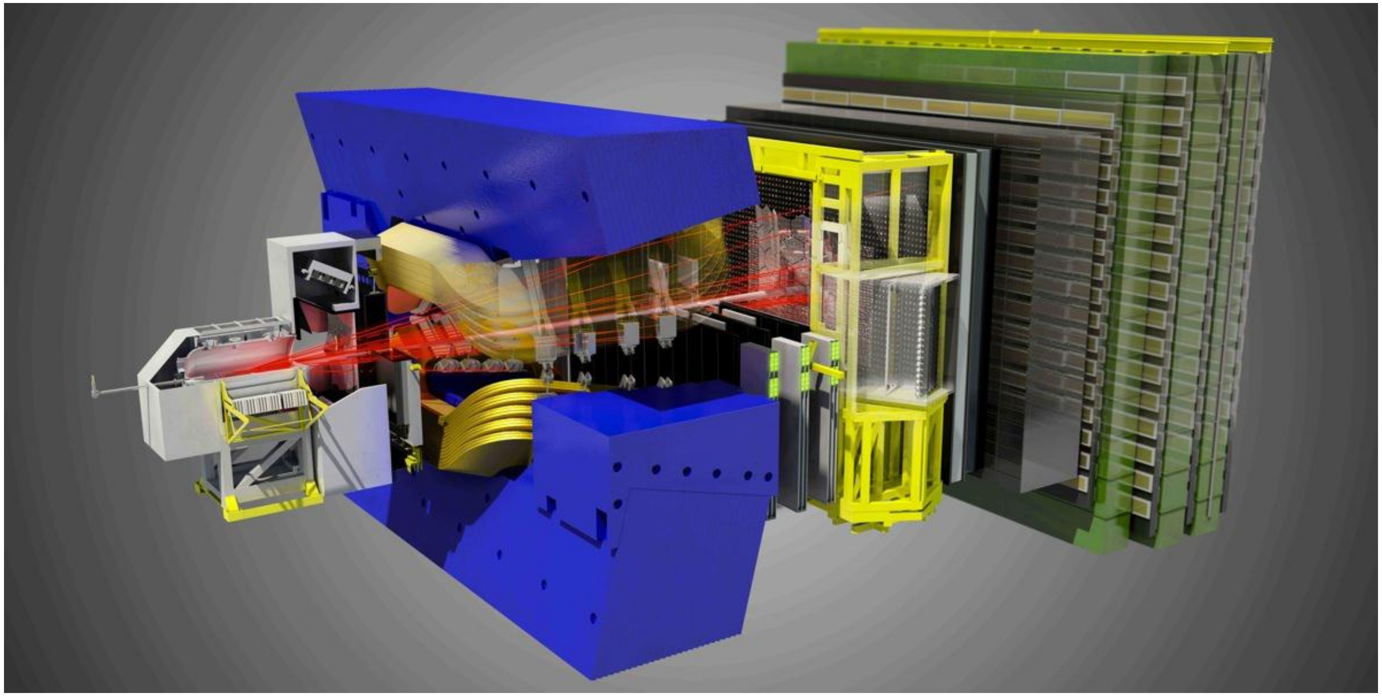
LHCb Overview



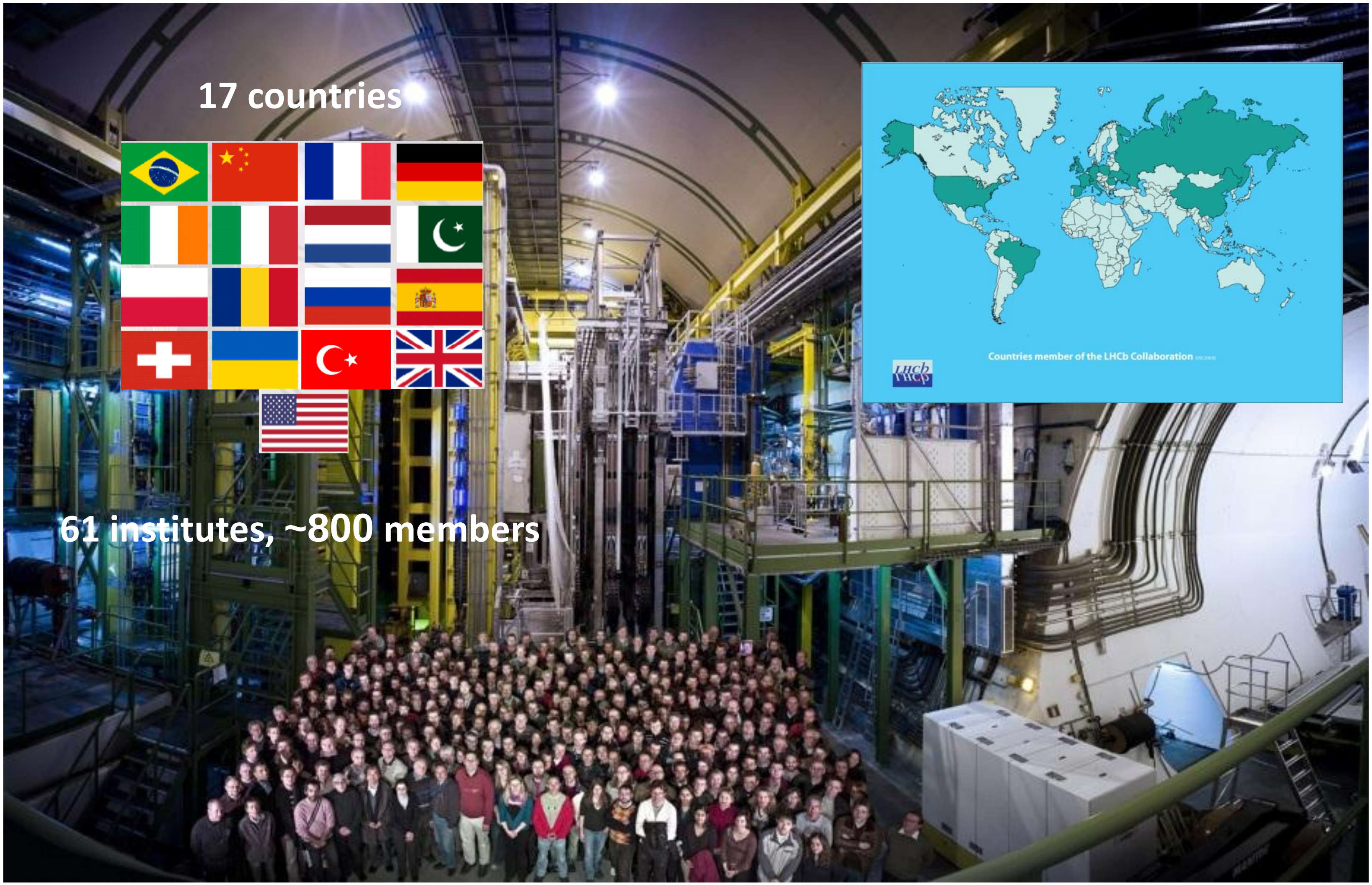
Barbara Storaci
on behalf of the LHCb Collaboration

CERN Council, December 14th, 2012

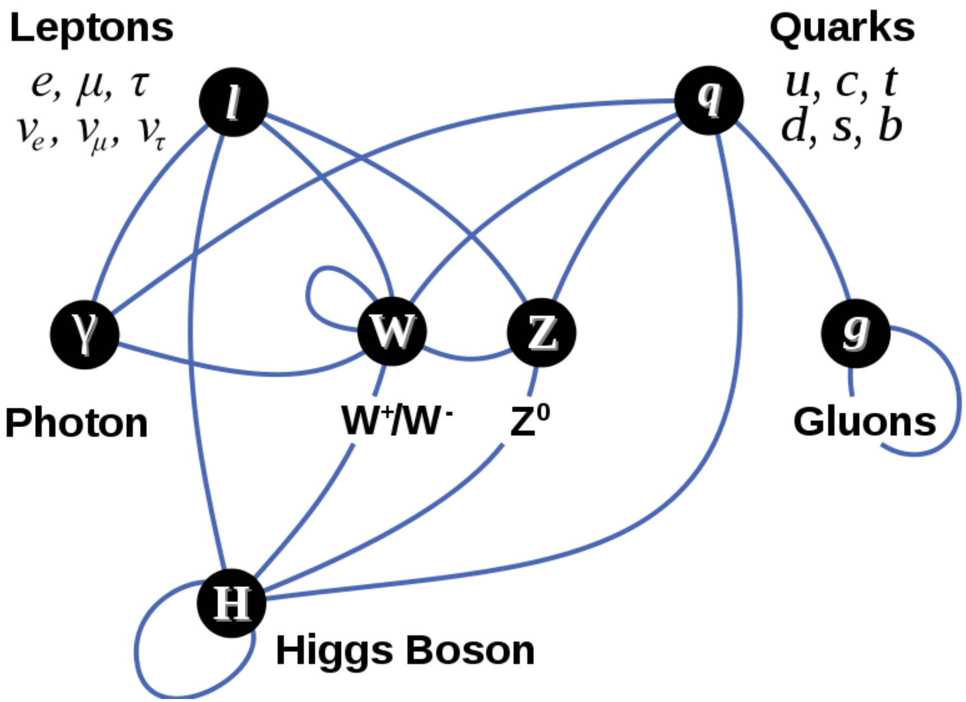
Overview

- Introduction
  - Collaboration
  - Type of physics considered
  - Detector
- Detector performances
- Selection of physics topics:
  - First evidence of the $B_s \rightarrow \mu^+\mu^-$ decay
  - D-mixing
  - Flavour-specific matter antimatter asymmetry
- Upgrade

Who are we?


