Heavy Flavour in a Nutshell

(for a 27-km annular nut at 1.8K)

Robert W. Lambert, CERN

Flavour physics timeline

EXPERIMENT

Rutherford: Proton

Chadwick: Neutron

Gell-Mann: Strange

AGS : CPV in Kaons

SLAC: Up+Down

SLAC: Charm

E288: Bottom

Argus: B-mixing

DØ + CDF: Top

1815 1919 1920 1932 1953 1963 1964 1968 1970 1973 1974 1977 1987 1995

Prout: Proton

Rutherford: Neutron

Cabbibo: angle

Gell-Mann: 8-fold way

Anderson: EWSB

Guralnik-Hagen-Kibble

Brout-Englert-Higgs-

GIM: charm

CKM: 3rd Generation

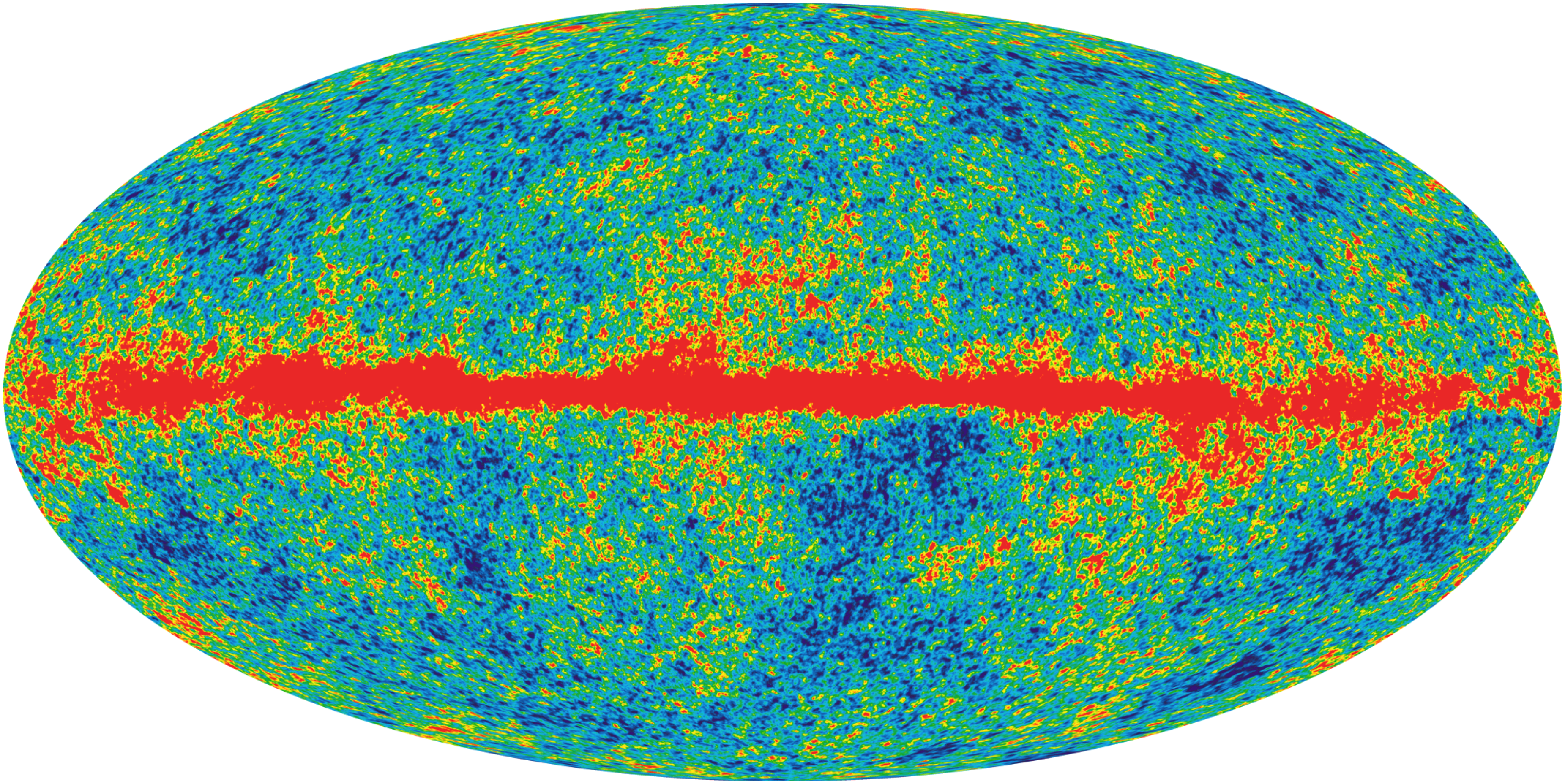
THEORY

Outline

1. Welcome to our universe
2. Introduction to flavour physics
3. Hottest new physics searches
4. Flavour-specific asymmetry

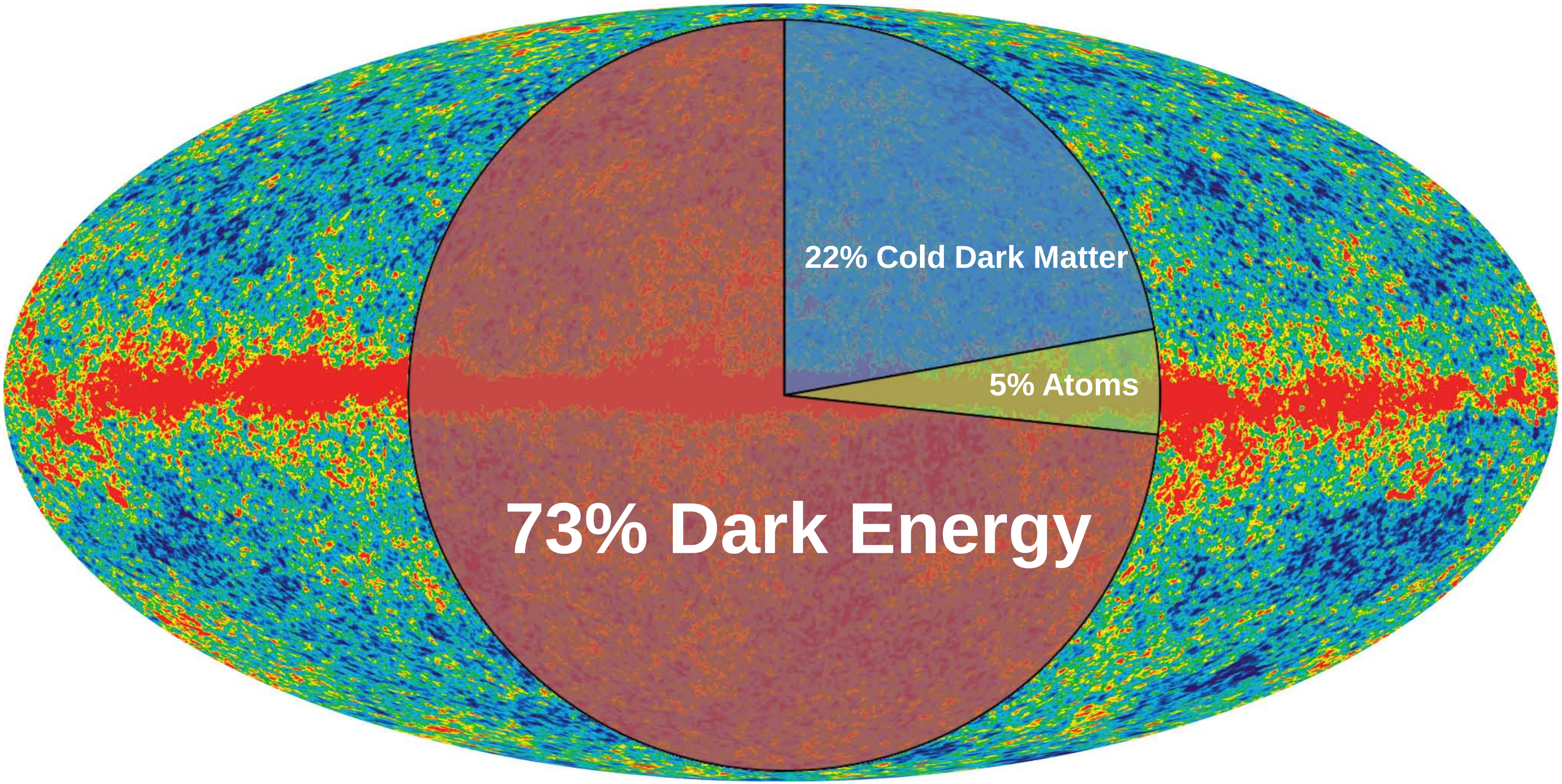
- Recent papers:
  - DØ measurement of A^b, 3.2σ deviation from the SM (May 2010)
    Evidence for an anomalous like-sign dimuon charge asymmetry
    PRL. 105, 081801 (2010)
  - Nierste and Lenz B-mixing update (Feb 2011)
    Numerical updates of lifetimes and mixing parameters of B mesons
    hep-ph arxiv:1102.4274
  - WMAP 7-year sky maps (Feb 2011)
    Seven-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Sky Maps, Systematic Errors, and Basic Results
    Jarosik, N., et.al., 2011, ApJS, 192, 14

Light

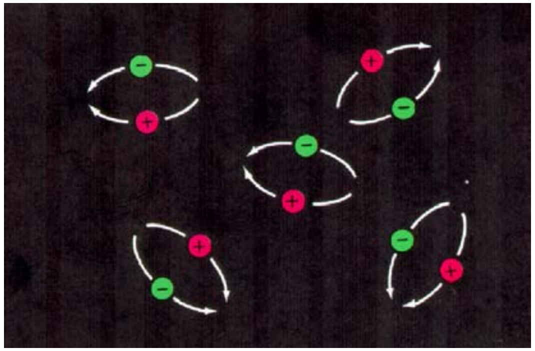


(13.75 ± 0.13) Gyr

Matter

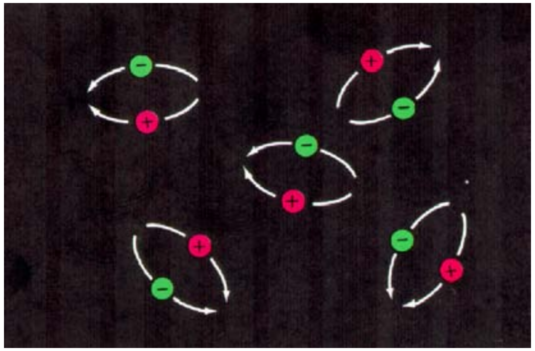


Antimatter



Matter + Antimatter = photons

Antimatter

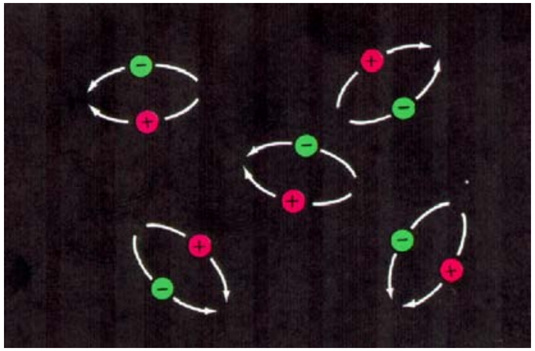


Matter + Antimatter = photons

CP-violation, CPV

observable difference between matter and antimatter

Antimatter



Matter + Antimatter = photons

CP-violation, CPV

observable difference between matter and antimatter

REALITY

$$\frac{n_{baryon}}{n_{\gamma}} = (5.5 \pm 0.5) \times 10^{-10}$$

You Are Here

SM (maximal CPV)

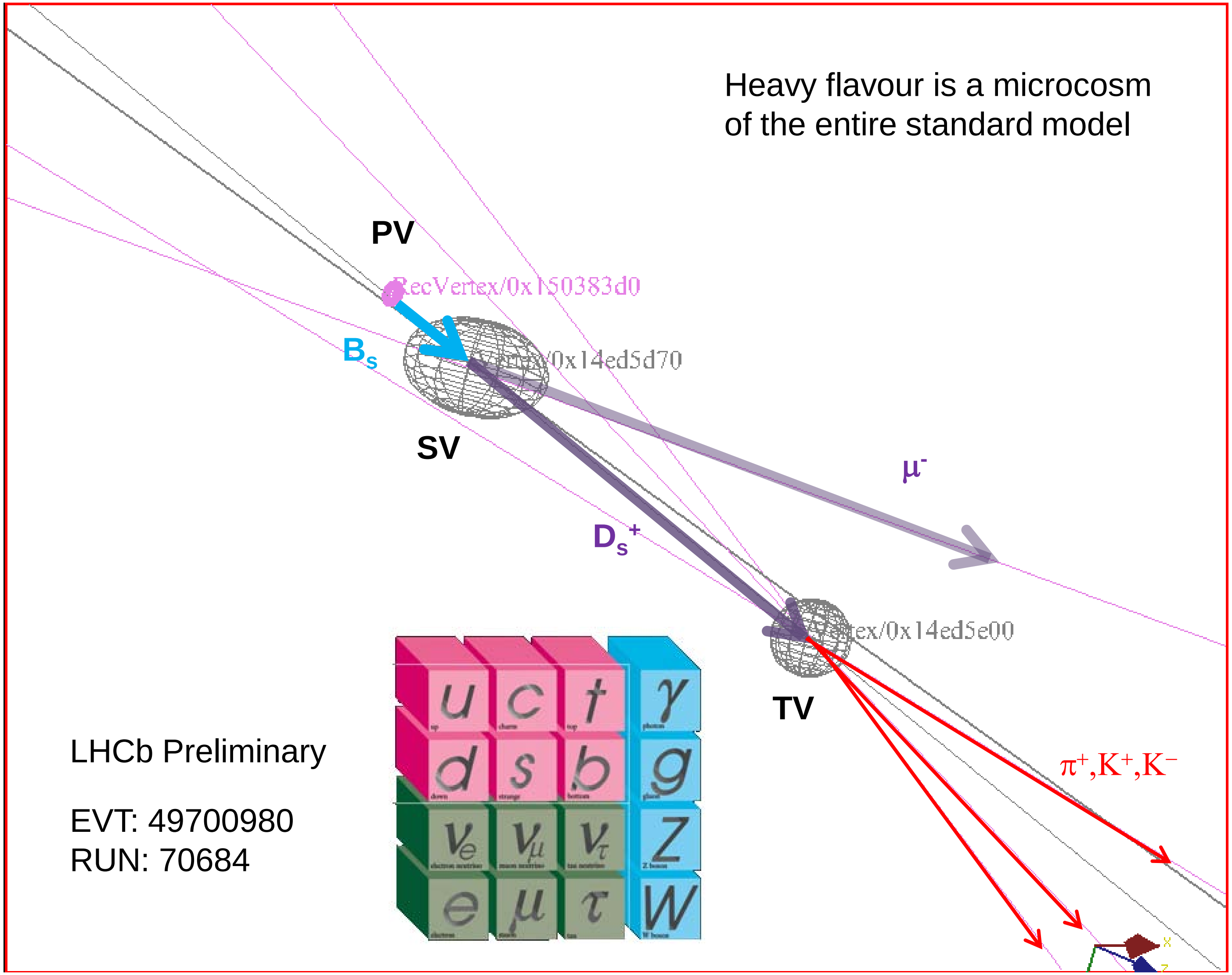
$$\frac{n_{baryon}}{n_{\gamma}} < 10^{-20}$$

Where did you go?

