LHCb experiment: status and selected results

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On behalf of the LHCb Collaboration

Outline

1. **Introduction to the LHCb Experiment**
2. **Running Conditions in 2011**
3. **Detector performance**
4. **Selected Physics Results**
   - Search for $B_s^0 \to \mu\mu$
   - Measurement of ϕ_s
   - Direct CPV in $D \to KK\pi$
5. **Summary**

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5. Summary

The Physics of LHCb Experiment

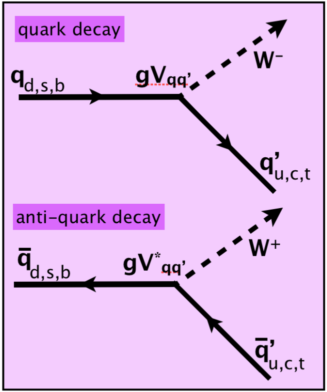
A dedicated experiment to study heavy flavour physics at the LHC

Focus on (indirect) searches for New Physics in CPV and rare decays:

- CP violation is one of the ingredients necessary for the generation of the baryon asymmetry observed in the universe
- Within the SM:
  - ✓ CP is only violated in the flavor changing processes (FCP)
  - ✓ All the CPV observables in terms of 4 parameters (1 single phase) - CKM
  - ✓ It is much too tiny to explain the observed baryon asymmetry
- New sources of CP violation are needed ➠ might show up in FCP
- In order to identify possible new sources, need excellent control of SM contributions

CP Violation in the Standard Model

- mass $\neq$ weak int. eigenstates ➠ quark mixing matrix V_{CKM}

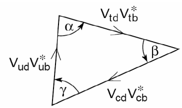


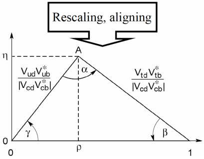
$$\mathbf{V}_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \qquad V_{CKM} \equiv \begin{pmatrix} 1 & 1 & e^{-i\gamma} \\ 1 & 1 & 1 \\ e^{-i\beta} & 1 & 1 \end{pmatrix}$$

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

- ➠ η: one single CPV phase in the SM
- ➠ unitarity ➛ triangles in the complex plane

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



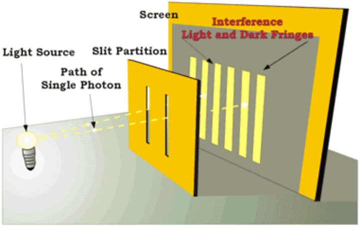


CP Violation: how do we observe ?

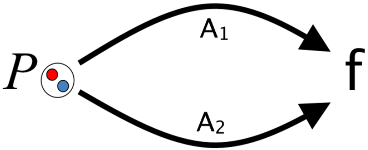
- comparing decay rates of particles and anti-particles:

$$\Gamma(P \to f) \neq \Gamma(\bar{P} \to \bar{f}) \Rightarrow CPV$$

- counting experiments $A_{CP} = \frac{\Gamma(P\to f)-\Gamma(\bar{P}\to\bar{f})}{\Gamma(P\to f)+\Gamma(\bar{P}\to\bar{f})}$
- observation of CPV is consequence of quantum interference among different amplitudes (*paths*)



classical double-slit interference



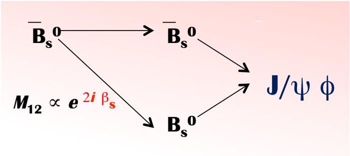
quantum *double-slit* interference

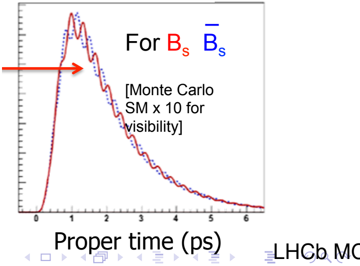
CP Violation: how do we observe ?

- comparing decay rates of particles and anti-particles:

$$\Gamma(P \rightarrow f) \neq \Gamma(\bar{P} \rightarrow \bar{f}) \Rightarrow CPV$$

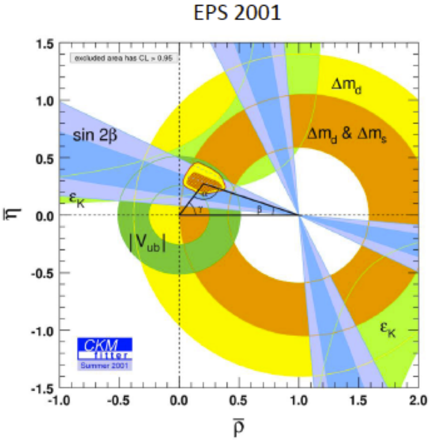
- counting experiments $A_{CP} = \frac{\Gamma(P\rightarrow f)-\Gamma(\bar{P}\rightarrow\bar{f})}{\Gamma(P\rightarrow f)+\Gamma(\bar{P}\rightarrow\bar{f})}$
- observation of CPV is consequence of quantum interference among different amplitudes (*paths*)
- neutral mesons oscillate ➛ CP asymmetry is time dependent !





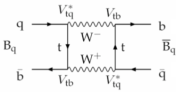
CP violation measurements

- Small CPV effects in K decays
- Large CPV in B decays
- Not yet observed in **charm** decays

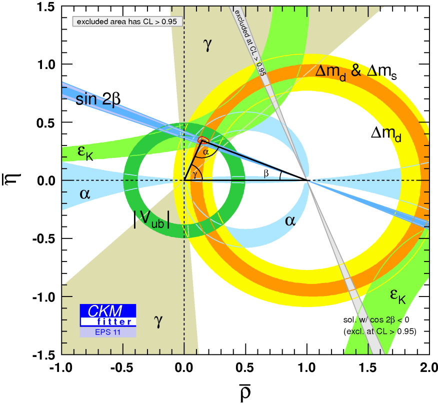


CP violation measurements

- Small CPV effects in K decays
- Large CPV in B decays
  - Excellent work by B factories and D0/CDF (and lattice QCD)
  - Still a lot to be done (γ and B_s^0)
- Not yet observed in **charm** decays
- So far, everything consistent with CKM
- There is still room for NP
  - comparing measurements which are sensitive to NP phases (*loop* diagrams)

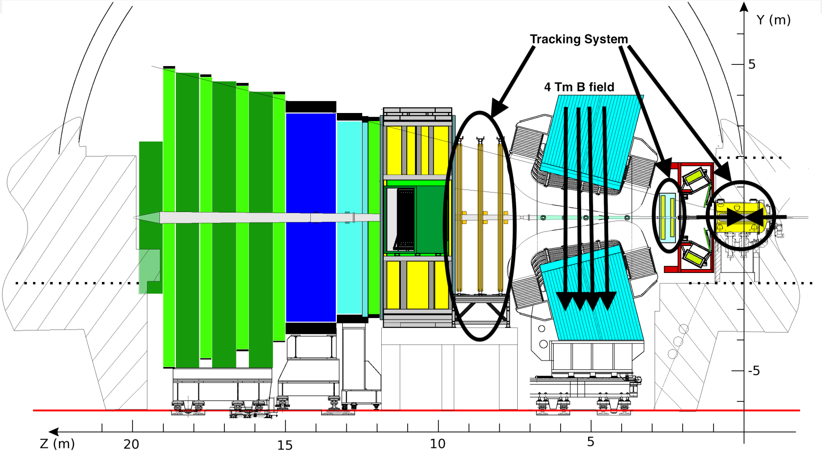


  - *loop* diagrams also appear in rare decays (modifying SM predictions)



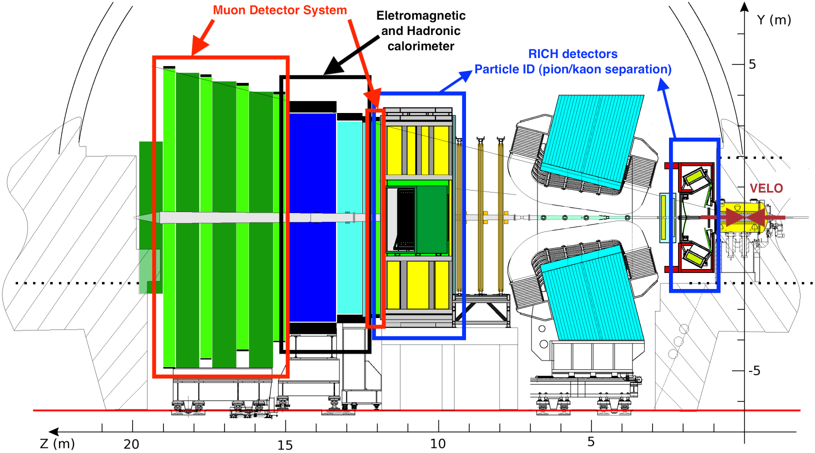
- main focus of LHCb
  indirect searches in contrast to *direct* searches by ATLAS and CMS

