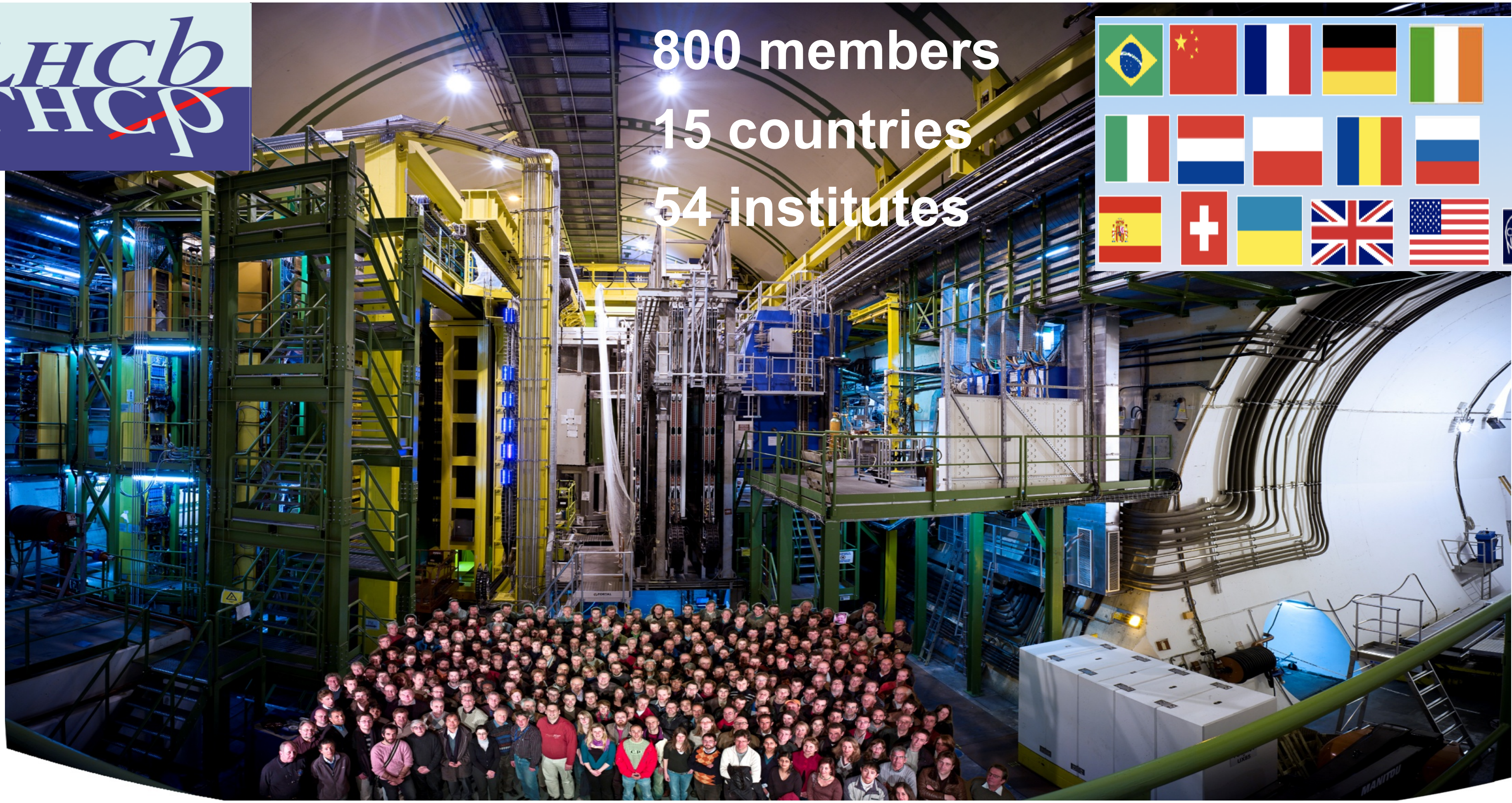
Main Results from LHCb



Cibrán Santamarina Ríos

Universidade de Santiago de Compostela

Outline

- Introduction:
  - *New Physics, CP Violation*.
- Spectrometer:
  - *Data Taking, VELO, Inner Tracker, RICH, Calorimeters*.
- Physics Results:
  - *CP Violation Results, Rare Decays, c-quark sector.*
- Conclusions.

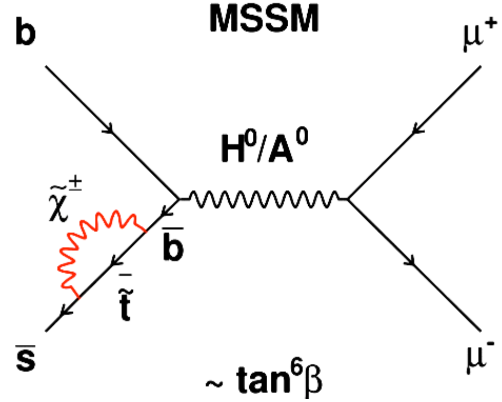
Introduction

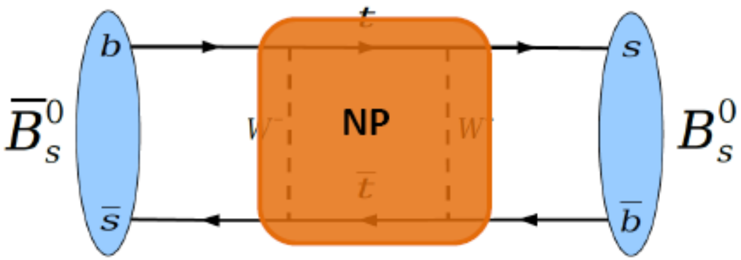
LHCb, New Physcis

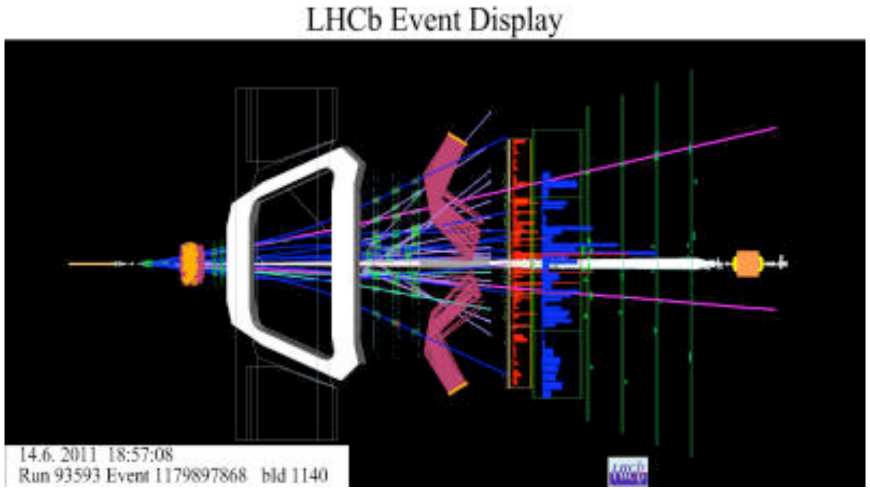
•LHCb is the dedicated **flavor physics** experiment at the LHC.

•ATLAS and CMS search ***direct*** production of new states
LHCb designed to search for ***indirect*** effect of such states on **charm** and **beauty** decays via virtual production in *loop* diagrams:

- Such an approach can be very powerful:
  eg B^0–B^0 mixing discovered at ARGUS (1987)
  $\rightarrow$ top quark unexpectedly heavy: $m(t) > 50$ GeV/c^2
  - $B_s \rightarrow \mu\mu$: SUSY? $B \propto \tan^6\beta / m_A^4$.
  - $B_d \rightarrow \mu\mu K_*$: Right-handed currents?
  - $B_s \rightarrow J/\psi\phi$: Beyond-SM CPV?





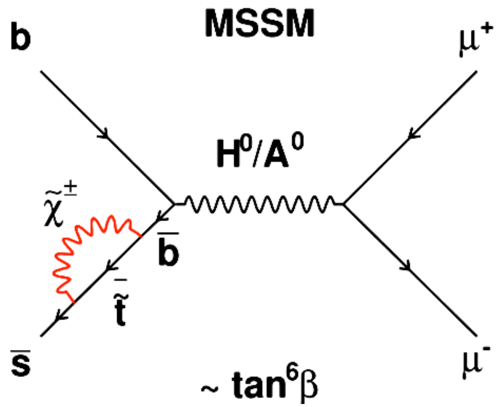


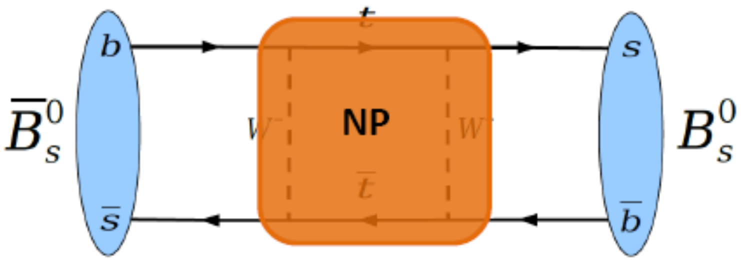
LHCb, New Physcis

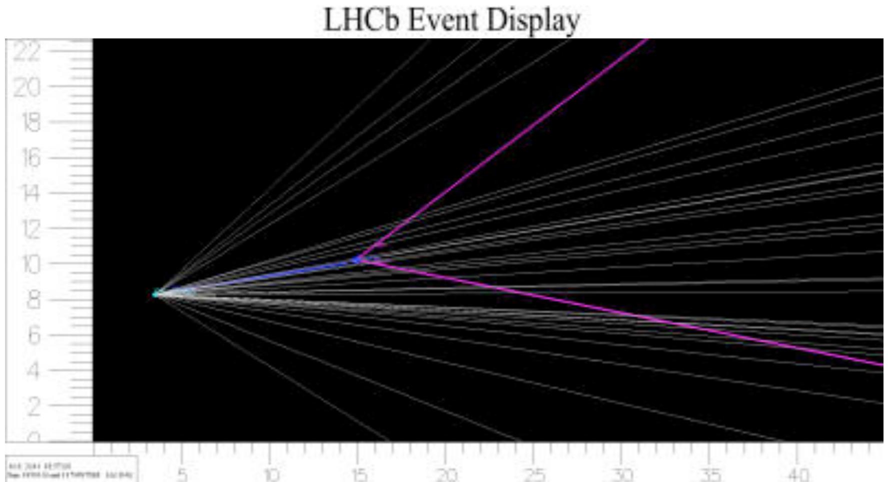
•LHCb is the dedicated **flavor physics** experiment at the LHC.

•ATLAS and CMS search ***direct*** production of new states
LHCb designed to search for ***indirect*** effect of such states on **charm** and **beauty** decays via virtual production in *loop* diagrams:

- Such an approach can be very powerful:
  eg B^0–B^0 mixing discovered at ARGUS (1987)
  → top quark unexpectedly heavy: $m(t) > 50$ GeV/c^2
  - $B_s \to \mu\mu$: SUSY? $B \propto \tan^6\beta / m_A^4$.
  - $B_d \to \mu\mu K_*$: Right-handed currents?
  - $B_s \to J/\psi\phi$: Beyond-SM CPV?

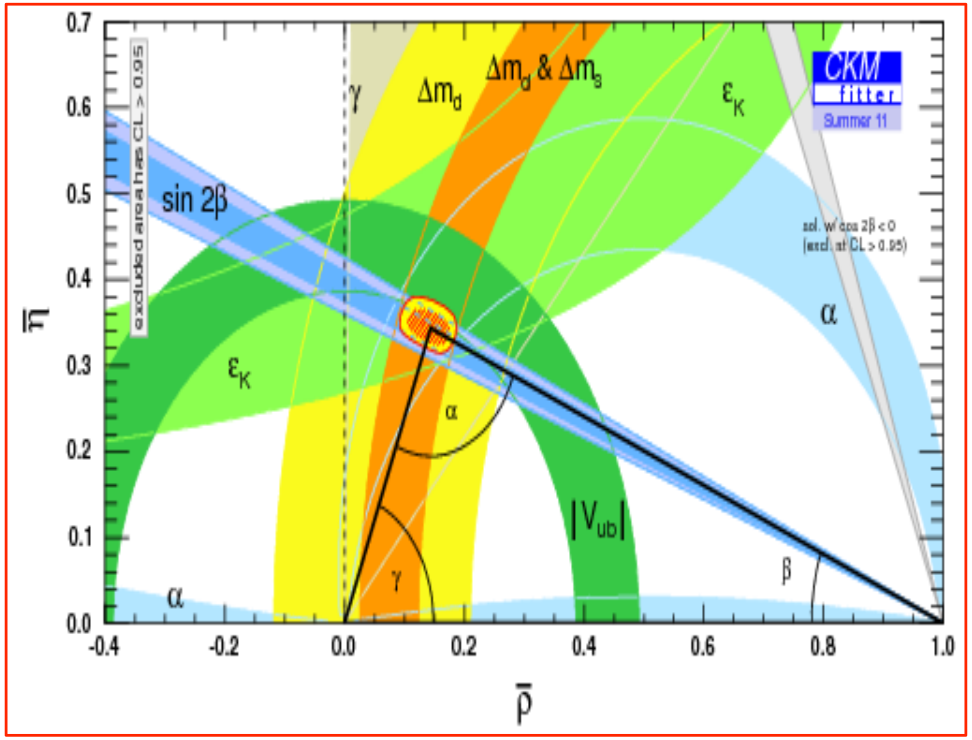






LHCb, CP violation

- SM CPV arises in the weak decays of hadrons from a *single* phase in the quark mixing (CKM) matrix (testing the Yukawa couplings to the quarks).
- Necessary to generate **matter-antimatter asymmetry.** Size in the SM too small to account for observed baryon/photon ratio → new physics expected.
- Direct CPV measurements.
  - SM CPV precise determination.
  - γ poorly known: depends on b → u decays. Higher statistics at LHC.
  - B_s sector not explored in detail.
  - CP violation in charm.



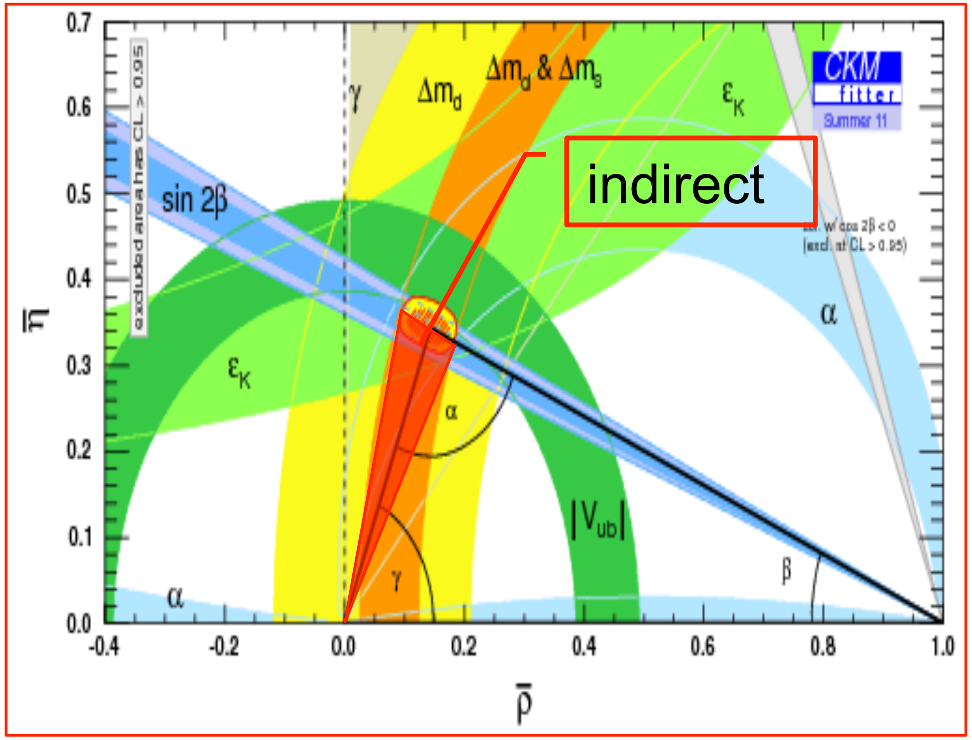
$$V = \begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1+A^2\lambda^4/2 \end{pmatrix} + O(\lambda^5)$$

$\arg V_{ub} \cong -\gamma$
$\arg V_{td} \cong -\beta$
$\arg V_{ts} \cong \beta_s+\pi$

$\beta_s \approx 1^\circ$ $\quad\beta \approx 22^\circ$ $\quad\gamma \approx 68^\circ$

LHCb, CP violation

- SM CPV arises in the weak decays of hadrons from a *single* phase in the quark mixing (CKM) matrix (testing the Yukawa couplings to the quarks).
- Necessary to generate **matter-antimatter asymmetry.** Size in the SM too small to account for observed baryon/photon ratio → new physics expected.
- Direct CPV measurements.
  - SM CPV precise determination.
  - γ poorly known: depends on b → u decays. Higher statistics at LHC.
  - B_s sector not explored in detail.
  - CP violation in charm.