Guys…? Guys…??

What does that have to do with heavy flavour physics?

A beautiful image



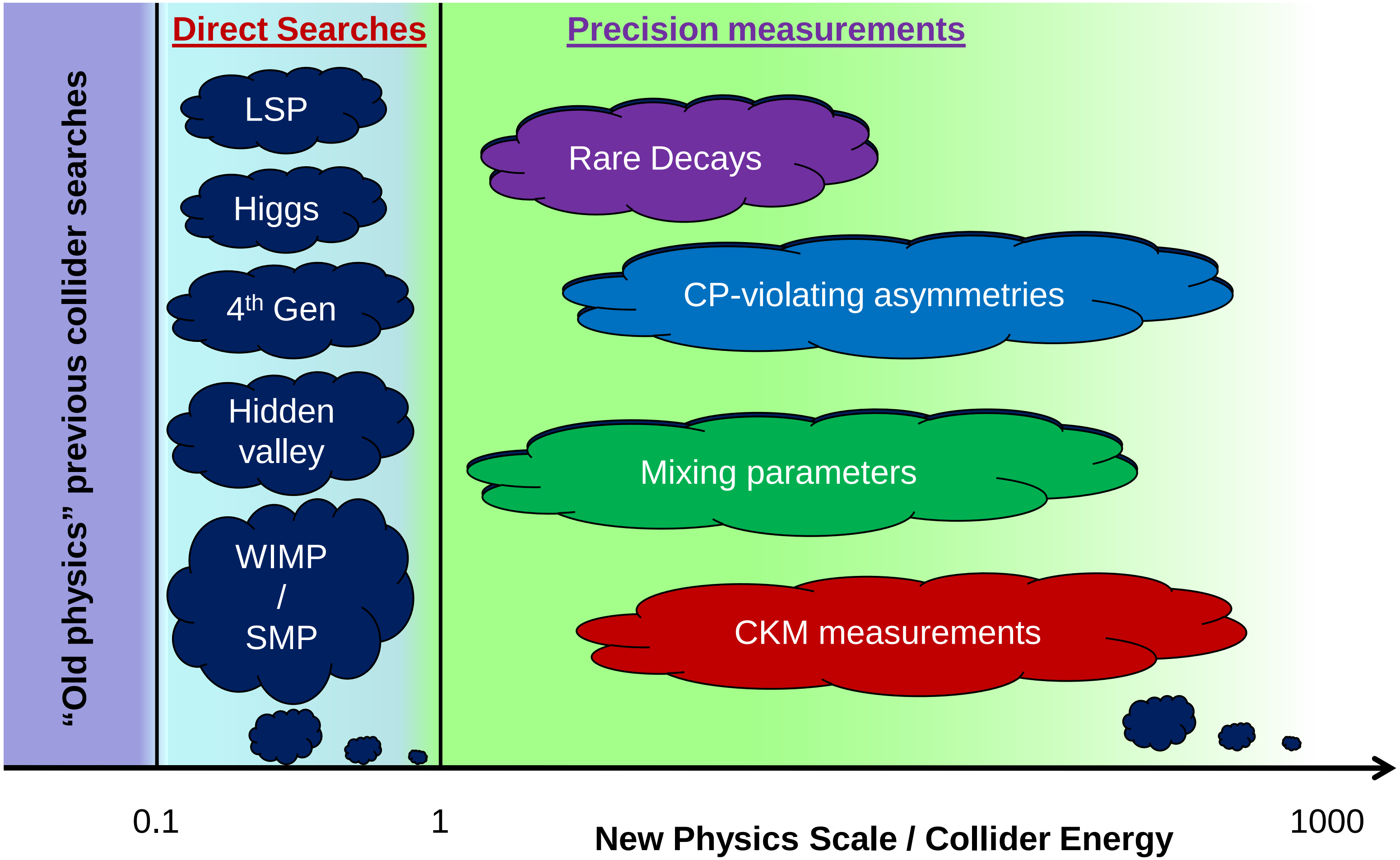
Heavy flavour is a microcosm of the entire standard model

LHCb Preliminary

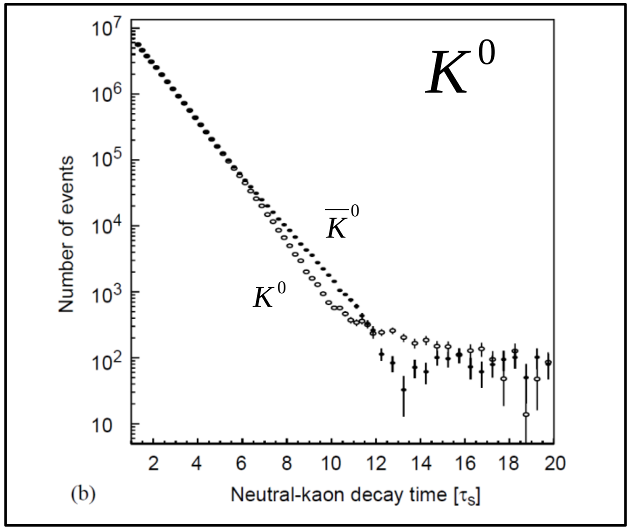
EVT: 49700980
RUN: 70684

Complementarity

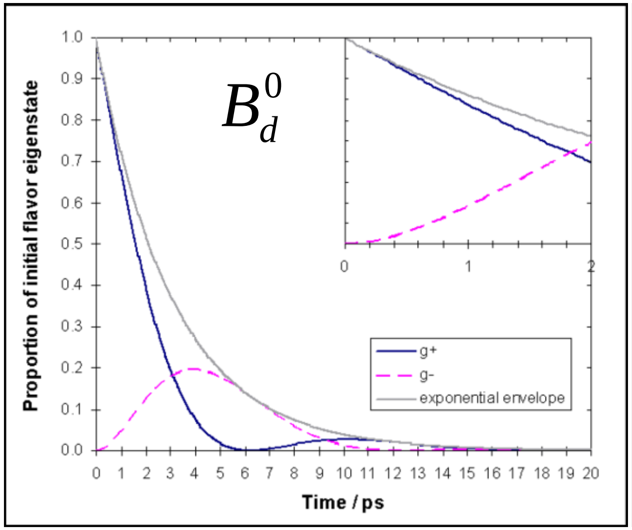
- There are in general two types of new physics searches



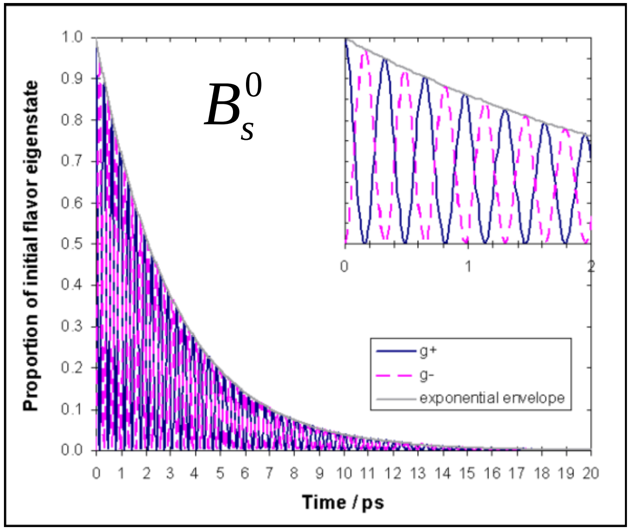
Neutral mesons are *weird*



(CPLear)



(PDG)



(PDG)

- *"mass-decay eigenstates are not the flavour eigenstates"*
  - Probably the weirdest phenomenon in physics!
- *"neither of those are the CP-eigenstates"*
  - CP-violation is very weird in itself
  - Observation of CPV in Kaons in 1964, before any predictions!

Burning Questions

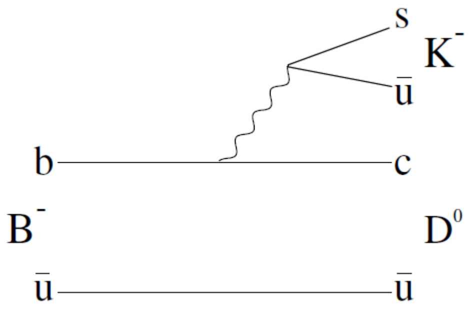
1. Where is the CP-violation we need?
2. What is the flavour structure of new-physics?

- But first we ask ourselves:
  - How can we best look for this new physics, and where?

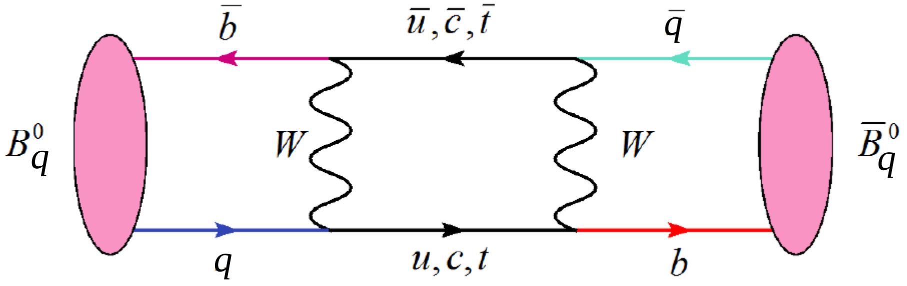
Looking for NP

1. Find a place where new physics is unlikely
2. Precisely measure well-predicted observables
3. Find a place where new physics could enter
4. Precisely measure related observables

Unlikely: tree-level decays



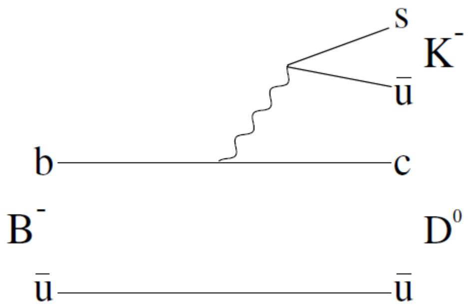
Likely: loops and penguins



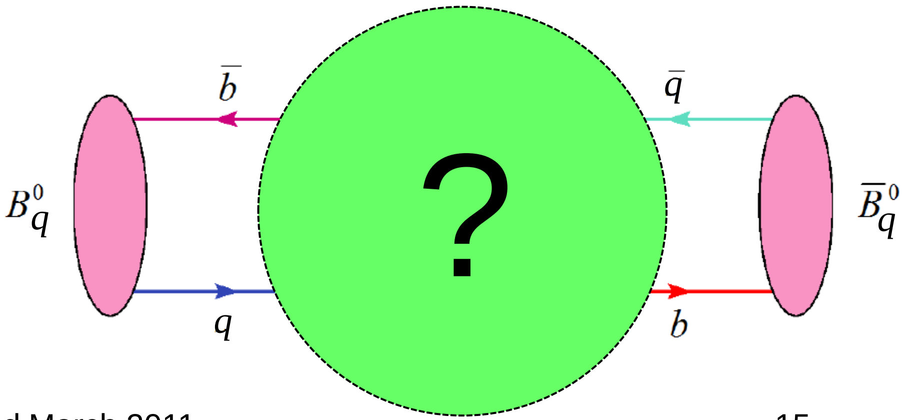
Looking for NP

1. Find a place where new physics is unlikely
2. Precisely measure well-predicted observables
3. Find a place where new physics could enter
4. Precisely measure related observables

Unlikely: tree-level decays



Likely: loops and penguins



Looking for CPV

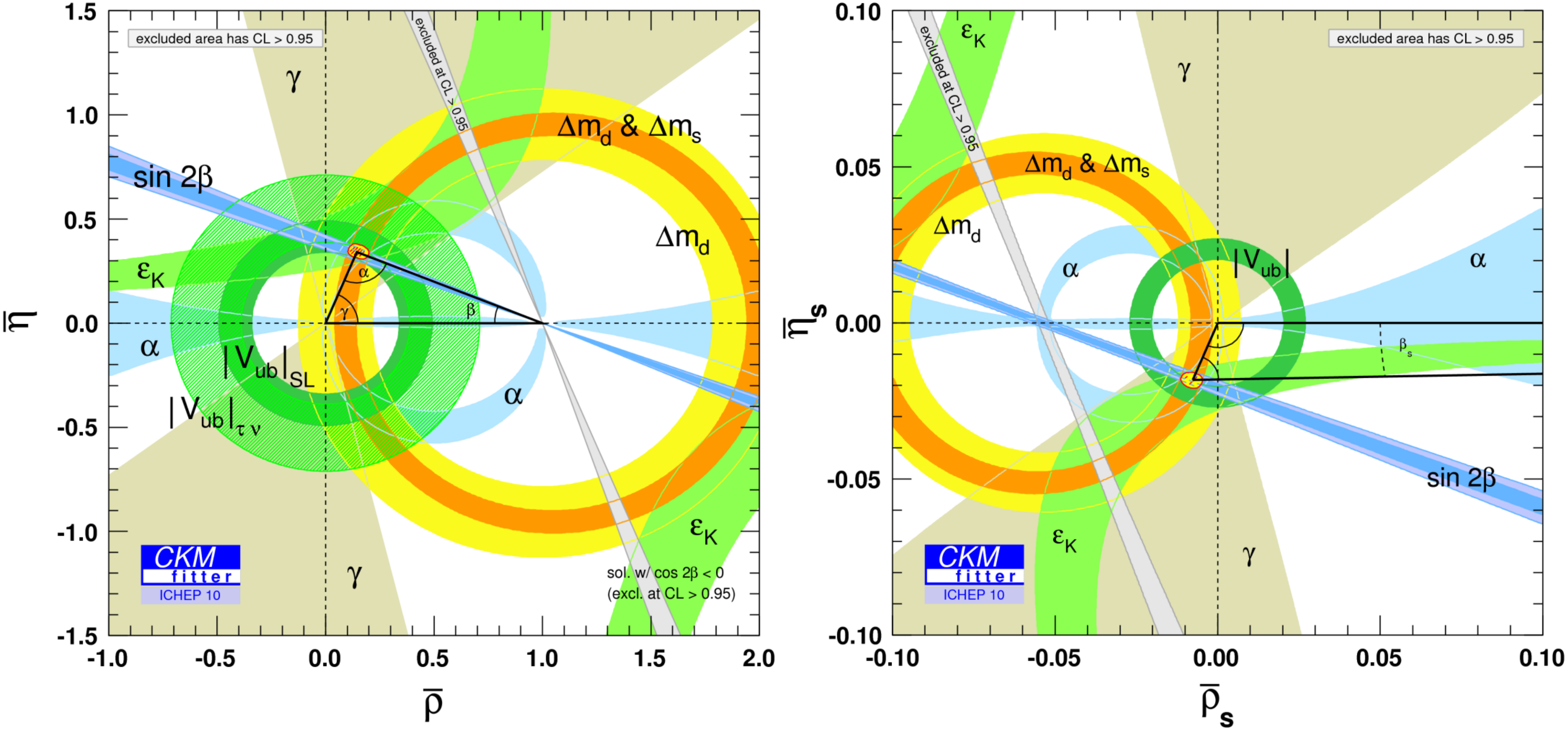
- SM has only one source of CPV, from the CKM, a phase

