

First physics results from LHCb

Hamish Gordon

University of Oxford

LC10 Frascati, 01-12-2010

For the LHCb Collaboration



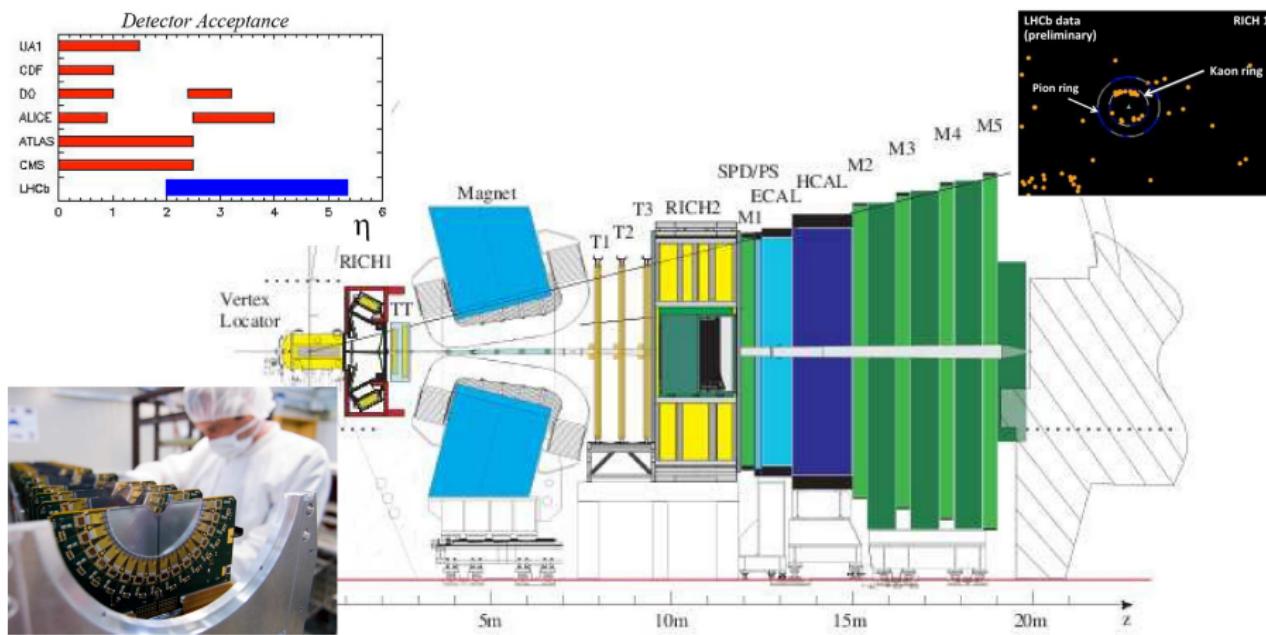
Outline

First physics results from LHCb

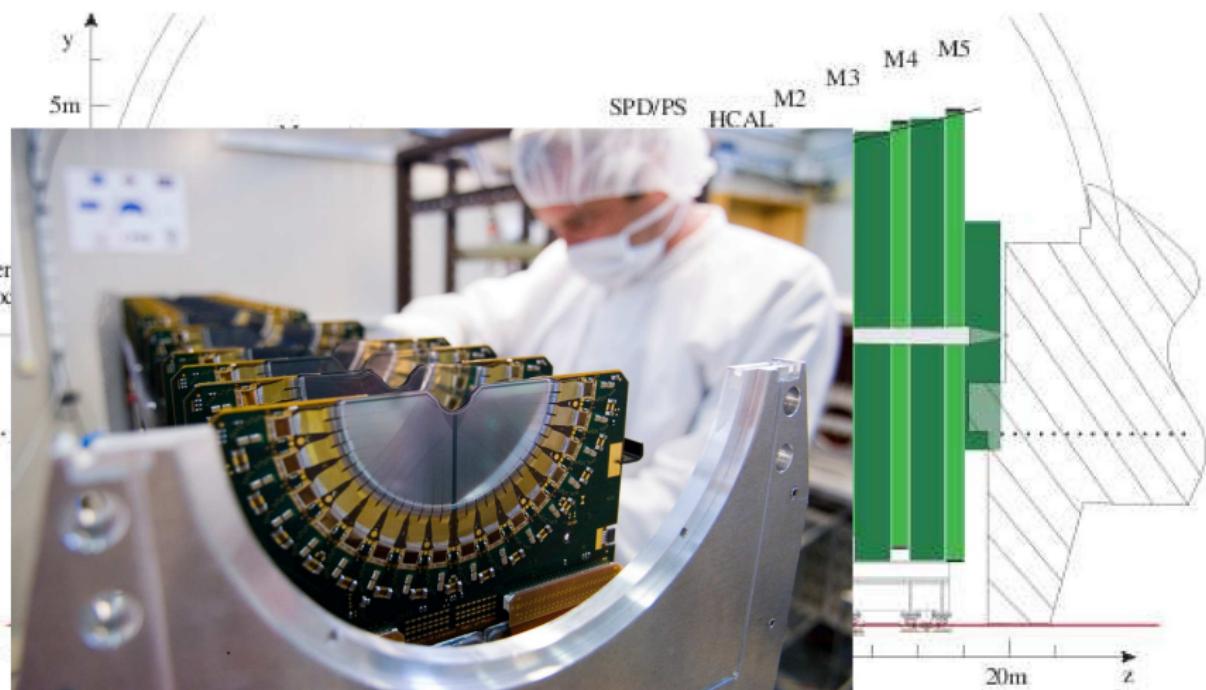
- ▶ Overview of experiment
- ▶ Key physics goals
- ▶ Detector performance
- ▶ Recently published or presented results
 - K_S^0 production
 - $b\bar{b}$ cross section
 - Quarkonia
 - Charm cross sections
- ▶ Outlook



