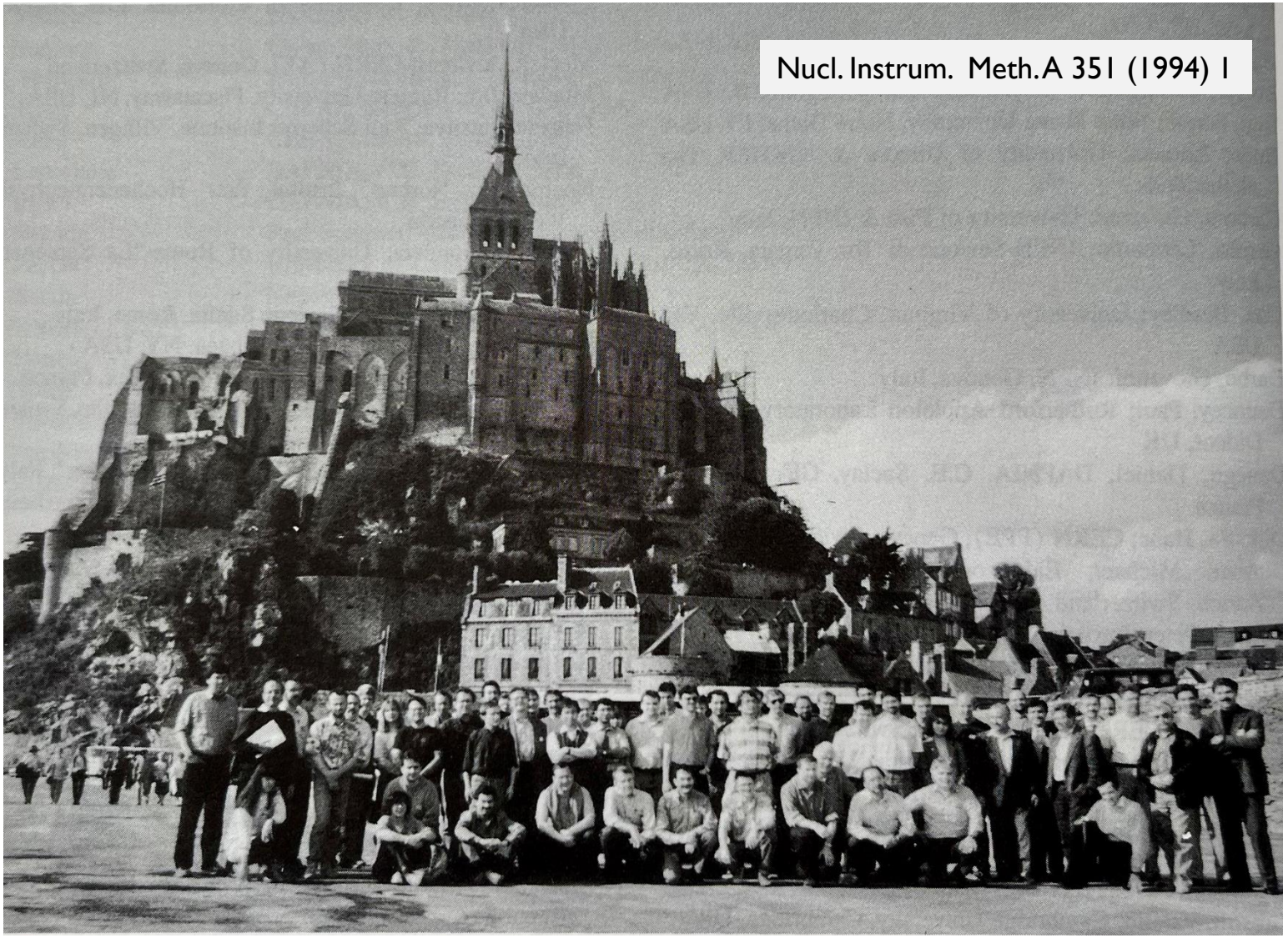


Peter Schlein
1932-2008

- Initiated by the "Father" of the Beauty conference series, Peter Schlein, and colleagues
- Began as a forum for discussion of comparison of different methods of B-physics experimentation
  - e^+e^- , LHC and the SSC, Hera-B

Nucl. Instrum. Meth. A333 (1993) 1

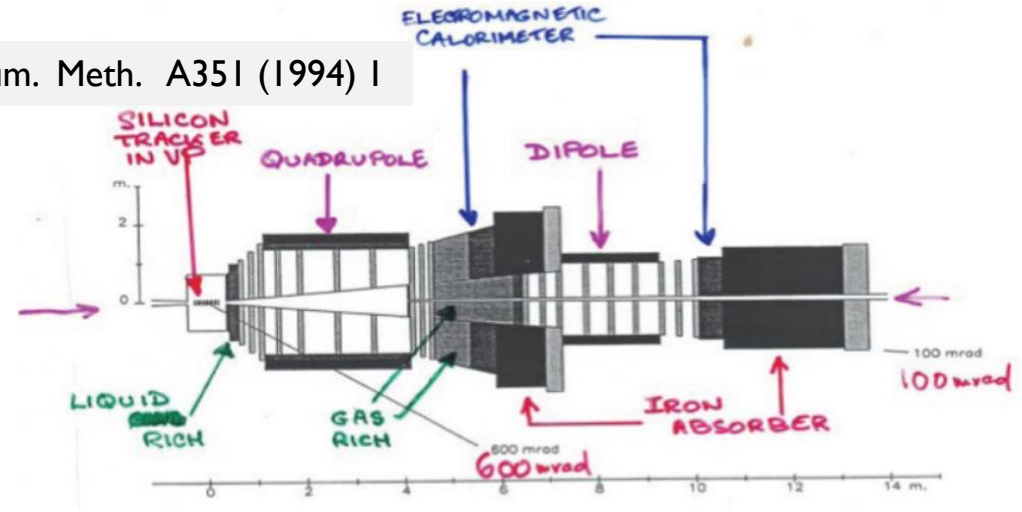
Beauty 1994 : Mont-Saint-Michel, France

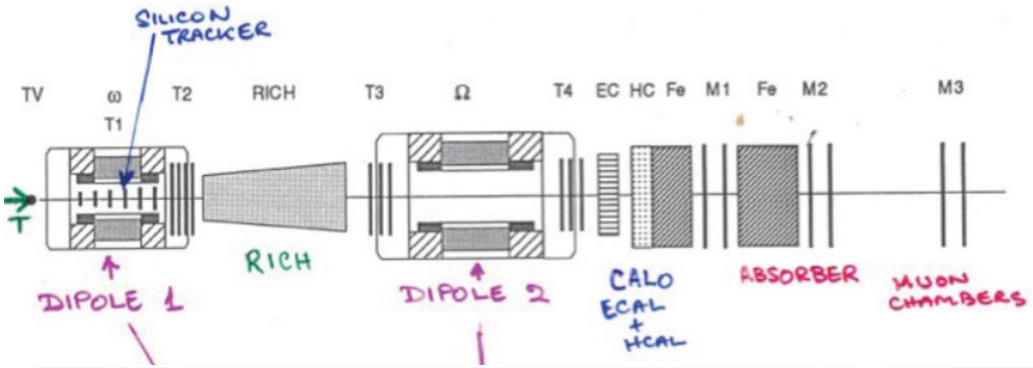


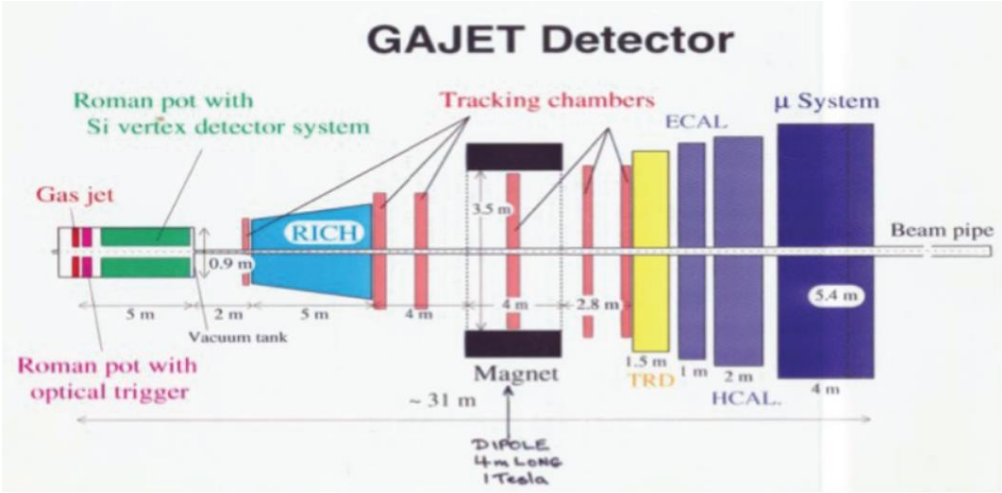
Beauty 1994

Nucl. Instrum. Meth. A351 (1994) 1

- Three proposals for B-physics at the LHC were presented (already introduced at Beauty '93)
  - COBEX (LHC Collider mode)
  - Large Hadron Beauty LHB experiment (beam extraction)
  - GAJET (internal gas jet target)
- And also HERA-B







CERN LHC Committee (LHCC) June 1994

- The LHCC discussed the relative merits of the three proposals. Conclusions (extracts):
  - None of the collaborations have the necessary resources.
  - Collider mode has the greater potential.
  - An optimized design of spectrometer does not exist yet.
  - The committee therefore encourages all participants from the three proposals to *join together* to prepare a new Letter of Intent for a new *collider-mode* b-physics experiment.

The "LHC-B" Letter of Intent

Memorandum
30th August 1994

CERN/LHCC/94-34
30 August, 1994

LHC-B

YET NOT b.

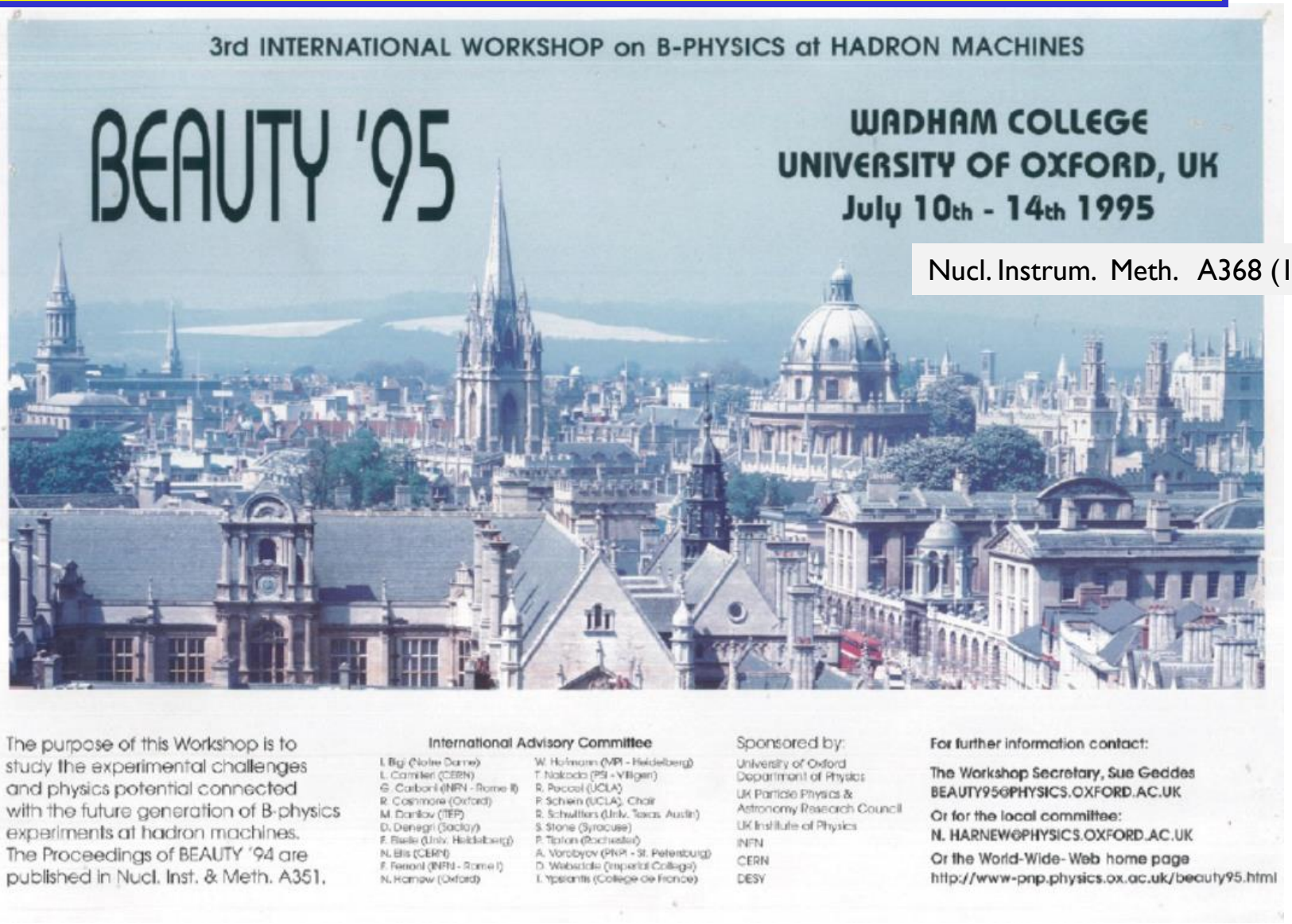
A Dedicated Collider Beauty Experiment
for the
Large Hadron Collider at CERN

