LHC*b* status report

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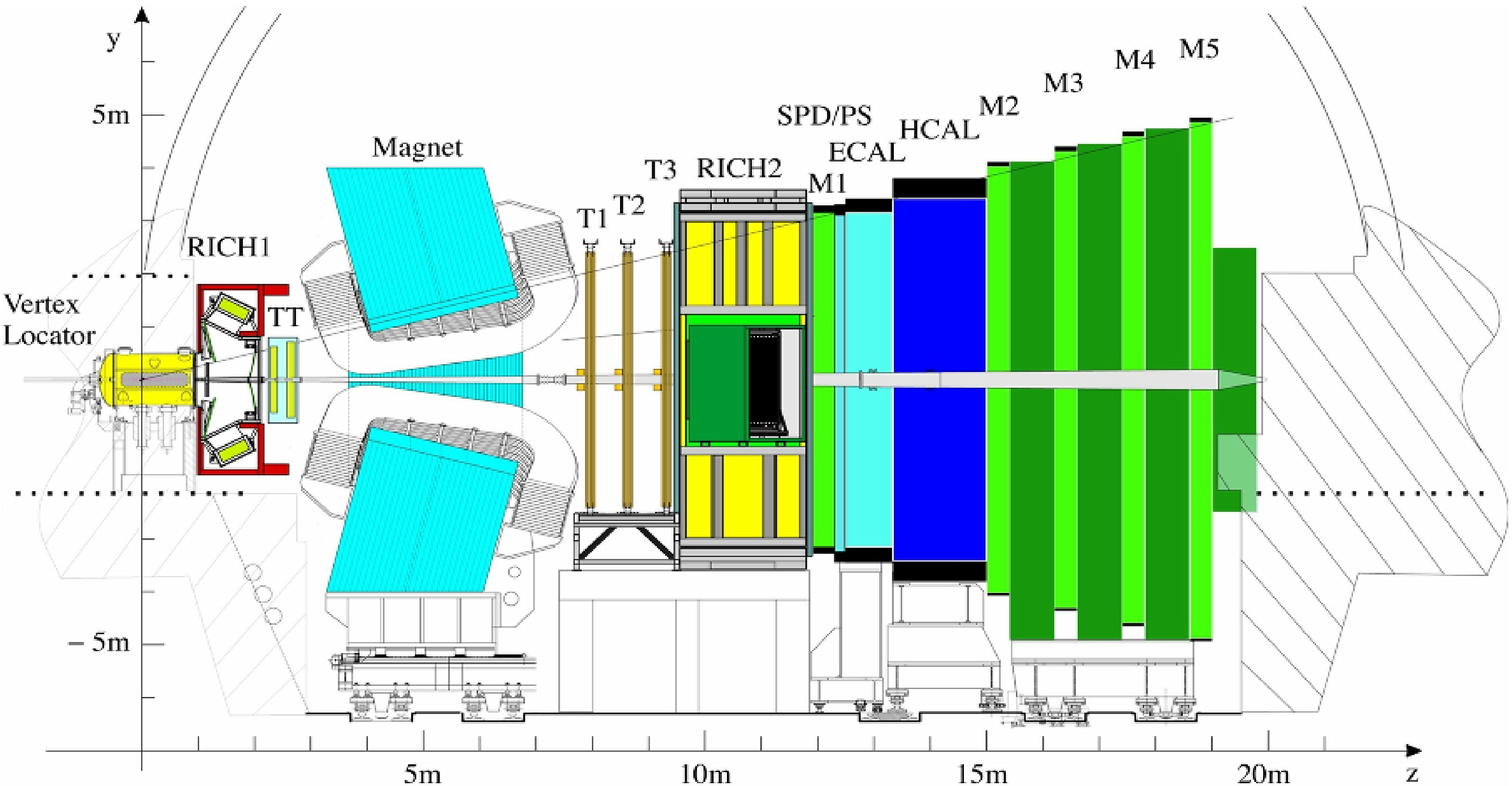
On behalf of the LHCb collaboration

LHCb detector: New Physics in the forward region

Search for New Physics by studying rare processes and precision CP violation measurements in B and D sectors



- Good vertexing - Measure B_d and B_s oscillations, reject prompt background
- Particle identification - Flavour tagging, misID background
- Calorimetry - Reconstruction of neutral particles (γ, π^0)
- Efficient trigger, including hadronic modes

LHCb performance in 2011

Very successful data taking in 2011

(thanks to the LHC crew!)

Instantaneous luminosity:

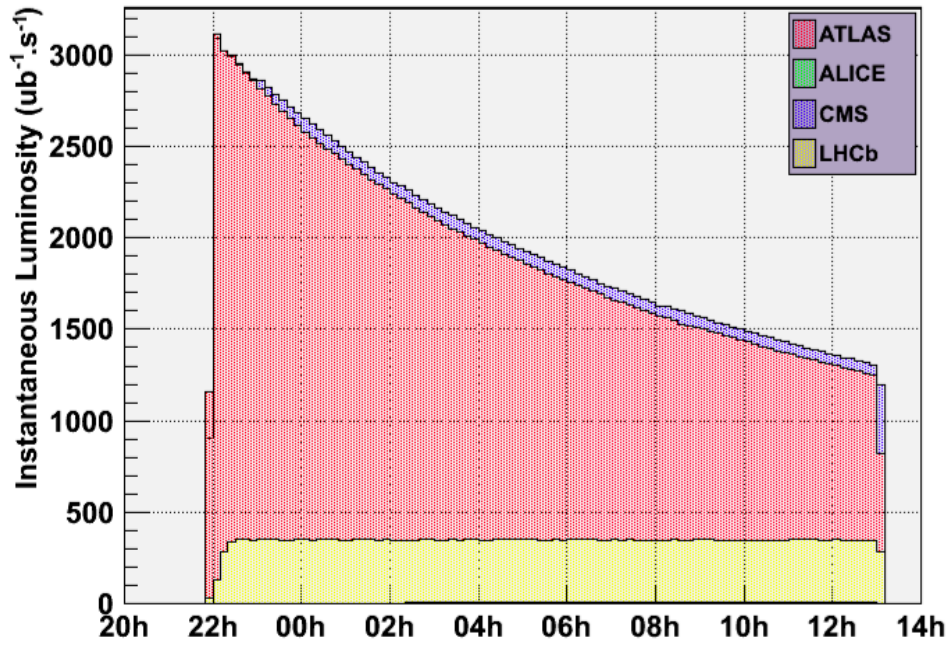
levelled at $(3\text{-}3.5)\times10^{32}\ \mathrm{cm^{-2}s^{-1}}$

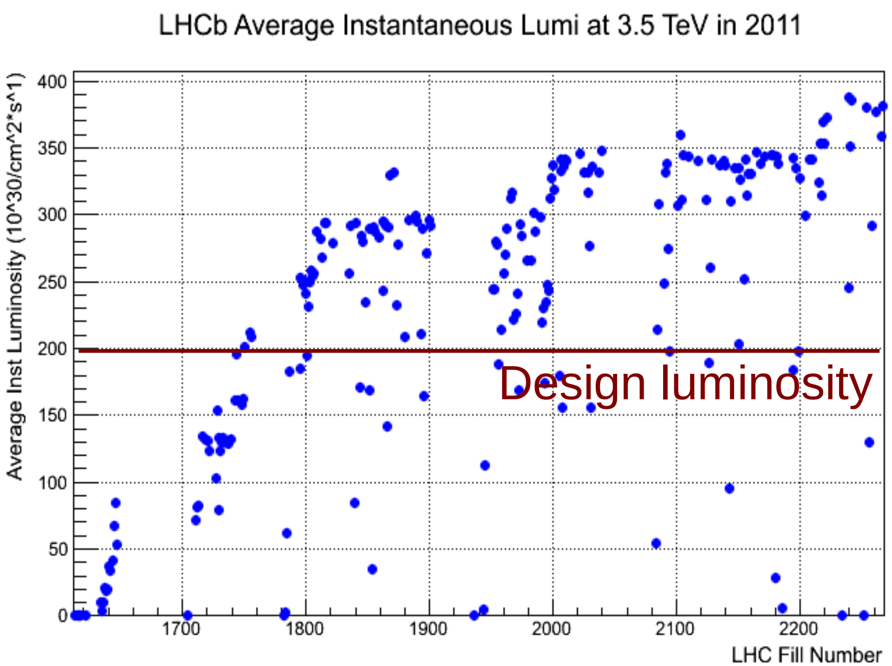
higher than design $2\times10^{32}\ \mathrm{cm^{-2}s^{-1}}$

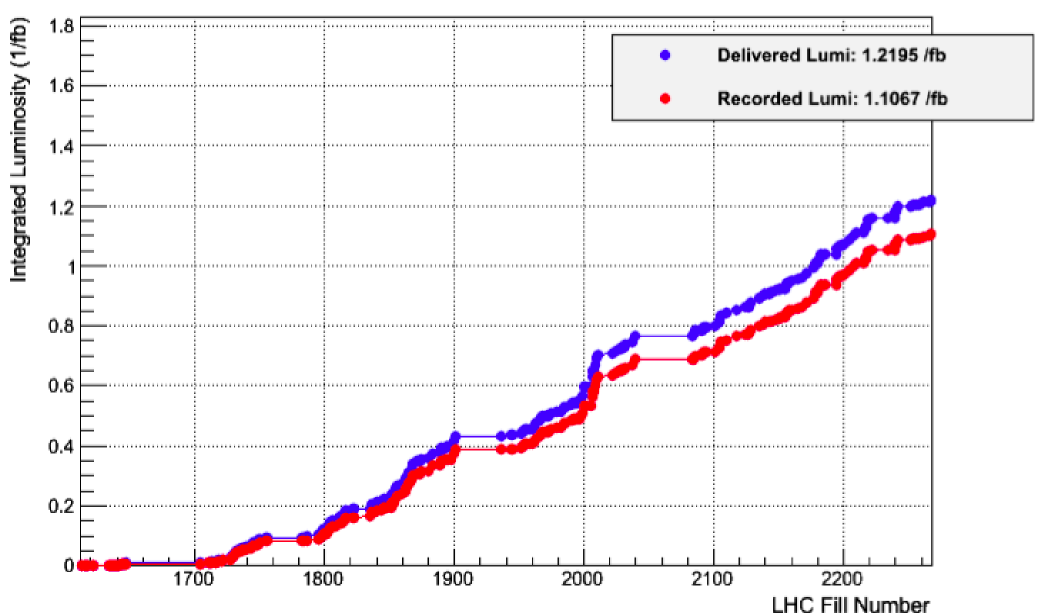
91% data taking efficiency

$1.2\ \mathrm{fb^{-1}}$ delivered by LHC

$1.04\ \mathrm{fb^{-1}}$ of analysis-quality data

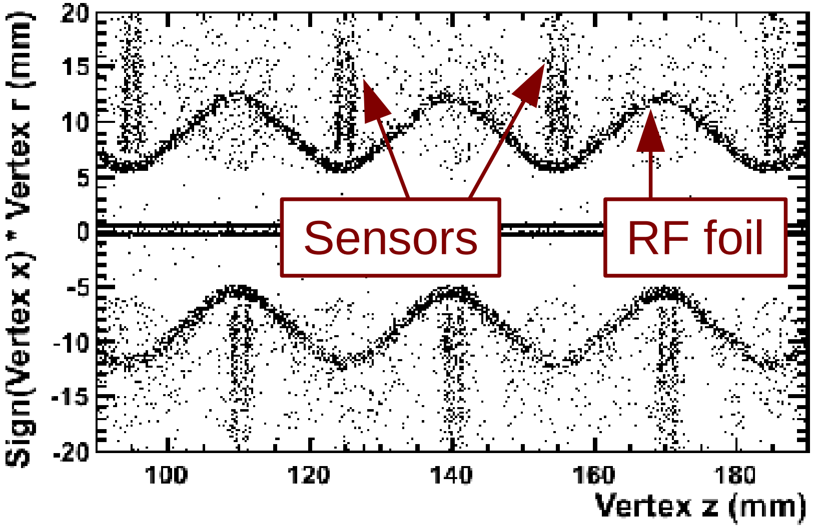




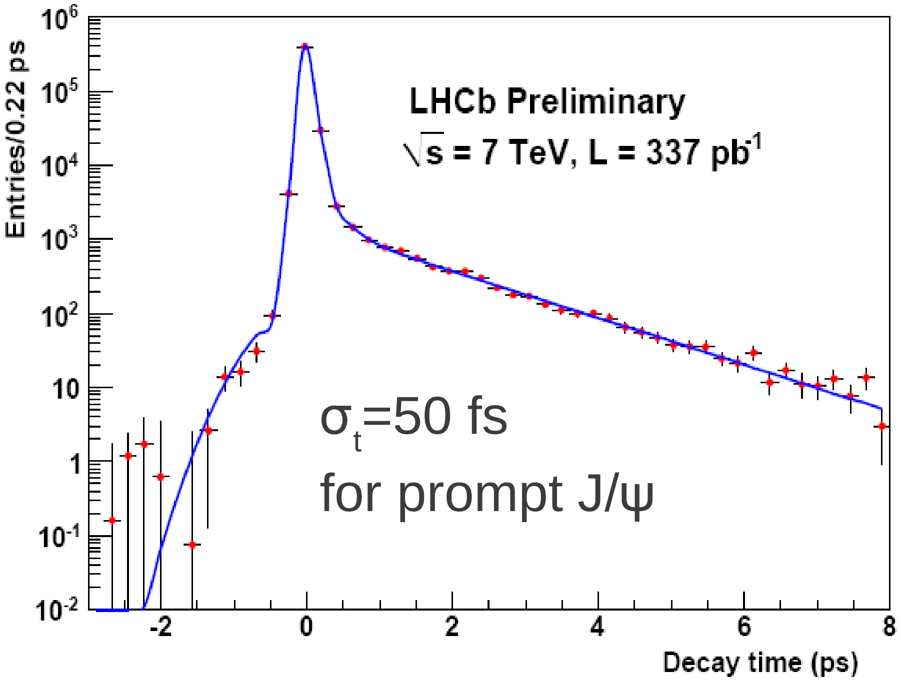


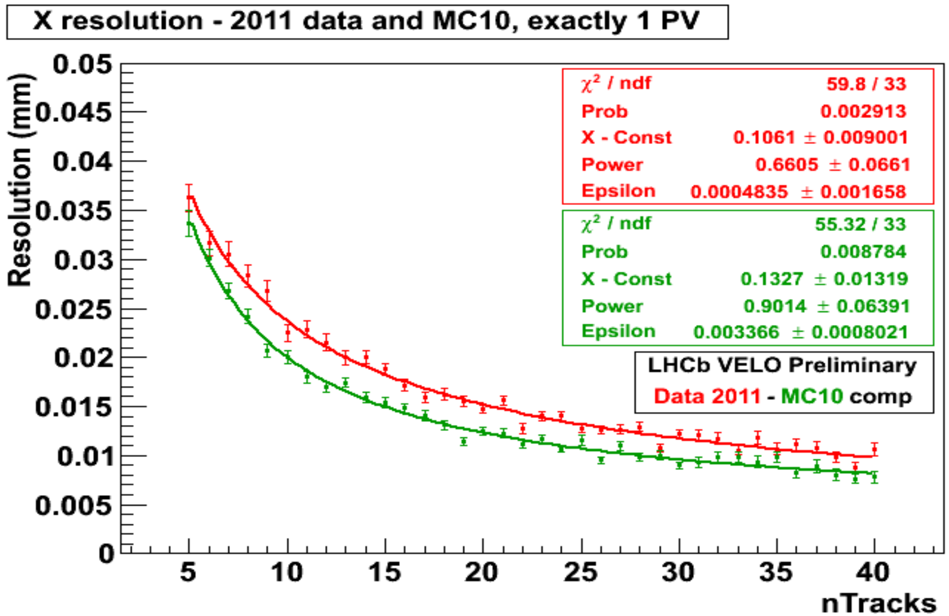
Vertexing

- Typical primary vertex resolution (with 30 tracks):
  - $\sigma_{x,y}$= 12 μm,
  - σ_z= 65 μm.
- Decay time resolution: 40-50 fs



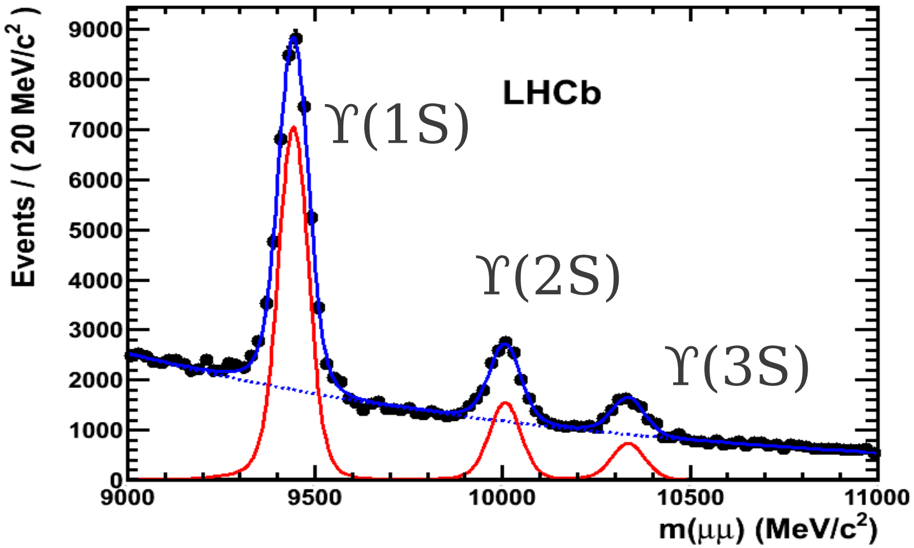
Hadronic vertices reconstructed in VELO used for “tomography” (check of MC description)