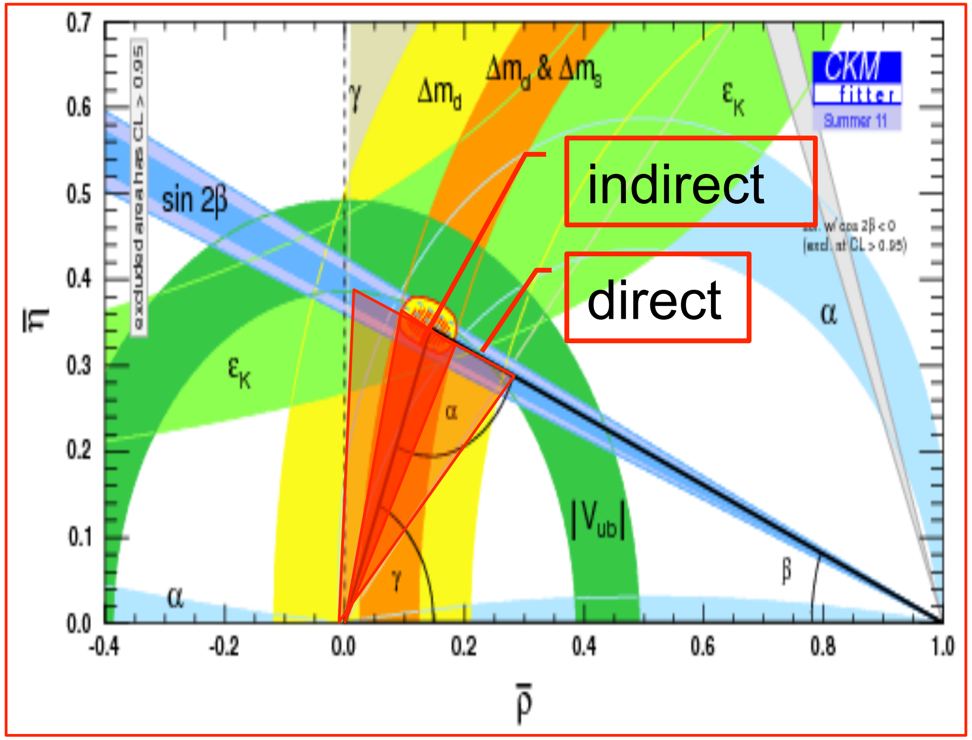
$$V=\begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1+A^2\lambda^4/2 \end{pmatrix}+O(\lambda^5)$$

$\arg V_{ub} \cong -\gamma$
$\arg V_{td} \cong -\beta$
$\arg V_{ts} \cong \beta_s+\pi$

$\beta_s \approx 1^\circ$ $\beta \approx 22^\circ$ $\gamma \approx 68^\circ$

LHCb, CP violation

- SM CPV arises in the weak decays of hadrons from a *single* phase in the quark mixing (CKM) matrix (testing the Yukawa couplings to the quarks).
- Necessary to generate **matter-antimatter asymmetry.** Size in the SM too small to account for observed baryon/photon ratio → new physics expected.
- Direct CPV measurements.
  - SM CPV precise determination.
  - γ poorly known: depends on b → u decays. Higher statistics at LHC.
  - B_s sector not explored in detail.
  - CP violation in charm.



$$V = \begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1+A^2\lambda^4/2 \end{pmatrix} + O(\lambda^5)$$

$\arg V_{ub} \cong -\gamma$
$\arg V_{td} \cong -\beta$
$\arg V_{ts} \cong \beta_s+\pi$

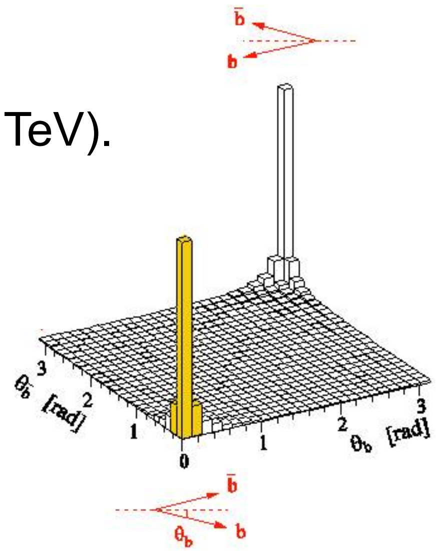
$\beta_s \approx 1^\circ \qquad \beta \approx 22^\circ \qquad \gamma \approx 68^\circ$

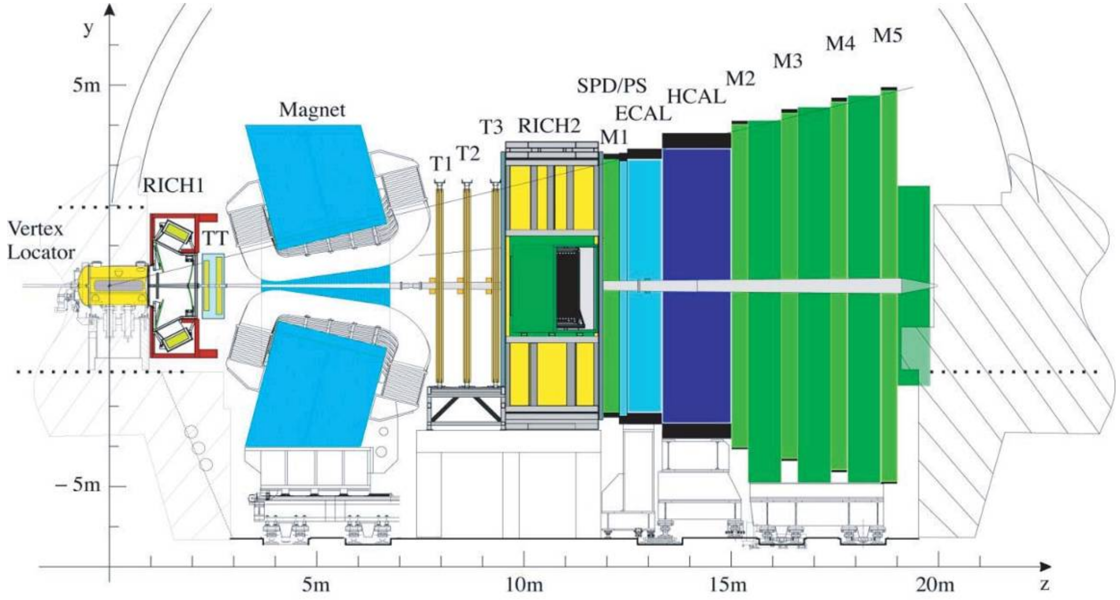
Spectrometer

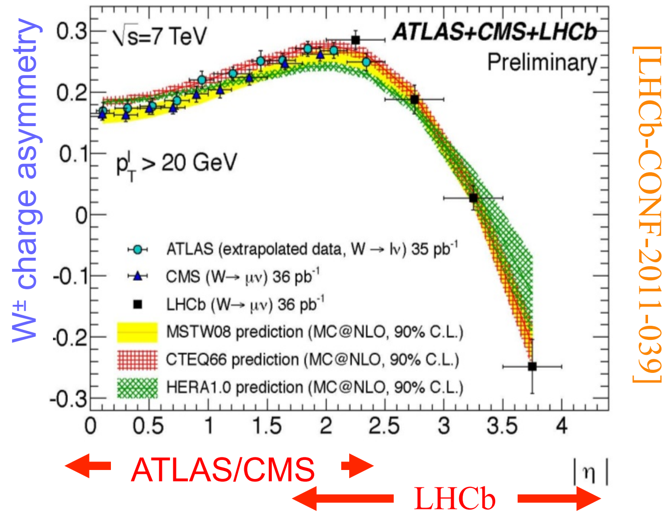
Spectrometer

- Low angle production → LHCb spectrometer design: forward (operating in collider mode).
- $b\bar{b}$ cross-section = 284 ± 53 μb at the LHC (pp collisions at √s = 7 TeV). [PLB **694** 209]

  ~ 100,000 $b\bar{b}$ pairs produced/second (10^4 × B factories)
  Charm production factor 20 higher! [CONF-2010-013]
- Warm dipole magnet. Polarity can be reversed.



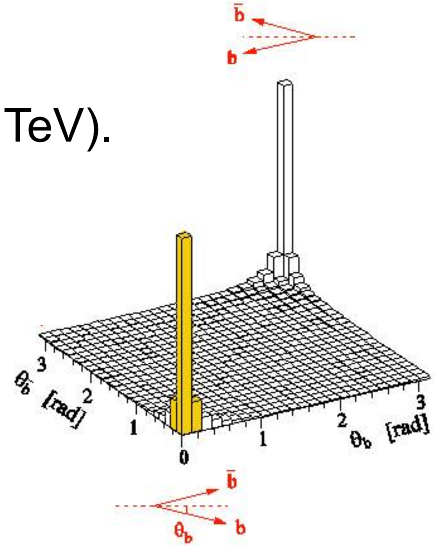


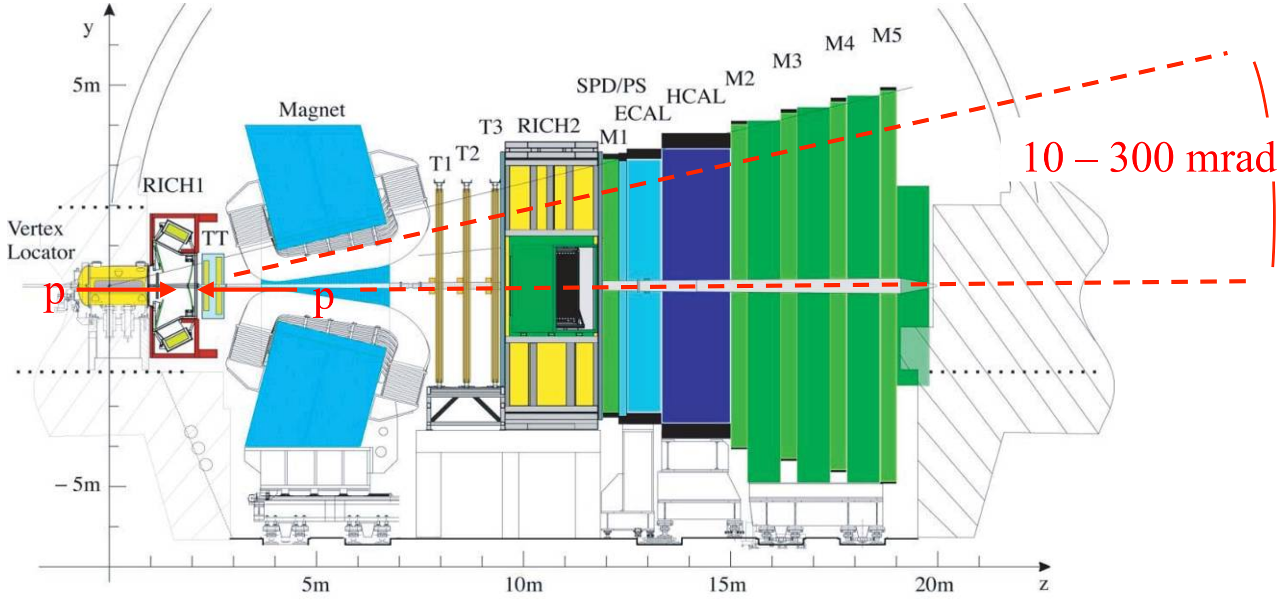


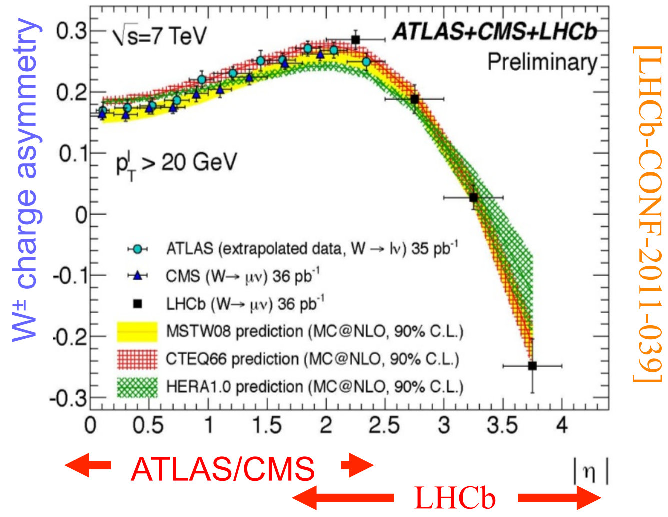
Spectrometer

- Low angle production → LHCb spectrometer design: forward (operating in collider mode).
- $b\bar{b}$ cross-section = 284 ± 53 μb at the LHC (pp collisions at $\sqrt{s}$ = 7 TeV). [PLB **694** 209]

  ~ 100,000 $b\bar{b}$ pairs produced/second (10^4 × B factories)
  Charm production factor 20 higher! [CONF-2010-013]
- Warm dipole magnet. Polarity can be reversed.

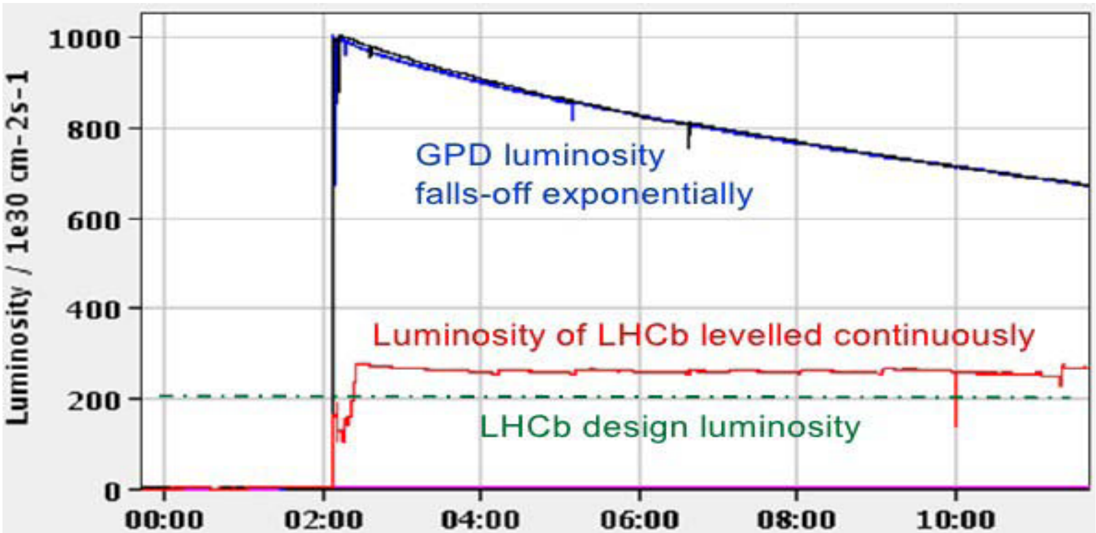


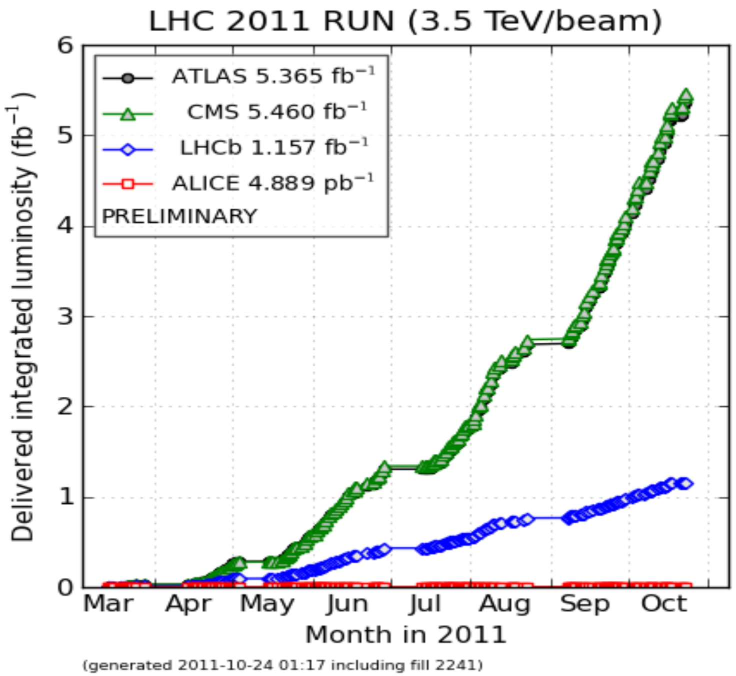




Data Taking

- Nominal luminosity = 2×10^{32} cm^{-2} s^{-1}. LHCb adapted to higher pileup (μ~2).
- Accumulated data in 2011: 1.1 fb^{-1} out of 1.22 fb^{-1}.
- Automatic adjustment of colliding beams offset: luminosity leveling.
- Sub-detectors all with > 98% active channels.
- Two level trigger. Rate reduction: 10 MHz input to 3 kHz. Event size ~35 kB.
- Data processing: Spanish TIER-2 center.

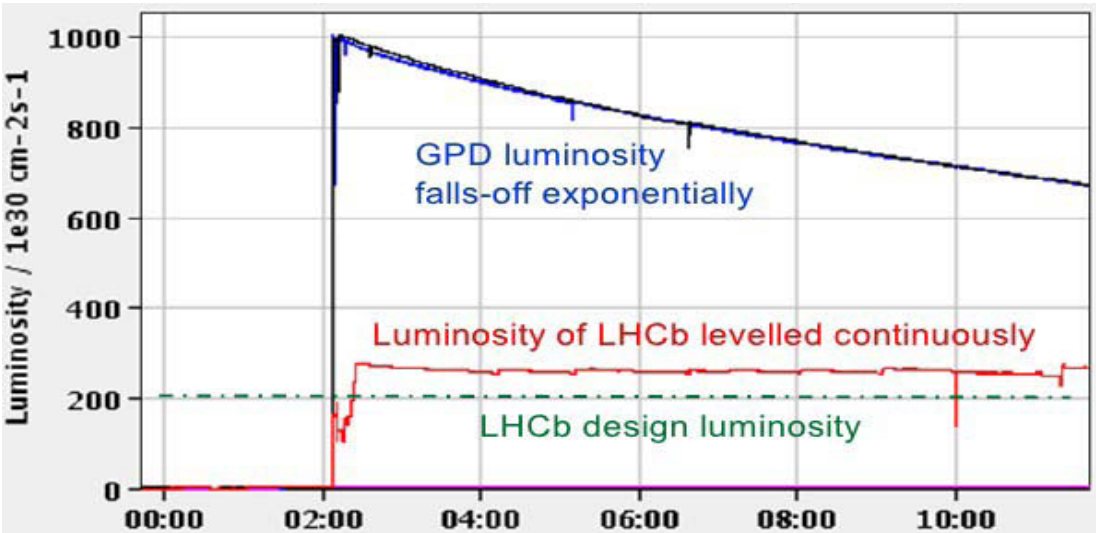


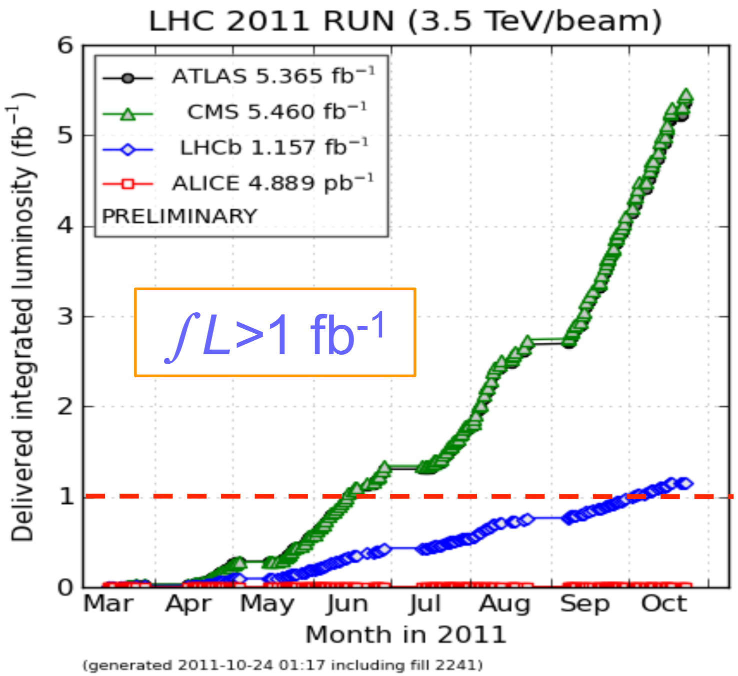


Cibrán Santamarina
U. Santiago de Compostela

Data Taking

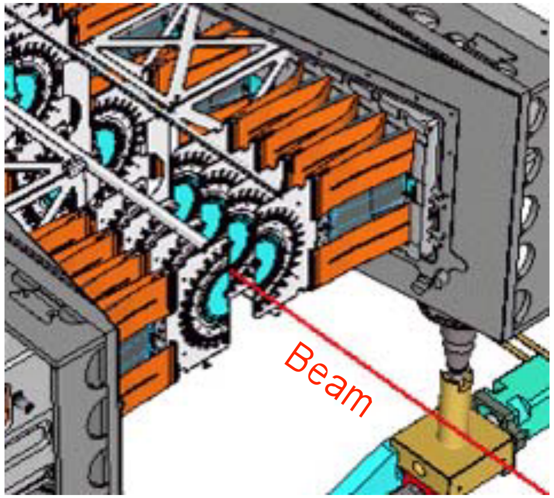
- Nominal luminosity = 2 × 10^{32} cm^{-2} s^{-1}. LHCb adapted to higher pileup (μ~2).
- Accumulated data in 2011: 1.1 fb^{-1} out of 1.22 fb^{-1}.
- Automatic adjustment of colliding beams offset: luminosity leveling.
- Sub-detectors all with > 98% active channels.
- Two level trigger. Rate reduction: 10 MHz input to 3 kHz. Event size ~35 kB.
- Data processing: GRID centers.

