LHCb: status and physics results

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on behalf of the LHCb collaboration

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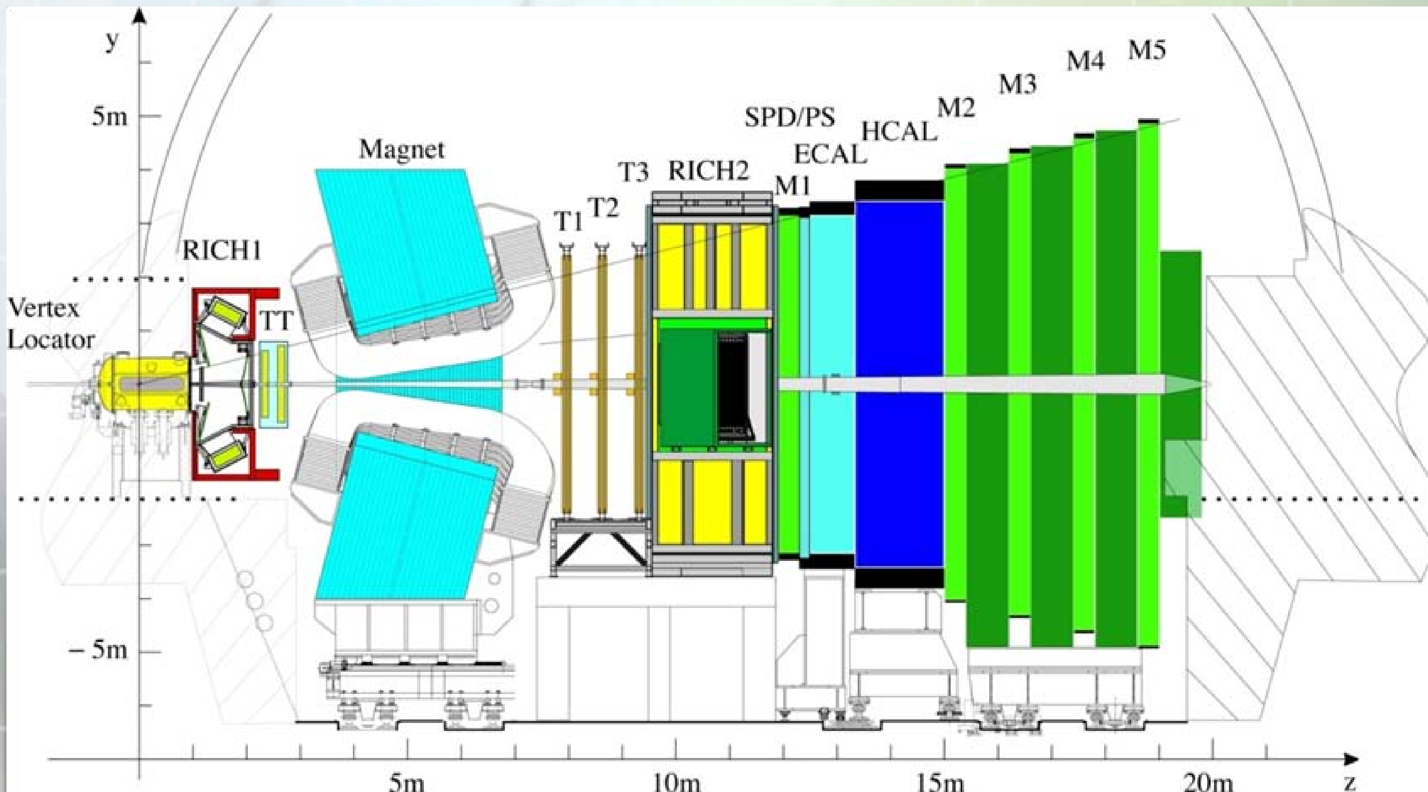
LHCb physics program

- LHCb experiment is dedicated for the heavy-flavour sector studies with main focus on the searches of the physics beyond Standard Model in beauty sector
  - large $b\bar{b}$ (~300 μb@35.5TeV) and $c\bar{c}$ (~6. mb@3.5TeV) production cross-sections
  - high luminosity
  - all species of beauty particles are produced
- Search for deviations from SM in known beauty/charm processes due to **indirect** contributions of new states (mainly via loop diagrams) ← access to higher mass scales
- Main directions of LHCb physics program:
  - Study of CP-violation in B-system
  - Search of new physics via rare B-decays
  - Charm physics
  - Production and spectroscopy

The LHCb detector

- Heavy quark pair production is peaked in the forward region → forward single arm spectrometer, solid angle coverage $1.9 < \eta < 4.9$
- Planar detectors, easier to assemble and to maintain
- High occupancy and significant radiation doses
- High background: ~1 of 200 collisions with b-quark, 1 of 10 - with c-quark → efficient trigger, also sensitive to many final states, powerful high bandwidth DAQ



LHCb tracking: components

Prerequisites: excellent vertex, IP and momentum resolution, e.g. to study fast B_s^0-oscillations

Components:

- **VErtex LOcator:**
  - primary/secondary vertices reconstruction and separation. Measurements as close as possible to the beams (8 mm). Movable 42r+42φ measuring silicon sensors, 2048 strips, pitch 37÷98 µm.
  - pile-up system: 4 extra sensors upstream the VELO to disable crossings with multiple interactions
- **Silicon tracker:** silicon microstrip detectors, ~200 µm pitch, arranged in stations of 4 stereo-layers (0°, +5°, - 5°, 0°)
  - 2 stations of the Tracker Turicensis upstream the magnet: reconstruction of long lived particles and better resolution to compensate for RICH1 scattering
  - 3 stations of the Inner Tracker downstream the magnet
- **Outer Tracker:** 3 stations of 4 stereo-layers (0°, +5°, - 5°, 0°), coupled with Inner Tracker. Straw tubes ø~5 mm, Ar-CO_2 70%-30% to ensure fast drift time < 50 ns
- **Dipole magnet** with a peak value of 1.1 Tesla, $\int B dl \approx 4$ TM

LHCb tracking: selected performance

- **Resolution for PV**: 25 tracks (13.0, 12.5, 68.5) μm / MC (10.7, 10.9, 58.1) μm

  [LHCBb-TALK-2011-205]

- **IP resolution for high Pt:** 13 μm (MC 11 μm)

  [LHCBb-TALK-2011-205]

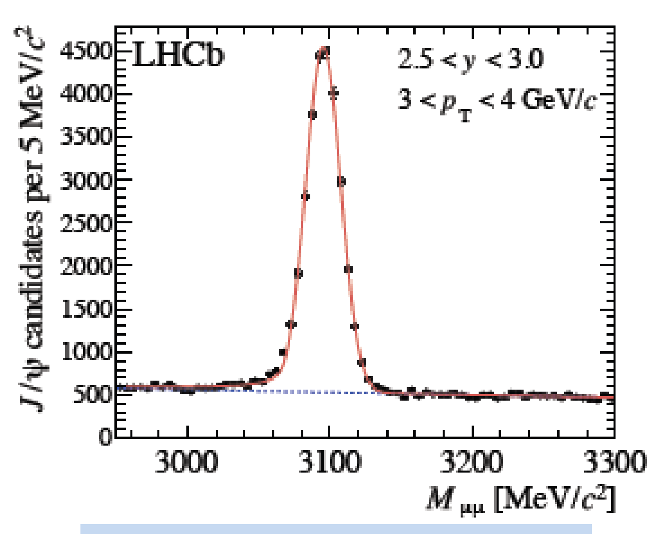
- **Momentum resolution**: J/ψ→μμ mass resolution σ≈12 MeV/c² , Δp/p = 0.4%

  [LHCBb-TALK-2011-207]

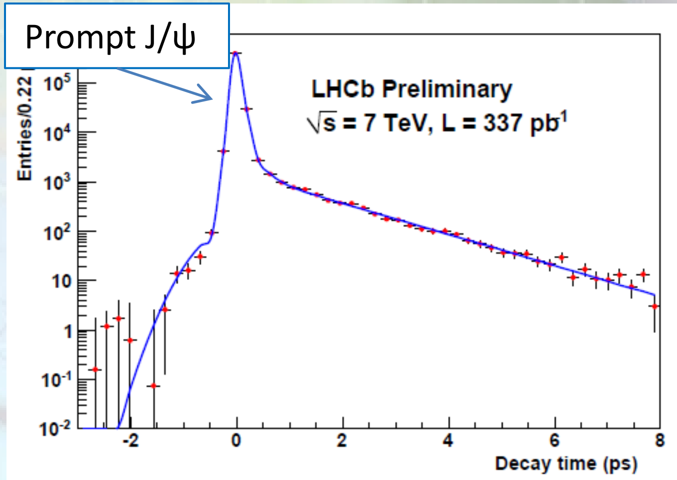
- **Efficiency**: from J/ψ→μμ analysis, 96% for long tracks. Agreement with MC and data is within 1%

  [LHCBb-TALK-2011-207]

- **Proper-time resolution**: [LHCb-CONF-2011-049]
  - from $B_s^0 - \overline{B}_s^0$ oscillation analysis with J/Ψϕ in final state, using prompt J/ψ→μμ
  - Effective decay time resolution is 50 fs with 2% systematic error (B_s^0 -oscillation period ~350 fs)

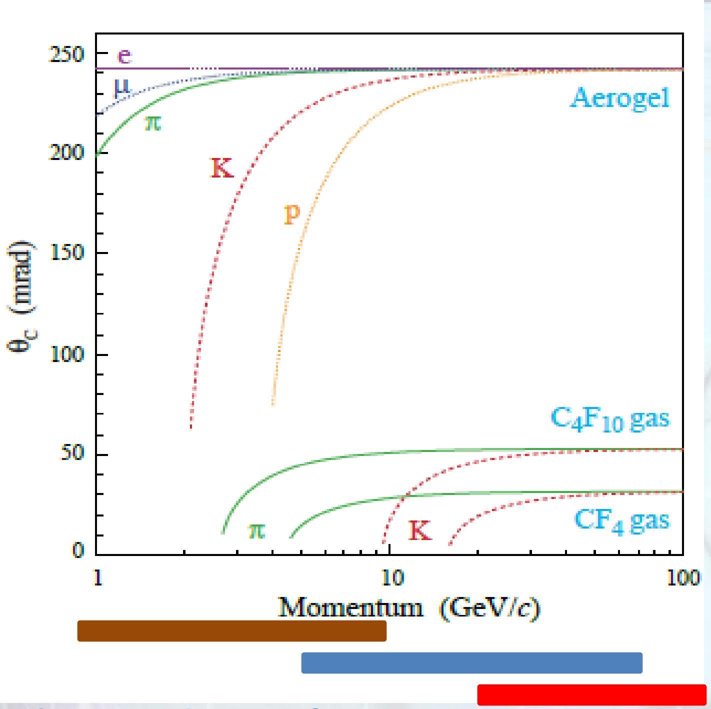


$J/\Psi \to \mu^+\mu^-$



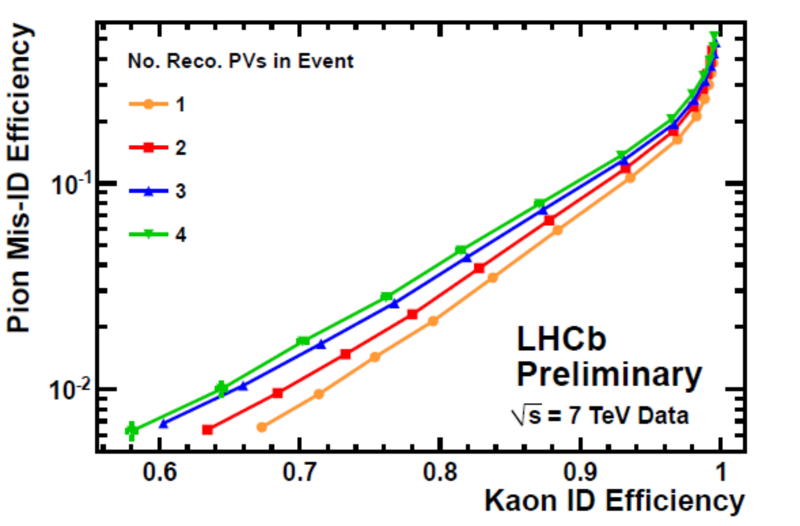
$\overline{B}_s^0 \to J/\Psi\phi$

LHCb PID: RICH system



π/K/p separation: two RICH detectors with three radiators:

- RICH1 upstream the magnet:
  - **Silica aerogel,** p 1÷10 GeV/c
  - **C_4F_{10} gas,** p up to 70 GeV/c
- **RICH2** downstream the magnet: CF_4 gas, up to 100 GeV/c



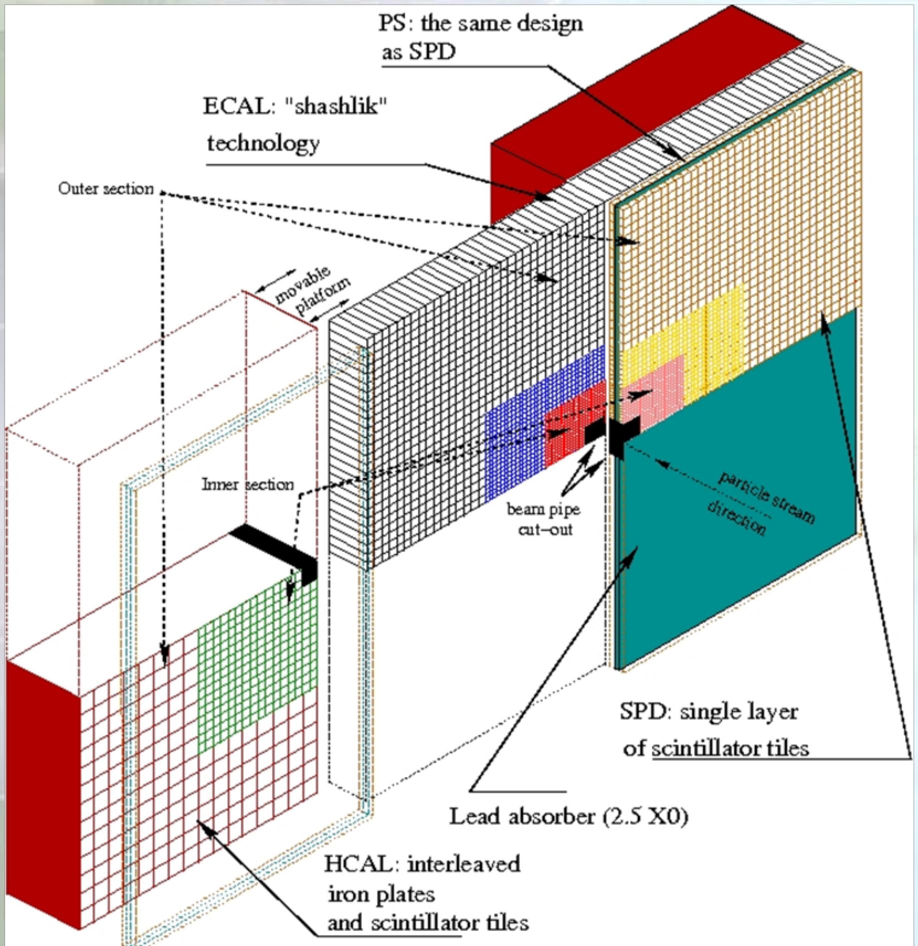
Particle ID performance of the RICH detectors for different number of PV

Selected performance:

[LHCb-TALK-2011-133]

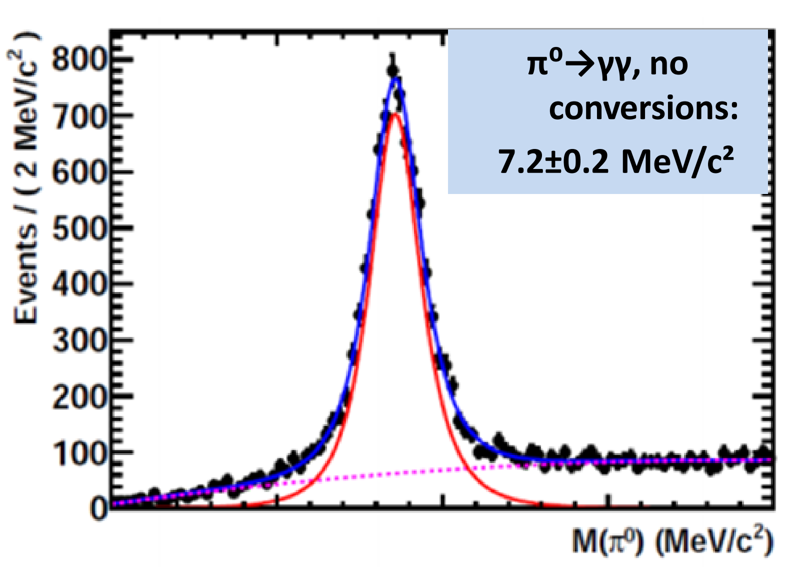
- **Cherenkov angle resolution:** 1.62 mrad RICH1 (gas) / 0.68 mrad RICH2 (MC: 1.5 mrad / 0.7 mrad)
- **Kaon identification efficiency** > 90% for **pion misidentification** < 5% over a large momentum range

LHCb PID: calorimetry



- Fast trigger on energetic e/γ/π^0/h, e/h separation, neutral particles ID
- Four sub-detectors of interleaved absorber/scintillator design with optical fiber readout
  - SPD: early e/γ discrimination
  - PS: e/π separation
  - ECAL: $\sigma E/E = (8. \div 10.)\%/\sqrt{E} \oplus 0.9\%$
  - HCAL: $\sigma E/E = 69\%/\sqrt{E} \oplus 9\%$

  !HCAL is only used in the trigger!

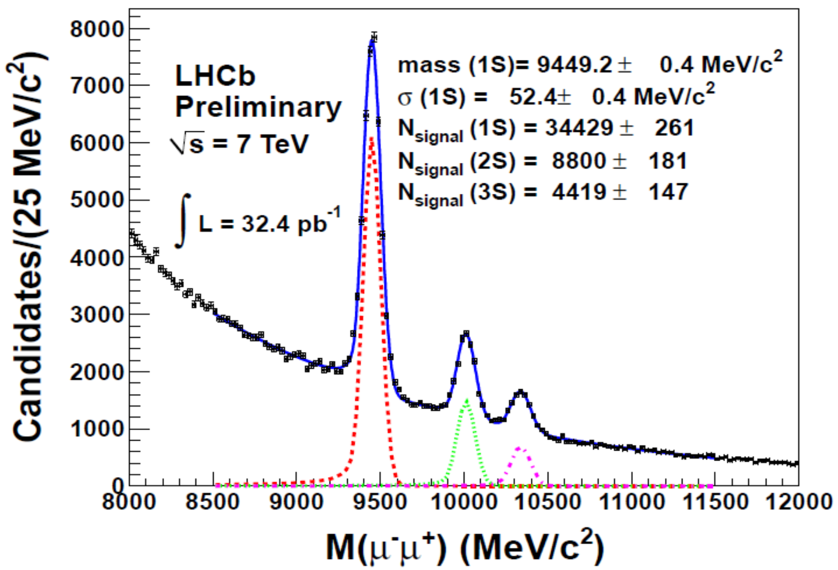


Selected performance: [LHCb-TALK-2011-106]

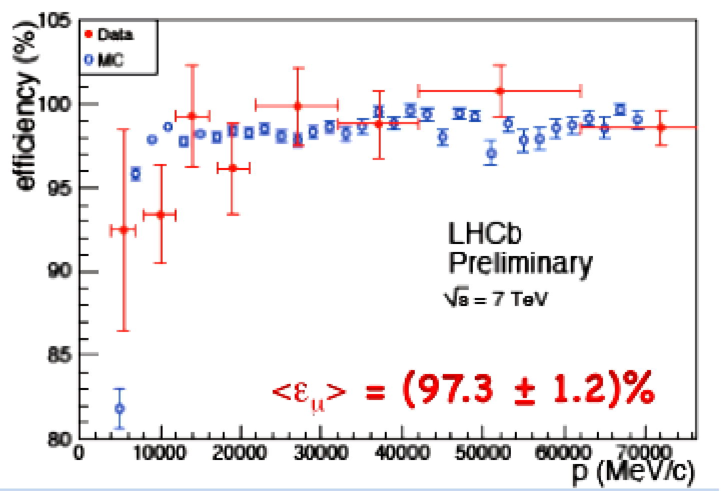
Present accuracy of calibration:

- Electromagnetic part ~2% (π^0+e/p + MIP)
- Hadronic part 2.5-3% (e/p + embedded rad. source)

LHCb PID: muon system



Family of Y-resonances, LHCb-CONF-2011-016



Efficiency from $J/\Psi \rightarrow \mu^+\mu^-$

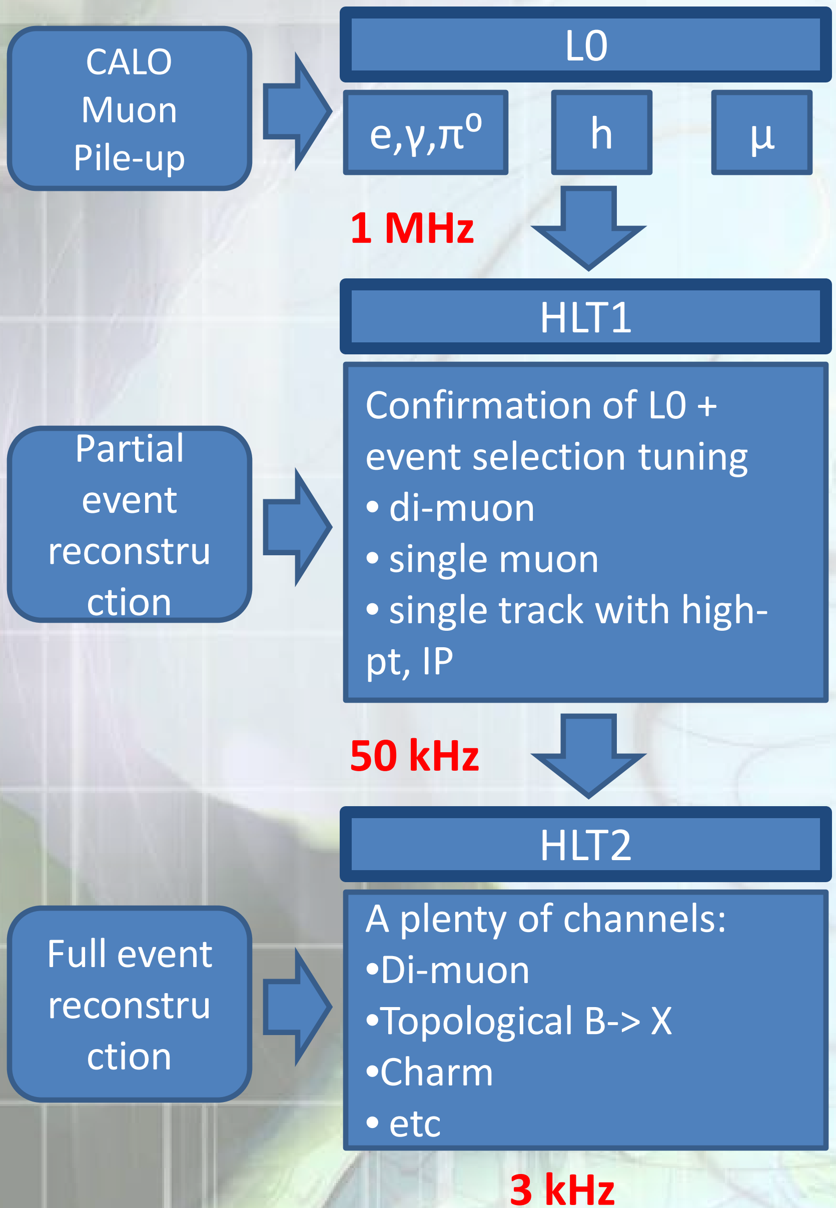
Muon system in LHCb is vital for the provision of fast trigger signal and offline muon identification

