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


**THEORY**

- Prout: Proton
- Rutherford: Neutron
- Gell-Mann: Angle
- Gell-Mann: EWSB
- Guralnik-Hagen-Kibble
- Cabbibo: angle
- Brout-Englert-Higgs
- Anderson: 8-fold way
- GIM: charm
- CKM: 3rd Generation

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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
(13.75 ± 0.13) Gyr
Matter

- 73% Dark Energy
- 22% Cold Dark Matter
- 5% Atoms

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Antimatter

Matter + Antimatter = photons
Antimatter

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CP-violation, CPV
observable difference between matter and antimatter
**Antimatter**

Matter + Antimatter = photons

- CP-violation, CPV
  - observable difference between matter and antimatter

**REALITY**

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

**SM (maximal CPV)**

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

- Where did you go?
- Guys...? Guys...??

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What does that have to do with heavy flavour physics?
Heavy flavour is a microcosm of the entire standard model

LHCb Preliminary
EVT: 49700980
RUN: 70684
There are in general two types of new physics searches:

1. Direct Searches
   - LSP
   - Higgs
   - 4th Gen
   - Hidden valley
   - WIMP
   - SMP

2. Precision measurements
   - Rare Decays
   - CP-violating asymmetries
   - Mixing parameters
   - CKM measurements

New Physics Scale / Collider Energy:

- "Old physics" previous collider searches
- "New physics" future collider searches

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Neutral mesons are weird

- “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!
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

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Looking for NP

1. Find a place where new physics is unlikely
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Unlikely: tree-level decays

\[ B^- \rightarrow \bar{u} \rightarrow u \rightarrow K^- \]

Likely: loops and penguins

\[ B_q^0 \rightarrow \bar{b} \quad \bar{B}_q^0 \rightarrow q \quad b \]
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 $\gamma$ is not well known
Looking for flavour (1)

- $B_d \rightarrow K^* \mu \mu$ has both loops and penguins!

- Amongst many observables $A_{fb}$ is sensitive to SUSY

---

e.g.

```
B_d \rightarrow K^* \mu \mu
```

---

![Graphs and diagrams showing $A_{fb}$ vs. $q^2$ for different models and experiments: CDF, SM, BELLE, BABAR.](image)

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Looking for flavour (2)

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

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

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

LHCb:
$$B(B_s^0 \rightarrow \mu^+\mu^-) < 5.6 \times 10^{-8}$$
$$B(B^0 \rightarrow \mu^+\mu^-) < 1.5 \times 10^{-8}$$
Looking for CP (2)

- CP-asymmetry in decays (Direct CP-violation)

- Interesting hint: the $B \to K\pi$ “puzzle”

- Precision two-body $B$-decays will be very interesting
Mixing can be modified in both magnitude and phase

Define a complex number parameter $\Delta_q$ 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??
Evidence for an anomalous like-sign dimuon charge asymmetry


We measure the charge asymmetry $A$ of like-sign dimuon events in 6.1 fb$^{-1}$ of $p\bar{p}$ 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: $A_{sl}^b = -0.00957 \pm 0.00251$ (stat) $\pm 0.00146$ (syst). This result differs by 3.2 standard deviations from the standard model prediction $A_{sl}^b(SM) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$ and provides first evidence of anomalous CP-violation in the mixing of neutral $B$ mesons.

PACS numbers: 13.25.Hw; 14.40.Nd
Very difficult measurement

Observe

\[ N(\mu^+\mu^+) \neq N(\mu^-\mu^-) \]

Flavour-specific asymmetry from $B^0$-mixing in the SM:

In the standard model $a_{fs}$ is almost negligible

\[
A^b \approx \frac{a^s_{fs} + a^d_{fs}}{2} \quad SM = (-2.0 \pm 0.3) \times 10^{-4} \quad D\emptyset \approx (-1 \pm 0.3)\%
\]
Situation could really be cleared up by LHCb
Current status

- LHCb is reconstructing both $B^0_s \rightarrow D_s^+ \mu^+ \nu_\mu$ and $B^0_d \rightarrow D_d^+ \mu^+ \nu_\mu$

- LHCb is catching up with DØ very quickly

$$\mu \phi \pi \text{ sample}$$

$\sim 100k \ D_s^0 \text{ in 5 \ fb}^{-1}$

$\sim 100k \ D_s^0 \text{ in 0.2 \ fb}^{-1}$
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 D\bar{\phi}
  - Need a clever new method

\[
\Delta A_{fs} = \frac{a^s_{fs} - a^d_{fs}}{2} = (2.1 \pm 0.3) \times 10^{-4}
\]

NB: D\bar{\phi} (inclusive)
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
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 $\gamma$, $B_{s/d} \rightarrow \mu \mu$, $B_d \rightarrow K^* \mu \mu$, $B_s \rightarrow J/\psi \Phi$ ...