17 countries
61 institutes, ~800 members
Countries member of the LHCb Collaboration
LHCb

Introduction: the Standard Model



- Matter made of quarks and leptons
- The interactions between particles are mediated by particles called bosons.
- Masses generated through the Higgs mechanism

Standard Model confirmed by a wealth of experiments in the last 30 years…
… still NOT considered the final model … it leaves some open questions

Introduction: few of the open questions

Why is the universe made of matter?

Matter and anti-matter were produced in the big bang

But matter and antimatter annihilate when they meet

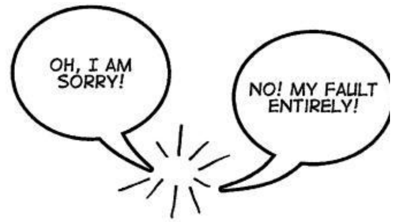
Needed an asymmetry to allow it:

- CP violation in the Standard Model does not seem to be enough

Introduction: few of the open questions

Why is the universe made of matter?

Matter and anti-matter were produced in the big bang



But matter and antimatter annihilate when they meet

Needed an asymmetry to allow it:

- CP violation in the Standard Model does not seem to be enough

Dark Matter

Presence of dark matter in the universe?

None particles in the Standard Model are satisfactory candidates for it

What is the dark matter made of?

Introduction: few of the open questions

Why is the universe made of matter?

Matter and anti-matter were produced in the big bang

But matter and antimatter annihilate when they meet

Needed an asymmetry to allow it:

- CP violation in the Standard Model does not seem to be enough

Looking for New Physics

Dark Matter

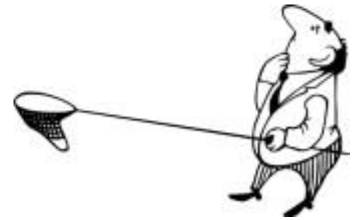
Presence of dark matter in the universe?

None particles in the Standard Model are satisfactory candidates for it

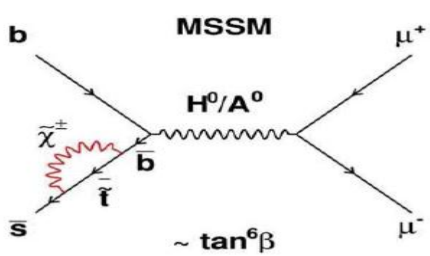
What is the dark matter made off?

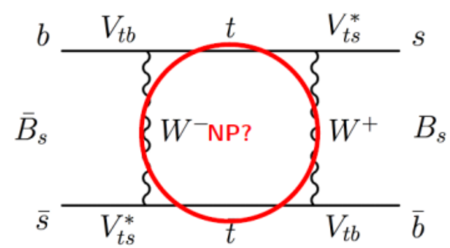
Where can we find new physics?

Direct Search (Atlas and CMS): look for the production of new particles



Indirect Search (LHCb): look for effect due to the presence of new particles in the loop





Enhancement of the branching fraction of very rare decays

Effects on the value of Standard Model parameters (<u>precise measurements</u> to look for discrepancy)

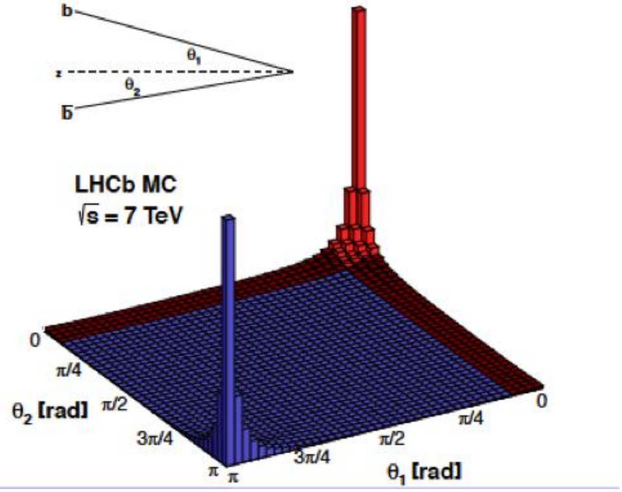
Precise measurements (I)

- B-physics:
  - Precise theoretical prediction
  - Several final states accessible
  - Clear experimental signature
  - Indirect search (complementary approach to Atlas and CMS)

B hadrons are made of quarks:

- B mesons ($q\bar{b}$):
  - In the talk: $B^0(d\bar{b})$ and $B_s^0(s\bar{b})$
- B baryon (qqb)

"B mesons are the elephants of the particle zoo – they are heavy and they live long."
(attributed to Thomas Schietinger)

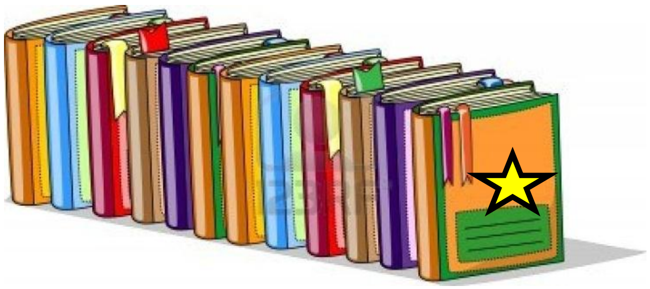


- 100,000 $b\bar{b}$ pairs produced per second
- $b\bar{b}$ pairs produced at low angle in the same forward or backward cone

Precise measurements (II)

The LHCb experiment has an unusual shape for running in collider mode

ATLAS/CMS: sub-detectors surrounding the entire collision point (like an onion)



LHCb: ~20m of stacked sub-detectors (like books on a shelf)
→ easy access to sub-detectors

Require a **sophisticated** detector for **precise** measurements

1. Close to the beam
2. Vertex and Tracking capabilities
3. Distinguish particle in the final state (Particle identification)

Precise measurement difficult in presence of too many primary vertexes (needed low luminosity)

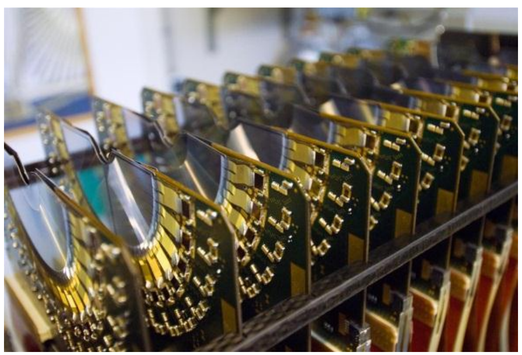
Overview

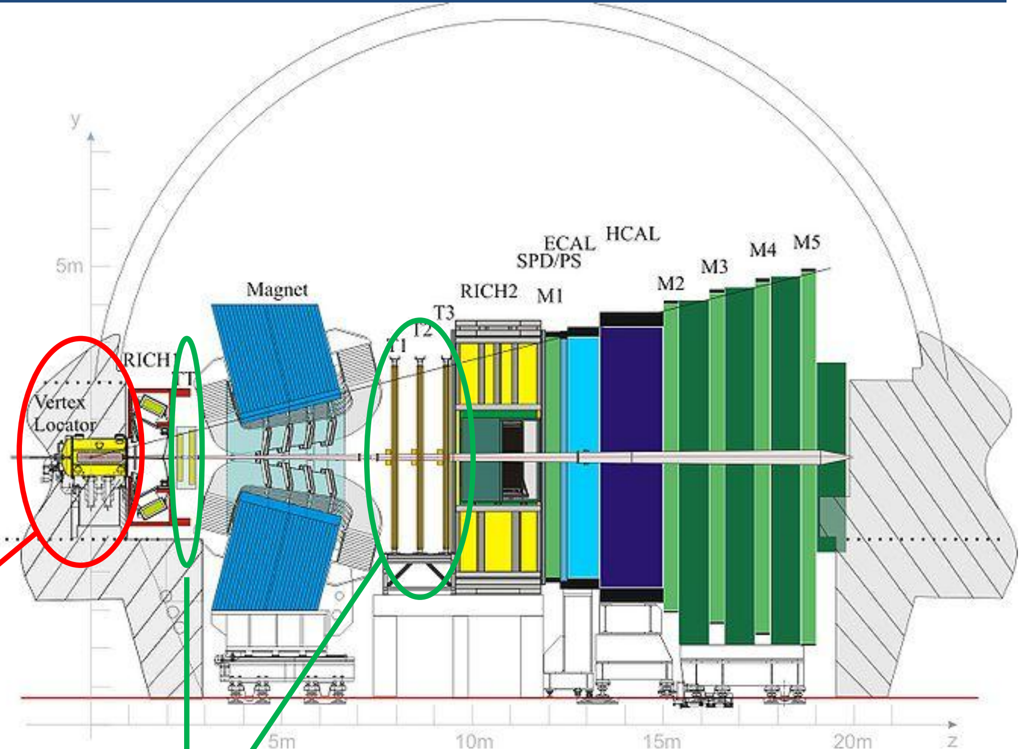
- Introduction
  - Collaboration
  - Type of physics considered
  - Detector
- **Detector performances**
- Selection of physics topics:
  - First evidence of the $B_s \to \mu^+\mu^-$decay
  - D-mixing
  - Flavour-specific matter antimatter asymmetry
- Upgrade

The LHCb experiment (I)

Required a **sophisticated** detector for **precise** measurements

1. Close to the beam
2. Vertex and Tracking capabilities
3. Distinguish particle in the final state (Particle identification)