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Observe this and any NP phase with interference:
  - Need observables with two competing amplitudes
- SM phase manifests most obviously in the *b*-quark system
- Measure in many different ways to constrain the same phase

CKM - status

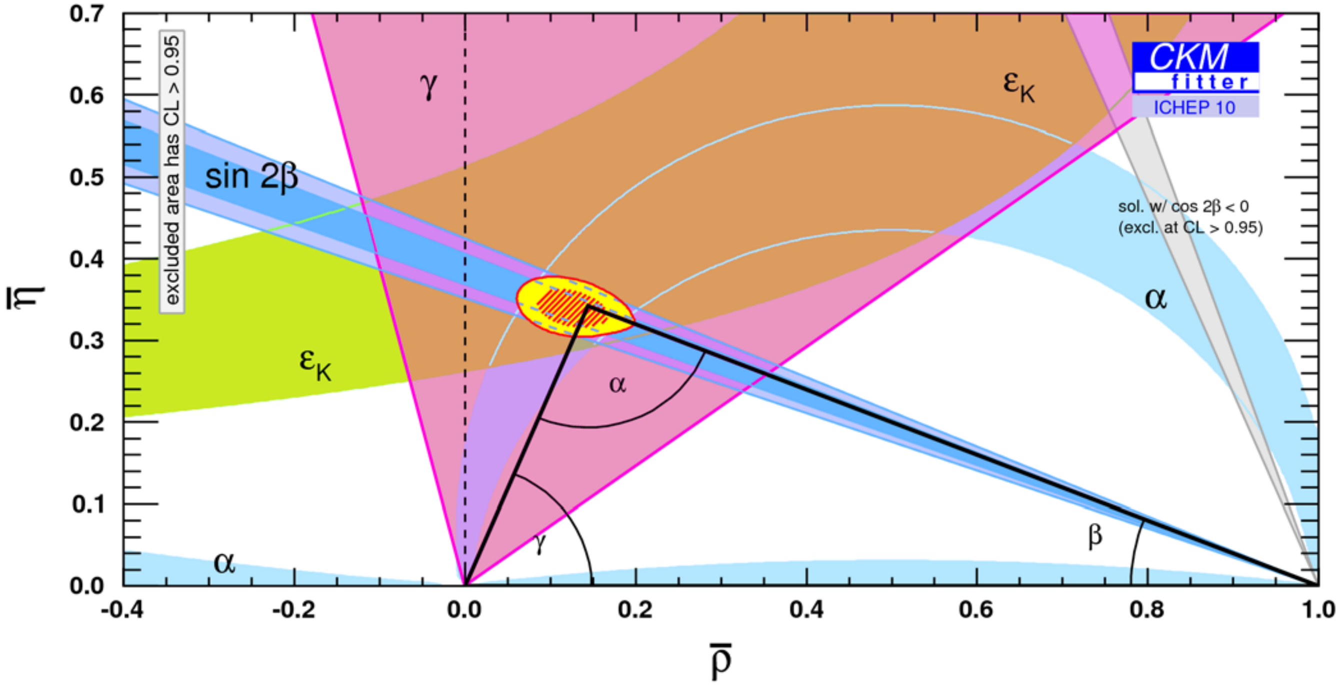
- Plot everything together on a single graph
- Everything is consistent ... so far ...



Hottest new physics searches

Looking for CP (1)

- Check CP-violating observables
- Disagreement would point to CPV new physics

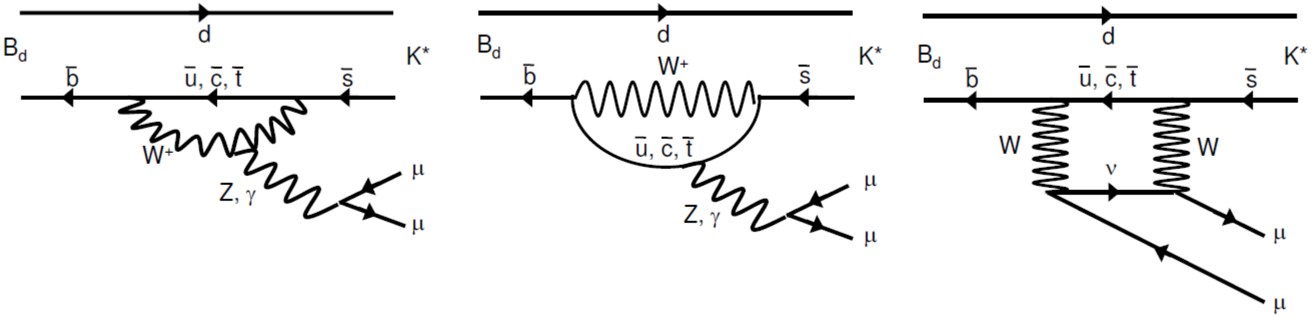


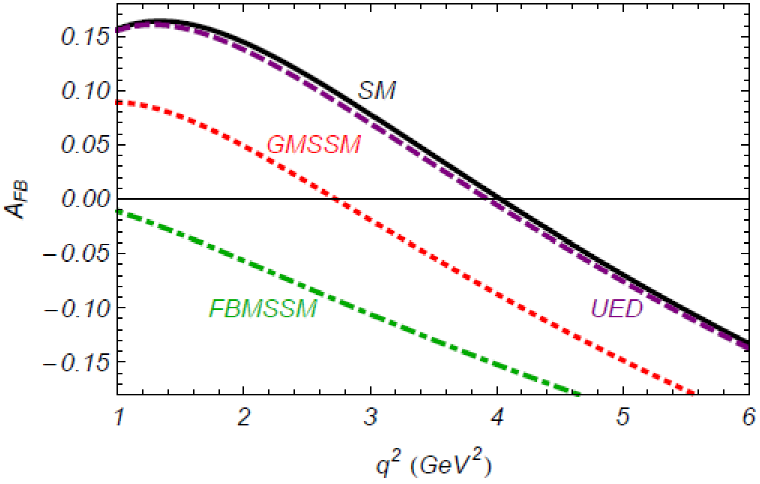
- No hints yet, but the angle γ is not well known

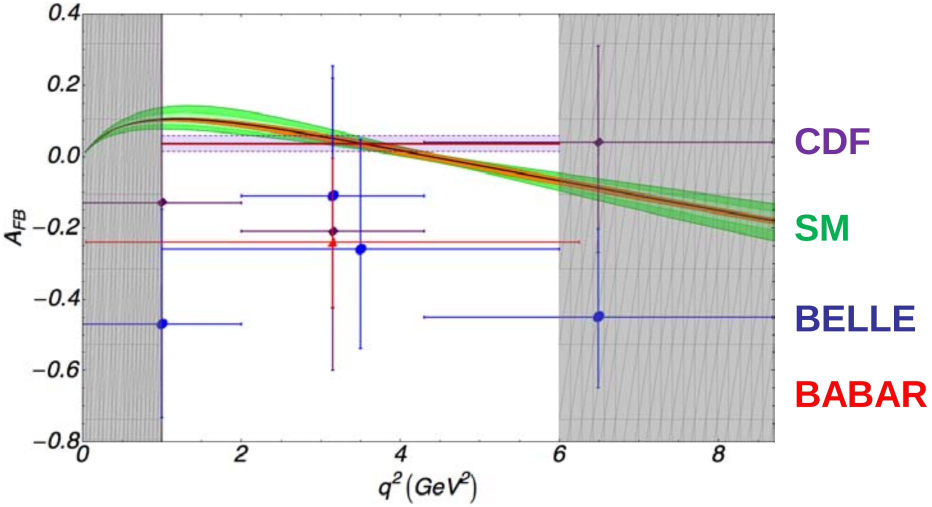
Looking for flavour (1)

- $B_d \to K^*\mu\mu$ has both loops and penguins!
- Amongst many observables A_{fb} is sensitive to SUSY

e.g.



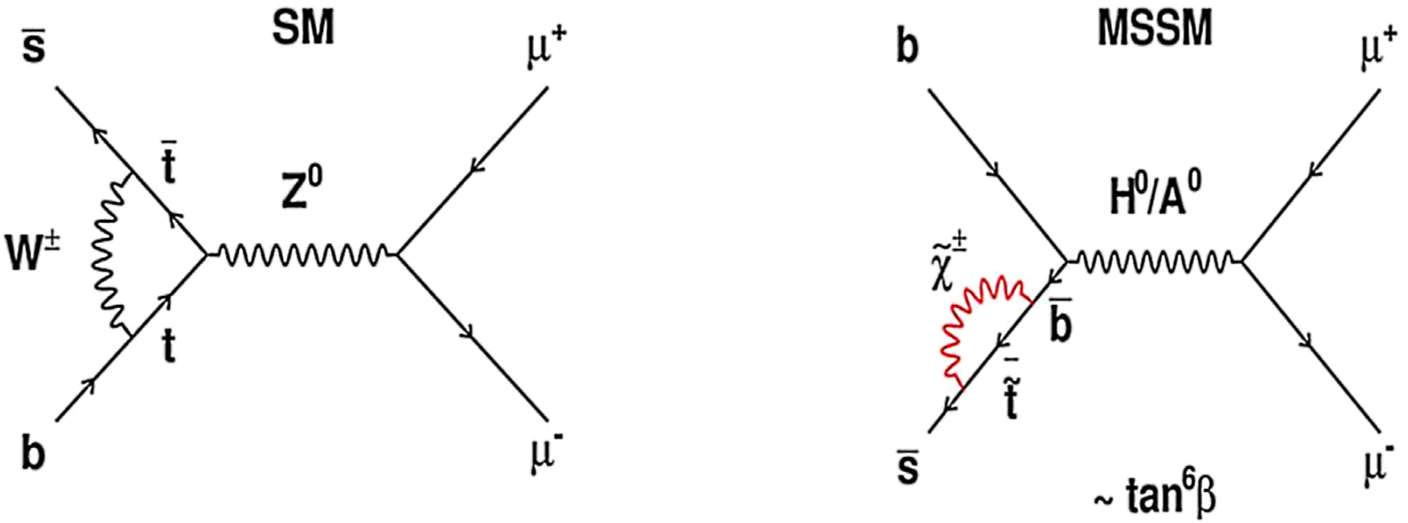




Looking for flavour (2)

- Very rare decays, where SM BR predictions are very good
- In the case of $B_{s/d} \to \mu\mu$, the rate is very sensitive to SUSY

e.g.



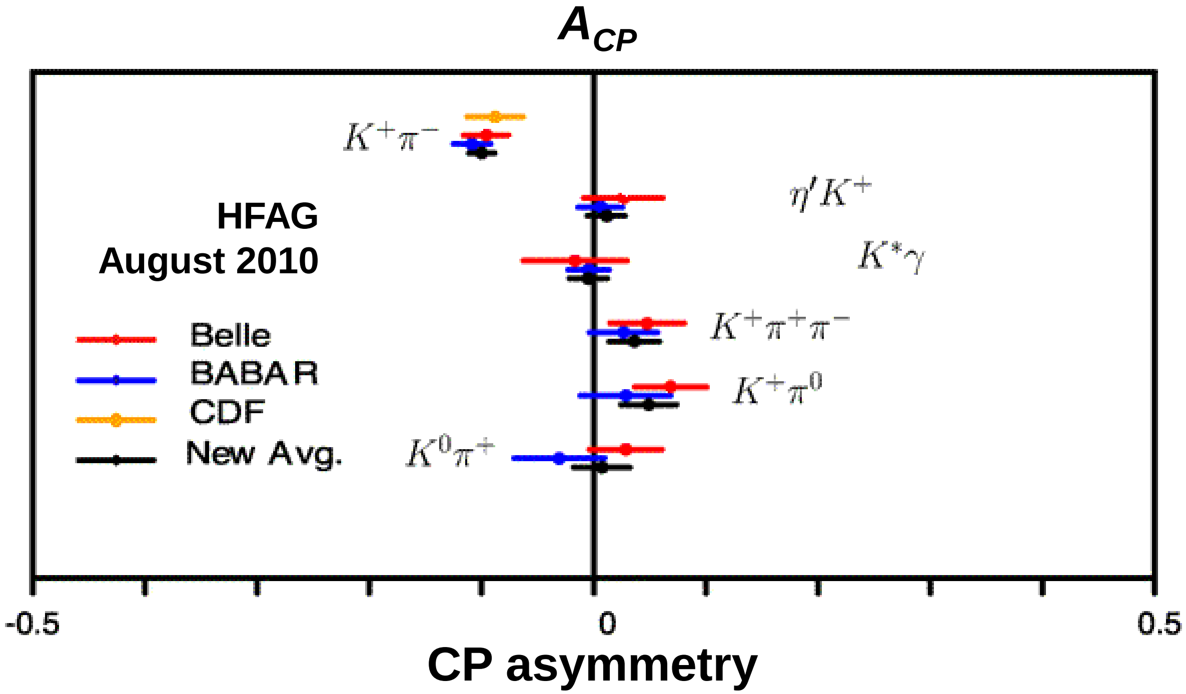
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\rm SM} = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{\rm SM} = (1.0 \pm 0.1) \times 10^{-10}$$