MEMORANDUM

Abstract

This memorandum is in response to the request from the LHCC for a progress report, in time for their 31 August meeting, from the new B-collaboration formed around a "Dedicated B-Physics Experiment". We are pleased to report that the former COBEX, GAJET and LHB groups have successfully merged. We have already had two combined collaboration meetings and have a third scheduled for 1 September, 1994. A 6-member executive committee is in place. Working groups have been formed and are functioning constructively. We are proceeding towards completion of a Letter-of-Intent by the end of 1994. The present status of our new collaboration, which we are presently referring to as LHC-B, appears on the following pages.

The "LHC-B" Collaboration is formed

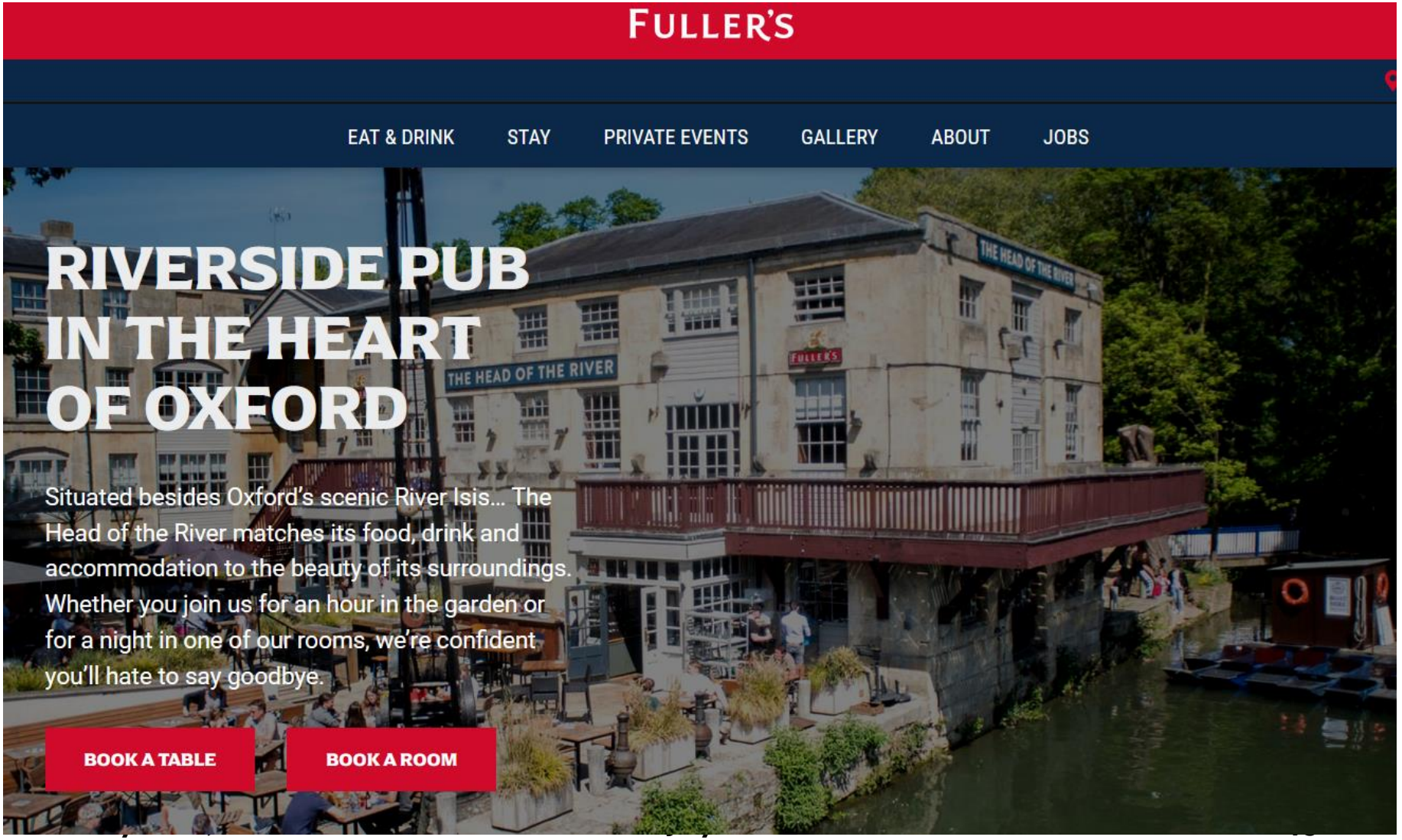


Nucl. Instrum. Meth. A368 (1996) 1

Beauty 1995 Oxford

Example of how to take a good group photo (courtesy Stuart Bebb)

A Google search : “Beauty 1995 workshop Oxford group photo”



Beauty 1996, Rome

Nucl. Instrum. Meth. A384 (1996) 1

- The Babar and Belle experiments are well in preparation
- "LHC-B" pushes towards a Technical Proposal
- BTeV at the Tevatron gets initial approval towards a Technical Proposal
- The first $B^0 \rightarrow J/\psi\ K^0_S$ signal is observed at a hadron collider (CDF)

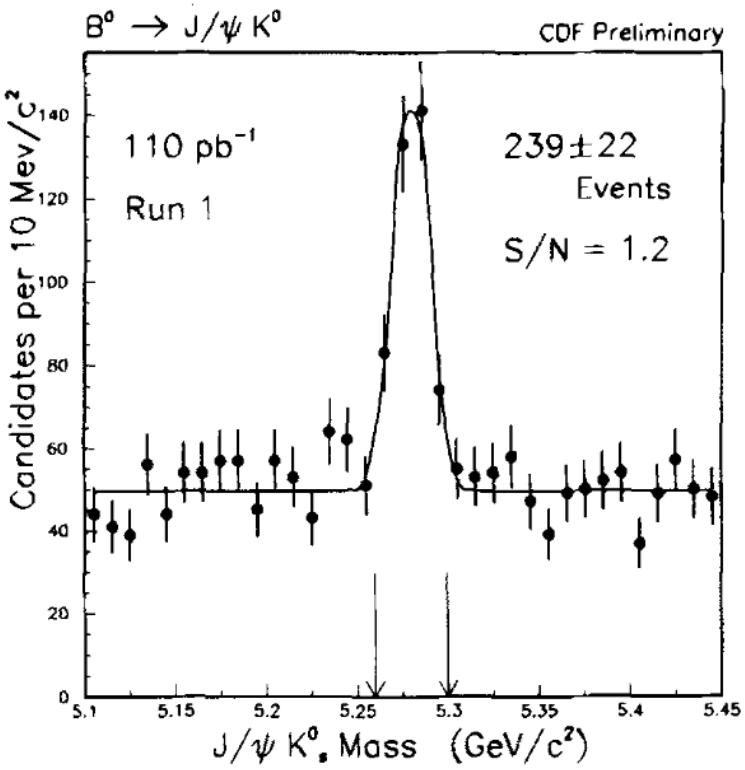
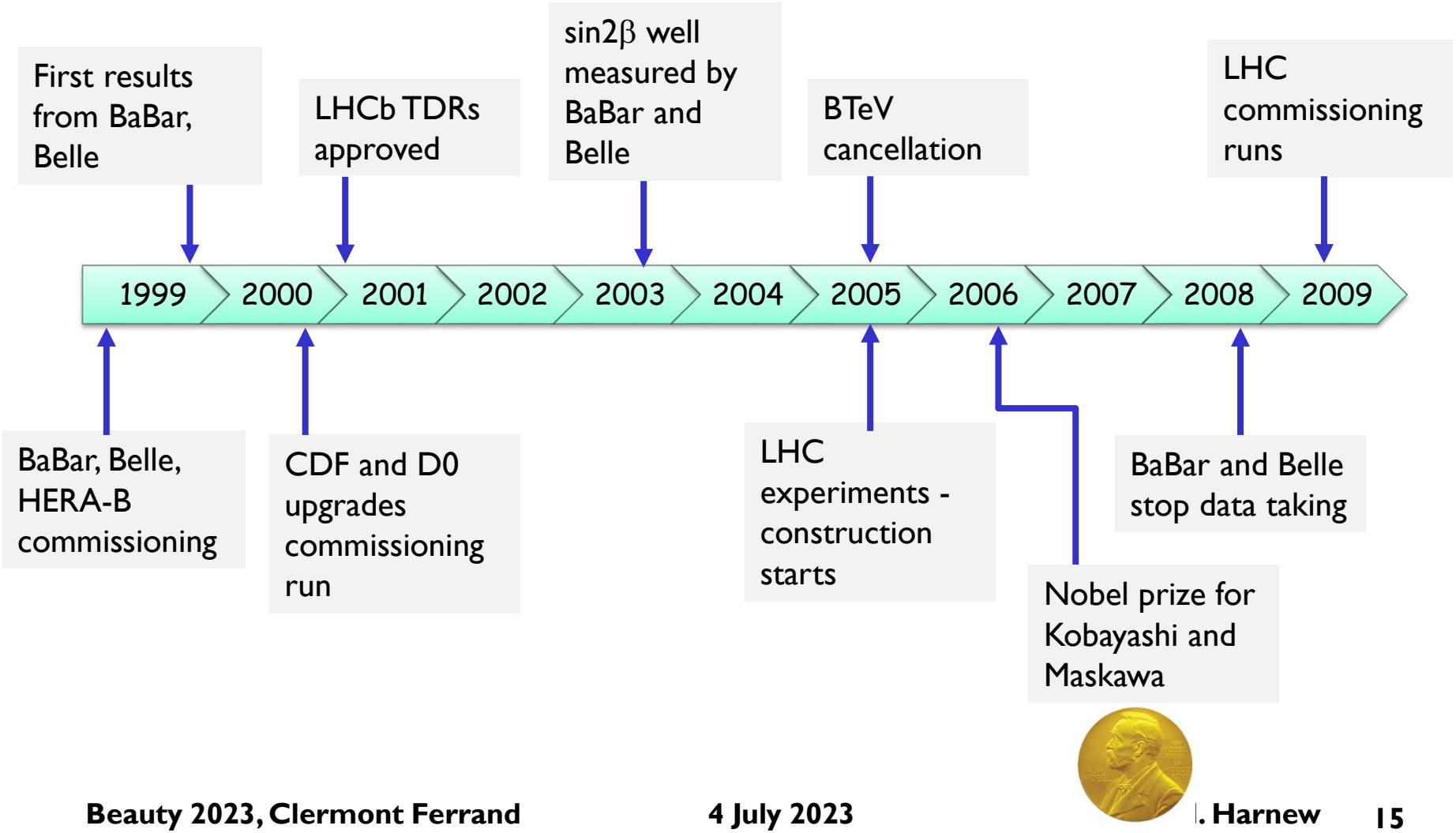


Fig. 10. The total number of B mesons collected in 110 pb^{-1} of data for the decay to $J/\psi + K^0_S$. It is from this starting point from which our arguments of CP violation reach in Run-II proceed.

