A Brief History of B Physics (in the UK)

From Before KM…

…to After the LHC?

Steve Playfer

IoP Half-day meeting, Lancaster, November 12th 2008

The Dark Ages (1960s)

Once upon a time there were only three quarks (u,d,s) and one mixing angle

1963 $\sin\Theta_c = 0.26$ (Cabibbo, PRL 10, 531)

1964 – Discovery of CP violation in neutral Kaons (Christenson et al, PRL 13,138)

Small and unexpected asymmetry $|\varepsilon| = 2.3 \times 10^{-3}$

1967 – Sakharov (JETP 5,24) proposes three conditions for baryon asymmetry of universe
One of these is CP violation, but the Kaon asymmetry is not enough!

1972 and all that…

The Nobel Prize in Physics 2008

1/2 to Kobayashi & Maskawa

(Prog. Theo. Phys. 49,2,652)

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

"…as late as 2001, the two particle detectors BaBar and Belle detected broken symmetries independent of each other… exactly as Kobayashi & Maskawa had predicted"

The Middle Ages (1974-1983)

1974 - Discovery of the J/ψ at Brookhaven/SLAC

Evidence for c quark (PRL 33,1404 & 1406)

1977 - Discovery of the Y(1S) at Fermilab

Evidence for b quark (PRL 39, 252)

1983 - Reconstructed B mesons at CLEO/CESR

$M(B_d) = (5274 \pm 2 \pm 2)$ MeV/c^2 (PRL 50, 881)

1983 - Measurement of b quark lifetime at PEP

$\tau_b = (1.2 \pm 0.4 \pm 0.3)$ ps (PRL 51, 1316)

Before 1983 the New World (of B Physics) was unknown to Europeans?

The Renaissance (1981-1987)

1981 - Bigi & Sanda note the observability of CP violation in B decays (NPB 193, 85)

The Reformation of B physics begins at DESY

1986 - Observation of B_d mixing by ARGUS
$\chi_d = 0.17 \pm 0.05$ (PLB 192, 245)

1986 - Bigi & Sanda make predictions based on large B_d mixing (NPB 281, 41)

The Age of Enlightenment (1989-1999)

- LEP at CERN produces millions of Z bosons
  - LEP experiments (ALEPH, DELPHI, L3, OPAL) collected 2M events each
  - 15% of Z bosons decay to b quarks
  - All types of B hadrons are produced
  - Large boost of b quarks in lab frame

- SLC at SLAC produces a few 100k Z bosons (SLD)
  - Polarized e^+/e^- beams
  - Precision vertexing with CCDs (built in UK)

- LEP Heavy Flavour Working Group
  - Founded in 1999 to combine results
  - Precursor of HFAG

The CLEO (R)evolution

1982 - CLEO 1 collects 10^4 Y(4S)->BB events

1993 - CLEO II collects 10^6 Y(4S)

New tracking and CsI calorimeter.

Only 1 Interaction Region in CESR.

2001 - CLEO III collects 10^7 Y(4S)

New tracking and RICH detectors.

Important B Physics results (1990s)

- Forward-backward asymmetry in Z->bb
- Precision measurements of B lifetimes
- Time-dependent B_d mixing
  (and search for B_s mixing)
- Measurements of V_{cb} and V_{ub} from
  semileptonic b->clv and b->ulv decays
- Radiative Penguin decay b->sγ (CLEO 1993)
- Charmless hadronic B decays B->Kπ/$\pi\pi$

The Industrial Revolution (1993-2008)

Between 1986 and 1993 there were at least
21 e^+e^- B factory concepts and proposals
(Jonathan Dorfan, B factory Symposium 27/10/08)

- Symmetric Storage Rings (PSI, Novosibirsk)
- Asymmetric Rings (ISR, PEP-II, KEK-B, CESR-B)
- Colliding Linacs (UCLA, Amaldi/Coignet)
- Linac+Ring (JLAB)

The industrial revolution eventually took
place at PEP-II and KEK-B

BaBar and Belle

Collisions at the Y(4S) with asymmetric energies used to boost B mesons in lab frame

PEP-II: 9 GeV e^- on 3.1 GeV e^+
KEK-B: 8 GeV e^- on 3.5 GeV e^+

Total data recorded ~10^9 BB pairs (1999-2008)

BaBar: 531/fb of which 433/fb Y(4S), 30/fb Y(3S)

Belle: 862/fb of which ~730/fb Y(4S), ~30/fb Y(5S)

BaBar and Belle detectors operated in "factory" mode with good vertexing, particle ID and calorimetry

- Observation of CP violation in $B \to J/\psi K_s$ (2001)
  $\sin 2\phi_1 = 0.58 \pm 0.33 \pm 0.10$ (Belle PRL 86, 2509)
  $\sin 2\beta = 0.59 \pm 0.14 \pm 0.05$ (BaBar PRL 87, 091801)