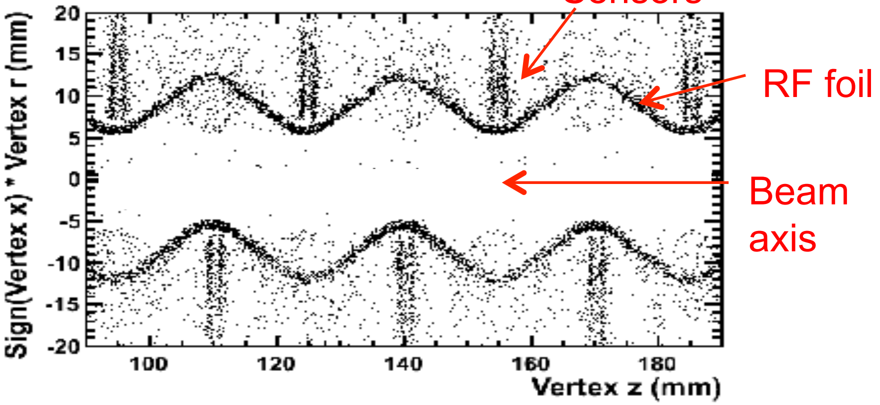




VELO

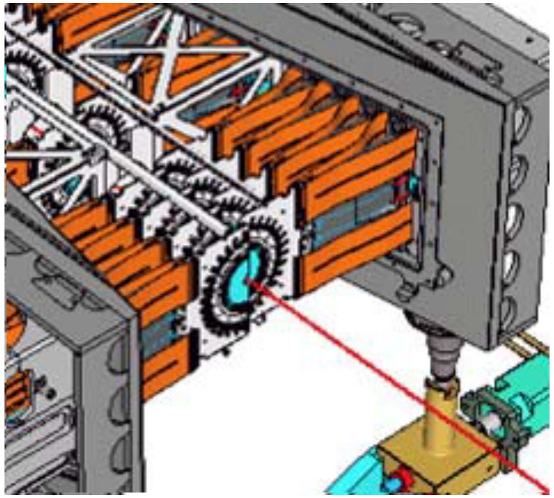
- **Vertex Locator** (VELO):
- Primary vertex and *B* decay vertices.
- 21 modules of back-to-back silicon sensor disks, *R*-ϕ strip geometry.
- Retracted for safety during beam injection.
- 300 μm-thick silicon, 2048 strips/sensor, 40 μm inner pitch.
- IP resolution=12 μm for high p_T tracks.
- For 25 track vertex: σ_x = 13 μm, σ_z = 70 μm.
- Proper-time resolution: **σ_t = 40 fs**. $B_s - \bar{B}_s$ oscillations measured.

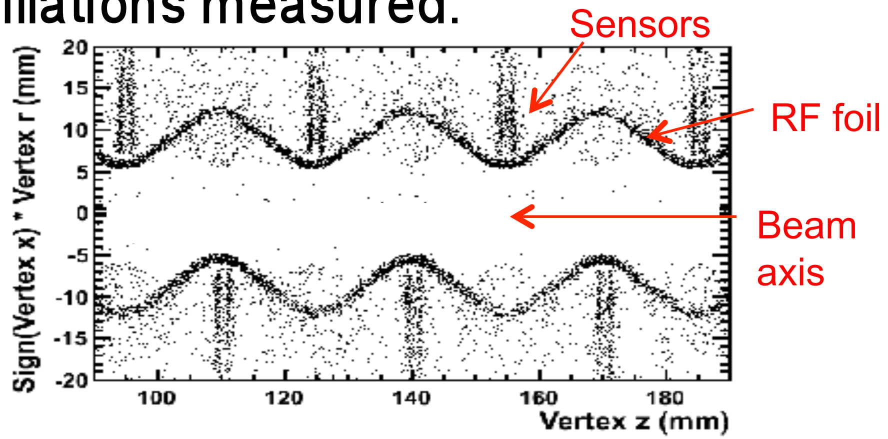




VELO

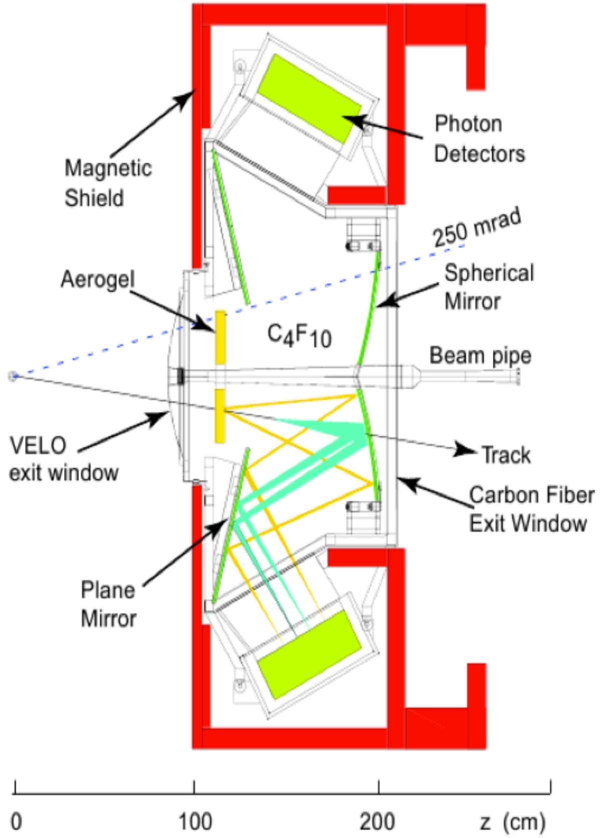
- **Vertex Locator** (VELO):
- Primary vertex and *B* decay vertices.
- 21 modules of back-to-back silicon sensor disks, *R*-ϕ strip geometry.
- Retracted for safety during beam injection.
- 300 μm-thick silicon, 2048 strips/sensor, 40 μm inner pitch.
- IP resolution=12 μm for high p_T tracks.
- For 25 track vertex: σ_x = 13 μm, σ_z = 70 μm.
- Proper-time resolution: **σ_t = 40 fs**. $B_s - \bar{B}_s$ oscillations measured.





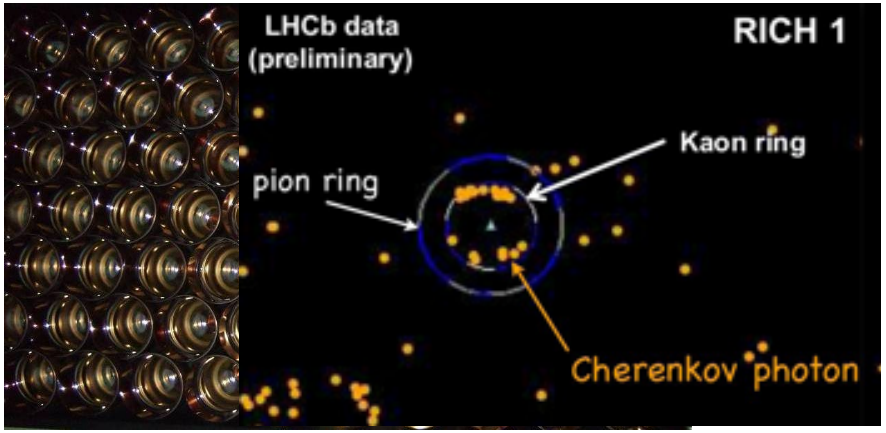
PID

- Charged particles identified with two Ring-imaging Cherenkov detectors covering $2 < p < 100$ GeV/c.
- High efficiency and Low noise Hybrid Photon Detectors (HPDs):
  500 tubes each with 1024 pixels.
- Cherenkov angle resolution 0.66 mrad per photon (in RICH 2).
- Kaon id efficiency > 90% for pion misid < 5% over a large p range.
- Muon system: 5 layers of detectors.
- μ ID eff. ~ 97% for $\pi \rightarrow \mu$ misID rate ~ 1%.

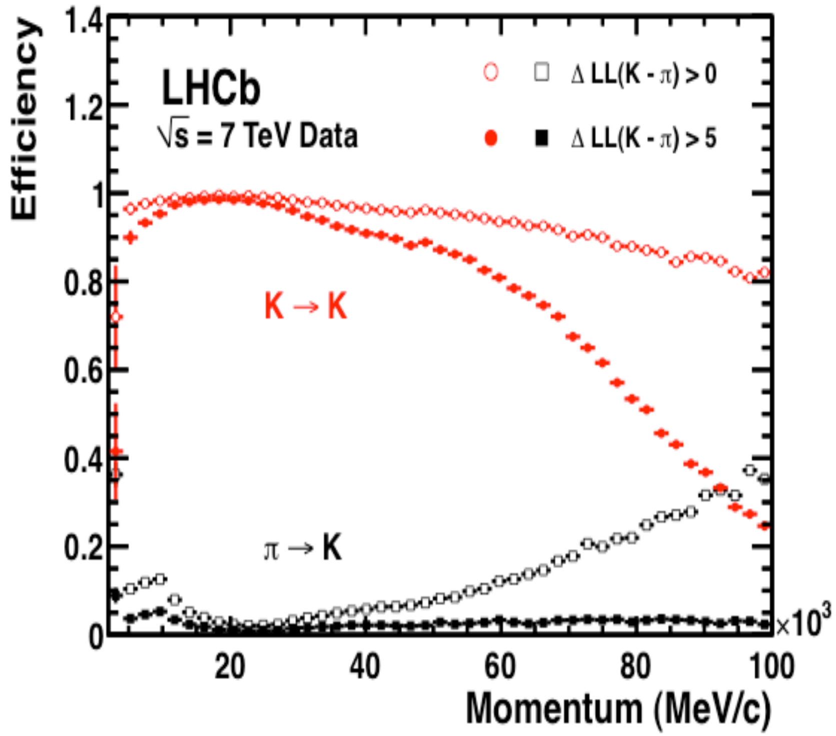


PID

- Charged particles identified with two Ring-imaging Cherenkov detectors covering $2 < p < 100$ GeV/c.
- High efficiency and Low noise Hybrid Photon Detectors (HPDs): 500 tubes each with 1024 pixels.
- Cherenkov angle resolution 0.66 mrad per photon (in RICH 2).
- Kaon id efficiency > 90% for pion misid < 5% over a large p range.
- Muon system: 5 layers of detectors.
- μ ID eff. ~ 97% for $\pi \rightarrow \mu$ misID rate ~ 1%.



Data

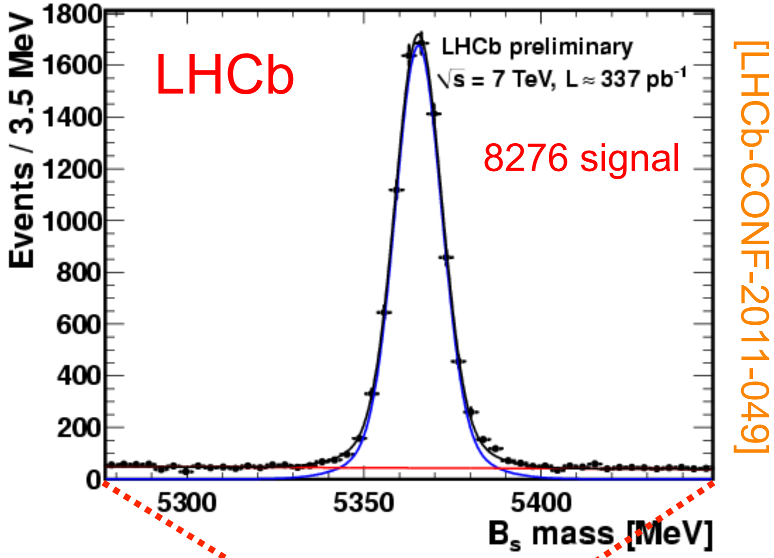


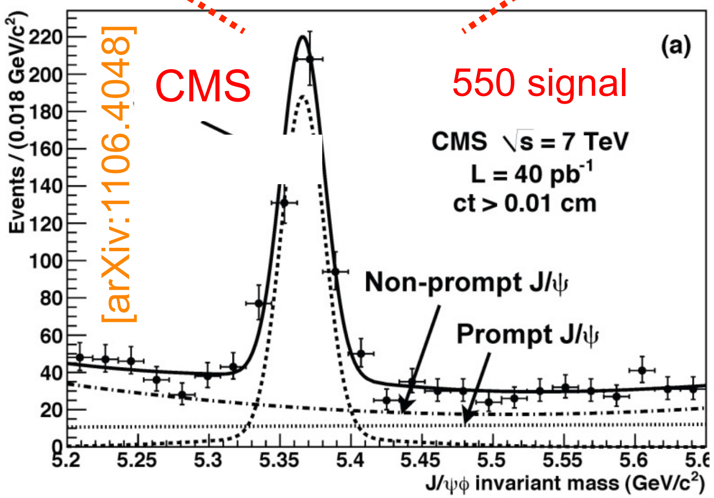
Tracker

- **TT** and **Inner Tracker**: silicon microstrips ~ 200 m pitch. 12 m^2 of silicon 4 layers with (0º, +5º,-5º, 0º) stereo angle.
- **Outer Tracker**: drift chamber with 5 mm diameter straws gas $Ar/CO_2/O_2$ (70:28.5:1.5).
- Resolution: **$\Delta p/p$ = 0.4–0.8% (2–100 GeV/c)**.
- $B_s \to J/\psi\, \phi$ selection ($J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$): **$\sigma(m_B)$ = 7 MeV/c^2 (LHCb).**

  ~ 20 MeV/c^2 (ATLAS/CMS)

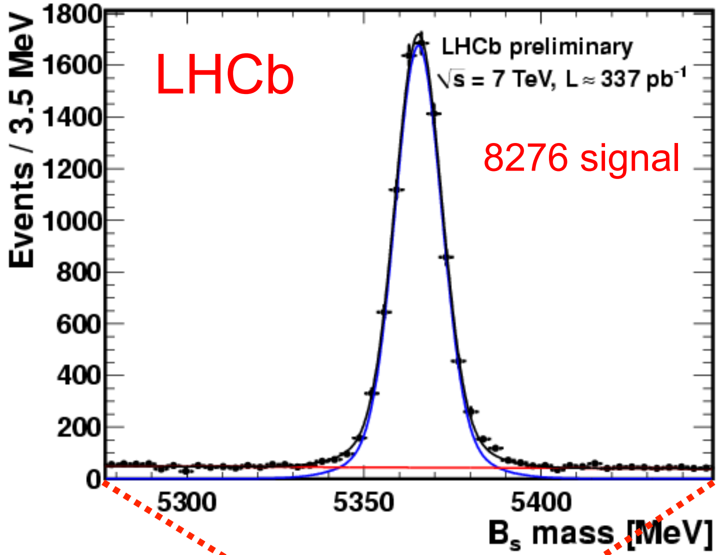
  yields/pb^{-1} and S/B lower.



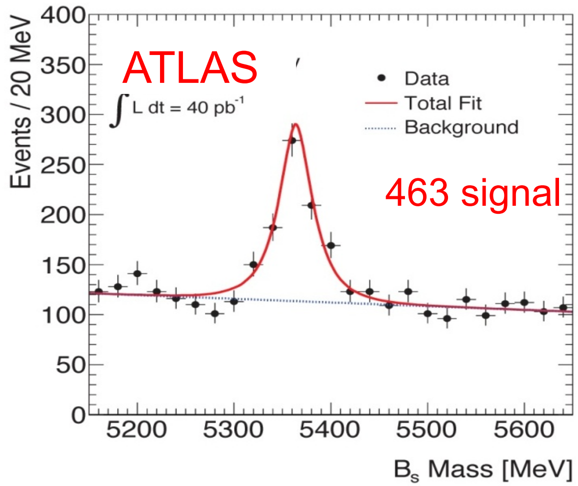


Tracker

USC



[LHCb-CONF-2011-049]



[ATLAS-CONF-2011-092]

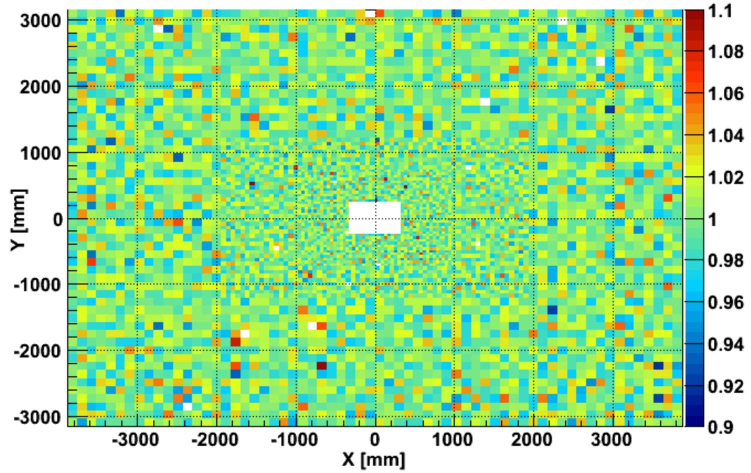
- **TT** and **Inner Tracker**: silicon microstrips ~ 200 m pitch. 12 m^2 of silicon 4 layers with (0º, +5º,-5º, 0º) stereo angle.
- **Outer Tracker**: drift chamber with 5 mm diameter straws gas $Ar/CO_2/O_2$ (70:28.5:1.5).
- Resolution: **Δ p/p = 0.4–0.8% (2–100 GeV/c)**.
- $B_s \to J/\psi\,\phi$ selection ($J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$):
  $\sigma(m_B)$ = 7 MeV/c^2 (LHCb).
  ~ 20 MeV/c^2 (ATLAS/CMS)
  yields/pb^{-1} and S/B lower.