The LHCb Detector

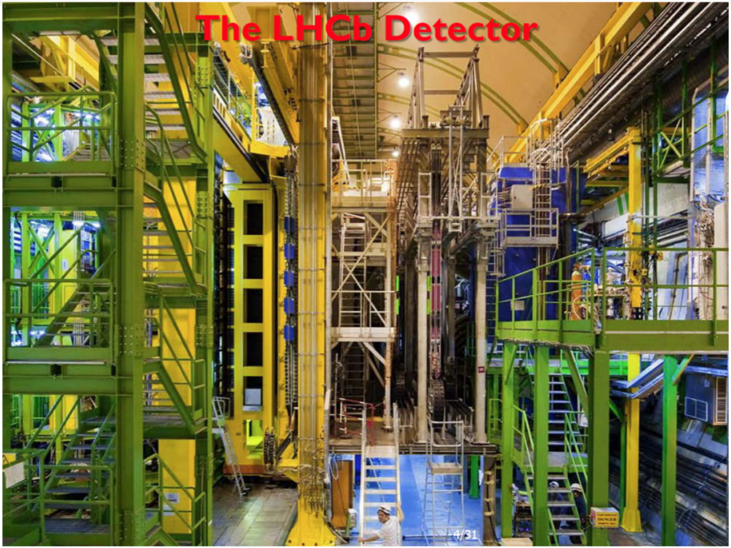


Forward spectrometer to exploit forward-peak production
Total $\sigma_{b\bar{b}}$ = 284$\pm$53 μb at the LHC [PLB 694 209]
$\sim$ 100,000 $b\bar{b}$ pairs/second (10^4 B factories !)
20 $\times$ more charm [CONF-2010-013]

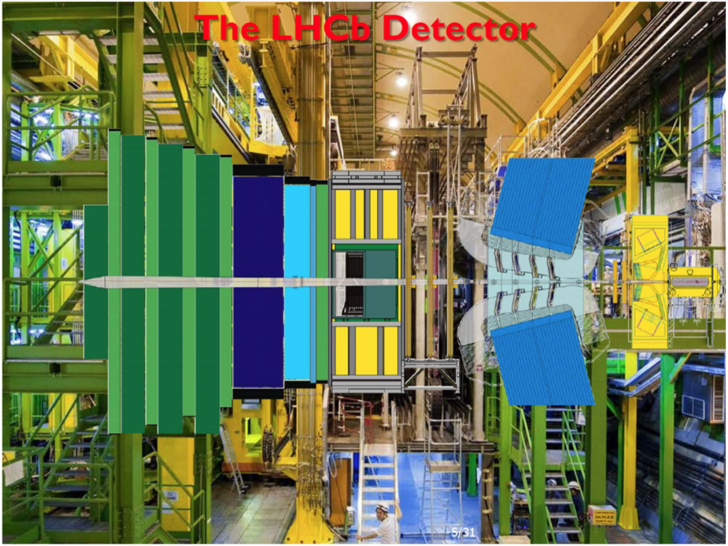
The LHCb Detector



Visit to the cavern



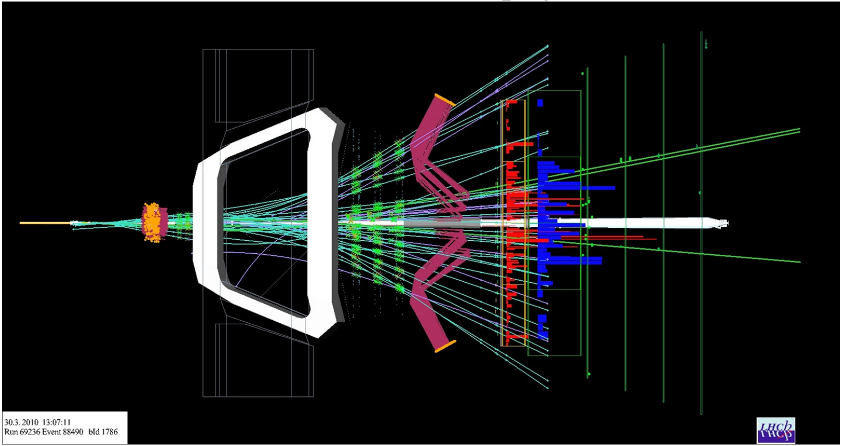
Visit to the cavern



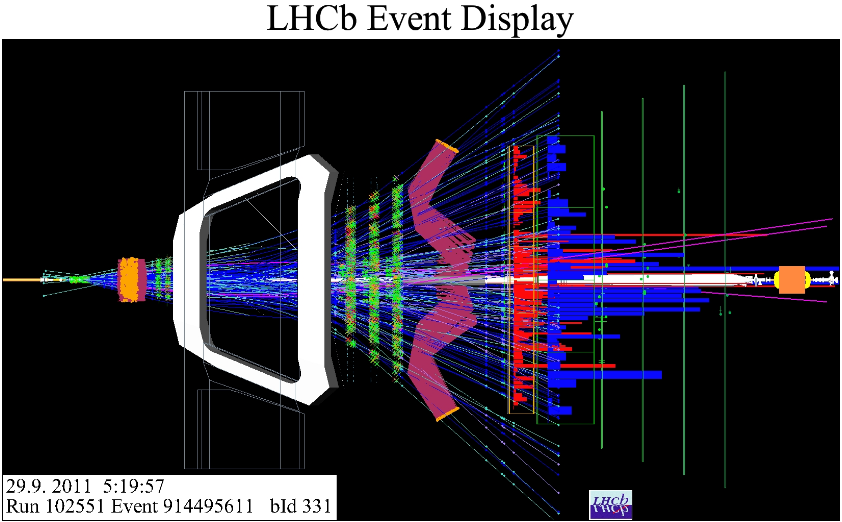
Collaboration

Typical events

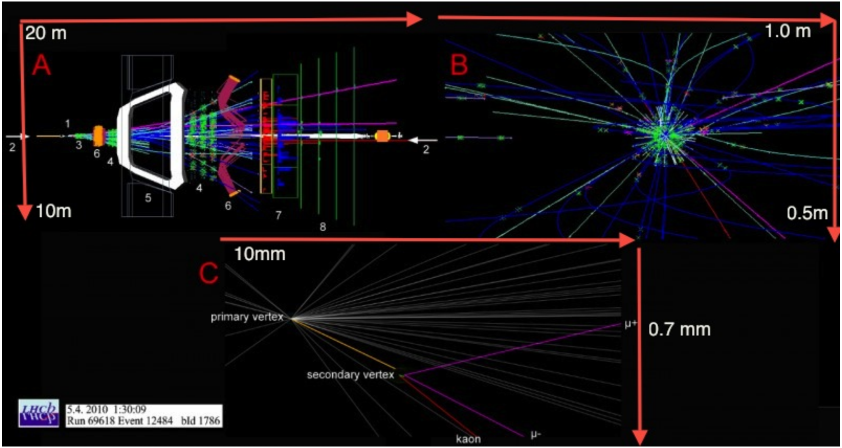
LHCb Event Display



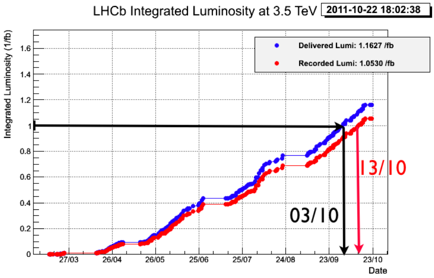
Typical events



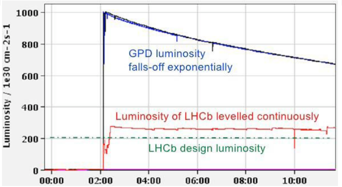
More details on a typical event



Luminosity and Pile-Up

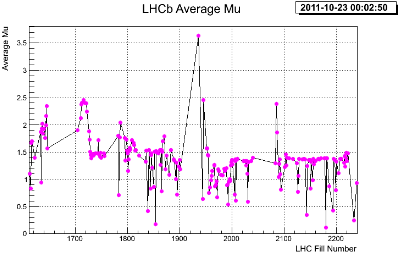


1 fb^{-1} goal acomplished on October 13th!