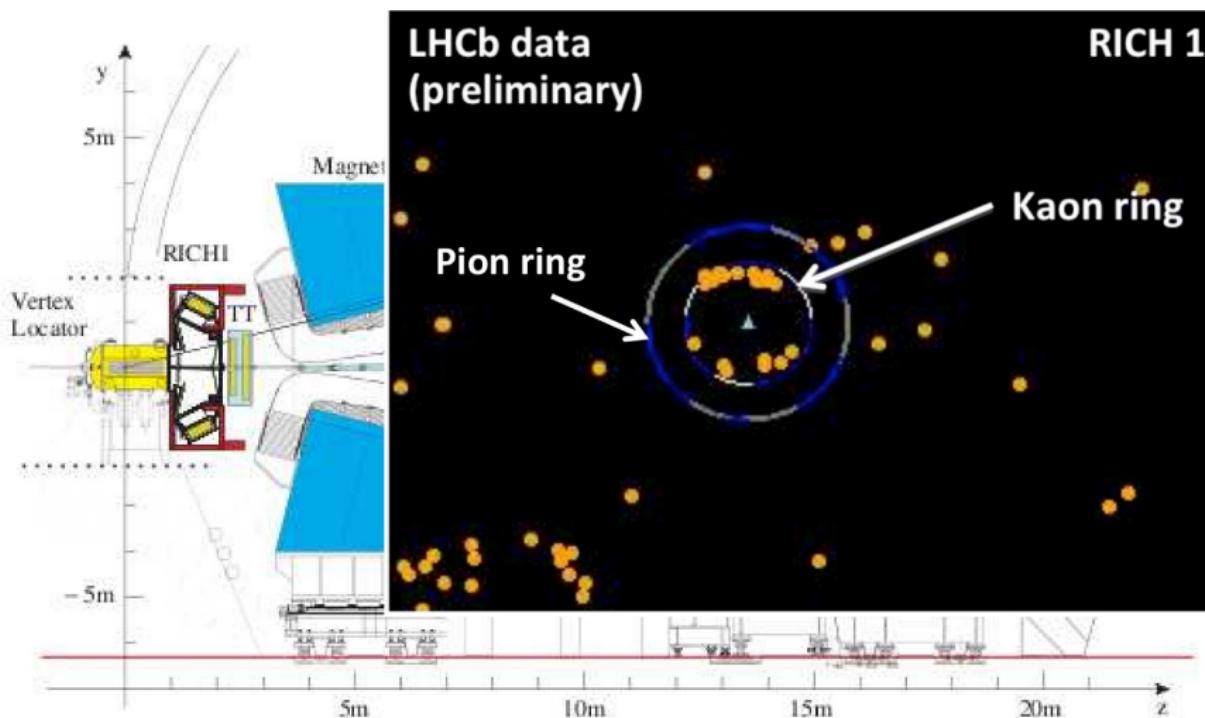
The LHCb experiment



The LHCb experiment



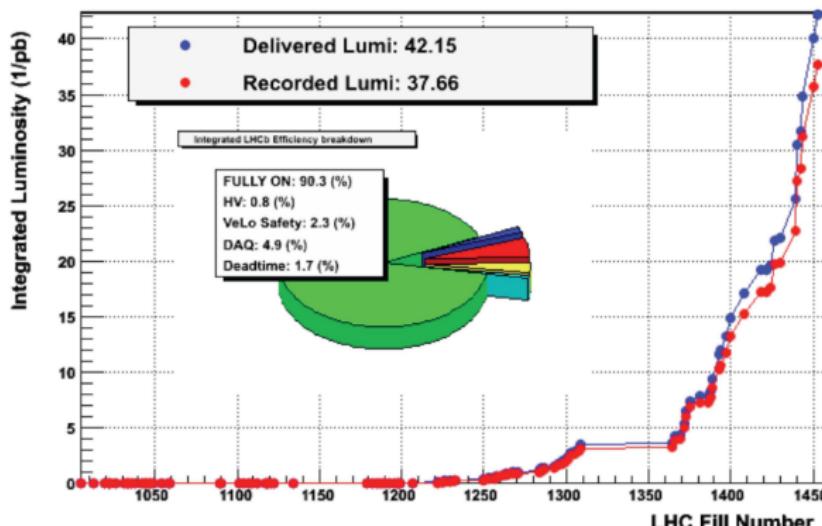
The LHCb experiment



The 2010 dataset

Approximately 37 pb^{-1} of data on tape

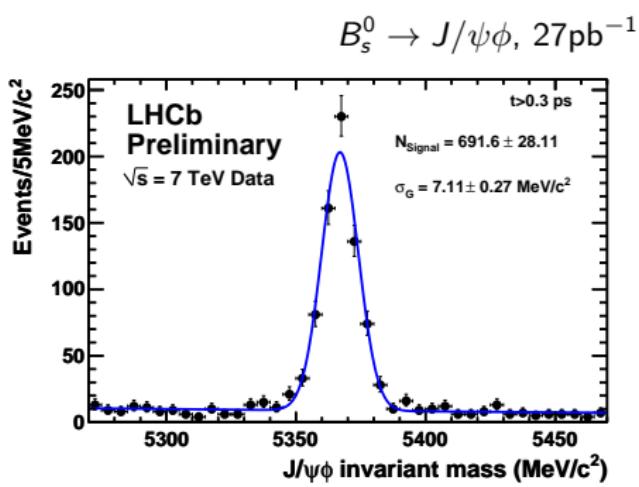
- ▶ LHCb has been operating at mean interactions per bunch crossing $\mu = 2.4$; design $\mu = 0.4$
- ▶ Detector has performed well in challenging and fast-changing conditions



Key physics goals for LHCb in 2010-11

LHCb's most promising new physics (NP) searches for next year:

- ▶ Branching ratio/new physics search in $B_s^0 \rightarrow \mu^+ \mu^-$
- ▶ Measurement of Φ_s in $B_s \rightarrow J/\psi \phi$
- ▶ Asymmetries in $B \rightarrow K^* \mu \mu$
- ▶ Asymmetries in semileptonic B decays
- ▶ Searches for CP violation in charm

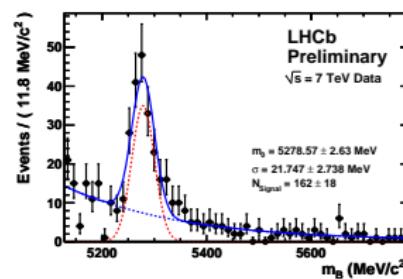


Longer term prospects for LHCb

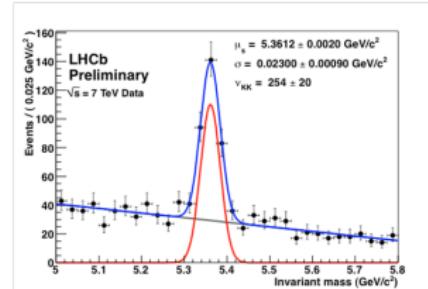
Example: measurement of γ :

- ▶ Expected uncertainty on γ is 4.8° from first 2fb^{-1} (at 14TeV)
- ▶ LHCb expects 1fb^{-1} of data next year; 6fb^{-1} of data in the “first run”
- ▶ Compare gamma from loops (sensitive to NP through penguins) with gamma from trees (not sensitive)
- ▶ Examples (trees):
 - $B^- \rightarrow D^0(K^-\pi^+)K^-$,
 - $B^- \rightarrow D^0(K_S^0\pi^+\pi^-)K^-$
- ▶ Examples (loops): $B_s^0 \rightarrow K^+K^-$ and $B^0 \rightarrow \pi^+\pi^-$ combined

$B^- \rightarrow D^0(K^-\pi^+)K^-$, $\sim 14\text{pb}^{-1}$



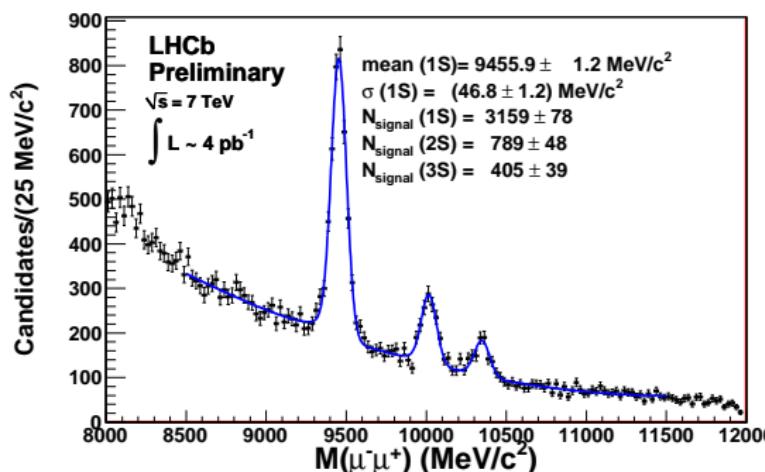
$B_s^0 \rightarrow K^+K^-$



LHCb performance (1)

Mass resolutions good and improving with latest detector alignment

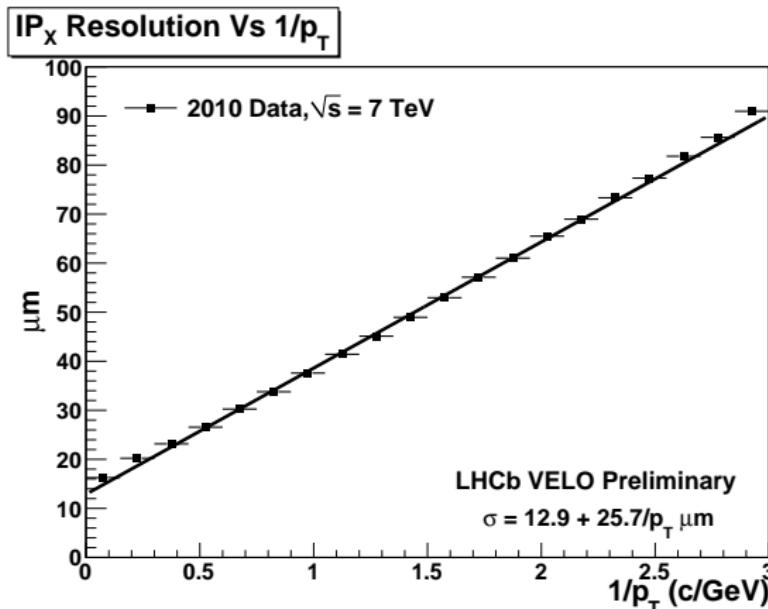
- ▶ Important for background suppression in $B_s \rightarrow \mu\mu$ search
- ▶ Below: $\Upsilon \rightarrow \mu^+\mu^-$, $\sigma(1S) = 47$ MeV (data), 40 MeV (Monte Carlo)