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!
Backups are often required
Acknowlegements

- 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 $\beta_s$ 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](http://arxiv.org/abs/1103.2465)
  - Detector paper: J. of Instrumentation (No. 3 pp. S08005P)
  - “Roadmap” of physics analyses: arXiv:0912.4179
    - Chapter 2: $\gamma$
    - Chapter 3: $B \rightarrow K\pi$
    - Chapter 5: $B_{s/d} \rightarrow \mu\mu$
    - Chapter 6: $K^* \mu\mu$
  - $\Delta A_{fs}$ studies:
    - N. Brook *et al.*, CERN-LHCb-2007-054

- **CPLear**: Kaon mixing: *Physics Reports, Volume 374, Issue 3, Pages 165-270 (January 2003)*

- **Experimental averages**:

- **More on $B \rightarrow K\pi$**

- **CDF $B_{s/d} \rightarrow \mu\mu$**: CDF Public Note 9892 (preliminary)
Further introduction
Gravity

(13.75 ± 0.13) Gyr

Afterglow Light Pattern 400,000 yrs.

Dark Ages

Development of Galaxies, Planets, etc.

Dark Energy Accelerated Expansion

Inflation

Quantum Fluctuations

1st Stars about 400 million yrs.

Big Bang Expansion

13.7 billion years

WMAP
Antimatter

Matter + Antimatter = photons

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

REALITY

SM (maximal CPV)

\[
\frac{n_{\text{baryon}}}{n_\gamma} < 10^{-20}
\]

Mass of entire solar system: \(2 \times 10^{30}\) kg

Mass of largest asteroid, Ceres: \(10^{21}\) kg

Area ~ Kazakhstan: Population ~ one small dog

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CPV in the SM is ensconced in a single unitary matrix

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

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

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Mixing observables
The most basic hamiltonian of anything

\[ H = i \frac{d}{dt} |X\rangle = \left( M_x - i \frac{\Gamma_x}{2} \right) |X\rangle \]

Because:

\[ |X\rangle(t) \sim e^{-iHt} \sim e^{(-iM-\Gamma)t} \]

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

![Diagram showing $B_q^0$ and $\bar{B}_q^0$ states with $b$, $u, c, t$, and $\bar{q}$ transitions]

- Simplest one-line Hamiltonian is now a matrix

$$i \frac{d}{dt} \left( \begin{pmatrix} B_q^0(t) \\ \overline{B}_q^0(t) \end{pmatrix} \right) = \left( M_q - \frac{i}{2} \Gamma_q \right) \overline{B}_q^0(t)$$

- Off-diagonal elements provide mixing and interference
So, it’s not a diagonal matrix… OK

let’s diagonalize it to find:

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

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

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

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

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

\[
\phi_q = \arg\left\{ -\frac{M_{12}^q}{\Gamma_{12}^q} \right\} \quad \text{and/or} \quad \alpha_{f^q_s} = \text{Im}\left\{ \frac{\Gamma_{12}^q}{M_{12}^q} \right\}
\]

- All very predictable observables in the SM
Flavour-specific asymmetry

… a smoking gun for new physics??
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:

   \[ b\bar{b} \rightarrow \mu^+\mu^+ \neq b\bar{b} \rightarrow \mu^-\mu^- \]

5. Which comes from $B^0$-mixing:

   \[ b\bar{b} \Rightarrow \bar{B}^0B^0 \sim \bar{B}^0\bar{B}^0 \rightarrow \mu^+\mu^+X \neq b\bar{b} \Rightarrow \bar{B}^0B^0 \sim B^0\bar{B}^0 \rightarrow \mu^-\mu^-X \]

➢ In the standard model it is almost negligible

\[ A^b \approx \frac{a_{fs}^s + a_{fs}^d}{2} \]

\[ SM = (-2.0 \pm 0.3) \times 10^{-4} \]

\[ D\emptyset \approx (-1 \pm 0.3)\% \]
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:

\[ a_{SM}^f \approx \text{Im} \left\{ \frac{\Gamma_{12}^{SM}}{M_{12}^{SM}} \right\} \]
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 $\Theta$

\[
a^{NP} \approx \text{Im}\left\{ \frac{\Gamma^{SM}_{12}}{M^{SM}_{12}} \right\} \cos \Theta - \text{Re}\left\{ \frac{\Gamma^{SM}_{12}}{M^{SM}_{12}} \right\} \sin \Theta
\]
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 $\Theta$
  - (first part is just the SM value)

\[
a^{NP} \approx a_{fs}^{SM} \cos \Theta - \text{Re} \left\{ \frac{\Gamma_{12}^{SM}}{M_{12}^{SM}} \right\} \sin \Theta
\]
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 $\Theta$
  - (first part is just the SM value)

$$a^{NP} \approx 2.1 \times 10^{-5} \cos \Theta + 4.0 \times 10^{-3} \sin \Theta$$