Five tracking stations:

- M1 (GEM + MWPC) upstream the Calorimeter System to improve the pt-measurement in the trigger
- M2-M5 (MWPC) interleaved with Fe absorber downstream calorimeter system

- **Selected performance:**
  [LHCb-PROC-2011-039]
  - **Efficiency** is studied with J/ψ→μμ decays, found to be 97.3±1.2% at p(μ)>4GeV/c, good agreement with MC
  - **μ/π and μ/K misidentification rates** below 1% for p(μ)>20GeV/c

LHCb trigger system

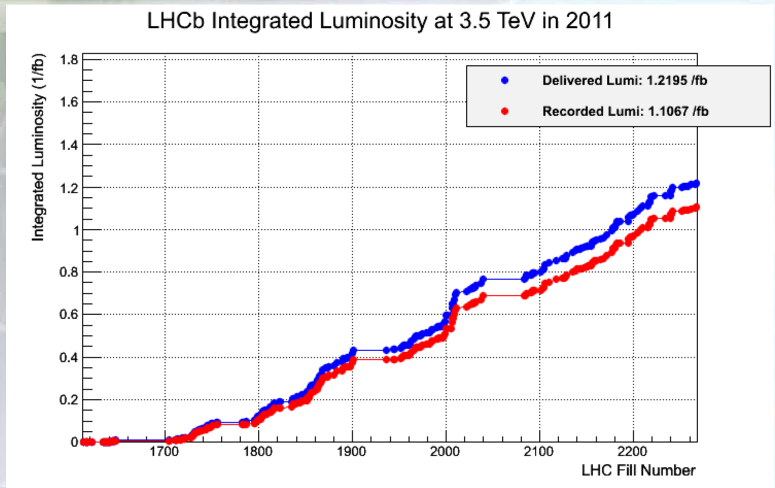


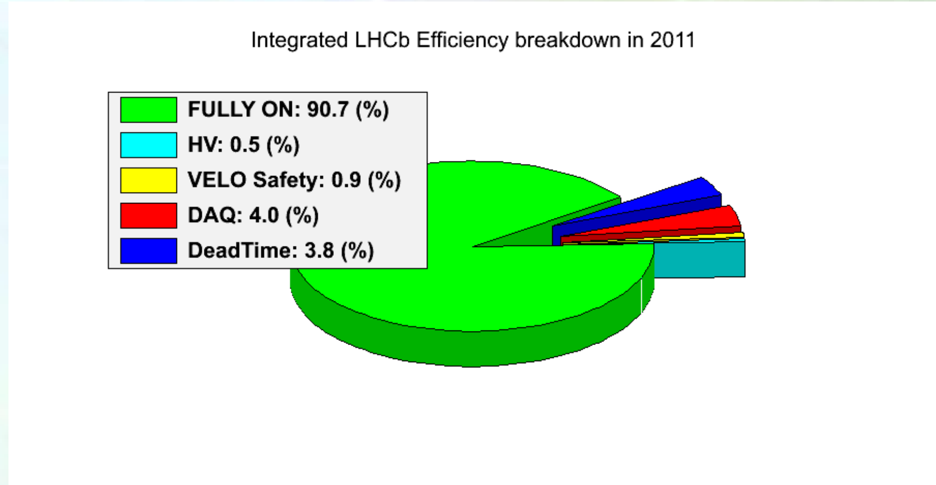
Two-level trigger

- **Level-0 trigger**: synchronous 40 MHz, hardware-based, signature of b-events – high-pt particles, threshold 1÷3 GeV/c
- **High Level Trigger**: asynchronous, software on ~1350 processor farm. Interesting final states are selected using flexible inclusive and exclusive criteria to adapt to changing running conditions and to optimize the physics yield
- **Running conditions**:
  - First half of 2010: loose criteria (low lumi) Conditions are favorable for hadronic B-decays and charm studies
  - Starting from summer 2010: selection is optimized for b-physics
- Typical overall L0×HLT **efficiencies range** from 30 % (multibody hadronic) – 90% (dimuons)

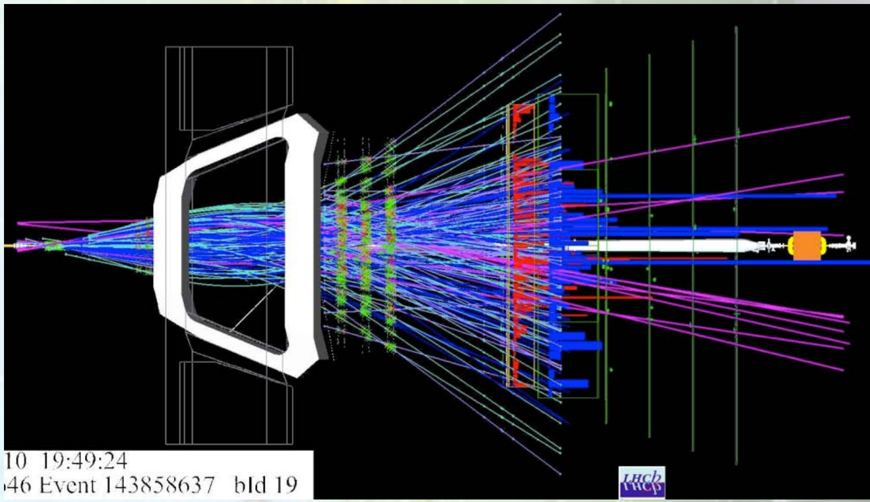
[LHCb-TALK-2011-108]

LHCb in 2011





- LHCb should operate at lower luminosity L than LHC is capable to provide to keep occupancies at reasonably low level (reconstruction, rad. damage etc) → **lumi leveling** by controlling the bunch overlap.
  - Present settings (@3.5 TeV, ~half of nominal bunches): $L=3.5 \times 10^{32}$ cm^{-2} s^{-1} with average number of interactions $\mu <= 1.5$/event
  - TDR settings (@7TeV): $L=2. \times 10^{32}$ cm^{-2} s^{-1} with $\mu = 0.4$/event
- For LHCb data taking-2011 is over. Statistics recorded: 38 pb^{-1} (2010) + 1.107 fb^{-1} (2011) with average efficiency 91% (2011)



Typical LHCb event

Selected physics results

$b\bar{b}$ and $c\bar{c}$ cross-sections

- **Beauty production (2)**

Values, extrapolated to full polar angle:

– $\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 44 \mu b$ via fraction of *J/Ψ* from b, using (2.9+12.2) nb^{-1} (2010)
[*Eur. Phys. J. C* **71 (2011) 1645**]

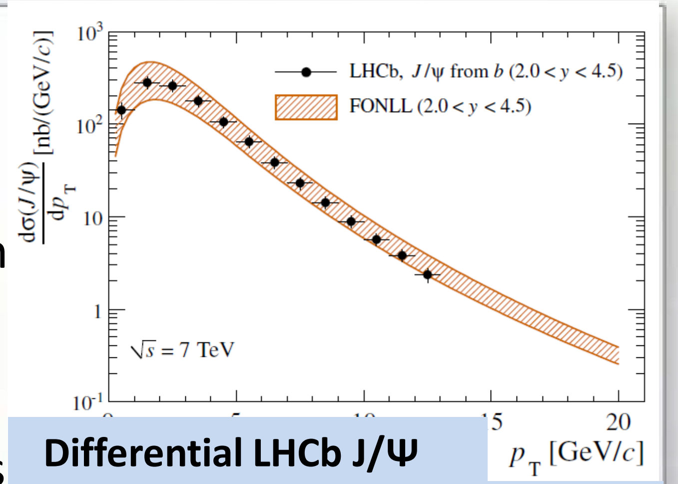
– $\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49 \mu b$ via decays of b hadrons into final states containing a D^0 and a muon, using 5.2 pb^{-1} (2010)
[Physics Letters B 694 (2010) 209–216]

Good agreement with theory predictions

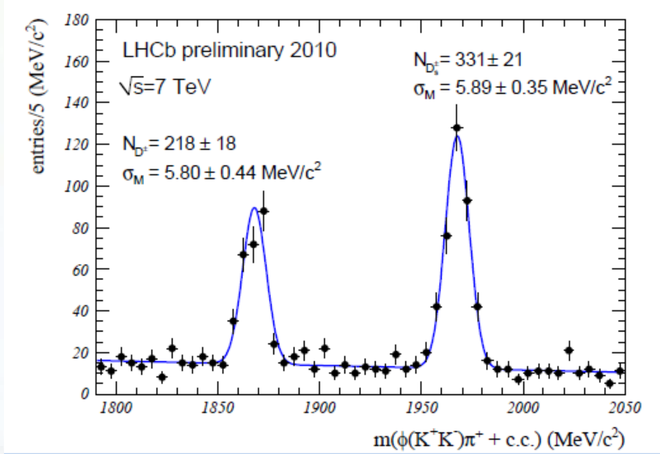
- **Charm production (1)**

– $\sigma(pp \to c\bar{c}X) = 6.10 \pm 0.93 mb$ via decays of D^0, D^+, D^{*+}, D_s^+, using 1.81 nb^{-1} (2010)
[LHCb-CONF-2010-013]

About 20 times the value of the $b\bar{b}$-cross-section



Differential LHCb J/Ψ from b and FONLL prediction



Reconstructed mass peaks
$D^+ / D_s^+ \to \phi(K^+K^-)\pi^+$

Measurement of the ratio of b-hadron production fractions

- $f_q \equiv B(b \to B_q)$, *q=u,d,s* - the fraction of neutral B-mesons amongst all weakly-decaying bottom hadrons.
- Precise knowledge is important for any absolute branching ratio measurements in B_s^0 sector
- Three measurements from LHCb:
  - $f_s/(f_u + f_d) = 0.134 \pm 0.004^{+0.011}_{-0.010}$ via semileptonic decays of b-hadrons, identified by the detection of a muon and a charmed hadron, using 3 pb^{-1} (2010), [LHCb-CONF-2011-028]
  - $f_s / f_d = 0.250 \pm 0.024^{stat} \pm 0.017^{sys} \pm 0.017^{theor}$ via branching fraction ratio $B_s^0 \to D_s^- \pi^+ / B^0 \to D^- K^+$, using 35 pb^{-1} [arXiv:1106.4435]
  - $f_s / f_d = 0.256 \pm 0.014^{stat} \pm 0.019^{sys} \pm 0.026^{theor}$ via branching fraction ratio $B_s^0 \to D_s^- \pi^+ / B^0 \to D^- \pi^+$, using 35 pb^{-1} [arXiv:1106.4435]
- Combined value [LHCb-CONF-2011-034]

  $f_s / f_d = 0.267^{+0.021}_{-0.020}$ assuming $f_u \equiv f_d$

  Good agreement with LEP and Tevatron: $< f_s / f_d >_{LEP,Tevatron} = 0.271 \pm 0.027$

No dependence on pt and rapidity has been observed

Search for rare B-decays (1)