LHCb performance (2)

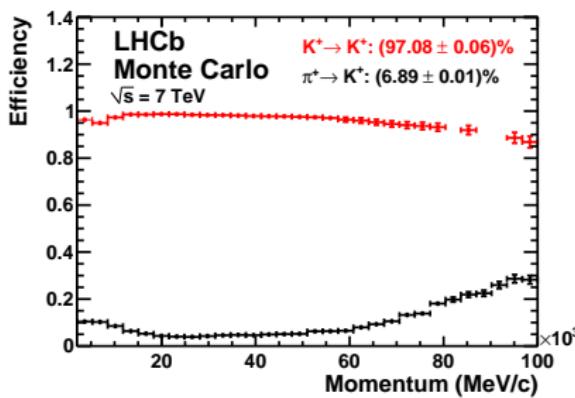
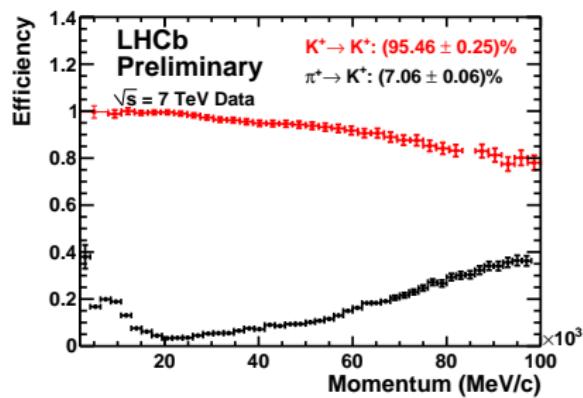
Impact parameter resolution extremely precise

- ▶ Important for separating charm into prompt and D from B components



LHCb performance (3)

Particle identification also close to Monte Carlo



LHCb first results

- ▶ K_S^0 production
- ▶ $b\bar{b}$ cross sections
- ▶ Quarkonia
- ▶ Open charm cross sections

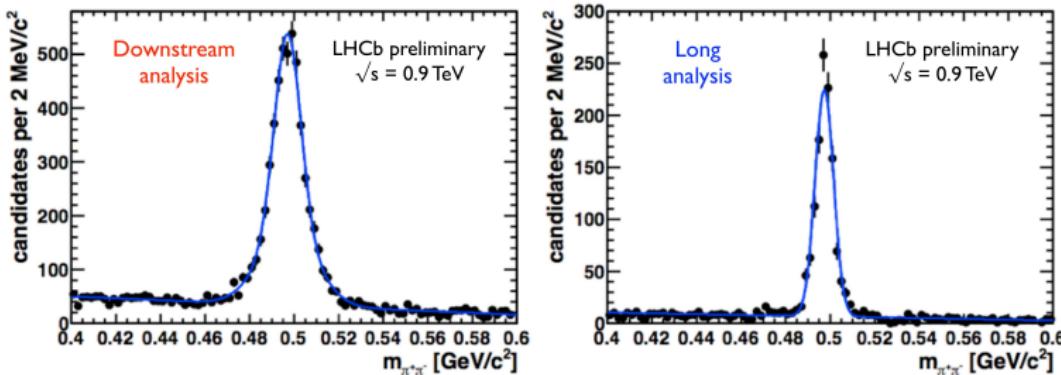
There are results I don't have time to talk about: inclusive ϕ production, $\Lambda/\bar{\Lambda}$, $p\bar{p}$, W and Z cross sections, ...

Introduction

Aim: To measure the production cross section for K_S^0

- ▶ Cross section $\sigma = \frac{Y}{\epsilon L(BR)}$ for yield Y in integrated luminosity L for efficiency ϵ and decay mode branching ratio (BR)
- ▶ Luminosity in 2009 data calculated by determining size of beams from positions of primary vertices
- ▶ Excellent test of the precision of the VELO and trackers
- ▶ First published paper (PLB **693** 69 (2010))

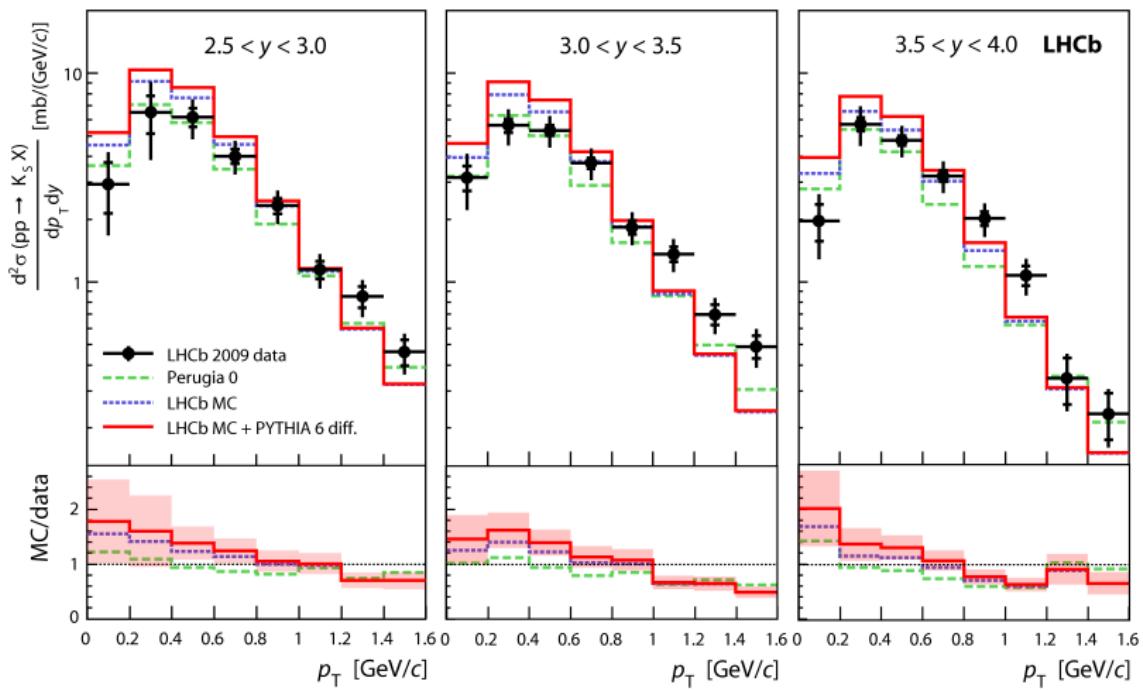
K_S^0 Signals in $6.8 \mu b^{-1}$ (2009)



	Downstream	Long
Beam-gas subtracted yield in beam-beam	4801 ± 84	1182 ± 36
Mean mass (MeV/c^2)	497.12 ± 0.14	497.31 ± 0.13
Mass resolution (MeV/c^2)	9.2	4.0
Total yield in beam-gas	56 ± 10	15 ± 6

(PDG: 497.61 ± 0.02)

Results ($6.8 \mu b^{-1}$, $\sqrt{s} = 900 GeV$)



LHCb published results

- ▶ K_S^0 production
- ▶ $b\bar{b}$ cross sections
- ▶ Quarkonia
- ▶ Open charm cross sections