CDF Prelim:
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 43 \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 7.6 \times 10^{-9}$$

LHCb:
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 5.6 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.5 \times 10^{-8}$$

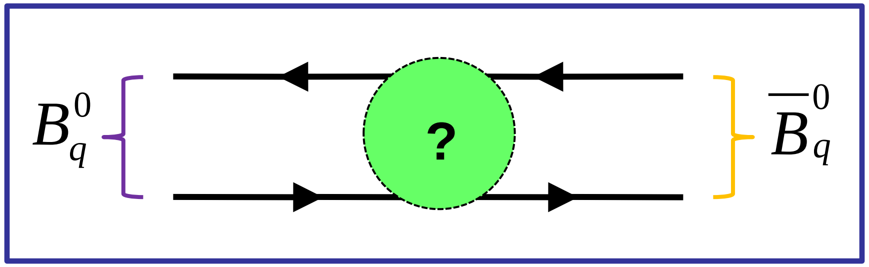
Looking for CP (2)

- CP-asymmetry in decays (Direct CP-violation)
- Interesting hint: the B→Kπ “puzzle”



- Precision two-body *B*-decays will be very interesting

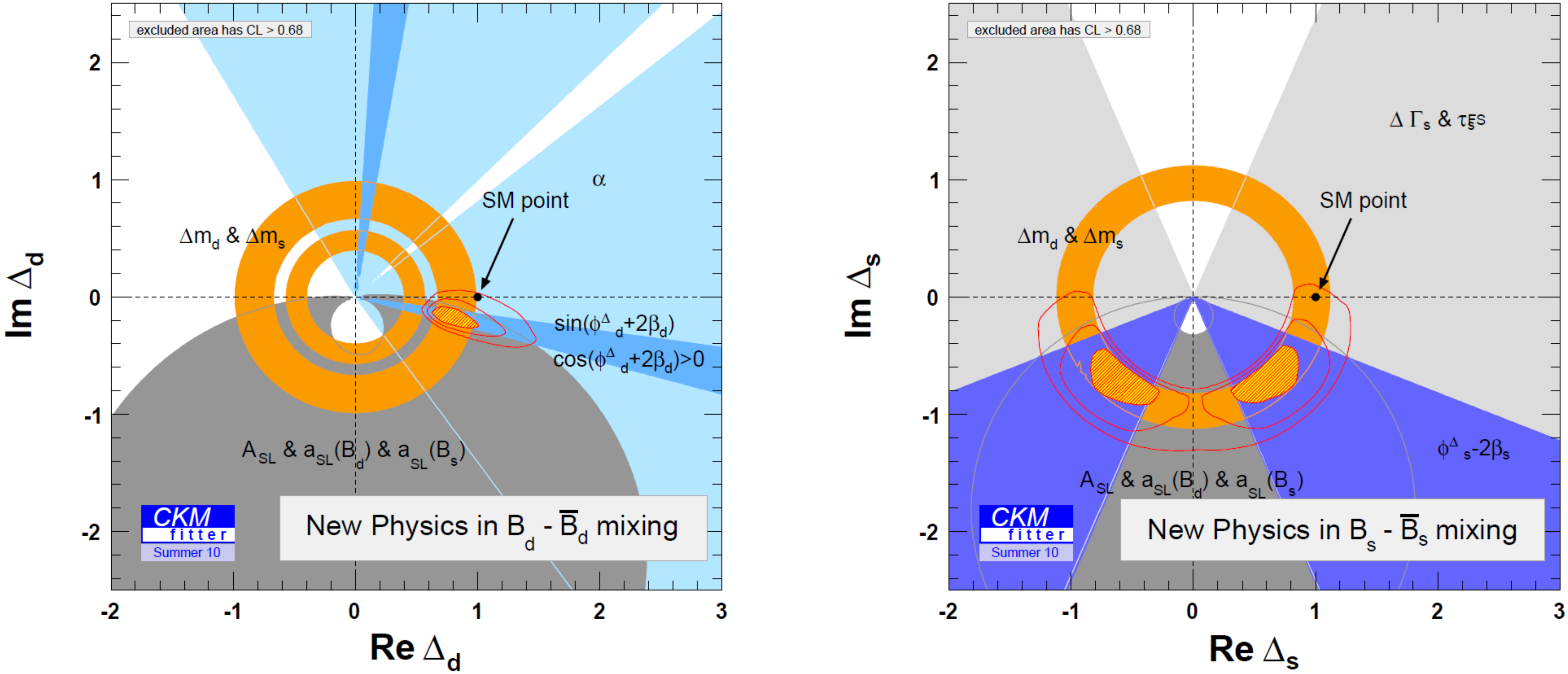
Looking for both



- Mixing can be modified in both magnitude *and* phase
- Define a complex number parameter Δ_q for the new physics
- Just like we did with the CKM
  - Collect all the measurements together
  - Plot all at once in 2D (complex plane)

Status: NP in mixing?

- SM is **disfavoured** by 3.6σ

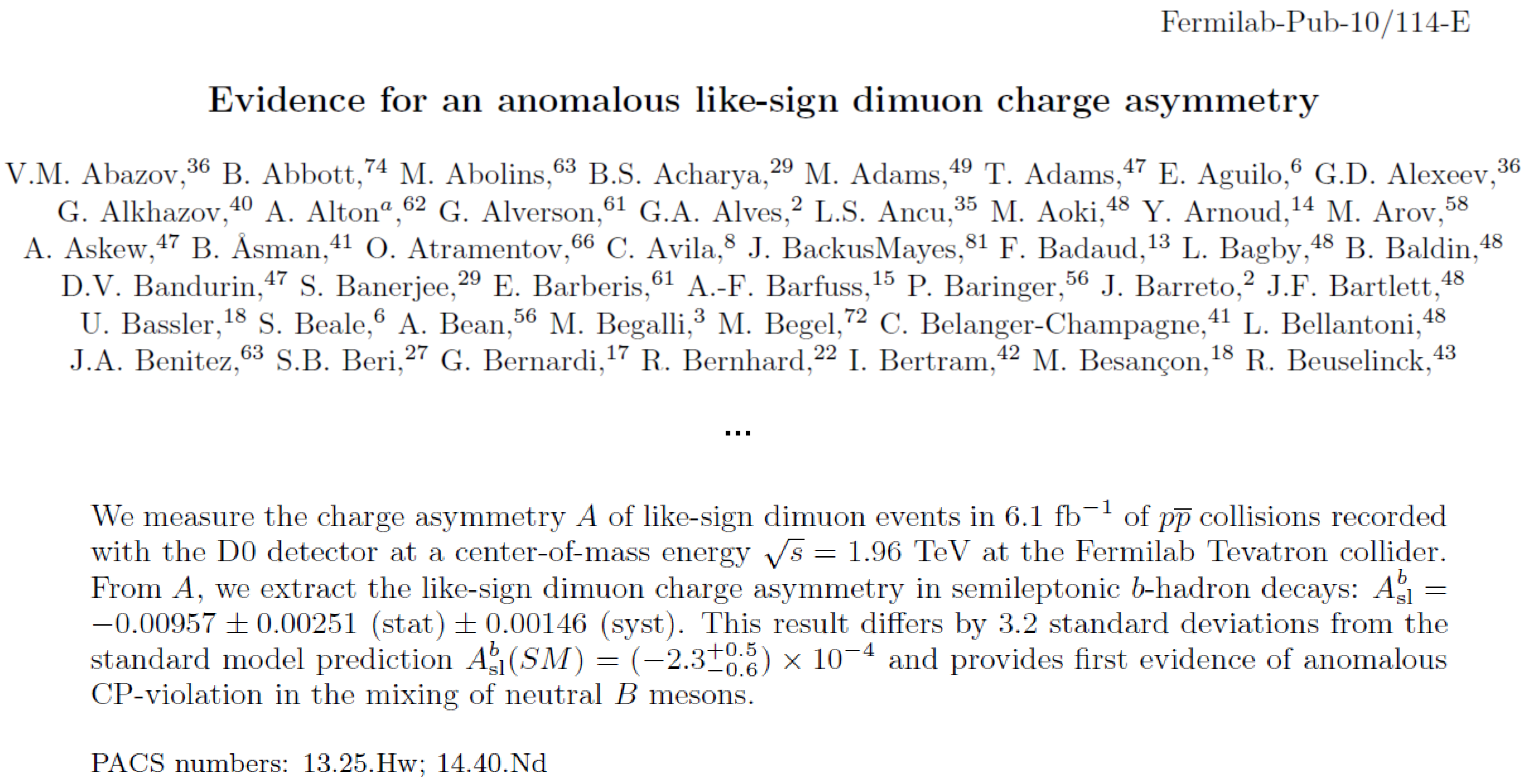


- Owing a lot to the recent DØ measurement

Flavour-specific asymmetry

… a smoking gun for new physics??

Surprise!



Fermilab-Pub-10/114-E

Evidence for an anomalous like-sign dimuon charge asymmetry

V.M. Abazov,[36] B. Abbott,[74] M. Abolins,[63] B.S. Acharya,[29] M. Adams,[49] T. Adams,[47] E. Aguilo,[6] G.D. Alexeev,[36] G. Alkhazov,[40] A. Alton[a],[62] G. Alverson,[61] G.A. Alves,[2] L.S. Ancu,[35] M. Aoki,[48] Y. Arnoud,[14] M. Arov,[58] A. Askew,[47] B. Åsman,[41] O. Atramentov,[66] C. Avila,[8] J. BackusMayes,[81] F. Badaud,[13] L. Bagby,[48] B. Baldin,[48] D.V. Bandurin,[47] S. Banerjee,[29] E. Barberis,[61] A.-F. Barfuss,[15] P. Baringer,[56] J. Barreto,[2] J.F. Bartlett,[48] U. Bassler,[18] S. Beale,[6] A. Bean,[56] M. Begalli,[3] M. Begel,[72] C. Belanger-Champagne,[41] L. Bellantoni,[48] J.A. Benitez,[63] S.B. Beri,[27] G. Bernardi,[17] R. Bernhard,[22] I. Bertram,[42] M. Besançon,[18] R. Beuselinck,[43]

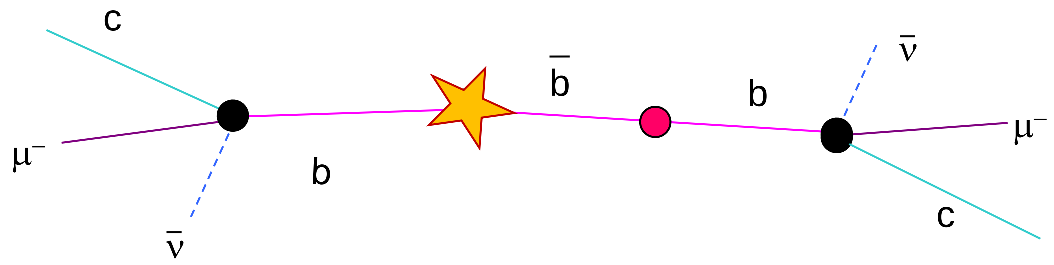
...

We measure the charge asymmetry A of like-sign dimuon events in 6.1 fb^{-1} of $p\overline{p}$ collisions recorded with the D0 detector at a center-of-mass energy $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron collider. From A, we extract the like-sign dimuon charge asymmetry in semileptonic b-hadron decays: $A^b_{\text{sl}} = -0.00957 \pm 0.00251 \text{ (stat)} \pm 0.00146 \text{ (syst)}$. This result differs by 3.2 standard deviations from the standard model prediction $A^b_{\text{sl}}(SM) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$ and provides first evidence of anomalous CP-violation in the mixing of neutral B mesons.

PACS numbers: 13.25.Hw; 14.40.Nd

Translate

- Very difficult measurement
- Observe $N(\mu^+\mu^+) \neq N(\mu^-\mu^-)$
- Flavour-specific asymmetry from B⁰-mixing in the SM:

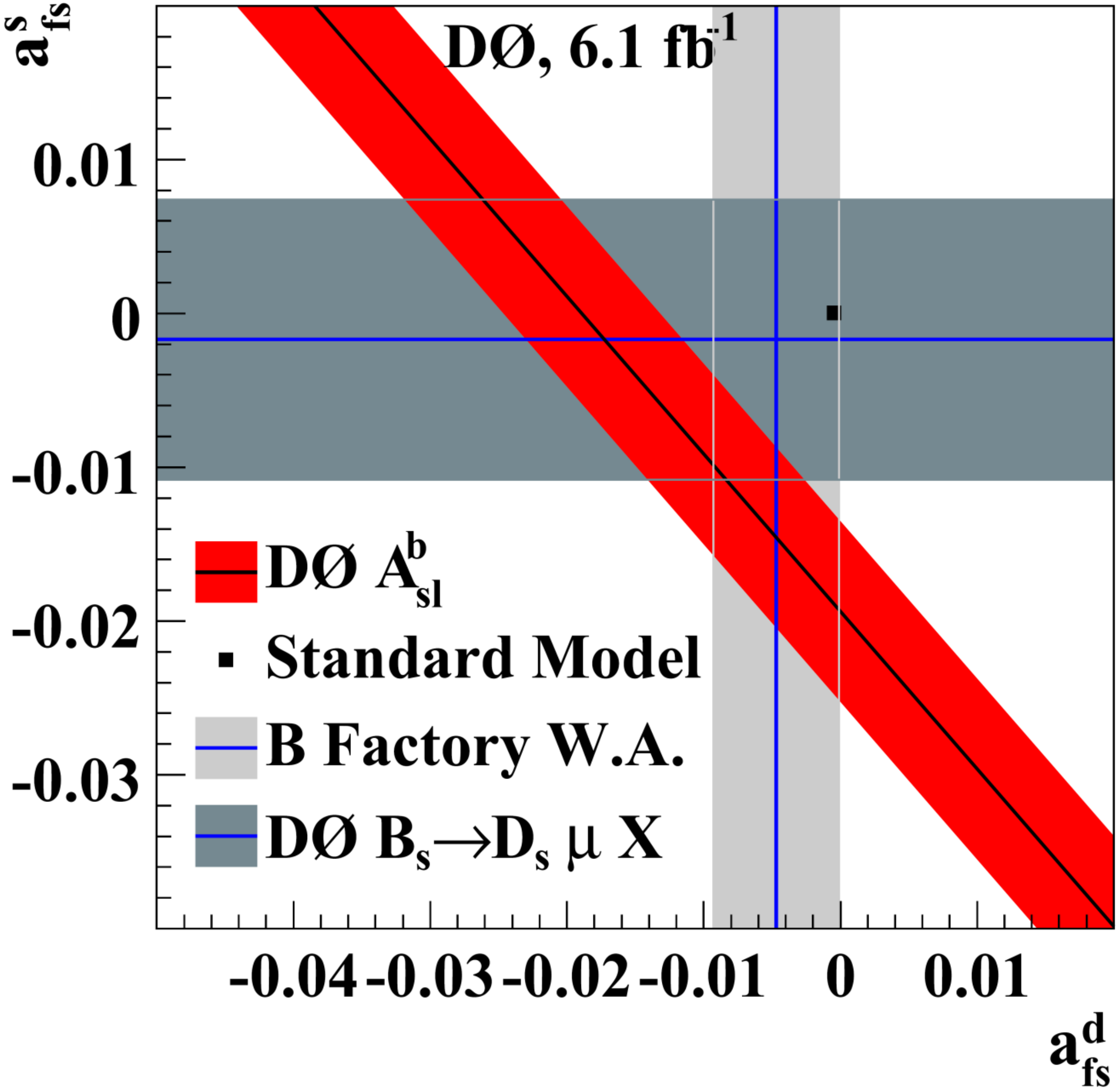


CP asymmetry in mixing, a_{fs}

- **In the standard model a_{fs} is almost negligible**

$$A^b \approx \frac{a_{fs}^s + a_{fs}^d}{2} \qquad SM = (-2.0 \pm 0.3) \times 10^{-4} \qquad D\varnothing \approx (-1 \pm 0.3)\%$$

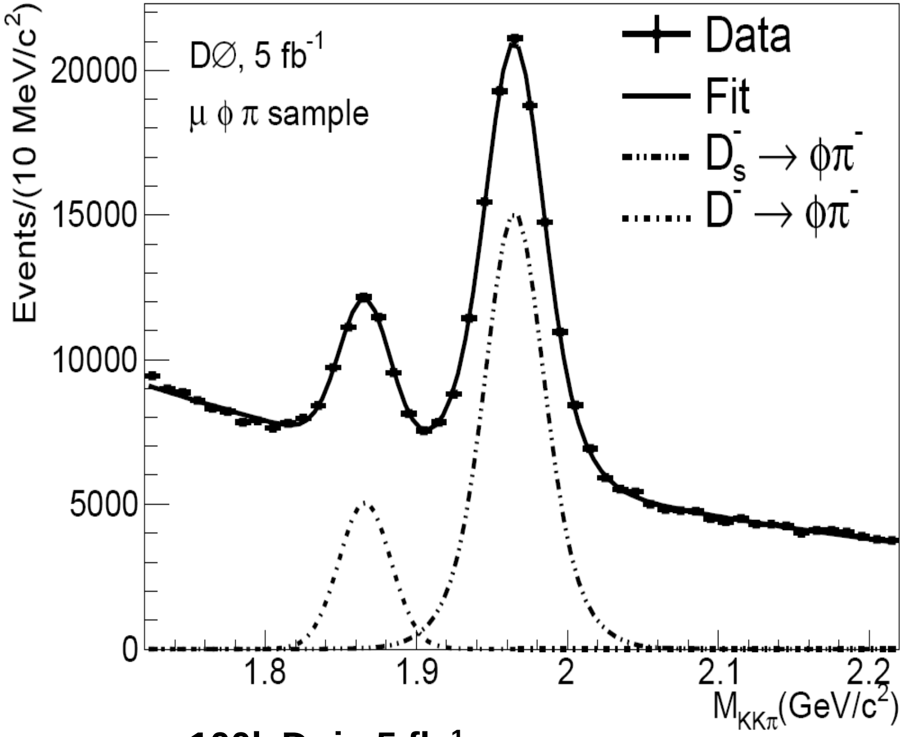
Hot Topic



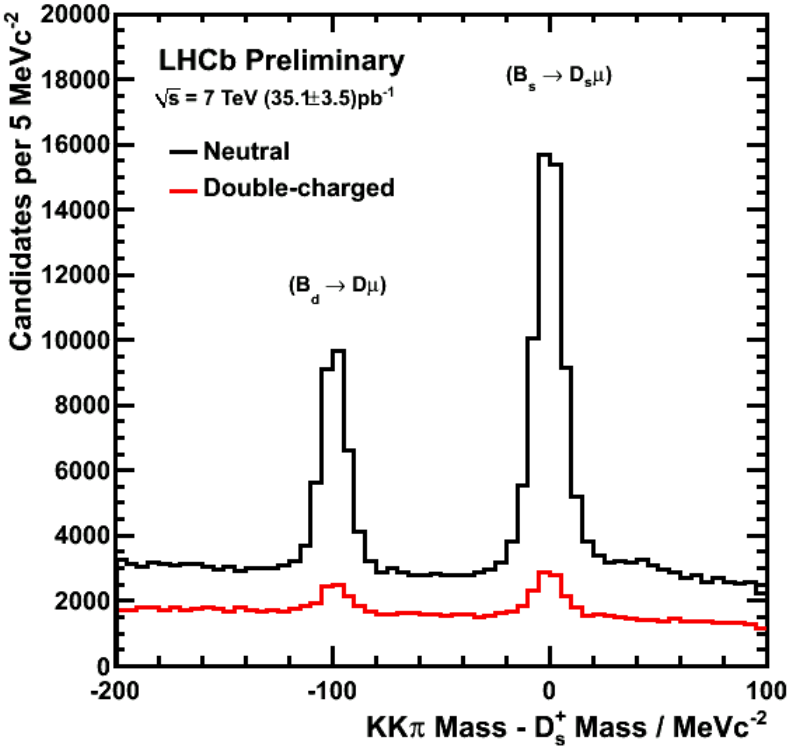
Situation could really be cleared up by LHCb

Current status

- LHCb is reconstructing both $B_s^0 \to D_s^{\mp}\mu^{\pm}\nu_\mu$ and $B_d^0 \to D_d^{\mp}\mu^{\pm}\nu_\mu$
- LHCb is catching up with DØ very quickly



~100k D_s in 5 fb^{-1}



~100k D_s in 0.2 fb^{-1}

Experimental Challenge

- LHC is a pp-collider, not a p$\bar{p}$-collider
- LHCb is in the forward region
  - Can’t measure the same thing as DØ
  - Need a clever new method

NB: DØ
(inclusive)

$$\left(A^{b} \sim \frac{a_{fs}^{s} + a_{fs}^{d}}{2} \sim -\left(2.0 \pm 0.3\right) \times 10^{-4} \right)$$

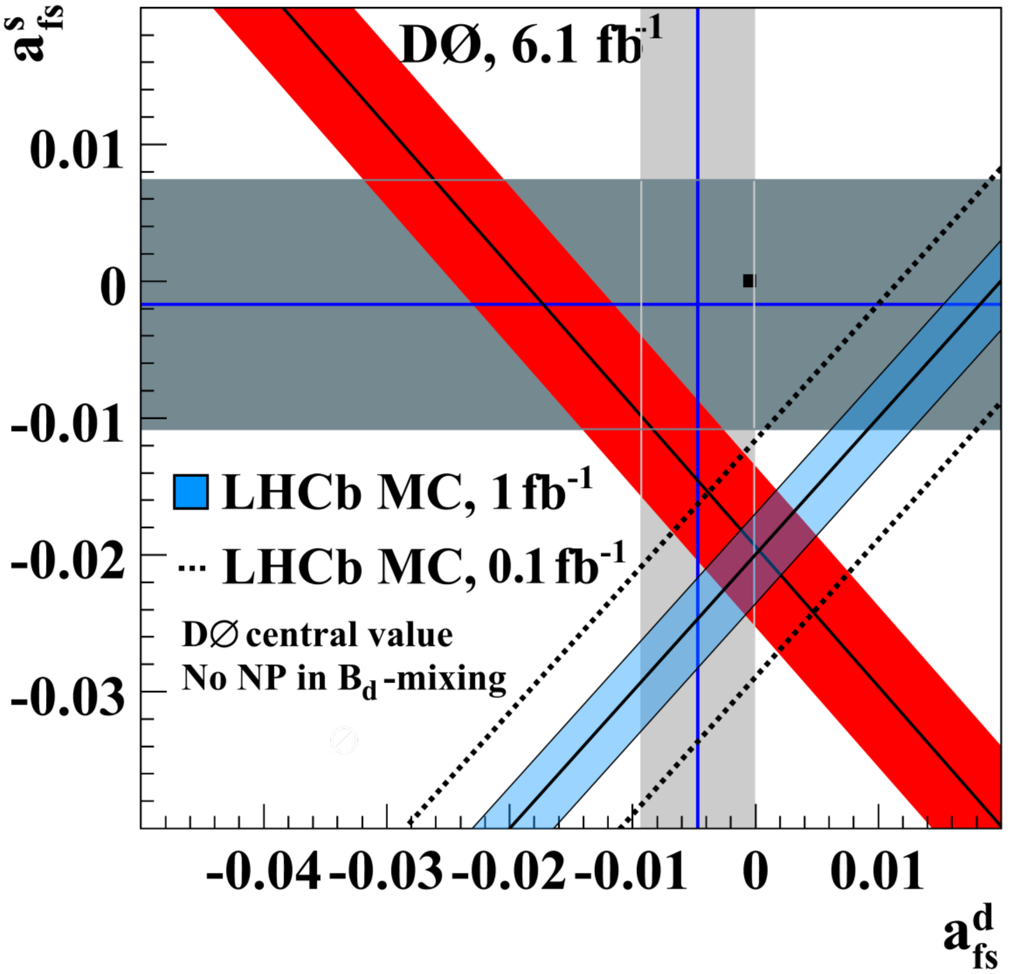
- Subtract two asymmetries to eliminate systematics

LHCb
(subtraction)

$$\boxed{\Delta A_{fs} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2} = \left(2.1 \pm 0.3\right) \times 10^{-4}}$$

After 1fb^{-1} of LHCb

- LHCb measurement cuts at right-angles to DØ



Only one example of the great physics on the way from LHCb

Summary

? Need new physics to explain the observed universe

  - ✓ LHC is a discovery machine
  - ✓ Precision measurements complement direct searches

✓ LHCb is the flavour experiment at the LHC

  - ✓ $B \rightarrow K\pi$, CKM-angle γ, $B_{s/d} \rightarrow \mu\mu$, $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow J/\psi\Phi$ ...

? We've seen a hint of new physics already from DØ

  - ✓ LHCb will make an early complementary measurement

➢ This is only the start of the LHC era, so ....

  - ▪ Stay tuned for the latest experimental results!

End

- Backups are often required

Acknowledgements

- Ulrich Kerzel for discussions on two-body *B*-decays
- Guy Wilkinson and Thomas Ruf for their great advice
- Johannes Albrecht for discussions on $B_s \rightarrow \mu\mu$
- The CKM-fitter members of LHCb for updating the β_s plot, pointing out to me a long-standing physics goof in our TDR and other publications, and for putting up with my crazy questions about their fitting methods

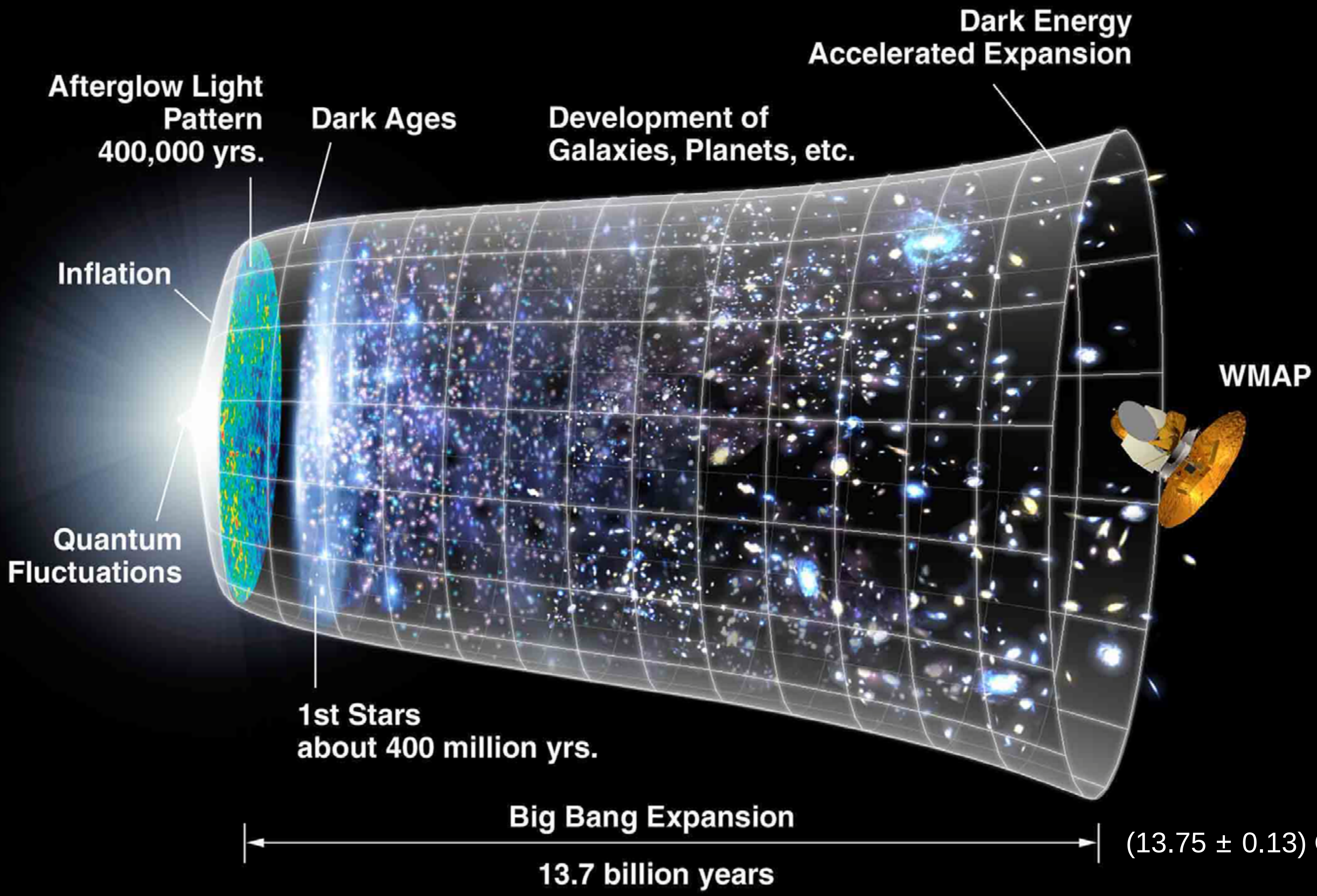
Further References

- LHCb:
  - $B_s \rightarrow \mu\mu$ first result: http://arxiv.org/abs/1103.2465
  - Detector paper: J. of Instrumentation (No. 3 pp. S08005P)
  - “Roadmap” of physics analyses: arXiv:0912.4179
    - Chapter 2: γ
    - Chapter 3: $B \rightarrow K\pi$
    - Chapter 5: $B_{s/d} \rightarrow \mu\mu$
    - Chapter 6: $K^* \mu\mu$