- 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 $\delta_p \sim 10^{-2}$
  - Detector asymmetry $\delta_c \sim 10^{-2}$
  - Background asymmetry $\delta_b \sim 10^{-3}$

- Use a, time-dependent, untagged, simultaneous fit to $B_s + B_d$

- Subtract two asymmetries to eliminate detector component

\[
\Delta A_{fs} = \frac{a^{s}_{fs} - a^{d}_{fs}}{2} = (2.1 \pm 0.3) \times 10^{-4}
\]
At the LHC we have extra complications in the measurement

Polluting asymmetries, which are all much larger than $a_{fs}$

- Production asymmetry $\delta_p \sim (10^{-2})$
- Detector asymmetry $\delta_c \sim (10^{-2})$
- Background asymmetry $\delta_b \sim (10^{-3})$

Use a, time-dependent, untagged, simultaneous fit to $B_s + B_d$

Subtract two asymmetries to eliminate detector component

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

NB: DØ

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

\[ A_{fs}^q(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} \]

\[ A_{fs}^q(t) = \frac{a_{fs}^q}{2} - \left( \frac{a_{fs}^q}{2} \right) \frac{\cos(\Delta m_q t)}{\cosh(\Delta \Gamma_q t / 2)} \]

10^{-3} -> 10^{-5}
The simple formula

\[ A_{fs}^q(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} \]

\[
A_{fs}^q(t) = \frac{a_{fs}^q}{2} - \frac{\delta_c^q}{2} - \left( \frac{a_{fs}^q}{2} + \frac{\delta_p^q}{2} \right) \cos\left(\Delta m_q t\right) \cosh\left(\Delta \Gamma_q t / 2\right) + \frac{\delta_b^q}{2} \left( \frac{B}{S} \right)^q
\]

- Polluting asymmetries are much larger than \( a_{fs} \)
  - Detector asymmetry \( \delta_c \) \( \sim (10^{-2}) \)
  - Production asymmetry \( \delta_p \) \( \sim (10^{-2}) \)
  - Background asymmetry \( \delta_b \) \( \sim (10^{-3}) \)
We measure time-dependent decay rates:

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

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

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

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

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

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

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

where: \( x_1 = A_c + a_{fs} \) \hspace{1cm} \( x_2 = 2A_cA_p \) \hspace{1cm} \( x_3 = 2A_p - a_{fs} \)

- production asymmetry is an initial state asymmetry

- Changes the mixing amplitude, does not 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 ($f=KK\pi \mu$)

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

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

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

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

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

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

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

- MC sensitivities, Real data yields and systematics
  - 0.1 fb\(^{-1}\) $\sigma \sim 5 \times 10^{-3}$ ... First result (2011)
  - 1.0 fb\(^{-1}\) $\sigma \sim 2 \times 10^{-3}$ ... $5\sigma$ observation? (2012/2013)
LHCb projections
$J/\psi \Phi$

CDF+D0, 9fb$^{-1}$ EACH

LHCb MC!

LHCb 10TeV

SM value

Uncertainties on $b\bar{b}$ cross-section and BRvis($B_s^0 \rightarrow J/\psi\phi$)
$K^*\mu\mu$

**BaBar**
- 657M $b\bar{b}$-pairs

**LHCb MC 1fb$^{-1}$**

- $\sqrt{s} = 7$ TeV
- $\sigma_{bb} = 219$ μb

4.0σ SM exclusion
µµ

LHCb will exclude most SUSY models this year!

- 95% CL exclusion
- 90% CL exclusion

LHCb projection from 37pb⁻¹
\(\sqrt{s}=7\) TeV

- 5 \(\sigma\) discovery
- 3 \(\sigma\) evidence

Luminosity (fb⁻¹)
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 $\sin \phi_s$
  - $\sigma(\phi_s) = 0.05c$ in 1 fb$^{-1}$

- $\alpha_{fs}^s$
  - Effectively Measures
  
  $$\text{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right) \cos \Theta - \text{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right) \sin \Theta$$

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

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