Introduction

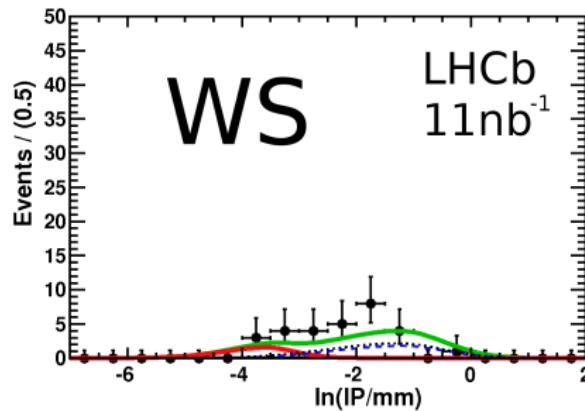
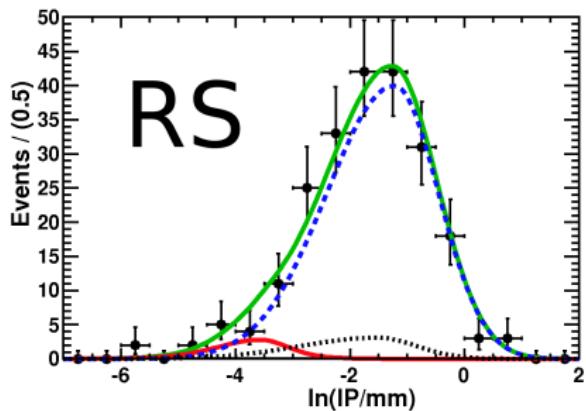
Measure using semileptonic B decays

- ▶ $b \rightarrow D^0 X \mu^- \bar{\nu}_\mu$ with $D^0 \rightarrow K^- \pi^+$
- ▶ Published October 10 (PLB **694** 209 (2010))
- ▶ 2 samples: 3nb^{-1} data taken with open trigger and 11nb^{-1} with muon trigger

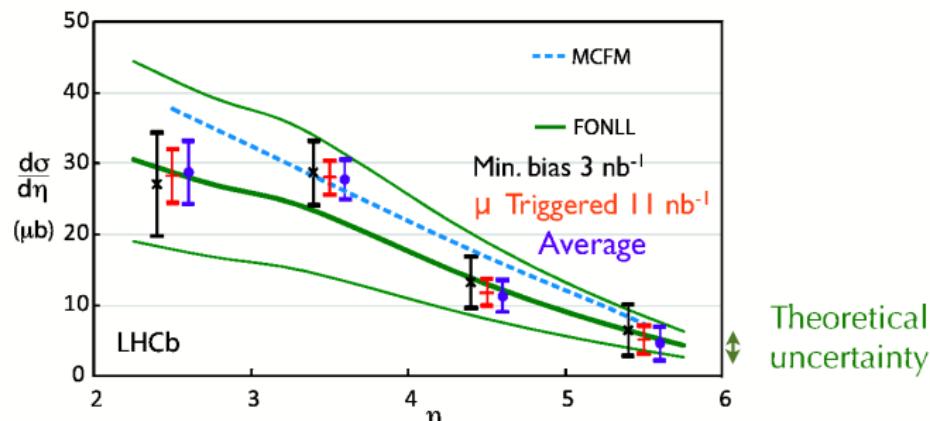
Removing prompt charm background

Use impact parameter distribution

- 2D unbinned log-likelihood fit to mass($K^- \pi^+$) and $\ln(\text{impact parameter})$
- Fix mass distribution shape using prompt sample of $D^0 \rightarrow K^- \pi^+$
- Allows simultaneous estimation of prompt charm background and other background (combinatorics, etc)

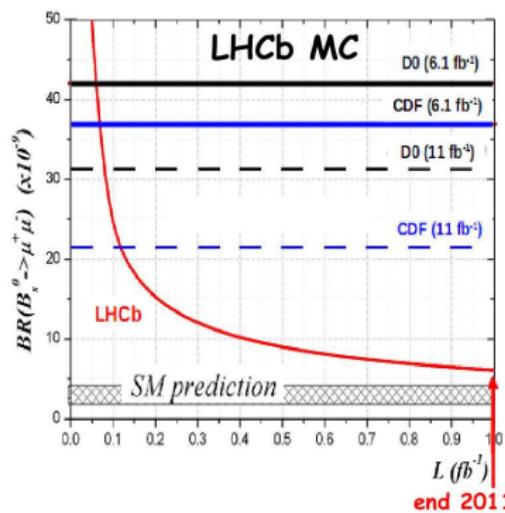
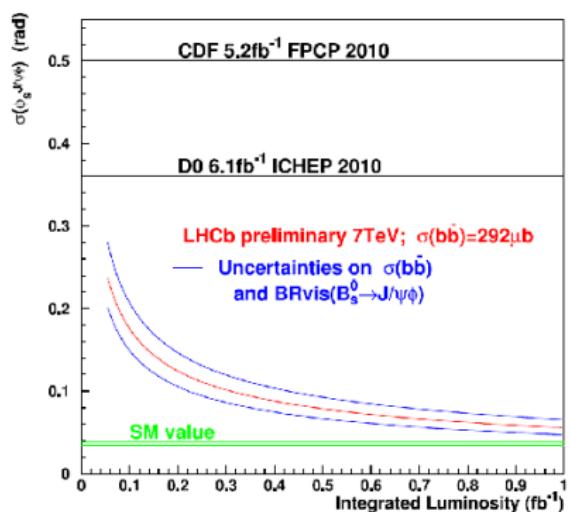


Results: $b\bar{b}$ cross section in bins of η



- ▶ 17% systematic (not shown) dominated by uncertainties in luminosity and Monte Carlo representation of the tracking efficiency
- ▶ Extrapolate to full rapidity range: cross section at 7TeV = $284 \pm 20 \pm 49 \mu\text{b}$
- ▶ MCFM: NLO with a PDF MSTW8NL <http://mcfm.fnal.gov>
- ▶ FONLL: CTE6.5 PDF; NLO + improvements with the resummation of p_t logarithms. Includes the b-quark fragmentation into hadrons. Cacciari, Nason, Mangano and others

Perspectives for new physics



Cross section used to determine LHCb sensitivity to Φ_s in $B_s \rightarrow J/\psi \phi$ (left) and $B_s^0 \rightarrow \mu^+ \mu^-$ (right)

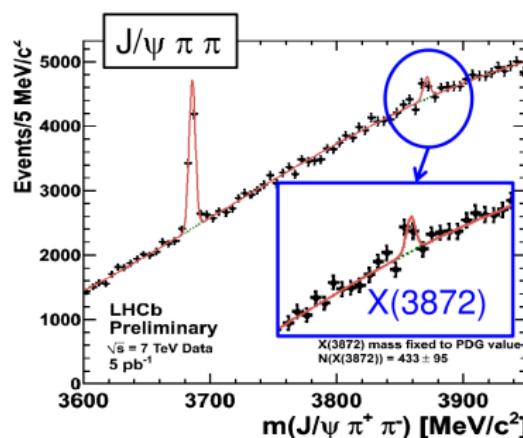
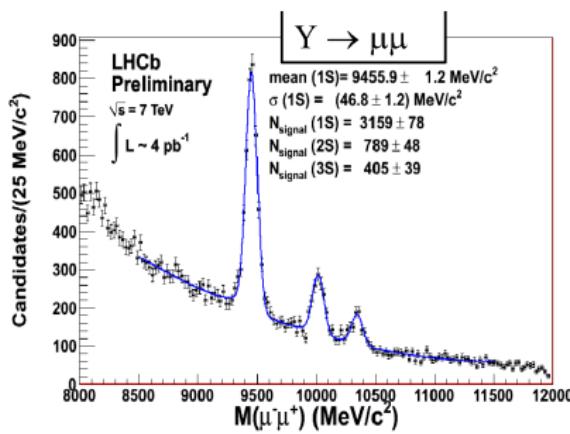
LHCb first results

- ▶ K_S^0 production
- ▶ $b\bar{b}$ cross sections
- ▶ Quarkonia
- ▶ Open charm cross sections

Introduction

Key results published or soon to be published

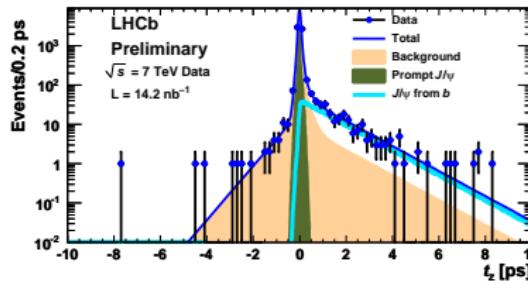
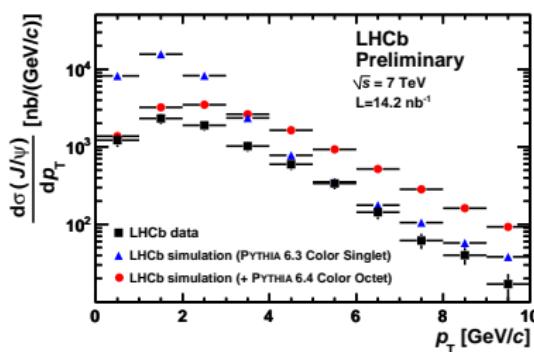
- ▶ J/ψ cross section
- ▶ $\Upsilon(1S)$ cross section
- ▶ $X(3872)$ confirmation (see below)
- ▶ ... and others ...