Nucl. Instrum. Meth. A384 (1996) 79

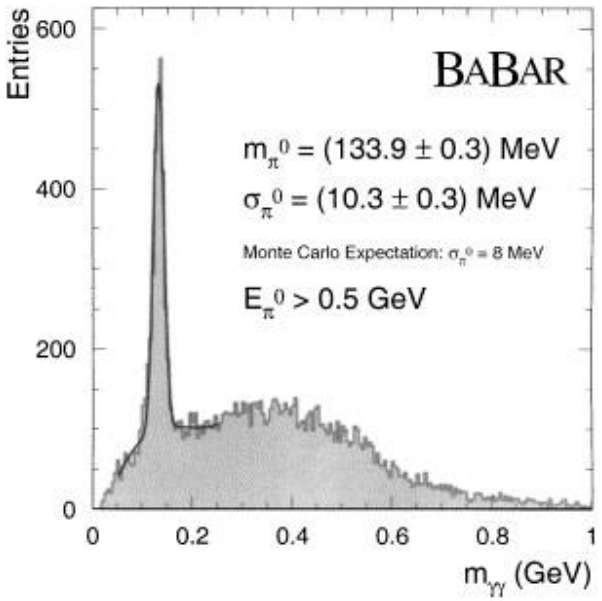
The e^+e^- and Tevatron era : 1999-2009



Beauty 1999, Bled, Slovenia.

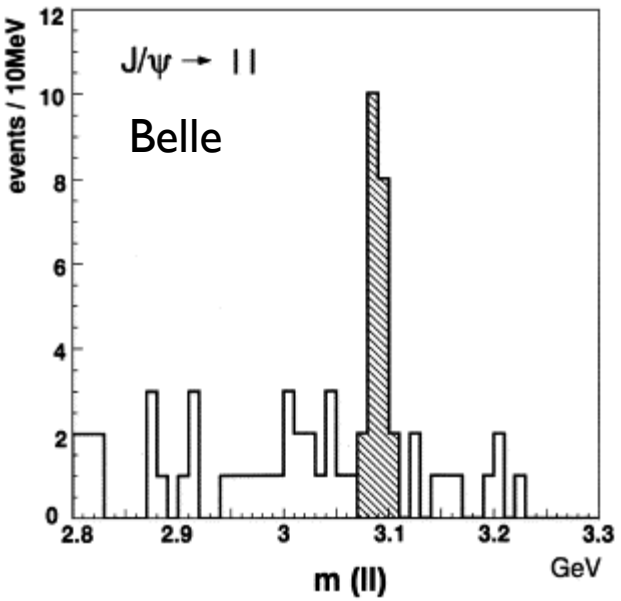
Nucl. Instrum. Meth. A384 (2000) 1

- Belle, BaBar, Hera-B commissioning and producing first results



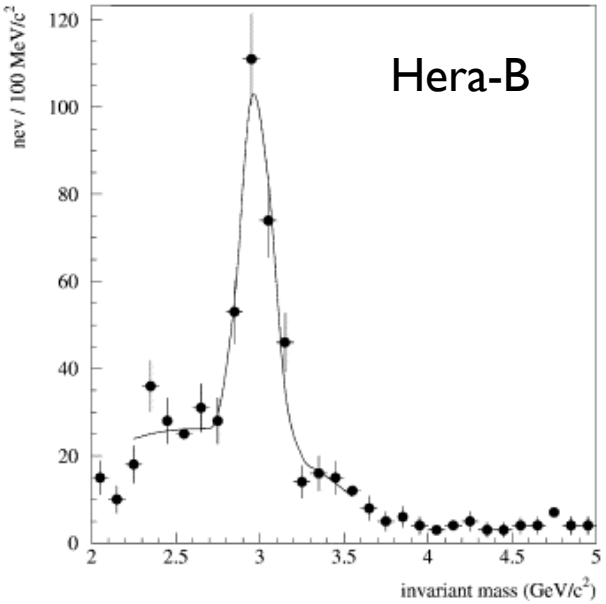
Two photon invariant mass

Nucl. Instrum. Meth. A384 (2000) 71



Two lepton invariant mass

Nucl. Instrum. Meth. A384 (2000) 75



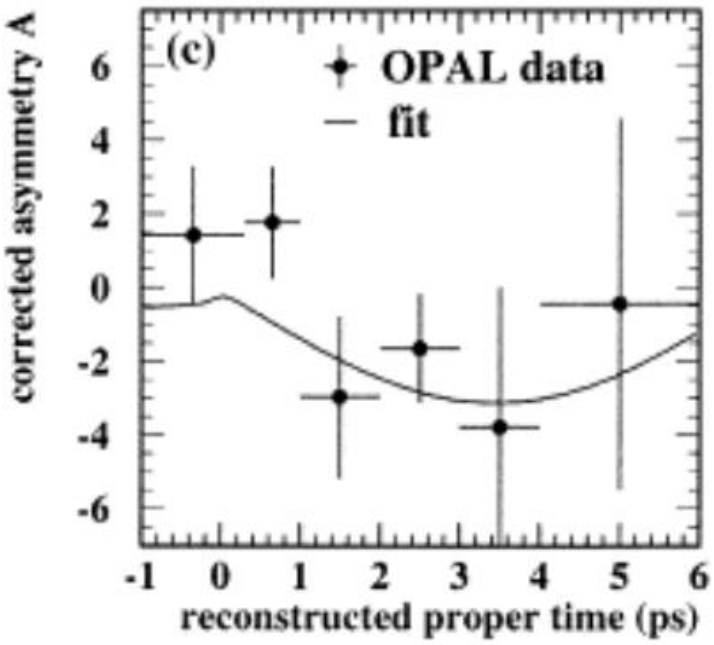
Two electron invariant mass from a common vertex

Nucl. Instrum. Meth. A384 (2000) 176

Beauty 1999, cont'

- Opal and CDF experiments provide hints of non-zero sin 2β and CP violation

sin 2β = 3.2 ± 1.9 ± 0.5



Nucl. Instrum. Meth. A384 (2000) 37

sin 2β = 0.79 ± 0.44

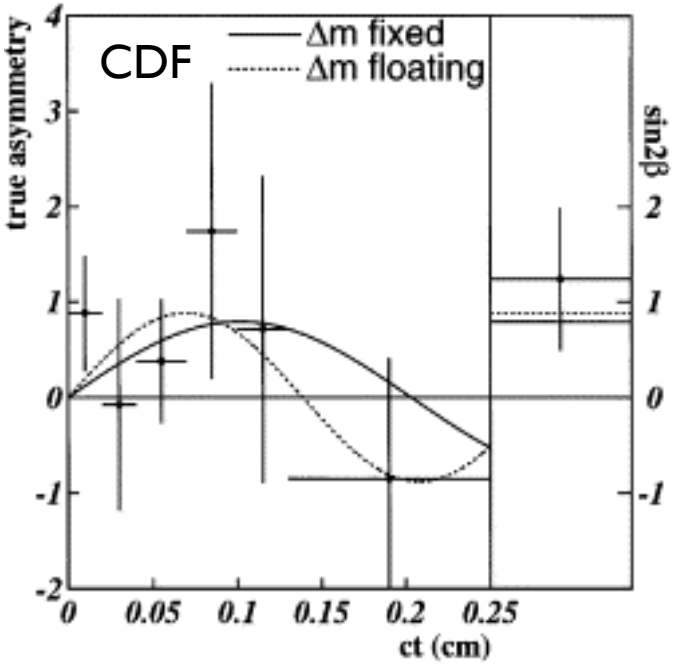


Fig. 17. The CP asymmetry in the two $B^0 \to J/\Psi K_S^0$ subsamples: on the left-hand side, as a function of the proper time, in the sample with precise *ct* information; and on the right-hand side, integrated over the proper time (a single point), in the sample with imprecise *ct* information.

Nucl. Instrum. Meth. A384 (2000) 106

Beauty 2003, Pittsburgh

- sin 2β (sin 2φ_1) at Babar/Belle well established
- Belle : sin 2φ_1 = $0.733 \pm 0.057 \pm 0.028$
- First measurements of α and γ emerging

AIP Conference Proceedings 722 (2004) 42

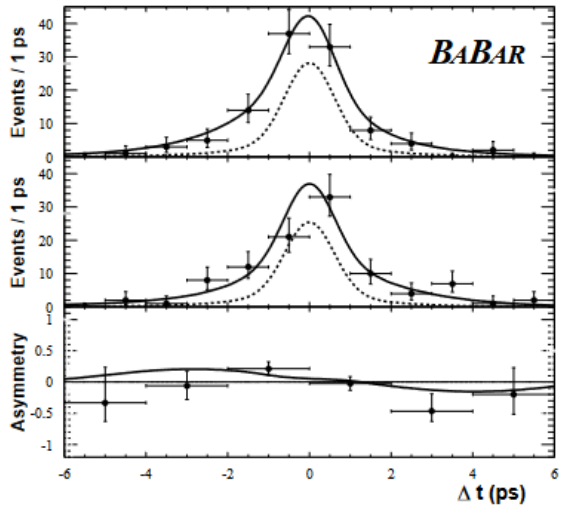
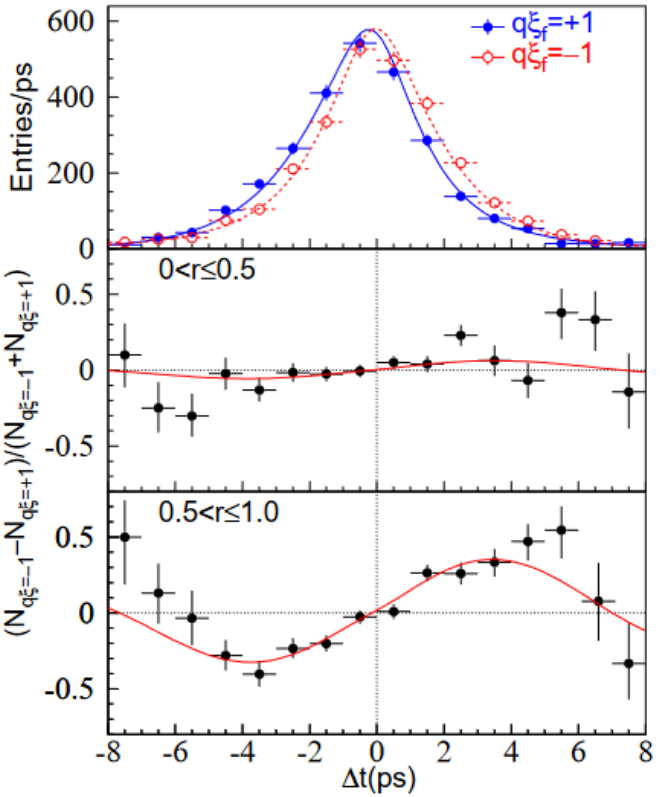


FIGURE 2. BaBar's decay-time distributions for B^0 (top) and $\bar{B}^0$ (middle) decays to $\pi^+\pi^-$ and the resulting charge asymmetry.

AIP Conference Proceedings 722 (2004) 1



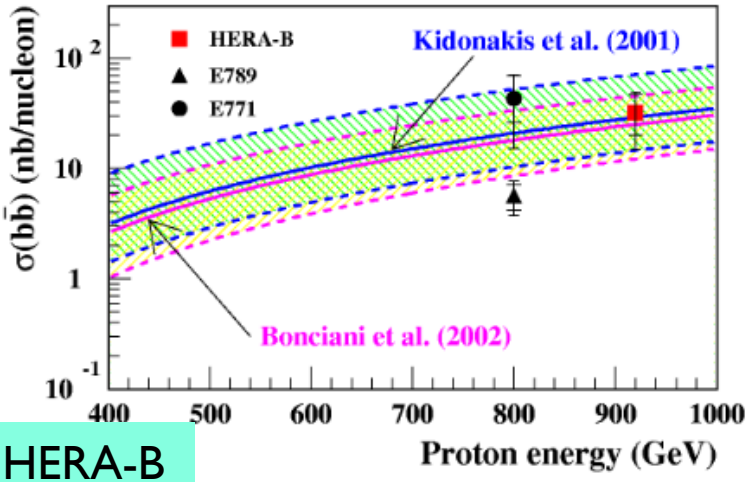
Belle

FIGURE 1. Measurement of $\sin(2\phi_1)$ using 140 fb^{-1} collected by the Belle detector. (a) Proper time difference for each flavor; $q = +1$ and -1 denotes B^0 and $\bar{B}^0$, respectively. ξ_f is the CP eigenvalue of the final states. (b) The raw asymmetry for the poorly flavor-tagged sample. (c) The raw asymmetry for the well-tagged sample.