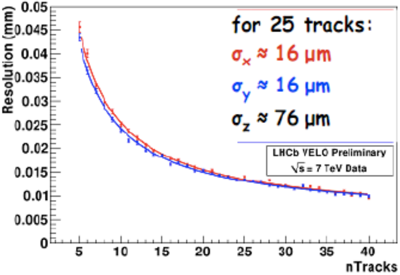
automatic tuning of offset of colliding beams

allows luminosity levelling



Already operating at $\sim$1.75$\times$ design luminosity and $\sim$ 3.5μ (visible interactions)

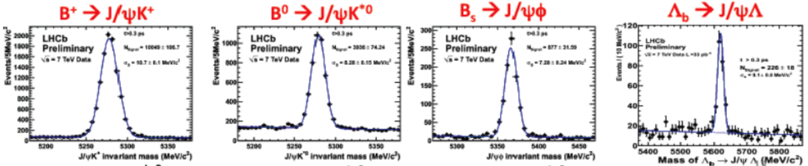
Vertex Locator (VELO)



- Primary Vertex: 16 μm in x and y
- Impact Parameter: 14.4 μm + 19.5/pT μm
- Only 8 mm from the beam, must be retracted during injection !
- Proper time resolution: $< \tau >$ 50 fs

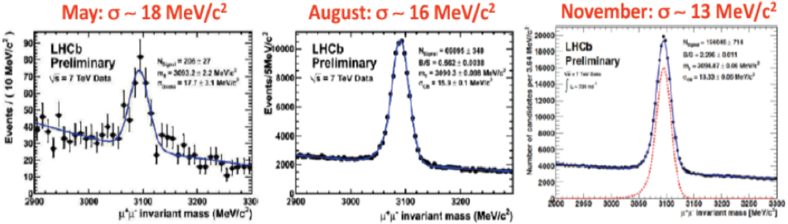
VELO: highest resolution vertex detector at LHC

Tracking System and Mass resolutions



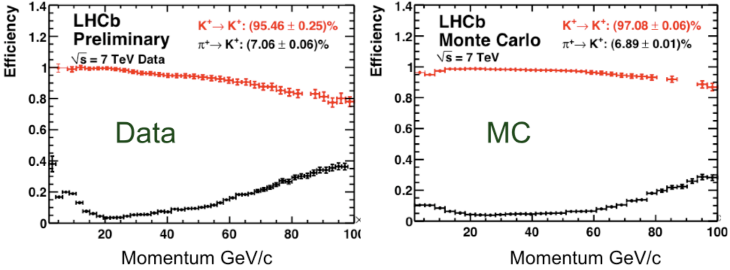
σ~11 MeV/c² σ~8 MeV/c² σ~7 MeV/c² σ~9 MeV/c²

Evolution of J/ψ → μ⁺μ⁻ mass resolution with time (MC ~ 12 MeV/c²)

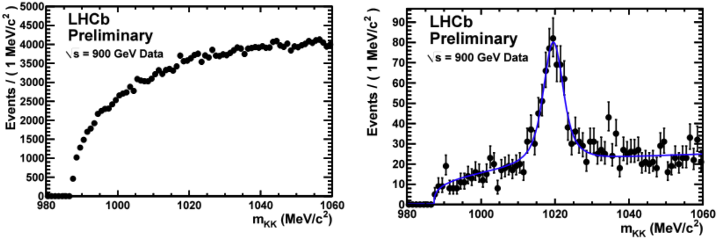


Momentum resolution $\frac{\sigma_p}{p} = 0.4\text{-}0.8\ \%$

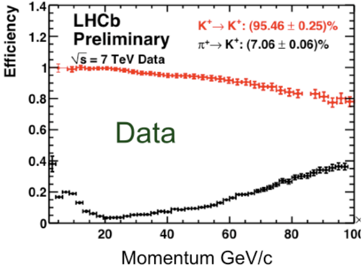
Particle ID: RICH detectors



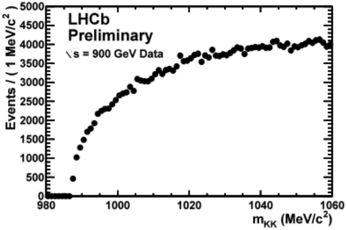
$\phi \to K^+ K^-$



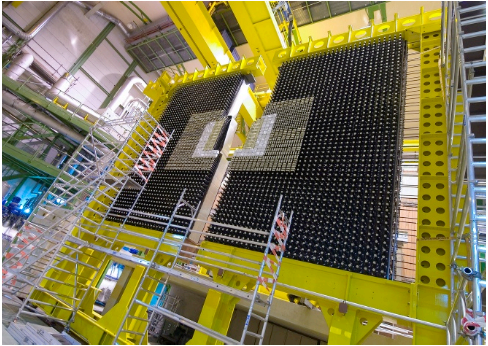
Particle ID: RICH detectors



$\phi \rightarrow K^{+}$

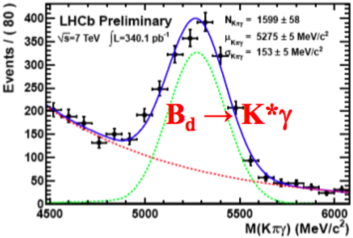


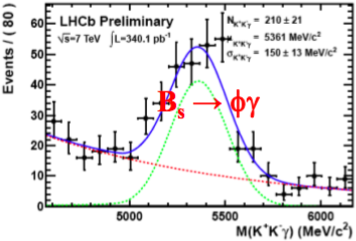
Particle ID: Calorimeter



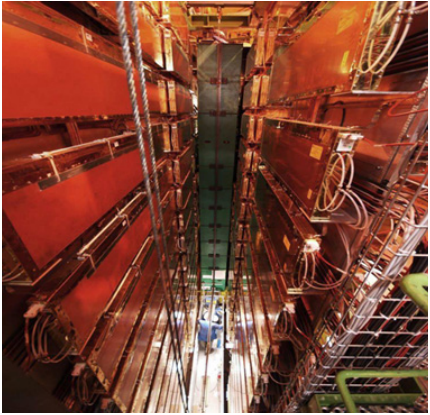
$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B^0_s \to \phi\gamma)} = 1.52 \pm 0.14(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.12(f_s/f_d)$$

[LHCb-CONF-2011-055]

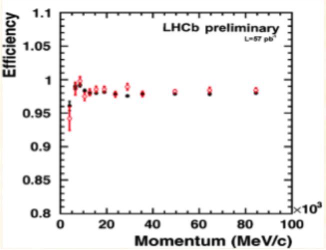


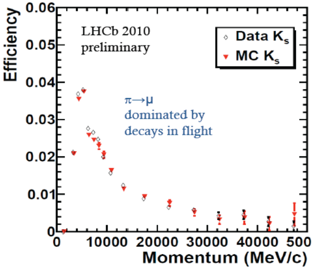


Particle ID: Muon Identification



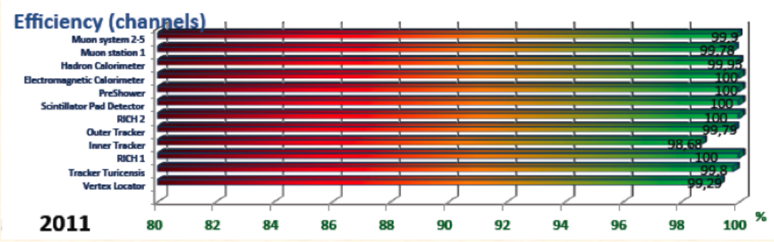
MWPC/GEM
126k front-end channels
97% muon efficiency
<2% pion misid



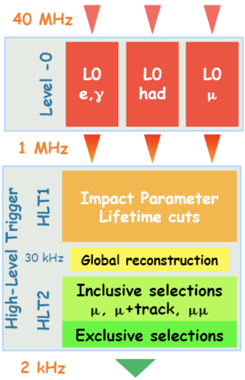


Overall Detector performance

All Sub-detectors are > 98% active



Trigger



- Level-0 in hardware
  on p_T of e, μ, h to reduce rate to 1 MHz
  Typical thresholds: 1–3 GeV
- High Level Trigger in software
  HLT efficiencies high ($>$ 80 %)
- Typical overall L0 $\times$ HLT efficiencies:
  30 % (multibody hadronic) – 90% (dimuons)

LHCb published results:

Published papers (R. Aaij *et al.* [LHCb Collaboration]):

- "Observation of J/ψ pair production in pp collisions at $\sqrt{s} = 7 TeV$,"
  $[arXiv : 1109.0963[hep - ex]]$ (accepted by Phys. Lett. **B**).
- "Measurement of the inclusive phi cross-section in pp collisions at sqrt(s) = 7 TeV,"
  Phys. Lett. **B703** (2011) 267-273.
- "Measurement of V^0 production ratios in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV,"
  JHEP **1108** (2011) 034.
- "Determination of f_s/f_d for 7 TeV pp collisions and a measurement of the branching fraction of the decay $B_d \rightarrow D^- K^+$,"
  $[arXiv : 1106.4435[hep - ex]]$ (accepted by PRL).
- "Search for the rare decays Bs$\rightarrow$ mumu and Bd$\rightarrow$mumu,"
  Phys. Lett. **B699** (2011) 330-340.
- "Measurement of J/psi production in pp collisions at sqrt(s)=7 TeV,"
  Eur. Phys. J. **C71** (2011) 1645.
- "First observation of $B_s \rightarrow D_{s2}^{*+} X \mu\nu$ decays,"
  Phys. Lett. **B698** (2011) 14-20.
- "First observation of $B_s \rightarrow J/\psi f_0(980)$ decays,"
  Phys. Lett. **B698** (2011) 115-122.
- "Measurement of $\sigma(pp \rightarrow b\bar{b}X)$ at $\sqrt{s} = 7$ TeV in the forward region,"
  Phys. Lett. **B694** (2010) 209-216.
- "Prompt K_s production in pp collisions at sqrt(s)=0.9 TeV,"
  Phys. Lett. **B693** (2010) 69-80.