J/ψ results

J/ψ cross section not well described by colour singlet nor colour octet models as implemented in LHCb Monte Carlo

- ▶ Inclusive cross section measured in $2.5 < y < 4, p_T < 10$ GeV as $7.65 \pm 0.19 \pm 1.1^{+0.87}_{-1.27} \mu\text{b}$ (final uncertainty due to polarization)
- ▶ Lifetime z-projection used to separate prompt J/ψ from J/ψ from b and thereby measure both J/ψ and $b\bar{b}$ cross sections
- ▶ To be updated shortly with 5pb^{-1} of data



LHCb first results

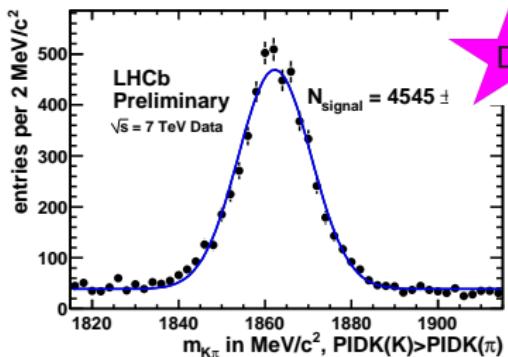
- ▶ K_S^0 production
- ▶ $b\bar{b}$ cross section
- ▶ Quarkonia
- ▶ Open charm cross sections

Introduction

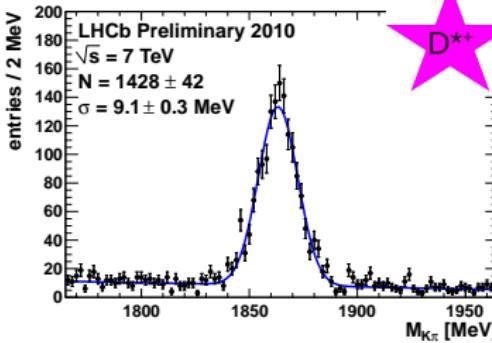
Aim to measure cross sections of D^0 , $D^* +$, D^+ , D_s^+ , Λ_c^+ in bins of y and p_t from $0 < p_t < 8$ GeV and $2 < y < 4.5$

- ▶ For final analysis, use the first 14nb^{-1} of data where the trigger has a low p_t threshold
- ▶ So far have results on the first 1.8nb^{-1} of data for D^0 , $D^* +$, D^+ , D_s^+
- ▶ Publication will follow in early 2011
- ▶ Cross section $\sigma = \frac{Y}{\epsilon L(BR)}$ for yield Y in integrated luminosity L for efficiency ϵ and decay mode branching ratio (BR)
- ▶ Take efficiency from Monte Carlo, using data and calibration samples to correct the Monte Carlo results where necessary

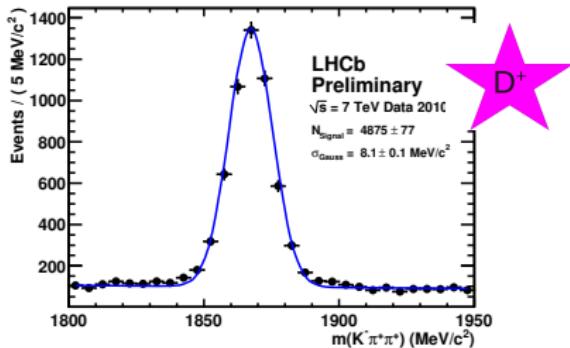
Signals in $1.8nb^{-1}$



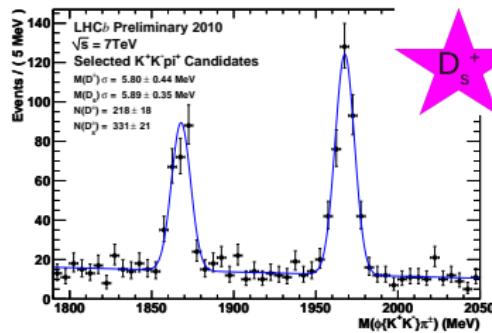
D^0



D^{*+}



D^+

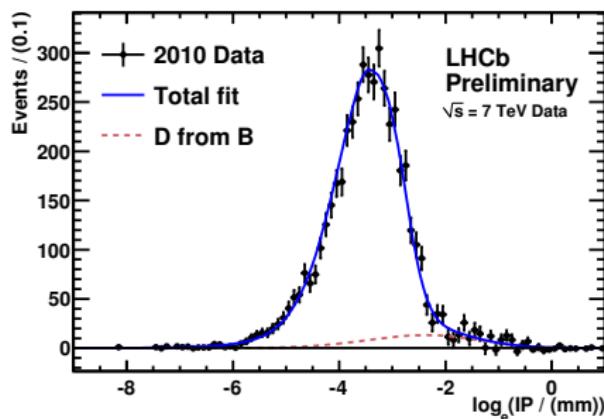


D_s^+

Subtraction of D from B

Converse to procedure for subtraction of prompt charm in $b\bar{b}$ cross section analysis

- ▶ Use mass distributions to determine background fraction and $\ln(\text{impact parameter wrt primary vertex})$ distributions to determine fraction of D from B decays



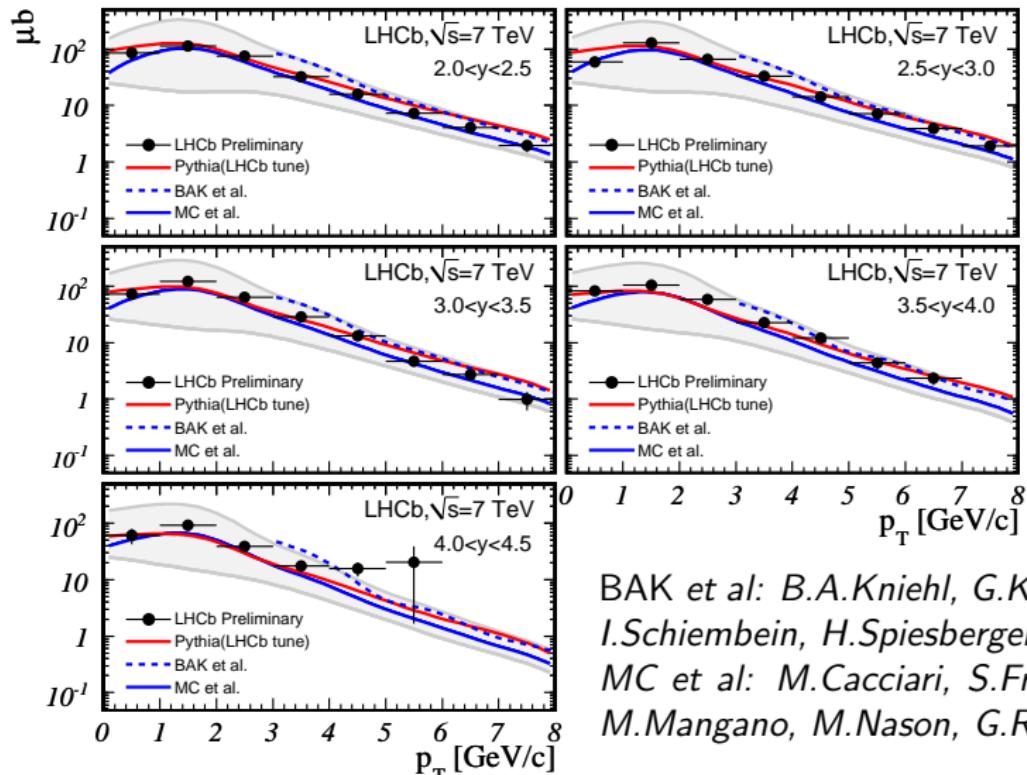
- ▶ Sum over IP distributions in each p_t , y bin, (sideband-subtracted using the mass distribution)