  - ΔA_{fs} studies:
    - R.W. Lambert, CERN-THESIS-2009-001
    - N. Brook *et al.*, CERN-LHCb-2007-054
- CPLear: Kaon mixing: Physics Reports, Volume 374, Issue 3, Pages 165-270 (January 2003)
- Experimental averages:
  - CKM fitter group : http://ckmfitter.in2p3.fr/
  - HFAG ($B \rightarrow K\pi$): http://www.slac.stanford.edu/xorg/hfag/rare/ichep10/acp/index.html
- More on $B \rightarrow K\pi$
  - Theory Status: S. Mishima from CKM 2010, arXiv:1101.1501
  - New Physics : S. Baek *et al.*, arXiv:hep-ph/0412086
- CDF $B_{s/d} \rightarrow \mu\mu$: CDF Public Note 9892 (preliminary)

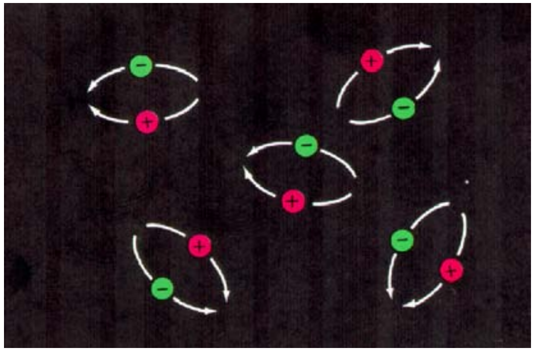
Further introduction

Gravity



(13.75 ± 0.13) Gyr

Antimatter



Matter + Antimatter = photons

CP-violation, CPV

observable difference between
matter and antimatter

REALITY

$$\frac{n_{baryon}}{n_{\gamma}} = (5.5 \pm 0.5) \times 10^{-10}$$

SM (maximal CPV)

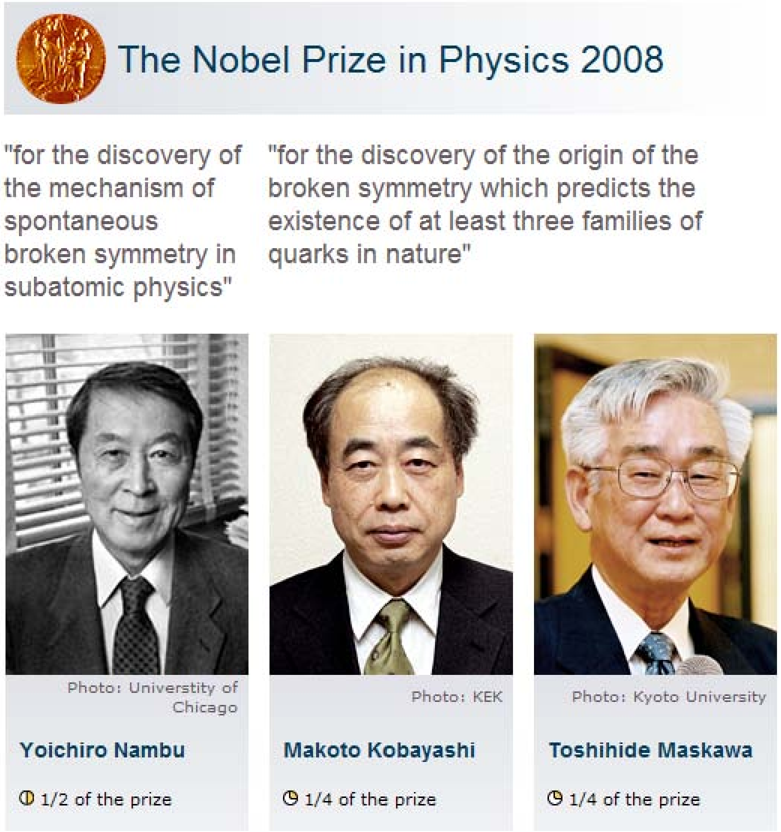
$$\frac{n_{baryon}}{n_{\gamma}} < 10^{-20}$$

Mass of entire solar system: 2x10^{30} kg → Mass of largest asteroid, Ceres: 10^{21} kg

Area ~ Kazakhstan: Population~one small dog

CKM and CPV

- CPV in the SM is ensconced in a single unitary matrix



The Nobel Prize in Physics 2008

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

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

Photo: University of Chicago

Yoichiro Nambu

◑ 1/2 of the prize

Photo: KEK

Makoto Kobayashi

◔ 1/4 of the prize

Photo: Kyoto University

Toshihide Maskawa

◔ 1/4 of the prize

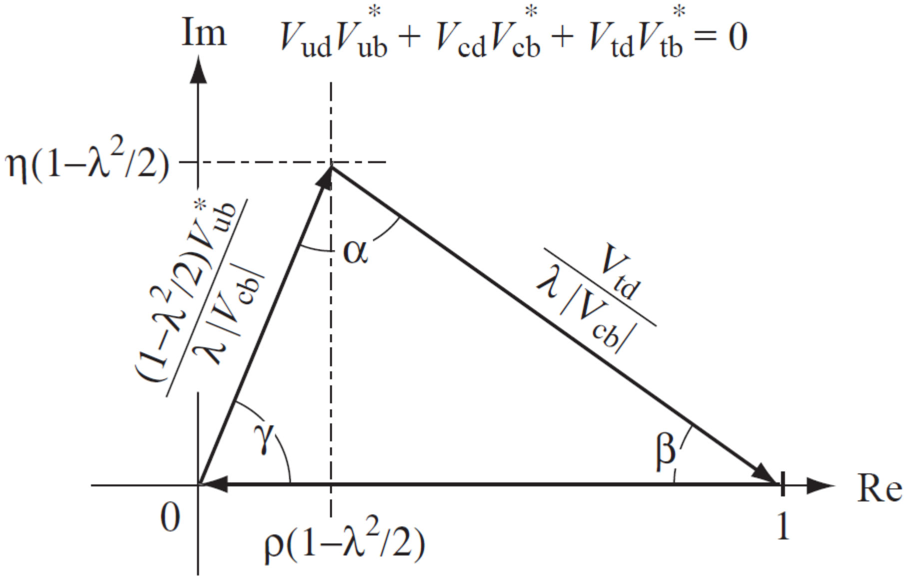
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- The CKM matrix
- Three real parameters
- One complex phase violates CP

- The phase is most readily observed in the *b*-quark system

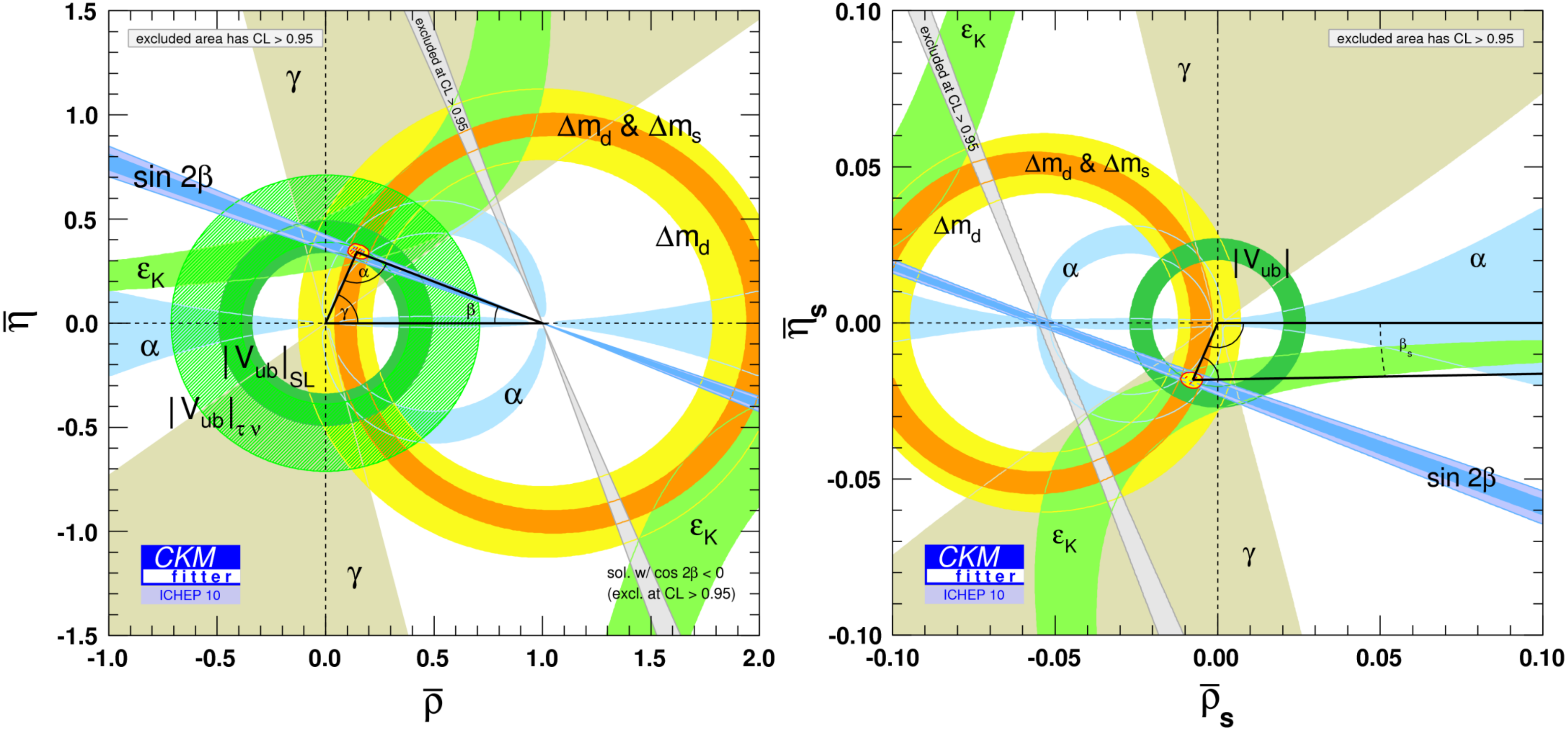
Unitarity Triangles

- Product of rows and columns are constrained by unitarity
- Of the nine relationships, six form a unitarity triangle
- The most well-known triangle is:



CKM - status

- Couplings, rates and mixings constrain magnitudes
- Asymmetries and mixings constrain phases



Mixing observables

QM 101

- The most basic hamiltonian of anything

$$H = i\frac{d}{dt}\left|X\right\rangle = \left(M_X - \frac{i}{2}\Gamma_X\right)\left|X\right\rangle$$

- Because:

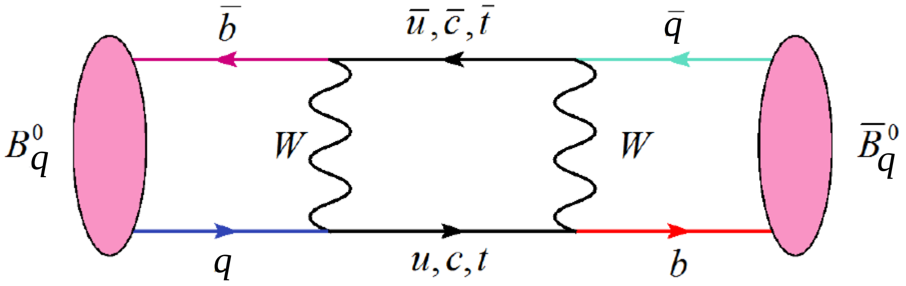
$$\left|X\right\rangle(t) \sim e^{-iHt} \sim e^{(\underset{\uparrow}{-iM}\,\underset{\uparrow}{-\Gamma})t}$$

Wave-like propagation

Decay

Mixing

- It’s weird, it’s confusing… it must be quantum mechanics
- In the *b*-system, for example, we have two coupled states



- Simplest one-line hamiltonian is now a matrix

$$i\frac{d}{dt}\begin{pmatrix} \left|B_q^0(t)\right\rangle \\ \left|\bar{B}_q^0(t)\right\rangle \end{pmatrix} = \left(\underline{\underline{M}}_q - \frac{i}{2}\underline{\underline{\Gamma}}_q\right)\begin{pmatrix} \left|B_q^0(t)\right\rangle \\ \left|\bar{B}_q^0(t)\right\rangle \end{pmatrix}$$

- Off-diagonal elements provide mixing and interference

Mass-decay

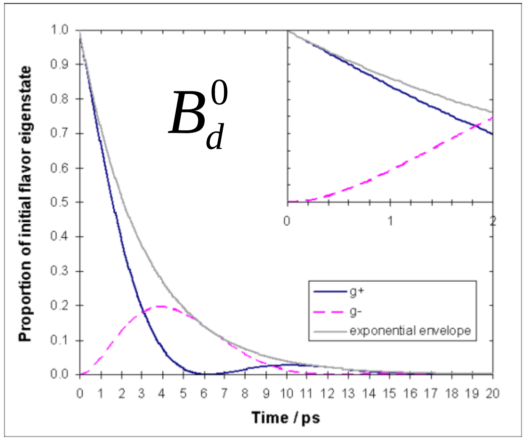
- So, it’s not a diagonal matrix… OK
- let’s diagonalize it to find:

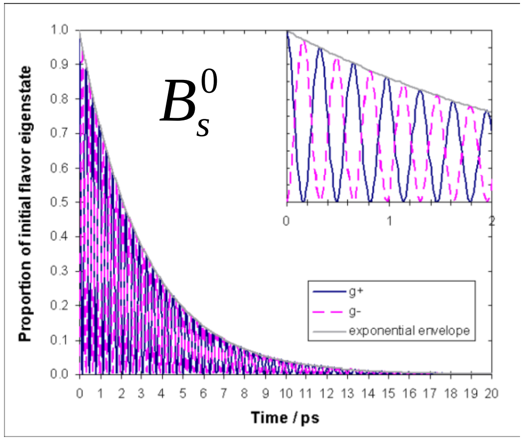
$$\left|B_H\right\rangle(t) \sim e^{-iHt} \sim e^{(-iM_H - \Gamma_H)t}$$

$$\left|B_L\right\rangle(t) \sim e^{-iHt} \sim e^{(-iM_L - \Gamma_L)t}$$

These are the mass-decay-eigenstates

- Not the flavour states, a time-dependent mixture of them!