Tracking and calorimetry

Momentum resolution:
$\delta p/p = 0.35 \div 0.55\%$



Two-body invariant mass resolution:

$\sigma(\mu\mu)=15$ MeV/c^2 at J/ψ

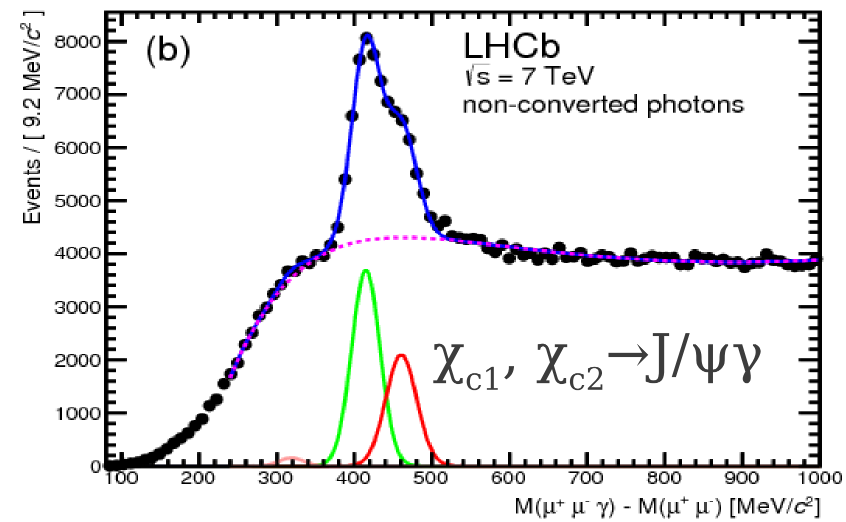
$\sigma(\mu\mu)=45$ MeV/c^2 at $\Upsilon(1S)$

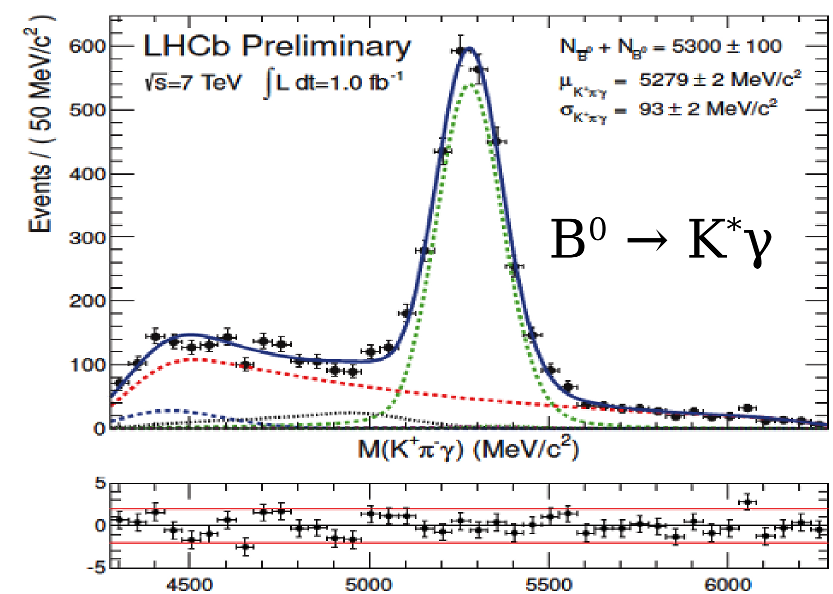
Momentum scale calibrated to 0.5 per mille precision.

A number of world-best b meson and baryon mass measurements, systematic error ~0.2 MeV/c^2.

ECAL: $\sigma_E/E=10\%/\sqrt{E} \otimes 1\%$

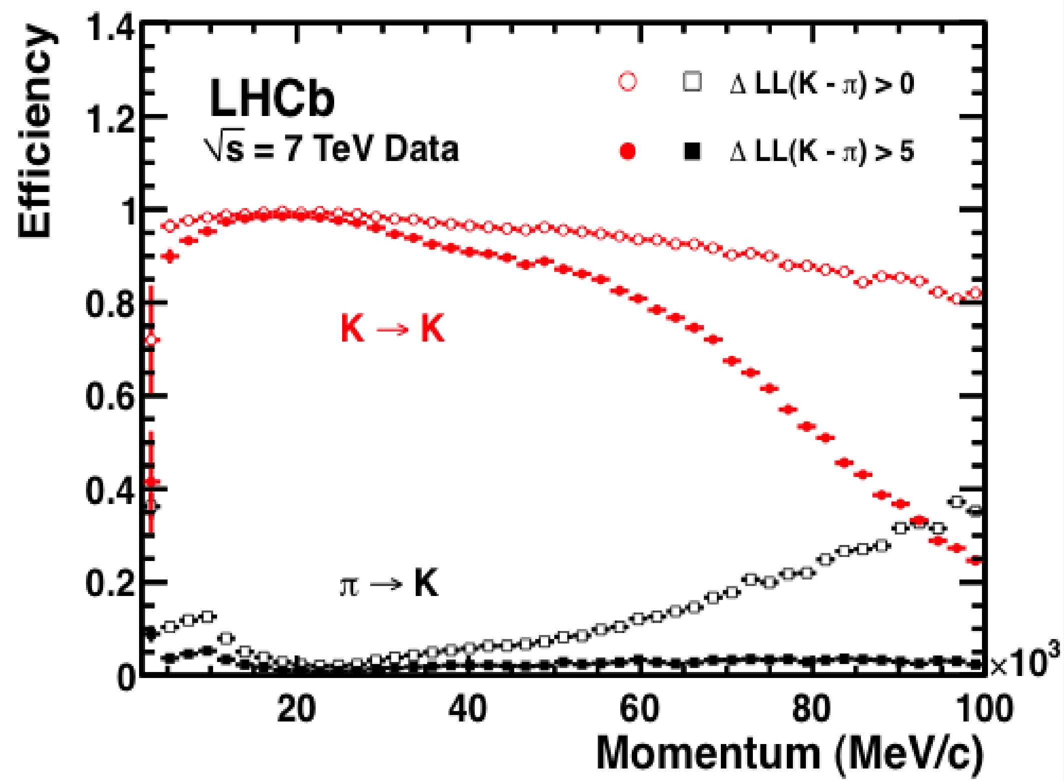
HCAL: $\sigma_E/E=80\%/\sqrt{E} \otimes 10\%$

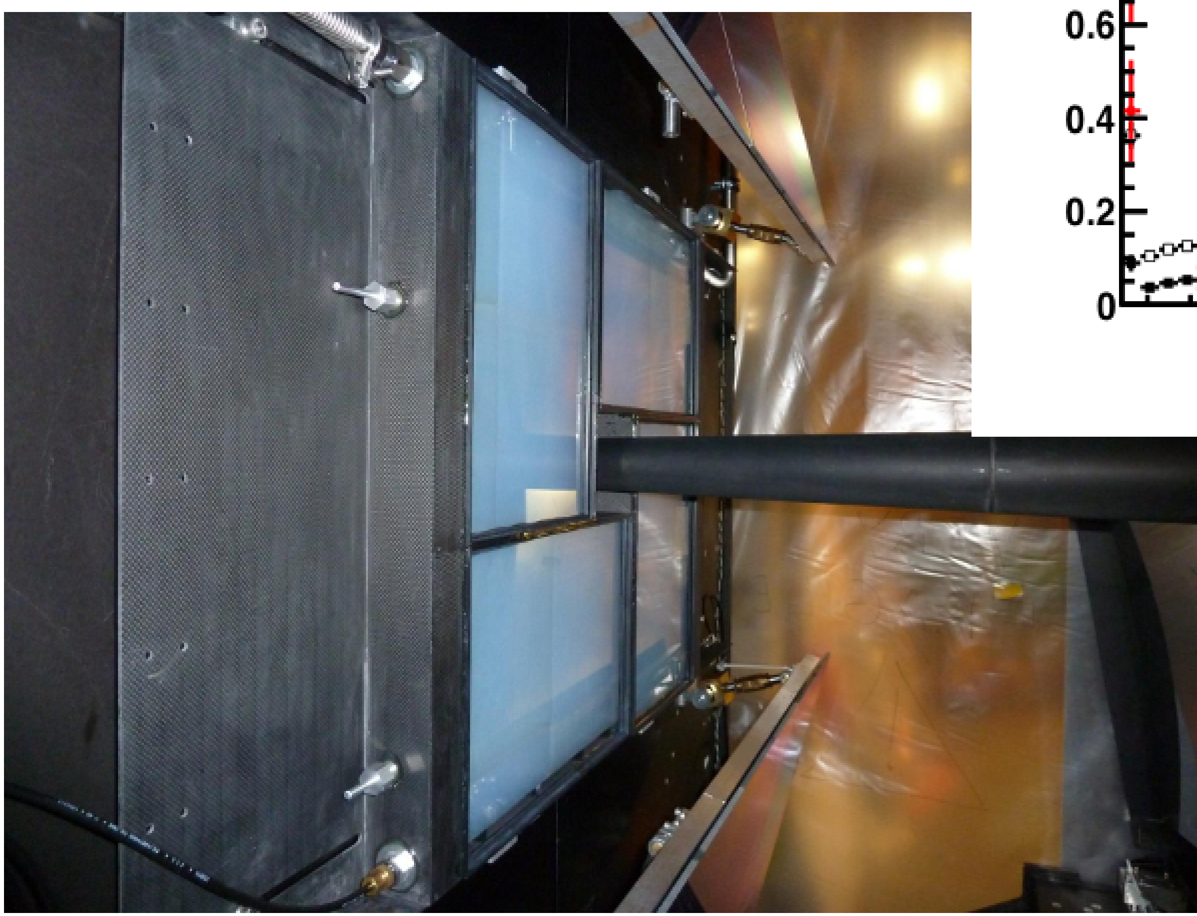




Particle identification

Two RICH detectors with aerogel and C_4F_{10} radiators, π/K/p separation in the momentum range 3-100 GeV/c





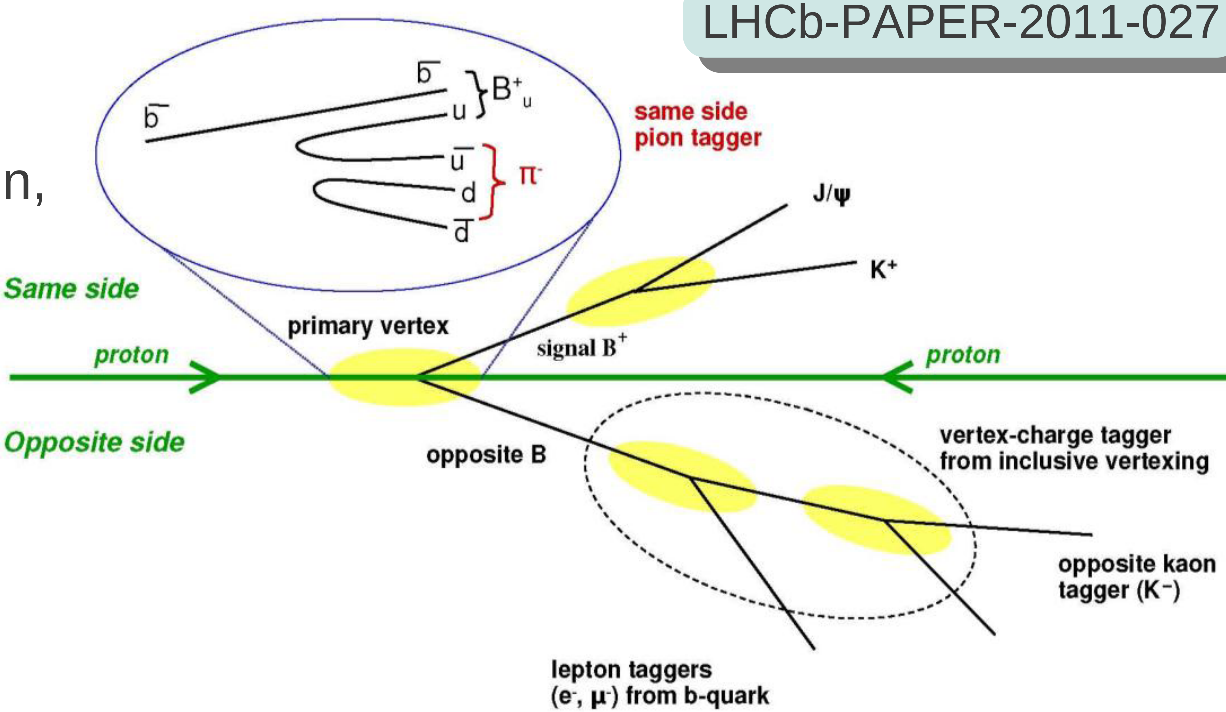
New gas-tight aerogel box is installed in January 2012, to prevent aerogel degradation due to C_4F_{10} filling.

Flavour tagging

LHCb-PAPER-2011-027

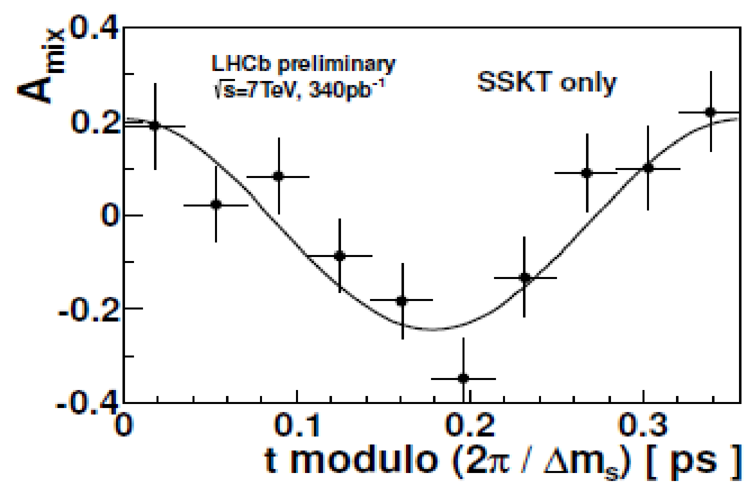
Use information from

- Opposite side:
  Charge of kaon, muon, electron, charge of tracks from the secondary vertex
- Same side:
  Charge of associated track



Tagging performance calibrated on data: $B \to J/\psi K$ sample

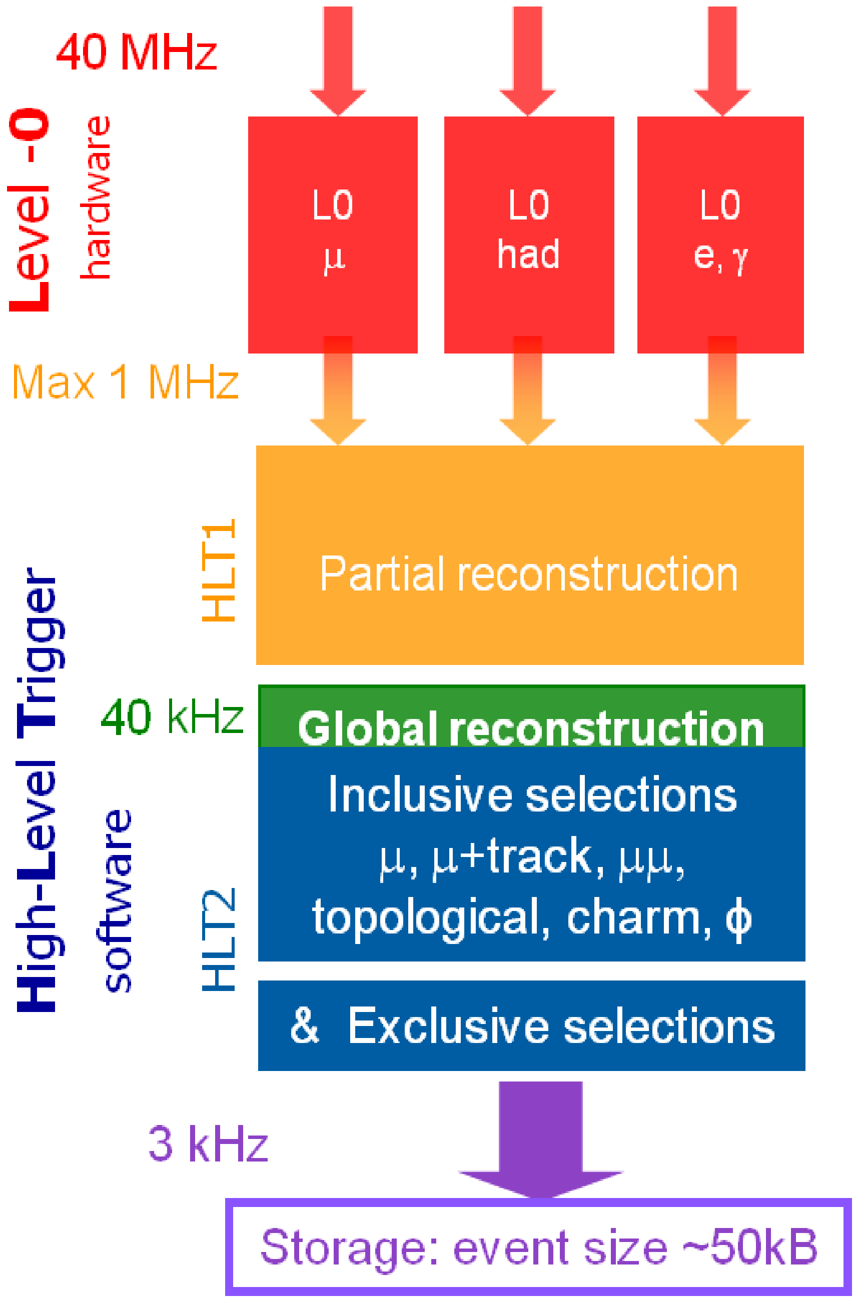
Expect further improvement from same-side tagging (in preparation)