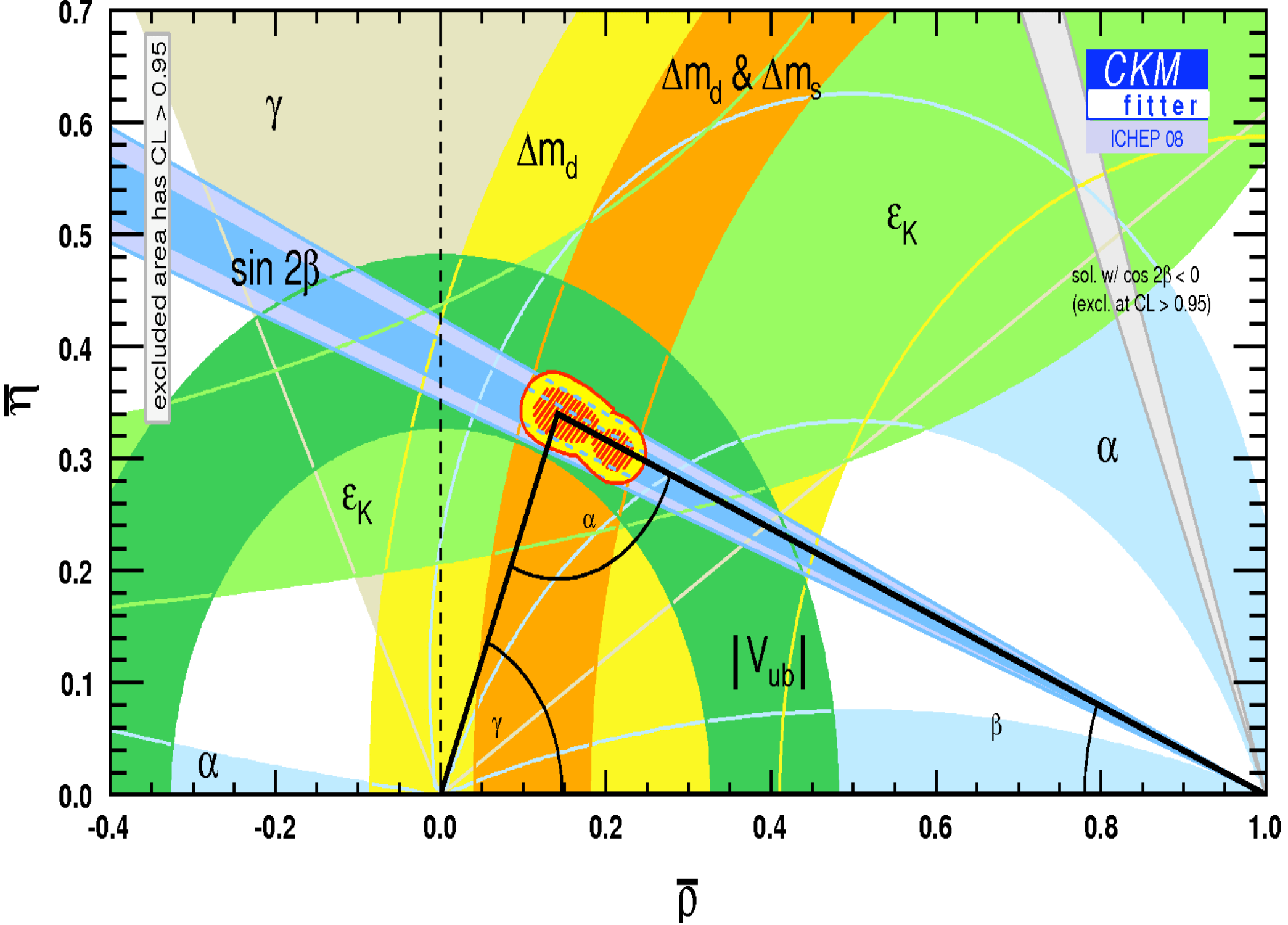
- Direct CP violation in $B \to K\pi$ (2004)
  (BaBar PRL 93, 131801, Belle PRL 93, 191802)

- Evidence for D mixing (2007)
  $D \to K\pi/\pi K$: time-dependence (BaBar PRL 98, 211802)
  $D \to K\pi/KK$: $y = (1.31 \pm 0.32 \pm 0.25)\%$ (Belle PRL 98, 211803)

- Measurement of angle α from $B \to \pi\pi/\rho\pi/\rho\rho$

- Time-dependent CP violation in hadronic (and radiative) penguin decays

- Rare decays $b \to d\gamma$, $b \to s l^+ l^-$ and $B^+ \to \tau^+ \nu$


CKM
fitter
ICHEP 08
excluded area has CL > 0.95
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
γ
Δm_d & Δm_s
Δm_d
ε_K
sin 2β
α
ε_K
α
|V_ub|
γ
β
α
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
η̄
ρ̄

The B(ritish) Empire (1989-2008)

There are no b quarks in the UK–
we have to import them from overseas!

UK physicists have colonized most of the world's laboratories (CERN, SLAC, FNAL, DESY)

We sent a few missionaries to KEK and CLEO

Major population centres in 2008:

BaBar (10 institutions/~50 members)
CDF/D0 (7 institutions/~80 members)
LHCb (8 institutions/~120 participants)
ATLAS/CMS (17 institutions/~400 participants)

B Physics at Hadron Colliders

Proton-antiproton collisions at E_{CM}~2 TeV at Tevatron (Fermilab)
Run 1: 1993-1996 Run 2: 2001-2009/10?