AIP Conference Proceedings 722 (2004) 23

Beauty 2003, cont'

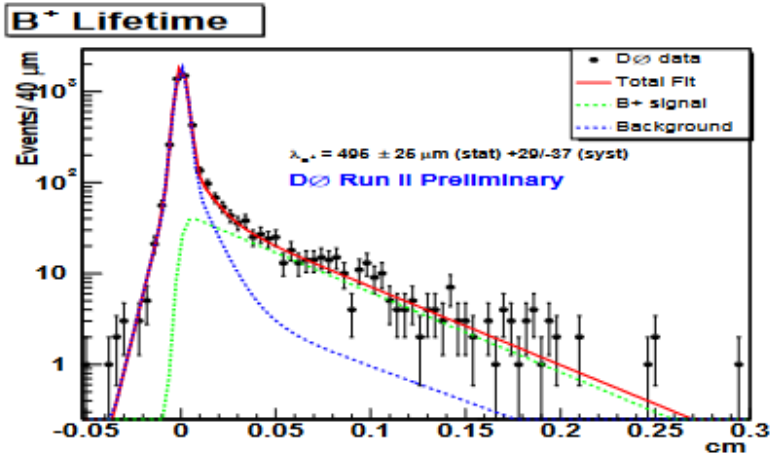
- CDF and D0 setting the standards for B physics at hadron machines
- B lifetime measurements
- But sadly Hera-B's physics output was very limited



HERA-B

FIGURE 9. Comparison of the HERA-*B* (2000) $\sigma(b\bar{b}$ measurement value with other experiments and the theoretical predictions.

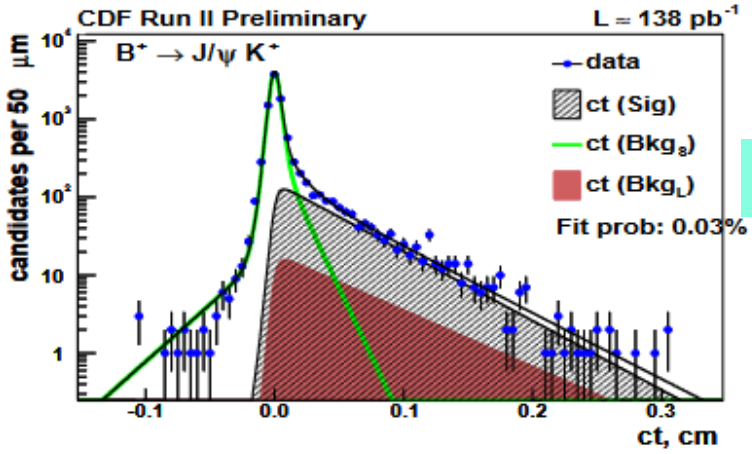
AIP Conference Proceedings 722 (2004) 57



D0

FIGURE 2. Fit result for $c\tau(J/\psi K^+)$ at DØ.

AIP Conference Proceedings 722 (2004) 167



CDF

FIGURE 3. Fit projection $c\tau(J/\psi K^+)$ at CDF.

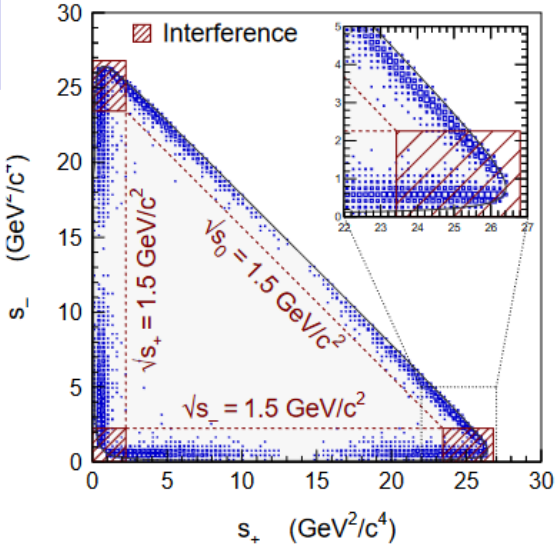
Beauty 2005, Assisi, Italy

Nucl.Phys.B Proc.Suppl. 156 (2006) 1

- BaBar and Belle make first measurements of CKM angle α (φ_2)
  - $\alpha = (103 \pm 9 \pm 11)^\circ$

- LHC experiment R&D now at an end, construction started !

- Sadly this year BTeV was cancelled by the DoE



BaBar

Figure 3. Dalitz plot for $B^0 \to \pi^+\pi^-\pi^0$ decays.

Nucl.Phys.B Proc.Suppl. 156 (2006) 29

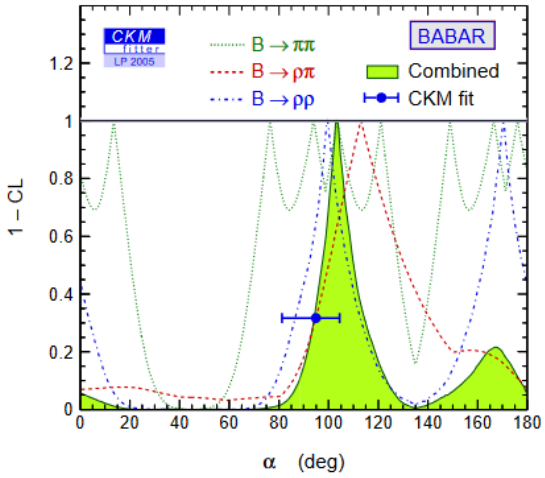


Figure 4. Confidence level versus α for all modes.

Beauty 2006, Oxford revisited

Nucl.Phys.B Proc.Suppl. 170 (2007) 1

- BaBar and Belle make first measurements of CKM angle gamma (φ_3) in $B^+ \rightarrow D^{(*)}K^{+(*)}$

BaBar	Belle
$(92 \pm 41 \pm 11 \pm 12)^\circ$	$(53^{+15}_{-18} \pm 3 \pm 9)^\circ$

Nucl.Phys.B Proc.Suppl. 156 (2006) 70

- CDF measures the B_S oscillation frequency to >5 σ : Δm_S = 17.77 ± 0.10(stat) ± 0.07(syst) ps^{-1}.

Nucl.Phys.B Proc.Suppl. 156 (2006) 129

- A quote from the Editorial (Harnew and Wilkinson)
  - "As this is the last conference in the series before the start-up of the LHC, Beauty 2006 was a timely opportunity to review the status of the field. "

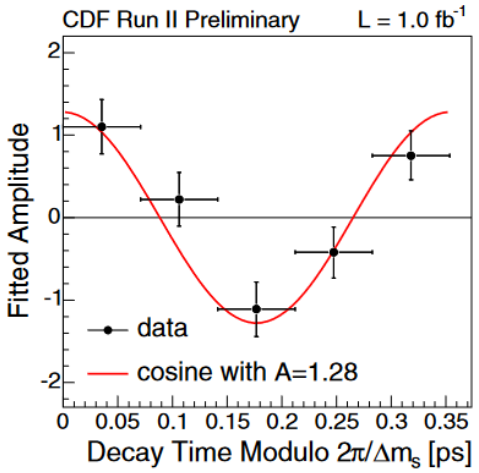


Figure 8. The $B_s^0 - \bar{B}_s^0$ oscillations signal, in the hadronic sample, measured in bins of proper decay time modulo the measured oscillation period $2\pi/\Delta m_s$. The figure is described in the text.

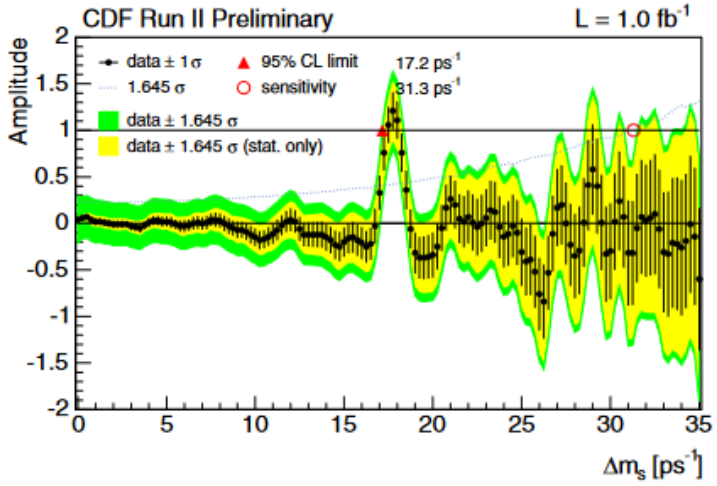


Figure 6. Δm_s amplitude scan. The dotted line represents $1.645\sigma_{\mathcal{A}}$ and indicates a sensitivity of 31.3 ps^{-1}.

Beauty 2009, Heidelberg

Proceedings of Science BEAUTY2009 (2009)

- End of data taking for BaBar and Belle (~1.5 ab^{-1} total) . An amazing legacy of results presented at the conference
  - the observation of $B \to \tau\nu$
  - the forward-backward asymmetry in $B \to K^* l^+ l^-$,
  - Beta known to 1°
  - α known to 5°,
  - γ known to better than 15°