Flavour tagging performance in $B_s \to J/\psi\varphi$ analysis (opposite-side taggers only):

Mistag probability ω	$(36.81 \pm 0.18 \pm 0.74)$ %
Tagging efficiency ε_{tag}	(32.99 ± 0.33) %
Tagging power $\varepsilon_{tag}(1-2\omega)^2$	$(2.29 \pm 0.07 \pm 0.26)$ %

Trigger in 2011



L0: Hardware trigger
Require a high-p_T particle

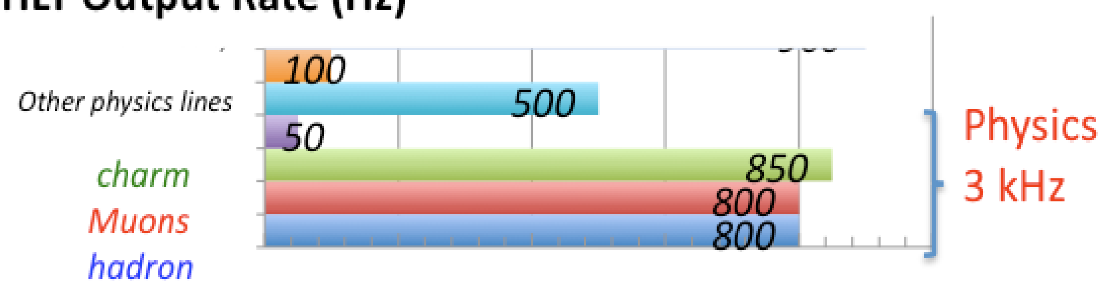
HLT: Two-level software trigger
Trigger farm (26k cores)

- HLT1: Require high-p_T displaced track
- HLT2: Full reconstruction

Typical overall efficiency:
Dimuon: 80%, Hadronic: 30%

In 2011, run with 50% higher output rate than designed (2 kHz → 3 kHz), limited by CPU for reconstruction and by disk storage

HLT Output Rate (Hz)



Main physics results with 2011 dataset

Many results with 2011 dataset reported at winter conferences

- Roadmap measurements…
  - Tree-level determination of γ
  - CPV in charmless two-body B decays
  - β_s measurement in $B_s \to J/\psi\varphi$
  - Search for $B_s \to \mu\mu$
  - Angular analysis of $B^0 \to K^*\mu\mu$
  - Radiative B decays
- … and beyond:
  - CP violation in charm
  - Other rare decays:
    $D\to\mu\mu$, $B_s\to\mu\mu\mu\mu$,
    $B_s\to\varphi\mu\mu$, $B^+\to\pi^+\mu\mu$
  - β_s measurement in $B_s \to J/\psi\pi\pi$
  - First observations in hadronic B decays
  - Studies of exotic states (X,Y,Z)

"Roadmap of selected key measurements of LHCb"
LHCb-PUB-2009-029

Will concentrate on most recent results with full 2011 dataset.

Many interesting results not covered:
- Soft QCD
- Electroweak physics
- Heavy flavour production and spectroscopy

To be reported at DIS next week

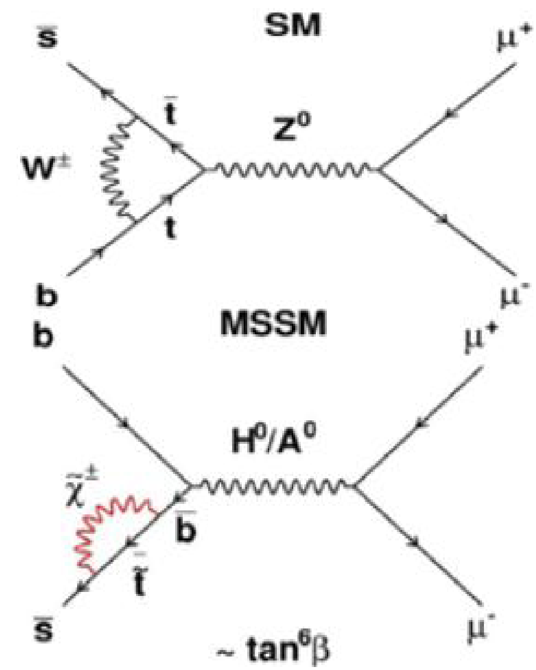
Rare decays: $B_s \to \mu^+\mu^-$

One of the most sensitive probes of New Physics

- Standard Model: FCNC, helicity suppressed:
  $Br(SM) = (3.2 \pm 0.2) \times 10^{-9}$

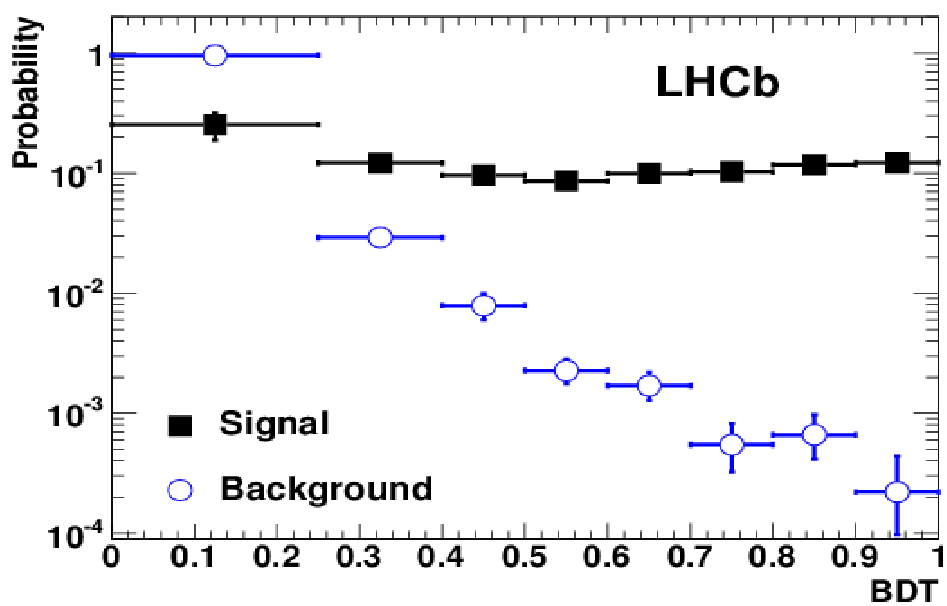
- Can be enhanced in NP models.

MSSM: $\mathbf{BR} \propto \left(C_{S,P}^{MSSM}\right)^2 \propto \frac{\tan^6\beta}{M_A^4}$



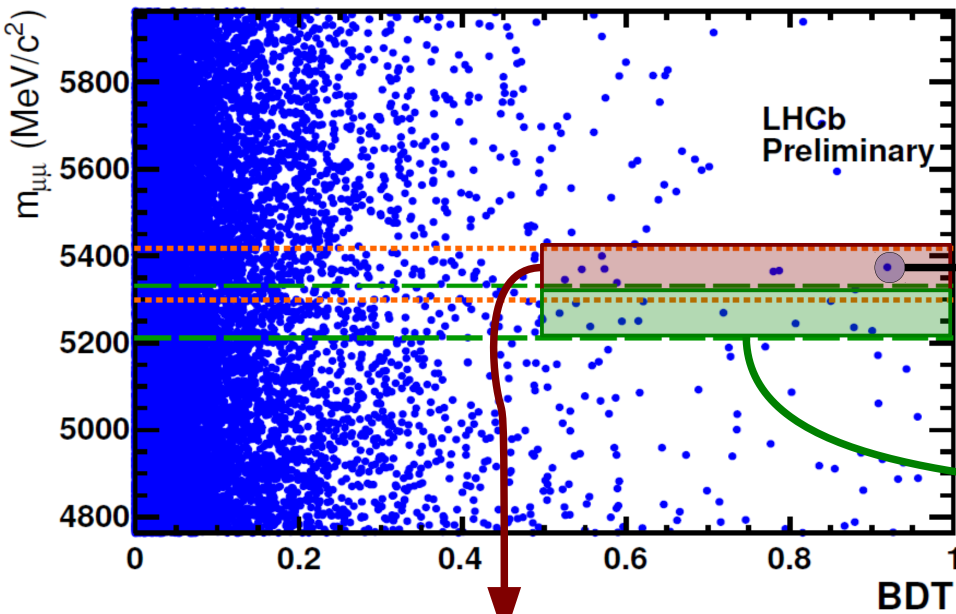
1 fb^{-1}, LHCb-PAPER-2012-007

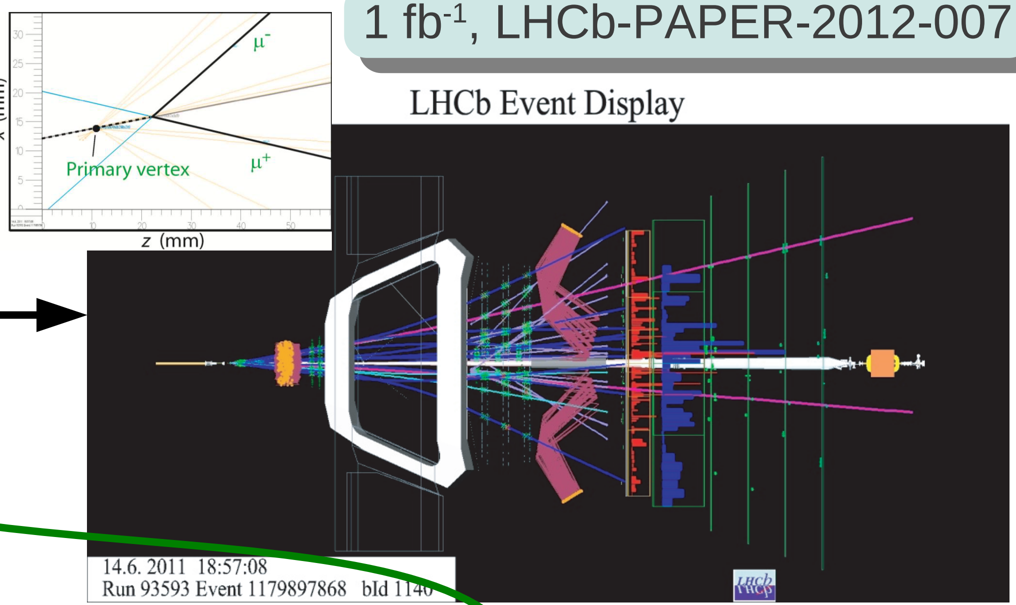
- Use two variables
  - $\mu^+\mu^-$ invariant mass
  - BDT based on variables that select good-quality secondary vertex, well-separated from the PV
- Results in 2D bins, BDT vs. mass

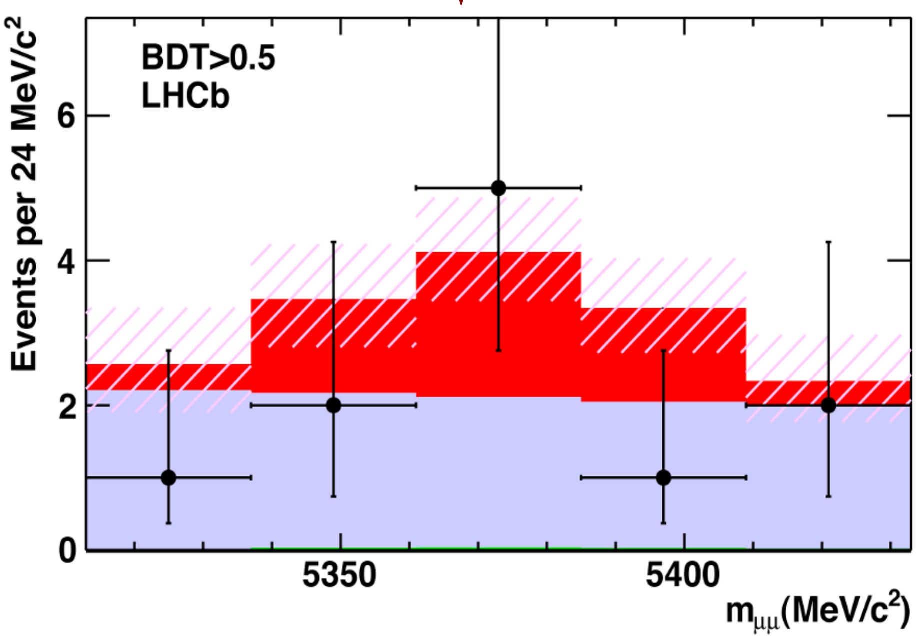


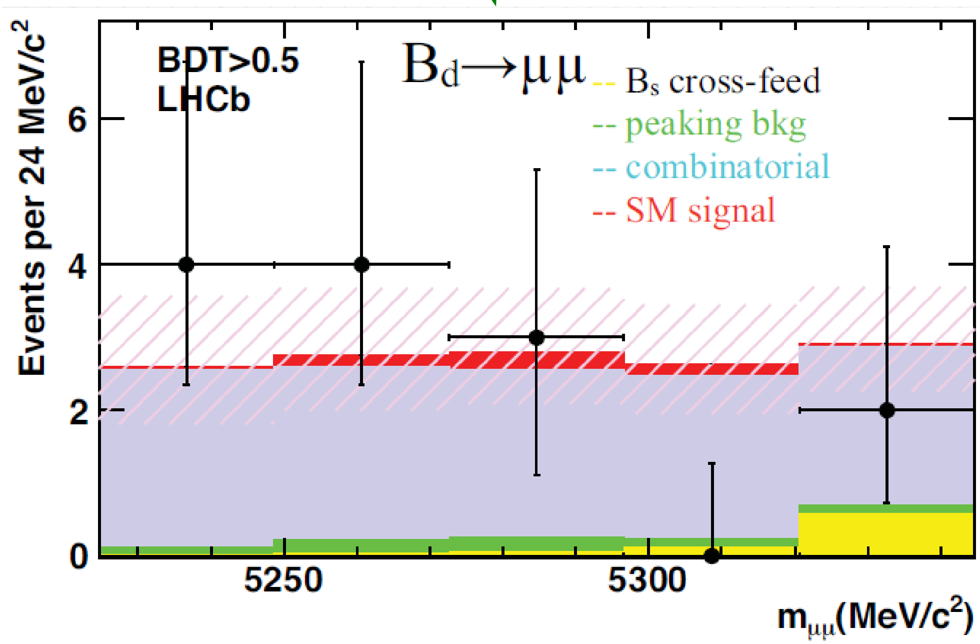
Rare decays: $B_s \to \mu^+\mu^-$

1 fb^{-1}, LHCb-PAPER-2012-007





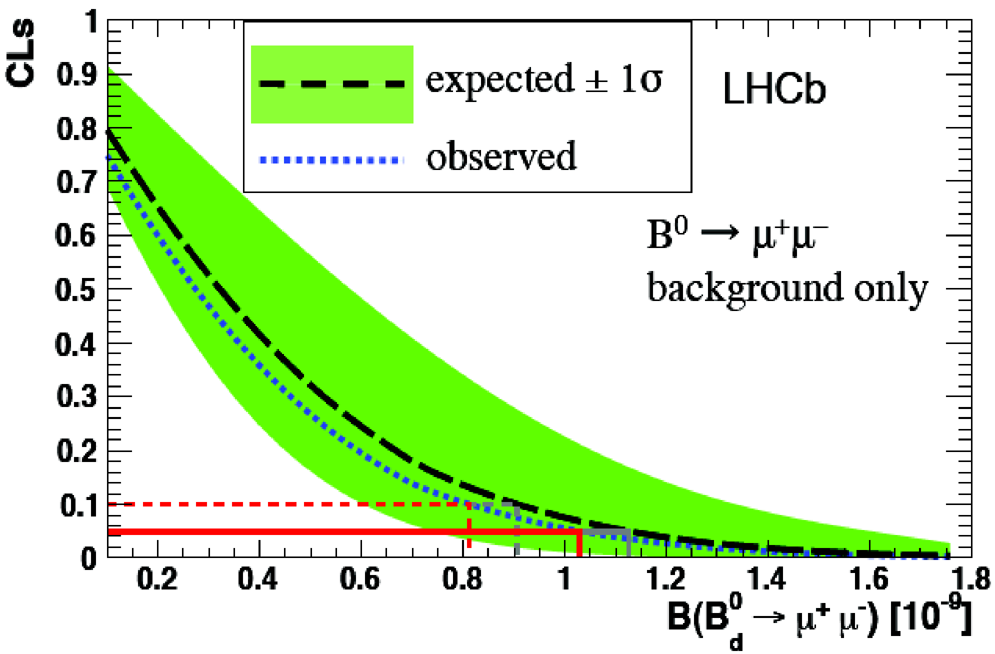


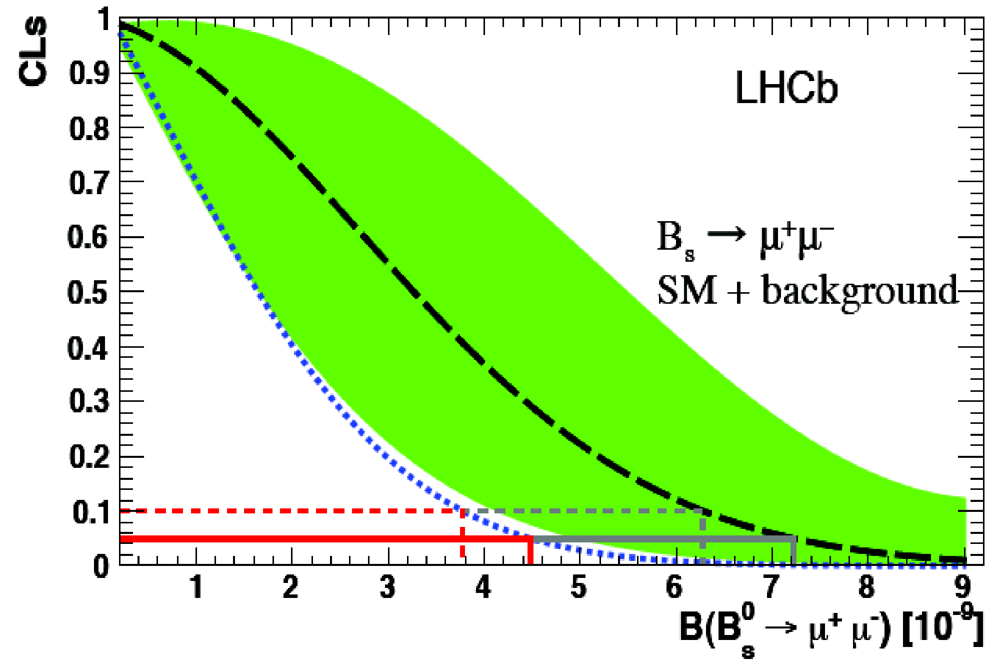


Rare decays: $B_s \to \mu^+\mu^-$

1 fb^{-1}, LHCb-PAPER-2012-007

	CDF	CMS	Atlas	LHCb	SM
Luminosity (fb^{-1})	10	4.9	2.4	1.1	
$Br(B_d \to \mu^+\mu^-)$ 95% CL ($\times 10^{-9}$)	4.6	1.8		1.03	0.10 ± 0.01
$Br(B_s \to \mu^+\mu^-)$ 95% CL ($\times 10^{-9}$)	31	7.7	22	4.5	3.2 ± 0.2
Central value ($\times 10^{-9}$)	13^{+9}_{-7}			$0.8^{+1.8}_{-1.3}$	