Vertex Locator: silicon strip detector

- Two moving halves
  - Openable during injection phase
  - Few mm from the beam line during data taking
- Excellent vertex resolution

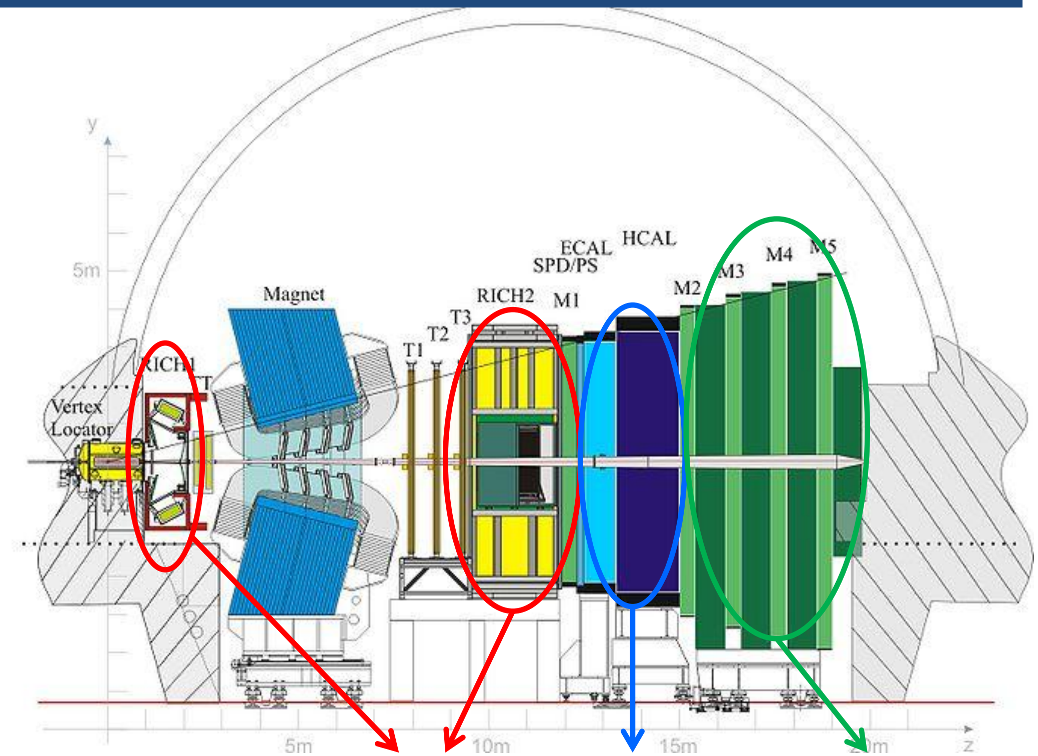
Tracking system: silicon+straw tube technologies

- Excellent mass resolution: ~24MeV/c^2 for 2-body B decays
- Tracking efficiency >96% for long tracks

The LHCb experiment (II)

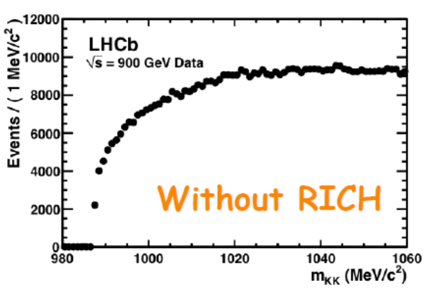
Required a **sophisticated** detector for **precise** measurements

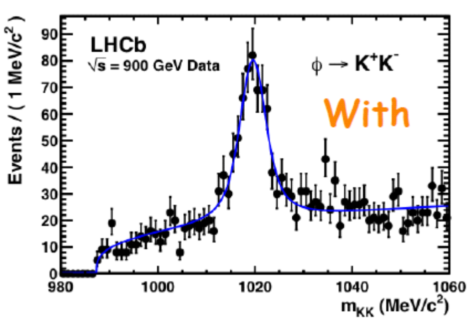
1. Close to the beam
2. Vertex and Tracking capabilities
3. Distinguish particle in the final state (Particle identification)



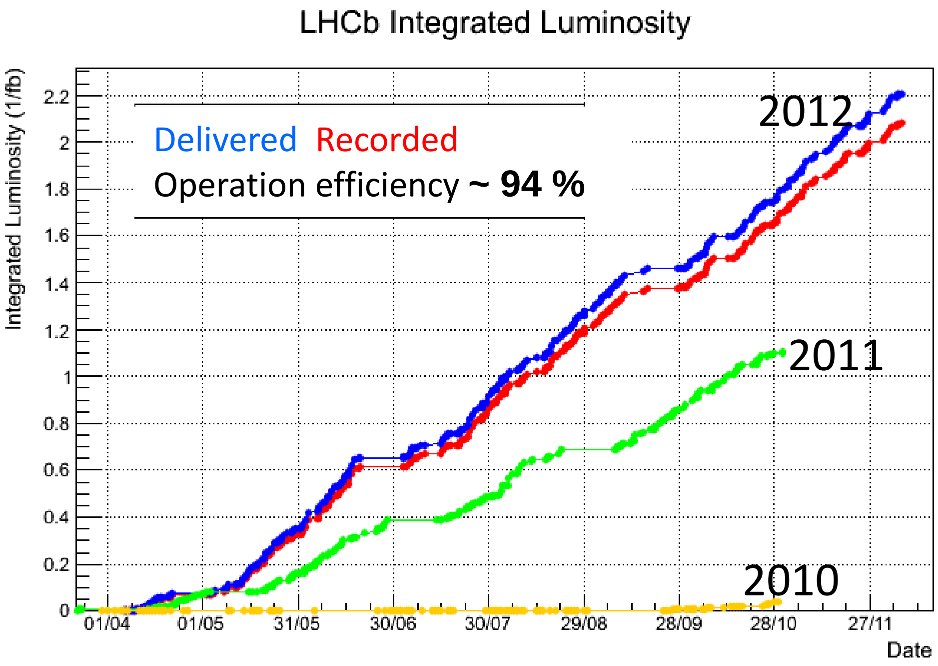
Particle Identification: RICHes + calorimeters + muon stations

- Allows to distinguish particles in the final states
- Peculiarity of LHCb: 2 RICH detectors:
  - Designed to distinguish K and π
  - Allows precise measurement of hadronic decays:
    - e.g. $B_s^0 \to D_s^- \pi^+$ vs $B_s^0 \to D_s^- K^+$
- Allows strong suppression of combinatorial background





LHCb operation status



Precise measurement set constraint on the maximum luminosity to run at

BUT

…we manage to run at a luminosity two times higher than the designed one!

- **High data storage rate: 5kHz**
- Trigger optimized for beauty and charm physics

These years of data taking and high quality physics were possible also thanks to the exceptional performance of the machine!

Overview

- Introduction
  - Collaboration
  - Type of physics considered
  - Detector
- Detector performances
- Selection of physics topics:
  - First evidence of the $B_s \to \mu^+\mu^-$ decay
  - D-mixing
  - Flavour-specific matter antimatter asymmetry
- Shut down and upgrade

LHCb physics program

Where can we look for New Physics?

- Rare and very rare decays
- CP violation in Beauty and Charm physics
- Precision electroweak physics in the forward direction (Z/W bosons)
- Discovery of new exotic states using the excellent mass resolution of LHCb
- Search for unexpected long living particles and displaced vertices
- …

- 83 papers **(more than 1 paper per week in 2012!)**
- 101 conference notes (preliminary results)
- Most results based on 2011 data, many more result will come soon (we have already collected twice the statistics we already analyzed)!

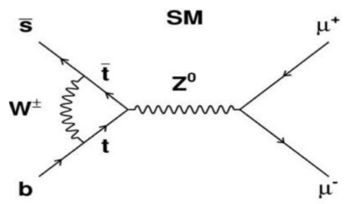
Selection of topics

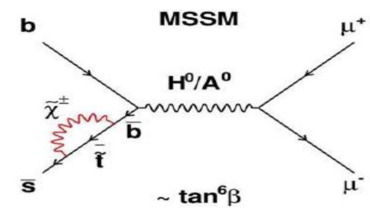
1. First evidence of the $B_s^0 \to \mu^+\mu^-$
2. Example of c-physics: $D^0 - \overline{D^0}$ mixing
3. Flavour-specific matter antimatter asymmetry

$B^0_{(s)} \to \mu^+\mu^-$ decay

Very rare decay in the SM:

Mode	SM prediction
$B_s \to \mu^+\mu^-$	$(3.54 \pm 0.30) \times 10^{-9}$
$B^0 \to \mu^+\mu^-$	$(0.11 \pm 0.01) \times 10^{-9}$



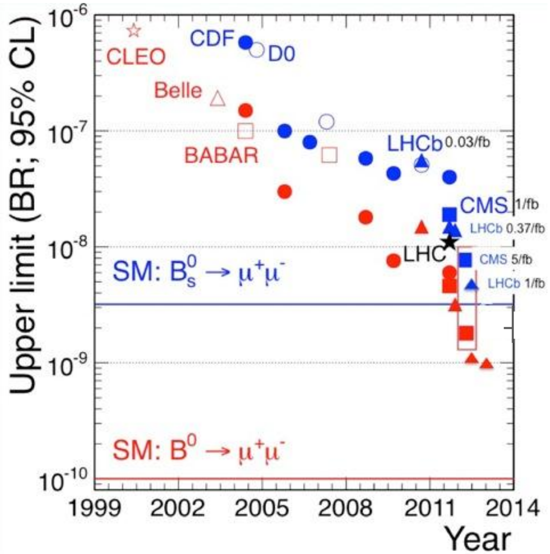


Features:

- Branching Fraction (BF) very well predicted in SM
- Fully reconstructable leptonic final state
- Never seen before, expected enhancement of the BF in several NP scenarios
- Useful to discriminate between NP scenarios

Searching it since 25 years

First attempt by ARGUS (1987)



Situation before October 2012 (95%CL):

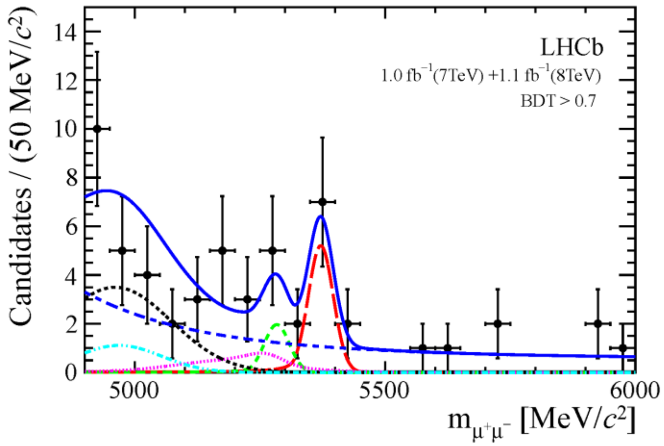
Atlas: $BF(B^0_s \to \mu^+\mu^-) < 22 \cdot 10^{-9}$

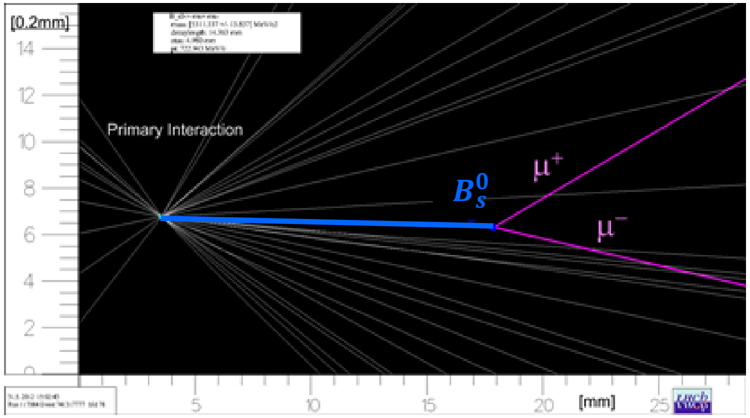
CMS: $BF(B^0_s \to \mu^+\mu^-) < 7.7 \cdot 10^{-9}$

LHCb: $\boldsymbol{BF(B^0_s \to \mu^+\mu^-) < 4.5 \cdot 10^{-9}}$

LHC combination: $BF(B^0_s \to \mu^+\mu^-) < 4.2 \cdot 10^{-9}$

1st evidence of the $B_s^0 \rightarrow \mu^+\mu^-$ decay





Measured Branching Fraction:

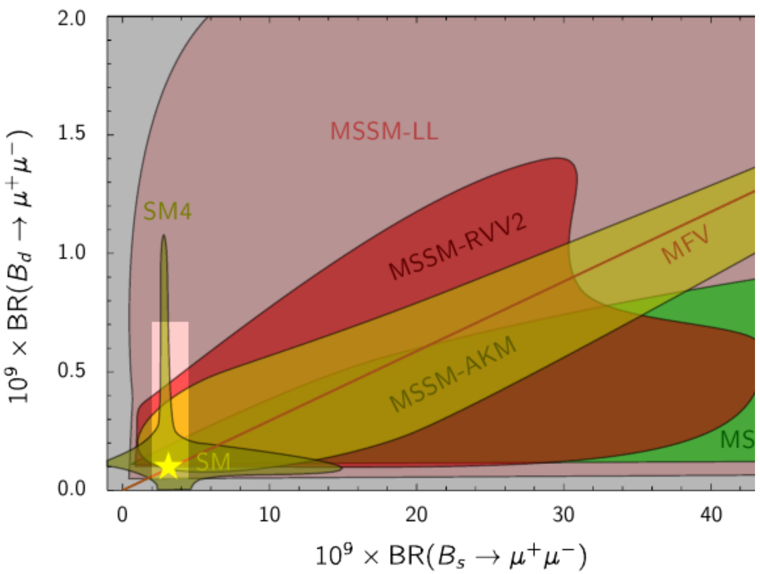
$$B_s^0 \rightarrow \mu^+\mu^- = (3.2^{+1.4}_{-1.2}(stat)^{+0.5}_{-0.3}\,(syst)) \cdot 10^{-9}$$

Tightest upper limit set:

$$B^0 \rightarrow \mu^+\mu^- < 9.4 \cdot 10^{-10}$$

- Results compatible with SM
- Strong constraint put on NP-scenarios

Physics implications:



Selection of topics

1. First evidence of the $B_s^0 \rightarrow \mu^+\mu^-$
2. Example of c-physics: $D^0 - \overline{D^0}$ mixing
3. Flavour-specific matter antimatter asymmetry

Not only B-Physics

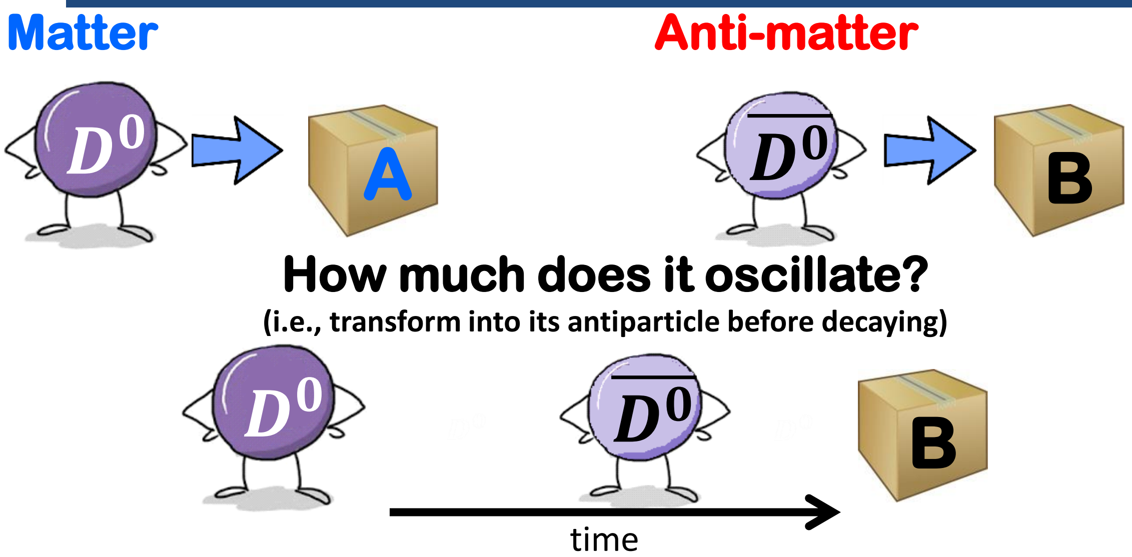
… also Charm Physics

- Charm production at LHC ~20 times more than beauty
- Charm quarks lighter than beauty quarks
  - Theory predictions more difficult
  - But new physics effect complementary to the one in the b-sector

Example: $D^0 - \overline{D^0}$ mixing

- Neutral meson oscillates between matter and anti-matter
  - Oscillation of neutral kaons and B-mesons well established
  - Evidence of charm mixing from other experiments (no observation yet from a single measurement)
- Charm mixing predicted to be small in the Standard Model
- First step to study CP violation in the *D* oscillations

$D^0 - \overline{D^0}$ mixing (I)



$D^0 - \overline{D^0}$ oscillation very slow:

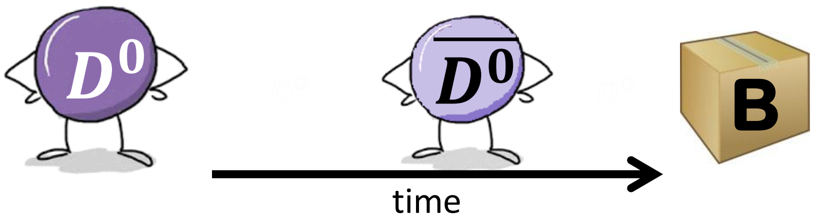
- The full oscillation period cannot be observed
- Necessary to look for small changes in B/A as a function of decay time:
  - No mixing: B/A constant
  - Mixing: B/A parabolic

$D^0 - \overline{D^0}$ mixing (I)

Matter **Anti-matter**

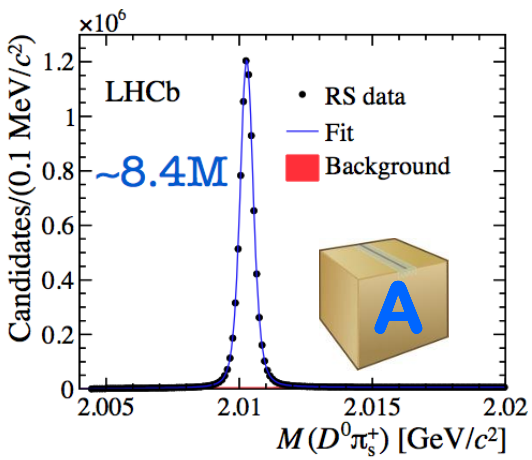
How much does it oscillate?