PoS BEAUTY2009 (2009) 062

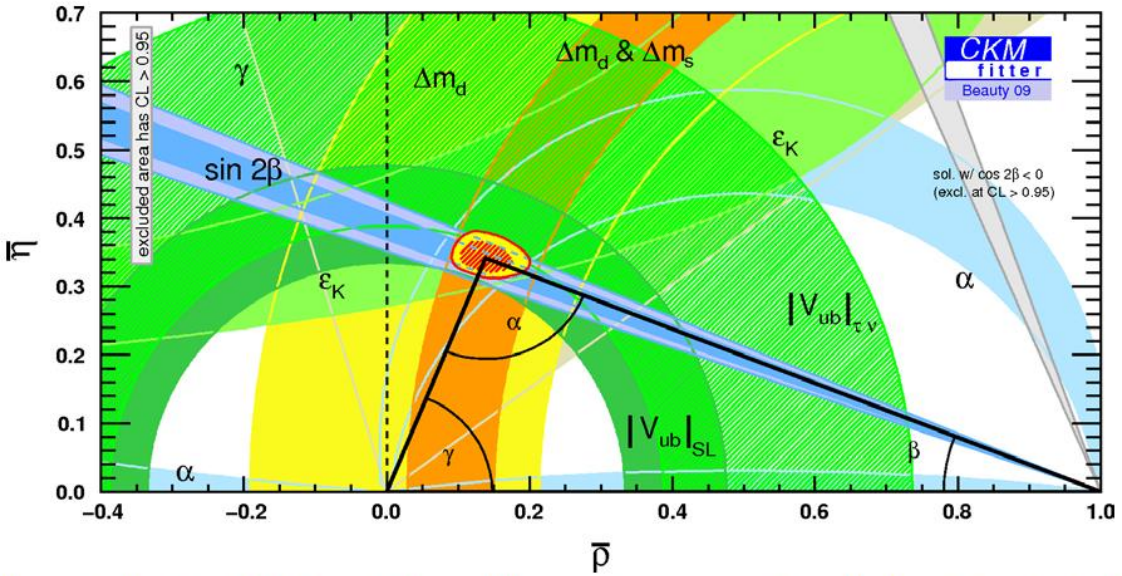
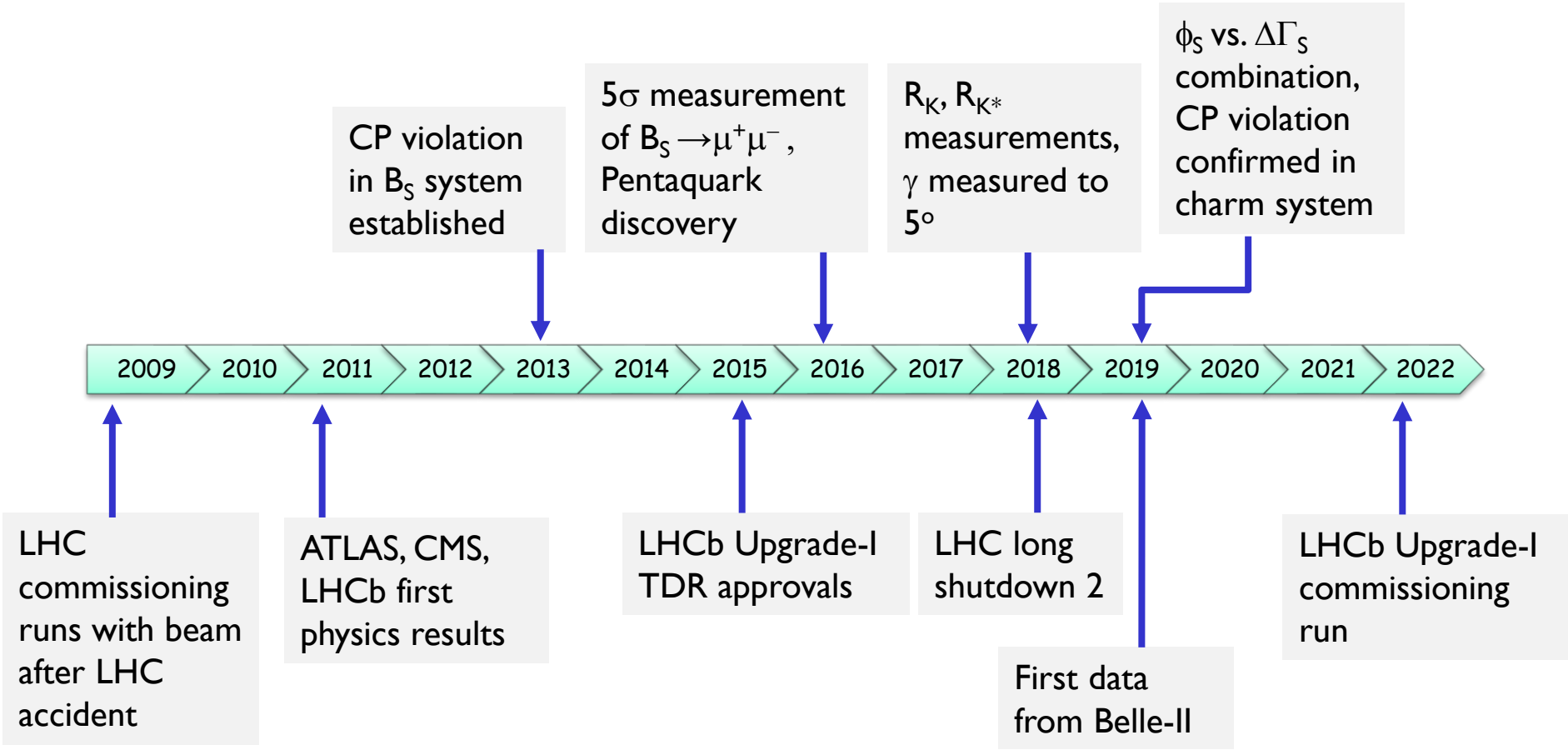


Figure 5. The state of the art, as of Beauty 2009, in constraints on ρ and η. The level of precision and level of consistency is striking.

The LHC era : 2009-2022



Beauty 2009, cont'

- First data from the LHC experiments (despite the LHC accident in 2008)
  - First lifetime measurements

Proceedings of Science BEAUTY2009 (2009)

ATLAS

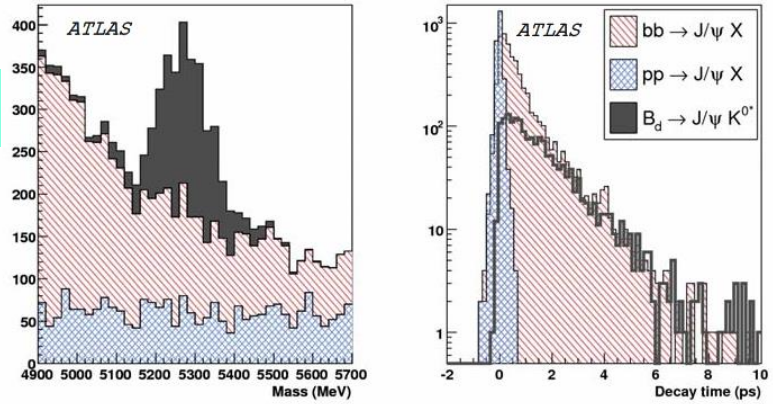
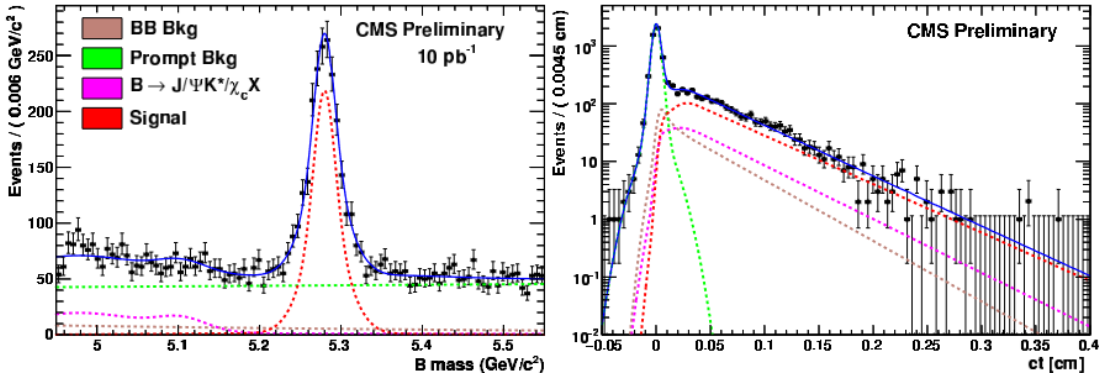


Figure 6: Distributions of the reconstructed B_d^0 mass and decay time expected with integrated luminosity of 10 pb^{-1}.

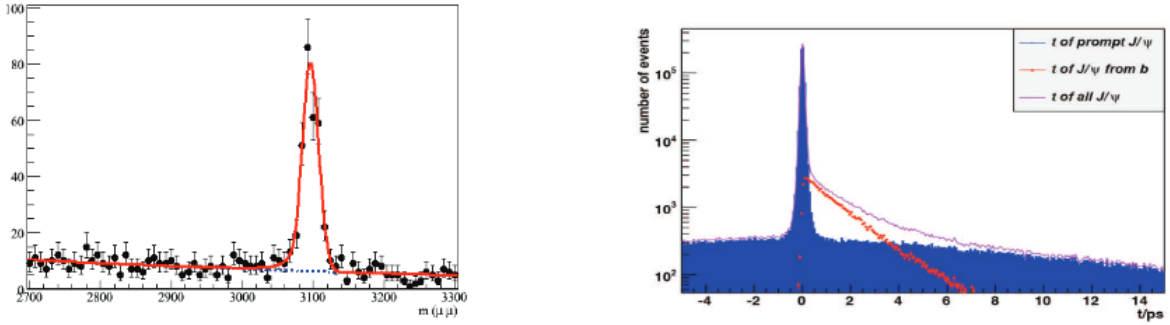
PoS BEAUTY2009 (2009) 030

CMS



PoS BEAUTY2009 (2009) 029

LHCb



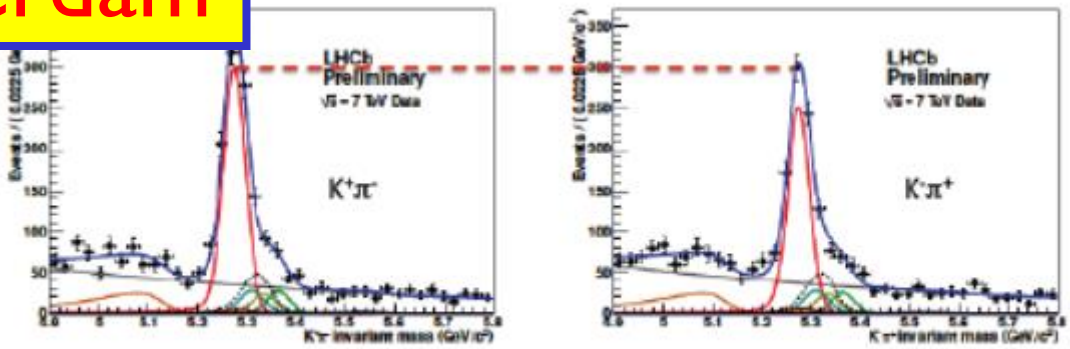
PoS BEAUTY2009 (2009) 031

Figure 6: Left: J/ψ mass distribution for 19 M MB events. The mass resolution is about 11 MeV/c^2. Right: the distribution of the discriminant variable t for prompt J/ψ and J/ψ from b decays.

Beauty 2011 Amsterdam

Proceedings of Science BEAUTY2011 (2011)

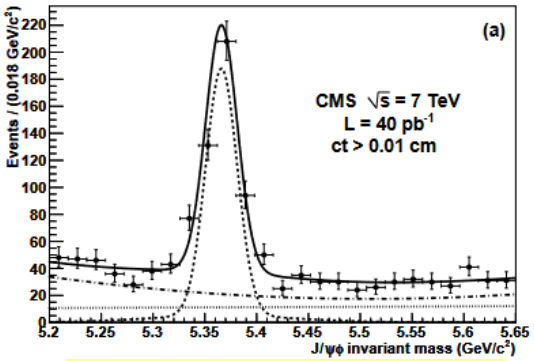
- First *physics* from the LHC experiments
  - Observation of direct CP violation in $B \to K^+\pi^-$ at LHCb
  - $B_S \to J/\psi\ \phi$ decays



Raw CP asymmetry in $B_s \to \pi K$ decays: 0.15 ± 0.19

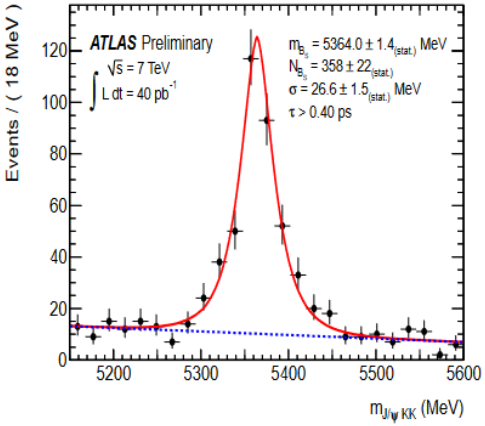
LHCb

PoS BEAUTY2011 (2011) 021



CMS

PoS BEAUTY2011 (2011) 003



ATLAS

PoS BEAUTY2011 (2011) 013

Following results from the Tevatron in 2009-2011

PoS BEAUTY2011 (2011) 043

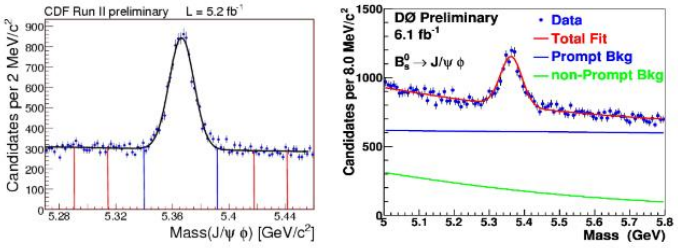
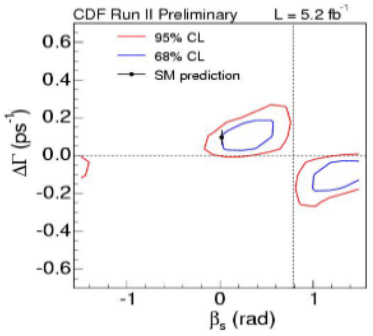
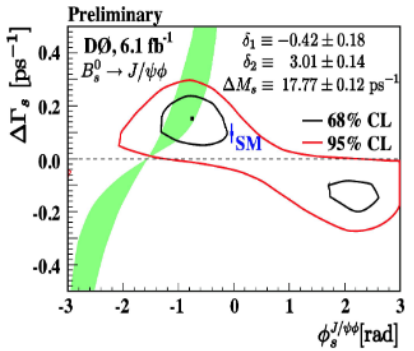


Figure 1: $J/\psi\phi$ invariant mass distribution observed by CDF (left) and DØ (right).