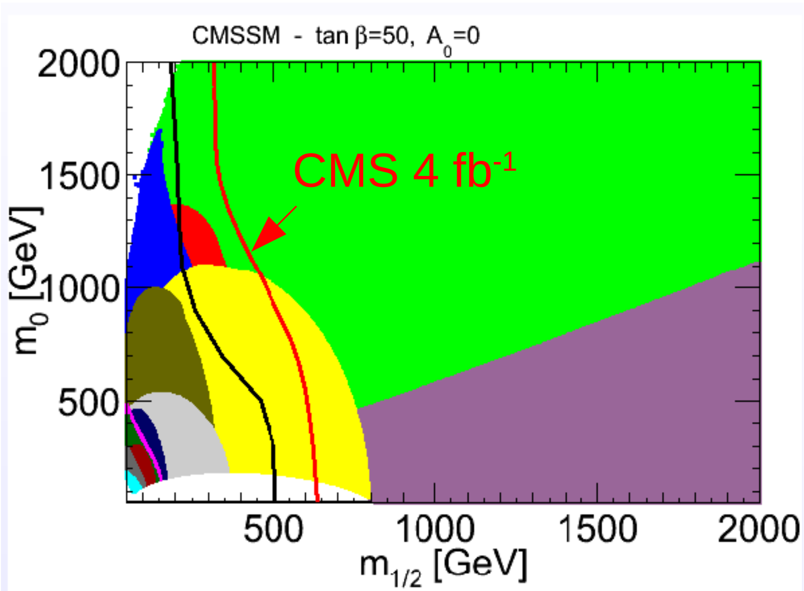


95% $B_s \to \mu^+\mu^-$ upper limit already close to Standard Model value.

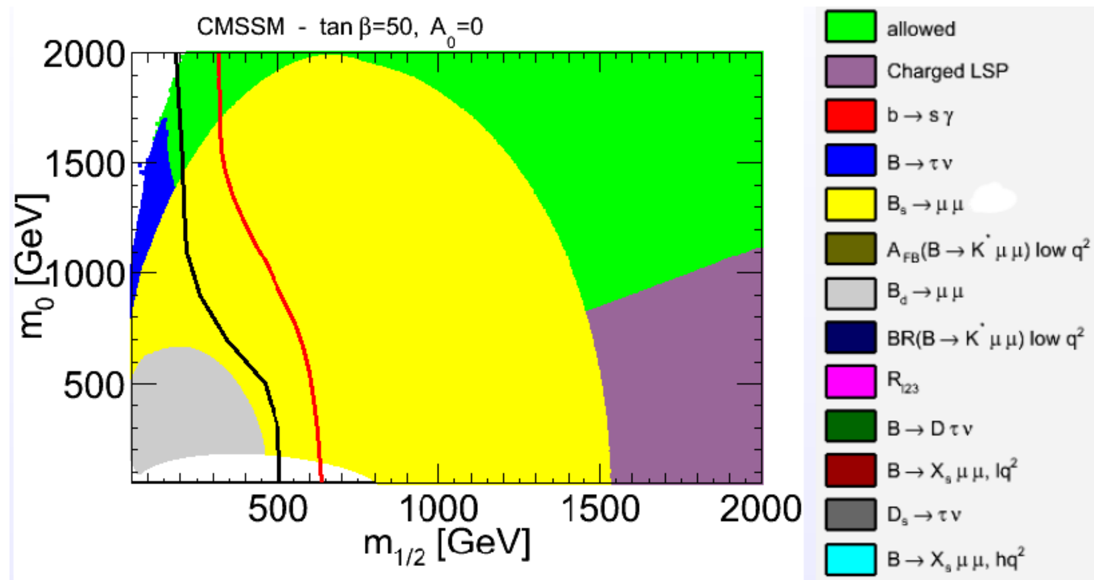
Rare decays: $B_s \to \mu^+\mu^-$

N. Mahmoudi, "Direct and indirect searches for New Physics", Moriond QCD 2012

Implications of LHCb result on SUSY parameters (with $\tan\beta = 50$)



$\Rightarrow$

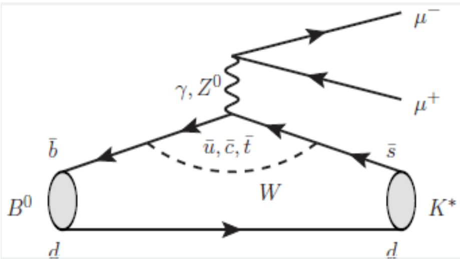


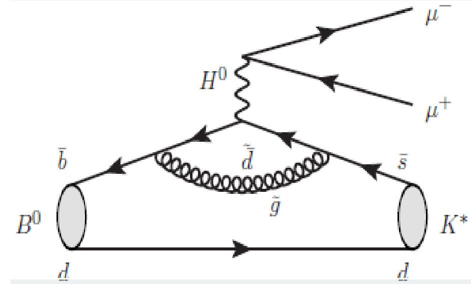
TeV-scale SUSY with large $\tan\beta$ is practically excluded

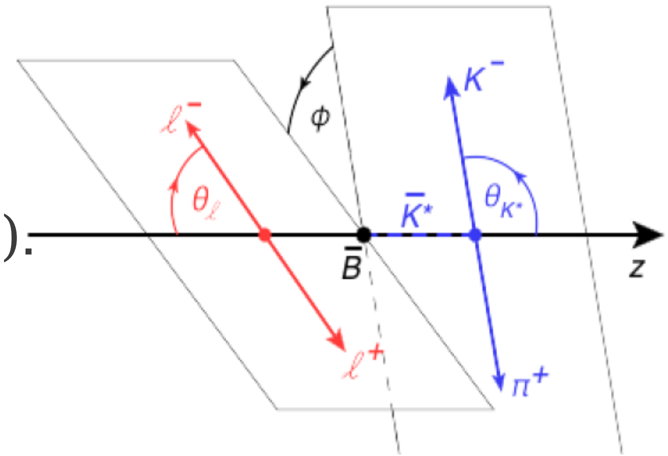
NP that reduces $B_s \to \mu^+\mu^-$ amplitude already discussed by theorists.

Rare decays: $B^0 \to K^* \mu^+ \mu^-$

1 fb^{-1}, LHCb-CONF-2012-008







FCNC process, can be affected by presence of NP.

Measure angular distributions as functions of $q^2 = m^2(\mu\mu)$.

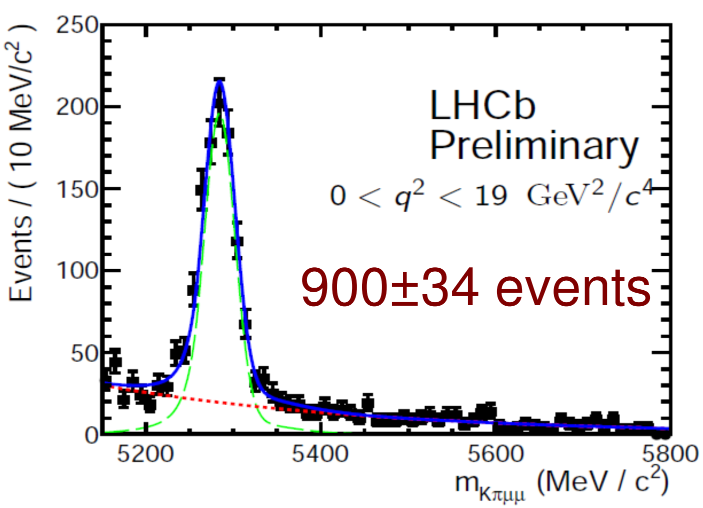
K^* polarization F_L, forward-backward asymmetry A_{FB}.

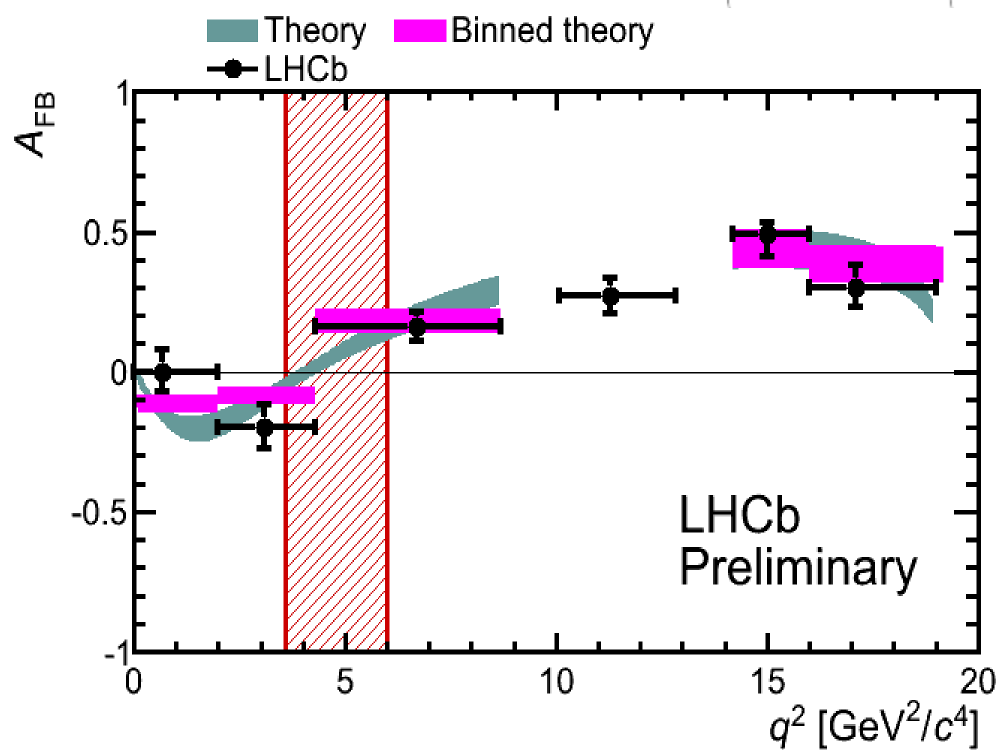
q^2 where $A_{FB}=0$ is well predicted in SM:

$$q^2\,(A_{FB}=0) = (4 - 4.3)\ \mathrm{GeV}^2/c^4$$

First measurement of zero crossing point:

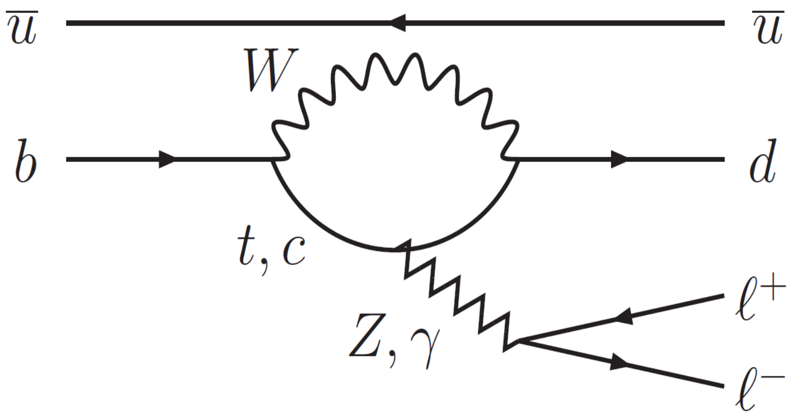
$$q^2(A_{FB}=0) = 4.9^{+1.1}_{-1.3}\ \mathrm{GeV}^2/c^4$$

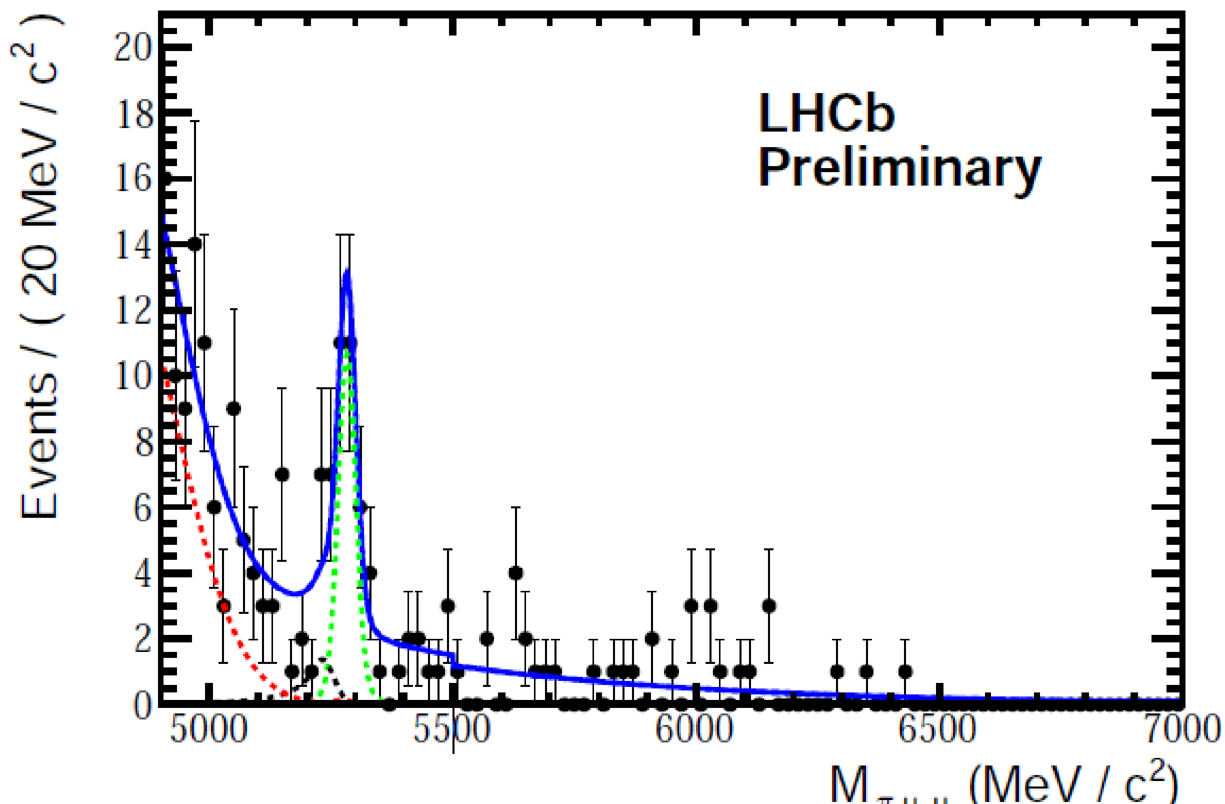




Rare decays: $B^+ \to \pi^+ \mu^+ \mu^-$

1 fb^{-1}, LHCb-CONF-2012-006





$b \to d\ell\ell$ transition,

SM prediction:

$Br = (1.96 \pm 0.21) \times 10^{-8}$

x25 smaller than $B^+ \to K^+ \mu^+ \mu^-$

(misID is a challenge)