Calibration of our source: production, searches or first observations

+60 contributions to conferences, half of which should be transformed to papers until end of year

Selected Results

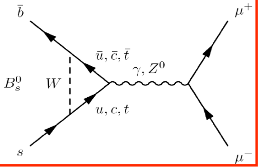
- Search for $B_s^0 \rightarrow \mu\mu$
- Direct CPV in $D \rightarrow KK\pi$
- Measurement of ϕ_s

$B^0_{s,d} \to \mu^+\mu^-$ Motivation

- Decay is in the SM only allowed via FCNC.
- Helicity suppressed
- BR($B_s \to \mu^+\mu^-$) = $(3.2 \pm 0.2) \cdot 10^{-9}$

  BR($B^0 \to \mu^+\mu^-$) = $(1.0 \pm 0.1) \cdot 10^{-10}$

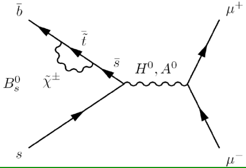
  [A.J.Buras,arXiv:1012.1447/Phys. Rev. D 80 (2009) 014503]



- Sensitive to New Physics (e.g. MSSM)

$$c_{S,P}^{MSSM} \propto \frac{m_b \cdot m_\mu \cdot \tan^3 \beta}{M_A^2}$$

- Probing models with extended Higgs sector



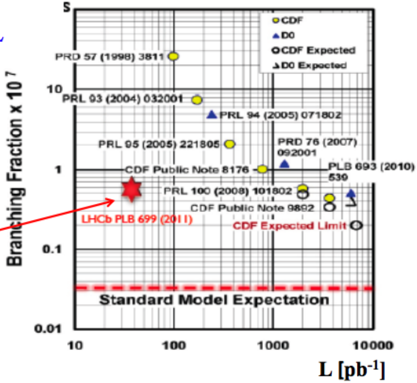
Very sensitive to new physics, in particular SSM with large tanβ

$B_s^0 \to \mu^+\mu^-$ Status before EPS2011

Published $B_s \to \mu\mu$ limits @ 95% CL

Experiment	Data set	Limit
CDF	3.7 fb^{-1}	4.3 x 10^{-8}
D0	6.1 fb^{-1}	5.1 x 10^{-8}
LHCb	0.036 fb^{-1}	5.6 x 10^{-8}

LHCb (Phys. Lett. B699 (2011) 330)
equivalent to CDF with
~100 times less luminosity



July 2011: CDF presents new result (7 fb^{-1} [arXiv:1107:2304])

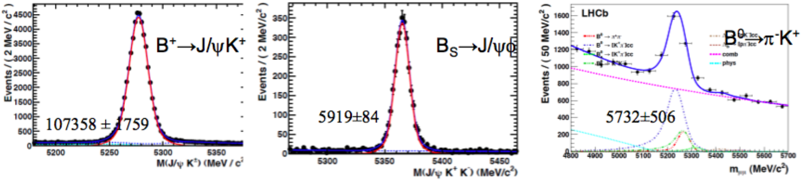
- 2.8σ deviation from background only hypothesis BR=$(1.8^{+1.1}_{-0.9}) \times 10^{-8}$
- 1.9% compatibility with background+SM hypothesis

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

- $\mathrm{BR}(B_s \to \mu\mu) = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{cal}}{\epsilon_{sig}} \times \frac{N_{sig}}{N_{\mathrm{cal}}} = \alpha_{cal} * N_{sig}$
- Define normalization channel(s)
- Define selection criteria (signal and normalization)
- Estimate efficiencies (signal and normalization)
- Measure yields and calculate BR
- If no clear signal observed:
  - estimate expected $N_{sig}(BR) = \frac{BR}{\alpha_{cal}}$
  - estimate expected N_{bg} in signal region
  - compute upper limit according to compatibility to observed number of events [J. Phys. G 28 (2002) 2693]

$B_s^0 \to \mu^+\mu^-$ Strategy: normalization factors

Normalization factors



Normalization channel branching

Fragmentation ratio $f_s/f_d = 0.267^{+0.021}_{-0.020}$ *combined LHCB measurements

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon^{\mathrm{REC}}_{\mathrm{cal}}\,\epsilon^{\mathrm{SEL|REC}}_{\mathrm{cal}}\,\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{cal}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\,\epsilon^{\mathrm{SEL|REC}}_{\mathrm{sig}}\,\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{sig}}} \times \frac{f_{\mathrm{cal}}}{f_{B_q^0}} \times \frac{N_{B_q^0\to\mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha_{\mathrm{cal}} \times N_{B_q^0\to\mu^+\mu^-}$$

Calculated from MC

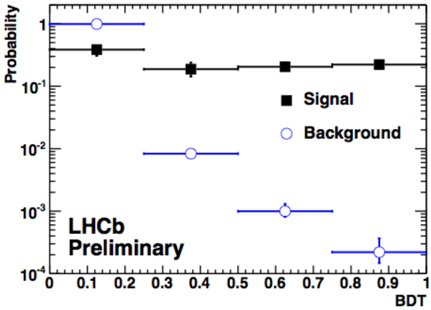
Measured from data

Number of events in normalization channel

$\alpha = 0.966 \pm 0.096$ $\alpha = 1.27 \pm 0.35$ $\alpha = 0.92 \pm 0.22$

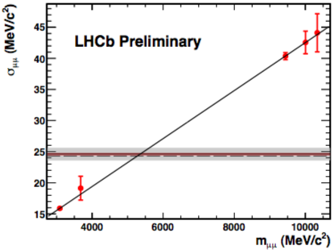
$B_s^0 \to \mu^+\mu^-$ Strategy: BDT calibration

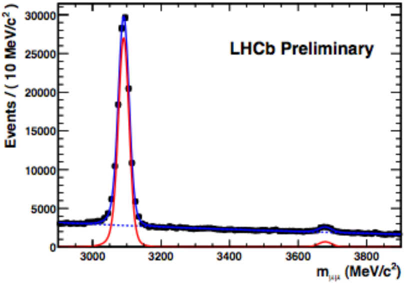
- Expected Background and Signal yields estimated in 2D ($\mu\mu$ mass vs BDT) plane
- BDT: multivariate estimator combining vertex and geometrical variables
  - BDT optimization using MC
  - Calibration using data
    ✓$B \to h^+h^-$ for signal
    ✓sidebands for background

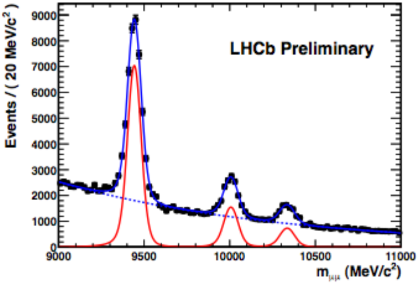


$B_s^0 \to \mu^+\mu^-$ Strategy: mass calibration

- Crystal Ball shape with average value from $B_s^0 \to K^+K^-$
- Resolution interpolated from $c\bar{c}$ and $b\bar{b}$ states



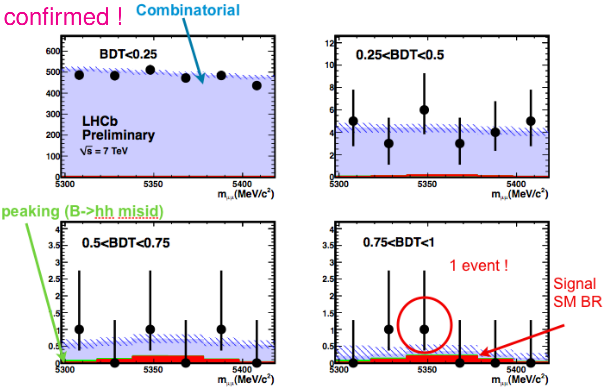




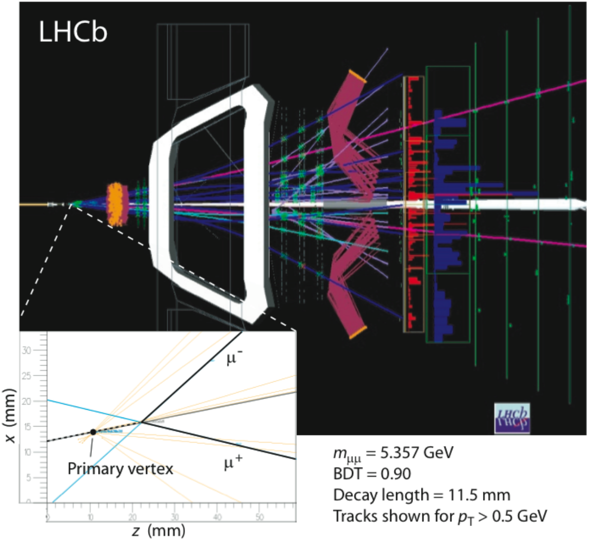
$B_s^0 \to \mu^+\mu^-$ Results (LHCb)