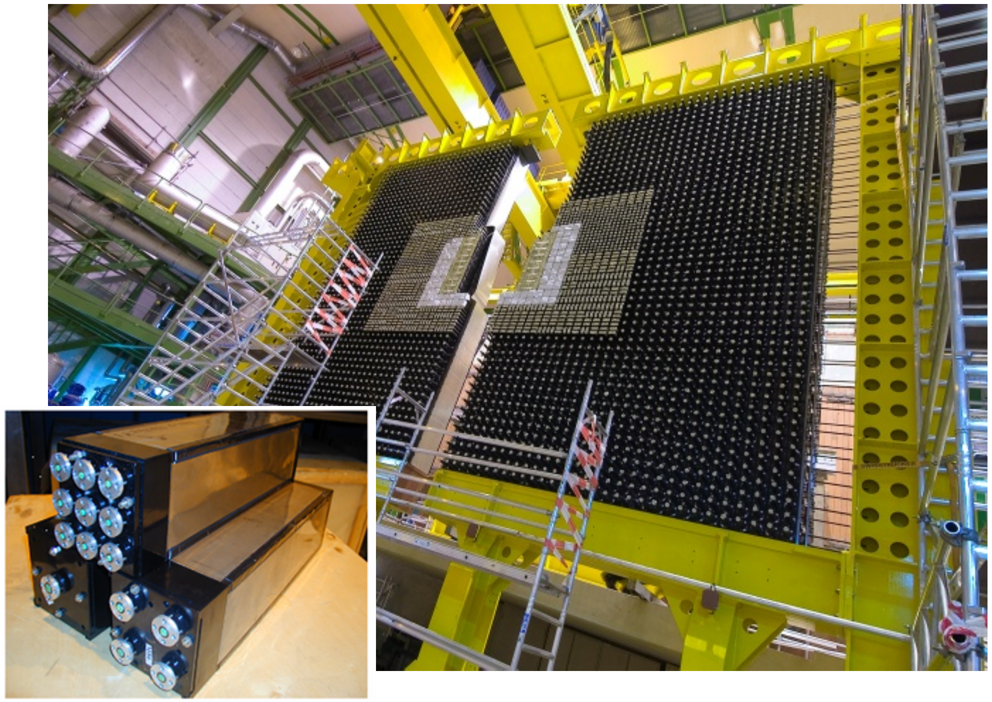
Calorimeters

- SPD: improves multi-interaction performance.
- ECAL: Shashlik Pb-scintillator $\sigma(E)/E = 10\% / \sqrt{E} \oplus 1\%$.
- HCAL: Tile Fe-scintillator $\sigma(E)/E = 80\% / \sqrt{E} \oplus 10\%$.

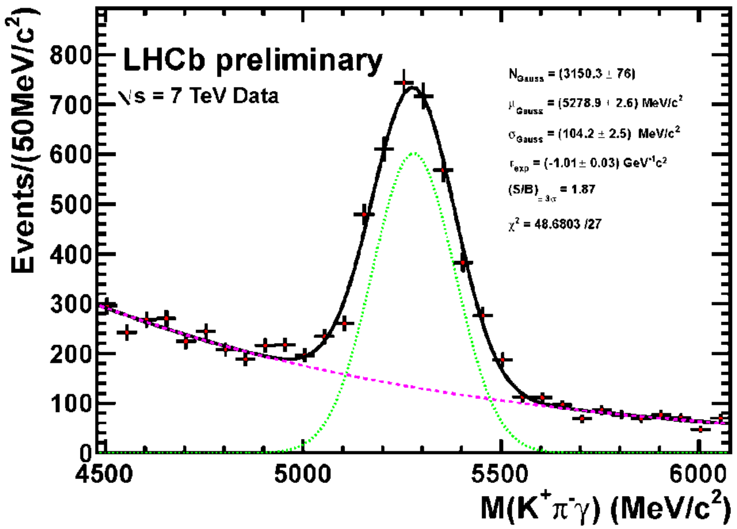
UB

Energy flow





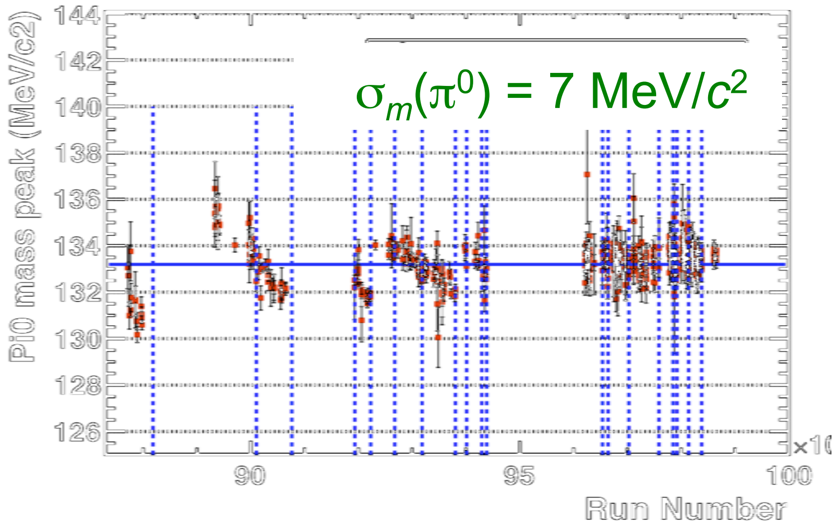
$B^0 \rightarrow K^* \gamma$ (σ_m = 104 MeV/c^2)

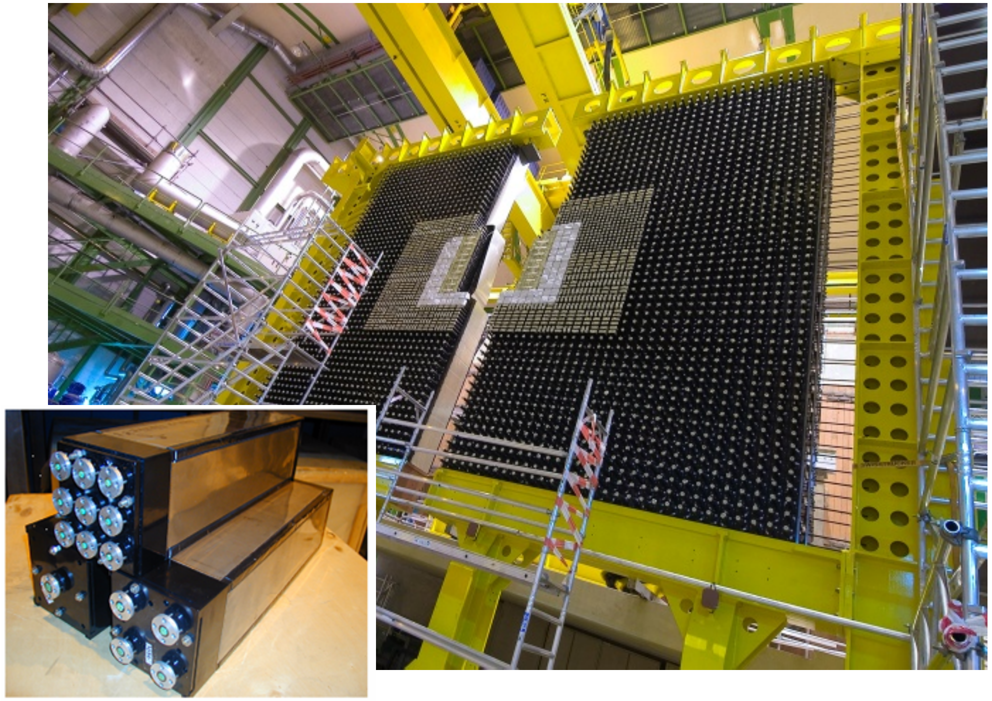


Calorimeters

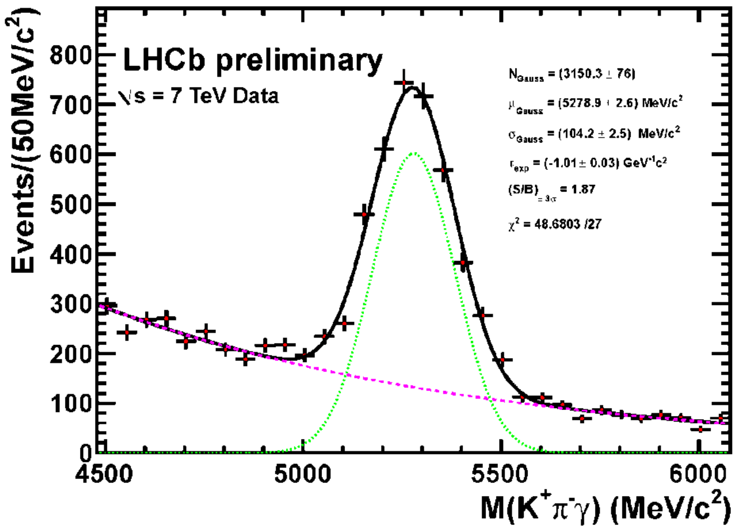
- SPD: improves multi-interaction performance.
- ECAL: Shashlik Pb-scintillator $\sigma(E)/E = 10\% /\sqrt{E} \oplus 1\%$.
- HCAL: Tile Fe-scintillator $\sigma(E)/E = 80\% /\sqrt{E} \oplus 10\%$.

UB





$B^0 \to K^* \gamma$ (σ_m = 104 MeV/c^2)



Physics Results

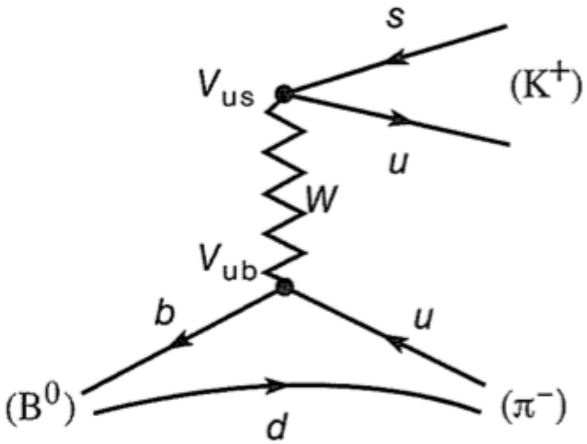
Direct CP Violation in Decays

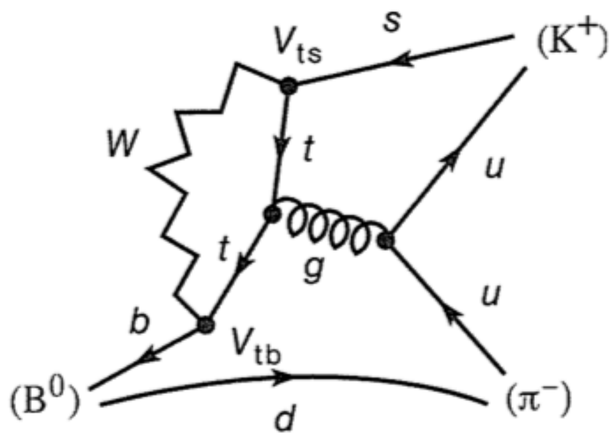
•Complex Amplitudes: interference produces different effect in particle and antiparticle.

•Decays with Tree and Penguin contributions: interference between two diagrams.

$$A_1 = |A_1| e^{i\phi_1} e^{i\theta_1}$$
$$\bar{A}_1 = |A_1| e^{i\phi_1} e^{-i\theta_1}$$

$$A_2 = |A_2| e^{i\phi_2} e^{i\theta_2}$$
$$\bar{A}_2 = |A_2| e^{i\phi_2} e^{-i\theta_2}$$

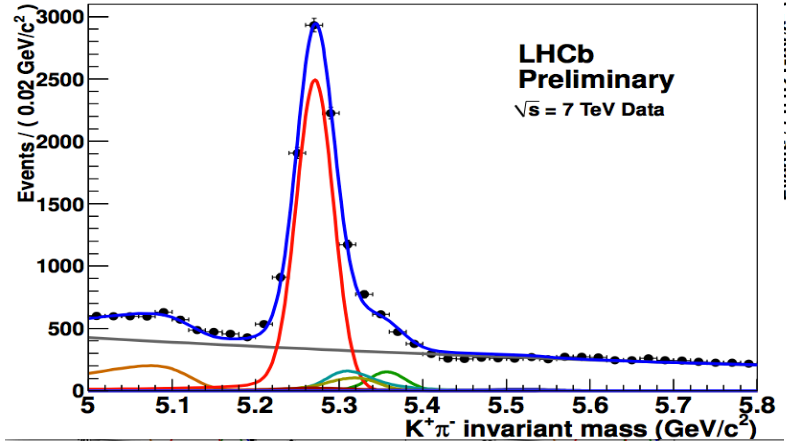


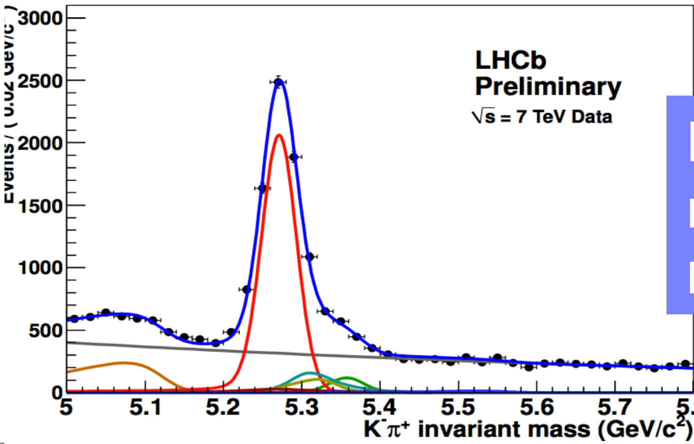


$$|A_1 + A_2|^2 - |\bar{A}_1 + \bar{A}_2|^2 = -4|A_1||A_2| \sin(\phi_1 - \phi_2) \sin(\theta_1 - \theta_2)$$

Direct CP Violation in Decays (2)

LHCb-CONF-2011-042

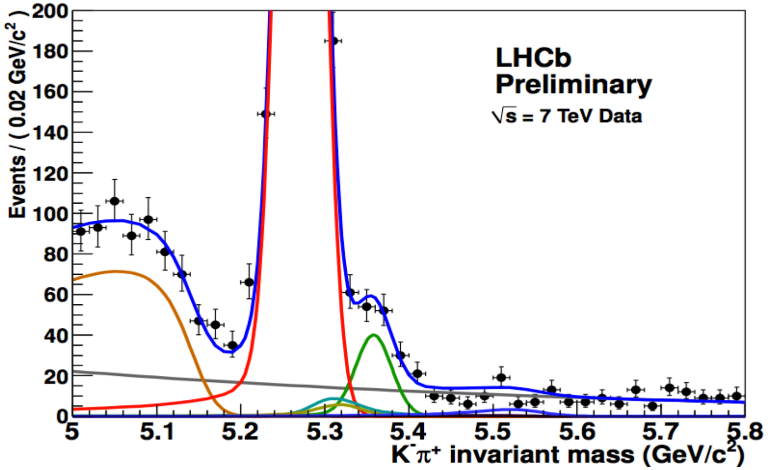


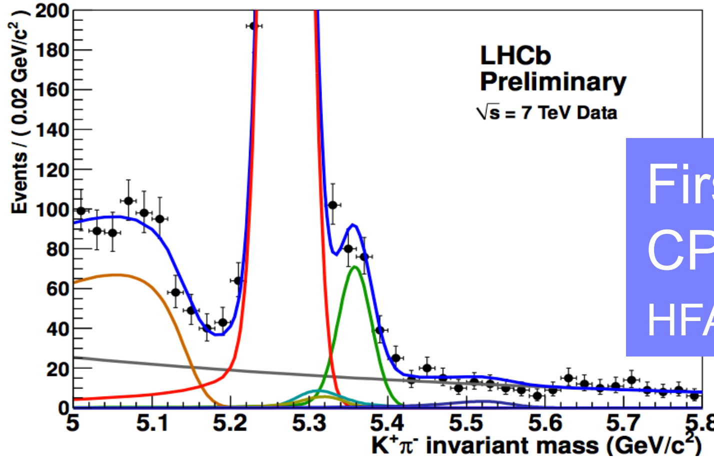


Most precise single measurement!

HFAG: -0.098 ± 0.013

$$A_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)} = -0.088 \pm 0.011 \pm 0.0008$$





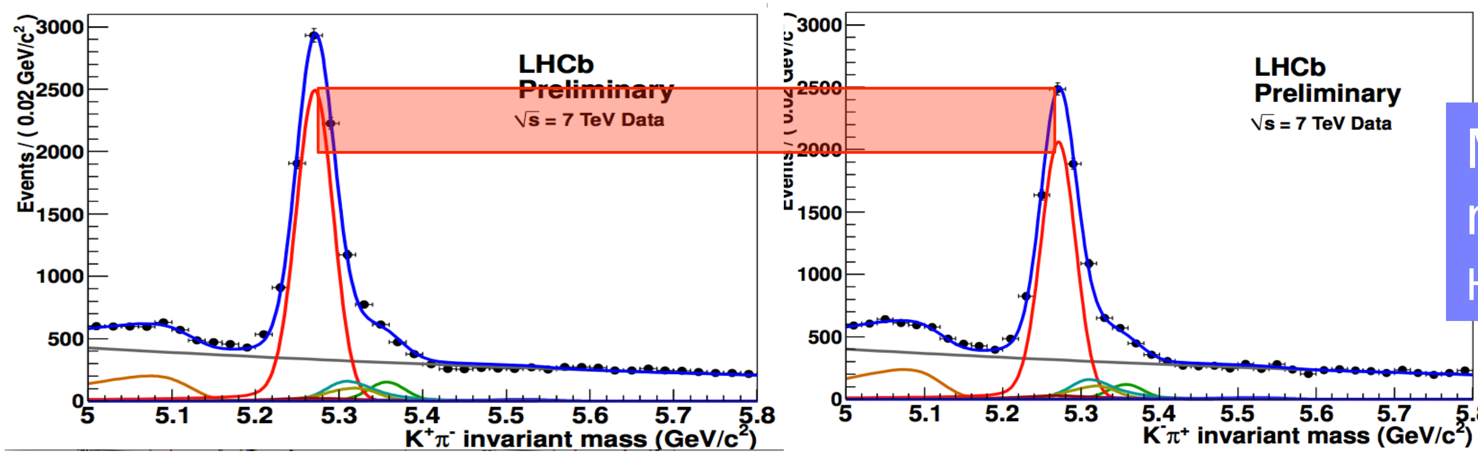
First Evidence of CPV in B_s!