25±6 signal events, 5.2σ significance

First observation of $b \to d\ell\ell$ transition,

$Br(B^+ \to \pi^+\mu^+\mu^-) = (2.4 \pm 0.6(stat) \pm 0.2(syst))x10^{-8}$

In a good agreement with SM prediction

The rarest B decay ever observed

CP violation: $B^\pm \to DK^\pm$

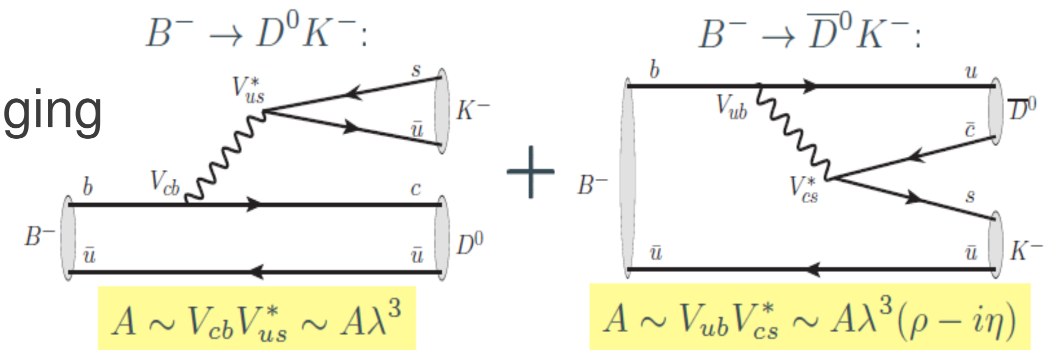
1 fb^{-1}, LHCb-PAPER-2012-001

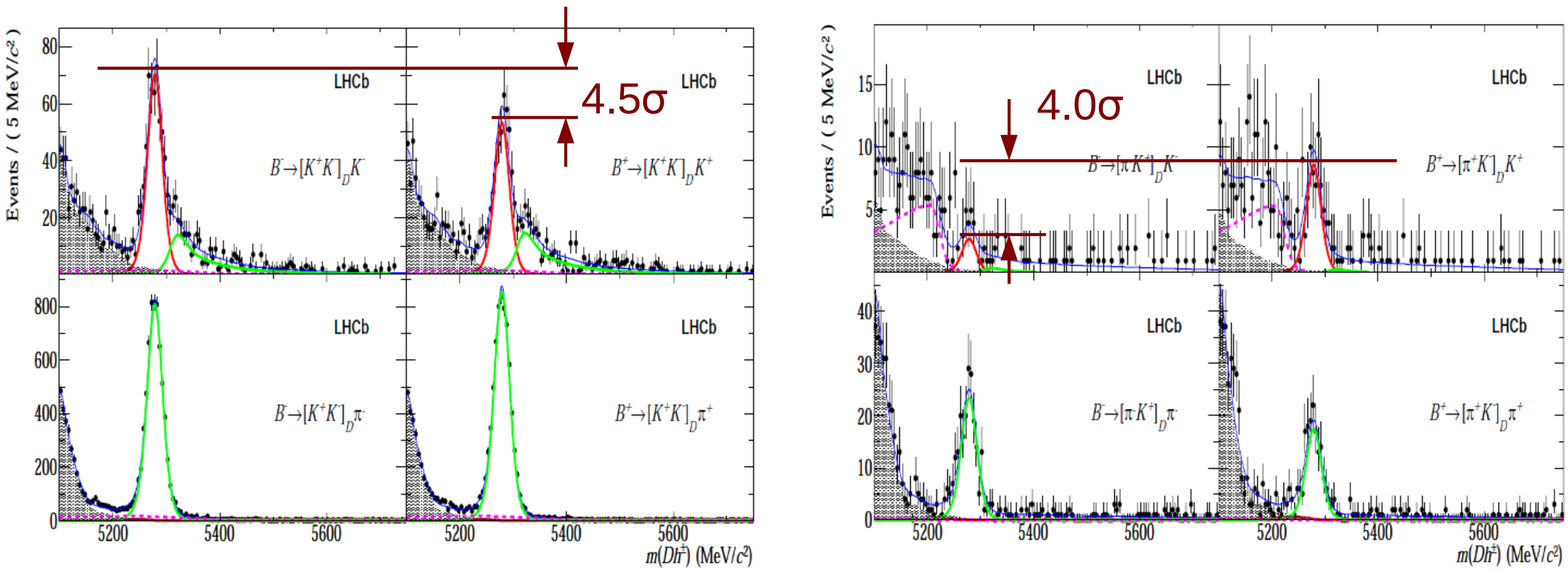
Access CKM phase γ through interference of $V_{cb}V^*_{us}$ and $V_{cs}V^*_{ub}$ amplitudes.

Tree-level measurement, SM reference.

Theoretically clean, experimentally challenging

- GLW mode: $D \to KK$, $\pi\pi$
- ADS mode: fav. $B \to DK$, sup. $D \to K\pi$ and sup. $B \to DK$, fav. $D \to K\pi$

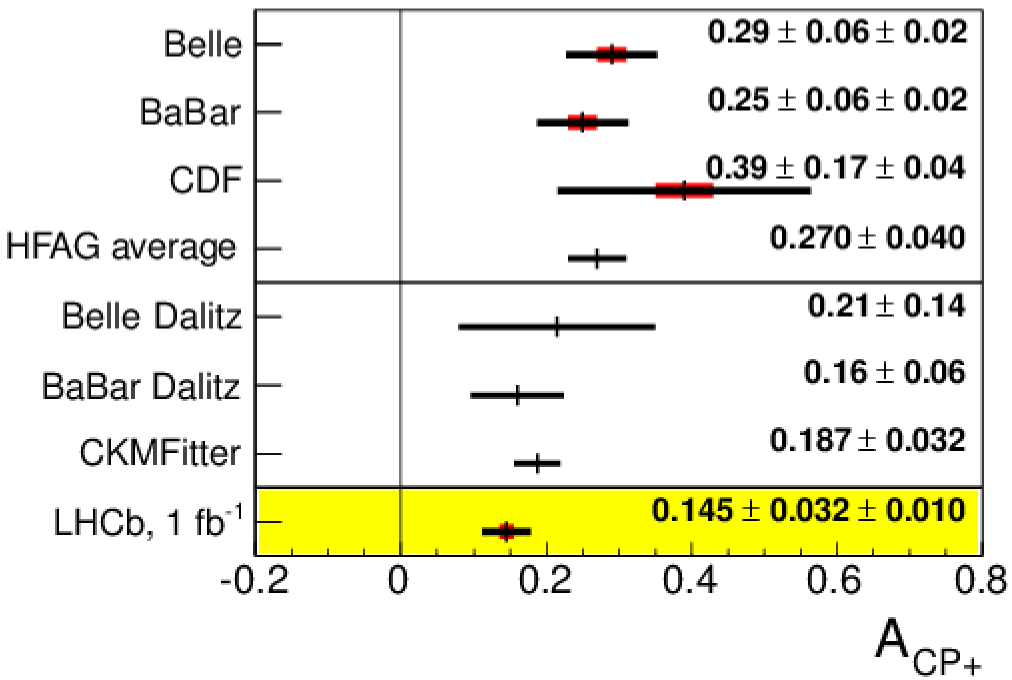


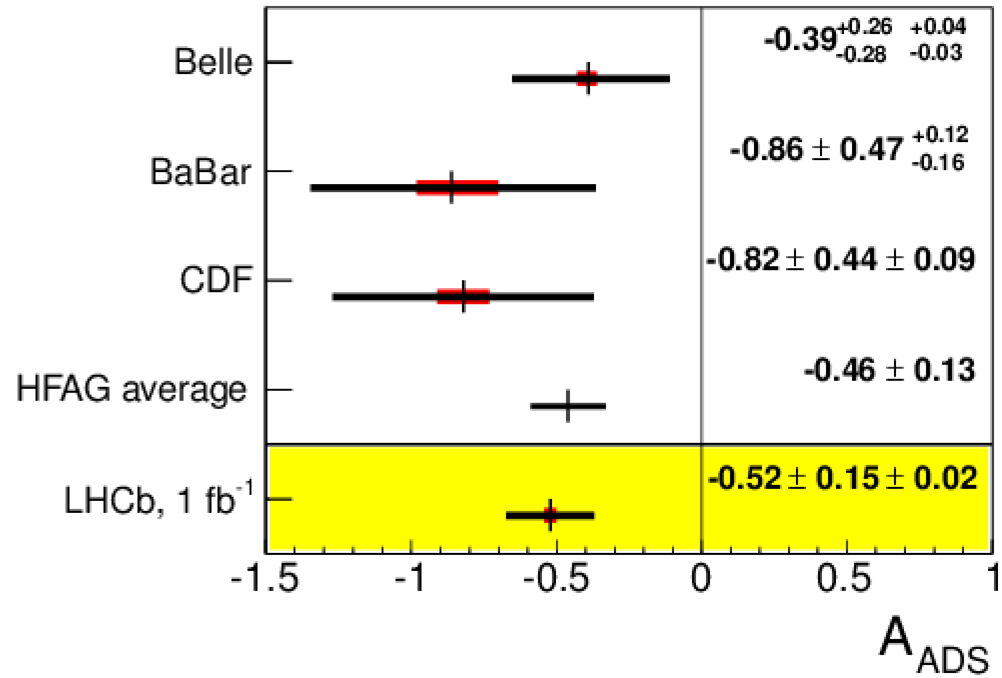


5.8σ observation of CP violation in the combination of $B \to D(hh)K$ modes

CP violation: B± → DK±

1 fb⁻¹, LHCb-PAPER-2012-001





Measured observables, e.g. asymmetries, depend on γ as well as other unknown parameters:

$$A_{CP\pm} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}. \qquad A_{ADS} = \frac{2 r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{r_B{}^2 + r_D{}^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\gamma}$$

Measurement of γ in B→DK, D→hh modes alone suffers from ambiguities.

Combination with other modes is required to constrain γ:

B→D($K_s$hh)K, B→D(hh)Kππ, B^0→DKπ, B_s→Dϕ, etc.

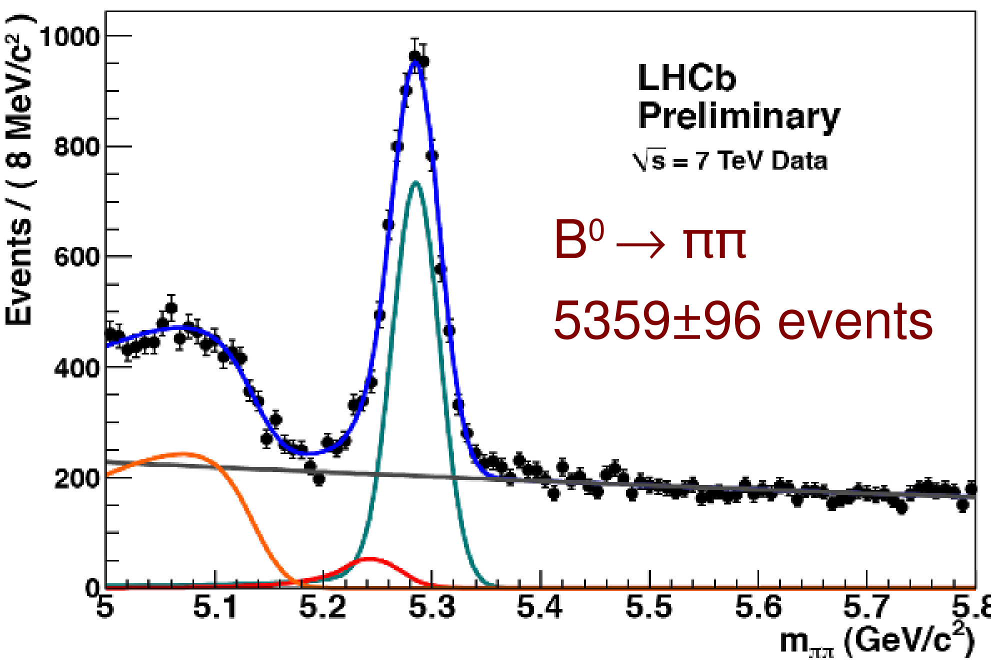
CP violation: $B^0 \to \pi\pi$, $B_s \to KK$

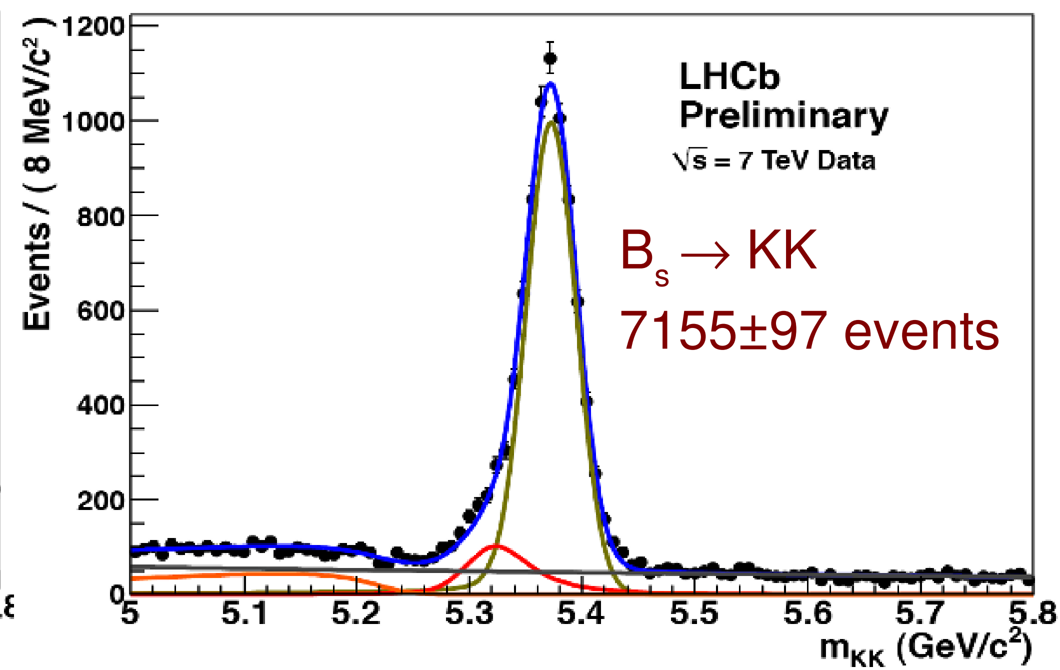
0.69 fb^{-1}, LHCb-CONF-2012-007

Time-dependent CP violation:

$$\mathcal{A}_{CP}(t) = \frac{\Gamma_{\bar{B}\to f}(t) - \Gamma_{B\to f}(t)}{\Gamma_{\bar{B}\to f}(t) + \Gamma_{B\to f}(t)} = \frac{\mathcal{A}^{dir}\cos(\Delta M t) + \mathcal{A}^{mix}\sin(\Delta M t)}{\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \mathcal{A}^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}t\right)}$$

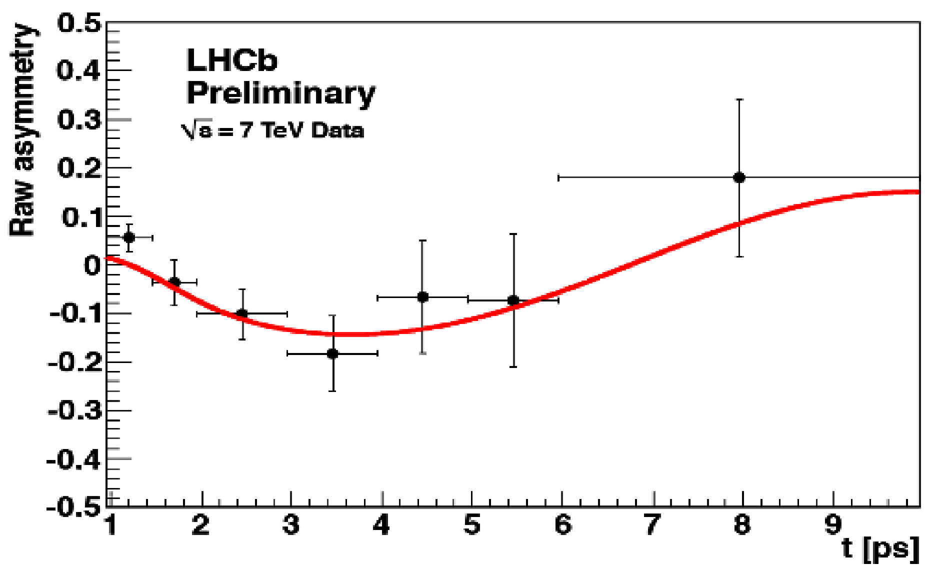
Invoking U-spin symmetry, can constrain CKM phase γ by analysing $B^0 \to \pi\pi$ and $B_s \to KK$ decays