Upper limits at 95% CL:

- LHCb: BR$< 1.5 \times 10^{-8}$ (0.3 fb^{-1}) [LHCb-2011-037]
- CMS: BR$< 1.9 \times 10^{-8}$ (1.1 fb^{-1})
- LHCb+CMS Combined: BR$< 1.1 \times 10^{-8}$ [LHCb-2011-047,CMS-PAS-BPH-11-019]
- CDF Excess over SM not confirmed !



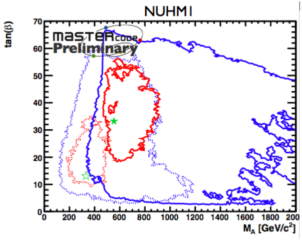
Our best candidate



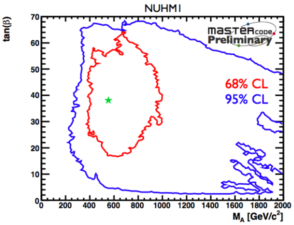
$m_{\mu\mu} = 5.357$ GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for $p_T > 0.5$ GeV

Impact of $B_s^0 \to \mu^+\mu^-$ Results

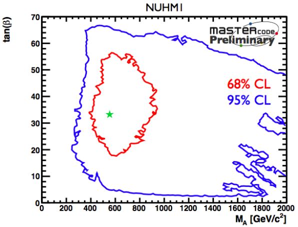
As an example: F. Ronga at the Workshop *LHC results for TeV scale physics* CERN, August 2011



First LHC data



Direct searches only



$B_s \to \mu\mu$ included [1]

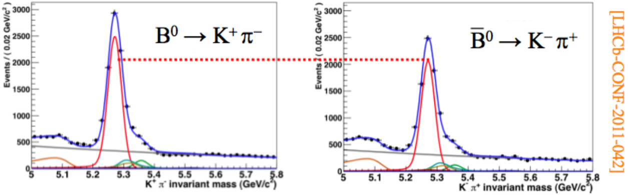
while direct searches push towards large *tan*β, $B_s \to \mu\mu$ pushes back to lower values

[1] MasterCode (J. Ellis et al.) (http://www.cern.ch//mastercode)

Direct CP Violation in B decays

Using the particle identification capability of LHCb, can isolate clean samples of the different decays contributing to 2-body $B \to h^+h^-$ ($h = \pi$, K, p)

$B^0 \to K^+\pi^-$: *direct* CP violation (in decay) clearly visible in raw distributions



Corrections required for detector and production asymmetries controlled using $D^0 \to K^-\pi^+$, $B^0 \to J/\psi K^{*0}$ samples: percent-level effects

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

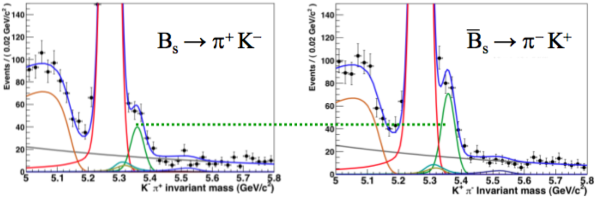
in good agreement with world average: $-0.098 \pm ^{0.012}_{0.011}$

Most precise, and first 5σ observation of CP violation in hadronic machine

Borrowed from *R. Forty on behalf of LHCb Collaboration, ICATPP, Como, 3–7 October 2011*

Direct CP Violation in B decays

Adjusting the selection, can enhance the $B_s \to \pi^+ K^-$ contribution
$\to$ First 3σ evidence for CP asymmetry in B_s decays



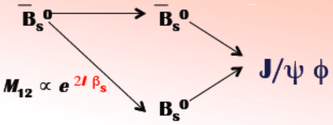
$A_{CP}(B_s \to \pi^+ K^-) = 0.27 \pm 0.08 \pm 0.02$

Eventual goal to measure time-dependent asymmetries *eg* $B_{(s)} \to \pi^+\pi^-, K^+K^-$
$\to$ determine CKM angle γ from *loop* decays

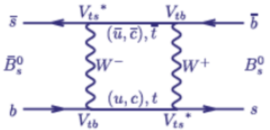
Compare to many other γ measurement from *tree* decays (*eg* $B_{(s)} \to D_{(s)}K$)
$\to$ determine any contribution from new physics

Borrowed from *R. Forty on behalf of LHCb Collaboration, ICATPP, Como, 3–7 October 2011*

CP violation in the interference between mixing and decay



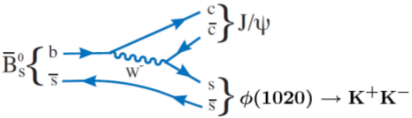
- Analogue of sin(2β) measurement in the B_s
- SM: dominated by mixing (V_{ts} in box diagram)
  - well predicted : $\phi_s = -0.036 \pm 0.002$
  - very close to zero
- NP can introduce large phases
- Fit decay rates for B_s^0 and $\bar{B}_s^0$



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

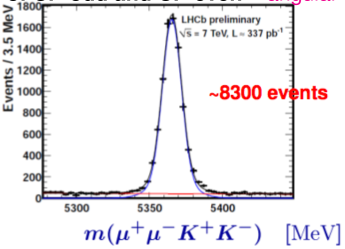
Measurement in LHCb

- two most interesting modes



- narrow φ resonance --> clean
- vector-vector final state ("P-wave")

mixture of CP-odd and CP-even ➠angular analysis



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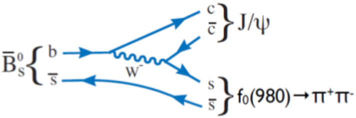
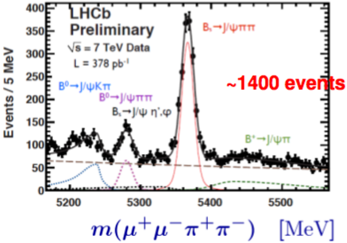


- first seen by LHCb, last winter
  - predicted by Stone and Zhang ('07)
  - BF about 20% of Bs->J/ψφ

CP-odd



LHCB-CONF-2011-051

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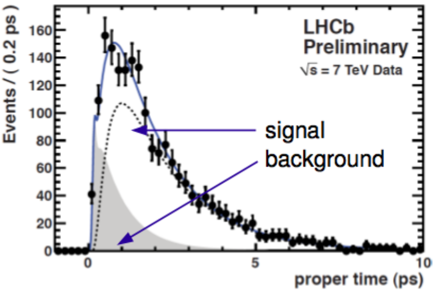
Borrowed from W. Hulsbergen (Nikhef) *on behalf of the LHCb collaboration*

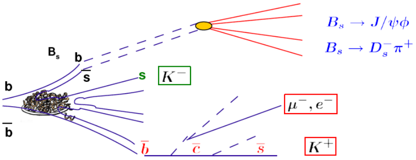
Maximum likelihood fit for $B_s \to J\psi f_0$

- fit to mass, time and flavour tag
- fit for **2** physics parameters
  - $\Delta\Gamma_s$, ϕ_s
  - Γ_s: taken from $B_s \to J/\psi\phi$
  - Δm_s: taken from $B_s \to D_s\pi$



$$\frac{d\Gamma(B \to f)}{dt} = N_f e^{-\Gamma t}\left[\cosh\left(\frac{\Delta\Gamma t}{2}\right) - \eta_f \cos(\phi_s)\sinh\left(\frac{\Delta\Gamma t}{2}\right) \mp \underbrace{\eta_f \sin(\phi_s)\sin(\Delta m\, t)}_{\text{CP asymme}}\right]$$