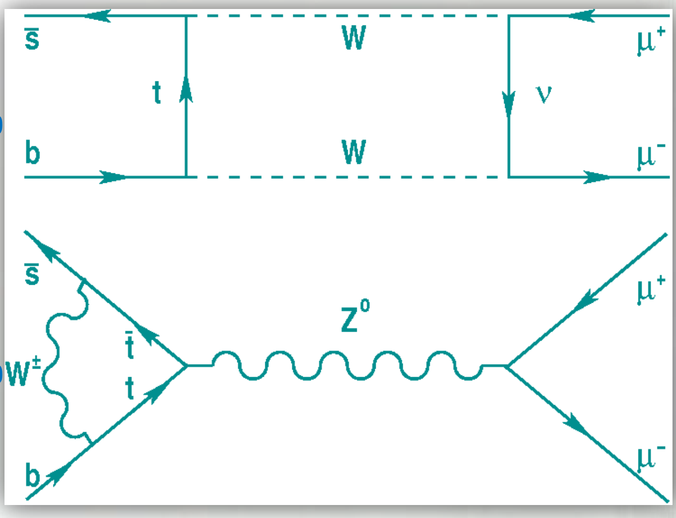
$B_{(s)} \to \mu\mu$ are highly suppressed in the SM:

$$B(B_s^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \bullet 10^{-9}$$

$$B(B^0 \to \mu^+\mu^-) = (0.10 \pm 0.01) \bullet 10^{-9}$$

Any significant enhancement will mean non-SM contribution

SM



Tevatron results (95% C.L.):

- **D0, 6.1 fb⁻¹**
  $B(B_s^0 \to \mu^+\mu^-) < 5.1 \bullet 10^{-8}$
- **CDF (prelim), 7 fb⁻¹**
  $B(B^0 \to \mu^+\mu^-) < 6 \bullet 10^{-9}$
  $B(B_s^0 \to \mu^+\mu^-) < 4.0 \bullet 10^{-8}$

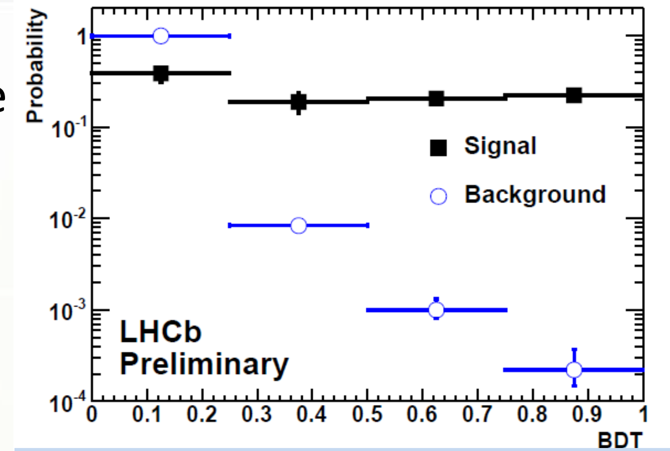
CDF(prelim), 7 fb⁻¹: the excess of events over background, compatible with:

$$B(B_s^0 \to \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \bullet 10^{-8}$$

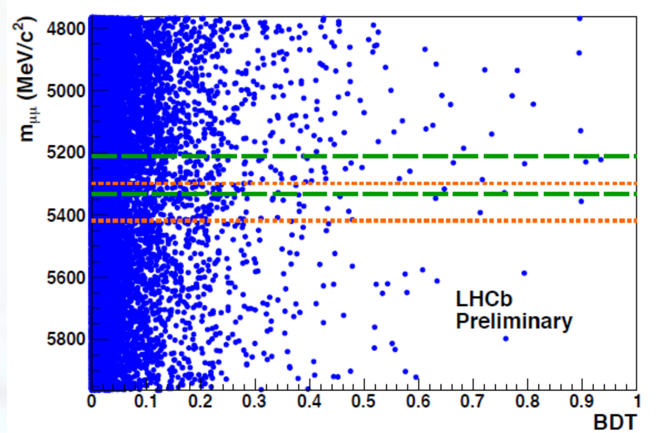
Search for rare B-decays (1)

Searches for $B^0_{(s)} \to \mu\mu$ in LHCb

- each selected event is given the probability to be signal or background according two variables:
  - Invariant mass of di-muon pair (6 bins)
  - Output of **B**oosted **D**ecision **T**ree combining 9 topological and kinematical observables (4 bins):
    - B^0-meson lifetime
    - B^0 -meson impact parameter
    - B^0 -meson transverse momentum
    - minimum impact parameter significance for muons
    - minimum distance between muon tracks
    - the isolation of the two muons wrt any other track
    - minimum pt of two muons
    - the cosine of the polarization angle between the muon momentum in the B^0 -rest frame and the vector perpendicular to the B^0 momentum and the beam axis
    - Bs isolation criterion
- Parameters are selected on the basis of Monte Carlo
- BDT-response is calibrated on real data using $B^0_{(s)} \to h^+h^-$ for the signal and $B^0_{(s)} \to \mu^+\mu^-$ from sidebands for the background



Probability of signal and background events in bins of BDT



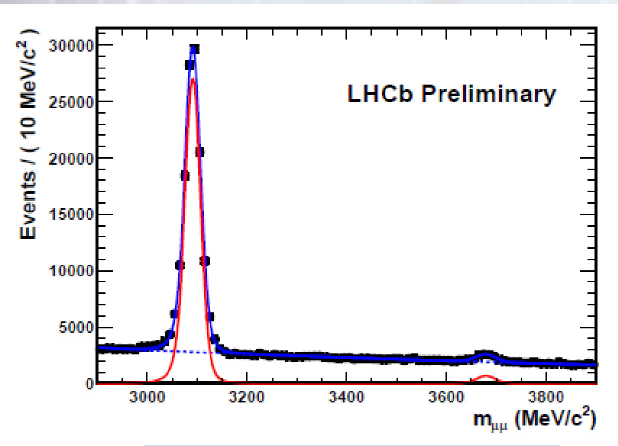
Distribution of selected dimuon events in the invariant mass vs BDT plane.

Search for rare B-decays (1)

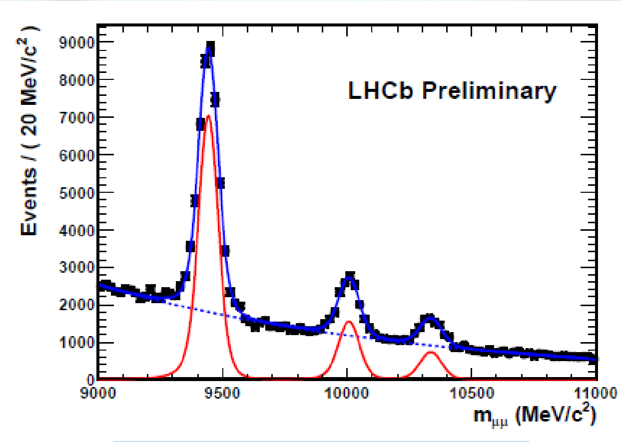
- **Normalization:** total number of b-measons is calculated using channels with well known branching ratios $B^+ \to J/\Psi K^+, B_s^0 \to J/\Psi \phi(KK)$, $B^0 \to K^+\pi^-$ and measured by LHCb fraction f_s / f_d
- **Invariant mass calibration:**
  - Position: from $B^0 \to K^+\pi^-, B_s^0 \to K^+K^-$
  - resolution: linear interpolation between the measured resolution of charmonium and bottomonium resonances decaying to two muons

$$M(B_s^0) = (5358.0 \pm 1.0) MeV / c^2 \qquad \sigma(B_s^0) = (24.6 \pm 0.2^{stat} \pm 1.0^{sys}) MeV / c^2$$

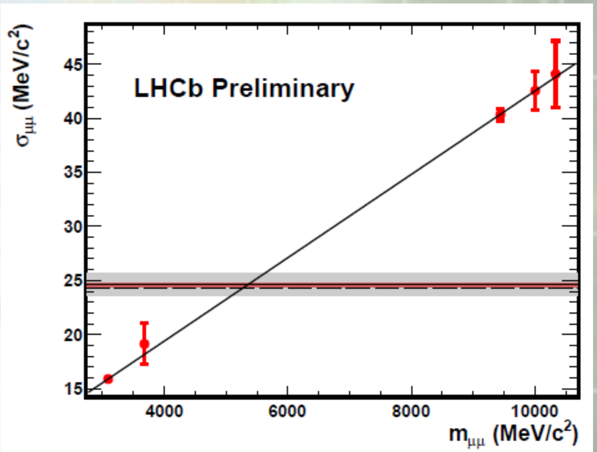
$$M(B^0) = (5272.0 \pm 1.0) MeV / c^2 \qquad \sigma(B^0) = (24.3 \pm 0.2^{stat} \pm 1.0^{sys}) MeV / c^2$$



J/Ψ and ψ(2S)



Υ(1S), Υ(2S), Υ(3S)



Search for rare B-decays (1)

- **LHCb results** (2)
  - 37 pb^{-1} (2010), **[PLB 699 (2011) 330–340]**

    $B(B_s^0 \to \mu^+\mu^-) < 4.3(5.6)\bullet 10^{-8}$ at 90%(95%) C.L.

    $B(B^0 \to \mu^+\mu^-) < 1.2(1.5)\bullet 10^{-8}$ at 90%(95%) C.L.
  - 300 pb^{-1} (2011), **[LHCb-CONF-2011-037]**

    $B(B_s^0 \to \mu^+\mu^-) < 1.3(1.6)\bullet 10^{-8}$ at 90%(95%) C.L.

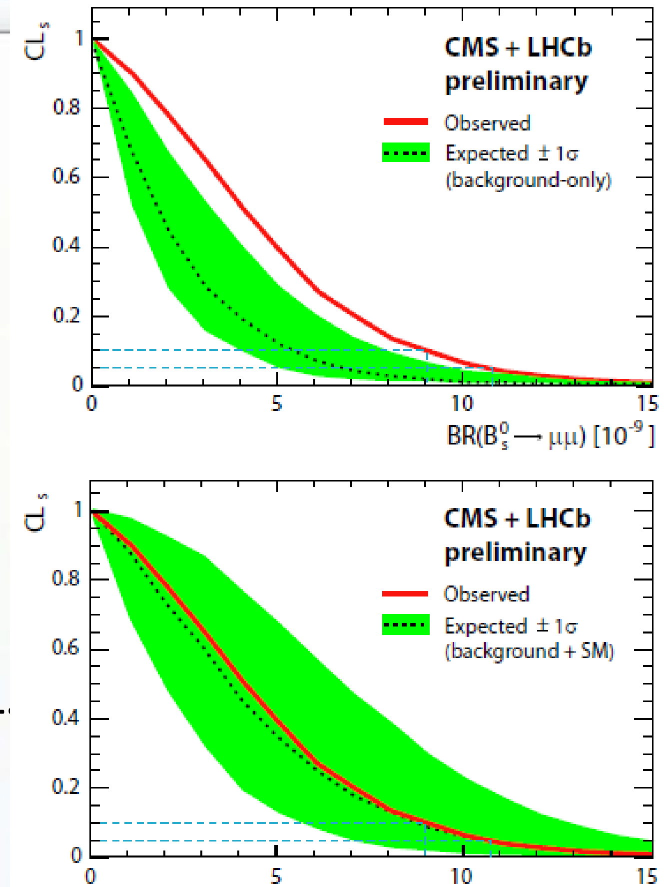
    $B(B^0 \to \mu^+\mu^-) < 4.2(5.1)\bullet 10^{-9}$ at 90%(95%) C.L.
  - combined limits, **[LHCb-CONF-2011-037]**

    $B(B_s^0 \to \mu^+\mu^-)(2010/11) < 1.2(1.5)\bullet 10^{-8}$ at 90%(95%) C.L.
- **Combined LHCb + CMS**

  [LHCb-CONF-2011-047, CMS PAS BPH-11-019]

  $B(B_s^0 \to \mu^+\mu^-) < 0.9(1.08)\bullet 10^{-8}$ at 90%(95%) C.L.