HFAG: 0.39 ± 0.17

$$A_{CP}(B_s^0 \to \pi K) = \frac{\Gamma(\bar{B}_s^0 \to \pi^- K+) - \Gamma(B_s^0 \to \pi^+ K^-)}{\Gamma(\bar{B}_s^0 \to \pi^- K^+) + \Gamma(B_s^0 \to \pi^+ K^-)} = 0.27 \pm 0.08 \pm 0.02$$

Direct CP Violation in Decays (2)

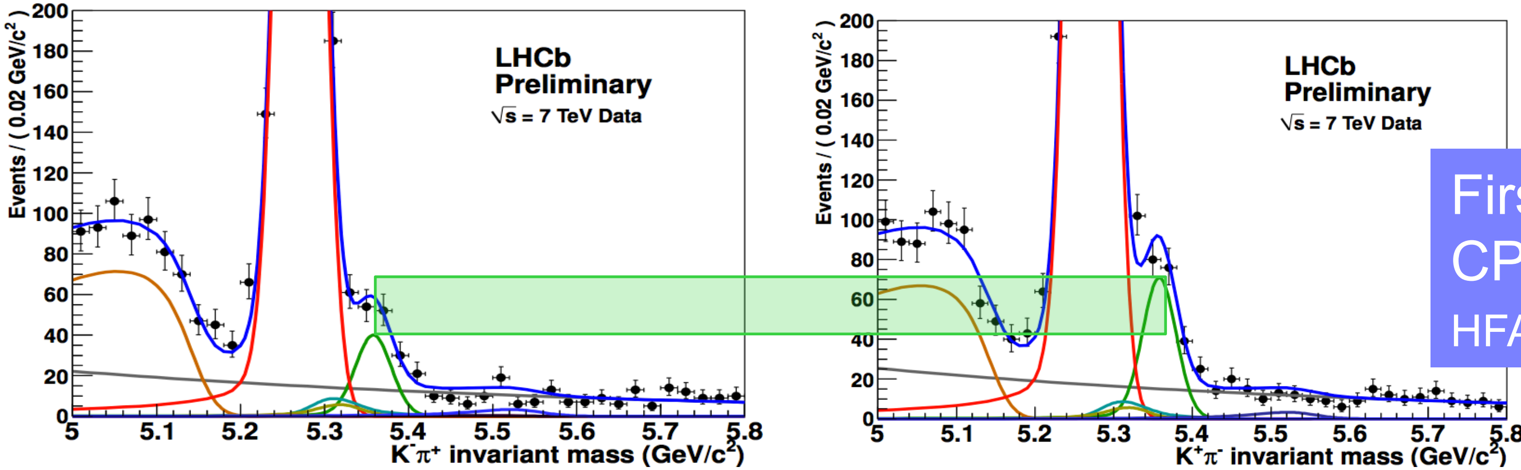
LHCb-CONF-2011-042



Most precise single measurement!

HFAG: -0.098 ± 0.013

$$A_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)} = -0.088 \pm 0.011 \pm 0.0008$$



First Evidence of CPV in B_s!

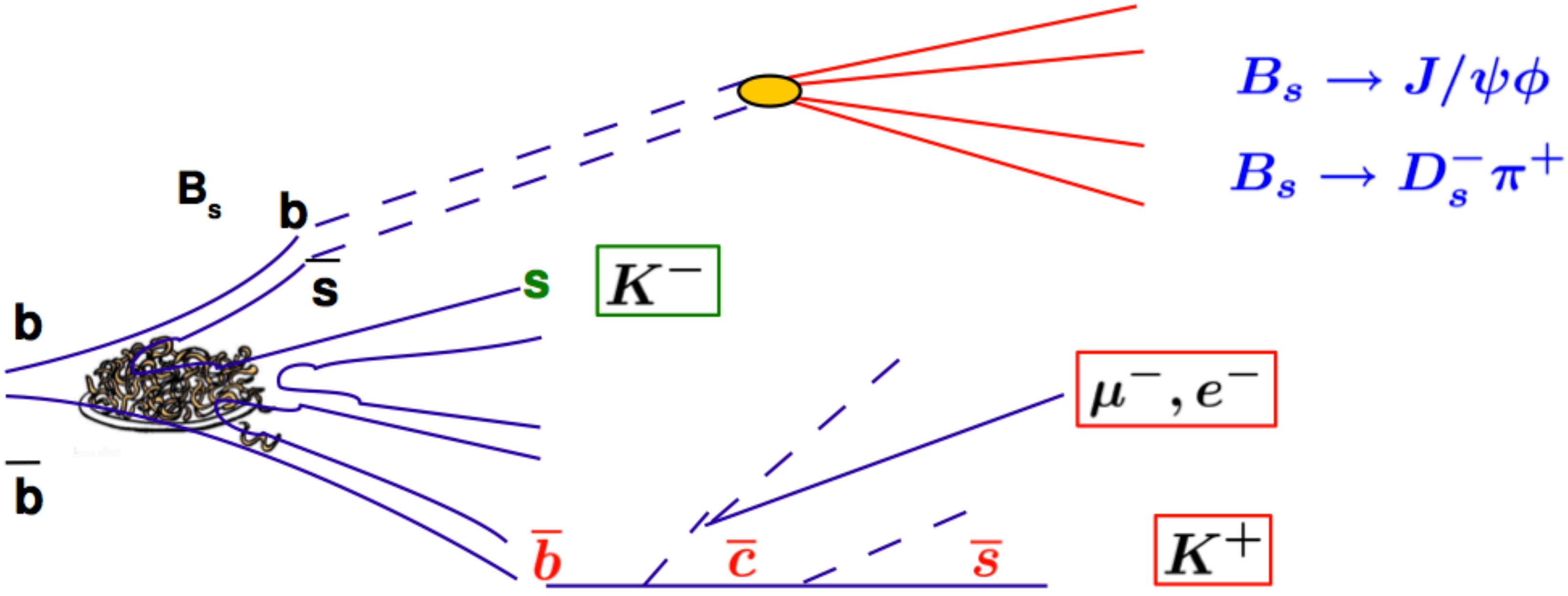
HFAG: 0.39 ± 0.17

$$A_{CP}(B_s^0 \to \pi K) = \frac{\Gamma(\bar{B}_s^0 \to \pi^- K+) - \Gamma(B_s^0 \to \pi^+ K^-)}{\Gamma(\bar{B}_s^0 \to \pi^- K^+) + \Gamma(B_s^0 \to \pi^+ K^-)} = 0.27 \pm 0.08 \pm 0.02$$

Tagging

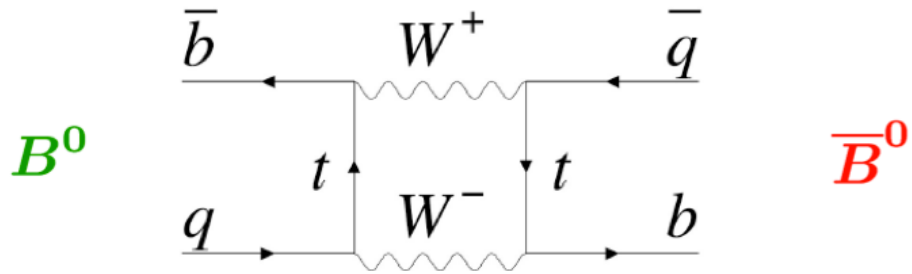
- Tagging of production flavor (B or $\bar{B}$) important for mixing and CP analyses.
- Performance calibrated using control channels such as $B^+ \to J/\psi K^+$.
- Tagging power: $\varepsilon(1-w)^2 = (3.2 \pm 0.8)\ \%$ (Opposite Side).
  $(1.3 \pm 0.4)\ \%$ (Same Side).

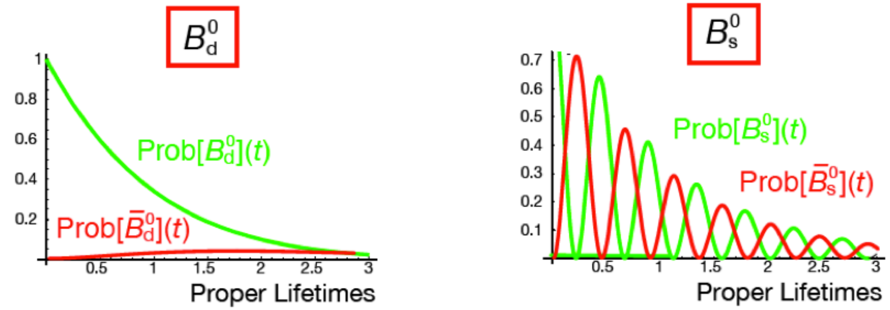
determined with B_s mixing.

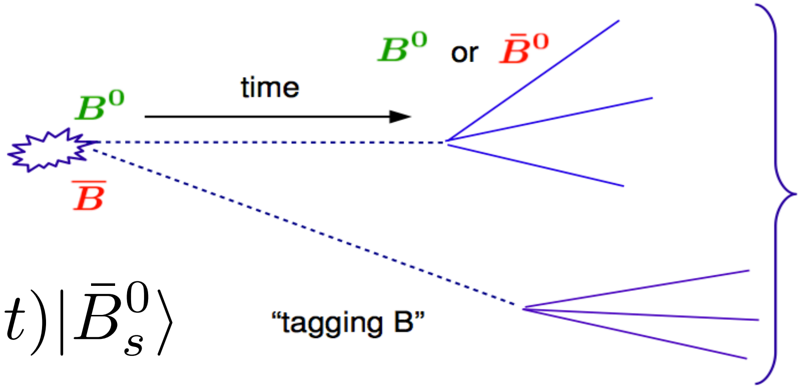


Oscillations

- Flavor eigenstates ≠ mass eigenstates.
- Matter-antimatter oscillations.
- Frequency: mass eigenvalues difference.
- Sensitivity to NP.
- Requires tagging.







"signal B"

"tagging B"	B^0	$\overline{B}^0$
B	mixed	unmixed
$\overline{B}$	unmixed	mixed

$$|\Psi(t)\rangle = a(t)|B_s^0\rangle + b(t)|\bar{B}_s^0\rangle$$

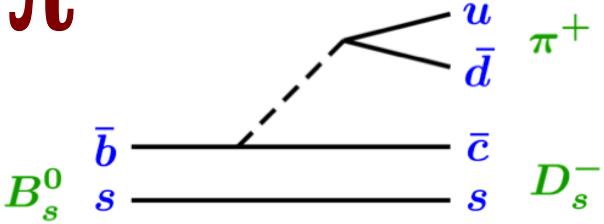
$$i\frac{d}{dt}\begin{pmatrix} a(t) \\ b(t) \end{pmatrix} = \left[\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21} & \Gamma_{22} \end{pmatrix}\right]\begin{pmatrix} a(t) \\ b(t) \end{pmatrix}$$

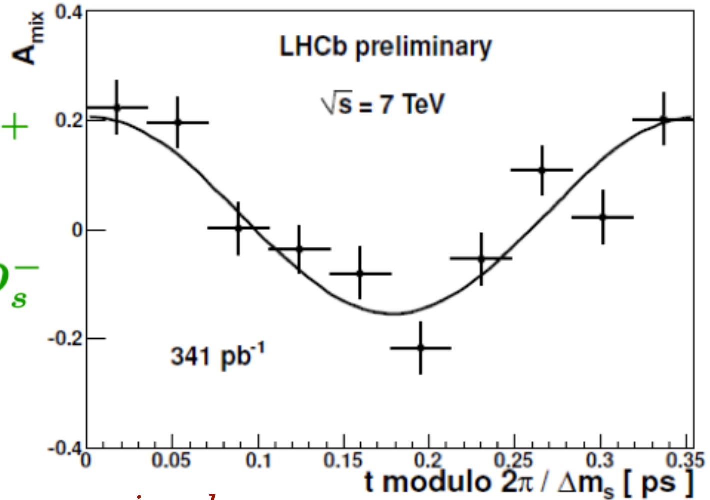
$$\mathbf{M}|B_L^0\rangle = M_L|B_L^0\rangle$$

$$\mathbf{M}|B_H^0\rangle = M_H|B_H^0\rangle$$

$|B^0_{L,H}\rangle$ have also definite decay widths: $\Gamma_{L,H}$

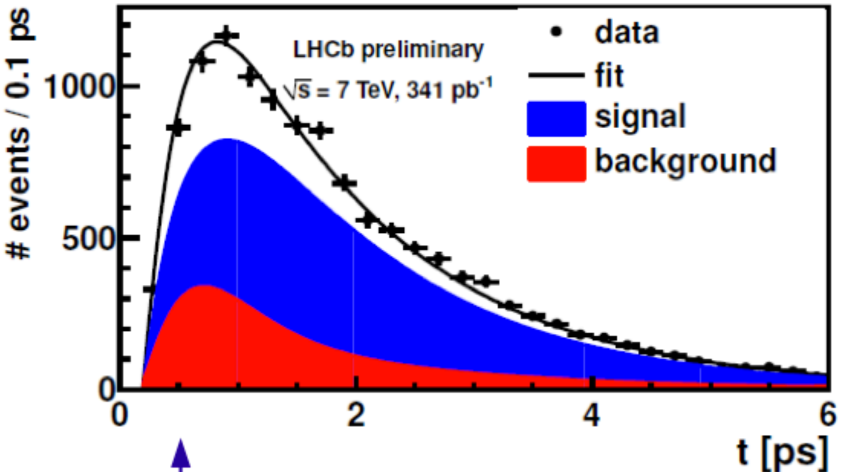
$B_s^0 \rightarrow D_s^- \pi^+$

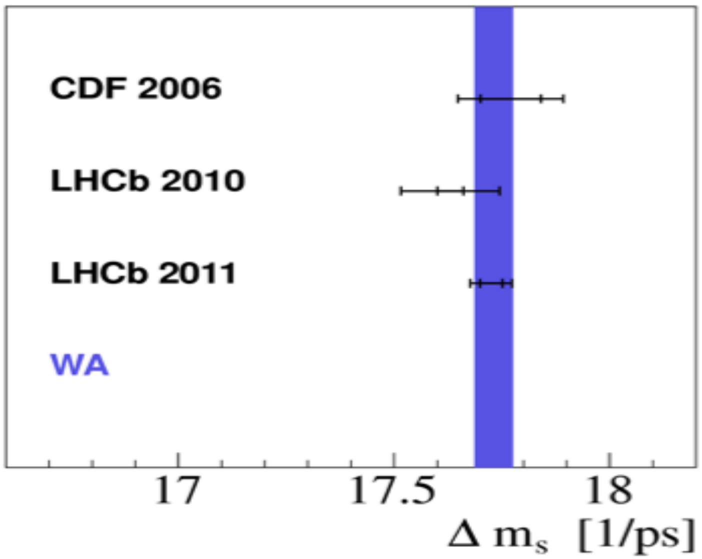




- Easily accessible: event selection based on Kaon ID (RICH), track impact parameters, vertex χ^2.
- Event yield in ~340/pb.

$$A^{mix}(t) = \frac{N^{unmixed} - N^{mixed}}{N^{unmixed} + N^{mixed}} = \cos(\Delta m t)$$



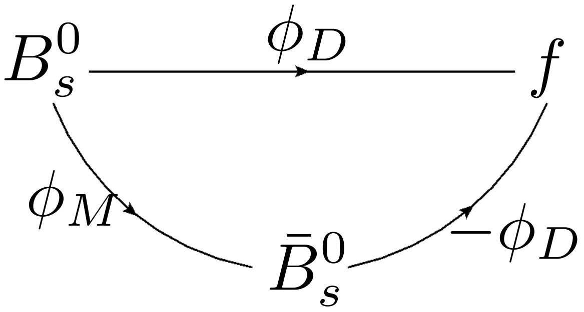


- Preliminary result: [LHCb-CONF-2011-050]

$$\Delta m_s = (17.725 \pm 0.041 \pm 0.026) ps^{-1} \qquad \Delta m_s^{SM} = (16.8^{+2.6}_{-1.5}) ps^{-1}$$

Indirect CP Violation

- Interference: direct decay and decay after oscillation.
- Decay into a final state $|f\rangle$.
- Oscillations between the meson and the anti-meson.
- Two possible ways of accessing the final state with a relative phase.



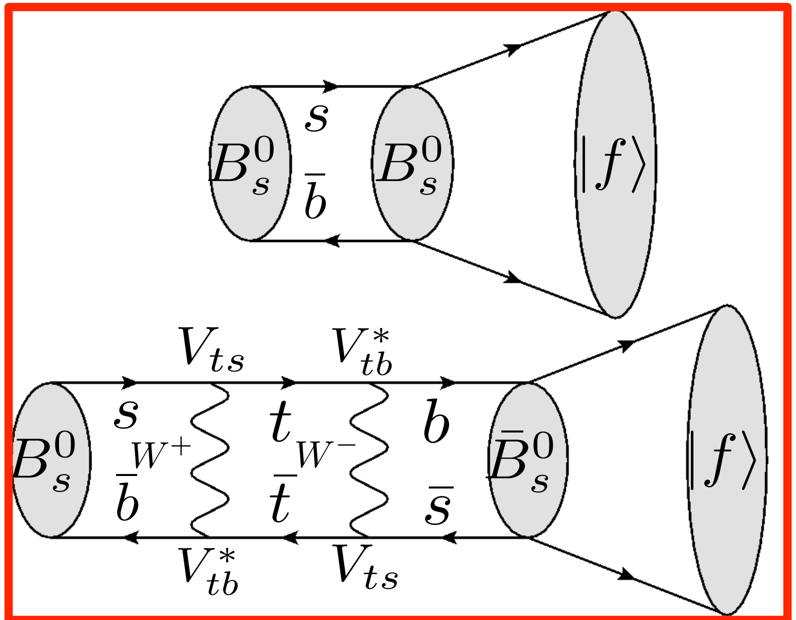
$$\phi_M \simeq 2\arg(V_{ts}V_{tb}^*)$$

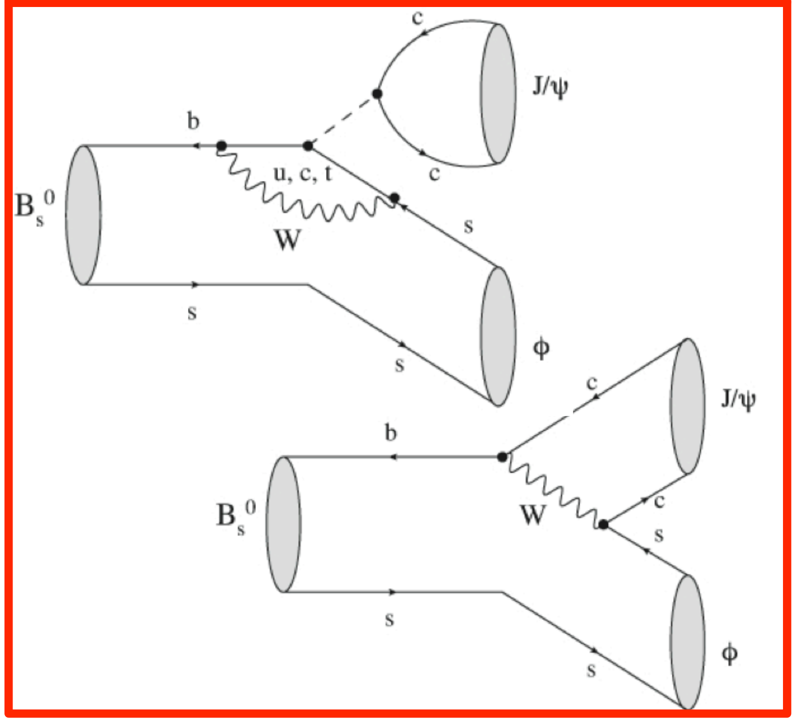
$$\phi_s = \phi_M - 2\phi_D$$

$$\phi_s^{J/\psi\phi,SM} \simeq 0.0368 \pm 0.0017\, rad$$

$$\phi_s = \phi_s^{SM} + \phi_s^{\Delta}$$

- Deviation of the SM implies New Physics.
- Events: time oscillation depending on ϕ_s.
- Requires tagging.