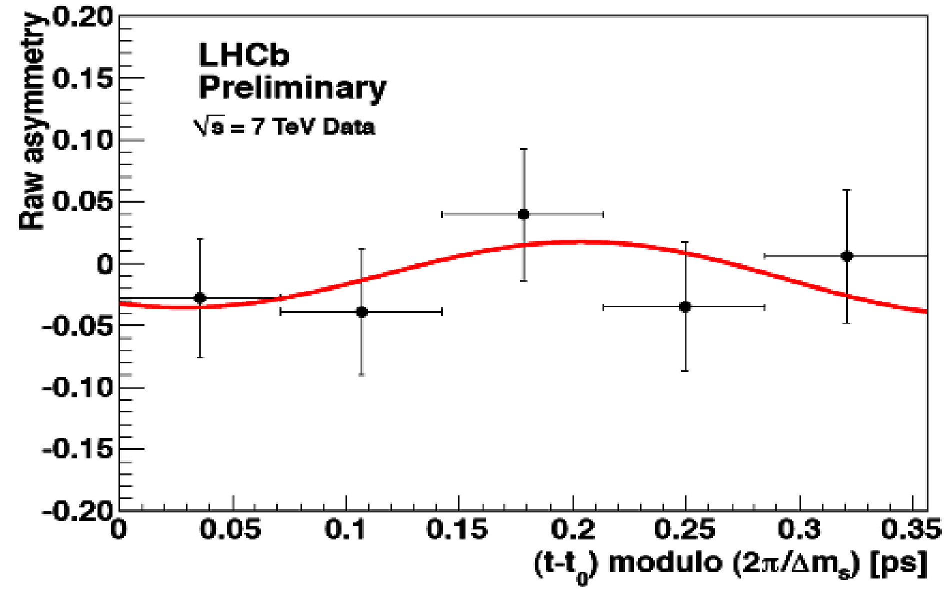


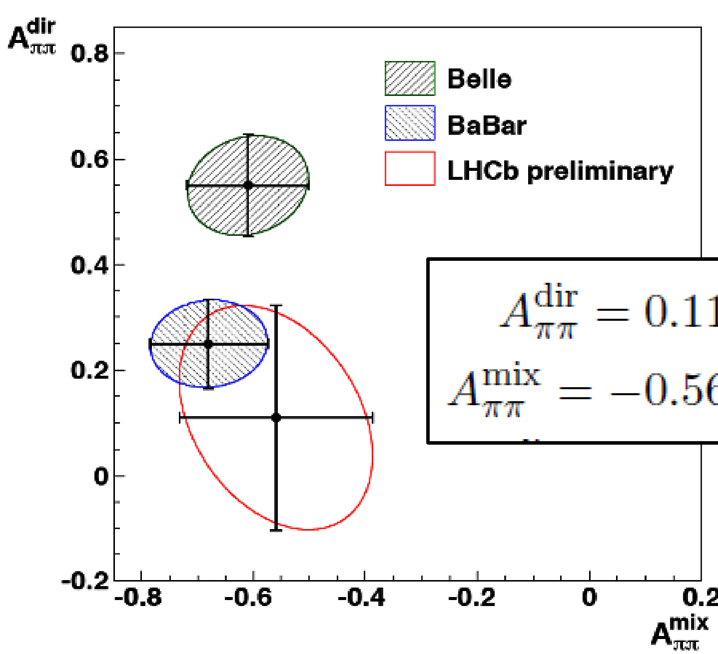


CP violation: $B^0 \to \pi\pi$, $B_s \to KK$

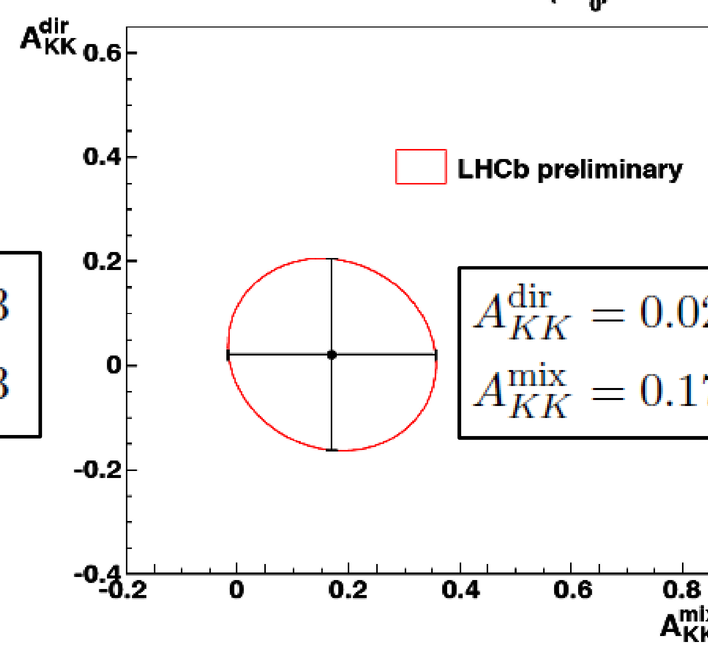
0.69 fb^{-1}, LHCb-CONF-2012-007







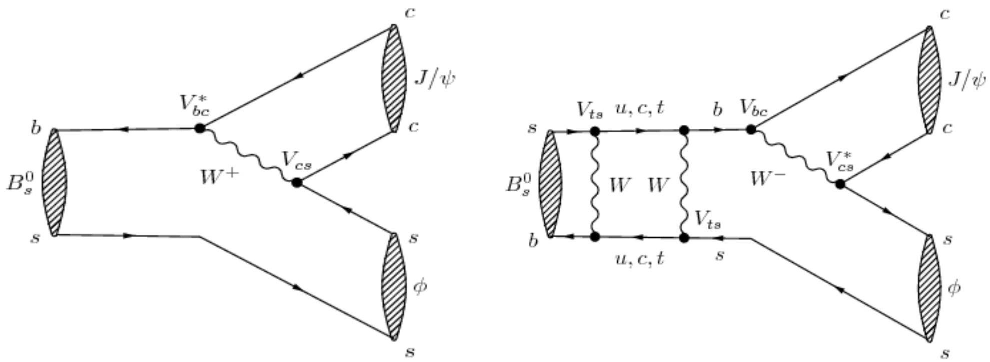
$$A_{\pi\pi}^{\mathrm{dir}} = 0.11 \pm 0.21 \pm 0.03$$
$$A_{\pi\pi}^{\mathrm{mix}} = -0.56 \pm 0.17 \pm 0.03$$



$$A_{KK}^{\mathrm{dir}} = 0.02 \pm 0.18 \pm 0.04$$
$$A_{KK}^{\mathrm{mix}} = 0.17 \pm 0.18 \pm 0.05$$

CP violation: $B_s \to J/\psi\ \varphi$

1 fb^{-1}, LHCb-CONF-2012-002



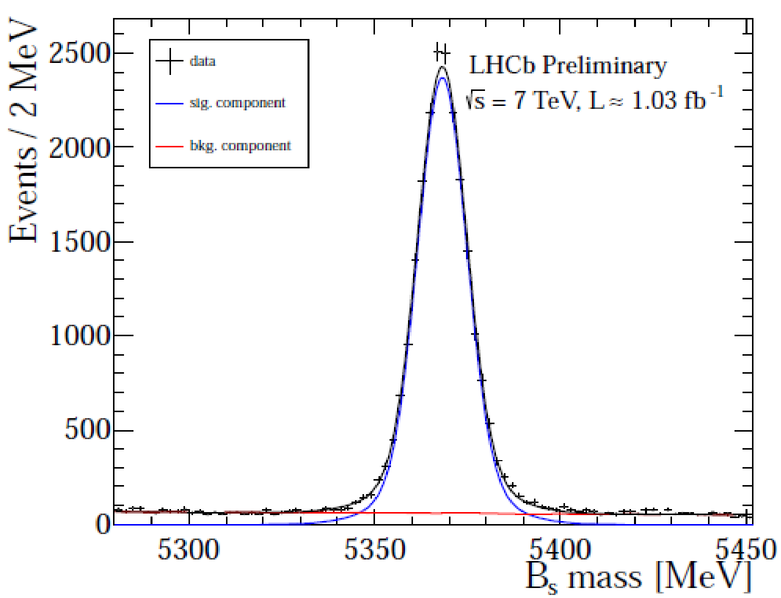
Interference of $B_s \to J/\psi\varphi$ decays with and without mixing

In SM, small phase difference:

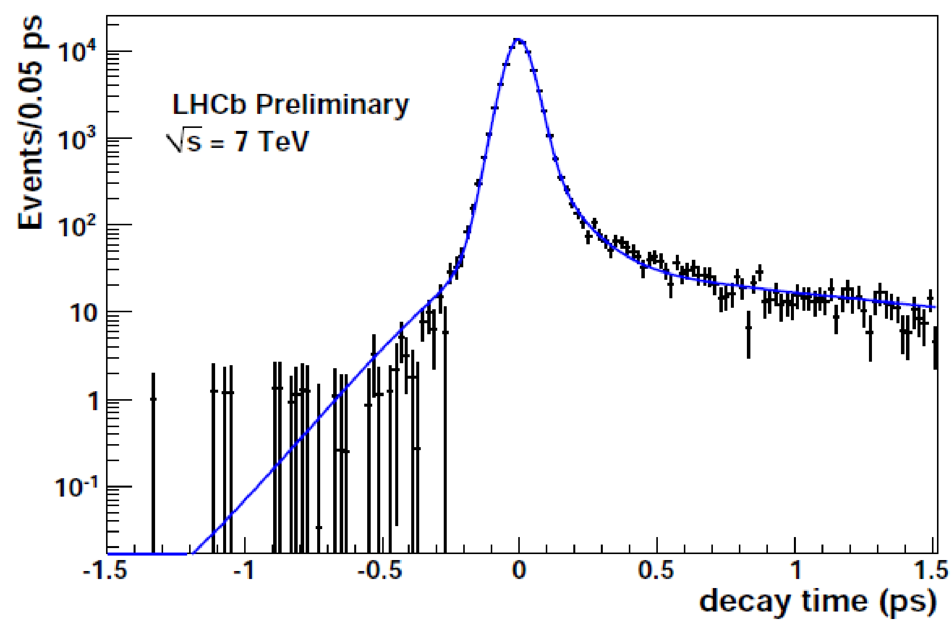
$$\varphi_s = -0.036 \pm 0.002$$

Measurement involves a number of advanced analysis techniques:

- Flavour tagging to identify the initial B_s flavour
- Decay time measurement to measure oscillations
- Angular analysis to distinguish between CP-odd and CP-even states (P → VV decay)



21200 $B_s \to J/\psi\varphi$ candidates

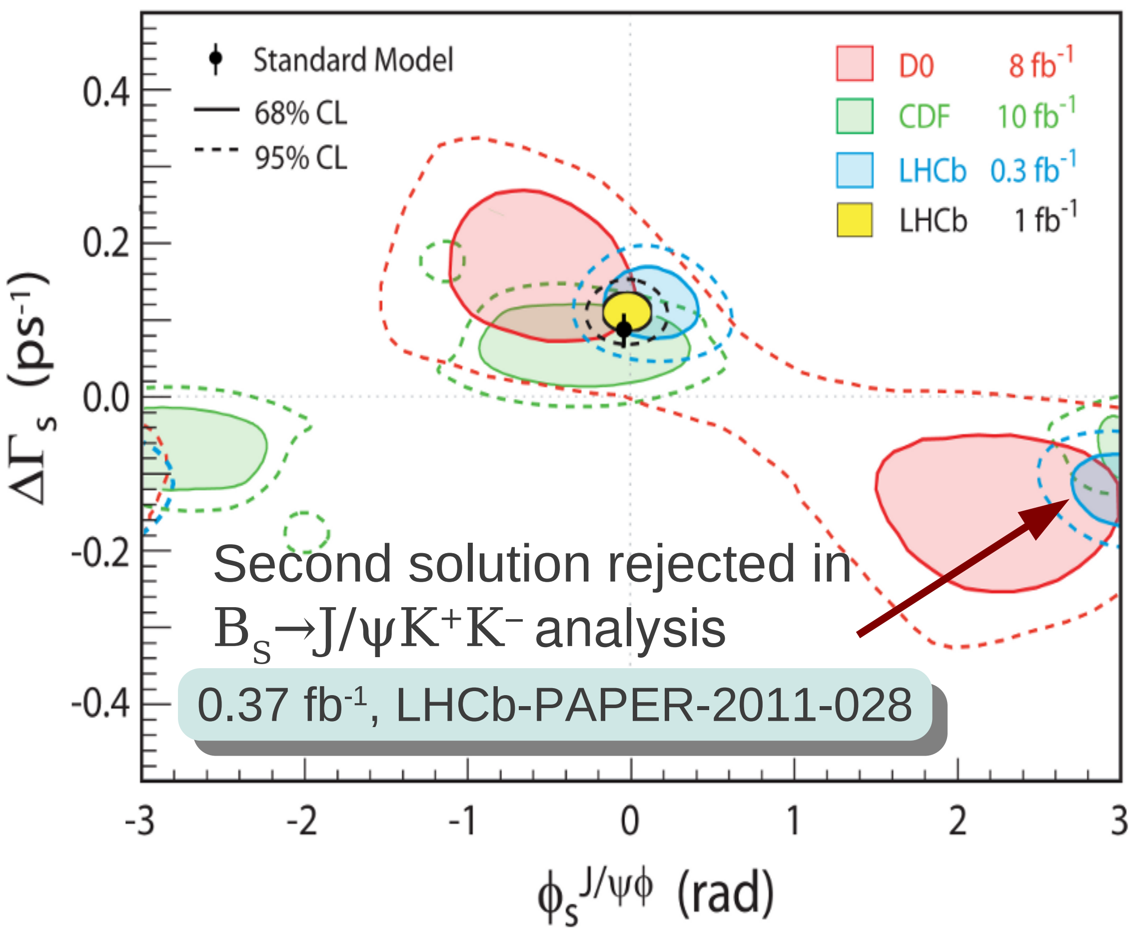


CP violation: $B_s \to J/\psi\ \varphi$

1 fb^{-1}, LHCb-CONF-2012-002

$\Delta\Gamma_s = 0.116 \pm 0.018 \pm 0.006\ \mathrm{ps}^{-1}$

$\varphi_s = -0.001 \pm 0.101 \pm 0.027$



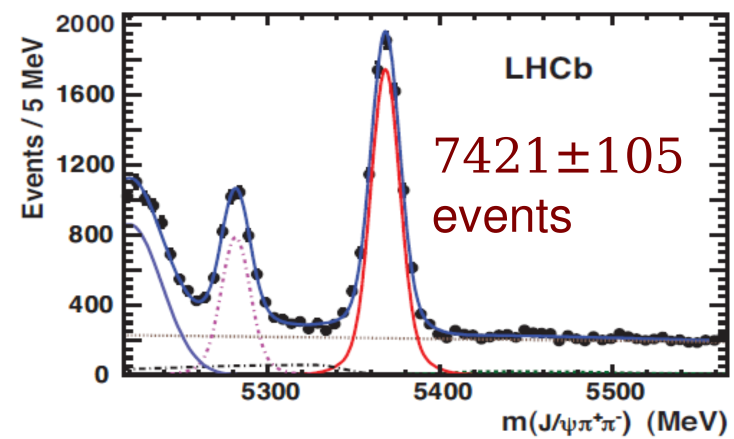
Second solution rejected in $B_s \to J/\psi K^+K^-$ analysis