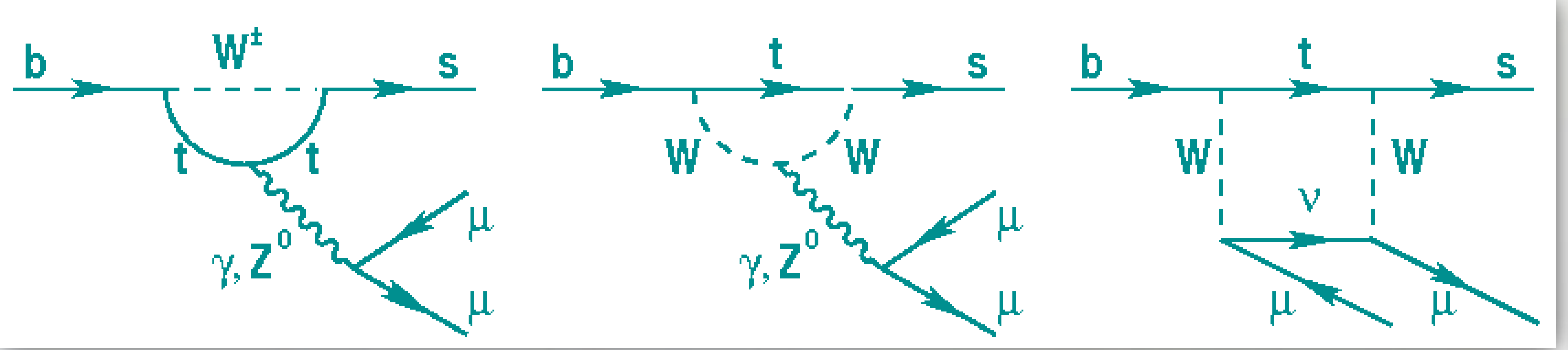
  An enhancement of the branching ratio by more than 3.4 times the Standard Model prediction is excluded at 95% C.L.



The observed (solid curve) and expected (dotted curve) CLs values, for background only (top) and background plus SM signal (bottom). Green: ±1σ interval

Search for rare B-decays (2)

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



New physics can manifest via new particles in loop-order diagrams and seen via analysis of angular distributions

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}q^2} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_K\,\mathrm{d}q^2} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

See next slide

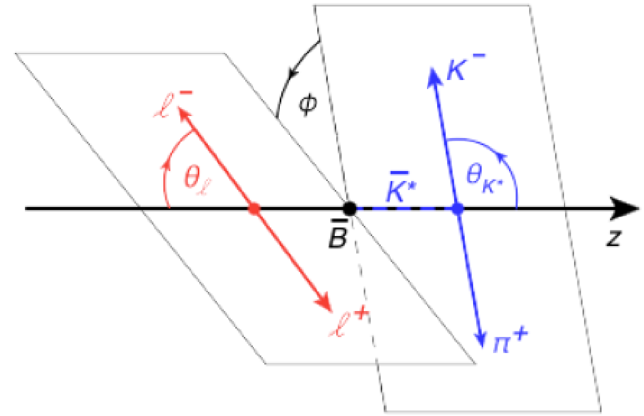
Search for rare B-decays (2)

Observables measured in LHCb (6 bins in $1 < dq^2 < 6$ GeV²):

– $A_{FB}(q^2) = \dfrac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$ the forward-backward asymmetry of the dimuon system in the μμ-rest frame

– F_L - the fraction of longitudinal polarization of the K⁰

– Differential branching cross-section dB/dq² (normalized with respect to the $B^0 \to J/\Psi K^{*0}$ decay rate to cancel systematics)



q^2 Invariant mass squared of the dimuon system $q^2 = m^2_{\mu^+\mu^-}$.

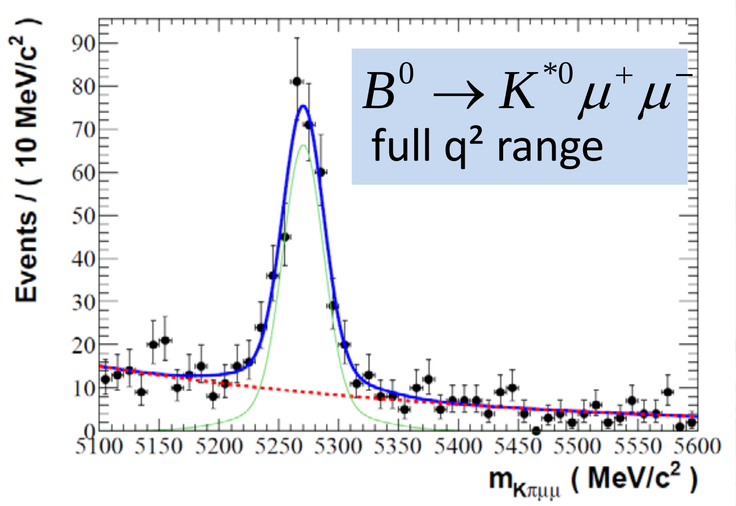
θ_ℓ Angle between the direction of the μ^- in the $\mu^+\mu^-$ rest frame and the direction of the $\mu^+\mu^-$ in the $\bar{B}_d$ rest frame.

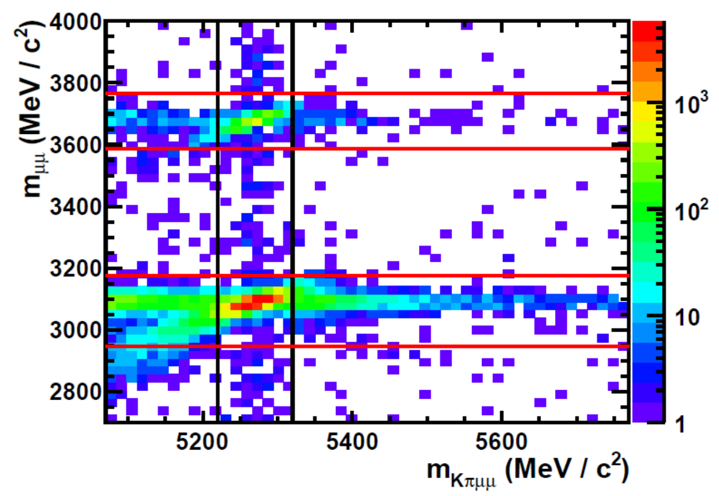
θ_K Angle between the kaon in the $\bar{K}^{*0}$ rest frame and the $\bar{K}^{*0}$ in the $\bar{B}_d$ rest frame.

ϕ Angle between planes defined by $\mu^-\ \mu^+$ and the $K\pi$ in the $\bar{B}_d$ frame.

Search for rare B-decays (2)

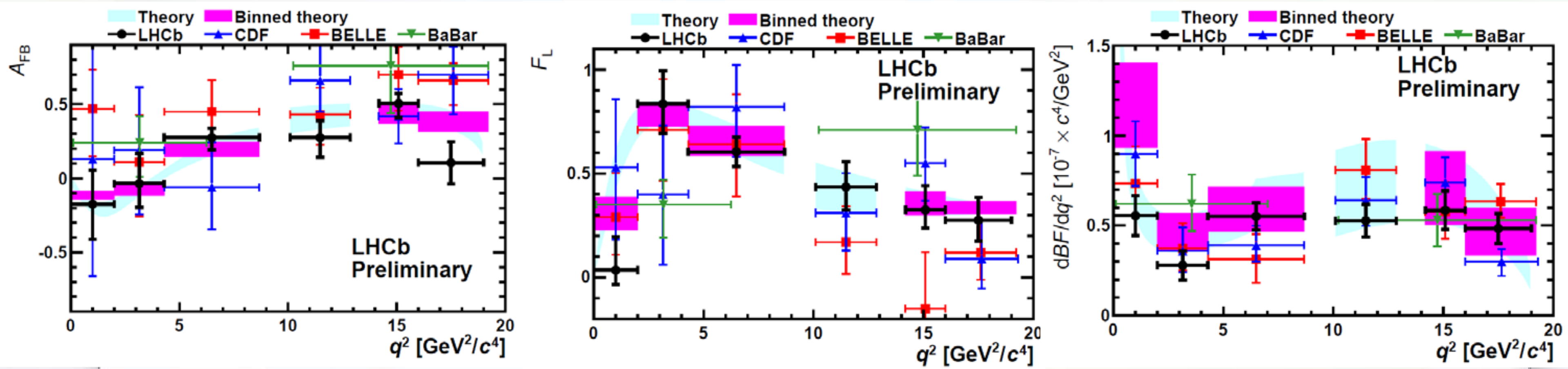
- signal selection: output of BDT
  - constructed on the basis of B-kinematics, B-vertex quality, daughter track quality, impact parameter and kaon, pion and muon particle identification. Calibrated on $B^0 \to J/\Psi K^{*0}$
- regions around $B^0 \to J/\Psi K^{*0}$ and $B^0 \to \psi(2S)K^{*0}$ are removed
- fits of mass spectra to extract observables are validated with MC and $B^0 \to J/\Psi K^{*0}$





Scatter plot of dimuon invariant mass vs $m_{K\pi\mu\mu}$

Search for rare B-decays (2)



LHCb results, 309 pb^{-1} (2011), [LHCb-CONF-2011-038]

are in good agreement with SM, Babar and Belle

LHCb:

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

$$F_L = 0.57^{+0.11}_{-0.10} \pm 0.03$$

$$\frac{dB}{dq^2} = (0.39 \pm 0.06 \pm 0.02) \bullet 10^{-7}$$

Theory prediction:

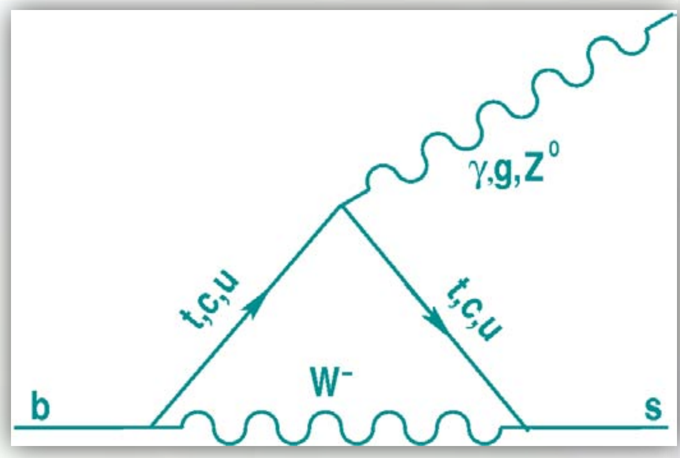
$$A_{FB} = -0.04^{+0.03}_{-0.03}$$

$$F_L = 0.74^{+0.06}_{-0.07}$$

$$\frac{dB}{dq^2} = (0.50^{+0.11}_{-0.10}) \bullet 10^{-7}$$

Search for rare B-decays (3)

- Radiative penguin decays
  - branching ratios
  - isospin asymmetry: strong sensitivity to new physics effects
  - photon polarization: in the SM photons are ~100% polarized