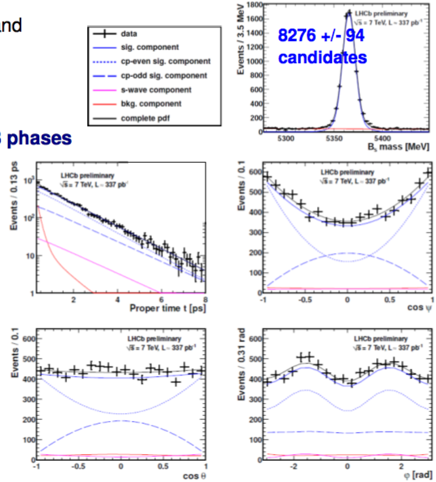
acceptances and resolutions taken into account as well as flavour tag dilutions



Maximum likelihood fit for $B_s \to J\psi\phi$

- MLL fit to mass, time, angles and flavour tag decision
- fit for **9** physics parameters
  - **amplitudes: 3 sizes and 3 phases**
  - Γ_s, $\Delta\Gamma_s$, ϕ_s
- Δm_s taken from $B_s \to D_s\pi$
- goodness of fit, using "point-to-point dissimilarity test" (*) gives P-value of 0.44

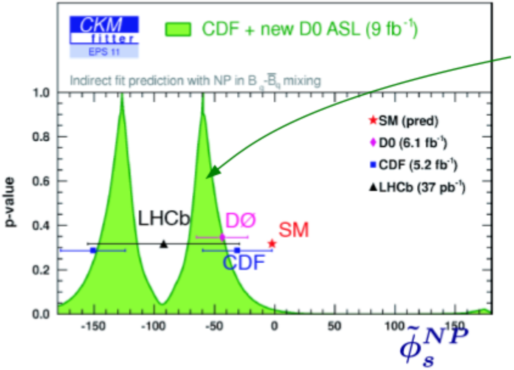
(*) see eg. M. Williams, JINST 5 (2010) P09004 [arXiv:1006.3019 [hep-ex]]

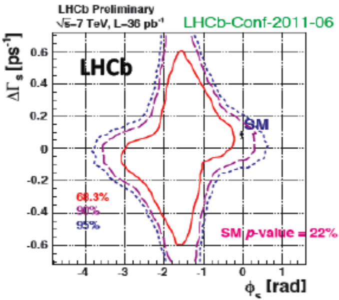


Borrowed from W. Hulsbergen (Nikhef) *on behalf of the LHCb collaboration*
More details given by R.M. Villalba (Cinvestav) - D0 measurement with 8fb^{-1}

Experimental Status before LP 2011

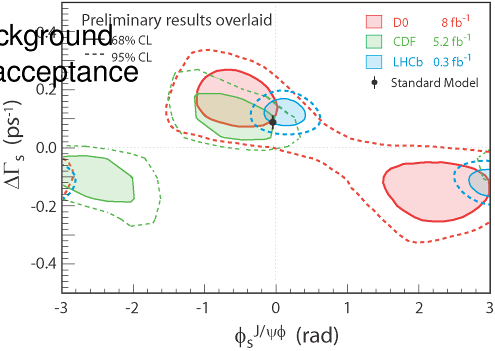
- CDF, D0 and LHCb measurements consistent with SM
- However, all of them above prediction
- Together with D0 ASL ➠ hint of NP?





Experimental status after LP 2011

- LHCb combination of $J/\psi\phi$ with $J/\psi f_0$:
  $\phi_s = 0.03 \pm 0.16 \pm 0.07$
  [LHCb-CONF-2011-056]
- Expect improvements in both statistical and systematic errors
- Main systematic from background description and angular acceptance
- No evidence for NP !
- First 4σ measurement of non-zero $\Delta\Gamma_s$



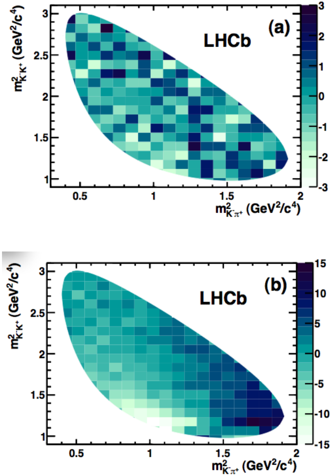
Direct CP violation in $D^{\pm} \to h^{\mp} h^{+} h^{-}$

- 2 body-decays: time dependent or time integrated counting experiments
- 3 body-decays: sum of many interfering amplitudes
  ➠ search for differences in the interference pattern across the Dalitz plot
- SM predictions for D decays difficult to compute
  ➠ null for CF decays
  ➠ $\mathcal{O}(10^{-3})$ for SCS decays [Phys. Rev. D 75 (2007) 036008]
- NP at loop level could generate enhancements up $\mathcal{O}(10^{-2})$
- Experimental status in $D^0 \to K^-\pi^+\pi^+$:
  - ➠ CLEO-C: no CPV ∼20k decays [Phys.Rev.D 78 (2008) 072003]
  - ➠ BABAR: no CPV with ∼40k decays [Phys.Rev.D 71 (2005) 091101]
  - ➠ BELLE: no CPV with ∼240k decays [arXiv:1110.0694]
    $A_{CP}(D^+ \to \phi\pi^+) = (+0.51 \pm 0.28 \pm 0.05)\%$

Model Independent Analysis

Look at the statistical significance of the asymmetry across the DP[2]

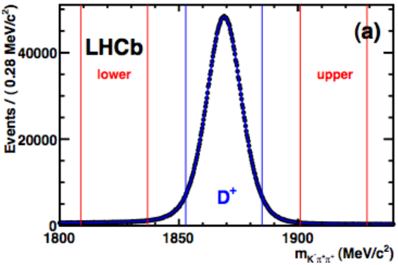
- $S_{CP} = \frac{N_+ - N_-}{\sqrt{N_+ + N_-}}$
- Distribution of S_{CP} is Gaussian in the absence of CPV
- Deviations from Gaussian ➟ evidence for CPV
- $\sum_i (S^i_{CP})^2$ is a χ^2: use p-value as a test of compatibility with NO CPV hypothesis[a]
- Toy MC Example $D \to KK\pi$
  - 4^o phase difference is introduced in the $\phi\pi$ amplitude (bottom) compared to no CPV (top)
  - large local asymmetries along the ϕ mass washed out in the integrated measurement

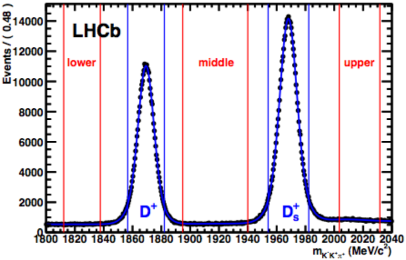


[a] [Phys.Rev.D 78 (2008) 051102]

[2] I. Bediaga *et al*, [Phys.Rev.D 90 (2009) 096006]

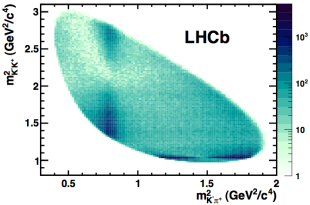
Event Yields in Signal and Control Samples



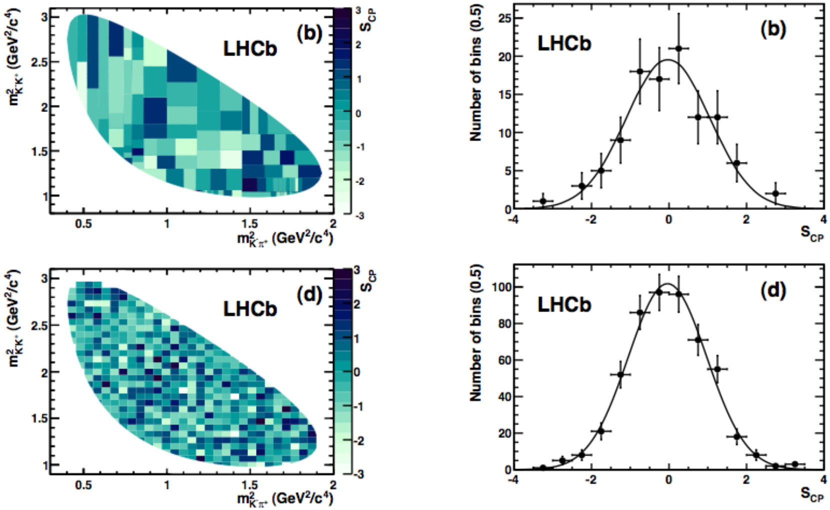


370k events signal events (37 fb^{-1})

- Magnet up and down data combined
- Control samples: CF modes and sidebands
- $D_s \to KK\pi$ ($\sim$ statistics)
  - same topology, background
- $K\pi\pi$ ($10\times$ statistics)
  - same production
- uniform and *adaptative* binnings
- no fake assymmetry detected!