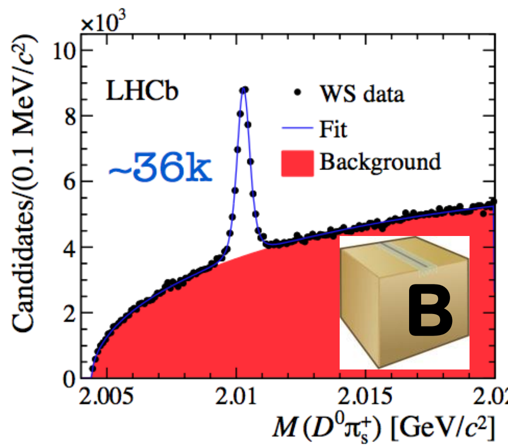
(i.e., transform into its antiparticle before decaying)



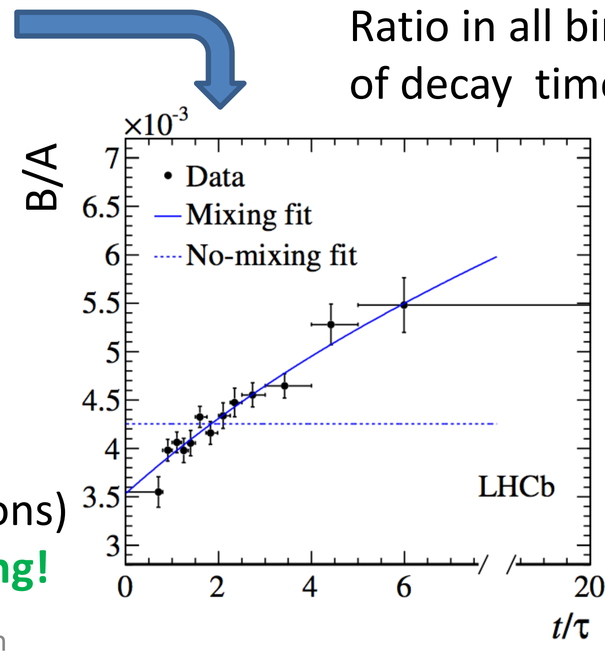
$D^0 - \overline{D^0}$ oscillation very slow:

- The full oscillation period cannot be observed
- Necessary to look for small changes in B/A as a function of decay time:
  - No mixing: B/A constant
  - Mixing: B/A parabolic





Ratio in all bins of decay time



No-mixing hypothesis excluded (at 9.1 standard deviations)

First single measurement observation of charm mixing!

Selection of topics

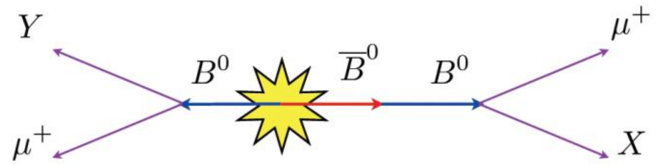
1. First evidence of the $B_s^0 \to \mu^+\mu^-$
2. Example of c-physics: $D^0 - \overline{D^0}$ mixing
3. Flavour-specific matter antimatter asymmetry

Flavour-specific matter antimatter asymmetry

Evidence of asymmetry **not consistent with the SM** by the DØ experiment (2010, updated 2011)

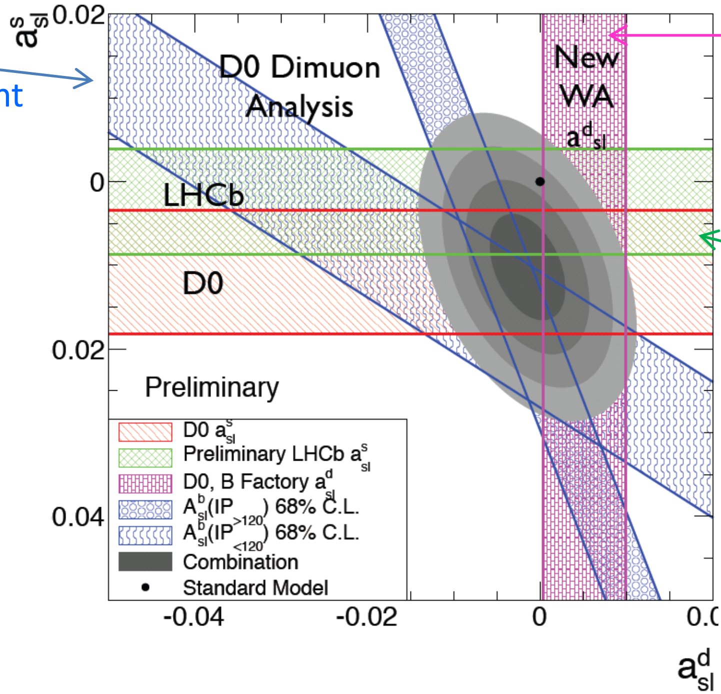
- More events with two negative muons than events with two positive muons

Sign of new physics?



$$A_{sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

DØ experiment ($B^0 + B_s^0$)



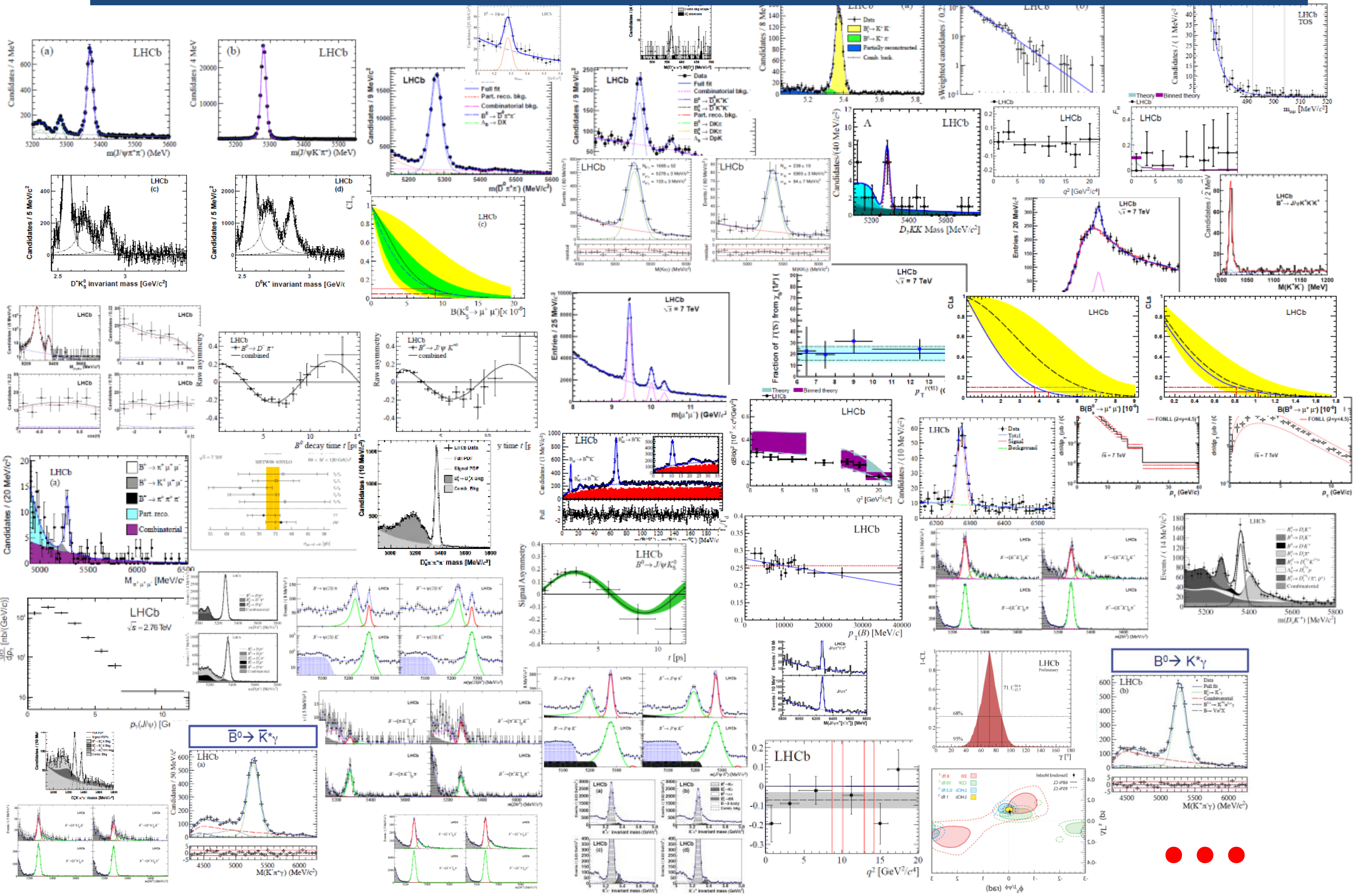
DØ experiment + B-factories (B^0)

LHCb experiment (B_s^0)

LHCb result in agreement with SM

Needed more data for a conclusion

But 2012 was much more…



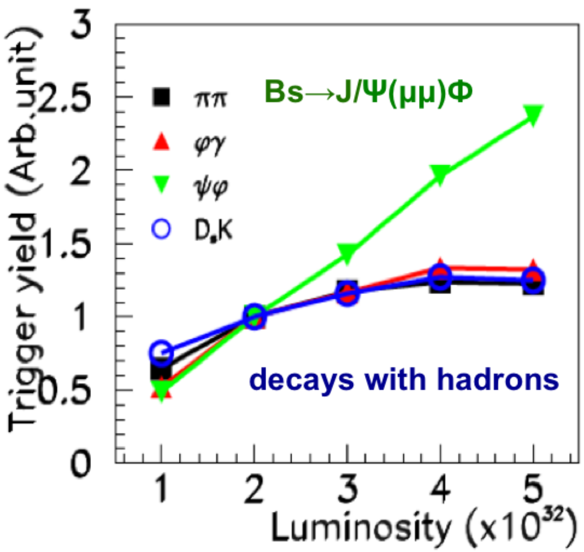
Overview

- Introduction
  - Collaboration
  - Type of physics considered
  - Detector
- Detector performances
- Selection of physics topics:
  - First evidence of the $B_s \to \mu^+\mu^-$ decay
  - D-mixing
  - Flavour-specific matter antimatter asymmetry
- Upgrade