World average (BABAR, BELLE, CLEO)

$$B(B^0 \to K^{*0}\gamma)(HFAG) = (4.33 \pm 0.15) \bullet 10^{-5}$$

$$B(B_s^0 \to \phi\gamma)(HFAG) = (5.7^{+2.1}_{-1.8}) \bullet 10^{-5}$$

$$\frac{B(B^0 \to K^{*0}\gamma)}{B(B_s^0 \to \phi\gamma)} = 0.7 \pm 0.3$$

Theory (NNLO)

$$B(B^0 \to K^{*0}\gamma)(NNLO) = (4.3 \pm 1.4) \bullet 10^{-5}$$

$$B(B_s^0 \to \phi\gamma)(NNL0) = (4.3 \pm 1.4) \bullet 10^{-5}$$

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

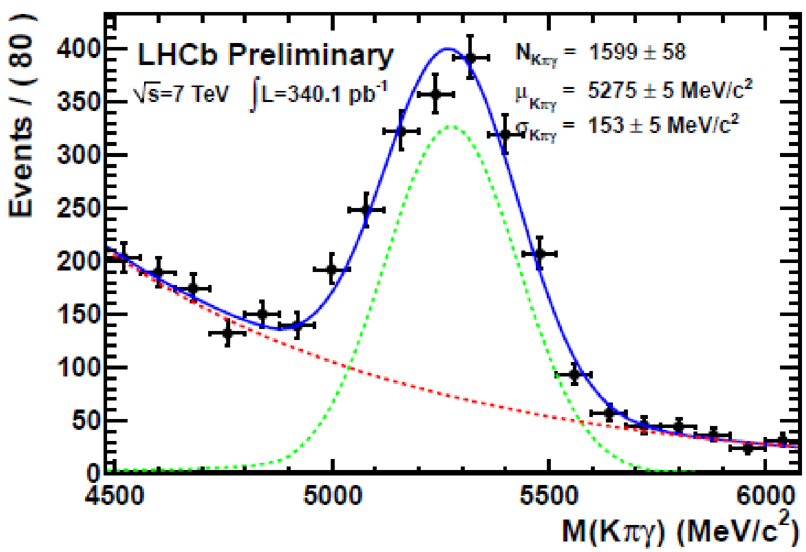
Search for rare B-decays (3)

- LHCb preliminary, using 340 pb^{-1}(2011), [LHCb-CONF-2011-055]

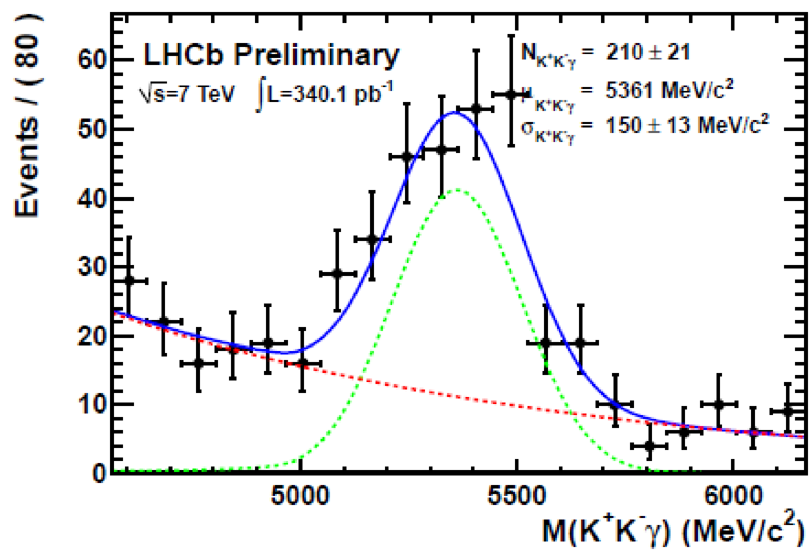
$$\frac{B(B^0 \to K^{*0}\gamma)}{B(B_s^0 \to \phi\gamma)} = 1.52 \pm 0.14^{stat} \pm 0.10^{sys} \pm 0.12^{f_s/f_d}$$

within 1.6 standard deviations with the theory prediction

Statistics of ~1÷2 fb^{-1} is required to access other observables



$B^0 \to K^{*0}\gamma$

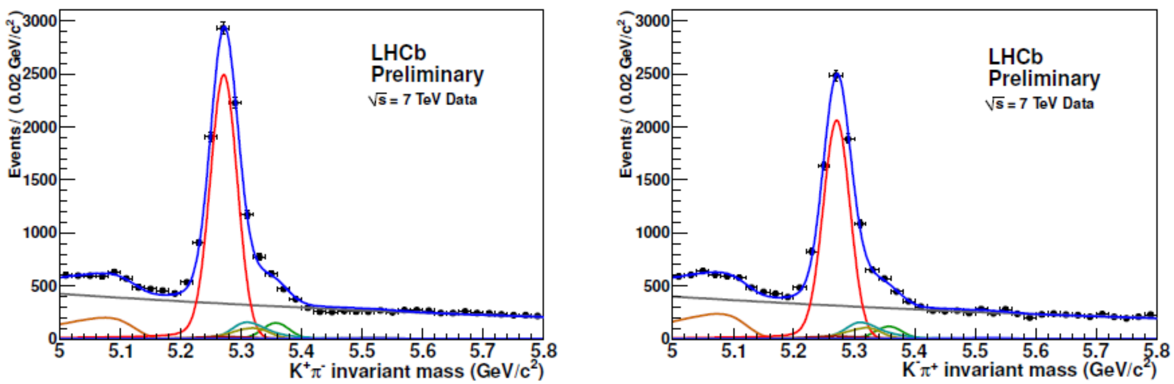


$B_s^0 \to \phi\gamma$

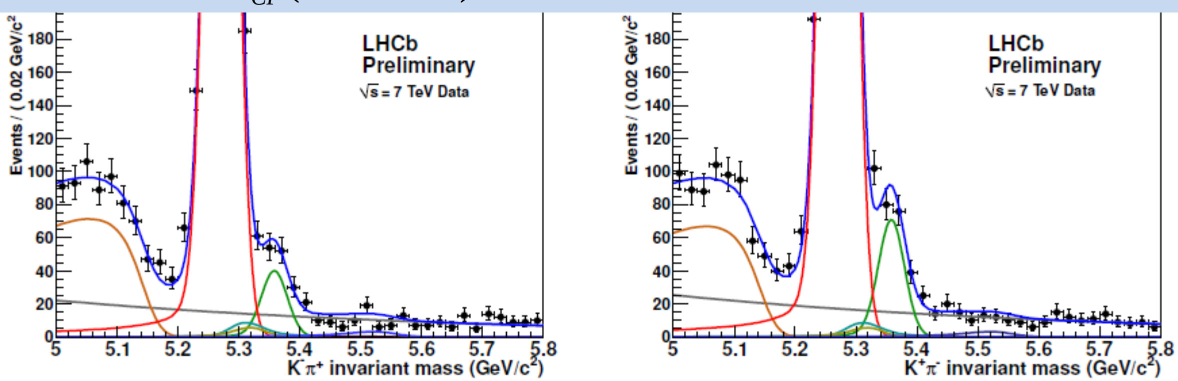
Direct CP-violation in B/Bs system via charmless decays

sensitive probe to CKM-matrix and good test for new physics

$$A_{CP}(B^0 \to K\pi) = \frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)} \quad A_{CP}(B_s^0 \to K\pi) = \frac{\Gamma(\overline{B}_s^0 \to \pi^-K^+) - \Gamma(B_s^0 \to \pi^+K^-)}{\Gamma(\overline{B}_s^0 \to \pi^-K^+) + \Gamma(B_s^0 \to \pi^+K^-)}$$



$K^+\pi^-$ and $K^-\pi^+$ invariant mass spectra, event selection adopted for the best sensitivity on $A_{CP}(B^0 \to K\pi)$



π^+K^- and π^-K^+ invariant mass spectra, event selection adopted for the best sensitivity on $A_{CP}(B_s^0 \to K\pi)$

- LHCb, 320 pb^{-1} (2011), [LHCb-CONF-2011-042]

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

The best measurement in the world, good agreement with current world average

$$A_{CP}(B^0 \to K\pi)(\mathrm{HFAG}) = -0.098^{+0.012}_{-0.011}$$

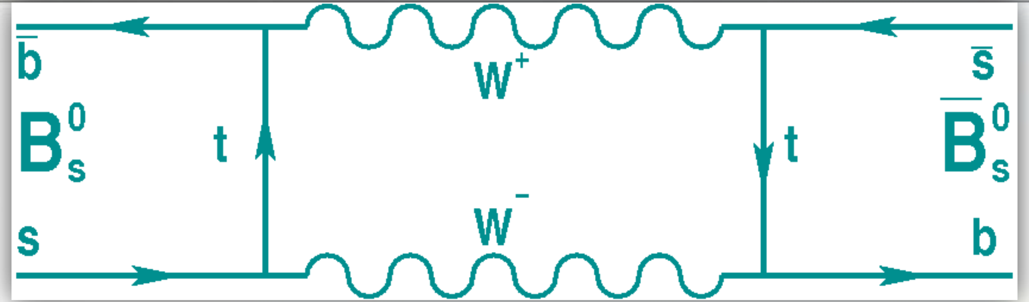
- LHCb, 320 pb^{-1} (2011), [LHCb-CONF-2011-042]

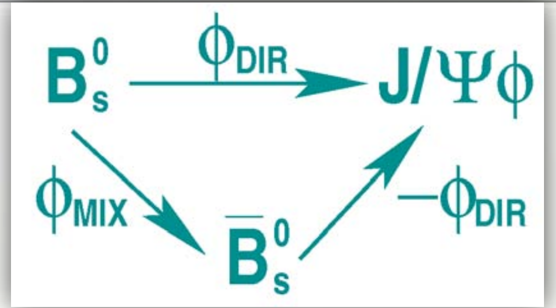
$$A_{CP}(B_s^0 \to K\pi) = 0.27 \pm 0.08 \pm 0.02$$

good agreement with CDF

$$A_{CP}(B_s^0 \to K\pi)(CDF) = 0.39 \pm 0.15 \pm 0.08$$

Time dependent CP-violation in Bs system via mixing





- Measure CP violation through interference of decays with and without mixing: CP violating phase $\phi_s = \phi_{MIX} - 2\phi_{DIR}$
- New physics can provide extra contribution to ϕ_s
- "Golden mode" for B_s^0 system is the decay $\overline{B}_s^0 \to J/\Psi\phi$
  - SM: ϕ_s is small and precisely known

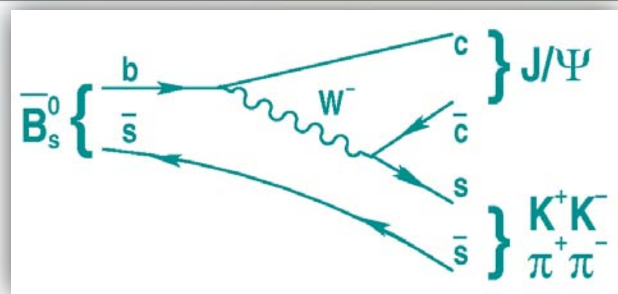
$$\phi_s \approx -2\beta_s = -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.036 \pm 0.002 rad$$