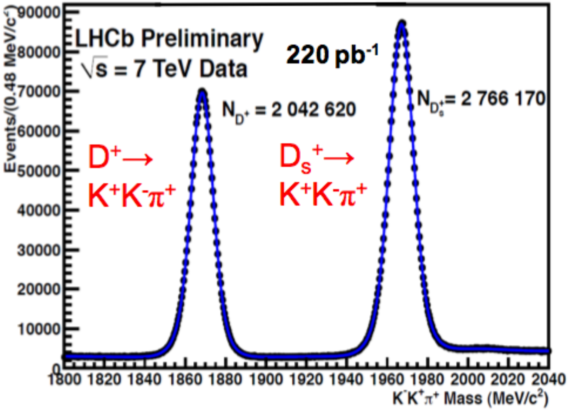


Results



No hint of New Physics in the 2010 data!

Prospects for 2011



Expect to select almost 10 M signal events with 2011 data
Also other CS and DCS suppressed modes
(charged Higgs at tree level?)

Summary

- LHCb demonstrated excellent performance in 2010/2011
- in a much higher multiplicity environment than anticipated
- all key techniques are shown to work
  - ✔ Momentum calibration for precision mass measurements
  - ✔ Particle ID
  - ✔ Flavor tagging
  - ✔ Time-dependent measurements
  - ✔ Angular analyses
- high impact results during summer
- many results not mentioned here...

Future: Upgrade

Referees' view of Physics programme:
"Case for flavour physics with 50 fb-1 compelling"

- pass from "exploration" to "precision measurements" phase
- requires reading out the whole detector in a 40 MHz rate
- require changes to detectors and readout electronics
  - VELO sensors (pixels or strips?)
  - RICH readout electronics
  - Tracking stations: straw + fiber or silicon
  - Addition of a Time of flight system
- accumulate $5fb^{-}1$ before 2017 shutdown
- installation during 2017 shutdown
- work at L=10^{33} cm^{2}s^{-}1 and $\mu \sim 2.13$

Future: Upgrade

	Exploration	Precision studies
Current LHCb	Search for $B_s \to \mu^+\mu^-$ down to SM value Search for mixing induced CP violation in B_s system $(2\beta_s)$ down to SM value Look for non-SM behaviour in forward-backward asymmetry of $B^0 \to K^*\mu^+\mu^-$ Look for evidence of non-SM photon polarisation in exclusive $b \to s\gamma^{(*)}$	Measure unitarity triangle angle γ to $\sim 4°$ to permit meaningful CKM tests Search for CPV in charm
Upgraded LHCb	Search for $B^0 \to \mu^+\mu^-$ Study other kinematical observables in $B^0 \to K^*\mu^+\mu^-$, e.g. $A_T(2)$ CPV studies with gluonic penguins e.g. $B_s \to \phi\phi$ Measure CP violation in B_s mixing (A^s_{fs})	Measure $\mathcal{B}(B_s \to \mu^+\mu^-)$ to a precision of $\sim 10\%$ of SM value Measure $2\beta_s$ to precision $< 20\%$ of SM value Measure γ to $< 1°$ to match anticipated theory improvements Charm CPV search below 10^{-4} Measure photon polarisation in exclusive $b \to s\gamma^{(*)}$ to the % level

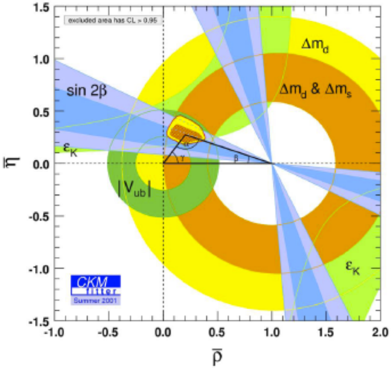
and more: lepton number violation, low mass majorana neutrinos, eletroweak and QCD.

We know NP must be there, we don't where.
Come and join us !

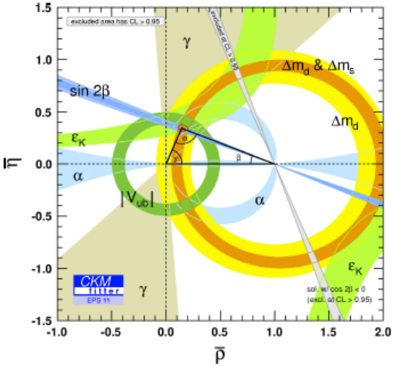
BACKUP

CKM matrix - Evolution in the last 10 years

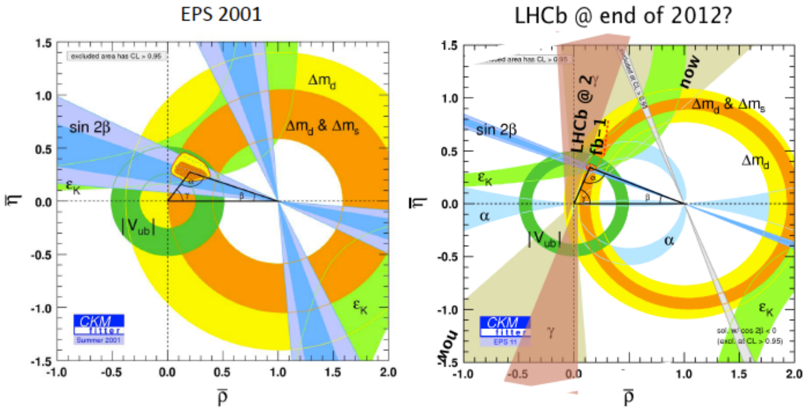
EPS 2001



EPS 2011



CKM matrix - end of next year !



LHCb can pin down the error on gamma to 10°–5° in 2011–2012

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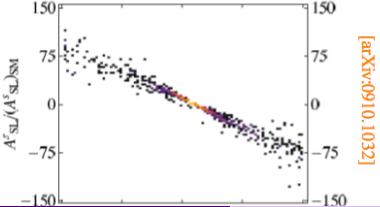
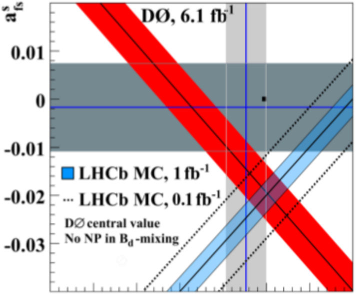
Flavour specific asymmetry

A_{SL}

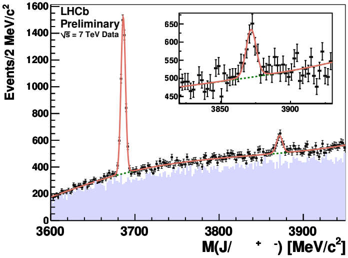
- Strong interest in semileptonic (or flavour-specific) asymmetry due to D0 result for dimuon asymmetry (comparing # of $\mu^+\mu^+$ and $\mu^-\mu^-$ events)
  $A_{SL} = (-9.57 \pm 2.51 \pm 1.46) \times 10^{-3}$ [arXiv:1005.2757] (expect $< 10^{-3}$ in SM)
- Same approach difficult at pp machine due to production asymmetries
  Instead use semileptonic decays, $B_{(s)} \to D^+_{(s)}\,(K^+K^-\pi^+)\,\mu^-\,X$
  Result from LHCb expected soon
- Note: if A_{SL} *is* large, expected to see large ϕ_s in most models

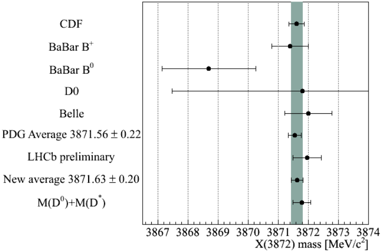




Observable	Standard Model prediction	Theory error[b]	Present result[c]	Future error[d]	Future facility
$\vert V_{us}\vert$ $(K \to \pi \ell \nu)$	Input	$0.5\% \to 0.1\%_{\rm Latt}$	0.2246 ± 0.0012	0.1%	K factory
$\vert V_{cb}\vert$ $(B \to X_c \ell \nu)$	Input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super-B
$\vert V_{ub}\vert$ $(K \to \pi \ell \nu)$	Input	$10\% \to 5\%_{\rm Latt}$	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super-B
γ $(B \to DK)$	Input	$<1°$	$(70^{+27}_{-30})°$	3°	LHCb
$S_{B_d \to \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \to \psi\phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \to \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \to \phi\phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \to K^*\gamma}$	Few $\times$ 0.01	0.01	-0.16 ± 0.22	0.03	Super-B
$S_{B_s \to \phi\gamma}$	Few $\times$ 0.01	0.01	—	0.05	LHCb
$A^d_{\rm SL}$	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
$A^s_{\rm SL}$	2×10^{-5}	$<10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \to s\gamma)$	<0.01	<0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B \to \tau\nu)$	1×10^{-4}	$20\% \to 5\%_{\rm Latt}$	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super-B
$\mathcal{B}(B \to \mu\nu)$	4×10^{-7}	$20\% \to 5\%_{\rm Latt}$	$<1.3 \times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s \to \mu^+\mu^-)$	3×10^{-9}	$20\% \to 5\%_{\rm Latt}$	$<5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \to \mu^+\mu^-)$	1×10^{-10}	$20\% \to 5\%_{\rm Latt}$	$<1.5 \times 10^{-8}$	?	LHCb
$A_{\rm FB}(B \to K^*\mu^+\mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \to K\nu\bar{\nu}$	4×10^{-6}	$20\% \to 10\%_{\rm Latt}$	$<1.4 \times 10^{-5}$	20%	Super-B