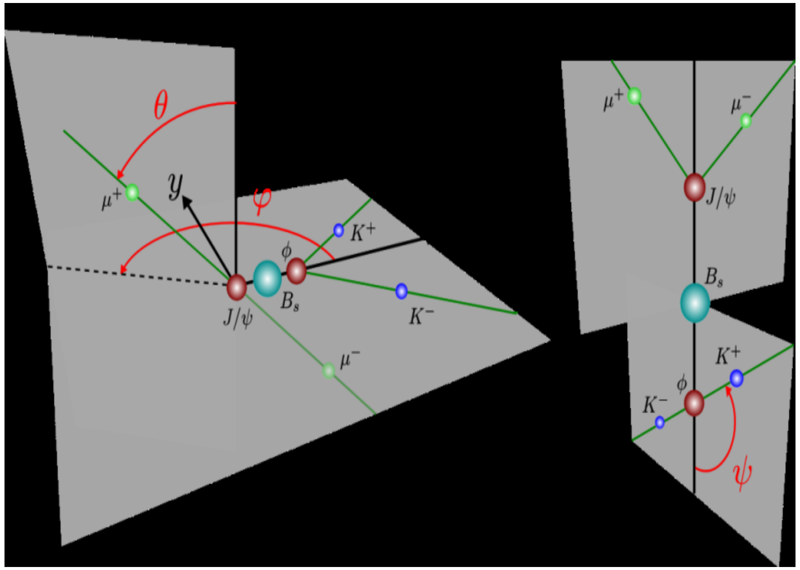


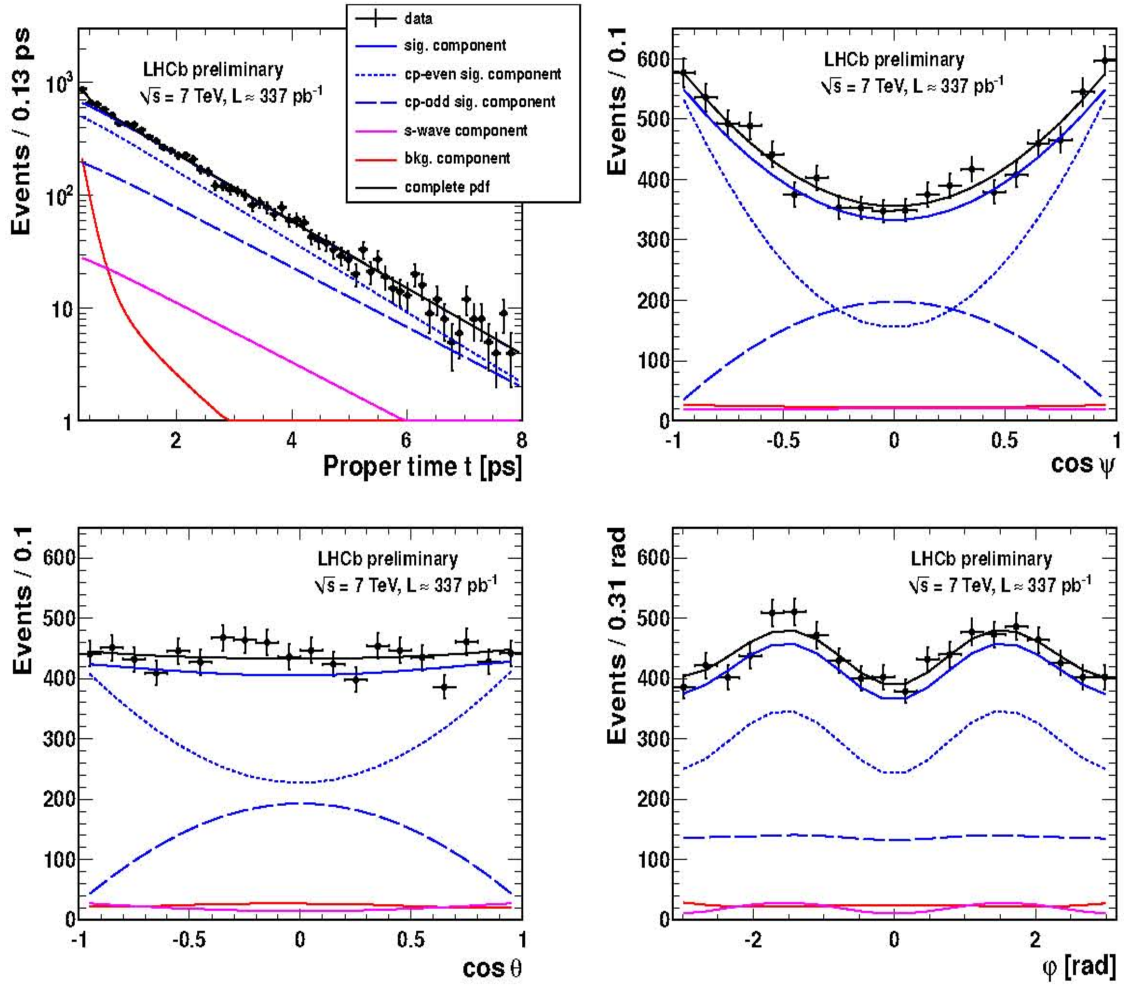


ϕ_s in $B_s^0 \to J/\psi\phi$

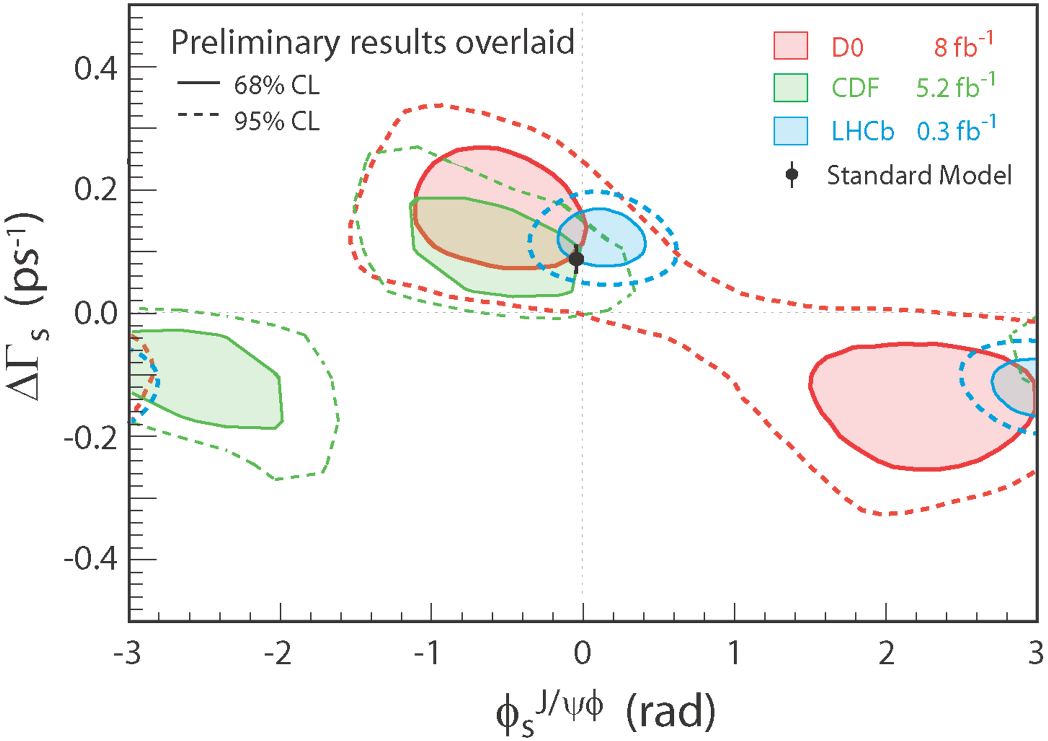
- First Tevatron measurements: indicated large values of ϕ_s.
- Discrepancies with SM: almost 3σ.
- VV final state: mixture of CP-odd and CP-even components.
- Separated using an angular analysis.

[LHCb-CONF-2011-049]





ϕ_s in $B_s^0 \rightarrow J/\psi\phi$



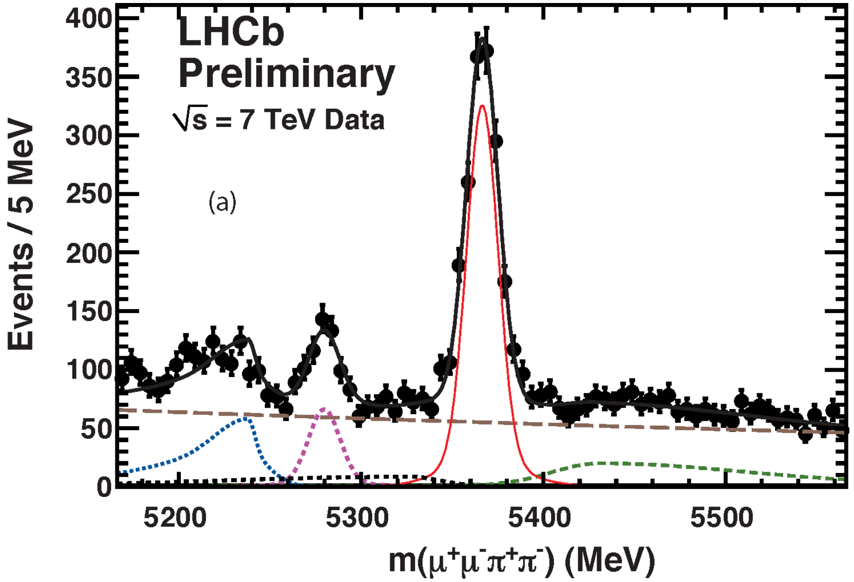
- Results correlated with $\Delta\Gamma_s$, width difference of the B_s mass eigenstates.
- Contours in (ϕ_s vs $\Delta\Gamma_s$) plane.
- Ambiguous solution: ($\phi_s \rightarrow \pi - \phi_s$, $\Delta\Gamma_s \rightarrow -\Delta\Gamma_s$).
- LHCb: consistent with SM.
- First significant direct measurement: $\Delta\Gamma_s = 0.123 \pm 0.029 \pm 0.008\ ps^{-1}$.

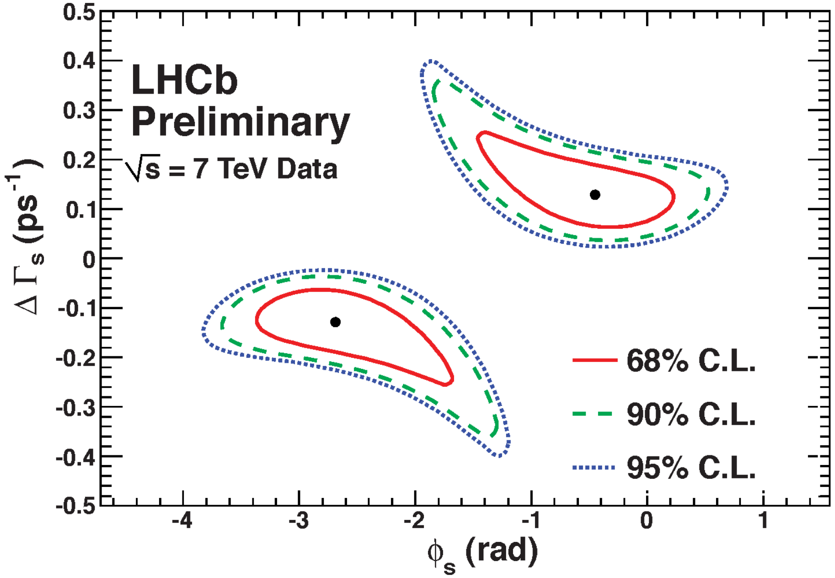
$$\Gamma(B_q \rightarrow f) = |A_f|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \eta_f \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \eta_f \sin\phi_s \sin(\Delta m_s t)\right],$$

$$\Gamma(\overline{B}_q \rightarrow f) = |A_f|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \eta_f \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - \eta_f \sin\phi_s \sin(\Delta m_s t)\right].$$

$$\boxed{\begin{aligned} \phi_s^{J/\psi\phi,SM} &\simeq 0.0368 \pm 0.0017\ rad \\ \phi_s^{J/\psi\phi} &= 0.13 \pm 0.18 \pm 0.07\ rad \end{aligned}}$$

ϕ_s in $B_s^0 \to J/\psi\ f_0(980)(\to \pi\pi)$



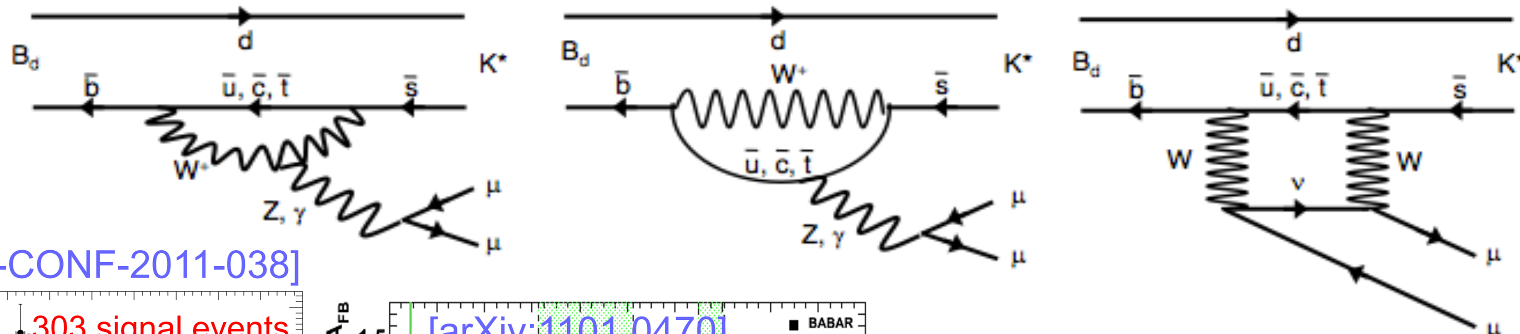


- Discovered by LHCb in February.
- Promptly confirmed by Belle and CDF.
- 378 pb^{-1}.
- Flavor tagging based on decay of the other b-hadron: efficiency=2.13%.
- Time dependent fit of the data:

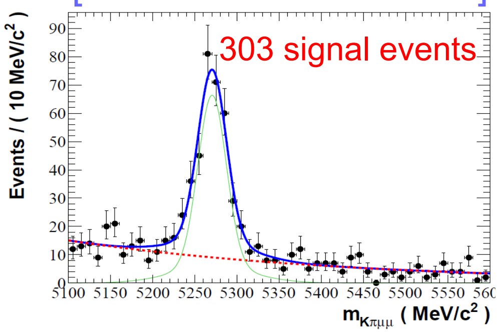
$$\phi_s^{J/\psi f} = -0.44 \pm 0.44 \pm 0.02\ rad$$

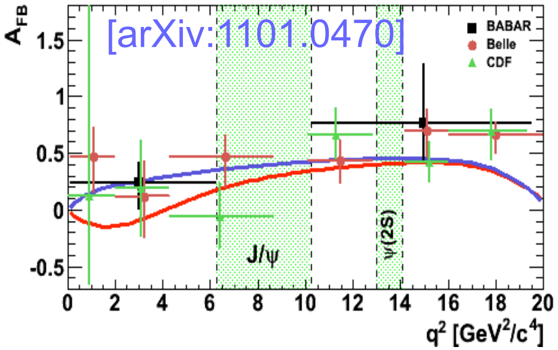
$$\phi_s^{J/\psi\phi + J/\psi f} = 0.03 \pm 0.16 \pm 0.07\ rad$$

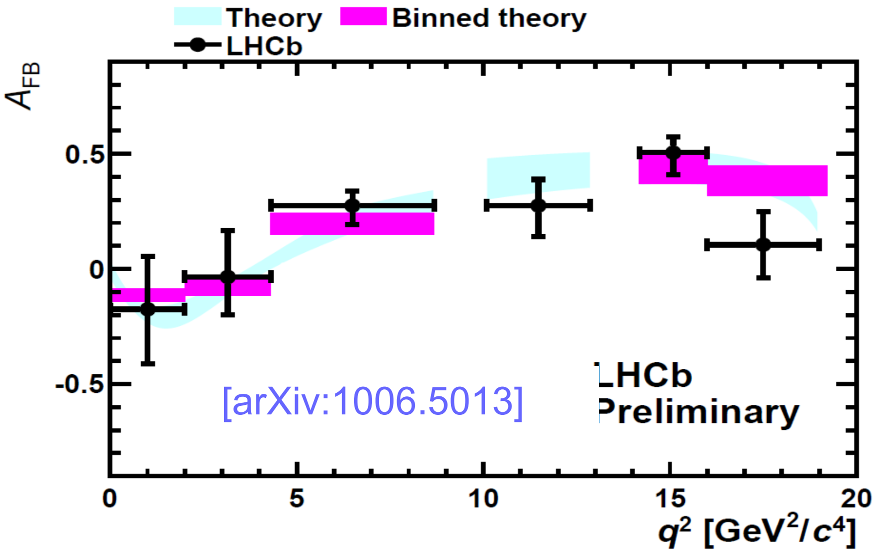
$B^0 \to K^*\mu^+\mu^-$



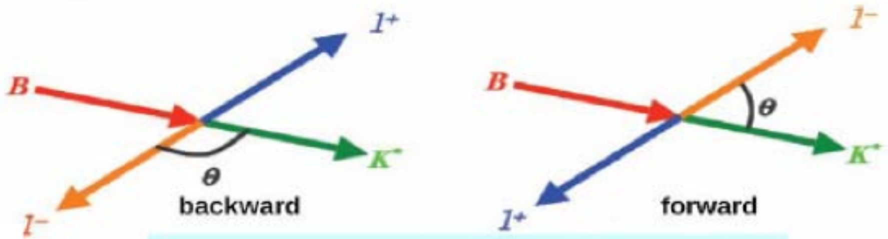
[LHCb-CONF-2011-038]





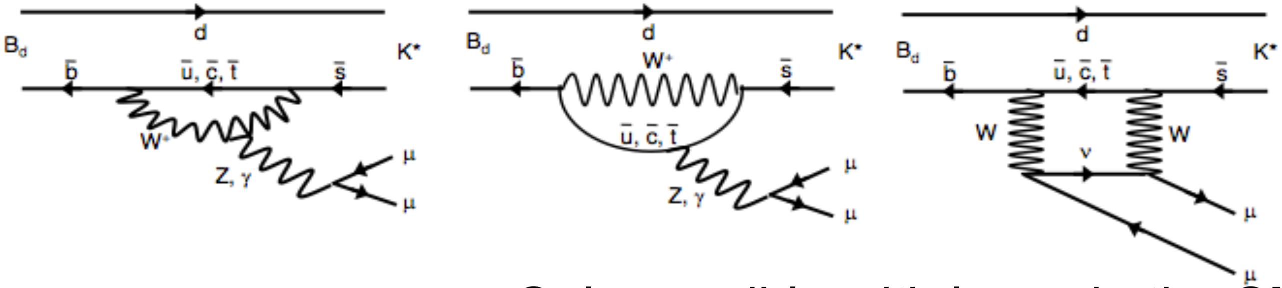


- Only possible with loops in the SM.
- Tiny BR.
- NP: at the same level as SM.
- LHCb: 303 events with 309 pb^{-1}. .
- A_{FB}: sensitive to helicity structure.
- Previous results: discrepancy.
  LHCb: agrees with SM.