σ_{bb} (p_T>5GeV, |y|<1) ~1.5nb

CDF and D0 have collected 2.8/fb each
(~10 Million high p_T b quarks)

Proton-proton collisions at E_{CM}~14 TeV at LHC (CERN) starting in 2009

ATLAS and CMS can measure high p_T b quarks
LHCb is a dedicated forward spectrometer

Important results from Tevatron

- Discovery of top quark (1995)
  $m_t = 176 \pm 8 \pm 10$ GeV (CDF PRL 74, 2626)

- Observation of Bs mixing (2006)
  $17 < \Delta m_s < 21/ps$ (D0 PRL 97, 021802)
  $\Delta m_s = 17.77 \pm 0.10 \pm 0.07/ps$ (CDF PRL 97, 242003)

- Bs semileptonic charge asymmetry
  $A_{SL} = (1.23 \pm 0.97 \pm 0.17) \times 10^{-3}$ (D0 PRL 98, 151801)

- Constraints on Bs lifetime difference $\Delta\Gamma_s$ and Bs mixing phase $\phi_s = 2\beta_s$

- Masses and lifetimes of B_s, B_c, Λ_b

LHCb

Angular coverage Θ<300mrad

(most bb pairs are in the forward direction)

σ(bb) ~500μb out of σ(inel.) ~60mb

Large boost, good vertexing and particle ID

Nominal year of 2/fb is ~10^{12} bb pairs

2×10^5 bb/s at luminosity 5×10^{32}

Useful rate depends on trigger p_T thresholds

Main physics goals:

- Bs lifetime difference $\Delta\Gamma_s$ and mixing phase ϕ_s
- CKM angle γ from B(s)->D(s)K
- Sin 2β(s) in hadronic penguins
- Rare decays B_d->$K^{*0}\mu^+\mu^-$ and B_s ->$\mu^+\mu^-$

ATLAS

Large general purpose detector
Rapidity coverage $|y|<2.5$ (tracking)

Nominal year at luminosity 10^{33} is ~$5x10^{12}$ bb
At luminosity 10^{34} 23 collisions/crossing @40MHz

Useful rate depends on trigger p_T thresholds (for μ)
Thresholds rise as luminosity increases!

Main B physics goals:

- Bs lifetime difference $\Delta\Gamma_s$ and mixing phase ϕ_s
- Rare decays $B_d \to K^{*0}\mu^+\mu^-$ and $B_s \to \mu^+\mu^-$

A B(right) Future? (>2013)

- LHCb plan detector upgrade to handle multiple collisions/crossing (luminosity of ~2×10^{33})
  Has potential to eventually collect 50/fb

- KEK-B plans upgrade to luminosity $4-8 \times 10^{35}$
  Has potential to eventually collect 20-50/ab

- SuperB conceptual design for Frascati $1-2 \times 10^{36}$
  If approved could deliver 100/ab

- Super LHC and ATLAS/CMS upgrades

(but can B physics still be done at higher luminosity?)

Given recent STFC decisions will the UK still be doing B physics with x10-100 more luminosity?

Source of CP Violation for Baryon Asymmetry of the Universe

George W.S. Hou (侯維恕)
National Taiwan University

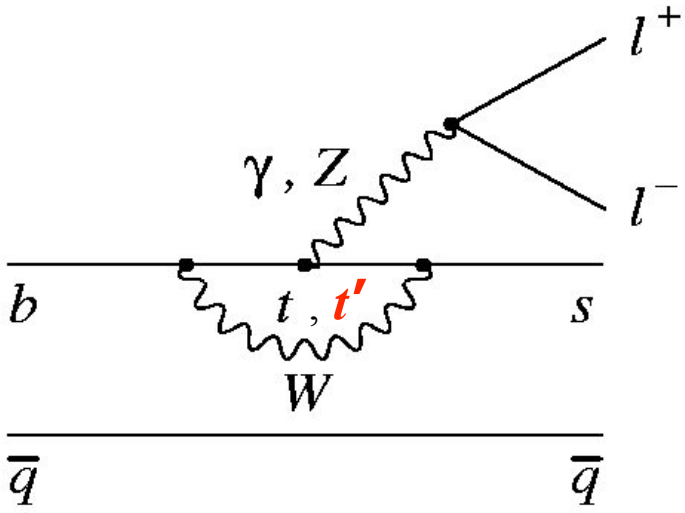
ICHEP 2008
arXiv:0810.3396

In Public: the big question B Physics has been addressing

In Private: CP violation in B/K decays does not account for the baryon asymmetry of universe (by $x10^{10}$)

…but it could if you add a t' quark (4th generation)

- New physics in electroweak penguins
  - Solves the two Kπ puzzles
  - Different Sin2β in penguins
  - Should see effects in b→ sll



- New physics in mixing diagrams
  - Large phase ϕ_s in B_s mixing (Tevatron)
  - Different Sin2β in $J/\psi K_s$? (Soni, CKM 2008)
  - Effects in D mixing?