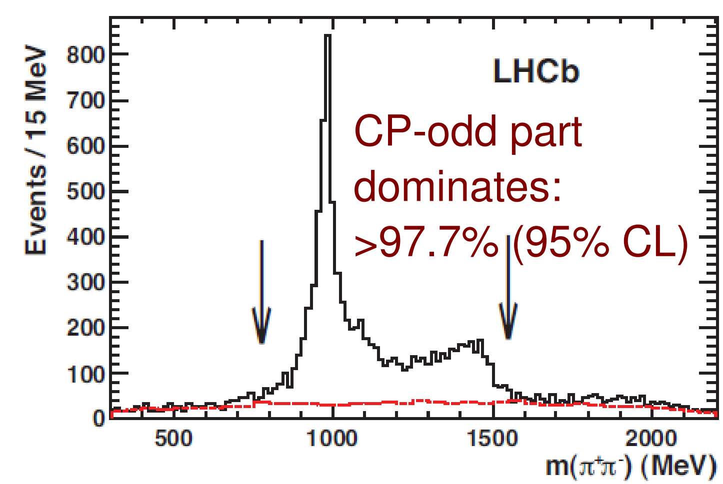
0.37 fb^{-1}, LHCb-PAPER-2011-028

1 fb^{-1}, LHCb-PAPER-2012-006

Similar measurement in $B_s \to J/\psi\pi^+\pi^-$

$\varphi_s = -0.02 \pm 0.17 \pm 0.02$

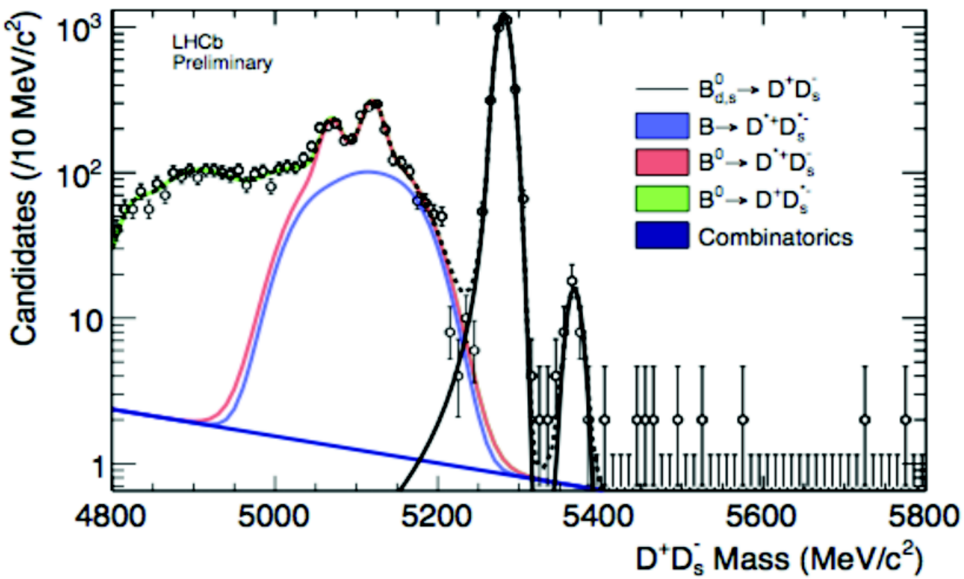


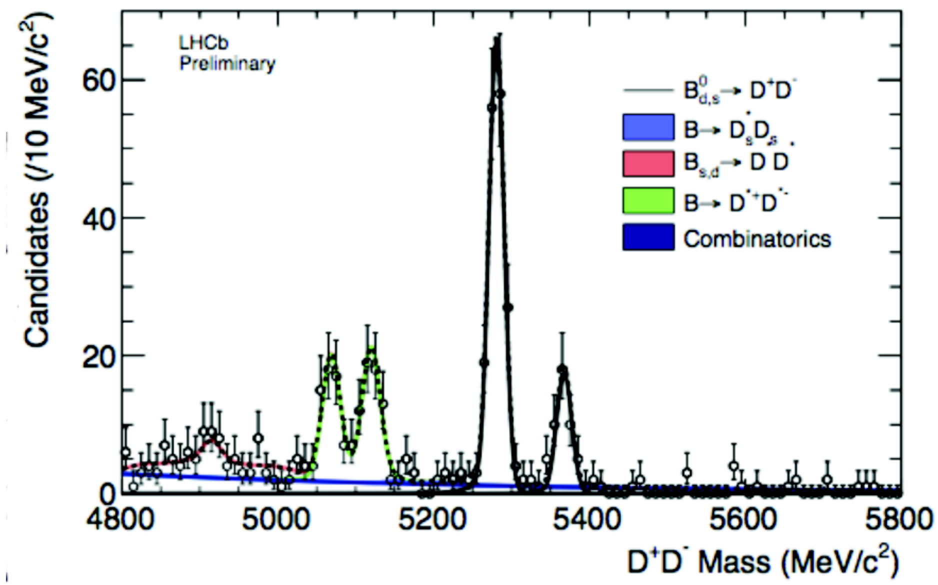


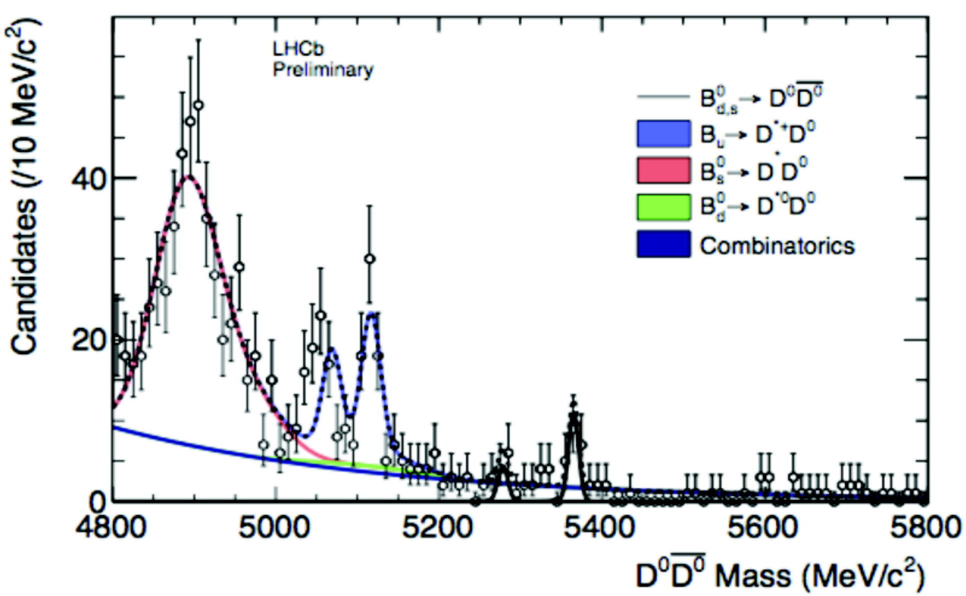
Combined result: $\varphi_s = -0.002 \pm 0.083 \pm 0.027$

Some new observations: B→DD

1 fb^{-1}, LHCb-PAPER-2012-001







$Br(B_s \to DD_s)/Br(B^0 \to DD_s) = 0.048 \pm 0.008 \pm 0.004$

Significance: 10σ

$Br(B_s \to D^+D^-)/Br(B^0 \to D^+D^-) = 1.00 \pm 0.18 \pm 0.09$

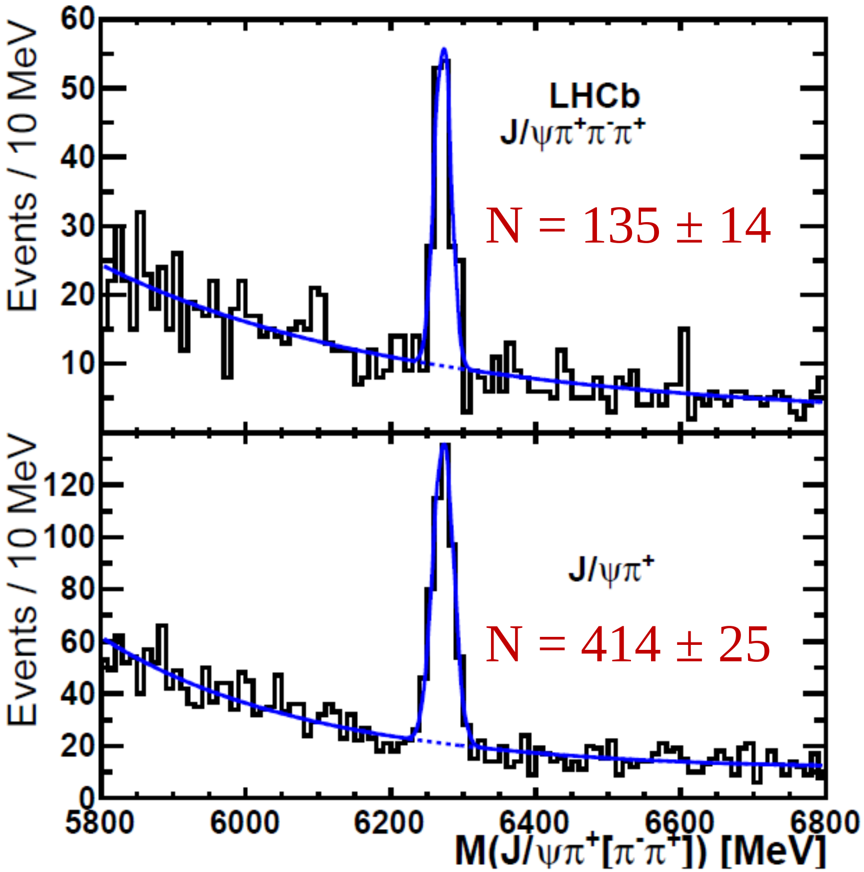
Significance: 10σ

$Br(B_s \to D^0\bar{D}^0)/Br(B^- \to D^0D_s) = 0.015 \pm 0.004 \pm 0.002$

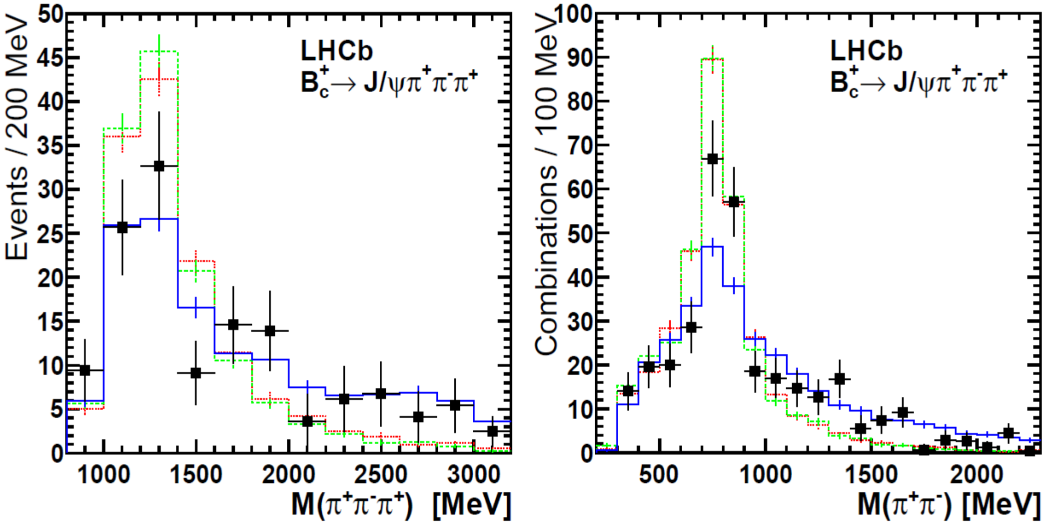
Significance: 5.4σ

More new observations: $B_c \to J/\psi\pi^-\pi^+\pi^+$

0.8 fb^{-1}, LHCb-PAPER-2011-044



- Br consistent with QCD sum rules
- Multibody dynamics is studied:



Dominated by $B_c^+ \to J/\psi\, a_1^+$, $a_1^+ \to \rho^0\pi^+$.

$$\frac{BR(B_c^\pm \to J/\psi 3\pi^\pm)}{BR(B^\pm \to J/\psi\pi^\pm)} = 2.41 \pm 0.30_{stat} \pm 0.33_{syst}$$

Charm physics

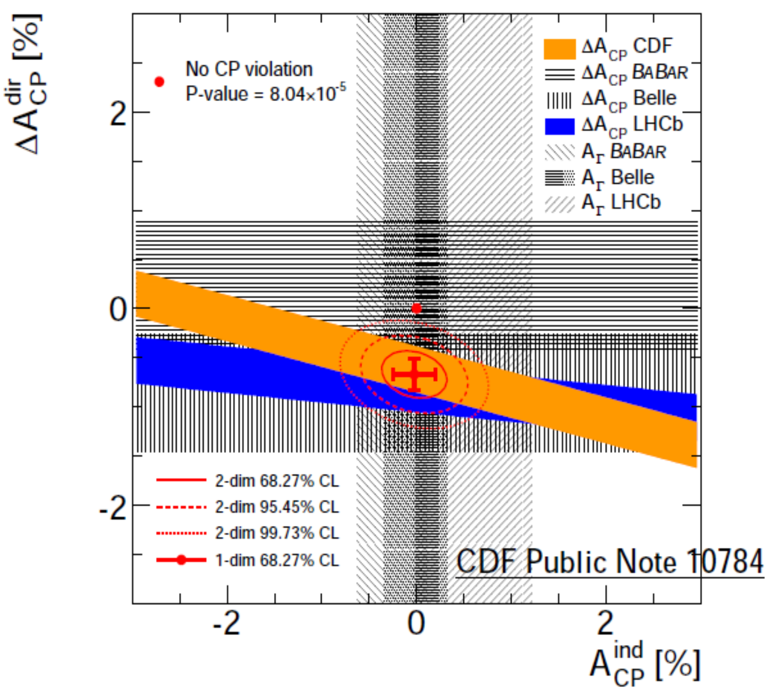
- CP violation in charm:

  Evidence for direct CPV in D→hh

  $\Delta A_{CP} \equiv A_{CP}(KK) - A_{CP}(\pi\pi)$

  $\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$

  0.6 fb^{-1}, PRL 108, 111602 (2012)



  Recent confirmation by CDF

  More charm CPV studies to come...

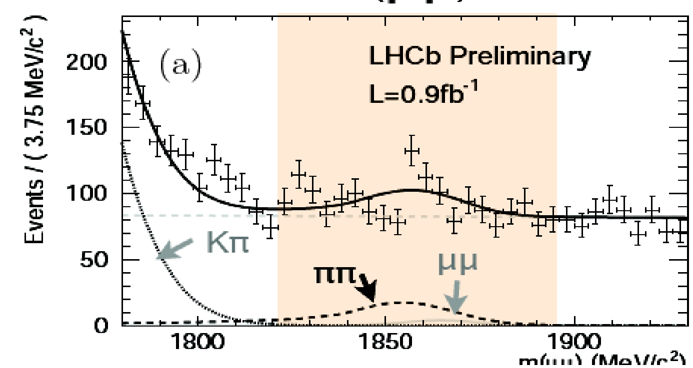
- Rare charm decays:

  Search for D→μμ

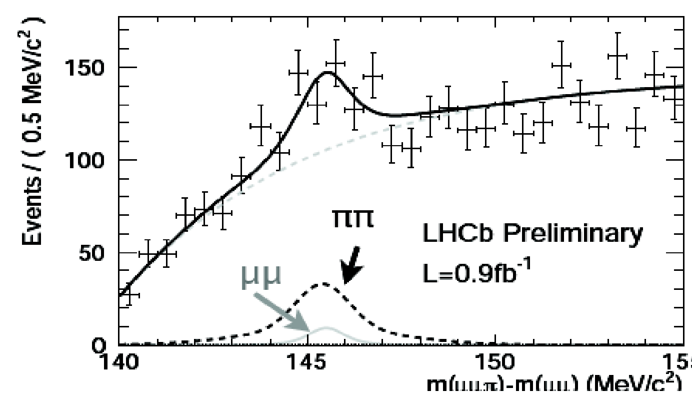
  0.9 fb^{-1}, LHCb-CONF-2012-005

  Use tagged D from D*→Dπ

  m(μμ)



  Δm for m(μμ)∈[1820, 1880] MeV



$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3 \cdot 10^{-8}$ at 95% CL

Preparation for 2012

- Bunch energy increases to 4 TeV
  Will run at $4 \times 10^{32}\ cm^{-2}s^{-1}$ $\Rightarrow$ expect 25% increase in $b\bar{b}$ rate
- Better control of systematics:
  - Introduce vertical external crossing angle (instead of horizontal one), to ensure that the crossing angle is the same for both polarities.
  - For better control of detector asymmetries, need to change magnet polarity frequently to follow change in running conditions. Compromise with LHC: run with 3 polarity switches between technical stops (flip every 1.5 weeks).
- Aim is to collect 1.5 fb^{-1} in 2012.
- Aim to take as much data as possible before long shutdown: increase trigger rate from 3 kHz (2011) $\rightarrow$ 4.5 kHz

Trigger improvements for 2012

- Trigger has to cope with the increased rate due to luminosity and beam energy increase.
- HLT farm will increase by 10% (1200 additional cores)
- Deferred trigger:
  - The whole farm is idle between fills
  - Instead:
    - Buffer L0-filtered events to local disks (200 Gbytes/node is available)
    - Run HLT on buffered data between fills
    - Equivalent to 10%-20% gain in CPU
- Improvements in tracking and vertexing performance
  - Downstream tracking in trigger (tracks with no hits in VELO: K_S,Λ)

    Gain a factor of 3.5 for $D \rightarrow K_S \pi^+ \pi^-$: golden mode for mixing and CPV in charm
- Increased physics rate is challenging for data storage:
  - Bandwidth for analysis skims for 2012 is limited by available storage: ~35 Mbytes/sec.
  - A lot of effort to stay within this bandwidth: data compression, event size reduction, tighter selections.

LHCb upgrade: physics programme

LHCb upgrade LoI
CERN-LHCC-2011-001

LHCb will run in its current configuration until the end of 2017, expect to take 5-7 fb^{-1}.

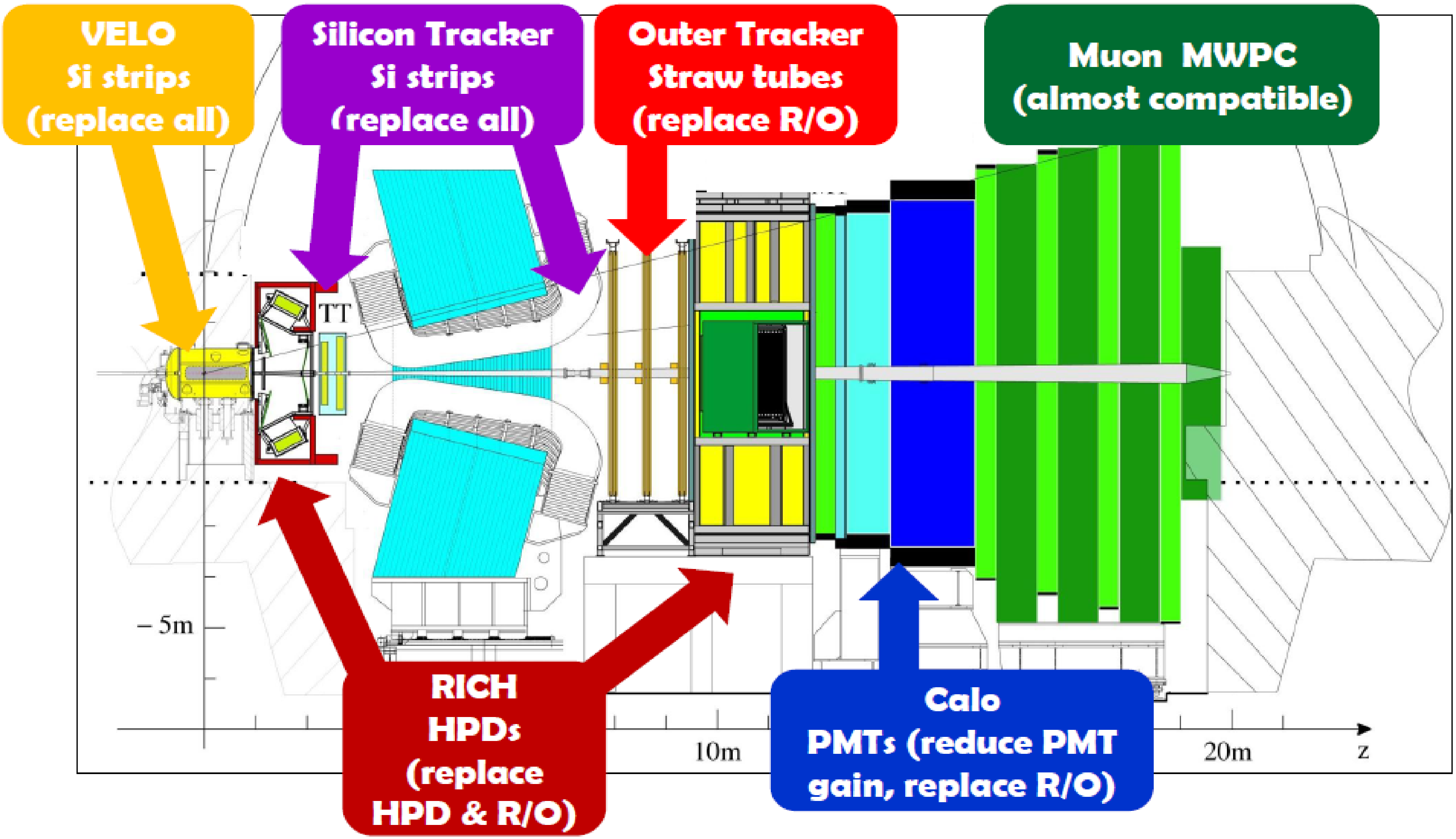
There is a rich physics programme for integrated luminosities up to 50 fb^{-1}

Type	Observable	Current precision	LHCb (5 fb^{-1})	Upgrade (50 fb^{-1})	Theory uncertainty
Gluonic penguin	$S(B_s \to \phi\phi)$	-	0.08	0.02	0.02
	$S(B_s \to K^{*0}\bar{K}^{*0})$	-	0.07	0.02	< 0.02
	$S(B^0 \to \phi K^0_S)$	0.17	0.15	0.03	0.02
B_s mixing	$2\beta_s\ (B_s \to J/\psi\phi)$	0.35	0.019	0.006	~ 0.003
Right-handed currents	$S(B_s \to \phi\gamma)$	-	0.07	0.02	< 0.01
	$\mathcal{A}^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	-	0.14	0.03	0.02
E/W penguin	$A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-)$	-	0.14	0.04	0.05
	$s_0\ A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	-	4%	1%	7%
Higgs penguin	$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	30%	8%	$< 10\%$
	$\frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)}$	-	-	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim 20°$	$\sim 4°$	0.9°	negligible
	$\gamma\ (B_s \to D_s K)$	-	$\sim 7°$	1.5°	negligible
	$\beta\ (B^0 \to J/\psi\, K^0)$	1°	0.5°	0.2°	negligible
Charm CPV	A_Γ	2.5×10^{-3}	2×10^{-4}	4×10^{-5}	-
	$A_{CP}^{dir}(KK) - A_{CP}^{dir}(\pi\pi)$	4.3×10^{-3}	4×10^{-4}	8×10^{-5}	-

Updated

Framework TDR to be submitted to LHCC in June 2012 (schedule, cost and resources for the upgrade) together with an update of physics performance based on real data

LHCb upgrade: detector modifications



- Need to read out at full 40 MHz speed to gain from increased luminosity.
- Fully software trigger running at 40 MHz.
- Aim to increase the rate for muonic channels by x5, hadronic by x10 wrt. current setup.