Future

- Ready for p-Pb run (beginning next year)
- 2015-2017: run at optimal possible conditions (25ns bunch spacing) collecting additional $5\ \mathrm{fb}^{-1}$
  - center of mass energy of 13TeV will allow to nearly double the annual signal yields

Most of the cases we will be limited by the statistics



Framework TDR has been endorsed for approval by the LHCC

Planning the upgrade (after 2018)

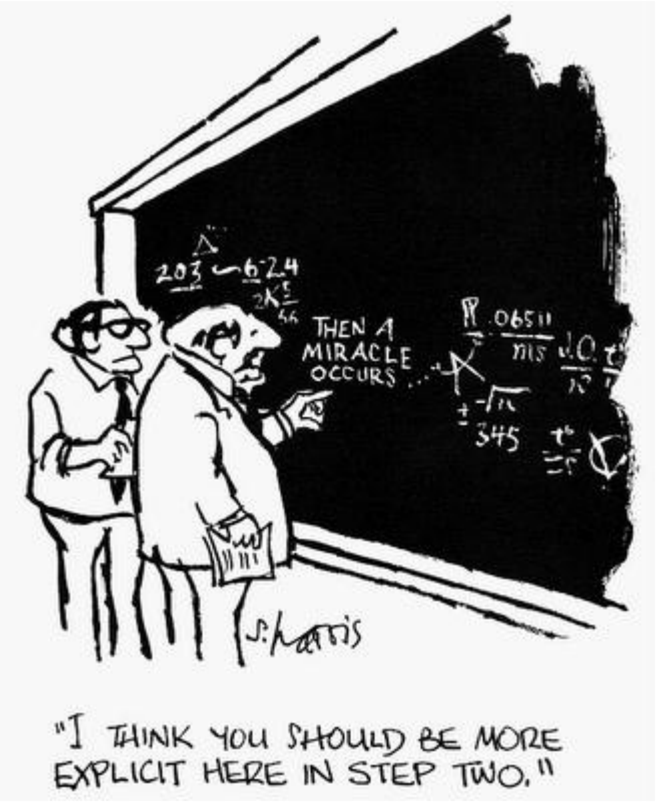
- Raise operating luminosity up to $2 \cdot 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (now $4 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$)
- Read out LHCb at 40 MHz – full software trigger
- Increase annual signal yield (at least a factor of 10)
- Collect $50\ \mathrm{fb}^{-1}$ (over 10 years)

Conclusions

- Excellent data taking year:
  - All sub-detectors perfectly working
  - Able to run in conditions beyond our design expectation
  - Most results based on 2011 data, many more result will come soon
  - Ready for p-Pb run in 2013

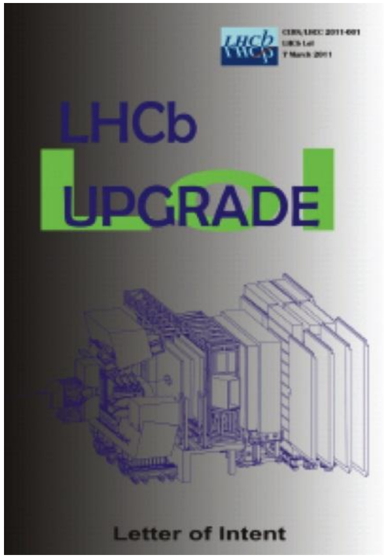
- Leading role in beauty and charm sectors:
  - Increased precision in SM parameters
  - Probing the region accessible for new physics scenarios
  - First evidence of the $B_s^0 \to \mu^+\mu^-$
  - More and more (no time to show the results)
- Still hungry: preparing the 2015-2017 data taking period and the upgrade (>2019) for more physics

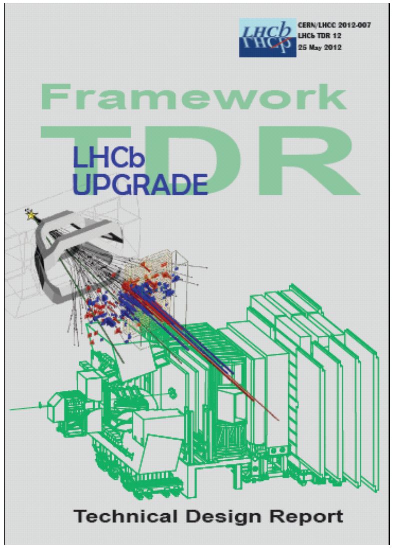
Backups


THEN A MIRACLE OCCURS...
S. Harris
"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

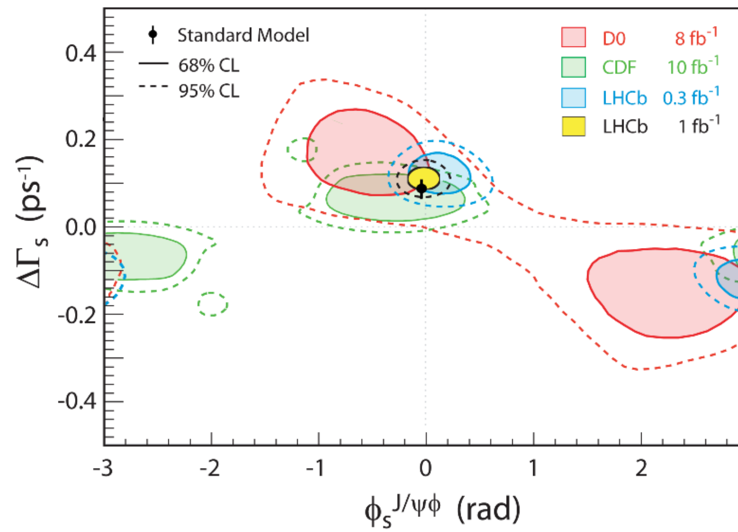
Upgrade roadmap

- March 2012 submitted the letter of intent (fully endorsed)
- May 2012 submitted framework TDR (fully endorsed)
- Preparing sub-system TDR (to be submitted next year)
- Expected to be ready for installation in 2018



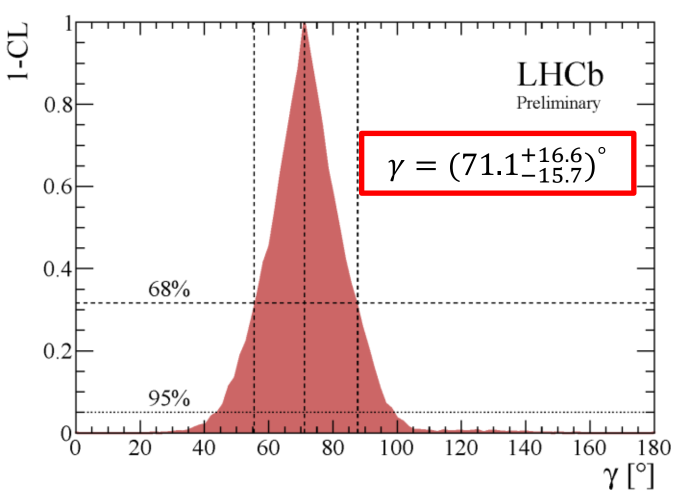


Other 2012 results (I)



Φ_s : search for CP violation from NP in B_s^0 mesons (cross check with precise theoretical predictions)

- SM prediction: $\Phi_s = -0.036 \pm 0.002$
- **LHCb: $\Phi_s = -0.002 \pm 0.083 \pm 0.027$** (preliminary, from combination of $B_s^0 \to J/\phi\psi$ and $B_s^0 \to J/\phi\pi^+\pi^-$)
  - **In agreement with SM prediction!**
  - **First 5σ observation of $\Delta\Gamma_s$**
  - **WB measurements of $\Delta\Gamma_s$ and Φ_s**
  - **Exploited interference with S-wave to solve the ambiguity**



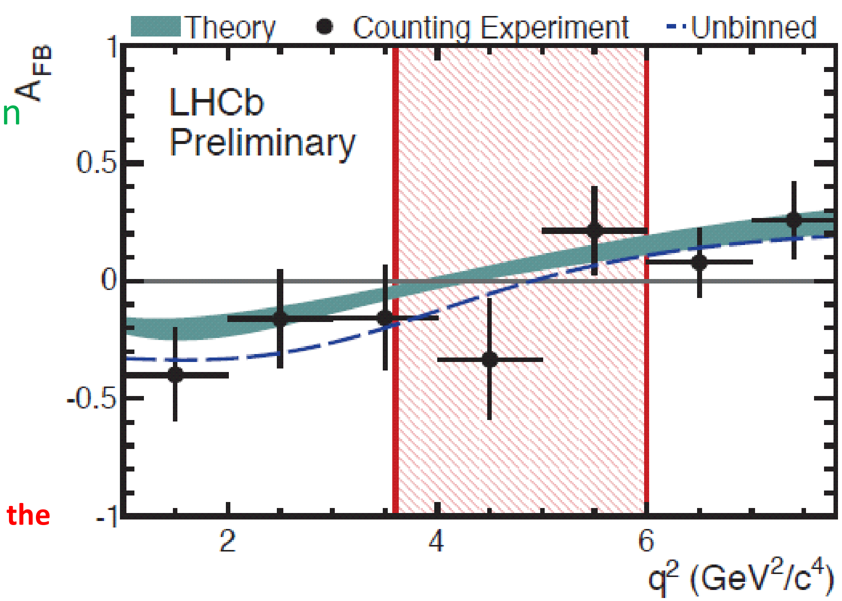
Angle γ of the unitarity triangle:

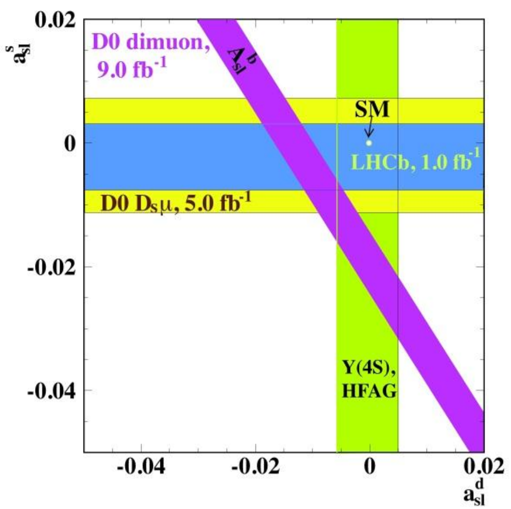
- Current uncertainty ~12°
- Several techniques (GLW, ADS, GGSZ) all exploited in LHCb
- **First singular experiment observation of direct CP asymmetry in $B \to DK^\pm$ (5.8 σ)**
- **First observation suppressed decay $B^\pm \to [\pi K]_D h$ with $h = \pi, K$**
- **First observation of suppressed ADS decays $B^\pm \to [\pi^\pm K^\mp \pi^+ \pi^-]_D h$ with $h = \pi, K$**

Other 2012 results(II)

$B^0 \to K^*\mu^+\mu^-$ **: FCNC loop diagram potentially sensitive to NP**

- Angular observables sensitive to several NP models
- Most precise measurement of the angular observables in $B^0 \to K^*\mu^+\mu^-$
- World first measurement of the zero-crossing point: $q^2(A_{FB}=0) = 4.9^{+1.1}_{-1.3} GeV^2$
- **Consistent with SM**
- Word most precise CP-asymmetry [SM: A_{CP}=$O(10^{-3})$]:
  $A_{CP}(B^0 \to K^*\mu^+\mu^-)$ =-0.072 $\pm$0.040 $\pm$0.005
- Isospin asymmetry:
  - $B^0 \to K^{*0}\mu^+\mu^-$ vs $B^+ \to K^{*+}\mu^+\mu^-$ **: consistent SM**
  - $B^0 \to K^0\mu^+\mu^-$ vs $B^+ \to K^+\mu^+\mu^-$ **: tension with prediction at the level of 4σ, difficult to interpret**





Measurement of the flavour-specific matter antimatter asymmetry

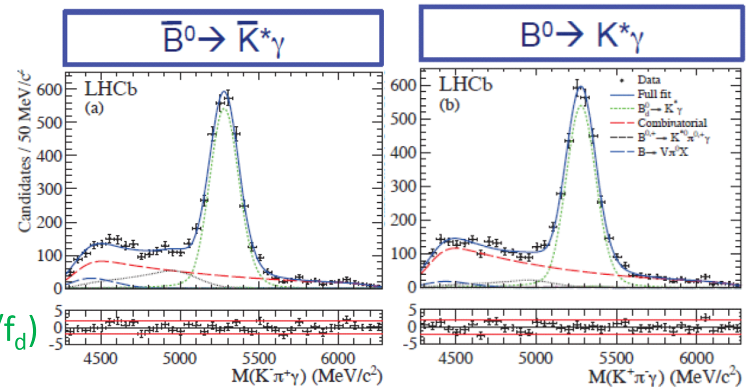
- Indication of CP violation in the muon system from D0 in 2010 (3.9σ discrepancy with the SM)
- This differences can be express as an asymmetry
- LHCb: most precise determination of the asymmetry for the B_s meson: a_{sl}^s =(-0.24 $\pm$0.54 $\pm$0.33)%

Consistent with SM

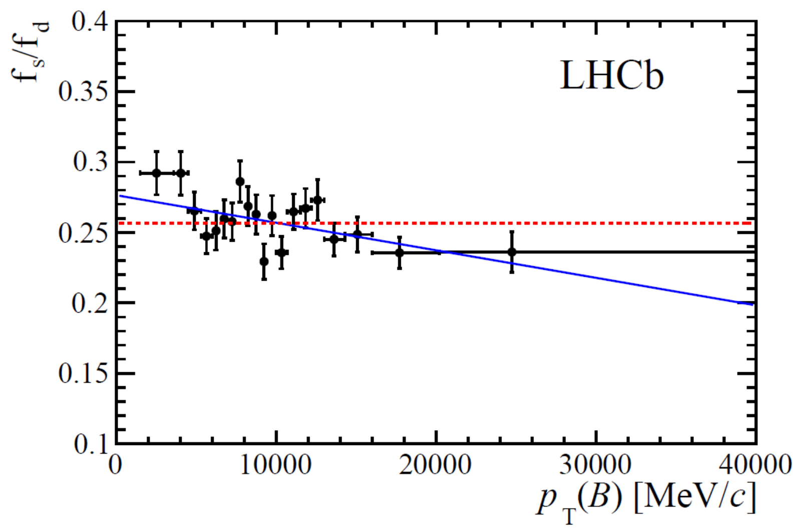
Other 2012 results(III)

Direct CP-asymmetry in $B^0 \to K^*\gamma$:

- SM prediction $(-0.61 \pm 0.43)\%$
- LHCb (1fb^{-1}):
  - $A_{CP}(B^0 \to K^*\gamma) = (0.8 \pm 1.7 \pm 0.9)\%$
  - $\frac{BR(B^0 \to K^{*0}\gamma)}{BR(B_s^0 \to \phi\gamma)} = 1.23 \pm 0.06\,(\text{stat}) \pm 0.04\,(\text{syst}) \pm 0.10\,(f_s/f_d)$



Consistent with SM



Fragmentation fraction ratio f_s/f_d:

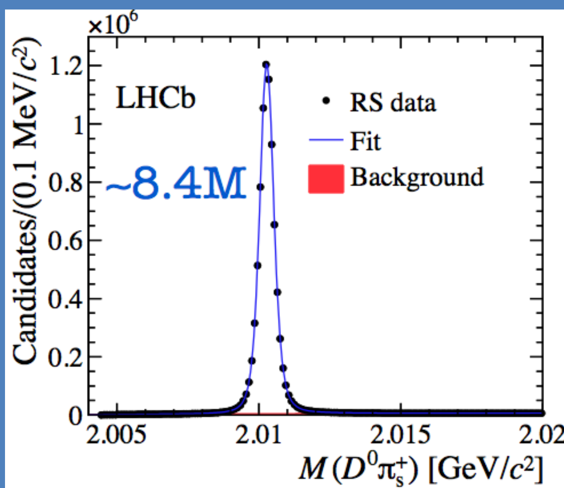
- Key ingredient in all B_s^0 measurements normalized to B^0 mode (ex. $B_s^0 \to \mu^+\mu^-$)
- Measured with semileptonic decays and with hadronic decays
- Studied its dependency as a function of B-meson kinematics
- Word best measurement:
  $f_s/fd = 0.256 \pm 0.020$
- First evidence of a dependency as a function of the $p_T(B)$

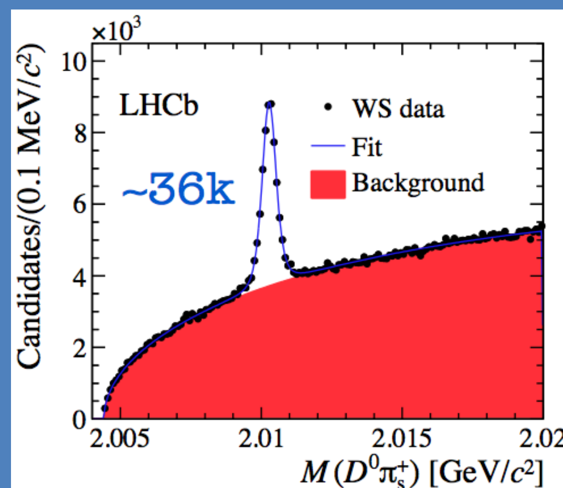
$D^0 - \overline{D^0}$ mixing (II)

Hp1) No mixing: $R = \frac{WS(t)}{RS(t)}$ constant

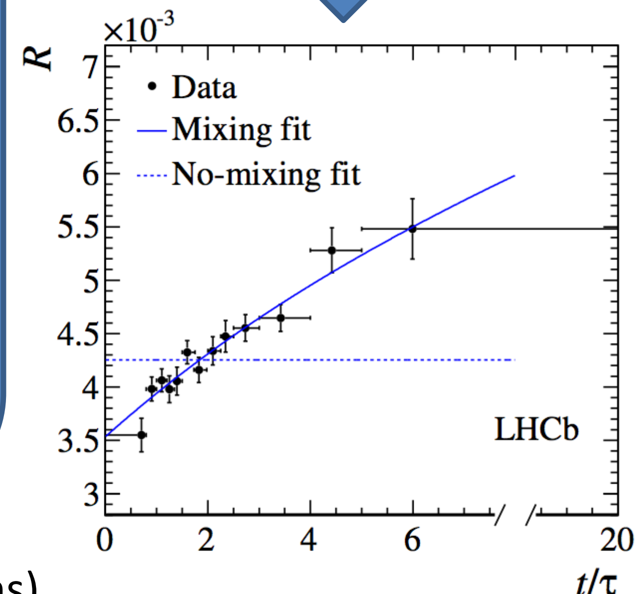
Hp2) Mixing: $R = \frac{WS(t)}{RS(t)}$ increasing with time