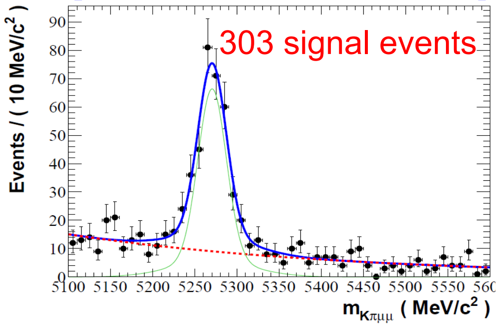


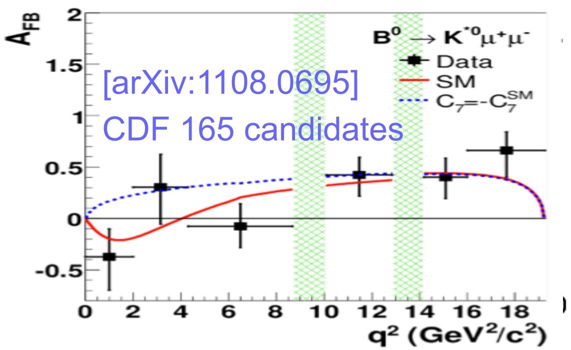
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

$B^0 \rightarrow K^*\mu^+\mu^-$

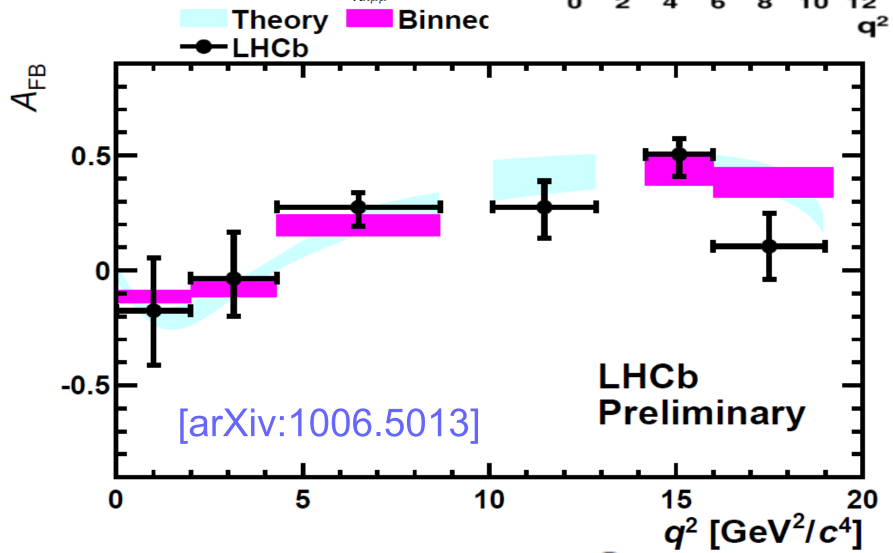


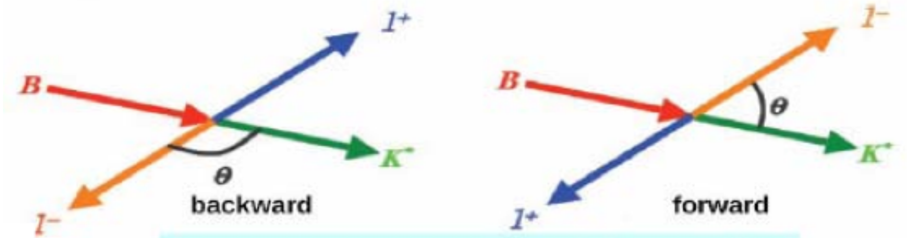
[LHCb-CONF-2011-038]





- Only possible with loops in the SM.
- Tiny BR.
- NP: at the same level as SM.
- LHCb: 303 events with 309 pb^{-1}. .
- A_{FB}: sensitive to helicity structure.
- Previous results: discrepancy. LHCb: agrees with SM.





$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

$$1 < q^2 < 6\,\mathrm{GeV}^2$$

$$A_{FB} = -0.10^{+0.14}_{-0.14} \pm 0.05$$

theory

$$A_{FB} = -0.04^{+0.03}_{-0.03}$$

B fragmentation f_s/f_d

- Required in B_s BR measurements.
- Average of three independent measurements. [Accepted by PRL]
  - Exclusive hadronic modes:

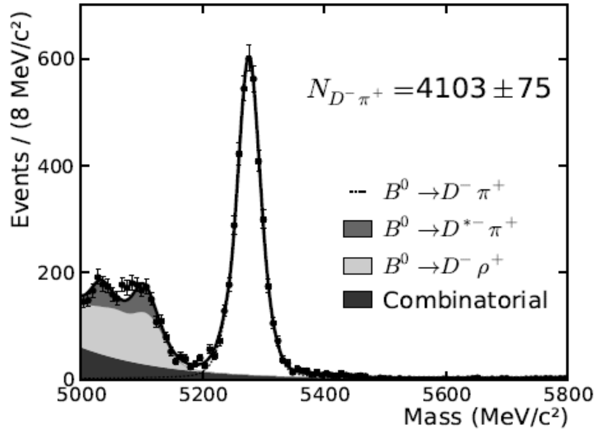
    $B_s \to D_s^-(K^+K^-\pi^-)\pi^+$ to $B_d \to D^-(K^+\pi^-\pi^-)\pi^+$.
  - Ratio of:

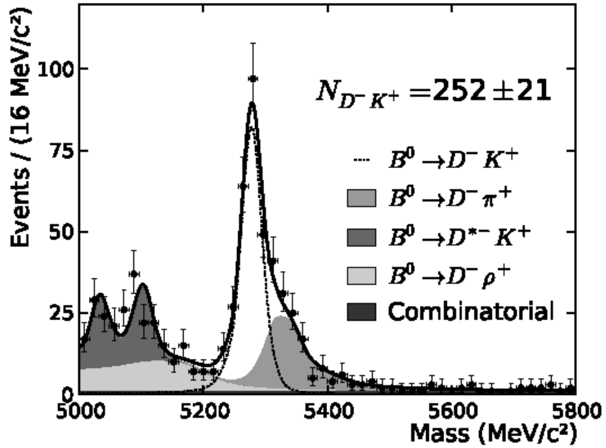
    $B_s \to D_s^-\pi^+$ to $B_d \to D^-K^+$.
  - Ratio of inclusive semileptonic modes:

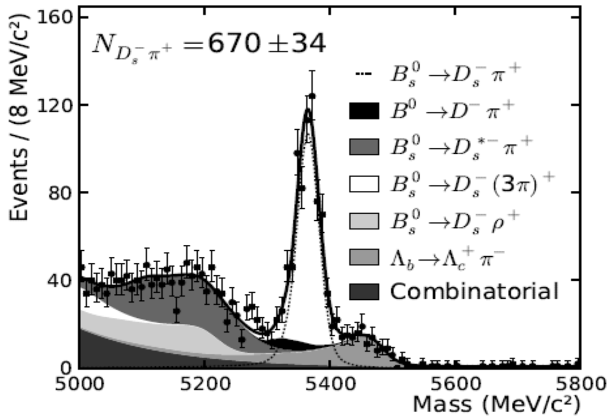
    $D^0X\mu\nu$, $D^-X\mu\nu$ and $D_sX\mu\nu$.
- Combined result: $\left(\dfrac{f_s}{f_d}\right)_{LHCb} = 0.267^{+0.021}_{-0.020}$
- Similar to LEP and Tevatron result:

$$0.271 \pm 0.027$$

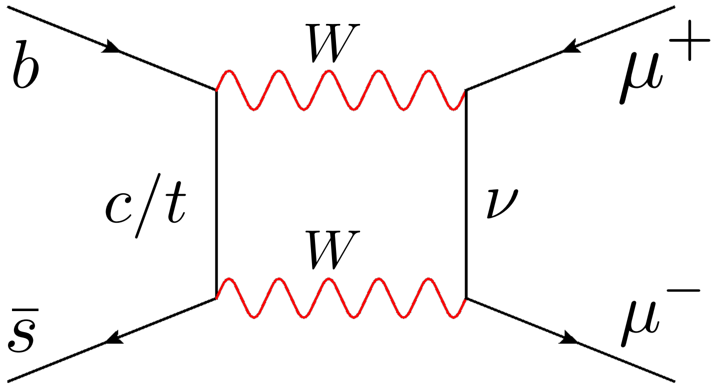
USC

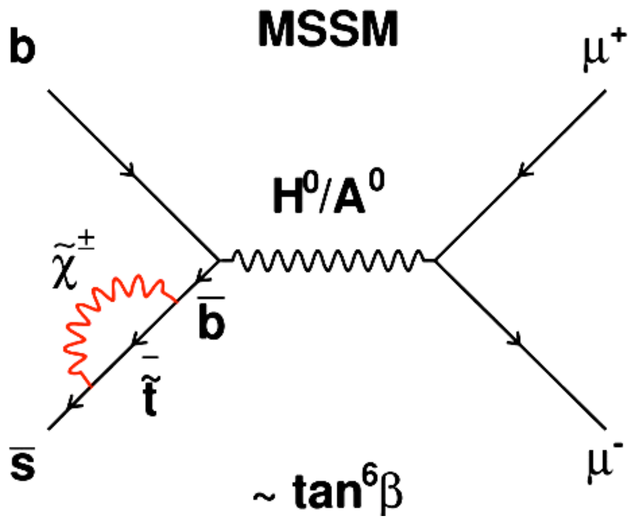






$B_s^0 \to \mu^+\mu^-$



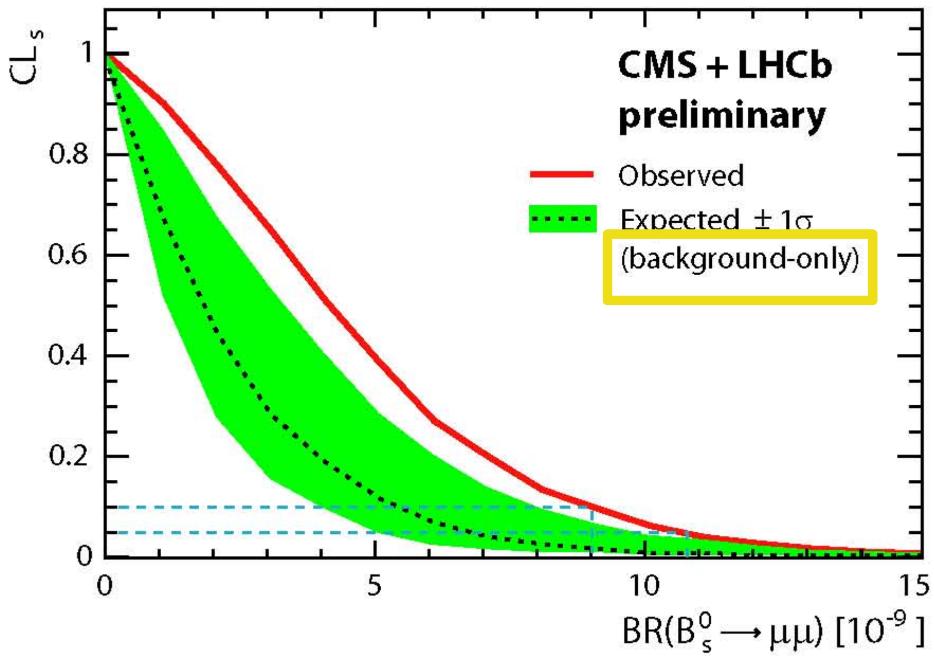


USC

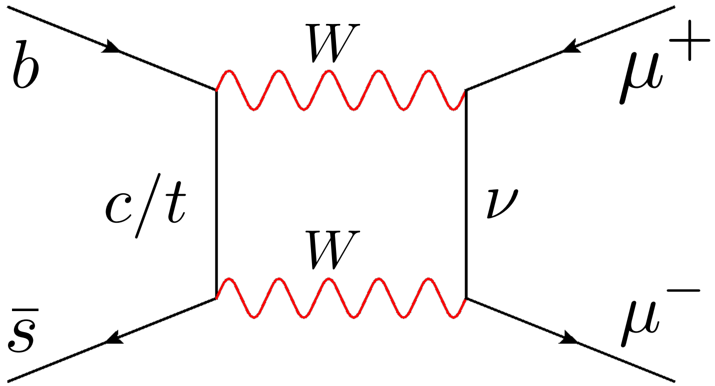
- Strongly suppressed in SM by GIM and helicity.
- $\mathcal{BR}^{SM}(B_s^0 \to \mu^+\mu^-) = (3.35 \pm 0.32) \times 10^{-9}$.
- SUSY: enhancement of this decay by $\tan^6\beta$.
- Other possibilities: extra dimensions, little Higgs, Technicolor,…

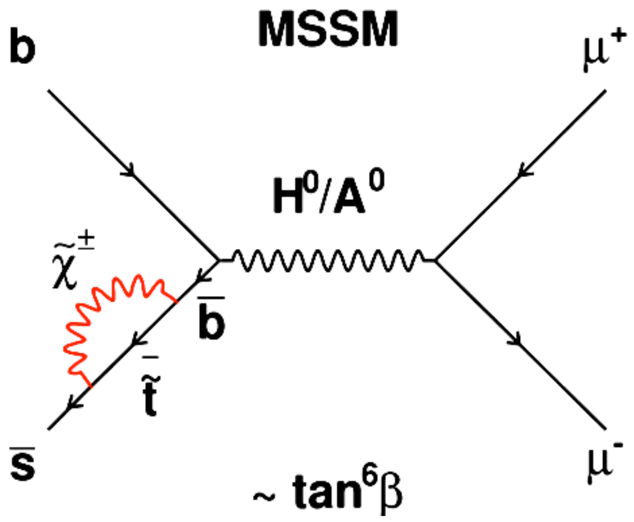
(see contributions from D. Martínez Santos+X. Cid).

- $\mathcal{BR}^{LHCb+CMS} < 11 \times 10^{-9}$ @ 95% CL.
- Still room for NP, but less and less.



$B_s^0 \to \mu^+\mu^-$



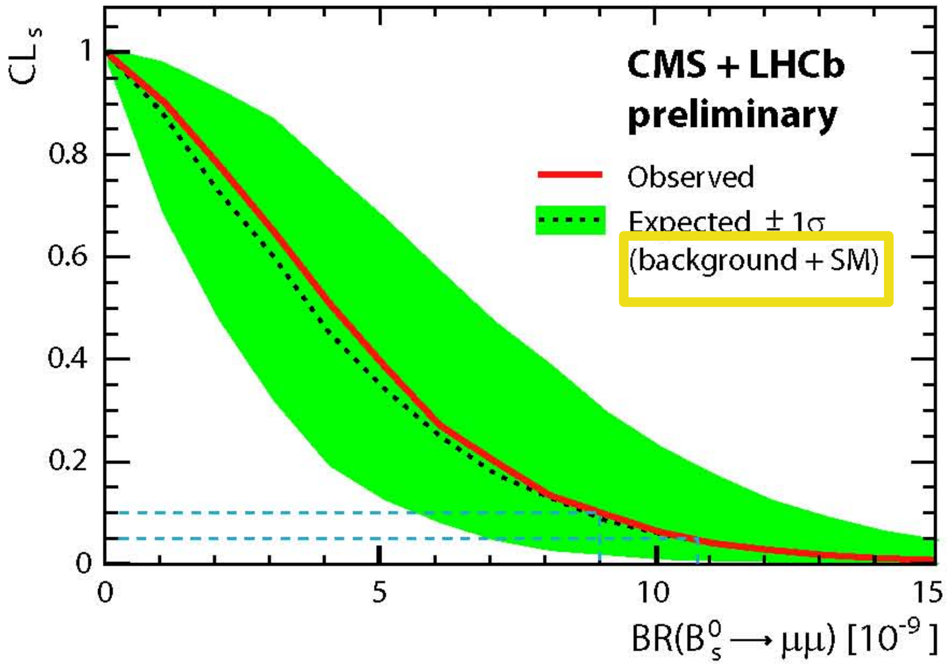


USC

- Strongly suppressed in SM by GIM and helicity.
- $\mathcal{BR}^{SM}(B_s^0 \to \mu^+\mu^-) = (3.35 \pm 0.32) \times 10^{-9}$.
- SUSY: enhancement of this decay by $\tan^6\beta$.
- Other possibilities: extra dimensions, little Higgs, Technicolor,…

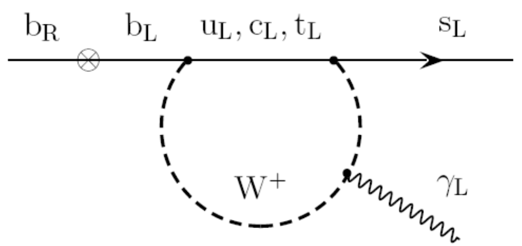
(see contributions from D. Martínez Santos+X. Cid).

- $\mathcal{BR}^{LHCb+CMS} < 11 \times 10^{-9}$ @ 95% CL.
- Still room for NP, but less and less.