Observables

- Four simple observables:
  1. Average width $\overline{\Gamma}, \Gamma_{11} + \Gamma_{22}$
  2. Average mass $\overline{M}, M_{11} + M_{22}$
  3. Width Difference $\Delta\Gamma_q = \left(\Gamma_H^q - \Gamma_L^q\right) = 2\left|\Gamma_{12}^q\right| \arg\left\{\frac{\Gamma_{12}^q}{M_{12}^q}\right\}$
  4. Mass Difference $\Delta m_q = \left(M_H^q - M_L^q\right) = 2\left|M_{12}^q\right|$

- And we also have **a phase**, which violates CP:

$$\phi_q = \arg\left\{-\frac{M_{12}^q}{\Gamma_{12}^q}\right\}$$

and/or

$$a_{fs}^q = \mathrm{Im}\left\{\frac{\Gamma_{12}^q}{M_{12}^q}\right\}$$

- All very predictable observables in the SM

Flavour-specific asymmetry

… a smoking gun for new physics??

Translate

1. p$\bar{p}$-interactions within a symmetric experiment
2. Correct all experimental biases (magnets, mis-id …)
3. Observe $N(\mu^+\mu^+) \neq N(\mu^-\mu^-)$
4. In the SM, the favoured way to make charge asymmetry is if:

$$b\overline{b} \longrightarrow \mu^+\mu^+ \quad \neq \quad b\overline{b} \longrightarrow \mu^-\mu^-$$

5. Which comes from B⁰-mixing:

$$b\overline{b} \Rightarrow \overline{B}^0 B^0 \sim \overline{B}^0 \overline{B}^0 \to \mu^+\mu^+ X \quad \neq \quad b\overline{b} \Rightarrow \overline{B}^0 B^0 \sim B^0 B^0 \to \mu^-\mu^- X$$

➢ **In the standard model it is almost negligible**

$$A^b \approx \frac{a_{fs}^s + a_{fs}^d}{2} \qquad SM = \left(-2.0 \pm 0.3\right) \times 10^{-4} \qquad \text{DØ} \approx \left(-1 \pm 0.3\right)\%$$

Discovery Potential

- a_{fs} is very sensitive to new physics (NP) even if:
  - Tree-level processes are SM-dominated
  - SM flavour structure
  - Unitary CKM
- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays
- Usual formula is modified:

$$a^{SM} \approx \mathrm{Im}\left\{ \frac{\Gamma_{12}^{SM}}{M_{12}^{SM}} \right\}$$

Discovery Potential

- a_{fs} is very sensitive to new physics (NP) even if:
  - Tree-level processes are SM-dominated
  - SM flavour structure
  - Unitary CKM
- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays
- If we allow a single NP phase in the mixing Θ

$$a^{NP} \approx \mathrm{Im}\left\{\frac{\Gamma_{12}^{SM}}{M_{12}^{SM}}\right\}\cos\Theta - \mathrm{Re}\left\{\frac{\Gamma_{12}^{SM}}{M_{12}^{SM}}\right\}\sin\Theta$$

Discovery Potential

- a_{fs} is very sensitive to new physics (NP) even if:
  - ❖ Tree-level processes are SM-dominated
  - ❖ SM flavour structure
  - ❖ Unitary CKM
- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays
- If we allow a single NP phase in the mixing Θ
  - (first part is just the SM value)

$$a^{NP} \approx a_{fs}^{SM} \cos\Theta - \mathrm{Re}\left\{\frac{\Gamma_{12}^{SM}}{M_{12}^{SM}}\right\}\sin\Theta$$

Discovery Potential

- a_{fs} is very sensitive to new physics (NP) even if:
  - Tree-level processes are SM-dominated
  - SM flavour structure
  - Unitary CKM

- With very weird scenarios (like *leptoquarks*)
  - Probe NP mixing, interference and/or decays

- If we allow a single NP phase in the mixing Θ
  - (first part is just the SM value)

$$a^{NP} \approx 2.1\times10^{-5}\cos\Theta + 4.0\times10^{-3}\sin\Theta$$

- Up to **200-times** the SM!!! [[[... still... < DØ measurement]]]

Flavour-specific asymmetry

At LHCb

Experimental Challenge

- At the LHC we have extra complications in the measurement
- Polluting asymmetries, which are all much larger than a_{fs}
  - Production asymmetry δ_p ~(10^{-2})
  - Detector asymmetry δ_c ~(10^{-2})
  - Background asymmetry δ_b ~(10^{-3})
- Use a, time-dependent, untagged, simultaneous fit to B_s+B_d
- Subtract two asymmetries to eliminate detector component

$$\boxed{\Delta A_{fs} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2} = (2.1 \pm 0.3) \times 10^{-4}}$$

Experimental Challenge

- At the LHC we have extra complications in the measurement
- Polluting asymmetries, which are all much larger than a_{fs}
    - Production asymmetry δ_p ~(10^{-2})
    - Detector asymmetry δ_c ~(10^{-2})
    - Background asymmetry δ_b ~(10^{-3})
- Use a, time-dependent, untagged, simultaneous fit to B_s+B_d
- Subtract two asymmetries to eliminate detector component

$$\boxed{\Delta A_{fs} = \frac{a_{fs}^{s} - a_{fs}^{d}}{2} = (2.1 \pm 0.3) \times 10^{-4}}$$

NB: DØ $$\left(A^{b} \sim \frac{a_{fs}^{s} + a_{fs}^{d}}{2} \sim -(2.0 \pm 0.3) \times 10^{-4} \right)$$

The simple formula

$$A^q_{fs}(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})}$$

$$A^q_{fs}(t) = \frac{a^q_{fs}}{2} - \left(\frac{a^q_{fs}}{2} \right) \frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t / 2)}$$

10^{-3} -> 10^{-5}

The ~~simple~~ Very Complicated formula

$$A^q_{fs}(t) = \frac{\Gamma(f)-\Gamma(\bar{f})}{\Gamma(f)+\Gamma(\bar{f})}$$

$$A^q_{fs}(t) = \underbrace{\frac{a^q_{fs}}{2}}_{10^{-3} \to 10^{-5}} \underbrace{-\frac{\delta^q_c}{2}}_{10^{-2}} - \left(\frac{a^q_{fs}}{2} \underbrace{+\frac{\delta^q_p}{2}}_{10^{-2}}\right)\frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)} \underbrace{+\frac{\delta^q_b}{2}\left(\frac{B}{S}\right)^q}_{10^{-3}}$$

$$\delta_c = \frac{\varepsilon(\bar{f}_i)}{\varepsilon(f_i)} - 1$$

$$\delta_p = \frac{N(\bar{I}_0)}{N(I_0)} - 1$$

$$\delta_b = \frac{\bar{B}/\bar{S}}{B/S} - 1$$

- Polluting asymmetries are much larger than a_{fs}
  - Detector asymmetry δ_c ~(10^{-2})
  - Production asymmetry δ_p ~(10^{-2})
  - Background asymmetry δ_b ~(10^{-3})

Simplify

- We measure time-dependent decay rates:

$$\Gamma(f) = Ne^{-\Gamma t}(1 + A_c)\left[(1 + A_{fs})\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (2A_p - A_{fs})\cos(\Delta m t)\right]$$

$$\rightarrow Ne^{-\Gamma t}\left[(1 + A_c + A_{fs})\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (2A_p - A_{fs} + 2A_pA_c)\cos(\Delta m t)\right]$$

$$\Gamma(\bar{f}) \rightarrow Ne^{-\Gamma t}\left[(1 - A_c - A_{fs})\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (A_{fs} - 2A_p + 2A_pA_c)\cos(\Delta m t)\right]$$

- A_c, A_p and A_{fs} are correlated and cannot be separately fitted
- First, reparameterise

Reparameterise

- Just to make it easier to see what we’re doing…

$$\Gamma(f) = Ne^{-\Gamma t}\left[(1+x_1)\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2+x_3)\cos(\Delta m t)\right]$$

$$\Gamma(\bar{f}) = Ne^{-\Gamma t}\left[(1-x_1)\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2-x_3)\cos(\Delta m t)\right]$$

where: $x_1 = A_c + a_{fs}$ $x_2 = 2A_cA_p$ $x_3 = 2A_p - a_{fs}$

- production asymmetry is an *initial state asymmetry*
- Changes the mixing amplitude, <u>does not</u> change the physics
- Fit for x_1 independently, which now only has detector asym

The subtraction method

- Take B_s/B_d with the same final states (f=KKπ μ)

$$\Gamma(f) = Ne^{-\Gamma t}\left[(1+x_1)\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2+x_3)\cos(\Delta m t)\right]$$

$$\Gamma(\bar{f}) = Ne^{-\Gamma t}\left[(1-x_1)\cosh\left(\frac{\Delta\Gamma t}{2}\right) + (x_2-x_3)\cos(\Delta m t)\right]$$

$$\text{where:}\quad x_1 = A_c + a_{fs} \qquad x_2 = 2A_cA_p \qquad x_3 = 2A_p - a_{fs}$$

- All production asymmetry is in x_2/x_3, just throw it away

- Measure the **difference** between B_s and B_d

$$\Delta A_{fs}^{s,d} = \frac{x_1^s - x_1^d}{2} = \frac{a_{fs}^s - a_{fs}^d}{2}$$

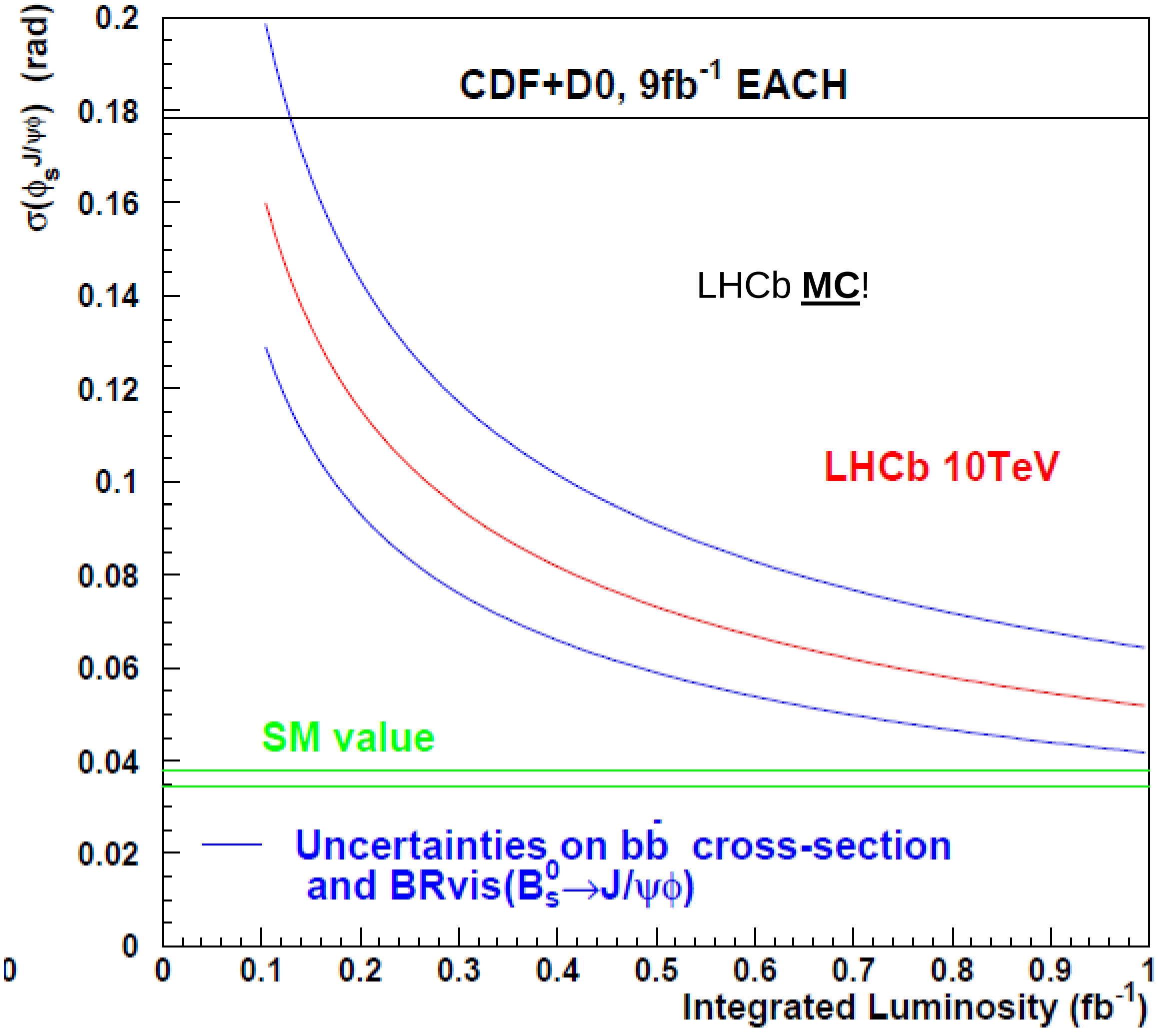
$$SM = \left(+2.5^{+0.5}_{-0.6}\right)\times 10^{-4}$$