  - Experimentally: studied by CDF and D0, most precise result (D0):

$$\phi_s^{J/\Psi\phi}(D0) = -0.56^{+0.36}_{-0.32}$$

Time dependent CP-violation in Bs system via mixing

LHCb: presently the measurement of ϕ_s in two channels (other promising decays are under study)



$$\overline{B}^0_s \to J/\Psi\phi$$

Vector-vector final state,

almost pure P-wave,

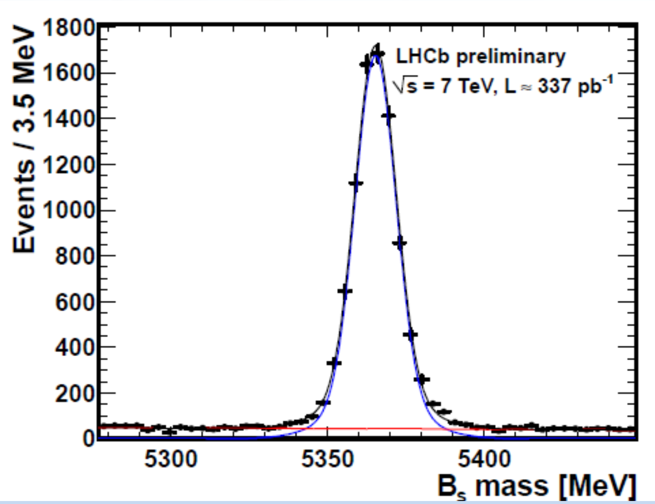
angular analysis is required

$$\overline{B}^0_s \to J/\Psi f_0(980),\ f_0 \to \pi^+\pi^-$$

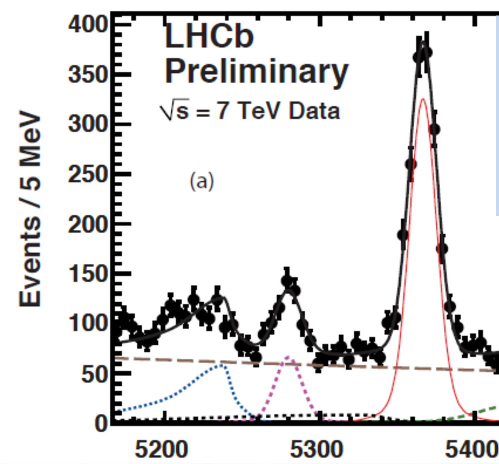
CP-odd state,

S-wave,

no angular analysis is needed



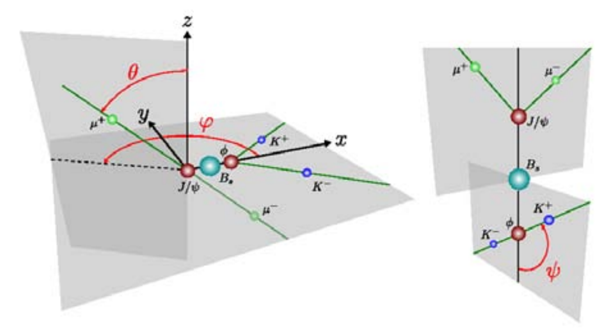
Reconstructed invariant mass distribution for $\overline{B}^0_s \to J/\Psi\phi$ candidates



First observation was done by LHCb Phys. Lett. B 698 (2011)

Reconstructed invariant mass distribution for $\overline{B}^0_s \to J/\Psi f_0(980)$ candidates

Time dependent CP-violation in Bs system via mixing: angular analysis for J/Ψϕ



P and S-wave contributions are separated including information on decay angles.
Unbinned maximum likelihood fit with the following set of parameters:

- average B_s^0-decay width Γ_s
- the decay width difference between B_s^0 mass eigenstates $\Delta\Gamma_s$
- oscillation frequency $\Delta m_s = 17.725 \pm 0.041 \pm 0.026 \mathrm{ps}^{-1}$

(LHCb measurement LHCb-CONF-2011-50)

- Phase ϕ_s
- $A_0(t), A_{\|}(t), A_{\perp}(t)$ - three complex angular amplitudes at t=0, P-wave
- $A_s(t)$ - one complex angular amplitude at t=0, S-wave

The decay rates are invariant under the simultaneous transformation:

$$\phi_s \leftrightarrow \pi - \phi_s, \Delta\Gamma_s \leftrightarrow -\Delta\Gamma_s$$

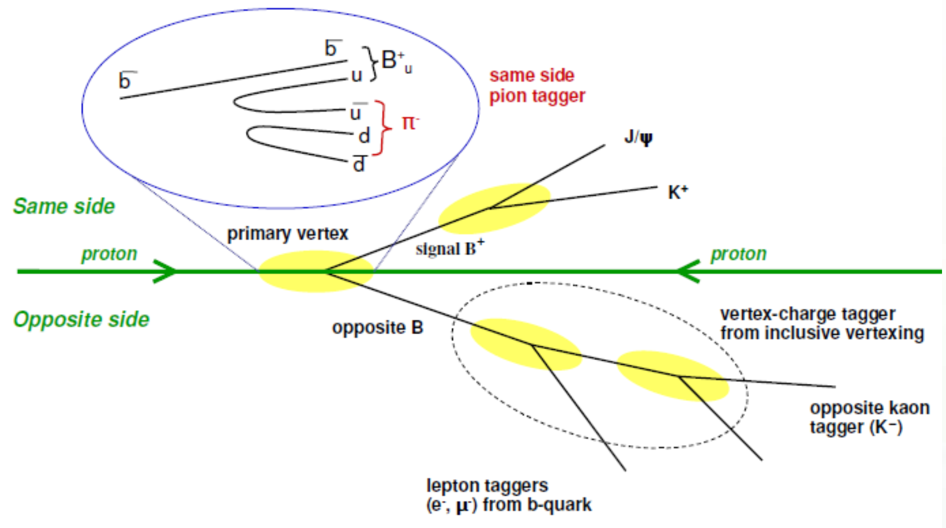
$$\delta_{\|} \leftrightarrow -\delta_{\|}, \delta_{\perp} \leftrightarrow \pi - \delta_{\perp}$$

where δ are phases of angular amplitudes A

It is possible to resolve this two-fold ambiguity by measuring the phase of the S-wave contribution as function of invariant KK-mass (Y. Xie et al., JHEP 0909:074, (2009)) ← to be done

Time dependent CP-violation in Bs system via mixing: flavour tagging

- Determine the initial flavour state of signal B-meson (b or anti-b).



Detailed description and performance optimization: in LHCb-CONF-2011-003

- Two methods are developed for LHCb:
  - **Same Side Tagging:** using other s-quark, which accompanies signal b-quark; identified as Kaon ← work in progess, to be used (in this analysis) in 2012
  - **Opposite Side Tagging:** via other b-quark using high pt muons, electrons, kaons and the net charge of an inclusively reconstructed secondary vertex, all finally combined

Time dependent CP-violation in Bs system via mixing: flavour tagging

Flavour tagging for $\overline{B}_s^0 \to J/\Psi\phi$ and $\overline{B}_s^0 \to J/\Psi f_0(980)$ is optimized and calibrated using well known $B^+ \to J/\Psi K^+$ and $B^- \to J/\Psi K^-$ decays as well as $\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}$ (for cross-checks)

Effective tagging efficiency Q= ε D², where

- ε - efficiency to obtain a tagging decision
- D=(1-2ω) – experimental dilution
- ω – mistag probability

$\overline{B}_s^0 \to J/\Psi\phi$	$\overline{B}_s^0 \to J/\Psi f_0(980)$
ε = (24.9±0.5)%	ε = (25.6±1.3)%
D = 0.277±0.006±0.016	D = 0.289
Q = (1.91±0.23)%	Q = 2.13%

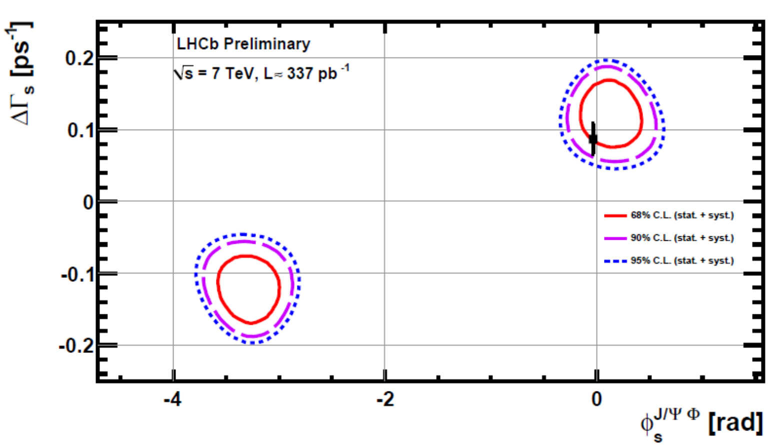
Time dependent CP-violation in Bs system via mixing: results I (J/Ψϕ)

- Other important factors: decay time resolution (50 fs, estimated from prompt J/Ψ, see above), various acceptance-related effects (estimated/corrected on the basis of MC)
- $\overline{B}_s^0 \to J/\Psi\phi$ results using 337 pb^{-1}, [LHCb-CONF-2011-049]

$$\phi_s^{J/\Psi\phi} = 0.13 \pm 0.18^{stat} \pm 0.07^{sys}\, rad$$

$$\Gamma_s = 0.656 \pm 0.009^{stat} \pm 0.008^{sys}\, ps^{-1}$$

$$\Delta\Gamma_s = 0.123 \pm 0.029^{stat} \pm 0.011^{sys}\, ps^{-1}$$



The world's most precise measurement of ϕ_s and Γ_s

The first direct evidence for a non-zero value for $\Delta\Gamma_s$

Work in progress!

Time dependent CP-violation in Bs system via mixing: results II

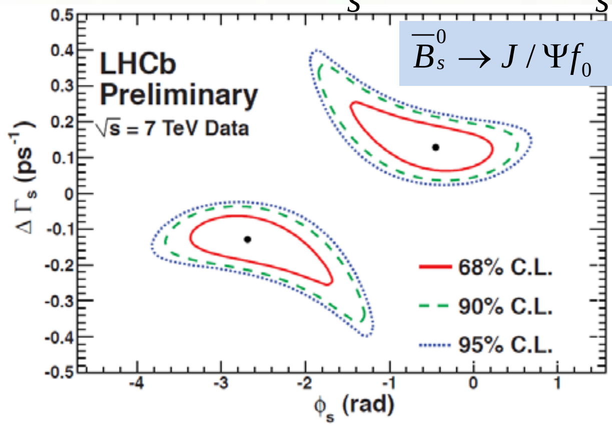
- $\overline{B}_s^0 \to J/\Psi f_0(980)$ results using 337 pb^{-1}, [LHCb-CONF-2011-051]
- CP-odd final state, not possible to determine Γ_s and $\Delta\Gamma_s$ simultaneously
  - Γ_s from $\overline{B}_s^0 \to J/\Psi\phi$ analysis

$$\phi_s^{J/\Psi f_0} = -0.45^{+0.45}_{-0.57}\,rad$$

$$\Delta\Gamma_s = 0.128^{+0.057}_{-0.043}\,ps^{-1}$$

  - Both Γ_s and $\Delta\Gamma_s$ from $\overline{B}_s^0 \to J/\Psi\phi$

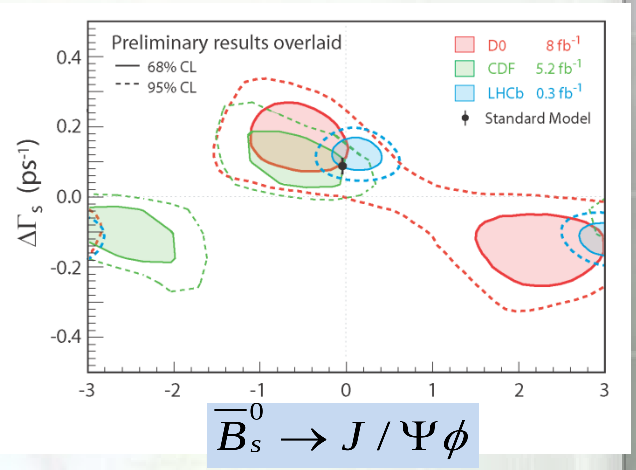
$$\phi_s^{J/\Psi f_0} = -0.44 \pm 0.44 \pm 0.02\,rad$$



- Combination of both channels,

[LHCb-CONF-2011-056]

$$\phi_s = -0.03 \pm 0.16^{stat} \pm 0.07^{sys}\,rad$$



LHCb data are well consistent. So far - no evidence for new physics

Charm sector: search for time integrated CP-asymmetry in $D^0 \to h^+h^-$ decays

- Charm sector: up to now no evidence for CP-violation has been found
- Three types of CP-violation:
  - in mixing, different rate of $D^0 \to \overline{D}^0$ and $\overline{D}^0 \to D^0$
  - in decay: amplitudes of process and its conjugate differ
  - in interference: between mixing and decay diagrams
- Physics beyond SM can contribute to both direct and indirect parts up to O(%)

Indirect component (in mixing)
SM: universal for CP eigenstates and expected to be very small (« $O(10^{-3})$)

Direct component (in decay and in interference)
SM: depends on final state, expected to be $O(10^{-3})$ or less