Subsystems TDRs to be ready by the end of 2013

Conclusion

- A lot of interesting results in heavy flavour physics obtained by LHCb.
  - Thanks to the excellent performance of the machine and detector.
- Most roadmap measurements updated with 1 fb^{-1} and reported at winter conferences.
  - Expanding our physics programme beyond the roadmap: prepare for exciting new results already this spring and summer
- All results are well consistent with SM so far.
  - Except for CP violation in charm, which *may* (or may not) be the evidence of NP.
- 44 papers submitted to journals, 73 conference papers.
  - 120% more than December LHCC
- Looking forward to continue:
  - Trigger improvements in 2012, aim to collect 1.5 fb^{-1} with increased trigger efficiency, especially for charm decays.
  - Upgrade programme aiming at 50 fb^{-1}.

Backup

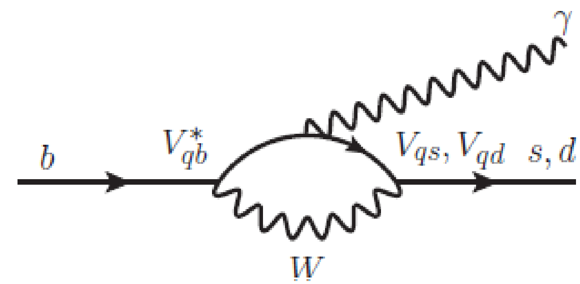
CP violation: $B^0 \to K^*\gamma$

1 fb^{-1}, LHCb-CONF-2012-004

SM prediction for CP asymmetry:

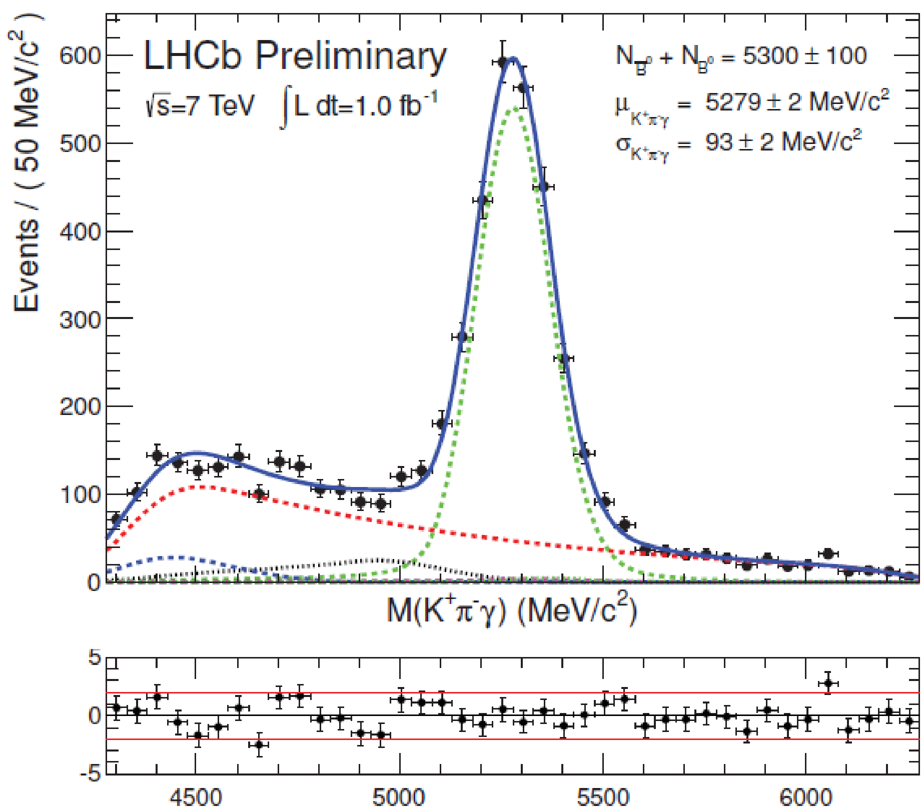
A_{CP} = -0.0061±0.0043

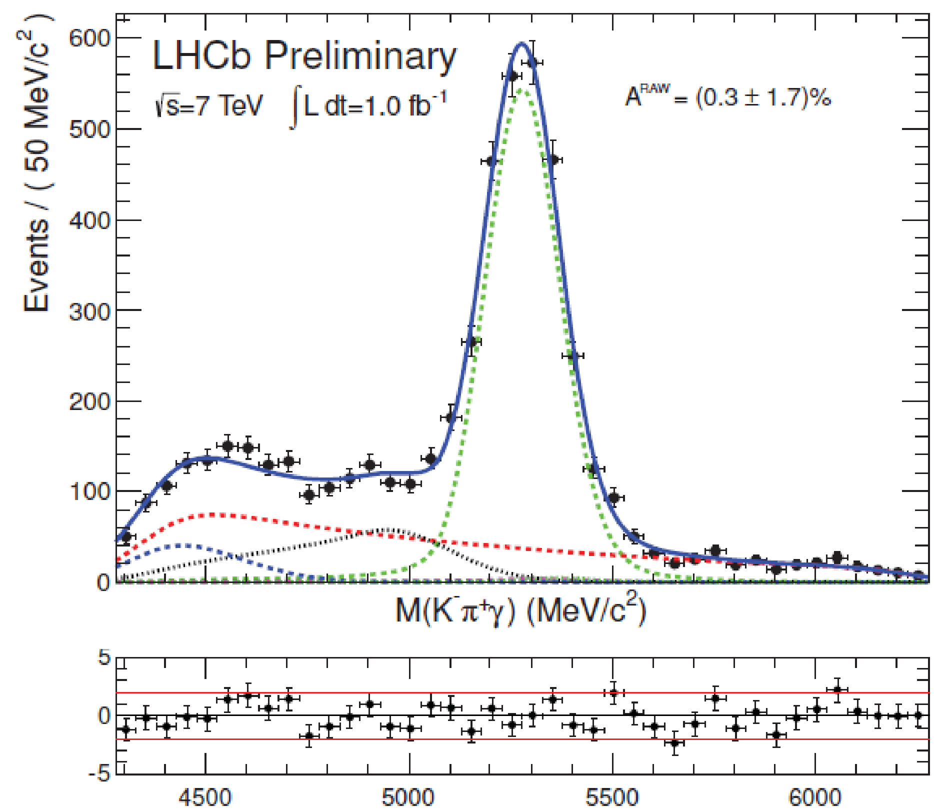
Smaller theoretical uncertainty than in Br.



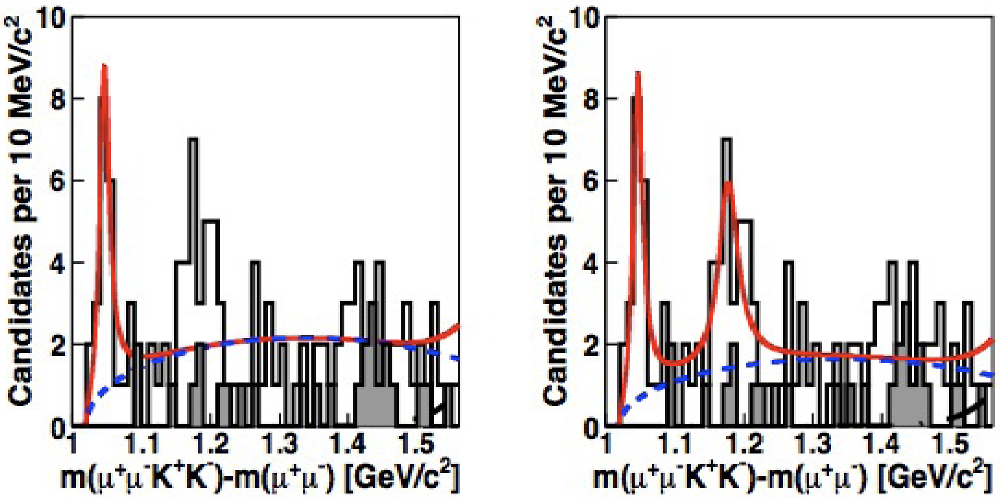
Measured CP asymmetry:

$A_{CP}(B^0 \to K^{*0}\gamma) = +0.008 \pm 0.017(\text{stat}) \pm 0.009(\text{syst})$

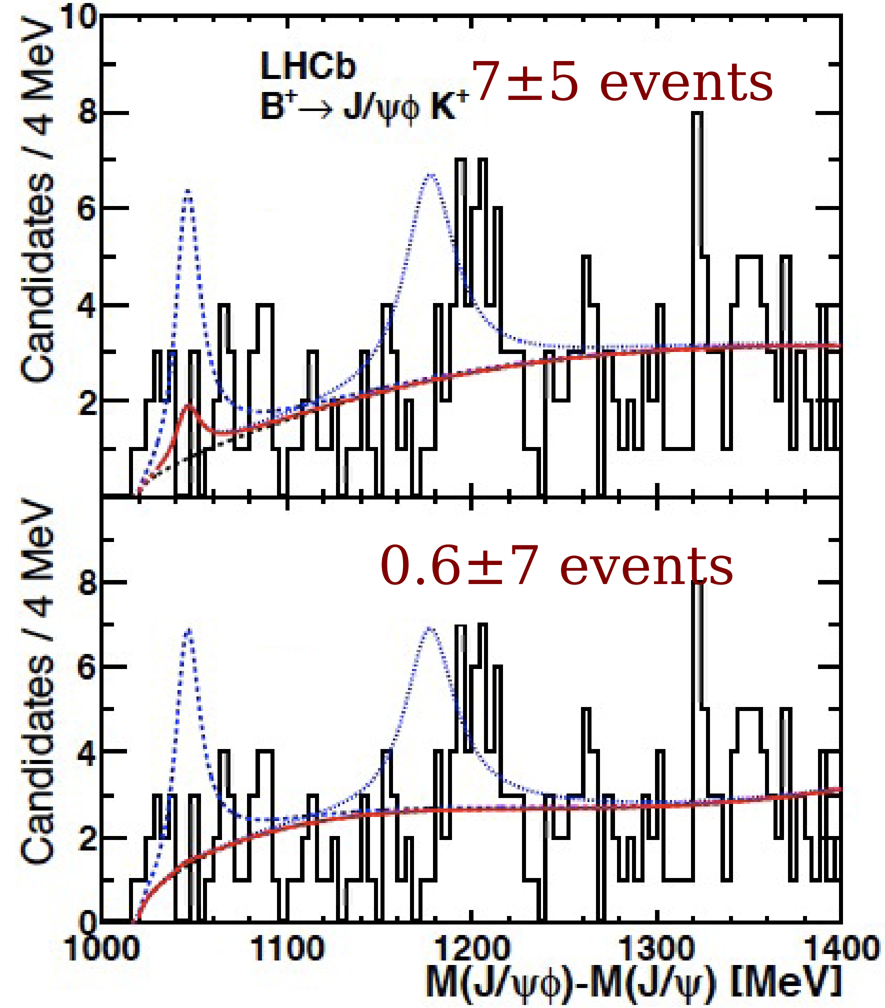




Non-observations: X(4140)



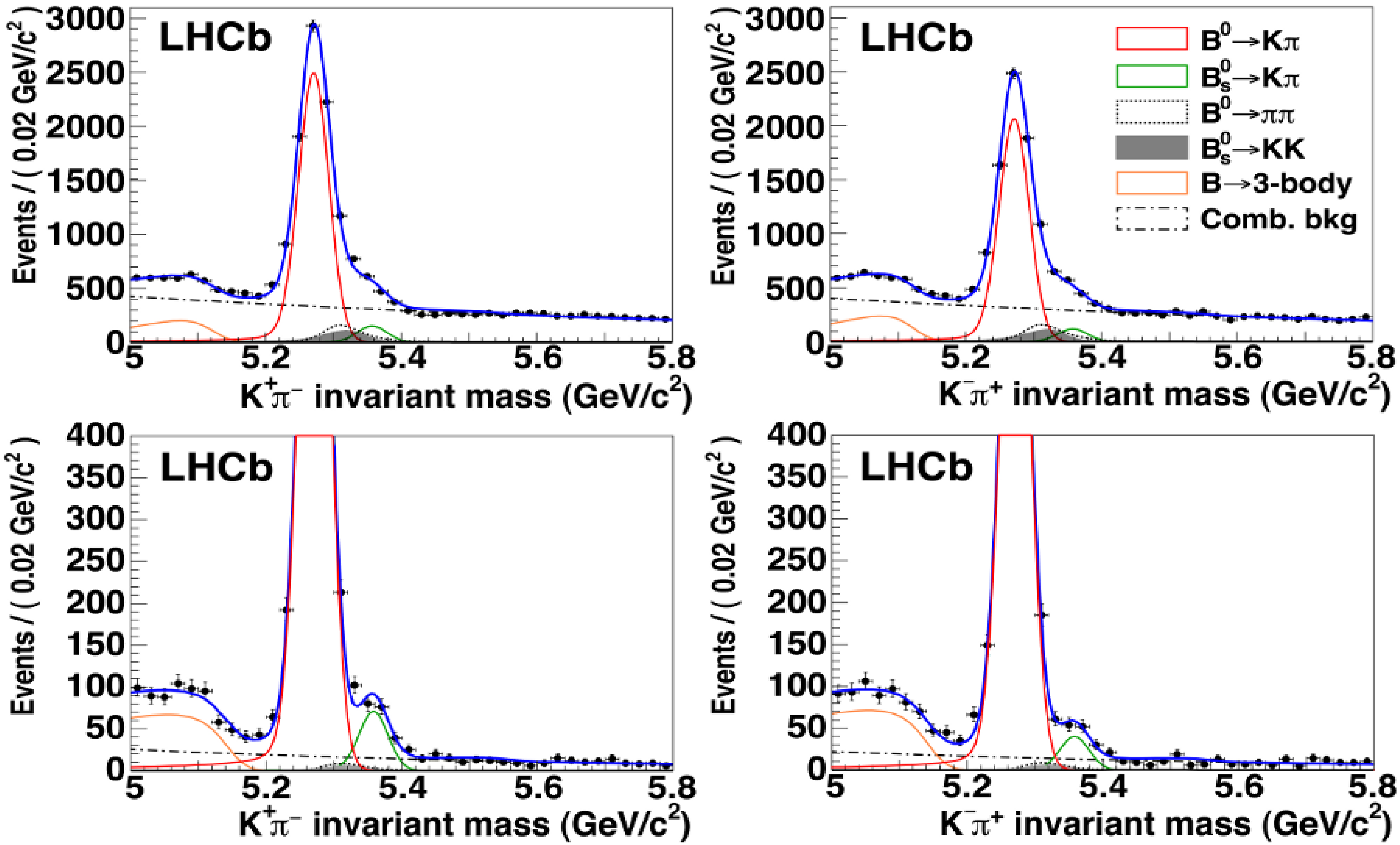
0.37 fb^{-1}, LHCb-PAPER-2011-033



- X(4140)→J/ψφ observed by CDF in B→J/ψφK
  - 19±6(stat)±3(syst) events at $M = 4143.4^{+2.9}_{-3.0} \pm 0.6$ MeV/c^2
  - 22±8 events (3.1σ) at $M = 4274.4^{+8.4}_{-6.7} \pm 1.9$ MeV/c^2
- X(4140) not confirmed by LHCb:

CP violation: $B_{(s)} \to K\pi$

0.35 pb^{-1}, arXiv:1202.6251



$$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011\,(\mathrm{stat}) \pm 0.008\,(\mathrm{syst})$$

$$A_{CP}(B_s^0 \to K\pi) = 0.27 \pm 0.08\,(\mathrm{stat}) \pm 0.02\,(\mathrm{syst})$$