Beauty 2013, Bologna

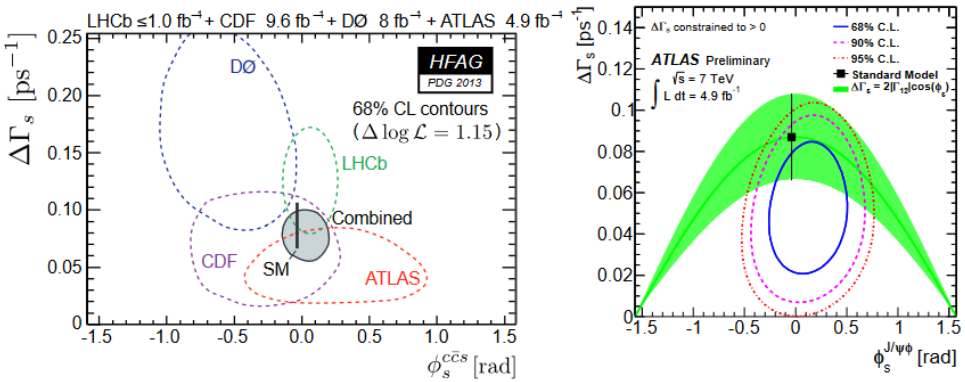
Proceedings of Science BEAUTY2013 (2013)

- The LHC experiments start to push the boundaries
  - First evidence for $B_S \to \mu^+\mu^-$ from LHCb

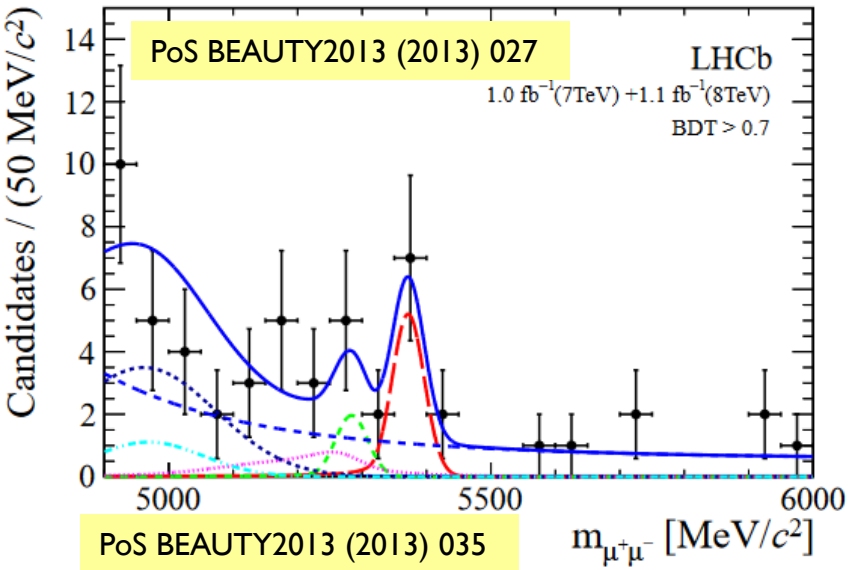
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2^{+1.4}_{-1.2}(\text{stat})^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$$

  - Much improved constraints on the B_S mixing phase in $B_S \to J/\psi\,\phi$ decays
  - D^0-$\overline{D^0}$ mixing : first >5σ observation in single experiment (9.1σ) from LHCb

ATLAS

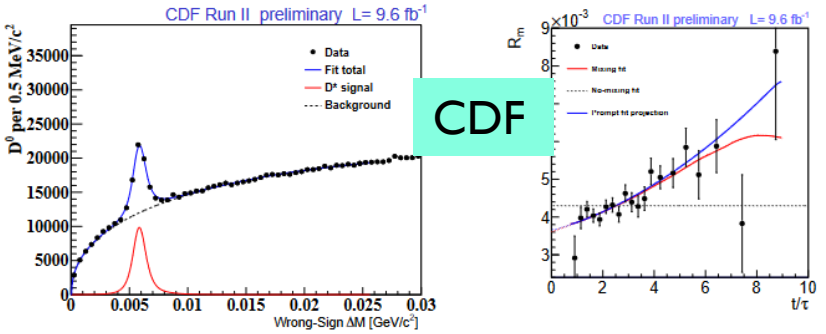


PoS BEAUTY2013 (2013) 060

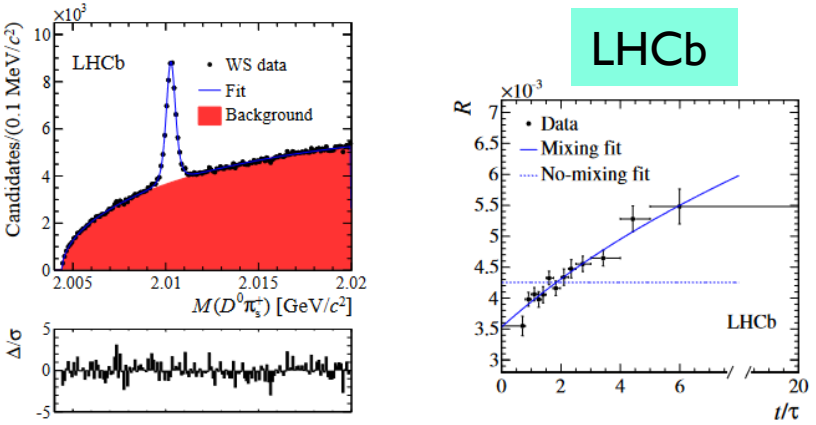


PoS BEAUTY2013 (2013) 035

CDF

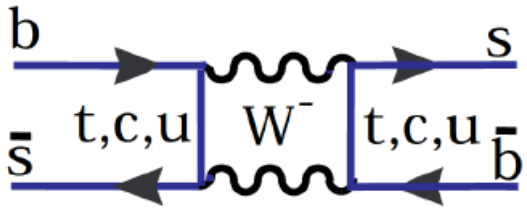


LHCb

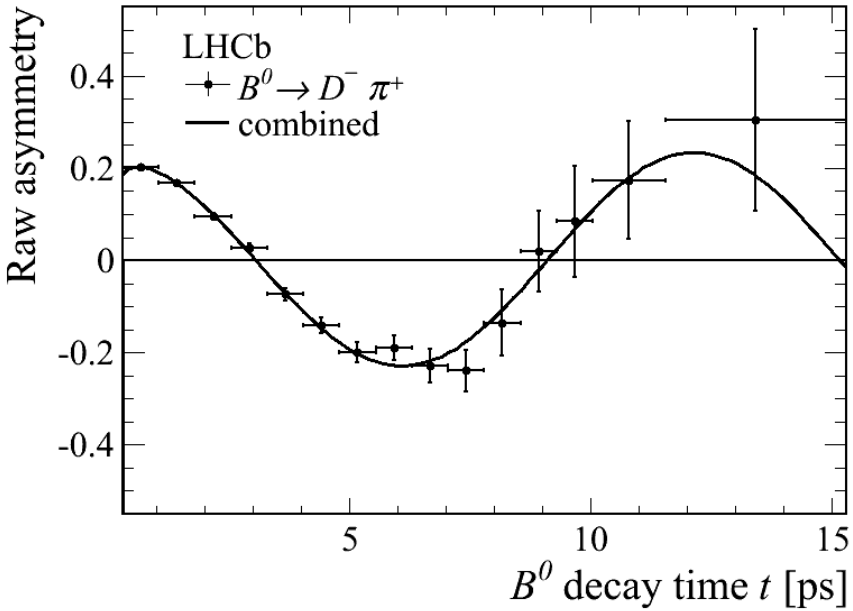


PoS BEAUTY2013 (2013) 034

and new $B_{(s)}$ mixing results

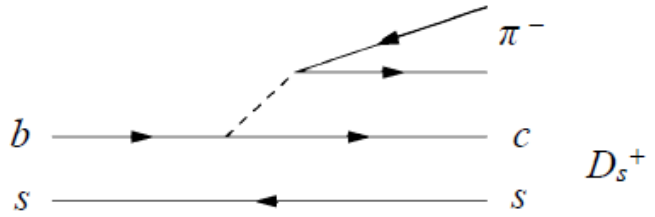


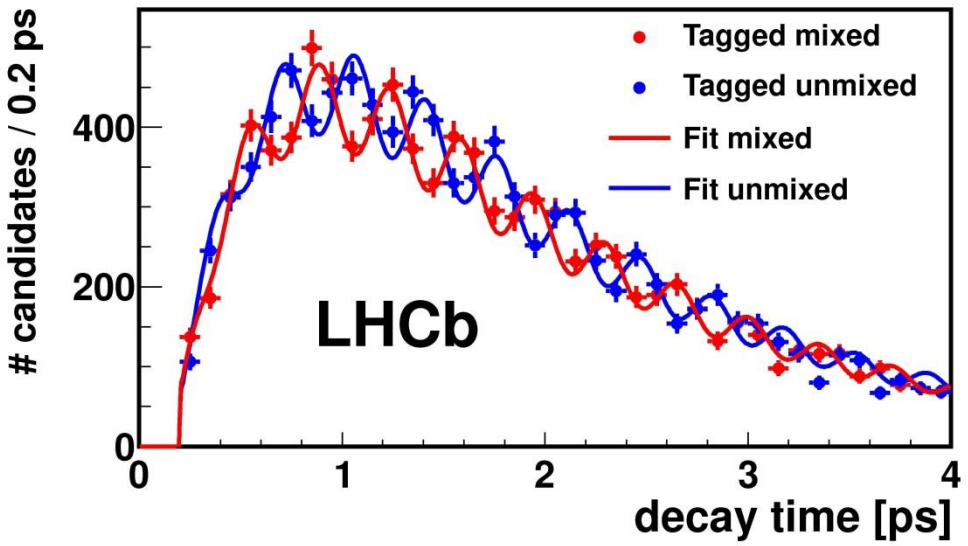
$$\frac{N(B^0 \to B^0) - N(B^0 \to \overline{B^0})}{N(B^0 \to B^0) + N(B^0 \to \overline{B^0})}$$



$\Delta m_d = 0.5156 \pm 0.0051 \pm 0.0033\ ps^{-1}$

Phys.Lett B721 (2013) 24-31





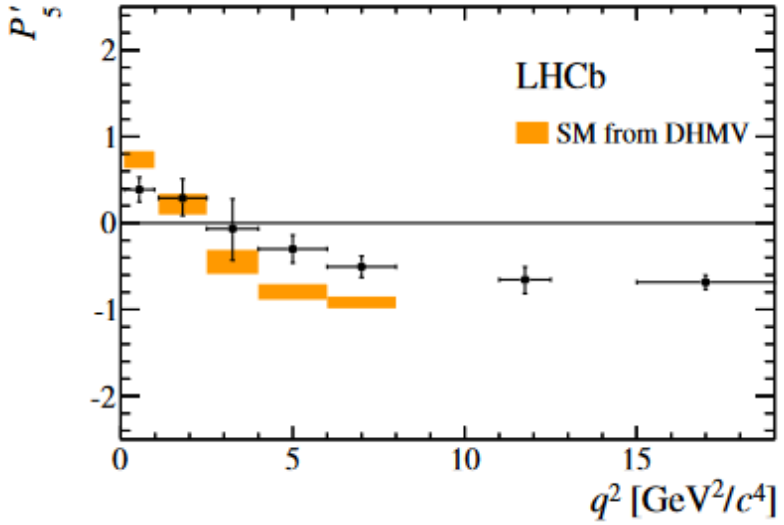
$\Delta m_s = 17.768 \pm 0.023 \pm 0.006\ ps^{-1}$

J. Phys. 15 (2013) 053021

Beauty 2014, Edinburgh

Proceedings of Science
BEAUTY2014 (2014)

- In 2014, *International Conference on B-Physics at Hadron Machines* becomes *International Conference on B-Physics at Frontier Machines*
  - Improved gamma combination measurements to 9°
  - $B \to K^* \mu\mu$ so-called P5' variable from LHCb
  - Belle-II preparation started