Data events for RS and WS sample in a bin of t





Ratio in all bins of t

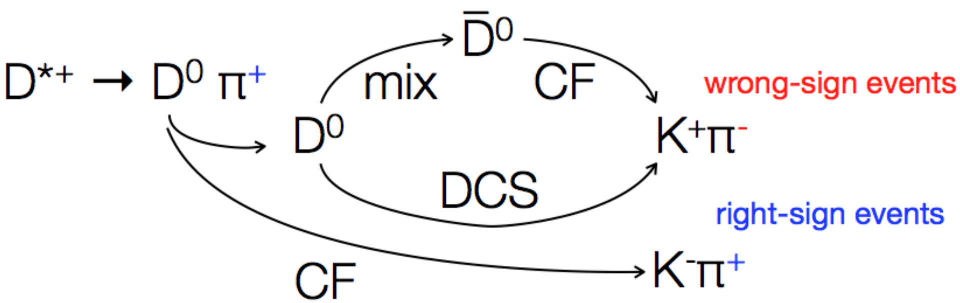


No-mixing hypothesis excluded (at 9.1 standard deviations)

First single experiment observation of charm mixing!

$D^0 - \overline{D^0}$ mixing (I)

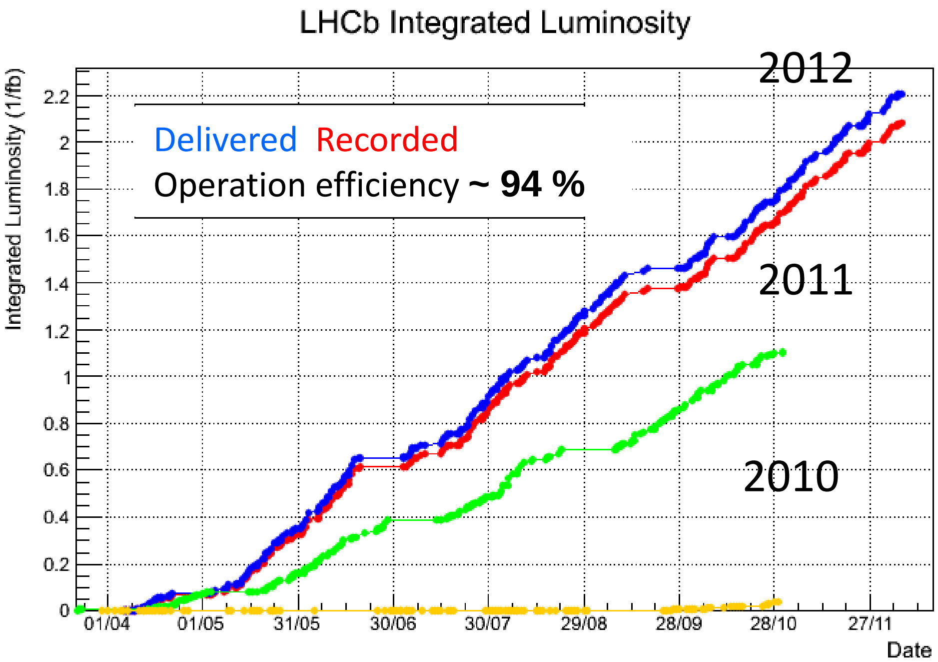
- D^0 decays most of the time into $K^-\pi^+$
- $\overline{D^0}$ decays most of the time into $K^+\pi^-$
- Taken $D^{*+} \rightarrow D^0\pi^+$
  - **Right sing (RS):** final state from D^0 is $K^-\pi^+$
  - **Wrong sign (WS):** final state from D^0 is $K^+\pi^-$



In case of mixing: D^0 can become (oscillate) a $\overline{D^0}$ before decaying

$\rightarrow$ more time = more probability to oscillate

LHCb operation status

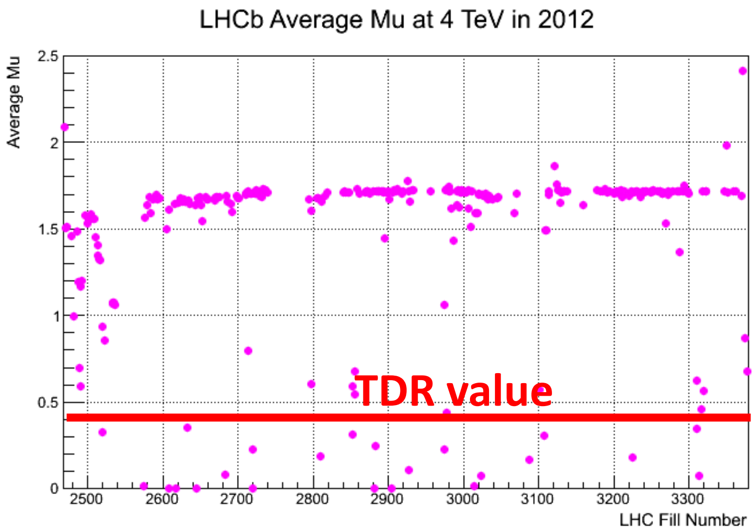


LHCb designed to run at lower luminosity than ATLAS and CMS…

BUT

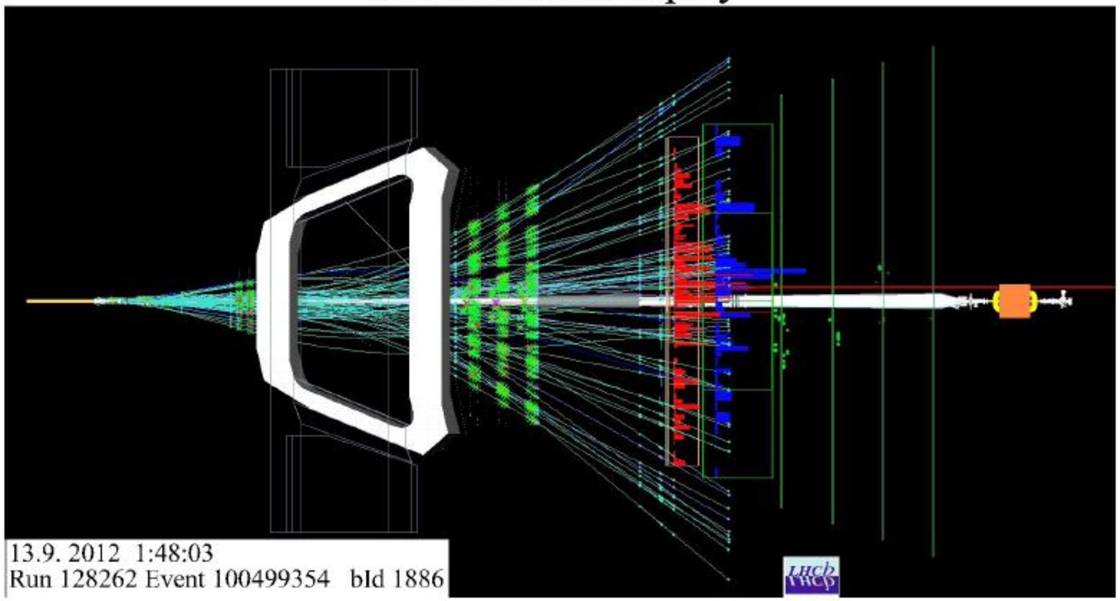
…we run at already at two times more than the designed one!

Running with an average number of processes per crossing more than 3 times bigger than the design ones



First experience with ions

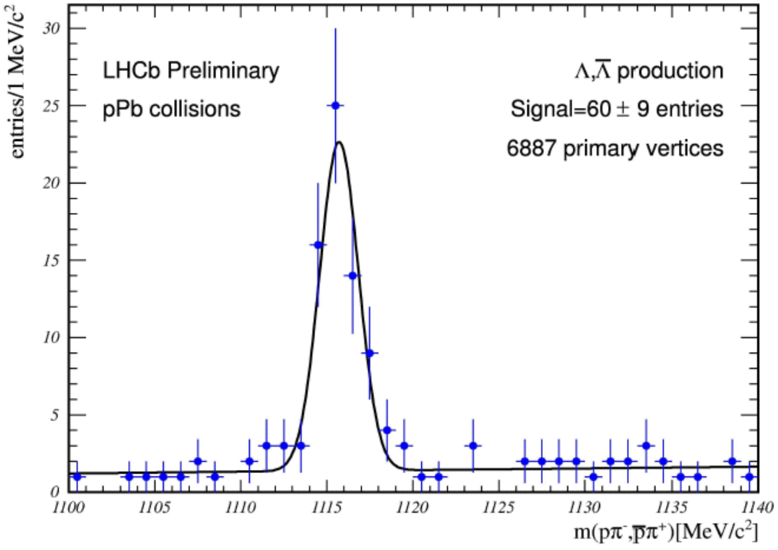
LHCb Event Display



First experience with pPb collisions in September:

- Stable conditions
- Multiplicity in the detector compatible with pp collisions

Lambda production



- Various resonances already reconstructed offline
- Ready for the pPb physics data taking early next year