Charm sector: search for time integrated CP-asymmetry in $D^0 \to h^+h^-$ decays

- LHCb: the measurement of the difference in integrated CP asymmetries between $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$. If D^0 is reconstructed as a part of $D^{*+} \to D^0 \pi^+$ decay chain, than:

$$A_{RAW}(f)^* \equiv \frac{N(D^{*+} \to D^0(f)\pi^+) - N(D^{*-} \to \overline{D}^0(\overline{f})\pi^-)}{N(D^{*+} \to D^0(f)\pi^+) + N(D^{*-} \to \overline{D}^0(\overline{f})\pi^-)}$$

$$A_{RAW}(f)^* = A_{CP}(f) + A_D(f) + A_D(\pi_{soft}) + A_P(D^{*+})$$

$$A_{CP}(f) \approx a_{CP}^{dir}(f) + \frac{<t>}{\tau} a_{CP}^{indir}$$

where $A_{CP}(f)$ is intrinsic physics CP asymmetry, $A_D(f)$ is the asymmetry for selecting $D^0 \to f$, $A_D(\pi_{soft})$ is the asymmetry for selecting the soft pion in D^{*+} decay, $A_P(D^{*+})$ is the production asymmetries for prompt D^{*+},

<t> - is the average proper time in the sample used, τ – true D^0 lifetime

- Difference $\Delta A_{CP} = A_{RAW}(K^+K^-)^* - A_{RAW}(\pi^+\pi^-)^*$ **cancels** all **systematics** as well as **sensitive** (almost) **only to the direct CPV-component**:

$$\Delta A_{CP} = [a_{CP}^{dir}(K^+K^-) - a_{CP}^{dir}(\pi^+\pi^-)] + \frac{\Delta <t>}{\tau} a_{CP}^{indir}$$

Charm sector: search for time integrated CP-asymmetry in $D^0 \to h^+h^-$ decays

- LHCb **preliminary** result, using 620 pb^{-1} of 2011:

$$\Delta A_{CP} = [-0.82 \pm 0.21^{stat} \pm 0.11^{sys}]\%$$

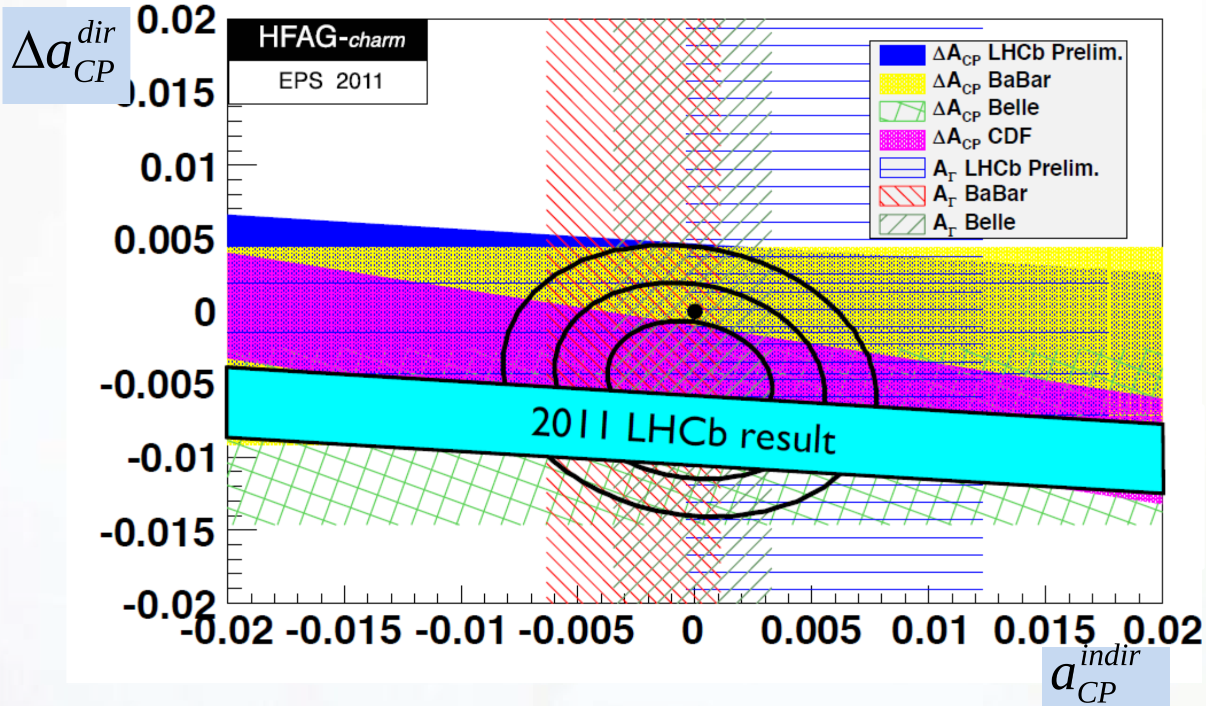
The significance is 3.5σ.

Already world's most sensitive search for CP-violation in singly-Cabibbo-suppressed charm decays. Another ~500 pb^{-1} are to be analyzed

- Contribution of indirect CP-violation mostly cancels:

$$\frac{\Delta < t >}{\tau} = \frac{< t_{KK} > - < t_{\pi\pi} >}{\tau} = (9.8 \pm 0.9)\%$$

Charm sector: search for time integrated CP-asymmetry in $D^0 \to h^+h^-$ decays



LHCb band is superimposed by hand, not HFAG approved

HFAG world-average values, taking into account LHCb lifetime acceptance and neglecting correlations in world-average values:

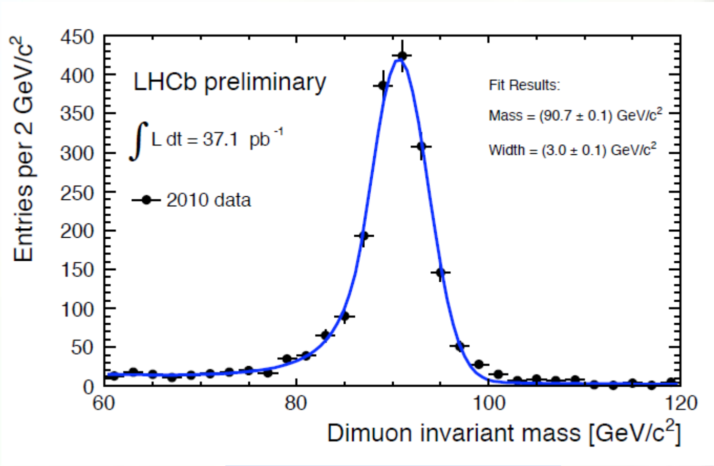
$$\Delta A_{CP} = \Delta a_{CP}^{dir} + \frac{\Delta < t >}{\tau} a_{CP}^{indir} = (-0.45 \pm 0.27)\%$$

LHCb value is ~1σ away

More details on analysis: HCP2011 presentation "Search for CP violation in two-body charm decays at LHCb" by Mat Charles (14/11/2011)

Electroweak sector: W and Z production

- W/Z cross-sections: up to 10% uncertainty in theoretical predictions mostly coming from parton distribution functions. LHCb can help to constrain PDFs
- Present LHCb measurements (2)



$Z \rightarrow \mu^+\mu^-$

(pt(lepton)>20, 2.<η(lept)<4.5, 60<M(Z)<120 GeV)

37.1 pb^{-1} (2010)

[LHCb-CONF-2011-039]

$$Z \rightarrow \mu^+\mu^-$$

$$W \rightarrow \mu\nu$$

37.5 pb^{-1} (2010) + 210 pb^{-1}(2011)

[LHCb-CONF-2011-041]

$$Z \rightarrow \tau\tau \rightarrow (\mu\nu\nu)(\mu\nu\nu)$$

$$Z \rightarrow \tau\tau \rightarrow (\mu\nu\nu)(e\nu\nu)$$

Electroweak sector: W and Z production

- **Z→μ⁺μ⁻**

$$\sigma(Z \to \mu\mu) = 74.9 \pm 1.6^{stat} \pm 3.8^{sys} \pm 2.6^{lumi}\ pb$$

- **Z→τ⁺τ⁻**

$$\sigma(Z \to \tau\tau, e\mu) = 79 \pm 9^{stat} \pm 8^{sys} \pm 4^{lumi}\ pb$$

$$\sigma(Z \to \tau\tau, \mu\mu) = 89 \pm 15^{stat} \pm 10^{sys} \pm 5^{lumi}\ pb$$

$$\sigma(Z \to \tau\tau, comb) = 82 \pm 8^{stat} \pm 7^{sys} \pm 4^{lumi}\ pb$$

- **W→μν**

$$\sigma_{W^+}(+) = 808 \pm 7^{stat} \pm 28^{sys} \pm 28^{lumi}\ pb$$

$$\sigma_{W^-}(-) = 634 \pm 7^{stat} \pm 21^{sys} \pm 22^{lumi}\ pb$$

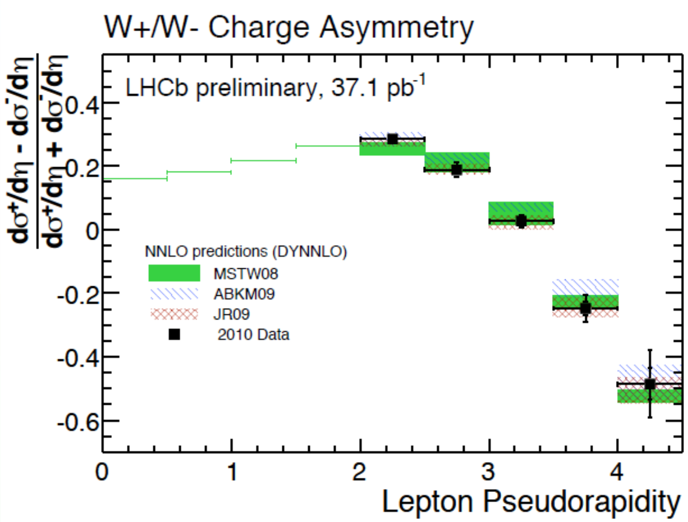
$$\sigma_{W^+}(+)/\sigma_{W^-}(-) = 1.28 \pm 0.02 \pm 0.01$$

- **Combined:**

$$\frac{\Gamma(Z \to \tau\tau)}{\Gamma(Z \to \mu\mu)} = 1.09 \pm 0.17$$

$$\sigma_{W^+}(+)/\sigma_{W^-}(-) = 1.28 \pm 0.02 \pm 0.01$$

$$(\sigma_{W^+}(+) + \sigma_{W^-}(-))/\sigma_Z = 19.3 \pm 0.5 \pm 0.8$$



- **Mutual consistence**
- **Consistence with NNLO predictions**
- **Ratio Γ(Z→ττ)/Γ(Z→μμ) is consistent with lepton universality**
- **Inclusion of LHCb W-asymmetry data in PDFs already caused slight reduction of uncertainty in the large x-region: from 18% to 13%**

[M. Ubiali, Assessment of the impact of LHC W lepton asymmetry data on PDF fits, 04/05/11, Working Group on Electroweak precision measurements at LHC]

Conclusions

- LHCb has been successfully running during 2010-2011 period with very good detector and trigger performance collecting more than 1. fb^{-1} of physics data in 2011
- Using only 2010 + ~1/3 of 2011 statistics LHCb obtained the results competitive with Tevatron and B-factories and also did several world's most precise measurements. So far results are in agreement with SM.
- With full statistics processed it will be possible to improve the accuracy of current measurements and to access other interesting processes / observables
- LHCb physics program includes a lot of interesting topics which were not discussed in this presentation:
  - Tomorrow: $b\bar{b}$ quarkonia production at LHCb
  - Tomorrow: B_c -production at LHCb
  - For the rest: please visit LHCb web-portal http://lhcb.web.cern.ch/lhcb/