JHEP 02 (2016) 104

Beauty 2016 Marseille

Example of how NOT to take a group photo

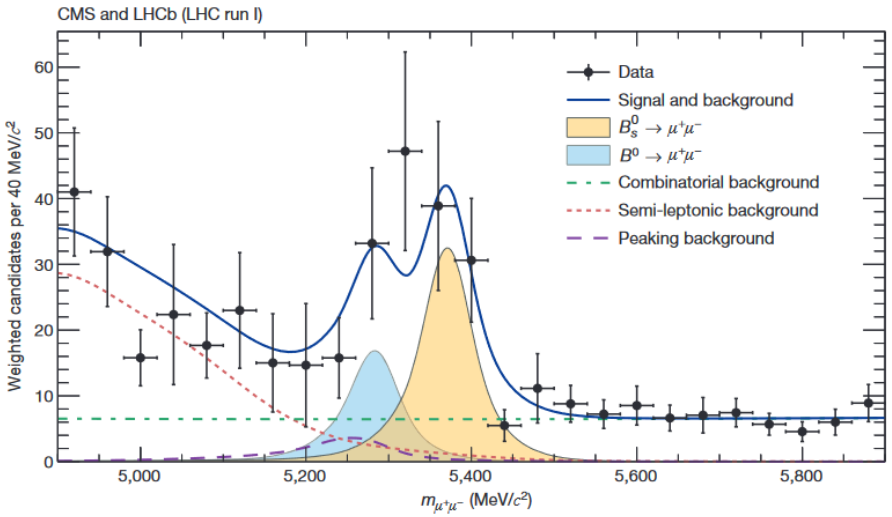
Beauty 2016, cont'

Proceedings of Science
BEAUTY2016 (2016)

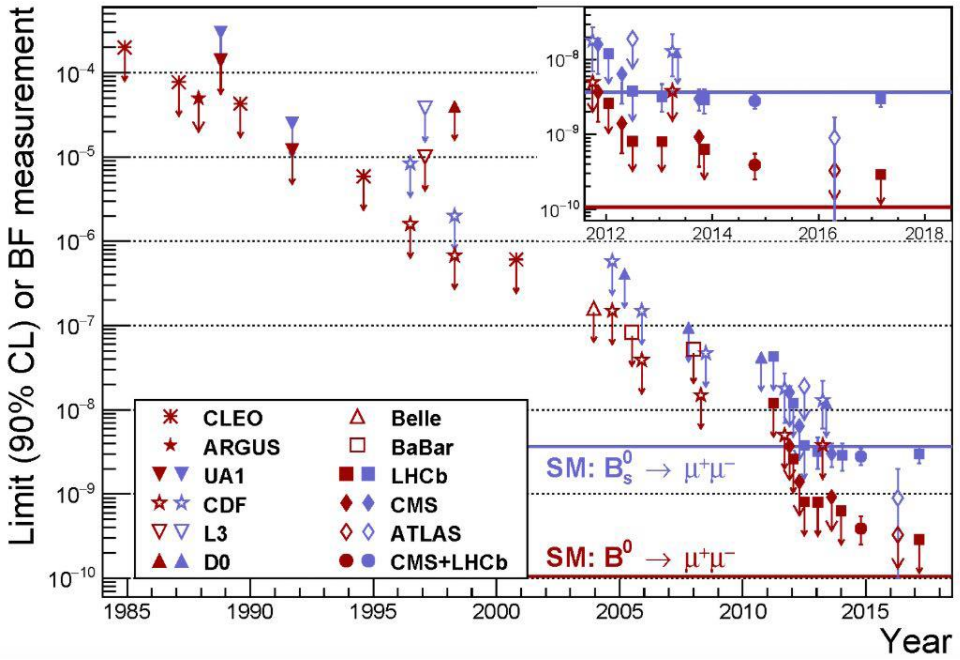
- Observation of $B_S \rightarrow \mu^+\mu^-$ and evidence for $B \rightarrow \mu^+\mu^-$ LHCb and CMS combination

The combined fit leads to the measurements $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$ and $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$

Finally after 35 years of searching !

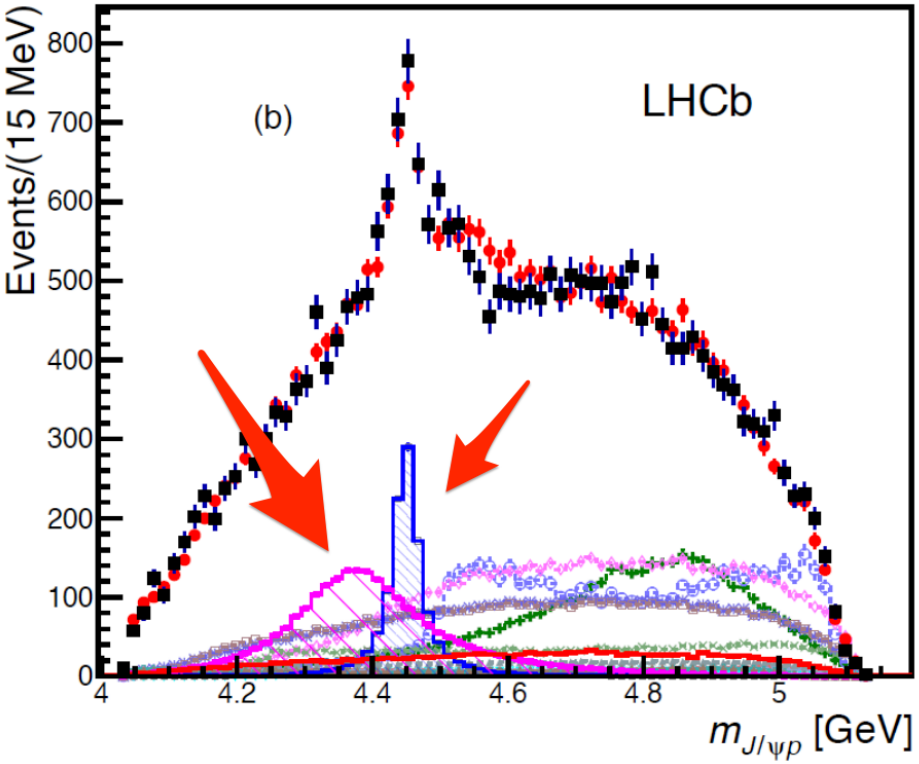


Nature 522, 68–72 (2015)

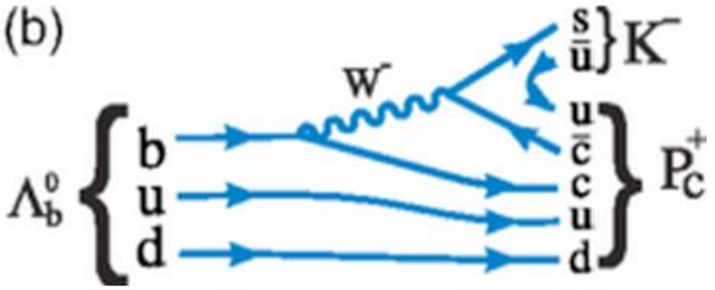


and the pentaquark discovery

PRL 115 (2015) 072001



$P_c^+ \rightarrow J/\psi\, p$



$P_c^+(4380)$: M = 4380±8±29 MeV , Γ = 205±18±86 MeV

$P_c^+(4450)$: M = 4449.8±1.7±2.5 MeV , Γ = 39±5±19 MeV

9 sigma

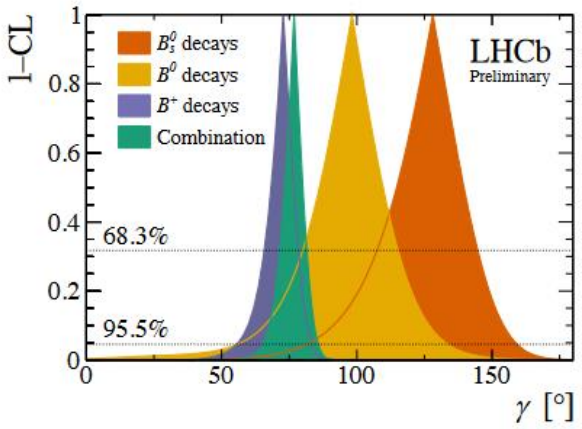
12 sigma

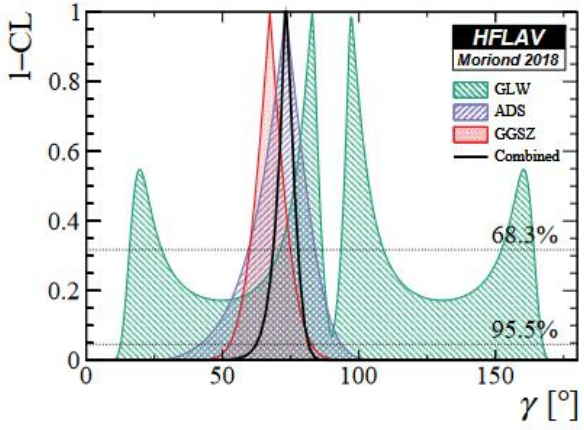
Beauty 2018, La Biodola

Proceedings of Science
BEAUTY2018 (2018)

- Gamma measured to 5°

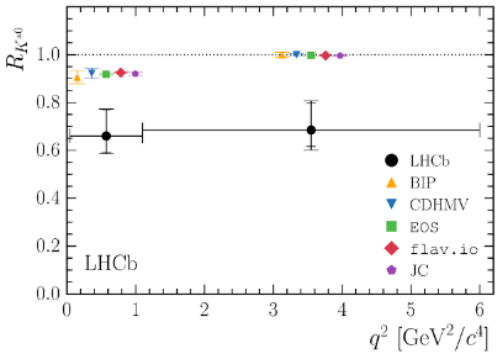
PoS BEAUTY2018 (2018) 004

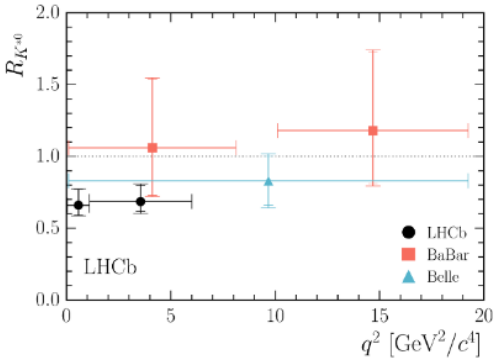




$$\gamma = (74.0^{+5.0}_{-5.8})^\circ$$

- R_K & R_{K^*} anomalies emerge at 2.5σ level. Significant excitement!