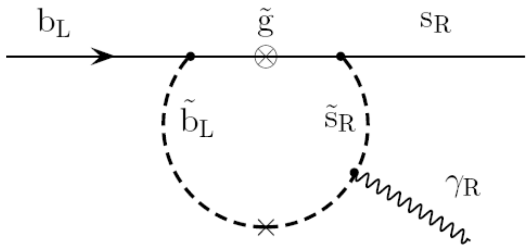


$B_s^0 \rightarrow \phi\gamma$

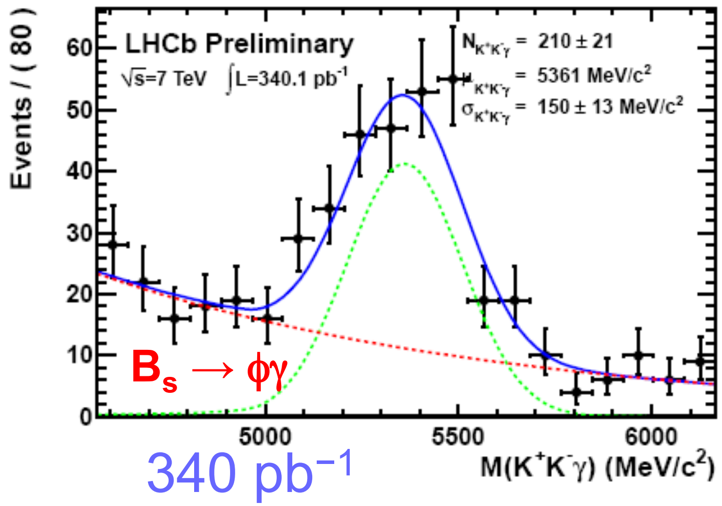
(CPAN-2011 contribution from A. Puig)



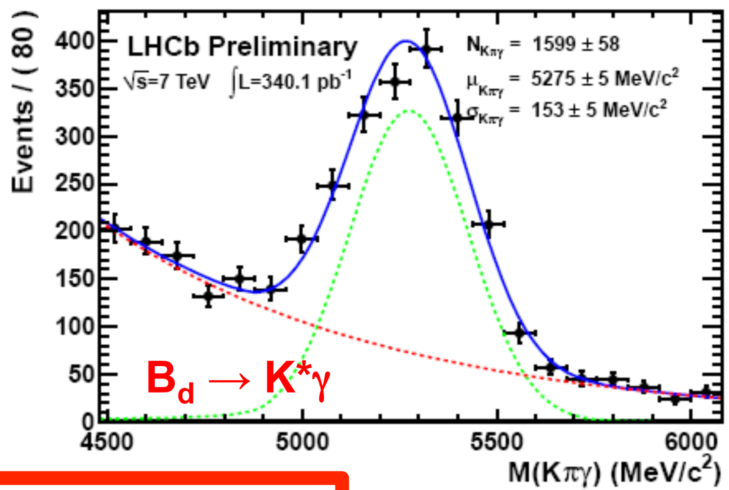
Dominant SM quark level diagram: left handed photons



MSSM diagram with right-handed photons



$340\ \mathrm{pb}^{-1}$



$$R(t) \propto e^{-\Gamma_s t}\left[\cosh(\Delta\Gamma_s t/2) + \boxed{A_\Delta}\sinh(\Delta\Gamma_s t/2)\right]$$

- A_Δ sensitive to fraction of right-handed photons (even small ϕ_s)
- $A_\Delta \sim 0$ in SM, can be enhanced by NP with large RH currents.

LHCb: $$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.52 \pm 0.14(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.12(f_s/f_d)$$ [LHCb-CONF-2011-055]

Theory: $$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.0 \pm 0.2$$

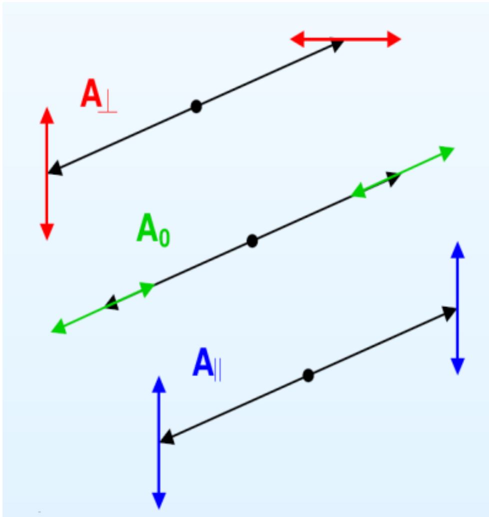
HFAG: BABAR+BELLE+CLEO $$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 0.7 \pm 0.3$$

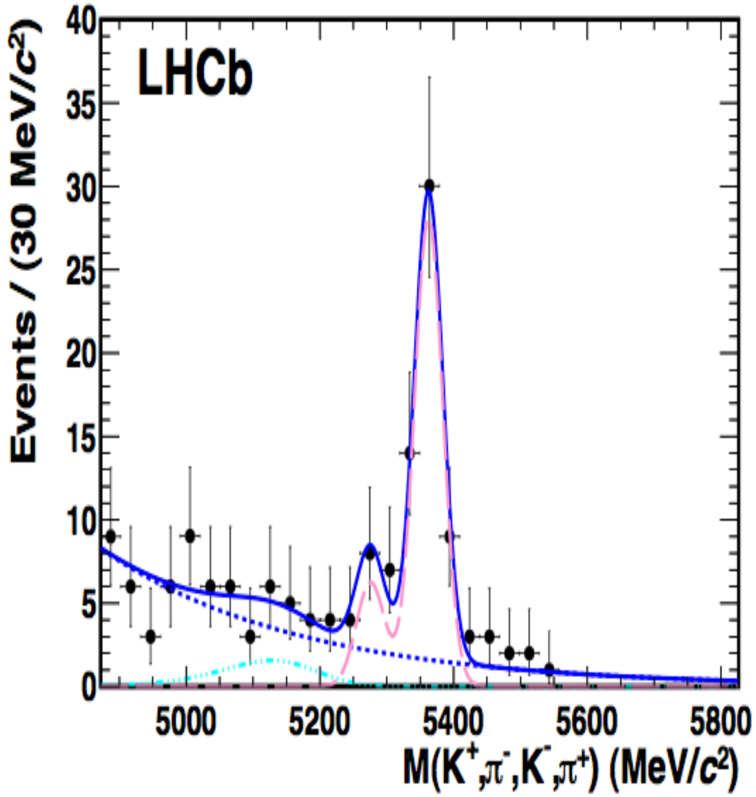
$B_s^0 \to K^{*0}(\to K^+\pi^-)\bar{K}^{0*}(\to K^-\pi^+)$

(CPAN-2011 contribution from P. Álvarez Cartelle)

USC

- LHCb discovery.
- Signal yield: $N(K^+\pi^-K^-\pi^+)$= 49.8 ± 7.5(stat.).
- Significance: 10.9σ.
- 1st test U-spin symmetry.





LHCb:

$$\boxed{\mathcal{B}(B_s^0 \to K^{*0}\bar{K}^{*0}) = (2.81 \pm 0.46(stat) \pm 0.45(syst) \pm 0.34(f_s/f_d)) \times 10^{-5}}$$

$$\boxed{f_L = |A_0|^2 = 0.31 \pm 0.12(stat.) \pm 0.04(syst.)}$$

Theory with exp. input from $B \to K^*\phi$

$$\boxed{\mathcal{B}(B_s^0 \to K^{*0}\bar{K}^{*0}) = (0.79^{+0.43}_{-0.39}) \times 10^{-5} \quad f_L = 0.72^{+0.16}_{-0.21}}$$

CP violation in charm

•CP in charm mixing. Strategy: search for a non-zero asymmetry in:

$$A_\Gamma = \frac{\tau(\bar{D} \to K^+K^-) - \tau(D \to K^+K^-)}{\tau(\bar{D} \to K^+K^-) + \tau(D \to K^+K^-)}$$

•And a CP violating angle in:

$$y_{CP}(\phi) = \frac{\hat{\Gamma}(D^0 \to K^+K^-)}{\hat{\Gamma}(D^0 \to K^-\pi^+)} - 1$$

• Preliminary result on 2010 data:

y_{CP}=(−0.55 ± 0.63 ± 0.41)%, y_{CP} (HFAG) = (1.107 ± 0.217)%

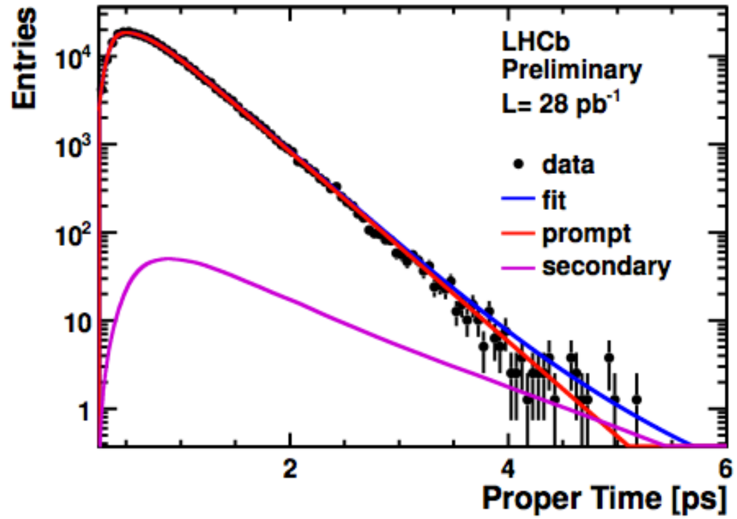
A_Γ =(−0.59 ± 0.59 ± 0.21)%, A_Γ (HFAG) = (0.123 ± 0.248)%

• Not conclusive. Needs better precision.

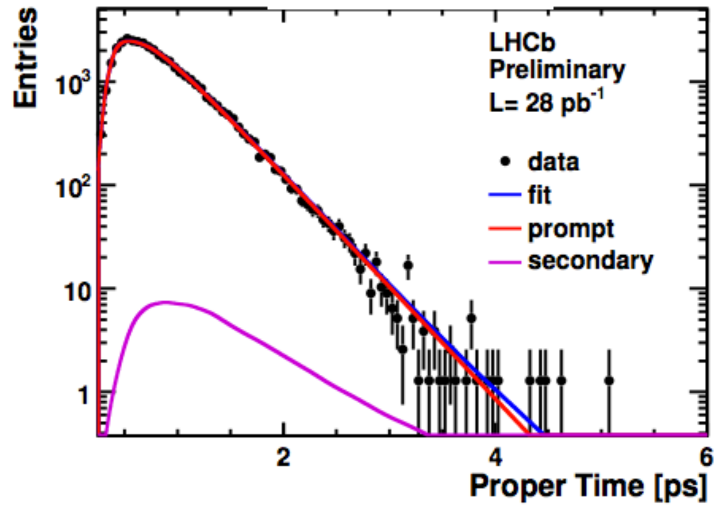
[LHCB-CONF-2011-054] [LHCB-CONF-2011-046]

•Also CP violation search in Cabibbo $D^+ \to K^+K^-\pi^+$ suppressed decays. No evidence.

$D^0 \to K^-\pi^+$



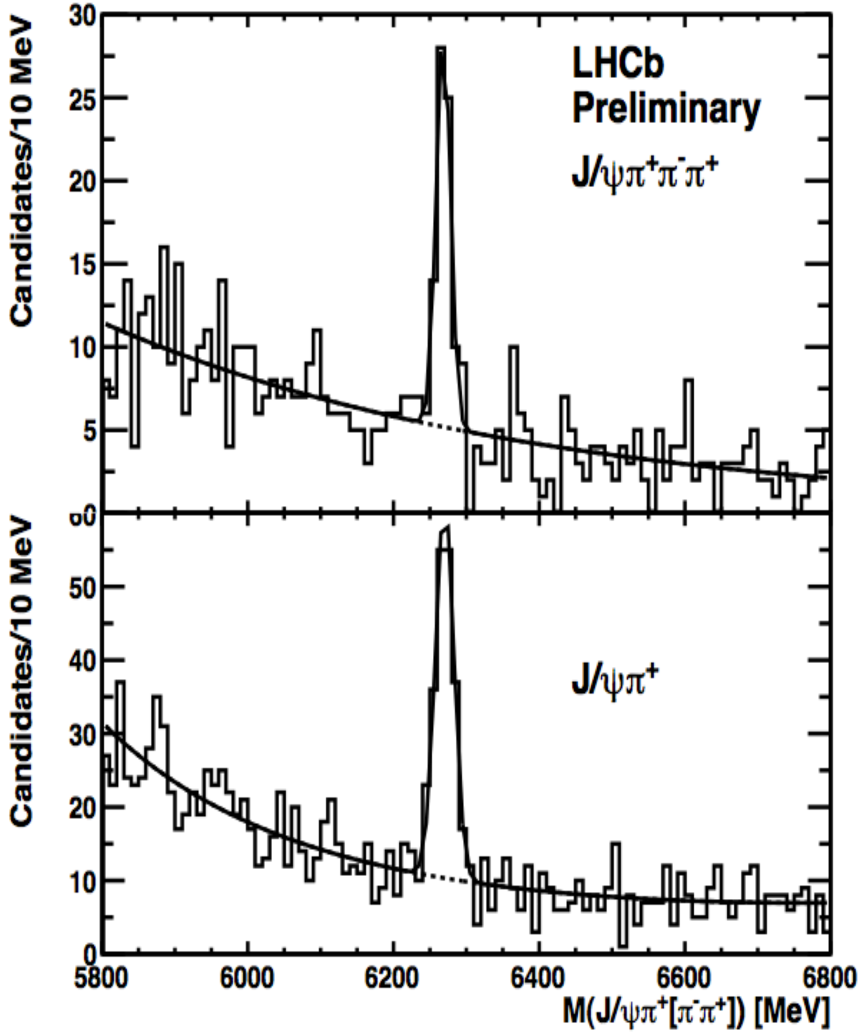
$D^0 \to K^+K^-$



Charm and Beauty at the same time

- $B_c^+ \rightarrow J/\psi\pi^+\pi^-\pi^+$: first time observed.
- B_c^+ discovered by CDF (1998).
- Significance 6.8σ.
- Third B_c^+ decay mode detected.
- $$\frac{BR(B_c^+ \rightarrow J/\psi\pi^+\pi^-\pi^+)}{BR(B_c^+ \rightarrow J/\psi\pi^+)} = 3.0 \pm 0.6 \pm 0.4$$

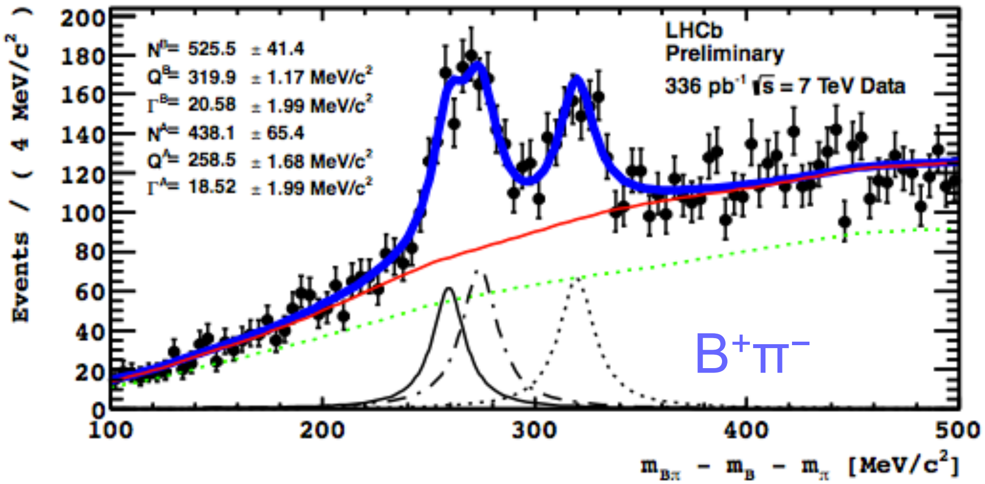
  in agreement with the theoretical predictions.



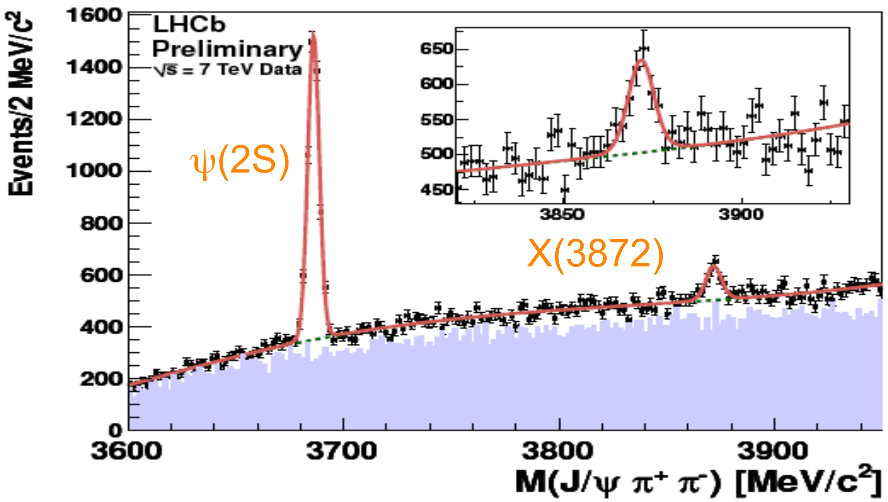
More Resonances

- Properties of Excited B mesons predicted by Heavy Quark Effective Theory in the limit of infinite b-quark mass:
  - Orbital angular momentum L.
  - Angular momentum of the light quark $j_q=|L\pm1/2|$.
  - Total angular momentum $J=|j_q\pm1/2|$.
- B_1^+ discovered by LHCb and evidence of B_2^{+*}.
- Mysterious charm resonance X(3872) already seen at Tevatron and b-factories detected.
- With mass: $M_{X(3872)} = 3871.96 \pm 0.46(stat) \pm 0.10(syst)$ MeV/c^2 .

[LHCb-CONF-2011-053]



[LHCb-CONF-2011-021]



Conclusions

- LHCb is taking data at the LHC with high efficiency.
  - Luminosity above design, **1.1 fb^{-1} recorded**.
- Detectors working according to specification:
  - Excellent mass and time resolution, particle ID…
- World-best measurements of various physics parameters:
  - Δm_s, $\Delta\Gamma_s$, ϕ_s, BR($B_s \to \mu^+\mu^-$), masses, lifetimes, etc.
- So far good agreement with the Standard Model.
  $\rightarrow$ New physics constrained in the flavor sector.
- Still room for new physics, higher precision required.
- Other remarkable results: *new decay modes, c-quark resonances, penguins, EW, QCD*…
- LHC continues in 2012, then 2014-17 at ~14 TeV $\rightarrow$ ~ 5 fb^{-1}.
- Upgrade of LHCb detector planned for 2018 to take 10× more data: 50 fb^{-1}.

Backup

Soft QCD Results in the High-η

(see contribution from A Camboni)

- Remarkable input to the theory.
- Strangeness production:
  - K^0_s at $\sqrt{s}$ = 0.9 TeV: harder p_T spectrum as compared to MC.
  - ϕ at $\sqrt{s}$ = 7 TeV: largely underestimated by the event generators.
- V0 ratios at 0.9 and 7 TeV:
  - $\bar{\Lambda}/\Lambda$ ratio: smaller in data than predicted in simulation, particularly at high rapidity.
  - Λ/K^0_s significantly larger than predicted at both collision energies.
- $\bar{p}/p$ ratio slightly lower than Perugia 0 at $\sqrt{s}$ = 0.9 TeV, good agreement data-MC at $\sqrt{s}$ = 7 TeV
- Charged particle production at $\sqrt{s}$ = 7 TeV: underestimated in most generator tunes.
  - Differences smaller for hard events.

K^0_s cross section