X(3872) observation





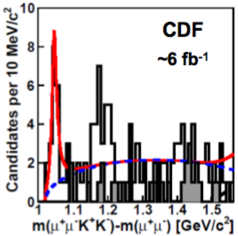
- Discovered in 2003 in Belle, was later seen in BaBar, CDF and D0
- CDF and Belle/BaBar measurements favor $J^{PC} = 1^{++}$
- $D^{*0}\bar{D}^0$ state ? Still not clear ! Tetraquark ?
- Measure mass, width and quantum numbers with 2011-2012 data
- 16000 events expected in 2011 data ($\sim$ 200 from B decay)
- LHCb: Excellent potential to contribute to “exotic”meson espectroscopy

Search for X(4140)

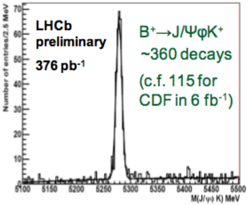
Search for the X(4140)

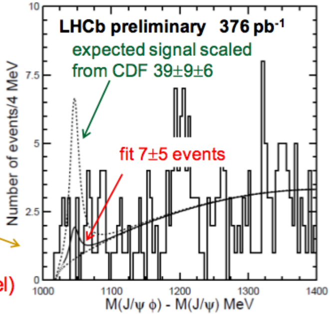
Studies of other possible exotics are underway.

CDF reported observation of narrow structure, X(4140), in the m(J/ΨK⁺K⁻)-m(J/Ψ) spectrum in $B^+ \to J/\Psi\varphi K^+$ events [arXiv:1101.6058]. LHCb now has a large sample of these decays.



LHCb-CONF-2011-045





Background model is 3- body phase space convolved with resolution

LHCb does not confirm presence of X(4140).
2.4σ tension with CDF (using this bckgd model)

And more ..

Conclusions

The 19th particles and Nuclei International Conference (PANIC11)

LHCb delivers splendid input to Soft QCD physics in the high-η region

- K_S^0 production at $\sqrt{s} = 900$ GeV
  harder p_T spectrum as compared to MC
- $\bar{\Lambda}/\Lambda$ ratio lower than Perugia 0, in particular at high y
- $\bar{\Lambda}/K_S^0$ ratio higher than Perugia 0
- $\bar{p}/p$ ratio slightly lower than Perugia 0 at $\sqrt{s} = 900$ GeV
- ϕ production at $\sqrt{s} = 7$ TeV
  above Perugia 0 in the considered kinematical range
- track multiplicity generally higher on data than on MC
  – better agreement for hard events only

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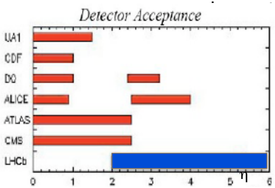
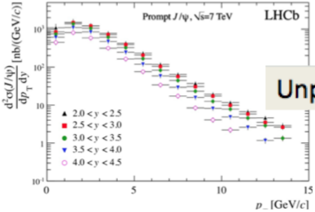
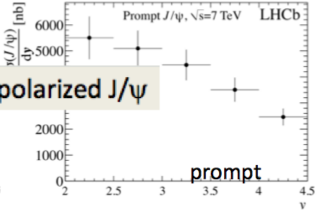
Heavy Flavour Production in LHCb

- The calculation of both quarkonia and open heavy flavour cross sections at hadron colliders within the QCD framework has been a long-standing challenge for theorists and experimentalists
- For quarkonia, until recently no model was able to reproduce measurements of both cross sections and polarization
- For open heavy flavours only recently calculations found an agreement
- LHC measurements will be crucial for the comprehension of open issues
- LHCb presents an ur ... ır to the other LHC experiments



J/ψ production

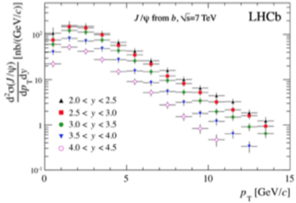


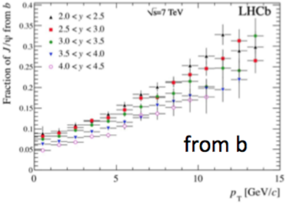


polarization

$$\sigma\,(\text{prompt } J/\psi, p_{\rm T} < 14\ \text{GeV}/c, 2.0 < y < 4.5) = 10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}\ \mu\text{b}.$$

dominant systematics (excluding polarization): tracking efficiency and luminosity





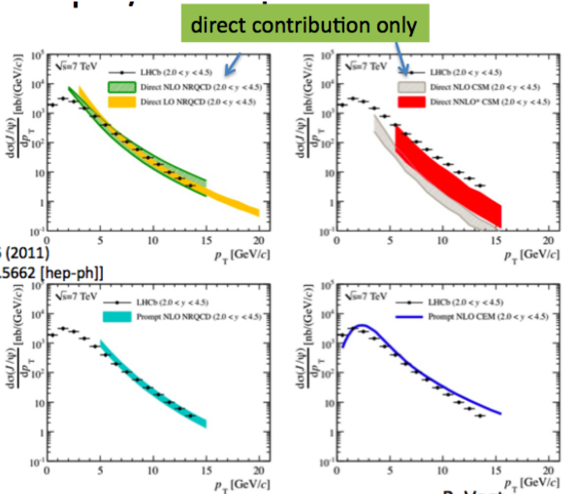
$$\sigma\,(J/\psi \text{ from } b, p_{\rm T} < 14\ \text{GeV}/c, 2.0 < y < 4.5) = 1.14 \pm 0.01 \pm 0.16\,\mu\text{b}.$$

Prompt J/Ψ: comparison with theory

P. Artoisenet
[PoS ICHEP 2010 (2010) 192]

M. Butenschön and B. Kniehl
[Phys. Rev. Lett. 106 (2011) 022301, arXiv:1009.5662 [hep-ph]]

J.-P. Lansberg
[Eur. Phys. J. C 61 (2009) 693, arXiv:0811.4005 [hep-ph]]



K. T. Chao et al.
[Phys. Rev. Lett. 106 (2011) 042002, arXiv:1009.3655 [hep-ph]]

R. Vogt
[Phys. Rep. 462 (2008) 125, arXiv:0806.1013 [nucl-ex]]

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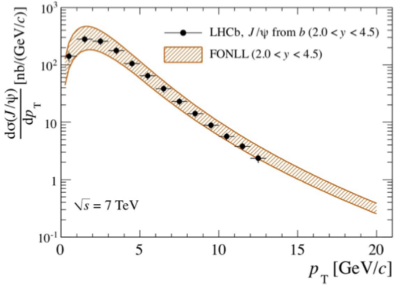
J/Ψ from b: comparison with theory



Cacciari et al., JHEP. 9805 (1998) 007
JHEP. 0103 (2001) 006

- $\sigma(J/\Psi$ from b, $2 < y < 4.5)$ = 1.14±0.01±0.16 μb (Eur. Phys.J. C71 (2011) 1645.)
- when extrapolated to the full solid angle ➠ $\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\mu$b
- In excellent agreement with another independent measurement using $b \to D^0\mu\nu_\mu X$: $\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\mu$b (PLB 694 (2010) 209.)

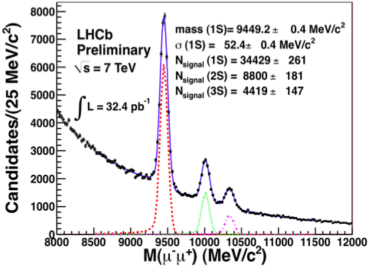
Bottomonium ($b\bar{b}$) states (Υ)

Υ production

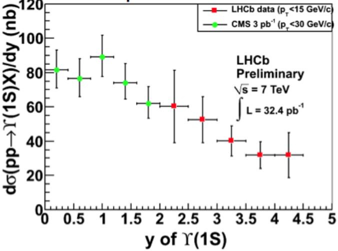
LHCb-CONF-2011-016

LHCb preliminary:

$$\sigma(\Upsilon(1S),\ P_t < 15\ \text{GeV},\ 2<y<4.5) = 108.3 \pm 0.7 \pm ^{30.9}_{25.8}\ \text{nb}$$



Comparison with CMS



Comparison with theory