JHEP08 (2017) 055

Beauty 2019, Ljubljana, Slovenia

Proceedings of Science
BEAUTY2019 (2019)

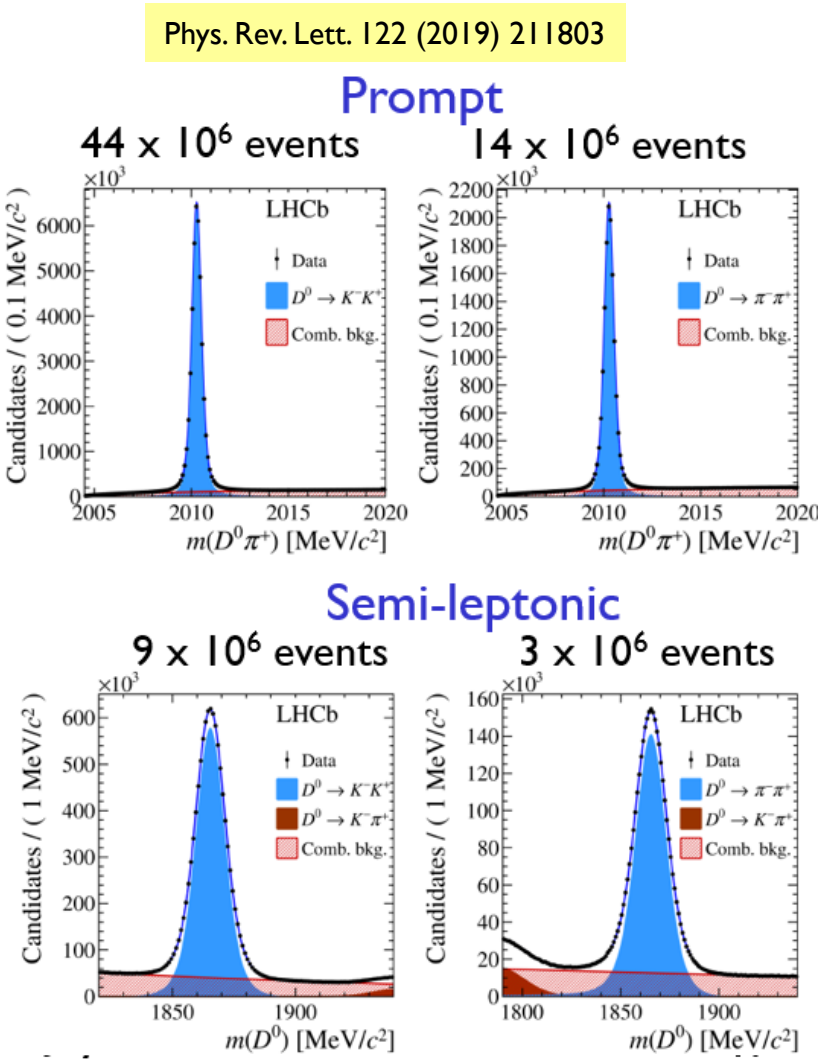
- Discovery of CP violation in charm from LHCb (5.3σ)

$$A(D \to f) = \frac{N(D \to f) - N(\bar{D} \to \bar{f})}{N(D \to f) + N(\bar{D} \to \bar{f})}$$

ΔA_{CP} = A(K⁻K⁺) - A(π⁻π⁺) = A_{CP}(K⁻K⁺) - A_{CP}(π⁻π⁺)

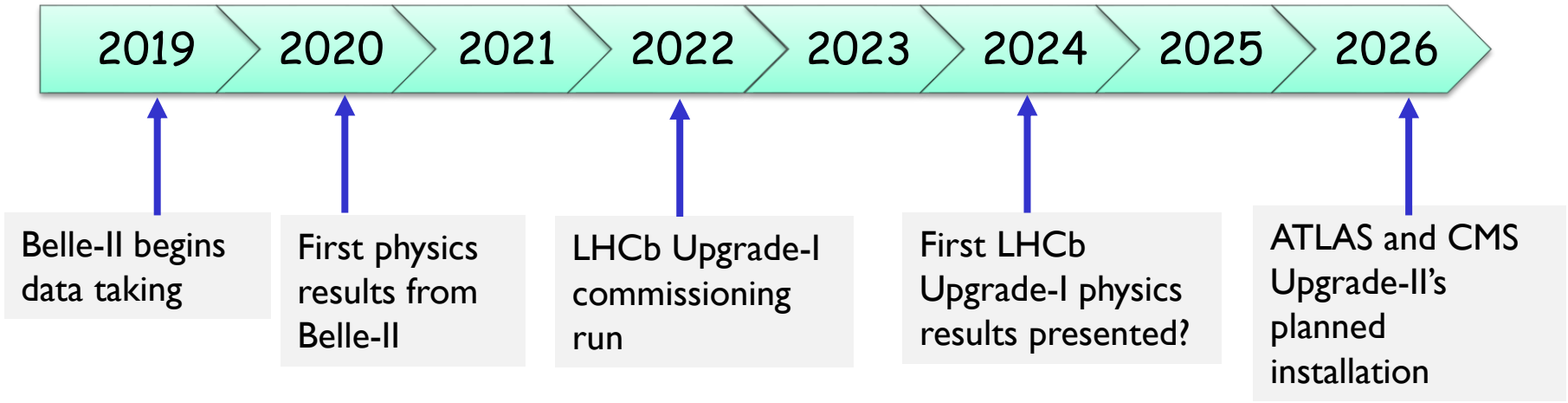
$$\Delta A_{CP} = [-15.4 \pm 2.9] \times 10^{-4}$$

Phys. Rev. Lett. 122 (2019) 211803



- Belle-II begins data taking !

The era of Belle-II and the LHC upgrades



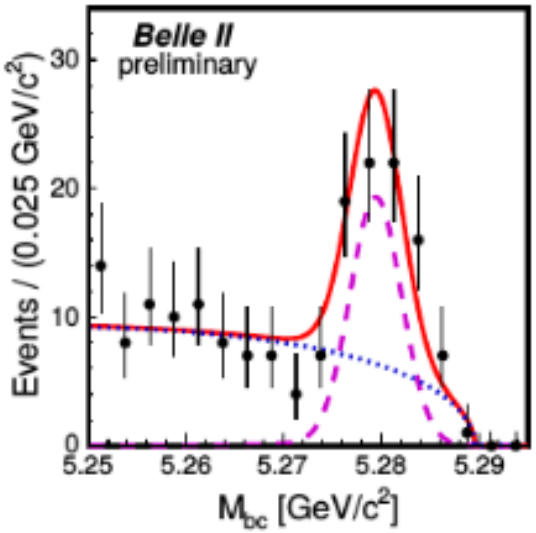
And LHCb Upgrade-II in 2033 !

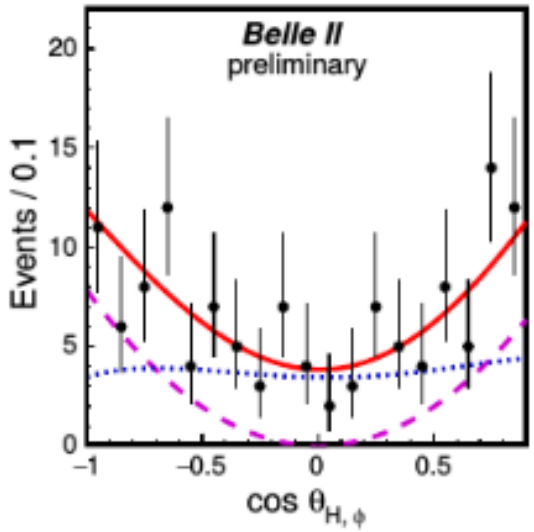
Beauty 2020, Tokyo, the first completely online conference

Proceedings of Science
BEAUTY2020 (2020)

PoS BEAUTY2020 (2020) 011

- First results from Belle-II !
- LHCb Upgrade-I in preparation (and LHC resumes operation in 2022)
- A new fresh exciting chapter for flavour physics starts !



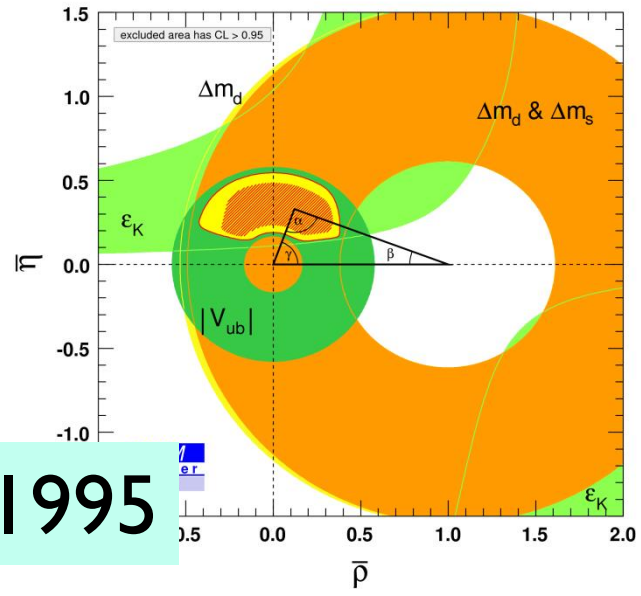


$B^+ \to \phi K^+$

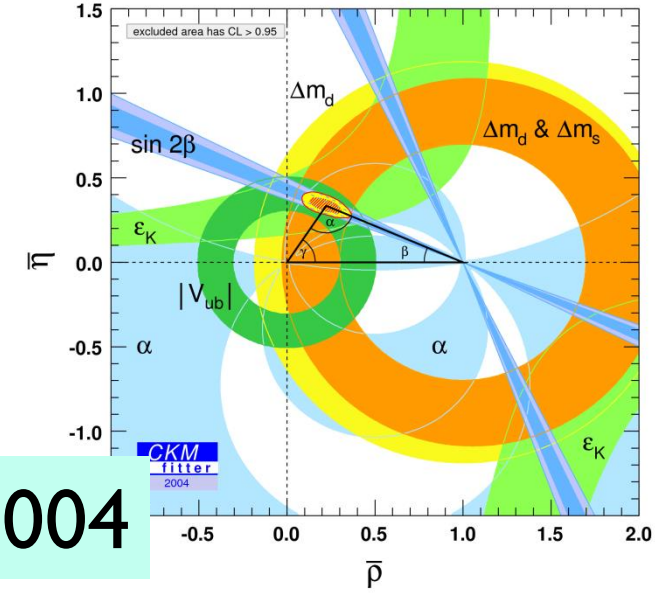
$\int L\,dt = 34.6\ fb^{-1}$

- data
- total pdf
- signal pdf
- continuum pdf

We have come a long way …



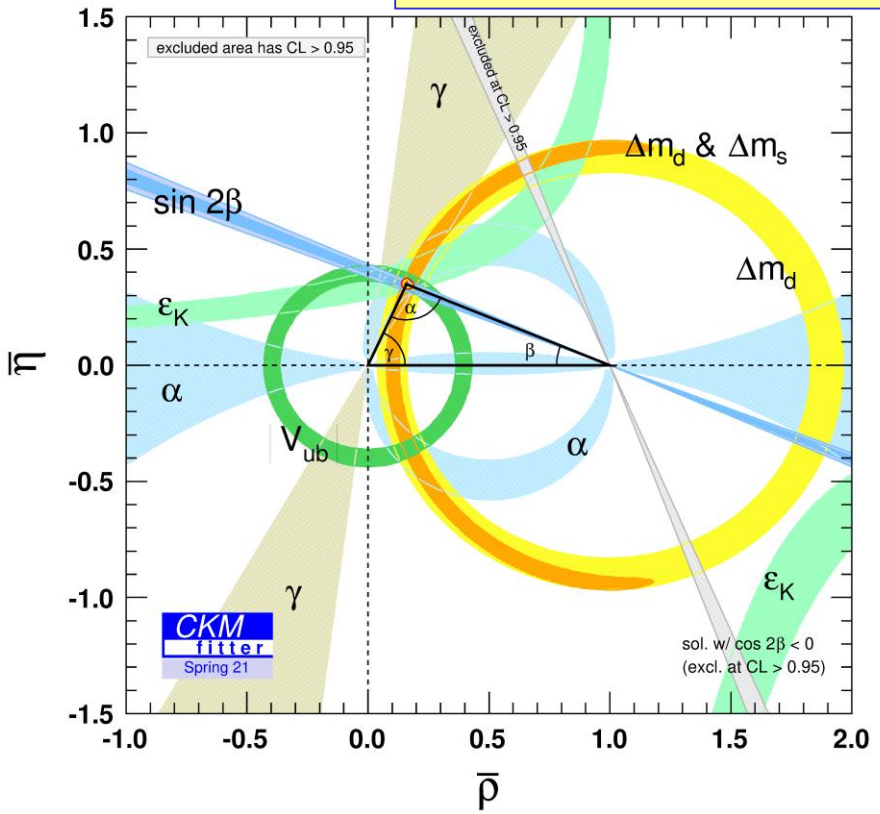
1995



2004

- Amazing progress in the last 30 years; the SM remains intact, but still a whole lot still to learn

http://ckmfitter.in2p3.fr



Today (dominated by LHCb for now)

Beauty 2023, Clermont Ferrand

Many more exciting new results !

Summary

- The Beauty conferences have always seen an enlightening mixture of theory and experiment (apologies to theoretical colleagues that I didn't highlight their many excellent contributions)

- The field of Flavour Physics has taken a huge leap over the conference's 30 year history
  - Exciting experimental developments
  - Unitarity Triangle measurements are consistent with the Standard Model and new physics is becoming constrained
  - Rare decays measured down to the one in a billion level, and whole families of new particle states
  - Nevertheless, there is still need for increased precision which Belle-II and the LHC upgrades will provide in future years

- We look forward to the next 30 years of Beauty conferences !