Systematics

- ▶ Systematic uncertainties are mostly constant across p_t and y
 - 10% uncertainty in luminosity measurement
 - 3% per-track uncertainty in Monte Carlo tracking efficiency
 - Particle-dependent fit systematics
 - Systematics for other small data-Monte Carlo differences (e.g. PID)
- ▶ Results on next slides do not show systematics that are correlated between bins (tracking efficiency and luminosity)

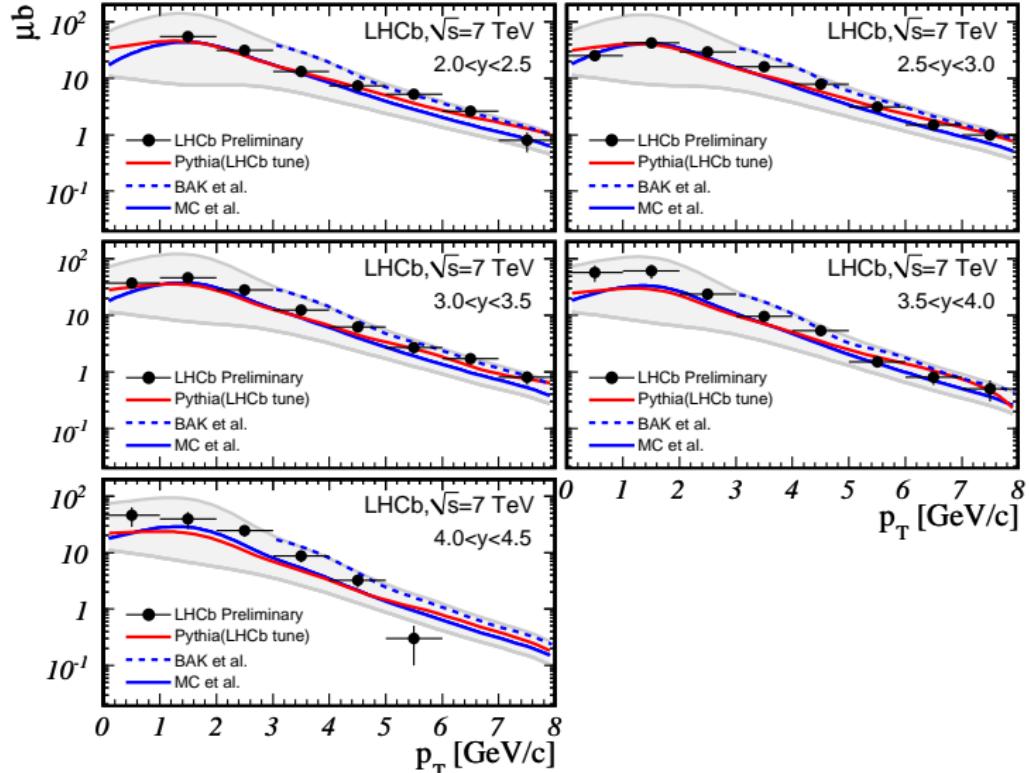
Preliminary (1.8nb^{-1}) results for D^0

$D^0 + \text{c.c.}$ cross-section



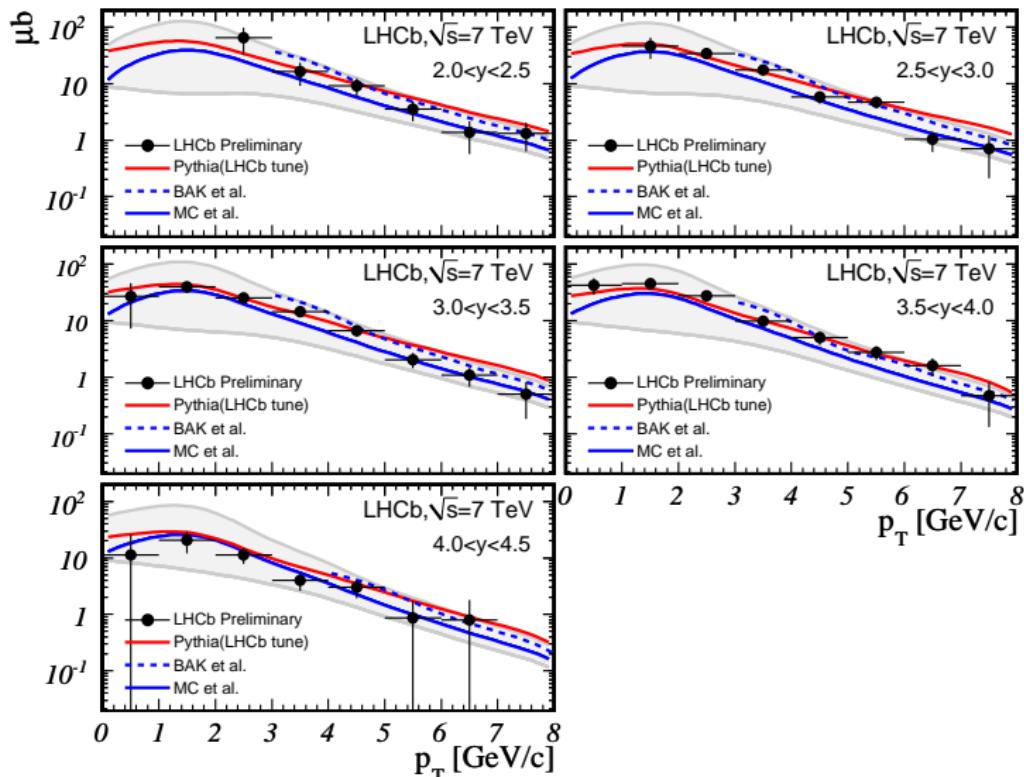
BAK et al: B.A.Kniehl, G.Kramer,
I.Schiembein, H.Spiesberger
MC et al: M.Cacciari, S.Frixione,
M.Mangano, M.Nason, G.Ridolfi