Projections

- MC sensitivities, Real data yields and systematics
  - 0.1 fb^{-1} σ~$5\mathrm{x}10^{-3}$ ... First result (2011)
  - 1.0 fb^{-1} σ~$2\mathrm{x}10^{-3}$ ... 5σ observation? (2012/2013)

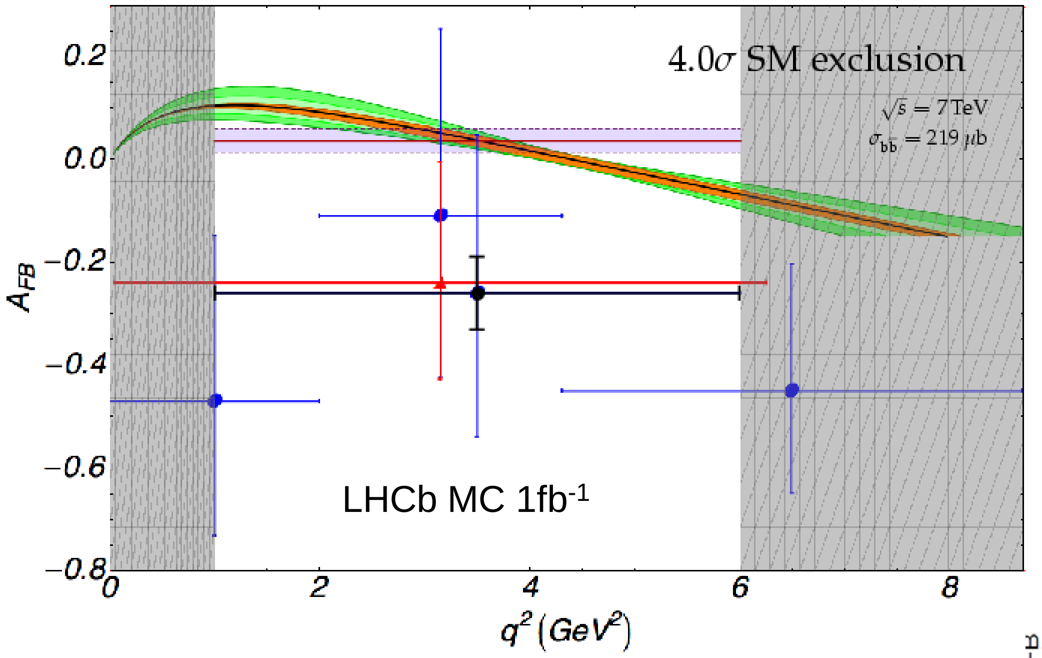
LHCb projections

J/ψ Φ

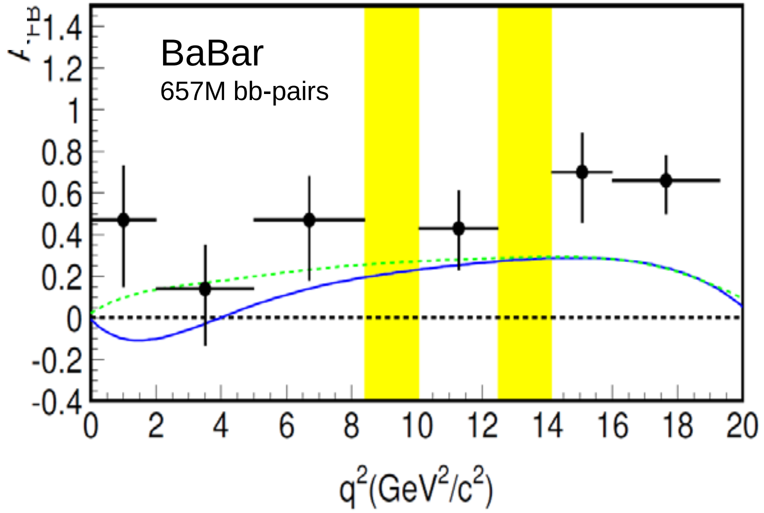


σ(φ_s^J/ψφ) (rad)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Integrated Luminosity (fb^-1)
CDF+D0, 9fb^-1 EACH
LHCb MC!
LHCb 10TeV
SM value
Uncertainties on bb̄ cross-section and BRvis(B_s^0→J/ψφ)

K*μμ



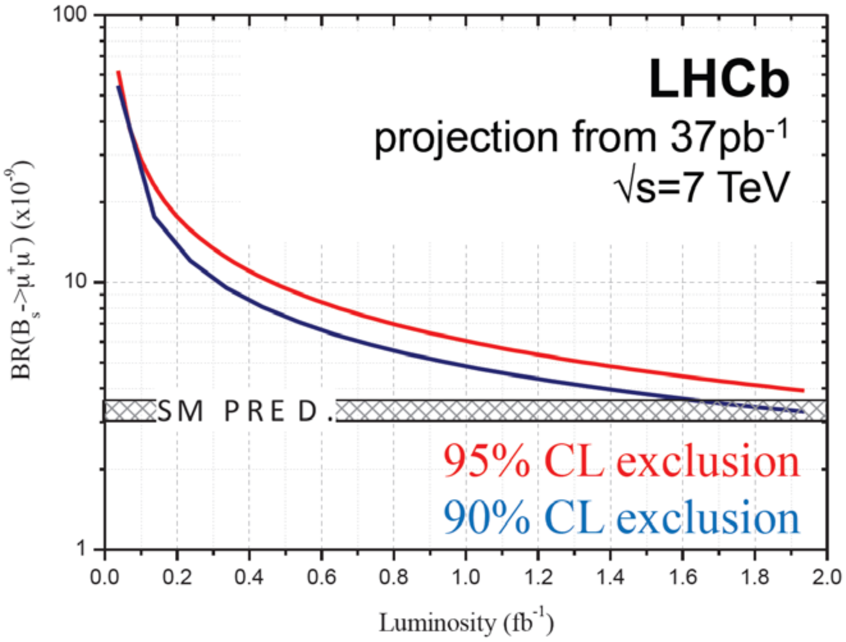
4.0σ SM exclusion
$\sqrt{s} = 7\,\mathrm{TeV}$
$\sigma_{b\bar{b}} = 219\,\mu b$
LHCb MC 1fb^{-1}
A_{FB}
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
2
4
6
8
$q^2\,(GeV^2)$

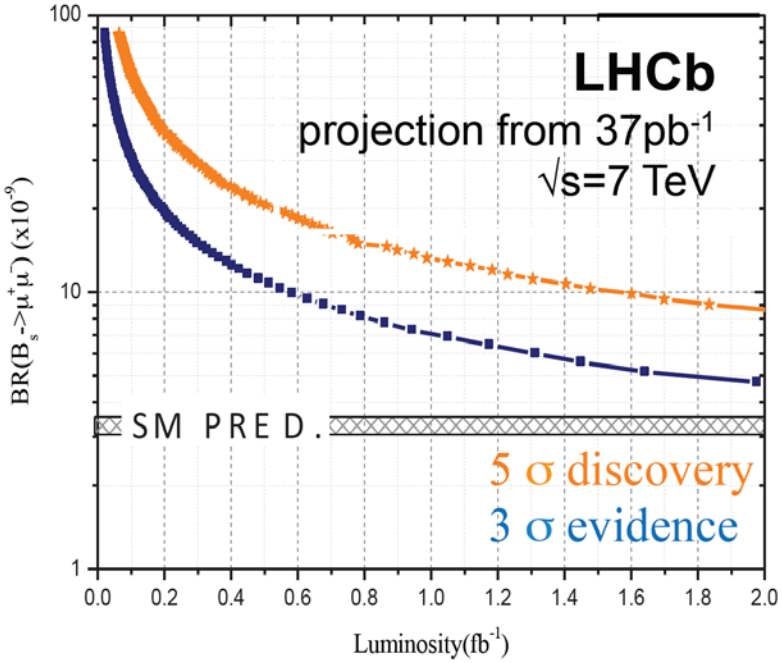


BaBar
657M bb-pairs
FB
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
2
4
6
8
10
12
14
16
18
20
$q^2(GeV^2/c^2)$

μμ

- LHCb will exclude most SUSY models this year!

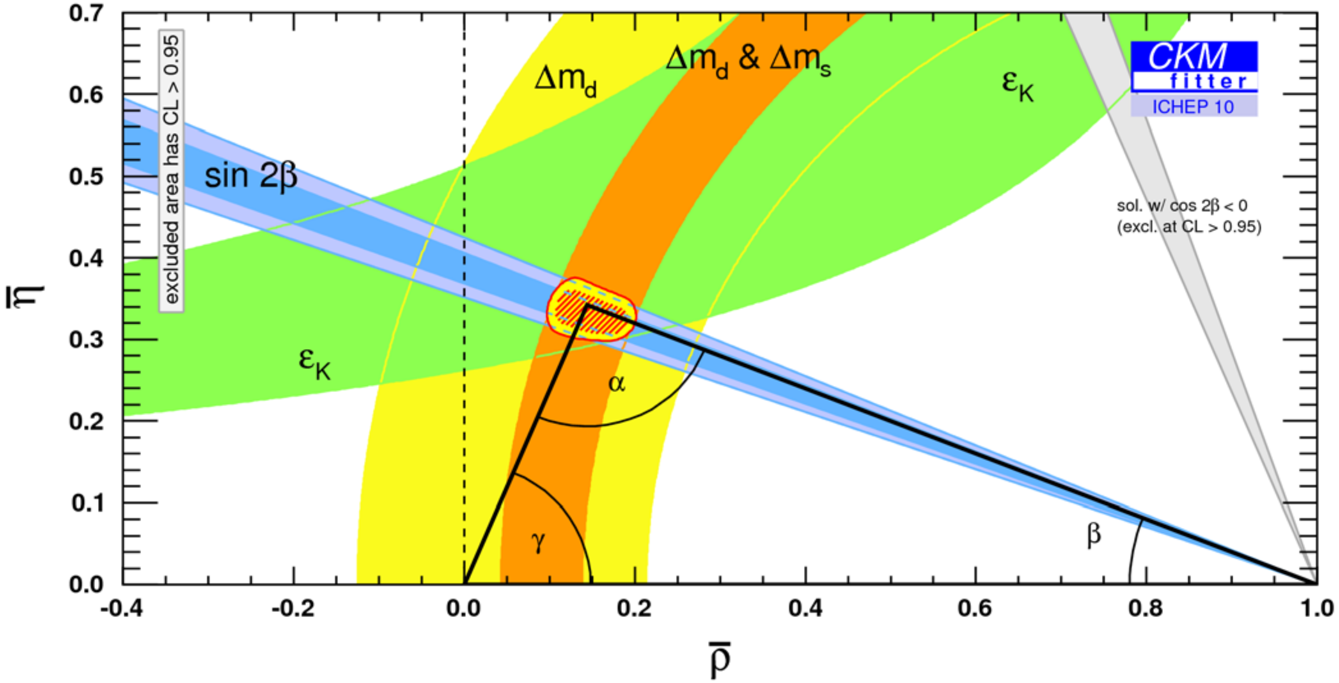




Misc

Looking for flavour (3)

- Check loop-level observables
- Would need a very accurate determination of dmd/dms

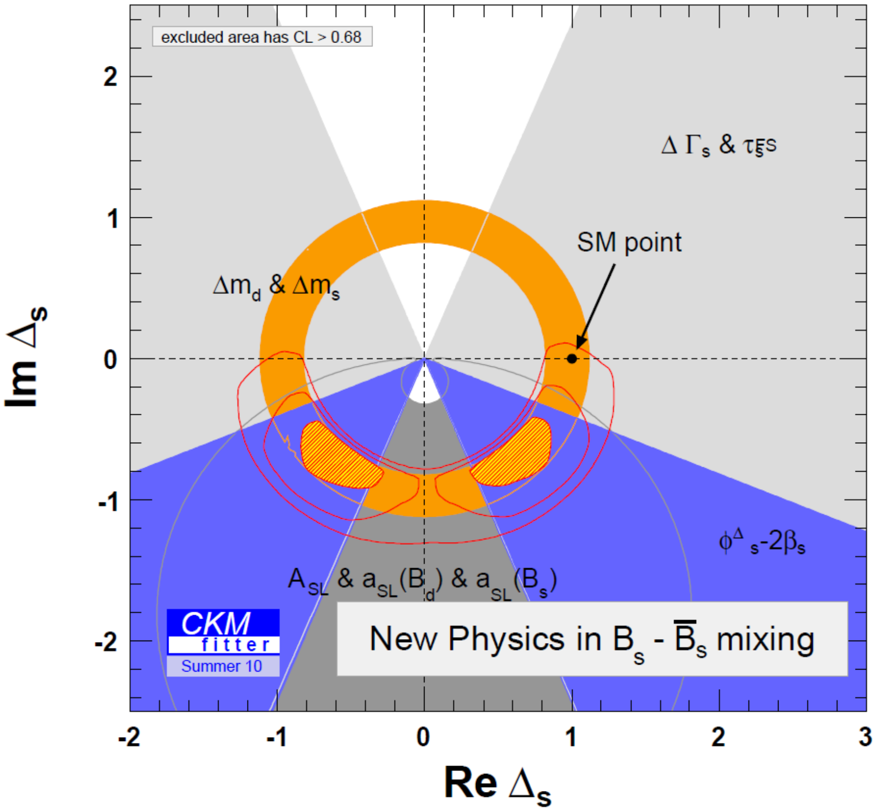


c.f. J/Ψ Φ

- $B_s^0 \rightarrow J/\psi\ \Phi$
  - Directly Measure sin ϕ_s
  - $\sigma(\phi_s)$ = 0.05^c in 1 fb^{-1}
- a_{fs}^{s}
  - Effectively Measures

$$\mathrm{Im}\left\{\frac{\Gamma_{12}}{M_{12}}\right\}\cos\Theta - \mathrm{Re}\left\{\frac{\Gamma_{12}}{M_{12}}\right\}\sin\Theta$$

  - $\sigma(\Theta)$ = 0.5^c in 1 fb^{-1}



- But they constrain NP differently
  - Effective power enhanced
  - NB physical limit of a_{fs} is at 4×10^{-3} < current DØ result!