Preliminary (1.8nb^{-1}) results for D^+ $D^+ + \text{c.c.}$ cross-section

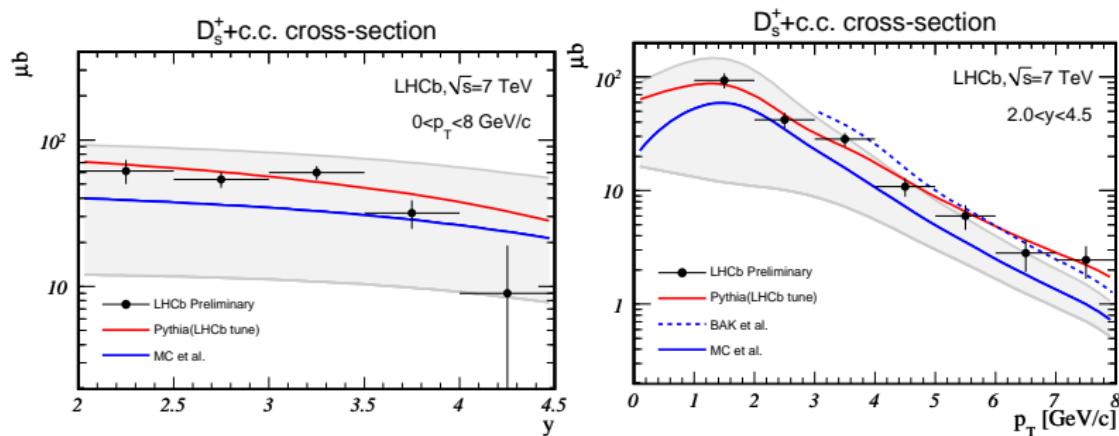


Preliminary (1.8nb^{-1}) results for D^*

$D^{*+} + \text{c.c.}$ cross-section



Preliminary (1.8nb^{-1}) results for D_s^+



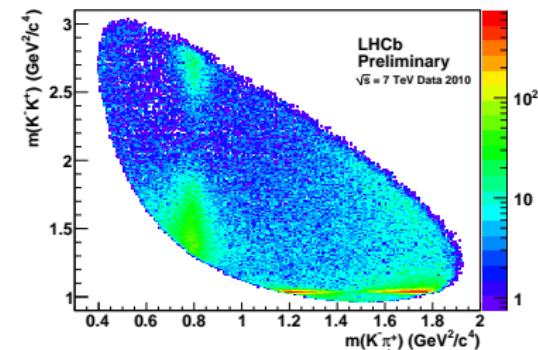
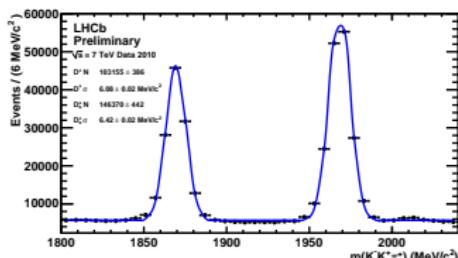
D_s^+ cross section in slices of y , left, and p_t , right

New Physics with charm

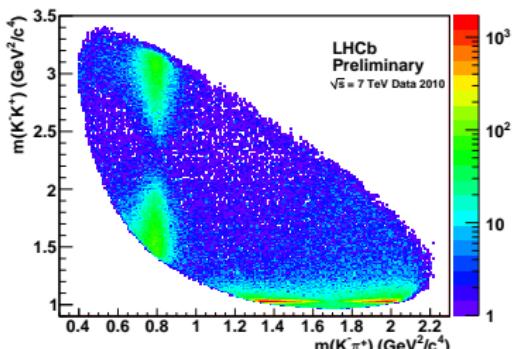
Example: Time-integrated search for direct CP violation in
 $D^+ \rightarrow hhh$

- ▶ Charm cross section 20 times larger than $b\bar{b}$ cross section
- ▶ Already have over 100,000 Cabibbo-suppressed (SCS)
 $D^+ \rightarrow K^- K^+ \pi^+$ decays on tape
- ▶ Hope to find evidence of direct CP violation via interference of tree and penguin diagrams in SCS decays

$$D_{(s)}^+ \rightarrow K^- K^+ \pi^+, \sim 10\text{pb}^{-1}$$



$$D_s^+ \rightarrow K^- K^+ \pi^+, \sim 10\text{pb}^{-1}$$



Outlook

LHCb is well placed to make world leading contributions to new physics searches in the next twelve months

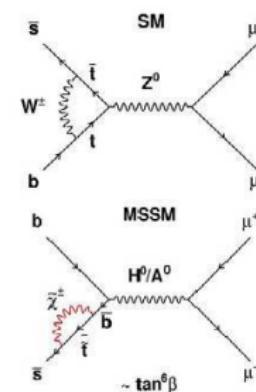
- ▶ The detector is performing extremely well
 - and its performance is improving rapidly
- ▶ Precise physics results can already be produced despite fast-changing running conditions
 - Key particle production measurements are already released
- ▶ Analyses with the highest discovery potential are well under way

BACKUP

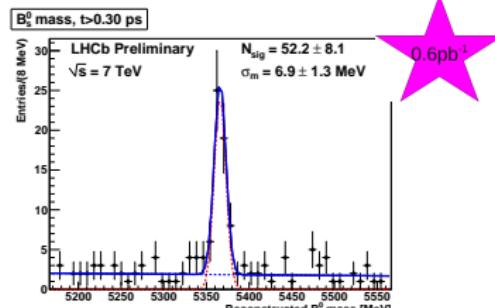
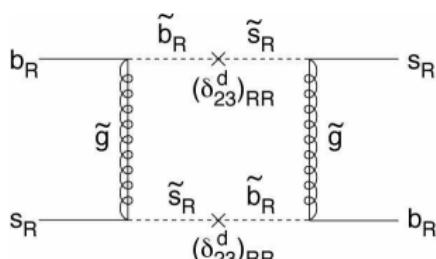
$$B_s^0 \rightarrow \mu^+ \mu^-$$

Aim: Limit branching ratio to $\mathcal{O}(10^{-8})$

- ▶ Suppressed penguin diagram
- ▶ Standard model BR $(3.35 \pm 0.32) \times 10^{-9}$
- ▶ Aim for binned likelihood fit in 3D space:
 - Geometrical likelihood (require good knowledge of B_s lifetime and impact parameter (IP), muon IP, muon isolation)
 - Invariant mass likelihood
 - Muon ID likelihood



Φ_s in $B_s \rightarrow J/\psi \phi$ (1)

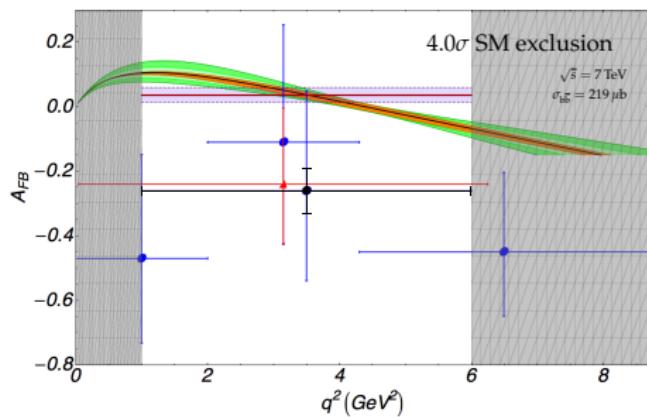


Aim: Search for new physics in box diagram, and measure B_s oscillation phase ϕ_s

- ▶ Almost pure $b \rightarrow ccs$ tree-level transition
- ▶ $\phi_s \sim -2\beta_s$ in the SM ($\beta_s = 0.0182 \pm 0.0009$)
- ▶ Untagged 3-angle analysis of $B^0 \rightarrow J/\psi K^*$
- ▶ Need to separate CP even and CP odd components of $J/\psi \phi$ final state
 - Time dependent angular analysis of tagged decays gives greatest sensitivity

Asymmetries in $B \rightarrow K^* \mu \mu$

- ▶ $B_d^0 \rightarrow K^* \mu^+ \mu^-$ is a FCNC mediated by box and penguin diagrams in the SM.
- ▶ Sensitive to new physics with contributions from right-handed currents or new scalar / pseudo-scalar operators through angular observables.



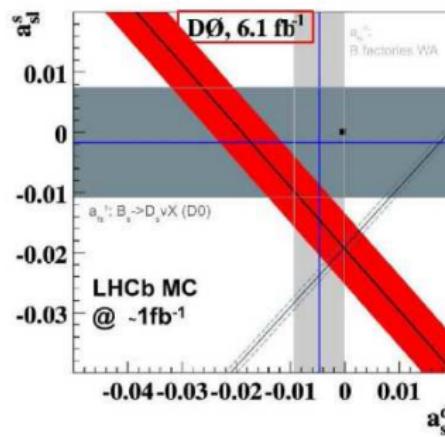
Asymmetries in semileptonic B decays

Interest in semileptonic asymmetries increased following D0 result

- ▶ Physics asymmetry $a_{fs}^s = \frac{\Delta\Gamma^s}{\Delta M^s} \tan \phi_s$
- ▶ Measured asymmetry $A_{fs}^q(t) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})}$ ($q = s$ or d)
- ▶ $A_{fs}^q(t) = \frac{a_{fs}^q}{2} - \frac{\delta_c^q}{2} - \left(\frac{a_{fs}^q}{2} + \frac{\delta_p^q}{2} \right) \frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)} + \frac{\delta_b^q}{2} \left(\frac{B}{S} \right)^q$

LHCb strategy

- ▶ Measure difference between asymmetries in B_s and B_d decaying to $D_{(s)}(KK\pi)\mu\nu$
- ▶ Then $\Delta a_{fs} = \frac{a_{fs}^s - a_{fs}^d}{2}$



Charm physics (1)

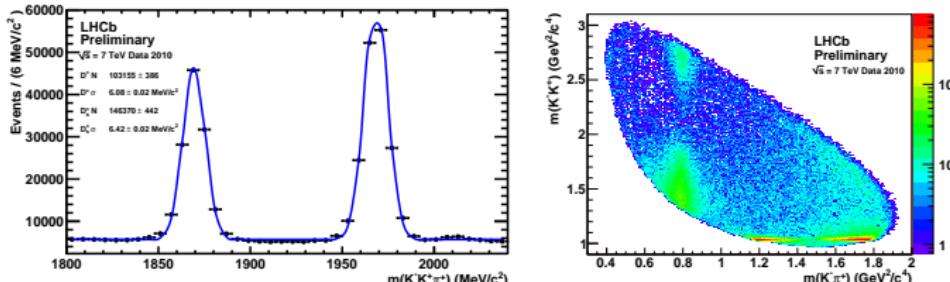
Time dependent analyses

- ▶ Search for lifetime asymmetry $A_\Gamma = \frac{\tau(\bar{D}^0 \rightarrow K^- K^+) - \tau(D^0 \rightarrow K^- K^+)}{\tau(\bar{D}^0 \rightarrow K^- K^+) + \tau(D^0 \rightarrow K^- K^+)}$
- ▶ Measurement of lifetime difference between CP-even and CP-mixed states $y_{CP} = \frac{\tau_{K-\pi^+}}{\tau_{K-K^+}} - 1$
- ▶ Key challenges: overcome impact of lifetime biasing cuts, remove secondary charm contribution
- ▶ Can surmount first obstacle by simply cutting on τ or by minimising bias in KK/Kpi ratio, and second via impact parameter fits (see later)

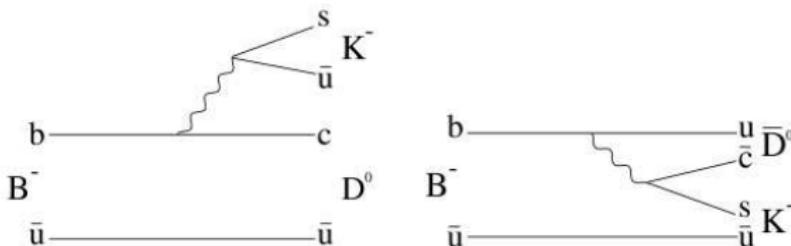
Charm physics (2)

Time integrated search for direct CPV

- ▶ Dalitz analyses of $D^+ \rightarrow K^- K^+ \pi^+$
- ▶ Avoid model dependence with binned study
- ▶ Significance of signal in bin $S_{CP} = \frac{N_{D^+} - N_{D^-}}{\sqrt{N_{D^+} + N_{D^-}}}$
- ▶ Once detector asymmetries are fully understood, can use control modes to cancel production asymmetries
- ▶ Require good understanding of asymmetry in backgrounds



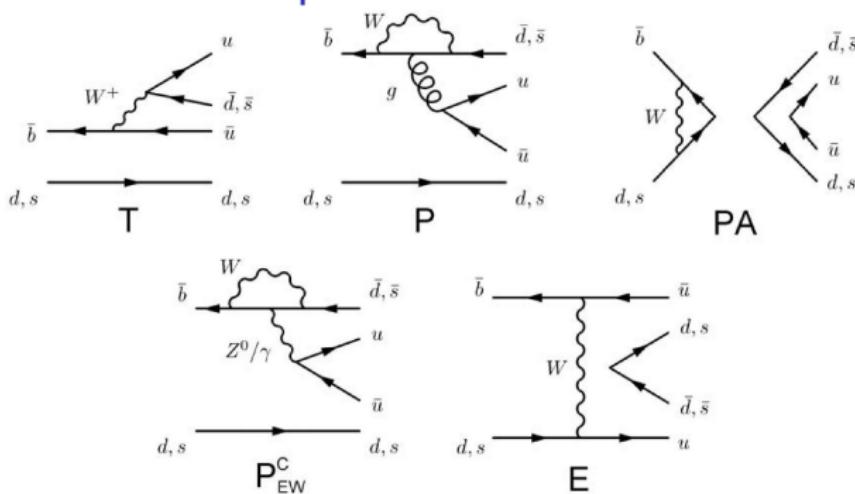
Gamma with trees



Phase difference between these diagrams is $\delta_B - \gamma$

- ▶ (δ_B is the strong-phase difference)
- ▶ GLW/ADS method: fit all $B^- \rightarrow D^0(h^+h^-)K^-$ rates (including Cabibbo-suppressed modes and extract γ from the CP asymmetry of the B decay)
- ▶ Dalitz plot method: use $B^- \rightarrow D^0(K_S^0h^+h^-)K^-$ to extract the phases from the Dalitz plot either with a model-dependent or a binned study (using strong phases from CLEO-c)
- ▶ Can also use 4-body modes or variants on the methods above!

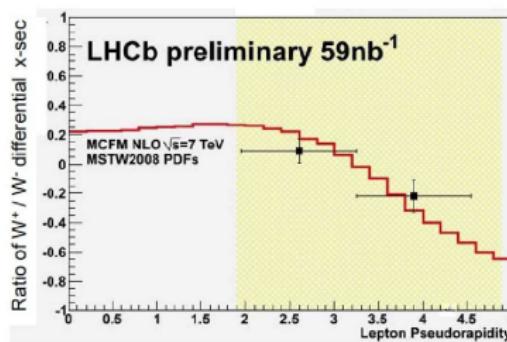
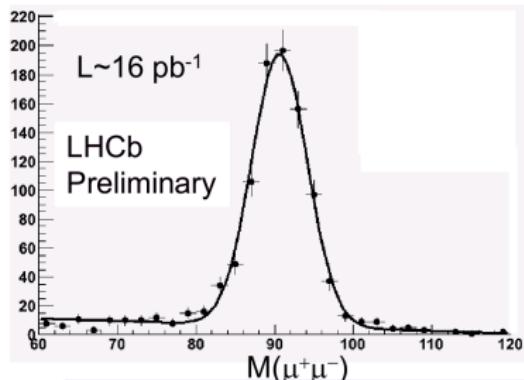
Gamma with loops



$B \rightarrow h^+ h^-$ sensitive to γ and also to ϕ_s and new physics

- ▶ Branching ratios of order 10^{-6}
- ▶ Exploit U-spin symmetry ($d \longleftrightarrow s$) for controls
- ▶ Extract γ , ϕ_s from CP asymmetries

W and Z



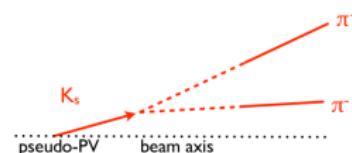
- ▶ For Z need $\mu^+\mu^-$ pair each with $p_t > 20$ GeV
- ▶ For W take 1 μ with $p_t > 20$ GeV and something with low p_t opposite it

K_S^0 analysis strategy

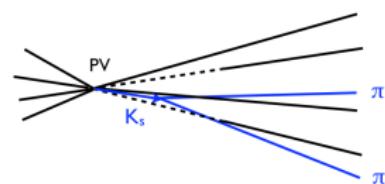
Two distinct analyses:

- ▶ Downstream track analysis uses no VELO hits (the VELO was open for the 2009 run)
 - High statistics, poor resolutions
- ▶ Long analysis uses VELO information
 - Low background, low statistics, good resolution
- ▶ Use the most precise value in each bin for the final result
- Don't combine results as uncertainties correlated

Downstream track analysis



Long track analysis



b, c cross section tracking efficiencies

Reconstruct right-sign and wrong-sign $K\pi$ and $K3\pi$ candidates

- ▶ Check tracking efficiency by comparing ratio of $K3\pi/K\pi$ in data and Monte Carlo (3% difference leads to 3% systematic uncertainty per track)

